Radial velocity surveys

Planet frequency rates and selection effects

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CfA
THE RV TECHNIQUE
The RV technique

\[ P_{pl} \]

\[ K \]
\[
K = \frac{28.4}{\sqrt{1 - e^2}} \frac{M_{\text{planet}} \sin i}{M_{\text{jupiter}}} \left( \frac{M_{\text{star}}}{M_{\text{sun}}} \right)^{-\frac{2}{3}} \left( \frac{P}{1\text{year}} \right)^{-\frac{1}{3}} \quad [m.s^{-1}]
\]
Improvement towards smaller masses

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\[ e = 0 \quad M_{\text{star}} = M_{\text{sun}} \]
Improvement towards smaller masses

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\( e = 0 \) \quad \text{and} \quad M_{\text{star}} = M_{\text{sun}}

<table>
<thead>
<tr>
<th>( P = 3.5 \text{ d} )</th>
<th>( P = 1 \text{ yr} )</th>
<th>( P = 12 \text{ yr} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>133</td>
<td>28</td>
<td>12</td>
</tr>
<tr>
<td>7</td>
<td>1.5</td>
<td>0.7</td>
</tr>
<tr>
<td>0.4</td>
<td>0.1</td>
<td>0.04</td>
</tr>
</tbody>
</table>
Improvement towards smaller masses

$$K = \frac{28.4}{\sqrt{1 - e^2}} \frac{M_{\text{planet \ sin \ i}}}{M_{\text{jupiter}}} \left(\frac{M_{\text{star}}}{M_{\text{sun}}}\right)^{-\frac{2}{3}} \left(\frac{P}{1 \text{year}}\right)^{-\frac{1}{3}} \quad [m.s^{-1}]$$

e = 0 \quad M_{\text{star}} = M_{\text{sun}}$

$$\log(M_{\text{planet \ sin \ i}}) \propto \log(K) + \frac{1}{3} \log(P)$$
Hot Jupiters
Hot Jupiters
Massive Jupiters
Hot Neptunes and Super Earths

Orbital Period [Days]
Hot Jupiters
Massive Jupiters
Jupiters
Hot Neptunes
and Super Earths

Orbital Period [Days]

First Publication Date

M_{\text{sin(i)}} [Earth Mass]

1 m/s
10 m/s
0.1 m/s

10^3
100
10
1

Hot Jupiters
Massive Jupiters
Jupiters
Hot Neptunes and Super Earths
Earth like

M_{sin(i)} [Earth Mass]
Orbital Period [Days]
First Publication Date

10 m/s
1 m/s
0.1 m/s
Active regions

a few m/s (Meunier+ 10)

~30 days

Dumusque+14
Active regions

A few m/s (Meunier+10)

~30 days

Dumusque+14
Magnetic Cycles

-5.05
-5.00
-4.95
-4.90
-4.85

Log(R'(hk)

53000
53500
54000
54500
55000
55500
56000
56500
57000

JD - 2400000 (d)

-10
-5
0
5
10

RV (m/s)

10 years

10 m/s

HARPS data
Stellar activity
Instrumental precision & Stellar signals
Atmosph. escape
Selection bias

Bright Stars

m/s precision for V < 7

less affected by stellar activity

Quiet Stars

Sampling
detection extremely sensitive to sampling
Correct for bias

- **Remove** all the detected planets from the RV measurements of a star

- **Inject a fake planet** at a given period in the RV measurement, and increase its mass until the signal is significant in a periodogram analysis.

- Detection limits for the RV measurement of a star at a given period

- Perform this analysis for **all periods**, for **all the stars** in the survey
HARPS survey
376 stars

$\text{f}_{\text{syst}} = 51 \pm 8\%$

KECK survey
166 Stars
For only 10% of the stars, the RV measurements are good enough to detect planets with masses between 1 and 5 $M_{\text{Earth}}$ and periods between 1 and 10 days.

If 10 planets have been detected in this region of the parameter space.

The unbiased occurrence rates if 100 planets, and not 10.
HARPS survey
376 stars

3 - 10 M$_E$
0 and 50 d
16 detections
20% complete
80 pl. after correction
-> 21%

Mayor+11

0 to 50 days
Occurrence rates around G-K dwarfs

Earth-mass planets are common within 50 days

Howard+12
Core accretion
Gravitational instability

Lichtenberg+15
CONSTRRAIN FORMATION SCENARIOS

Core accretion scenario

Observed population

Mordasini+12, Howard+12
Earth-mass planets are common within 50 days

What about Earth-mass planet in the Habitable Zone?
HABITABLE ZONE PLANETS AROUND M DWARFS

RV
• 3 < Msini < 10 M\textsubscript{Earth} : 0.2 HZ pl / star (Tuomi+14)
• 1 < Msini < 10 M\textsubscript{Earth} : 0.4 HZ pl / star (Bonfils+13)

TRANSIT
• 0.5 < Rpl < 1.4 R\textsubscript{Earth} : 0.5 HZ pl / star (Kopparapu +13, Dressing+13)
CHARACTERIZING PLANET COMPOSITION

RV
  Mass

TRANSIT
  Radius

Density
Composition of terrestrial planets

83% MgSiO$_3$ and 17% Fe
Composition of terrestrial planets

- Dressing+15

83% MgSiO$_3$ and 17% Fe

Limit between rocky and Gaseous planet (Rogers+15, Wolfgang+15)
Rossiter McLaughlin Effect