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Hot N_2 in Titan's upper atmosphere

P. Lavvas (1), R.V. Yelle (2), A. Heays (3), L. Campbell (4), M.J. Brunger (4,5), M. Galand (6), and V. Vuitton (7)
(1) Groupe de Spectroscopie Moléculaire et Atmosphérique, Université de Reims, Champagne-Ardenne, CNRS UMR 7331, France, (2) Lunar and Planetary Laboratory, University of Arizona, 1629 E University Blvd, 85723,AZ, USA (3) Leiden Observatory, Leiden University, P.O. Box 9513, 2300 RA Leiden, The Netherlands (4) School of Chemical and Physical Sciences, Flinders University, GPO Box 2100, Adelaide, SA 5001, Australia (5) Institute of Mathematical Sciences, University of Malaya, 50603 Kuala Lumpur, Malaysia (6) Space and Atmospheric Physics Group, Department of Physics, Imperial College London (7) Univ. Grenoble Alpes, CNRS, IPAG, F-38000 Grenoble, France
(panayotis.lavvas@univ-reims.fr / Fax: +33-3-26-91-31-47)

Abstract

We present a detailed model for the vibrational population of all non pre-dissociating excited electronic states of N_2, as well as for the ground and ionic states, in Titan's atmosphere. Our model includes the detailed energy deposition calculations presented in the past [1] as well as the more recent developments in the high resolution N_2 photo-absorption cross sections that allow us to calculate photo-excitation rates for different vibrational levels of singlet nitrogen states, and provide information for their pre-dissociation yields. In addition, we consider the effect of collisions and chemical reactions in the population of the different states. Our results demonstrate that a significant population of vibrationally excited ground state N_2 survives in Titan's upper atmosphere. This hot N_2 population can improve the agreement between models and observations for the emission of the c_4' state that is significantly affected by resonant scattering. Moreover we discuss the potential implications of the vibrationally excited population on the ionospheric densities.

1. Introduction

Airglow (induced by solar photons) and aurora (by magnetospheric particles) are fundamental molecular processes that allow us to characterize the high altitude regions of planetary atmospheres. For the N_2-rich atmosphere of Titan (as well as those of the Earth, Triton, and Pluto) the emission spectrum of excited nitrogen demonstrates multiple bands from the plethora of excited electronic states available and covers a large part of the electromagnetic spectrum. Airglow is just one of the processes that take place at the high altitude regions of planetary atmospheres, though, the other being the collisional de-excitation of the different N_2 states that eventually defines the atmospheric local heating rate. Therefore, a detailed description of the N_2-state population is necessary for understanding these two processes. In this study we present a new N_2-state model focusing on Titan's atmosphere.

We specifically focus here on the resulting vibrational distribution of the ground state that has not been addressed in the previous studies. The presence of vibrationally excited N_2 can have important consequences for the atmospheric chemistry; excited molecules can partake in processes that are energetically forbidden for the more abundant ground state molecules, in this way allowing for chemical reactions that normally are not considered possible under Titan's atmospheric conditions. Such mechanisms have been identified in the Earth's atmosphere where the N_2 vibrational population has an important influence on the ionospheric electron density [2].

2. Model Description

In this study we developed a new model for the N_2 states' population, specifically for Titan. The advantage of our model is that it calculates the population of all non pre-dissociating states of N_2 and utilizes the detailed energy deposition calculations for Titan's atmosphere we have performed in the past [1]. The latter include the high-resolution, state-specific cross sections of N_2 derived from theoretical calculations, which only became available in recent years [3], and have important ramifications for the energy deposition in the atmosphere and the excitation of different electronic states. In addition, our model includes a detailed description of the collisional processes that could affect the different states, including chemical reactions, suitable for Titan's atmosphere.

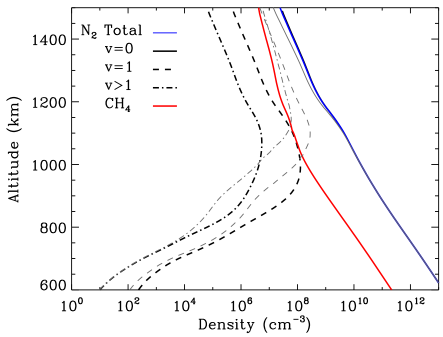

Figure 1: Density profiles for the ν=0, 1, and ν >1 vibrational levels for the nominal case compared with the total N_2 (blue) and CH_4 (red) density profiles. The thin gray lines represent the same results, but in the case that diffusion is not included in the calculations.

3. Results and Conclusions

Our results demonstrate that a significant population of vibrationally excited ground state molecules survives in Titan's upper atmosphere (Fig. 1). For the first excited vibrational level the density is comparable to that of methane, although the exact densities depend on the vibrational energy exchange rate with CH_4, which is not well constrained. We find that this vibrationally excited population of N_2 affects the resonant scattering for its excited singlet states and accounting for it leads to better agreement with the observed emissions from Cassini/UVIS. Particularly we find that the excited ground state levels result in a decrease of the CY(0,1) by a factor of 2, that is close to the required decrease (factor of 3) derived by [4] under the assumption of a thermal vibrational distribution (Fig. 2). In addition, we find that the non-thermal population brings the altitudes of peak emission for the CY(0,1) and CY(0,2) bands closer, in agreement with the observed peaks. Implications of the hot N_2 population on the other aspects of the ionosphere will be discussed.

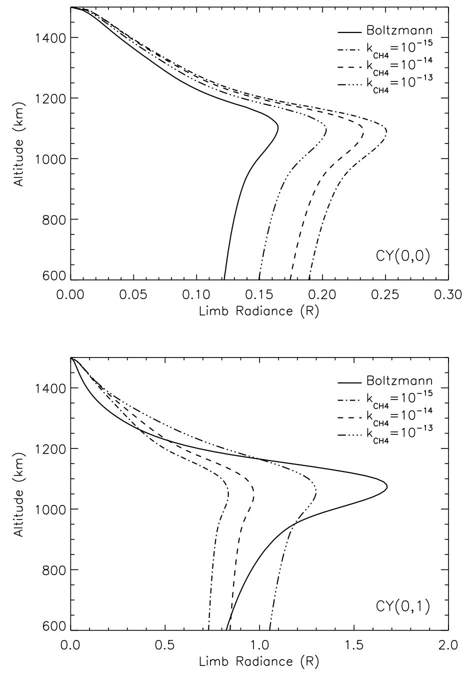

Figure 2: Limb radiances for the CY(0,0) and CY(0,1) transitions. Each panel presents the calculated emissions in spherical geometry, assuming different N_2 state vibrational distributions: solid lines correspond to a Boltzmann distribution at 150 K, while the broken lines correspond to the ground state vibrational distributions calculated with our model for the three different values of the vibrational energy transfer rate assumed between N_2 and CH_4. Their differences demonstrate the importance of the ground state population on the observable emissions.

References

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