Phase Calibration for the ngVLA

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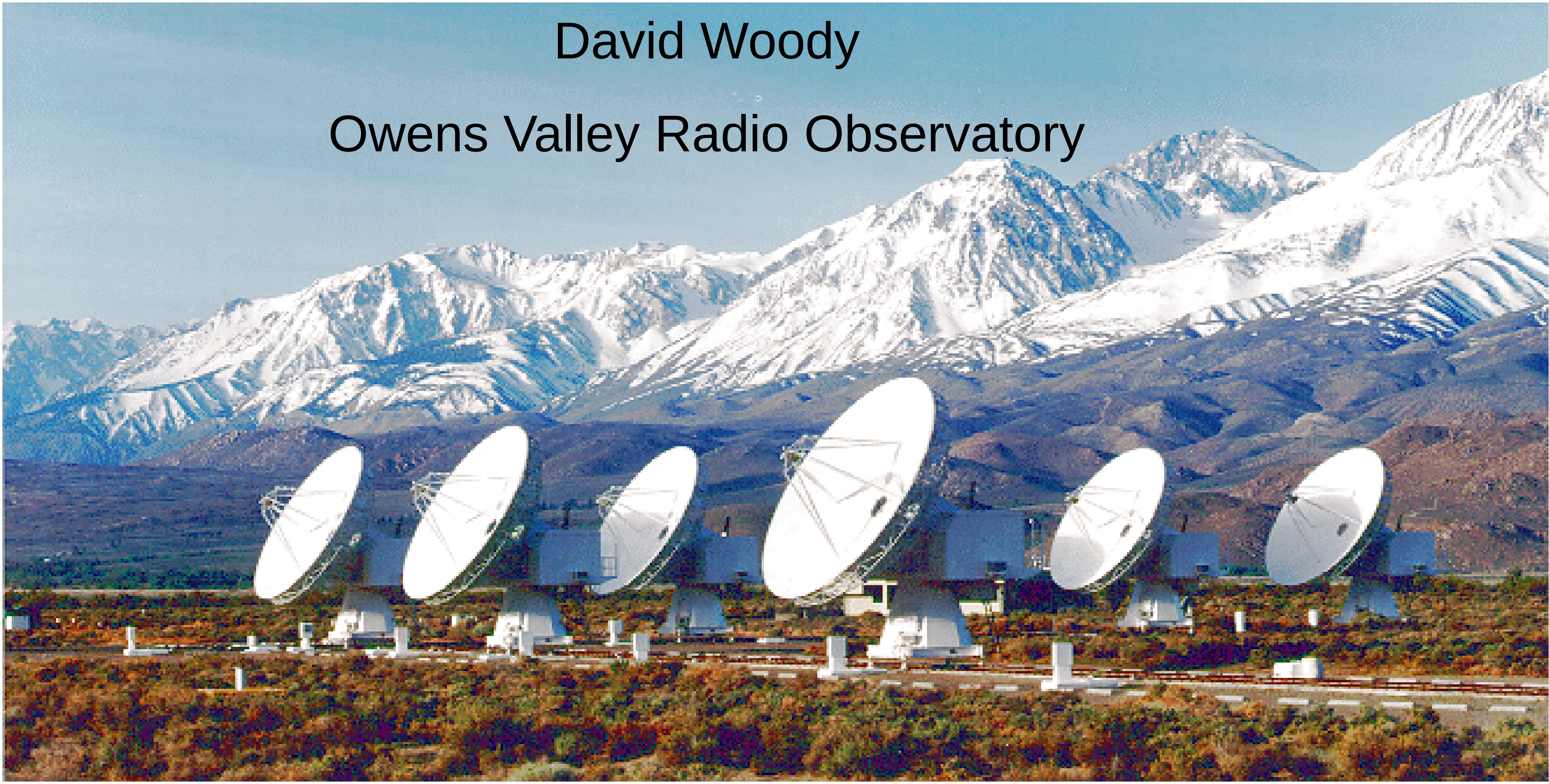
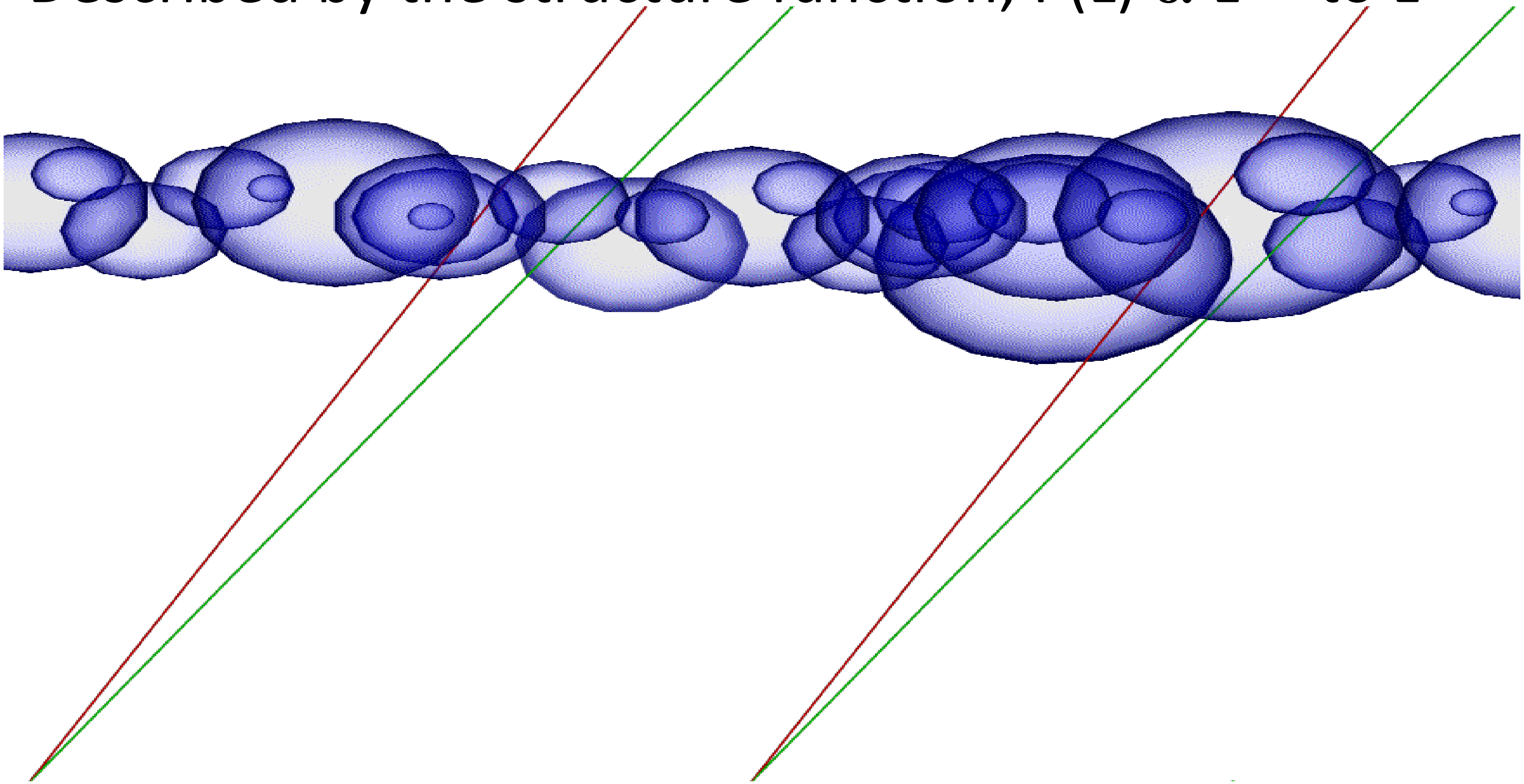


Outline

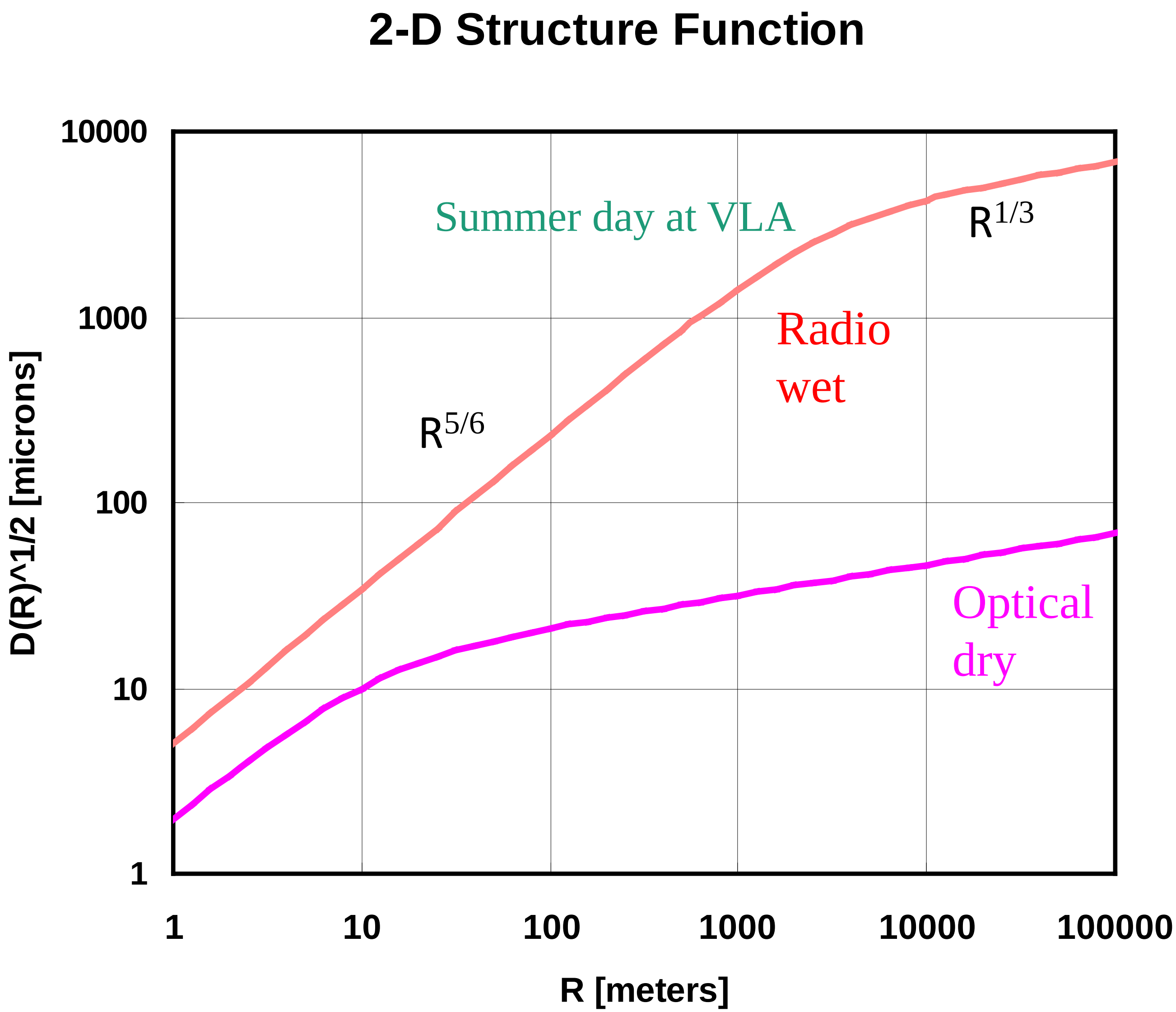
- Statement of the problem
- Possible solutions
  - Self-calibration using a known source in the FoV (won't cover this)
  - Fast switching phase calibration
  - Water vapor radiometer phase correction
  - Calibration array
- Comparison of techniques and Challenges
  - It is mostly software (new algorithms and data processing procedures)

Water is the problem

- Kolmogorov turbulence
- Frozen phase screen
- Moving at wind speed
- Described by the structure function; P(L) α $L^{8/3}$ to $L^{2/3}$

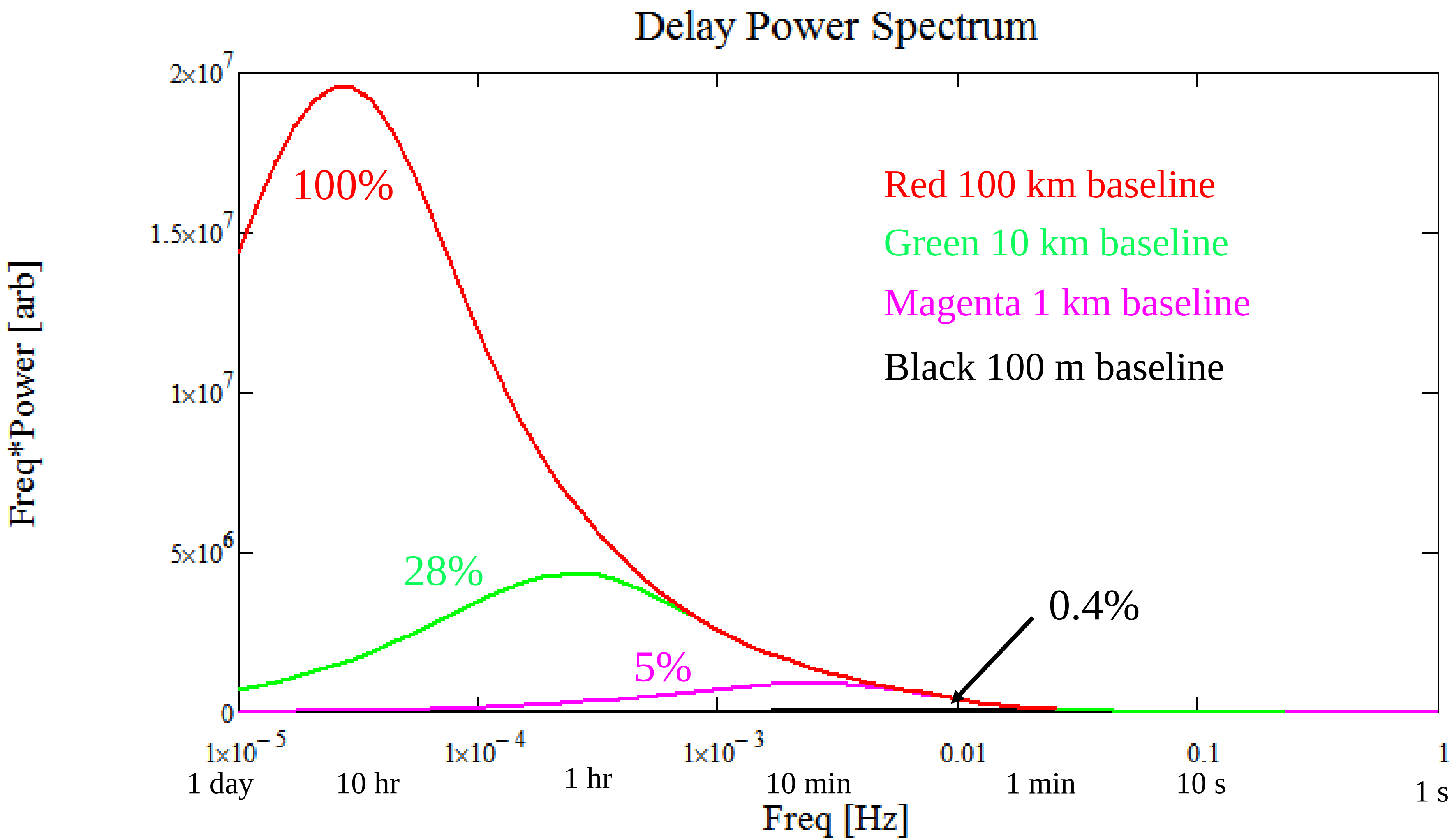


2-D structure function



What an interferometer sees

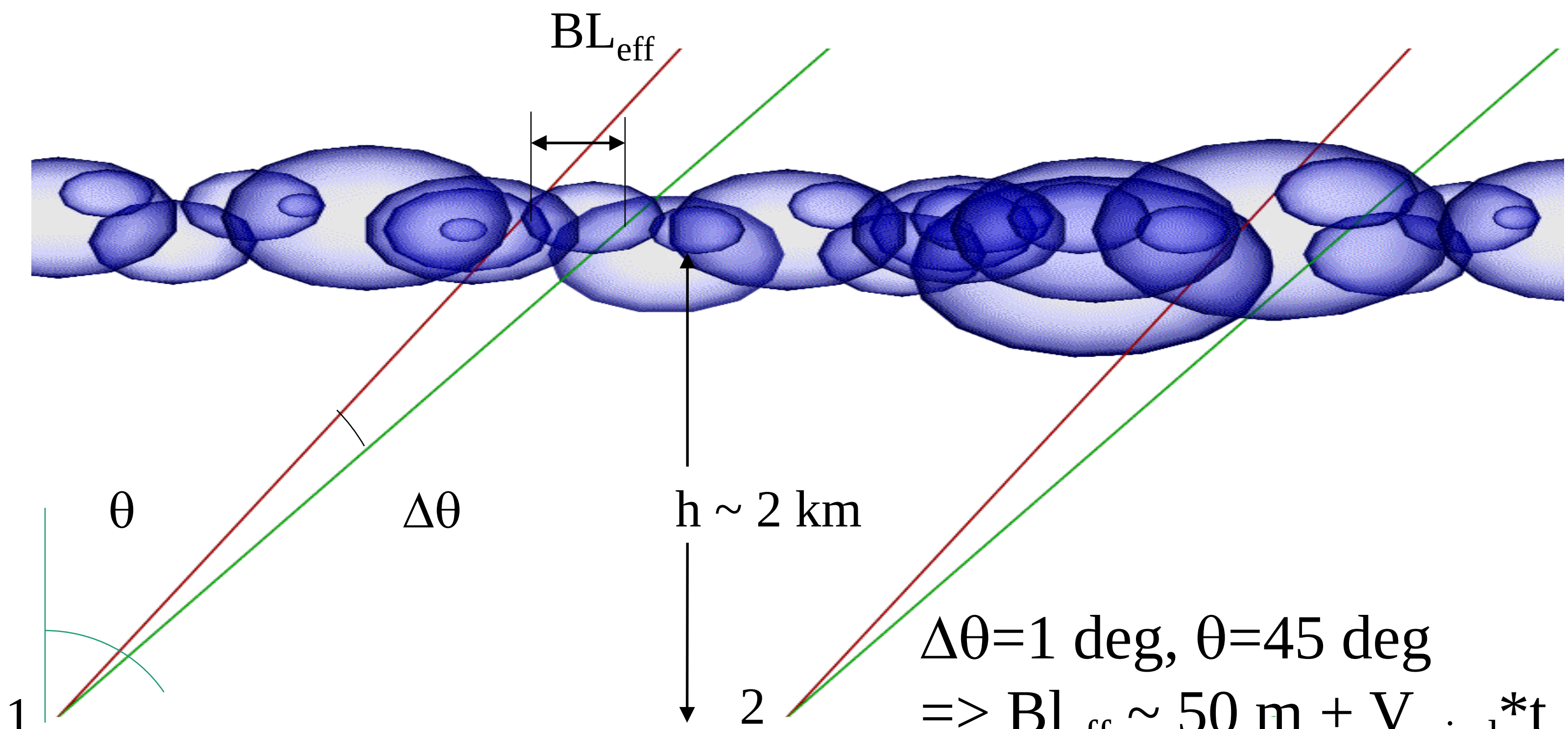
Calculated power spectrum for 10 m/s wind and 1 km thick turbulent layer



Area is proportional to the power in this plot

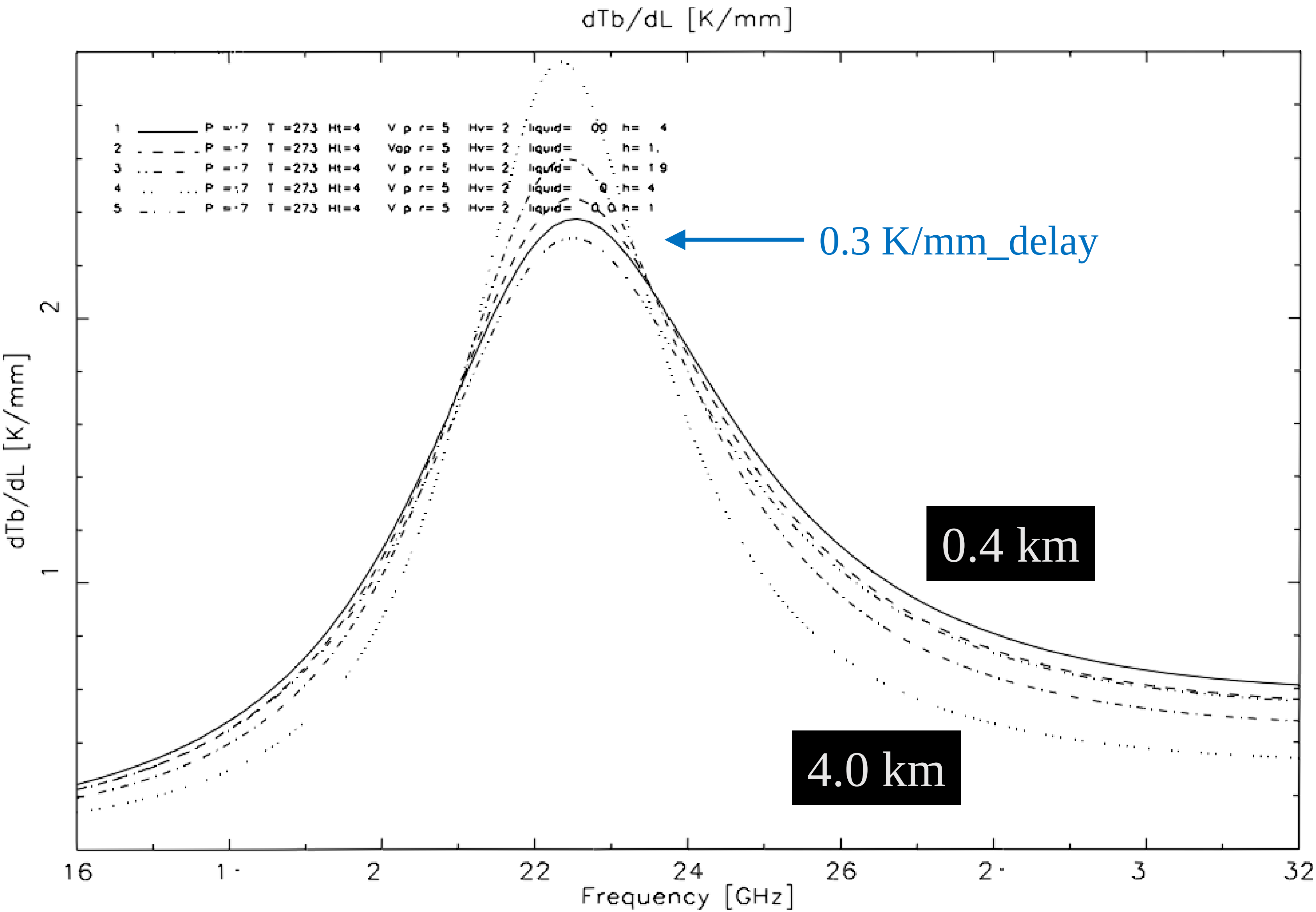
Normal calibration

Observe a nearby known "point" source to remove instrumental drifts and minimize the effect of baseline errors.
The telescope beams will pierce the water layer at different spots separated by $BL_{eff} \sim \Delta\theta\ h/\cos(\theta)$

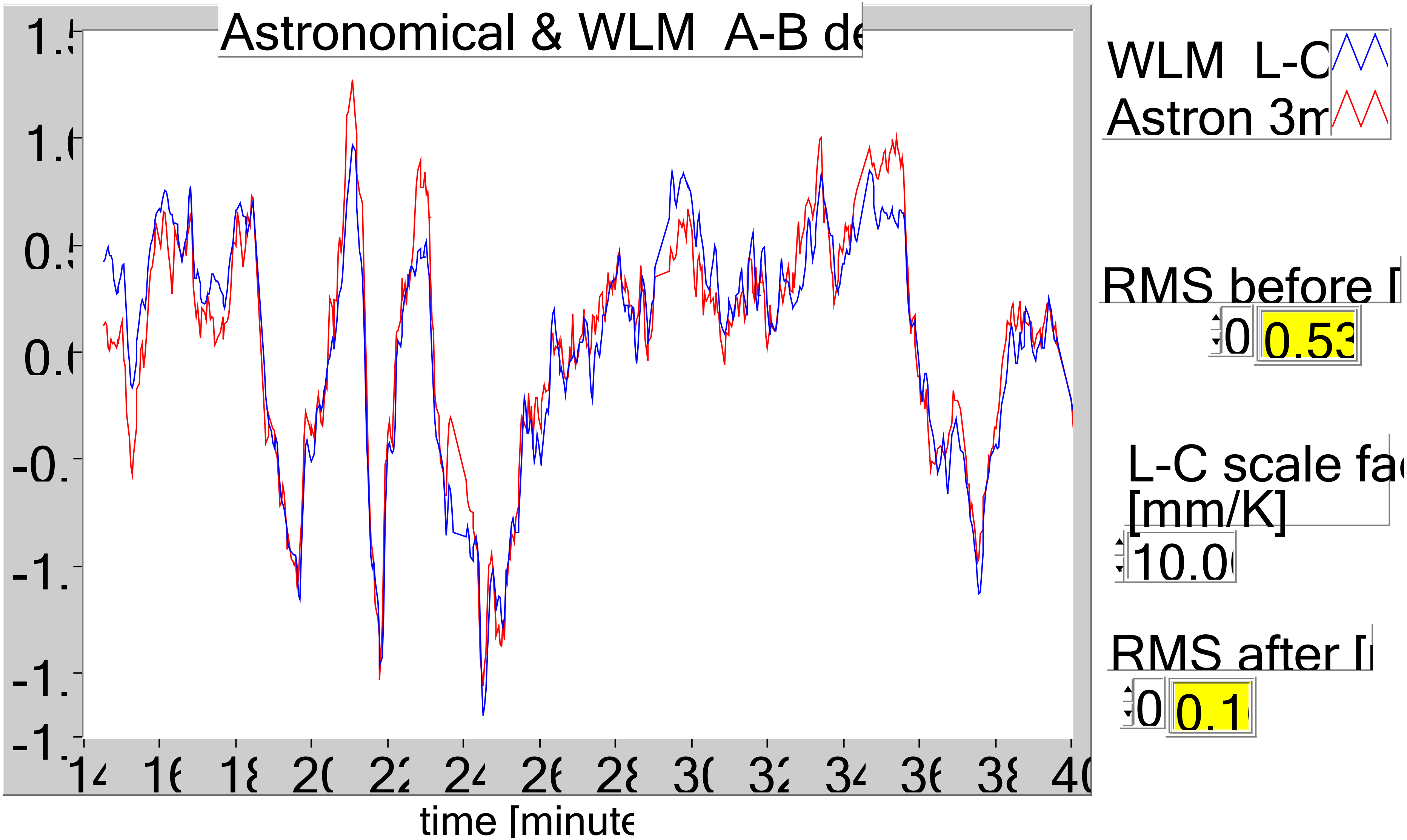


$\Delta\theta$=1 deg, θ=45 deg
=> $Bl_{eff} \sim 50\ m + V_{wind} * t_{cycle}$

22 GHz line shape vs. altitude

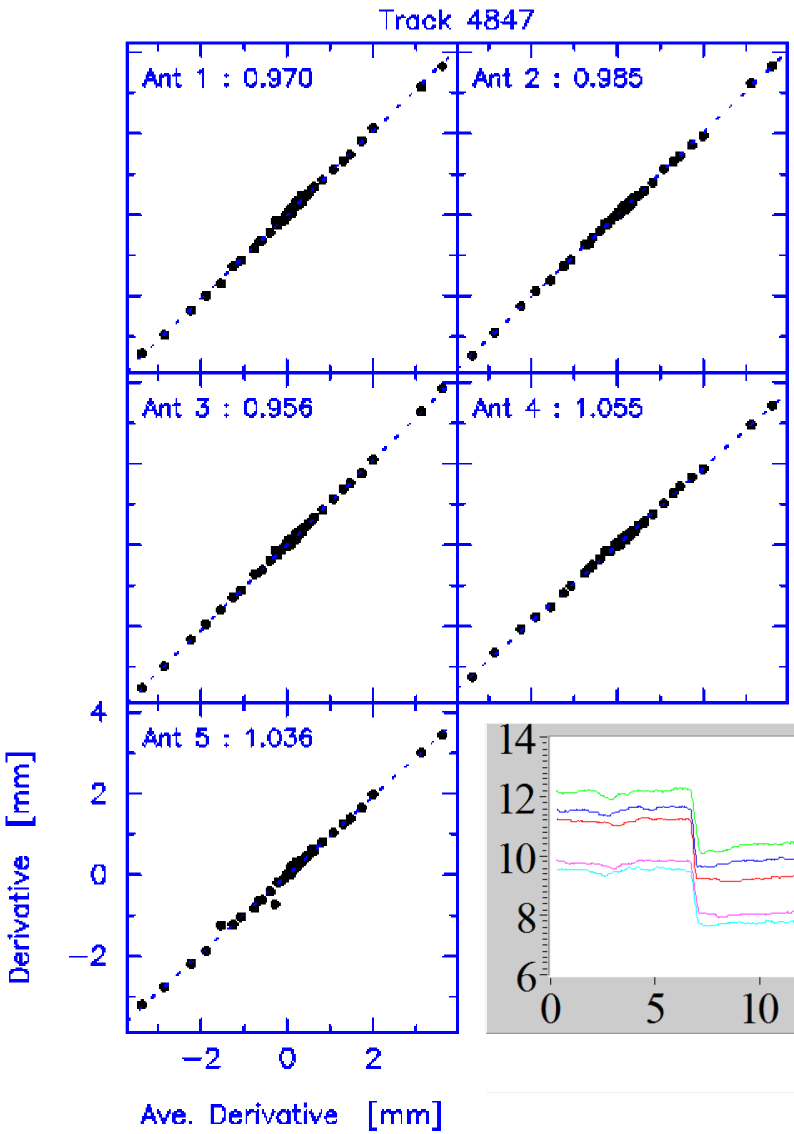


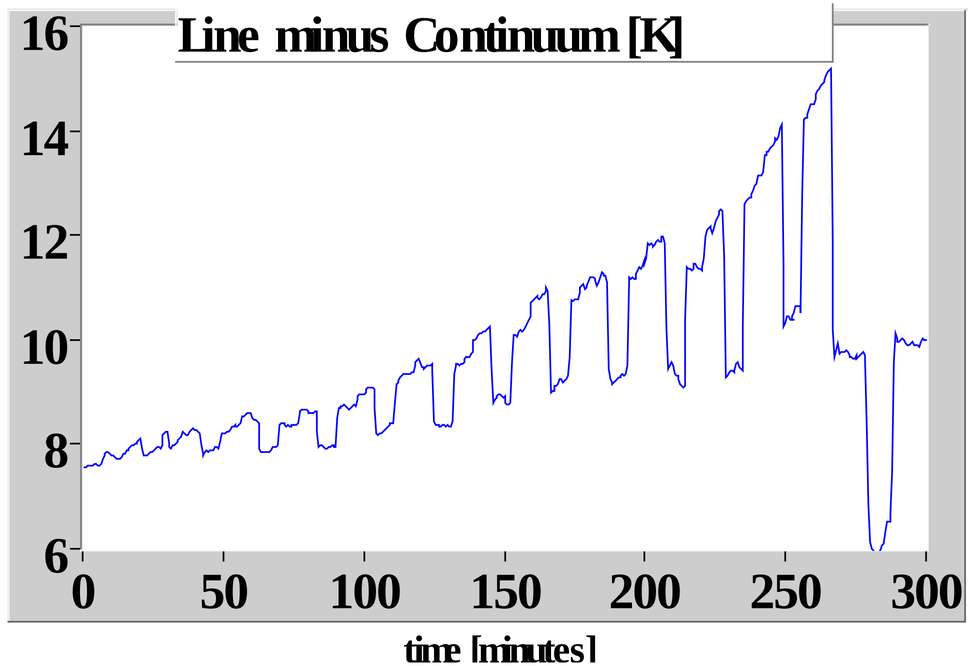
Example of good correlation

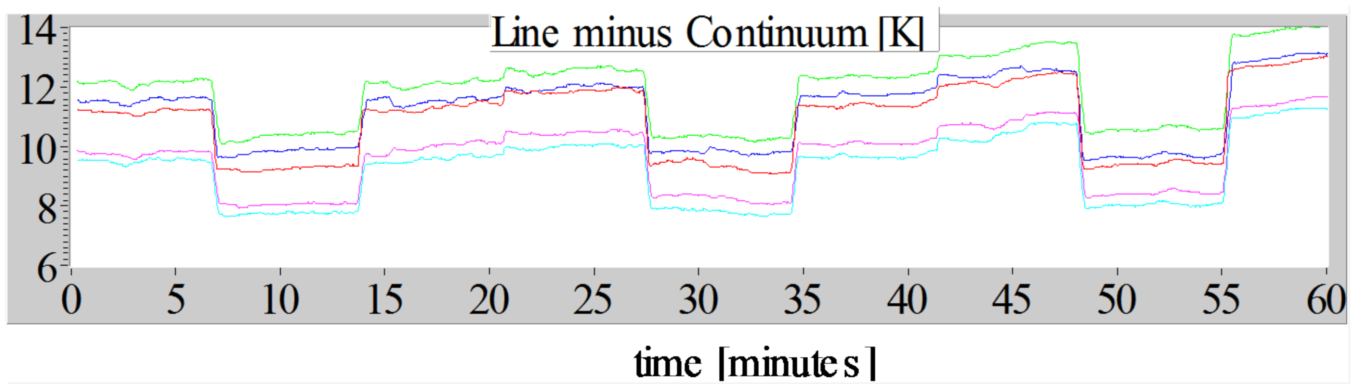


Coherence correction on a single source is relatively easy.

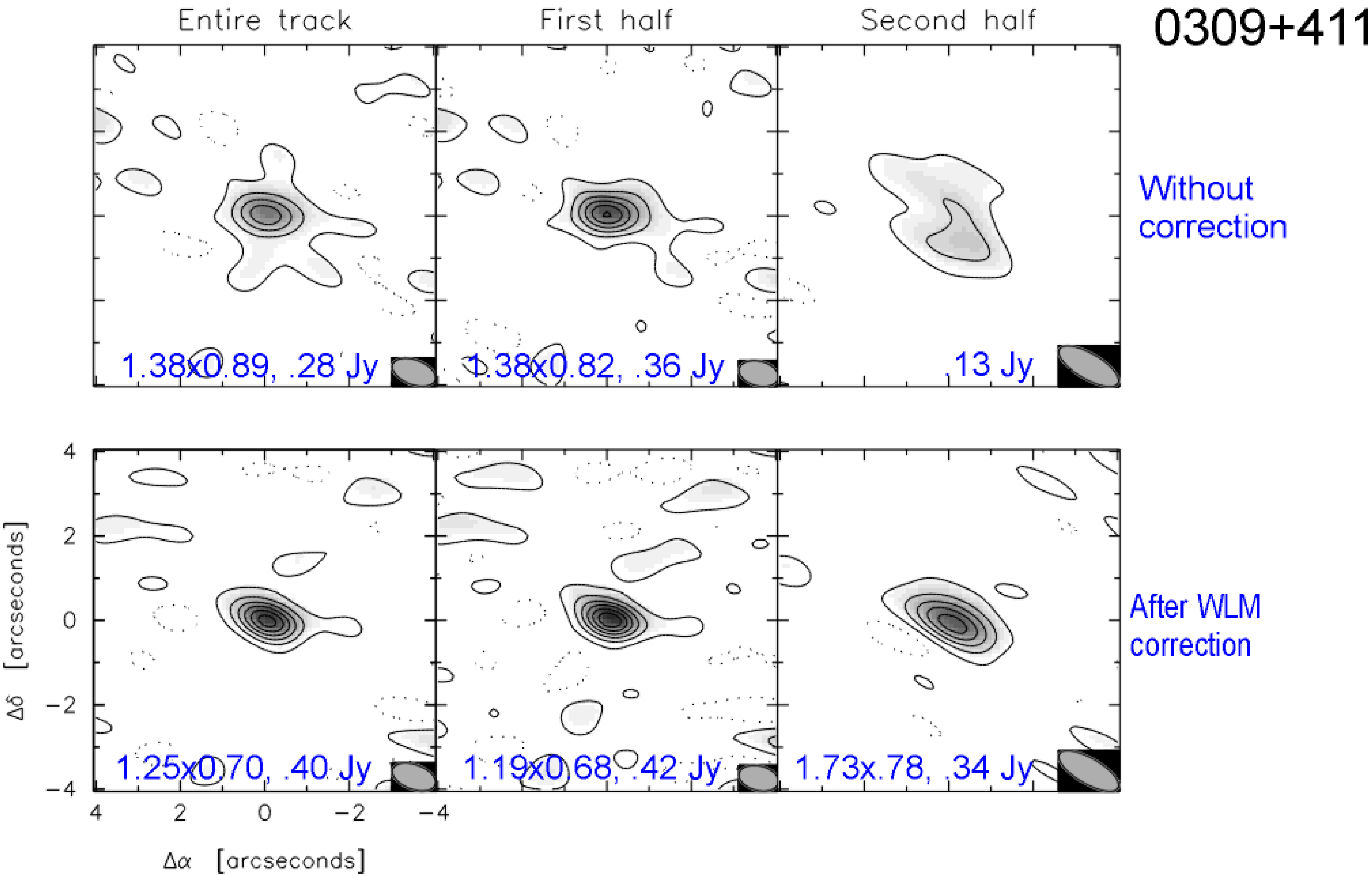
Normalizing WLM gains





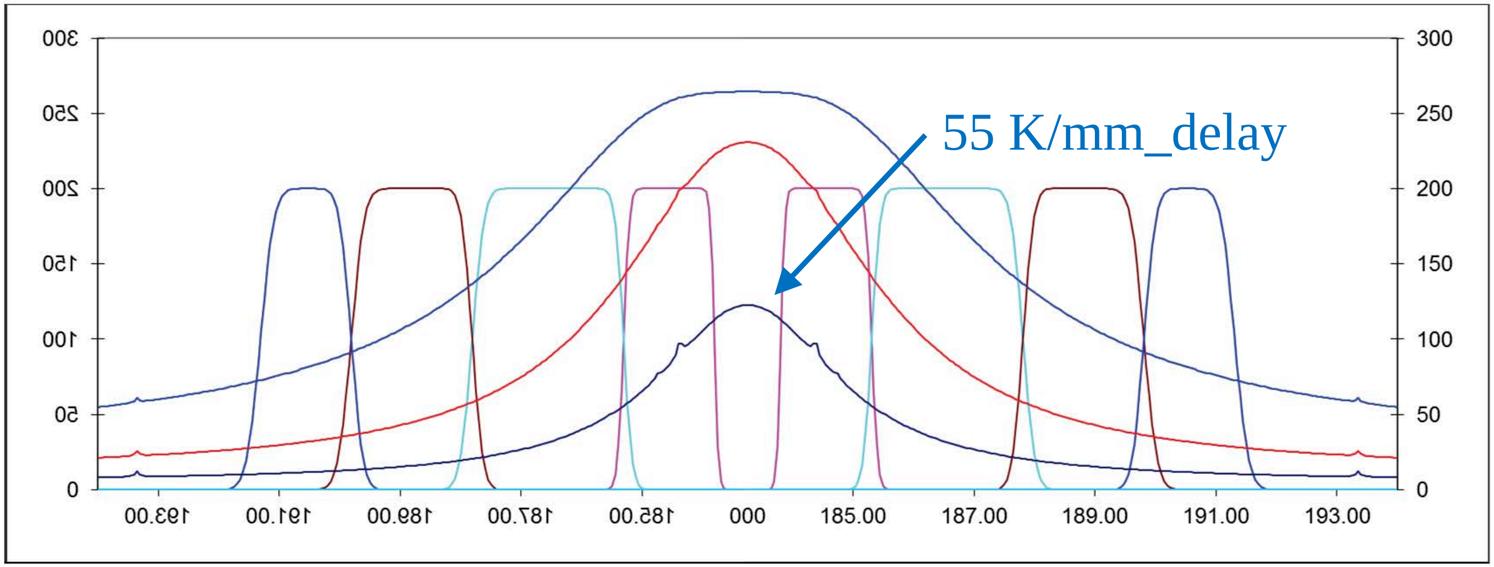


WLM phase correction works



ALMA 183 GHz WVR

- Double-sideband with LO at 183.3 GHz.
- Four IF channels. Shown here with line brightness for 0.3, 1 and 3mm of w.v. in path. See Memo 568.



- Internal hot and amb calibration. Chop at ~5Hz.
- Outputs are brightness temps. Normally 1 /sec.

From Hills presentation in Leiden May 2016

ALMA 183 GHz WVRs

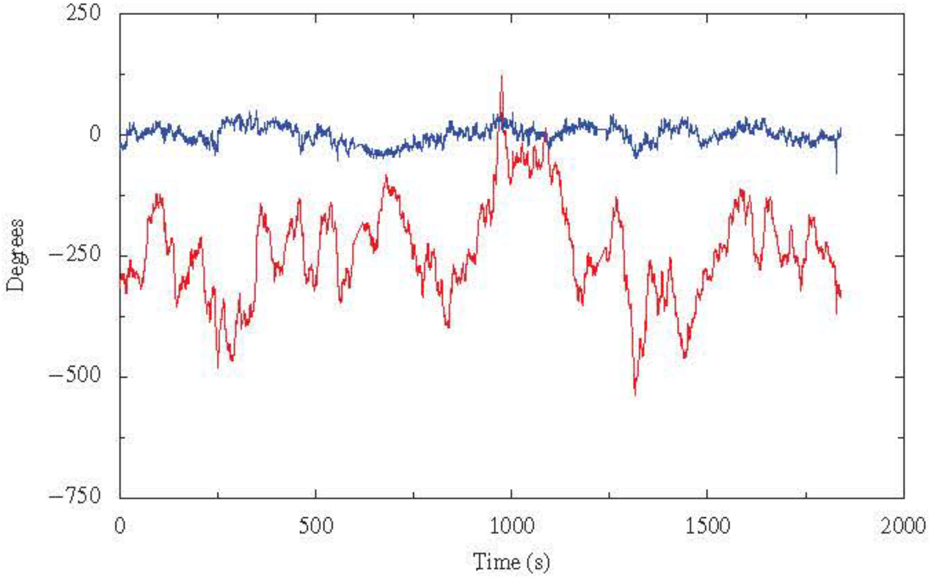


Fig. 8. Test observation at 90 GHz of a strong quasar on a ~650 m baseline with ALMA. The red line is the phase of the observed (complex) visibility on this baseline – note that for a quasar (or other point-like) source at the tracking centre of the interferometer we expect a constant phase in time. The blue line is the visibility phase after correction of the data based on the WVR signals and using the `wvrgcal` program.

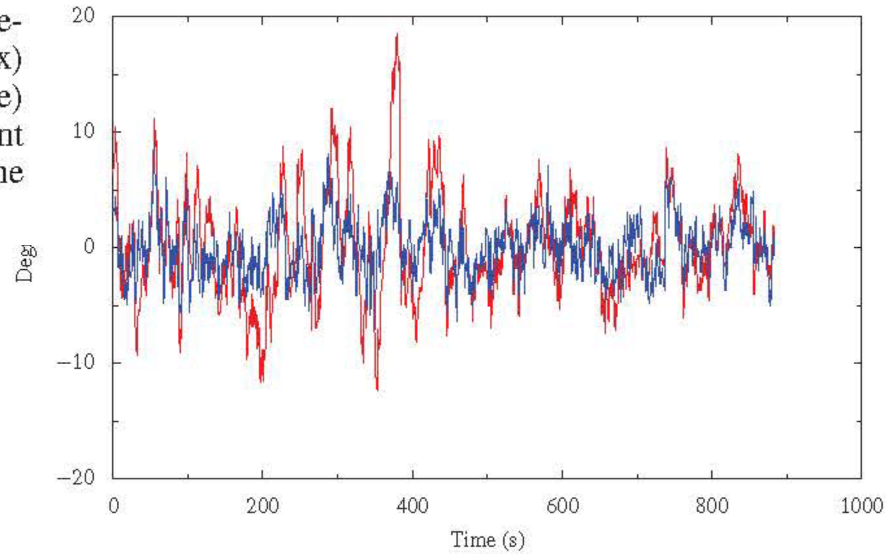


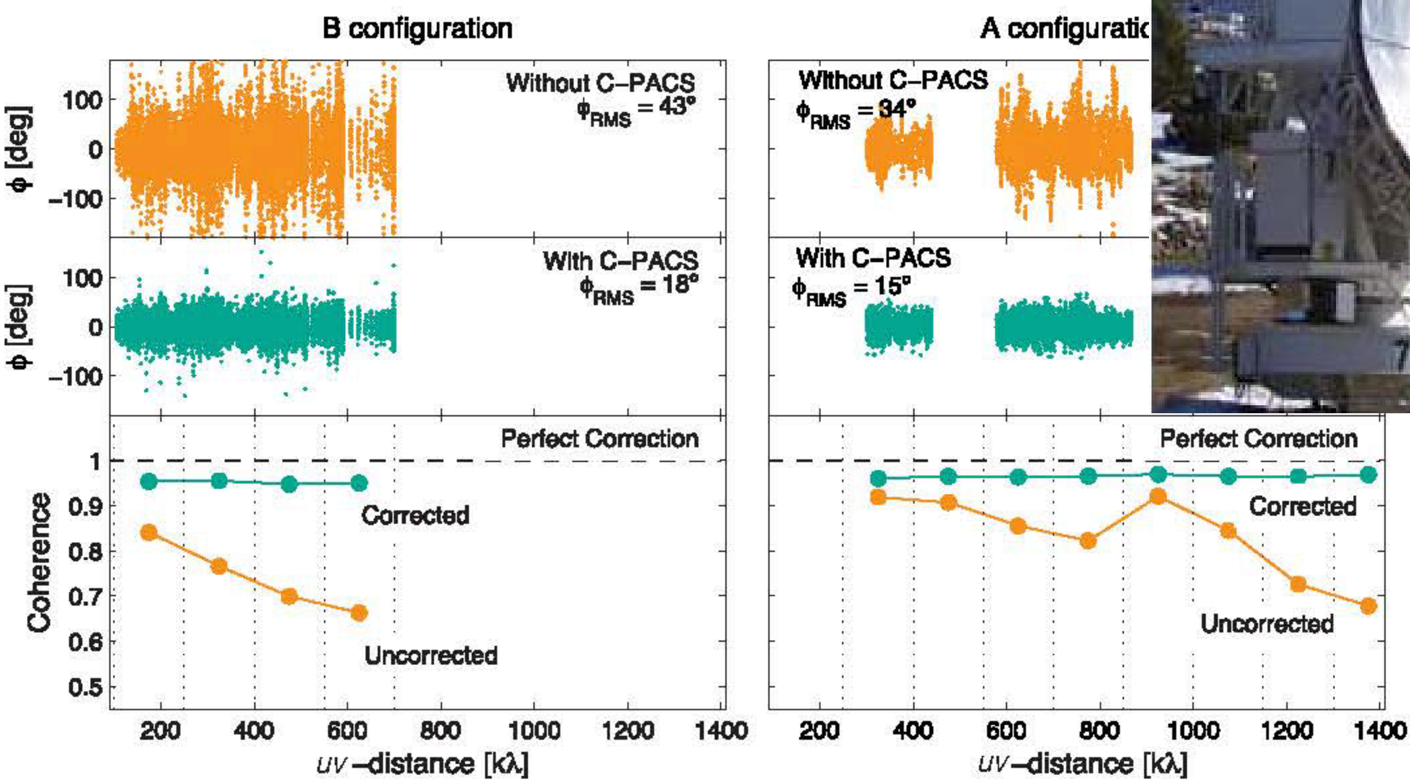
Fig. 9. Test observation on a short (~25 m) baseline in excellent weather conditions. The phase of the uncorrected astronomical visibility is again in red while the phase after WVR correction is in blue. Note the much smaller range of the vertical axis compared to Fig. 8.

From Nikolic et al A&A 552, A104 (2013)

C-PACS
(CARMA Paired Antenna Calibration System)

Pair the 3.5 m SZA antennas with the larger 10 m and 6 m antennas.

Small antennas observe the phase calibrator at 30 GHz while the larger antennas observe the target source at 230 GHz.



Multi-prong Approach

- **Fast antennas and software**
  - Useful for fast calibration, calibration cycle ~10 s
  - Useful for wide field mapping
  - Improve observing efficiency
- **Use astronomical receivers for 22 GHz water line**
  - Always available with low resolution auto-spectra
  - Investigate stability and possible rapid noise source calibration procedure
- Investigate array configurations that have many pairs of antennas that are appropriate for paired antenna calibration
  - Useful for special high dynamic range imaging

The key to calibrating the ngVLA is it's high sensitivity => close calibrators and shorter calibration cycles

Comparison of techniques

Fast calibration

+ **No new hardware**
+ Normal calibration procedures
- **Requires fast antennas (1 deg in a few seconds) and fast control software**
- Bl_{eff} ~50m
- Software to determine optimum calibrator and calibration cycle

WVR correction

+ **Easy to correct atmospheric coherence**
+ Can use slow antennas
- **Extra hardware?** High gain stability and accuracy, ~10^{-3}
- Need to fit or determine line shape parameters, may not work well with clouds
- Linking to calibrator phase is still a work in progress
- **New software and algorithms**

Calibration array

+ **Continuous "easy" to interpret correction**
+ Can work on short timescales
- **Requires ~double the number of antennas**, although smaller and lower surface accuracy
- **A second large correlator**
- Limited Bl_{eff} > ~50m
- **Lot's of new software and algorithms**

The key to calibrating the ngVLA is it's high sensitivity => close calibrators and shorter calibration cycles

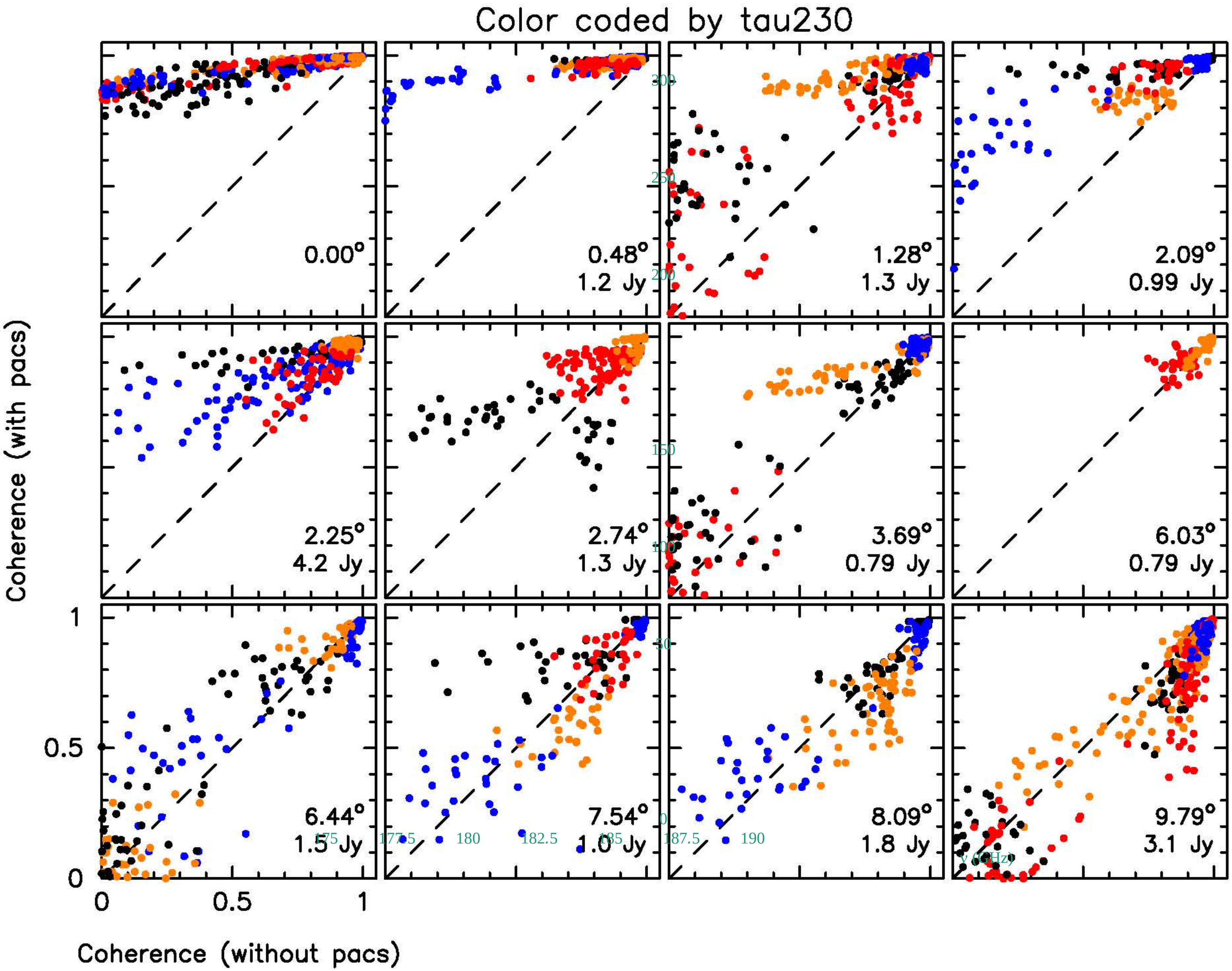
H_2O radiometer phase correction

Essentially all of the delay variation is caused by water in the atmosphere and the emission brightness is directly related to the column density.

H_2O emission and delay data

	mmDelay/mmH_2O	K/mmH_2O	K/mmDelay
Vapor			
22.2 GHz	**7.0**	**1.9**	**0.27**
183 GHz	**7.0**	**380**	**55**
continuum	**7.0**	**$2.4(f/100GHz)^2$**	**$0.35(f/100GHz)^2$**
Liquid			
continuum	**1.5**	**$400(f/100GHz)^2$**	**$270(f/100GHz)^2$**

C-PACS correlation improvement, but similar for all methods



OVRO 22 GHz **W**ater **L**ine **M**onitor

The WLM has a pickoff mirror near the Cass focus and uses the <u>full primary</u>.

Three analog filters are used to discriminate line emission from continuum emission.