THERMAL EMISSION CONSTRAINTS ON THE ATMOSPHERES OF URANUS AND NEPTUNE.
G. S. Orton[1], L. N. Fletcher[2], I. de Pater[3], J. I. Moses[4]. E. Lellouch[5], R. Moreno[5], B. M. Swinyard[6,7], M. D. Hofstadter[1], T. K. Greathouse[8]
[1]Jet Propulsion Laboratory, California Insitute of Technology, MS183-501, 4800 Oak Grove Drive, Pasadena, CA 91109, USA; glenn.orton@jpl.nasa.gov, [2]University of Oxford, Oxford, UK, [3]University of California, Berkeley, CA, [4]Space Science Institute, Boulder, CO, [5]Observatoire de Paris, Meudon, France, [6]Univ. College London, London, UK, [7]Rutherford-Appleton Laboratory, Chilton, Didcot, UK, [8]Southwest Research Institute, San Antonio, TX.

Introduction: We analyze photometric and spectroscopic observations of Uranus and Neptune from both spacecraft and Earth-based platforms, in order to create self-consistent models of their global-mean temperature profiles, bulk compositions and distributions of trace constituent gases. We have also begun to address the variability of these properties across the disk from spatially resolved imaging and spectroscopy.

Observations: Spacecraft observations of thermal emission from Uranus and Neptune include those from the Voyager IRIS spectrometer, the ISO Long-Wavelength Spectrometer and Short-Wavelength Spectrometer, the Spitzer Infrared Spectrometer (IRS), the Akari spacecraft, and the Herschel HiFi, PACS and SPIRE instruments. Ground-based observations include spectra from the Infrared Telescope Facility (IRTF), the United Kingdom Infrared Telescope (UKIRT) and the Caltech Submillimeter Observatory (CSO). They also include imaging and spatially resolved spectroscopy from the W. M. Keck Telescope, the Gemini North and South Telescopes, the Very Large Telescope, and the Subaru Telescope. Airborne filtered radiometric measurements of Neptune were made using the Stratospheric Observatory for Infrared Astronomy (SOFIA).

Uranus. Using IRS data, we constrained the mean temperature structure in the troposphere up to atmospheric pressures of ~2 bars using the collision-induced absorption of H_2. Temperatures in the stratosphere were constrained by H_2 quadrupole line emission. This model is consistent with Herschel PACS photometric measurements in the far infrared. We coupled the vertical distribution of CH_4 in the stratosphere with models for the vertical mixing that is consistent with the observed emissions of C_2H_2, C_2H_6 and C_4H_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 could be attributed to H_2S or PH_3. A ratio of this Uranus model spectrum and one derived from a thermophysical model of Mars is consistent with the ratio of spectra observed by Herschel's SPIRE instrument to within ±3% [1]. Stratospheric CO_2 and H_2O abundances are consistent with exogenic origins from comets or KBOs.

Spatially resolved thermal images of Uranus were made between 2006 and 2011 that are sensitive to temperatures in the upper troposphere of Uranus. They show a distribution of zonal-mean temperatures that is consistent with Voyager IRIS results except for the region near the emerging spring pole, which is colder than it was during the 1986 Voyager observations. Images of emission from stratospheric C_2H_2 show a morphology that is different from tropospheric emission, with broad polar regions significantly brighter (possibly warmer) than at low latitudes.

Neptune: Analysis of Neptune's disk-averaged mid-infrared spectrum has been done from the Akari spacecraft [2,3]. Unlike the case for Uranus, much of this spectrum is completely dominated by emission features of stratospheric hydrocarbons with little signature of the H_2 collision-induced continuum, except at wavelengths at and greater than 15 µm that are sensitive to temperatures at 0.1-0.3 bars [4]. At these wavelengths, the IRS spectrum is consistent with SOFIA/FORCAST filtered photometry, suggesting an upward recalibration of ground-based spectra [4]. Stratospheric temperatures are tied to the abundance of CH_4, and work is underway to analyze the IRS spectrum of Neptune to determine a CH_4/H_2 ratio using the H_2 S(1) quadrupole line, as was done for the Uranus IRS spectrum. Unlike Uranus, the submillimeter and millimeter spectra require no opacity source in addition to collision-induced H_2.

Thermal images and spatially resolved spectra of Neptune reveal a substantial inhomogeneity, with prominent brightening at the summer pole, extending from the upper troposphere to the stratosphere [3,5,6]. This is, in part, due to the long time scale of seasonal warming. Longitudinal inhomogeneity exists at high southern latitudes, with a bright feature occasionally detected offset from the true rotational pole [7].

References: [1] Swinyard et al. (2014) *Mon. Not. Roy. Astron. Soc.* In press. [2] Fletcher et al. (2010) *Astron. & Astrophys. 514*, A17. [3] Fletcher et al. (2013) *Icarus 231*, 146. [4] Burgdorf et al. (2003) *Icarus 164*, 244. [5] Orton et al. (2007). *Astron. & Astrophys. 473*, L3. [6] Greathouse et al. (2011) *Icarus 214*, 606. [7] Orton et al. (2011) *Planetary & Space Sci. 61*, 161.