A TEST OF THE "METHANE-THERMOSTAT" MODEL FOR PLUTO'S ATMOSPHERE

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A physical model for the temperature in Pluto's lower atmosphere has been developed by Yelle and Lunine [1], who postulate radiative heating and cooling by methane through the 3.3 μm and 7.8 μm bands, with thermal conduction to the surface. In this model, the presence of even a small amount of methane would cause the atmosphere to be isothermal near and above the 1 μbar level, with a temperature of about 106 °K. Hence, we refer to this model as the "methane thermostat" model and the predicted isothermal region of the atmosphere as the "methane-thermostat region". The temperature derived by this model implies mean molecular weight of Pluto's atmosphere is about 25 amu, so that a molecule substantially heavier than methane must be present.

The goal of our work is test their model by determining the thermal gradient in the methane-thermostat region. To do so, we have constructed a synthetic occultation light curve for an atmosphere that includes a thermal gradient, and fit this to an occultation by Pluto observed aboard the Kuiper Airborne Observatory (KAO) on June 9, 1988 [2]. This observation had been previously analyzed under the assumption of an isothermal atmosphere [2], but the success of an isothermal light curve does not in itself rule out a thermal gradient. The light curve produced by an increasing scale height (due to gravity or a thermal gradient) equals that produced by a smaller constant scale height, to first order in the derivative of the scale height [3]. Nevertheless, due to the second order terms, we can fit for a thermal gradient and find a formal error. Since the main purpose of the model is to detect the presence of any thermal gradient, we had some latitude in the form of the temperature profile. A convenient form is a power law, as the ratio of temperature to gravitational acceleration is simply expressed as a proportional to a power of the radius, r. In particular, the assumed equation for the temperature is $T(r) = T_0(r/r_0)^b$, where r_0 is the radius at half-light, T_0 is the temperature at half-light, and b is the parameter that would indicate a gradient. Note that for small values of b, the temperature is essentially linear with radius.

In deriving light curves, it is usual to assume that the radius of the planet is much larger than any physically relevant distances in the atmosphere, including the scale height, H_0. However, the effects of the dropped "small-body" terms are on the same order as the effects of a thermal gradient at the level necessary to substantiate or contradict the methane-thermostat model. Thus, we had to include the following small body effects : (i) the dependence of gravity on radius; (ii) the convergence of the light rays in a plane perpendicular to the differential refraction; (iii) terms of the form (r/r_0) which arise when integrating the bending angle over the path of a ray, and (iv) terms of the order (H_0/r).

The resulting fit to the entire KAO light curve gives $b = -0.68 \pm 0.85$, which implies $(1/T)\,(dT/dr) = (-5.6 \pm 7.0) \times 10^{-4}$, consistent with an isothermal atmosphere. For the methane thermostat temperature of 106 °K, the 3 σ limit on the thermal gradient is $|\,dT/dr\,| < 2.7 \times 10^{-3}$ °K / km.

The relevant portion of the KAO light curve is isothermal, as predicted by the methane thermostat model. However, the temperature could be lower than the predicted 106 °K if the main heating and cooling mechanisms are not the 3.3 μm CH_4 band and the 7.8 μm CH_4 band. For example, in Titan's upper atmosphere, the 13.7 μm band of acetylene dominates the cooling [4]. This band would be excited at lower temperatures than the 7.8 μm band of methane.

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