The Planet-Metallicity Correlation for Hot Jupiters

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[ESA/C. Carreau]
Background

• After just four hot Jupiters (51 Peg, 55 Cnc, ν And, Tau-Boo), it was observed hot Jupiter host stars appeared to be unusually metal-rich [Gonzalez 1997].

• The mean metallicity of these four hot Jupiter hosts is [Fe/H]=+0.22.
TABLE 2  Physical parameters of 51 Peg compared with those of the Sun

<table>
<thead>
<tr>
<th></th>
<th>Sun</th>
<th>Geneva photometry*</th>
<th>Spectroscopy†</th>
<th>Strömgren photometry and spectroscopy\textsuperscript{11}</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{eff}}$ (K)</td>
<td>5,780</td>
<td>5,773</td>
<td>5,724</td>
<td>5,775</td>
</tr>
<tr>
<td>log $g$</td>
<td>4.45</td>
<td>4.32</td>
<td>4.30</td>
<td>4.18</td>
</tr>
<tr>
<td>Fe/H</td>
<td>0</td>
<td></td>
<td></td>
<td>0.06\textsuperscript{‡}</td>
</tr>
<tr>
<td>M/H</td>
<td>0</td>
<td>0.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M_{\nu}$</td>
<td>4.79</td>
<td>4.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R/R_{\odot}$</td>
<td>1</td>
<td>1.29</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

M/H is the logarithmic ratio of the heavy element abundance compared to the Sun (in dex).
* M. Grenon (personal communication).
† J. Valenti (personal communication).
‡ But other elements such as Na\textsuperscript{i}, Mg\textsuperscript{i}, Al\textsuperscript{i} are overabundant, in excess of 0.20.
Origin

Gonzalez (1997) presented two origins for this correlation:

- **Self enrichment (aka pollution)** - the hot Jupiter sweeps chondritic material inwards when migrates (favoured).

- **Primordial** - giant planets form more readily in high metallicity environments.
Evidence for primordial origin

• **Santos et al. 2001** presented a volume limited sample of 43 stars from the CORALIE planet search. The [Fe/H] distribution and giant planet occurrence of this sample pointed to primordial enrichment.

• This was used to support the theory of giant planet formation via core accretion, as high primordial [Fe/H] would more readily form cores.
Correlation confirmed

• Subsequent larger studies confirmed correlation [e.g. Santos et al. 2004, Fischer & Valenti 2005, ++ others]

* K > 30 m/s
P < 4 yrs

Fischer & Valenti, 2005
The correlation for Hot Jupiters

- Hot Jupiters are intrinsically rare - from transit surveys only 0.1 to 0.4% [Gould et al. 2006, Bayliss & Sackett 2011, Howard et al. 2012]

- The vast majority (~75%) of Hot Jupiters have been discovered from ground based surveys (e.g. WASP, HATNet, HATSouth, KELT, etc).

- In this study we examine the metallicity correlation via the population of Hot Jupiters detected from wide-FOV ground-based surveys.
Advantages

• Large sample size - 174 hot Jupiters. Ground based surveys have monitored $\sim 10^6$ stars (c.f. Kepler $\sim 10^5$ stars, RV $\sim 10^3$ stars).

• Ground based surveys give a sample of Hot Jupiters free from any selection bias:
  • all stars in the FOV are monitored (no colour, spectral, activity, age cuts).
  • transit method is insensitive to planet mass.
  • transit method is insensitive to host star metallicity.
Disadvantages

• Ground based surveys do not have good [Fe/H] information about all stars monitored.
• Ground based detections do not make up a homogeneous sample - they cover different magnitude ranges and cover different galactic regions
• We are not able to (easily) recover a “fraction of stars with planet” metric.
Statistical Approach

• All Hot Jupiters with hosts V<15.5 from unbiased, wide-FOV transit surveys. Use SWEEP-Cat catalogue [Santos et al. 2013]. This gives a sample of 174 Hot Jupiters.

• Compare each detected hot Jupiter to an ensemble of stars with similar apparent magnitude and galactic coordinates using TRILEGAL Galaxy model [Girardi et al. 2005]

• Create a metric $\delta[Fe/H]$ as:

$$\delta[Fe/H] = [Fe/H]_{HJ} \, < \, [Fe/H]_{pop}$$
Raw metallicities of sample

\[ \text{[Fe/H]} = 0.08 \]
δ metalicities of sample

δ[Fe/H] = 0.20
Comparison of results

• Hot Jupiters show an $\delta[\text{Fe/H}]$ of $+0.20$ dex

• This is in remarkably close agreement to the general giant planet population:
  • $+0.21$ (Santos et al., 2003 - $e<0.3$)
  • $+0.12$ (Santos et al., 2003 - all $e$)
  • $+0.13$ (Fischer & Valenti, 2005 - all $e$)
  • $+0.18$ (Jofre et al., 2015 - subgiants)
  • $+0.15$ (Ghezzi et al., 2010 - slightly higher for Jupiter mass only)
  • $+0.20$ (Schlaufman & Gregory 2013 - Kepler gas giants)
Conclusions

• Hot Jupiters detected via ground-based transit surveys represent the best sample with which to test the planet-metallicity correlation for Hot Jupiters.

• The hot Jupiter metallicity enhancement is +0.20 dex - no different to the general population of gas giants (P<~4 years).

• The migration mechanism that led to hot Jupiters does not appear to be dependent on the metallicity environment.
Extra slides
Transiting “giant” planets
Exoplanet Densities

Bayliss et al., 2015 AJ, 150, 49.