Multiplicity and properties of Kepler planet candidates: High spatial imaging and RV studies at Calar Alto

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on behalf of
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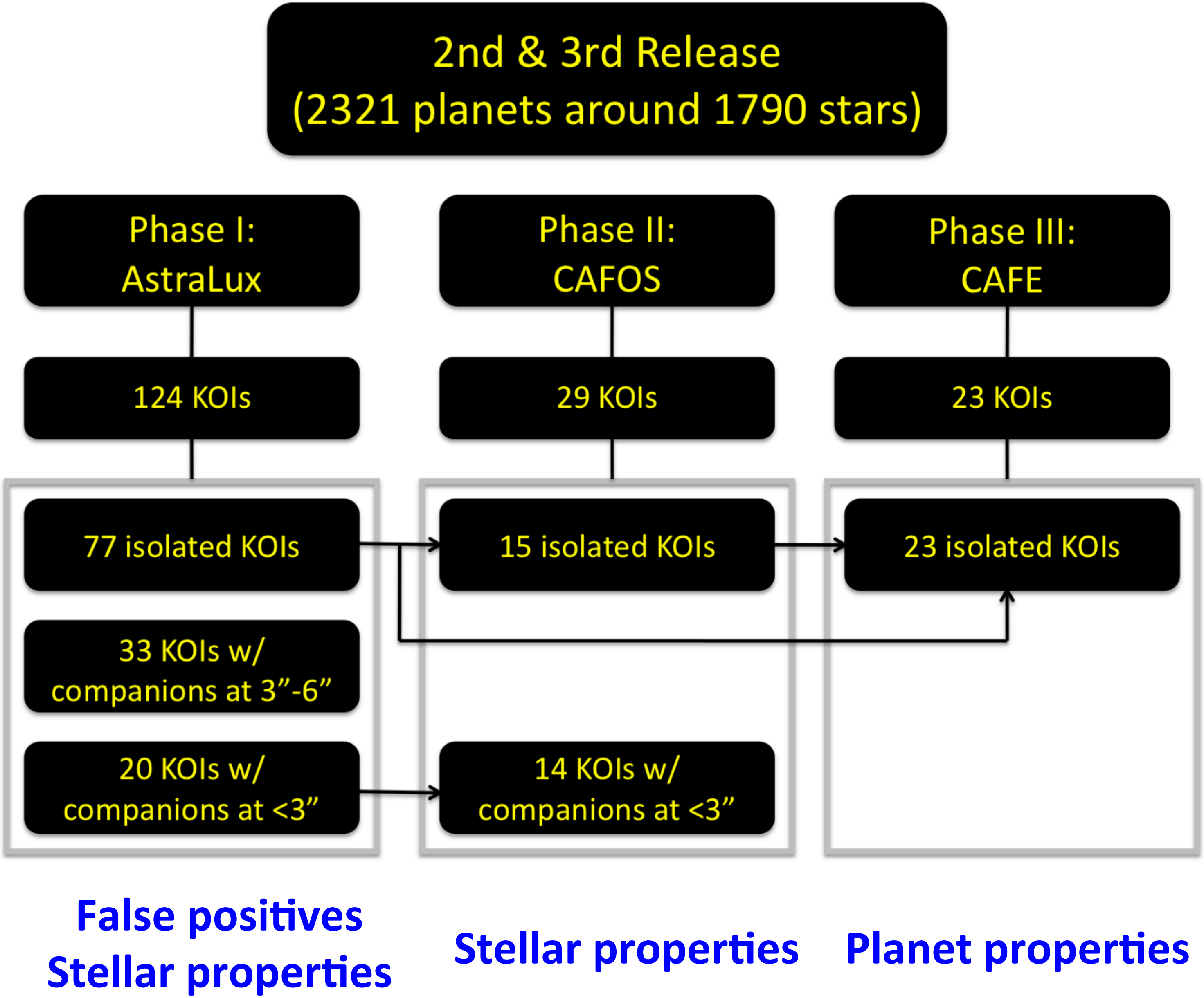
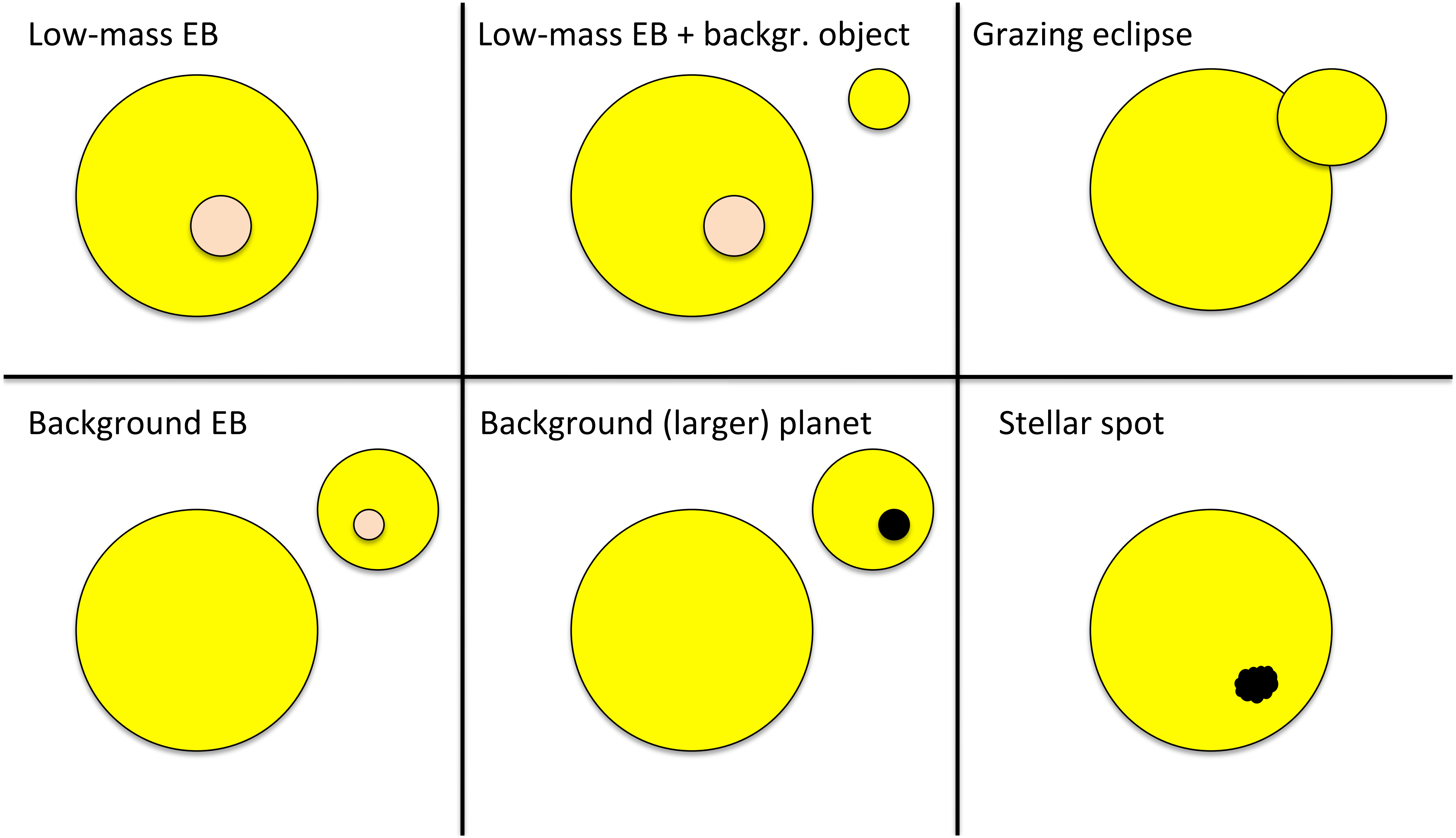


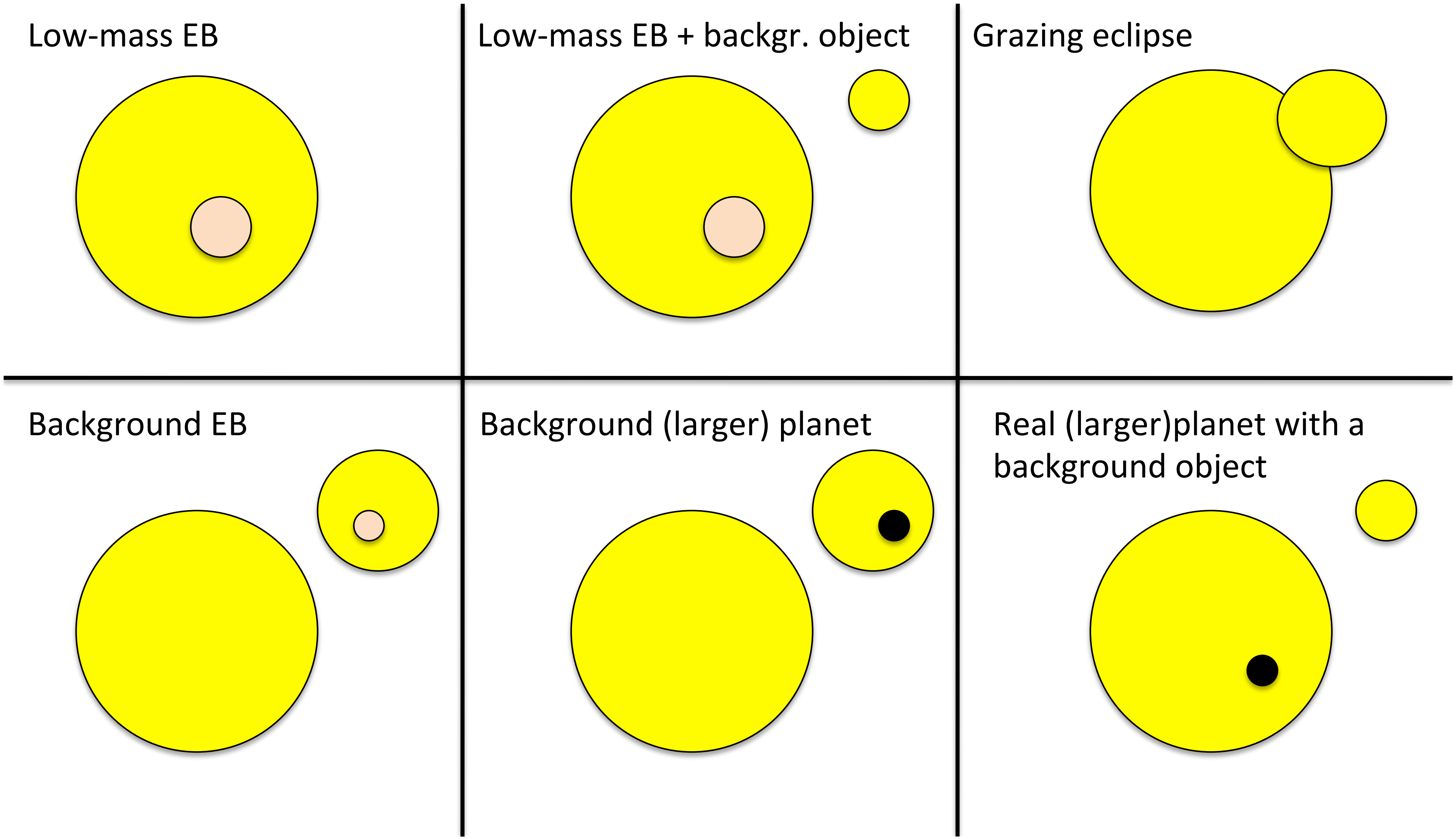
A three phases study: from high spatial resolution imaging, to reject **false positives** and study **multiplicity of the host star**, to high-spectral resolution for RV (and **planet properties**)

False positives



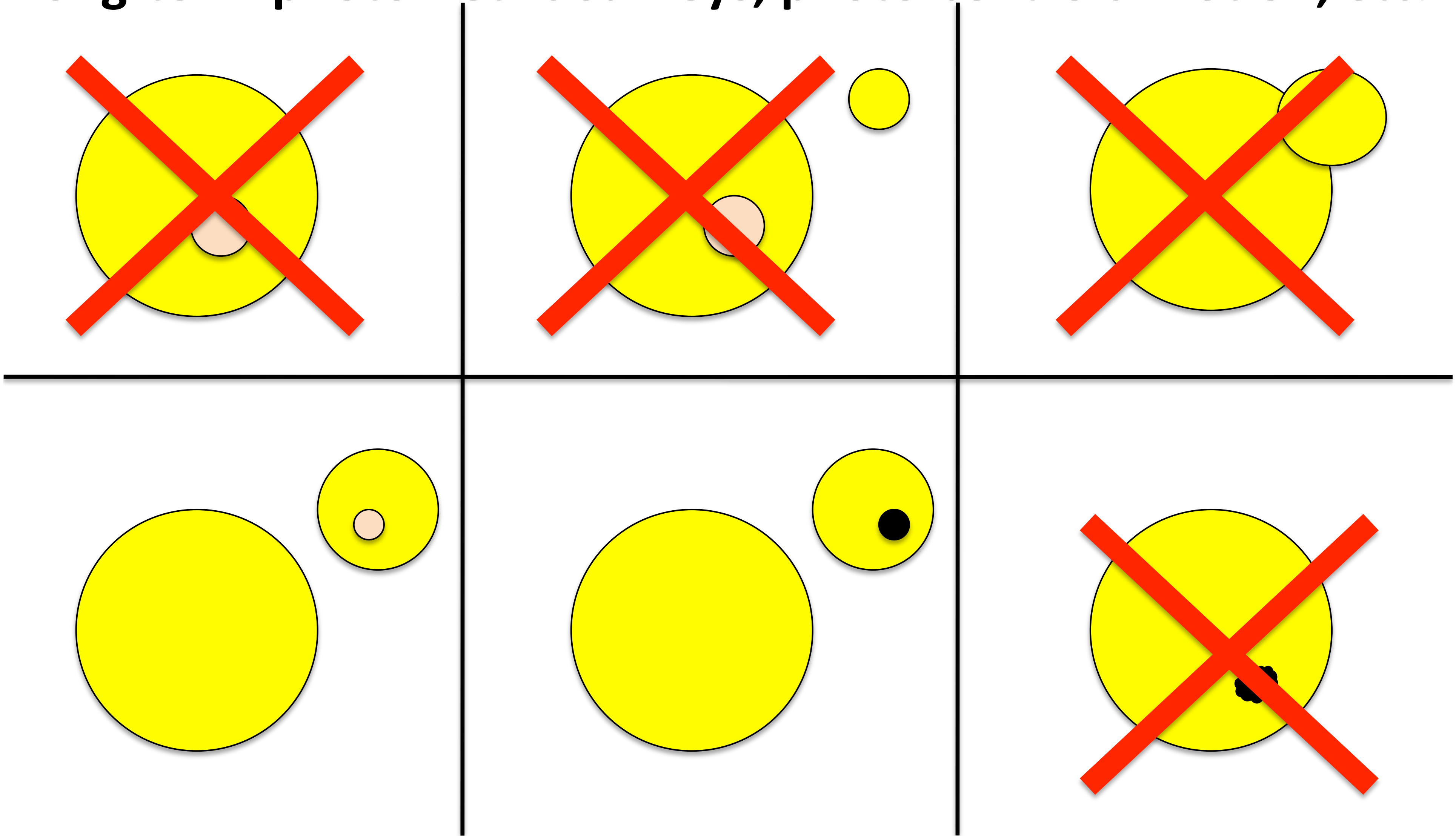
IMAGING: False positives

False positives



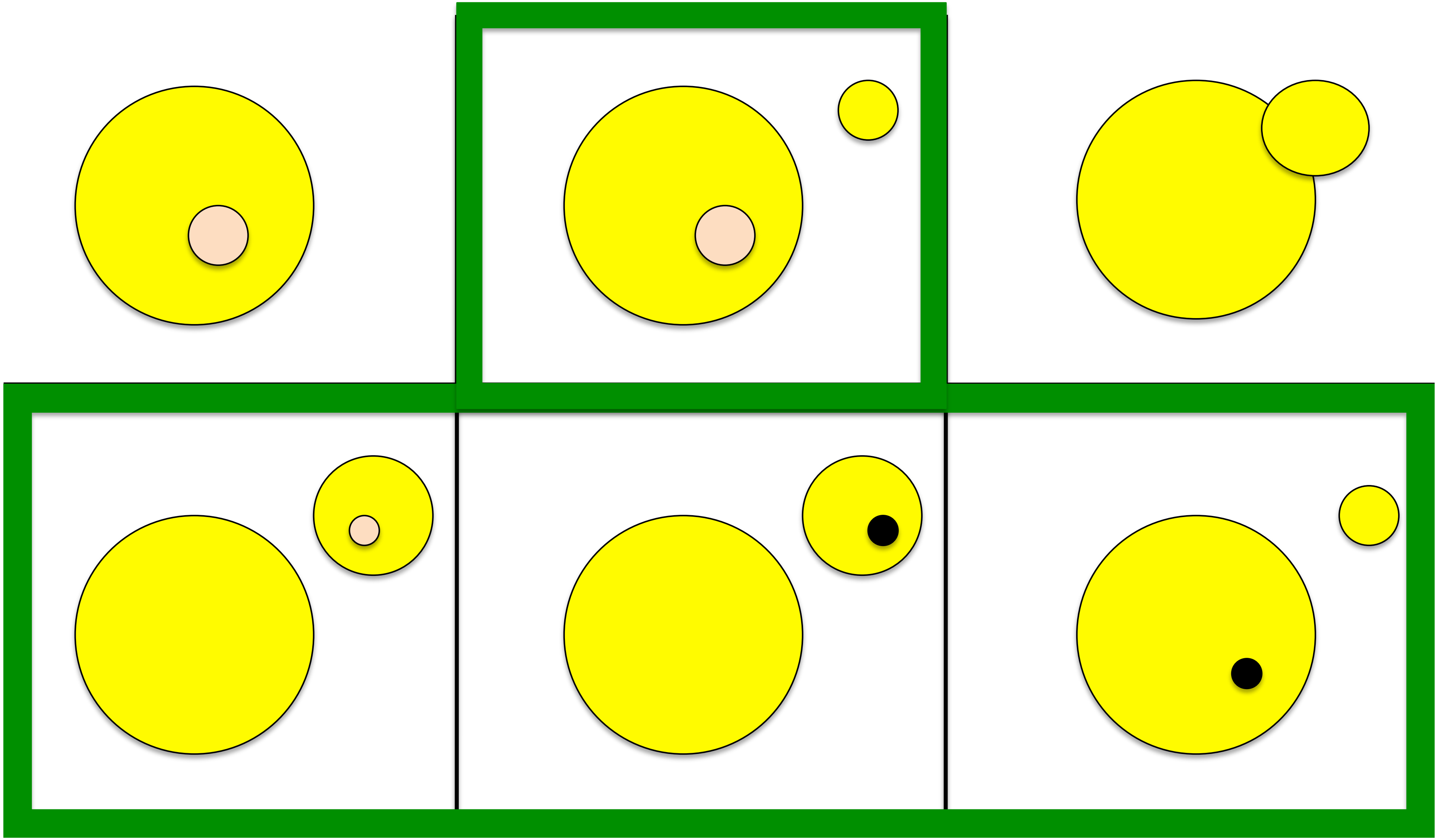
IMAGING: False positives

Configurations already rejected by other techniques such as long-term photometric surveys, photo-centroid motion, etc.



IMAGING: False positives

Configurations that can be rejected with our high-spatial resolution imaging

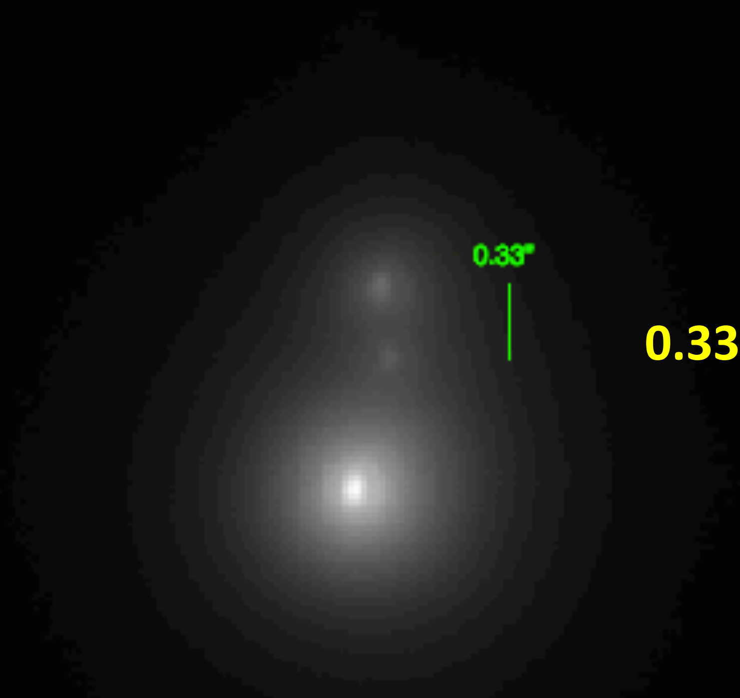


Phases of our follow-up

PHASE	Objetive	Instrument	Tipo de datos
1	- To detect isolated host - To detect multiple systems (2 or more stars)	AstraLux (Lucky Imaging)	High-spatial Resolution imaging
2	- Characterization host. - Characterization stellar companion: physical asociation?	CAFOS	Low-resolution spectroscopy
3	- Characterization star-planet and planet properties	CAFE	Stable, high-spectral resolution spectroscopy

Lucky imaging with Astralux

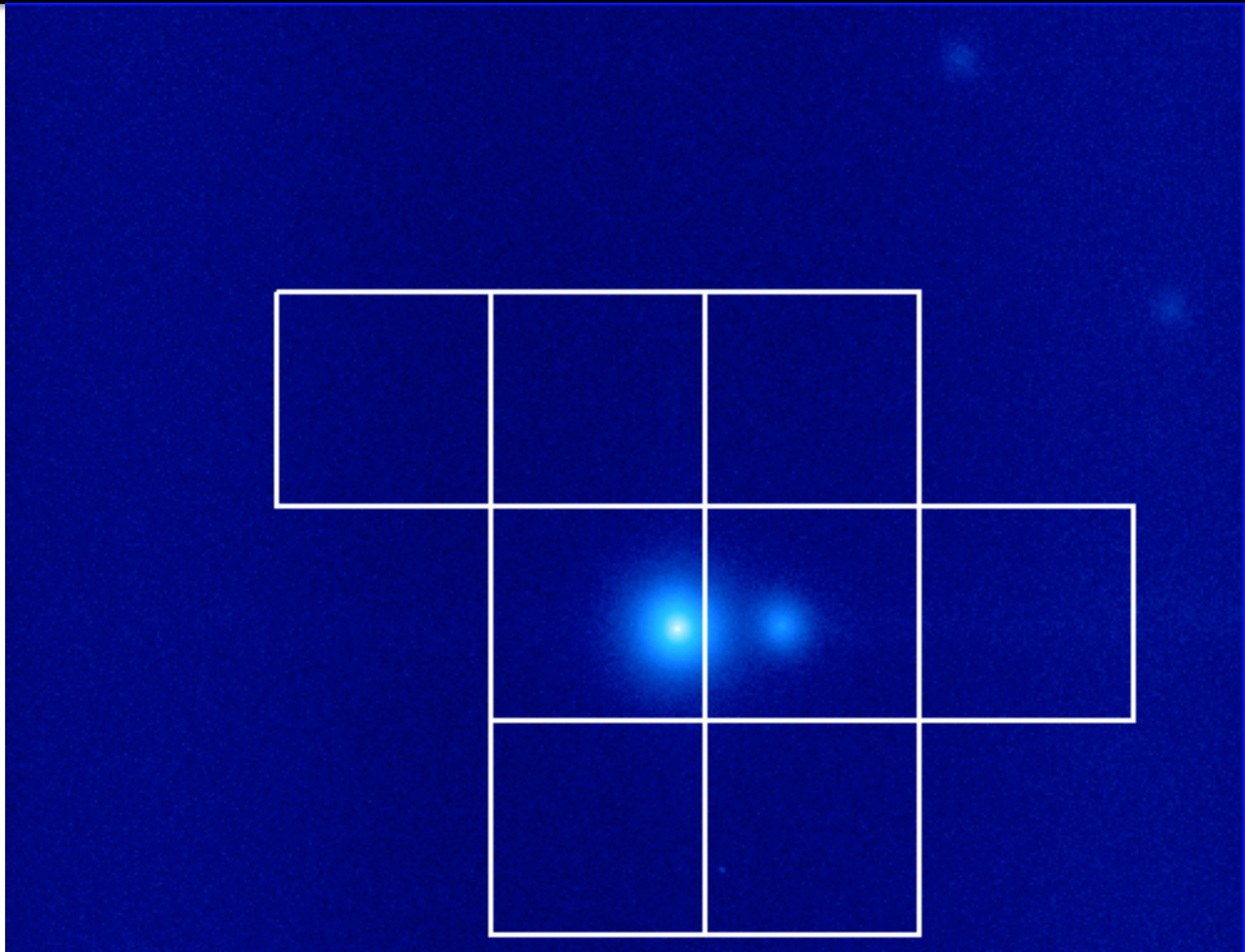
Calar Alto 2.2m



0.33"!!

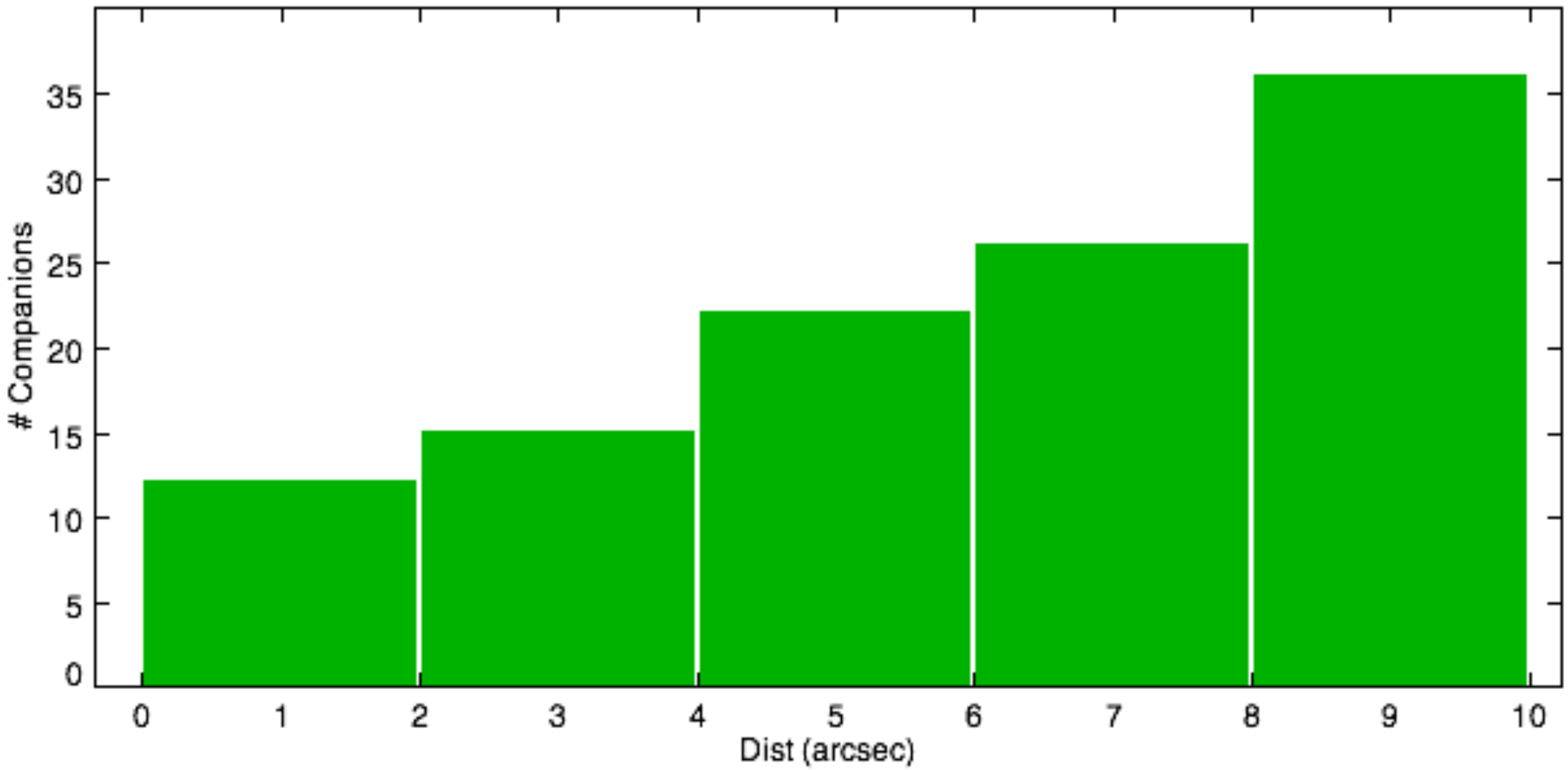
AstraLux is a Lucky-Imaging camera installed at the 2.2m telescope at Calar Alto. With a FOV of 24x24 arcsec, it obtains thousands of images of short-exposure time (tens of miliseconds, below the typical timescale of the atmosphere changes) to achieve diffraction-limited images of 0.1 arcsec.

The shape of the Kepler PSF: an important factor



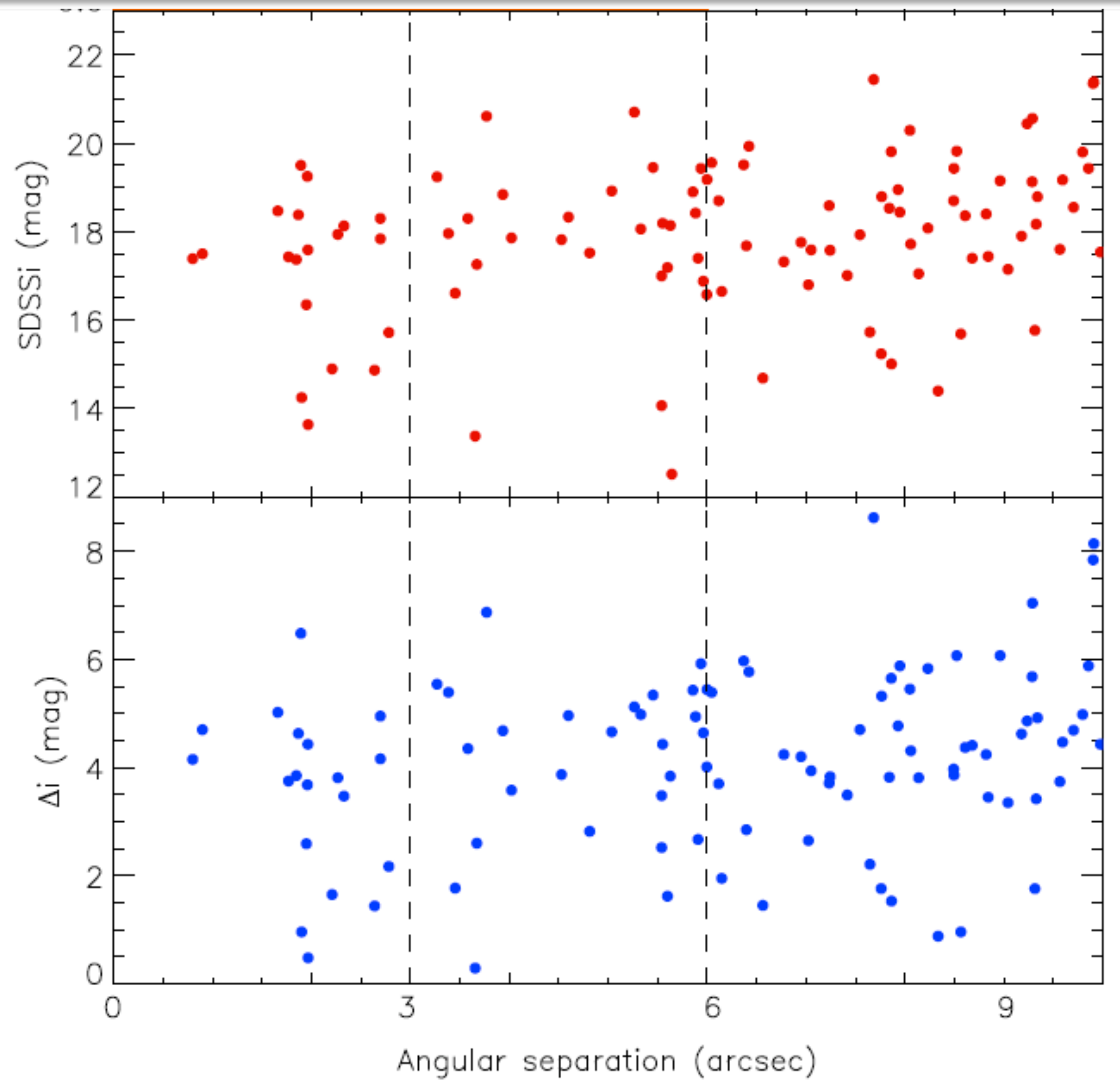
Our Astralux image with the Kepler psf overimposed. Each kepler pixel is 4x4 arcsec large and several pixels are used in the aperture. As in this image, several objects could lie inside the aperture, affecting photometry and eventually making planet smaller than they are.

Results: many visual companions



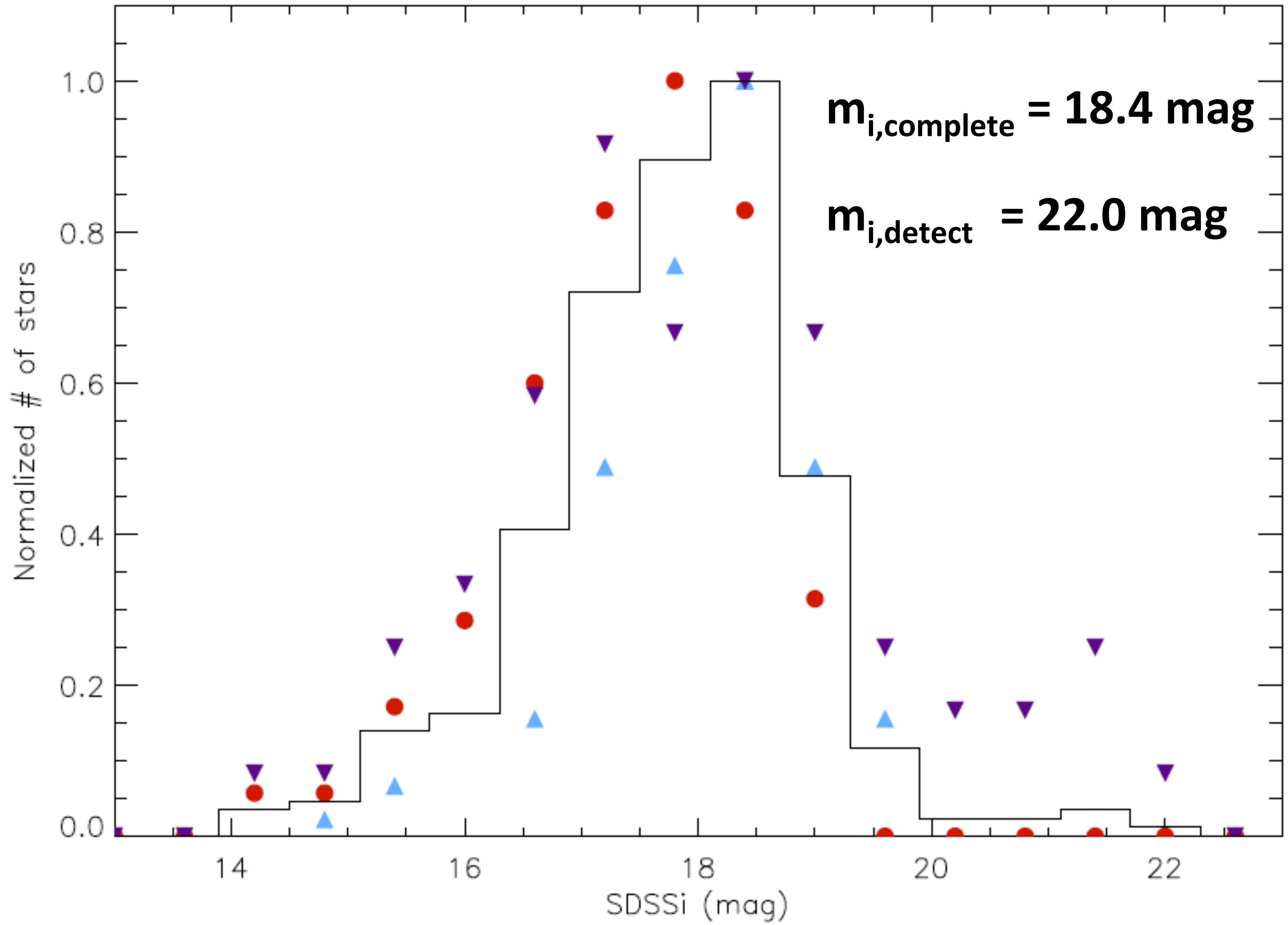
We have found 111 companions near the 98 observed hosts (closer than 10").

Results: many visual companions



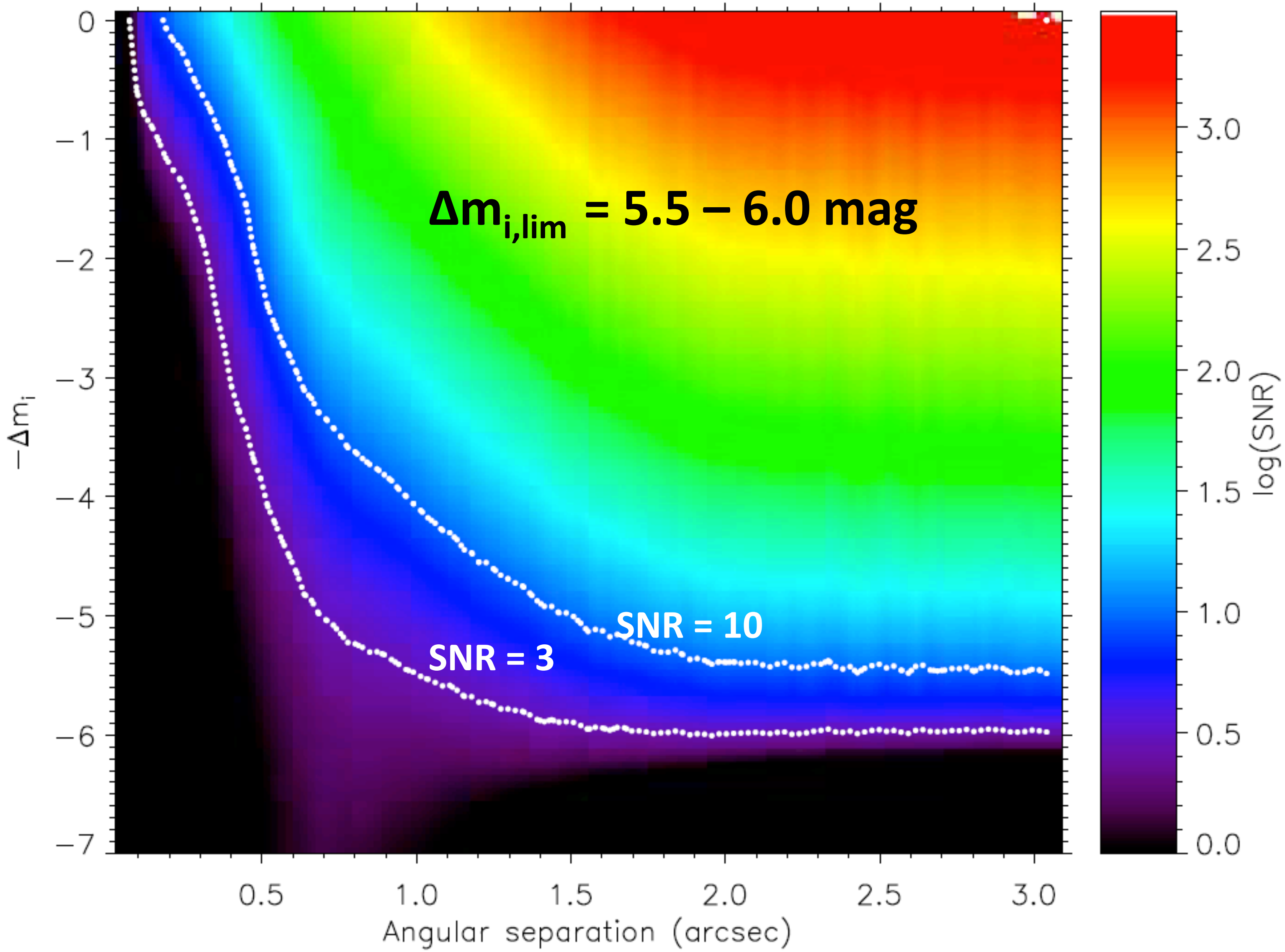
SDSS photometry can be recovered for most of it (no in the Kepler catalog)

Completeness and detectability limits



Detectability limits for our survey. We obtained deep images with the same exposure times as the scientific images to measure the number of detected stars on each magnitude bin.

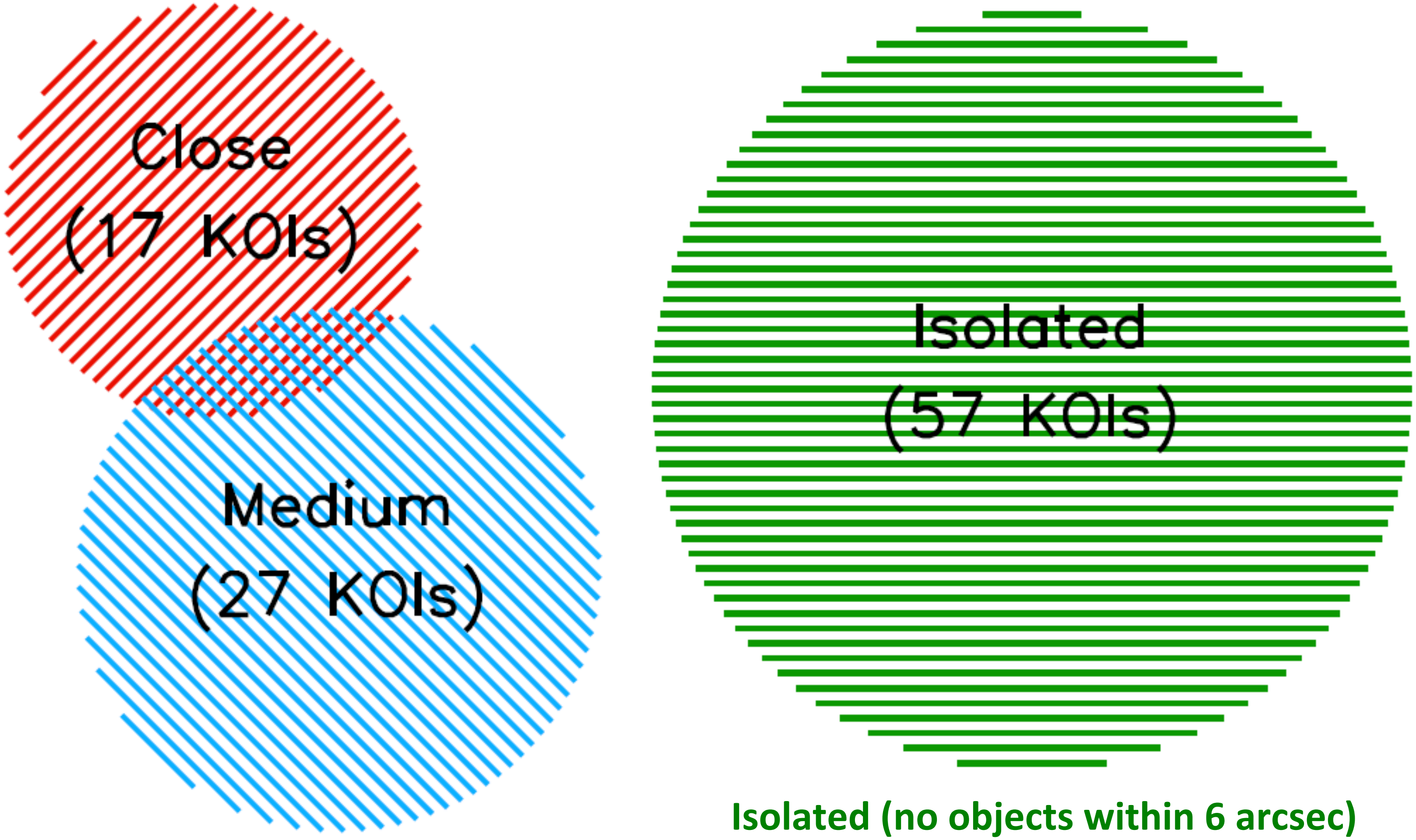
Sensibility limits



Our sensibility plots show that we reach 5.5-6.0 magnitudes for SNR=3 detections within 1 arcsec fro the target and magnitude differences of 3.0 mag for an object located at 0.4 arcsec.

RESULTS: visual companion

At least one object detected within 3 arcsec.

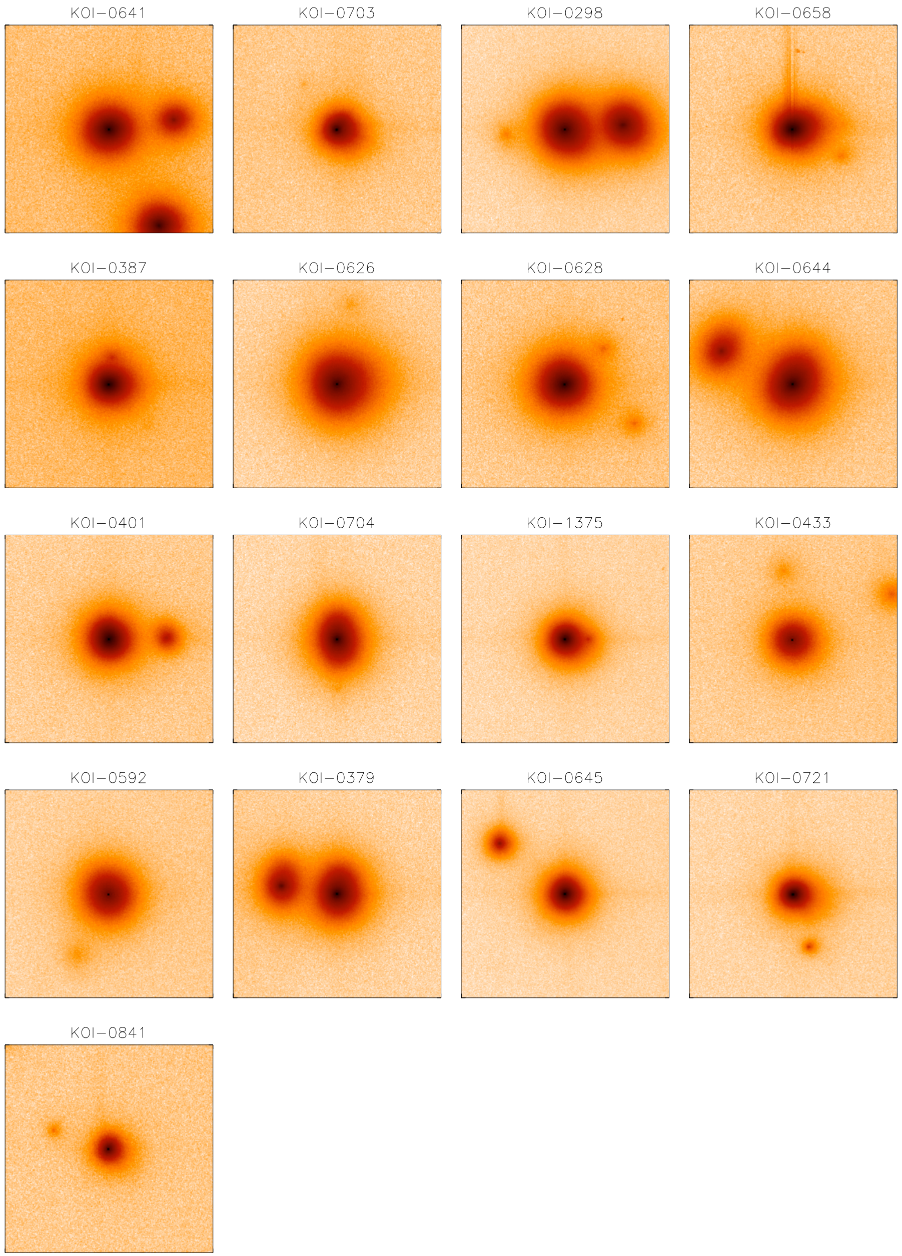


At least one object detected within 3-6 arcsec

Isolated (no objects within 6 arcsec)

Three objects are found to have both objects within 3 arcsec and 3-6 arcsec

RESULTS: physical companion



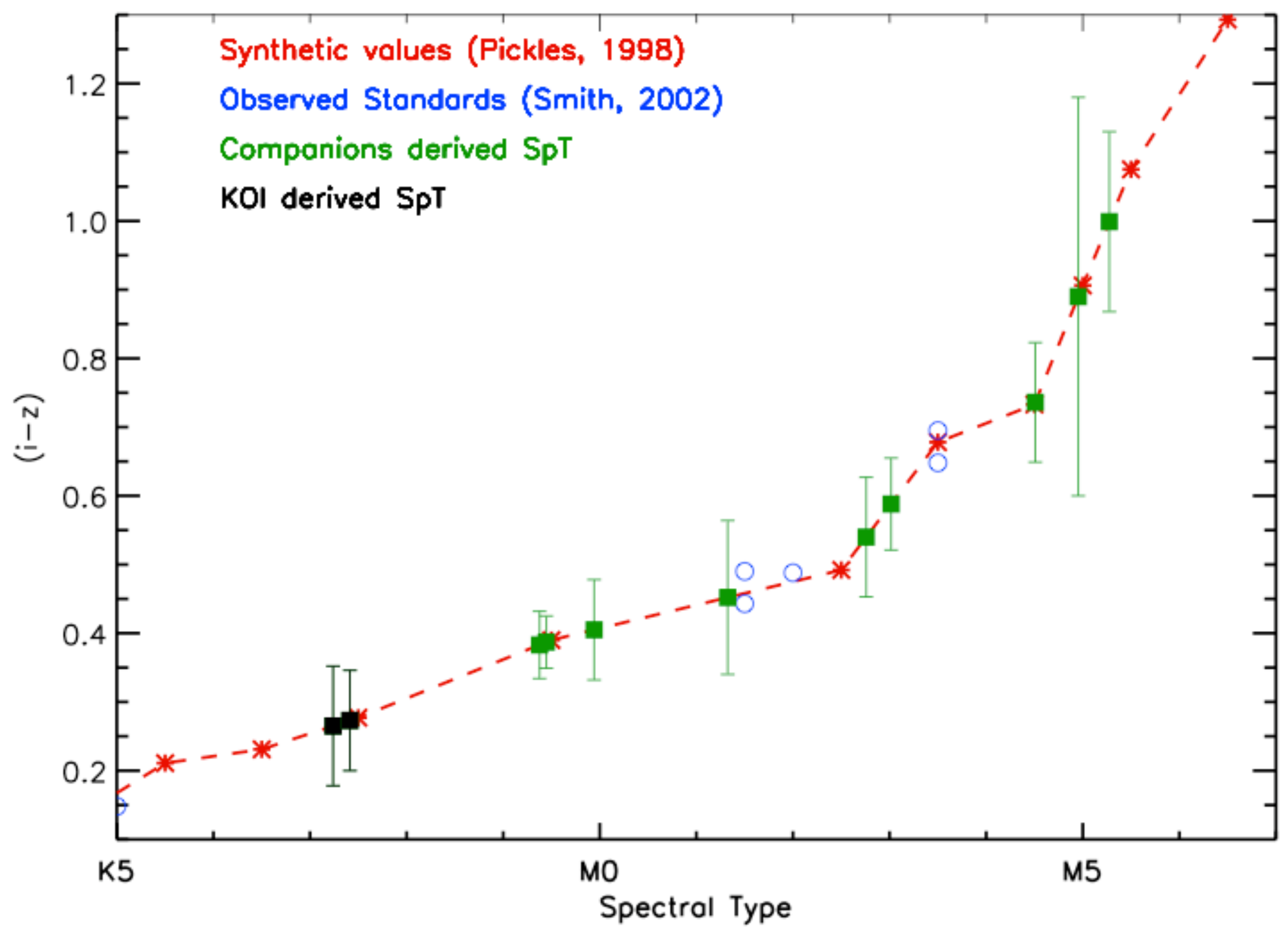
17 KOIs (hosts)

19 companions

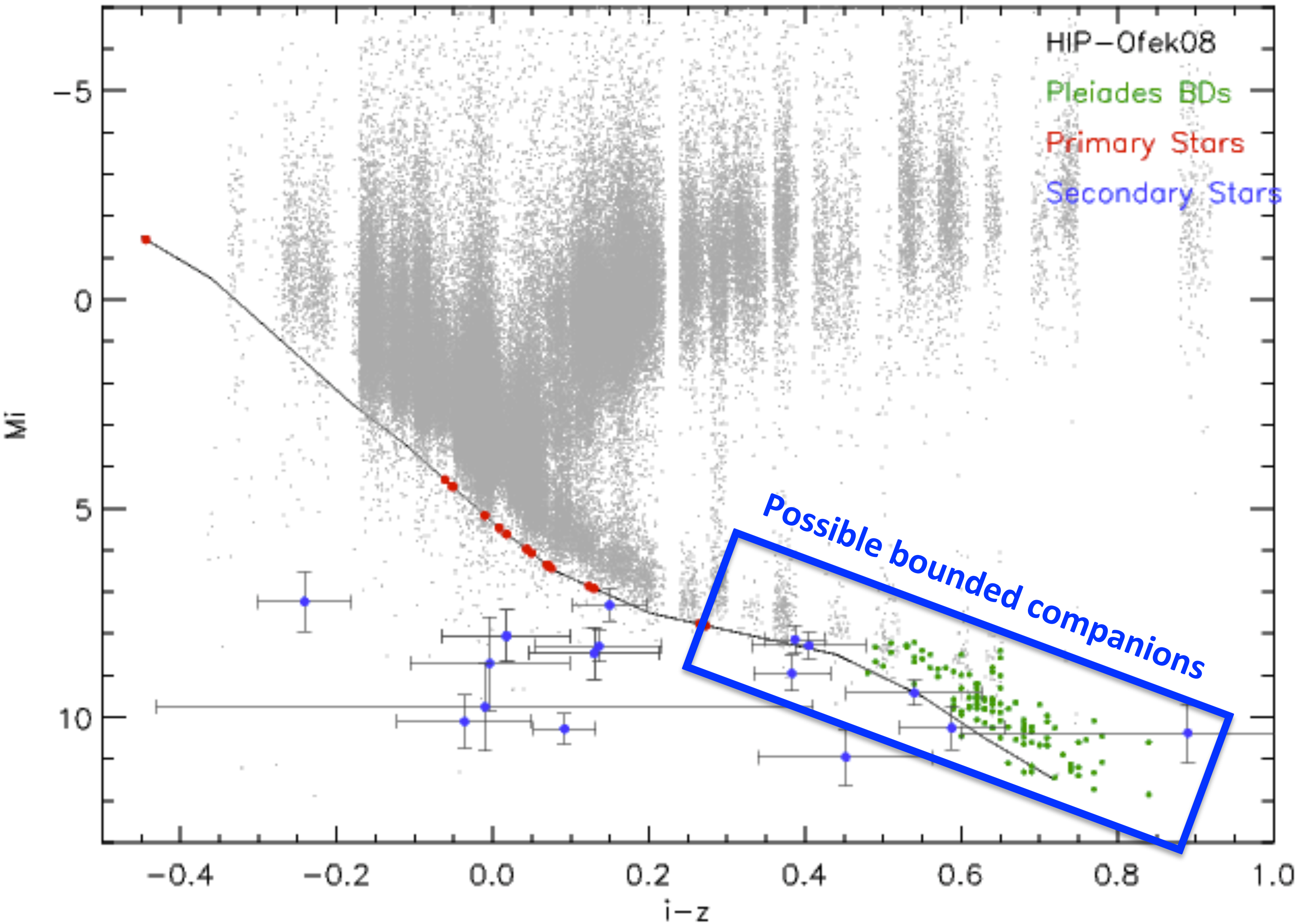
22 planet candidates

Characteristics of the companions

This spectral typing were only possible for objects with i-z > 0.21. Earlier-type objects do not present large differences in these color so that can not be classified. We have found 7 M-type companions and 2 late-K stars around our KOIs.



Characteristics of the companions



Planet parameter need to be recomputed if visual companion is present

Planet ID (KOI.Planet)	Cat. Depth (ppm)	NewDepth (ppm)	New R_p/R_* (10^{-2})
641.01	1080	1386 ± 113	3.7 ± 0.2
703.01	124	125 ± 1	1.1 ± 0.003
298.01	239	412 ± 59	2.0 ± 0.1
658.01	460	471 ± 8	2.2 ± 0.0
658.02	439	449 ± 7	2.1 ± 0.0
387.01	941	988 ± 83	3.1 ± 0.1
626.01	316	319 ± 3	1.8 ± 0.008
628.01	380	402 ± 17	2.0 ± 0.0
644.01	22486	28510 ± 555	16.9 ± 0.2
401.01	1986	2231 ± 124	4.7 ± 0.1
401.02	1411	1585 ± 88	4.0 ± 0.1
704.01	459	459 ± 0.0	2.1 ± 0.025
1375.01	2369	2527 ± 178	5.0 ± 0.2
592.01	440	440 ± 0.0	2.1 ± 0.024
379.01	251	363 ± 21	1.9 ± 0.1
645.01	169	201 ± 4	1.4 ± 0.0
645.02	193	229 ± 5	1.5 ± 0.0
721.01	190	196 ± 2	1.4 ± 0.059
433.01	2730	2905 ± 73	5.4 ± 0.1
433.02	12016	12788 ± 320	11.3 ± 0.1
841.01	2885	2986 ± 44	5.5 ± 0.0
841.02	4056	4198 ± 62	6.5 ± 0.0

Transit depth:

$$\Delta F = \frac{F_{nt} - F_t}{F_{nt}}$$

New depth:

$$\Delta F_{new} = (1 - 10^{-0.4 \Delta m_z}) \Delta F$$

Planet radius:

$$\frac{R_p}{R_*} = \sqrt{\Delta F}$$

Conclusions (I)

- High spatial resolution imaging is neede to validate the planet candidate.
- Isolated host: **58%**.
- More than **40 %** have stellar visual companions
- **17%** of the host have companions closer than **3”**.
- **8 possible bounded KIOs**

Phases

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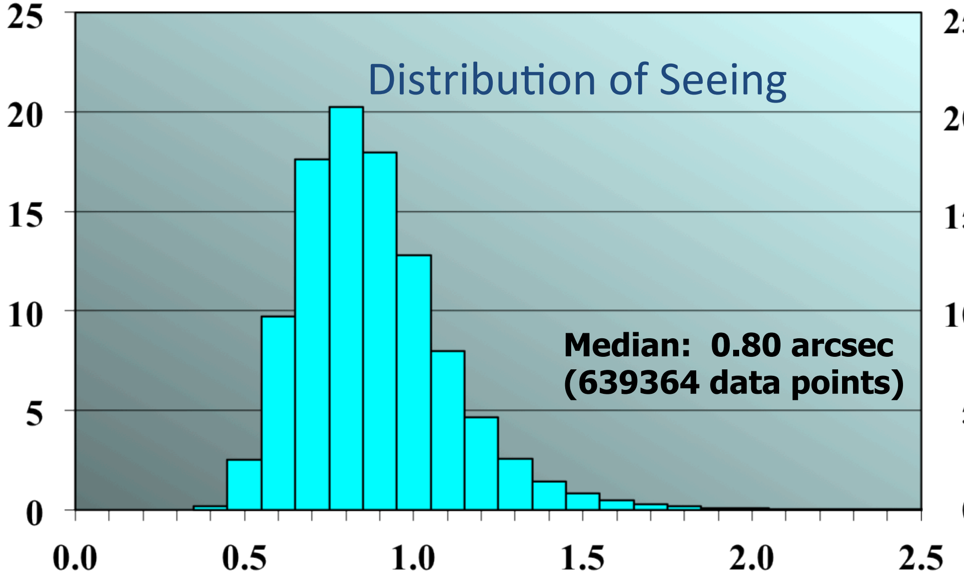
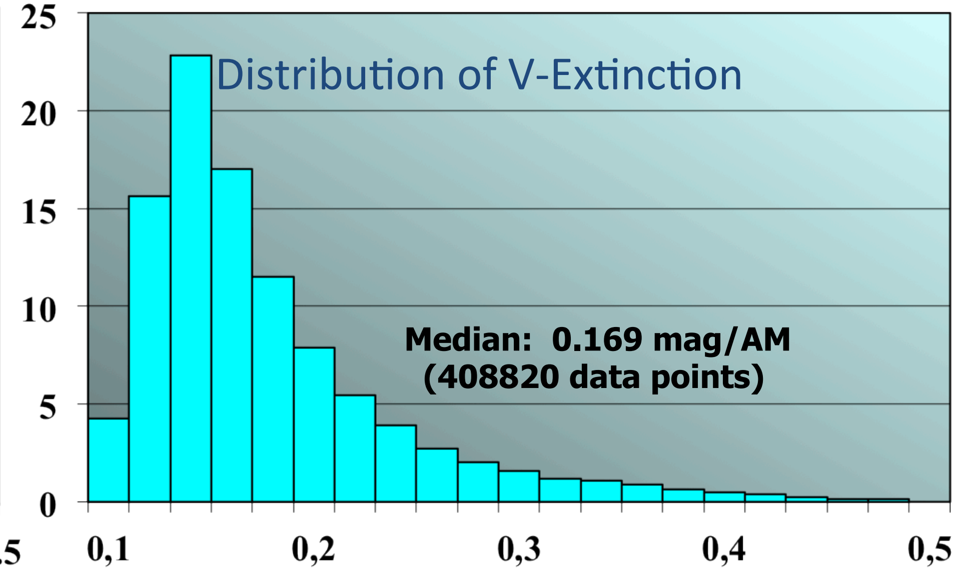
CAFÉ: the planetary system properties

- New spectrogram at Calar Alto.
- Commissioning in May-June 20111 (Aceituno et al. 2012)
- Since then, we have been using the Spanish GTO and open time

Calar Alto statistics





Period: Jan. 2005 – Oct. 2012

CAFÉ at 2.2m: commissioning data

Initial data: we see known planets

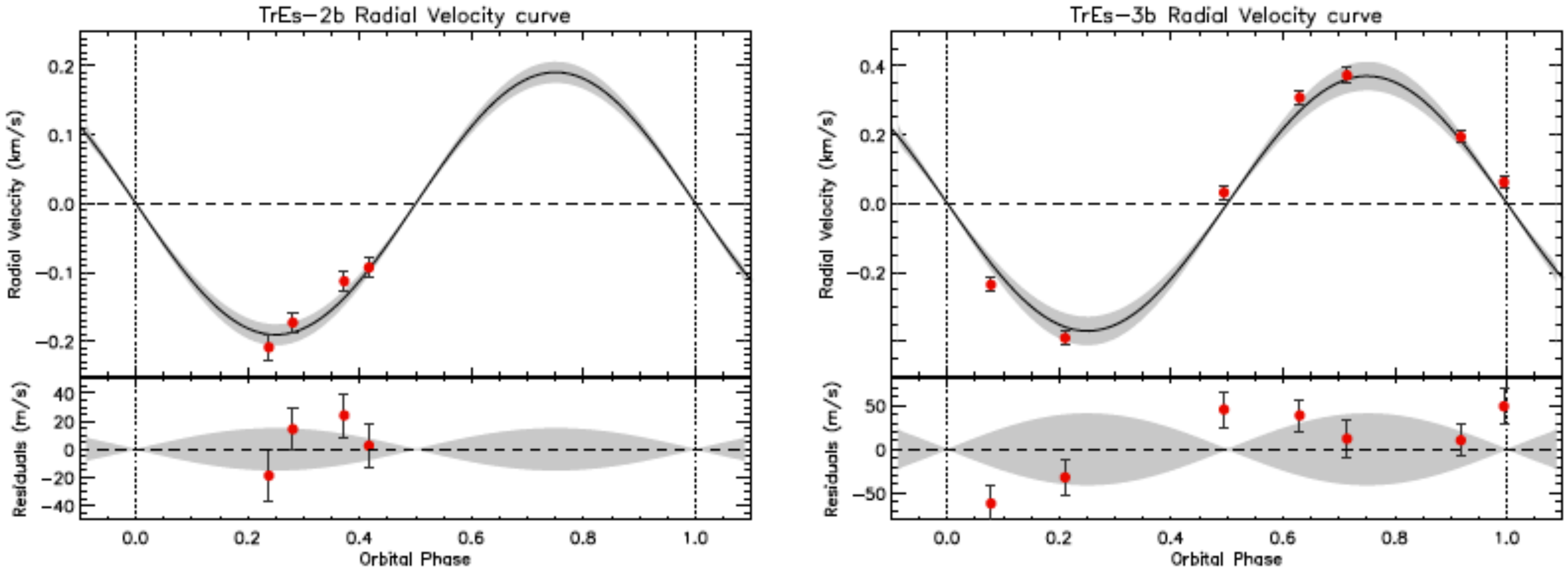
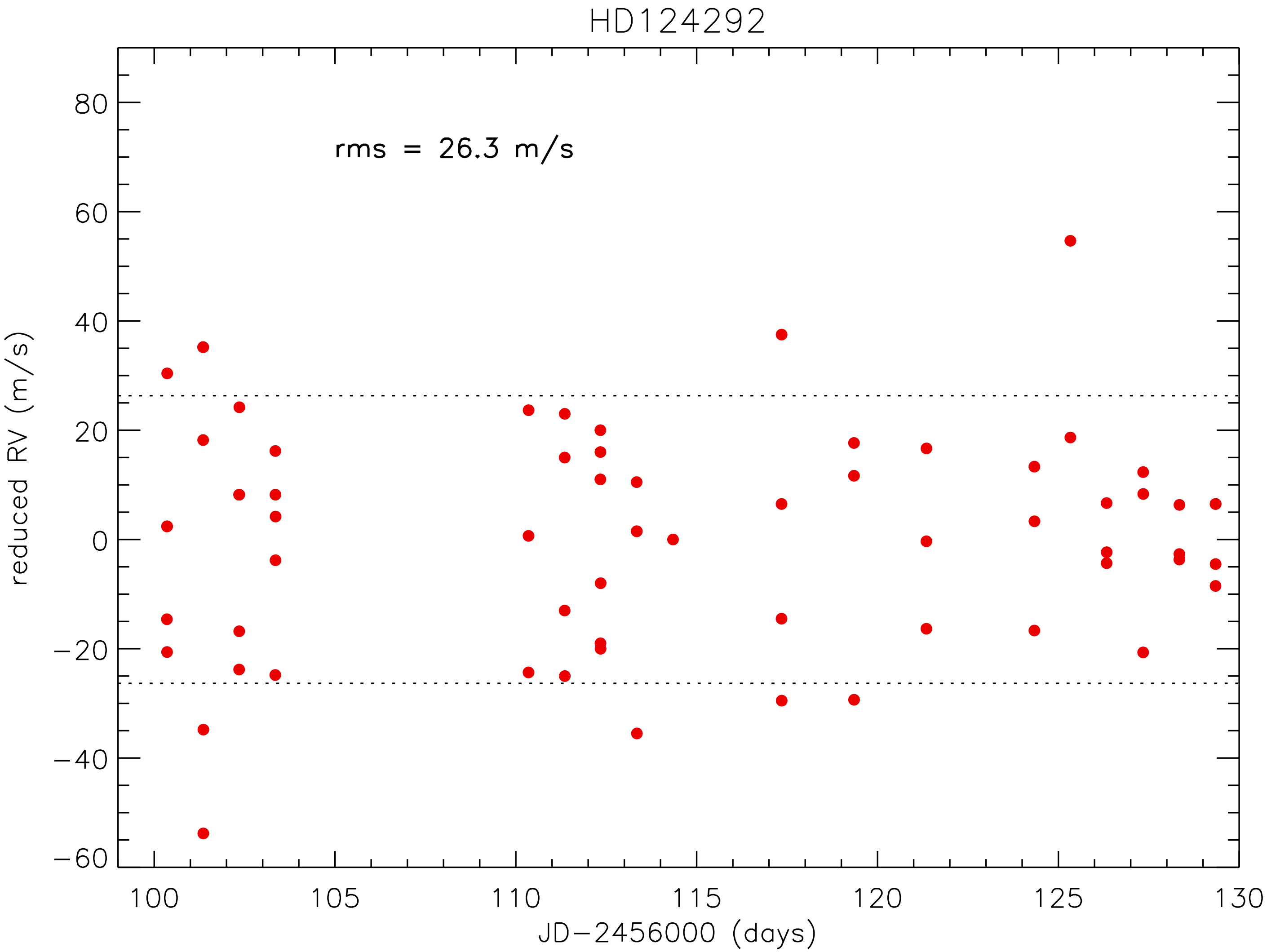


FIG. 15.— Radial velocity curves for two well-known extra-solar planets, TrEs-2b (*left-panel*), and TrEs-3b (*right-panel*), derived from the early measurements taken during the CAFE commissioning run. Red circles represent the derived values for the radial velocity. The black solid line represents the theoretical curve assuming the simple expression: $v_r = \frac{2\pi a}{P} sin(i) \frac{M_p}{M_p+M_s} sin(\phi)$ where a is the semi-major axis, P is the orbital period, i is the orbital inclination and ϕ is the orbital phase. The shaded region has been calculated by error propagation of the published values in the previous expression. The lower panel shows the residuals for the fit.

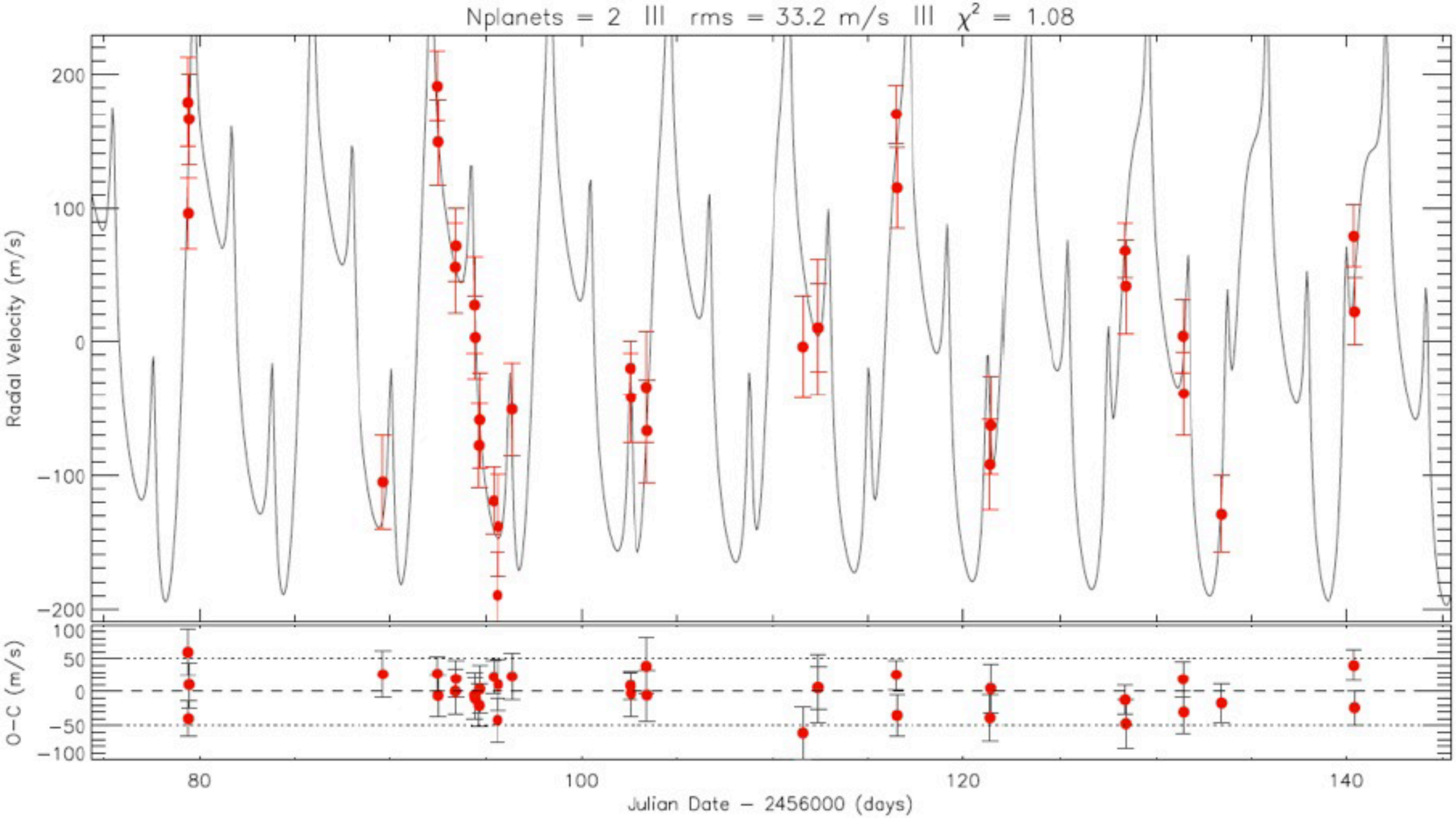
Aceituno et al. (2012), in press

Beyond our expectations: the RV accuracy



We are getting close to the optimal values: 10/s

First result: a multiple system



Planet #1		**Planet #2**	
Msin(i)	= 1.535 +/- 0.099 Mj	Msin(i)	= 0.501 +/- 0.091 Mj
ecc	= 0.293 +/- 0.045	ecc	= 0.531 +/- 0.089

Thanks!!!

And stay tuned