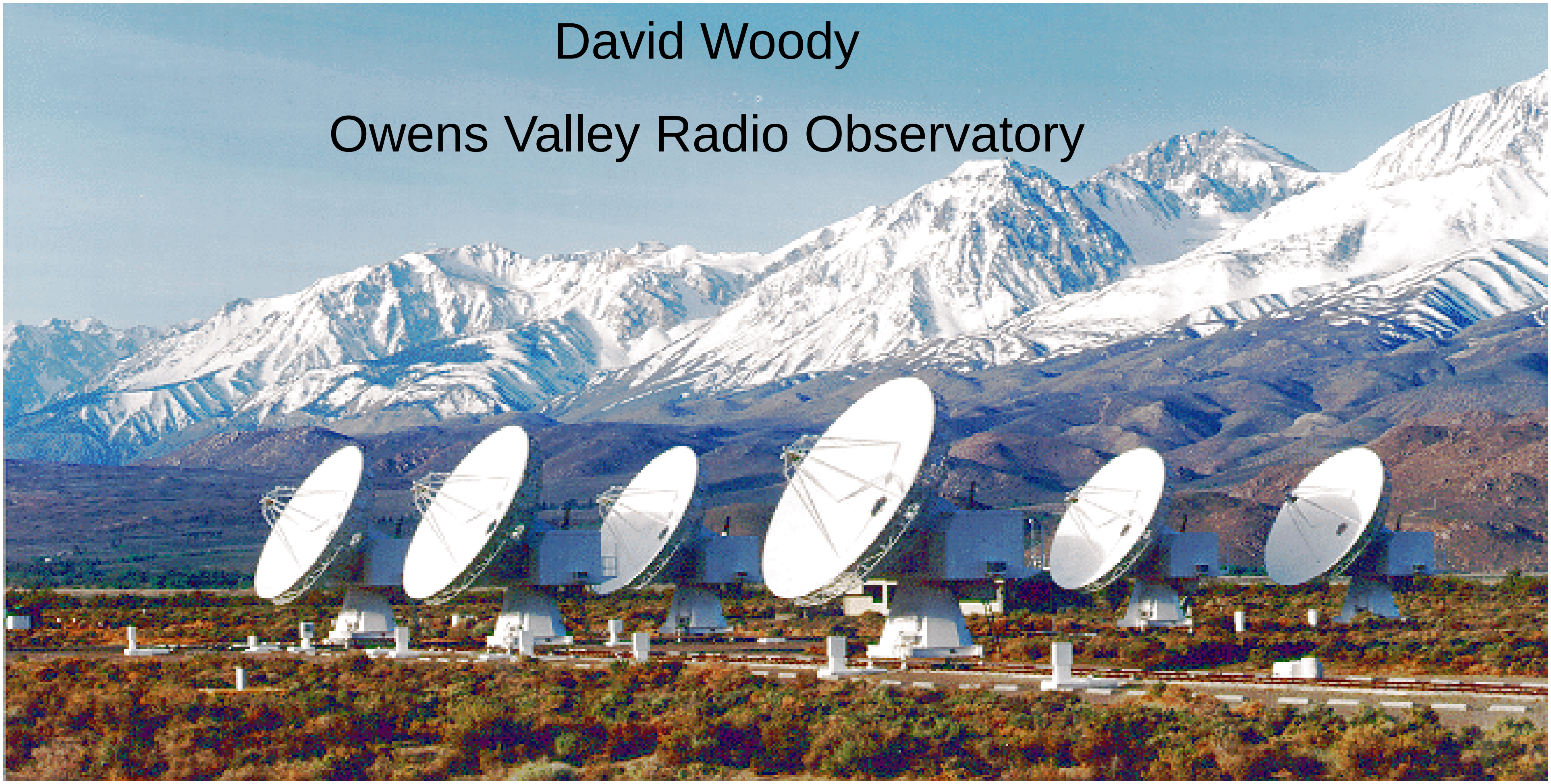
Phase Calibration for the ngVLA



David Woody

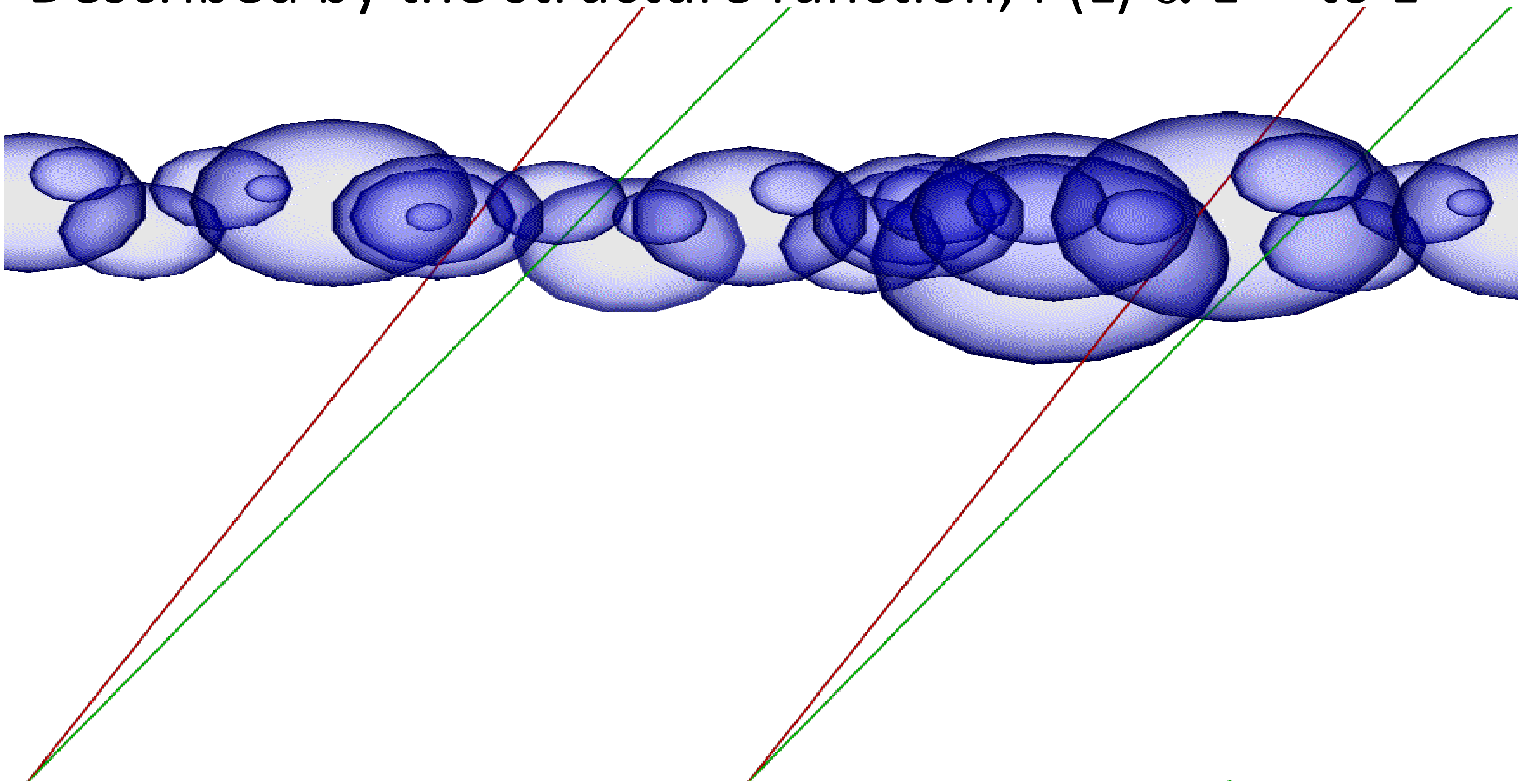
Owens Valley Radio Observatory

Outline

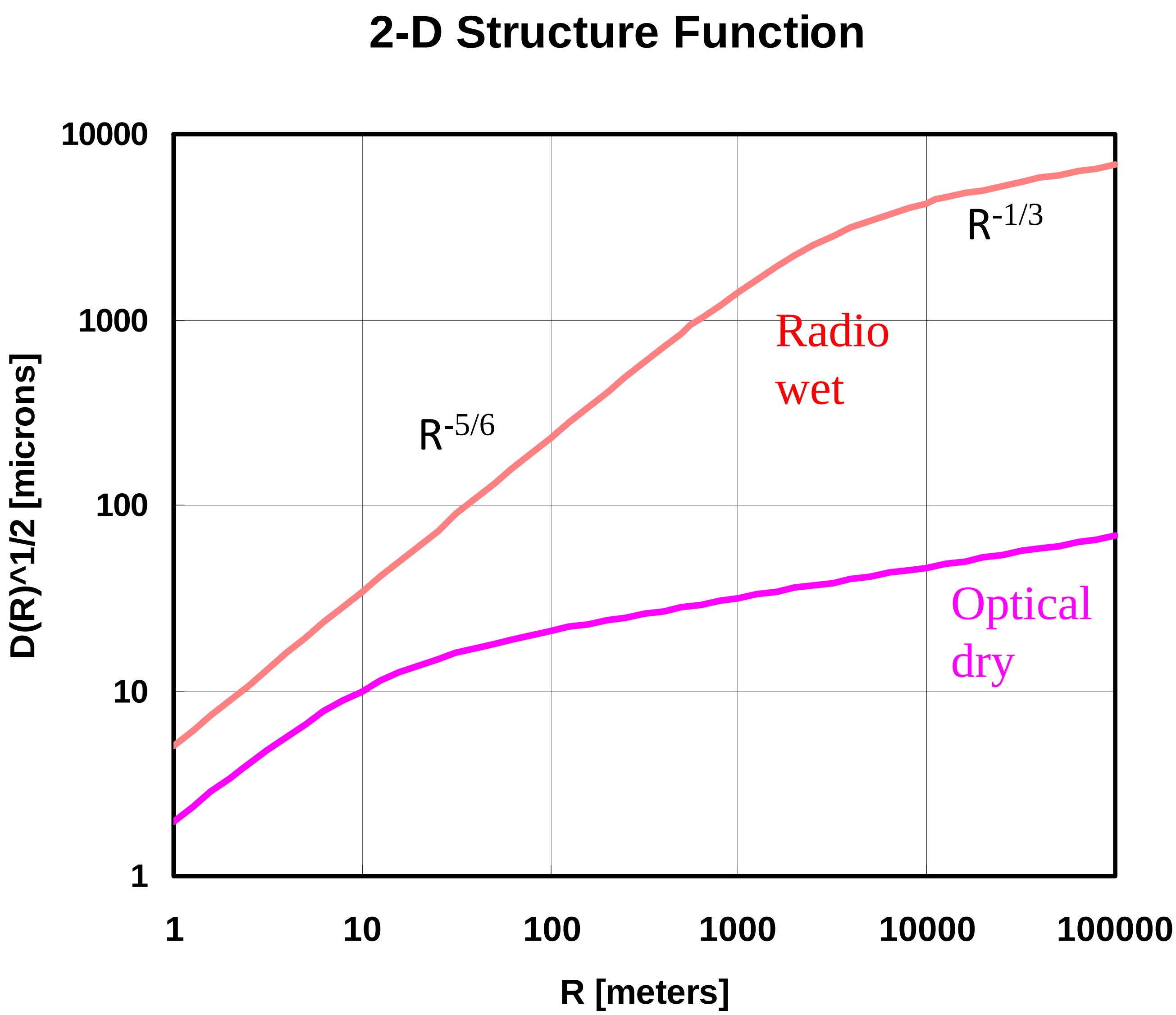
- Statement of the problem
- Possible solutions
  - Self-calibration using a known source in the FoV (won't cover this)
  - Fast switching phase calibration
  - Water vapor radiometer phase correction
  - Calibration array
- Comparison of techniques and Challenges
  - It is mostly software (new algorithms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

Water is the problem

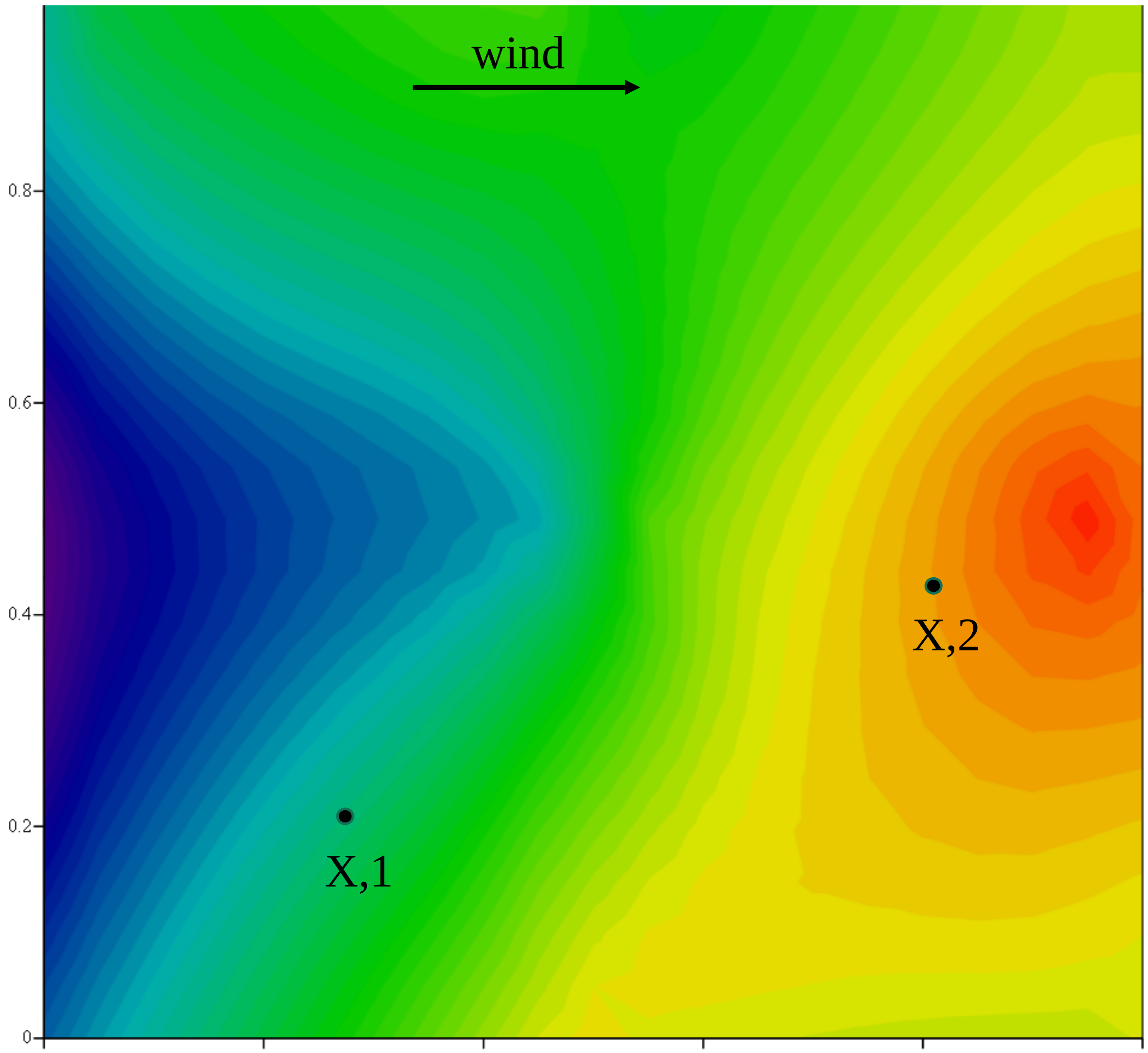
- Kolmogorov turbulence
- Frozen phase screen
- Moving at wind speed
- Described by the structure function; P(L) α $L^{8/3}$ to $L^{2/3}$



2-D structure function



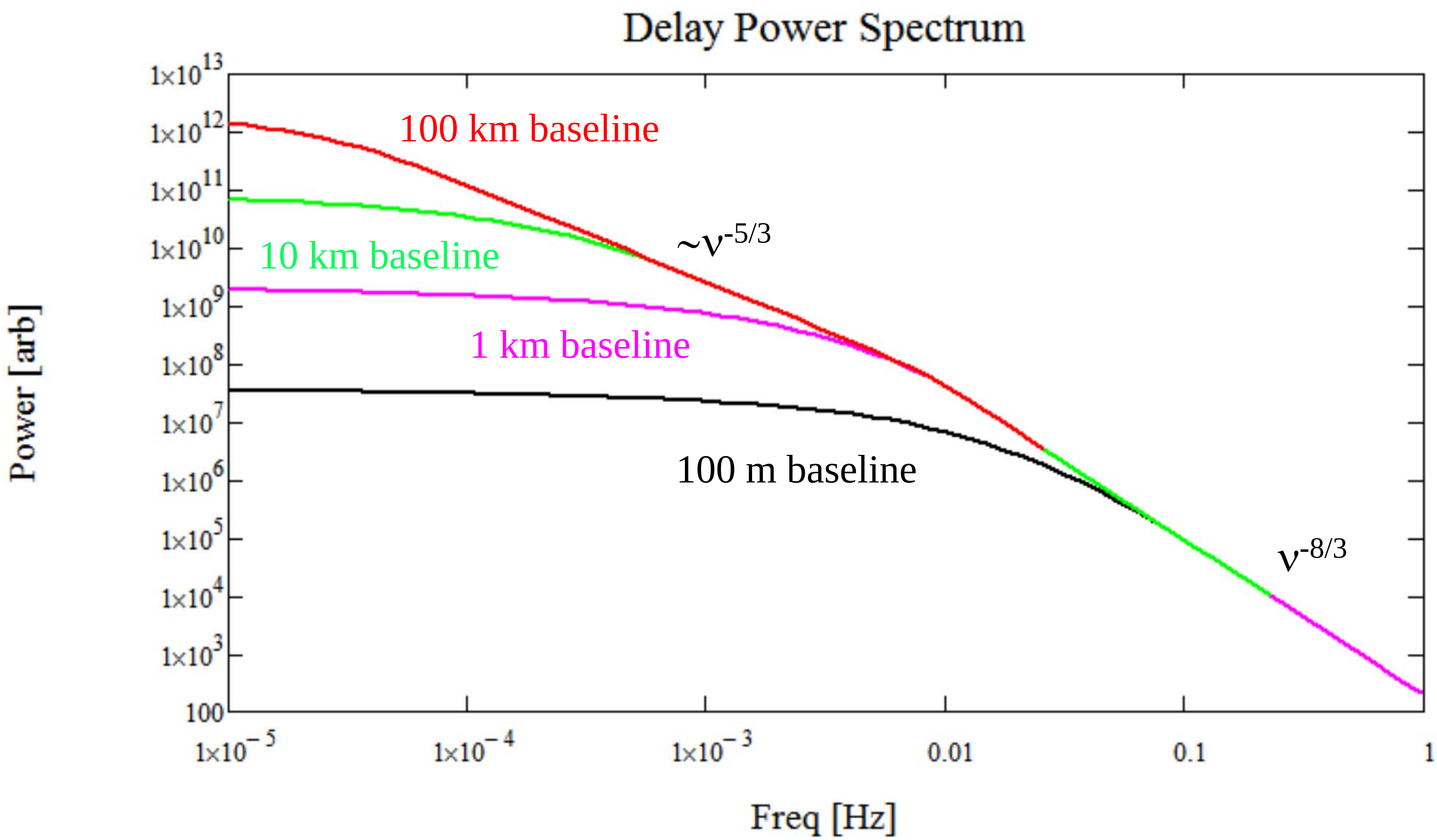
Simulated 2D phase screen



Target visibility sees the difference in delay between positions X,1 and X,2 in the phase screen which changes as the wind blows the frozen turbulence across the array.

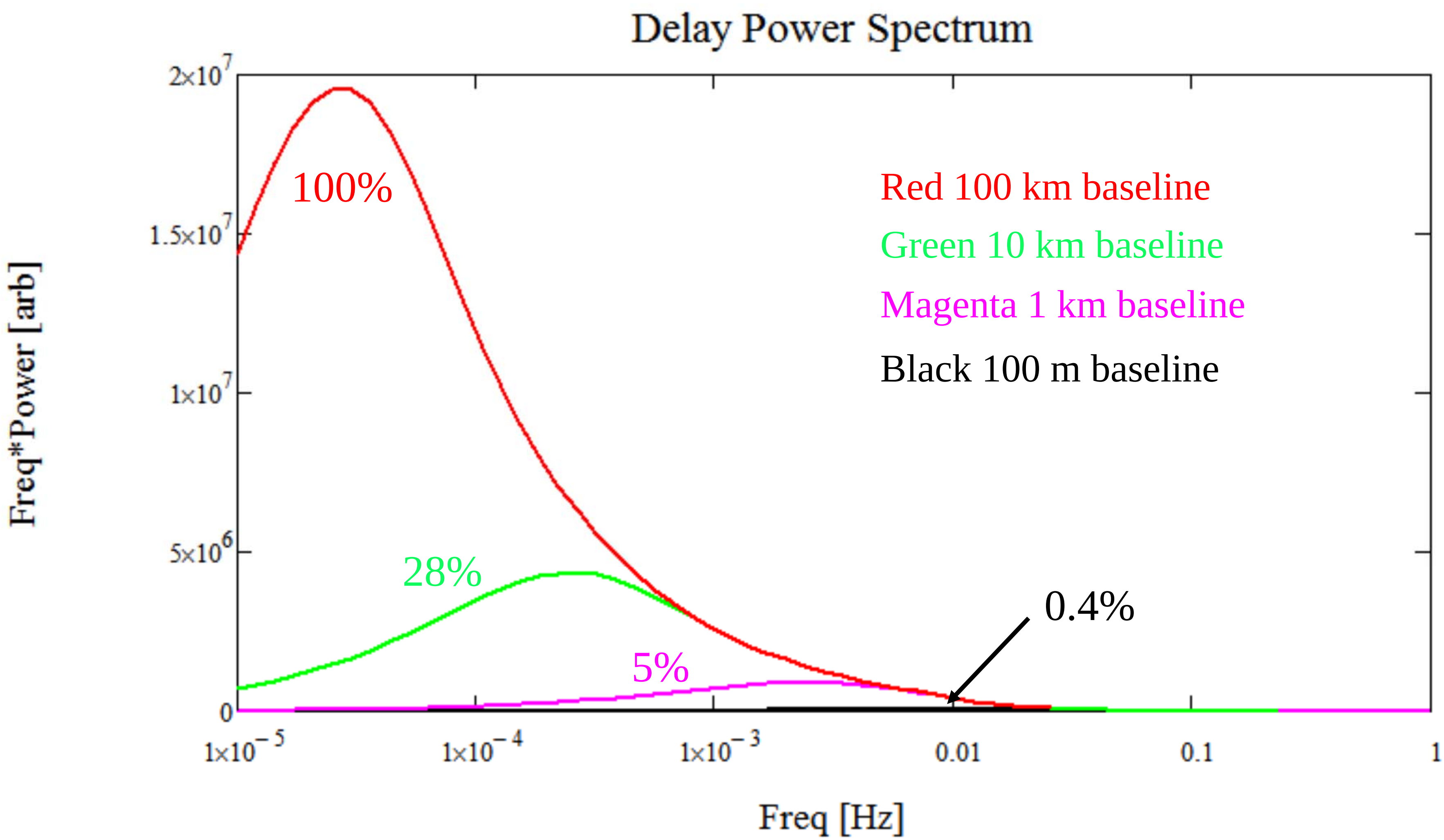
What an interferometer sees

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



What an interferometer sees

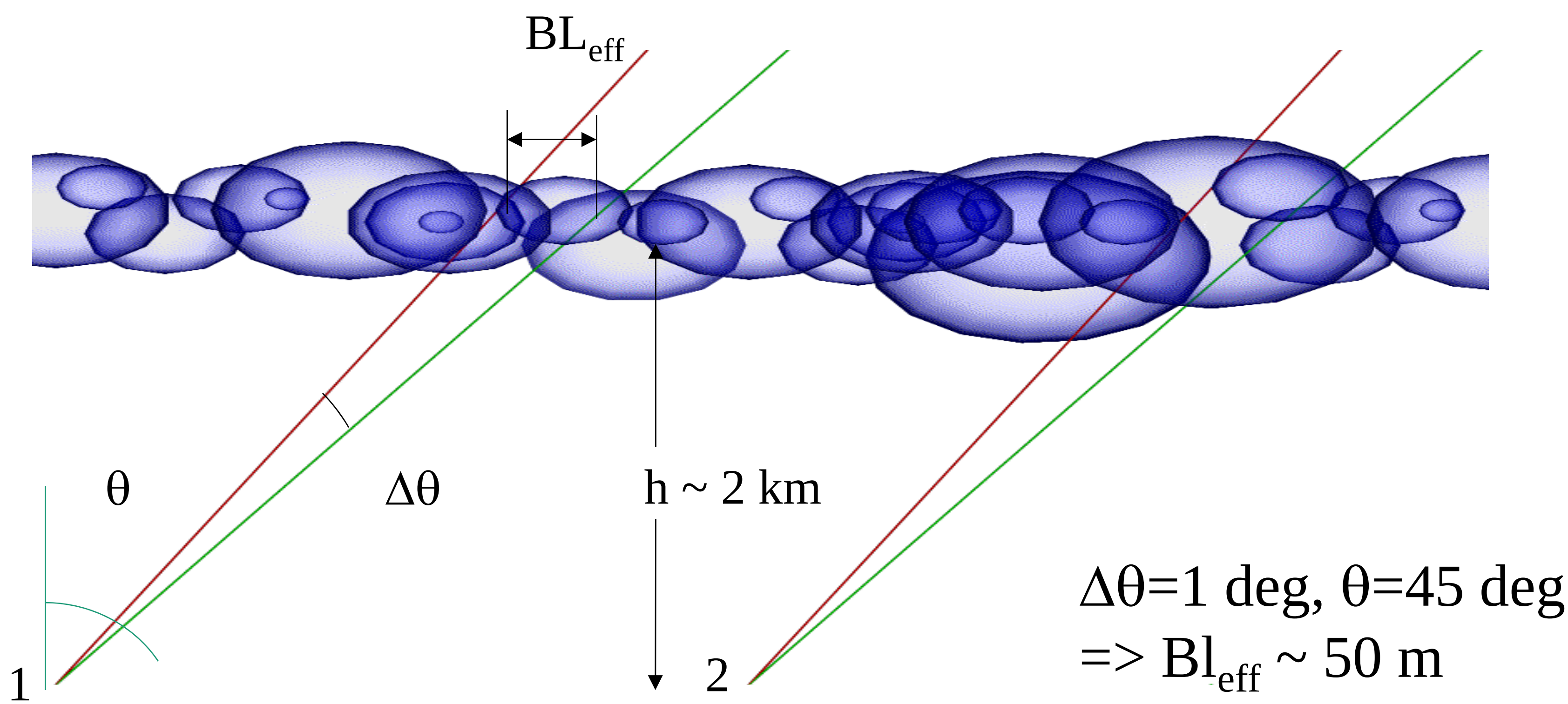
Calculated power spectrum for 10 m/s wind and 1 km thick turbulent layer



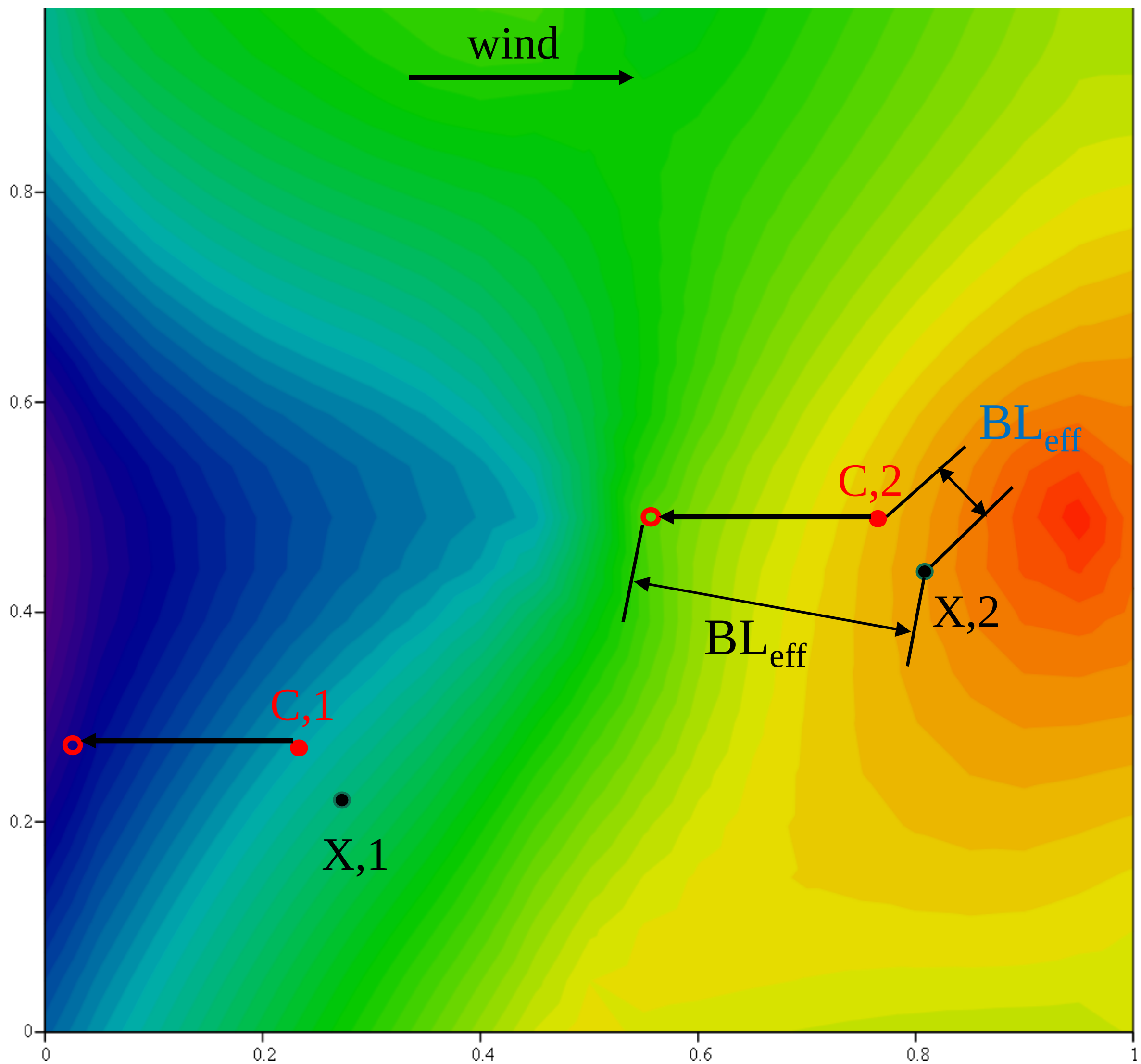
Area is proportional to the power in this plot

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 $BL_{eff} \sim \Delta\theta\, h/\cos(\theta)$



Fast switching phase calibration



Under normal "slow" calibration the phase screen will have moved a significant distance during a target-calibrator cycle, greatly increasing BL_{eff}

"Fast" switching speeds up the target-calibrator cycle to "freeze" the atmosphere to minimize the distance between where the target and calibrator beams pierce the phase screen.

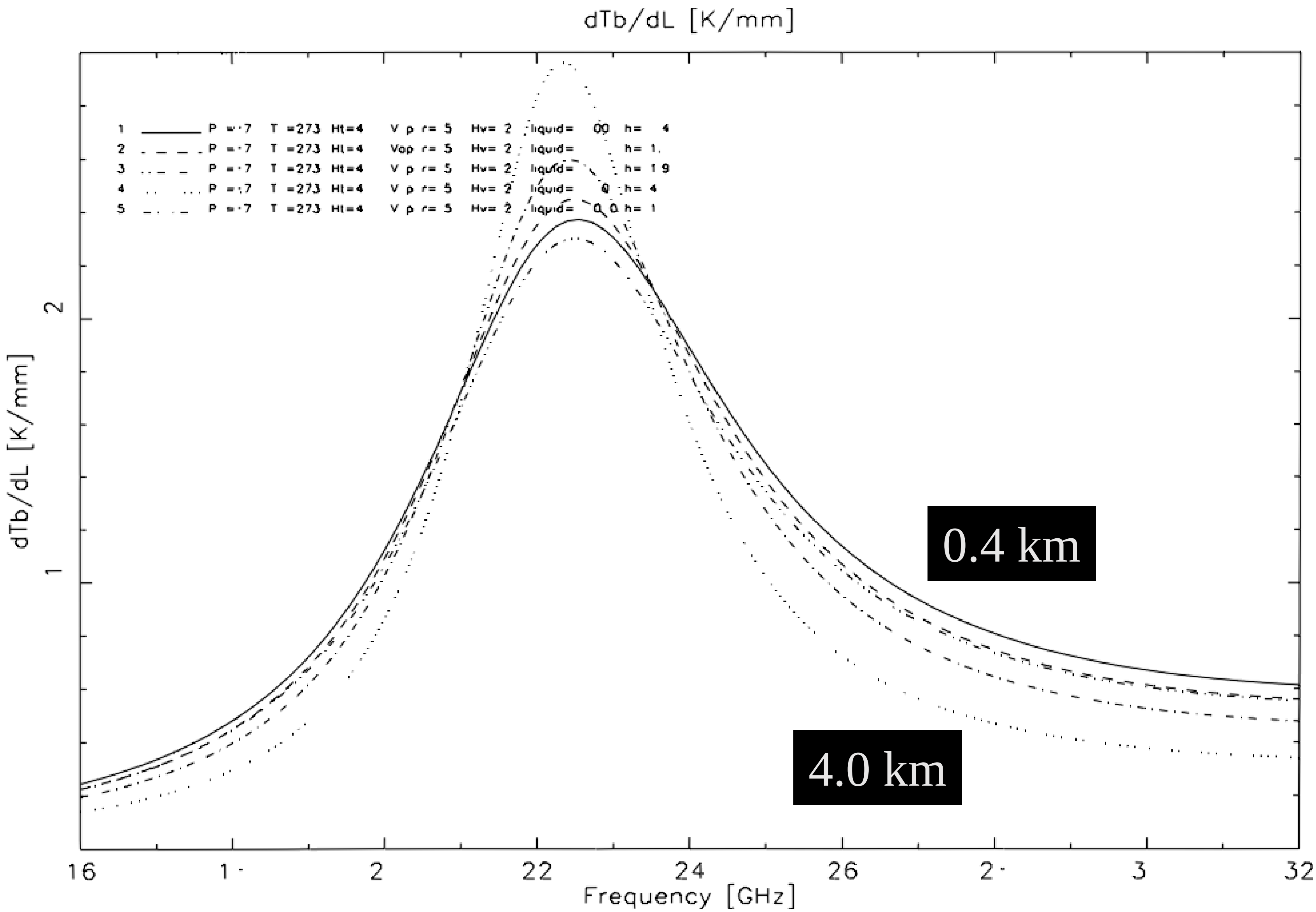
H_2O radiometer phase correction

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$(f/100GHz)^2$**

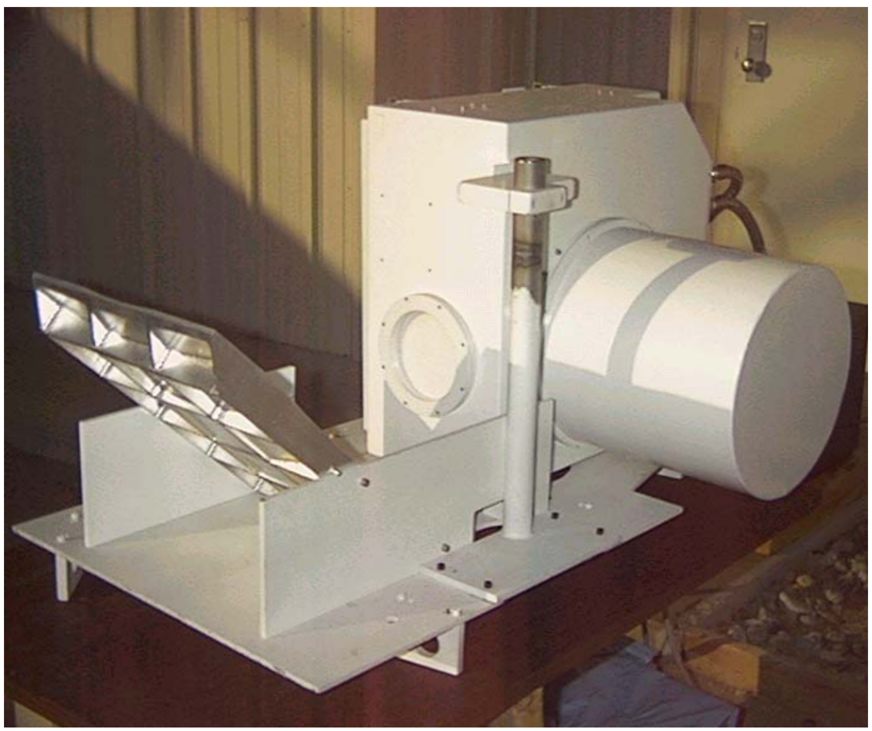
22 GHz line shape vs. altitude

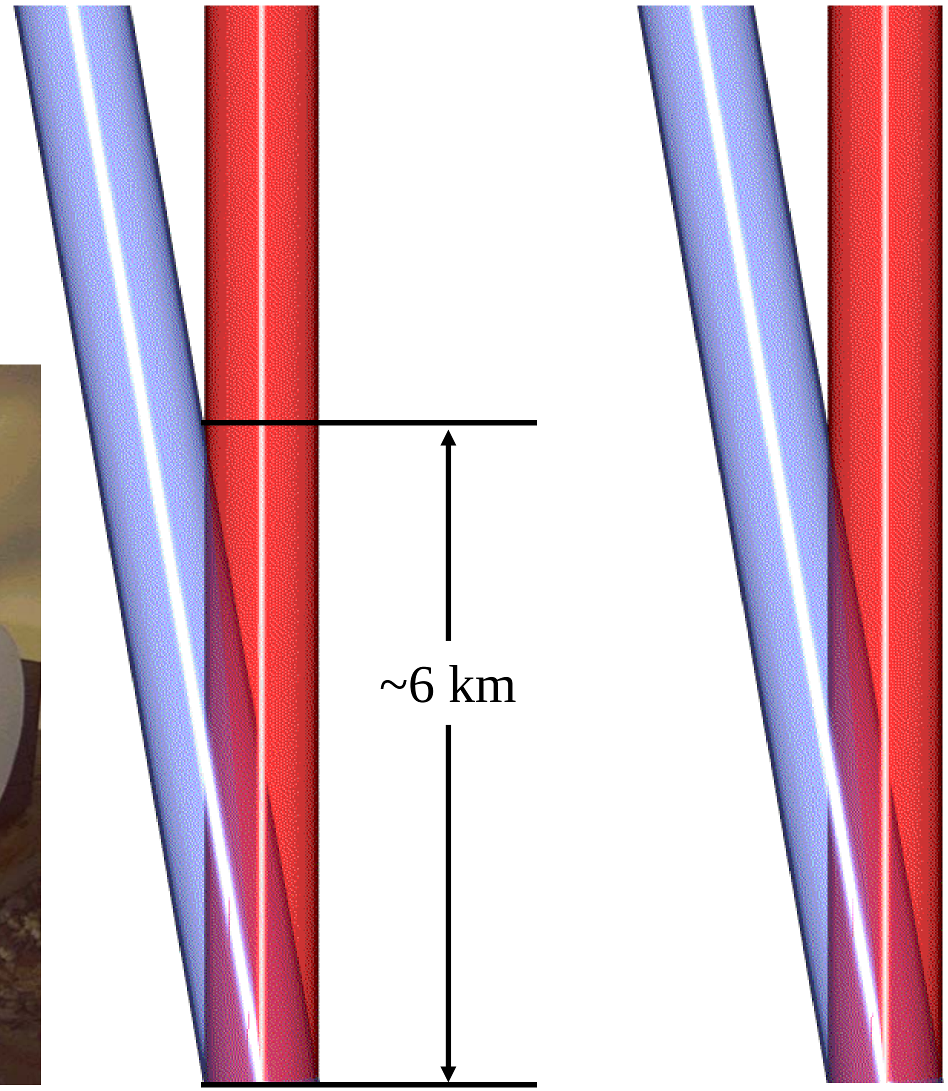


OVRO 22 GHz Water Line Monitor

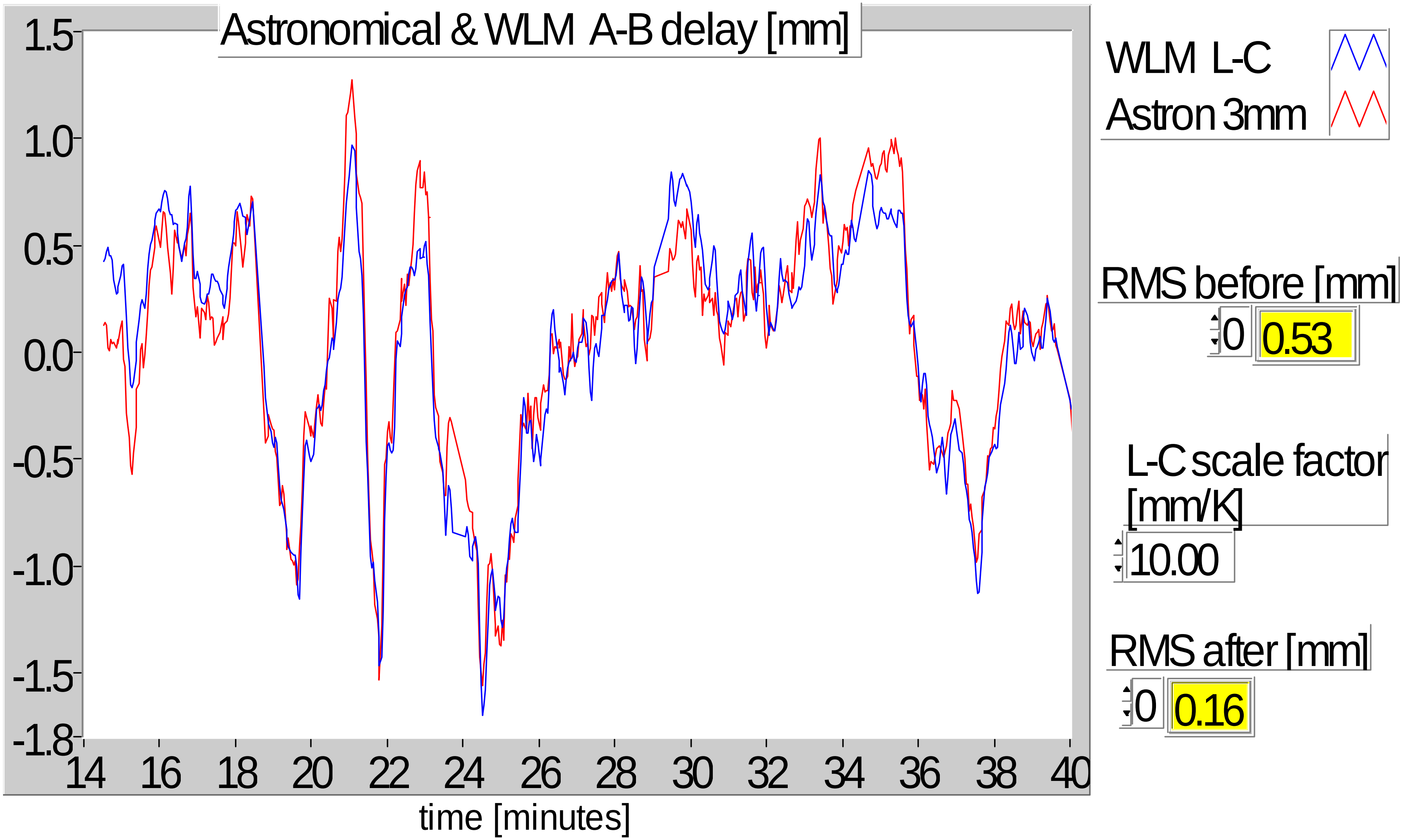
The WLM has a pickoff mirror near the Cass focus and uses the full primary.

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



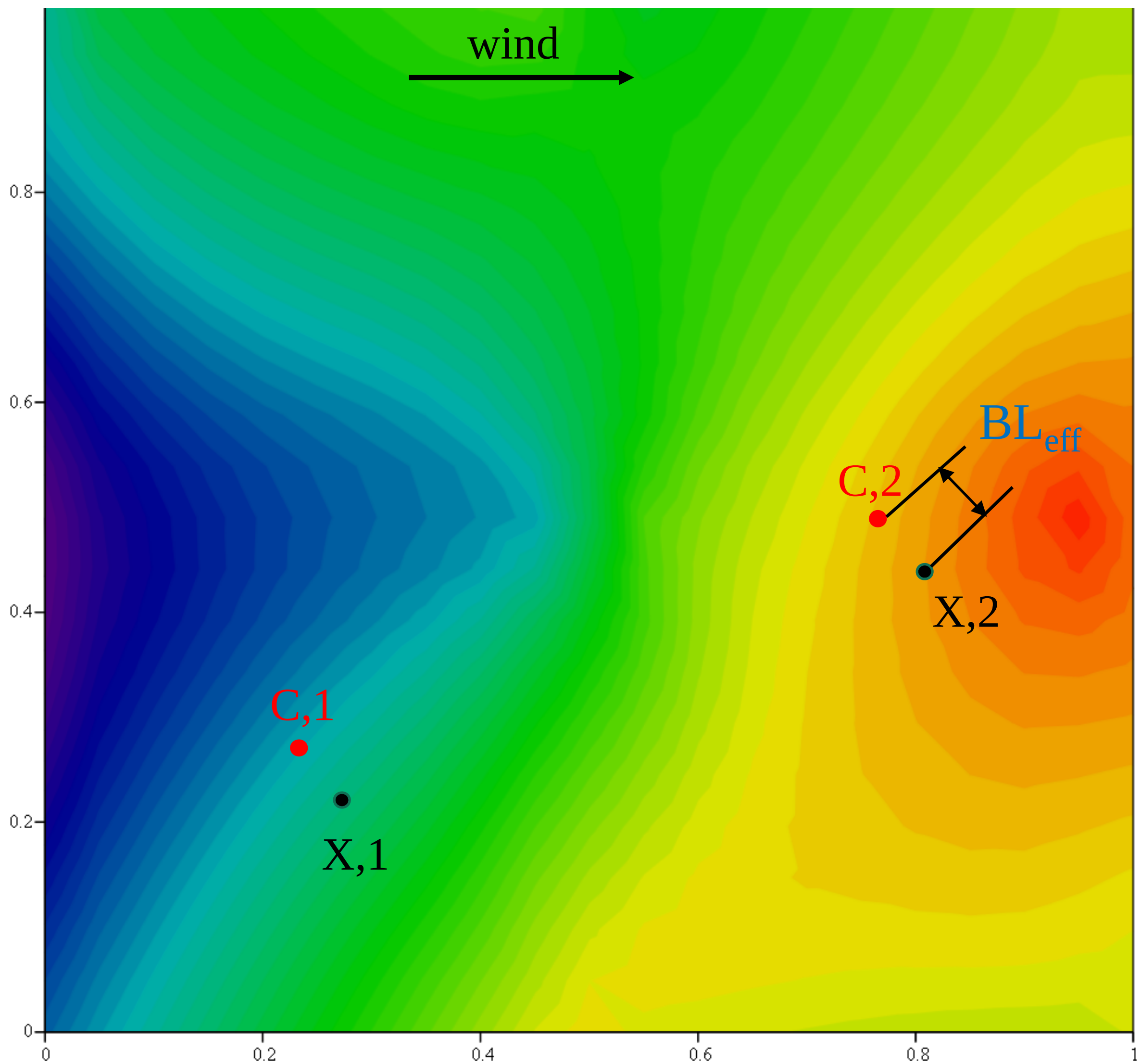


Example of good correlation



Coherence correction on a single source is relatively easy.

WVR phase calibration

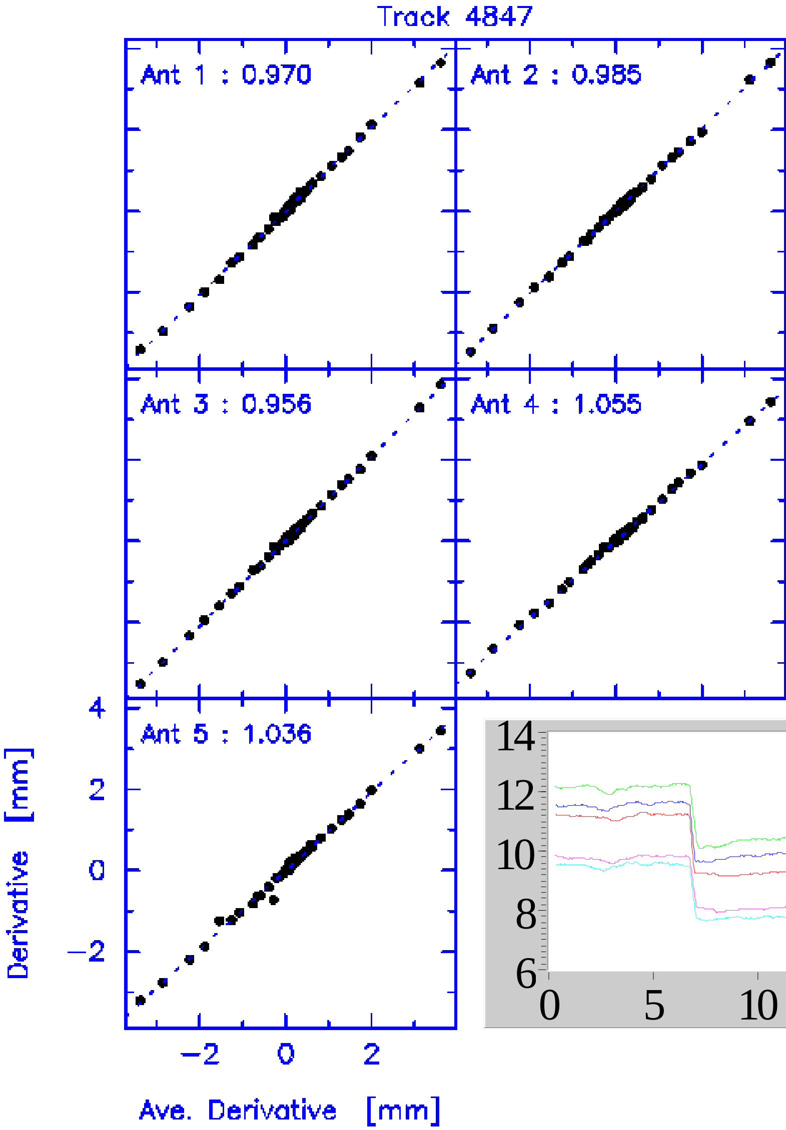


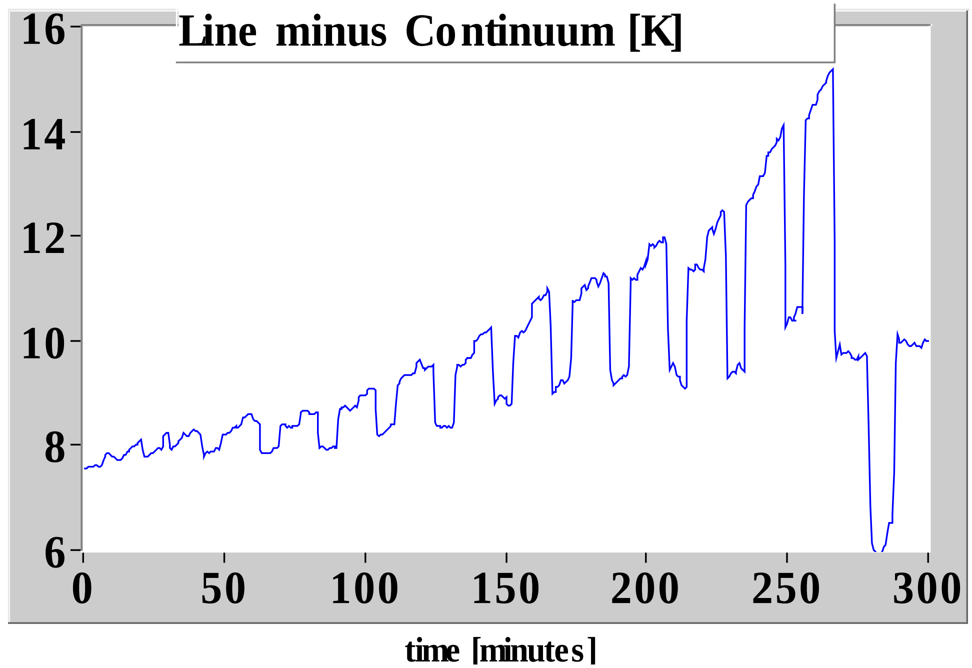
Coherence correction on a single source is relatively easy.

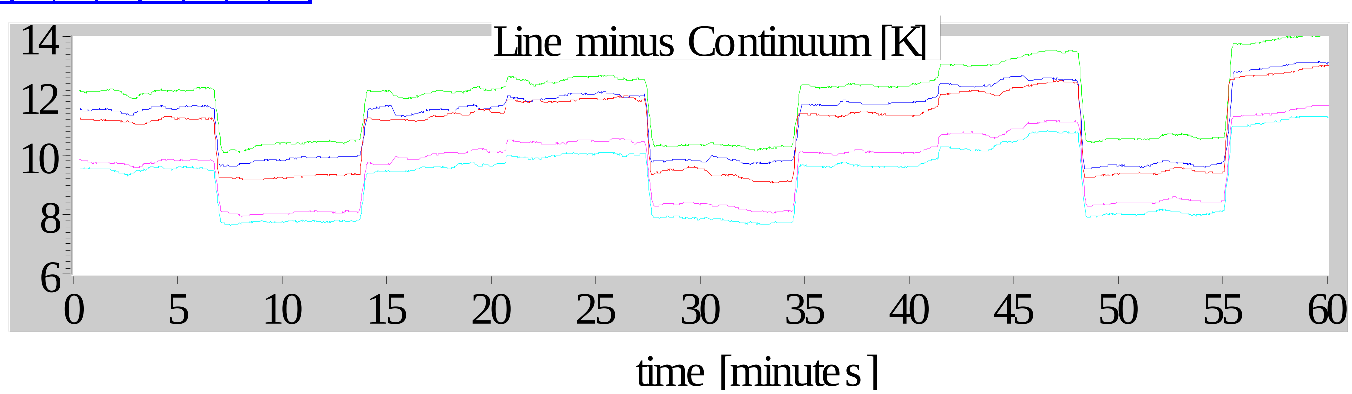
But **connecting the phase from the target to the calibrator requires high accuracy calibration**. The calibrator is at a different elevation angle and with a different amount of water vapor along the line of sight.

Other techniques are not capable measuring the atmospheric delay differences between two sources.

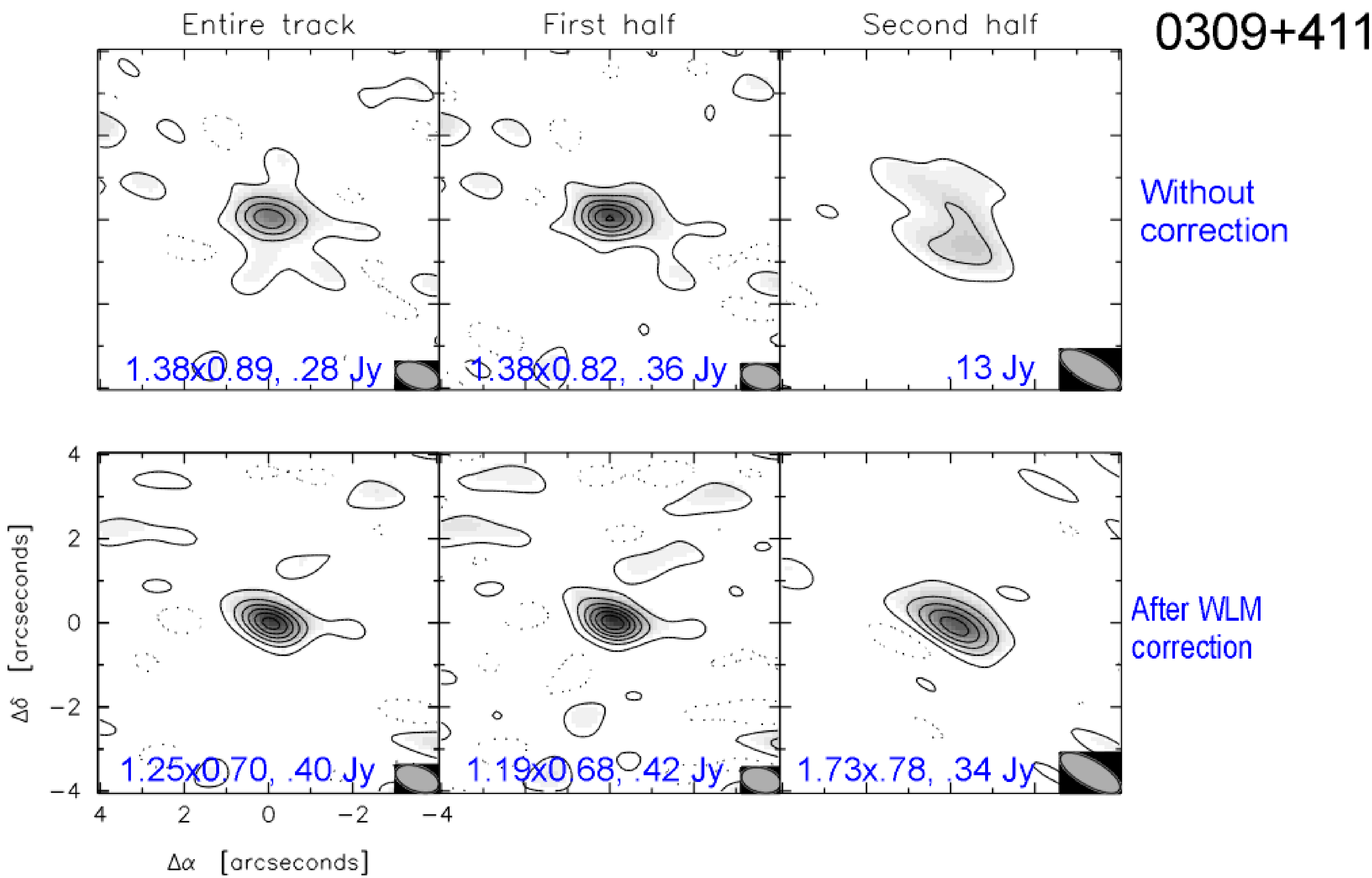
Normalizing WLM gains



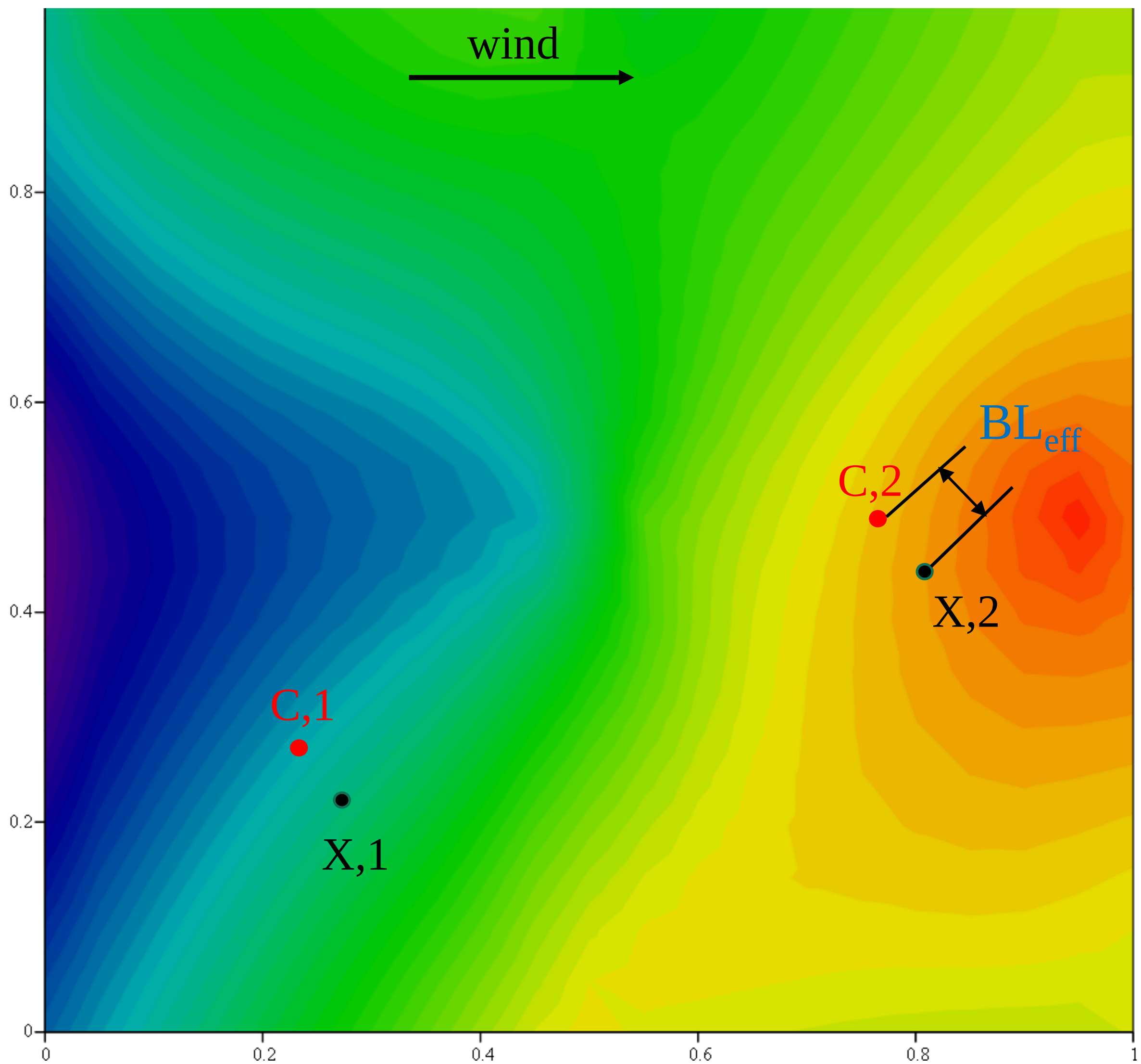




WLM phase correction works



Paired antennas (calibration array)

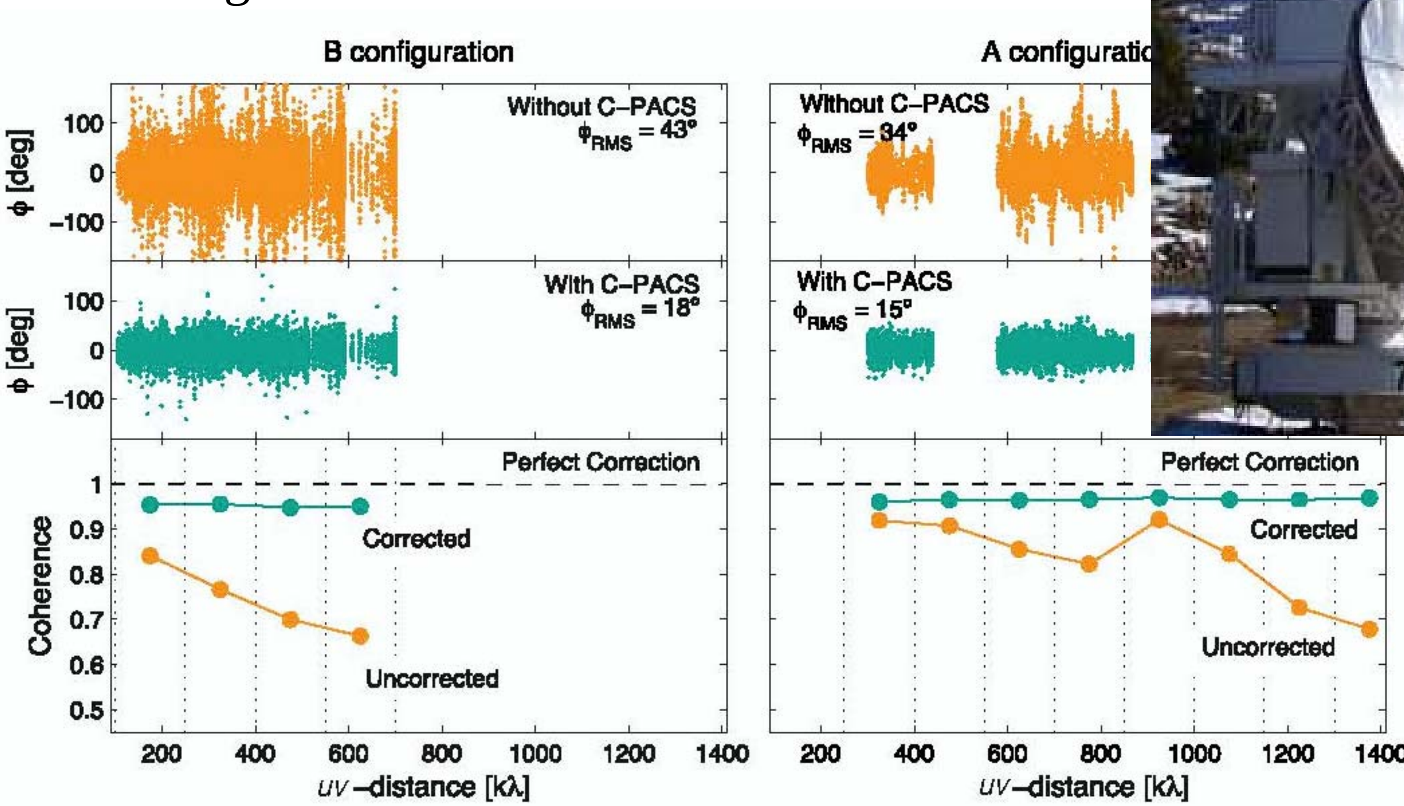


Use a second set of calibration antennas placed near the science antennas to observe the phase calibrator and continuously monitor the atmospheric delay fluctuations. Like perfect fast switching.

C-PACS
(CARMA Paired Antenna Calibration System)

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

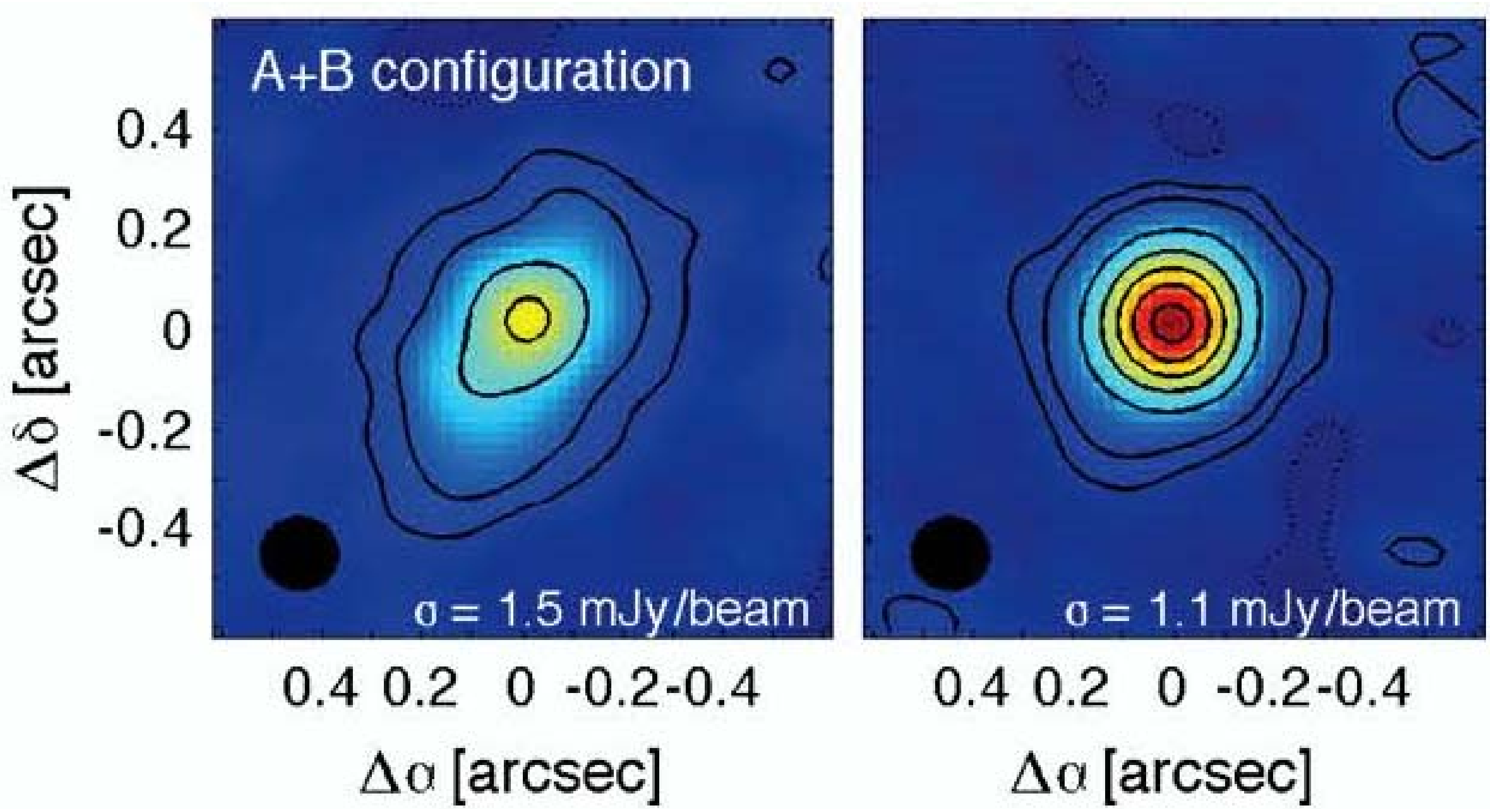
Small antennas observe the phase calibrator at 30 GHz while the larger antennas observe the target source at 230 GHz.



C-PACS worked

227 GHz observations of the
circumstellar disk around
the FU Orionis star PP 13S*

Without P-PACS   With P-PACS



Comparison of techniques

Fast calibration

+ **No new hardware**
+ Normal cal procedures
- Requires fast antennas, 1 deg in a few seconds
- Shorter cal integration time
  => brighter calibrators
  => more distant calibrators
- Limited $Bl_{eff} > \sim 50m$
- **Requires fast antenna, LO and correlator control software**

WVR correction

+ **Can correct the atmospheric delay between the calibrator and the target**
+ Longer cal integrations => closer calibrators
+ Can use slow antennas
- **Extra hardware**
- Need to fit or determine line shape parameters
- Needs high gain stability and accuracy, $\sim 10^{-3}$
- **New software and algorithms**

Calibration array

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

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

C-PACS correlation improvement