The Observed Structure and Variability of the Uranian Atmosphere

Mark Hofstadter (JPL)

With Bryan Butler (NRAO), Mark Gurwell (SAO), Heidi Hammel (SSI), Kathy Rages (Ames/SETI Inst.), Wes Lockwood (Lowell), and Michael Klein (JPL)

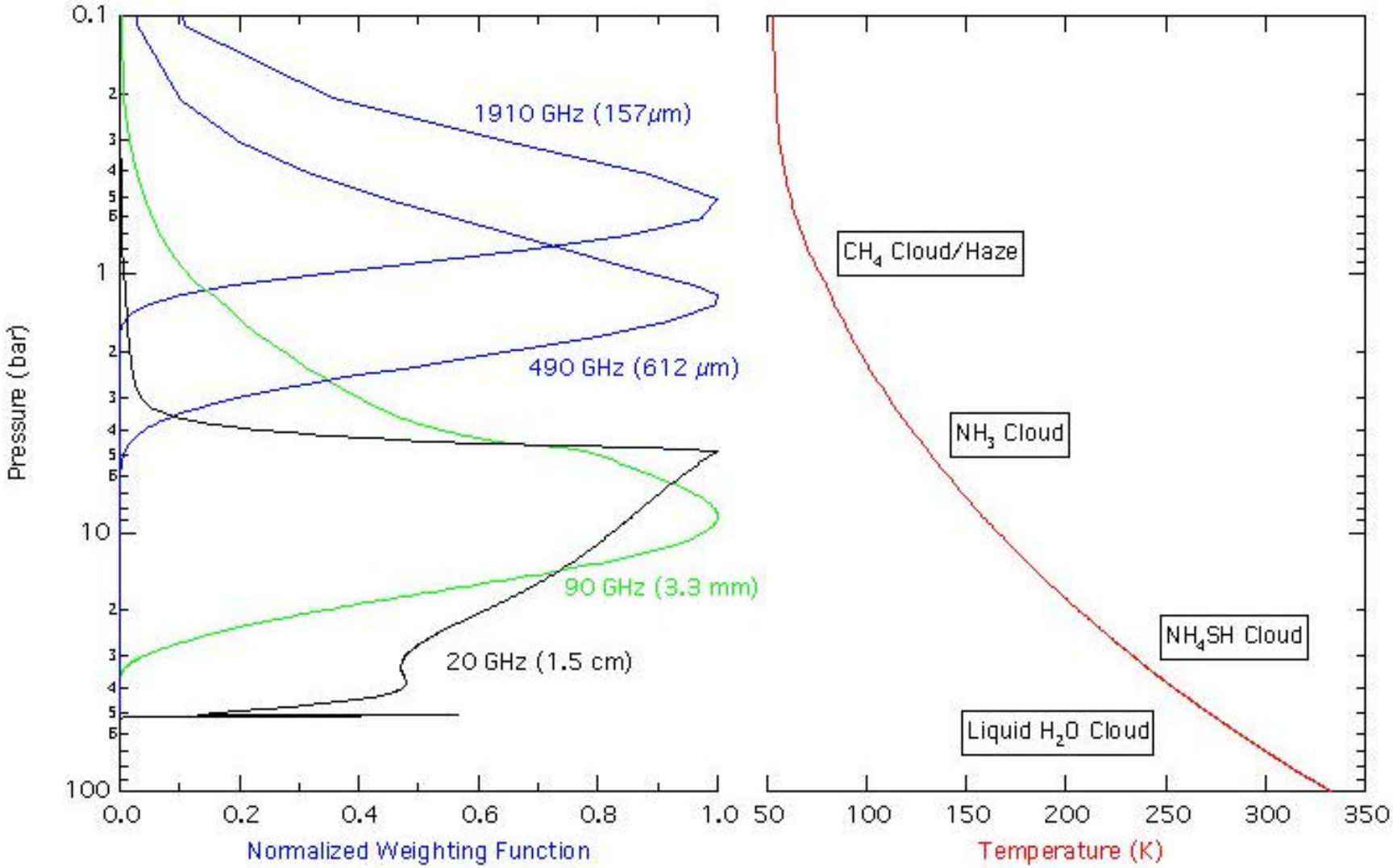
Outline

1. What I do.
2. Data sets considered.
3. Model of the atmosphere.
4. Recommendations/Conclusions.

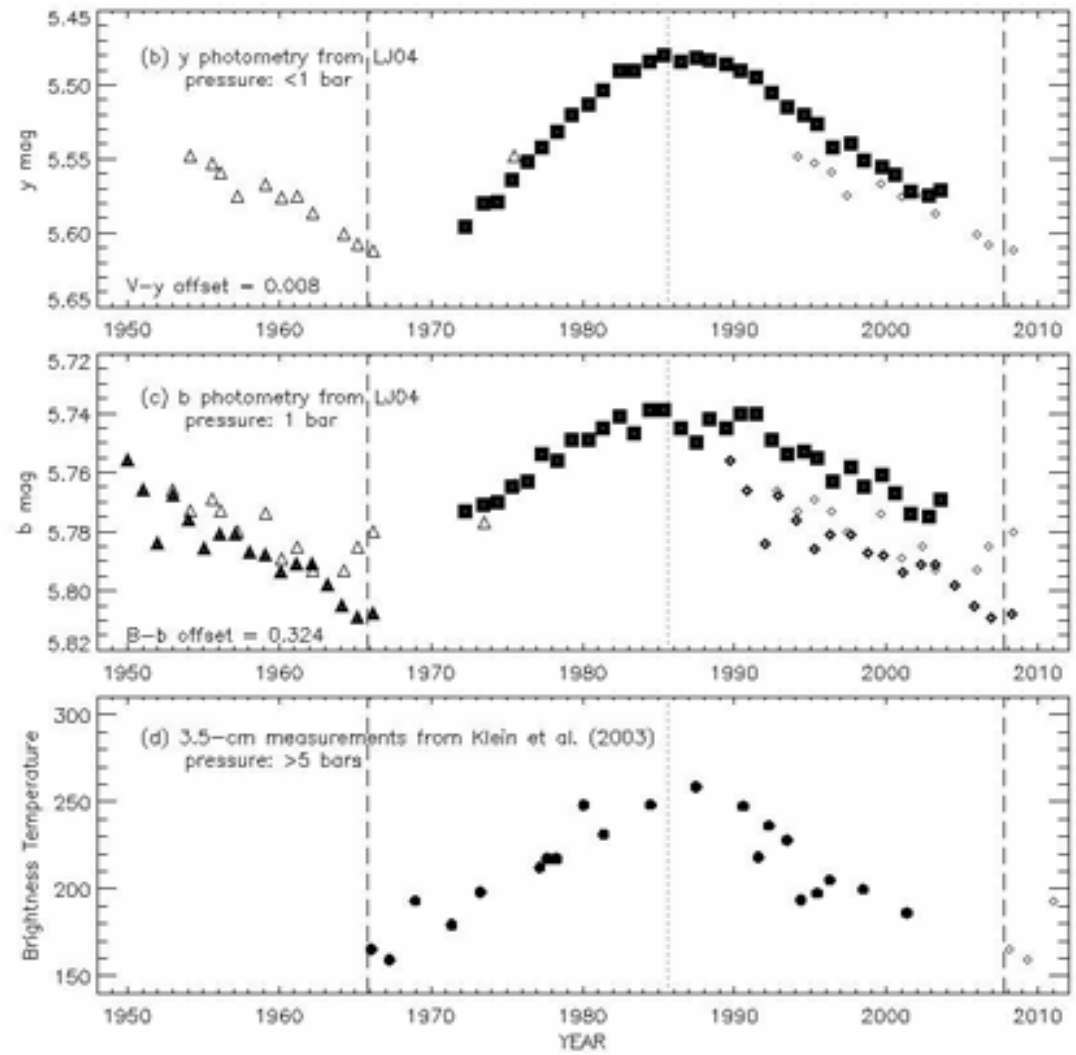
What I do

- My expertise is in continuum, centimeter wavelength observations of Uranus. I primarily use the Very Large Array to map the planet, and determine atmospheric properties as a function of location and time.
- Developed a radiative transfer forward model (Hofstadter and Butler, 2003, Icarus 165) that neglects scattering, contains H2, He, CH4, H2O, NH3, and H2S, and has the following opacity sources.
  - Ammonia vapor,
  - Water vapor,
  - H2 gas, pressure broadened by H2, He, and CH4,
  - Liquid water clouds.

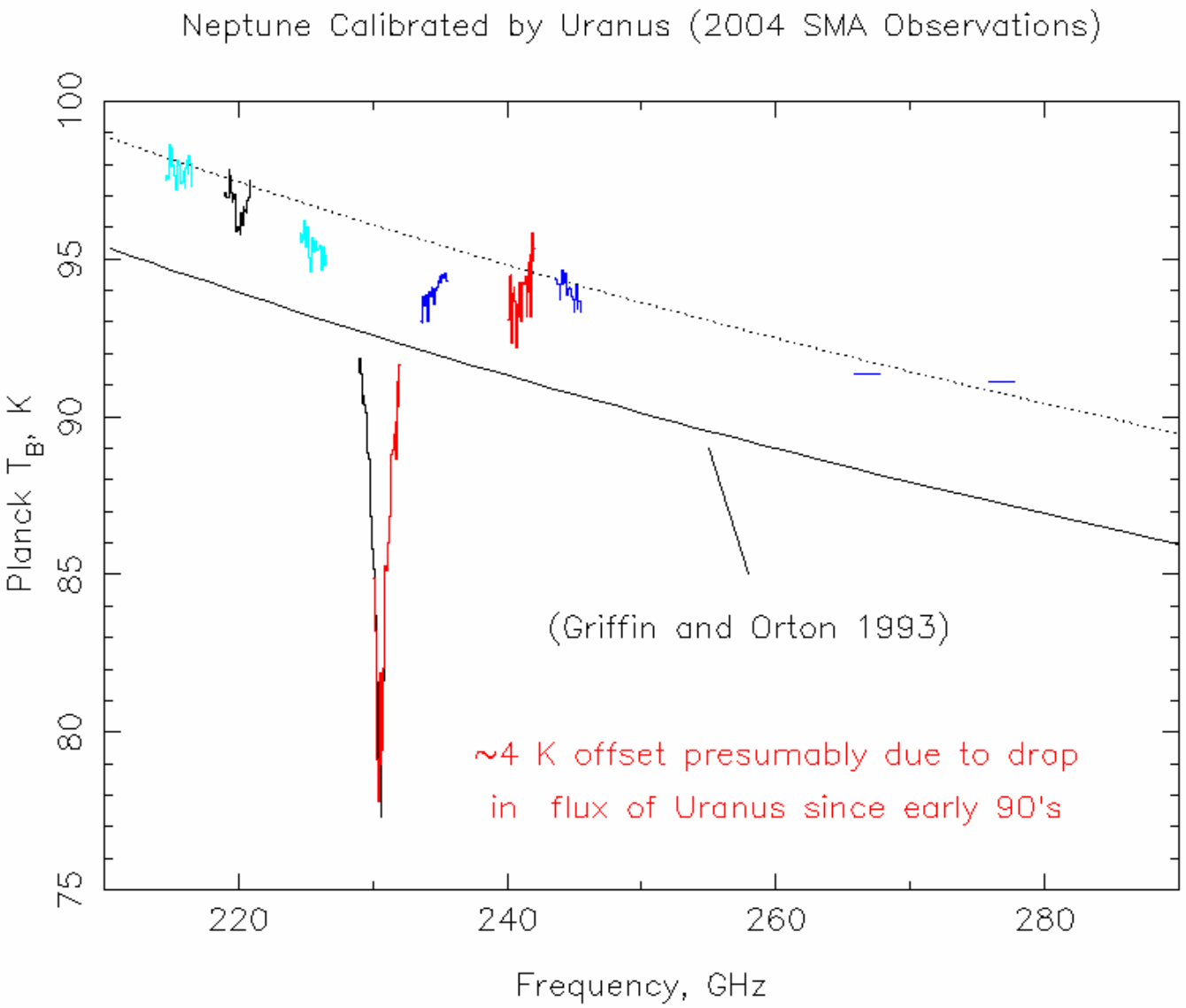
Atmospheric Profiles and Weighting Functions



Uranus is Variable in the Visible, Near-IR, and Radio

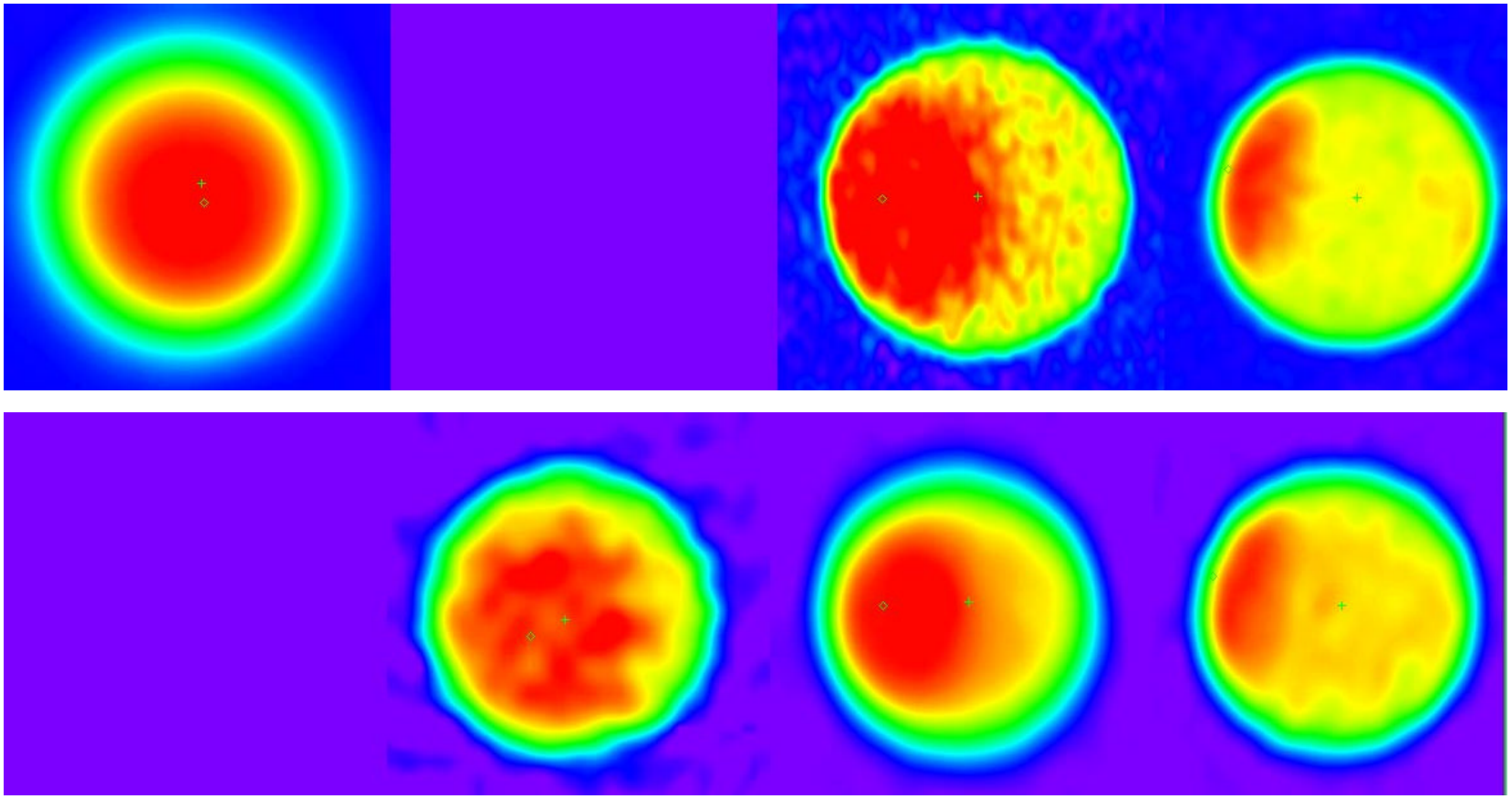


From Hammel and Lockwood, Atmospheric Variability on Uranus and Neptune: Seasonal, Solar-Driven, or Stochastic? *Icarus*, in press.



Mark Gurwell, Pers. Comm.

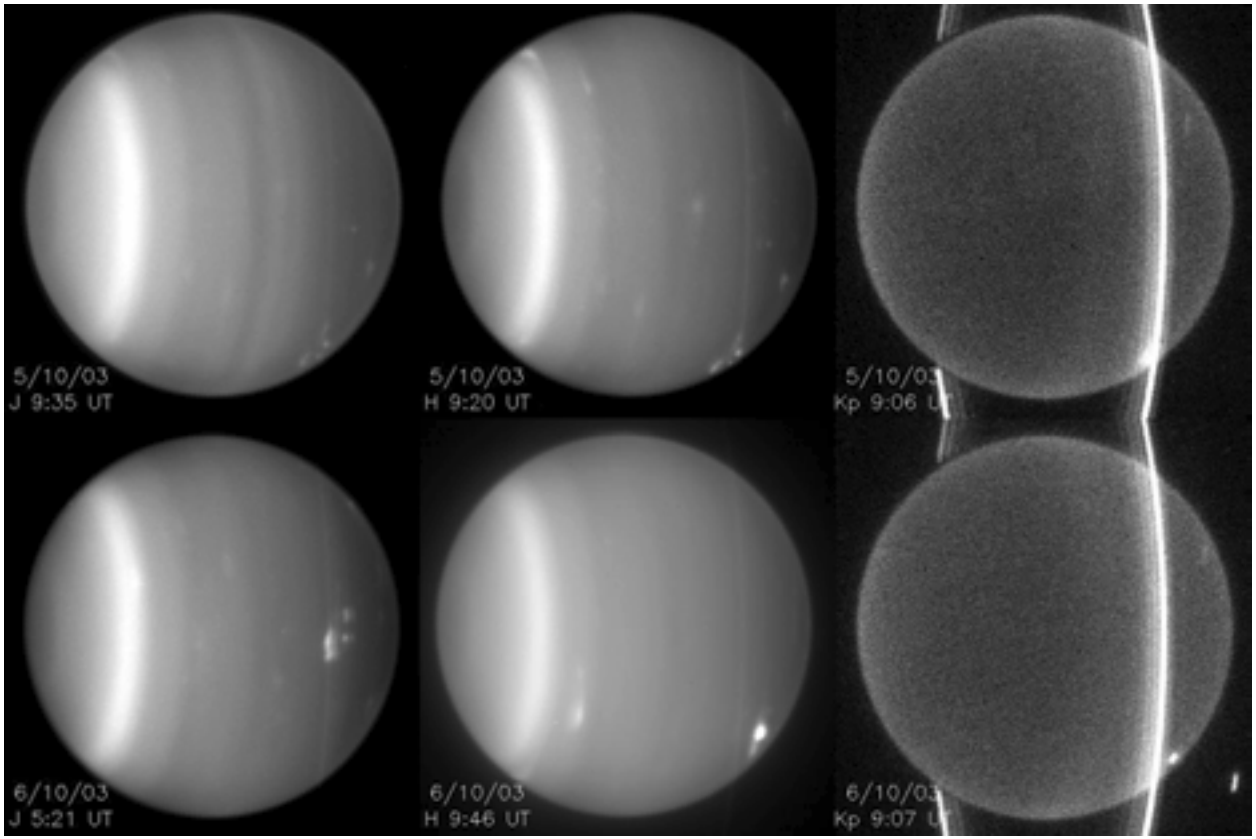
Spatial and Temporal Variability from the VLA



Spatial and Temporal Variability from Keck

5 Oct 2003

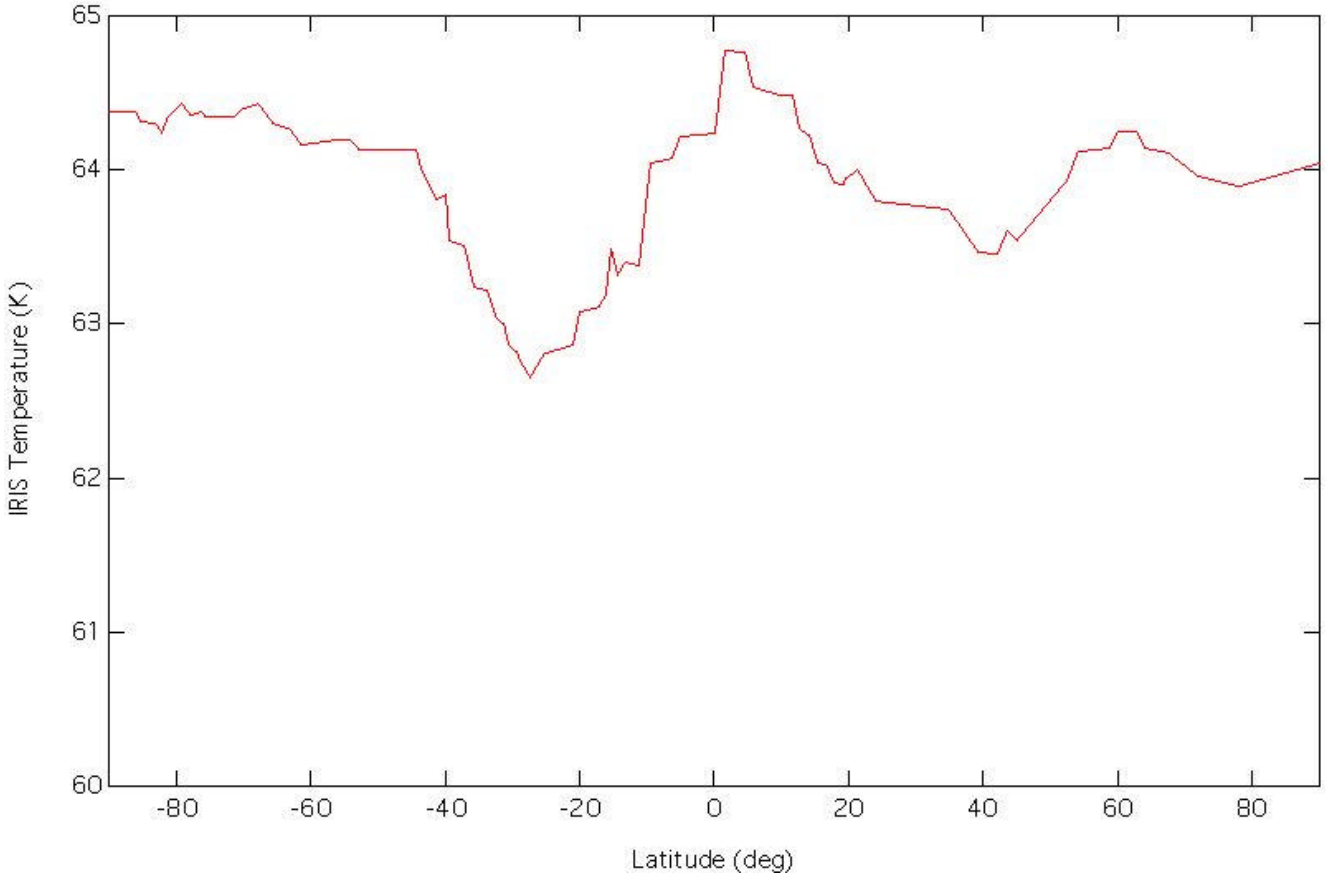
6 Oct 2003



J, 5:21 UT H, 9:46 UT K-prime, 9:07 UT

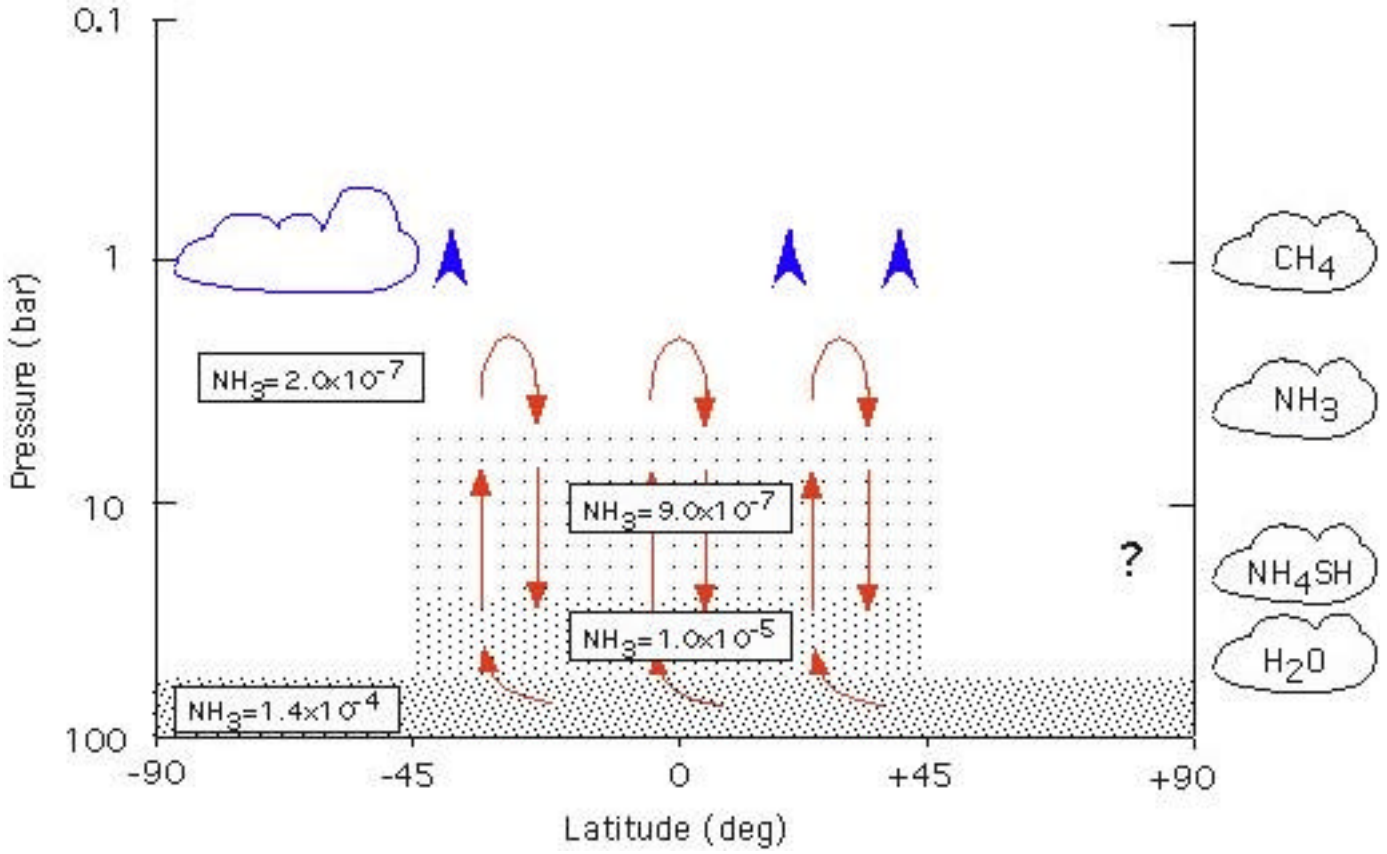
From Hammel and Lockwood, Atmospheric Variability on Uranus and Neptune: Seasonal, Solar-Driven, or Stochastic? *Icarus*, in press.

Temperature vs. Latitude Near Tropopause (~0.8 bar)



From Voyager IRIS in 1986. Flasar et al. 1987, JGR 92, 15011-15018

One Interpretation of the Radio and Visible Data



Some Questions I Addressed

- Does my code predict millimeter and submillimeter temperatures that are about right?

Yes!

- Do the spatial and seasonal variations of NH_3, H_2O, and CH_4 inferred from longer wavelengths influence the submm?

No, given the assumptions of no scattering and vapor equilibrium.

Questions to be Answered

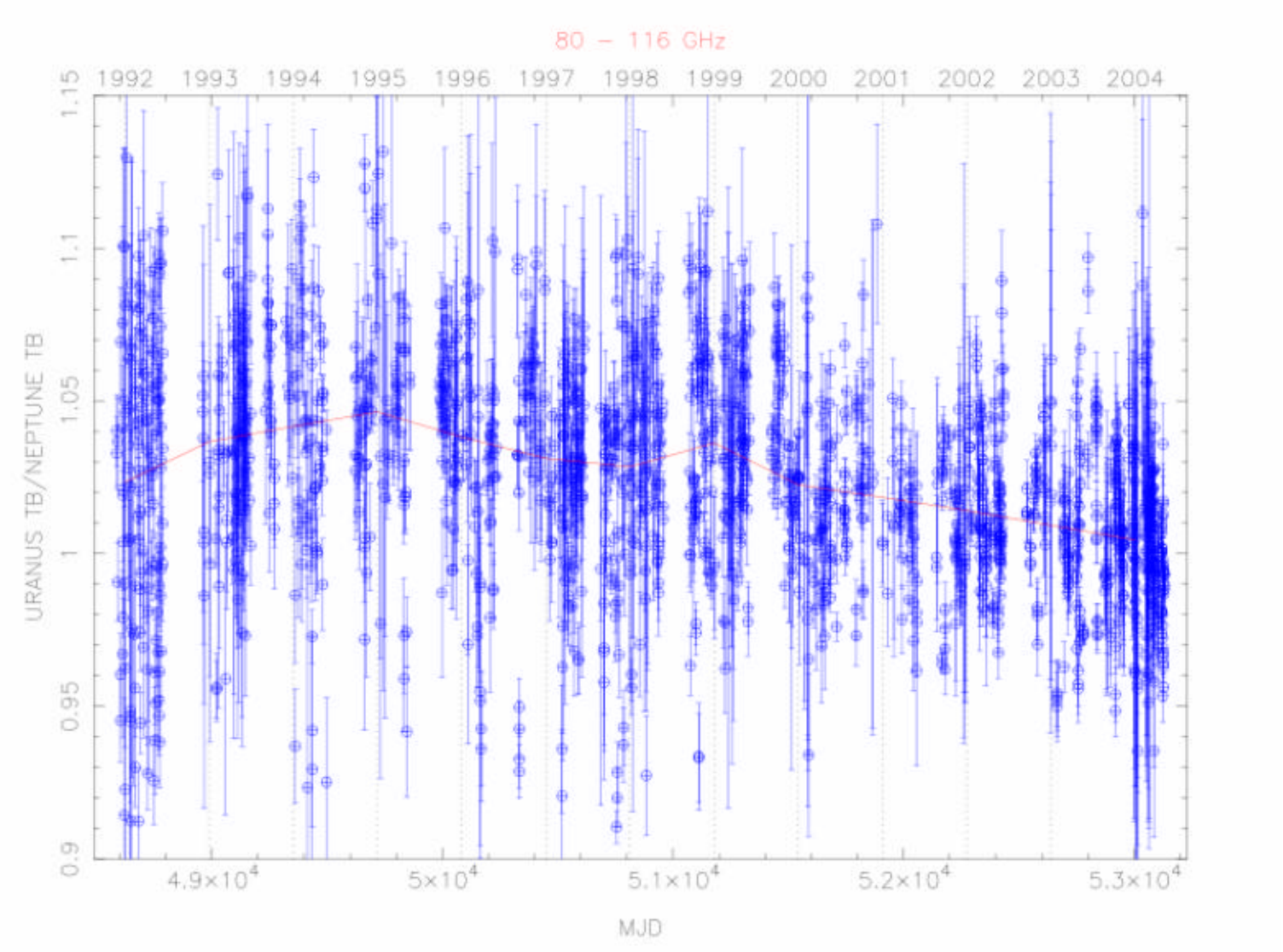
- Can the CH4 cloud and haze particles be large enough to matter at Herschel wavelengths?
- Can supersaturation of NH3 vapor (or other species) influence the submm spectrum?
- Are unmodeled species radiatively important?
- What is the accuracy of ground-based submillimeter measurements?
- Will the 2007 equinox be a time of significant change?

Conclusions

- Uranus is probably a good relative calibration source (meaning over time and perhaps frequency). With continued ground observations and additional modeling, it will be “stable” to ~5% over Herschel’s lifetime.
- Not clear if it can be used as an absolute calibration source to 5%. Need temperature retrievals and ground-based measurements accurate to that level.

Backup Slides

Uranus/Neptune from OVRO at 3 mm



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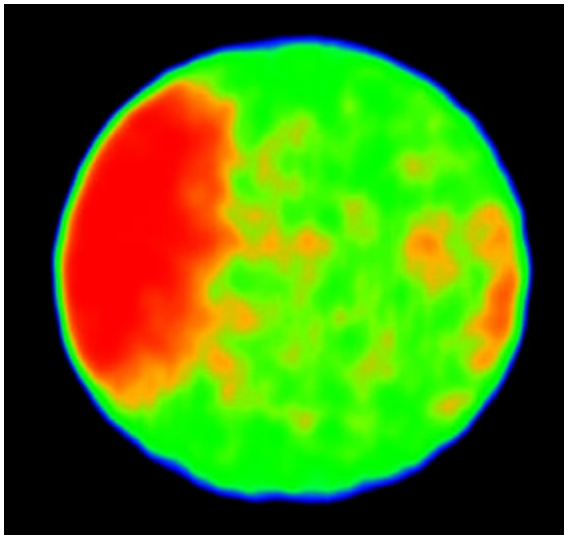
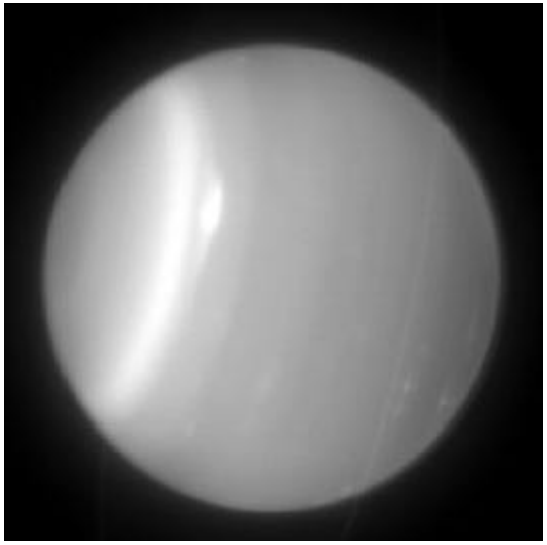
Fall/spring symmetry at 10s of bars, asymmetry near 1 bar



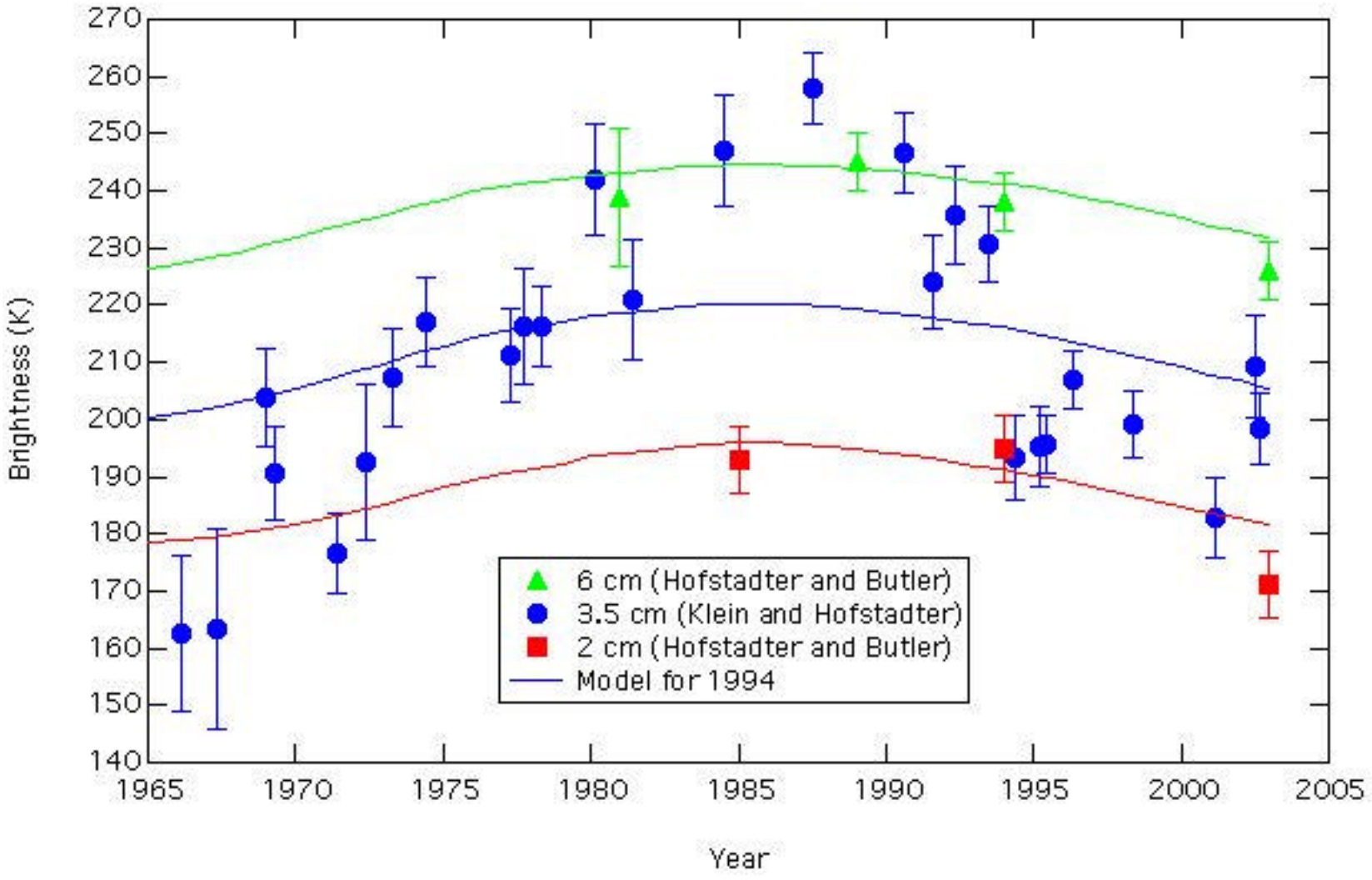
2 cm, July 2003

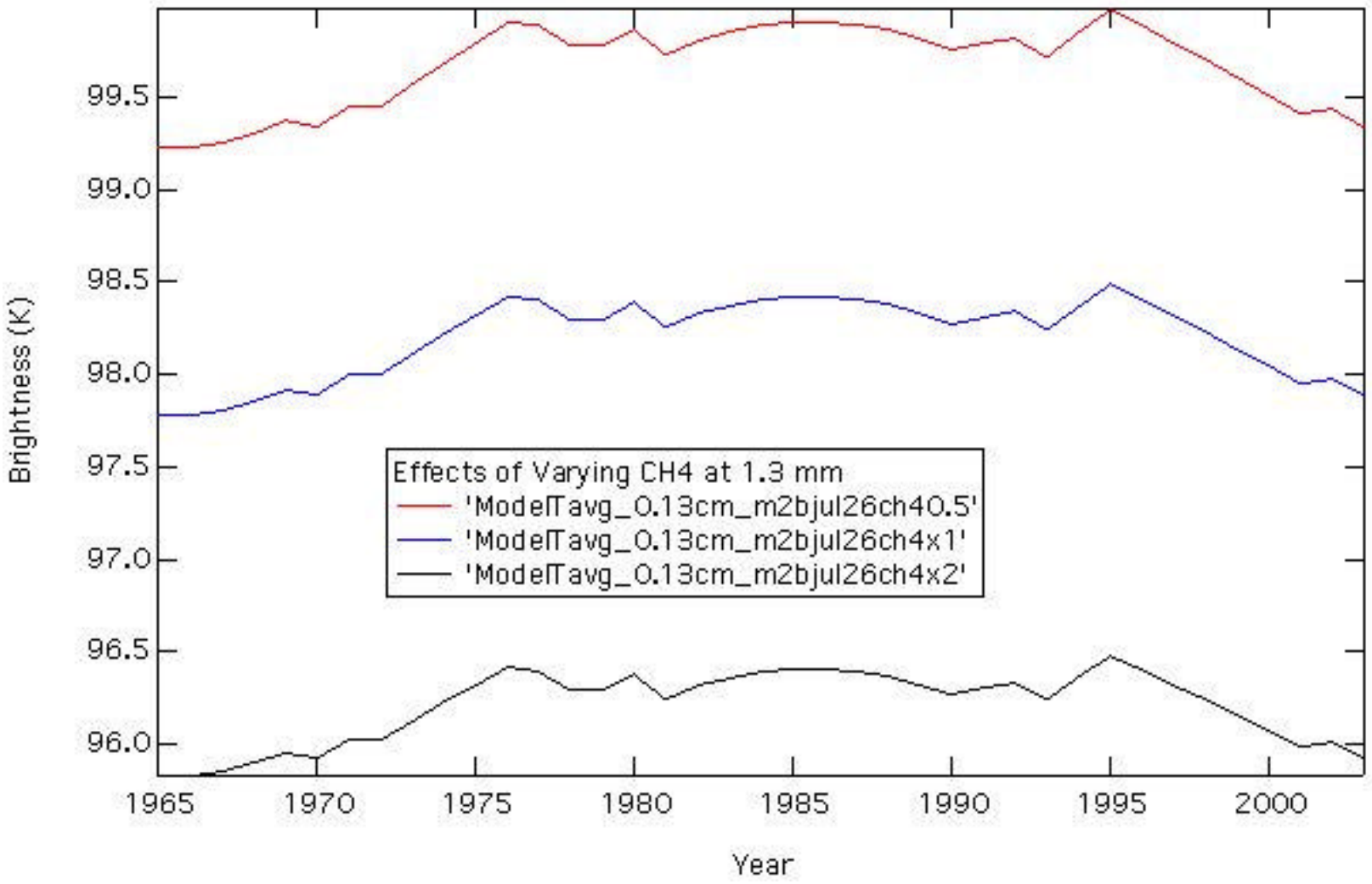


1.6 μm, October 2003

Hammel, de Pater, Gibbard, Lockwood, submitted to Icarus

- North-south asymmetry seen in the visible and near-IR suggests seasonal forcing controls convection and cloud formation in upper troposphere.
- The latest radio observations reveal significant symmetry at depth, suggesting we see deeper than is dominated by the seasonal wave.
- The data show how a deep atmosphere responds to solar forcing.


Brightness (K)
270
260
250
240
230
220
210
200
190
180
170
160
150
140
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year
6 cm (Hofstadter and Butler)
3.5 cm (Klein and Hofstadter)
2 cm (Hofstadter and Butler)
Model for 1994


Effects of Varying CH4 at 1.3 mm
'ModelTavg_0.13cm_m2bjul26ch40.5'
'ModelTavg_0.13cm_m2bjul26ch4x1'
'ModelTavg_0.13cm_m2bjul26ch4x2'
Brightness (K)
Year
99.5
99.0
98.5
98.0
97.5
97.0
96.5
96.0
1965
1970
1975
1980
1985
1990
1995
2000