Spectroscopic Characterization of Planet-Host Stars

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Kepler 10 – Artistic View

Wroclaw – Poland – 24/10/2011
Outline

- Introduction in extra-solar planets detections
  - Techniques
  - Radial velocities
  - Transits
  - Limitations of detection techniques

- Precise and homogeneous spectroscopic analysis
  - Metallicity correlation
  - Lithium in Planet-hosts. Lithium depletion is connected to planets?

- Other Stuff
  - GAIA ESO-Survey
  - Caup's Research
Extrasolar Planets

All Catalogs
update: 12 October 2011

All Candidates detected

- **Candidates detected by radial velocity or astrometry**
  update: 11 October 2011
  - 527 planetary systems
  - 643 planets
  - 76 multiple planet systems

- **Transiting planets**
  update: 08 October 2011
  - 171 planetary systems
  - 184 planets
  - 14 multiple planet systems

- **Candidates detected by microlensing**
  update: 14 June 2011
  - 12 planetary systems
  - 13 planets
  - 1 multiple planet systems

- **Candidates detected by imaging**
  update: 28 September 2011
  - 22 planetary systems
  - 25 planets
  - 1 multiple planet systems

- **Candidates detected by timing**
  update: 31 August 2011
  - 9 planetary systems
  - 14 planets
  - 4 multiple planet systems

695 planets

http://exoplanet.eu
Candidates detected by imaging
update: 28 September 2011

- 22 planetary systems
- 25 planets
- 1 multiple planet systems

Fomalhaut and orbiting planet. Credit: NASA, ESA and P. Kalas (University of California, Berkeley, USA)

Direct imaging of Beta Pictoris b as it orbits its Sun. (image credit ESO)

It can detect directly the planets.

However...

It is only working for “bright” planets
- It can detect smallest and furthest planets (Earth like, even smaller)
- can also detect “runaway” planets

However...
- Detection for a given target is unique (very unlikely to observed twice
- Very rare events
With Kepler it is sensitive enough to detect “real Earths”; get the size of the planets.

However...

- Need continuous observations
- False positives can be common
51 Peg - First Exoplanet discovered around a solar-type star.

mu. Ara (HD 160691): A planetary system discover with HARPS.

- The most successful technique
- Only gets the minimum mass (no orbital inclination)
- More sensible to detect massive planets which are close to the star
Radial Velocity
Limitations on detections

The Earth produces a $10 \text{ cm/s}$ variation in the Sun

**Instrumental Limitation?**

<table>
<thead>
<tr>
<th>Observatory</th>
<th>Current Instruments</th>
<th>Radial velocity precision:</th>
<th>First Light:</th>
</tr>
</thead>
<tbody>
<tr>
<td>La Silla</td>
<td>CORAVEL</td>
<td>300 m/s</td>
<td>~1981?</td>
</tr>
<tr>
<td>OHP</td>
<td>ELODIE</td>
<td>7 m/s</td>
<td>1993</td>
</tr>
<tr>
<td>La Silla</td>
<td>CORALIE</td>
<td>3 m/s</td>
<td>1998</td>
</tr>
<tr>
<td></td>
<td>FEROS</td>
<td>25 m/s</td>
<td>1998</td>
</tr>
<tr>
<td></td>
<td>HARPS</td>
<td>1 m/s</td>
<td>2003</td>
</tr>
<tr>
<td>OHP</td>
<td>SOPHIE</td>
<td>2 m/s</td>
<td>2006</td>
</tr>
</tbody>
</table>

**Future Instruments:**

<table>
<thead>
<tr>
<th></th>
<th>ESPRESSO</th>
<th>~10 cm/s</th>
<th>2016?</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLT</td>
<td>CODEX</td>
<td>~2-3 cm/s</td>
<td>2022?</td>
</tr>
<tr>
<td>ELT</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The Earth produces a 10 cm/s variation in the Sun

Stellar Astrophysics Limitation?

Stellar oscillations:
- Periods: 5-7 min.
- Amplitudes: ~1m/s

Stellar spots:
- Can produce a false positive
- Connected with stellar activity cycles
The Earth produces a 10 cm/s variation in the Sun.

**Stellar Astrophysics Limitation?**

- **Stellar oscillations:**
  - Periods: 5-7 min.
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  - Can produce a false positive
  - Connected with stellar activity cycles

**Solution / Work Around:**

- **Observation Strategies:**
  - Observe a target for at least 15 min to cancel the oscillations
  - Observe Non Active Stars
  - Avoid young stars.

Different observations strategies can improve detections (Dumusque et al. 2010)
ExtraSolar Planets

HD10180 - a Multi-planetary System
Similar to Solar System...

Kepler 16b
The first planet orbiting a binary star

GJ876
3 planets orbiting a M star

Hot Jupiters
The first planets discovered like 51 Peg
ExtraSolar Planets Detection

![Graph showing the mass and epoch of extra-solar planets.](image)

- **Jupiter**
- **Saturn**
- **Neptune**
- **Earth**

Sérgio Sousa – Spectroscopic Characterization of Planet-Host Stars

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Spectroscopic Analysis of Planet Hosts

With the HARPS GTO (Guaranteed Time Observation) Program there are samples with hundreds of targets.

Need to derive fundamental spectroscopic parameters.

It is fundamental to have:

- Homogeneous Analysis
- Automatic Analysis
Spectroscopic Stellar Parameters Determination – Our method:

We determine $T_{\text{eff}}$, $\log g$, $[\text{M/H}]$ using a standard technique based on the excitation and ionization balance using the Equivalent Widths measurements for many iron lines.

Abundance determination is done in LTE.

Spectral Analysis done differentially to the Sun
Homogeneous Analysis

A statistical strong linelist

Improving the abundance statistics / Increasing the line list

standard procedure:

39 FeI, 16 FeII [5000Å-7715Å]

preliminary new large line list:

407 FeI, 73 FeII [4000Å-9000Å]

In the case of HARPS spectral coverage:

304 FeI, 60 FeII [3780Å-5303Å] and [5537Å-6910Å]

What about the atomic data for the lines?
Homogeneous Analysis

For a solar model (Teff: 5777 K, logg: 4.44, [Fe/H]: 0.00 dex)

Using VALD log gf we see a huge dispersion (~0.3 dex) in Fe abundance
Homogeneous Analysis

Differential analysis to the Sun

Using the Solar Spectrum

Perform a reverse analysis to compute new log gf for each FeI and FeII line in our linelist
Homogeneous Analysis

Differential analysis to the Sun

Using the Solar Spectrum

Perform a reverse analysis to compute \textbf{new log gf} for each FeI and FeII line in our linelist
Homogeneous and Automatic Analysis

Equivalent widths measurements

Problems:
- Many spectra to analyze
- “Manual” measurements are subjective

Problems in automatic measurements:
- Continuum position
- Blended Lines

IRAF – splot routine...
Homogeneous and Automatic Analysis

ARES
Automatic Routine for line Equivalent widths in stellar Spectra

**DOWNLOADS:**
- ARES
- Users
- Manual/Paper
- Support Page

**EXTRA:**
- Teff
- LR Code

**ARES**

ARES is a C++ code developed for the measurement of Equivalent Width of absorption lines in stellar spectra.

The code reads a 1D FITS spectra and fits the requested lines in order to calculate the Equivalent width.

The Code is described in the paper by S. G. Sousa, N. C. Santos, G. Israelian, M. Mayor, M. J.P.F.G. Monteiro (2007, A&A, 469, 783), where the user can see the results of tests of this code for several types of spectra.

http://www.astro.up.pt/~sousasag/ares/
Homogeneous and Automatic Analysis

Taking out systematic bad lines, checked in iron abundance analysis for the HARPS spectra sample

**Final line list:** 263 FeI, 36 FeII
Homogeneous and Automatic Analysis
Overview Sketch

- ARES Input Parameters (depend on S/N)
- Spectrum 1D (normalization not necessary)
- Linelist - FeI and FeII (~300 lines)
- Model Grid - Kurucz
- atomic data log gf computed using solar spectrum
- Interpolation Code
- MOOG
- Minimization Code based on Downhill Simplex Method
- Spectroscopic Parameters Teff, logg, [Fe/H], vtur
- EWs measurements
Comparison with other Works

Effective Temperatures - other works

(Sousa et al. 2008)
Comparison with other Works

Surface gravities

(Sousa et al. 2008)
Comparison with other Works

Metallicity [Fe/H]

- (a) [Fe/H] (Bensby) mean diff.: -0.00, nº stars: 20
- (b) [Fe/H] (Valenti) mean diff.: 0.01, nº stars: 196
- (c) [Fe/H] (Fuhrmann) mean diff.: -0.01, nº stars: 15
- (d) [Fe/H] (Santos 2004) mean diff.: 0.03, nº stars: 21
- (e) [Fe/H] (Edvardsson) mean diff.: -0.05, nº stars: 16

(Sousa et al. 2008)
The Largest Volume Limited Sample

HARPS Program 2 Volume limited - spectra quality

Fig. 1. Distribution of the signal-to-noise ratio of the final spectra compilation.

Precise Teff, log g, [Fe/H] for 582 FGK stars from the volume limited HARPS Sample
The Largest Volume Limited Sample

**Fig. 4.** Comparison between the spectroscopic derived effective temperature \( \text{T}_{\text{eff}} \) (c) and \([\text{Fe/H}]\) (d) with the ones presented in Casagrande et al. (2011) respectively.
The Largest Volume Limited Sample

CORALIE SAMPLE: 1250 stars for which 522 stars have spectroscopically derived [Fe/H]

Summary:
TOTAL: 1250+582 (1830 stars)
Volume limited
(1104 out of 1830) 60 %, with homogeneous spectroscopic determination)

Fig. 6. Comparison between the [Fe/H] derived from the CORALIE CCF and the [Fe/H] derived through our spectroscopic method.
The Largest Volume Limited Sample
[Fe/H] Distributions

Fig. 7. Metallicity distributions for the CORALIE sample (top panels), the HARPS sample presented in this work (middle panels), and the union of the two samples (bottom panels). The left panels show the full samples distribution of [Fe/H], while the center plots for each sample shows the planet host [Fe/H] distribution.
- more than 650 extra solar planets discovered.

- correlation between the presence of a giant planet and the metallicity of their host star; (Gonzalez 1997, Santos et al. 2001)

- several discovered planets in the Neptune-mass regime;

- Metallicity correlation still valid for low mass planets?

Udry et al. (2006)
The Largest Volume Limited Sample

Planet Mass distribution

number of planets

n° planets: 137

log((M_p sin i)/M_J)

10

5

0

-2

-3

1

2

0

-1

-1

A

B

C

D
The Largest Volume Limited Sample

Planet frequency dependence on most massive planet in system and [Fe/H]

<table>
<thead>
<tr>
<th>[Fe/H] bin</th>
<th>nstars</th>
<th>np</th>
<th>tnp (full)</th>
<th>np</th>
<th>tnp (A)</th>
<th>np</th>
<th>tnp (B)</th>
<th>np</th>
<th>tnp (C)</th>
<th>np</th>
<th>tnp (D)</th>
</tr>
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<tbody>
<tr>
<td>[-0.6, -0.5]</td>
<td>25</td>
<td>2</td>
<td>(3.77%)</td>
<td>2</td>
<td>(3.77%)</td>
<td>2</td>
<td>(0.00%)</td>
<td>2</td>
<td>(3.77%)</td>
<td>0</td>
<td>(0.00%)</td>
</tr>
<tr>
<td>[-0.5, -0.4]</td>
<td>81</td>
<td>1</td>
<td>(1.23%)</td>
<td>1</td>
<td>(1.23%)</td>
<td>0</td>
<td>(0.00%)</td>
<td>0</td>
<td>(1.23%)</td>
<td>1</td>
<td>(0.00%)</td>
</tr>
<tr>
<td>[-0.4, -0.3]</td>
<td>118</td>
<td>2</td>
<td>(1.69%)</td>
<td>0</td>
<td>(0.00%)</td>
<td>2</td>
<td>(1.69%)</td>
<td>0</td>
<td>(0.00%)</td>
<td>0</td>
<td>(0.00%)</td>
</tr>
<tr>
<td>[-0.3, -0.2]</td>
<td>222</td>
<td>6</td>
<td>(2.70%)</td>
<td>4</td>
<td>(1.80%)</td>
<td>2</td>
<td>(0.90%)</td>
<td>2</td>
<td>(0.90%)</td>
<td>2</td>
<td>(0.90%)</td>
</tr>
<tr>
<td>[-0.2, -0.1]</td>
<td>296</td>
<td>12</td>
<td>(4.05%)</td>
<td>11</td>
<td>(3.72%)</td>
<td>1</td>
<td>(0.34%)</td>
<td>5</td>
<td>(1.69%)</td>
<td>6</td>
<td>(2.03%)</td>
</tr>
<tr>
<td>[-0.1, 0.0]</td>
<td>336</td>
<td>14</td>
<td>(4.17%)</td>
<td>11</td>
<td>(3.27%)</td>
<td>3</td>
<td>(0.89%)</td>
<td>4</td>
<td>(1.19%)</td>
<td>7</td>
<td>(2.08%)</td>
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<tr>
<td>[0.0, 0.1]</td>
<td>291</td>
<td>21</td>
<td>(7.22%)</td>
<td>21</td>
<td>(7.22%)</td>
<td>0</td>
<td>(0.00%)</td>
<td>10</td>
<td>(3.44%)</td>
<td>11</td>
<td>(3.78%)</td>
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<tr>
<td>[-0.1, 0.2]</td>
<td>191</td>
<td>17</td>
<td>(8.90%)</td>
<td>16</td>
<td>(8.38%)</td>
<td>1</td>
<td>(0.52%)</td>
<td>4</td>
<td>(2.09%)</td>
<td>12</td>
<td>(6.23%)</td>
</tr>
<tr>
<td>[-0.2, 0.3]</td>
<td>97</td>
<td>21</td>
<td>(21.65%)</td>
<td>20</td>
<td>(20.62%)</td>
<td>1</td>
<td>(1.03%)</td>
<td>6</td>
<td>(6.19%)</td>
<td>14</td>
<td>(14.43%)</td>
</tr>
<tr>
<td>[-0.3, 0.4]</td>
<td>43</td>
<td>11</td>
<td>(25.58%)</td>
<td>11</td>
<td>(25.58%)</td>
<td>0</td>
<td>(0.00%)</td>
<td>4</td>
<td>(9.30%)</td>
<td>7</td>
<td>(16.28%)</td>
</tr>
</tbody>
</table>

Total planets: 107

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Planet formation models:

Simulated planets formed (by Core Accretion) around stars with different metal content;

(Mordasini et al. 2007)
The Largest Volume Limited Sample

- Jovian planets easier to form in metal rich environments
- Neptunian planets should be found in a wider range of stellar metallicities.
- Lower mass planets may even be preferentially found orbiting metal poorer stars.

This observational hints is supported by recent planet formation models based on the core accretion paradigm (Ida & Lin 2004; Benz et al. 2006).
More Stuff...

Lithium and planet hosts: (pdf)

GAIA ESO Survey:
Lithium and planet hosts: 

GAIA ESO Survey: (pdf)
More Stuff...

Lithium and planet hosts:

GAIA ESO Survey:
CAUP's Research

Origin and Evolution of Stars and Planets
- Star Formation and Early Evolution
- Planetary Systems
- Stellar Populations and Evolution of stars

Galaxies and Observational Cosmology
- Galaxies and Clusters
- Structure Formation, Dark Energy and Fundamental Physics

http://www.astro.up.pt
CAUP's Research:

Cosmology:
(pdf)

Stellar Evolution:

Extrasolar Planets:
http://www.astro.up.pt/exoeartths/
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Cosmology:

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