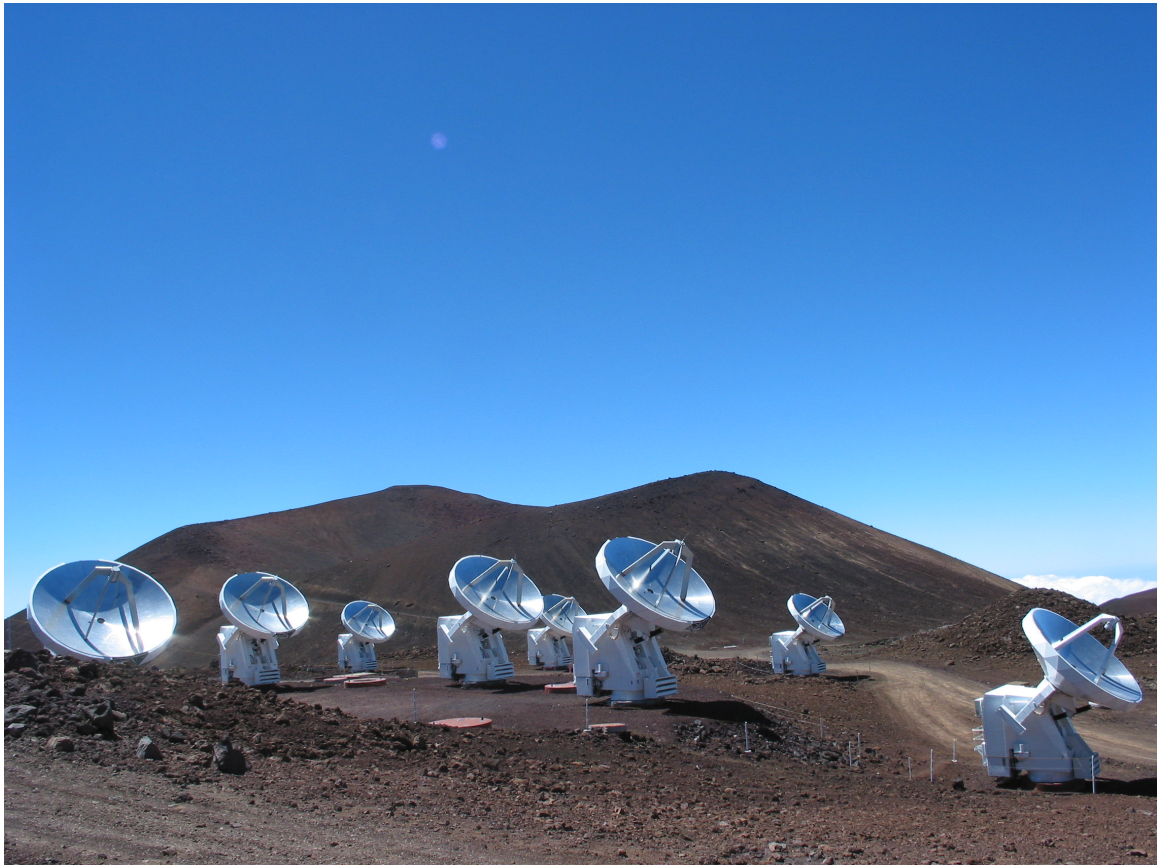
The *am* atmospheric model and applications to WVR and phase correction



Scott Paine
Smithsonian Astrophysical Observatory
Submillimeter Receiver Laboratory

Wettzell – 2006 Oct 9

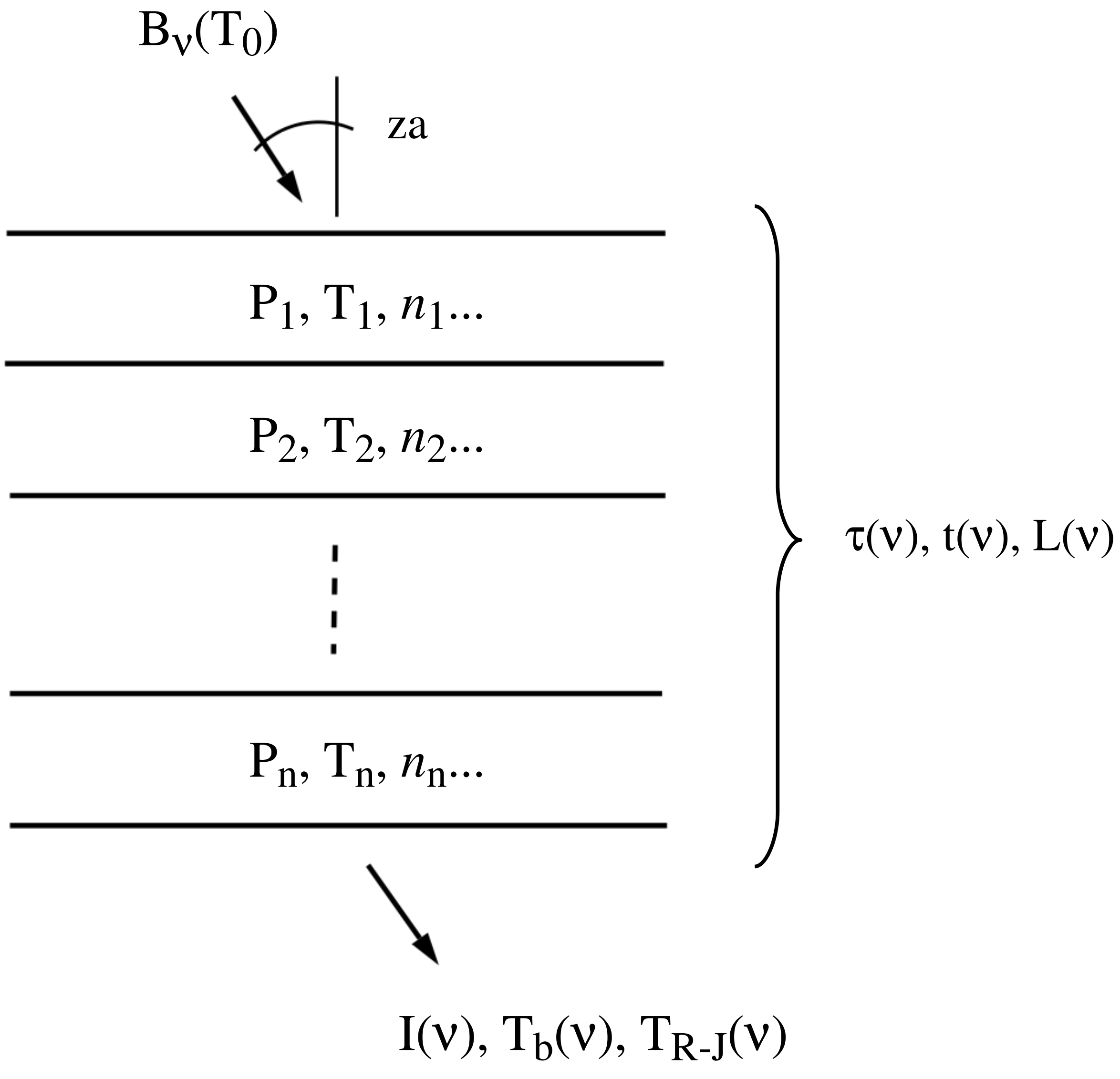
Outline

- The *am* atmospheric propagation code
  - What it does
  - How to use it
- Applications of *am* to WVR and phase correction
  - ALMA 183 GHz WVR at the SMA
  - Wet delay computation for phase transfer

am

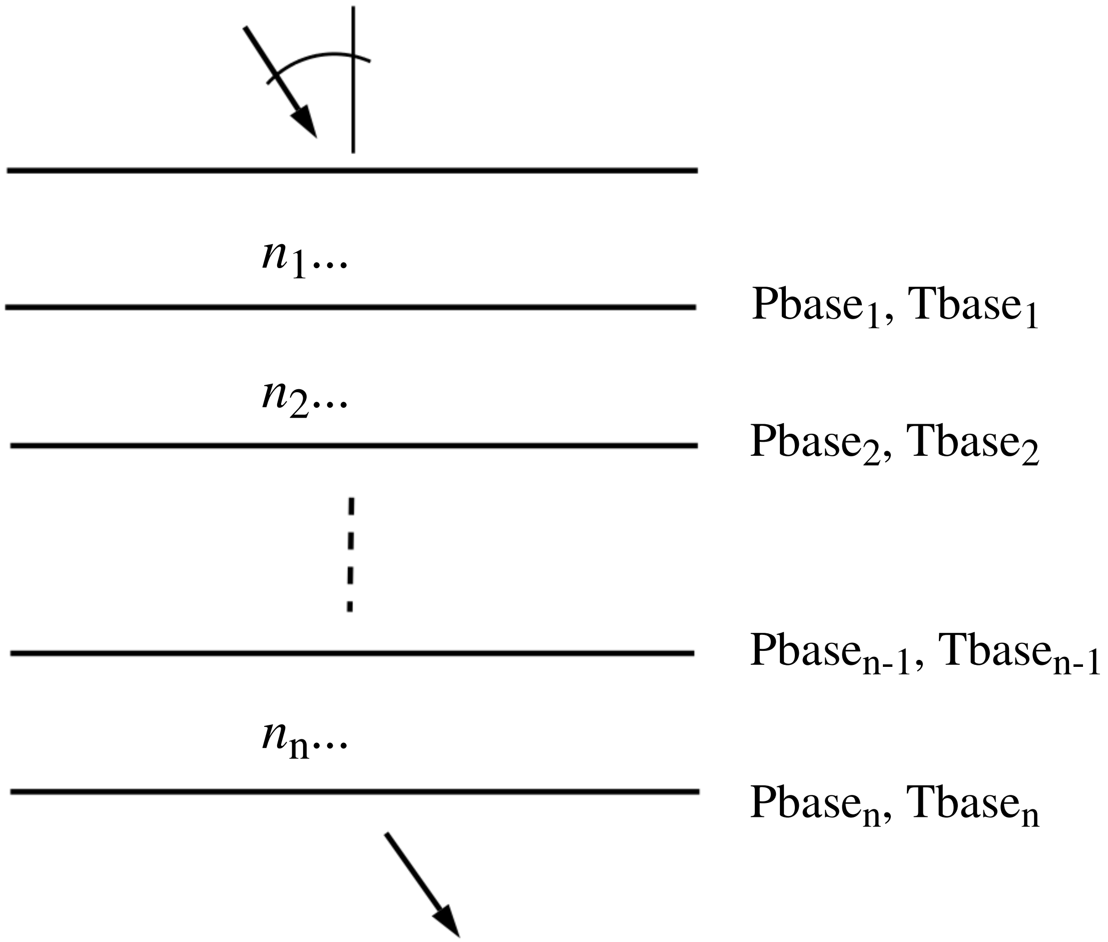
- A general-purpose LTE propagation model for submillimeter (0 – 15 THz) atmospheric applications
- Models described by easy to use configuration file language
- General fitting capability – any model parameter can be tagged as a fit variable
- Works well alone or as a software component
- High performance – disk and memory caching, multicore support (v. 4.1)

Basic n-layer radiative transfer model



Pressure, temperature, list of species and column densities defined for each layer.

Hydrostatic models



Column densities may be defined explicitly, or implicitly via mixing ratio.

am column types

- Line-by-line
  - CH_4, CO, H_2O, N_2O, O_2, O_3
  - Uses HITRAN04 data to 15 THz
  - Lineshape selectable by layer
- Collision-induced absorption
  - N_2-N_2, N_2-air, O_2-O_2, O_2-air
  - well validated by lab data

…

am column types, continued

- H_2O continuum
  - In contrast with dry CIA, coexistence with dipole-allowed line spectrum makes this complicated.
  - Currently, *am* implements simple ν^2 dependent self- and air-broadened continua, with lineshape-dependent coefficients.
  - Valid in red wing of H_2O rotation band ($\nu < 1.5$THz)
  - Needs to be improved in *am* – better models are available (e.g. MT_CKD)

…

am column types, continued

- Spectrally-flat attenuation with different zenith angle dependences
  - `atten` – constant loss
  - `atten_sec(za)` – grey absorbing medium
  - `atten_sec^2(za)`, `atten_sec^2(za)` for modeling elevation-dependent spillover loss

Using *am*

A simple example: looking at a 77 K cold load through water vapor. One layer, with one column type defined on that layer.

```
f  0 THz  1.5 THz  50 MHz
output  f GHz  Tb K  tx
T0  77 K
```

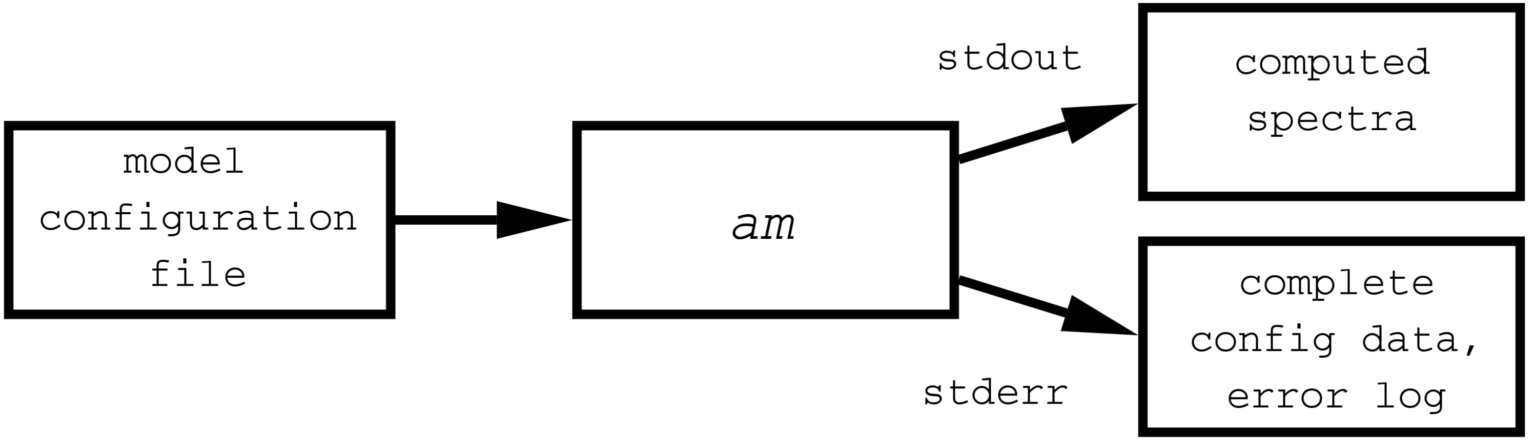
Header sets up frequency grid, desired outputs, and background temperature. Many other parameters can go here.

```
layer
P 1 atm
T 293 K
column h2o 10 um_pwv
```

Layer description

Model configuration file
coldload.amc

Cold load example – running the model



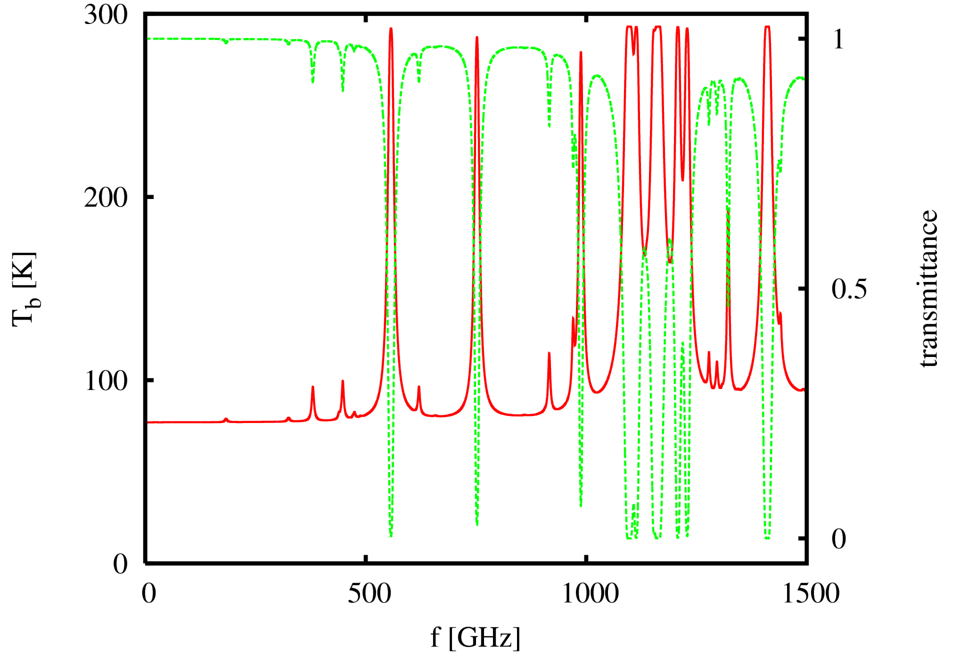
Command line:

```
$ am coldload.amc > coldload.out
```

Cold load example - output

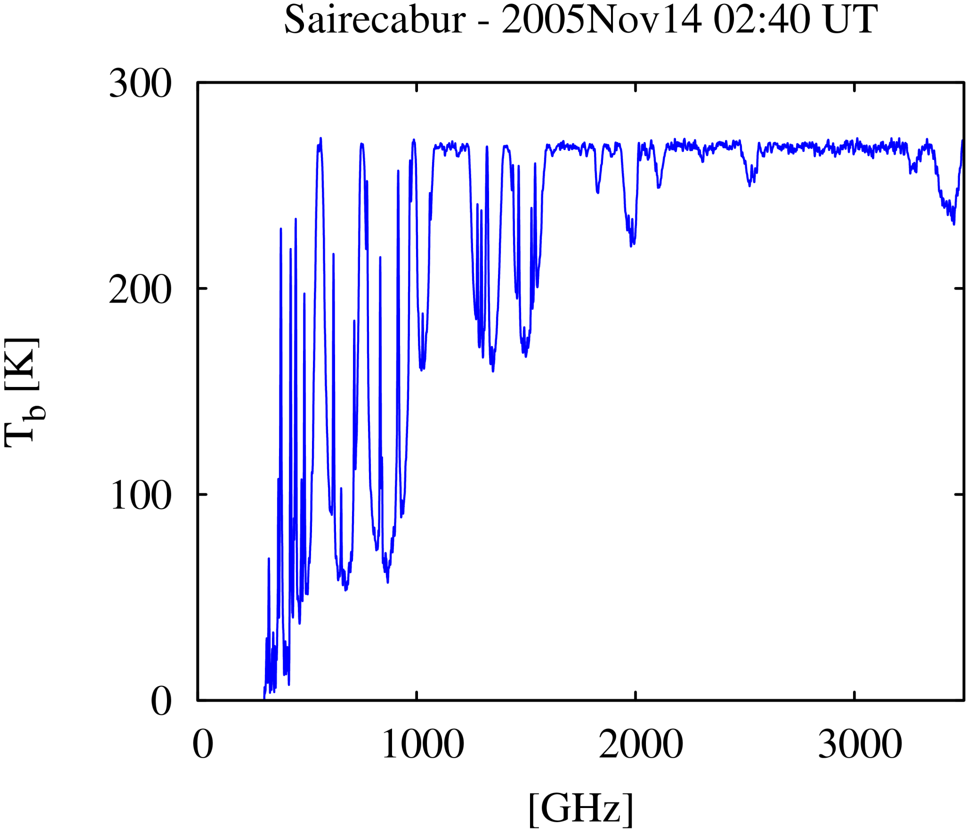
f	T_b	tx
.		
.		
7.520500e+02	2.872049e+02	2.692367e-02
7.521000e+02	2.872320e+02	2.679766e-02
7.521500e+02	2.872486e+02	2.672072e-02
7.522000e+02	2.872546e+02	2.669267e-02
7.522500e+02	2.872501e+02	2.671342e-02
7.523000e+02	2.872352e+02	2.678302e-02
7.523500e+02	2.872096e+02	2.690163e-02
7.524000e+02	2.871735e+02	2.706953e-02
.		
.		

coldload.out



Second example – fit to FTS spectrum

- Fit measured T_b spectrum, at instrumental resolution
- Compute fully resolved transmittance, for astronomical calibration



Second example – fit to FTS spectrum

```
f 0 GHz  3500 GHz  5.0 MHz
output f GHz  Tb K  tx
za 0 deg
ils sinc 2.35 GHz  Tb
tol 1e-5

fit Tb 2005Nov14_024019.tsk
fit_tol 1e-5

Nscale h2o 0.2 0.05
Nscale o3 1.112

T0 2.7 K

layer
Pbase 3 mbar
T 252 K
column n2air hydrostatic
column o2 hydrostatic
column o3 hydrostatic 2.591e-6
.
.
```

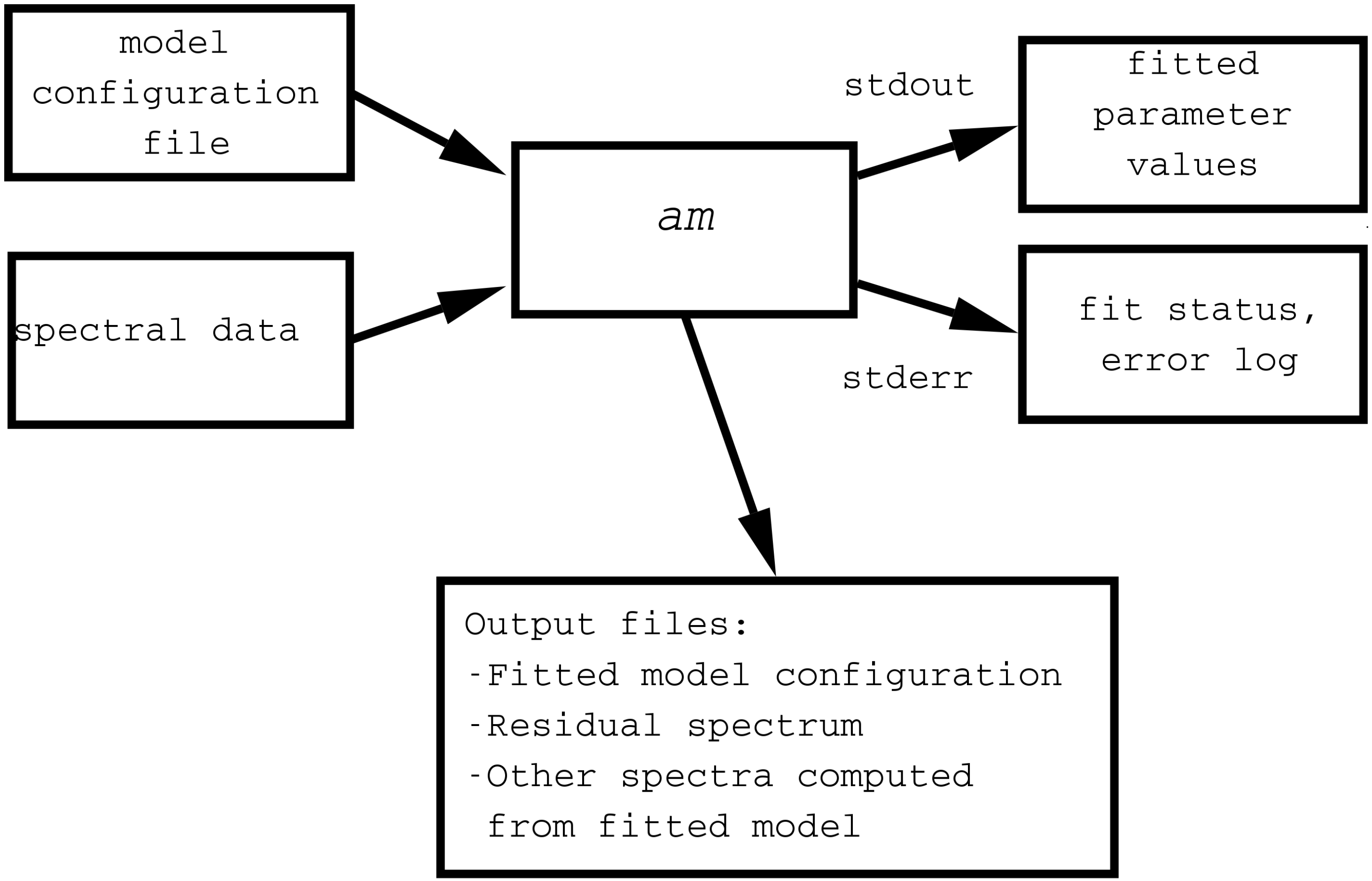
```
.
.
layer
Pbase 520 mbar
T 261.5 K
column n2air hydrostatic
column o2 hydrostatic
column o3 hydrostatic 0.043e-6
column h2o hydrostatic 0.076e-2

layer
Pbase 531 mbar
T 265 K  1 K
column n2air hydrostatic
column o2 hydrostatic
column h2o hydrostatic 0.135e-2 0.05e-2
```

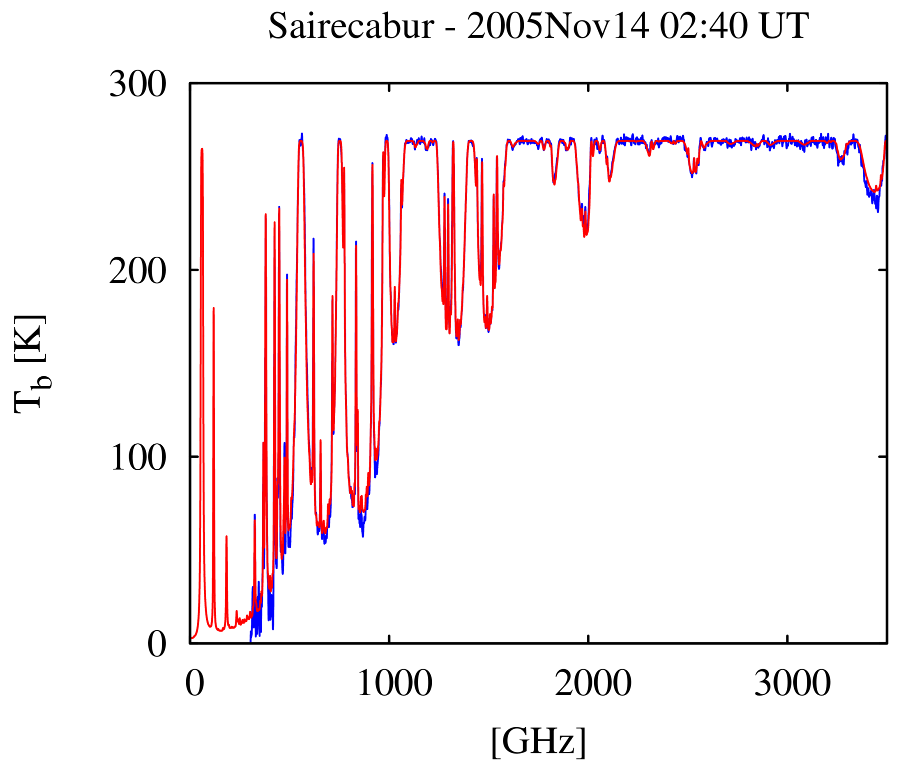
Starting with a forward model configuration:

- Add fit control lines to header (data source, convergence tol)
- Tag fit variables (shown in **blue**) by adding characteristic scale

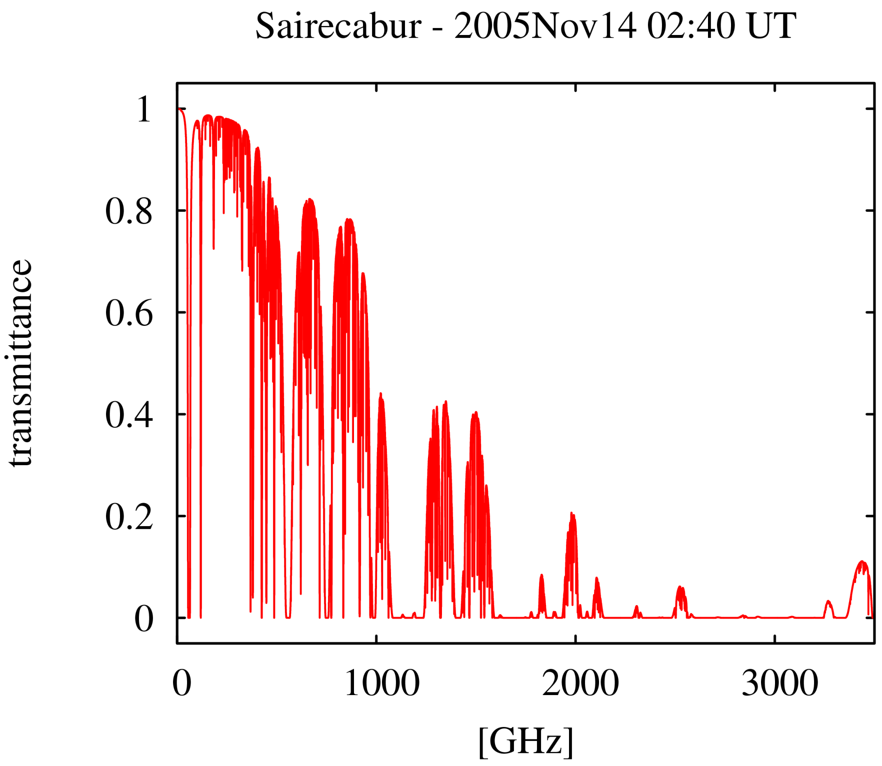
Running the fit



FTS example – fit output



Data in blue, fit at FTS resolution in red



Fully-resolved transmittance computed from model fit

Applications to WVR and phase correction

- ALMA WVR test at the SMA (R. Hills et al.)
  - line fits
  - analyzing loss and spillover
- Phase transfer (T. Hunter, SMA)
  - compare dispersion of modeled wet delay with simultaneous phase measured in two astronomical bands.

ALMA WVR test at the SMA

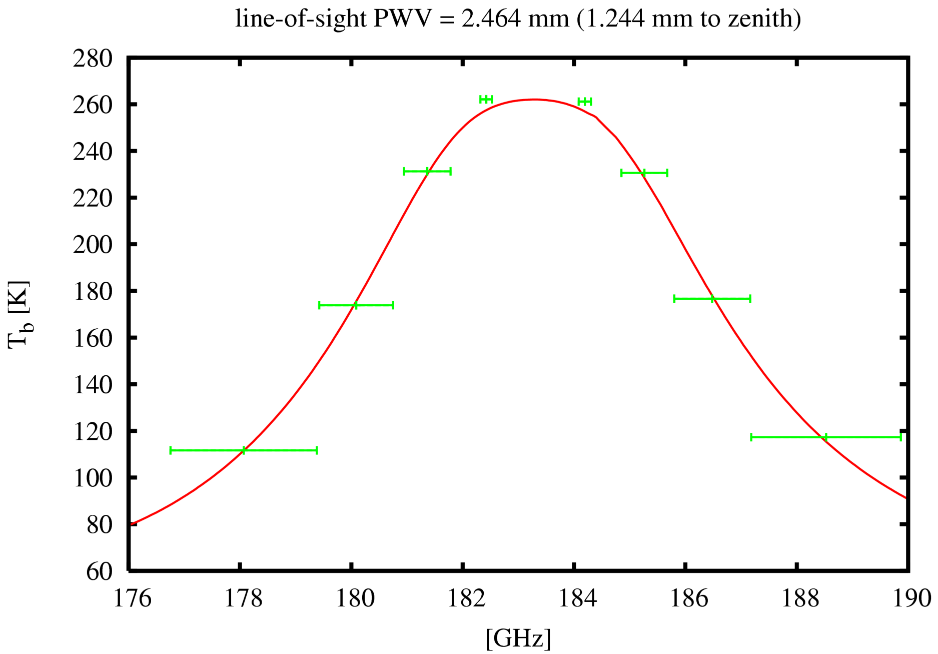
- Tried *am* model fits to ALMA WVR channel data.
- Various approaches to fitting H_2O profile
  - Scale median chilled-mirror sonde profile
  - Two-step profiles
- PWV estimates from *am* fits are no better than simpler approach applying direct coefficients to channel temperatures.
- Model is a useful tool for analyzing systematics, e.g. optical loss and spillover in WVR-SMA system

Fitting WVR data (correlator version)

am-readable data file:

```
.
.
set za 59.686000 deg
set layer 8 Pbase 619.000000 mbar
set layer 8 Tbase -0.500000 C
set Nscale h2o 0.504739
 178.066  111.805    2.626   1.0000
 180.087  173.976    1.327   1.0000
 181.363  231.385    0.836   1.0000
 182.422  262.660    0.210   1.0000
 184.194  261.502    0.221   1.0000
 185.262  230.879    0.822   1.0000
 186.482  176.603    1.366   1.0000
 188.527  117.382    2.688   1.0000
end
set za 59.677000 deg
set layer 8 Pbase 619.000000 mbar
set layer 8 Tbase -0.600000 C
set Nscale h2o 0.504874
 178.066  111.625    2.626   1.0000
 180.087  173.866    1.327   1.0000
 181.363  231.245    0.836   1.0000
 182.422  262.129    0.210   1.0000
 184.194  261.141    0.221   1.0000
 185.262  230.639    0.822   1.0000
 186.482  176.623    1.366   1.0000
 188.527  117.292    2.688   1.0000
end
.
.
```

telescope elevation and met. data

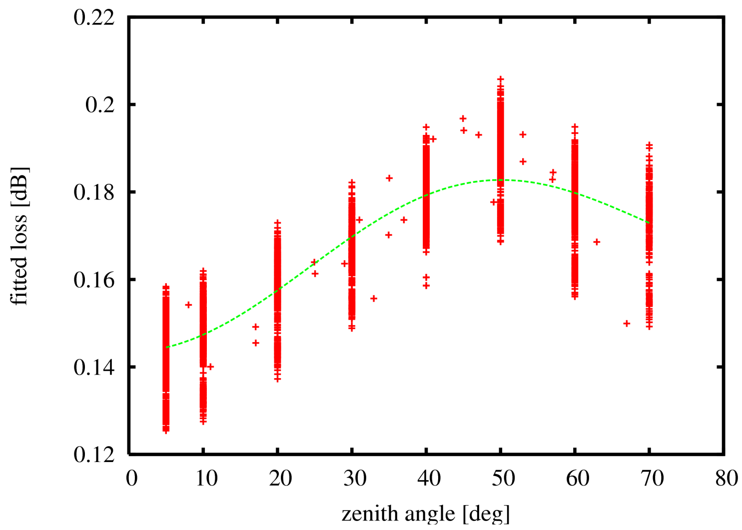


Analyzing WVR loss and spillover

```
.
.
layer
Pbase 630 mbar
T 267 K
column n2air hydrostatic
column n2o hydrostatic
column o2 hydrostatic
column h2o 100 um_pwv 10 um_pwv

layer
Pbase 630 mbar
T 285 K
column atten 0.2 dB 0.05 dB
```

Put variable loss at base of model, and fit multiple skydips




```
.
.
layer
Pbase 630 mbar
T 267 K 1 K
column n2air hydrostatic
column n2o hydrostatic
column o2 hydrostatic
column h2o 200 um_pwv 10 um_pwv

layer
Pbase 630 mbar
T 285 K
column atten 0.1435 dB
column atten_sin^2(za) 0.0201 dB
column atten_sin^2(2za) 0.0284 dB
```

Put resulting fitted elevation dependence into model

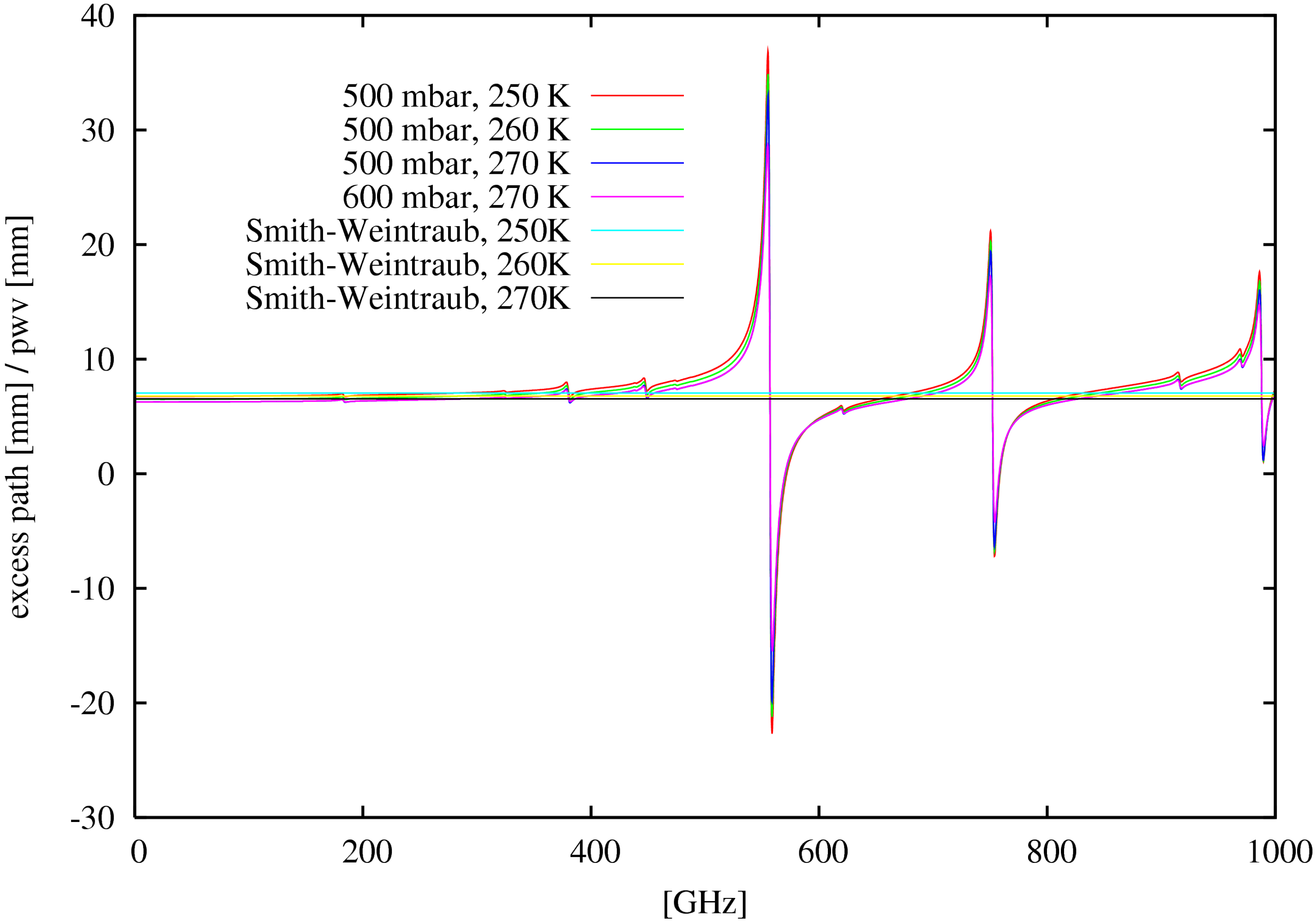
- Loss was comparable to expectation for optics design (R. Williamson)

Phase Transfer

- Need to transfer delay estimate from WVR frequency to observing frequency, or perhaps between observing frequencies.
- In the submillimeter, dispersion in wet delay cannot be neglected:

f [GHz]	*Lw* [mm] / PWV [mm] @ P=600 mbar, T=270 K
230	6.4
345	6.7
460	7.2
490	7.7
690	6.8

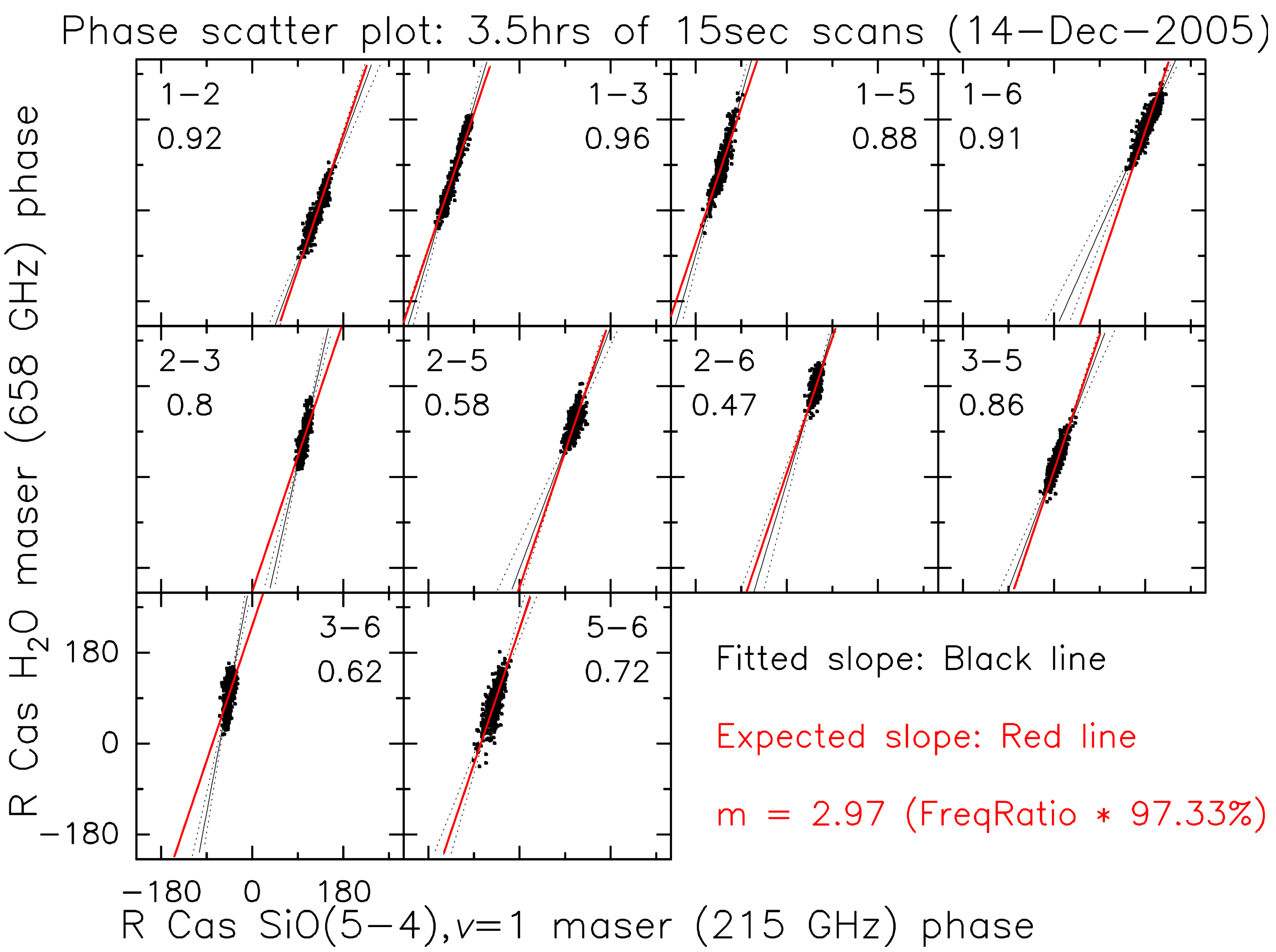
Computed wet delay versus Smith-Weintraub



Phase transfer at the SMA (T. Hunter, 2005 Dec.)

- Looked at a bright astronomical source (R Cas.) with two receivers, at two frequencies (215 GHz SiO maser and 658 GHz H_2O maser)
- Compared simultaneous phase fluctuations between frequencies on all baselines (for 5 antennas) for 3.5 hours of 15 s integrations.
- From *am*, $Lw_{658} / Lw_{215} = 0.97$, so the expected phase ratio is 0.97 * (658 / 215) = 2.97

Phase transfer at the SMA



(T. Hunter, SMA)

Phase transfer at the SMA

- Agreement between expected and measured dispersion was good on some baselines, but not on others
- Differences may reveal system problems (system software or atmospheric delay model)
- Accurately computed wet delay is important in interpreting results

See http://cfarx6.harvard.edu/am for

- Source code
- Documentation
- Configuration file cookbook