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Study of non-LTE impact on the observations of Exoplanet Atmospheres

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Abstract

We present recent developments of our work studying the impact of non-LTE on the observations of the middle and upper atmosphere (MUA) of planets. The emphasis is given to CO_2 and CH_4 non-LTE models in the MUA for Trappist-1e and GJ1214b as well as other solar system planets. We simulate planetary spectra of CO_2 at 4.3 µm and CH_4 at 3.3 µm under LTE and non-LTE conditions at nadir geometries. We discuss the implication in accounting for non-LTE when simulating observations with current and future observatories (e.g., HST, JWST, Keck, ELTs, LUVOIR, OST).

1. Introduction

Over the last decade there has been significant progress in measuring the atmospheric infrared and near-infrared transmission and emission from a wide variety of exoplanet atmospheres using the transit and secondary eclipse methods. Recent moderate spectral resolution measurements of mid-sized planets have revealed relatively flat spectra indicating hazy conditions in their atmospheres ([1], [2]). However, the lack of spectral resolution of current measurements and the sparse wavelength coverage available has made any conclusions tentative at best. Upcoming instruments, such as the Near Infrared Spectrograph (NIRSpec) on board James Webb Space Telescope (JWST), will finally provide high-resolution observations of exoplanet atmospheres.

For solar system planet atmospheres, the distinguished feature of the high-resolution observations are the strong molecular emissions in narrow spectral intervals originating from the middle and upper atmospheric layers. The analysis of these high-resolution spectra requires detailed accounting for non-LTE (non-Local Thermodynamical Equilibrium) to properly extract properties of these atmospheres such as molecular abundances, temperature/pressure distributions, winds, etc. [3]. In giant and terrestrial exoplanets that orbit close to their parent stars, the non-LTE conditions begin to prevail due to the decrease in atmospheric pressure and strong pumping of molecular levels from absorption of stellar radiation. As a result, the exoplanet atmospheres will exhibit non-equilibrated emissions which can be much stronger than the intrinsic planetary and LTE atmospheric emission.

2. Non-LTE Code Package

In this study, we applied the ALI-ARMS (for Accelerated Lambda Iterations for Atmospheric Radiation and Molecular Spectra) code package and model. ALI-ARMS [4] is based on the Accelerated Lambda Iteration technique [5] developed for the non-LTE analysis of stellar spectra. The code has been successfully applied to the non-LTE analysis of space observed spectra of CO_2 at 4.3 and 15 µm, H_2O at 6.3 µm, O_3 at 9.6 µm and OH at 1.6 and 2.0 µm of the Earth's and Martian atmospheres [6] - [10] and is currently being used for non-LTE analysis of the CASSINI/CIRS and VIMS spectra of CH_4 at 7.6 and 3.3 µm of Titan, Saturn and Jupiter atmospheres.

3. Non-LTE Results

In order to estimate the extent of the non-LTE effect, we simulated exoplanet spectra of CO_2 at 4.3 µm and CH_4 at 3.3 µm for Trappist-1e (Figure 1) and GJ1214b (not shown), respectively under LTE and non-LTE conditions at nadir geometries. The non-LTE strongly impacts both the structure of the CO_2 4.3 µm spectra and intensity of the Trappist-1e emission. The non-LTE radiance around 4.27 µm is a factor of 7 stronger than that for LTE conditions. Figure 2 displays vibrational temperatures (Tvibs) of the CO_2 vibrational levels. Compared to kinetic temperature, Tvib shows the extent at which a vibrational level is in non-LTE throughout the atmosphere. The CO_2 Tvib for the 4.3 µm first excited level significantly deviates from the kinetic temperature, due to strong absorption of near-infrared stellar radiation at 1-2.7 µm region that leads to large differences seen between LTE and non-LTE spectra for Trappist-1e. Similar effects are seen for CH_4 3.3 µm emissions and vibrational levels for GJ1214b (not shown).

Figures

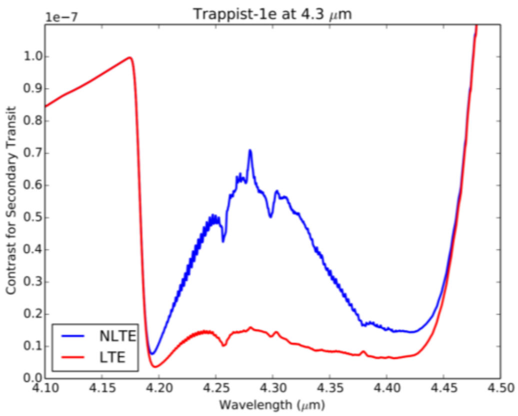

Figure 1: Limb + Nadir Integrated Emissions of Trappist-1e at 4.3-µm. NLTE (blue) and LTE (red) emissions are compared and show up to a factor of 7 difference in the center of the band.

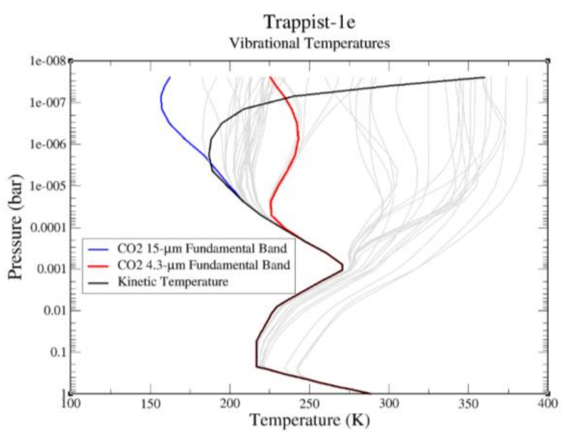

Figure 2: Vibrational Temperatures of CO_2 vibrational levels for Trappist-1e. Blue – Fundamental band for 15-µm. Red – Fundamental band for 4.3-µm). Black- Kinetic Temperature profile

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