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Mean Thermal and Compositional Properties of Uranus from Combined Spitzer, ISO, Herschel and Ground-Based Observations

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We derived models for the mean thermal structure and composition of the atmosphere of Uranus from a suite of spacecraft and ground-based observations. A family of models of the atmospheric temperature and composition derived from the Spitzer Infrared Spectrometer (IRS) data (Orton et al. 2013, submitted to Icarus) have been updated to include the significant influence of H2-H2 dimers on collision-induced absorption that was used to constrain the vertical temperature profile in the upper troposphere down to the 2-bar pressure level. IRS observations of H2 quadrupole lines provided additional constraints on temperatures in the lower stratosphere at pressures less than 100 mbar. We applied additional constraints on this family of models from Hershel PACS observations of HD (Feuchtgruber et al. 2013, Astron. & Astrophys. in press). We have also constrained the He/H2 ratio that characterizes the bulk composition of the atmosphere from previously unpublished observations by the ISO Short-Wavelength Spectrometer (SWS) and confirmed values originally derived by the Voyager IRIS and Radio Sub-System experiment (Conrath et al. 1987. J. Geophys. Res. 92, 15003). We have coupled observational constraints on the vertical distribution of CH4 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. Spitzer and Hershel data provide substantial constraints on the abundances and distributions of CH3, CH4, C2H2, C2H6, C3H4, C4H2, H_2O and CO_2. At millimeter wavelengths, strategic ground-based observations from the United Kingdom Infrared Telescope (UKIRT) and Caltech Submillimeter Observatory (CSO) atop Mauna Kea, Hawaii, provide evidence that an additional opacity source in Uranus is required besides (i) the H2 collision-induced and absorption, including significant dimer contributions, and (ii) the NH3 absorption that is consistent with the longer-wavelength microwave spectrum. The most likely candidates for such absorption are H2S and PH3.