Recovering the inclination distribution of transiting exoplanets

Ross Church
Department of Astronomy and Theoretical Physics
Lund University

With Anders Johansen and Melvyn B. Davies

(astro-ph: 1206.6898)
Fundamental Question

Consider a planetary system with two transiting planets $2t$.

It could have planets that do not pass in front of our line of sight and hence which we do not see $3p2t, 4p2t, 5p2t$.

What can we say about the number of planets and their mutual inclinations from the transit data alone?
Does a planet transit?


\[ P(\text{transit}) = \frac{R_*}{a} \]
Do multiple planets transit?

"Flat" system

\[ P(\text{transit}) = \frac{R_\ast}{a_{\text{max}}} \]
Do multiple planets transit?

“Warm” 3p system
Do multiple planets transit?

“Hot” 3p system
Transit probability ratios

As (intrinsically 3-planet) systems become hotter:

\[ \frac{N(2t)}{N(3t)} \text{ increases} \]
\[ \frac{N(1t)}{N(3t)} \text{ increases} \]
\[ \frac{N(1t)}{N(2t)} \text{ increases} \]
Application: Kepler 16-month sample

We consider just 1t, 2t and 3t systems (plus some other criteria to ensure a clean sample)

Kepler data from Batalha et al. (2012)
What if all planetary systems are multiple?

We build a sample of intrinsically 3-planet (“3p’”) systems.

Observe them from randomly chosen directions and see how many 1t, 2t, 3t systems we see.

Use observed 3t systems as templates.

One free parameter: the distribution of inclinations.
Results

Increasing inclination spread
**Results**

- **Increasing inclination spread**
- **Maximum possible inclination spread**

Graph showing a linear relationship between $2t/3t$ and $lt/3t$. The graph indicates an increasing trend as $lt/3t$ increases, with a peak at the 'Kepler' point.
Excess of large, single planets

\[
\frac{P}{\text{days}} \quad R/R_E
\]

1p, 2p, 3p
Possible causes of the "Kepler dichotomy"

- Sample contamination
  e.g. Fressin et al. (2013)

- Intrinsic dynamical instability at higher mass
  Johansen et al. (2012)

Formation process?

Post-formation scattering?
Summary

Transit photometry alone strongly constrains planetary inclinations

Multiple planetary systems are mostly flat

Planetary systems containing a close, large planet form a separate, different population