Calibration Models for Uranus and Neptune

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- Mark Gurwell, CfA
- Imke de Pater, U. Calif. Berkeley

Funding

- Orton, Hofstadter, de Pater: NASA Planetary Atmospheres (Spatial and temporal variability in atmospheric structures of Uranus and Neptune)
- Butler, Gurwell: institutional funding
- Hofstadter, Orton (pending): NASA Planetary Astronomy (Observations of spatial and temporal variability in atmospheric structure)

Calibration Objectives

– To be addressed in workshop:

- Cross-calibrate thermophysical models of Mars and Jupiter with those of Uranus and Neptune

- Transfer the high-accuracy radiometric measurements of spacecraft and internal calibration systems to a more general system

Calibration Objectives

Presented here:

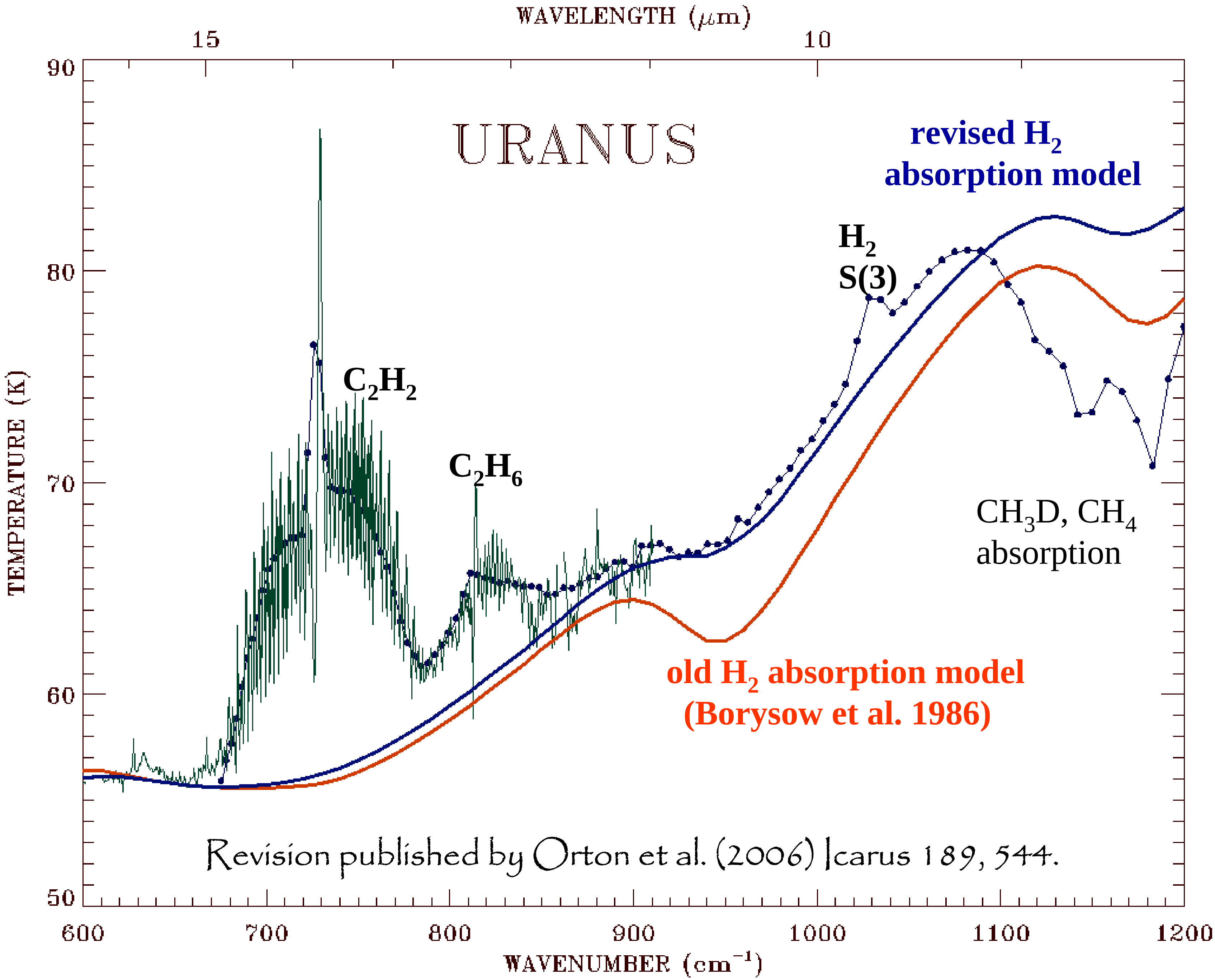
- Evaluate the temperature structure of current standard models using Spitzer IRS observations.

- Determine meridional (latitudinal) variability of temperatures to predict latitudinal variability of radiances.

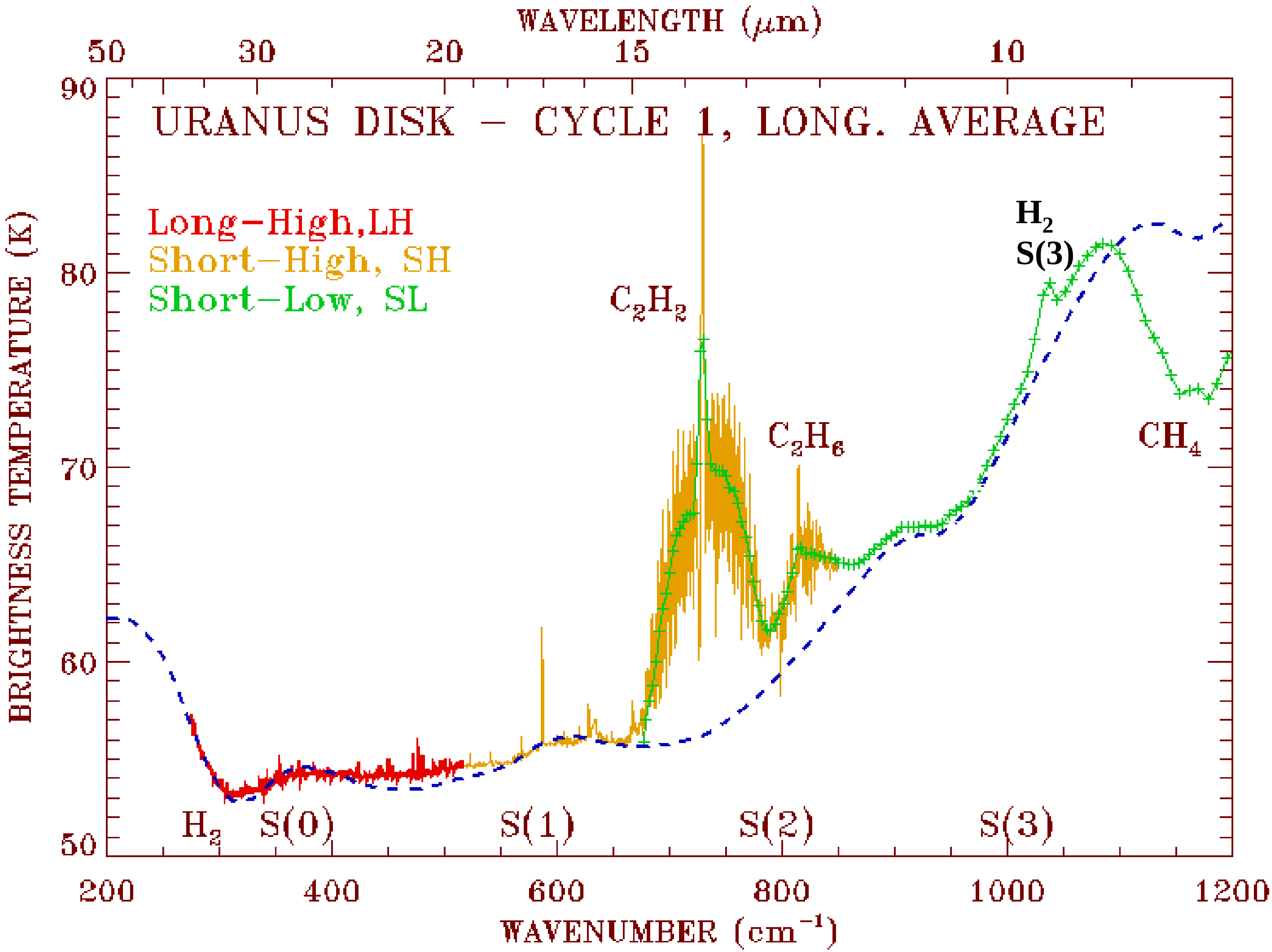
- Assess time variability, independently of the slow changes of the projection of spatially-dependent variations.

Spitzer IRS Observations of Uranus

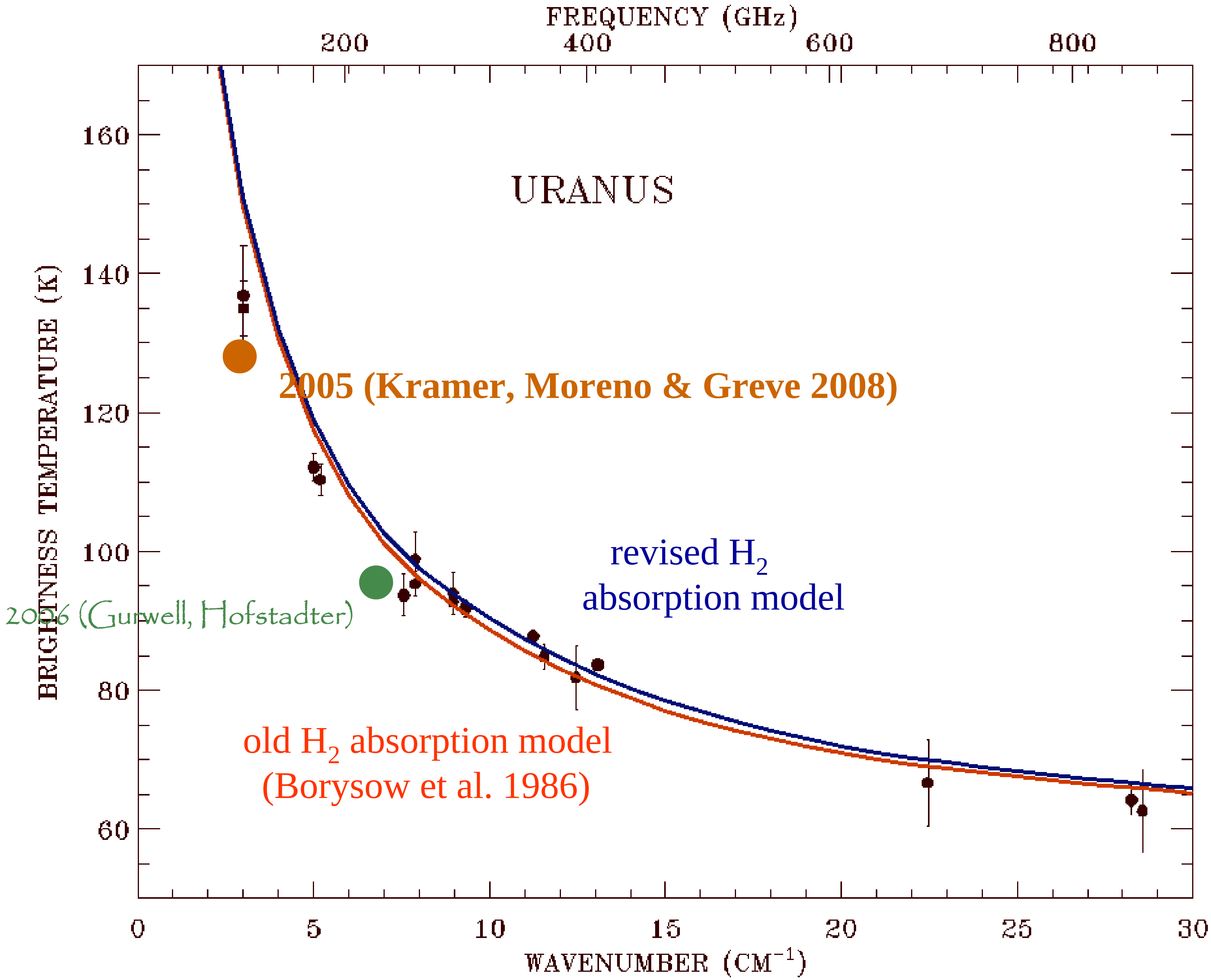
- Observations currently used date from Cycle1
- Longer integration times and multiple redundancies between orders obtained in December, 2007, in Director Discretionary time as a part of Uranus “equinoctal studies” (also justified by Herschel calibration needs)
- These data are have not yet been released, but should be soon, work to be done over next 6 months by graduate-student intern, Cécile Merlet (Ecole Normale Sup., Paris), arriving 12 Feb.

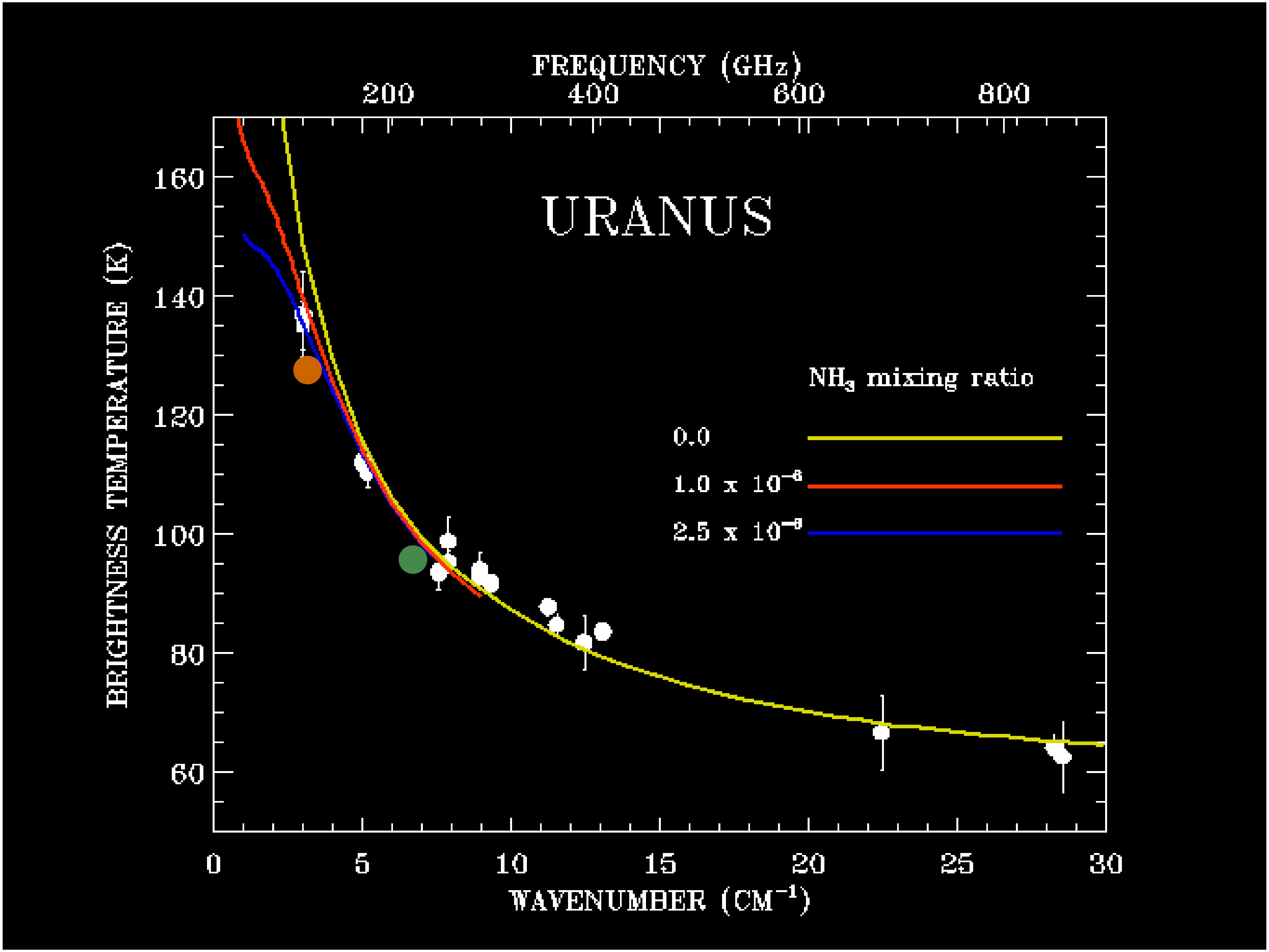


WAVELENGTH (μm)
15
10
90
80
70
60
50
600
700
800
900
1000
1100
1200
WAVENUMBER (cm⁻¹)
TEMPERATURE (K)
URANUS
revised H2 absorption model
H2 S(3)
C2H2
C2H6
CH3D, CH4 absorption
old H2 absorption model (Borysow et al. 1986)
Revision published by Orton et al. (2006) Icarus 189, 544.

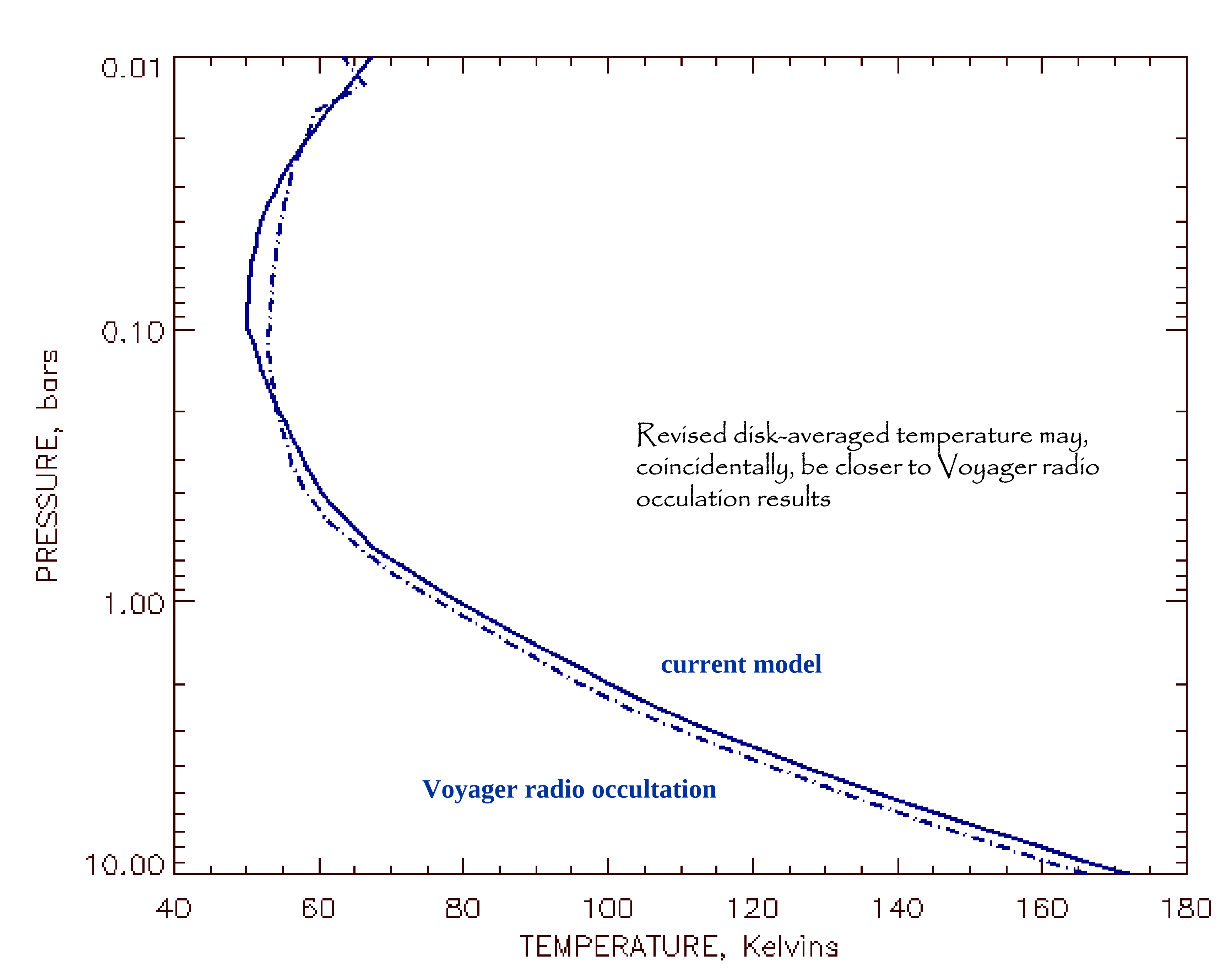


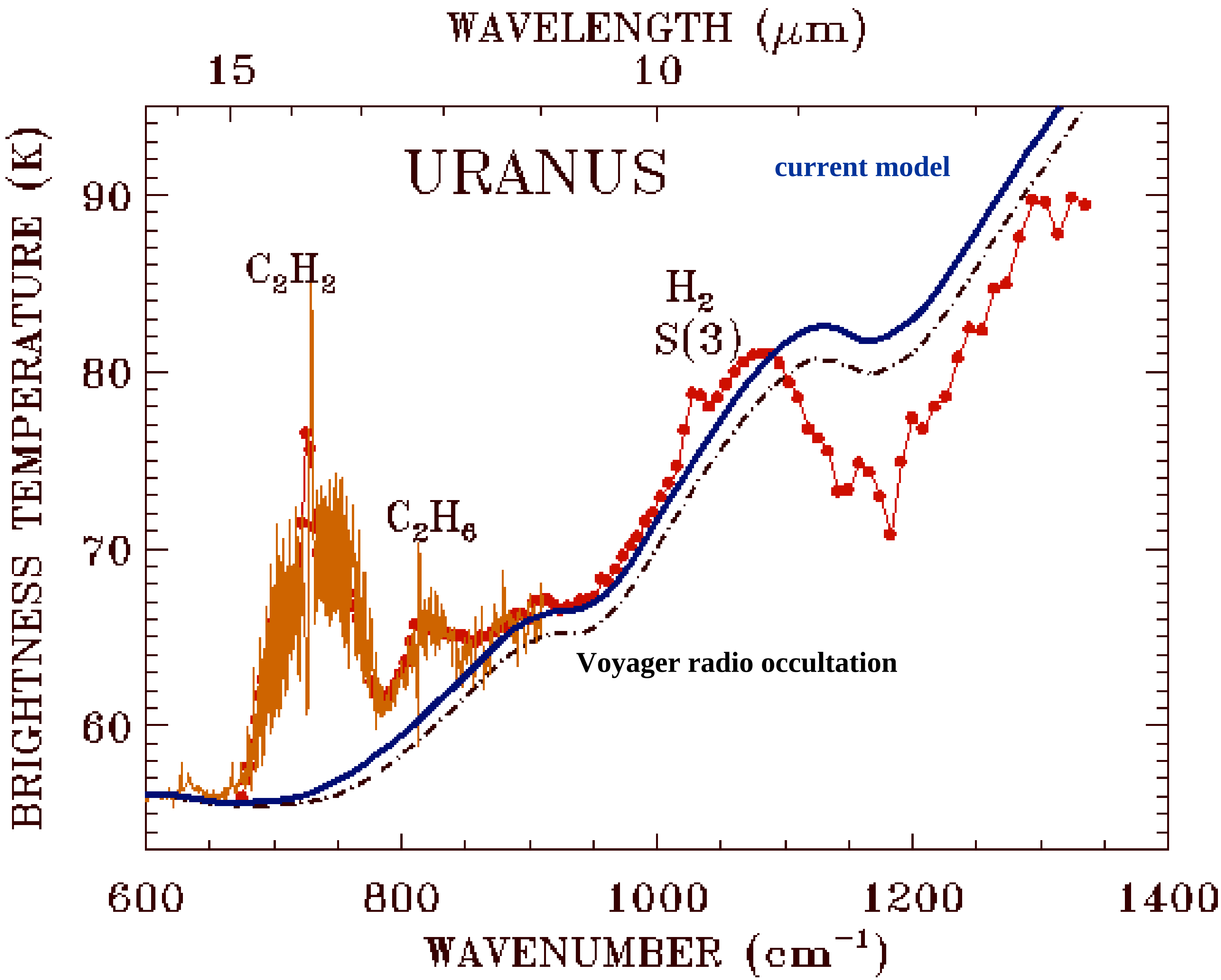
WAVELENGTH (μm)
50
30
20
15
10
URANUS DISK – CYCLE 1, LONG. AVERAGE
Long-High,LH
Short-High, SH
Short-Low, SL
C_2H_2
C_2H_6
H_2
S(3)
CH_4
BRIGHTNESS TEMPERATURE (K)
90
80
70
60
50
H_2 S(0)
S(1)
S(2)
S(3)
200
400
600
800
1000
1200
WAVENUMBER (cm^{-1})


FREQUENCY (GHz)
200
400
600
800
URANUS
160
140
120
100
80
60
BRIGHTNESS TEMPERATURE (K)
2005 (Kramer, Moreno & Greve 2008)
revised H_2
absorption model
2006 (Gurwell, Hofstadter)
old H_2 absorption model
(Borysow et al. 1986)
0
5
10
15
20
25
30
WAVENUMBER (CM^{-1})



FREQUENCY (GHz)
200
400
600
800
URANUS
BRIGHTNESS TEMPERATURE (K)
160
140
120
100
80
60
NH$_3$ mixing ratio
0.0
1.0 x 10^{-6}
2.5 x 10^{-6}
0
5
10
15
20
25
30
WAVENUMBER (CM^{-1})

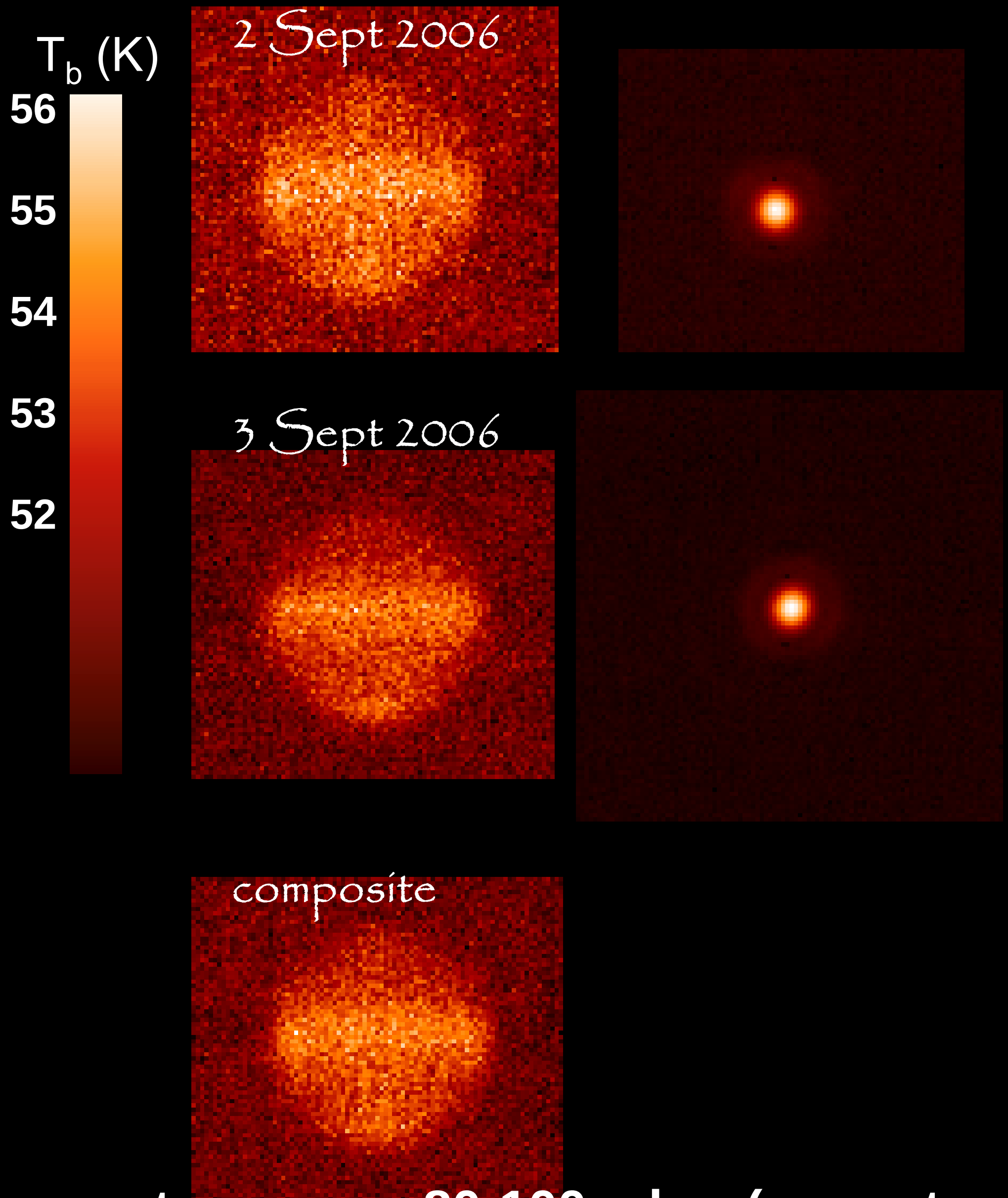

0.01
0.10
1.00
10.00
PRESSURE, bars
40
60
80
100
120
140
160
180
TEMPERATURE, Kelvins
Revised disk-averaged temperature may, coincidentally, be closer to Voyager radio occulation results
current model
Voyager radio occultation


WAVELENGTH (μm)
15
10
URANUS
current model
C_2H_2
C_2H_6
H_2
S(3)
Voyager radio occultation
BRIGHTNESS TEMPERATURE (K)
90
80
70
60
600
800
1000
1200
1400
WAVENUMBER (cm^{-1})

Ground-Based Thermal Images of Uranus

- First mid-infrared observation of Uranus
- ESO, Very Large Telescope (VISIR instrument), 2-3 September 2006 (UT), with Therese Encrenaz and Cedric Leyrat
- 1-μm wide filter centered at 18.7 m
- Spectral region controlled by collision-induced H2
- Sensitive to upper tropospheric/lower stratospheric temperatures

Uranus at 18.7 μm
VISIR/UT3 Observations, ESO/VLT, 2 – 3 September 2006

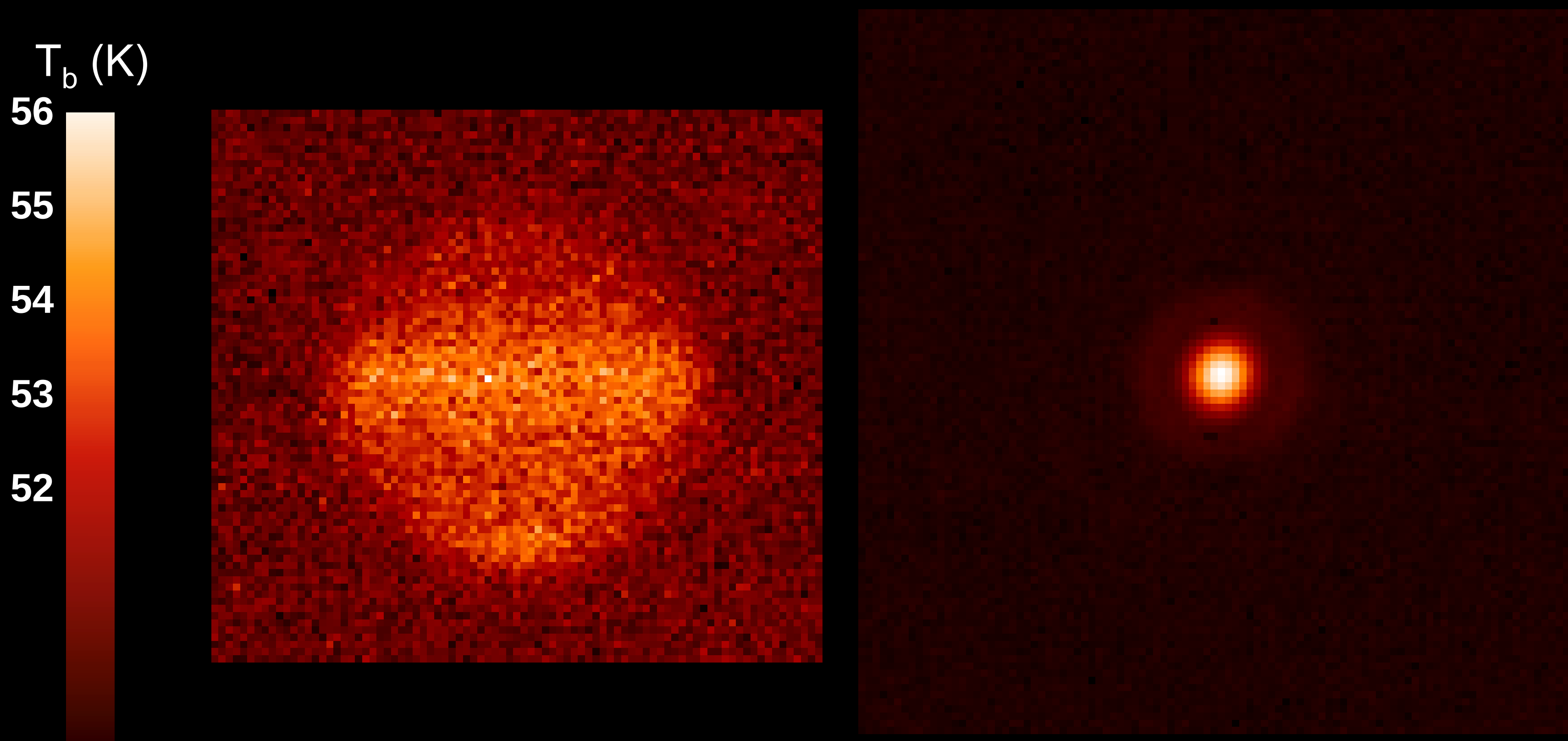


Sensitive to temperatures near 80-100 mbar (upper troposphere)

Uranus at 18.7 μm

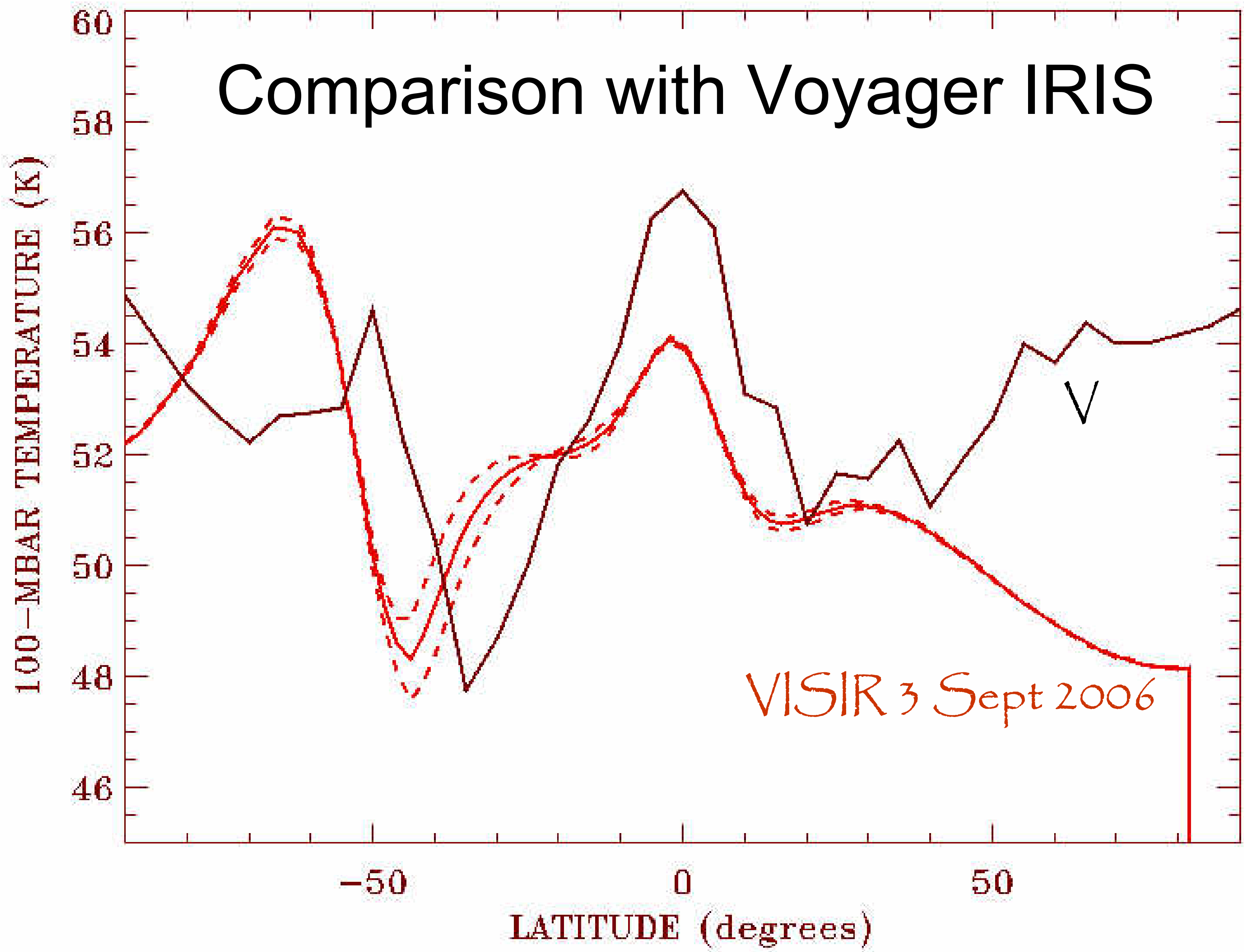
VISIR/UT3 Observations, ESO/VLT, 3 September 2006

(best observation set)



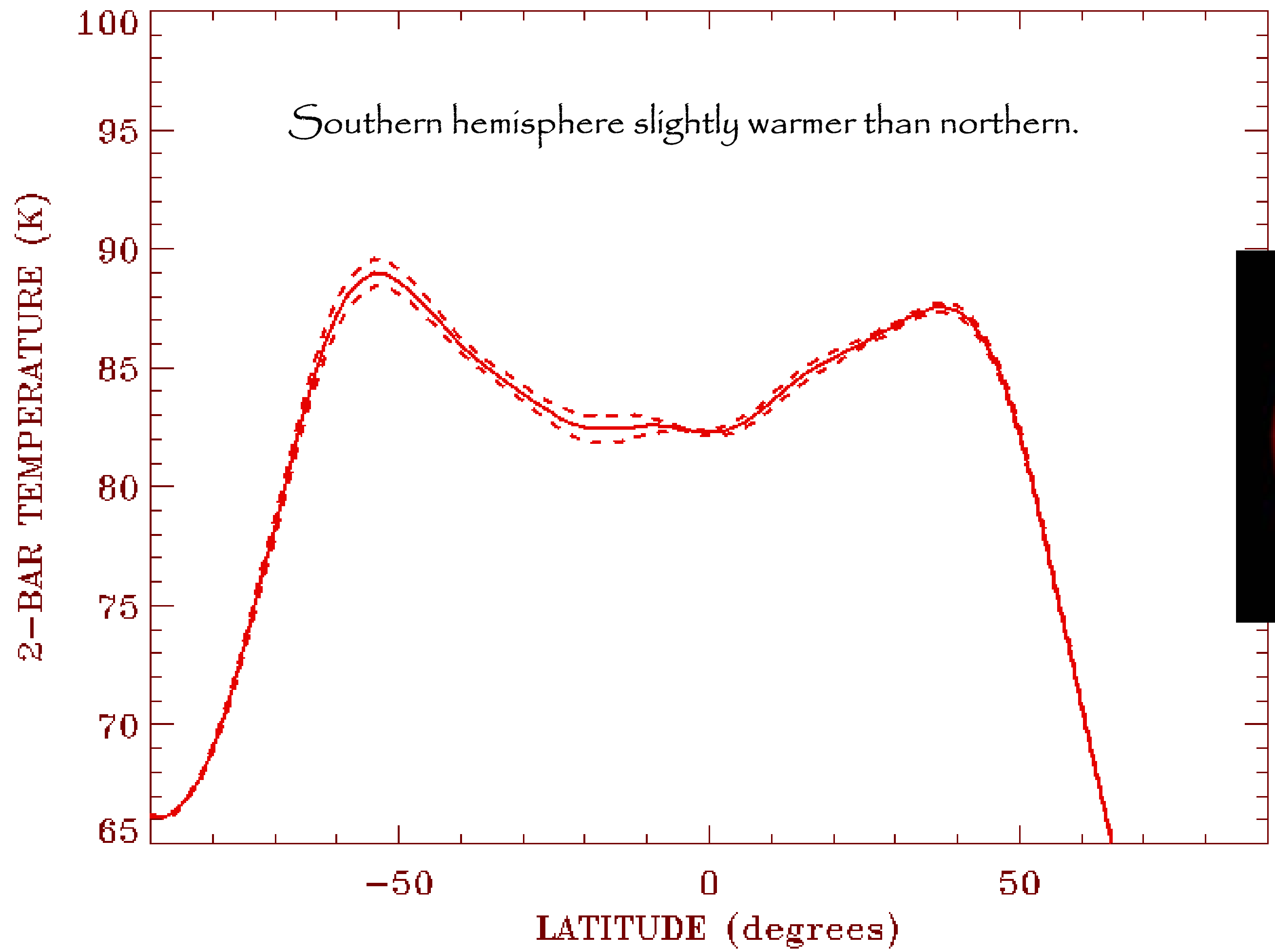
Sensitive to temperatures near 80-100 mbar (upper troposphere)

Comparison with Voyager IRIS



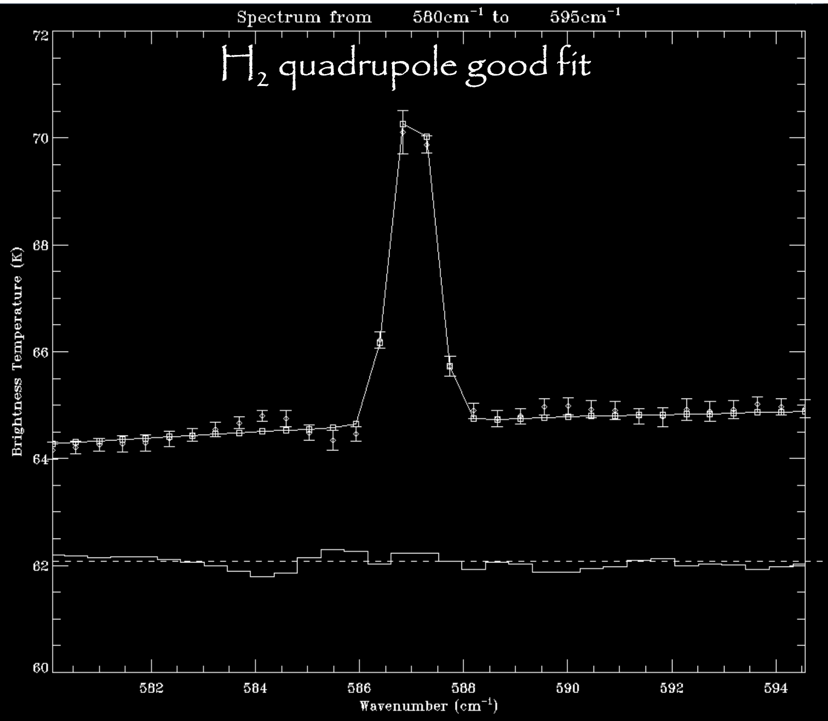
Uranus 220-GHz SMA

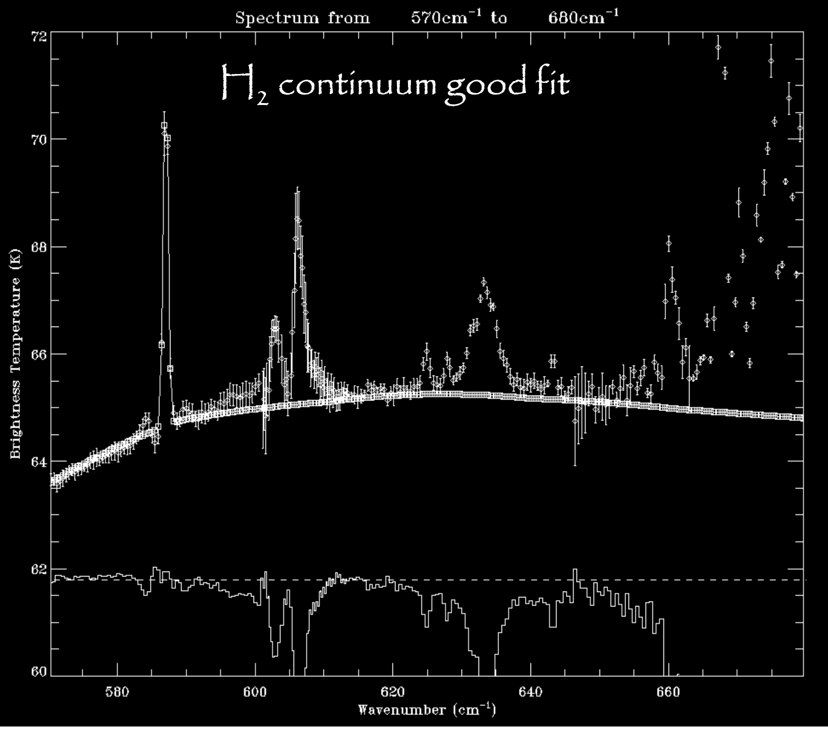
- Sensitive to temperatures near p=2 bar
- Zonal-mean T(2 bar) recovery does not yet account for beam size

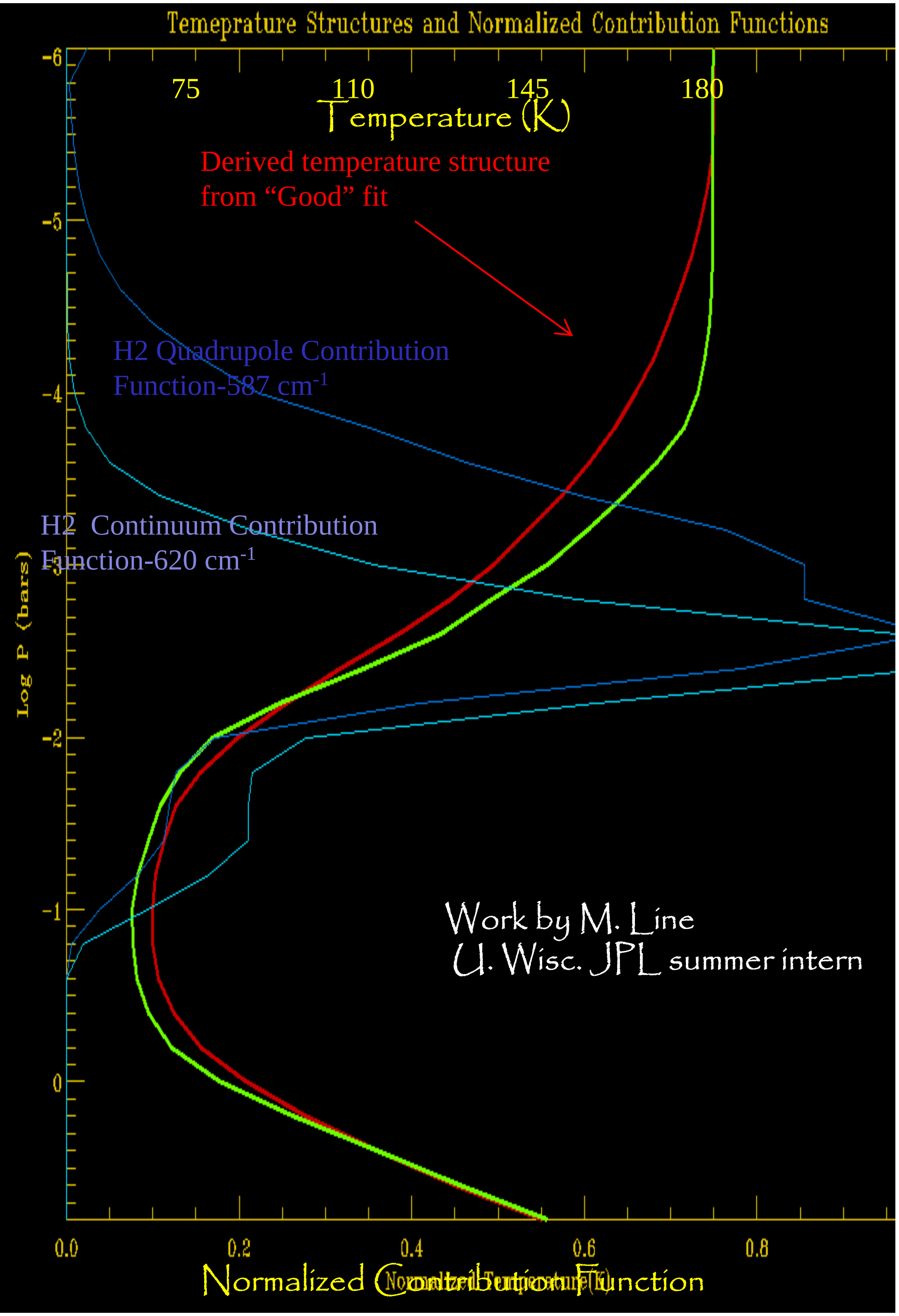


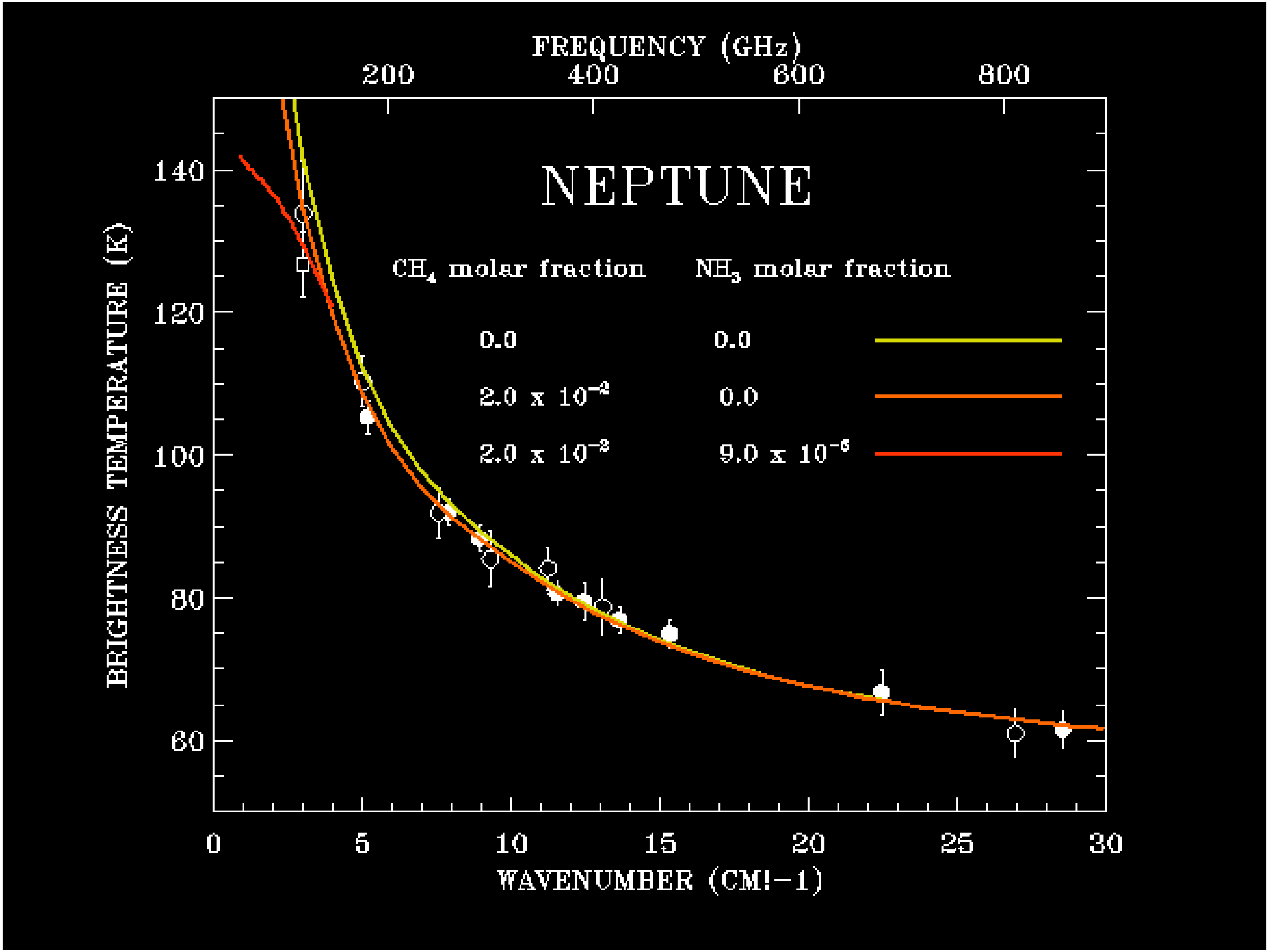
Spitzer IRS Observations of Neptune

- Observations currently used are from Cycles 1 and 2
- Cycle-2 observations have longer integration times and sky background checks
- Data have been checked “by hand” for “rogue” pixels by Amanda Mainzer (JPL)
- Spectrum shows portion of spectrum sensitive only to T(p) (the collision-induced H_2 absorption) over a narrower spectral range than Uranus


Spectrum from 580cm-1 to 595cm-1
H2 quadrupole good fit
Brightness Temperature (K)
72
70
68
66
64
62
60
582
584
586
588
590
592
594
Wavenumber (cm-1)


Spectrum from 570cm-1 to 680cm-1
H2 continuum good fit
Brightness Temperature (K)
72
70
68
66
64
62
60
580
600
620
640
660
Wavenumber (cm-1)


Temeprature Structures and Normalized Contribution Functions
75
110
145
180
Temperature (K)
Derived temperature structure
from "Good" fit
H2 Quadrupole Contribution
Function-587 cm-1
H2 Continuum Contribution
Function-620 cm-1
Log P (bars)
-6
-5
-4
-3
-2
-1
0
Work by M. Line
U. Wisc. JPL summer intern
0.0
0.2
0.4
0.6
0.8
Normalized Contribution Function



FREQUENCY (GHz)
200
400
600
800
NEPTUNE
CH_4 molar fraction
NH_3 molar fraction
0.0
0.0
2.0 x 10^{-2}
0.0
2.0 x 10^{-2}
9.0 x 10^{-6}
BRIGHTNESS TEMPERATURE (K)
60
80
100
120
140
0
5
10
15
20
25
30
WAVENUMBER (CM!-1)

Ground-Based Thermal Images of Neptune

- Gemini N, (Michelle instrument) 4-5 July 2005 (UT) with Heidi Hammel
  - 7.8 µm (CH_4 emission) stratospheric emission
  - 12.5 µm (C_2H_6 emission) stratospheric emission

- ESO, VLT (VISIR instrument), 2-3 September 2006 (UT), with Therese Encrenaz and Cedric Leyrat: various filters:
  - 8.7 µm (CH_4, CH_3D emission) stratospheric emission
  - 12.5 µm (C_2H_6 emission) stratospheric emission
  - 17.8, µm (H_2 "CIA" emission) tropospheric emission
  - 18.7 µm (H_2 "CIA" emission) tropospheric emission

- Gemini S, (T-Recs instrument): 2007
  - 17 July (7.9 µm) stratospheric emission
  - 30 Aug (12.5 µm) stratospheric emission
  - 19 Sep (7.9 µm) stratospheric emission
  - 21 Sep (12.5 µm) stratospheric emission

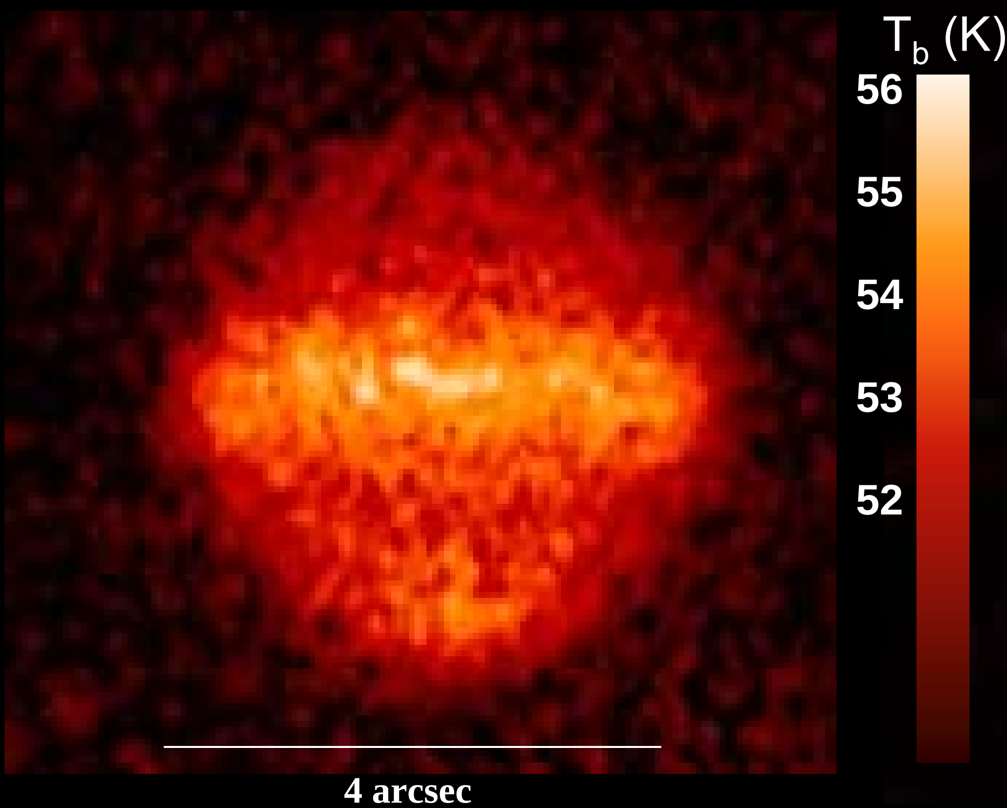
- 17.8, 18.9 µm controlled by collision-induced H_2

- 7.9, 8.7 µm sensitive to stratospheric temperatures, CH_4 abundance

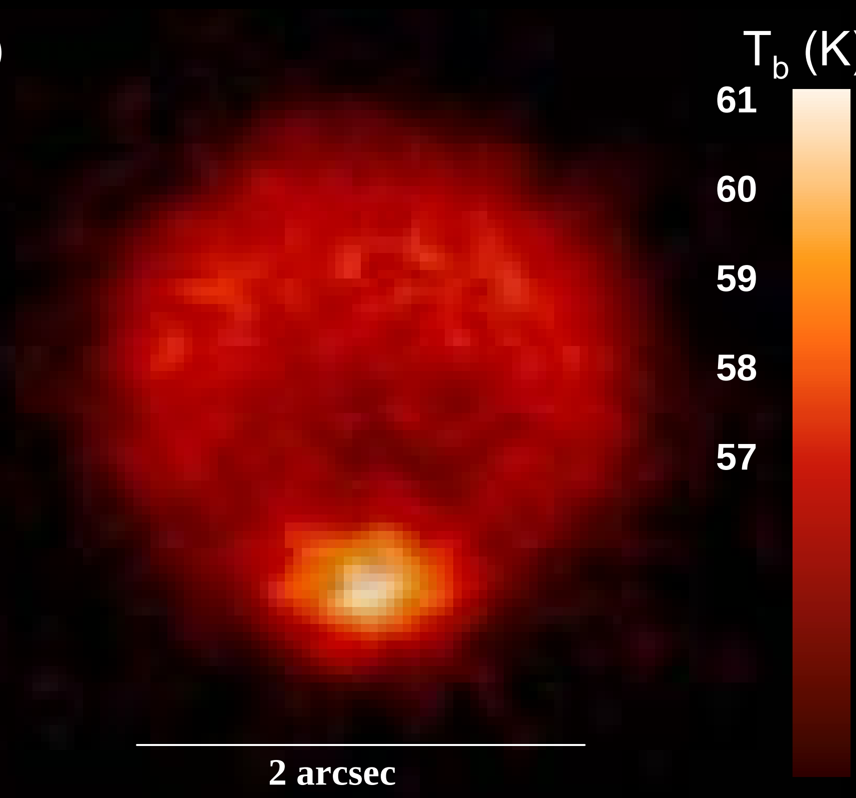
- 12.5 µm sensitive to stratospheric temperatures, C_2H_6 abundance

Uranus and Neptune at 18.7 μm
VISIR/UT3 Observations, ESO/VLT, 2 – 3 September 2006

3 Sep 2006, 4:02 UT

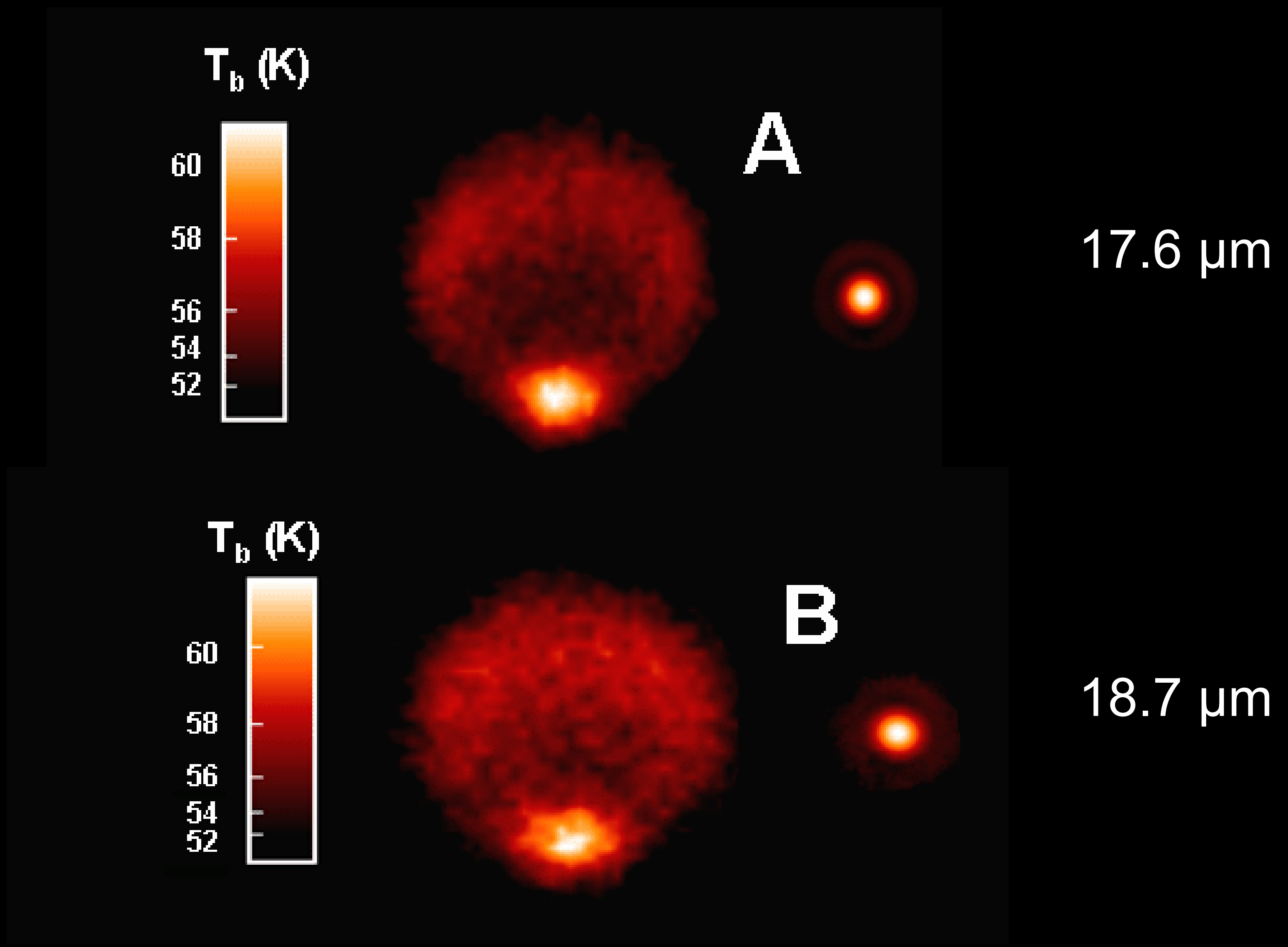


3 Sep 2006, 1:44 UT

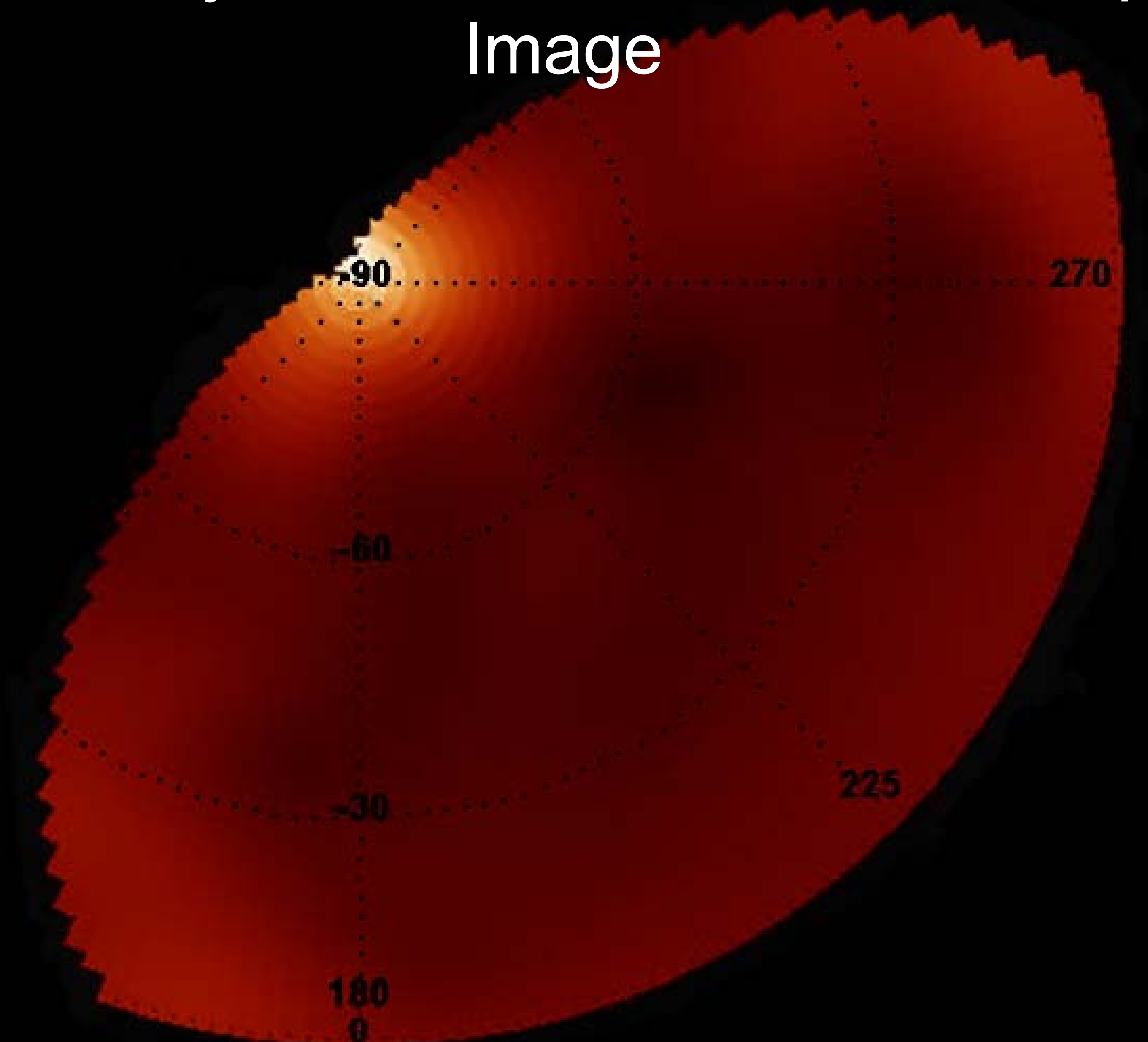


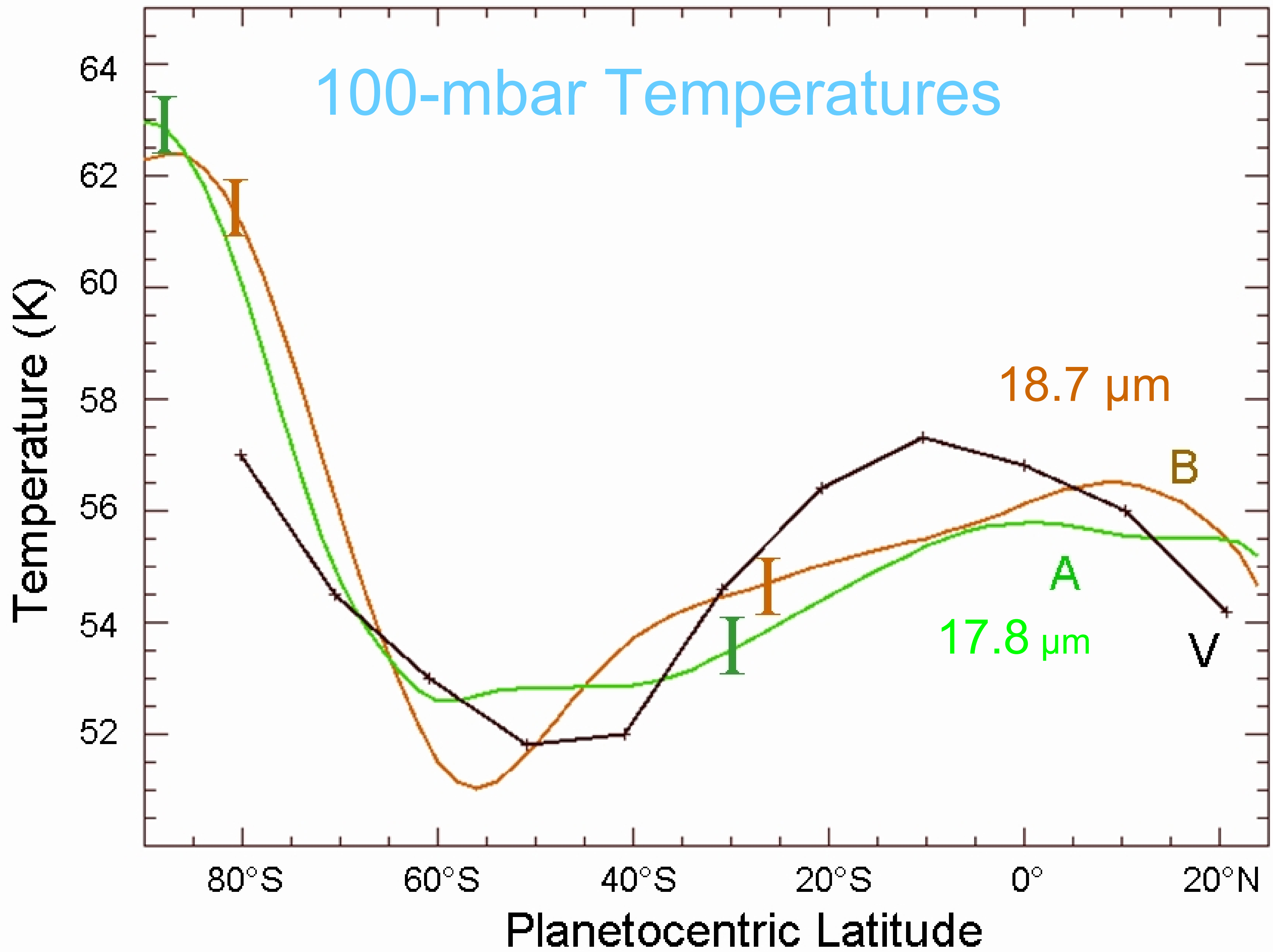
Sensitive to temperatures near 110 mbar (upper troposphere)

Observations with VISIR, Very Large Telescope
1-2 September 2006



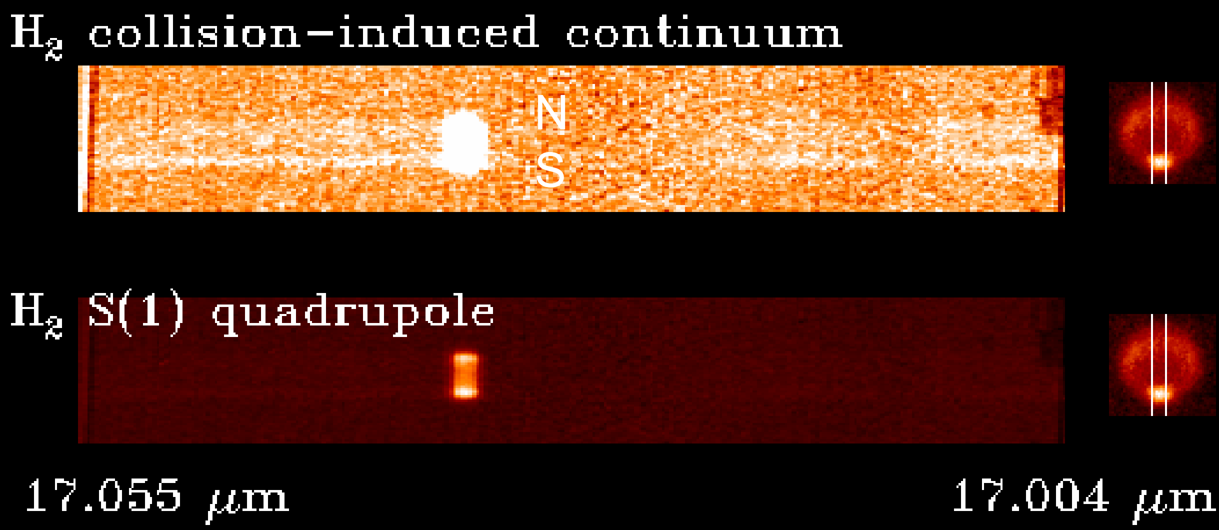
Polar Projection of Deconvolved 17.6-μm Image



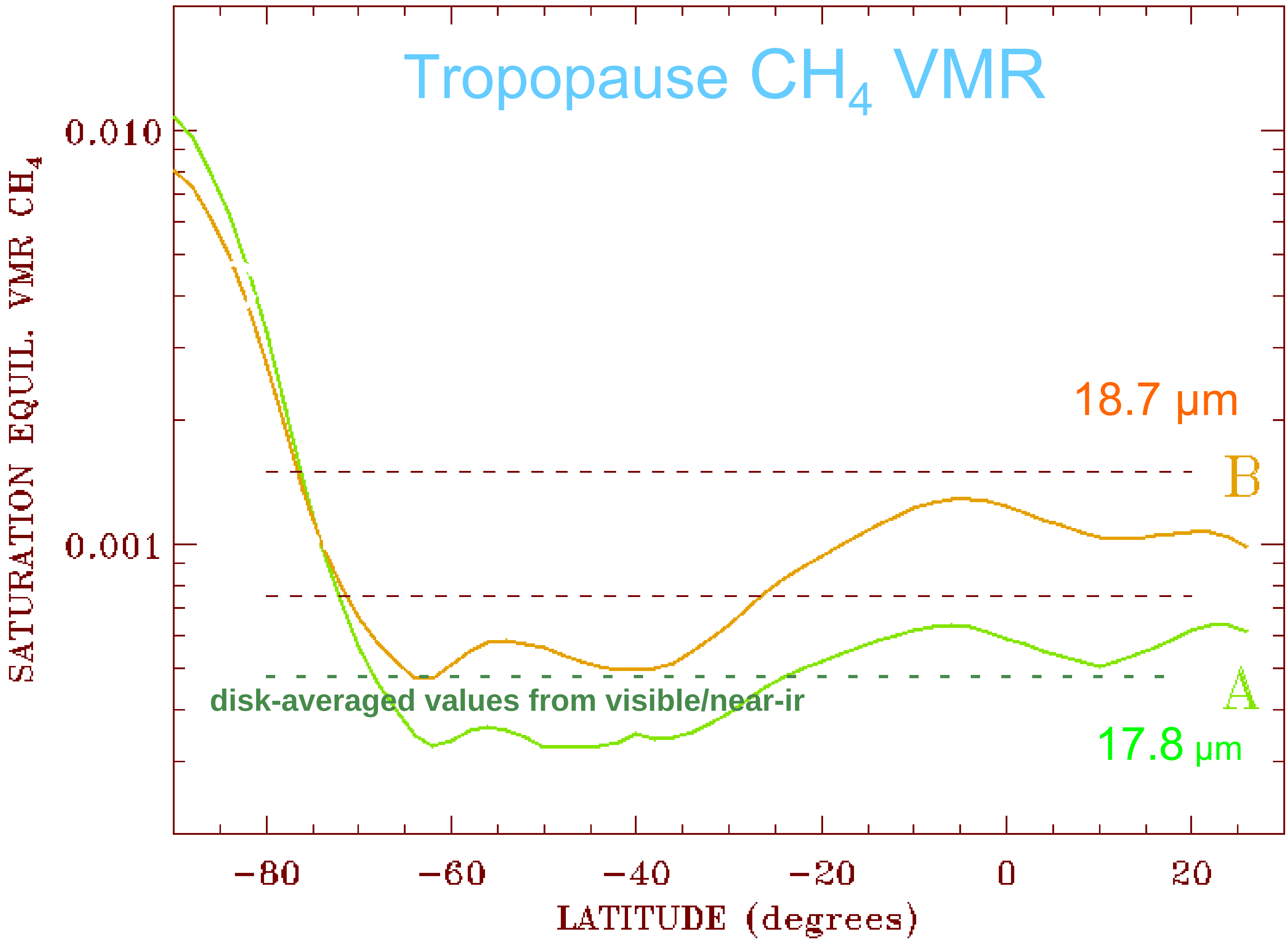


100-mbar Temperatures
Temperature (K)
64
62
60
58
56
54
52
80°S
60°S
40°S
20°S
0°
20°N
Planetocentric Latitude
18.7 µm
B
A
17.8 µm
V

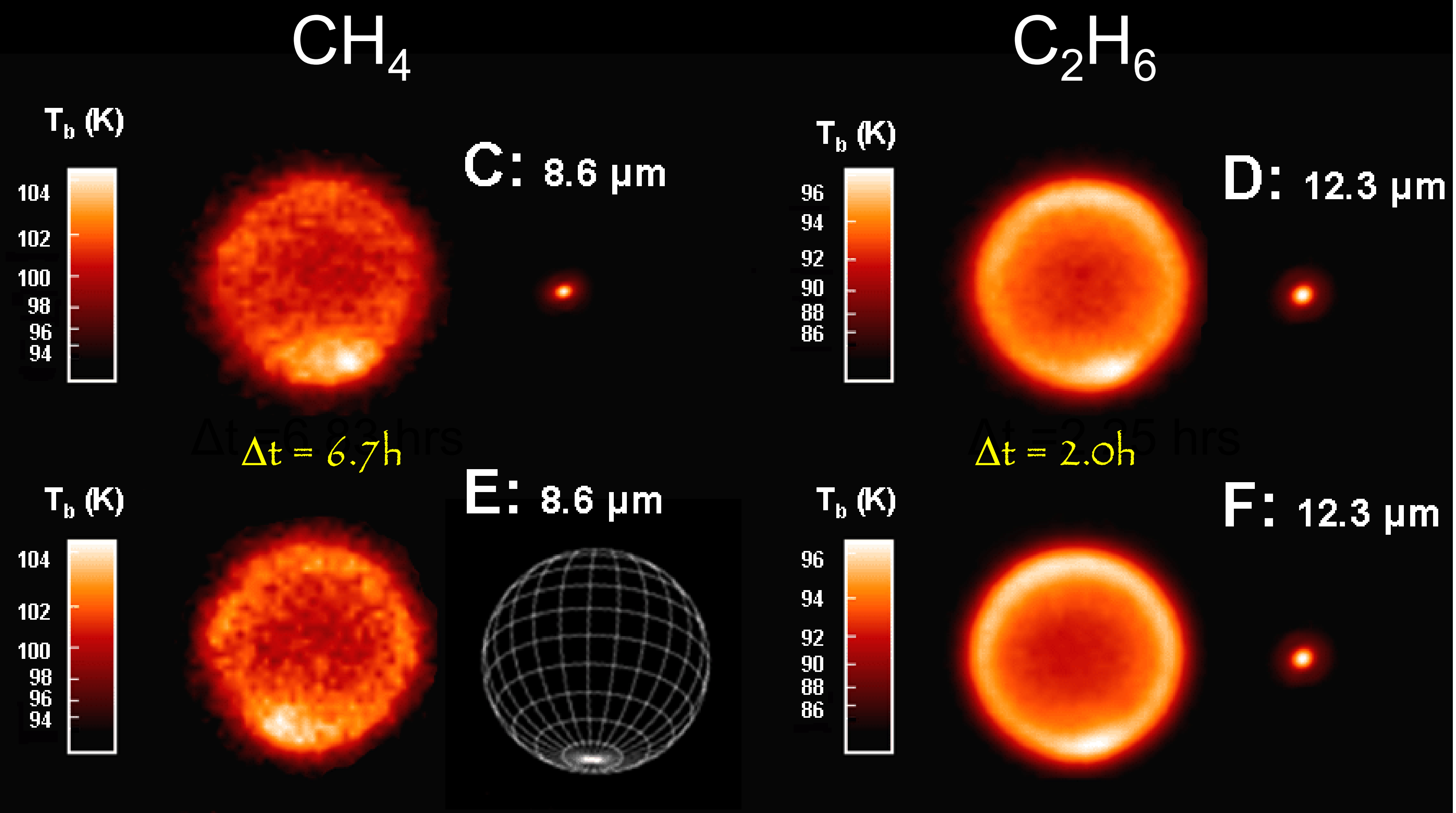
Spatially resolved spectroscopy of of H_2 S(1) quadrupole, sensing 0.1-mbar stratospheric temperatures:

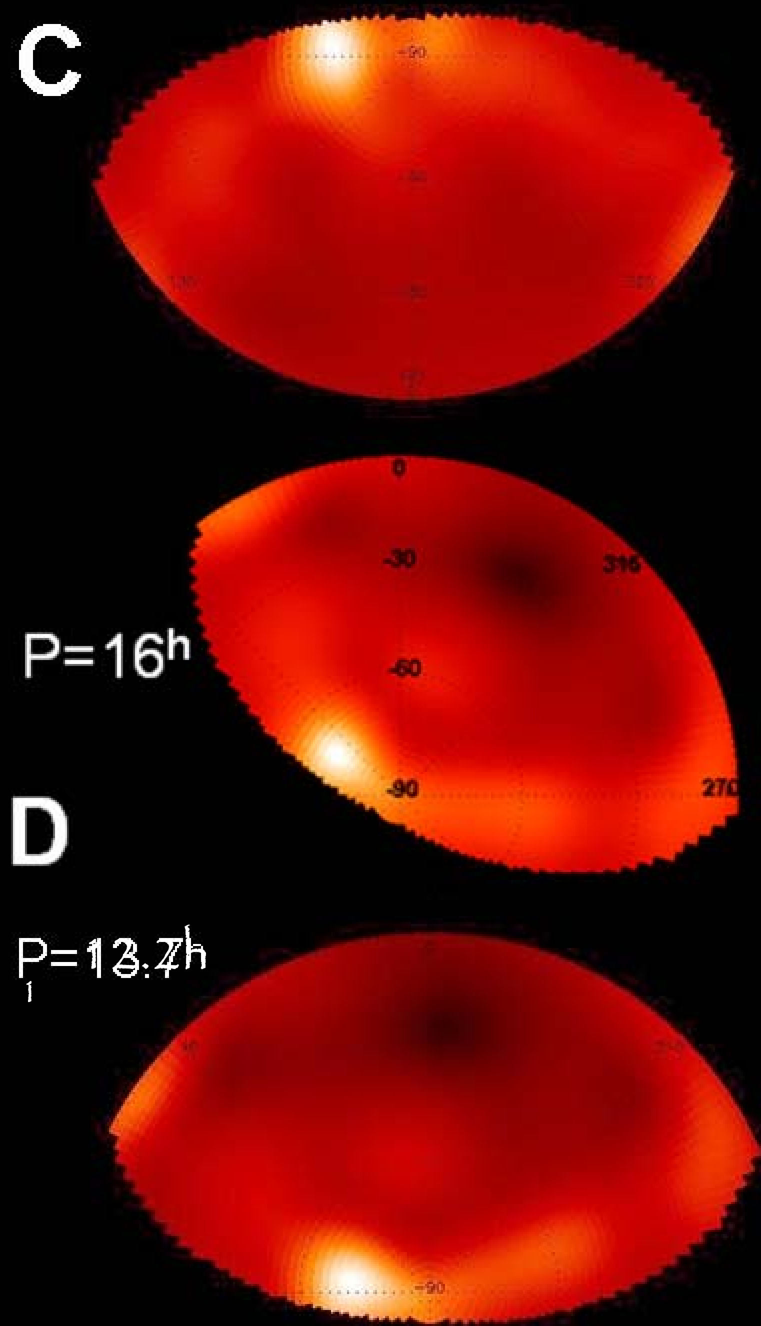


- Continuum is like image: 100-mbar temperature are 9 K warmer in the south
- Center of H_2 quadrupole line: 0.1-mbar temperatures are only 3 K warmer in the south
- Confirms that a CH_4 gradient must exist at p ~ 0.1 mbar to explain the steep latitudinal gradient in CH_4 emission:


Tropopause CH_4 VMR
SATURATION EQUIL. VMR CH_4
0.010
0.001
18.7 μm
B
A
17.8 μm
disk-averaged values from visible/near-ir
−80
−60
−40
−20
0
20
LATITUDE (degrees)

Stratospheric Emission



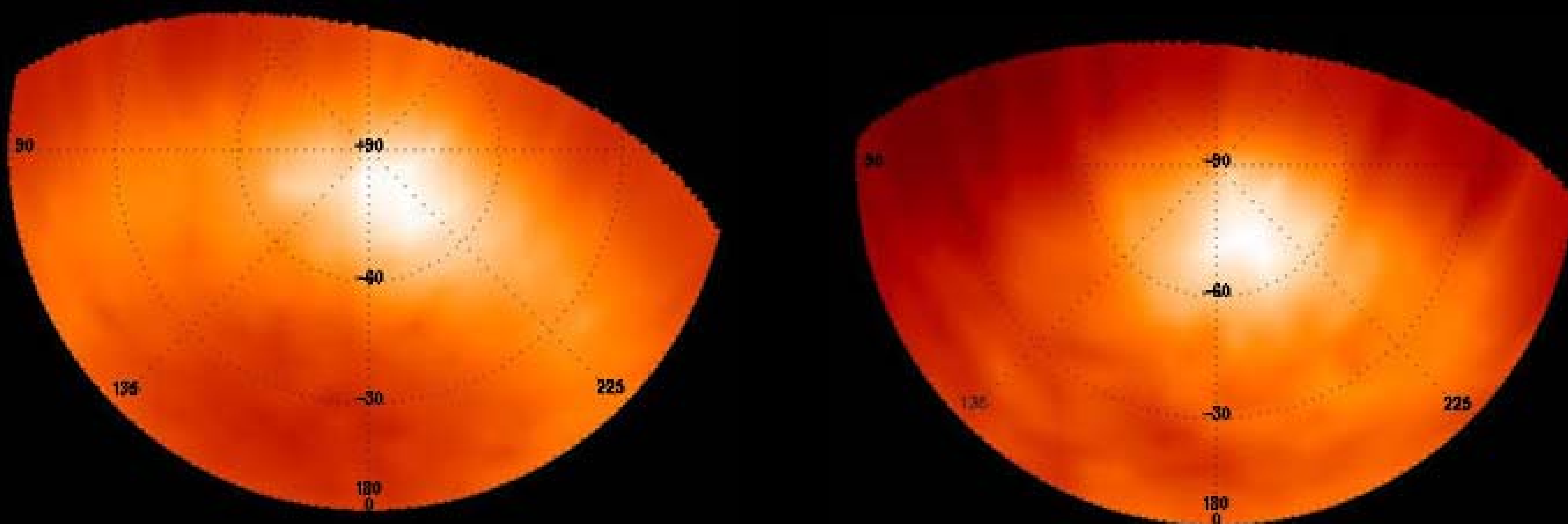


16h (magnetic) rotation period requires there to be two features

A single feature requires the local rotation rate to be 12.2h (close to the period of the local winds)

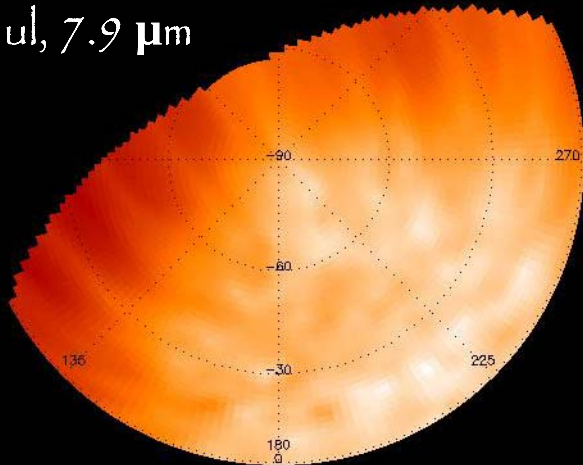
Similar feature seen in Gemini/North 7.9-μm thermal images 4 July 2005

(but temperature variation is lower amplitude,~1 K)

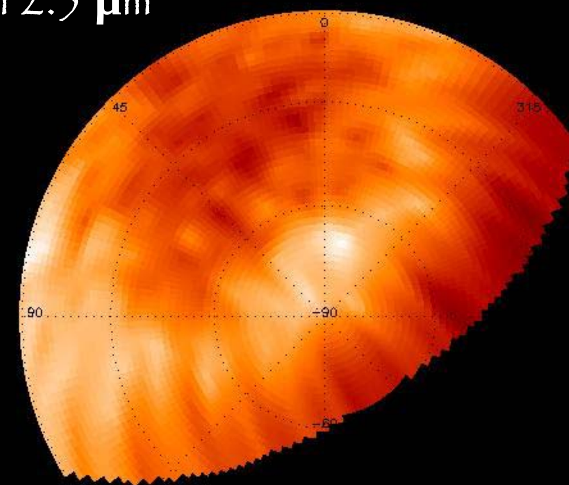


No such features seen in Gemini/South (T-Recs) 7.9- or 12.5-µm thermal images in July-Sept 2007

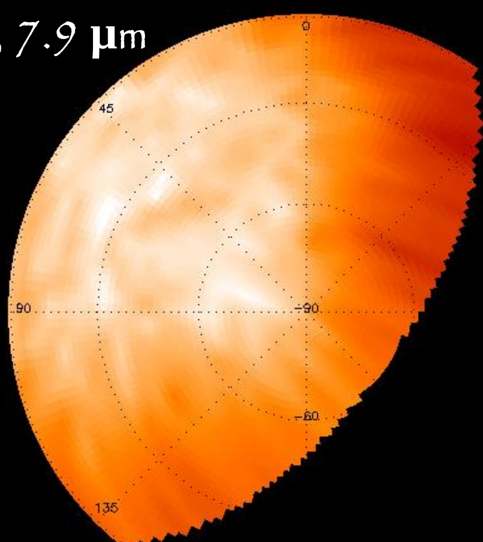
17 Jul, 7.9 µm



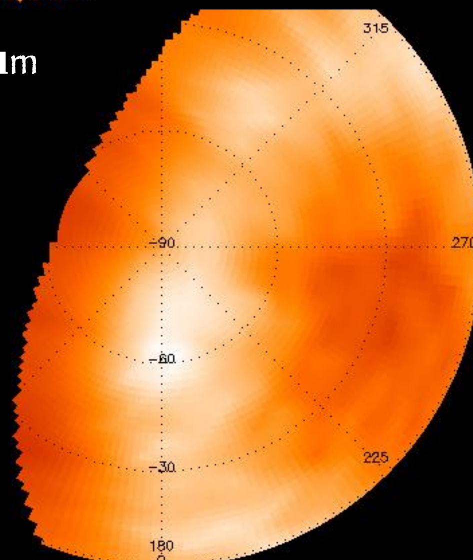
30 Aug, 12.5 µm



19 Sep, 7.9 µm



21 Sep, 12.5 µm



Tentative Conclusions

- No significant variations of tropospheric emission are seen over rotation of Uranus and Neptune from Spitzer spectra at different longitudes
- Variations of temperatures not seen spatially above the current SNR
- Slow variations are seen in Uranus, where spatial measurements show the “spring pole” significantly colder than Voyager (work in progress in next few weeks)
- Substantial unpredictable variations are seen in Neptune, but only in the stratosphere

To be done

- Continued observations
  - 16 hrs of VLT (VISIR) time on Uranus (spatiallly resolved imaging at new wavelengths and spectroscopy)
  - 16 hrs of VLT (VISIR) time on Neptune (spatially resolved imaging at new wavelengths and spectroscopy)
  - Collaborative work will be done, requesting GranTeCan (Canaricam in mid-ir) time with Agustin Sanchez-Lavega (U. del Pais Vasco)
  - Time will be requested from Subaru and Gemini for 2008b (scientific case must be strong)
- Continued work to model Spitzer observations of Uranus and Neptune
- Incorporation of formal retrieval algorithm (Oxford U.), Leigh Fletcher (new JPL NASA postdoc)
- Continued modeling to understand spatial variability and distinguish true time variations from changing geometry: assess recent vs pre-1990 observations of spectrum

Wavelength Range	Date of Observation	Spatial Res. (Y/N)	Object	Instru-ment	Comments
Microwave					
0.7 - 20 cm	1978 – present	Yes	U	VLA	Accuracy 5% (Precision 1%) on recent data (*e.g.* Fig. 4, Hofstadter and Butler 2003), 10% on earliest (Briggs and Andrew 1980)
1.3 - 6 cm	2006	Yes	U, N	VLA	Data just taken
3.5 cm	1965 – present	No	U	DSN	Accuracy 10% (Klein and Hofstadter 2006)
3.3 mm to 1 cm	2001 – 2002	No	M, J	WMAP	Defines high-accuracy (1%) Mars calibration, scaled to CMB dipole
0.7 – 6 cm	1982 – present	No	U, N, M	VLA	Perley & Butler (2006), VLA flux scale. Accuracy <3%, 5 and 10% at 1.3 and 0.7 cm, respectively. Precision 0.1%.
1.3 – 6 cm	1982 – 1991	Yes	N	VLA	1982,1986 (de Pater and Richmond 1989), 1990 (de Pater *et al.* 1991), 1991 (Hofstadter 1993). Accuracy ~10%.
0.7 – 20 cm	2003, 2006	Yes	N	VLA	Martin (2006), reduction in progress.
MM & Sub-MM					
1.3, 0.9, 0.4 mm	2006	Yes	U, N	SMA	Scheduled for summer
1.3, 2.6 mm	1990 – present	No	U, N	OVRO	Gurwell (in preparation) Accuracy 10 to 15%
1.0, 1.5 mm	1995	No	U, N	CSO	Weisstein and Serabyn (1996)
0.35,1.0 mm	~1999	No	J	CSO	Serabyn and Pardo (in preparation) Accuracy 5%.
0.35 - 3.3 mm	1982-1984 1990-1992	No	U, N, M	JCMT	Orton *et al.* (1986) Griffin and Orton (1993)
Mid- to Far-IR					
35 - 200 µm	1996-1997	No	U, M U, N	ISO (LWS) (LWS & SWS)	Sidher *et al.* (2000), Mars and Uranus cross-calibration. Burgdorf *et al.* (2003), calibrated using Uranus standard model.
30 - 50 µm	1986 1989	Yes	U N	Voyager IRIS	Precision 3% (Conrath *et al.* 1998, and references therein)
7 - 24 µm	1986 - 1989	No	U, N	IRTF	Orton *et al.* (1987, 1990)
8 - 20 µm	2003	Yes	N	Keck	Martin (2006)
7, 11 µm	2005	Yes	N	Gemini/N	Hammel (in preparation)
7 - 37 µm	2004-2006	No	U, N	Spitzer	Orton *et al.* (2005) Accuracy 10-13%
17 - 20 µm	2006	Yes	U, N	VLT	Scheduled for 2006 Aug 30 – Sep 3

1.3 mm obtained

18.6 µm obtained