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Temperature Structure and Composition of Uranus Derived from Observations by ISO, Spitzer, Herschel, and Ground-Based Telescopes Coupled with Photochemical Models

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Abstract

The combined power of absolutely calibrated photometry and spectroscopy of Uranus has been combined to create self-consistent models of its global-mean temperature profile, bulk composition, and vertical distribution of gases.

1. Introduction

We derived models for Uranus from a suite of spacecraft and ground-based observations that include the Infrared Space Observatory's Long- and Short-Wavelength Spectrometers (ISO/LWS and SWS), Spitzer's Infrared Spectrometer (IRS), and the Herschel Space Telescope PACS instruments, together with strategic ground-based observations from the United Kingdom Infrared Telescope (UKIRT) and Caltech Submillimeter Observatory (CSO) atop Mauna Kea, Hawaii

2. Temperatures

Observations of the broad, virtual continuum provided by the collision-induced absorption of H_2 have constrained the temperature structure in the troposphere; this was possible up to atmospheric pressures as high as 2 bars. Temperatures in the stratosphere were constrained by emission from H_2 quadrupole lines. ISO and Spitzer observations together have defined a broad range of the H_2 continuum that is sensitive to the He/H_2 ratio, which we find is not far from values determined by the Voyager-2 investigations.

3. Gases and Photochemistry

Our work to date has coupled the vertical distribution of CH_4 in the stratosphere of Uranus with models for the vertical mixing that are consistent with the mixing ratios of hydrocarbons whose abundances are primarily influenced by dynamics rather than chemistry, a best value for a simple vertically uniform eddy diffusion rate lies in the range of 1180-1560 cm^2 s^{-1}, consistent with a stratospheric CH_4 volume mixing ratio of $4.5\pm1.5 \times 10^{-5}$, and a CH_3D/CH_4 ratio of $2.5\pm0.9 \times 10^{-4}$. Spitzer and Hershel data provide substantial constraints on the abundances and distributions of CH_3, CH_4, C_2H_2, C_2H_6, C_3H_4, C_4H_2, H_2O and CO_2. At millimeter wavelengths, there is evidence that an additional opacity source in Uranus is required besides (i) the H_2 collision-induced absorption and (ii) the NH_3 absorption that is consistent with the longer-wavelength microwave spectrum. This opacity can reasonably (but not uniquely) be attributed to H_2S.

4. Programmatic Importance

The globally averaged model for Uranus is additionally useful because it serves as one of the calibration sources for Herschel instruments, and they provide a starting point for planning atmospheric studies by interplanetary missions. This model for global-mean properties serves as a template from which models of spatial variability can develop from existing and planned spatially resolved imaging and spectroscopy of thermal emission.

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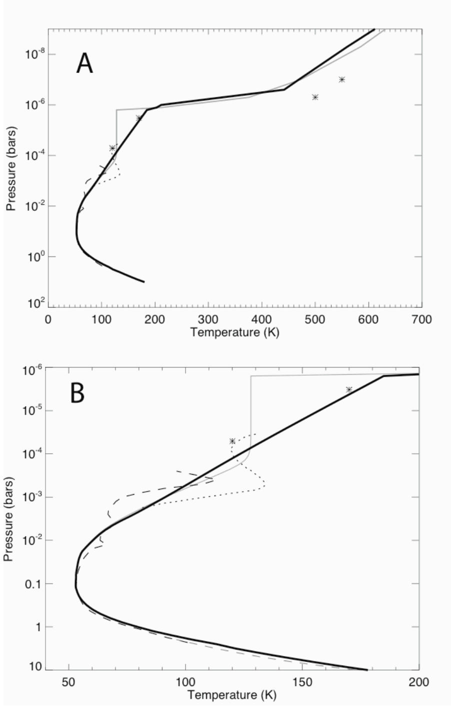

Figure 1. Best-fit global mean temperature profiles derived from Spitzer IRS observations, showing the full profile (A) and detail (B). The thick solid line indicates the nominal profile. The solid gray line indicates an alternative profile with an isothermal upper stratosphere that matches the Spitzer IRS data equally well but is inconsistent with the "compromise" temperature profile developed by Herbert et al. [1] given by the asterisks. The dashed curve represents the results of the Voyager RSS profile [2]. The dotted curve represents the results of Bishop et al. [3].

References

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[3] Bishop et al. In Neptune and Triton, U. Arizona Press, p. 427, 1990.