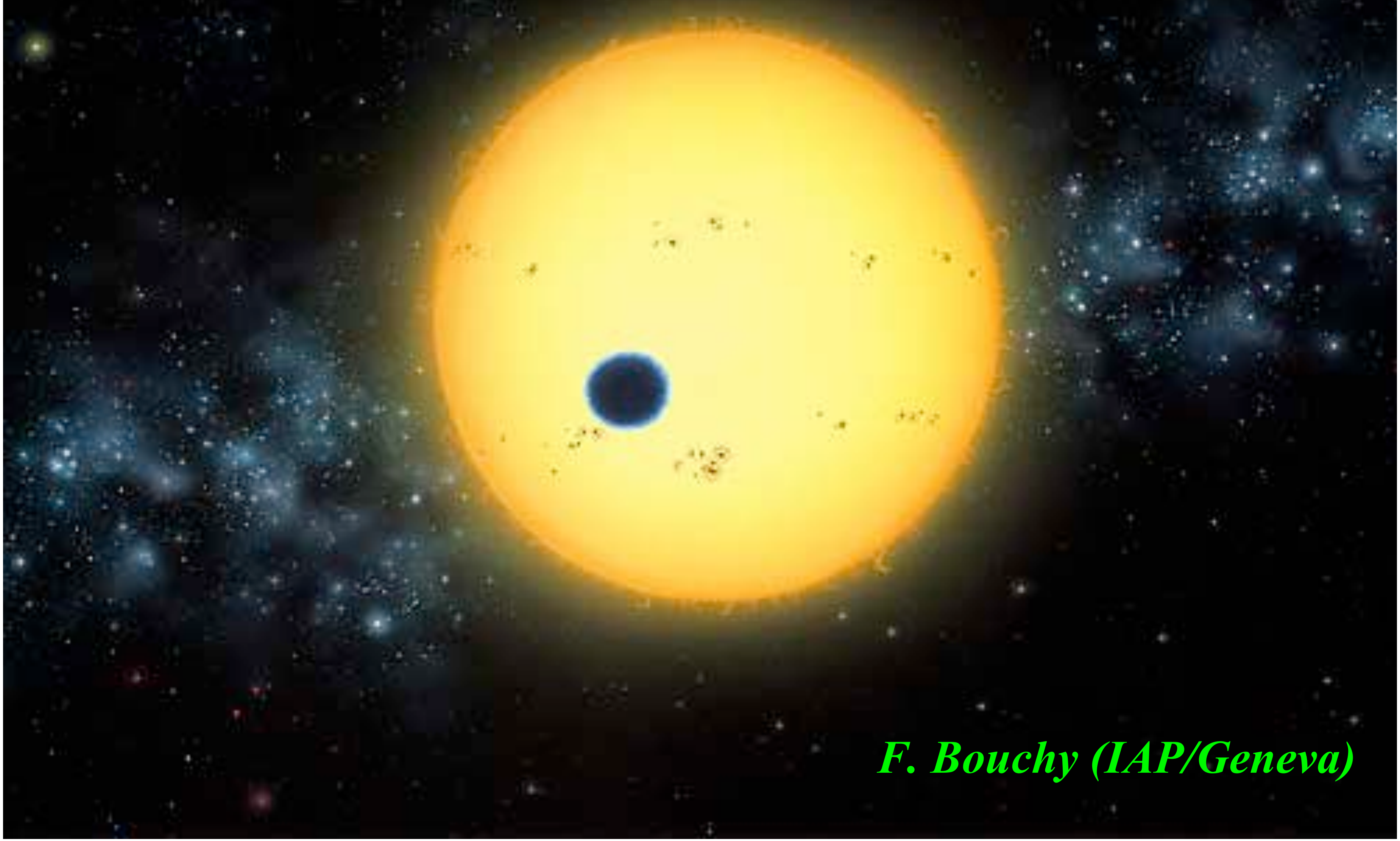
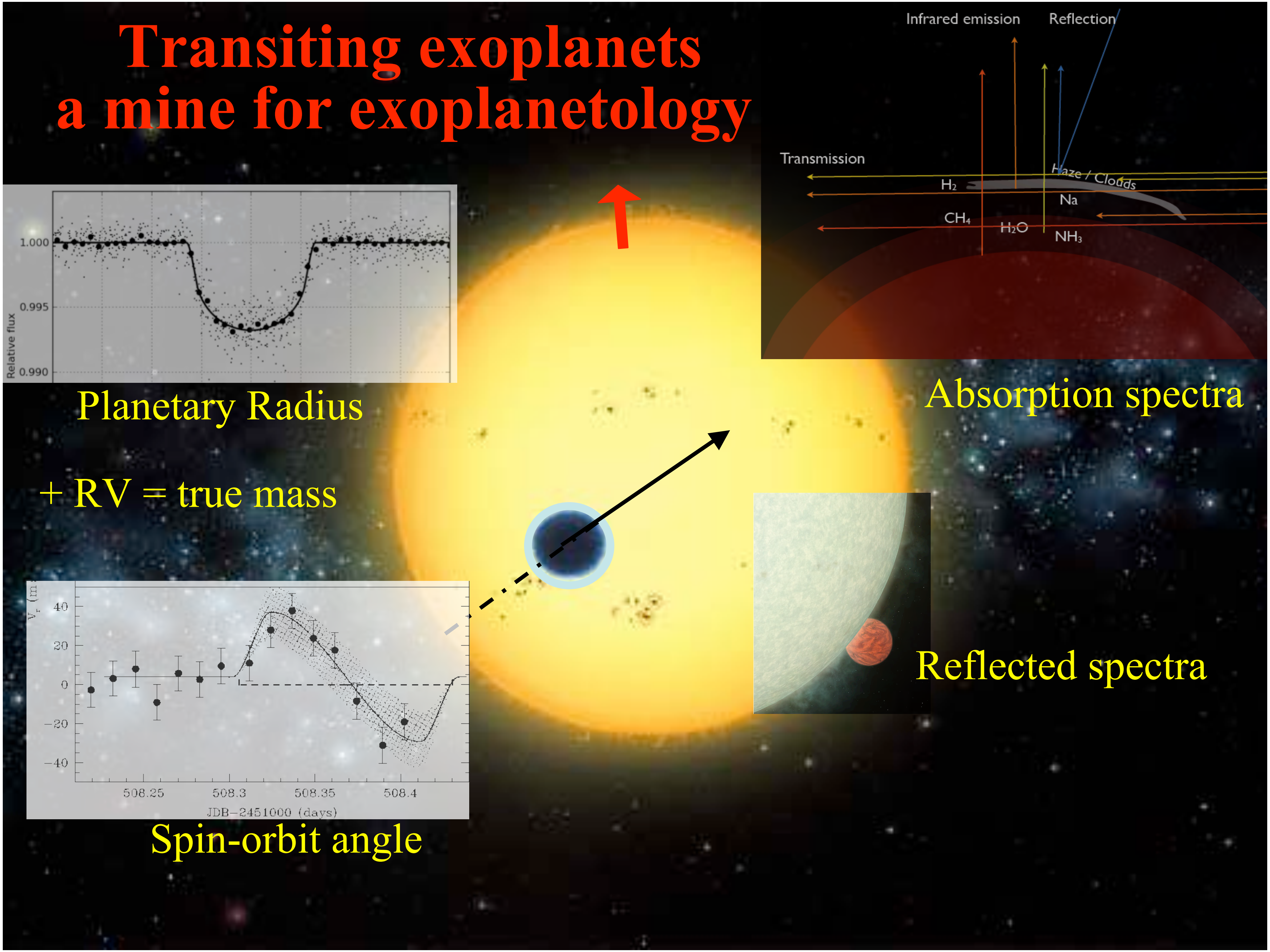
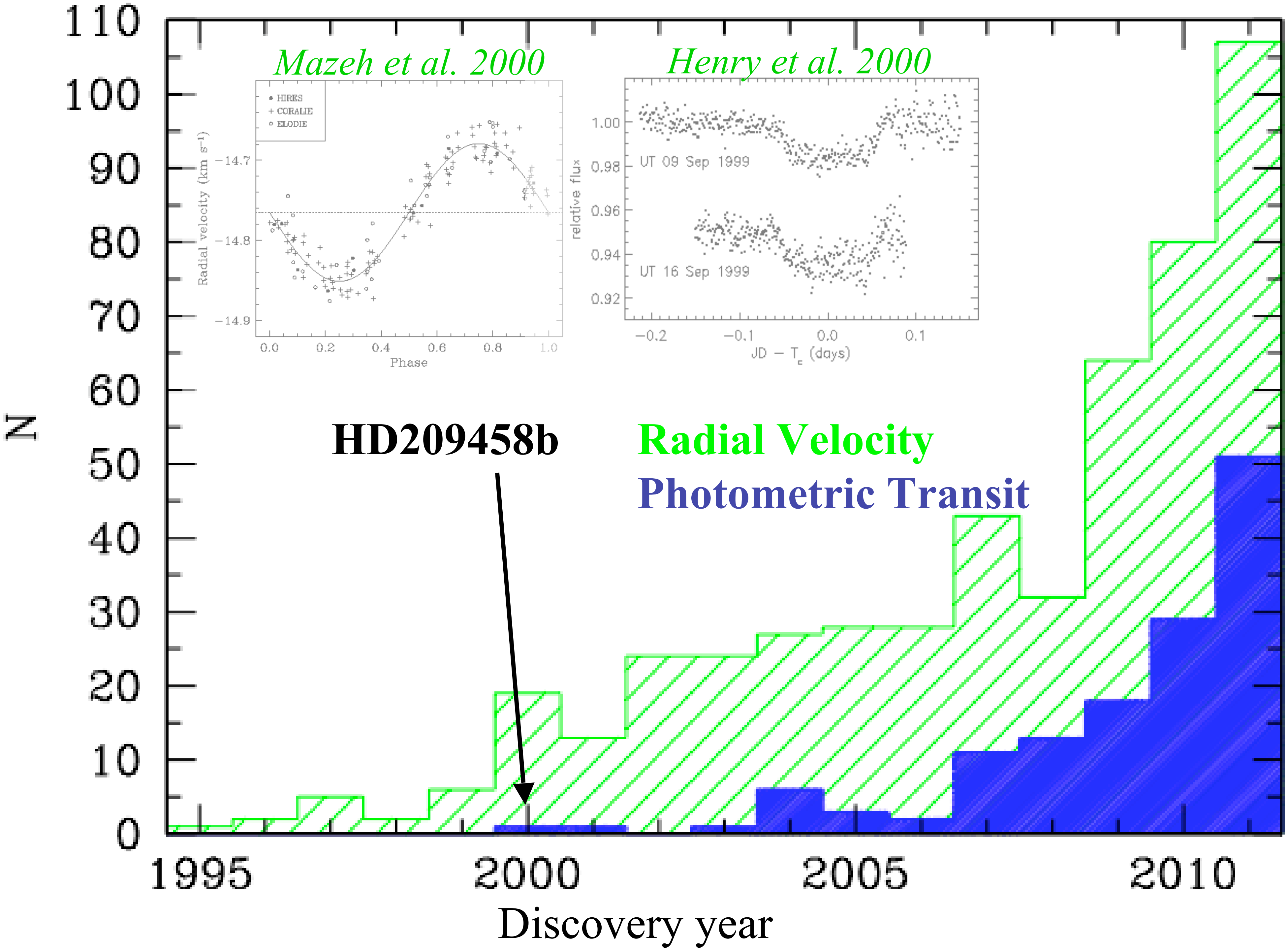
Detection, validation and characterization of transiting exoplanets

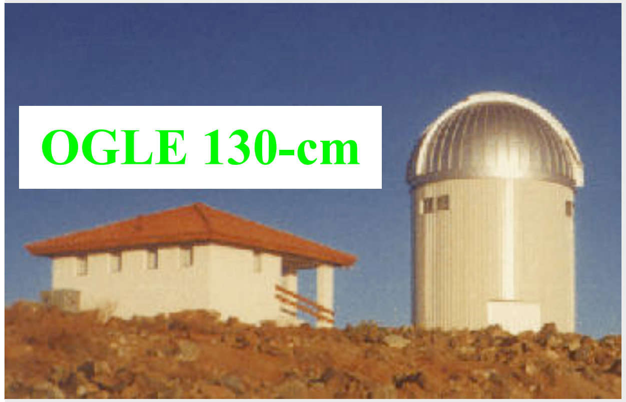


F. Bouchy (IAP/Geneva)

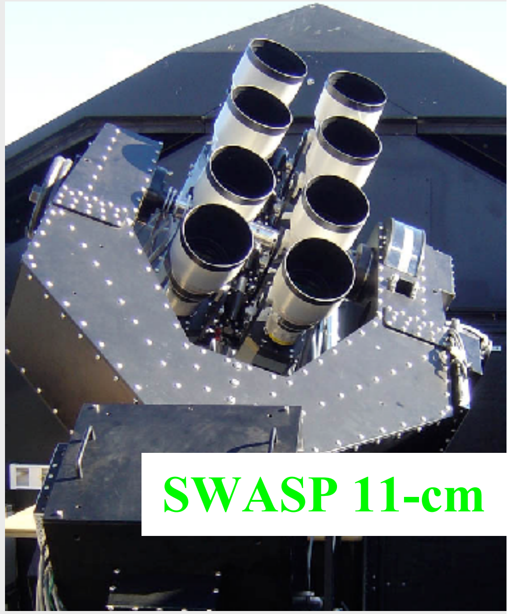

Transiting exoplanets
a mine for exoplanetology
Infrared emission
Reflection
Transmission
Haze / Clouds
H_2
Na
CH_4
H_2O
NH_3
Absorption spectra
1.000
0.995
0.990
Relative flux
Planetary Radius
+ RV = true mass
Reflected spectra
40
20
0
−20
−40
508.25
508.3
508.35
508.4
JDB−2451000 (days)
Spin-orbit angle

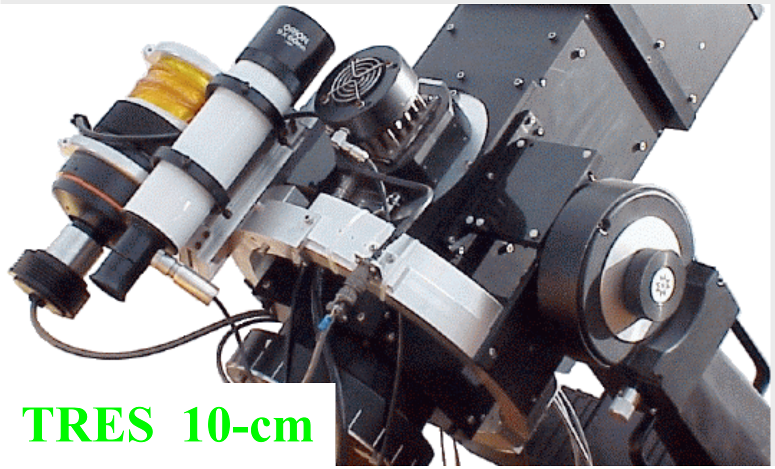


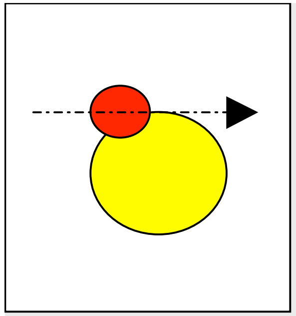
Mazeh et al. 2000
HIRES
CORALIE
ELODIE
Radial velocity (km s−1)
Phase
Henry et al. 2000
relative flux
UT 09 Sep 1999
UT 16 Sep 1999
JD − Tc (days)
HD209458b
Radial Velocity
Photometric Transit
N
Discovery year



Ground and space photometric surveys for search for transiting planet candidates

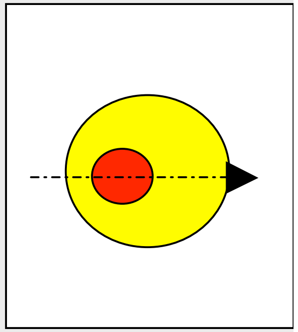


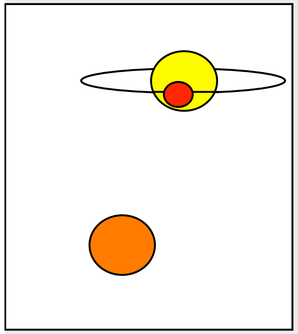




Grazing eclipsing binaries

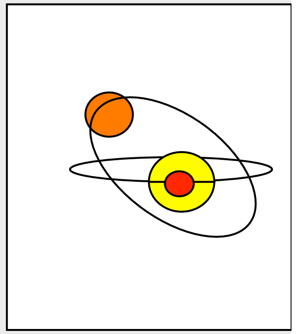
Eclipsing M dwarfs

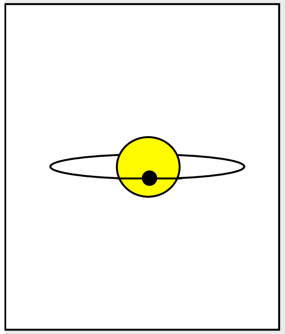




Background eclipsing binaries
(inside photometric window)

Blended eclipsing binaries
(inside seeing)





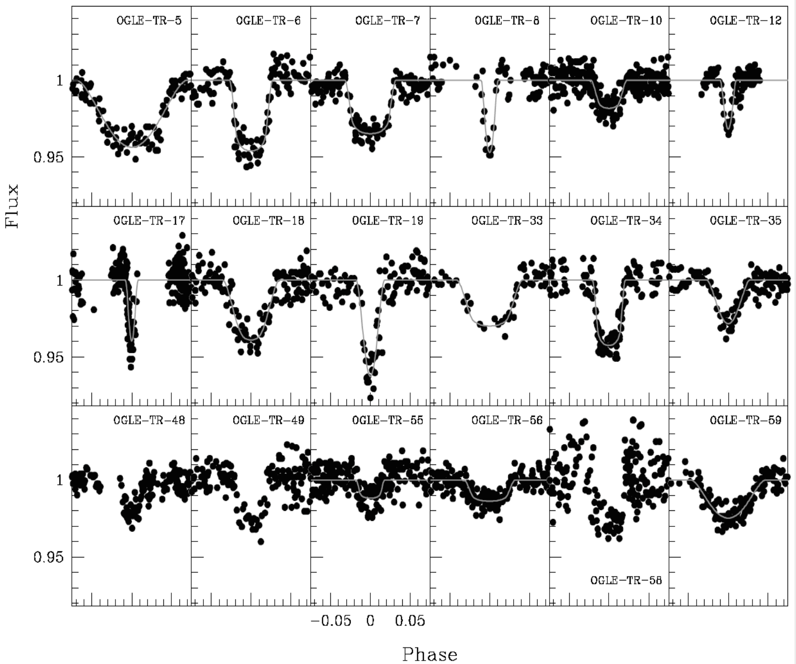
Transiting planets

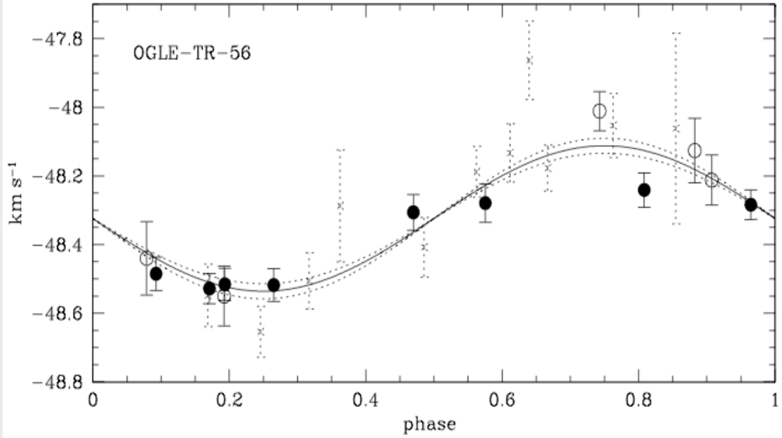
False Positives Rate > 35% - 90%

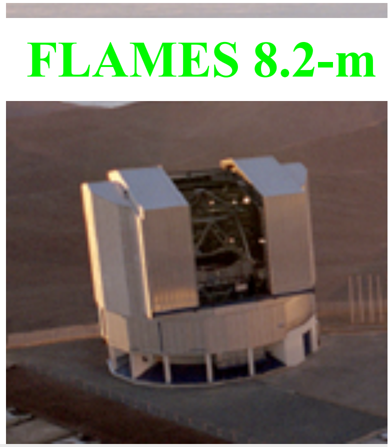
Radial Velocity Follow-up

Main goals:
- establish the nature of the transit events
- characterize the mass and eccentricity

By-product:
- Central star spectroscopic parameters
- Stellar activity indicators and corrections
- Spin-orbit angle measurement
- Long term follow-up (multiple systems)



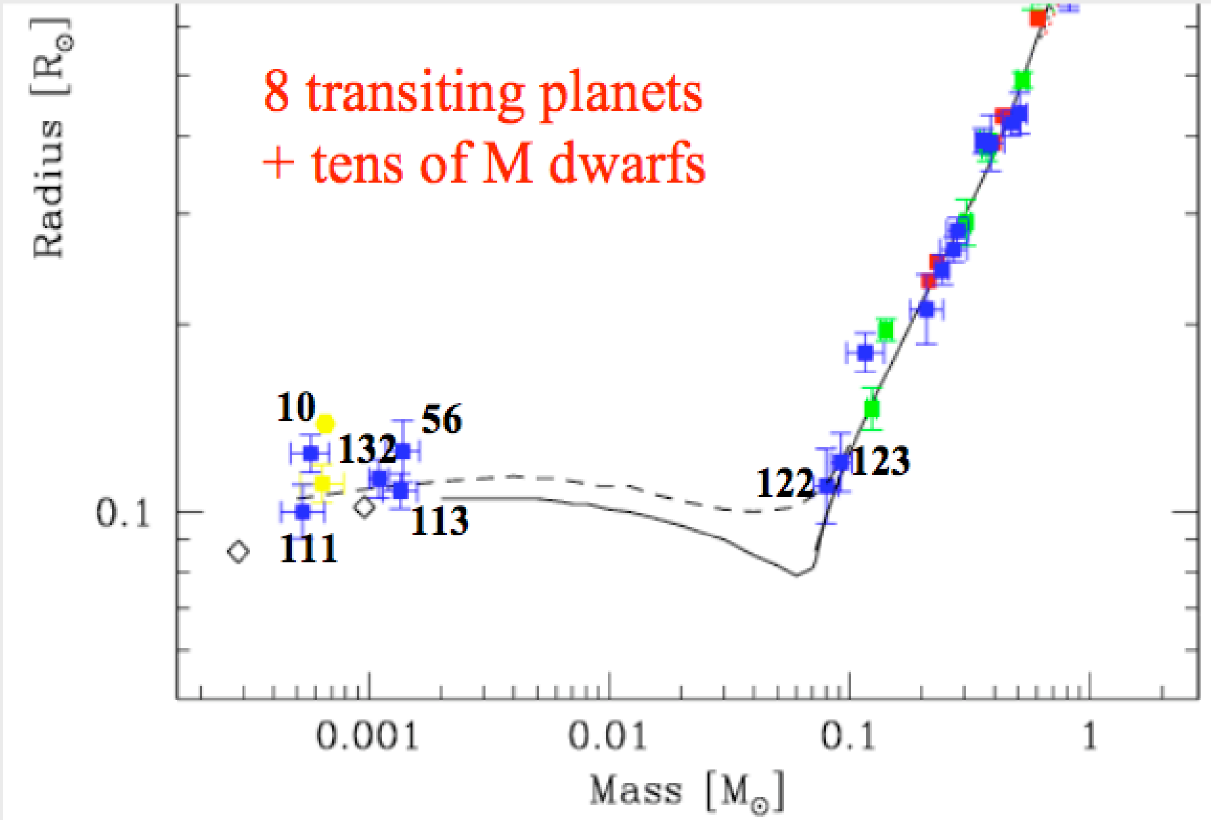




Radial velocities of more than 80 candidates with UVES-FLAMES (VLT)

137 transiting candidates

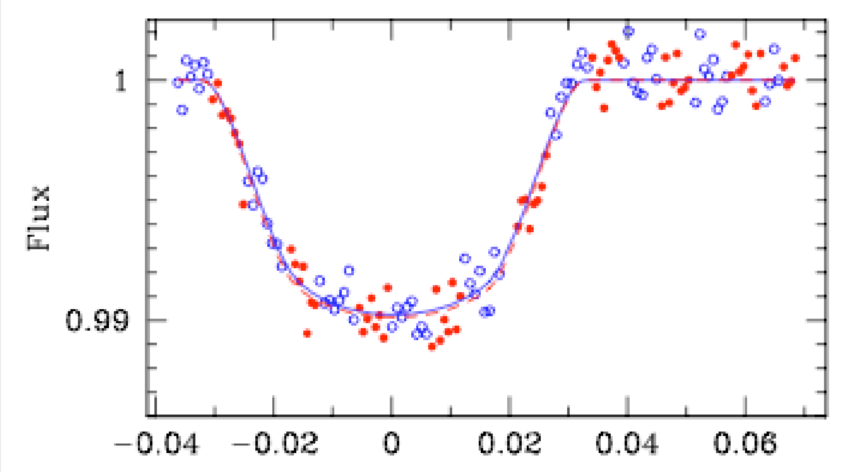
Dreizler et al. 2003
Konacki et al. 2005
Bouchy et al. 2004, 2005
Pont et al. 2004, 2005



Additional Photometric Observations of OGLE transits

with FORS1 (VLT), VIMOS (VLT), SOFI (NTT), GROND (2.2m)

mmag photometry for accurate radius, ephemeris, secondary transit and search for TTVs.

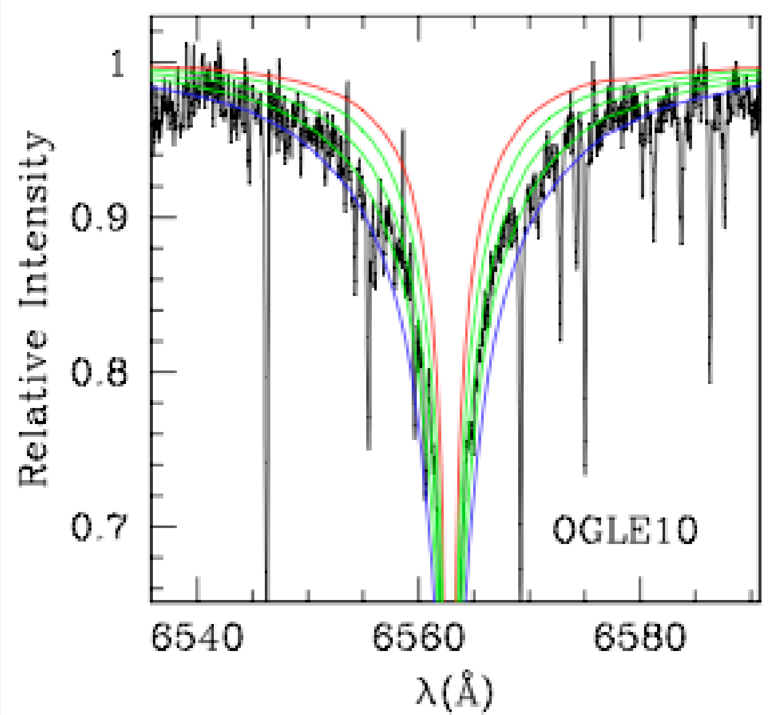


Pont et al. 2007, Minniti et al. 2007, Diaz et al. 2007, Udalski et al. 2008, Snellen et al. 2009, Adams et al. 2011

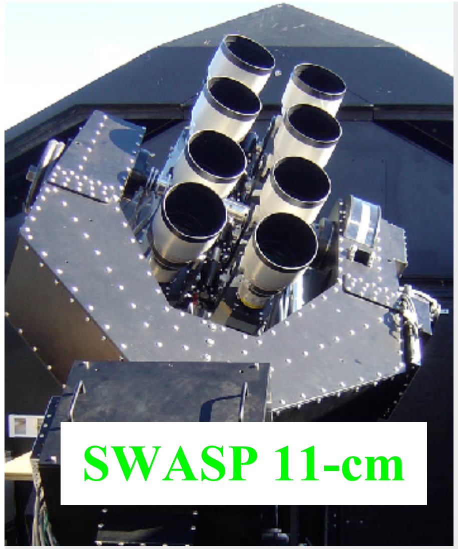
Additional Spectroscopic Observations of OGLE planet host stars

with UVES (VLT)

planet host stars characterization and chemical abundances



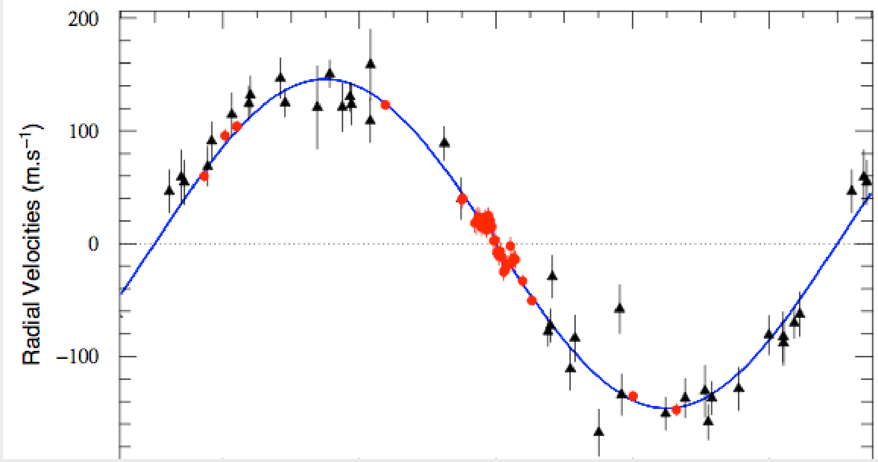
Santos et al. 2006



Radial Velocity follow-up of WASP-South

with CORALIE (1.2m) and HARPS (3.6m)

More than 30 new transiting planets
in the South Hemisphere

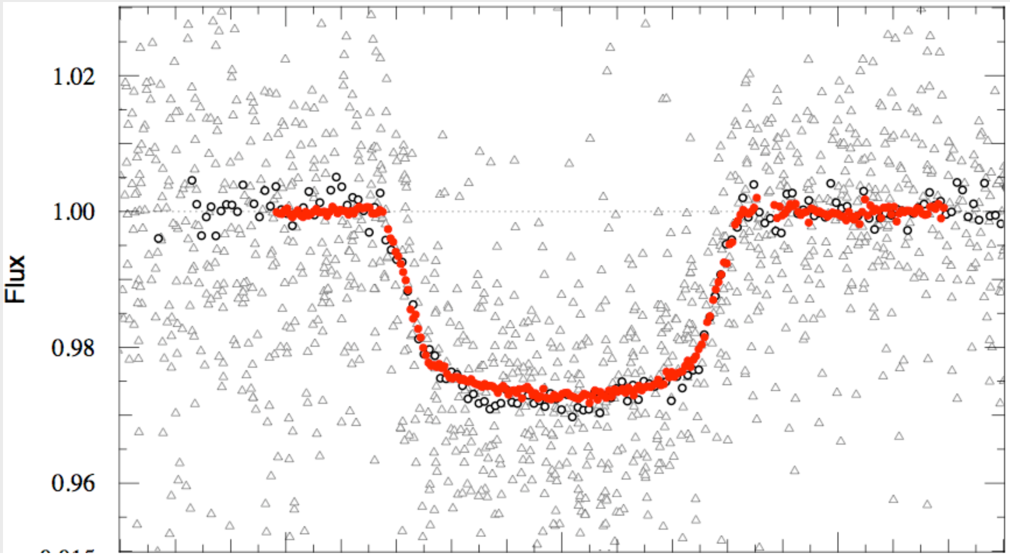


Triaud et al. 2010, Hellier et al. 2010, Queloz et al. 2010, Gillon et al. 2011, Anderson et al. 2012

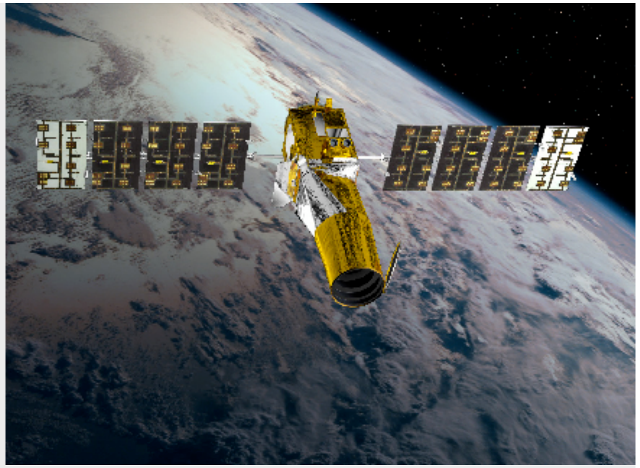
Photometric follow-up of WASP

with FORS2 (VLT), SOFI (NTT), ISAAC (VLT), HAWK1 (VLT), Euler (1.2m), Trappist (0.6m)

Gillon et al. 2009, 2012
Caceres et al. 2011



CoRoT transiting candidates

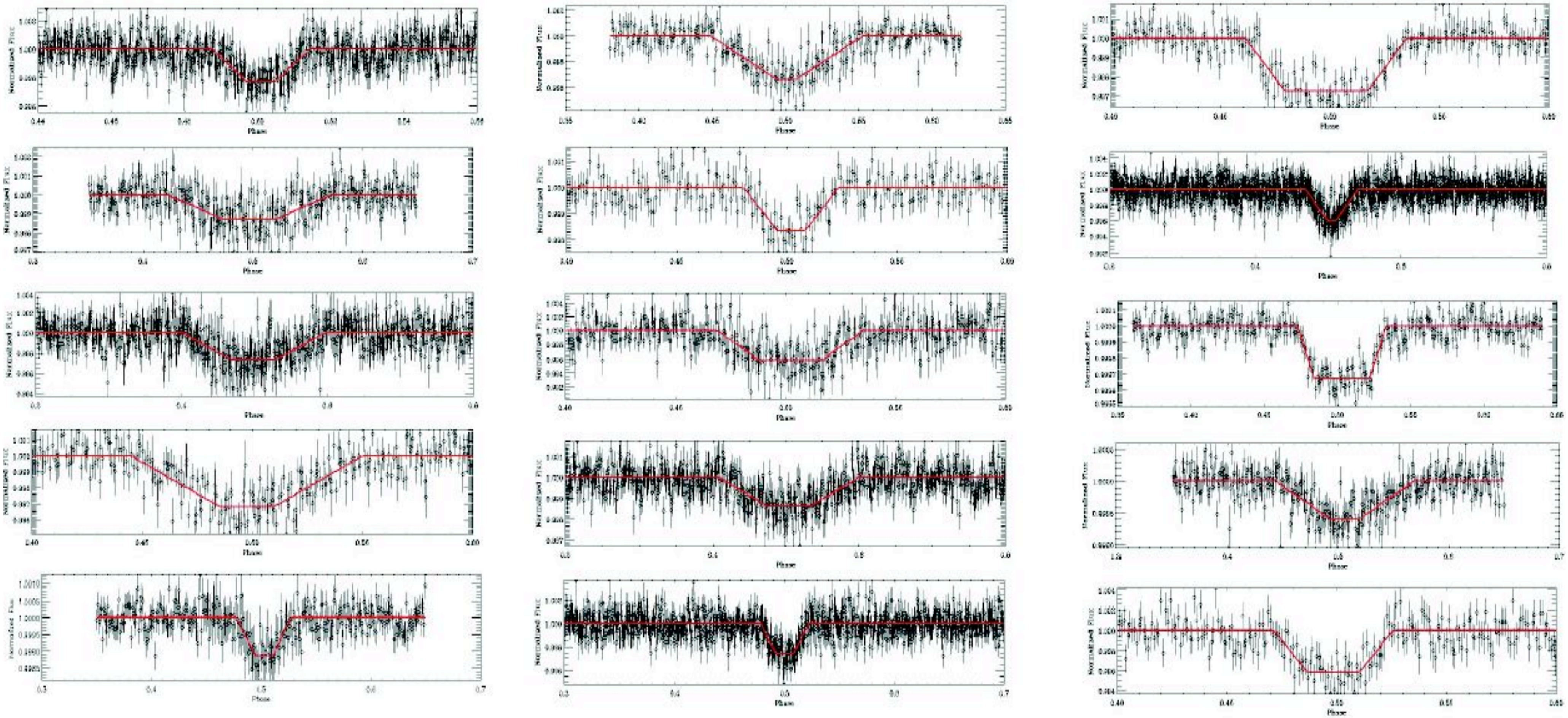


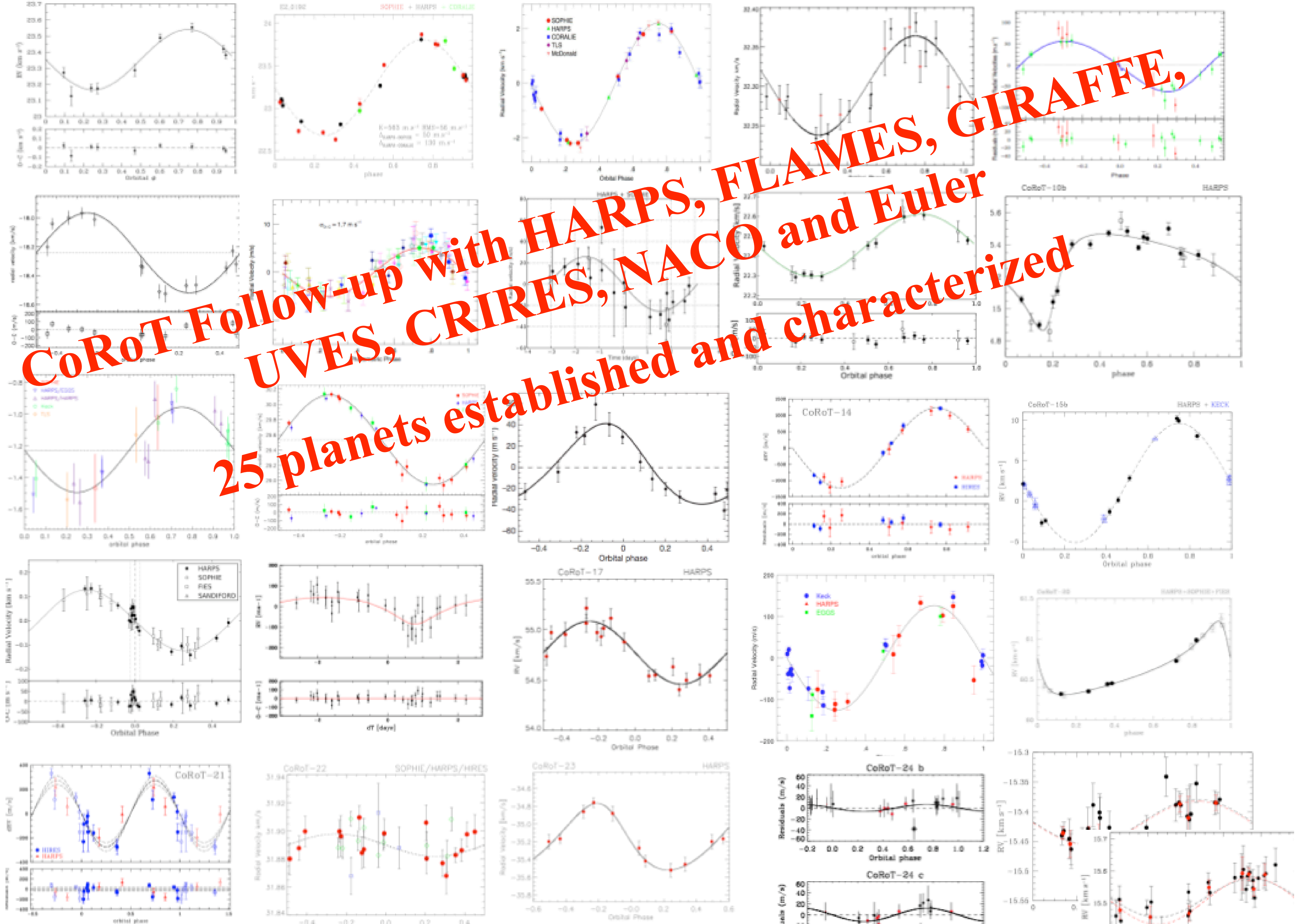
Since start of 2007

24 CoRoT runs   170’000 observed stars

~ 700 planetary candidates

~ 350 high priority planetary candidates
with follow-up observations





CoRoT Follow-up with HARPS, FLAMES, GIRAFFE, UVES, CRIRES, NACO and Euler

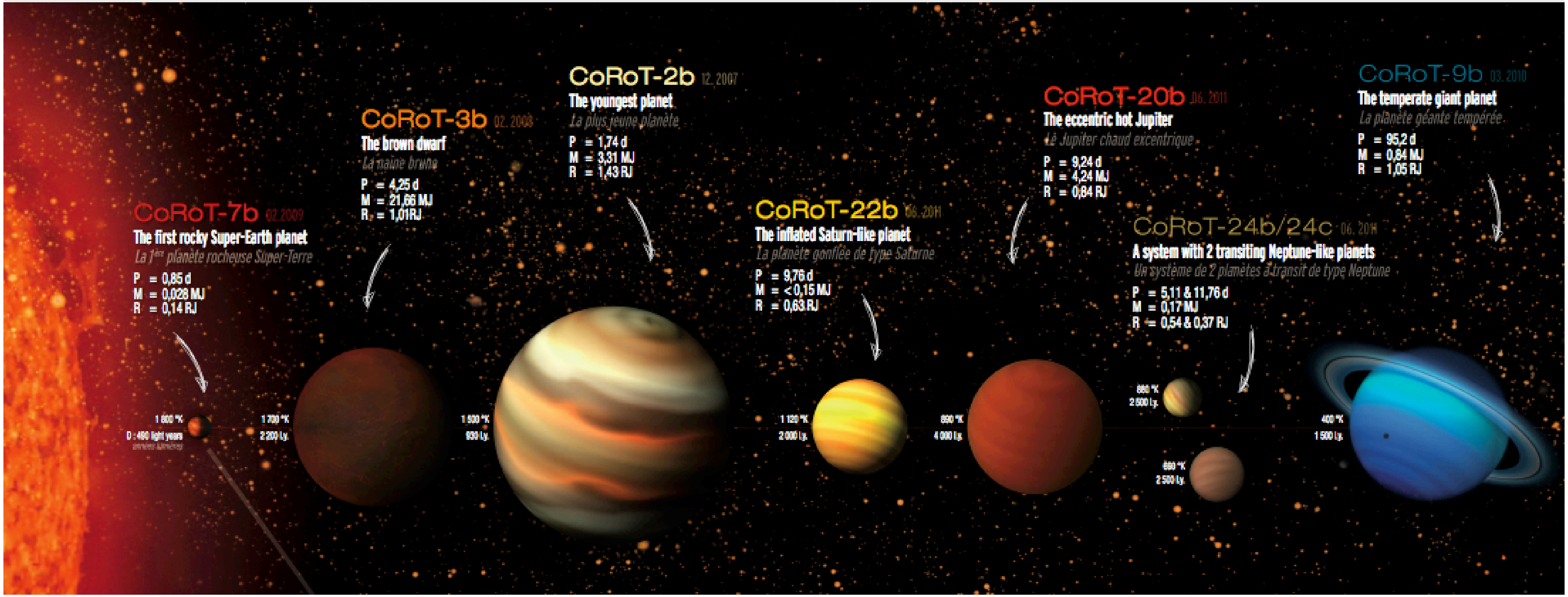
25 planets established and characterized

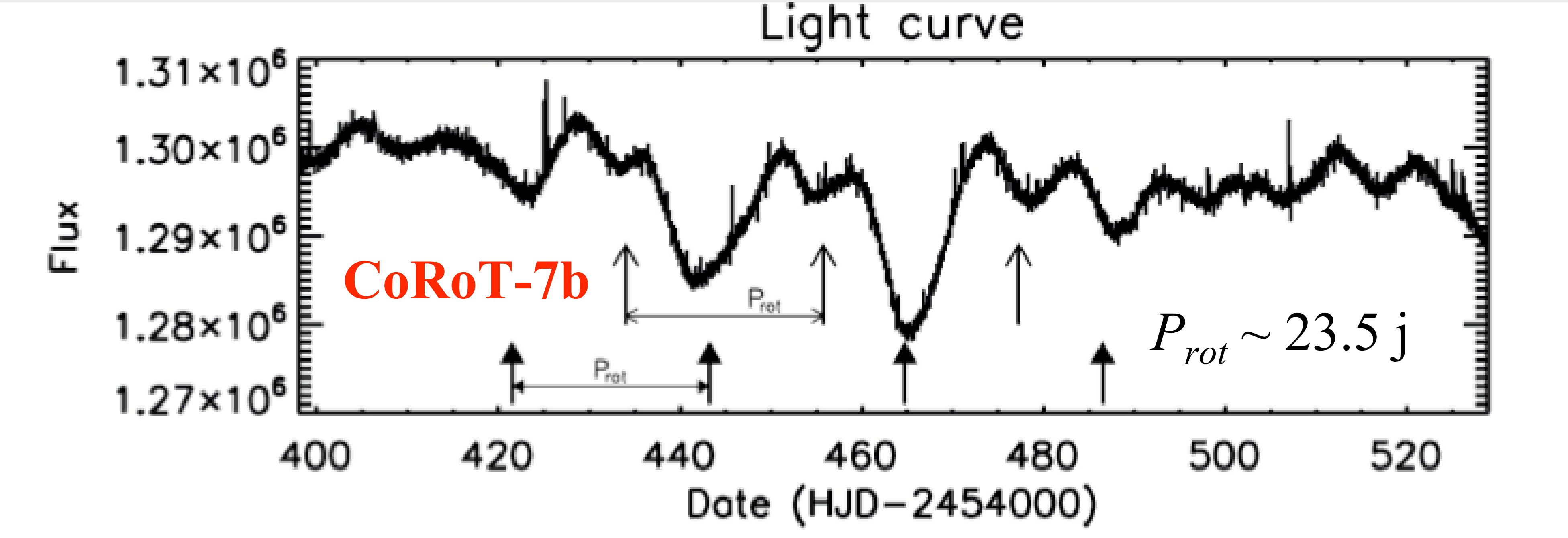
Some Faint and small-size candidates are waiting for Espresso (VLT)

CoRoT highlights

CoRoT-2b: young inflated
CoRoT-3b and 15b : brown dwarves
CoRoT-7b : first super-Earth
CoRoT-9b : temperate giant
CoRoT-10b, 20b, 23b : eccentric hot Jupiter
CoRoT-8b, 22b : Saturn-like
CoRoT-24b,c : first CoRoT transiting system

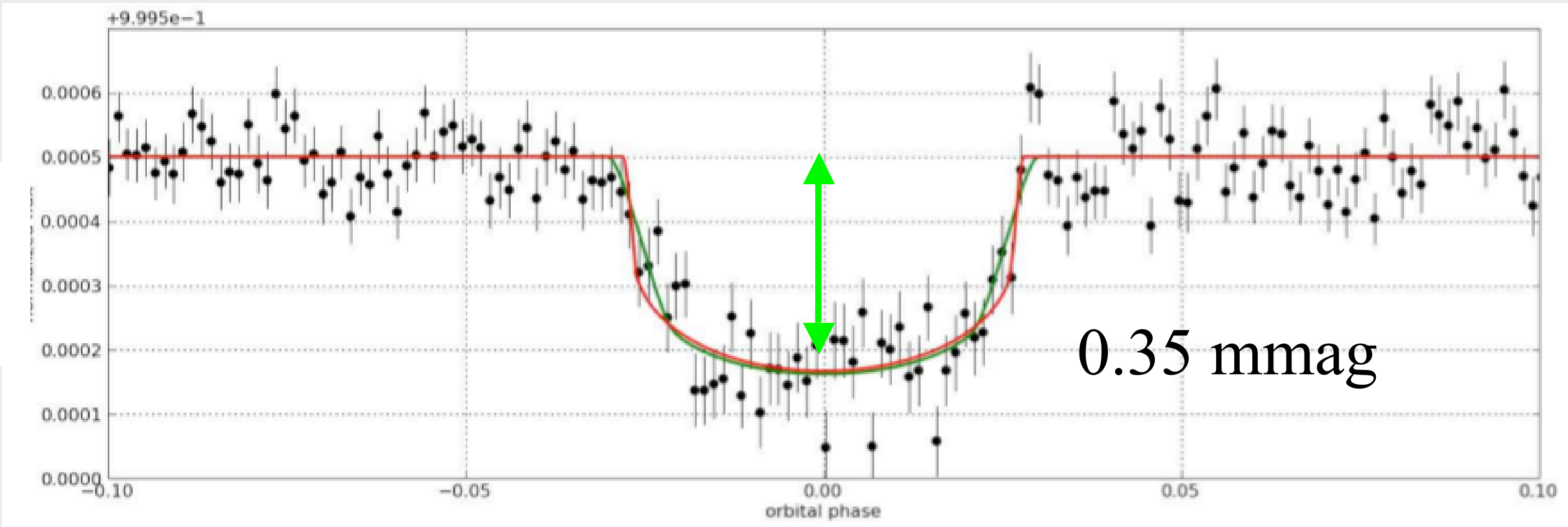
Alonso et al. 2008
Deleuil et al. 2008
Bouchy et al. 2010
Deeg et al. 2010
Bonomo et al. 2010
Borde et al. 2010
....





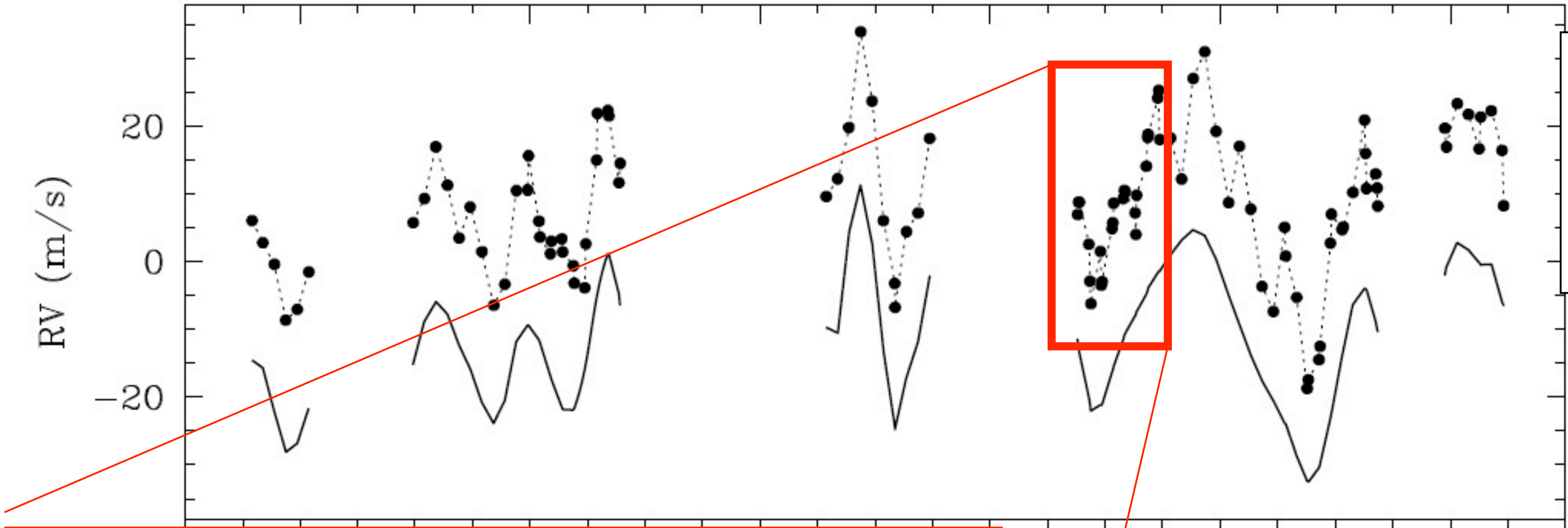
$P_{orb} = 0.854$ d

$r = 1.7$ R⊕

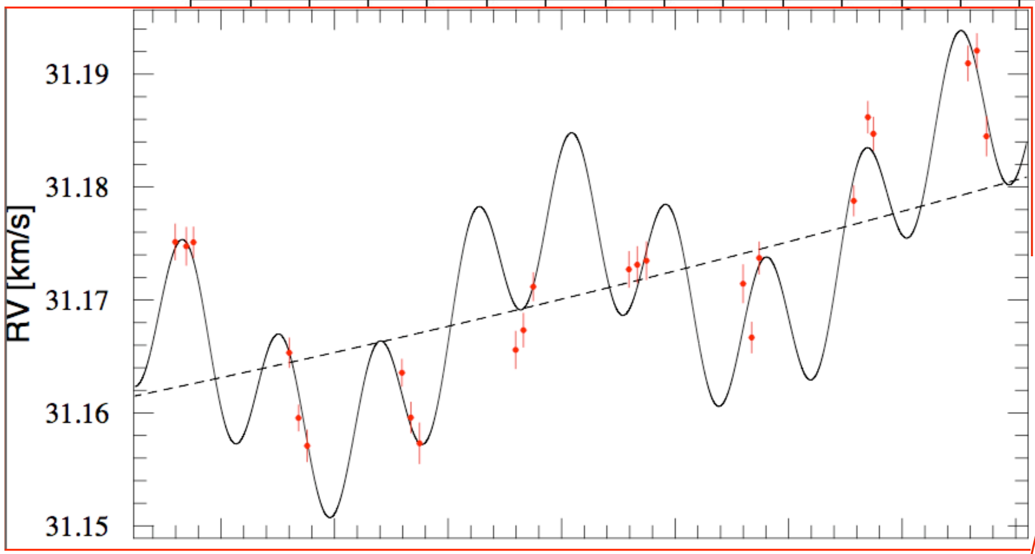


Léger et al. 2009

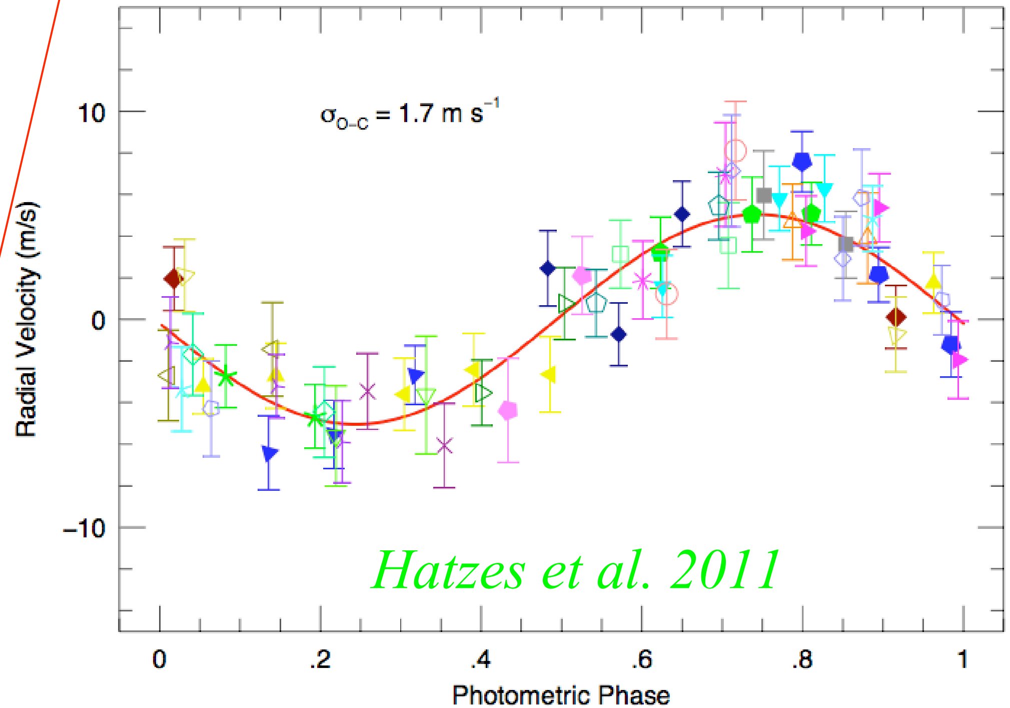
CoRoT-7 observed with HARPS



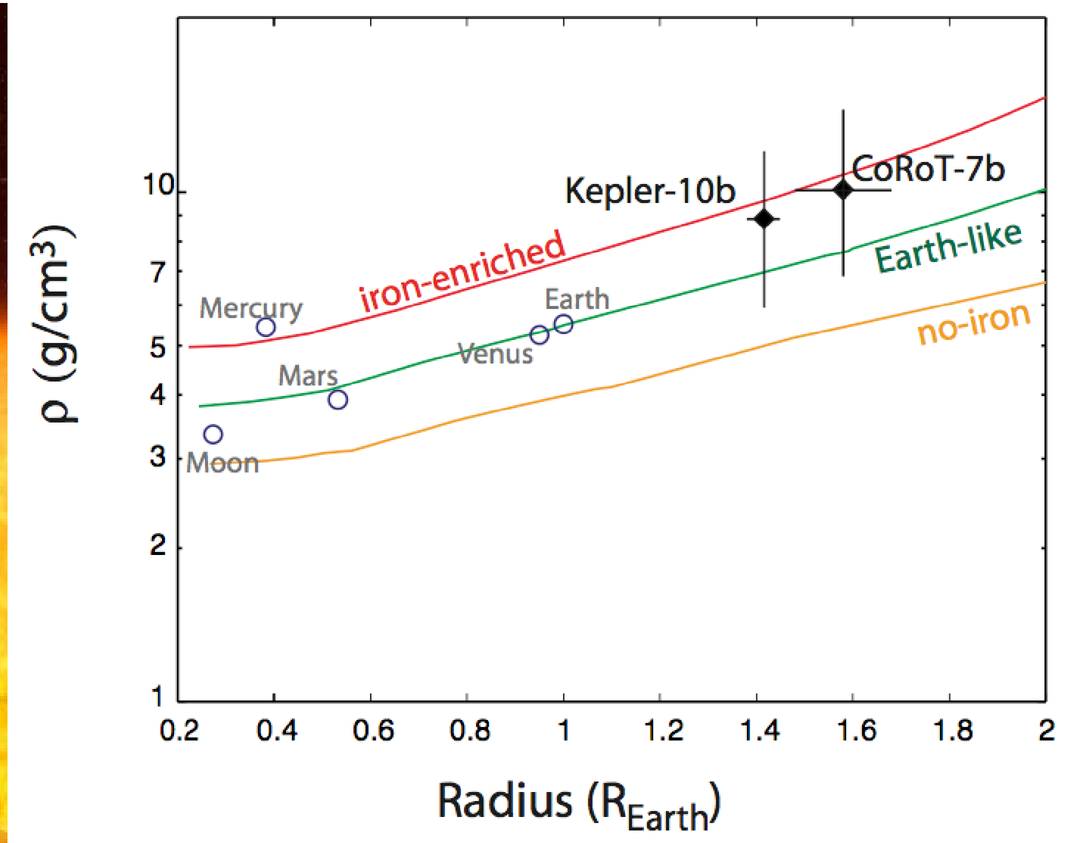
Harmonics decomposition at P_{rot}, $P_{rot}/2$ and $P_{rot}/3$
Coherence time ~18 d



Queloz et al. 2009



Hatzes et al. 2011



CoRoT-7b

$P = 0.8536$ d

$a = 0.017$ AU

$e = 0$

$m = 7.4 \pm 1.2\ M_{Earth}$

$r = 1.58 \pm 0.1\ R_{Earth}$

$\rho = 10.4 \pm 1.8\ g.cm^{-3}$

CoRoT-7c

$P = 3.70$ d

$a = 0.046$ AU

$e = 0$

$m = 8.4 \pm 0.9\ M_{Earth}$

Spectroscopic transits observed with HARPS (3.6m)

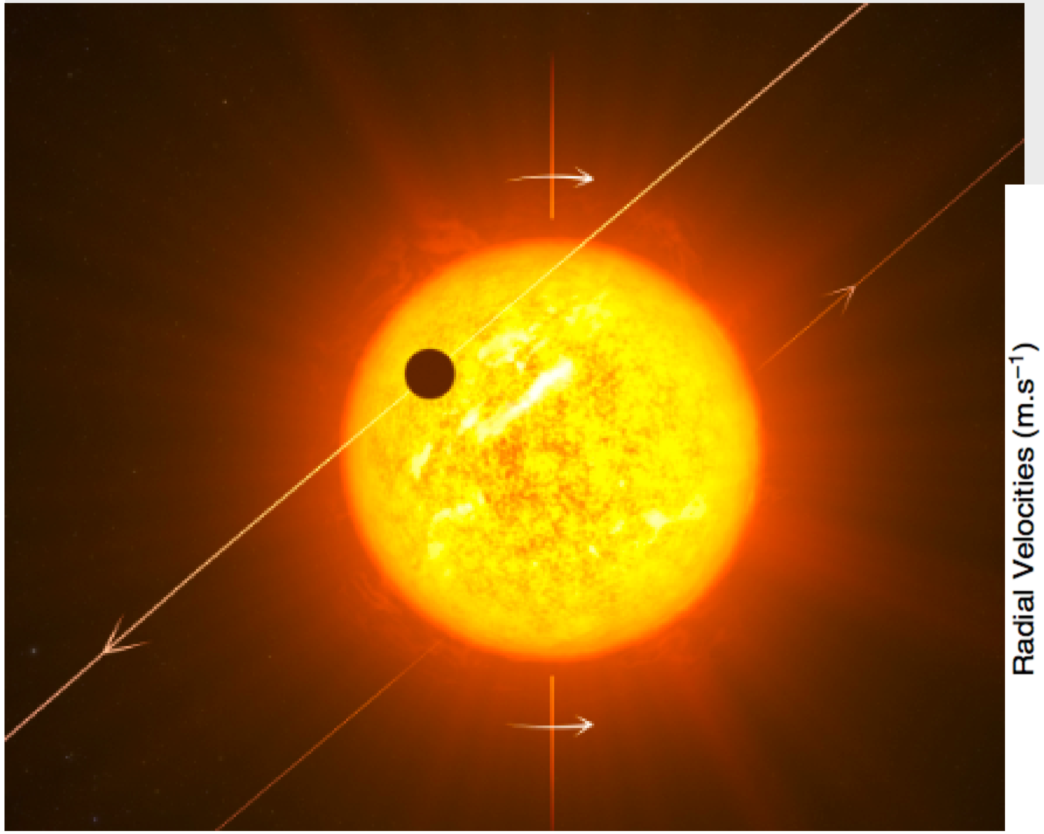
Rossiter-McLaughlin effect → spin-orbit obliquity

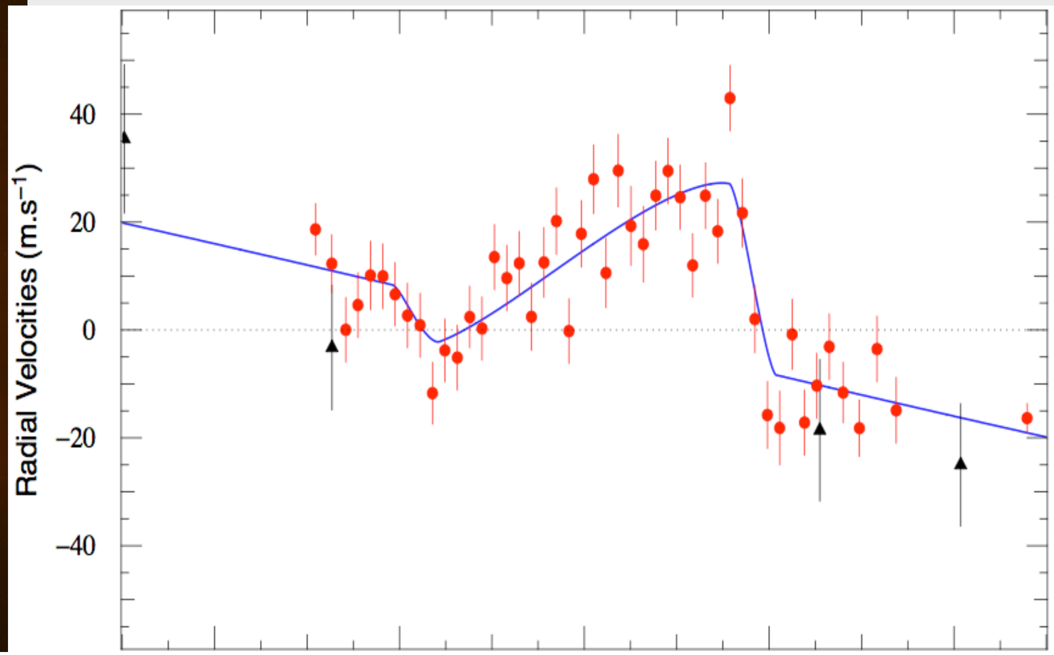
More than 45% of Hot-Jupiters are misaligned

→ Kozai mechanism + tidal friction

Disc migration alone cannot explain observed misalignment

Bouchy et al. 2008, Pont et al. 2009
Triaud et al. 2010, 2012
Hebrard et al. 2011, Guenther et al. 2011



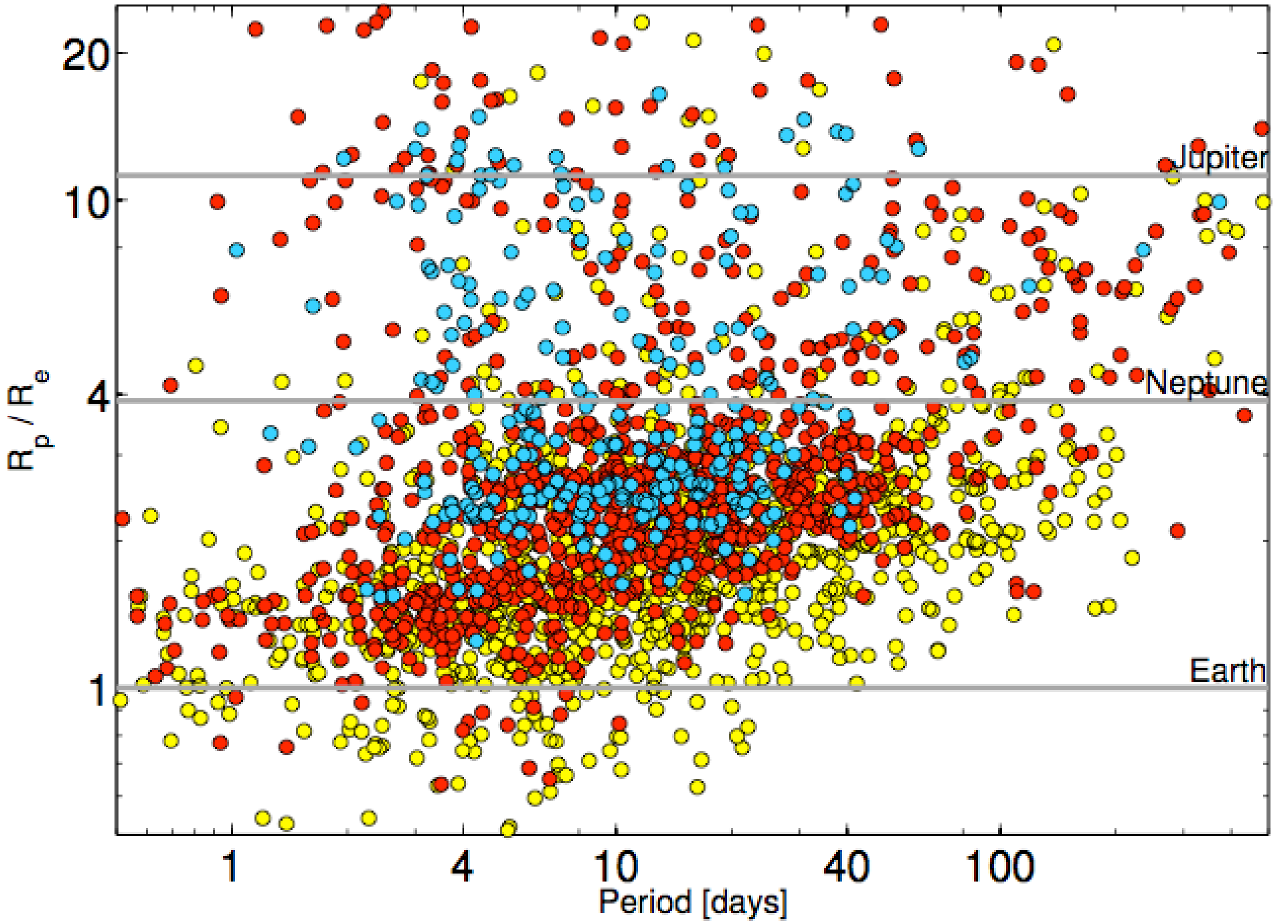


Kepler transiting candidates

Launch in march 2009
1 single North field of view (~156'000 stars)
observed up to end 2016

2321 candidates found within the 16 first months of data

Batalha et al. 2012



Kepler Highlights

- Transiting multi-planetary systems

Kepler-11b,c,d,e,f,g / 18b,c,d / 20b,c,d,e,f / 36b,c

- Transiting rocky planet

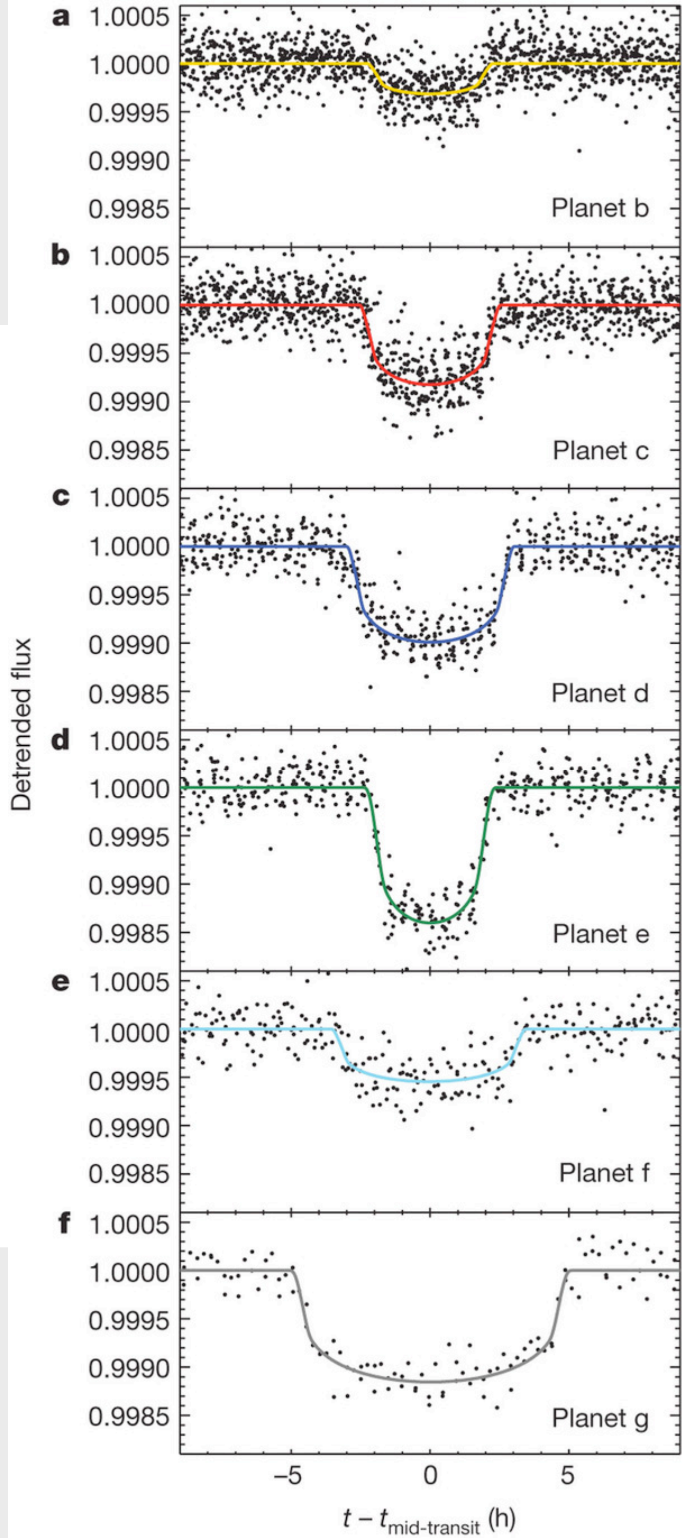
Kepler-10b

- A 2.4 Rearth planet in the habitable zone

Kepler-22b

- Circumbinary planets

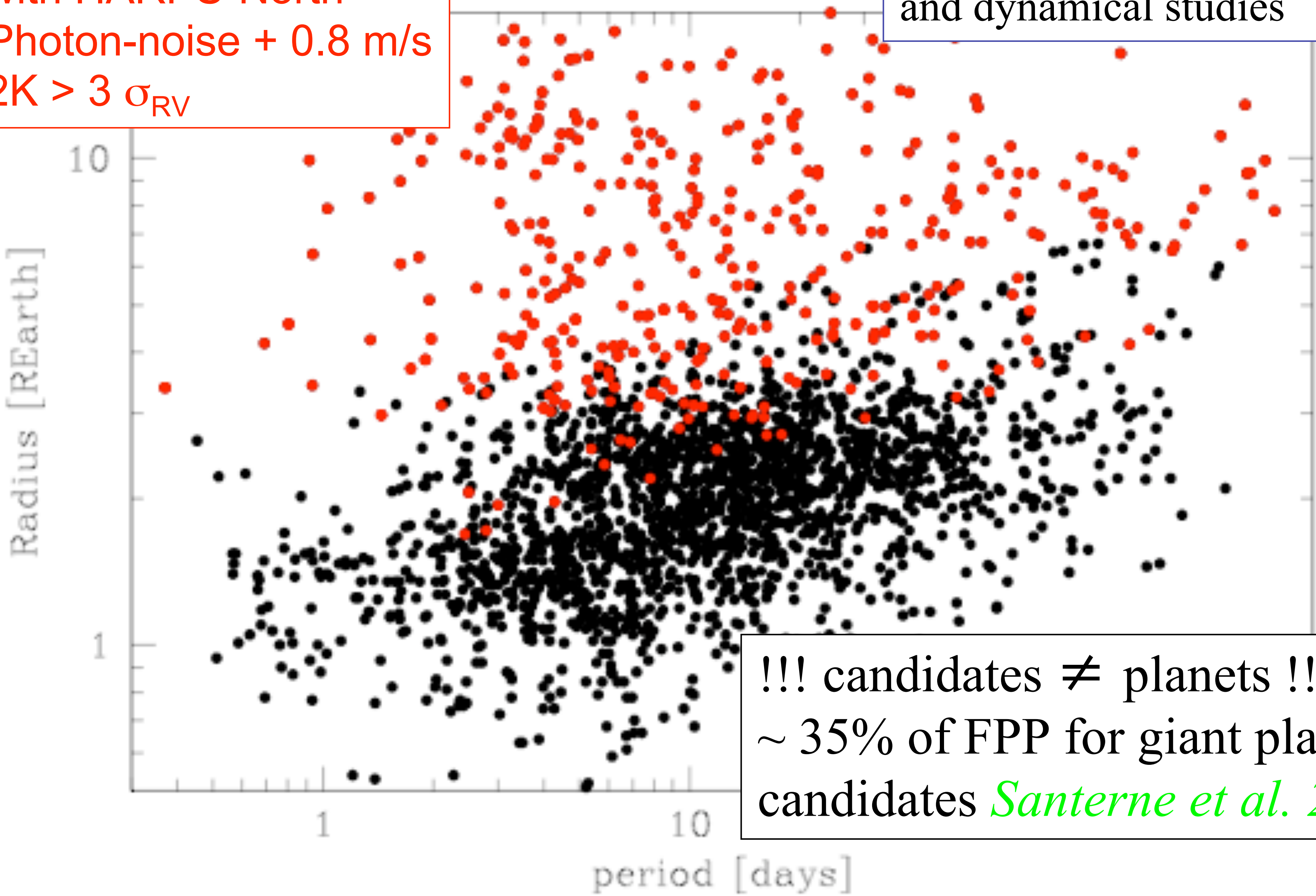
Kepler-16b, 34b, 35b, 47b,c



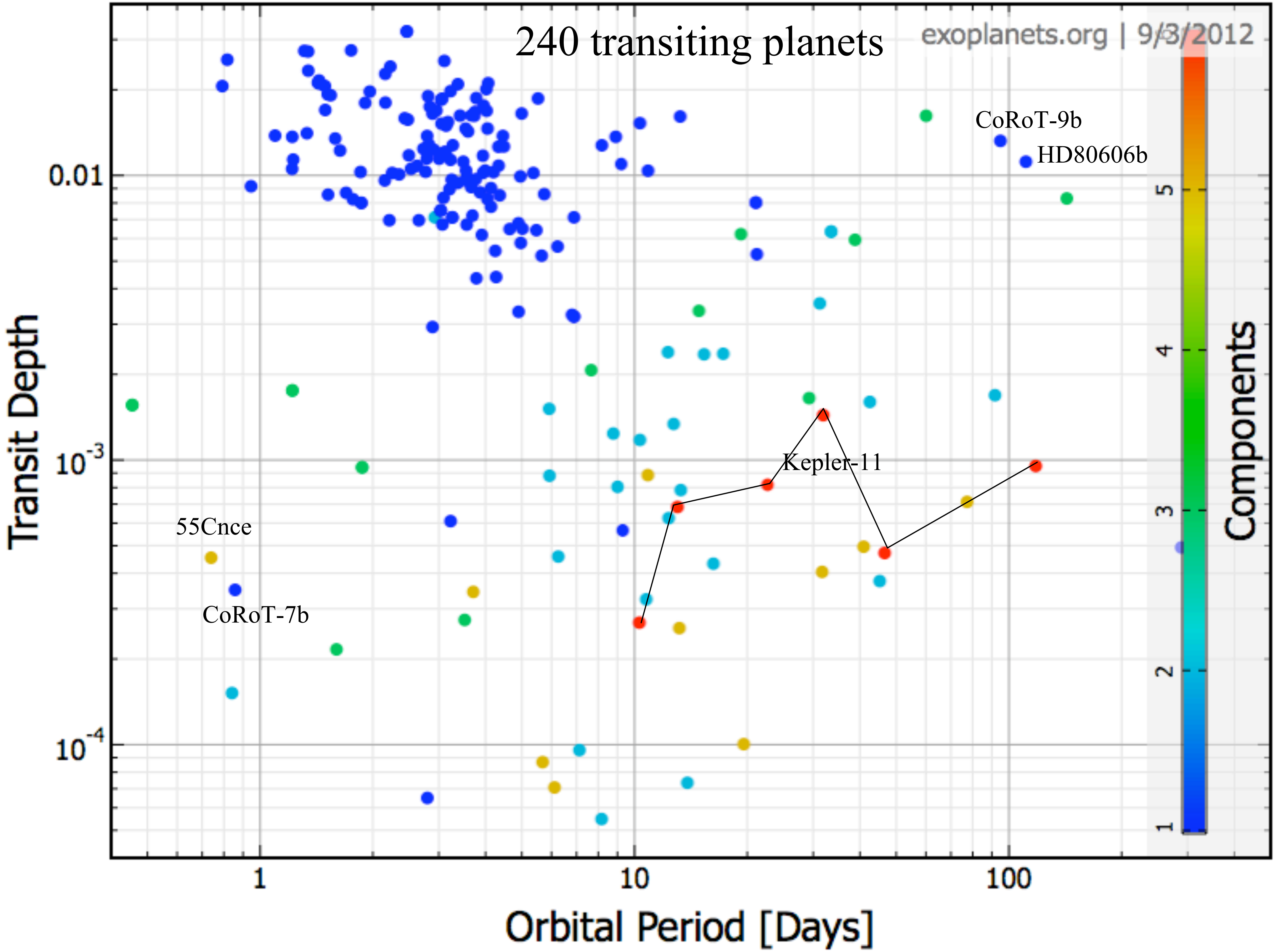
Kepler planetary candidates

Mass characterization with HARPS-North
Photon-noise + 0.8 m/s
$2K > 3\ \sigma_{RV}$

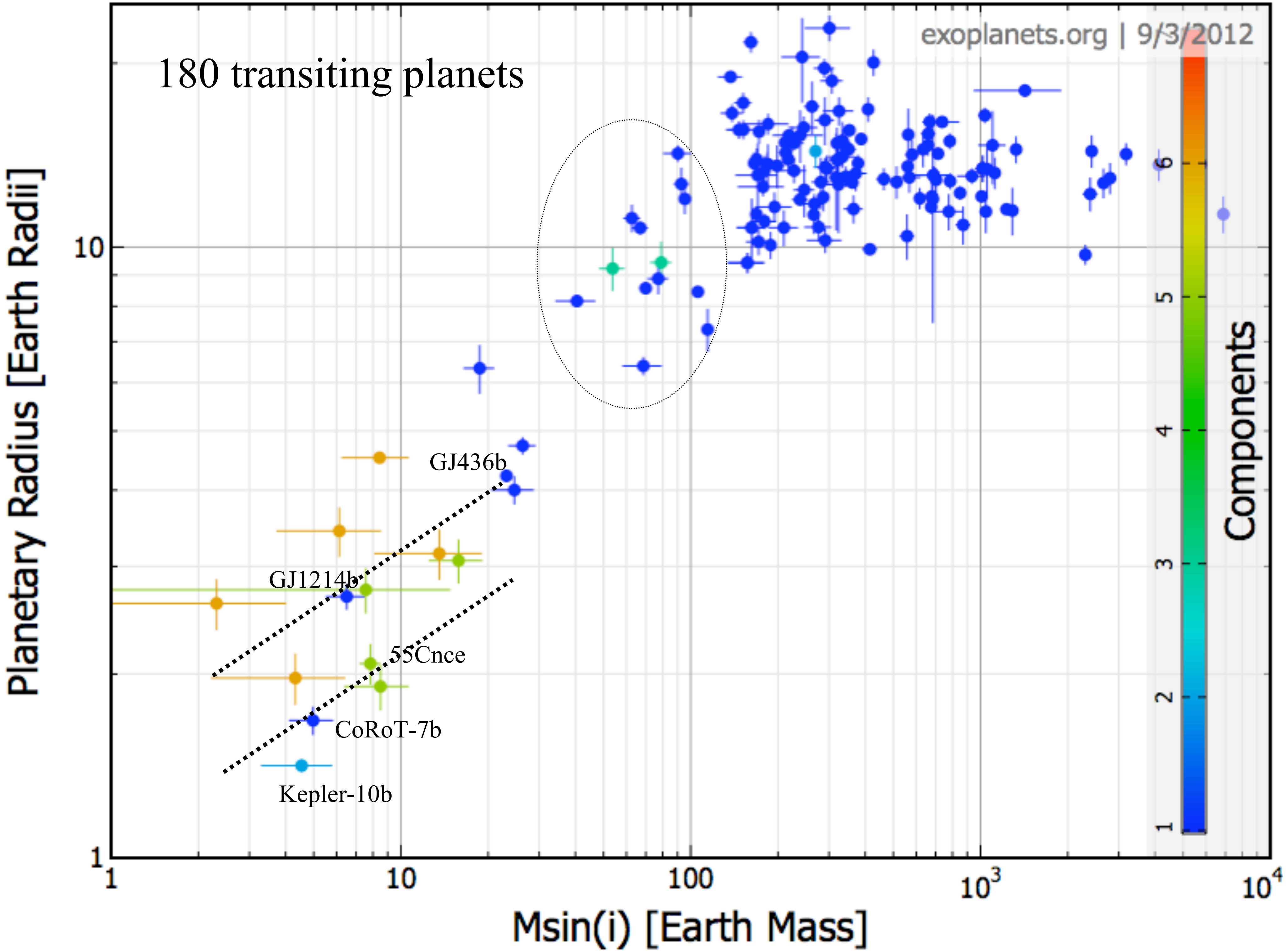
Mass upper limit through TTVs and dynamical studies



!!! candidates $\neq$ planets !!!
~ 35% of FPP for giant planetary candidates *Santerne et al. 2012*

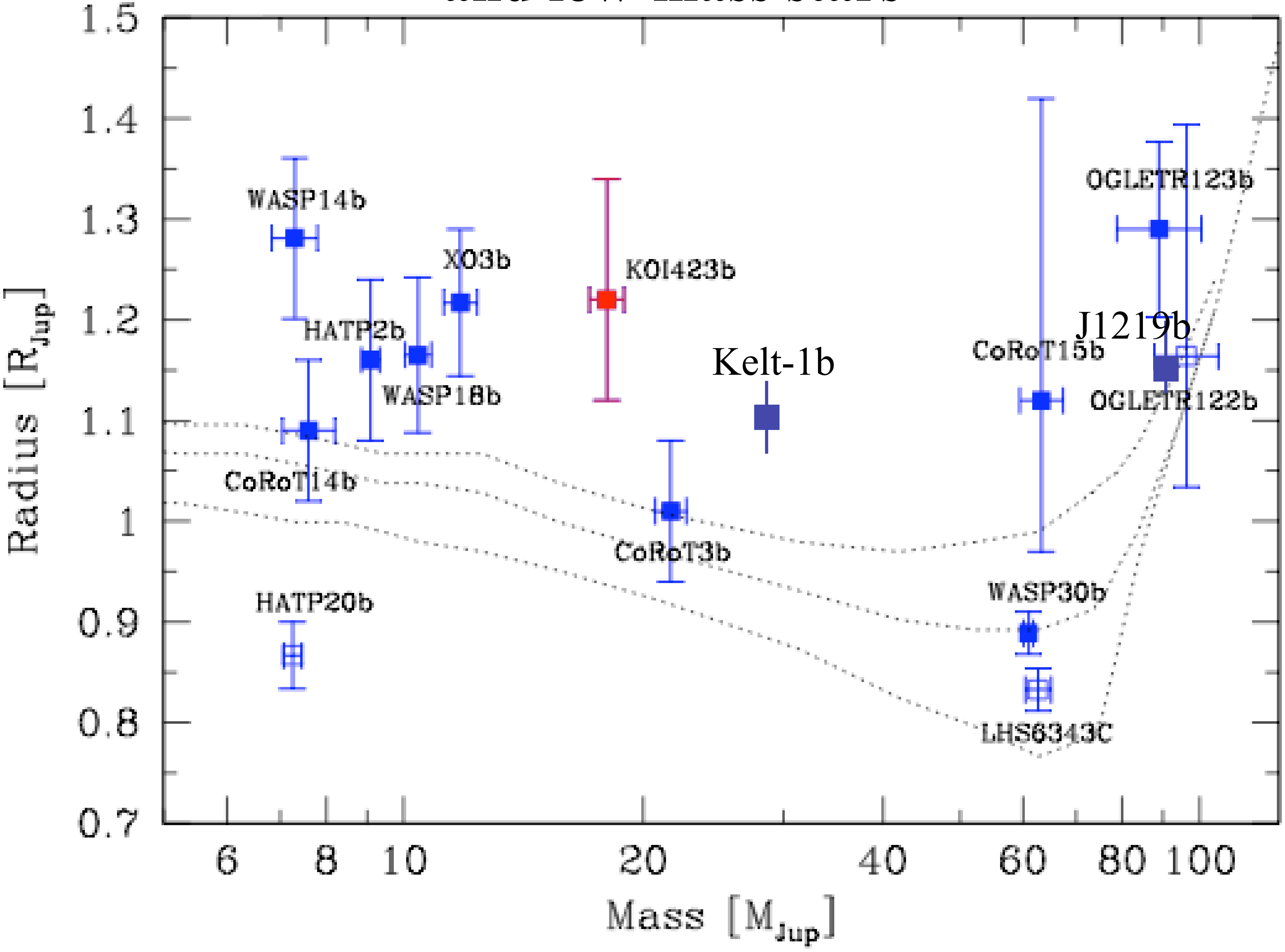


240 transiting planets
exoplanets.org | 9/3/2012
CoRoT-9b
HD80606b
Kepler-11
55Cnce
CoRoT-7b
Transit Depth
0.01
10^{-3}
10^{-4}
Orbital Period [Days]
1
10
100
Components
1
2
3
4
5



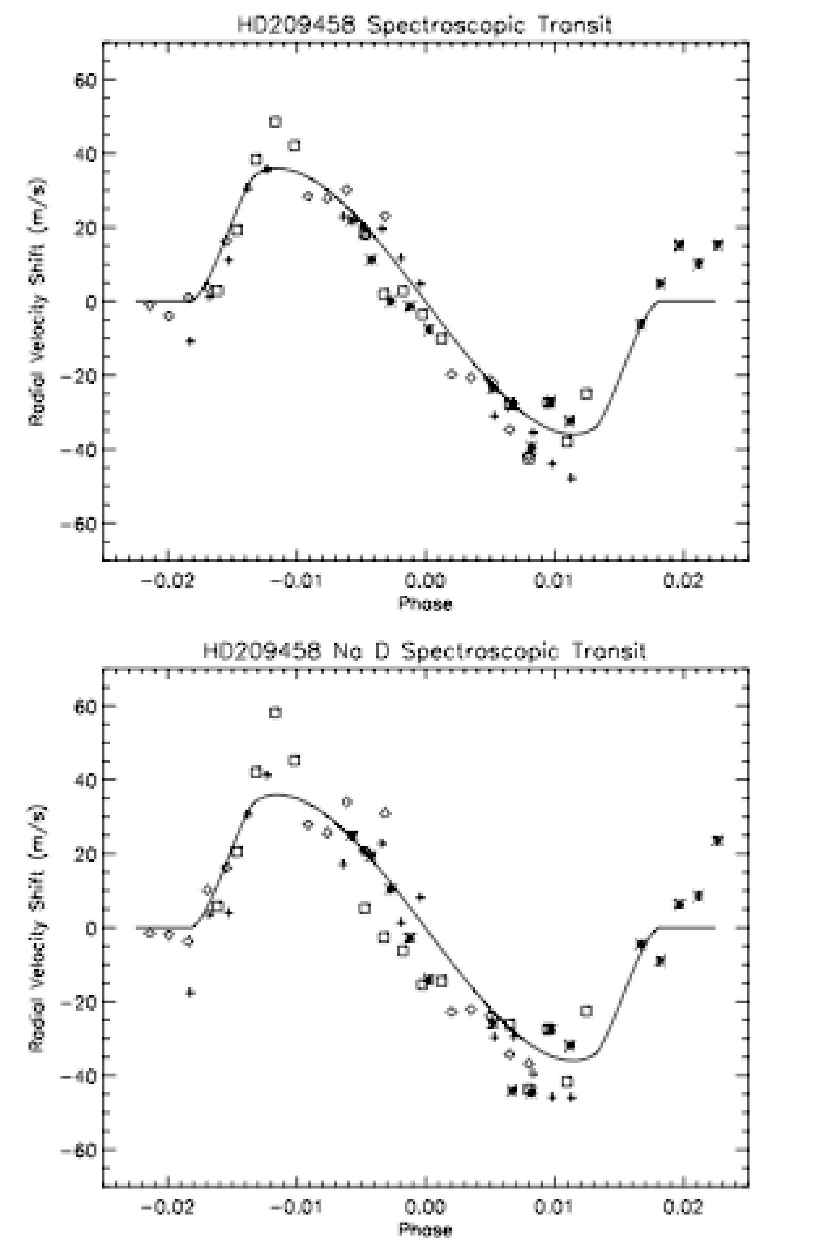
180 transiting planets
exoplanets.org | 9/3/2012
Planetary Radius [Earth Radii]
Msin(i) [Earth Mass]
Components
GJ436b
GJ1214b
55Cnce
CoRoT-7b
Kepler-10b
1
10
100
10^3
10^4
1
2
3
4
5
6

From massive planets to brown-dwarfs and low-mass stars



UVES (VLT) probes the atmosphere of HD209458b using the spectroscopic transit (Rossiter effect)

Snellen 2004



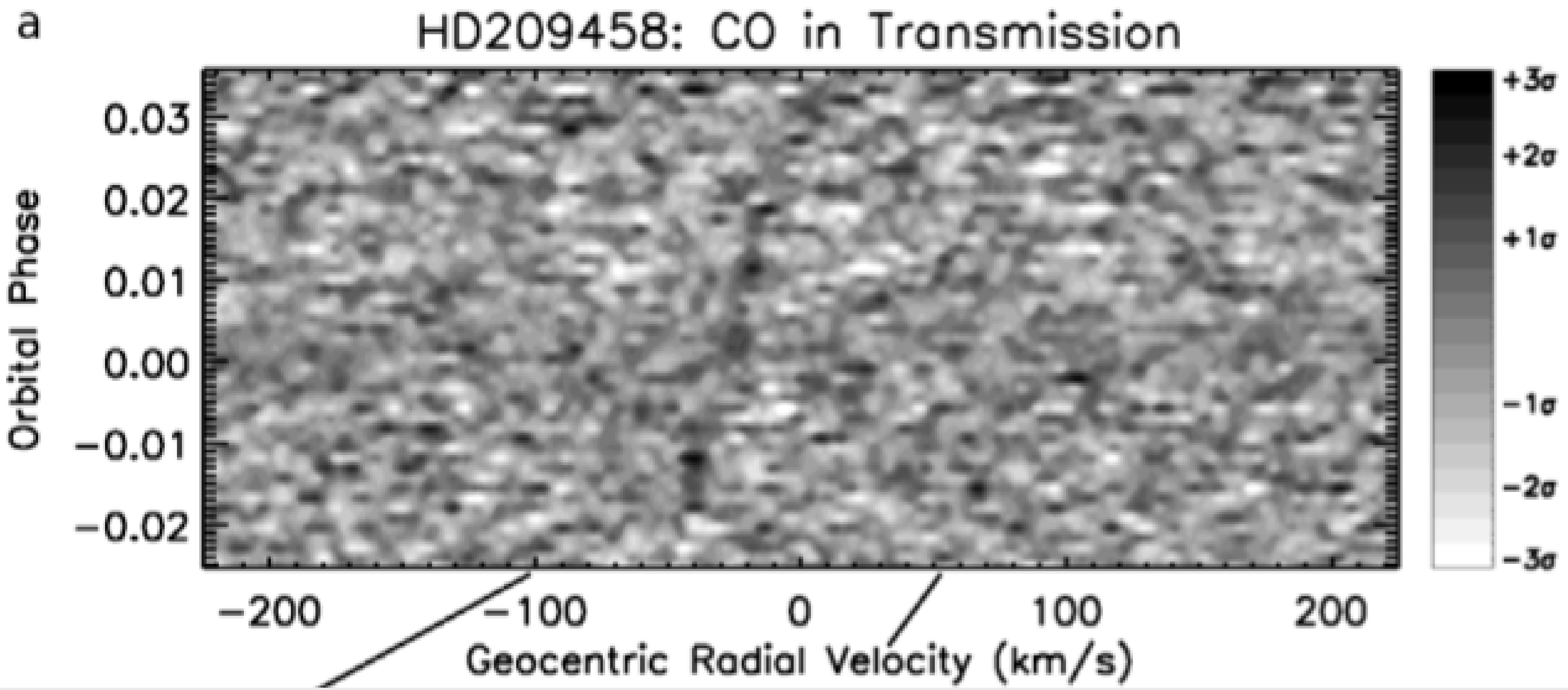
Amplitude of the RV anomaly (directly proportional to the effective size of the transiting planet) seems slightly higher in the Sodium D lines

Also used on

WASP-17b *Wood et al. 2011*

and CoRoT-2b *Czesla et al. 2012*

CRIRES (VLT) detects CO lines from the HD209458b atmosphere ⟶ orbital velocity of HD209458b



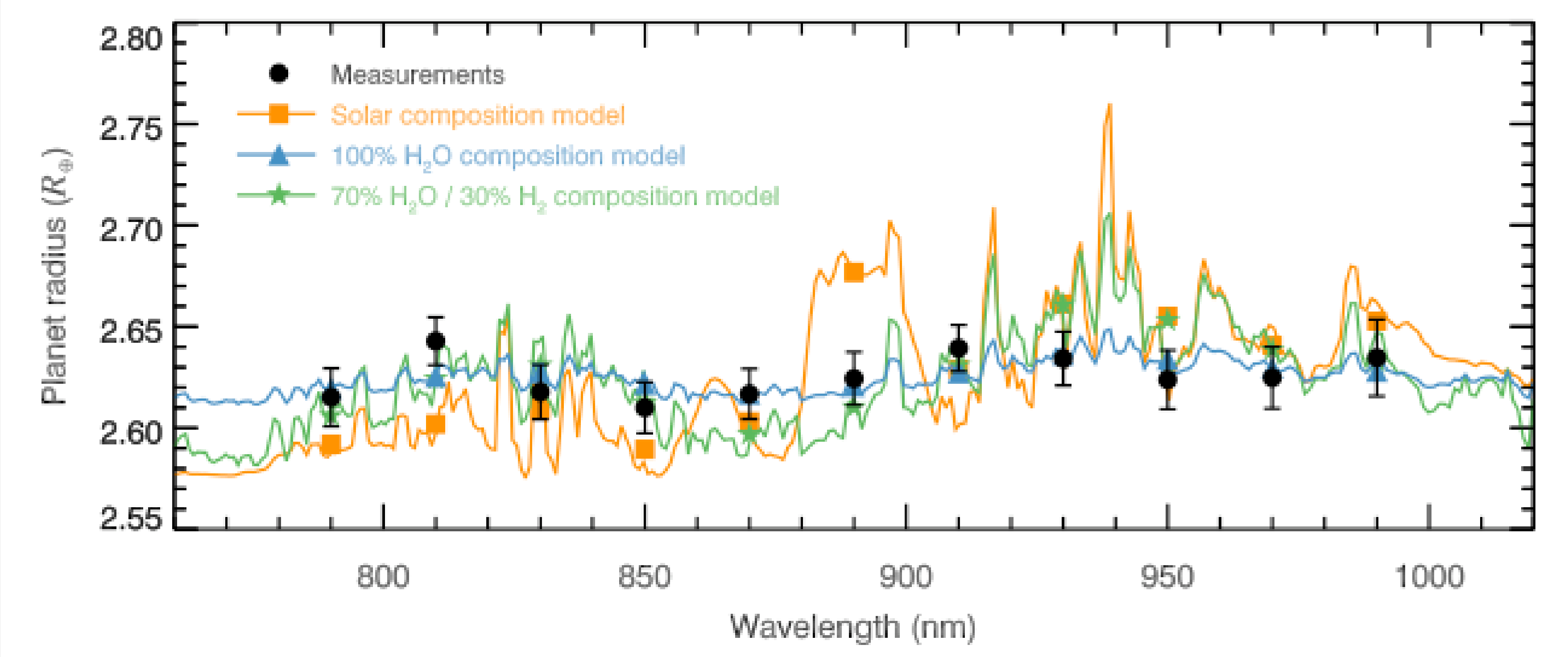
Snellen et al. 2010

GJ1214b Super-Earth atmosphere analysed with FORS (VLT)

Bean et al. 2010

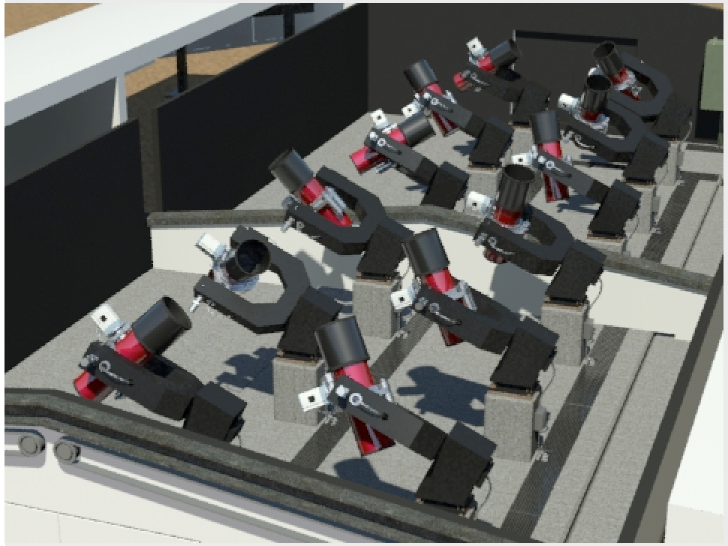
The lack of features in the spectrum rules out atmosphere composed primarily of hydrogen.

Consistent with a dense water vapour atmosphere or atmosphere blanketed by clouds or hazes hiding the signature of hydrogen



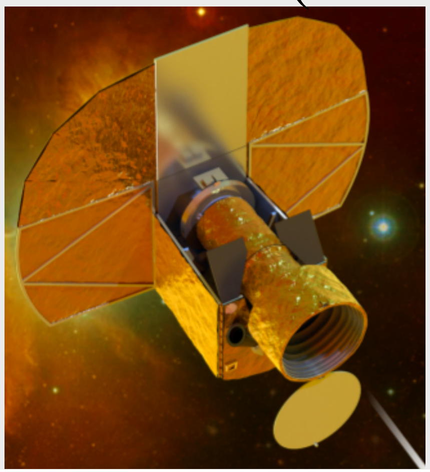
Future : transiting planets around bright stars !!!

Accurate radius AND mass determination
from Earth-like to Brown-Dwarf companion
+ further planetary atmosphere studies

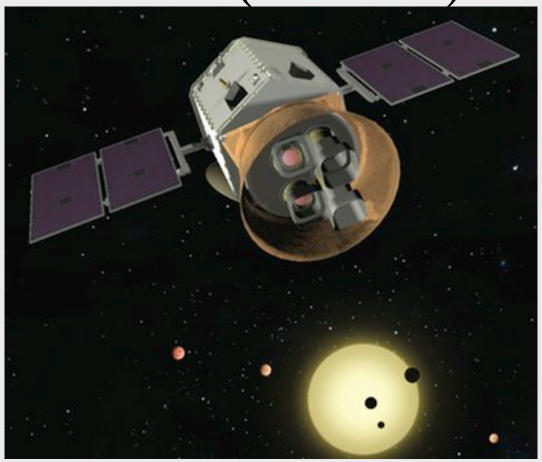


NGTS (Paranal) [under construction]
Search for transiting Neptunes
around brigth K dwarfs

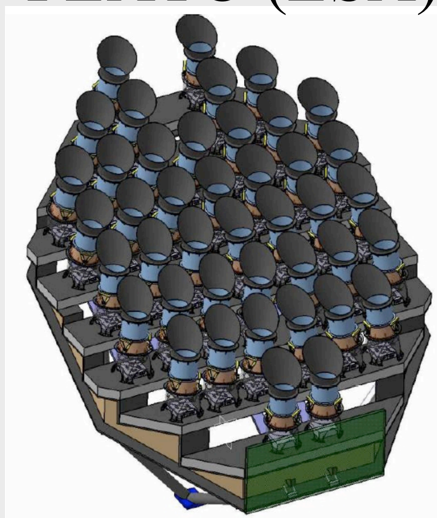
CHEOPS (ESA)



TESS (NASA)



PLATO (ESA)



Ground-based follow-up of transits is mandatory

- **Radial Velocity** = nature, accurate mass, eccentricity, spin-orbit obliquity, additional companions

- **Photometry** = contamination, accurate radius, TTVs

- **Spectroscopy** = Stellar parameters, planetary atmosphere

High flexibility and reactivity are a critical advantage