Binary Population Models of PLATO fields

Ulrich Kolb
Department of Physical Sciences
Outline

• **Binary systems**
  – false positive avoidance
  – binary statistics exploitation

• **Lessons from Kepler**
  – constrain binary properties at formation
  – create synthetic target list from synthetic KIC
    • synthetic EB sample
    • asteroseismic binaries

• **Exploratory models for PLATO fields**
Lessons from Kepler

• ~2500 EBs in http://keplerebs.villanova.edu

• Full synthetic population (Farmer, Kolb & Norton 2013)
  – create synthetic Kepler Input Catalog (KIC): 450,000 stars
  – reproduce target selection: 150,000 stars

• Synthetic eclipsing binary sample (Farmer & Kolb 2014)
  – select EBs
  – create light curves
  – run Kepler pipeline to extract catalog parameters
Stellar parameters in synthetic KIC
SCP-derived (colour) vs real (grey)

- demonstrates non-linear bias in stellar parameters derived from Stellar Classification Program (SCP)

Farmer, Kolb & Norton 2013
Target-selected synthetic sample

Generate **synthetic image** to determine S/N for each star

map synthetic stars onto Kepler CCD

use pixel response function and focal plane geometry

determine optimum aperture
Target selection

Boosts main-sequence stars by 75% → 80%
Suppresses evolved stars by 25% → 20%

<table>
<thead>
<tr>
<th>Type</th>
<th>Pre</th>
<th>Post</th>
<th>Relative difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS &amp; MS</td>
<td>68.1%</td>
<td>74.8%</td>
<td>+9.8%</td>
</tr>
<tr>
<td>GB &amp; MS</td>
<td>11.7%</td>
<td>6.3%</td>
<td>-46%</td>
</tr>
<tr>
<td>WD &amp; MS</td>
<td>8.0%</td>
<td>8.5%</td>
<td>+6.3%</td>
</tr>
<tr>
<td>CHe &amp; MS</td>
<td>5.7%</td>
<td>5.5%</td>
<td>-3.5%</td>
</tr>
<tr>
<td>WD &amp; GB</td>
<td>3.3%</td>
<td>1.7%</td>
<td>-49%</td>
</tr>
<tr>
<td>WD &amp; CHe</td>
<td>2.0%</td>
<td>1.85%</td>
<td>-7.5%</td>
</tr>
<tr>
<td>GB &amp; GB</td>
<td>0.28%</td>
<td>0.17%</td>
<td>-39%</td>
</tr>
<tr>
<td>Total number</td>
<td>215,814</td>
<td>110,084</td>
<td>-49%</td>
</tr>
</tbody>
</table>
Kepler’s eclipsing binaries

Catalog  http://keplerebs.villanova.edu/

Secondary eclipse depth $> 10^{-4}$

<table>
<thead>
<tr>
<th></th>
<th>detached</th>
<th>Semi-detached</th>
<th>contact</th>
<th>ellipsoidal</th>
<th>unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q0/1 44 days</td>
<td>52%</td>
<td>8%</td>
<td>25%</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>1879 v1 Psra et al 2011</td>
<td>977</td>
<td>150</td>
<td>470</td>
<td>131</td>
<td>130</td>
</tr>
<tr>
<td>Q0-Q2 125 days</td>
<td>58%</td>
<td>7%</td>
<td>22%</td>
<td>6%</td>
<td>7%</td>
</tr>
<tr>
<td>2165 v2 Slawson et al 2011</td>
<td>1261</td>
<td>152</td>
<td>469</td>
<td>137</td>
<td>147</td>
</tr>
</tbody>
</table>

current v3 (2014; beta) contains 2646 systems
here: consider only $1 \, \text{d} < P < 40 \, \text{d}$, use v2, and exclude contact systems
Kepler’s eclipsing binaries
Farmer & Kolb 2014

• How to make a synthetic Kepler EB sample:
  – generate EB sample in Kepler field
  – compute synthetic light curves with noise
  – determine if eclipses are detectable & receive EB flag
  – compute EB parameters using Kepler EB pipeline

• EB pipeline  Prša et al 2008, 2011
  – re-sample light curve with set of polynomials
  – fit model using neural network – EBAI
  – requires training set – 35,000 light curves
  – bias?
EB period distribution
for different initial mass ratio distributions $n(q) \sim q^s$

**Figure 4v12:** The period distribution of the synthetic binaries at different points in the pipeline for the $s=y$ model. The IPD is the initial period distribution for all binaries in the synthetic input catalogue, while PDPD is the present day period distribution of all binaries in the synthetic catalogue. The EB period distribution is also shown for the detached and semi-detached systems.

**Figure 4v13:** Filled histogram: the period distribution of the Kepler EB catalogue for detached and semi-detached systems with period between 1.4 days. Coloured lines: the period distribution for different IMRD values of $s$ for detached and semi-detached systems with periods between 1.4 days averaged over 1 year run. Representative 1 standard deviation uncertainty bars are shown.

**Kepler EB catalog**

![Graph showing period distribution for different initial mass ratio distributions $n(q) \sim q^s$.](image)
Fig. 13.— Period distribution for the 259 confirmed companions. The data are plotted by the companion detection method. Unresolved companions such as proper motion accelerations are identified by horizontal line shading, spectroscopic binaries by positively sloped lines, visual binaries by negatively sloped lines, companions found by both spectroscopic and visual techniques by crosshatching, and CPM pairs by vertical lines. The semimajor axes shown in AU at the top correspond to the periods on the x-axis for a system with a mass-sum of 1.5 $M_\odot$, the average value for the pairs. The dashed curves show a Gaussian fit to the distribution, with a peak at $\log P = 5.03$ and standard deviation of $\sigma \log P = 2.28$. 

- $s = \text{Raghavan}$
- $s = \log \text{flat a}$
reconstructed period distribution at birth
Asteroseismic binaries

• Binaries with detectable solar-like oscillation spectra from both components
• How many should Kepler field deliver?

Miglio, Chaplin, Farmer, Kolb, Girardi, Elsworth, Appourchaux, Handberg 2014
Asteroseismic binaries

- predominantly have
  - mass ratio near unity
  - two giants
- of order 200 expected
Exploratory study on selected synthetic fields
Rowden, Farrell, Farmer & Kolb 2014

• fields centered at longitude $l = 65\ \text{deg}$
  – 10 deg wide strip, latitude $5\ \text{deg} < b < 55\ \text{deg}$
  – 1 deg x 1 deg square

• focus on shallow eclipses with $m_V < 16$ and binary blends with $m_V < 23$

$$\Delta m_{\text{blend}} = -2.5 \log(\text{transit depth})$$
Eclipsing binaries

- Undetectable
- Recognisable binaries
- Potential false positives
Contribution by different binary classes

**Rarer classes**

- AGB
  - $P_{\text{orb}} \geq 10^3 \, \text{d}$
- Core helium burning
  - $P_{\text{orb}} \geq 30 \, \text{d}$
- Neutron stars
- White dwarfs

**More common classes**

- Main sequence
- RGB

Distribution of 80 representations of a test field, $M_V \leq 16.0$, $b = 5.5^\circ$-54.5$^\circ$, $l = 59.5^\circ$-70.5$^\circ$. 
Always detached

Present mass transfer

Presently detached

Previous mass transfer

Distribution of 80 representations of a test field, $M_V \leq 16.0$, $b = 5.5^\circ - 54.5^\circ$, $l = 59.5^\circ - 70.5^\circ$. 
False Positives: Shallow Eclipsing Binaries

Average number of systems in 20 simulations, $M_V \leq 16.0$, $b = 5.5^\circ$-$54.5^\circ$ (1$^\circ$ bins), $l = 64.5^\circ$-$65.5^\circ$. Measured secondary eclipse depth $< 0.00001$. 
False Positives: Blends

Average number of systems in 20 simulations, $M_V \leq 26.0$, $b = 5.5^\circ-54.5^\circ$ ($1^\circ$ bins), $l = 64.5^\circ-65.5^\circ$. Measured secondary eclipse depth $< 0.00001$. 
Conclusions

• **Population synthesis** is vital tool for **survey** science
  – adaptation to survey characteristics crucial and difficult

• **Kepler Binaries**
  – EB period distribution constrains *period distribution at formation*
  – about 200 asteroseismic binaries expected to emerge – constrain *mass ratio distribution at formation*
  – (EBAI output subject to artefacts and bias, need bespoke re-analysis of all 2500 EB)

• **PLATO 2.0**
  – need well-defined selection criteria for PIC/target list
  – bright false positives can be excluded on basis of all-sky catalogues
  – blend contribution down to $m_V = 23$ requires statistical approach
  – blend and EB statistics is rich hunting ground for constraining binary processes