

Uranus in 2012 from HST STIS: Methane Depletion in North Polar Region Indicates Nonseasonal Origin

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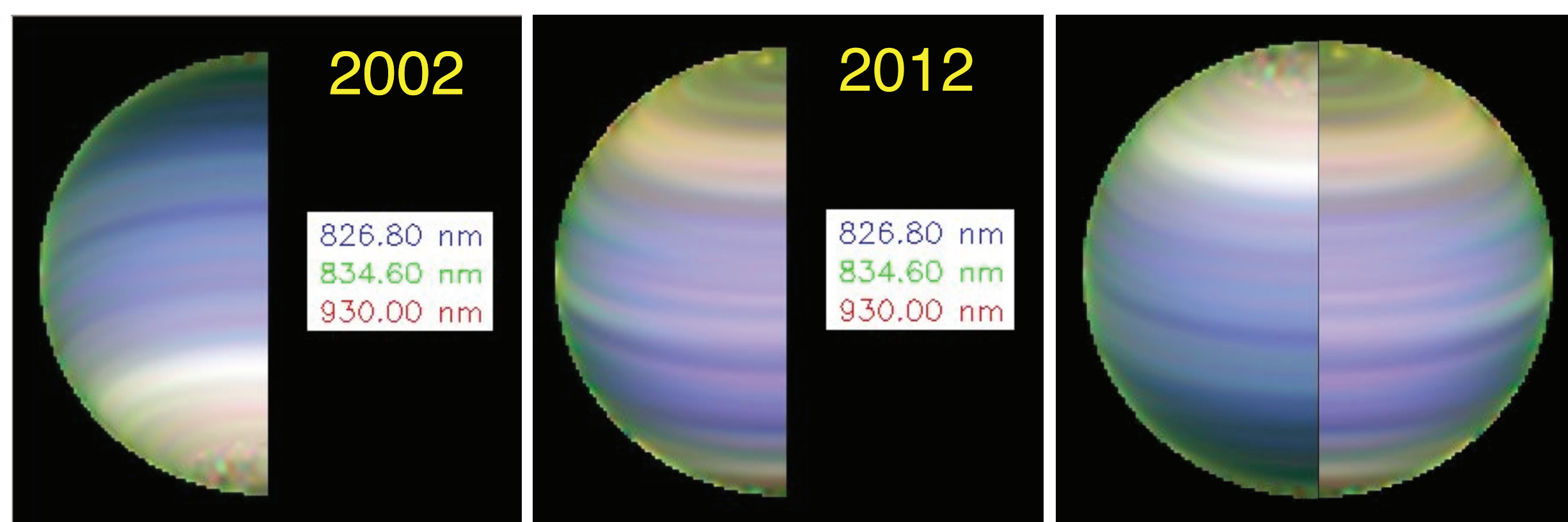


Figure 1: Color composite of fitted center-to-limb smoothed images for 2002 and 2012. The right image inverts the 2002 vertically for a more direct comparison. Note that sub-observer latitudes are -20.5° and $+18.7^\circ$ for 2002 and 2012, respectively, so the latitudinal correspondence is not exact. The blue, green, and red wavelengths are CIA-dominated, mostly methane dominated, and methane-only wavelengths, respectively. The blue color at low latitudes is due to increased absorption by methane. The southern high latitudes in 2002 were brighter and whiter than in 2012, which could be due to aerosol abundance or property differences between southern fall and northern spring.

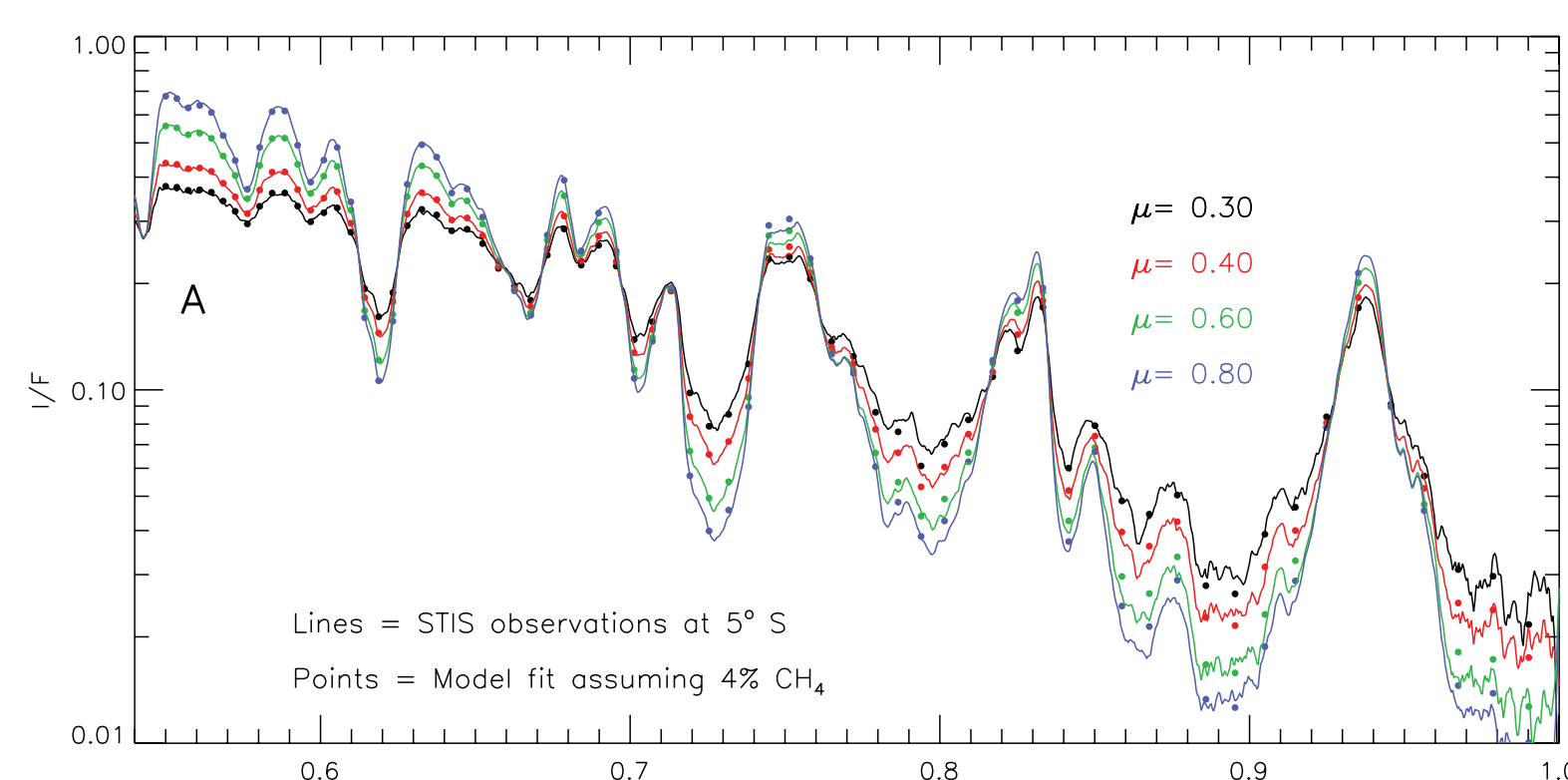
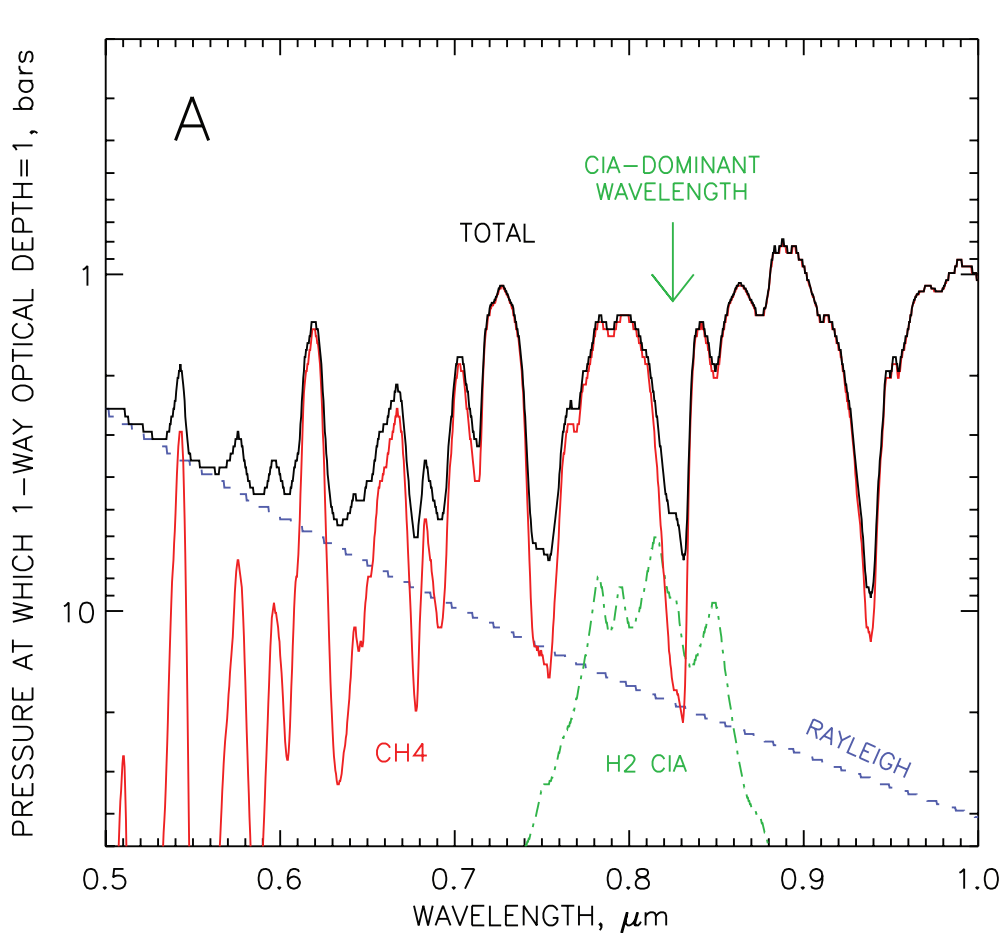


Figure 2: Above, penetration depth vs. wavelength as limited by different opacity sources. Note the greater importance of H2 CIA near 825 nm. Right, Example model fits assuming two different deep methane mixing ratios. The fit errors near 825 nm are a sensitive indicator of the mixing ratio of methane to hydrogen.

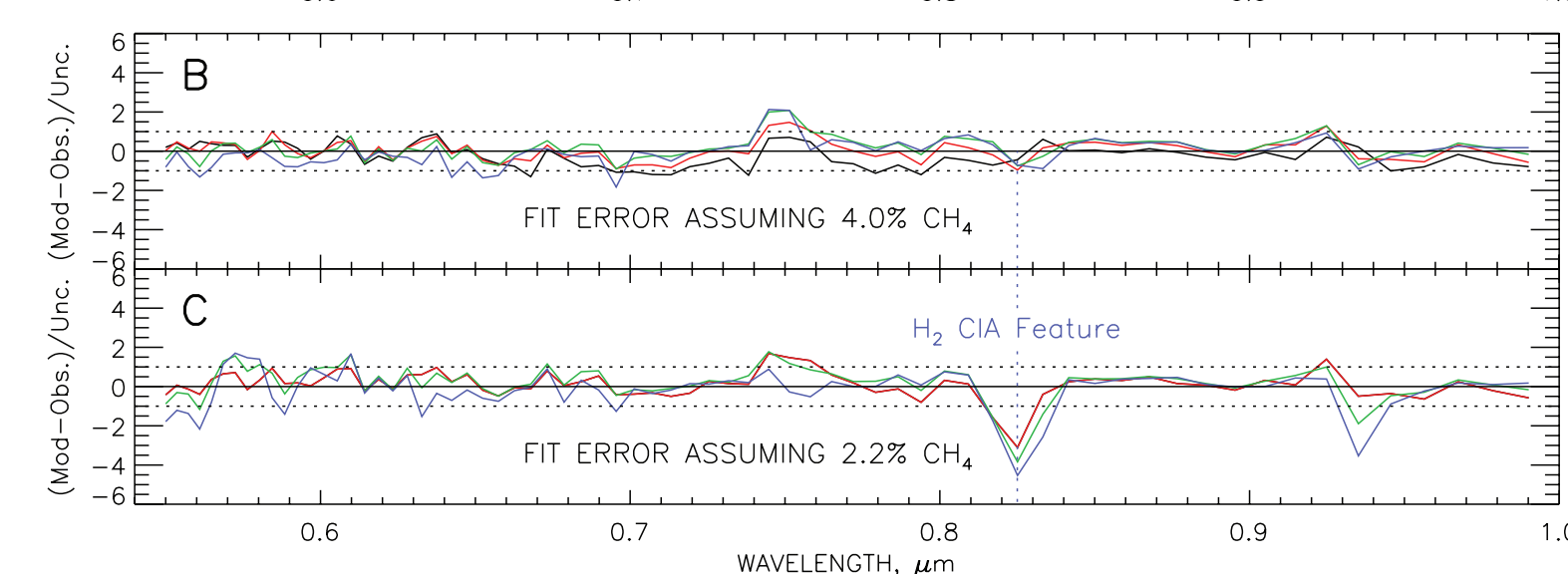


Figure 3: Shift-and-add and highpass filters applied to Uranus' 2003 South (left) and 2011 North (right) polar regions (30° - 90° latitude) reveal a large asymmetry in cloud features poleward of 60° , suggesting very different degrees of polar convection, a likely seasonal effect.

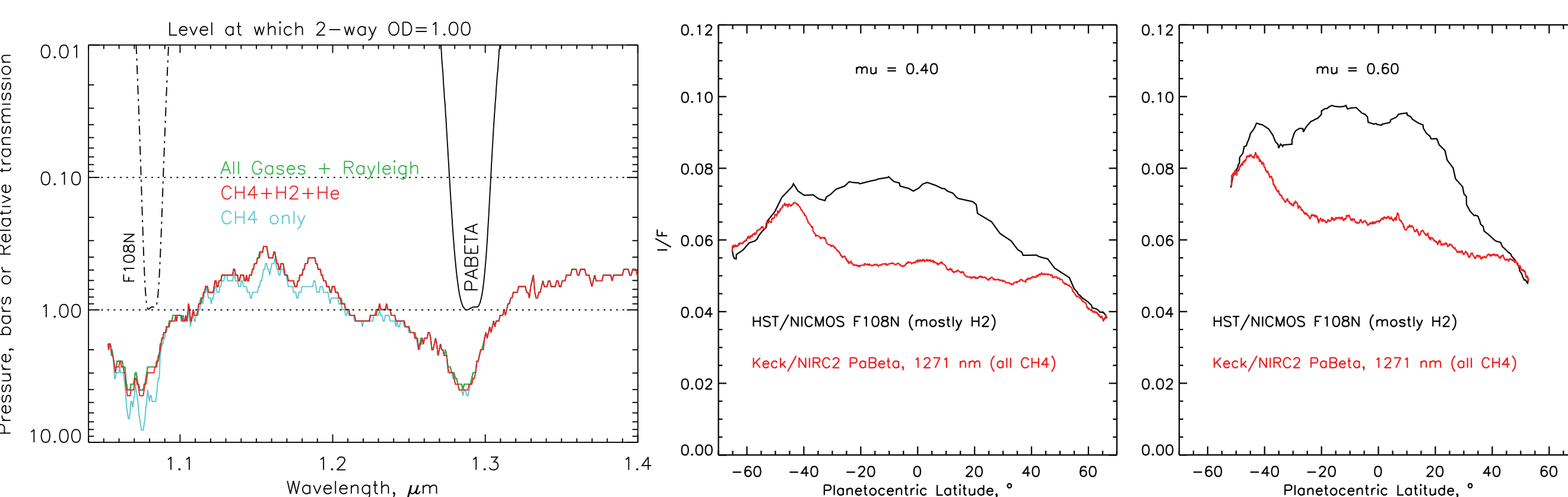


Figure 4: Left, penetration depths of NICMOS F108N filter and Keck NIRC2 PaBeta filter are similar, but F108N has absorption from methane and hydrogen CIA, whereas PaBeta absorption is almost all due to methane. Right, 2007 brightness vs. latitude for the two filters, at fixed observer zenith cosine angles. At high latitudes in both hemisphere the two profiles agree with each other quite closely. But at low latitudes, the profile for the methane-dominated wavelength is substantially depressed relative to the hydrogen-dominated, indicating that upper tropospheric methane absorption is much higher at low latitudes than at high latitudes.

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Background: On 27 and 28 September 2012, Hubble's Space Telescope Imaging Spectrograph (STIS) observed Uranus (GO 12894, L. Sromovsky PI). The result is a hyperspectral data cube of one half of the planet with spectral coverage of 300-1000 nm. The observations were designed to characterize latitudinally (from about 50° S to the north pole) the vertical structure of aerosols and global distribution of methane after the planet's 2007 equinox. These observations form a unique counterpart to similar observations made in 2002 (GO 9035, E. Karkoschka PI) when Uranus' south pole was in view (see **Figure 1**). In 2002, Uranus was found to have a depletion of methane in southern mid-to-high latitudes (Karkoschka & Tomasko 2009, Sromovsky et al. 2011). Characterizing this distribution is possible by the simultaneous sounding of both hydrogen and methane spectral absorption regions (see **Figure 2**). As Uranus' northern hemisphere came into view, it became apparent from near-IR observations of the troposphere (sensing to about 10 bars), that the north and south hemispheres were asymmetric in brightness, and that unexpectedly rapid seasonal changes were taking place (Sromovsky et al. 2009). The north polar region also has what appear to be many small convective features poleward of 60° N, in stark contrast to the south polar region (Sromovsky et al. 2012, see **Figure 3**). Sromovsky et al. (2012) speculated this difference could be due to a seasonally-forced methane abundance asymmetry. However, 2007 NICMOS F108N and Keck NIRC2 PaBeta (1271 nm) equinox imagery suggest that the north polar region is also depleted in methane (**Figure 4**), as do 2009 IRTF SpeX observations (Tice et al. 2013).

Global Distribution of Methane in 2012: Karkoschka & Tomasko (2009) estimated the latitude variation of methane mixing ratio using a simple model to fit the spectral region where hydrogen and methane have comparable effects on the observed I/F spectrum. They assumed that in the 819-835 nm region, the I/F spectrum would behave as a reflecting layer attenuated by methane and hydrogen in proportion to their relative absorption strengths, i.e.

$$I/F = \exp(C_0 + C_1 \times k_{CH_4} + C_2 \times k_{H_2}), \quad (1)$$

where k_{CH_4} and k_{H_2} are absorption coefficients of methane and hydrogen, respectively. The simplification in this method is assuming a value for k_{H_2} , which varies with temperature and the square of density, whereas k_{CH_4} is essentially independent of temperature and pressure. We use 50 wavelengths from 819 nm to 825 nm, and a nonlinear fitting method to find coefficients for eqn. 1 for the latitudes observable in 2002 and 2012. **Figure 5** shows sample fits to four different latitudes. The ratio C_1/C_2 is roughly proportional to the methane mixing ratio, and can be scaled to values found from radiative transfer modeling results. **Figure 6** shows the deduced methane mixing ratio vs. latitude. **These profiles strongly suggest that there is a permanent and roughly symmetric depletion of methane at both the north and south poles.** The north/south symmetry is not perfect, however. Differences between -30° and 30° latitude may be due to season changes in aerosol abundances, and the high amplitude oscillations in north polar regions may be connected to possibly convective features seen in near-IR images (Figure 3).

Radiative Transfer Modeling and Vertical Structure: As was done for the 2002 STIS data in Sromovsky et al. (2011), we modeled the methane abundance and vertical aerosol structure of Uranus in 2012 using full multiple scattering radiative transfer methods. We looked at both a vertically diffuse aerosol model, as described in Karkoschka & Tomasko (2009), and a compact layer model as described in Sromovsky et al. (2011). **Figure 7** compares the aerosol layer structure for these two models. We find somewhat better fits to the spectra with the compact layer model, but that is not too surprising considering the finer scale distribution of optical depth with height allowed by that model. For the basic compact layer model, good fits to the spectra can be obtained using any methane deep mixing ratio greater than 3%. This is not the case for all latitudes however. North of 50° , fit quality declines if we assume a fixed 4% deep mixing ratio with latitude. The increasing fit error at 825 nm indicates that a lower methane mixing ratio is required at high latitudes. Higher quality fits can be obtained with either a profile with a lower deep mixing ratio, or by modifying the profile to deplete the methane at higher altitudes, an alternative that is more physically realistic according to Sromovsky et al. (2011). In fact, the best fits at high latitudes are obtained when methane depletion is limited to ~ 3.5 bars.

Coming Soon: A paper describing this work is in preparation, to be submitted to Icarus!

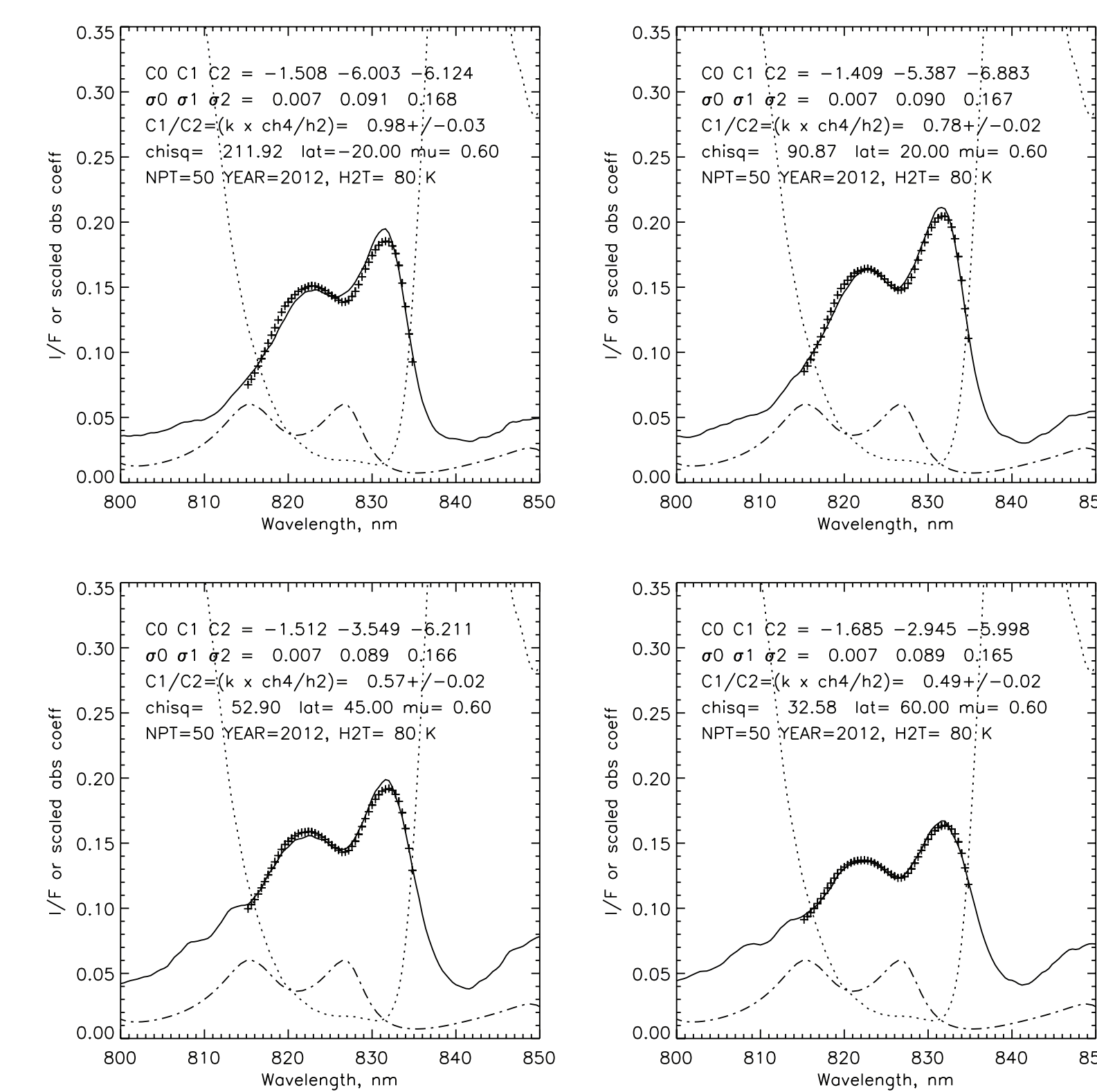


Figure 5: Fits to 2012 I/F spectrum for observer zenith angle 0.6 for four sample latitudes, using the simplified model (given in eqn. 1) from Karkoschka & Tomasko (2009). The solid curves are measurements and model values (+) are in best agreement for $T_{H_2} \approx 80$ K.

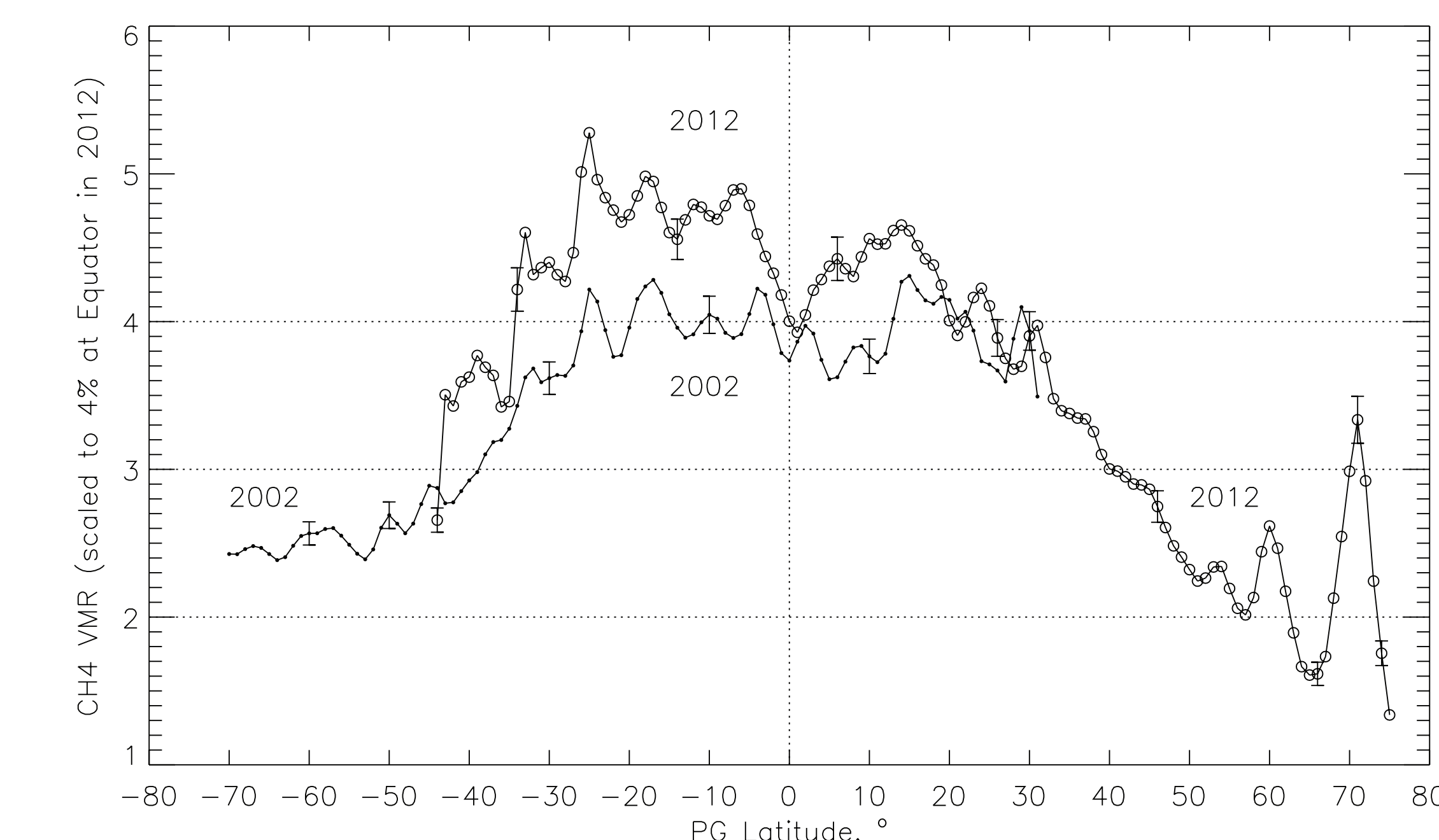


Figure 6: The ratio C_1/C_2 , which is roughly proportional the methane/hydrogen mixing ratio, scaled so that the 2012 methane mixing ratio is 4% at the equator, a value determined by radiative transfer modeling. This scaling also results in a mixing ratio at 60° that is close to the value from radiative transfer results.

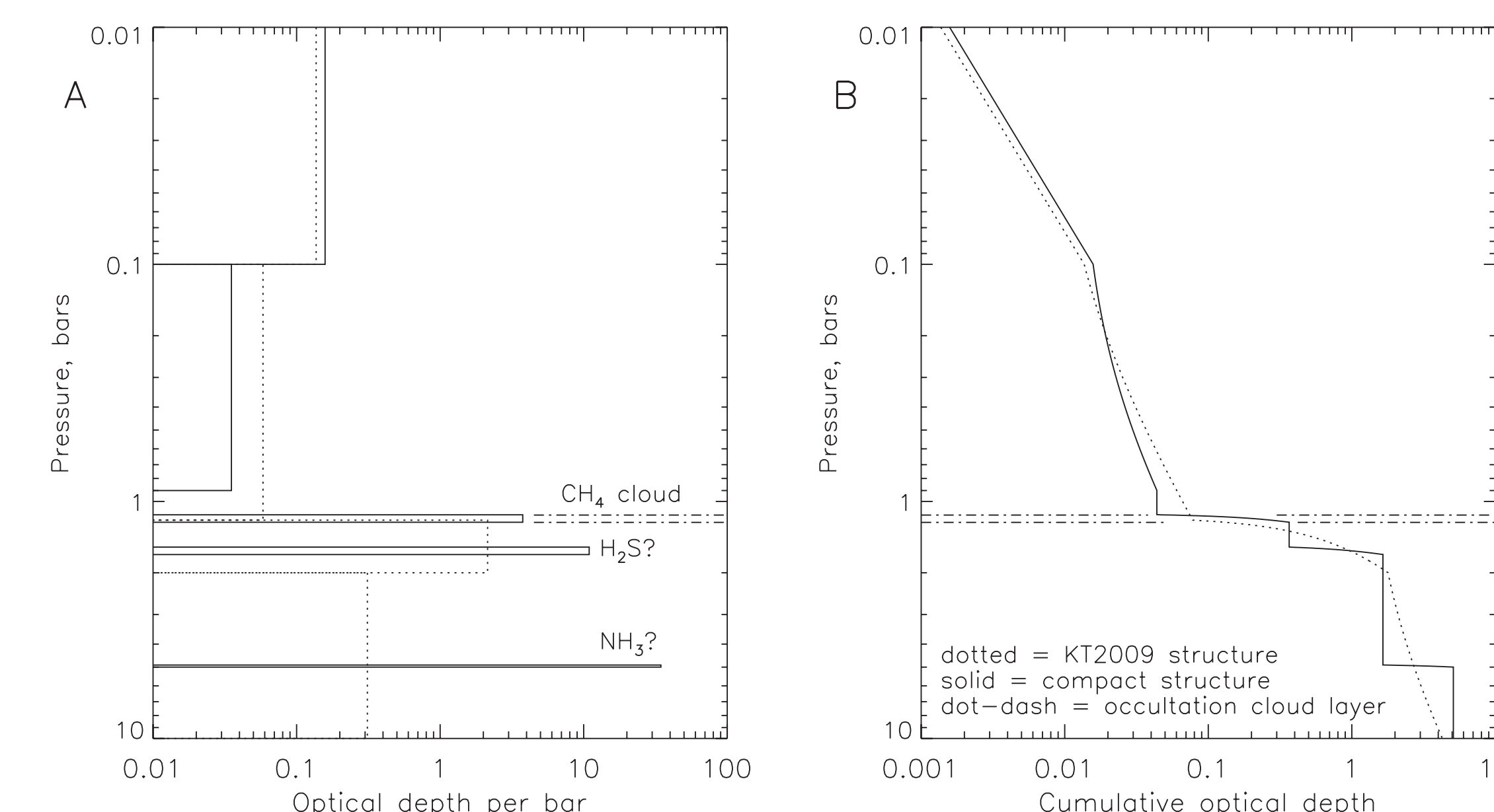


Figure 7: Comparison of diffuse and compact vertical cloud structure models. Left, the dotted line traces out the optical depth per bar of the diffuse model, and the solid lines trace out the compact model. At right the cumulative optical depth is shown for each model. Horizontal dot-dash lines indicate the location where Voyager radio occultation data implies cloud opacity (Lindal et al. 1987).

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