EPSC Abstracts
Vol. 10, EPSC2015-302, 2015
European Planetary Science Congress 2015

Stratospheric benzene and hydrocarbon aerosols in Saturn's auroral regions

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Abstract

Saturn's polar upper atmosphere exhibits significant auroral activity, however, its impact on stratospheric chemistry (*i.e.* the production of benzene and heavier hydrocarbons) and thermal structure is poorly documented. Here we report on the first measurement of benzene column abundance in Saturn's polar stratosphere, together with the first detection of spectral signatures of the polar haze in the thermal infrared, based on limb measurements from the Composite Infrared Spectrometer (CIRS) on board Cassini. We then evaluate the radiative impact of the polar haze.

1. Introduction

Saturn's polar regions are characterized by permanent dark polar caps in the UV, generally attributed to the presence of polar stratospheric hazes ([2, 3]) possibly produced by the precipitation of energetic auroral electrons ([4]). The aerosol sizes and optical properties have been derived in the UV and visible from HST observations ([5, 6]) but little is known about their infrared properties or radiative impact. In parallel, the disk-average benzene (C_6H_6) column density has been measured in the stratospheres of Jupiter and Saturn from ISO ([7]). Modeling studies suggest that ion chemistry plays a key role in producing benzene and polar aerosols in Jupiter's polar atmosphere (eg., [8]), but the role of ion chemistry has not been studied in the case of Saturn's atmosphere. In this context, our goal is to search for tracers of ion chemistry (benzene and aerosols) in Saturn's neutral stratosphere.

2. Cassini/CIRS data analysis

2.1 Temperature retrievals

We analyse four datasets acquired in limb viewing geometry between 2007 and 2012 by the Composite Infrared Spectrometer onboard Cassini at latitudes 40°N, the equator, 35°S and 80°S (within the polar cap). The thermal emission of Saturn's atmosphere was recorded in the range 580–1480 cm^{-1} with a spectral resolution between 0.5 cm^{-1} and 1.5 cm^{-1}. We first employ the forward radiative transfer model coupled to the bayesian inversion method described in [9] to retrieve vertical temperature profiles from the analysis of the ν_4 methane band (1200–1370 cm^{-1}) and of the H_2-H_2 and H_2-He collision-induced emission (590–660 cm^{-1}). These profiles are constrained between 20 mbar and a few μbar. Secondly, vertical profiles of the volume mixing ratio of various hydrocarbons can be retrieved from the analysis of their emission bands.

2.2 Benzene retrievals

A benzene emission band at 673 cm^{-1} is clearly detected at 80°S (Fig. 1) and more marginally at 40°N. We find that the retrieved benzene profiles are very sensitive to the choice of the prior profile, but that the C_6H_6 column density integrated between 3-mbar and 0.2-mbar is a robust quantity. Upper limits are derived at the equator and 35°S. Benzene is found slightly enhanced at 80°S compared to other latitudes. In contrast, the photochemical model of [1] (which only includes neutral chemistry) predicts a maximum benzene abundance at the equator, and about 50 times less at 80°S. This suggests that ion chemistry plays a key role in producing benzene in Saturn's polar stratosphere, similarly to Jupiter's stratosphere.

2.3 Aerosol retrievals

At 80°S, after the retrieval of the temperature and hydrocarbon profiles, our best-fit spectra still do not match the observations in several spectral regions (see Fig. 2) and we additionally retrieve aerosol opacity profiles in small, independent, spectral regions (10 to 20 cm^{-1} wide) to derive the spectral dependency of the haze opacity. These profiles are constrained between ∼3 mbar and 0.1 mbar. The haze integrated

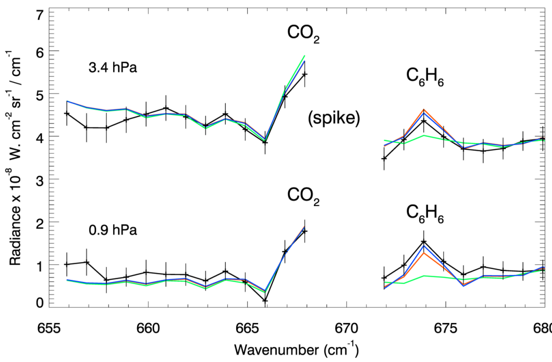

Figure 1: Cassini/CIRS limb spectra acquired at two different tangent pressure levels at 80°S (in black). Best-fit synthetic spectra are overplotted, corresponding to the retrieval of the CO_2 mixing ratio alone (in green, no benzene opacity) or to the simultaneous retrieval of CO_2 and C_6H_6 mixing ratios (in blue and red, assuming different C_6H_6 vertical distributions).

opacity exhibits distinct spectral bands centered at 700, 750, 780, 1390 and 1450 cm^{-1}, similarly to Titan's aerosol signatures in the thermal infrared, which have been assigned to vibration modes of aliphatic and aromatic hydrocarbons [10].

We then evaluate the radiative impact of this polar haze on the thermal structure using a seasonal radiative-convective model of Saturn's atmosphere [11]. We assume that aerosols are spherical particle aggregates with a radius of 0.1 μm and use Mie scattering theory to compute their extinction coefficient. We find that the polar haze induces a net stratospheric heating during summer reaching +6 K at the 10-mbar pressure level, and a net stratospheric cooling during winter reaching -5 K at and above the 0.1-mbar pressure level.

3. Summary and Conclusions

On Saturn's auroral region (80°S), benzene is found slightly enhanced compared to its equatorial and mid-latitude values. This contrasts with the photochemical model of [1] and advocates for the inclusion of ion-related reactions in Saturn's chemical models. The polar stratosphere is also enriched in aerosols, with spectral signatures consistent with aromatic and aliphatic hydrocarbons. We estimate this polar haze to warm the middle stratosphere by 6K in summer, hence it could partly account for the warm polar hood observed in Saturn's summer stratosphere.

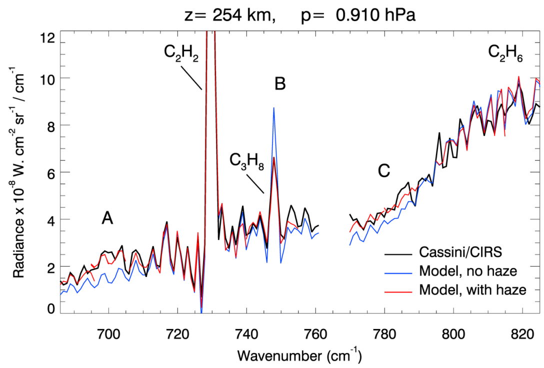

Figure 2: Cassini/CIRS limb spectra acquired at 80°S compared with best-fit synthetic spectra, with or without including the retrieval of haze opacity. A, B and C highlight the location of the main aerosol signatures.

Acknowledgements

Part of this work was funded by the French ANR under grant agreement ANR-12-PDOC-0013.

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