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Monitoring Saturn's Upper Atmosphere Density Variations and He Mixing Ratio Using Cassini Helium 584 Å Airglow Observations

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Abstract

The atmosphere of Saturn is mainly composed of H_2 and neutral atomic helium. The study of He 584 Å brightnesses is interesting as the EUV (Extreme UltraViolet) planetary airglow have the potential to yield useful information about mixing and other important parameters in its thermosphere. Resonance scattering of sunlight by He atoms is the principal source of the planetary emission of He 584 Å. The helium is embedded in an absorbing atmosphere of H_2 and since it is heavier than the background atmosphere, it's concentration falls off rapidly above the homopause. The scattering region (i.e. where the absorption optical depth in H_2 is less than 1) generally lies well above the homopause. As the eddy diffusion coefficient, K_z, increases in the middle atmosphere, more helium is mixed into the scattering region and thus the reflected intensity increases.

Specifically, He emissions come from above the homopause where optical depth τ=1 in H_2 and therefore the interpretation depends mainly on two parameters: He mixing ratio of the lower atmosphere and eddy mixing profile, K_z. The occultations of Koskinen et al. (2015) give K_z with an accuracy that has never been possible before and the combination of these occultations and airglow analyses can therefore can provide estimates of the mixing ratio in the lower atmosphere.

Using Cassini UVIS data and powerful modeling and analysis techniques, we can address longstanding questions regarding the He mixing ratio in Saturn's atmosphere and upper atmosphere density variations using the observed He 584Å airglow. We discuss results of work to determine the Saturnian mixing ratio of He and constrain dynamics in the upper atmosphere of Saturn with particular attention to the Grand Finale end of mission analyses.

1. Principal Parameters

The principal parameters involved in determining the He 584 Å albedo are:

- f_{He}, the helium volume mixing ratio well below the homopause,
- the eddy diffusion coefficient at the homopause, K_h,
- the solar He 584 Å flux and line shape, and
- the atmospheric temperature profile, T(z).

Parkinson et al. (1998) used a reference model atmosphere where f_{He} = 0.033 ± 0.025 from the Voyager IRIS measurements (Conrath et al., 1984), but also explored other values. For their reference conditions they chose $K_h = 10^6 - 10^9$ cm^2 s^{-1}.

2. Methodology

Reference model atmospheres of Parkinson et al. (1998) are superseded by those determined by Koskinen et al. (2015) giving precise stellar occultation values for the mixing ratios of He, atomic H, H_2, and CH_4. Also evaluated are hitherto unprecedented accurate temperature and eddy mixing profiles, T(z) and K_z. Koskinen et al. (2018) predict f_{He} = 0.11 +/- 0.02; vary our model atmosphere using new T(z) and K_z over this range for input to radiative transfer (RT) model. Apply resonance scattering model to the He 584 Å problem using the Feautrier technique to solve the equation of radiative transfer assuming partial frequency redistribution (Gladstone, 1982; Parkinson et al., 1998; Parkinson et al., 2006; 2019).

Choose Koskinen et al. (2015) stellar occultation observations for analysis:

Case 1: ST31 Dec 2008 (long. 17.9^{o}N) [Solar minimum]
Case 2: ST42 Oct 2014 (long. 5.85^{o}S) [Solar maximum]

3. Figures

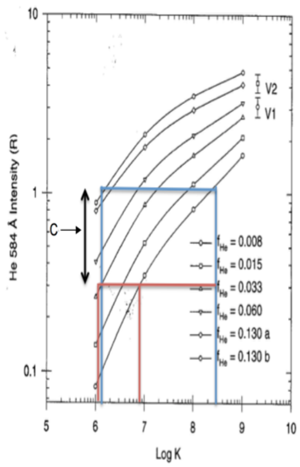

Figure 1: Variation of He 584 A emergent intensity with K_h for Voyager 1 and 2, Cassini 2004, 2008, 2014.

4. Summary and Conclusions

Run the RT code for both cases $f_{He} = 0.11$:

Case 1: 2.7 R from RT model; 2.5 R from Cassini data analysis

Case 2: 3.7 R from RT model; 3.6 R from Cassini data analysis

Compare Observations with RT calculations: GOOD AGREEMENT! (cf. Figure 1)

It would appear that the Cassini epoch He 584 Å brightness for this sample set is quite variable when compared with the Voyager epoch with the corresponding effects consistent with and illustrated by both observations and modelling.

Clear evidence for short term and longer term variation!

Saturnian He 584 Å airglow is not fully explained by using "simple" solar flux values. This may be due to geometry (latitude/longitude), observation corresponding to lower/higher K_z profile at this particular moment, ring shadowing, and/or temperature profile. This can be ameliorated using S. Edgington "adjusted" solar flux calculations!

Using stellar occulation atmospheres combined with powerful RT code provide precise method for monitoring upper atmospheric density variations using the He 584 Å airglow.

Methodology also provides method to obtain/constrain He mixing ratio in the deep atmosphere; ST42 model atmosphere and EUV2013_153_1640 observation case closely match in He 584 Å brightness for He mixing ratio of 0.11. More analysis required for 0.11 +/- 0.02 to determine the He mixing ratio in the deep atmosphere.

References

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