Atmospheric Delay Correction

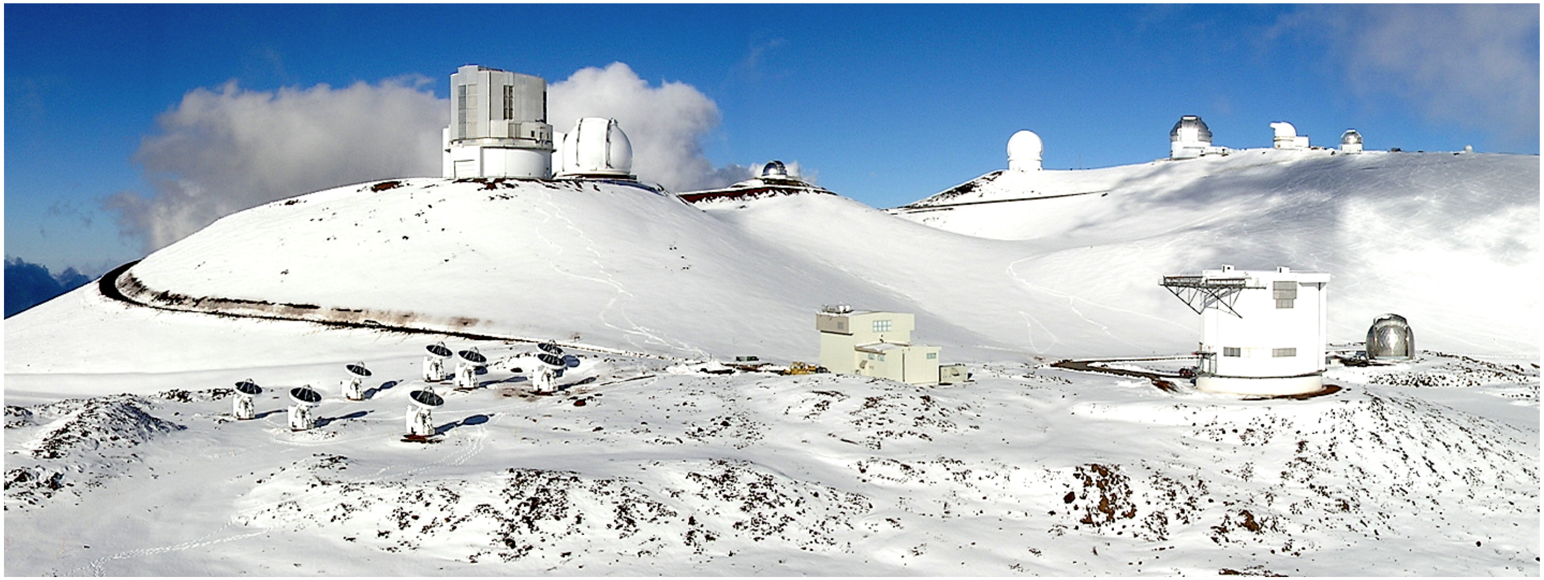
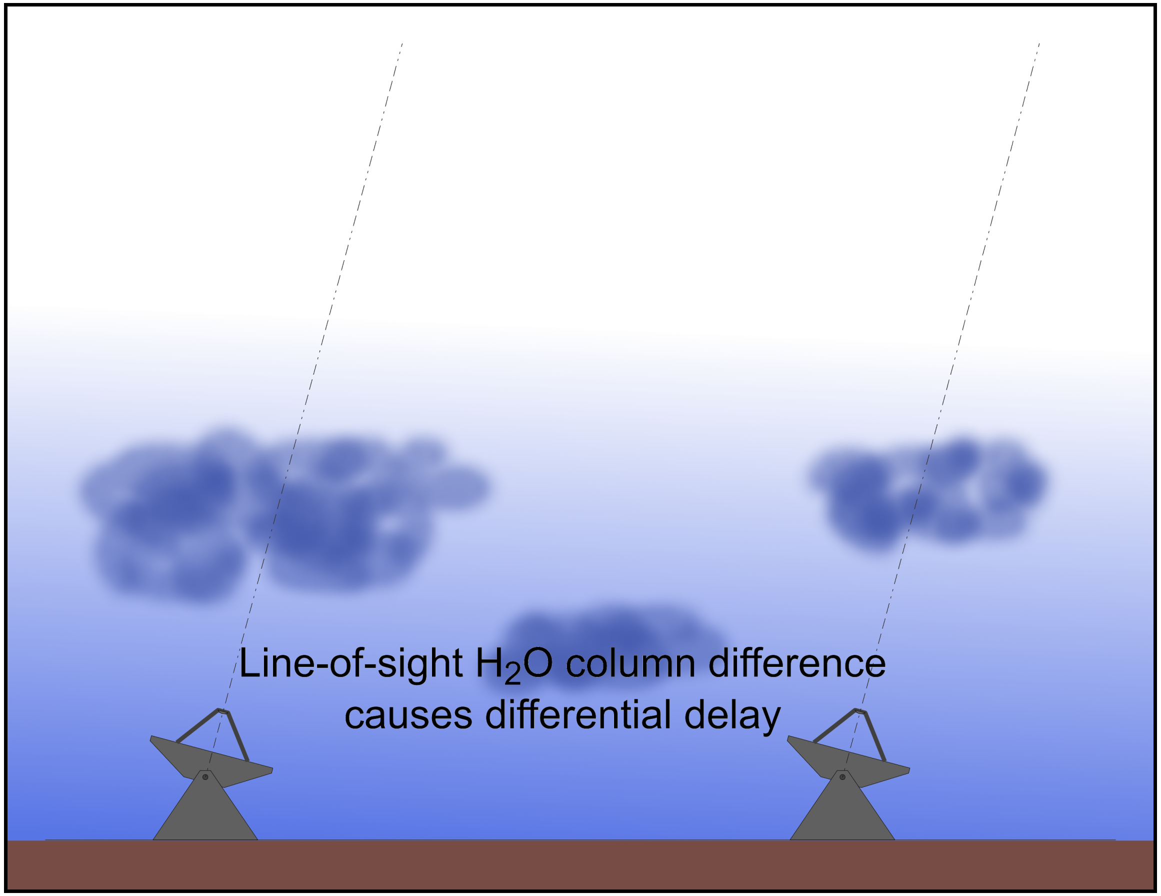


photo: Paul Yamaguchi

- Mitigating wet path delay via O_3 radiometry
- SMA cabin spectrometers
- Optics, calibration, and receiver issues
- Current status

SMA Advisory Committee – 2010 Oct 12
S. Paine

The wet path delay problem

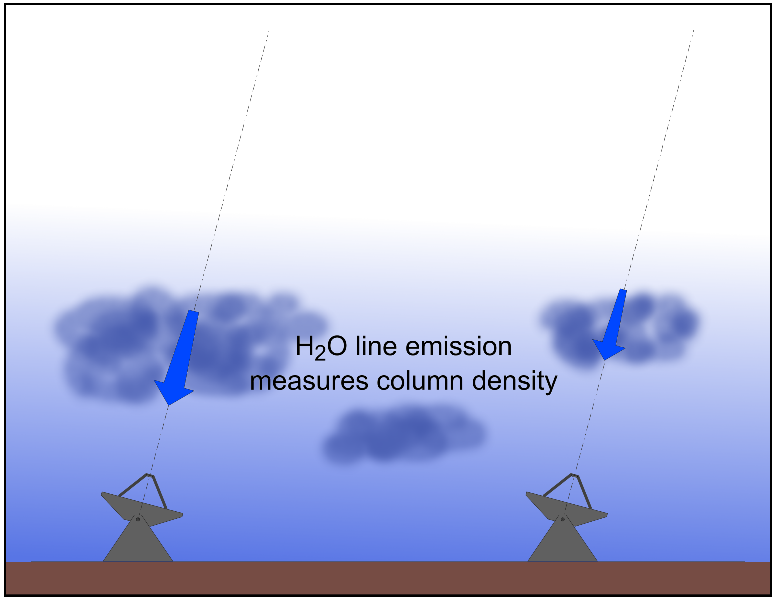


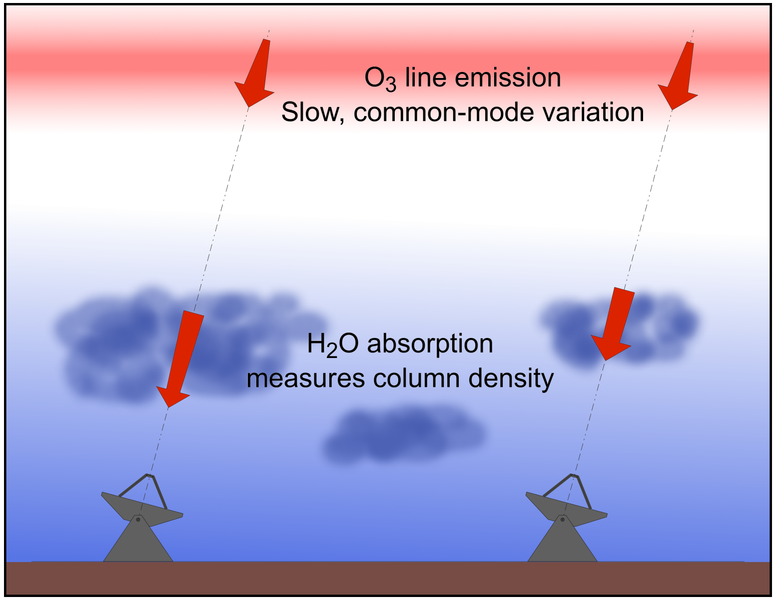
Example: At 690 GHz (435 μm), the excess path is 6.8 · PWV, leading to complete loss of coherence for line-of-sight PWV differences of ~50 μm

Mitigating wet path delay

- Atmospheric radiometry
  - 22 GHz / 183 GHz line (IRAM / ALMA)
  - H_2O continuum
  - Ozone line (SMA, in development)
- Astronomical reference source
  - Fast switching (ALMA)
  - Paired antennas (CARMA)

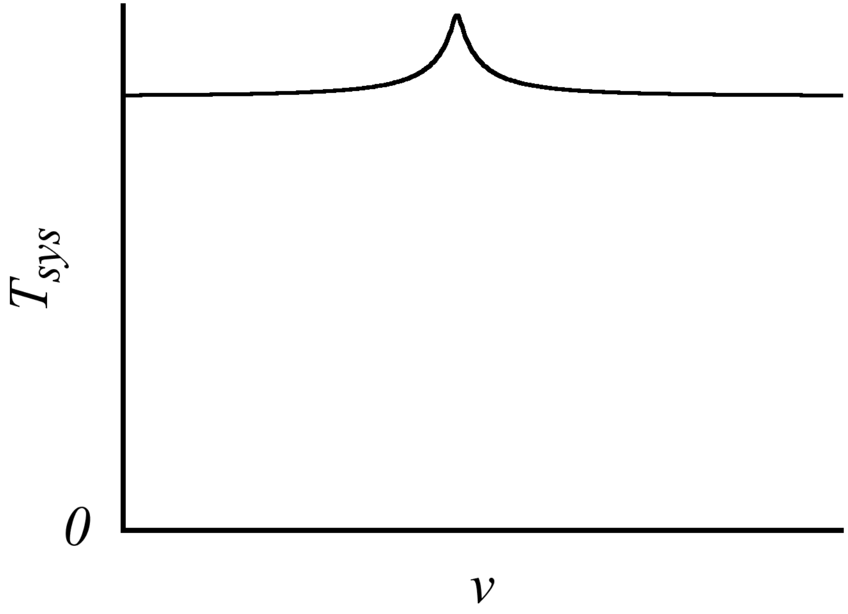
Measuring H_2O with O_3

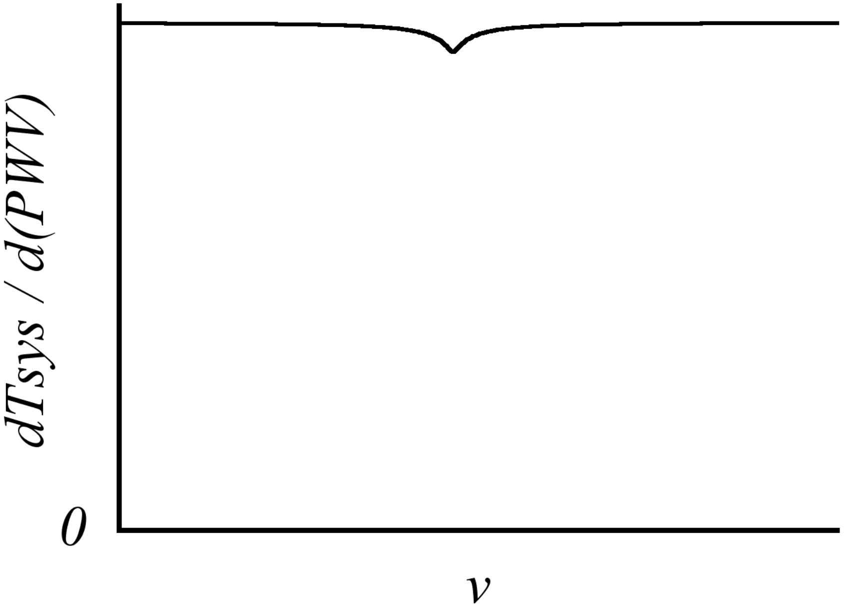




- Continuum absorption by H_2O in the troposphere attenuates O_3 line emission.
- Measure changes in attenuation with the active astronomical receiver.
- O_3 variations are slow, and common-mode over array.

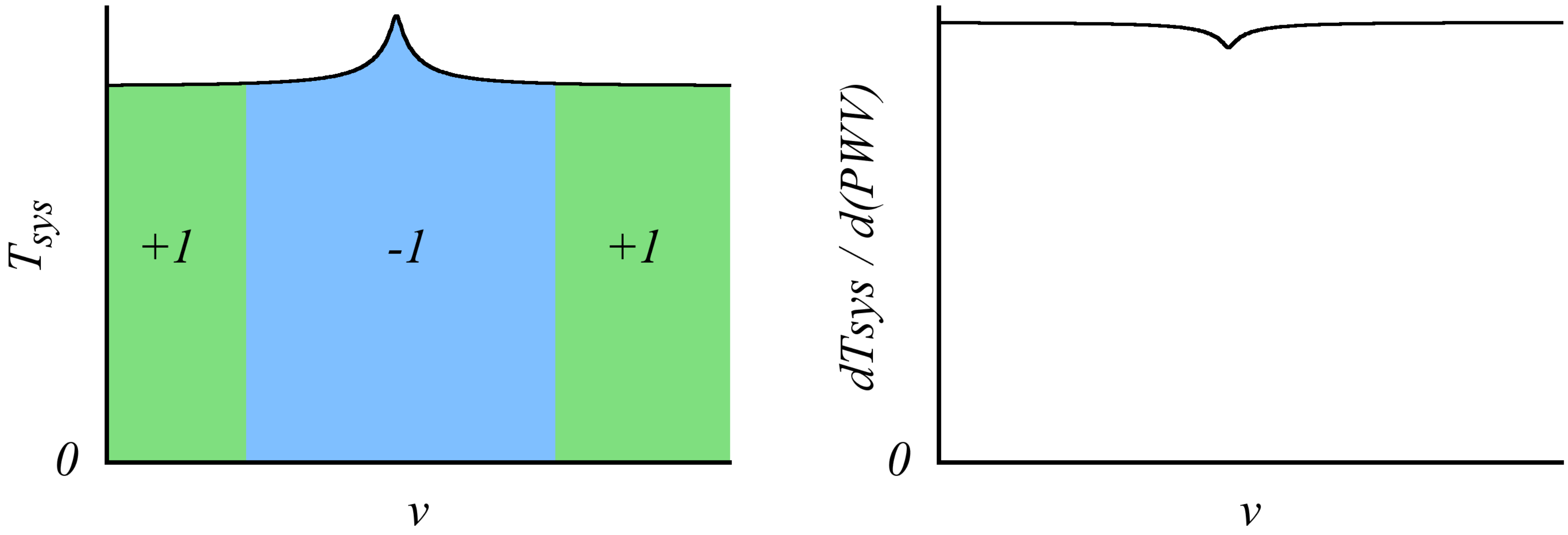
Weighting function





- Example: choose a weighting function $w(v)$ which selects for PWV fluctuations, rejects receiver gain fluctuations
- Note that $dT_{sys} / dg \propto T_{sys}$, so require that $\int w(v) \cdot T_{sys}(v) dv = 0$.

Weighting function

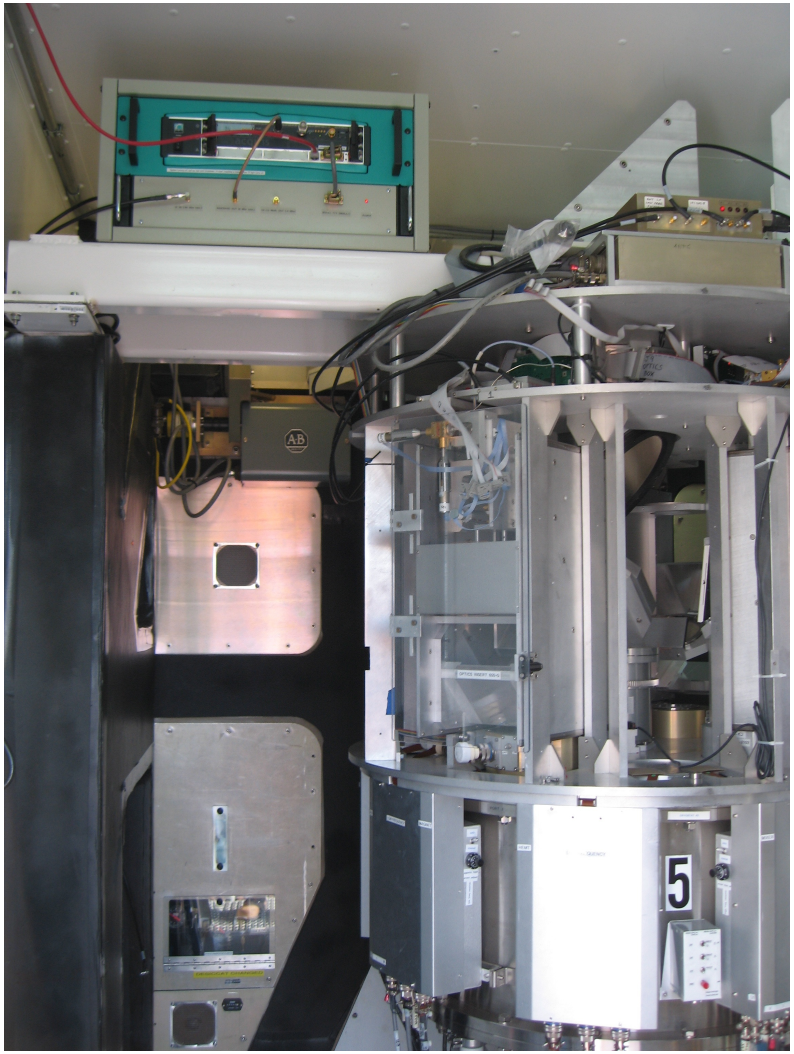


- Simple choice: symmetrically-weighted boxcar to measure line contrast, cancel gain fluctuations.
- Optimal weight function might need to reject baseline ripple, etc.
- Require accurate spectral calibration of the receiver.

New hardware development

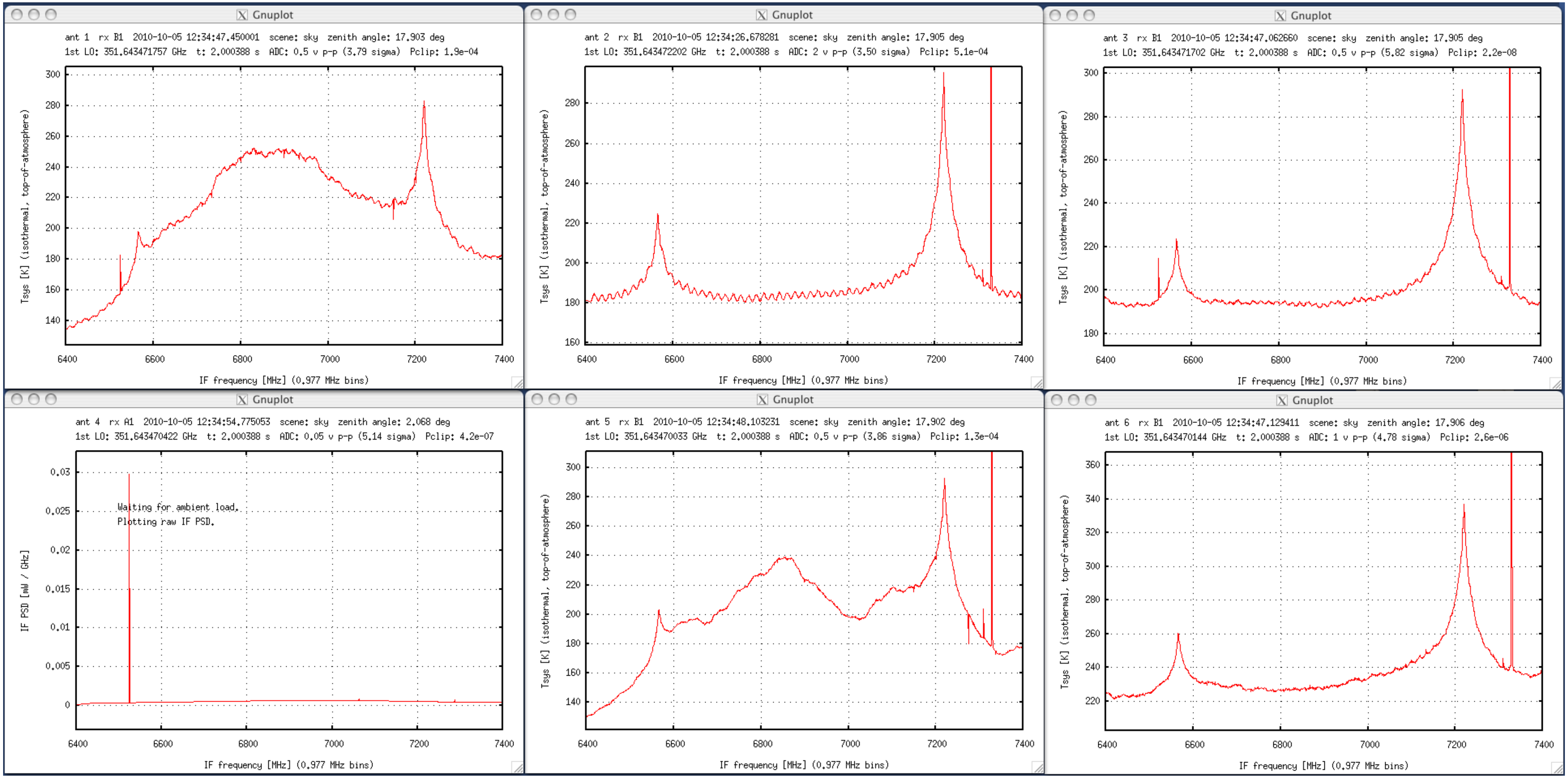
- SMA correlator can't simultaneously auto- and cross-correlate all antennas; other practical issues.
- SMA chunk power detectors don't offer sufficient resolution, stability affected by phase rotators.
- Solution – dedicated single-dish backends for:
  - Delay correction / atmospheric radiometry
  - System testing
  - Astronomy

SMA cabin spectrometers



- 2 Gs / s, 16K channel FFT analyzer (Acqiris/Agilent)
- 1 GHz spectral window tunable across IF with programmable downconverter, 3.6 GHz – 8 GHz.
- Fed from auxiliary BW doubler port, independent of astronomical signal path.
- 6 units in operation, 2 ready in Hilo, one lab spare in Cambridge.
- Operate continuously, with opportunistic calibration.
- 5 ms minimum integration cycle

Snapshot during observation – 350 GHz

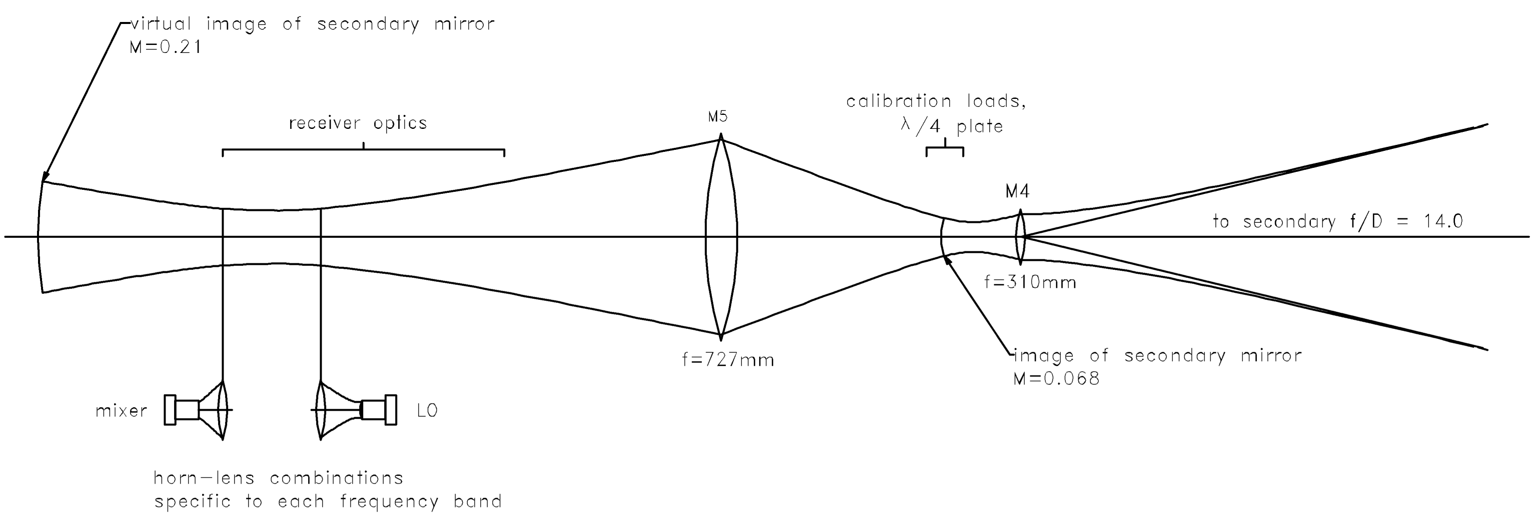


Isothermal T_{sys}*, 6.4 GHz – 7.4 GHz. Note baseline ripple, distortion in antennas 1 & 5.

Practical issues

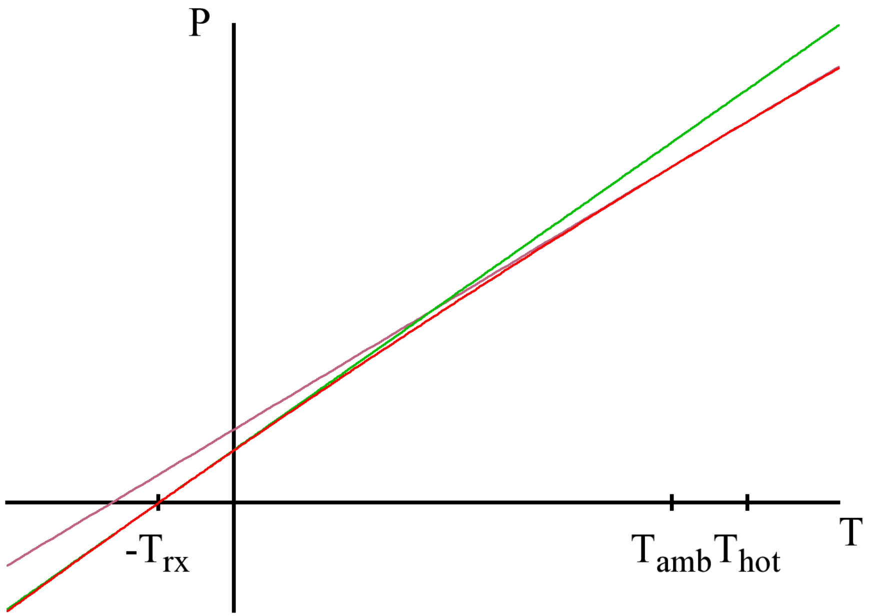
- Baseline ripple – varies with mixer RF match
  - Receiver to subreflector
  - Receiver to cal loads
- Receiver calibration
  - Gain compression affects two-load calibration
  - Mixer IF match can change with RF loading
- Analysis is complicated by DSB operation
- Modify hardware, or understand effects well enough to handle algorithmically.

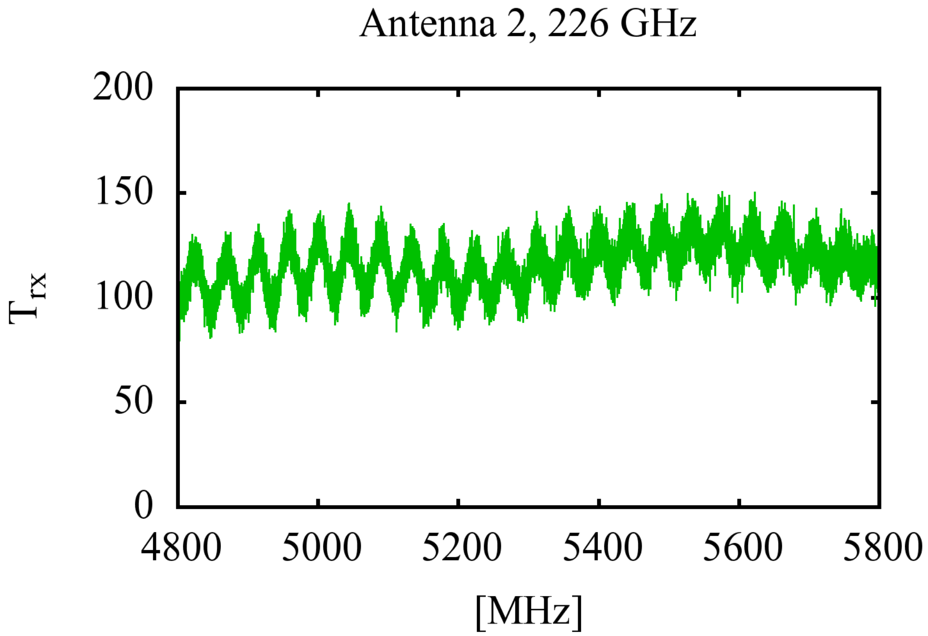
SMA optics and baseline ripple



- SMA optics have pupils at subreflector, cal loads, and receiver feed aperture
  - Good design for an interferometer element, not so good for an atmospheric radiometer
- Efficient optical coupling between pupil planes promotes baseline ripple.
  - Periods: Rx – cal load = 46.7 MHz; Rx – subreflector = 17.8 MHz
  - Cal load ripple has been minimized by tilting the loads.
  - Subreflector ripple shifts with focus tracking during observations

Cal load ripple and gain compression





- Compression leads to overestimate of T_{rx}.
- Ripple is magnified by the small difference between T_{amb} and T_{hot}.
- Alternative – use sky dip normalized to one load.

Isothermal sky dip

Start with an isothermal sky dip:

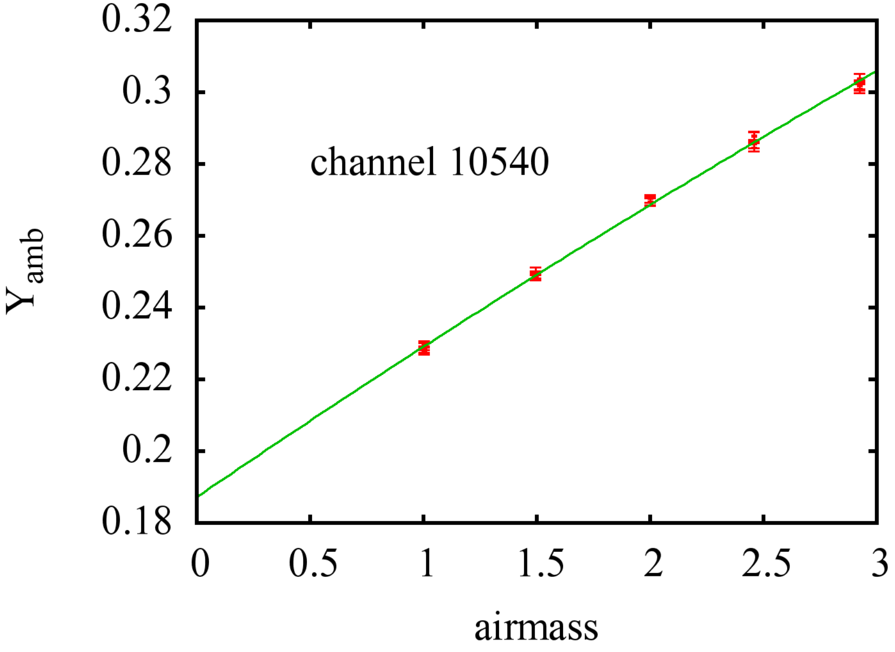
$$P_{sys} = P_{rx} + g\,T_{atm}\left(1 - e^{-\tau_z m}\right) + g\,T_{cb}\,e^{-\tau_z m}$$

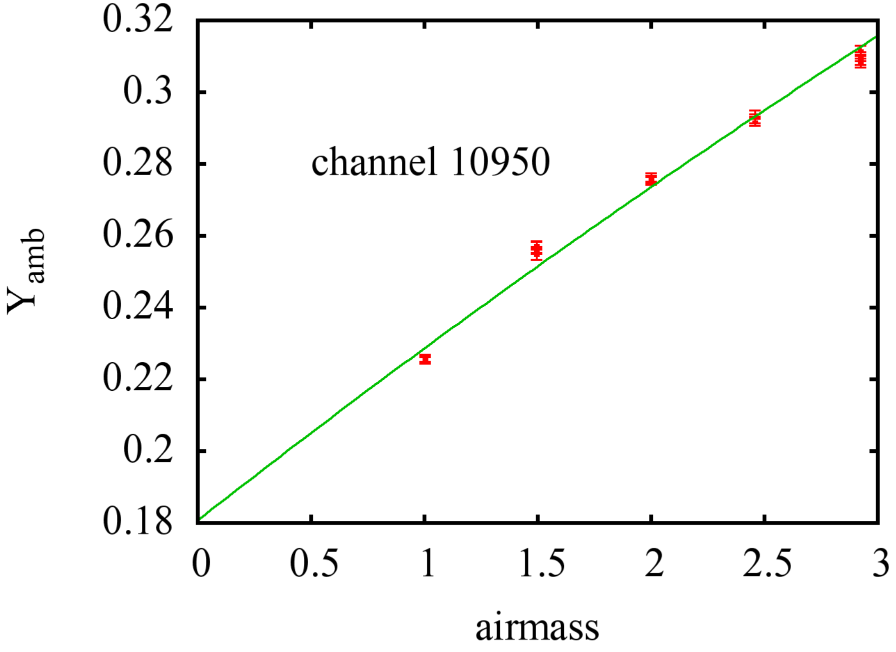
Eliminate gain with Y-factor relative to ambient load:

$$Y_{amb} = \frac{1}{T_{rx} + T_{amb}}\left[T_{rx} + T_{atm}\left(1 - e^{-\tau_z m}\right) + T_{cb}\,e^{-\tau_z m}\right]$$

Vary air mass m and fit T_{rx}, zenith opacity τ_z, for each channel.
For DSB, strictly valid only for $\tau_z \ll 1$.

Good and bad channels from one sky dip





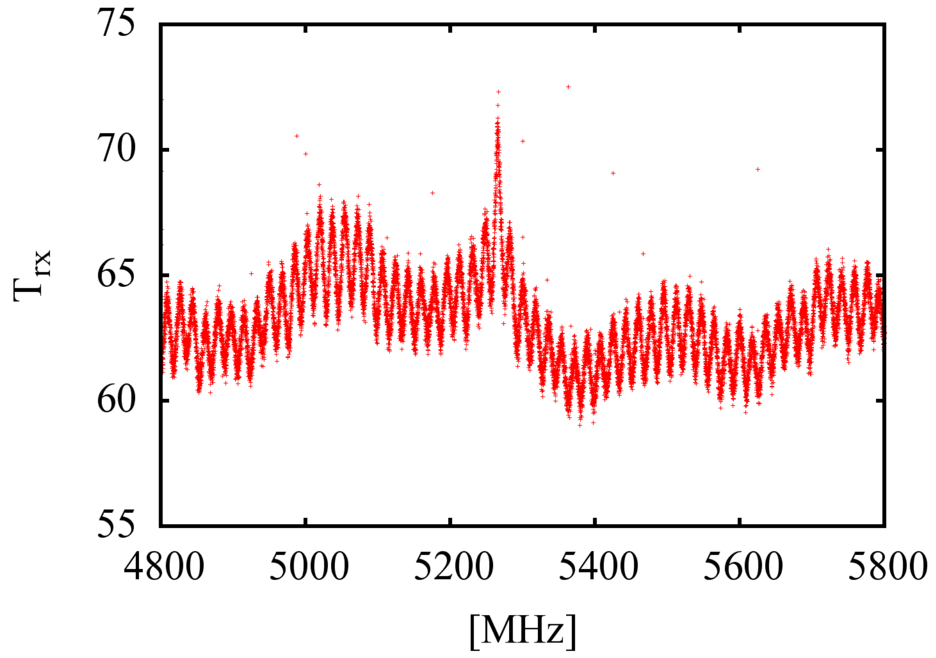
$T_{rx} = 63.7(4)\ \mathrm{K}$
$\tau_z = 0.0571(5)$
$\chi^2 = 1.15$

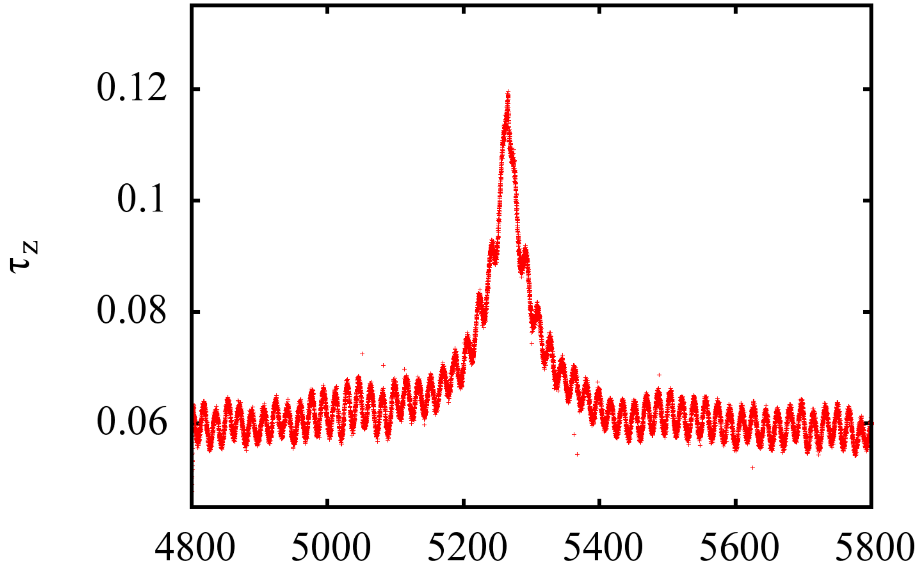
$T_{rx} = 60.9(1.0)\ \mathrm{K}$
$\tau_z = 0.0651(17)$
$\chi^2 = 10.3$

Error bars correspond to $S/N = \sqrt{B\,t}$
Channel bandwidth $B = 61\ KHz$, integration time $t = 1\ \mathrm{s}$
Four points per airmass

SMA Advisory Committee – 2010 Oct 12
S. Paine

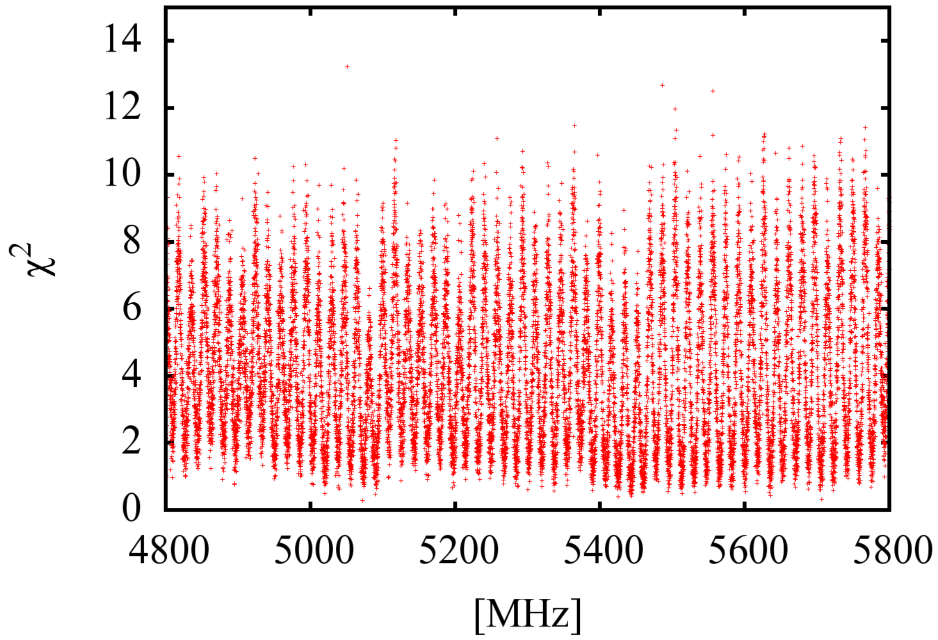
Sky dip – all channels (antenna 1)



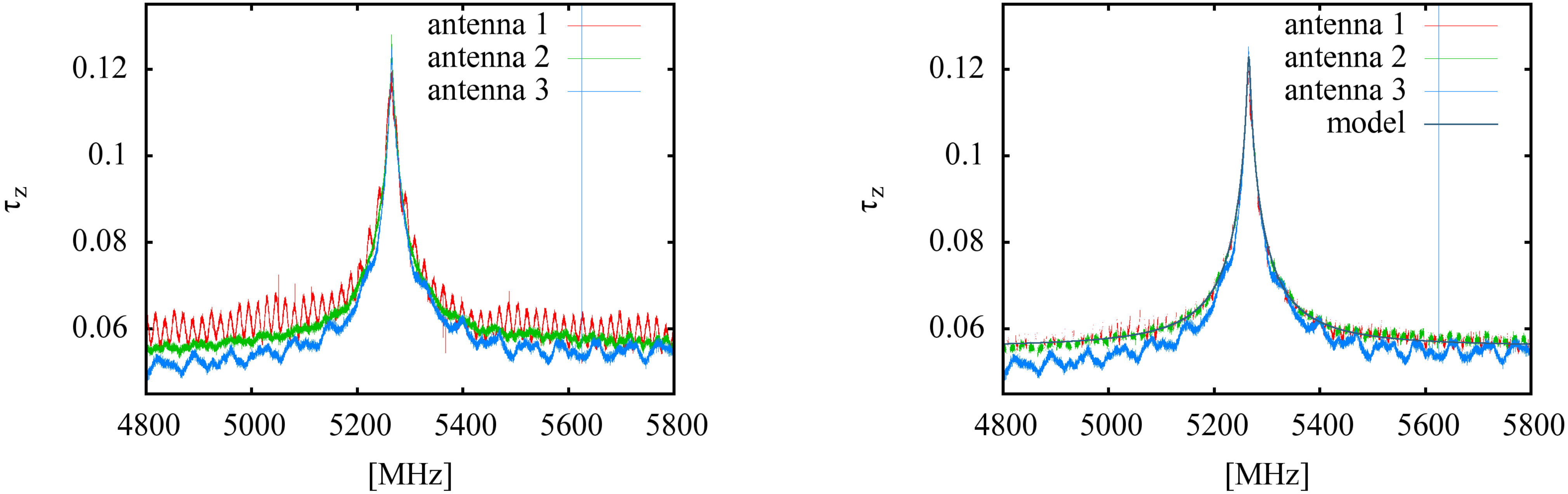


Here, T_{rx} includes all optical losses and elevation-independent spillover.

(Note discrepancy near center of 231.281 GHz O_3 line, as DSB τ_z approximation breaks down.)



Sky dip – filtered by $\chi^2 < 2$ (antennas 1,2,3)



- Measured simultaneously, so τ_z should be similar.
- Note that χ^2 filter on dip fit can't help with cal load ripple affecting antenna 3.
- Model is Mauna Kea median profiles scaled to 1170 μm PWV, 234 DU O_3.
- SCHIAMACHY assimilated ozone over MK on this date was 289 DU.
  - Discrepancy from DSB τ_z approximation, and receiver sideband ratio.

Current status

- Cabin spectrometers work well and are very reliable.
- Issues with optics and receivers have been identified and mostly understood.
- Cal load performance is significantly improved.
- Algorithms must be developed to minimize sensitivity to irreducible instrumental effects.
- Delay correction tests this year – some data already taken.