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An empirical model of Saturn's thermosphere based on Cassini/UVIS occultations

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Abstract

Stellar and solar occultations obtained by the Cassini/UVIS instrument constitute the most extensive dataset on a giant planet upper atmosphere to date. These observations cover different latitudes and times during the 13-year duration of the Cassini mission, ranging from 2005 until the end of mission in 2017. They allow for the retrieval of the H_2 density and temperature structure of the thermosphere and constrain temporal variability. We present an empirical model designed to match these data that will be made available to the community in order to enable access to the retrieved temperatures and densities. The result is a useful constraint on models of Saturn's upper atmosphere and a necessary input for models of the ionosphere and, for example, dayglow and auroral emissions. It will also be a useful tool in planning of future missions to study Saturn's atmosphere.

1. Introduction

The Cassini/UVIS instrument observed more than 70 stellar occultations and more than 20 solar occultations between 2005 and the end of the Cassini mission in 2017. Stellar occultations are observed simultaneously in the EUV and FUV channels [1] and used to retrieve temperature and densities for H_2, CH_4 and some minor hydrocarbons in the mesosphere and thermosphere [2, 3]. Solar occultations are observed in the EUV channel and used to retrieve temperature and densities of H_2 and CH_4 in the thermosphere [4]. They also provide an upper limit on H densities near the exobase. The observations cover different times and latitudes from the equator to the poles. In particular, more than 30 stellar occultations were obtained in 2016 and 2017 that provide a snapshot of meridional trends in the upper atmosphere. We present an empirical model that matches the H_2 density and temperature in the thermosphere. The uncertainties in this model represent the variability of the atmosphere over time.

2. Methods

Saturn is the most oblate of the giant planets in the solar system and therefore, our model is given in oblate spheroidal coordinates [5]. This approach allows us to identify density and temperature trends without interference from the general shape of the pressure density levels. Occultations in the EUV channel yield H_2 density and temperature as a function of planetocentric latitude and radial distance from Saturn's center. The latitude probed does not change significantly during occultations and the profiles are vertical for practical purposes. The oblate spheroidal 'altitude' coordinate ξ is defined so that the family of curves for which $\xi =$ constant forms a system of confocal ellipses. The oblate spheroidal latitude Φ is different from planetocentric latitude. The transformation from a system of radial distances r and planetocentric latitudes ϕ_{pc} to the oblate spheroidal coordinates is:

$$\cosh \xi = \frac{d_1 + d_2}{2f} \quad (1)$$

$$\cos \Phi = \frac{d_1 - d_2}{2f} \quad (2)$$

$$d_1 = \sqrt{r^2 + 2rf\cos(\phi_{pc}) + f^2} \quad (3)$$

$$d_2 = \sqrt{r^2 - 2rf\cos(\phi_{pc}) + f^2} \quad (4)$$

$$f = \epsilon R_S \quad (5)$$

where f is the focal distance, ϵ is the eccentricity of the Saturn ellipsoid and R_S is the equatorial radius. Note that our fits to the data in these coordinates assume zonal symmetry, justified by Saturn's relatively fast rotation.

3. Summary and conclusions

Our results constrain the shape of the density levels in the thermosphere and temperature as a function of latitude and height. For example, Figure 1 shows density as a function of spheroidal latitude for

$\cosh\xi = 2.3675396$ based on occultations from 2005-2015. This density level corresponds to an equatorial radius and altitude of 61592 km and 1324 km, respectively. The dashed line is a preliminary model fit to the data. We note that oblate spheroidal coordinates set up a system of second order confocal ellipsoids of revolution or Clairaut spheroids (i.e., the gravitational potential is defined by zonal harmonic J_2). If the density levels conformed with this shape, we would expect the density to be constant along surfaces of constant ξ. The deviations in Figure 1 represent the combination of higher order terms (J_4, J_6, ...) in gravitational potential and meridional trends in the thermosphere. We will provide a similar fit to the data at all altitudes that will incorporate all of the available occultations.

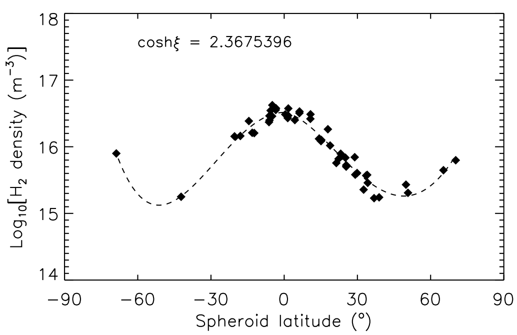

Figure 1: Retrieved occultation densities (diamonds) from 2005-2015 corresponding to an equatorial altitude of 1324 km as a function of spheroidal latitude Φ. The dashed line is a fourth order polynomial fit.

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