Testing the ALMA WVR's on the Submillimeter Array

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the AWVR testing collaboration:

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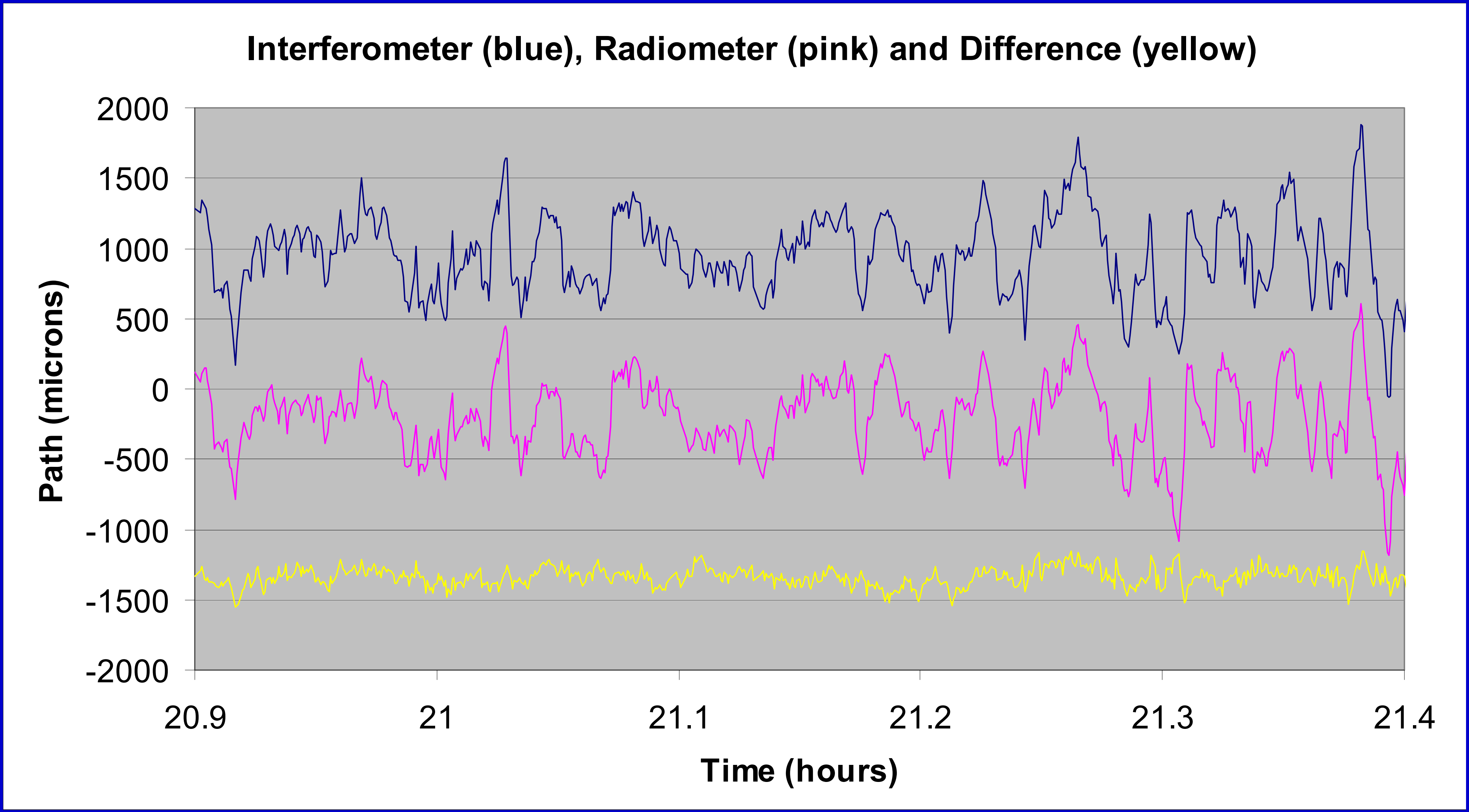
WVR Workshop, Wettzell, Germany, Oct 2006

ALMA radiometers on SMA – it works!



Why is this hard?

- Goal is to measure path fluctuations to ~15 to 50 microns (50 to 160 fs!) for total water vapour of 0.5 to 4mm (~3 to 25 mm of total path), so << 1% of total.
- Essentially making two absolute measurements and then taking the difference.
- So radiometers have to be very sensitive (~ 60mK with 1 second integration) and stable, but also match each other very well in calibration, channel frequencies, coupling to sky…
- Saving grace is that we only need short term fluctuations and values over a small region of sky.

Steps along the way:

- Lab testing: stability, beams, frequency response...
- Side by side tests on Mauna Kea
- Sky dips
- Interferometry:
  - Deglitch
  - Unwrap
  - Sidebands
- Radiometers:
  - Convert brightness temperatures to path
  - Timing, "Tune-up", de-spike.

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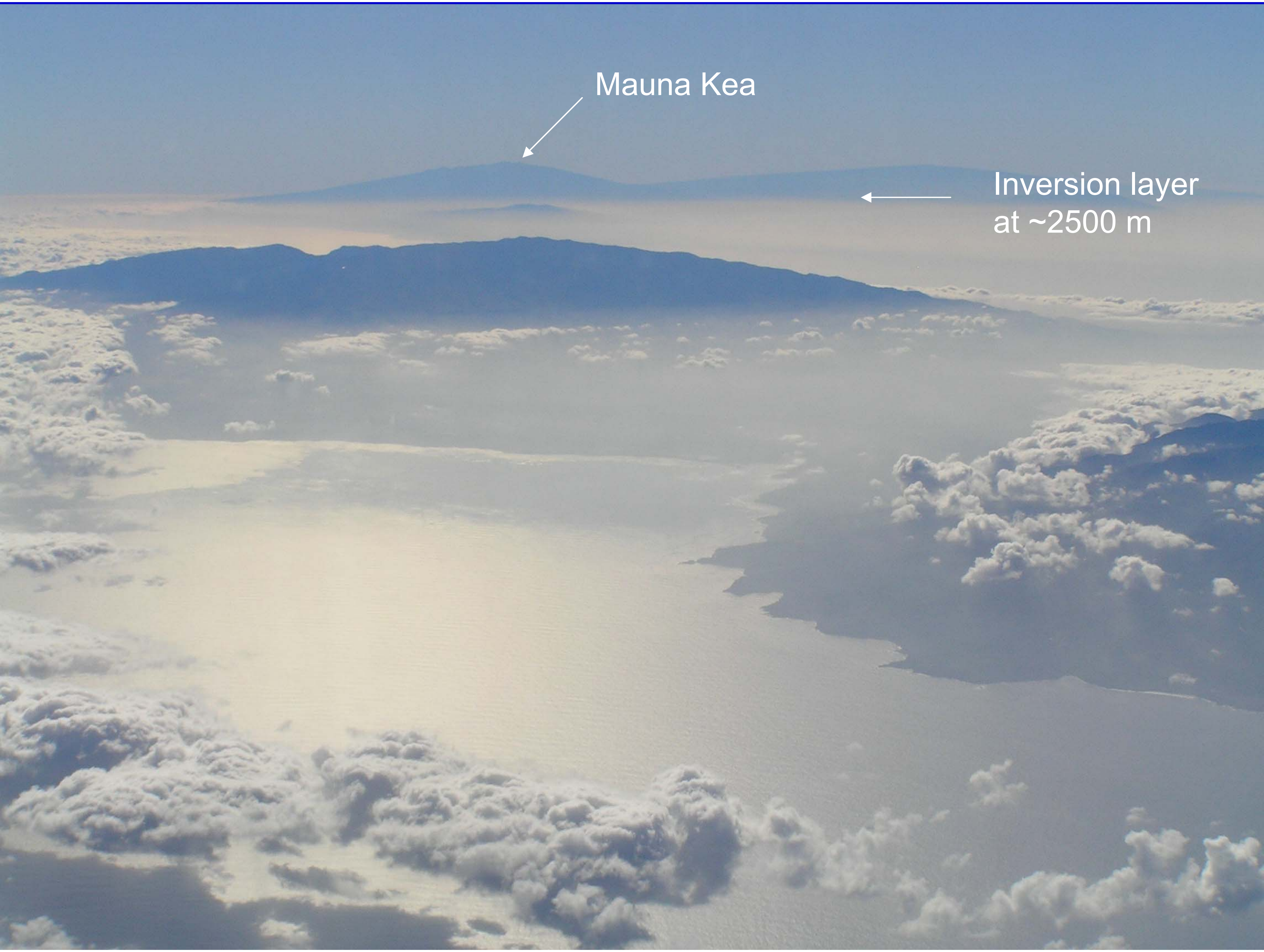
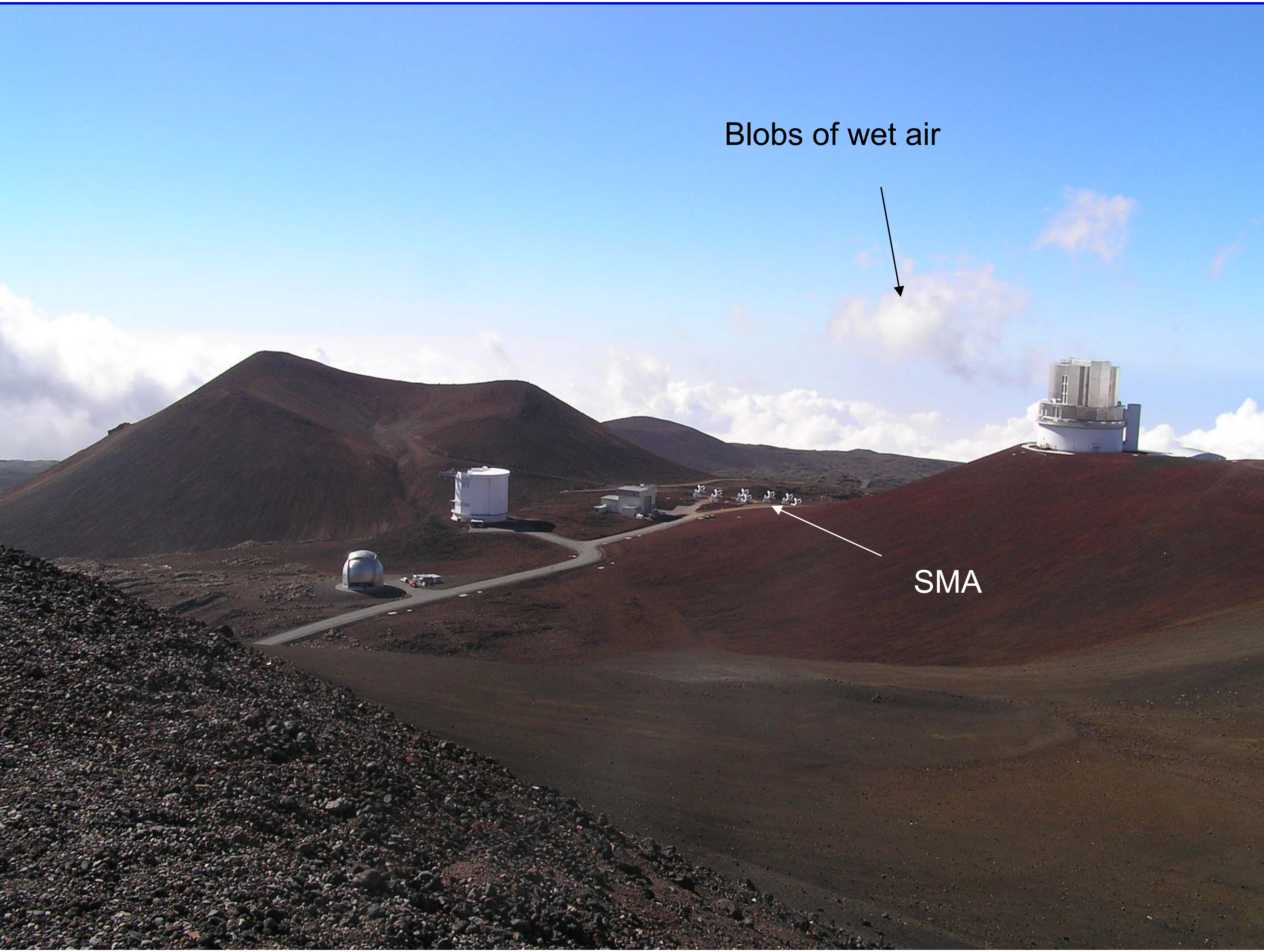
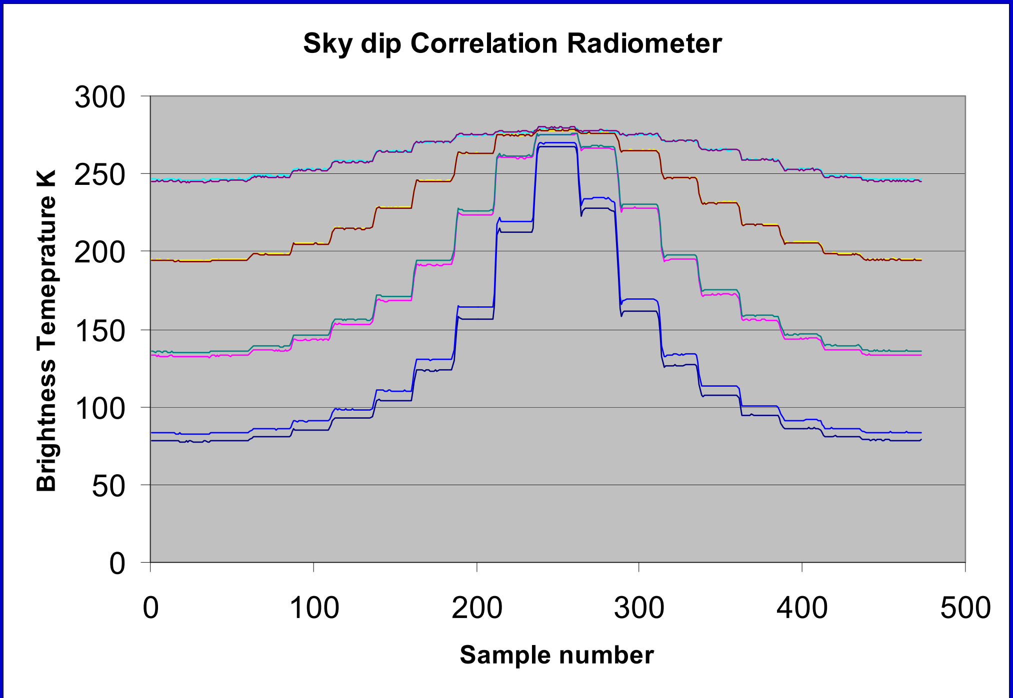
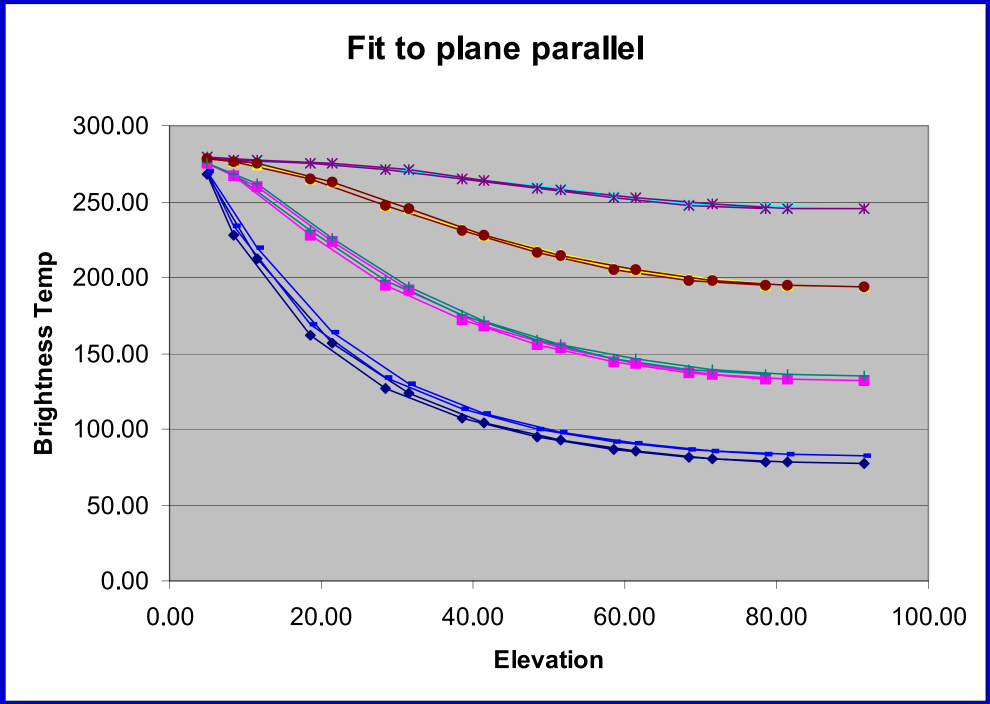

Mauna Kea
Inversion layer
at ~2500 m


Blobs of wet air
SMA

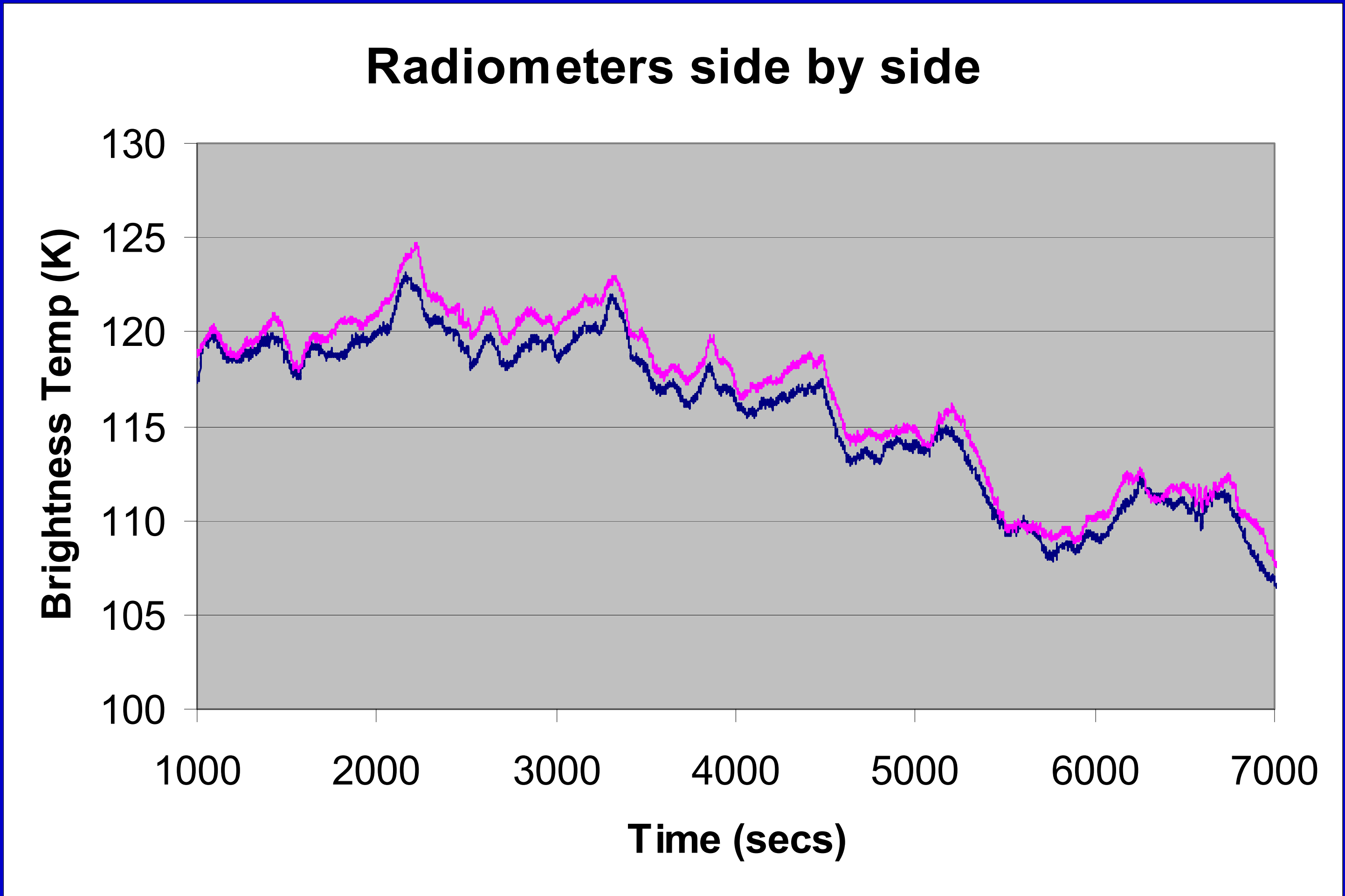
First test Radiometers OFF the antennas

- IF atmosphere is stable can do sky dips to check the calibration, etc. Looked fine.





Compare Radiometers looking at same sky



- Good – not perfect due to different beams?

Then install on telescopes

- Radiometers pick off the beam from the sky by using a polarizing grid plus (lots of) optics – see Ross Williamson's talk at this meeting.
- Need to check losses and spill-over. Use sky dips – find some elevation dependence – see Scott Paine's talk at this meeting.
- Also had to cut out LO leakage into astronomical receivers – additional grid. Some offsets from reflections.

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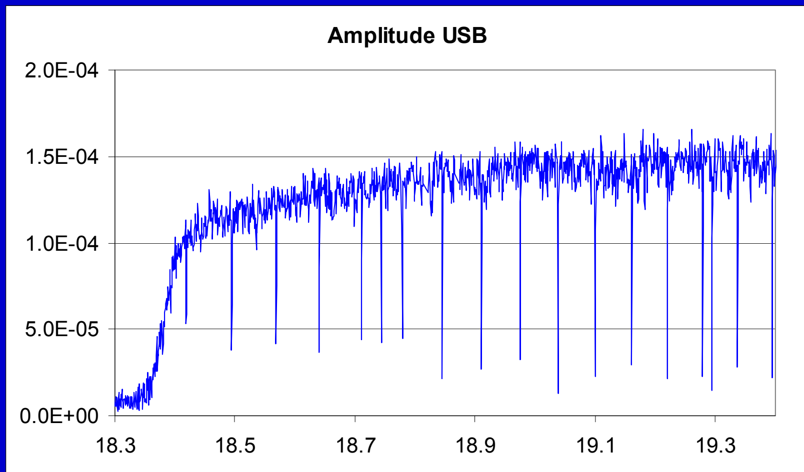
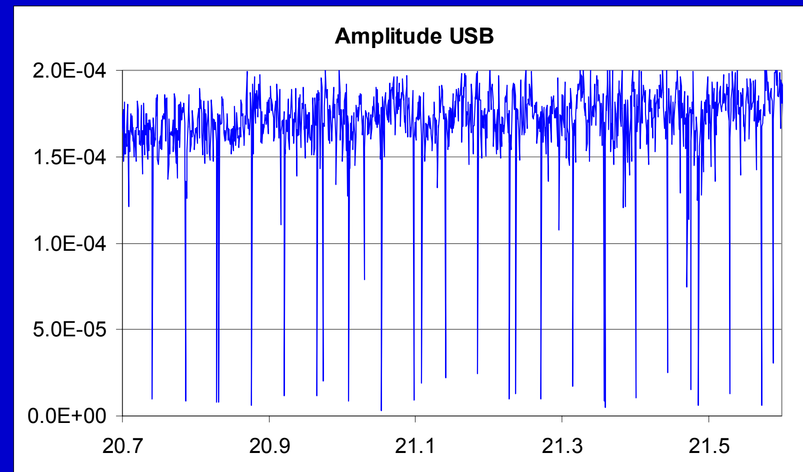
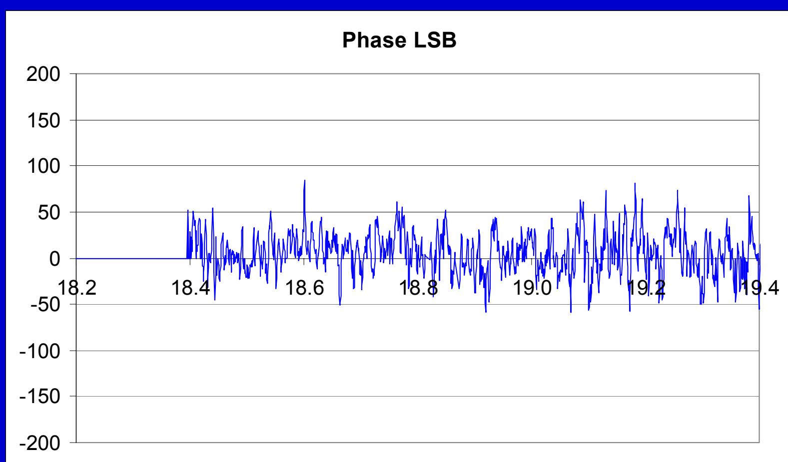
Radiometer

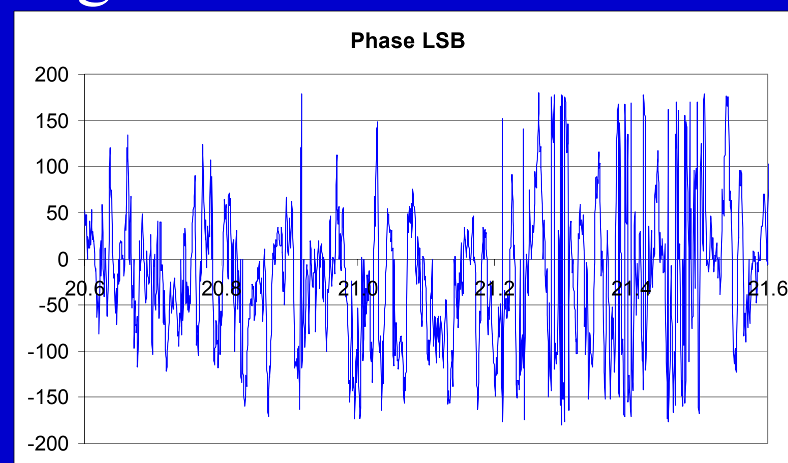
Interferometer Data





Dropouts seen. Theses are caused by reading out every 2.6 secs which is faster than software designed to do. Edit these out.

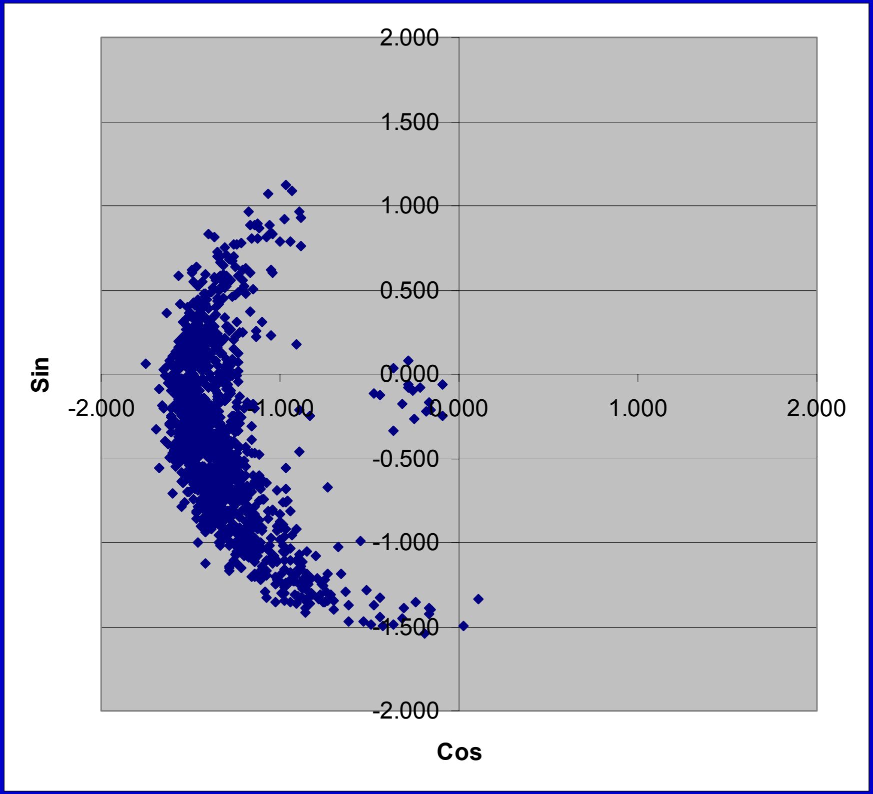


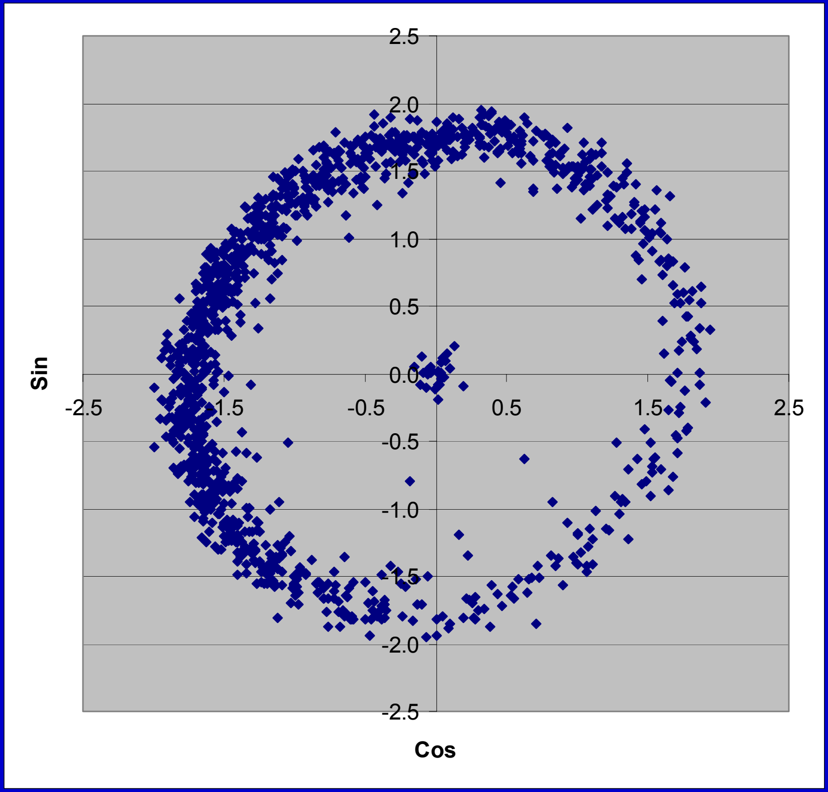


Phase fluctuation > 180 degrees at end

Phase Unwrapping

- Plot Phase and Amplitude as complex quantity

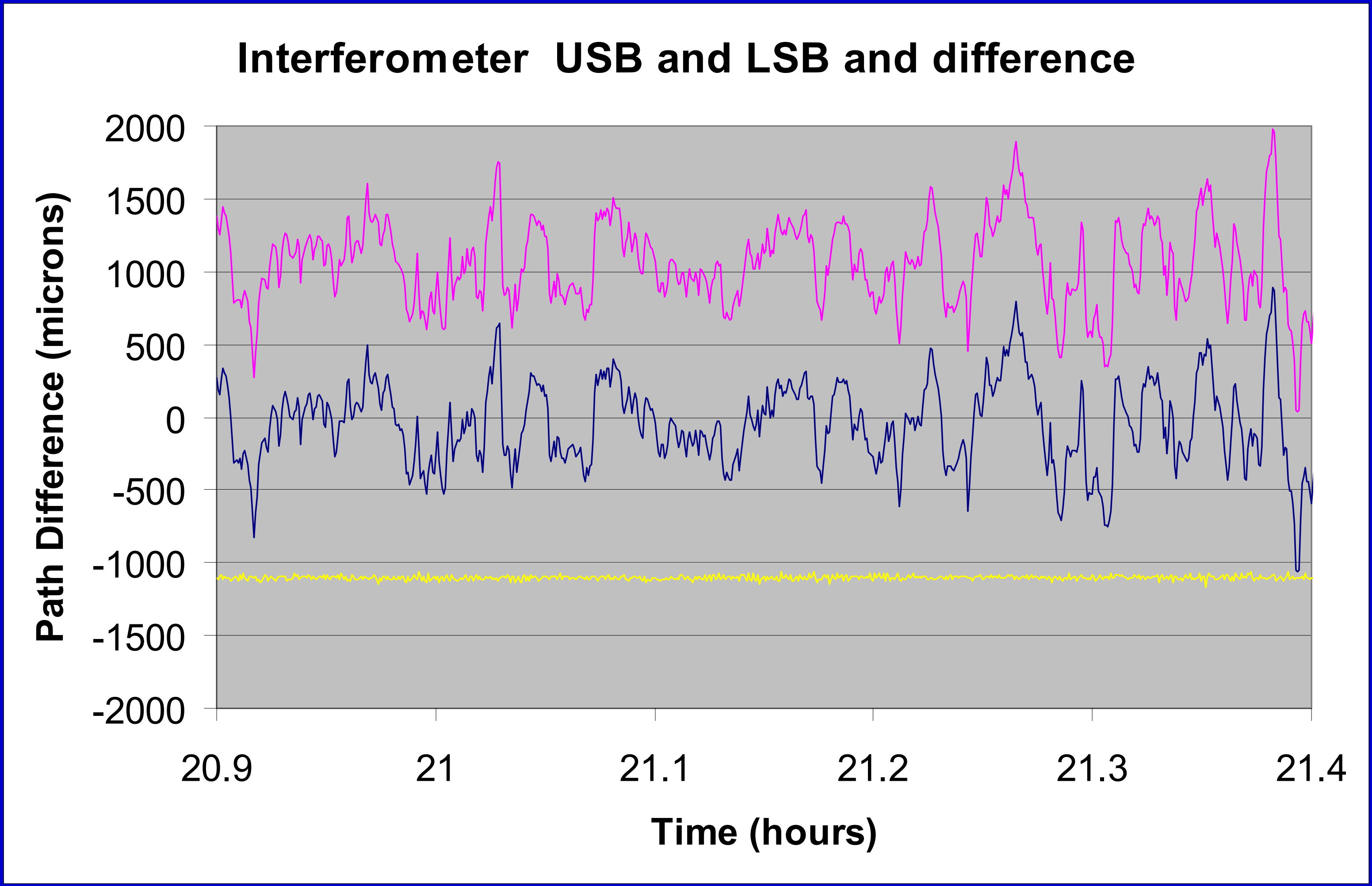




- Join up the dots! Only an issue when phase very bad

Interferometer has 2 independent sidebands

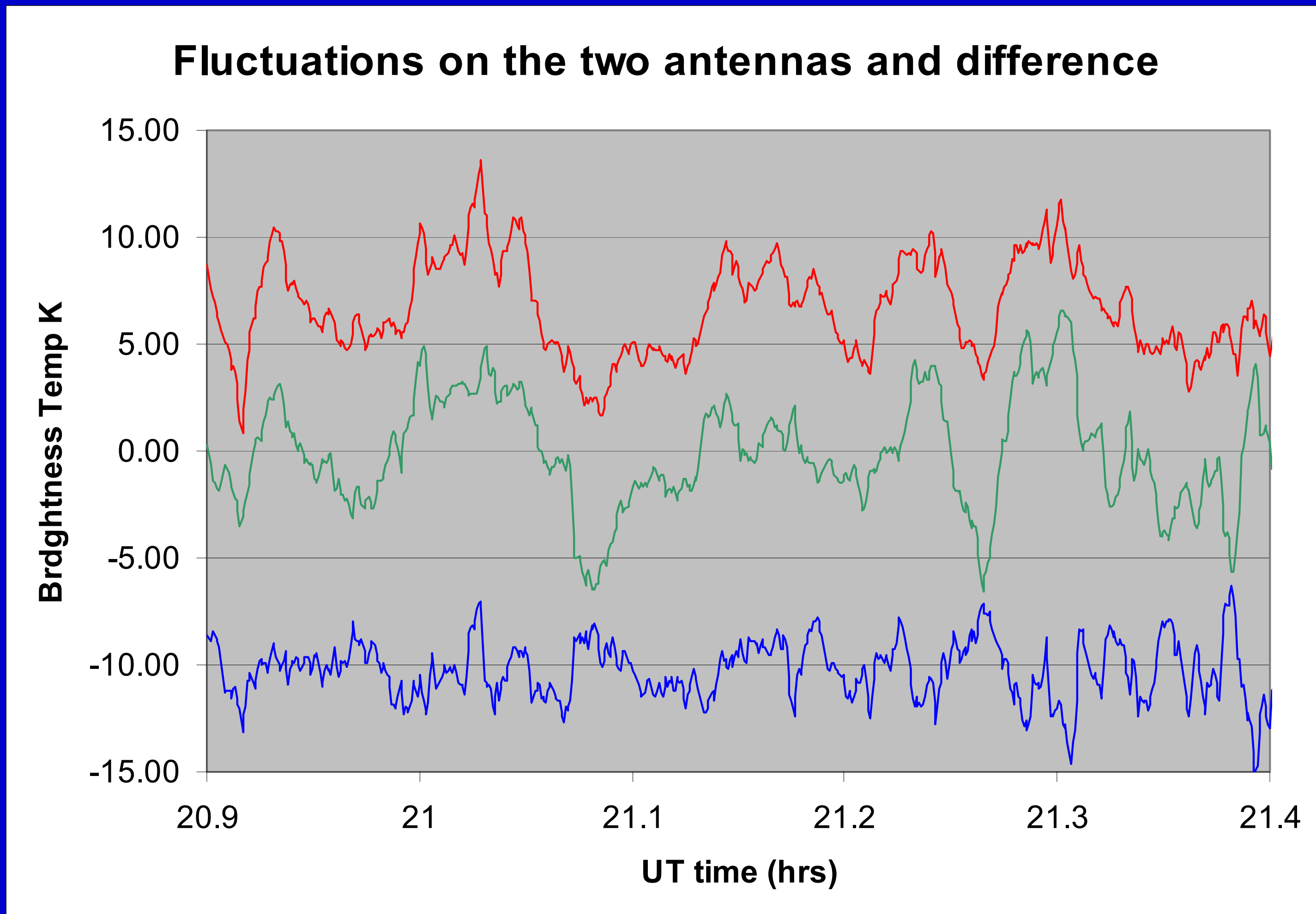
- Convert these to path. Differences indicate noise.



rms 295 microns: difference 15 !

Radiometer Data

- We want the differences between the two radiometers:



Conversion from Brightness Temp to Path

- First option is to fit a simple model to the outputs of the 4 (or 8) temperatures seen in the 4 filters. Possibilities:
  - fit only total water
  - water plus temperature, or
  - 2 layers with some water in each and different temperatures
- Then find path for that model (remember that water-to-path conversion depends on temperature).
- Find that you have to be careful in fitting too many parameters to each individual set of data.

Conversion from Brightness Temp to Path 2

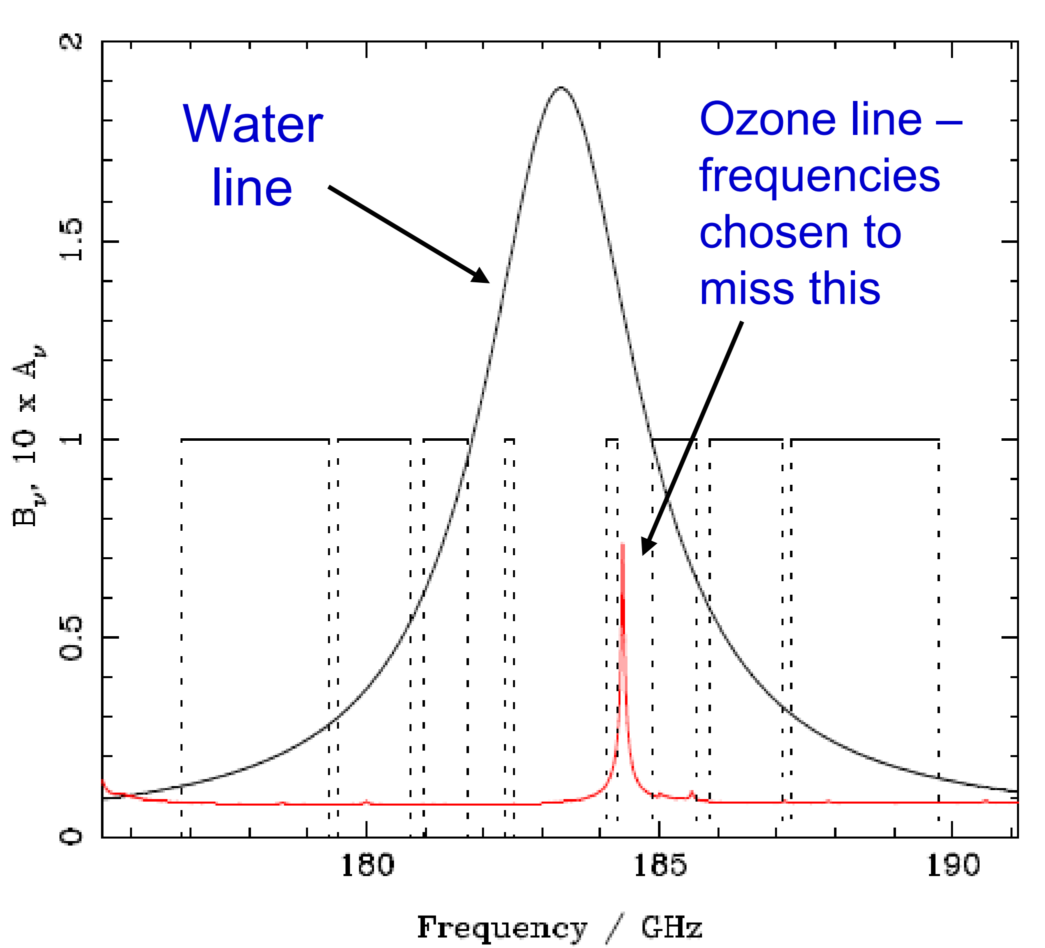
- Simplified approach:

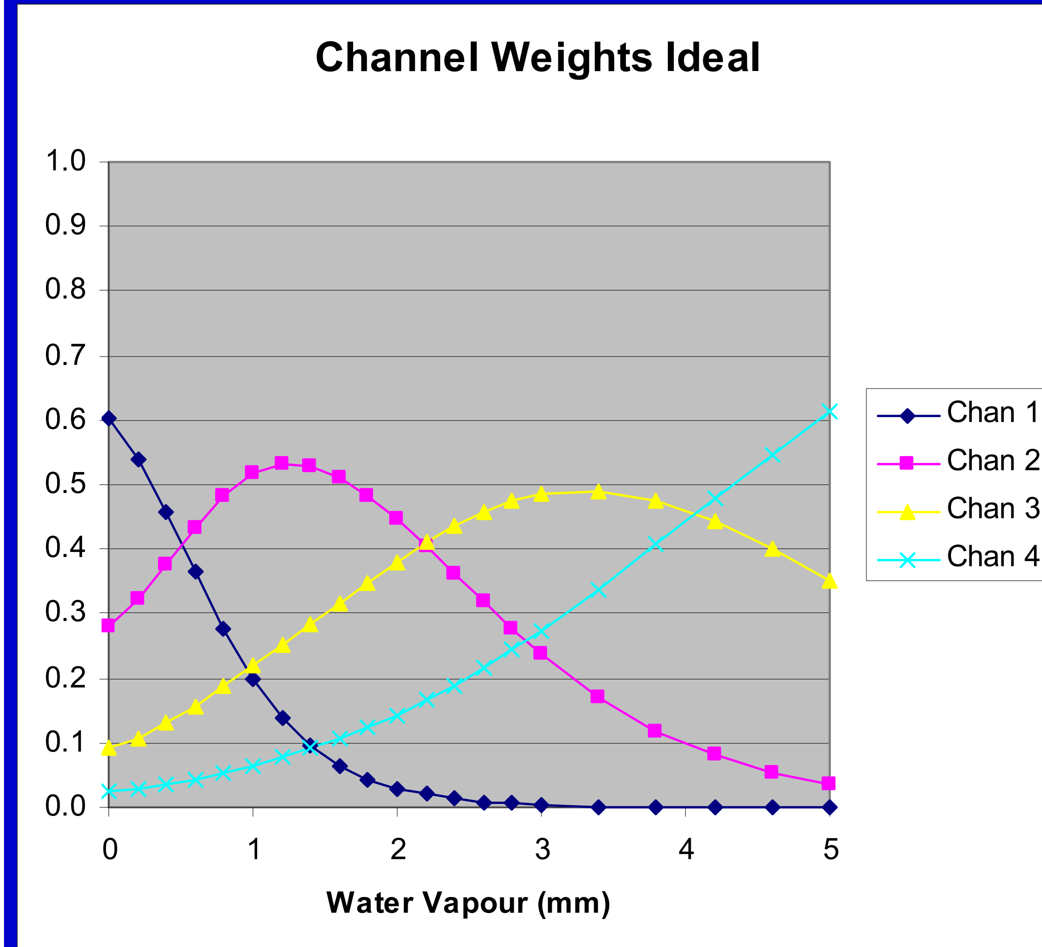
  $T_b = T_{atm}\,(1 - e^{-\tau})\,, \quad \tau \sim E\,w \quad$ and $\quad p \sim R\,w$

  where w is the amount of water and p the path, E is the emissivity and R is the refractivity
- For fluctuations this leads to $\Delta T_b = E\,(T_{atm} - T_b)\,\Delta w$

  and so $\Delta p = R\,\Delta T_b\,/\,E\,(T_{atm} - T_b)$
- Do this for each channel individually to give 4 estimates of the path fluctuation. Take weighted mean taking account of sensitivity and noise.

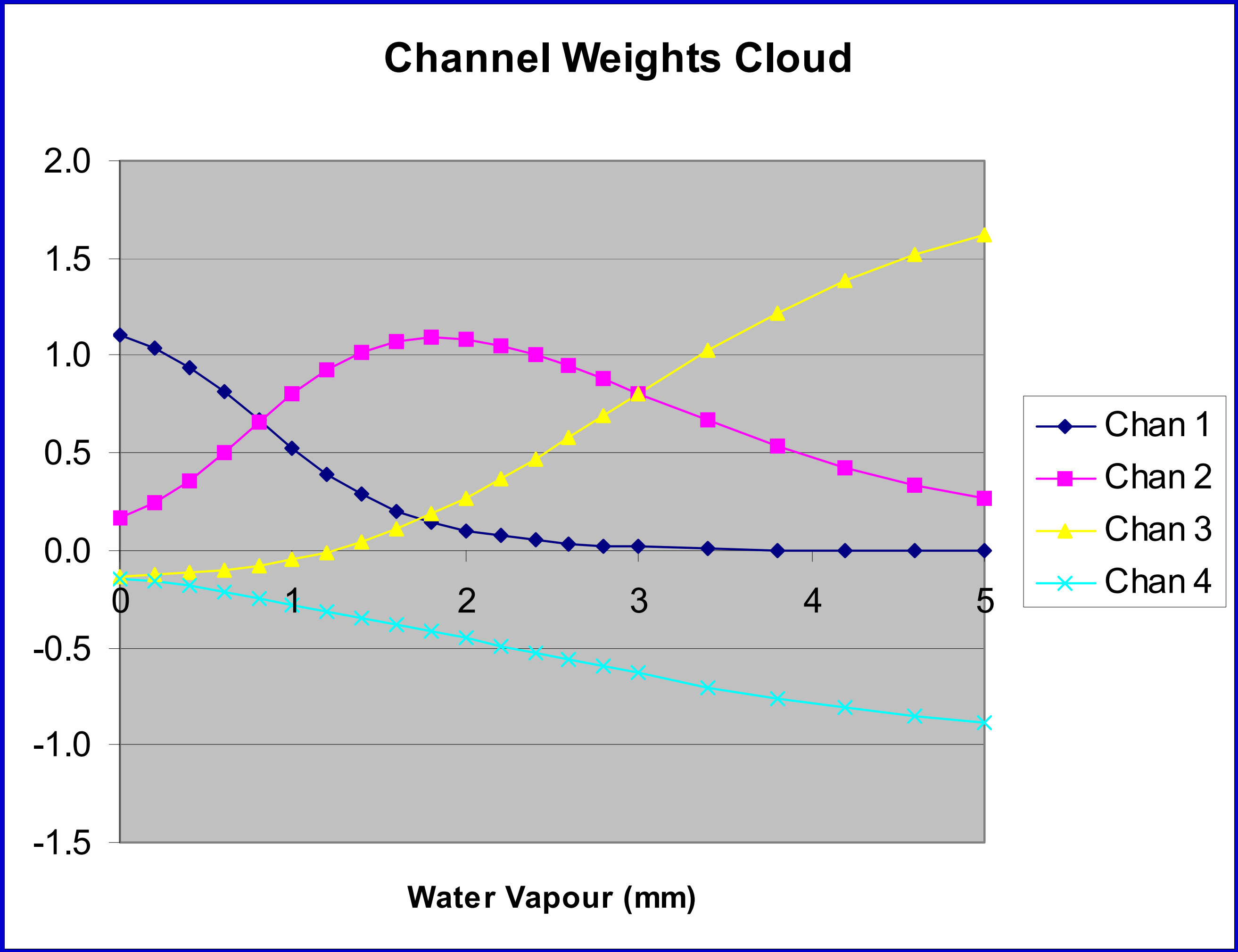
Weights for the channels





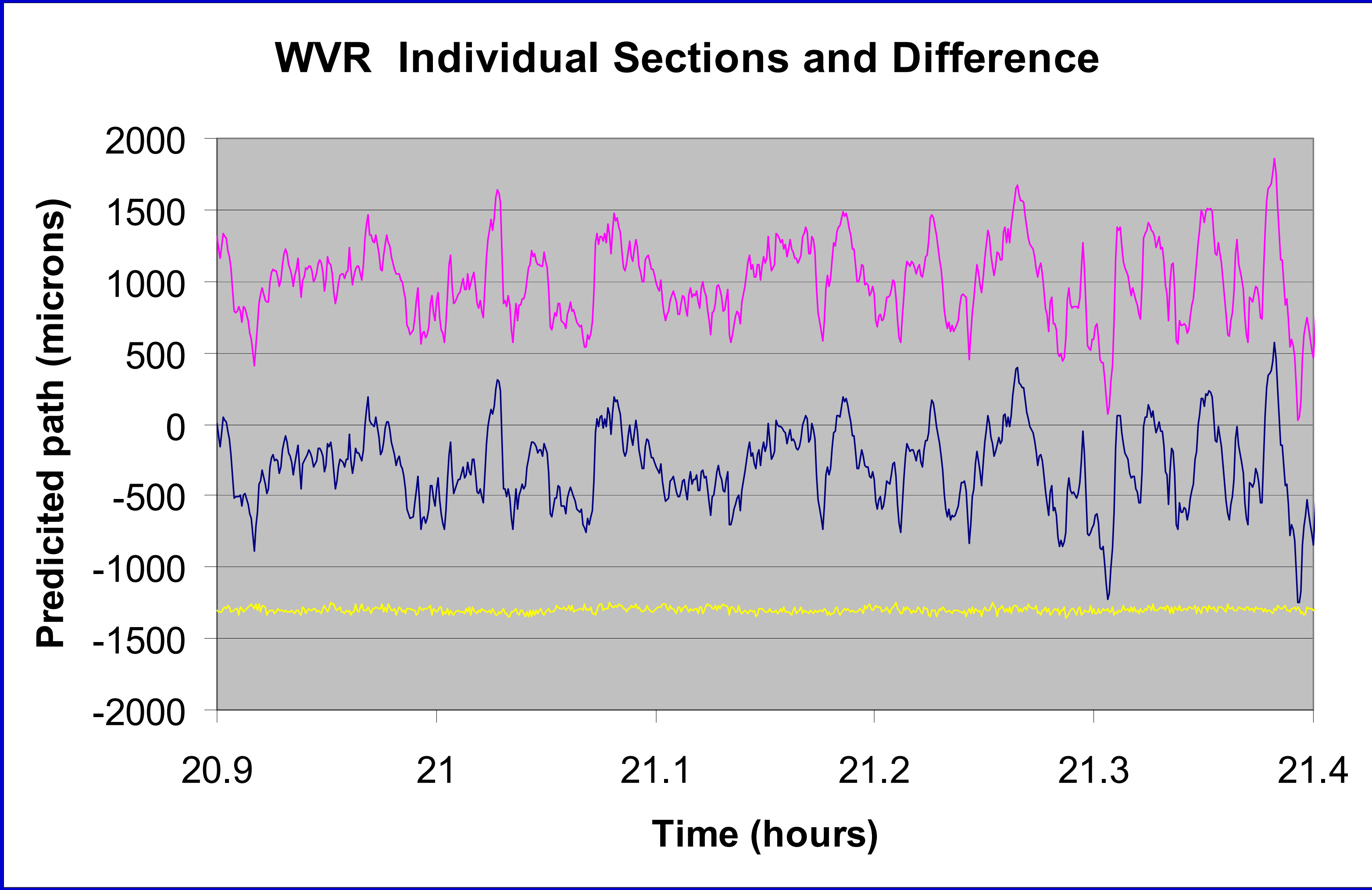
Can discriminate against thin cloud

- Effectively taking difference on and off the line
- Some sacrifice of sensitivity in doing this



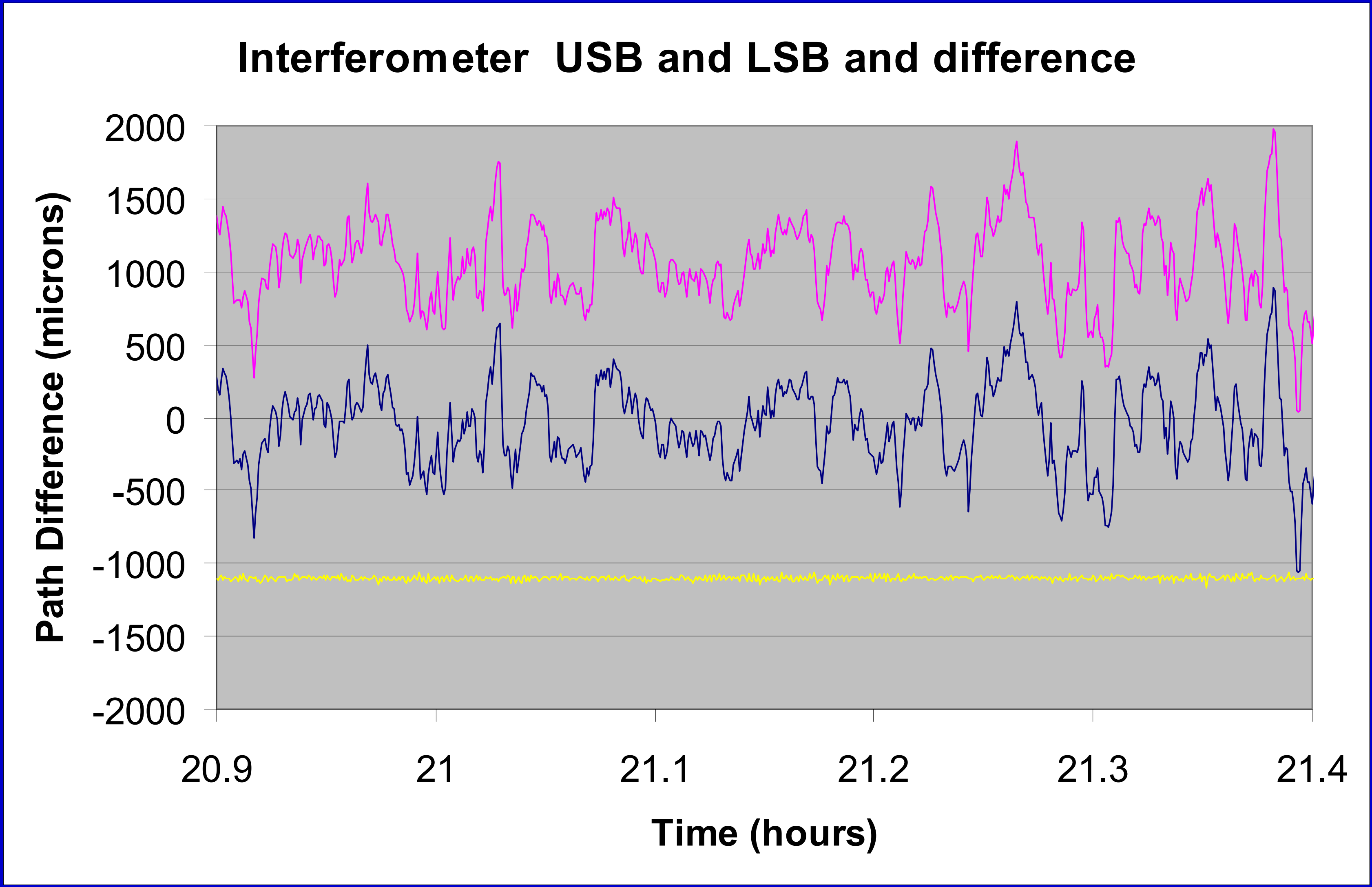
Noise level of Radiometers

- Each radiometer has 2 sets of 4 channels – reduce independently:



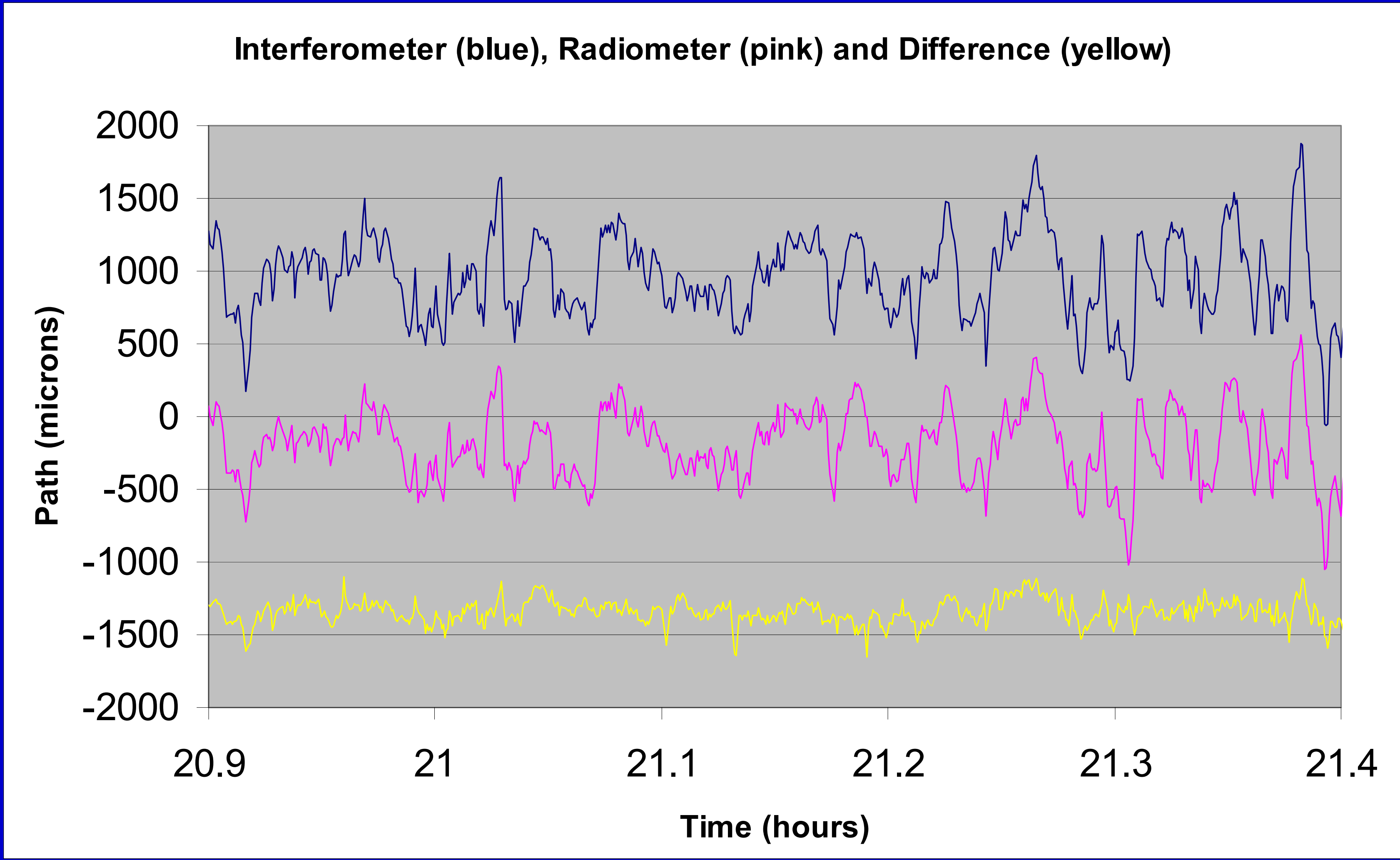
rms 283 microns: difference 19!

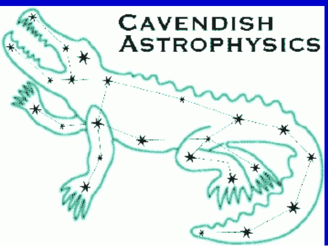
Remember what we had from the Interferometer



rms 295 microns: difference 15 !

So now put these together

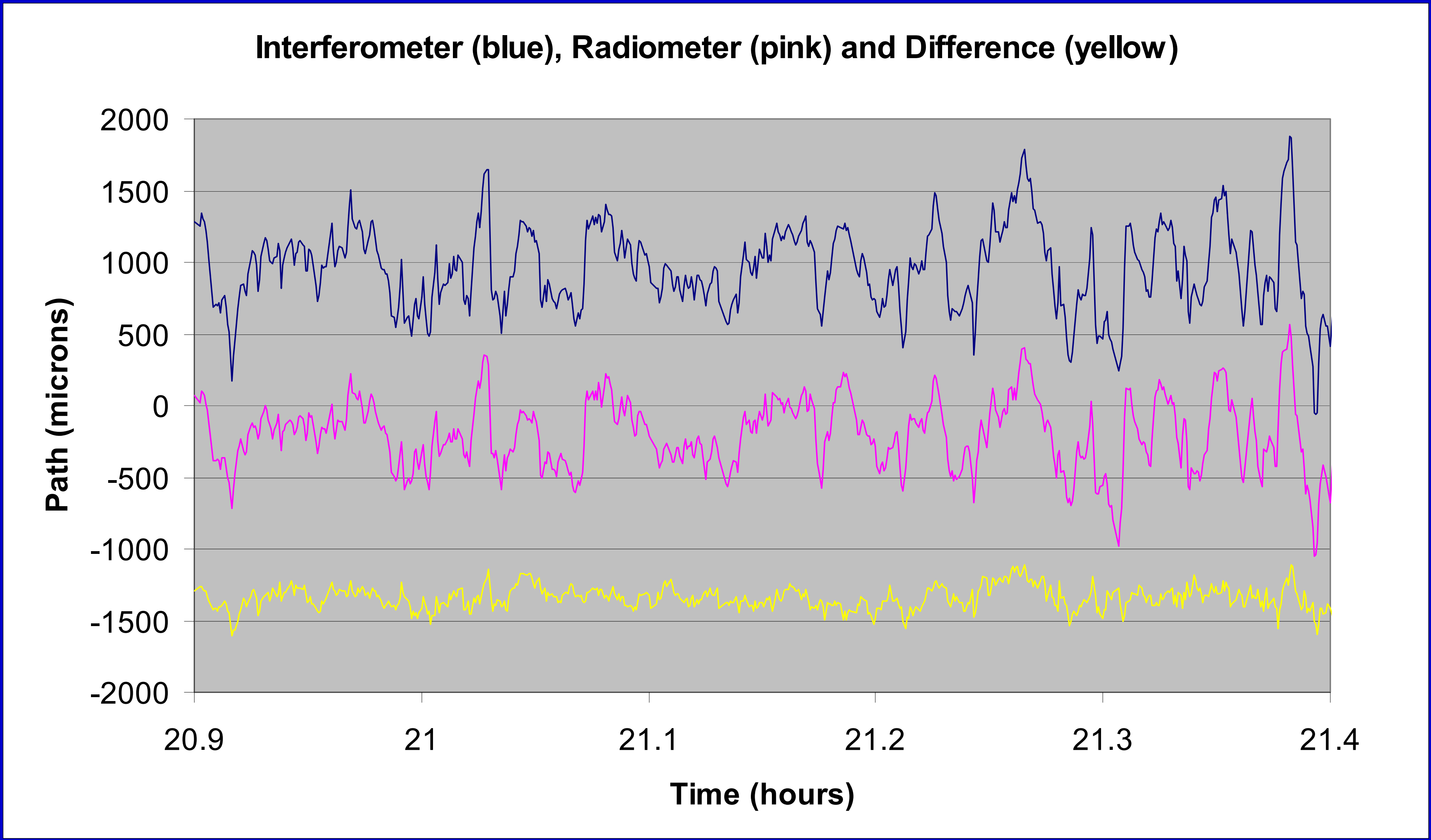




rms of residual 82 microns

WVR Workshop, Wettzell, Germany, Oct 2006

Remove samples taken during Calibrations



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rms of residual 78 microns

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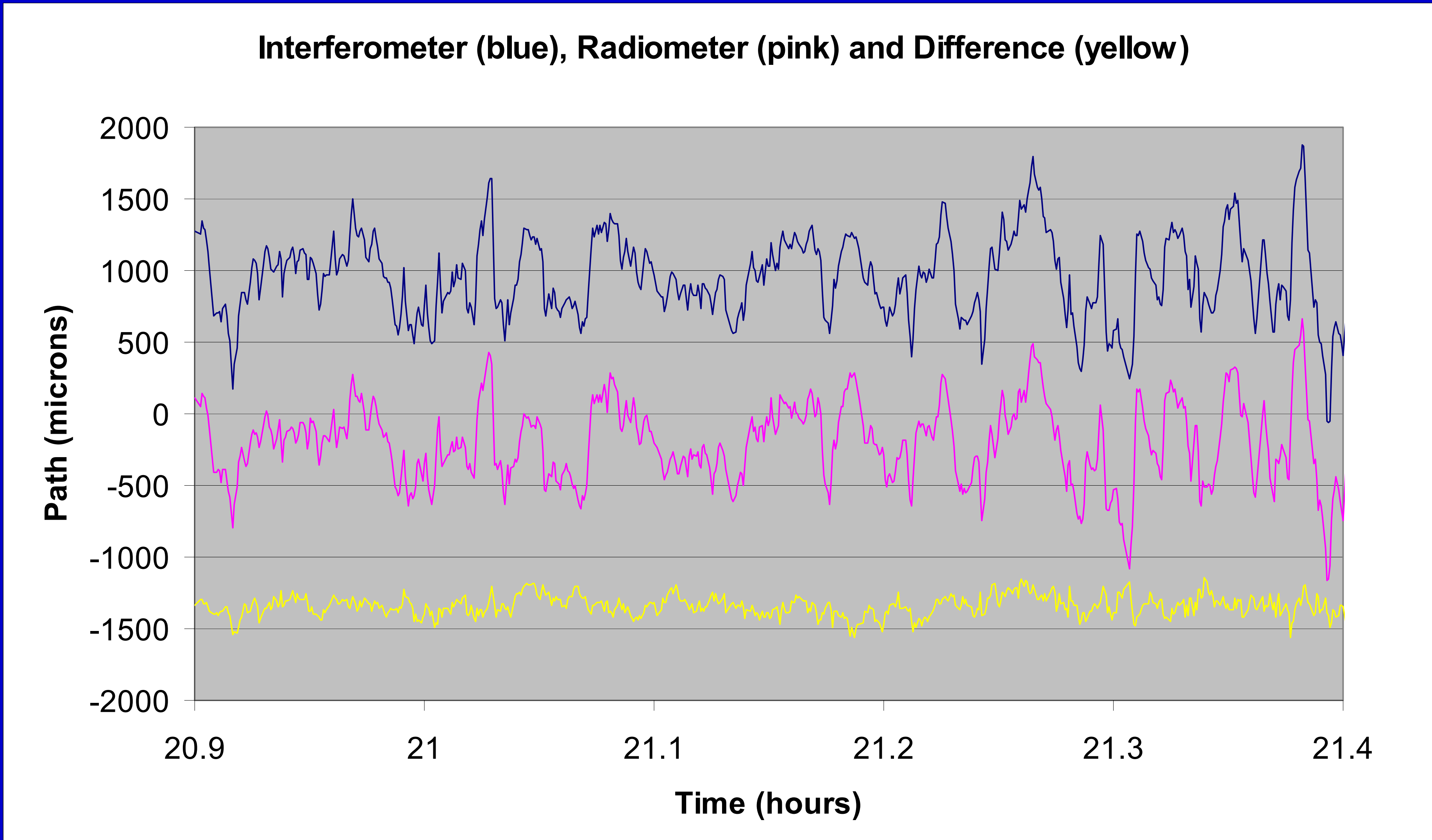
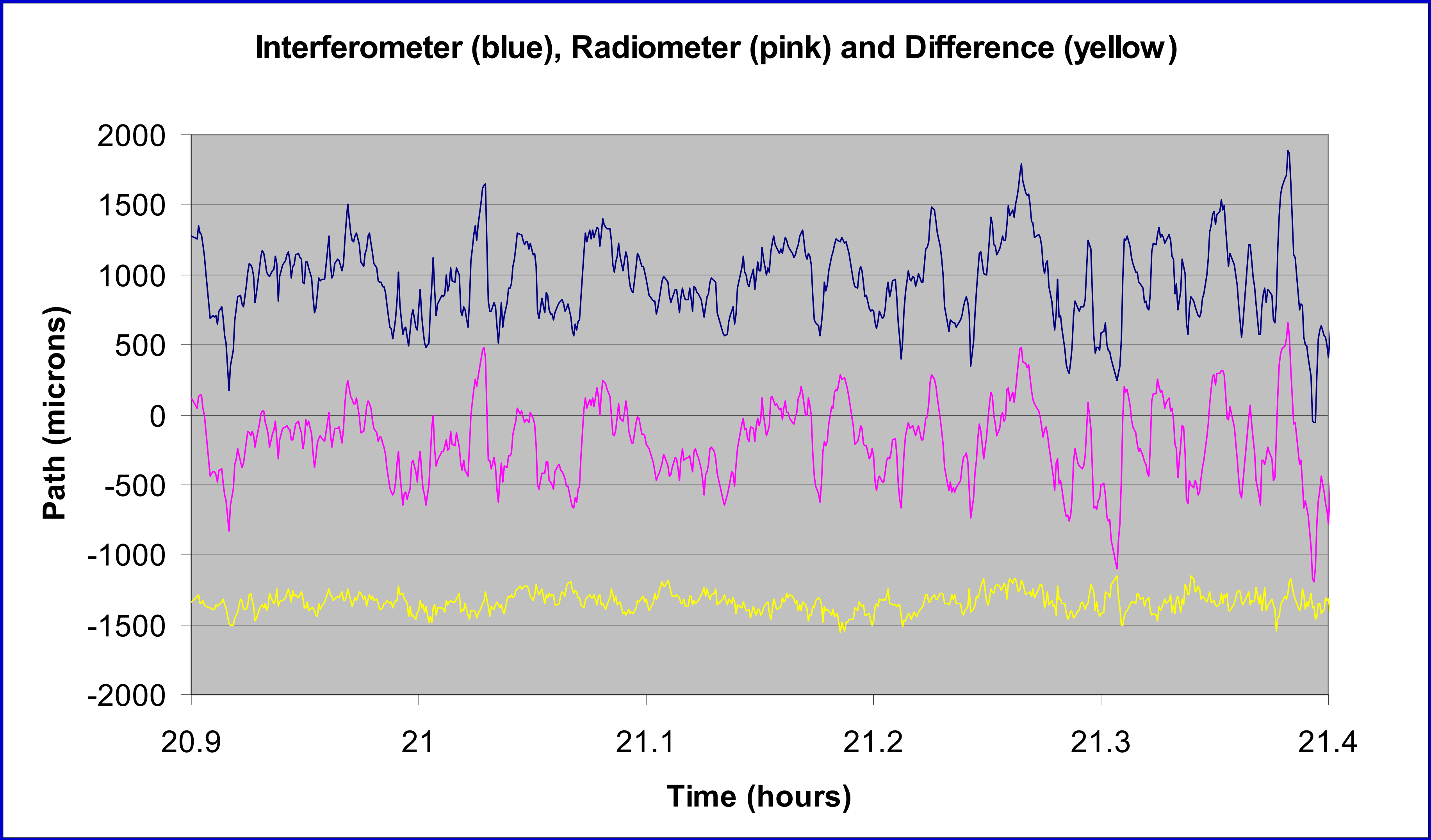
Adjust Scale Factor to optimum – 1.13



rms of residual 70 microns

Optimum weights instead of model



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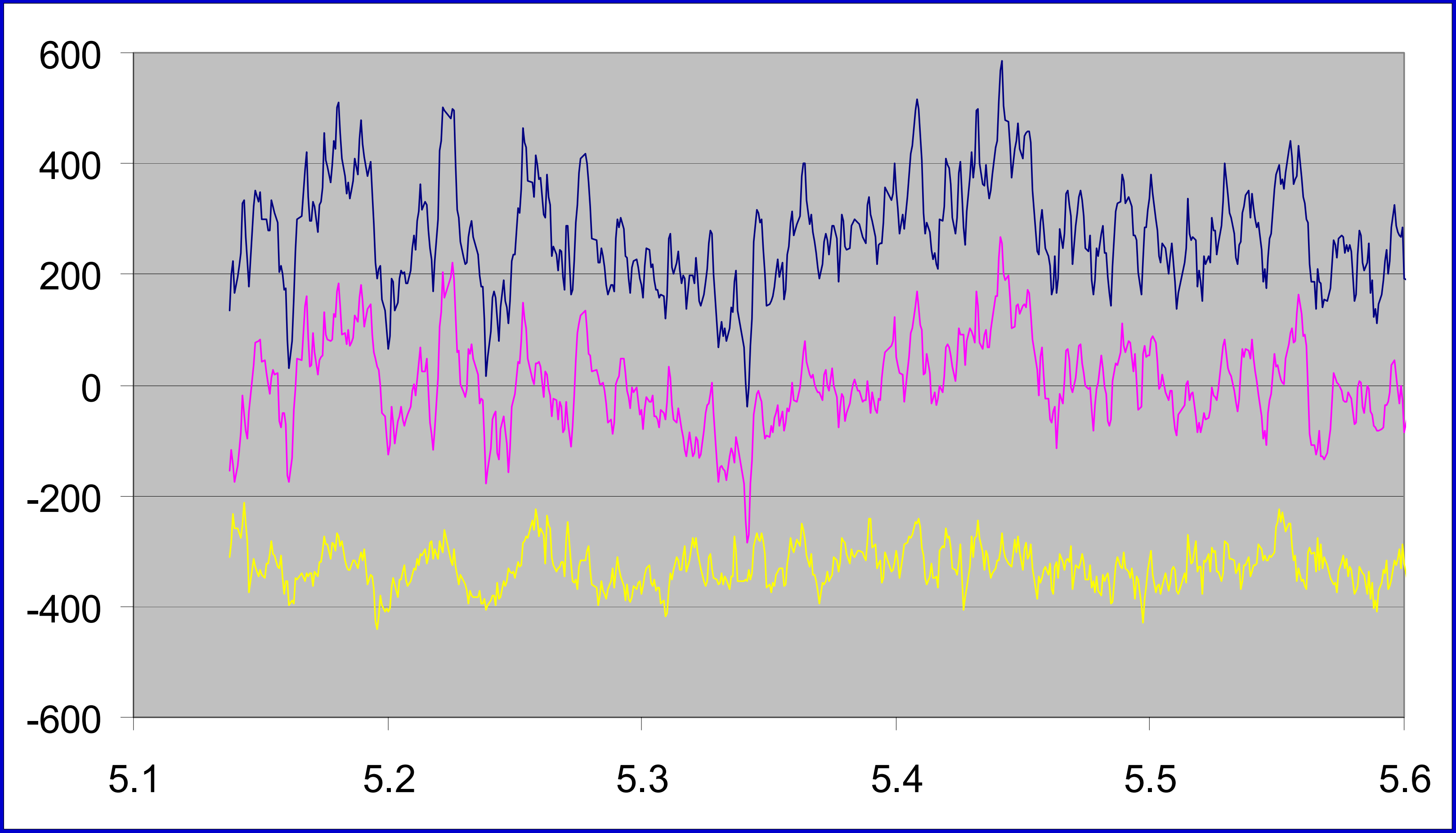
rms of residual 69 microns

So why don't we do better?

- NOT noise
- Instrumental effects in Interferometer – not at this level
- Instrumental effects in Radiometer – can't think what
- Single temperature assumption – need to check
- Mismatch of WVR and Interferometer beams – perhaps
- Uncorrelated dry component – seems most plausible
- <u>But still doing pretty well.</u> Coherence in this data at 1.3mm observing wavelength goes from ~14% to ~90%!

Another Example – Evening

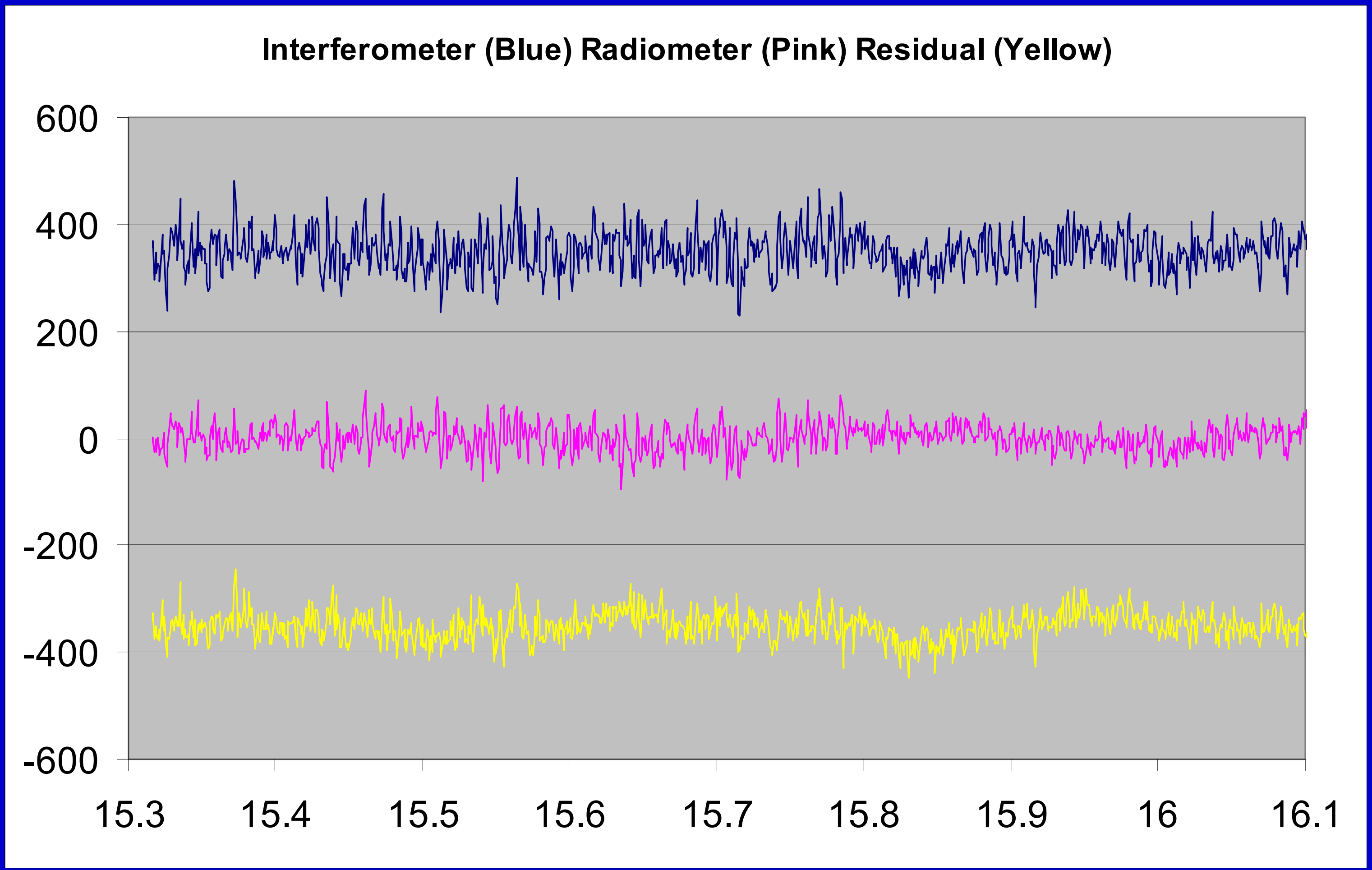
- Here total rms = 83 microns   residual = 27 microns



noise contribution ~ 12 microns

Very stable conditions – Night-time

- Total path rms 37 microns, residual 27, noise ~15



Clear excess noise on Interferometer

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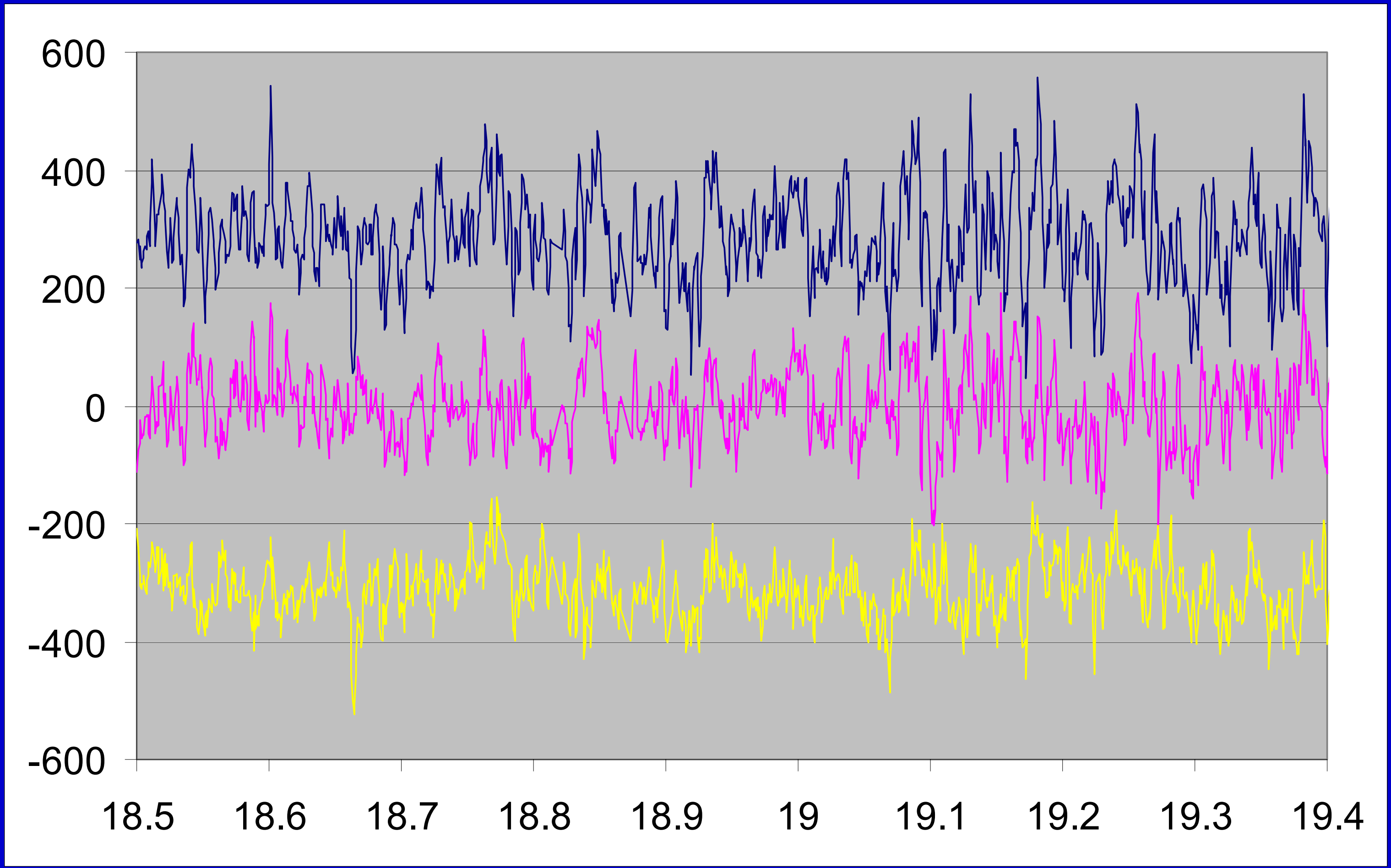
Thin Cloud Passing Over

- Total path fluct 80 microns, residual 49, noise ~ 14



Some question whether this is all sky

Conclusions

- Correction is meeting the ALMA specifications under good conditions. It should do better when various interferometer problems have been fixed.
- Factor of ~4 reduction in phase variations seems to be about the best we can do so far. (But this is a factor ~16 reduction in the amount of de-correlation loss).
- When wet clouds are present we definitely do less well.
- Hope (!) that ice clouds are less of a problem.
- Key question outstanding is whether we can “carry” the wvr correction from a source to a nearby reference.