Characterizing Titan's atmosphere with UV observations

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Abstract

Titan is unique for its dense atmosphere, composed primarily of molecular nitrogen, with an active methane hydrological cycle, dense global haze cover and pronounced seasonal variability. Currently, the prime platform for Titan observations is the Cassini orbiter, with remote sensing instruments from the radio to the ultraviolet. However, even with the extension of the Cassini mission to 2017, it will still have covered only 13 years of Titan's 29.5 years seasonal cycle. Past observations (Pioneer, Voyager, ground-based, Earth orbit and Cassini) and models indicate that the structure of Titan's atmosphere reverses with the seasons. Thus, continued observations from Earth or orbital telescopes will be necessary to follow-up on Cassini observations, to determine how Titan's atmosphere varies over the rest of its year. Due to Titan's global haze cover, UV observations are sensitive to the upper atmosphere, at the stratosphere and above, where the haze is formed from the products of methane and nitrogen UV photodissociation. Measurements of the scattering (on reflected light observations) and absorption (on occultation observations) provide constraints to the haze properties, necessary in the analysis of IR observations of the surface and lower atmosphere and of the seasonal variation in the atmospheric structure. Here we review past UV observations of Titan's atmosphere, and explore the possibility of high vertical resolution on Titan's upper atmosphere with observations of stellar occultations in the UV, which probe the stratosphere, mesosphere and thermosphere.

Past occultations: ground-based

Occultations provide a unique opportunity to resolve the vertical structure of Titan's atmosphere, even from Earth. As Titan moves over a star, time-resolved observations can probe narrow altitude regions where the light is refracted and absorbed in Titan's atmosphere. As the relative velocity between Earth and Titan is typically in the range 15-45 km/s, observations with temporal resolutions of seconds translate into vertical resolutions of tens of kilometers on Titan's atmosphere, a high resolution considering that optical to UV observations probe from Titan's stratosphere (~ 200 km altitude) to its thermosphere (~1200 km altitude). Due to absorption by Titan's dense haze, the shorter wavelengths probe the highest altitudes in the atmosphere.

To date, the only Titan occultations observed from Earth, that we are aware of, are ground-based, in the optical range. Figure 1 shows some example lightcurves, which reveal the gradual absorption as Titan moves over the star, and in some cases (depending on the geometry) the central flash, when the starlight is refracted around the solid surface, from behind Titan. These can be inverted to constrain the vertical profile of the haze opacity and atmospheric density and, from these, the profiles of temperature and wind velocities (ex: Sicardy *et al.*, 2006). Figure 2 shows the complex caustic pattern of the central flash, for several locations along the path of the eclipse of November 2003. Figure 3 is an example of a temperature profile retrieved from this occultation

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Past occultations: UV

Titan occultations have been observed in the UV by the spectrometers aboard Voyager (UVS) and Cassini (UVIS).

These go beyond the refractivity profiles obtained from photometry, as they provide altitude resolved absorption spectra, which can constrain the vertical profiles of the products of Titan's photochemistry: haze density, optical depth and scattering, and abundances of CH_4, C_2H_2, C_2H_4, C_2H_6, C_4H_2, HCN, HC_3N have been previously measured (ex: Koskinen *et al.*, 2011), as shown in figures 4 and 5.

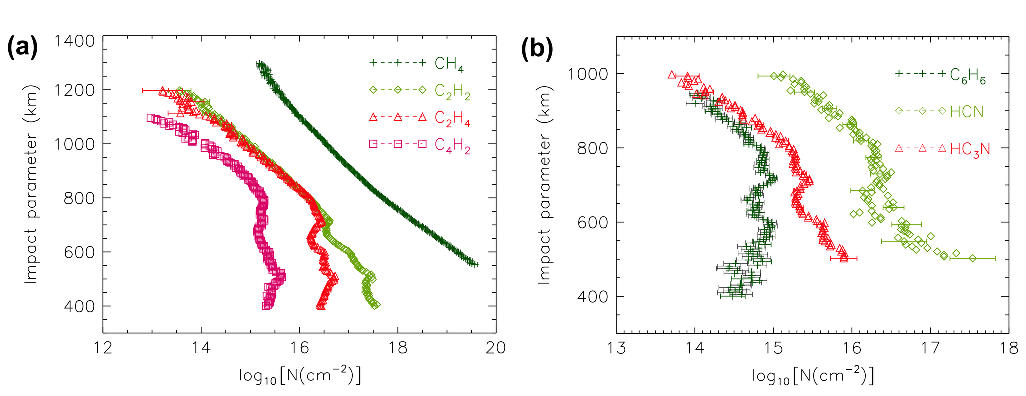

Figure 5 - Vertical profiles of hydrocarbons and nitriles derived from Cassini UVIS spectra of a stellar occultation. From figure 20 of Koskinen *et al.* (2011).

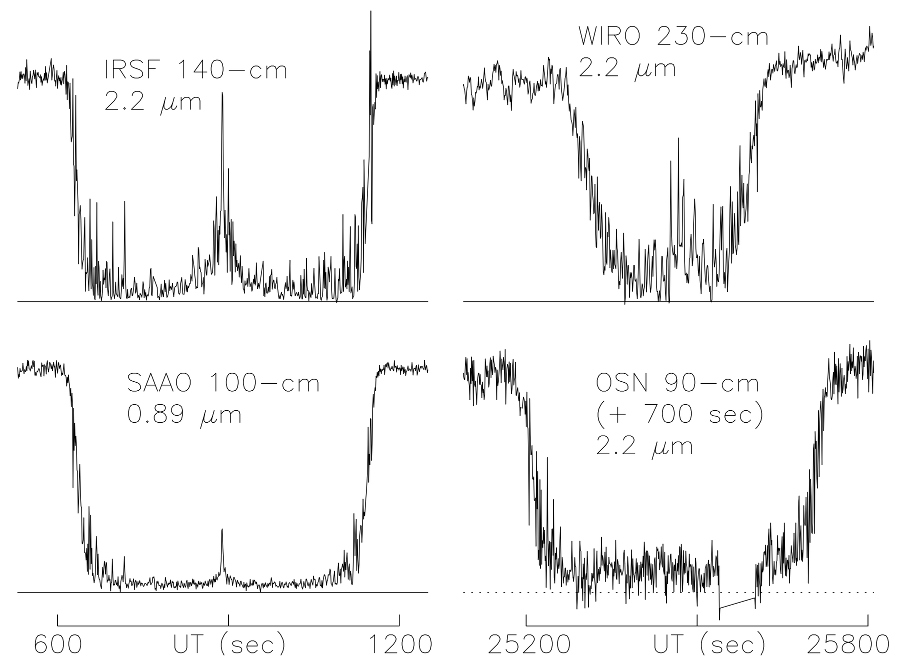

Figure 1 - Some lightcurves of Titan's 14 November 2003 occultation of star TYC 1343-1615-1. The profiles during ingress and egress probe different altitudes in Titan's atmosphere. The central flash comes from light refracted around Titan's solid surface, when the star is behind it. From figure 4 of Sicardy *et al.* (2006).

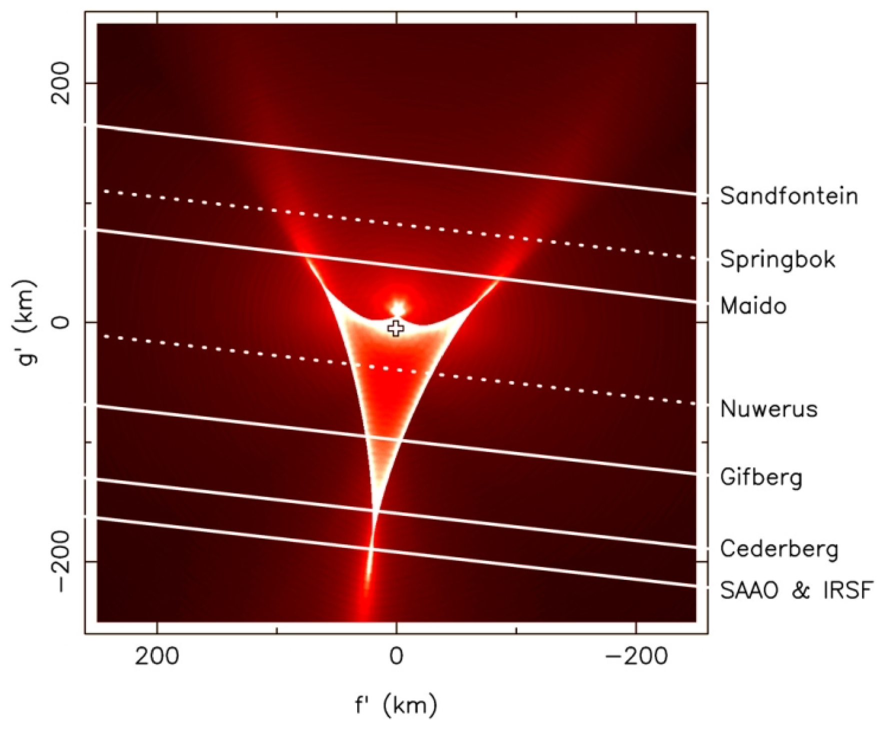

Figure 2 - A sample caustic pattern of a central flash. Calculated for the Titan occultation of 14 November 2003 of star TYC 1343-1615-1. The locations spanned by several observation locations on Earth are indicated. From figure 12 of Sicardy *et al.* (2006).

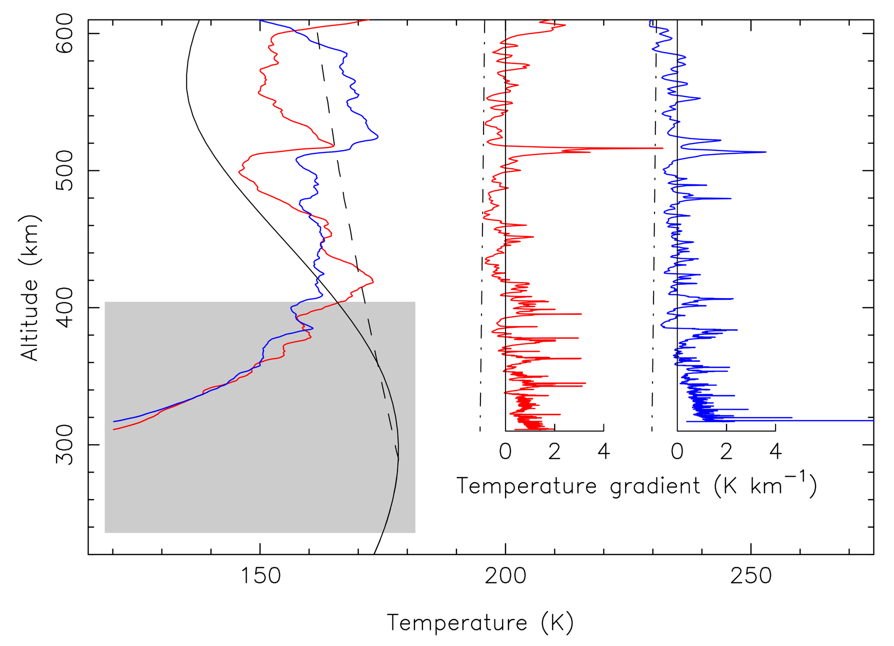

Figure 3 - Sample temperature profiles derived from the Titan occultation of 14 November 2003 of star TYC 1343-1615-1. Red line: ingress profile. Blue line: egress profile. The black lines show model profiles, from Yelle 1991 (full line) and Vervack *et al.* 2004 (dashed line). The inset shows the corresponding gradient profiles, compared to the adiabatic lapse rate (black dot-dsahed lines). The gray area indicates the region where the profiles are influenced by the haze absorption. From figure 9 of Sicardy *et al.* (2006).

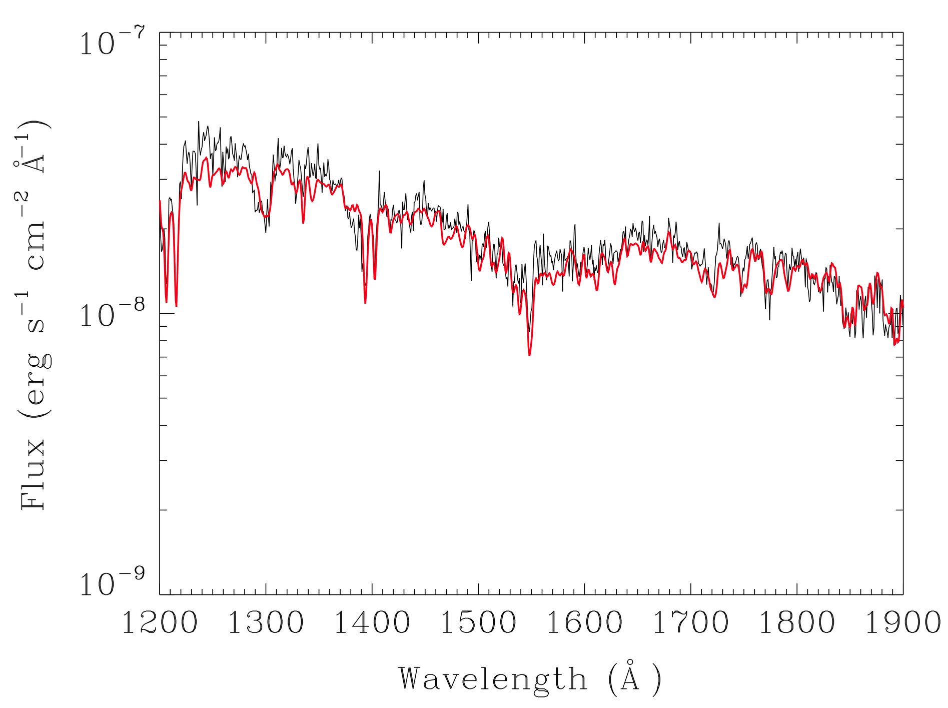

Figure 4 - An example of observed spectra of ε Cma: During a Titan occultation, observed by Cassini UVIS (black line) and from the IUE archive. Both were sampled at the same spectral resolution, with a grid spacing of 0.78 Å. From figure 1 of Koskinen *et al.* (2011).

Past occultations: HST FGS

Another possibility that has been recently identified is the use of the high temporal resolution of the HST's Fine Guidance Sensors. The 40 Hz temporal resolution translates to a spatial resolution on Titan's atmosphere of hundreds of meters. Additionally, FGS' high spatial resolution, at the 1 mas-level, could provide high precision on the location on Titan's disk (~0.8") of the stellar path for an occultation observed with another HST instrument.

As an example, figure 6 shows a FGS lightcurve from an occultation by a 500 m Kuiper belt object, which was found by data-mining the HST archive (Schlichting *et al.*, 2009).

Future occultations: Prediction

To predict future occultations, high precision is needed both in the astrometry of the star and in the future orbit of the platform. Titan's large angular diamenter (0.8") means that more extensive catalogs, such as UCAC2, Tycho 2 and Tycho 3 can be used, increasing the number of predicted events.

We will proceed in this work by calculating the future Titan occultations from standard catalogs, and how far into the future occultations can be predicted, given the precision of future HST orbital elements, which is likely to be the limiting factor.

We will also examine the need for astrometrical observations of the field where occultations will occur (as done by Assafin *et al.*, 2012), to predict the locations of the eclipses in Titan's atmosphere.

Future occultations: UV with HST

Spectroscopy - STIS and COS are well-suited to produced time resolved UV occultation spectra. With the MAMA detectors, which produce enough temporal resolution, their G140L gratings can obtain spectra easily comparable to Cassini UVIS observations (figure 4).

Imaging - In addition to STIS and COS UV imaging, ACS can also be used to make UV broadband lightcurves, similar to those made in the optical from ground-based telescopes. These have the advantage of better spatial resolution, producing a light curve with only a small fraction of Titan's light, thus allowing the use of fainter stars (making eclipses more common).

We will proceed in this work by evaluating the observability of future occultations with STIS, ACS, FGS and NICMOS, producing simulated data to verify how well these can constrain Titan's atmosphere. These tests are needed to determine whether STIS or COS will be best suited to obtain spectra, as well as to choose between STIS, COS and ACS for lightcurves.

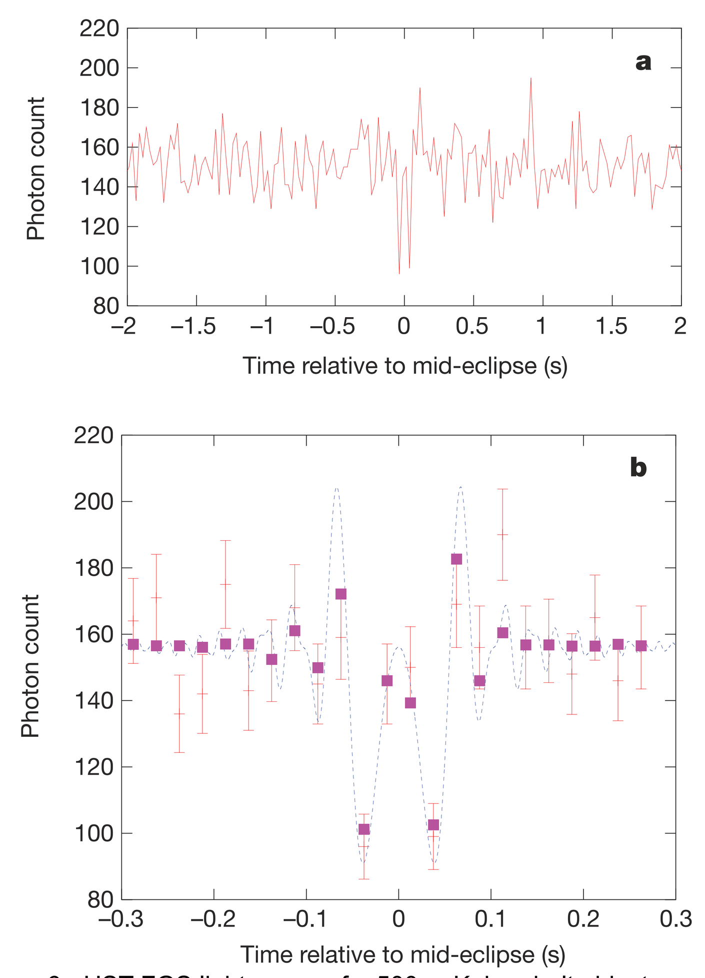

Figure 6 - HST FGS lightcurves of a 500 m Kuiper belt object occultation of a star. In the lower panel, the red bars are the FGS flux measurements with Poisson errorbars, blue line is the diffraction pattern, and the squares are the simulated 40 Hz lightcurve. From figure 1 of Schlichting *et al.* (2009).

References

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