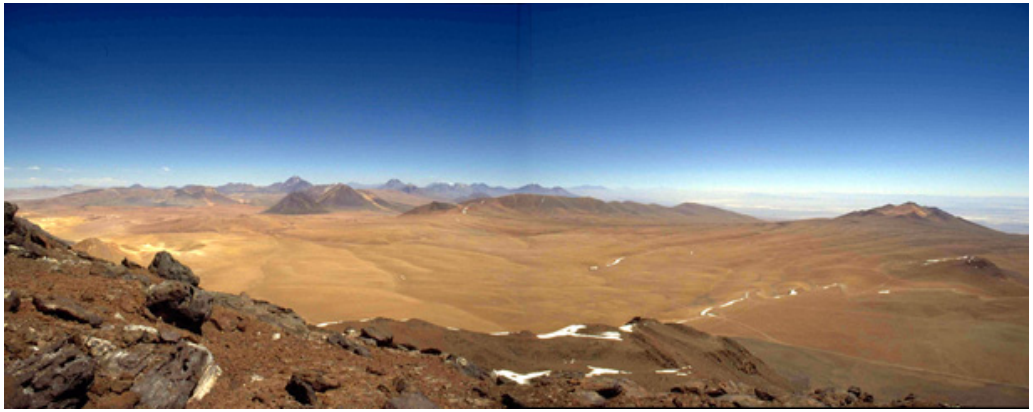
AMPATH 2003:ALMA

The Atacama Large Millimeter Array (ALMA)



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Division of Astronomical Sciences

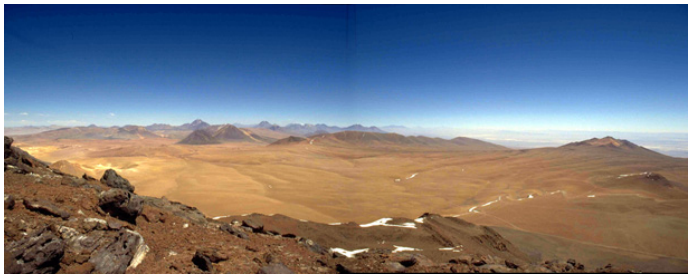
National Science Foundation

Latin America

- **Substantial astronomy capital investment has recently been made or is planned in Latin America, *.e.g:***
  - **Chile**
    - **Gemini South**
    - **VLT**
    - **ALMA**
    - **Very large (>>8m) optical telescope(s)**
  - **Mexico**
    - **LMT**
  - **Argentina**
    - **Auger**

➢ **Though all are unique, ALMA may serve as a useful paradigm for the challenges these projects can be expected to face.**

ALMA Basics



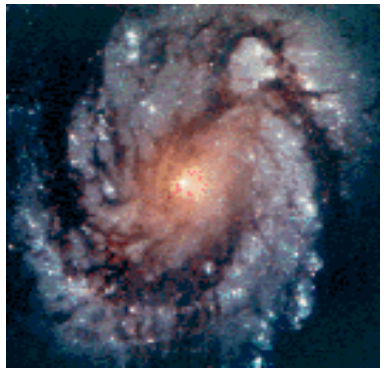
- ALMA is an interferometer that will operate in the mm and submm portions of the radio spectrum
- ALMA is an international project
- The lead US agency for ALMA is NSF
- The lead US institution for ALMA is the National Radio Astronomy Observatory (NRAO)
- NRAO is managed for NSF by Associated Universities, Inc. (AUI)
- AUI fulfills the role of US/NA legal interface with Chile
- ALMA will be constructed in northern Chile
- US ALMA construction was initiated in FY2002
- ALMA will cost about $800M in current-year (*i.e.*, inflated) dollars

Atacama Large Millimeter Array

- Evolved out of U.S. Millimeter Array (MMA, 1984) and European LSA (1995) concepts
- U.S.-European Project (50%-50%)
- Northern Chile site
- Scope: 64 12m antennas, 4 receiver bands
- Costs (FY 2000 dollars):
  - Total Cost: $552M
  - U.S. Share: $276M (less $20M CDN share)
  - Operations: ~$35M/yr
- 9-year construction timeline
- Japan may join

ALMA Science Requirements

- **Detect CO emission from the Milky Way at z = 3 (Universe < ¼ present age, distance ~ 4.5 Gpc)**
- **Image 1 Solar-mass protoplanetary disks at 150pc**
  - > **Physical & kinematic structure (including tidal gaps)**
  - > **Chemical and isotopic composition**
  - > **Magnetic field structure**
- **Precision imaging at < 0.1 arcsecond resolution**

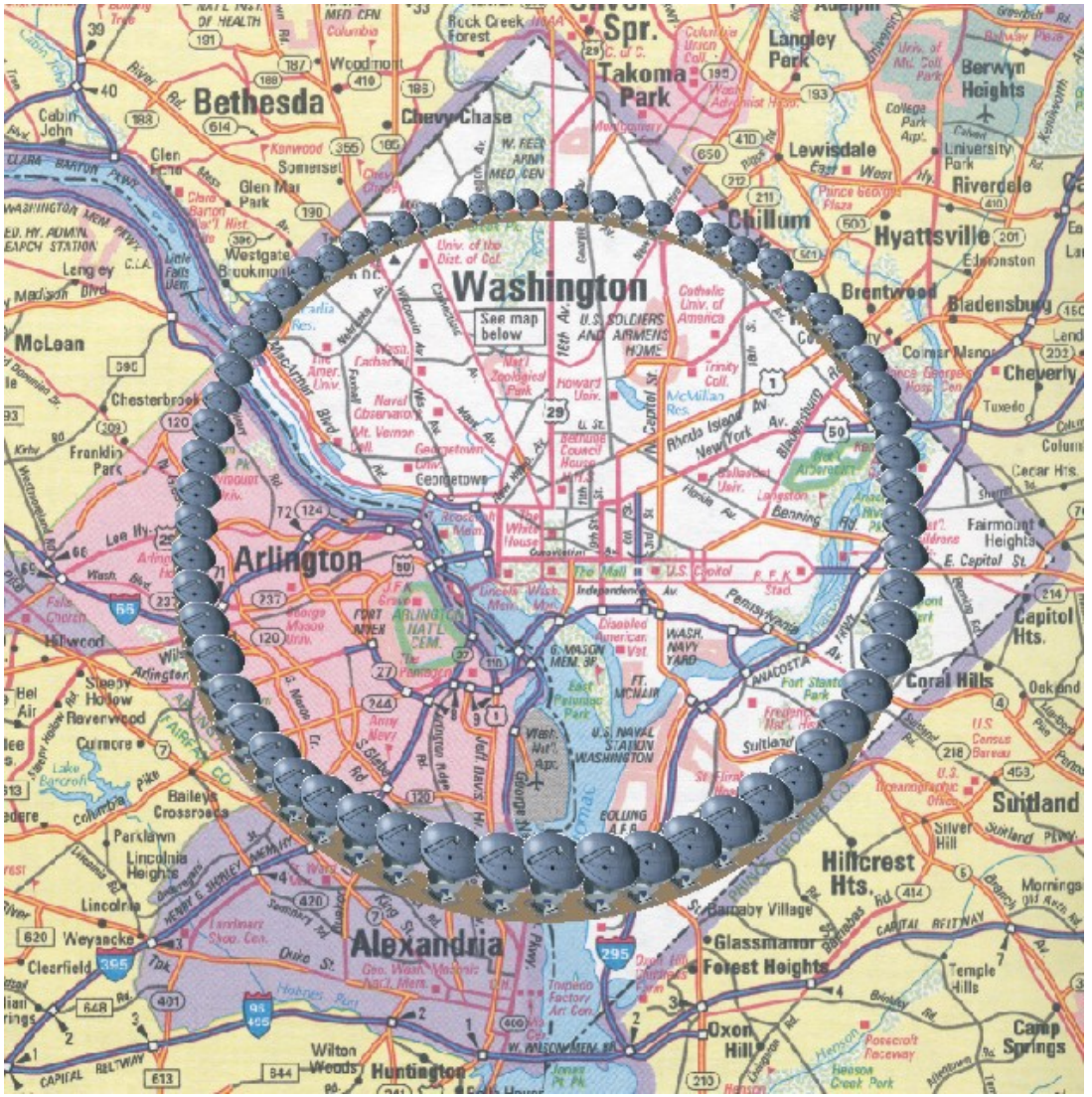


Why an Array?

- The angular resolution of a radio telescope improves as diameter increases
- There are physical limits to the size of a single antenna
- The multiple antennas of an array can be thought of as the unfilled aperture of a much bigger antenna
- Earth rotation fills in aperture during observation session
- The more antennas, the more sensitive the array will be and the quicker it will make images.

ALMA Baselines Are Variable: “Zoom Lens”

Maximum Detail At Largest Antenna Separations...



Why Millimeter-Waves?

- **The interstellar medium is transparent to mm radiation: Star birth and star death are unveiled**
- **Spectral line observations provide:**
  - > **Gas motions -- collapse, turbulence**
  - > **Isotopic and elemental compositions and abundances**
  - > **Gas temperature**
- **Continuum observations provide:**
  - > **Dust temperature**
  - > **Sites of star birth**
  - > **Opportunity to discover new planets around other stars**

- **The signals from distant objects were emitted when the Universe was younger – sensitive enough telescopes can observe the first generations of stars and galaxies**

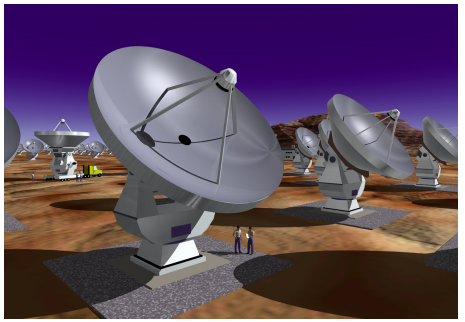
Scope Of Baseline ALMA

- **64 12 meter antennas**
  - 25μ RMS surface accuracy (20μ goal)
  - 0.6 arcsec RMS pointing accuracy
  - 15μ RMS phase error
  - Performance in 9 m/s wind
  - Transportable
- **Five array configurations**
  250m – 14km diameter
- **4 dual-polarization receiver bands**
  - Band 3 (89 GHz – 116 GHz)
  - Band 6 (211 GHz – 274 GHz)
  - Band 7 (275 GHz – 370 GHz)
  - Band 9 (602 GHz – 720 GHz)
- **Frontend 4 K cryostat**, can accommodate 10 receiver "cartridges"
- **Fixed-tuned broadband** multiplier-drivers for all bands
- **Photonic LO** Reference at ~100 GHz
- **Fixed-tuned broadband** multiplier-drivers for all bands
- **4 or 8 GHz IF** bandwidth per polarization
- **120 Gbps** fiber optic transmission from each antenna
- **Correlator**
  - 64 antennas
  - 250 MHz – 8 GHz BW per polarization
  - 64 – 4096 channels/product
  - 2 or 4 bit correlation format
- **Computing**
  - 6 MB/s sustained data rate (60 MB/s peak)
  - Automated scheduling
  - Pipeline data processing using AIPS++
  - Networked archiving of all raw and associated calibration and derived data

ALMA: An International Partnership

- An International Partnership was a deliverable of Phase I
- US/Canada:
  - North American coalition
  - $20M (US)
- Europe
  - Phase I: European coalition spearheaded by ESO
  - Phase II: ESO
- Chile: Host Country
- Japanese participation:
  - Perhaps after JFY2004
  - Probably not equal partner

Partnership Status



- U.S.-European Phase I Project
  - June 1999 – September 2001 (US cost $32M)
  - "Confederated" parallel projects
- Congress initiated U.S. construction in FY 2002
  - FY 2002: $12.5M
  - FY 2003: $30M (proposed)
- ESO Council approved construction in 2002; 2003 start
  - http://www.eso.org/projects/ALMA
- Baseline project will proceed as NA-ESO bilateral
  - As host country, Chile has special privileged status
  - If Japan enters, she will contribute enhancements (off critical path), and capital buy-down
- Detailed Chile agreements will finalize in 2003

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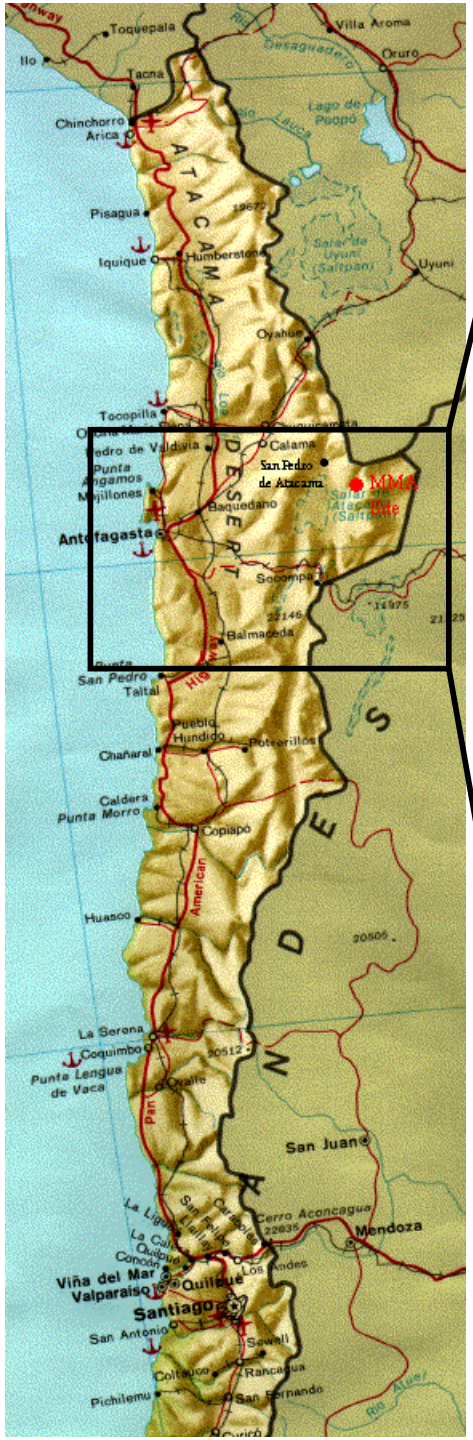

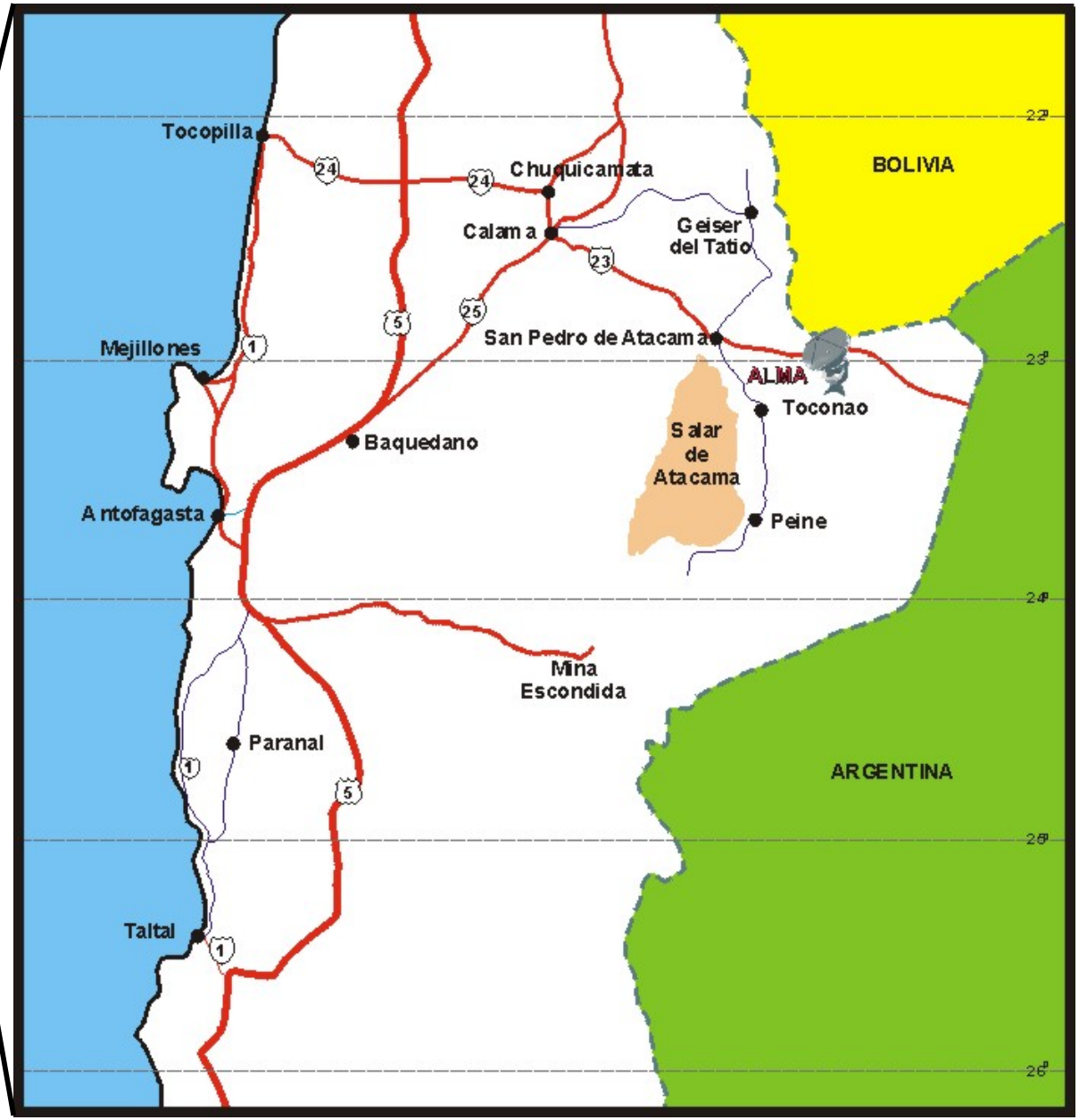

ALMA Site Location

Array Site: Llano de Chajnantor

Chajnantor Environs

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Operations Support Center Site

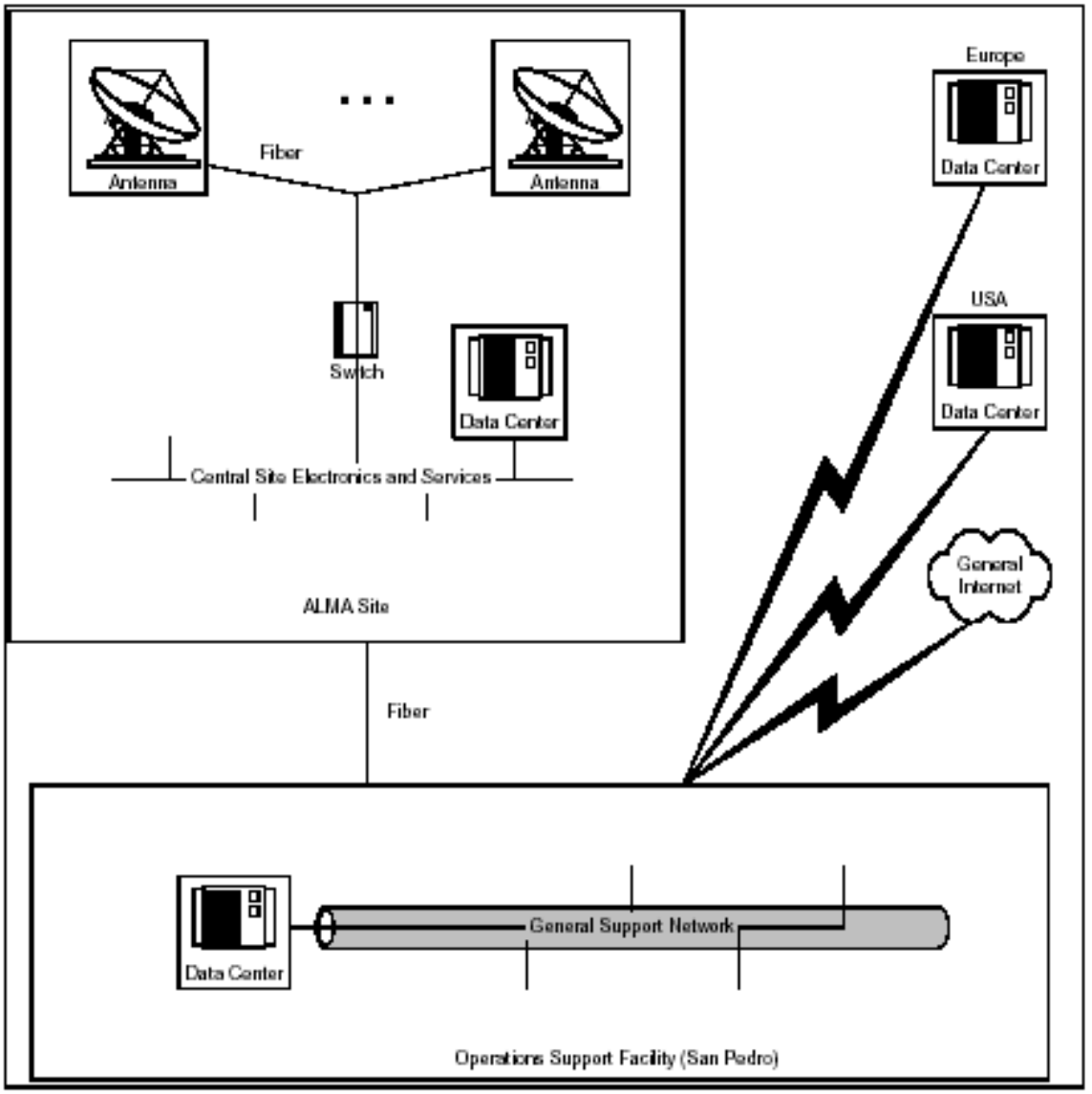
ALMA Costs

- "Bottom-up" approach to contingency
- ALMA Agreement minimizes exchange of funds
- Project denominated in deliverables
- Construction Cost: $552.4M (FY 2000 dollars)
  - Cost With Inflation: $727M
  - U.S. Share with inflation: $344M
  - U.S. Share will be reduced by Canada
  - Cost based on detailed U.S.-European WBS
  - Stable since developed
- Operating costs ~$34M/yr (FY 2000 dollars)

ALMA Computing Challenges

- Usual Array Challenges (*e.g.,* pipelining)
- High Speed (into archive)
  - 60 MB/s specified; 72 MB/s goal, sustained peak rate
  - 6 MB/s average
- Dynamical observation scheduling
  - Frequencies
  - Sources
- Remote observers
- General User Base
  - No “black belt” in interferometry required
  - Transparency and automated optimization
- Frequency *terra incognita*
  - What else will be needed?

Physical Overview



ALMA Sites and Computing Functions

- **Array Operations Site (AOS)**
  - Llano de Chajnantor (5050m altitude)
  - Correlator, with fiber to OSF
  - Antenna Monitor and Control
- **Operations Support Facility (OSF)**
  - 1 square km area, on access road 2/3 of way to Toconao, (2800m altitude)
  - Array operations
  - Quick-look data reduction
  - Data storage
  - Connection to web TBD
- **ALMA Santiago**
  - Location TBD
  - Standard pipeline reduction
  - Quality assessment
  - Archive production
- **Regional Support Centers (U.S., Europe, Japan, Chile)**
  - Proposal handling
  - User support and scheduling
  - Archive hosting and archival research support

ALMA Computing Tasks

- User and Operator Tasks
  - Array Monitor and Control (2-way) [O]
  - Signal transmission [O]
  - Signal correlation [O]
  - Calibration [O,U]
  - Imaging
    - Data reduction and calibration [U]
    - Quick-look [O,U]
    - Final [U]
  - Array queuing and scheduling [O]
  - Observation planning and observer support [U]

Some Final Considerations…

- **Potential IT Bottleneck:**
  - Physical: OSF to Chilean Backbone
  - Cost: connection
- **International projects – perhaps the wheel will turn**
- **But in astronomy, the international character of projects is unlikely to change:**
  - Small number of extraordinary sites
  - Need for return on investment

Backup Material

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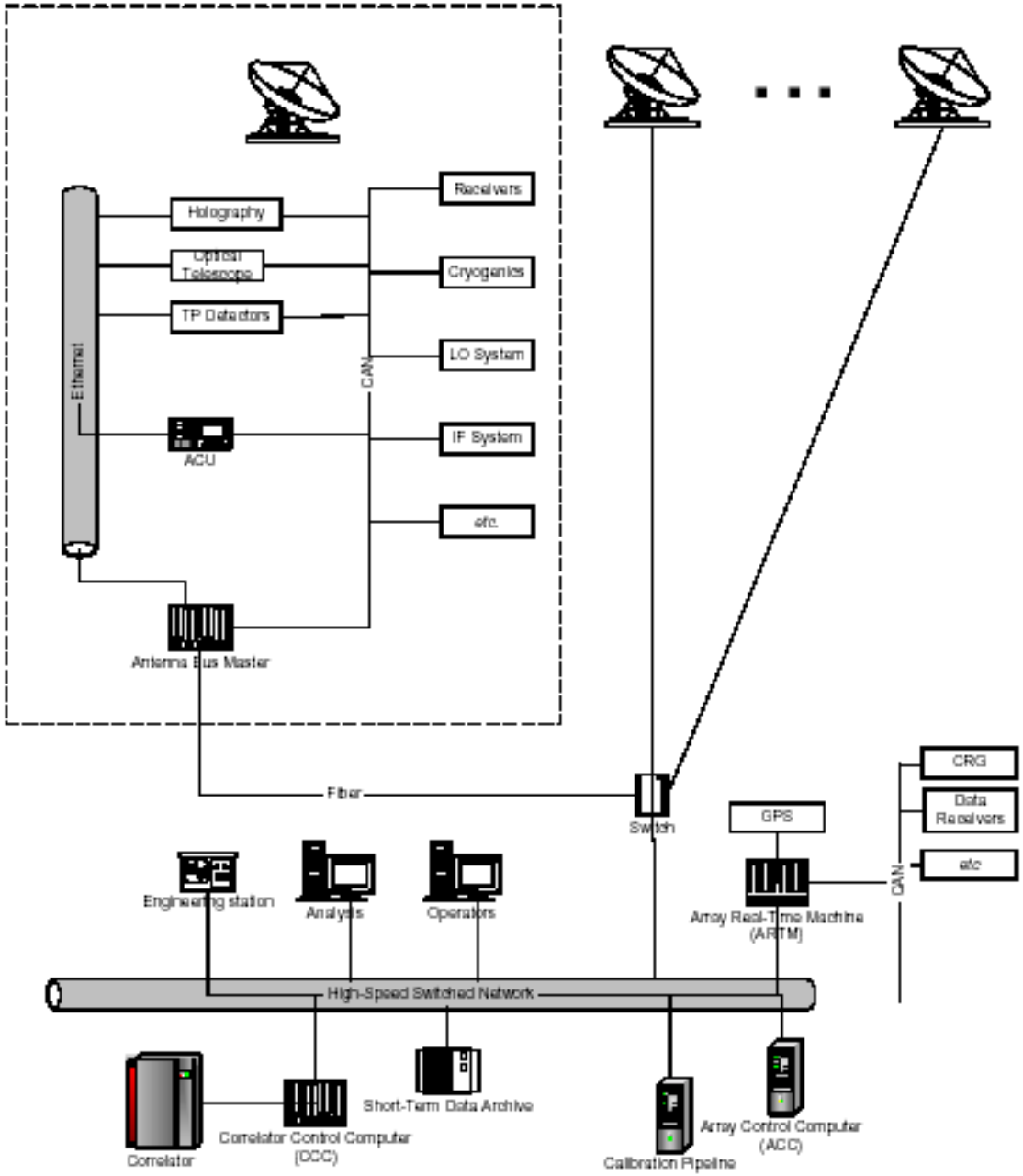
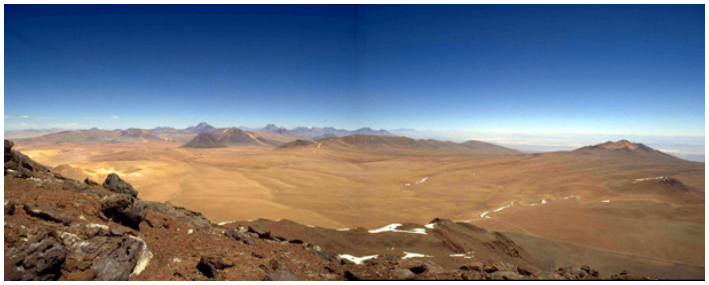
ALMA Site Computer Layout

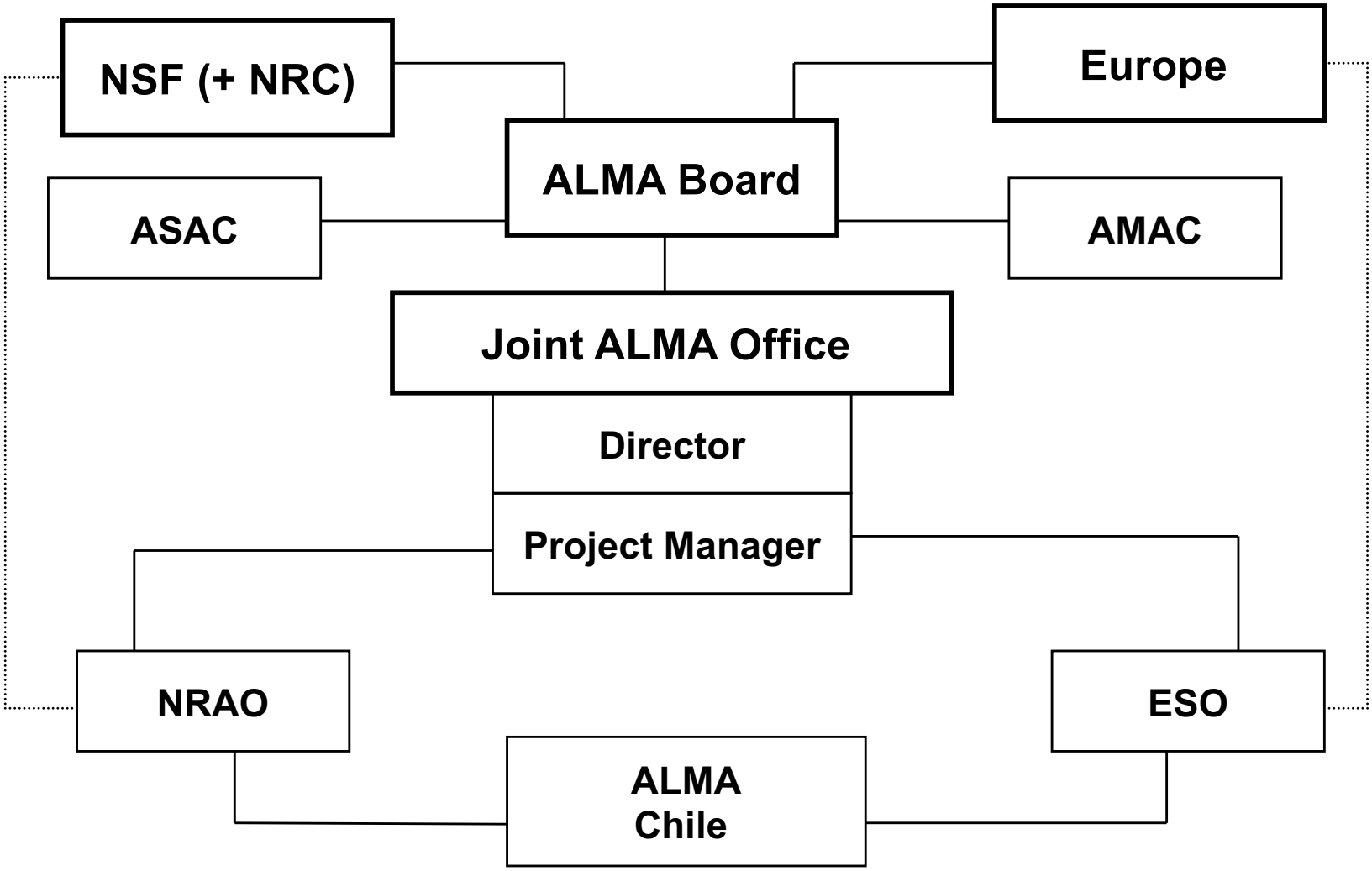


ALMA and Chile



- **Chile provides:**
  - > **Land – no cash**
  - > **Legal, privileged framework for Executives to operate ALMA**
  - > **Stable access to the ALMA site through an "onerous concession" (*i.e.*, rent)**
- **Chile receives:**
  - > **10% of observing time**
  - > **Seat on ALMA Board for Chilean, scientific issues**
  - > **Annual benefits to:**
    - **Chilean Astronomical Community**
    - **Indigenous Peoples**
    - **Chilean Public**

ALMA Organization



ALMA Organization

- **Structure defined by International ALMA Agreement**
  - Agreement is the core document: Chile and (possibly) Japan will join through supplementary documents
  - Covers both construction and operations
  - Agreement approved, waiting signature
- **ALMA Organization:**
  - Joint ALMA Board (4+4+1)
  - Joint ALMA project/observatory office
    - Director
    - Project Manager
    - Project Scientist
    - Project Engineer
  - Joint Management and Science Advisory committees
  - NSF retains external and internal advisory committees