EPSC Abstracts
Vol. 6, EPSC-DPS2011-695-2, 2011
EPSC-DPS Joint Meeting 2011

Chemical profiles in Neptune's atmosphere as derived from EVLA and historical radio observations

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Abstract

We present results from modeling the chemical composition of the atmosphere of Neptune. Our models employ radiative transfer calculations to generate synthetic spectra from 0.03 to 21 cm for comparison with full-disk observations from 1966 to present. This observation dataset is augmented with spatially resolved observations from the Very Large Array and its recent improvement, the Expanded Very Large Array, allowing for the investigation of the chemical abundances' variance with latitude and longitude.

1. Introduction

In recent years, it has become increasingly evident that the planets Uranus and Neptune are not just more similar to each other than to the other giant planets Jupiter and Saturn, but they are better thought of as a separate class of planet: ice giants. Unlike the gas giants Jupiter and Saturn, Uranus and Neptune are relatively small, composed primarily of ices rather than hydrogen and helium, and have magnetic fields oriented far from their rotational axes. In order to properly understand this class of planets and extend this knowledge to better understand similar exoplanets, it is necessary to distinguish the inherent properties of the ice giant class from the more variable characteristics of Uranus and Neptune.

A powerful tool in the field of comparative planetology is the determination of a planet's chemical composition. In determining the abundance of different species as a function of depth, it becomes possible to ascertain the locations of the cloud decks in the planet's atmosphere. This information is also useful in probing the dynamics of the planet's atmosphere, since abundances that differ from equilibrium may be indicative of vertical motion.

To this end, we have assembled an extensive collection of observations of Neptune, at wavelengths ranging from 0.03 to 21 cm. This part of the spectrum probes the deep atmosphere from a few bars to tens of bars. In this atmospheric region we are able to investigate the H_2S, NH_3, NH_4SH, and H_2O clouds (or the lack thereof). With these observations we employ a radiative transfer model to determine the abundance profiles of numerous chemical species in the atmosphere of Neptune.

2. Observations

In modeling the Neptunian atmosphere, we make use of four datasets. Most of the Neptunian reference spectrum comes from the compilation of historical data by de Pater and Richmond [2], who presented full-disk observations of Neptune acquired between 1966 and 1989; and the similar compilation of DeBoer and Steffes [1], spanning 1989—1994. These collections are augmented by unpublished observations acquired between 1991 and 2009 at the James Clerk Maxwell Telescope (JCMT) and Caltech Submillimeter Observatory (CSO) on Mauna Kea, and the Very Large Array (VLA) in Socorro, NM (Fig. 1) [3]. Unlike the other historical data, the VLA observations comprise spatially resolved views of the Neptunian disk at 1.3, 2.0, and 3.6 cm (Fig. 2). Lastly, our most recent dataset consists of further observations of Neptune from the VLA, which has been recently upgraded to the Expanded Very Large Array (EVLA). This dataset consists of observations at 1 and 6 cm with greater sensitivity than the VLA data, and was acquired in the summer of 2011.

3. Model

In modeling the atmosphere of Neptune, we started with the *Voyager 2* temperature-pressure profile down to a depth of 1.7 bars [5], extended to deeper pressures following a wet adiabat. Our models employed radiative transfer calculations to construct synthetic spectra of Neptune, accounting for emission and absorption, but not scattering. We included calculations involving H_2, CH_4, H_2O (both vapor and condensed), NH_3, H_2S, and PH_3. While keeping the hydrogen-to-helium mixing ratio at 85%/15%, we varied the abundance profiles of each of the other species to determine which atmospheric conditions best replicate the observations. While most cloud layers do not have prominent effects upon the emission or absorption in this part of the spectrum, we can deduce their presence from the composition profiles: for example, a dearth of NH_3 and H_2S at a given pressure level would indicate the presence of a NH_4SH cloud.

As can be seen in Fig. 2, Neptune's atmospheric structure is not uniform with latitude and longitude. Over the course of our investigations, we divided the Neptunian atmosphere into different regions as suggested by the spatially-resolved data, demarcated by latitude and longitude. We imbued each region with different chemical profiles in order to reconstruct the image data. For the full-disk photometry we combined the effects of all regions to simulate the overall planetary disk as seen from Earth.

4. Figures

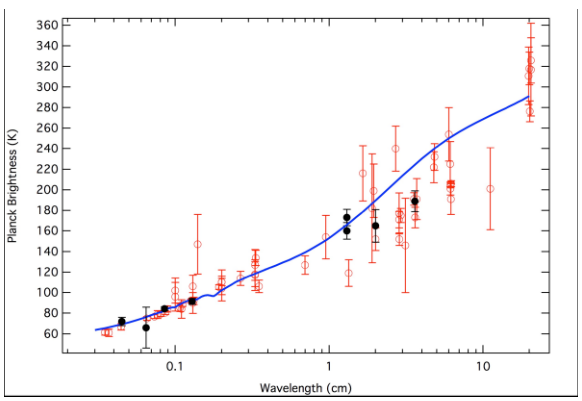

Figure 1: A plot of the full-disk observations of Neptune used in this observation. The published data from [2] and [1] are shown as open red circles, while the unpublished data from [3] are shown as filled black circles. A synthetic Uranus spectrum, the result of a refined version of the model used in [4], is shown for comparison. Note how the Neptune data differ from the Uranus model, particularly in the 2-10 cm region.

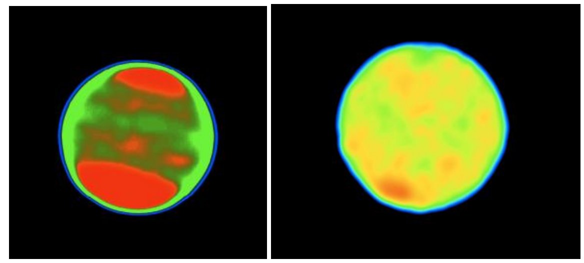

Figure 2: VLA image of Neptune (right) at 1.3 cm, acquired in 2006. Each planet's south pole is oriented near the bottom of the image. Neptune exhibits some variation, having an equatorial region slightly dimmer than the rest of the disk, and a bright region near the south pole. Uranus, obtained from the VLA at greater spatial resolution and signal-to-noise ratio, is shown at left for comparison.

Acknowledgements

The investigators wish to thank the Expanded Very Large Array, operated by the National Radio Astronomy Observatory, for granting observing time early in the facility's new-and-improved state.

This research was supported by an appointment to the NASA Postdoctoral Program at the Jet Propulsion Laboratory, administered by Oak Ridge Associated Universities through a contract with NASA.

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