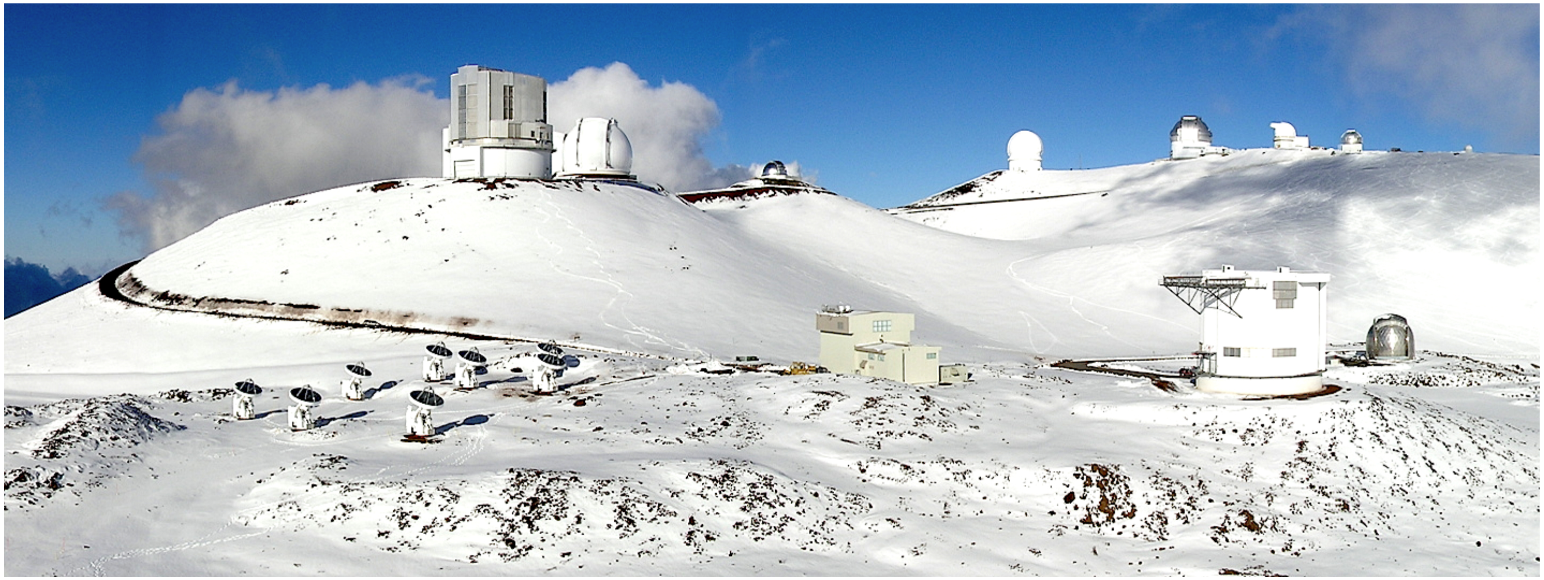
Atmospheric Phase Correction for Submillimeter Interferometry Using Stratospheric Ozone Line Emission



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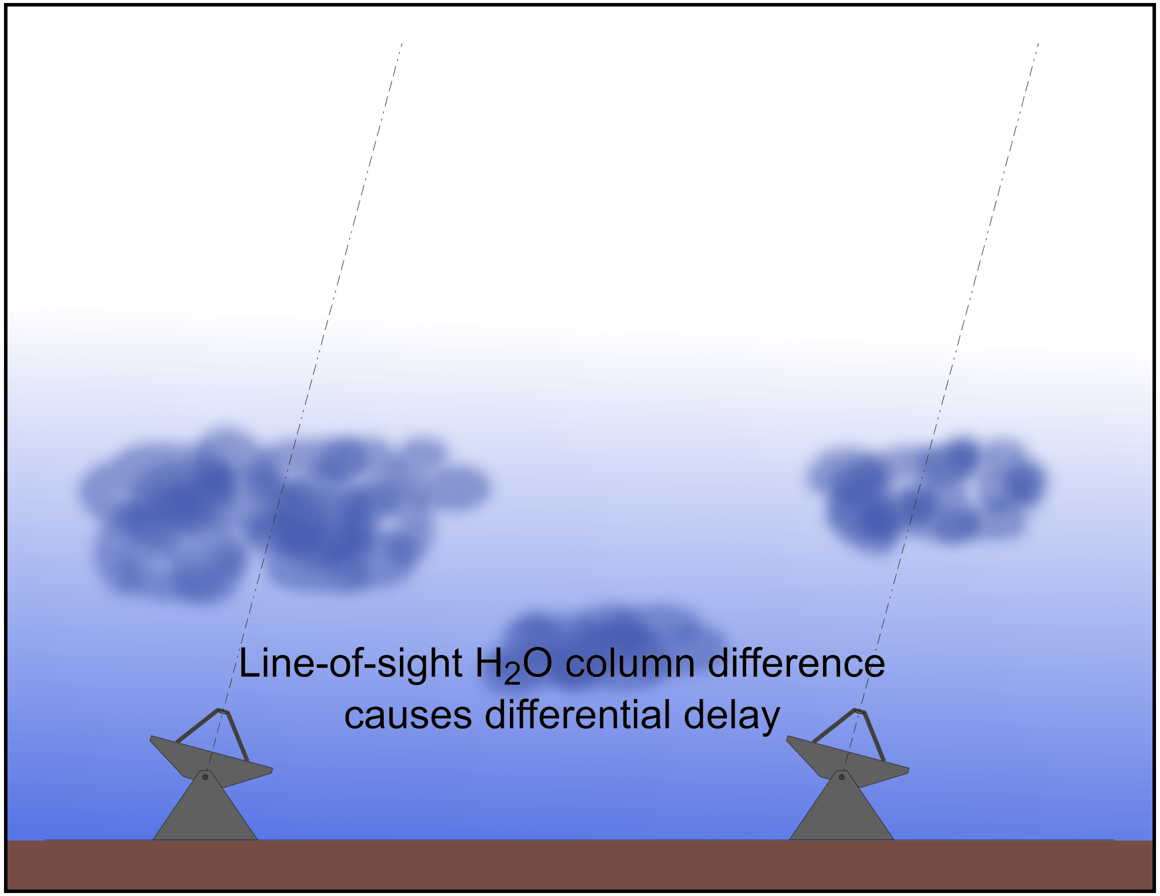
Outline

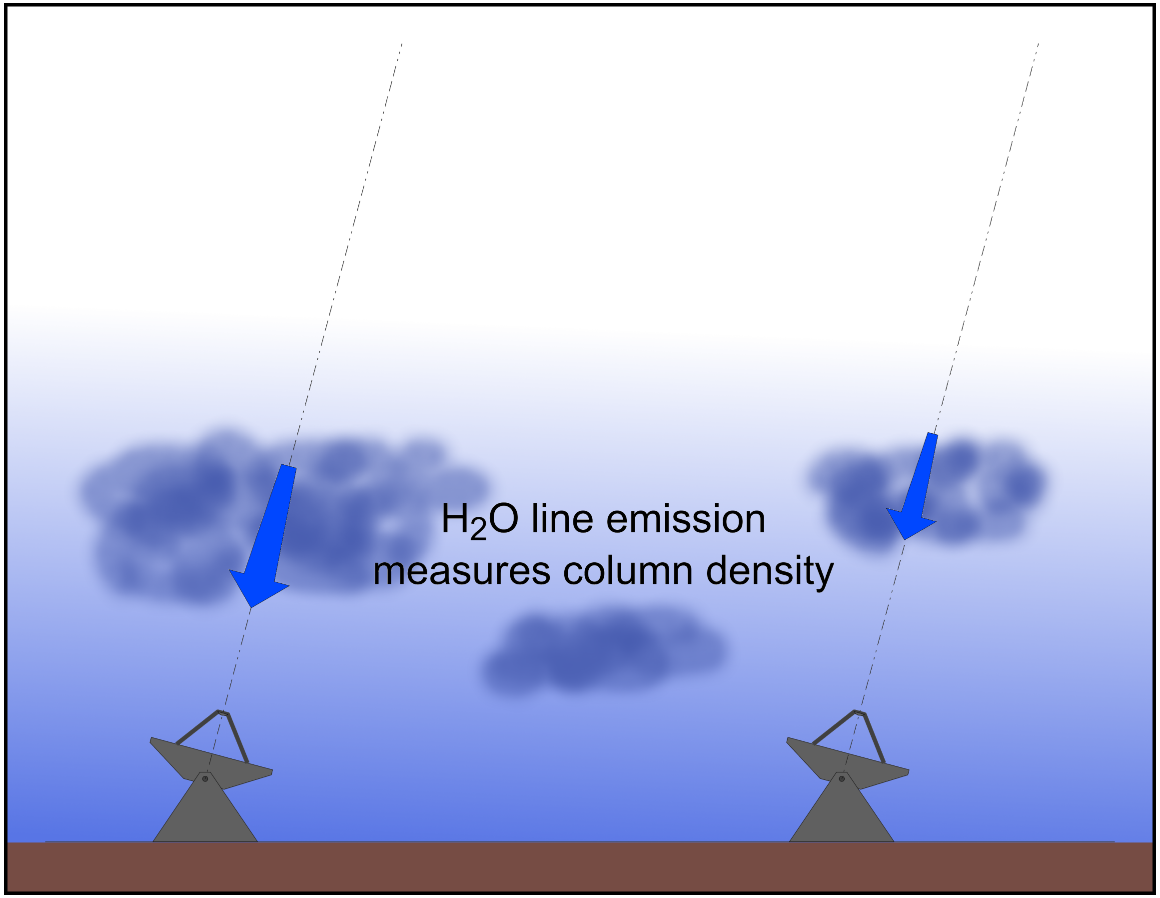
- Introduction – comparing H_2O and O_3 radiometry for wet path delay mitigation
- Spatial and spectral properties of O_3 in the atmosphere
- Current progress at the SMA

The wet path delay problem



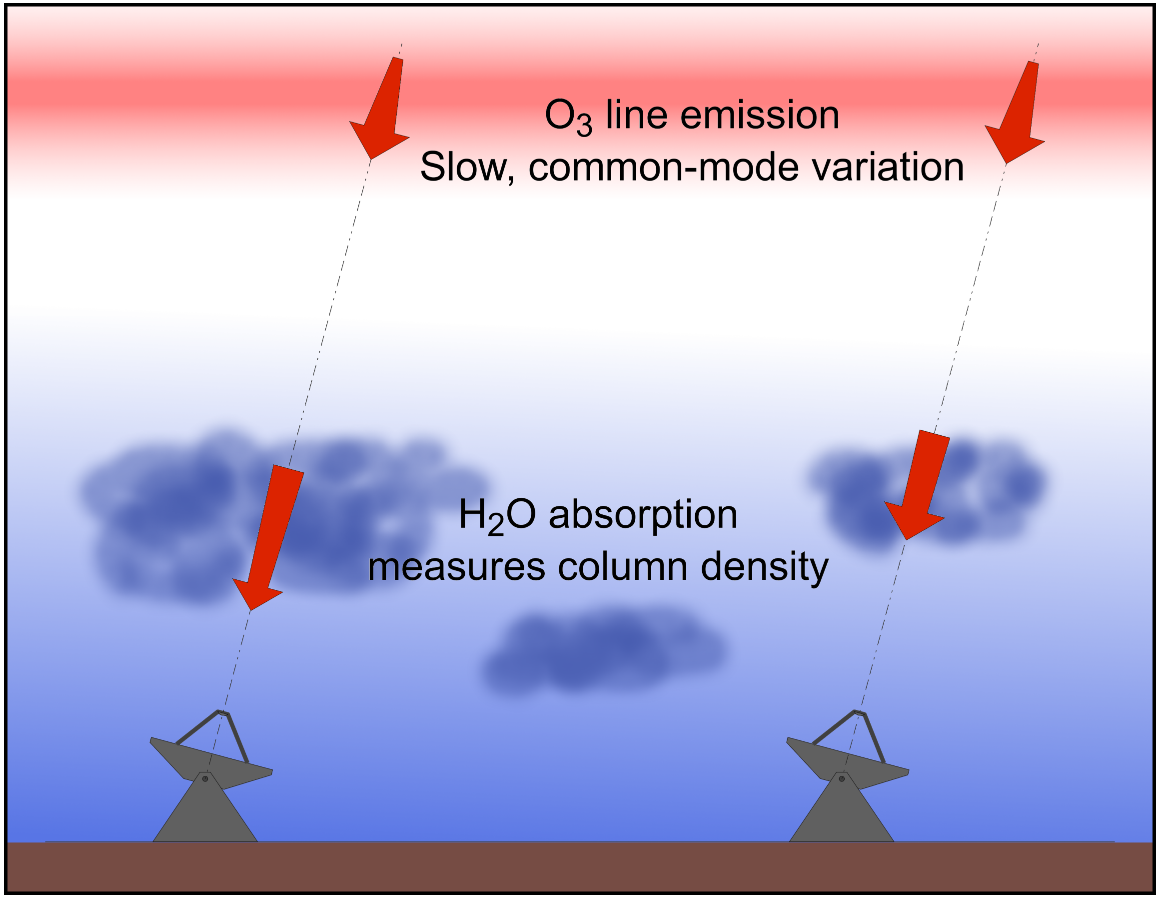
Example: At 690 GHz (λ = 435 μm), the excess path is 6.8 $\cdot$PWV, leading to complete loss of coherence for line-of-sight PWV differences of ~50 μm

Water vapor radiometry



- Look at H_2O line (typically 22 GHz or 183 GHz) in emission with dedicated multi-channel receiver at each antenna.
- Line width ~3 GHz

Ozone radiometry



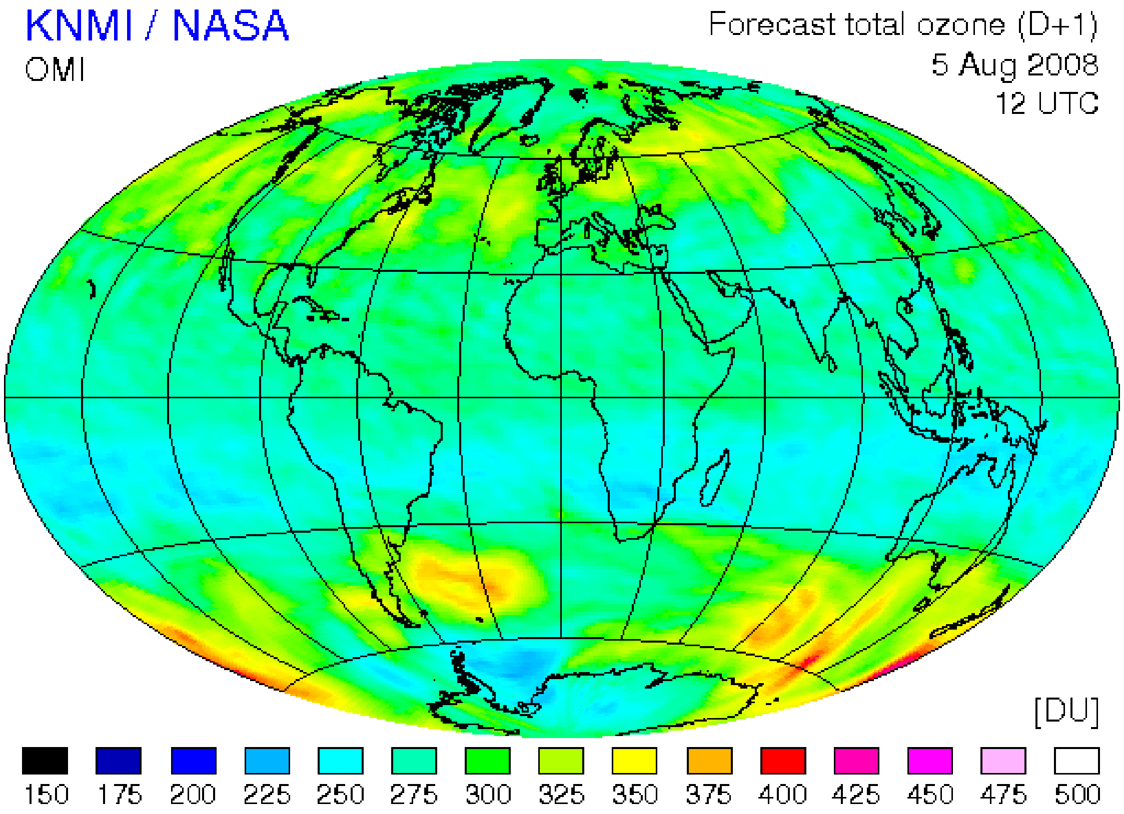
- Look at O_3 line in passband of astronomical receiver
- Foreground H_2O absorption reduces O_3 line contrast
- Line width ~100 MHz

Comparing methods

- Water vapor radiometry
  - Measures H_2O in emission
  - Broader line offers better inherent sensitivity
  - Requires auxiliary broad band receiver

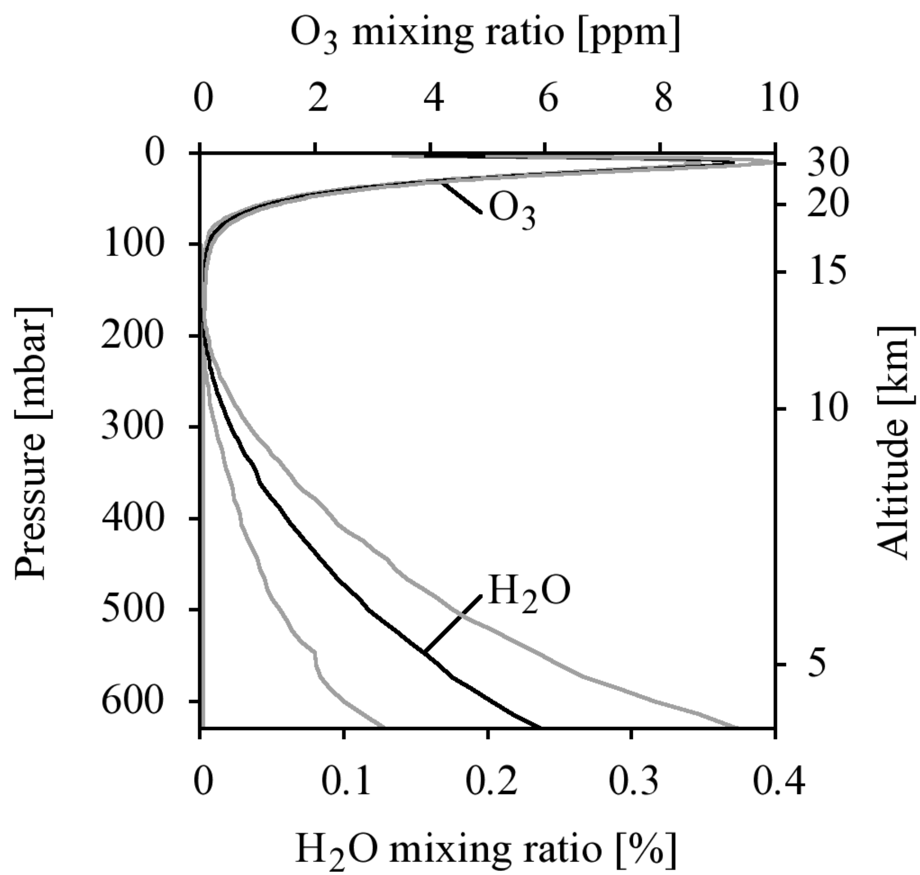
- Ozone radiometry
  - Measures H_2O in transmission
  - Narrower line offers better stability – all analog elements of signal path are common-mode
  - Uses astronomical receiver, measures along same beam

O_3 column variability



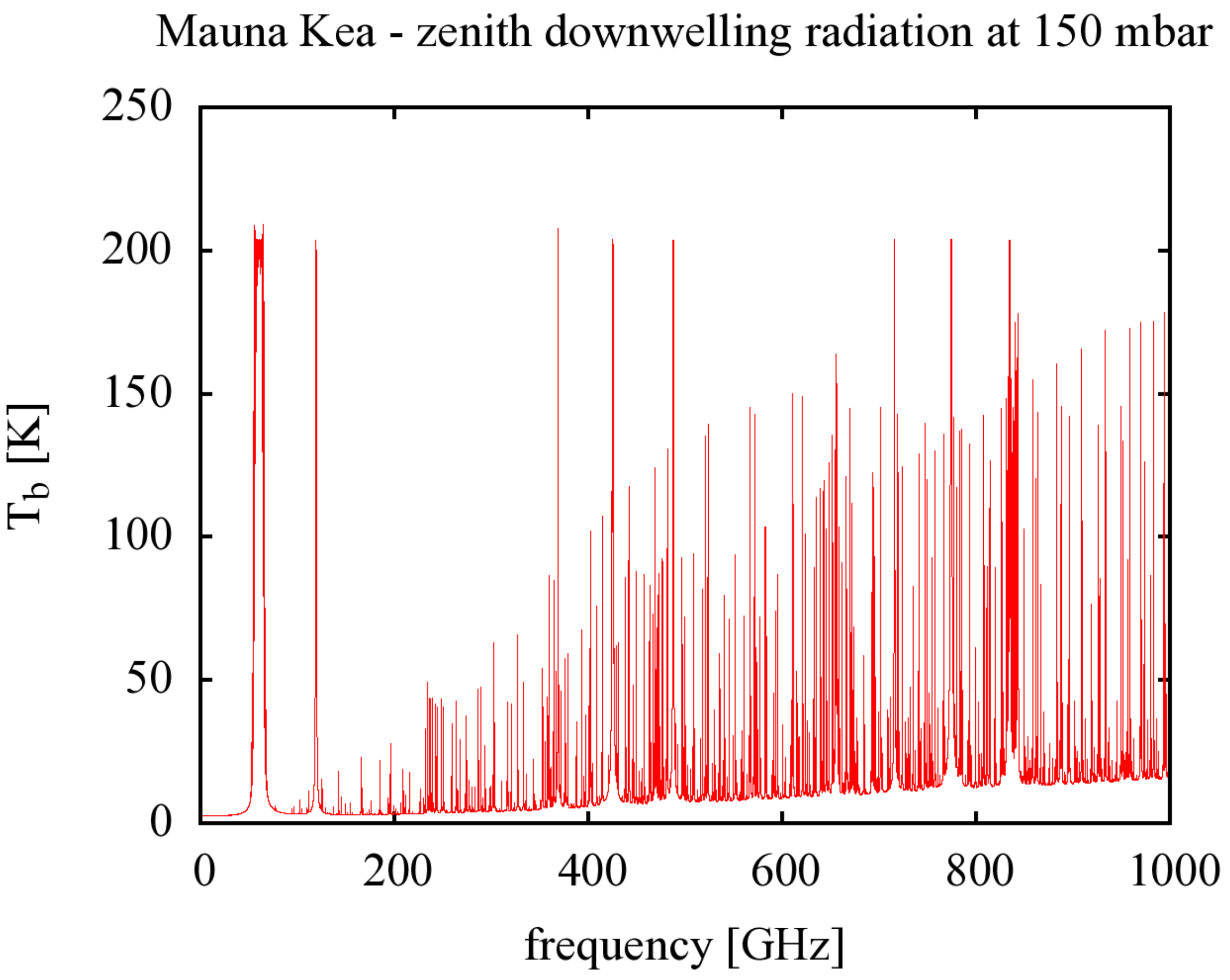
- OMI satellite data are assimilated into ESA TEMIS multi-day forecast model
- Variations are slow (<10% /day), 95% range is ±20% over the year at Mauna Loa, Hawaii
- Variations are common-mode over radio telescope array

Vertical profiles of H_2O and O_3



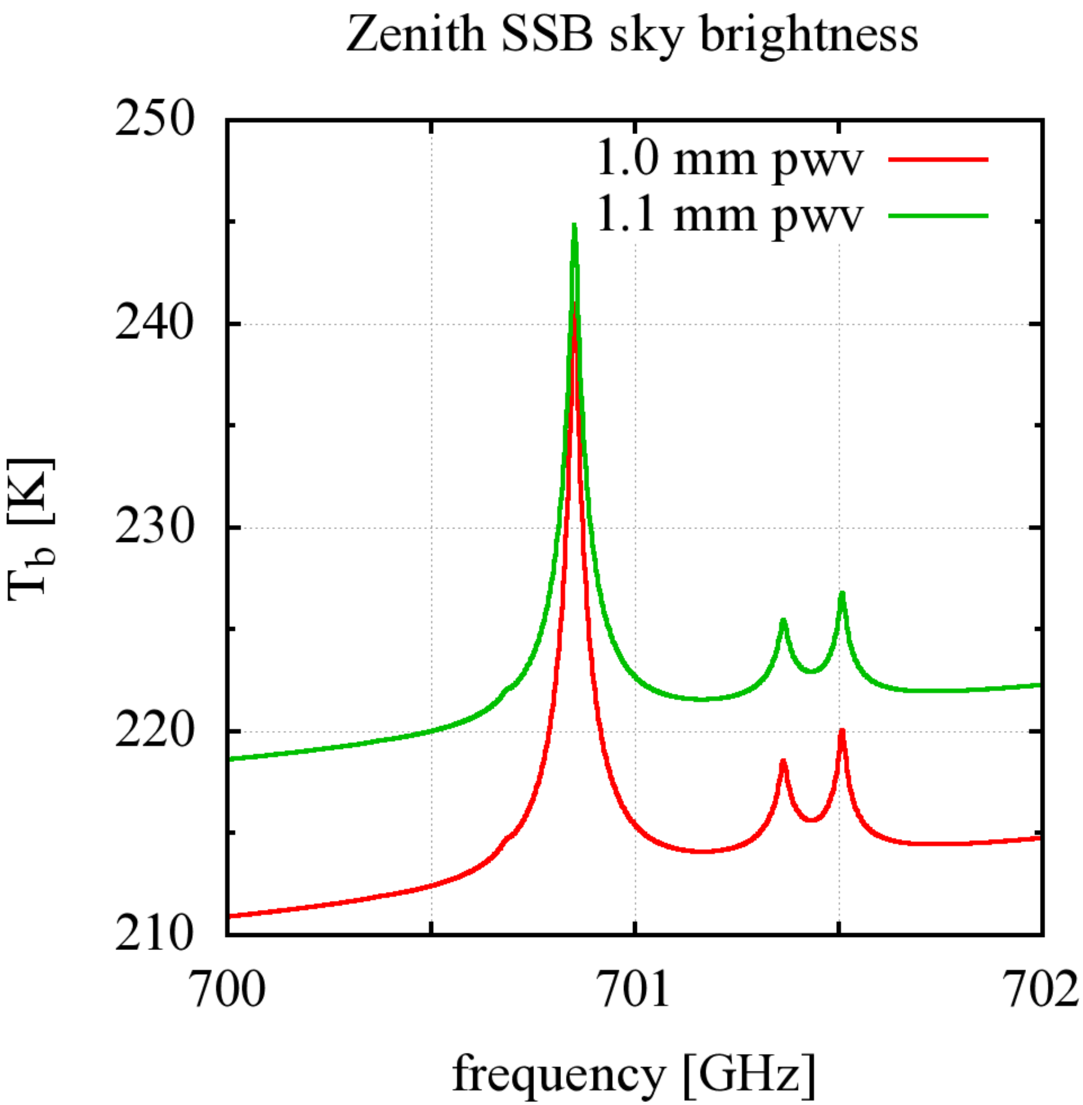
Mauna Kea, Hawaii. Quartile profiles compiled from NOAA CMDL ozonesonde data for 1984-2004.

Downwelling spectrum at tropopause

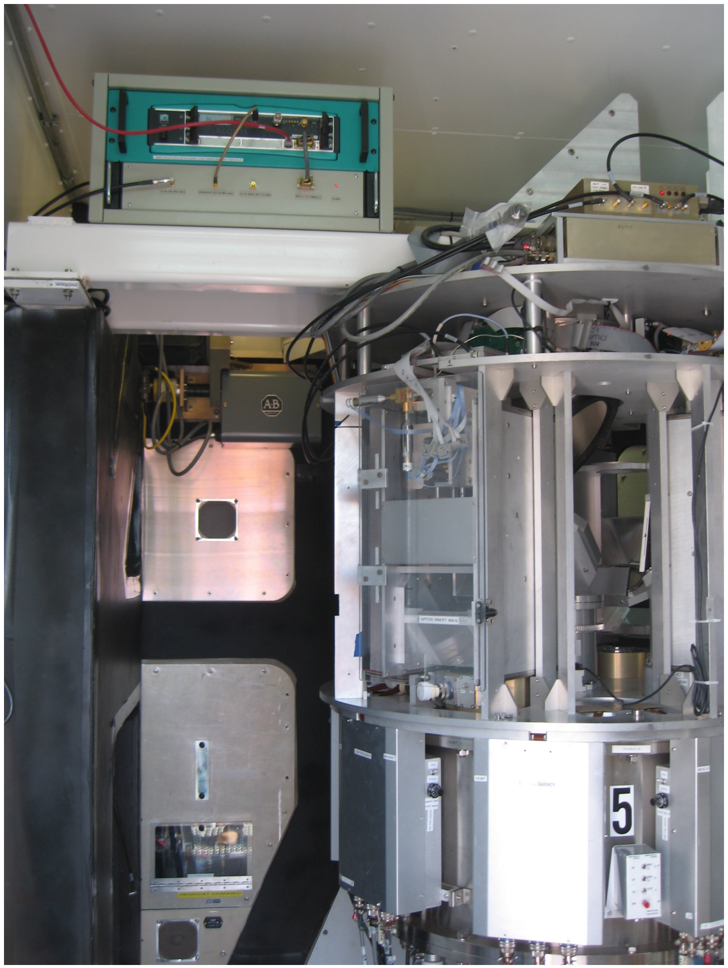


Example – O_3 at 700.9 GHz

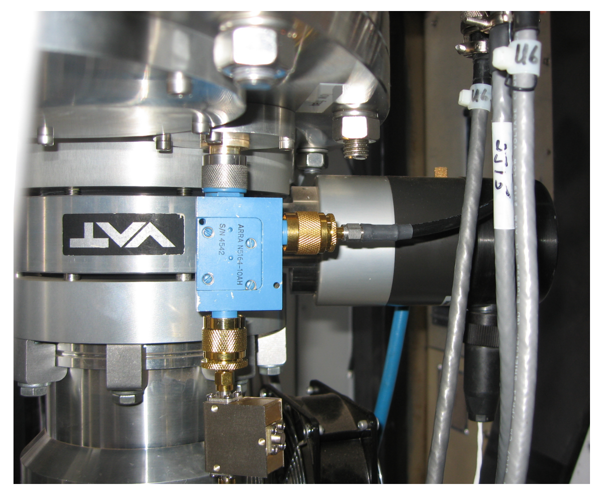
- O_3 line in USB of SMA with CO 6→5 in LSB
- 100 μm pwv change produces 680 μm path change (560° phase change).
- Change in line contrast is 1.1 K DSB, when averaged over 100 MHz equivalent width.
- For T_{sys} = 500 K, t = 2.5 s, 100 MHz bandwidth, ΔT = 32 mK.
- Equivalent sensitivity is 23 μm path change (19° phase change).
- For two-antenna difference, phase sensitivity is 27°, corresponding to 11% loss.



Progress at the SMA

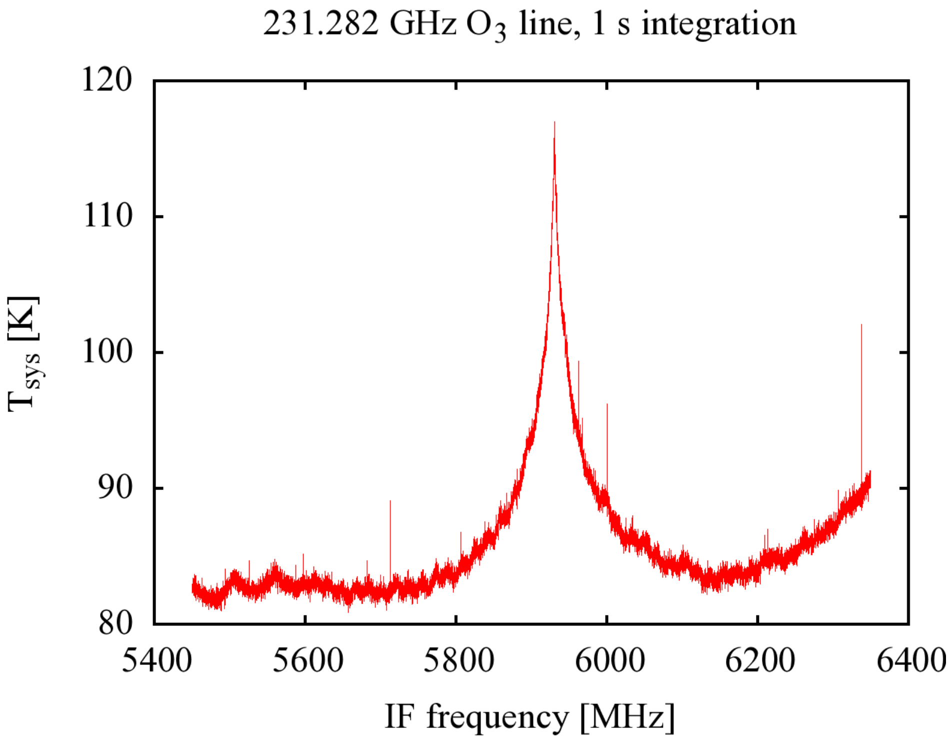


- New dedicated back end fed by IF tap
- 2 Gs / s , 16k channel FFT analyzer (Acqiris AC240)
- 1 GHz spectral window tunable across SMA IF by a programmable downconverter
- Single-antenna tests since January 2008, second system installed June 2008.

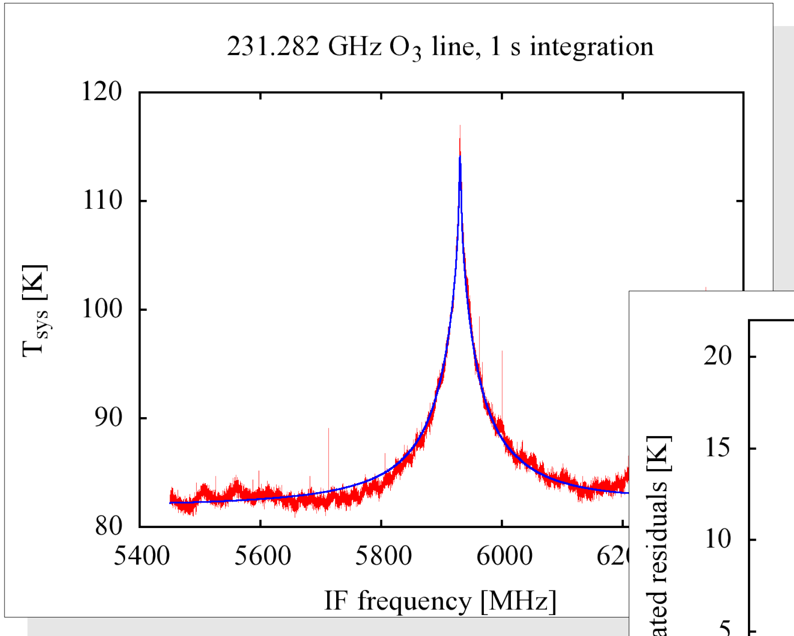


SMA O_3 line spectrum

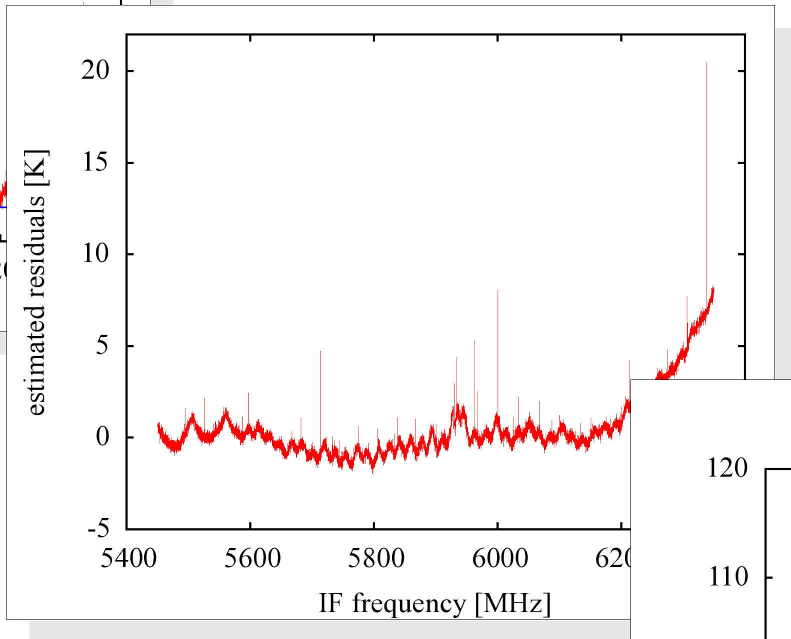
- 1 s integration, 61 kHz channels, so noise is about 0.4 K / channel at T_{sys} = 100 K
- Note fast uncalibrated baseline ripple from subreflector reflection – varies with elevation, focus tracking.
- Also RFI from digital clocks, but affected bandwidth is minimal.
- With an accurate atmospheric model, ripple and RFI which vary slowly in time can be rejected by recursive filtering.



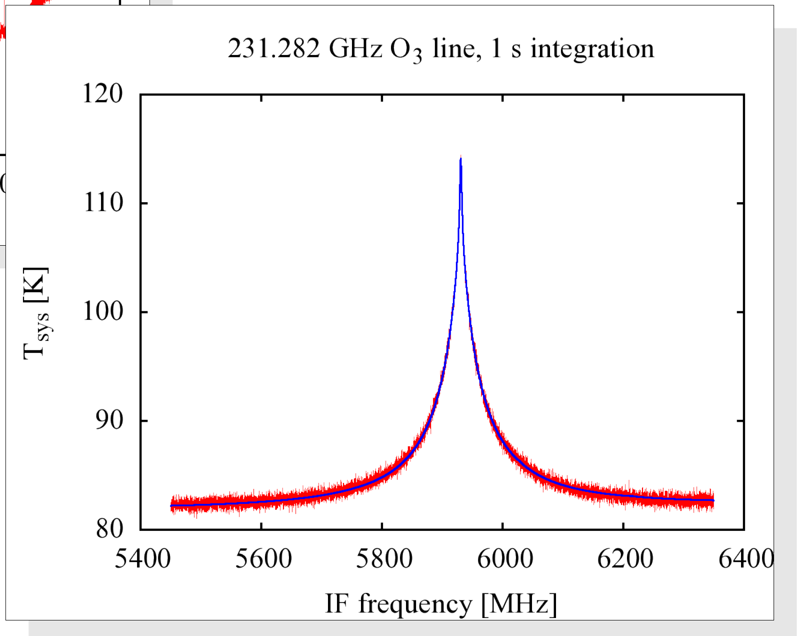
Recursive Filtering



Fit line, using residuals $\mathbf{r}_n$ corrected by prior estimate $\mathbf{R}_{n-1}$ to compute fit estimator



Corrected spectrum



Compute new estimate

$$\mathbf{R}_n = (1-\varepsilon)\,\mathbf{R}_{n-1} + \varepsilon\,\mathbf{r}_n$$

In this example, $\varepsilon = 0.2$

Next steps

- Begin two-antenna tests
  - Correlation of large-scale fluctuations between near antennas
  - Delay correction tests on quasar
- Improvements to SMA calibration
- Algorithm development
  - Track receiver gain fluctuations between cals
  - Make best use of real time meteorological data