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Chile: Global Astronomical Platform and Opportunity for Diplomacy

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Over the past fifty years, most Chileans hardly noticed as their country went from being a place where astronomy barely existed to an "astronomical platform" hosting more than half the world's optical observation and radio-astronomical infrastructure.

Within its borders, Chile currently houses nearly all major European telescopes and perhaps 50 percent of the observation capacity of countries such as the United States, Canada, and increasingly Japan. This trend continued in 2013 with the opening of the Atacama Large Millimeter/submillimeter Array (ALMA) radio-astronomical complex, operated by a consortium of North American, Japanese, and European universities.

As for human capital, Chile went from having a community of no more than a handful of astronomers to boasting more than a hundred PhDs in the field. A decade ago, only one university granted postgraduate degrees in astronomy, whereas today three do so.

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Chile is currently a scientific hub where research is conducted on diverse astronomical topics, including the origin and formation of the universe, the identification of "exoplanets" where traces of life might be found, as well as the composition of the universe and the laws governing its behavior. Furthermore, this research is increasingly conducted with the significant participation of Chilean astronomers.

The first section of this paper elaborates on why Chile has become a world astronomical platform and outlines the agreements and incentives developed to capitalize on Chile's natural suitability for astronomy. This is followed by a description of the four pillars of Chile's astronomical policy and strategy, and thereafter a review of the large astronomical projects constructed in Chile based on this strategy. The penultimate section refers to the actions Chile is pursuing to protect "dark, clean, and silent skies," and the fifth and final section explores the future of broader astronomical diplomacy.

Chile's Natural and Institutional Capital

The question behind this explosive growth in astronomical capacity is, why Chile?

The answer is connected to the recently developed concept of "natural laboratories," which describes the conjunction of special space, climate, biodiversity, or geographic conditions that facilitate scientific study in certain disciplines. Chile benefits from unique natural-laboratory conditions, which, combined with a small but excellent scientific community, provide an exceptional opportunity to promote national development by attracting Big Science projects.

Outstanding natural laboratories in Chile include oceans, arid lands, the Antarctic region, volcanoes, geothermal energy, seismic activity, and concentrations of Mediterranean and subantarctic biodiversity. However, one natural laboratory has especially rare characteristics: the clear and dry skies in the country's north between latitudes 21°S and 32°S. Overall, these atmospheric conditions allow for exceptional astronomical observation and explain why the international community has been so keen to build large observation centers in our country.

These natural advantages allow Chile to fill key gaps in global innovation, research, and development (I&R&D) networks. But other, institutional advantages contribute as well to Chile's success at attracting foreign investment in astronomy, including:

1. A stable economic, legal, and political environment
2. Fiscally supportive policies exempting observatories from many taxes and duties
3. Diplomatic status for researchers, with all the implied privileges and exemptions, which promotes access to government and simplifies customs
4. Chilean investment in infrastructure, such as roads and electrical and data transmission
5. A supportive legislative environment (e.g., the recent establishment of an astronomical reserve in the Atacama Desert)
6. A generally supportive population at large.

The Ministry of Foreign Affairs (MFA), as the official government agency responsible for astronomical policy, provides robust support for scientific research, which in turn sends a clear signal to the international community intended to attract additional projects. Hence, the MFA has taken a role not only as a science administrator but also as a proactive force that seeks to facilitate the establishment of new research facilities, laboratories, and observatories in our country.

Four-Pillar Astronomical Strategy to Encourage Investment

In 2008, the Energy, Science, and Technology & Innovation Division (DECYTI) within the MFA took over responsibility for astronomical policy, and as part of that effort the division designed and implemented a four-pillar Astronomical Strategy consisting of (1) astronomical science, (2) astro-engineering development, (3) education, science, and culture, and (4) country image and tourism.

Pillar 1: Astronomical Science

The first pillar has been the most visible in the strategy. Whereas the earliest astronomical observatories were installed more than fifty years ago, recently the rate has accelerated. Today, Chile is home to such world-renowned research resources as:

- Cerro Tololo Inter-American Observatory and Gemini Observatory
- Las Campanas Observatory
- La Silla and Paranal observatories
- ASTE and NANTEN2 telescopes
- ALMA radio-astronomical complex

Additionally, as negotiated prior to construction of the observatories, international consortia agreed to include "development funds" for astronomy, astro-engineering, instrumentation, and education in Chile. Such funding streams total nearly $2 million per year for the Gemini, European Southern Observatory

(ESO), and ALMA projects alone. These funds are administered jointly by the foreign consortia, Chile's MFA, and the National Commission for Scientific and Technological Research (CONICYT).

Currently, more than 50 percent of the world's large telescopes are located in Chile, and by 2022 Chile that proportion could rise to 70 percent of the world's optic and radio-astronomical observation capacity.

Pillar 2: Astro-Engineering Development

Up until a few years ago, the primary focus of astronomical work in Chile was related to the policy outlined under the first pillar. However, with the implementation of the 2008 strategy, development of astro-engineering and astronomy-related technology has played a more prominent role in Chilean scientific policy.

Observatories in Chile not only use advanced optic, mechanic, mechatronic, robotic, and informatics technology, they also demand the design of new instruments that enlist technology currently available only in prototype phase. This field has enormous potential to advance I&R&D in Chile, with technological advances geared initially toward the needs of astronomy but easily expandable into other arenas. The complexity of the observations and the equipment required to perform them has already driven remarkable progress in areas such as the internet, adaptive optics, quantum mechanics, and complementary metal-oxide semiconductor (CMOS) sensors on digital cameras. These advances involve not only the technology itself but also the associated human capital. In this sense, the presence of astronomical observatories in Chile has spawned an "engineering school" of colossal dimensions.

The growing investment in telescopes located in northern Chile represents an opportunity for the country's industry as well, since astronomy requires sophisticated infrastructure and technology. For example, over the past five years, 25 percent of the construction and maintenance contracts for the ESO have been awarded to Chilean companies. To facilitate the transfer of technology and innovation to Chilean industry, the Ministry of Economy created an industry liaison officer position to connect the opportunities associated with installation of new telescopes with national industry and university research centers focused on engineering, electronics, and other related disciplines.

The ultimate goal is not only to provide professional astronomical facilities and Chilean expertise but also to use these projects to trigger innovative development in other areas that can boost national productivity.

Pillar 3: Education, Science, and Culture

Having astronomical facilities located in our country offers an opportunity to stimulate interest in science at both the professional and amateur levels.

Spurring significant growth in the professional scientific community has been identified as a sine qua non for jump-starting development. To support this objective, legislation has been passed to ensure that every astronomical facility established in the country reserves 10 percent of its observation time for Chilean astronomers or resident foreigners affiliated with a Chilean academic institution. This 10 percent is not automatically granted to researchers; rather, Chilean astronomers propose projects that are evaluated by their international peers, and only those of sufficiently high quality are assigned time on the telescopes. Chile has excellent investigators, but the relatively small number cannot constitute the critical mass that would allow participation in many Big Science projects. As such, this legislation is designed to foster local scientific expertise.

At the amateur level, municipalities and universities have promoted the installation of telescopes and extension activities, and important results include the presence of observation centers in different regions, municipalities, and private tourist facilities. The astronomical activity in Chile represents an opportunity to encourage scientific vocational endeavors among youth and spur the next generation of scientists.

Pillar 4: Country Image and Tourism

The Fundación Imagen de Chile Foundation (Image of Chile Foundation) and the undersecretary of tourism have partnered to portray Chile as a hub of scientific research. Such support for research in astronomy and other natural laboratories powers the advance toward a knowledge-based society characteristic of developed countries in the twenty-first century.

Simultaneously, the enhancement of Chile's scientific image can contribute to its attraction for tourists. Astro-tourism in particular can showcase a country that bridges its profound historical with its ambitious goals for the future. Great potential exists to promote new tourist destinations in locations that feature astronomical facilities and can be connected with native traditions, thereby providing a multifaceted experience for international visitors. Countries such as Mexico have a huge head start in such areas and can serve as a model for expanding Chile's tourism industry. As such, a cooperative project between Chile and Mexico is already under way to maximize this collaboration.

Projects Yielded by the Astronomical Strategy

The four-pillar Astronomical Strategy has been central in attracting four large projects to Chile that will come into operation between 2015 and 2021, including:

- Tokyo Atacama Observatory (TAO) telescope (www.ioa.s.u-tokyo.ac.jp)
- Large Synoptic Survey Telescope (LSST) (www.lsst.org)
- Giant Magellan Telescope (GMT) (www.gmto.org)
- European Extremely Large Telescope (E-ELT) (www.eso.org)

Construction of these projects means that in 2022, Chile will be home to an estimated 70 percent of the Earth's optical and radio-astronomical observation capacity, as noted under Pillar 1. Moreover, Caltech and a group of universities and foundations from the United States, Japan, China, and India are currently in the planning stages for the Thirty Meter Telescope (TMT). If the facility were constructed in Chile, our country could house nearly 90 percent of the world's observation capacity. In late 2016, construction was started on a Chile-China center for astronomical observation, and additional cooperative possibilities are being explored for eventual observatory centers in Chile with countries such as China, Russia, and India.

In each of these projects, the government, through its diverse agencies (e.g., CONICYT, Ministry of National Assets, Ministry of Economy, National Development Bank [CORFO], and regional governments), and under coordination of the Ministry of Foreign Affairs through its DECYTI, has participated in negotiations that have ensured their installation in Chile.

Enormous opportunities continue to emerge that would boost Chile's profile as a worldwide astronomical platform. Hence, the government has given full support to the Chilean astronomical community to increase the likelihood that our country becomes the headquarters for the International Astronomical Union for the planned rotation in 2024.

Chile's "Dark Skies" as a Potential World Heritage Site

Clear, dark skies aren't predestined to exist forever. One of the biggest threats is "light pollution": luminosity reflected in the atmosphere due to human activity. Chile has a particular duty to uphold the conditions that make us a unique natural laboratory. From an economic perspective, dark skies are a natural resource that can be used to obtain financial benefits. As such, the Ministry of the Environment, with the support from the Office for Protection of the Quality of the Northern Skies

of Chile (OPCC, in its Spanish acronym), has recently promulgated regulations to protect our dark skies and, in turn, the economic benefit derived from astronomical facilities located in our country. Measures include:

1. Facilitation of access to land and long-term concessions for scientific facilities.
2. Declaration of "protected scientific areas" and regulation of these areas to isolate observatories from electromagnetic interference and industrial activity (especially geothermal mining).
3. Establishment and enforcement of clear rules and norms for public lighting.
4. Creation of environmental standards for particulate pollution.

Yet such measures are not enough. Our ambition is that astronomical observatories, which have their own intrinsic and historical value, be designated national monuments in each country where they exist and ultimately declared World Heritage Sites by the UN Scientific, Educational, and Cultural Organization (UNESCO). In this way, we could count on more and better alternatives to protect dark skies and ensure the continuity of future astronomical observation projects. We seek to use UNESCO mechanisms to protect the universal value that these sites have for humanity.

This work will require much cooperation among countries that have natural-laboratory conditions for astronomy, such as the United States, Mexico, Argentina, Chile, Spain, and South Africa. Applying the concept behind World Heritage Sites to dark skies would entail a new process for astronomical sites; therefore, collaboration between countries and UNESCO would be key to establishing a set of criteria for such declarations. Demonstrating the universal value of a site and its importance to future generations would demand thoughtful consideration and innovative interpretations of what it means to be a World Heritage Site.

Based on the goals outlined in our Astronomical Strategy and the opportunity provided through UNESCO, Chile has decided to pursue World Heritage Site designation for its observatories. This will be a long path, but the process will facilitate a meaningful dialogue wherein the government has the responsibility to promote understanding of its goals among citizens while the observatories must demonstrate the social value of their work to local communities. Education and diffusion of ideas will be fundamental to this effort, and the end result will protect not only our common scientific heritage but also the cultural heritage that belongs to all citizens.

Diplomacy for Astronomy

Chile's Astronomical Strategy exemplifies how the Chilean government and the MFA aim to support international astronomical observation by protecting our natural laboratories. Furthermore, it identifies astronomy as having a clear and effective social impact in the pursuit of our development goals.

Diplomacy in its modern sense seeks to create comprehensive networks among diverse countries. In this arena, science—and hence science diplomacy—can play a decisive role in identifying opportunities for international collaboration. Astronomy can bring only positive outcomes and has the potential to create profound and lasting relationships among various peoples.

Beyond all the considerations and objectives described in this article, we must remain aware that protecting dark skies will allow men and women to exercise their right to observe the vast heavenly expanses with the naked eye. This right has been fading of late, but it must be recovered so that our children can know the indescribable beauty known by generations upon generations before them of the undimmed nighttime sky. SD

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