Sky positions of the known transiting extrasolar planets

The symbol size is larger for the brighter systems (roughly proportional to the apparent V magnitude).
Mass versus radius

planets on the left

host stars on the right
Step 1: model the transit light curve

Fit a simple geometrical model to the data

I use the Jktebop code
Step 1: model the transit light curve

Fit a simple geometrical model to the data

I use the JKTEBOP code

Derived parameters:

\[ P_{\text{orb}} \] orbital period

\[ k = r_b/r_A \] ratio of planet to star radius

\[ r_A = R_A/a \] fractional radius of star

\[ i \] inclination of the orbit
Step 2: physical properties

- Light curve: \( P_{\text{orb}} \quad r_A \quad k \quad i \)
Step 2: physical properties

- Light curve: $P_{\text{orb}}$, $r_A$, $k$, $i$
- Radial velocities:
  - stellar velocity amplitude $K_A$
  - orbital shape $e$, $\omega$
Step 2: physical properties

- **Light curve:** $P_{orb}$, $r_A$, $k$, $i$
- **Radial velocities:**
  - stellar velocity amplitude $K_A$
  - orbital shape $e$, $\omega$
- **Spectral synthesis:** stellar $T_{eff}$ and $[\frac{Fe}{H}]$
Step 2: physical properties

- Light curve: $P_{\text{orb}}$, $r_A$, $k$, $i$
- Radial velocities:
  - stellar velocity amplitude $K_A$
  - orbital shape $e$, $\omega$
- Spectral synthesis: stellar $T_{\text{eff}}$ and $[\text{Fe}/\text{H}]$
- Interpolate in stellar models:
  - find best-fitting mass for the star
  - find most likely age for the system
Step 2: physical properties

- Light curve: $P_{\text{orb}}, r_A, k, i$
- Radial velocities:
  - stellar velocity amplitude $K_A$
  - orbital shape $e, \omega$
- Spectral synthesis: stellar $T_{\text{eff}}$ and $[\frac{Fe}{H}]$
- Interpolate in stellar models:
  - find best-fitting mass for the star
  - find most likely age for the system
- Get planet mass and radius
  ⇒ surface gravity ⇒ atmosphere studies
  ⇒ density ⇒ composition and core size
  ⇒ composition and core size ⇒ formation scenario
Step 2: physical properties

- Light curve: $P_{\text{orb}}$, $r_A$, $k$, $i$
- Radial velocities:
  - stellar velocity amplitude $K_A$
  - orbital shape $e$, $\omega$
- Spectral synthesis: stellar $T_{\text{eff}}$ and $[\frac{\text{Fe}}{\text{H}}]$ (using $T_{\text{eff}}$)
- Interpolate in stellar models:
  - find best-fitting mass for the star
  - find most likely age for the system
- Get planet mass and radius
  $\Rightarrow$ surface gravity $\Rightarrow$ atmosphere studies
  $\Rightarrow$ density $\Rightarrow$ composition and core size
  $\Rightarrow$ composition and core size $\Rightarrow$ formation scenario
Homogeneous studies of transiting planets

- Light curve fit: JKTEBOP
- Limb darkening:
  - five different laws
- Contaminating light
  - constraints from high-resolution imaging

Light curve of WASP-2 (Southworth et al. 2009)
Homogeneous studies of transiting planets

- Light curve fit: JKTEBOP
- Limb darkening:
  - five different laws
- Contaminating light
  - constraints from high-resolution imaging
- Orbital eccentricity
  - constraints from RVs and occultation timings
- Numerical integration
  - deal with long Kepler and CoRoT exposure times

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- Numerical integration
  - deal with long Kepler and CoRoT exposure times
- Error analyses
  - white noise: Monte Carlo
  - red noise: residual permutation
Homogeneous studies of transiting planets

- Physical properties from extra constraint:
  - five different stellar theoretical models
  - also try eclipsing binary calibration

Comparison between stellar models and eclipsing binary star systems
Homogeneous studies of transiting planets

- Physical properties from extra constraint:
  - five different stellar theoretical models
  - also try eclipsing binary calibration

- Now done 83 transiting systems
  - CoRoT, *Kepler*, KOI, HAT, GJ, HD, TrES, WASP, XO

Homogeneous studies of transiting planets

- Physical properties from extra constraint:
  - five different stellar theoretical models
  - also try eclipsing binary calibration
- Now done 83 transiting systems
  - CoRoT, Kepler, KOI, HAT, GJ, HD, TrES, WASP, XO
- TEPCat: http://www.astro.keele.ac.uk/jkt/tepcat/
**TEPCat – homogeneous studies**

TEPCat: Homogeneous studies physical properties without errorbars

This table contains the physical properties measured for the systems studied in my series of papers on the Homogeneous studies of transiting extrasolar planets. The properties are obtained from directly measured quantities (effective temperature, metal abundance, reflex velocity amplitude, and light curve parameters) with an extra constraint that the properties of the star agree with the predictions of theoretical stellar evolutionary models.

For many of the physical properties the use of these theoretical models results in a systematic uncertainty. In such cases two sets of errorbars are given, the first of which is the statistical error and the second of which is the systematic error. I also include a reference to the Homogeneous studies paper in which the results can be found for each system.

Click here for details of the quantities and their units  
Click here for a full table (includes errorbars for each quantity)  
Click here for the table in machine-readable ASCII format  
Click here for the table in machine-readable CSV format  
Click here to return to the TEPCat main page

<table>
<thead>
<tr>
<th>System</th>
<th>Stellar properties</th>
<th>Planetary properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mass (M☉)</td>
<td>Radius (R☉)</td>
</tr>
<tr>
<td>CoRoT-1</td>
<td>0.95</td>
<td>1.131</td>
</tr>
<tr>
<td>CoRoT-2</td>
<td>1.018</td>
<td>0.907</td>
</tr>
<tr>
<td>CoRoT-3</td>
<td>1.403</td>
<td>1.575</td>
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<td>CoRoT-4</td>
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</tr>
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<td>CoRoT-5</td>
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<td>1.054</td>
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</tr>
<tr>
<td>CoRoT-7</td>
<td>0.884</td>
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</tr>
<tr>
<td>CoRoT-8</td>
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<td>0.898</td>
</tr>
<tr>
<td>CoRoT-9</td>
<td>0.960</td>
<td>0.938</td>
</tr>
</tbody>
</table>

TEPCat: Physical properties of transiting planets without errorbars

This table contains a summary of the physical properties for all known transiting extrasolar planetary systems. I include those systems for which a detailed study has been published in a refereed journal or on the arXiv preprint server. Most systems have been studied multiple times, so for these I select what I consider to be the best measurements. By necessity the results for many of the planetary systems have been assembled from multiple papers, so are not guaranteed to be internally consistent. I give a reference to the discovery paper and the paper from which most of the results were taken for each system.

Click here for details of the quantities and their units
Click here for a full table (includes errorbars for each quantity)
Click here for the table in machine-readable ASCII format
Click here for the table in machine-readable CSV format
Click here to return to the TEPCat main page

<table>
<thead>
<tr>
<th>System</th>
<th>Orbital period</th>
<th>Eccentricity</th>
<th>Semimajor axis (AU)</th>
<th>Teff (K)</th>
<th>[Fe/H] (dex)</th>
<th>Mass (Msun)</th>
<th>Radius (Rsun)</th>
<th>log(g) (cgs)</th>
<th>Density (psun)</th>
<th>Mass (Mjup)</th>
<th>Radius (Rjup)</th>
<th>Gravity (m/s2)</th>
<th>Density (pjup)</th>
<th>Equil temp</th>
<th>Discovery reference</th>
<th>Main recent reference</th>
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</thead>
<tbody>
<tr>
<td>55 Cnc e</td>
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<td>0.057</td>
<td>0.01654</td>
<td>5195</td>
<td>+0.31</td>
<td>0.905</td>
<td>0.943</td>
<td>4.43</td>
<td>0.0251</td>
<td>0.1939</td>
<td>10.65</td>
<td>0.259</td>
<td>1915</td>
<td>arXiv:1105.0415</td>
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<tr>
<td>CoRoT-1</td>
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<td>0.02538</td>
<td>5950</td>
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<td>0.95</td>
<td>1.131</td>
<td>4.311</td>
<td>0.660</td>
<td>1.03</td>
<td>1.551</td>
<td>10.65</td>
<td>0.259</td>
<td>1915</td>
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<td></td>
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<tr>
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<td>0.02854</td>
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<td>4.530</td>
<td>1.362</td>
<td>3.62</td>
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<td>1.066</td>
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<td>0.05783</td>
<td>6740</td>
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<td>1.403</td>
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<td>4.191</td>
<td>0.395</td>
<td>21.96</td>
<td>1.037</td>
<td>506</td>
<td>18.4</td>
<td>1695</td>
<td>2008A&amp;A...481L.889D</td>
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<tr>
<td>CoRoT-4</td>
<td>9.202</td>
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<td>0.00120</td>
<td>6190</td>
<td>+0.05</td>
<td>1.194</td>
<td>1.148</td>
<td>4.396</td>
<td>0.790</td>
<td>0.731</td>
<td>1.160</td>
<td>13.5</td>
<td>0.438</td>
<td>1058</td>
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<td>CoRoT-5</td>
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<td>0.09</td>
<td>0.5004</td>
<td>6100</td>
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<td>1.025</td>
<td>1.051</td>
<td>4.405</td>
<td>0.88</td>
<td>0.469</td>
<td>1.182</td>
<td>8.3</td>
<td>0.265</td>
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<td>1.043</td>
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<td>1.66</td>
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<td>2010A&amp;A...512A..14F</td>
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<tr>
<td>CoRoT-7</td>
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<td>0.01650</td>
<td>5250</td>
<td>+0.12</td>
<td>0.884</td>
<td>0.96</td>
<td>4.42</td>
<td>1.00</td>
<td>0.0220</td>
<td>0.166</td>
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<td>4.5</td>
<td>1910</td>
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<td>CoRoT-8</td>
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<td>0.0633</td>
<td>5080</td>
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<td>0.878</td>
<td>0.898</td>
<td>4.475</td>
<td>1.21</td>
<td>0.216</td>
<td>0.712</td>
<td>10.6</td>
<td>0.56</td>
<td>922</td>
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<td>CoRoT-9</td>
<td>95.274</td>
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<td>0.4027</td>
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<td>0.950</td>
<td>0.938</td>
<td>4.476</td>
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<td>0.826</td>
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<td>19.1</td>
<td>0.69</td>
<td>413</td>
<td>2010Natur.464..384D</td>
<td></td>
</tr>
</tbody>
</table>

http://www.astro.keele.ac.uk/jkt/tepcat/
TEPCat – observable quantities

TEPCat: Basic observable properties of transiting planets

This table contains basic observable quantities all known (published) transiting extrasolar planets. The quantities comprise the sky position (J2000), V magnitude, latest orbital ephemerides, and the transit duration and depth. Transiting planets are denoted with a "TEP" and transiting brown dwarfs with a "BD". The transit depth is only approximate as it varies with wavelength.

The times of mid-transit are taken from published studies, which use a range of different time conventions (and do not always clearly state which). The most common is HJD(UTC), but BJ D(UTC), HJD(TDB) and BJD(TDB) are also regularly used. The difference between HJD and BJD is only a few seconds, but the offset between UTC and TDB is currently 56.186s. A good explanation of this was given by Eastman et al. (2010PASP..122..935E). If precise timings are needed then you should refer to the reference given in the final column of the table below.

Click here for details of the quantities and their units
Click here for the table in machine-readable ASCII format
Click here for the table in machine-readable CSV format
Click here to return to the TEPCat main page

<table>
<thead>
<tr>
<th>System</th>
<th>Type</th>
<th>Right ascension</th>
<th>Declination</th>
<th>V mag</th>
<th>Transit length (d)</th>
<th>Transit depth</th>
<th>Time of mid-transit</th>
<th>Orbital period (d)</th>
<th>Ephemeris reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS Cnc e</td>
<td>TEP</td>
<td>08 52 36.13</td>
<td>+28 19 53.0</td>
<td>5.95</td>
<td>0.0734</td>
<td>0.045%</td>
<td>2455733.0087 ± 0.0012</td>
<td>0.736549 ± 0.000004</td>
<td>2012A+A...593A..28G</td>
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<tr>
<td>CoRoT-1</td>
<td>TEP</td>
<td>06 48 19.17</td>
<td>−03 06 07.8</td>
<td>13.6</td>
<td>0.10439</td>
<td>2.3%</td>
<td>2454524.6231 ± 0.0002</td>
<td>1.508966 ± 0.000006</td>
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<tr>
<td>CoRoT-2</td>
<td>TEP</td>
<td>19 27 06.50</td>
<td>+01 23 01.4</td>
<td>12.57</td>
<td>0.09446</td>
<td>3.2%</td>
<td>2454237.53556 ± 0.00021</td>
<td>1.740935 ± 0.000010</td>
<td>2010A+A...511A...3G</td>
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<tr>
<td>CoRoT-3</td>
<td>BD</td>
<td>19 28 13.27</td>
<td>+00 07 18.6</td>
<td>13.29</td>
<td>0.153</td>
<td>0.25%</td>
<td>2454283.13388 ± 0.00024</td>
<td>4.2567994 ± 0.000035</td>
<td>2009A+A...505.377T</td>
</tr>
<tr>
<td>CoRoT-4</td>
<td>TEP</td>
<td>06 48 46.72</td>
<td>−00 40 22.0</td>
<td>14.0</td>
<td>0.184</td>
<td>1.3%</td>
<td>2454141.36416 ± 0.00089</td>
<td>9.20265 ± 0.00037</td>
<td>2008A+A...488L...43A</td>
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<tr>
<td>CoRoT-5</td>
<td>TEP</td>
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<td>0.117</td>
<td>1.4%</td>
<td>2454400.19685 ± 0.00002</td>
<td>4.037962 ± 0.000019</td>
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<tr>
<td>CoRoT-6</td>
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<td>2454595.6144 ± 0.00022</td>
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<tr>
<td>CoRoT-7</td>
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<td>0.034%</td>
<td>2454398.0769 ± 0.00015</td>
<td>0.853590 ± 0.000006</td>
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<td>0.7%</td>
<td>2454390.03311 ± 0.00078</td>
<td>6.21381 ± 0.00057</td>
<td>2011MNRAS.417.2166S</td>
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<tr>
<td>CoRoT-9</td>
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<td>13.246 ± 0.00022</td>
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</table>

http://www.astro.keele.ac.uk/jkt/tepcat/
ON THE DETERMINATION OF THE ORBITAL ELEMENTS OF ECLIPSING VARIABLE STARS. I

BY HENRY NORRIS RUSSELL

§ 1. Statement of the problem.—Bauschinger, in his exhaustive work on the determination of orbits, remarks concerning the problem of determining the elements of the orbit and the dimensions and brightness of the component stars of an eclipsing variable from the observed light-curve:¹ “Der Zusammenhang zwischen den Grössen-, Formen- und Helligkeitsverhältnissen der Körper und den Elementen der elliptischen Bahn einerseits und der Lichtkurve anderseits ist aber ein so komplizierter, dass man eine allgemeine Theorie wohl kaum aufstellen kann, sondern die Lösung von Fall zu Fall den vorliegenden Verhältnissen anpassen muss.”

It is the purpose of the present discussion to show under what circumstances, and to what degree, this problem may be regarded as determinate (in view of the limited accuracy of photometric observations), and to develop formulae and tables which make the solution of the problem, when it is determinate, a simple matter.

In the most general case, the number of unknown quantities to be determined is considerable. The relative orbit will in general be eccentric, and the two components of the system unequal in size and brightness. They may present the appearance of disks not uniformly illuminated, but darkened toward the limb, and may also be elongated toward one another by their mutual attraction, and brighter on the side receiving the radiation of the companion than on that remote from it.

For a complete specification of such a system we must therefore know at least r3 quantities, as follows:

<table>
<thead>
<tr>
<th>Orbital Elements</th>
<th>Eclipse Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-major axis</td>
<td>Radius of larger star</td>
</tr>
<tr>
<td>Eccentricity</td>
<td>Radius of smaller star</td>
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<td>Longitude of periastron</td>
<td>Light of larger star</td>
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</table>