VLBI with NOEMA
(NOrthern Extended Millimeter Array)

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Calibration of NOEMA VLBI data

(or: how to produce the flux scale and Tsys for a phased array)

NOEMA – one quick look

Plateau de Bure

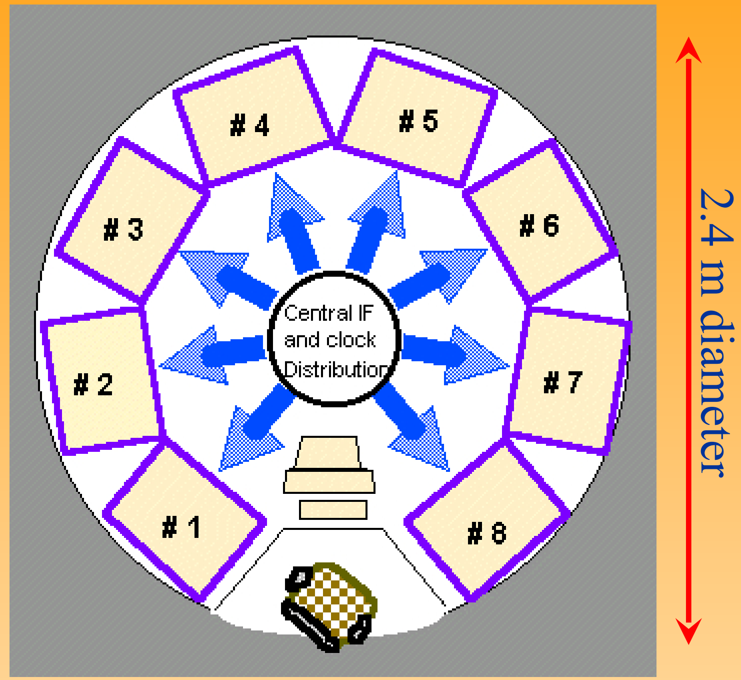
Hautes Alpes, France

Altitude 2550m

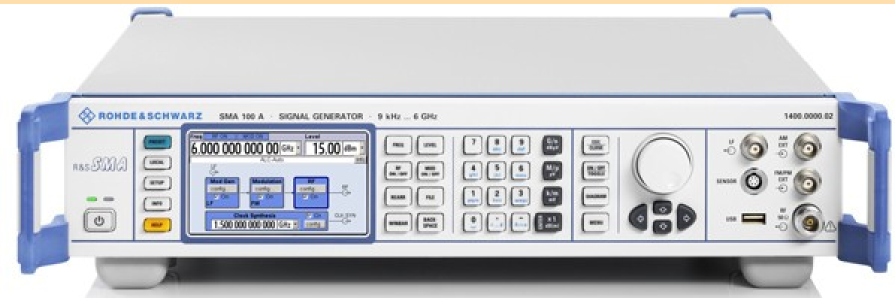
NOEMA VLBI equipment today

Swiss EFOS-38 maser (built in 2006), with low phase noise quartz

Mark4 Formatter + Mark5A recorder



Narrow-band correlator (2000)



Rohde & Schwarz SMA100 B22 frequency generator

Only the Narrow-band correlator is VLBI capable, not the more recent continuum WIDEX backend.

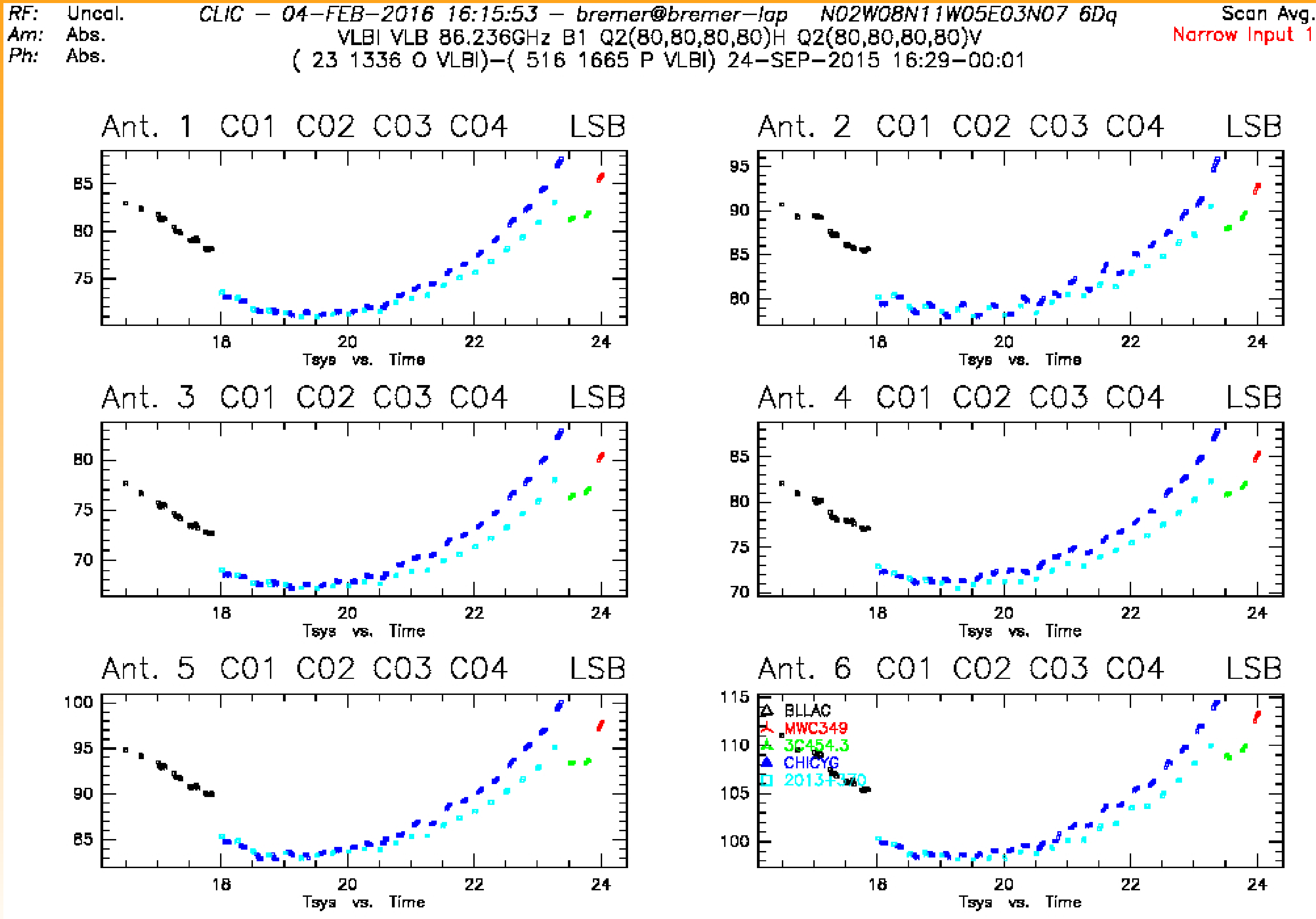
The phased array operation is currently limited to 1 Gbit/sec data rates

Calibration steps

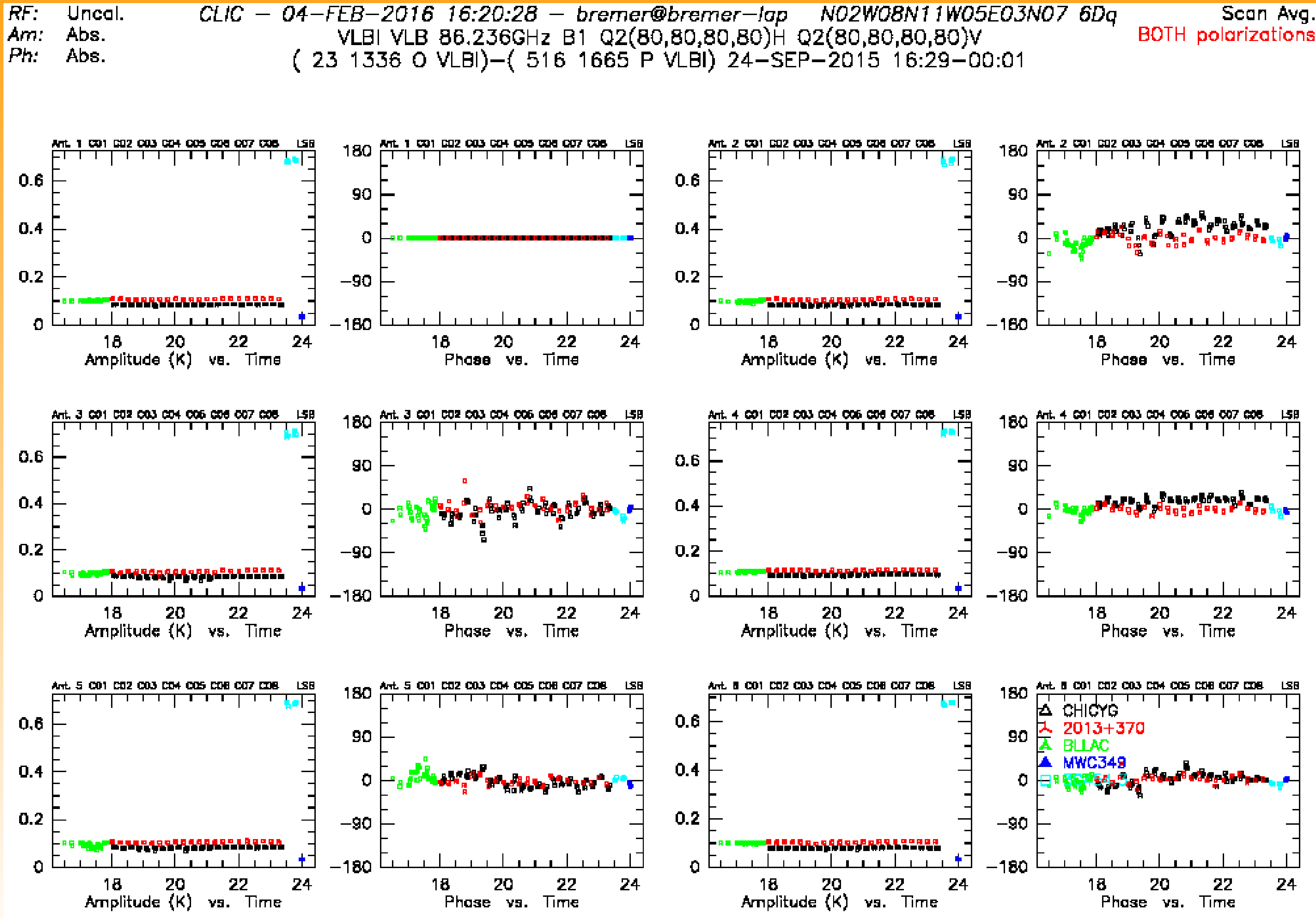
- On the antennas: hot/cold load calibration
- Explain the sky temperature with an atmospherical model
- With the opacity from the atmospherical model, calculate the system temperature for each antenna

Special point for an interferometer: The interferometric amplitudes in Kelvin are the normalized autocorrelations multiplied by the system temperature.

System temperature (Example LCP)

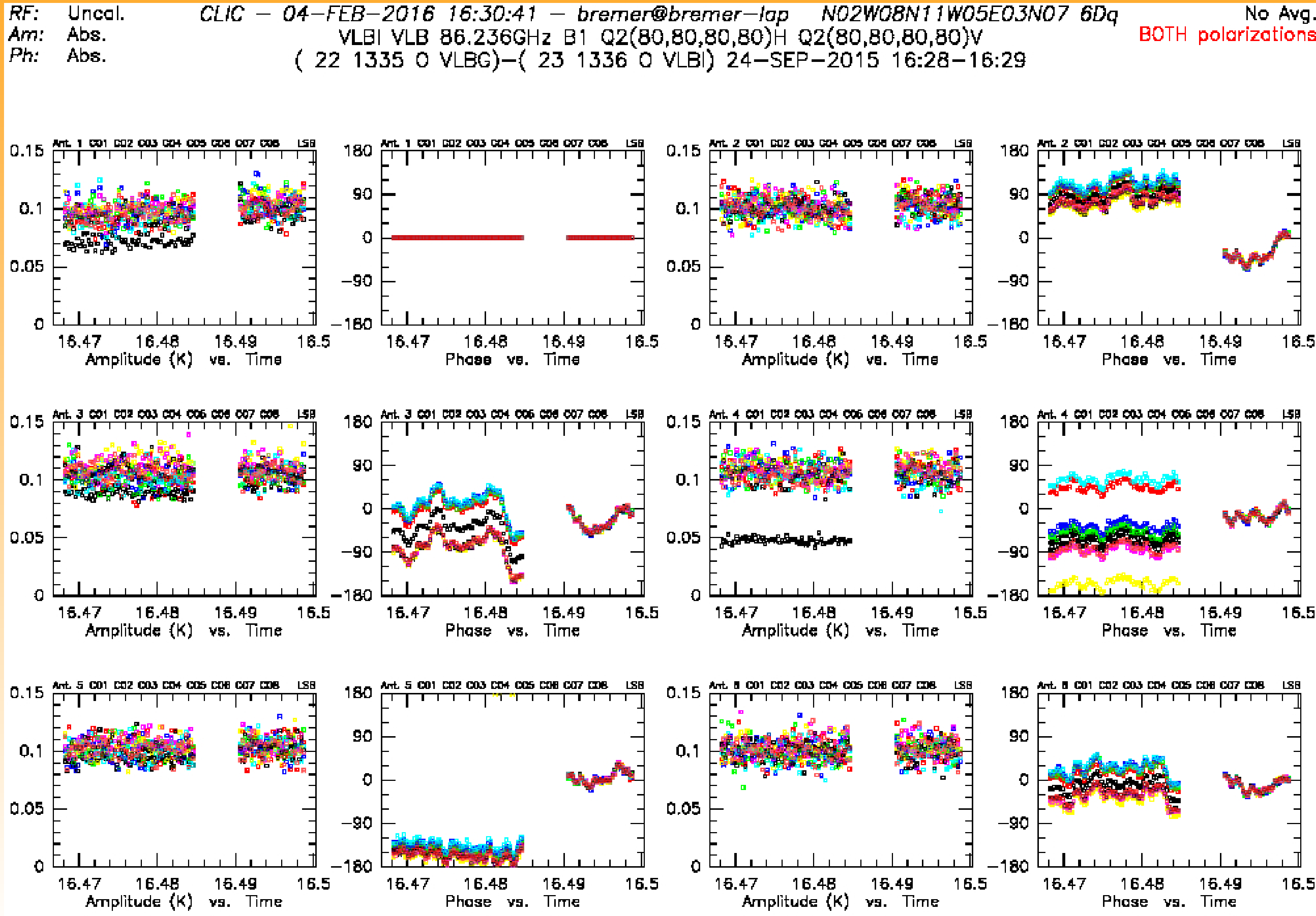


Amplitudes and phases by antenna [Kelvin]

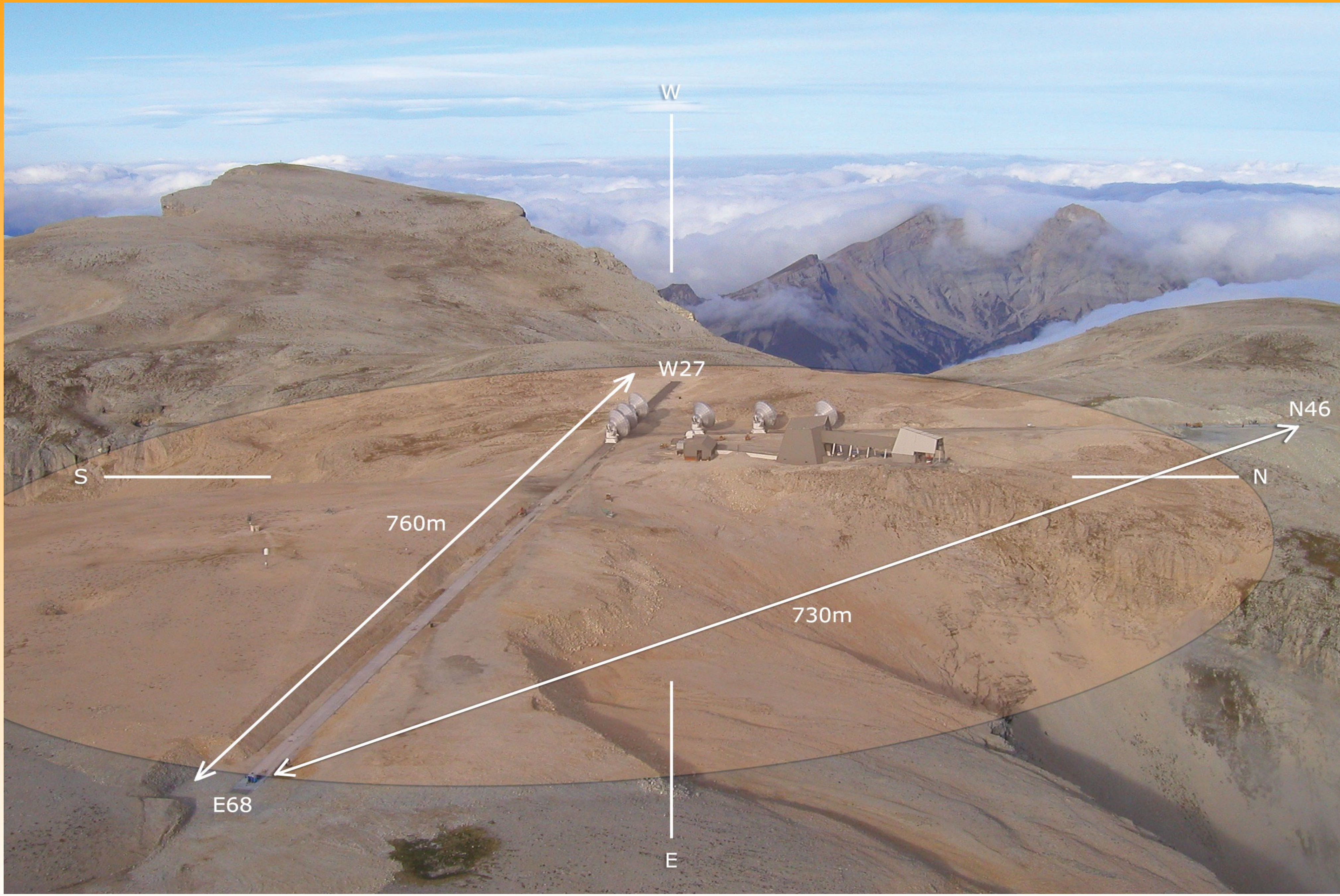


Real time: pointing, focus ***and phasing.***

Correctly phased, the system adds the other antennas in each spectral unit coherently to the reference antenna (A1 in this case)



This is easier in compact configuration!



These were local interferometric data. Where does the phased array come in?

- The old Plateau de Bure Narrowband correlator has dedicated adder modules for up to 6 antennas inside its cross-correlator units. These add the raw antenna data streams together with only coarse “hardware” signal path delay corrections.
- In VLBI mode, we switch OFF a number of corrections that are normally applied on the local correlations (fine delay corrections, bandpass calibrations) by the realtime computer system.
- We loose some efficiency (approx. 25%) in VLBI mode because these corrections are missing, but they would be too expensive on the raw data streams. The obtained local data can be used to calibrate the VLBI phased array data.

NOEMA VLBI flux calibration:

Two steps:

- the absolute flux scale of the observed targets: Can use a primary flux calibrator and the NOEMA WIDEX backend (3.6 GHz per polarization)
- Transfer this scale to the narrow-band backend that is in VLBI mode and determine the antenna efficiencies

What primary calibrators can we use?

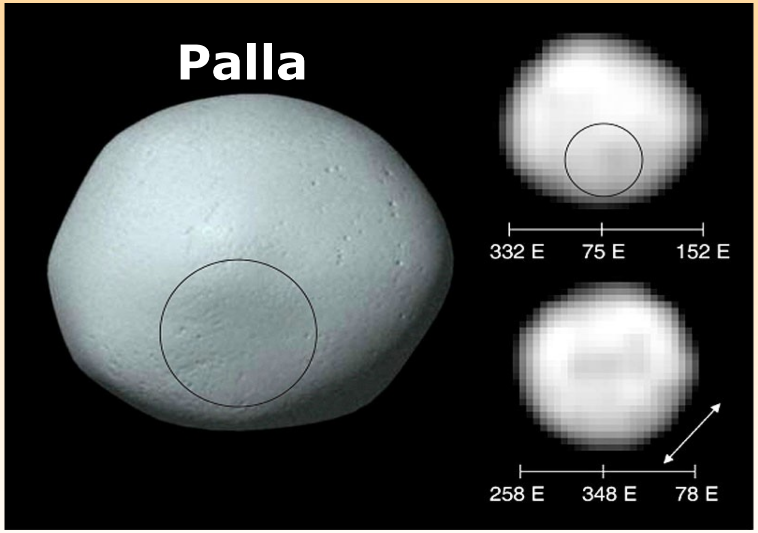
Sometimes used but problematic:

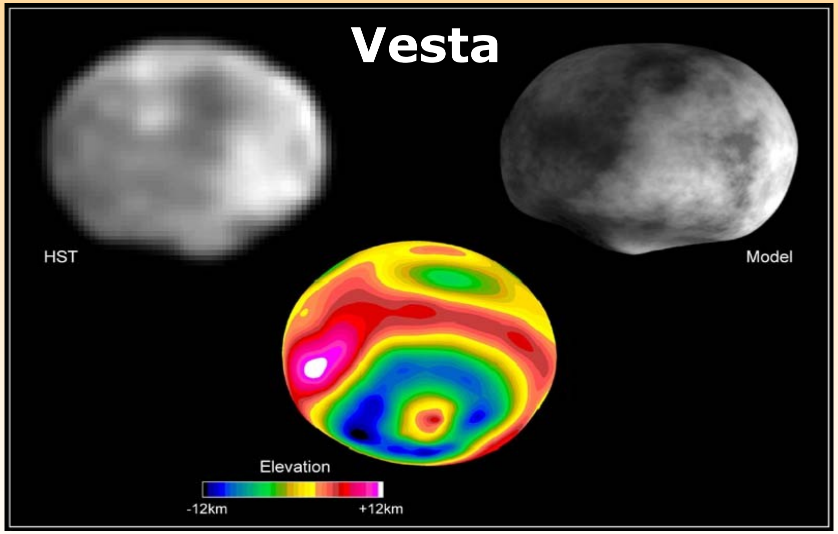
Antenna Efficiencies: decorrelation is neglected

Planets: already resolved at 3mm, spectral absorption lines (e.g. Mars, Jupiter, Saturn), slowly time variable, not always visible.

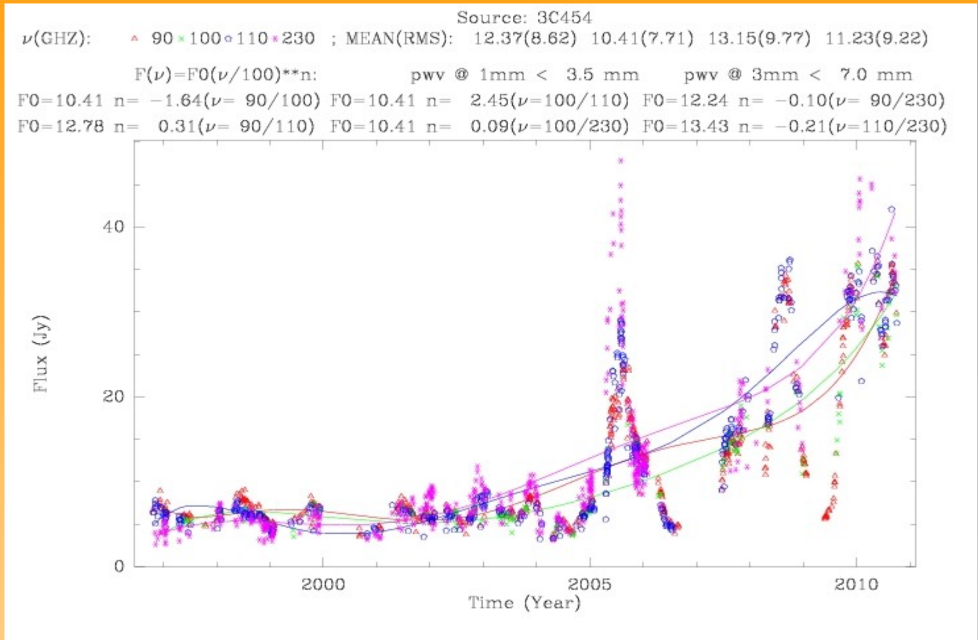
Moons of outer planets: often too close to the parent planet (we need at least 3 primary beams distance), flux models less known

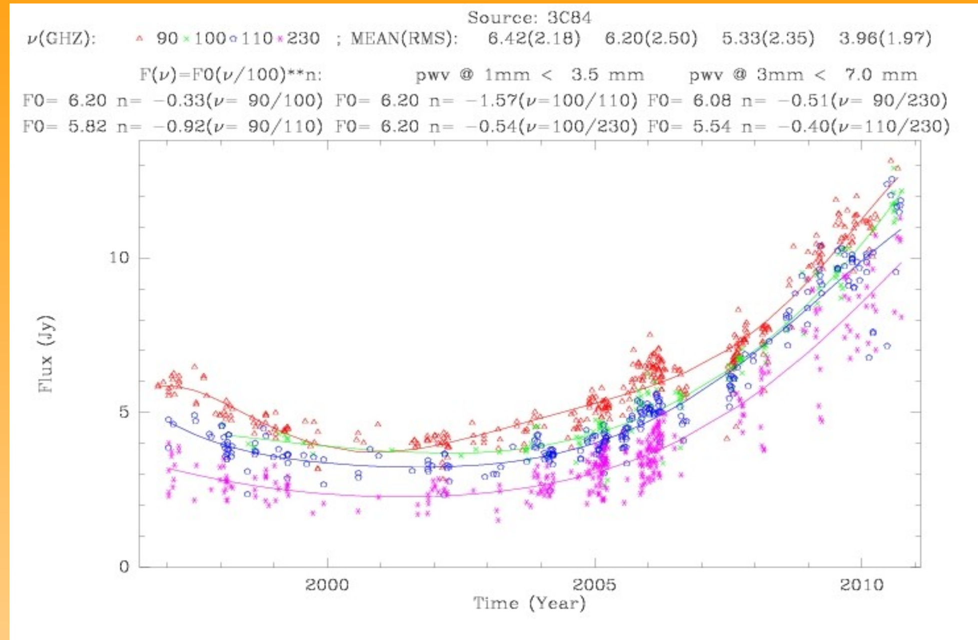
Minor Planets: fluxes can vary within a day, models not well known (that could change with ALMA)

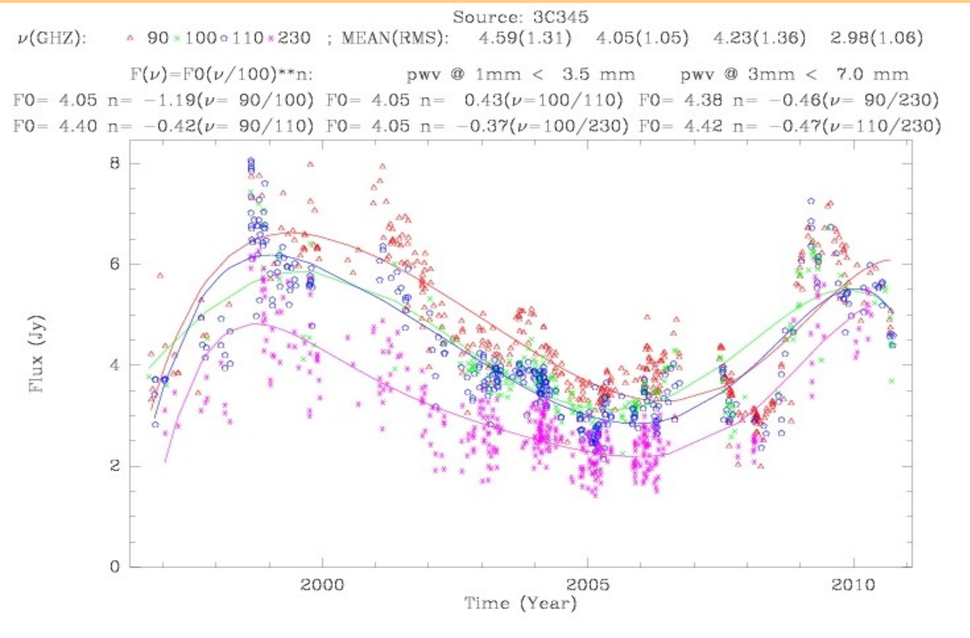


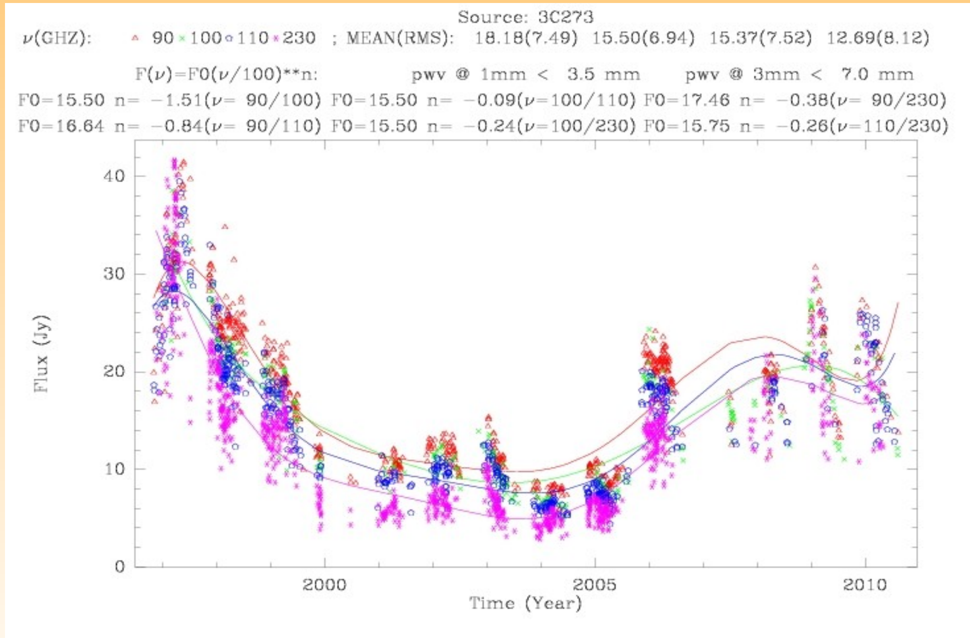


Time variability of quasars



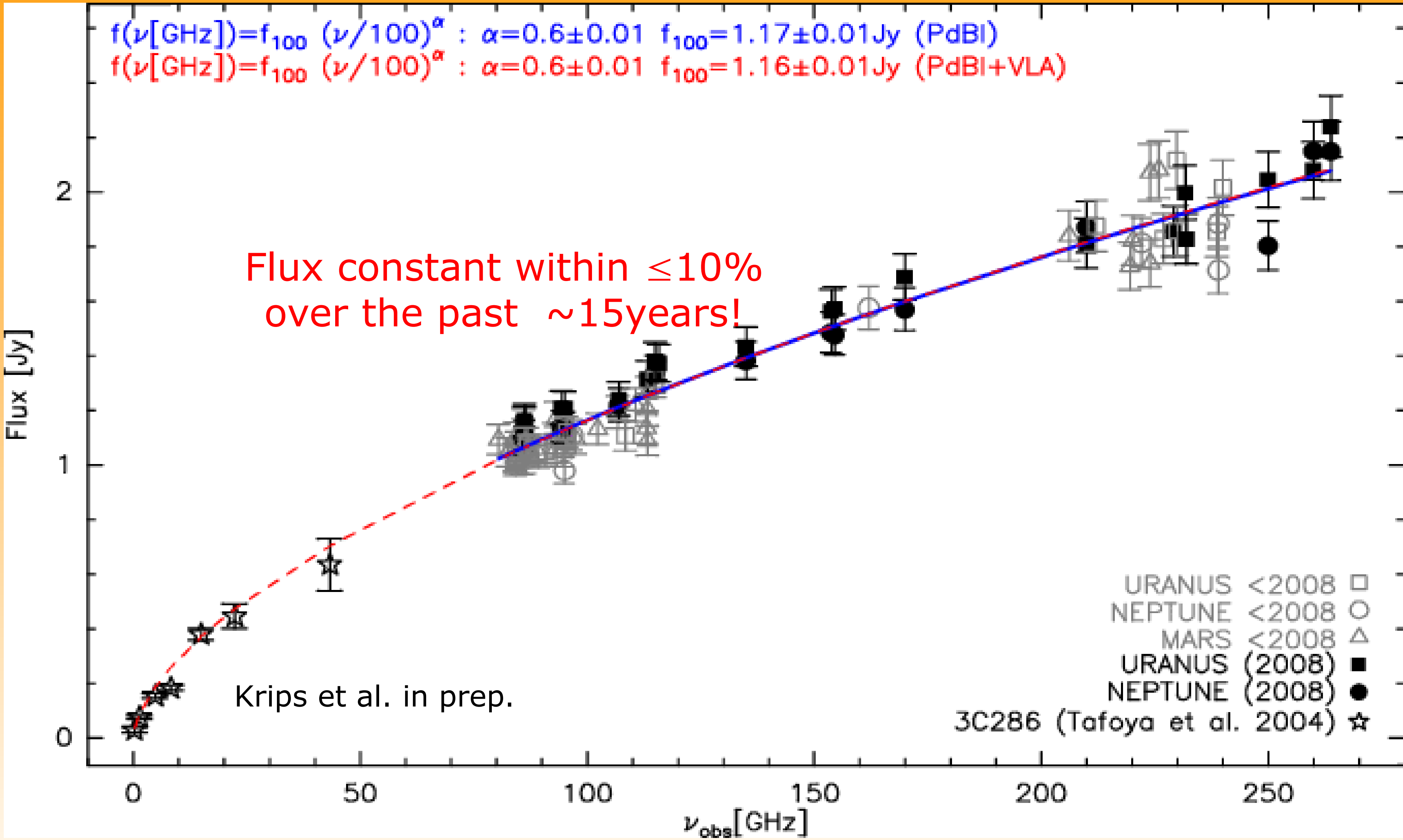






Courtesy M. Krips (IRAM)

Best solution so far (NOEMA): Radio star MWC349



Courtesy M. Krips (IRAM)

Now we include the antenna efficiencies into the phased array System Temperature

Required: a system temperature that includes the phase noise.

From the parallel running cross-correlations and autocorrelations we have

- Tsys [Kelvin] for each antenna i
- Efficiency E (in Kelvin/Jansky) for each antenna i
- phases P averaged over the desired time resolution per antenna i, relative to the reference antenna

$$T_{sys} = N_{ant} \cdot \sum_{i=1}^{N_{ant}} E_i \cdot \left(\sum_{i=1}^{N_{ant}} \sqrt{\frac{E_i}{T_{sys\ i}}} \cdot cos P_i \right)^{-2}$$

- if the source is too weak, extended or a line source: use the latest available point-source phasing efficiency instead.
- Write out these Tsys values into an AIPS compatible file and we are done!

Thank you!