Atacama Large Millimeter/ submillimeter Array - ALMA

Status & Overview

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ALMA Project Manager

on behalf of the ALMA Project Development Team

ESO July 2006

ALMA

- International project to build & operate a large (66-antenna) millimeter/submm (λ ~0.85-3mm) array at high altitude site (5000m) in northern Chile.
- Project began in 2002; Japan joined in 2004; project redefined/rebaselined 2005; construction, hardware production lines underway, software in development; early science ~2010, full science operations 2012.
- This talk – overview & status of the project.

ALMA – Major Elements

- Partners: ESO+Spain – US (NSF)+Canada (NRC) – Chile – Japan ...*Taiwan*

- **Array Operations Site – AOS**
- **Operations Support Facility – OSF**
- **Santiago Central Offices – SCO**
- **ALMA Regional Centers – ARCs + ARClets**

- During full operation, the estimated flow into archive ~ 100 Tbytes per year

- Dataset: proposal, u-v data, a reference image with pipeline processing history, calibration data… modern radioastronomy

ALMA Science Requirements

- High Fidelity Imaging.
- Precise Imaging at 0.1” Resolution.
- Routine Sub-mJy Continuum Sensitivity.
- Routine mK Spectral Sensitivity.
- Wideband Frequency Coverage.
- Wide Field Imaging Mosaicking.
- Submillimeter Receiver System.
- Full Polarization Capability.
- System Flexibility.

Technical Specifications

- 54 12-m antennas, 12 7-m antennas, at 5000 m altitude site.
- Surface accuracy ±25 μm, 0.6” reference pointing in 9m/s wind, 2” absolute pointing all-sky.
- Array configurations between 150m to ~15 -18km.
- 10 bands in 31-950 GHz + 183 GHz WVR. Initially:
  - 86-119 GHz “3”
  - 211-275 GHz “6”
  - 275-370 GHz “7”
  - 602-720 GHz “9”
- 8 GHz BW, dual polarization.
- Flux sensitivity 0.2 mJy in 1 min at 345 GHz (median cond.).
- Interferometry, mosaicing & total-power observing.
- Correlator: 4096 channels/IF (multi-IF), full Stokes.
- Data rate: 6MB/s average; peak 60-150 MB/s.
- All data archived (raw + images), pipeline processing.

ALMA Median Continuum Sensitivity

(1 minute; AM=1.3; 75% Quartile opacities λ>1mm, 25% λ <1mm)

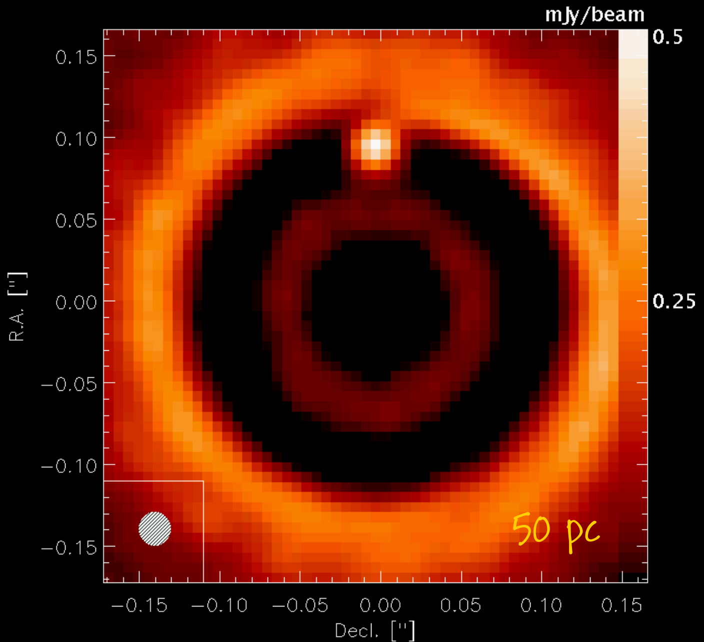
Frequency (GHz)	Continuum (mJy)	Line 1 km s^{-1} (mJy)	Line 25 km s^{-1} (mJy)
35	0.02	5.1	1.03
110	0.027	4.4	0.89
140	0.039	5.1	1.01
230	0.071	7.2	1.44
345	0.12	10	1.99
675	0.85	51	10.2
850	1.26	66	13.3.

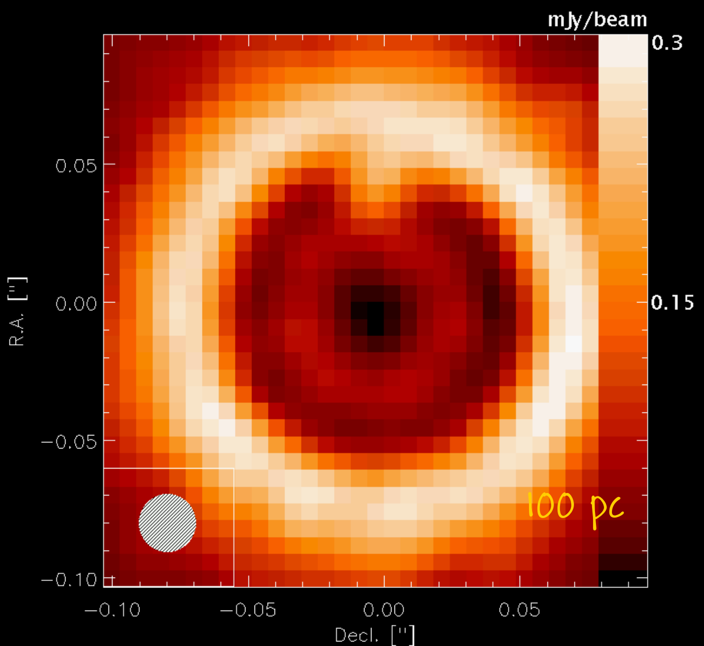
* First light band

Brightness Temperature Sensitivity

1 min, AM 1.3, 1.5mm, *0.35 PWV, 1 km/s

Frequency (GHz)	B_{max} 0.2km T_{cont} (K)	B_{max} 0.2km T_{line} (K)	B_{max} 10km T_{cont} (K)	B_{max} 10km T_{line} (K)
35	0.002	0.050	0.48	130
110	0.003	0.049	0.84	120
230	0.0005	0.054	1.3	140
345	0.0014	0.12	3.6	300
490	0.0030	0.23	7.6	580
675*	0.0046	0.28	12	690
850*	0.011	0.58	27	1400





$M_{planet} / M_{star} = 0.5\ M_{Jup} / 1\ M_{sun}$

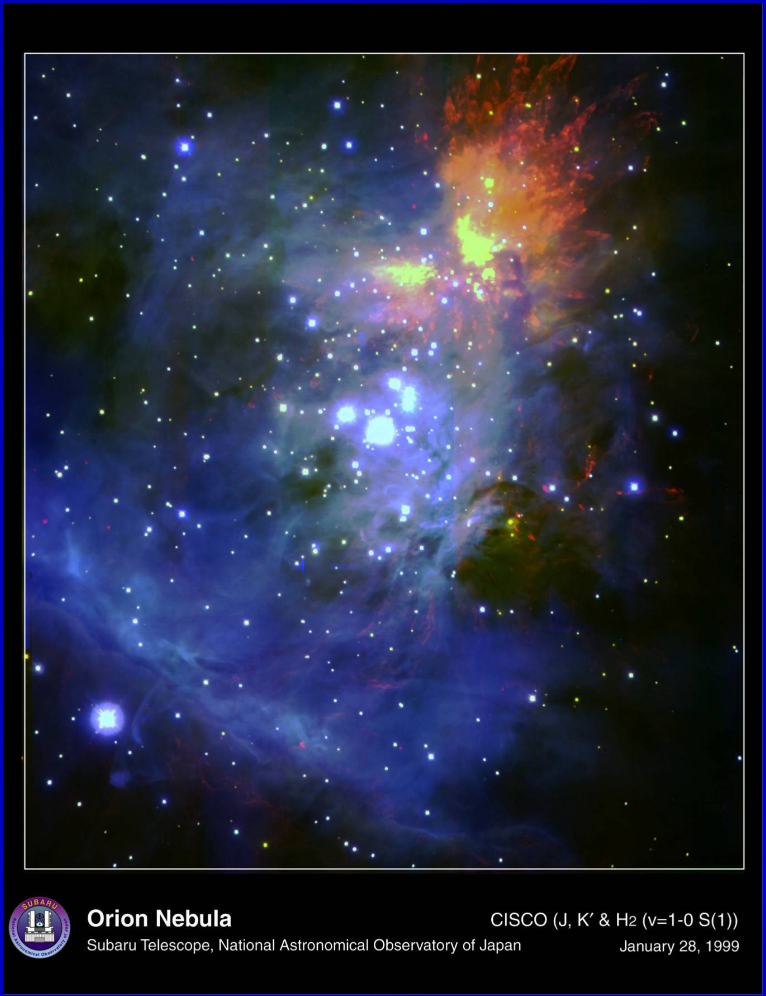
Orbital radius: 5 AU

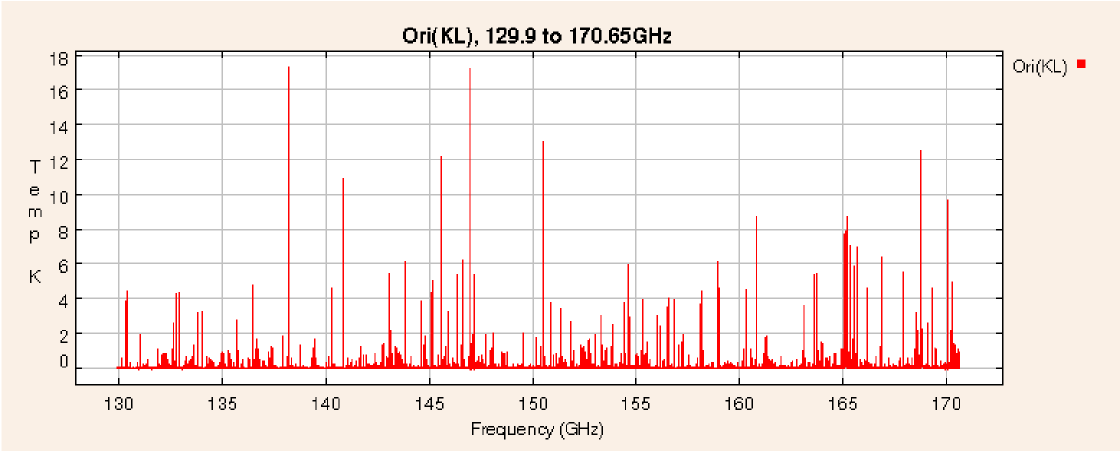
Disk mass as in the circumstellar disk around the Butterfly Star in Taurus

(ALMA: 10km, t_{int}=8h, 30° phase noise)
Wolf & D'Angelo (2005)
astro-ph / 0410064

ALMA Key Science 2: Astrochemistry

Spectrum courtesy B. Turner (NRAO)

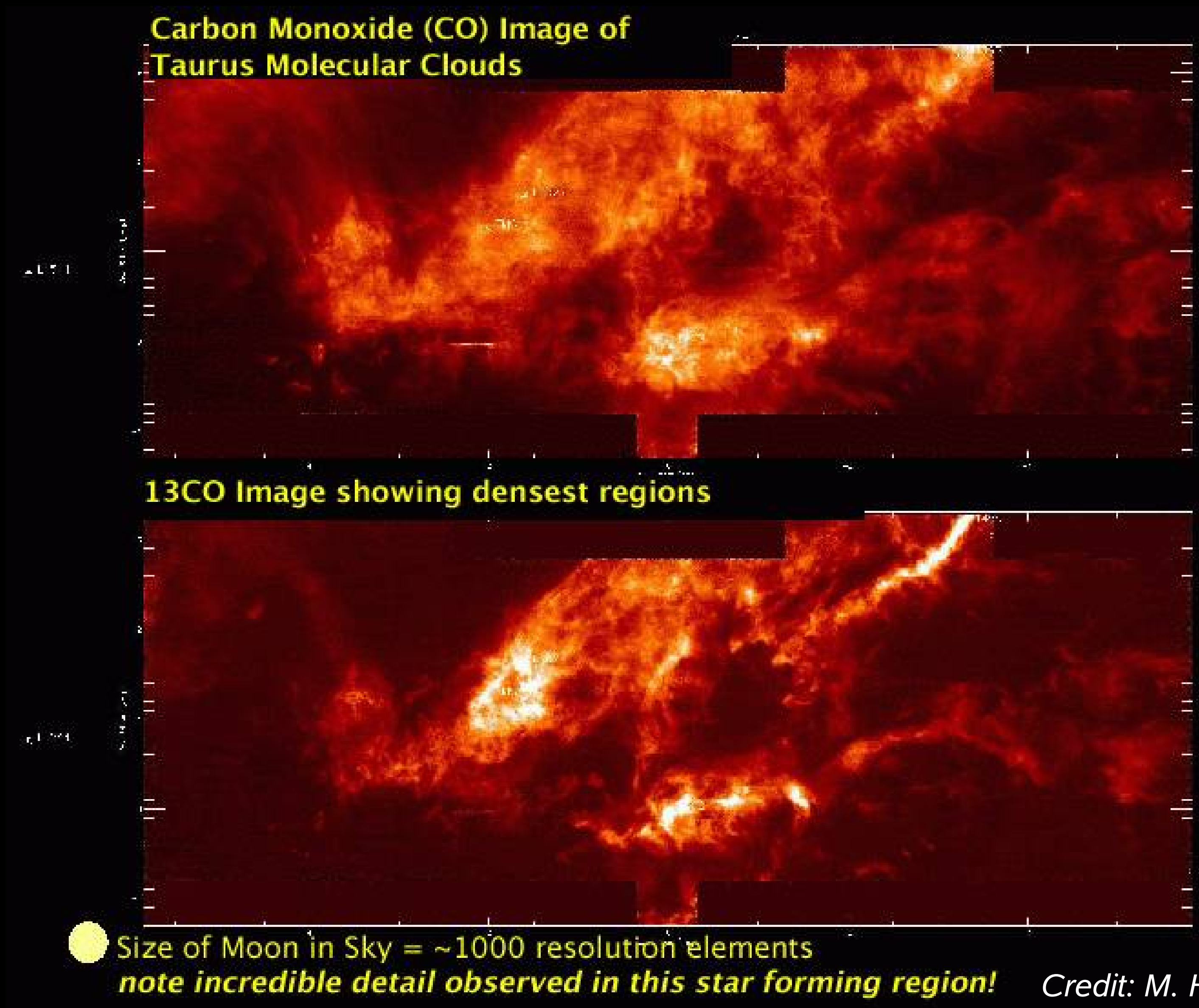




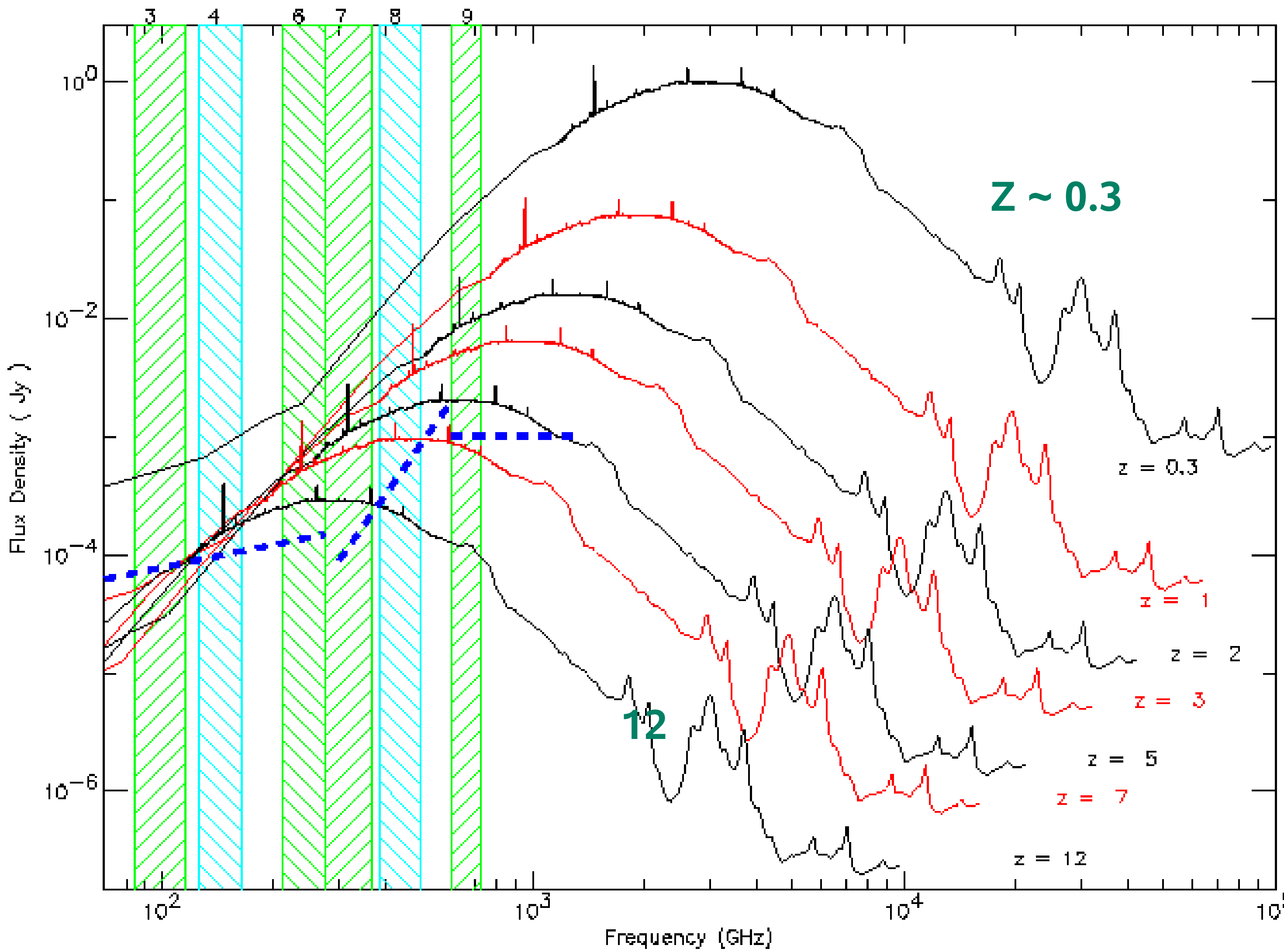
- Millimeter/submillimeter spectral components dominate the spectrum of planets, young stars, many distant galaxies.

- Most of the observed transitions of the 125 known interstellar molecules lie in the mm/submm spectral region—here some 17,000 lines are seen in a small portion of the spectrum at 2mm.

ALMA Key science 3: Interstellar Medium



Credit: M. Heyer


3
4
6
7
8
9
Flux Density (Jy)
10^0
10^{-2}
10^{-4}
10^{-6}
10^2
10^3
10^4
10^5
Frequency (GHz)
Z ~ 0.3
z = 0.3
z = 1
z = 2
z = 3
z = 5
z = 7
z = 12
12

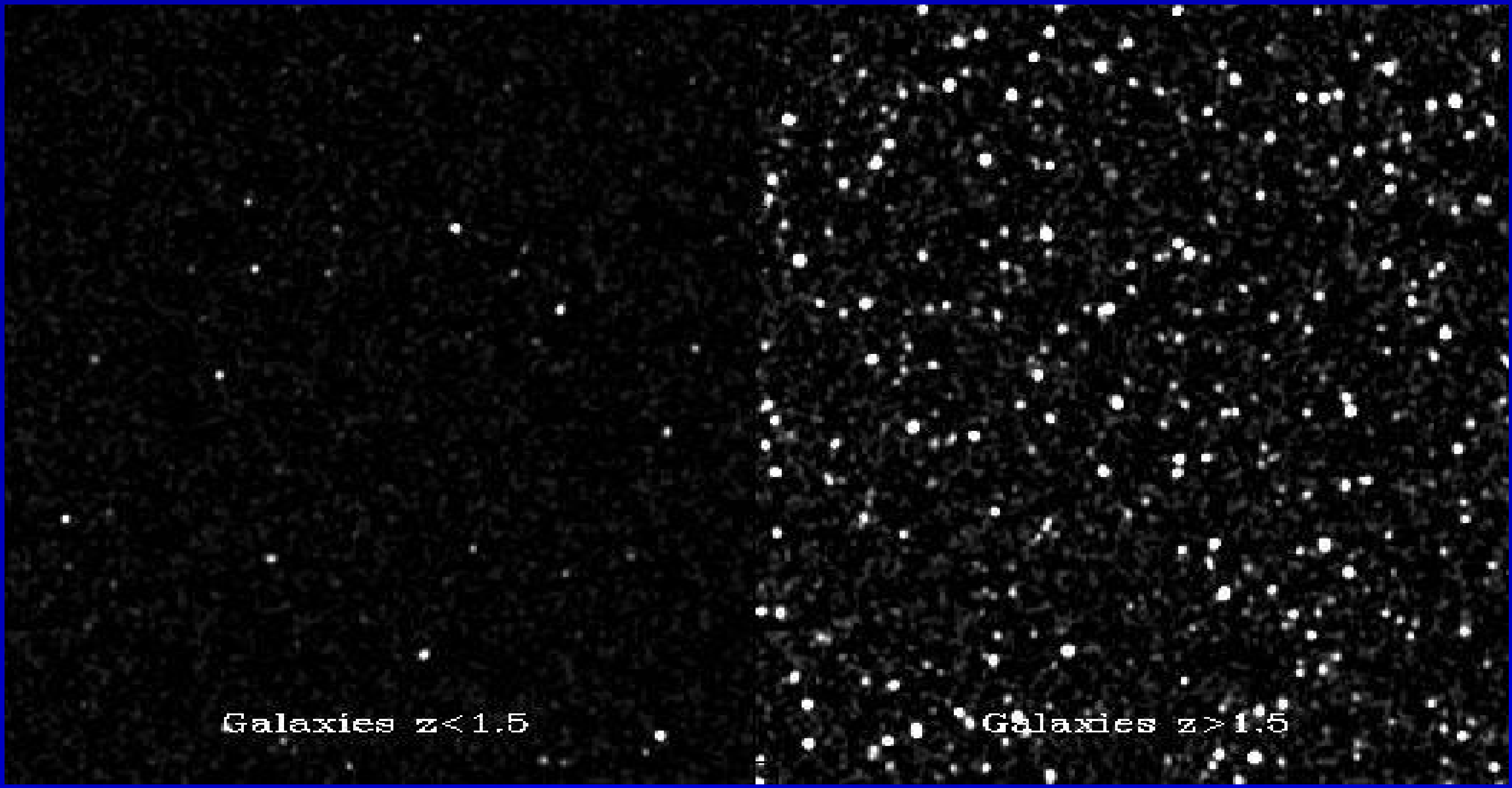
HDF: Rich in Nearby Galaxies

Nearby galaxies in HDF

Distant galaxies in HDF (z>2)

Source: K. Lanzetta, SUNY-SB

ALMA DF: Rich in Distant Galaxies



Nearby galaxies in ALMA DF   Distant galaxies in ALMA DF

+128 projects in first 3yrs – DRSP…


N
W
E
S
Image © 2008 NASA
© 2005 Google

ALMA Site

ALMA

Paranal

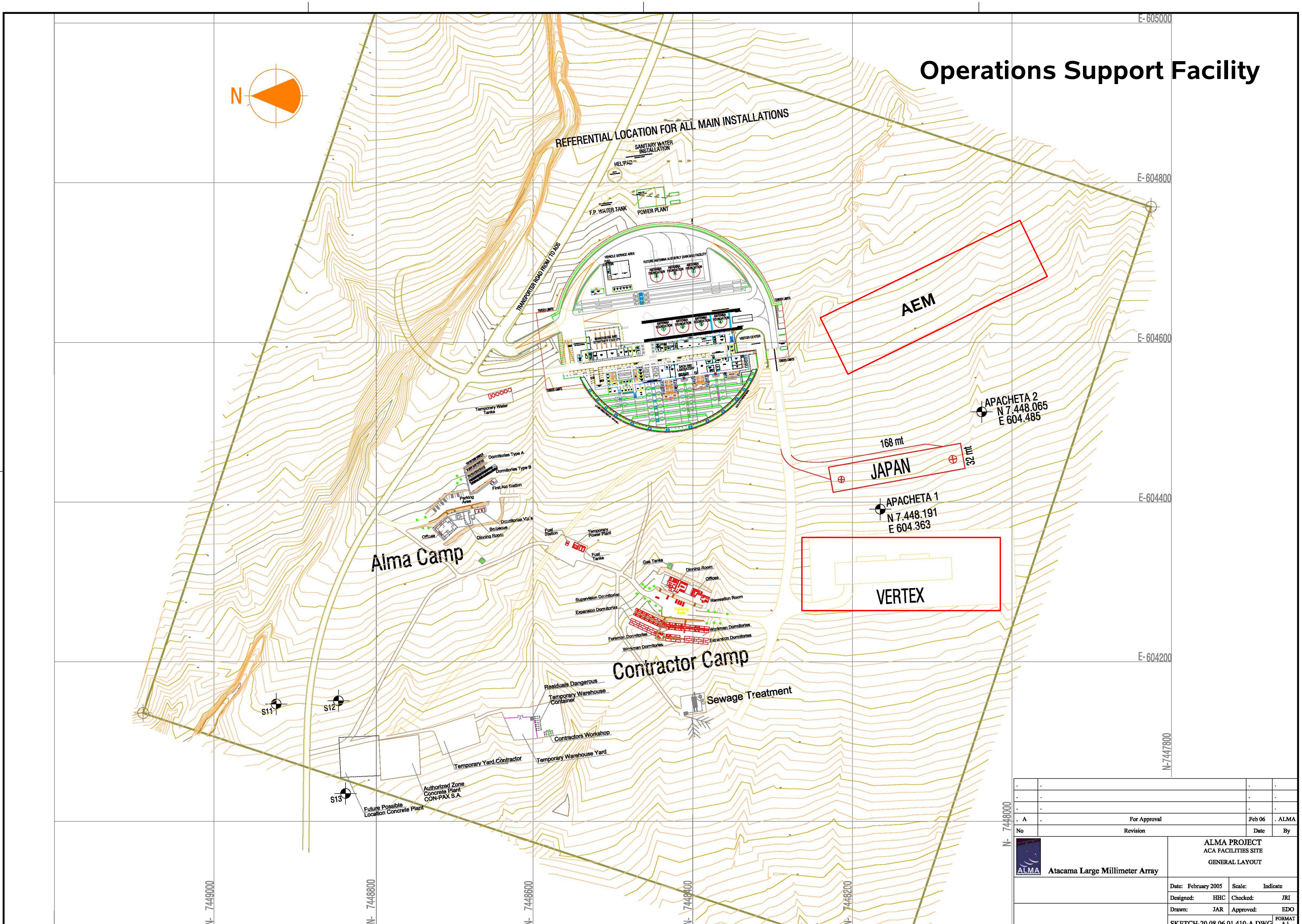
La Serena

Santiago

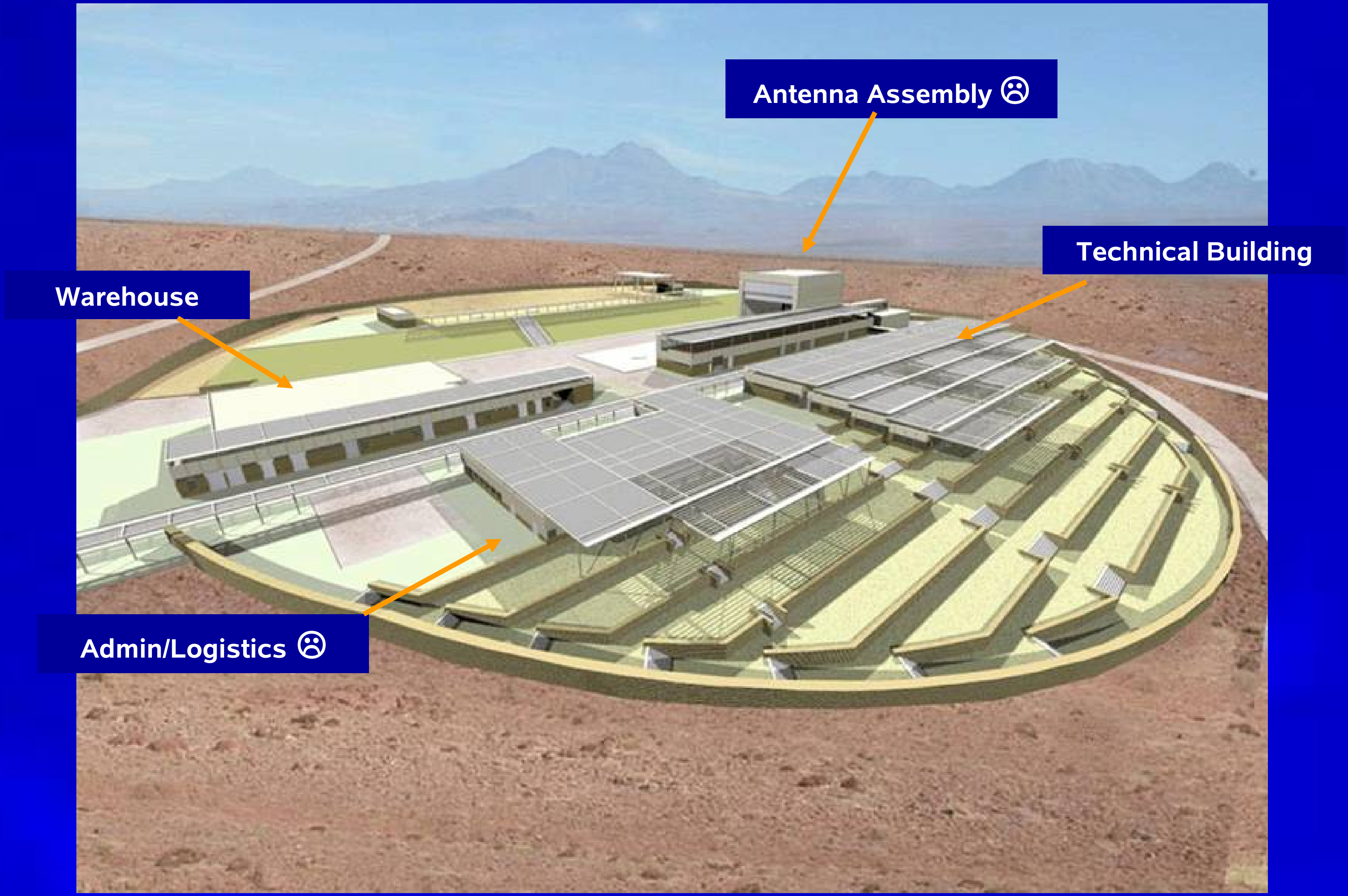

Atacama Desert, Northern Chile


OSF Rd – July 2006
To AOS (43km)
OSF Site (15km)
60
PELIGRO
PARE

Operations Support Facility



Operations Support Facility



Contractors Camp

Antenna Contractor Area (Vertex) – March 2006


08/03/2006

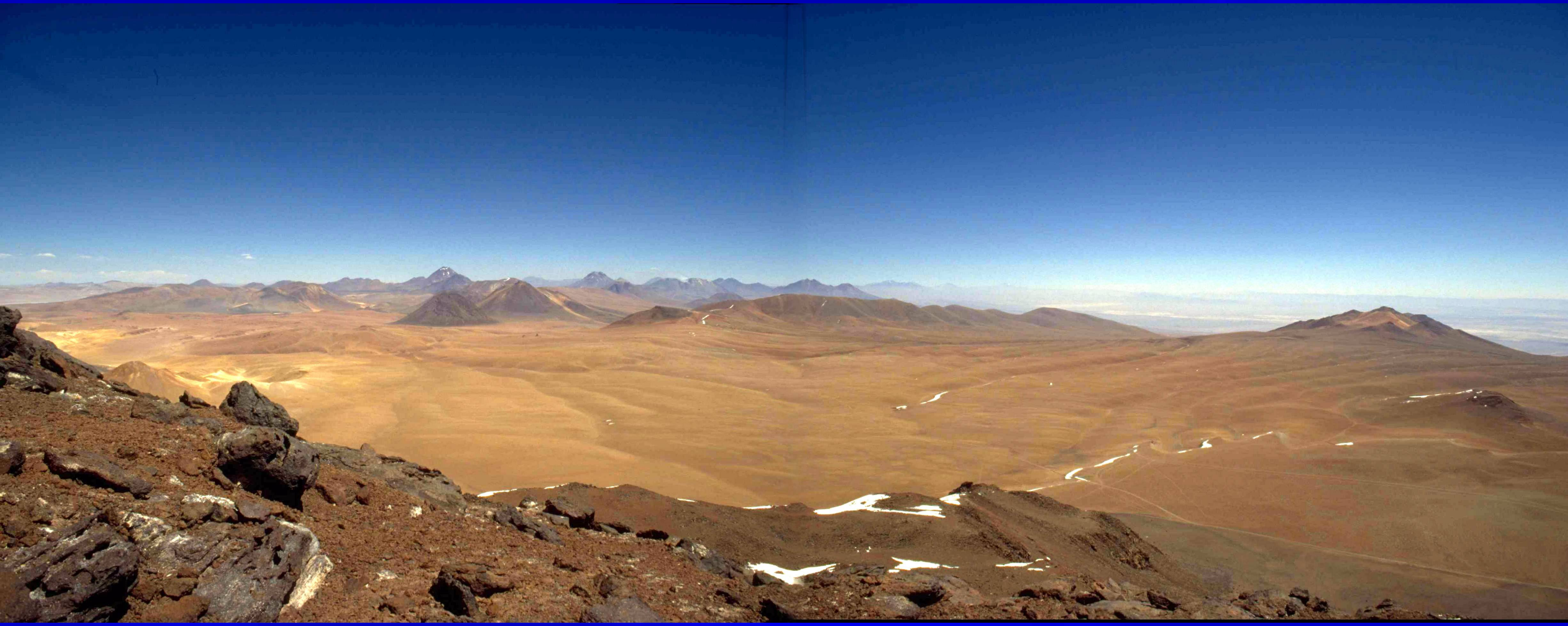

Antenna Contractor Area (Vertex) – Nov 2006


Lascar – April 2006

Road: OSF-AOS - Transporter

5000m Chajnantor plateau – looking south

Array Operations Site

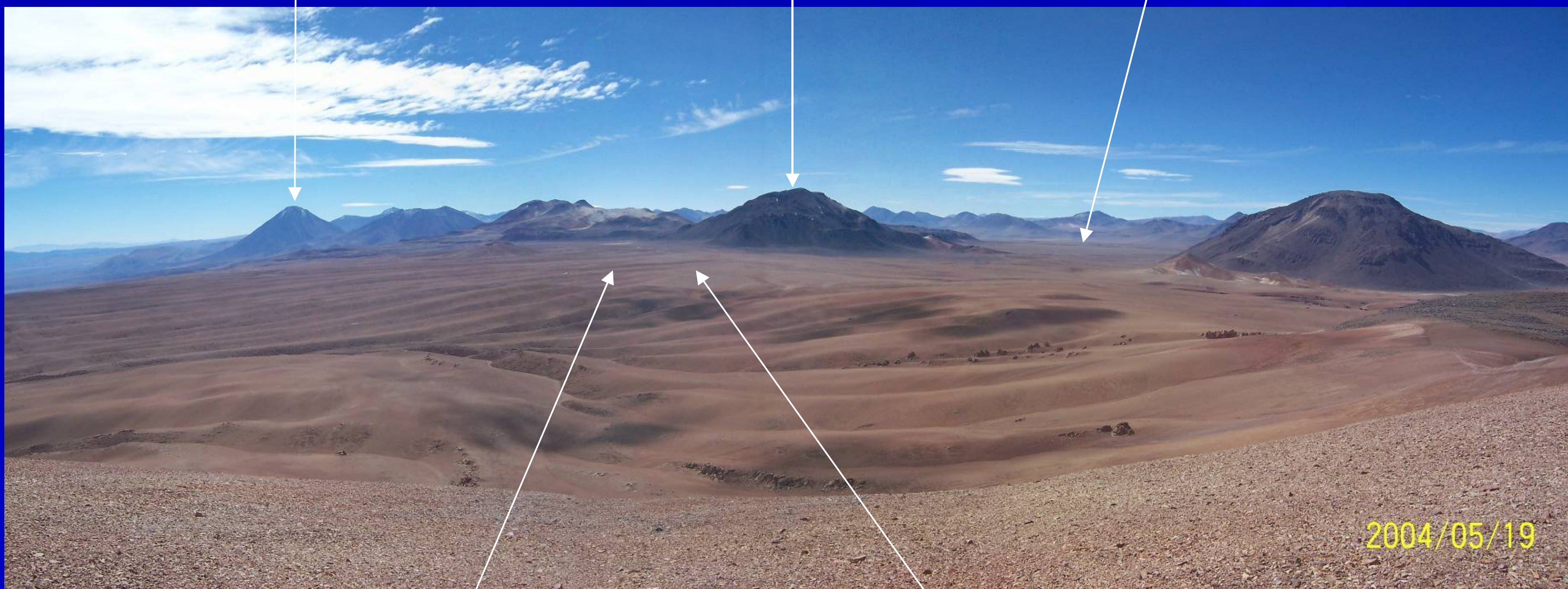


Chajnantor Plateau – looking north

V. Licancabur

Cº Chajnantor

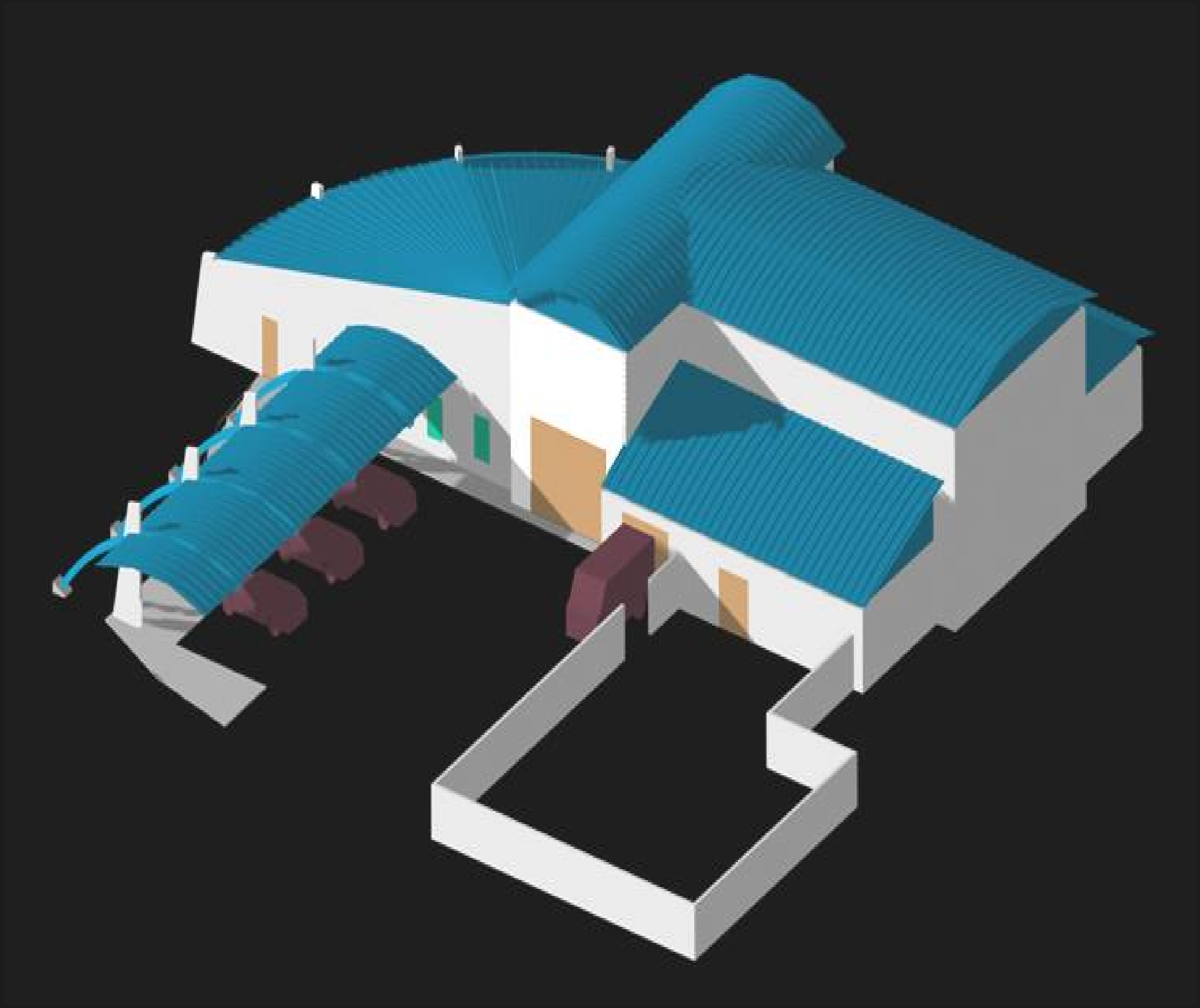
Pampa La Bola



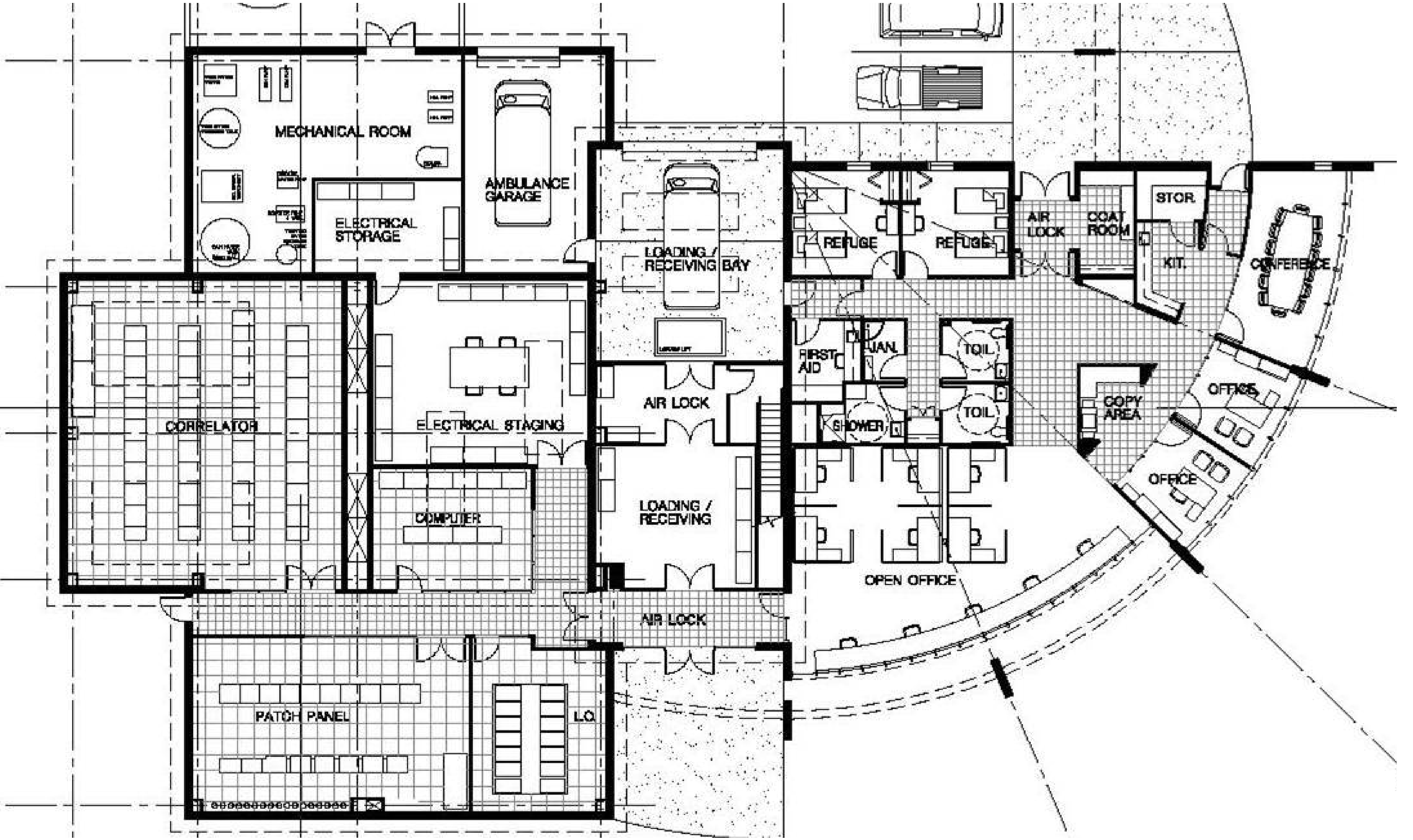
AOS TB

Center of Array

Array Operations Site - Technical Building



AOS layout



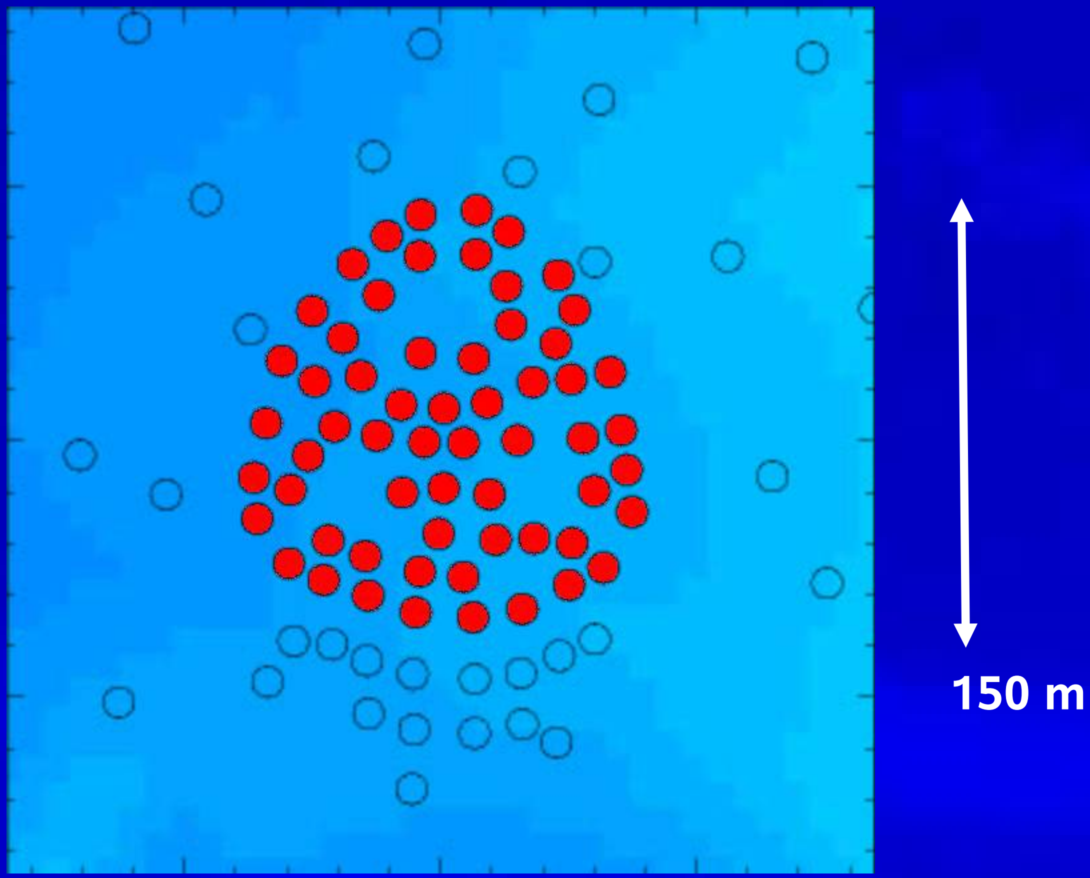
MECHANICAL ROOM
AMBULANCE GARAGE
ELECTRICAL STORAGE
LOADING / RECEIVING BAY
REFUGE
REFUGE
AIR LOCK
COAT ROOM
STOR.
KIT.
CONFERENCE
CORRELATOR
ELECTRICAL STAGING
FIRST AID
JAN.
TOIL
TOIL
SHOWER
COPY AREA
OFFICE
OFFICE
AIR LOCK
COMPUTER
LOADING / RECEIVING
OPEN OFFICE
AIR LOCK
PATCH PANEL
LO.

AOS Technical Building – July 2007

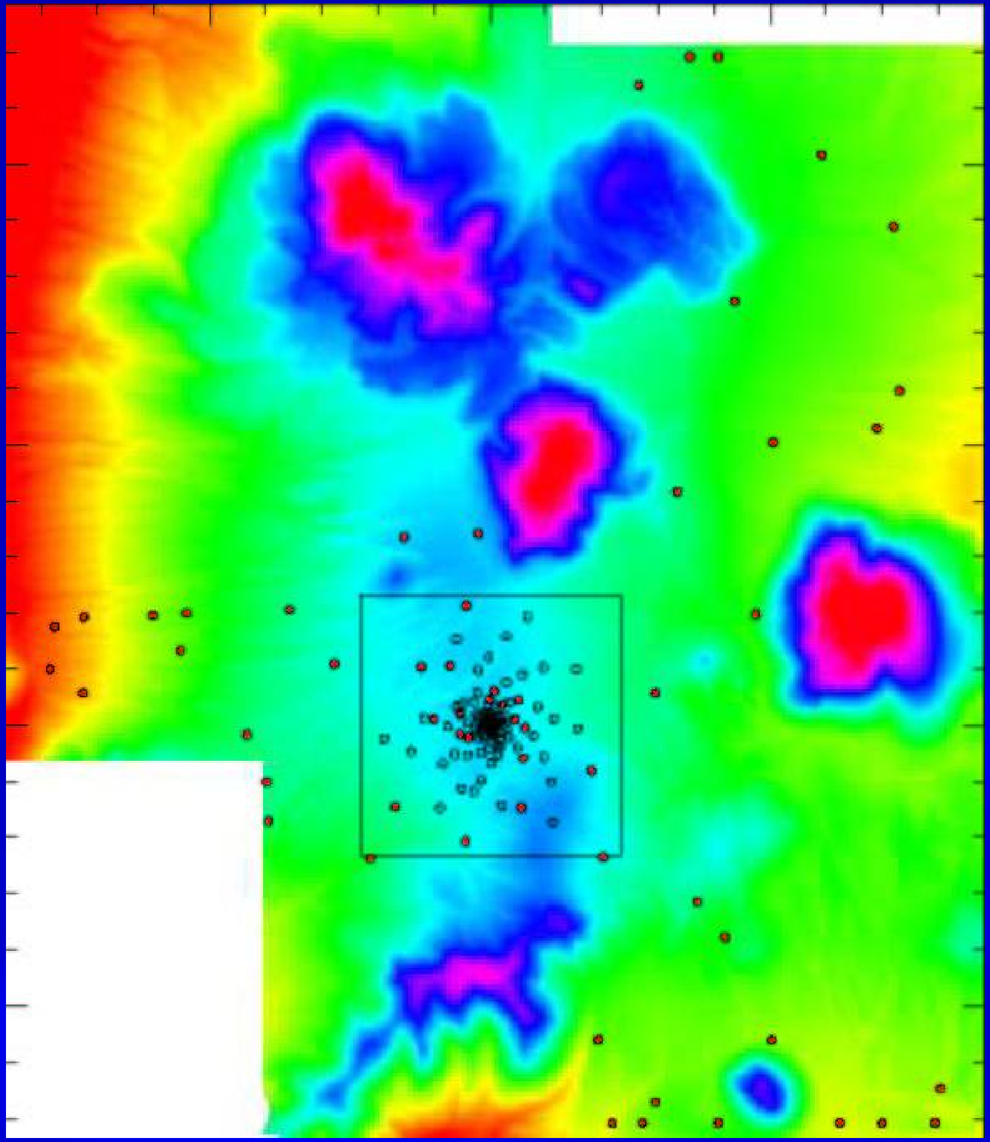

Array Center


19.04.2006

Antenna Configurations (compact)



Antenna Configurations (max, example)



10,000m

4 mas @ 950 GHz

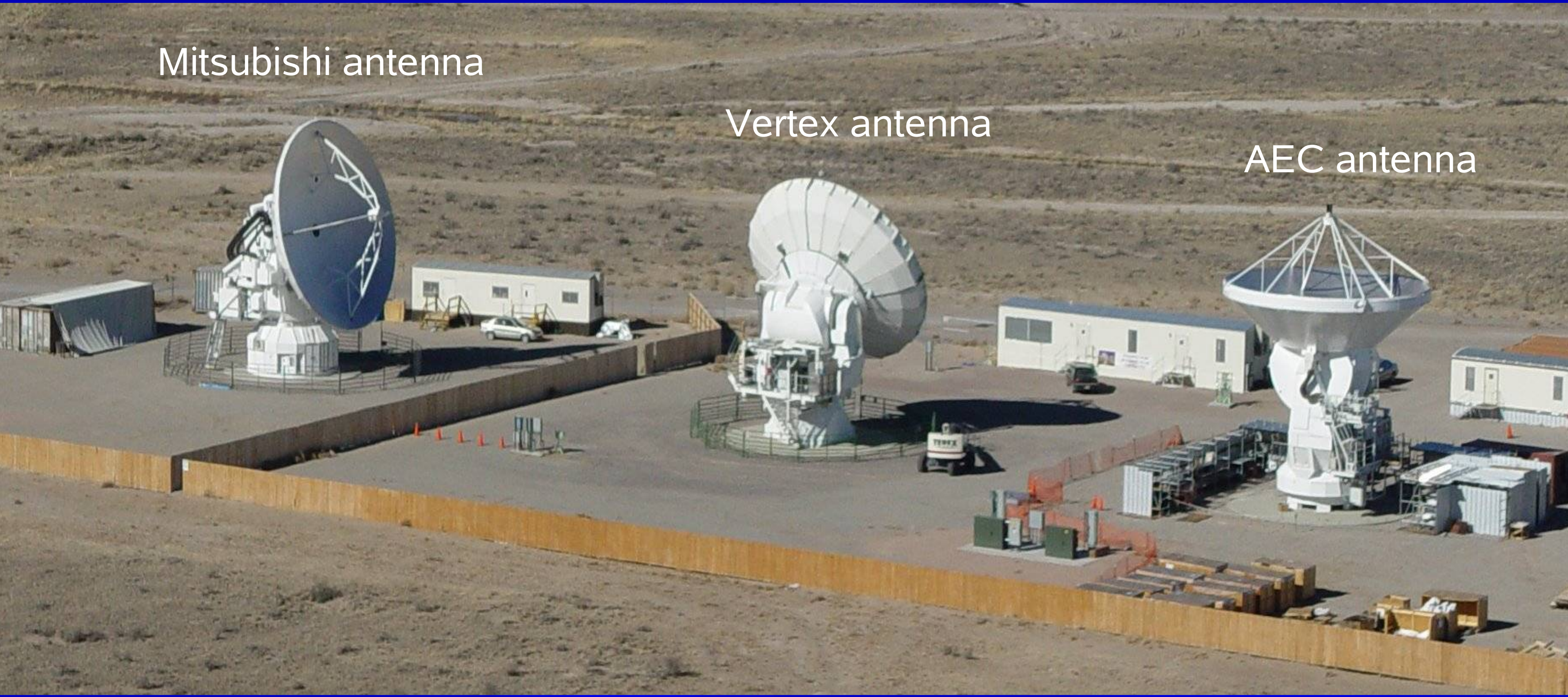
Antennas

- Demanding ALMA antenna specifications:
  - Surface accuracy (25 µm)
  - Absolute and offset pointing accuracy (2 arcsec absolute, 0.6 arcsec offset)
  - Fast switching (1.5 deg sky in 1.5 sec)
  - Path length (15 µm non-repeatable, 20 µm repeatable)
- To validate these specifications: three prototype antennas built & evaluated at ATF (VLA site)
- Three production contracts – US, Europe, Japan (General Dynamics/Vertex, Alcatel EIE MT Aerospace, Mitsubishi)

AEC Prototype Antenna

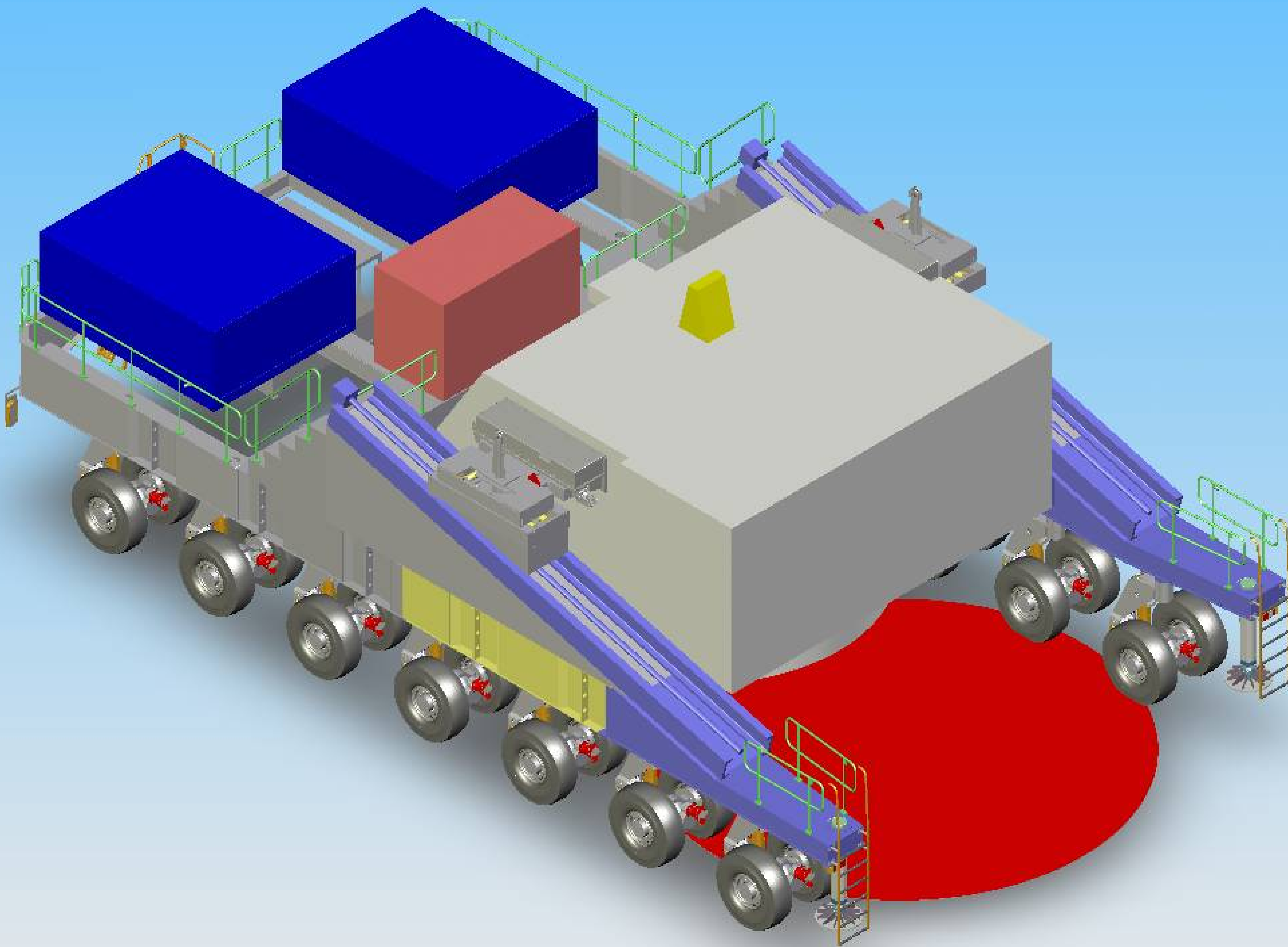
Vertex Prototype Antenna

Prototype Antennas at ATF

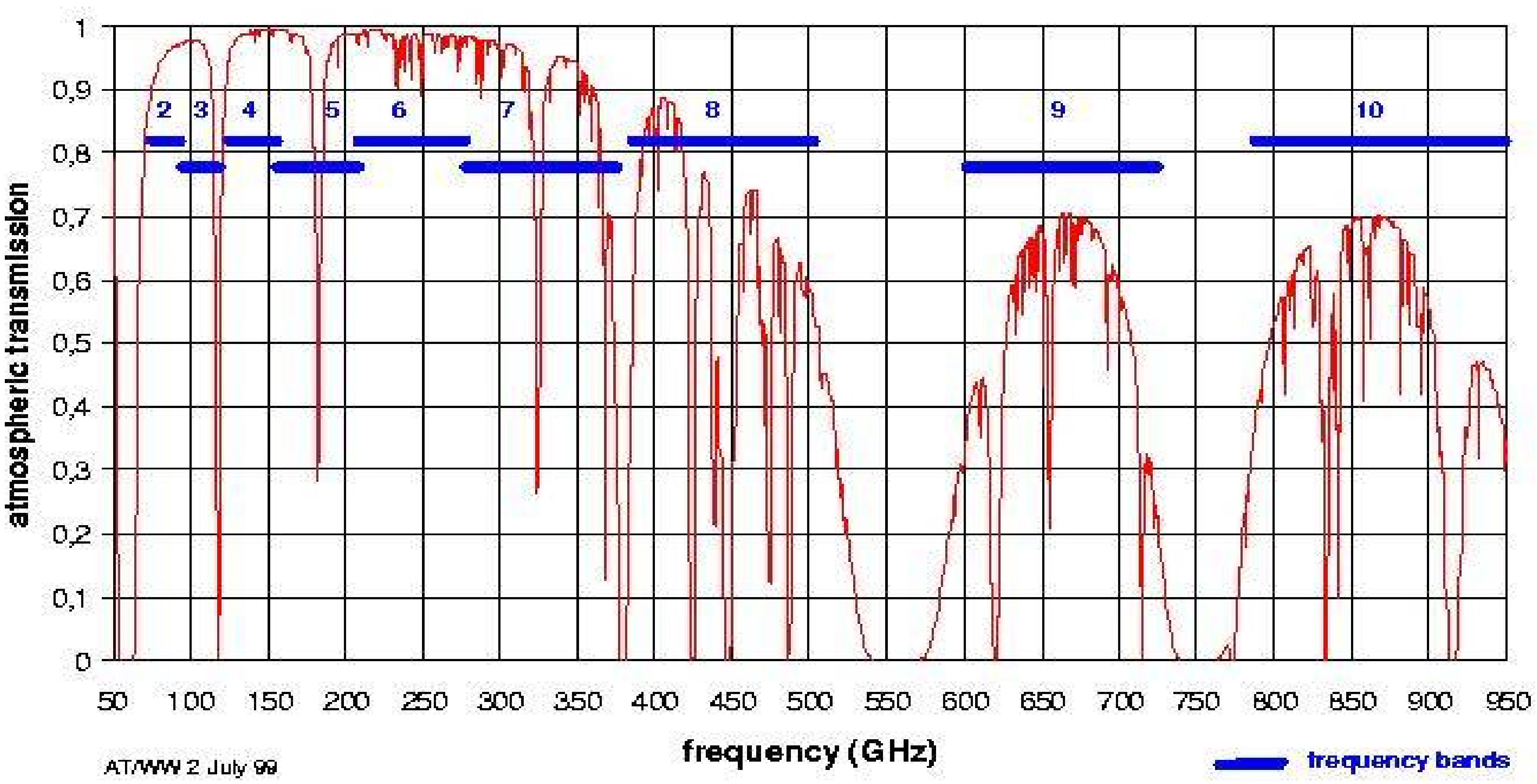


12-m, Carbon Fiber Support Structure

ALMA Transporter (PDR July 2007)



Atmospheric transmission at Chajnantor, pwv = 0.5 mm

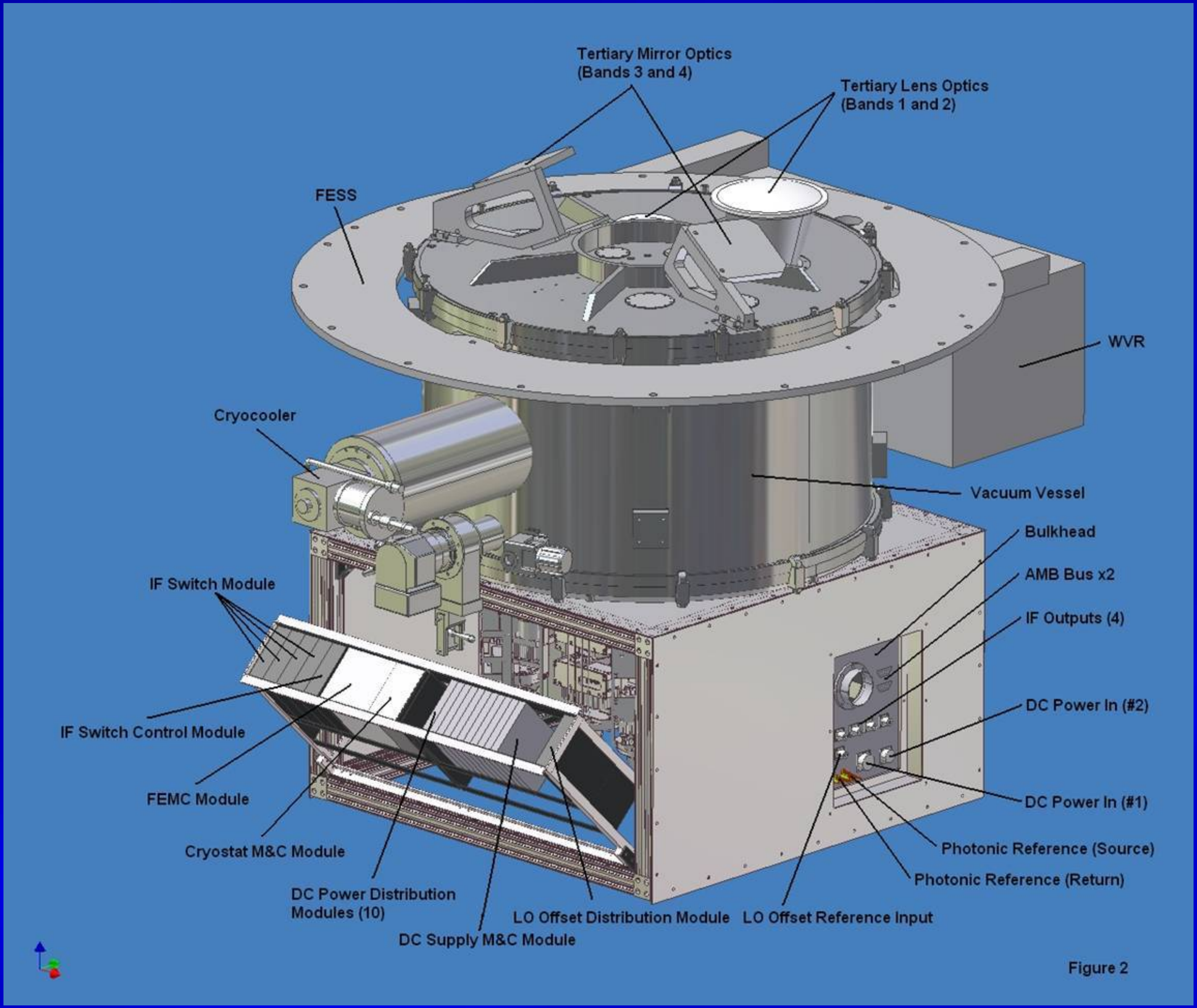


Receivers/Front Ends

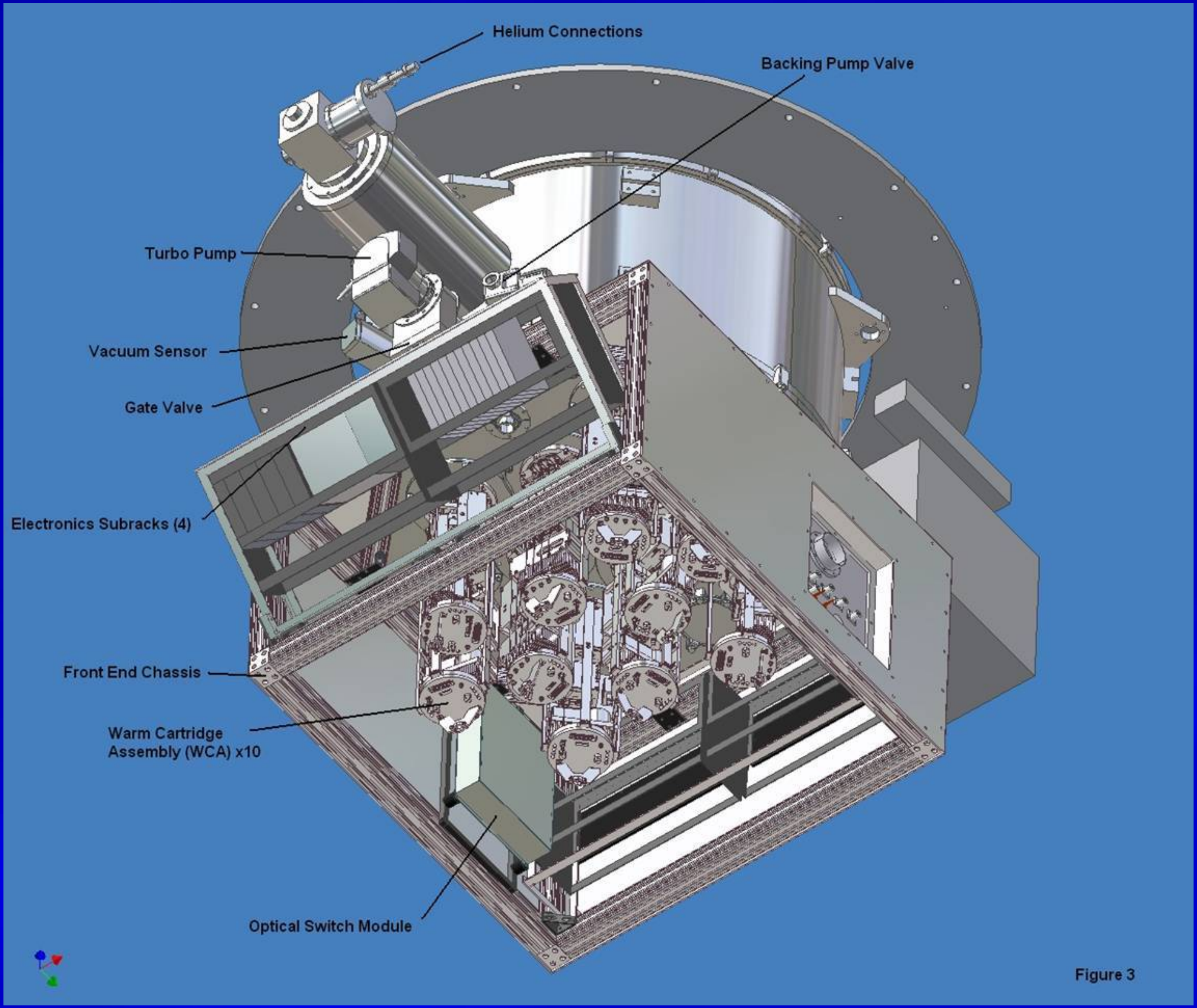
ALMA Band	Frequency Range	Receiver noise temperature		Mixing scheme	Receiver technology
		T_{Rx} over 80% of the RF band	T_{Rx} at any RF frequency		
1	31.3 – 45 GHz	17 K	28 K	USB	HEMT
2	67 – 90 GHz	30 K	50 K	LSB	HEMT
3	84 – 116 GHz	37 K	62 K	2SB	SIS
4	125 – 169 GHz	51 K	85 K	2SB	SIS
5	163 - 211 GHz	65 K	108 K	2SB	SIS
6	211 – 275 GHz	83 K	138 K	2SB	SIS
7	275 – 373 GHz	147 K	221 K	2SB	SIS
8	385 – 500 GHz	98 K	147 K	DSB	SIS
9	602 – 720 GHz	175 K	263 K	DSB	SIS
10	787 – 950 GHz	230 K	345 K	DSB	SIS

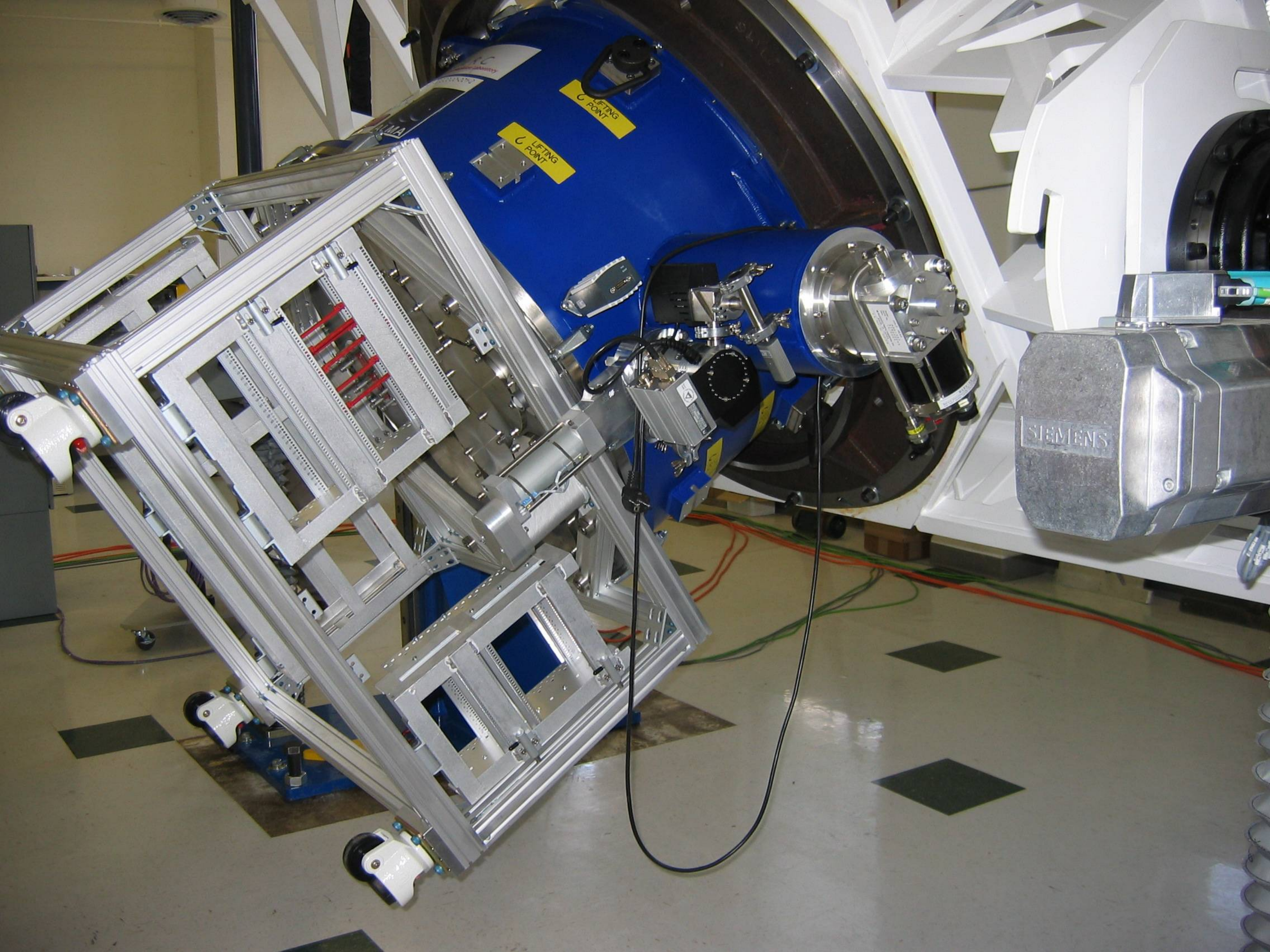
- **Dual, linear polarization channels:**
  - **Increased sensitivity**
  - **Measurement of 4 Stokes parameters**
- **183 GHz water vapour radiometer:**
  - **Used for atmospheric path length correction**

Front End assembly

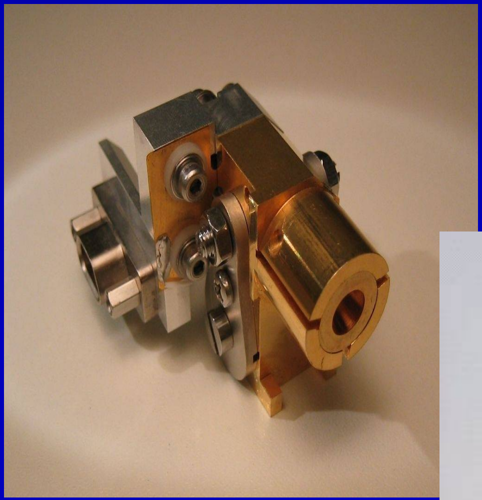


Front End assembly




LIFTING POINT
LIFTING POINT
SIEMENS

Front End – Band 9



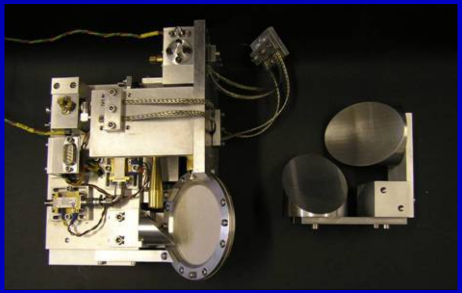
Band 9 mixer assembly

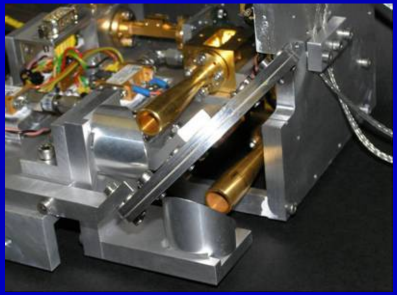
Band 9 cartridge #1 front and back

Water Vapor Radiometer

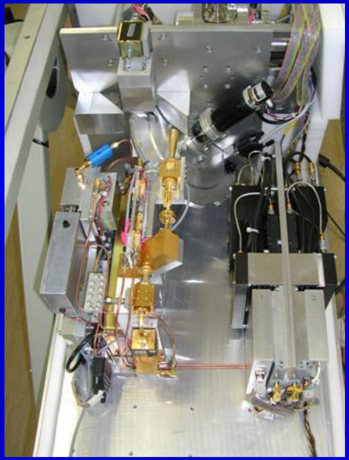
- Development status
  - Two prototype WVRs (Cambridge and Onsala) have been completed and fully tested
  - Key performance of both prototypes is in agreement with requirements
  - Testing underway at SMA

Correlation WVR RF Front End

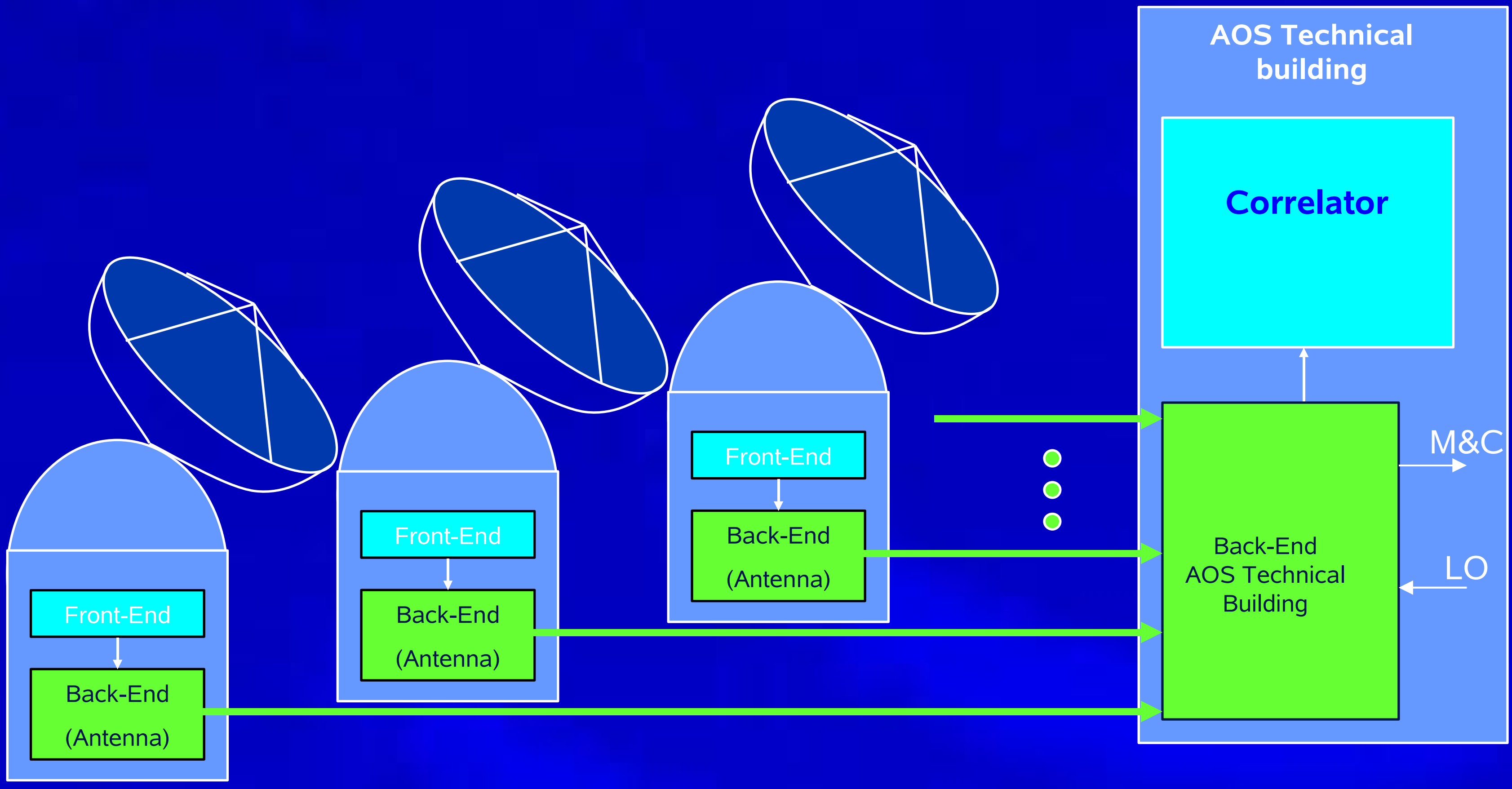




Dicke switched WVR RF Front End

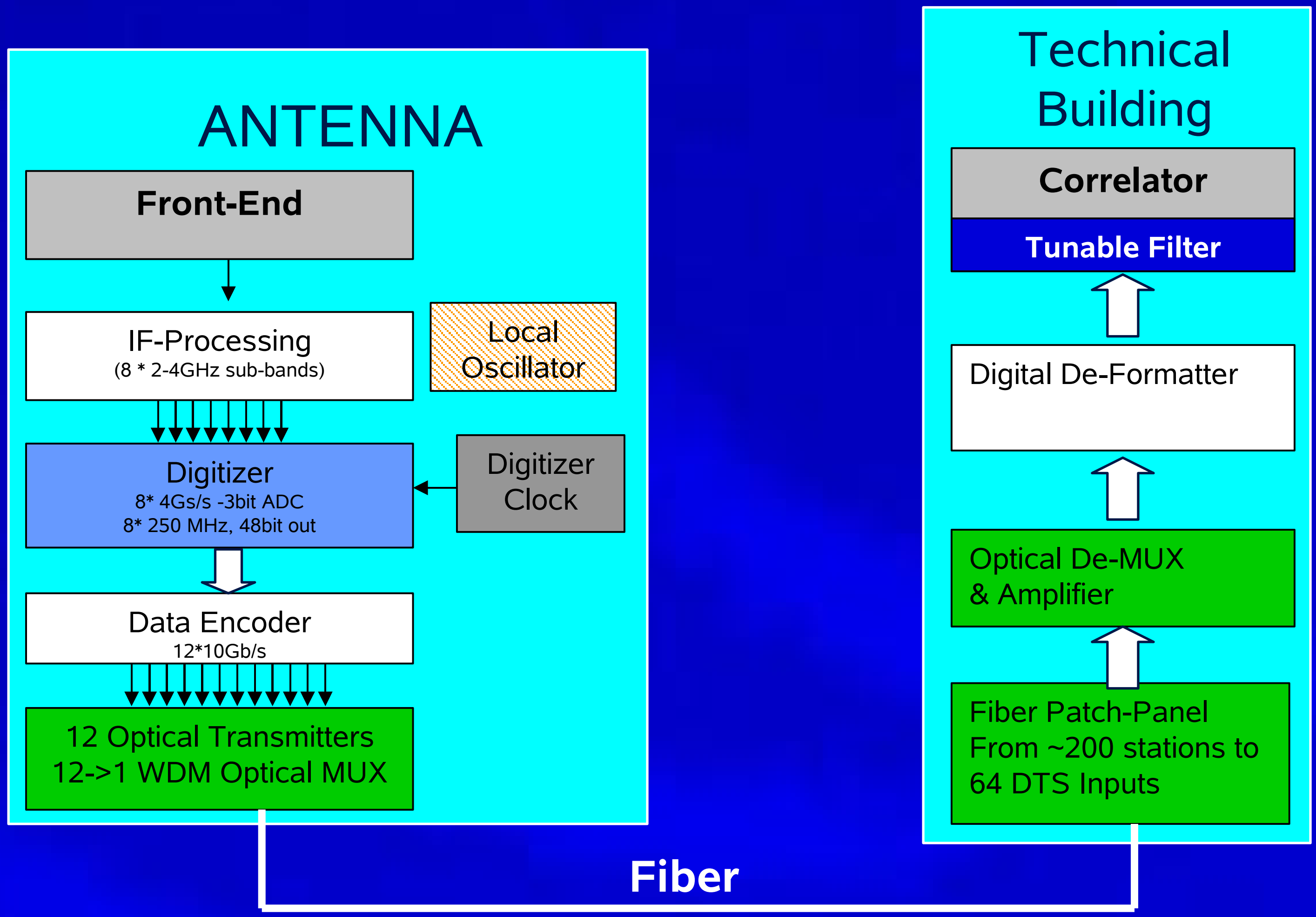


Back End – Data Transmission

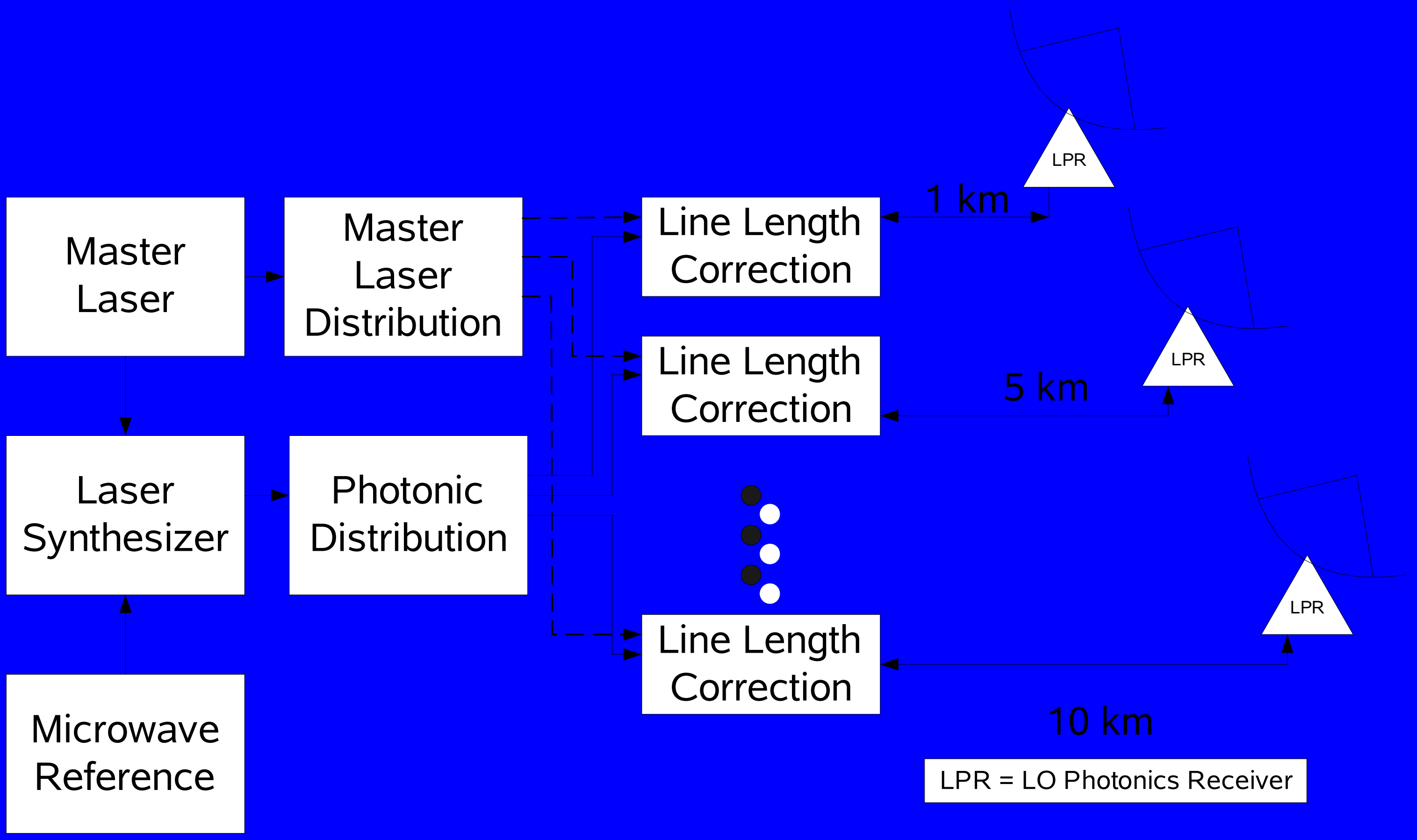


~200 WDM Modulated fiber links 120Gb/s
~200 1Gb Ethernet links (bi-directional)
~200 Phase accurate LO reference

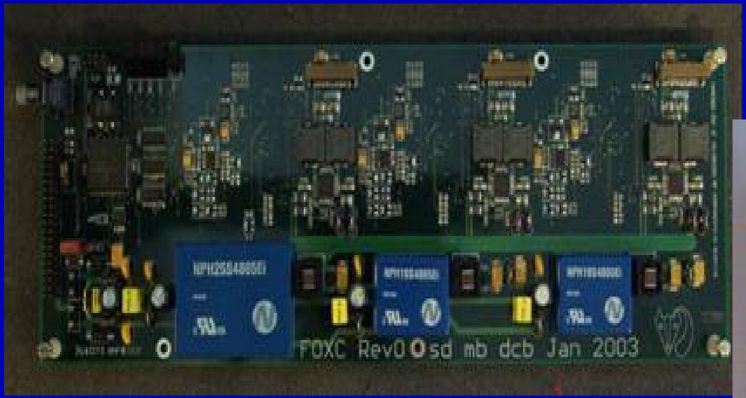
Back End → Correlator



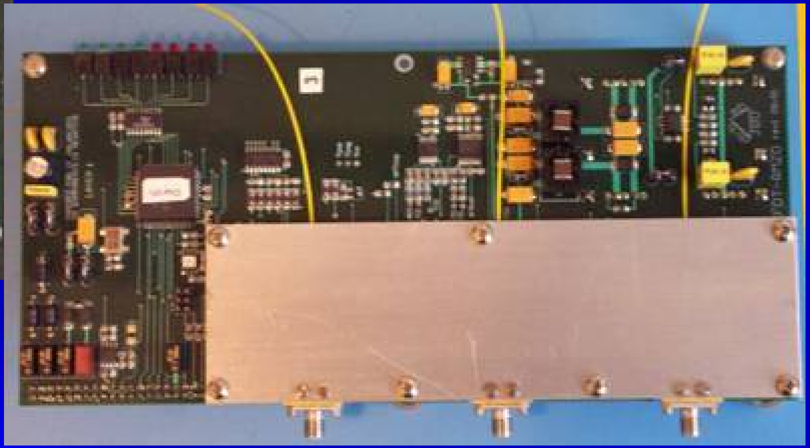
LO reference



Back End – Optical DTS



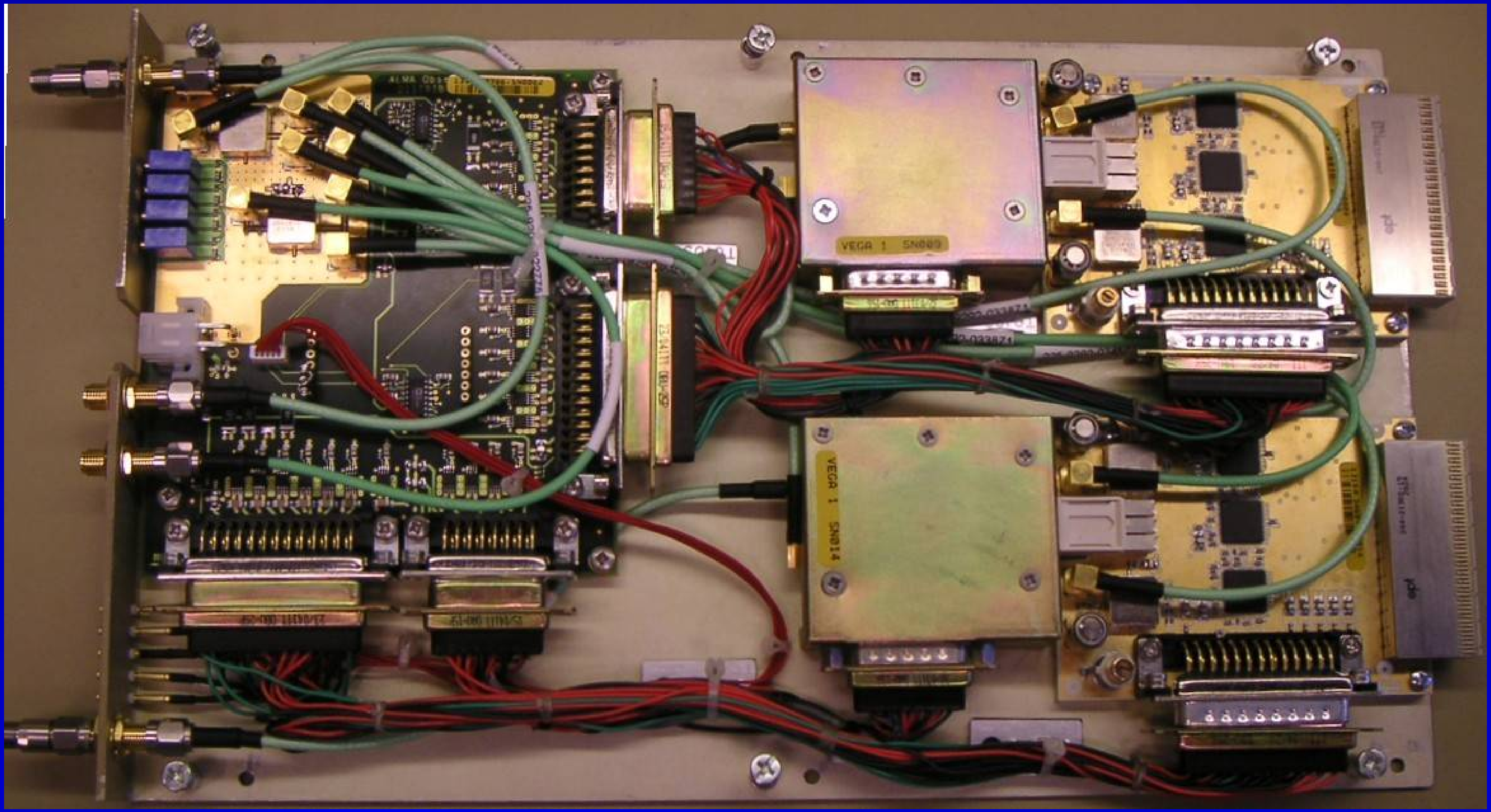
Optical Transmitter



Optical Receiver >

< Optical Amplifier Demux

4 Gsa/sec UB Digitizer Assembly



Correlator Specifications

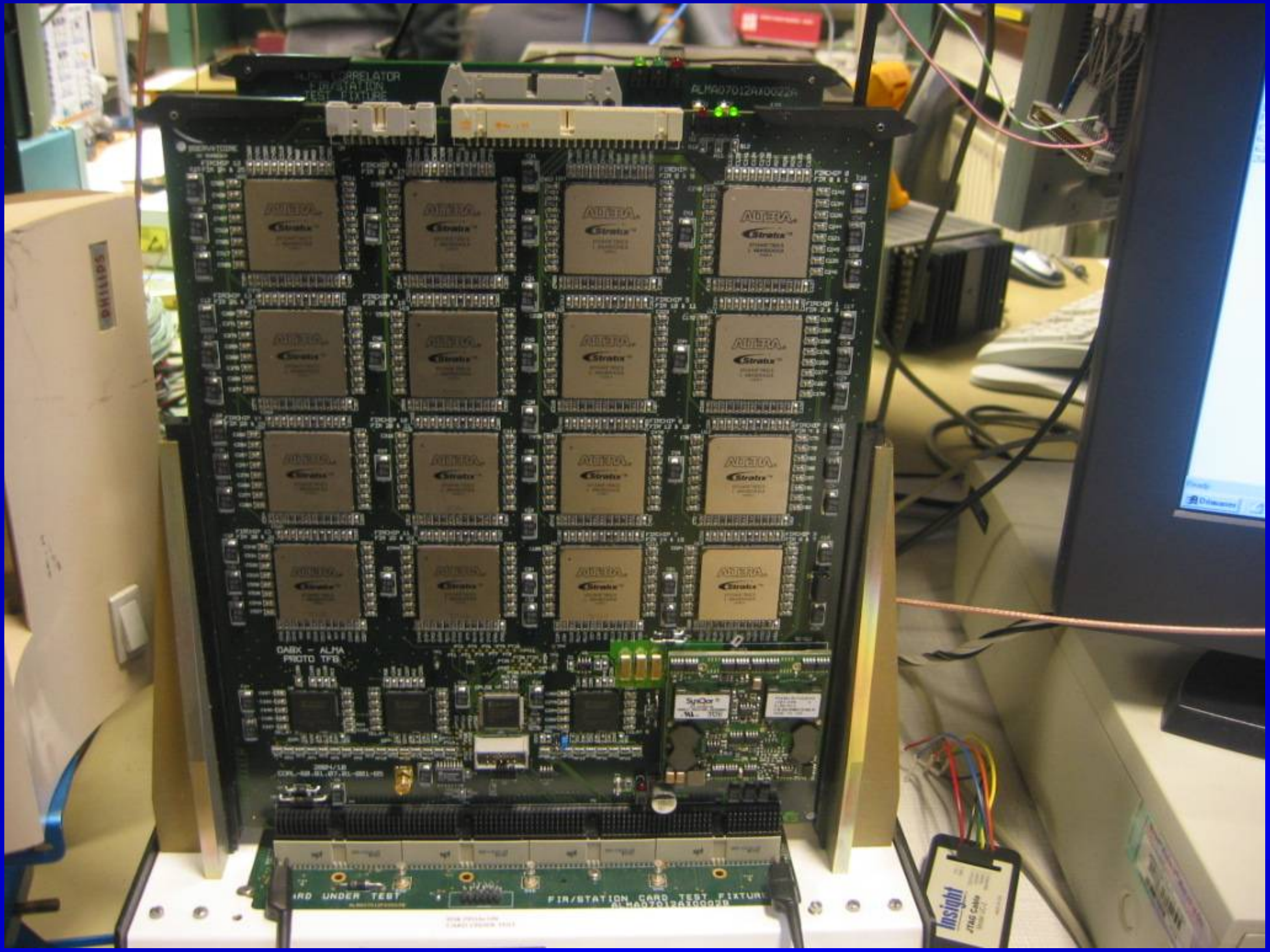
Number of antennas	64
Number of IF pairs per antenna	4
Max. sampling rate per IF pair	2 x 4 GHz
Digitizing format	3 bit, 8 level
Correlating format	2 bit, 4 level
Max. delay range	30 km
Channels per IF pair	4096
Autocorrelation channels per baseline	1024
Polarization	Full stokes (4 products)

First quadrant of correlator completed August 2007…

Correlator Quadrant #1 (of 4)

Complete correlator contains 2912 printed circuit boards and 5200 interface cables; there are more than 20 million solder joints.

Tunable Filter Bank prototype



The TFB accepts a 2 GHz-wide digital signal and provides 32 independently tunable digital outputs, each filtered to a bandwidth of 62.5 MHz, which can be placed anywhere in the 2 GHz band. The outputs are sent for cross-correlation.

Computing

- The fundamental output of the CIPT will be a ~2M SLOC “end to end” software system running on over 200 computers on 4 continents.

- Difficult distributed development – software engineering practices, travel

- Using aips++ (CASA) as offline system

Pipeline – Quicklook Display Simulator

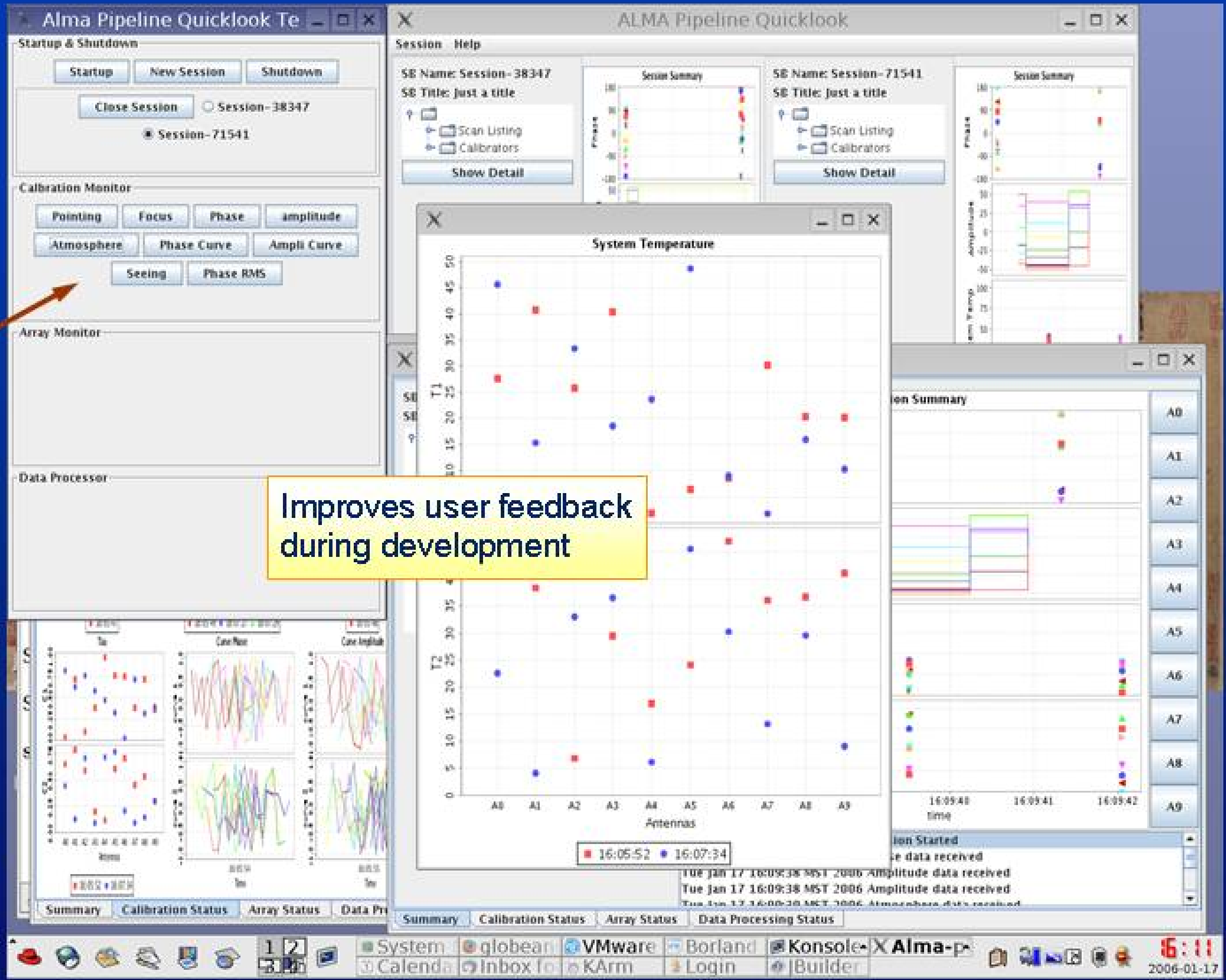
QuickLook Simulation test environment:

To generate simulated data and start a session in standalone mode:

ALMA Pipeline Quicklook Test GUI:

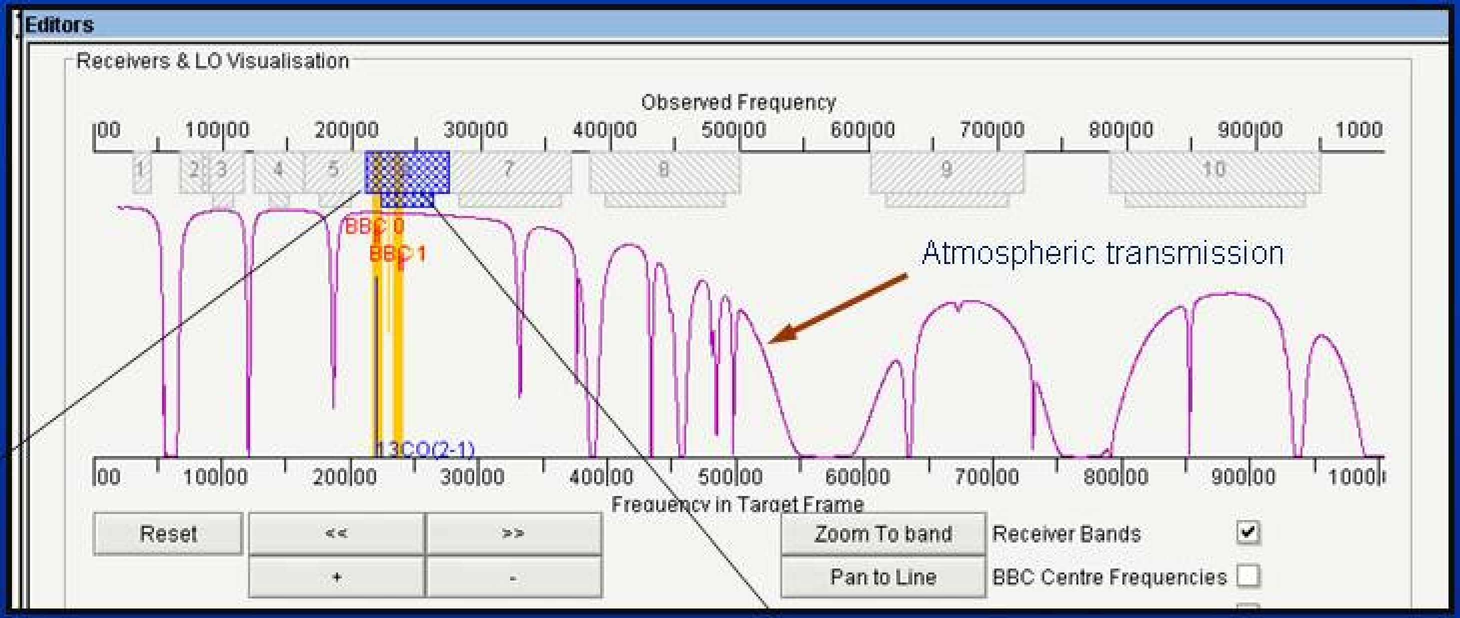
- Start/shutdown session
- Start parallel session
- Create TelCal calibration points normally received over DataCapture.

Click e.g., pointing, to see data on summary & detail plots.

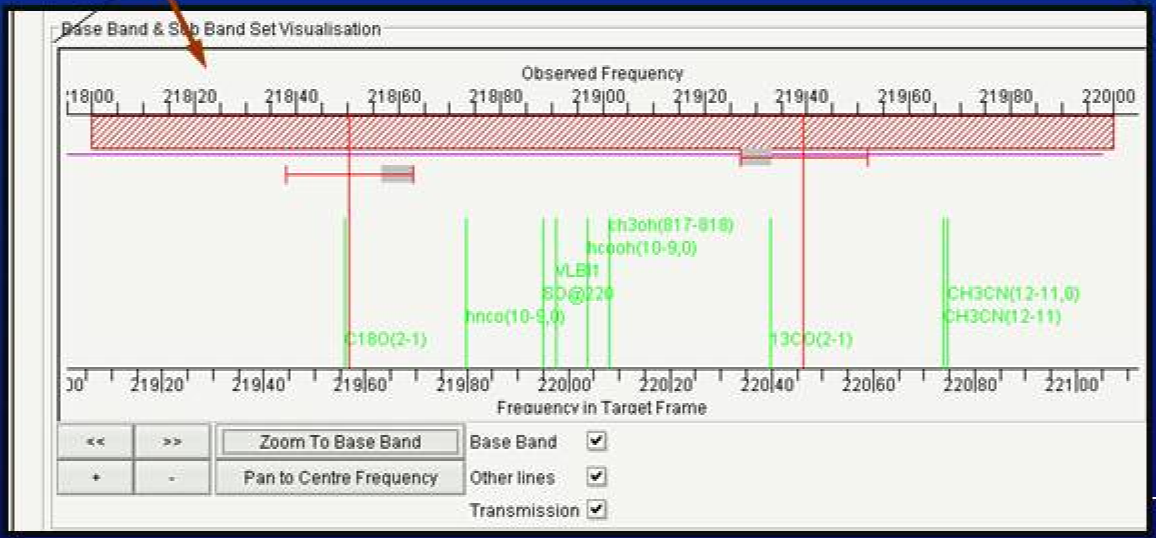


Improves user feedback during development

Observing Tool

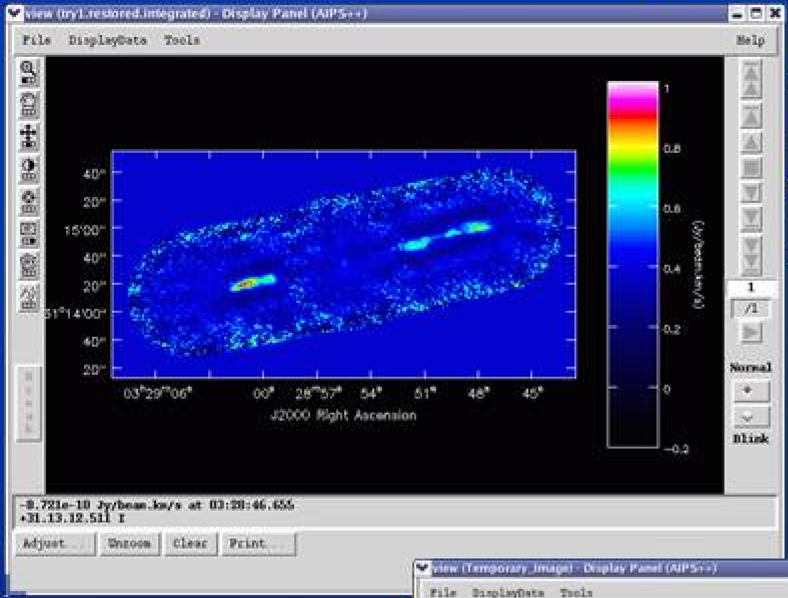


Band 6 close up showing lines in spectral database and windows on selected lines.

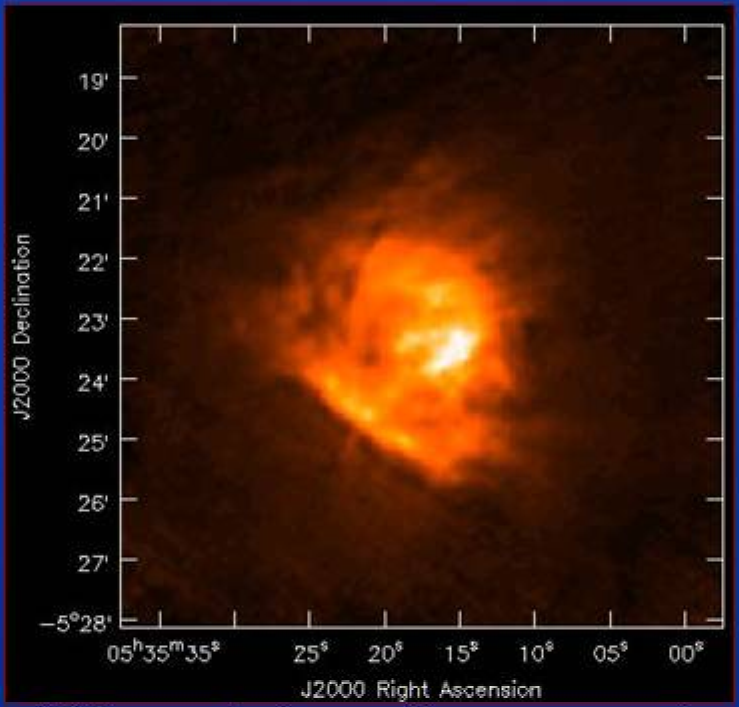


Target source visual representation of correlator setup to observe multiple lines at 1mm Band 6 ($C^{18}O$ 2-1 & ^{13}CO 2-1)

Selected Test 2,3 Results

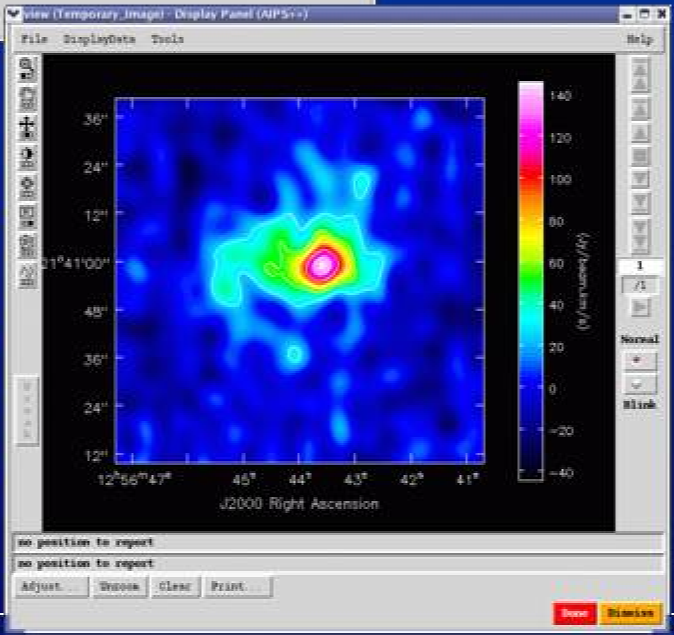


VLA SiO(1-0) mosaic, CLEAN deconvolution



Orion nebula continuum mosaic: VLA mosaic + GBT single dish on-the-fly image. Combined mosaic image produced using joint deconvolution, multi-scale CLEAN

BIMA mosaic + 12m single dish CO(1-0) mosaic, This moment 0 map produced from joint 'feathered' image cube



Budget

- Original (2002) estimate: many unknowns
- Construction project began in 2002; technical & project issues by early 2004 – need to rebaseline program
- ALMA-J – Japanese join ALMA late 2004
- Complex international collaboration model…

- 2005 – bottoms-up rebuild of technical scope, budget, integrated schedule – 40% increase, modify program – 50 antennas.

- Cost to complete (then-yr) ~US$1 Billion.
- ESO: additional funds; NA: in process, likely.
- Operations: begin 2006, ramp to 2012.

Schedule

- First fringes: **ATF Sept 2006.**
- AOS, OSF: construction… **complete 2008.**
- Antennas: **#1 2007, #2 2007… #50 2011.**
- Front Ends: **#1 2007, production.**
- DTS: **production.**
- Correlator: **Q1 complete… Q4 2008.**
- Software: **R3… AIVC 2006, Ops 2008.**

- Call for Early Science: **Q2 2010**
- Early Science: 2011
- Full Operations: 04 **Sep 2012**

Japan – ALMA-J

- New partner: Preliminary agreement signed NSF-ESO-NINS Sept 2004; final agreements signed July 2006.
    - **Four additional 12-m antennas (total power)**
    - **Twelve 7-m diameter antennas in compact configuration: Atacama Compact Array**
    - **Separate ACA correlator**
    - **Receiver: Bands 4, 8… 10**

<u>Atacama Compact Array – ACA</u>

- Significantly improves low surface brightness sensitivity of ALMA; add precision total power data
- Full project schedule integration completed

ALMA + ACA →
Atacama Large Millimeter/submillimeter Array

ALMA

ATACAMA LARGE MILLIMETER ARRAY

www.alma.info

The Atacama Large Millimeter Array (ALMA) is an international astronomy facility. ALMA is a partnership between Europe, North America and Japan, in cooperation with the Republic of Chile. ALMA is funded in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC), in Europe by the European Southern Observatory (ESO) and Spain. ALMA construction and operations are led on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI), on behalf of Europe by ESO, and on behalf of Japan by the National Astronomical Observatory of Japan.