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A framework of elements influencing the generation of knowledge spillovers from Big Science centers: a comparative analysis

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Acronyms and Abbreviations

ALMA	Atacama Large Millimeter/Submillimeter Array
ATLAS	A Toroidal LHC Apparatus
AURA	Association of Universities for Research in Astronomy
BIC	Business Incubation Center
CERN	European Organization for Nuclear Research
CMS	Compact Muon Solenoid
CLIOS	Complex, Large-scale, Interconnected, Open System
COME-ON	CGE Observatory of Meudon ESO ONERA
CONICYT	Comisión Nacional de Investigación Científica y Tecnológica
CORFO	Corporación de Fomento de la Producción
E-ELT	European Extremely Large Telescope
EFDAJET	European Fusion Development Agreement
EMBLE	European Molecular Biology Laboratory
ESA	European Space Agency
ESO	European Southern Observatory
GDP	Gross Domestic Product
GTC	Gran Telescopio Canarias
GTO	Guaranteed Time Observation
HARPS	High Accuracy Radial velocity Planet Searcher
ILL	Institut Laue Langevin
ILO	Industrial Liaison Office
LHC	Large Hadron Collider
NASA	National Aeronautics and Spatial Administration
NRAO	National Radio Astronomy Observatory
NOW	Netherland Organization for Scientific Research
SPC	Scientific Policy Committee of ESO
TIMMI2	Thermal Infrared Multimode Instrument
TMT	Thirty Meter Telescope
TWG IMKTT	Thematic Work Group on Innovation Management and Knowledge/ TT
TT	Technology Transfer
VLT	Very Large Telescope
XFEL	Free-Electron Laser Facility

Abstract

In this thesis, we developed a theoretical framework describing the factors that influence the generation of knowledge spillovers from the Big Science centers to industry. Through a nine-month field research, we compared two examples of Big Science center, embedded in different contexts: the astronomical observatories in Chile and CERN in Europe. The two cases have historically had different results in terms of knowledge and technology transfer efficiency. CERN is famous for its capacity in generating knowledge spillovers, while, the examples of knowledge transfer from astronomical observatories to the industry in Chile are almost absent. We identified several elements influencing the spillovers potentiality. These elements are related to the characteristics of the Big Science center, the policies adopted by the different stakeholders involved in the Big Science ecosystem, the effectiveness and coordination of the surrounding network, the attractiveness of the supply market generated by the center procurement, and the characteristics of the technologies requested. The cases evidence gave rise to a set of 41 theoretical propositions explaining the elements of the Big Science ecosystem influencing the origin of knowledge spillovers. Implications for researchers, policy-makers and Big Science organizations are discussed.

Abstract in italiano

In questa tesi abbiamo sviluppato un quadro teorico per descrivere i fattori che influenzano la generazione da parte dei centri di Big Science di *knowledge spillover* a favore dell'industria. Attraverso una ricerca sul campo di nove mesi, abbiamo confrontato due esempi di centro di Big Science, inseriti in contesti differenti: gli osservatori astronomici in Cile e il CERN in Europa. I due casi di studio hanno storicamente avuto diversi risultati in termini di efficienza nel trasferimento di tecnologia e conoscenza. Il CERN è famoso per la sua capacità di generare *knowledge spillover*, mentre sono scarsi gli esempi di trasferimenti di conoscenza dagli osservatori astronomici all'industria in Cile. Abbiamo identificato diversi elementi che condizionano la potenzialità di creare *spillover*. Questi elementi sono correlati con le caratteristiche del centro di Big Science, le politiche adottate dagli *stakeholder* coinvolti nell'ecosistema della Big Science, l'efficacia e la coordinazione del network circostante, l'attrattività del mercato di fornitura derivante dal *procurement* del centro, e le caratteristiche delle tecnologie necessarie. L'evidenza dei casi di studio ci ha portato a definire 41 proposizioni teoriche che spiegano come i fattori determinati dall'ecosistema della Big Science influiscano sulla generazione di *knowledge spillover*. Nell'elaborato verranno presentate anche implicazioni per ricercatori, *policy-maker* e organizzazioni di Big Science.

Executive Summary

The Big Science centers are large scientific facilities involving cutting-edge technologies and advanced equipment that have the potential to generate economic benefits and technological spillovers. Those kind of advantages, however, do not always occur. If in the case of CERN, in Europe, the examples of technological spillovers are numerous and the economic effects generated are relevant, the case of astronomical observatories in Chile does not present the same positive results.

The objective of this thesis is to construct a theoretical framework explicating the origin of technological spillovers from Big Science centers to society, and in particular to firms.

To this end, we aim at investigating the following research questions:

RQ1: What are the elements that permit the generation of knowledge spillovers from astronomical observatories to firms?

RQ2: Why in some contexts knowledge spillovers from Big Science centers originate and in others not?

In order to answer the research questions, we used the grounded theory method as methodological approach. With this method, the theory is supposed to emerge from in-depth case studies (Glaser and Strauss 1967). We described and analyzed two Big Science centers case studies: the astronomical observatories in Chile and the CERN, well-known for its spillovers generation capacity.

To gather the necessary information regarding the case study of the astronomical observatories, we realized a preliminary field research (Merriam 2009) in Chile and, consequently, an inductive multiple case study analysis with different unit of analysis (Yin, Case Study Research: Design and Methods 1994). During a period of nine months in Chile, we analyzed the astronomical observatories and the related ecosystem conducting interviews and visiting astronomical observatories. Furthermore, we use the CLIOS methodology (Sussman, et al. 2007) to obtain a systemic overview of the astronomical observatories in order to understand the behavior of this complex system.

The data collected during the stay in Chile, were reorganized in order to extrapolate interesting findings on how the ecosystem works and on which are the relevant stakeholders.

To have a first overview of the astronomical observatories in Chile, we modeled the lifecycle of an observatory, underlining, in each phase, the opportunities for firms, and we mapped the relevant stakeholders that participate in the astronomical ecosystem.

The data gathered allowed us to answer to the research questions.

We identified six fields of analysis that permit to classify the elements influencing the generation of knowledge spillovers from Big Science centers. These are:

- The Big Science perspective: The intrinsic characteristics of the Big Science center and its organization and policies;

- The market generated by Big Science projects;
- The political perspective: The nature of the agreements with the government, the policy of funding and the policy of technology transfer of the political institutions;
- The universities and their collaboration with Big Science centers;
- The network perspective;
- The technological perspective.

From the analysis and the comparison between the two case studies, it emerged that the divergence of these elements affects the knowledge spillovers generation capacity of the Big Science centers, causing different results in terms of knowledge and technology transfer efficiency.

Following these perspectives of analysis, we made a comparison between CERN and the astronomical observatories in Chile. The case evidence gave rise to 41 theoretical propositions, each of which is empirically testable.

The most relevant propositions are reported in the table below:

Field of analysis	***Theoretical Propositions***
Big Science perspective: intrinsic characteristics	• The location of a Big Science center depends from several reasons (geographical, climatic, political etc.) and determines an impact over the center ecosystem and network • The geographical dispersion of the facilities represents an obstacle to the creation of new knowledge and to the transfer of tacit knowledge within the organizations, due to the impossibility of technicians and engineers to interact continuously with each other. • Cultural divergences between the organizations and the host countries may create problems of integration and local collaboration.
Big Science perspective: policies and organization	• The lack of managerial competences within the Big Science center and the absence of a proactive and structured technology transfer policy limit the opportunities for openness to external collaborations. • The Big Science organizations policy of industrial return prevents host countries industries from participating in many middle and high technological projects, when the host country is not a member state.

	• A well working Industrial Liaison Office (it acts as a link between national industry and Big Science centers) is fundamental for the effectiveness of the procurement process.
Market-generated by Big Science projects	• The long-term duration, the complex technological requirements and the demand uncertainty reduce the attractiveness of the market. • The facilities dimensions and the high maintenance need increase the attractiveness of the market. The maintenance procurement policy may increase the opportunities for firms. • The majority of the firms enters Big Science projects as a mean to improve their visibility in the market and extend their range of business opportunities.
Political perspective	• The lack of a unique agreement policy between Big Science organizations and host countries arises the managerial complexity, because of the several actors involved in the relationship. It may also be more complicated for the industrial partners to start a collaboration. • Agreements clauses, considering the technological participation of member states, improve the technology transfer and spillover possibilities. • The presence of different and continuous opportunities of funding is fundamental for the development of scientific instruments. • The presence of a clear and formal knowledge transfer policy, the formalization of the Industrial Liaison Office and the coordination between the institutional actors are fundamental.
Universities and collaboration with Big Science centers	• The absence of coordination between the research fields of the universities reduces their competitiveness in the Big Science sector. • The lack of a large national scientific institute coordinating universities and institute obstacles the creation of a national scientific strategy.
Network perspective	• A closed community limits the creation of networks and obstacles the building of social capital necessary for the effectiveness of the knowledge transfer within a collaboration. • The absence of coordination among the actors strongly obstacles the creation of collaborations between Big Science centers and industry.

	• It is important for the centers to keep strong relationship with firms also outside of the collaboration in order to create a dynamic ecosystem with the possibility to generate innovation.
Technological Perspective	• Modular architectures enable business opportunities for a larger number of firms and facilitate the technology transfer. • The Big Science center operators' perception of the technology lifecycle can be out of date, and may obstacle the launch of new collaborations with firms. • The transferability of the technologies influences the capacity of Big Science centers to generate technological and knowledge spillovers. • The transferability of technologies depends also on the existence of suitable firms that may collaborate with the Big Science center and may be object of the transfer.

Table 1: Table of the main theoretical propositions.

From the analysis and the comparison between the two case studies, it emerged that the divergence of these elements affects the knowledge spillovers generation capacity of the Big Science centers, causing different results in terms of knowledge and technology transfer efficiency.

The case of the astronomical observatories in Chile testify that some divergences in the management of political affairs, in the policies adopted and in the characteristics of the facilities may lead to completely different situations.

Furthermore, we proposed some initiatives that could enhance the actual situation of the astronomical observatories cluster in Chile:

- ***Renegotiation of the agreements between Chile and the international astronomical organizations****: Including clauses that consider the technological collaboration of Chilean firms in some projects. The claim is legitimated by the fact that Chile is offering its unique climatic location at more advantageous conditions than other countries (e.g. Spain and Hawaii).*

- ***The creation of a large national astronomical institute****: It would improve the coordination among universities and scientists, and would define of a national scientific strategy.*

- ***The institution of a large national facility****: A large astronomical national project could encourage the birth of a high-technological industrial cluster in Chile and improve Chilean scientific community and companies' reputation. A similar initiative was undertaken by the Spanish government, with positive results.*

Moreover, we identified some general implications that could be useful for researchers, policy-makers and Big Science centers management.

Regarding the researchers, our study demonstrates that it is possible to build a theoretical framework explicating how context factors affect a Big Science ecosystem. This framework represents a starting point for more accurate analysis of the perspectives identified. The theoretical propositions presented here should be tested in larger empirical samples to assess their generality.

Implications for policy-makers are that they must valorize the Big Science centers as invaluable means to catalyze industrial development and innovation, increasing the efforts to facilitate the origin of collaborations between Big Science centers and industry. Some actions, they could undertake:

- *Policy-makers should individuate a formal and well-defined national strategy related to Big Science.*
- *Political institutions should focus their attention on the creation of a well-coordinated network that involves Big Science centers, universities and industry to take advantage of the synergies between them.*
- *Political institutions should enhance the formality of their relationships and processes involving Big Science organizations in order to increase efficiency, transparence and give more effectiveness to their actions.*

There are some implications also for the design and management of Big Science center, and for universities:

- *The proximity of Big Science centers to universities and industrial conurbations could help the development of an ecosystem linked to the Big Science center.*
- *Big Science centers should improve the knowledge and technology transfer in the host countries, in order to generate economic and technological benefits for industry and society.*
- *The integration of managerial competences in the management of Big Science centers could enhance the effectiveness of knowledge transfer policies.*
- *Universities should coordinate their research efforts in order to gain competitiveness for the Big Science projects*.

To conclude, we can affirm that, through this research, we attempted to give a more accurate and wider look at the characterizing elements of Big Science centers than the past research on this matter did.

The main limitations of this study are:

- The generality of our findings is obviously constrained by the case studies and the contexts analyzed. Even though grounded theory method allows generalization, similar studies in other contexts would be useful to refine our findings.

- We have developed a theoretical framework that offers a wide and complete overview of the factors that influence the generation of knowledge spillovers to firms. However, a deeper analysis following the perspectives identified could be useful.
- We did not focus our attention on how knowledge is transferred, but on the elements that enable the knowledge transfer from Big Science center to firms. Further studies about the context of astronomy could be useful to provide more context-independents conclusions.

Among the advantages, the most important is the replicability of the study. The theoretical framework we created could be adapted to other contexts.

The authors trust that this study could help to motivate the research on Big Science centers, and that our findings could provide an initial step towards the resolution of the current shortcomings of the existent literature.

Executive Summary in italiano

I centri di Big Science sono complessi scientifici di grandi dimensioni che fanno uso di tecnologie all'avanguardia e attrezzature avanzate. Essi sono in grado di creare benefici economici e *spillover* tecnologici per la società. Tuttavia, questi benefici non sempre vengono generati. Se ad esempio il caso del CERN è emblematico per i rilevanti effetti economici e i vari esempi di *spillover* tecnologici generati, il caso degli osservatori astronomici in Cile non presenta risultati altrettanto positivi.

L'obiettivo di questa tesi è di costruire un quadro teorico che spieghi le origini degli *spillover* tecnologici dai centri di Big Science alla società, e in particolare alle aziende, al fine di comprendere la divergenza di risultati nei diversi casi.

A questo fine, ci poniamo le seguenti domande di ricerca:

DR1: Quali sono gli elementi che permettono la generazione di *knowledge spillover* dagli osservatori astronomici alle imprese?

DR2: Perchè i *knowledge spillover* dai centri di Big Science in alcuni casi vengono generati e in altri no?

Per rispondere a questi quesiti abbiamo usato come approccio metodologico quello della *grounded theory*. Con questo metodo, si suppone che la teoria emerga dallo studio dettagliato di uno o più casi (Glaser and Strauss 1967). Abbiamo descritto e analizzato due casi di Big Science: gli osservatori astronomici in Cile, e il CERN, famoso per la sua capacità di generare *spillover*.

Per avere accesso alle informazioni necessarie riguardanti il caso studio degli osservatori astronomici, abbiamo realizzato una ricerca sul campo (Merriam 2009) in Cile, e, in seguito un'analisi induttiva dei casi studio con diverse unità di analisi (Yin, Case Study Research: Design and Methods 2009). Durante un periodo di 9 mesi in Cile, abbiamo analizzato gli osservatori astronomici e l'ecosistema a essi relazionato, attraverso una serie di interviste e visite agli osservatori. Inoltre, abbiamo fatto uso della metodologia CLIOS (Sussman, et al. 2007) per ottenere una prospettiva sistematica degli osservatori astronomici e comprendere a fondo il comportamento di questi complessi sistemi.

Per avere una prima visione generale del sistema degli osservatori astronomici in Cile, abbiamo modellato il ciclo di vita degli osservatori, sottolineando per ciascuna fase quali fossero le opportunità generate per le aziende cilene. Inoltre, abbiamo mappato le relazioni tra i principali *stakeholder*, per capire come essi possano influenzare la nascita di opportunità di collaborazione tra gli osservatori e le imprese cilene.

I dati ottenuti ci hanno quindi permesso di rispondere alle domande di ricerca.

Abbiamo identificato sei prospettive di analisi in cui abbiamo classificato gli elementi che possono influenzare la generazione di *knowledge spillover* da parte dei centri di Big Science. Questi sono:

- Prospettiva del centro di Big Science: Le caratteristiche intrinseche, l'organizzazione e le politiche del centro di Big Science.
- Il mercato generato dal centro di Big Science.
- Prospettiva politica: La natura degli accordi tra centri di Big Science e istituzioni politiche e le politiche di finanziamento e di trasferimento tecnologico delle istituzioni politiche.
- Università e loro relazione con i centri di Big Science.
- Prospettiva del network.
- Prospettiva tecnologica.

Dall'analisi e dal confronto tra i due casi studio, possiamo affermare che la divergenza degli elementi identificati condiziona la capacità di generare *spillover* di conoscenza da parte dei centri di Big Science, causando risultati divergenti in termini di trasferimento tecnologico e *knowledge spillover*.

Seguendo il quadro teorico dettato dalle prospettive di analisi, abbiamo confrontato il CERN e gli osservatori astronomici in Cile. Le evidenze del caso ci hanno permesso di scrivere 41 proposizioni teoriche, di cui ciascuna delle quali è verificabile empiricamente.

Le proposizioni più rilevanti sono riportati nella seguente tabella:

Prospettiva di analisi	*Proposizioni teoriche*
Prospettiva del centro di Big Science: caratteristiche intrinseche	• La localizzazione di un centro di Big Science dipende da diversi fattori (geografici, climatici, politici) e ha un impatto sulla creazione dell'ecosistema connesso al centro. • La dispersione geografica dei complessi scientifici rappresenta un ostacolo alla creazione di nuova conoscenza e al trasferimento di conoscenza tacita all'interno dell'organizzazione scientifica, a causa dell'impossibilità da parte di tecnici e ingegneri di interagire continuamente tra di loro. • Le divergenze culturali tra il centro di Big Science e i Paesi che ospitano i complessi scientifici possono creare problemi di integrazione e ostacolare le collaborazioni con enti locali.
Prospettiva del centro di Big Science: politiche e organizzazione	• L'assenza di competenze manageriali all'interno del centro di Big Science e l'assenza di una proattiva e strutturata politica di trasferimento tecnologico ostacolano la nascita di nuove opportunità di collaborazione con aziende locali. • La politica di ritorno industriale per i Paesi membri, attutata da molte organizzazioni di Big Science, ostacolano la partecipazione di aziende del paese ospitante (se non è Paese membro dell'organizzazione) in progetti di media e alta tecnologia. • Un ben funzionante Industrial Liaison Office (ente che fa da tramite tra il centro di Big Science e le industri nazionali) è fondamentale per l'efficacia del processo di approvvigionamento del centro di Big Science e la partecipazione di industrie nazionali a questo processo.
Mercato generato dai progetti di Big Science	• Le relazioni di lungo termine, i complessi requisiti tecnologici e l'incertezza della domanda riducono l'attrattività del mercato generato dal centro di Big Science. • Le dimensioni del centro di Big Science e gli alti bisogni che esso ha in termini di servizi di manutenzione aumentano l'attrattività del mercato. La strategia di approvvigionamento di servizi di manutenzione del centro di Big Science può aumentare le opportunità per le industrie. • La maggior parte delle imprese iniziano collaborazioni con centri di Big Science per aumentare la loro visibilità nel mercato.
Prospettiva Politica	• La mancanza di un'unica politica per gli accordi tra organizzazioni di Big Science e paesi ospitanti accresce la

	complessità manageriale, a causa dei numerosi attori coinvolti nella relazione. • Le clausole degli accordi, che prevedono la partecipazione tecnologica dei paesi membri, migliorano il trasferimento tecnologico e la possibilità di *spillover*. • La presenza di diverse e durature opportunità di finanziamento è fondamentale per lo sviluppo di strumentazione scientifica. • La presenza di una chiara e formale politica per il trasferimento tecnologico, la formalizzazione del ruolo dell'Industrial Liaison Office e la coordinazione tra gli attori istituzionali hanno una grande importanza.
Università e la collaborazione con i centri di Big Science	• La mancanza di coordinazione sugli ambiti di ricerca delle università riduce la loro competitività nel settore della Big Science. • L'assenza di un istituto scientifico nazionale, che coordini università e istituti, ostacola la definizione di una strategia scientifica nazionale.
Prospettiva del network	• Una comunità scientifica chiusa limita lo sviluppo del *network* e ostacola la costruzione del *social capital*, necessario per l'efficacia del trasferimento tecnologico all'interno delle collaborazioni. • La mancanza di coordinazione tra gli attori ostacola fortemente la nascita di collaborazioni tra i centri di Big Science e l'industria. • Per i centri di Big Science è importante mantenere solidi contatti con le aziende anche all'infuori della collaborazione in modo da creare un ecosistema dinamico con la possibilità di generare innovazione.
Prospettiva tecnologica	• Le architetture modulari abilitano possibilità di business per un numero maggiore di imprese e facilitano il trasferimento tecnologico. • La percezione del ciclo di vita delle tecnologie, da parte degli operatori dei centri di Big Science, può essere antiquata e perciò ostacolare lo sviluppo di nuove collaborazioni con le aziende. • La trasferibilità delle tecnologie influenza la capacità dei centri di Big Science di generare *spillover* tecnologici e di conoscenza. • La trasferibilità delle tecnologie dipende anche dall'esistenza o meno di imprese idonee che possano collaborare con il centro di Big Science ed essere oggetto del trasferimento tecnologico.

Tabella: Tabella delle principali proposizioni teoriche.

Dall'analisi e dal confronto tra i due casi di studio, è emerso che la divergenza tra questi elementi condiziona la capacità dei centri di Big Science di generare *knowledge spillover*, determinando differenti risultati in termini di efficienza nel trasferimento tecnologico e di conoscenza.

Il caso degli osservatori astronomici in Cile testimonia come dalle differenze nella gestione delle relazioni politiche, nelle caratteristiche dei complessi scientifici e nelle politiche adottate possano scaturire situazioni completamente diverse.

Inoltre, abbiamo proposto alcune iniziative che potrebbero migliorare l'attuale situazione del cluster degli osservatori astronomici in Cile:

- ***La rinegoziazione degli accordi tra il Cile e le organizzazioni astronomiche internazionali****: Includendo clausole che prevedano la collaborazione tecnologica di imprese cilene nei progetti di Big Science. La richiesta è legittimata dal fatto che il Cile sta offrendo la sua location climatica unica a condizioni molto più convenienti rispetto ad altre nazioni (e.g. Spagna e Hawaii).*

- ***La creazione di un istituto astronomico nazionale****: L'istituto accrescerebbe la coordinazione tra università e scienziati, e potrebbe definire la strategia scientifica nazionale.*

- ***La costruzione di un complesso astronomico nazionale****: La costruzione di un grande complesso astronomico nazionale potrebbe facilitare la nascita, in Cile, di un cluster di imprese di alta tecnologia e favorire lo sviluppo della comunità scientifica e della reputazione delle aziende cilene. Un'iniziativa simile è stata intrapresa dal governo spagnolo con risultati estremamente positivi.*

A conclusione della nostra ricerca, abbiamo identificato delle implicazioni generali che possono rivelarsi utili per ricercatori, *policy-maker* e *management* dei centri di Big Science.

Per quanto riguarda i ricercatori, il nostro studio dimostra come sia possibile sviluppare un quadro teorico per spiegare il modo in cui i fattori del contesto condizionino l'ecosistema della Big Science. Questo quadro teorico rappresenta un punto di avvio per analisi più approfondite seguendo le prospettive individuate. Le proposizioni teoriche presentate in questa ricerca potranno essere verificate in ulteriori contesti empirici in modo da valutarne la genericità.

Per i *policy-maker*, invece, le implicazioni riguardano la valorizzazione dei centri di Big Science come preziosi strumenti per catalizzare lo sviluppo industriale e l'innovazione, incentivando le iniziative per facilitare lo sviluppo di collaborazioni tra di essi e l'industria. Alcune azioni che possono essere intraprese sono:

- *I policy-maker dovrebbero definire una strategia nazionale relativa alla Big Science che sia formalizzata e chiara.*

- *Le istituzioni politiche dovrebbero focalizzare la loro attenzione sullo sviluppo di un network coordinato che racchiuda i centri di Big Science, le università e l'industria, in modo da beneficiare delle sinergie tra i vari attori.*

- *Le istituzioni politiche dovrebbero incrementare la formalità delle loro relazioni e dei processi che coinvolgono le organizzazioni di Big Science, in modo da aumentare l'efficienza, la trasparenza e dare maggiore efficacia alle iniziative.*

Altre implicazioni sono indirizzate al *management* dei centri di Big Science e alle università:

- *La vicinanza dei centri di Big Science alle università e alle conurbazioni industriali potrebbe agevolare lo sviluppo di un ecosistema collegato al centro scientifico.*

- *I centri di Big Science dovrebbero incrementare il trasferimento tecnologico e di conoscenza verso i paesi ospitanti con l'obiettivo di generare benefici economici e tecnologici per la società e l'industria.*

- *L'integrazione di competenze manageriali all'interno dei quadri direttivi dei centri di Big Science potrebbe migliorare l'efficacia delle politiche di trasferimento di conoscenza.*

- *Le università dovrebbero coordinare i loro sforzi nella ricerca in modo da essere più competitive nell'ambito dei progetti di Big Science*.

In conclusione possiamo affermare che, attraverso questa ricerca, abbiamo cercato di fornire una visione più accurata ed ampia degli elementi caratteristici dei centri di Big Science, rispetto a ciò che è stato presentato dalla letteratura esistente.

Le principali limitazioni di questa ricerca sono:

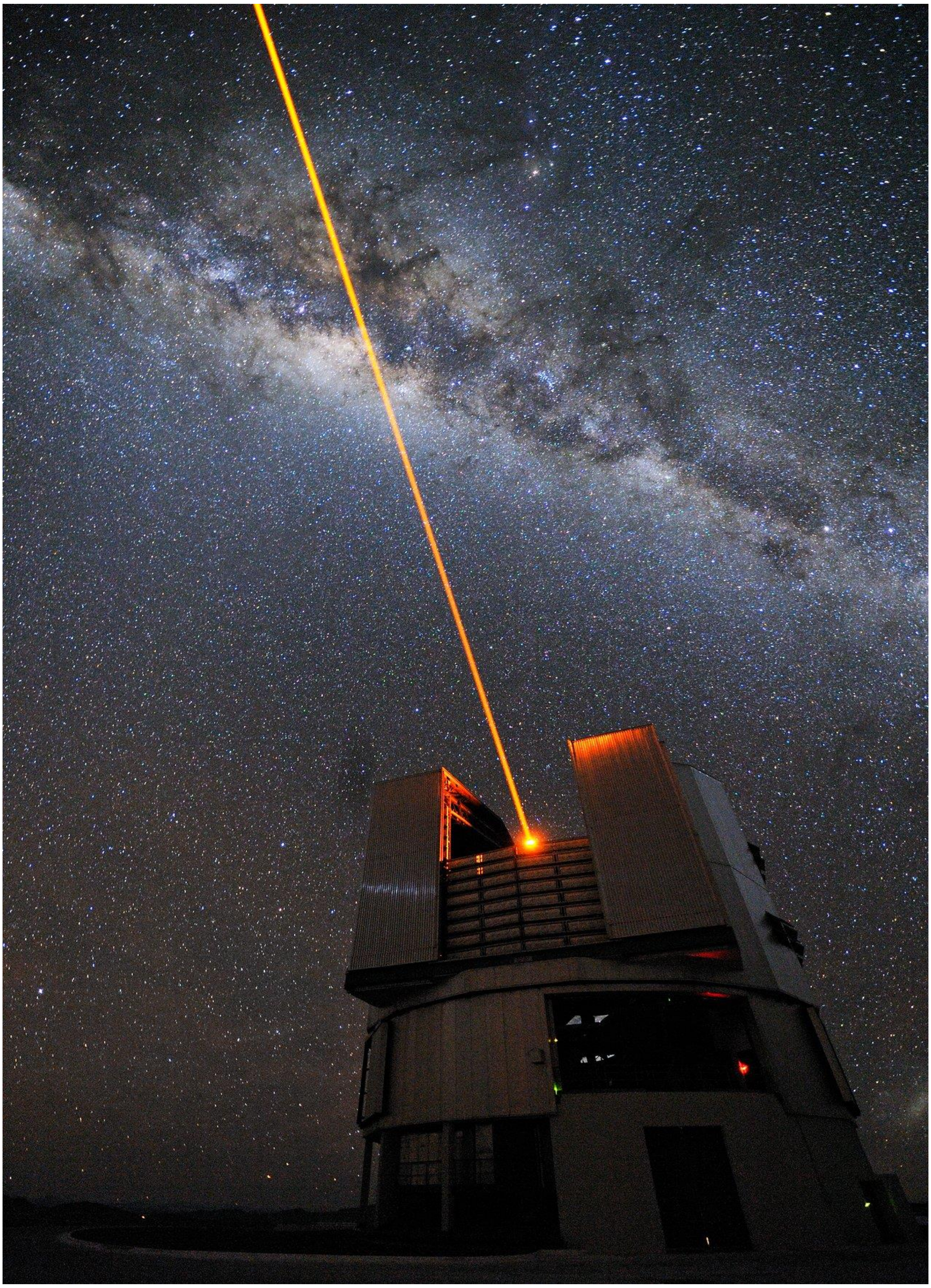
- La genericità delle nostre conclusioni è ovviamente limitata dai casi di studio e dai contesti analizzati. Nonostante il metodo della *grounded theory* permetta la generalizzazione, studi simili al nostro, realizzati in ecosistemi differenti, potrebbero essere utili per testare le nostre conclusioni.

- Abbiamo sviluppato un quadro teorico che offre un'ampia e completa panoramica sui fattori che influiscono sulla generazione di *knowledge spillover* verso le aziende. In ogni caso, un'analisi più approfondita seguendo le prospettive individuate potrebbe essere di aiuto

- Non abbiamo focalizzato la nostra attenzione sul come si trasferisca la conoscenza, ma sugli elementi che abilitano il *knowledge transfer* dai centri di Big Science all'industria. Ulteriori studi all'interno del settore dell'astronomia potrebbero essere utili per ottenere conclusioni maggiormente indipendenti dal contesto specifico del Cile.

Tra i vantaggi di questa ricerca, il più importante è la replicabilità dello studio. Il quadro teorico che abbiamo sviluppato può essere adattato ad altri contesti di analisi.

Gli autori hanno fiducia che questo studio possa essere di aiuto per motivare ulteriori ricerche sul tema dei centri di Big Science, e che le nostre conclusioni possano rappresentare un primo passo verso il superamento dei limiti della letteratura attualmente esistente su questo argomento.



A powerful laser beam is launched from the VLT´s 8.2-metre Yepun Telescope and excites sodium atoms high in the Earth´s mesosphere, creating an artificial star at 90 km altitude. The Laser Guide Star (LGS) is part of the VLT´s adaptive optics system, which allows astronomers to correct images and spectra for the blurring effect of the atmosphere. Across the upper part of the image is the Milky Way. The dark lanes are huge clouds of interstellar dust, opaque to visible light. The ancient Andean civilizations saw in these dark nebulae their constellations, with the shapes of common animals, such as the lama, here visible on the right. The ESO´s Very Large Telescope is composed of four 8.2-metre Unit Telescopes (UTs, where Yepun is UT4) plus four 1.8-metre movable Auxiliary Telescopes (ATs).

Credit: *G. Hüdepohl/ESO (www.atacamaphoto.com).*

1. Introduction

The use of large-scale instruments and facilities to perform ambitious experimental projects is a growing phenomenon that has already changed the method to carry out scientific research. Scientists and historians of science use the term Big Science to indicate this way of conducting scientific research. The huge facilities and infrastructures constructed are called Big Science centers.

Big Science centers are complex systems that involve high-tech equipment and frontier-pushing technologies. Due to the huge amount of technological knowledge they manage, the centers are able to generate technological spillovers to society and to contribute to the economic and technological development of their host country, and of the entire world.

Probably the best-known example of a spillover stemming from Big Science is the invention of the World Wide Web at the "Conseil Européen por la Recherche Nucléaire" (CERN) in 1989. Initially conceived as a mean to improve the sharing of information between scientists, today the Web is the world biggest information space. Other examples include the Grid Computing, also developed at CERN, or the Global Positioning System, known as GPS, invented in a scientific center run by the US Department of Defense (Florio and Sirtori 2015).

Technological spillovers, however, do not always occur. The case of astronomical observatories in Chile is an example of how the establishment of Big Science centers have not yet generated the expected technological and economic benefits in the host country.

The purpose of this thesis is to identify the factors influencing the generation of spillovers from the Big Science projects and to define a theoretical framework explicating the generation of spillovers from the centers in order to motivate why in some contexts knowledge spillovers from Big Science centers happen, and in others not.

The current literature about Big Science has not yet focused enough attention on this topic. The existing studies on the innovation potential of Big Science centers analyzed the organizational learning within the collaboration between Big Science centers and industry (Autio, Hameri and Vuola 2004, Autio, Bianchi-Streit and Hameri 2003). These studies identified the conditions that optimize the collaboration between firms and Big Science centers, allowing the generation of technological spillovers. However, as we illustrate in this research, these findings do not explicate why, in some cases, knowledge spillovers from Big Science centers do not happen.

For this reason, we think that the definition of an accurate framework of elements influencing the generation of knowledge spillovers from Big Science centers could be an important contribution to the existent literature.

Furthermore, this thesis could also help policy-makers and managers. The theoretical propositions emerging from this thesis, in fact, represent a guideline for the implementation of successful policies to sustain the knowledge and technology transfer from Big Science centers to industry.

The methodological approach pursued in this thesis is the grounded theory method (Glaser and Strauss 1967), where the theory is supposed to emerge from in-depth case studies. In our research, the theoretical framework will derive from the analysis of two Big Science cases: the astronomical observatories of Chile and the CERN, well-known for its spillover generation capacity.

The study of the Chilean astronomical observatories was accomplished through a field research that we realized in Chile for the duration of nine months. During this period, with the support of a professor and a colleague from the Pontificia Universidad Catolica de Chile, we analyzed the observatories cluster and collected data, thanks to more than 20 interviews and a visit to the Gemini South Observatory.

Astronomical observatories are large facilities that require advanced technologies and are supported by international scientific organizations. Therefore, they represent a unique opportunity for the economic and technological development of Chile.

Chile is the country with the highest number of astronomical infrastructures in the world and, according to some estimates, by the year 2020 Chile will concentrate over 70% of the world's large astronomical observatories (CONICYT 2012).

Chile is endowed with a natural laboratory for astronomic observation thanks to its unique geography. The Atacama Desert in the north of the country is the driest non-polar place in the world. The absence of humidity is fundamental for astronomy since water absorbs light. The country also has two mountain chains, the Andes and the Cordillera de la Costa, which allow the location of observatories in remote mountaintops away from the urban light pollution. At high altitudes, the air is thinner and this reduces atmospheric distortions. These mountaintops are also located near the Pacific Ocean, where the cold Humboldt Current and the Pacific Anticyclone limit air distortions and the formation of clouds. The resulting environment increases the observation time available for the observatories.

Some of the largest observatories have been built in Chile, including the Very Large Telescope (VLT) of the European Southern Observatory (ESO), the Gemini South telescope managed by the Association of Universities for Research in Astronomy (AURA) and the Atacama Large Millimeter/Submillimeter Array (ALMA), which is the largest astronomical interferometer of radio telescopes of the world.

Even if the presence of these Big Science centers, involving high-tech equipment and technologies, granted the development of the Chilean astronomers' community, the advantages for Chile, from the technological and economic perspectives, are still scant.

In this thesis, we will identify the factors that obstacle the generation of knowledge spillovers from astronomical observatories to firms and we will define a general theoretical framework describing these elements and their context sensitivity.

The thesis is structured as follows: in Chapter 2, we review the literature about Big Science centers and how knowledge spillovers are created; in Chapter 3, we present the research questions; in Chapter 4 we describe the research methodology and introduce the case studies; in Chapter 5 we analyze the case studies and finally in Chapter 6 we report our conclusions.

The appendix contains detailed information about the different astronomical observatories analyzed in this study, and other detailed studies.

2. Literature Review

This chapter will be structured as follows:

- The first section contains an overview of the literature existing on Big Science centers, where we will show the evolution of the studies on Big Science centers, and present the most relevant one.
- In the second part, that is properly the literature review, we will organize the existing literature, in order to reach our objective to understand how knowledge spillovers originate in different contexts. We will firstly characterize Big Science centers from a systemic perspective to understand their features and behavior, in order to attempt to find which elements enable the knowledge transfer to society and firms.

2.1. Overview of literature on Big Science centers

The trend of building large-scale facilities to conduct scientific research began to spread in the twentieth century. Scientists needed better instrumentation to test their theories and the governments began funding Big Science centers as a response to this demand (Weinberg 1967). As Big Science centers evolved, they not only produced important scientific discoveries, but also began to generate other types of technological spillovers to society. There are multiple cases of new technologies, scientific instrumentation, or even management techniques stemming from these centers. Furthermore, Big Science centers, due to their dimensions, characteristics and needs are able to create important economic benefits for the society.

The studies about the benefits generated by Big Science centers are not numerous. However, they can substantially be classified into two fields:

1. Quantitative Economic Studies: These studies mainly employ input-output analysis to assess the macro-economic impact of the centers and to calculate economic and financial ratios (CBRE 2010, Batelle 2011, Lindstrom 2009, Bianchi-Streit, et al. 1984).
2. Qualitative Innovation-related Studies: These studies employ qualitative methods to identify the innovation benefits and the technological spillovers generated by Big Science centers (Autio, Hameri and Vuola 2004, Autio, Bianchi-Streit and Hameri 2003, A.-P. Hameri 2000, Nordberg, Transaction costs and core competence implications of buyer-supplier linkages: the case of CERN 1997, Zuijdam, et al. 2011, Vuola and Hameri 2006).

The first typology counts a larger number of studies than the second one. These works evaluate the direct economic benefits generated by Big Science centers, but are not able to provide so much insight into how the Big Science centers are able to generate knowledge spillovers, acting as learning environments for firms collaborating with them.

The existence of secondary benefits generated by Big Science centers, beyond the mere economic ones, was reported by Bianchi-Streit et al. in a study of 1984 (Bianchi-Streit, et al. 1984). However, only from the end of the 90s, the researchers started to study the innovational aspect of Big Science centers.

These studies are mostly focused on the CERN ecosystem and investigate its innovational potential and the characteristics of the knowledge spillovers it generates. A study of Nordberg on the contracts between CERN and firms attempted to identify the benefits that the suppliers could obtain thanks to the collaboration with CERN (Nordberg 1994). Other studies investigated the motivations that lead firms to start collaborations with Big Science centers (Autio, Hameri and Nordberg 1996, Nordberg 1994, A.-P. Hameri 1998).

The topic of knowledge and technology transfer from Big Science centers was examined by Autio et al. in their paper of 2004 (Autio, Hameri and Vuola 2004). They focused their attention on the organizational learning within a collaboration between firms and CERN, explicating how firms could enhance the knowledge transfer from the scientific centers. They proposed a set of theoretical propositions, which describes how the Big Science centers could operate as sources of learning for industrial suppliers and how their industrial collaborations could successfully lead to the generation of knowledge spillovers. In another paper, Autio proposed a theoretical framework illustrating the technological innovation potential provided by Big Science facilities over their life cycle (Autio 2014).

Reviewing the literature on the topic, we found that there are some gaps. There are sufficient studies on which are the innovational benefits generated by Big Science centers and the motivations that lead firms to start a collaboration with them. There are also scientific works showing why and how the Big Science centers could operate as learning environments for industrial suppliers. However, it emerged that there are no sufficient studies explicating why the knowledge transfers in some cases occur and in others not. Furthermore, the lack of scientific works focused on contexts, different from CERN, is another important gap.

The literature review we present in the next section better clarifies which are these gaps and their relevance.

2.2. Big Science centers as Complex Systems

The purpose of this chapter is to characterize Big Science Centers from a system perspective, describing their main components and the architectural features governing their behavior, and to understand how they are able to generate knowledge spillovers to society.

Big Science centers are complex systems involving remarkable resources—both economic and human—and many technological subsystems. The European Extremely Large Telescope (E-ELT), for example, will cost approximately €1.5 billion and its parent institution, the

European Southern Observatory (ESO), employs 730 staff members distributed between the headquarters in Germany and the facilities in Chile (ESO, Cogen 2015).

Big Science centers also involve sophisticated infrastructures that require highly sophisticated, even frontier-pushing technologies. The Large Hadron Collider at CERN, for example, is the most complex experimental facility ever built. It includes the world largest and most powerful particle accelerator, which lies in a 27-kilometer tunnel, buried 175 meters beneath the France-Switzerland border (O'Luanaigh 2014).

Beyond these structural characteristics, Big Science centers are complex because of the many governments, institutions and general stakeholders involved in their development and operations (Chompalov, Genuth and Shrum 2001). The ATLAS project, one of the four experiments conducted at the Large Hadron Collider, involves more than 3000 physicists, which belong to 179 institutes from 38 different countries (Boisot, 2011). Similarly, the Association of Universities for Research in Astronomy (AURA) is a consortium of 39 U.S. universities and 7 International affiliate universities. Thus, different local, national, or international institutions may influence the behavior of a Big Science center (Autio, 2014).

To analyze the different institutional spheres is a complex task, especially considering that each stakeholder involved joins the Big Science projects for different reasons. For example, the international scientific community may expect new astronomical discoveries from an observatory, while local institutions in the host country may search for an economic return or technological spillovers from the project. Stakeholders' goals may be concurrent or divergent and this factor adds another layer of evaluative complexity to the system (Sussman, Dodder, McConnell, Mostashari, & Sgouridis, 2007).

Another characteristic of the Big Science centers is their long life cycle. The costs and the benefits related to the Big Science centers are not perfectly determined initially, and may evolve over the time (Florio and Sirtori 2015). For example, the La Silla observatory in Chile was built 50 years ago. The High Accuracy Radial Velocity Planet Searcher (HARPS) instrument, currently mounted on La Silla's 3.6-metre telescope, was commissioned 40 years after the building of the observatory. Planning for new instrumentation requires modular architectures and a long-term economic commitment of the stakeholders to sustain the Big Science center.

The dimension, the multi-stakeholders environment and the technological complexity of Big Science centers imply that their influence goes beyond the borders of science. Those facilities are able to generate a relevant economic return and technological development.

2.3. Benefits generated by Big Science centers, technological spillovers and knowledge flows

Big Science centers have the potential to generate economic benefits (Beise & Stahl, 1999; Rosenberg, 1992; Rosenberg & Nelson, 1994). These benefits can be direct or indirect.

Direct benefits include employment and business opportunities for individuals and firms thanks to the construction, consolidation, maintenance and operation of the Big Science center (Zuijdam, Boekholt, Deuten, Meijer, & Vermeulen, 2011).

Indirect benefits, instead, refer to the economic and social advantages caused by the knowledge flowing from the scientific centers to the society.

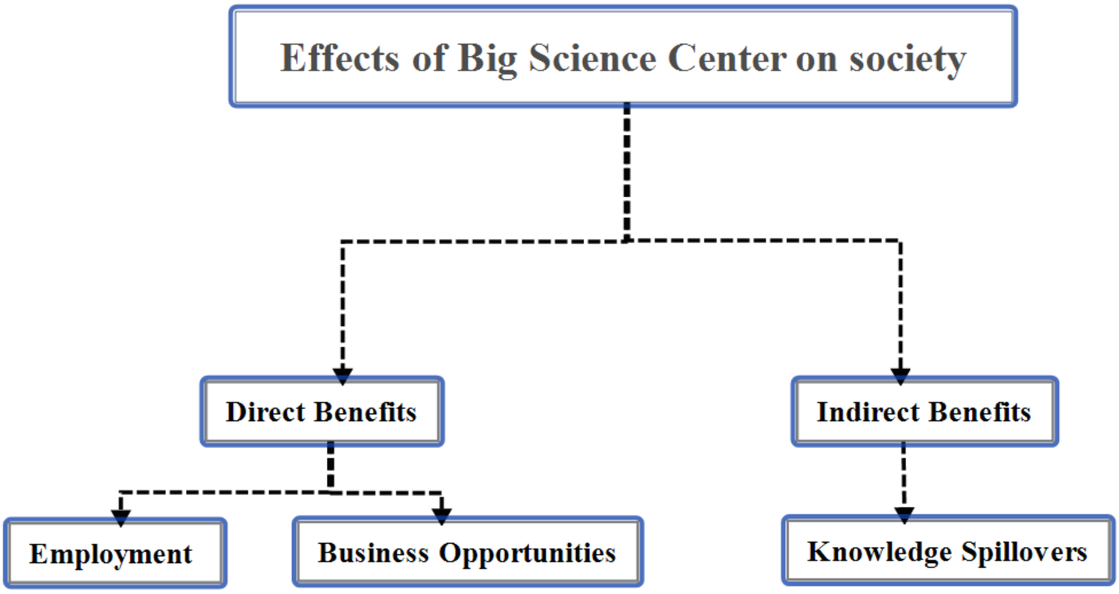


Figure 1: Benefits generated by Big Science centers.

Big Science centers, in fact, are able to generate innovation and technological development (Autio, Hameri and Vuola 2004, Rosenberg e Nelson 1994). The reason is that Big Science centers, to reach their scientific objectives, must design and build scientific instruments with technological requirements that often overcome the technology currently available on the market (Autio, Bianchi-Streit e Hameri 2003). The new technological knowledge created can be transferred to firms that collaborate with the centers, or to other industrial contexts enhancing the technological advance.

In this section, the focus is on the indirect benefits generated by Big Science centers.

We classify the knowledge flows from Big Science centers to firms and, successively, we identify the elements that allow the generation of knowledge spillovers from the Big Science centers to industry.

Various typologies of knowledge spillovers that can originate from Big Science centers. Big Science centers, in fact, manage and combine a huge amount of different knowledge typologies (Bressan 2004, Bressan e Boisot 2011).
We identified five different typologies of knowledge spillovers: scientific knowledge spillovers, technological knowledge spillovers, access to a knowledge network, organizational benefits and market learning benefits.

1. ***Scientific knowledge spillovers***: Scientific discoveries expand the scientific information available to firms to carry out their technological activities and their R&D processes (Salter and Martin 2001).

2. ***Technological spillovers***: the collaboration with a Big Science center allows firms to learn about new technologies, new instrumentation, new techniques and new methodologies (Salter and Martin 2001). Thanks to their technical and scientific resources, Big Science center can help firms to improve their competencies and innovation processes (Autio, Hameri and Vuola 2004) and to create spin-offs from contract work (Autio, Hameri e Nordberg 1996).

3. ***Access to a knowledge network***: From the firm point of view, the collaboration with a Big Science center opens the doors to a world-wide community of research and technological development (de Solla Price 1984) and to new commercial and innovational opportunities (Cohendet 1997). Big Science centers, due to their collaboration with different firms and institutions are powerful hubs for the development of networks (Lauto e Valentin 2013). Furthermore, in the world of the scientific research, where informality in the relations is fundamental (Faulkner, Senker e Velho 1995, Rappa e Debackere 1992), collaborating with Big Science centers can significantly improve the reputation of a firm, and consequently provide the possibility of new commercial opportunities (Autio, Hameri e Nordberg 1996).

4. ***Organizational benefits***: they consist in the learning of new managerial techniques or in new ways to configure the firm processes (Cohendet 1997). Thanks to the collaboration with Big Science centers, the industrial partners may improve their organizational competences and capabilities, in the fields of logistics, new product development, and so on.

5. ***Market learning benefits***: The firm collaborating with a Big Science center learns about new, or emerging, international or specialized markets. Big Science centers permit to the supplier companies to gain insights of the opportunities of such markets and to act as lead users (Von Hippel 2005) – lead users face needs that will be general in a marketplace, and face them earlier than the others, taking advantage in terms of experience and flexibility - (Boisot 2011).

All these knowledge spillovers can originate from the Big Science centers in three ways: diffusion of scientific knowledge, training of human capital, and collaborations with firms.

a) ***Diffusion of new scientific knowledge***. This flow of knowledge is strongly linked with the main objective of these centers: the scientific research. The new scientific knowledge may be disseminated among society through publications, conferences, patents, new software products and algorithms (Autio 2014), but also through technological innovations produced by the center itself (Bianchi-Streit, et al. 1984).

b) ***Training of highly-qualified human capital***: students, researchers and other stakeholders working within Big Science centers often develop relevant technological and problem-solving skills (Salter and Martin 2001). These skills can feed the expertise of the companies where they will be employed (Cohendet 1997).

c) ***Collaboration with firms***: Collaborations are the best way to transfer knowledge from Big Science centers to firms. Firms that participates to Big Science projects are exposed to the knowledge environment of the Big Science center, and knowledge spillovers can easily be a consequence of this kind of technological relationships.

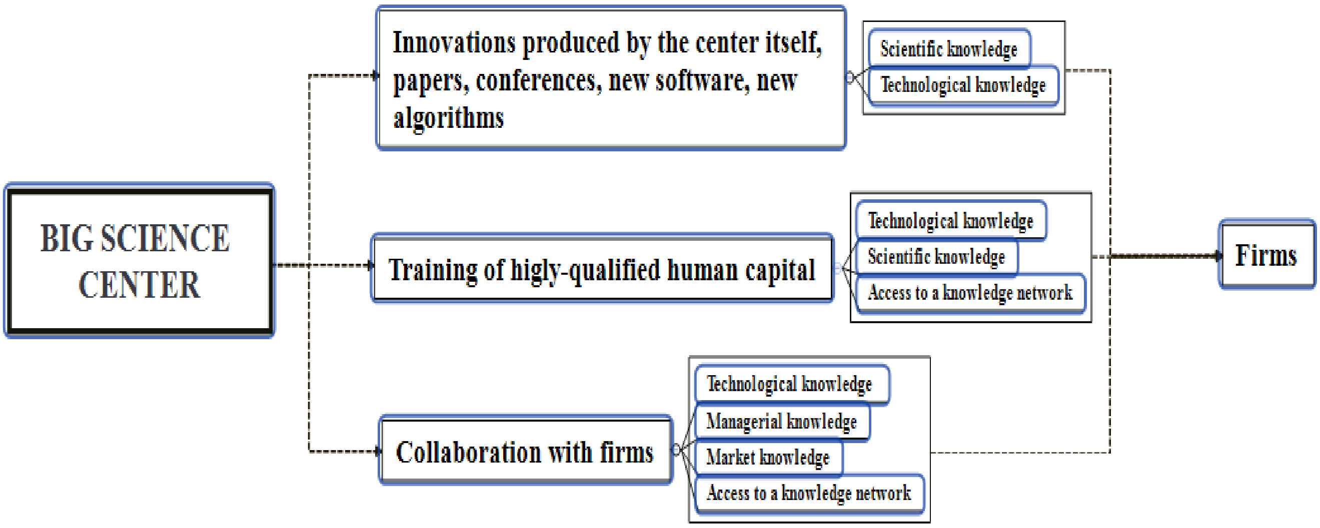


Figure 2: Knowledge Flows from Big Science centers to firms

2.3.1. Elements influencing the generation of knowledge spillovers

In this section, we focus our interest on the elements that influence the generation of knowledge spillovers from Big Science center to industry. In line with the main purpose of this thesis, our interest is on the generation of knowledge spillovers through the collaboration between the centers and their supplier firms. This kind of knowledge transfer is heavily influenced by the Big Science center nature and by the context where it stands.

Firstly, we will describe the elements, emerging from literature, which guarantee an optimal collaboration between Big Science center and firms. A successful collaboration, in fact, is an essential factor for the generation of knowledge spillovers.

Reviewing the literature, there are two elements that enhance the actors coordination, enabling the generation of knowledge spillovers to industry: the build-up of *social capital* and the *absorptive capacity* of the firms.

The social capital is the sum of the actual and potential resources embedded within, and derived from the network of relationship possessed by an individual or social unit (Nahapiet e Ghoshal 1998). Social capital regulates the knowledge disclosure and the knowledge transfer by: 1) increasing the willingness of the parties to provide each other access to their contact networks, 2) increasing trust and strengthening norms of reciprocity, 3) increasing knowledge overlaps and thereby shared knowledge and understanding between parties, and by soliciting the co-alignment of organizational goals (Autio, Bianchi-Streit e Hameri 2003).

The absorptive capacity is an organization's ability to acquire useful knowledge from its involvement with a relationship with another organization (Child, Ihrig and Merali 2014, Cohen and Levinthal 1990). A firm that owns absorptive capacity is able to develop and to combine existing knowledge and the newly acquired and to apply the newly acquired knowledge in products or services that can generate financial benefits (Zahra e G. 2002).

The dynamic of knowledge creation and knowledge transfer in the scientific fields is an element that can be influenced by the nature of the Big Science center and by the context where it operates (Autio 2014). For this reason, these elements are affected by the network, the environment, the institutions and the other stakeholders. These characteristics determine the potential of the Big Science center to generate spillovers.

The build-up of social capital within a collaboration with a Big Science center can be influenced by the sector and the context. In fact, it depends on several factors such as the complementarity of organizational resources (Nahapiet e Ghoshal 1998) and the compatibility of organizational goals (Dyer e Singh 1998), but also on the characteristics of the technological knowledge that will be shared, and by the propensity of the actors to interact (Bressan e Boisot 2011).

The technological knowledge of the individuals derives from the scientific sector where the collaboration takes place. Similarly, the actors' propensity to interact and the network that an individual is able to create depend on the nature of the network and its characteristics. For example, in some cases, the scientists' communities can be quite closed to the external and this may disadvantage the propensity of individuals to interact.

In closed social networks, knowledge quickly becomes redundant, and the potential for creating knowledge and for radical innovations may decrease (Burt 1992, Nohria e Eccles 1992). Similarly, also the network potential to generate knowledge spillovers may be reduced.

The absorptive capacity of a firm is mostly influenced by the diversity of background and by the prior related knowledge of the organizations that are collaborating (Cohen and Levinthal 1990). These factors depend strongly on the context in which the firms operate. Of course, it is different to establish a collaboration in high-technologic countries, as European ones in the case of CERN, or in countries that only recently are developing their technological industrial sectors, such as Chile in the case of astronomical observatories.

2.4. Literature gap

Consulting the literature on the benefits generated by Big Science centers, we found some gaps. First, there are few studies about the benefits generated by astronomical Big Science facilities for the society, and particularly for Chile, the country with the greatest number of astronomical infrastructures. In fact, the academic literature on technological spillovers stemming from Big Science projects is scarce and the few existing articles and books are mostly focused on the CERN case.

The existent studies, focused on astronomy, affirm that there are several benefits deriving from the establishment of an astronomical observatory (Soares Fernandes 2011, Science and Technology Facilities Council 2010): some of these studies focus on the opportunities of technologic transfer to other sectors and to the academic benefits (Chilean Ministry of Economy 2012), others focus on the actions to do in order to exploit the potentiality of the presence of the observatories (CONICYT 2012). However, there are not studies that attempt to explain how these benefits are generated.

In second place, being almost all the studies focused on the CERN reality, there is a lack of literature on how the benefits, that the Big Science centers can generate, may vary, changing the context where the Big Science center stands.

Third, existing literature has focused its attention on the elements that influence the success of a collaboration between firms and Big Science centers and the generation of knowledge spillovers (Autio, Hameri and Vuola 2004). However, as seen, these elements are not enough to explicate the divergence of results in different contexts. In our opinion, there are not sufficient studies about the context factors that influence the origin and the development of a collaboration between Big Science centers and industry.

Therefore, the gaps we found is:

- The lack of studies about the elements that influence the origin and the development of collaborations between firms and Big Science centers.
- The lack of a theoretical framework that attempt to explicate why knowledge spillovers originate in some contexts and not in some others.

3. Research Questions

In the literature review, we analyzed the scientific studies regarding Big Science centers and their collaboration with industry, describing the centers from a system perspective, characterizing their potential benefits for society and identifying the elements influencing the generation of knowledge spillovers and technology transfer.

We recognized the gaps of the existing literature that has not yet focused its attention on: the elements influencing the origin and the development of the Big Science collaborations with industrial partners, and the definition of a theoretical framework explicating the importance of the context, where the Big Science center stands, for the generation of knowledge spillovers.

Following the presented literature review, and considering the gaps identified in the state-of-the-art literature, the following research questions arise:

RQ1: What are the elements that permit the generation of knowledge spillovers from astronomical observatories to firms?

By answering this first question, a better understanding could be achieved regarding how knowledge spillovers from astronomical observatories can be generated. It would be the starting point to answer the second question.

RQ2: Why in some contexts knowledge spillovers from Big Science centers originate and in others not?

This question will be answered comparing two case studies: CERN and astronomical observatories in Chile. The answer to this question can contribute towards filling the gap regarding the lack of a theoretical framework that attempt to explicate which are the elements that allows the generation of knowledge spillovers from Big Science centers in different contexts.

The contribute of this thesis to the existent literature is the proposal of a theoretical framework of elements influencing the origin and the development of collaborations between firms and Big Science centers in order to motivate why in some contexts knowledge spillovers from Big Science centers happen, and in others not.

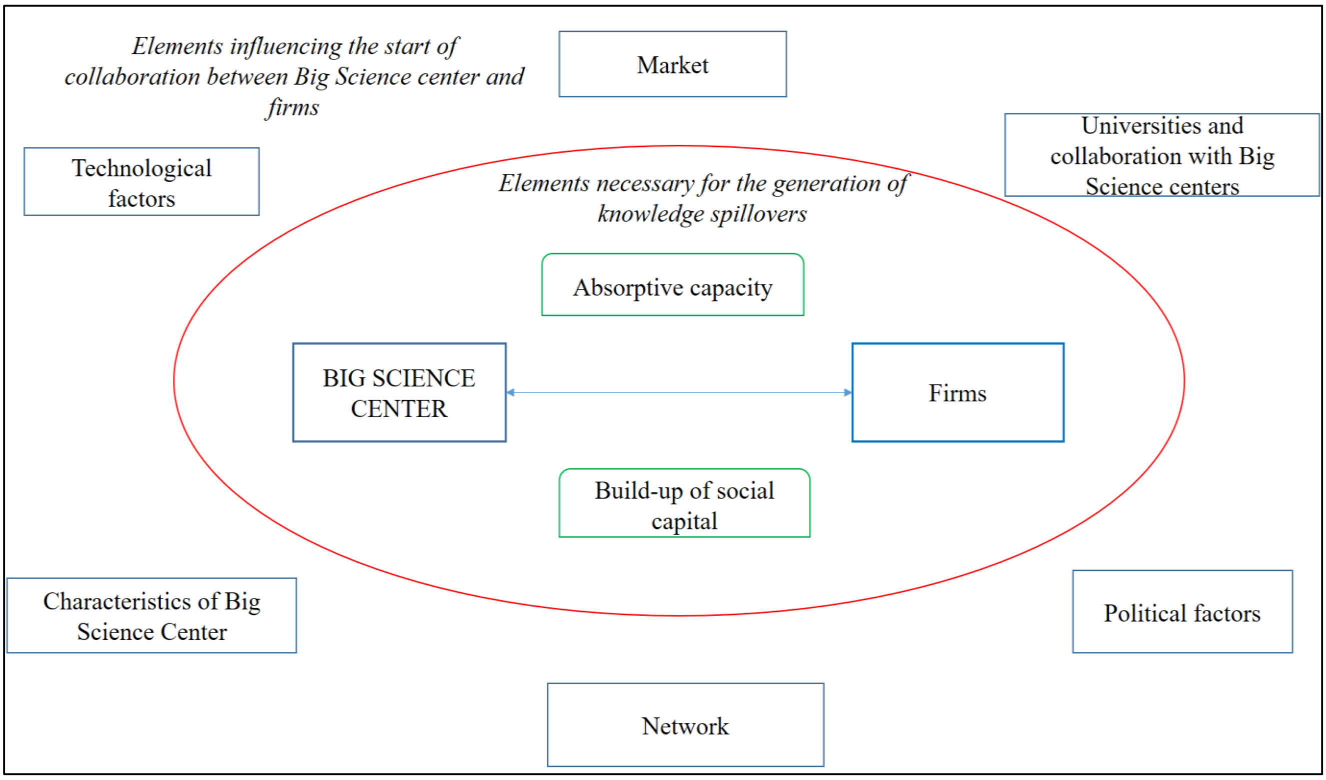


Figure 3: Framework of the elements that influence the origin of a collaboration between Big Science centers and firms and the generation of knowledge spillovers.

4. Methodology

In this study, we applied the grounded theory method to develop our theoretical framework in order to describe the observed entities and provide an answer to the research questions.

In the grounded theory method, the theory is supposed to emerge from in-depth case studies (Glaser and Strauss 1967). Therefore, we did not develop a preconceived theoretical framework that would then be refined through the cases. Rather, we sought to analyze the cases to determine what would emerge from them (Eisenhardt 1989).

The methodological approach we used in the development of this qualitative study consisted in a preliminary field research (Merriam 2009) and a consequent inductive multiple case study analysis with different embedded units of analysis (Yin, Case Study Research: Design and Methods 1994).

In the analysis, we contrasted two case studies: the case study of the astronomical observatories of Chile and the CERN one. We chose to adopt a multiple-cases research design, because it allows doing a comparison between two different realities and is the best tool to examine directly the innovation process and the knowledge and technology transfer mechanisms (Salter and Martin 2001). Furthermore, we used multiple units of analysis (Yin, Case Study Research: Design and Methods 2009). The units of analysis are the Big Science center itself, the supplier firms, involved in the operations, and the collaboration between them.

The choices we made try to balance the objectives of the present study with the available time and resources for this work. By going ahead with this methodological approach, we also relied on the findings of the related literature that showed that analogue approaches achieved satisfactory results while studying the similar ecosystem of CERN (Autio, Hameri and Vuola, A framework of industrial knowledge spillovers in big-science centers 2004).

4.1. Research Design

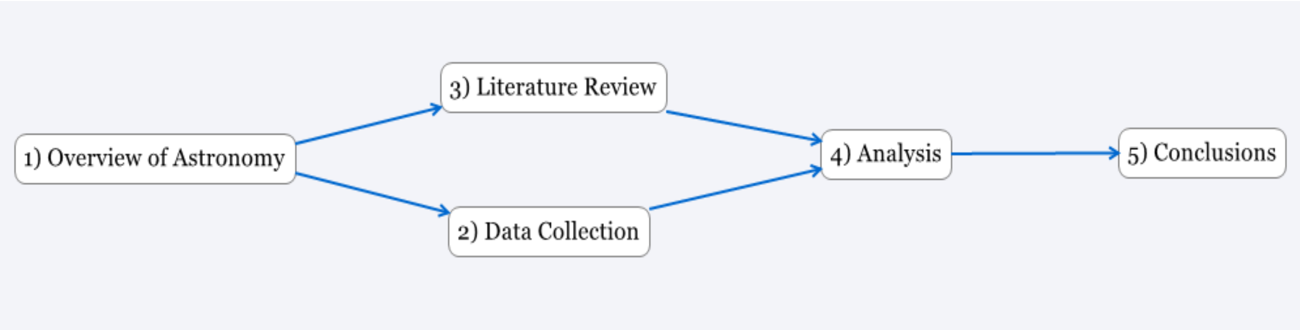


Figure 4: Scheme of the Research Process.

The figure shows the five phases of the research process followed to conduct the study.

In the first phase, after our arrival at Chile in the October 2015, we needed to take an overview of the astronomical ecosystem in order to understand the current situation in the world and in Chile. Therefore, in the first weeks, we used the methodology of Complex, large-scale, interconnected, open, sociotechnical (CLIOS) Process (Sussman, et al. 2007) to model and analyze the complex system of astronomical observatories.

In particular, we accurately analyzed the La Silla Observatory, built and operated by ESO, and the Atacama Large Millimeter/Submillimeter Array Observatory (ALMA). Detailed information about these two astronomical observatories are reported in Appendix.

This preliminary modeling step allowed us to become acquainted with the technological layers of the astronomical facilities and the organizations and institutions involved in their operations.

Thereafter, in November 2015, we began the data collection phase: an extensive field research study about the Chilean astronomy ecosystem with the objective of obtaining useful information to characterize the case studies. The field study lasted for 8 months, ending in June 2016.

A key moment of this step was our participation at the astro-engineering workshop "Taller de Astroingenieria 2015", which was held in Santiago de Chile and lasted three days, from the 24th to 26th of November 2015. We attended at about 50 lectures, on the subject of astronomy, of speakers from astronomical organizations (ESO, AURA, NRAO), Chilean institutions, universities and supplier firms. The workshop was a useful occasion to meet people involved in the astronomical and astro-engineering ecosystem and a perfect mean to network and arrange the future interviews.

Consequently, we started conducting the interviews from November 2015 until June 2016. Since our objective was to gather information about the astronomical ecosystem in Chile and to analyze it from different perspectives, we chose to select for our interviews people from the four main stakeholders' typologies involved in the astronomy network: Universities, International Astronomical Organizations, Political Institutions and Supplier Firms.

The interviews were carried on by us along with a colleague from the Pontificia Universidad Catolica. We first contacted the interviewees by email in order to arrange a meeting. The interviews were conducted face-to-face, except for two by Skype and one by telephone. The meetings were done in the offices of the interviewees and all the conversations were audio-recorded.

The majority of the interviews were carried on in Chile: in Santiago and at the Gemini South Observatory in the Region of Coquimbo. Other interviews were conducted in Rome and Milan, in Italy, with managers of Italian supplier firms.

The interviews were semi-structured and we arranged a specific and different question schedule for each interviewee depending on its role and experience in the astronomical or industrial ecosystem.

The main topics of the interviews were the collaboration between astronomical observatories and industry, the possibility of knowledge and technology transfers and the knowledge spillovers.

The interviews also dealt with the specific astronomical ecosystem of Chile, the network between the political and scientific institutions, and the interviewees' opinions about the future development of the situation and potential improvements. If the interviewees did not adequately explain something, we asked additional non-directive questions to obtain further details.

We finished the interviews asking the interviewees to introduce us to other actors involved in astronomy, following a *snowball procedure* until we reached a satisfying saturation (Merriam 2009).

The interviews were systematically audio-recorded and later transcribed to ensure *internal reliability* (Eisenhardt 1989). At the same time, to ensure *external reliability* we contrasted as much as possible our qualitative evidence with other information sources, like quantitative reports and studies, press articles and research papers.

Collectively, during the course of the study, we collected over than twenty interviews, which lasted between 30 minutes and 2 hours and a half, gathering more than 15 hours of recordings. Non-original material (press articles, reports, conference lectures and scientific articles), combined to approximately 40 additional documents.

The stakeholders we interviewed, identified by their role in the astronomy ecosystem, are represented in the bellowing table. For more details about the interviews, see the Appendix A.V. Interviews, Detailed Information.

Interviews	
	Number of stakeholders interviewed
Universities: Full and Assistant Professors at Pontificia Universidad Catolica de Chile and Universidad de Chile.	***6***
Astronomical Organizations: Director of Observatory, Head of Departments, astronomers, engineers.	***8***
Political Institutions: Institutional roles from the Ministry of Economy of Chile, Ministry of Foreign Affairs of Chile and CONICYT.	***4***
Firms: Managers of firms that have collaborated or collaborate with astronomical observatories and other Big Science organizations.	***3***

Table 2: Table of the stakeholders interviewed during the research.

Another source of information was our visit at the Gemini South Observatory on 15th of January 2016, a useful direct field observation of one of the largest optical telescopes of the southern hemisphere and an opportunity to follow the astronomers as they were working. During the visit, we also recorded more than 5 hours of interviews with several AURA astronomers and engineers.

Meanwhile, we began the literature review phase, reviewing scientific articles and papers about Astronomy, Big Science and the interaction between Big Science centers and industry.

Regarding the case study of CERN, we analyzed the existing literature about the topic and the principal sources of information were the following:

1. The works of Autio, Hameri and their colleagues at CERN. These studies present relevant analysis regarding the generation of knowledge spillover to firms at CERN.
2. The studies of Boisot and Bressan, which investigate the process of knowledge creation at CERN.
3. The reports of CERN about technology and knowledge transfer, which illustrate case studies and examples of technology transfer at CERN.

This material, together with press articles, conference lectures and scientific articles about CERN, combined to more than 30 documents, guaranteeing a satisfactory and well-defined overview of the CERN ecosystem.

Later, we entered the analysis phase. We used the qualitative data, extrapolated from the interviews and the other sources of information, to compare the two case studies according to the defined units of analysis (Yin, Case Study Research: Design and Methods 2009).

The output of this step is the analysis that we present in Chapter 5, where we contrast the case studies following several perspectives in order to identify the factors that permit or obstacle the generation of knowledge spillovers and technology transfer from the Big Science centers.

After the detailed critical comparison of the factors of the section 5.1, in the table of the section 5.2 we summarize our theoretical propositions and the corroborating empirical evidence from our case studies. The case evidence gave rise to 41 theoretical propositions, each of which is empirically testable.

Finally, we expressed the conclusions. The findings are presented in Chapter 6 in the form of possible positive initiatives, managerial implications and a general concluding discussion of the emerging theoretical framework.

4.2. Introduction to the two case studies

In this section, we will give a brief overview of the two cases studies object of the thesis: the CERN and the large astronomical observatories in Chile. The overviews deal with a general description of the organizations and a brief focus over the collaboration between the Big Science center and industry.

4.2.1. Large astronomical observatories in Chile

From the second half of the 20th century the international astronomical organizations of the world started to build astronomical observatories in Chile, due to its particular geographic and climatic conditions. Today, Chile concentrates approximatively the 70% of the main astronomical observatories of the world (CONICYT 2012). Some of the largest observatories, like the Atacama Large Millimeter/Submillimeter Array (ALMA) -the largest radio-telescope array of the world- and the Very Large Telescope (VLT) of ESO, are already located in Chile.

Each astronomical observatory involves advanced equipment and instruments in various technological fields as optics, interferometry, mechanics, electronics and information technology. The presence of scientific centers with high technologic needs is an opportunity for the Chilean economy – nowadays founded on the exploitation of raw materials as copper - of developing new hi-tech sectors in the country, and for Chilean firms to reach new business opportunities and innovation.

Each phase of the observatory lifecycle -from the construction of the telescope to the development of instrument and the maintenance of the observatory- present opportunities for firms and scientific institutes.

Firms are strongly involved in the phase of telescope building. In fact, the detailed design, the construction of the dome, the mechanical structure, mirrors or antennas, cooling systems and various services (as power distribution, optical fiber, systems maintenance) are all furnished by firms.

The operational phase of an observatory, on the other hand, especially presents opportunities to supply maintenance services or IT products. Further opportunities for firms may originate from the collaboration with universities and institutes in the development of astronomical instruments.

The main characteristics of the technological solutions required by the astronomical observatories are the unicity of the parts needed and the high technological degree, which usually overcome the technology currently on the market. These characteristics imply a strong collaboration between firms and astronomical organizations. The firms selected as suppliers must often deal with advanced and highly specialized technological knowledge to satisfy the requirements.

However, some benefits have already been generated for Chile, as shown by the increase of the number of astronomers and researchers. Instead, from the point of view of industrial spillovers, the results are still scant. The number of Chilean firms that have collaborated with astronomical observatories is small, and no spin-offs have born from astronomical observatories. Furthermore, the few collaborations between Chilean firms and observatories have been focused especially on the maintenance of the facility and the provision of medium-low technological products.

The barriers to the generation of spillovers from observatories to firms in Chile are of various nature: institutional, technological, market-related and firms-related

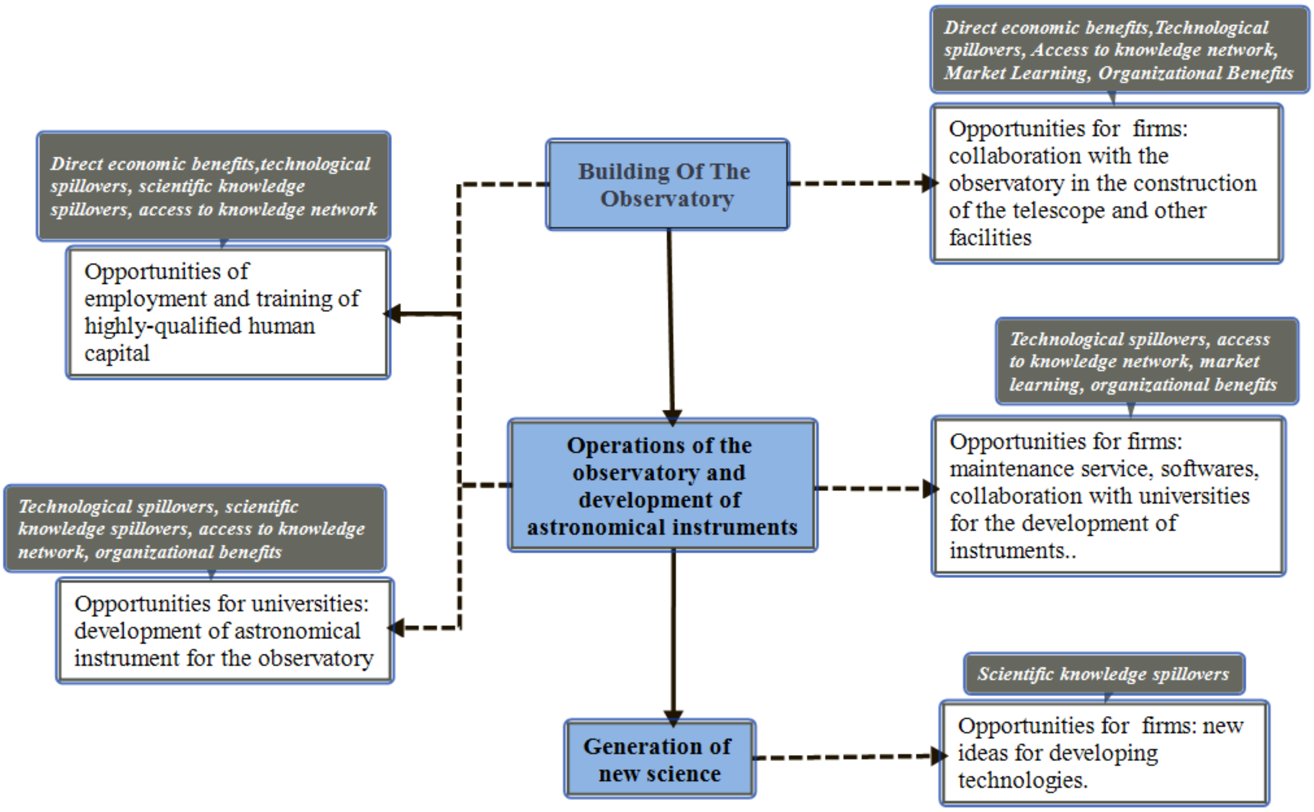


Figure 5: Lifecycle scheme of an astronomical observatory, the opportunities for firms and spillovers generable in each lifecycle phase.

4.2.1.1. The stakeholders

The building and operations of a large astronomical observatory involves different stakeholders. Besides the astronomical organizations, national, international and local institutions, universities and firms are involved. In this section, we will give a brief description of what is the role of the different stakeholders within the astronomical observatories ecosystem.

International Astronomical Organizations: These organizations are multi-institutional collaborations. These are the product of the collaboration between different country governments (ESO), or institutions (AURA is a collaboration between universities from USA and other countries). These organizations usually have a big staff of astronomers and technicians and own several observatories. All the biggest astronomical organizations of the world, own astronomical observatories in Chile. For a list of all the astronomical organizations present in Chile and their observatories, see Appendix A.I. Astronomy in Chile: List of large astronomical observatories present in Chile.

Chilean institutions: Several Chilean institutions are involved in relationships with astronomical observatories.

The Ministry of Foreign Affairs of Chile: To build an astronomical observatory, astronomical organizations have to sign an agreement with the Chilean Government. The nature of the deal depends on the nature of the astronomical organization. The agreement with ESO, that is a collaboration between different countries, is a treaty between the Chilean Government and all the country that constitute ESO. In the case of AURA, the agreement is a convention between the universities and the Universidad de Chile. All the agreements with observatories are ratified and managed by the Ministry of Foreign Affairs, which recognize to astronomical observatories a diplomatic status and the taxes exemption.

The National Commission of Scientific and Technological Research (CONICYT): The main tasks of this commission are: 1) to represent the Chilean government in some convention signed with astronomical observatories,2) to manage the funds to be allocated to the astronomical development in the country, 3) to manage the Astronomic Park of Chajnantor and the Chilean observation time of Gemini South and Apex telescope.

The Office of Industrial Liaison (Oficina de enlace industrial) of the Ministry of Economy: this office is involved in the promotion of the development of frontier technology by the Chilean university, and acts as a link between Chilean firms and astronomical organizations.

The Corporation of Promotion of the Production (CORFO): The objective of this institution is promoting the competitiveness and the productive diversification of the country through policy of funding and innovation.

Universities: Since the development of astronomical instruments is usually commissioned to institute and universities by the astronomical organizations, Chilean universities could have an important role in the system and could act as promotor of technological development for Chilean firms. Unfortunately, since today, there are few examples of instrument developed for observatories by Chilean universities. Furthermore, the Universidad de Chile signed agreements with some astronomical organizations (e.g. AURA) and it allocates the distribution of the observation time reserved to Chilean projects.

Firms: Nowadays, only few Chilean firms are collaborating with astronomical observatories, and the products supplied by them are often manufacture of low technological level and maintenance services.

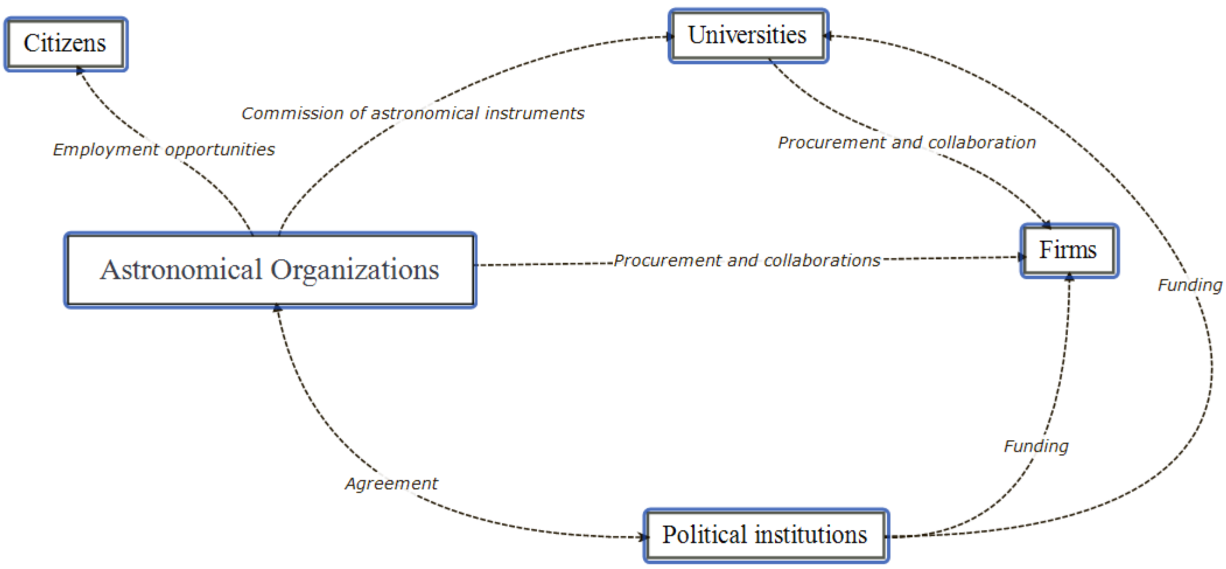


Figure 6: Map of the stakeholders of the astronomical ecosystem.

4.2.2. CERN

The European Organization for Nuclear Research (CERN) is a European research organization that operates the largest particle physics laboratory in the world. Founded in 1952, CERN is located in a northwest suburb of Geneva, Switzerland, on the Franco-Swiss border. In 2016, CERN has 22 member states. The laboratory has 2.513 staff members and hosts some 12.313 fellows, associates, apprentices as well as visiting scientists and engineers, representing 608 universities and research facilities (CERN 2013).

At CERN, physicists and engineers are probing the fundamental structure of the universe. In order to achieve its basic research mission, CERN designs, constructs and operates large-scale particle accelerators and detectors. Each one of these facilities represents a complex Big Science project.

CERN currently operates a network of six accelerators and decelerators. The accelerators boost beams of particles to high energies before the beams are made to collide with each other or with stationary targets. Each machine in the chain increases the energy of particle beams before delivering them to experiments or to the next more powerful accelerator. Detectors observe and record the results of these collisions and can be seen as the equivalent of astronomical instruments mounted at the telescopes.

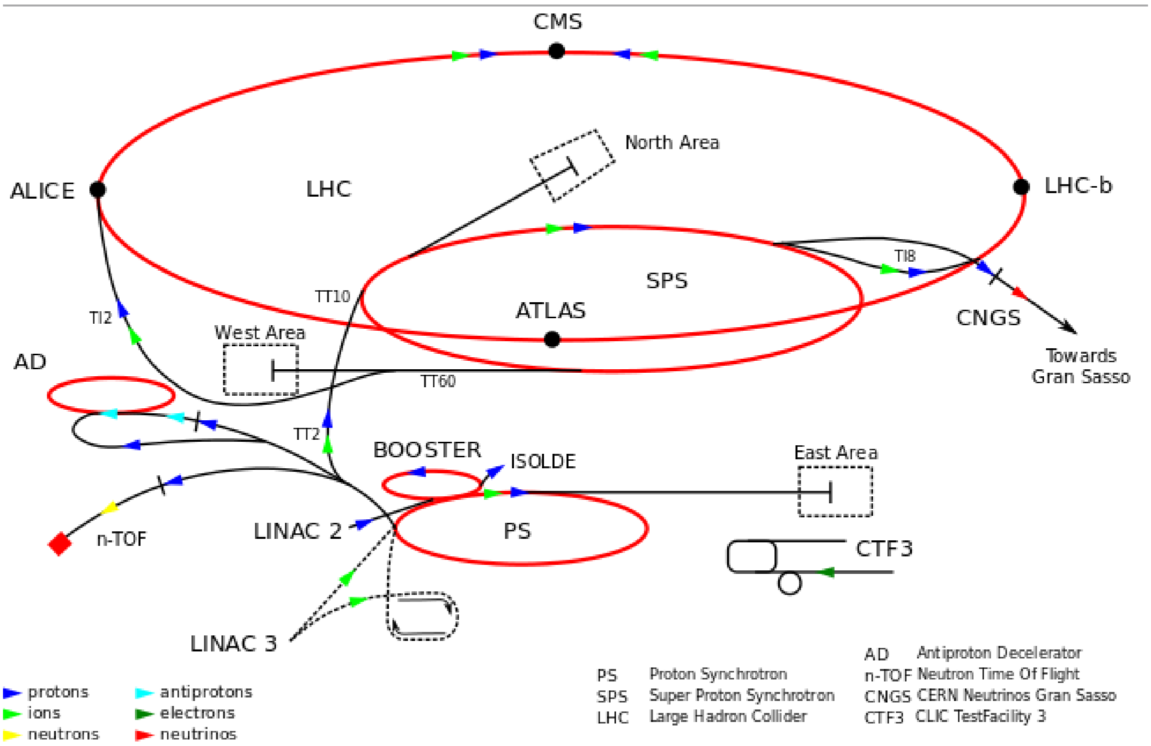


Figure 7: Map of the CERN accelerator complex (Forthommel 2011).

The main components in an accelerator are the accelerating elements and, in a circular machine, the bending magnets. The particles are accelerated inside a vacuum. The accelerating elements and magnets surround the vacuum system. Finally, a control system is needed to operate the accelerators (Nordberg 1997).

The Large Hadron Collider (LHC), for example, is the largest and most powerful particle collider ever built. Designing and constructing a large-scale accelerator and detector systems is a long-term process: its construction lasted ten years, and several scientists, engineers, universities and firms collaborated in the project. Seven detectors have been constructed at the LHC. Among them, we number ATLAS and CMS. Each one of these projects constitutes a collaboration involving numerous actors and institution.
LHC constitutes and extremely complex technological system with technological requirements that often cannot be satisfied by the state-of-the-art technologies (Autio, Hameri and Vuola, A framework of industrial knowledge spillovers in big-science centers 2004).

The collaboration between CERN and European industry is strong and advanced thanks to the high technological degree of European firms and the CERN procurement policy, which guarantees an industrial return to its member states.
CERN has also a large history of spin-offs, technological spillovers and knowledge and technology transfers.
The CERN Knowledge and Technology Transfer Group manages the relationship between the organization and the industrial partners. Every year the Group publishes a Knowledge Transfer Report in order to present the future opportunities and the past year achievements (CERN 2016).

5. Analysis

In this section, we identify which are the factors that enable or obstacle the generation of knowledge spillovers and technology transfer from astronomical observatories. To identify the factors, we will compare the astronomical observatories with the CERN through different perspectives, corresponding to the different fields of analysis. Then, we will define a theoretical framework explicating the origin, transfer and appropriation of knowledge spillovers from Big Science centers.

The perspectives of analysis are:

- **a)** The Big Science perspective:
    - **1.** Intrinsic Characteristics;
    - **2.** Organization and Policy;
- **b)** The market generated by Big Science projects;
- **c)** The political perspective:
    - **1.** The nature of the agreements;
    - **2.** The policy of funding;
    - **3.** The knowledge and technology transfer policy;
- **d)** The universities and their collaboration with Big Science centers;
- **e)** The characteristics of the network;
- **f)** The technological perspective.

5.1. Differences between CERN and astronomical observatories

In this section, we will contrast the found elements in the two study-cases. Generally, we will use the European Southern Observatory (ESO) and AURA as comparison to CERN.

a) The Big Science perspective

The characteristics of the Big Science center, its management and its policy strongly influence the generation of knowledge spillovers to firms. Big Science centers, in fact, are not all identical. They may vary in:

- **Intrinsic characteristics**
  - Type (Single site, distributed, mobile, virtual) (Simmonds, et al. 2013);
  - Geographic and climatic needs of the facility;
  - Scientific area;
  - Culture.
- **Organization and Policy**
  - Management;
  - Knowledge and Technology Transfer Policy;
  - Procurement Policy;
  - Collaboration Policy with other Institutions.

a.1) Intrinsic Characteristics of the Big Science center

In this section, we will discuss the intrinsic characteristics of the Big Science center that can influence the generation of knowledge spillovers.

First of all, the dimension of the facility increases the needs of the facility, and therefore the opportunities of collaboration for the firms. Astronomical observatories are facilities of medium-big size, while CERN currently has the biggest Big Science center existing in the world. The Large Hadron Collider (LHC) is the largest Big Science plant ever built. Due to its bigger dimensions, the necessities of CERN are far higher than those of the observatories. With the next generation of astronomical facilities, the dimensions will sensitively increase, nearing the needs of these Big Science centers to those of CERN. Other relevant intrinsic characteristics are reported in the following table, and discussed in the next paragraphs.

Intrinsic characteristics	***Astronomical observatories***	***CERN***
Type	Multiple Facilities	Unique
Geographical and climatic needs and location	Skies quality, Aridity, Altitude. Observatories are located in remote areas in the Atacama deserts.	No particular needs. CERN is located at Geneva, Switzerland at the center of Europe
Scientific area	Terrestrial Observational Astronomy	Physics of Particles

Table 3: Intrinsic characteristics of Big Science centers.

a.1.1) Type of facilities

The type of facilities indicates the way of working of a Big Science center.

Astronomical organizations, in order to conduct its scientific mission, use more than an observatory. Between the different kinds of astronomical observatories, there is complementarity. Some telescopes, for example, are used to conduct surveys, scanning continuously the sky and individuating "objects" of astronomical interest. Successively, other kinds of telescopes (optical, infrared, radio etc.) take images of the object in order to decipher particular characteristics, only visible under a specific wavelength.

The telescopes are often located in clusters in locations with specific climatic conditions, which are optimal for the astronomical observation (e.g. La Silla Observatory, Cerro Tololo Observatory and the Astronomical Park of Atacama).

However, at the same time, astronomical observatories of a single organization may be located at great distances between them (e.g. The ESO observatory of La Silla is distant almost 600km from the ESO Paranal observatory).

This geographical dispersion of the facilities may be an obstacle to the creation of new knowledge and especially to the transfer of tacit knowledge within the organizations, due to the impossibility of technicians and engineers to interact continuously with each other. CERN, differently, is a unique facility located in a single place. The presence of a unique location, where conduct its research, facilitates the creation and sharing of knowledge.

a.1.2) Geographical and climatic needs

The geographical and climatic needs lead the building of the astronomical observatories in isolated locations, far from the cities and with specific requirements. Astronomical observatories in Chile are located on the top of hills and mountains in desert areas, far away from the luminous pollution of big conurbations. The distance from cities and cultural centers is an obstacle to the creation of a solid ecosystem of firms and universities linked to the Big Science center.

Furthermore, as emerges from the interviews we made with some technicians of Gemini South Observatory, the remote locations of astronomical observatories may create logistic problems that can discourage firms from starting their collaboration. However, on the contrary, the extreme geographical position of the facilities is an opportunity for specialized Chilean firms that have a long history of collaborations within the mining sector, which present similar logistic issues.

Otherwise, CERN does not required particular geographical and climatic conditions. Its location in Switzerland was driven mainly for political reasons: the neutrality of the country during the difficult years of the Cold War ensured the exclusively use of the scientific facilities for peaceful purposes. The scientific heritage and the highly specialized manpower were the other reasons which led to the choice of Switzerland (Bourquin 2010).

CERN location in Geneva, an area rich of firms and scientific institutions in the heart of Europe, surely helps the creation of an industrial ecosystem collaborating with the scientific center. A prove of the existence of such ecosystem are the industrial return rates of Switzerland and France, which show the large commitments that CERN carries on in the countries. Switzerland had a rate of 3,42 in 2015, while France obtained 1,91, two of the three highest values among the member countries.

Detailed data about the 2015 CERN commitments are available in the Appendix A.VII. Procurement Process CERN.

Figure 8: A panoramic view of the Chajnantor Plateau shows the site of the Atacama Large Millimeter/submillimeter Array (ALMA), taken from near the peak of Cerro Chico. (ESO / B. Tafreshi twanight.org).

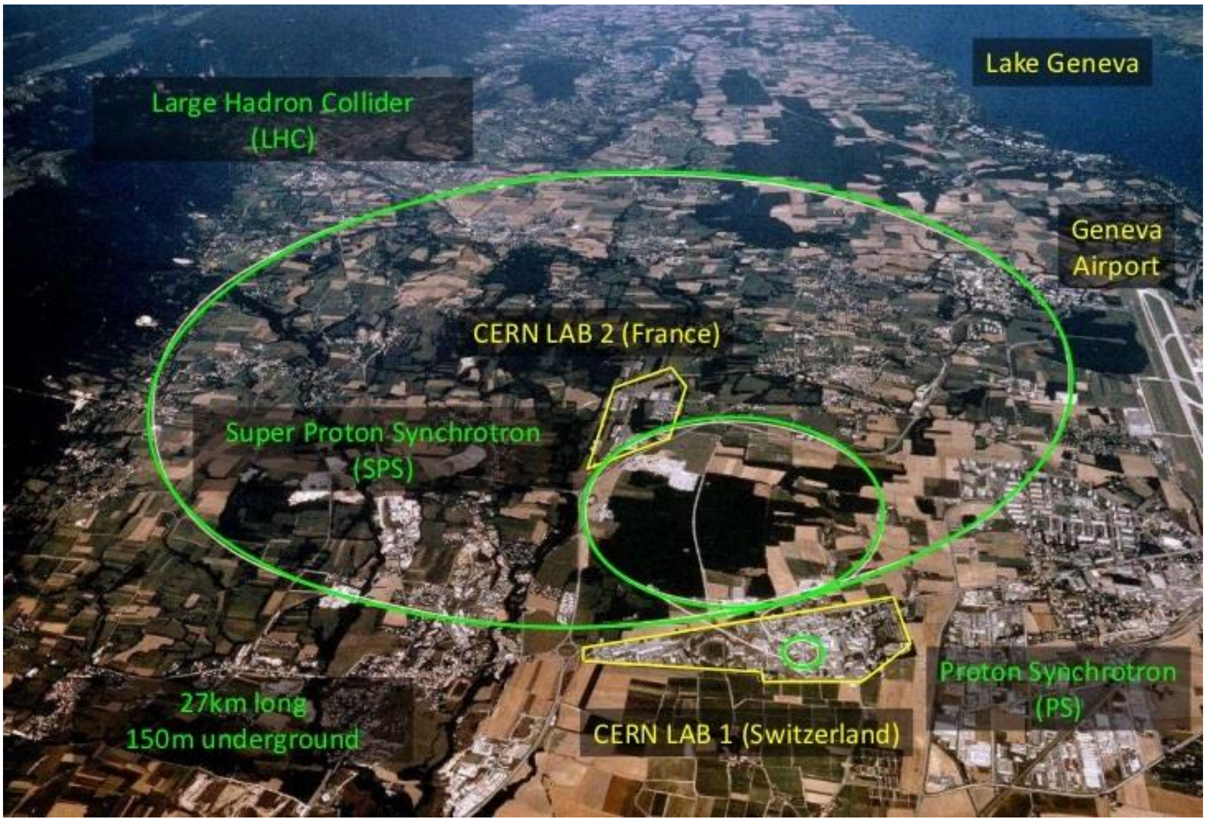


Figure 9: The CERN, located at few miles from Geneva (Truther).

a.1.3) Scientific area

Another factor, which enables a differentiation between Big Science centers and influences the generation of knowledge for firms, is the scientific area of interest of the Big Science organization. This element determines the impact that the new scientific discoveries may have over the human society and, therefore, the value that the scientific knowledge produced has for the industrial partners.

Some scientific areas present a higher correlation between the scientific results obtained and the development of marketable products. In the case of physics of particles, the discoveries, historically, have had a big impact on the industrial ecosystem (Milford 1977). For example, discoveries as radioactivity, nuclear fission, photoelectric effect have been fundamental for the development of the technology of the XX and XXI century. The astronomical discoveries, differently, have had a minimum effect on the industrial society, and seldom create direct business opportunities (Rosenberg, et al. 2016).

a.1.4) Culture

Any Big Science center is characterized by its internal culture. It depends, above all, from the culture of the community of scientists involved and from the national heritage of the Big Science organization.

CERN is a European organization located in the hearth of Europe, where there are not deep cultural differences between the various countries and there is a common high technological and scientific level. Astronomical observatories, instead, are usually property of international institutions that decide to install their facilities in other countries – the host country can also not be a member state of the organization (e.g. Chile with ESO) and may present a lower level of technological and scientific development. This cultural difference may represent an obstacle to the integration between the Big Science center and the host society, and may reduce the collaboration between the stakeholders.

During the first years after the arrival of foreign astronomical organizations in Chile, the integration between the observatories and the Chilean society was not easy. Astronomical observatories, in fact, were seen as foreign bodies in the country and the establishment of occidental organizations was seen as a kind of colonialism (Barandiaran 2015). A reason of this difficulty are also the cultural difference existing between Chile and Europe. Chile, in fact, at the arrival of the astronomical organizations was economically, politically and socially less developed, compared with the European countries. In the last decades of XX century, Chile, like many Latin American countries, lived a period of political instability and dictatorship that reduced drastically the investments in scientific research and prevented the creation of a large scientific community. Such situation represented an obstacle to the collaboration between Chilean stakeholders and the observatories (Barandiaran 2015).

Another example of cultural integration problems between international scientific organizations and native culture is reported in Hawaii, with the building of the Thirty Meter Telescope. In fact, Hawaiian people have been conducting a series of protests because of the choice of the top of Mauna Kea as the location for the telescope. The Mauna Kea is considered the most sacred mountain of Native Hawaiian religion and culture. The protests have been so effective that the Supreme Court of Hawaii invalidated the TMT's building permits. That is an example of how the difficult integration between different cultures may become the failure reason of a successful collaboration between local and foreign stakeholders, and even of the Big Science project itself.

a.2) Organization and Policy

In this section, we will analyze the organization and policy of Big Science centers and we will define how these features may affect the generation of knowledge spillovers to industry.

a.2.1) Management

The management of CERN resides in the Director General, appointed for a term of five years, and in the Council. That organ is composed of not more than two delegates from each member states who can be accompanied by scientific advisers (Article V of the CERN Convention). The Council is the CERN's decision-making organ that determines the policy in scientific, technical and administrative matters; it has all powers to achieve CERN's objectives: it approves the programs and adopts, by a two-thirds majority of member states represented and voting, the parts of the budget for the different projects. The Council meets at least once a year and each member state has one vote. The unanimity is required for the admission of new member states and for amendments of the CERN Convention. The Council also appoints a Scientific Policy Committee (SPC), composed of distinguished European physicists, which has the task of giving advice on the priorities of research programs and the allocation of the research effort. The SPC also makes an annual assessment on the achievements of CERN with regard to the past annual scientific goals (Cogen 2015).

The management of ESO is a bit different from CERN. Like CERN, ESO has two statutory bodies, the Council and the Director. The Council is the plenary organ where every member country is represented with two delegates and at least one of them shall be an astronomer. Each member state has one vote in the Council. Experts may also accompany delegations. The Council elects from among its members a chairperson who hold office for one year. The Council meets at least once a year at the headquarters in Garching, Germany. The presence of delegations of two-thirds of the member states is necessary to constitute a quorum at any meeting.

The Article V of the ESO's Convention defines the Council powers as (a) to determine the policy of ESO in all matters; (b) to approve the budget and draw up financial arrangements; (c) to supervise procurement and approve and publish the annual accounts; (d) to decide on the composition of the staff and approve the recruitment of personnel; (e) publish an annual report; (f) to approve the by-laws; and (g) to exercise authority to take the measures necessary to ensure the day-to-day operation.
In general, the decisions of the Council are taken by an absolute majority of the member states represented and voting (Article V-6 of the ESO's Convention). The unanimity is necessary for decisions concerning the location of the observatory, for the admission of a new member state and for special contributions.
The Council has several committees, which prepare the Council meetings: the Finance Committee; the Scientific Technical Committee; the European Science Advisory Committee;

the E-ELT Science and Engineering Committee; the La Silla Paranal Committee; and the Users Committee.
The Director General heads the secretariat of the organization. The Council appoints the Director General for a fixed term of office (Article VI of the Convention). He is responsible for the general direction of ESO and represents ESO in civil actions. He submits an annual report to the Council and attends the Council meetings in a consultative capacity, unless the Council decides otherwise. The Director General is assisted by scientific, technical and administrative personnel, who are appointed by the Director General (Cogen 2015).

ESO's astronomical observatories are in Chile, far away from the central headquarters of Garching, Germany. Astronomers manage the majority of those astronomical facilities, as it happens also for AURA's observatories (e.g. GEMINI Observatory).
As it emerges from the interviews we made with astronomers, in some astronomical organizations, there is probably a lack of people with a managerial background. The observatories follow the directives that the headquarters' management sends, but the communication of ideas and issues that originate from the observatory environment, seems problematic.
That situation may limit the opportunities for efficiency, innovation and openness to external collaborations.

Differently, in CERN, managerial competences are present in areas related to the technology transfer and the collaboration with industry. A valid example is the Knowledge Transfer Group, the department in charge of the management of the knowledge and technology transfer processes. The managers of the Group present diversified backgrounds spacing from engineering to physics, science and management expertise (CERN KT Group 2016)

a.2.2) The knowledge and technology transfer policy

The transfer of knowledge and technology is an important objective in the activity of most Big Science organizations. Here we will describe and analyze the issue from the perspective of the Big Science international organizations, CERN and ESO. Later, in the section c.3, we will deal with the perspective of political stakeholders, member states and Chile.

CERN has a formal department dedicated to knowledge and technology transfer since 1988, the actual name is CERN's Knowledge Transfer Group whose mission is to maximize the technological and knowledge return to the Member States and promote CERN's image as a center of excellence for technology (Nilsen and Anelli 2016).

The CERN's Knowledge Transfer Group has three main tasks: the identification of technologies, or expertise, which can be object of transfer, the decision of the dissemination strategy and the promotion of CERN technologies to industry. The results of the activity are published each year in the CERN Knowledge Transfer Report (CERN 2016).

The potential transferrable technologies, in CERN, are identified in three ways: a) by direct and informal contacts of CERN members that have a technology or know-how of potential market interest with the Knowledge Transfer Group, b) by the presence of Departmental Knowledge Transfer Coordinators in each Department that act as link between the

Department and the Knowledge Transfer Group, and c) thanks to the institution of Knowledge Transfer Innovation Days that permit department members to showcase their ideas on potential knowledge transfer cases (CERN 2016).

The active dissemination of CERN knowledge to the business sector happens through three basic modes:

- Non-commercial transfer: seminars, informal contacts, publications, staff exchange and training;
- Commercial transfer: collaborations, technical services, consultancy, contract research, licensing and sale of intellectual property;
- New company generation: spin-offs and start-up companies.

Externally from CERN location, a network of business incubation centers (BICs) of CERN technology has been established in the last one and a half year and there are currently eight BICs in CERN's member states. The BICs support the development and exploitation of innovative ideas in technical fields related to CERN activities (Nilsen and Anelli 2016).

Figure 10: Map showing the current location of BICs of CERN technologies and the partner organizations (Nilsen and Anelli, 2016).

Differently from CERN, ESO has no formal policy regarding knowledge and technology transfer. ESO recognizes it as a valuable process that can lead to economic, social and cultural benefits and, within the constraints of its mandate and resources, provides active encouragement to the process.

ESO develops state-of-the-art equipment and awards large contracts to industry for high-tech projects, so the process of technology transfer has been taking place for many years, as stated by the results of a survey carried out to identify and quantify past and present examples of technology transfer at ESO (ESO 2016).

However, the lack of a formal knowledge and technology transfer policy and the absence of a strategy for active dissemination may limit the potential benefits that ESO can provide to his industrial partners and to society. The CERN case may constitute an excellent example to organize and formalize a knowledge and technology transfer division in ESO.

a.2.3) The procurement policy

The procurement process takes on great importance in the analysis of the relationship between Big Science center and their supplier firms. The process characteristics influence the effectiveness of the knowledge and technology transfer between the actors and the possibility to generate spillovers.

The procurement policy of CERN and ESO are similar in many aspects, because both have the same background as European international organizations, but differs in some interesting points.

The objective of the procurement in CERN and ESO is the same: to reach technical excellence at an affordable cost. The bids must fulfil all the necessary technical, financial and delivery conditions and, at the same time, there is the need to keep overall cost as low as possible (Nordberg 1997) (A. Silverman 2012).

In both cases, there is the condition to entail a fair distribution of the contracts among the member states, guaranteeing a right "industrial return", which is measured through each country's "return coefficient", a ratio between the percentage of expenditures in an individual member state and its percentage contribution to the budget (Tamai 2015).
In ESO, the industrial return is only a principle in the procurement strategy, there is no requirement for "juste retour", but there is a strong expectation from the member states of an equitable distribution (Geeraert 2013). On the contrary, in CERN the industrial return is a criterion in the phase of bids selection, in fact, through the "alignment rule", bids from poorly balanced member states are privileged in the contract adjudication (A. Silverman 2012).

The firms that take part in the procurement process come from four kinds of sources: firms can propose themselves, ESO/CERN staff can propose them, the procurement department indicates firms or the Industrial Liaison Office (ILO) of the member state proposes them. In the case of ESO, the ILOs may add firms for contracts that exceed 150000€, while in the case of CERN the threshold of the ILOs intervention is 10000CHF (about 9300€) (Geeraert 2013) (A. Silverman 2012).

Moreover, CERN, differently from ESO, has large technical capabilities onsite and, traditionally, CERN's engineering resources first design, construct and test the prototypes in order to better define the technical requirements. Therefore, CERN has been able to retain its position against suppliers bargaining power. The well-defined technical specifications have also made CERN so far rather immune to the potential hazards of supplier switching (Nordberg 1997).

Another difference is that in ESO the procurement strategy is based on the principle of outsourcing all what can be efficiently performed by outside partners (industry or institutes) while keeping inside ESO the tasks where ESO has a long and specific experience not readily available outside. The consequences of this statement are that ESO procures from vendors no more than what they are experienced and limits contractors' on-site involvement to those tasks that local ESO personal cannot do efficiently (Geeraert 2013) (Tamai 2015). This may safe ESO's core competences and keep the overall sourcing cost lower, but at the same time probably may limit the suppliers' opportunities for knowledge sharing and technology transfer.

From the Chilean point of view, the logic of the industrial return, present in the European organizations' procurement policy, constitutes a natural obstacle for the growth of the collaboration between the Big Science centers and national firms. Actually, the Chilean industry does not participate in the high technological contracts placed by astronomical observatories and one of the reasons is the exclusion determined by the condition of not being a member state.

The Chilean ILO has a fundamental role also from the procurement perspective, as it should enable Chilean industry to participate in that kind of project, bypassing the non-member state condition of the country.

Another element, that discourages Chilean firms from entering a collaboration with Big Science centers, is the high emphasis of tender price as selection criterion during the procurement process. The firms' managers that we interviewed underlined that the margins of the ESO and CERN procurement market are quite low and that may exclude the participation of companies from countries that are not competitive in the global market.

Detailed information about ESO and CERN procurement are provided in the Appendix.

a.2.4) Collaboration policy with other institutions

In Big Science projects, the collaboration between different institutions and organizations is a key factor to success. It ensures an increase in the potential for knowledge disclosure and a broader access to resources (information, capital, staff etc.).

Thanks to these collaborations, the Big Science center may become a powerful networking hub (Lauto e Valentin 2013). From the firm point of view, the possibility to join such a network of institutions and organizations brings benefits in terms of improved firm's reputation, access to scientific expertise and more commercial and innovational opportunities (Autio, Hameri e Nordberg, A framework of motivations for industry-big science collaboration 1996).

In astronomy, there are not steady collaboration agreements between the institutions. The collaboration is limited to occasional exchange of scientific data or launch of joint projects. The most valuable example is the ALMA observatory that is a partnership of the ESO, the

U.S. National Science Foundation (NSF) and the National Institutes of Natural Sciences (NINS) of Japan in cooperation with the Republic of Chile.

Differently, in Europe there is the EIROforum, an organization consisting of eight European intergovernmental scientific research organizations devoted to fostering mutual activities. The eight organizations are ESO, CERN, ESA, European Fusion Development Agreement (EFDA JET), European Molecular Biology Laboratory (EMBL), European Synchrotron Radiation Facility (ESRF), European XFEL Free-Electron Laser Facility (European XFEL) and the Institut Laue Langevin (ILL).

The mission of EIROforum is to combine the resources, facilities and expertise of its member organizations to support European science in reaching its full potential. The EIROforum also works closely with industry to foster innovation and to stimulate the transfer of technology thanks to a thematic working group on Innovation Management and Knowledge / Technology Transfer (TWG IMKTT), a coordination platform aimed at enhancing the cooperation of the EIROforum organizations in the areas of innovation, knowledge, and technology transfer.

ESO and CERN also signed a cooperation agreement on 18th of December 2015. The agreement encourages the coordination of services, tools and resources, in addition to the sharing of best practices in many areas. The organization of joint seminars and workshops is another area of proposed coordination, along with possible exchange of staff.

Moreover, it is common that firms, which have worked with ESA or CERN, collaborate also with ESO. An example is a small sized Italian firm that developed with ESA an innovative electroforming process and few years later started working with ESO, making the electroformed nickel panels for the European antennas of ALMA. The collaboration agreement between ESO and ESA made it possible to that firm to enter a new, but similar, market and so expand its business opportunities.

b) The market generated by Big Science centers

One of the main barriers to the growth of the collaboration between astronomical observatories and industry is the scarce attractiveness, for Chilean firms, of the market generated by the procurement of these Big Science centers.

In first place, it is important to distinguish between three typologies of goods needed by astronomical observatories:

1) ***Procurement of items of medium-low technological level and maintenance services for the observatory;***

2) ***Procurement of goods and industrial services of high technological level, like the maintenance of high technological equipment;***

3) ***Procurement of astronomical instruments, which usually is committed to institutes and universities.***

Our focus is on the second typology of goods since they have a higher potential to generate knowledge spillovers. The procurement of such high technological goods is mostly concentrated in the construction phase of the Big Science facility.

The procurement of high technological goods for astronomical observatories constitutes a niche market, which has two main characteristics that may discourage firms from entering the sector: a) the irregularity and the low volume of the demand, b) the high relation-specific investment requested to produce specific technologies, c) the importance of reputation and prior collaborations.

b.1) Irregularity of the demand and high relation-specific investments

The construction of a new telescope is a long term and not recurring event and this leads to the irregularity of the demand of the sector. The decision to build a new astronomical facility is driven by the need to solve a scientific question and by the technological advance. Each generation of new telescopes, on average, have a gap of twenty years from the former.

In second place, firms that decide to collaborate with Big Science centers have to face an important relation-specific investment. The majority of the technologies needed by observatories are not present on the market when requested. Therefore, the companies have to invest capital, time and human resources in order to acquire the necessary technological competences and to manage the collaboration with the scientific center.

To conclude, the uncertainty of the demand derived from the observatories may discourage the industrial suppliers from investing in the development of cutting-edge technologies. Furthermore, the scarce demand volume may not constitute a “critical mass”, which could enable the construction of a production platform, required to start a viable product development strategy and to penetrate new markets.

The features of the market generated by CERN procurement are similar. The building of new accelerators and detectors is a long-term project similar to that of telescopes. However, there are some differences between the two cases.

A first difference is the dimension of the market generated by the procurement. CERN in 2014 spent approximatively 300 million € for its procurement (CERN 2015). The European Southern observatory – one of the biggest astronomical organization of the world- in the same year spent around 100 million € (ESO 2015). Furthermore, the number of contracts drawn up yearly by CERN is far higher than that signed by ESO.

A second difference is that, the procurement of high technological goods is not concentrated only in the construction phase of accelerators, decreasing the instability and the irregularity of the demand and increasing the attractiveness for firms. It is due to two reasons:

- CERN outsources a bigger number of goods and services than ESO during the phases of operations and maintenance. For example, ESO keep inside tasks as design and implementation of telescope control systems, AIV and the maintenance/coating of large mirrors (Tamai 2015).

- The dimensions of CERN infrastructures are bigger than that of ESO, and this means a larger amount of projects of consolidation and maintenance needs of high technological level.

b.2.) Importance of reputation and prior collaborations

The marketing manager of a small-medium size high technological firm, which has been working in many Big Science projects with ESA and ESO, affirmed in respect of the Big Science sector that:

"In order to succeed in this market, it is important to improve company network participating to conferences, meetings, industry days and to interact with people and organizations"

In the Big Science sector, the reputation of the firm and the experience deriving from prior participations are key success factors.

The project manager of an Italian prime contractor, that will manage the construction of the ESO E-ELT main structure, explained that the majority of the firms enters Big Science projects as a mean to improve their visibility in the market and so extend their range of business opportunities in the same sector or similar ones.

In astronomy, the technological inheritance from previous projects is fundamental. Few firms possess sufficient skills to work with the strict specifications required by astronomical organizations and, therefore, to have a "name" is important. In such a sector, a firm, already known as a provider of innovative and efficient technological solutions thanks to prior participations in high technological projects, has many more opportunities.

The Big Science organizations like ESO, CERN, ESA and NASA need to trust in their industrial suppliers, especially when they are working at frontier-pushing technological instruments, so they give great importance to firms' history and their commitment and results in previous projects.

Also in CERN, the previous considerations about reputation and prior participations are valid. In Markus Nordberg's study emerged that the most relevant motivation for firms to become CERN suppliers is to achieve "marketing benefits" in terms of reference and image lifting, in other words, to improve their reputation and find more business opportunities.

Moreover, differently from ESO, where prior collaborations do not give firms any formal advantage in the procurement process, in CERN, during the supplier selection process, among the relevant factors, there are CERN's previous experience with the firm and an assessment of its technological capabilities.

c) The political perspective

c.1) The nature of agreements with Big Science centers

Big Science international organizations, in order to establish a research center, must sign an agreement with the stakeholders of the host country. Those agreements are very relevant since they define the kind of relationship that stands between the parts and the conditions that they must respect.

The CERN was born with the signing by the 12 founding member states (including the host countries, Switzerland and France) of the Convention for the Establishment of a European Organization for Nuclear Research in Paris on 1 July 1953. The convention stated the principles of the financial contributions from the member states and gave to CERN a legal status in the member countries (Cogen 2015).
Switzerland was chosen as the host country of the facility after a referendum kept in 1953 (CERN 2016). The reasons of the choice are the neutrality of Switzerland, which ensures the exclusively use for peaceful purposes, the important scientific heritage and the highly specialized work force present in the country (Bourquin 2010).
Since part of the installations of CERN also run over French territory, Switzerland and France signed a Convention on 13 September 1965, which deals with the extension onto French territory of the site of the European Organization for Nuclear Research (Cogen 2015).
The agreements CERN signed with the host states, Switzerland and France, gave to the organization a diplomatic status, tax exemption in both countries and defined the conditions to build and operate the scientific facilities and the headquarters.
However, Switzerland and France are above all member states and there are not remarkable differences between CERN relationship with them and CERN relationship with the other member countries.

Regarding the agreements between Chile and the astronomical international organizations, there are three different typologies: the one that was stipulated with ESO, the one of AURA and the case of the Gemini South Observatory.

ESO, as an organization of states, negotiated the agreement directly with the Chilean government. In 1963, ESO signed a convention that granted them diplomatic immunity, exempted ESO from applying Chilean labor law, and granted them tax exemption (McCray 2004). Chile is not an ESO's member state, it was recognized as host country, but, differently from the member states, has a limited participation in the ESO's management, projects and procurement.

In 1997, the executive government of Chile, under the pressure of the scientific community and lawmakers, renegotiated the Convention of 1963 with ESO, in order to put Chile on a more equal footing with foreign astronomers and staff. The new agreement forced ESO to apply aspects of Chilean labor law and granted Chile 10% of the telescopes' observation time, to be used for projects submitted by astronomers at Chilean institutions. Anyway, the foreign observatories retained their diplomatic status and tax exemptions (Barandiaran 2015).

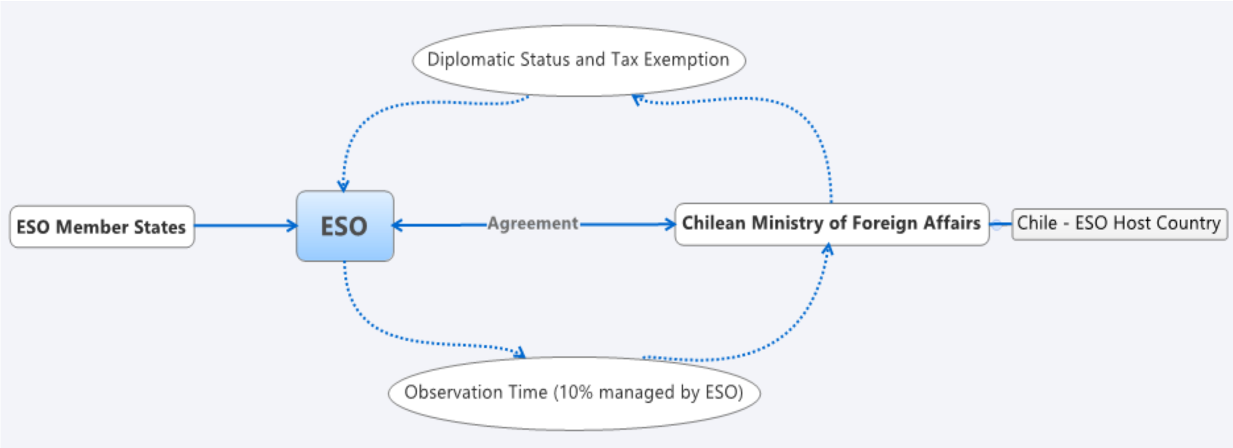


Figure 11: Agreements between Astronomical Organization and political institutions, ESO-Chile

On the contrary, AURA, as an organization of universities autonomous of the government, from the beginning of its experience in Chile has worked in partnership with the University of Chile, with whom signed a collaboration agreement.

The relationship is managed by the Ministry of Foreign Affairs. The observatories received diplomatic status and the organization was granted tax exemptions in the country. In exchange for these benefits, the organization pay the state an annual fee to cover the cost of renting the land telescopes are built on, astronomy postgraduate studentships at Chilean universities, and funds to benefit the local communities where the telescopes are located, such as scholarships and educational projects. Chile also receives a percentage of telescopes' observation time that has to be negotiated between the two parts (generally, it is the 10%, like for ESO's observatories). The University of Chile manages the allocation of the observation time through the Chilean National TAC (Time Allocation Committee), which is organized two times a year and selects the best research projects submitted by Chilean astronomers.

The University of Chile became a member of AURA in 1992 and the Catholic University of Santiago joined the organization in 1997. Since then, Chilean astronomers have been actively participating in scientific and administrative operations (Blanco 2001).

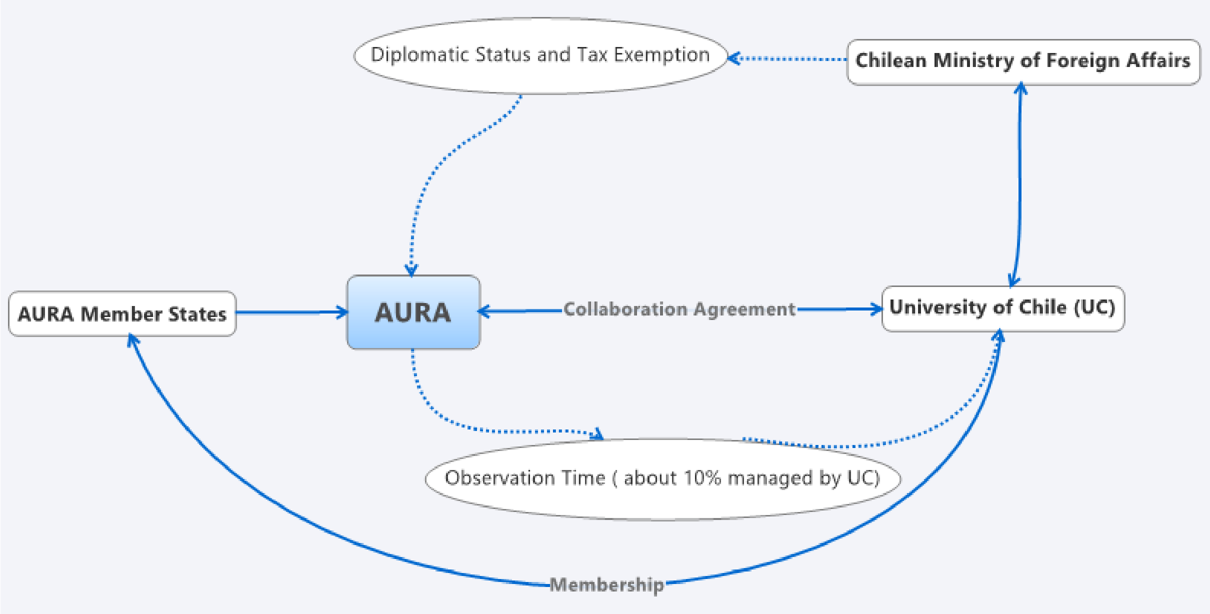


Figure 12: Agreements between Astronomical Organizations and Political Institution, AURA- Chile

A special case is that of the Gemini South Observatory. The Gemini telescopes, Gemini South in Chile and Gemini North in Hawaii, were built and are operated by a consortium consisting of Chile, the United States, Canada, Brazil, Argentina, and Australia. The partnership is managed by AURA, but, differently from AURA's observatories, Gemini signed an agreement directly with the Ministry of Foreign Affairs and the Chilean observation time is allocated by the CONICYT.

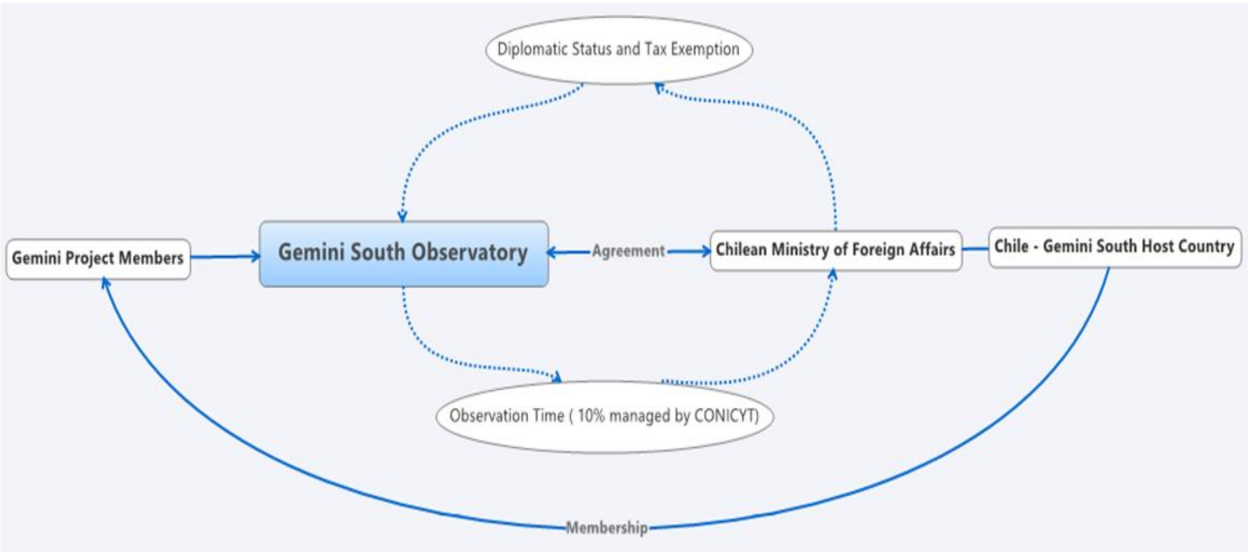


Figure 13: Agreements between Astronomical Organizations and political institutions, GEMINI-Chile

The three different agreement typologies presented display the absence of a unique and well-defined relationship model between the international astronomical organizations and the Chilean government and institutions. This situation implies an incremental complexity in managing the collaboration, because of the many and different actors involved.

Chile was chosen as host country for astronomical facilities because of its unique natural conditions, which make the country the best place in the world for building optical and radio telescopes. As emerge from the interviews we made and some studies, Chile is not fully exploiting the quality of its skies with the only acknowledgment of the 10% of observation time. As stated by the study of Alvarez et al., Chile could start to impose taxes to observatories and would still be the best location in the world to host astronomical observatories (Alvarez, et al. 2010).

It is a fact that the foreign observatories do not pay value added tax (of 19% in Chile) on their annual expenditures, for an amount between US$5 to 80 million per year. If taxed, that would generate money that could be used for research and education (Leighton 2014).

In addition, many complain that the observation time granted to Chile by the agreements is insufficient. Other host countries negotiated better conditions: for example, Hawaiian institutions receive 15% and Spanish ones 20% of the total observation time (Leighton 2014).

Moreover, the agreements signed until today, both with ESO and AURA, do not report any advantage for Chilean firms. There are no clauses in the agreements regarding the assignment of projects to Chilean industry, like the CERN and ESO member states' industrial return.

A common belief, highlighted by many astronomers and Chilean institutions managers we interviewed, is that a renegotiation of the agreements between Chilean government and astronomical organizations could be necessary. More observation time would determine more research opportunities for Chilean astronomical community, while new clauses, that consider the technological participation of Chilean industry in the future projects, would improve the technology transfer and spillover possibilities.

In the world of astronomy, Spain is a positive example since the country obtained a growth of its industrial and scientific sector thanks to the building of astronomical observatories in its territory. The agreements signed with the astronomical organizations granted observing time of exclusive use for Spanish astronomers' projects and considered the assignment of the construction of high-technological parts of the telescopes to Spanish firms.

The recent agreement for the E-ELT observatory construction represents a first step towards a more active Chilean collaboration within those Big Science projects. The project manager of the prime contractor for the construction of the E-ELT structure stated in our interview that a condition in their contract with ESO obliges them to consider a predetermined industrial return for Chile.

c.2) Policy of funding

The policy of funding has a fundamental impact over the relationship between Big Science organizations and their political stakeholders, affecting the centers' operations and projects.

Consequently, it has also important consequences for the collaboration between Big Science centers and firms.

In ESO and CERN, each member state must contribute to the fixed common costs of the organization. The scale of contribution is based on the average national income of each member state for three latest years for which statistics are available. Moreover, ESO and CERN also generates outside resources by EU-funded projects, for example ESO participates in the EU's ASTRONET network which brings together a group of European funding agencies in order to establish a strategic planning mechanism for European astronomy (Cogen 2015).

Funding for science in Chile has historically been erratic and low. In 2011, just 0.44% of Chile's gross domestic product was spent on science (Catanzaro 2014). The funds available for astronomical projects are issued by the Scientific and Technological Research Commission (CONIYCIT).

As it emerged from different interviews with astronomers and institutional roles from the CONICYT, there are four different funds offered by CONIYCIT.

Three of them are funds reserved to post-doctoral researchers:

b) FONDECYT, which finances grants for individual research projects;
c) ALMA&GEMINI, which finances grants for training and development;
d) CAS China-CONIYCIT CHILE, which finances post-doctoral researchers at Chilean institutions.

The fourth fund is the QUIMAL that finances grants for the design and construction of astronomical instruments and the development of astronomical technology for state-of-the-art-research.

The total amount of the fund emitted to design and construction of astronomical instrument is low. In 2012 the first funds were issued and the amount was of 177M CLP (about 250.000$), which corresponds to the 5% of the total funds emitted.

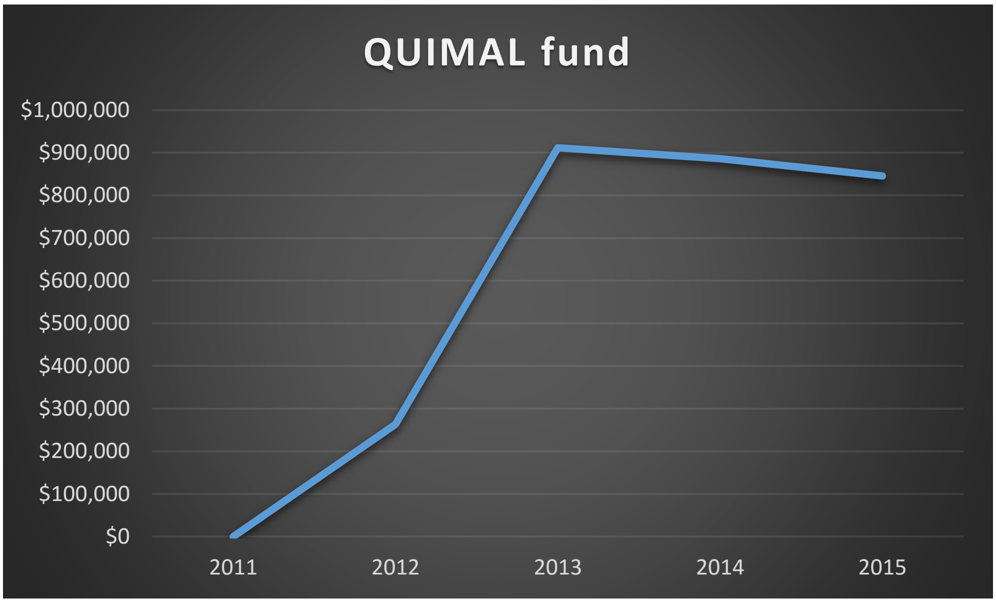


Figure 14: Trend of funding by government in the development of astronomical instruments in Chile. Data are reported in US$.

In Europe and US another important source of funding are private investors like foundations or philanthropists, which invest in scientific projects. That is quite common, mainly in US, where there are private foundations that strongly provide grants for scientific projects[1]. In Europe, an example of private investors is the one of the ATLAS detector of CERN, which was also funded, in part, with private funding.

In Chile, the private funding provided by firms, foundations or philanthropists is scarce. Probably one of the main reasons is the scarce and difficult participation of Chilean companies and laboratories to the astronomical projects.

What emerges from the data and the interviews is that the opportunities to receive funds to build scientific instruments are far higher in Europe and US than in Chile. The following figures shows the level of expenditure in Research and Development of Chile.

[1] Private foundation eureka is an example of private foundation providing funds for astronomy in U.S.A.https://eurekasci.com/funding

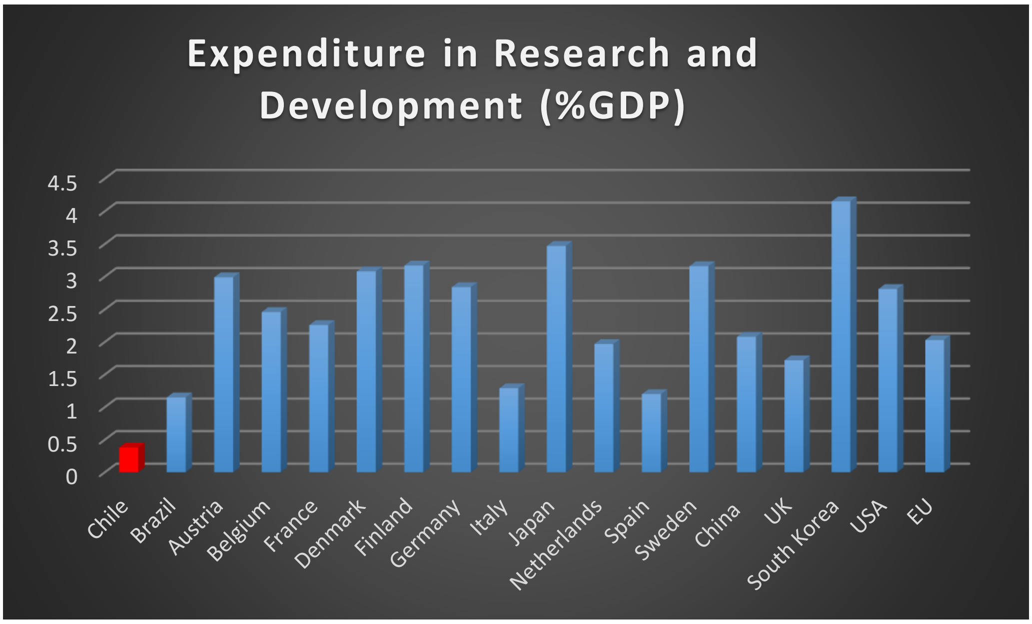


Figure 15: Expenditure in R&D per country (%GDP). Data are sourced by Eurostat, and refers to 2014, except for Brazil (2012), USA, Japan and South Korea (2013)

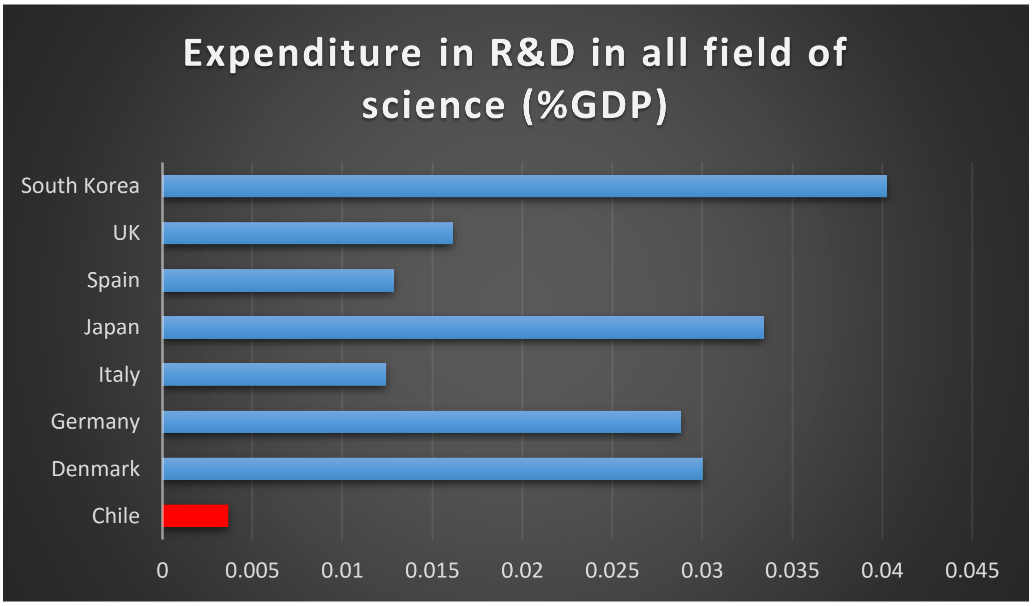


Figure 16: Expenditure in R&D in all field of science. Data includes private and public investments. Data are sourced by OECD and refers to 2012.

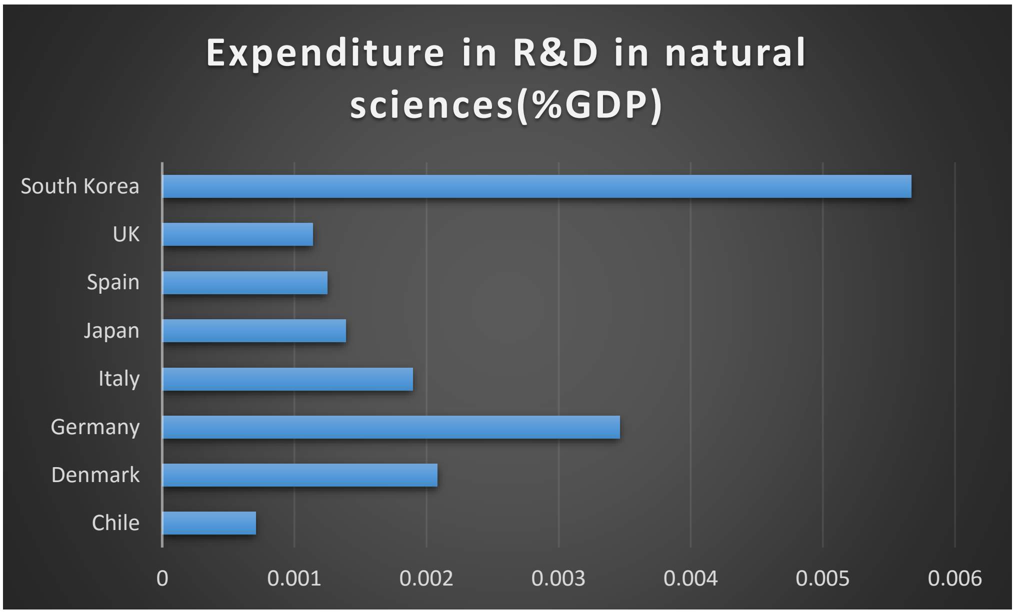


Figure 17: Expenditure in R&D in natural sciences (%GDP). Data includes private and public investments. Data are sourced by OECD and refers to 2012.

c.3) Policy of knowledge and technology transfer

Regarding the perspective of political stakeholders, one of their principal purposes in their interaction with Big Science centers, is to enable and improve the technology transfer from the centers to the society and the national industry.

In Europe, each CERN's member state instituted an Industrial Liaison Office (ILO). The role of the ILO is to establish contacts between the Big Science center and potential suppliers and to support CERN in its search for the different suitable suppliers in their respective country in order to maximize the chance to distribute the CERN contracts, as fairly as possible, amongst suppliers in the different member states (A. Silverman 2012).

The ILOs are also important from the technology transfer point of view, as they enable the technological collaboration and so the exchange of knowledge between the centers and national industry.

In addition, ESO member states instituted their own ILOs, as a mean to link national firms with ESO procurement.

In some countries, such as Netherlands and Switzerland, it has been created a collaboration among the various national ILOs who are employed at scientific and university institutes.

In the Dutch case, the creation of this collaboration is an initiative of the NWO Institute, which is the responsible for the national coordination of Big Science projects for CERN, ITER and ESA and funds the scientific research in Netherlands. Thanks to the support provided by NWO, the ILOs can realize their tasks more effectively (Big Science 2016).

In Chile, the focus on technology transfer from astronomical projects starts only recently. Before the focus was only on the development of astronomy by an academic point of view.

In 2012 Chile instituted an Industrial Liaison Office ("Oficina de Enlace Industrial") that acts as a link between observatories, of the different astronomical organizations, and Chilean firms. The Chilean ILO is part of the Innovation Division in the Ministry of Economy and its role is recognized by ESO.

As it emerges from our interview with the manager of the Chilean ILO, nowadays the Office still has a mainly informal task. The ILO is relatively new and still has ill-defined responsibility. The success of the Office is mainly dependent from the informal network that the manager in charge can build with firms and astronomical organizations' staff.

The Chilean government has also started to edit documents that report studies made on the opportunities of technology transfer offered by astronomy in Chile. For example, in May 2011, the National Commission for Scientific and Technological Research (CONICYT) formed a working group charged to evaluate current capabilities in Chilean industry and universities related to producing technology with applications in astronomy, and to provide recommendations to boost such activity in Chile. The output of the study was a Roadmap for the fostering of technology development and innovation in the field of astronomy in Chile (CONICYT 2012).

Moreover, in 2012 the Chilean Ministry of Economy commissioned a larger study named "Capacidades y Oportunidades para Industria y Academia en las actividades relacionadas o derivadas de la Astronomía y los grandes observatorios astronómicos en Chile", whose objective was a deeper understanding of the Chilean actual situation in astronomy and the definition of possible future opportunities for industry and universities (Chilean Ministry of Economy 2012).

The government has also been organizing events and workshops where the firms can meet the astronomical organizations and get informed about their procurement process and needs. One example is the "Astro-engineering Workshop 2015" of the last November in Santiago, which has been organized yearly since three years ago.

The coordination between the Industrial Liaison Office, national industry, organizations issuing funds, the Big Science partners and the initiatives and studies funded by the Ministry takes on great importance as a mean to increase firms' involvement and so generate technology transfer and possible spillovers.

In the case of Chile, a formalization of the ILO role and network may improve the process efficiency and the participation of Chilean industry. Moreover, it would avoid possible future problems in the eventuality of a staff change within the Office, which, in the actual situation, would imply the loss of the current contact network.

d) Universities and collaboration with Big Science centers

Universities and scientific institutes, beyond their important scientific research, have a fundamental role in the development of technologies for the Big Science centers. In fact, Big

Science centers usually commission the construction of scientific instruments to universities and scientific institutes.

The building of those extremely complex instruments by local universities may represent an interesting business opportunity for firms. In addition, the competitiveness of universities in the development of such equipment may constitute a mean to encourage the industrial technological development.

As emerge from an interview we made with an ESO engineer, the procurement process of the scientific instruments follows the same principles of the ESO industrial procurement: the astronomical organization publishes the specifications required by the astronomical instrument and the institutes, which want to participate, enter the procurement process presenting their proposal. The difference stays in the identification of suitable suppliers, which is through a "scientific council delegate", in the remuneration by Guaranteed Time Observation (GTO) and in the reimbursement of hardware cost. Therefore, universities and scientific institutes collaborate and form research consortia in order to present successful and competitive projects. Each member of the consortium should develop a part of the instrument within a collaborative and proactive environment. This kind of organization implies that the number of potential suppliers, involved in the project, is generally small, one for each component.

Regarding astronomy in Chile, Chilean universities, despite the advantage of being located near to the astronomical observatories, have not been able to participate to the construction of relevant astronomical instruments. Until today, there is only a case of astronomical instrument developed by a Chilean university for an international astronomical observatory: the "Multi Object Optical and Near Infrared Spectrograph" for the Very Large Telescope (VLT) of ESO, developed by the Pontificia Universidad Catolica de Chile. As it emerges from our interviews with astronomers, professors and engineers, there are some factors that cause the scarce competitiveness of Chilean universities in the construction of astronomical equipment. These factors are:

- ***The lack of coordination between the various universities.***
- ***The lack of a national astronomical institute.***

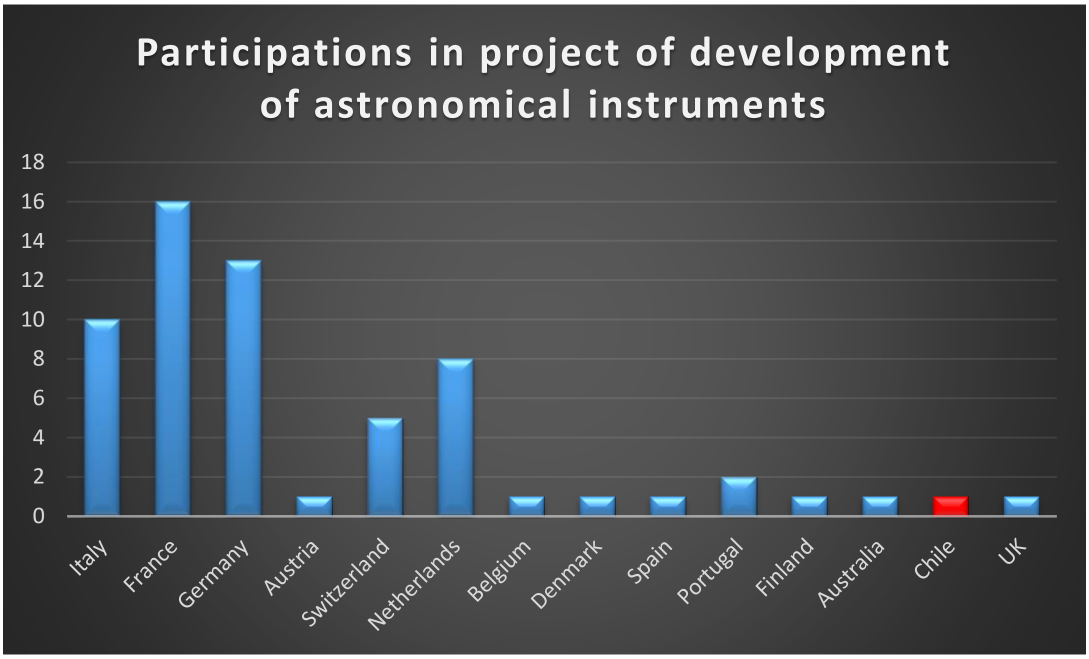


Figure 18: Number of participations, for each country, in the development of astronomical instruments for the ESO observatories of La Silla and Paranal in the last 20 years.

As we said previously, astronomical instruments are usually developed by consortia of universities and institutes. In Europe, there is full coordination between institutes and universities. A well-defined collaboration between the actors allows a better use of the core-competences that each one of them possess. Collaborations may be established between institutes of the same country (e.g. the TIMMI2 was a project completely developed in Germany, while the COME-ON was completely developed in France), or institutes from different European states.

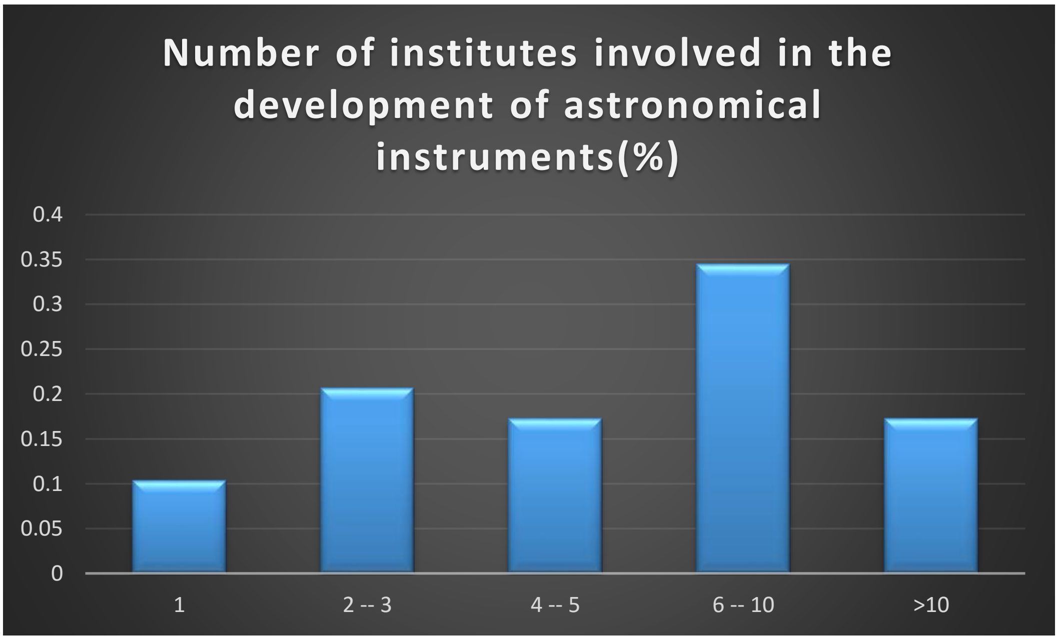


Figure 19: Number of institutes involved in the development of astronomical instruments (%). Data refers to the projects commissioned by ESO for the observatories of La Silla and Paranal since 2000.

The Figure 19 shows as the collaborations between different institutes are usually the ones awarded by ESO with the astronomical instruments contracts. The data refers to the largest projects of astronomical instruments commissioned by ESO for the observatories of La Silla and Paranal in the last 20 years.

The birth of these collaborations between universities or institutes is often the product of national and international scientific strategies defined by the national institutes (for example, the "Istituto di Astrofisica", in Italy, and the "Institut Nacional des Sciences de l'Univers", in France, have the task of managing and coordinating the scientific investigation inside and outside the country). The presence of these kind of institutes permits to the universities and scientific institutes to follow a formalized scientific strategy, enabling also an optimal coordination between them and the national or international scientific partners.

Nowadays, in Chile, there are no national astronomical institutes, which could define a clear scientific strategy, and in the last decade, each Chilean university has focused its resources on a different astronomical topic, reducing the chances of collaborative research and the potential for technological development.

Furthermore, Chilean universities could increase their collaboration with foreign institutes, in order to get access to more competences and to be more competitive in the market of the astronomical instruments. Another aspect emerging from the data, in fact, is that the collaborations involving several countries, usually, are abler to obtain contracts. In the last 20 years, the most important astronomical instruments commissioned by ESO for the observatories of La Silla and Paranal, have often been developed by collaborations involving more than a country, as shown by the following image.

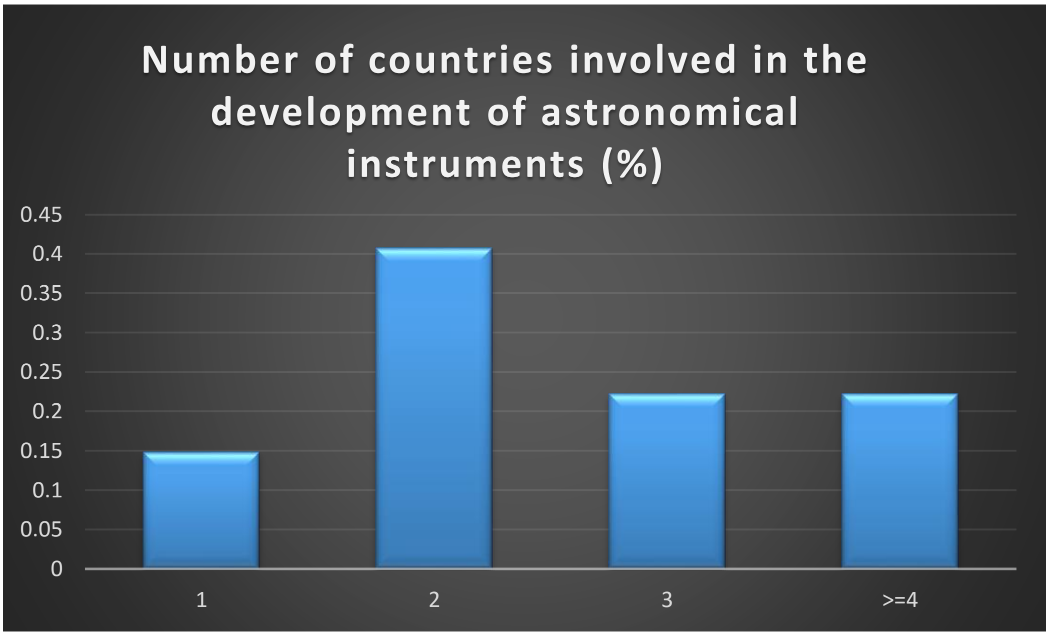


Figure 20: Number of countries involved in the development of astronomical instruments (%). Data refers to the projects commissioned by ESO for the observatories of La Silla and Paranal since 2000

Another advantage of collaborating with foreign institutes is the increase of the reputation of the Chilean universities. This aspect could increase the opportunities of participating in new project of development of astronomical instruments, since reputation is a fundamental factor in the scientific ecosystem.

e) Characteristics of the network

Each Big Science center is involved in a particular network, which is determined by the environment where the center stands and affects the collaboration between the actors. The network in which a Big Science center is involved is constituted by scientists, universities, political institutions, firms and other stakeholders.

There are some common characteristics shared by the Big Science centers networks. A relevant and widespread characteristic is the great informality that characterize the relationships and interactions between the different stakeholders and the Big Science organization.

However, there are dissimilarities between the networks of different Big Science centers.

Emerging from the interviews we carried out, the main differences between the network surrounding the astronomical observatories in Chile and the one of CERN are:

- The characteristics of the scientists' community: In astronomy the scientists' community is smaller and it is difficult to involve local firms in the network;
- The coordination between the different actors of the network, which appears to be scarce and complex in the case of astronomy.

e.1) Characteristics of the scientists' community

One of the astronomers of a Chilean university, we interview, states:

"Astronomers' community in Chile is small, and everybody knows each other."

The astronomers' and astro-engineers' community in Chile is quite small and concentrated in the laboratories of five universities: Pontificia Universidad Catolica, Universidad de Chile, Universidad Tecnica Federico Santa Maria, Universidad de Concepcion and Universidad de Valparaiso (Chilean Ministry of Economy 2012).

On the contrary, CERN is an open scientific organization and involves scientists from 608 institutes and universities around the world. The worldwide collaboration of scientists, which have at their disposal the CERN infrastructure and machines, encourages the exchange of ideas and the formulation of new projects (Cogen 2015).

The interaction between astronomical observatories and Chilean firms is not yet developed. As emerges from our interviews with Chilean astronomers and managers from the Chilean Ministry of Economy, the collaboration and networking between scientific centers and firms is incipient, informal and the contacts with industry are limited to engineers and technicians. An engineer from ESO states:

"The role of engineers and technicians within the observatory is fundamental, because they have the contacts with firms"

Differently, the CERN network is wide and CERN has strong relationships with firms. Those collaborations are managed by specific departments, like the Knowledge Transfer Group and the Procurement and Industrial Service Group, and are subsidized by various initiatives, such as the institution of public-private partnership like Open La[2]. Those partnerships allowed the creation of a wide network, which may generate business opportunities for the actors involved in. Other initiatives of CERN that aim at fostering the collaboration with industry are the institution of BICs and the events organized to network with firms, like industry days and workshops.

The openness of a community to the outside represents the disposition of the individuals of the community to interact and the capacity they have to build their network. In this way, we can state that a closed community:

1) Limits the generation of a heterogeneous network and the ideas, and opportunities that it can offer.

2) Obstacles the creation of social capital, necessary to guarantee the effectiveness of the knowledge transfer within a collaboration (Autio, Hameri and Vuola 2004).

e.2) Coordination among the actors

An astronomer of a Chilean university, during an interview, stated:

"In Chile, the actors involved in astronomy are disconnected. Universities, political institutions, astronomers and other stakeholders are not coordinated among them."

The absence of coordination among the actors is one of the biggest obstacles to the creation of a successful collaboration between Big Science centers and industry. The lack of coordination, in fact, does not allow defining a strategical approach for the collaboration and does not permit the efficient employment of the opportunities that the presence of Big Science centers in the country offers.

At any level of the Chilean astronomical ecosystem, the lack of coordination appears evident. For example, the scarce coordination among the political institutions is proved by the absence of a formal strategy to regulate the relationship with observatories, which, during their operations, must often communicate with different institutions.

In the case of CERN, the coordination among the actors of the network is surely higher. All, the Big Science center, political institutions, universities and firms are well coordinated and share their objectives.

[2] Open Lab is a project that has the aim to accelerate the development of IT technologies. To this partnership, participate various universities and leading ICT companies like Oracle and Microsoft.

f) The technological perspective

Big Science centers are extremely complex projects and different technologies are involved in the construction and operation of the facilities. In order to analyze correctly the characteristics of the technologies, it is useful to distinguish among the different technological levels. A possible classification of the technologies used in a Big Science center is shown in the following table.

	Characteristics	Examples	Impacts
Frontier technologies	Technologies developed for the first time for scientific aims. These technologies are characterized by high risk and uncertainty.	Detectors, accelerators, mirrors, some technologies for scientific instruments, algorithms for the image analysis.	• These technologies can potentially have a substantial impact in other application contexts. • They may generate relevant technological knowledge spillovers.
Consolidated technologies of middle-high level	Technologies of middle-high level yet tested in other contexts. These technologies are characterized by middle risk and uncertainty.	Optical fiber, communication technologies, robotics, Big Data.	• The adjustment of these technologies to the Big Science context may improve the quality and the performances of the supplier firms. • New market opportunities may become available for firms. • New applications to other contexts may be identified.
Undifferentiated technologies	Common technologies used in other contexts. These technologies are characterized by low risk and uncertainty.	Hardware, electrical interfaces, civil works, auxiliary infrastructures.	• The benefits correspond to the mere economic return of the contract. • The supply of these technologies to Big Science centers seldom generates technological knowledge spillovers.

Table 4: Classification of the technologies used at astronomical observatories.

As it emerges from the table, the technologies that can potentially generate more knowledge spillovers to industry are the frontier technologies and the middle-high level technologies.

A categorization of the technologies used in astronomical observatories is presented in the following scheme.

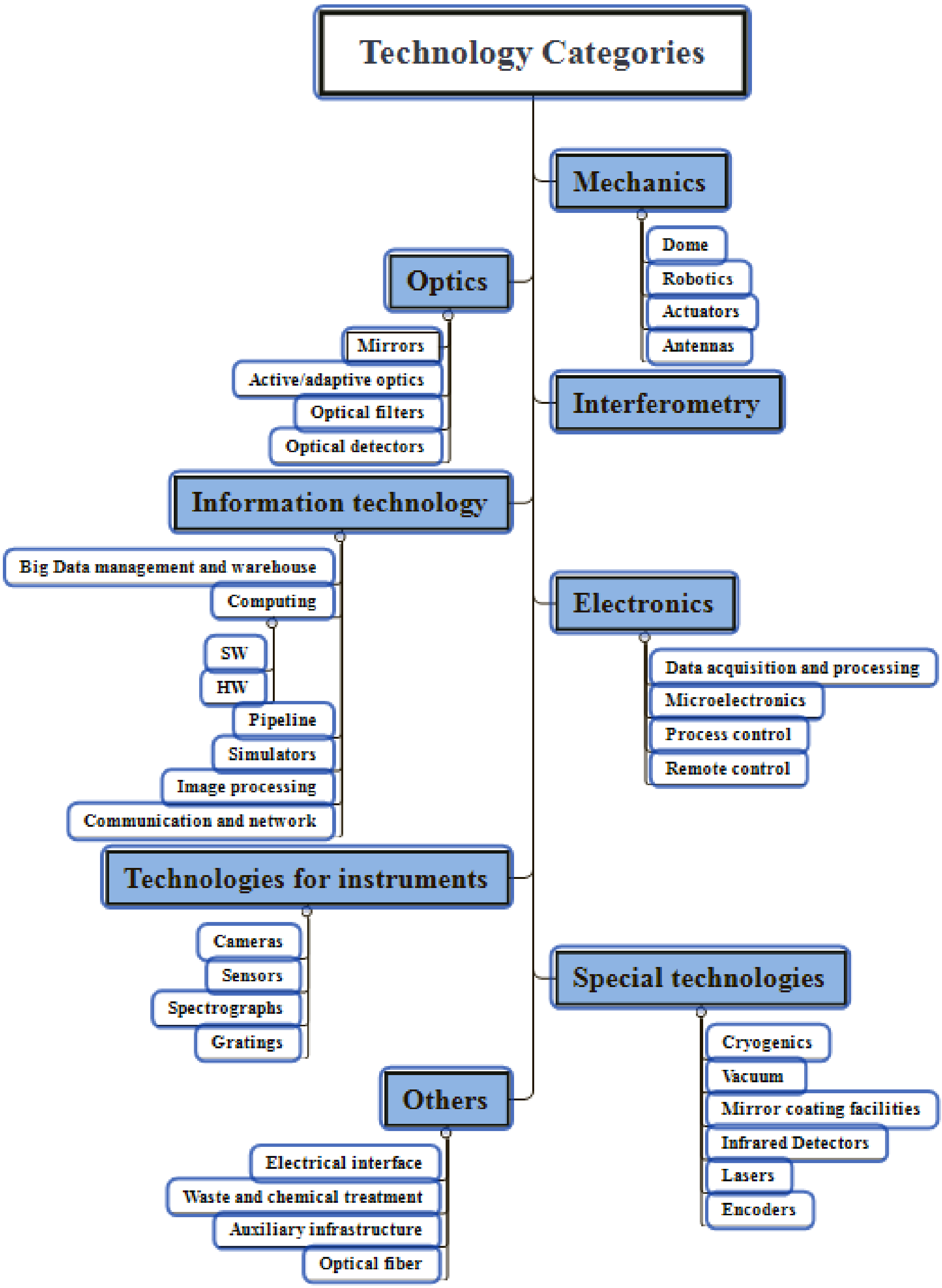


Figure 21: Categories of technologies used at astronomical observatories.

The majority of the technology categories involved are sophisticated technologies, which may be classified as frontier or consolidated middle-high technologies. Other technologies, classified as others in the scheme, do not possess a high degree of technological advance and potential for spillover generation. These kind of technologies are, nowadays, the ones that Chilean firms mostly supply.

In the following scheme, we present a categorization of the technologies used at CERN.

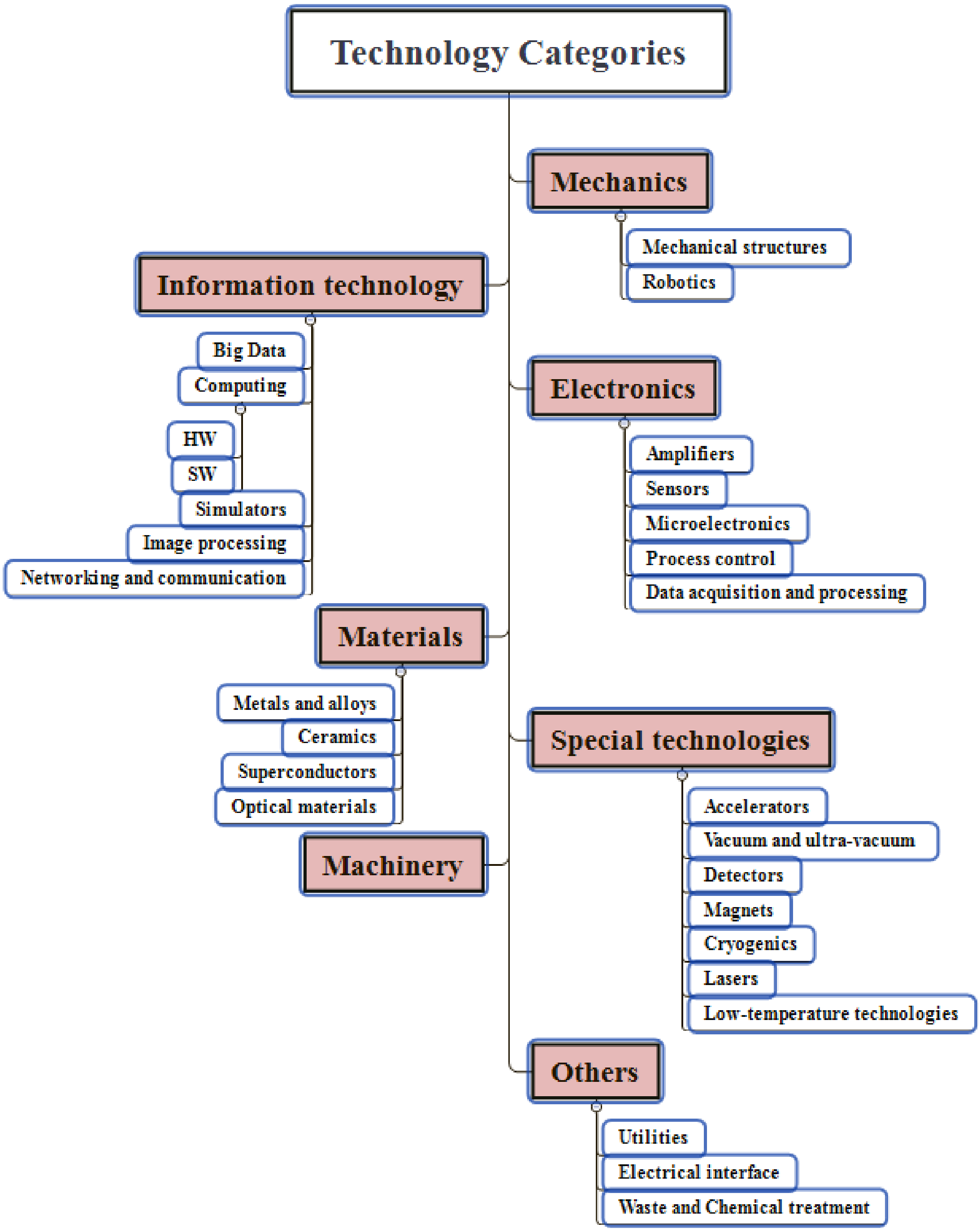


Figure 22: Technologies used at CERN.

Analyzing more deeply the technological features, we identified some factors that influence the generation of knowledge spillovers to the firms. These factors are:

- Modularity
- Life Cycle

- Technological Area
- Novelty
- Transferability to other contexts

f.1) Modular architecture

Product are defined modular when they can be decomposed into a number of components that are able to connect, interact, or exchange resources in some way (Schilling 2000).

The building of equipment with a large number of components interacting among them, represent an opportunity for a larger number of firms than the building of a non-modular equipment. Therefore, the modularity of the equipment required by Big Science centers influences the number of potential collaborations with firms and therefore the generation of knowledge spillovers deriving from these.

The modular architecture of the technologies used within the Big Science center influence the generation of knowledge spillovers because create better conditions for firms in two ways:

i. Modular architecture implies more business opportunities for a larger number of firms. In fact, the various parts of the equipment can be developed separately, and the designer of the telescope have only to take care about the interfaces between the components.
ii. Modular architecture facilitates maintenance and consolidation projects, increasing the effectiveness of knowledge transfer to the firms. In fact, it's easier to better and modify the various parts, without modifying the entire architecture.

The equipment used by Big Science centers are generally characterized by a large number of connected components. Telescopes are composed by several different components, belonging to several different technological areas. For a more detailed description of the technological components of a telescope, see Appendix.

Accelerators and detectors used at CERN, also have a high degree of modularity. In this case, due to the bigger dimension, the number of components is also more numerous that for astronomical observatory.

In conclusion, as regards the modularity of the technologies there are not big differences between the two cases, apart from the number of components that is bigger for CERN.

f.2) Lifecycle and novelty of the technologies

The lifecycle, as well as the evolution speed of the technology are factors that influence indirectly the generation of knowledge spillovers to firms. In fact, a shorter lifecycle and a high degree of novelty of the technologies involved in the Big Science center, create more business opportunities for firms, since the needs of Big Science center to renovate their technologies and to acquire new technologies are higher and recurrent over the years.

The lifecycle of the technologies used in a Big Science center depends on the characteristics of the technology. Generally, the lifecycle of the frontier technologies used in the Big Science centers is long, while the lifecycle of low-middle technology may be variable.

The core technologies of the telescopes, such as the mirrors, the mechanics and the dome have the same lifecycle of the entire telescope, which generally have a lifecycle of approximatively thirty years. Accelerators and detectors at CERN have an even longer lifecycle.

Auxiliary technologies used at the telescope have different lifecycles, depending on the technological area they belong. Hardware, software and control systems, for example, have a long lifecycle that may have a lifecycle of twenty years. Other technologies, such as communication technologies are more subjected to the novelties.

However, it is common that at the telescopes, differently than at CERN, some overcome technologies are used due to a different perception of their lifecycle from the astronomers. From an interview with an engineer of the Gemini South Observatory, in fact, emerges that astronomers prefer to use obsolete and less performant hardware and software than new ones that they are not interested in learning how to use.

The different perception of the lifecycle of middle technologies between astronomers and engineers is an obstacle to the creation of new collaboration between the observatories and firms.

Similarly, the novelty of technologies used at Big Science center depends on the characteristics of the technology.

The development of core technologies is driven by the scientific demands and they are developed exclusively for new facilities. Big Science centers, universities and specialized firm continuously carry on research projects to get advance in this technologies. However, often, the achievement of the objective may last several years. For example, the degree of novelty of mirrors is not really high. Significant improvements in the development of mirrors are findable only after a long arch of time.

The same things can be said about the core technologies used at CERN. The periods of development of new technologies in this case can be also longer, as testified by the development time of an accelerator.

The degree of novelty of the other technologies, such as their lifecycle, can be variable. There are some technologies with an elevate degree of novelty, like IT technologies.

The elevate degree of novelty may cause a gap between the technologies used at the Big Science center and the actual technologies. In fact, when the project is conceived, the technologies chosen are at the state of the art, but it may not be at the state of art when the Big Science center is operating, as happen at the Gemini South observatory with IT technologies.

To conclude this paragraph, we can state that the low novelty degree and the high lifecycle of core technologies reduce the number of collaborations, and increase the time firms have to invest in the relationship with the Big Science center. Otherwise, the high novelty degree of other technologies may be an opportunity for firms. However, the different perception of the lifecycle from the users of the technologies may be an obstacle to the upgrade of these.

f.3) Transferability of technologies

The transferability of a technology to other sectors is clearly a factor that influence the generation of technological spillovers from the Big Science center to the firm.

To do a detailed analysis of the technologies' transferability is not our purpose. In this thesis, our interest is only to evaluate there are technologies that potentially may be transferred to other areas, and if historically there were examples of these transfers in the two cases.

From the interviews, historical cases of technology transfer from astronomy, and a study of the Ministry of Economy of Chile (Chilean Ministry of Economy 2012) emerge that the technologies with the highest degree of transferability are:

- Adaptive optics: This technology in the past was transferred to the area of ophthalmology (Chilean Ministry of Economy 2012). Other applications are in medical images and remote control.
- Optical detector: Possible applications are in the field of medicine, mining, and security.
- Antennas and receptors: There are historical examples of technology transfer to telecommunications, industrial sensors and Internet of Things.
- Big Data: This is one of the areas that presents more possibilities of transferring the technology. The management of big data base is a phenomenon that in a recent future will diffuse to numerous fields, and nowadays astronomical observatories act as pioneers in this technology. Possible applications are in medical data, industrial data, big volume of data generated by sensors and others.
- Computing: This kind of technologies can be useful for the management and the analysis of data, the processing of signals.
- Image Processing: Possible applications are in engineering and medicine.
- Actuators

In the following image, we propose a classification of the technologies that potentially can be object of transfer to other areas.

	Low-medium technological level	High technological level
Low Transferability	Electrical interfaces, utilities.	Mirrors, Spectrographs, Domes, Gratings, Optical Filters, Lasers
High Transferability	Optical fiber, Sensors, Communication and network technologies, Computing, Cryogenics, Encoders	Robotics, Antennas, Detectors, Image Processing, Computing, Adaptive optics, Big Data, Remote control

Table 5: Transferability of technologies from astronomical observatories.

The sectors that present more opportunities of technology transfer from astronomy are medicine, mining, security, analysis and management of Big Data.

A similar categorization was made for CERN. In the case of CERN, historically there was several example of technology transfers to other areas. The technology categories more subjected to the technological transfer are cryogenics, detectors, information technology, magnets, electronics and vacuum. The area that present more opportunities of technology transfer from CERN are medicine, biology, aerospace, security, analysis, and management of Big Data.

From the previous considerations, it is possible to affirm that in both the two cases there are several technologies that can be object of transfers to other context.

However, it is important to remember that the transferability of a technology depends also on the existence, in the country, of firms that can be object of the technology transfer and on their absorptive capacity (Autio, Hameri and Vuola 2004). In Chile there is one of the strongest mining sectors in the world. Meanwhile, the biomedical sector is not well developed (Chilean Ministry of Economy 2012). On the contrary, in Europe all the sectors that can be object of technology transfer are well developed.

5.2. Table of theoretical propositions

Field of analysis	***Theoretical propositions in the Big Science context***	***Astronomical Observatories in Chile***	***CERN***
Big Science Perspective - Intrinsic Characteristics	1. The location of a Big Science center depends on several reasons (geographical, climatic, political etc.) and determines an impact over the center ecosystem and network.	• The observatories location is dependent on geographical and climatic conditions.	• The choice of CERN location was driven only by political reasons.
	2. The geographical dispersion of the facilities represents an obstacle to the creation of new knowledge and to the transfer of tacit knowledge within the organizations, due to the impossibility of technicians and engineers to interact continuously with each other.	• The distance between the observatories, the astronomical organizations headquarters and universities entails difficult tacit knowledge transfer.	• Unicity of facilities: CERN scientific staff mainly operates in Geneva, Switzerland. This implies an easier creation and transfer of tacit knowledge.
	3. The proximity to cities and cultural centers is an advantage for the creation of a solid scientific and industrial ecosystem linked to the Big Science center.	• The facilities are far from the cities: ○ Observatories may have difficulties in generating an ecosystem because of the distance from other stakeholders.	• The CERN is located near to the city of Geneva, Switzerland: • ○ There is an ecosystem of firms and universities

		○ Observatories face more logistical problems because of the distance from cities and extreme climatic and geographical conditions.	operating in the proximities of CERN. ○ CERN location does not imply relevant logistic problems.
	4. Cultural divergences between the organizations and the host countries may create problems of integration and local collaboration.	• The facilities of astronomical organizations are located in different regions and countries. Astronomical projects may involve different cultures and face integration problems (e.g. TMT and its problems with Hawaiian local tribes).	• CERN is located in a single location in the center of Europe. There are not relevant cultural differences.
Big Science Perspective – Organization and Policy	1. Lack of managerial competences within the Big Science centers: the absence of managers with proper managerial skills may limit the opportunities for efficiency, innovation and openness to external collaborations. 2. Importance of a proactive and structured technology transfer policy from the Big Science centers: thanks to the formal policy, the firms could be	• Astronomical facilities are often managed by scientists without a proper managerial background. • ESO and AURA observatories do not have a formal knowledge and technology transfer policy.	• In the CERN, managerial competences are present in areas related to the technology transfer and the collaboration with the firms (e.g. Knowledge Transfer Group). • CERN has a proactive and structured technology transfer policy that favors

	more aware of the opportunities and receive support in technical matters by the scientific centers.		the generation of knowledge transfer.
		• ESO recognizes technology transfer as a valuable process that can lead to economic, social and cultural benefits and, within the constraints of its mandate and resources, provides active encouragement to the process.	• There is a formal department dedicated to knowledge and technology transfer since 1988. • Externally from CERN location, a network of business incubation centers (BICs) of CERN technology has been established. There are currently eight BICs in CERN's member states.
	3. The Big Science organizations policy of industrial return prevents host countries industries from participating in many middle and high technological projects, when the host country is not a member state.	• ESO pursues the policy of the industrial return for the member states of the organization. This policy only exists in European projects. • Chile does not have an industrial return clause because is not a member of ESO.	• The policy of the industrial return for member states is present also in CERN procurement. • The industrial return represents a criterion in the phase of bids selection.
	4. Importance of well-working ILOs (Industrial Liaison Office) for the effectiveness of the procurement process.	• ILOs have a fundamental role in the procurement process coordinating ESO and industry.	• ILOs have a fundamental role in the procurement process coordinating CERN and industry.
	5. Competitiveness and efficiency: firms must be able to offer excellent technical solutions at the lowest price. It can exclude firms from		

	countries that are not competitive in the global market. 6. In Big Science projects, the collaboration between different institutions and organizations is a key factor to success. It ensures an increase in the potential for knowledge disclosure and a broader access to resources (information, capital, staff etc.).	• Price emphasis as a selection criterion in the procurement process. • There are not steady collaboration agreements between the astronomical institutions. The collaboration is limited to occasional exchange of scientific data or launch of joint projects (e.g. ALMA Project).	• Price emphasis as a selection criterion in the procurement process. • In Europe, the EIROforum is an organization consisting of eight European intergovernmental scientific research organizations devoted to fostering mutual activities. ESO, CERN and ESA belong to the EIROforum.
Market generated by Big Science projects – Characteristics of the Market	1. The long-term duration, the complex technological requirements and the demand uncertainty reduce the attractiveness of the markets. 2. Important relation-specific investments: the firms invest capital, time and human resources in order to acquire the necessary technological competences and to manage the collaboration with the scientific center.	• The ESO in 2014 spent around 100 million € for its procurement. • High demand uncertainty of technological projects. • Long-term and highly specific technological projects.	• CERN in 2014 spent approximatively 300 million € for its procurement. • High demand uncertainty of technological projects. • Long-term and highly specific technological projects.

	3. The facilities dimensions and the high maintenance need increase the attractiveness of the market. The maintenance procurement policy may increase the opportunities for firms.	• Outsourcing of basic services. • With the larger facilities of the next decade, procurement needs may increase. • Low and Middle technological maintenance is outsourced (e.g., Cryogenics in AURA) or conducted by an internal maintenance crew. • High technology maintenance is conducted by a specialized internal team or by the laboratory that constructed the astronomical instrument.	• Low and middle technological maintenance is often outsourced. • The dimension of the infrastructures implies many opportunities for industrial partners. • High technology maintenance is conducted by a specialized internal team or by the firm/laboratory that constructed the instrument.
Market generated by Big Science projects – Reputation and Previous Collaborations	1. The Big Science organizations need to trust in their industrial suppliers and they give great importance to firms' history and their commitment and results in previous projects. 2. The majority of the firms enters Big Science projects as a mean to improve their	• In astronomy, the technological inheritance from previous projects is fundamental. • Prior collaborations of the firms in ESO projects are important but do not constitute a formal advantage in the procurement process.	• The reputation of the firm is an important factor in order to obtain a supply contract. • Prior collaborations with CERN constitute a formal advantage for firms in the procurement process. • The most relevant motivation for firms to become CERN suppliers is

	visibility in the market and extend their range of business opportunities.		to achieve “marketing benefits” in terms of reference and image lifting.
Political Perspective – **Agreements**	1. The benefits granted to the Big Science organizations by the political institutions are tax exemption and diplomatic status. 2. Member countries of Big Science organizations have some advantages in the procurement process. 3. The lack of a unique agreement policy between Big Science organizations and the host country arises the managerial complexity, because of the several actors involved in the relationship. It may also be more complicated for the industrial partners to start a collaboration.	• ESO and AURA observatories in Chile received diplomatic status and are granted tax exemption. • Chile is only a host country for ESO, not a member state. Chile receives the 10 % of telescopes observation time for its scientific projects. In other countries, like USA and Spain, this percentage is sensitively higher (15% in Hawaii, and 20% in Canarias). • Each observatory in Chile negotiates different conditions for its settlement. ○ ESO negotiated with Chilean government resulting on legal treaties. ○ AURA negotiated directly with the University of Chile.	• CERN received diplomatic status within the host countries and is granted tax exemption. • CERN host countries (Switzerland and France) are also member states. • CERN adopted a unique policy and negotiated the same conditions with its member states.

	4. Importance, for the host country, of the agreements negotiation as a mean to improve the participation of national industry. 5. Agreements clauses, considering the technological participation of member states, improve the technology transfer and spillover possibilities.	○ GEMINI signed an agreement directly with the Ministry of Foreign Affairs. • Chilean industry is quite absent from high-technological astronomical projects since Chile has not an industrial return clause in the agreements.	• Member states industry participates actively to the CERN projects thanks to the industrial return clause.
Political Perspective - Policy of Funding	1. Funding opportunities: The presence of different and continuous opportunities of funding is fundamental for the development of scientific instruments.	• Public investment in science from Chilean government has always been erratic and low. In 2011, just 0.44% of Chile's gross domestic product was spent on science. • Astronomical projects in Chile have only public funding (CONICYT). • There are four different funds offered by CONIYCIT and only one of them is available for the	• The public investment in science from European Union and the different member states are among the highest in the world. • In CERN, each member state must contribute to the fixed common costs of the organization. The scale of contribution is based on the average national income.

		development of astronomical instruments.	• CERN has multiple funding sources (private and public).
Political Perspective - Knowledge and Technology Transfer Policy	1. Importance of a clear and formal knowledge and technology transfer policy from the political stakeholders. 2. The formalization of the role and the network of the ILO may enhance the collaboration of the national industry with Big Science organizations. 3. Coordination between the institutional actors: A better coordination between the ILOs and the organizations issuing funds may improve the effectiveness of the tasks.	• Chile has no clear knowledge and technology transfer policy. • In 2012, Chile instituted an Industrial Liaison Office with the main objective of linking its industry to the Big Science centers. • Chilean ILO is relatively new and does not have formalized procedures. ILO's task success is dependent on the informal network that the person in charge may build. • Chilean ILO does not have the possibility to provide fund.	• European countries usually have a well-defined and clear technology transfer policy. • CERN countries instituted Industrial Liaison Offices (ILO) as a mean to link their national industry to the Big Science center. • The European ILOs have more formalized procedures, and do not depend on the informal network built by the person in charge. • European ILOs usually collaborate with other national and international ILOs and often have the resources to provide funding (e.g. Netherlands, UK and Switzerland).
Universities and their Collaboration	1. The building of extremely complex Big Science instruments by local	• There are partnerships between Chilean universities and observatories (ALMA-	• There is collaboration between European universities and CERN in

with Big Science centers	universities may represent an interesting business opportunity for firms. 2. A network including firms and universities increase the opportunities of generating innovations and knowledge transfer. 3. Lack of coordination between the local universities: the absence of coordination between the research fields of the universities reduces their competitiveness in the Big Science sector. 4. Lack of a large national scientific institute: a national scientific institute may improve the coordination among the universities and may define a national scientific strategy (eg. Istituto Astrofisica italiano)	UTFSM partnership), but not collaborations for the development of astronomical instruments (except for the incipient MOONS Project, Pontificia Universididad de Chile). • There is scarce coordination between Chilean universities in their research fields. Each one has been developing different technologies. • Chile does not have a national organization that may coordinate the different stakeholders.	the development of technologies. Furthermore, CERN promote collaboration between universities and firms for the development of new solutions (e.g. OpenLab). • In Europe (CERN and ESO), there is coordination between the research fields of the universities in order to achieve a high specialization degree. • In Europe, there are national scientific institutes that coordinate the different stakeholders. Furthermore, these institutes are usually protagonists in the development of instrumentation.
Characteristic of the network	1. Each Big Science center is involved in a network, which is determined by the environment where the center stands and affects the	• The astronomers' and astro-engineers' community in Chile is small.	• CERN is an open scientific organization and involves scientists from 608 institutes and universities around the world.

	collaboration between the actors. 2. A widespread informality characterizes the relationships and interactions between the different stakeholders and the Big Science organizations. 3. It is important to keep strong relationship with firms also outside of the collaboration in order to create a dynamic ecosystem with the opportunity of generating innovation. 4. The absence of coordination among the actors is one of the biggest obstacles to the creation of a successful collaboration between Big Science centers and industry. 5. A closed community limits the development of networks and obstacles the creation of the social capital necessary for the effectiveness of the knowledge transfer within a collaboration.	• The collaboration and networking between astronomical observatories and firms is incipient, informal and the contacts with industry are limited to engineers and technicians. • In Astronomy, there is low human capital transfer to other areas. This contributes to the weakness of the network between Chilean firms and astronomy. • In Chile, the actors involved in astronomy are disconnected. Universities, political institutions, astronomers and other stakeholders are not coordinated among them.	• CERN has strong relationships with firms managed by specific departments, like the Knowledge Transfer Group and the Procurement and Industrial Service Group. • CERN improves its industry network with different initiatives: institution of public-private partnership, Business Incubation Centers (BIC), industry days and workshops. • In CERN, the coordination among the actors of the network is high. The Big Science center, political institutions, universities and firms are well coordinated and share their objectives.

Technological Perspective - Modularity	1. Modular architectures enable business opportunities for a larger number of firms, because the various parts can be developed separately. 2. Modular architectures increase the effectiveness of the technological knowledge transfer, since they facilitate maintenance and consolidation projects.	• Modularity: astronomical facilities employ technology with a high degree of modularity. The instruments are developed in different countries and assembled later.	• Modularity: CERN has technology with a high degree of modularity. They are developed in different countries and assembled later. • CERN instruments are larger and have more components.
Technological Perspective - Lifecycle	1. The large technology lifecycles limit the procurement needs of the Big Science centers, but improve the maintenance opportunities for industry. 2. The Big Science center operators' perception of the technology lifecycle can be out of date, and may obstacle the launch of new collaborations with firms.	• Core technologies (mirrors, detectors, control systems etc.) usually have long lifecycles. • Other technologies have lifecycles that can be variable. • There is a different perception of the lifecycle of middle technology between astronomers and engineers.	• Core technologies (accelerator, detectors etc.) used at CERN usually have a long lifecycle. • Other technologies have lifecycles that can be variable.
Technological Perspective - Novelty	1. Core technologies have usually a low novelty degree, due to the difficulty to make advances in these technologies. This	• The development of core technologies is driven by scientific demand. Usually the novelty degree of these technologies is not high.	• The development of core technologies is driven by scientific demand. Usually the novelty degree of these technologies is not high.

	characteristic reduces the opportunities for collaboration with industry and increases the relation-specific investments firms have to do. 2. Other technologies: There is often a gap between the technologies used at Big Science centers and the newest ones, due to the large time elapsing from the facility design to the operation phase. This may represent an opportunity for firms.	• Novelty degree of the other technologies used at telescopes is variable. • Technology is at the state of the art when the telescope project is conceived but it may not be at the state of the art when the observatory is operating.	• Novelty degree of the other technologies used at CERN is variable.
Technological Perspective - Transferability	1. The transferability of the technologies influences the capacity of Big Science centers to generate technological and knowledge spillovers. 2. The transferability of technologies also depends on the existence of suitable firms that may collaborate with the Big Science center and may be object of the transfer.	• There are different technological fields that offer transferability opportunities. • The sectors that can be object of technology transfer are medicine, mining, security, analysis and management of Big Data. • In Chile the sector of mining is well developed. The others sectors are still in their development phase.	• There are different technological fields that offer transferability opportunities. • The sectors that present more opportunities of technology transfer are medicine, biology, aerospace, security, Big Data • In Europe, all the sectors are already well developed.

Table 6: Theoretical propositions.

6. Conclusions

We set out this thesis to contribute to the understanding of the reasons why some Big Science centers are more able than others in generating knowledge spillovers to industry.

Our objective is to create a set of theoretical propositions to explain the elements of the Big Science environment influencing the generation of knowledge spillovers.

We compared two different examples of Big Science centers, embedded in different contexts. The two cases, CERN in the European environment, and the astronomical observatories in Chile, have historically had different results in terms of knowledge and technology transfer efficiency. CERN, in fact, is famous for its capacity in generating knowledge spillovers, while, the examples of knowledge transfer from astronomical observatories to the industry in Chile are quite absent.

Through this analysis, we attempted to give a more accurate and wider look at the characterizing elements of Big Science centers than the past research on this matter did.

The previous studies, focused on input-output analysis, do not provide much insight into which are the critical variables that influence the economic and technological impact of Big Science centers. Other studies, focused on the knowledge transfer potential of Big Science centers, give a relevant contribution to the understanding of the typologies of knowledge spillovers and on the characteristics of the transfer itself (Autio, Hameri and Vuola 2004). However, they do not offer several insights about how the different surrounding contexts may influence the origin of collaborations between local firms and Big Science centers and, therefore, the potential for the generation of knowledge spillovers to industry.

Comparing the two cases, it emerges, that both cases present opportunities for knowledge and technology transfer to industry. However, in the case of astronomical observatories in Chile, some factors create obstacles to the generation of knowledge spillovers to firms.

The main finding of this research is the description of the theoretical framework explicating the various elements that affect the potential of Big Science centers of generating knowledge spillovers. These elements may be related to the proper characteristics of the Big Science center, the policies adopted by the different stakeholders involved in the Big Science ecosystem, the effectiveness and coordination of the surrounding network, the attractiveness of the supply market generated by the center procurement and the characteristics of the technologies requested by the Big Science center.

The main differences between the two cases stands in the management of the political affairs, the policies adopted, and the characteristics of the facility. As regards the technological perspective, there are not great differences between the two cases.

6.1. Conclusions on the case of astronomy

In this section, we present our conclusions on the specific case of the astronomical observatories in Chile.

Chile is worldwide-recognized one of the best place on the Earth to conduct astronomical observation, due to its perfect natural and climatic conditions. From our research emerges that Chile is not well exploiting this natural advantage.

In fact, if from the academic point of view, Chile has been taking advantage of the astronomical ecosystem, as testified by the growing number of Chilean astronomers, the Chilean economy has not yet benefited from the installation of large observatories in the country.

Multiple reasons are shown in the table of the factors influencing the generation of knowledge spillovers. Among them, there are the proper characteristics of the astronomical observatories, which generally are clustered in remote areas far from cities and cultural centers. Such condition, different from that of CERN complicates the creation of an environment connected to the Big Science center, and therefore the knowledge transfer to local firms.

Another element, which obstacles the collaboration between the observatories and the industry, is the scarce coordination between the main actors of the ecosystem that prevent the definition by the political institutions of a formal and shared strategy related to astronomy.

In the table of section 5.2, are reported 41 theoretical propositions that could be a basis for policy-makers and other stakeholders to define corrective actions in order to create the best conditions for the development of successful collaborations between the astronomical observatories and firms.

Furthermore, we individuated initiatives that could enhance the actual situation:

a) Renegotiation of the agreements between Chile and the international astronomical organizations.

Nowadays, the main benefit included in the agreements between Chile and the astronomical organizations is the acknowledgment of the 10% of the observation time to Chilean projects. A study affirms that Chile is not fully exploiting the quality of its skies with only this acknowledgment (Alvarez, et al. 2010). As stated by this study, Chile could start imposing taxes to observatories and would still have the best conditions in the world to host astronomical observatories.

Moreover, the actual agreements do not report any advantage for Chilean firms. There are no clauses in the agreements regarding the assignment of projects to Chilean industry, like the CERN and ESO member states' industrial return.

Therefore, a renegotiation of the agreements between Chile and the astronomical organizations, as the one achieved in 1997, could be necessary. More observation time would determine more research opportunities for Chilean universities, while new clauses, which could consider an industrial return for Chilean industry in the future projects, would improve the technology transfer and spillover possibilities.

b) The creation of a large national astronomical institute.

Chile, proportionally to its population, possess a relevant number of astronomers, which conduct their research in the universities and their laboratories.

The introduction of a large national astronomical institute would facilitate the establishment of a national scientific strategy related to astronomy, and improve the coordination among the scientist and universities. The majority of European countries already present this kind of institutes, and the results obtained are positive in terms of coordination and effectiveness.

c) The institution of a national facility.

Chile, nowadays, has different national telescopes but does not have a national observatory of relevant dimension. The construction of a national observatory could develop a high-technology national industry involved in Big Science projects.

A successful example is that of GRANTECA S.A, a Spanish public company born to participate to the project of a national observatory. This public firm was constituted because of the decision of the Spanish Government to build one of the largest telescopes in the world: the "Gran Telescopio CANARIAS" (GTC), also known as the Great Canary Telescope. It is a 10.4 m (410 in) reflecting telescope located at the Roque de los Muchachos Observatory on the island of La Palma, in the Canaries, Spain.

GRANTECA S.A. was created with the objective of designing and building that observatory. The GTC project was funded by the Spanish Government and by the Autonomous Government of Canarias Islands using European funds. The project was carried on with the participation of foreign institutes like University of Florida and the Instituto de Astronomia de la Universidad Nacional Autonoma de Mexico (GTC, 2014). As of 2015, it is the world's largest single-aperture optical telescope.

The GTC project helped Spain to develop its high-technology potential, improving the capabilities and the expertise of the firms that participated.
An astronomical project of such dimension could help Chile to achieve the same benefits. It may encourage the birth of a high-technological industrial cluster in Chile, as it happened in Spain, and it may improve Chilean scientific community and companies' reputation, bringing more opportunities to collaborate as high-technological partners in other international projects of the big science sector.

6.2. Implications and possible actions

The contribution of this research to the current literature is the identification of a theoretical framework to explicate the factors influencing the development of the collaboration between Big Science centers and industry.

Our thesis entails implications for researchers, policy-makers and management.

Regarding the researchers, our findings suggest that the interface between firms and public research is complex and affected by a large number of elements. The stakeholders' policies and relationships, the environment and the characteristics of the Big Science center strongly influence the effectiveness of the scientific center in transferring its knowledge and technology to the society.

Our study demonstrates that it is possible to build a theoretical framework to explicate how these factors affect the Big Science ecosystem. This framework represents a starting point for more accurate analysis of the perspectives identified. The theoretical propositions presented here should be tested in larger empirical samples to assess their generality.

The study has also implications for policy-makers in the field of scientific research. Policy-makers must understand that the Big Science centers offer an invaluable potential to catalyze industrial R&D and innovation, and the economic benefits resulting from the establishment of a Big Science center in the country may greatly exceed the monetary value of the single procurement expenditure.

Policy-makers should increase their efforts in order to facilitate the development of collaborations between Big Science centers and national industries.

The policies defined by the political institutions contribute to the achievement of the necessary conditions for the collaboration between firms and Big Science centers.

We individuated some actions:

- ***Policy-makers should individuate a formal and well-defined national strategy related to the Big Science ecosystem.***

- ***Political institutions should focus their attention on the creation of a well-coordinated network that involve Big Science centers, universities and industry to take advantage of the synergies between them.***

- ***Political institutions should enhance the formality of their relationships and processes involving Big Science organizations, in order to increase efficiency, transparence and give more effectiveness to their actions.***

There are some implications also for the design and management of Big Science centers, and for universities:

- ***The proximity of Big Science centers to universities and industrial conurbations could help the development of an ecosystem linked to the Big Science centers.***

- ***Big Science centers should improve the knowledge and technology transfer in the host countries, in order to generate economic and technological benefits for industry and society.***

- ***The integration of managerial competences in the management of Big Science centers could enhance the effectiveness of knowledge transfer policies.***

- ***Universities should coordinate their research efforts in order to gain competitiveness.***

6.2. Limitations

The limitations of our study should be considered for future improvements in its methodology and when attempting to extract conclusions using the presented results.

First, the generality of our findings is obviously constrained by the case studies and the contexts analyzed. Even though the grounded theory method allows theoretical generalization, the empirical generality remains an issue to be examined in further studies. Our thesis is limited to the cases of CERN and astronomical observatories in Chile, and similar studies in other contexts would be useful to refine our findings.

Second, we have sought to develop a theoretical framework that offers a wide and complete overview of the factors that influence the generation of knowledge spillovers to firms. We compared CERN and astronomical observatories through different fields of study. However, a deeper analysis in the various field of study would be useful in order to discover more characterizing elements. For example, we did not conduct a rigorous comparison between the technologies used in Big Science centers.

Third, in this thesis, we focused our attention on the elements that enable the knowledge transfer from Big Science to firms, and not on how knowledge is transferred. This issue has yet been object of other studies (Autio, Hameri and Vuola 2004, Autio, Bianchi-Streit e Hameri 2003), but further studies about the context of astronomy would serve to provide more contexts-independent conclusions.

7. References

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APPENDIX

A.I. Astronomy in Chile: List of large astronomical observatories present in Chile

Chile is the country with the greater amount of large astronomical observatories, and the number of the infrastructures is expected to grow in the next decades. In the following table, we propose a list of the more relevant.

Name	***Location***	***Typology***	***Organization***	***Countries involved***	***Description***
Cerro Tololo Inter-American Observatory	Cerro Tololo, 80km east of La Serena at 2200m altitude; Coquimbo Region	Optical/Infrared Telescope	Association of Universities for Research in Astronomy (AURA)	United States of America, Chile	Seven telescopes with diameters between 0.m and 4m.
La Silla Observatory	Cerro La Silla, 160 km north of La Serena, at 2000m altitude; Coquimbo Region	Optical/Infrared Telescope	European Organization for Astronomical Research in the Southern Hemisphere (ESO)	Germany, Belgium, Denmark, Spain, Finland, France, Netherlands, Italy, Portugal, Switzerland, Sweden, UK, Czech Republic	Three telescopes of 3.6 m,3.5m and 2.2 m operated by ESO, and other national telescopes.
Las Campanas Observatory	Cerro Manqui at 2500m altitude; Atacama Region	Optical/Infrared Telescope	Carnegie Institution of Washington, Harvard University, Massachusetts Institute of Technology (MIT), University of Michigan and University of Arizona	United States of America	Two telescope of 6.5m each (Magellan I and Magellan II), and two smaller telescopes of 2.5m and 1m. The 24.5m Giant Magellan Telescope is being

					constructed at a foreseen cost of USD 70 million.
Southern Astrophysical Research Observatory (SOAR)	Cerro Pachon, 2700m altitude; Coquimbo Region	Optical /Infrared Telescope	Brazilian Ministry of Science and Technology (MCT), National Optical Astronomy Observatory (NOAO), University of North Carolina at Chapel Hill (UNC), Michigan State University (MSU).	United States of America, Brazil	4.1m diameter optical/Infrared telescope
Gemini South Observatory	Near Cerro Pachon, 2722m altitude; Coquimbo Region	Optical/infrared telescope	Gemini Observatory; Association of Universities for Research in Astronomy (AURA) is the executive agency for Gemini Observatory	United Stated of America, Brazil, Argentina, United Kingdom, Australia, Canada	8.1m optical/infrared telescope
Paranal Observatory	Cerro Paranal, 2400m altitude; Antofagasta Region	Optical /Infrared Telescope	European Organization for Astronomical Research in the Southern Hemisphere (ESO)	Germany, Belgium, Denmark, Spain, Finland, France, Netherlands, Italy, Portugal, United Kingdom, Czech Republic, Sweden, and Switzerland.	Four 8.5 meter telescopes or Very Large Telescope (VLT), four 1.8m Auxiliary Telescopes used as interferometric array(VISA), two wide-range telescopes (one of 4m and one of 2.6m)
University of Tokyo Atacama Observatory	Cerro Chajnantor at 5640m altitude, Antofagasta Region	Optical/ Infrared Telescope	University of Tokyo	Japan	1m infrared telescope and 6.5m telescope to be installed

Large Synoptic Survey Telescope(LSST)	Cerro Pachon, 2700m altitude, Coquimbo Region	Optical/infrared telescope	LSST Corporation formed by approximatively 20 private institutions and universities	United States of America	8.4m telescope
European Extremely Large Telescope	Cerro Amazonas. 2800m altitude; Antofagasta Region	Optical/ Infrared Telescope	European Organization for Astronomical Research in the Southern Hemisphere (ESO).	Germany, Belgium, Denmark, Spain, Finland, France, Netherlands, Italy, Portugal, United Kingdom, Czech Republic, Sweden, and Switzerland.	39.5m segmented telescope to be build. The most ambitious optical telescope in the world
Atacama Pathfinder Experiment (APEX)	Llano de Chajnantor, 5100m altitude; Antofagasta Region	Radio telescope	European Southern Observatory (ESO), Max Planck Institute for Radio Astronomy (MPIfR), Onsala Space Observatory (OSO).	ESO countries, Germany, Sweden	Millimetric and submillimetric 12m antenna
Atacama Cosmology Telescope Project (ACT Project)	Cerro Toco, 5400m altitude	Radio telescope	Princeton University, University of Pennsylvania, NASA/GSFC, University of British Columbia, NIST , Pontificia Universidad Católica de Chile , University of KwaZulu-Natal, Cardiff University, Rutgers University, University of Pittsburgh, Columbia University, Haverford College, INAOE, LLNL, NASA/JPL, University of Toronto, Universityof Cape Town,	United States of America, Spain, United Kingdom, Canada, Chile	6m radio telescope.

			University of Massachusetts and York College, CUNY.		
Atacama Submillimeter Telescope Experiment (ASTE)	Llano de Chajnantor, 5100 m altitude; Antofagasta Region	Radio Telescope	National Astronomical Observatory of Japan (NAOJ) operates the telescope; Japanese universities and Universidad de Chile	Japan, Chile	10m submillimeter antenna
NANTEN2 Project	Llano de Chajnantor, 5100m altitude; Antofagasta Region	Radio Telescope	Nagoya University, KOSMA (Cologne University), Argelander Institute (Bonn University), ETH Zurich, Radio Astronomic Observatory Seoul (Seoul National University), Universidad de Chile, University of New South Wales.	Japan, Germany, Australia, Switzerland, Chile, South Korea	4m Submillimeter antenna
Atacama Large Millimeter/Submillimeter Array (ALMA)	Cerro Chajnantor, 5100m altitude; Antofagasta Region	Radio Telescope	National Radio Astronomy Observatory (NRAO), ESO; National Astronomical Observatory of Japan (NAOJ)	United States of America, Japan, ESO countries	66m Submillimeter antennas. It’s the world’s largest radio observatory.
Polarbear	Cerro Toco, 5200m altitude, Antofagasta Region	Radio Telescope	University of California at Berkeley, Lawrence Berkeley National Lab, University of Colorado at Boulder, University of California at San Diego, Laboratoire Astroparticule & Cosmologie,	United States of America, Canada, United Kingdom, France and Japan	3.5m telescope(Huan Tran Telescope) and attached to the telescope is the POLARBEAR experiment, which is an array of bolometers cooled.

			Imperial College, KEK, McGill University, Cardiff University.		
Cornell Caltech Atacama Telescope (CCAT)	Cerro Chajnantor, 5612m altitude; Antofagasta Region	Radio Telescope	The CCAT consortium includes Cornell University, California Institute of Technology with the Jet Propulsion Laboratory, University of Colorado, University of British Columbia for a Canadian university consortium, the UK Astronomy Technology Centre on behalf of the United Kingdom, and Universities of Cologne and Bonn.	United States of America, Canada,United Kingdom, Germany	25m submillimeter antenna
Cosmology Large Angular Scale Surveyor (CLASS)	Cerro Toco, 5200m altitude; Antofagasta Region	Radio Telescope	Johns Hopkins University (JHU) in Baltimore, NASA Goddard Space Flight Center in Greenbelt	United States of America	Survey Telescope
Chajnantor Observatory	Chajnantor plateau, 5100m; Antofagasta Region	Radio Telescope	California Institute of Technology(Caltech), Universidad de Chile and Univesidad de Concepcion	United States of America, Chile	Interferometer of 13 elements

Table 7: List of astronomical observatories present in Chile.

A.II. Modeling astronomical observatories

In order to understand and analyze the astronomical observatories we used a methodology called CLIOS Process that is useful to organize in a systemic way the entities of an astronomical observatory. This methodology was elaborated by a team of researchers leaded by the Professor Joseph M. Sussman of the Massachusetts Institute of Technology(MIT) and a user guide was presented for the first time in 2007 (Sussman, et al. 2007).

In order to conduct the analysis and the modeling of the observatories, we chose two astronomical observatories located in Chile, the cluster of telescopes of La Silla and the Atacama Large Millimeter Array (ALMA). In the following section, we will introduce the two observatories and present a brief summary of their history. Then, in the section D, we will report the application of the CLIOS Process to the case of astronomical observatories.

A.III. Astronomy in Chile: Overview and History of La Silla and ALMA

A.III.1. ESO & La Silla

The history of the La Silla observatory is correlated to the history of ESO (European Southern Observatory), since La Silla was the first astronomical observatory built by ESO. Therefore, we will first introduce ESO and its history.

The European Southern Observatory is a 16-nation intergovernmental research organization for ground-based astronomy. The organization is composed entirely by European countries, with the exception of Brazil that in 2010 submitted its interest in accession (the process is still pending)[3].

The idea that European astronomers should create a common large observatory was introduced by the astronomer Walter Baade in 1953 at the University of Leiden (Madsen 2012). The idea of creating scientific collaborations between European countries was part of the social trend, permeating European society in the Second postwar period, of establishing cooperation between European countries in order to avoid the mistakes of the past. The first “European” scientific collaboration that saw the light was the European Council for Nuclear Research (CERN) in 1954, because of an agreement among 12 European countries.

The idea of Walter Baade very quickly took shape and by the beginning of 1954 a formal statement was signed in Leiden by 12 leading European astronomers. One of the main elements of the statement was that an astronomical observatory was to be established in the Southern hemisphere (more precisely in South Africa), due to the necessity of studying the southern skies, at that time relatively unexplored and at to the presence of object of particular interest for Europe’s astronomers like an easy access to the center of Milky Way (Madsen 2012).

In 1960, it was taken the decision that ESO would be an intergovernmental organization, and not only a join facility between national organizations. The main cause of this decision was surely the growing cost of the project. In 1962 representative of France, Germany, the Netherlands, Belgium and Sweden signed the ESO Convention that was completely ratified in the 1964. The Convention of 1962 was strongly inspired by the CERN convention. The relationship between CERN and ESO has always

[3] ESO & Brazil FAQ: http://www.eso.org/public/chile/about-eso/faq/faq-eso-brazil/

been strong and 1970 a formal agreement of collaboration was signed between the two European organizations (Madsen 2012).

Like previously said, the initial decision was of locating the observatory in South Africa. The decision of placing the observatory in Chile was taken by the ESO Committee in 1963, after having analyzed a report showing the comparison of the data collected in South Africa and in the North of Chile(more accurately in Cerro Tololo, in the IV Region de Coquimbo). The superiority of the climatic and observing conditions unanimously convinced the Committee. The question of where exactly establish the observatory was resolved only in the 1964. In fact, initially the preferred site was Cerro Morado, a site indicated by AURA[4], an American universities association that at that time yet had started astronomical activities in Chile on the Cerro Tololo. Cerro Morado is sited on the territory of AURA and establishing the observatory on this mountain will mean, for ESO, having a kind of relationship with AURA. However, ESO, as an international organization at intergovernmental level, possessed a legal status that was difficult to reconcile with that of AURA that is an association of national universities. This fact took ESO to start considering other alternatives. Finally, ESO decided to choose Chinchado-North, also called La Silla after its shape, as location for its observatory. In 1963, ESO signed a contract with the Government of Chile, the Convenio[5], for the purchase of an area of 672 km² including the mountain of La Silla for a price of 8000 US$ (Madsen 2012).

La Silla is a mountain situated in the southern part of the Atacama desert, 600 km north of Santiago de Chile and at an altitude of 2400 meters. With the acquisition of La Silla, new infrastructures were created like an office in La Serena, the Camp Pelican(a base camp established where the road from Pan-American highway reaches the foot of the hills that lead up to La Silla) with six houses, the road from Camp Pelican to the top of La Silla and at the same time a guesthouse of ESO was established in Santiago(in 1967 the Chilean headquarter of ESO would be built in Santiago). In 1969 the observatory was finally inaugurated.

The decisions related to the construction of the telescopes were taken by the Instrument Committee. The first telescopes to become operational at La Silla were the 1-metre photometric telescope, the GPO(Grand Prisme Objectif) and the 1.5-metre telescope, all built in the ‘60s . There are three major telescopes located at La
Silla: the ESO 3.6-meters telescope inaugurated in 1976, the 2.2-metres telescope that starts its operations in 1984 and the New Technology Telescope that saw its first light in 1989. A more accurate description of these telescopes will be done in the following paragraphs. Other telescopes, now decommissioned, placed at La Silla are the 1.4-metre CAT (Coudé Auxiliary Telescope), the Swedish ESO Submillimeter Telescope, SEST. Furthermore, at La Silla there are also some national telescopes. These telescopes, which are of property of one of the member state, or of an institute in one of these states, use ESO Service and in compensation ESO obtain fraction of the observing time. These telescopes are : the German Bochum 61 cm, the Danishes 50 cm photoelectric telescope (or SAT) and 1.5-metre, the 0.9-metre Dutch telescope, three Swiss Telescopes (a 0.4-metres,a 0.7-metres and a 1.2-metre Leonhard Euler Telescope), three Frenches telescope (MarLy 1-metre telescope, the Marseille 0.36-metre telescope and the TAROT), the Belgian TRAPPIST and the Italian REM.

[4] Association of Universities for Research in Astronomy.
[5] Electronic Version of the Convenio between ESO and Chilean Government:
https://www.eso.org/public/archives/books/pdf/book_0016.pdf

Year	*Event*
1953	The idea that European astronomers should create a common large observatory is introduced by the astronomer Walter Baade.
1954	A formal statement is signed in Leiden by 12 leading European astronomers
1954	An ESO Committee is formed
1962	Representatives of France, Germany, the Netherlands, Belgium and Sweden sign the ESO Convention.
1964	The Chilean site of La Silla is chosen as the site of the observatory.
1964	La Silla operation comprise: an office in La Serena, Camp Pelican and the project of the road from Camp Pelican to the top of La Silla
1967	The headquarter in Santiago is inaugurated
1967	Denmark joins ESO
1968	Two telescopes are placed in La Silla: the 1.5-metre telescope and the GPO
1969	The observatory of La Silla is inaugurated
1971	The 1-metre telescope is erected
1976	The ESO 3.6-metre telescope sees its first light
1982	Italy joins ESO
1984	The MPG/ESO 2.2-metre telescope is inaugurated
1987	The Swedish ESO Submillimeter Telescope see its first light
1989	The New Technology Telescope, the first telescope with a system of active optics, starts its operations
1990	The first instrument of adaptive optics is inaugurated at the ESO 3.6-metre
1998	The Very Large Telescope on Cerro Paranal sees its first light
2013	ALMA, the Atacama Large Millimeter Telescope, is fully operational

Table 8: Timeline of La Silla observatory.

A.III.1.1.ESO 3.6-metre telescope

It was in the 1976 that the ESO 3.6-metre telescope saw the light. The construction of this telescope was one of the most important point of the initial program released with the Convention of 1962.The 3.6-metre telescope is an optical and near-infrared telescope. The telescope, as it was planned, is a quasi-RitcheyChretien with a primary mirror of 3.5 meters in diameter. The telescope had three foci: an f/3 prime focus at the top of the telescope with a camera including a Gascoigne plate corrector (later replaced by a triplet corrector offering a wider field of view), an f/8 Cassegrain focus below the primary mirror and an f/30 coudé focus placed below the observing floor. The telescope was designed to have an equatorial mount with a combined horsefoe and fork structure. The instrumentation plan for the 3.6-metres initially was very modest. In fact, the only instrument mounted on the telescope were a camera on the prime focus, a photometer and a Boller & Cliven spectrograph. Successively several instrument was mounted at the telescope: spectrograph like the CES and the CASPEC, multi-purpose instruments like the EFOSC, EFOSC2(later mounted at the NTT), infrared multimode instrument like TIMMI and TIMMI2 and several others. An important feature of the ESO 3.6-metre telescope is that it was the first telescope with an instrument of adaptive optics[6], the COME-ON, and then followed by COME-ON+ and ADONIS, user-friendly upgrades of the first. Nowadays only an instrument is still mounted at the telescope, the HARPS (High Accuracy Radial Velocity Planet Searcher), also called by astronomers the “planet hunter HARPS is a unique fiber-fed echelle spectrograph able to record at once the visible range of a stellar spectrum with very high spectral resolving power. HARPS searches nightly for exoplanets. The instrument searches for planets in orbits around other stars (exoplanets) through the measurement of accurate stellar radial velocities. Thanks to these instruments more than one hundred extrasolar planets have been detected.

A.III.1.2.The New Technology Telescope

The 3.58-metre New Technology Telescope(NTT) was inaugurated in 1989. It is an optical and near-infrared telescope and has a Rictchey-Chretien optical design. The primary mirror of the telescope has a diameter of 3.58 meters and the telescope has an alt-azimuth mount and tow Nasmyth foci. This telescope was the first in the world to have a computer-controlled main mirror. This technology is called active optics and allows adjusting the shape of the mirror during observation by actuators in order to preserve the optimal image quality. Another technological breakthrough of the telescope is the octagonal enclosure.

Several instrument was mounted at the telescope. Examples are the EMMI, the ESO Multi-mode instrument, a multi-mode spectro-imager, the high-resolution imagers SUSI-1 and SUSI-2 and the infrared spectrometer IRSPEC. Currently there are two instruments available at the NTT: a) Son of ISAAC , SOFI, a large field Infra-red spectro-imager. This instrument was installed at the Nasmyth focus of the NTT in the 1997 and was built to detect near-infrared light. This kind of light propagates much better through dust, allowing astronomers to study the objects behind the clouds. Therefore, the scientific goal of this instrument is to observe distant galaxies and objects. SOFI has made many contributions with images or through spectroscopy, especially in the study of brown dwarfs. B) The EFOSC2, or ESO Faint Object Spectrograph and Camera version 2. This instrument saw first light on the NTT in 1989. EFOSC2 was created for its versatility. In fact, like its predecessor, EFOSC2 is able to work in many different modes with strong performance. In this way, EFOSC2 is at the same time an imager, a spectrograph, a coronagraph, a polarimeter and a spectropolarimeter.

[6] Adaptive optics is a technology used to reduce the effects of atmospheric distortion

A.III.1.3. The MPG/ESO 2.2-metre Telescope

The history of the MPG/ESO 2.2-metres telescope at ESO began on the first year of the 1980s. It was built by the Max-Planck-Institut fur Astronomie with the aim of placing it in Namibia. Unfortunately, it was never erected in Namibia because of political reason. In order to avoid the telescope would be unutilized; the German institute signed an agreement with ESO: the agreement foreseen the 25-year loan of the telescope from German organization to ESO, on the condition that ESO installed the telescope at its own cost and that the Max-Planck-Institut would receive 25% of the available observing time. The telescope was erected in 1983 and in the same year, the telescope saw its first light.

The 2.2-metres is an optical and near-infrared telescope with a Ritchey-Chretien optical design. It has a primary mirror of a diameter of 2.2 meters and was designed to have an equatorial fork mount. This telescope played an important role in ESO's experimentation on the remote control of telescopes, being one of the three telescopes remotely controlled by the ESO headquarter, in Garching, Germany. The initial instrumentation of the telescope was a photographic camera and the Boller & Chiven spectrograph with a CCD camera. In 1988 the ESO's first infrared imager, IRAC, was mounted on the telescope and in 1992
IRAC2 took the place of IRAC. Currently there are three instrument working at the telescope: a) the 67Milion-Pixel WFI(Wide Field Imager) : with a field size larger than the full Moon the instrument allowed to obtain detailed views of extended celestial objects to very faint magnitudes. It was the first of a new generation of survey instruments and it would avoid the discovery of interesting and unusual celestial objects that would then be studied with large telescopes like the VLT. The Wide Field Imager was developed by a collaboration between ESO, the Max-Planck-Institut fur Astronomie and the Osservatorio Astronomico di Capodimonte in Naples. b) the Fibre-fed Extended Range Optical Spectrograph (FEROS). It allows having a high resolution, high efficiency and a great versatility providing in a single spectrogram almost complete spectral coverage. It would be used to search for extrasolar planets with high-precision radial-velocity measurement, to investigate the field of asteroseismology and for spectroscopic investigation of timedependent phenomena in stellar atmosphere .c) GROND, a GRB(Gamma-ray bursts) optical detector. It allows to takes images simultaneously in seven colors in order to follow-up Gamma-ray burst[7].GROND has been built by the Max-Planck Institut fur Extraterrestrische Physik in collaboration with the Landessternwarte Tautenburg and ESO and became operational in 2007.

A.III.2. ALMA Observatory

The Atacama Large Millimeter/Submillimeter Array (ALMA) is an astronomical interferometer of radio telescopes in the Atacama Desert of northern Chile. It consist of 54 12-meter diameter antennas and 12 7-meter diameter antennas.

ALMA is the largest astronomical ground based global collaboration. It is a huge project based on a partnership of institutions and organizations from a wide number of countries, each bringing its own management, organizational features and scientific and technological objectives. This creates a rich environment around the project thanks to different expertise and experiences, but it is also a challenge due to the high complexity to build and provide the science users and the public a unified project.

[7] Gamma-ray bursts are short flashes of energetic gamma rays lasting from less than a second to several minutes and they release a tremendous quantity of energy, which made them detectable for a fleeting moment in the optical and in the near infrared.

A.III.2.1.History

The birth of ALMA project dates back to the end of the last century. In Europe, North America and Japan there were scientists and astronomers studying large millimeter/submillimeter array radio telescopes. In particular, there were three projects: the Millimeter Array (MMA) of the United States, the Large Southern Array (LSA) of Europe, and the Large Millimeter Array (LMA) of Japan. After thorough investigations, it became clear that the amount of the investment for those ambitious projects was too high to be sustained by a single community. The first step toward the creation of Alma came on 25-26 of June 1997, when the NRAO (National Radio Astronomy Observatory) and the ESO (European Southern Observatory) signed an agreement at NRAO Headquarters in Charlottesville, Virginia, to pursue a common astronomical project that merged the MMA and LSA. The basic elements of the paper were to work towards a joint project of 64 12-metre antennas, located at the high (submillimetre-friendly) Chilean site of Chajnantor, funded on a 50/50 basis by Europe and the US. ESO and NRAO so started working together in technical, scientific and management groups to organize and coordinate the joint project between the two observatories with the participation of Canada and Spain(that later became a member of ESO).

On 10 June 1999, ESO and NSF (National Science Foundation, USA), the NRAO's funding agency, signed the agreement for the three-year design and development phase (Phase One) at NSF Headquarters in Arlington, Virginia. In addition, in February 2000 were awarded the two contracts for the prototypes of the antennas.

In parallel, preparations for the construction phase, Phase Two, were going forward. At the June 2002 meeting in London, the ESO Council formally approved "European participation through ESO in the baseline Bilateral ALMA Phase II at the 50% level". On 25 February 2003, the two organizations signed the agreement.

The testing of the first prototype antenna started in April 2003. The site was Socorro in New Mexico that is well known to radio astronomers because it is the home of the Very Large Array radio telescope (VLA).The prototype test phase turned out to be difficult due to the high accuracy required, the late delivery of the antennas and the strict time schedule. The first set of tests was concluded in April 2004, but they were inconclusive. Despite these difficulties, the ALMA partners took the next step by the end of 2003, moving towards the procurement of the full set of antennas. According to the bilateral agreement, each partner would deliver half of the total number of antennas.

At a meeting in October 2005the baseline project was redefined with the reduction of the number of antennas in order to achieve a cost saving, but maintaining the possibility to reach the primary science goals. The project would now comprise 50 12-metre antennas, 25 to be delivered by each party, at an estimated cost of 750 million US dollars. By the end of 2005, the ESO Council approved the project and the budget, while the NRAO received the approval from the National Science Foundation (NSF) by the middle of 2006.

Meanwhile, Japan, through the NAOJ (National Astronomical Observatory of Japan), formulated and defined its participation in the project: ALMA received a proposal from the NAOJ whereby Japan would provide the ACA (Atacama Compact Array), an array of four 12-metre antennas and twelve 8-metre antennas, and three additional receiver bands for the large array. The agreement between ESO, NRAO and NAOJ was signed on September 14, 2004 (this agreement was subsequently amended in July 2006).The bilateral ALMA project thus became "Enhanced ALMA", with 66 antennas, about the same number as the original European/North American project had foreseen. Since 2006, ALMA is a partnership of Europe (32.5%), Japan (25%) and North America (32.5%), in cooperation with Chile (10%).

In parallel, in April 2005, a joint antenna evaluation group concluded that both the proposals by Vertex RSI, the American supplier, and EIE/Alcatel Space/MT Mechatronics, the ESO supplier, submitted in response to the call for tender, were technically acceptable. Therefore, in June 2005 NRAO signed the supply contract with Vertex RSI, while ESO signed the deal with the consortium led by Alcatel Alenia Space (including EIE and MT Aerospace) on 7 December 2005. The ESO contract of 147 million euro was the largest ever signed in ground-based astronomy in Europe. The contracts foresaw the delivery of 25 antennas, but contained an option for an additional seven antennas.

Much discussion had also focused on the development of the necessary electronics, including the front ends with the receivers and cryogenic systems. It was decided that each partner would establish a regional Front-end Integration Centre (FEIC), one in the US, one in Europe and one in Taiwan, which had become a partner of Japan. Furthermore, in early 2003 a Joint ALMA Office was established in Santiago de Chile, with staff from all partners.

In March 2007, the first observations were carried out with two ALMA antennas, not from Chajnantor, but using two prototypes at the ALMA test site in New Mexico. The first of the antenna transporters arrived in Chile in February 2008 and the first ALMA antenna, from Japan, was moved up to the high site in September 2009. By March 2009, all components for the first European antenna had arrived in Chile and integration could start. The antenna was accepted in early 2011.

The phase of Early Science started in the second half of 2011, with a little delay respect to the scheduled timeline, with the release of the first images to the press. The array has been operative since March 2013 starting it first operational cycle of observation.

A.III.2.2. Science Objectives

The Alma Array give an incredible combination of angular resolution, spectral resolution, sensitivity and imaging fidelity at the shortest radio wavelengths. It is an instrument capable of producing detailed images of the formation of galaxies, stars and planets. It will observe the galaxies in their starting stages at edge of the Universe and it will image the stars and planets being formed in gas clouds near the sun.

A.IV. CLIOS Process applied to astronomical observatories

Before starting the process of modeling, we will introduce the concepts of CLIOS, CLIOS process and furthermore we will justify its applicability to the specific case of the astronomical observatories.

A.IV.1. Introduction

As outlined in the CLIOS User Guide (2007) CLIOS stands for Complex, large-scale, interconnected, open, sociotechnical systems. These characteristic will be better illustrated in the next paragraph. CLIOS Systems are a class of engineering systems that have a relevant social and environmental impact. To predict the behavior of these systems is really difficult mainly because of:

- There are many components or subsystem interacting.
- A high number of agents or an high degree of human agency is involved in the system.

CLIOS Process was developed with the aim of solving this problem. Sussman define CLIOS Process like an instrument that can help understanding CLIOS System's underlying structure and behavior and furthermore it can be useful for the identification and the deployment of strategic alternatives that can improve the system's performance (Sussman, et al. 2007).

In our research, we have used CLIOS mainly for better understanding the structure and the behavior of the complex system of astronomy.

A.IV.2. CLIOS Process overview

The CLIOS Process consists of 3 stages (phases) covered in 12 steps:

i. Representation: which is primarily a graphical illustration of the CLIOS System
ii. Design, evaluation and selection: which analyses and prescribes alternative strategies
iii. Implementation: of the strategies followed by monitoring and evaluation

The stage of Representation has the objective of understanding and visualizing the structure and behavior of the system. In this stage, there will be the description of the system and its structural representation.

The stage of Design, Evaluation and Selection is the more creative phase of the whole process. Firstly, there is a refinement of the goals established in the first step, followed by the identification of performance measures. Further strategic alternatives for performance improvements of the system are designed. Then these alternatives will be evaluated and finally there will be the selection of the best performing bundle of strategic alternatives.

In the stage of Implementation there will be the implementation of the strategic decision in the physical domain and the institutional sphere, and the consequent control of the System's performance.

In our research, we only use the first stage of the Process.

A.IV.3. Application of CLIOS to astronomical observatories

Astronomical observatories can be identified like CLIOS System. We can see like these entities possess the primary CLIOS System characteristics:

i. **Complexity**: Sussman stated that a ": A system is complex when it is composed of a group of interrelated components and subsystems for which the degree and nature of relationship is imperfectly known, with varying directionality, magnitude and timescales of interaction".

   There are several type of complexity. Astronomical observatories are characterized by:

   - **Structured Complexity**: A system has structured complexity when has a large number of interconnected parts. Astronomical observatories have a large number of interconnected subsystems and depend on several other systems, such as the socio-economic, the educational, the technological, the infrastructural, the labor and manpower and the environment systems. Astronomical observatories have a great impact on the social and economic aspects of the country in where they are installed. At the same time, the presence of astronomical observatories can influence the educational system of the country and its specialization in astronomy. Furthermore, the construction and the maintenance of an astronomical observatory clearly influence and is influenced by infrastructures, technologies and quality of the manpower.

- **Nested Complexity**: Nested complexity refers to the fact that a complex physical/technical system is embedded with an institutional system that itself is characterized by structural and behavioral complexity. The building of an astronomical observatory is the result of several interactions between different institutions like astronomical organizations, national and local institutions, universities and other stakeholders. Furthermore, the building of an astronomical observatory, for example, is subject to institutional and regulatory interactions.

- **Evaluative Complexity**: It reflects the multi-stakeholder environment in which astronomical observatories exists, and means that what may be good performance to one stakeholder may not be as good to another one. The multi-stakeholder environment exists both inside the scientific organizations and outside. Big Science centers, in fact, are usually collaborations between various institutions or between various countries (Chompalov, Genuth and Shrum 2001). The Association of Universities for Research in Astronomy (AURA) is a consortium of 39 U.S. universities and 7 International affiliate universities. Furthermore, there are stakeholders, outside of the scientific organization, that have influence on astronomical observatories, and are influenced by it, such as national and local institutions, firms, citizens, universities. Each one of these actors may have different objectives: for example, the goal of astronomical organizations is to make important scientific discoveries and to have the best instrumentation to lead their investigations at the best conditions. Instead, for the political institutions of the country the main goal is to exploit the establishment of astronomical observatories in the country with the aim of creating a high-qualified class of scientists and provide the economic and technological development for the country. These goals may be concurrent or divergent and this presents some evaluative complexity for the system performance, and therefore can be difficult to make a decision about what to do.

ii. **Large-scale**: Sussman states "Impacts generated by CLIOS Systems are large in magnitude, long-lived and geographically extended”. The impact of an astronomical observatory has clearly a large magnitude. In fact, astronomical observatories are Big-Science facilities and the discoveries produced in these centers have a strong impact on all the scientific community worldwide. Furthermore, often, the lifecycle management of an astronomical observatory is geographically extended in the way that companies and institutions from all the world participate in the building, the maintenance and the operations of these scientific centers.

iii. **Interconnected**: This feature consists in the fact that a CLIOS system often is interconnected with other CLIOS system. Astronomical observatories are connected to other socio-technical systems such as education and national administration for the achievement of its goals.

iv. **Open**: A system is open when it includes social, political and economic aspects beyond the technical one. Astronomical observatories obviously include these aspects.

v. **Socio-technical**: Astronomical observatories are socio-technical system because not only cover technical aspects in running the system, but also cover issues of a socio-technical nature and the achievement of social and economic goals.

A.IV.3.1. Representation of the system of astronomical observatories

In this paragraph, we will try to apply the CLIOS process to the specific case of astronomical observatories. More precisely, in order to pursue our objective of modeling the system of astronomical observatories, we will especially use the Phase 1 of the CLIOS Process: Representation. This stage helps in the understanding of the system by examining the structures and behaviors of the physical subsystems and the institutional sphere and the interactions between them

A.IV.3.1.1. Describing the CLIOS system: Checklist

As first step of the phase of representation, Sussman suggests to create some checklists to serve as a high-level examination of the CLIOS System. The list should address the question: "what is about the system that makes it interesting". The first of the checklists is the characteristics checklists that may relate to the various features of the system. The second checklist captures opportunities and issues of the CLIOS System.

a) Characteristic Checklist

a) Temporal and Geographical Scope

- The observatories intend to create astronomical knowledge.
- Astronomical discoveries have a global relevance.
- The development of astronomical technologies can affect other industries.
- International astronomical observatories are complex international scientific partnerships, which are an emergent policy instrument through which countries seek to improve their technological and innovation capabilities in specific sectors via collaboration.
- The observatories are intended for permanence, but always propose innovative technologies.
- The deployment of the projects is continuous and timeless.

b) Technologies and Systems

- A high number of different technologies is involved within an observatory
- Complexity of technologies and continuous development of new technologies
- Applicability of technologies to other industries
- Developing new technologies implies great investments
- Necessity to coordinate a high number of stakeholders in the processes of decision-making and of development of technologies.

c) Natural Physical Conditions

- Chile has the best climatic conditions for conducting astronomical researches.
- Complexity of the building and management of the observatories in extreme natural conditions (desert areas, and elevate mountains)

d) Key Economic and Market Factors

- The development of the astronomical industry can lead to a growth of Chilean economy, as well as the economy of other countries.
- Investments in technologies are usually high, but are shared by a great number of stakeholders.
- The technological level of the main Chilean industries is generally medium-low.

e) Social and Political Factors and Controversies

- Chile is politically and financially stable.
- Chile government support the development of the astronomical sector in Chile.
- Astronomical sector can be seen like a potential economic engine for the nation.
- The presence of a great number of stakeholders (political and scientific) acting in the same area can cause coordination problems.

f) Historic development

- Observatories are the results of international agreements between different institutions.
- Observatories are object of long-time projects.
- Projects have investment from both the governments and institutions.
-

b) Opportunities/Issues/Challenges Checklist

Opportunities

- Chilean Government: Government can benefit through an improvement of international relationships with the other countries and through an increase of the foreign investments in Chile.
- Private Sector: Chilean companies can: 1) benefits through the increase of supply contracts due to the existence of the observatories on Chilean territory. 2) benefits through the development of technologies in the astronomic industry that can be used in other fields.
- Education: The Chilean educational system can be affected positively by the creation and the development of innovative technologies in its territory and thus can become an important cultural hub worldwide.

Issues

- How Science Technology and Innovation derived from astronomical observatories can contribute to economic growth and societal progress?
- What are the elements that influence the generation of economic benefits for the country?
- What are the policy lessons from Chile's Big Science center case and what can other countries learn from this experience?

A.IV3.1.2. Identification of Subsystems in the Physical Domain and Actor Groups in the Institutional Sphere

In order to understand the behavior of the CLIOS system it's necessary to identify the structure determining the major subsystem that make up the physical domain and the main actor groups in the institutional sphere and how they relate to one another on a macro level.

a) Physical Subsystems

The subsystem identified are:

1. **Socio-economic Subsystem**
2. **Education Subsystem**
3. **Technology Subsystem**
4. **Infrastructure and localization Subsystem**
5. **Labor and manpower Subsystem**
6. **Environment Subsystem**
7. **Observatory Subsystem**

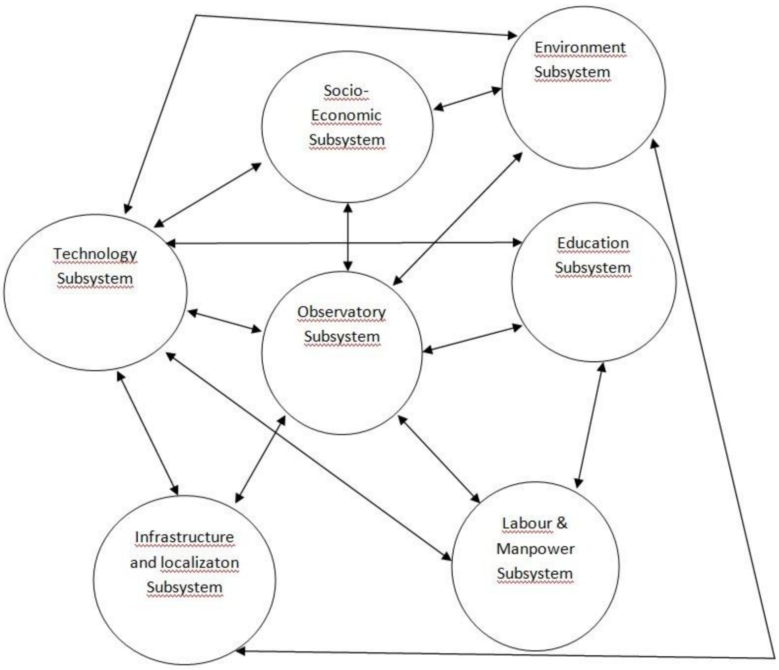

Figure 23: Subsystems of Astronomical Observatory system.

b) Institutional Sphere

We can classify five groups of principal actors acting on the physical domain:

1. Astronomical Organizations (ESO, ALMA, AURA, …)
2. National and local administrative, regulatory and advisory agencies

3. Universities and institute

4. Private Sector and Professional associations

5. Citizens group and civil society

Group	***Description***	***Actors***
Astronomical Organizations	Organizations instituted by different countries (ESO) or universities (AURA) aimed at the astronomical research. These organizations build the largest astronomical observatories.	European Southern Observatory (ESO), Association of Universities for Research in Astronomy (AURA), National Science Foundation via the National Radio Astronomy Observatory (NRAO), Association National Research Council of Canada,
National and local administrative regulatory and advisory agencies	All the political institutions that have a role in the astronomical ecosystem.	Republic of Chile, Ministry of Economy of Chile, Comisión Nacional de Investigación Científica y Tecnológica (CONICYT), Corporación de Fomento de la Producción (CORFO), other local administrative agencies
Universities and institutes	These entities conduct astronomical researches and have relationships with astronomical organizations. Furthermore, universities and institutes are the entities commissioned by astronomical organizations to build astronomical instruments.	Several universities and research center in Chile and all over the world
Private Sector and Professional associations	Firms collaborate with astronomical organization in all the lifecycle of the observatory.	Chilean and foreign companies; Astronomical associations
Citizens group and civil society	Citizens can gain benefits from the installation of astronomical observatories in the country (i.e. Employment). At the same time, the building of an observatory may be a threat for the indigenous populations living near the site.	Chilean population and indigenous populations living near the sites of observatories

Table 9: Institutional sphere.

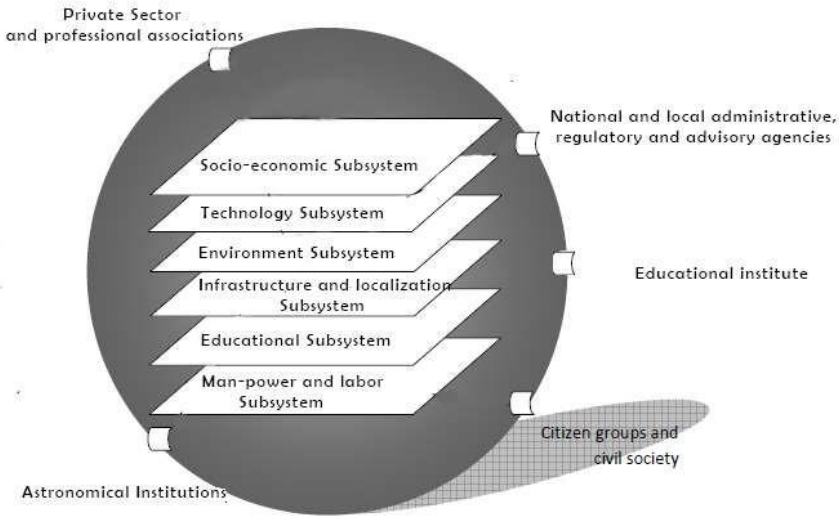

Figure 24: Physical domain and Institutional Sphere.

A.IV.3.2. Populating the Physical Domain and the Institutional Sphere

In this stage, the aim is to identify the major components in each subsystems and the links between them.

The CLIOS User guide explains that the components of the physical domain are of three different types:

- ***Regular components*** refer to concepts or can contain complex internal structure. These are the most common components.
- ***Policy levers***: these are components of the physical domain that are directly controlled or influenced by decisions of the actors of the institutional sphere.
- ***Common Drivers***: These are components that are shared across many subsystems of the physical domain.

a) Physical Domain

Socio-economic Subsystem

The economic benefits generated by the establishment of Astronomical observatories in a country can be of different types:

- Direct benefits for Chilean companies resulting from being suppliers of the observatories
- Collaboration, knowledge sharing and technologic development: An increase of the technologic knowledge resulting from collaboration with observatories could take Chilean companies to be more competitive on the market and will allow them to better their efficiency, productivity and effectiveness
- New sector: There will be the possibility of the establishment of a hi-tech sector related to astronomical observatories but with the opportunity of extending the business to other sectors.

- Investments: An increase of foreign investment in the country
- Employment: The presence of observatories can generate new employment opportunities for the citizens

Regular Components		***Description***
1	*Product and Process Innovation*	It refers to the development of new and better products and processes
2	*Jobs*	It refers to those jobs gained as a result of the existence of the observatories
3	*New market opportunities*	It refers to the birth of all the businesses related to the implementation of observatories in the Chilean territory
4	*Income*	Income can increase due to an increase of market opportunities
5	*Productivity*	Due to better processes or better products
6	*Increase of margin*	Refers to the increase of margin due to a better quality of product or process
7	*Social impacts*	People can have benefits by the development of the astronomical industry in the country like: a) an increase of the common scientific knowledge of the citizens,
8	*Internationalization*	Refers to the presence in Chile of people coming from all over the world due to the presence of several observatories in the country.
9	*International awareness*	Chile will be associated like the country of astronomy in the world
10	*Investments in technologies*	Refers to the capacity of companies and of the government to invest in technologies
Common drivers		***Description***
1	*Product and process innovation*	Refers to the development of new and better products and processes
2	*Technological knowledge*	Refers to the increase of technological knowledge related to the presence of the observatories
3	*Astronomical activities and technologies*	It indicates all the activities related to the establishment of astronomical observatories
4	*Financial risk*	The financial risk indicates the risk of investing in activities related to astronomy.
5	*Economic activity*	This is an indicator of the level and the wealth of the economy of the country
6	*Jobs*	Refers to the employment rate and the possibilities of employment in the country
7	*Specific technologies*	This refers to all the technologies that are specific for astronomical observatories.
Policy levers		***Description***

1	*Innovation policy*	Innovation policy governs the research areas of priority for the country. Innovation policy is extended to include intellectual property rights and laws. It also outlines the standards of products, processes and services in the innovation ideas
2	*Labor policy*	policy may include matters like the constitutive number of local personnel within an organization or the representation of marginalized individuals and gender balance
3	*Local and foreign investment policy*	Investment policy covers issues such as incentives offered to investors and the level of local ownership required in any investment
4	*Industrial policies*	The objective of these policies is to protect and preserve competition and to develop successful industrial policies for the country. Each sector ideally has its own industry policy and a regulator on the commercial interaction within the sector

Table 10: Socio-Economic subsystem.

Education Subsystem

The development of astronomical infrastructure on the Chilean territory can surely improve the quality of the Chilean universities in the field of astronomy. Furthermore, the collaboration between these Big-Science center and education can generate knowledge that can be applied to other disciplines.

Regular Components		***Description***
1	*Institutional learning*	Formalized training following a systematic structure.
2	*Skills*	It Indicates the skills and the abilities of students.
3	*Collaboration with university*	It indicates the relationship between the Big-Science centers and universities or research center
4	*Fame of universities*	The fame of Chilean universities can increase due to its specialization in astronomical subject
5	*Learning mechanism*	It indicates the way in which the knowledge is shared between the actors.
Common Drivers		***Description***
1	*Population*	It refers to the total population of the country.
2	*Research and Development*	This component indicates the presence of activities of R&D.
3	*Skilled labor.*	It refers to the part of population that have peculiar skills.
4	*Astronomical activity and technologies*	It indicates all the activities related to the establishment of astronomical observatories

5	*Technological knowledge*	It refers to the increase of technological knowledge related to the presence of the observatories
6	*Specific technologies*	This refers to all the technologies that are specific for astronomical observatories.
Policy levers		***Description***
1	*Innovation policy*	Innovation policy governs the research areas of priority for the country. Innovation policy is extended to include intellectual property rights and laws. It also outlines the standards of products, processes and services in the innovation ideas.
2	*Education Investment Policy*	This refers to an investment policy specific to the education sector which is an extension of the overarching investment policy within the country
3	*Knowledge Partnership policy*	It refers to all the activities (of private companies as well public ones) that have the aim of create relationship and partnership in order to share knowledge between the actors.

Table 11: Education subsystem.

Labor and Manpower

The establishment of astronomical observatories can surely create new opportunities of employment for the citizens. Citizens can be employed directly by observatories or they can become suppliers of these. At the same time, it will be the creation of a new class of skilled workers with high technologic knowledge. This fact can create the opportunity of creating new hi-tech businesses, also not directly related to the astronomy.

Regular Components		***Description***
1	*Unskilled labor*	It refers to that part of workers that do not have peculiar skills.
2	*Aggregate labor supply*	It indicates the aggregate supply of labor of the country.
3	*Aggregate labor demand*	It refers to the aggregate demand of labor of the country.
4	*Employers satisfaction*	It indicates the level of satisfaction of workers.
5	*Formal sector opportunities*	It indicates the direct opportunities of work generated by the presence of astronomical activities.
6	*Informal Sector Opportunities*	It refers to the opportunities of generating business related to the presence of astronomical activities in the country.
Common Drivers		***Description***
1	*Population*	It refers to the total population of the country.
2	*Skilled labor*	It refers to the part of population that have peculiar skills.
3	*Economic activity*	This is an indicator of the level and the wealth of the economy of the country.
4	*Jobs*	It refers to the employment rate and the possibilities of employment in the country.

Policy levers		Description
1	*Labor policy*	Labor policy may include matters like the constitutive number of local personnel within an organization or the representation of marginalized individuals and gender balance
2	*Local and foreign investment policy*	Investment policy covers issues such as incentives offered to investors and the level of local ownership required in any investment.

Table 12: Labor and manpower subsystem.

Technology Subsystem

Astronomical observatories can be considered like big case of technologies. In fact, in the running of an observatory there are several types of technology involved in the processes. Furthermore, the technologies used within observatories are often technologies of frontier. Obviously, the presence of so advanced technology in the country can help Chile to develop a hi-tech industry.

Regular Components		Description
1	*Telescope structure*	It refers to the mechanical structure of the telescope.
2	*Dome*	It is a structure useful for the protection of the telescope.
3	*Mechanics and Robotics*	All the mechanics and robotics parts necessary to the operations of the telescope.
4	*Mirror*	The mirrors are the light-gathering surfaces of a telescope. Each telescope has more than one mirror.
5	*Astronomical Instruments*	Astronomical instruments have the task to analyze the light entering in the telescope. These are complex equipment formed by other parts like spectrograph, cameras, grimes and others.
6	*Antennas*	Antennas are the most important part of a radio telescope. They act as the mirrors in reflecting telescope.
7	*Cryogenics*	Cryogenics are necessary to maintain a good and stable temperature within the astronomical instruments and the data archives.
8	*Others technologies specific for telescopes*	This component indicates all the others technologies used by the telescopes (lasers, detectors, filters …).
9	*Hardware and Software*	It refers to all the hardware and software technologies used at the observatories. It includes software of analysis of data, image processing and simulators.
10	*Big Data*	It refers to the big archives of data used by astronomical organizations.
11	*Control system and Remote control*	It refers to the technological solutions that allows to control the telescope and the management of its data (also from large distances)

12	*Other technologies*	It includes all the other technologies used at the observatories (such as electrical and hydraulic interface, materials and others).
Common Drivers		***Description***
1	*Location*	It refers to the location of the astronomical observatory.
2	*Astronomical activities and technologies*	It refers to the core activities of the observatories and to the core technologies
3	*Technological knowledge*	It refers to the knowledge of technicians, engineers and astronomers about the technologies.
4	*Financial risk*	The financial risk indicates the risk of investing in activities related to astronomy.
5	*Product and process innovation*	It refers to the development of new and better products and processes
6	*Research and development*	This component indicates the presence of activities of R & D.
7	*Skilled labor*	It refers to the part of population that have peculiar skills.
8	*Economic activity*	This is an indicator of the level and the wealth of the economy of the country
9	*Specific technologies*	This refers to all the technologies that are specific for astronomical observatories.
Policy levers		***Description***
1	*Observatories Management & Design*	It includes the design choice of the observatory and how it is administrated.
2	*Operations*	It refers to the management of the operations of the observatory.
3	*Local and foreign investment.*	Investment policy covers issues such as incentives offered to investors and the level of local ownership required in any investment.
4	*Innovation policy*	Innovation policy governs the research areas of priority for the country. Innovation policy is extended to include intellectual property rights and laws. It also outlines the standards of products, processes and services in the innovation ideas.
5	*Energetic policy*	It regulates the consumption of electricity.
6	*Environmental policy*	This policy is aimed at the preservation of the environment. It includes the policies of preservation of the cleanness of the air.
7	*Knowledge partnership policy*	It refers to all the activities (of private companies as well public ones) that have the aim of create relationship and partnership in order to share knowledge between the actors.

Table 13: Technology subsystem.

Infrastructure and localization Subsystem

The location of observatories in remote area imply a series of infrastructural intervention. In fact, roads, electricity and other utilities have to be made available to the observatory users.

Regular Components		Description
1	*Altitude*	It refers to the altitude of the astronomical observatory.
2	*Roads*	Refers to the roads and more generally to the transport infrastructure of the astronomical center
3	*Core Building*	Refers to the structures dedicated to the astronomical activities
4	*Other buildings*	Indicate the other buildings useful to the working of the observatory.
Common Driver		**Description**
1	*Location*	Refers to the location of the astronomical observatory.
2	*Technical facilities*	Refers to all the facilities useful for the life of an astronomical center
3	*Astronomical activities and technology*	Refers to the core activities of the observatories and to the core technologies
4	*IT infrastructure*	Refers to all the IT components necessary to the working of the observatory (PC, Data Base, LAN, Knowledge Management System etc.).
5	*Utilities*	It includes the electric and hydraulic systems and other utilities.
6	*Transport system*	It refers to all the means of transport used by the observatory.
Policy levers		**Description**
1	Local and foreign investment policy	Investment policy covers issues such as incentives offered to investors and the level of local ownership required in any investment
2	Energetic policy	It regulates the consumption of electricity.
3	Environmental policy	This policy is aimed at the preservation of the environment. It includes the policies of preservation of the cleanness of the air.
4	Observatory management & design	It includes the design choice of the observatory and how it is administrated.

Table 14: Infrastructure and localization subsystem.

Environment Subsystem

Particular climatic and natural conditions are among the requirements that astronomical organizations pretend when they choose a location for their observatories. At the same time, the building of astronomical observatories may have impact on the surrounding environment.

Regular Components		Description
1	*Electric requirement*	It refers to the electrical consumption within the observatory
2	*Water requirement*	It refers to the water consumption within the observatory.
3	*Air pollution*	This component indicates the degree of pollution of the air. A high air pollution degree may compromise the quality of observations.
4	*Electromagnetic pollution*	It refers to the electromagnetic pollution caused by the emission of electromagnetic waves. A

		high electromagnetic degree may compromise the quality of observations.
5	*Wastes Production*	It refers to the production of wastes of the observatory.
Common Drivers		***Description***
1	*Location*	It refers to the location of the astronomical observatory.
2	*Astronomical activities and technologies*	Refers to the core activities of the observatories and to the core technologies.
3	*Utilities*	It includes the electric and hydraulic systems and other utilities.
4	*Transport system*	It refers to all the means of transport used by the observatory.
Policy Levers		***Description***
1	*Environmental policy*	This policy is aimed at the preservation of the environment. It includes the policies of preservation of the cleanness of the air.
2	*Energetical policy*	It regulates the consumption of electricity.
3	*Observatories Management & Design*	It includes the design choice of the observatory and how it is administrated.

Table 15: Environment subsystem.

A.V. Interviews, Detailed Information

The names of the interviewers are kept secret. Brief descriptions of their role are reported below.

a) University
   1. Associated Professor at the Electric Engineering Department, Pontificia Universidad Catolica de Chile and member of the Instrumentation Lab at the Astro-engineering center of Pontificia Universidad Catolica de Chile.
   2. Associated Professor at the Institute of Astrophysics, Pontificia Universidad Catolica de Chile and member of the Centro de Astrofisica y Tecnologias Afines (CATA)
   3. Full Professor at the Astronomy Department, Universidad de Chile and Cerro Calán Observatory and member of Comisíon Nacional de Investigacíon Científíca y Tecnológica (CONICYT).
   4. Assistant Professor at the Computer Science Department, Pontificia Universidad Catolica de Chile and researcher at the Millennium Institute of Astrophysics.
   5. Full Professor at the Astronomy Department, Universidad de Chile and former manager of the Astronomy Program at CONICYT.
   6. Academic at the Astronomy Department, Universidad de Chile and member of the Centro de Astrofísica y Tecnologías Afines.

b) Astronomical Organizations
   1. Full Astronomer at the European Southern Observatory and ESO's Representative in Chile.
   2. Manager of the Department of Computing at Atacama Large Millimeter/submillimeter Array (ALMA).
   3. Head of Mission of Association of Universities for Research in Astronomy (AURA) Observatory in Chile and Director of Cerro Tololo Inter-American Observatory.
   4. Engineer and manager at ESO, Project Manager of the E-ELT Project.
   5. Science Operations Specialist in Gemini Observatory and academic at the Astronomy and Physics Department, University of La Serena.

c) Political Institutions
   1. Member of the Energy, Science, Technology and Innovation Department, Ministry of Foreign Affairs of Chile.
   2. Project Manager at the Innovation Department, Ministry of Economy of Chile.
   3. Coordinator of the Atamaca Astronomic Park.

d) Firms
   1. Sales and Marketing Director at Media Lario Ltd., a company supplying advanced optical components and optical systems, that provided the panel for the antennas of ALMA.
   2. Project Manager in the E-ELT Project for the consortium Astaldi-Cimolai.

We, also, visited the Astronomical Observatory of Gemini South, situated in Cerro Pachon, in the region of Coquimbo. This observatory, together with Gemini North situated in Hawaii, was built by a consortium consisting of the United States, Canada, Chile, Brazil, Argentina, and Australia, and is operated by the Association of Universities for Research in Astronomy (AURA). At the observatory, we interviewed five staff members.

A.VI. Procurement Process ESO

Technology Needs in Astronomy:
Optics, Detectors, Mechanical Structures, Cooling and chiller system, HVAC, Cranes and handling equipment, Mirror coating facilities, Actuators, Controllers, SW, Power grid connection and generation systems, Power distribution, Transportation of goods, Waste and chemicals treatment, (Pulsed) laser at specific frequency/wavelength, Consultancy (RAMS, PA, QA) ***Total Contracts 10 years (2005-2014): 996 Million EUR.***

The Procurement strategy in ESO is based on the principle of outsourcing all what can be efficiently performed by outside partners (industry or institutes) while keeping inside ESO the tasks where ESO has a long and specific experience not readily available outside.

For example, ESO mainly outsources: the detailed design, construction and integration of large structures (e.g. the Dome and telescope Main Structure); the high-precision optical mirror production; the design, construction and integration of astronomical science instruments by consortia of astronomical institutes.
On the contrary the core competences of ESO, which are kept inside the organization, are: specification, design and implementation of telescope control systems; the assembly, integration and verification of high-precision opto-mechanical units; the maintenance and coating of large mirrors.

Other principles of ESO's procurement strategy are:

- Specify the product or service needed at functional/performance level, rather than at design level;
- Procure complete system to minimize interface issues and limit ESO resources needed to follow-up contracts;
- Procure from a vendor no more than what he is experienced, keeping the risk clear;
- Ensure enough competition to keep price low;
- Geographical return;
- Limit contractors' on site involvement to those tasks that local ESO personal cannot do efficiently;
- Assessment of Technology Readiness Level (TRL), to estimate technology maturity of Critical Technology Elements (CTE) during the acquisition process.

The overall objective is to reach technical excellence at an affordable cost, in accordance with the key principles for public procurement: non-discrimination, transparency, accountability, fairness, economy and efficiency. In order to achieve this goal, the ESO Financial Rules and Regulations require the use of competitive tendering, preferably within ESO member states and Chile, with the contracts awarded to the lowest priced technically and managerial compliant tender.

The Procurement Policy also entails, as much as possible, a fair distribution of the contracts among the ESO member states: it is the Industrial Return, there is no requirement for "juste retour", but there is a strong expectation from the member states of an equitable distribution. It is measured through each country's "return coefficient", a ratio between the percentage of expenditures in an individual member state and its percentage contribution to the budget.

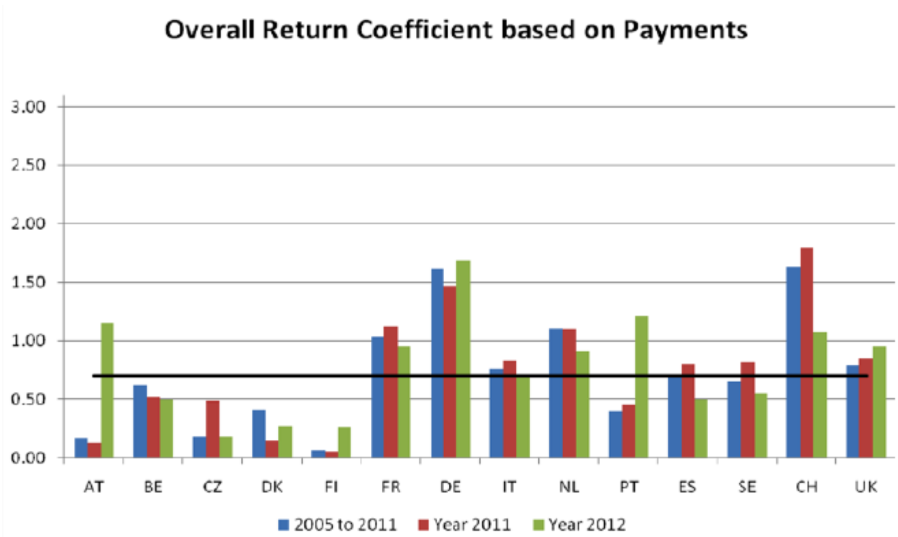

Figure 25: Industrial return for each member state 2006-2011,2011,2012; Geeraer, ESO Portugal

ESO Procurement Process:

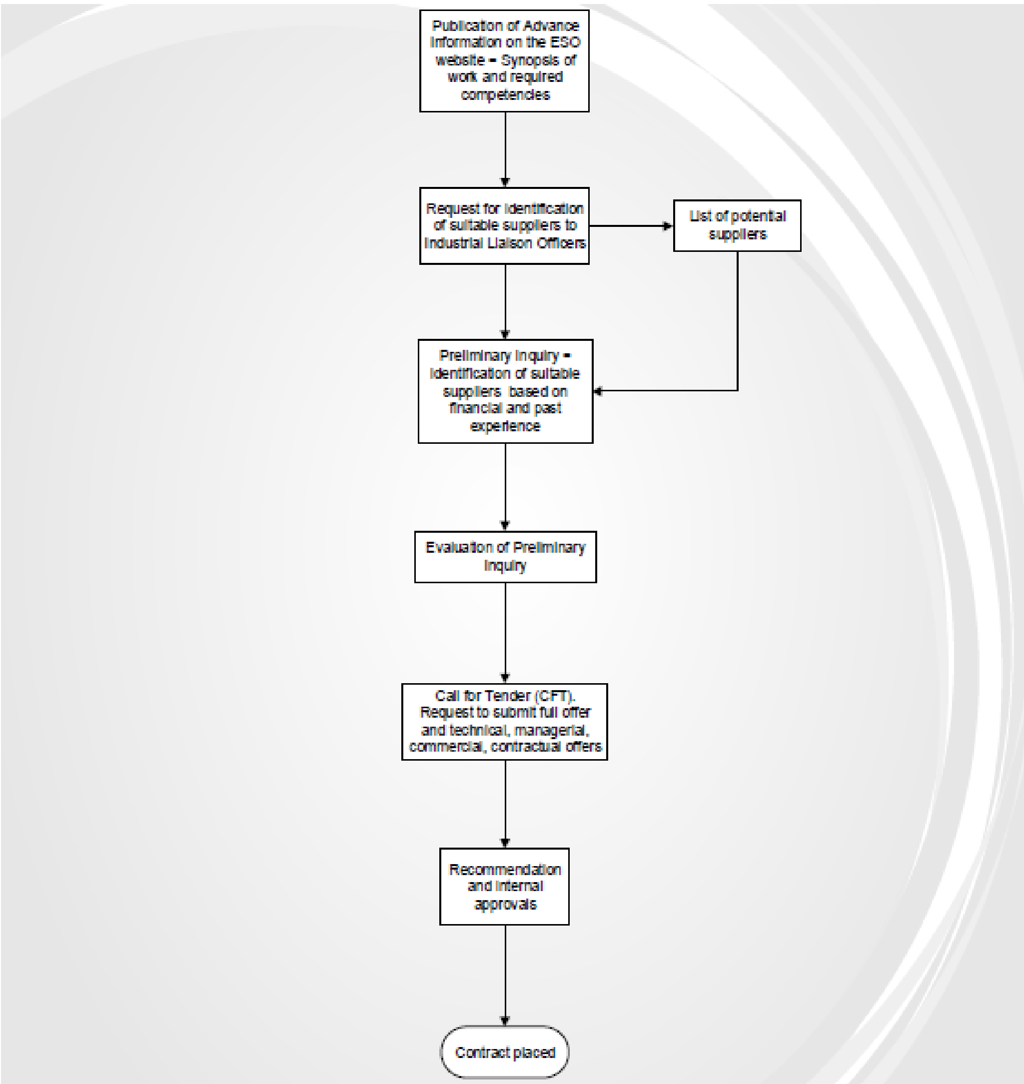

Figure 26: ESO Procurement Process for Procurements above 150K € (ESO).

ESO selects the recipients of its procurement actions from three different sources: its supplier database plus its staff's own knowledge, the ILOs' suggestions (Industrial Liaison Offices, one for each member state plus Chile) and self-applications of companies interested in the forthcoming procurements announced on the ESO web page.
ESO gives a great importance to the quality of its tenders and expects the same from the bidders: there is "one shot only", there is no room for improving a tender after its submission.

During the procurement process there is a first evaluation of the managerial/technical characteristics of tenders, performed without knowledge of the prices. The lowest prices compliant tender is awarded the contract. The contracts are regulated by ESO's own set of contractual conditions.
For procurements above 150k€, an internal committee is constituted to follow through the evaluation and adjudication process.

The procurement process involves the use of three instruments:

- ***Request for information*** (RfI), to collect written information about the capabilities of various suppliers;
- ***Price Inquiries***, for goods and services which are "standard" and do not call for an extensive definition of requirements, the schedule is ad-hoc, typically 3 to 4 weeks; the values are <150k€;
- ***Call for Tender*** (CFT), it is announced on the ESO Procurement web page and consists in two steps:
    1) Preliminary Inquiry: it is a selection based on technical and financial suitability, the result is a consolidated list of qualified companies, no more than 5 companies per each MS (response time: 4 weeks);
    2) Competitive Call for Tender: CFT sent to all qualified companies (response time: 6 weeks).

ESO also collaborates with different institutes to build instruments to be used at the telescopes. In these cases, are applied the same principles as for industrial procurements. The difference stays in the identification that is via a "scientific council delegate" and in the remuneration that is via Guaranteed Time Observation (GTO) and the reimbursement of hardware cost.

ESO Industrial Liaison Offices:

The role of the Industrial Liaison Office (ILO) is to establish contacts between ESO and potential suppliers and to support ESO in its search for the different suitable suppliers in their respective country in order to maximize the chance to distribute the ESO contracts as fairly as possible amongst suppliers in the different member states.
Each member state of ESO may appoint an ILO. The member state appoints an ILO by announcing the appointment in a letter to the Director of Administration of ESO.
As ILO, an individual from an entity, public or private body or association, can be appointed. However, in order to prevent conflict of interest situations to occur, a given ILO cannot be an ESO staff member.
Ideally, the ILO has a broad network in the Member States Industry.
In order to assist the ILO in fulfilling its role and achieve the maximum added value for ESO the ILOs are involved at an early stage in the selection phase of the procurement process by giving them the opportunity to suggest suitable suppliers for procurements above 150 K EURO. This is a systematic step in the procurement process before the Preliminary Inquiry or Call for Tender is issued for these

procurements. In order to be able to find suitable candidates in their member state the ILOs are provided at this stage with the following information: a synopsis of the project, the major competencies that the potential bidders should have and a list of companies, which ESO has identified as potential bidders so far. The ILO can share the synopsis and the required competencies with potential bidders. The reaction period for the ILO is three weeks.

A.VII. Procurement Process CERN

Technology Needs in CERN: particle detectors, computer systems and communications, vacuum &low temperature, electronics, mechanical structures, electrical engineering and energy, civil engineering and buildings, design studies. ***Total Commitments 2010: 247,0 MCHF. (225,23 M€).***

Actors of the process:

- *CERN users*: The users at CERN are either the divisions or external research teams visiting CERN and participating in the major projects. They define what they need, find a budget and make requests. They can also suggest possible suppliers.
- *CERN Procurement Group* (in the Finance Department): ensures that CERN procurement rules are obeyed, selects firms to contact and manages the adjudication process.
- *Industrial Liaison Office (ILO)*: one for each member state, ensures that member state's firms are well represented as possible suppliers and offers help and assistance to member state's firms during the whole procurement process.
- *Supplier*: responds to price enquiry or market survey, makes firm known to ILO, CERN (supplier database) and end users.

The procurement strategy of CERN follows from its mission and from the process of meeting research goals. After the physics goals of future programs have been defined, the technical solutions and concrete engineering designs follow. These are transformed to technical specifications that start the purchasing procedure. The CERN Procurement Group manages the purchasing procedure.

Traditionally, CERN's engineering resources first design, construct and tests the prototypes. Then, a general technical specification is drafted to attract companies from all member states and from unrelated industries. CERN has the necessary technical capabilities on-site and so it has been able to retain its position against suppliers bargaining power. Due to heavy competition, suppliers may change in the follow-up contracts. Well-defined technical requirements have made CERN so far rather immune to the potential hazards of supplier switching.

Procurement Policy:

The CERN procurement policy states that the bids must fulfil all the necessary technical, financial and delivery conditions and, at the same time, there is the need to keep overall cost for CERN as low as possible. Moreover, there is the objective to achieve balanced industrial returns for the member states.

The industrial return coefficient of a member state for supply contracts for a given twelve-month period starting on 1^{st} March is defined as: the ratio between that member state's percentage share of all purchases of supplies (excluding purchases funded by non-member states) during the preceding four calendar years and that state's percentage contribution to the budget over the same period.

CERN tries to minimize supplier dependency and the risk of being caught up in a toot specialized and costly market. This could happen if too few suppliers dominated the market. CERN attempts to avoid such dangers by making an effort to invite a sufficiently large number of potential suppliers to bid. A policy requirement is that a least three competitive tenders must be sought for the purchase of supplies and services and the invitations to tender must be limited to manufacturers and contractors located within the territories of member states.

The firms that will take part in the procurement process come from four kind of sources: they can propose themselves, users can propose them, the Procurement Service can select them from CERN's supplier database or the ILO's can propose them.

Procedures for obtaining offers vary considering the purchase amount:

- For requirements not exceeding 10.000 CHF, users may issue price enquiries directly and the provided CERN procurement rules are followed. There is little chance for ILO team or Procurement to add firms unless invited to do so. At least three written offers must be sought for requirements above 5.000 CHF. The manufacturers or suppliers should be located in CERN's Member States and the orders are handled by a centralized Purchasing Pool.
- For purchases between 10.000 CHF and 200.000 CHF, the Procurement Service always issues Price Enquiries (PE). The ILO team gets informed and can add firms for orders above 50K. Users can also suggest firms. The contract is adjudicated by the firm that presents the lowest offer – free carrier price that complies with the technical, financial and delivery requirements (transport charges are not a penalty).
- For purchases exceeding 200.000 CHF, the Procurement Service Issues Market Surveys (MS) and Invitations to Tender (IT). The ILO team gets informed and can add firms. Users can also suggest firms. Only companies, which have fulfilled the qualification criteria of the market survey concerned, will be considered during the final selection. The factors in firm selection are the likelihood that the selected firm will submit a bid, CERN's previous experience with the firm, the firm's Member State contribution and it Industrial Return Coefficient. The supply contracts are awarded based on the lowest compliant bid to the firm whose bid complies with the technical, financial and delivery requirements.

The procurement process involves the use of three instruments:

Price enquiries: are drafted and issued by Procurement Service and include a cover letter, technical specification, tender form and a technical questionnaire. The deadline for bidders to submit bid is at least 4 weeks from the mailing date.

Market Surveys: are used to select the firms to be invited for the tender. Their purpose is to pass information to industry on future requirements, allow ILOs to propose potential bidders, update and improve CERN's supplier database and allow CERN to draw up a final list of qualified bidders. Are drafted and issued by Procurement Service and include a cover letter, a brief technical description, qualification criteria and a qualifying questionnaire which must be fully completed. The suppliers have at least 4 weeks to reply and the survey is valid up to 12 months from the date of issue.

Invitation to Tender (IT): it contains a cover letter, technical specification, tender form, a technical questionnaire. The deadline for bidders to submit a bid is at least 4 weeks from the mailing date. Sometimes the potential bidders are invited to a conference where complex aspects of the contract may be explained.

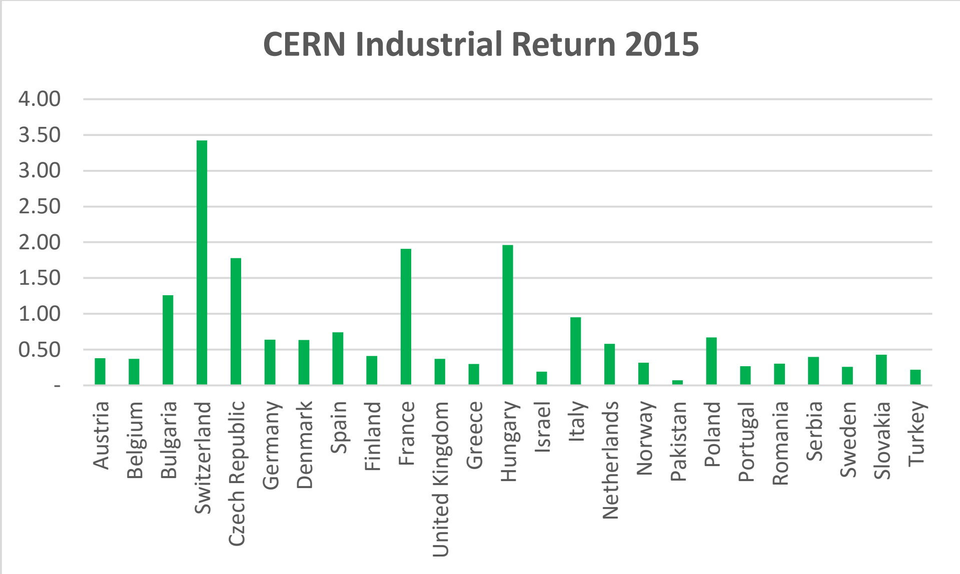

Figure 27: Industrial Return ratio for CERN member states in 2015.