Understanding planet formation through asteroseismology

Kepler & K2 SciCon V

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Asteroseismology utilizes the full Kepler time series and can be used to gain deep knowledge of a star and its planets.

Kepler-410, Van Eylen et al. 2014
Five years ago, photo-evaporation models predicted that some close-in planets would lose their entire atmosphere, and:

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  - Fulton et al. 2017
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- **Asteroseismology**
  - 2% precision
  - Silva Aguirre et al. 2015
  - Van Eylen et al. 2018, 2019
How does photo-evaporation lead to a radius valley?

Envelop Mass Fraction

Mass-loss timescale [Myr]

Stable to Evaporation

Completely Stripped

Unstable to Evaporation

Planet Radius [$R_c$]

Initial

(a)

(b)

(c)

(d)

Combined

Owen & Wu 2017
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- Small atmospheres are unstable to evaporation
- Small envelope mass = large envelope size

Owen & Wu 2017
The radius valley is a function of orbital period (incident flux) and divides planets with atmosphere from stripped cores.

Lopez & Fortney 2013

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Owen & Wu 2013
The location of the radius valley depends on orbital period and core composition.
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See also poster by James Owen!
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Setting out to observe this valley, early Kepler results look rather disappointing.
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Precise stellar and planetary parameters bring the radius valley into view.

See also talks BJ Fulton & Travis Berger (Gaia), and Cintia Fernanda Martinez!
Precise stellar and planetary parameters bring the radius valley into view.

We did a very careful transit modeling because we used transit durations to constrain orbital eccentricities for the same sample (Van Eylen et al. 2019).
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\[ \sigma_{\text{multi}} = 0.083^{+0.015}_{-0.020} \text{ and } \sigma_{\text{single}} = 0.32 \pm 0.06 \]
We find a **very empty radius valley.**
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Using support vector machines, we measure its precise **location & slope:**

\[
\log_{10}(R) = -0.09^{+0.02}_{-0.04} \log_{10}(P) + 0.37^{+0.04}_{-0.02}.
\]
Comparing the slope to photo-evaporation models reveals core composition (+ evaporation physics).

Van Eylen et al. 2018
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- Slope consistent with photo-evaporation predictions
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- Slope consistent with photo-evaporation predictions
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- Alternatives. Slope inconsistent with late gas poor formation, but perhaps core-powered mass-loss: see talk Hilke Schlichting and poster Akash Gupta
Precise asteroseismic stellar radii detect an empty radius gap.

The radius gap has a negative slope consistent with photo-evaporation models.

Terrestrial cores, in situ formation

Homogeneous core composition

Future:

- Mean densities of planets? Function of stellar type? → TESS

Challenge: find a planet firmly inside the gap

See also orbital eccentricities → Van Eylen+ 2019