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Monitoring the anticipated seasonal reversal of Uranus' cooling thermosphere

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Abstract

We describe an ongoing program begun in the early 1990s to monitor the seasonal change of the temperature of Uranus' thermosphere through observation of the emission spectra of H_3^+ and H_2. The observations are medium resolution spectra obtained in the near-infrared K- and L-bands. These two species probe different effective depths in the thermosphere and ionosphere having different radiative time constants. The monitoring now extends half a season past the 2007 equinox; yet it continues to show the secular downtrend in temperature seen since the observations began in 1992. So far, there is no sign of the seasonal reversal in termperature anticipated since equinox. The epochs of the reversals are expected to reveal the characteristic response times for the thermosphere/ionosphere in response to external forcing that would be diagnostic of the nature of this forcing and help to constrain the source of the Uranus' unexplained high thermospheric temperature.

1. Introduction

An open question since the Voyager epoch is the cause of the excessively high temperatures observed in the upper atmospheres (thermosphere and ionosphere) of all the giant planets, which are over 3 times hotter than can be explained by the solar EUV input alone. All proposed processes have serious problems in supplying enough power. Resolving this question would solve a 35 year old problem in planetary astronomy. Uranus may be the most promising outer planet for investigating the source of this excess heating because of the strong solar forcing from a spin axis that lies close to the orbital plane. Answering this question for Uranus may resolve it for all major planets. Even narrowing the search would be beneficial to progress by filtering suggested heating processes. H_3^+ is the primary coolant above the homopause, at $\sim 1\ \mu$bar; but it is absent below owing to chemical reaction with hydrocarbons sequested there. By contrast, vibrationally excited H_2 quadrupole line emission occurs throughout the thermosphere, effectively originating from a greater depth than the H_3^+ emission. Since 1992, ground-based observations have shown that the H_3^+ temperature of Uranus' ionosphere has been declining by 8 K/yr on average, lagging past the 2007 equinox (and 2009 aphelion).

2. Method and Results

We treat the continuation of the temperature downtrend past the 2007 equinox as the result of a phase lag in a simple oscillating dissipative system, forced by seasonally varying insolation and resulting dynamics. The phase lag, along with the orbital period of T=84 yrs, yields the dissipative time constant τ_R at the emitting depth of this system. This constant characterizes the response time of the thermosphere to external forcing [1], whether the forcing is radiative or dynamic. Dissipation occurs by the direct radiation to space. For Uranus near 300-430 mbar, $\tau_R \sim 130$ yrs [2]. However, the radiative constant is much shorter in the thermosphere due to its much lower heat capacity and elevated temperature. So τ_R represents a non-radiative, or dynamical, characteristic time constant that contains information on the nature of the process that dominates over the radiative heating of Uranus' thermosphere.

Adding an additional heat source to a solar-heated radiative model raises the temperature, and thus the radiative cooling rate, and reduces τ_R at the emission level, which results in a lower phase lag. Ultimately, we aim to investigate the depth the primary heating source in Uranus' thermosphere by including a parametric heat source in a simple radiative model and varying its depth and other parameters to fit the observed phase lags and both extracted temperatures. Source proximity and direction may be inferred from the progressive dissipation of the heating energy flux as it traverses the thermosphere. The H_2 emission may be enhanced more by a process that transports energy upwards into the thermosphere than downwards from above; and vice versa for the H_3^+ emission. The constraint on depth is greater if both phase lags can be determined. However, even one minimum may suffice to constrain the source depth usefully if the resulting fit is sufficiently robust.

Figure 1 illustrates the long-term downtrend in the H_3^+ temperature of Uranus' upper atmosphere, while Fig. 2 compares the short term variability of Uranus' upper atmosphere from 2012 to 2018 [3]. By 2018, the H_2 temperature also exhibited a comparable decline, dropping to ∼500 K from ∼620 K in 1995 and from a longitudinal minimum of ∼680 K in 1993 [4]. Although H_2 is cooler, its emission tends to follow the warmer H_3^+ emission vs. longitude. But its orbital phase lag is expected to be greater because it effectively originates deeper in the thermosphere (at O(1 μbar) vs. O(0.3 μbar) for H_3^+), where the radiative time constant is longer.

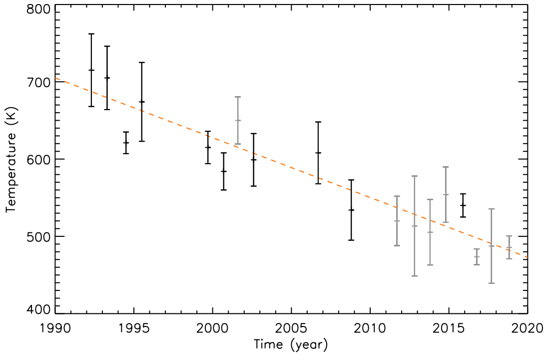

Figure 1: The long-term behavior of the H_3^+ temperature of Uranus' upper atmosphere, as derived from fitting H_3^+ spectra. The error bars indicates either the uncertainty in the fits, or the range of values over an observing run, whichever is greater. The dashed line shows the linear best fit to the temperatures, with a slope of $-8°$K/year. The trend is clearly decreasing through the 2018 apparition, well beyond the 2007 equinox. [3]

3. Summary and Conclusions

No sign of the anticipated seasonal reversal in the temperature of Uranus' thermosphere has yet occurred. Further monitoring is needed and planned to capture the seasonal reversal epochs. Seasonal phase lags are not expected to extend more than a season past equinox; i.e., past 2028 if driven by insolation. However, since the downtrend appears to have been established by 1996, 12 years after the 1986 solstice, one might expect an uptrend to be established 12 years after the 2007 equinox. That would be around 2019, the present. So the reversal may be imminent if the model of seasonal change through forcing insolation is correct.

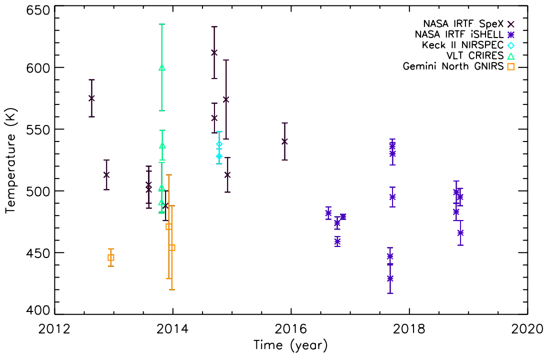

Figure 2: . The short term H_3^+ temperature variability of Uranus' upper atmosphere derived from individual nights from 2012 to 2018. There is signifiant variability between each individual observation. [3]

Acknowledgements

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