Interferometry @ mm

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Italian Node of ALMA Regional Center

Slides & contributions from
Arturo Mignano

http://www.alma.inaf.it/index.php/Courses

Ideas and slides borrowed from

IRAM interferometry school

http://www.iram-institute.org/EN/content-page-331-7-67-331-0-0.html

NRAO interferometry school

https://science.nrao.edu/science/meetings/2016/15th-synthesis-imaging-workshop

LOFAR school

http://www.astron.nl/lofarschool2016/

European Radio interferometry (ERIS) school

https://www.eso.org/sci/meetings/2015/eris2015.html

Synthesis Imaging in Radio Astronomy: II – The "White Book"

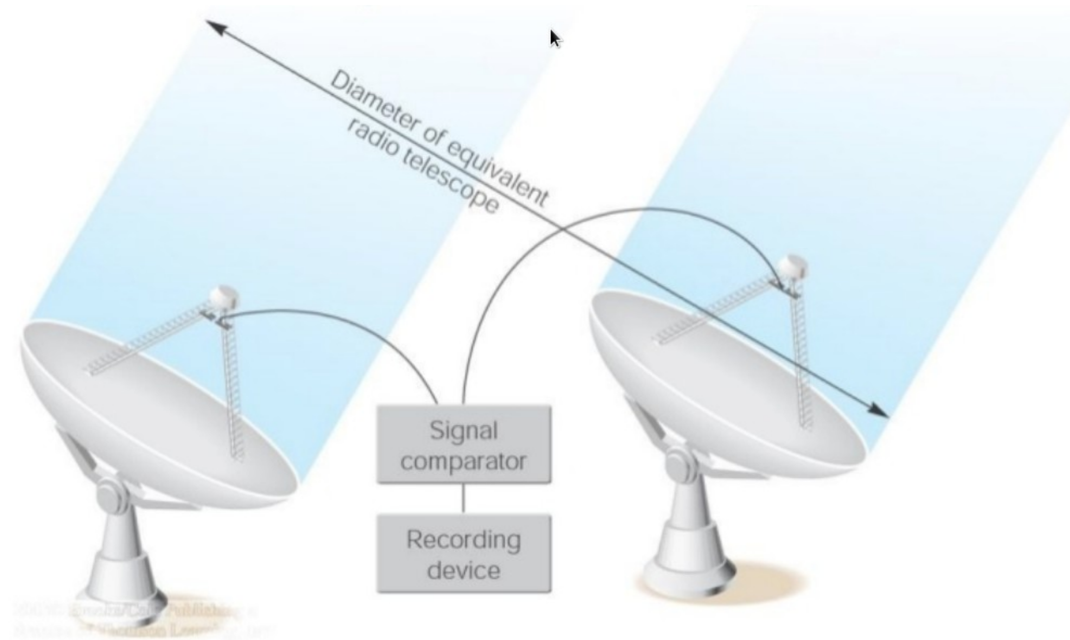
Virtual Radio Interferometer
http://www.narrabri.atnf.csiro.au/astronomy/vri.html

Interferometry basics

Field of View?

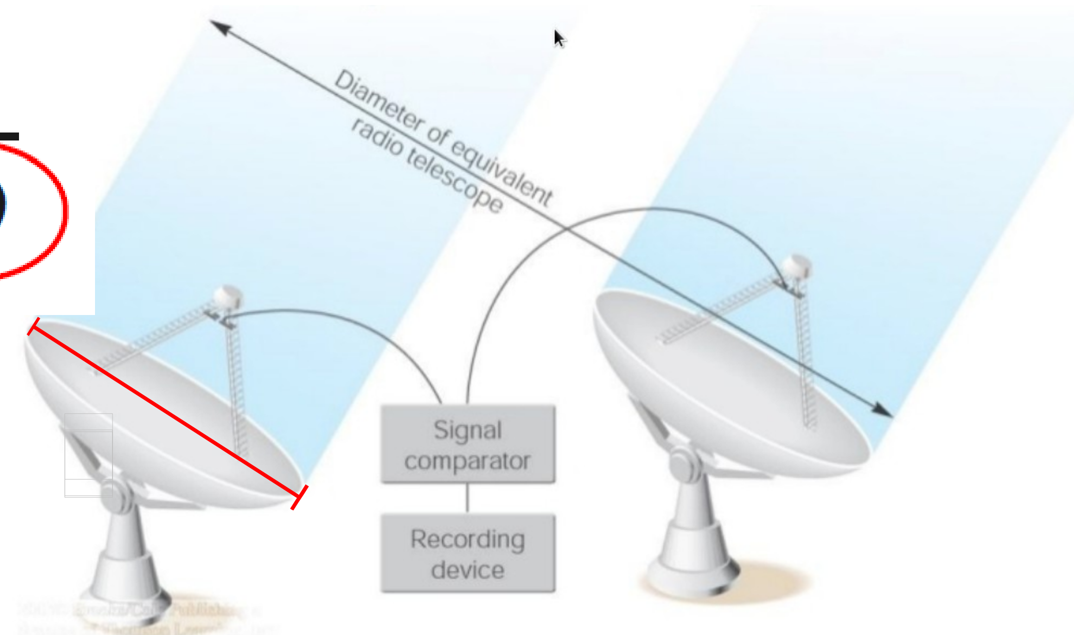
Resolution?

Largest recoverable scale ?



Interferometry basics

Field of View $FOV \propto \frac{\lambda}{D}$

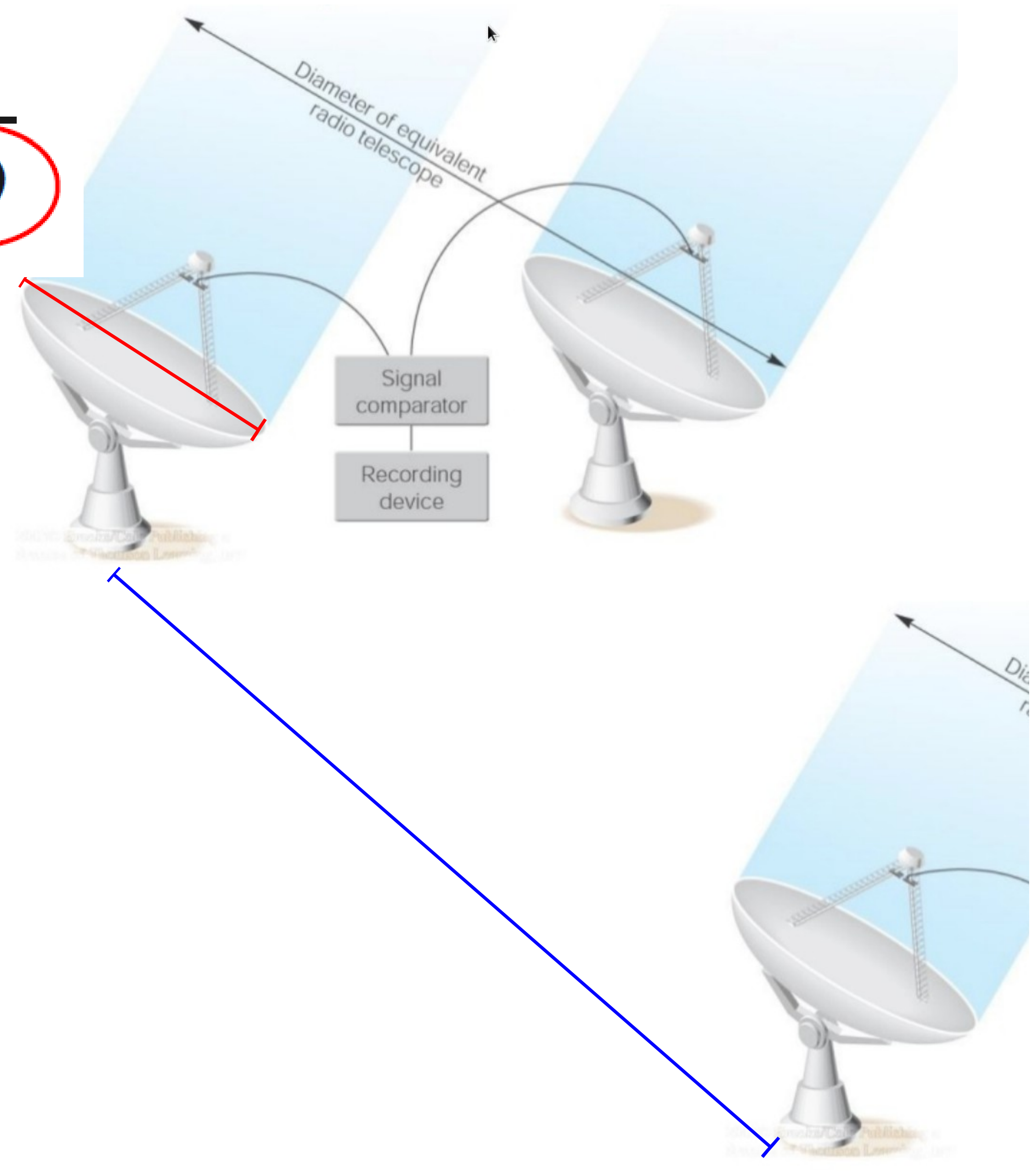


Interferometry basics

Field of View $FOV \propto \frac{\lambda}{D}$

Resolution

$$\theta_{res} \approx \frac{\lambda}{B_{max}}$$



Interferometry basics

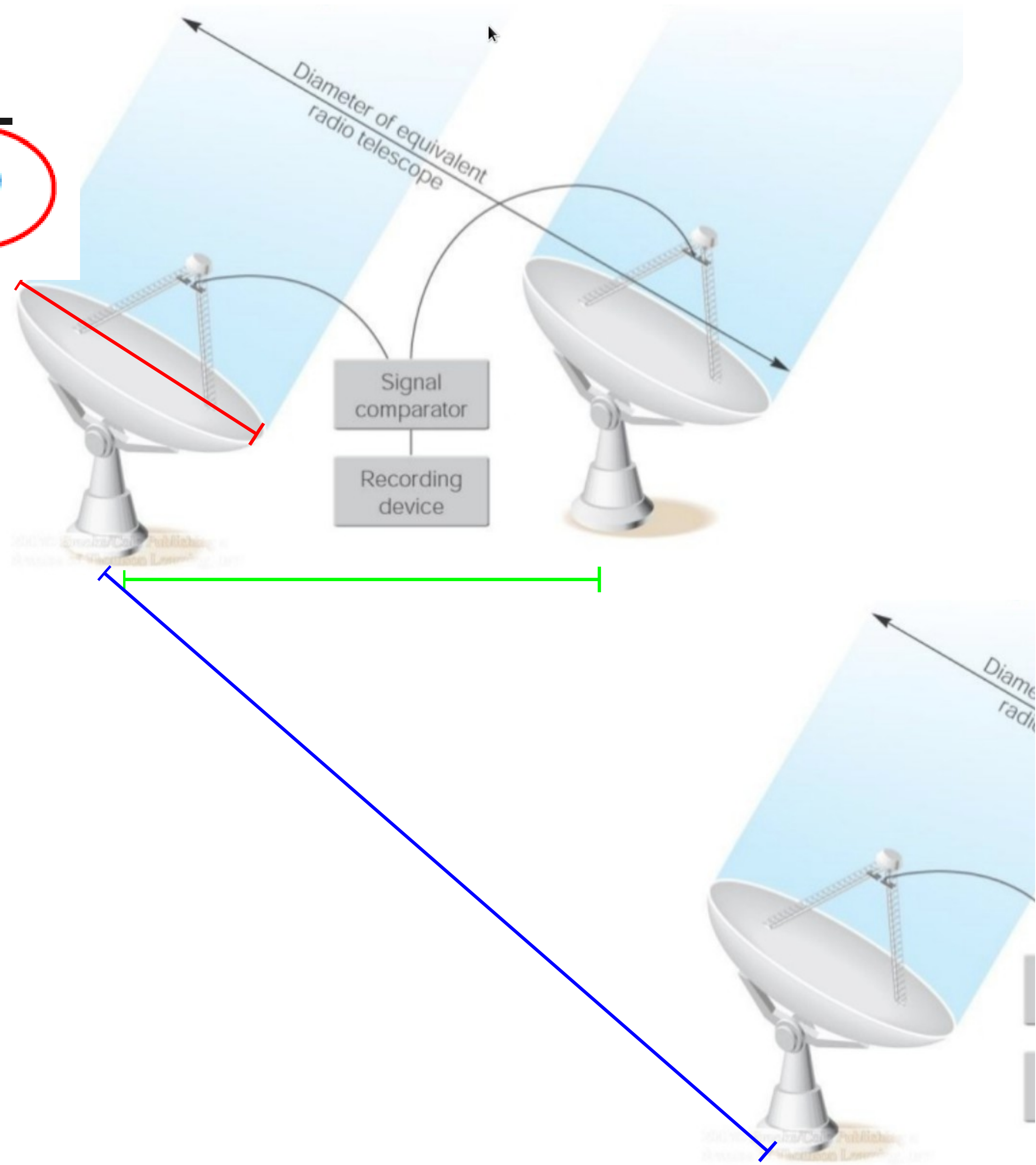
Field of View $$FOV \propto \frac{\lambda}{D}$$

Resolution

$$\theta_{res} \approx \frac{\lambda}{B_{max}}$$

Maximum recoverable scale

$$\theta_{MRS} \approx \frac{\lambda}{B_{min}}$$

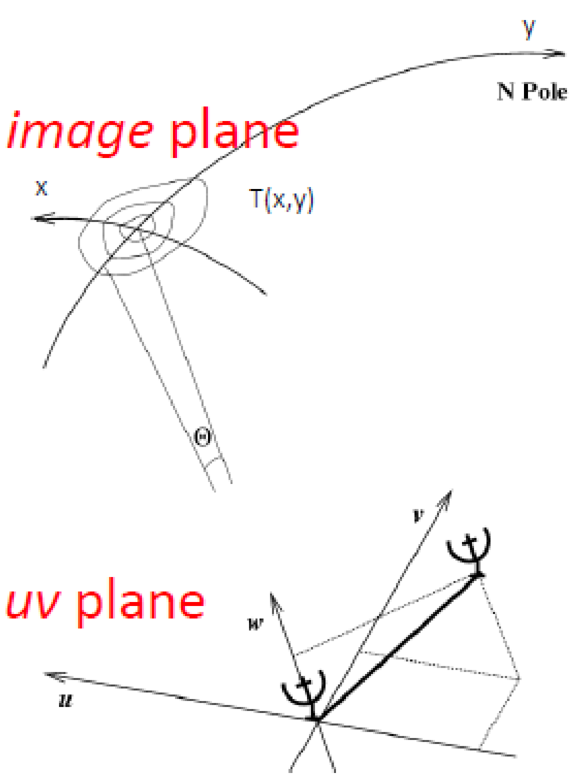


Interferometry basics

Indeed the CORRELATOR performs a more complicated operation (i.e. the true cross-correlation) to deliver VISIBILITIES:

$$V^{ij}(\tau_g) = \langle V^i V^j \rangle = lim_{T\to\infty} \int_{-T/2}^{T/2} V^i(t)\, V^{j*}(t+\tau_g)\, dt$$

In the (2-D) uv-plane each visibility samples the FT of the (2-D) B(θ,ϕ)



(van Cittert-Zernike theorem)

Fourier space/domain

$$V(u,v) = \int\int T(x,y) e^{2\pi i(ux+vy)} dxdy$$

$$T(x,y) = \int\int V(u,v) e^{-2\pi i(ux+vy)} dudv$$

Image space/domain

Interferometry basics

In the next two weeks we are going to deal with

visibilities and **uv plane**

To get familiar with them you can play with

- a java applet online:

http://www.narrabri.atnf.csiro.au/astronomy/vri.html

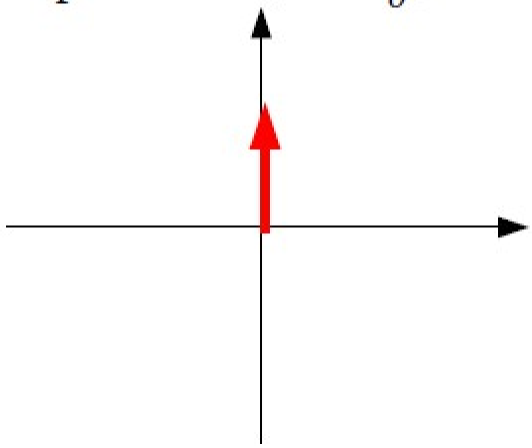
- or a python script written by Ivan Marti-Vidal (nordic ARC node) APSYNSIM

https://launchpad.net/apsynsim

Interferometry basics

1 D

1. *The pulse:* $\delta(x - x_o)$



Dirac function

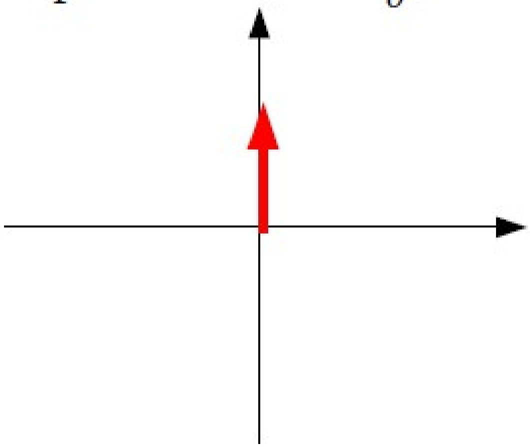
$\mathcal{FT}$?

Fourier Transform

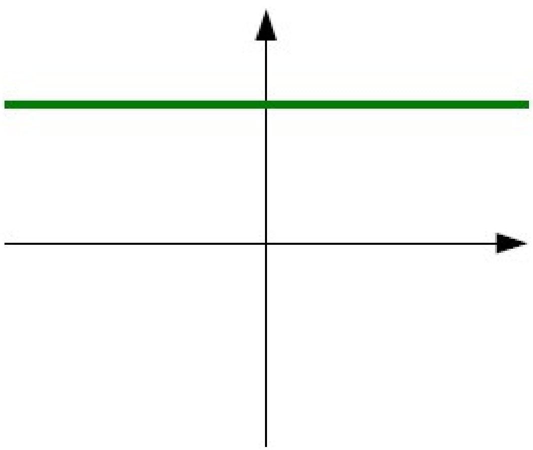
Interferometry basics

1 D

1. *The pulse:* $\delta(x - x_o)$



Dirac function



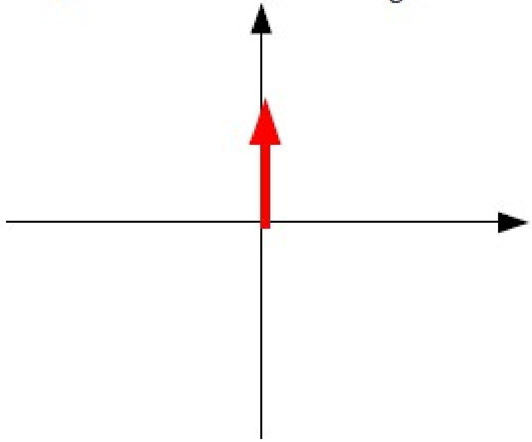
Fourier Transform

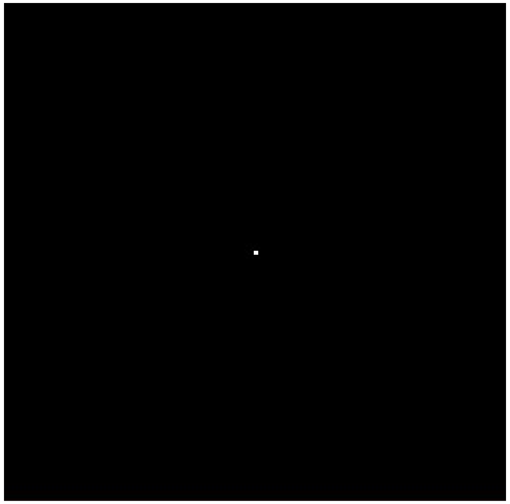
Interferometry basics

1 D

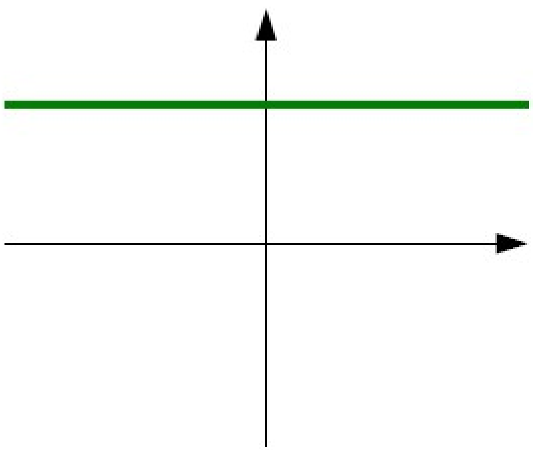
2 D

1. The pulse: $\delta(x - x_o)$





Point source in the sky



$\mathcal{FT}$?

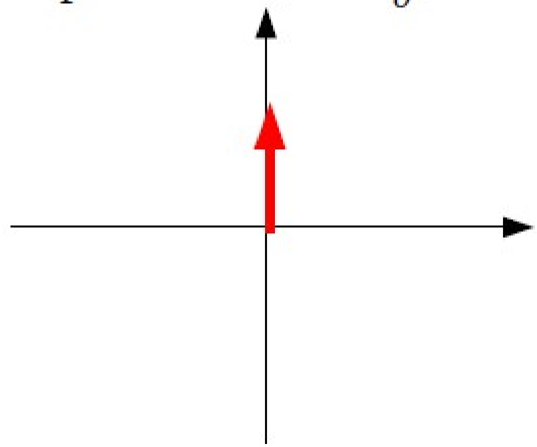
Ideal uv plane

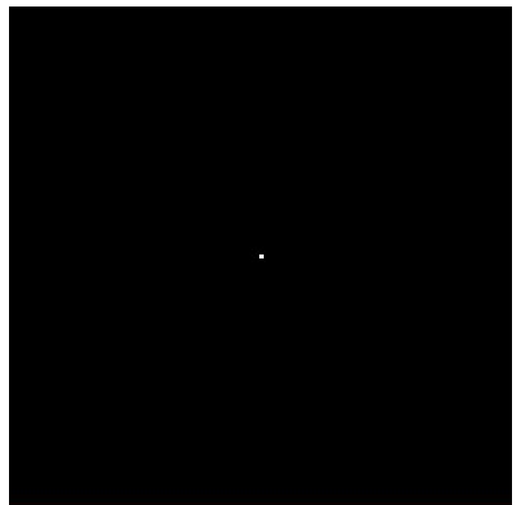
Interferometry basics

1 D

2 D

1. *The pulse:* $\delta(x - x_o)$





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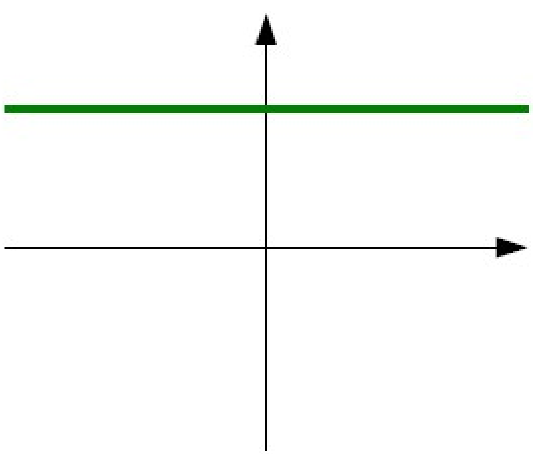
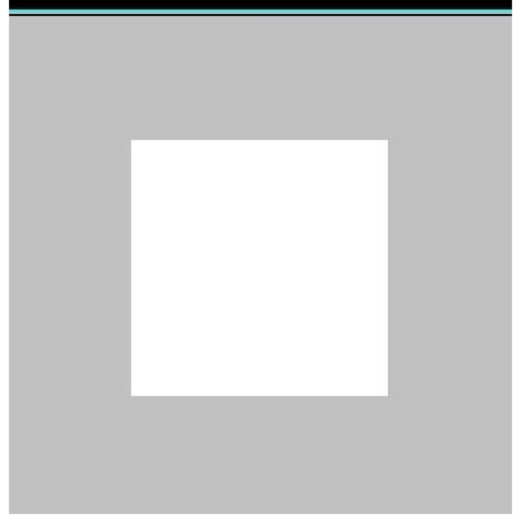
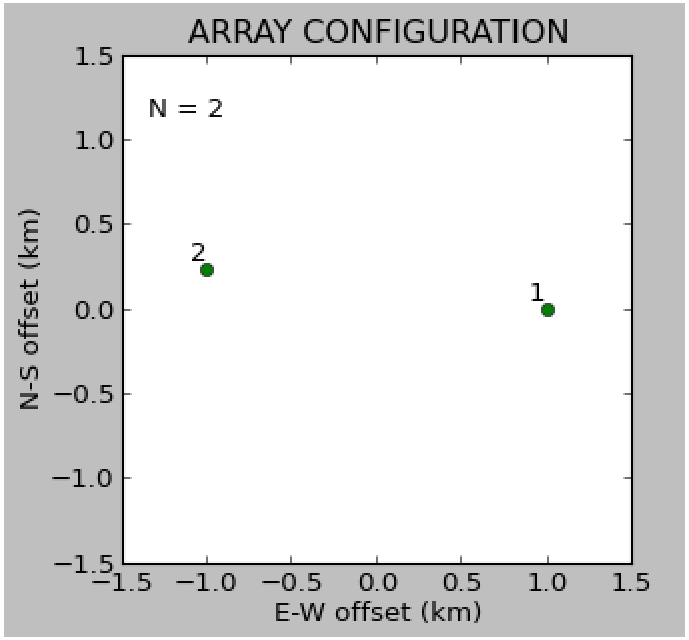


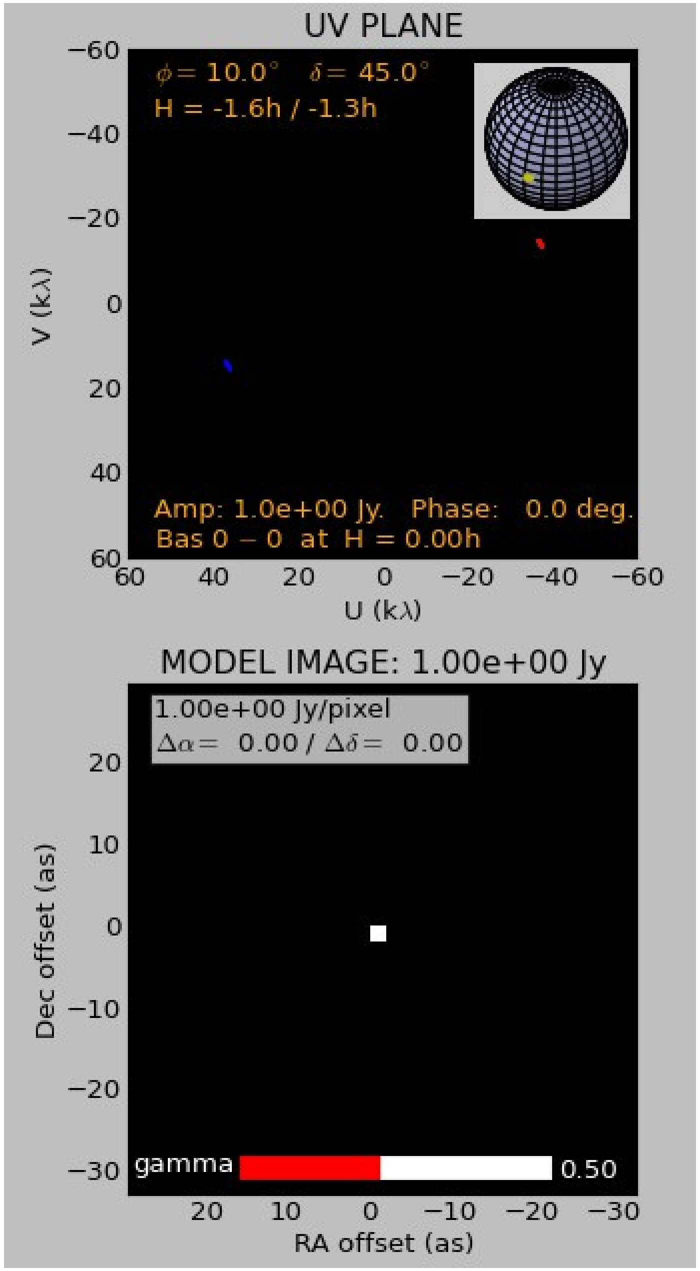
Ideal uv plane



Interferometry basics

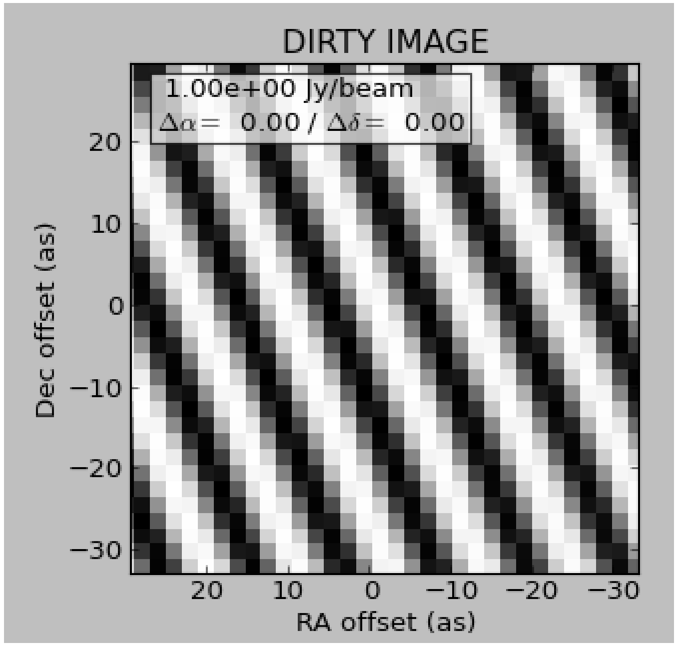
Snapshot observation
with two antennas
1 baseline





← uv-coverage

Resulting image



Interferometry basics

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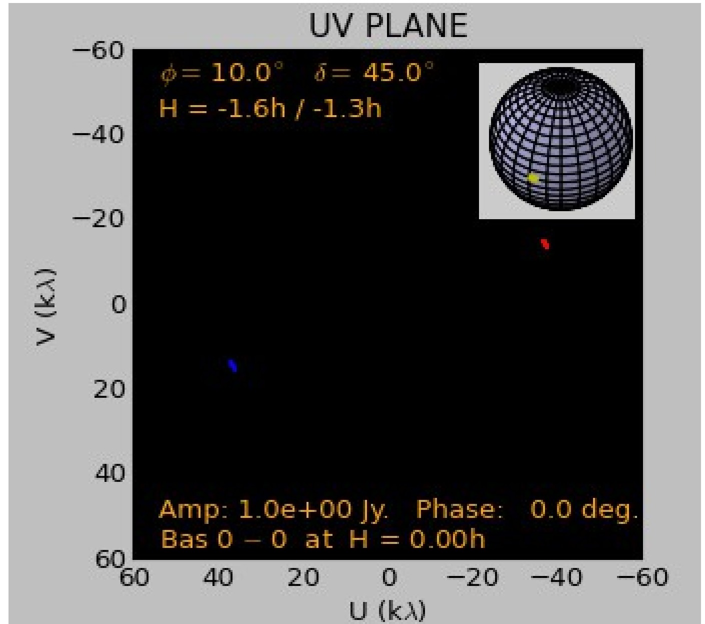
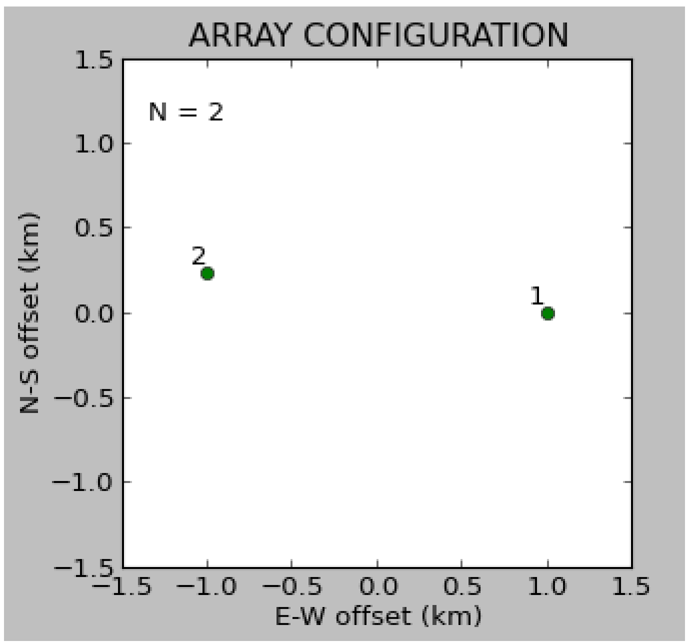
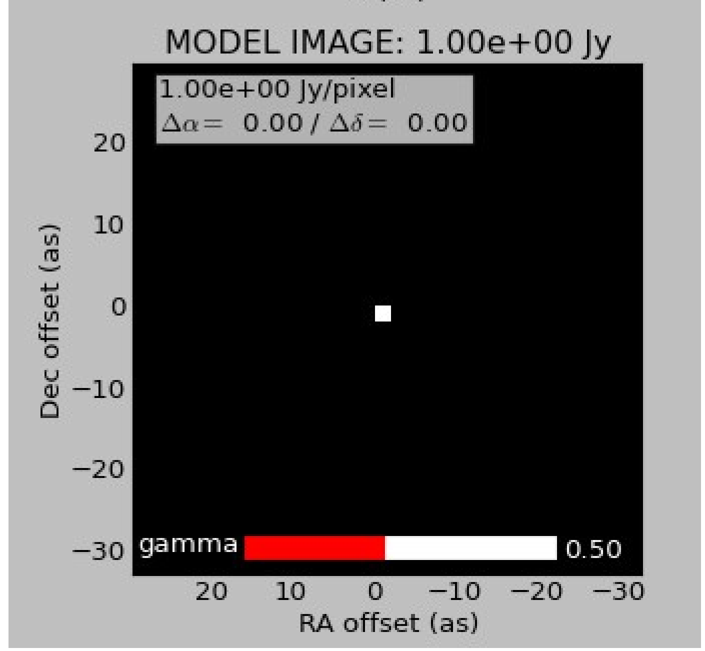
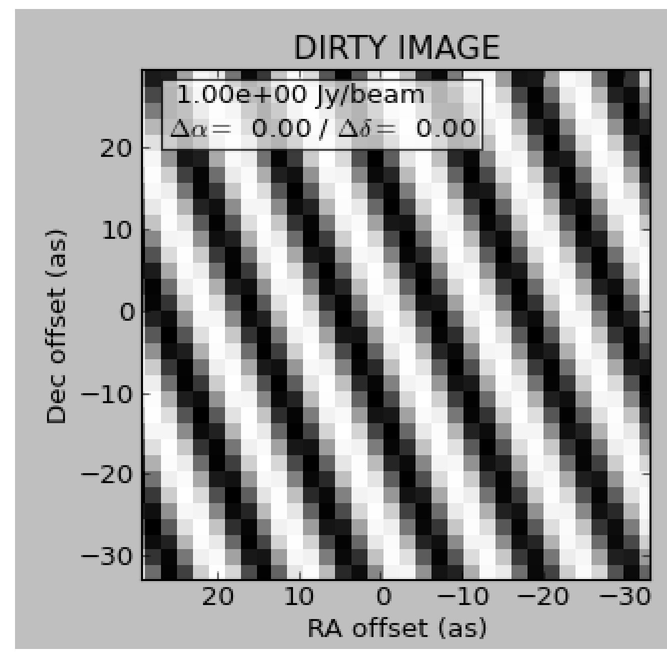


← uv-coverage





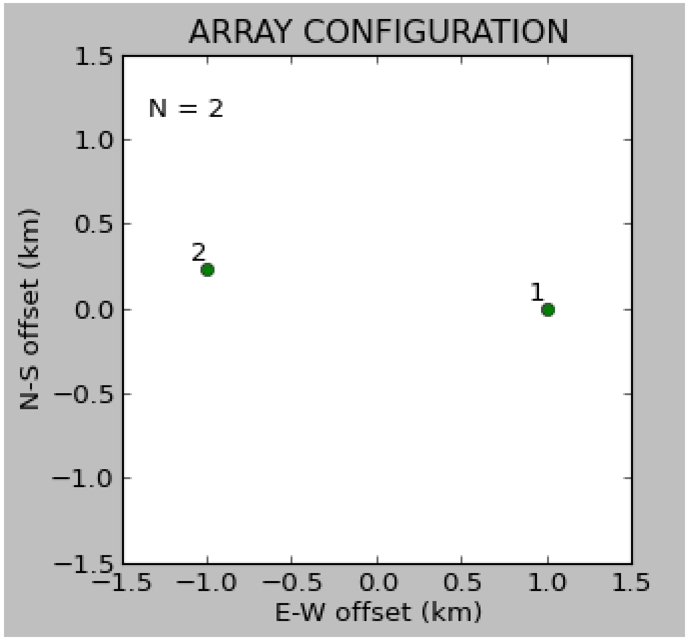
Resulting image

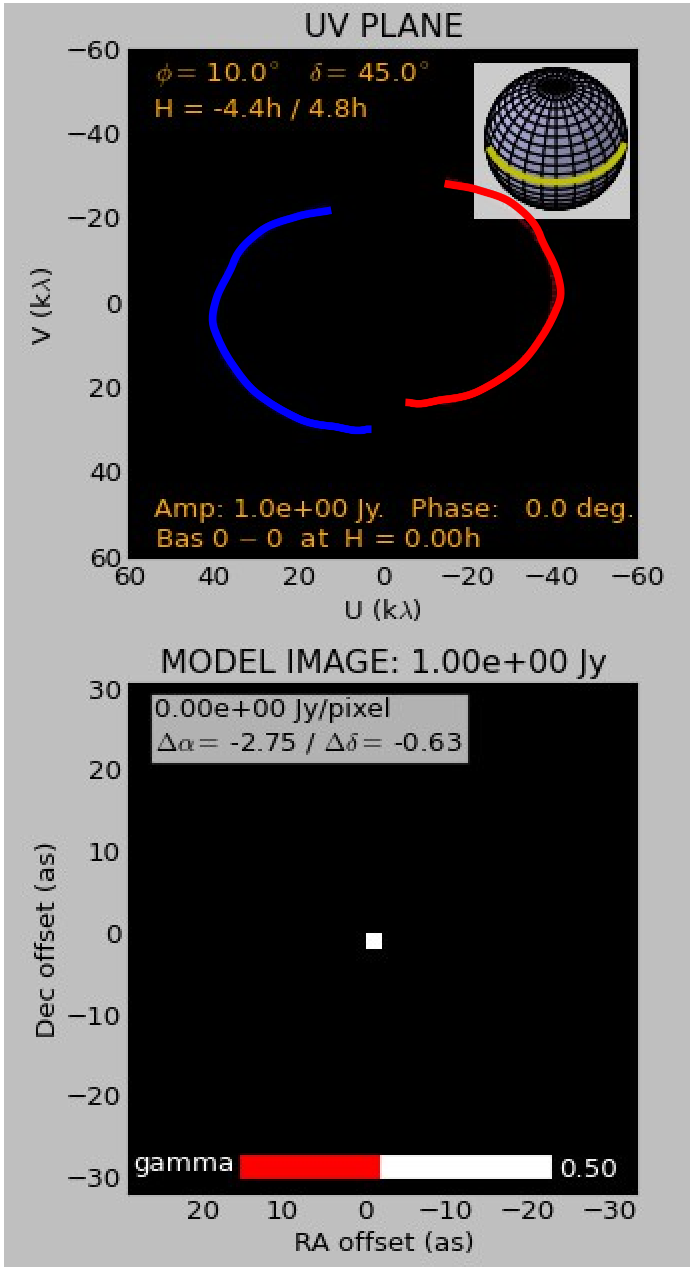


If antennas are closer?

Interferometry basics

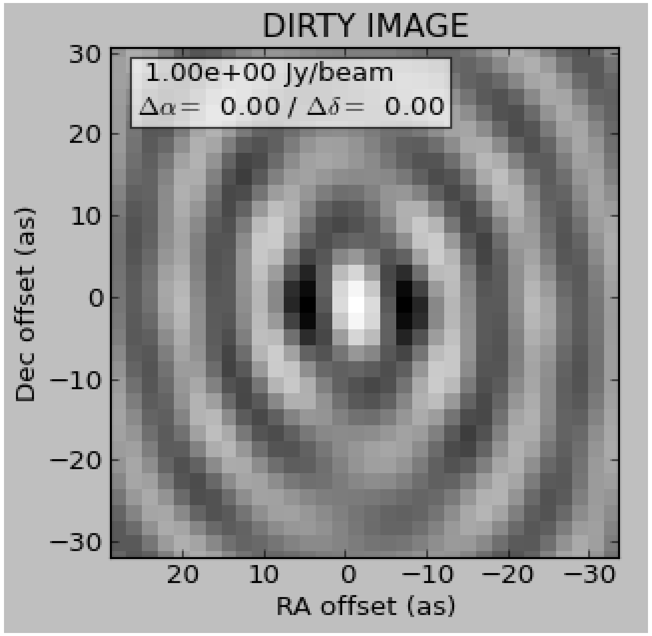
8 hrs observation
with two antennas
1 baseline (~2 km)





← uv-coverage

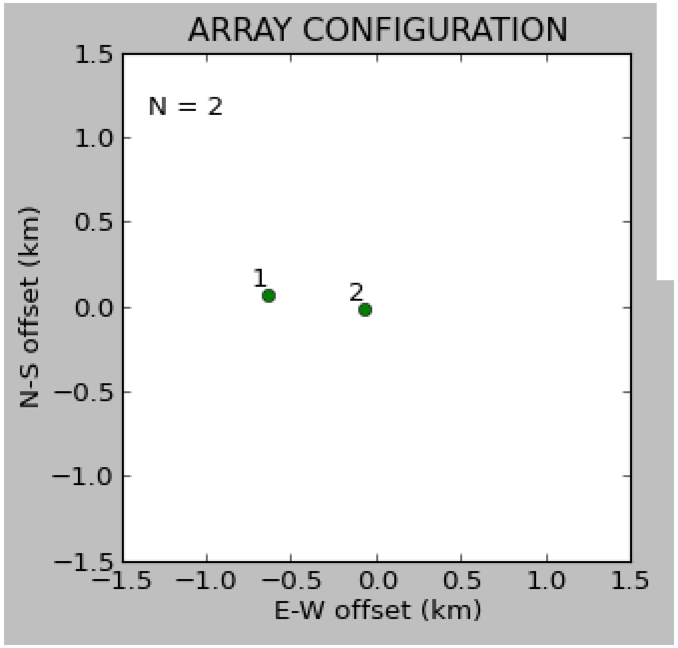
Resulting image



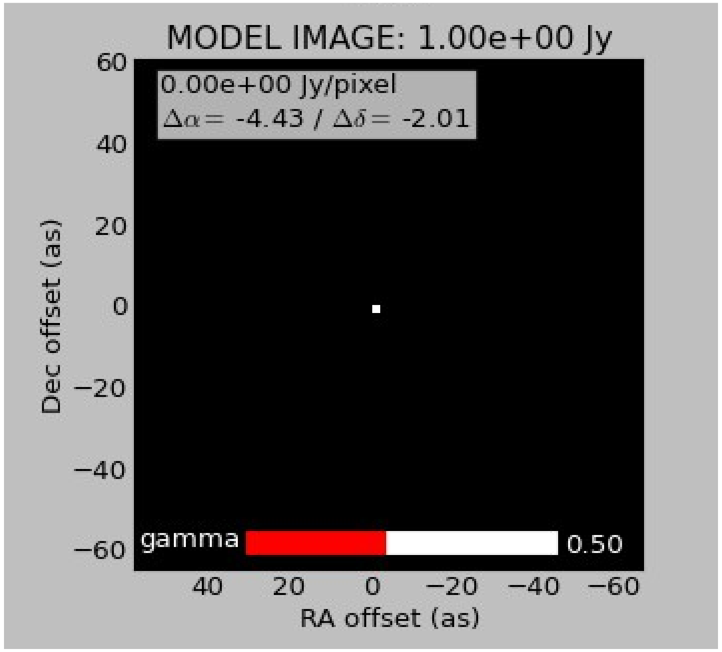
Interferometry basics

← **uv-coverage?**

8 hrs observation
with two antennas
1 baseline (~800 m)



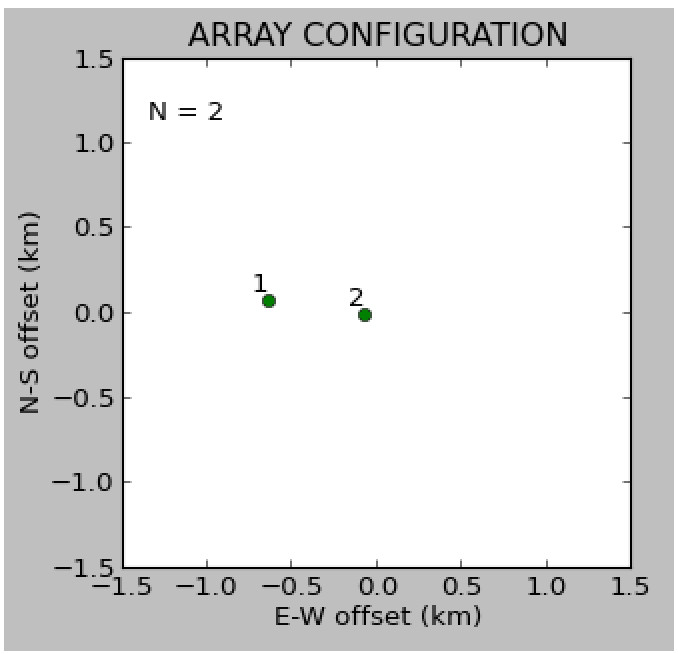
Resulting image ?

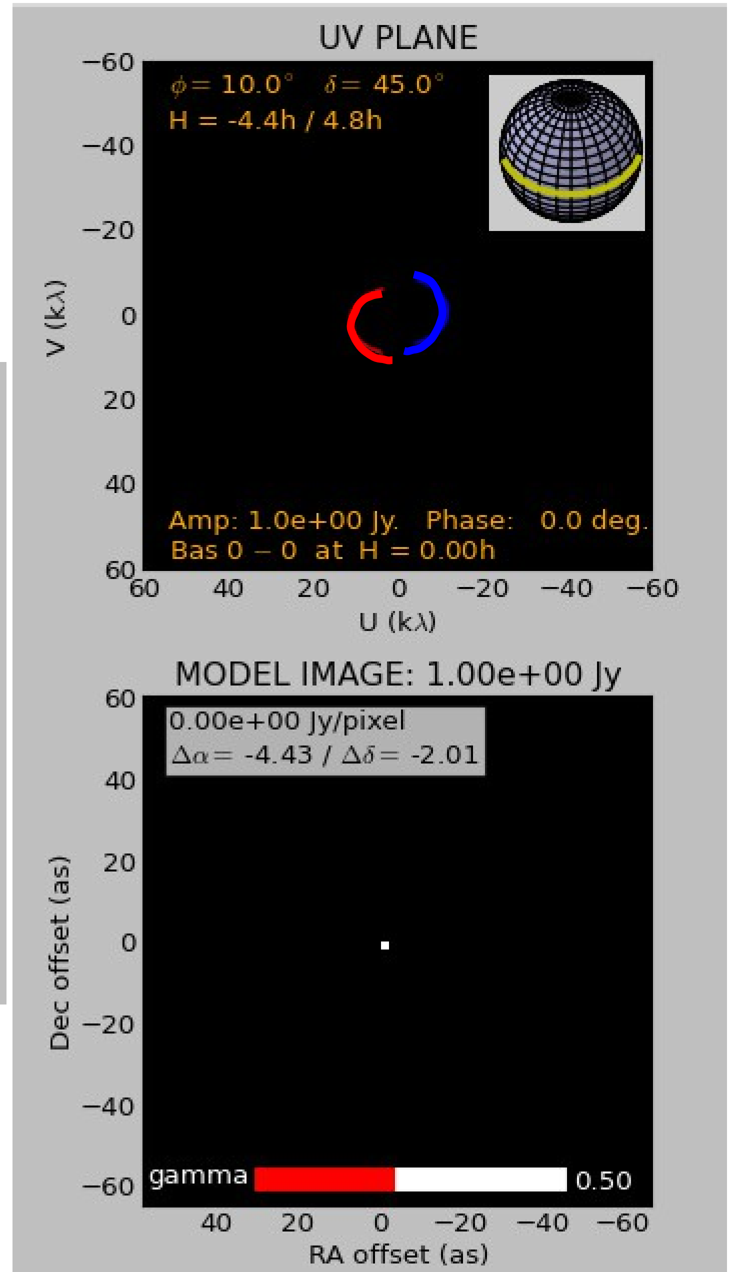


If antennas are closer?

Interferometry basics

8 hrs observation
with two antennas
1 baseline (~800 m)





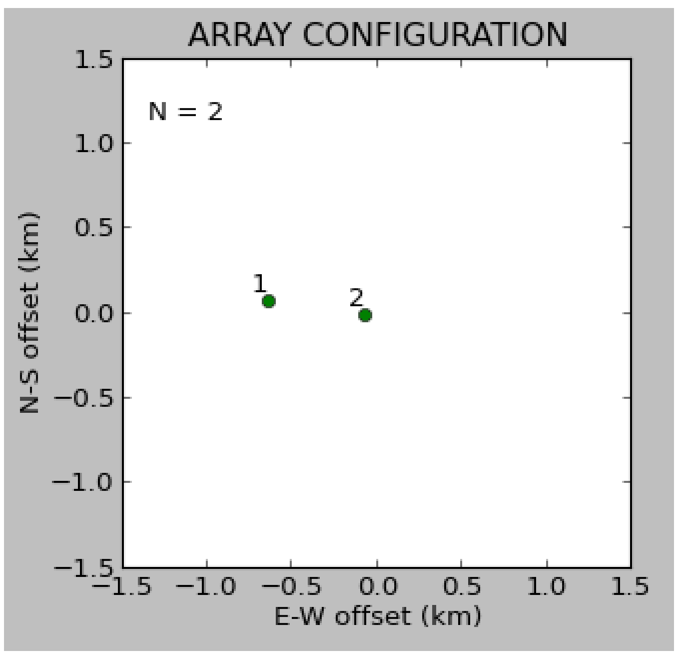
← uv-coverage

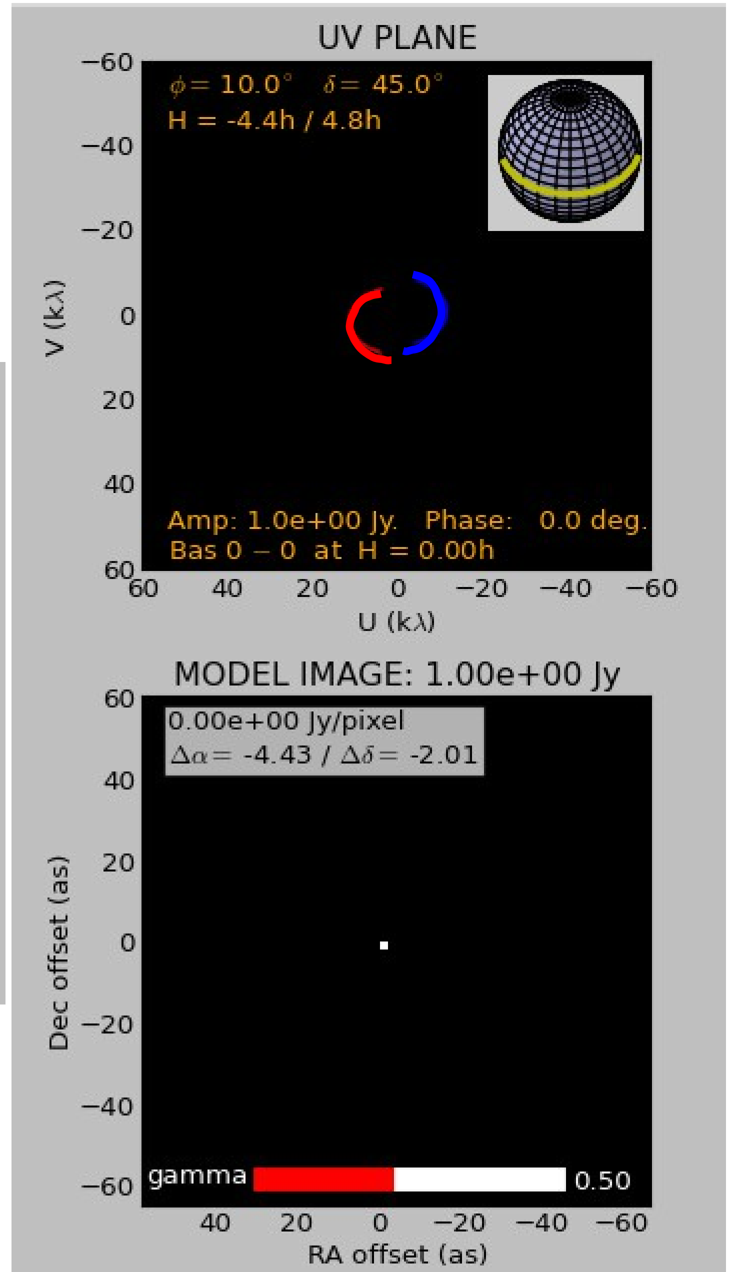
Resulting image

↓

Interferometry basics

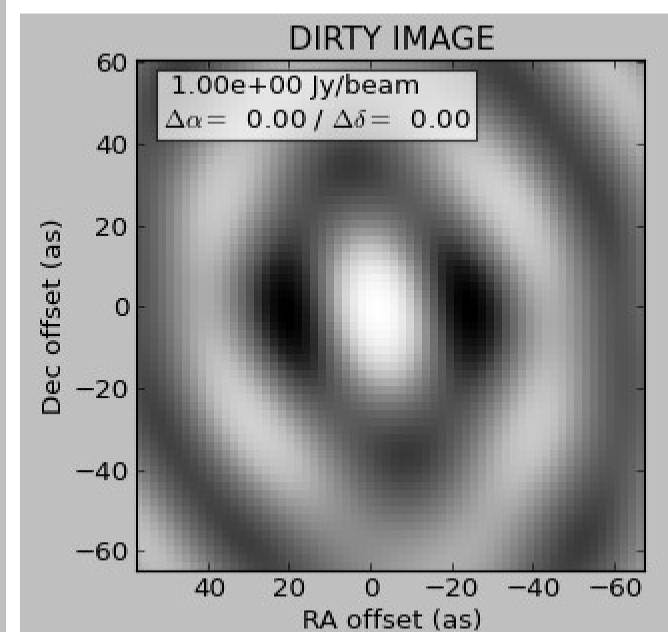
8 hrs observation
with two antennas
1 baseline (~800 m)





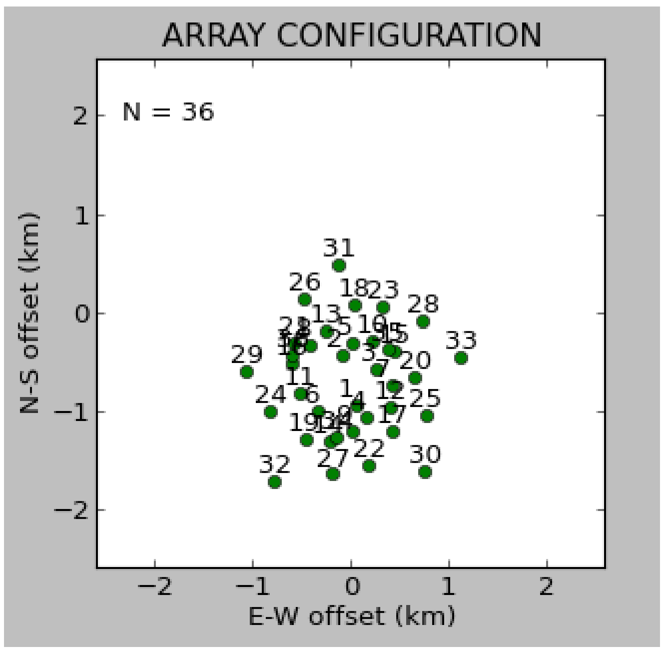
← uv-coverage

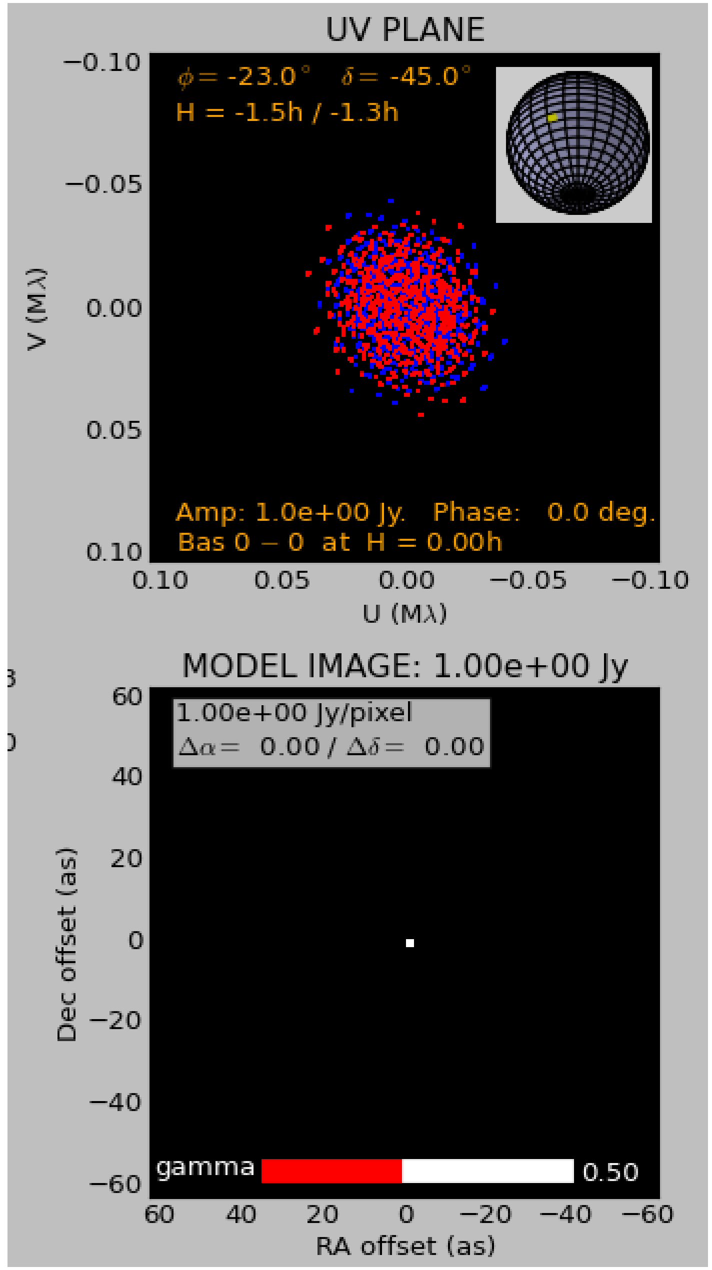
Resulting image



Interferometry basics

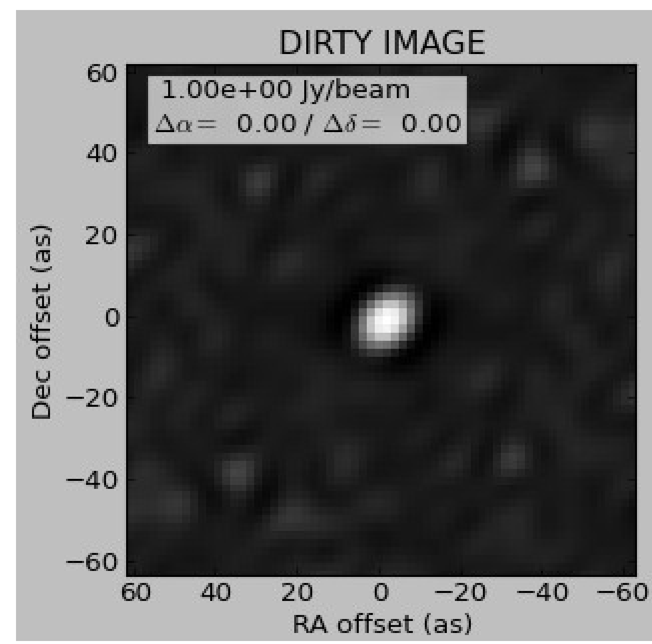
Snapshot observation
with 36 antennas
1260 baselines



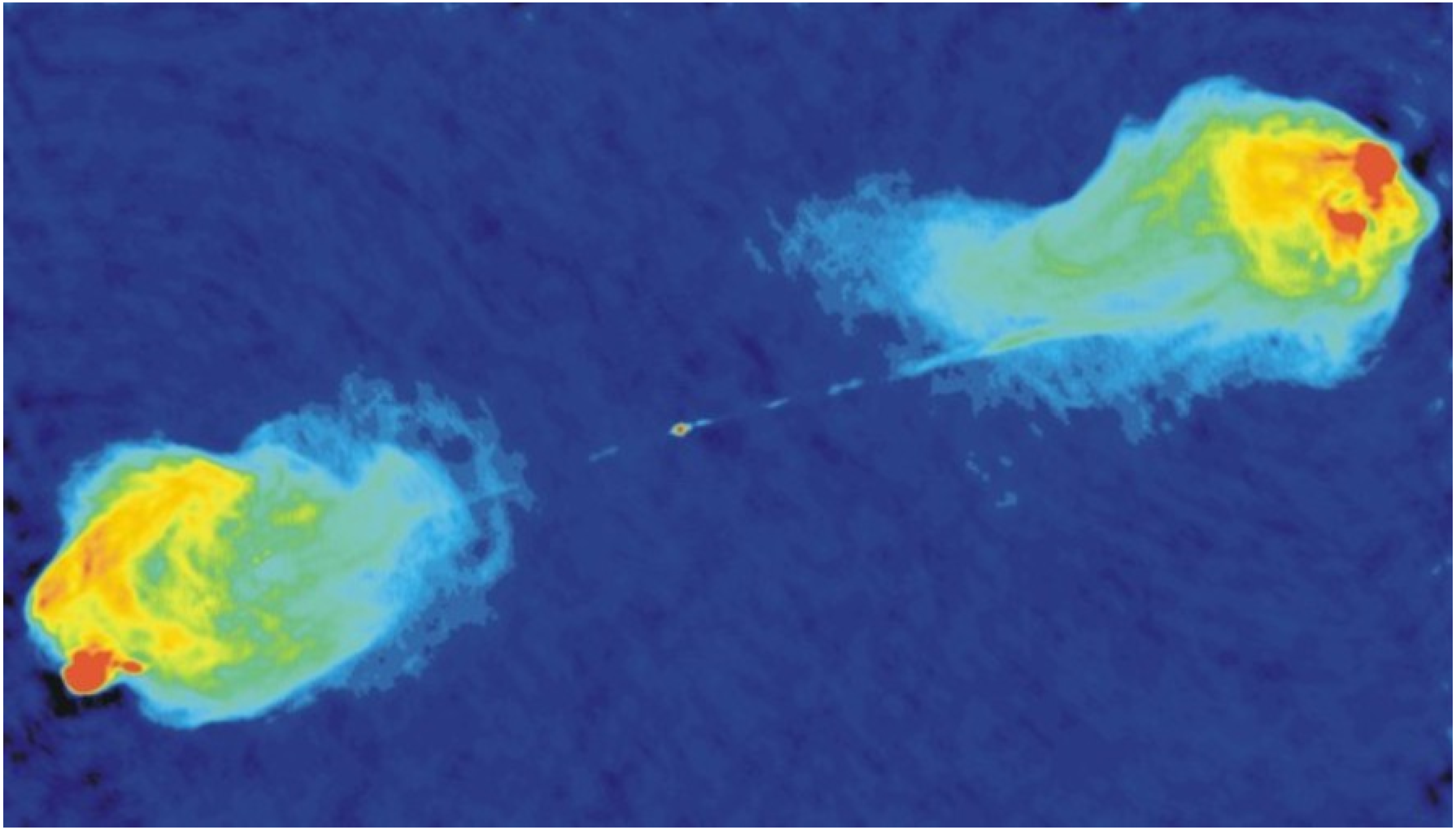


← uv-coverage

Resulting image



How to get this image of Cygnus A?



Credit: Image courtesy of NRAO/AUI; R. Perley, C. Carilli & J. Dreher

Peculiarities @ mm

With increasing frequency:

- **No external human interferences in the data**

- **No ionospheric effect**

- Tropospheric effects: absorption and delay of signal
  - → stronger weather dependency
  - → T_{sys} dominated by atmospheric noise

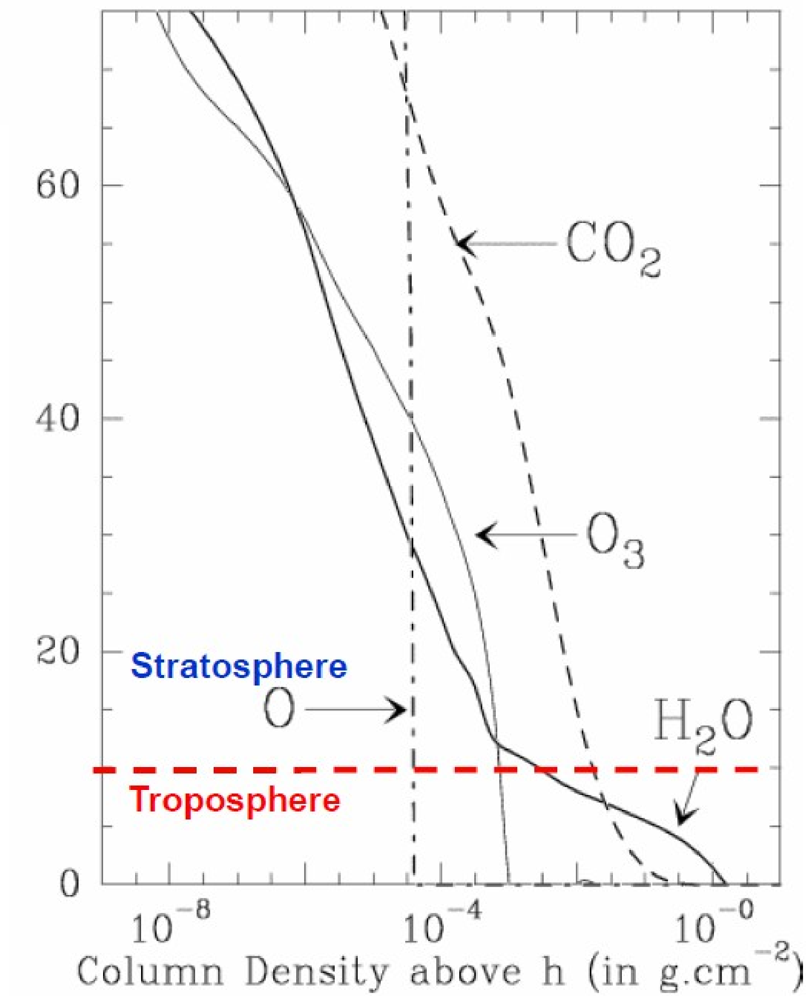
- Time variability of quasars increases
  - → which flux calibrators?

Peculiarities @ mm

The role of the troposphere

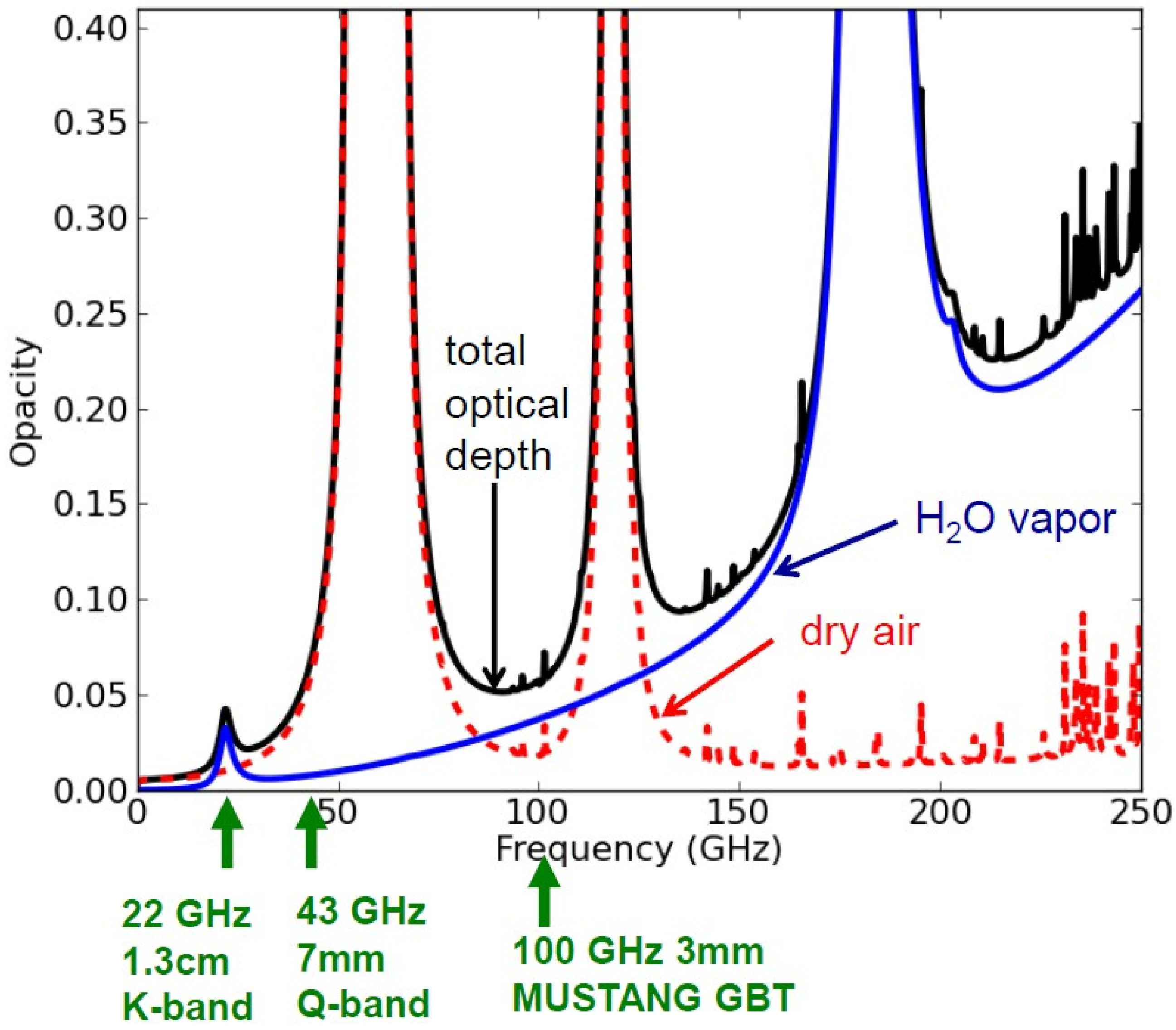
- H_2O (mostly vapor)
- "Hydrosols" (water droplets in clouds and fog)
- "Dry" constituents: O_2, O_3, CO_2, Ne, He, Ar, Kr, CH_4, N_2, H_2
- clouds & convection = time variation

Column density as function of altitude



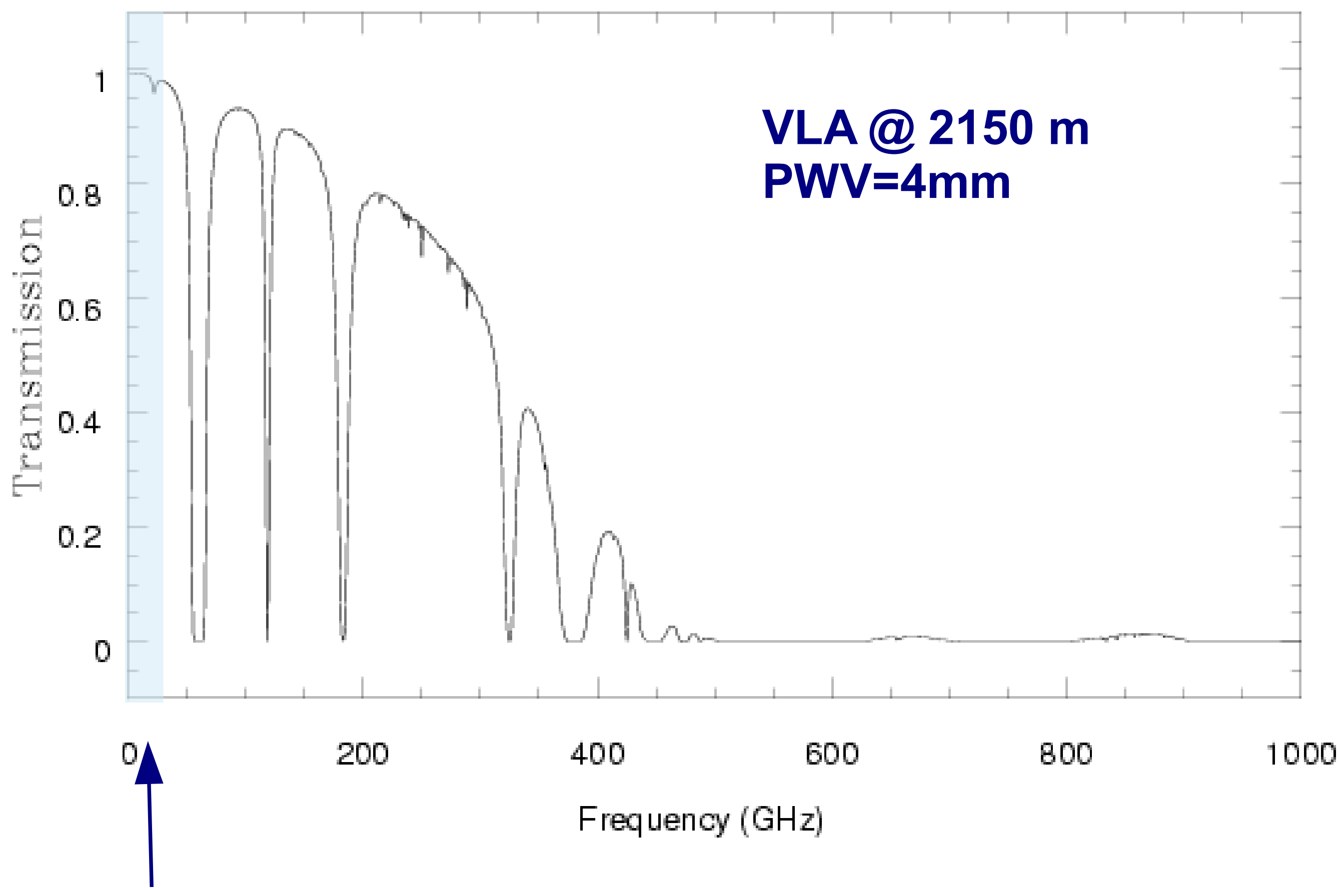
Peculiarities @ mm

Optical depth as function of frequency



Peculiarities @ mm

Tropospheric opacity depends on altitude

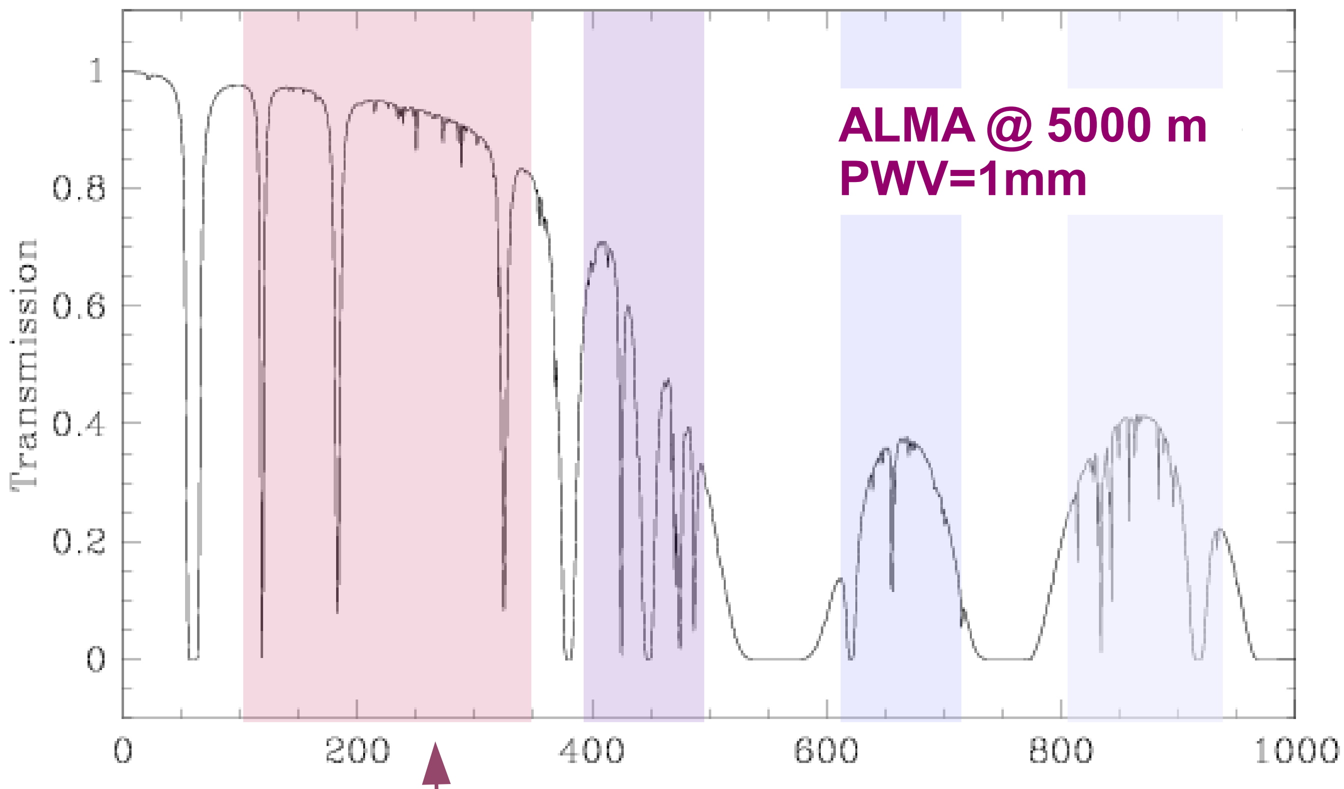


VLA bands

Atmospheric transmission not a problem @ $\lambda >$ cm

Peculiarities @ mm

Tropospheric opacity depends on altitude

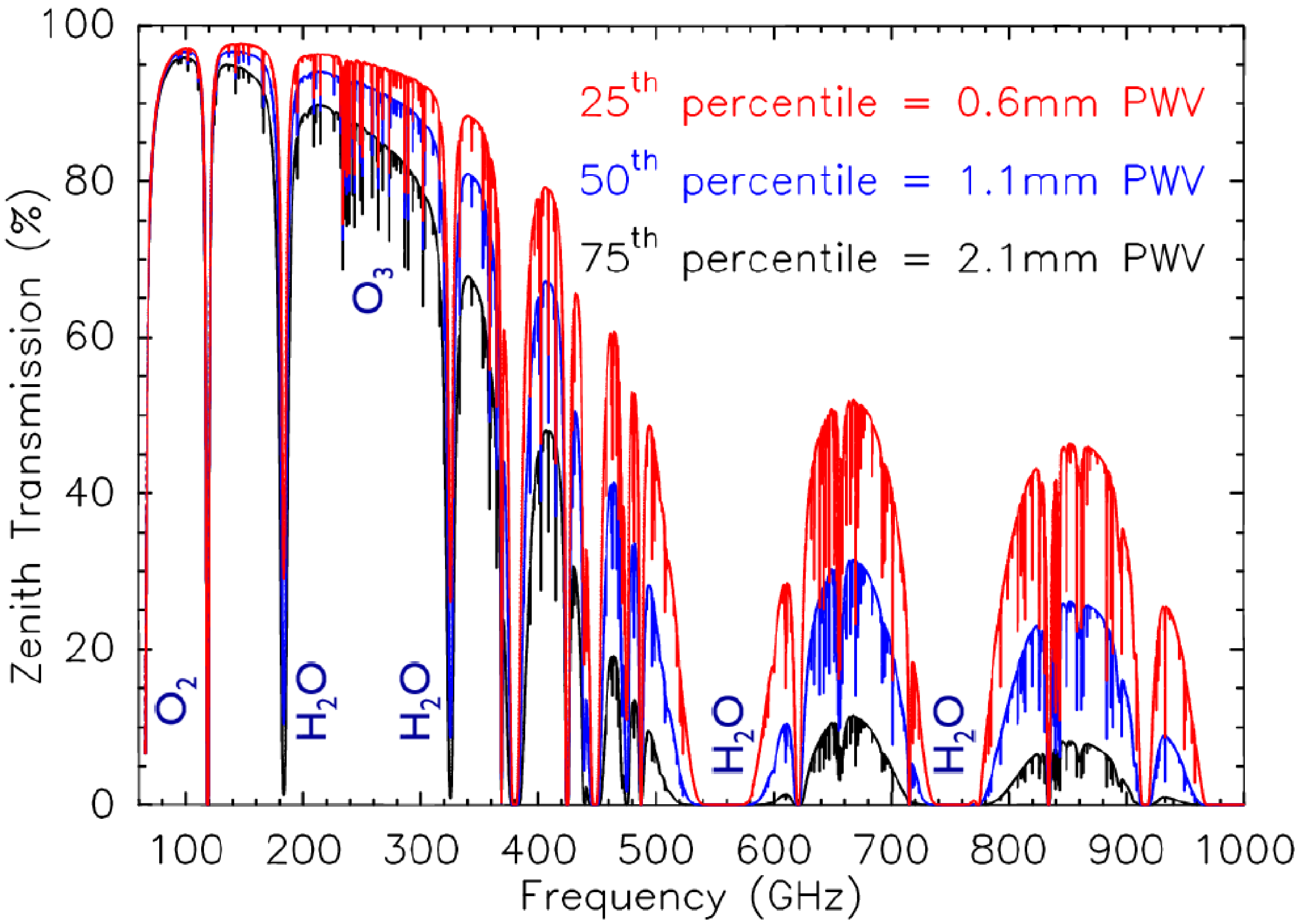


Difference due to the scale height of water vapor

ALMA bands

Peculiarities @ mm

PWV= Precipitable Water Vapour



Peculiarities @ mm

What the antenna measures is

$$T_{SYS} = T_A + T_R$$

and the system temperatures is largely dominated by the "receiver" temperature (tens of K, depending on the observing frequency).

e.g. to observe a 1 Jy source with a 10 m radiotelescope we have to measure T_A ~ 0.04 K against T_{sys} ~ 100 K

$$T_{sys} \sim T_{atm} (e^{\tau} - 1) + T_{rx} e^{\tau}$$

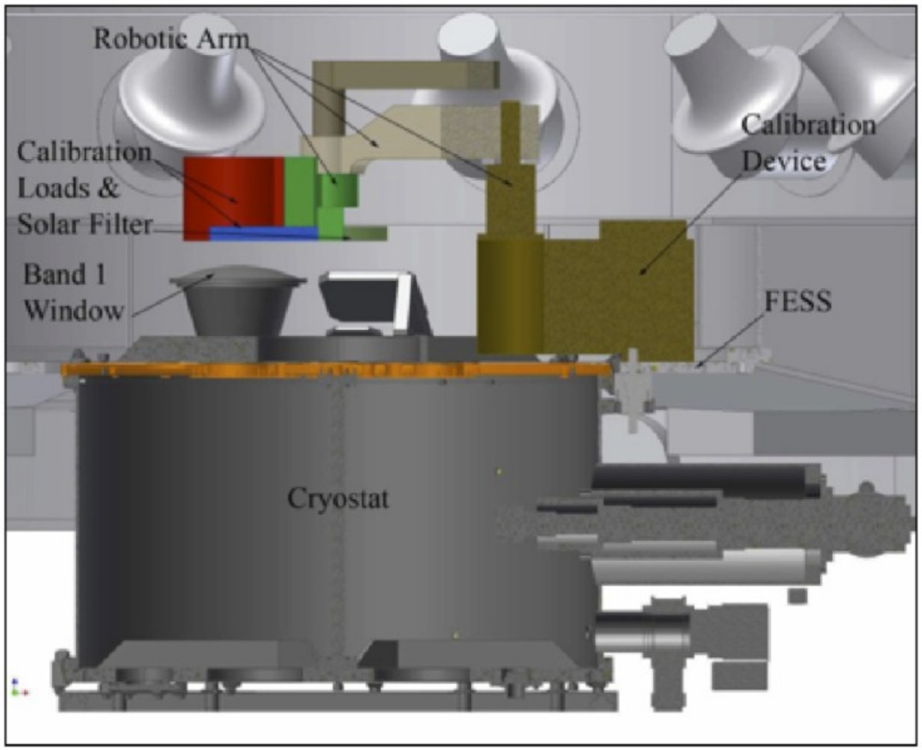
At lower frequencies T_{rx} is dominant

At higher frequencies (mm/submm) the noise associated with the atmosphere T_{atm} is dominant, and acts like a blackbody emitter, attenuating the astronomical signal

Peculiarities @ mm

System noise temperature

ALMA front end are equipped with an Amplitude Calibration Device (ACD)

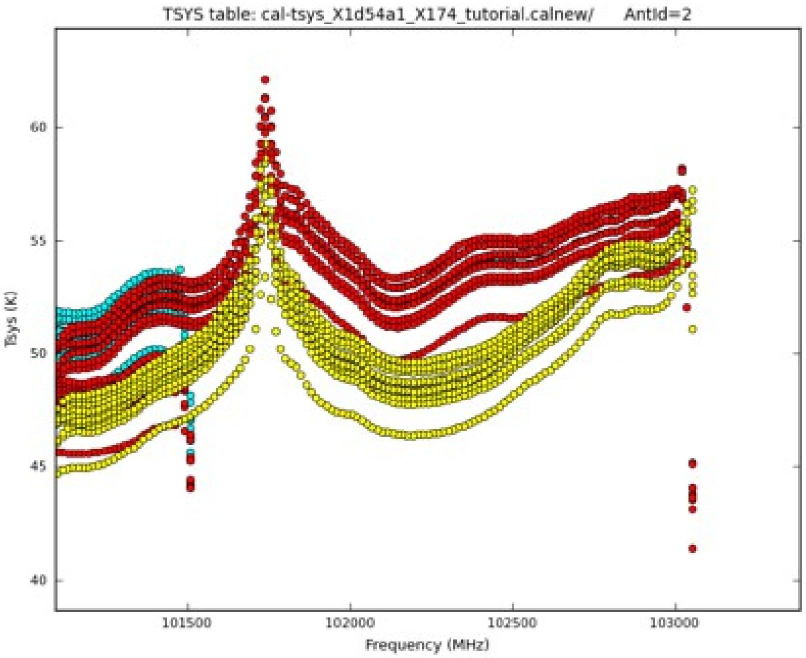


To measure T_{sys} and T_{rx} stored in tables

Every scan could have a Tsys measurement, but <400 GHz relatively constant ~10min.
Tsys spectra are applied off-line to the correlated data.

Assuming correlated data in units of % correlation multiplication by Tsys will change the unit to Kelvin

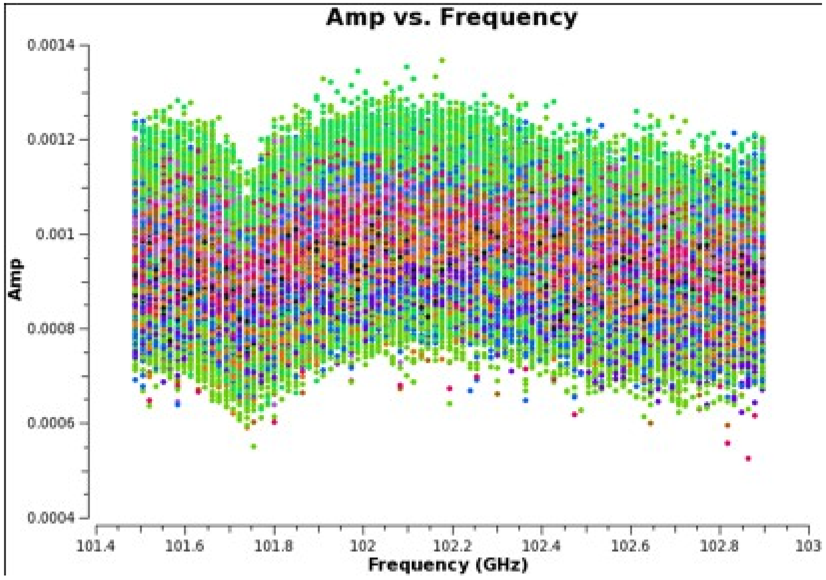
Peculiarities @ mm



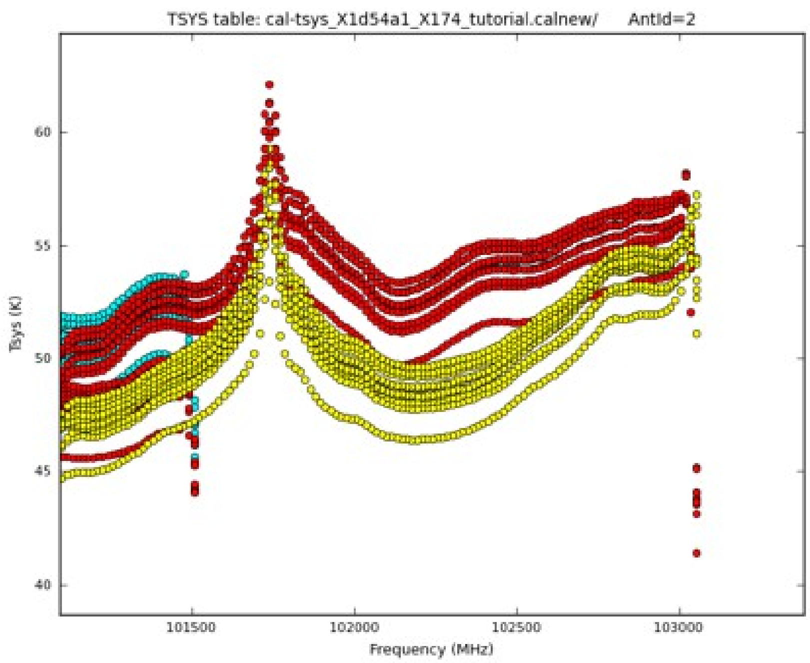
Tsys calibration

Spectral Tsys
band 3 (~100 GHz)

Before



Peculiarities @ mm



Tsys calibration 

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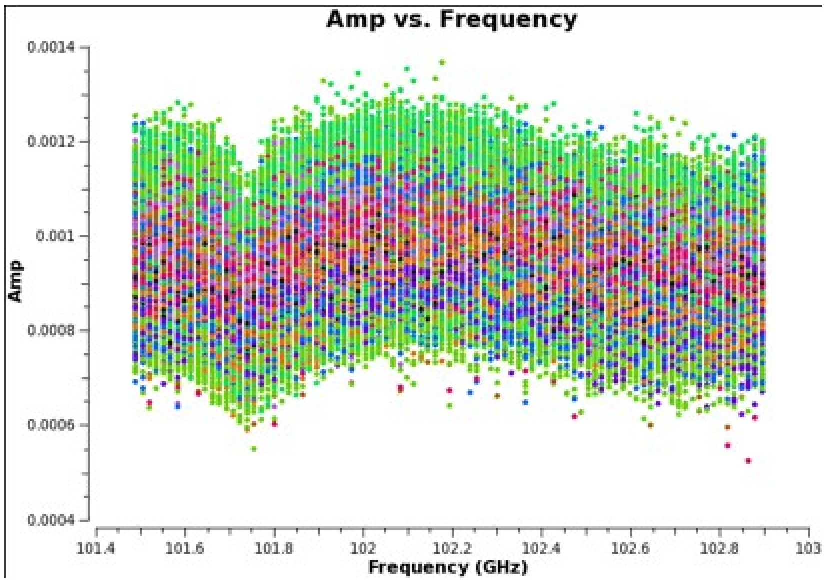
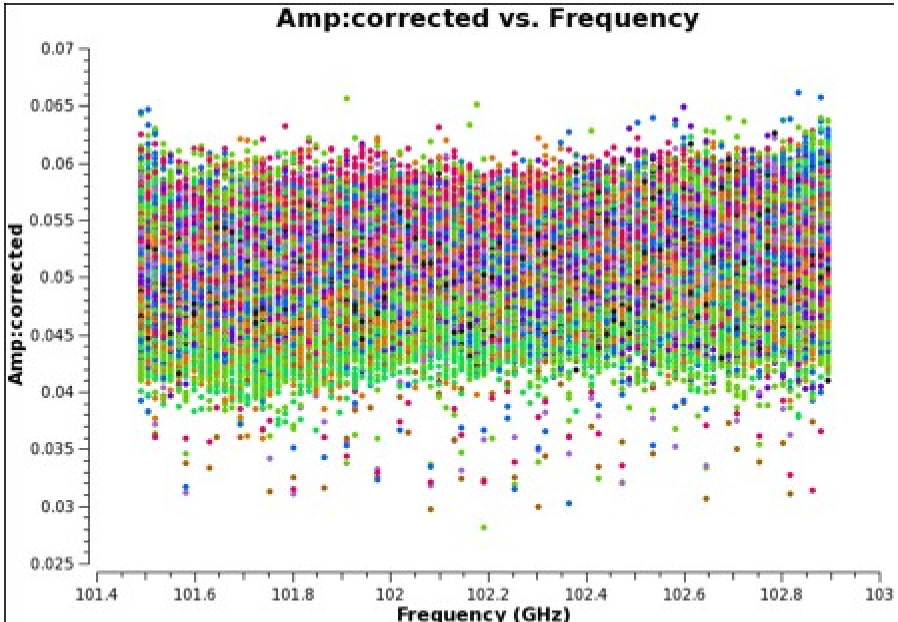


After

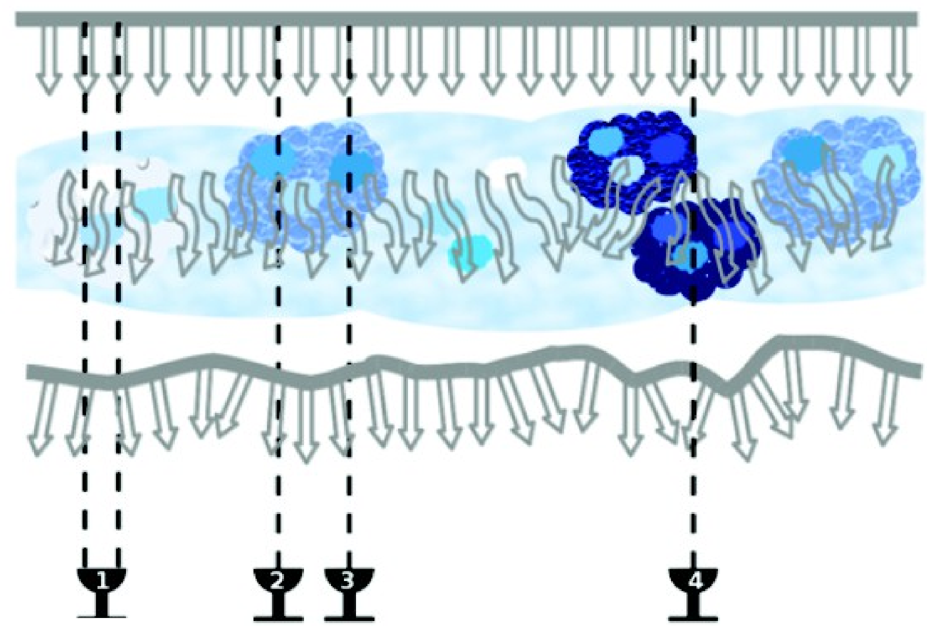


Peculiarities @ mm

Mean effect of atmosphere on Phase

Variations in precipitable water vapor (PWV) cause phase fluctuations, worse at higher frequencies, resulting in:

- Phase shift due to refractive index $n \neq 1$
- Low coherence (loss of sensitivity)



Patches of air with different pwv
(and hence index of refraction)
affect the incoming wave front differently.

Antenna 1, 2, 3 see slightly different disturbances

Sky above antenna 4 varies independently

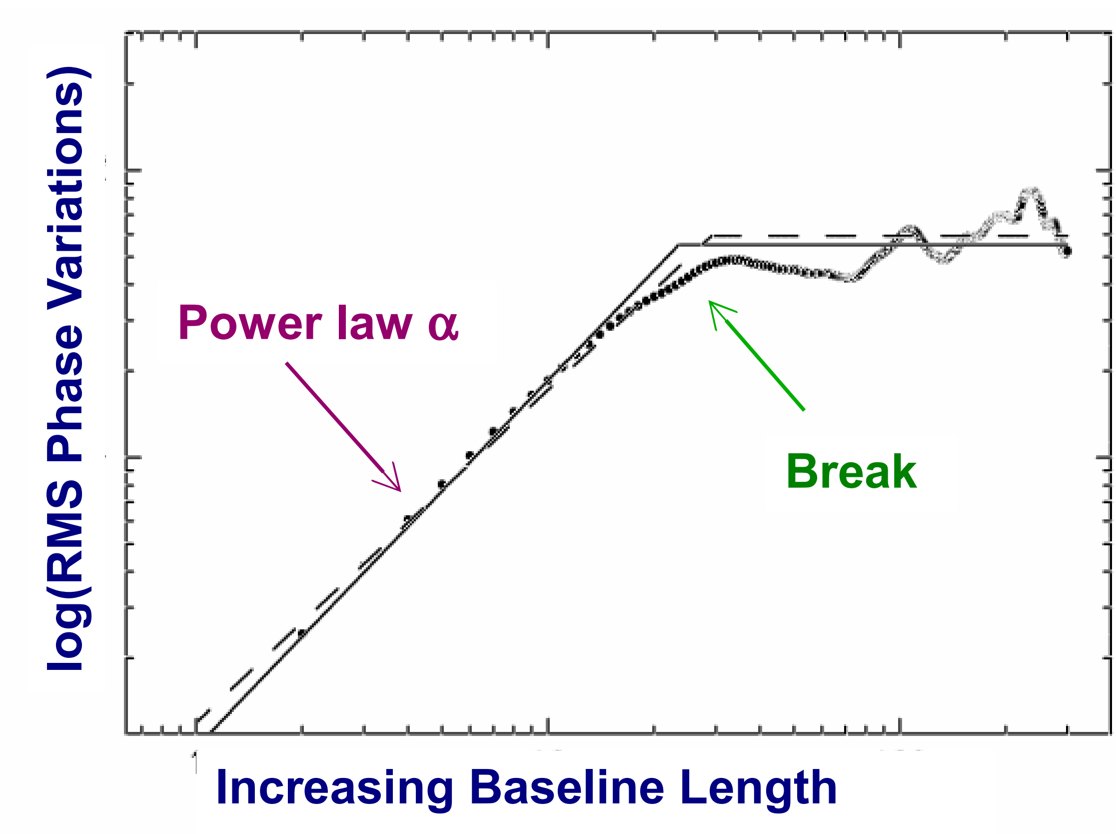
The phase change experienced by an e.m. wave can be related to pwv

$$\varphi_e \approx \frac{12.6\pi}{\lambda} \cdot pwv$$

Hogg, Guiraud, & Decker, 1981

Peculiarities @ mm

Atmospheric phase fluctuations



Phase noise

Kolmogorov turbulence theory

$$\varphi_{rms} = \frac{K\, b^{\alpha}}{\lambda}$$

b=baseline length (km)
α = 1/3 to 5/6 (thin or thick atmosphere)
λ = wavelength (mm)
K constant (~100 for ALMA)

The break is typically @ baseline lengths few hundred meters to few km (scale of the turbulent layers)

Break and maximum are weather and wavelength dependent

Peculiarities @ mm

Atmospheric phase fluctuations → decorrelation

We lose integrated flux because visibility vectors partly cancel out

$$\langle V \rangle = V_o \langle e^{i\varphi} \rangle = V_o e^{-(\varphi_{rms}^2)/2}$$

$$\varphi_{rms} = 1 \text{ radian} \rightarrow \langle V \rangle = 0.60\, V_0$$

In summary
Fluctuations in the line-of-sight pwv of an antenna
cause phase variations of the order of ~30 deg / sec at 90 GHz,
and scales linearly with frequency....

$$\varphi_e \approx \frac{12.6\pi}{\lambda} \cdot pwv$$

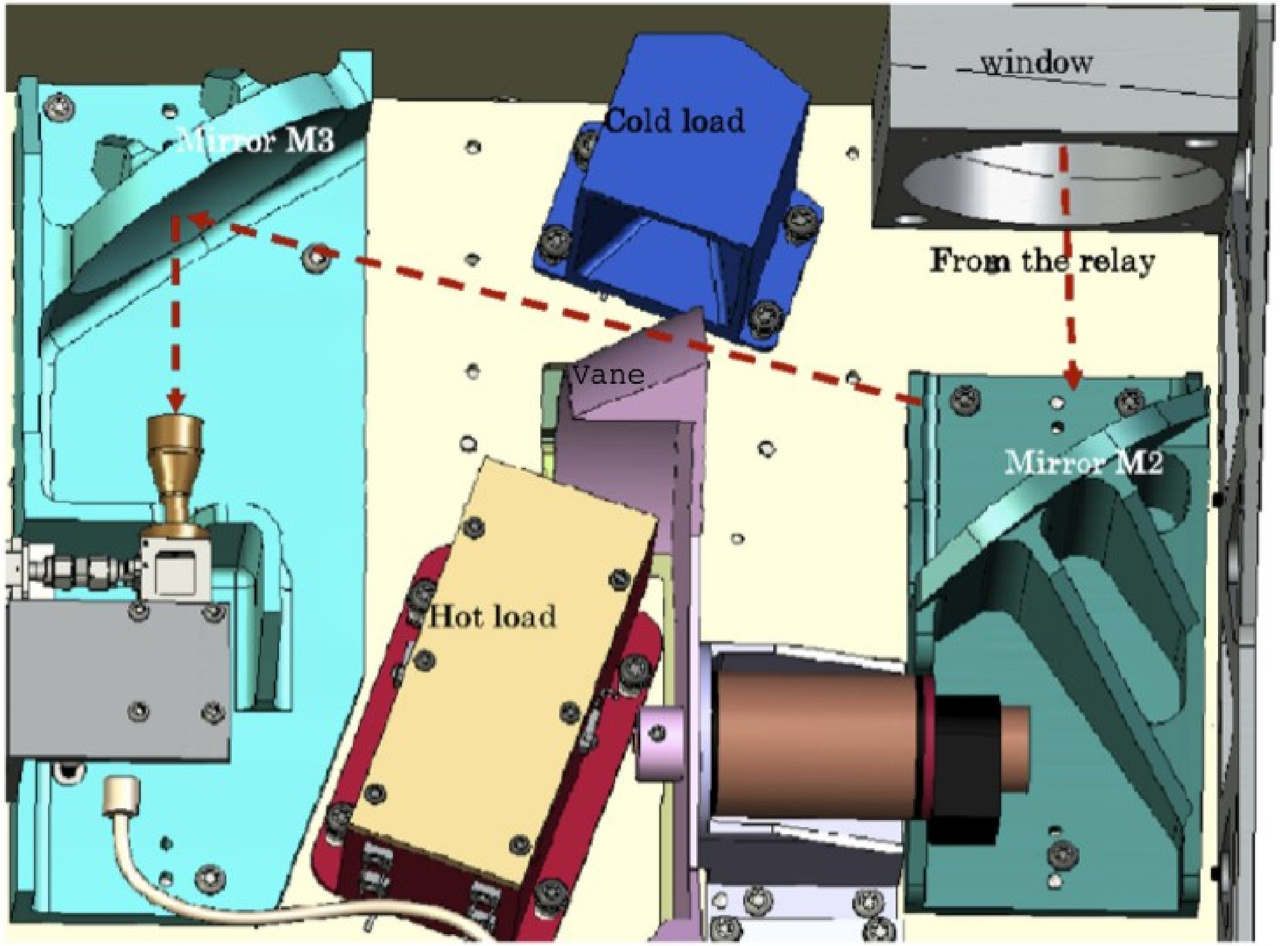
and the phase noise is worse at longer baselines...

$$\varphi_{rms} = \frac{K\, b^{\alpha}}{\lambda}$$

Peculiarities @ mm

WVR correction

Each ALMA 12 m antenna has a water **vapour radiometer**



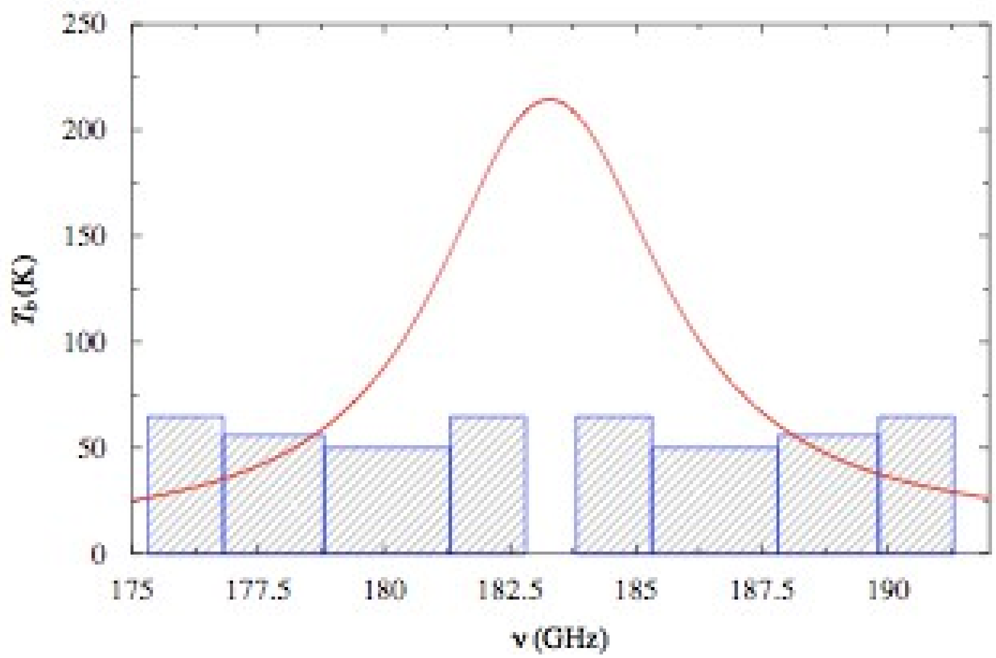
Peculiarities @ mm

WVR correction

Each ALMA 12 m antenna has a water **vapour radiometer**

Four “channels” flanking the peak of the 183 GHz water line

Data taken every second



Peculiarities @ mm

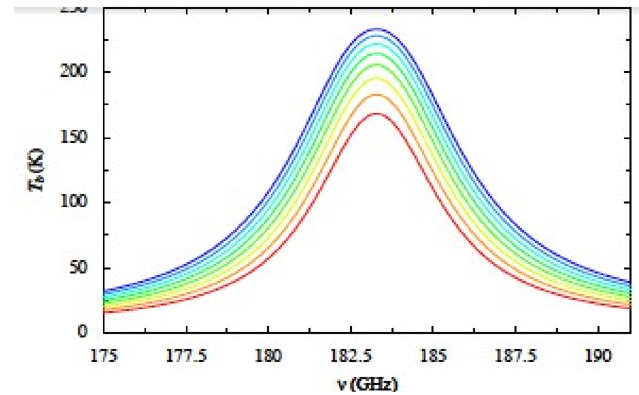
WVR correction

Each ALMA 12 m antenna has a water **vapour radiometer**

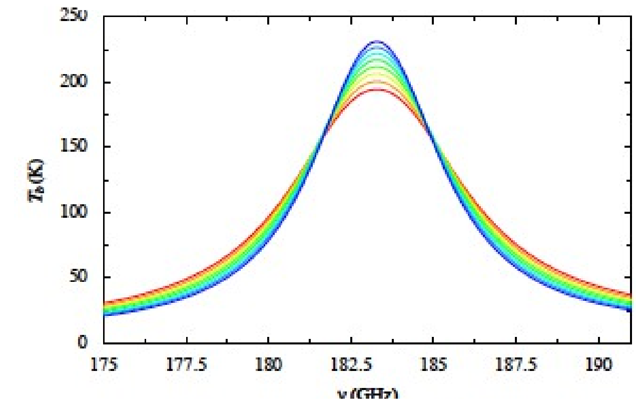
Four “channels” flanking the peak of the 183 GHz water line

Data taken every second

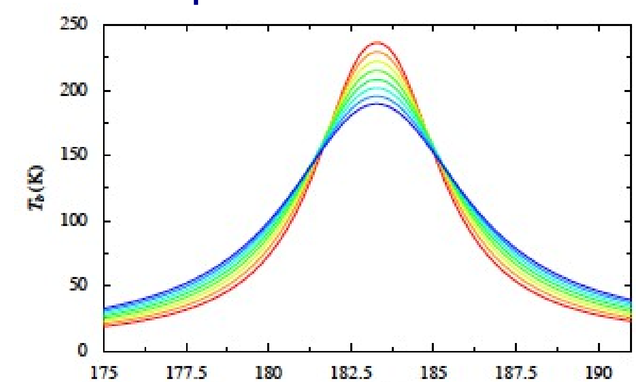
Convert 183 GHZ brightness to PWV (wvrgcal):
model PWV, temperature and pressure
compare to the observed “spectrum”
compute the correction:



PWV from 0.6 to 1.3 mm



Temperature 230-300 K

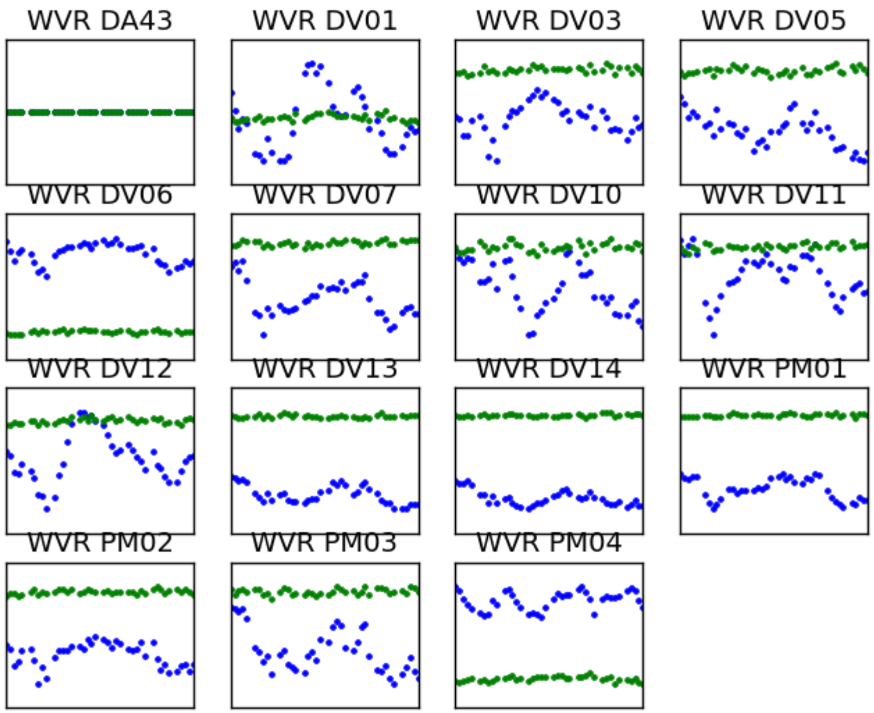


Pressure 400-750 mBar

Peculiarities @ mm

WVR correction

Band 6 (230 GHz)

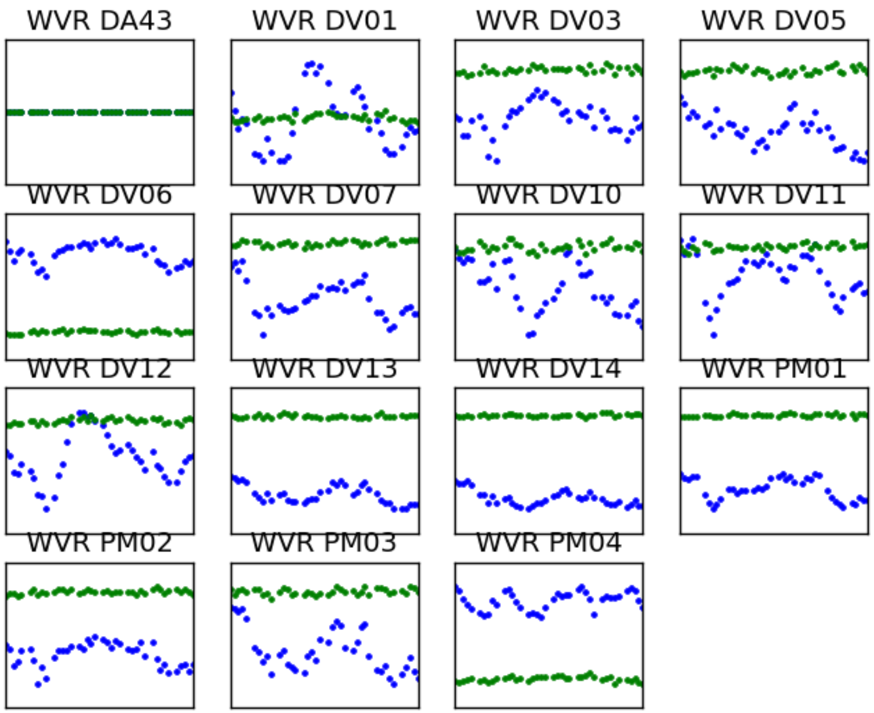


Raw phases & WVR corrected phases

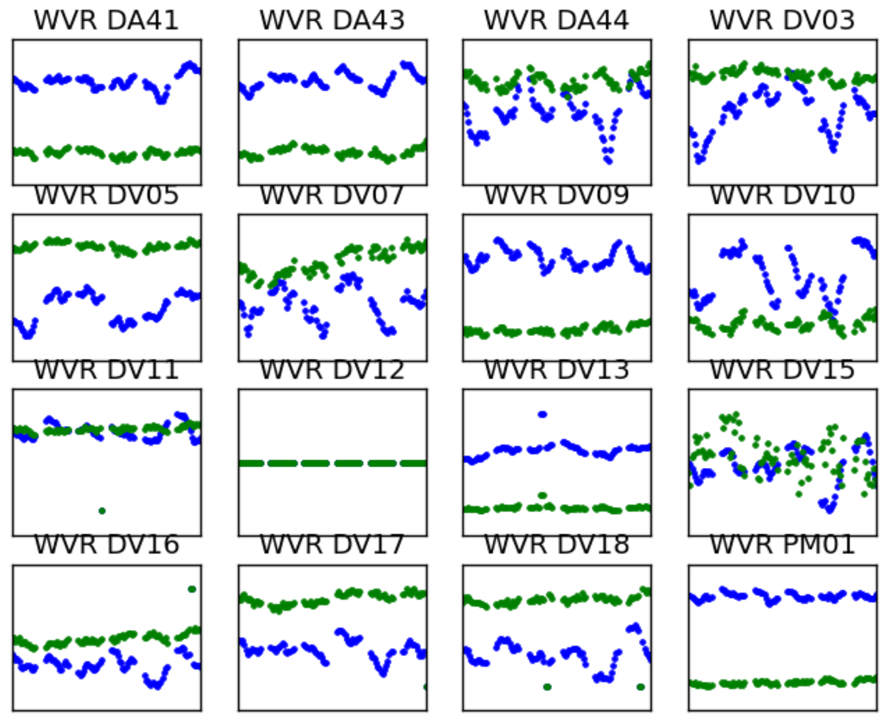
Peculiarities @ mm

WVR correction

Band 6 (230 GHz)



Band 7 (340 GHz)



Raw phases & WVR corrected phases

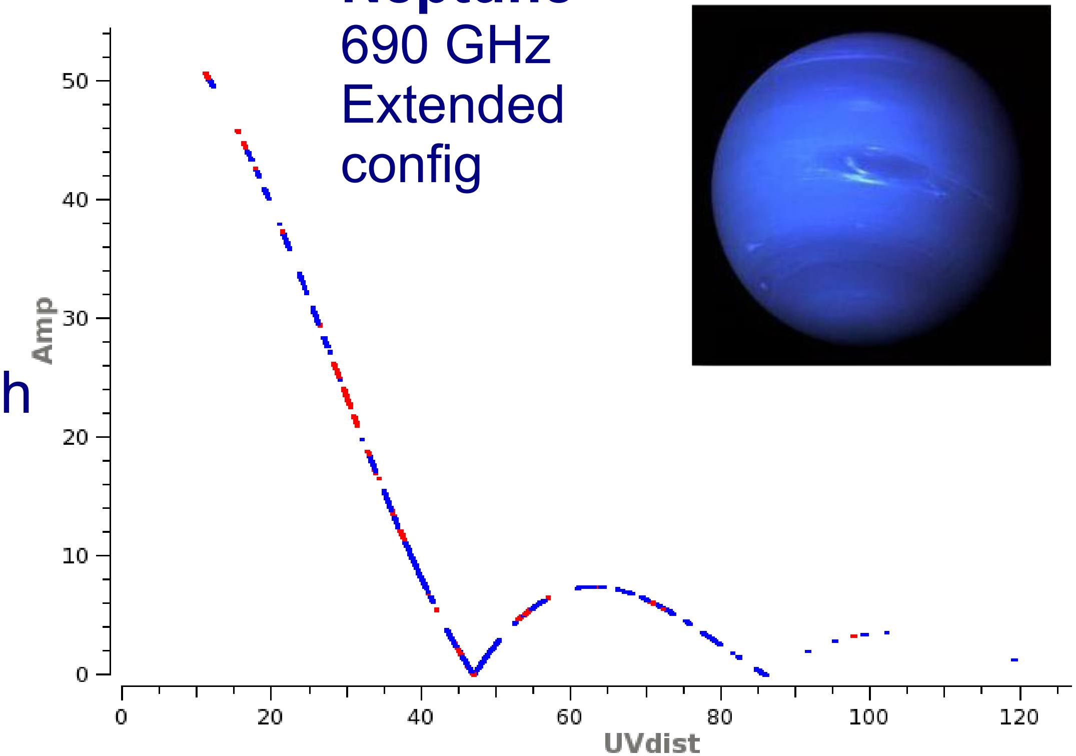
Peculiarities @ mm

Flux calibrators

- Quasars are strongly time-variable and good models do not exist at high frequencies

- Solar System bodies are used as primary flux calibrators (Neptune, Jovian moons, Titan, Ceres) but with many challenges:
  - all are resolved on long baselines
  - brightness varies with distance from Sun and Earth
  - line emission present → need models

Neptune
690 GHz
Extended
config

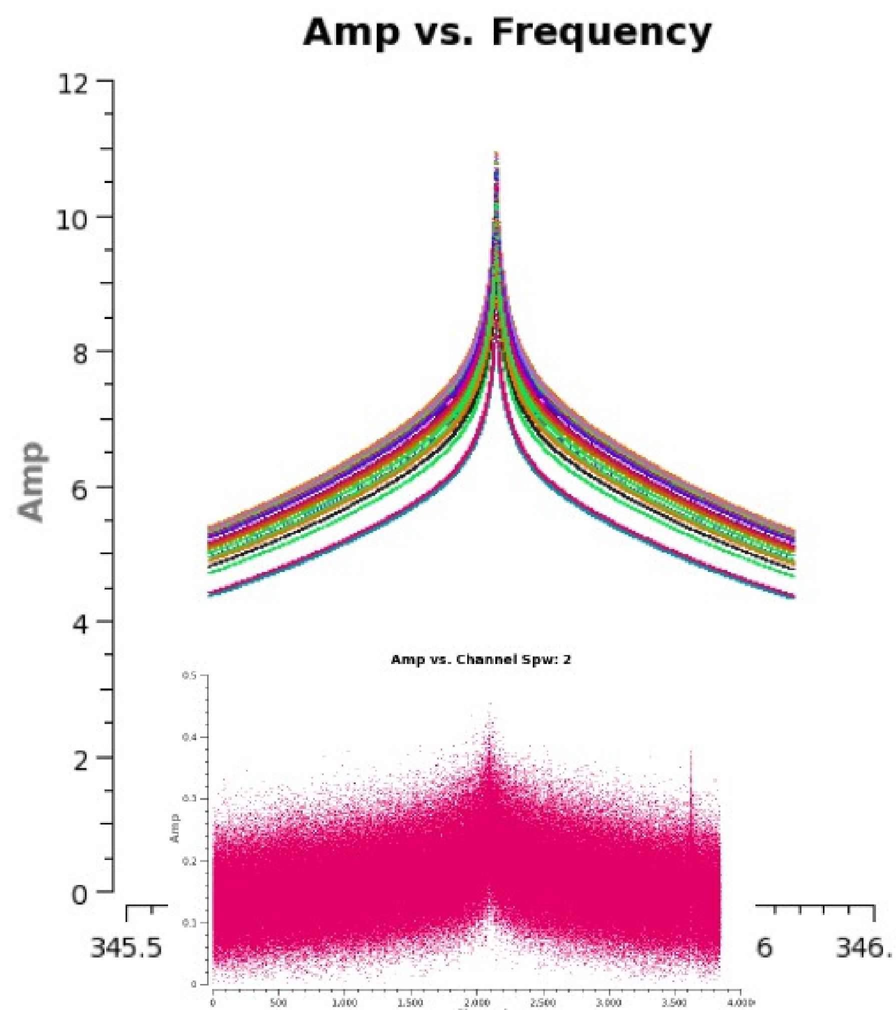


Other possibilities: asteroids,
red giant stars...
Monitoring of point-like quasars

Peculiarities @ mm

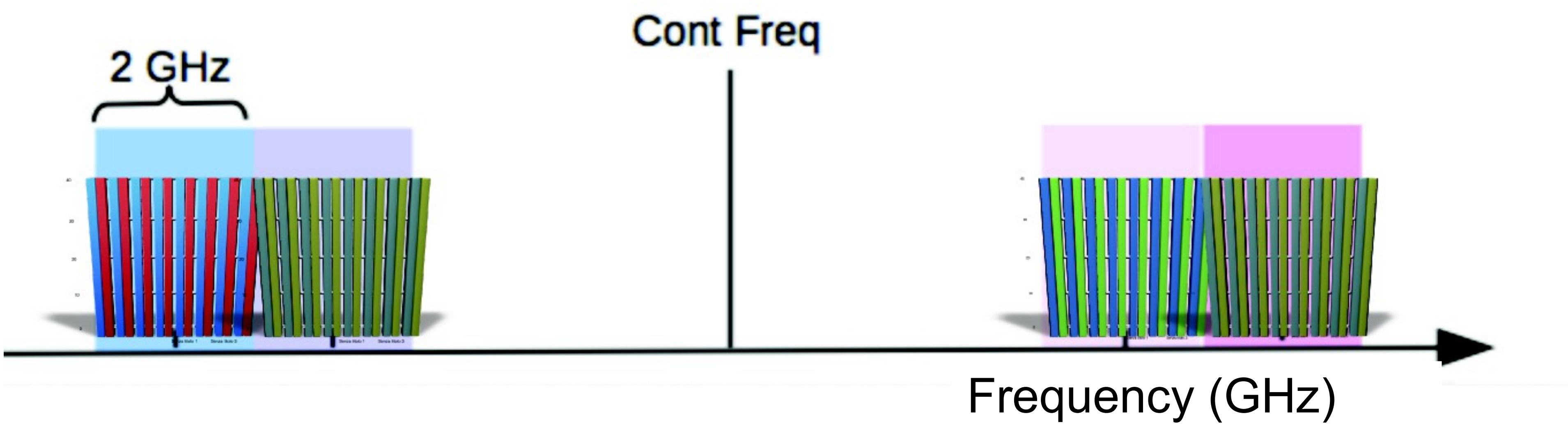
Flux calibrators

Model spectral lines: CO in Titan



Interferometric data

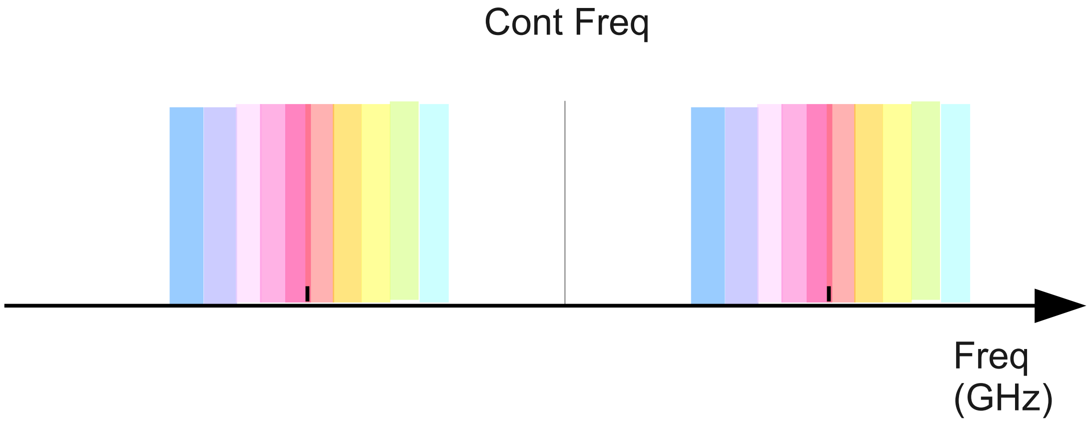
Modern interferometric observations are taken in multi-channel mode regardless if they are continuum or line observations

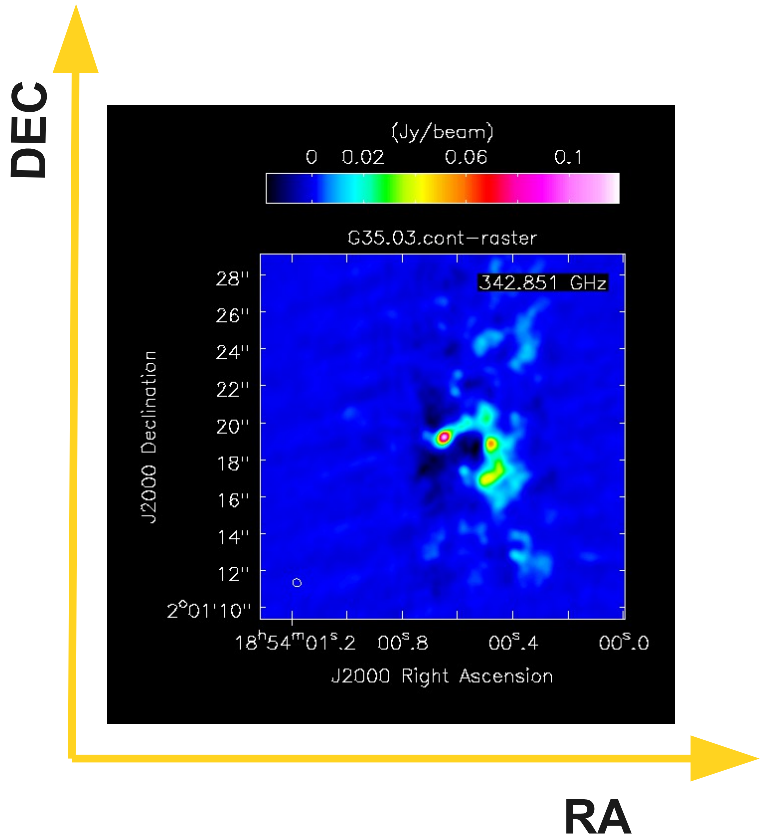


Data are actually **data cubes:**
from each channel (freq, velocity) 1 uv-plane

Interferometric data

Continuum images are obtained combining all the (line-free) channels.



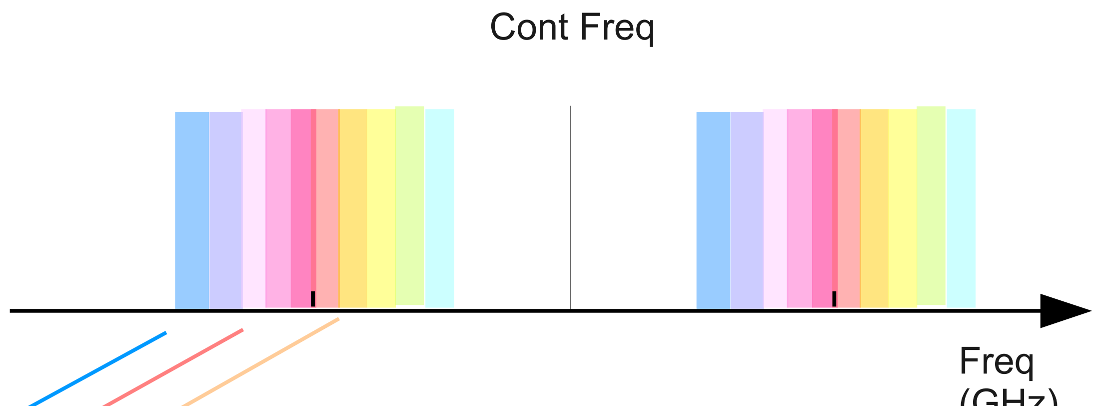


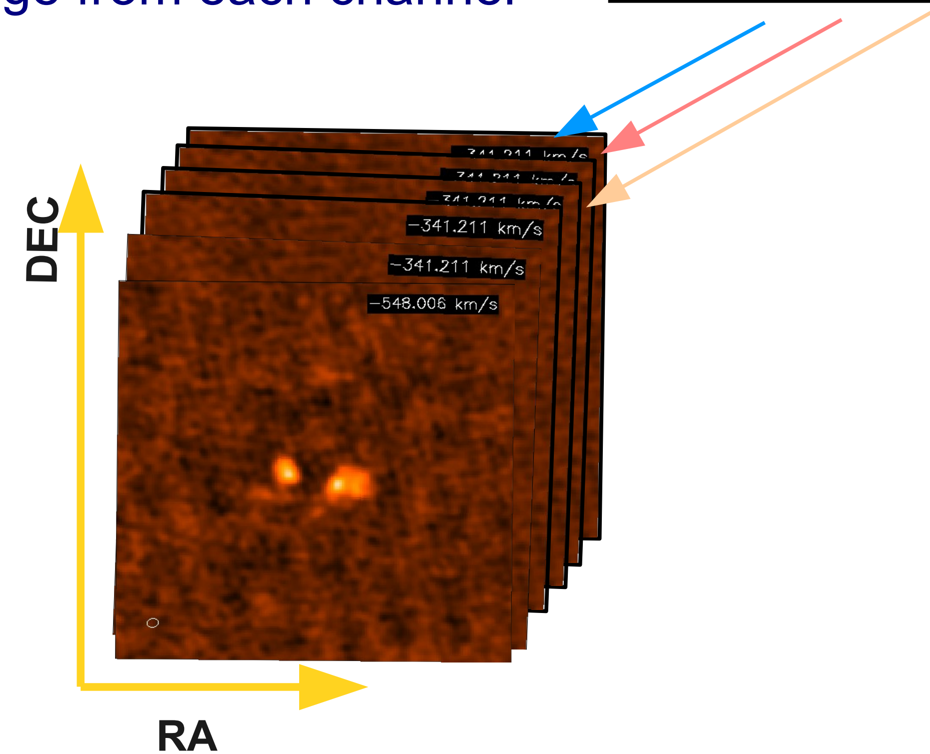
The resulting image is a 2-Dimensional image at the central frequency.

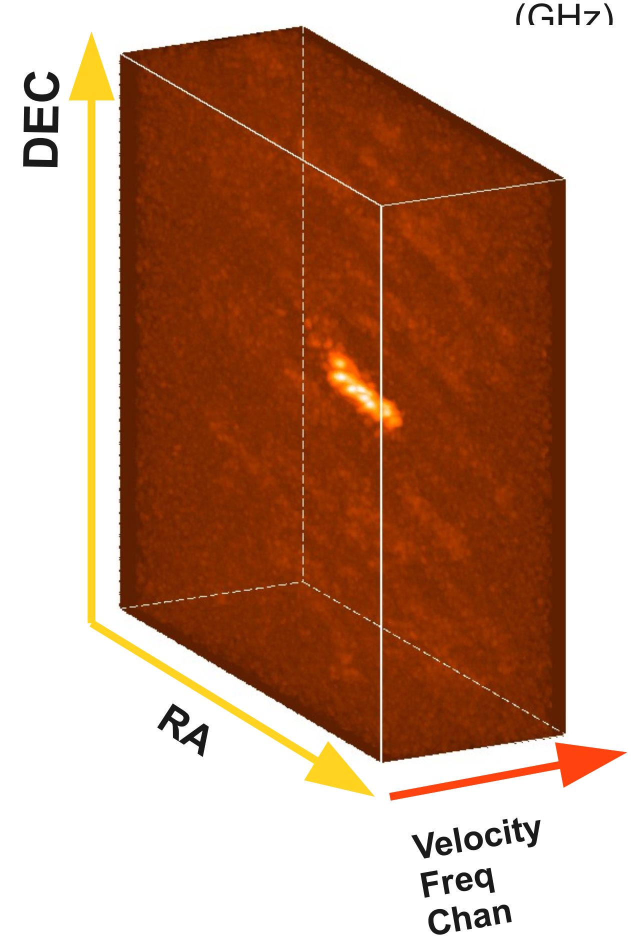
Interferometric data

Spectral line images
are 3-dimensional.

One image from each channel

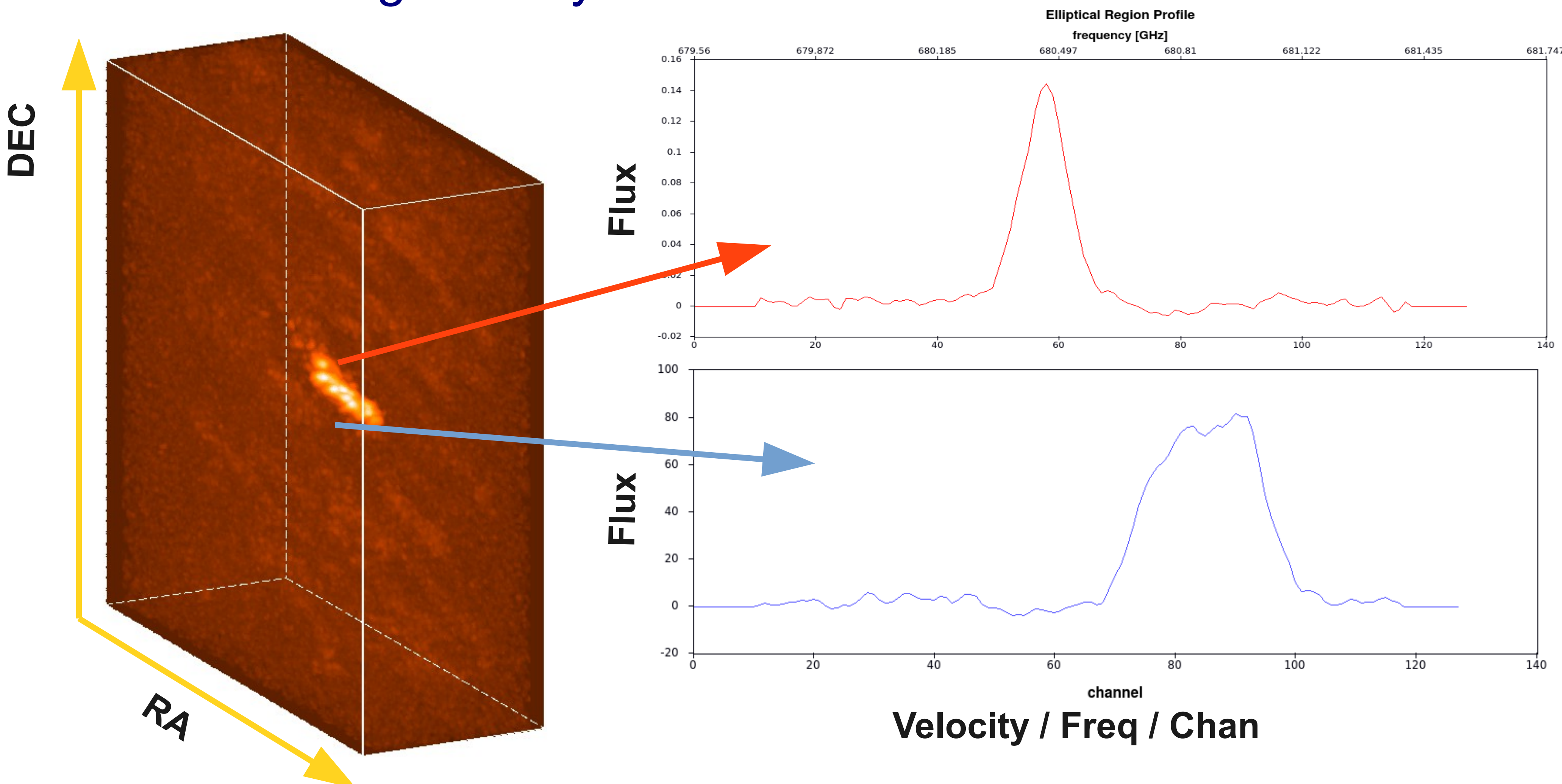






Spectral lines

1-D slice along velocity axis



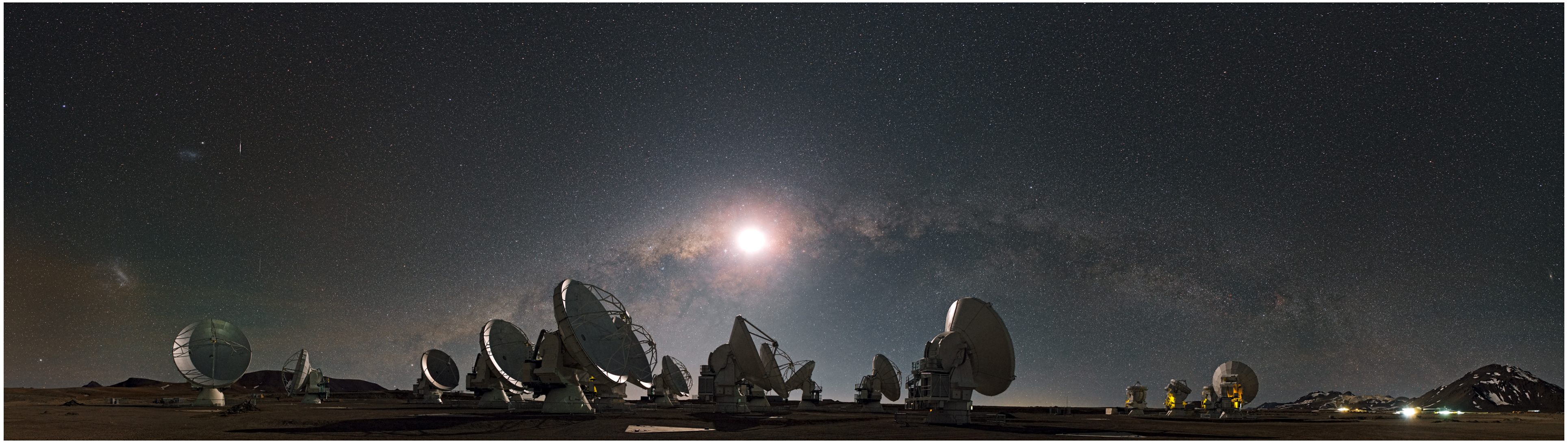
From each pixel one spectrum

EUROPEAN ARC
ALMA Regional Centre || Italian

ALMA REGIONAL CENTRE ITALY
is Bologna

Introduction to ALMA

Jan Brand, Rosita Paladino – ALMA Regional Centre, Italian node

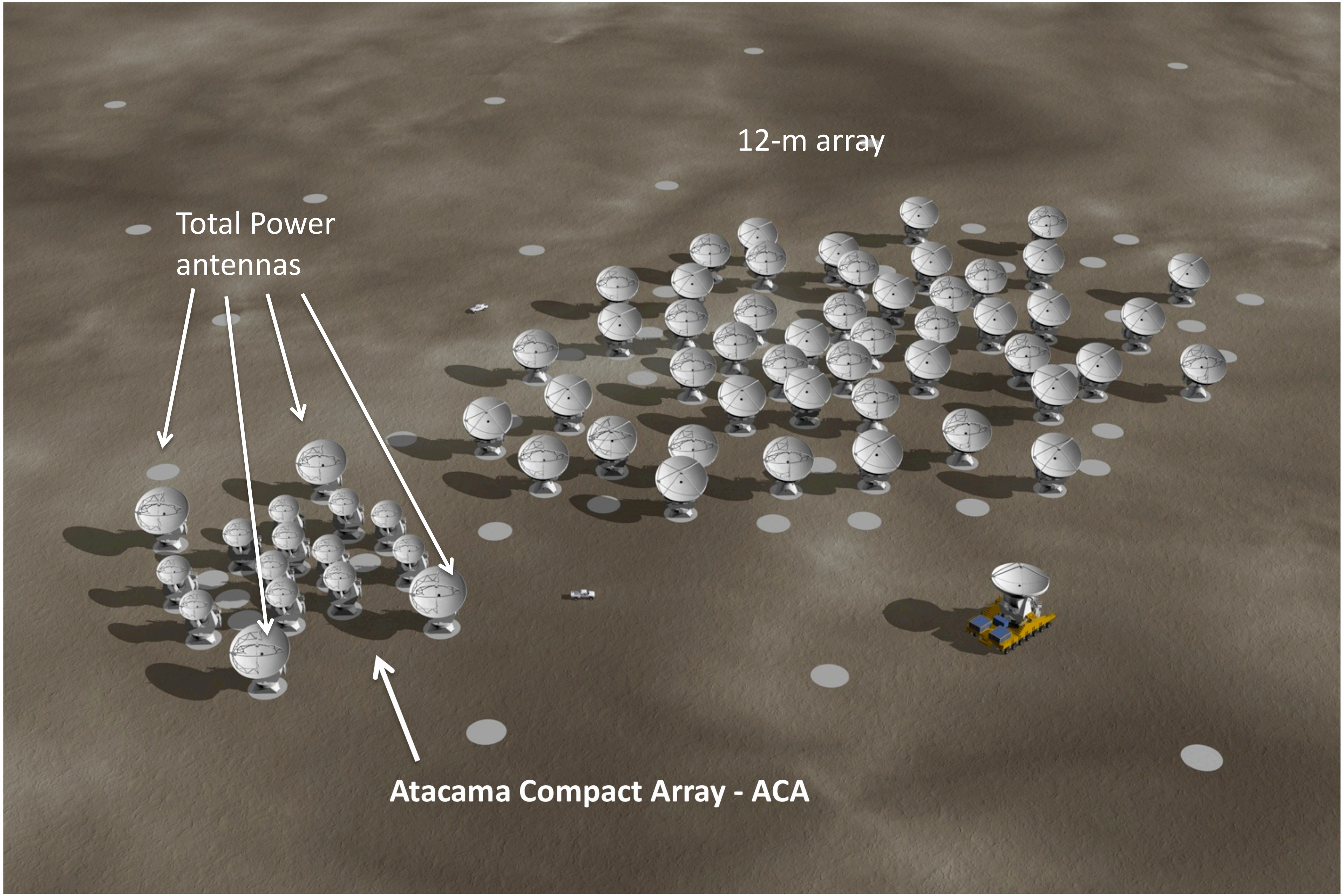


ALMA observes the cool (10's – 100's K) universe – thermal radiation at (sub)mm wavelengths: dust (continuum) and molecules (rotational transitions).

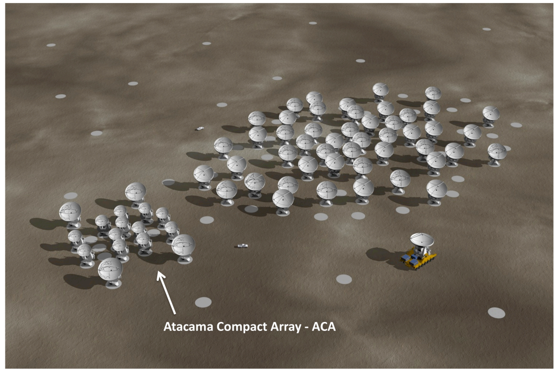
Main 'science drivers' ('level 1 science goals') of ALMA:

* Detect emission line of CO/C^+ in a normal MW-like galaxy at z=3 in < 24 hrs.
* Image (resolve) the gas kinematics in protoplanetary disks around young Sun-like stars in the nearest molecular clouds (d=150 pc)
* Provide high (~ 1000) dynamic range images at 0.1 arcsec resolution

ALMA operates at frequencies between 30 and 950 GHz. Requires high and dry site (to reduce effect of atmospheric absorption lines of e.g. H_2O, O_2, O_3).


12-m array
Total Power antennas
Atacama Compact Array - ACA

THE AMBITIOUS ALMA PROJECT



\# Dry site (low pwv)
\# low T_{sys}
\# > 6500 m^2 effective area
\# 1225 baselines (main array)
\# short spacings with ACA, TP-ants.

Excellent instantaneous uv-coverage and high sensitivity:
< 0.05 mJy @ 100 GHz in 1 hr

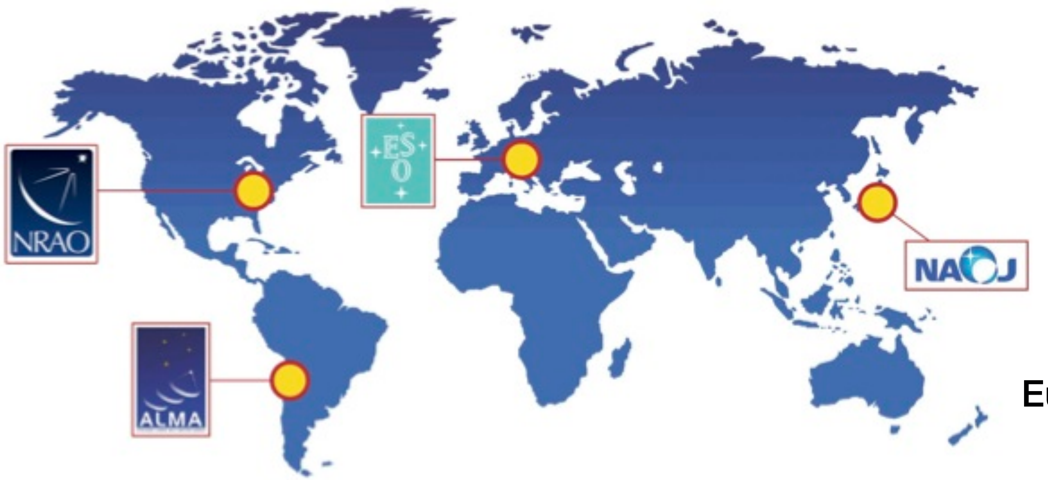
\# baselines up to b_{max} = 16 km

Sub-arcsec resolution:
40 mas @ 100 GHz
5 mas @ 900 GHz

\# 10 spectral bands 30-950 GHz
\# 70 correlator modes

High flexibility in spectral studies

ORGANIZATIONAL STRUCTURE



Joint ALMA Observatory:

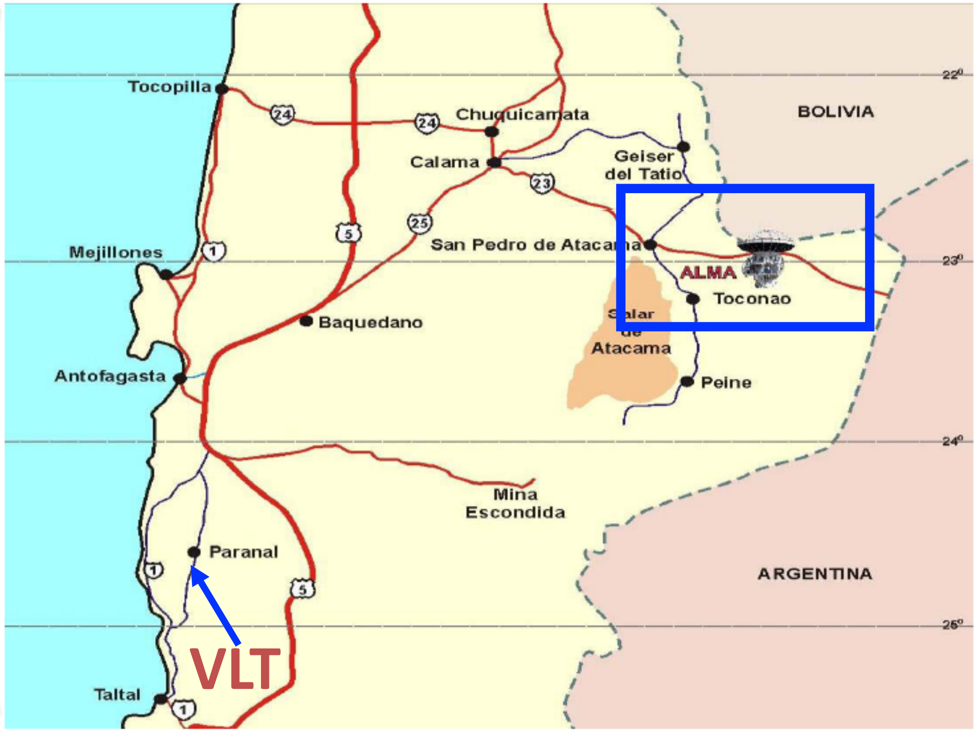
Europe (ESO): 33.75%
North America (NRAO): 33.75%
East Asia (NAOJ): 22.5%
Chile: 10%

European ARC nodes

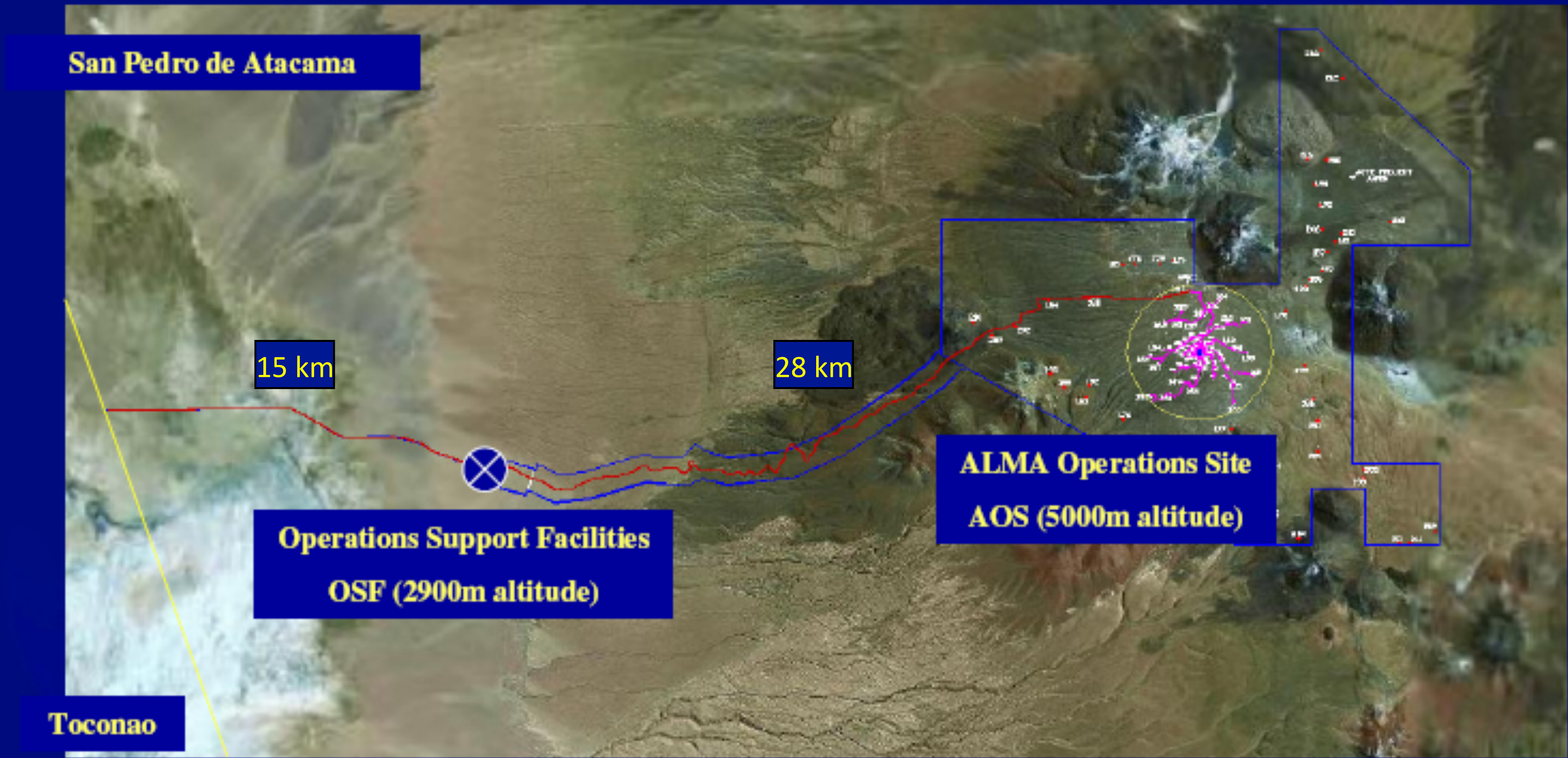
In Europe:

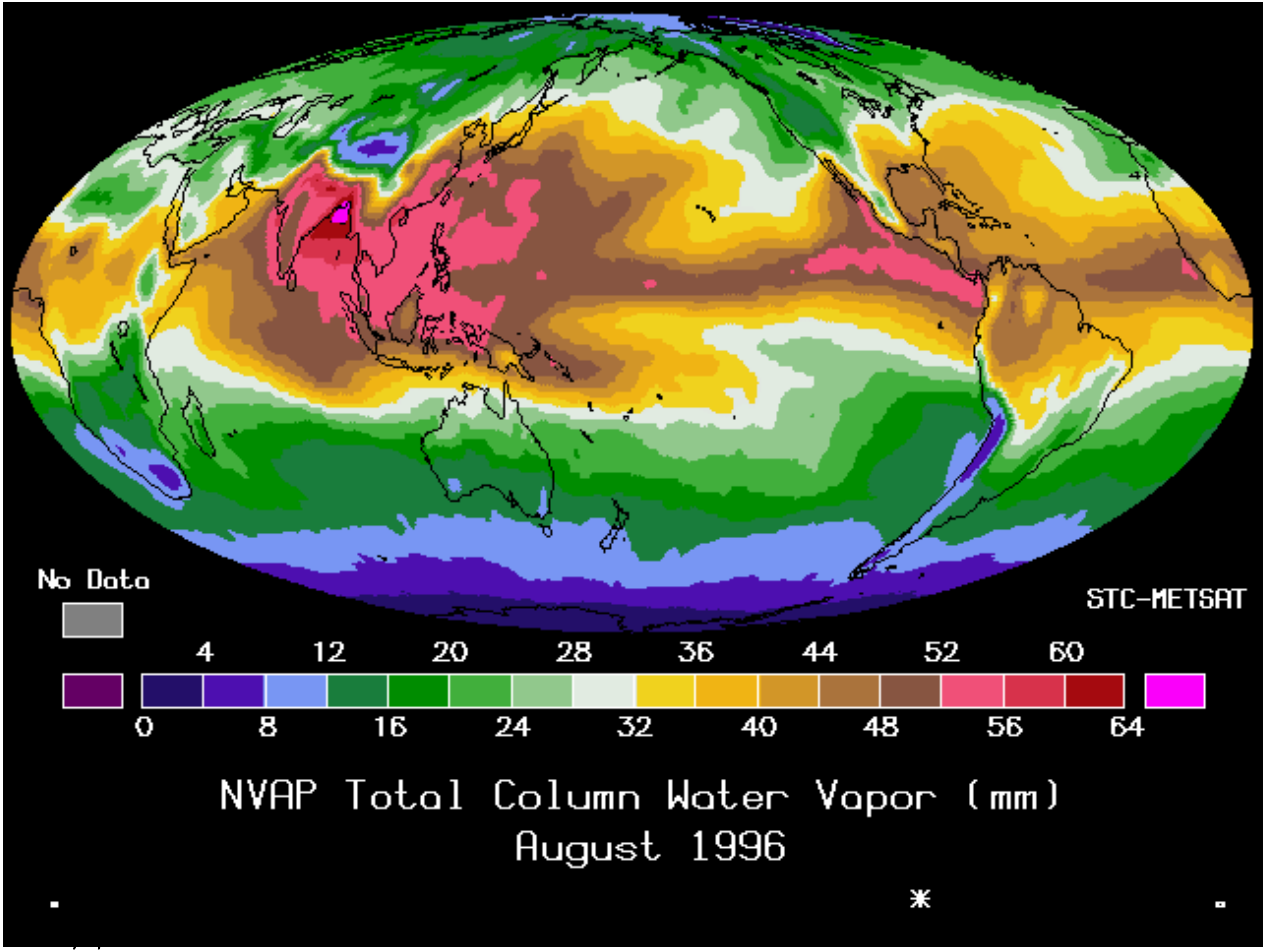
A network of 7 ARC-nodes and
1 Centre of Expertise, coordinated
by the central node at ESO.


PERU
Arica
Iquique
South Pacific Ocean
BOLIVIA
Atacama Desert
Antofagasta
PARAGUAY
Chañaral
Isla San Ambrosio
Isla San Félix
CHILE
Coquimbo
ARGENTINA
Valparaíso
SANTIAGO
San Antonio
Rancagua
Archipiélago Juan Fernández
Concepción
Talcahuano
Lebu
Temuco
Puerto Montt
SOUTH AMERICA
Easter Island and Isla Sala y Gomez are not shown.
South Atlantic Ocean
Strait of Magellan
Punta Arenas
0 200 400 km
0 200 400 mi
www.theodora.com/maps

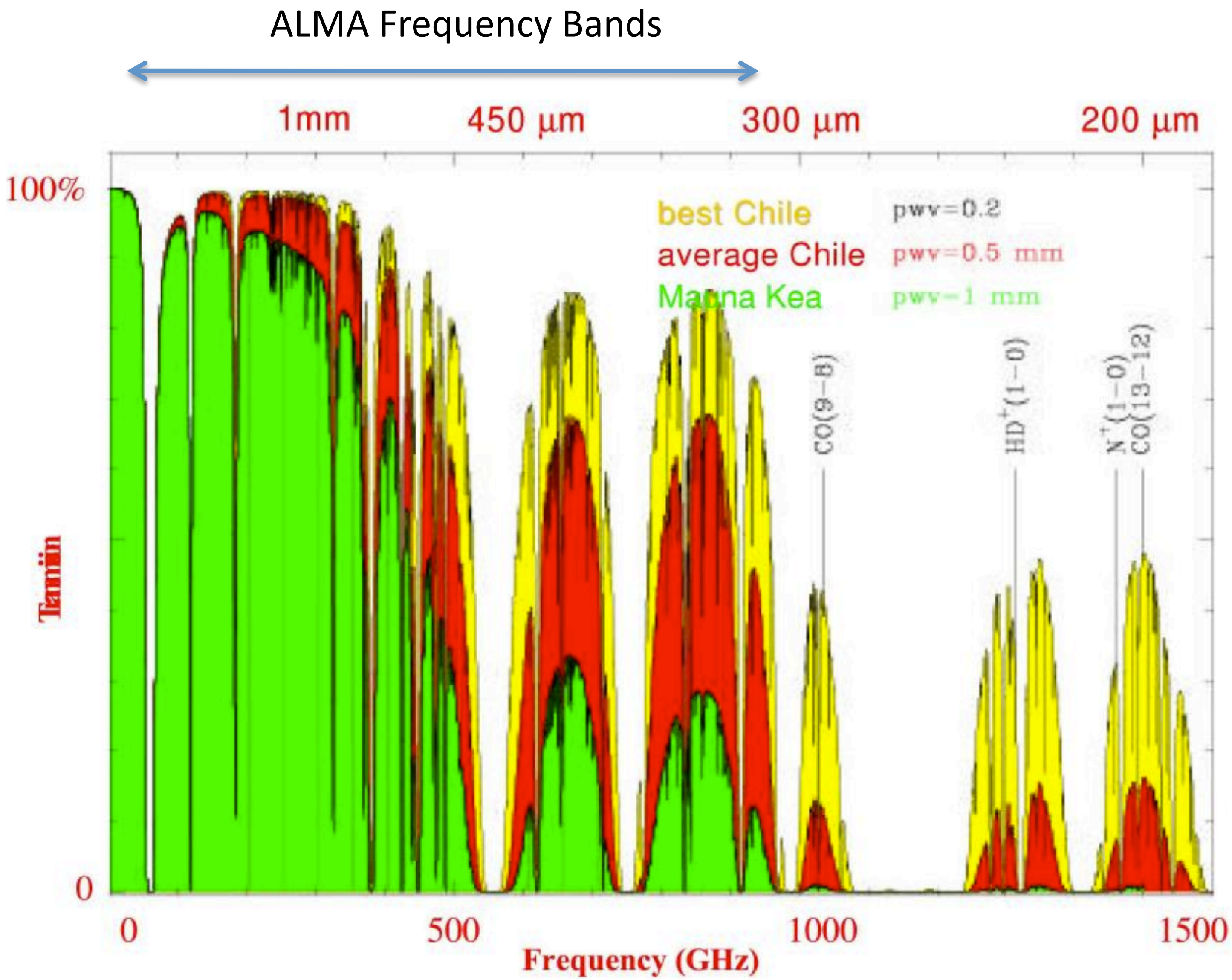

Tocopilla
Chuquicamata
BOLIVIA
Calama
Geiser del Tatio
Mejillones
San Pedro de Atacama
ALMA
Toconao
Baquedano
Salar de Atacama
Antofagasta
Peine
Mina Escondida
Paranal
ARGENTINA
VLT
Taltal
22º
23º
24º
25º

ALMA Site

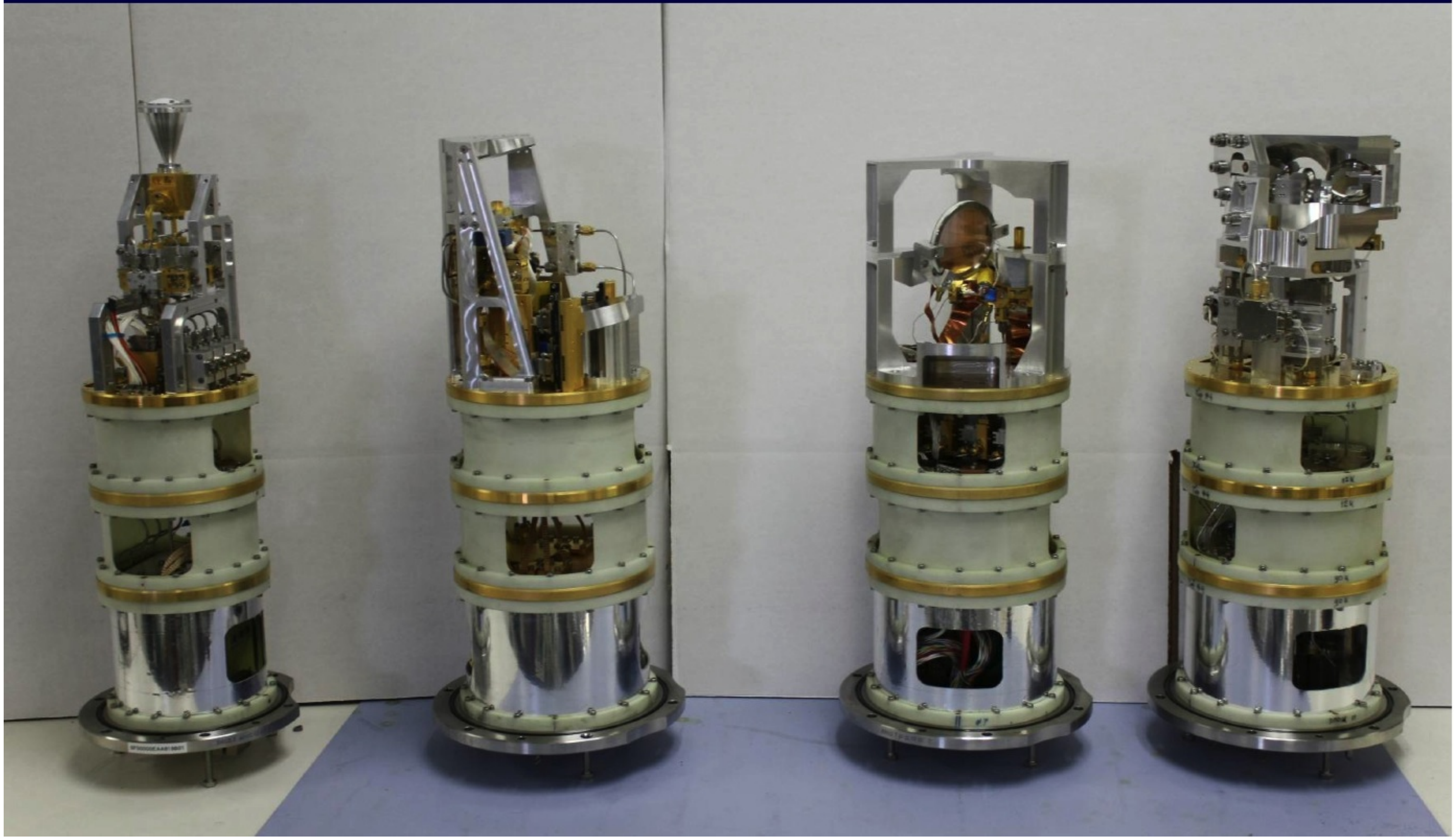

San Pedro de Atacama
15 km
28 km
Operations Support Facilities
OSF (2900m altitude)
ALMA Operations Site
AOS (5000m altitude)
Toconao


No Data
STC-METSAT
4 12 20 28 36 44 52 60
0 8 16 24 32 40 48 56 64
NVAP Total Column Water Vapor (mm)
August 1996

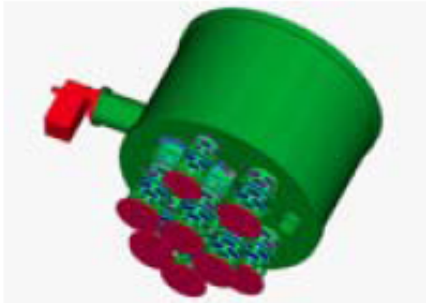
ATMOSPHERIC TRANSMISSION

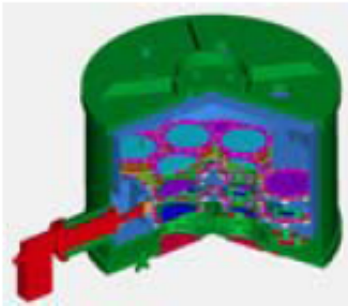


Bands 3 (84-116 GHz), 6 (211-275 GHz), 7 (275-373 GHz), and 9 (602-720 GHz) SIS "cartridges"



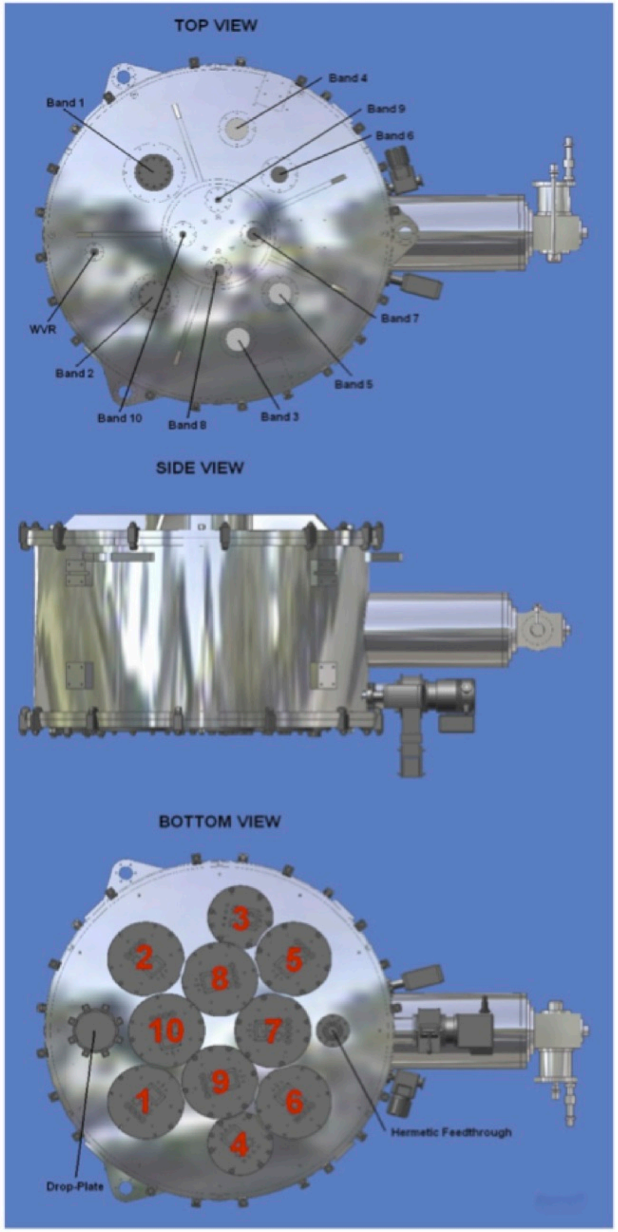
Front End Design





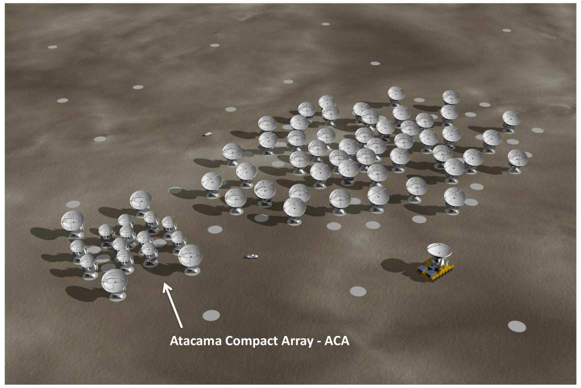
- Diameter ~ 1 m
- External optics top of dewar

- 10 Cartridges plugged from bottom
- Each cartridge contains one frequency



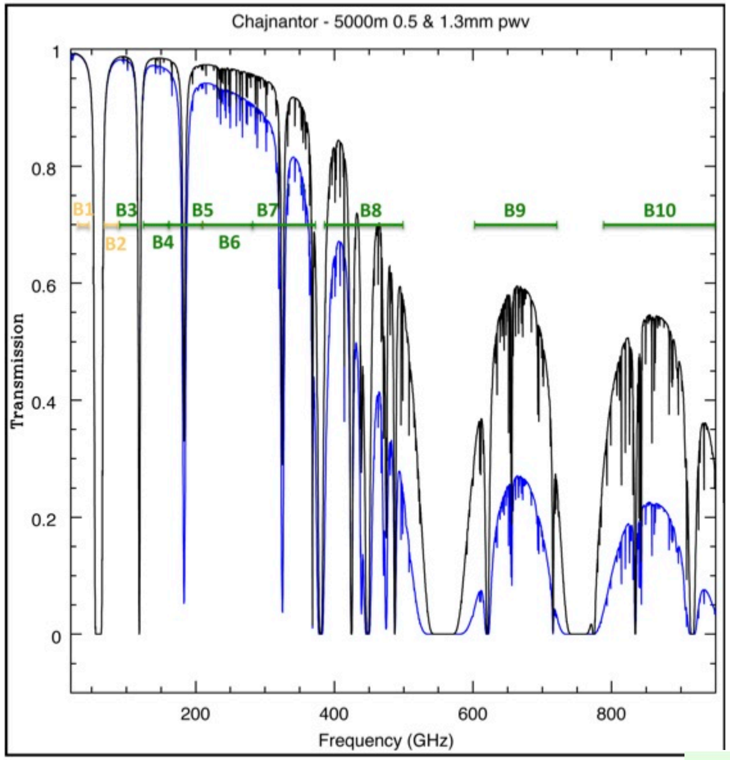
ALMA *Full Operations Specifications*

	Specification
Number of Antennas	*50×12 m (12-m Array), plus 12×7 m & 4×12 m (ACA)*
Maximum Baseline Lengths	*0.15 - 16 km*
Angular Resolution (")	*~0.2" × (300/ν GHz) × (1 km / max. baseline)*
12 m Primary beam (")	*~20.6" × (300/ν GHz)*
7 m Primary beam (")	*~35" × (300/ν GHz)*
Number of Baselines	*Up to 1225 (ALMA correlators can handle up to 64 antennas)*
Frequency Coverage	*All atmospheric windows from 84 GHz - 950 GHz (with possible extension to ~30 GHz)*
Correlator: Total Bandwidth	*16 GHz (2 polarizations × 4 basebands × 2 GHz/baseband)*
Correlator: Spectral Resolution	*As narrow as 0.008 × (300/ν GHz) km/s*
Polarimetry	*Full Stokes parameters*



Been ramping up to this since Cycle 0.
Not quite there yet… no later than Cycle 7

Also with incomplete array one can do groundbreaking science.
Since 2011 ALMA is offered to users in "Early Science".
The sixth cycle (Cycle 5) has just started (1 Oct.).
More antennas, receivers, observing modes etc. with each cycle.
Now: max. 43 antennas in use at any time.



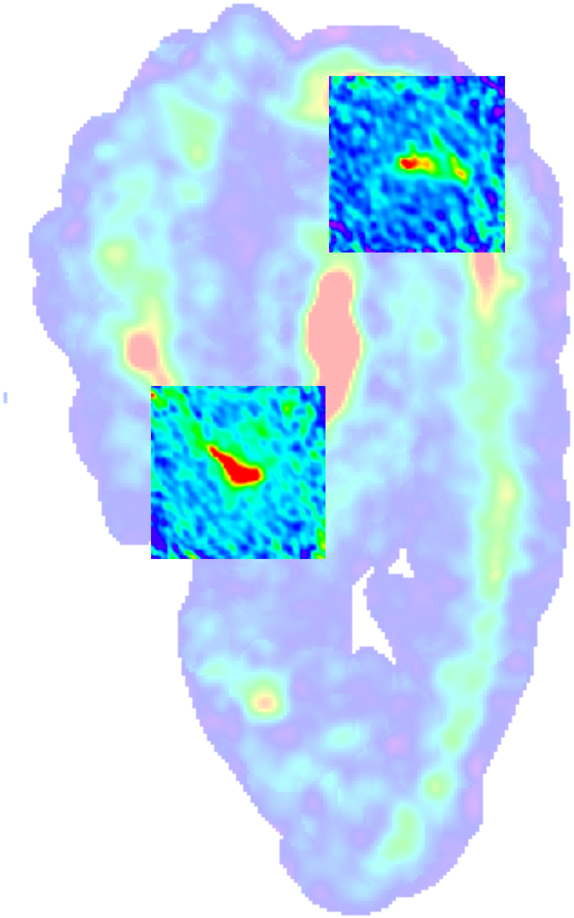
CYCLE 5 AVAILABLE RECEIVERS

(Oct. 2017 – Sep. 2018)

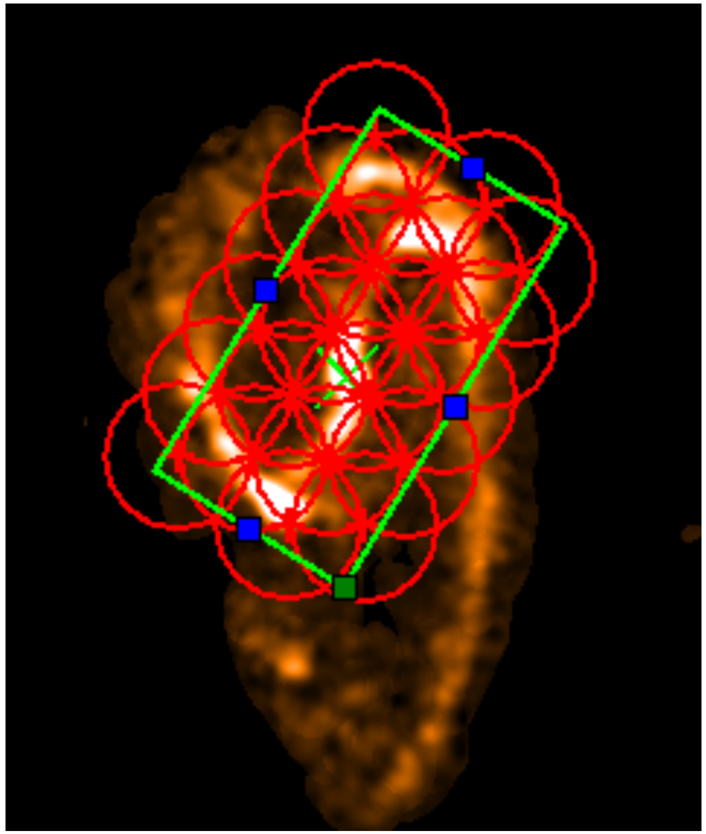
Green: bands available in Cycle 5

Band	Frequency (GHz)	Wavelength (mm)	FOV (arcsec)	Cont Sens (mJy/beam)
3	84 – 116	2.6 – 3.6	73 – 53	0.088
4	125 – 163	1.8 – 2.4	49 – 38	0.12
5	163 – 211	2.4 – 1.1	38 – 22	0.12
6	211 – 275	1.1 – 1.4	29 – 22	0.12
7	275 – 373	0.8 – 1.1	22 – 16	0.22
8	385 – 500	0.6 – 0.8	16 – 12	0.42
9	602 – 720	0.4 – 0.5	10 – 8.5	2.0
10	787 – 950	0.3 – 0.4	7.8 – 6.5	4.6

ALMA's incredible sensitivity: NGC3627 ALMA Cycle 3 proposal Rosita



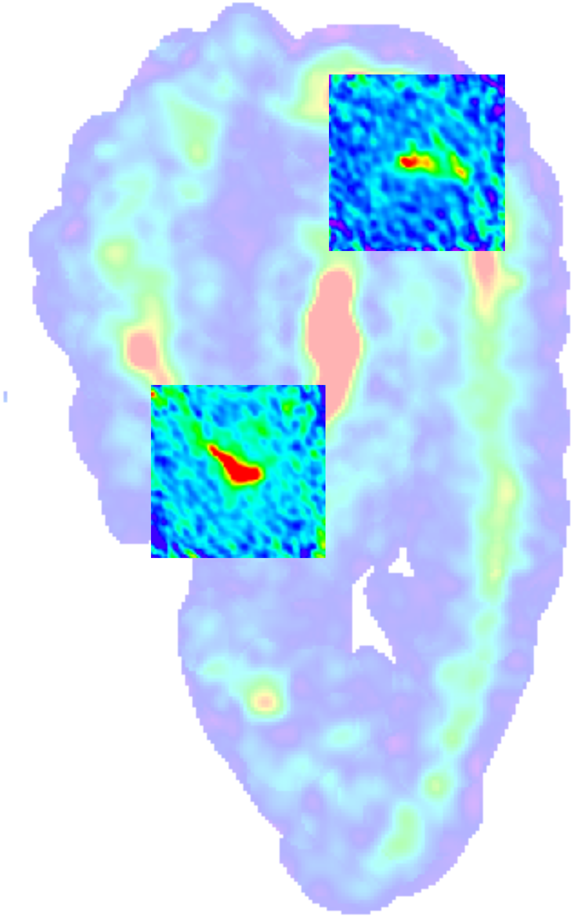
CO(1-0) with IRAM PdBI



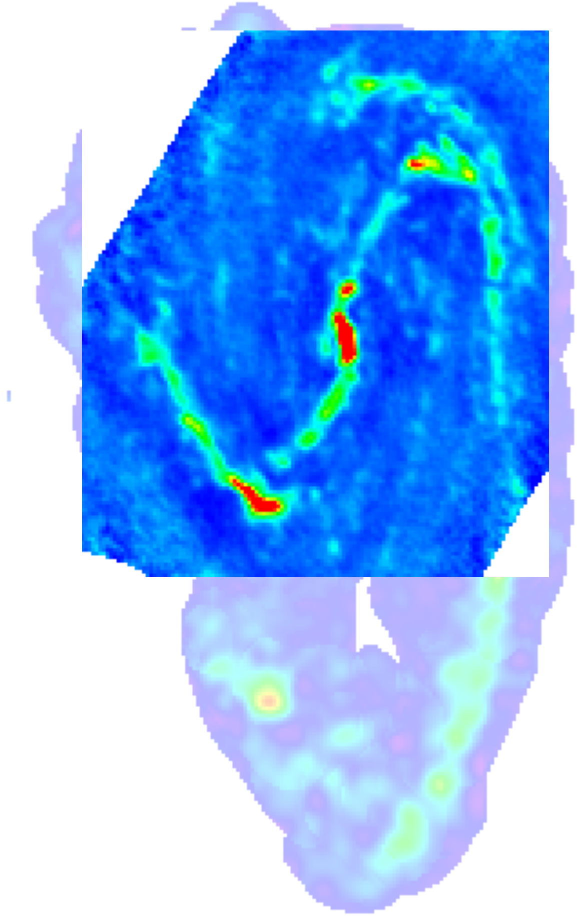
Proposal ALMA Cycle3
Mosaic of 22 pointings in band 3

Paladino et al., 2008

NGC3627 ALMA compact configuration data



CO(1-0) with IRAM PdBI
Resolution ~ 2 arcsec ~ 100 pc
8 hrs per pointing



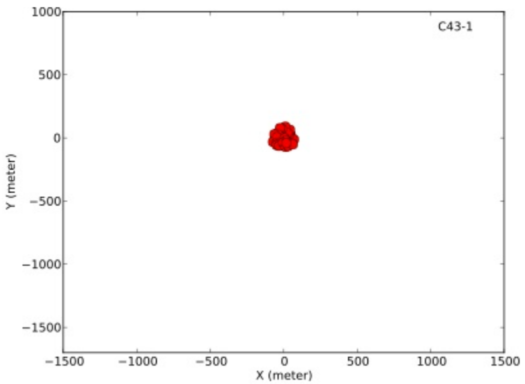
CO(1-0) with ALMA
Resolution ~ 2 arcsec ~ 100 pc
Observing time 1.5 hrs

Paladino et al.

ARRAY CONFIGURATIONS

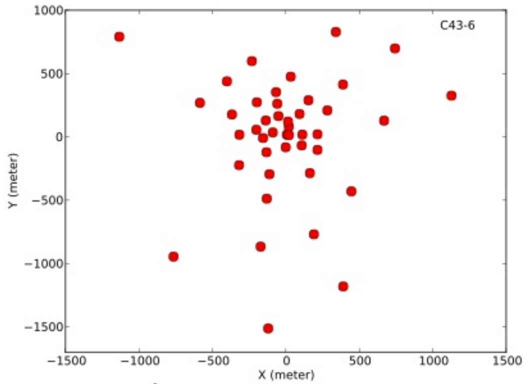
ALMA is a reconfigurable interferometer for (sub)mm astronomy.
There will be ca. 10 reconfigurations during Cycle5 at the end of which the array is expected to have imaging properties similar to one of the nine representative configurations used to characterize the advertised imaging capabilities and to estimate the observing times. Some configurations are visited more than once.

C43-1 15-161 m



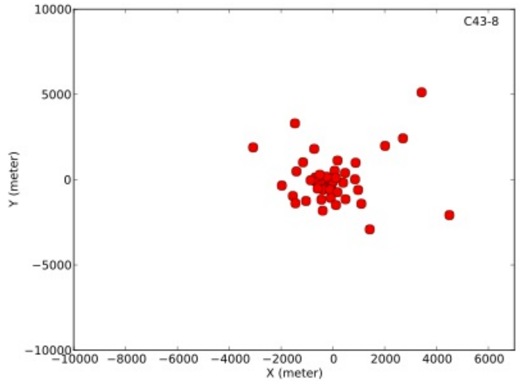
1 km

C43-6 15-2500 m



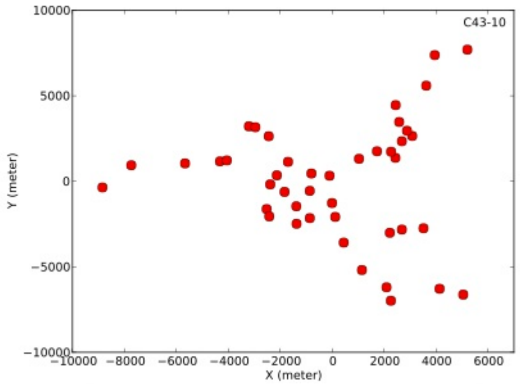
2 km

C43-8 110-8500 m



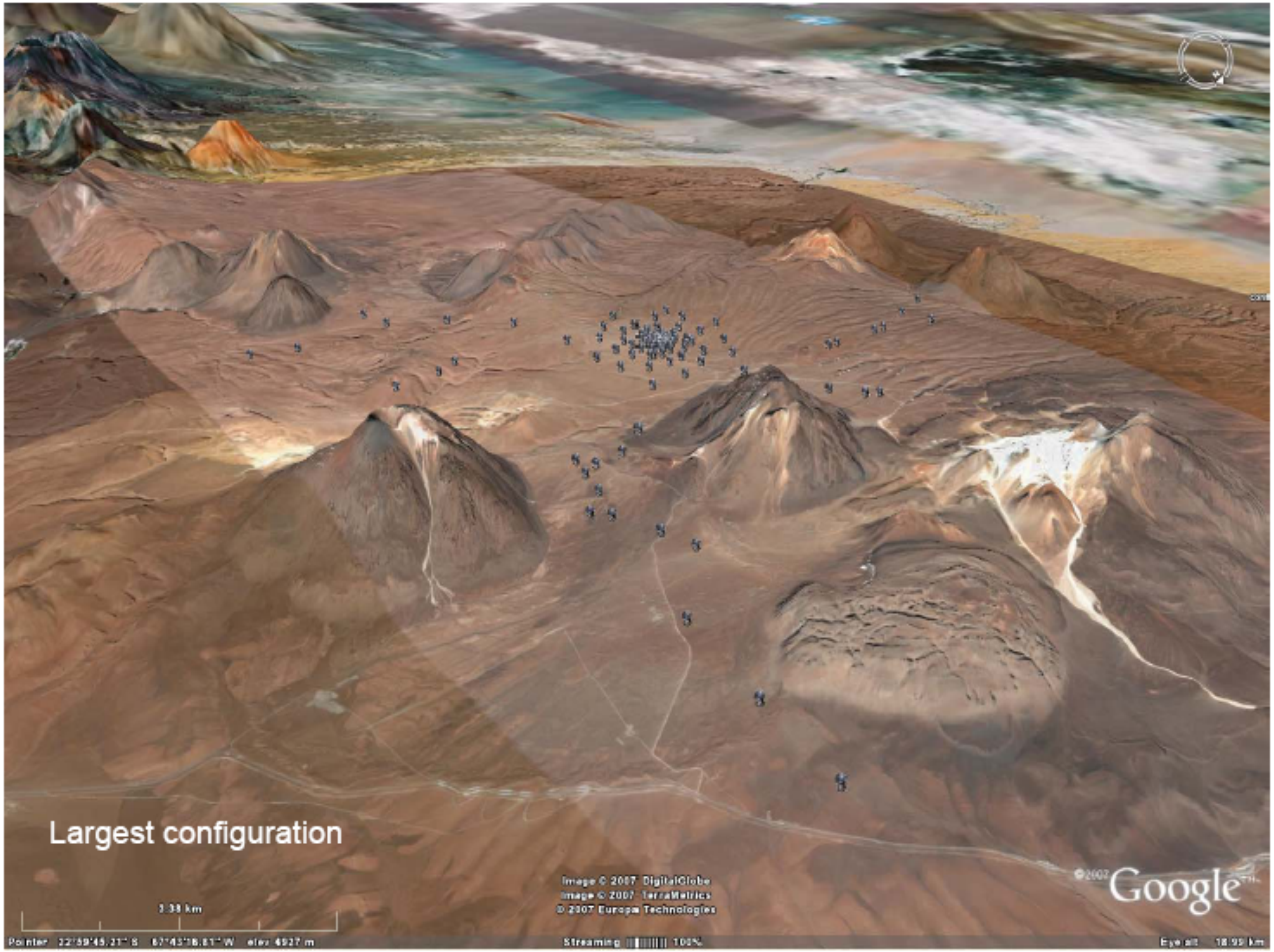
8 km

New configuration every 2-4 weeks.



16 km

C43-10 244-16200 m

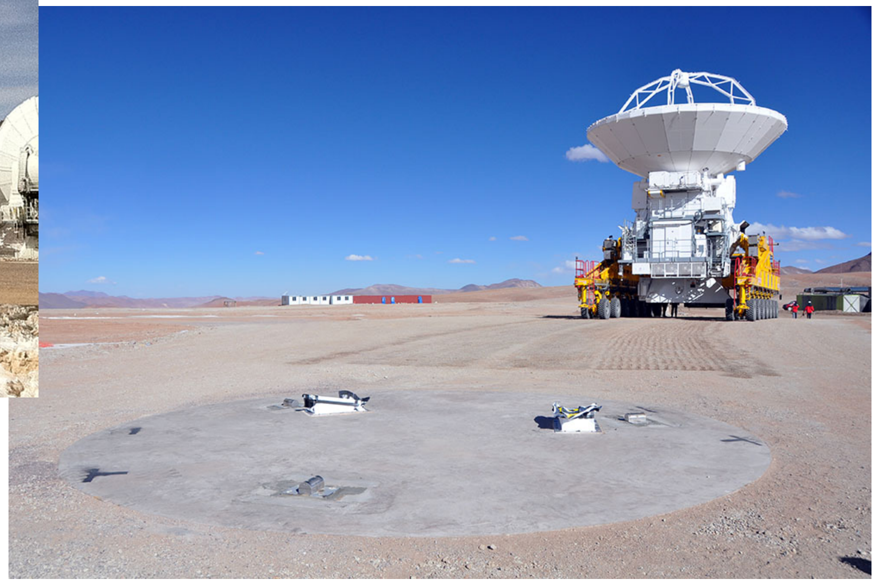

Largest configuration
3.38 km
Image © 2007 DigitalGlobe
Image © 2007 TerraMetrics
© 2007 Europa Technologies
©2007 Google
Pointer 22°59'45.21" S 67°43'18.81" W elev 4927 m
Streaming 100%
Eye alt 18.99 km

The ALMA Antenna Transporter

ESO Press Photo 45b/07 (5 October 2007)


First Move of an ALMA Antenna
(July 8, 2008)





MRS / LAS and Angular resolution

MRS = Maximum Recoverable Scale   LAS = Largest Angular Scale

Resolution (arcsec): 0.2 x (300GHz/f) (1km/b_{max})

MRS / LAS (arcsec): 124 x (1m/b_{min}) (300GHz/f)

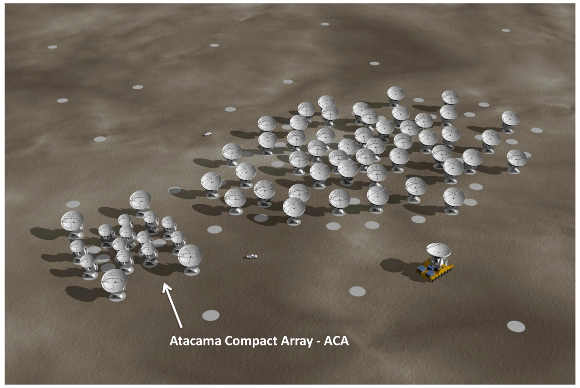
FOV (arcsec): 20.6 x (300GHz/f)

MRS / LAS is a "guideline for the largest angular structure on which some of the flux of a smooth structure can be reasonably recovered by the interferometer." (Cycle5 primer)

i.e. anything much larger will (start to) be 'resolved out': the **missing flux** problem, intrinsic to interferometers.

To recover this emission, additional observations needed, including observations with More compact configurations (with the 12-m array, the 7-m array, or single-dish [TP])

Only certain combinations of arrays are allowed.



Role of ACA

- **Supplement the 50-element array data with**
  - **Short baseline data (7-m antennas)**
  - **Total power data (12-m antennas)**

  ⇒***Enhance fidelity of ALMA images***
  (overcome "*missing-flux*" problem)

- **Stand-alone mode of operation**

  ⇒Available for ***target-of-opportunity*** observations, wide-field surveys, etc.

Spectral setup: sidebands, basebands & spectral windows

Observed sky frequencies need to be down-converted before being sent to the correlator.

For this to occur, the signal from the source is mixed with that of a (set of) Local Oscillator(s) which results in the creation of 2 sidebands, ‘upper’ and ‘lower’:

For the lower sideband (LSB): (F_{LO1} - IF_{lo}) to (F_{LO1} - IF_{hi})
For the upper sideband (USB): (F_{LO1} + IF_{lo}) to (F_{LO1} + If_{hi})

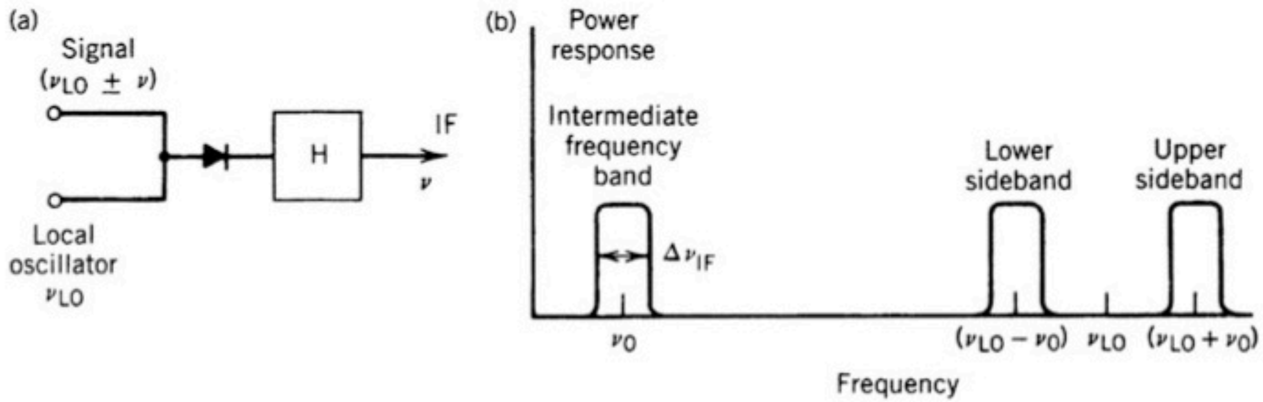


Fig. 6.1 Frequency conversion in a radio receiving system. (**a**) Simplified diagram of a mixer and a filter H that defines the intermediate-frequency (IF) band. The nonlinear element shown is a diode. (**b**) Signal spectrum showing upper and lower sidebands that are converted to the IF. Frequency ν_0 is the center of the IF band.

Spectral setup: sidebands, basebands & spectral windows

2 sidebands, 'upper' and 'lower':

For the lower sideband (LSB): $(F_{LO1} - IF_{lo})$ to $(F_{LO1} - IF_{hi})$
For the upper sideband (USB): $(F_{LO1} + IF_{lo})$ to $(F_{LO1} + If_{hi})$

NB: for <u>both</u> polarizations!

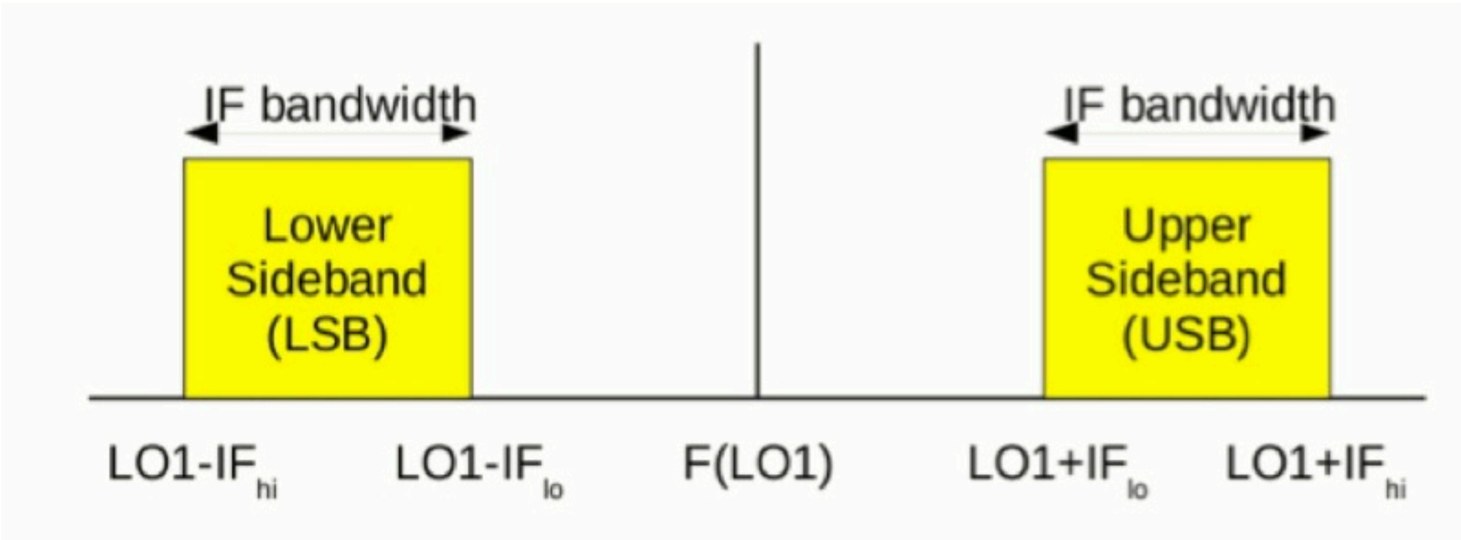


Figure 4.2: IF ranges for the two sidebands in a heterodyne receiver.

Spectral setup: sidebands, basebands & spectral windows

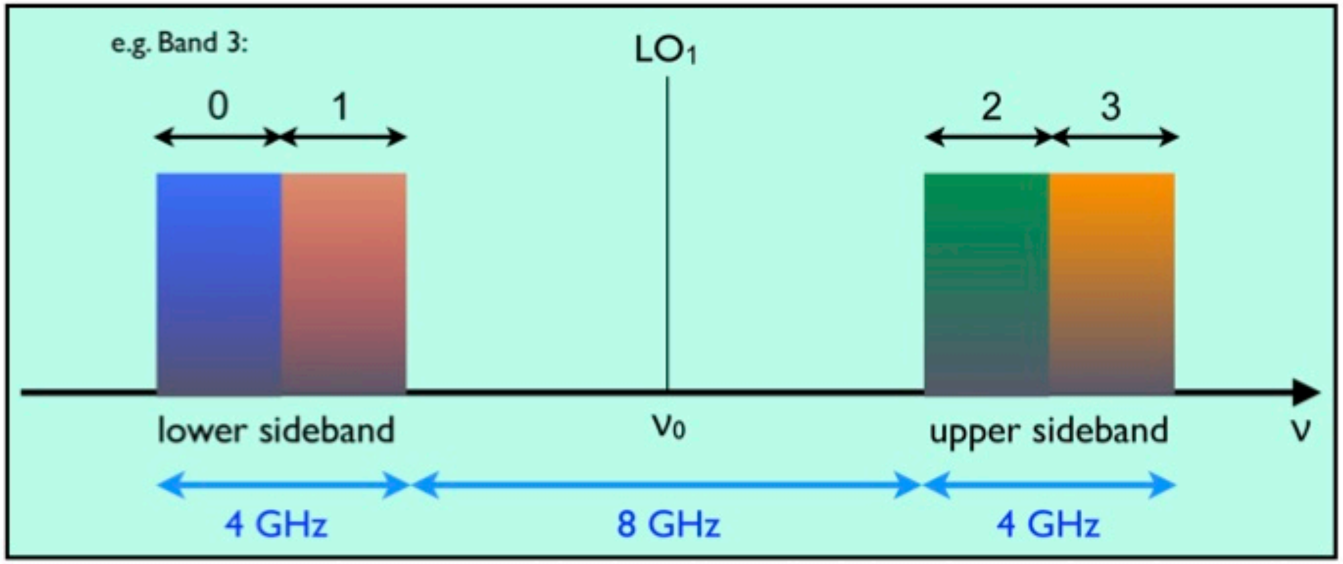


Figure 31: *A graphical view of basebands and sidebands. Basebands may be tuned to overlap if the user wishes, or may be located so as to maximize the total bandwidth (as shown). Each baseband may be further subdivided into as many as 8 spectral windows. Up to four spectral windows per baseband will be available during Cycle 5.*

Within these sidebands, ALMA produces 4 x 2 GHz basebands that can be placed inside each sideband.

NB: basebands are not independent: overlapping BBs do not reduce noise

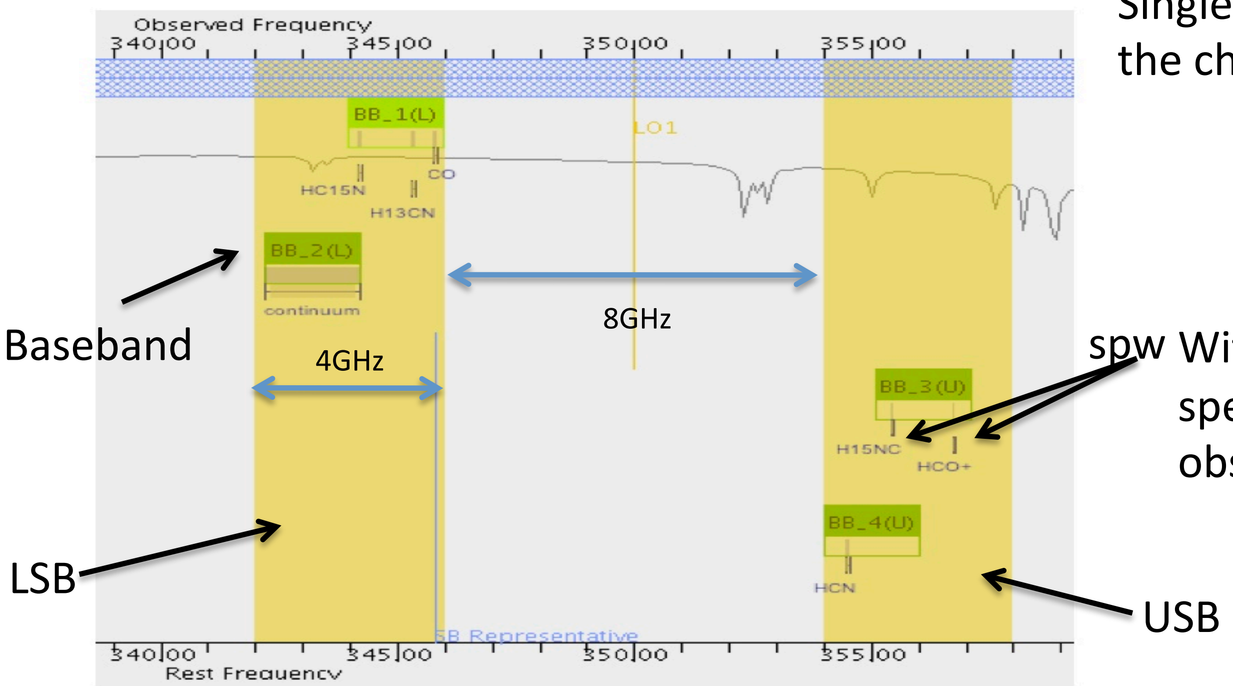
Spectral setup: sidebands, basebands & spectral windows

Bandwidth (MHz)	Spectral res (MHz)	Number of channels
1875	31.2	120
58.6	0.0305	3840
117	0.061	3840
234	0.122	3840
469	0.244	3840
938	0.488	3840
1875	0.976	3840

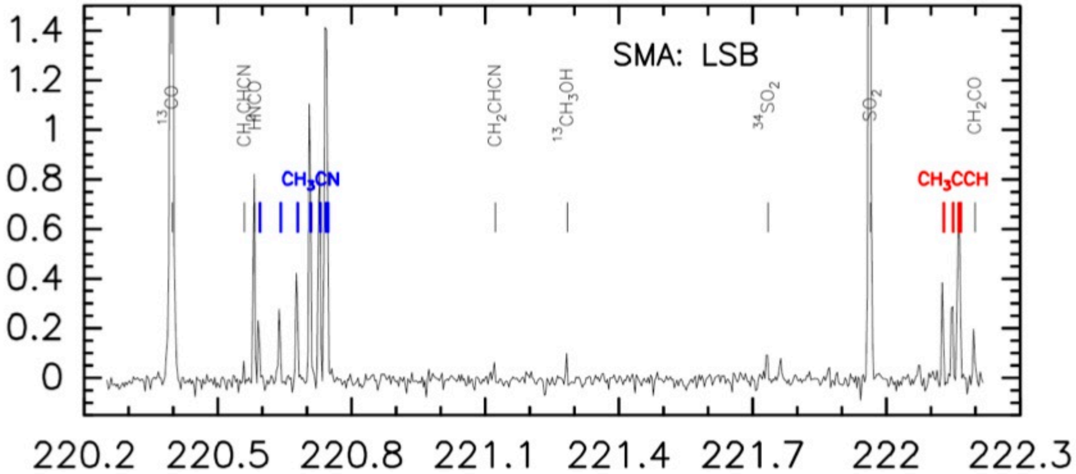
Continuum (BW_{tot} = 7.5GHz)

Spectral lines

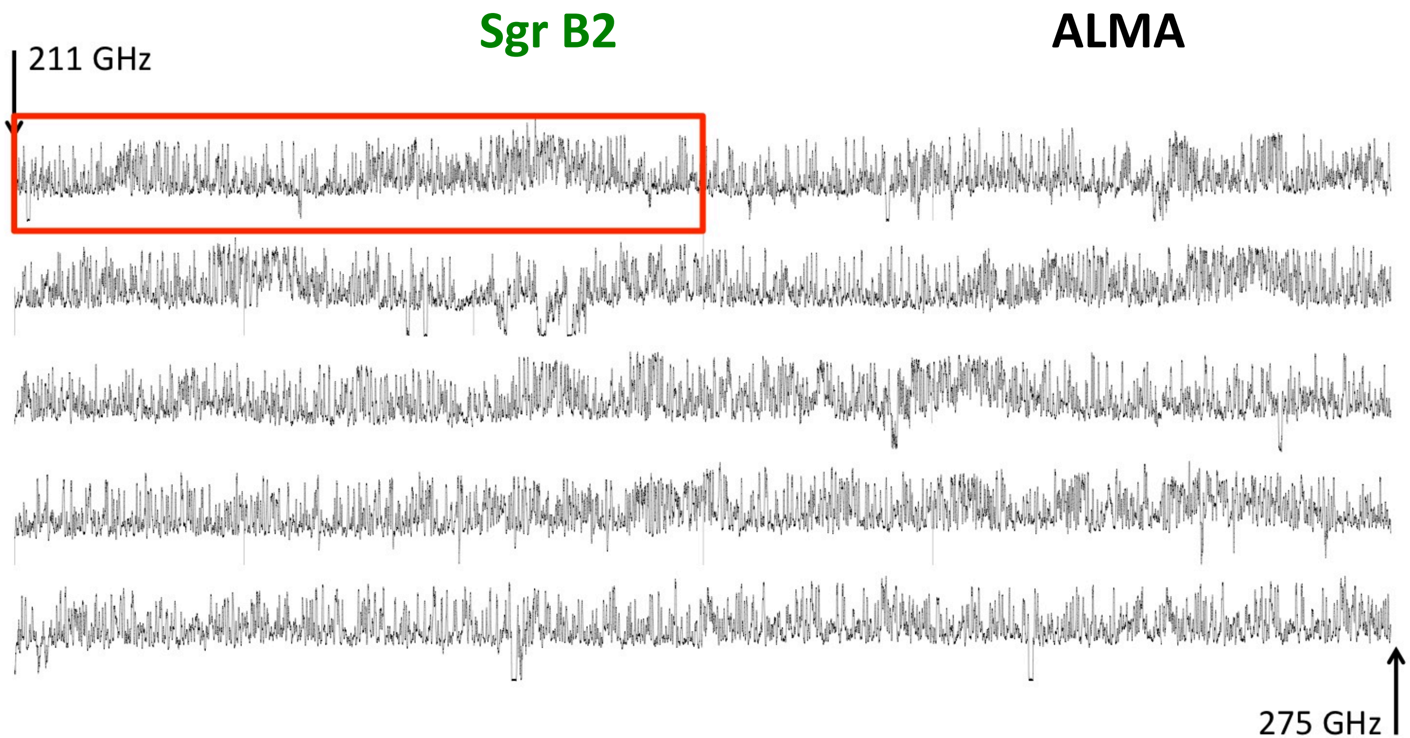
Full Stokes => half the channels.
Single pol (instead of Dual): double the channels.



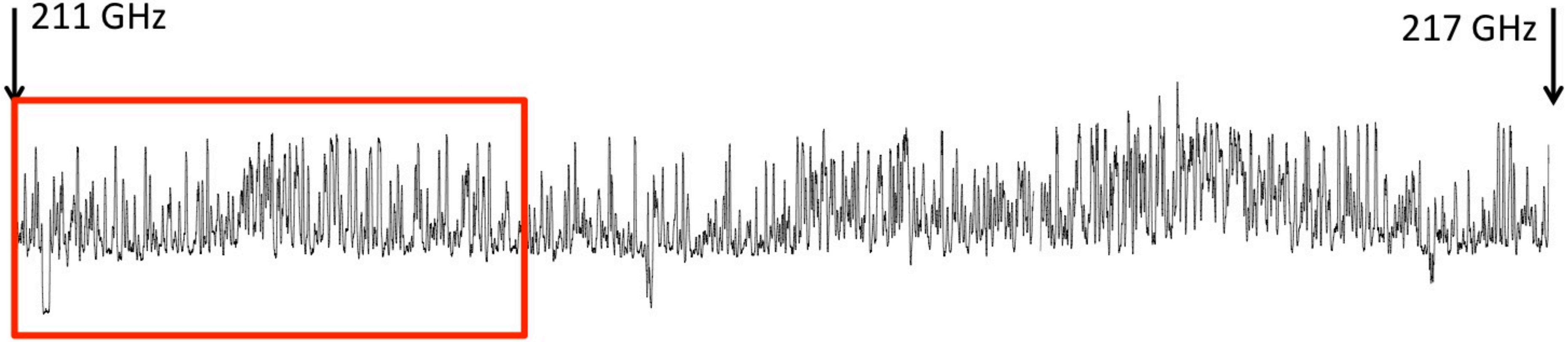
Within each baseband up to 4 spectral windows can be placed to observe lines or continuum.



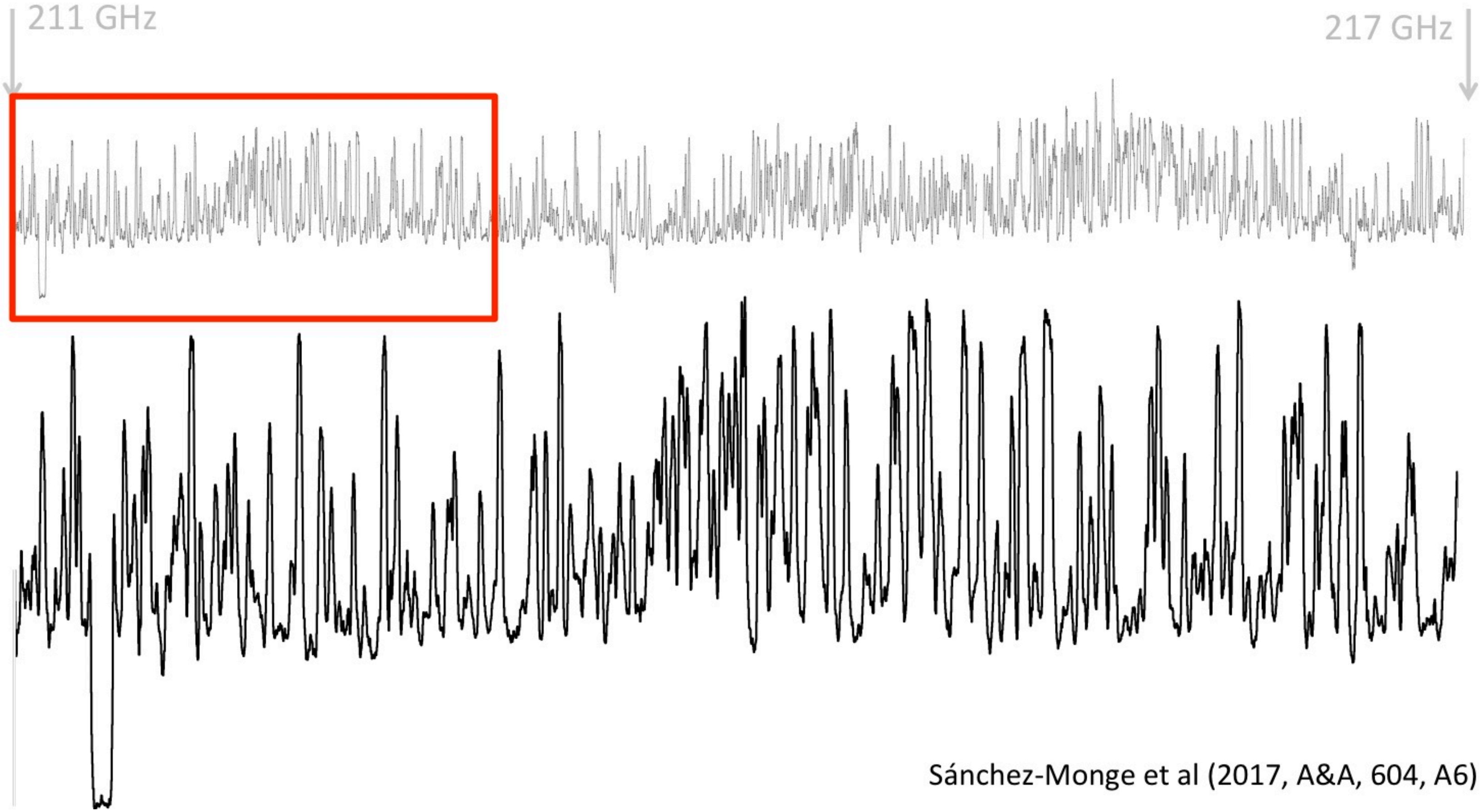
"It's the sensitivity, stupid"



Sánchez-Monge et al (2017, A&A, 604, A6)

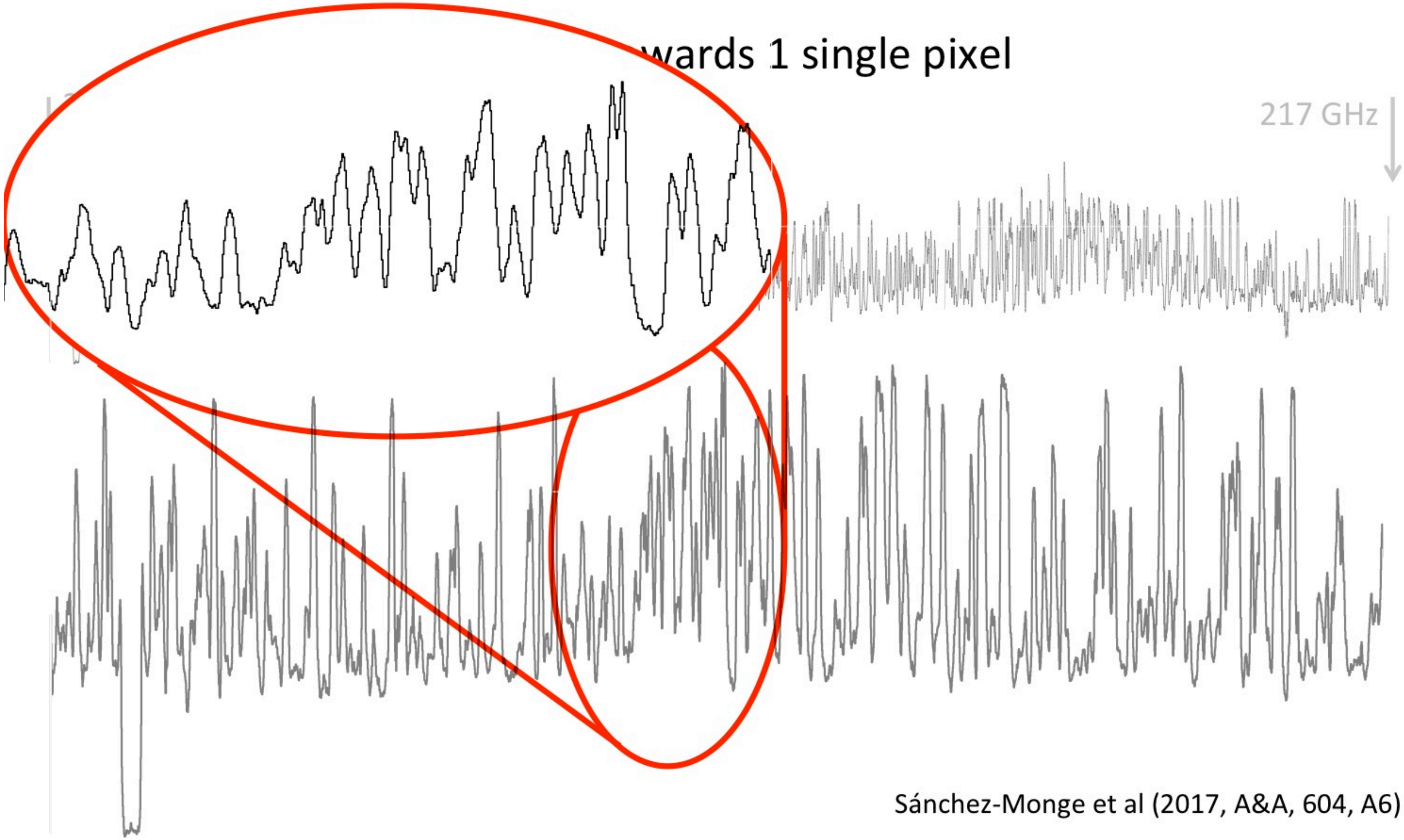

211 GHz
217 GHz

Sgr B2



Sánchez-Monge et al (2017, A&A, 604, A6)

Sgr B2



Sánchez-Monge et al (2017, A&A, 604, A6)

Early science: observations with incomplete array, limited suite of receivers, selected observing modes, restricted baseline range – since 2011 (6 Calls for Proposals so far).

And already it has obtained beautiful and unexpected results!

Check out:

-Press releases (http://www.almaobservatory.org/en/press-room/press-releases)

-Published papers (http://telbib.eso.org; from there get direct access to the data!).

… and there is much, much more.

For news and press releases:
www.almaobservatory.org

For ALMA status, proposals, archive mining:
www.almascience.eso.org

For publications using ALMA data:
telbib.eso.org

Also www.eso.org/sci/publications/messenger/ often has ALMA news, images etc.

Website Italian node of the EU ALMA Regional Centre:
www.alma.inaf.it

Lab calendar – High-frequency part (ALMA)

Week 1
Oct. 9: Ore 9:30 – 12. Lezioni frontali [Mon] ★
Oct. 10-11: Ore 9:15 – 12 [Tue-Wed]
Oct. 12-13: Ore 9:15 – 17 [Thu-Fri]

Week 2
Oct. 16: Ore 9:15 – 13 [Mon]
Oct. 17-18: Ore 9:15 – 12 [Tue-Wed]
Oct. 19-20: Ore 9:15 – 17 [Thu-Fri]

Week 3
Oct. 23-27: mornings mandatory; Start ore 9:15.

★Solo lunedi 9 ott.: IRA, quarto piano, sala seminari

Tutti gli altri giorni: IRA, primo piano, sala 318