Atmosphere Retrieval of Planetary Mass Companions with the APOLLO Code

A Case Study of HD 106906b and Prospects for JWST

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of H_2O in the transmission spectrum. The strongest H_2O features occur in the JWST MIRI instrument wavelength range and are comparable to the estimated systematic noise floor of 50 ppm for a cloudless atmosphere. We also explore additional chemical complexity within the 1-D model by introducing other species into the atmosphere and discuss their impact on the transmission spectrum.

203.03 — The Origin of Heavy-element Content Trend in Giant Planets via Core Accretion

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We explore the origin of the trend of heavy elements in observed massive exoplanets. Coupling of better measurements of mass (M_p) and radius of exoplanets with planet structure models enables estimating the total heavy element mass (M_z) in these planets. The corresponding relation is characterized by a power-law profile, $M_z$$
propto$ $M_p^{3/5}$. We develop a simplified, but physically motivated analysis to investigate how the power-law profile can be produced under the current picture of planet formation. Making use of the existing semi-analytical formulae of accretion rates of pebbles and planetesimals, our analysis shows that the relation can be reproduced well if it traces the final stage of planet formation. In the stage, planets accrete solids from gapped planetesimal disks and gas accretion is limited by disk evolution. We find that dust accretion accompanying with gas accretion does not contribute to M_z for planets with $M_p < 10^3 M_{earth}$. Our findings are broadly consistent with those of previous studies, yet we explicitly demonstrate how planetesimal dynamics is crucial for better understanding the relation. While our approach is simple, we can reproduce the trend of a correlation between planet metallicity and M_p that is obtained by detailed population synthesis calculations, when the same assumption is adopted. Our analysis suggests that pebble accretion would not play a direct role at the final stage of planet formation, whereas radial drift of pebbles might be important indirectly for metal enrichment of planets. Detailed numerical simulations and more observational data are required for confirming our analysis.

203.04D — Heavy Ion Escape from Terrestrial Exoplanets

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The most potentially observable habitable zone planets are found around M-dwarfs, therefore characterizing their long term atmospheric stability is important. Ion loss in particular is critical to study because electric fields provide additional escape energy to heavy species that could make up volatile rich atmospheres. We used a global hybrid plasma model to systematically study how ion escape processes vary from solar system expectations due to the extreme conditions found at the habitable zone of a typical M-dwarf. To isolate the effects of different stellar influence properties we incrementally changed each parameter, allowing our interpretation to be more generalizable across systems.

We found that while both the ion loss morphology and rates were dictated by the resultant plasma environment, there was not a straightforward relationship between energy input and ion outflow due to ion production limitations. It is thus important to consider under what conditions scaling laws derived by observations of solar system planets begin to break down when applied to more extreme environments. Additionally, the asymmetric plasma environment created by a nearly flow aligned interplanetary magnetic field lead to asymmetric ion outflow, possibly creating observable atmospheric asymmetry in tidally locked planets.

We also investigated the influence of intrinsic planetary magnetic field on the ion escape. Although terrestrial planets around M-Dwarfs are likely to be un- or weakly-magnetized, even a weak magnetic field is capable of changing the dynamics of the solar wind interaction. Our results reflect a balancing act between magnetic standoff pressure and polar outflow, where the presence of a magnetic field enhances escape to a certain point before beginning to inhibit it.

203.05 — Atmosphere Retrieval of Planetary Mass Companions with the APOLLO Code: A Case Study of HD 106906b and Prospects for JWST

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We present retrieved atmospheric properties for the very low mass companion, HD 106906b, which is spatially resolved from its host star, using APOLLO, a spectral retrieval code designed for flexibility of atmosphere models. APOLLO allows retrieval on both transit and emission spectra of planets to determine molecular abundances as well as comparison of different parameterizations of the thermal structure and cloud properties. We compare fits of our models to high signal-to-noise spectra of HD 106906b, a 10-20 Jupiter mass early L-type companion orbiting a 10-15 Myr old binary system at 730 AU projected separation, obtained with SINFONI on the ESO VLT (Daemgen et al. 2017). Using these models, we measure molecular abundances and present constraints on cloud properties. Comparing the retrieved abundances of volatile species (e.g. C/O) to those of the host star, we can speculate on whether this object may have formed much closer to its host star through a core accretion-like mechanism and was later dynamically ejected to larger orbital separation. Because HD 106906b is a prime target for JWST, we present a similar analysis of model JWST spectra for this object to demonstrate the performance of APOLLO with data obtained over a broader wavelength regime (e.g. 0.6 to 5 microns).

203.06 — O₂-Dominated Atmospheres for Potentially Habitable Environments on TRAPPIST-1 Planets

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Small exoplanets of nearby red dwarf stars present the possibility to find and characterize habitable worlds within the next decade. TRAPPIST-1, an ultracool red dwarf star, was recently found to have seven Earth-sized planets of predominantly rocky composition. The planets e, f, and g can have a liquid water ocean on their surface given appropriate atmospheres of N_2 and CO_2. Particularly, climate models have shown that the planets e and f can sustain a global liquid water ocean, for ≥0.2 bar CO_2 plus 1 bar N_2, and ≥2 bars CO_2, respectively. These atmospheres are irradiated by ultraviolet emission from the star's moderately active chromosphere. Using an atmospheric photochemistry model, we investigate how the irradiation drives chemical reactions in the atmospheres of TRAPPIST-1 e and f, where we assume habitable compositions predicted from the climate models and include the effects of lightning and oxidation of the crust. Our models show that chemical reactions driven by the irradiation in the atmosphere produce and maintain more than 1 bar of O_2 and 0.1 bar of CO if the CO_2 is ≥0.1 bar. Because of this O_2 runaway, the habitable environments on the TRAPPIST-1 planets entail an O_2-dominated atmosphere, with co-existing CO, CO_2, and N_2. The sole process that would prevent the O_2 runaway is a direct recombination of O_2 and CO in the ocean, a reaction not found on Earth but might be facilitated biologically. Our results indicate that O_2 and CO should be considered together with CO_2 as the primary molecules in the search for atmospheric signatures from potentially habitable planets of TRAPPIST-1 and other red dwarf stars.

203.07 — Internal Structure and CO₂ Reservoirs of Habitable Water-Worlds

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Water-worlds are water-rich (>1% water by mass) exoplanets. If located at an appropriate orbital separation from their host star (i.e. in the habitable zone) they may have the potential to host a global surface water ocean. Water-worlds likely accrete a comet-like mixture of volatiles, leading to CO_2-rich compositions, with between 3 mol% to 30 mol% CO_2 relative to water. In this study, we constrain the hydrosphere structures, CO_2 contents and CO_2 reservoirs in the interiors of water-worlds. We couple a sophisticated equation of state that accurately reproduces experimental phase boundaries of CO_2-H_2O mixtures to models of planet interior structure and atmospheric radiative transfer. We determine that neither the atmosphere, ocean, nor clathrate layer (if present) can be the main CO_2 reservoir on habitable (liquid ocean-bearing) water-worlds that accreted more than 11 wt% volatiles. The largest potential reservoir of CO_2 inside of habitable water-world hydrospheres is likely to be CO_2 ice trapped in the high-pressure water ice mantle. Consequently, the atmospheric composition of a water-world does not necessarily reflect the total mass of volatiles accreted during the formation of the planet, nor the relative proportions of CO_2 and H_2O in the hydrosphere. Instead, the CO_2 molar fraction in the atmosphere is determined by the post-accretional cooling history of the planet. Detailed modeling of the post-accretional cooling of water-worlds is needed to determine whether CO_2 ice burial could allow water-worlds to have liquid water oceans or whether the evolution of the planet would generically lead to too much atmospheric CO_2 for the planets to be habitable.