Searching for Hot Jupiters around Cool Stars

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**Theory**

Exoplanets - the hot new field

Crossfield et al, 2015

Here's Looking At You... Looking at Me?

Crossfield et al, 2015

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Exoplanets - the hot new field

Sizes of Kepler Planet Candidates
*Tots as of January 6, 2015*

- **Earth-size** (<1.25 R_☉) - 808
- **Super Earth-size** (1.25 - 2 R_☉) - 1,233
- **Neptune-size** (2 - 6 R_☉) - 1,542
- **Jupiter-size** (6 - 15 R_☉) - 260
- **Larger** (15 - 25 R_☉) - 49

Exoplanets are everywhere!

Source: NASA

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Sizes of Kepler Planet Candidates
Totals as of January 6, 2015

- Super Earth-size: 1,233
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- Larger: 49

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Exoplanets are everywhere!
But some seem to be more rare...

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How does transiting work?

Planets can transit their host stars, resulting in a dip in the star's light. This effect can be used to detect and study exoplanets. The transit method is particularly useful for detecting rocky planets similar to Earth.

The diagram illustrates the concept of transiting. The upper part shows the geometry of a transit event, with the star and planet in their relative positions. The lower part shows the flux (light) variation over time, with the transit depth and duration highlighted.

Key terms:
- Planet: reflection
- Star: radiation
- Occultation
- Inclination
- Transit depth
- Transit duration
- Limb darkening
- Geometry
- Inclination

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Why have a small project?

- **Concept**: Best candidates for transit spectroscopy
- **Planetary formation model unclear**: Only small sample sizes in other surveys

Kovacs et al., 2013
Pan-STARRS1

1.8m mirror

1.4 Gigapixels

0.248′′ / pixel

g, r, i, z, y filter

7 sq. deg. FOV

Haleakala

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42 sq. deg FOV
3+4 fields
3 years of data
1400-4000 points
42 sq. deg FOV
3+4 fields
3 years of data
1400-4000 points

dust :(

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Survey for transiting planets around cool main-sequence stars - special interest for M dwarfs

Observing time: June 2009 – October 2012 (180h)

Data in i-band

7 slightly overlapping fields  42 sq. deg FOV

4 million stars with more than a thousand of data points

~ 50,000 M dwarf targets in the FOV

ESA
Quality could be better....
Our goal

- Reliable selection of M dwarfs
- Remove red, distant giant stars
- Cope with varying amounts of extinction in the FOV

How we do it?

- SED fitting of PS1 griz+JHK (2MASS) magnitudes
- Using 6 different synthetic SED models
- Extinction fit $\rightarrow$ dustmap from Schlegel et al., 1998
- Proper motion cuts

Does it work?

- Yes! About 50,000 selected targets
PROJECT

M dwarf selection

Good host star characterization possible

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OVERVIEW

EXOPLANET THEORY

PROJECT PROPERTIES

MONTÉ-CARLO TRANSIT INJECTIONS

CANDIDATES

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Our method - transit injections

Stellar distribution → Merge → Star characterization

<table>
<thead>
<tr>
<th>Signal Creation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiply</td>
</tr>
<tr>
<td>Injection</td>
</tr>
<tr>
<td>Recover</td>
</tr>
<tr>
<td>Pan-Planets Pipeline</td>
</tr>
<tr>
<td>Repeat</td>
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</tbody>
</table>

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Results for M dwarfs

- Complete set of transit injections for all 50000 M dwarfs with 200 repetitions
- Detection efficiency of over 60% for 1d < p < 3d
- Lower efficiency of 15% for 3d < p < 10d
- Null result would mean: new upper limit of ~0.4%

Results for other main-sequence stars

- Efficiency of 15% - 10% for 1d < p < 3d
- We expect to find one Hot Jupiter per field
MONTE-CARLO SIMULATIONS  M dwarf sensitivity

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Monte-Carlo Simulations - New fraction limits

Obermeier et al. (in prep.), 2015
Confirmed brown dwarf + M dwarf system

Confirmed 16th mag M dwarf system with p = 0.74 d
Simulated Hot Jupiter around an M dwarf

Simulated HJ around a 17th mag M dwarf with p = 1.07 d

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THEORY RECAP

How does transiting work?

- Planet: reflection
- Star: radiation

Inclination

Occultation

Secondary flux

Transit duration

Transit depth

Normalized stellar flux

Transit

Limb darkening

Geometry

Inclination

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What we start with:
- Stars characterized with SED fitting + proper motion
- V-fitting algorithm used for period detection

More precise refitting with MCMC:
- Priors from SED fitting (radius, limb darkening)
- Priors from BLS fitting (transit duration, depth, period, t0)
- Determine best-fitting properties+errors

What we have:
- ~10 M dwarf Hot Jupiter candidates
- ~15 K, G, F dwarf Hot Jupiter candidates
- ~200 M dwarf eclipsing binaries
- ~15 white dwarf variable objects
M dwarf Hot Jupiter candidate

\[ p = 0.416 \text{d} \]
\[ R \sim 0.98 \text{ R}_J \]
CANDIDATES

M dwarf Hot Jupiter candidate

$p = 2.86 \text{ d}$

$R \sim 0.85 \text{ R}_J$
K dwarf Hot Jupiter candidate

\[ p = 2.66 \text{ d} \]

\[ R \sim 1.02 \text{ R}_J \]
Transit-like event in a variable 14th mag system

Normalized flux vs. phase

\[ p = 2.63 \text{ d} \]
Possible white dwarf planetary transit

Sharp transit event in a 16th mag white dwarf

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Possible white dwarf planetary transit

Complete transit features visible!

Sharp transit event in a 16th mag white dwarf

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CANDIDATES

How do we detect transits?

How will we follow up candidates?

- 10 nights at McDonald observatory (Texas)
  ➔ Reconnaissance LRS, possible RV measurement
- ~14 nights at SpeX, IRTF (Hawaii)
  ➔ Dedicated LRS/MRS for eclipsing M dwarf binaries
- ~20 nights at Wendelstein (Bavaria)
  ➔ Confirm periods
  ➔ Rule out false detections (red noise residuals)
  ➔ Improve transit shape estimate
  ➔ Record different bands
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Conclusion

- Pan-Planets is capable of detecting Hot Jupiters
- We will more accurately assess the occurrence rate
- We received time to follow up all candidates
- Next months: finish follow-up phase
- Publish!