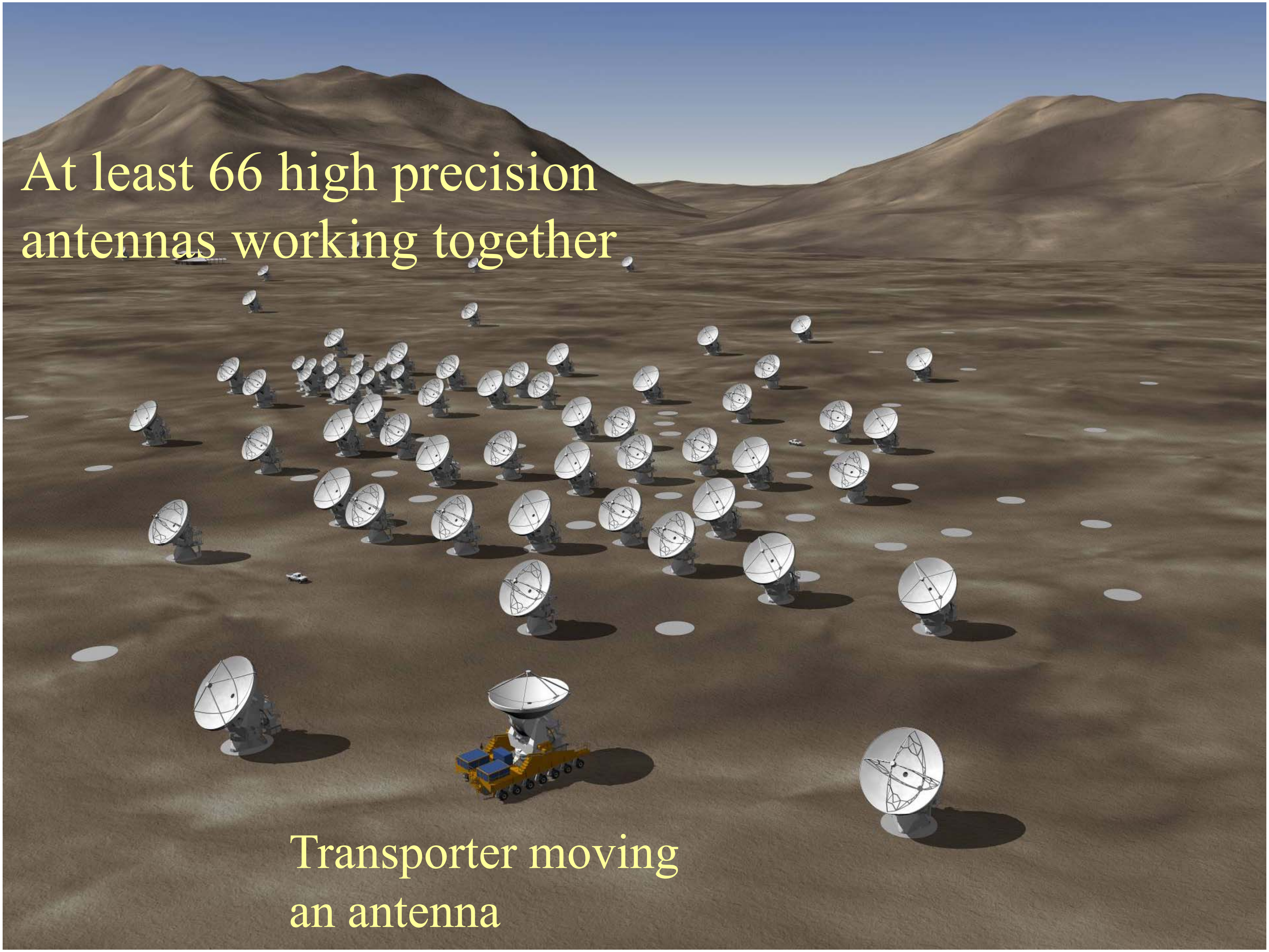
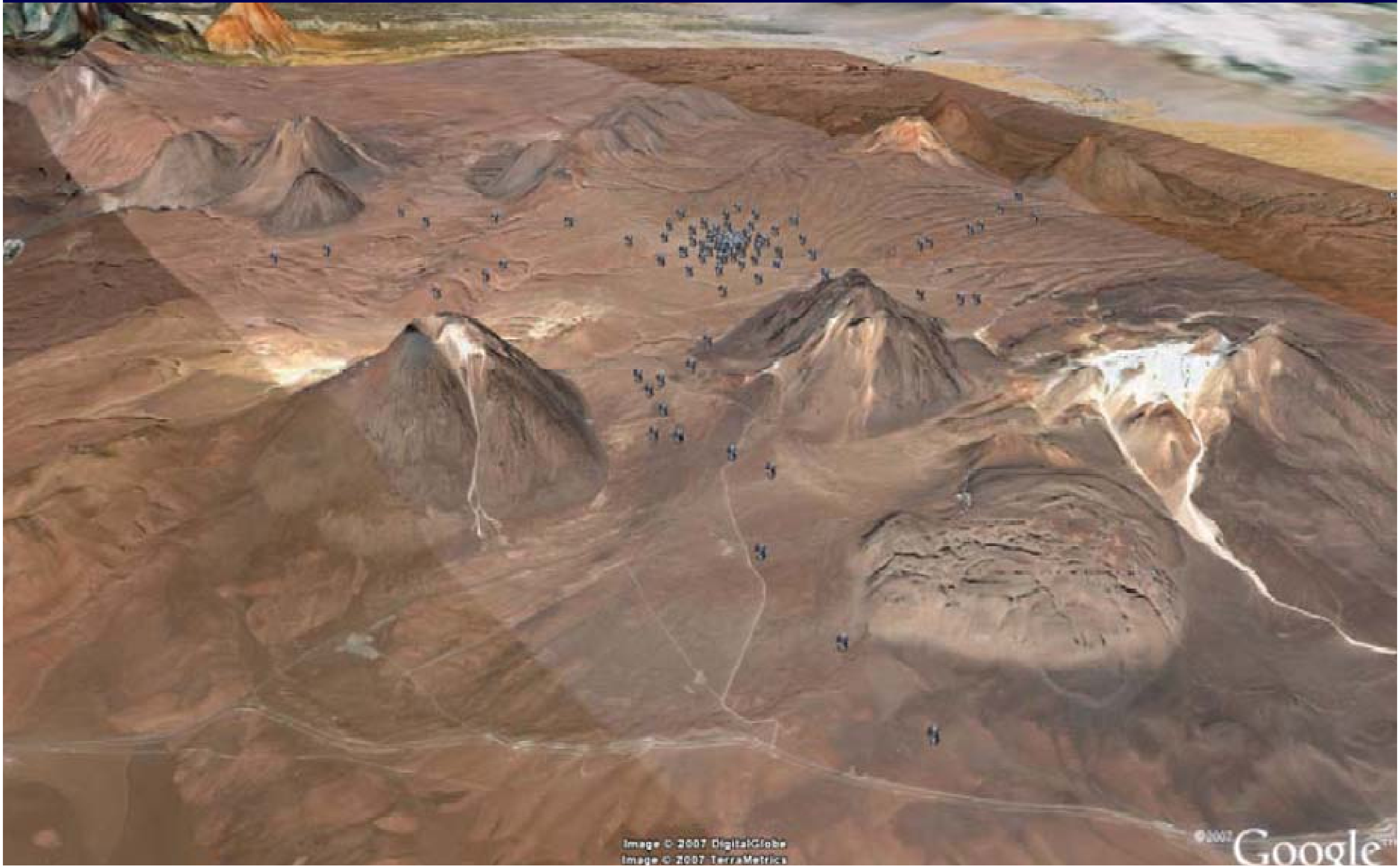
ALMA
An Inter-Continental Project

Richard Hills

Project Scientist


At least 66 high precision antennas working together
Transporter moving an antenna

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



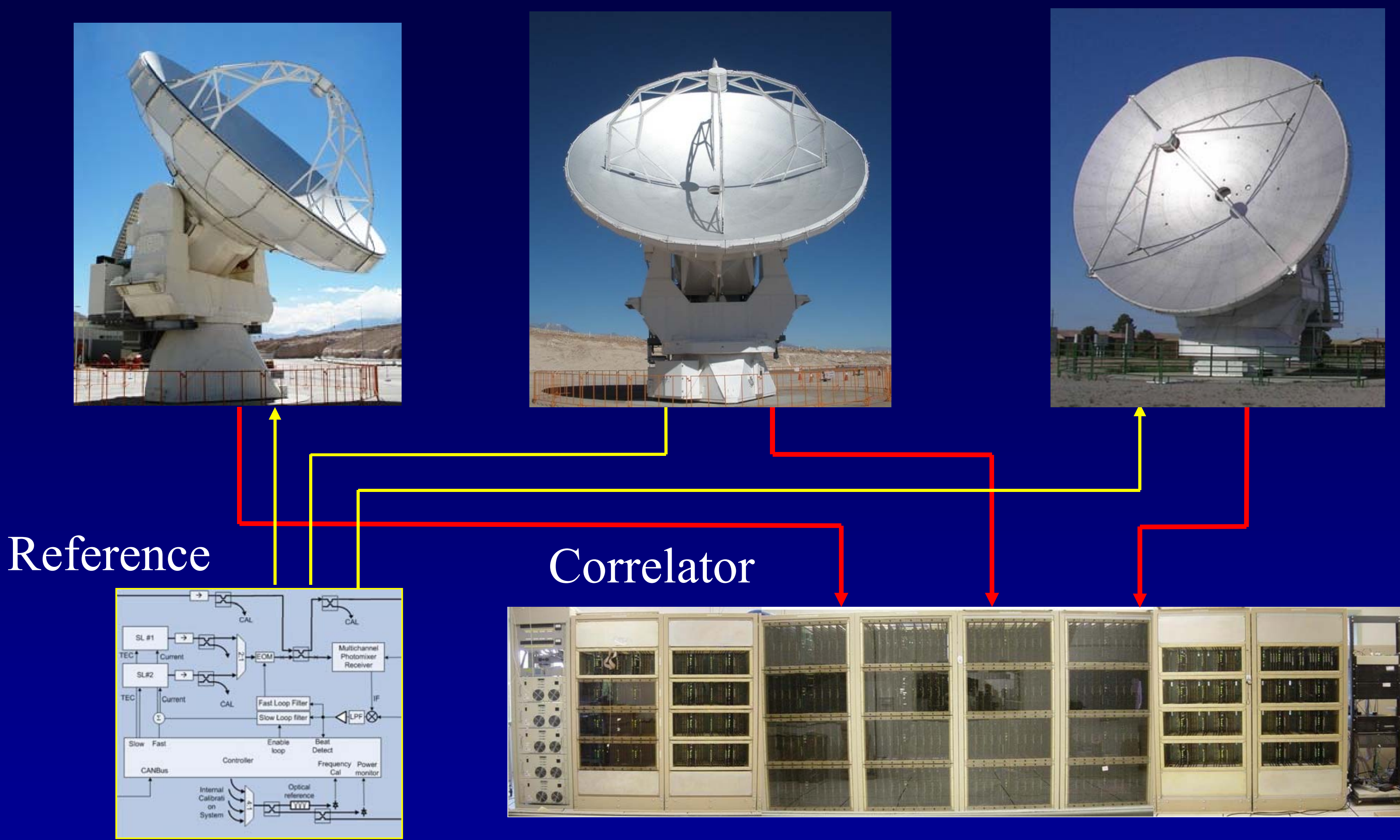
Chajnantor Plateau – looking north

V. Licancabur

Cº Chajnantor

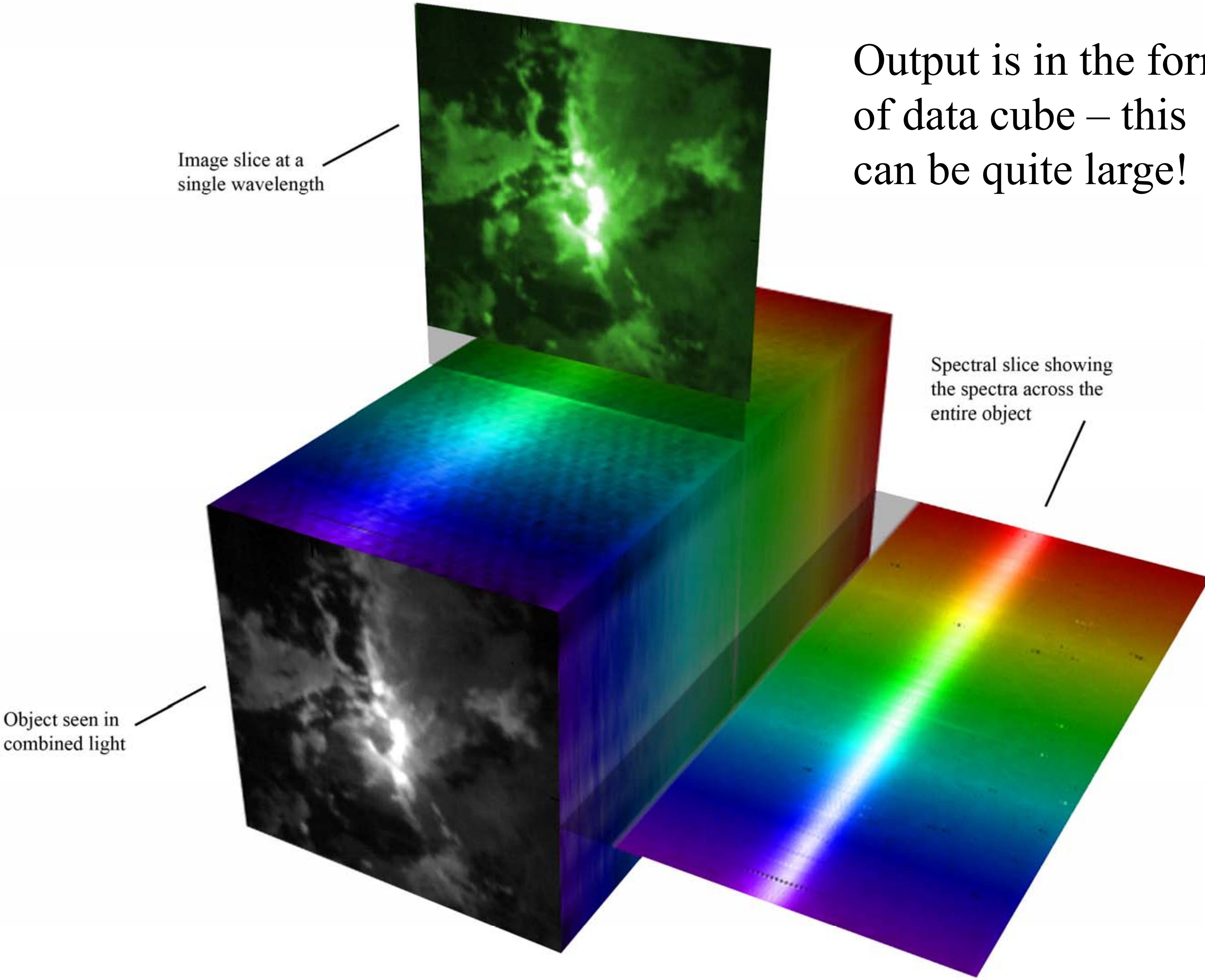
Pampa La Bola

Center of Array



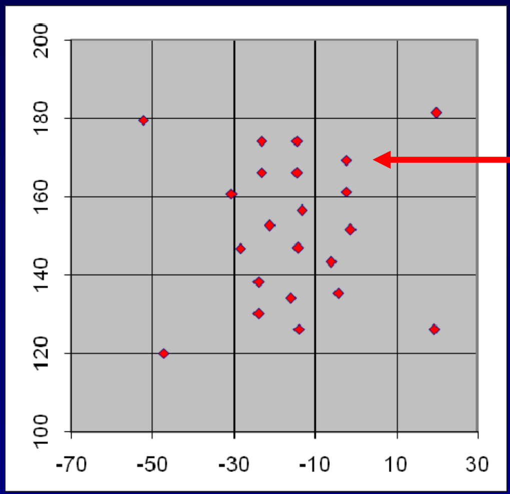
- Signals are amplified and digitized at the antennas and then combined in two big correlators. 120 Gb/s per antenna!
- Extensive use of <u>photonics</u> for this and to synchronize the receivers which has to be done at the ~25 femto-second level.

Output is in the form of data cube – this can be quite large!

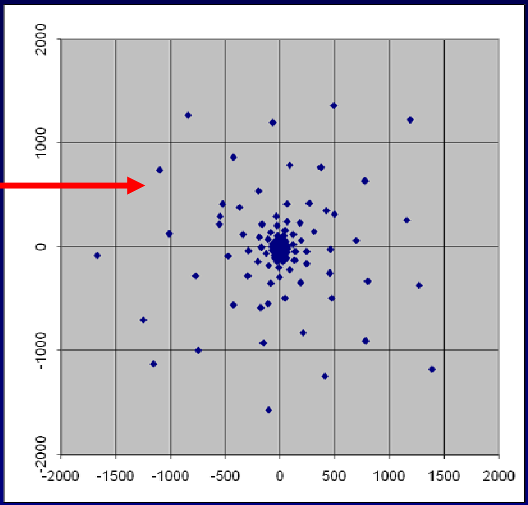


Antenna can be moved on a special-purpose transporter

We need different arrangements of the antennas for looking at different things. The spread-out arrangements show the details but we loose the big picture



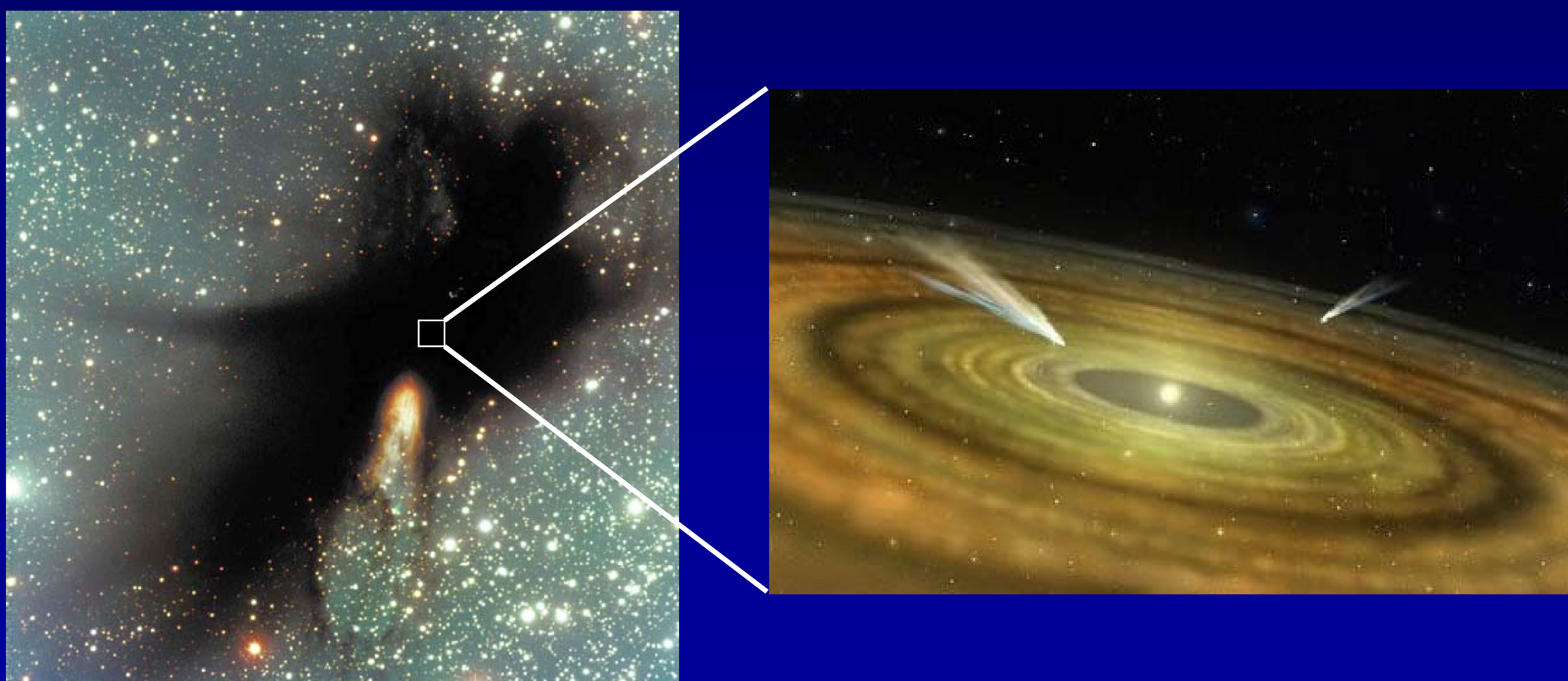
Antennas



Resolution depends on separation between the antennas

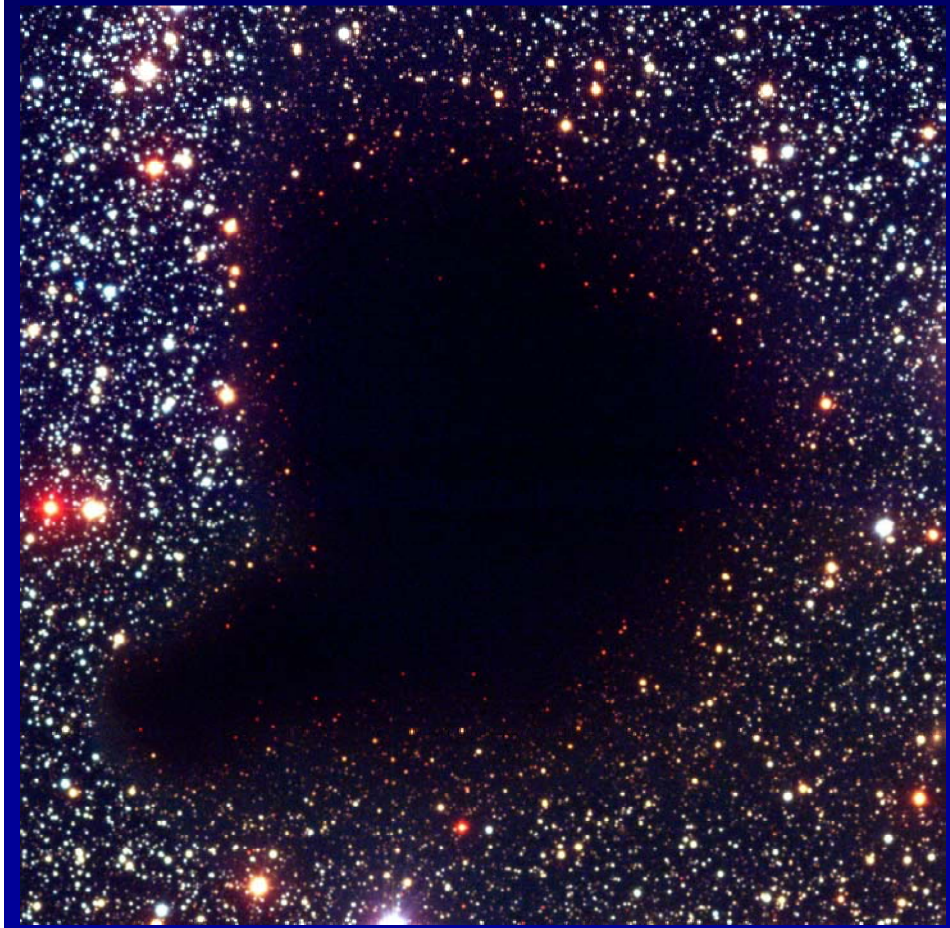
What will ALMA do (1)

Make images of new stars being formed, with planets emerging from the disks around them.

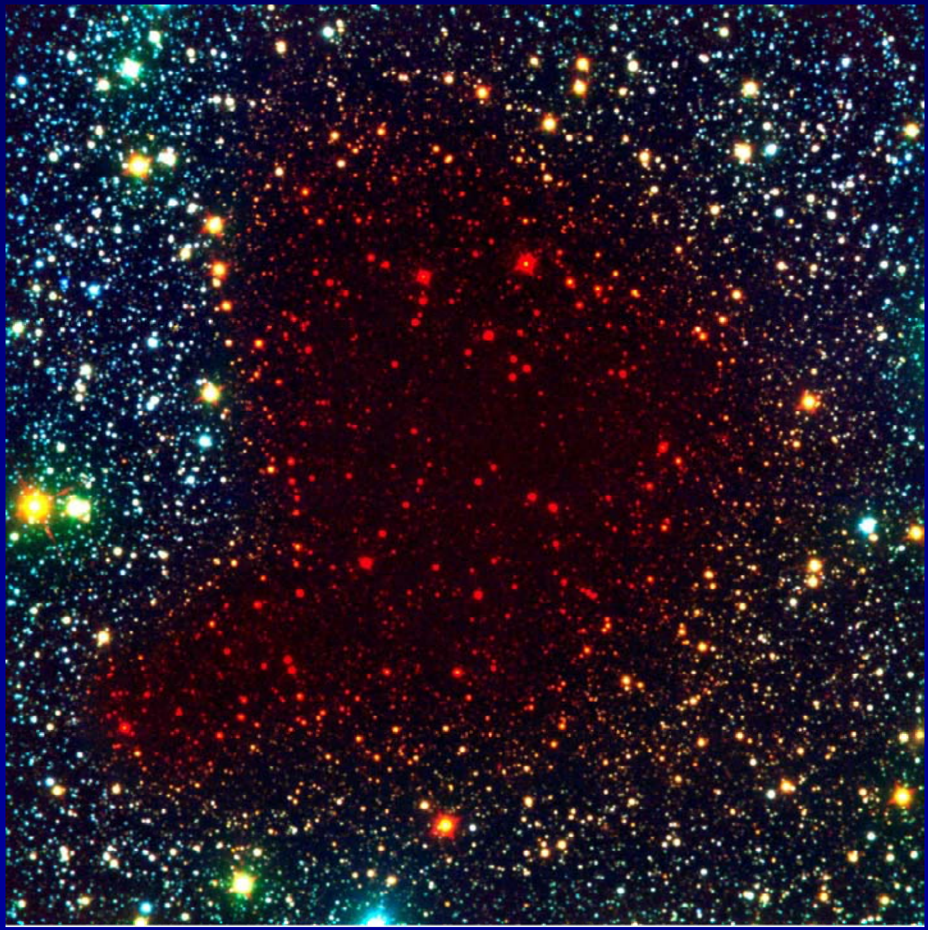


We know that stars and planets (like our Solar System) form in Dark Clouds

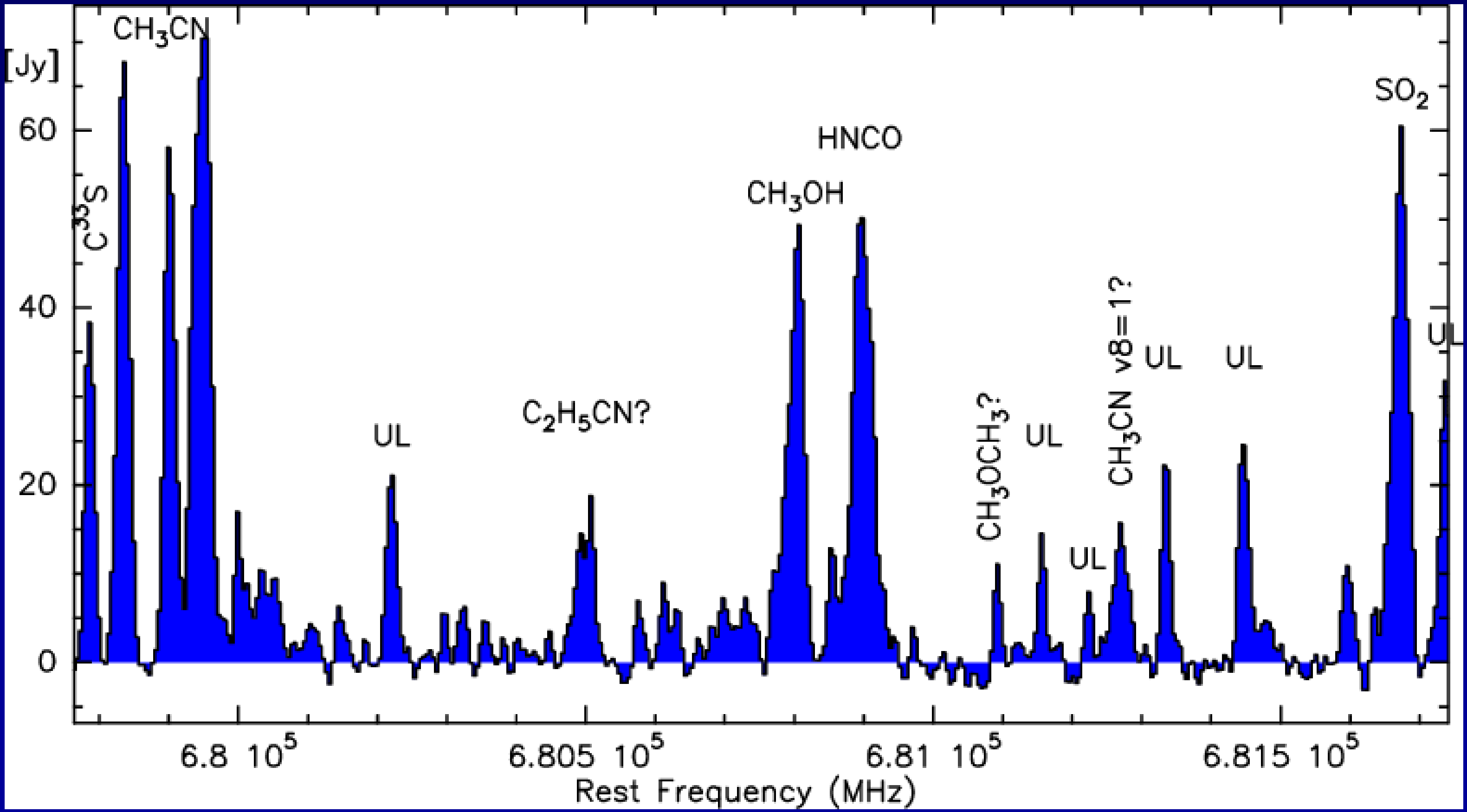
Visible



Infrared



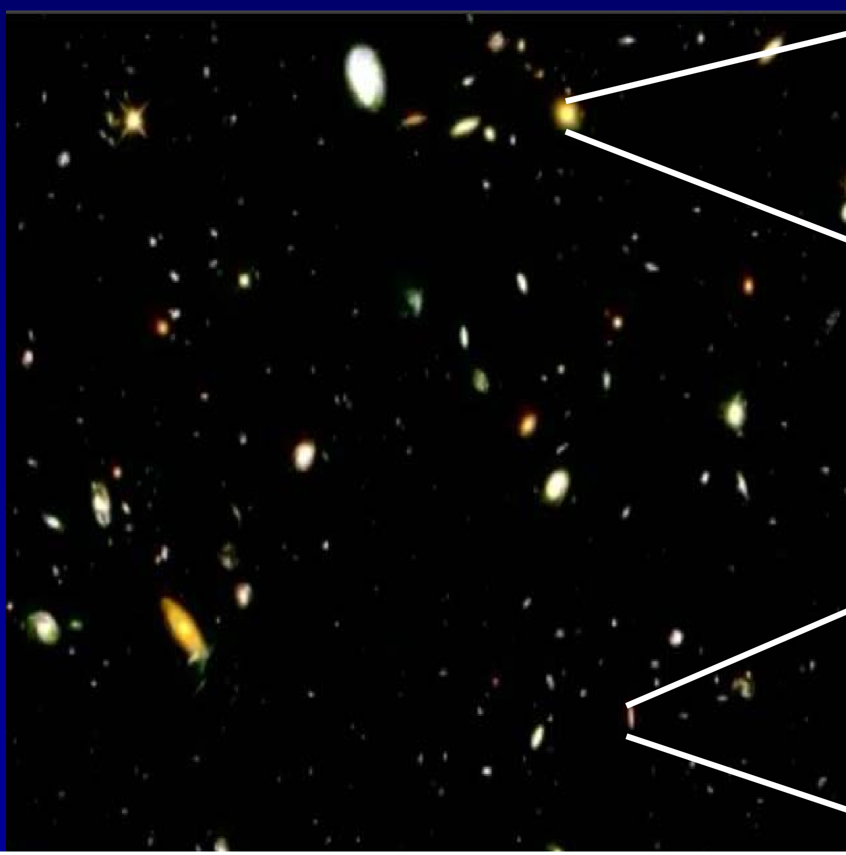
The clouds are basically "smog". Dust and a mixture of different gases. Each gas emits at different frequencies so we can see what is in the clouds. The earth was made from such stuff.



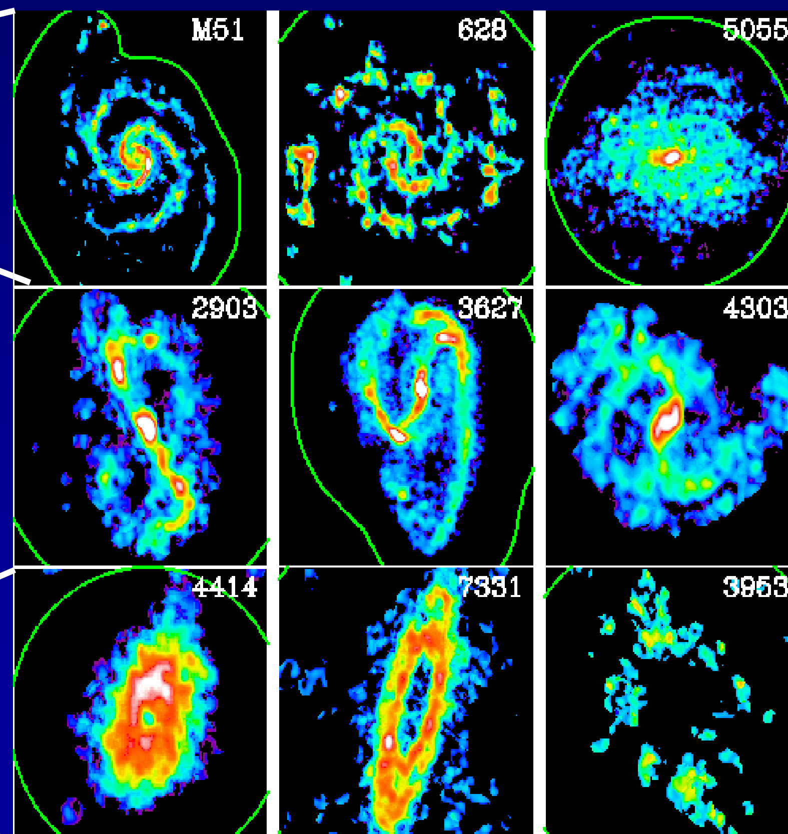
What ALMA will do (2)

Our galaxy, the Milky Way, contains ~100 billion stars.
ALMA will image galaxies billions light-years away.
We expect to see entire galaxies being formed back then.

Hubble image of distant galaxies



Mm-wave images of near galaxies

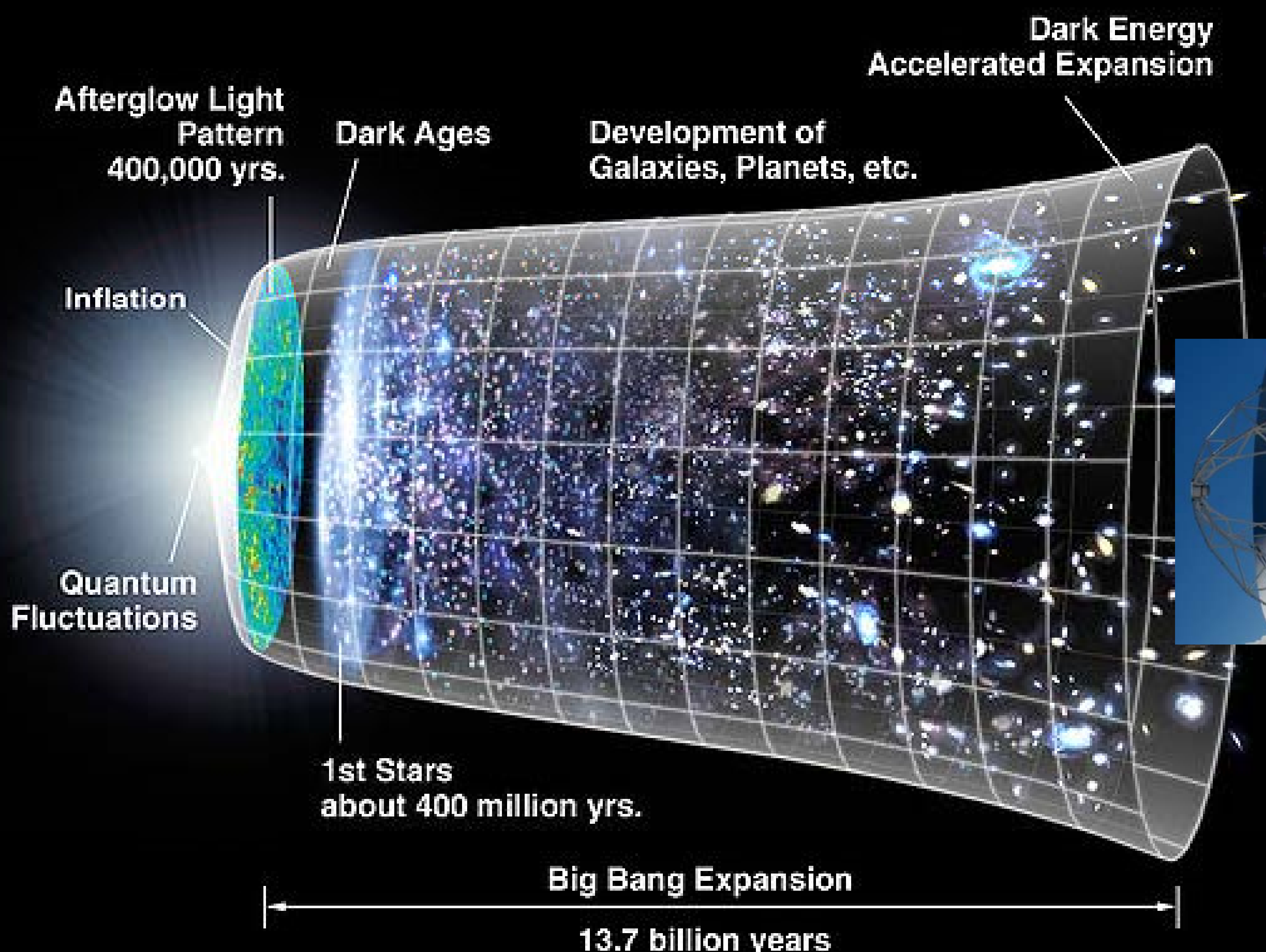


What ALMA will do (3)

The most distant galaxies that we have seen so far lie at a red-shift of about 6. They are more than 12 billion light years away. Between them and the Big Bang, at 13.7 billion years ago, lie the "Dark Ages". The first stars, galaxies and black holes must have formed then.

We hope that ALMA will be able to catch faint glimmers of light (well heat !) from these objects. This is seen as a key step in learning how our universe came to be the way it is.

From the Big Bang to the Present Day



and lots of other things…

- Investigate planets in our own solar system and of the moons orbiting around them
- Study the surface of the sun and solar flares
- See the remains of stars that have blown themselves up
- Quasars, pulsars, black holes, jets, outflows…. the whole cosmic “zoo” of strange and wonderful things will all be seen from a fresh perspective with ALMA.

ALMA Predicted Sensitivity

(1-σ, **1 minute**; AM=1.3; water values correspond roughly to the quartiles)

Frequency GHz	Zenith Water mm	Continuum mJy	Line 1km/s * mJy
35	2.3	0.03	8
110	2.3	0.05	7
140	2.3	0.06	8
230	2.3	0.1	11
345	1.2	0.2	18
410	1.2	0.4	31
675	0.5	0.7	41
850	0.5	1.4	72

*Spectral line sensitivity scales inversely with square root of velocity resolution. So for 25km/s, which might for example be used for a galaxy, divide by 5.

Angular resolution

(FWHM arc seconds. Source at ~70 degrees elevation)

	Maximum baseline length in meters			
Frequency GHz	160	750	3000	15000
35	13.3	2.83	0.71	0.141
110	4.2	0.90	0.23	0.045
140	3.3	0.71	0.18	0.035
230	2.0	0.43	0.11	0.022
345	1.3	0.29	0.07	0.014
410	1.1	0.24	0.06	0.012
675	0.7	0.15	0.04	0.007
850	0.5	0.12	0.03	0.006

Brightness Temperature Sensitivity

Continuum in Kelvins (Rayleigh-Jeans)

(1-σ, **1 minute**; AM=1.3; water values as given for point source values)

	Maximum baseline length in meters			
Frequency GHz	160	750	3000	15000
35	2.5E-04	5.4E-03	8.6E-02	2.2E+00
110	4.1E-04	9.0E-03	1.4E-01	3.6E+00
140	4.9E-04	1.1E-02	1.7E-01	4.3E+00
230	8.2E-04	1.8E-02	2.9E-01	7.2E+00
345	1.6E-03	3.6E-02	5.8E-01	1.4E+01
410	3.3E-03	7.2E-02	1.2E+00	2.9E+01
675	5.7E-03	1.3E-01	2.0E+00	5.0E+01
850	1.1E-02	2.5E-01	4.0E+00	1.0E+02

Note the extremely good sensitivity in the compact configurations, but also the unavoidable increase for long baselines (T_b scales as square of baseline).

Brightness Temperature Sensitivity

Spectral Line in Kelvins (Rayleigh-Jeans) 1km/s

(1-σ, **4 hours**; AM=1.3; water values as given for point source values)

	Maximum baseline length in meters			
Frequency GHz	160	750	3000	15000
35	4.2E-03	9.3E-02	1.5E+00	3.7E+01
110	3.7E-03	8.1E-02	1.3E+00	3.3E+01
140	4.2E-03	9.3E-02	1.5E+00	3.7E+01
230	5.8E-03	1.3E-01	2.0E+00	5.1E+01
345	9.5E-03	2.1E-01	3.3E+00	8.4E+01
410	1.6E-02	3.6E-01	5.8E+00	1.4E+02
675	2.2E-02	4.8E-01	7.6E+00	1.9E+02
850	3.8E-02	8.4E-01	1.3E+01	3.3E+02

Again these values should be divided by the square root of the desired velocity resolution in km/s if 1km/s is not the appropriate value.

Timeline

- 1980's initial ideas in North America, East Asia and Europe for large millimetre-wave arrays.
- 1990's lots of talk, fund-raising … leading to an MOU to do a joint project.
- ~2000 agreements – choice of site, detailed design and development, agreements, reviews, "rebaselining"… leading to current definition:
  - Designed to be a research tool for the whole community
  - At least 54 twelve-meter antennas (four for "zero-spacings") with configurations from ~160m to 15km, plus 12 seven-meter antennas in a compact array.
  - Seven receiver bands covering ~85 to ~950 GHz.
  - Continuum, spectral-line and polarization capabilities, plus solar and planetary observing, and pulsars.

Where are we now?

- Buildings essentially done (except residence)
- Roads, power, foundations, well under way
- Antennas, electronics and scientists arriving
- Testing underway

5000m: occupied, installing systems

3000m: offices in use, labs & control room being set up.

Foundations for the Compact Array – nearly done. Power and fibres next.

<u>Four</u> MELCO Antennas being tested (non-interferometrically!)

Two Vertex Antennas provisionally accepted – Nine more on site in various stages of assembly

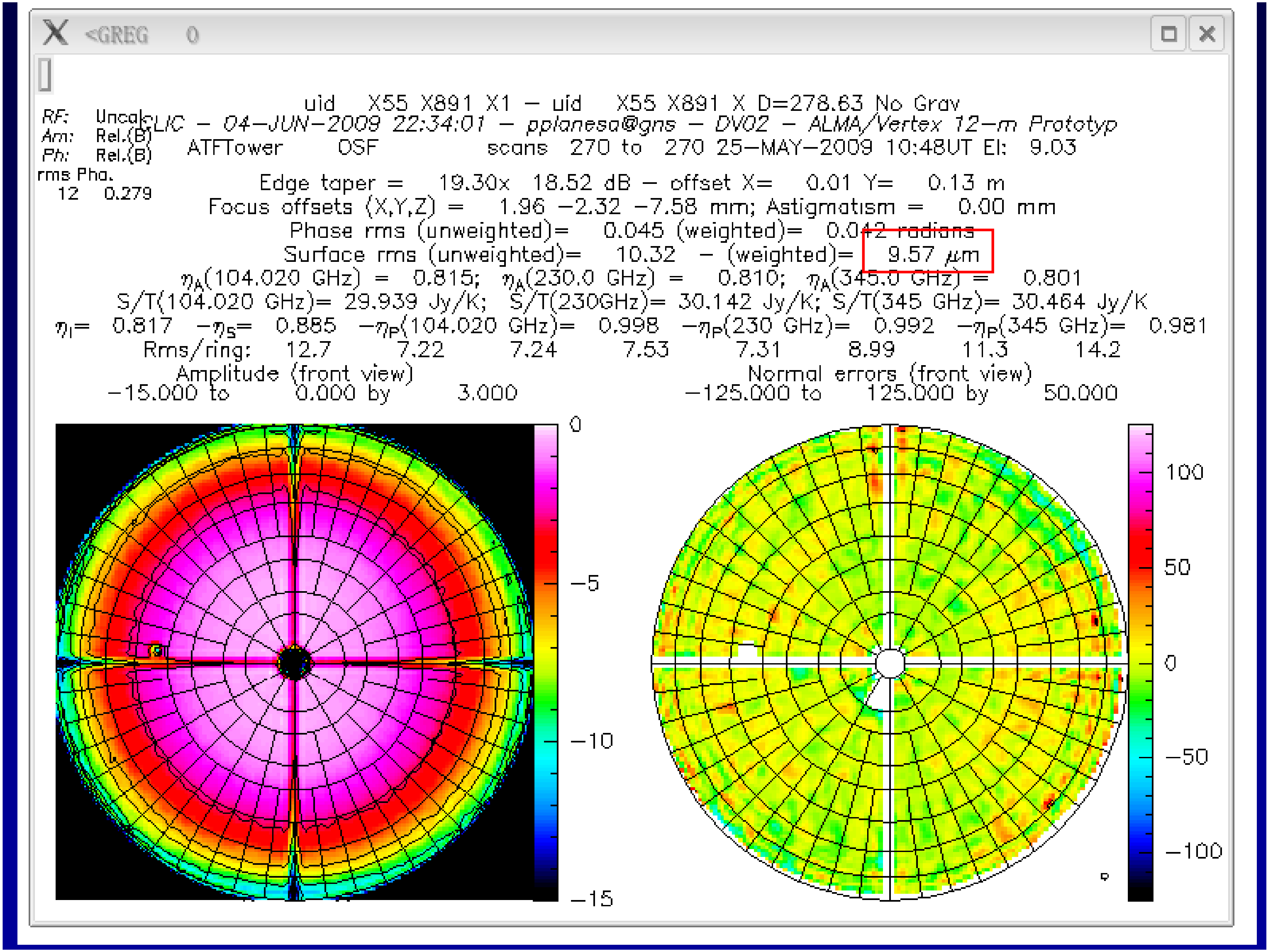
Photo – Lewis Knee

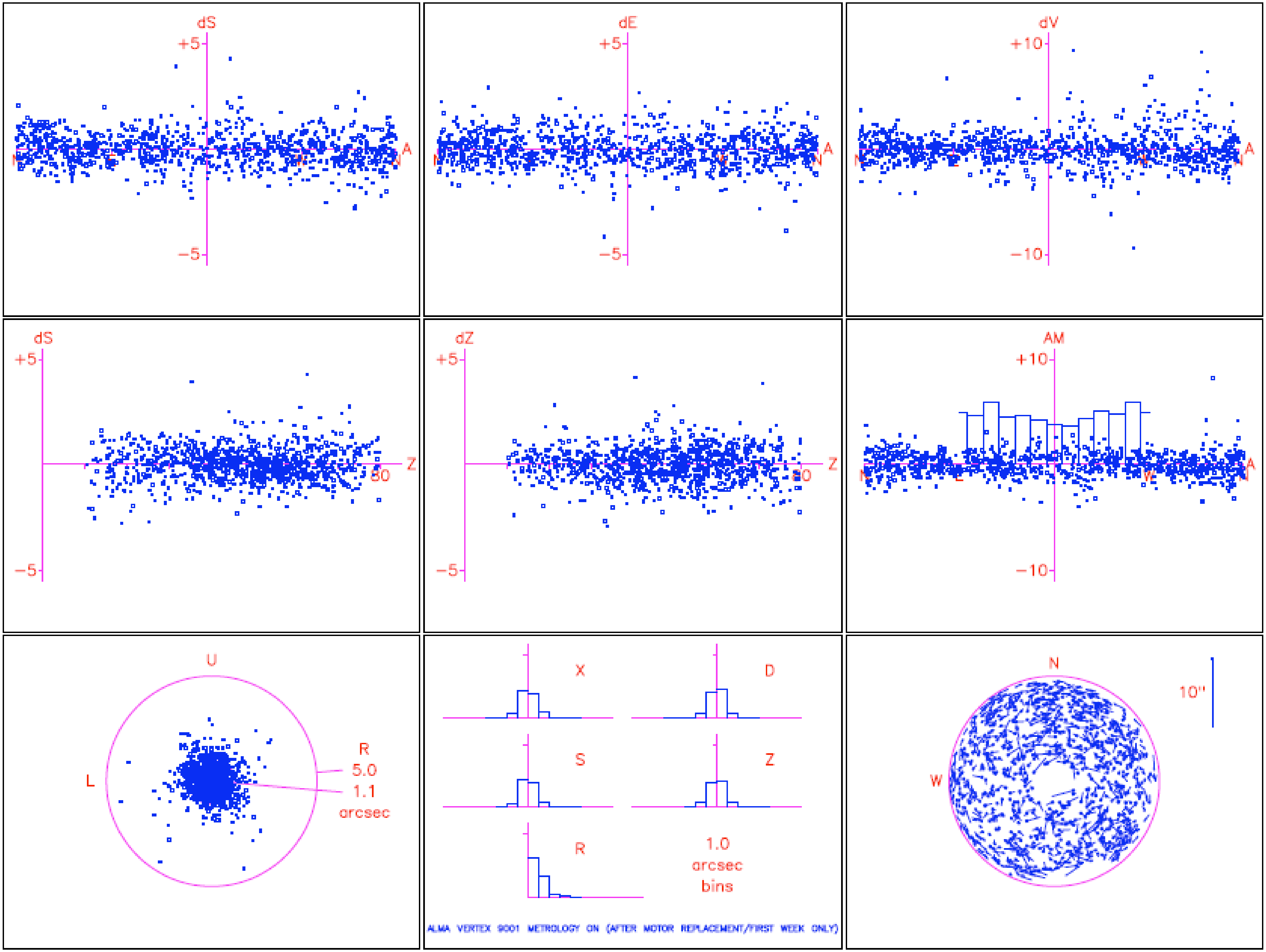
AEM: design All-CFRP upper section

AEM : Three dishes plus cabins and one base on site

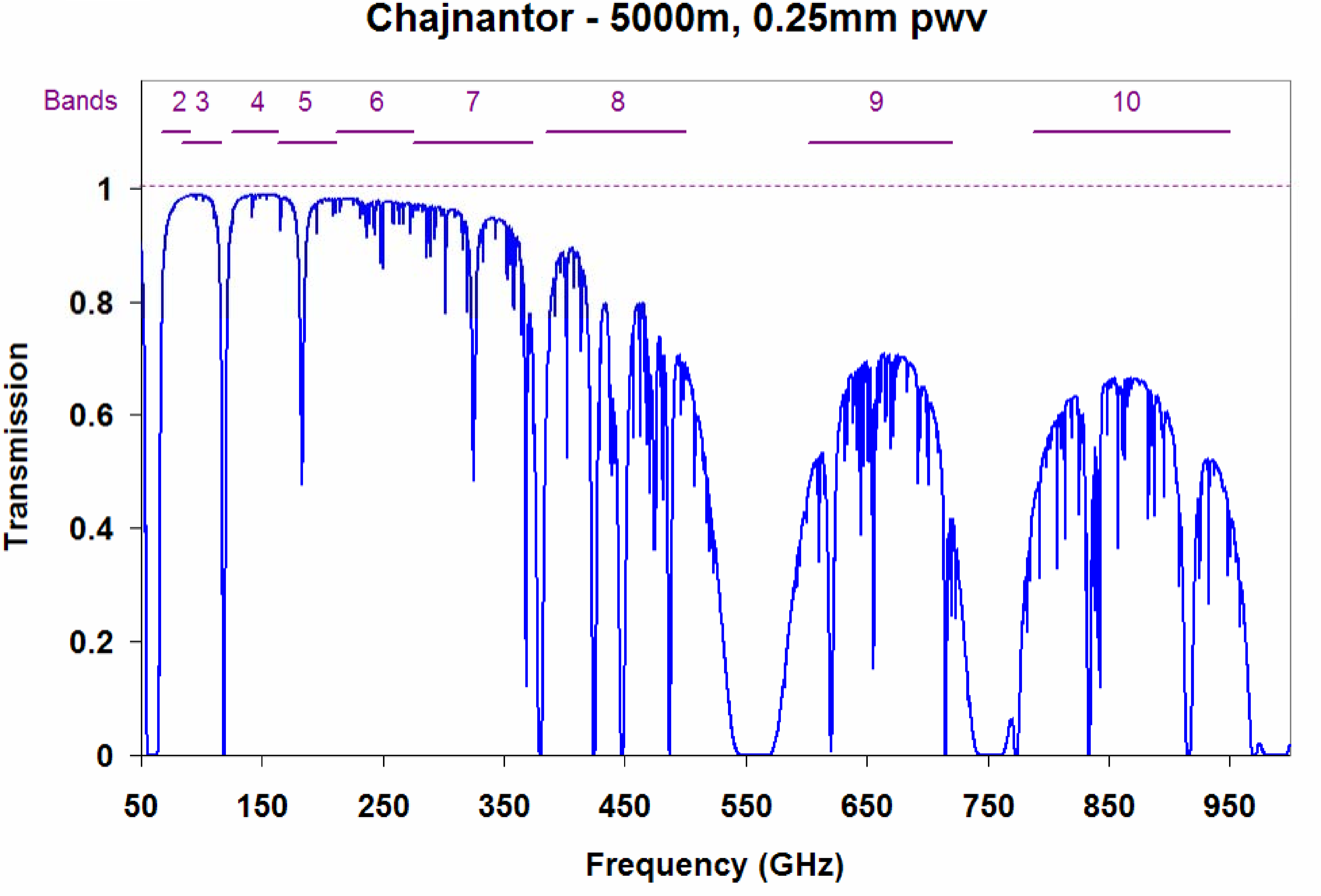

Both Transporters
are Operational
WACKER

Dishes measured by holography at 104 GHz
Use source on tower at ~300m distance and correct for the curved wavefront


<GREG 0
uid X55 X891 X1 – uid X55 X891 X D=278.63 No Grav
RF: Uncal
Am: Rel.(B)
Ph: Rel.(B)
CLIC – 04–JUN–2009 22:34:01 – pplanesa@gns – DV02 – ALMA/Vertex 12–m Prototyp
ATFTower OSF scans 270 to 270 25–MAY–2009 10:48UT El: 9.03
rms Pha.
12 0.279
Edge taper = 19.30x 18.52 dB – offset X= 0.01 Y= 0.13 m
Focus offsets (X,Y,Z) = 1.96 –2.32 –7.58 mm; Astigmatism = 0.00 mm
Phase rms (unweighted)= 0.045 (weighted)= 0.042 radians
Surface rms (unweighted)= 10.32 – (weighted)= 9.57 μm
ηA(104.020 GHz) = 0.815; ηA(230.0 GHz) = 0.810; ηA(345.0 GHz) = 0.801
S/T(104.020 GHz)= 29.939 Jy/K; S/T(230GHz)= 30.142 Jy/K; S/T(345 GHz)= 30.464 Jy/K
ηI= 0.817 –ηS= 0.885 –ηP(104.020 GHz)= 0.998 –ηP(230 GHz)= 0.992 –ηP(345 GHz)= 0.981
Rms/ring: 12.7 7.22 7.24 7.53 7.31 8.99 11.3 14.2
Amplitude (front view)
–15.000 to 0.000 by 3.000
Normal errors (front view)
–125.000 to 125.000 by 50.000
0
–5
–10
–15
100
50
0
–50
–100

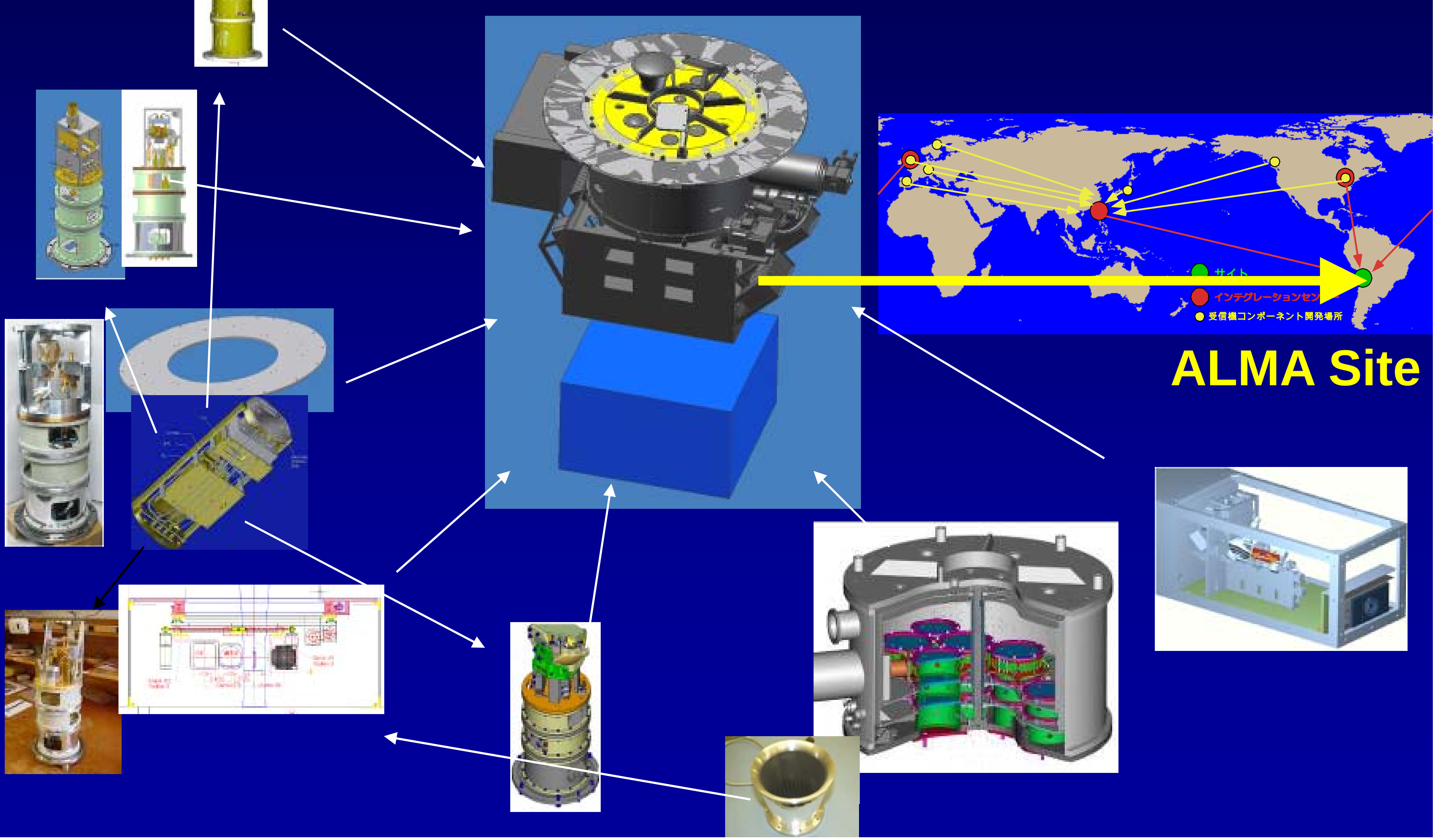

dS
+5
−5
N
E
W
A
dE
+5
−5
dV
+10
−10
dS
+5
−5
Z
80
dZ
+5
−5
Z
80
AM
+10
−10
N
E
W
A
U
L
R
5.0
1.1
arcsec
X
D
S
Z
R
1.0
arcsec
bins
ALMA VERTEX 9001 METROLOGY ON (AFTER MOTOR REPLACEMENT/FIRST WEEK ONLY)
N
W
10"

Receivers – up to 10 cartridges in one cryostat



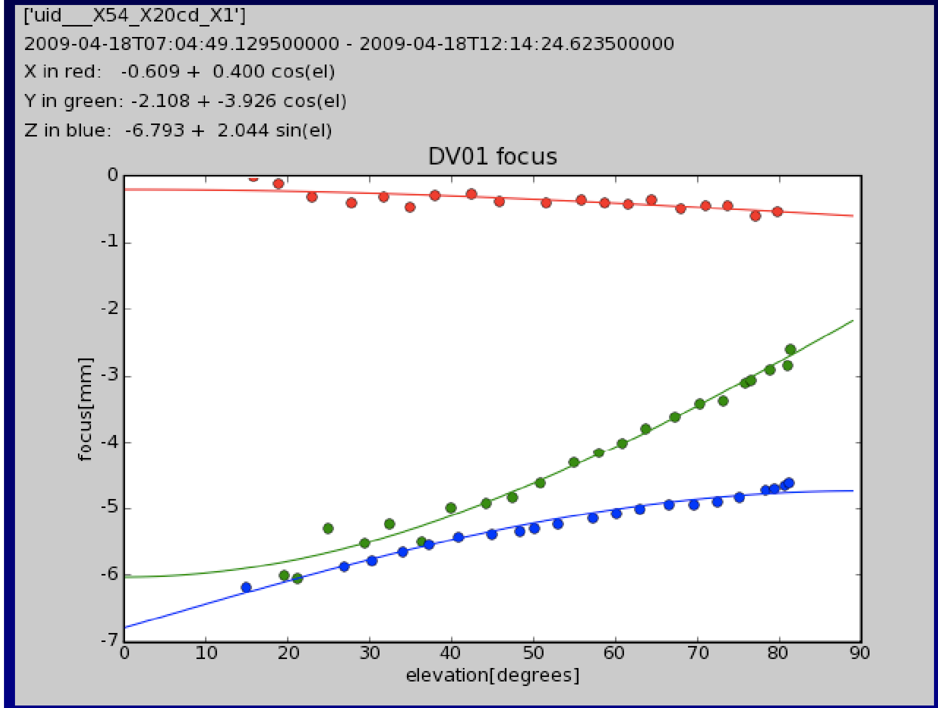
ALMA Front End System Integration

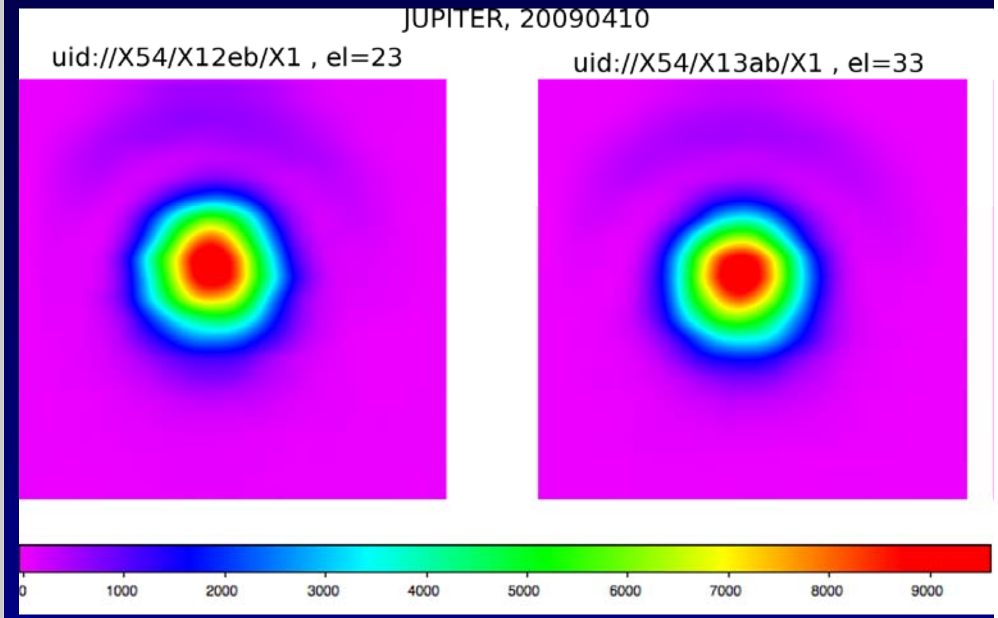
3 FE Integration Centers: NA, EU, EA

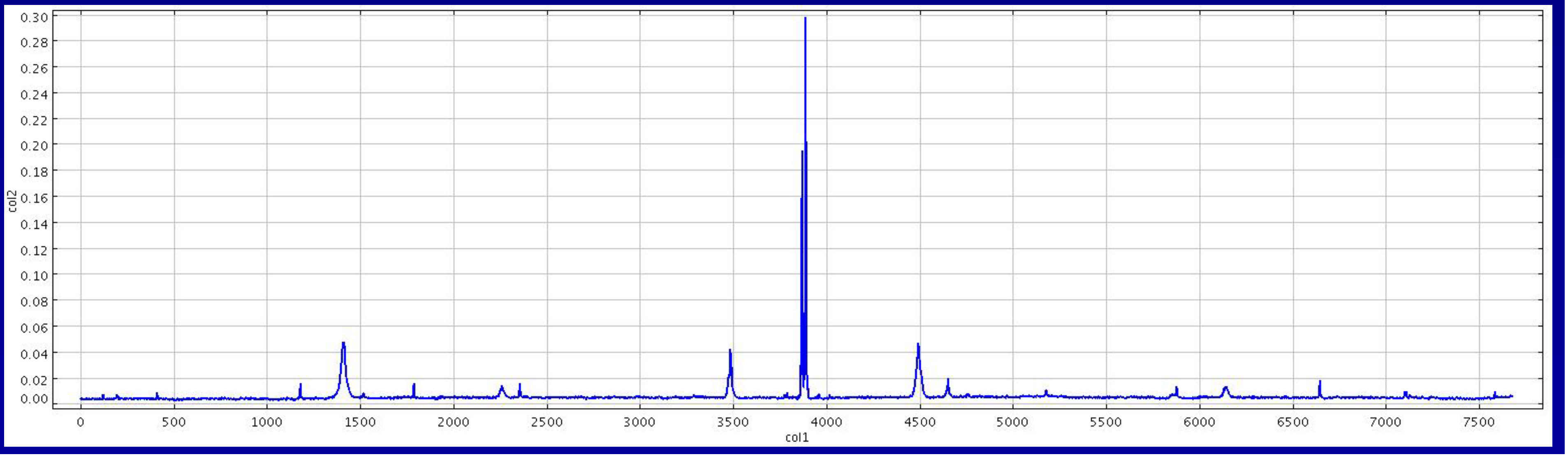


So now tests of THREE antennas are in full swing.

Working through pointing, focus, beams, sky dips…

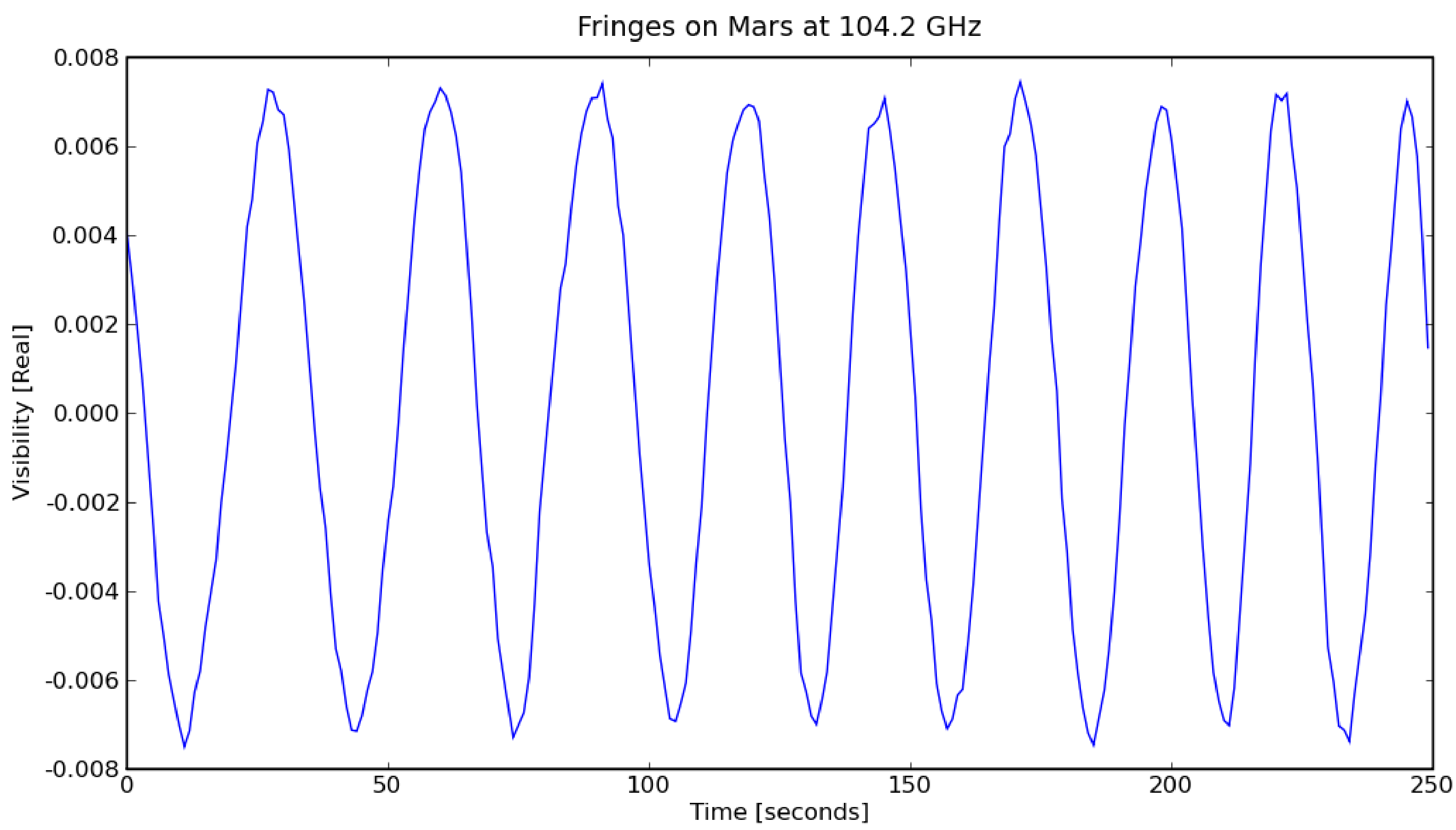




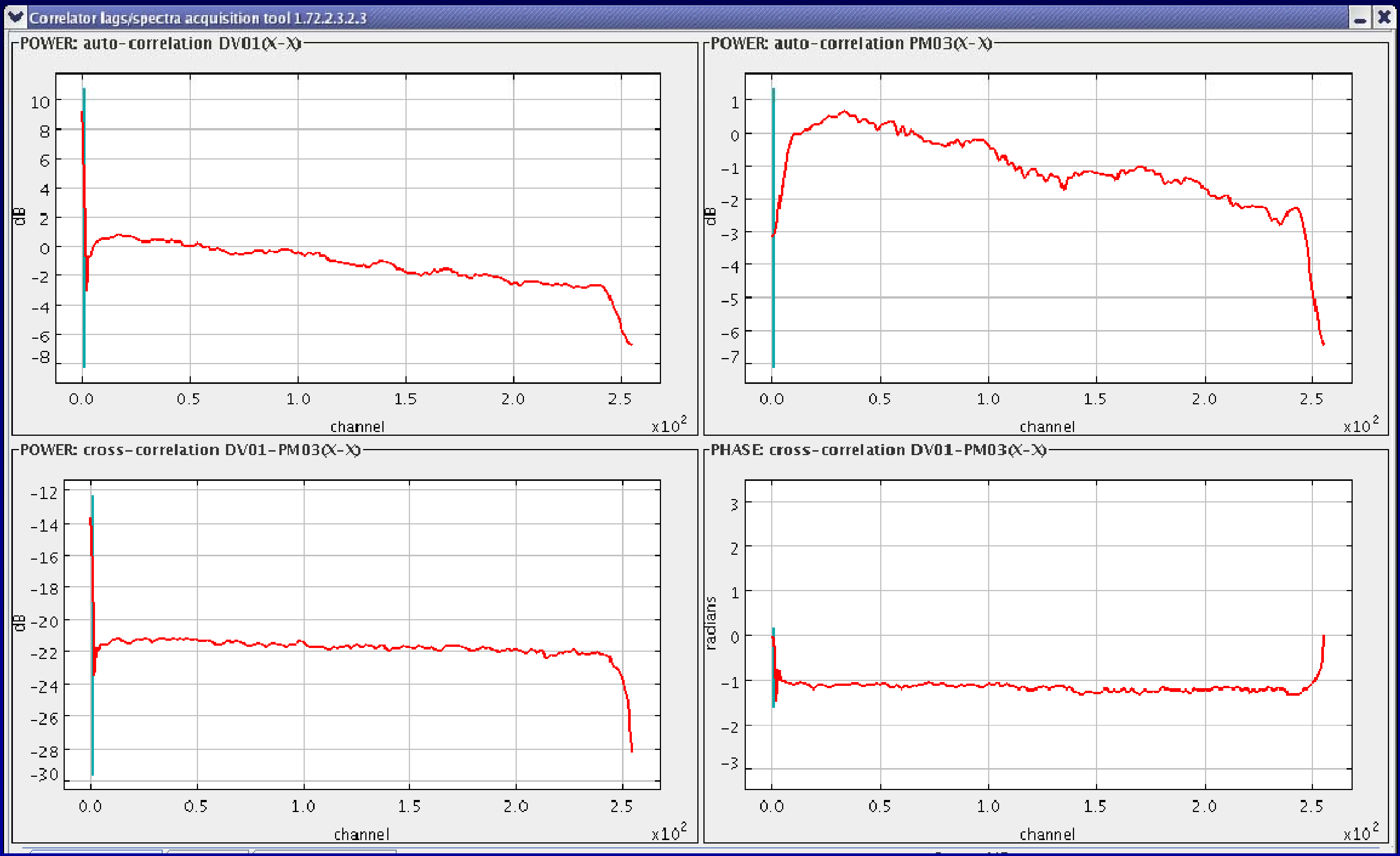


And so to the first fringe !

30th April 2009



For the experts….

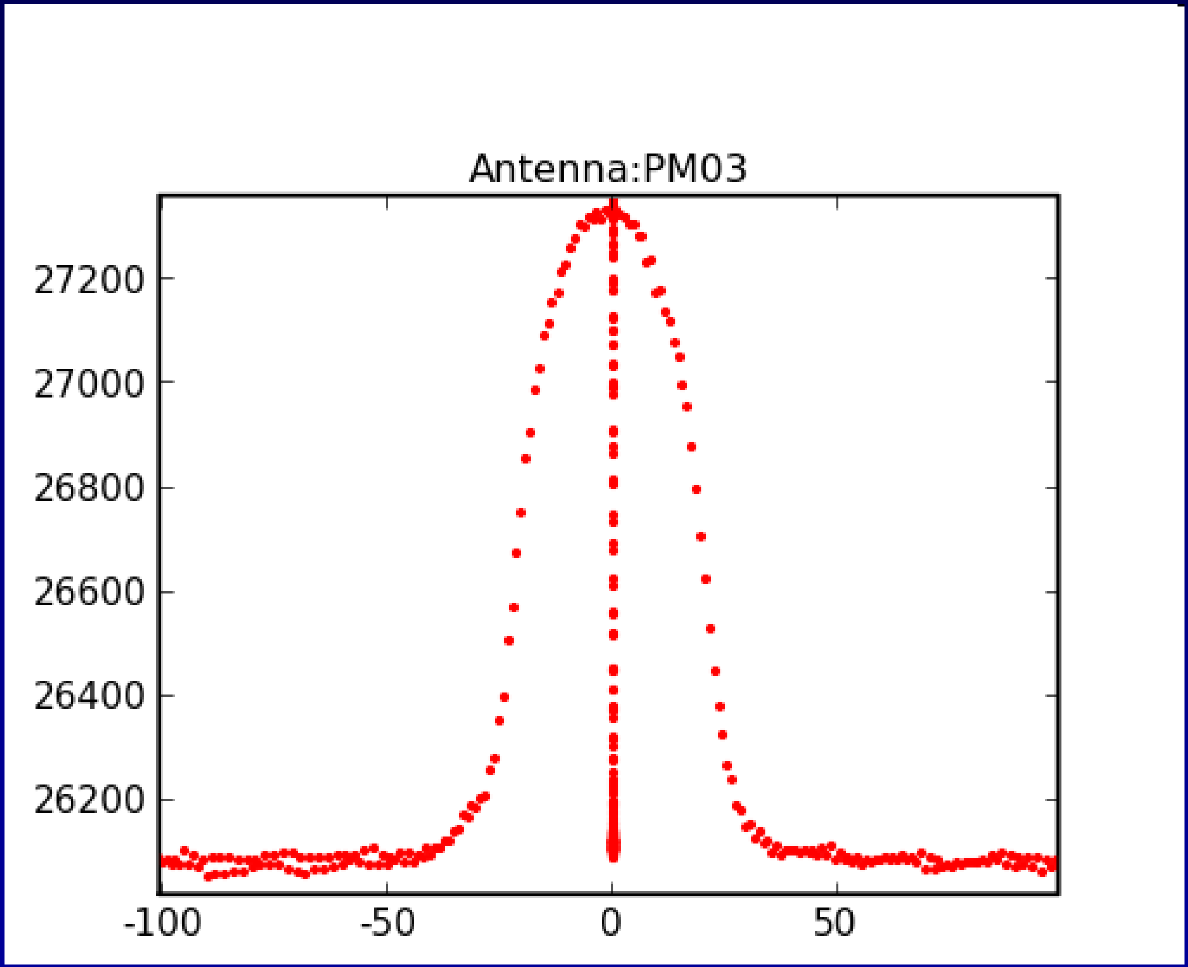


Recent results

Scan of Jupiter at 690 GHz.

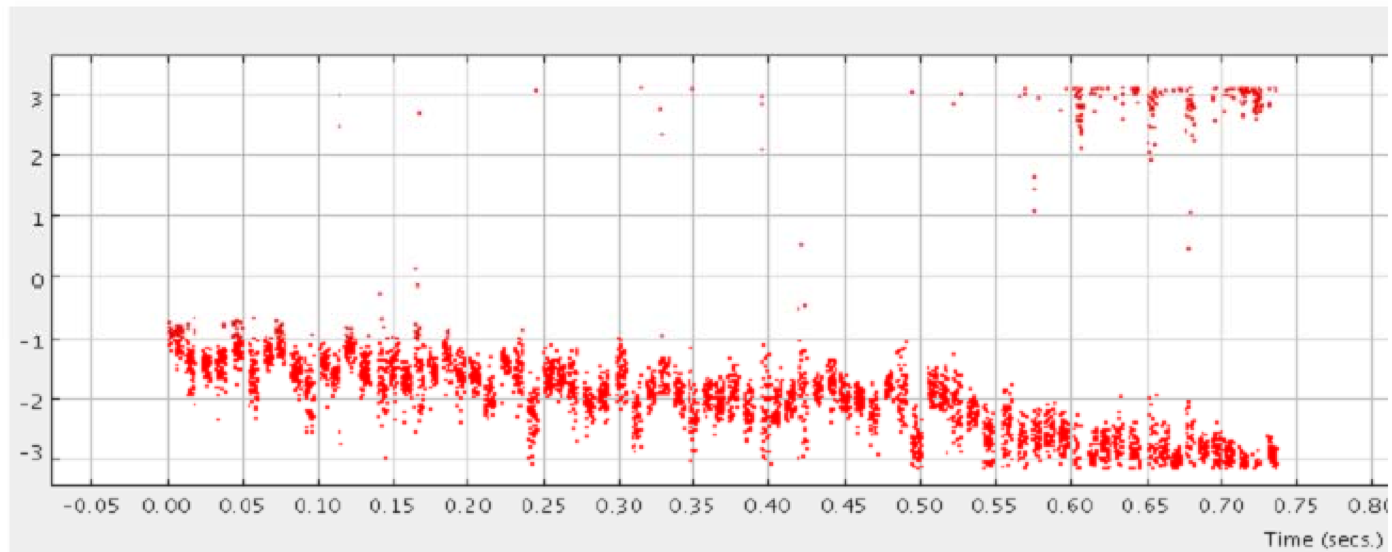
(from the OSF !)

July 4th 2009

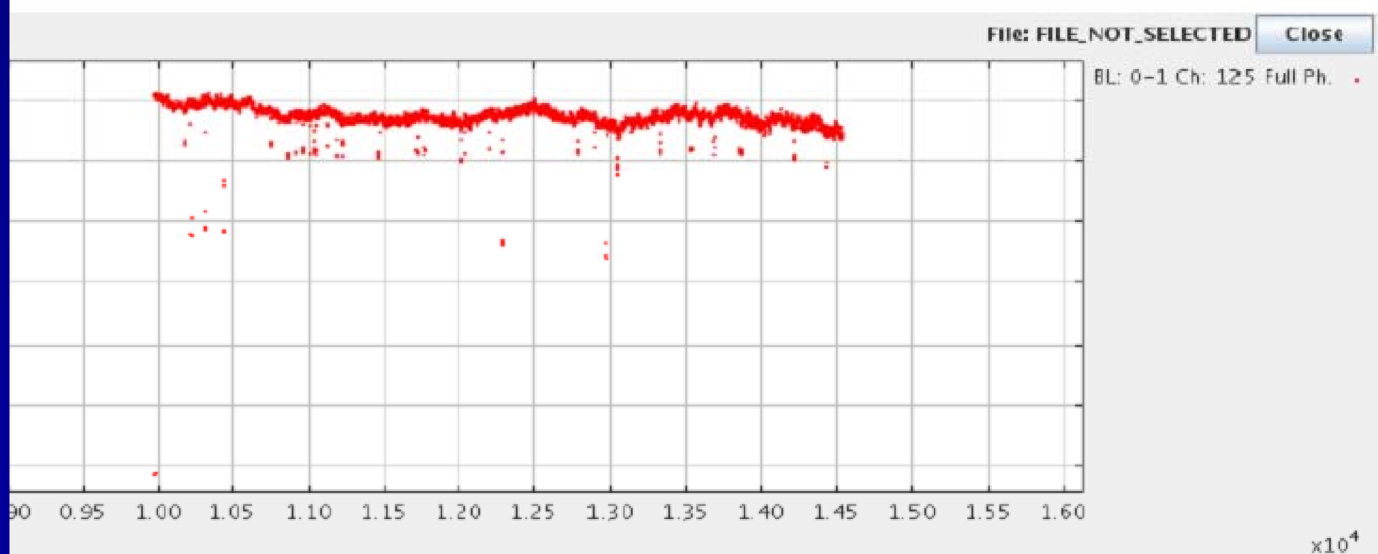


Phase is now reasonably stable

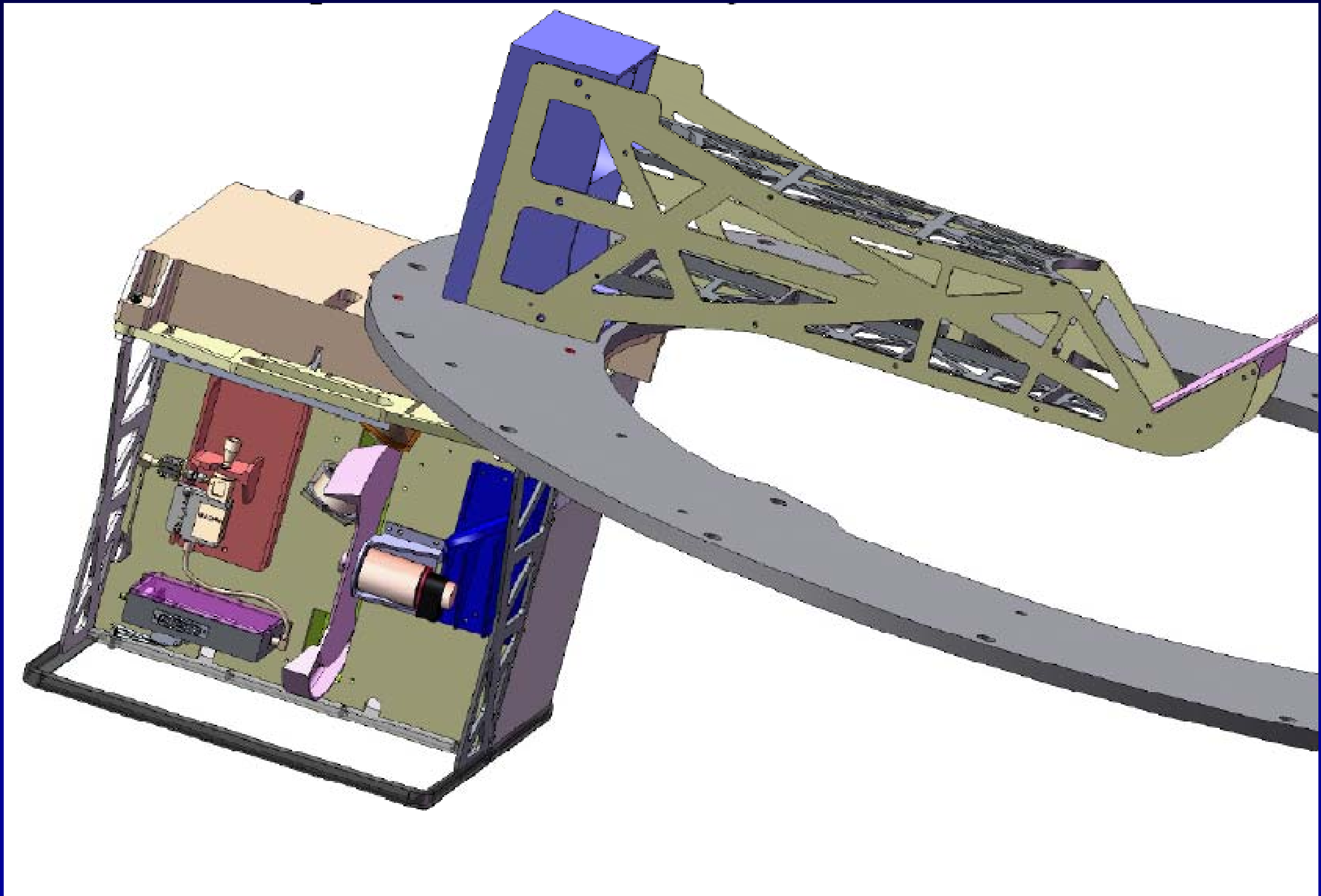
- Upper – ~70 sources

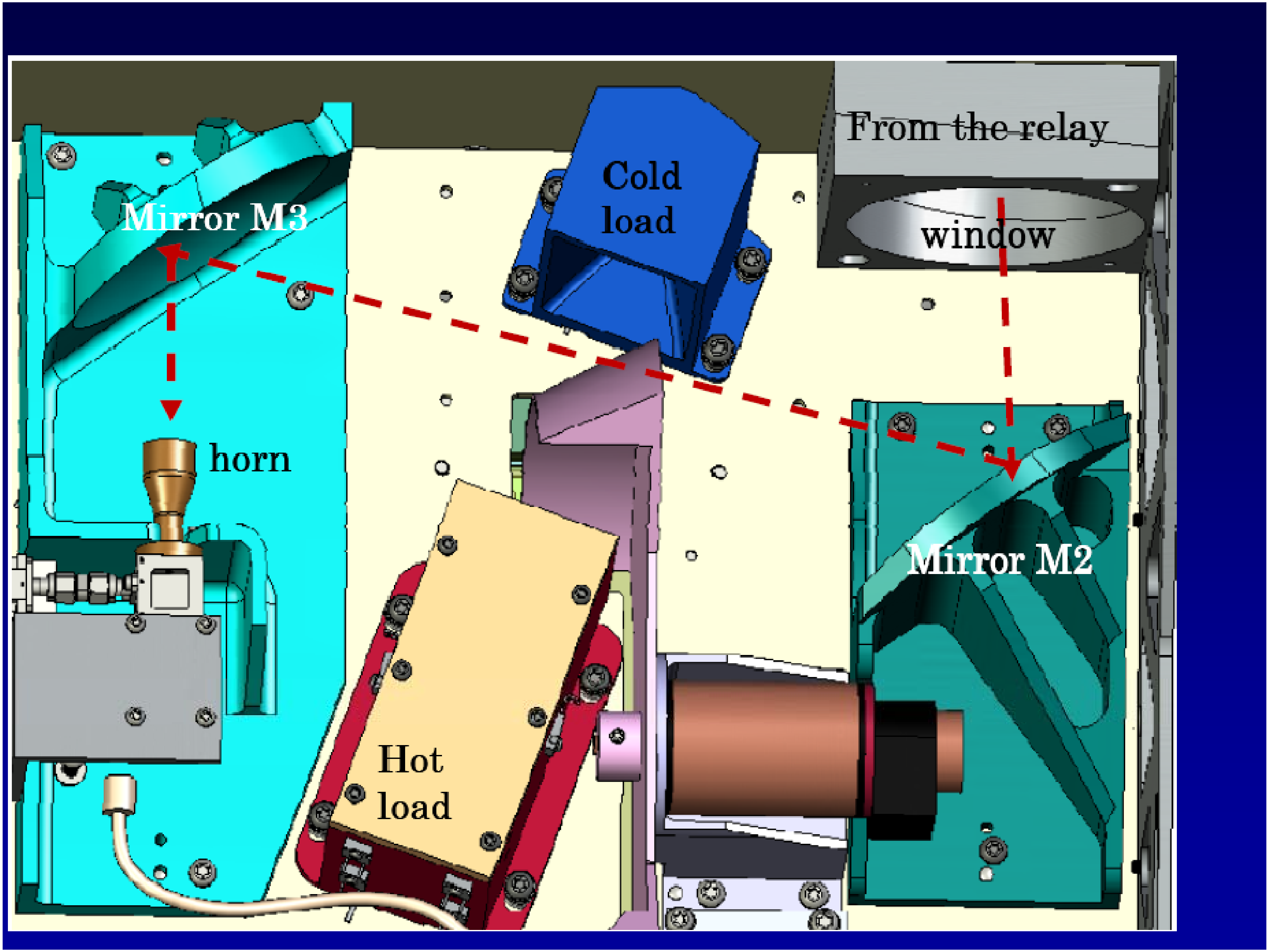


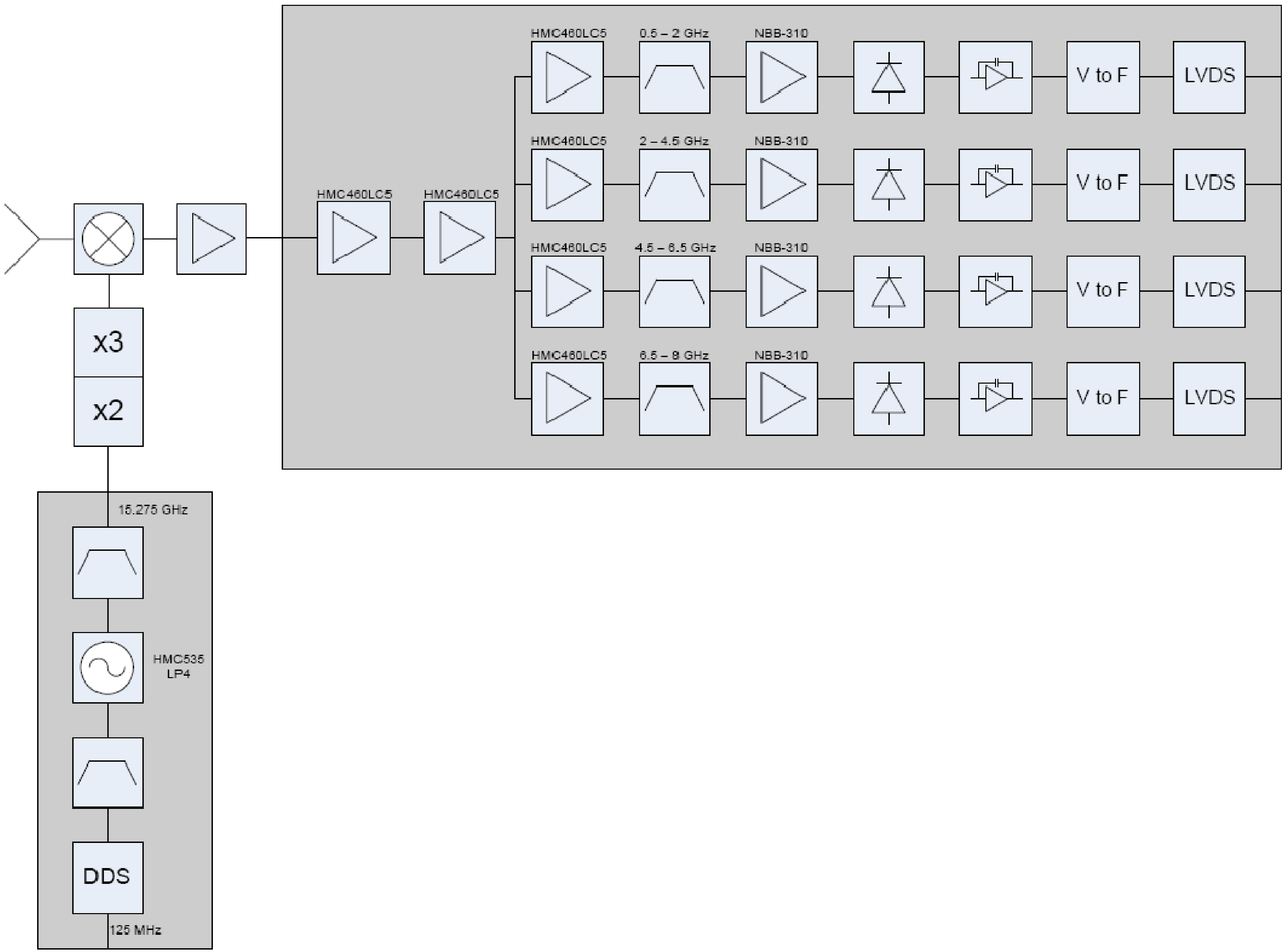
- Lower – long track



183 GHz WVR for phase correction

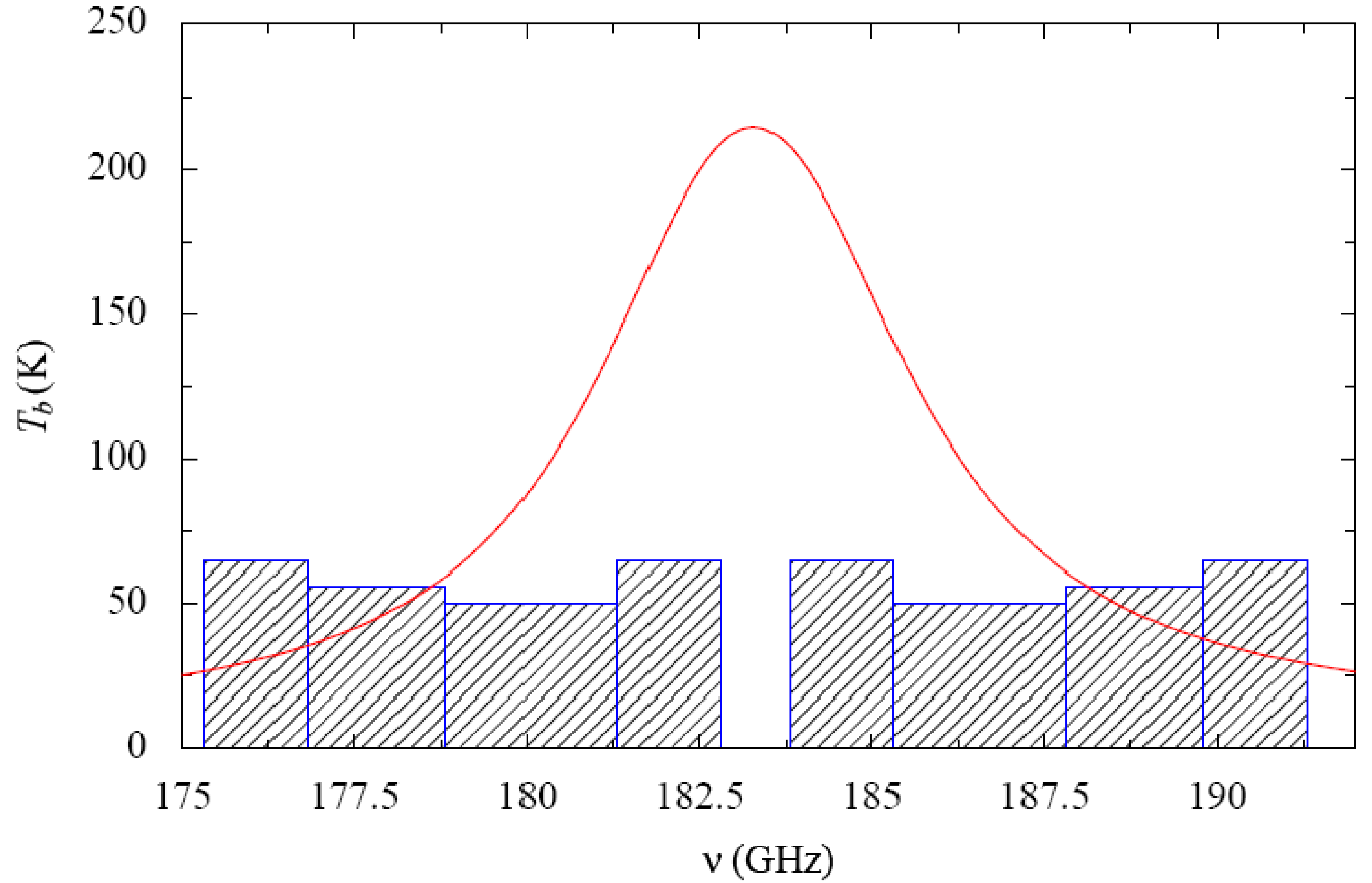



From the relay
Cold
load
window
Mirror M3
horn
Mirror M2
Hot
load

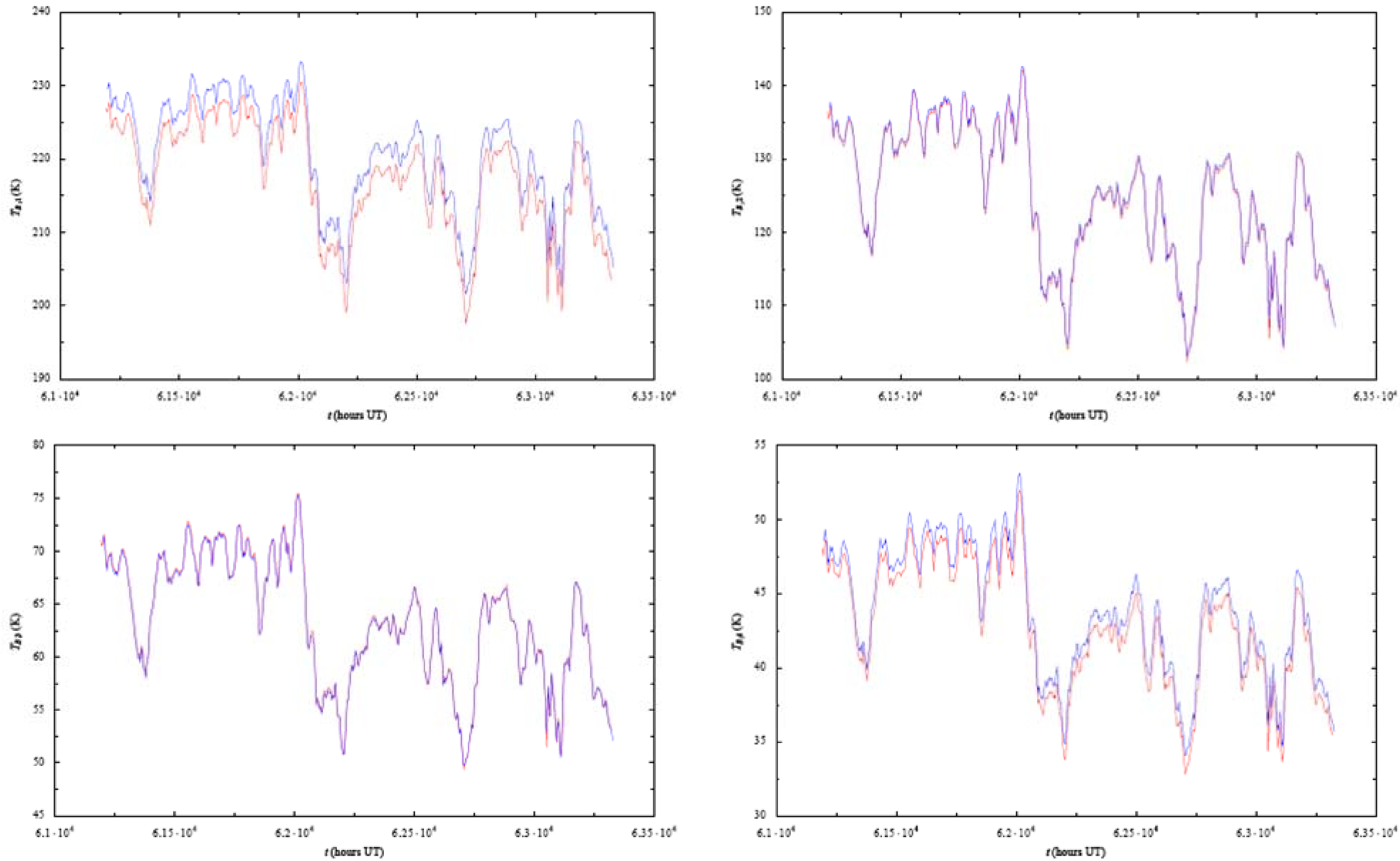


HMC460LC5
0.5 – 2 GHz
NBB-310
V to F
LVDS
HMC460LC5
2 – 4.5 GHz
NBB-310
V to F
LVDS
HMC460LC5
HMC460LC5
HMC460LC5
4.5 – 6.5 GHz
NBB-310
V to F
LVDS
HMC460LC5
6.5 – 9 GHz
NBB-310
V to F
LVDS
x3
x2
15.275 GHz
HMC535
LP4
DDS
125 MHz

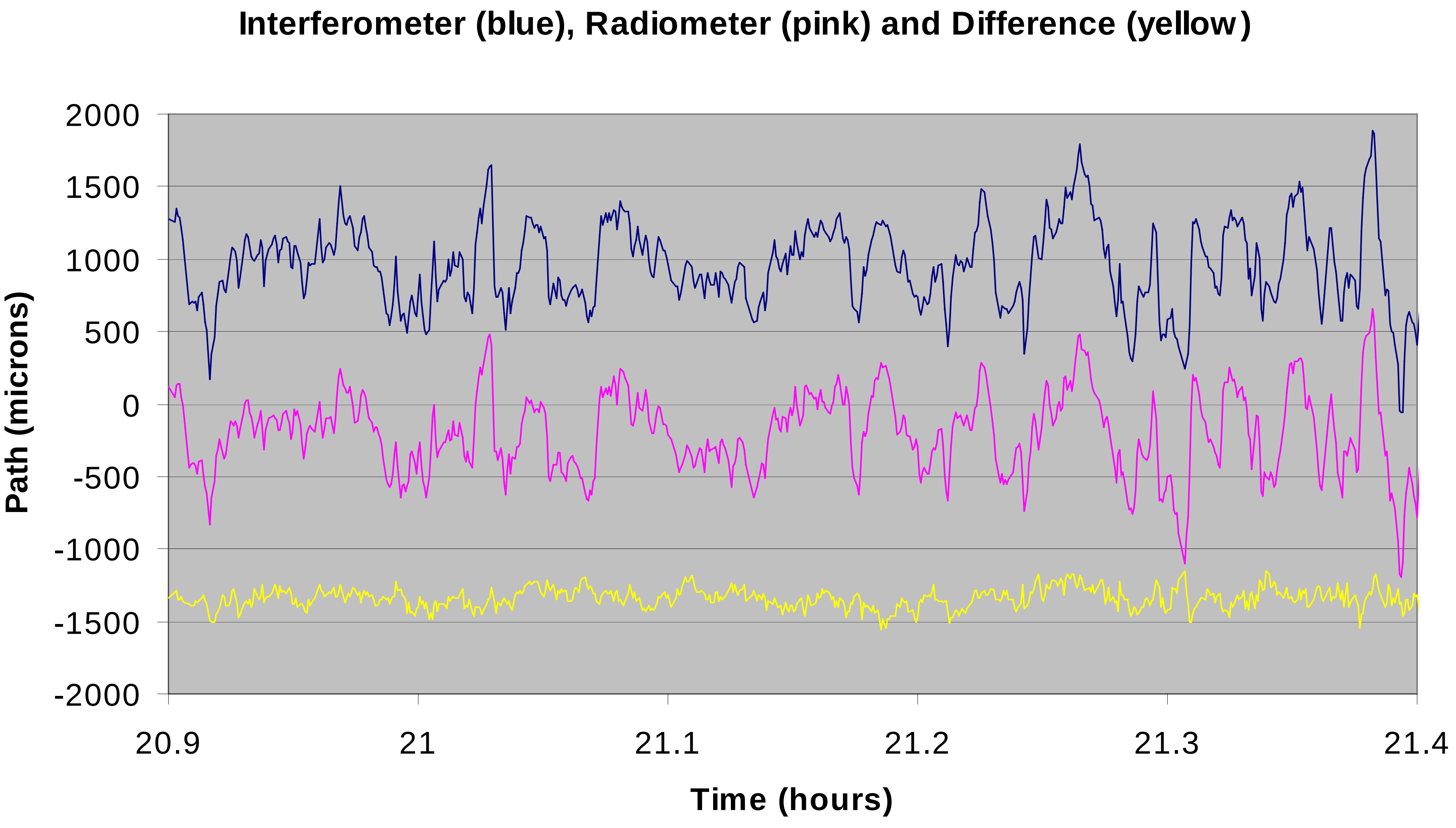
Radiometers are double-sideband Schottky devices with four IF channels covering the line and Trx ~1000K



Two radiometers looking straight up at high site



Test of phase correction at the SMA



Next steps

- Sept/Oct: First tests of antennas and other systems at high site (5000m) while interferometer tests continue at 2900m
- Move second antenna up mid-November
- Goal is to have fringes with 3 antennas by the end of 2009
- Commissioning and Science Verification in full swing throughout 2010.
- Early Science start in second half of 2011.
- Inauguration in late 2012.

Early Science

- At least 16 antennas with 4 receiver bands on all of them, more on some.
- Number of antennas available will build up quite fast through 2011 and 2012. (Sensitivity goes as N, imaging complexity as N^2.)
- Baselines of at least 250m (1km goal) to start with, moving on to long baselines in 2012.
- Proper systems for user support in place:
  - applications process
  - tools for preparing observations
  - user-friendly data reduction system (CASA)
  - support from ALMA Regional Centers

Goals for end of 2012

- Regular operation with ≥ 50 fully-equipped[1] antennas. (This includes both 12m and 7m antennas.)
- All antenna stations complete, providing synthesis mapping with high fidelity using the full set of array configurations.
- Simultaneous operation of ≥ 4 subarrays possible.
- Capability for combining data from the12m array with data from the ACA including "zero-spacing" data, and multi-configuration images
- Linear and circular polarization, including mosaicing of sources that are larger than the primary beam.
- High time resolution observations, e.g. of solar flares.
- All major software systems available and working in a way that allows astronomers who are not synthesis experts to use ALMA.
- Accurate calibration of all the above.

[1]Fully-equipped means a minimum of four receiver bands – typically bands 3, 6, 7, and 9 plus some of 4, 8 and 10, plus a full set of electronics, radiometers and calibration devices.

www.alma.cl

The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership of Europe, North America and East Asia in cooperation with the Republic of Chile. ALMA is funded in Europe by the European Organization for Astronomical Research in the Southern Hemisphere (ESO), in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC) and the National Science Council of Taiwan (NSC) and in East Asia by the National Institutes of Natural Sciences (NINS) of Japan in cooperation with the Academia Sinica (AS) in Taiwan. ALMA construction and operations are led on behalf of Europe by ESO, on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI) and on behalf of East Asia by the National Astronomical Observatory of Japan (NAOJ). The Joint ALMA Observatory (JAO) provides the unified leadership and management of the construction, commissioning and operation of ALMA.