# Submm Calibration

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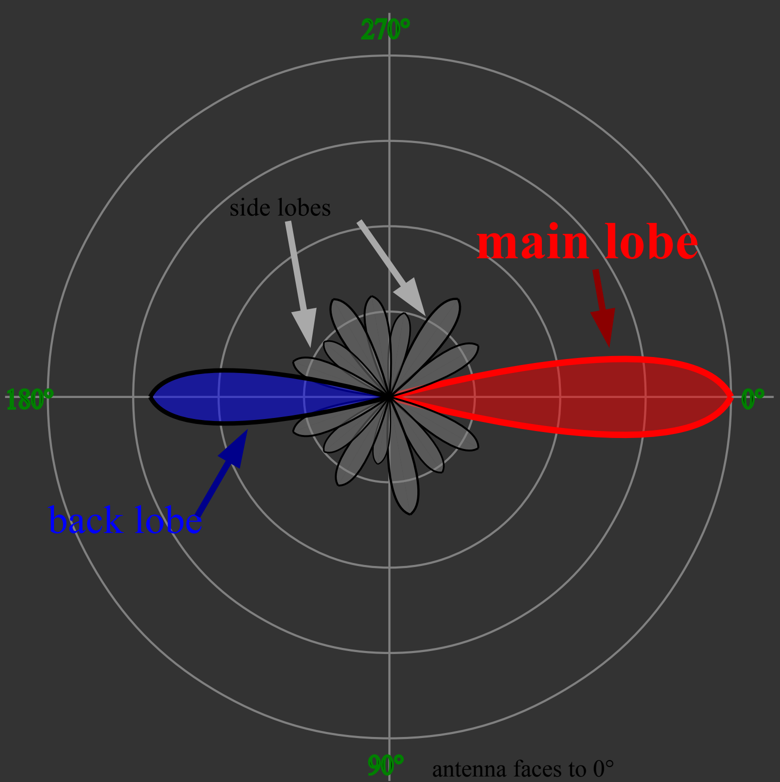
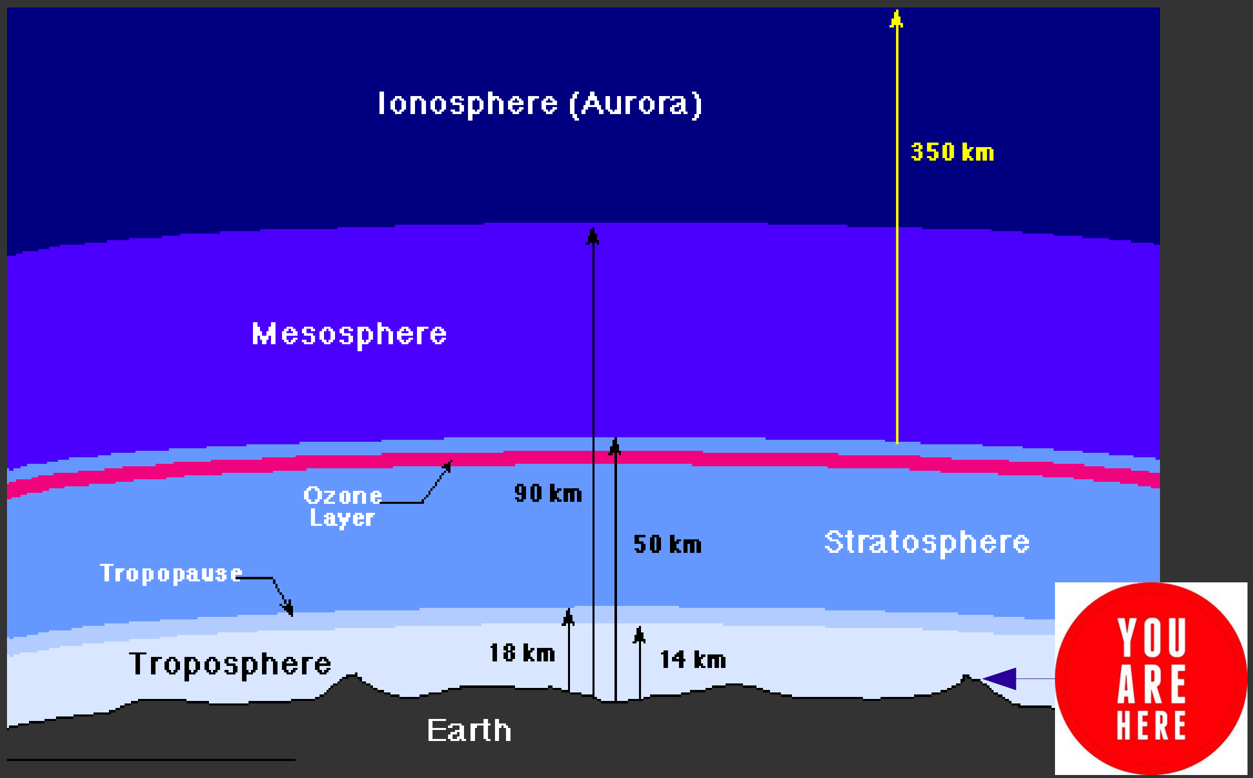
APEX Training – MPIfR – 2014 March 6

# Calibration - two goals:

Opacity correction

… and phase correction → ALMA

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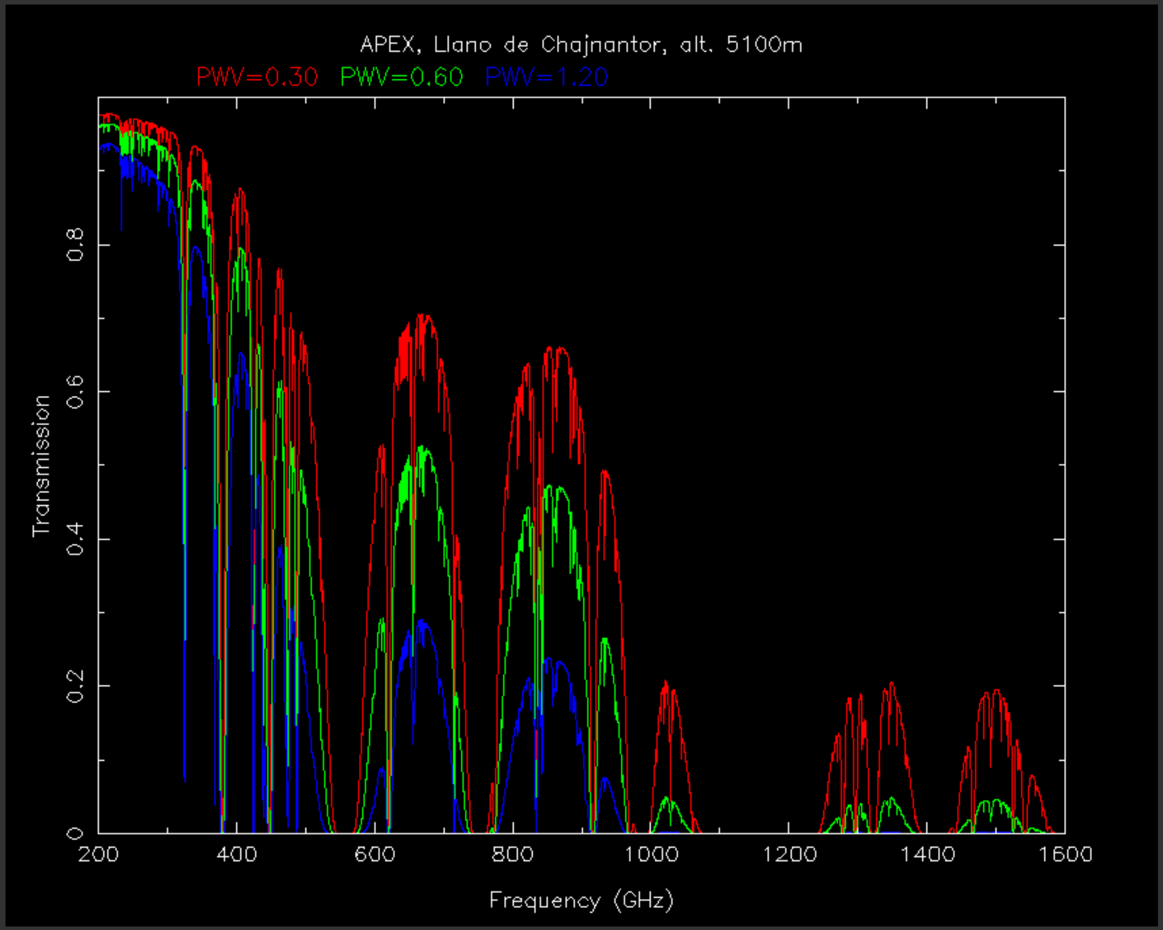
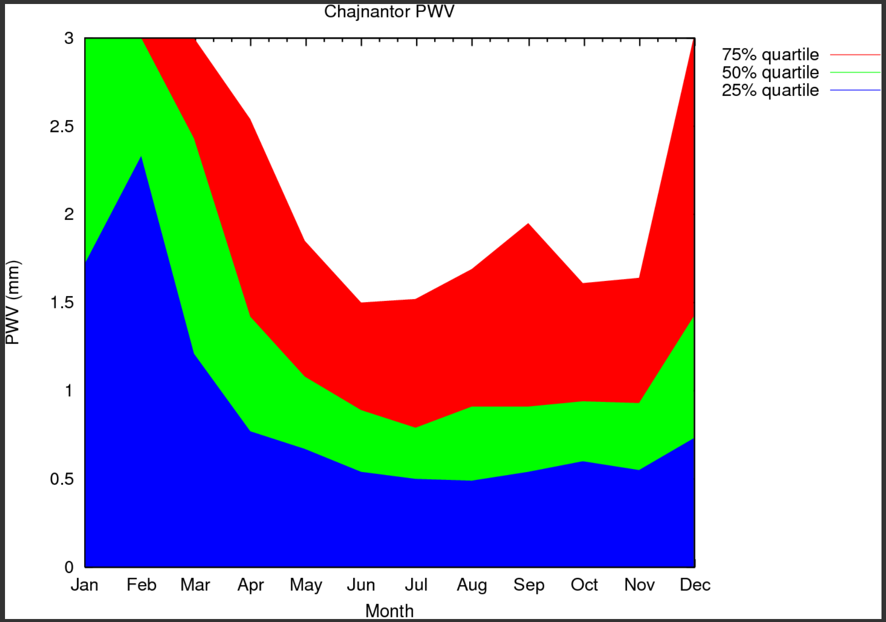
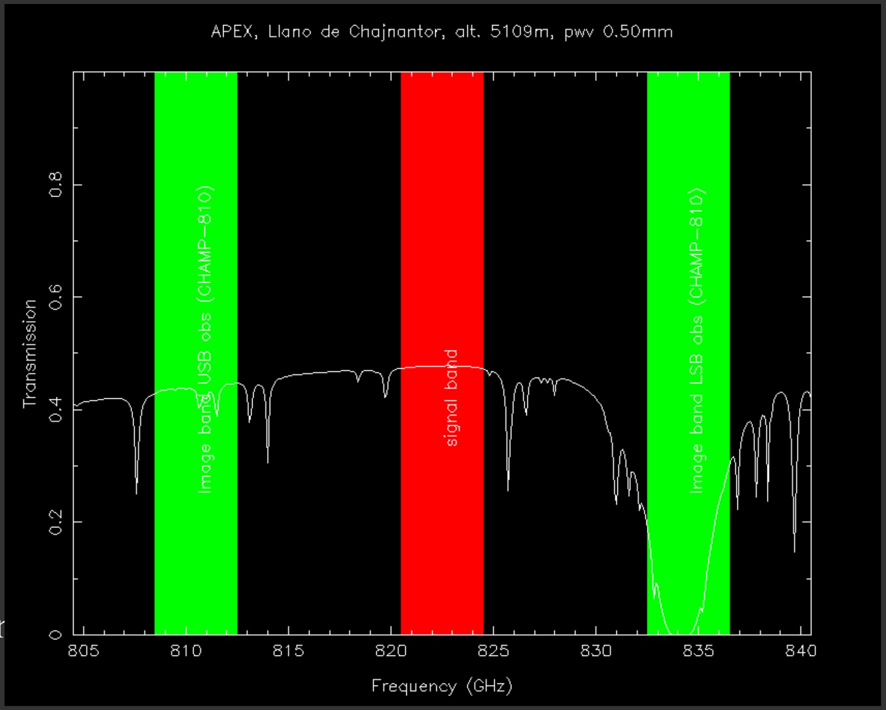
Temperature calibration... but of what ?

# Atmospheric Transmission at Chajnantor

http://www.apex-telescope.org/sites/chajnantor/atmosphere/



# Basic Equations: "CSO" method

- Prerequesite: Receiver and backend are LINEAR.

  $V_{hot} = G(T_{amb} + T_{rx})$

  $V_{sky} = G\{F_{eff}\ T_{sky}\ (1-e^{-\tau}) + (1-F_{eff})T_{amb} + T_{rx}\}$

  $\Delta V_{cal} = V_{hot} - V_{sky} = G\ F_{eff}\ T_{amb}\ \exp(-\tau)$ if $T_{amb} = T_{sky}$ (e.g., CSO)

  $\Delta V_{sig} = V_{on} - V_{off} = G\ T_A'\ \exp(-\tau)$

- Antenna Temperature ($T_A^*$) → forward-beam brightness temperature outside atmosphere: $T_A^* = T_A' / F_{eff}$

- *Fictive* temperature useful for the "chopper wheel" calibration method: $T_A^* = T_{amb}\ \Delta V_{sig}\ / \Delta V_{cal}$

- Generalized case: $T_{amb} \neq T_{sky}$, different G factors for signal and image band, Rayleigh-Jeans approximation invalid.

# Opacity correction

Calibration measurement (every 5-15 minutes):

calibrate('cold') → observes sky (reference position), hot load, cold load (10 sec each) → count rates $C_{sky}$ ,$C_{hot}$, $C_{cold}$

Yields count rate to power conversion:

$r = (P_{hot}-P_{cold}) / (C_{hot}-C_{cold})$ with

$P_{load} = [\ B(T_{load},\nu_s)+gB(T_{load},\nu_i)\ ] / [1+g]$

(g is the sideband gain ratio)

Calculate power received from sky:

$P_{sky}= P_{hot}+r(C_{sky}-C_{hot})$ but correct for spillover

Determine pwv from comparison of $P_{sky}$ with atmospheric model (ATM, Pardo et al. 2001) → opacity correction:

$\tau_{\nu,Z} = a(\nu, p_{amb}) + b(\nu, p_{amb})$ pwv

# Flux Calibration

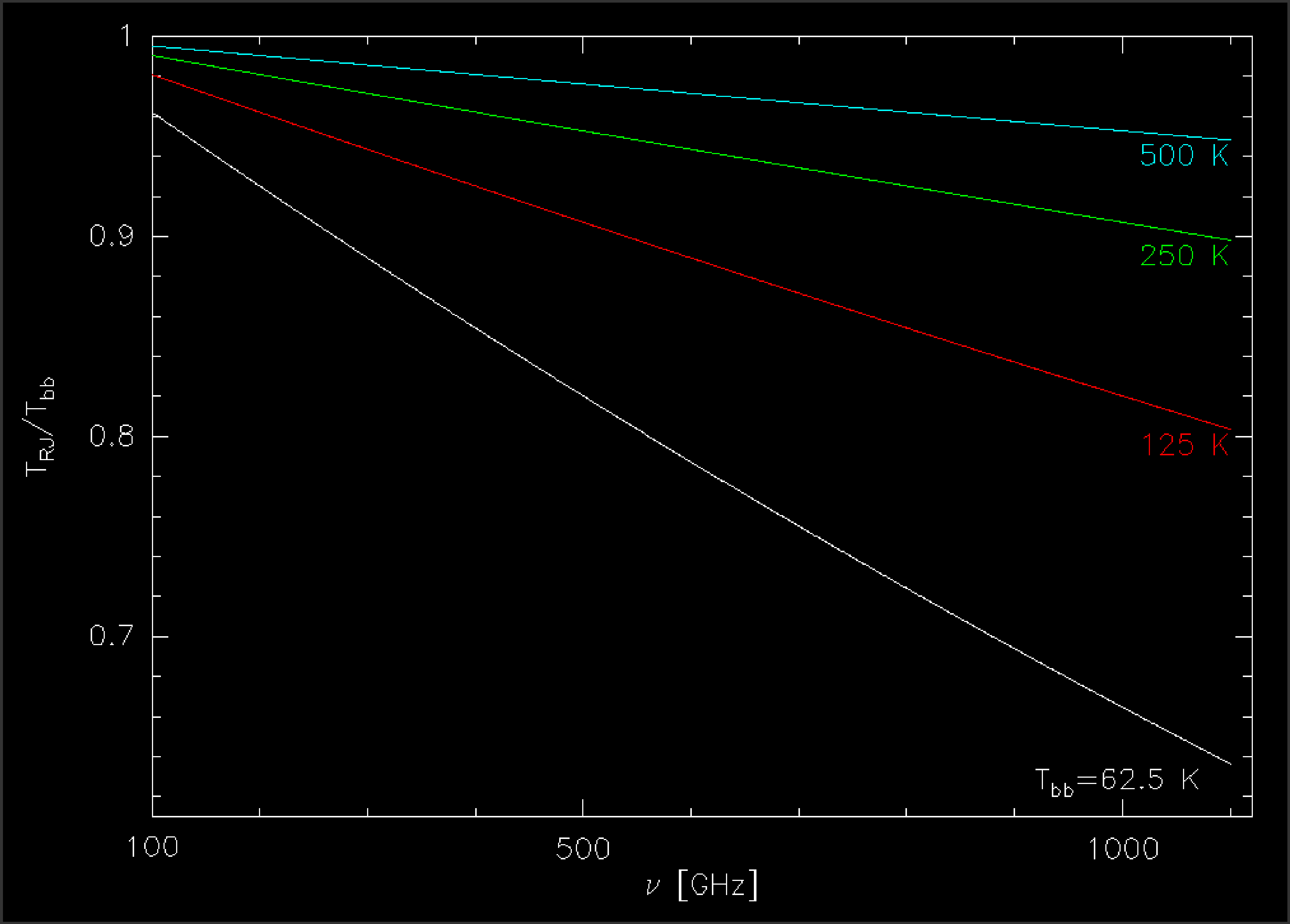
$T^*_A = T_{cal}\, \Delta V_{sig} \,/\, \Delta V_{cal}$ with

$$\begin{aligned} T_{\rm cal} \;=\;& (1+G_{\rm im})\Big[J(\nu_{\rm s},T_{\rm ATM}) - J(\nu_{\rm s},T_{\rm bg})\Big] \\ &+(1+G_{\rm im})\Big[J(\nu_{\rm s},T_{\rm cab}) - J(\nu_{\rm s},T_{\rm ATM})\Big]\exp(\tau_{\rm s}A) \\ &+G_{\rm im}\Big[J(\nu_{\rm s},T_{\rm ATM}) - J(\nu_{\rm s},T_{\rm bg})\Big]\Big[\exp((\tau_{\rm s}-\tau_{\rm i})A) - 1\Big] \\ &+(1+G_{\rm im})/F_{\rm eff}\Big[J(\nu_{\rm s},T_{\rm chop}) - J(\nu_{\rm s},T_{\rm cab})\Big]\exp(\tau_{\rm s}A) \end{aligned}$$

where $J(\nu,T)$ are Rayleigh-Jeans temperatures:

$J(\nu,T) = B_\nu(T)\, c^2/(2k_B\nu^2)$

# Rayleigh Jeans Correction



# Temperature Scales

**Table 3.** Equations for antenna temperature and brightness temperature.

| | Antenna temperature, $T_a'$ (temperature of equivalent resistor) | Brightness temperature, $T_b$ (temperature of equivalent black body) |
|---|---|---|
| in general: | $S = \frac{2k}{A_e} \frac{\int T_a' \, d\Omega_r}{\int P \, d\Omega_b}$ | $S = \frac{2k}{\lambda^2} \int T_{mb} \, d\Omega_r = \frac{2k}{\lambda^2} \int T_b \, d\Omega_s$ |
| point source: | $S = \frac{2k}{A_e} T_a'$ | $S = \frac{2k}{\lambda^2} T_{mb} \, \Omega_b$ |
| gaussians: | $S = \frac{2k}{A_e} T_a' \frac{\theta_r^2}{\theta_b^2}$ | $S = \frac{2k}{\lambda^2} T_{mb} \, 1.133 \, \theta_r{}^2$ |
| formulae: | $\frac{S}{\mathrm{Jy}} = \frac{3516}{\epsilon_{ap}} \frac{D^{-2}}{\mathrm{m}^{-2}} \frac{T_a'}{\mathrm{K}}$ | $\frac{S}{\mathrm{Jy}} = 2.64 \frac{\lambda^{-2}}{\mathrm{cm}^{-2}} \frac{T_{mb}}{\mathrm{K}} \frac{\theta_r^2}{\mathrm{arcmin}^2}$ (for gaussians) |

Downes, Radio Astronomy Techniques (1989), Lect. Notes Phys. 333, 351

# Conversion to meaningful flux units

- Main-beam averaged temperature of equivalent black body:

  $T_{mb} = T'_A/B_{eff} = T^*_A\, F_{eff} / B_{eff}$

- Practical use: same for different telescopes if the source is spatially resolved.
- Equivalent flux unit: Jy/beam, i.e.,

  $S = 2k_B\, T_{mb}\, \Omega_{mb}/\lambda^2$

- Values known for primary and secondary calibrators.

# Calibration in practice

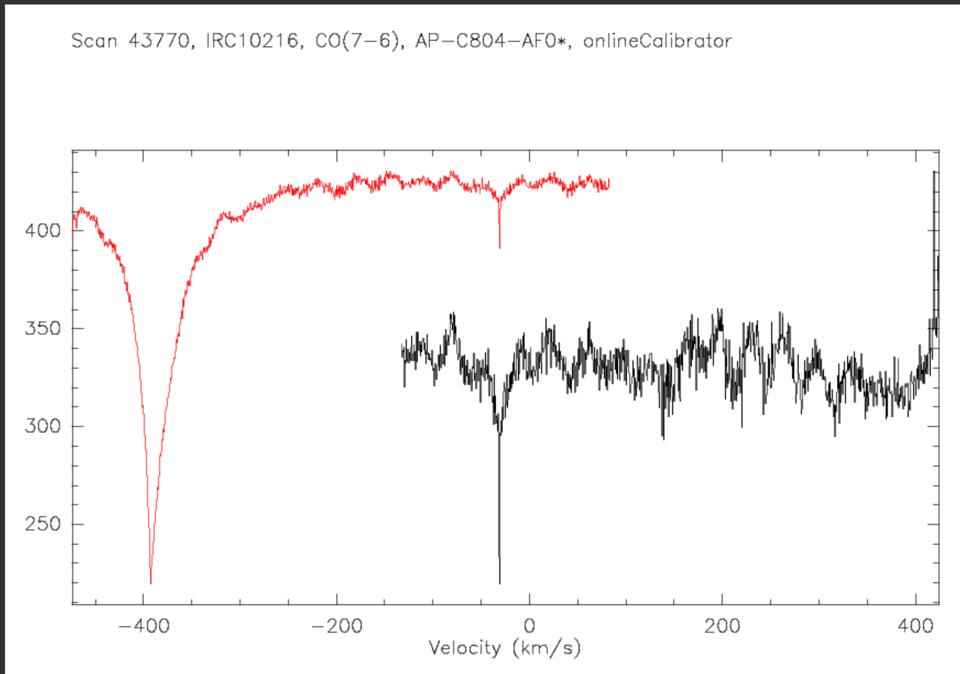
- Low water vapor (pwv < 1mm): use radiometer if no convergence.
- Only one opacity used for a spectral baseband (=CLASS spectrum).
- The calibrator cuts a baseband into 10 sub-bands from which an average opacity correction is derived.
- If one baseband contains a strong atmospheric feature, this leads to “platforming” in the resulting spectrum (i.e., the concatenated basebands) → use apexOfflineCalibrator with

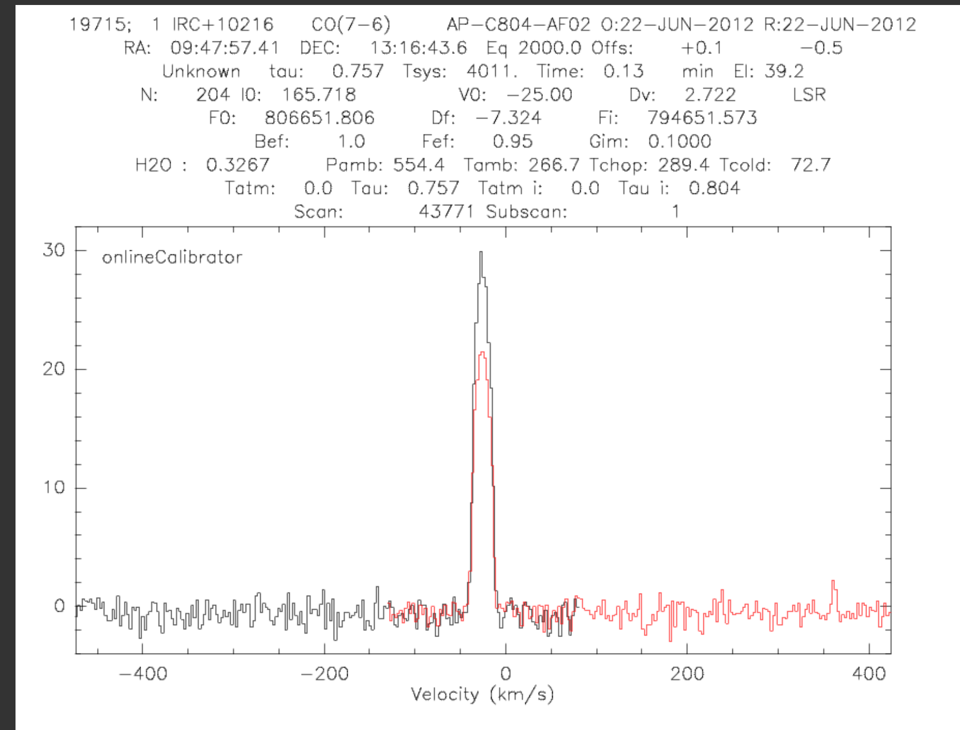
```
setCalMode('newATM',calResolution='atmRes')
```

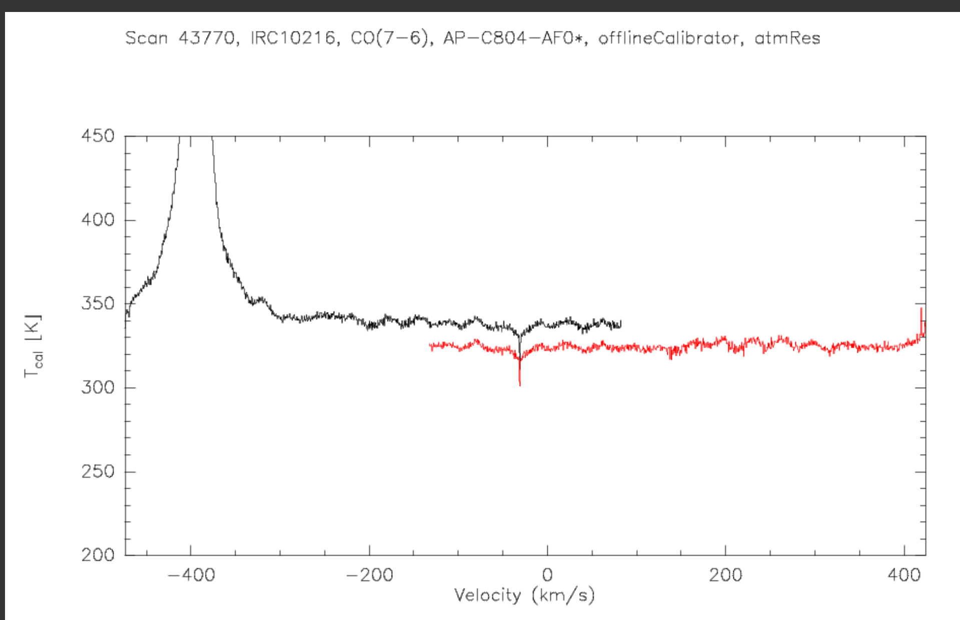
→ recommended: chunks of 128 channels (4.88 MHz for XFFTS)

```
setCalMode('newATM',calResolution='full')
```

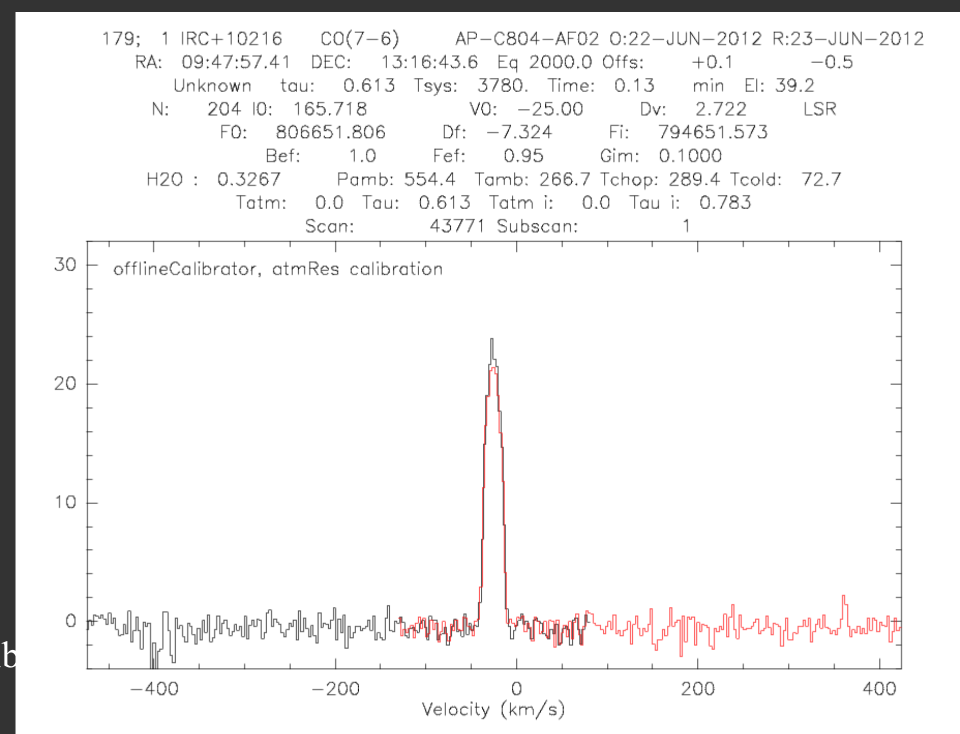
→ time consuming, granularity.


Scan 43770, IRC10216, CO(7−6), AP−C804−AF0*, onlineCalibrator
400
350
300
250
−400
−200
0
200
400
Velocity (km/s)


19715; 1 IRC+10216 CO(7−6) AP−C804−AF02 O:22−JUN−2012 R:22−JUN−2012
RA: 09:47:57.41 DEC: 13:16:43.6 Eq 2000.0 Offs: +0.1 −0.5
Unknown tau: 0.757 Tsys: 4011. Time: 0.13 min El: 39.2
N: 204 I0: 165.718 V0: −25.00 Dv: 2.722 LSR
F0: 806651.806 Df: −7.324 Fi: 794651.573
Bef: 1.0 Fef: 0.95 Gim: 0.1000
H2O : 0.3267 Pamb: 554.4 Tamb: 266.7 Tchop: 289.4 Tcold: 72.7
Tatm: 0.0 Tau: 0.757 Tatm i: 0.0 Tau i: 0.804
Scan: 43771 Subscan: 1
onlineCalibrator
30
20
10
0
−400
−200
0
200
400
Velocity (km/s)


Scan 43770, IRC10216, CO(7−6), AP−C804−AF0*, offlineCalibrator, atmRes
450
400
350
300
250
200
T_cal [K]
−400
−200
0
200
400
Velocity (km/s)

n Calib


179; 1 IRC+10216 CO(7−6) AP−C804−AF02 O:22−JUN−2012 R:23−JUN−2012
RA: 09:47:57.41 DEC: 13:16:43.6 Eq 2000.0 Offs: +0.1 −0.5
Unknown tau: 0.613 Tsys: 3780. Time: 0.13 min El: 39.2
N: 204 I0: 165.718 V0: −25.00 Dv: 2.722 LSR
F0: 806651.806 Df: −7.324 Fi: 794651.573
Bef: 1.0 Fef: 0.95 Gim: 0.1000
H2O : 0.3267 Pamb: 554.4 Tamb: 266.7 Tchop: 289.4 Tcold: 72.7
Tatm: 0.0 Tau: 0.613 Tatm i: 0.0 Tau i: 0.783
Scan: 43771 Subscan: 1
offlineCalibrator, atmRes calibration
30
20
10
0
−400
−200
0
200
400
Velocity (km/s)

Literature:

Downes, Radio Astronomy Techniques (1989), Lect. Notes Phys. 333, 351

Polehampton, E. Hafok, H., APEX Calibration and Data Reduction Manual, 2010, APEX-MPI-MAN-0012

(on observer@display2:calibrator_man.pdf)