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Simulation of Transmission Spectra to Characterize Atmosphere of Exoplanets

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Today, more than three thousand exoplanets have been confirmed and other millions waiting to be discovered. In addition to determine their physical and precise orbital parameters of exoplanets atmosphere is of important to characterize. This will allow us to investigate their evolution and eventually to see the possibility for some exoplanets to harbor a living system. By using the TAU Code. TAU Code is a 1D which simulate transmission spectroscopy with radiative transfer concept. We undertake simulations of exoplanets transmission spectra in the near infrared in order to retrieve transmission spectral profiles of these exoplanets. The simulations adopted thermal profile as well as absorption cross-section as a wavelength function for each modeled absorber or trace molecule H_2O (0.24 – 0.34 microns) and C_2H_6 (0-20 microns). The results of this calculation provide scale height, optical depth, transit depth and absorption spectra of absorber. Simulation of transmission spectra of C_2H_6 to determine the abundance in the atmosphere of gaseous exoplanets such as HD 189733b, HD 209458b, WASP 12b, WASP 21b, WASP 25b, Corot 2b, Corot 13b, Kepler 17b, Hat 32b, and Hats 19b. While H_2O simulation was carried out to determine the abundance of these molecules on terrestrial exoplanets such as Kepler 442b, Kepler 186f, and Kepler 62f. Our result gave scale height 89% compared to existing data, and total number density of H_2O is 5.42×10^{25} m^{-3} for Jupiter's atmosphere.

Keywords: Atmosphere, Planet, Exoplanet, TAU code, Spectra.

1. INTRODUCTION

There are 3,397 exoplanets already confirmed until October 2016 and other millions will be discovered soon. Determining of physical characteristics is important since we can investigate their evolution and possibility for living system, called habitable zone. There are some important parameter for finding habitable zone exoplanets, namely radius exoplanets to its parent star, type and star age, shape of the planet orbit, mass of the planet and its atmosphere, and also the composition of atmosphere that could effect to reflectivity and climate condition in the planet itself. The others some boundaries that collected in a catalogue of Kepler habitable zone candidates using four model of habitable exoplanets to its host star [1].

One of the methods to search and characterize physical parameters of exoplanets is planetary transit, specifically is a way that allows us to study about the atmospheric spectra of planet. Since that is a wide range of spectra, aerosol abundances, gas and temperature can be constrained by near-infrared and thermal infrared region spectral [2]. One of a big challenge for this research, we need a high-resolution spectrum that maybe can be done by the future work of James Webb Space Telescope [3]. The other way to deal with it is using a simulation. The simulation for using near infrared spectra already done by Hollis et.al, called TAU code. This code is a 1D which simulate transmission spectroscopy with radiative transfer concept, and gave the HD 189733b H_2O molecule spectra. Since this simulation does not clear, the specific result are compared between simulation and real data, we try to use simulation and add some input for modeling

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gaseous and terrestrial exoplanets. Thus, in this work aimed to knowing how precise this simulation compared to observation result.

2. METHODOLOGY

The TAU code simulations are using C++ language for making thermal profile as well as absorption cross-section as function wavelength for each modeled absorber or trace molecule in near infrared spectra. The peak of the spectra may lead us to determine the abundance each molecule in the atmosphere [4]. The concept simulation of transmission spectra is measuring atmospheric spectra when primary transit. The primary transit chosen since the dimmer of the light curve got the deepest value, which mean maximum contribution from the planet. Input data for this code are Pressure-temperature profile, absorption cross-section, radius, gravity, atmospheric temperature and mass of planet, radius and mass of the parent star and also semi mayor axis, and bulk composition. The limitation of the problem of this research is that it only covers each level atmosphere corresponding to altitude using hydrostatic assumption. Since gravity and atmospheric temperature are less available for many exoplanets, we modeled into two synthetic model characteristics of exoplanets, gaseous and terrestrial. For gaseous exoplanet we modeled with Jupiter parameter such as temperature profile [5], gravity, bulk composition H_2 85% and He 15% and atmospheric temperature of Jupiter that is 165 K. The molecule tracers are H_2O (0.24 – 0.34 microns) and C_2H_6 (0- 20 microns), are chooses based on photolysis product of CH_4 by UV and also C_2H_6 molecule abundance at stratospheric Jupiter [6]. The second model, we used earth atmosphere profile with bulk composition N_2 72.803%, O_2 20.94%, Ar 0.015 and CO_2 0.003%, the molecule tracer is H_2O, since those molecules are abundance in Earth atmosphere respectively.

Data of tracer molecule can be downloaded from HITRAN website (http://hitran.org/xsc/#) or the others open source data, and the intrinsic planet parameter from exoplanet online catalog (exoplanet.eu). There are some optional input, such as collision induced absorption (CIA) is consequence from absorption cross- section and stellar radius as a function of wavelength then stellar radius assumed constant. The computation provides height scale, optical depth, transit depth and absorption spectra of absorber. Instantaneous result given in terminal are number density of surface, mean molecular density μ, scale height z, layer on the atmosphere n, these parameters are valuable when we identification over preliminary result in this code. The others parameter that we can measured are peak absorber, transit depth and optical depth. Cloud in the atmospheric planetary system does not covered yet by TAU code, so the model could not give a detail effect about geometry approximations or Mie scattering theory. Some limitation of this projects is also not being a chemical equilibrium, no time variation, dynamics, heat transfer and does not model photochemistry.

3. RESULT AND DISCUSSION

Preliminary identification for identifying how good this simulation is with testing the atmospheric planets in the solar system, there are Jupiter and Earth. Our result gave scale height 24.061 km the reference is 27 km, which mean 89% compared to existing data, the total number density of H_2O is 5.42×1025 m-3 and mean molecular weight is 2.3 g/mol for Jupiter's atmosphere. The Earth parameter are scale height 8.79 km from simulation and 8.5 km from the reference and also 28.92 g/mol compared to 28.97 g/mol. Subsequently, we make spectral models of ten gaseous exoplanets, there are HD 189733b, HD 209458b, WASP 12b, WASP 21b, WASP 25b, Corot 2b, Corot 13b, Kepler 17b, Hat 32b, Hats 19b and terrestrial exoplanets, Kepler 442b, Kepler 186f, and Kepler 62f. We were successful three earth like exoplanets since the Earth like exoplanets have a few characteristic parameter information. So there are 13 model spectra, these spectra model of each exoplanet show the variation value was peak absorber, a transit depth, and optical depth.

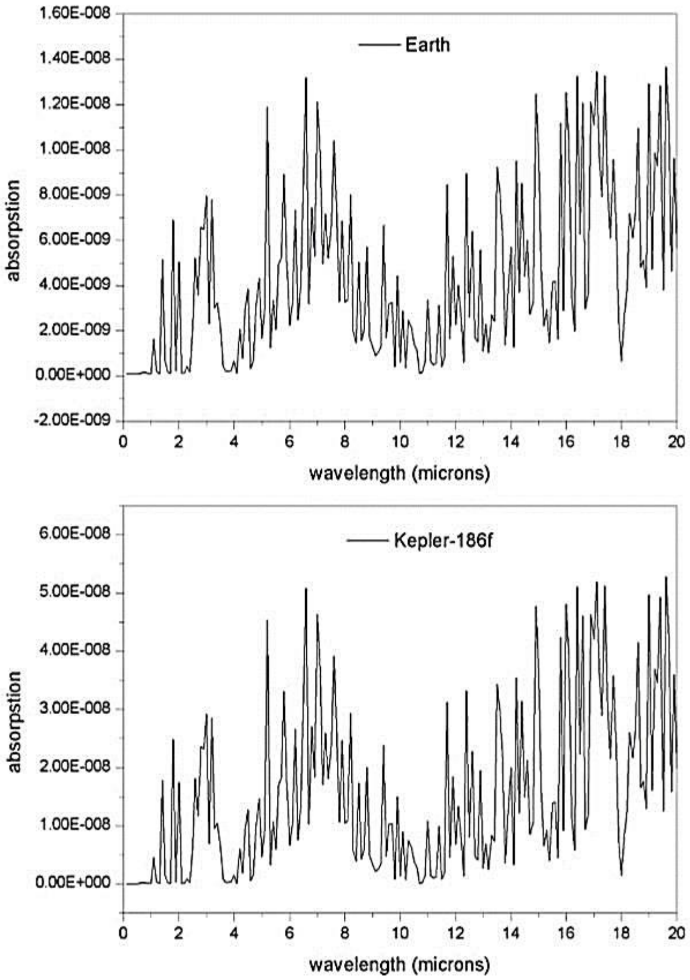

Figure. 1. H_2O molecular spectra of Earth atmosphere and a terrestrial exoplanet

The figure 1 and figure 2 show different planet gave different absorber peak value for the same absorber. We were successful modelled 15 H_2O spectra, for gaseous and terrestrial also the Earth and Jupiter for comparison, but only 11 C_2H_6 spectra since we just modelled gaseous planet. After got the spectral peak we make the graph to take relation between absorber peaks to transit depth for each molecule.

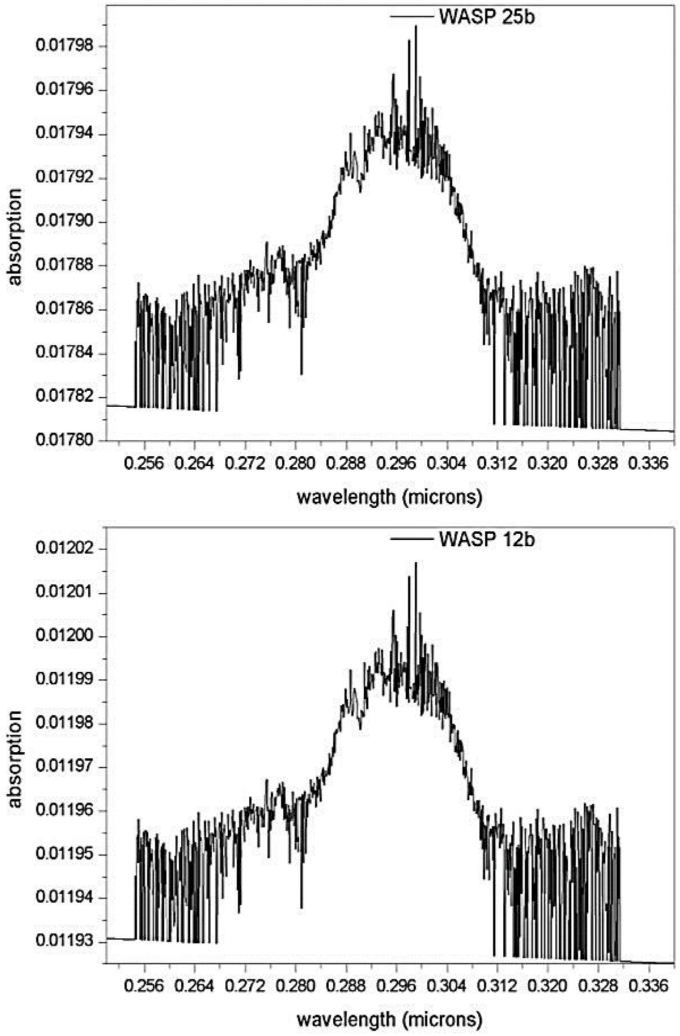

Figure. 2. C_2H_6 molecular spectra of two gaseous exoplanets.

The possible comparison for gaseous exoplanets, we modelled two different molecular tracer absorber water H_2O figure 3 and ethylene C_2H_6 on the figure 4. The peak variation gives the relation to variety of transit depth each planet. The Transit depth is given form distance ration of planet and its parent star. Please explain why author not use H_2O in figure 2.

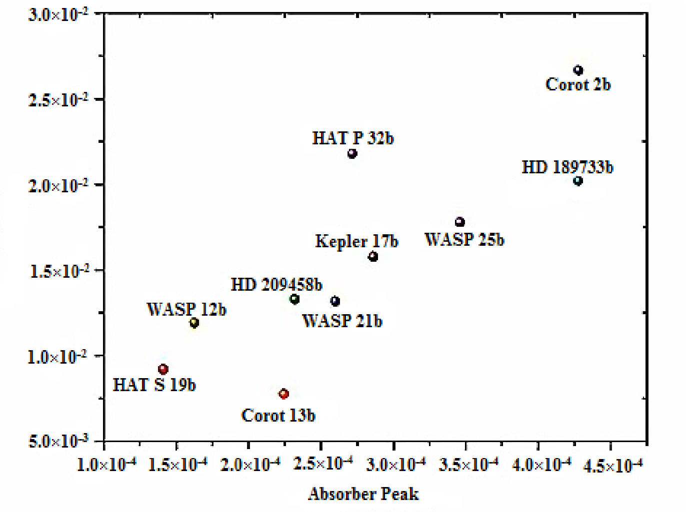

Figure. 3. Peak of absorption H_2O to transit depth of gaseous exoplanets.

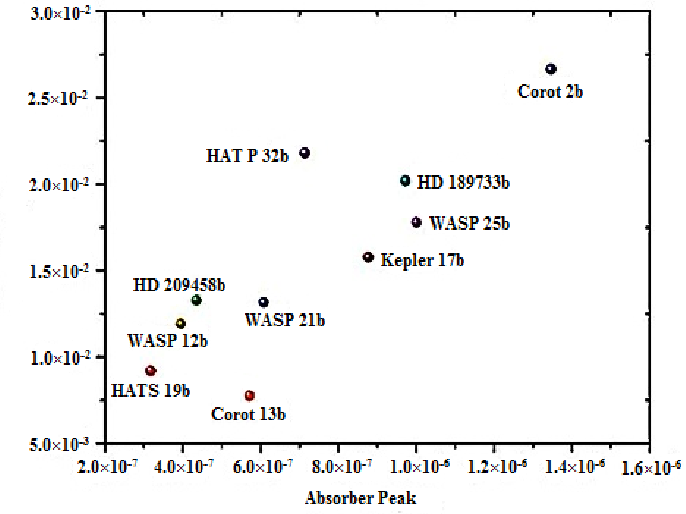

Figure. 4. Peak of absorption C_2H_6 to transit depth of gaseous exoplanets.

The other result is relation between radius ratio (Rp/Rs) form planet to host star and transit depth, shown on the figure 5. Since the rank of transit depth between terrestrial and gaseous have a big lap, so we could not make in a graph to see the comparison. Figure 5. show that the higher the peak correlate to the deeper the transit. This result is similar with the early hypothesis which state that the number of molecular density absorber in atmospheric layer determine how much intensity can be observed and depend on the process transit depth every exoplanet.

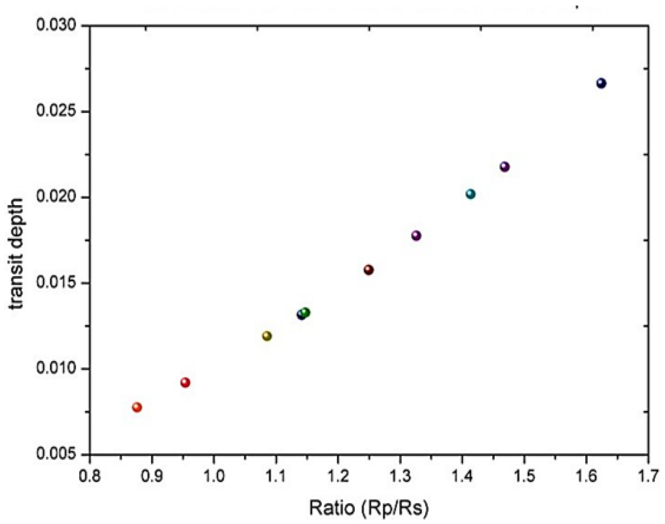

Figure. 5. Correlation between of radius ratio and transit depth for gaseous exoplanet

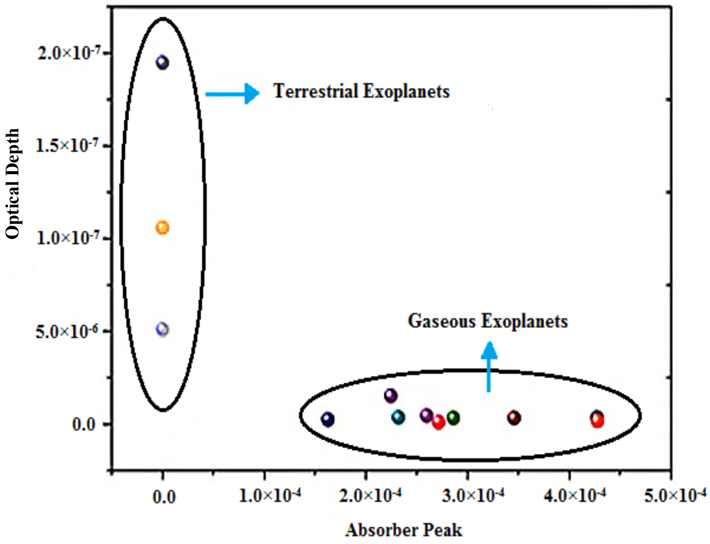

Figure. 6. The total value of optical depth terrestrial and gaseous exoplanet. Gaseous have a high value of absorber peak to terrestrial, however the optical depth is to low

How deep the optical depth become a key point to answer where the molecule. Thus, the graph relation between peak absorber with the optical depth are shown in figure 6. Form the graph that shown the comparison of terrestrial and gaseous exoplanet between optical depths to absorber peak of H_2O molecule, we can conclude that gaseous exoplanet optically thin of the water molecule than the terrestrial exoplanet. This research results could contribute for determining the characteristic of exoplanet that predicated as a habitable zone based on absorber abundance from the simulation

4. CONCLUSION

The TAU code has successfully given a primary result to characterize exoplanet spectra, that already gave spectral value for planet compared to our result that gave scale height 89% to existing data and the total number density of H_2O is 5.42 x 10^{25} m^{-3} for Jupiter atmosphere. We already made spectra models of then gaseous exoplanets like Jupiter, including HD 1897733b and WASP 12b and also three earth like exoplanets. The spectral lead us that larger value for absorption is equivalent planetary radius. Optical depth can determine from radius of planet to its host star and peak of absorber. In near future work this project, we can look at the result if we make higher atmospheric temperature of exoplanet, since many of the hot Jupiter. By using TAU code, we can simulate the abundance of molecules in the atmosphere of exoplanets, as a first step to study exoplanets further in the future.

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