STRATOSPHERIC PHOTOCHEMISTRY ON URANUS: LESSONS FROM SPITZER OBSERVATIONS.

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Introduction: Constraints concerning the stratospheric composition of Uranus have been sparse because the low atmospheric temperatures and low hydrocarbon abundances make Uranus extremely faint at thermal-infrared wavelengths. Uranus' weak internal heat source (unlike that of the other giant planets) seems to suppress vertical motions, preventing methane from being carried to high stratospheric altitudes and inhibiting the buildup of hydrocarbon photochemical products. The Infrared Spectrometer (IRS) on board the Spitzer spacecraft is two orders of magnitude more sensitive that previous space-based instruments, enabling the first-ever detections of C_2H_6, CH_3C_2H, and C_4H_2 on Uranus [1], as well as providing additional useful abundance information for previously-detected species like CH_4, C_2H_2, and CO_2.

Existing photochemical models for Uranus [2-6] do not adequately explain these recent observations. One complication is that the global-average C_2H_2 abundance appears to be increasing with time [cf. 1,7,8]. Part of this apparent increase could be due to geometric factors; i.e., due to the fact that the equatorial region, which was observed to have higher hydrocarbon abundances during the Voyager era [cf. 4,5,9,10], has been rotating into view and increasingly dominating the global-average picture. However, recent observations seem to indicate actual increases in hydrocarbon abundances with time, most likely due to an increase in stratospheric temperatures or vertical mixing. A second complication is that oxygen species have now been detected in the stratosphere of Uranus [1,11,12], and the photochemical models need to be updated to examine the influence of oxygen species.

I have developed a one-dimensional model of hydrocarbon and oxygen photochemistry and vertical diffusion on Uranus [6], using the Caltech/JPL KINETICS code [13], to help determine the magnitude of and potential reasons for the observed temporal variations in hydrocarbon abundances, as well as to constrain the magnitude and potential sources of external oxygen species entering the Uranus atmosphere. The hydrocarbon reaction list and other photochemical details are taken from [6], with the free parameters (eddy diffusion coefficient profile, methane abundance, oxygen influx) adjusted such that the Spitzer observations [1] are reproduced.

Results: Figure 1 shows the results for three models that reproduce the observations from different times and/or regions of the planet. The green dashed line represents the situation in the Voyager-era polar region [e.g., 10], which had been in sunlight for many years: eddy diffusion coefficients and CH_4 mixing ratio are low, and hydrocarbon production is suppressed. The red dotted line represents the equatorial regions in the Voyager era [e.g., 5] and is consistent with the global-average picture a decade later when the ISO data were acquired [8]. The light-blue solid line represents the situation today, as is illustrated by recent Spitzer data [1]. Clearly, the eddy diffusion coefficients and methane abundance need to be increased from the previous models in order to explain the Spitzer data.

Conclusions: Observations [1,7,8] indicate that the global-average C_2H_2 abundance on Uranus is increasing with time. At least some of this increase may be due to the fact that low-latitude regions dominate the current view of the disk. However, it also seems that atmospheric mixing may be more vigorous than in the Voyager era, the stratospheric methane abundance may be increasing, and/or stratospheric temperatures may be increasing in low-latitude regions as the seasons change on Uranus. Note that the model that is designed to fit the Spitzer data (light-blue solid line) underestimates the observed C_2H_2 abundance by a factor of ~4. This model uses the Voyager temperature profile. If temperatures are ~2 K warmer near 10 mbar than in the Voyager era, then C_2H_2 condensation would occur at deeper levels, and the model column abundance would match observations.

We also find that a CO_2 influx of 4×10^3 cm^{-2} s^{-1} best matches the Spitzer data, compared with a H_2O influx of (0.6-1.6) $\times$ 10^5 cm^{-2} s^{-1} [12]. The observed CO_2 abundance is greater than can be explained by reaction of OH with the observed stratospheric abundance of CO [14], suggesting that the CO_2 itself may be entering the Uranus atmosphere (e.g., from the ablation of icy grains, or some other source).

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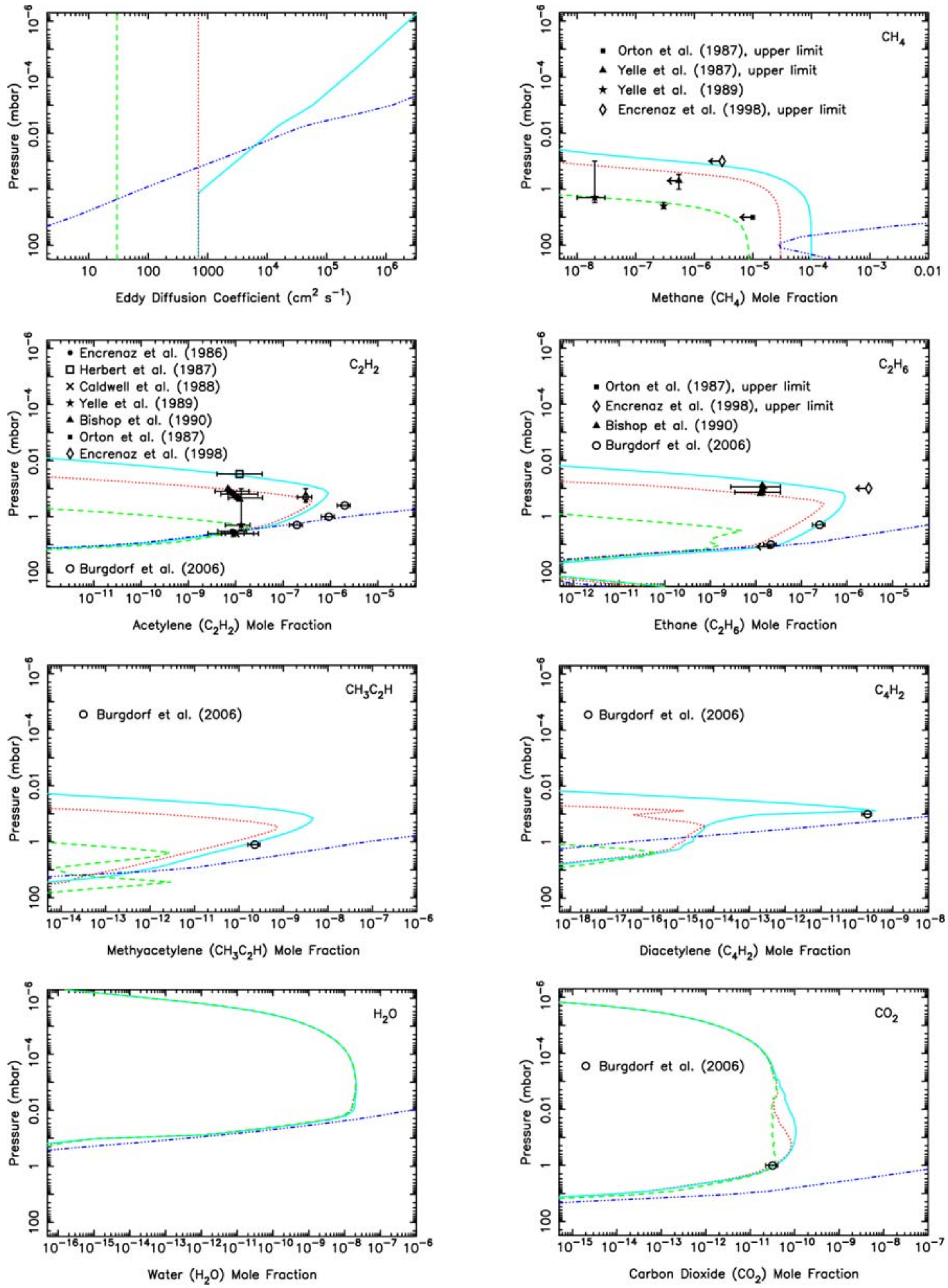

Figure 1. Mixing ratio profiles for Uranus from three different models (lines) compared with observations (data points). The solid, dotted, and dashed lines differ in the eddy diffusion coefficient profile (top left) and the assumed stratospheric methane abundance (top right). The triple-dot-dashed line represents the CH_4 molecular diffusion coefficient (top left) or the saturation vapor curve (all other figures).