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UV/dayglow remote sensing of CO_2 techniques for the thermosphere of Mars

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Abstract

The remote sensing of the Martian upper atmosphere is a challenge which, if met, could help improve our understanding of the planet's thermosphere as well as the aerobraking activities of future space missions.

In this work, we present several techniques to retrieve the CO_2 density between 120 and 180 km from the UV dayglow observations, and their application to the Mars Express SPICAM observations. Some of the very fast techniques developed here could be improved by in-situ measurements, for example with NASA MAVEN.

1. Introduction

The large variations in density of the upper atmosphere of Mars, observed during aerobraking activities, or by star occultation [1] are one of the major issues for low Mars orbit activities, as these variations must be carefully checked to avoid inaccurate braking and re-entry angles. Moreover, because the upper atmosphere is one of the key parameters of the evolution of the Martian atmosphere, a better understanding of these thermospheric processes is necessary to determine the processes that led to the escape of most of the gases. Finally, in the perspective of comparative planetology, it is important to understand the interaction of Mars, with its very specific crustal fields, and the solar wind; for that, a perfect knowledge of the thermosphere density is necessary.

In that context, it is important to develop remote sensing techniques to characterize the thermosphere. Since in-situ measurements are fuel-consuming (the satellite has to probe the low altitude layers of the thermospheres, and therefore undergo aerobraking), and not adapted for very small entry missions, we have developed techniques based on the planet's airglow.

Photons and electron impacts may excite molecules, atoms, and ions, which can then emit in very specific wavelengths. With the SPICAM instrument onboard Mars Express [2], it is possible to observe these emissions at the limb of the planet, reconstruct the altitude profiles of the emissions, and, with inversions and remote sensing techniques, to retrieve some thermospheric parameters.

The technique presented here consists in observing the $O(^1S)$ emission at 297.2nm (or 557.7nm for future visible instruments) to retrieve the CO_2 density.

2. The SPICAM observations

The Mars thermosphere is, between 100 km and 200 km, mainly composed of CO_2, therefore, any observations in that range of altitudes is strongly influenced by this sole species. The SPICAM instrument onboard Mars express is able to observe, between 150 and 300 nm, the emissions of the Cameron Bands of CO, of the $CO_2^+(B)$ doublet, and of the $O(^1S)$ transauroral line [3]. In nearly 40 orbits, the spectrometer observed in limb scanning mode, a geometry comparable to that of remote sensing instruments of the Earth's atmosphere, such as the NASA TIMED/SABER instrument [4].

3. The Aeroplanets model

3.1 The model

The Aeroplanets model is primary a photo/electron transport model, it computes the ionization, excitation, dissociation of atoms and molecules in a planetary atmosphere by photon and electron impact [5, 3, 6, 7] . It can also be coupled with other models, for example for computing cosmic ray/proton ionization (citation).

For these computations, the model uses the latest cross sections, compiled in the AtMoCIAD database, and is also able to compute the propagation of the uncertainties of these parameters.

Sensitivity studies of the model shows that the intensity of the three emissions observed by SPICAM are quasi-exclusively (99%) driven by the CO_2 density, therefore being good proxies for the observation of its density.

This model is used as the forward model for the remote sensing of the Martian thermosphere.

3.2 Inversion of the CO_2 density

The density of CO_2 is inverted through a Levenberg-Marquardt technique using the Aeroplanets model. The agreement between the different lines is very good, proving the accuracy of this technique. Moreover, our studies shows that when we suppose an isothermal barometric profile for the atmosphere above the production peak, it is possible to compute the density with only two parameters: the altitude of the emission peak, and the slope of the decrease of the emission above that peak. Such a fast atmospheric inversion must however be taken with caution because the atmosphere may sometimes not be isothermal.

4. Summary and Conclusions

The successful inversion of the CO_2 density in the thermosphere of Mars brings new perspective for future instrumentation and monitoring of the upper atmosphere of Mars. Along with the improvement of aerobraking activities, it is also a good tool for improving the Global Circulation Models through data/model comparisons. The technique presented here is in active development to retrieve more atmospheric parameters.

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