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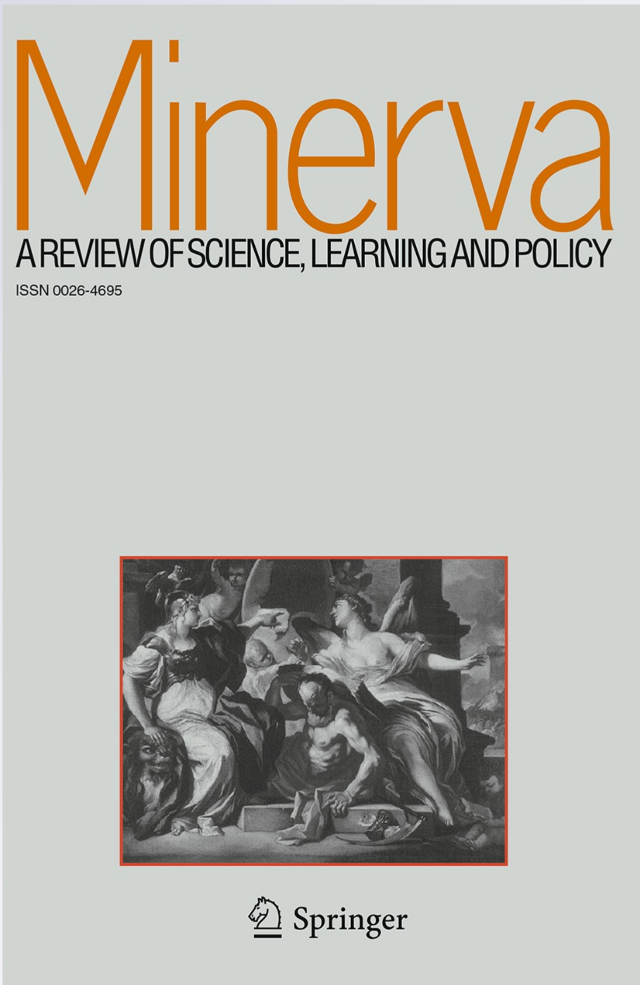

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Reaching for the Stars? Astronomy and Growth in Chile

Javiera Barandiaran[1]

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Abstract While scholars and policy practitioners often advocate for science and technology transfer as a motor for economic growth, many in Latin America have long warned of the pitfalls of such top-down, North-South transfers. To many in Latin America, scientific aid or cooperation from the North has often reproduced hierarchies that perpetuate dependency. Large astronomy observatories located in Chile – with a high price tag, cutting-edge technology, and seen to answer seemingly arcane research questions – seem ripe for reproducing precisely these kinds of hierarchical relationships. Using data from documents, interviews, and a site visit to Gemini South, one of several large telescopes in Chile, this paper takes a historical perspective to examine how resilient these hierarchical relationships are. Over forty years, astronomy in Chile grew thanks to new policies that fostered cooperation among universities and gave locals privileged access to the telescopes. But the community also grew in ways that reproduced dependency: foreign science benefits significantly, the Chilean state operates in top-down ways, and its support for science leaves it blind to the benefits high-tech telescopes deliver to Chile, which are not linked to export-led growth. The state appears as both an obstacle and an enabler to the growth of a national scientific community.

Keywords Big Science · Astronomy · Chile · Development · Periphery

Over 2,000 square kilometers of land host large astronomy observatories in Chile. Starting in the 1960s, telescope construction boomed: by 2020, Chile will concentrate 70% of the world's "viewing capacity" (Catanzaro 2014a). Until the

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late 1990s, these observatories were largely inaccessible to Chilean astronomers. But this changed after 1997, when the Chilean government came under pressure to negotiate improved conditions with the international organizations that run these observatories. Furthermore, in 2000 Chile, Argentina and Brazil became members of one such observatory, the Gemini South Telescope. As a result, local astronomers have access to the instrument, but at a cost that absorbs a significant portion of the national budget for science. In these and other ways, the study of the origin, composition and behavior of the stars and galaxies feels like a contradictory pursuit in a developing country like Chile. Each day astronomers drive to the telescopes—some of the most technically advanced machinery on earth running at exacting standards of precision and efficiency—to uncover fundamental truths about the universe; yet the drive is along a dirt road on which barefoot children play. They live in makeshift homes and attend precarious schools though they live in Chile, Latin America's richest economy.[1] Such poverty alongside the telescopes prompts many South American scientists to wonder about their proper role in society and how their countries benefit from their work.

These telescopes are archetypical big science, with a high price tag, cutting-edge technology and research questions that reach the frontiers of current knowledge (McCray 2004). These delicate instruments throw into stark terms the technology and knowledge gap between the global North and South. From telescopes to synchrotrons, economically advanced countries are investing in big science around the world, often justifying this as a form of development. However, in Latin America, the introduction of technologies from the advanced economies at the center of scientific production has often been regarded as colonialism by other means (Beigel 2013; Sabato 2004; Shinn et al. 1997; Vessuri 1987). These critiques accuse foreign technologies and the governments that introduce them of reproducing hierarchical relationships that keep Latin American countries dependent on technologies and expertise from the North, as they subvert the local research agenda away from the problems of poor, developing countries, towards universal scientific questions (Arocena & Sutz 2005; Fressoli, Dias & Thomas 2014; Kreimer 2006).

Chile's foreign astronomy observatories seem ripe for reproducing these kinds of hierarchical relationships. This paper takes a historical perspective to examine how resilient these hierarchical relationships are. I find that over forty years, astronomy in Chile grew thanks to new policies that fostered cooperation among universities (not states) and gave locals privileged access to the telescopes. But the community also grew in ways that reproduced dependency, evidenced in three things. First, foreign scientific organizations and researchers benefit significantly from many of the new opportunities created by the telescopes. Second, the Chilean state makes decisions about science in top-down, authoritarian ways that exclude the scientific community. Third, the Chilean state's support for science is based on the promises of export-led growth. This leaves the state blind to the benefits high-tech telescopes deliver to Chile, and demonstrates one way in which the state remains committed to a development model based on exports rather than entrepreneurship (Chang 2007).

[1] Measured in GDP per capita by the World Bank (http://data.worldbank.org/. Accessed March 10, 2015).

Though unique in its scale, the tale of Chile's foreign observatories can yield lessons about science and technology as aid today. Chile's trajectory shows just how hard it is to build "scientific community" and "research infrastructure," both important to how scientists practice their work. This article argues that the main obstacle is the state itself; through periods of dictatorship and democracy, Chile's governments have provided erratic support for science and often subordinated science to the state's interests in diplomacy, growth, and others. At the same time, the state's support is essential to fostering a national scientific community. This argument is laid out in four sections. The first provides a theoretical framing on big science in general and then in Chile. This is followed by a short note on methods. The next three sections are the article's empirical core: (1) the arrival of telescopes in Chile and how international science organizations shaped relationships with local partners; (2) the growth of Chile's astronomy community and how it did not successfully redefine its relationship to the state; and (3) the telescope's commercial linkages and returns, and how the state fails to see these. At the end, there is a short conclusion.

Big Science in the Center and Periphery

"There is an enormous potential for using astronomy as a tool for stimulating international development," says the International Astronomical Union (IAU 2012). But for communities and scientists in developing countries to benefit requires concerted effort. The IAU's General Assembly recognized this in its ten-year strategic plan that advocates for programs to build research capacity, provide training and education, and other measures in developing countries around the world. The IAU's plan is but one example of several efforts to use big science for development. Another is the particle accelerator project, called SESAME, being built in Jordan with support from the United Nations and others (Almohsen 2013). Recently, the European Union and governments like Italy and Australia expanded their scientific presence on the African continent, by introducing new funding programs, naming new science attachés, and other steps (Perkins 2012; Williamson 2015; Makoni 2011; Dickson 2012; Tatalovic 2014).

Advocates of big science for development sometimes hold optimistic, almost deterministic, views of technology's transformative abilities. Jordan's SESAME project is promoted as a route to peace: society could learn from watching scientists from opposite sides of the Palestinian conflict cooperate on high energy physics. Simply, "Middle East synchrotron seeks peace through cooperation" (Almohsen 2013). New telescopes being built in South Africa are similarly promoted as generative of a peaceful society. In a recent interview, scientist Ian Jones of the Goonhilly Earth Station in the UK emphasized, among other things, that South African villages might benefit from broadband access because the telescopes required installing new cables. This promises to improve life there because, Jones explained, "communication is a key driver of peace. It's essential to be able to talk to each other" (Frank 2014). Although the cables' main purpose is to connect the telescopes to research centers in Europe, so as to "get the data out of Africa" as a

German consultant described it, local communities would also somehow be transformed. Furthermore, "in terms of hard science, the benefits for Africa [from telescopes in South Africa] have already been profound," putting the continent on "the world's astronomical map" (Senthiligam & Spaull 2014). In short, and as summarized by an editor at SciDEV.net, a web-based news service that promotes science for development, "science and technology cooperation can help build modern economies, create jobs, and cut aid dependence" (Williamson 2015).

To be sure, technologies re-shape the world around them. But scholars of science have long emphasized that culture, discourses, and legacies influence this process and the organization of science (Knorr-Cetina 1999; Traweek 1992; Winner 1980). In Latin America, a central influence on scientific and technological practices is the legacy of dependency that juxtaposes science on the periphery to that done at the center, meaning the economically advanced countries of North America and Europe. Scholars of science in South American countries have examined the range of "survival" strategies local scientists use to do their work despite the adversities, which include erratic funding, difficult access to equipment, lack of students, political interventions, and others (Benchimol 1999; Cueto 1997; Diaz, Texera & Vessuri 1983; Kreimer 2007). A central survival strategy is to cooperate with foreign scientists, an opportunity that big science projects like telescopes, synchrotrons, or particle colliders seem particularly apt to promote.

However, alongside the benefits, international scientific cooperation poses challenges for scientists on the periphery. One such challenge concerns the potential for international cooperation to distort local scientists' research interests, shifting their attention away from issues that are locally relevant (Kreimer 2006; Kreimer & Zabala 2006). For Latin American scholars and scientists, science is not universal but deeply embedded in global economic structures (Fressoli et al. 2014; Sabato 2004). The pursuit of scientific knowledge for its own sake, exemplified by astronomers' interest in the deep origins of the universe, is often considered irrelevant to countries full of poverty and injustices. The feeling of contradiction science can generate was elegantly captured in director Patricio Guzman's 2011 film, *Nostalgia for the Light*. Set in the Atacama Desert, Guzman juxtaposes astronomers' high-tech research against a group of women's resolute search for the human remains of some of the disappeared in the 1970s–80s by Chile's military. Guzman's masterpiece asks, as a society, why do we dedicate so many resources to understand the distant past, when we know so little about our recent political and social history? Why study the stars, when the soil beneath holds so many secrets? At Gemini South, an Argentinean astronomer similarly felt that "it is difficult to decide to invest in astronomy when people are dying of Chagas disease" (interview 08/11-13/2009). Chagas disease is a potentially fatal and crippling illness that affects the rural poor in Argentina, Brazil, Chile and elsewhere in South America. His reference points to this perceived trade-off between research that is relevant to a developing country versus so-called universal research (Kreimer & Zabala 2006; Zabala 2010).

A distinct but related challenge involves peripheral scientists' quest to gain status and prestige on par with scientists at the center. Post World War II, U.S. foundations like Rockefeller and Ford travelled to South America to provide funding and recommendations on how to improve scientific activities, which often involved replicating U.S. institutions and evaluation mechanisms (Vessuri 1994). At that time, in the turbulent geopolitics of the 1960s, some scientists and students resented these interventions and denounced colleagues who accepted U.S. scientific aid (Beigel 2013). Today, these kinds of frustrations are targeted at the requirement to publish in English-language academic journals indexed by global companies like Thomson Reuters (Vessuri et al. 2014). Quality in science is increasingly measured in a handful of quantifiable ways: publications ranked by the journal's impact factor, patents, and degree of international collaboration (see Van Noorden 2014). These are challenges common to scientists on the periphery, but big science throws the stakes into sharp relief. "Obviously, big science can only be supported by very rich countries. Scientists in rich countries know this and consequently they are suspicious about the quality of scientific work done in poor countries" (Traweek 1992: 104). Big science is thus a privileged window into how this global scientific hierarchy operates. The IAU's strategic plan recognized as much when they focused on delivering aid, not science, to the middle income countries where they operate.

Big Science in Chile

Against the technological optimism of IAU, the history of foreign observatories in Chile is less than rosy. Though the terms of Chile's partnership with the foreign observatories have improved dramatically in the last four decades, as detailed in the pages that follow, recently discontent began to rise. Workers went on strike just as operations got underway at ALMA, the Atacama Large Millimeter/submillimeter Array, the world's premier radio telescope (Witze 2013). And scientists have been calling on the government to improve Chile's share of the benefits; according to the director of the astronomy program at the Chilean science agency, Conicyt, "This country has given enormous advantages to the international consortia…It's time that Chile participates in a more active way" (Catanzaro 2014a: 205). These demands recognize Chile's subordinate position, and also the myriad transformative impacts telescopes have had. This paper traces these transformations, how they occurred, and what factors impeded deeper transformations to Chilean science. By telling this as a story of foreign dominance and attempts to transform it, this paper reflects on what conditions produce international cooperations that challenge global scientific hierarchy. These conditions are set less by foreign scientific organizations or local scientific communities, than by developing country's governments. Next, I briefly review key features of the Chilean state's science policies.

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 2014a). For the past two decades, the state has favored private universities over public ones, reflecting deep-seated distrust of universities, particularly the flagship University of Chile. In the late 19th and early 20th centuries, Chile's political elites feared that universities threatened conservative Catholicism (Schell 2013). Only in the progressive atmosphere of the 1950s–60s universities expanded, a process that was abruptly interrupted in 1973 by the military coup. University spots for students rose from 55,600 in 1967, to 146,000 in 1973, and back down to 118,000 in 1982

(Constable & Valenzuela 1991). After the return to democracy in 1990, universities began to grow again, and today more than half of college-age students are enrolled in higher education (Barandiaran 2012). Nonetheless, in 2005, Chile's scientific community was still very small: about 2,600 researchers worked in Chilean universities and regularly published in peer-reviewed journals (Allende et al. 2005). Across the continent, funding for science is low and working conditions at universities are relatively poor (Arocena & Sutz 2005; Rodríguez Medina 2014; Schwartzman 2008; Vessuri 1986).

In addition to funding problems, the legacies of military intervention continue to hurt academic life in Chile, Argentina, Brazil, and other countries where such atrocities occurred. In Chile, the military regime broke the University of Chile into smaller units, shut down many departments, and privileged narrow, technical degrees (Constable & Valenzuela 1991). Repression in Argentina was so severe that many scholars, including many physicists and astronomers, went into exile, while in Brazil the military government showed relative clemency with scientists (Schwartzman 1991; Adler 1987; Hurtado de Mendoza & Vara 2007). Dictatorship in Chile and Argentina produced a generational break scholars have yet to fully explore, and that still shapes relationships between younger and older researchers (Visacovsky 2002).

For all these reasons, in Chile or Argentina it is difficult to speak of a "national scientific community" with a research "infrastructure" as is typically found in countries at the center of scientific activity. National scientific communities exist when they have an "infrastructure" consisting of sustained funding, at a sufficiently high level, that employs a certain proportion of the population in science, with sufficiently dense communication networks among scientists (Traweek 1992: 104). In Argentina, for example, Hurtado de Mendoza and Vara (2007) note that research into nuclear power started without any such community nor infrastructure in place. Instead, the community developed in response to the opportunity, which was introduced and grew thanks to decisions made by the government without consulting scientists. Similarly in Chile, an astronomy community did not exist prior to the installation of the telescopes (although individual Chilean scientists did play an important role).

Recent efforts to create a scientific community with a research infrastructure have focused almost exclusively on economic growth. In 2005, the Chilean government introduced a new royalty on mining income to support science, technology, and innovation, particularly in five strategic clusters: aquaculture, mining, biotechnology applied to agriculture, tourism and off-shore services (CNIC 2007). Funding went into scholarships, research centers, and a new National Center for Innovation and Competitiveness, justified by appeals to scientific excellence and the need to strengthen links to international universities and industry. Chile's science agency, Conicyt, launched generous funding to support "centers of excellence" that required scientists to obtain matching funds from non-government sources, preferably industry.[2] As detailed in the pages that follow, scientists

[2] http://www.conicyt.cl/pia/sobre-pia/lineas-accion/centros-cientificos-y-tecnologicos-de-excelencia-programa-de-financiamiento-basal/. Accessed March 4, 2015.

criticized several aspects of this new policy. Briefly, it introduced too much economics into decisions about science, reinforced quantitative productivity indicators, and deepened Chile's dependence on the export of raw materials (interviews 07/28/2009A; 07/28/2009B; 07/30/2009B; 08/10/2009A; 07/06/2009; 07/14/2009A; 07/14/2009B). In defining economic growth narrowly as the export of raw materials, state officials missed an opportunity to break past economic dependencies and begin to imagine new kinds of high-tech entrepreneurship (Chang 2007; Maloney 2007).

In short, it was a policy in which astronomy seemed irrelevant, and yet astronomers were among the most successful. This was because the astronomers' obtained matching funds from foreign scientific organizations dedicated to astronomy (e.g., IAU, ESO and AURA, introduced below). According to the program manager at Conicyt, other scientists had a hard time finding non-governmental support (interview 07/10/2009). To many the astronomers' success was ironic – a science seemingly far removed from commercial applications was the most successful in obtaining matching funds (at least initially) (interviews 07/10/2009; 07/22/2009; 07/29/2009). From the perspective of scholarship on science on the periphery, this episode has more significant undertones; foreign scientific organizations used their financial muscle to support a science few associated with economic growth, which was the state's policy goal. Those concerned about dependency would see in this episode evidence that the telescopes perpetuate dependency, because foreign organizations appear to be subverting the government's export-led growth agenda.

In this context, the Chilean astronomy community and its research infrastructure have grown dramatically, but have they grown in ways that redefined the community's relationship with the state? As briefly reviewed here, the Chilean state's commitment to science has been erratic, weak, and authoritarian, and the analysis that follows shows that astronomy is not an exception. The arrival of the telescopes has not helped to generate a research infrastructure as exists in central countries. Nonetheless, the Chilean astronomy community, as well as the Argentinean and Brazilian ones, have become partners in Gemini South, making this a particularly interesting case of foreign-led big science that incorporates three peripheral countries as partners. As scholar Pablo Kreimer (2006) asked, this is an ideal case to ask if Chilean scientists are integrated or dependent?

Methods

Data proceed from documents, interviews, and a site visit to Gemini South, one of several large telescopes in Chile. Government laws and documents, press releases and newspaper articles were used to reconstruct the history of telescope projects. Materials proceed largely from three organizations: the European Southern Observatory (ESO), a public organization supported by European states for the promotion of astronomy; the Association of Universities for Research in Astronomy (AURA), a coalition of mostly U.S. universities which manages U.S. observatories funded by the U.S. National Science Foundation; and the Chilean Ministry of

Foreign Affairs. Furthermore, in August 2009 I spent two days at Gemini South, sponsored by Gemini and the Social Science Research Council. There, I interviewed Chilean and Argentinean Gemini employees, including astronomers, engineers, and public outreach staff, and received an intensive tour of the telescope's facilities. Finally, the broader context is informed by interviews I conducted with leading Chilean scientists across disciplines, Chilean managers of science, and Argentinean astronomers at the National University of La Plata in July and August 2009. To protect respondents' anonymity all names and identifying characteristics have been changed.

From Diplomacy to Science in Chilean Astronomy

At the southern edge of the Atacama Desert, the mountains around the coastal city of La Serena were chosen as the home for the first generation of high-tech telescopes in Chile. In 1958, University of Chile Professor Federico Rutllant visited the United States to raise interest in building telescopes in Chile (Blanco 2001). Several years later, in 1962–64, AURA, Carnegie, and ESO purchased from the Chilean government several hundred square kilometers around the mountains of Tololo, Pachón and La Silla, within 200 kilometers of La Serena, for the construction of high-technology observatories (Table 1; Fig. 1). During these years, Northern astronomers became interested in studying the sky from the southern hemisphere, and chose Chile because the high Andes Mountains provide over 300 clear nights a year. This is due to climatic conditions — the cold Humboldt Current along the Pacific Ocean creates an extremely dry and stable atmosphere that can be accessed at high elevations along the Andes — supplemented by human conditions. At the time, Chile had a relatively small population and little artificial light. The success of the first projects paved the way for the expansion of observatories, as Chile built a political, institutional and physical infrastructure to facilitate their continued expansion (Gordon 2005). AURA played a particularly important role in building this infrastructure in ways that benefitted Chile's astronomy community because it fostered cooperation among universities, rather than among states.

As an organization of universities, AURA from the start worked in partnership with the University of Chile. Following the initial contact established by Professor Rutllant, the University of Chile became a member of AURA and astronomers there participated in administrative and scientific operations (McCray 2004; Blanco 2001). In contrast, as a private institution, access to the Carnegie Observatories was and continues to be significantly more difficult, while the Europeans, organized as a government agency, negotiated directly with the Chilean government. Because AURA was an organization of universities autonomous of the government, it had to incrementally solve administrative issues like visas and tax benefits (Blanco 2001). This led AURA to seek ways in which to develop stronger local ties; thus, for example, in 1967 AURA appointed Puerto Rican astronomer Victor Blanco to direct its first large telescope in Chile, Cerro Tololo, in part because he spoke Spanish fluently and would find it easier to deal with the authorities. As Blanco recalled in a memoir, these abilities became extremely important during the political turmoil of

Table 1 Large observatories in Chile (until 2010)

Observatory Name	Owner	Year saw light	Target community	Construction costs (millions)	Operating costs (millions)
La Silla	ESO	1966	Survey science	n/a	ESO operating costs are EU€140. E-ELT estimated costs are EU€50
Very Large Telescope	ESO	1999	Adaptive and Infra-red Optics	US$500	
Extremely Large Telescope	ESO	2024	Advanced Adaptive Optics	EU€1 billion	
Las Campanas	Carnegie Mellon	1969	Survey science	US$700 (for newest telescope)	n/a
Cerro Tololo Inter-American Observatory	AURA	1962	Adaptive and Infra-red Optics	n/a	US$8
Gemini S. at Cerro Pachon	AURA & Partners	2002	Adaptive and Infra-red Optics	US$100	US$10 (for North and South)
SOAR	U.S. Universities & Brazil	2004	Adaptive and Infra-red Optics	US$28	n/a
Observatorio Armazones	Catholic U. of the North (Chile)	1995	Adaptive and Near Infra-red Optics	n/a	n/a
ALMA	International Consortium	2011	Radio Astronomy	US$800	US$33

Table 1 continued

Observatory Name	Nearest city	Altitude (meters)	Land (sq. km.)	Land tenure	Type of telescope
La Silla	La Serena	2400	825	Purchased 30/10/1964	Several
Very Large Telescope	Antofagasta	2635	725	Donated by decree 1988	Four 8.2 meter telescopes
Extremely Large Telescope		3060	180 + 360 "reserve"	Donated by decree 2010 (Reserve 50 yr. concession)	42 meter telescope
Las Campanas	La Serena	2300	258	Purchased 21/11/1968	Several. New GMT will have 7 mirrors of 8.2 meters
Cerro Tololo Inter-American Observatory	La Serena	2215	320	Purchased 25/11/1962	Several
Gemini S. at Cerro Pachon	La Serena	2722			Twin telescope of 8.2 meters; Gemini North is in Hawaii
SOAR	La Serena	2215			4.3 meter telescope
Observatorio Armazones	Antofagasta	2200	527	5 year concessions; 2011 transfer to ESO	Several
ALMA	San Pedro de Atacama	5000	176	50 year concession from 2003	66 antennas with diameters of 12 and 7-meters

Compiled from official websites, press releases, and newspapers when necessary

N/A data not available

Fig. 1 Map of northern Chile with main cities and astronomy observatories. *Stars* Astronomy Observatories; *Red dots* Cities; *Horseback figure* Areas of important agricultural or tourism activity; *Falling rocks figure* Areas with major operating mines. (Color figure online)

the late 1960s and the 1973 military coup, when he successfully kept the telescope running and observations on schedule (Blanco 2001). Likewise, years later, at its Gemini South telescope AURA became the first organization to create an outreach office with journalists and educational staff, an initiative that was later imitated by other telescopes.

In contrast, as an organization of states, ESO conducted operations 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 significant tax exemptions (Decreto 18 of 4 April 1964). ESO opened its offices not in La Serena, as AURA and Carnegie did, but in the national capital, Santiago, on land donated by the government close to other foreign embassies (Gordon 2005; McCray 2004). In addition, in 1988, ESO received 725 square kilometers around the mountain of Paranal, 120 kilometers south of the city of Antofagasta in the northern Atacama Desert, for the construction of the "Very Large Telescope" (VLT)[3]. Though the historical record is thin, it appears the donation had been in preparation for some time. Pinochet's military government in 1977 expropriated these lands from a family, and in 1986 declared them a "science reserve for mining purposes," effectively forbidding any mining activities there without presidential approval (Decreto 52, 17 July 1986). Another 527 kilometers were added to this reserve in the early 1990s (Decreto 71, 2 May 1991). As an organization of states, ESO negotiated directly with the Chilean state rather than with Chilean scientists. Unlike AURA, ESO had no need to appoint a Spanish-speaking director because it had no administrative hurdles to resolve incrementally. Instead, it needed access to the central government in Santiago, hence the significance of locating its offices alongside other embassies.

Unexpectedly, a dispute over the Paranal site provided part of the catalyst for a renegotiation of the 1963 Convention. In 1993, the original owners took ESO and the government to court claiming the lands had been illegally expropriated. Though the case was eventually dismissed, it sparked a broader re-examination of foreign observatories in Chile. After the transition to democracy in 1990, and with a growing economy, Chilean representatives were more confident and challenged the government to explain how foreign science supported national objectives. Their challenge echoed the common concern of science done on the periphery, where international cooperation distorts local scientists' interests away from locally relevant research. Thus concerned, law-makers put pressure on the executive government to renegotiate the 1963 Convention to put Chile on a more equal footing with foreign astronomers and personnel (Decreto 1766 of 17 May 1997). Most significantly, the question of access was resolved by forcing ESO to grant 10% of the telescope's viewing time to projects proposed by astronomers at Chilean institutions. ESO also accepted applying aspects of Chilean labor law – including the right to bargain collectively – to locally hired staff.

Despite these gains, the extent to which a partnership between the foreign observatories and the University of Chile or the Chilean government exists should not be over-stated. The Chilean state has taken several steps to subordinate local

[3] ESO press releases of 20 February, 31 March, 18 and 19 April 1995.

laws, policies, and the scientific community to foreign scientific interests. After 1997, foreign observatories retained diplomatic status and tax exemptions. Observatories do not pay value added tax (19% in Chile) on annual expenditures, which range from US$5 to 80 million per year. If taxed, that would generate money that could be spent on research and education (Leighton 2014). In addition, many complain that Chile's allotted 10% viewing time as host is insufficient; Hawaiian institutions receive 15% and Spanish ones receive 20% (Leighton 2014). These numbers, together with the relatively cheaper costs of construction Chile offers (between US$200 and 300,000 less per viewing hour than in Spain or Hawaii), point to the continued presence of a global scientific hierarchy.

Foreign observatories are also exempt from Chilean environmental laws and benefit from Chile's lack of regulation compared to the United States or European Union countries. Although in Chile every project must submit an environmental impact assessment, astronomy observatories are exempt. Observatories have environmental impacts: to make room for the VLT, the peak of Paranal was truncated 40 feet to create a platform for construction and 60,000 liters of water are trucked from Antofagasta, 120 kilometers away, every day to sustain the on-site staff. ESO's website describes the observatory at Paranal as "a true oasis in the desert," with a swimming pool, indoor gardens, and accommodations for 75 people — a man-made oasis with environmental impacts that were not evaluated because ESO did not submit an environmental impact report. It is important to note that AURA voluntarily submitted such a report when considering Armazones for its own Thirty Meter Telescope (it was finally built in Hawaii), and that recently ESO's practices have shifted. In 2002, ESO submitted an environmental impact assessment for ALMA, which required construction of a 43 kilometer "super highway" through the desert, an overhead power line, and a base camp with capacity for 500 people at 5,000 meters above sea level.

The Chilean state has also acquiesced to concessions that would be unthinkable in the global north. For example, these observatories use lasers that can blind airplane pilots and hamper communication efforts (Environmental Impact Declaration for the Thirty-Meter Telescope, 2008). In contrast to the U.S., in Chile lasers are not regulated. Supervision is in the hands of the Civil Aeronautical Division, but without a legal framework it is unclear what control or enforcement is possible. The risks Chileans face from the use of such lasers in the territory thus remain out of public scrutiny. Similarly out of public view are issues like water and electricity consumption, two extremely scarce resources in the Atacama Desert. Thirty miles south of Paranal is the village of Paposo, with no regular access to water, yet no efforts exist to coordinate water services with the telescopes.[4] Meanwhile, the Chilean government footed the bill to bring electricity to the Llano of Chajnantor, where ALMA is located, saving ESO EU€7 million per year. In a diplomatic negotiation where the Chilean government has so far only been too eager to accept more telescopes, the environmental and economic costs of the observatories, and who bears them, are often left out of public scrutiny.

[4] Personal communication with engineers involved in a project to bring water to Paposo, June 2009.

The Chilean state has also been a willing donor of land. The Europeans in particular continue to benefit from land grants that have not been extended to the North Americans. European observatories have received over 1,400 square kilometers compared to just 320 given to the North American telescopes (Table 1). This includes lands for the European Extremely Large Telescope (E-ELT) in Armazones, near Paranal. To out-bid Spain, the Chilean government took land away from the Catholic University of the North to give to ESO. In the 1990s, the Catholic University of the North received this land to develop observatories, as it did, both independently and in collaboration with foreign universities. Although the Catholic University of the North will benefit from proximity to the E-ELT, the university also lost responsibilities and autonomy to manage its own small telescope. Having these duties is important for building capacity. The Catholic University of the North's loss illustrates the classic trade-off scientist on the periphery face (Kreimer 2006); for Catholic U. scientists, the benefits of international cooperation came with a loss of control over resources they formerly called their own. This is an example of foreign scientific interests, with the support of the state, marginalizing local scientific research infrastructures.

The terms of the renegotiated 1997 Convention provide two additional examples of how the Chilean state has continued to subordinate the national scientific community. First, though it is a legal text negotiated by state officials, not scientists, the 1997 Convention specifies how Chilean astronomers should evaluate projects in line for viewing time at the foreign observatories. Annex A of decree 1766 (May 17, 1997) defines a five-point scale to evaluate projects. A judge also assigns to each a number of nights for viewing. The text does not specify who appoints the judges, nor if a highly ranked proposal can receive "0" nights for viewing. Article 11 of the same decree asserts repeatedly that only "competitive" and "worthy" projects will receive viewing time. Furthermore, of Chile's 10%, half must be dedicated to projects on which Chileans collaborate with scientists from other ESO member countries. These provisions appear selected to mollify ESO concerns that a poor country like Chile could not produce quality science, much as in Japan's early steps into big science (Traweek 1992). Second, some law-makers suggested removing the University of Chile's faculties to "freely enter into agreements with foreign parties" (Boletin 1665-19-02 of Congressional Science and Technology Commission, 17 April 1996). Though the majority rejected this, it reflects a history of measures the state has taken against the autonomy of public universities (Barandiaran 2012). Together, these small examples demonstrate the state's systematic efforts to subordinate the national scientific community and control its research infrastructure in ways that hurt its autonomy.

Building a Scientific Community

Astronomy is one of the oldest forms of science practiced in Chile, first by indigenous communities, as Gemini South's outreach department underscores, and since 1853 at the national observatory. The same is true in Argentina and Brazil, where national observatories were founded in 1883 and 1827 respectively. Because of this long history, astronomy is an ideal discipline with which to study and compare the evolution of scientific communities over time. Furthermore, in 2000 these three communities —astronomers in Chile, Argentina and Brazil— came together as partners in Gemini South, along with the United States, United Kingdom, Canada and Australia. Gemini South is an 8-meter telescope owned and operated by AURA, along with its twin Gemini North located in Hawaii. While for years AURA pursued the Gemini project, for astronomers in Chile and Argentina the project arrived suddenly: in both countries, politicians decided to join the partnership after consulting little or not at all with local scientists. When astronomers from Chile, Argentina, and Brazil gained access to Gemini, they challenged global scientific hierarchies. However, the force of this challenge was tempered by the top-down, autocratic ways in which decisions about science and astronomy have been made. The comparison with Argentina and Brazil helps to highlight how Chile's astronomy community, while it has positively grown, has not been able to improve its status or autonomy from the state. As a result, science policy reflects political and foreign interests, more than those of Chilean astronomers.

Chilean and Argentinean astronomers were thankful for the opportunities Gemini provided, but also concerned by the top-down way in which their governments decided to participate. In Chile, the decision to become a partner in Gemini South was a diplomatic move by the government that cost US$9 million plus US$700,000 in annual operating costs. In exchange, Chilean astronomers gained another 5% viewing time, in addition to the 10% they enjoy as hosts. Chilean astronomers criticized that joining Gemini South absorbed more than half of the annual budget for astronomy research, when they did not need access to more viewing time thanks to the 1997 Convention (McCray 2004). Similarly, in Argentina astronomers complained that participating in Gemini South consumed their annual research budget. Until they gained access to Gemini, the best available to Argentinean astronomers was a 1984 2-meter telescope. The jump from 2 to 8 meters produces an exponential increase in viewing capacity; with Gemini, "you can see someone's nose at a distance of 20 kilometers," according to Gemini outreach staff (interview 08/11-13/2009). This jump requires changing how research is conceived (McCray 2004), and Argentinean astronomers faced a steep learning curve. However, because the decision to join was out of their hands, and in light of Argentina's changing economic fortunes, how could they know whether to invest the time and effort to learn to use Gemini if it could just as easily be taken away from them? (interview 06/21/2009; 08/11-13/2009). This episode illustrates that in Chile and Argentina research infrastructures are being built without the input of those who are supposed to benefit the most. Such authoritarian decision-making results in subordinated national scientific communities (Hurtado de Mendoza & Vara 2007).

Chile's community of scientists doubled between 1990 and 2000, and astronomy was one of the fastest growing fields. This growth was achieved thanks to legal requirements forced by ESO in the 1997 Convention and to the incentives introduced by the allocation of 10% viewing time to Chile. The 1997 Convention forced ESO and the state, and later AURA and other telescopes, to commit to nurturing the Chilean astronomy community. The legal text states that, "The

Table 2 Funding for astronomy research in Chile

In millions of Chilean pesos (year)	
Total awarded Fondecyt research projects for astronomy, 1980–2000	2,275.80 (2000)
Total awarded through the Astronomy program, 2005–2007	1,178.53 (2006)
Total awarded through the Basal Program for Centro de Astrofisica y Tecnologias Avanzadas (CATA)	7,000.00 (2006)
Nucleo Milenio de Estudios de Supernovas	222.00 (2008)

Government of Chile, on its part, will attach increasing importance to the financing of training and research activities in the field of astronomy and related disciplines and technologies with the aim of supporting the efficient use by Chilean scientists of the astronomical installations located in Chile" (ESO Press Release 06/93; Decreto 1766 of 17 May 1997). As a result, funding for astronomy increased, and with it the size of the community. Between 1980 and 2000, astronomers received approximately 1.4% of funds disbursed through the main source of scientific funding (Conicyt 2001). In addition, AURA and other North American organizations created a special fund for astronomy administered by Conicyt (Table 2). All told, between 2006 and 2010 funding for Chilean astronomy increased from \$2 to \$6.8 million (Catanzaro 2014a).

After Chile received 10% viewing time on the telescopes, four new astronomy departments, all with PhD programs, were created with funding from ESO, AURA and other international organizations (Allende et al. 2005; since then, another opened). The 2005 scientific census counted 63 astronomers, twice as many as in 1993, and 40 PhD students, up from just five in the early 1990s. The case of the University of La Serena is illustrative. It introduced a degree in astronomy in 2001, almost 40 years after Gemini's offices opened across the street, to take advantage of the newly available viewing time. Compared to the 90% of the time available to all astronomers, Chile's time was under-used—in the late 2000s, twice as much viewing time was solicited than was available, creating a "pressure" factor of two, while ESO estimates the pressure on its telescopes varies between four and six (interviews 08/11-13/2009).[5] Some universities marketed themselves globally to attract faculty interested in accessing this comparatively uncompetitive viewing time (interview 07/29/2009). But most of the new astronomy faculty now joining Chilean universities are not Chilean. Until recently, the University of Concepcion had five foreign and two Chilean astronomy professors. At U. Valparaiso, eight out of nine were from outside Chile. In La Serena, the astronomy faculty is almost entirely from Argentina and Brazil. Chilean scientists and students are benefiting from sharing with foreign colleagues, but the dominance of foreigners hurts the formation of an autonomous, well-organized national scientific community (Barandiaran 2015; Beigel 2013; Vessuri 1994).

Three brief disputes further illustrate different ways in which Chile's and Argentina's scientific communities are excluded from decision-making. Together,

[5] The pressure factor varies considerably between telescopes and over time. See http://www.eso.org/sci/observing/phase1/p92/pressure.html. Accessed March 1, 2015.

these disputes demonstrate a pattern of top-down decision-making where the state dominates how research infrastructures develop. The first dispute involves the Argentinean government's decision to participate in Gemini South, taken and renewed without consulting local astronomers. As a result, each time Argentina's participation was up for renewal, uncertainties would set in: would Argentina's government, often starved for foreign currency, discontinue payments to Gemini? Why should it continue them when science wins few votes? To Argentinean astronomers who sit outside the political process, the government's choice could be based on any number of influences, pressures, or considerations. This includes competing pressures from within the astronomy community. One year, for example, astronomer Felix Mirabel proposed abandoning Gemini and optical astronomy in favor of radio astronomy. Good arguments for and against exist; radio astronomy might provide more opportunities for producing novel findings, but more astronomers benefit from optical telescopes (interview 08/11-13/2009). Whatever the merits of each, the point is that in Argentina the national organization of astronomers does not have the infrastructure to recommend to the government what and how to choose. Instead, astronomers feel at the mercy of the government and other forces beyond their control.

The second dispute involves scholarships in Chile. After 2005, the government increased scholarships for PhD training dramatically; between 2008 and 2010, approximately 500 Chilean students left the country to pursue a PhD abroad with government support.[6] Many Chilean faculty were concerned and angry (interview 07/15/2009; 07/14/2009A; 07/14/2009B). They worried that this weakened PhD programs in Chile, as the best students would leave the country. Many feared students would not return, despite the requirement to do so, perpetuating legacies of the brain drain whereby scientists stay abroad rather than return to practice science at home. These concerns were grounded in their own often subpar working conditions; without state support for universities, including more hiring and research funding, where will these students work if and when they return? Since then, scholarships abroad have been reduced to less than 400 spots per year, while scholarships at home have risen to 750 spots per year. But this adjustment is more likely due to the falling price of copper (Chile's chief source of foreign currency), than to the scientific community's influence on government. During this same period, the government went without naming a new director of Conicyt and then rejected a proposal popular among scientists to create a new ministry for science and technology (Cantanzaro 2014b). Speaking to the journal *Nature*, Chilean ecologists and astronomers complained of their lack of influence on government (Catanzaro 2012, 2014a; Guerrero & Arroyo 2014).[7]

The third dispute impacts what scientific research projects are selected for viewing time on Gemini. At Gemini, national committees select and rank projects based on different criteria: the project's novelty, complementarity with existing

[6] http://www.conicyt.cl/becas-conicyt/estadisticas/extranjero/doctorado-becas-chile/. Accessed March 6, 2015.

[7] In early March 2015, the government decided to re-visit this decision. http://www.mascienciaparachile.cl/?p=7163. Accessed March 5, 2015.

work, potential for short-term results and publications, or simply "its beauty" (interview 08/11-13/2009). National committees vary in how much importance they give each criteria and in their institutional make-up, thus they vary also in how well they represent each country's scientific community. In Chile and Argentina, the national science agency appoints members to this committee, while in Brazil the national observatory does so. As a result, Brazil's national committee that controls access to Gemini reflects Brazilian astronomers to a much greater degree than Chile or Argentina's committee. This matters because national committees prioritize projects differently; some select projects that complement other work, or that help build international collaborations, or that will lead to more papers published quickly. In addition, project selection can be very subjective – a Gemini astronomer concluded, "in the end, each evaluator [on the national committee] votes with his heart" (interview 08/11-13/2009). In Chile, the president appoints the director of Conicyt, who decides who sits on Gemini's national committee. This episode again illustrates ways in which the state makes decisions on behalf of Chile's astronomers.

Chile's astronomy community has grown dramatically thanks to the role of AURA, the provision for 10% viewing time to Chilean institutions, and increased funding from the government and ESO. For all these reasons, and against IAU's technological optimism, the telescopes alone in Chile did little for local astronomers. The contrast with Argentina is illustrative; there, the community was much larger even without any large telescopes thanks to government support for science. Anecdotally, in 1993, about 30 Chilean astronomers practiced science, compared to over 150 Argentinean astronomers who participated at that year's Annual Congress of Argentina's Astronomy Association (interviews 08/11-13/2009).

Astronomy-Society Linkages: Returns of Science

Given the distance between a better understanding of the origins of stars and commercial products, why do governments support such expensive scientific pursuits? In the United States, national security and military interests were often important (McCray 2004). These appeals are difficult in Chile, Argentina and (perhaps to a lesser extent) Brazil, where the military is suspect and has historically consumed relatively small amounts of foreign technology (Hurtado de Mendoza & Vara 2007; Adler 1987). Instead, the Chilean government has been interested in big science as a site to promote scientific "excellence" and economic growth. However, as staff and scientists at Gemini South were quick to point out, the state is failing to recognize the whole range of benefits telescopes like Gemini can have for Chile. The state's blinders reflect its commitment to international indicators of success, from exports to counts of scientific publications indexed in international databases (Vessuri et al. 2014). Chile's political elite and managers of science have not recognized the astronomers' success at winning research funds as indicative of the need to broaden the underlying conception of "economic growth" to include activities that are not export-oriented.

The principal benefits telescopes like Gemini South create for Chile lie in human resources. Gemini South is a typical large telescope; it employs about 200 people, of which just 30 are astronomers and 80 are Chilean. The model Gemini South employee is a Chilean engineer, like Pablo Perez, whose curriculum provides some insight into the relative dearth of policies that help locals reach such positions (interview 08/11-13/2009). Perez is senior electronics technician at Gemini South and is responsible for the critical transition between day and night operations. The telescopes impose an unforgiving schedule; an hour of lost viewing time has an opportunity cost of approximately US$10,000. Each day, about 12 projects from 80 must be selected for viewing that night. To select these, staff must know about the characteristics and requirements of each candidate research project; the state of each instrument on the telescope; expected climatic conditions; problems or mishaps from the night before; upcoming galactic events; and upcoming commitments. Every night instruments break or fail to work as expected, and climatic conditions change, requiring emergency interventions from experts in engineering, electronics and astronomy. At 9 a.m. each morning the night crew debriefs the day crew on the previous night's events, and again at 4 p.m. the day crew debriefs the night crew on the day's events. It is a 24-hour, 7-days a week job, done in two-week shifts. Perez learned all this only by doing. He was born in La Serena to a middle class family and completed a bachelors' degree in engineering at the local university. Like many other employees I spoke with, he learned the second essential skill for this job — English— through personal circumstances. He worked his way up over 30 years, from the electronics laboratory in the city to the telescope on the hill. Perez never had the opportunity to study further nor to specialize; with higher credentials, he may have been able to negotiate better conditions at Gemini or at another employer.

Just as telescopes like Gemini South far exceed the technological prowess of any locally available machine, so the staff who work there develop skills and knowledge that set them apart. These experiences make them candidates to join the nation's "intellectual reserve" that can be called on in times of great need like war or disaster to mobilize complex technological systems (Mukerji 1989). Latin American students, employees, and scientists who worked at Gemini South are aware of this. For example, one PhD student soon realized that "even if we put together all the capacity and resources in all the universities, institutes and relevant centers of Argentina, we would still not have the possibility of building something like [Gemini South] in any reasonable span of time" (interview 08/11-13/2009). Nearly all Chilean Gemini employees appeal to the skills they have, and their ability to operate in a high-pressure, high-risk, high-responsibility setting, to justify the substantially higher than average wages they receive. Anecdotally, local PhD students have gone on to work in the optics industry in Cordoba, Argentina; in the aerospace industry in Brazil; to create software spin-off companies in Chile; in addition to academic positions across the region. Likewise, the telescopes have had a strong impact on the local engineering curriculum.

However, the contributions of telescopes like Gemini South to the country's intellectual reserve, local engineering firms, or other, unexpected innovations, are not monitored by the state. For example, no data exists on how many students from Chile, Brazil, or Argentina have trained at Gemini South or where they go afterwards. Similarly, the state does not track positive spillovers to local engineering firms. Large telescopes are less a single machine than a conglomerate of instruments, each highly adapted to its tasks. During my visit to Gemini South, two new instruments were being installed: a revolutionary star-shaped laser and a new lens called the Flamingo-II. The star-laser system was manufactured by Lockheed Martin, where it is classified as a weapon capable of bringing down airplanes. Though manufactured in the U.S., the laser still had positive spillovers in Chile—for example, the high-security case in which the laser sits was designed and built by local engineering firms. Likewise, the Flamingo-II was designed and built at the University of Florida, following a list of 900 requirements formulated by Gemini scientists. Gemini South spent US$600,000 to replace just one broken detector on the Flamingo-II—another piece of classified military technology and the only sample outside the U.S. For this and other instruments to work properly, conditions need to be just right, and cooling posed a particular challenge. Another Chilean engineering firm solved the problems with cooling by developing a specially adapted helium-cooling system for the telescope. Yet another unexpected positive spillover exists outside the observatories: the push to reduce artificial light pollution has led to local designs for street lights that reduce upward glare and new forms of cooperation between municipalities and central government agencies needed to install these.

Rather than track these kinds of local professional opportunities, the state keeps records of publications, patents, and projects that scientists participate in (interviews 07/30/2009A; 07/10/2009). These records reflect dominant ideals of accountability and of economic growth as something led by exports, not local high-tech industries. When the National Center for Innovation proposed investing public funds in research centers in five strategic clusters, scientists were outraged. The clusters privileged raw materials Chile already exports in large quantities (fish, agro-industry, minerals). In their view, despite the lip service paid to innovation, the government continued to focus on the export of raw materials, rather than think about how to develop the conditions for Chileans to create firms to participate in high-tech, digital, or telecommunications industries. Whether Chilean PhD students trained at Gemini South went on to create software companies, engineering firms, or work in high-tech industries in Argentina or Brazil, all this would remain a mystery to a government still focused on export-led growth. One critical astronomer summarized the problem by saying that "here [in South America] it is still little understood that high-tech astronomy is a direct injection of capital into the high-tech industries" (interview 08/11-13/2009).

Conclusions

It is common for scientists and development experts from the global North to argue that international cooperation and access to technologies will improve opportunities for locals in South America. In a special issue of *Nature* on science in South America, the editor opened with exactly this message: "International researchers can help to improve the scientific enterprise in South America" (Editor 2014).

While the potential is certainly there, the trajectory of foreign observatories in Chile shows that proximity to the technology alone does little to help local scientists (and even less for local communities), without the active participation of the scientific community, universities, and the state. In Chile, the greatest gains for the astronomy community came thanks to AURA's partnership with the University of Chile, which allowed some Chilean scientists to participate in these large telescopes from the get-go, and to the 1997 renegotiation of the terms of agreement with ESO. The terms of the agreement were renegotiated in a democratic atmosphere, where law-makers were willing and able to hold the state and its foreign partners to a higher standard. Nonetheless, a global hierarchy was maintained: the Chilean state protected observatories' tax and other legal exemptions.

The Chilean state, working together with ESO, often made concessions to facilitate the observatories' entry into Chile, even when these ran contrary to the interests of Chilean universities and scientists. The state expropriated land and equipment from the Catholic University of the North to give to ESO, and some law-makers even suggested that the University of Chile should not be legally able to sign international cooperation agreements, as it had done with AURA. The Chilean state has also adopted a number of policies that scientists find objectionable –from defining how astronomy projects should be evaluated, to sending PhD students abroad in massive numbers, to evaluating scientists by counting publications indexed in central scientific journals. Though scientists initially welcomed the turn to innovation launched in 2005, they found the narrow focus on raw materials for exports unoriginal and wasteful – it promoted science to maintain the same development model. The continued subordination of Chile's scientific community, even as it has grown tremendously, is now producing discontent among scientists (Catanzaro 2012, 2014a; Guerrero & Arroyo 2014).

The state's shortcomings only emphasize the importance of the state's support for building a scientific community and a research infrastructure. Steady and sufficient public support is crucial. Any benefits arising from AURA's partnership with the University of Chile remained accessible to just a few until law-makers stepped in to negotiate a 10% viewing allocation to Chile as host. This, together with the scholarship opportunities introduced later, is helping to raise a new generation of Chilean astronomers. However, more ethnographic research is needed to understand how the overwhelming presence of foreigners shapes the growth of a national scientific community, and how knowledge and practices are communicated across generations formed in vastly different circumstances –ranging from repression to economic boom. Dependency still shapes scientific practices in Chile, including in astronomy, as evidenced by the financial weight of ESO and AURA, the dominance of foreign astronomy faculty, the state's authoritarian decision-making, and its blindness to the range of benefits telescopes offer.

Interviews

06/21/2009 Astronomers at U. La Plata, Argentina
07/06/2009 Natural scientist at a Basal-funded center, Chile
07/10/2009 Manager at Conicyt, Chile
07/14/2009A Manager at National Innovation Council, Chile
07/14/2009B Engineer at Catholic U., Chile
07/15/2009 Engineer at U. of Chile, Chile
07/20/2009 Biologist at Basal-funded center, Chile
07/22/2009 Climate scientist with Basal funding, Chile
07/28/2009A Mathematician at Basal-funded center, Chile
07/28/2009B Biologist at Basal-funded center, Chile
07/29/2009 Manager at U. Concepcion, Chile
07/30/2009A Manager at U. Austral, Chile
07/30/2009B Natural scientist at private research center, Chile
08/10/2009A Natural scientist at U. Chile, Chile
08/10/2009B Manager at Fondos Milenio, Chile
08/11-13/2009 Astronomers, engineers, and other staff at Gemini South

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