Radial Velocities in the Infra-Red

Results from a first CRIRES campaign

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TOE, 19th October 2009
Exploring the near-IR

Measuring RVs in the near-IR is interesting to:

- Observe optically faint M dwarfs;
- Explore a favorable planet-to-star contrast;
- Reduce spot’s effect on RV.

but there are some technical issues to overcome...

- Detector Properties (CMOS vs CCD);
- Atmospheric Transmission;
- Establishment of a reliable wav. calib.
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Spots mimicking Planets

Stellar line deformation creates a RV signal!
Spots mimicking Planets

**Bisector** measures the line profile and can be used to identify spots’ effect

Detectability of bisector variation decreases faster than the impact of line asymmetries on RV (Sahar & Donahue 1992)

Photometry and Ca II indicators can be used too but **none** of the three is **100% efficient**

We need a better diagnosis method!
Spots mimicking Planets

If an RV signal is created by a spot, it results from the contrast between the stellar disk and the cold spot.
Spots mimicking Planets

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If we observe in the IR, the amplitude of the effect will be significantly reduced!
Recently Setiawan et al. (2008) announced a giant planet (~10 M\textsubscript{Jup}) in a close-in orbit (0.04 A.U.). The discovery was based on FEROS RV and backed by:

- The lack of correlation between RV and BIS;
- The rotation period being estimated as smaller than the planet’s period.

But TW Hya is a slow rotator (<2 km/s) and the photometric period is hard to determine.
TW Hya: our campaign

We confirmed the optical RV orbit but we found that the amplitude of the signal depended on the correlation mask!

We used spot modeling (SOAP: Bonfils & Santos, in prep) and showed that the signal could be created by a spot.
**TW Hya: our campaign**

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**Can it be a spot?**
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CRIRES

The CRyogenic high-resolution InfraRed Echelle Spectrograph was developed by ESO and mounted on VLT UT1.

Explores the spectral range from 0.95 to 5.4 μm with a simultaneous wavelength coverage of λ/70 and provides a R of up to 100 000.

The detectors are four Aladdin III InSb arrays and a MACAO system is used to optimize the signal-to-noise ratio and the spatial resolution.

At an early stage, CRIRES was not provided with a precise wavelength reference system.
Calibrating Spectrographs

CRIRES is, by construction, stabilized in Pressure and Temperature: small IP profiles variations

Several authors have proved back in the 80’s that optical O₂ atmospheric lines were very stable, down to 5 m/s

Are there nIR equivalents that being sharp, deep and easy to identify, provide for a reliable wavelength calibration, without polluting too much our spectra?
Calibrating Spectrographs

CRIRES is, by construction, stabilized in Pressure and Temperature: small IP profiles variations

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Are there nIR equivalents that being sharp, deep and easy to identify, provide for a reliable wavelength calibration, without polluting too much our spectra?

CO$_2$ lines provide for all these characteristics, creating a ready to use, always present gas cell!
TW Hya: CRIRES

We observed TW Hya with CRIRES in the H band, domain where we could use the atmospheric CO$_2$ lines as wavelength reference.

The science observations were followed by the measurement of a RV standard, HD108309, known to be stable down to 5 m/s, to correct for unaccounted systematics.
The first data reduction yielded a clear result:

<table>
<thead>
<tr>
<th>RV [km/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.25</td>
</tr>
<tr>
<td>12.3</td>
</tr>
<tr>
<td>12.35</td>
</tr>
<tr>
<td>12.4</td>
</tr>
<tr>
<td>12.45</td>
</tr>
<tr>
<td>12.5</td>
</tr>
<tr>
<td>12.55</td>
</tr>
<tr>
<td>12.6</td>
</tr>
<tr>
<td>12.65</td>
</tr>
<tr>
<td>12.7</td>
</tr>
<tr>
<td>12.75</td>
</tr>
<tr>
<td>12.8</td>
</tr>
</tbody>
</table>

The graph shows CRIRES RV overplotted on SHL08 orbit with a 35 m/s dispersion.

Huèlamo et al. 2008, A&AL 489, 9
TW Hya: CRIRES (new results!)

Improved data reduction allowed for systematics pinpointing (such as telluric contamination) and we reached

5 m/s dispersion!

Gl86 by CRIRES (new results!)

Table 1. Orbital elements of Gliese 86 after correction of the 0.36 m s\(^{-1}\) d\(^{-1}\) linear drift of the \(\gamma\)-point.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>(P)</td>
<td>15.78</td>
<td>d</td>
</tr>
<tr>
<td>(T)</td>
<td>2451146.7</td>
<td>d</td>
</tr>
<tr>
<td>(e)</td>
<td>0.046</td>
<td>-</td>
</tr>
<tr>
<td>(V_o)</td>
<td>56.57</td>
<td>km s(^{-1})</td>
</tr>
<tr>
<td>(\omega)</td>
<td>270</td>
<td>-</td>
</tr>
<tr>
<td>(K_1)</td>
<td>380</td>
<td>m s(^{-1})</td>
</tr>
<tr>
<td>(f_1(m))</td>
<td>(8.9 \cdot 10^{-6})</td>
<td>m s(^{-1})</td>
</tr>
<tr>
<td>((O - C)^1)</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>(N)</td>
<td>61</td>
<td>-</td>
</tr>
</tbody>
</table>

\((^1)\) At \(T_0 = 2451500\) d

\((^1)\) Without the drift correction the O-C of the fit would be 13 m s\(^{-1}\)

![Graph of radial velocity vs. phase](image1.png)

Fig. 1. Phased orbital motion of Gliese 86 corrected from the long term drift. The solid line is the best fit orbit. See orbital elements in Table 1


CRIRES data reproduces well the published orbit!

Atmospheric Lines

The analysis of telluric lines present in HARPS data show they are extremely stable on the long term:

<table>
<thead>
<tr>
<th>Year</th>
<th># of points</th>
<th># of days</th>
<th># of points/day</th>
<th>time span [days]</th>
<th>photon noise [m/s]</th>
<th>σ [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>2025</td>
<td>9</td>
<td>225.0</td>
<td>73</td>
<td>1.30</td>
<td>10.4</td>
</tr>
<tr>
<td>2006</td>
<td>135</td>
<td>3</td>
<td>45.0</td>
<td>315</td>
<td>0.74</td>
<td>3.43</td>
</tr>
<tr>
<td>2007</td>
<td>146</td>
<td>11</td>
<td>13.27</td>
<td>136</td>
<td>0.48</td>
<td>3.05</td>
</tr>
<tr>
<td>2008</td>
<td>1805</td>
<td>43</td>
<td>43.16</td>
<td>134</td>
<td>0.79</td>
<td>7.96</td>
</tr>
<tr>
<td>2009</td>
<td>43</td>
<td>5</td>
<td>8.6</td>
<td>7</td>
<td>0.76</td>
<td>2.93</td>
</tr>
<tr>
<td>Total</td>
<td>4205</td>
<td>71</td>
<td>59.22</td>
<td>1587</td>
<td>1.02</td>
<td>10.7</td>
</tr>
</tbody>
</table>

Table 1: Statistics of RV determinations for all Tau Ceti data.

The measured RV variations are due to atmospheric phenomena and can be explained -- and corrected for -- using simple empirical models!
TW Hya & CRIRES: conclusions

- The probability that the CRIRES points are drawn from the announced planetary orbit is lower than $1 \times 10^{-6}$; spot theory prevails over the planet theory;
- By observing in the IR one can reduce the effects of spots on RV's;
- CRIRES can deliver accurate RV's, as the data on Gl 86 and the new reduction testify;
- Atmospheric Lines are stable down to 10 m/s on a 5 years timescale and better than that if you correct for atmospheric effects.