EPSC Abstracts
Vol. 7 EPSC2012-862-1 2012
European Planetary Science Congress 2012

Exploring the Atmospheres of the Ice Giants

Leigh N. Fletcher (1*), G.S. Orton (2), M. Hofstadter (2), P.G.J. Irwin (1), I. de Pater (3)
(1) Atmospheric, Oceanic & Planetary Physics, Department of Physics, University of Oxford, Clarendon Laboratory, Parks Road, Oxford, OX1 3PU, UK (2) Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA, 91109, USA. (3) University of California, Berkeley, Astronomy Dept., 601 Campbell Hall, Berkeley, CA 94720-3411, USA.
(*fletcher@atm.ox.ac.uk / Tel: +441865272089)

Abstract

Of all the planets in our solar system, the two ice giants Uranus and Neptune remain the least explored and poorly understood because of their great distance from Earth. And yet they occupy a unique position in the hierarchy of planetary types, being intermediate between gas giants with their enormous hydrogen-helium envelopes, and terrestrial-sized worlds and Super Earths. These ice giants, so-called because their bulk compositions are dominated by heavier elements, are a true frontier of our exploration of planetary atmospheres, having been visited only once by Voyager 2 in 1986 and 1989, and may be representative of a whole class of planetary objects throughout our galaxy. Even though Earth-based observations (ISO, Spitzer, Herschel, ground-based) have improved dramatically in the decades since Voyager 2, many questions about this unexplored region of our Solar System remain unanswered. Voyager revealed unexpected differences in the appearance, composition, dynamics and chemistry between these two worlds, which could ultimately help us to understand how planetary atmospheres form and evolve as a function of distance from their host stars. This talk will review our present understanding of ice giant atmospheres, and assess the key questions to be answered by future exploration.

1. Uranus

Uranus' atmosphere is unique in our solar system in that it (a) receives a negligible flux of heat from the deep interior, either due to inhibition of interior convection or an early loss of primordial heat; and (b) experiences extremes of seasonal forcing due to the high 98^{o} obliquity, with each pole spending 42 years in the shroud of winter darkness. Voyager measurements suggested that Uranus' evolution produced a planet with negligible self-luminosity, smaller than any other planet in our solar system. The ratio of absorbed to emitted power is near unity, suggesting that Uranus' interior is not fully convective (or that it suffered an early loss of internal heat). This unusual balance between internal and radiative heating means that Uranus' unique weather is governed principally by seasonal forcings. Despite the bland appearance of Uranus from Voyager, recent ground-based observations associated with Uranus' 2007 equinox have shown the planet to be more dynamically active than previously thought. Now, 26 years on since the Voyager 2 encounter, we have been able to study the planet from solstice through equinox to trace how temperatures, clouds and composition evolve with time. Uranus provides an extreme test of our understanding of planetary atmospheric dynamics; energy and material transport; seasonally-varying chemistry and cloud microphysics.

2. Neptune

Despite being the most distant planet from the Sun, Neptune has been shown to possess an extremely dynamic atmosphere, with atmospheric phenomena evolving over surprisingly short timescales. Unlike Uranus, Neptune has the highest ratio of emitted internal heat to absorbed sunlight measured in the solar system. The atmosphere features some of the most powerful zonal winds in the solar system; a bright polar emission similar to Saturn's stratospheric vortex; long-lived dark vortices that move latitudinally before they weaken and disappear; and upper tropospheric clouds that evolve so rapidly that the planet's appearance can change dramatically from one day to the next. Indeed, the vigour of these convective cloud formations has appeared to increase in the 23 years since the Voyager encounter in 1989. This rapid variability can be contrasted with the longevity of features in the atmosphere of Jupiter, or the relatively quiescent appearance of Saturn, making Neptune a unique environment for further study.

Neptune's 165-year orbit means that seasonal changes due to its 29^o obliquity occur over very long timescales, and we are only now beginning to unravel the effects of this solar input on the atmospheric thermal structure and photochemistry, as Neptune passed through summer solstice in 2005.

3. Comparative Icy Planetology

Advances in our understanding of these icy worlds will come from understanding both their similarities and differences. Visible, near-IR, thermal-IR and microwave observations in recent years have made significant progress in studying the cloud and haze properties, the occurrence of convective cloud activity and the large-scale circulations of their tropospheres and stratospheres. However, no predictive models of ice giant circulation exist, and we remain a long way from constraining the bulk inventory, vertical distribution, composition and optical properties of their clouds and hazes. These may include seasonally variable photochemical hazes in the high stratosphere, as well as condensation cloud decks of CH_4 (1-2 bar region), NH_3 and H_2S in the troposphere and convective cloud structures that appear to be seasonally modulated. The altitude of the H_2O condensation cloud is poorly constrained, as the predicted large water enrichment (10-50 times solar) and the cold atmospheric temperatures places the water cloud relatively deep and difficult to observe by remote sensing.

Of potentially broader significance is a determination of their chemical make up, which will ultimately require in situ exploration of both planets. Comparing the bulk compositions of the ice giants (elemental enrichments, isotopic ratios and noble gases) provides important clues about the nature of their deep interiors, and a window onto conditions in the icy outer solar nebula during the era of planetary formation. Uranus and Neptune are known to have substantial elemental enrichments in carbon and deuterium, but enrichments in other simple elements (N, S and O), their isotopic ratios (D/H, $^{12}C/^{13}C$, $^{14}N/^{15}N$, $^{16}O/^{17}O$) and the noble gases (He, Ne, Ar, Xe, Kr) have never been adequately constrained, and are an essential goal for any future exploration of the ice giants.

Acknowledgements

Fletcher is supported by a Glasstone Science Fellowship at the University of Oxford.