



The ALMA project and construction status

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What is ALMA

Atacama Large Millimetre/Submillimetre Array

- ALMA will be the world's largest interferometer for millimetre and sub-millimetre wavelengths
- It is in full construction in the Atacama desert
- Three sites in Chile
 - **ALMA Operations Site (AOS):** high, dry site, Chajnantor Plateau (5000m)
 - **Operations Support Facility (OSF):** Technical base (2900m) near San Pedro de Atacama
 - **Santiago** headquarters



ALMA Specifications

- 54 12-m antennas, 12 7-m antennas, at 5000m site
- Surface accuracy $< 25 \mu\text{m}$, 0.6" reference pointing in 9 m/s wind, 2" absolute pointing all-sky
- Array configurations between 150 m and $\sim 15\text{-}18$ km
- Angular resolution $\sim 40\text{mas}$ at 100 GHz (5mas at 900GHz)
- 10 bands in range 31 to 950 GHz + 183 GHz WVR
- 8 GHz IF bandwidth, dual polarization
- Interferometry, mosaicing & total-power observing
- Correlator: 4096 channels/IF (multi-IF), full Stokes
- All data archived (raw + images), pipeline processing



ALMA as an international collaboration

- ALMA is a collaboration between
 - ESO – Europe (14 member states of ESO)
 - With contributions from many institutes
 - NRAO – North America (USA, Canada), and
 - NAOJ – East Asia (Japan, Taiwan),
 - In collaboration with Chile
- Hardware and software is developed and built across the three partner regions
- In Chile, the *Joint ALMA Observatory* (JAO) commissions and operates ALMA
- ALMA costs ~1.2 billion €, shared among the partners

A global collaboration





Top Level Science Goals



1. Detect and map CO and [C II] in a Milky Way galaxy at $z=3$ in less than 24 hours of observation
2. Map dust emission and gas kinematics in protoplanetary disks
3. Provide high fidelity imaging in the (sub)millimeter at 0.1 arcsec resolution



ALMA 1-page status – Nov 2010

- Eight antennas installed at 5000m site and working as interferometer
- Fringes observed at bands 3, 6, 7, and 9
- Phase closure achieved
- CSV (Commissioning & Science Verification) ongoing since Jan 2010 – first exciting results
- ~30 antennas in various stages, 13 conditionally accepted
- 2 antenna transporters on site and in operation
- 11 front ends in Chile, more in testing and integration
- Infrastructure close to completion
- Further production underway for antennas, front ends, backends, infrastructure, ...

Eight Antennas at 5000m

- Currently eight antennas in use at 5000m
- Sixteen are scheduled for May 2011

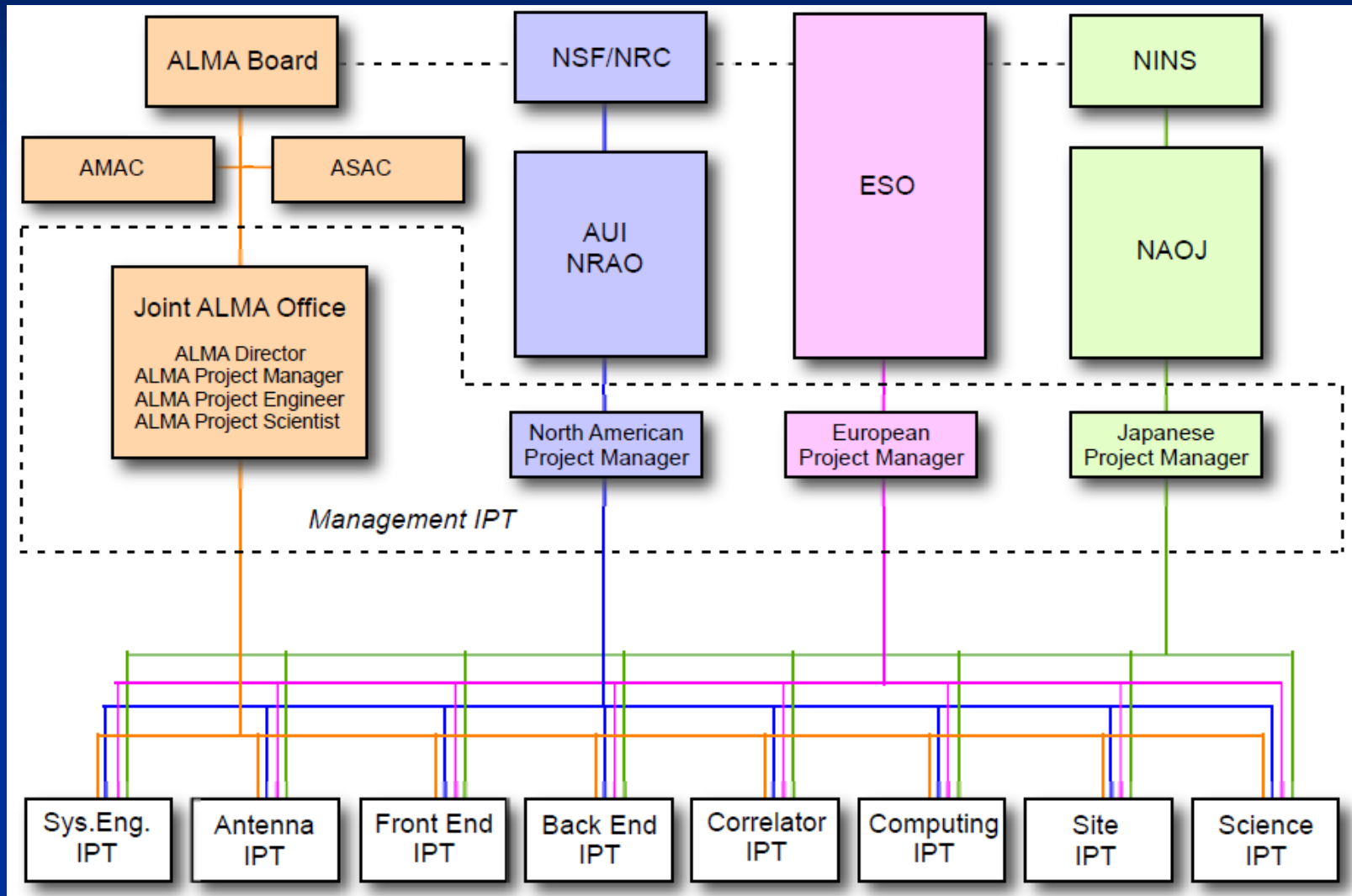




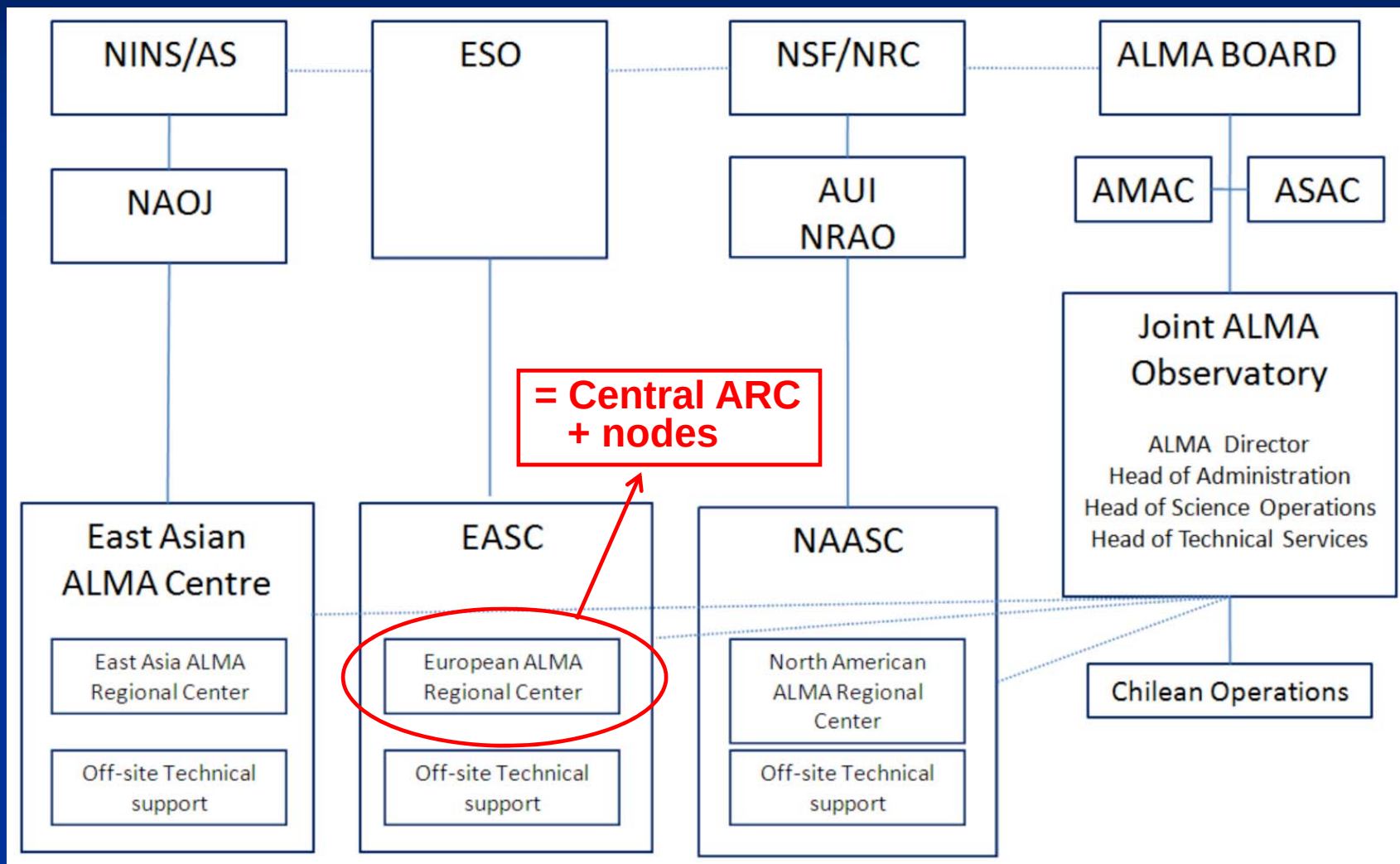
ALMA Organization

- ESO, AUI/NRAO, and NAOJ (the three “Executives”) decided to fund and jointly build/operate ALMA
- To this end, the *Joint ALMA Observatory (JAO)* has been created in Chile
- The ALMA Board has overall responsibility for the JAO
- Technical work is mostly carried out in IPTs
 - IPT = “Integrated Product Team”
 - Significant contributions from research institutes and industry

ALMA Management Structure during construction phase



ALMA Structure in Operations



Organizational challenges

- World wide distribution of a large and complex project
- Three administrative systems
- (At least) three mentalities
- (At least) three cultural backgrounds
- Complex – but necessary – management structure

Main ALMA contributions

IPT / Subproject	Europe	North America	East Asia
Site Development	ALMA Road to AOS OSF Technical Facilities OSF Residencia Santiago Central Office ALMA Power Supply 192 Antenna Foundations	Roads at AOS AOS Technical Facilities	Financial Contribution to Costs
Antennas	25 Antennas (12m) Two Antenna Transporters	25 Antennas (12m)	4 Antennas (12m) 12 Antennas (7m)
Front End	Band 7 (70) Band 9 (70) Cryostats (70) Water Vapour Radiom. (53) Calibration System (70) 26 Integrated Receivers	Band 3 Band 6 Monitor and Control 26 Integrated Receivers	Band 4 Band 8 Band 10 Integrated Receivers
Back End	Photomixers (hundreds) Digitizers Digitizer Clocks Multiplexers	Optical Transmitters Local Oscillators Digital Formatters Digital De-Formatters	
Correlator	Tunable Filter Boards	Correlator for 64 Ant	Correlator for 16 Ant
Computing	Software	Software	Software

ALMA location





Location



AOS (5000m)

OSF (2900m)

San Pedro de Atacama (2400m),
Atacama desert, Northern Chile



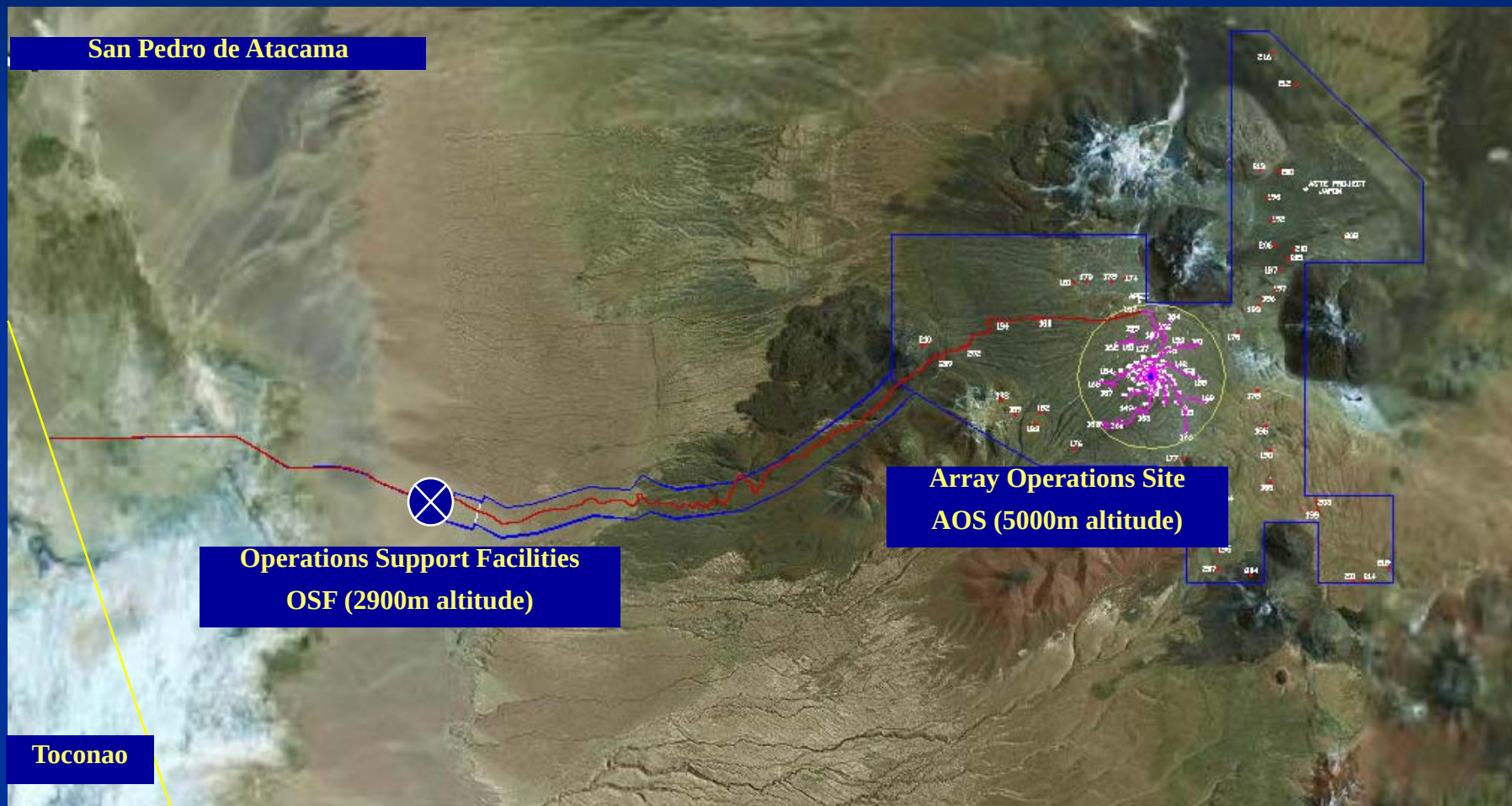
San Pedro de Atacama



Access to ALMA



Satellite image





Google-Earth view of site with antennas in the most extended configuration – baselines to 16km

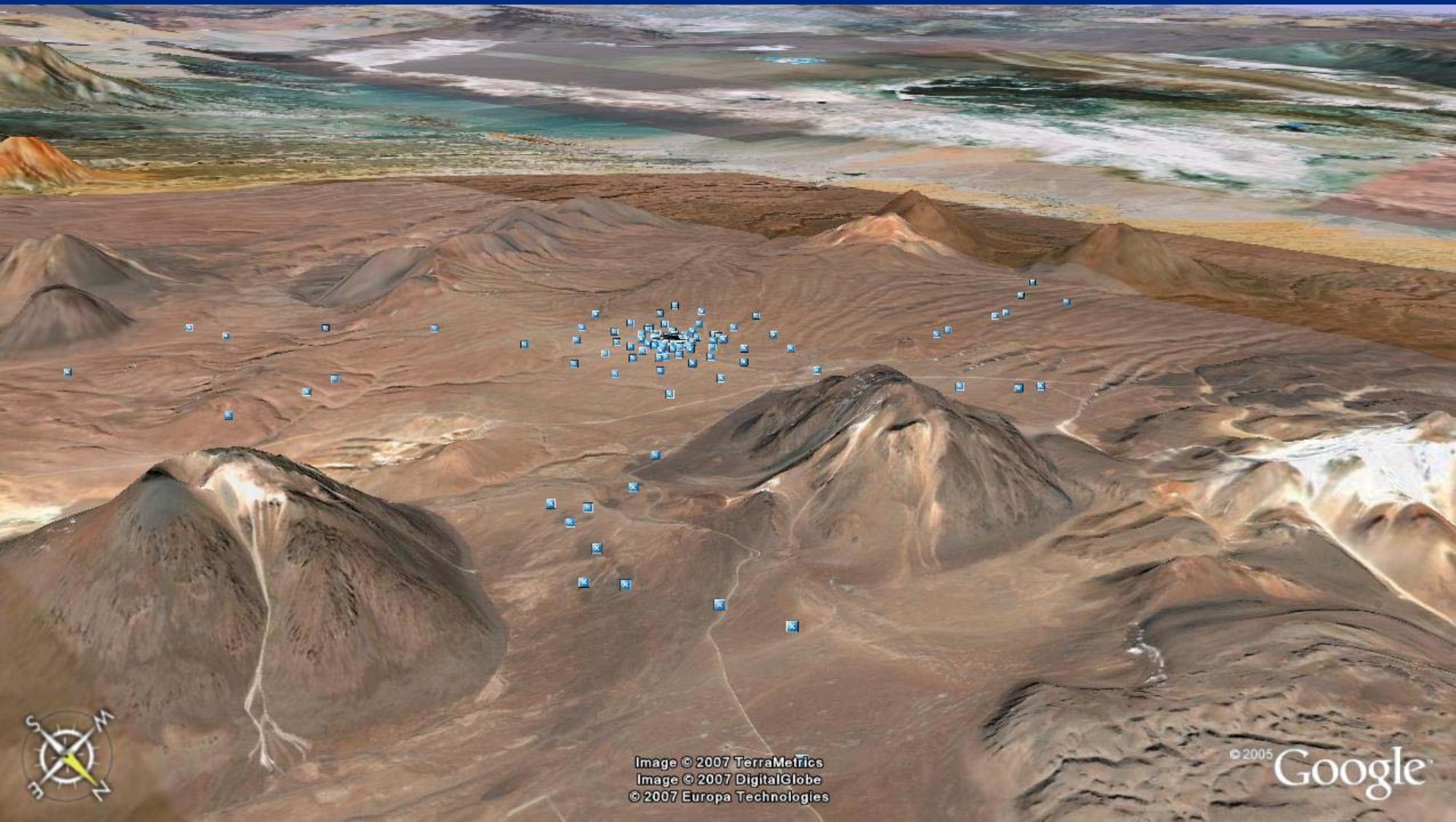


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Image © 2007 DigitalGlobe
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Three sites in Chile

- OSF – Operations Support Facility (2900m)
 - Operations Base: control room (operating)
 - Antenna integration (ongoing)
 - AIV (Assembly, Integration & Verification)=Equipping antennas
 - Technical Building etc.: Labs, maintenance, live & eat
- AOS – Array Operations Site (5000m)
 - 66 antennas, 192 antenna stations (foundations done)
 - Technical Building: correlator, LO reference (done)
- SCO – Santiago Central Office
 - “Home base” of ALMA (in use)

ALMA OSF (2900m)



- Antenna integration in three work areas
- Technical building, canteen, bedrooms, etc.
- About 500 people at the Operations Support Facility (OSF)



ALMA OSF (2900m)



Observing with ALMA: Ear

Site Infrastructure OSF

- OSF Technical Facility
 - Control Room
 - Computer Room
 - Antenna Assembly, Integration and Verification Area



ALMA OSF (2900m)





Llano de Chajnator (5000m) Array Operations Site -AOS



Picture was taken before ALMA construction started

Site Infrastructure Array Operations Site (AOS)

- AOS Technical Building completed in 2008
- Construction of the 192 antenna foundations making up the entire array configuration completed in 2009
- Construction of the infrastructure needed to make these functional antenna stations underway
 - Network of access roads
 - Power distribution
 - Fiber optic signal connection



ALMA AOS (5000m) Digital correlator

- Three (of four) quadrants installed, one in routine use
- Patch panel installed



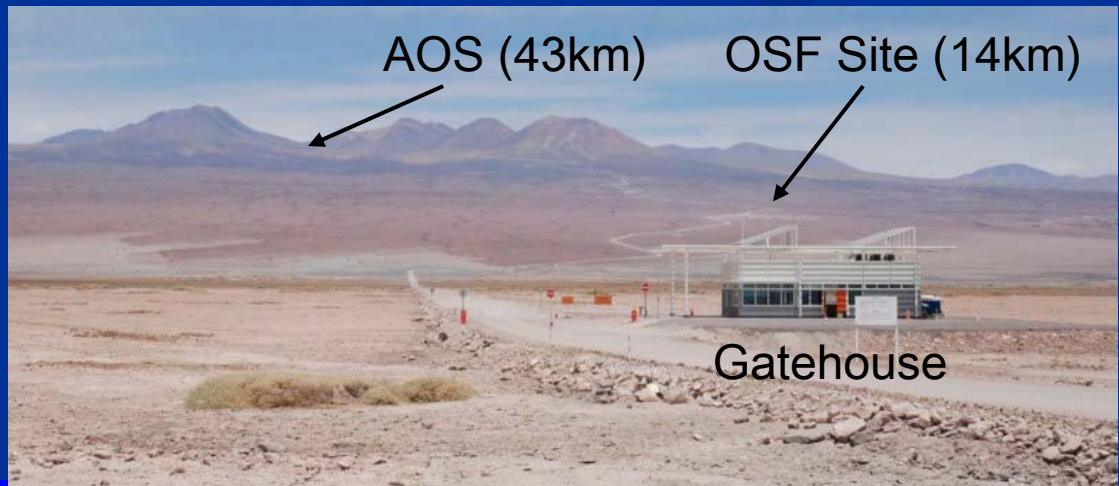
Site Infrastructure - Power

- ALMA needs 7 MW of electrical power (peak)
- To be generated at the OSF – Multi fuel generators
- Transmitted to AOS via a 29 km long 23 kV line
- Power supply includes “fly wheel” system
- Permanent power system construction will be completed August 2011 – meanwhile using generators at 5000m



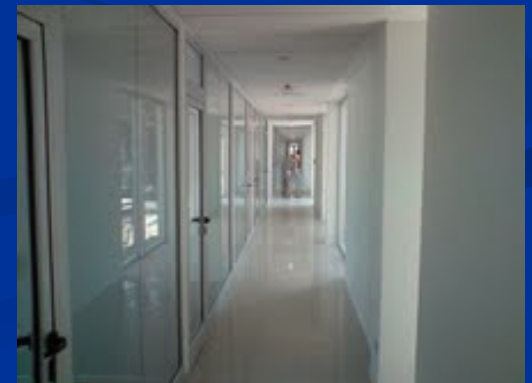
Site Infrastructure - Roads

- 43 km of roads from Chilean Highway 23 to OSF and AOS completed
 - 14 km from highway to OSF
 - 29 km from OSF to AOS (15m wide)
 - Road signs and crash barriers still to be installed
- >150 km of roads at the AOS under construction
 - Access to all antenna stations



Santiago Central Office

- On ESO premises in Santiago
- Completed in July 2010, ALMA staff moved in August





Antennas

- ALMA antennas are manufactured to a common specification by three contractors

<i>Partner/Contractor</i>	<i>Number to be supplied</i>	<i>Delivered to Site</i>	<i>Delivered to AIV</i>
North America / Vertex	25 12m	16	10
Europe / AEM Consortium (TAS-EIE-MTM)	25 12m	6	Mar 2011
East Asia / Mitsubishi Electric Corp	4 12m 16 7m	4 5	3 Jan 2011

Antennas



North American

12m antenna



European

12m antenna

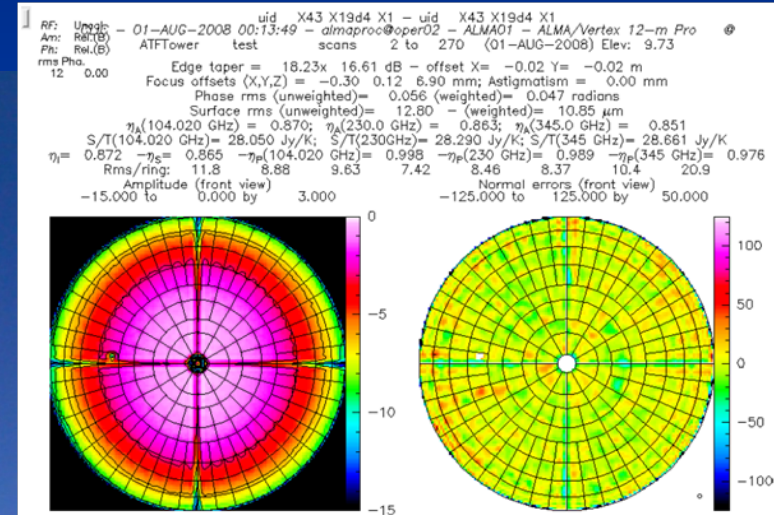


East Asian

12m antenna on
transporter in foreground
7m in background

North American (Vertex) antennas

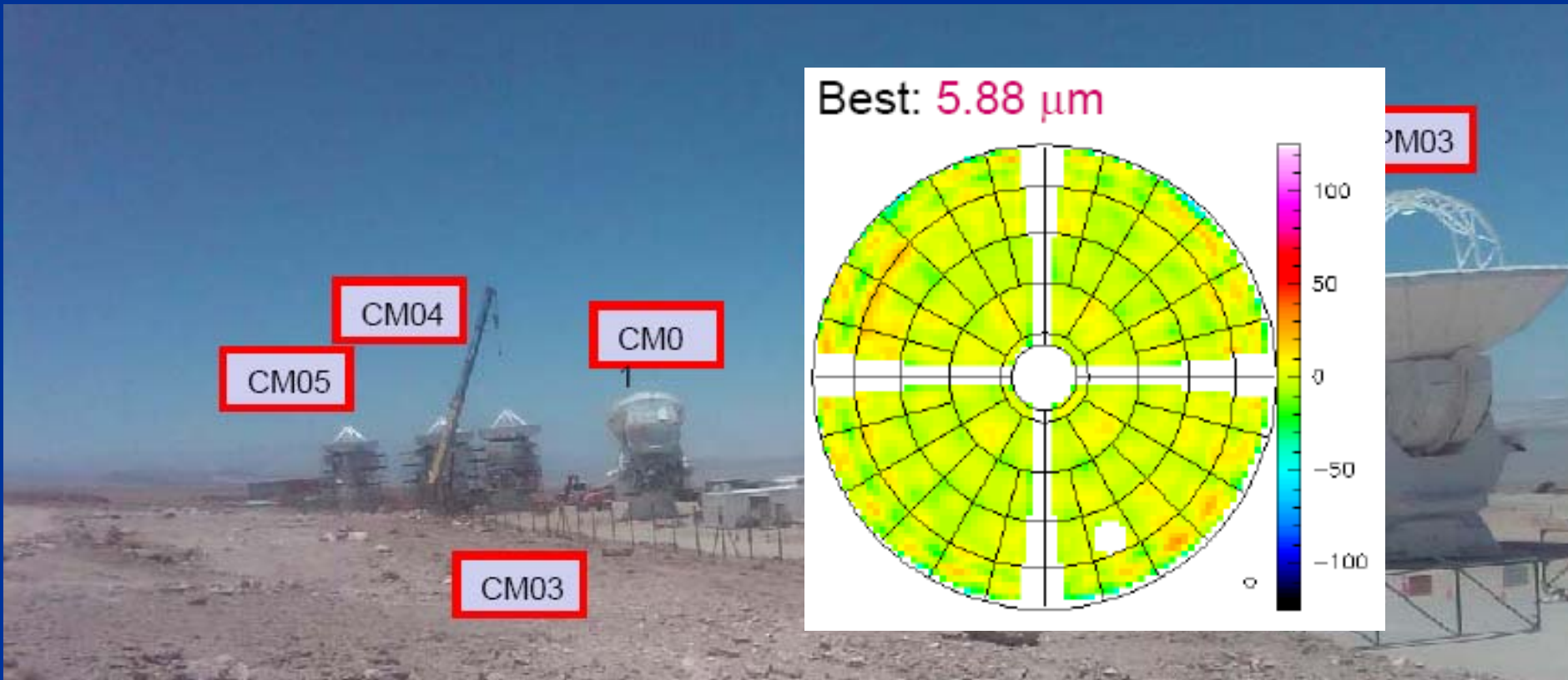
- 16 Vertex antennas in Chile in various stages
- 10 conditionally accepted



Surface 11 micron rms

Japanese (MELCO) antennas

- 4 x 12m in Chile (AOS/OSF)
- 5 x 7m at OSF, more 7m antennas to come



European (AEM) antennas

- Built by a consortium of
 - Thales-Alenia-Space (TAS) – France and Italy
 - European Industrial Engineering (EIE) – Italy
 - MT-Mechatronics – Germany
- Subcontractors in Italy, France, Spain, Germany, Denmark, UK, Switzerland, and Chile
- Six antennas in Chile, fully assembled, production line in Europe nominal
- First antennas in testing phase

European Antennas

- Six on site, fully integrated
- Acceptance of first antenna early 2011



First six European Antennas



Shipping from Europe



Observing with ALMA: Early Science, Grenoble



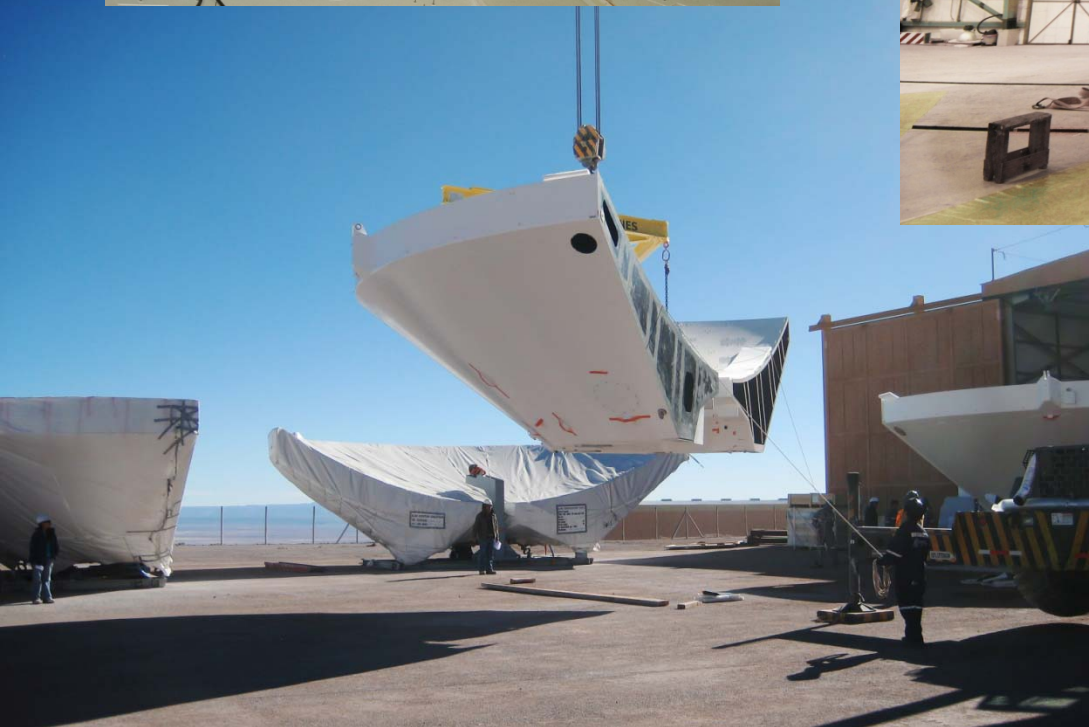
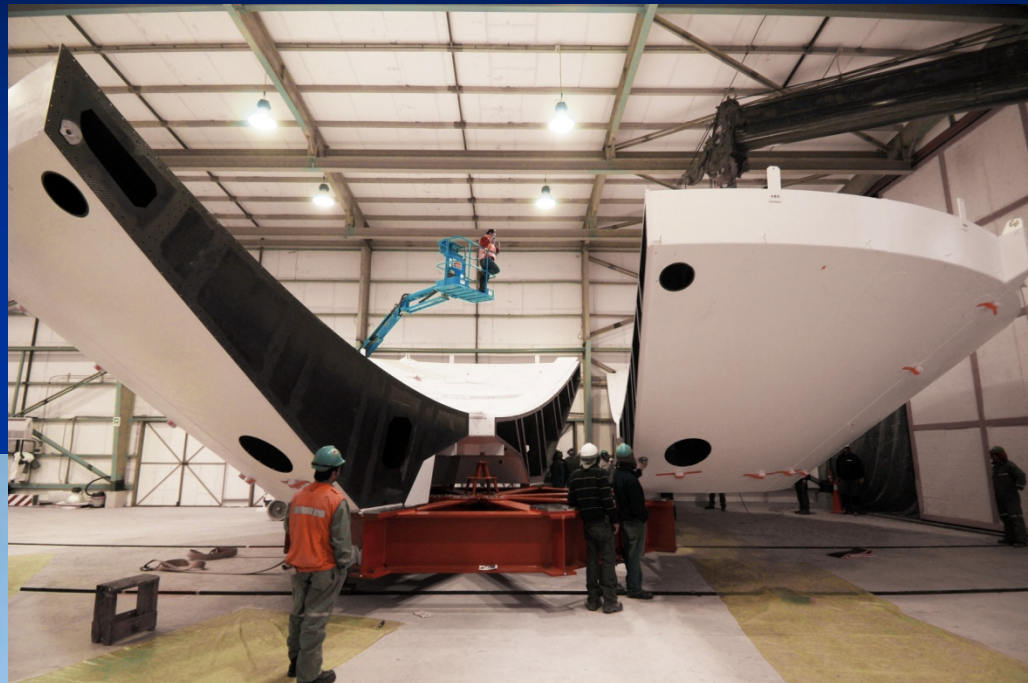
CONVOI
EXCEPTIONNEL

60

80

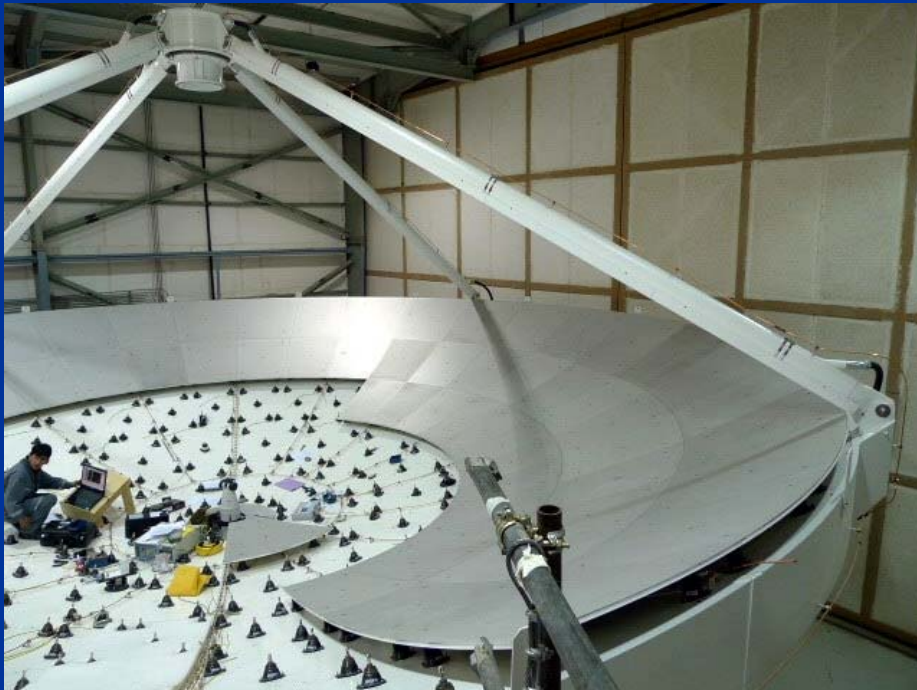
FAYMONVILLE

Reflector assembly



Reflector integration

- 120 panels per reflector
- Laser tracker measurement indicated ~ 30 micron rms for both reflectors *after mechanical installation*







Antenna #1 Acceptance Testing

- Antenna #1 in acceptance testing
- First results promising
 - First pointing done – 1"
 - First reflector result – 15 μm rms
- Acceptance testing until at least March 2011
 - No schedule contingency included

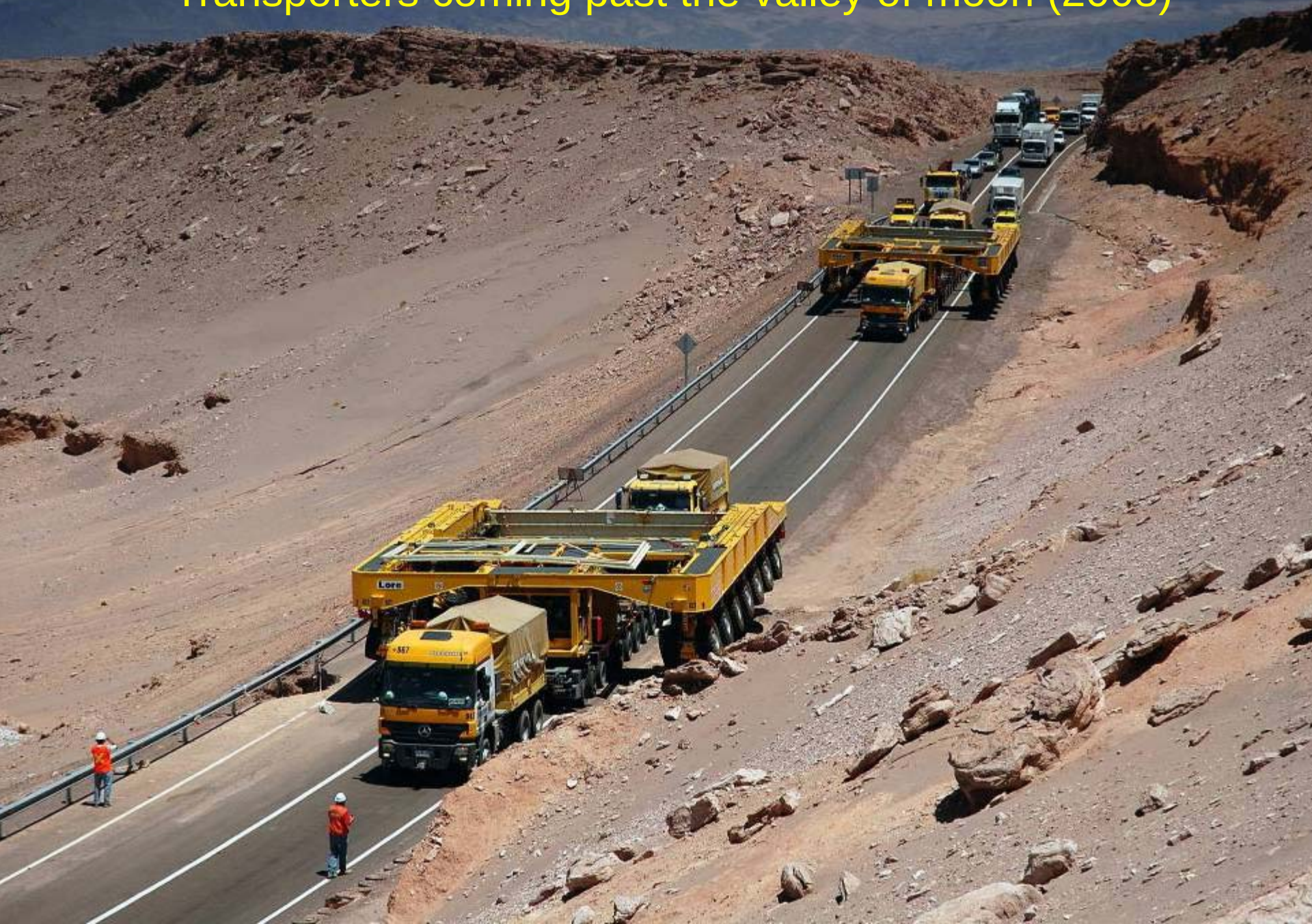


ALMA Antenna Transporters

- Two 120 ton transporters delivered by ESO
- In routine operation since 2008
- Custom design for special circumstances
 - Operation at 5000m altitude
 - Up to 10% slope
 - High precision positioning of antennas (~1 mm)



Transporters coming past the valley of moon (2008)



First antenna to 5000m (17 Sep 09)



First antenna to 5000m (17 Sep 09)

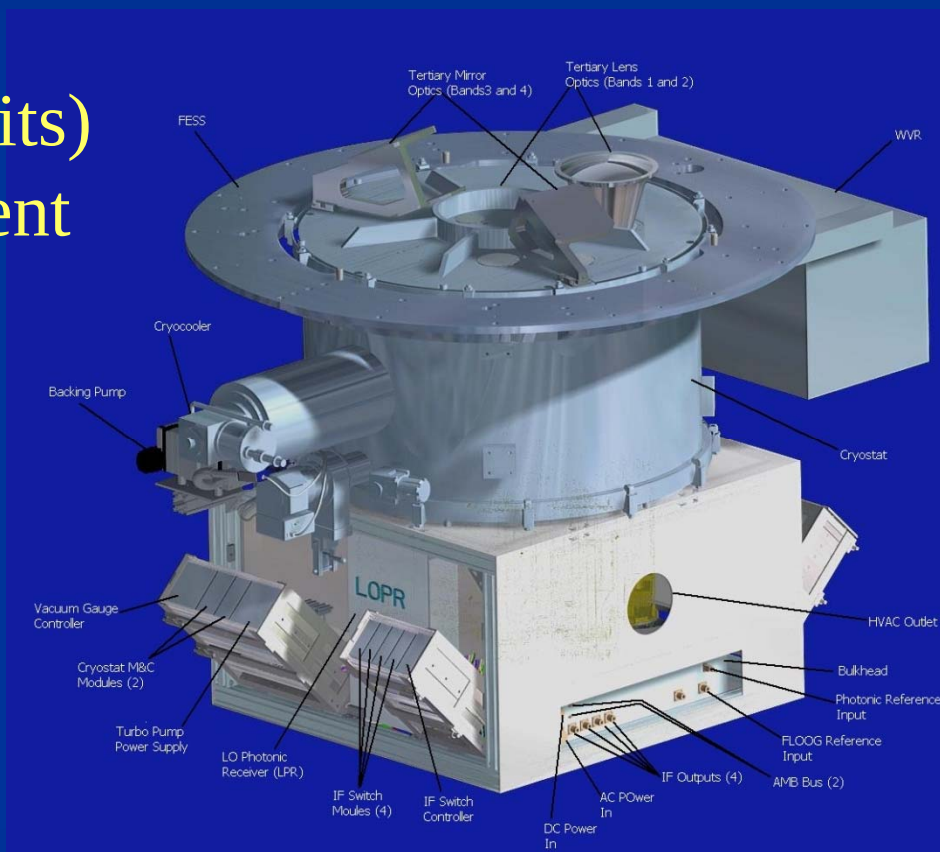


First antenna – arrival at AOS



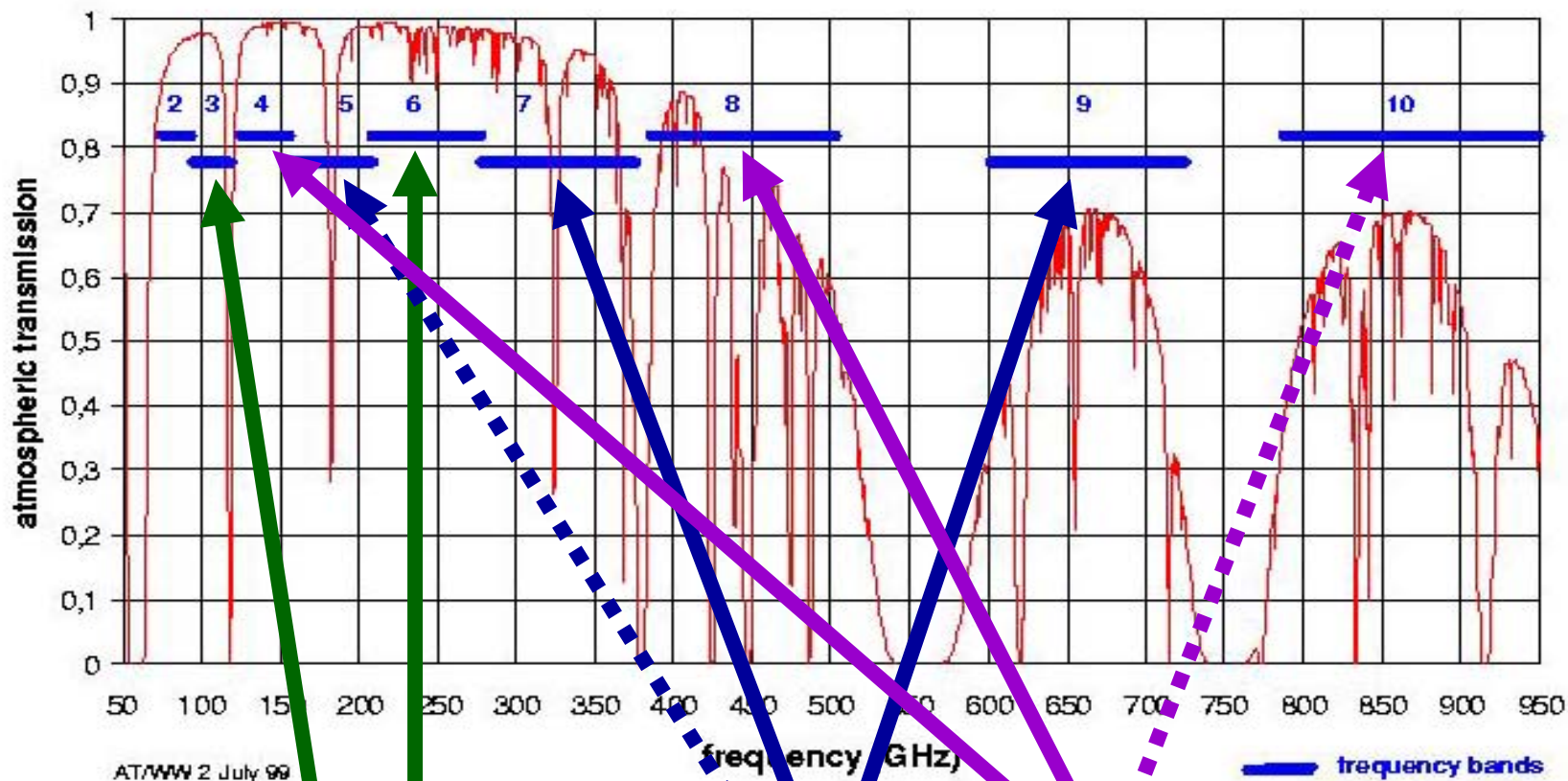
Front End Assemblies

- 10 bands from 30 GHz to 950 GHz in one cryostat
- Bands 3, 4, 6, 7, 8, and 9 in production
- Band 10 prototyping
- Band 5 EU funded (6 units)
- Band 1 under development



ALMA Frequency Bands

Atmospheric transmission at Chajnantor



North America

Europe

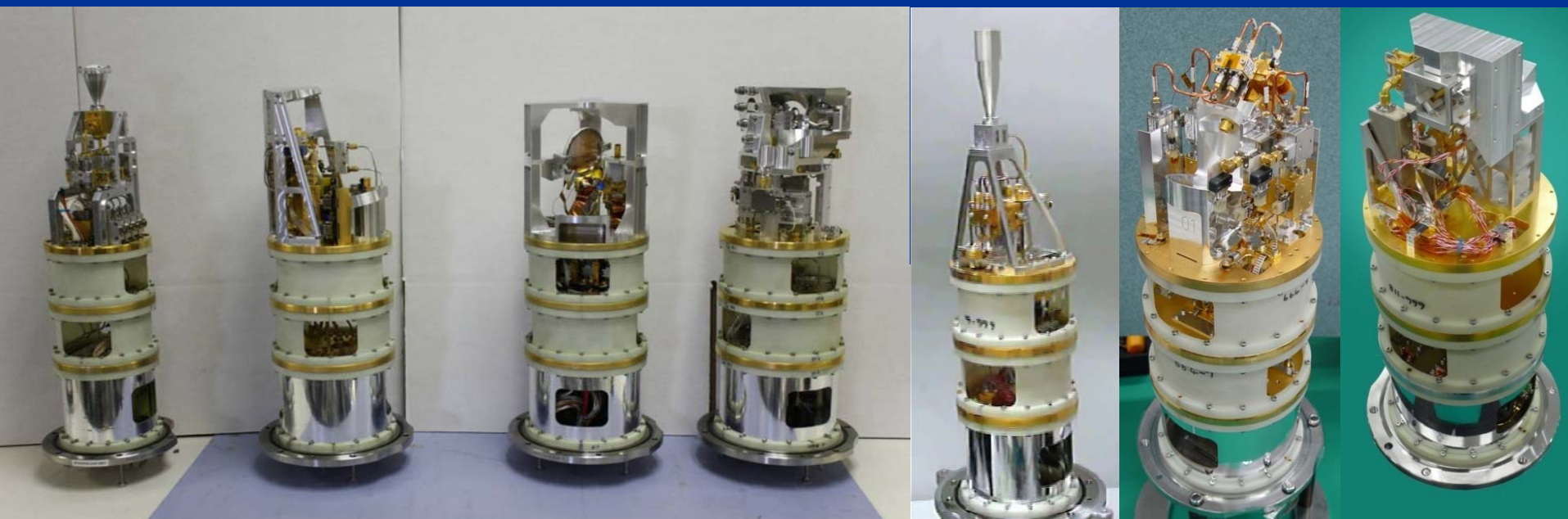
Japan

Receivers (Front Ends)

- Cold and warm cartridge assemblies for the primary four bands are well into production, and two more are close
- Two additional bands in development
- A few “low-tech” components have been late into production and delayed front end integration

Cartridge	Status	Completed
Band 3	Production	33
Band 4	Pre-production	2
Band 5	Development	6 in 2011
Band 6	Production	27
Band 7	Production	38
Band 8	Pre-production	4
Band 9	Production	47
Band 10	Development	prototype

Receiver Cartridges



Band 3

Band 6

Band 7

Band 9

Band 4

Band 8

Band 10

HIA

NRAO

IRAM

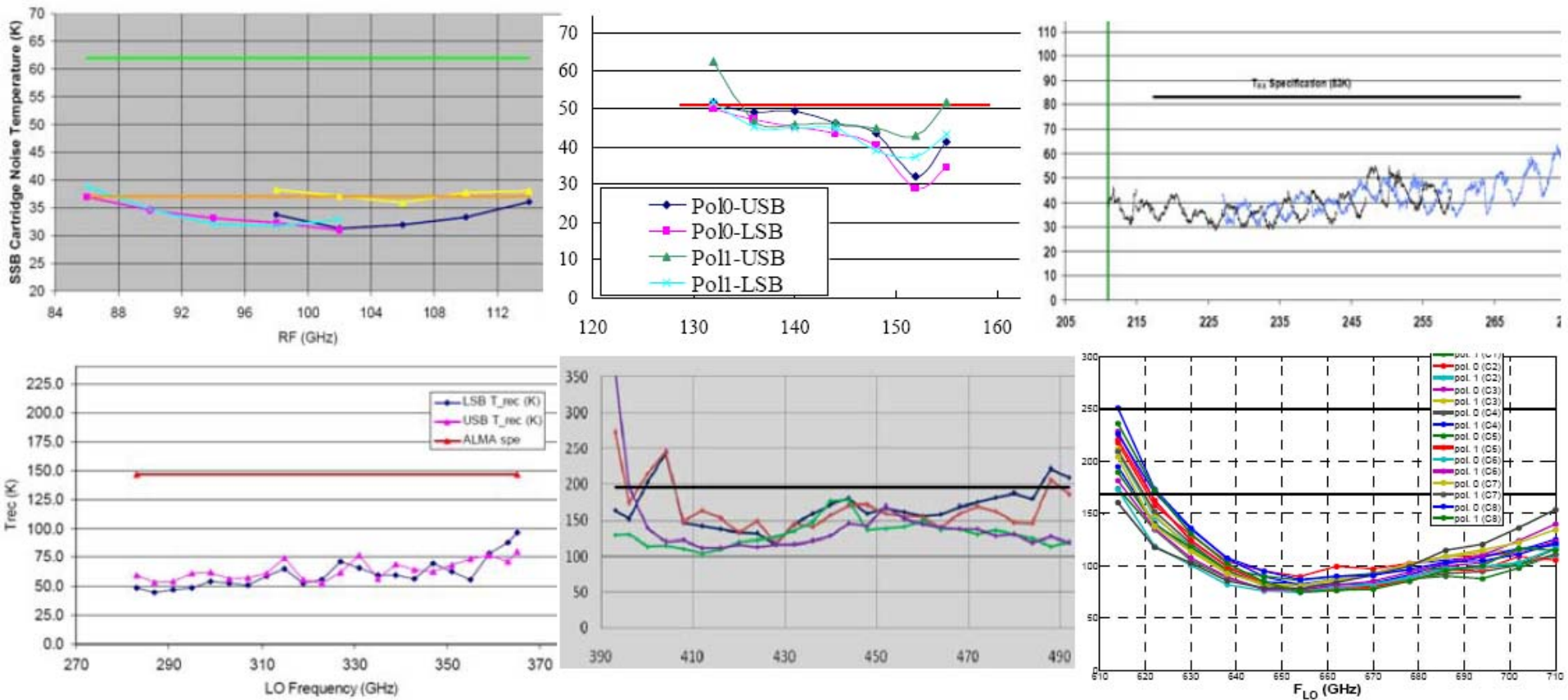
NOVA

NAOJ

NAOJ

NAOJ

Receiver performance



Cryostat production



Front End Integration

- Three Front End Integration Centers, RAL (UK), NRAO (USA), and ARL (Taiwan) in operation
- As of Nov 2010 eleven FE assemblies delivered to site and ten are integrated into antennas



Front End Installation



- Dedicated Front End Service Vehicle under development

Photonic Local Oscillator System

- The long, challenging development of the photonic local oscillator system completed in 2009
- Initial version of the central local oscillator installed, tested, and operational at the AOS Technical Building in October 2009
- System performance demonstrated up to 200m in severe environmental conditions



Digital Systems

- Digital signal processing components for the Back End Antenna Articles in full production
- 20 BE Antenna Articles delivered to site, 8 integrated into antennas
- All 4 quadrants of the 64-input corr. to be completed in early 2011
- ACA correlator installation, test and acc. to be completed in Q4/2010

ACA FX correlator at the AOS TB

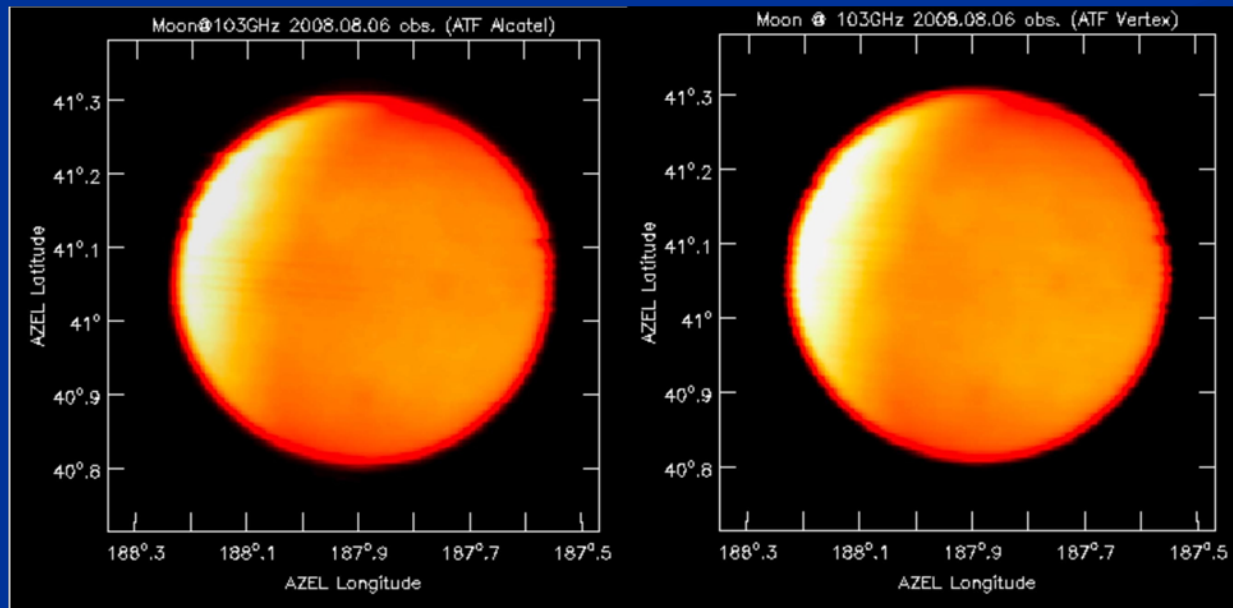
64-input XF correlator at the AOS TB



Software

- ALMA software development process features incremental CDRs and version releases to progressively increase functionality
- “Off-line” testing of software at the ALMA Test Facility in New Mexico and now with the two-antenna interferometer at the OSF Technical Facility has been invaluable

Early end-to-end software test – single dish OTF simultaneous mapping of the Moon with two antennas



Recent CSV Result – Band 7

ALMA test data –
not for scientific
use

To appear in the
ESO messenger

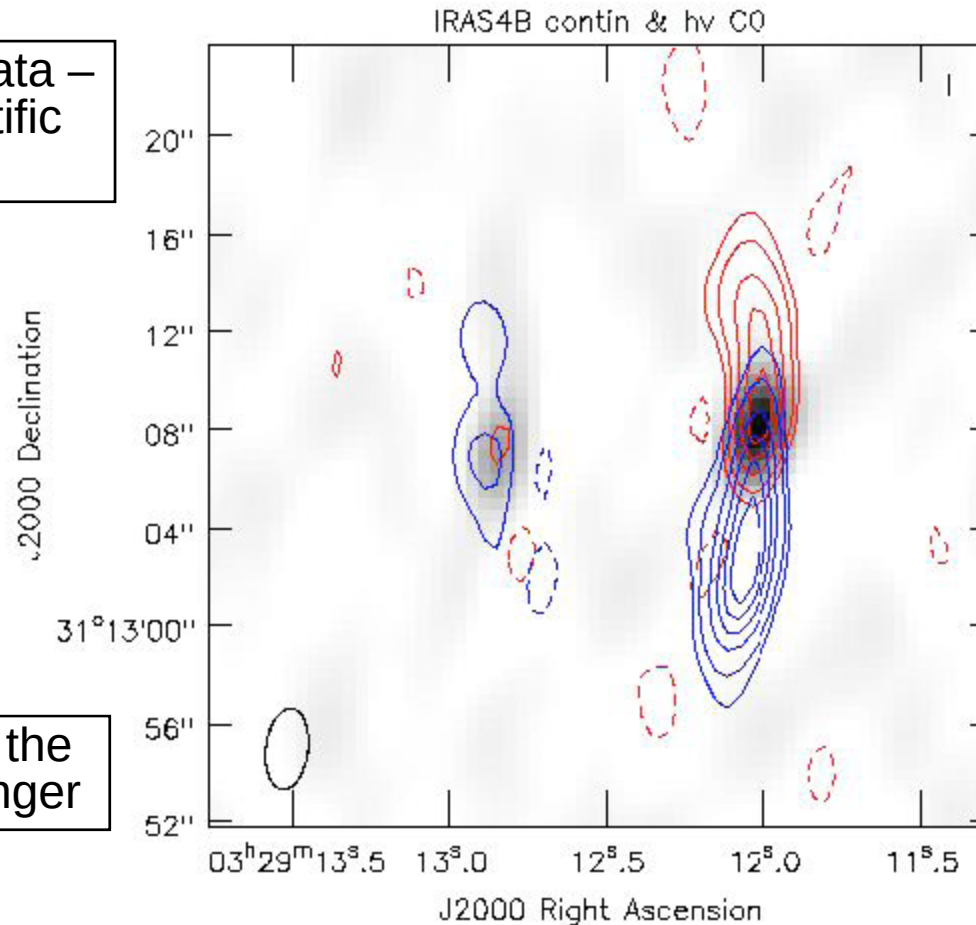
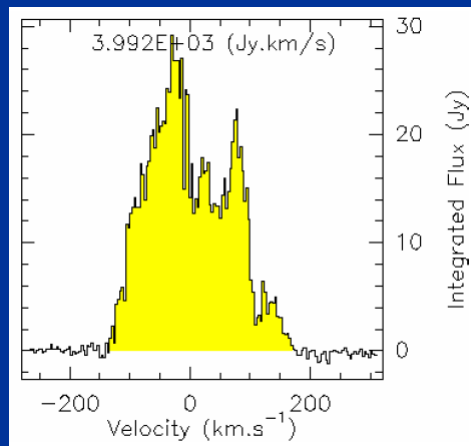


Figure 2. ALMA test data in Band 7 of the molecular outflow in NGC1333. The red and blue contours show the high velocity CO(3-2) emission while the 0.85mm continuum emission is shown as greyscale.

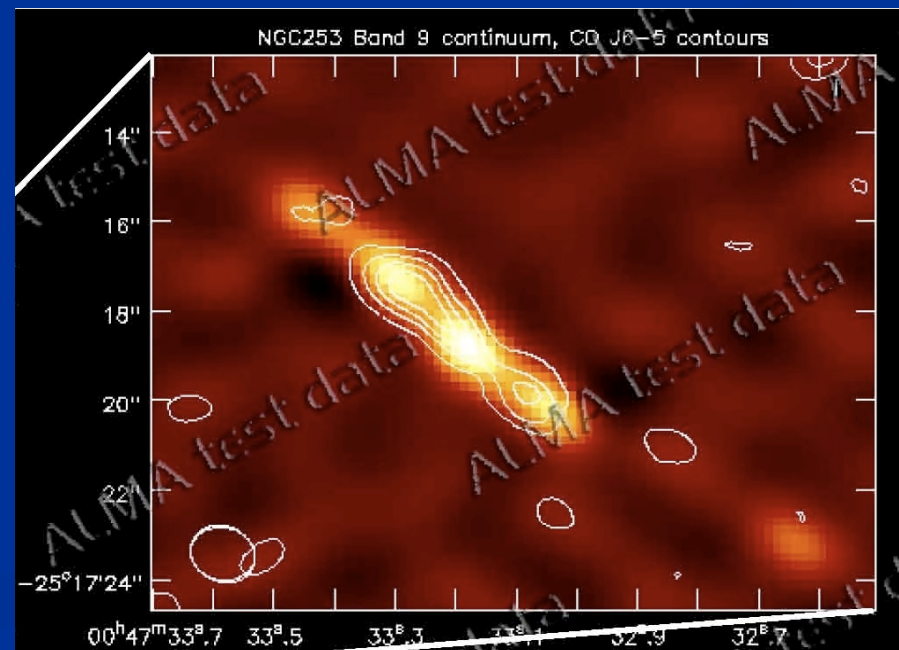
Recent CSV Result – Band 9

- Difficult high frequency observations
- Band 9 map of NGC253, cont.+ CO 6-5 contours
- Similar results for Band 6 and Band 7

ALMA test data – not for scientific use



Integrated CO 6-5
spectrum (uncalibrated)





Overall ALMA Timeline

- 1990's Chajnantor site and meteorology testing
- 2001 Europe, North America and East Asia agree to work towards a unified project
- 2004 Beginning of construction
- 2007 Arrival of first antennas in Chile
- 2008 Arrival of antenna transporters in Chile
Start of ALMA AIV, 1st antenna transport,
Acceptance of 1st ALMA antenna
- 2009 Move of three antennas to 5000m
Phase closure with three antennas at Chajnantor
- 2011 Early Science with 16 antennas
- 2013 Full science operations



ALMA in 2012/13

