Prioritizing the mass measurements of small planets with *Subaru*/IRD

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Problem

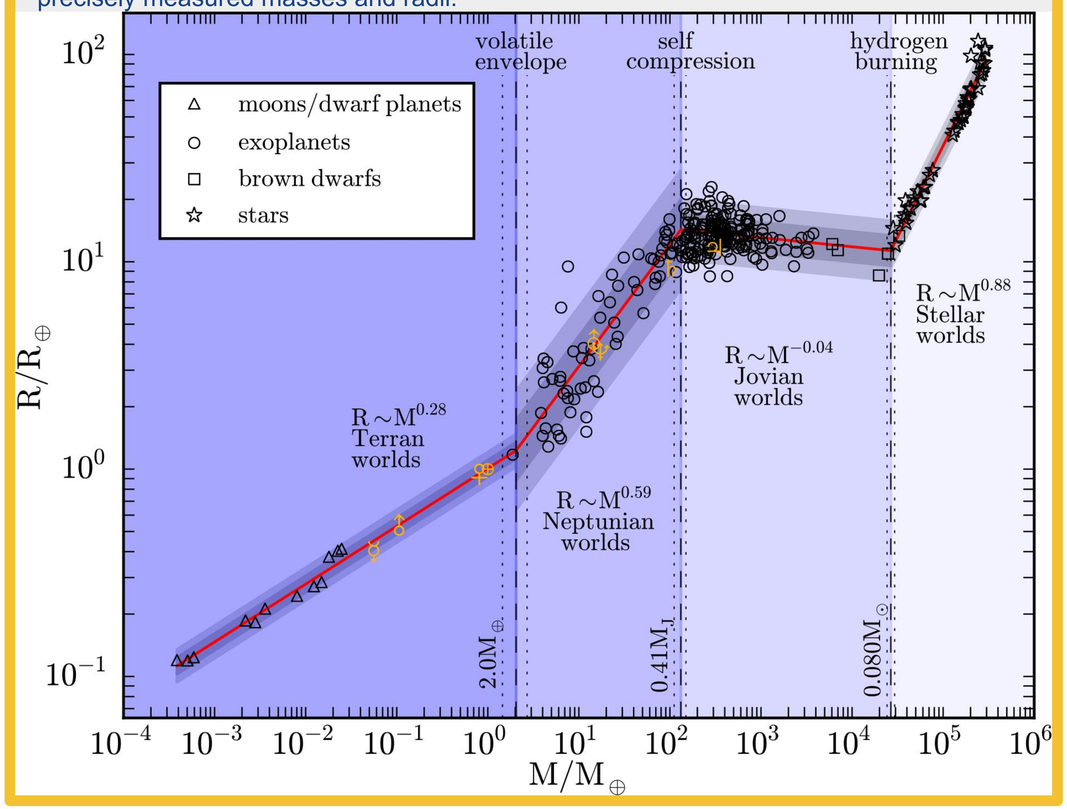
- **Significant uncertainties persist** in the **mass-radius (M-R)** relation, especially for the most interesting planets -- those of Terran to Neptunian size.
- Many small worlds can be equally well modeled as either **rocky or volatile-rich**.
- Planets in this size regime are high priority targets for future atmospheric study with ***JWST***, but large uncertainties in predicted **atmospheric scale height** complicates target prioritization, which is essential for optimal use of the ~$10B observatory.

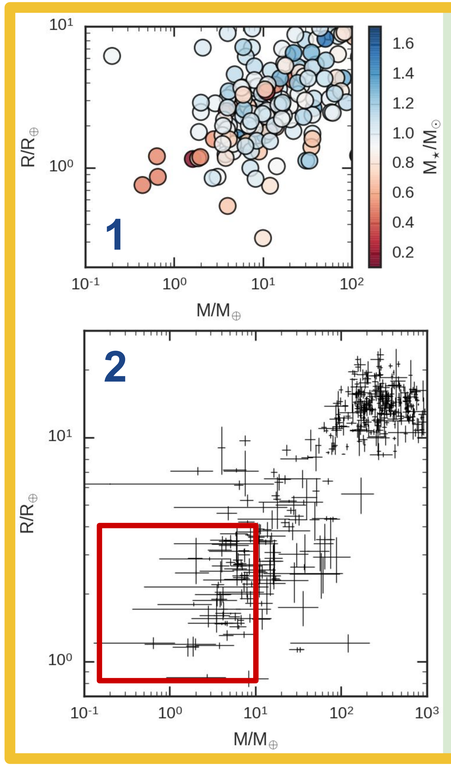
Goal

- **We want to improve the M-R relation for small planets** via optimal use of the *Subaru* telescope's new **Infrared Doppler (IRD)** instrument (Tamura et al. 2012).
- **Late-type** stars have low mass and frequently host small planets, which makes them ideal targets for this purpose, but they are optically faint.
- **IRD is thus uniquely capable** of measuring the masses of small planets orbiting low mass stars due to the combination of its sensitivity in the IR and *Subaru's* large aperture.

Current knowledge

Recently Chen & Kipping (2016) updated the M-R relation across the full range of planetary to stellar regimes using a large calibration sample of known bodies with precisely measured masses and radii:

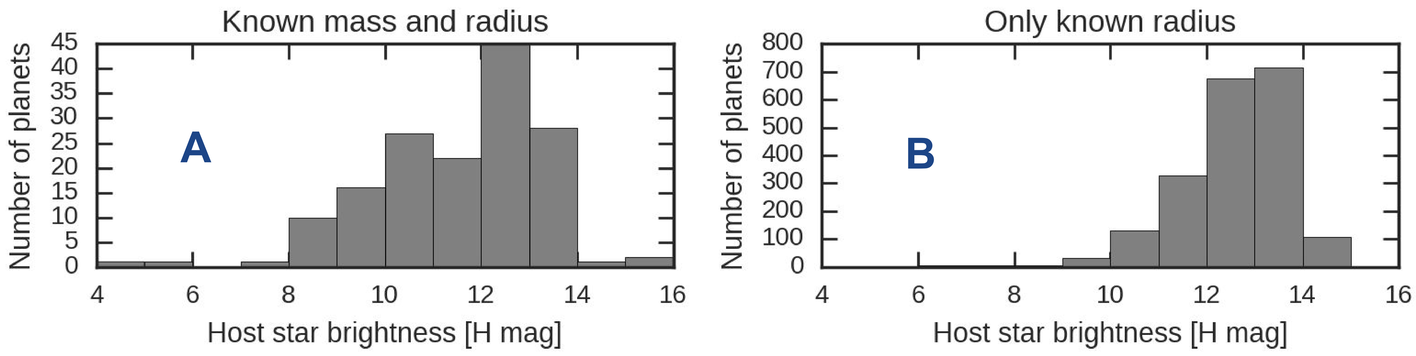




Approach

- Late-type host stars are ideal targets because the expected radial velocity (RV) **semi-amplitude (K) is maximized** for a given planet size due to the low stellar mass.
- Presently known **low mass planets tend to orbit low mass stars** (in part) because of this instrumental selection effect (see figure 1, above left). IRD will be able to populate the lower left regions of both figures 1 and 2 -- i.e. small, low mass planets.
- Presently known **small planets have large uncertainties in mass**, in particular near and below the Terran/Neptunian transition (marked in red in figure 2, below left).
- The impact of various factors must be considered in order to choose optimal targets:
  - Factors which impact overall SNR:
    - Host star **brightness** (*more photons → more signal*)
    - Host star **variability** (*stellar jitter limits RV precision*)
    - Host star **v*sin(i)** (*broader line profiles limit RV precision*)
  - Factors which impact RV semi-amplitude:
    - Host star **mass** (*lower mass star → more reflex motion*)
    - Planet **radius** (*more planet mass → more reflex motion*)
- Two reasons to **straddle the Terran/Neptunian transition**:
  - There is large scatter about the mean model for Neptunian planets, especially near the transition to Terran worlds.
  - Terran planets suffer from small number statistics due to the inherent difficulty of precise mass measurements for small semi-amplitudes.
- Therefore we should **target super-Earths and mini-Neptunes orbiting relatively bright, low mass, slowly rotating, quiescent stars**.
  - The **NASA K2 mission** is currently yielding large numbers of such discoveries.

Results



Two avenues for improving the M-R relation using IRD (accounting for *Subaru*'s observability constraints on Mauna Kea):

A. Planets straddling the Terran/Neptunian transition which already have measurements of both mass and radius (left). The benefit to the M-R relation is entirely due to the improvement in measurement precision.

B. Planets to be straddling the Terran/Neptunian transition which only have radius measurements (right). The benefit to the M-R relation is entirely due to the addition of new data points, which is especially important for the smallest planets which currently suffer from low number statistics.

Option A will be limited to only a few targets once other considerations are taken into account (i.e. activity, rotation, current precision). However, after eliminating faint/active stars from option B, there will still be a large number of good targets.

Conclusion: a combination of the above with a greater emphasis on option B will most likely produce the best results.