Onsala Space Observatory

The Swedish National Facility for Radio Astronomy
(VR & Chalmers)
located on the peninsula Onsala, 45 km S of Göteborg

25m cm-wave telescope

- built 1963
- the first high-sensitive maser radiometers
- detected interst. CH
- first intercontinental VLBI

- operating range: 0.8-1.8, 4.5-5.3, 6.0-6.7 GHz
- receivers: HEMT, $T_{rec} \approx$ 40-80 K
- spectrometers: >0.002 km/s resolution, <12.8 MHz bandwidth

20m mm-wave telescope

- built 1976
- largest mm-wave telescope for several year => astronomical molecular line discoveries
- first mm-wave VLBI

- operating range: 18-50, 84-116 GHz
- receivers: HEMT ($T_{rec} \approx 80$ K),
  SIS ($T_{rec} \approx 100$ K)
- spectrometers: >0.04 km/s resolution, <1.3 GHz bandwidth
- 2.2-12 GHz for astro/geo-VLBI

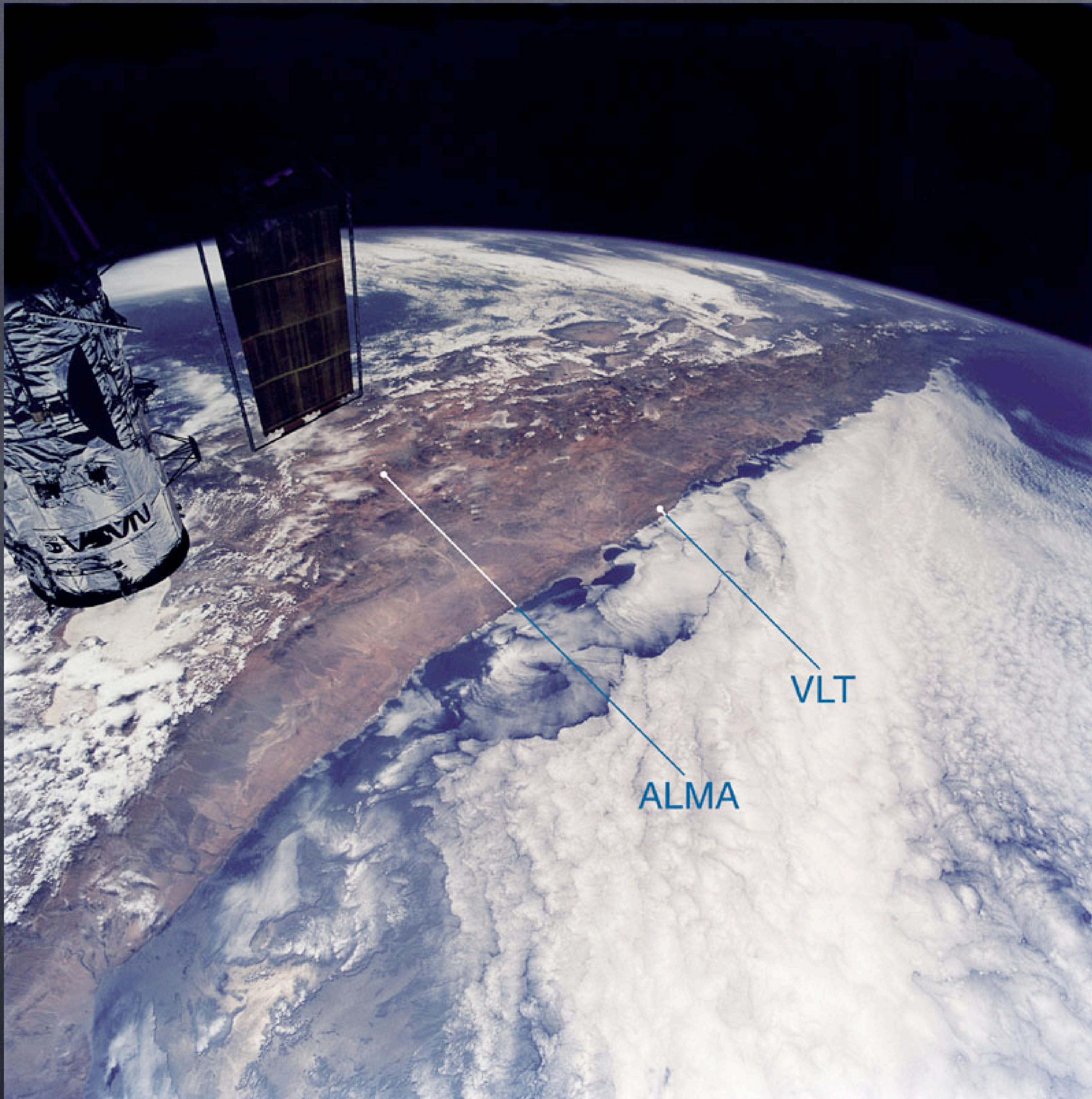
The Swedish-ESO Submillimetre Telescope (SEST), La Silla, Chile

1988

-

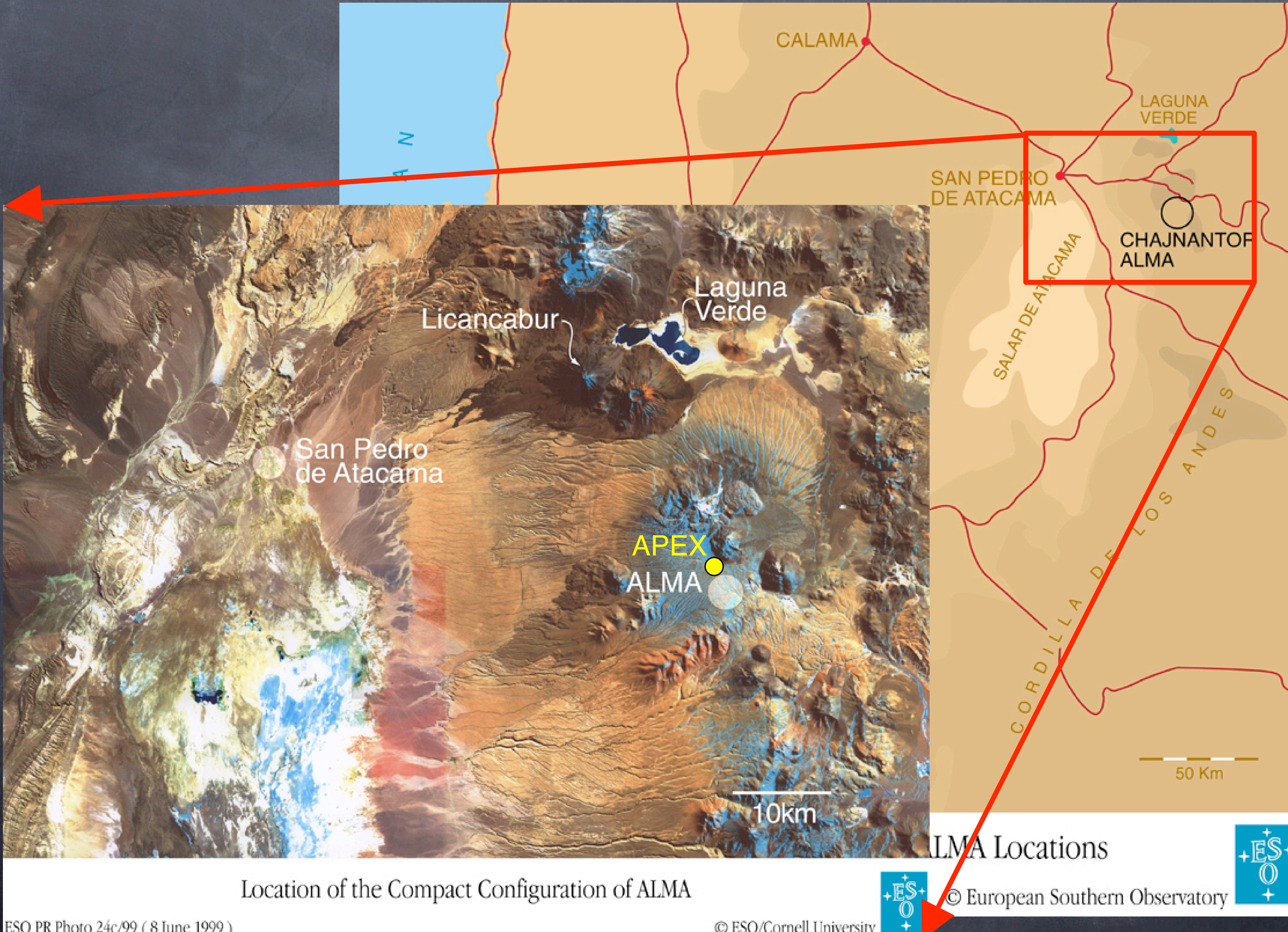
2003

A very successful project,
now in mothballs



View of Northern Chile (NASA Space Shuttle)

ESO PR Photo 24b/99 (8 June 1999)

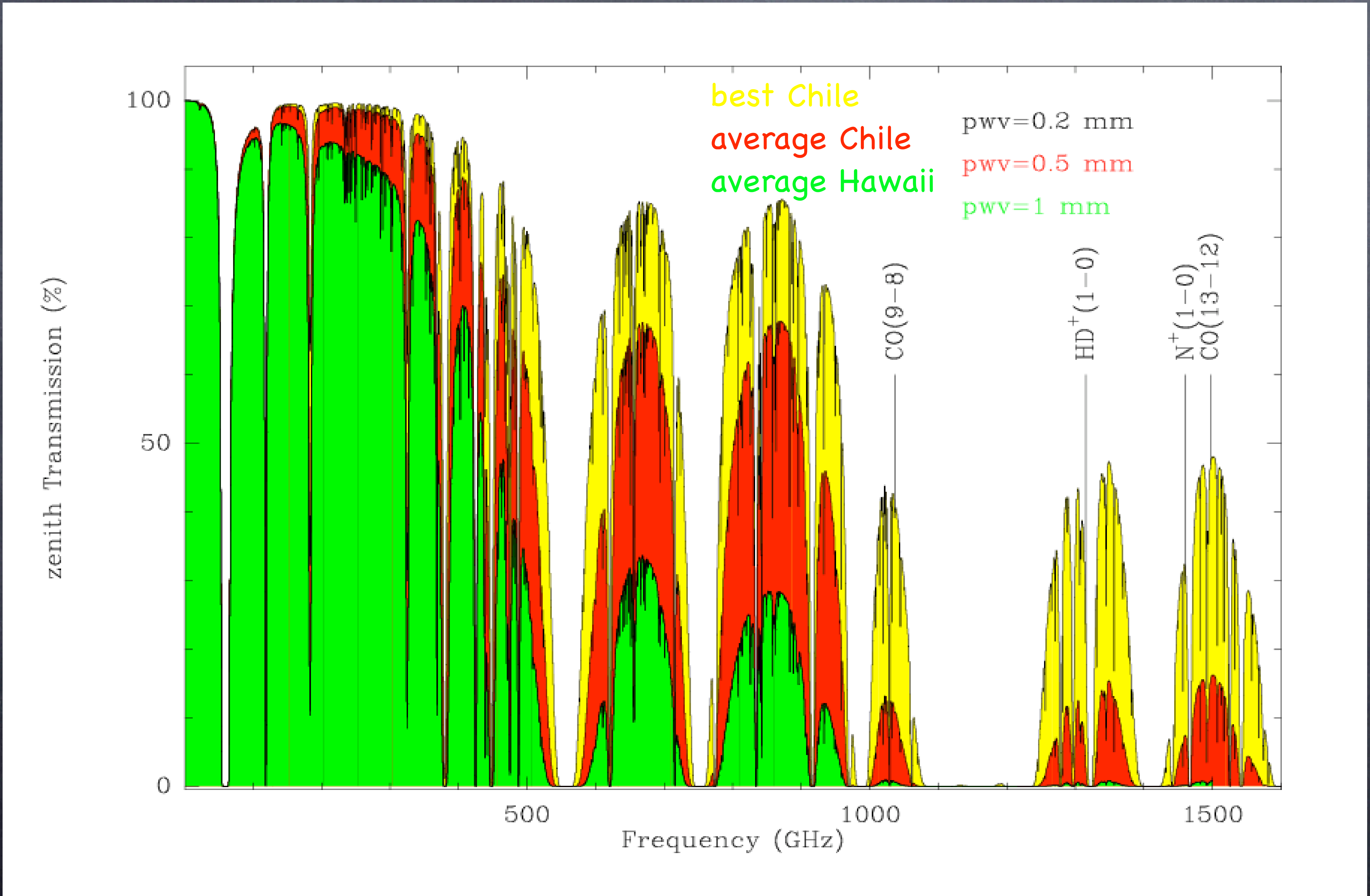


CALAMA
LAGUNA VERDE
SAN PEDRO DE ATACAMA
SALAR DE ATACAMA
CHAJNANTOR ALMA
CORDILLA DE LOS ANDES
50 Km
ALMA Locations
© European Southern Observatory
Laguna Verde
Licancabur
San Pedro de Atacama
APEX
ALMA
10km
Location of the Compact Configuration of ALMA
ESO PR Photo 24c/99 (8 June 1999)
© ESO/Cornell University

Llano Chajnantor (5100 m alt.) in the Chilean Atacama desert

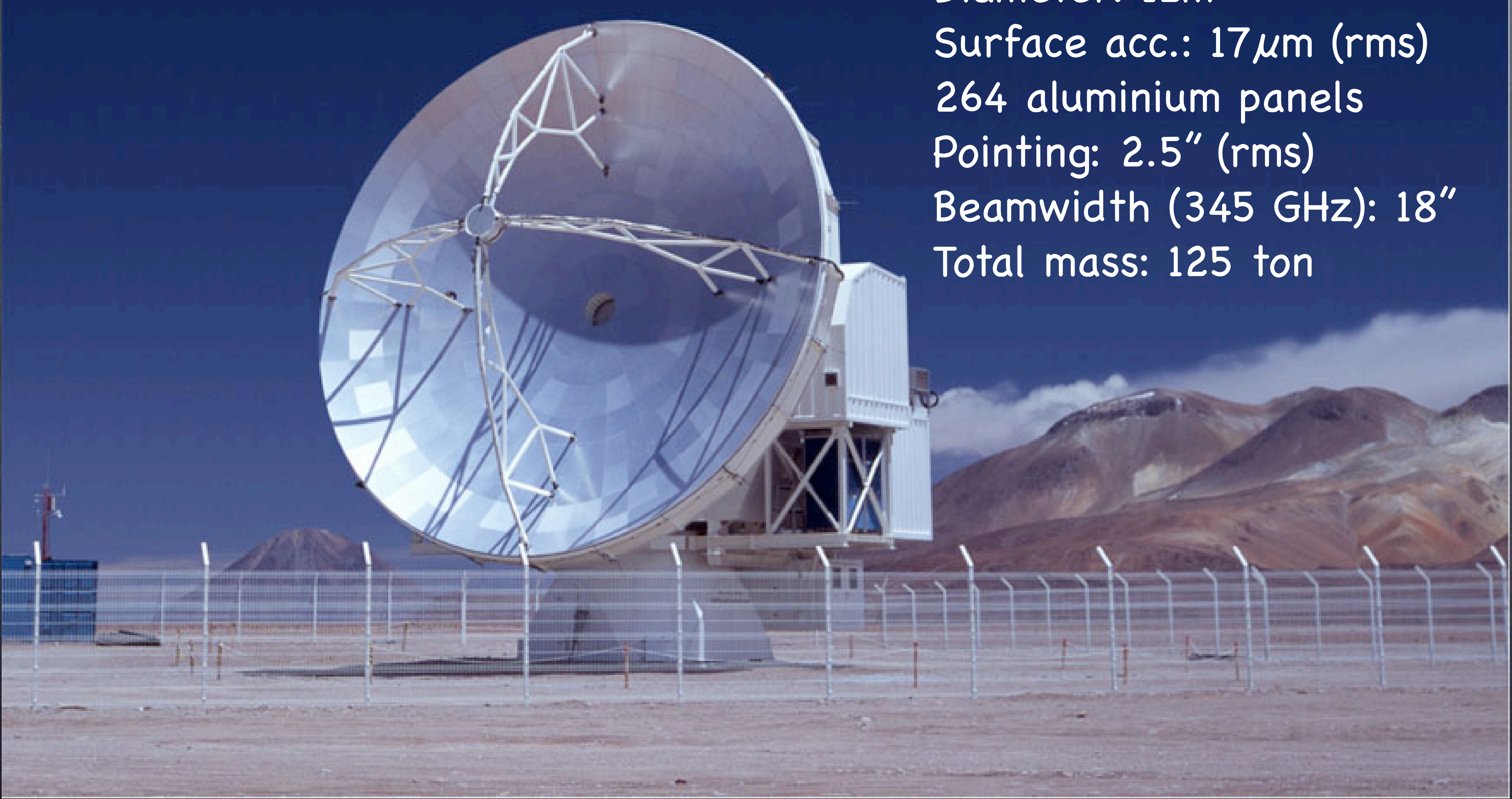
Atacama Pathfinder Experiment (APEX)

Atmospheric transmission



The Bolivian winter Jan-March

Division of costs and observing time
MPG 50%, ESO 27%, Sweden 23% (Chile 10%)



- Diameter: 12m
- Surface acc.: 17μm (rms)
- 264 aluminium panels
- Pointing: 2.5″ (rms)
- Beamwidth (345 GHz): 18″
- Total mass: 125 ton

Holographic measurements of surface accuracy

Receiver development:

Group for advanced receiver development ,Chalmers
group leader Victor Belitsky

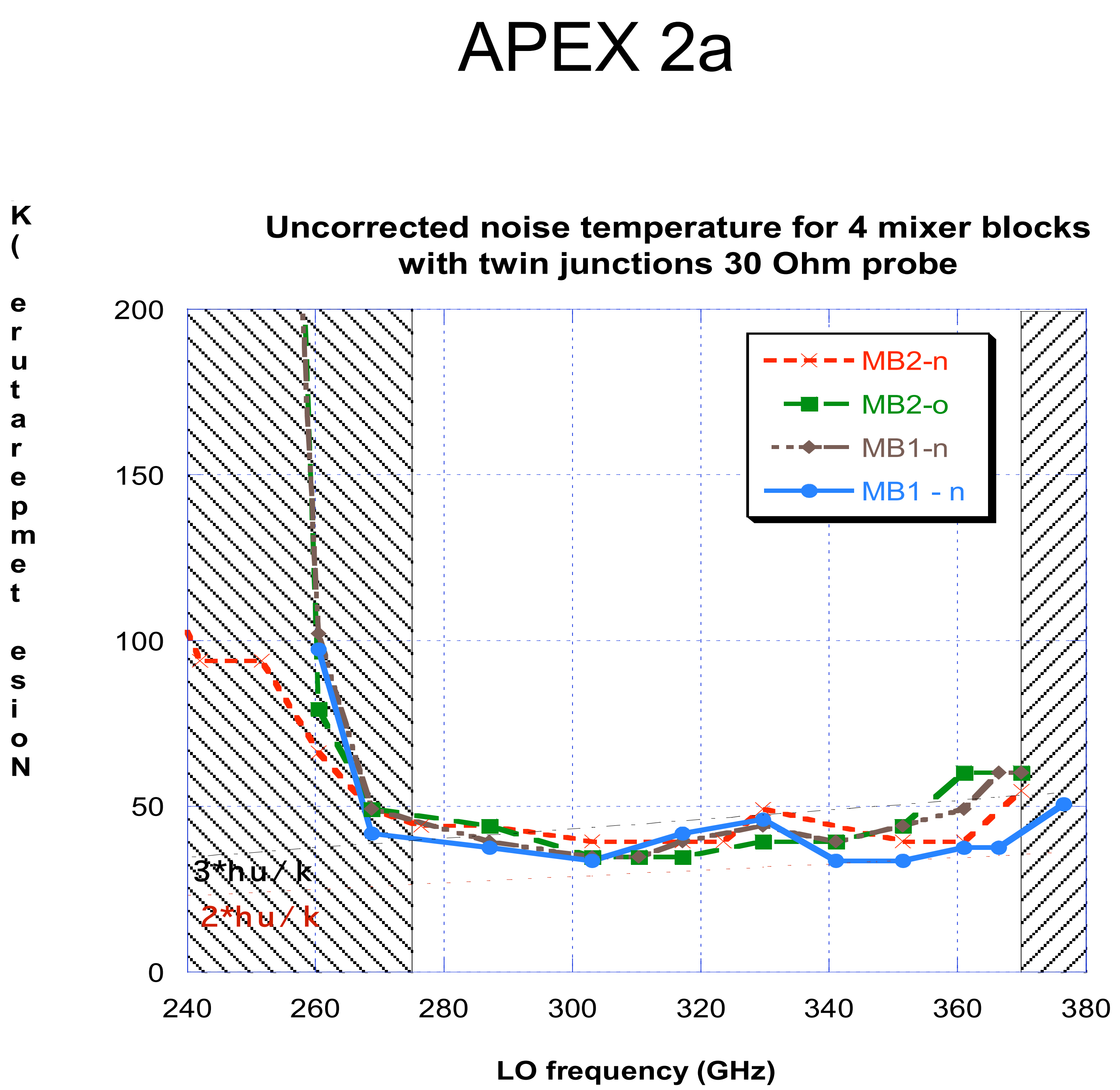
Common-user heterodyne instruments:

APEX:
- APEX-1, SIS 211-275 GHz
- APEX-2, SIS 275-370 Ghz
- APEX-3, SIS 385-500 GHz
- APEX-T2, HEB 1250-1400 GHz

- APEX-4, 600-700 GHz
- APEX-5, 780-950 GHz

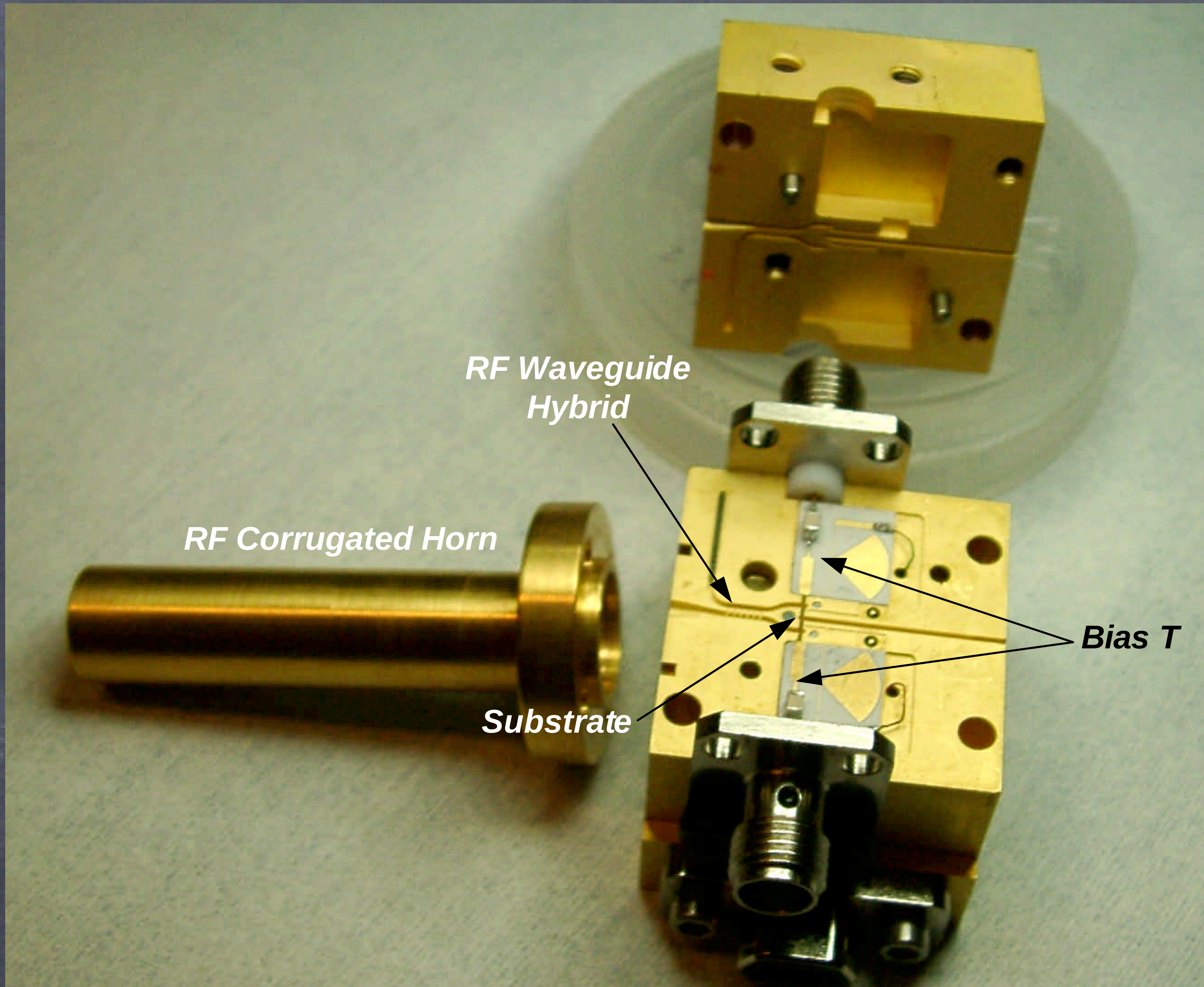
not approved,
nor financed

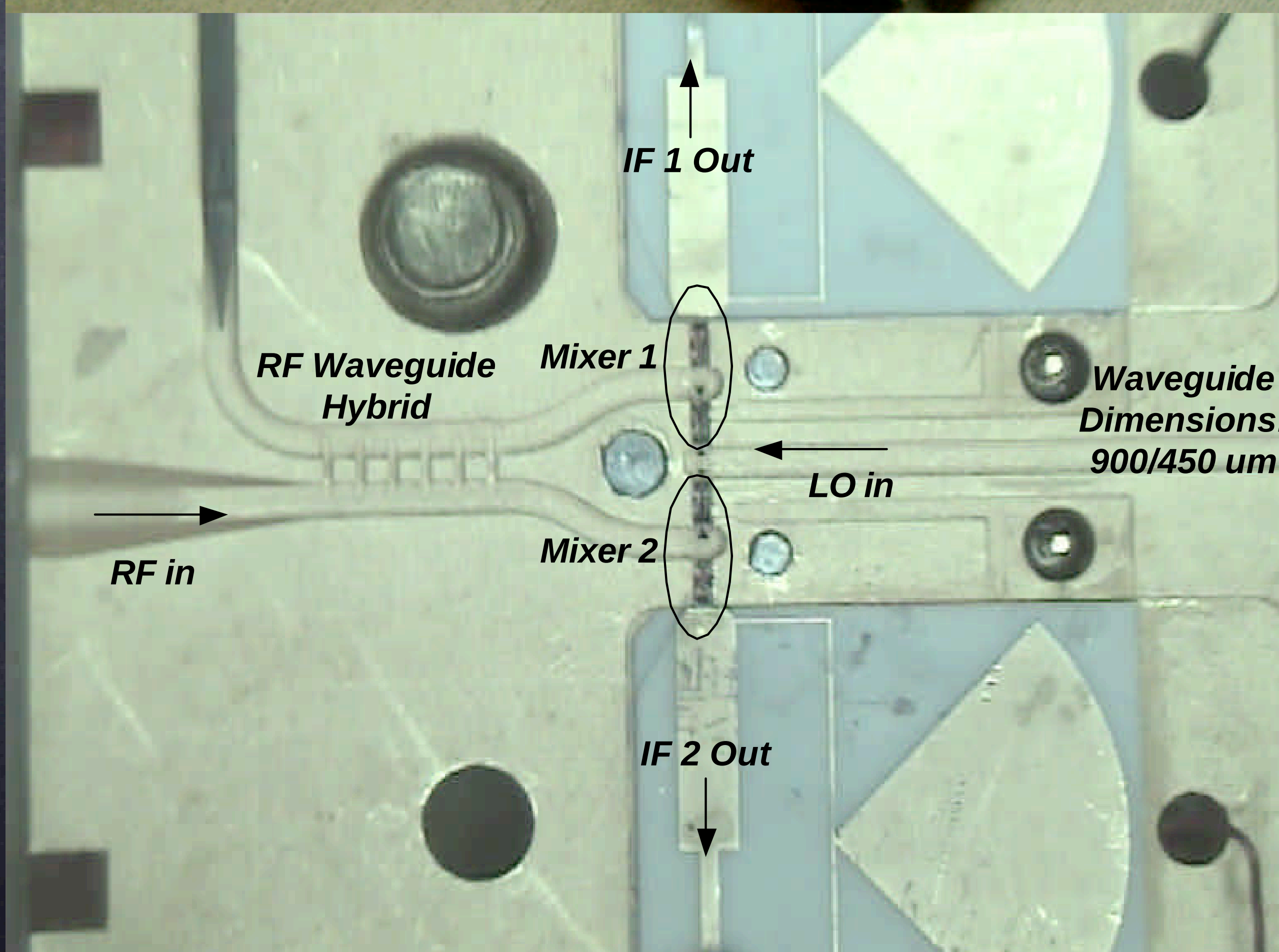
APEX2a: 350 GHz SIS heterodyne receiver

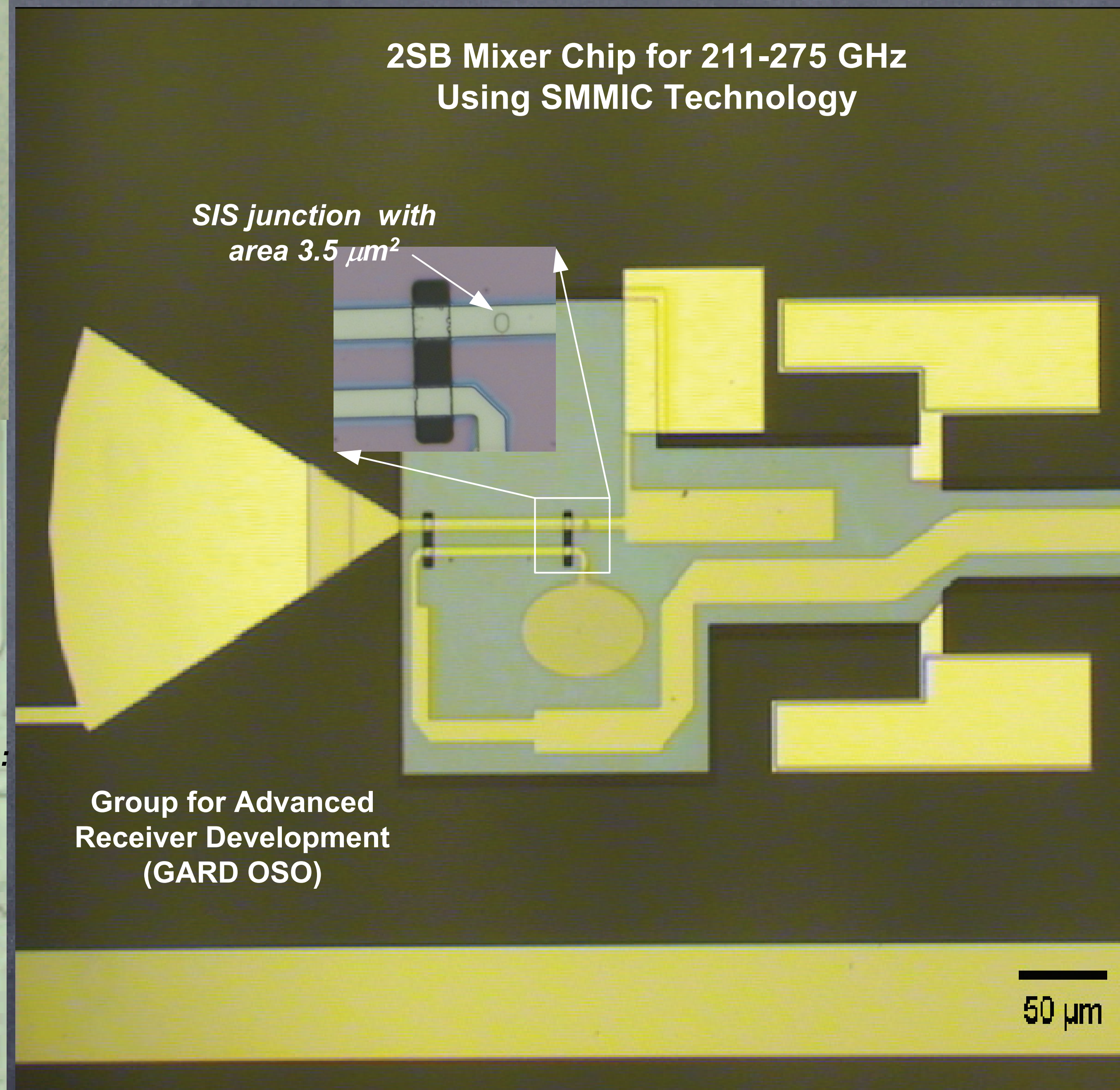


hf/k = 16.5 K

APEX1 SIS receiver at 230 GHz (1.3 mm)







Additional instruments

- LABOCA: 300 element bolometer array, 870 μm

- SABOCA: 37 element bolometer array, 350 μm

- 300 element bolometer array at 2mm, for the Sunyayev-Zeldovich effect

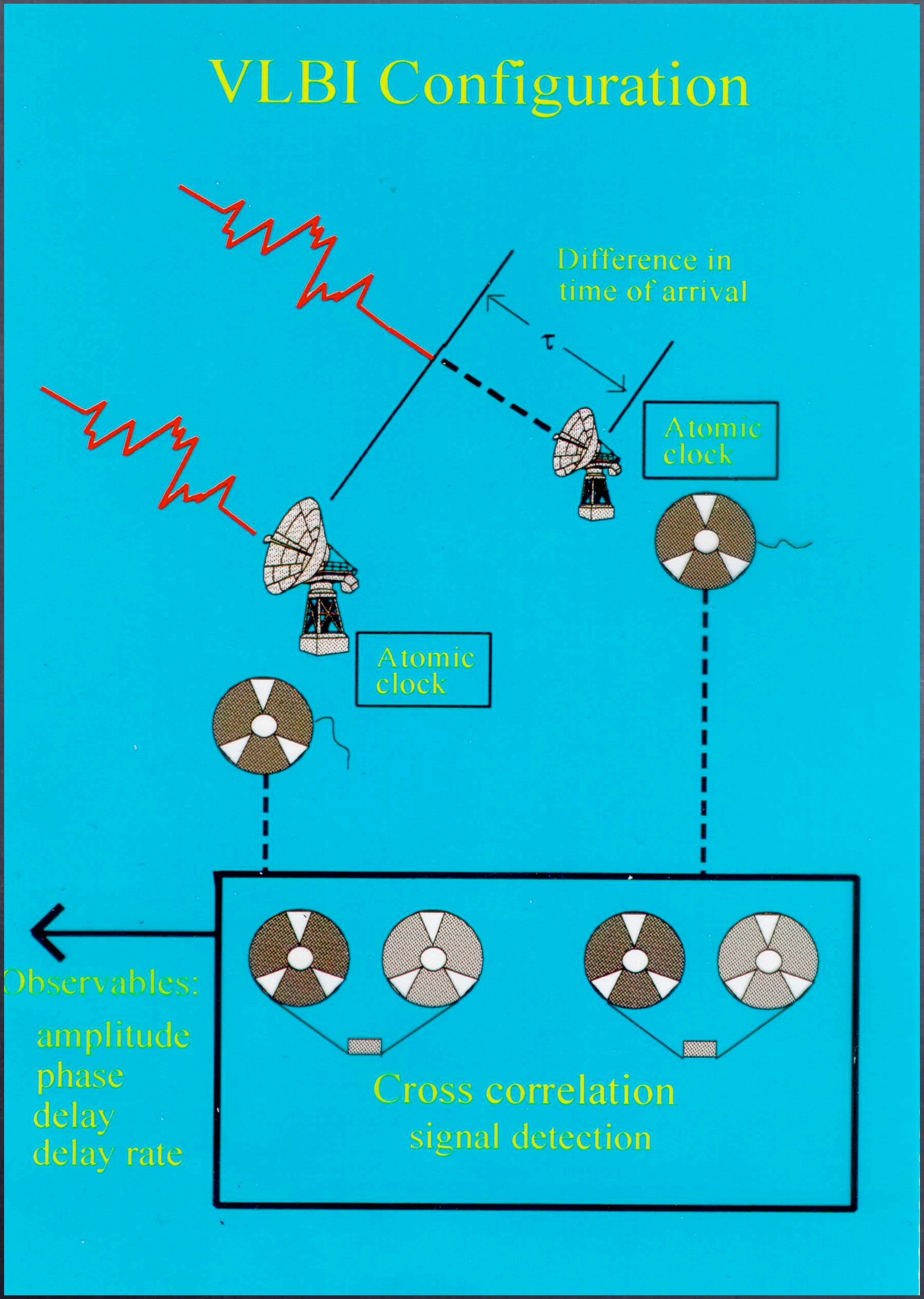
- FLASH: heterodyne receiver at 490 and 810 GHz

- CHAMP+: 2x7 element het. rec. array at 670 and 870 GHz

Sequitor (San Pedro de Atacama)

the observing base

Very Long Baseline Interferometry (VLBI)



A much larger telescope is synthesized => much higher angular resolution

OSO-Haystack (US): the first intercontinental baseline (1968)

OSO: the first mm wavelength VLBI yielding an angular resolution of 50 μarcs (1980)

OSO-Haystack: the current e-VLBI record, 512 Mbit/s through "dedicated light path" (2005)

≈100 days/year is used for VLBI observations at OSO

European VLBI network

Development of high-angular-resolution radio astronomy

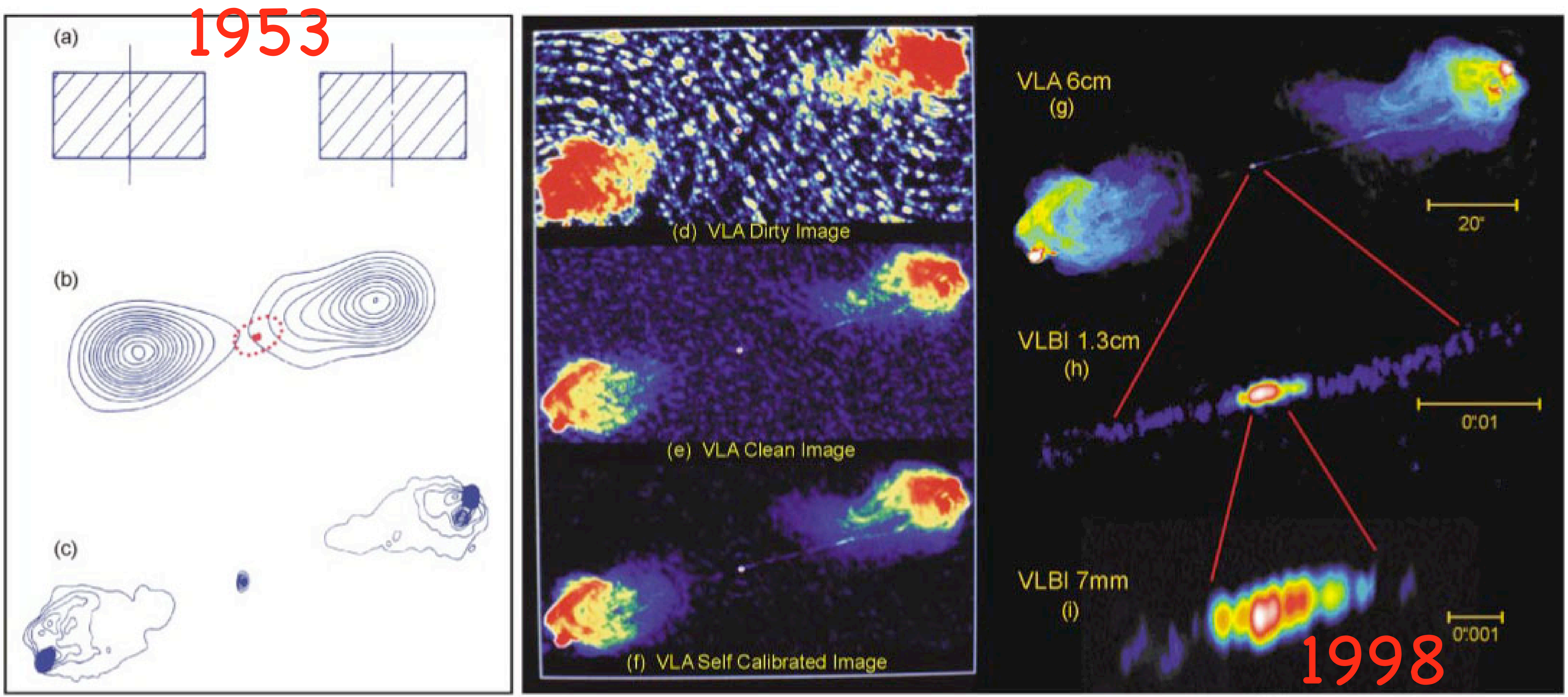


Figure 2 Illustration showing the improvement over the past half century in imaging the radio galaxy Cygnus A. (*a*) The intensity interferometer observations of Jennison & Das Gupta (1953). (*b*) Observations at 20 cm with the Cambridge 1-mile radio telescope (Ryle et al. 1965). (*c*) Observations with the 5-km radio telescope at 6 cm (Hargrave & Ryle 1974). (*d*) 6-cm VLA observations of Perley et al. (1984). (*e*) Same as in (*d*) but with CLEANing. (*f*) Same as (*d*) with CLEANing and self-calibration. (*g*) Self-calibrated CLEAN 6-cm image based on more extensive VLA observations by Carilli and Perley (see Carilli & Harris 1996). (*h*) Image of the nuclear region made with a 13-station global array working at 1.3 cm by Krichbaum et al. (1998). (*i*) The inner region of the nucleus imaged with a resolution of 0.00015 arcsec using an 8-station VLBI array at 7-mm wavelength (Krichbaum et al. 1998). The right hand panel of the figure was provided by T. Krichbaum.

Geodetic VLBI (crustal motion)

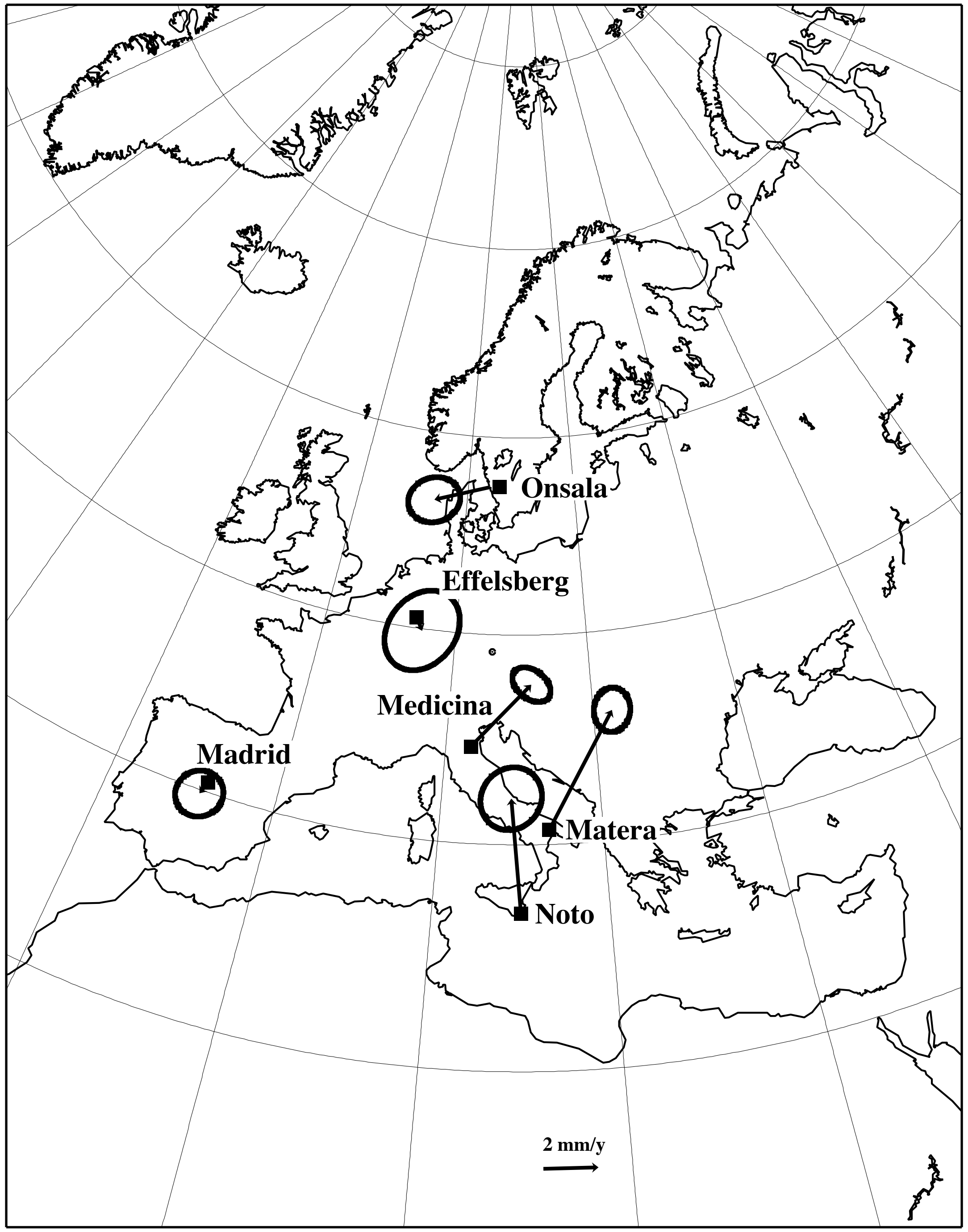


Figure 8: Horizontal site motion

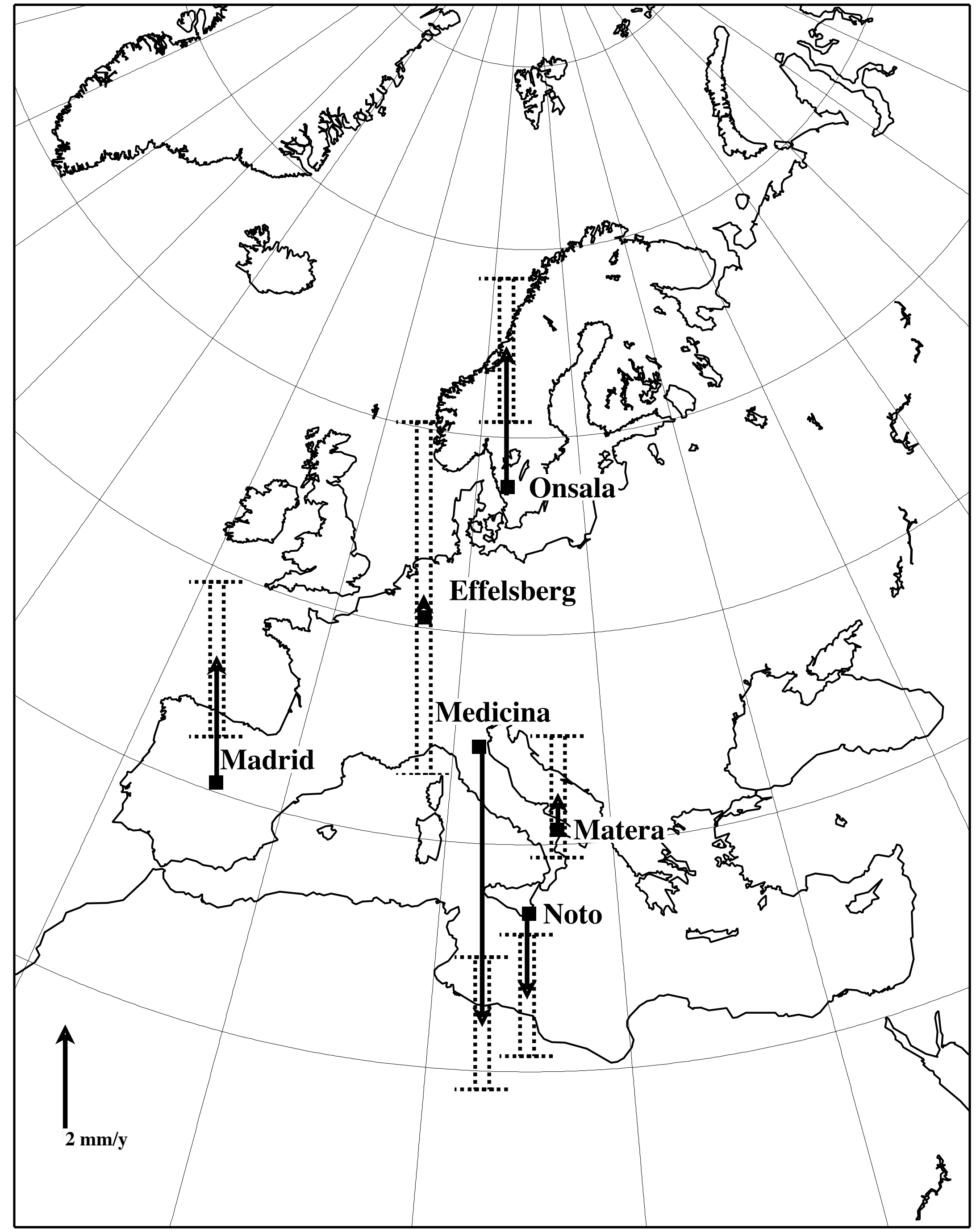
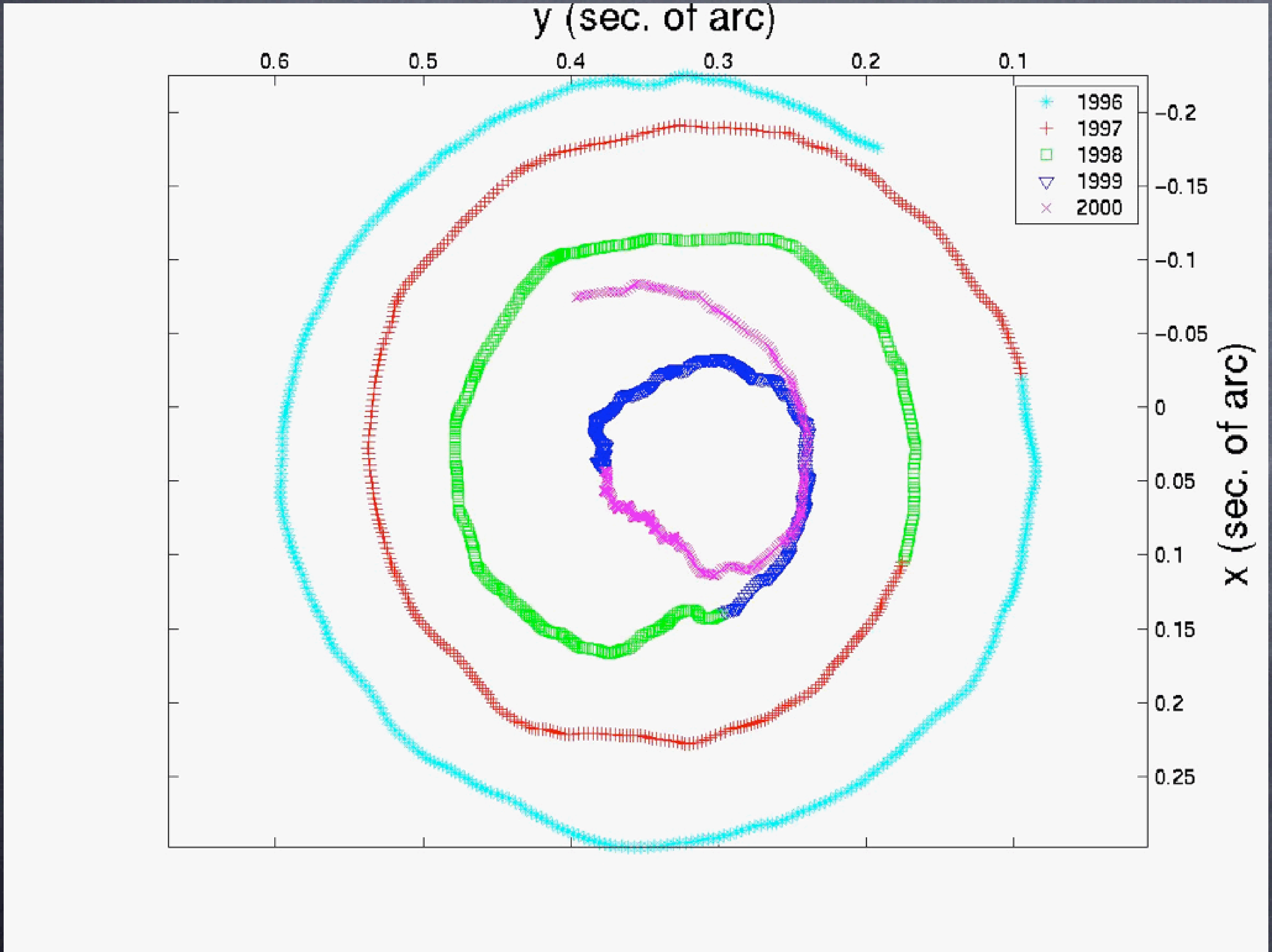


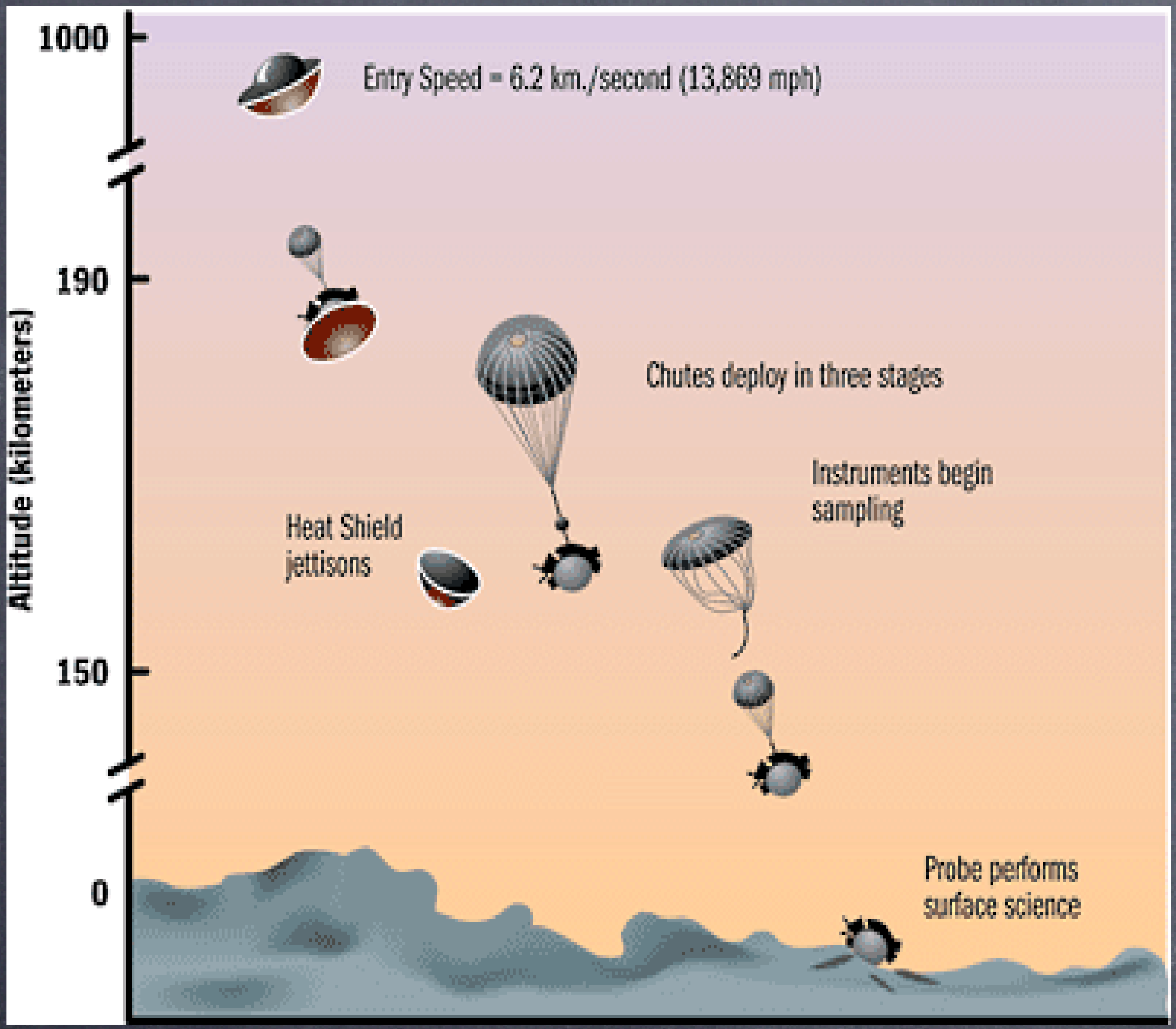
Figure 9: Vertical site motion

Geodetic-VLBI (polar motion)



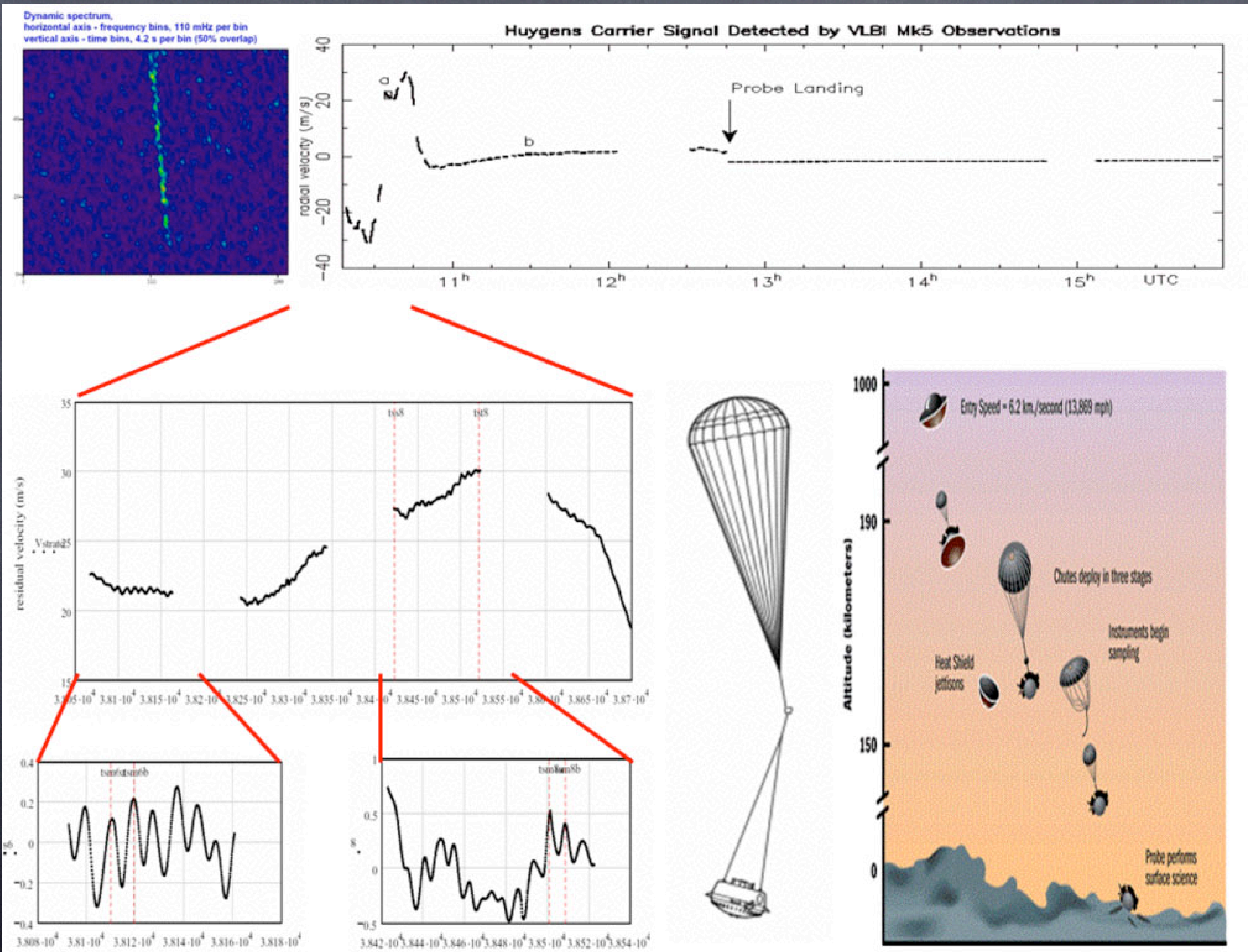
0.1″ ≈ 3m

Huygen's descent to Titan



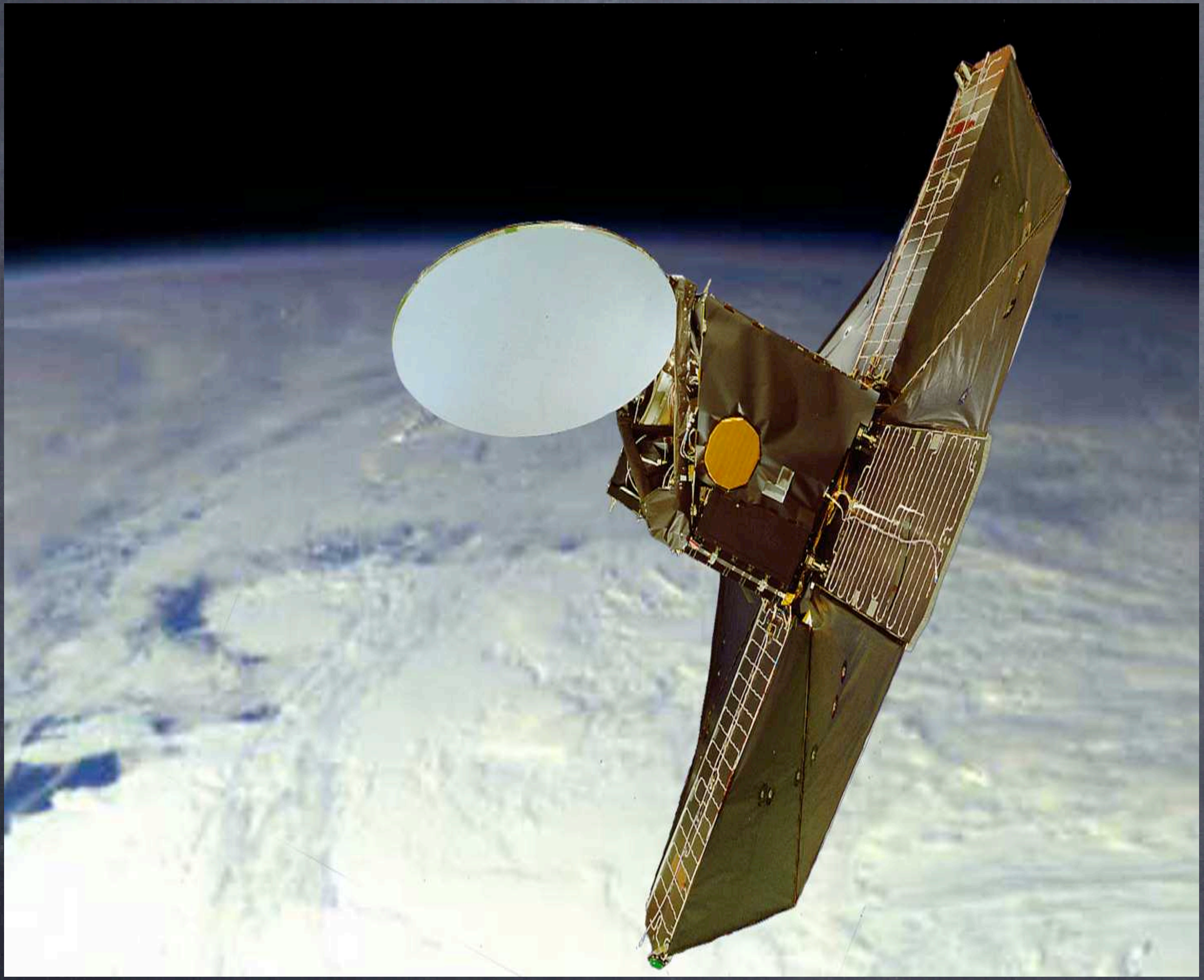
JIVE led Ground based VLBI Observations of the ESA Huygens Probe during its descent through the atmosphere of Titan…

Observations proved to be crucial due to communications failure in Cassini…



Dynamic spectrum,
horizontal axis - frequency bins, 110 mHz per bin
vertical axis - time bins, 4.2 s per bin (50% overlap)
Huygens Carrier Signal Detected by VLBI Mk5 Observations
radial velocity (m/s)
a
b
Probe Landing
UTC
residual velocity (m/s)
Entry Speed = 6.2 km./second (13,869 mph)
Chutes deploy in three stages
Instruments begin sampling
Heat Shield jettisons
Probe performs surface science
Altitude (kilometers)
1000
190
150
0

The Odin astronomy/aeronomy satellite



Participating countries: Sweden, France, Canada, Finland

Launched: Febr. 2001

Radiometer: 119 GHz, 487-585 GHz

Odin data centre at OSO

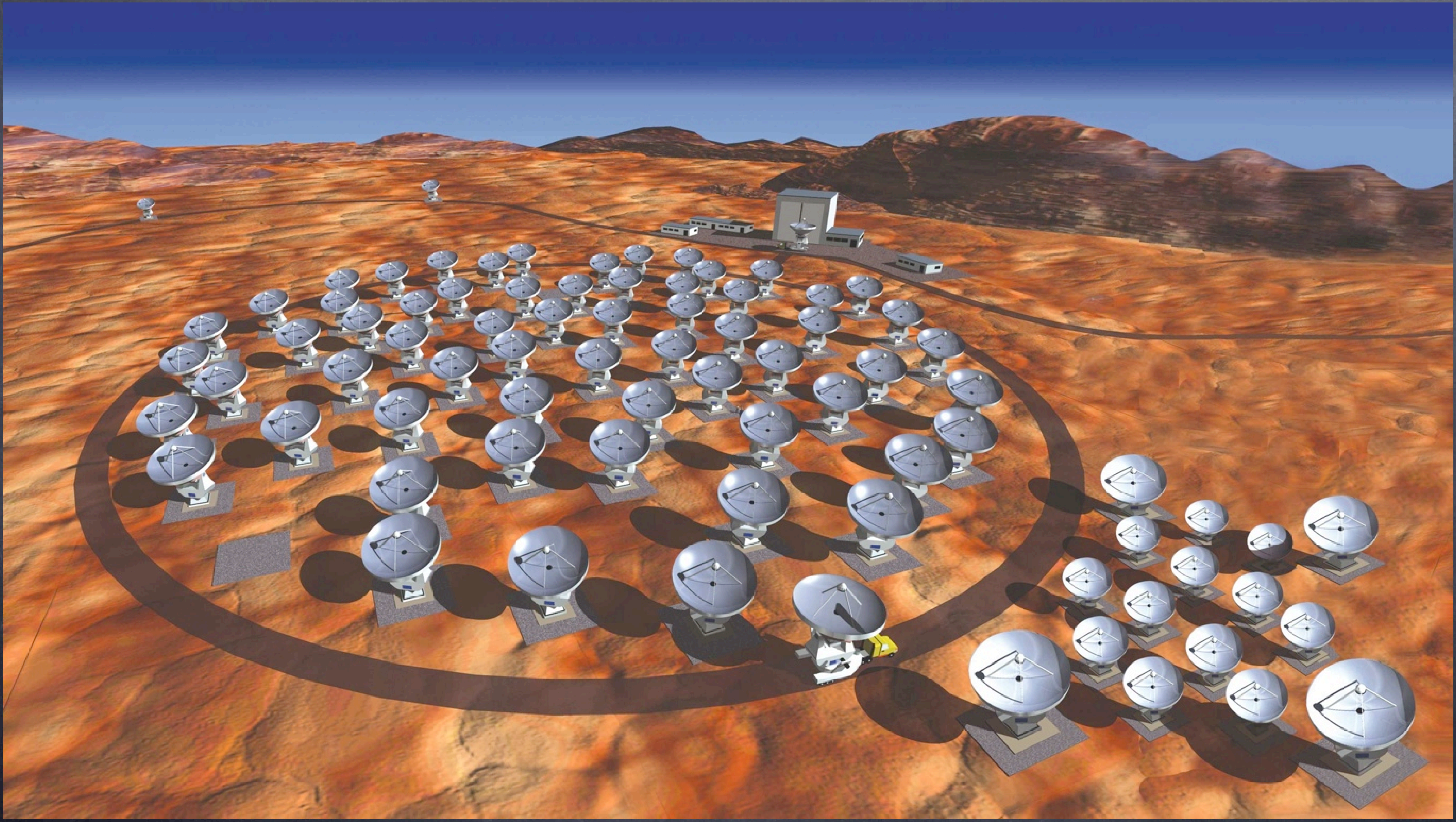
Astronomy and aeronomy project scientists at "OSO"

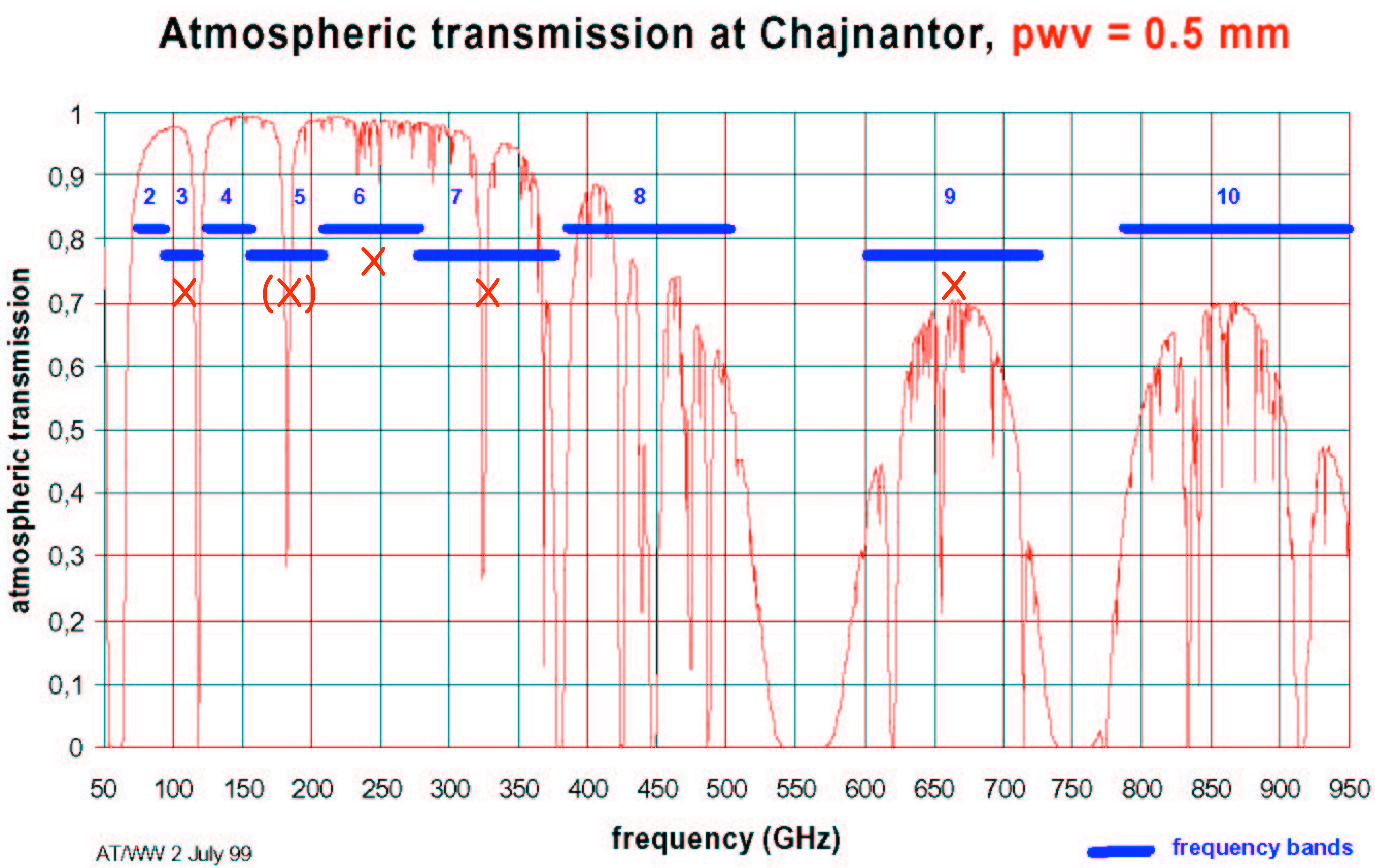
The Atacama Large Millimeter Array (ALMA)

- A collaboration between Europe, USA, and Japan to build:
  50 x 12m antenna array
  4 x 12m + 12 x 7m compact array

- Initially 4 bands: 115, 230, 345, 670 GHz
- Baselines: from 150 m to 18.5 km
- Angular resolution: < 0.01"
- Flux sensitivity: < 1 mJy in 10 min.
- Data rate: ≈ 10 Tbit/s

ALMA




Atmospheric transmission at Chajnantor, pwv = 0.5 mm
atmospheric transmission
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
frequency (GHz)
2
3
4
5
6
7
8
9
10
(X)
AT/WW 2 July 99
frequency bands

Continuous "Zoom" configuration (devised by John Conway, OSO)

- From 150-m to 4 km in a quasi-continuous zoom

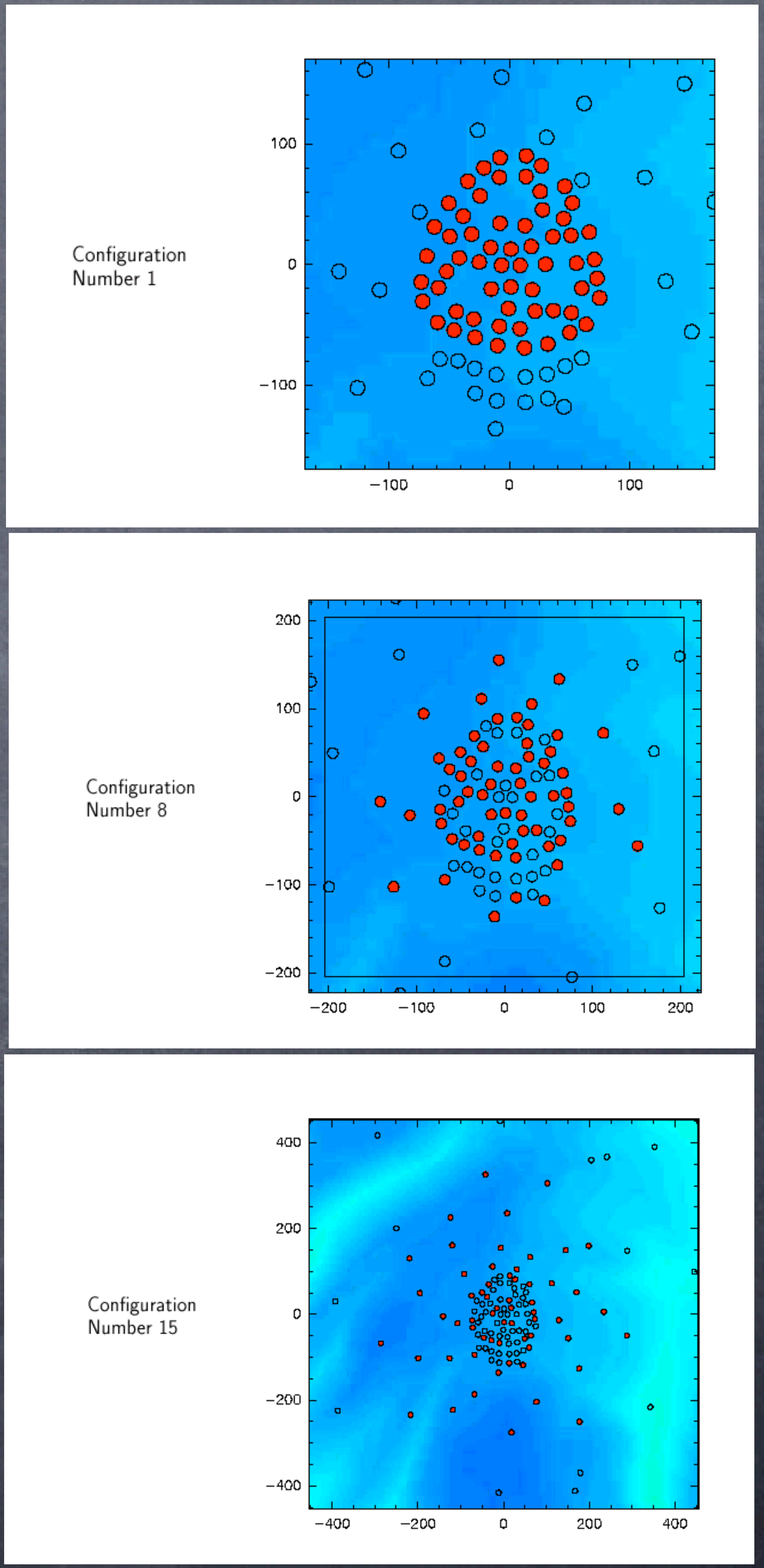
- Homogeneous beam properties for intermediate configurations

- Well defined move strategy

- 33 different configurations with 3 antenna moved each time, or 24 configurations with 4 antennas moved each time

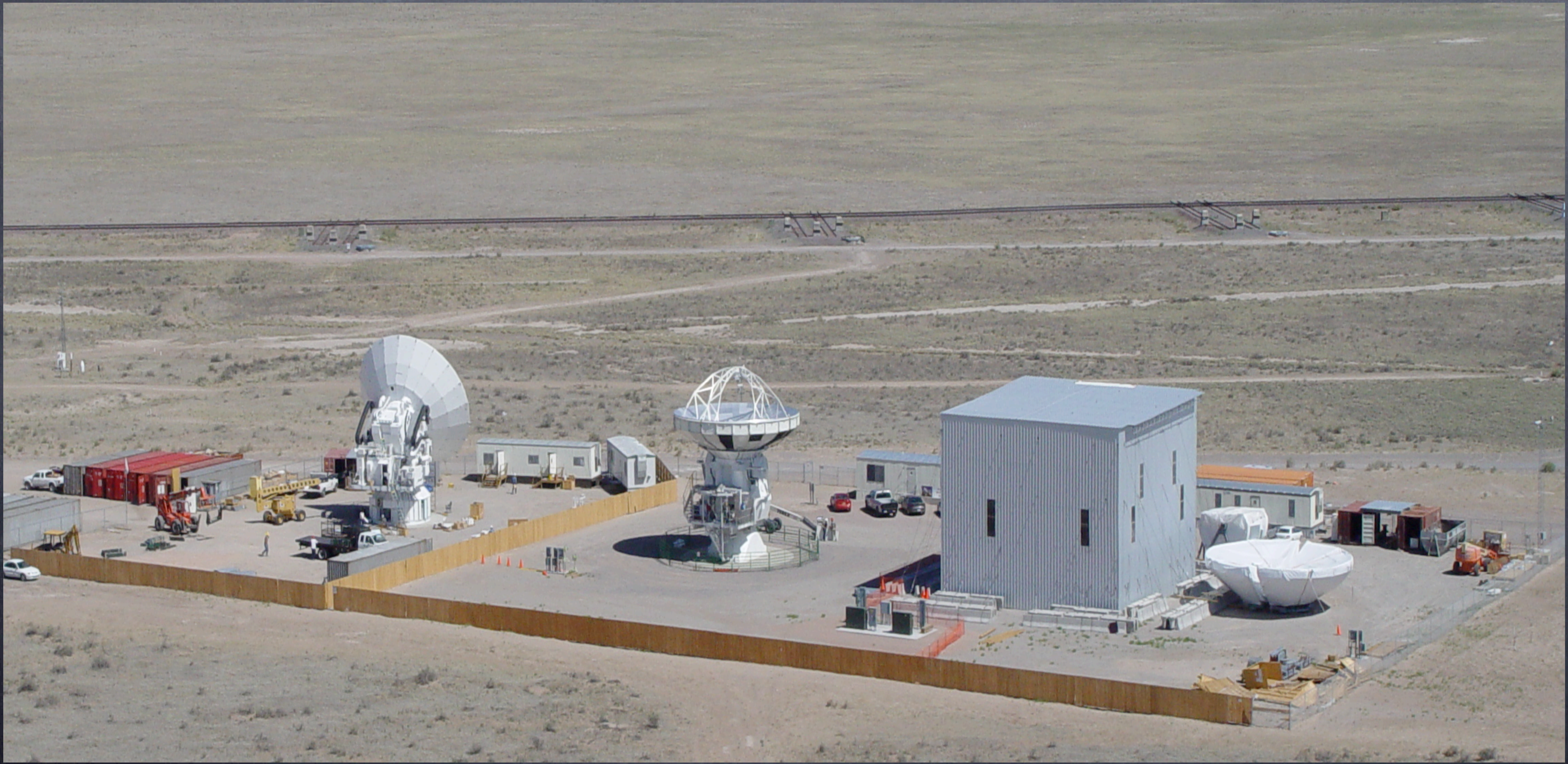
- Resolution changes by 9% (or 14 % for 4 ant.) at each step

- Flexible scheme: less than 2% sensitivity loss if configuration does not exactly match the required angular resolution.



Two antenna designs!!!!

Two prototypes (Alcatel & Vertex) at VLA site for testing



ALMA compared to existing mm-wave arrays

Collecting area 6000 m^2 (x 6 over existing)
Speed up time for a given sensitivity:

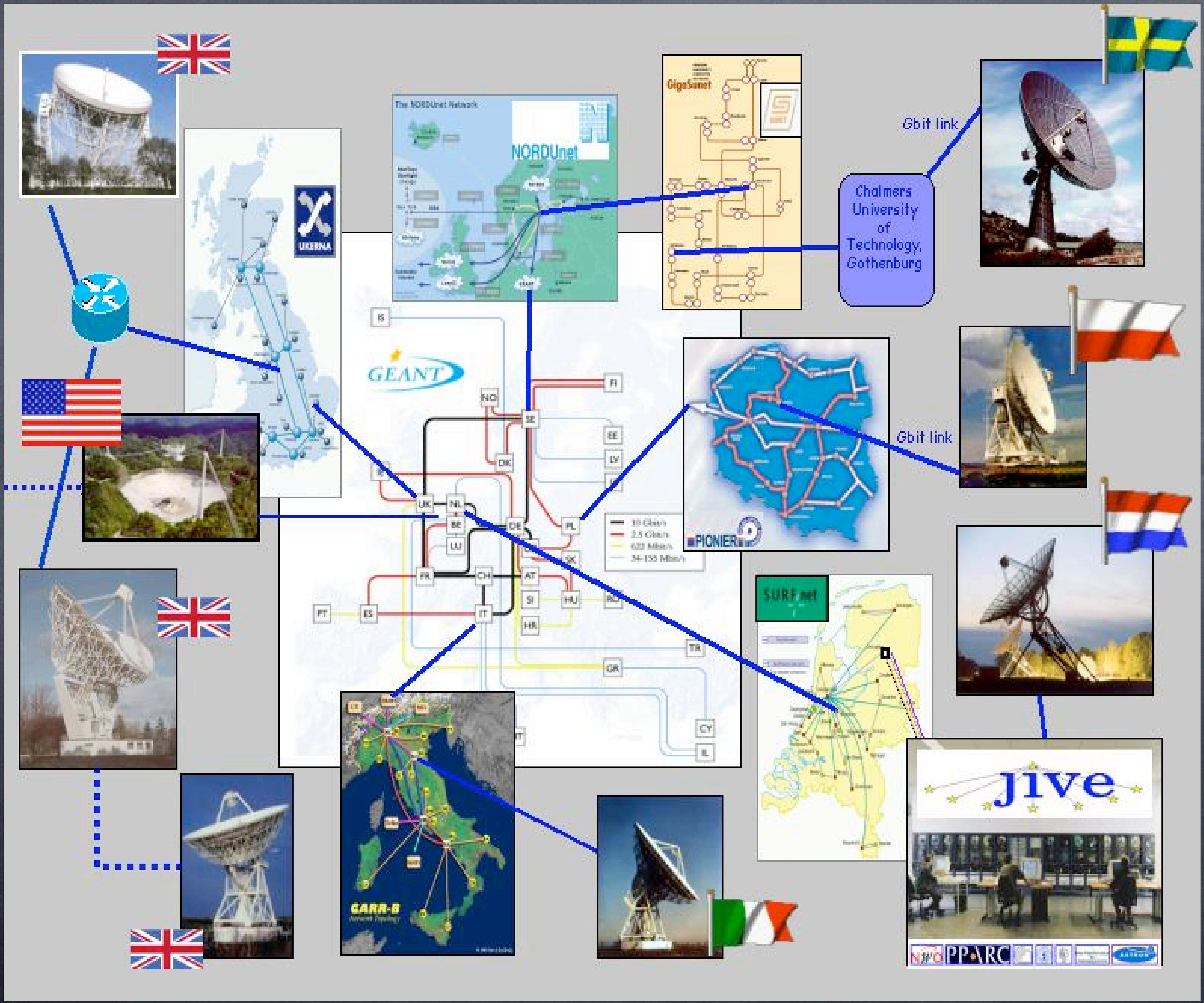
Collecting area	x 40
Bandwidth & pol	x 20 (continuum)
Receivers + site	x 10

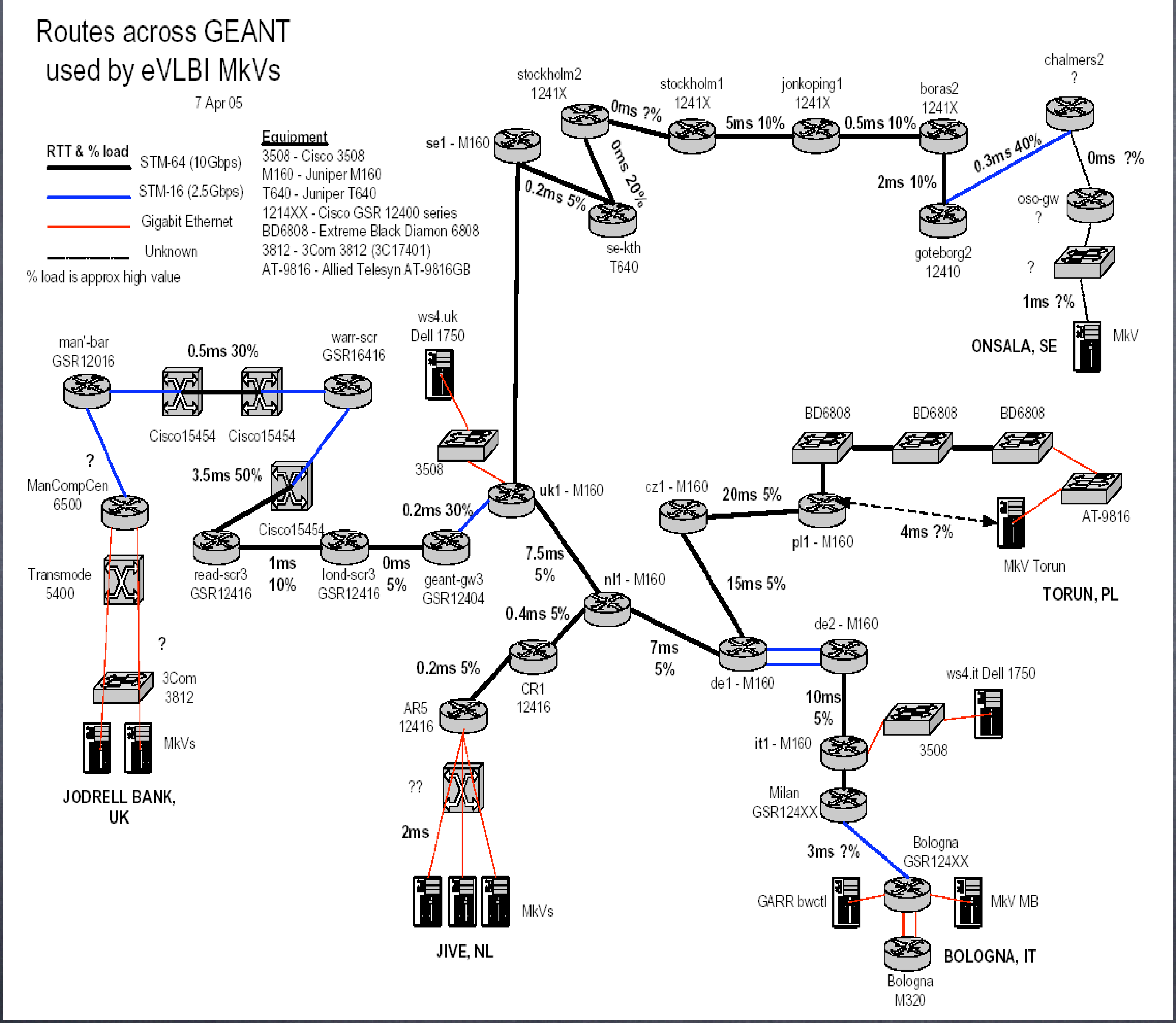
OVERALL x 8,000 for continuum observations
x 400 for line observations

T_b sensitivity 1K in 1hr for thermal emission
(100 times better than today)

ALMA timescale: unofficially 16 telescopes operating in 2010

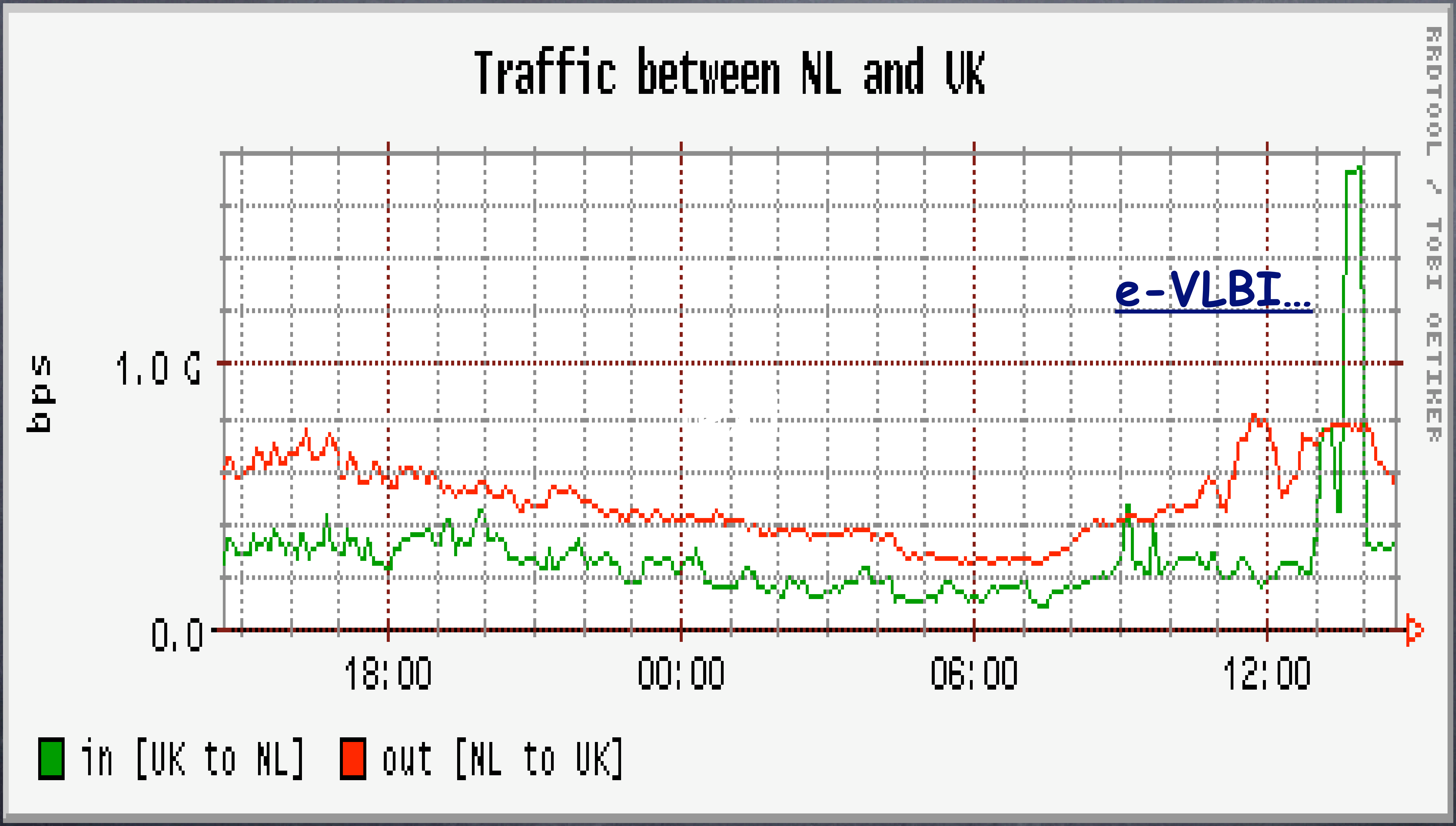
e-VLBI (real-time VLBI)





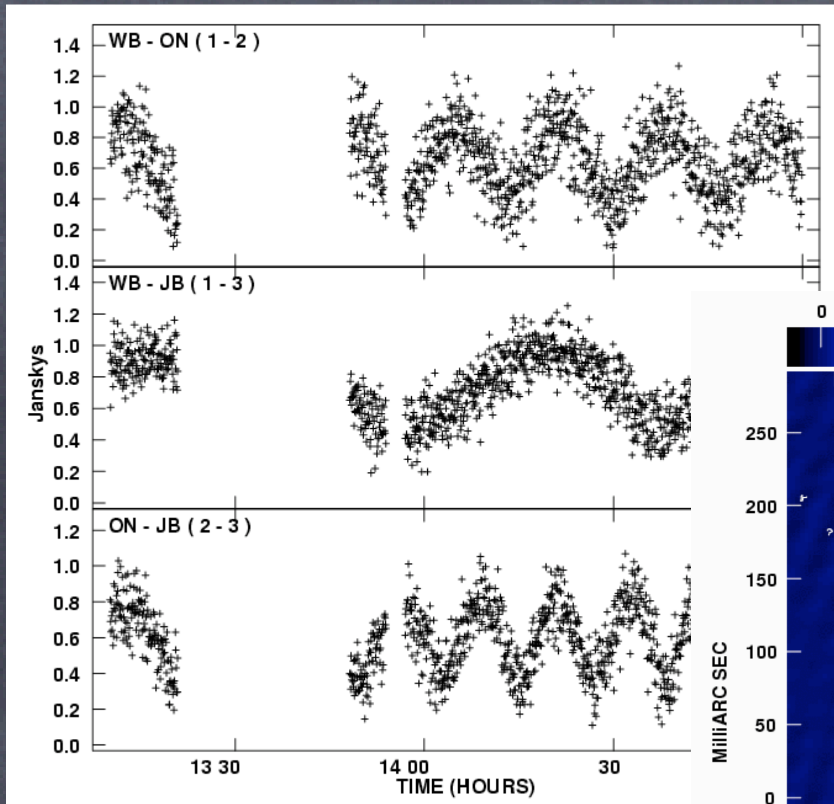
The data is not compressible, white noise

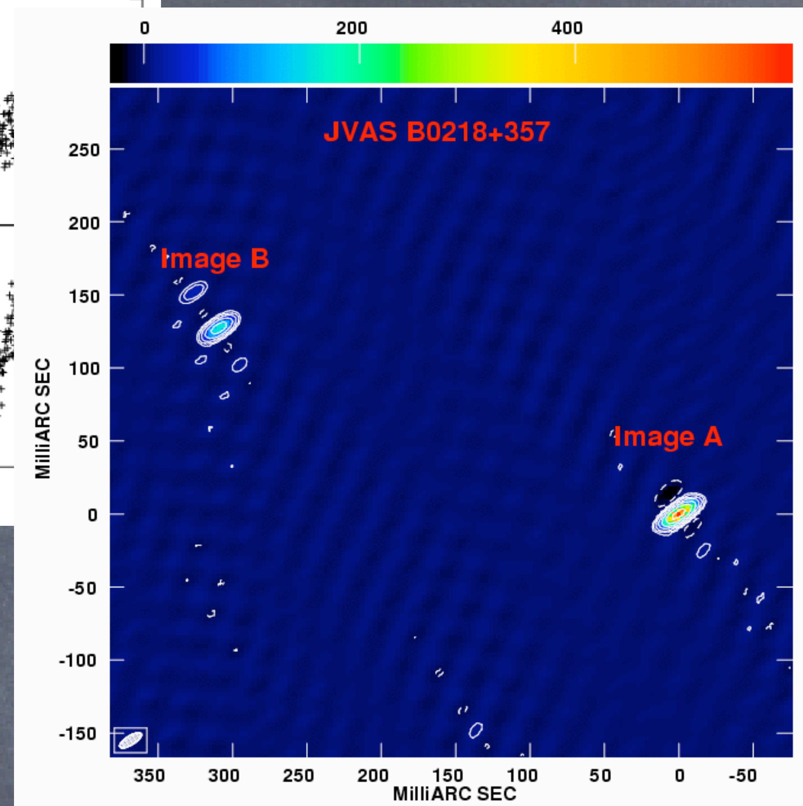
All data rates through network must be the same

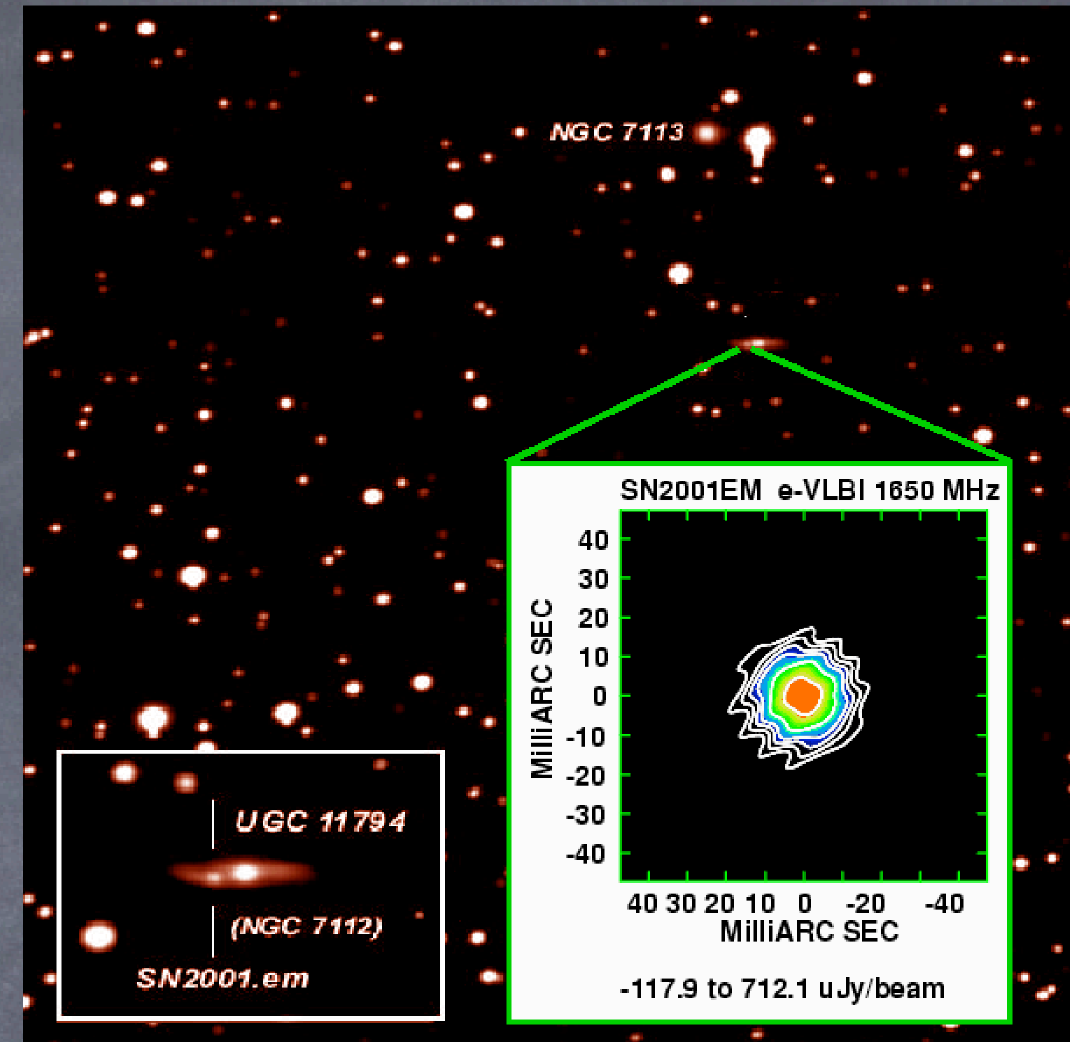


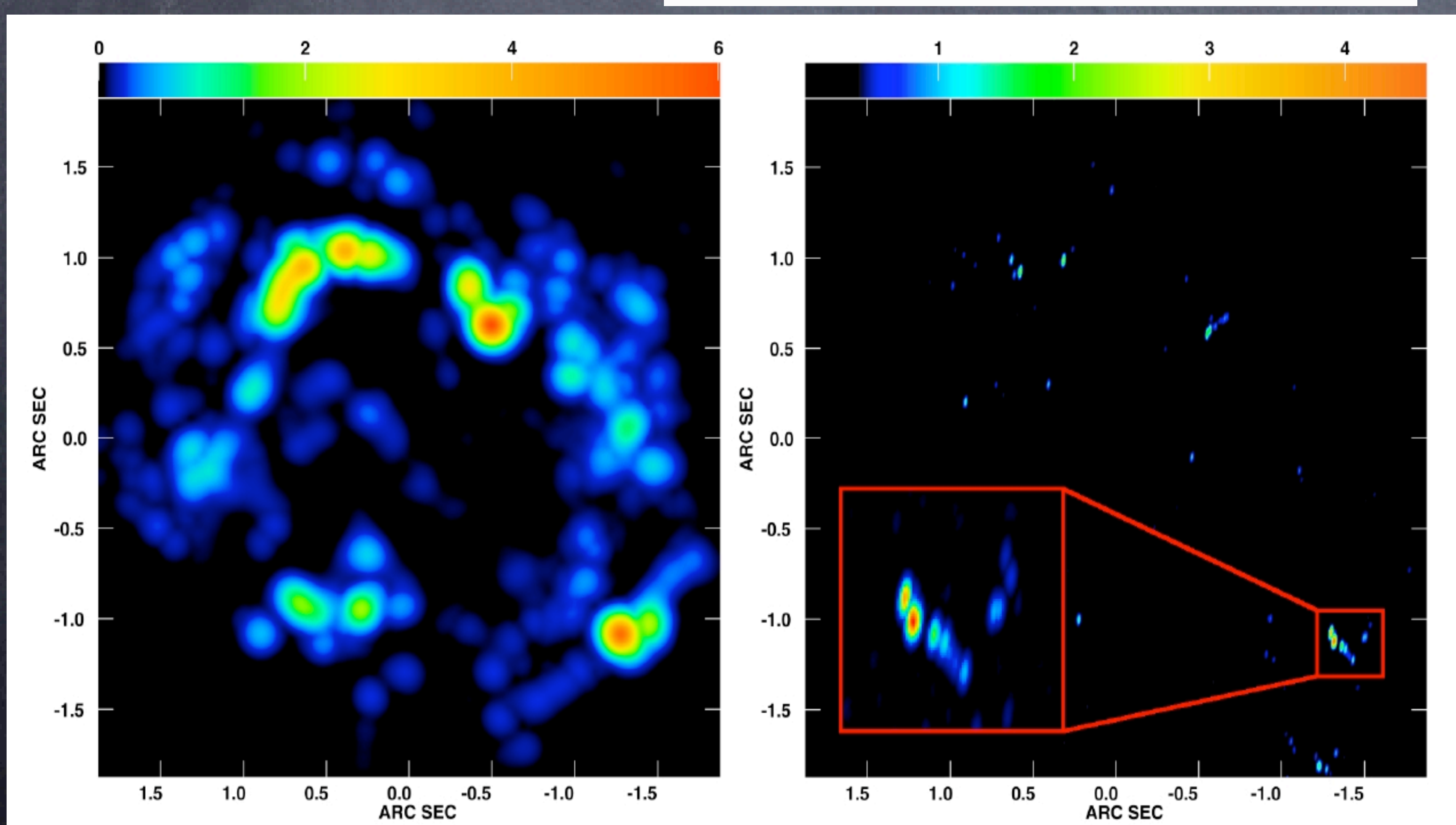
Traffic between NL and UK
bps
1.0 G
0.0
18:00
00:00
06:00
12:00
e-VLBI...
in [UK to NL]
out [NL to UK]
RRDTOOL / TOBI OETIKER

First e-VLBI Science



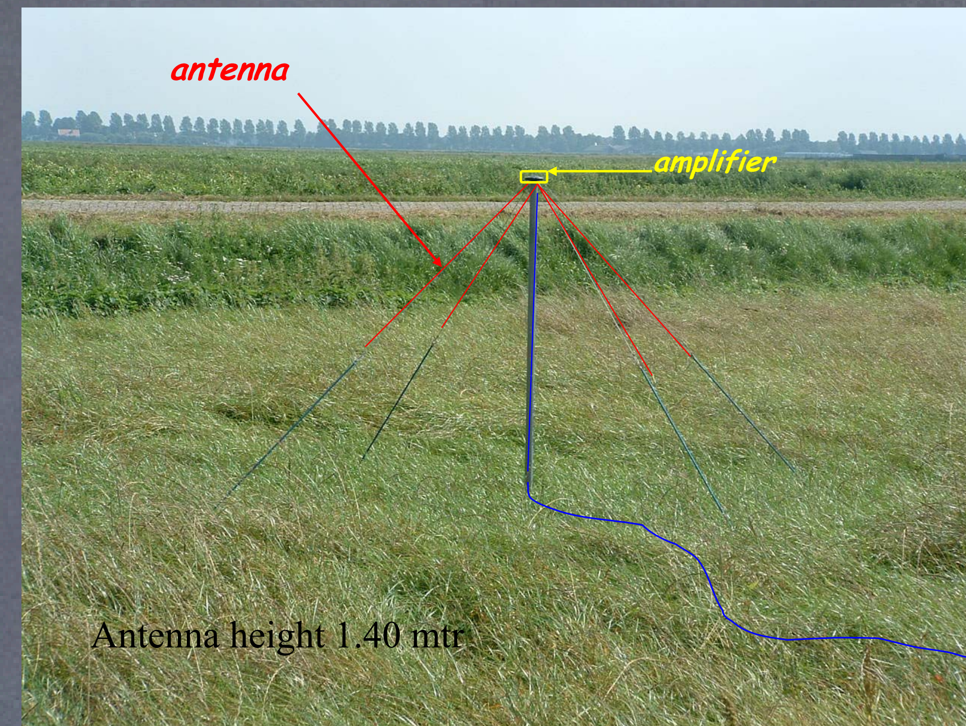






EU com. sci. at JIVE

Low Frequency Radio Array (LOFAR)

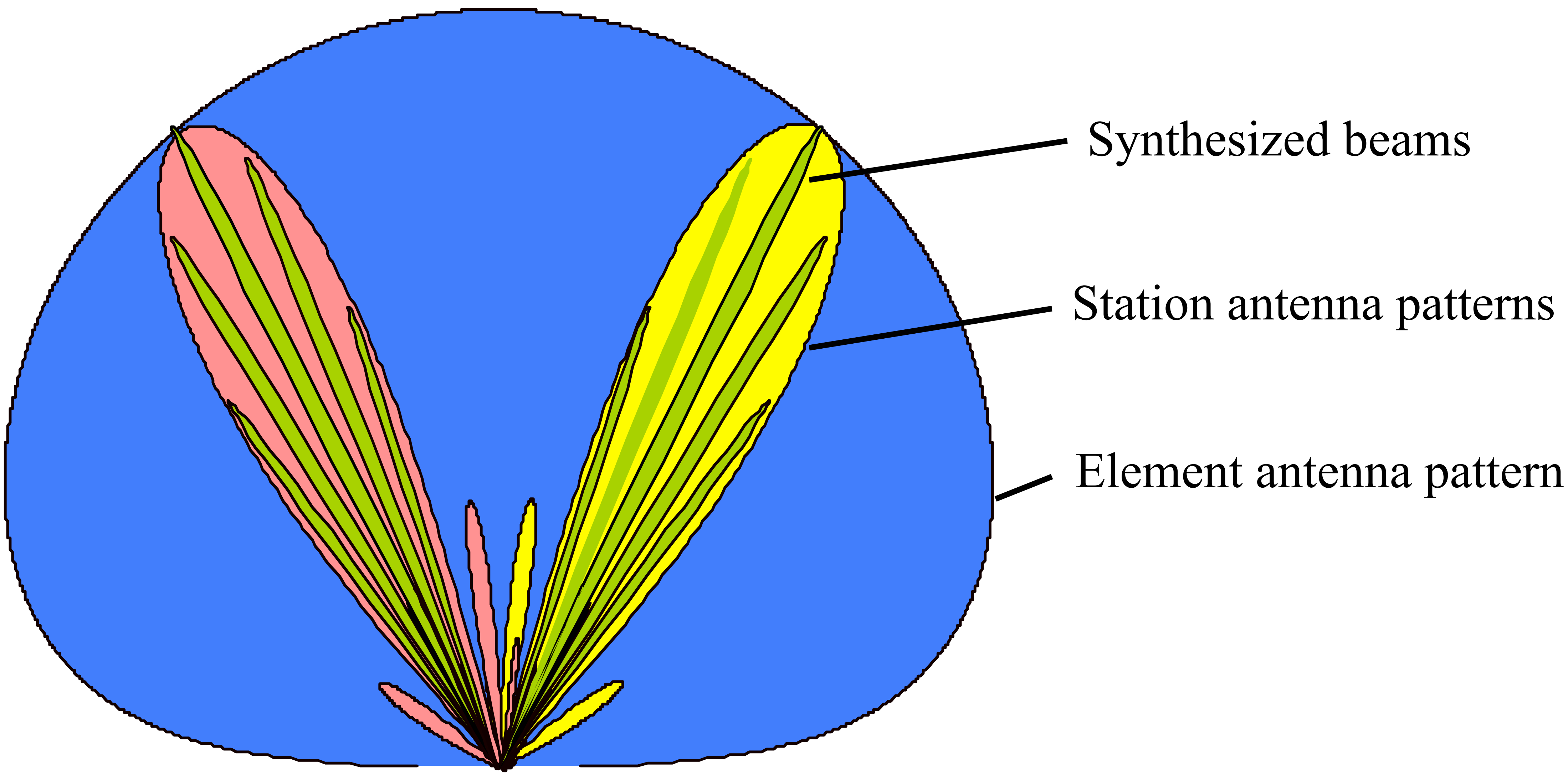


LBA

Replace **mechanical** signal processing with fully electronic processing

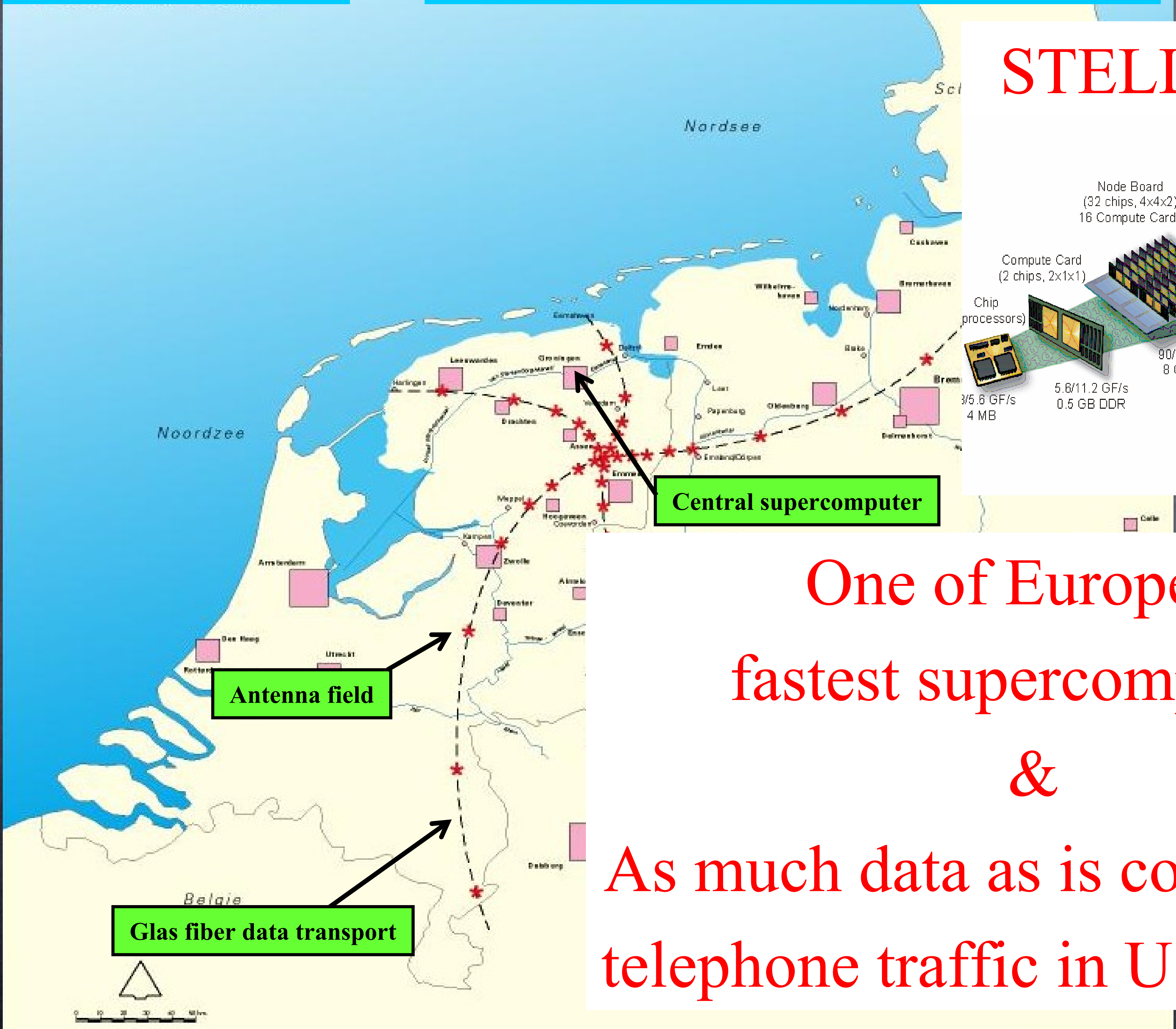
- Frequency range: 30-240 MHz, cheap antennae
- 15400 antennae, 77 stations with 200 antennae (LB/HB)
- 74 M€ secured (station cost 700 k€, 80m diameter)
- Germany: 6 (+6) stations
- France, Italy, United Kingdom, Sweden: ?
- Science data start: 2008

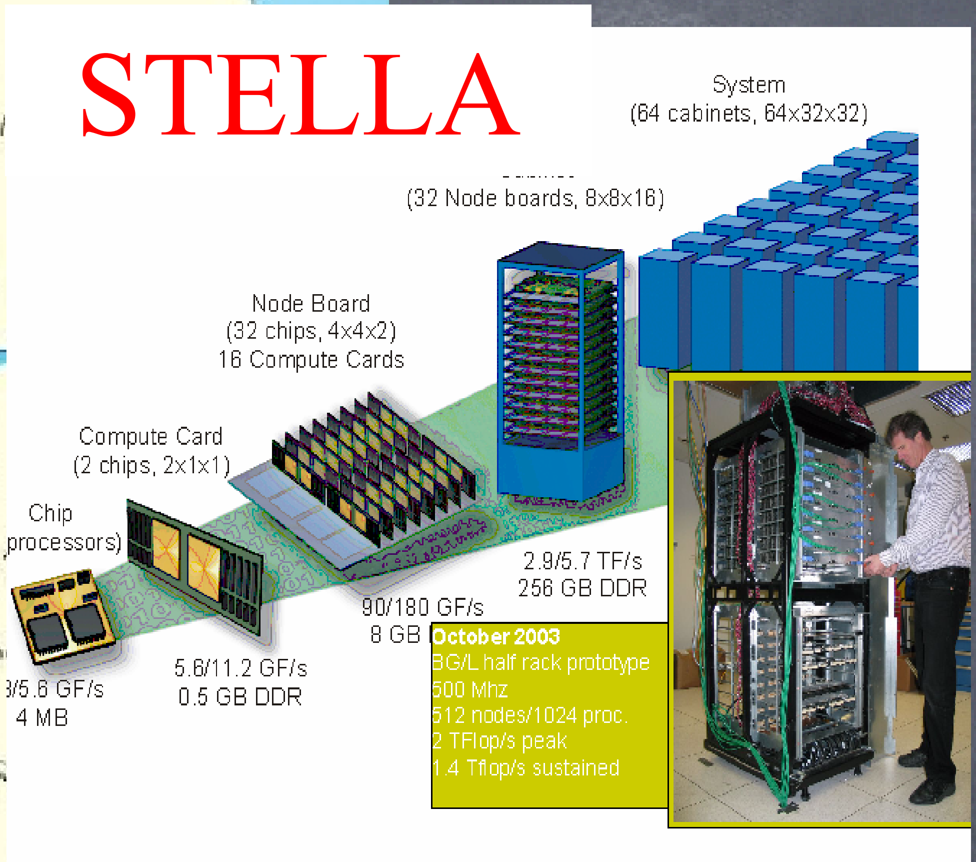
Multi-beaming (electronically)



Copies of signals
processed separately to give multiple beams

LOFAR software radiotelescope





One of Europe's

fastest supercomputers

&

As much data as is contained in

telephone traffic in US each sec.

LOFAR in 2008

- Total data generation rate: 22 Tbit/s
  - 77 sensor stations
- Edge processing: 116 Top/s
  - FPGA's for local signal conditioning
- Data transport to Central Processor: 0,8 Tbit/s
  - Raw Ethernet for max data rates
  - TCP/IP for lowest data rates
- Central processing: 43 Tflop/s
  - IBM BlueGene/L in LINUX cluster
  - Internally within correlator: 46 Tbit/s
  - I/O: 400 Gb/s / 50 Gb/s
- Data storage PetaByte
- Data output to end users: 40 Gbit/s
  - Output to Géant users: 20 Gbit/s

TIMELINE

Concept

1994
International Working Group

1995
Start of Prototyping

2000
Signing of first Memorandum of Agreement

2005
Signing of extended Memorundum of Agreement

2006
Site Ranking Decision

2009
Final Technology Decision

2010
Construction of pathfinder on site

2013
Early Science

2014
Construction of full array

2020
Full SKA operational!

Square Kilometer Array (SKA)
construction cost ≈ 1000 M€
running cost ≈ 100 M€

Argentina, Australia, China, South Africa

Economy

- VR running budget: 21.5 Mkr/yr
- Chalmers running budget: 6.5 Mkr/yr
- EU TNA: 530 k€ over 5 years

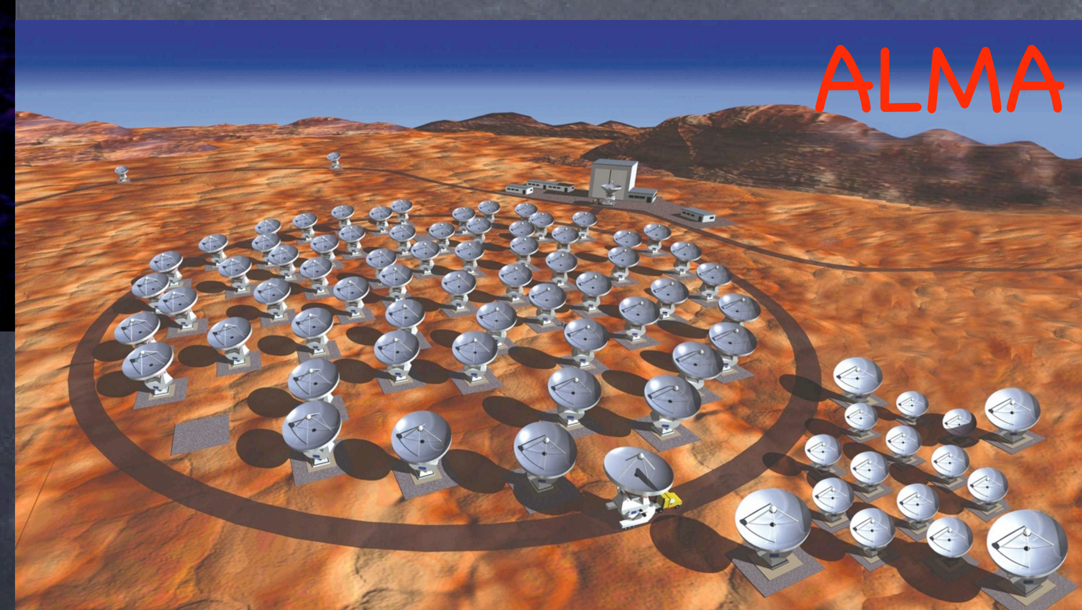
- VR+Wallenberg, APEX receivers: 16 Mkr
- VR, LOFAR planning grant: 675 kkr
- EU, SIS junctions: 420 k€ over 3 years
- EU, ALMA Band 5: 5.1 M€ over 5 years
- EU, EXPReS (e-VLBI): 135 k€ over 3 years
- ESO, Water vapour radiometer: 315 k€
- ESO, ALMA SiS junctions: 120 k€

OSO


APEX


EUROPEAN
vlbi
NETWORK
Jodrell Bank Lovell (UK)
Onsala 20m (SE)
Onsala 25m (SE)
Dwingeloo (NL)
jive
Jodrell Bank Mk2 (UK)
Metsähovi (FI)
Arecibo (PR)
Cambridge (UK)
Torun (PL)
Urumqi (CN)
Hartebeesthoek (ZA)
Westerbork (NL)
Wettzell (DE)
Seshan (CN)
Effelsberg (DE)
Medicina (IT)
Robledo (ES)
Yebes (ES)
Noto (IT)
VLBI


LOFAR
LOFAR


ALMA


SKA
© NFRA