National Aeronautics and Space Administration

FY23 Innovative Spontaneous Concepts Research and Technology Development (ISC)

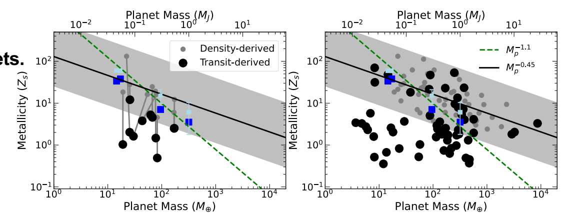
A Model for Planetary Envelope Composition Gradients: Setting the stage for a profound advance in our understanding of planetary interior structure

Principal Investigator: Mark Swain (326); **Co-Investigators:** Yasuhiro Hasegawa (326)

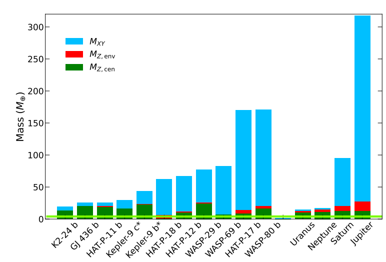
Objectives:

The objective of this project is to make use of existing estimates of the envelope and bulk metallicities of exoplanets to compute the metal distribution within exoplanets. This objective is achieved by the following four tasks. Task 1 is to derive the mass-based transit-derived metallicity from the abundance-based one that is the standard outcome of retrieval analysis of transit observations. Task 2 is to compare the transit-derived metallicity with the density-derived one to assess whether heavy elements are well mixed within (exo)planet interiors. Task 3 is to compute the heavy element mass distributed in both the central region and the envelope of planets, by adopting the well-mixed assumption. Task 4 is to identify any knowledge gaps that can be filled out by ongoing and future observations via space missions such as JWST and Ariel/Case.

Approach and Results:



Transit-derived and density-derived metallicities of solar and extrasolar planets. The former probes the abundance of metals in the outer envelope, while the latter does the bulk metal content. For comparison purpose, solar system planets are included. Transit-derived metallicities of exoplanets exhibit a diverse distribution, implying the importance of subsequent evolution processes in exoplanet atmospheres.



The mass budget of solar and extrasolar planets with the well-mixed assumption. Most heavy elements are concentrated in the central region of planets. Heavy elements in envelopes tend to increase with increasing planet mass. The horizontal light green line represents the core mass of 4 Earth masses.

Two major findings:

(1) The importance of subsequent atmospheric metallicity evolution is different for different exoplanets; one potential key question for the future work may be what physical process(es) and/or parameter(s) would control the efficiency and the outcome of subsequent atmospheric evolution.

(2) The computed metal distribution within planets depends heavily on the outcome of retrieval analysis, and hence uniform and systematic analysis of transit observations is the key to derive reliable insights.

Significance/Benefits to JPL and NASA:

This work provided novel insights about compositional gradients within exoplanets. We conclude that obtaining consistent results from different retrieval analyses would be a critical next step for the community to take, in order to derive a meaningful understanding of exoplanet atmospheres and their evolution. This finding is invaluable for both JPL/NASA as well as the community because ongoing observations by JWST and upcoming space missions such as Ariel/Case target a large number of exoplanets and obtain thousands of spectra, yet the accompanying interpretation of such observations depends heavily on retrieval analyses used as a part of data reduction.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

Clearance Number: CL#00-0000
Poster Number: RPC#

Publications:

Mark, Swain, Yasuhiro, Hasegawa, Daniel, Thorngren, Gael, Roudier (2023) Space Science Review, submitted

Yasuhiro, Hasegawa, Mark, Swain (2023) The Astrophysical Journal Letters, in prep

PI/Task Mgr. Contact Information:

mark.r.swain@jpl.nasa.gov