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Constraining spatial and temporal variations in Jupiter's vertical cloud and chromophore structure (2014-2018) with VLT/MUSE

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Abstract

MUSE/VLT observations of Jupiter have been made in the visible/near-IR (0.48-0.93μm) at high spectral resolution between 2014-2018, providing global context to Juno/MWR observations of the interior of Jupiter, and enabling cloud structure and colour to be better constrained between 0.1-1.5 bar. Significant changes were observed in the appearance of the northern hemisphere of Jupiter between 2014-2018. We find that a single heavily blue-absorbing chromophore can provide a good fit to all red regions of Jupiter, and that the chromophore is most likely to be located in the upper troposphere. We then apply our retrieval model to analyse changes in appearance particularly of the southern NTBs and of the GRS, and find significant changes in the high-altitude haze opacity associated with the former region.

1. Introduction

Significant changes in Jupiter's visible appearance have been observed since 2014. Here, we focus on changes in the northern hemisphere related to the October 2016 NTBs outbreak [5], and the Great Red Spot, which is observed to have shrunk in longitudinal size and become redder since 2012 [6]. We attempt to quantify these changes using the MUSE integral-field spectrograph [1], providing comprehensive wavelength coverage in the visible/near-IR (0.48-0.93μm), and providing global context to Juno observations of Jupiter's internal dynamics and composition, in order to further constrain vertical cloud structure at the level of the visible cloud layers, as well as the absorption spectrum and altitude of the 'chromophore' particles that colour Jupiter's belts and Great Red Spot.

2. Model and results

Our data consists of several sets of MUSE spectral image cubes between February 2014 and April 2018, which provide a time series of the development of the bright red haze layer in the NTBs, as shown in Figure 1, as well as of the colour changes of the GRS and the anticyclonic 'White Spot Z' (WSZ).

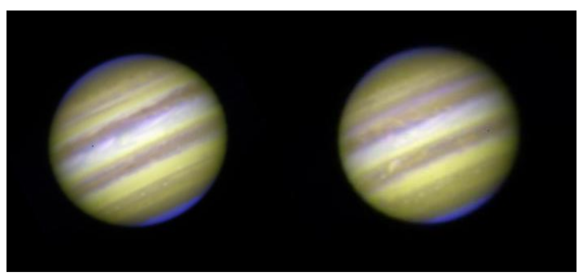

Figure 1: MUSE False colour image of Jupiter in (*left*) 9th March 2016, (*right*) 10th January 2017. Regions that are bright at 0.89μm are shown in blue

We attempt to validate the results of Sromovsky et al [7] through simultaneous retrievals with the NEMESIS radiative transfer and retrieval algorithm [4] of vertical cloud and chromophore structure, the latter modelled with the optical constants published in Carlson et al [2], which we refer to as 'Carlsophore'. Carlsophore was seen to produce a very poor fit to GRS spectra in 2017 and 2018. We therefore directly retrieve the imaginary refractive index spectrum of Jovian chromophore through NEB limb darkening analysis. This results in a chromophore which is able to provide a good fit to all red spectra.

The formation of a bright red band over the southern NTB following the 2016 outbreak [3] appears to correlate with cycles in high-altitude haze opacity around 20 degrees latitude. A noticeable change in the ammonia gas abundance is also found. This may indicate the increased flux of chromophore reactants into the upper tropospheric haze where chromophore is most likely formed. The long lifespan of the NTBs red band would indicate that it is located in a very dynamically stable region of the atmosphere, perhaps in the tropopause.

Summary and Conclusions

We use visible/near-IR spectra from MUSE/VLT to constrain cloud structure and colour in Jupiter's troposphere at high spectral resolution, and apply this data to track changes in the visible appearance of Jupiter's atmosphere between 2014-2018, thereby providing global context to Juno observations. We find that a single chromophore can explain red colour in the belts and the GRS, though a more blue-absorbing chromophore is required than that of Carlson et al [2], and that this chromophore is most likely produced at high altitude. The formation of a bright red haze layer in the southern NTB is correlated with changes in brightness at 0.89μm, corresponding to aerosols just below the tropopause.

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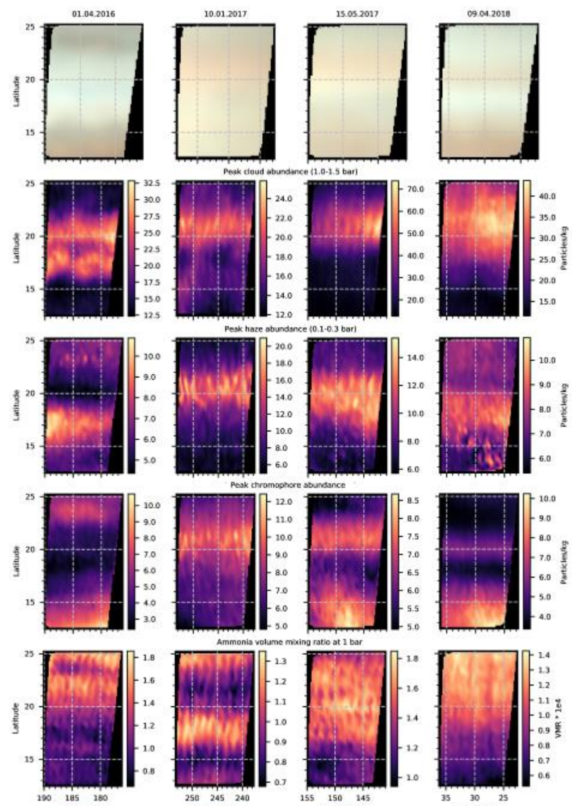

Figure 2: MUSE retrievals of the NTBs red band/NTropZ between 2016-2018, from top to bottom: RGB MUSE quasi-true colour image, cloud abundance below 1 bar, upper tropospheric haze abundance, chromophore abundance, ammonia volume mixing ratio at 1 bar. Aerosol abundances are given in units of particles/kg of atmosphere.