Multiplanetary Systems : An observer's view

Michel Mayor
University of Geneva

From 1990 to 2015 :
an improvement of the RV precision by about a factor 1000.

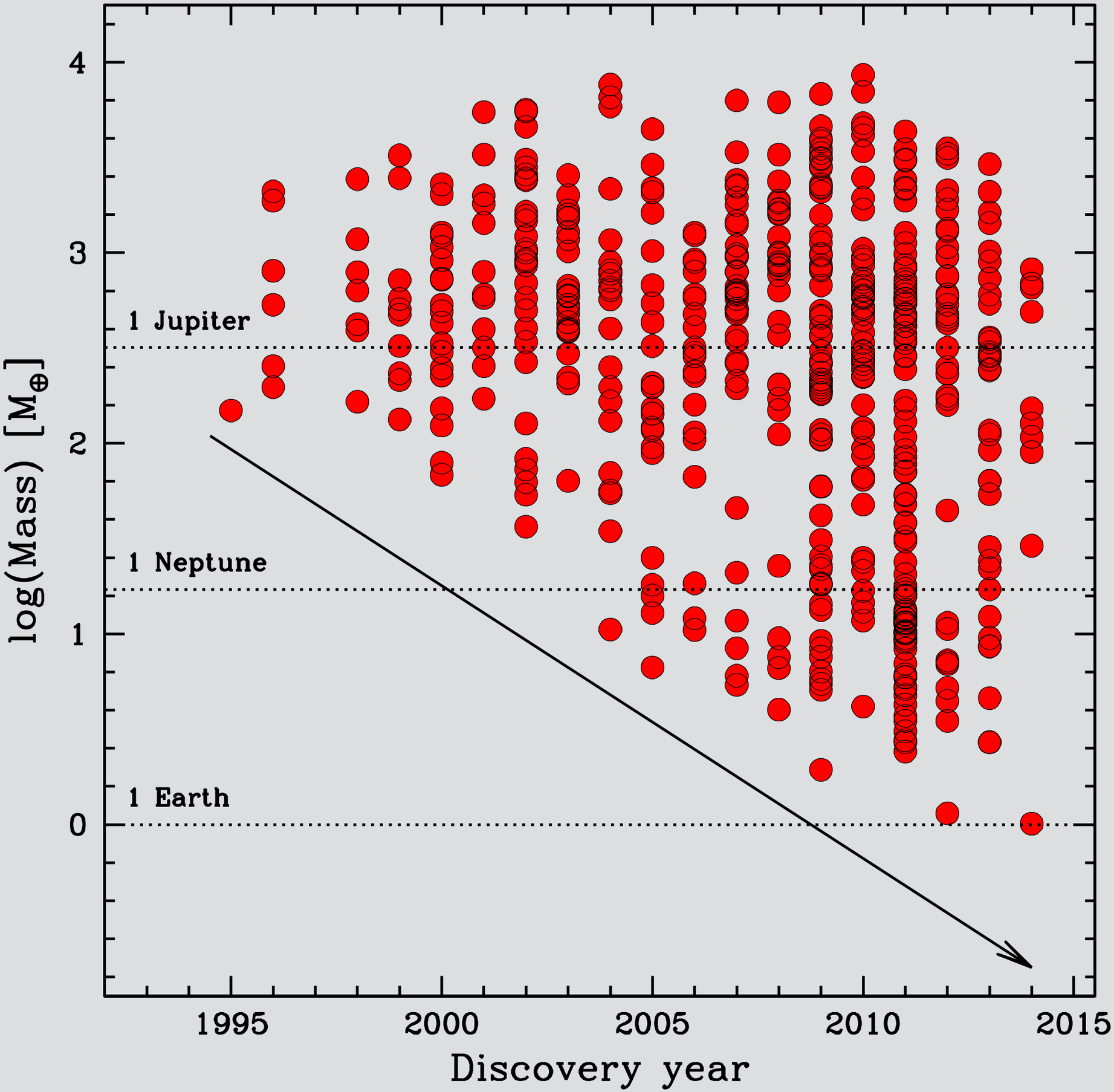
1985 : 250 to 500 m /s
today : 0.3 to 0.5 m/s (HARPS)

m2 sini HD114762 b 3500 M earth
m2 sini Alpha Cen Bb 1.07 M earth

An improvment of the smallest detected planet by a factor 3000 !

HARPS : Repeatability (short time) : better than 0.1 m/s
O-C of some orbits with a large number of measurements 0.75 m/s

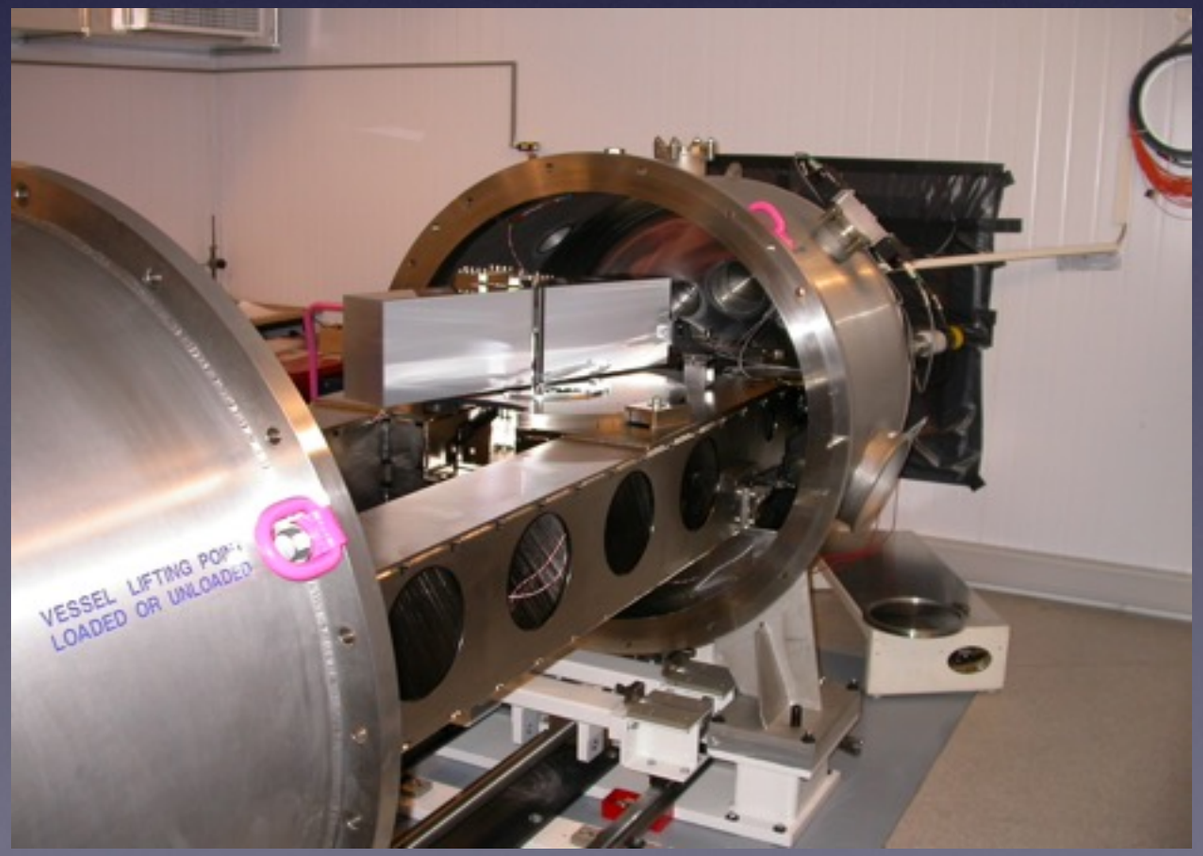
But ... acoustic noise, granulations, spots, solar cycle analogue !
... instrumental noises : CCD pattern, not perfect scrambling by fibers, calibration
Binning in phase (to eliminate short term noises , spots,...) 0.2 - 0.3 m/s


4
3
2
1
0
log(Mass) [M⊕]
1 Jupiter
1 Neptune
1 Earth
1995
2000
2005
2010
2015
Discovery year

Tools to search for multiplanetary systems

The HARPS spectrograph on the 3.60 m telescope

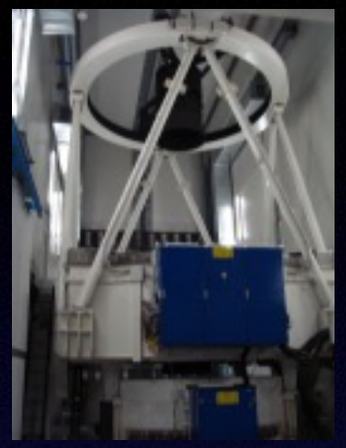
- Optical fibers
- Vacuum , thermal control (a few milli K during night)
- δλ/λ = 10 (-9) >>>> 0.3 m/s

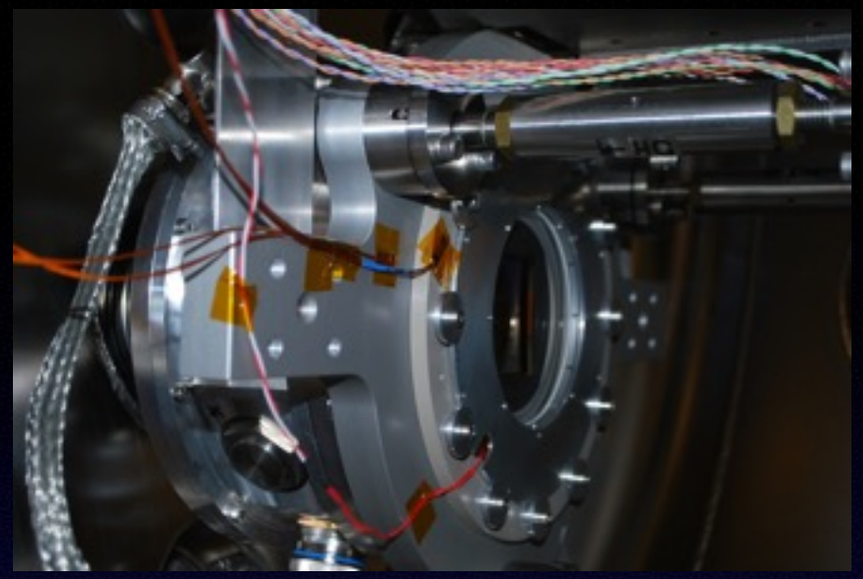


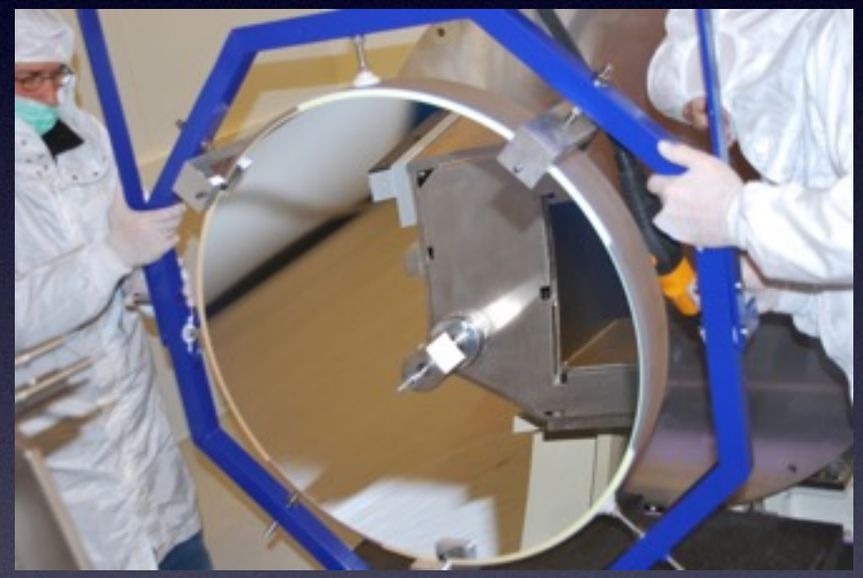
HARPS

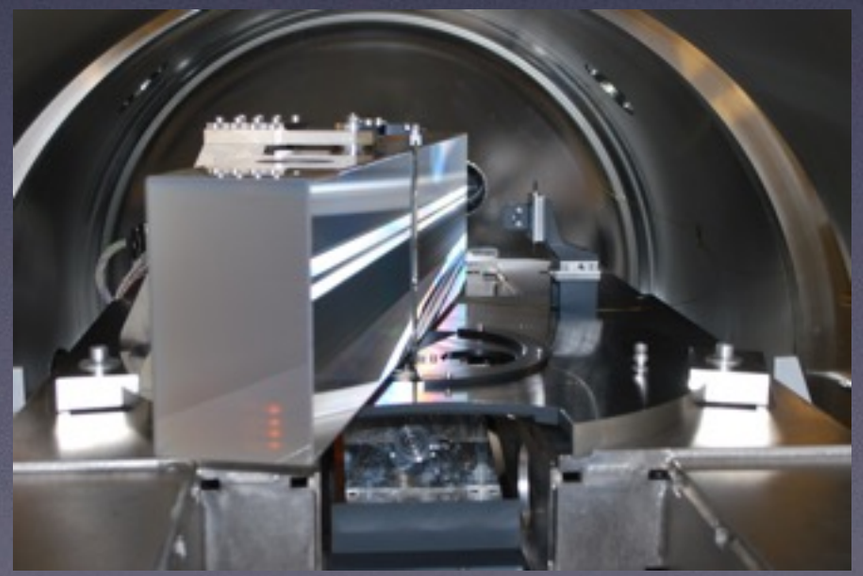
ESO-3.6m @ La Silla

HARPS @ La Palma

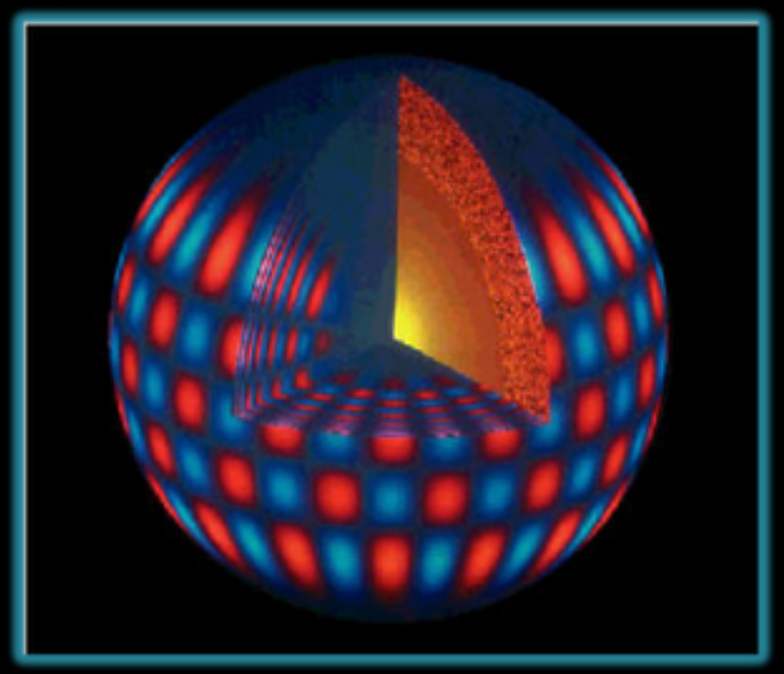


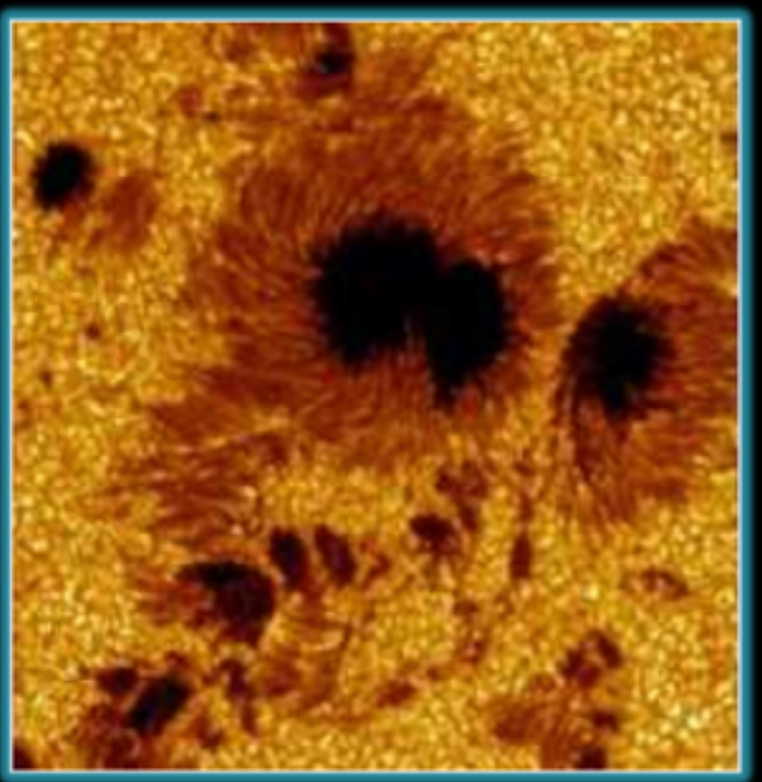


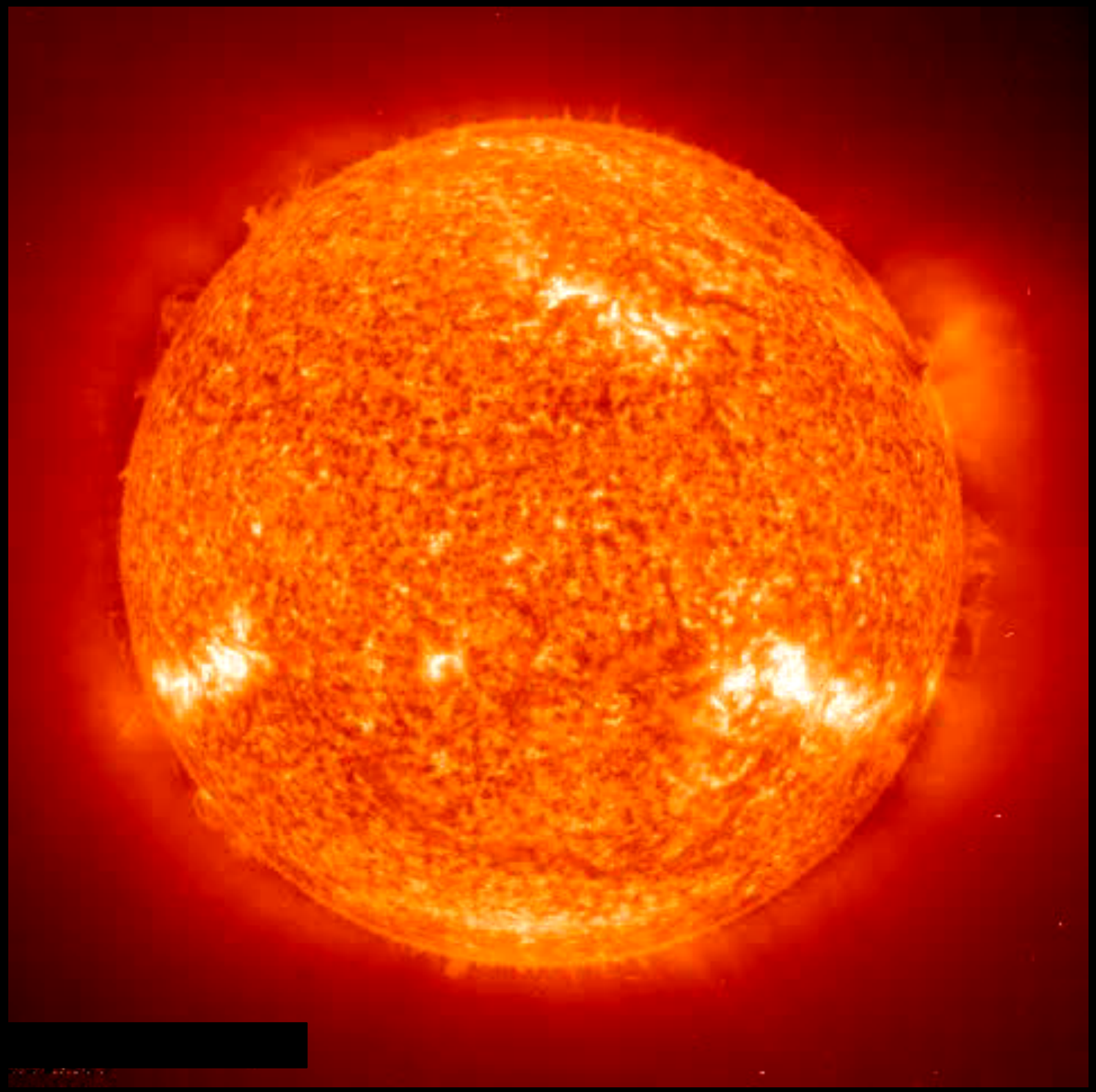




Stellar intrinsic limitations







Improvments :

... strategy of measurements to decrease the influence of acoustic and granulation noises.

... select non active stars, monitoring of Log HK and other indicators to detect and correct the influence of magnetic cycles. (Lovis , Dumusque)

... SW correction of the CCD patterns

... Octogonal fibers

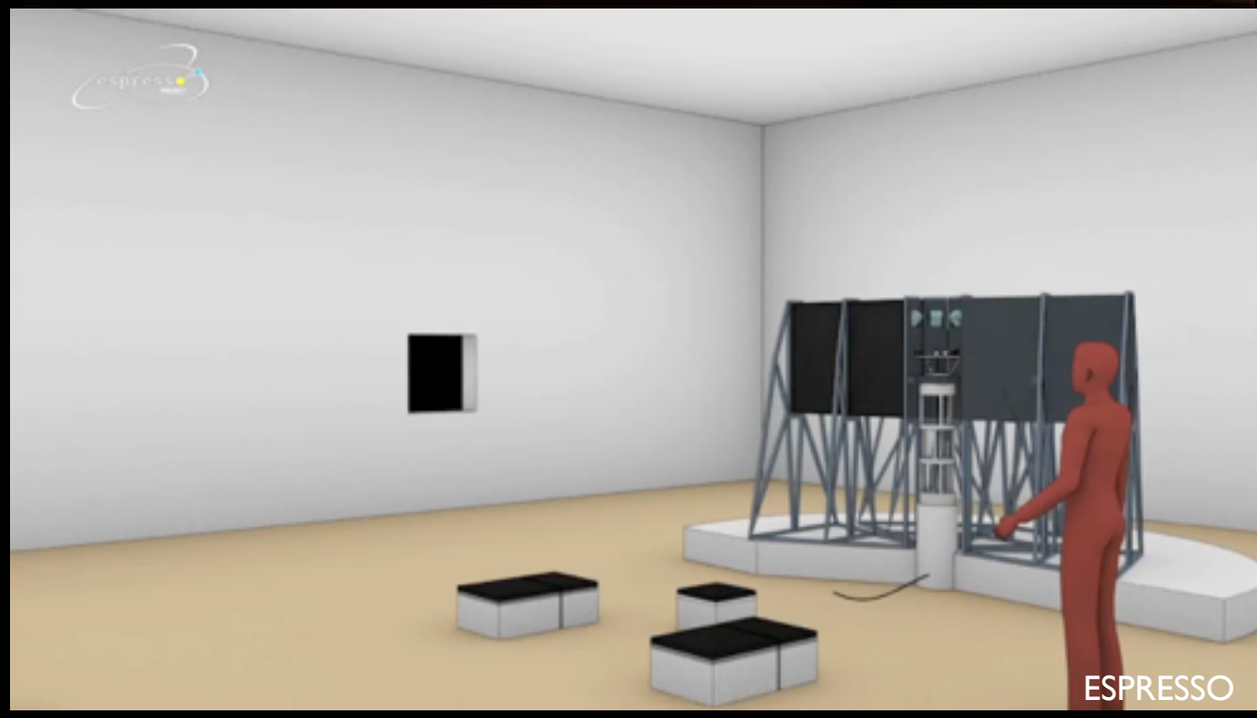
... Fix spacing FP, laser comb.

RV amplitudes of about 0.1 m/s are possible, but the number of measurements has to be very large (>> 100)

ESPRESSO a spectrograph for the VLT (diameter 8.2m)

«**E**chelle **SP**ectrograph for **R**ocky **E**xoplanets and **S**table **S**pectroscopic **O**bservations»

- Ultrastable spectrographe for the VLT
- Consortium : Switzerland, Italy, Portugal, Spain
- First light : 2017
- Expected precision RV : < 10 cm/s
- Goal : detection and characterization of small planets.



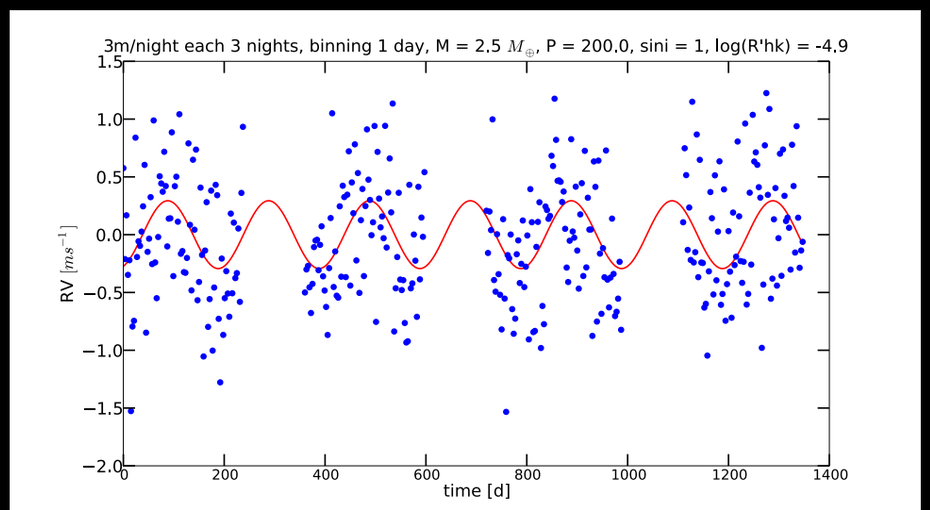
High precision radial velocities

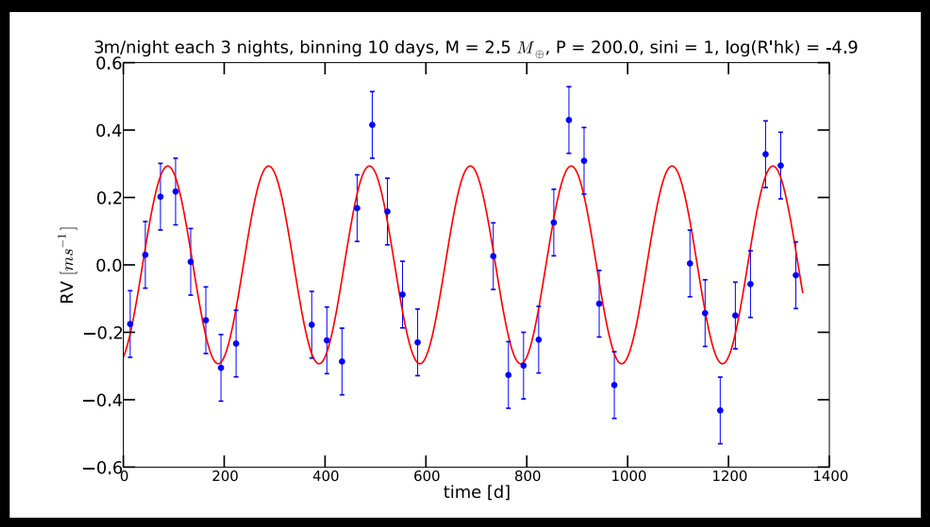
…Decrease intrinsic stellar noises (non active stars, strategy)

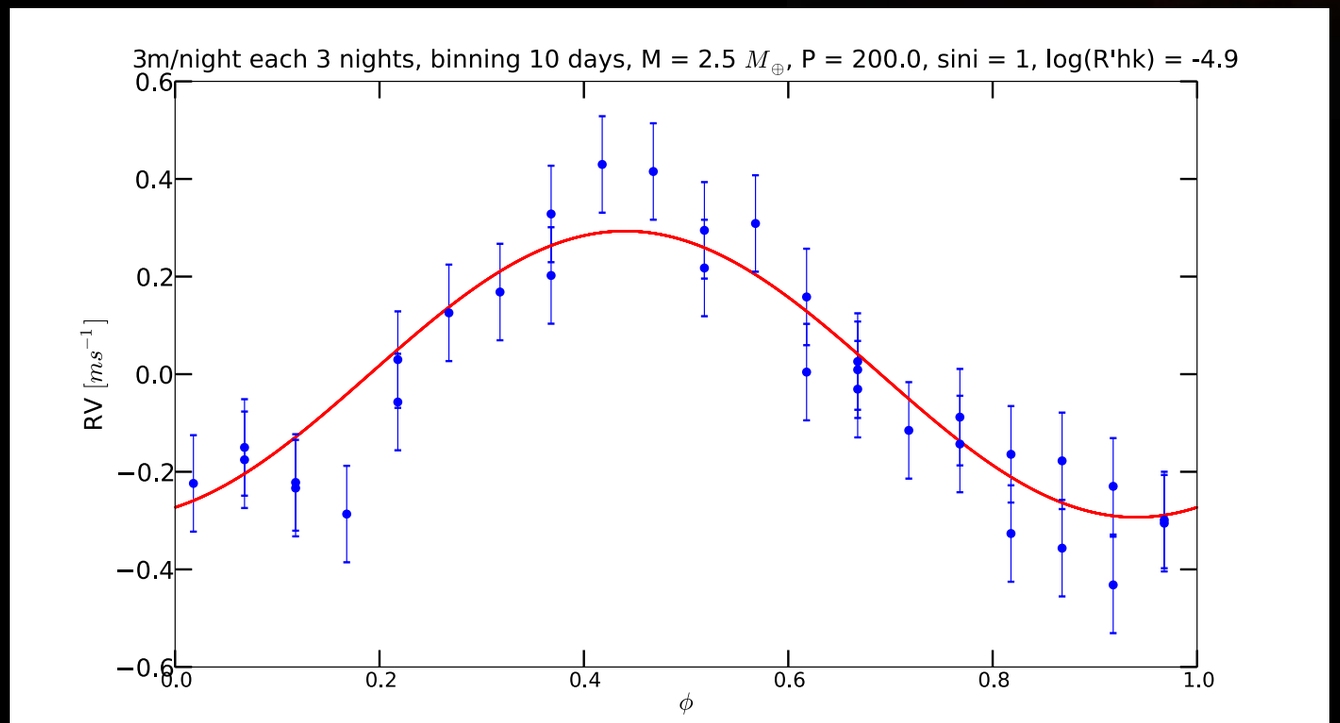
…Large collecting area (VLT)

…Ultra stable spectrograph (ESPRESSO/VLT, 2016)

Example : A 2.5 Earth-mass planet orbiting a non active-K star in the HZ (P=200 days)



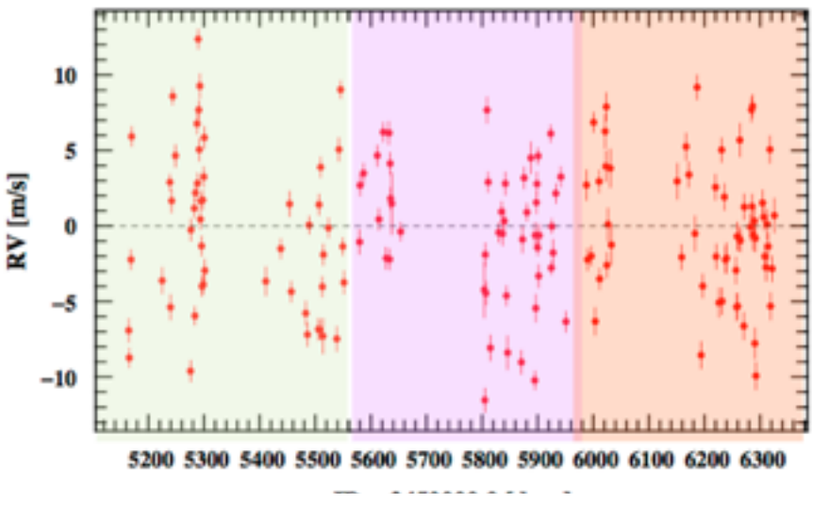


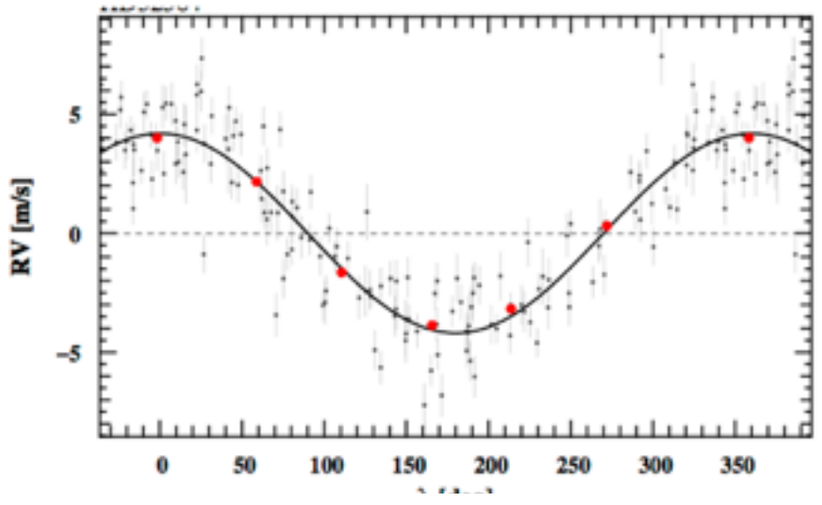


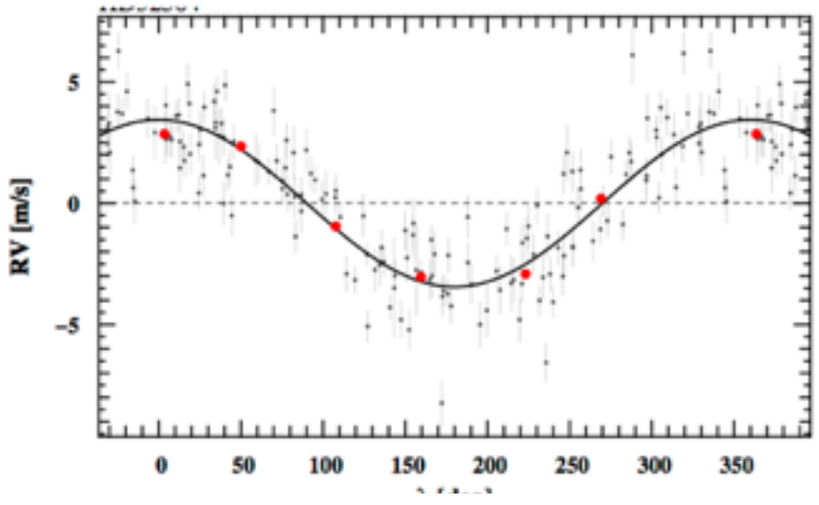
(Dumusque et al., 2010b)

Importance of the number of measurements

A new low mass multiple planetary system orbiting a nearby very quiet K dwarf



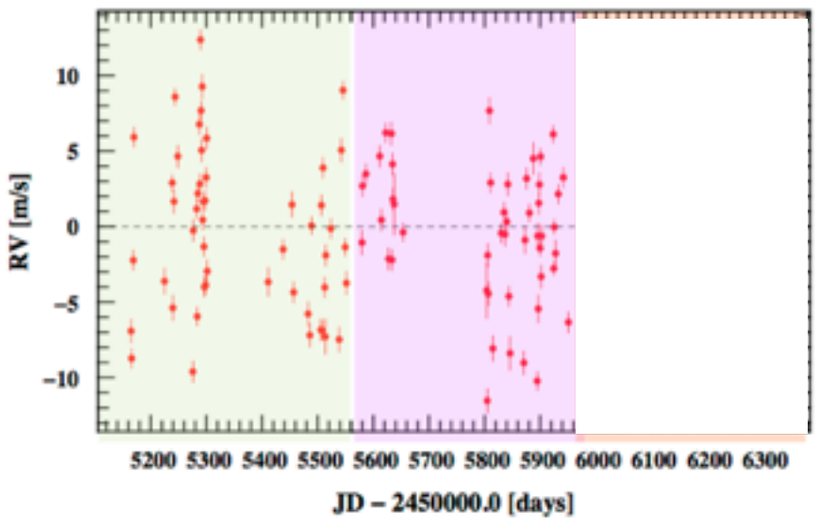


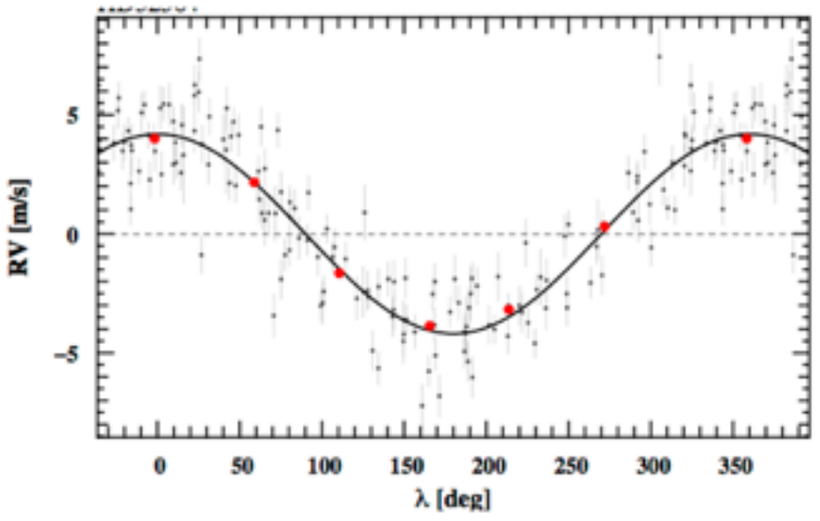


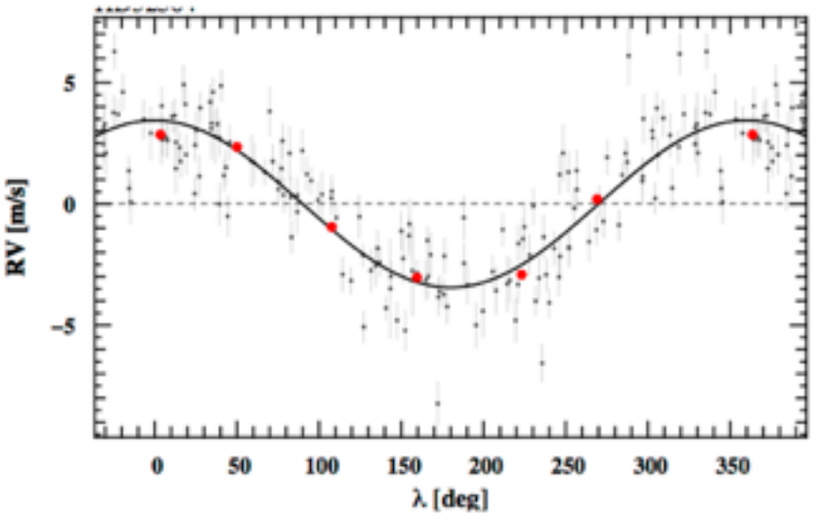
- 50 observations: a system with 2 planets
- (+ uncertainties due to aliasing)

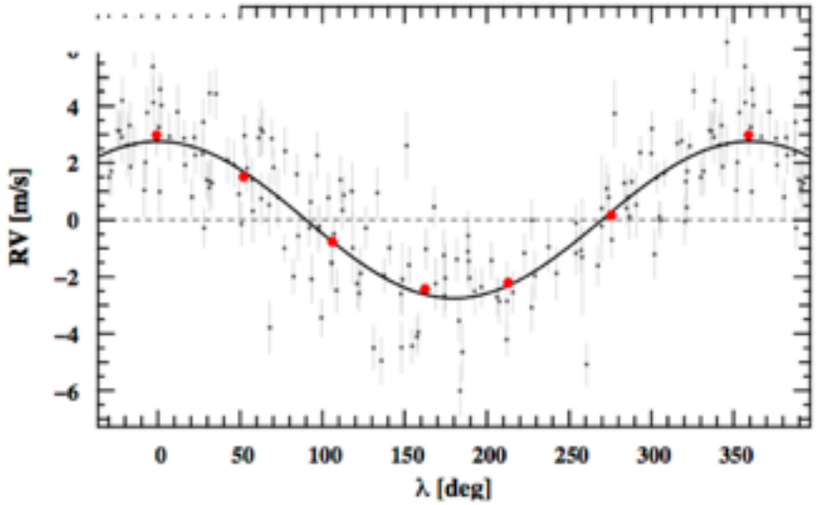
Importance of the number of measurements

A new low mass multiple planetary system orbiting a nearby very quiet K dwarf





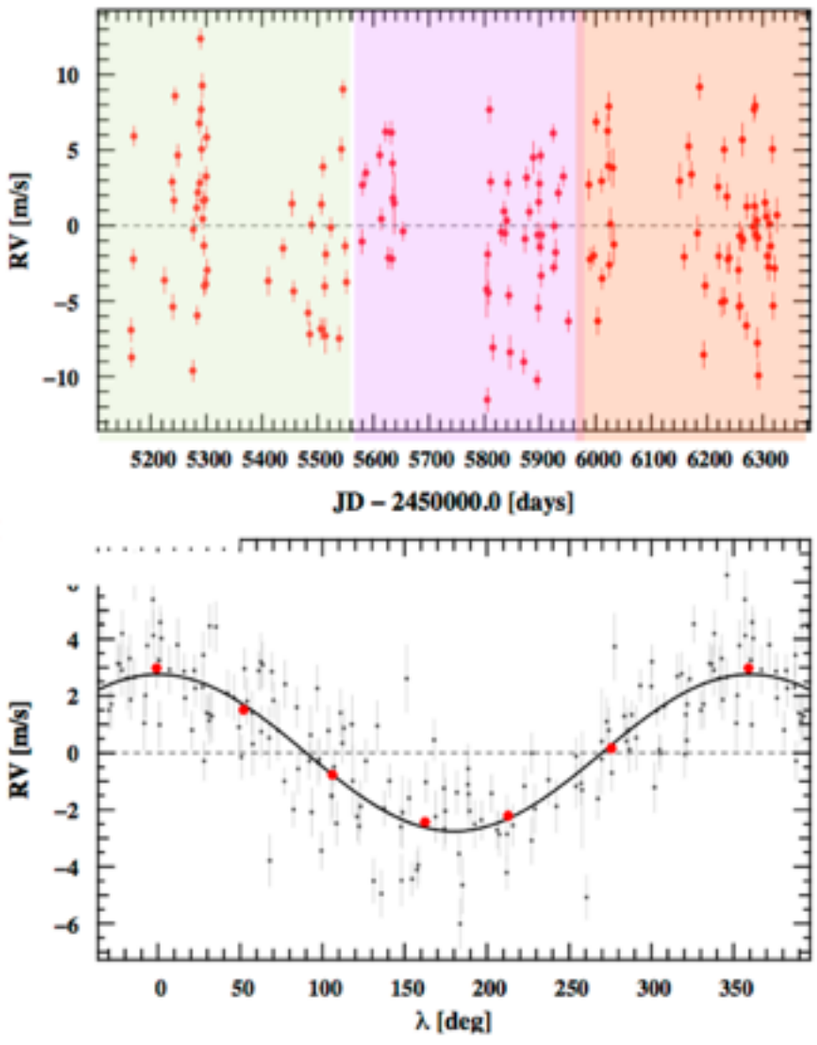


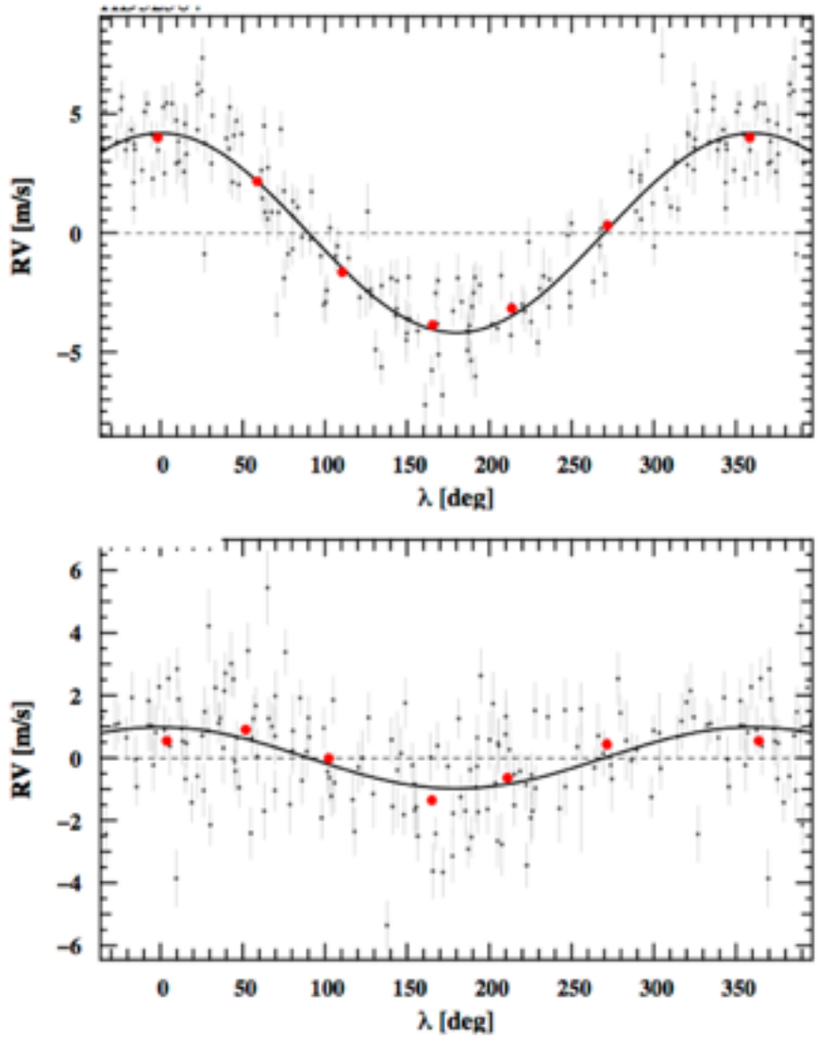


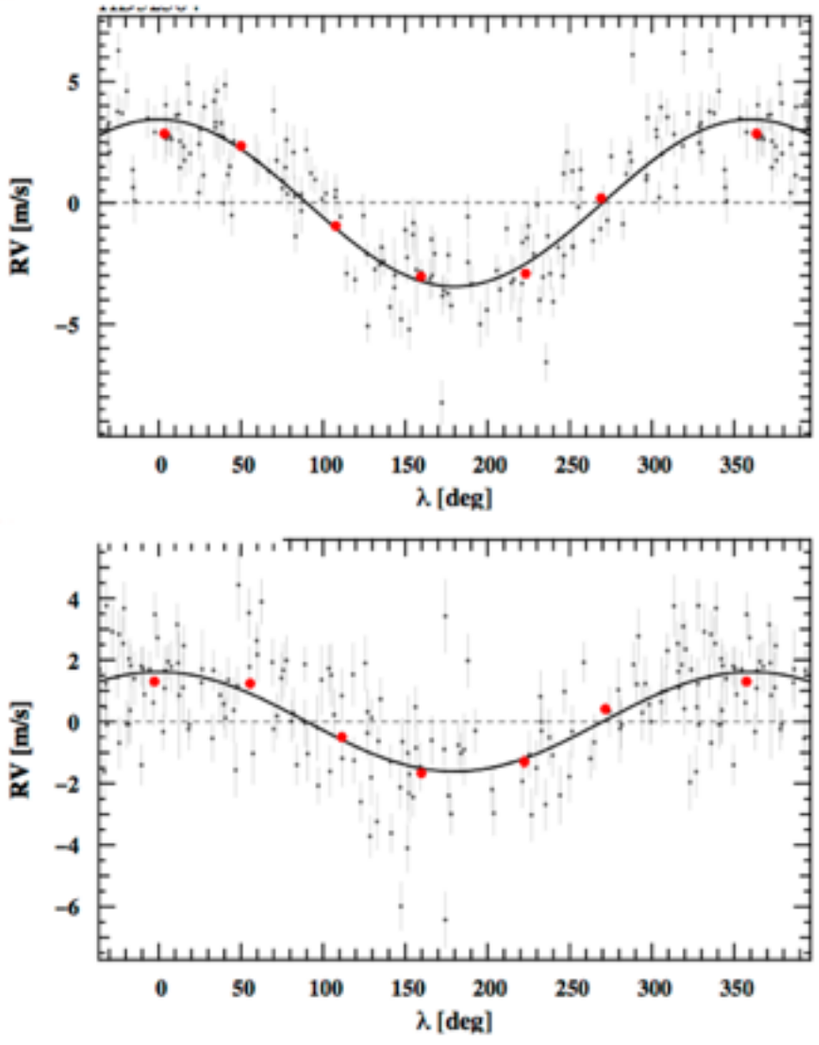
- 50 observations: a system with 2 planets
- (+ aliasing uncertainties)
- 100 observations: a system with 3 planets well defined.

Importance of the number of measurements

A new low mass multiple planetary system orbiting a nearby very quiet K dwarf







- 150 observations: a system with 5 planets.

=> requires a large number of measurements for a “complete” census!
(>150 meas !)

Statistical Properties of Super-Earths and Neptune-Mass Planets from the HARPS Survey

Unbiased exoplanet populations from the HARPS surveys

More than 500 nights of the 3.60 meter telescope @ la Silla
(more than 10 years of measurements)

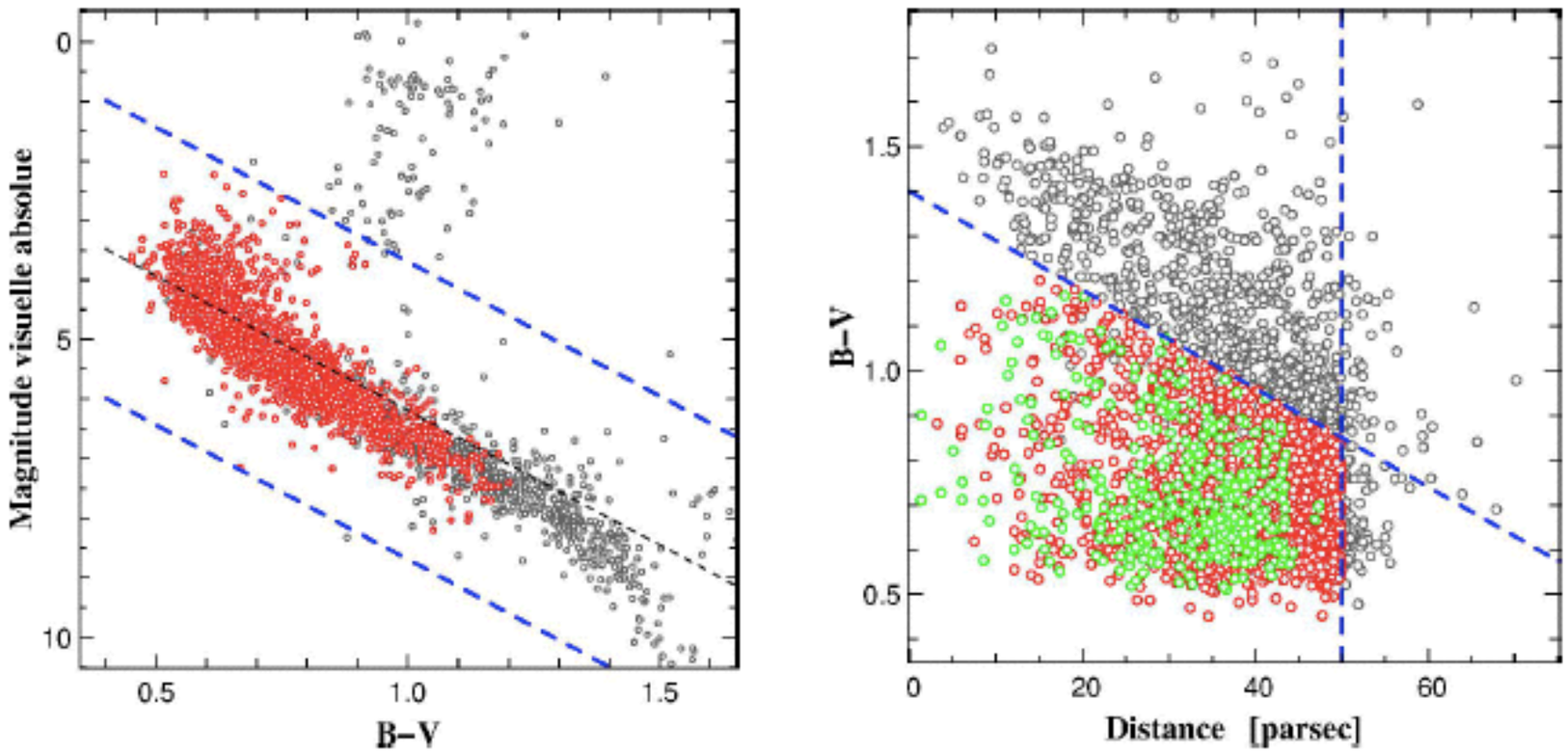


FIGURE 3.3 – Sélection de l'échantillon CORALIE. Les cibles Hipparcos de type spectraux F8 à M0 situées à moins de 50 pc du Soleil dans l'hémisphère sud et ayant une précision $\sigma_\pi \leq 5$ mas sont représentées en gris. Deux critères de sélection supplémentaires ont été utilisés pour la définition de l'échantillon CORALIE (en rouge). Une limite photométrique à 2.5 magnitudes de la séquence principale (à gauche) permet d'éliminer les géantes alors qu'une distance maximale fonction de la couleur permet d'écarter les étoiles tardives n'ayant pas un flux suffisant (à droite). Les cibles marquées en vert appartiennent également au programme HARPS (c.f. sect. 3.2).

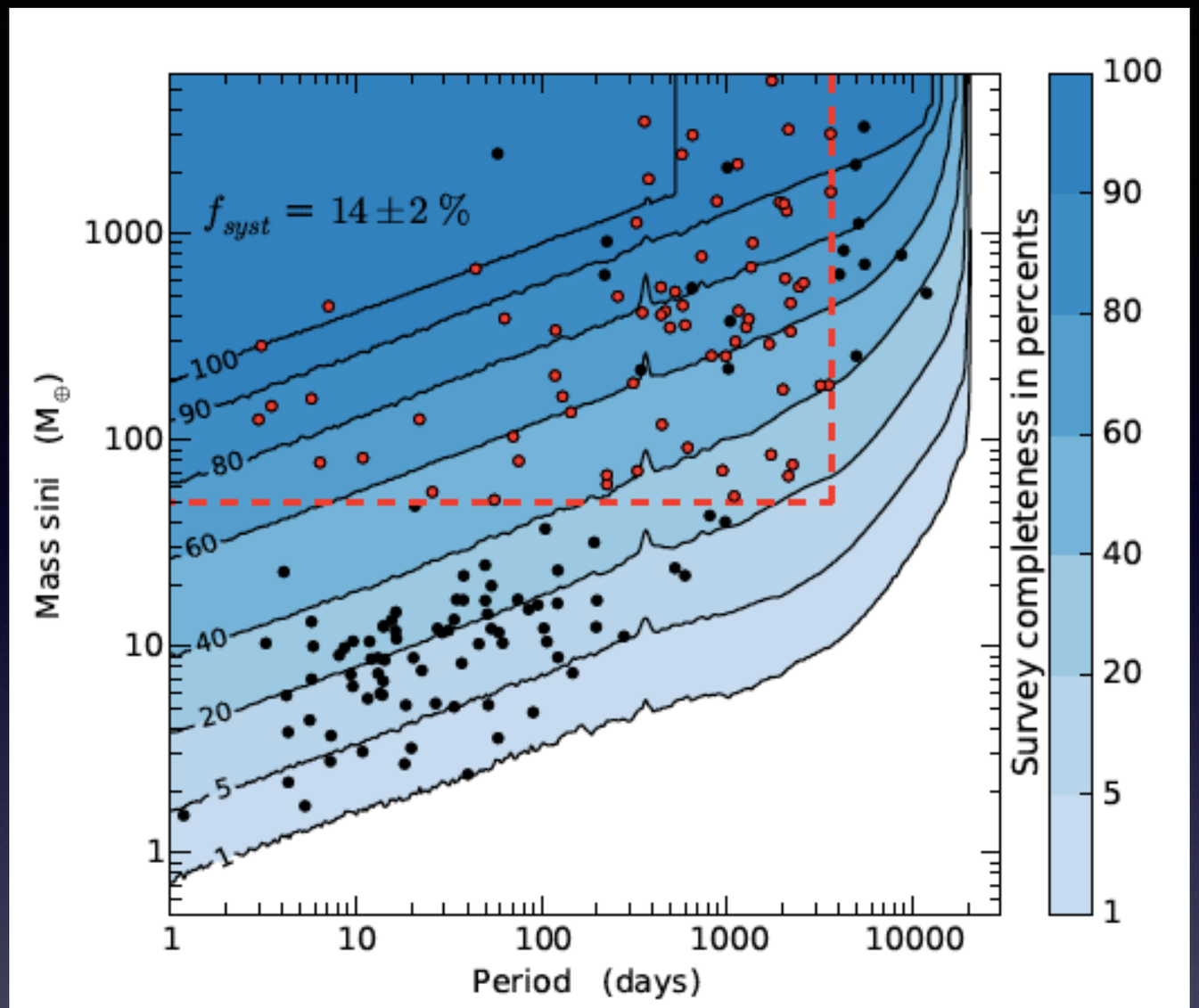


Fig. 5. Plot of the 169 planets of the considered HARPS+CORALIE sample in the $m_2 \sin i - \log P$ plane. The superimposed curves indicate the completeness of the survey. These detection probabilities are valid for the whole sample of 822 stars. After correcting for the detection bias, the fraction of stars with at least one planet more massive than $50\,M_\oplus$ and with a period smaller than 10 years is estimated to be $14 \pm 2\,\%$. The red points represent the planets which have been used to compute the corrected occurrence rate in the box indicated by the dash-dotted line. (Only one planet is taken account per system). The planets lying outside the box or being part of a system already taken into account are excluded; they are shown in black.

HD 10180 , 7 planets
HD 45364 , mmres 3/2
HD 65532, mmres 3/1
Mu Ara, 4 planets
GJ 876 , 3 planets
HD 202206 , 5/1 mmres
HD 82943

....

A lot of dynamically interesting systems studied by Jacques and A.Correia

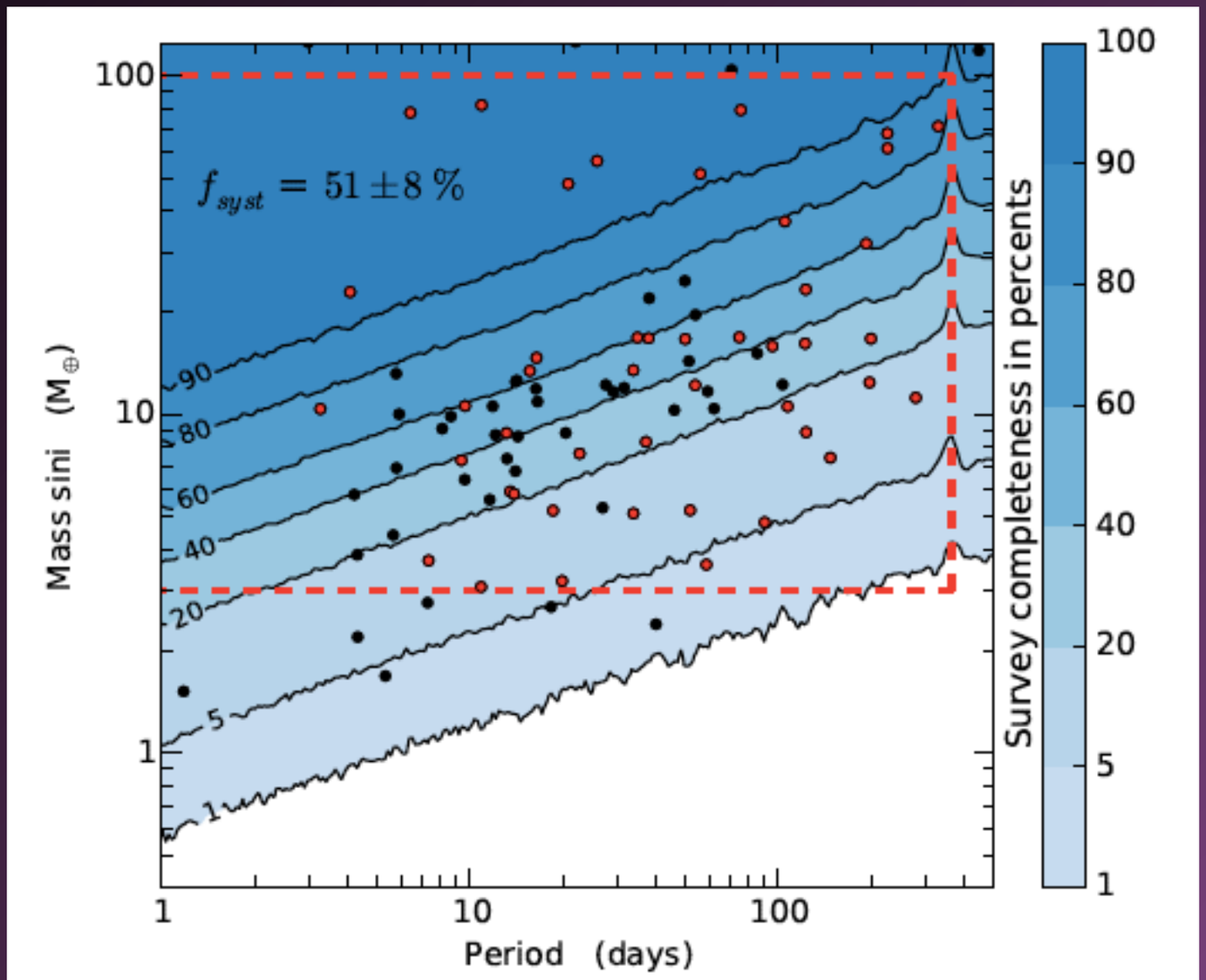
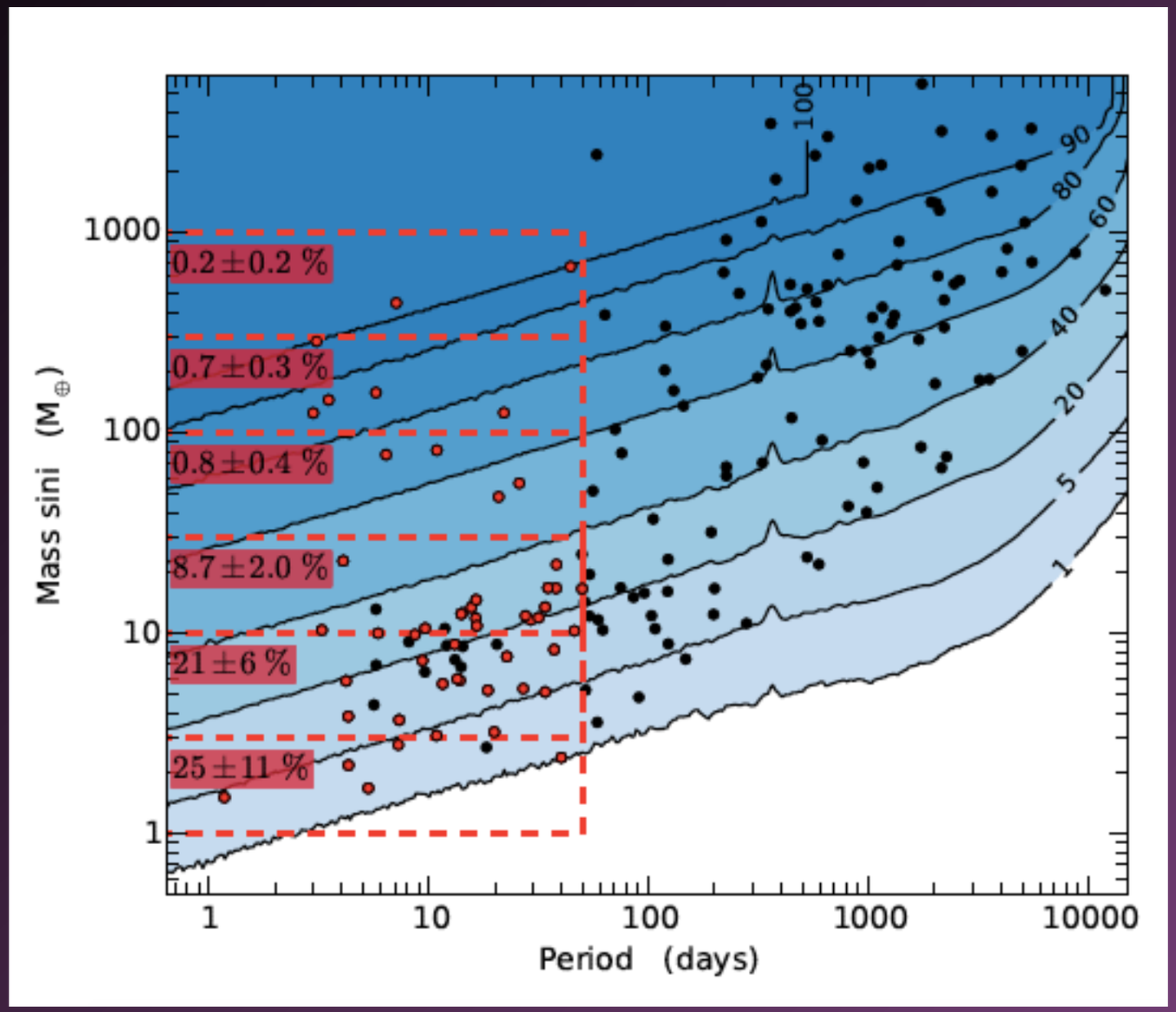
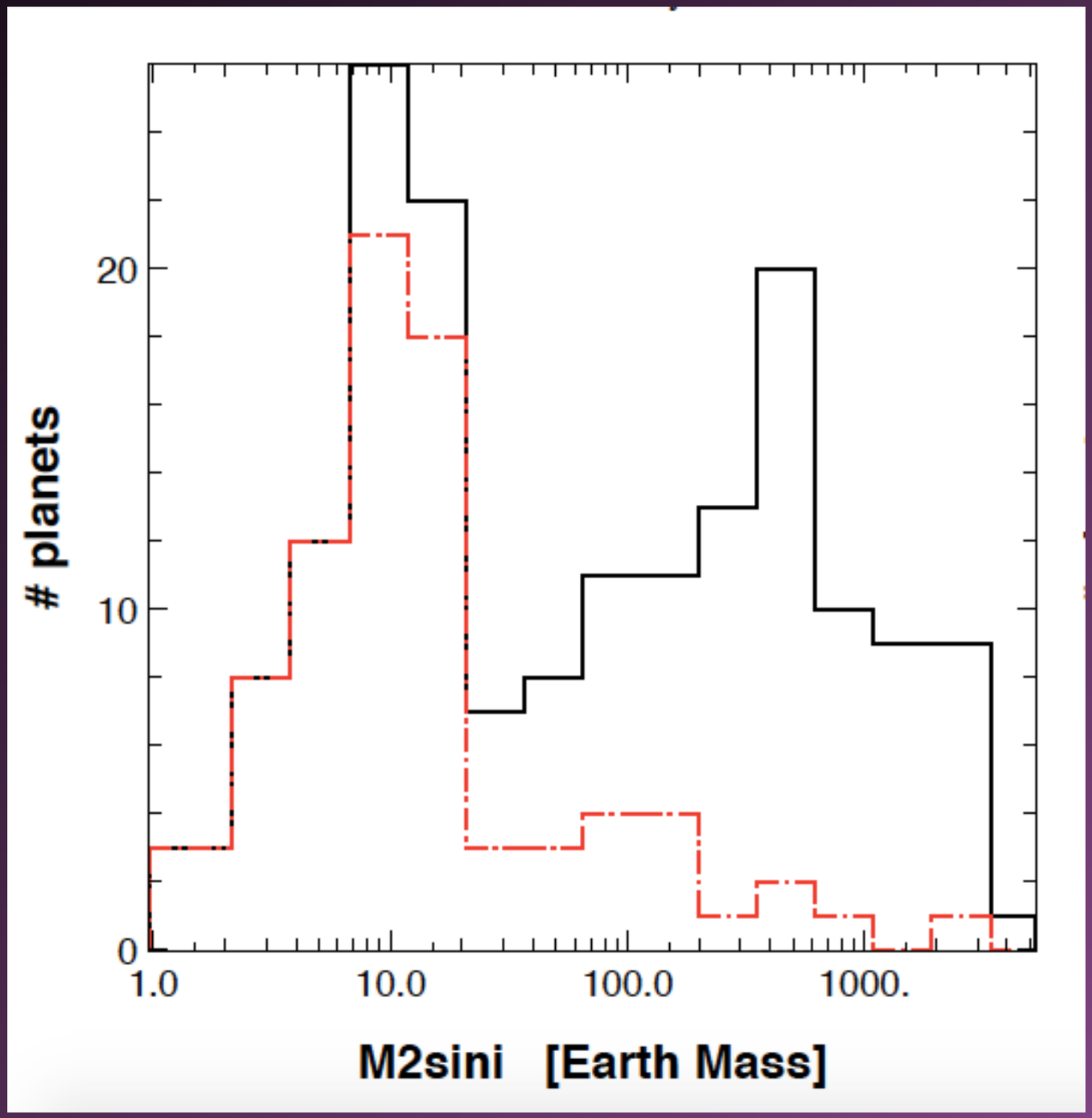
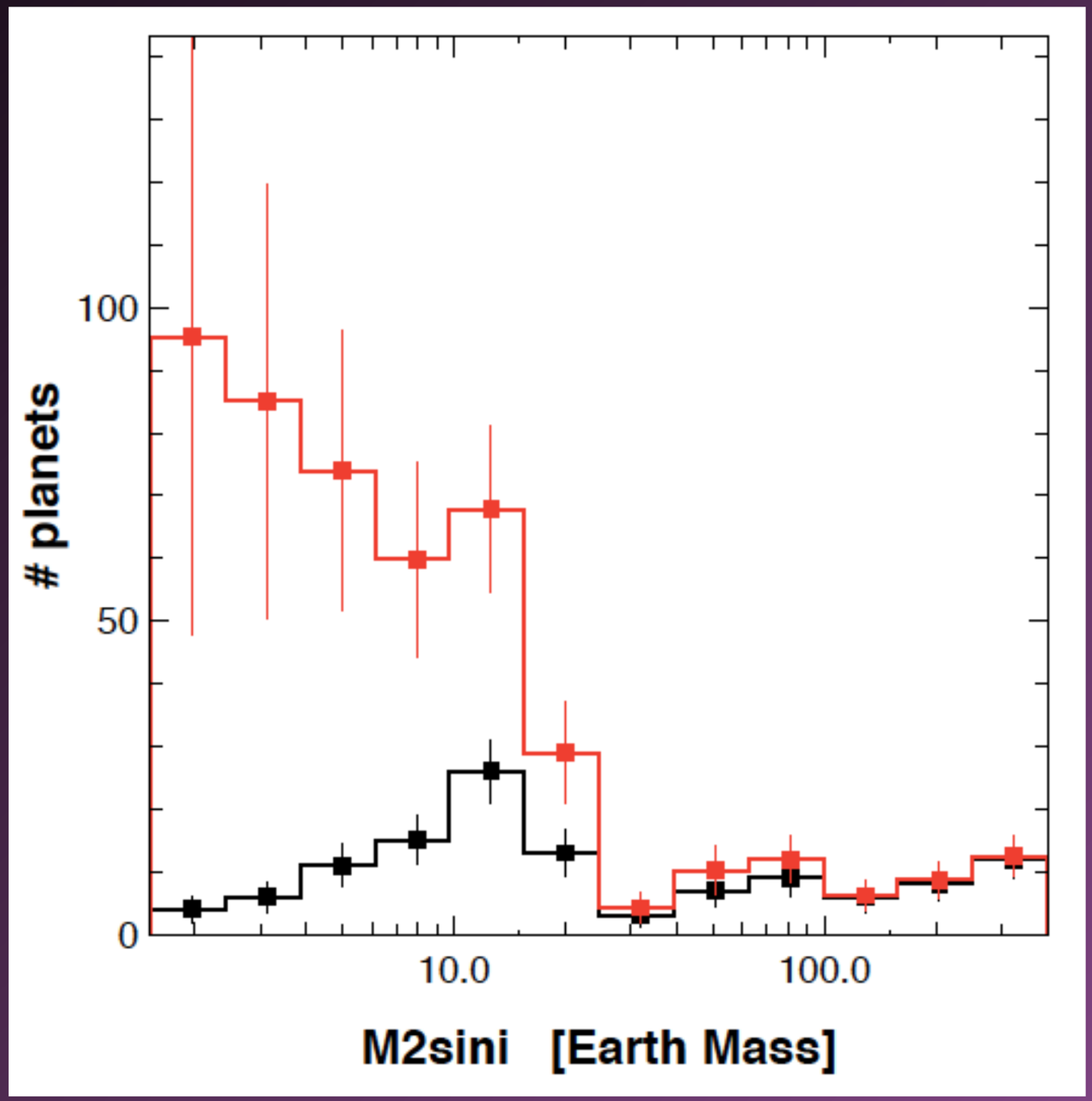


Fig. 6. Same as Fig. 5 but only for the HARPS subsample **of 376 stars**. The occurrence rate of planetary systems in the limited region between 3 and 100 $M_\oplus$, and with $P < 1$ year, is 51 ± 8 %. **Again, only one planet per system (represented by the red dots) have been considered for the computation of the occurrence rate.**



Warning : — have a look on uncertainties of orbital eccentricities of lowest mass planets !
— also: problem with the reality of some low mass planets


20
10
0
planets
1.0
10.0
100.0
1000.
M2sini [Earth Mass]


100
50
0
planets
10.0
100.0
M2sini [Earth Mass]

Two planetary populations with distinct properties

(and well separated in the mass histogram)

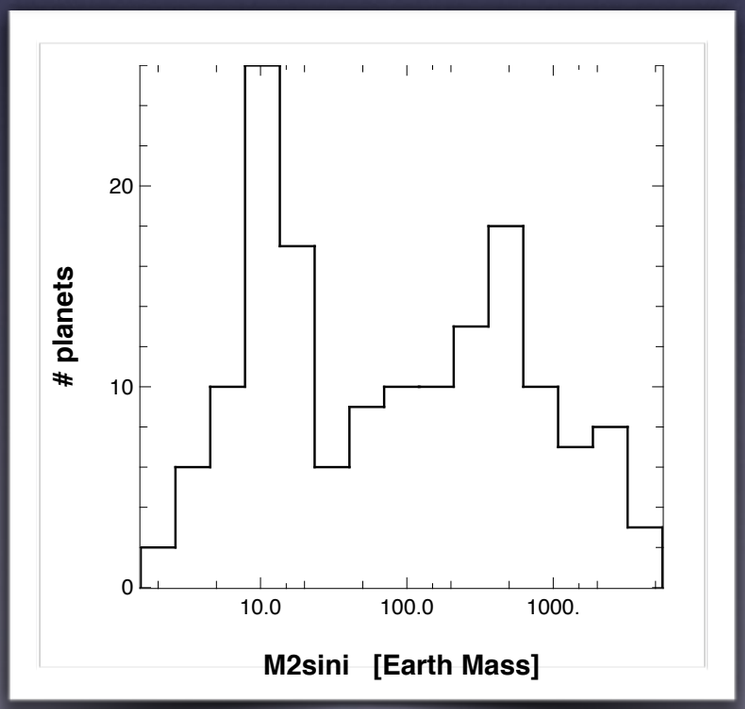
Planetary systems with masses smaller than 30 M_{earth}

Multiplicity > 70 %
Frequency decreasing after P=100d ?
Frequency not correlated with Fe/H

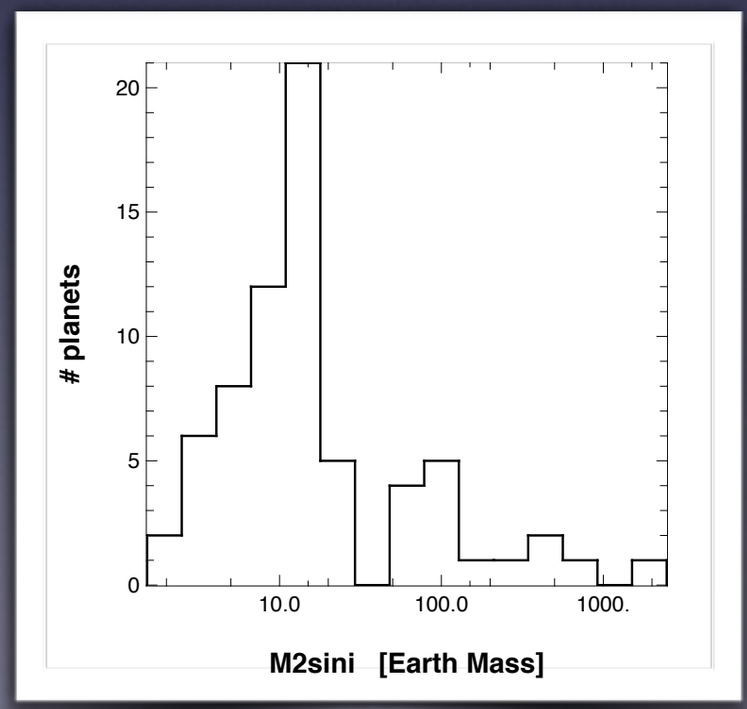
Planetary systems with gaseous giant planets

Multiplicity of about 25%
Frequency increasing with log P
Frequency strongly correlated with Fe/H

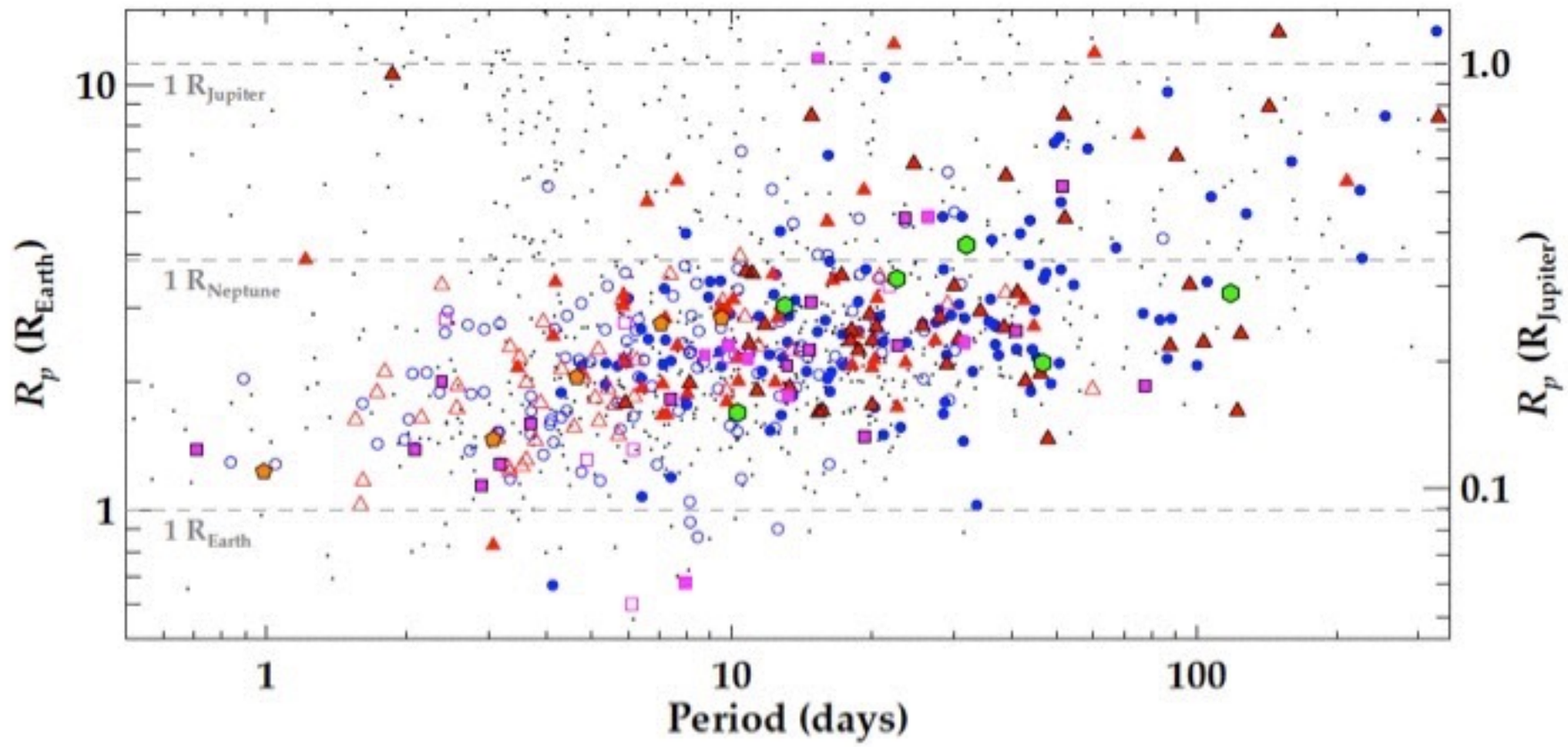
Detections in the global sample



...and for P < 100 days



Multi-transiting KEPLER candidates



Numbers of multiplanets:

115 doubles, 45 triples, 8 quads,

1 & 1 of five and six

Borucki et al. 2011
Lissauer, Ragozzine,
Fabrycky et al. 2011

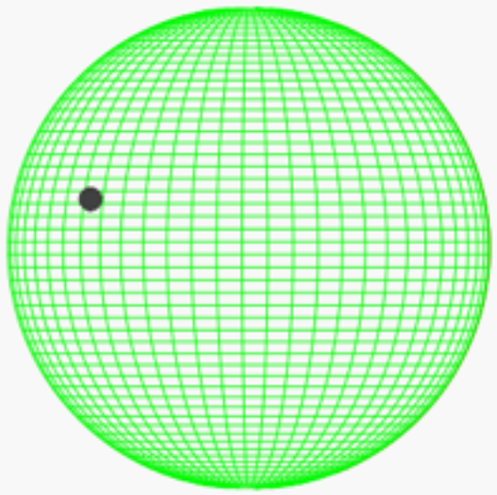
Scatter of orbital planes is about 1 degree !!!

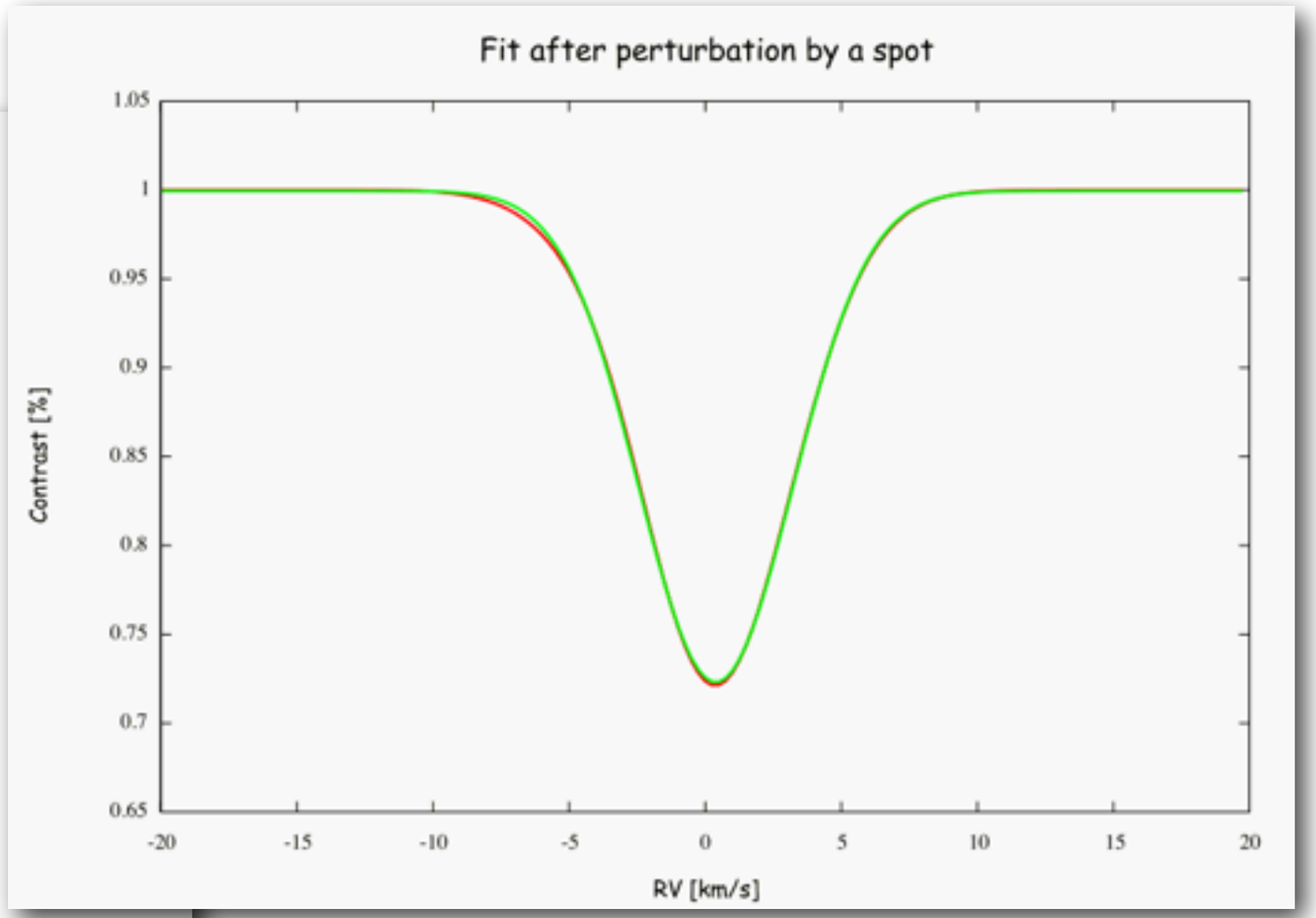
Planetary Transits

The relative inclination of orbital plane and stellar equatorial plane

... A new hint of complex dynamical interactions

The Rossiter - Mac Laughlin effect

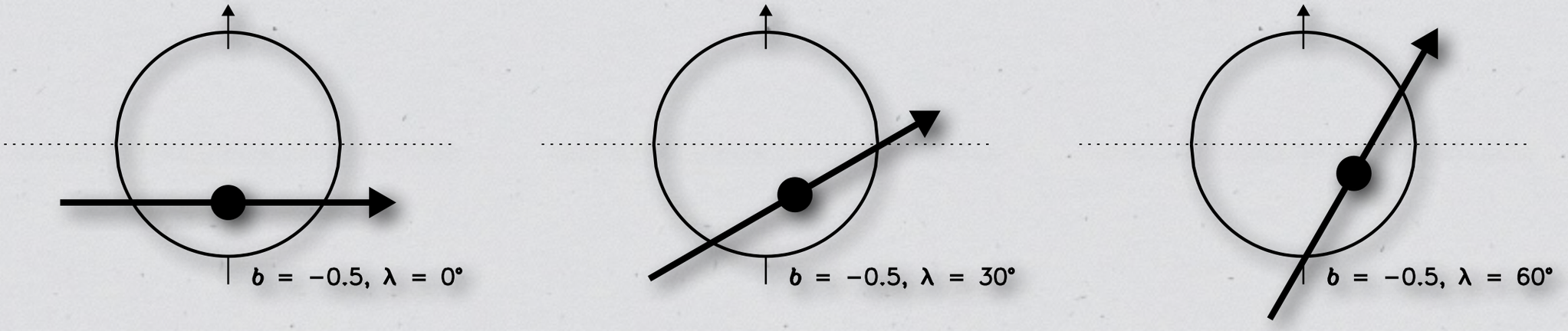




The transit of a planet in front of a rotating star creates a distorsion of stellar lines and an anomaly of the velocity curve

The Rossiter-McLaughlin effect

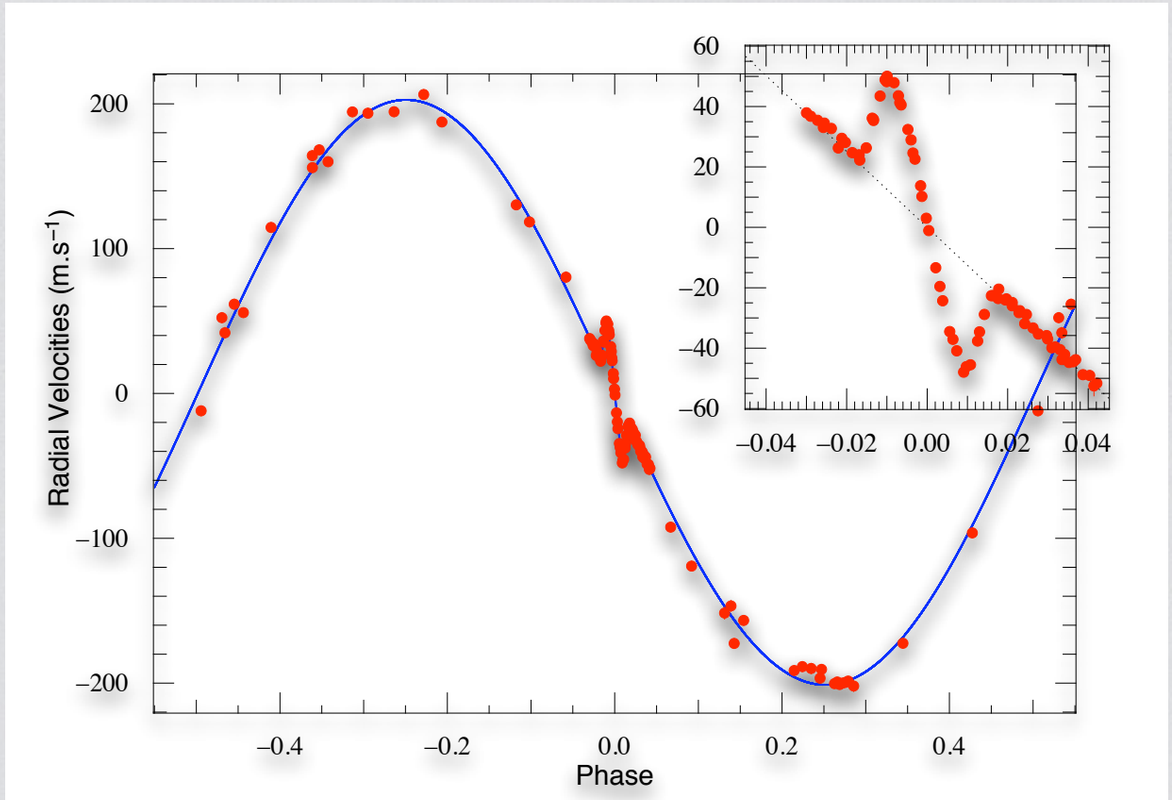
a spectroscopic transit



A coming diversity in spin-orbit angles:

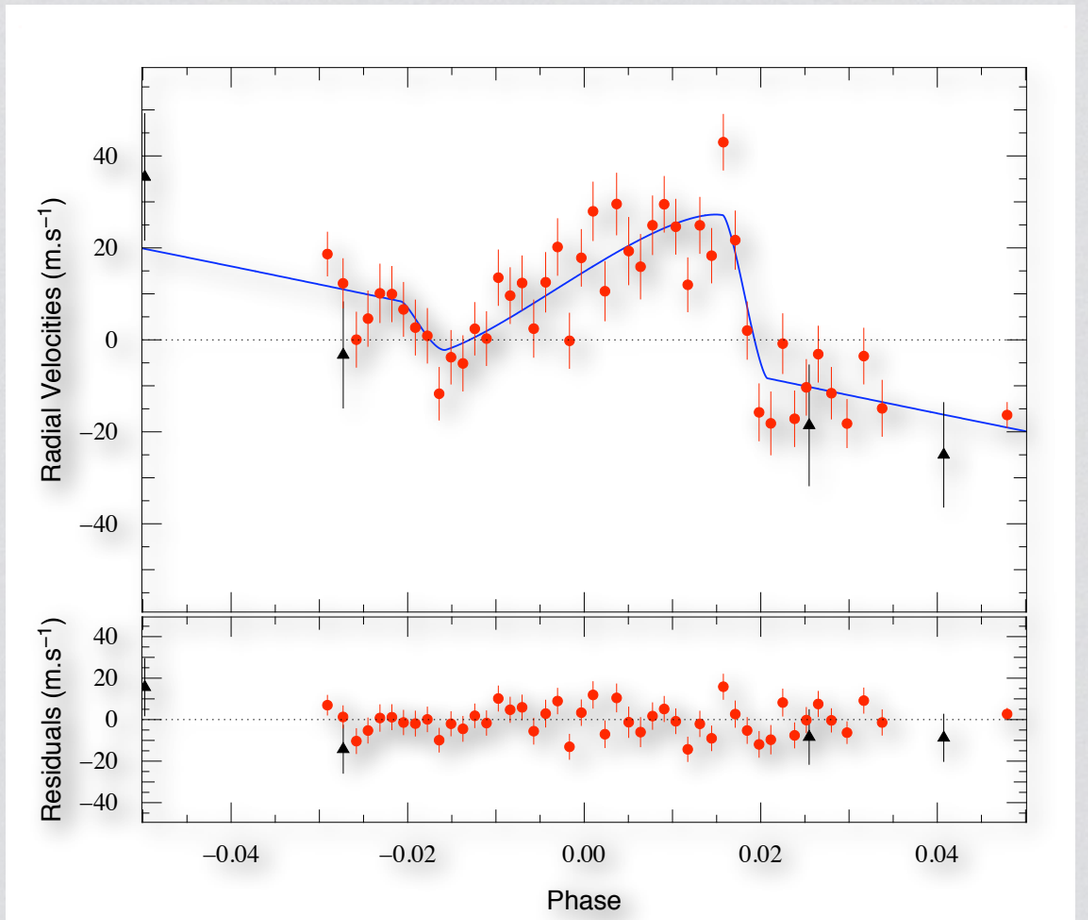
it allows to probe planetary formation

HD 189733b



Triaud et al. 2009

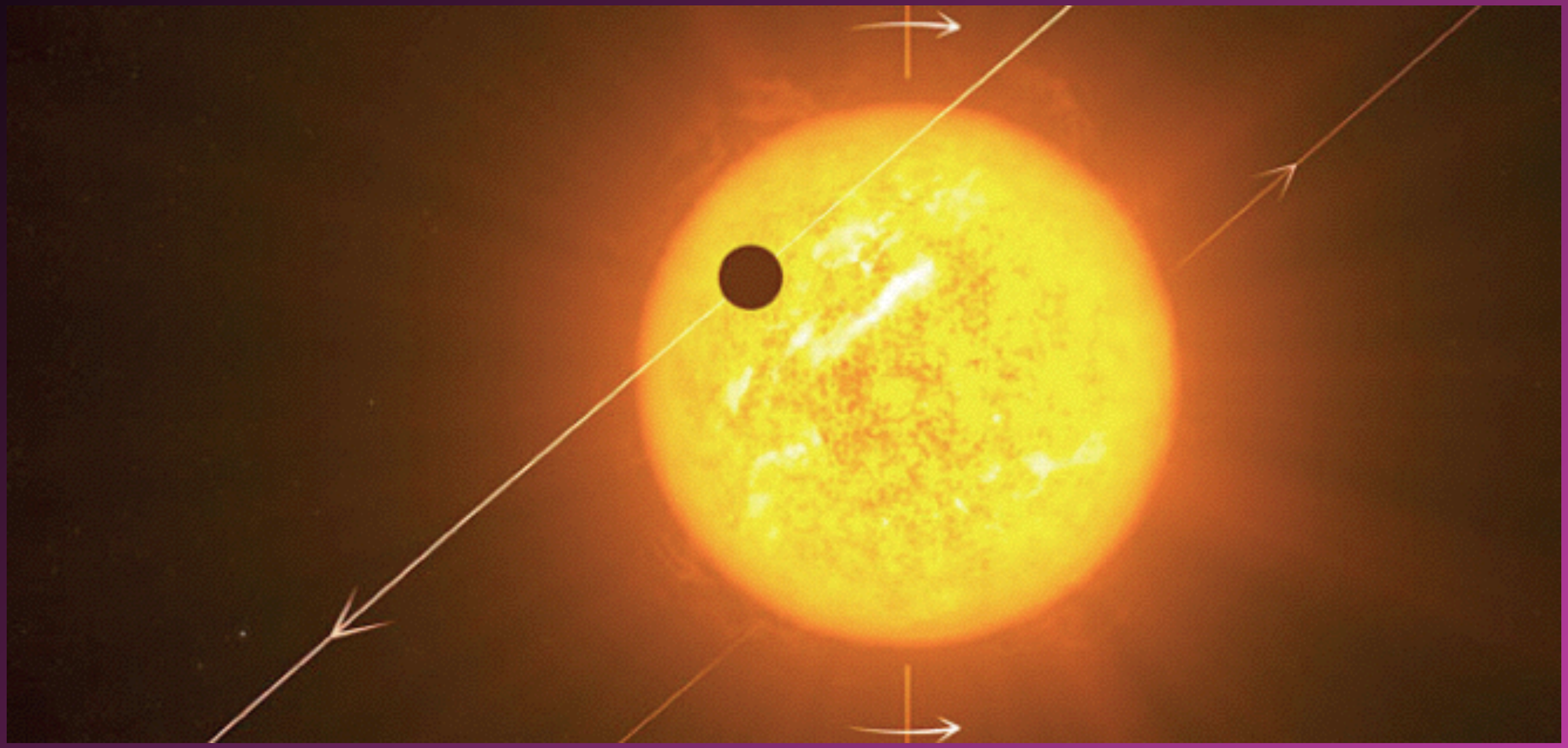
WASP-15b

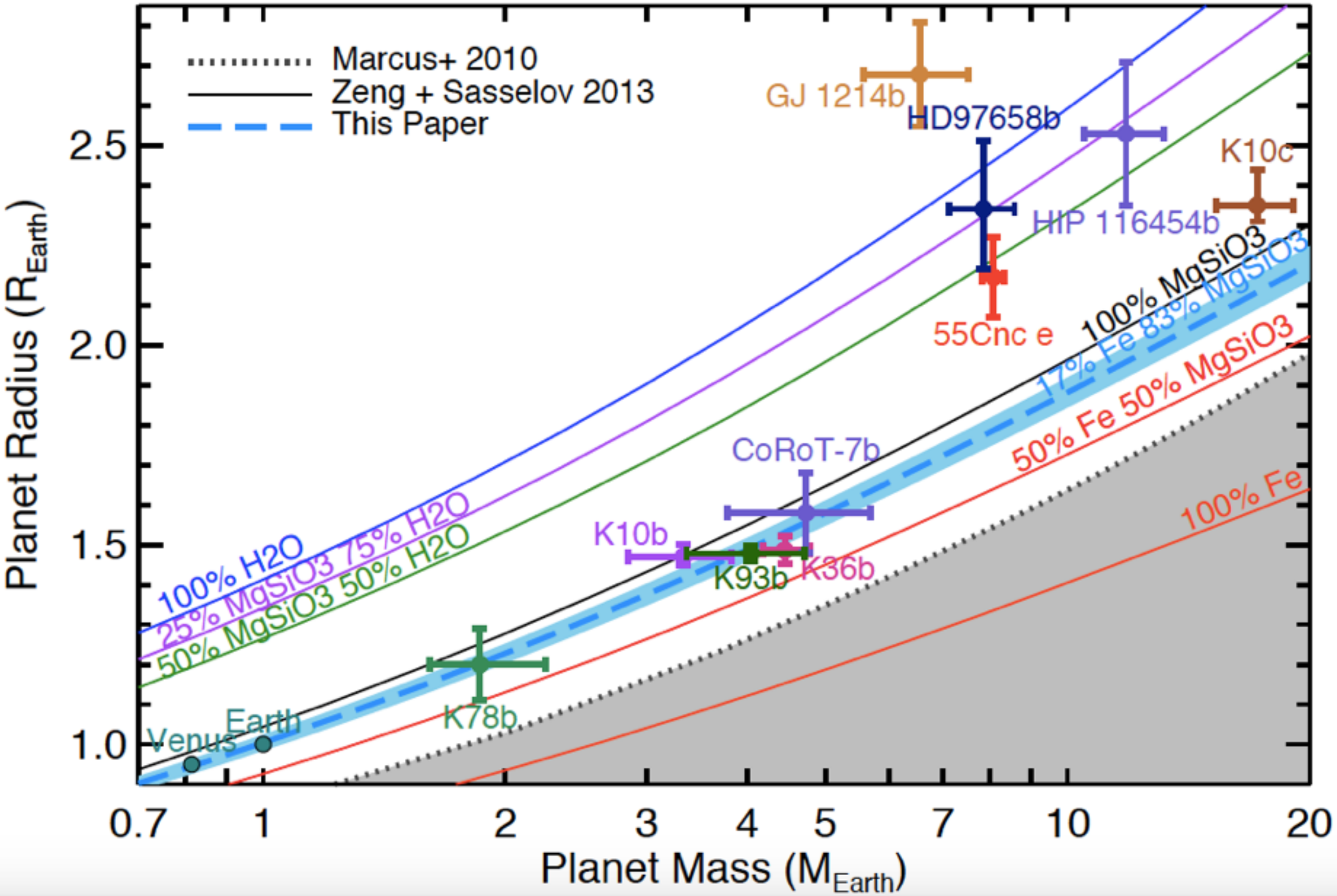


Triaud et al. 2010

An example of retrograde and inclined orbit : WASP 8b

Orbital migration is not the only explanation for the «Hot Jupiters»





Dressing et al.2015

Happy birthday Jacques