The case of the bright multiple system Kepler-410

"What asteroseismology can do for exoplanets"

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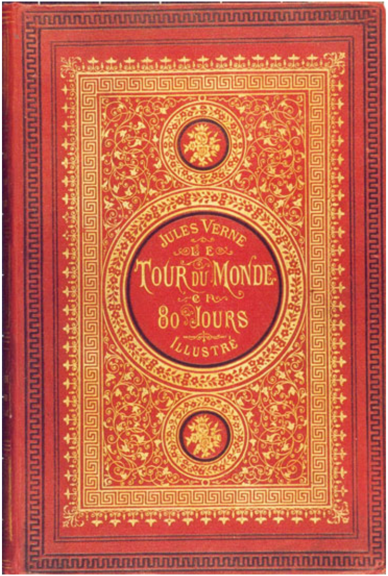
M. N. Lund, V. Silva Aguirre, T. Arentoft, H. Kjeldsen, S. Albrecht, W. J. Chaplin, H. Isaacson, M. G. Pedersen, J. Jessen-Hansen, B. Tingley, J. Christensen-Dalsgaard, C. Aerts, T. L. Campante and S. T. Bryson

Van Eylen et al. 2014: ApJ 782:14

July 2014

Le Tour du monde en quatre-vingts jours



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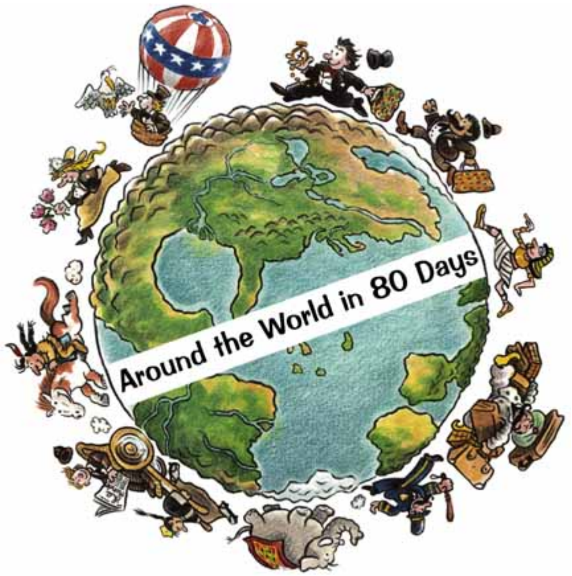

Le Tour du monde en quatre-vingts jours

How to find a planet in 15 minutes

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2. **Benchmark systems**:
   - bright stars
   - well-characterized stellar parameters (e.g. asteroseismology)
   - well-characterized planetary parameters
   - dynamics: eccentricities, TTVs, obliquities

How to find a *particularly interesting* planet

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and learn everything about it

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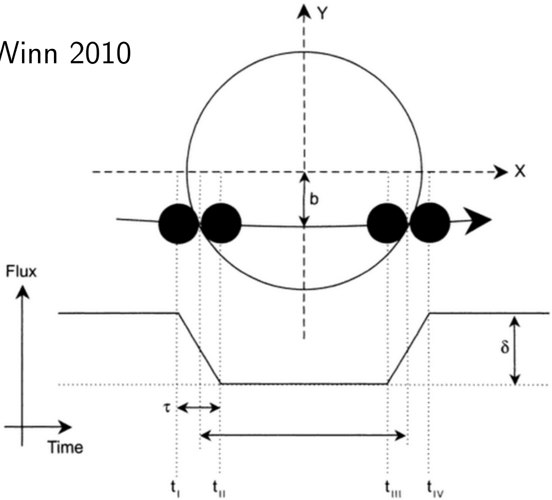
in 15 minutes!

Exoplanetary transit

Winn 2010



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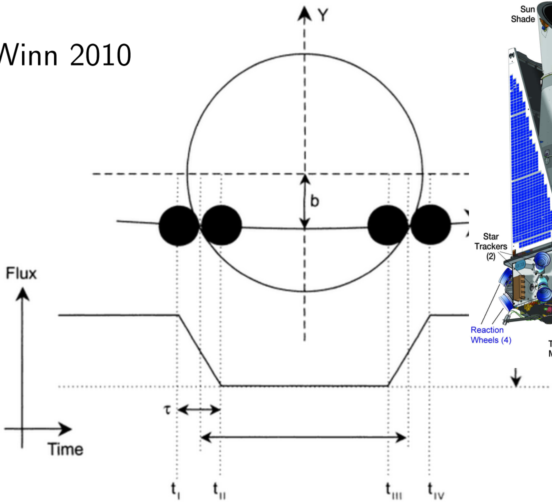
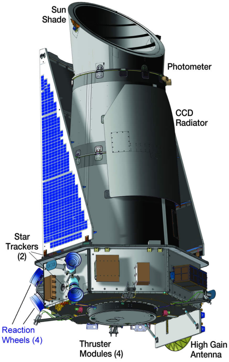
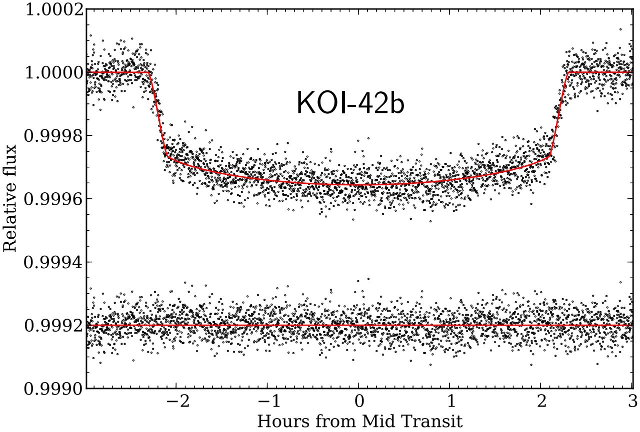


Kepler



Step 1: planetary candidate



- 2 Earth radii, 17 day period, magnitude = 9.4

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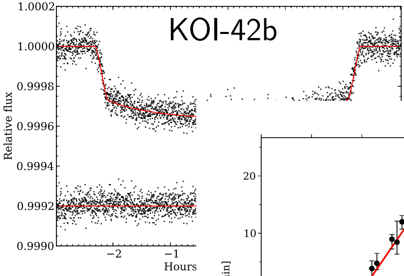

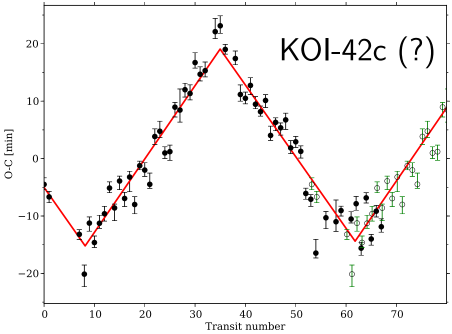

Transit timing variations indicate (at least) one more non-transiting planet

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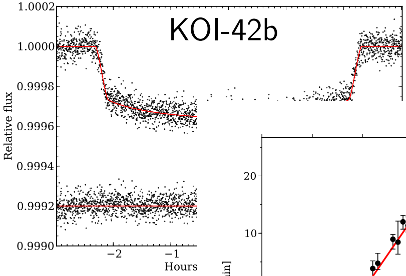
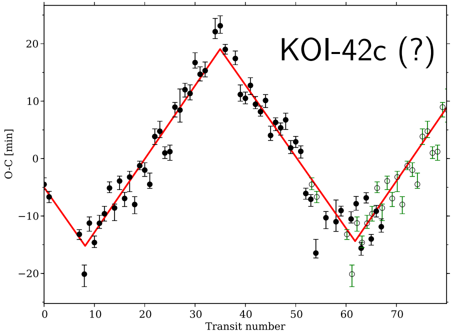


KOI known for years!



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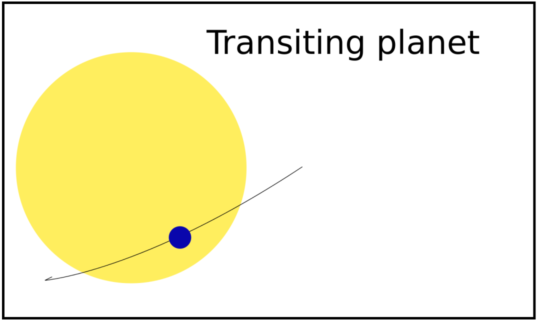

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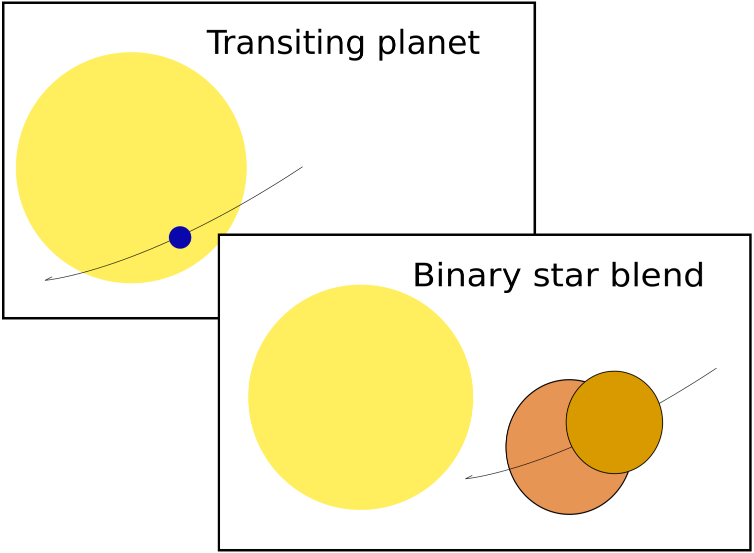

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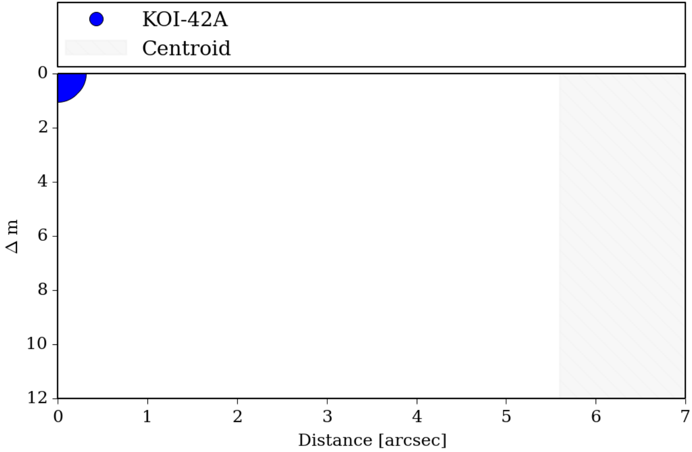

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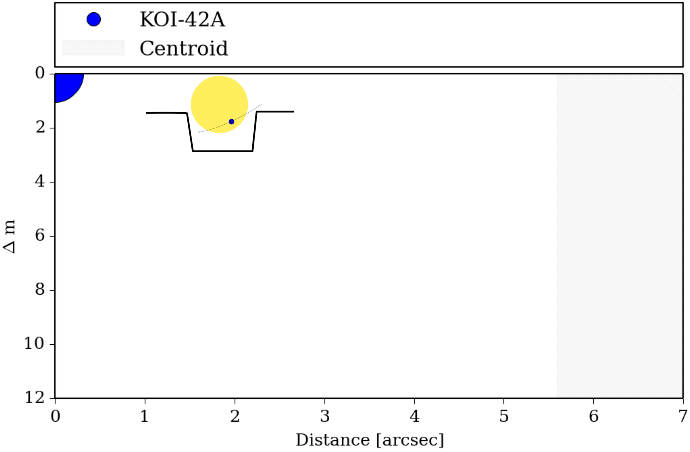

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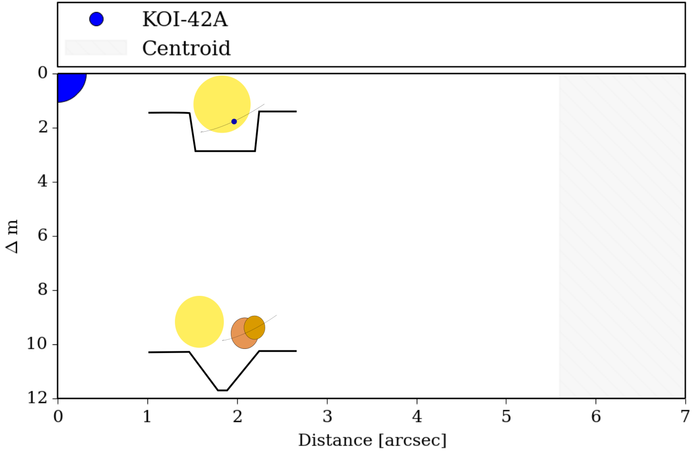

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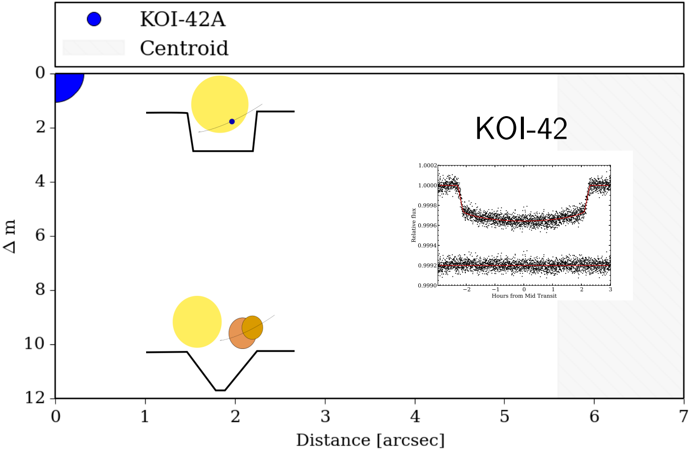

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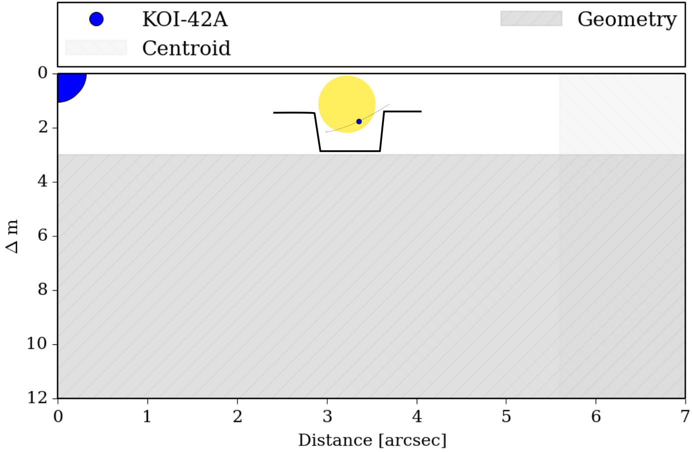

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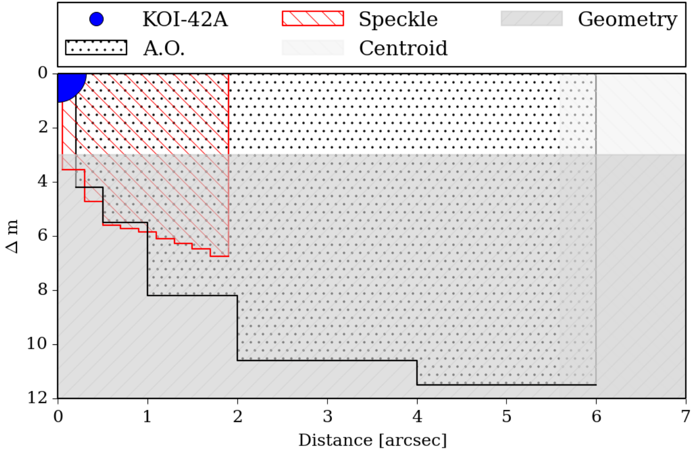

A.O.: Adams et al. 2012, Speckle: Howell et al. 2011

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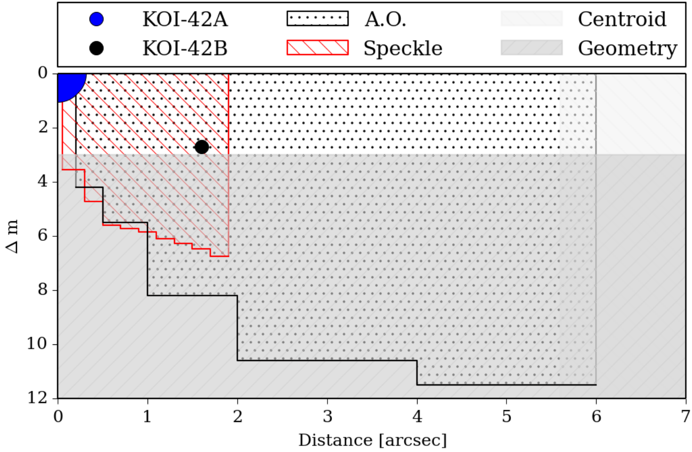

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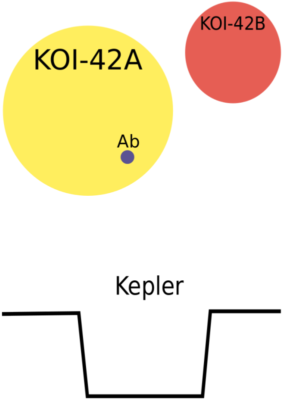
KOI-42A b or KOI-42B b?

KOI-42A b
small planet
diluted by $\approx 10\%$



KOI-42B b
larger planet
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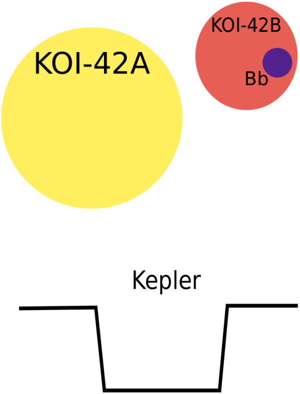

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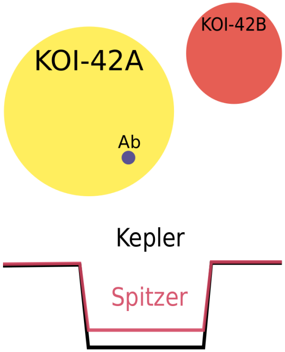

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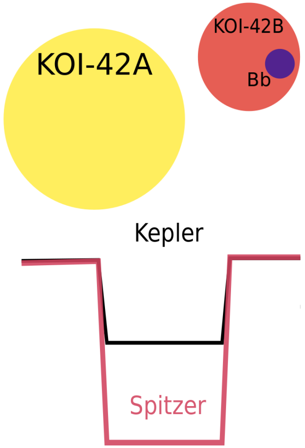
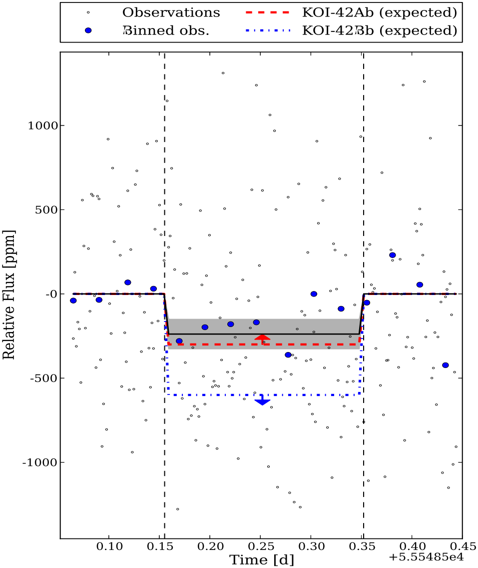
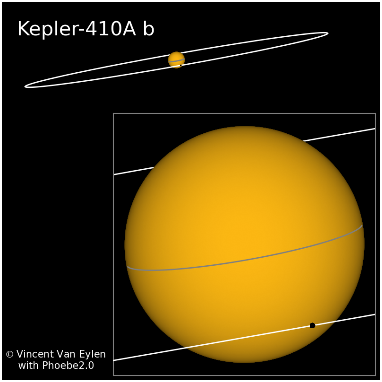


Planetary transit (Spitzer 4.5μm)



See also, e.g.:
Fressin et al. 2011 (Kepler-10c)
Ballard et al. 2014 (Kepler-93b)

We found a planet!



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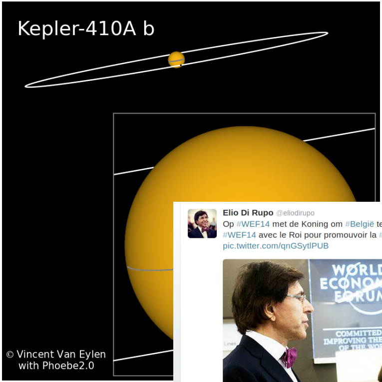
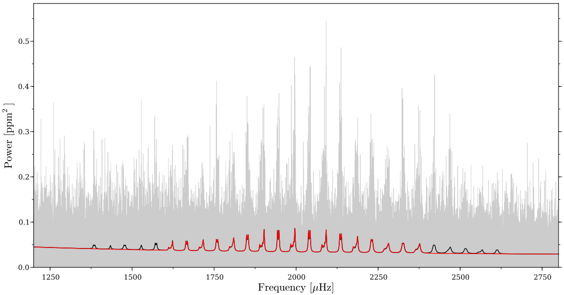


Asteroseismology: global stellar parameters

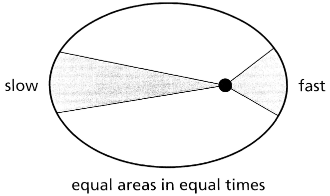


Comparison with models gives stellar parameters, e.g.:

$M_\star = 1.1214 \pm 0.033\ M_\odot$
$R_\star = 1.352 \pm 0.010\ R_\odot$
$\text{age} = 2.76 \pm 0.54$ Gyr

Eccentricities

- With radial velocities, full orbits can be measured, including eccentricity (large planets only)
- Transits do not give full orbits, but transit duration can be used as a proxi for eccentricity, using Kepler's laws:



Eccentricities

Kepler's law:

$$P^2 = \frac{4\pi^2 a^3}{G(M_\star + M_\mathrm{p})} \Rightarrow M_\star \approx \frac{4\pi^2 a^3}{GP^2}$$

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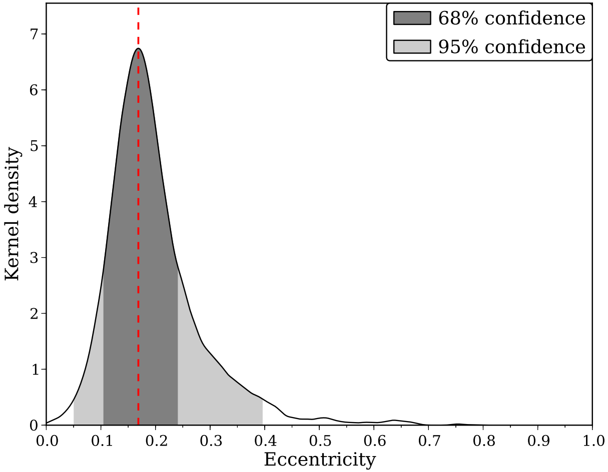
Inverted argument: **stellar density is known**:

$\Rightarrow$ find eccentricity from transit!

(e.g. Tingley et al. 2011, Dawson and Johnson 2012)

$\Rightarrow$ asteroseismology: $\rho_\star = 0.693 \pm 0.009$ g cm^{-3}

Eccentricity posterior



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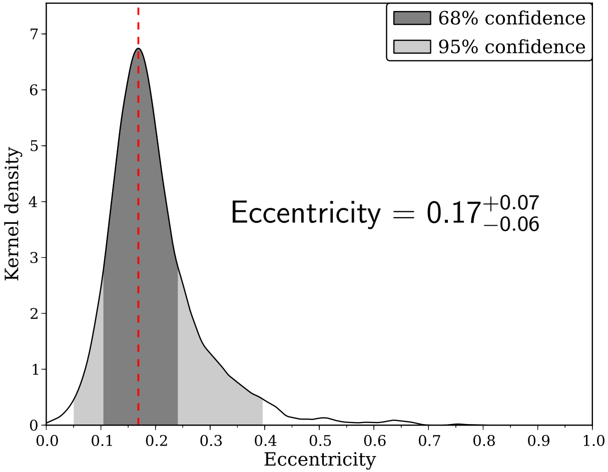
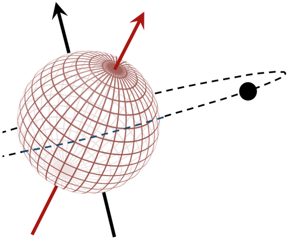


Stellar obliquity



Hot Jupiters display a wide range of obliquities, e.g.:
Winn et al 2010
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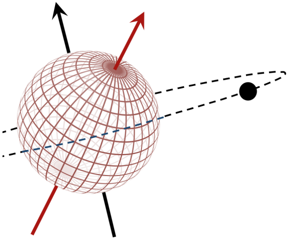
Due to planetary migration?
Or primordial misalignment of star-disk?

Stellar obliquity



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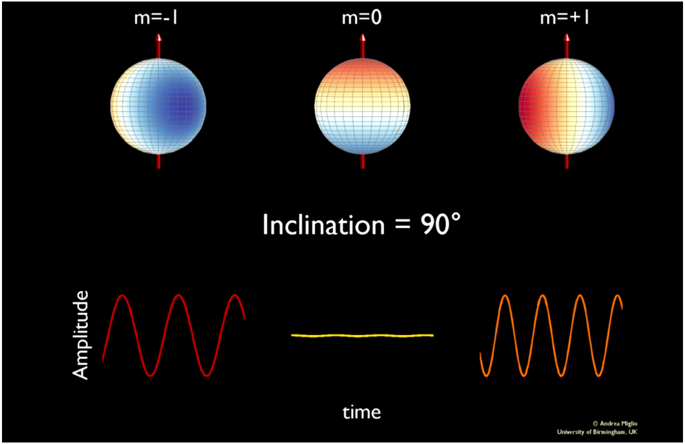
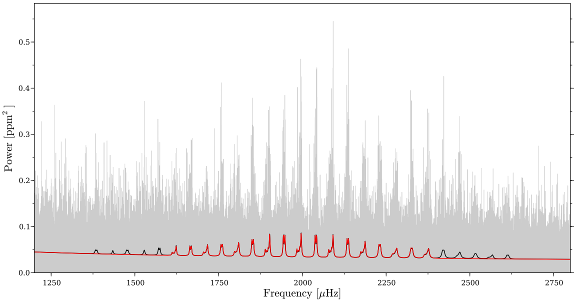
$\Rightarrow$ Observe obliquity of multi-planet systems

Rotational Splitting



Courtesy by Andrea Miglio

Rotational splitting: inclination and rotation



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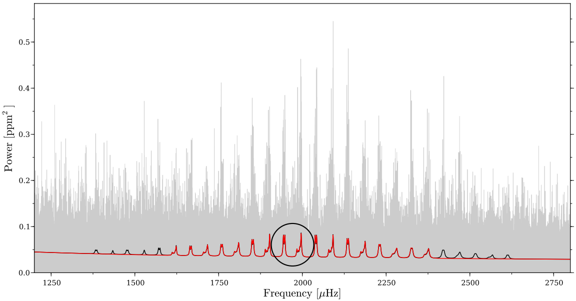

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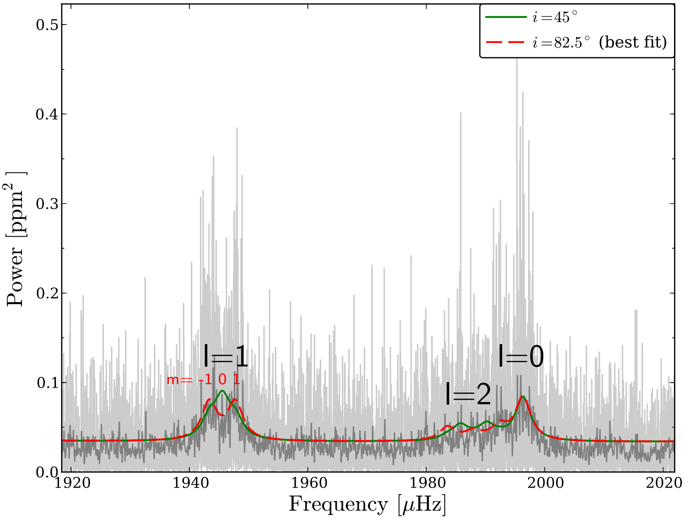

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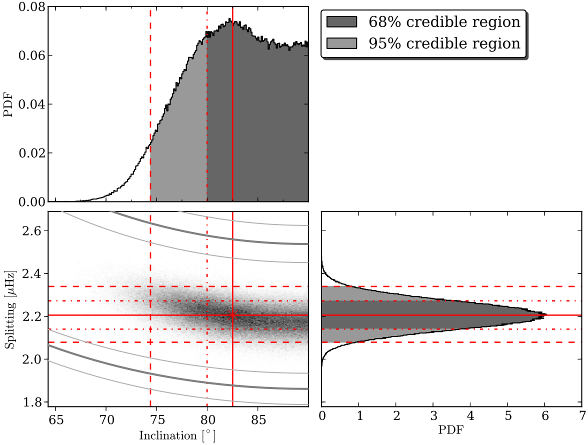

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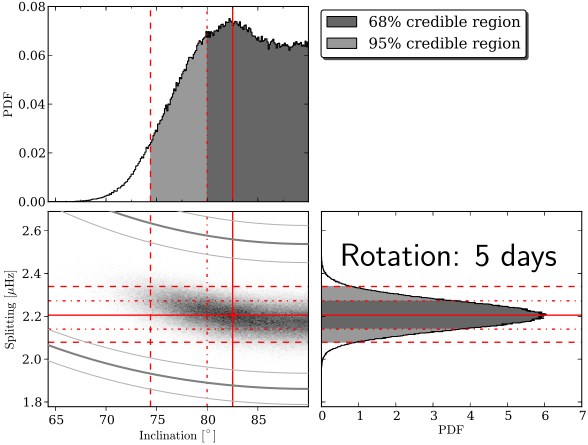
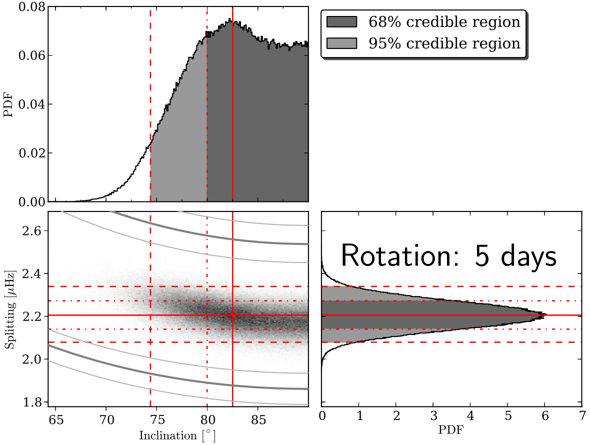


Inclination and rotation

$i = 82.5(-2.5, +7.5)^\circ$



Multi-planet systems have low obliquity?

Stellar inclination from asteroseismology:

- Kepler-410A: [80° - 90°]

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- KOI-94: $-6 + 13 - 11^\circ$ (Hirano et al. 2012) and $-11 \pm 11^\circ$ (Albrecht et al. 2013)
- Kepler-25: $7 \pm 8^\circ$ (Albrecht et al. 2013)

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But: Inclination Kepler-56: $47 \pm 6°$ (Huber et al. 2013) and 55 Cnc e (Bourrier and Hébrard 2014): $\lambda = 72 \pm 12°$

Conclusions

Find a *really interesting* planet...

- Candidate known for years, finally validated!
- Bright star ($V = 9.4$), small planet
- Multi-planet system: non-transiting planet(s) from TTVs

and learn (almost) everything about it...

- Precise stellar parameters (asteroseismology)
  $\Rightarrow$ precise planetary parameters
- Stellar density (asteroseismology)
  $\Rightarrow$ planetary eccentricity
- Stellar inclination (asteroseismology)
  $\Rightarrow$ obliquity

... in 15 minutes!

Extra slides

Parameters

Stellar parameters	**Kepler-410A**
Mass [$M_\odot$]	1.214 ± 0.033
Radius $R_\star$ [$R_\odot$]	1.352 ± 0.010
log g [cgs]	4.261 ± 0.007
ρ [g cm^{-3}]	0.693 ± 0.009
Age [Gyr]	2.76 ± 0.54
Luminosity [$L_\odot$]	2.72 ± 0.18
Distance [pc]	132 ± 6.9
Inclination $i_\star$ [$^\circ$]	$82.5^{+7.5}_{-2.5}$
Rotation period*, $P_{\rm rot}$ [days]	5.25 ± 0.16

Planetary parameters	**Kepler-410A b**
Period [days]	17.833648 ± 0.000054
Radius $R_{\rm p}$ [$R_\oplus$]	2.838 ± 0.054
Semi-major axis a [AU]	0.1226 ± 0.0047
Eccentricity e	$0.17^{+0.07}_{-0.06}$
Inclination i_p [$^\circ$]	$87.72\ ^{+0.13}_{-0.15}$