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Uranus's cloud and haze properties from VLT observations

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Abstract

In November 2014, the SINFONI Integral Field Unit Spectrometer on the Very Large Telescope (VLT) mapped Uranus in the 1.46 - 1.70 μm wavelength region. Images at different wavelengths clearly revealed the presence of discrete clouds [1], assumed to be composed of methane ice, and regions with different brightness patterns caused by latitudinal variations in the properties of aerosol. **Figure 1** shows VLT/SINFONI images of Uranus at selected wavelengths in which, for example, a bright region can be identified near the equator. In this work, we analyze through radiative-transfer simulations VLT observations to characterize the vertical distribution and optical properties of clouds and hazes in Uranus's atmosphere. We first tested three different atmospheric models consisting of different cloud and haze layers to choose the cloud model capable of fitting the observations over a wide range of emission angles. Subsequently, properties such as the optical depth, vertical distribution and scattering properties of clouds and hazes were retrieved at key locations to study their latitudinal variations and thus compare them with the bright patterns illustrated in **Figure 1**.

1. Description of the model

For the analysis of images illustrated in **Figure 1** the NEMESIS radiative-transfer and retrieval code [2] was used. We employed three different cloud models whose election of aerosol layers is based on results from previous work (e.g. [1,3]). The first model (M1) consists of a vertically extended haze layer based at the 0.19-bar pressure level, and a deep tropospheric cloud at ~2-bar level. The second model (M2) is similar to M1, but an additional tropospheric haze layer based at ~0.56-bar pressure level is added with a fixed fractional scale height (FSH) set to 0.08. The addition of this haze layer in M2 allows a variation of the haze particles size distribution and refractive index with altitude. The third model (M3) is similar to M2, but the tropospheric haze FSH is treated as a free parameter, thus allowing a vertical extended tropospheric haze. For the three models the pressure base and FSH of the deep cloud are fixed to the values deduced from VLT/SINFONI observations by [1], allowing only the optical depth to vary. The scattering properties of cloud and haze particles are computed using the Mie theory assuming a standard gamma size distribution and where the effective radius (r_{eff}), the effective variance (ν_{eff}) and the imaginary part of the refractive index are retrieved.

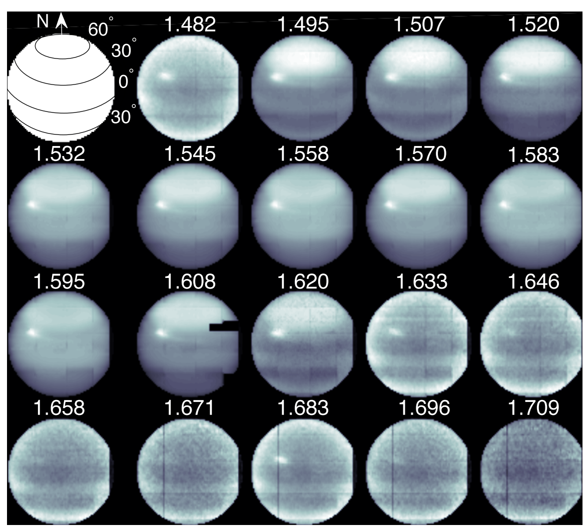

Figure 1: *VLT/SINFONI observations of Uranus at selected wavelengths on 11th November 2014.*

2. Main results

In order to compare the three models over a wide wavelength range and over a range of zenith angles, we conducted a number of limb-darkening analyses at different latitudes. For each latitude selected, six spectra taken at different emission angles (ranging from 20° to 75°) were fitted simultaneously. In terms of χ^2_{red}, we find that M3 provides the best results with values determined to be below 1.0 at most latitudes. For example, **Figure 2** shows a limb darkening analysis carried out at 5°N and for which a χ^2_{red} of 0.96 is obtained by M3.

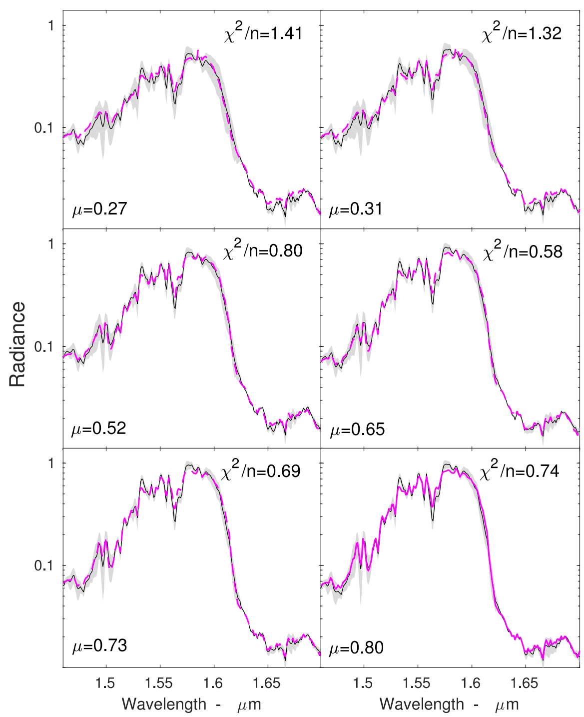

Figure 2: *Comparison of measured VLT/SINFONI spectra at ~5° N with M3 fits. The black solid lines with grey shaded errors are VLT spectra at 5°N with μ (cosine of the emission angle) values of 0.27, 0.31, 0.52, 0.65, 0.73 and 0.80. The shaded errors represent the random errors of the observed radiances and are computed by the VLT/SINFONI pipeline. The six spectra were fitted simultaneously using the M3 model (purple dashed lines) whose* χ^2_{red} *value is 0.96. The fits performed by M1 and M2 are not as good as for M1 since the* χ^2_{red} *values achieved by those models are 3.0 and 1.29, respectively.*

Once these different cloud models were tested, we then performed a number of limb-darkening analyses at different latitudes to retrieve the optical and physical properties of the hazes and the tropospheric cloud (size distribution, refractive index and opacity) at different key locations. We will discuss the implication of our observations for Uranus' cloud structure. For example, we find an increase of the stratospheric haze opacity at latitudes near to the equator (see **Figure 3**), region where a bright band can be identified in images illustrated in **Figure 1**.

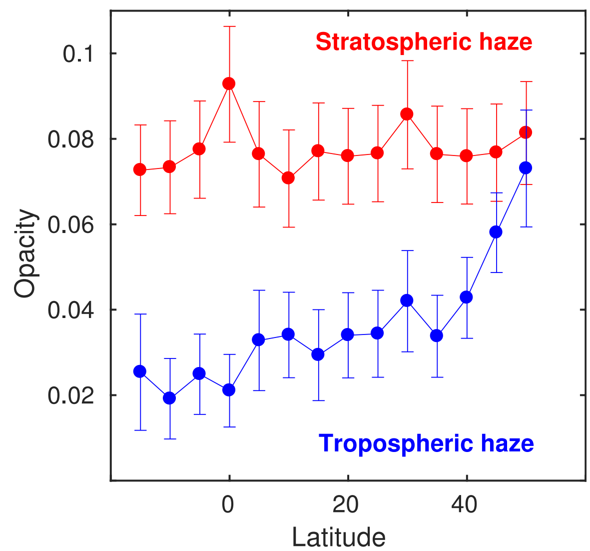

Figure 3: *Latitudinal variation of the stratospheric and tropospheric haze opacities at 1.6 μm.*

References

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