The Minimum Heavy Element Mass of Giant Planets, and its correlation with Stellar Metallicity

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Abstract

Planet Transit observations have revealed a population of Hot Jupiters with unexpectedly large radii. This yet undetermined physical mechanism seems to be correlated with the average stellar incident flux upon the planet. Transit observations combined with radial velocity data tell us about the mass and density of these planets, which in principle constrain the composition. However, for the large-radius planets the composition is difficult to determine because putting energy into the planet counteracts the effects of heavy elements ("metals"), which would otherwise shrink a planet.

Fortunately, a sample of transiting planets is now emerging at larger orbital distances and smaller incident fluxes that seem to be essentially unaffected by this heating mechanism. In this work we determine the interior heavy element mass for this population of less irradiated stransiting planets. There is a correlation between the stellar metallicity and the mass of heavy elements in its transiting planet. It appears all giant planets posses a minimum of ∼10-15 Earth masses of heavy elements, with planets around metal-rich stars being more metal-enriched. This relationship may provide a constraint on planet formation and evolution models.

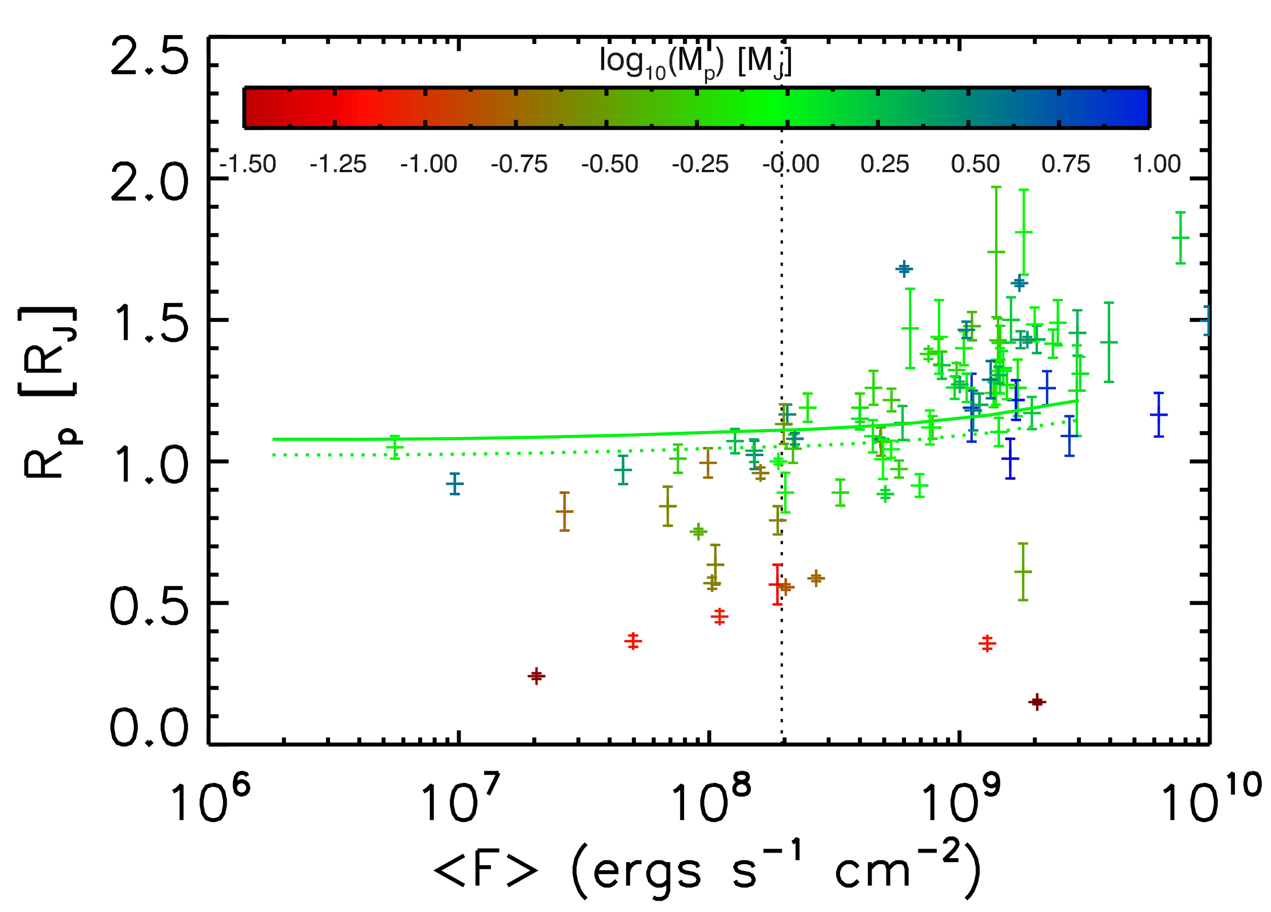

FIGURE 1: Planet radius as a function of average incident stellar flux. Planets are colored according to mass. Although the extra heating source is not certain, it is clear that it is more active at larger incident flux. We choose a cutoff of $\langle F \rangle < 2 \times 10^8$ ergs s^{-1} cm^{-2} in order to get the largest sample of planets before the range of radii significantly increase with increasing incident flux.

Methods

- Planets are modeled as a core of heavy element core with a Hydrogen/Helium envelope above
- Model atmosphere limits the net outflow of energy depending on incident flux [1]
- For all systems with $\langle F \rangle < 2 \times 10^8$ ergs s^{-1} cm^{-2}, the core mass is determined that fits the planet's observed radius.

We have found that when the heavy elements are homogeneously mixed with the Hydrogen and Helium this typically results in somewhat smaller planet radius and less metals are required in this model to explain a particular planet's radius.

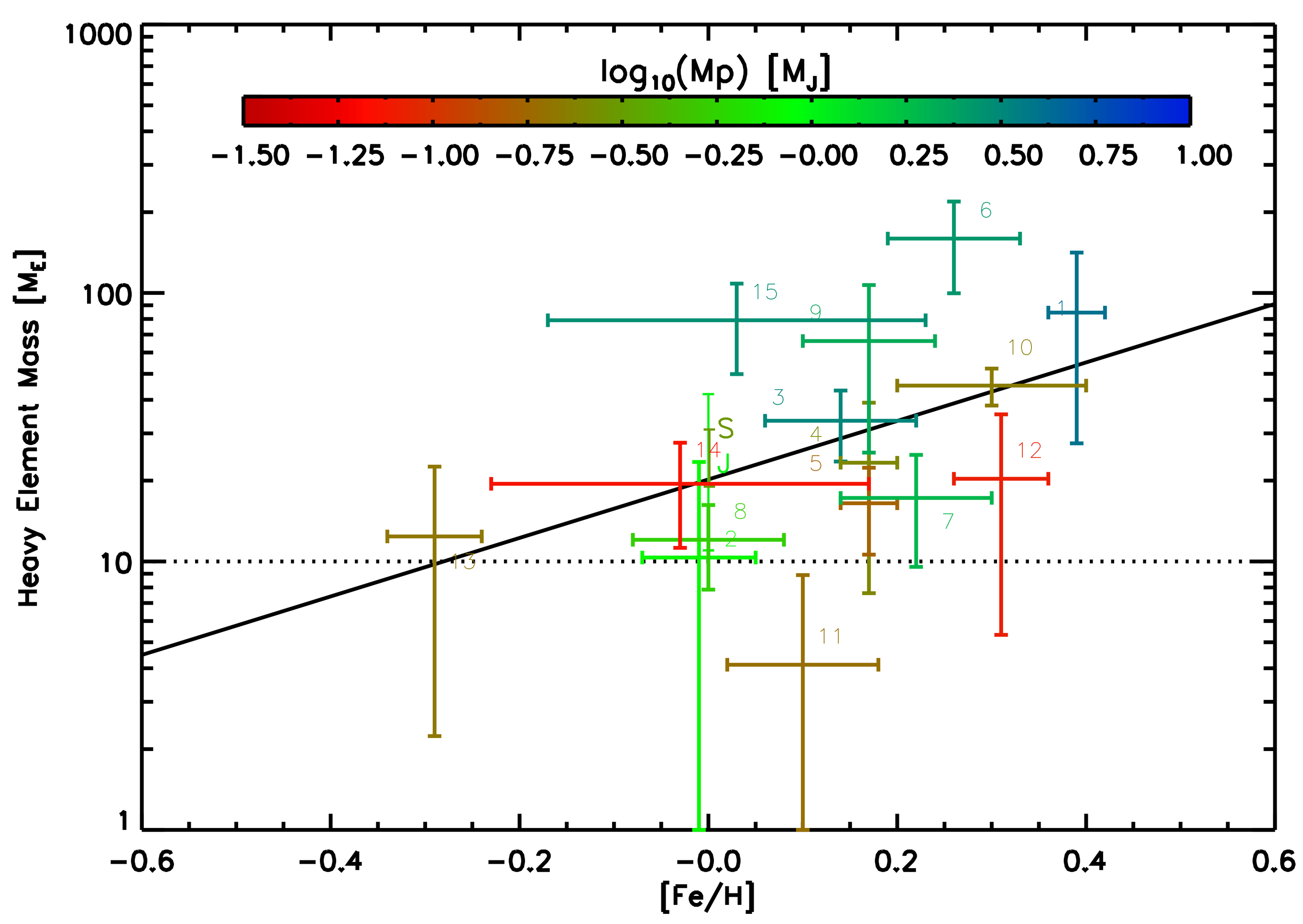

FIGURE 2: Relationship between the stellar metallicity and the model determined heavy element mass for exoplanets within our incident flux cut. Planets are similarly colored according to the planet's mass. The solid is the linear fit to $\log(M_Z)$ as a function of [Fe/H].

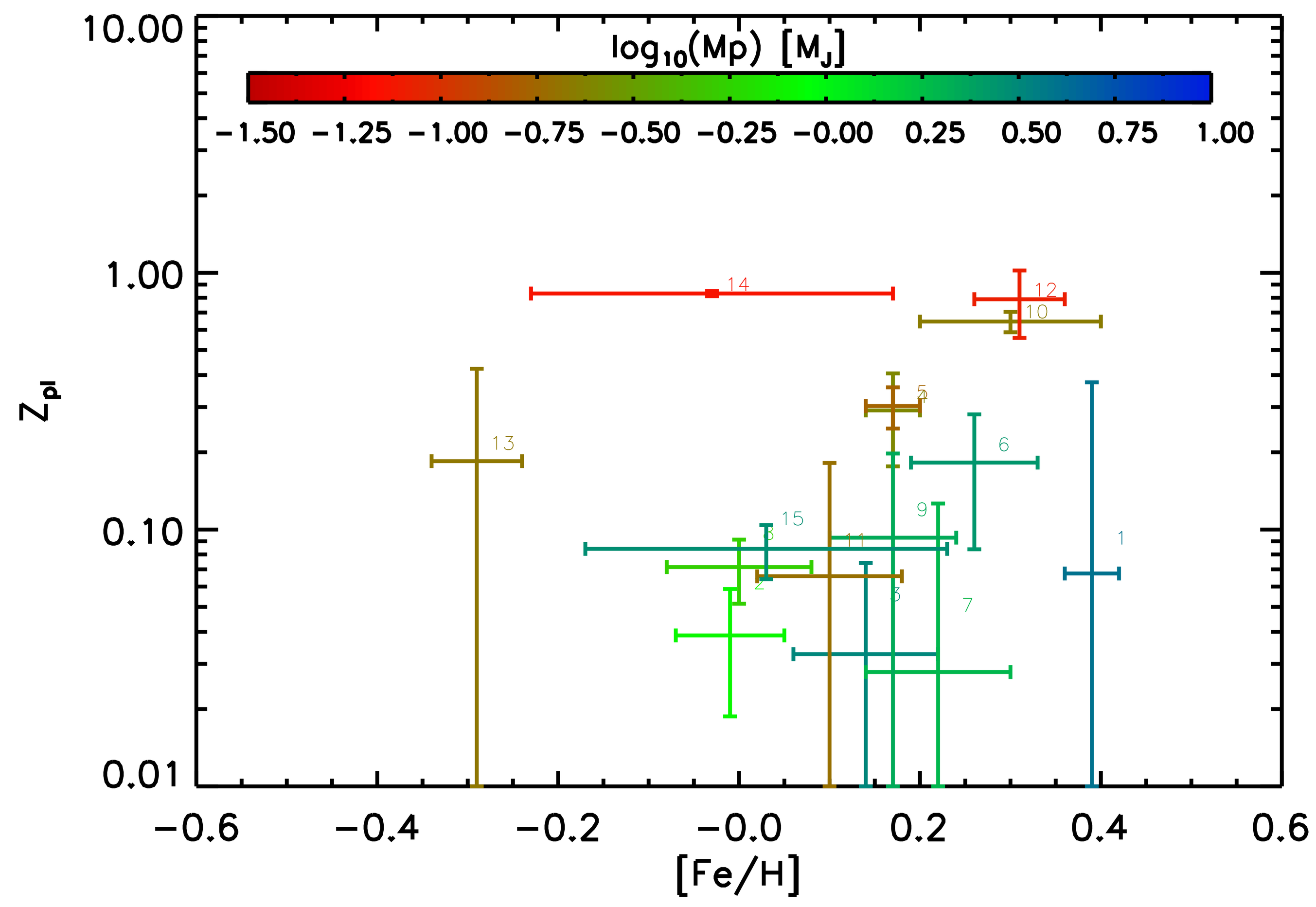

FIGURE 3: Relationship between the stellar metallicity and planet metal mass fraction. It appears that larger planets may tend to have lower metal mass fractions. Also, for a given mass planet, more metal rich systems tend to have planets with higher metal mass fractions.

Table of planet's used and their derived core mass

Number	Name	Mass	Radius	Age	$\langle F \rangle$	Core mass	References
1	HD 80606 b	3.940	1.030	7.0	1.67×10^7	81.1	[2, 3, 4, 3]
2	CoRoT-9 b	0.840	1.050	4.0	6.58×10^6	6.3	[5]
3	HD 17156 b	3.212	1.087	3.4	1.96×10^8	33.4	[6, 7]
4	Kepler-9 b	0.252	0.842	3.0	8.11×10^7	23.3	[8]
5	Kepler-9 c	0.171	0.823	3.0	3.14×10^7	14.9	[8]
6	CoRoT-10 b	2.750	0.970	2.0	5.38×10^7	159.4	[9]
7	HAT-P-15 b	1.946	1.072	6.8	1.51×10^8	17.2	[10]
8	HAT-P-17 b	0.530	1.010	7.8	8.91×10^7	12.0	[11]
9	WASP-8 b	2.240	1.038	4.0	1.79×10^8	66.2	[12]
10	CoRoT-8 b	0.220	0.570	3.0	1.22×10^8	44.7	[13]
11	HAT-P-18 b	0.197	0.995	12.4	1.18×10^8	4.1	[14]
12	HAT-P-11 b	0.081	0.422	6.5	1.31×10^8	20.3	[15]
13	HAT-P-12 b	0.211	0.959	2.5	1.90×10^8	12.4	[16]
14	GJ 436 b	0.074	0.377	6.0	4.03×10^7	19.5	[17]
15	WASP-10 b	2.960	1.080	1.0	2.10×10^8	79.1	[18, 19]

Conclusions

Previous work in determining the correlation between the metallicity of the star and the planet has required making an assumption about the heating mechanism in order to include the large radius planets [20]. The population of less irradiated giant exoplanets emprically do are not significantly affected by the unconstrained heating source. This allows us to use the density of these objects to put a constraint on the composition without making an assumption about the heating mechanism. The mass of metals or the metal mass fraction of these planets can be compared to the metallicity of the star. It appears that most planets have at least 10 M_E of heavy elements, consistent with the core accretion formation scenario. There appears to be a tendency for planets to have more metals around stars with more metals. This developing population should provide a check on planet formation models.

References

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