Broadband submillimeter measurements of planetary brightness temperatures

Herschel Calibration Workshop
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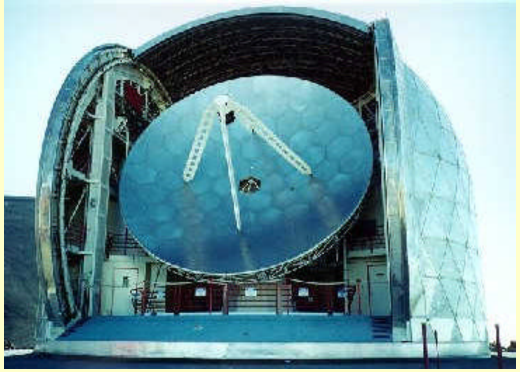
Juan R. Pardo, Departamento de Astrofísica Molecular e Infraroja, CSIC (Spain)
Gene Serabyn, California Institute of Technology (USA)

OUTLINE

- Goals of experiment.
- Instrument setup.
- Calibration procedures.
- Data acquisition and reduction.
- Off line data analysis.
- Main results.
- Recent improvements & results.
- Implications for Herschel.



Goals of the experiment

- Measurement of broadband absolute brightness temperature for the giant planets. Get around the problem of scattered meas.
- Measurement of broad lines from the main constituents of the giant planets.
- Search for key species in Venus.
- Establish data base for calibration purposes.

Frequency range

- 0.2-1.1 THz; 7-33 cm-1 / Resl. up to 5000
- Longward of ISO, overlap with Herschel.

Science Issues

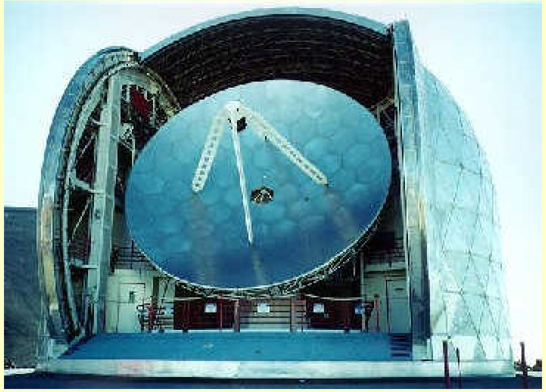
- Compositional differentes.
- Temperature structure.
- Vertical transport rates.
- Photolysis cycles.
- NH_3 lineshape, collision induced absorption...

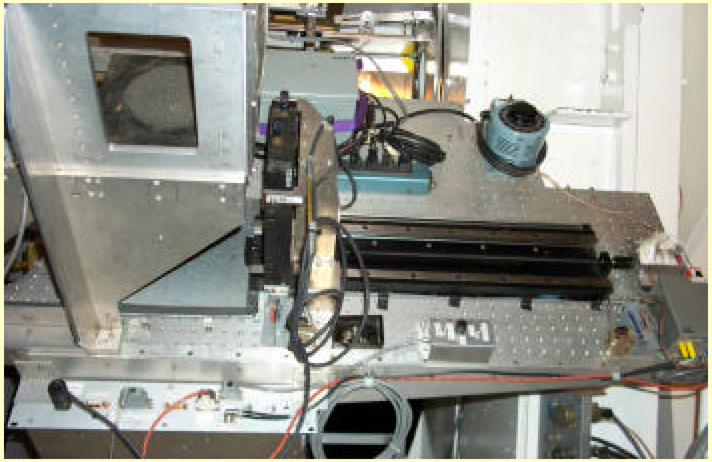
Observational requirements

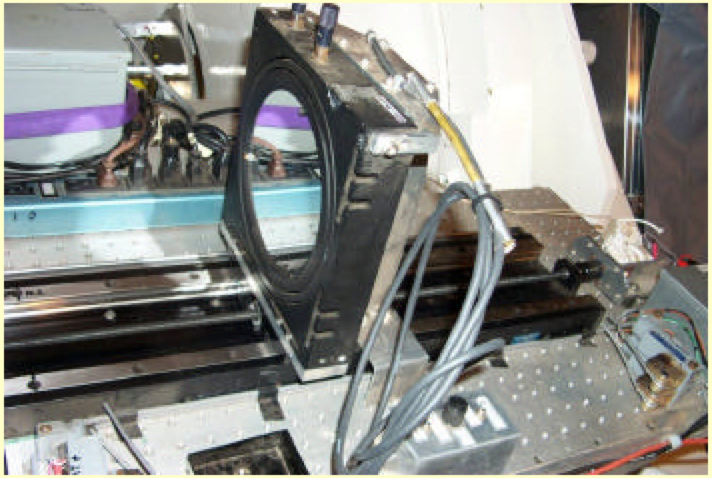
- Broadband requires FTS.
- Accurate atmospheric correction.
- Accurate beam coupling/efficiency corrections.
- Accurate flux calibration.

Experimental setup

Fourier Transform Spectrometer at the Caltech Submillimeter Observatory

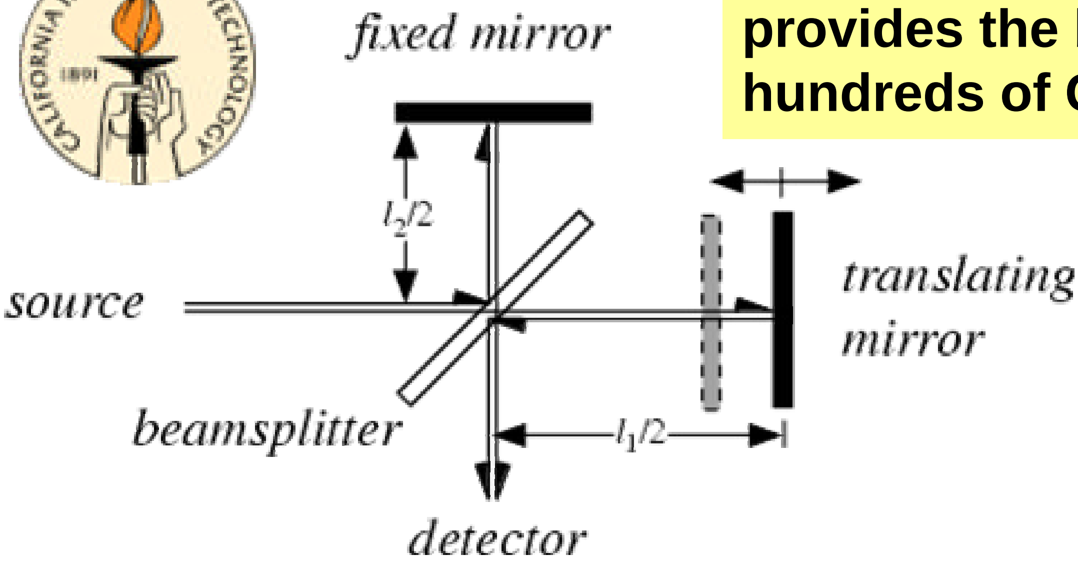






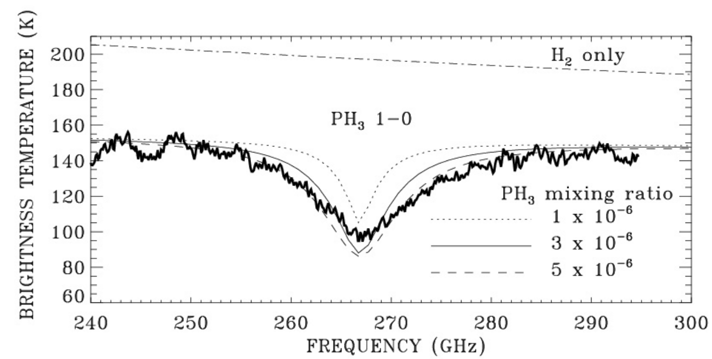
- ^{3}He cooled bolometer.
- 46 cm moving arm (200 MHz maximum resolution)
- Mounted on the Cassegrain focus of telescope.
- FOV of Winston Cones: 10", 20" & 30".
- Frequency filters to cover different atmospheric windows.
- Mounted 2-3 times per year for dedicated planetary & atmospheric measurements.

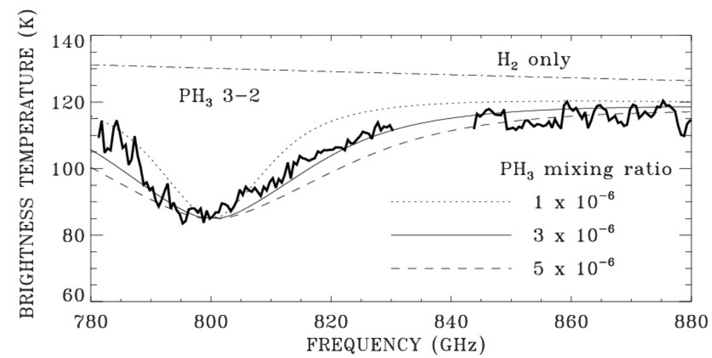
The instrument is simple but currently provides the best broadband (from tens to hundreds of GHz) submillimeter data.

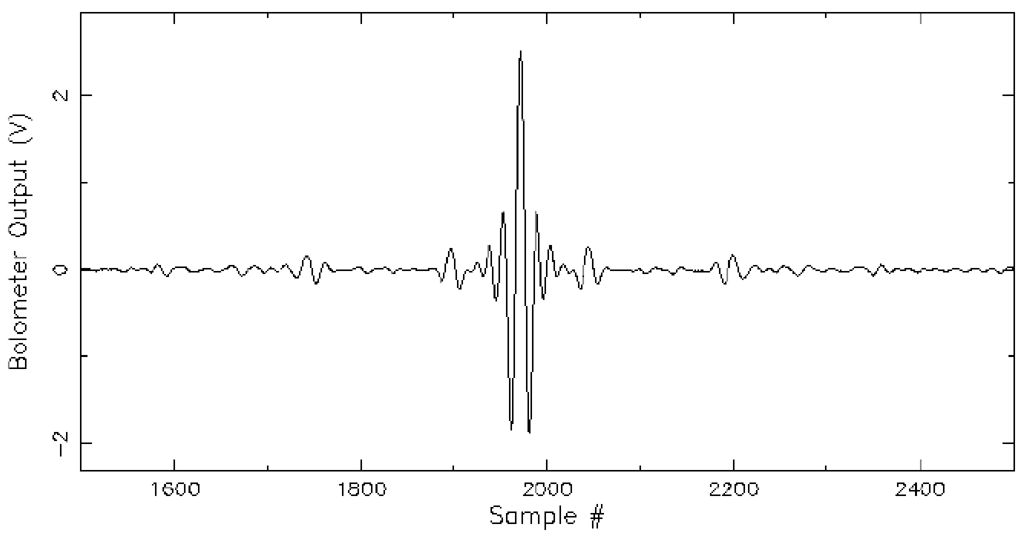


RESULTS OBTAINED IN THE PAST

First detection of PH_3 in Saturn





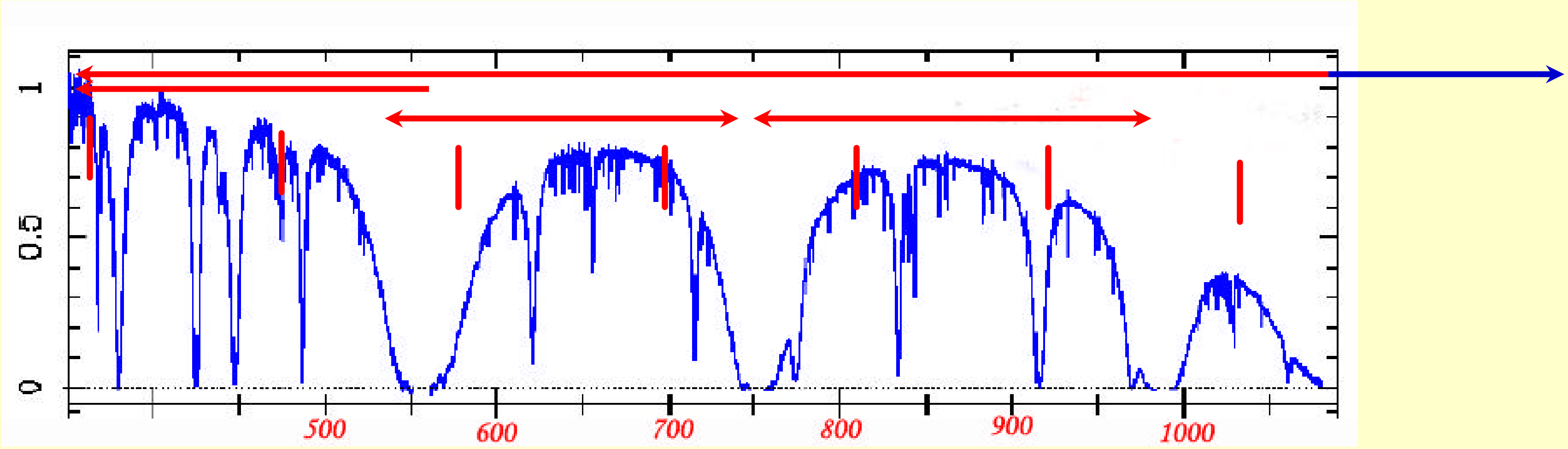


Two sided interferogram

Weisstein, E.W., Serabyn, E., Icarus, 123/1, 23-36 (1996).

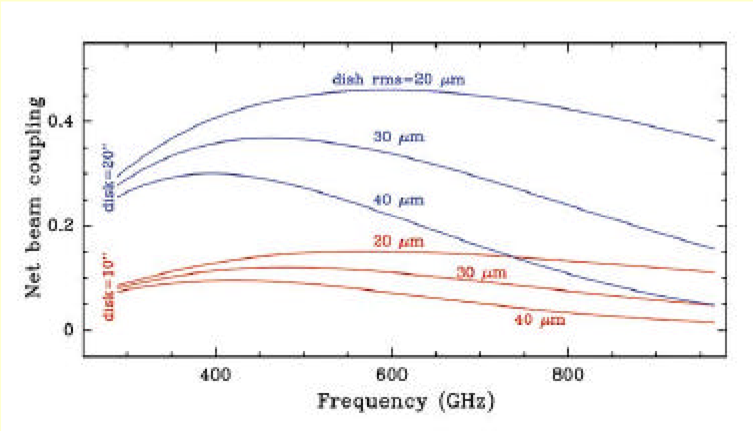
FTS: Available filters

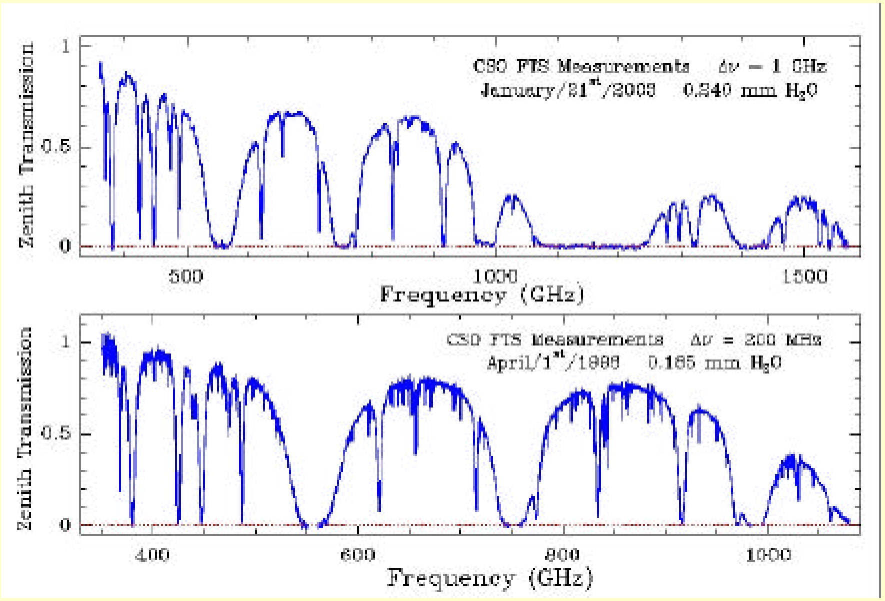
- CO: Doble Fabry-Perot designed to explore CO freqs.
- 550 GHz (low pass): to explore the low frequencies.
- 650 GHz: To explore 450 µm window.
- 850 GHz: To explore 350 µm.
- 750 GHz: To simultaneously explore the last two.
- 1.1 THz (low pass): To explore 300-1100 GHz.
- 1.6 THz (low pass): To explore 300-1600 GHz.



Calibration

We have to deal with two problems:





Coupling and efficiency terms

The Atmosphere

These two problems combined make extremely difficult to compare planetary measurements obtained in narrow bands with different intruments at different dates.

Calibration: The atmosphere

$$m(\nu) = \frac{V_{sou} - V_{sky}}{V_{ground} - V_{sky}}$$

is our measurement, where:

- $V_{sou} = G(\nu)\left[\eta_{sou}(\nu)P_{sou}(\nu) + (1-\eta_{sou}(\nu))P_{bgr}(\nu)\right]e^{-\tau_t(\nu)} +$
  $+ \; G(\nu)\left[\eta_{sky}(\nu)P_{sky}(\nu) + (1-\eta_{sky})P_{hot}\right]$
- $V_{sky} = G(\nu)\left\{\eta_{sky}(\nu)\left[P_{sky}(\nu) + P_{bgr}(\nu)e^{-\tau_t(\nu)}\right] + (1-\eta_{sky})P_{hot}\right\}$
- $V_{ground} = G(\nu)\eta_{hot}(\nu)P_{hot}(\nu)$; η_{hot}=1.0.

P: Spectra emitted by the different sources, h: Couplings to these sources, G: Optical-electrical gain factor

$$m(\nu) = \frac{\left[\eta_{sou}(\nu)P_{sou}(\nu) + (1-\eta_{sou}(\nu)-\eta_{sky}(\nu))P_{bgr}(\nu)\right]e^{-\tau_t(\nu)}}{\eta_{sky}\left[P_{hot}(\nu) - P_{sky}(\nu) + P_{bgr}(\nu)e^{-\tau_t(\nu)}\right]}$$

We want to extract: $T_{EBB,sou}(\nu)$

...after rearranging the equation

$$m(\nu) = \frac{\eta_{sou}(\nu)}{\eta_{sky}(\nu)} \frac{\frac{e^{-\tau_t}}{exp(h\nu/KT_{EBB,sou})-1}}{\frac{1}{exp(h\nu/KT_{hot})-1} - \frac{1-e^{-\tau_t}}{exp(h\nu/KT_e)-1}}$$

Two possibilities:

- $T_e(\tau_t,n) = T_{hot}$ (standard CSO T_A^* calibration)

$T^*_{PL,A} = m(\nu)(h\nu/k)[exp(h\nu/kT_{hot})-1]^{-1} =$

$(\eta_{sou}/\eta_{sky})\ (h\nu/k)[exp(h\nu/kT_{hot})-1]^{-1}$

Essentially TEBB,sou
except for coupling terms

Pardo, J.R., Serabyn, E., and Cernicharo, J., JQSRT, 68:419, 2001

- $T_e(\tau_t,n) = T_{hot} - LH\, f(\tau_t)$

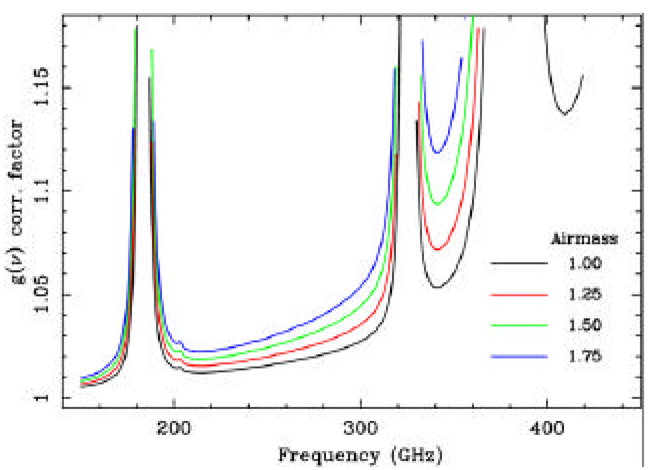
Mauna Kea

L: Tropospheric lapse rate 5.6 K(km)

H: Water vapor scale height 2.0 km

$$\mathbf{g}(t_t,n) = \left\{1 + \frac{LHf(\tau_t)}{T_{hot}} \left(\frac{h\nu/KT_{hot}}{1 - exp(-h\nu/KT_{hot})}\right)(e^{\tau_t} - 1)\right\}$$

g$(t_{t,}n)$



$T^{**}_{PL,A} = T^*_{PL,A}\ g(\nu) = (\eta_{sou}/\eta_{sky})\ (h\nu/k)[exp(h\nu/kT_{hot})-1]^{-1}\ g(\nu)$

PRIMARY CALIBRATION OBJECT: THE MOON

• Coupling and efficiency loses are not an issue on the Moon.

Requirement:

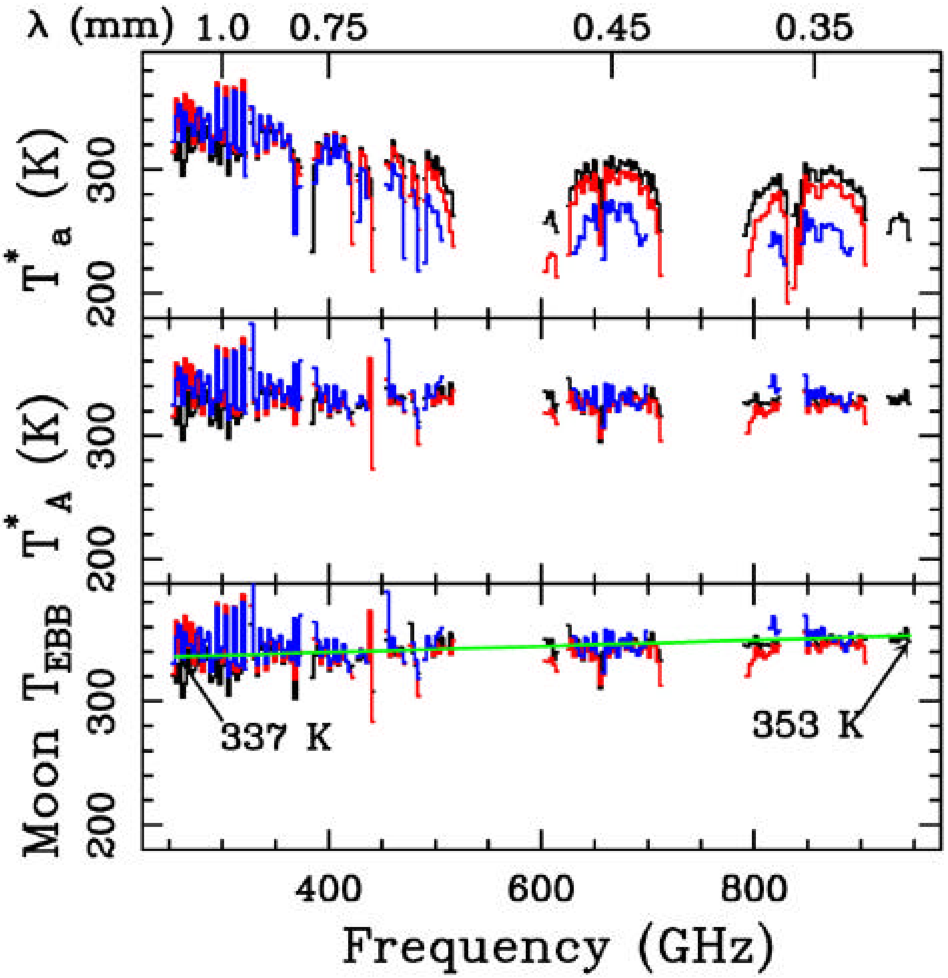
• Full Moon.

Problem:

• Standard calibration scheme not accurate for high τ due to vertical temperature gradient.

We need:

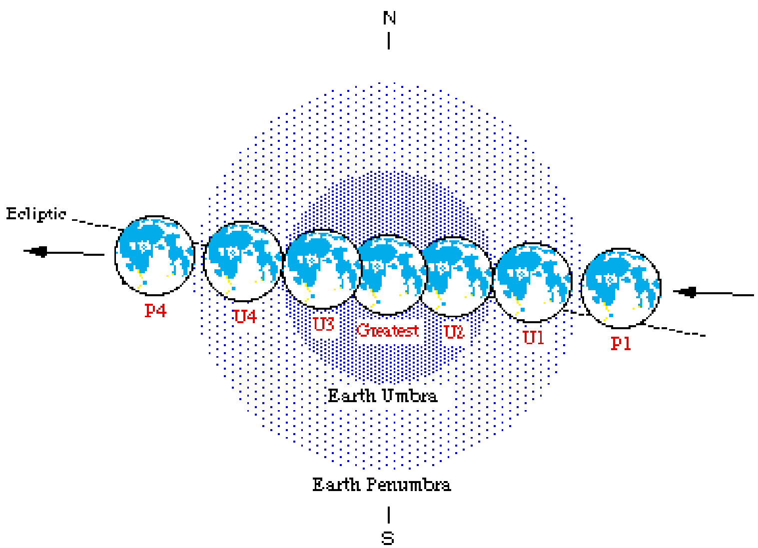
• τ-dependent correction scheme (it can be derived)



Elv=45º 0.5 mm H_2O 1.0 mm H_2O

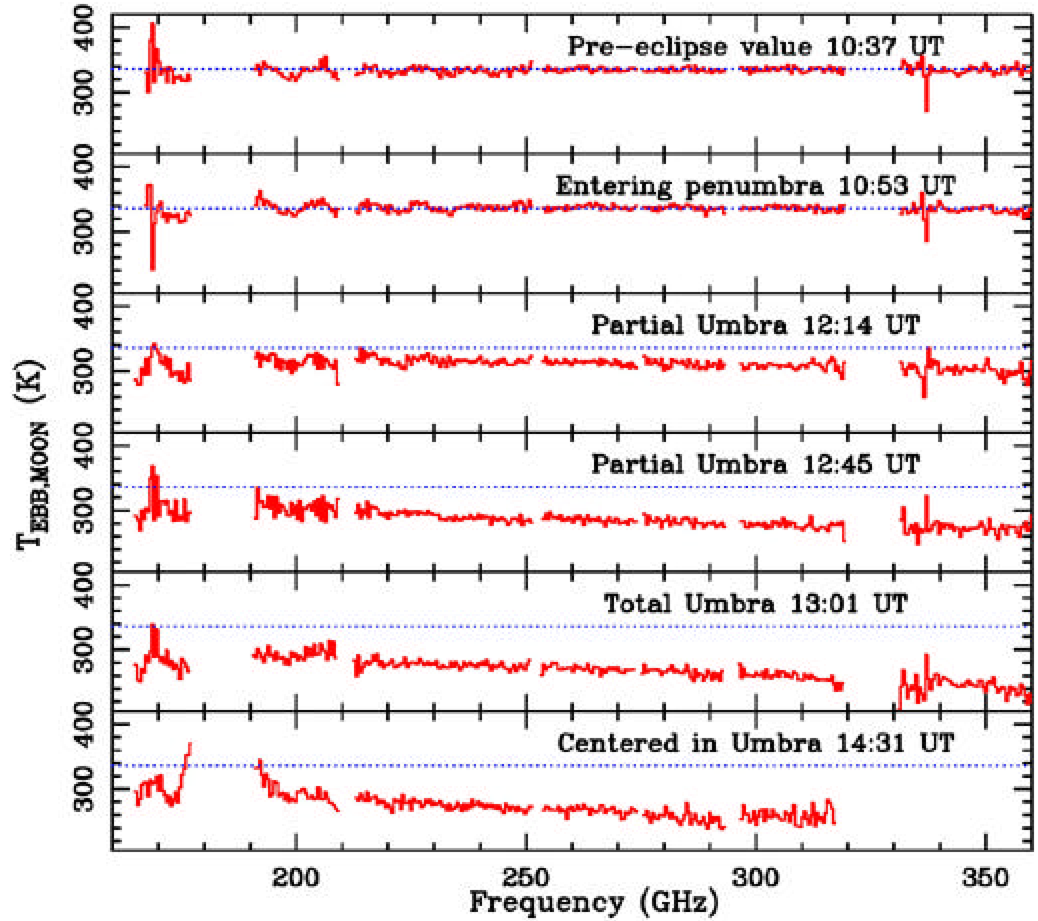
n(GHz)	tatm	f(t)	g(n)	tatm	f(t)	g(n)
345	0.1396	0.9653	1.0061	0.2492	0.9385	1.0112
460	0.6300	0.8485	1.0318	1.1741	0.7295	1.0696
650	0.8760	0.7932	1.0483	1.6486	0.6381	1.1163
850	1.0065	0.7649	1.0586	1.8223	0.6069	1.1390

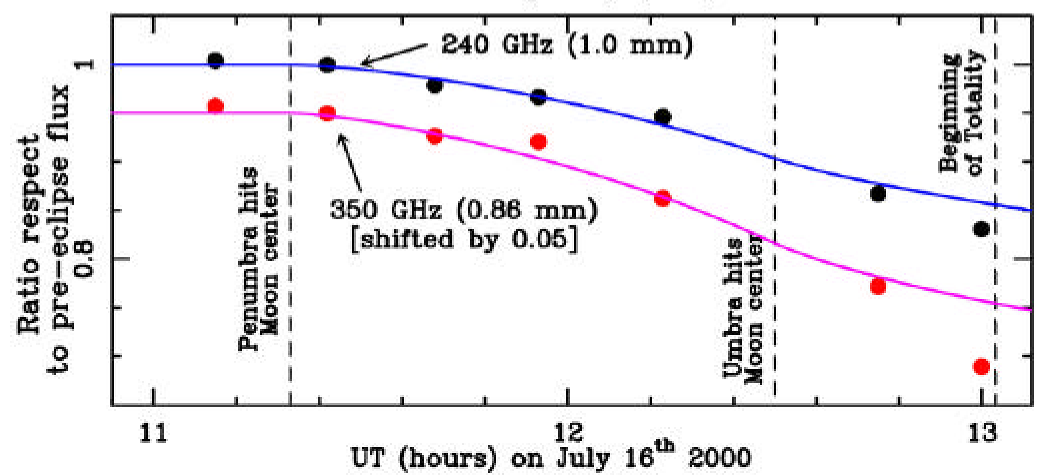
Application: Total Lunar eclipse of July 16th, 2000



Expected behavior:
Fastest temperature drop at shortest wavelengths due to less penetration.

Pardo, J.R., Serabyn, E., Wiedner, M.C., Icarus, submitted.

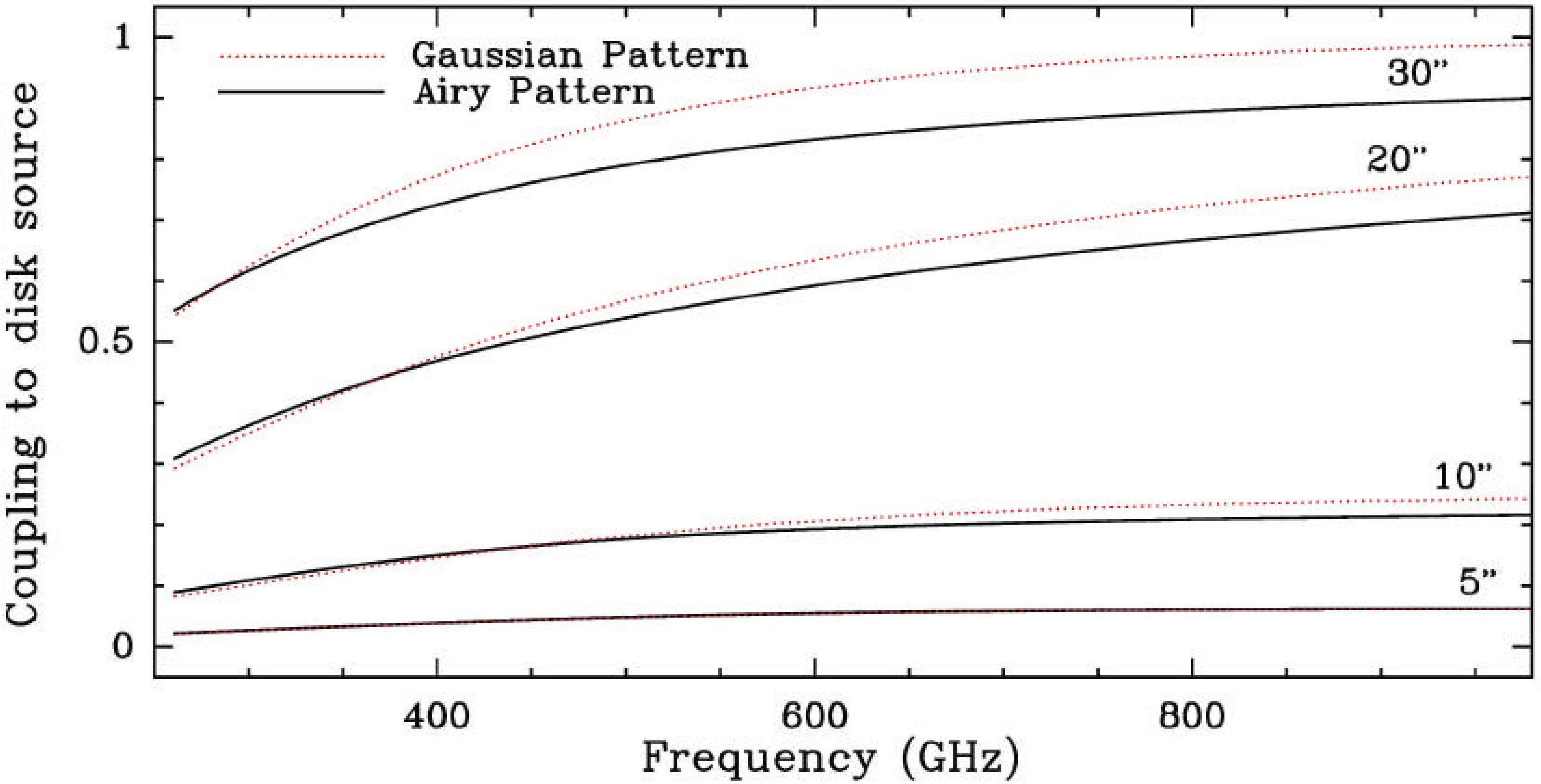




Calibration: Instrumental

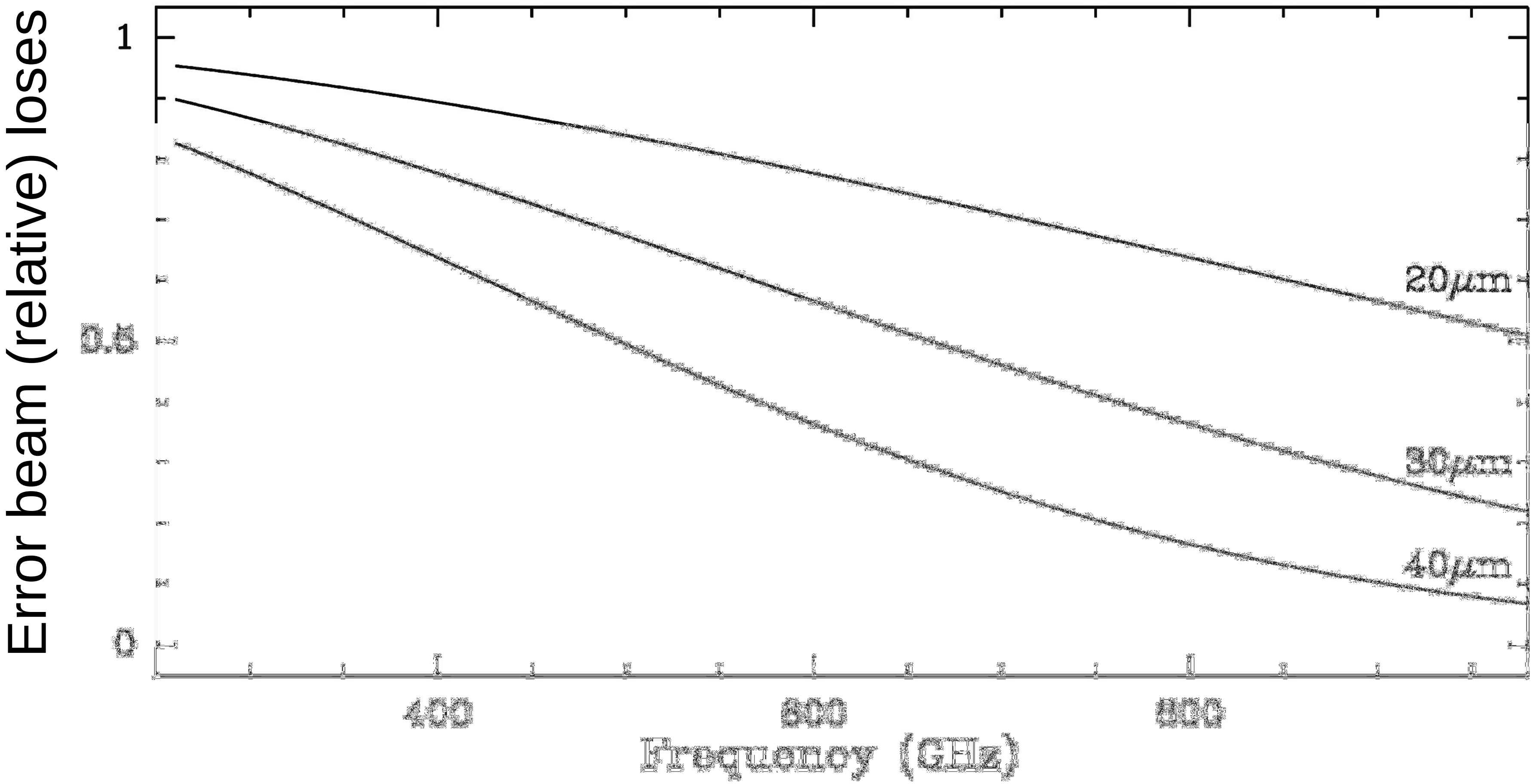
Coupling models to a disk source

Since we deal with a frequency range of ~ 700 GHz, the antenna HPBW changes from about 30" to 8".

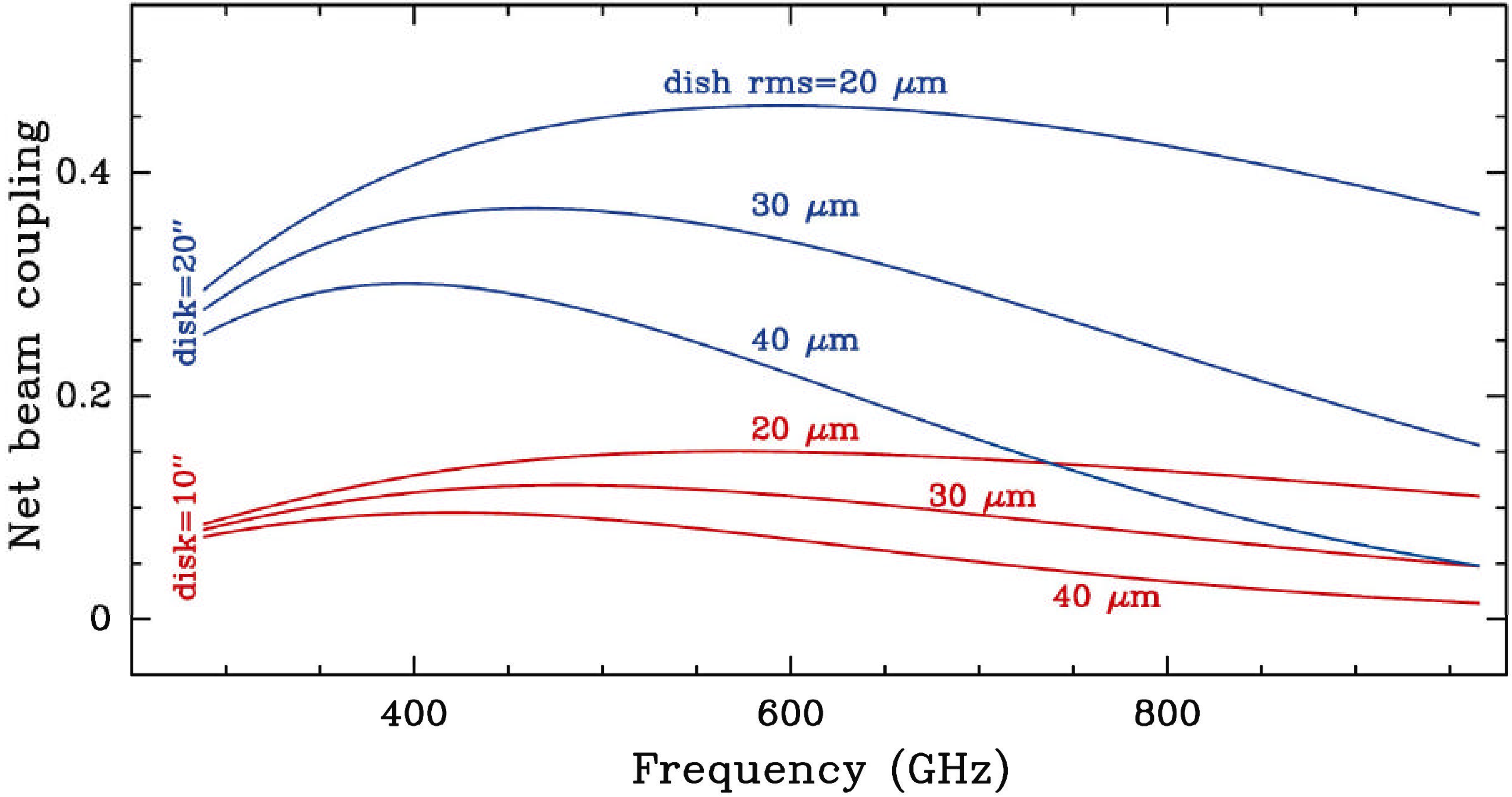


Loses due to the error beam

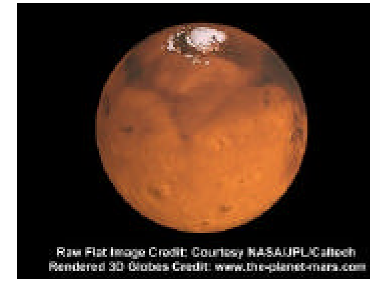
The error beam, related to the dish rms is responsible for an efficiency drop as ν increases.



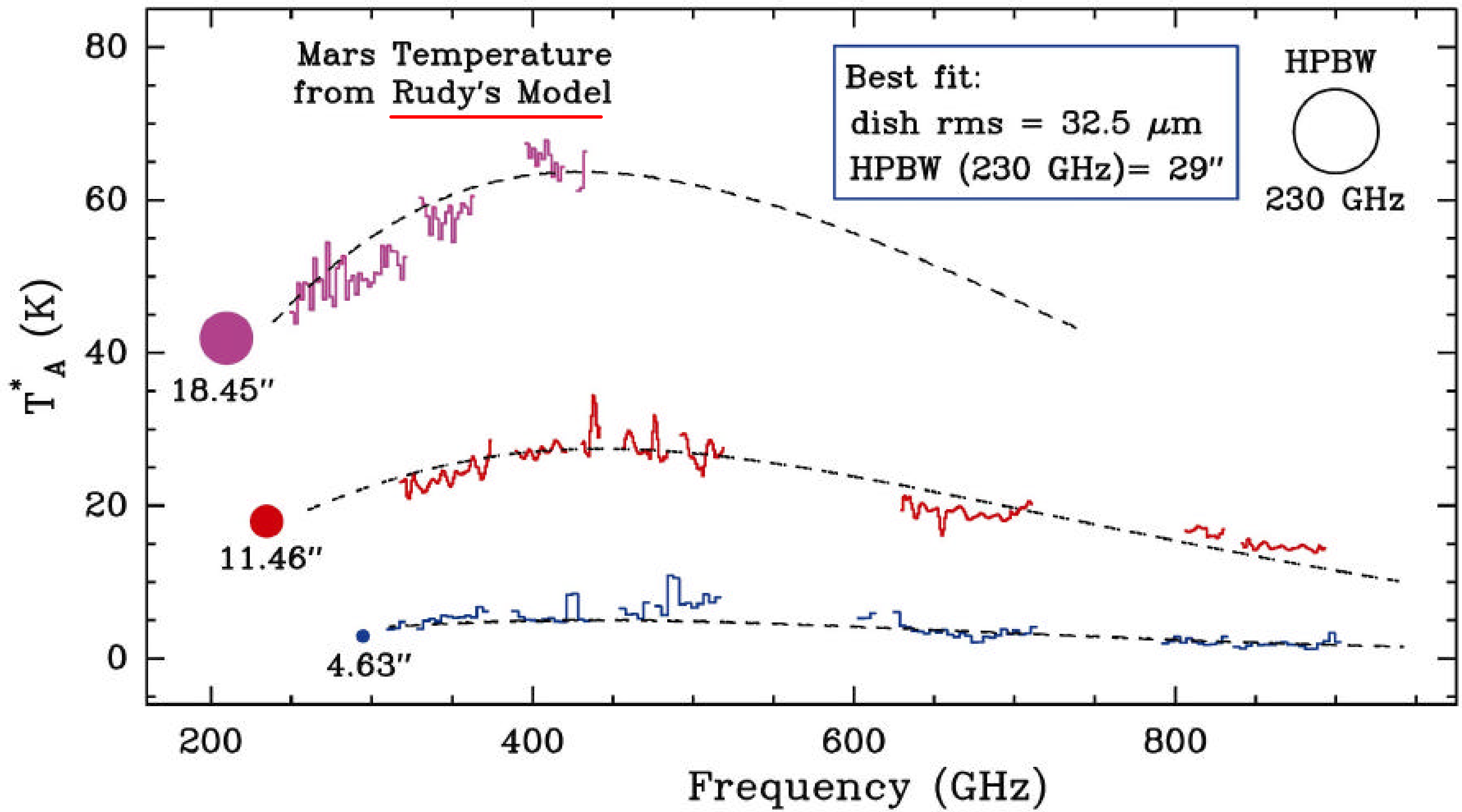
Beam pattern + Beam efficiency net effect



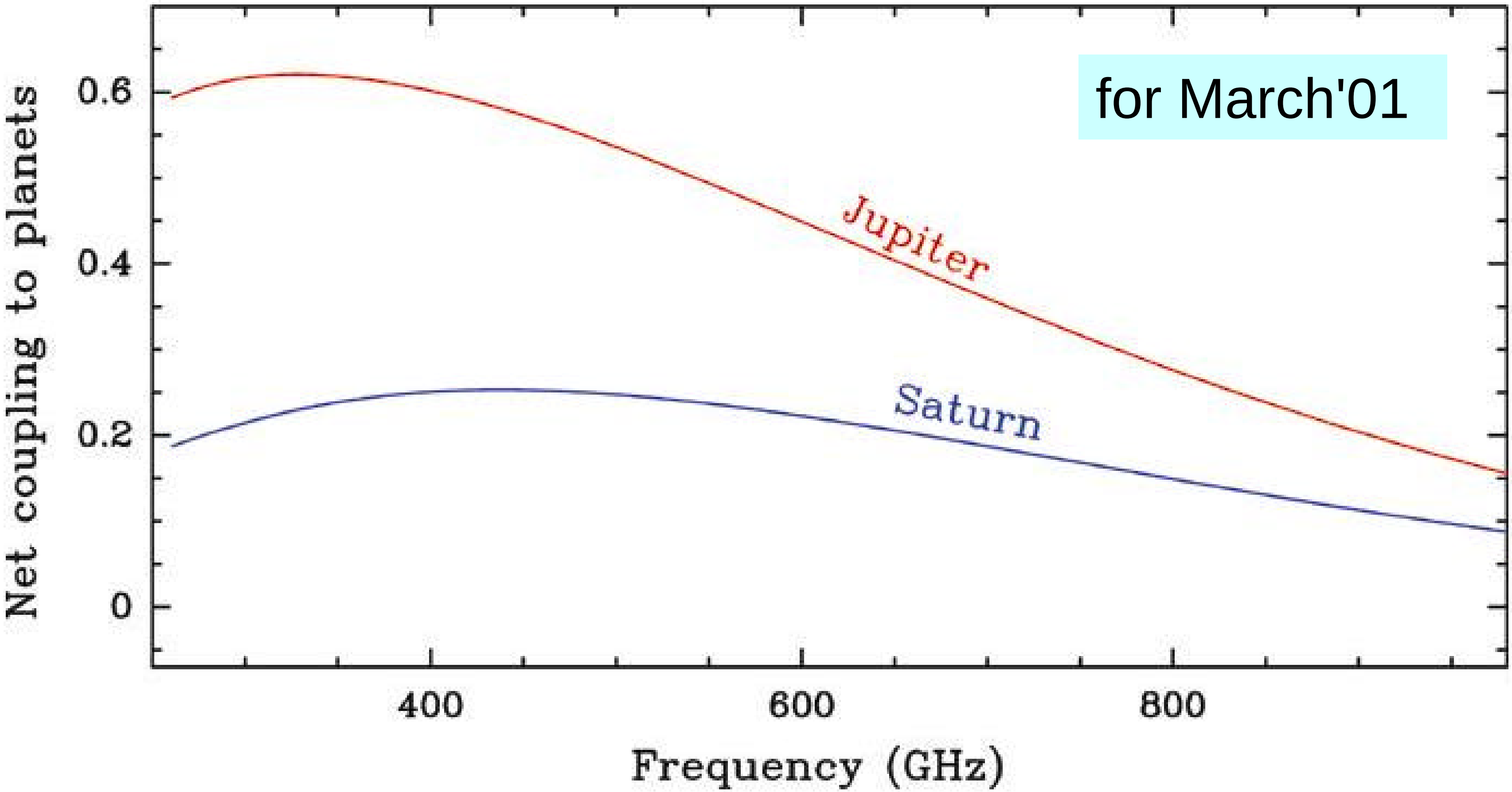
Effect evaluated on Mars

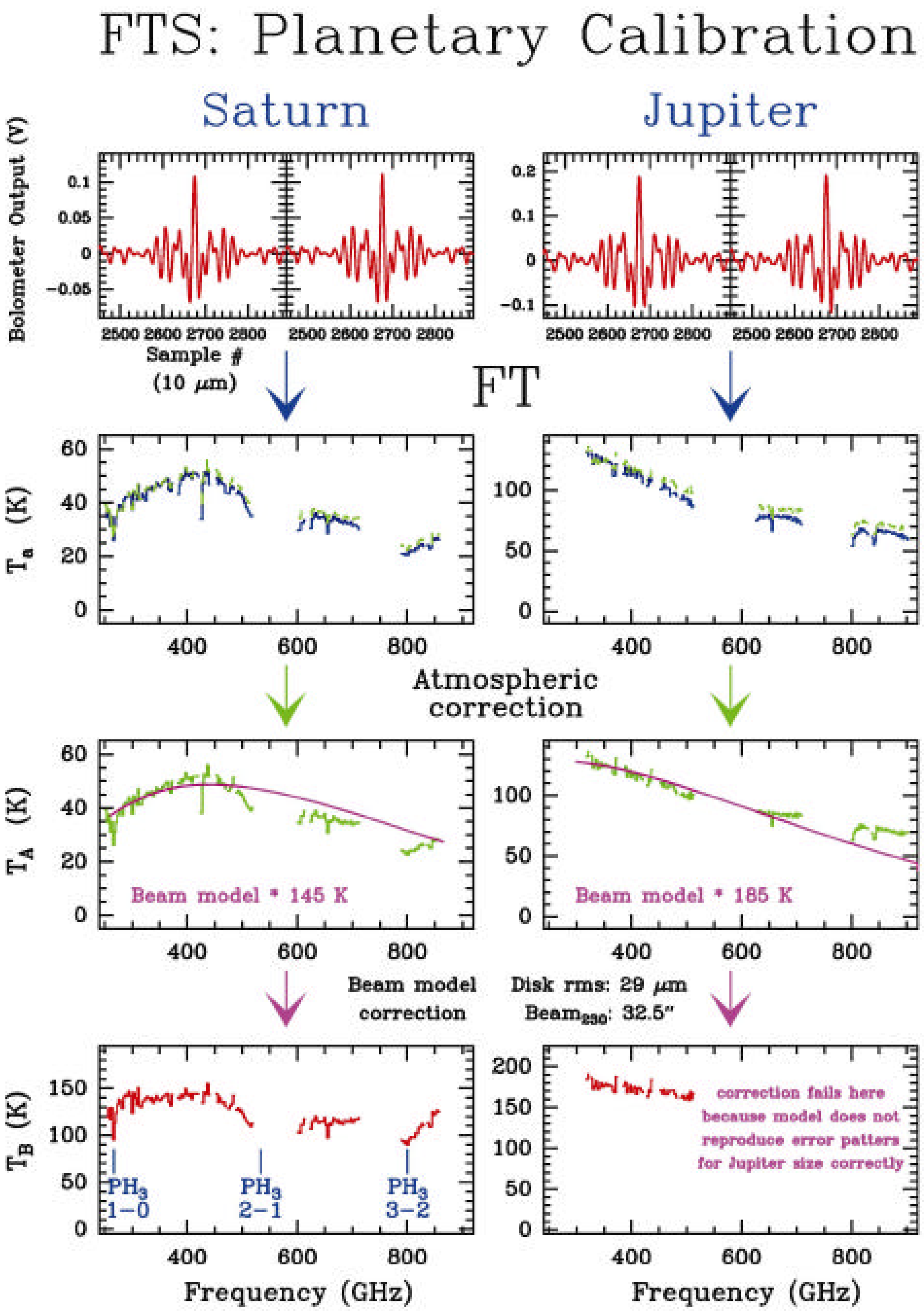


FTS: Main Beam Coupling and Error Pattern Parameters



...then, predictions are made for Jupiter and Saturn





March ´01

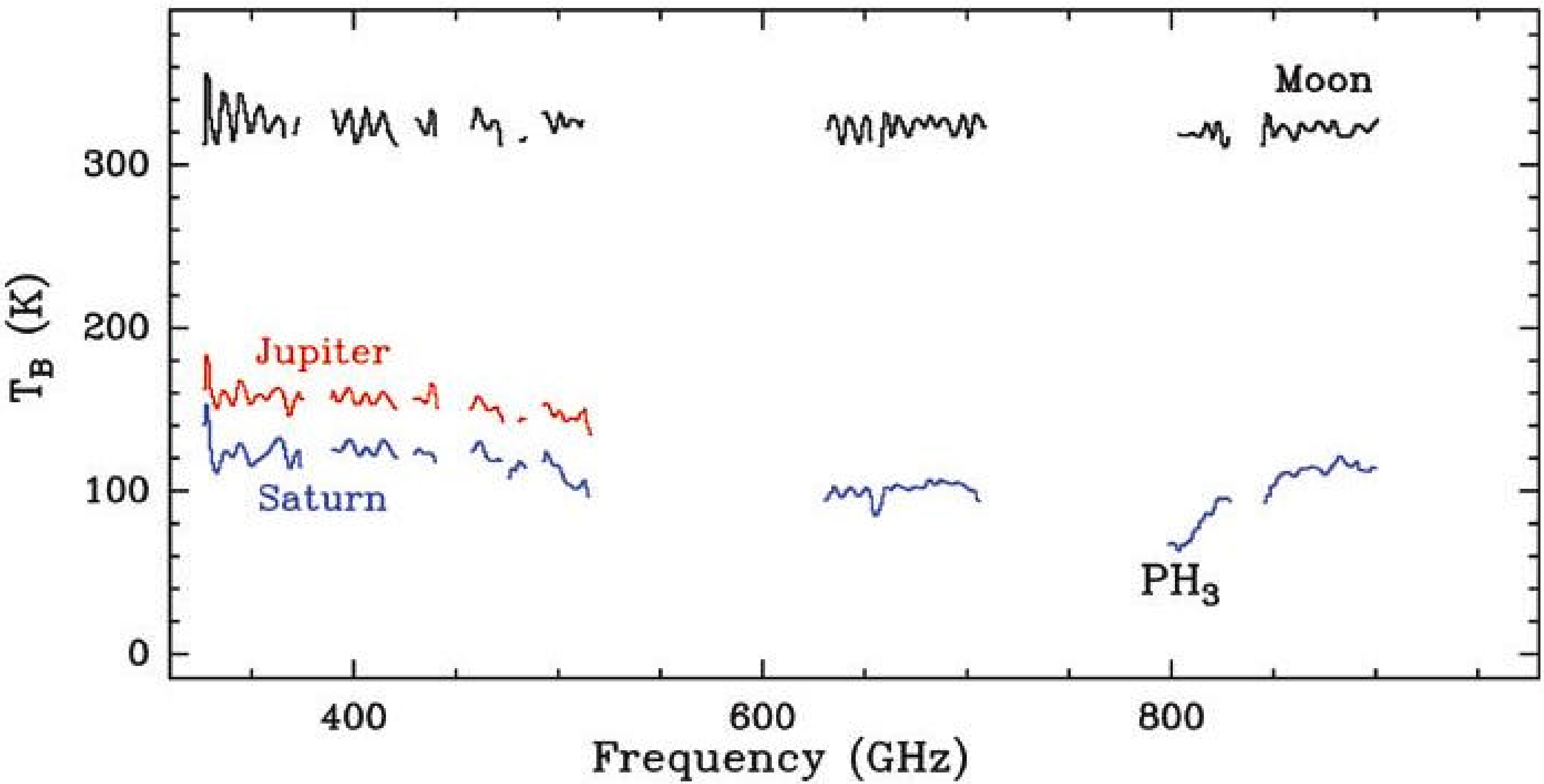
Raw data (interferograms)

Raw Planetary spectra

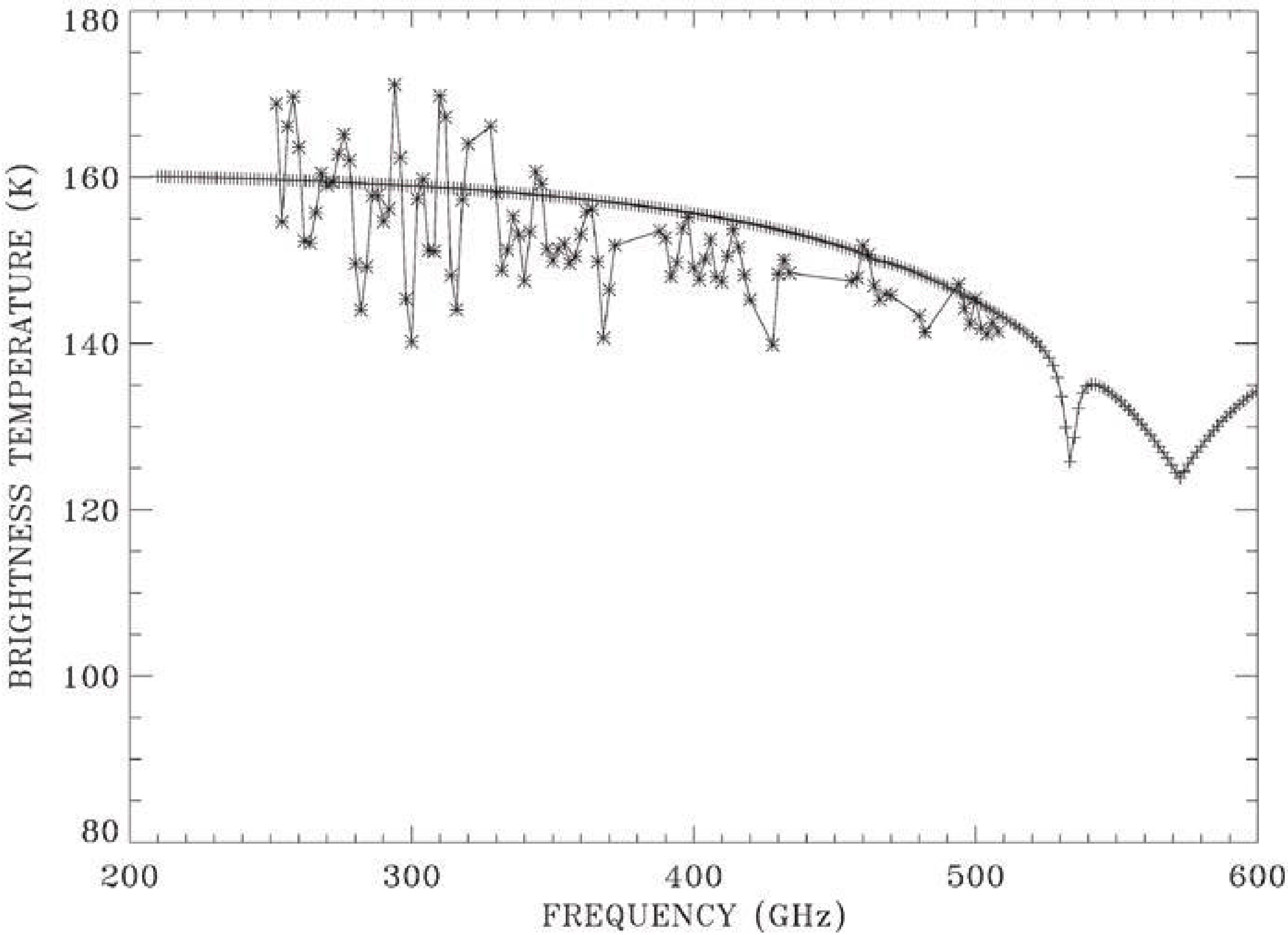
With atmospheric correction

With Instrumental correction

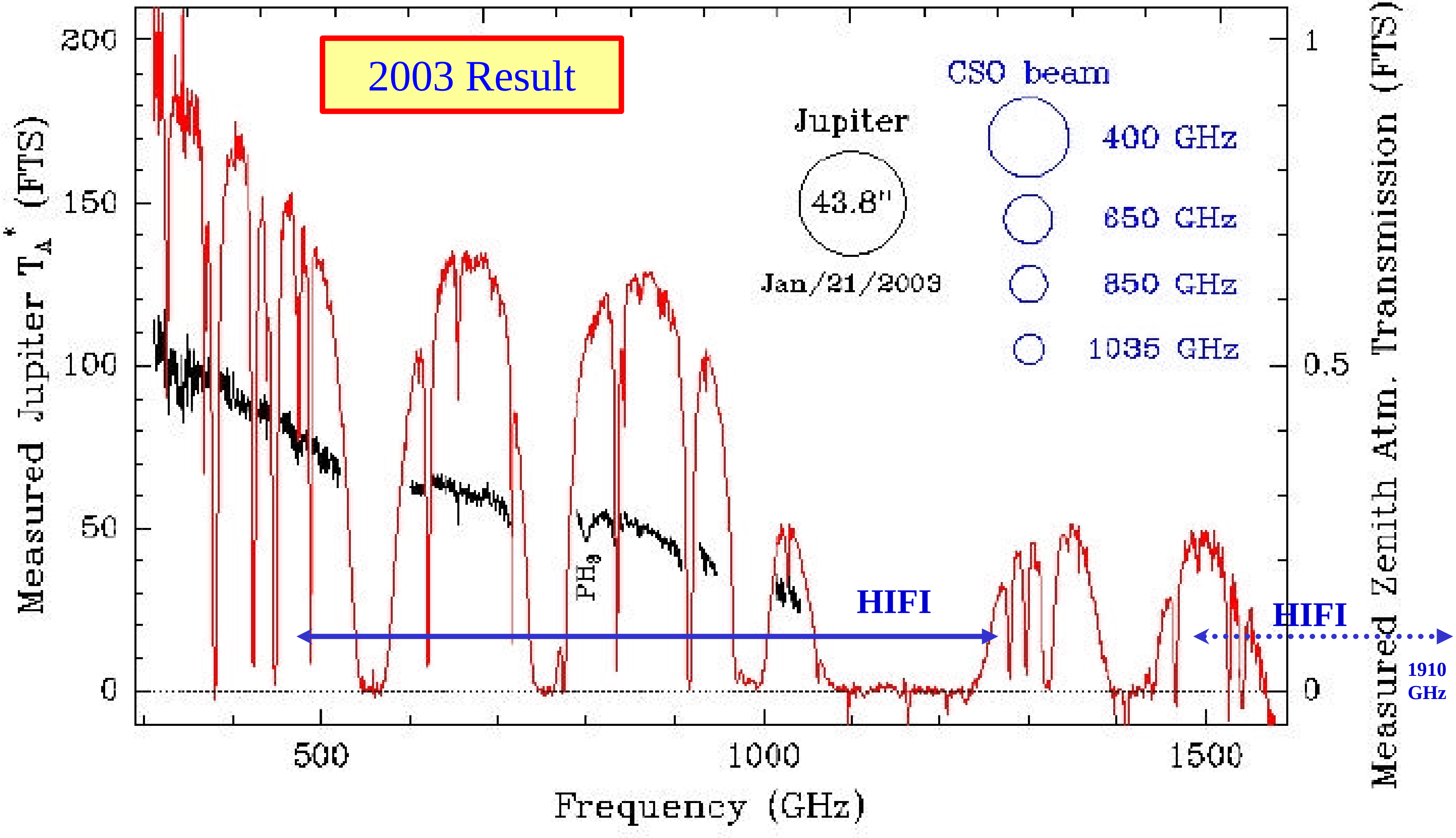
Final calibration of March '01



Comparison to a model: NH3 wing detected ?

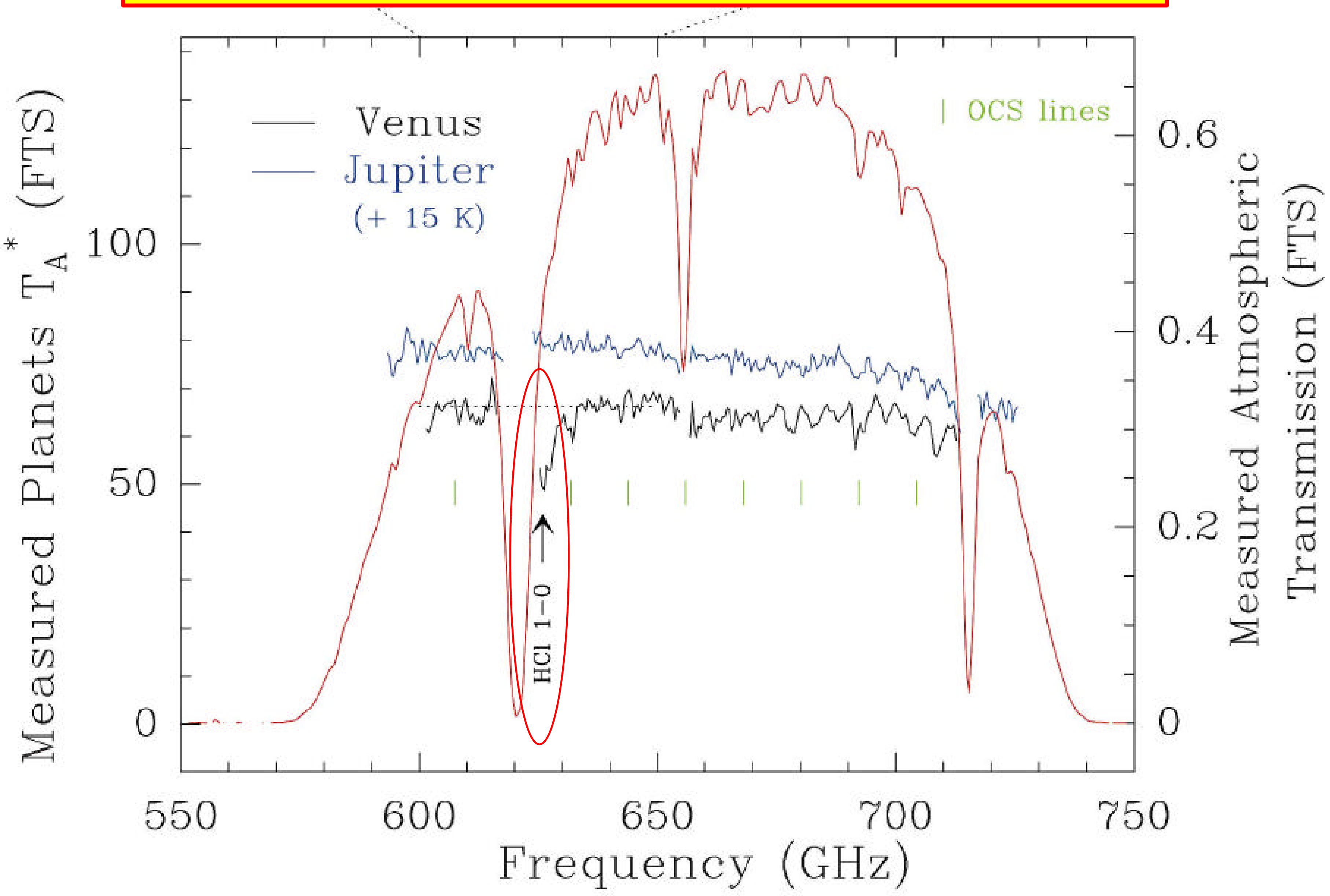


Recent progress: Best Jupiter Spectrum obtained a year ago

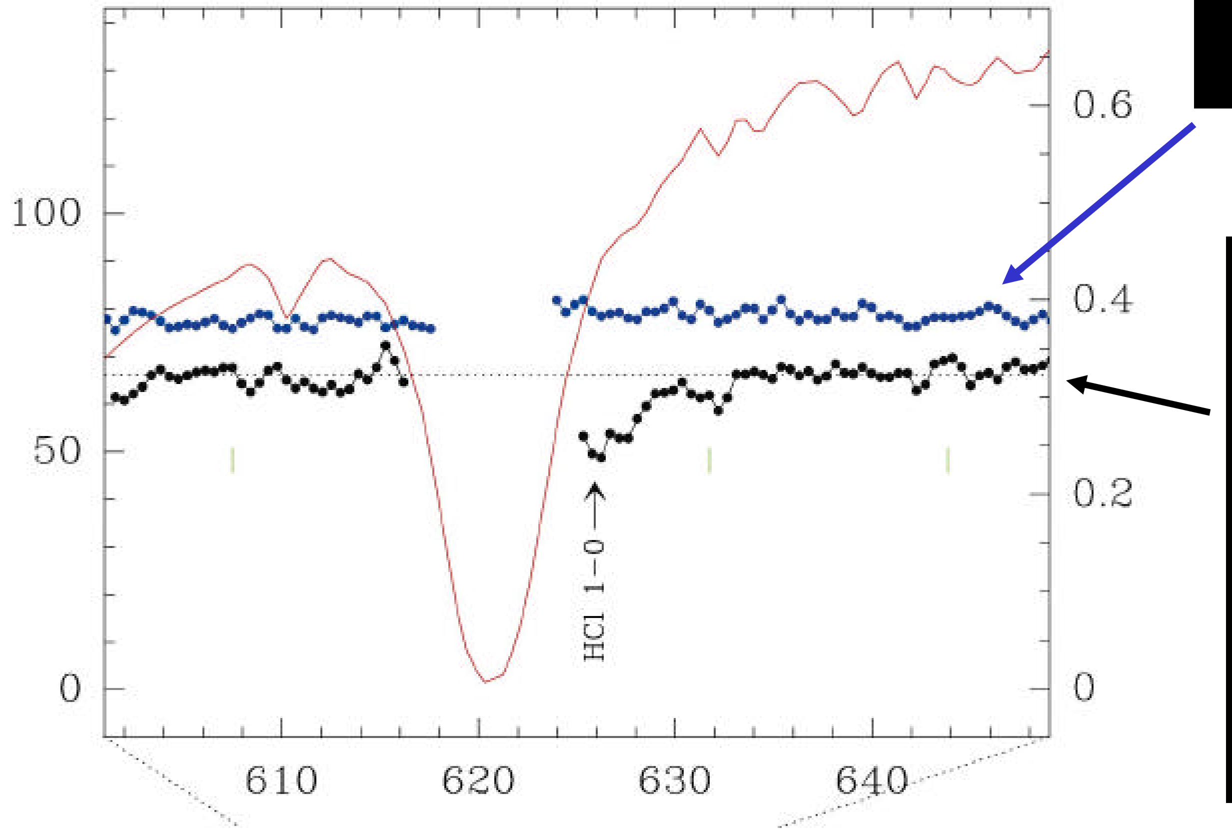


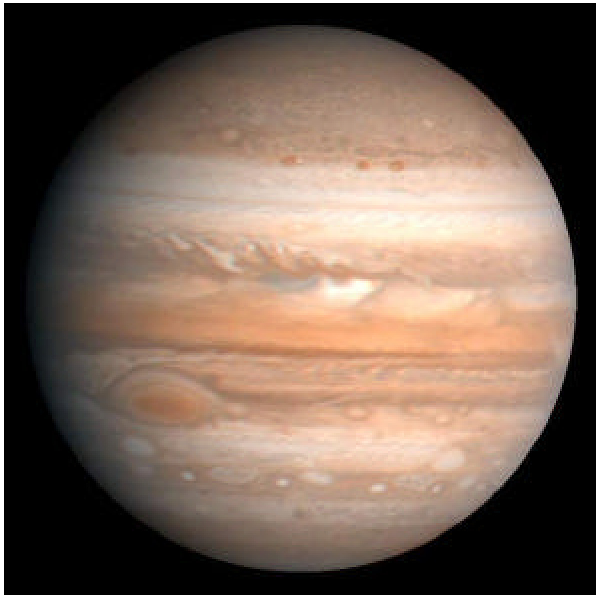
Mauna Kea, January 2003

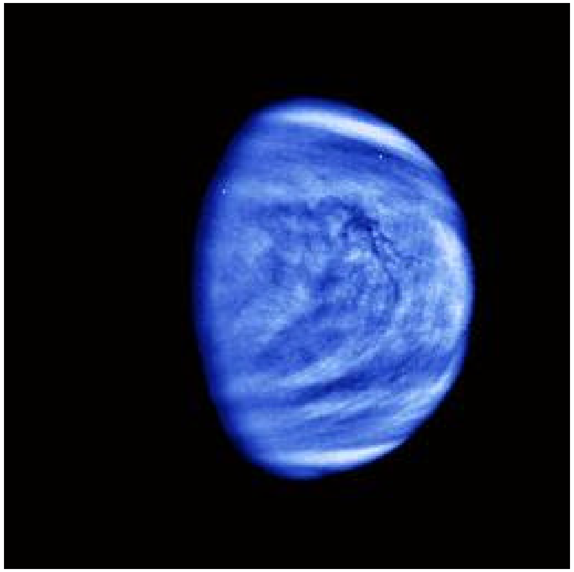
Venus results 450 µm window (January 2003)

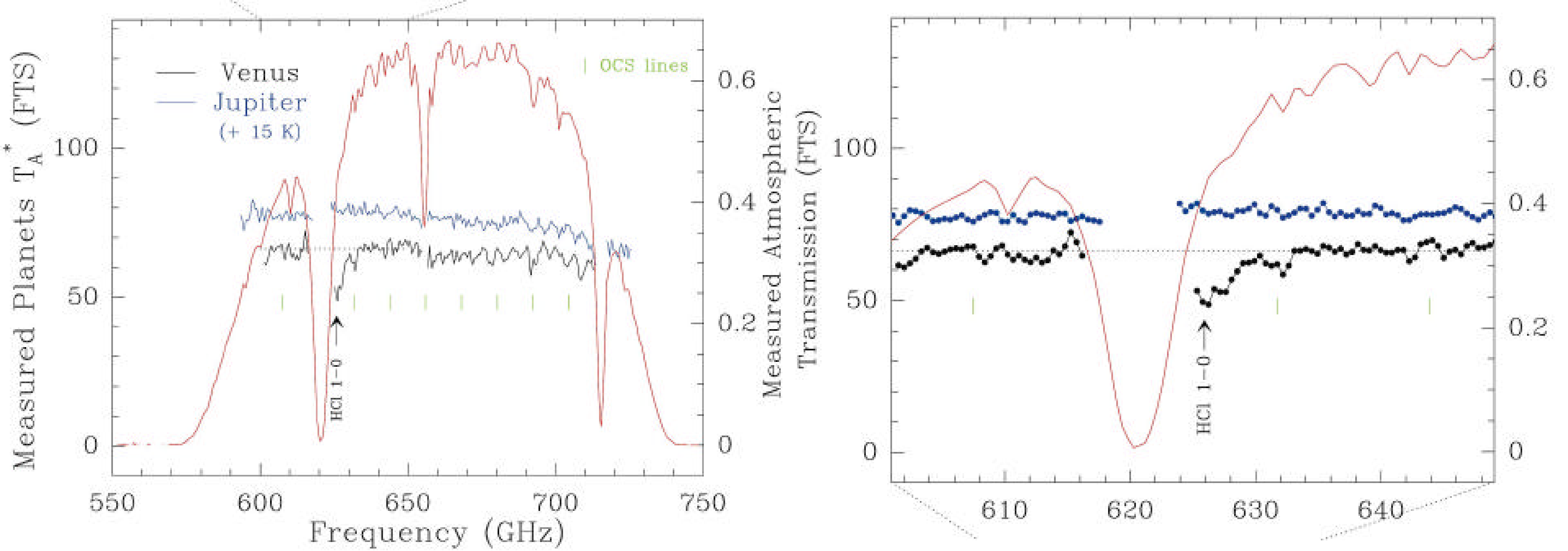


The result needs confirmation

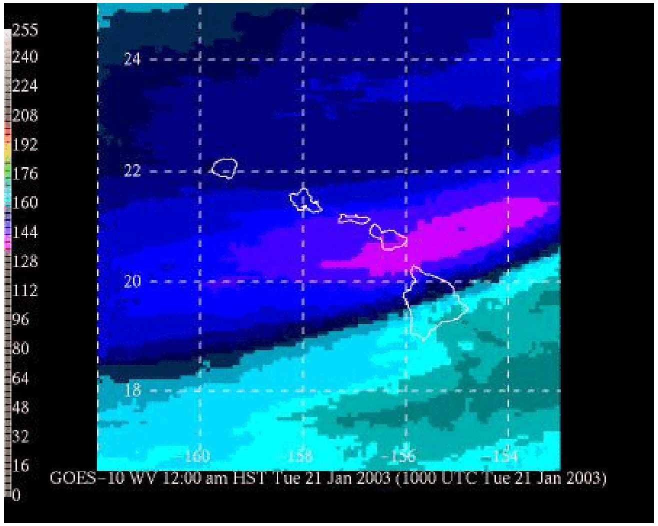


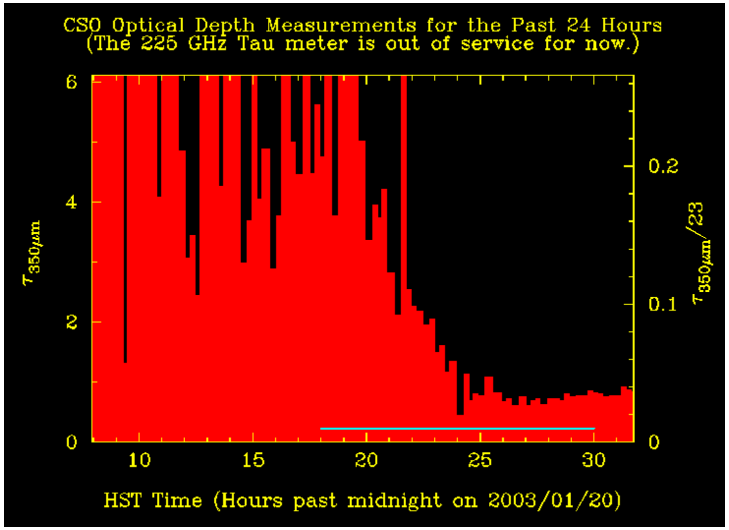




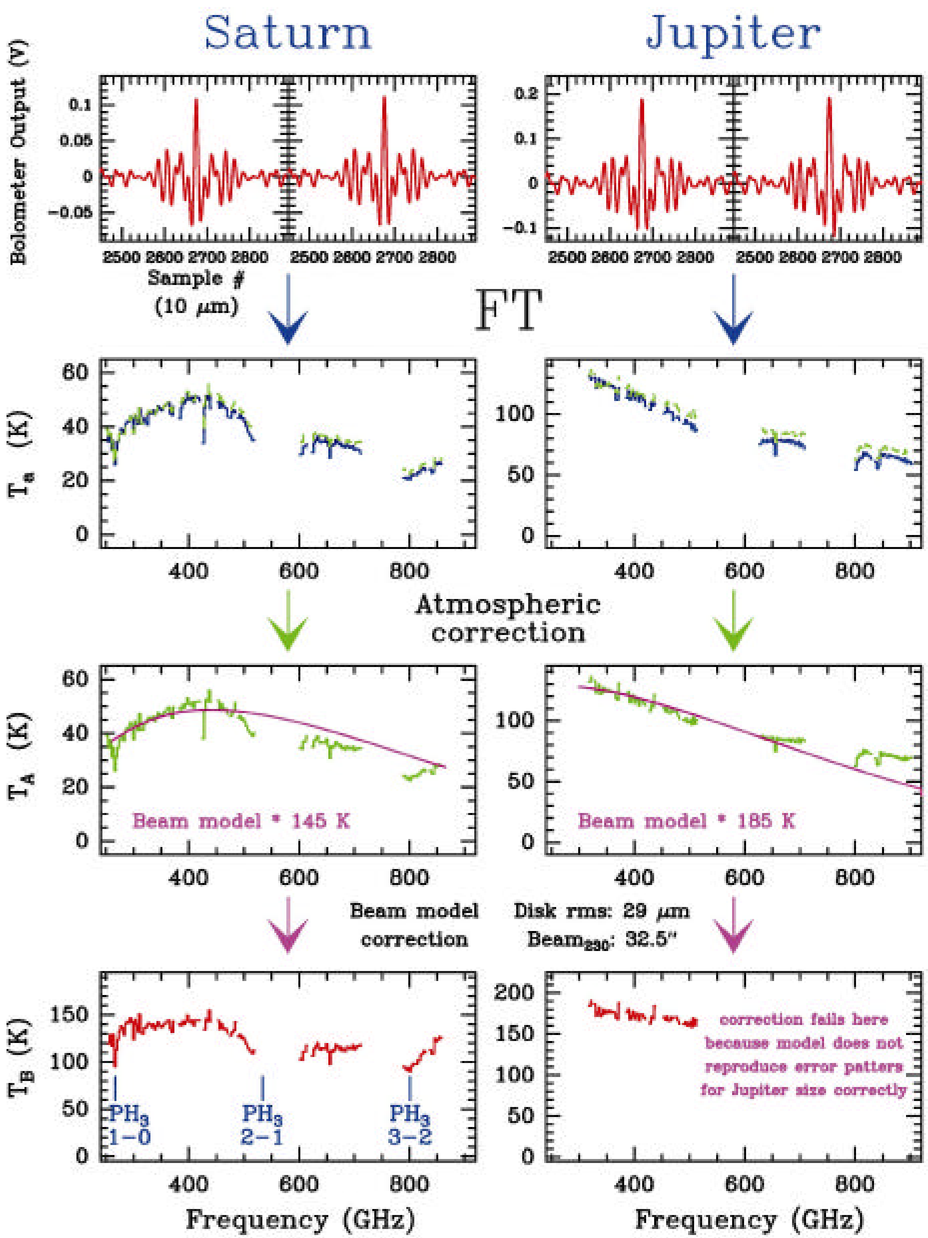


Venus: Possible detection of HCl 2003





FTS: Planetary Calibration



Conclussions

- Calibration steps understood and implemented.
- Reasonably good results on Jupiter for 330-500 GHz. New data for 300-1080 GHz of very good quality will be analyzed soon.
- Good results for Saturn for 330-920 GHz.
- Preliminary results on Uranus (200-300 GHz)
- Interesting results on HCl in Venus (626 GHz)

Future work

- Analysis of recent results.
- Comparison with models.
- Solve calibration problems seen in Jupiter at high frequencies.
- Further observations at the higher frequency end (near 1 THz).

Manpower needed

Implications for Herschel

- Jupiter and Saturn are potential calibration references in the submillimeter; where calibration sources are scarce.
- Our results have uncertainties around 10-15 % in the ranges specified for Jupiter and Saturn.

- Going down to 5 % will requiere a remendous amount of work. May not be feasible.