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<https://www.almaobservatory.org/en/videos/alma-shutdown-drone-images/>



**THE STORY OF
THE STORY:**

The ALMA Telescope

The Story of a Science Mega-Project
(Cambridge University Press, 2023)

Paul A. Vanden Bout, Robert L. Dickman, Adele L. Plunkett



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Dedication



Richard E. Hills



Robert (Bob) L. Brown



Koh-Ichiro Morita



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Dedication



Riccardo Giacconi



Norio Kaifu



Kwok-Yung (Fred) Lo



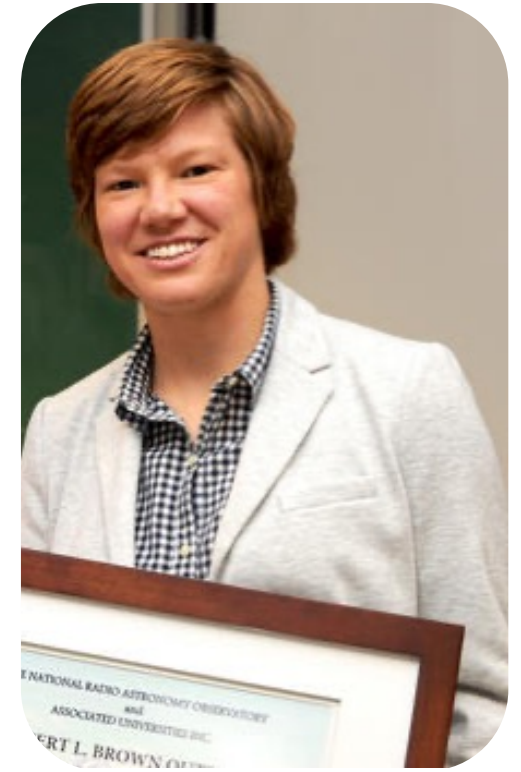
Authors



Paul A. Vanden Bout



Robert (Bob) L. Dickman



Adele Plunkett



What's inside?

- I. How does an international “big science” facility take shape?
- II. What was the path to deciding ALMA would go to Chajnantor?
- III. How did ALMA get its name?
- IV. Did ALMA meet expectations?



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I. How does an international “big science” facility take shape?



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Credit: ALMA



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France
Germany
Netherlands
Sweden
Belgium
Denmark
Italy
Switzerland
Portugal
United Kingdom
Finland
Czech Republic
Spain
Austria
Poland
Ireland



Japan
South Korea
Taiwan

USA
Canada
Taiwan

Chile

Trilateral ALMA Agreement

<https://alma-telescope.jp/assets/themes/alma/img/worldmap.jpg>

<https://www.eso.org/public/about-eso/memberstates/>



- NRAO's **Millimeter Array**
- Mid-1970s scientific staff meeting (Director D. Heeschen) discussed mm-wavelength interferometer as development project
- 1980's sci staff meeting (Director M. Roberts) posed facilities that could follow the recently completed VLA
- Early concept by (then postdoc) Frazer Owen in 1982 became MMA Memo #1.

MMA



- Europe's **Large Southern Array**
- Following SEST's (1987-2003) demonstrated success in southern hemisphere.
- ESO Millimetre Advisory Group formed in 1994.
- Science goals focused on CO transitions at 115 and 230 GHz.

LSA



- Japan's **Large Millimeter/Submm Array**
- Prior experience with the NRO millimeter interferometer in Nobeyama.
- Since 1983, proposed up to 30 10-m diameter antennas
- 1992 searches in Chile and Hawaii

LMSA



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National Radio Astronomy Observatory

Very Large Array

September 10, 1982

To: Scientific Staff, Engineers, Etc.

From: Frazer Owen **FNO**

Subject: The Concept of a Millimeter Array

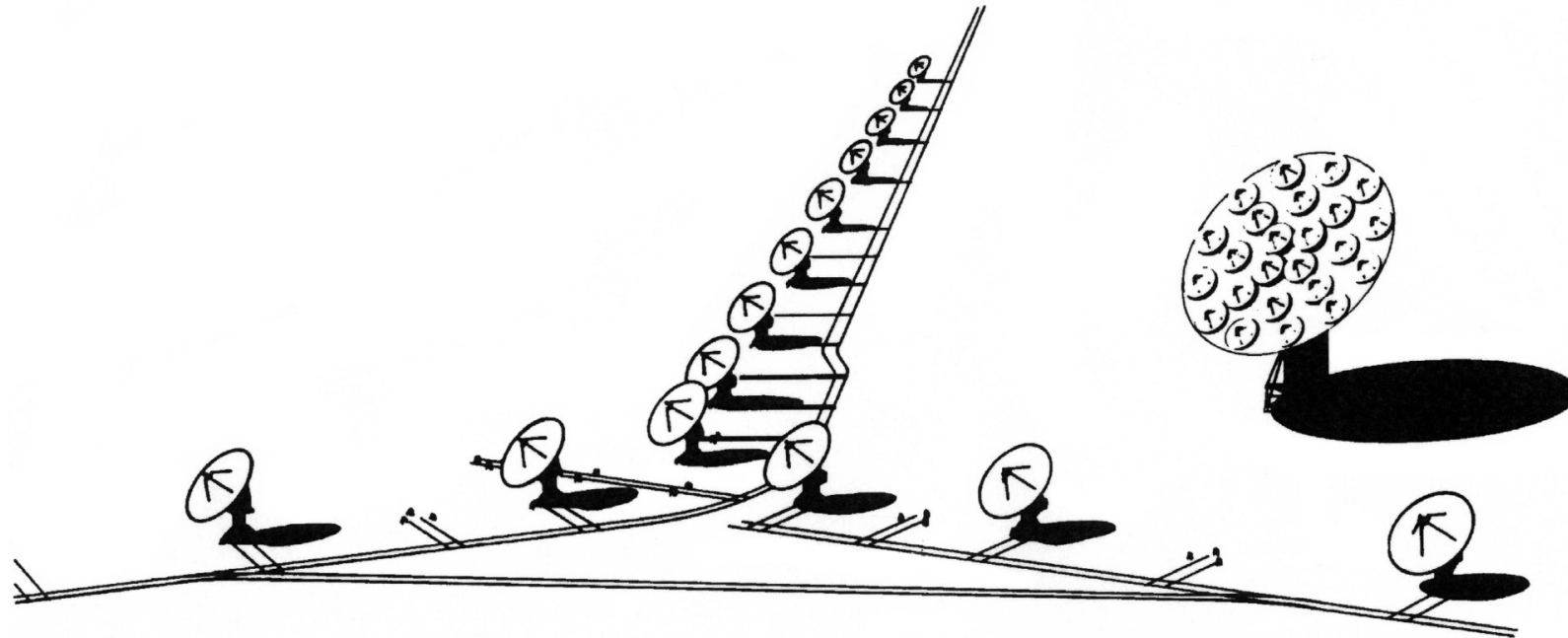
I. Introduction

The purpose of this report is to summarize the concept of a millimeter wave array which NRAO might build in the next 5 to 10 years. What is contained here within is just a concept and not a finished idea. I hope it can serve as a starting point for further definition studies possibly leading to a formal proposal for funds.

...millimeter wave array
which NRAO might build
in the next 5-10 years.

It thus seems obvious that instrumentally the time has come to consider larger arrays for operation at millimeter wavelengths. This seems a natural direction for NRAO given its experience with the VLA. About eight years ago NRAO did briefly discuss the possibility of millimeter interferometry. At that time it was thought that we should let the university community do the ground work. This has been and is in the process of happening. Now seems the right time to raise the question again.





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Credit: NRAO/AUI/NSF, CC BY 3.0





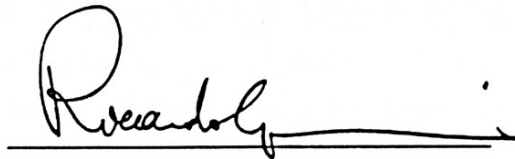
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Credit: NRAO/AUI/NSF, CC BY 3.0.



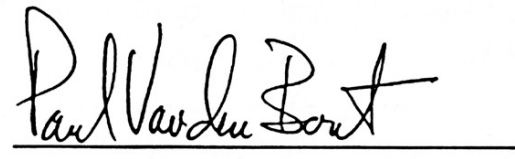
RESOLUTION

Whereas the development of millimeter-wavelength astronomy has shown the potential of large millimeter interferometric arrays for revealing the origin and evolution of stars and planetary systems, of galaxies, and of the Universe itself; the communities in the United States and Europe have proposed the construction of the Millimeter Array (MMA) and the Large Southern Array (LSA), respectively; and there is an opportunity through cooperation to achieve more than either community planned; we, as the observatories responsible for these projects and with the support of our communities, resolve to organize a partnership that will explore the union of the LSA and MMA into a single, common project to be located in Chile. Specifically, this partnership will study the technical, logistical, and operational aspects of a joint project. Of particular importance, the two antenna concepts currently under consideration will be studied to identify the best antenna size and design or combination of sizes to address the scientific goals of the two research communities. In doing so we will work through our observatories, utilizing the expertise in millimeter astronomy resident in research groups and institutions in our communities. Finally, we recognize that there are similar goals for millimeter astronomy in Japan, and cooperative activities with that project will continue.



R. Giacconi

European Southern Observatory



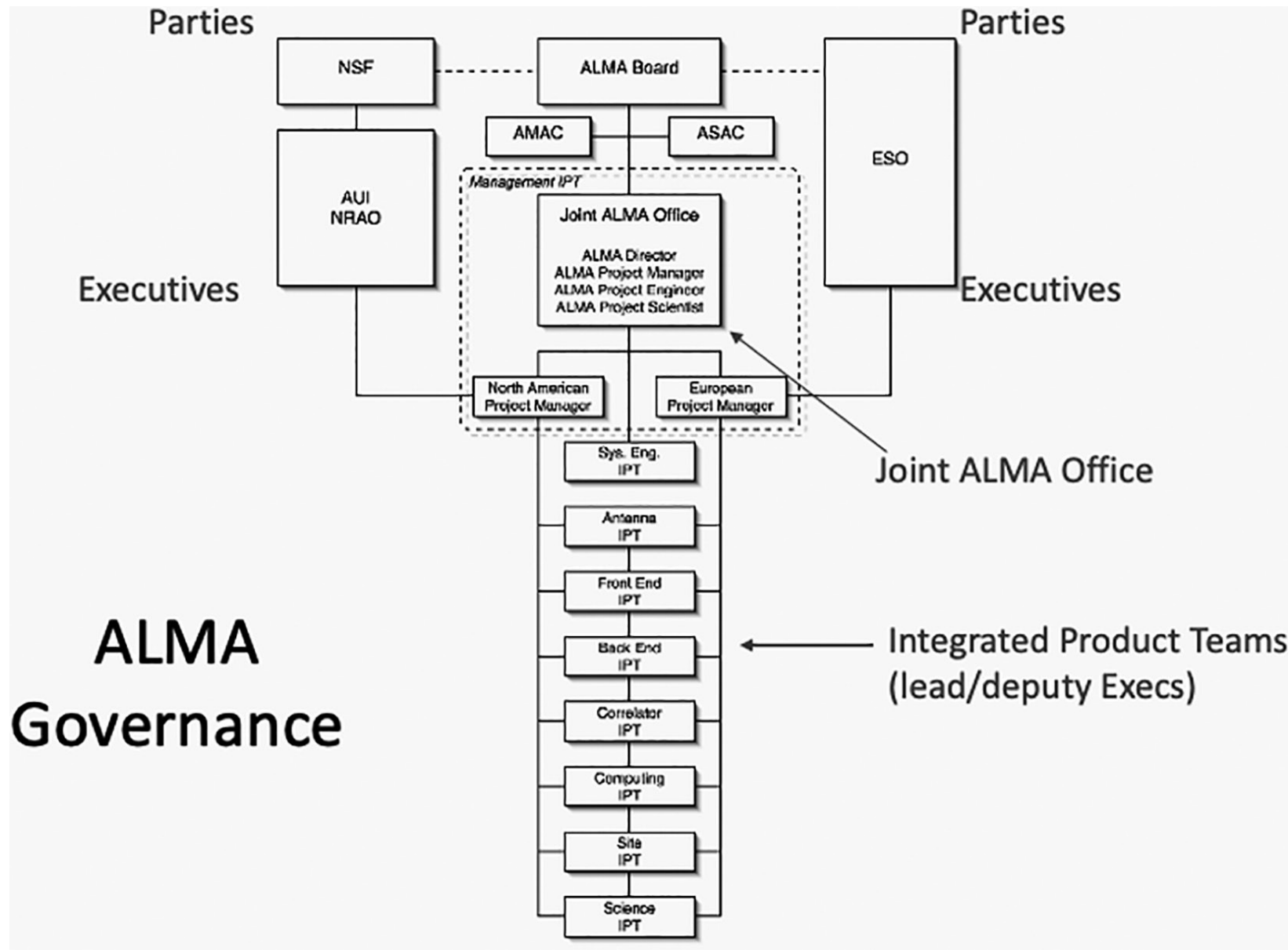
P. Vanden Bout

National Radio Astronomy Observatory



26 June 1997





ALMA Governance



Credit: NRAO/AUI/NSF, CC BY 3.0.



Atacama Large Millimeter/sub-millimeter Array

Japan entered ALMA in September 2004, bringing “Enhanced ALMA” to the project:

- the Atacama Compact Array (ACA) of (12) 7m antennas
- (4) 12m antennas
- Bands 4, 8, & 10 for the entire array
- ACA correlator



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Date: December 2015
Duration: 20 years



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Credit: ALMA/ESO/AUI/NINS, CC BY 4.0.



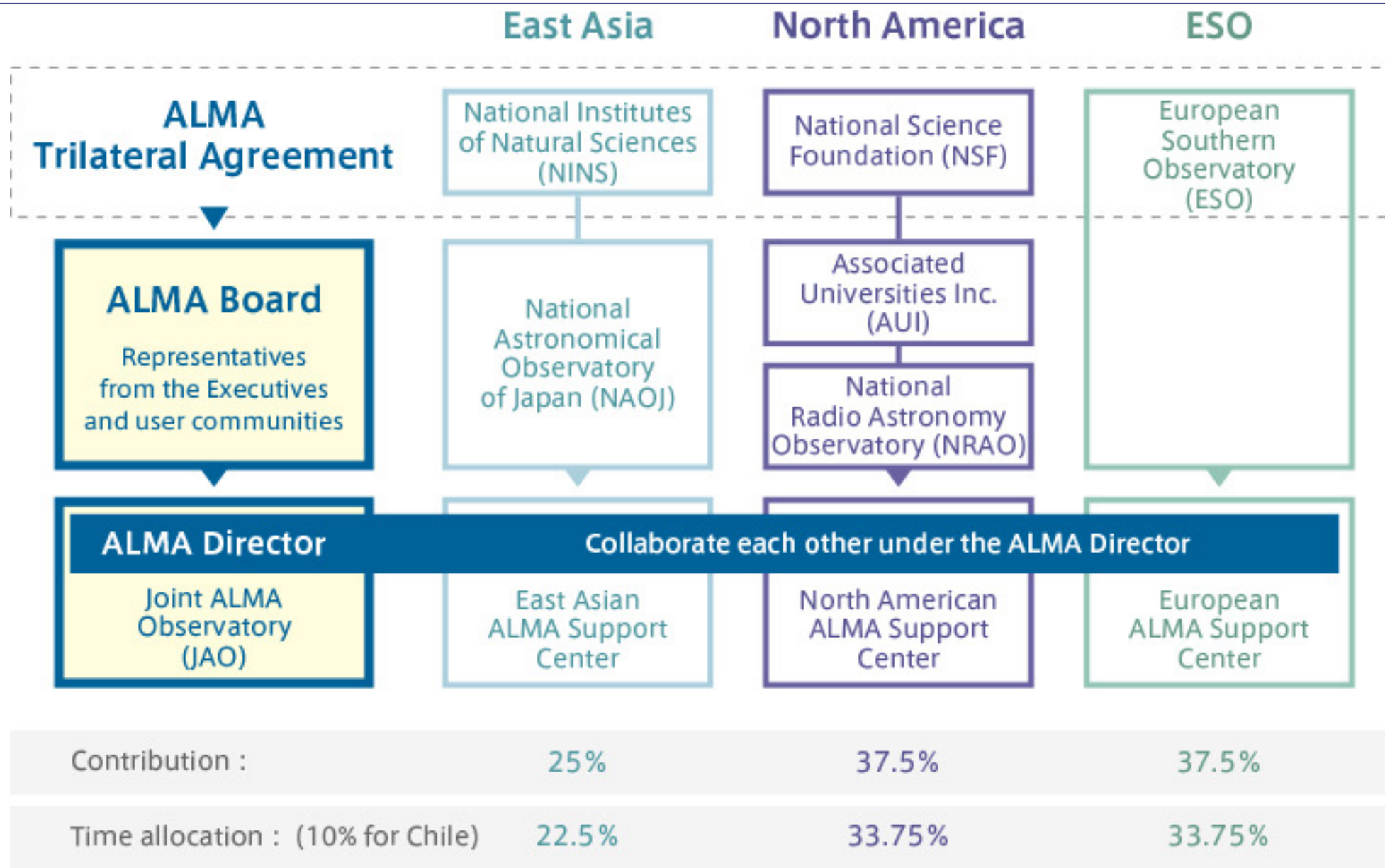
According to the ALMA Board (2022)

The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership of the **European Organisation for Astronomical Research in the Southern Hemisphere (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**.

ALMA is funded by **ESO** on behalf of its Member States, by **NSF** in cooperation with the **National Research Council of Canada (NRC)** and the **Ministry of Science and Technology (MOST)** in Taiwan and by **NINS** in cooperation with the **Academia Sinica (AS)** in Taiwan and the **Korea Astronomy and Space Science Institute (KASI)**.

ALMA construction and operations are led by **ESO** on behalf of its Member States; by the **National Radio Astronomy Observatory (NRAO)**, managed by **Associated Universities, Inc. (AUI)**, on behalf of North America; and by the **National Astronomical Observatory of Japan (NAOJ)** on behalf of East Asia. The **Joint ALMA Observatory (JAO)** provides the unified leadership and management of the construction, commissioning, and operation of ALMA.





https://alma-telescope.jp/assets/themes/alma/img/chart_en.jpg



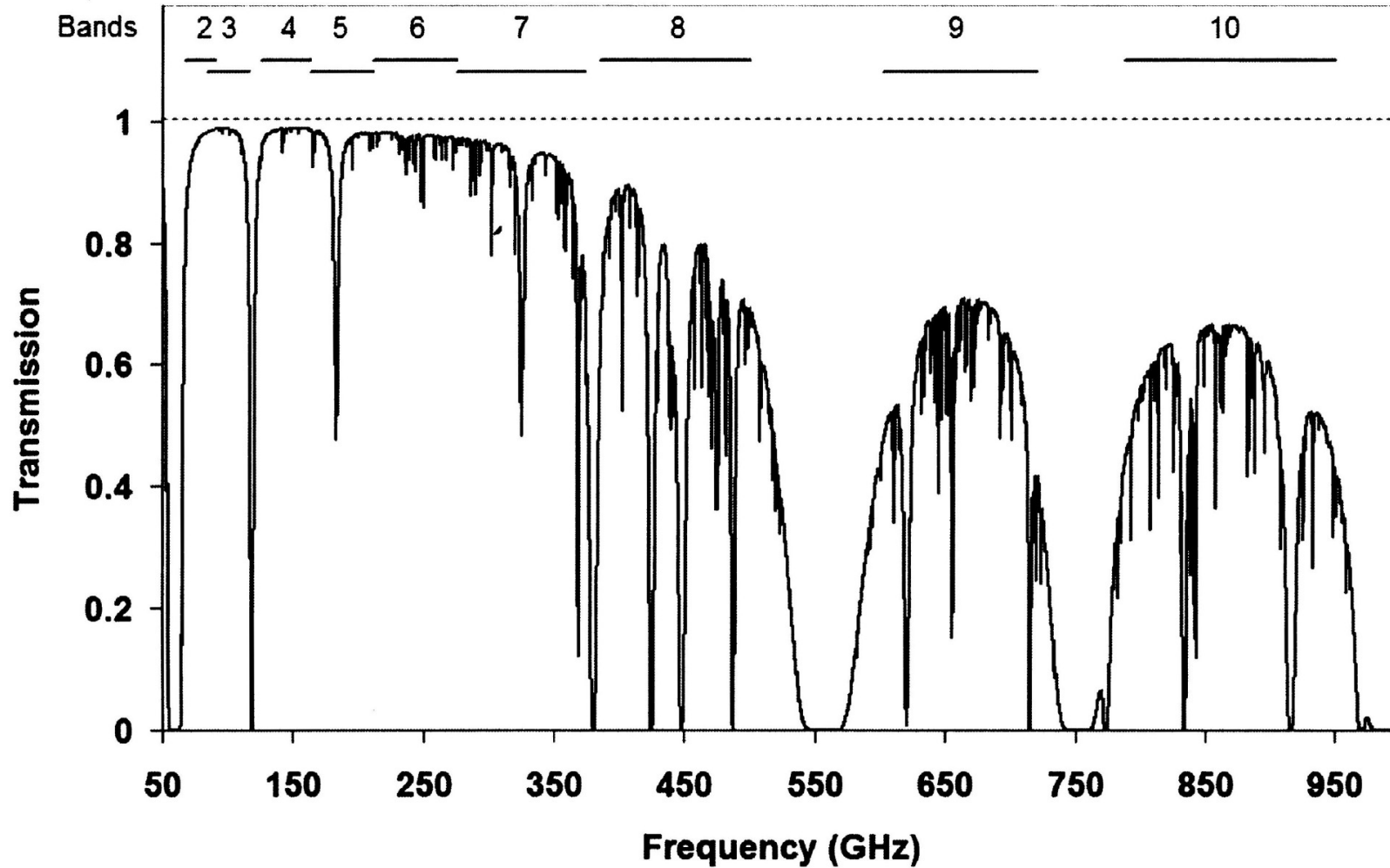
II. What was the path to deciding ALMA would go to Chajnantor?



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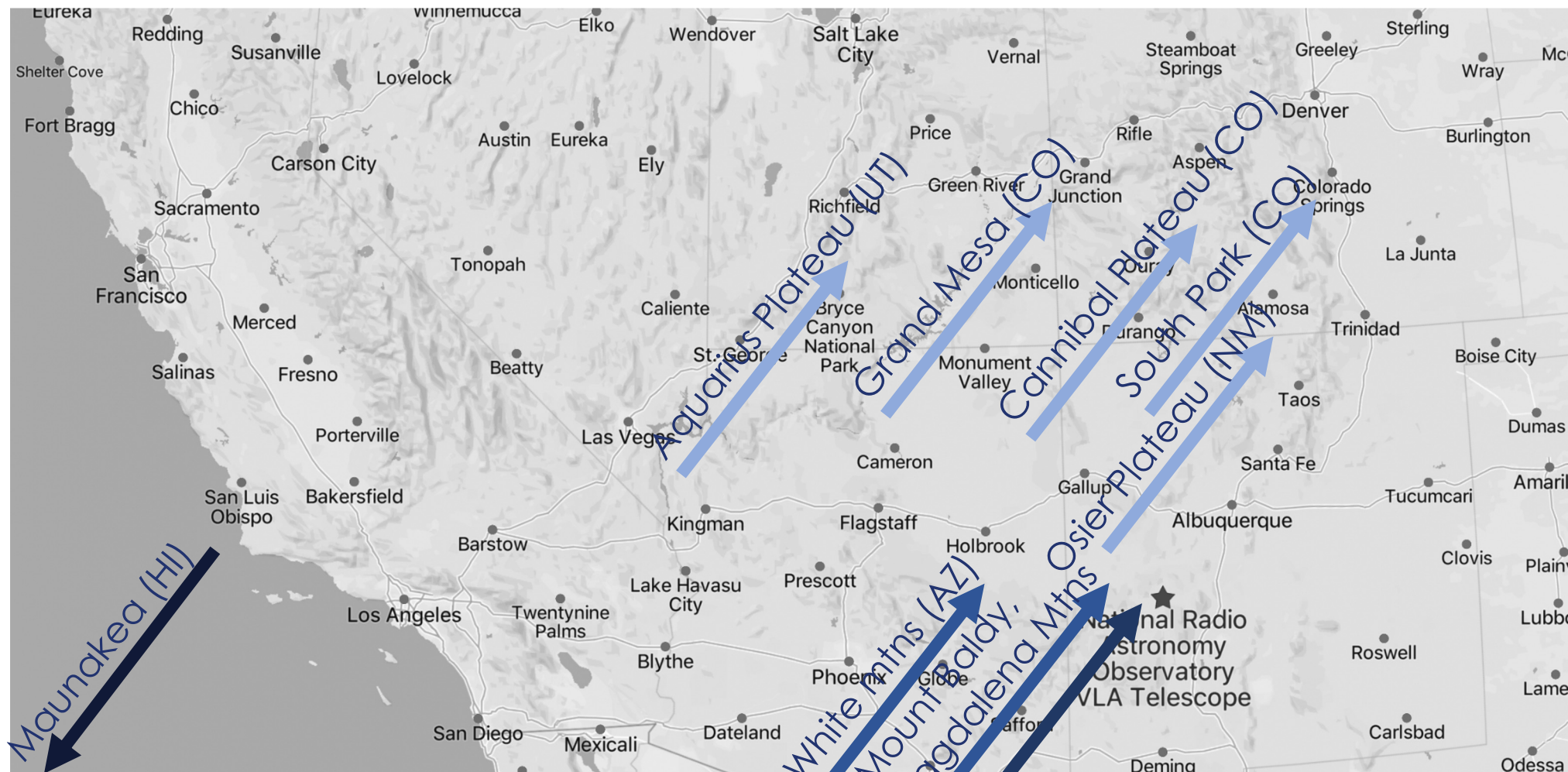
Chajnantor - 5000m, 0.25mm pwv



Courtesy of Juan Ramón Pardo, reproduced by permission.



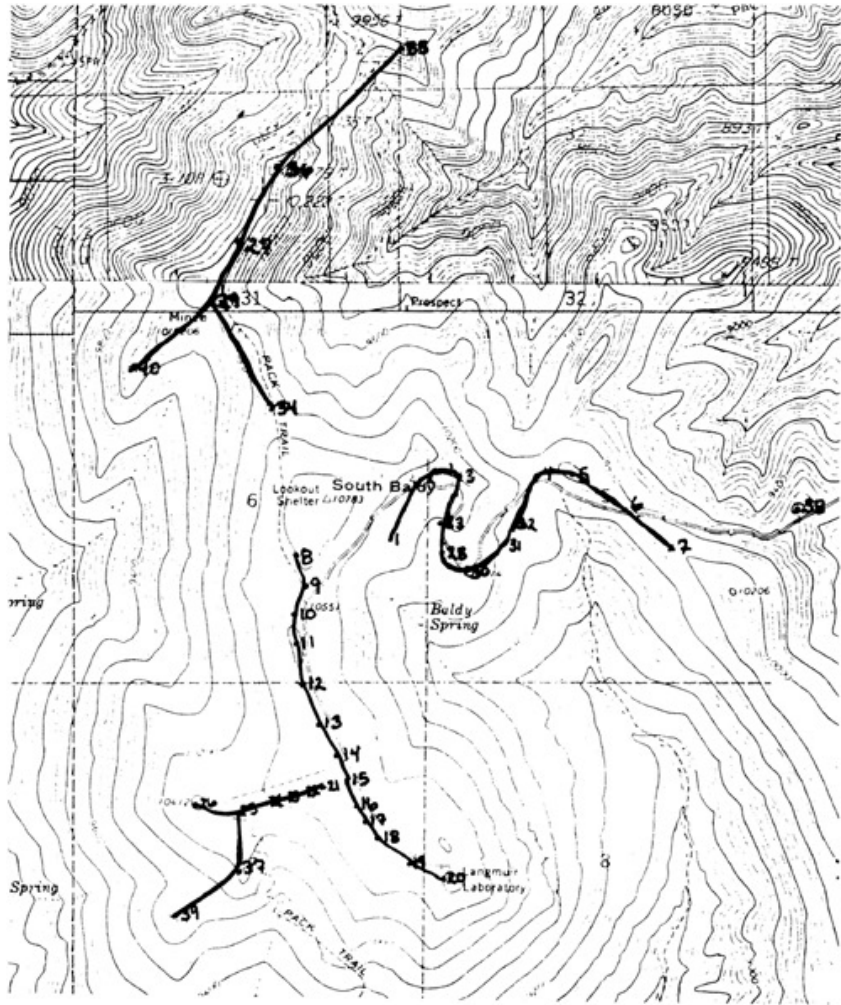
Possible US-based sites included...



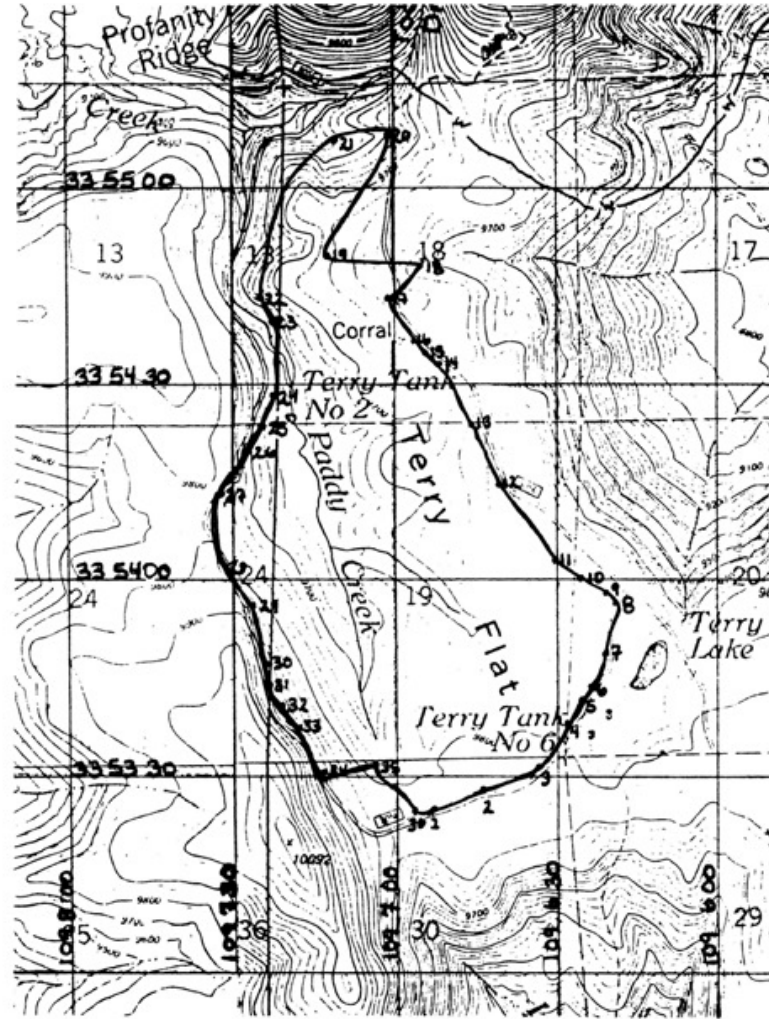
** labels imperfect

mapcarta.com

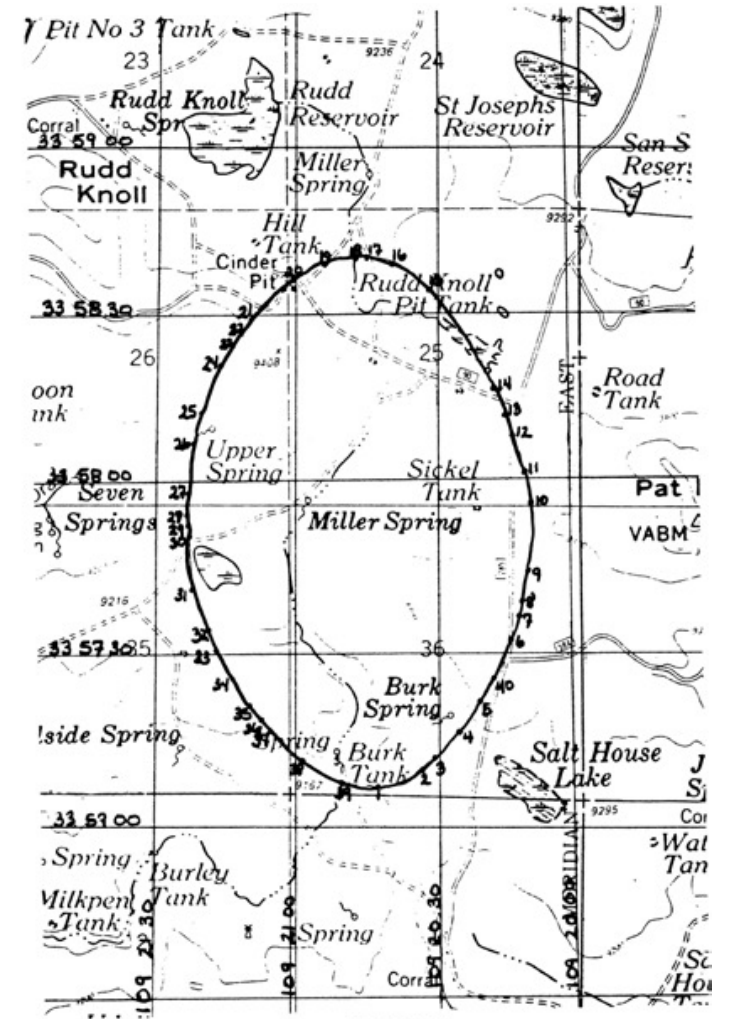




SCALE 1:24 000



SCALE 1:24 000



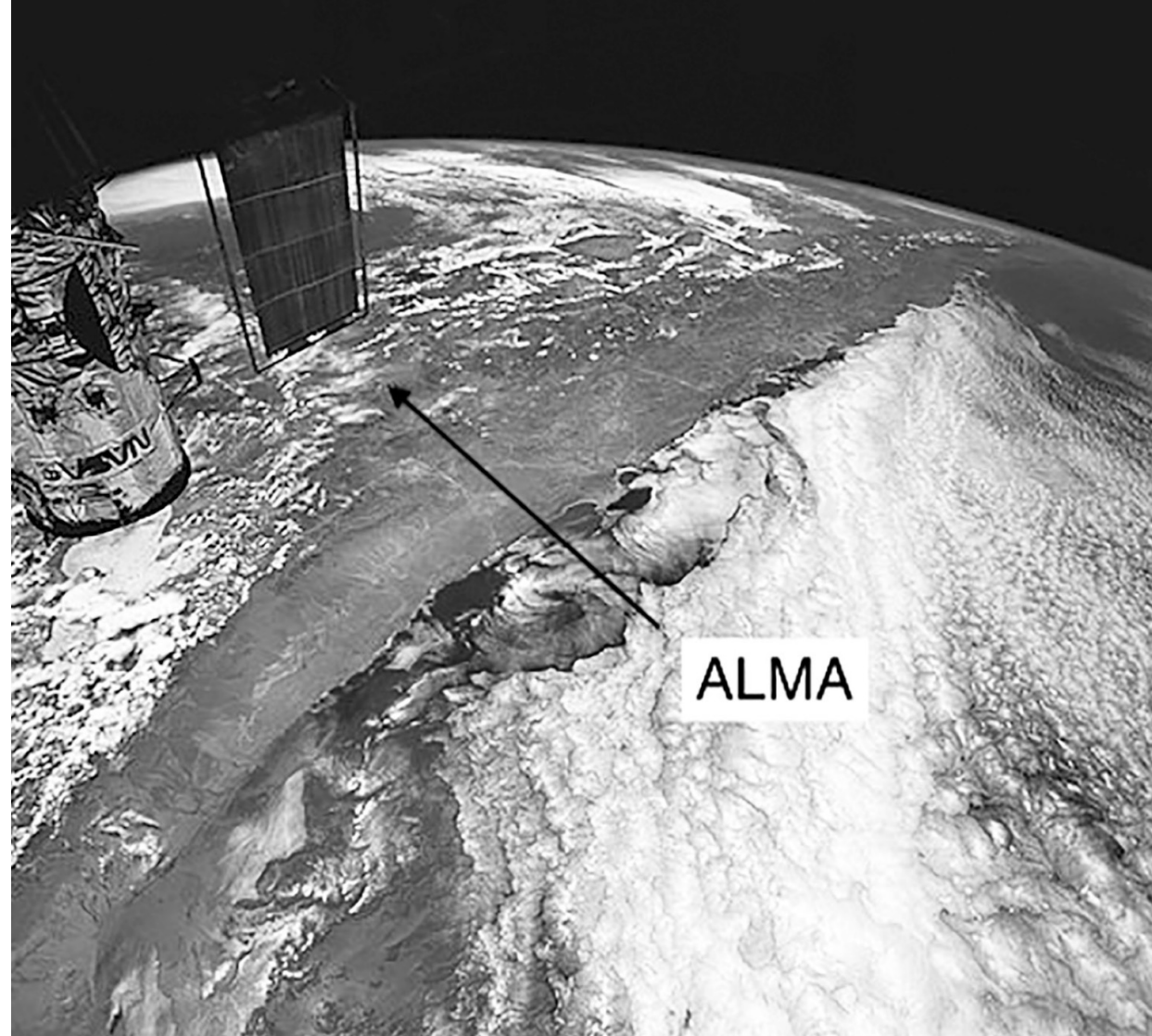
SCALE 1:24 000



Credit: Adapted from topographic maps of the US Geological Survey; NRAO/AUI/NSF



An international search led to Chile



Credit: Claude Nicollier; ESO,
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Early site searching in Chile



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Courtesy of M. Ishiguro, N. Ohashi



Local expertise and guidance proved critical.



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Vignette: Angel Otárola (ESO Chile)

“ There were too many to mention, but I must acknowledge the friendship and great collaboration I had with my colleagues Guillermo Delgado and Roberto Rivera, both of whom, sadly, did not live long enough to see the ALMA come to full operation and deliver great science for the scientific community. I think of them often. I am convinced ALMA was the product of a great collaboration that included various organizations with leaders who supported and stimulated all of us to do our best. Believe me, we had a lot of fun working together.



Exploration occurred throughout the Atacama Desert in '90s



Pampa El Chino 3300m



Pampa San Eulogio 3750m



Chajnantor 5050m



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Many people and teams were involved.



Masato Ishiguro



P. Vanden Bout, H. van Horn, B. Harris
near San Pedro



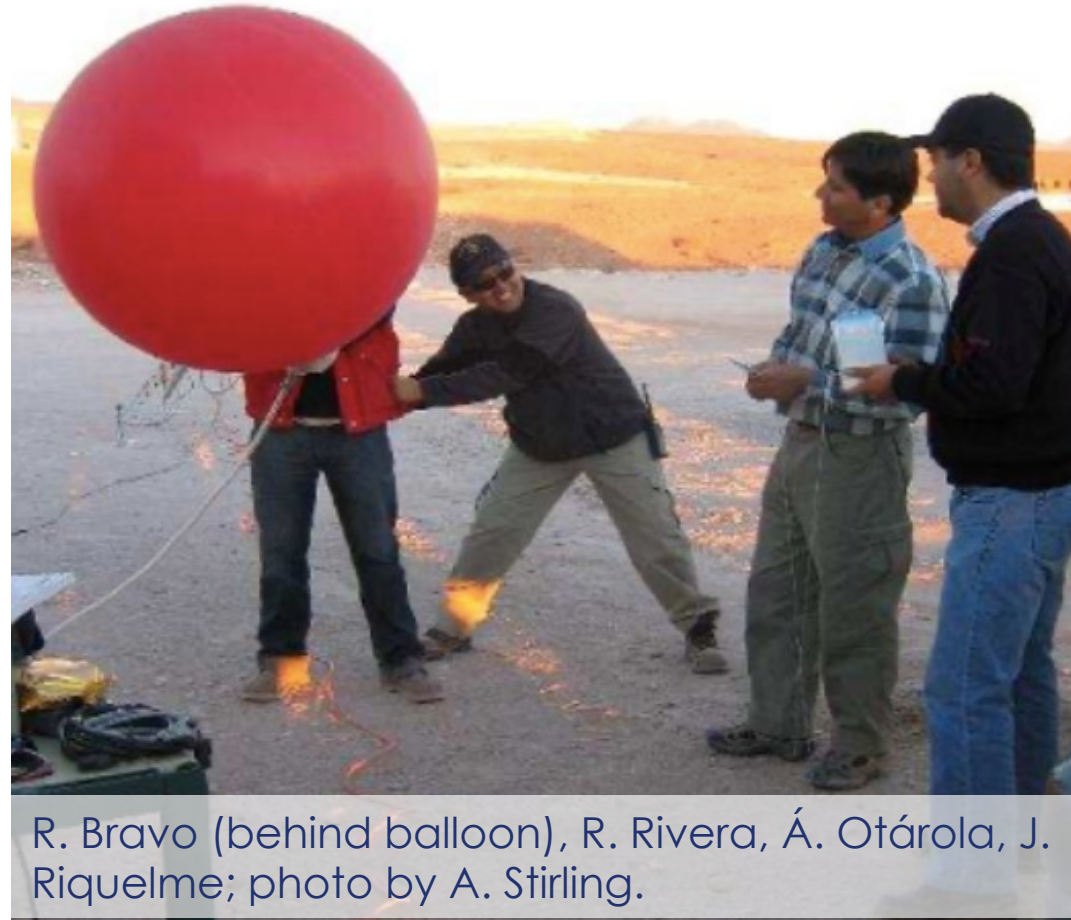
H. Quintana, A. Otárola, P. Vanden Bout, R. Brown (photo by
R. Giovanelli). near Ollagüe, on the border with Bolivia



Site Characterization



P. Napier, F. Owen, & Á. Otárola



R. Bravo (behind balloon), R. Rivera, Á. Otárola, J. Riquelme; photo by A. Stirling.



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Two days after the NSF reps visited San Pedro in 1994, Bob Brown wrote this email to Paul Vanden Bout:

The next day ... I drove with Geraldo Valladares back up the Paso de Jama to find a “real” site for the MMA. It was at that time that Geraldo and I ventured down the road to Bolivia only to be turned around by a guy pointing a rifle at us (Geraldo says ‘I do not like his face’). We then drove the opposite way, south, found the western entrance to the plateau by following the switchback road that goes to the sulfur mine on Cerro Toco and continued onto the Chajnantor Plateau. The plateau was perfect. I climbed up on a rock and excitedly took some panoramic pictures with Geraldo watching me perhaps wondering if I had lost my mind. I said to Geraldo, “Isn’t this a beautiful place? Can’t you just see it with the MMA antennas spread out in the distance?” Geraldo was very serious. He said, “Yes, but it is a beautiful place without the antennas.” ... That was October 26, 1994.



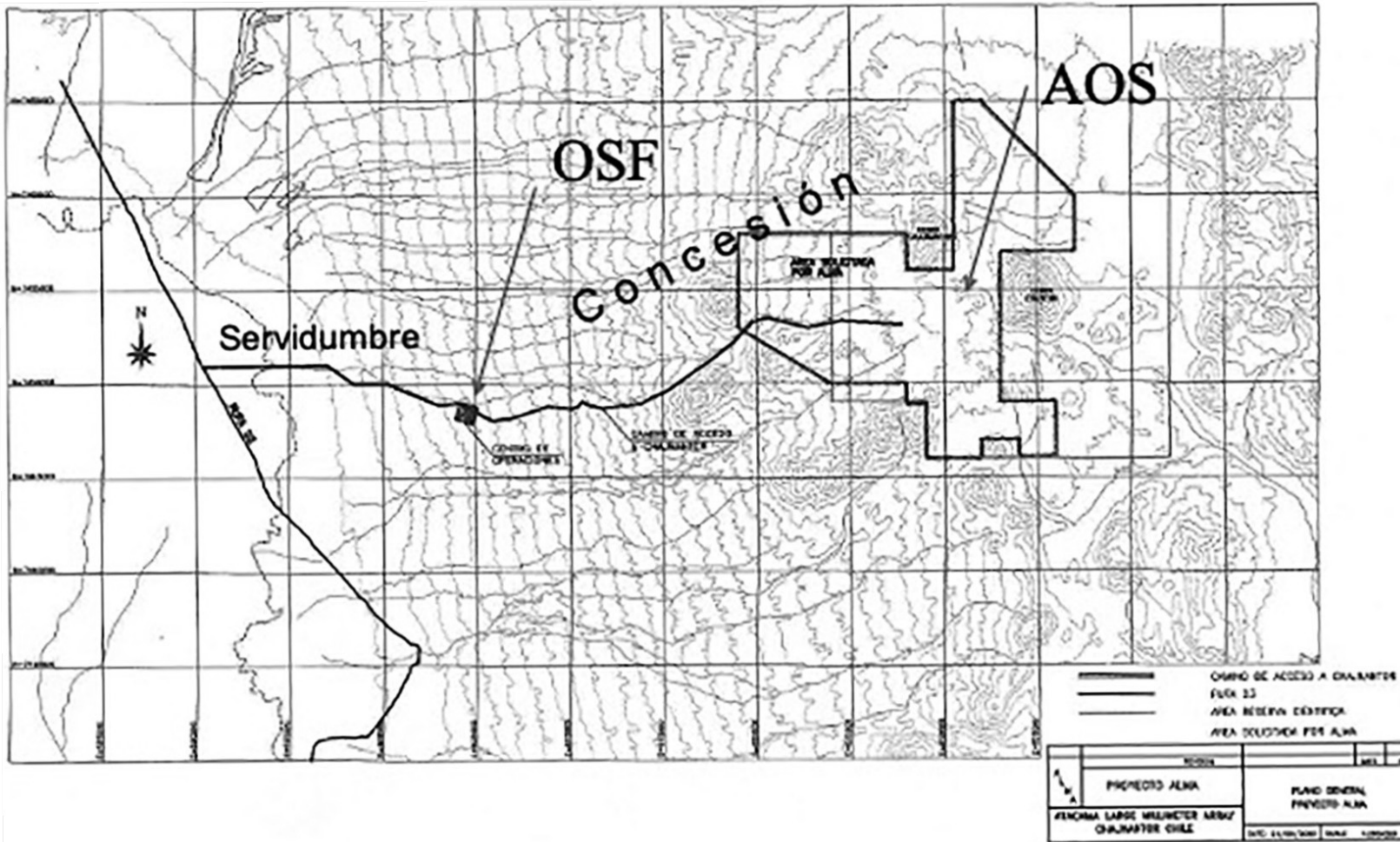
Llano de Chajnantor



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Photo by Simon Radford





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Instituto Geográfico Militar; NRAO/AUI/NSF

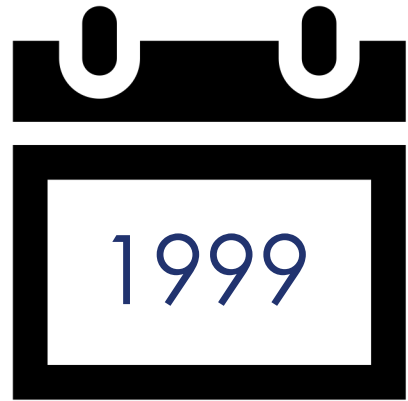


III. How did ALMA get its name?



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Paulo Cortes



Pablo Altamirano



**ATACAMA LARGE
MILLIMETER
ARRAY (ALMA)**



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Photos: LinkedIn



Vignette: Paulo Cortes (JAO)

“ The two of us sent an email with the name suggestions. ALMA got chosen. Looking back, it was the right name, given the discoveries that ALMA has enabled. About a year later, I started graduate school to get a PhD in astronomy and ended up working as a scientist for the NRAO at the place that I named – ALMA.

IV. Did ALMA meet expectations?



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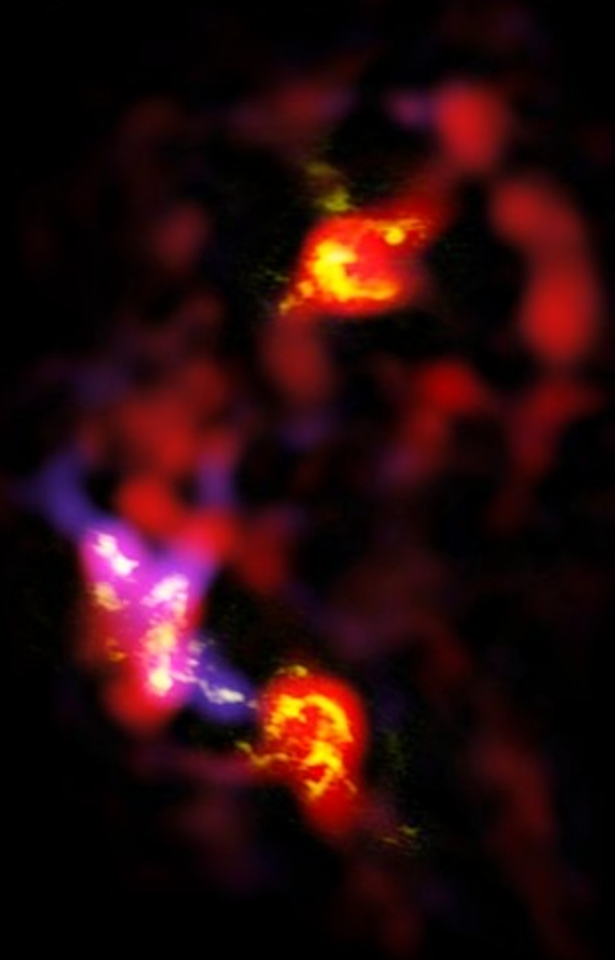




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Image credit: ESO





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ALMA (ESO/NAOJ/NRAO). Visible light image: ESO/Alberto Milani.

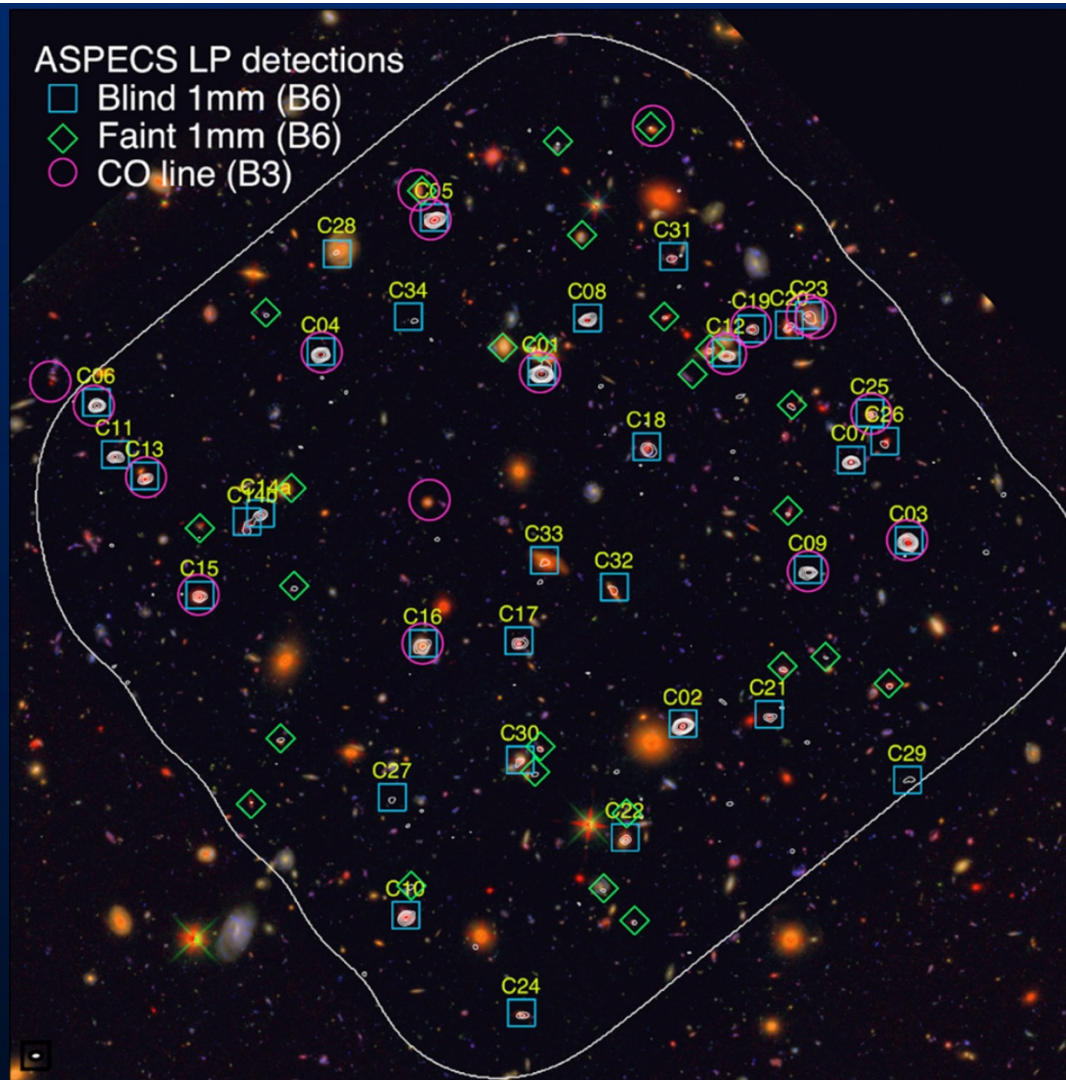


The ALMA Development Roadmap reported in 2018 that the three principal science goals had been accomplished.

- The ability to detect spectral line emission from CO or C+ in a normal galaxy like the Milky Way at a redshift of $z = 3$, in less than 24 hours of observation;
- The ability to image the gas kinematics in a solar-mass protoplanetary disk at a distance of 150 pc, enabling one to study the physical, chemical, and magnetic field structure of the disk and to detect the tidal gaps created by planets undergoing formation;
- The ability to provide precise images at an angular resolution of 0.1 arcsecond.

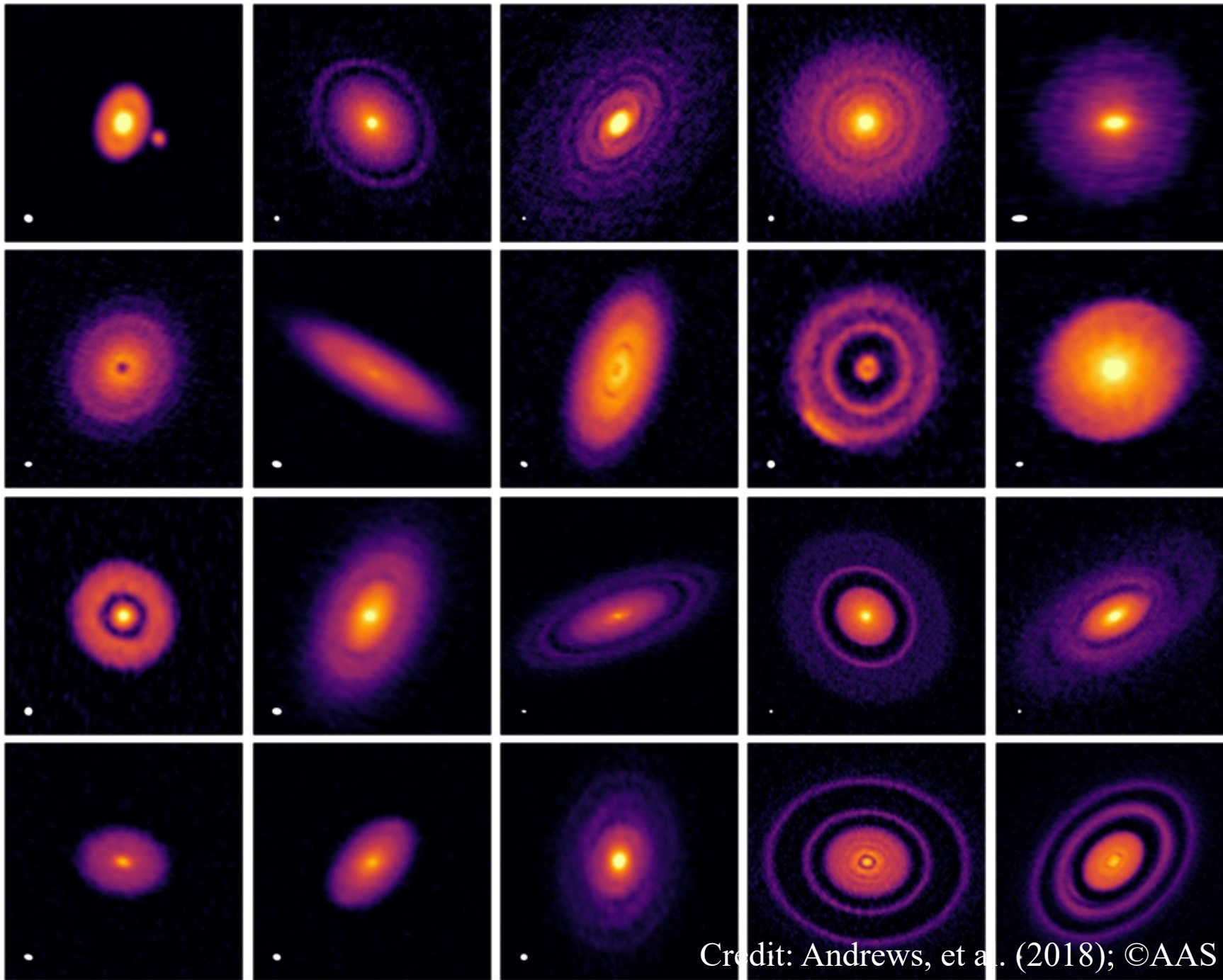
ASPECS LP detections

- Blind 1mm (B6)
- ◇ Faint 1mm (B6)
- CO line (B3)



ALMA detections:
molecular gas
dust
faint dust

Image credits: STScI, Arauna et al. 2020



Credit: Andrews, et al. (2018); ©AAS

Was it worth it?



If I had been shown this image [HL Tau] and told that I could have it for a billion dollars, I would have said – that's a bargain!

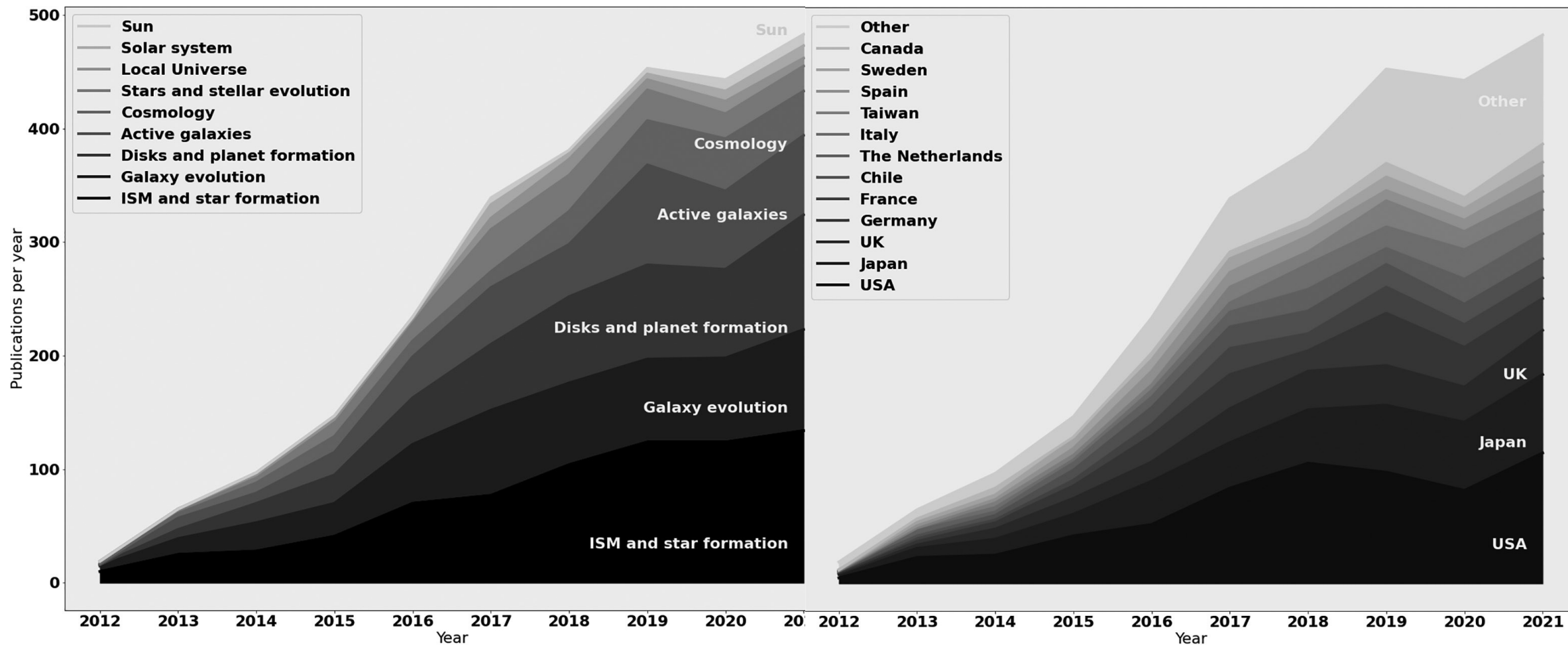
- Buell Januzzi (Steward Observatory Director)



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Was it worth it?



Credit: F. Stoehr, ESO



Vignette: Viviana Gúzman (U. Católica)

“ ALMA has changed the lives of many astronomers in the world, including in Chile.

“ ALMA will continue to make exciting discoveries, and I feel lucky to be in a position where I can make a contribution to the field of Astrochemistry...I have been given the chance to start training the younger generation in the field of astrochemistry and planet formation. My hope is that Chile will become a leader in these fields, and take advantage of the fantastic observatories we have in our country.



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Among the (many) lessons learned

- 1) Do not underestimate the importance of cultural differences.
 - Value what each partner brings to the collaboration.
 - Take care to be cognizant of differences in contracting, personnel policy and law, etiquette
- 2) Careful systems engineering is important for such a complex facility.
- 3) Mega-projects (and books) take decades to plan, build, and commission. And it's worth it – *in the end, it's all about the science.*
 - ...as well as the people, with whom it is a privilege to work.



Vignette: Pieter van der Kruit (Groningen)

“Incredibly, in the end every problem was overcome, even the apparently unsolvable ones. It was a great experience working with dedicated persons; I am extremely grateful ALMA came to be and to have been part of it.

Vignette: Patrick W. Donahoe (AUI)

“ The management of big science projects presents substantial scientific, engineering, informational, and human resource challenges... A successful ALMA project required people to work at a level outside their comfort limits and to effect fundamental changes within their organization. To this end, ALMA was most fortunate.



The ALMA Telescope The Story of a Science Mega-Project



<https://www.cambridge.org/core/books/alma-telescope/5C95C1D40C160F27C91BD0171DD5B0E8>

THALT2023 (20% off!) for purchase of book
Free eBook!



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Book Outline

Foreword
Preface

1 Interstellar Carbon Monoxide

2 What Now?

- 25 meter project, leading to the Barrett Report
- Millimeter arrays in Japan and Europe

3 The Millimeter Array

- A revised concept, steps to the MMA proposal, design and development

4 Searching for a Site

- Continental and abroad

5 Foreign Affairs

- Funding, international participation, selling the MMA abroad, and European and Japanese projects

6 Organizing ALMA

- Land concession, defining ALMA, and working towards an international project, including the ALMA Coordinating Committee

7 Contentious Matters

- The Bilateral ALMA Agreement, Japan joins ALMA, site negotiations and contracts, local staff and ALMA headquarters

8 Funding ALMA

- Funding in Europe, Japan, North America; and a project reset

9 Construction and Inauguration

- Groundbreaking, basic infrastructure, and high site specifics.
- Buildings, antennas, electronics software
- Local benefits of ALMA, and the inauguration in 2013.

10 Promises Fulfilled

- The ALMA Science Goals, Competition for Observing Time and Open Skies 194
- The ALMA Science Archive and publications
- Future prospects and conclusions

Appendix A: Radio Astronomy

Appendix B: Millimeter/Submillimeter Telescopes

Appendix C: Lessons Learned

Glossary, References, Index



Vignettes

- Leo Bronfman (U Chile)
- Paulo Cortes (JAO)
- Ewine van Dishoeck (Leiden)
- Pat Donahoe (AUI)
- Viviana Guzmán (U Católica)
- Masato Ishiguro (NAOJ)
- Pieter van de Kruit (Groningen)
- Angel Otárola (ESO Chile)
- Masao Saito (NAOJ)
- Peter Shaver (ESO)



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- NRAO staff who provided important information: Fred Lo, Frazer Owen, Peter Napier, Bill Porter, Al Wootten, Mark Gordon, Art Symmes, Harvey Liszt, Jeff Mangum, Nick Emerson, Jody Bolyard, Phil Jewell, Mark McKinnon,
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- April Burke and Michael Ledford of Lewis-Burke Associates, Carol McGuire, and Tim Clancy for important roles with AUI, NSF, and U.S. Congress.
- Ken Kellermann, Ron Ekers, and Miller Goss regarding selection of a publisher.
- Cambridge University Press: Vince Higgs, Sarah Armstrong



Acknowledgements (II)

Colleagues in the international astronomical community, whose intellects helped foreshadow ALMA and give it concrete form:

- Bob Wilson
- Peter Shaver
- Masato Ishiguro
- Pierre Cox
- Thijs de Graauw,
- Ewine van Dishoek
- Dennis Downes
- Pierre Encrenaz
- Alain Omont
- Alain Baudry
- Richard Kurz
- Torben Anderson
- Stephan Guilloteau



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For all-around support:

Rachel, Ineke, and Patricio



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The last words...



ALMA is a partnership of ESO (representing its member states), NSF (USA) and NINS (Japan), together with NRC (Canada), MOST and ASIAA (Taiwan), and KASI (Republic of Korea), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ.

The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.