Measuring the spin of the directly imaged sub-stellar companion GQ Lupi b

Henriette Schwarz

Ignas Snellen, Matteo Brogi, Remco de Kok, Jayne Birkby, Christian Ginski
Connection between formation and spin

[Snellen et al. 2014]
The spin of a planet arises from the accretion of angular momentum during its formation\textsuperscript{1-3}, but the details of this process are still unclear. In the Solar System, the equatorial rotation velocities and, consequently, spin angular momenta of most of the planets increase with planetary mass\textsuperscript{5}; the exceptions to this trend are Mercury and Venus, which, since formation, have significantly spun down because of tidal

An important step in the data analysis is the optimal removal of the stellar contribution along the slit, which for this class-A star consists mostly of a telluric absorption spectrum. The resulting spectra were cross-correlated with theoretical spectral templates constructed in a similar way as in our previous work on hot Jupiters\textsuperscript{10,11}, varying the planet’s atmospheric temperature pressure (T/p) profile and the abundances of carbon monoxide.
# New CRIRES observations

<table>
<thead>
<tr>
<th></th>
<th>HIP 78530 b</th>
<th>GSC 6214-210</th>
<th>GQ Lupi b</th>
</tr>
</thead>
<tbody>
<tr>
<td>K planet</td>
<td>14.1</td>
<td>14.9</td>
<td>13.3</td>
</tr>
<tr>
<td>K star</td>
<td>6.9</td>
<td>9.1</td>
<td>7.1</td>
</tr>
<tr>
<td>Angular separation</td>
<td>4.5&quot;</td>
<td>2.2&quot;</td>
<td>0.7&quot;</td>
</tr>
<tr>
<td>Age estimate</td>
<td>5 Myr</td>
<td>11 Myr</td>
<td>1 Myr</td>
</tr>
<tr>
<td>Planetary mass estimate</td>
<td>23 Mjup</td>
<td>17 Mjup</td>
<td>21.5 Mjup</td>
</tr>
</tbody>
</table>

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GQ Lupi b: a directly imaged sub-stellar companion

GQ Lupi

ESO VLT NACO June 2004

Neuhäuser, Guenther, Wuchterl, Mugrauer, Bedalov, Hauschildt
Cross-correlating with model spectra

Hot Jupiters
- Transmission spectra or thermal emission
- Fast orbital motion
  - Changing Doppler-shift of planetary lines
- No spatial separation from host

Young massive giants
- Directly imaged planets
- Slow orbital motion
  - Constant radial velocity shift relative to host
- Spatial separation from host
Data analysis: a spectrum for each slit position
CO detection, companion position
CO detection, companion position
CO & H$_2$O detection
The measured companion parameters

\[ \text{vsin(i)} = 6.0 \pm 0.8 \text{ km/s} \]
\[ \text{rv} = 2.1 \pm 0.4 \text{ km/s} \]
GQ Lupi b's CO signal is very narrow

**GQ Lupi b**
- Mass: 21.5 Mjup
- Radius: 3.5 Rjup
- Age: 0-5 Myr
- Teff: 2650 K

**Beta Pic b**
- Mass: 7 Mjup
- Radius: 1.65 Rjup
- Age: 8-20 Myr
- Teff: 1600 K
The stellar spectrum has molecular lines.

Components of the observed fstar for chip 3

<table>
<thead>
<tr>
<th>Observed spectrum</th>
<th>Atran telluric spectrum</th>
<th>Model CO spectrum</th>
</tr>
</thead>
</table>

arbitrary units
Removing stellar CO lines affects shape of planetary CO lines
Constraining the orbital parameters

LSMC constraints from astrometry on orbital elements of GQ Lupi b [Ginski et al. 2014]
Constraining the orbital parameters

\[ rv = 2.1 \pm 0.4 \, \text{km/s} \]
Constraining the orbital parameters

\[ rv = 2.1 \pm 0.4 \text{ km/s} \]
Summary

- Spin measurements of exoplanets may hold clues to the formation process
- Combining high dispersion spectroscopy and adaptive optics it is possible to measure the spin of directly imaged planets
- Molecular lines in colder stars present a challenge

- GQ Lupi b has a $v_{\sin(i)}$ of $6.0 \pm 0.8$ km/s
  - Rotates slowly, possibly because it is young and bloated