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Models for Temperature and Composition in Uranus from Spitzer, Herschel and Ground-Based Infrared through Millimeter Observations

Glenn Orton (1), Leigh Fletcher (2), Helmut Feuchtgruber (3), Emmanuel Lellouch (4), Raphael Moreno (4), Paul Hartogh (5), Christopher Jarchow (5), Bruce Swinyard (6,7), Julianne Moses (8), Martin Burgdorf (9), Heidi Hammel (10), Michael Line (11), Amy Mainzer (1), Mark Hofstadter (1), Goran Sandell (12), and Charles Dowell (1)

(1) Jet Propulsion Laboratory, MS 183-501, Pasadena, United States (go@scn.jpl.nasa.gov, 001 818 3934619), (2) University of Oxford, Oxford, UK, (3) Max Planck Institute for Extraterrestrial Physics, Garching, Germany, (4) Observatoire de Paris / LEISA, Meudon, France, (5) Max Planck Institute for Solar System Research, Lindau, Germany, (6) University College, London, London, UK, (7) Rutherford-Appleton Laboratory, Chilton, UK, (8) Space Science Institute, Boulder, Colorado, USA, (9) HE Space Operations, Bremen, Germany, (10) Association of Universities for Research in Astronomy, Washington, DC, USA, (11) California Institute of Technology, Pasadena, California, USA, (12) NASA Ames Research Center, Moffett Field, California USA

Photometric and spectroscopic observations of Uranus were combined to create self-consistent models of its global-mean temperature profile, bulk composition, and vertical distribution of gases. These were derived from a suite of spacecraft and ground-based observations that includes the Spitzer IRS, and the Herschel HIFI, PACS and SPIRE instruments, together with ground-based observations from UKIRT and CSO. Observations of the collision-induced absorption of H_2 have constrained the temperature structure in the troposphere; this was possible up to atmospheric pressures of $\sim$2 bars. Temperatures in the stratosphere were constrained by H_2 quadrupole line emission. We coupled the vertical distribution of CH_4 in the stratosphere of Uranus with models for the vertical mixing in a way that is consistent with the mixing ratios of hydrocarbons whose abundances are influenced primarily by mixing rather than chemistry. Spitzer and Herschel data constrain the abundances of CH_3, CH_4, C_2H_2, C_2H_6, C_3H_4, C_4H_2, H_2O and CO_2. The Spitzer IRS data, in concert with photochemical models, show that the atmosphere the homopause is much higher pressures than for the other outer planets, with the predominant trace constituents for pressures lower than 10 μbar being H_2O and CO_2. At millimeter wavelengths, there is evidence that an additional opacity source is required besides the H_2 collision-induced absorption and the NH_3 absorption needed to match the microwave spectrum; this can reasonably (but not uniquely) be attributed to H_2S. These models will be made more mature by consideration of spatial variability from Voyager IRIS and more recent spatially resolved imaging and mapping from ground-based observatories. The model is of 'programmatic' interest because it serves as a calibration source for Herschel instruments, and it provides a starting point for planning future spacecraft investigations of the atmosphere of Uranus.