“What asteroseismology can do for exoplanets”

The case of the bright multiple system Kepler-410

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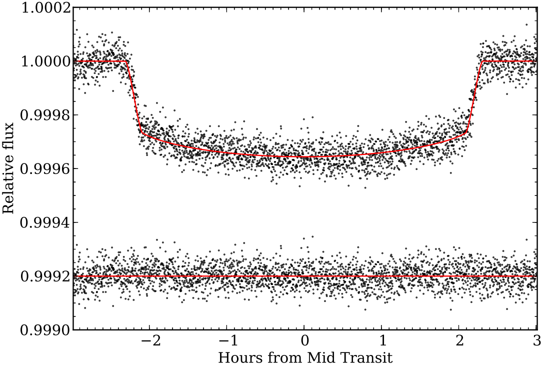
What can asteroseismology do?

1. **Characterisation** of the planet through characterisation of the host star
2. **Obliquity** through determination of the stellar inclination
3. **Eccentricity** of (small) planets from photometry alone using accurate stellar densities

KOI-42b (Kepler-410A b)



Van Eylen et al. 2014, ApJ

Excellent candidate:

- Kp = 9.4
- 4 years of Kepler short-cadence observations

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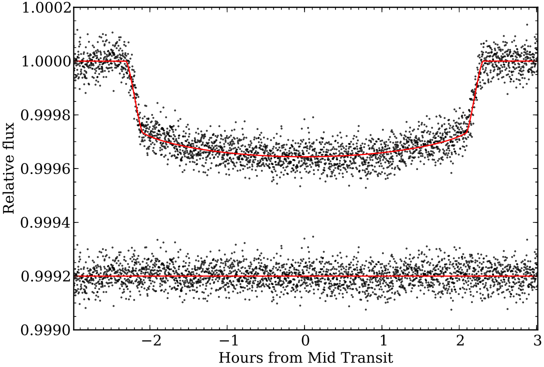

Van Eylen et al. 2014, ApJ

Excellent candidate:

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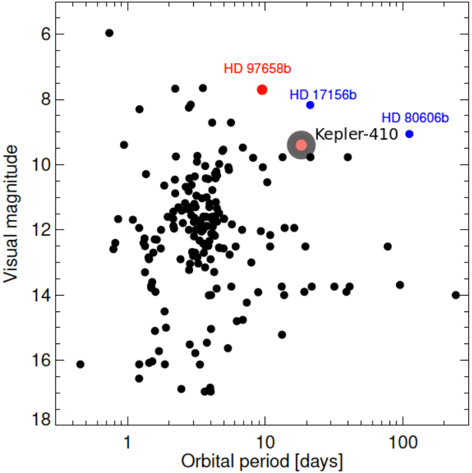
- 4 years of Kepler short-cadence observations

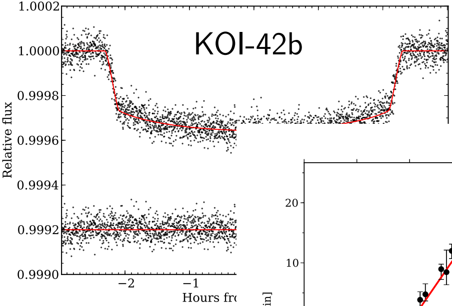
Small planet candidate (2.8 $R_\oplus$) in a 17 day period
$\Rightarrow$ RV amplitude $\propto$ 1 m/s: outside of range!

KOI-42b (Kepler-410A b)

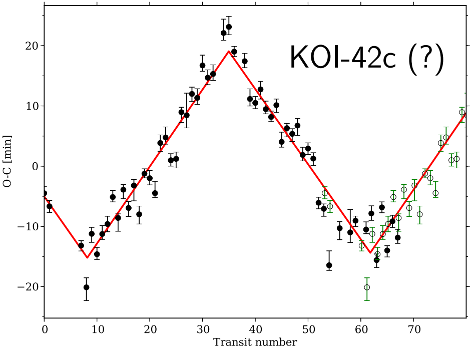


Adapted from Dragomir et al. 2013

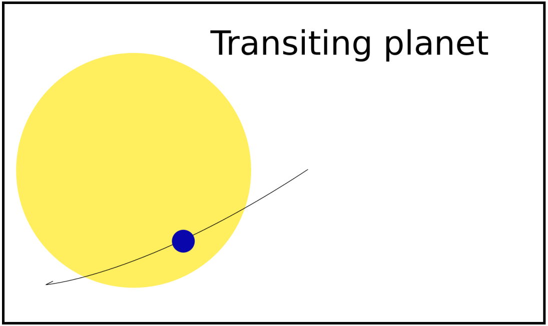
Transit timing variations



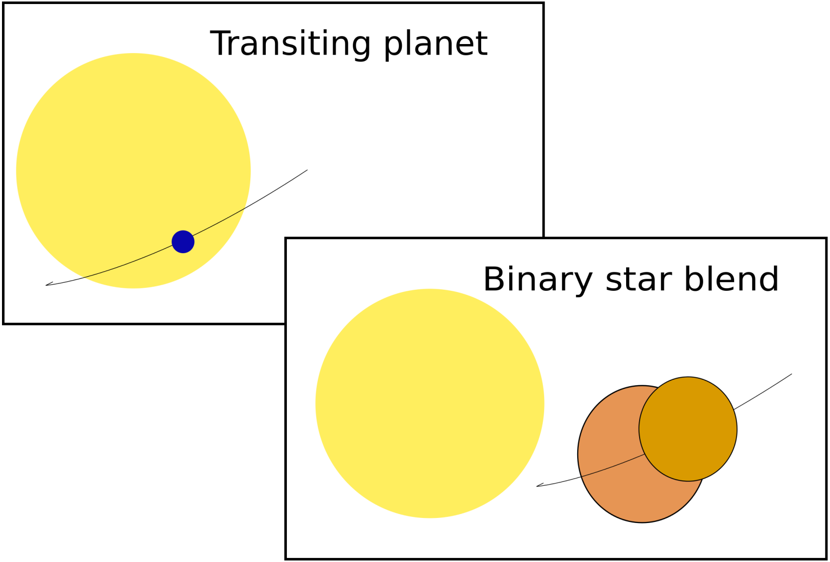
One or more non-transiting planets

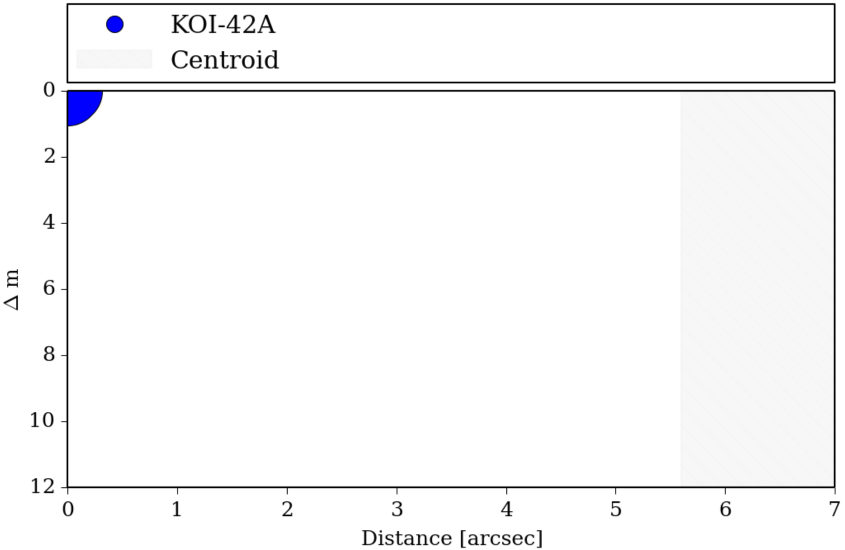


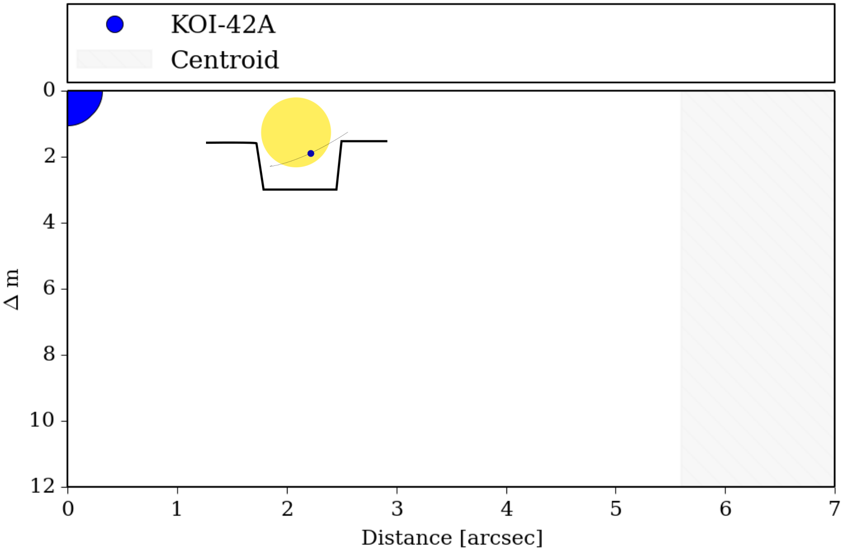
Planetary validation



Planetary validation




KOI-42A
Centroid
0
2
4
6
8
10
12
Δ m
0
1
2
3
4
5
6
7
Distance [arcsec]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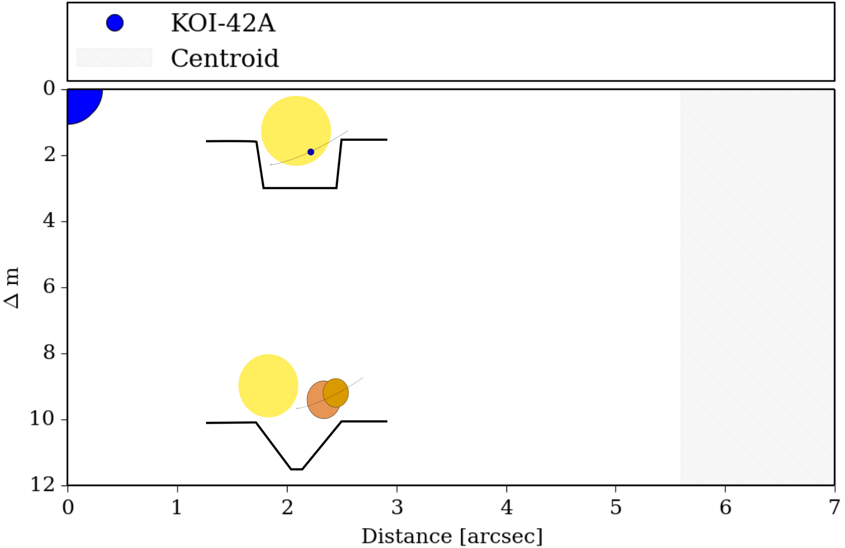

KOI-42A
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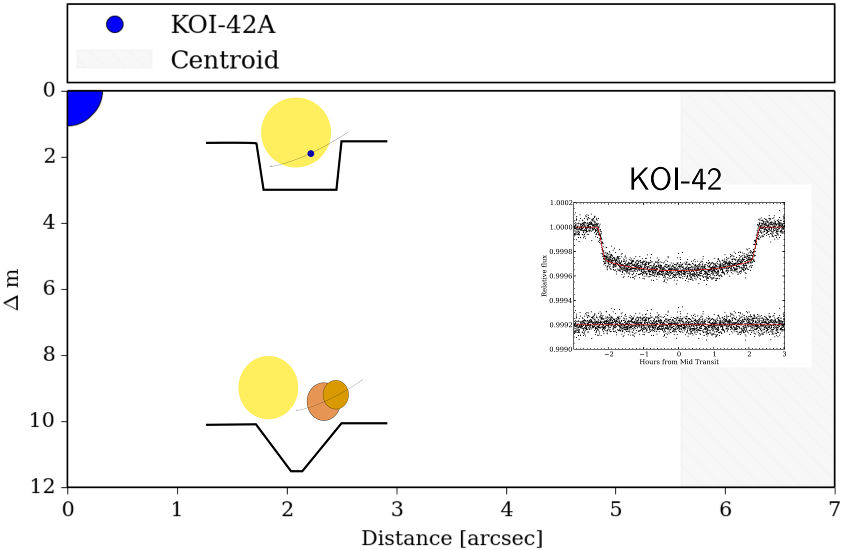
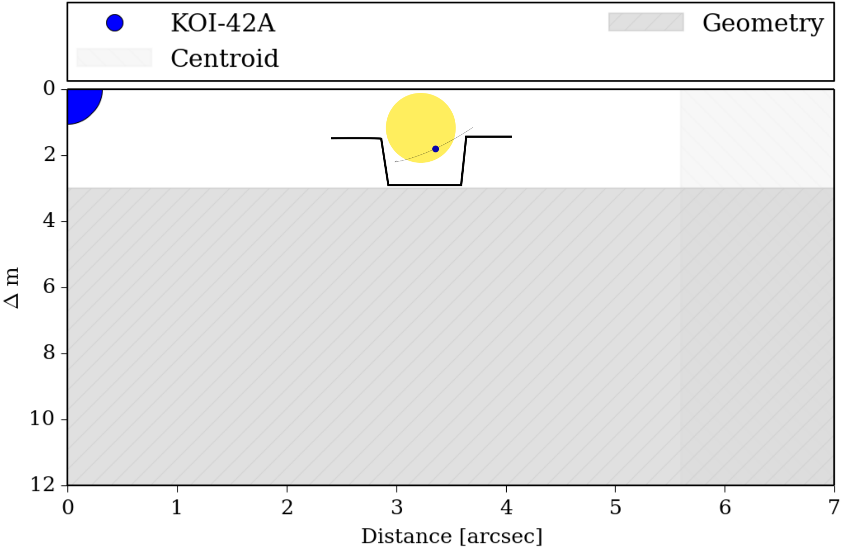

KOI-42A
Centroid
Δ m
Distance [arcsec]
KOI-42
Relative flux
Hours from Mid Transit


KOI-42A
Centroid
Geometry
0
2
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8
10
12
Δ m
0
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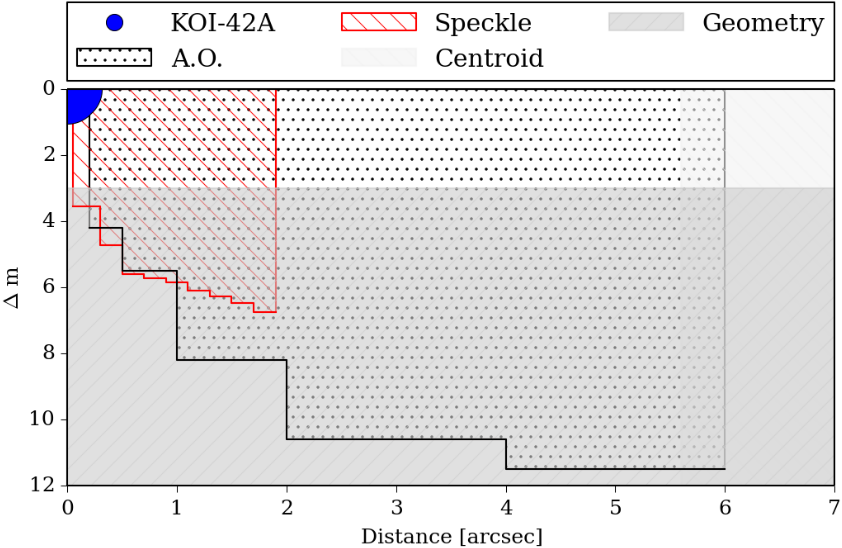
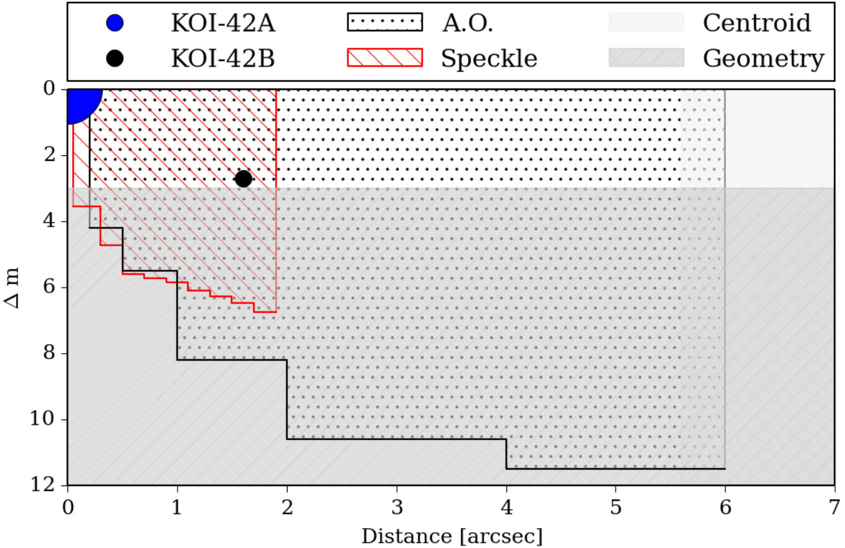


A.O.: Adams et al. 2012, Speckle: Howell et al. 2011



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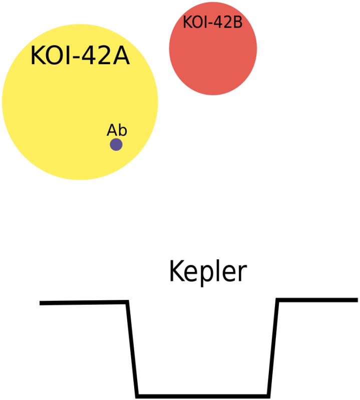
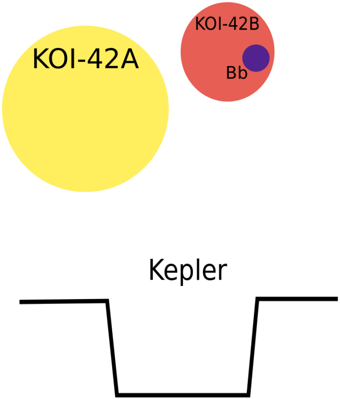
KOI-42A b or KOI-42B b?

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



KOI-42B b
larger planet
diluted by $\approx 90\%$

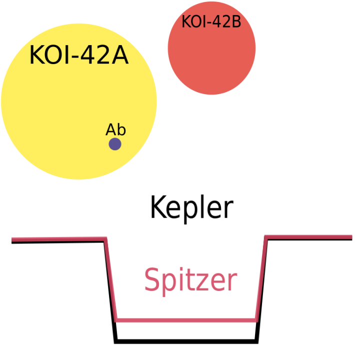


KOI-42A b or KOI-42B b?

KOI-42A b

small planet

diluted by ≈ 10%



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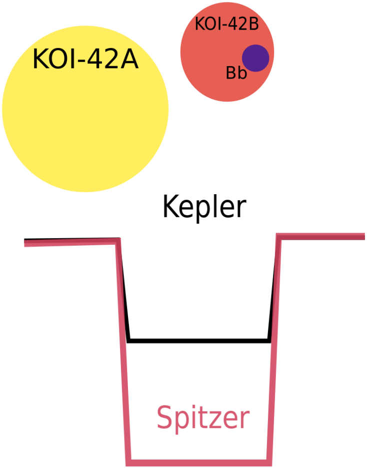
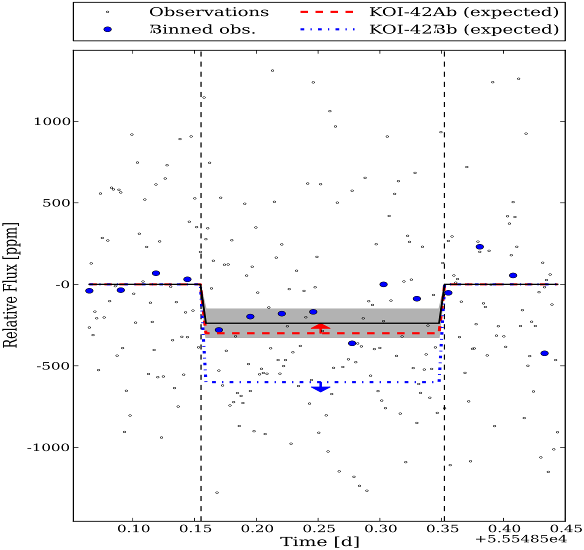


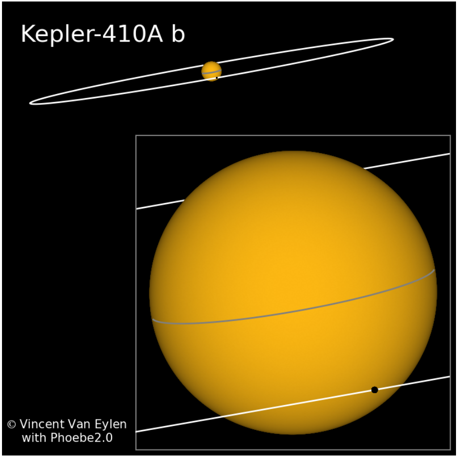
Planetary transit (Spitzer 4.5μm)



Van Eylen et al. 2014

Spitzer heritage archive
P.I.: David Charbonneau

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


Kepler-410A b
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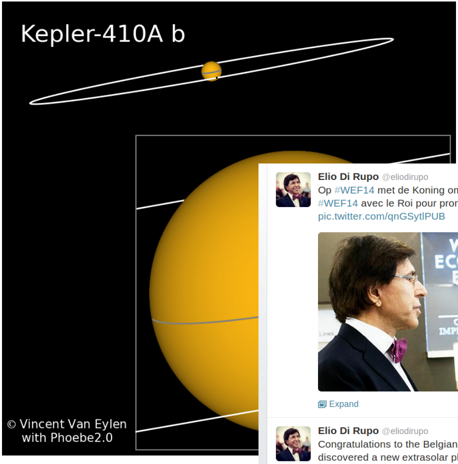
Kepler-410A b
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Elio Di Rupo @eliodirupo 51m
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Mijn felicitaties aan de Belg Vincent Van Eylen die met zijn team een nieuwe extrasolaire planeet heeft ontdekt! #Belgiantalent
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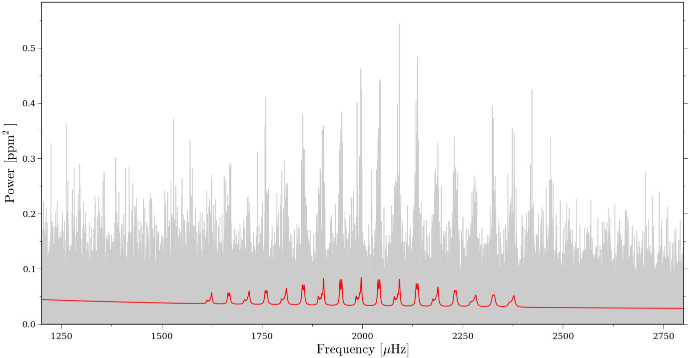
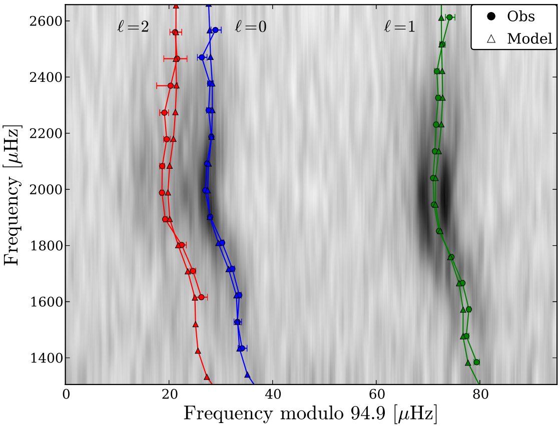
1. Characterisation of star and planet

Time series ⇒ power spectrum of oscillation frequencies



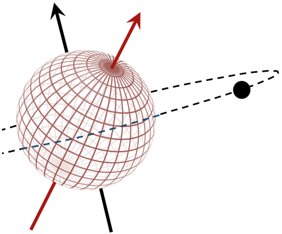
"Echelle diagram": global stellar parameters

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



2. Obliquity through stellar inclination

Courtesy Josh Winn



Hot Jupiters display a wide range of obliquities, e.g.:

Winn et al. 2010
Schlaufman 2010
Hébrard et al. 2011
Albrecht et al. 2012

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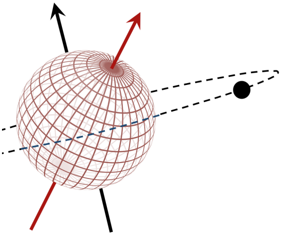

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- Planetary migration?

  (e.g. Rasio & Ford 1996, Matsumura et al. 2010, Fabrycky & Tremaine 2007)

- Primordial star-disk misalignment?

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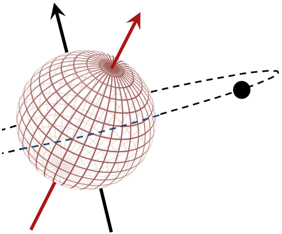

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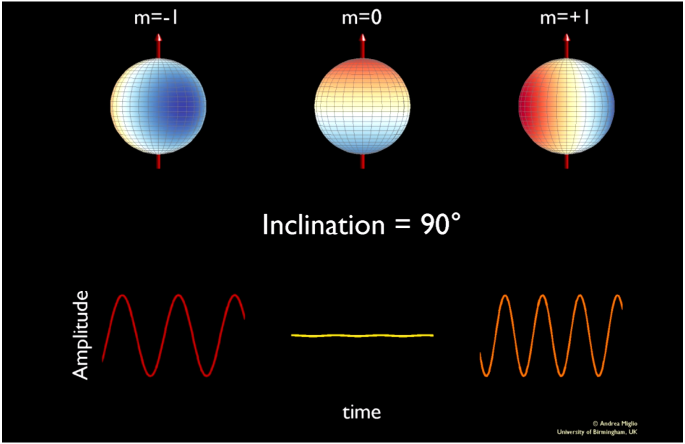
$\Rightarrow$ Obliquity measurements in multi-planet systems

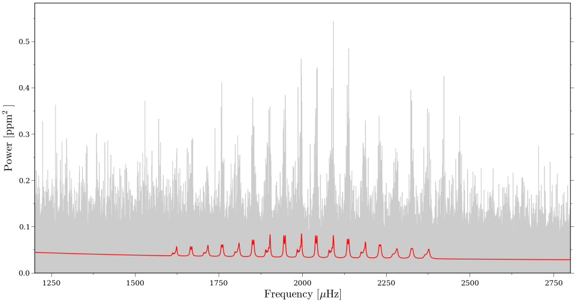
Rotational Splitting

Oscillation frequencies “split” due to stellar rotation



Courtesy by Andrea Miglio

Rotational splitting: inclination and rotation



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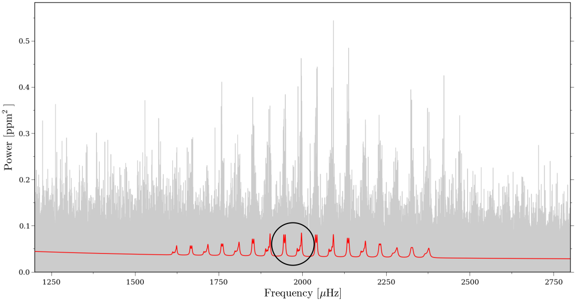

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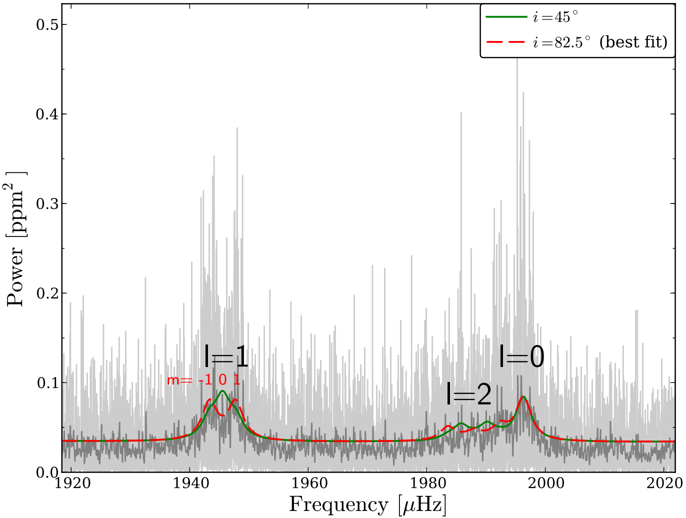

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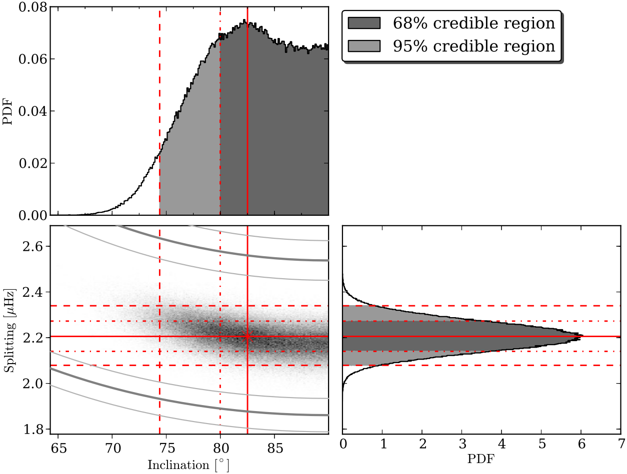
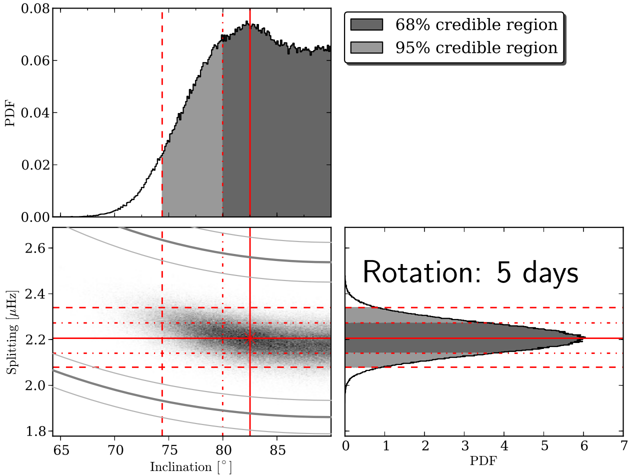


Van Eylen et al. 2014

Inclination and rotation



Van Eylen et al. 2014

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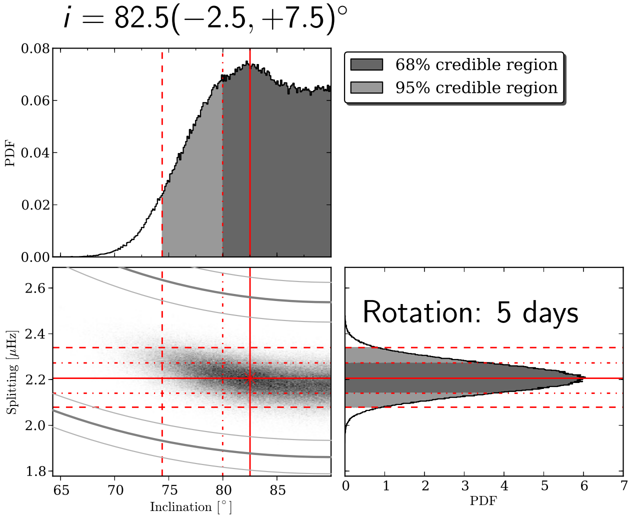
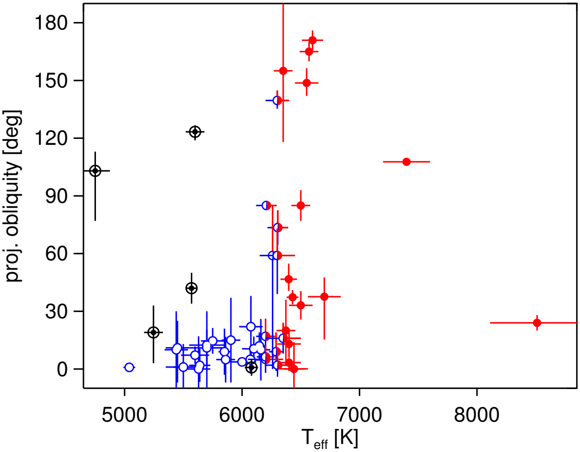


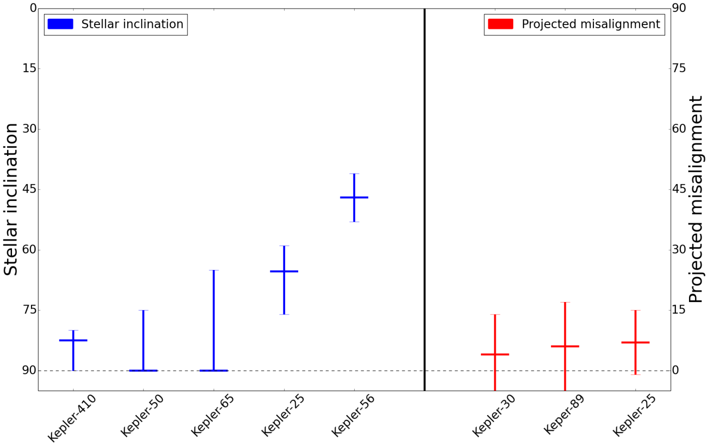
Van Eylen et al. 2014

Obliquity of single systems



Albrecht et al. 2012

Obliquity of multi-planet systems



Values from: Sanchis-Ojeda et al. 2012, Hirano et al. 2012, Albrecht et al. 2013, Chaplin et al. 2013, Huber et al. 2013, Van Eylen et al. 2014, Benomar et al. 2014

3. Eccentricity of planets without RV

Small planets: no RV possible. Eccentricity?

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(assuming a circular orbit)

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$v = 2\pi a/P$

$\Rightarrow T = \frac{PR_\star}{\pi a}$

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2. $R_\star/a \propto \rho_\star$ (from Kepler's law):

$$\begin{aligned} P^2 &= \frac{4\pi^2 a^3}{G(M_\star + M_\mathrm{p})} \\ &\Downarrow \quad \text{neglecting } M_\mathrm{p} \\ M_\star &\approx \frac{4\pi^2 a^3}{GP^2} \\ &\Downarrow \quad \text{divide by volume of the star} \\ \rho_\star &\approx \frac{3\pi}{GP^2}\left(\frac{a}{R_\star}\right)^3 \end{aligned}$$

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$\Downarrow$ neglecting M_p

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$\Downarrow$ divide by volume of the star

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- Directly from large frequency separation: $\Delta\nu \propto \sqrt{\rho_\star}$
- Easiest to determine!

Eccentricity without RV

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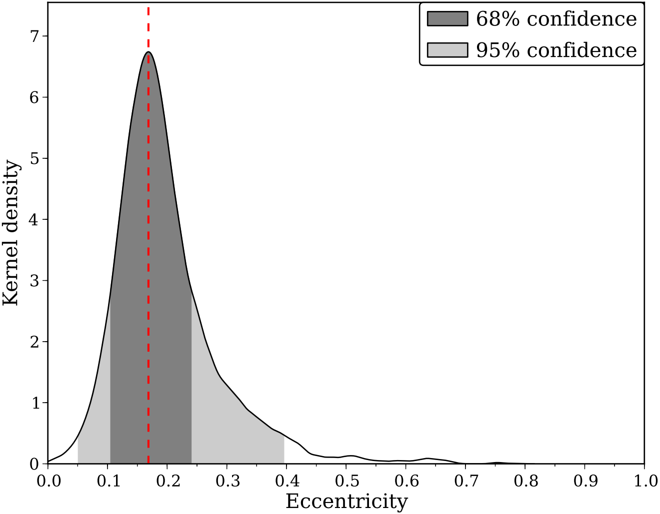
IF $1 \neq 2$: eccentric orbit

$\rho_{\star,\mathrm{transit}} \neq \rho_{\star,\mathrm{seismo}} \Rightarrow$ eccentricity

- $\rho_{\star,\mathrm{transit}}$ also depends on ω
- complications: false positives, blending, TTVs, ...

See e.g.: Seager and Mallen-Ornélas 2003, Tingley et al. 2011, Dawson and Johnson 2012, Kipping 2014

Eccentricity posterior



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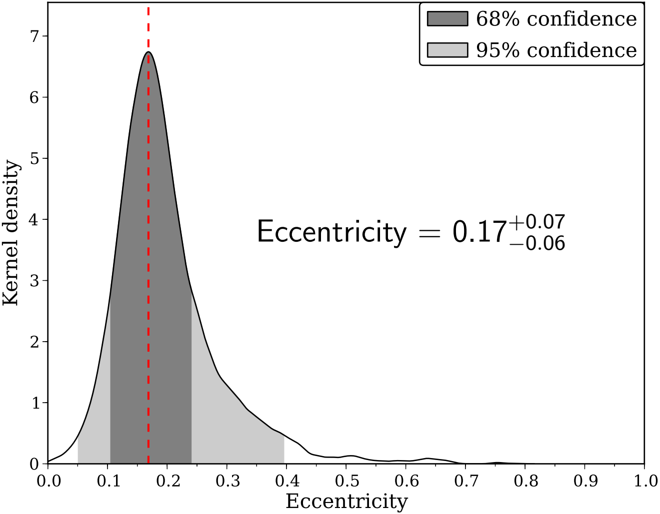
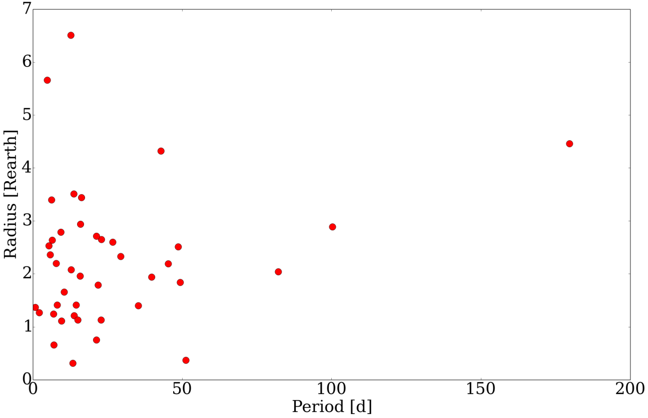
Eccentricity posterior



Van Eylen et al. 2014

Expanding the sample

Eccentricities beyond RV: small planets in multi-planet systems around bright stars



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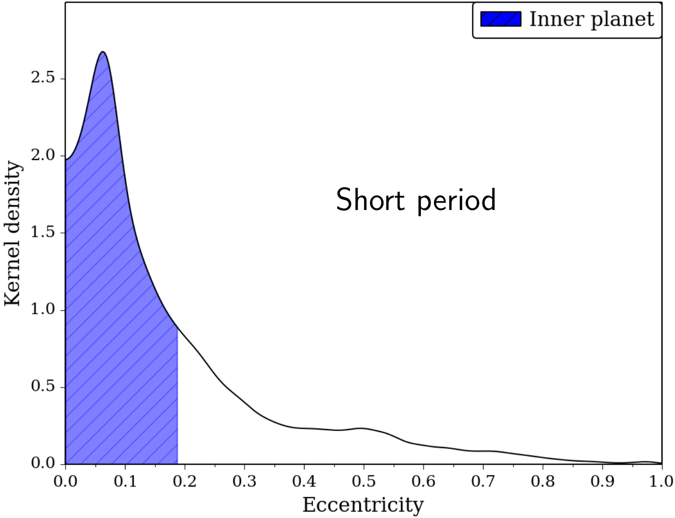

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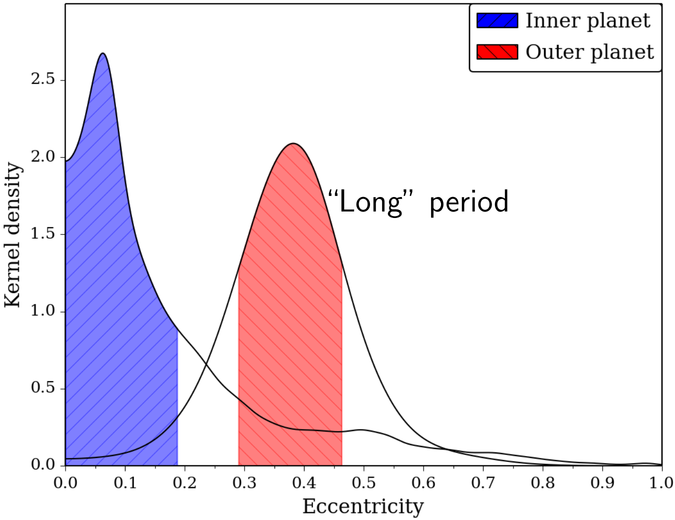

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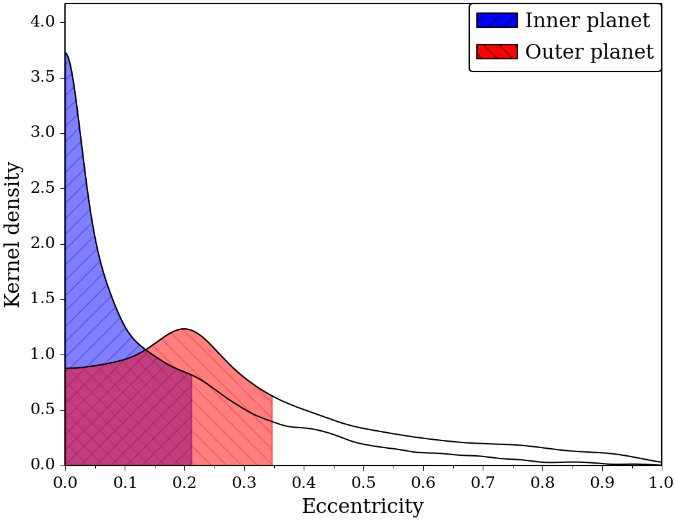

Conclusions: what can asteroseismology do?

1. **Characterisation** of the planet through characterisation of the host star
2. **Obliquity** through determination of the stellar inclination
3. **Eccentricity** of (small) planets from photometry alone using accurate stellar densities

Also: Kepler-410 is a fascinating system:

- Bright star ($V = 9.4$), small planet ($2.8\ R_{\oplus}$)
- Multi-planet system: non-transiting planet(s) from TTVs
- Multi-star system: Kepler-410A and Kepler-410B

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 [$^\circ$]	$87.72\ ^{+0.13}_{-0.15}$

Eccentricity vs. angle of periastron ω