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Constraints on the Bulk Composition of Uranus from Herschel PACS and ISO LWS Photometry, SOFIA FORCAST Photometry and Spectroscopy, and Ground-Based Photometry of its Thermal Emission

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We present thermal infrared observations of the disk of Uranus at 17-200 μm to deduce its global thermal structure and bulk composition. We combine 17-200 μm filtered photometric measurements by the Herschel PACS and ISO LWS instruments and 19-35 μm filtered photometry and spectroscopy by the SOFIA FORCAST instrument, supplemented by 17-25 μm ground-based photometric filtered imaging of Uranus. Previous analysis of infrared spectroscopic measurements of the disk of Uranus made by the Spitzer IRS instrument yielded a model for the disk-averaged temperature profile and stratospheric composition (Orton et al. 2014a Icarus 243,494; 2014b Icarus 243, 471) that were consistent with submillimeter spectroscopy by the Herschel SPIRE instrument (Swinyard et al. 2014, MNRAS 440, 3658). Our motivation to observe the 17-35 μm spectrum was to place more stringent constraints on the global para-H_2 / ortho-H_2 ratio in the upper troposphere and lower stratosphere than the ISO SWS results of Fouchet et al. (2003, Icarus 161, 127), who examined H_2 quadrupole lines. We will discuss the consistency of these observations with a higher para-H_2 fraction than implied by local thermal equilibrium, which would resolve a discrepancy between the Spitzer-based model and observations of HD lines by the Herschel PACS experiment (Feuchtgruber et al. 2013 Astron. & Astrophys. 551, A126). Constraints on the global para-H_2 fraction allow for more precise analysis of the far-infrared spectrum, which is sensitive to the He:H_2 ratio, a quantity that was not constrained by the Spitzer IRS spectra. The derived model, which assumed the ratio derived by the Voyager-2 IRIS/radio-science occultation experiment (Conrath et al. 1987 J. Geophys. Res. 92, 15003), is inconsistent with 70-200 μm PACS photometry (Mueller et al. 2016 Astron. & Astrophys. submittted) and ISO LWS photometric measurements. However, the model can be made consistent with the observations if the fraction of He relative to H_2 were increased from 15% to 20%. We will discuss the improved consistency of this He VMR with estimates of its abundance relative to hydrogen in the protosolar nebula (Asplund et al. 2009. Ann. Rev. Astron. Astrophys. 47, 481) and the expectation that helium rainout in Uranus and Neptune should be less important than in the atmospheres of Jupiter and Saturn.