Short-period planets of intermediate-mass stars

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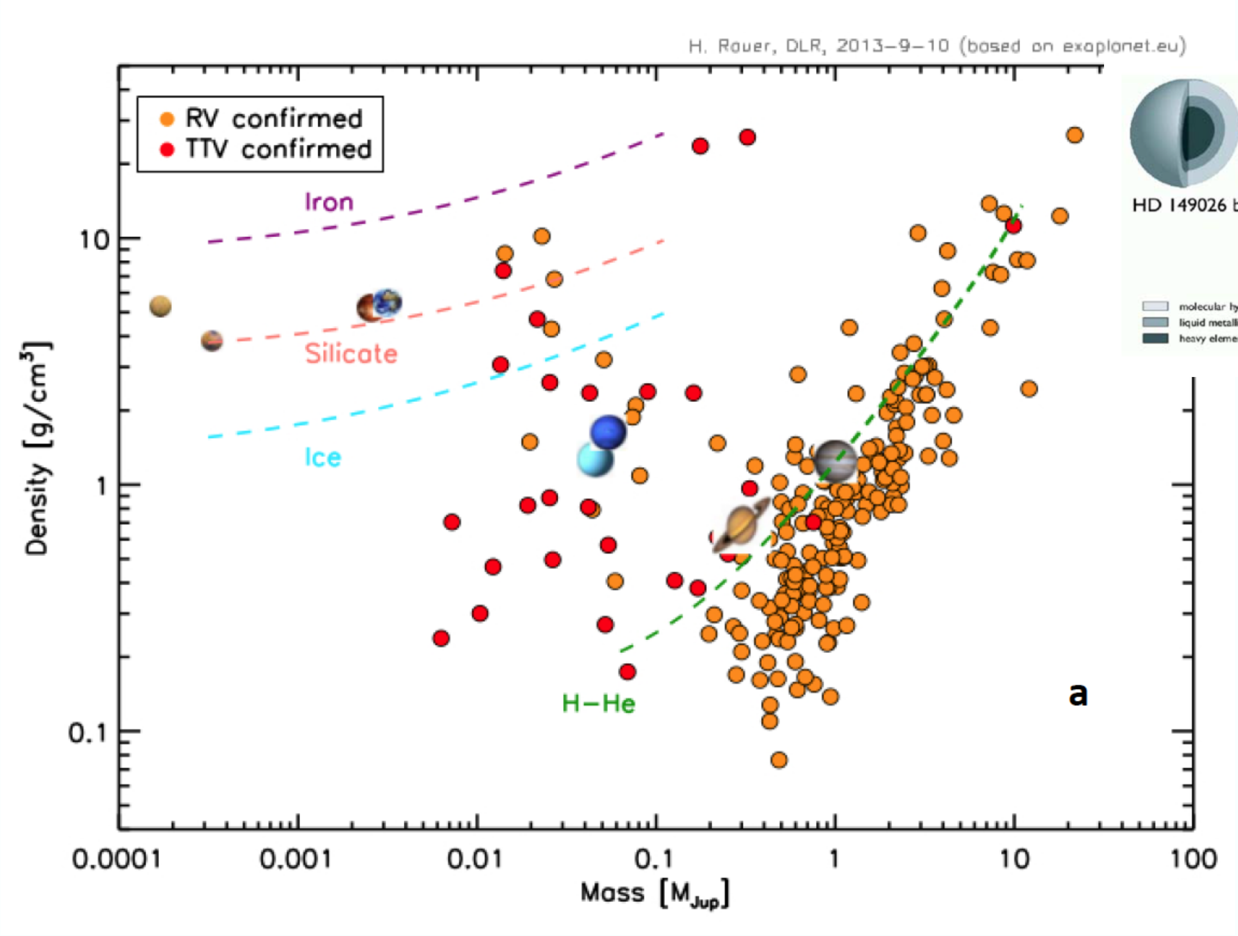
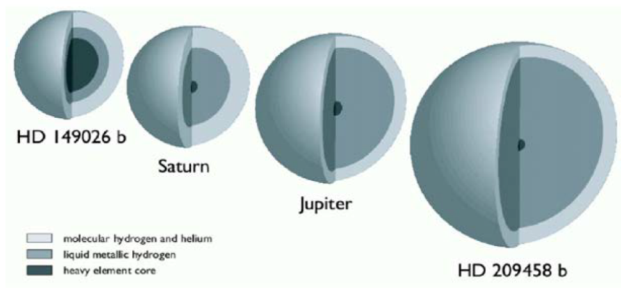
TLS

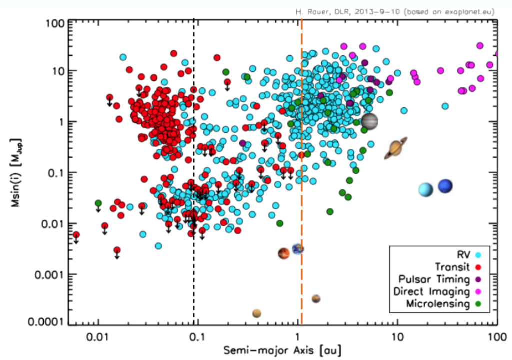
Two species of planets

--> Planets of $M \sim 10\ M_{Earth}$ with densities of 1-10 gcm^{-3}

--> planets with $M > 1\ M_{Jupiter}$ relation between mass and density



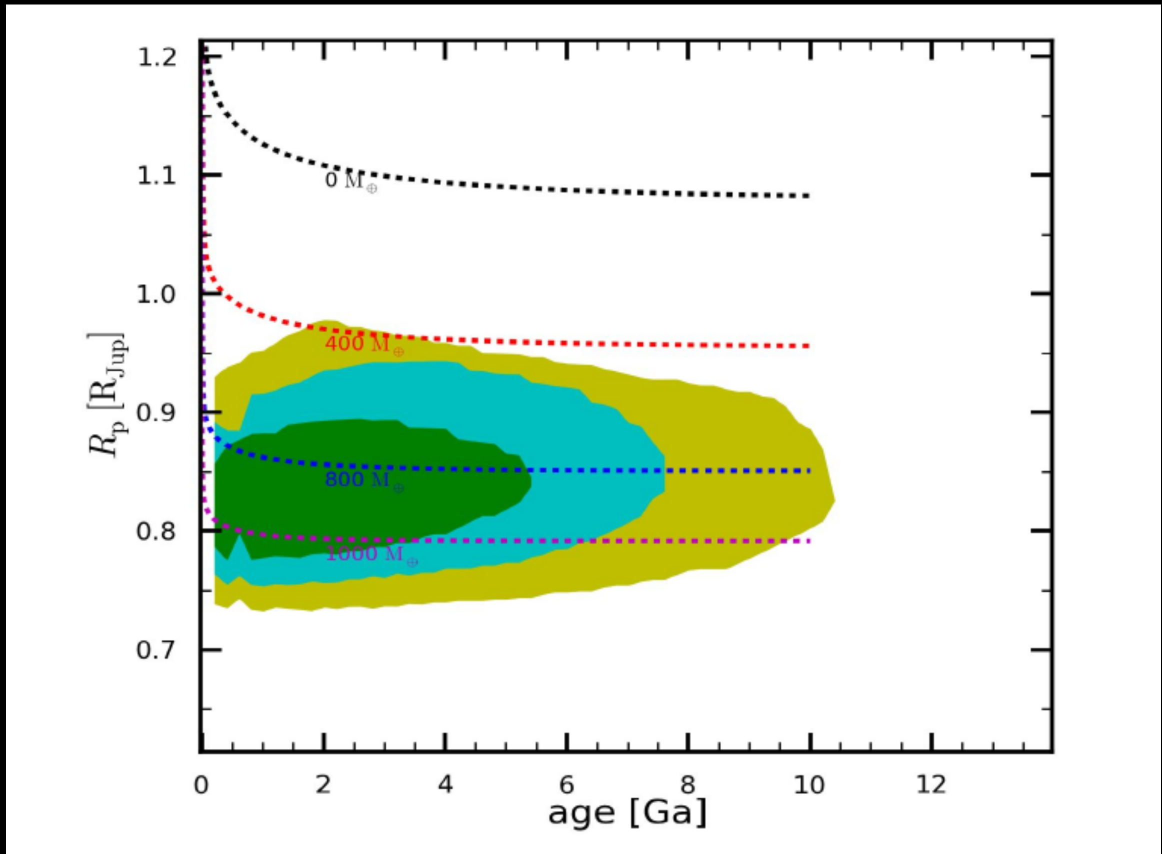




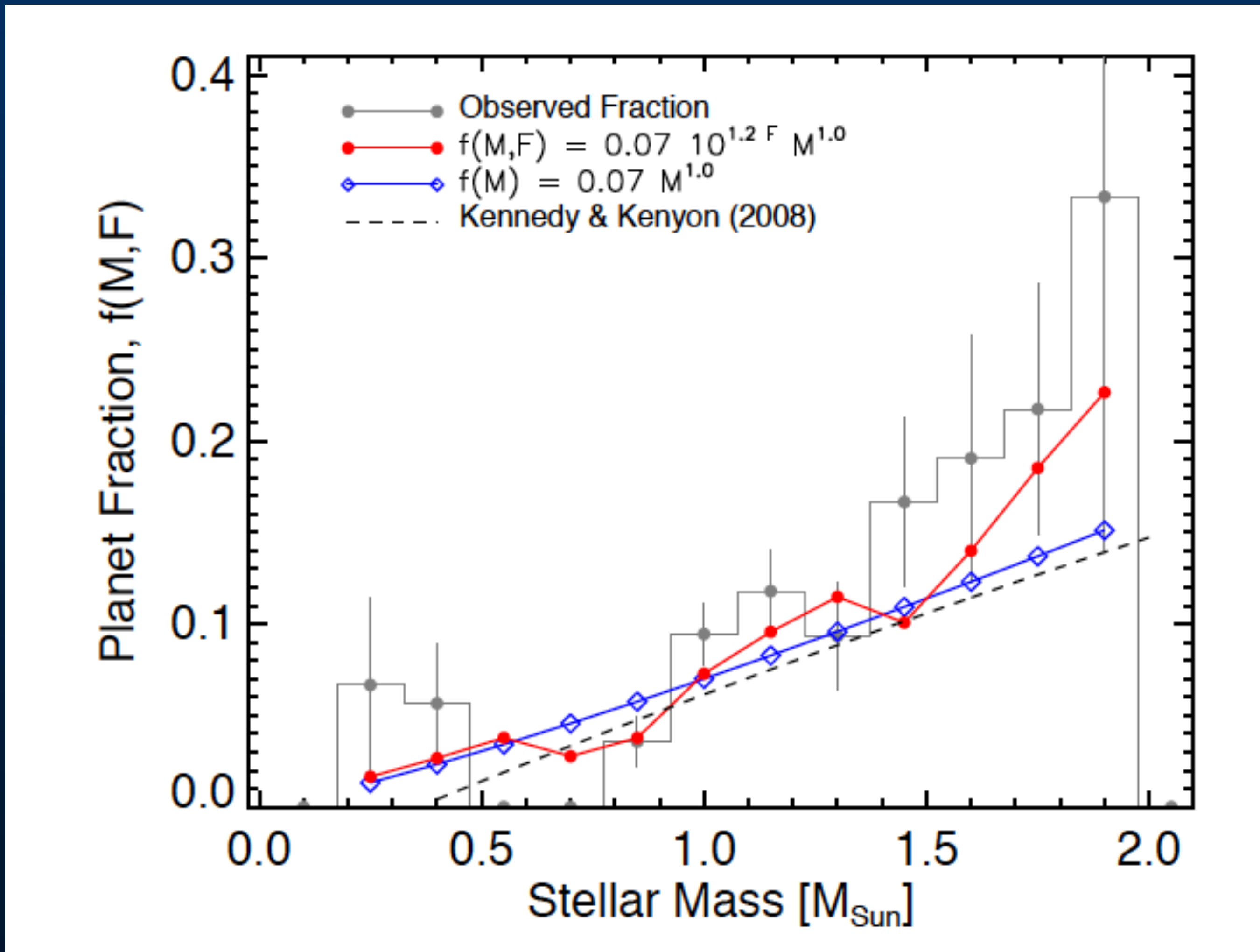
Rauer et al. 2014

A highlight was the discovery of CoRoT-20b:

A planet 4.24+/-0.23 M_{Jup} (=1350 M_{Earth}), with a core of 680 to 1040 M_{Earth} (between 55 and 77% of its total mass is the core), and a density 8.87+/-1.10 gcm^{-3} that is orbiting a star of 1.14+/-0.08 M_{sun} (Deleuil et al. 2012)

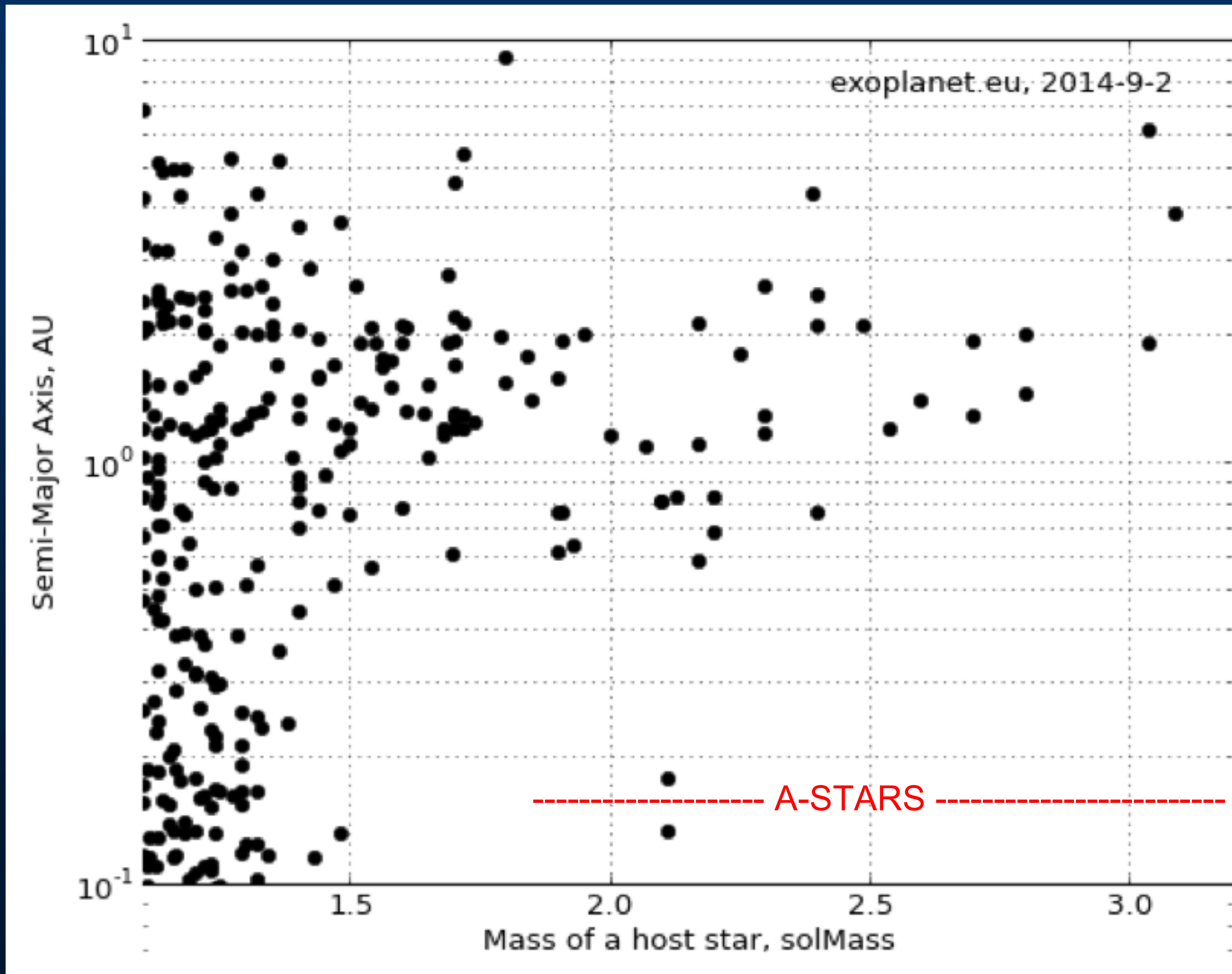


Surveys of giant stars show that massive stars also have a lot of massive planets.

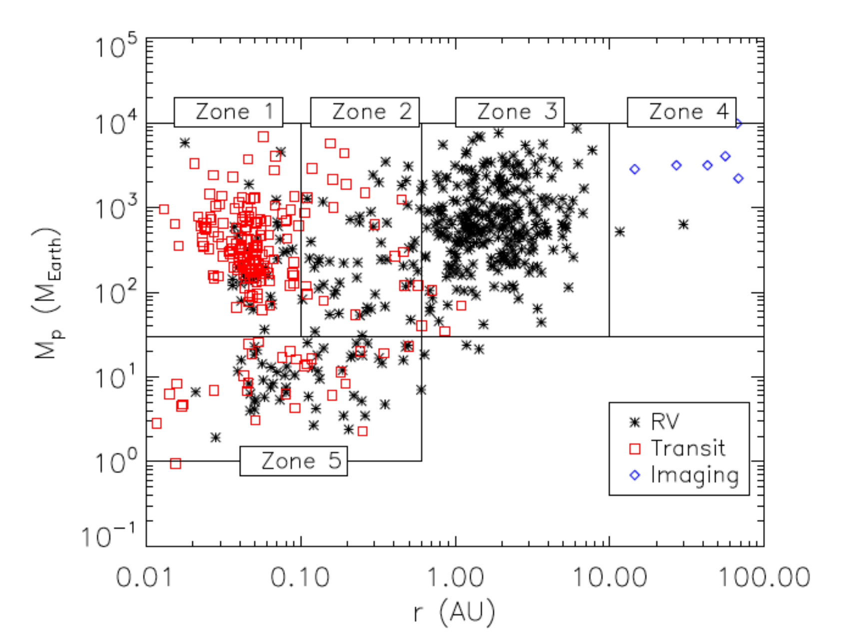


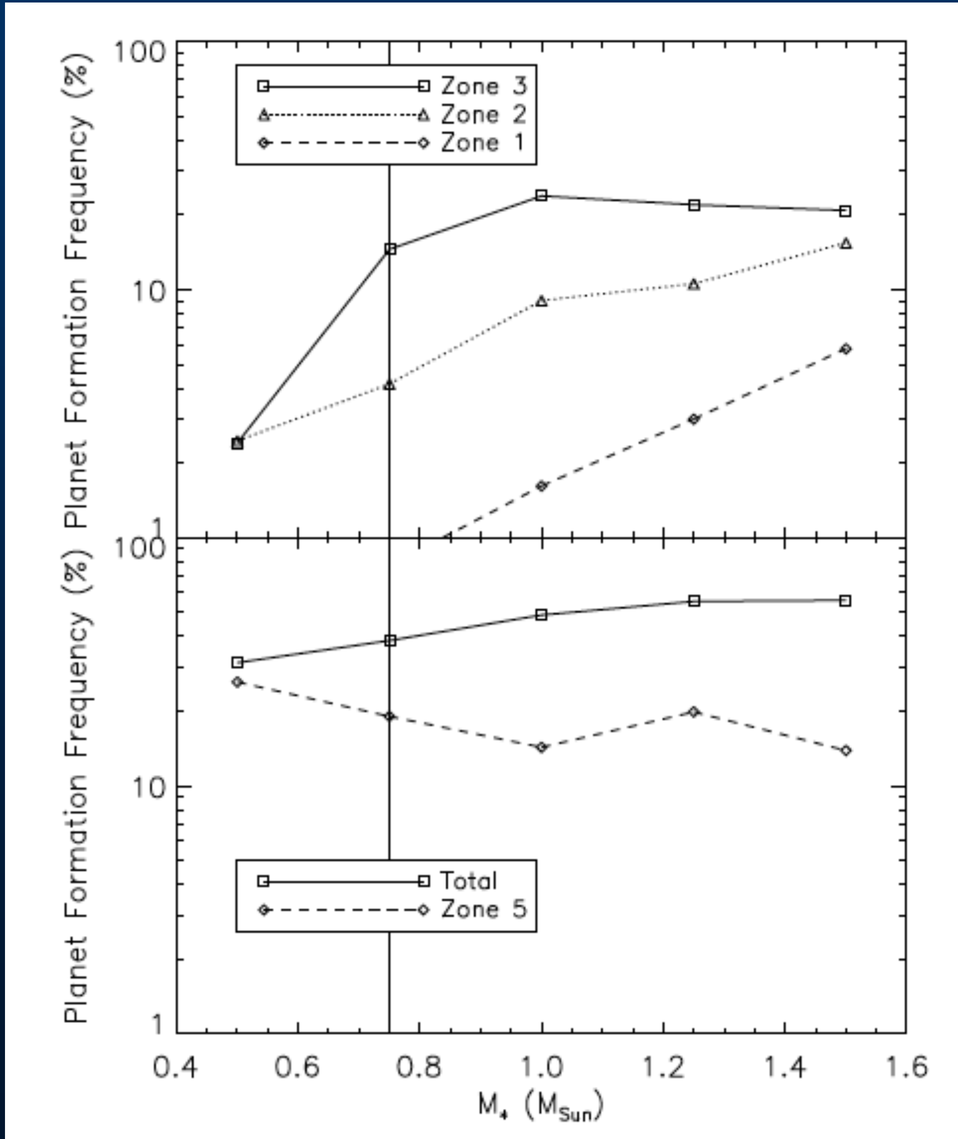
Johnson et al. 2010

No (massive) planets with 0.7 AU for stars with M>1.4 Msun



Yasuhiro Hasegawa and Ralph E. Pudritz 2014





Why is it interesting to search for short-period planets of intermediate-mass stars?

- **FORMARTION: Theory predicts that stars more massive than the sun should have a higher frequency of planets. However, the life-time of the disk is short (t_{disk}=2.5 Myrs for M*~1.0 M_{sun}, t_{disk}=1.2 Myrs for M*>1.3 M_{sun}).**

----> Is there enough time for the planets to form and migrate inwards?

- **EVOLUTION: Close-in planets of intermediate-mass stars would be engulfed when the star becomes a giant: How does this effect stellar evolution?**

- **EVOLTION: An A5V star is in the optical regime 14 times brighter than the sun! How does this affect the atmosphere of the planet?**

CoRoT

(Convection, Rotation et Transites planétaires)

Dec 27, 2006 to Nov 2, 2012

mass: 605 kg

Apertures of the telescope: 27 cm

Field of view: 4.5, 2.3 Square degrees per field

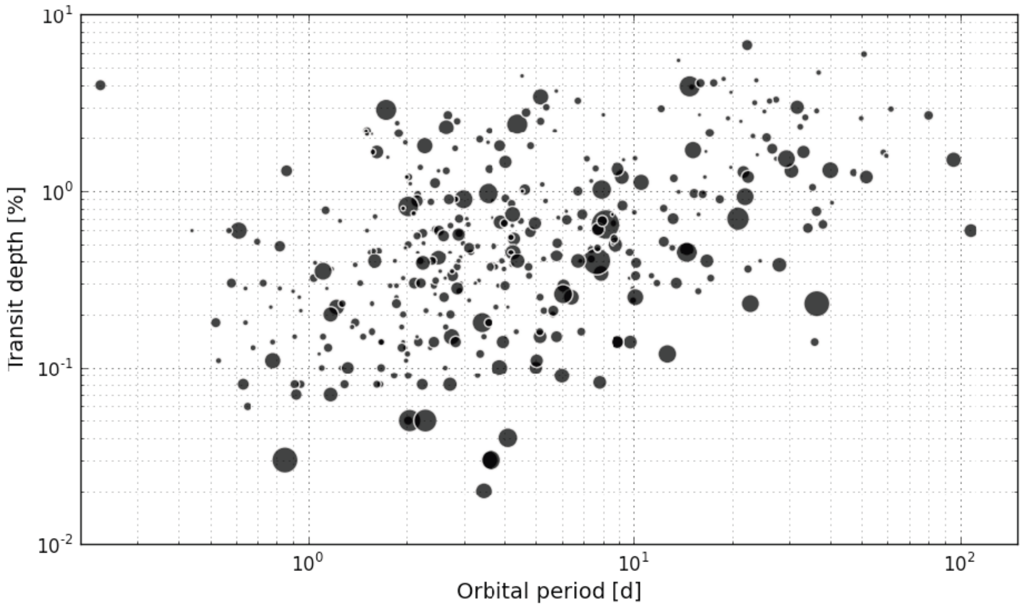
Harvest of CoRoT

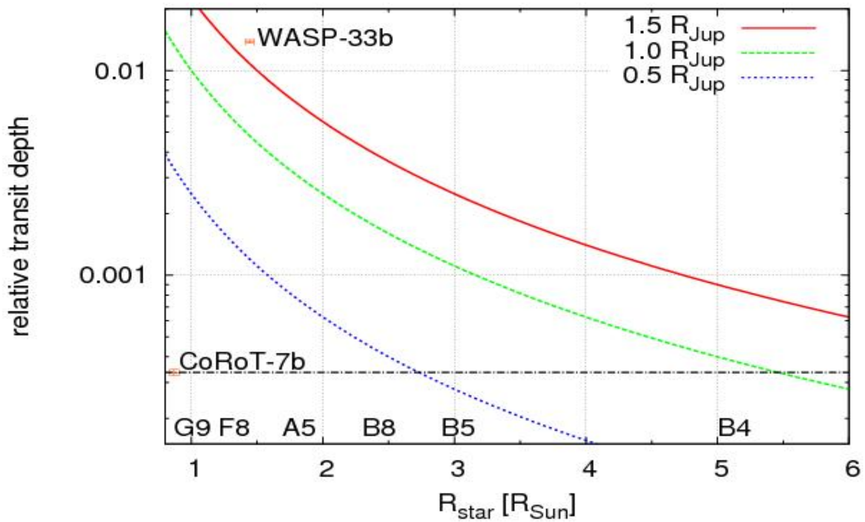
- 163664 stars with m_v=11-16.5 observed.
- 26 fields, with 58 square degrees in total observed.
- Shortest run 21 days, longest 152 days.
- Noise level 100,150, 250, ppm in 3h at m_v=12,13,14.
- 3-colour light-curves for m_v>15.
- 60% of all planets with 2-4 R_{Earth} detected for stars of m_v=14.
- **3900 stars with transits; 500 in the planetary regime.**
- Follow-up: > 200 nights for photometric FU (mostly 1-2m class telescopes); > 350 nights for RV FU (mostly 2-4 m class); 280 cases fully resolved: 19% diluted binaries; 27% undiluted binaries.
- 35 fully characterized planets.
- Unsolved cases: 20% too faint, 10% ephemeris lost,
- **---> 20% rotate too fast !**

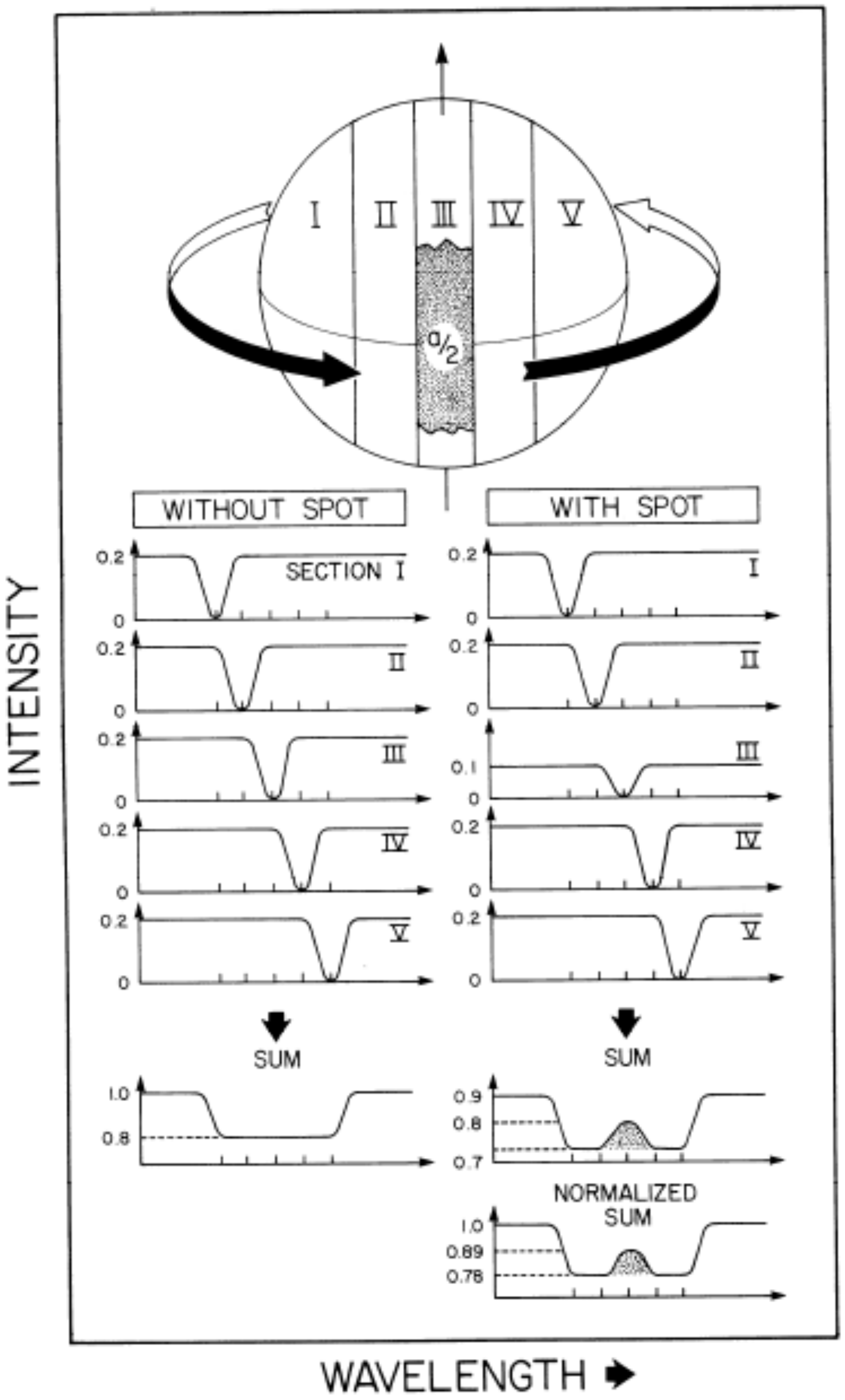
The planets of intermediate-mass stars should already be in the candidate list!

- **Candidates (from Santern), size of the dots indicates brightness of the star**

- **CoRoT has the capability to detect hot Jupiters of stars as early as B4V, and planets of 2 R_{Earth} around G-type stars**



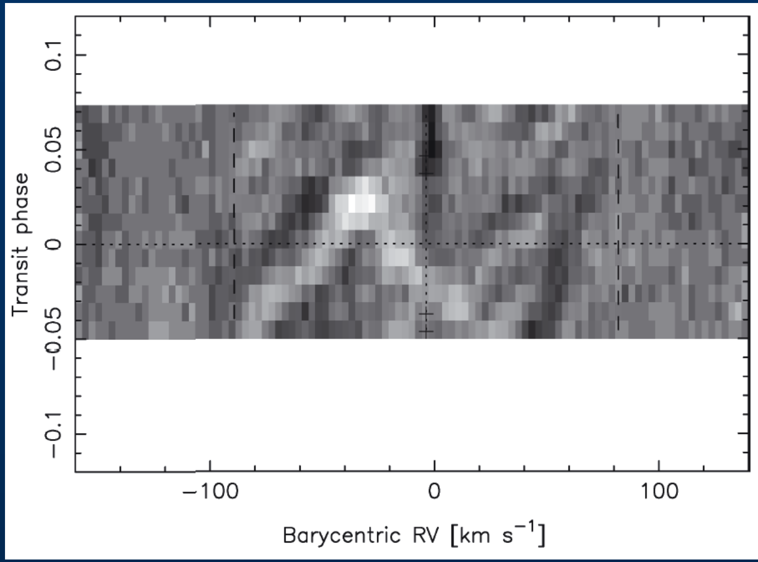


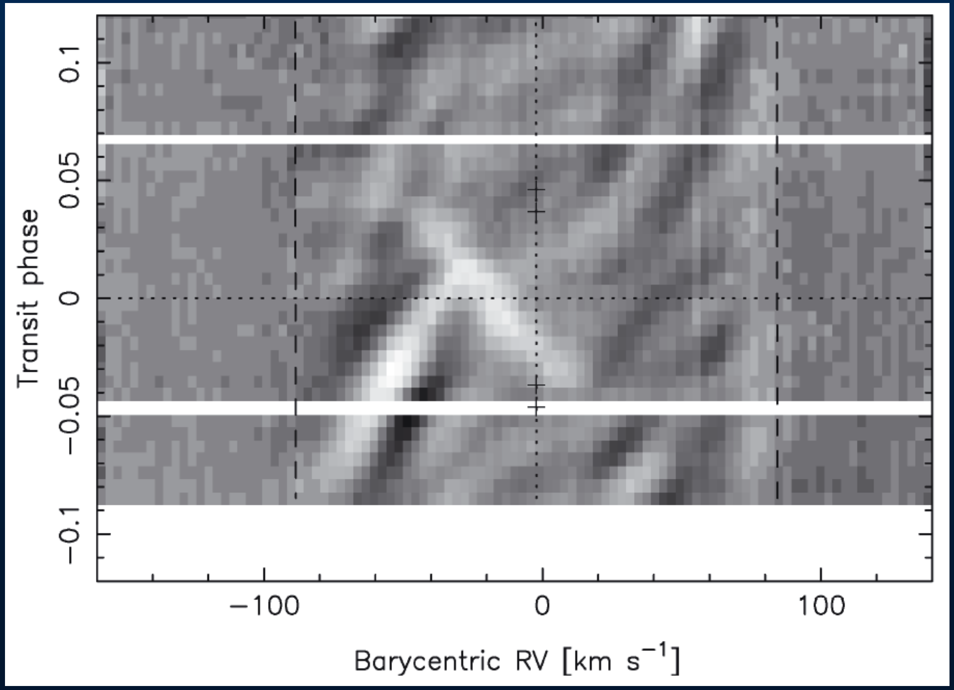


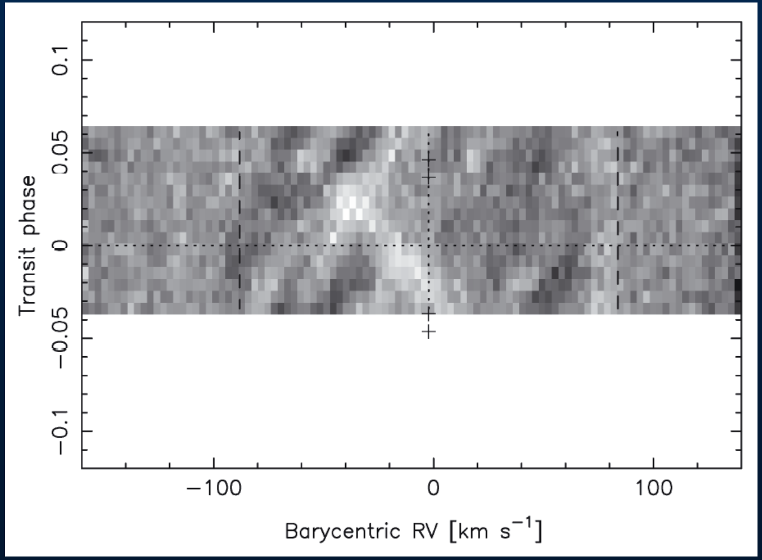
Detecting planets in rapidly rotating stars using time resolved spectroscopy

Volgt &Penrod 1983

**HD15082b (WASP-33b:)
Time series of the residual average spectral line: the “white” line from the middle right to the upper left is the signature of the planet (NOT, McDO, TLS-data)**







A survey for short period transiting planets of stars more massive than the sun using the CoRoT satellite

Excluding false-positives

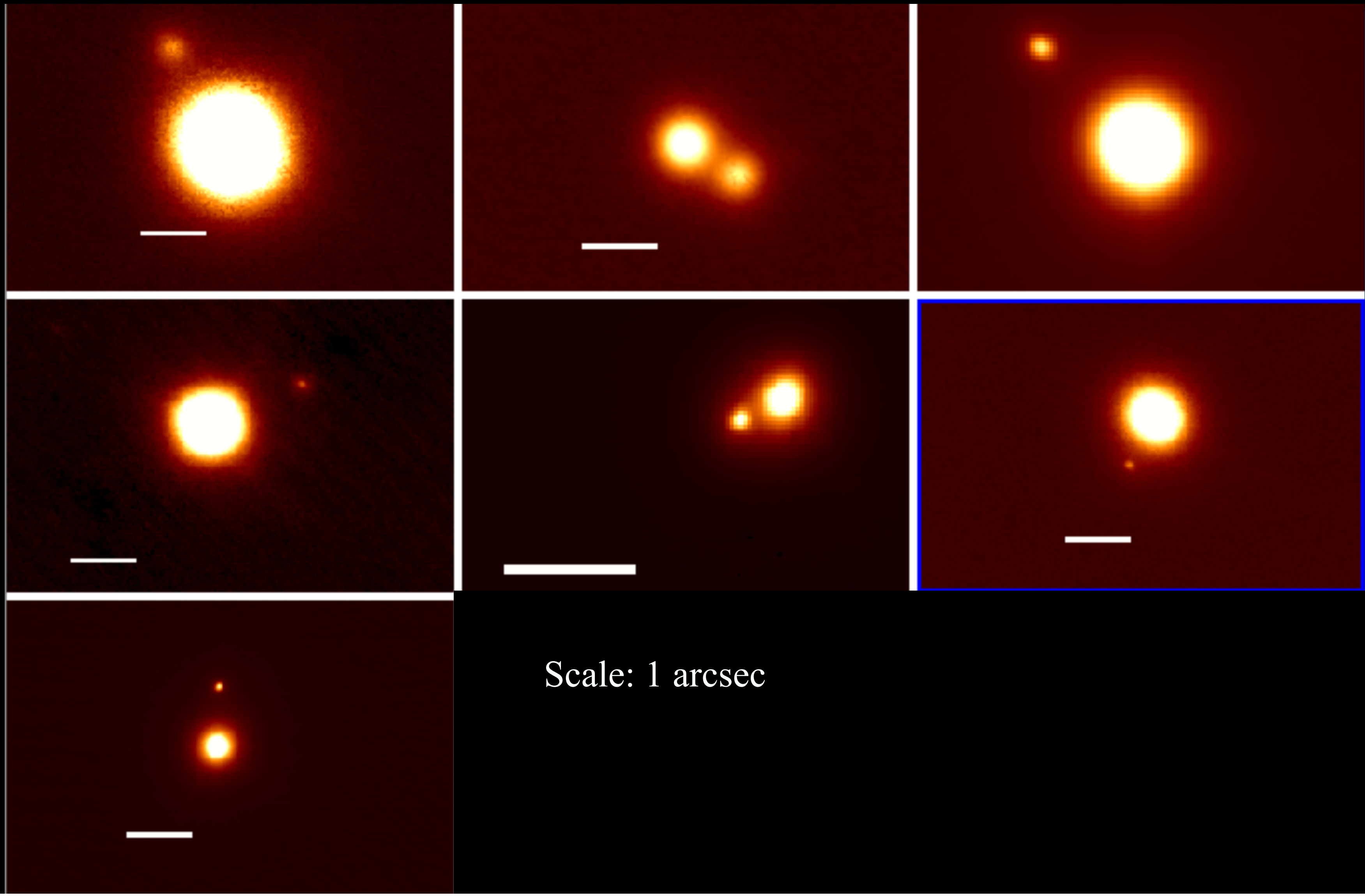
- Detailed modelling of the (multi-colour) LCs
- Photometry/low-resolution spectroscopy to exclude giant stars (consistence checks)
- Seeing-limited observation in and out of transit

---> AO-imaging

---> HR IR-spectroscopy

- Radial-velocity observations

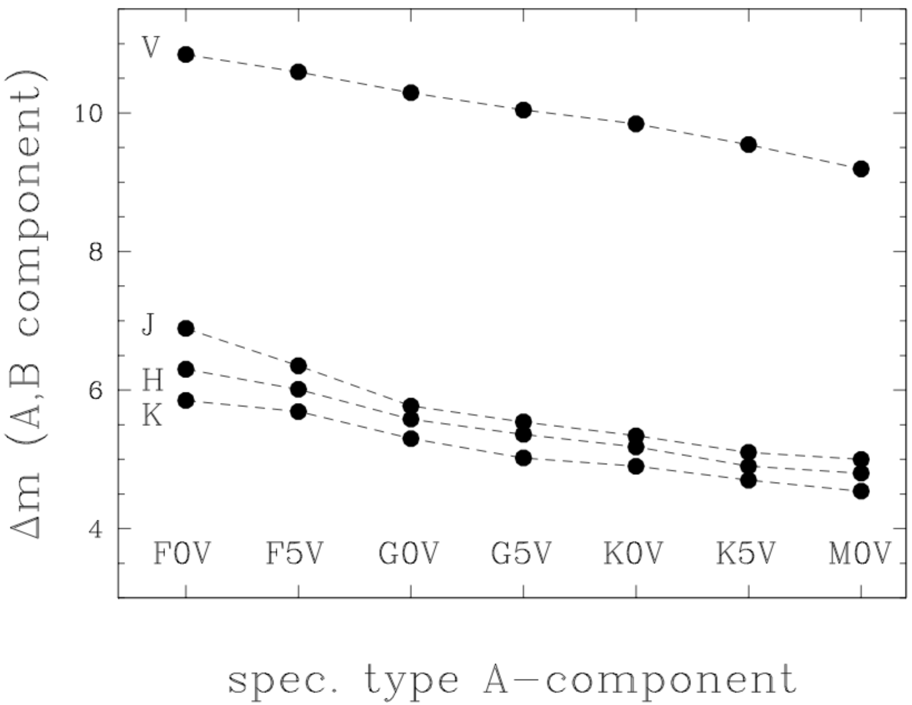
AO-imaging:
Expectation: <10% of the stars should have a companions.
Result: 30-40% have one!

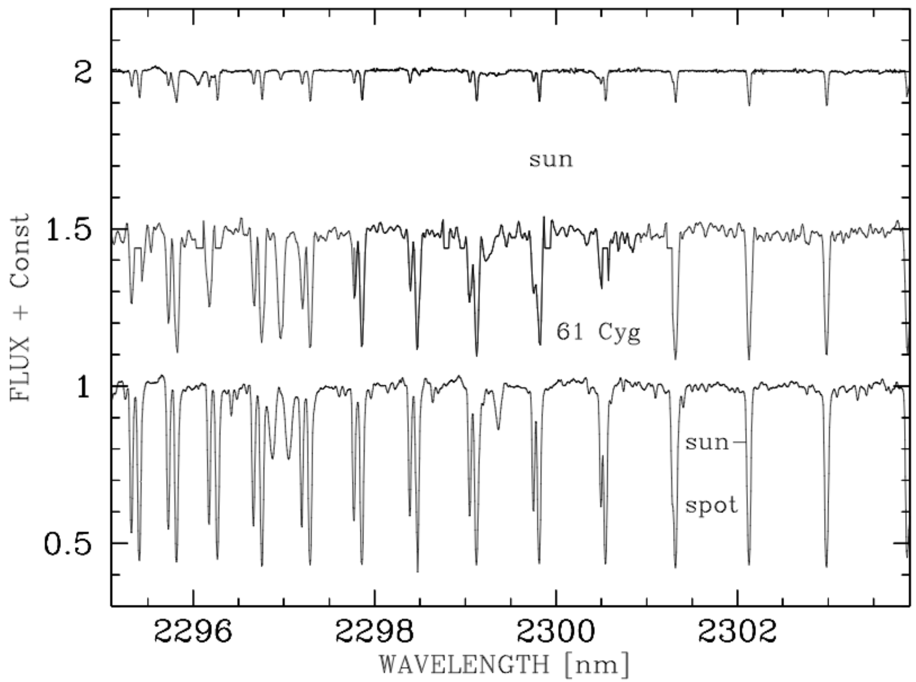


Scale: 1 arcsec

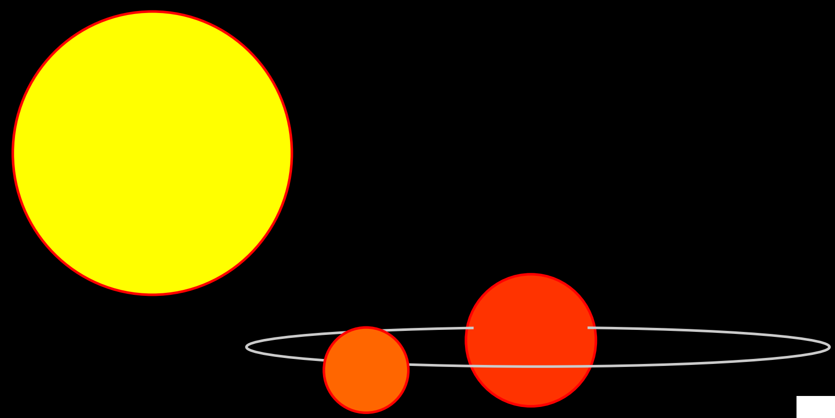
High resolution near-infrared spectroscopy to exclude companions

- The brightness difference between a solar-like star and a potential FP is much smaller in the IR than in the optical (upper Fig.: brightness difference between a primary and a secondary that mimics a transiting Jupiter-like planet).
- The CO-lines become stronger for cooler stars.

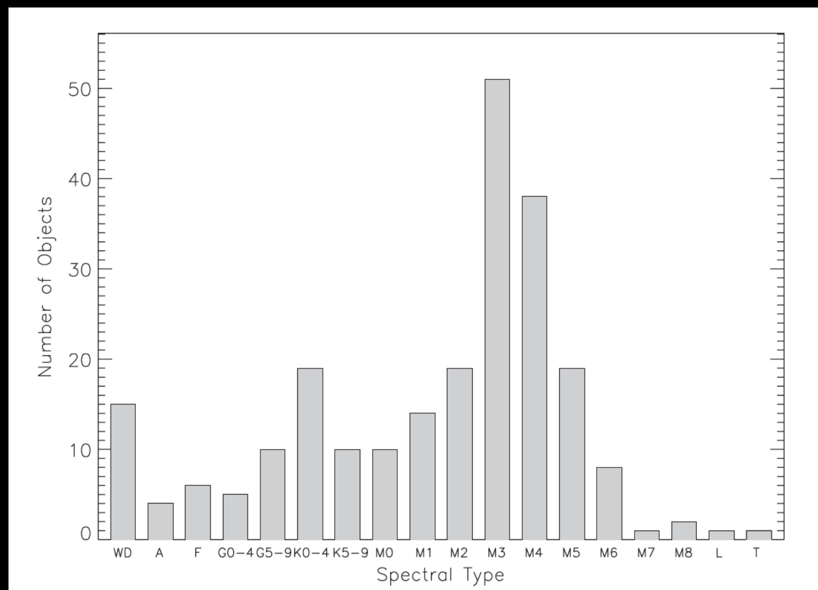




After the detailed light-curve analysis (consistence checks) and seeing limited observations, the remaining false-positives typically look like this!



Companions to stars within 10pc (Dietrich et al. 2012)



Sub-stellar companions orbiting stars with $M>1.1\ M_{sun}$ discovered by CoRoT

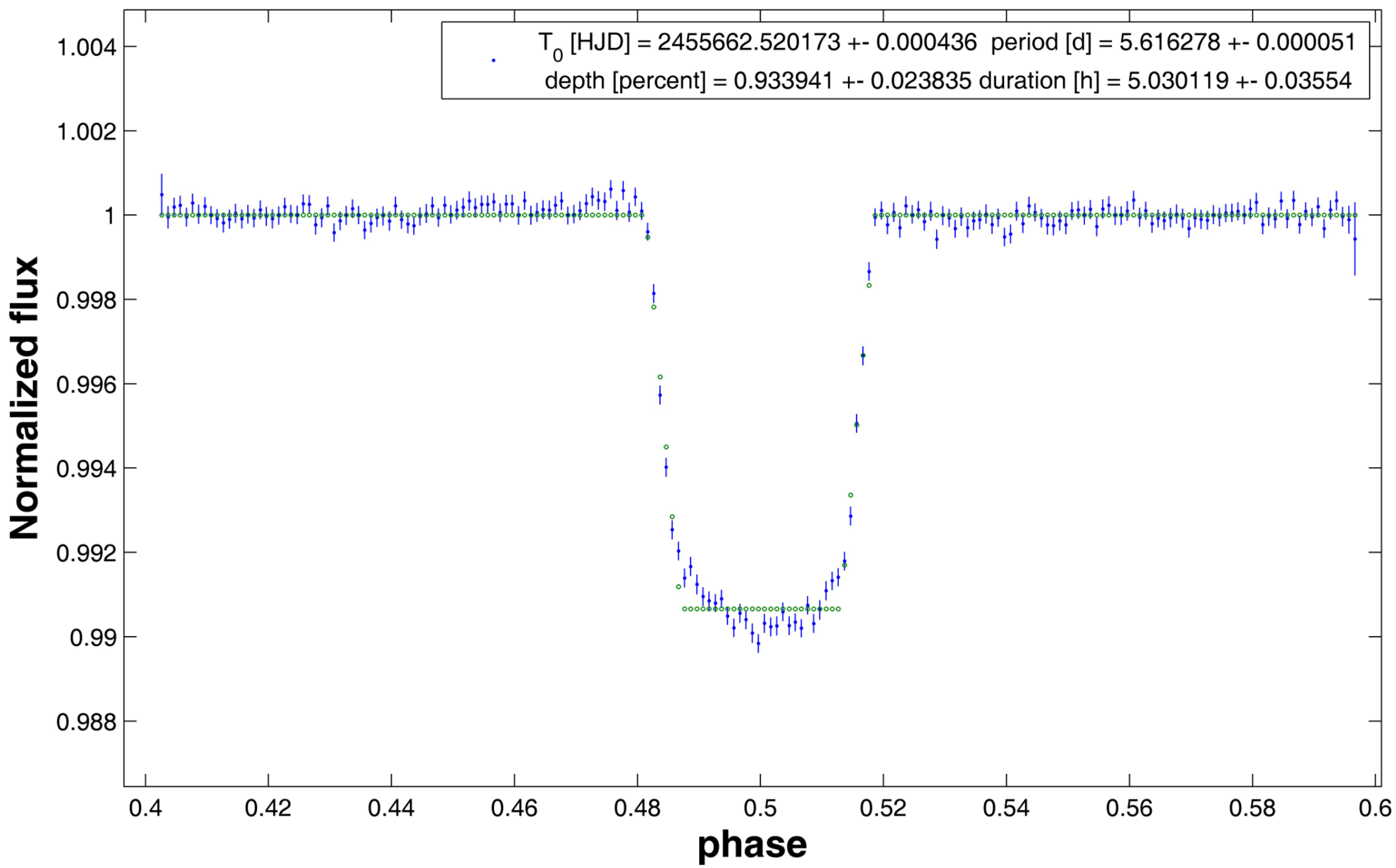
Name	M_{star}	Period[d]	Rplanet $[R_{Jup}]$	Mplanet $[M_{Jup}]$	Density $[g\ cm^{-3}]$
CoRoT-3b	1.37±0.09	4.3	1.01±0.07	21.7±1.0	26.4±5.6
CoRoT-15b	1.32±0.12	3.0	1.12±0.23	63.3±4.1	59±35
CoRoT-21b	1.29±-0.09	2.7	1.30±0.14	2.53±0.37	1.53±0.53
CoRoT-11b	1.27±-0.05	3.0	1.43±0.03	2.33±0.34	0.99±0.15
CoRoT-19b	1.20±-0.05	3.9	1.29±0.03	1.14±0.05	0.51±0.05
CoRoT-4b	1.16±-0.02	9.2	1.17±0.05	0.75±0.01	0.58±0.15
CoRoT-22b	1.15±-0.08	9.7	0.52±0.12	<0.15	<1.3
CoRoT-20b	1.14±0.08	9.2	0.84±0.04	4.24±0.23	9.87±1.10
CoRoT-23b	1.14±0.08	3.6	1.05±0.13	2.8±0.3	3.3±1.0
CoRoT-14b	1.13±0.09	1.5	1.09±0.07	7.6±0.6	7.3±1.5
CoRoT-32b	1.35±0.06	20	1.14±0.04	2.39±0.35	2.2±0.3
CoRoT-35b	1.4	5.6	1.9	<1.4	

A new object: CoRoT 35b

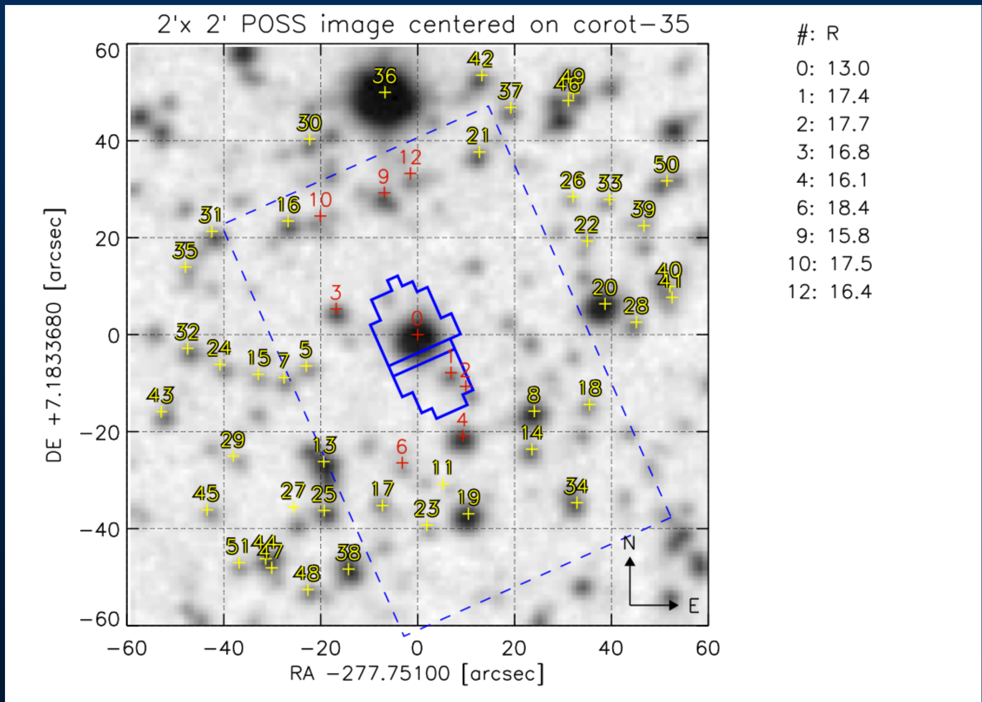
CoRoT-35b

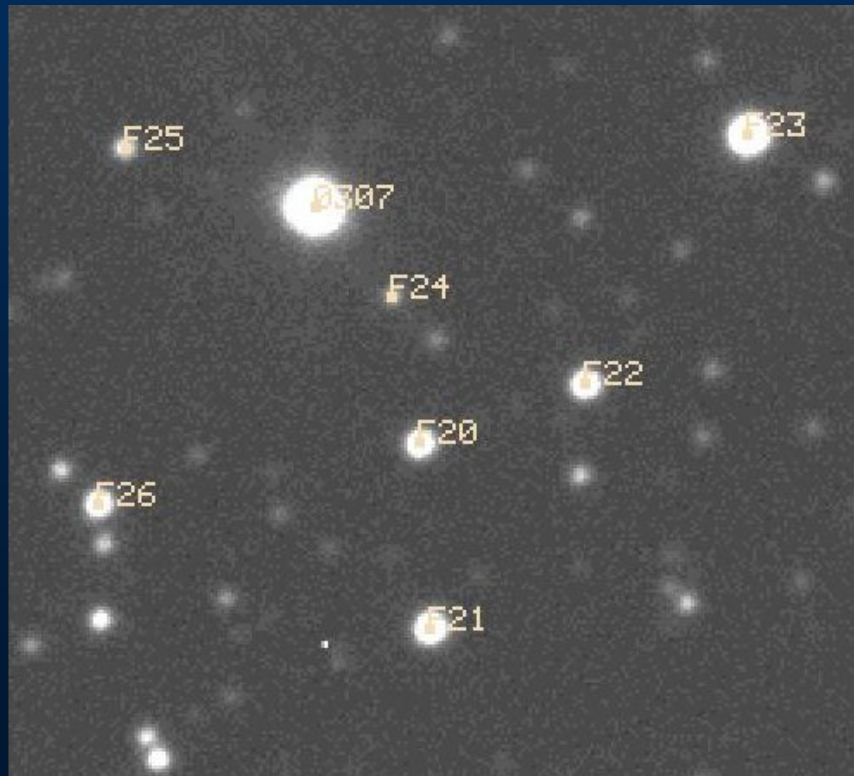
Mass / radius	1.43±0.04 M_{sun} 1.93±0.11 Rs_{un}
spectral type	F4V
T_{eff}	6430±100 K
log(g)	4.0±0.1
v sin i	21 kms^{-1}
[M/H]	0.0±0.0
Orbital period	5.616278±0.000051 days
Planet mass	<1.4 M_{jup}
Planet radius	1.9±0.1 R_{jup}
Orbital separation, a	0.064 AU = 7 R_{star}
Projected obliquity λ	90° VTLS-UVES, NOT-FIES

Transit light-curve obtained by CoRoT



Seeing limited imaging with 1-m WISE& IAC 0.8 m telescopes: Transit is detected on source!



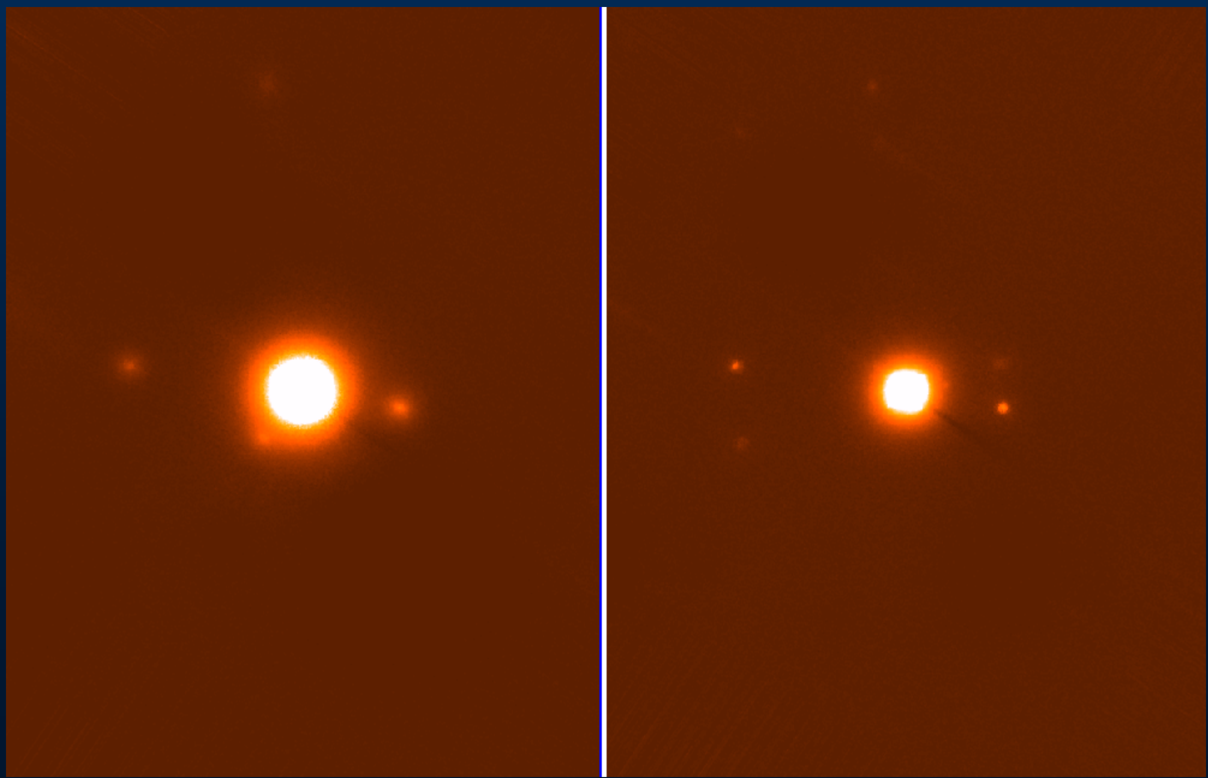


AO-imaging

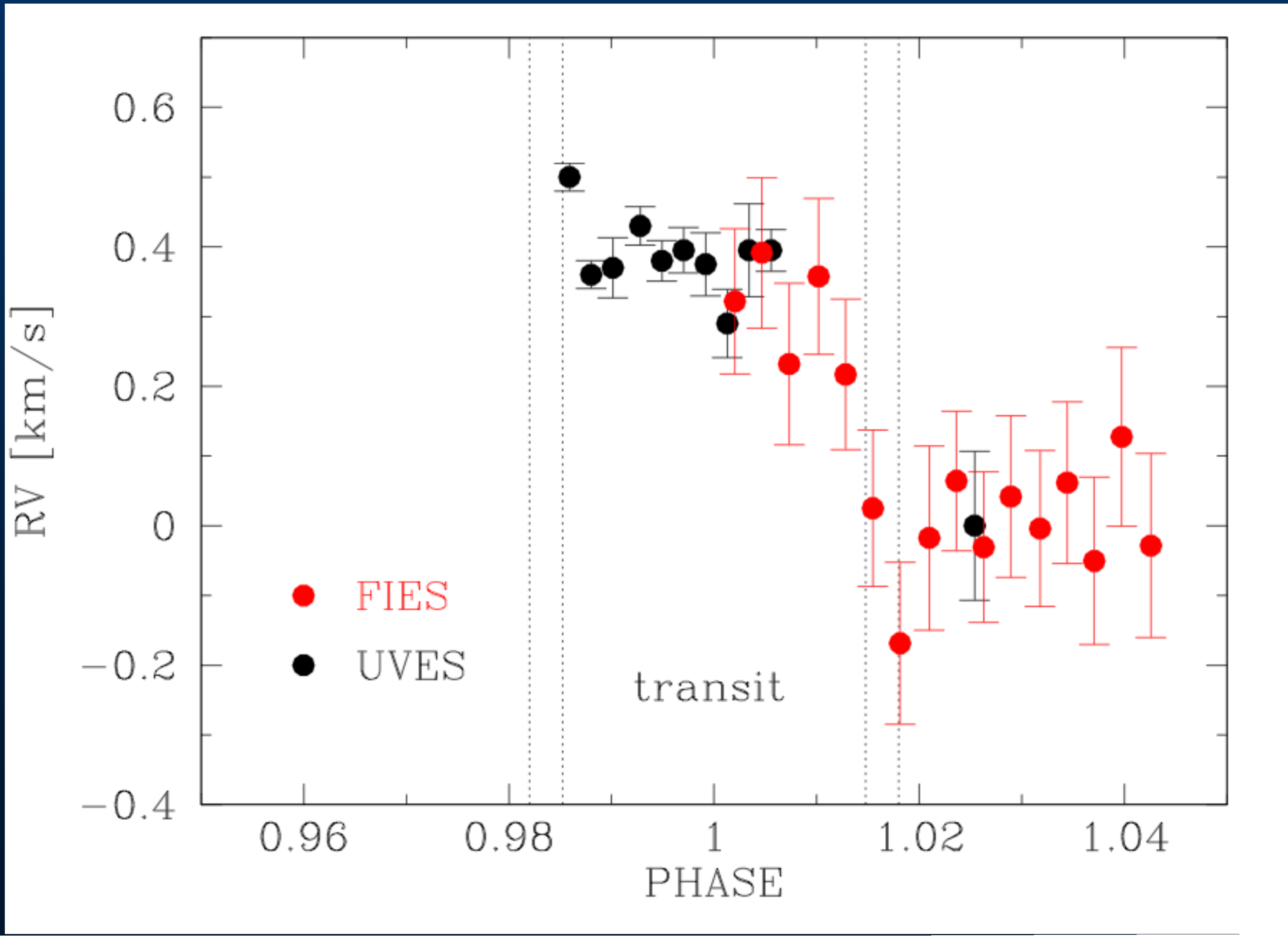
- PISCES@LBT in J and K-band
- CoRoT LC shows transit with period 5.6d, DF/F=0.9%
- V=13.055+/-0.066 --> we have to exclude stars of V=18.2 mag
- PISCES observations show two additional stars:

star1: 1.96 arcsec distance, J=15.7+/-0.1, K=16.2+/-0.1 --> fainter than V=18.2

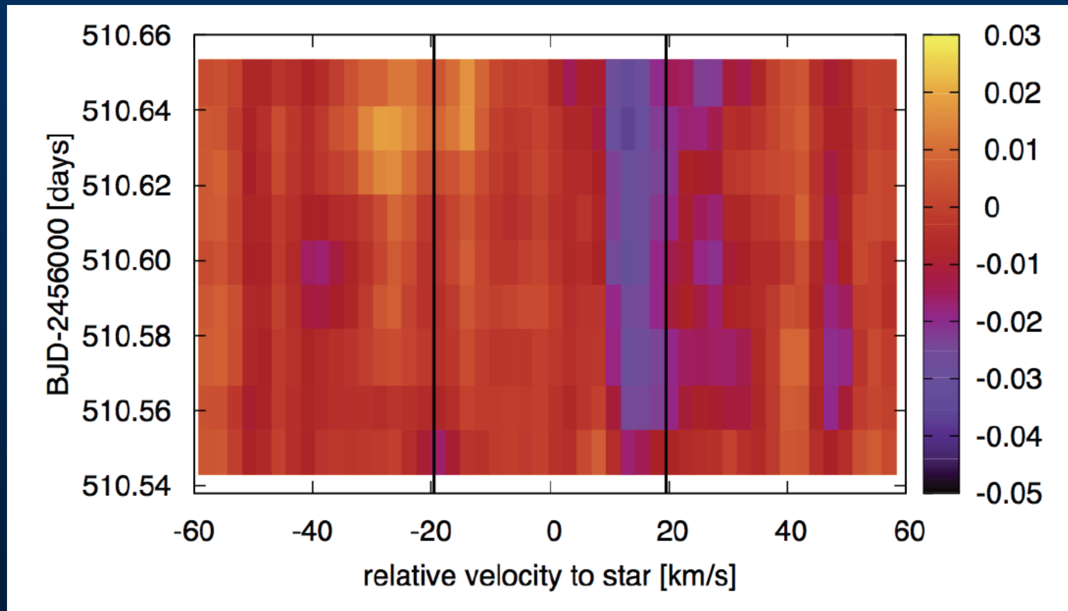
star2: 3.46 arcsec distance, J=17.1+/-0.1, K=16.8+/-0.1 --> fainter than V=18.2

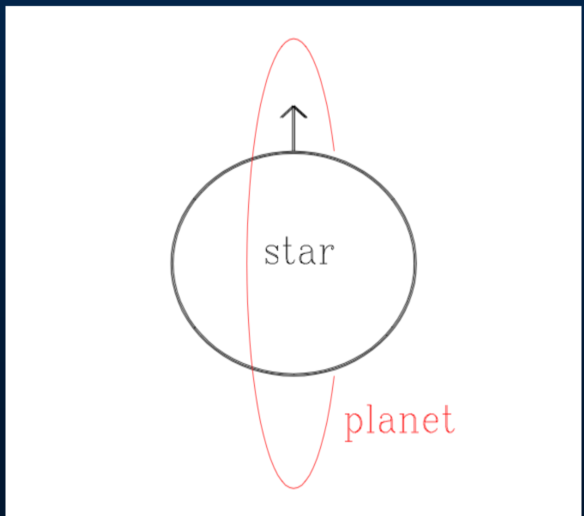


RV-measurements during the transit



Time-resolved spectroscopy of CoRoT-35b: The planet has a polar orbit!



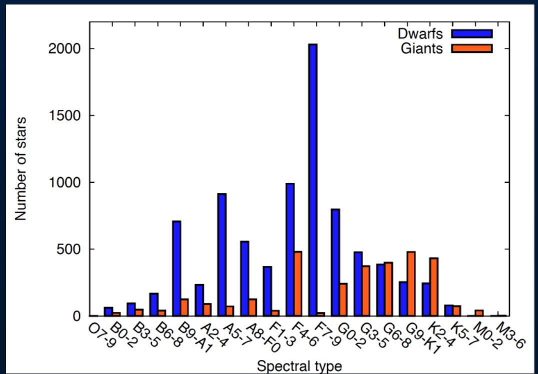


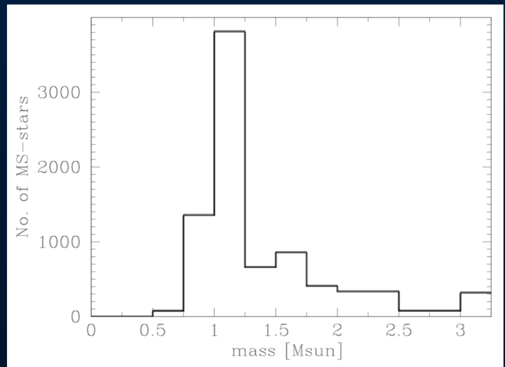
Statistics of the planet discoveries:

- **0-5% are orbiting stars of 1.3-3.2 M_{sun} ("A-stars")**
- **30-32% are orbiting stars of 1.1 to 1.3 M_{sun} ("F-stars")**
- **50-54% are orbiting stars of 0.9- 1.1 M_{sun} ("G-stars")**
- **13-16% are orbiting stars of 0.4-0.8 M_{sun} ("K-stars")**

The sample:

- **16% are stars of 1.3-3.2 M_{sun} ("A-stars")**
- **35% are stars of 1.1 to 1.3 M_{sun} ("F-stars")**
- **15% are stars of 0.9- 1.1 M_{sun} ("G-stars")**
- **5% are stars of 0.4-0.8 M_{sun} ("K-stars")**





Results:

---> We have surveyed 19 candidates with spectral-types B5V to F8V.

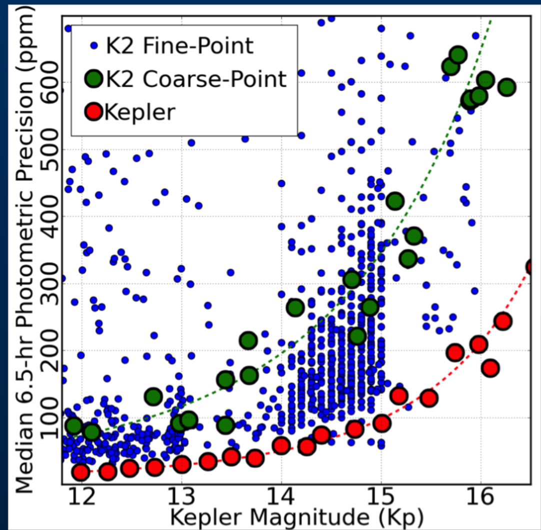
---> Although 25% of the CoRoT stars have masses in the range from 1.5 and 3.2 M_{sun}, we found only 1-2 that have sub-stellar companions.

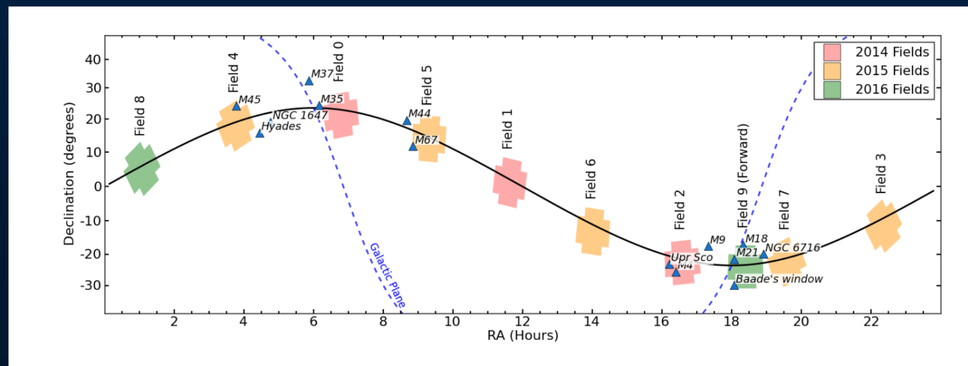
--> We do not find the same rapid increase of the frequency of massive planets for close-in planets as it is found for planets at large orbital distance (RV-surveys of giant stars).

---> The number of planets found for stars in the mass-range between 1.1 and 1.5 M_{sun} is within the errors the same as for solar-like stars.

Continue survey using Kepler 2 mission

- 300 ppm at V=14 in 3 hours (same as CoRoT)
- 10 fields, each observed for 80 days
- 1000 square degrees in total (17 times better than CoRoT).
- Field 0: 2014 Apr 30
- Field 1: 2014 Jul 22
- Field 2: 2014 Oct 14
- Field 3: 2015 Jan 5






Thank you
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A short look at Kepler data

- 2011: based on stellar statistics Morton & Johnson estimate the FP-art to be <10%.
- 2012: Santerne et al. obtain RV-measurements of 46 candidates with transit depth >0.4% and periods of less than 26d, from which they derive a FP-rate of 46%.
- 2012: Colón et al. obtain multicolour transit photometry 4 candidates with R < 6 R_{Earth}, two candidates are FP. The probability of identifying two false positives out of a sample of four targets is less than 1%, assuming an overall false positive rate for Kepler planet candidates of 10%.
- 2012: Lillo-Box et al. observes 98 candidates using lucky imaging. In 41.8% of the candidates, they find at least one additional star within 6 arcsec. In 17% there is at least one star within 2 arcsec. Of these, 42% of the same i-z colour as a physical companion.
- 2014: Gilliland et al. observes 23 cool, low mass planet candidates observed with HST. 6 have physical companions. This is 3 times higher than expected.

The first known transiting planet of a star with M_*>1.4 M_{sun} is HD15082b (WASP-33b)

mass	1.495±0.031 M_{sun}
spectral type	A5V
T_{eff}	7430±100 K
Log(g)	4.3±0.2
v sin i	90±10 kms^{-1}
[M/H]	0.1±0.2
Orbital period	1.2198669±0.0000012 days
Planet mass	<2.0 M_{jup} ?
Planet radius	1.497±0.045 R_{jup}
Orbital separation, a	0.02555±0.00017 AU = 3.79±0.67 R_{star}
Projected obliquity λ	251.2±1.0° TLS 254.2±1.2° McD 251.6±0.7° NOT

Known planets of stars with M> 1.4 Msun within 0.2 AU

Name of star	type	Mass of star [Msun]	Spectral type	Mass of planet [Mjup]	Semi-major axis [AU]
Kepler-340c	transit	2.11	?	?	0.178
Kepler-340b	transit	2.11	?	?	0.134
WASP-78b	transit	2.02+/-0.09	F8	1.16+/-0.1	0.0415+/0.0006
HD102956b	RV	1.68+/-0.11	A	0.96+/-0.05	0.081+/-0.002
WASP-82b	transit	1.63+/-0.08	F5	1.24+/-0.04	0.0447+/0.0007
WASP-71b	transit	1.572+/-0.062	F8	2.258+/-0.072	0.04631+/0.0006
WASP-100b	transit	1.57+/-0.1	F2	2.03+/-0.12	0.0457+/-0.001
WASP-79b	transit	1.56+/-0.09	F3	0.9+/-0.09	0.0539+/-0.0009
CoRoT-11b	transit	1.56+/-0.1	F6V	2.33+/-0.27	0.04351+/0.00036
WASP-90b	transit	1.55+/-0.1	F6	0.63+/-0.07	0.0562+/-0.0012
WASP-49b	transit	?	?	0.378+/-0.027	0.0378+/-0.027
OGLE2-TRL9b	transit	1.52+/-0.08	F3	4.34+/-1.48	0.0308+/-0.0005
HAT-P-40b	transit	1.512+/0.077	?	0.615+/-0.038	0.0608+/-0.0011
HAT-P-7b	transit	1.51+/-0.05	?	1.741+/0.028	0.0379+/-0.0004
WASP-33b	transit	1.495+/-0.031	A5	<4.59	0.02558+/-0.0023
HD38529b	RV	1.48+/-0.05	G4IV	0.78	0.131+/-0.0015
Kepler-40b	transit	1.48+/-0.06	F5IV	2.2+/-0.4	0.08+/-0.003
WASP-99b	transit	1.48+/-0.1	F8	2.78+/-0.13	0.0717+/-0.0016
KELT-1b	transit	1.471+/-0.045	F5	27.38+/-0.93	0.02472+/0.00039
WASP-76b	transit	1.46+/-0.07	F7	0.92+/-0.03	0.033+/-0.0005
WASP-88b	transit	1.45+/-0.05	F6	0.56+/-0.08	0.06431+/0.00064
Kepler-238b	transit	1.43+/-1.31	?	?	0.034
Kepler-238c	transit	1.43+/-1.31	?	?	0.069
Kepler-238d	transit	1.43+/-1.31	?	?	0.115
XO-3b	transit	1.41+/-0.08	F5V	11.79+/-0.59	0.0454+/-0.00082
CoRoT-3b	transit	1.41+/-0.08	F3V	21.77+/-1.0	0.057+/-0.003
HAT-P-39b	transit	1.404+/-0.051	?	0.599+/-0.099	0.0509+/-0.0006
HAT-P-33b	transit	1.403+/-0.096	F	0.763+/-0.117	0.0503+/-0.0011
Kepler-74b	transit	1.40+/-0.13	F8	0.68+/-0.09	0.084+/-0.014
PSR 1719-14b	pulsar	1.40	-	1.0	0.0044