FY24 Strategic University Research Partnership (SURP)

Conditioning the atmospheric environments of ice giants

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Objectives: 1. Develop an environmental model of Ice-Giant atmospheres for a mean atmospheric state and its variability using a fully non-linear dynamics integrated with realistic radiative transfer and cloud microphysics. 2. Create an empirical climatological databased. Combine the model results and observations using a Bayesian statistical framework.

Background: The Ice Giants Uranus and Neptune, exhibit unique properties. Uranus emits no observable internal heat and its axial tilt is close to 90^{o}. Neptune continually creates planetary-scale storms. They are not only key to understanding solar-system formation and evolution, but also our closest analogs to most detected exoplanets. This collaboration will strengthen the interaction between the University of Michigan and JPL, combining model simulations and their constraining observations.

Approach and Results 1: Environmental model simulation. We created a new spatially resolved model for an Ice Giant environment, based on a Gas-Giant model (Li & Chen 2019). We initialize the model with 30x solar CH_4 and H_2S, and 1x solar abundance for NH_3. The simulation starts in a chemical-equilibrium state with random perturbations in vertical convection. It evolves into a steady state. A simulation snapshot (Fig. 1), shows that the CH_4 cloud **does not form** cloud decks, only localized CH_4 storms. An H_2S cloud deck starts to appear at about 2 bars, suggesting that the cloud deck observed in PHARO images (see below) is most likely H_2S with CH_4 clouds only in transient spots. Little NH_3 cloud is formed at the same level as H_2S cloud. NH_4HS clouds, formed at 50 bars, fare trapped below the 10-bar level; higher up, NH_4HS starts to release NH_3, decreasing the H_2S partial pressure.

Comparing our results with the equilibrium model output, the cloud density of our model is smaller than the nominal cloud density by 5 orders of magnitude for all species. The result is sensitive to the cloud microphysics, which controls how fast do clouds turn into precipitation. In the future, we will compare our model with the PHARO data to constrain cloud microphysics.

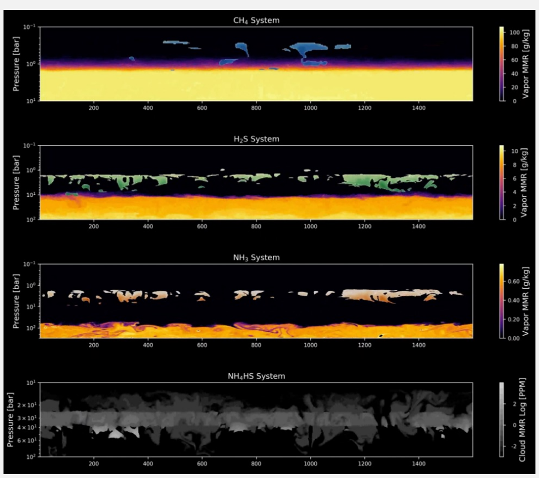

Figure 1. Cloud-resolving simulations of ice giants. From top to bottom, we have simulated CH_4, H_2S, NH_3 and NH_4HS clouds. The NH_3 cloud plotting range is enhanced 1000x compared to the other clouds

Significance/Benefits to JPL and NASA: This work is critically relevant to the Solar System Exploration Program. With the planning for dedicated missions to explore these planets underway, our work will fill a knowledge gap that will inform the spacecraft instrument development and payload.

Approach and Results 2: Empirical climatological data base. Focusing on developing microphysical models for clouds and hazes, we acquired contemporary near-infrared images. Over 9 observing nights, we used the Adaptive-Optics-stabilized PHARO instrument on the 200-inch Hale Telescope at Palomar Mountain, California. We gathered a rich data set of data on Uranus and Neptune at multiple wavelengths, processing ~200 images acquired over the last two years. Photometric calibration is currently underway, which will be use to derive cloud and haze properties. Our efforts yielded high-quality images of the Ice Giants (see Figs. 2 and 3).that are valuable records of current atmospheric conditions. Once the photometric calibration of the data is completed, we will use the data to analyze long-term properties and evaluate shorter-term discrete features.

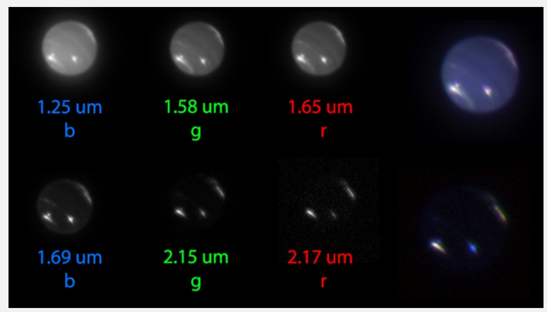

Figure 2: Neptune images taken on 2024 July 29. The rotational axis runs lower-left to upper-right. The right-hand images are false-color composites using the three left-hand images as the RBG channels. Three highly reflective cloud-forming features are visible. The disk of the planet (top row) displays zonal bands, indicating heterogenous deep clouds. The wavelengths of images in the bottom row are in strong CH_4 and H_2 absorption features, allowing only the highest particles to be detected.

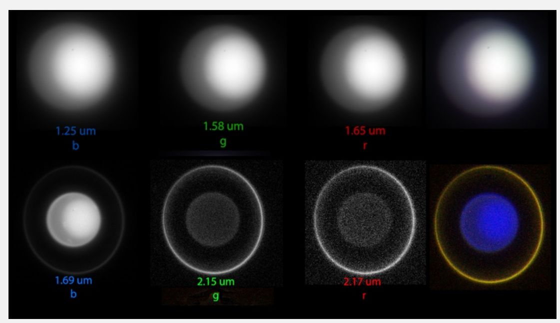

Figure 3: Same as Figure 2, but for Uranus. The north polar hood cloud feature is easily visible, with the north rotational pole being in the center of the white disk on the right side of the planet. Hints of lower-latitude clouds features are seen in these images.

References

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