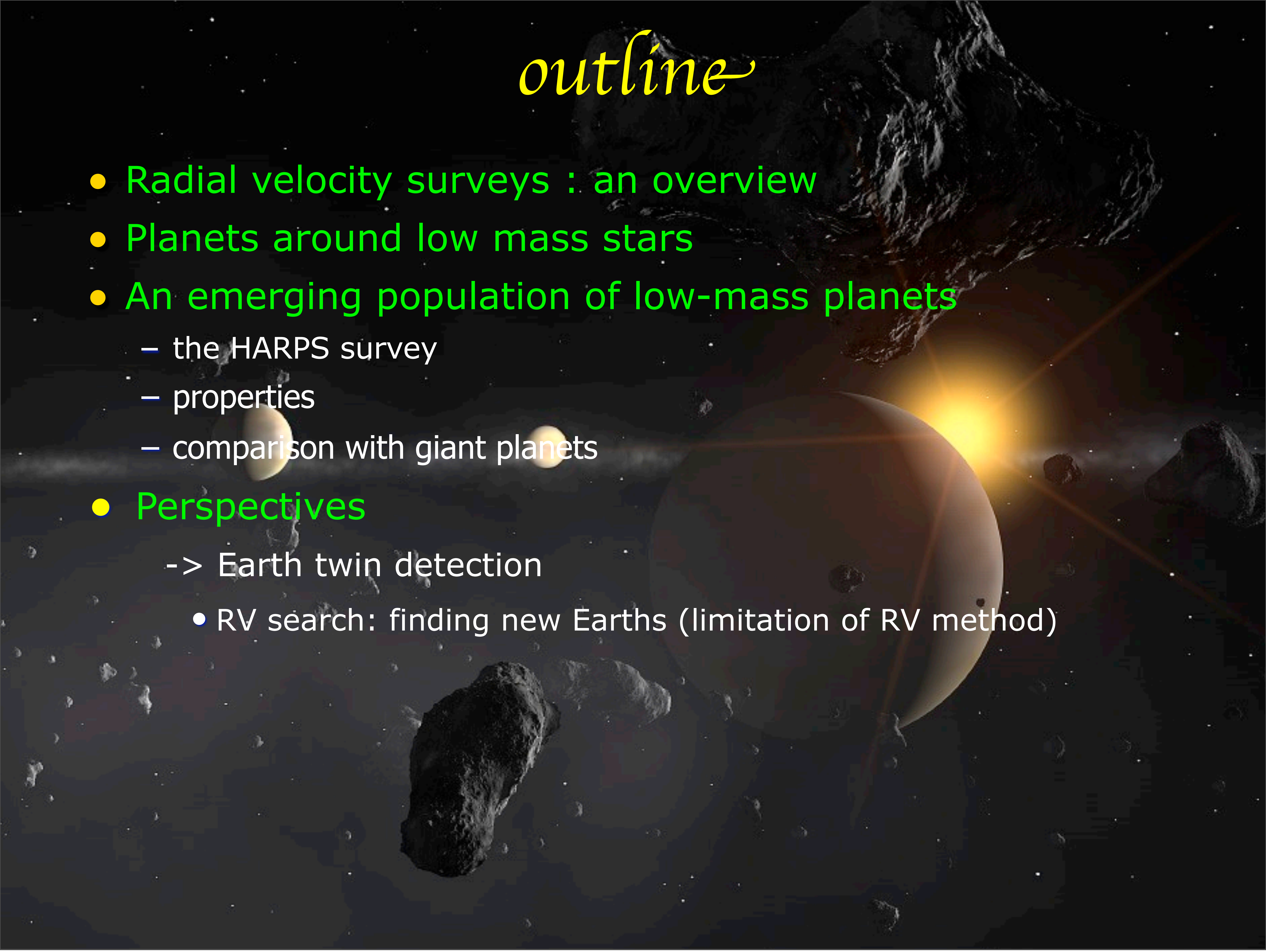
Overview of radial velocity surveys and planets discoveries

Michel Mayor Geneva University

Tuesday, March 30, 2010



outline

- Radial velocity surveys : an overview
- Planets around low mass stars
- An emerging population of low-mass planets
  - the HARPS survey
  - properties
  - comparison with giant planets
- Perspectives

-> Earth twin detection

- RV search: finding new Earths (limitation of RV method)

The HARPS Search for Southern Extra-Solar Planets
The metal-deficient sample

PI: N. Santos Cols: M. Mayor, F. Bouchy, F. Pepe, D. Queloz, S. Udry, X. Dumusque, P. Figueira, C. Melo, S. Sousa

Sample:

~100 FGK dwarfs with -0.5<[Fe/H]<-2.0

Goal:

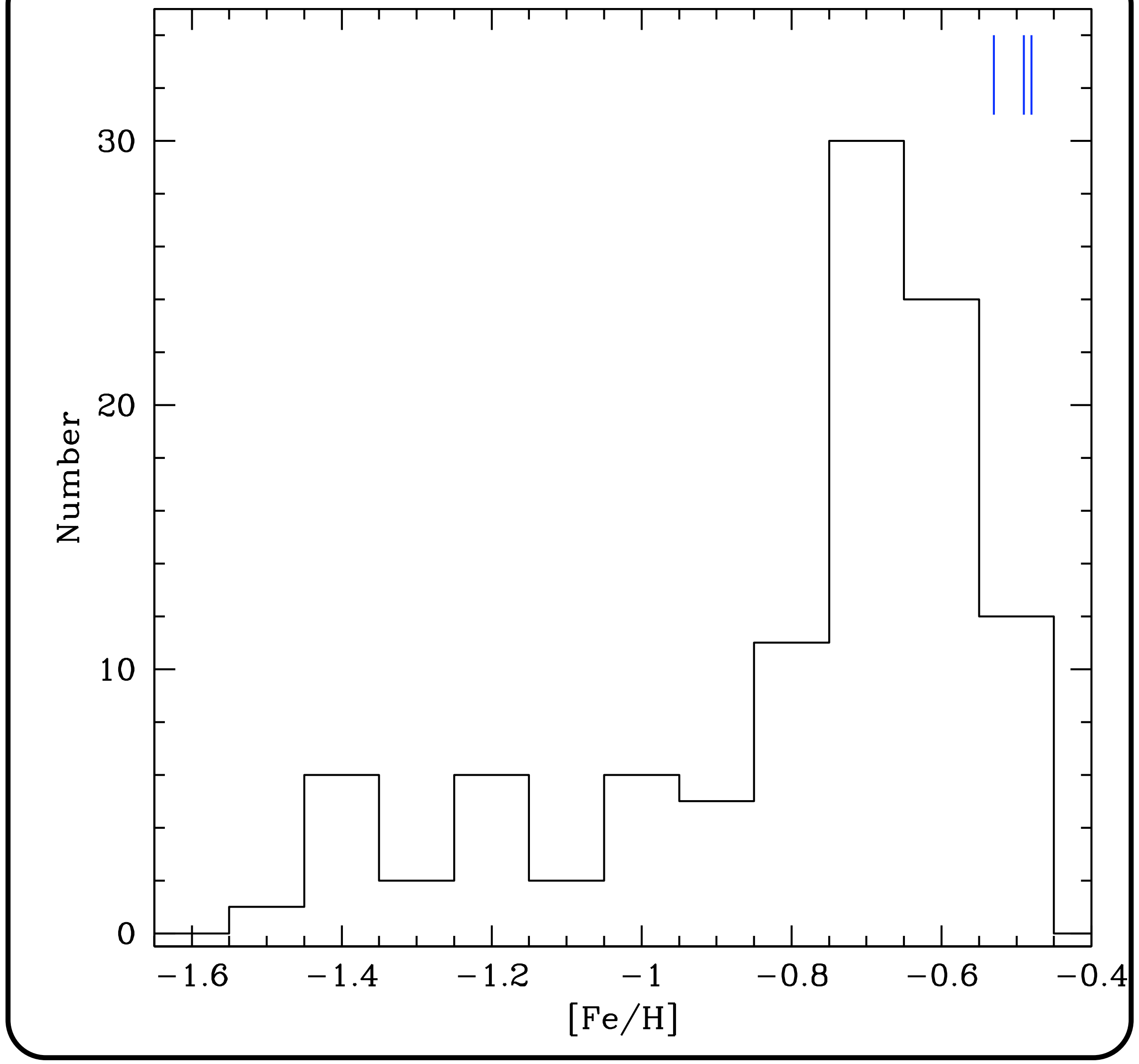
Study giant planet frequency in metal-poor domain

Results:

- 3 new giant planets in long period (P>1.5 yr) orbits (HD171028b, HD181720b, HD190984b)
- Lower frequency rate than solar-metallicity stars
- Long period giant planets are not rare around moderately metal-poor stars?
- Still all planets in metal-rich tail of the sample

Future (now):

- Extend study to incidence of Neptunes/Super-Earths around moderately metal-poor stars
- Further test planet formation models



The Keck/HIRES Metal-Poor Planet Search

Sozzetti, PI. Co-Is: Latham, Torres, Carney, Laird, Stefanik, Boss, Korzennik

SURVEY OUTLINE

1) 200 stars (Carney-Latham and Ryan samples), no close stellar companions, 2.0 < [Fe/H] < -0.6, Teff < 6000 K, V < 12

2) Reconnaissance for gas giant planets within 2 AU, to gauge the role of competing models of giant planet formation

3) Campaign duration: 3 years

4) Typical RV precision achieved: 5-10 m/s

MAIN FINDINGS

A) No giant planets (K > 100 m/s) within 2 AU of metal-poor stars: confirmed and extended previous findings

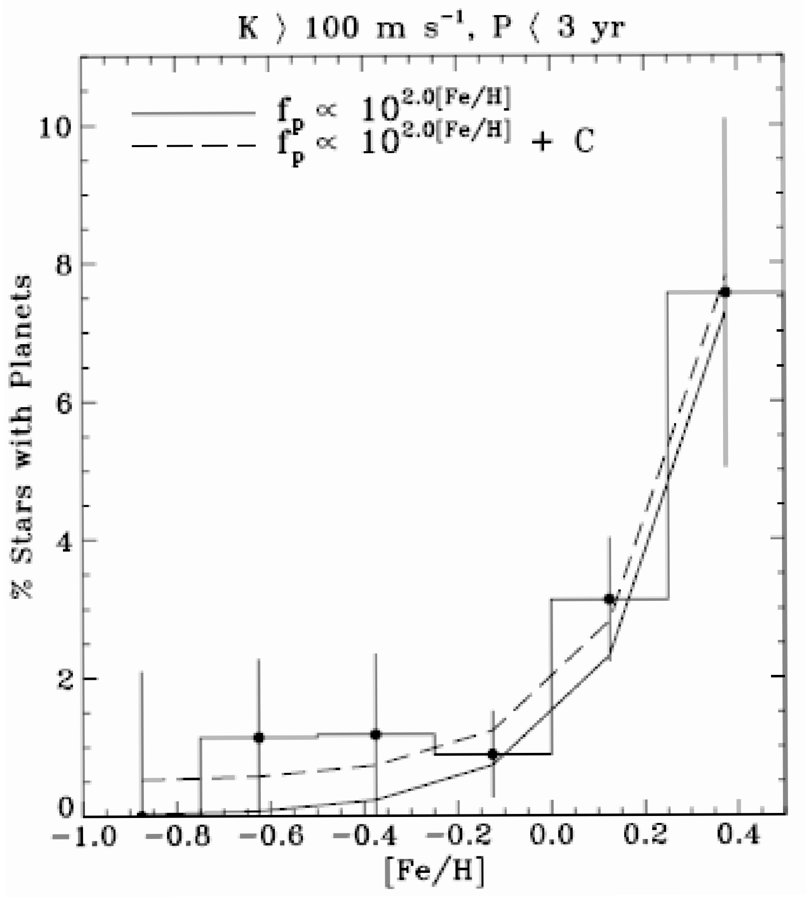
B) Can say very little on low-mass (K < 30 m/s) planets

C) ~6% of the stars have long-period companions (follow-up with direct IR imaging to ascertain their nature)

D) Average giant planet frequency is $F_p < 0.67\%$ (1σ)

E) F_p(-1.0<[Fe/H]<-0.5) a factor of several lower than F_p([Fe/H]>0.0), but indistinguishable from F_p(-0.5<[Fe/H]<0.0).

G) F_p([Fe/H]) appears bimodal, but no clear conclusion can be made. Need better statistics!



Where to go from here?

1) Expand the sample size;
2) Lower the mass sensitivity threshold;
3) Search at longer periods.

The HARPS Search for Southern Extra-Solar Planets

The volume limited sample

PI: G. Lo Curto Cols: W. Benz, F. Bouchy, G. Hebrard, C. Lovis, M. Mayor, C. Moutou, D. Naef, F. Pepe,
D. Queloz, N. C. Santos, D. Segransan, S. Udry

Sample

Non-active, slowly rotating dwarf stars, from F2V to M0V, within 57.5pc.

Goal

Obtain high accuracy orbital elements of Jupiter-mass planets in a volume limited sample of the solar neighborhood.

Strategy

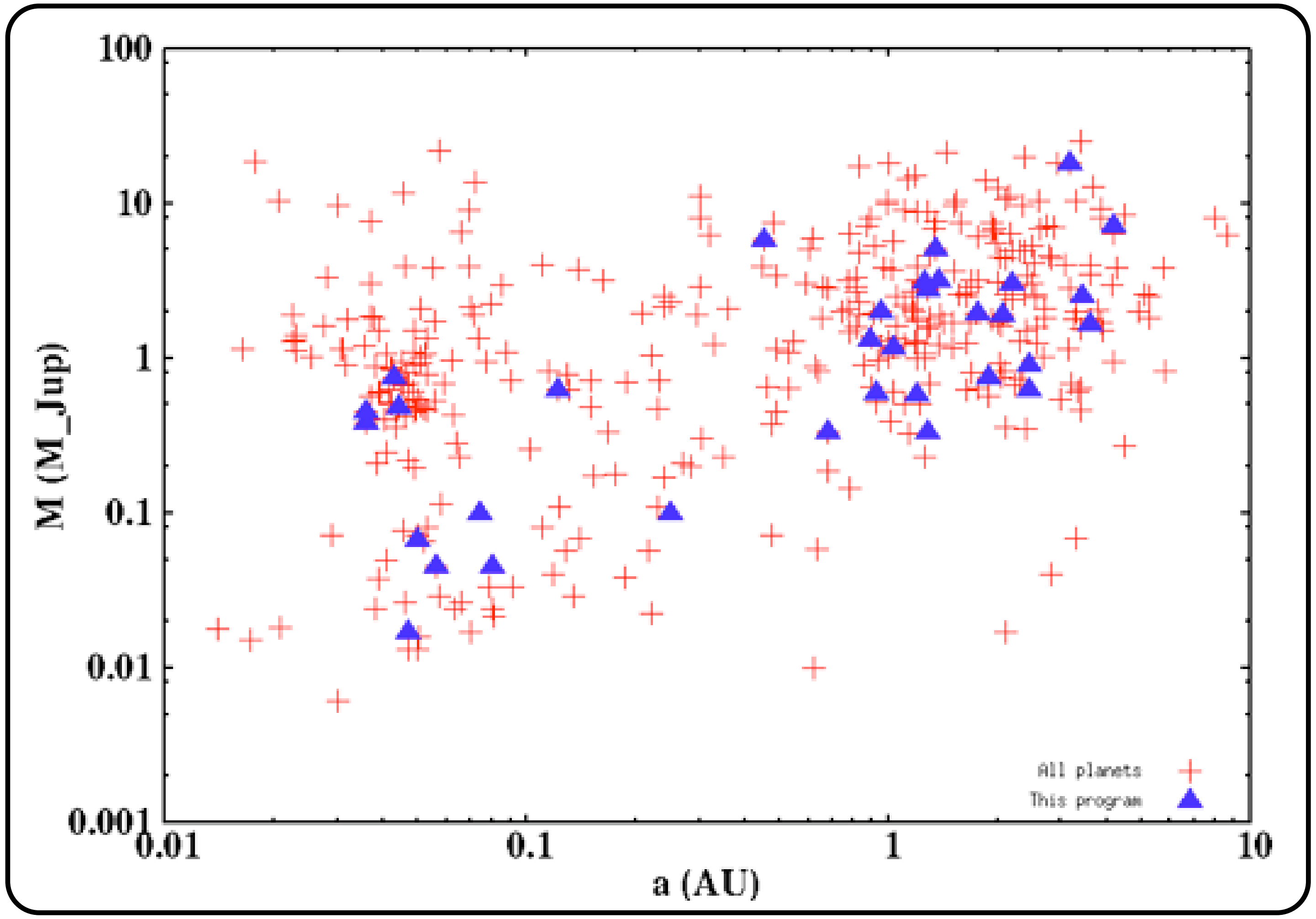
Large survey, aiming to high detection rates with moderate RV precision. Fast observations, with a required SNR of 40 and a RV precision of 2-3m/s.

Results

We have detected 32 extra-solar planets, 7 of them in multiple systems.

Many of our targets have yet insufficient measurements.

The survey is continuing…



Searching for Planets around Evolved Intermediate-Mass (1.5-5$M_\odot$) Stars

■Okayama 1.88m, Japan (**B. Sato** et al.)
  □**300 GK giants** (V<6), since 2001
  □10 planets and 1 brown dwarf

■Xinglong 2.16m, China (**Y.-J. Liu** et al.)
  □**100 GK giants** (V~6), since 2005
  □1 planet and 1 brown dwarf

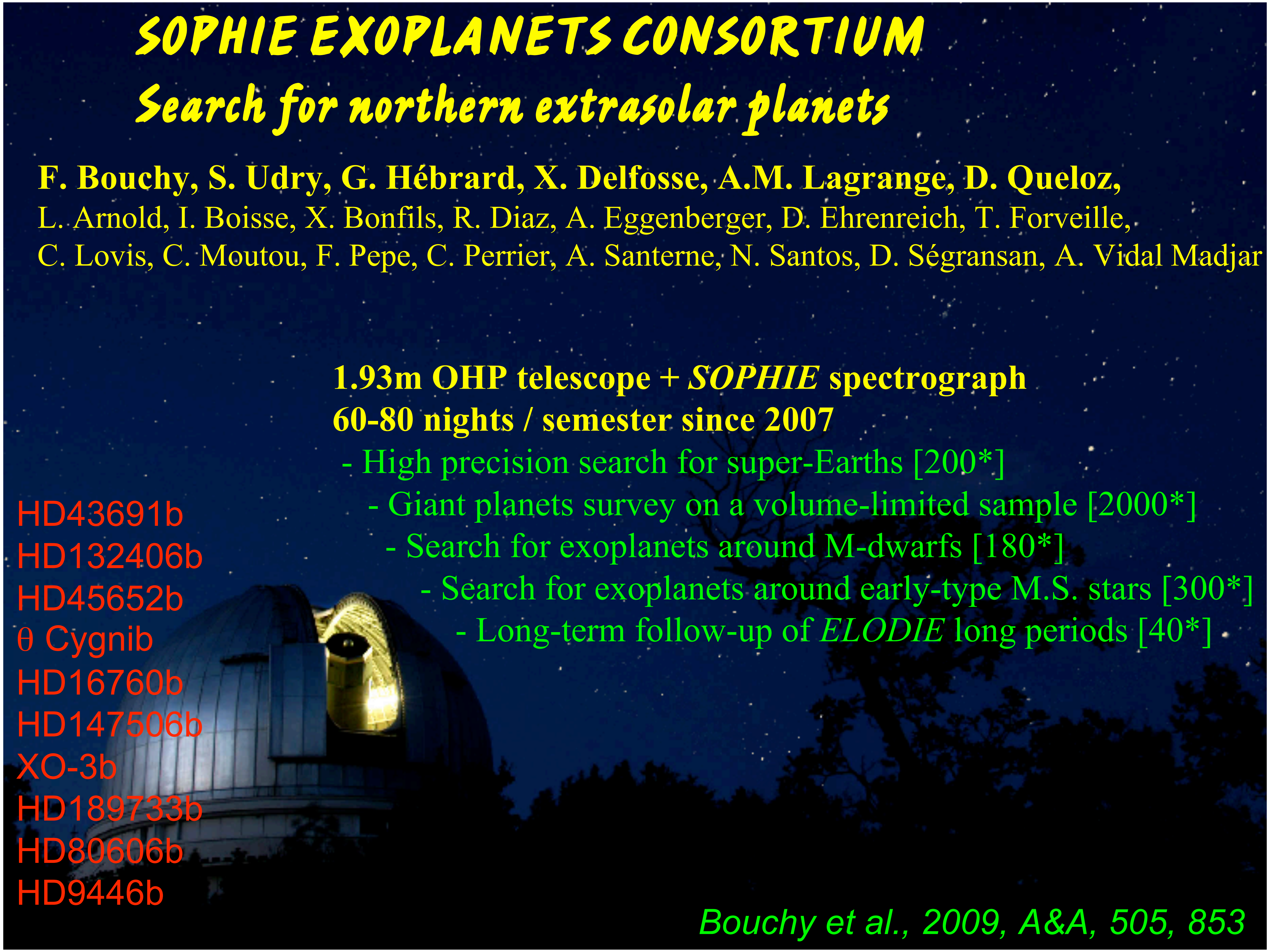
■Bohyunsan 1.8m, Korea (**I. Han** et al.)
  □**190 GK giants** (V<6.5), since 2005
  □1 brown dwarf

■Subaru 8.2m, Japan (**B. Sato** et al.)
  □**>200 GK giants** (6.5<V<7), since 2006
  □Tens of candidates

■RTT 1.5m, Turkey (**S. Selam** et al.)
  □**50 GK giants** (V~6.5), since 2008

East-Asian
Planet Search
Network
(EAPSNET)

Understanding properties of planets (frequency, mass, orbit, etc.) as a function of stellar properties (mass, evolutionary stage, etc.)



SOPHIE EXOPLANETS CONSORTIUM

Search for northern extrasolar planets

F. Bouchy, S. Udry, G. Hébrard, X. Delfosse, A.M. Lagrange, D. Queloz,
L. Arnold, I. Boisse, X. Bonfils, R. Diaz, A. Eggenberger, D. Ehrenreich, T. Forveille,
C. Lovis, C. Moutou, F. Pepe, C. Perrier, A. Santerne, N. Santos, D. Ségransan, A. Vidal Madjar

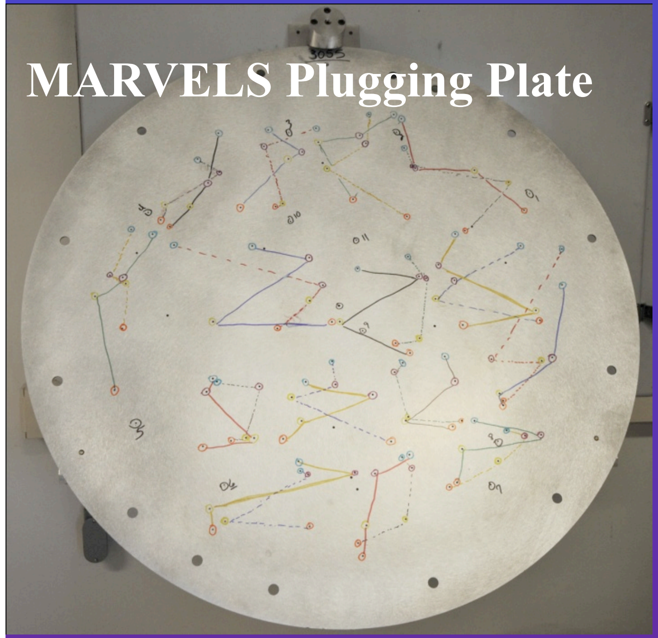
1.93m OHP telescope + *SOPHIE* spectrograph
60-80 nights / semester since 2007

- High precision search for super-Earths [200*]
- Giant planets survey on a volume-limited sample [2000*]
- Search for exoplanets around M-dwarfs [180*]
- Search for exoplanets around early-type M.S. stars [300*]
- Long-term follow-up of *ELODIE* long periods [40*]

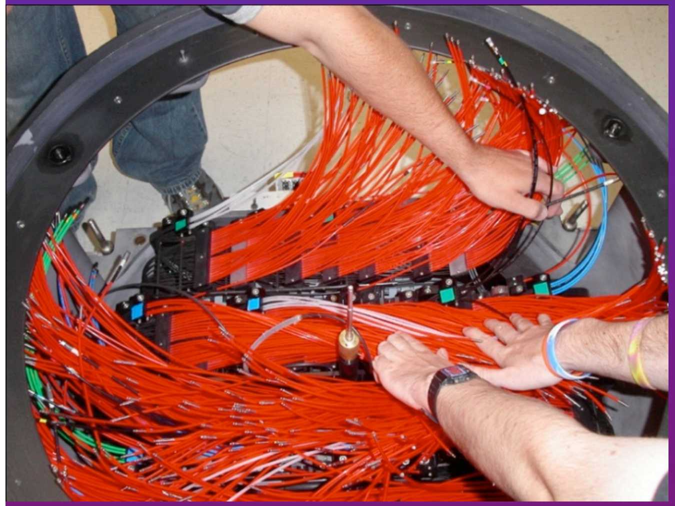
HD43691b
HD132406b
HD45652b
θ Cygnib
HD16760b
HD147506b
XO-3b
HD189733b
HD80606b
HD9446b

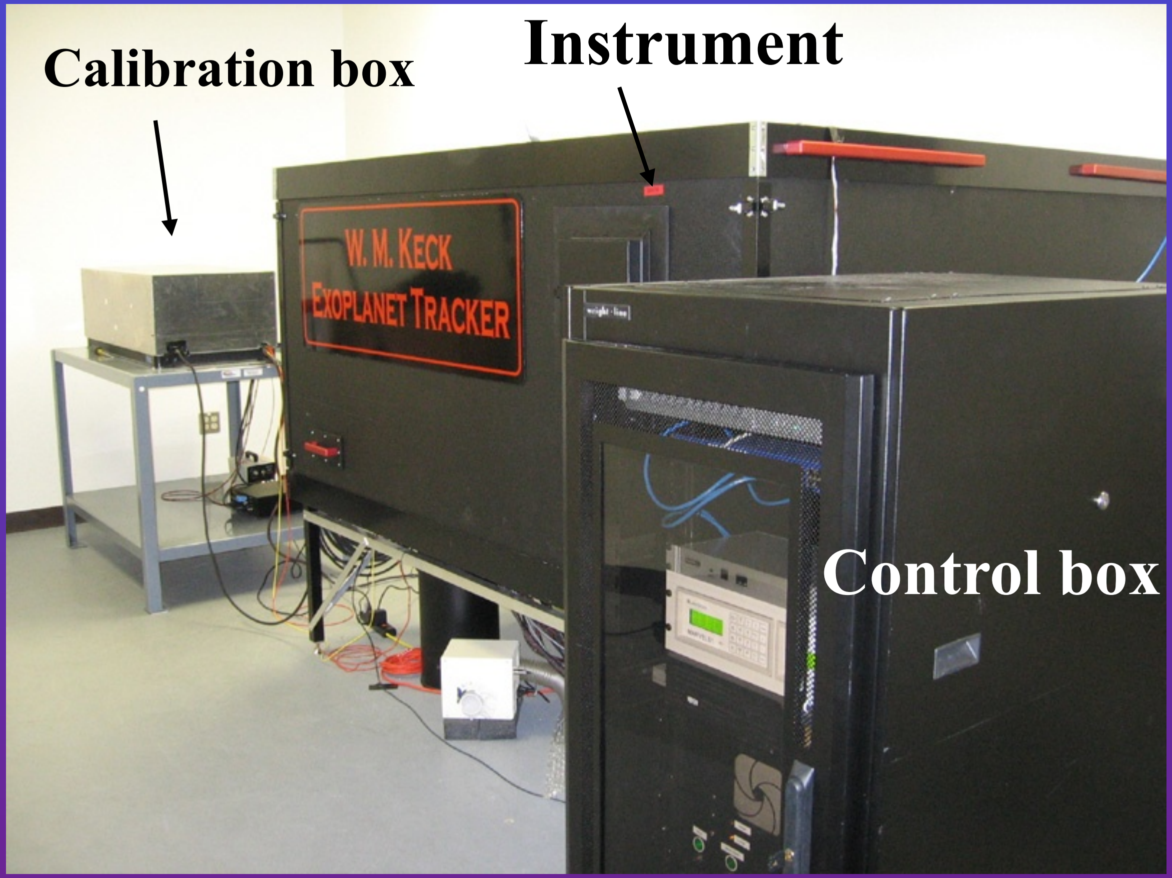
Bouchy et al., 2009, A&A, 505, 853

The SDSS-III MARVELS Exoplanet Survey, 2008-2014
PI: Jian Ge (Univ. of Florida)


MARVELS Plugging Plate

MARVELS Fibers

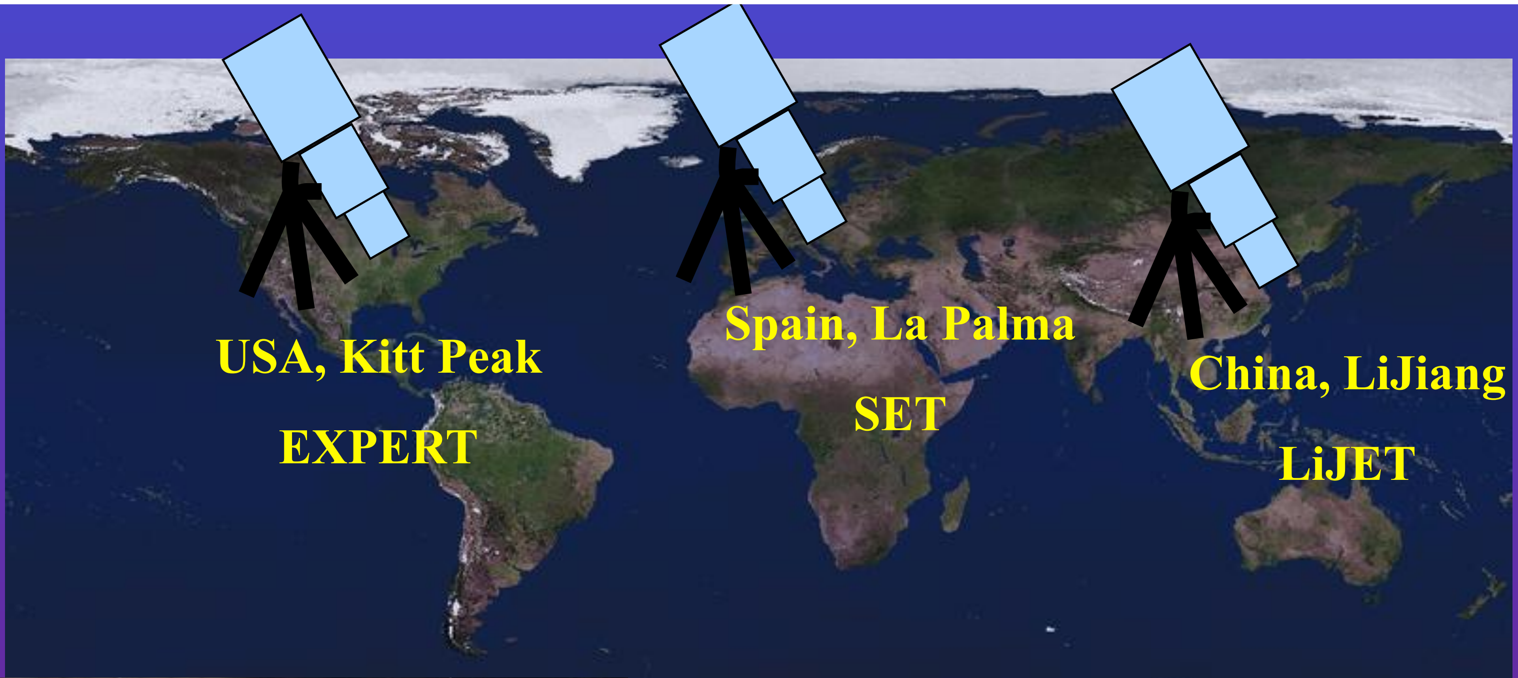


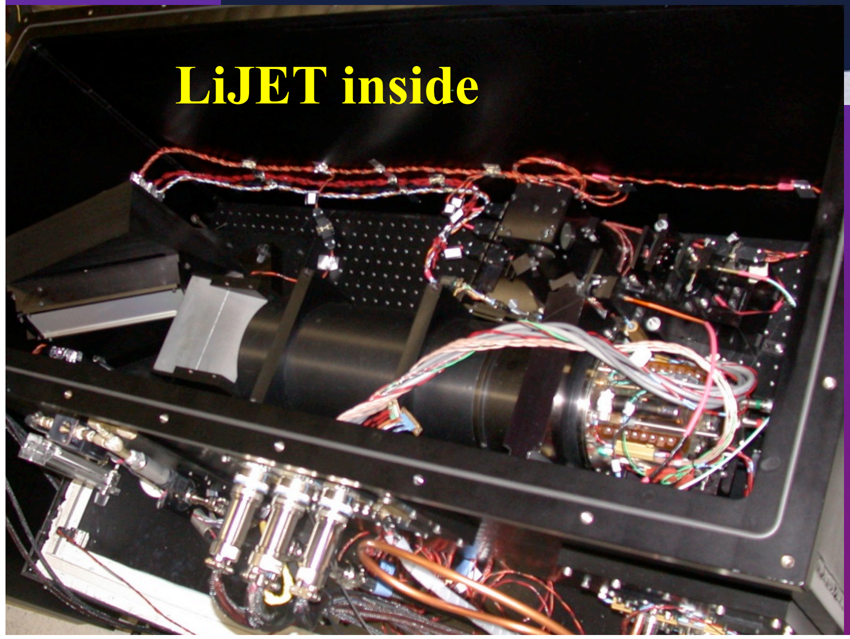


- A large-scale planet survey using multi-object Doppler instruments (60 objects in 08-10, 120 objects in 10-14)
- To monitor a total of 11,000 V=7.6-12 FGK dwarfs, subgiants & giants with minimal metallicity and age biases for detecting and characterizing ~150 new giant planets

Global Extremely High Precision Exoplanet Tracker Network

Jian Ge (UF), Tinggui Wang (China), Eduardo Martin (Spain)



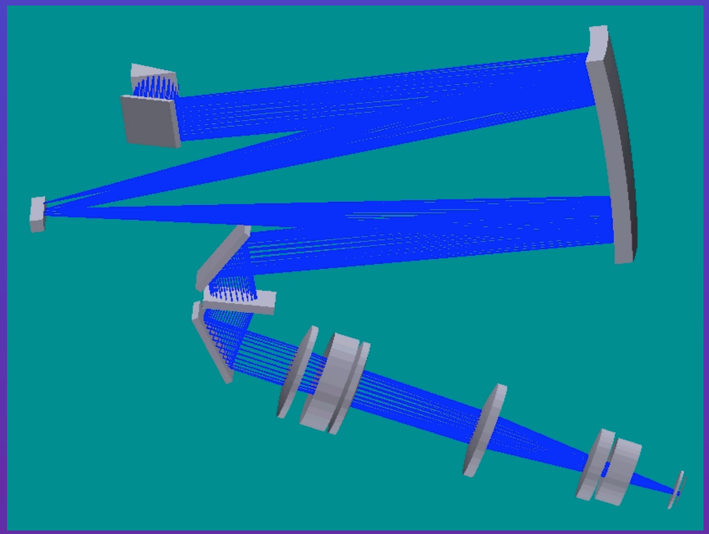


- •0.39-0.70 μm, R=18,000, with dispersed fixed-delay interferometer approach
- •0.5-1 m/s in 30 min for V< 8 solar type stars with 2 m telescopes
- •ΔP~2 mpsi, ΔT~4mK, <10m/s drifts per day
- • Science operation: EXPERT (Apr. 10), LiJET (Sept. 10) , and SET (11?)

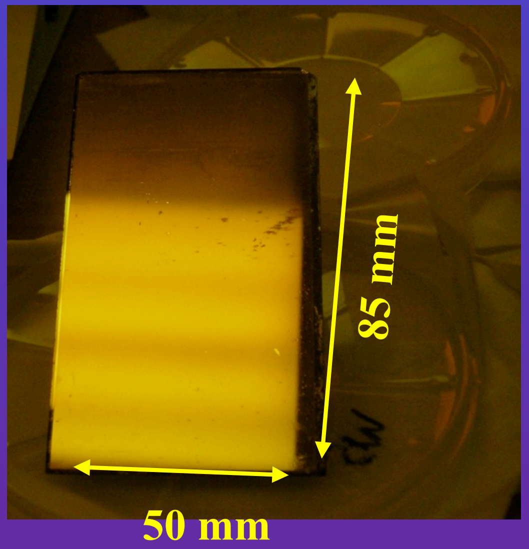
Florida IR Silicon immersion grating spectromeTeter (FIRST) & IR Exoplanet Tracker (IRET), Jian Ge (UF) & Steve Osterman (Colorado)

APO 3.5m Telescope

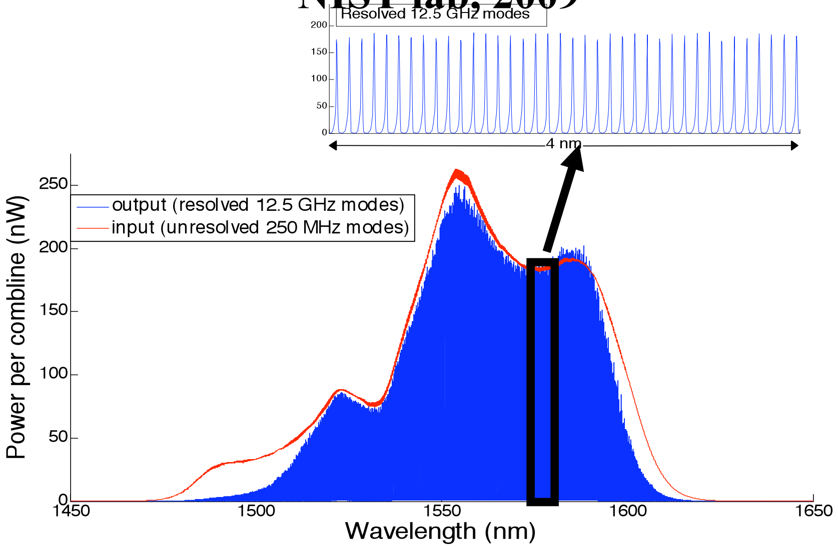
FIRST Optical Layout



Silicon immersion grating



IR laser comb spectral lines measured in the NIST lab, 2009



- •FIRST mode with R=55,000, 1.4-1.8 um simultaneously with 2kx2k H2RG
- •IRET mode, R=25,000 with a dispersed fixed delay interferometer, 0.8-1.35 um simultaneously with 2kx2k H2RG
- •Commissioning in Fall 2010, ~2 m/s for a H~8 M5V dwarf in 20 min
- •Primary targets: M dwarfs and young stars

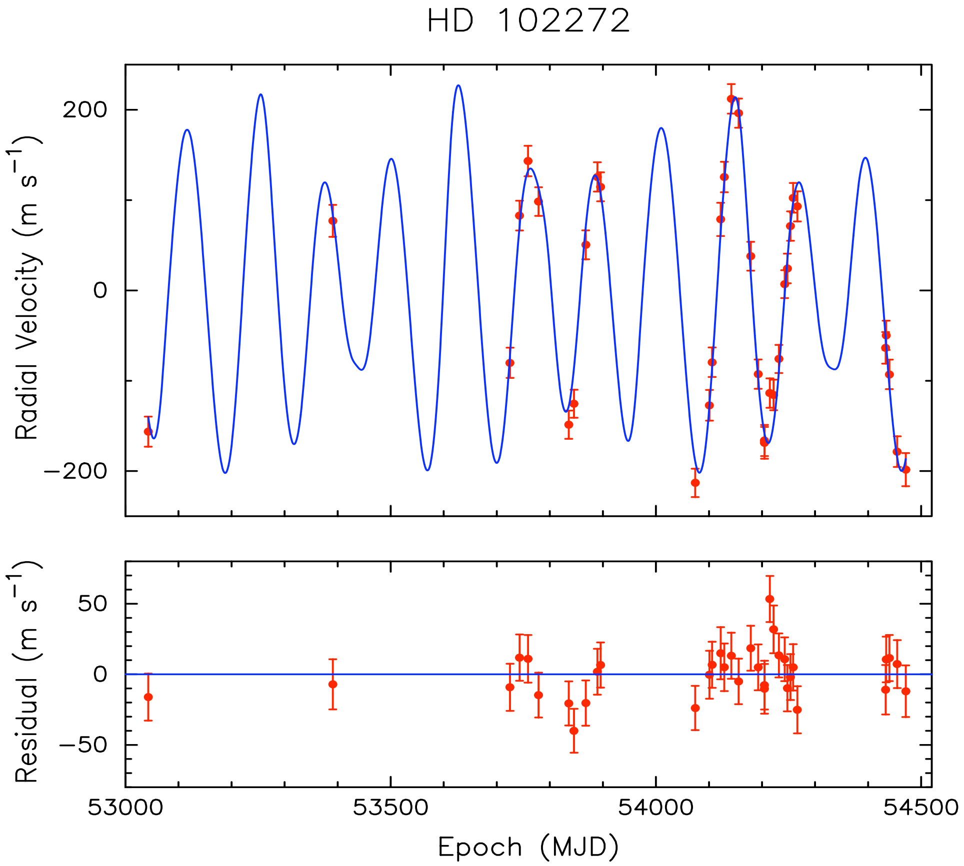
The Penn State – Toruń Centre for Astronomy Planet Search (PTPS)

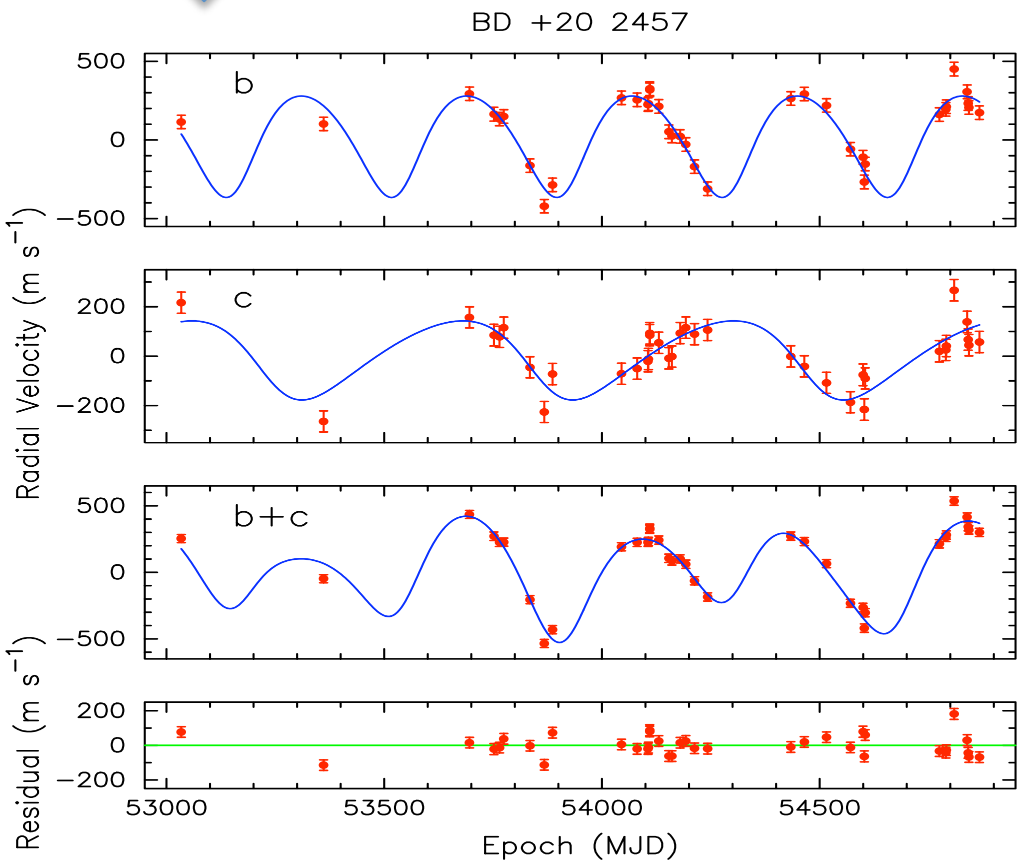
Current PTPS collaboration:
- Penn State: A. Wolszczan, S. Gettel
- TCfA: A. Niedzielski, M. Adamów, G. Nowak, P. Zieliński

Goal: A search of ~ 1000 GK-giants for substellar companions

Instrumentation:
- 9.2-m Hobby-Eberly Telescope (HET)
- High Resolution Spectrograph (HRS, R=60,000), I_2-cell

Highlights:
- the most compact planet orbit around a giant (0.6 AU)
- two brown dwarf – mass companions to a giant





The NASA-UC Eta-Earth Survey for Low-mass Planets From Keck Observatory

Andrew Howard & Geoff Marcy

- RV survey of 230 nearby GKM dwarfs
- Search for low-mass planets (Msini = 3–30 MEarth)
- Constrain population of low-mass planets and planet formation theory

Next Talk . . .

The HARPS Search for Southern Extra-Solar Planets
The M-dwarf sample

PI: X. Bonfils   Cols: Bouchy, Delfosse, Forveille, Gillon, Lovis, Mayor, Pepe, Santos, Udry, Queloz,

Sample:

~400 brightest M dwarfs < 20 pc

Goals :

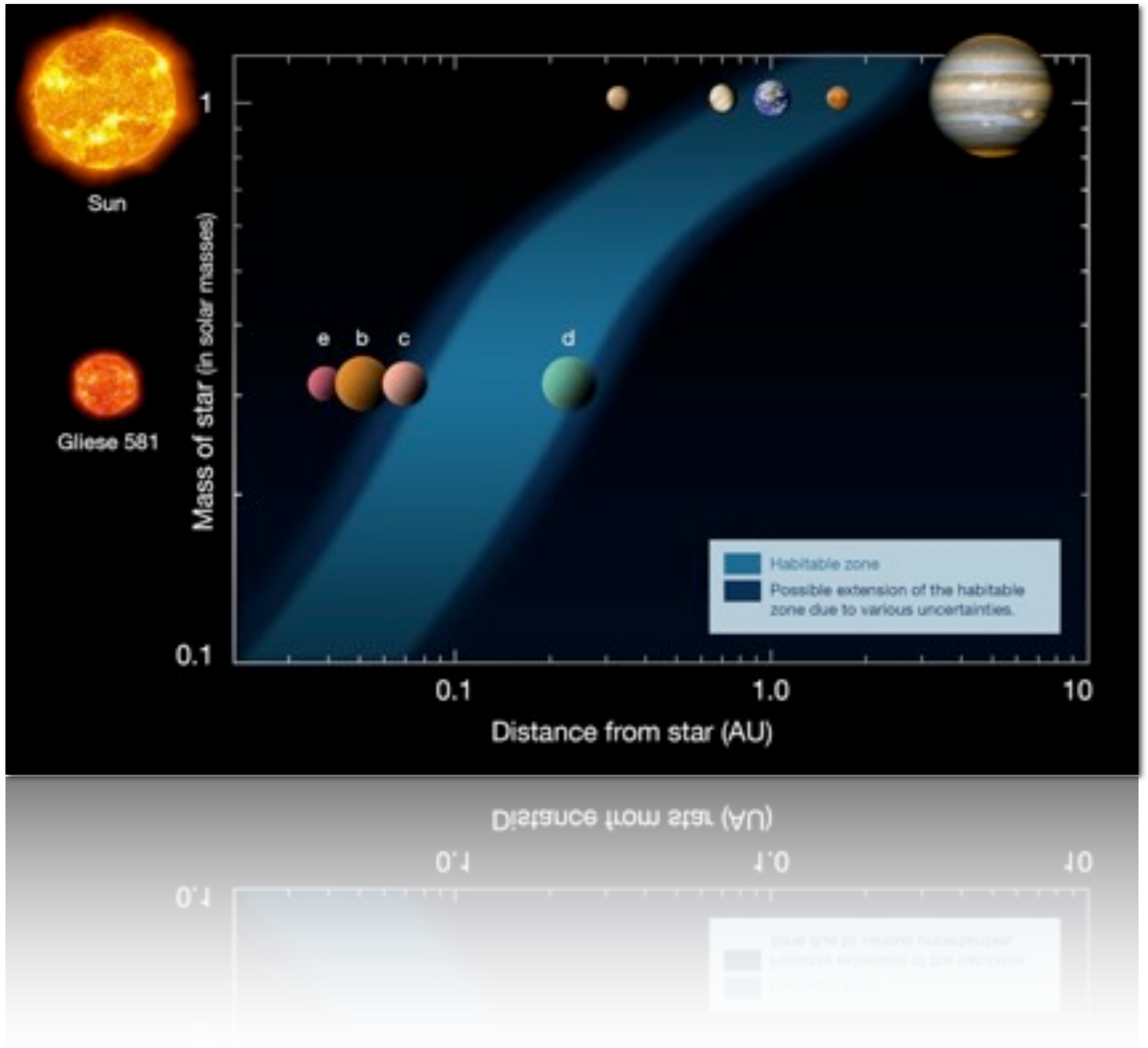
Probe the dependance on stellar mass
Detect low-mass & habitable planets

Results:

- 11 planets (7 hosts)
- 9/10 of M-dwarfs planets w/ *m* sin *i* < 20 Mearth
- lowest-mass planets (GJ 581e; *m* sin *i* = 1.9 Mearth)
- first prototype of an habitable planet (GJ 581 d)
- statistical results :
  - few Jupiter-mass planets
  - super-Earth are common (>30%)

Future (now):

- 300/400 M dwarfs are screened for
  - short-period (P<15 d)
  - low-mass planets (>3 Mearth)
- Further test planet formation models



LAOG

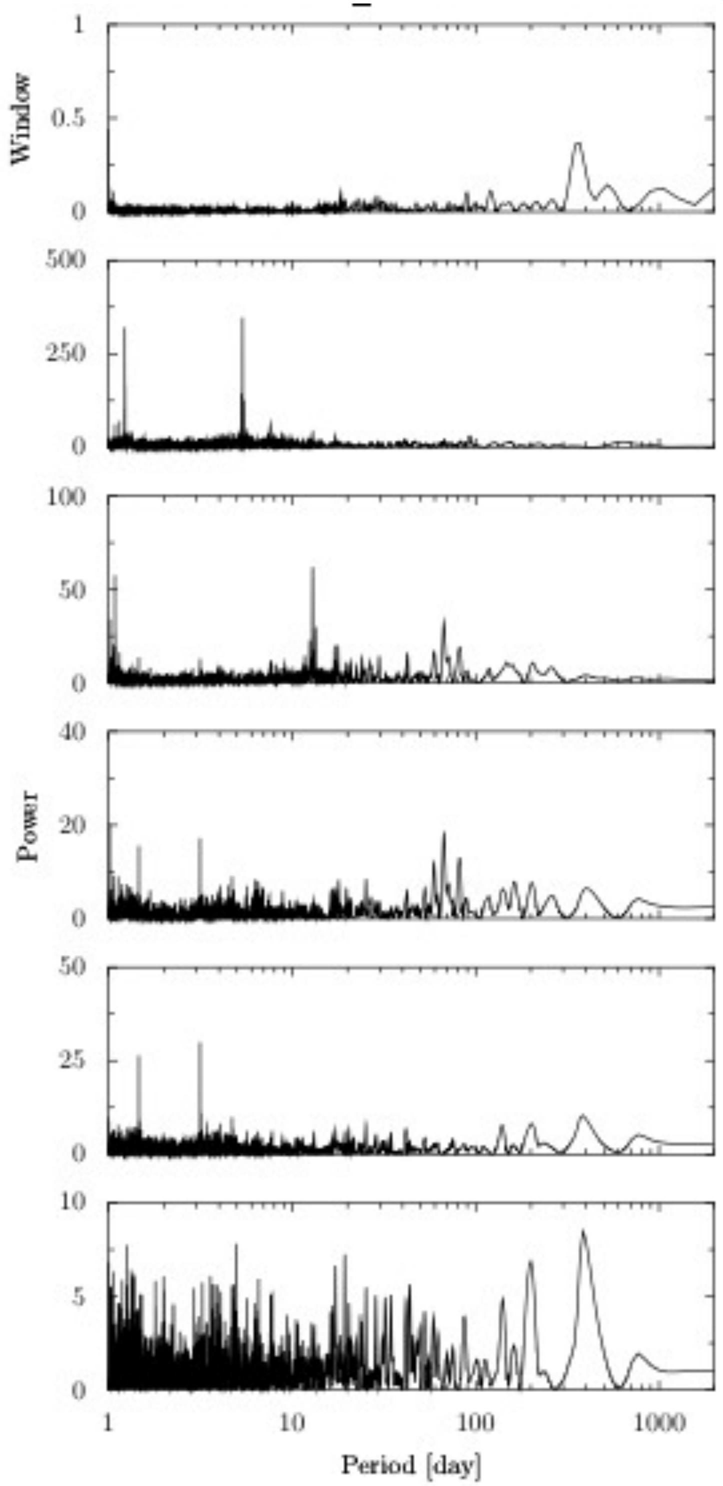
OBSERVATOIRE DE GENÈVE FONDÉ EN 1772

ULg UNIVERSITÉ de Liège

Centro de Astrofísica da Universidade do Porto

IAP

GJ 581



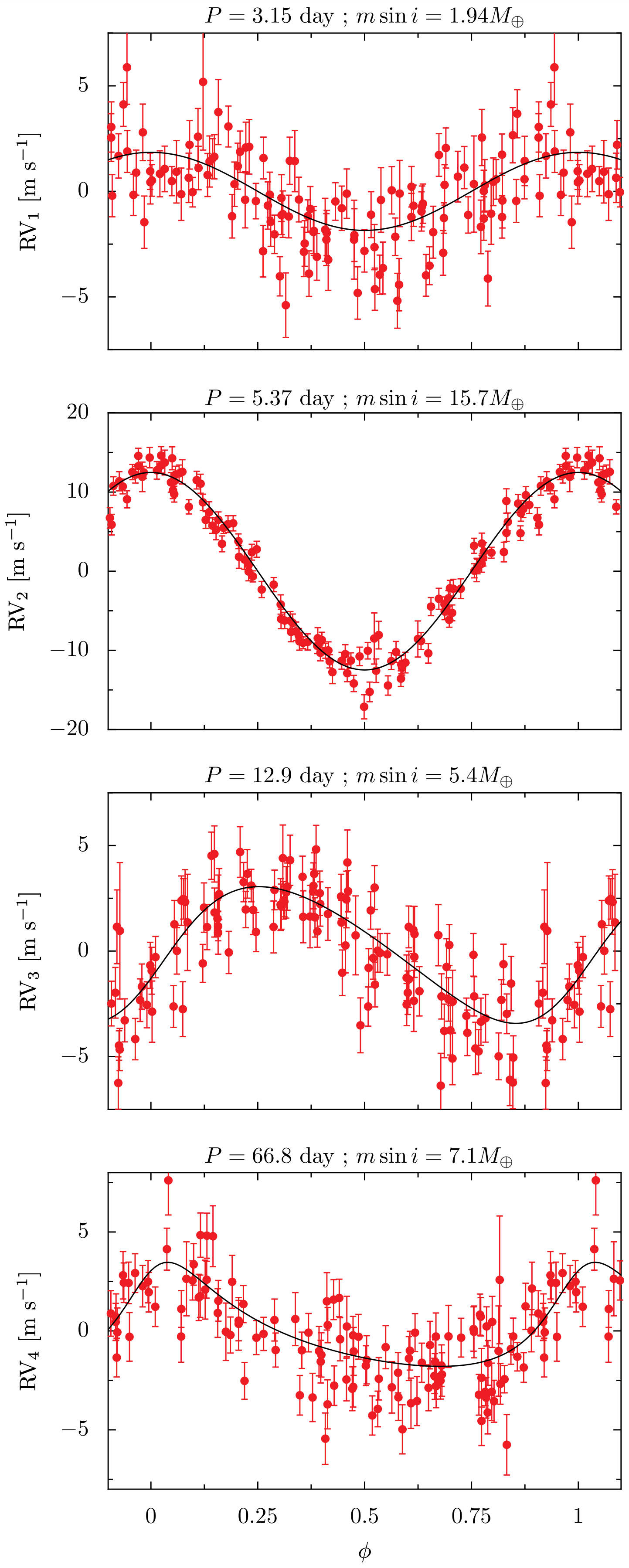
2009
… a 4th planet

- planets have : 1.9, 16, 5 & 7 M⊕

3.2, 5.6, 13 & 67 d

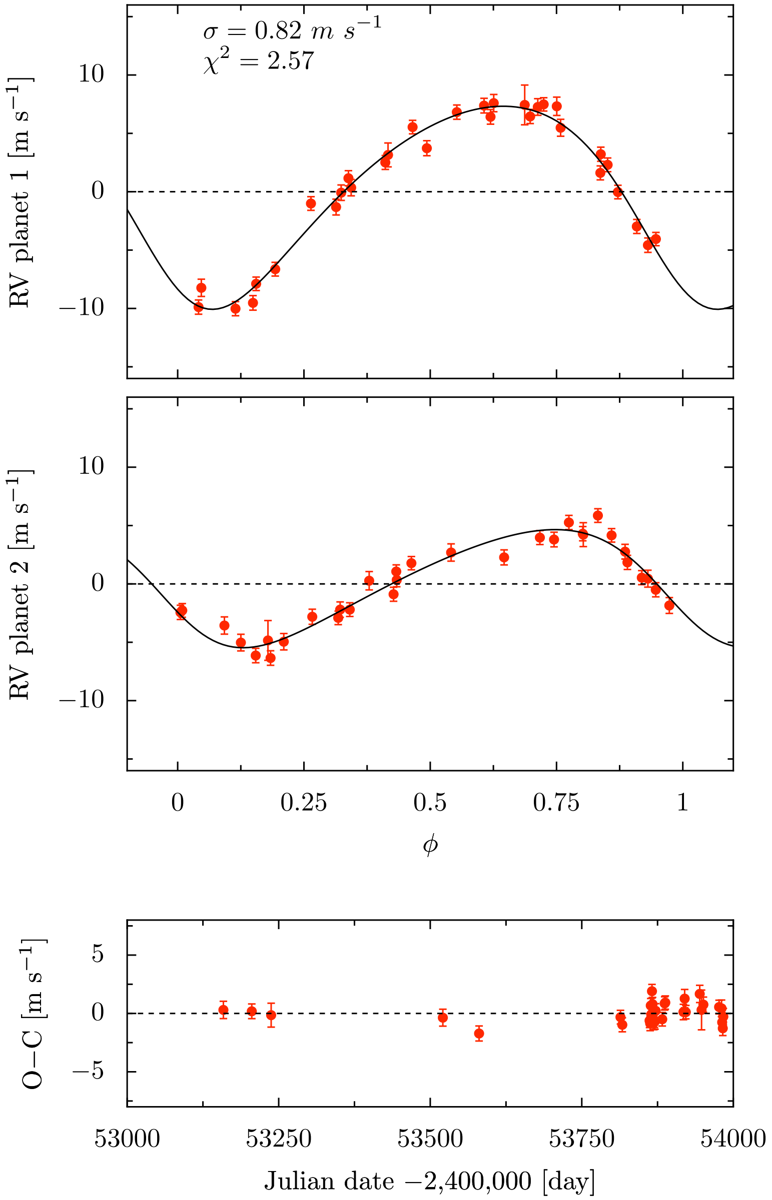
- Gl581d's period is revised :

83 d -> 67 d



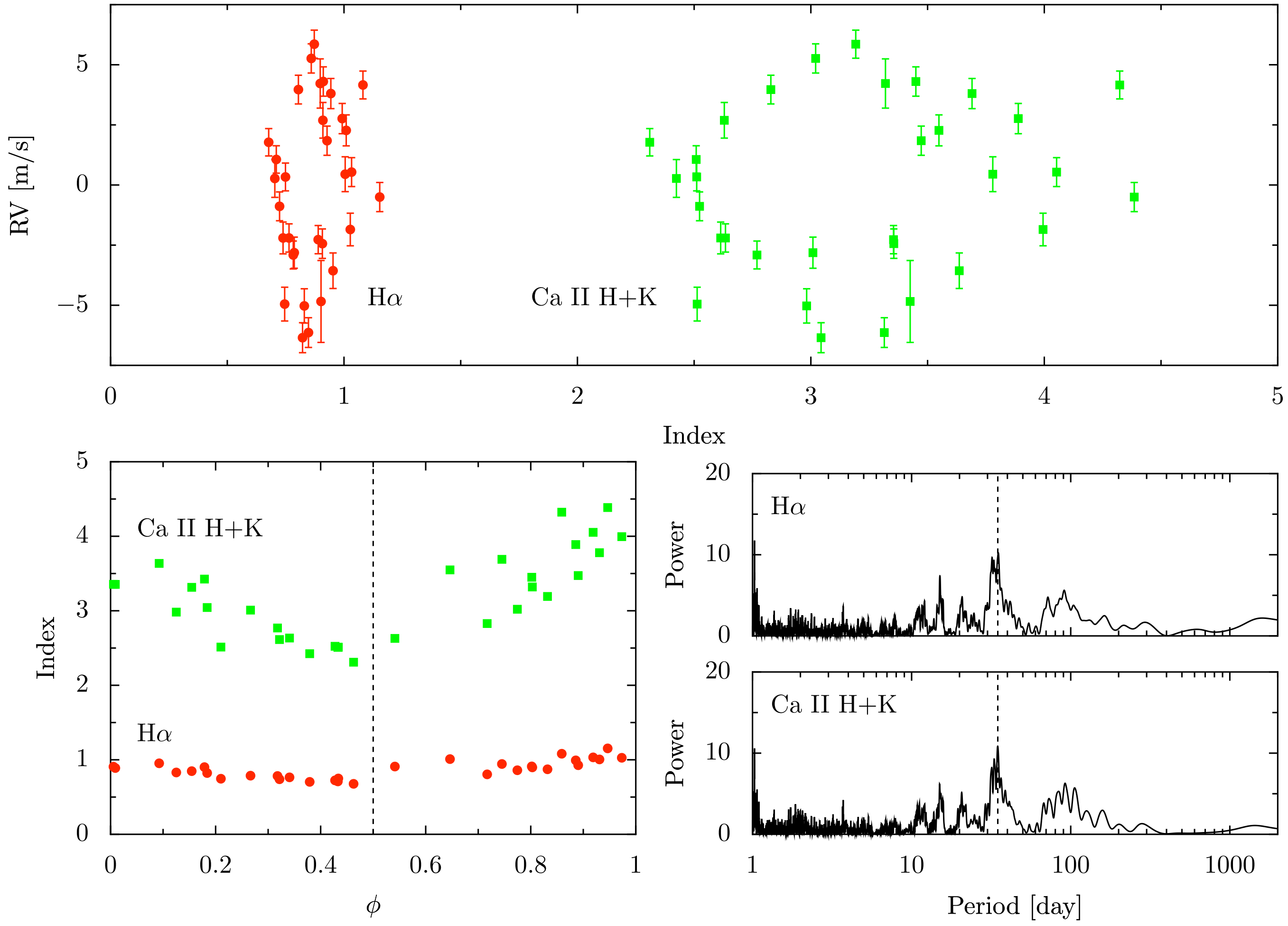
Mayor et al. (2009)

GJ 674



2-planet Keplerian model

Parameters		GJ 674 b	Spot
P	(day)	4.7	35
e		0.2	0.2
w	(deg.)	143	113
K	(m/s)	8.7	5.06
m2 sin i	(M⊕)	11.1	12.6
a	(AU)	0.039	0.147

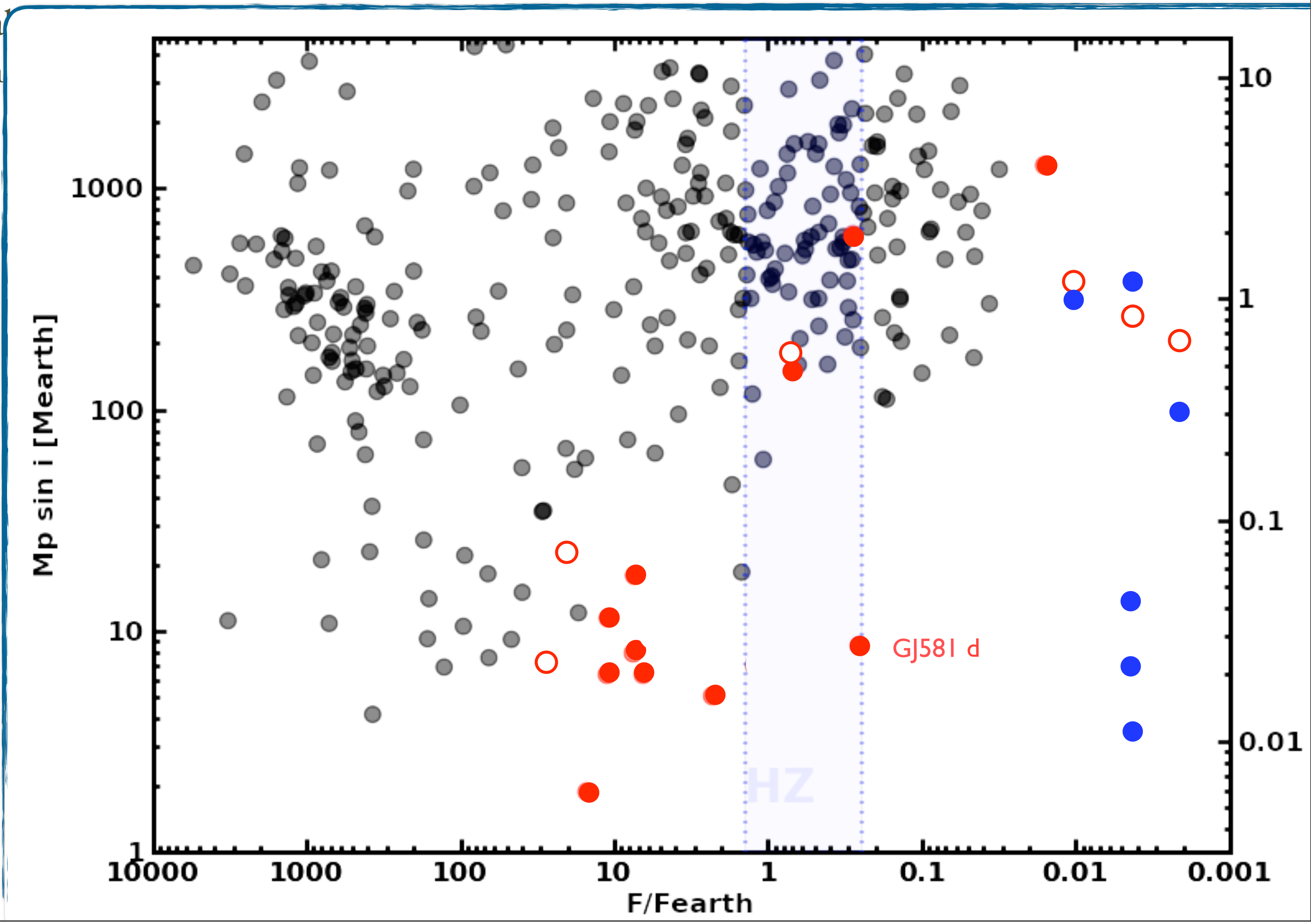


Bonfils et al. (2007)

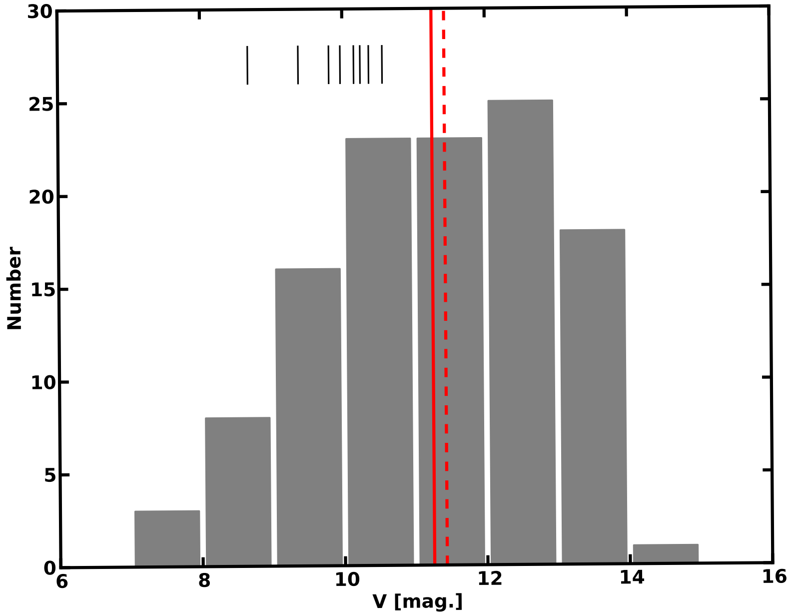
- ○ all planets

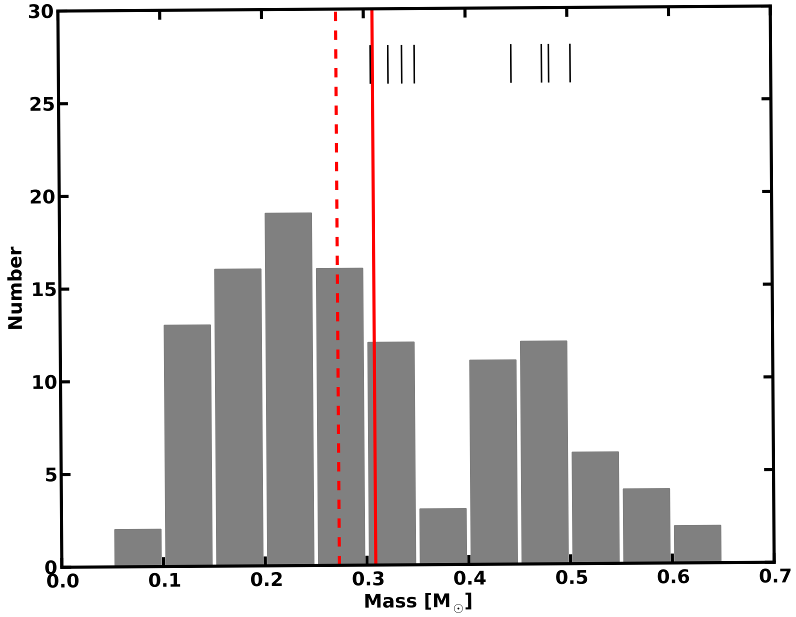
Around M dwarfs :

- ○ radial velocity (Keck/Lick/AAT)
- ● radial
- ● μ-len



Sample distributions : Masses & Magnitudes





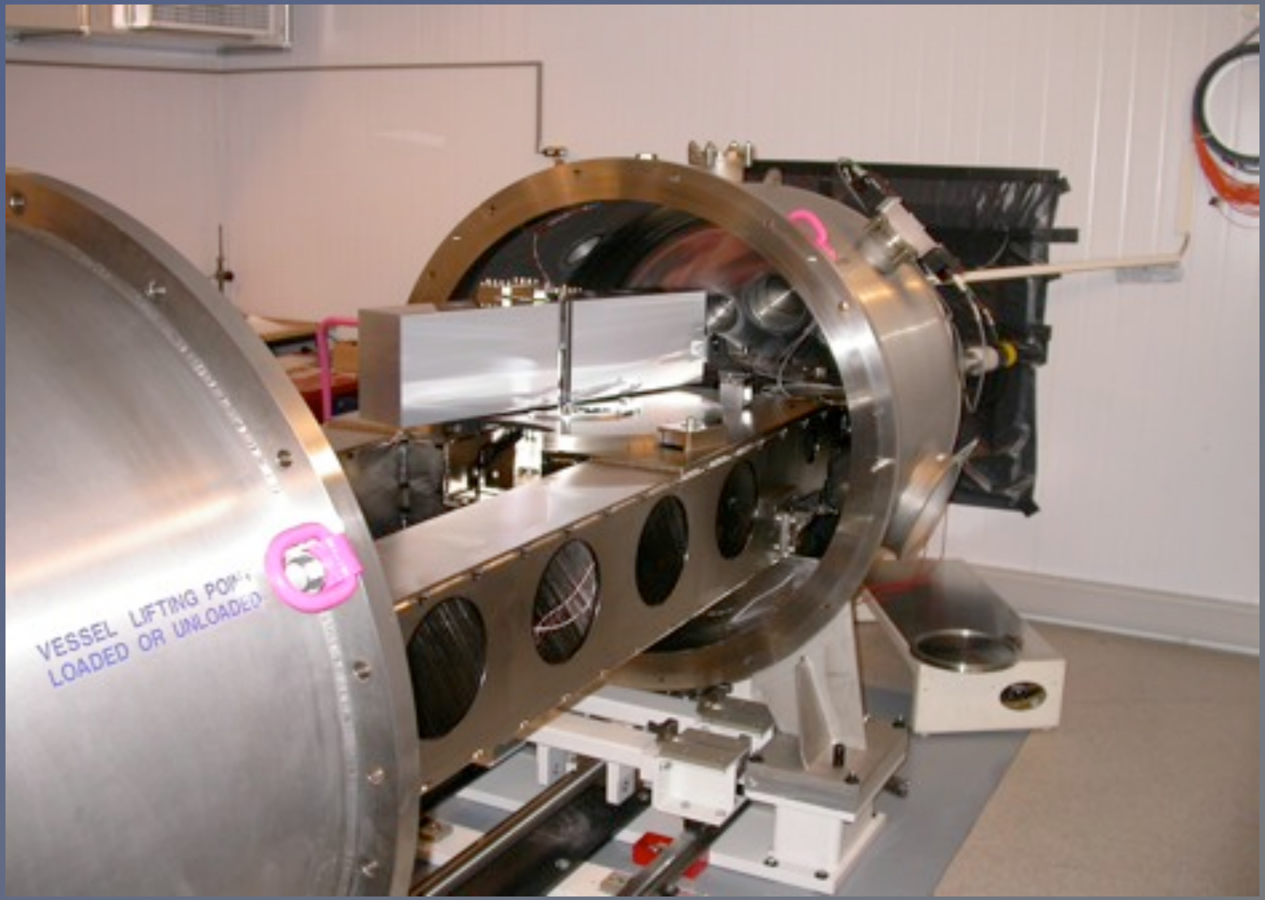
Signature of formation or selection bias ?

`Bonfils et al. (2010, in prep.)`

The HARPS search for low-mass planets

- Sample of ~400 slowly-rotating, nearby FGK dwarfs from the CORALIE planet-search survey
- HARPS log(R'_HK) => ~250 good targets
- Observations ongoing since 2004
- Focus on low-amplitude RV variations

  => about 50% of HARPS GTO time



HARPS

ESO-3.6m @ La Silla

Ida & Lin 2008

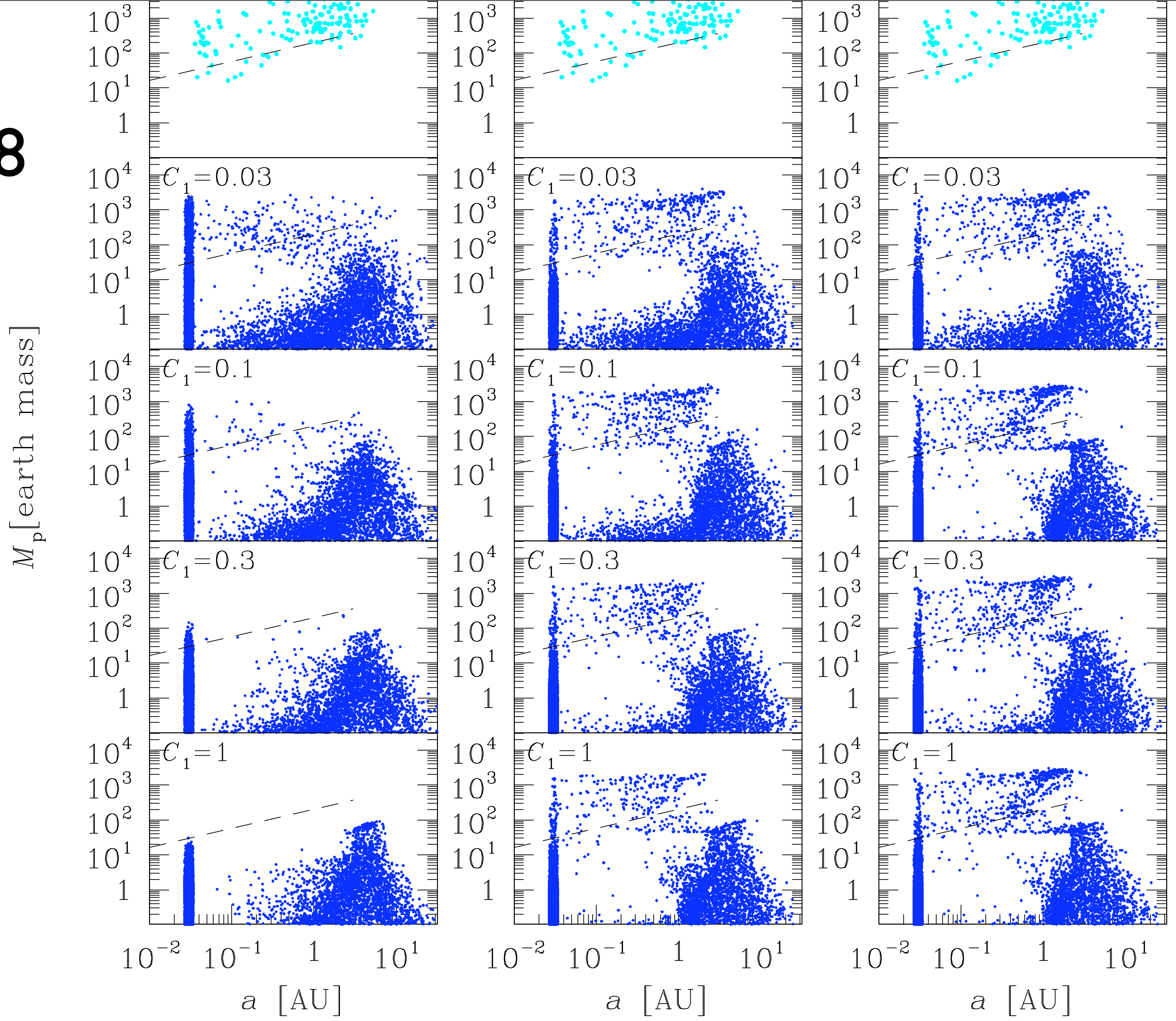
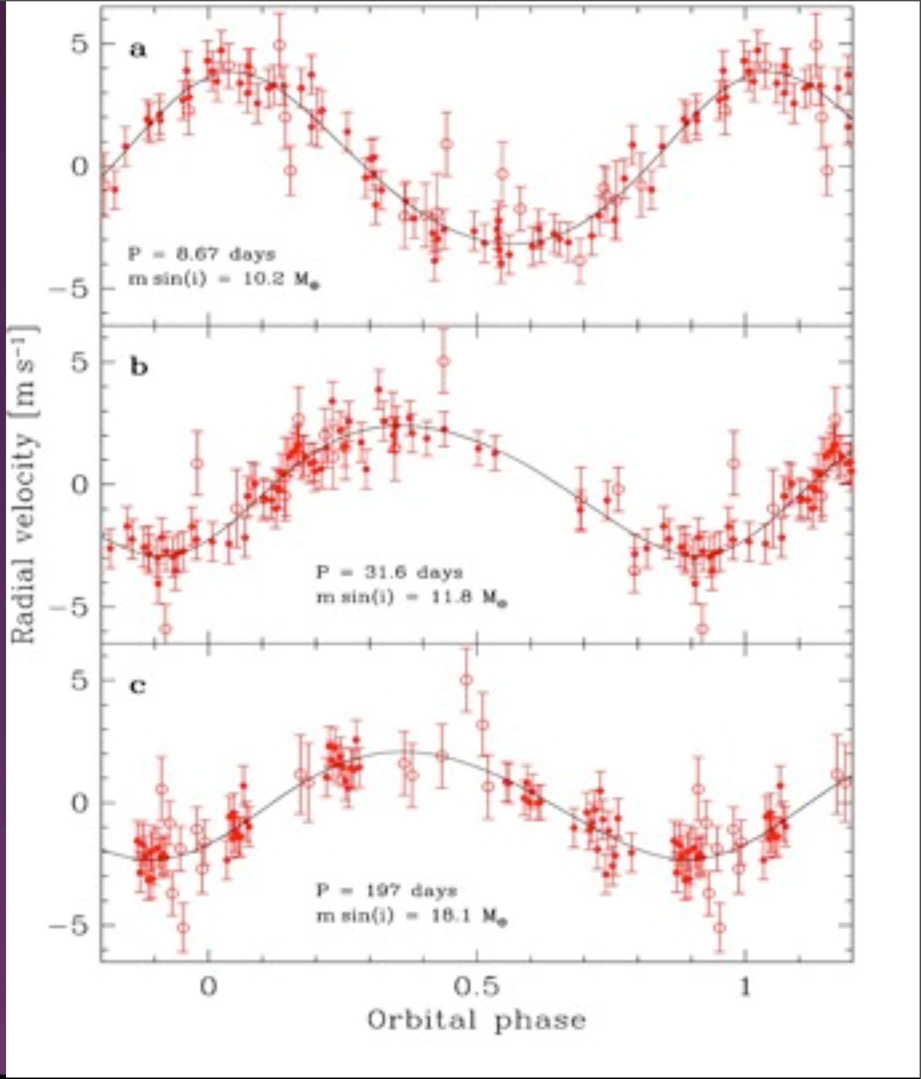


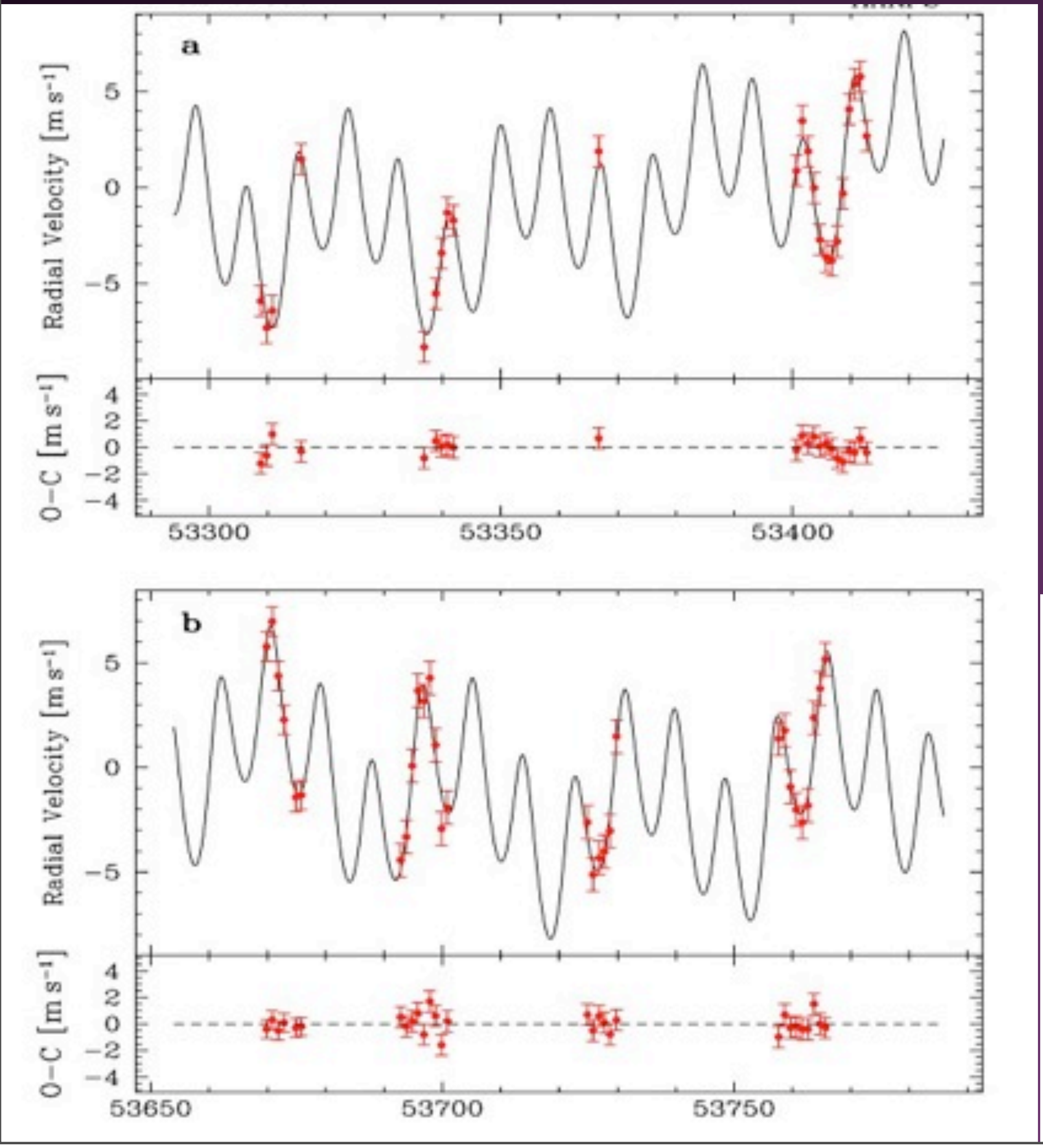
Fig. 3.— The mass and semimajor axis distribution of extrasolar planets. Units of the mass ($M_{\rm p}$) and semimajor axis (a) are earth mass ($M_\oplus$) and AU. (a) The results in disks without the Σ_g bump due to the coupling effect of MRI activity and the ice line, (b) those with the bump in Σ_g but without the Σ_d enhancement, and (c) those with both the effects. The top panels are observational data of extrasolar planets (based on data in http://exoplanet.eu/) around stars with $M_* = 0.8$–$1.25M_\odot$ that were detected by the radial velocity surveys. The determined $M_p \sin i$ is multiplied by $1/\langle \sin i \rangle = 4/\pi \simeq 1.27$, assuming random orientation of planetary orbital planes. The other panels are theoretical predictions with $M_* = 0.8$–$1.25M_\odot$ for various values of C_1. The

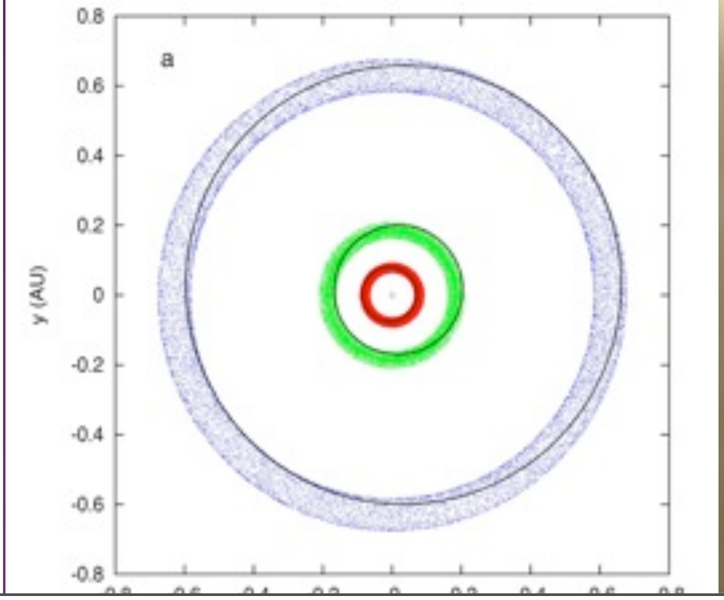
HD 69830: A trio of Neptunes

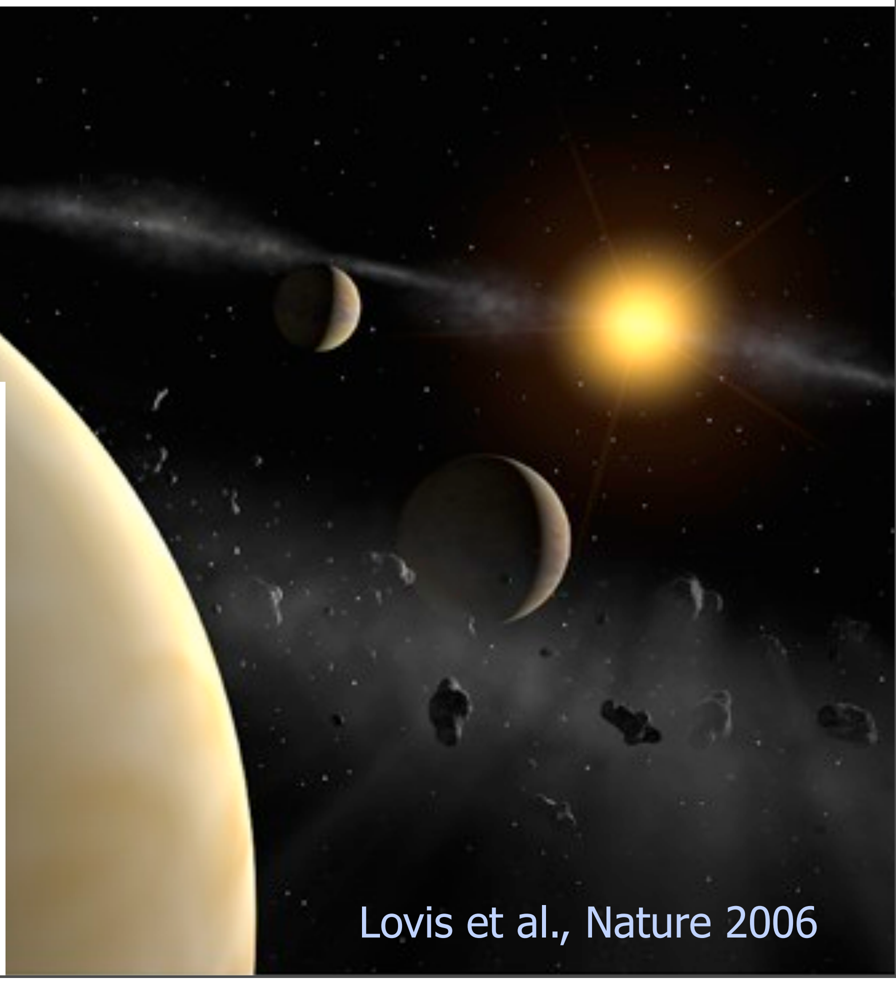
P1 = 8.67 days	a = 0.078 AU	M sini = 10.2 M_{Earth}
P2 = 31.6 days	a = 0.186 AU	M sini = 11.8 M_{Earth}
P3 = 197 days	a = 0.63 AU	M sini = 18.1 M_{Earth}

HARPS@3.6-m telescope, ESO La Silla









Lovis et al., Nature 2006

An emerging population of Hot Neptunes and Super-Earths

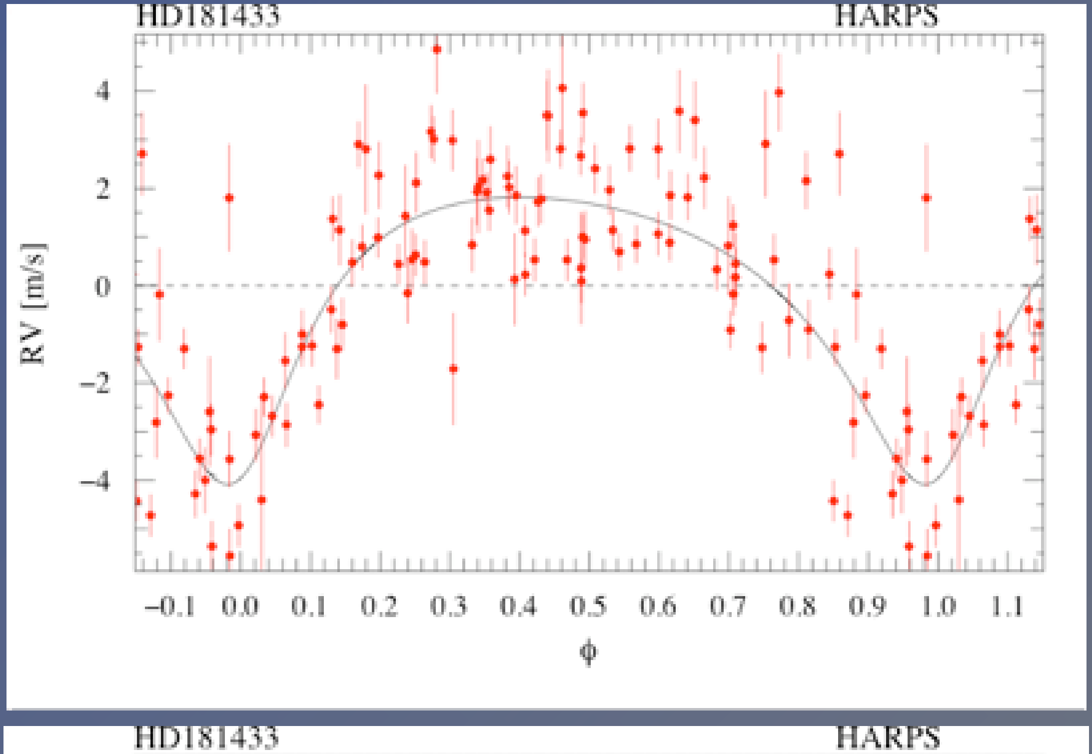
Bouchy et al. A&A 2009

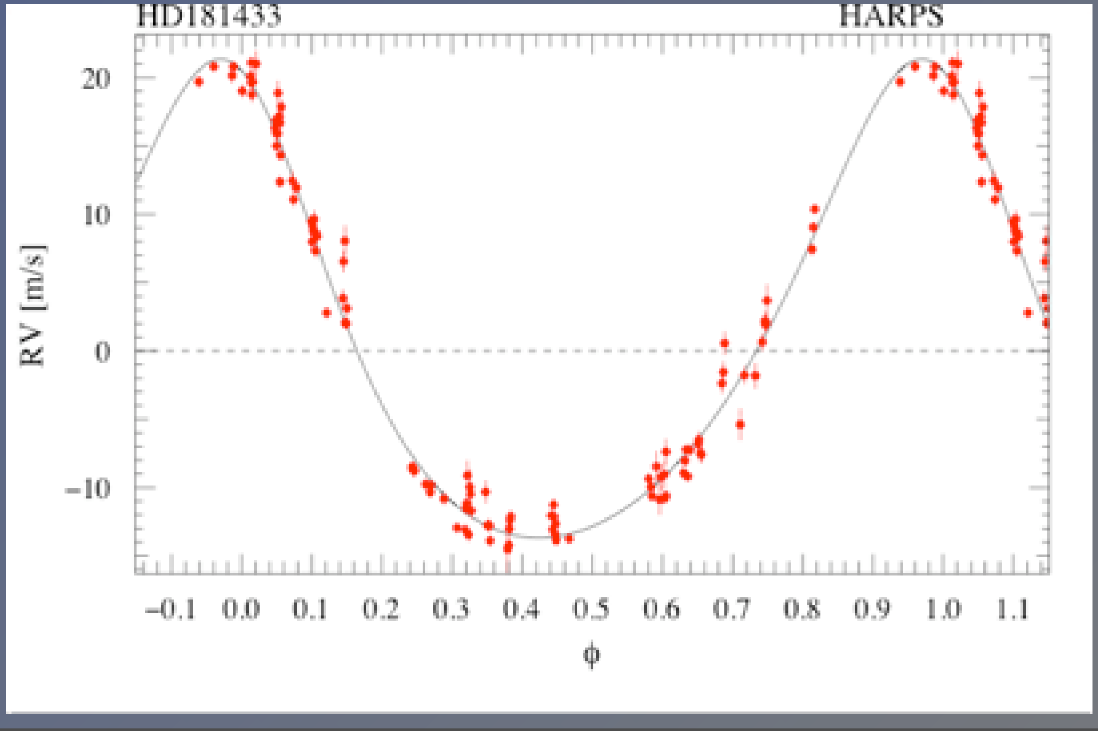
P_1 = 1024 days
e_1 = 0.23
m_1 sini = 0.72 M_{Jup}

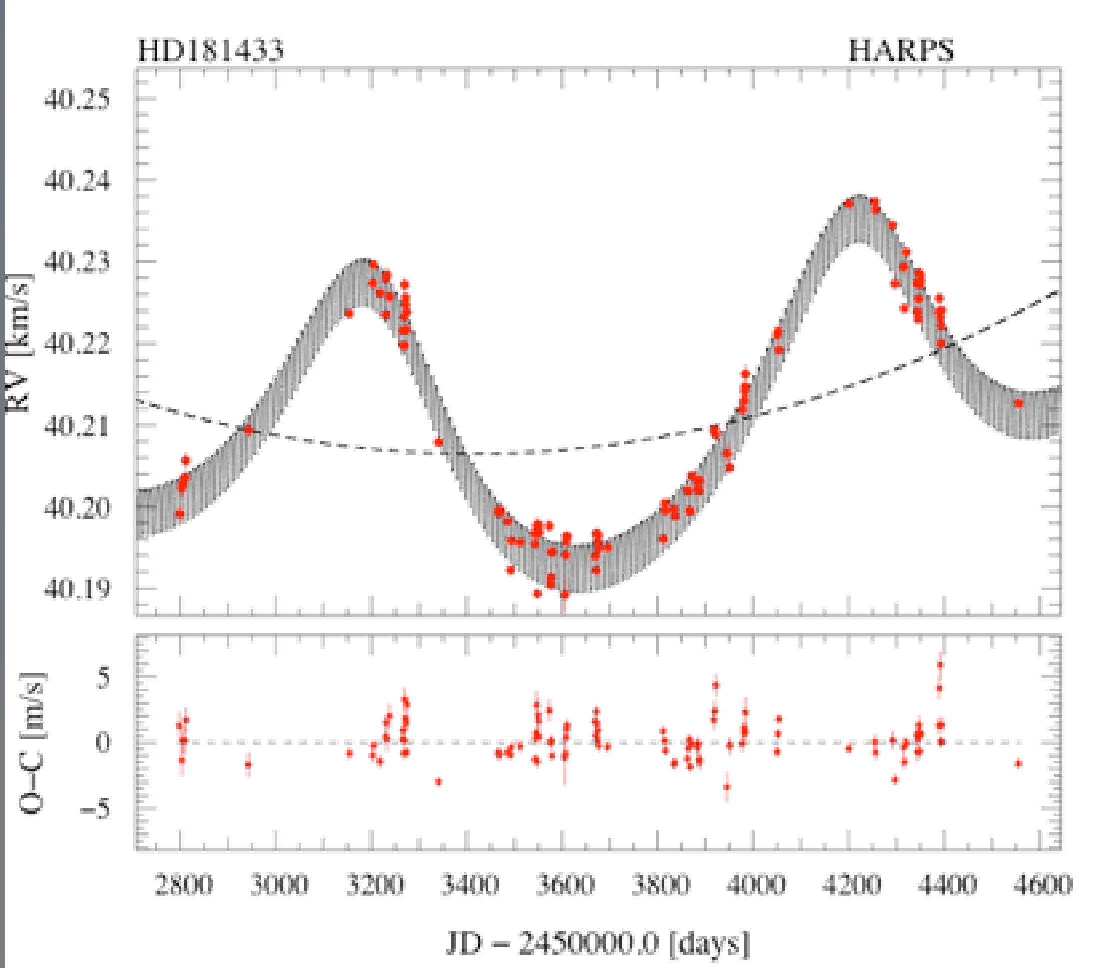
P_2 = 9.37 days
e_2 = 0.40
m_2 sini = 7.5 $M_\oplus$

HD 181433
K3 IV
d = 26 pc
m = 8.4
[Fe/H] = +0.33

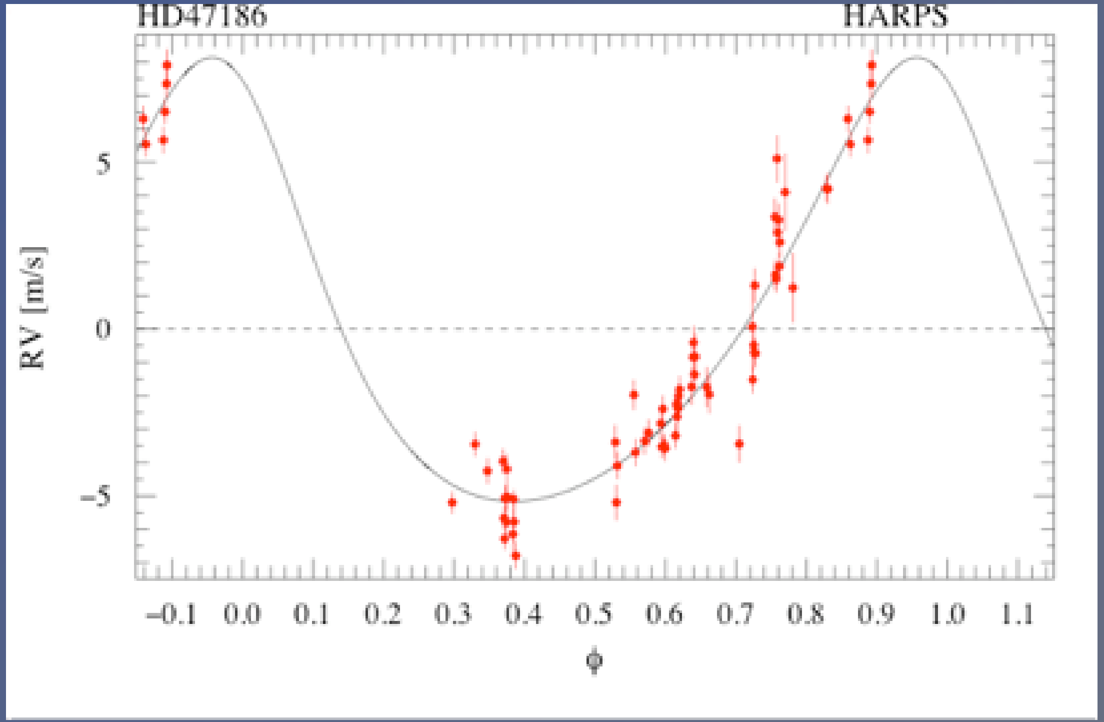
Another triple system

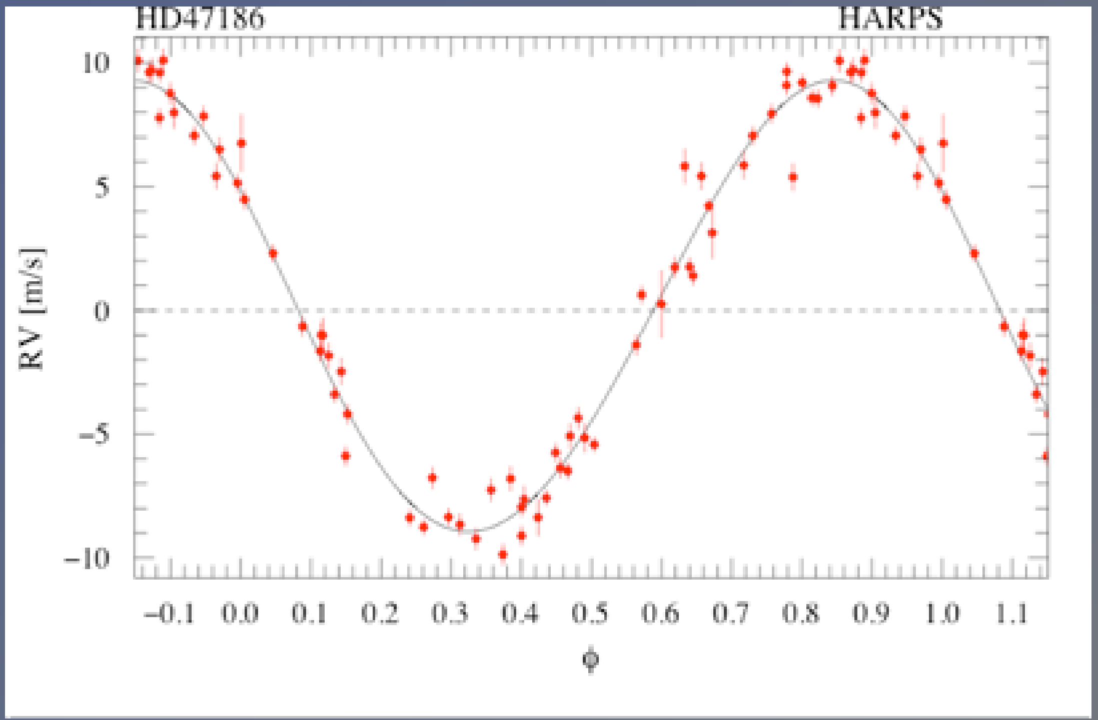






A system with a Saturn and a Hot Neptune



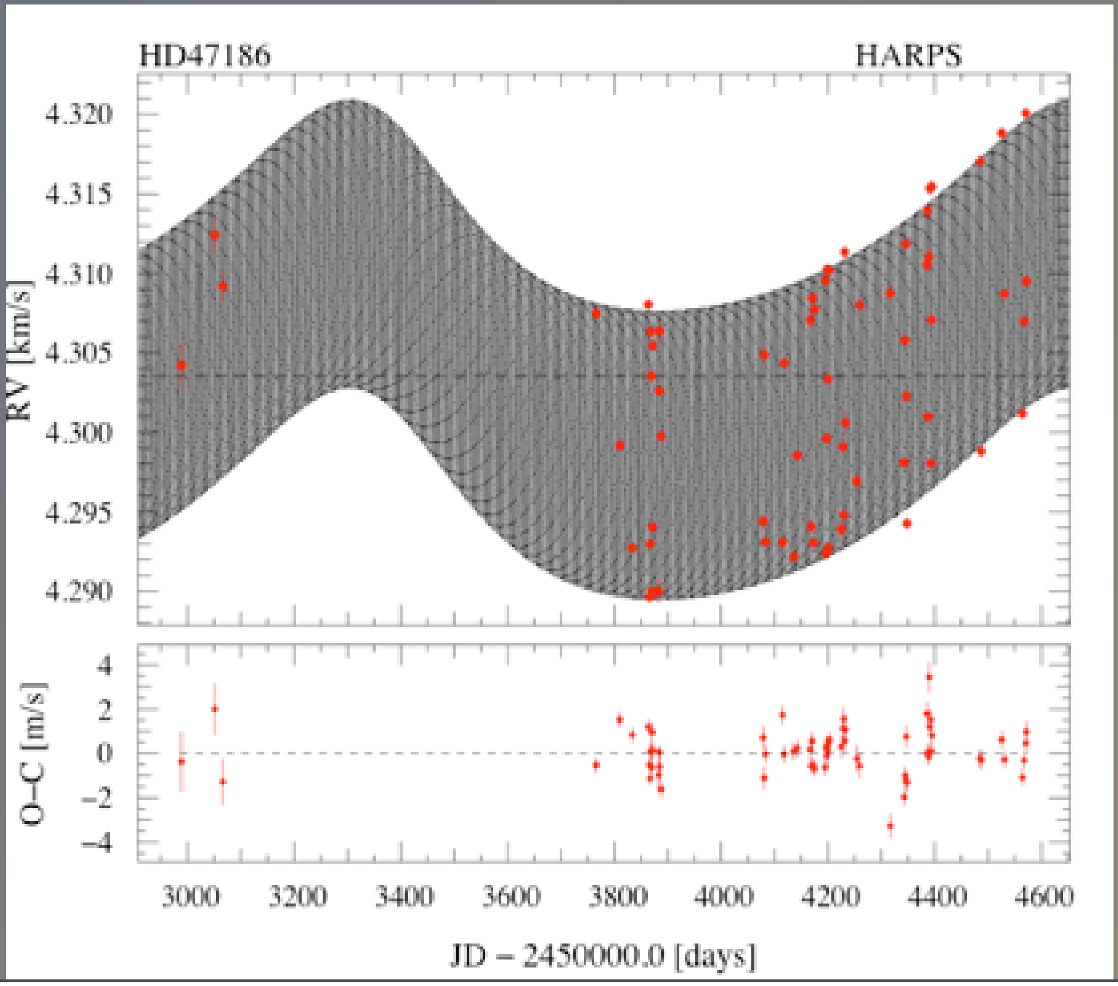


P_1 = 1350 days
e_1 = 0.27
m_1 sini = 0.36 M_{Jup}

P_2 = 4.08 days
e_2 = 0.0
m_2 sini = 23 $M_\oplus$

HD 47186
G6 V
d = 38 pc
m = 7.8
[Fe/H] = +0.23

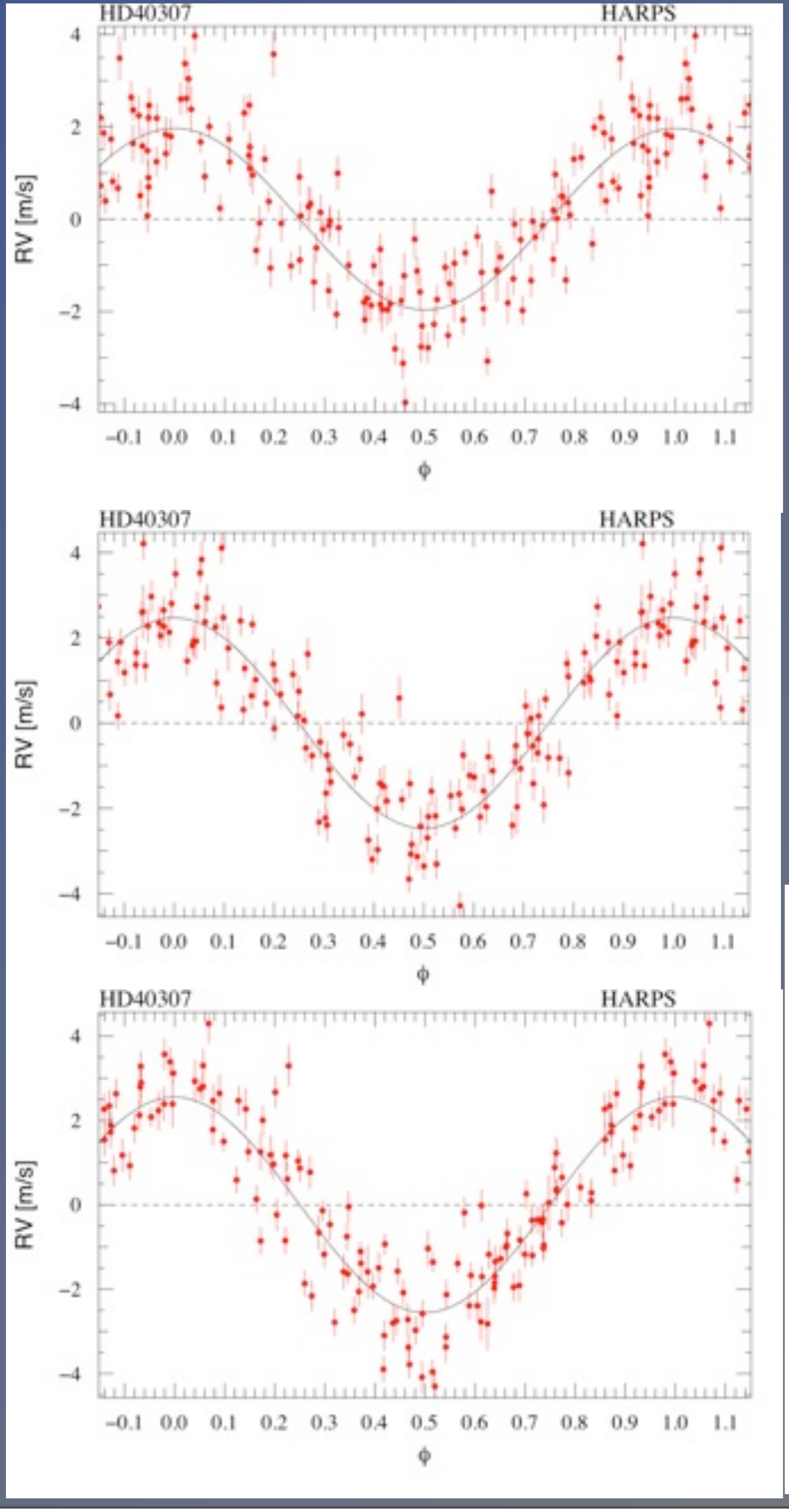
O-C = 0.94 m/s
66 measurements



Bouchy et al. A&A 2009

A system with 3 Super-Earths

Mayor et al. A&A 2009



P_1 = 4.31 days
e_1 = 0.02
m_1 sini = 4.3 $M_\oplus$

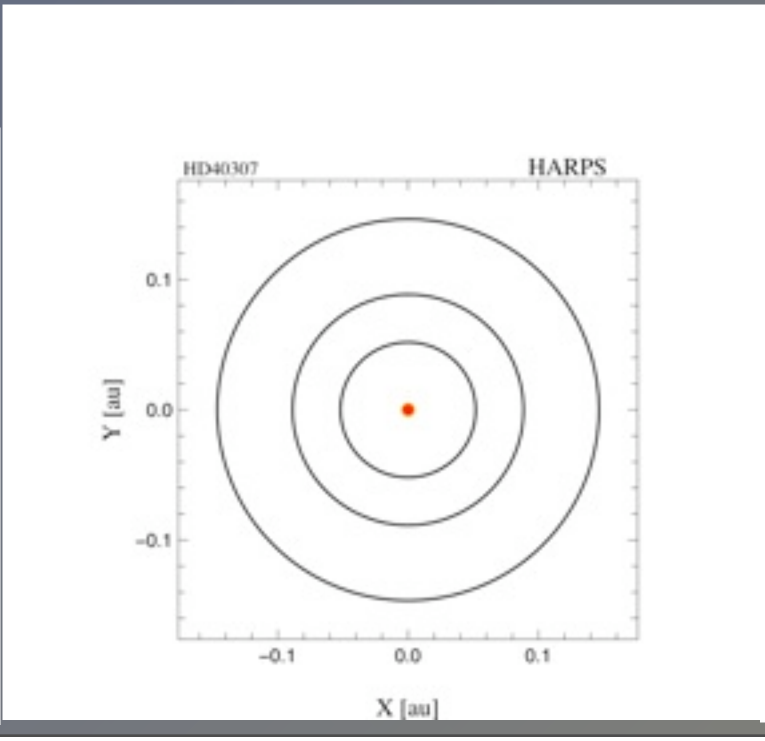
P_2 = 9.62 days
e_2 = 0.03
m_2 sini = 6.9 $M_\oplus$

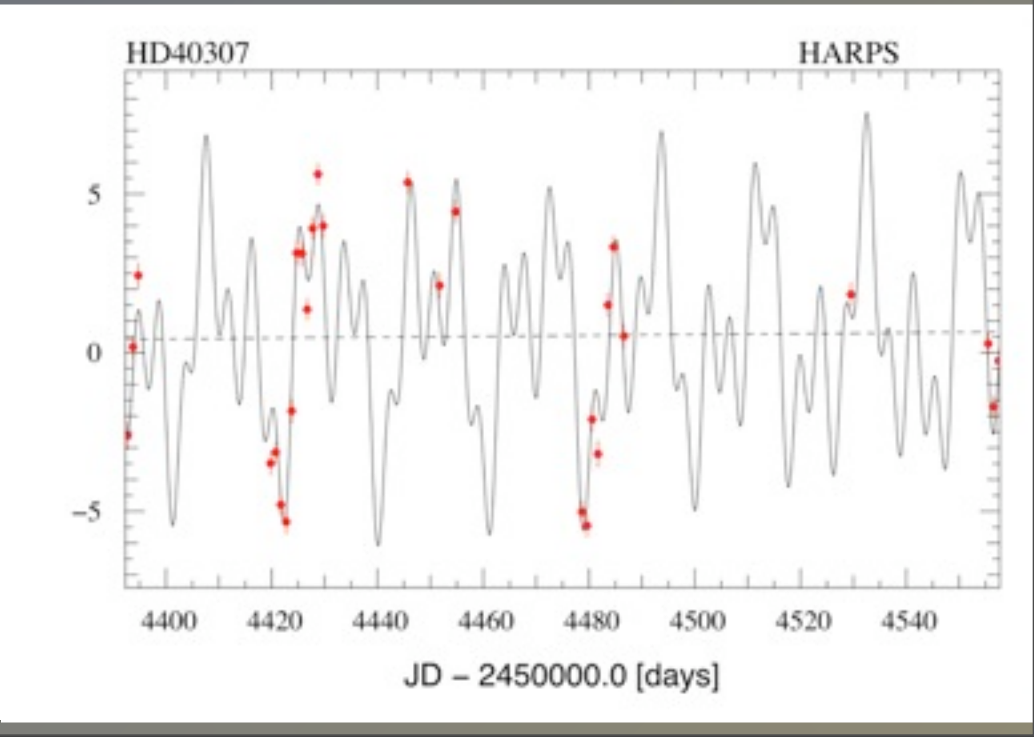
P_3 = 20.5 days
e_3 = 0.04
m_3 sini = 9.7 $M_\oplus$

HD 40307
K2 V
Dist 12.8 pc
[Fe/H] = -0.31

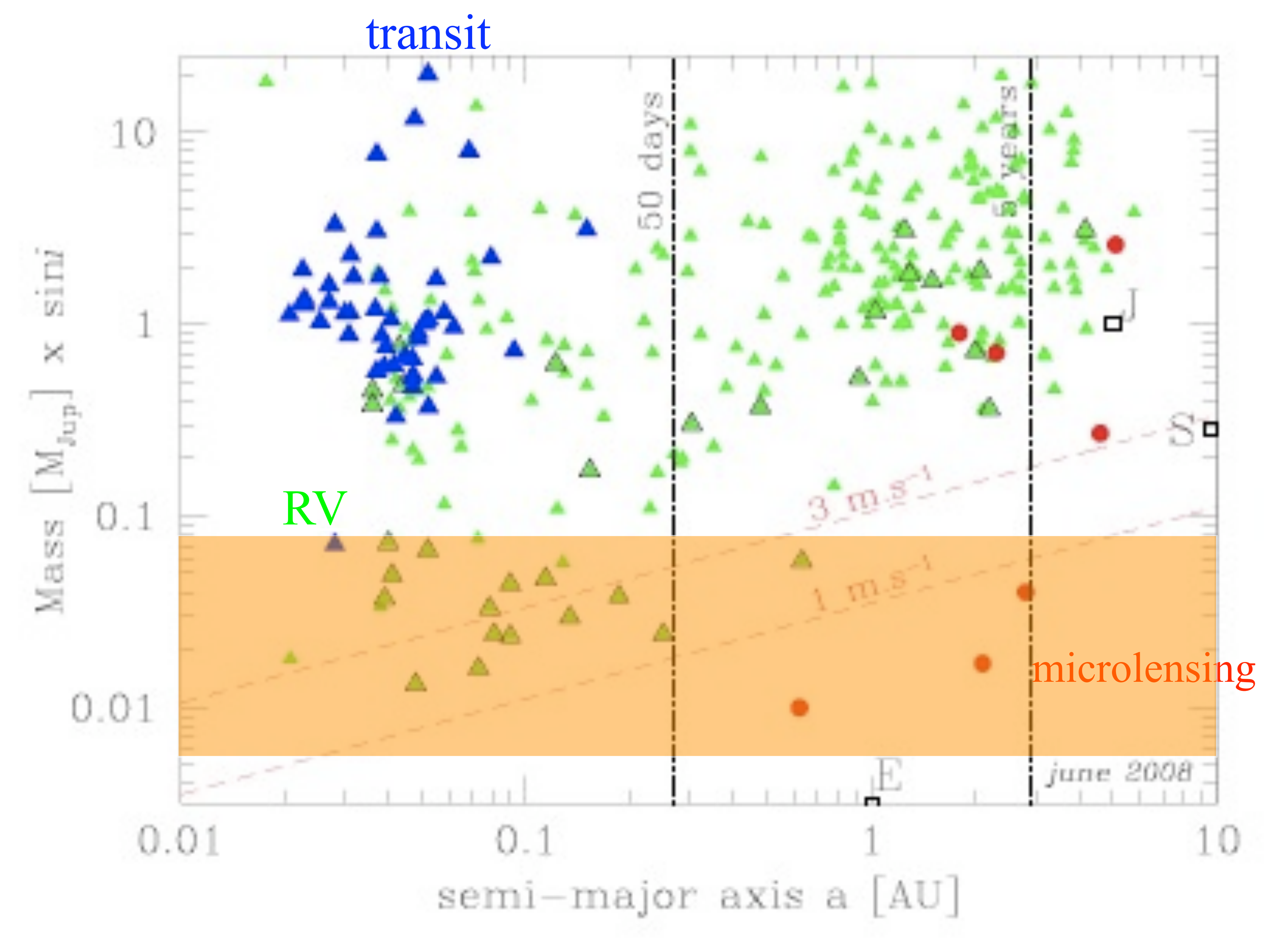
O-C = 0.85 m/s
135 observations

+ drift = 0.5 m/s/y



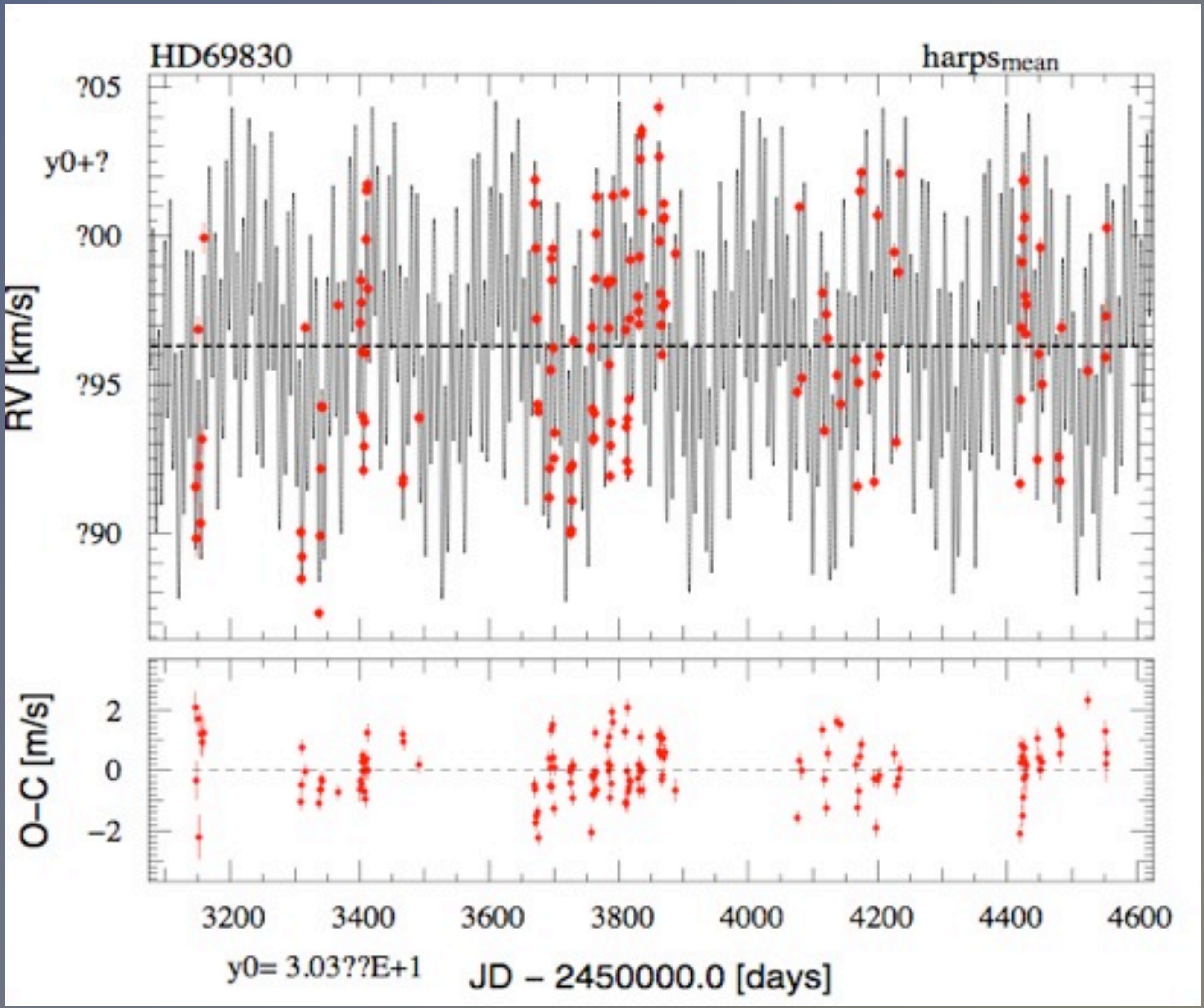


Observations:
small mass planets everywhere?



Difficulty/Strategy to detect this population ?

- Multi-planet systems very common -> complex RV curves
- Widely different timescales involved (3 orders of magnitude in period)
- Optimal data sampling a priori unknown
- Stellar low-frequency noise varies from star to star (~0.5-2 m/s)



-> Best strategy: perform high-cadence measurements (7-10 consecutive nights)

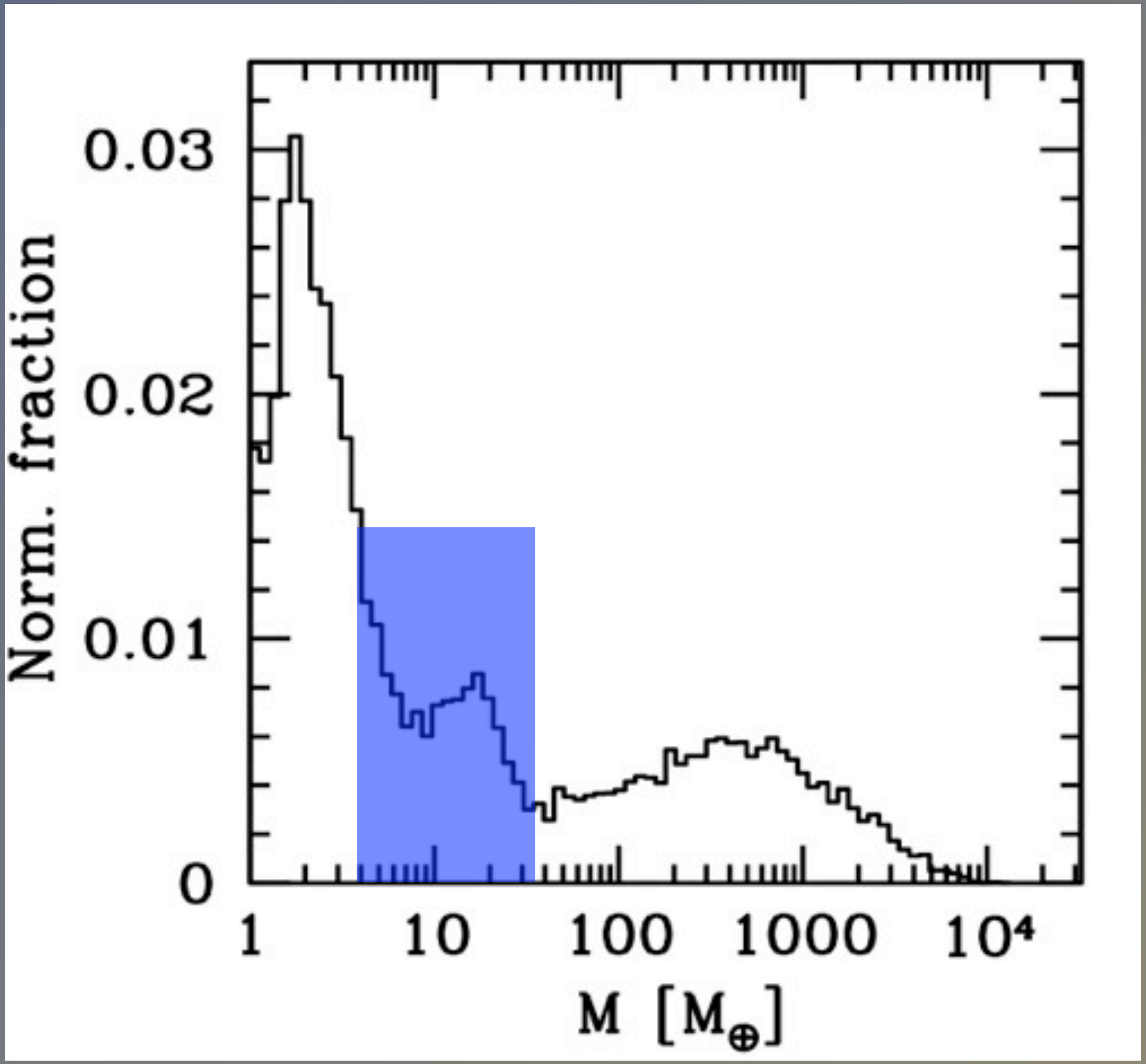
-> Less stars, but more measurements per star

-> High frequency series of observations for > 250 stars

The quest for the low-mass population

Core-accretion models predict a significant increase in population below 20-30 $M_{\oplus}$

Ida & Lin 2008
Mordasini et al. 2009



Are we detecting this population ?

Are we detecting this population ?

Yes !

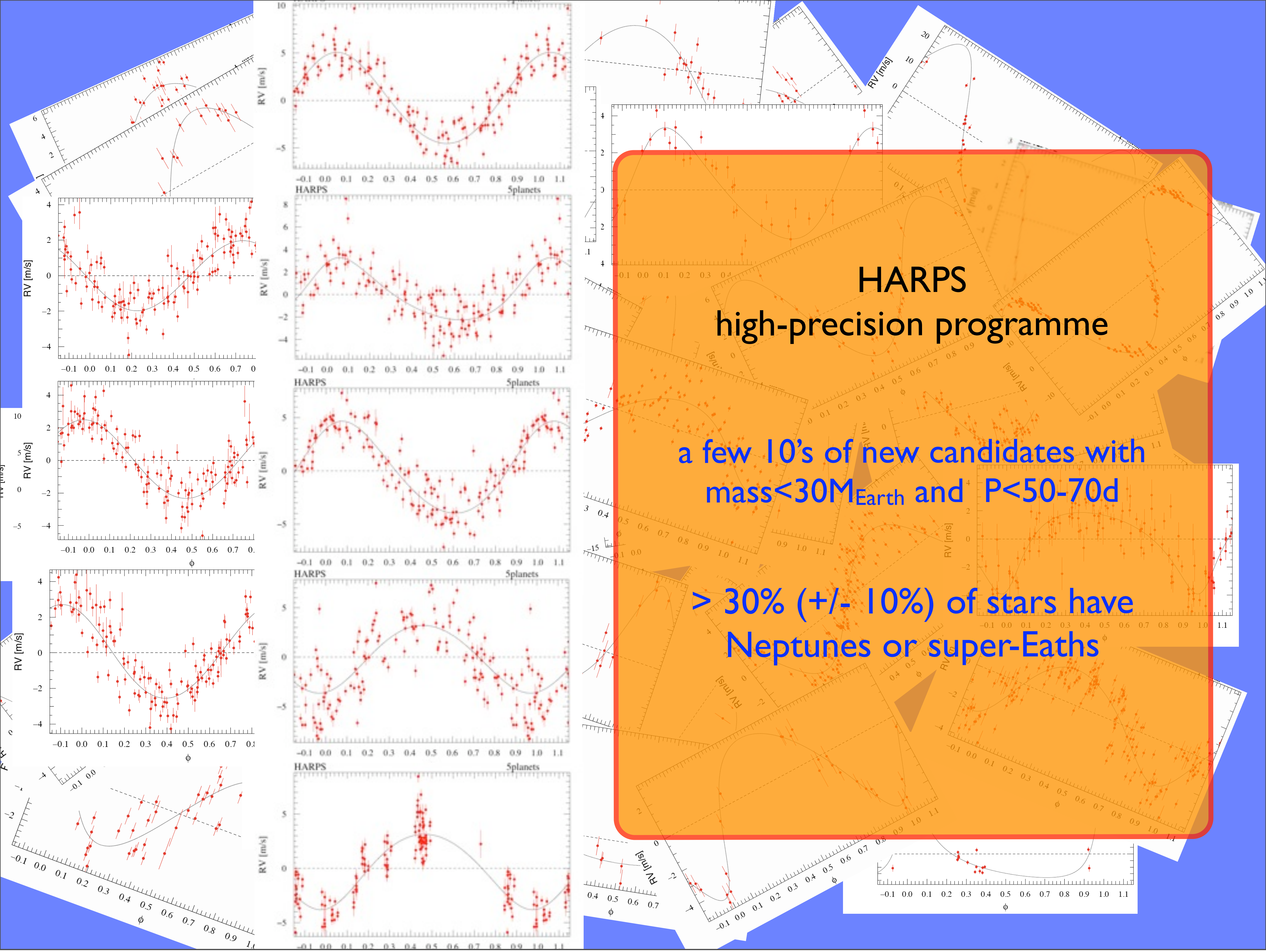
Are we detecting this population ?

Yes !

Number of candidates with :

1) $m \sin i < 30\ M_{\oplus}$
2) $P < 50\text{-}70$ days

Significance of periodogram peaks, F-test



HARPS
high-precision programme

a few 10's of new candidates with mass<30M$_{\mathrm{Earth}}$ and P<50-70d

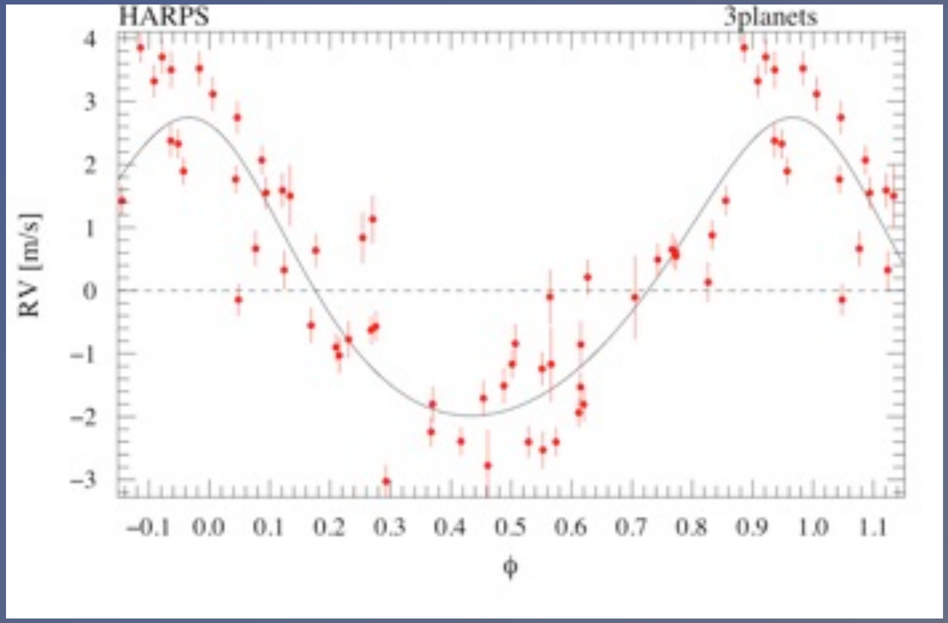
> 30% (+/- 10%) of stars have Neptunes or super-Eaths

Some Candidates overview (2)

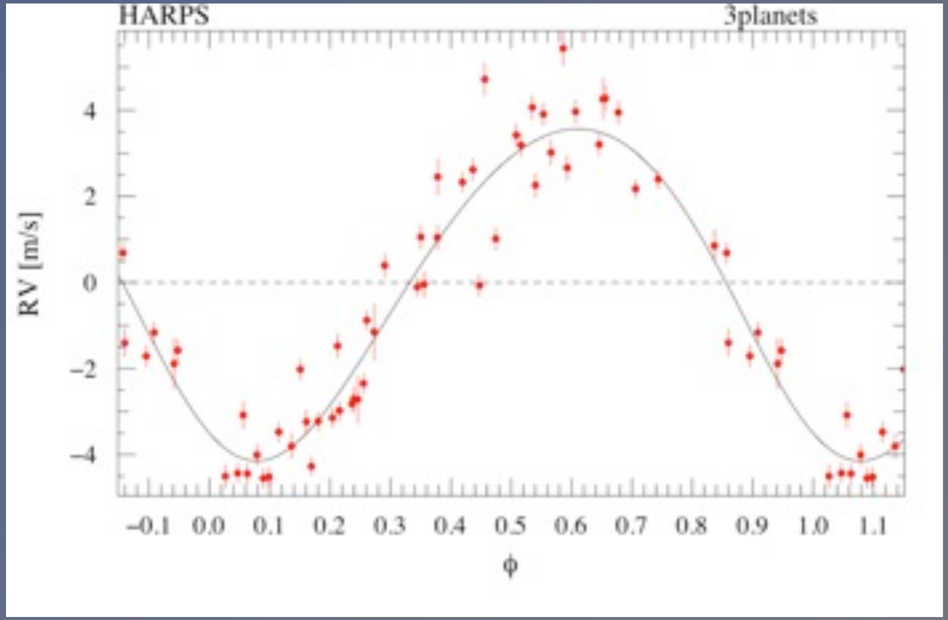
A 3-planet system with
2 Neptunes + 1 super-Earth

55 observations
O-C = 0.8 m/s

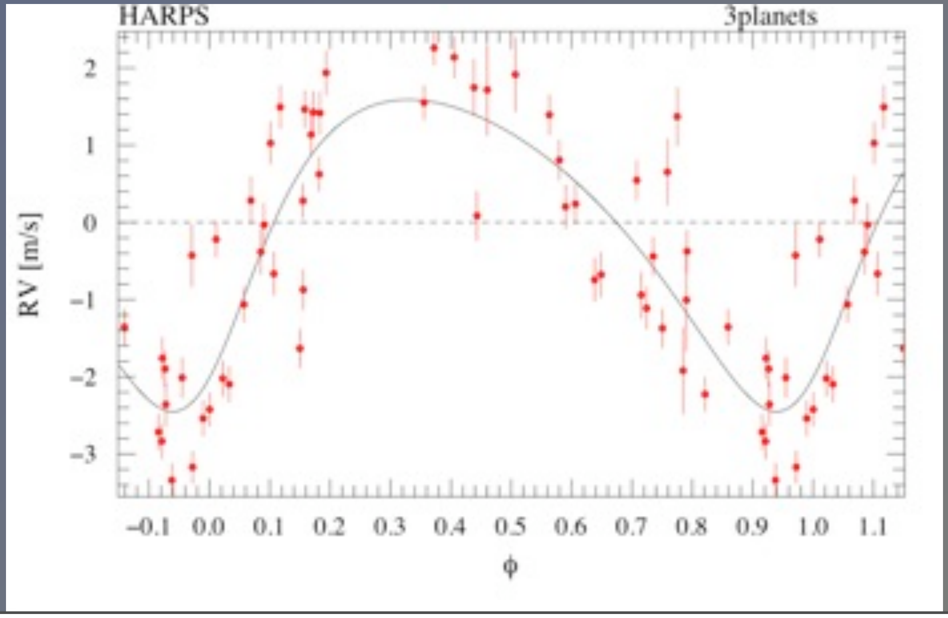
$e_1 = 0.16$
$m_1 \sin i = 5.4\ M_\oplus$

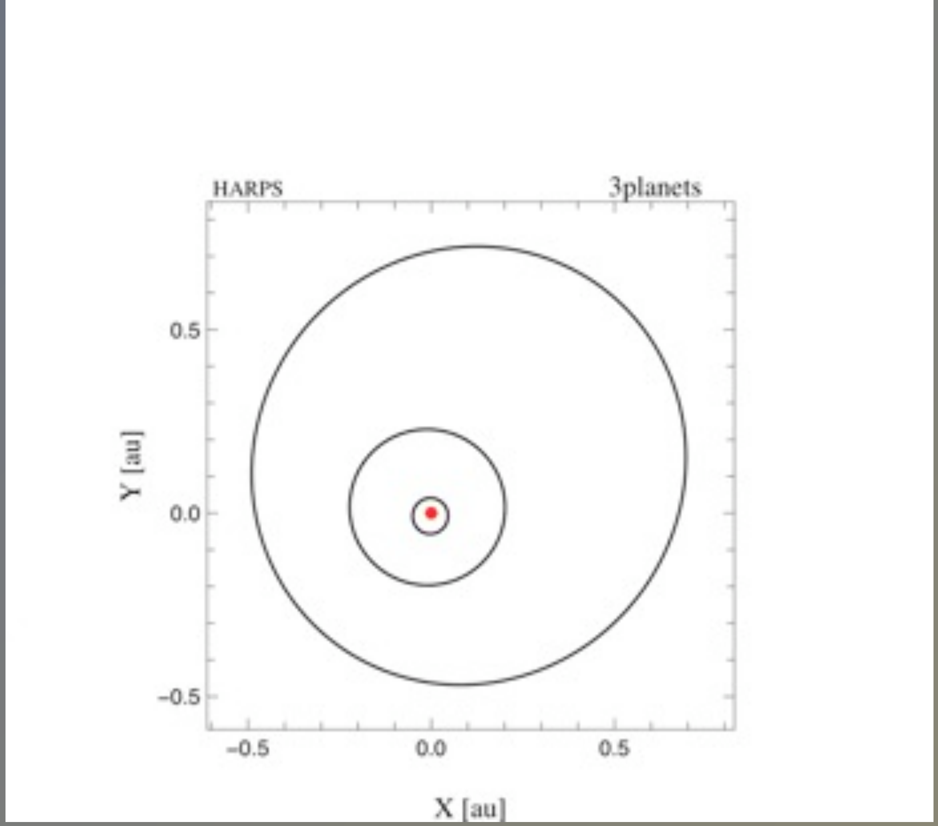


$e_2 = 0.09$
$m_2 \sin i = 18.5\ M_\oplus$



$e_3 = 0.27$
$m_3 \sin i = 15.9\ M_\oplus$

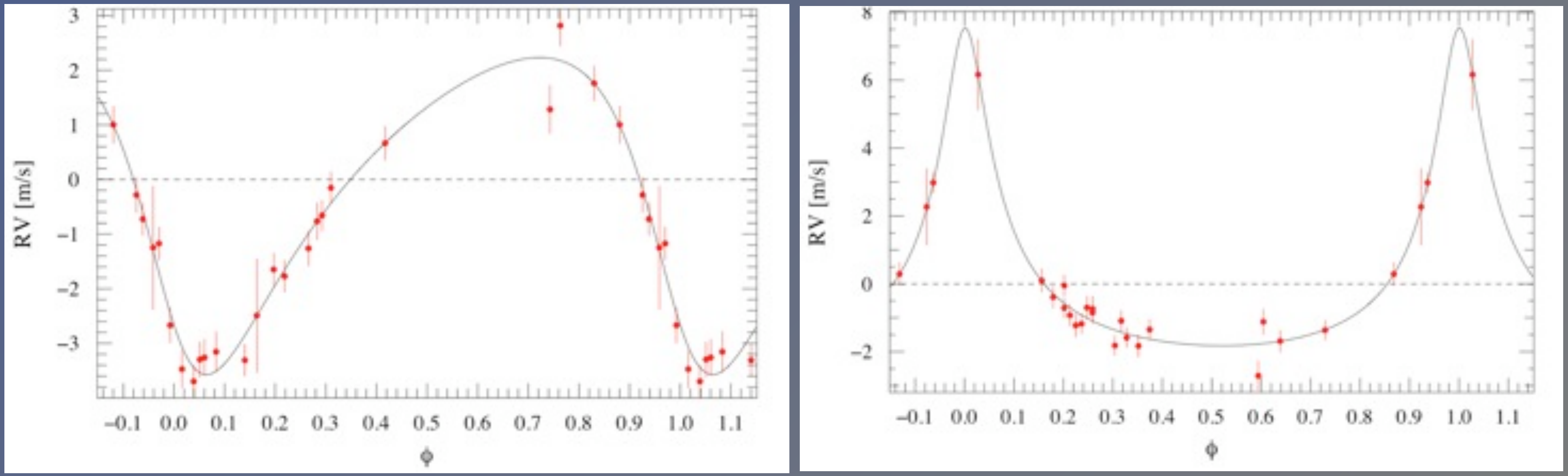




Some Candidates overview (4): 2 planet systems

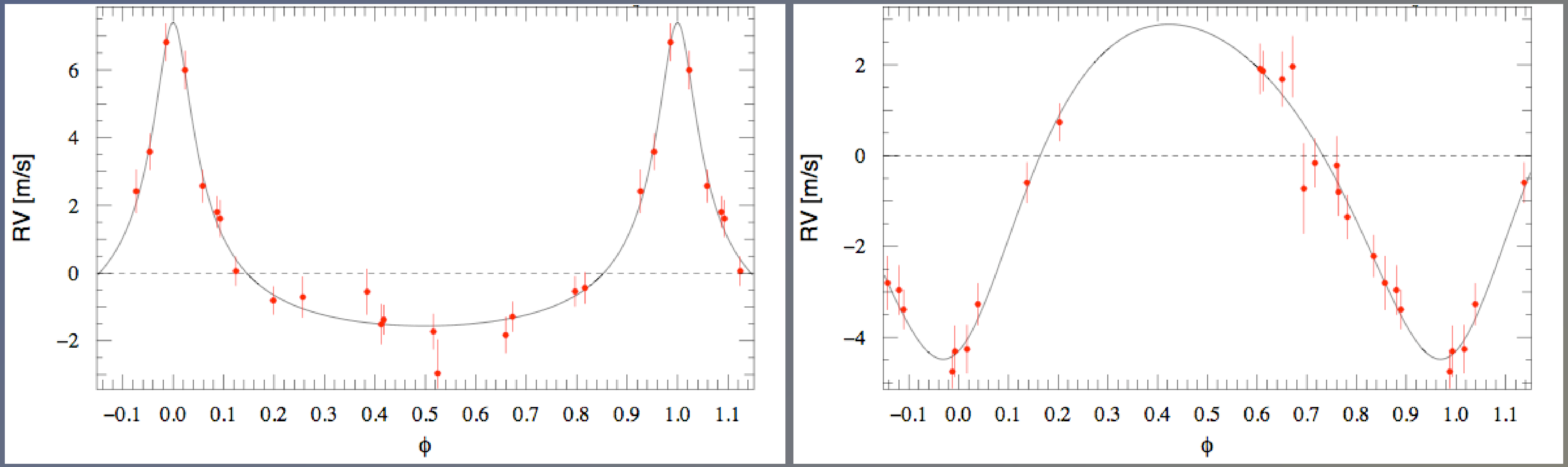
P_1 = 44.1 days
e_1 = 0.34
m_2 sini = 13.2 $M_\oplus$

P_2 = 86.9 days
e_2 = 0.61
m_2 sini = 22.5 $M_\oplus$



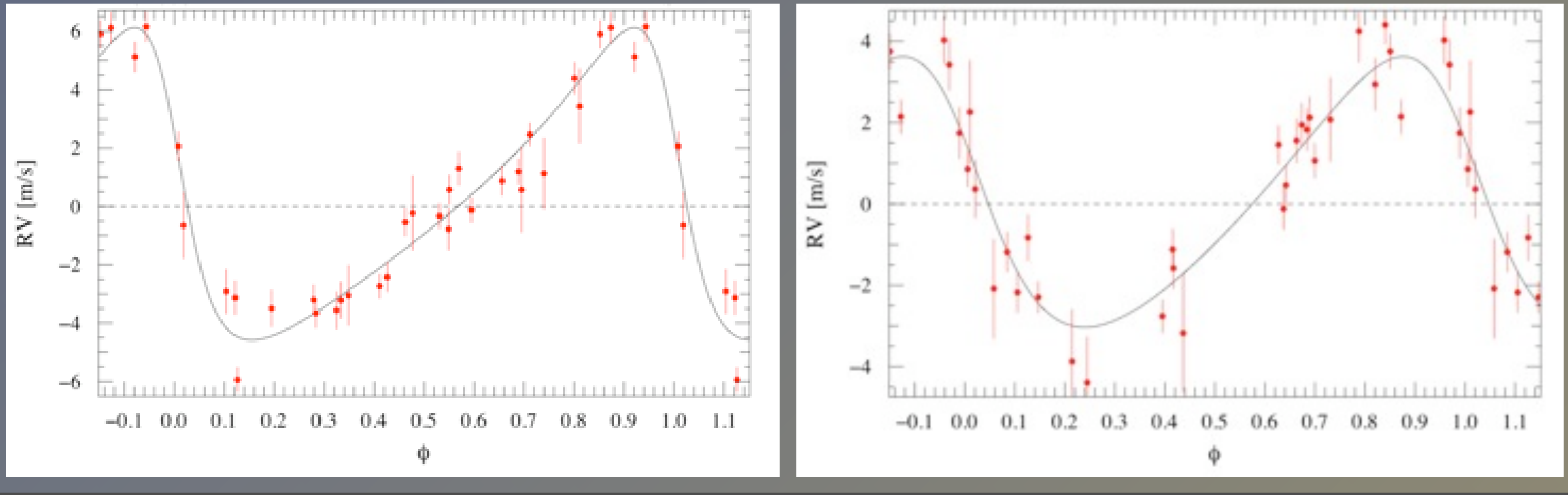
P_1 = 7.44 days
e_1 = 0.65
m_2 sini = 10.4 $M_\oplus$

P_2 = 45.5 days
e_2 = 0.23
m_2 sini = 20.0 $M_\oplus$



P_1 = 14.07 days
e_1 = 0.45
m_2 sini = 15.6 $M_\oplus$

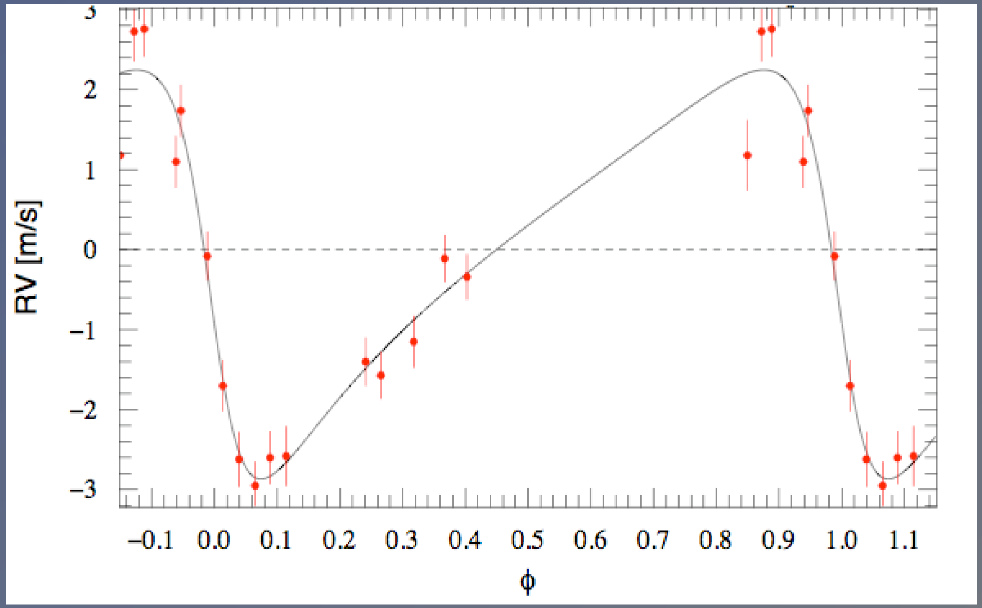
P_2 = 96.4 days
e_2 = 0.23
m_2 sini = 20.0 $M_\oplus$



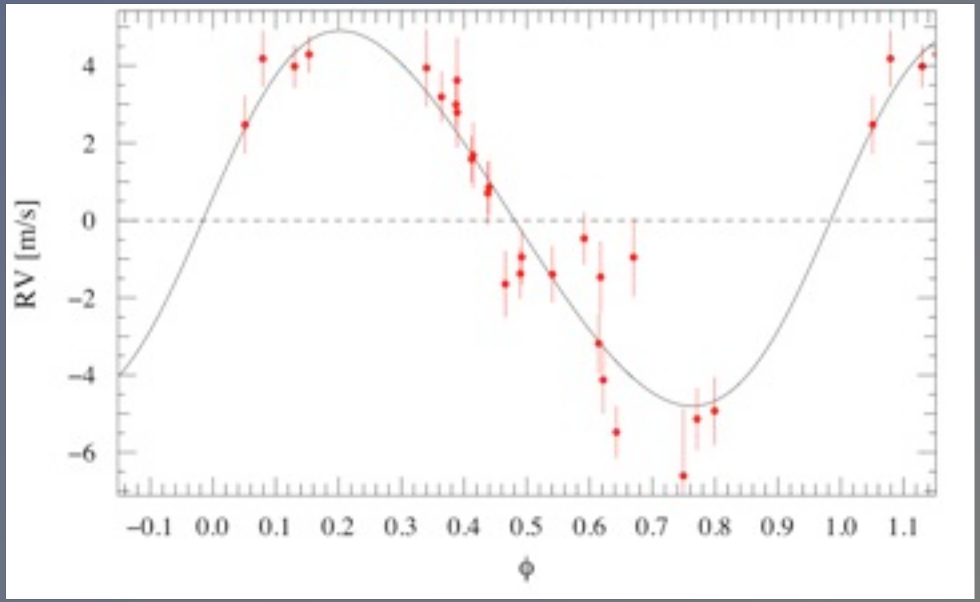
Some Candidates overview (5)

single planets

P_1 = 39.6 days
e_1 = 0.5
m_2 sini = 9.7 $M_\oplus$



P_1 = 38.9 days
e_1 = 0.1
m_2 sini = 23.1 $M_\oplus$

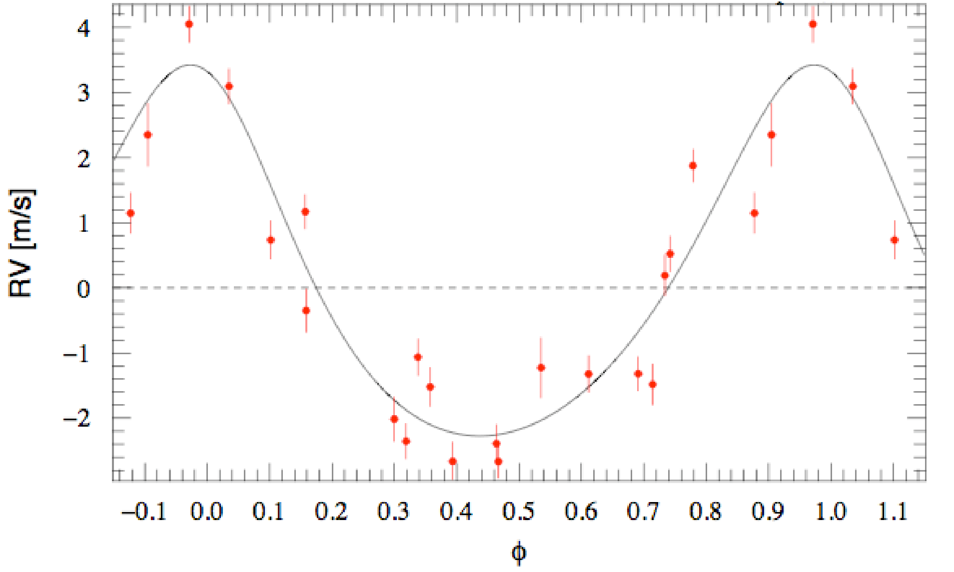


Some Candidates overview (6)

P = 2.34 days

e = 0-0.2

m sini = 5.8 $M_\oplus$

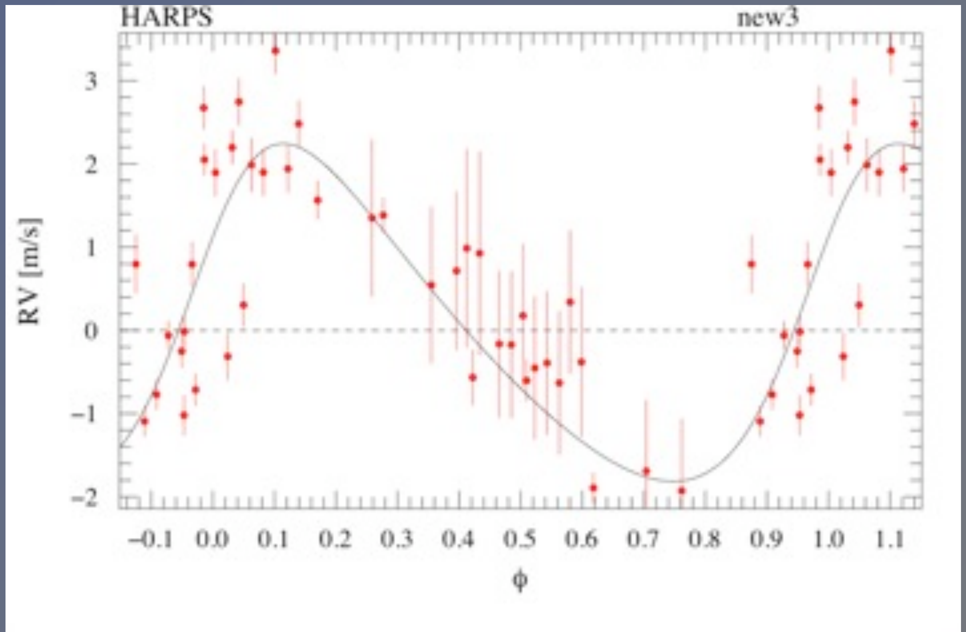


single-planet system

P_1 = 51.59 days

e_1 = 0.235

m_2 sini = 8.4 $M_\oplus$

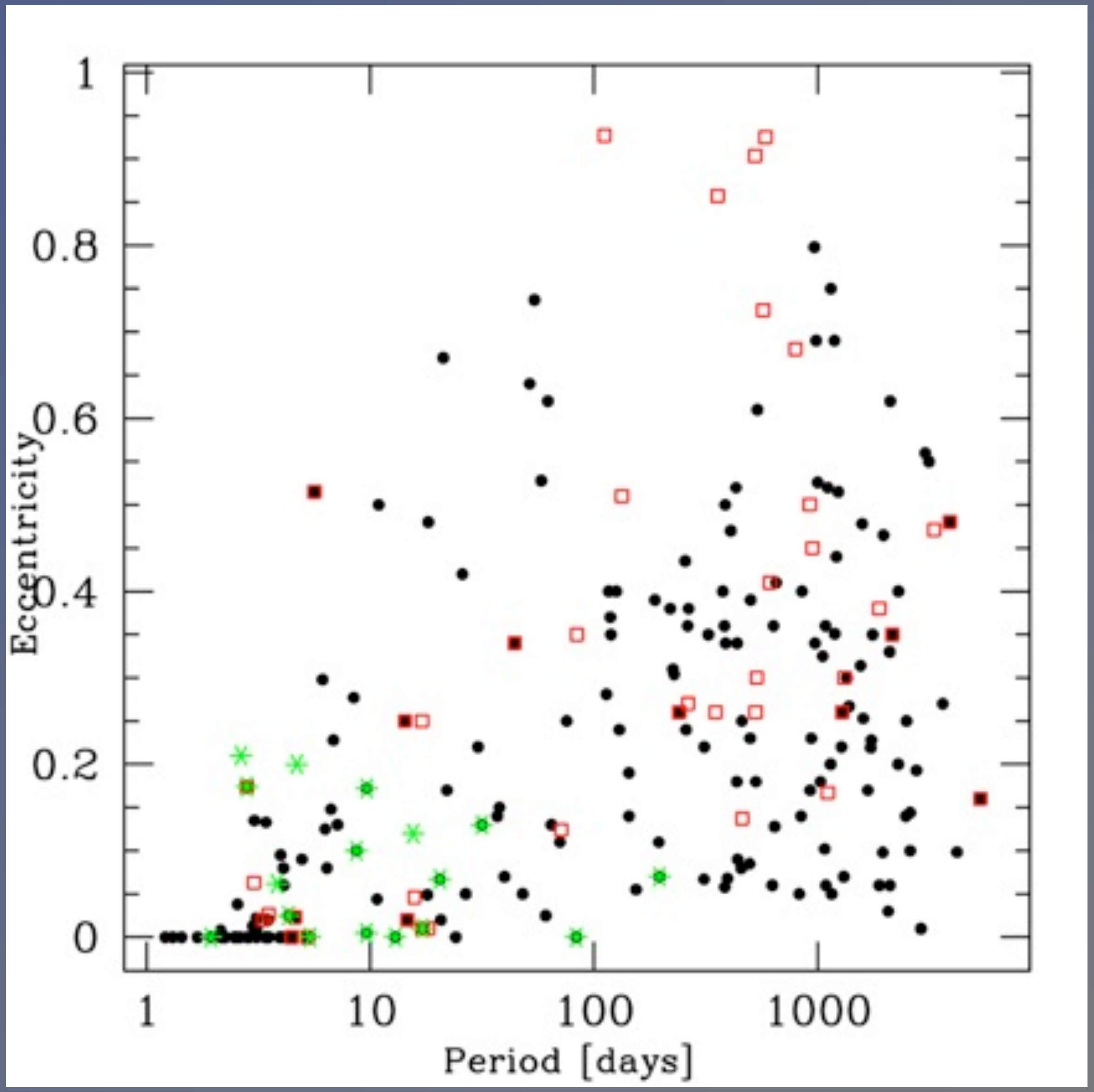


+ a drift

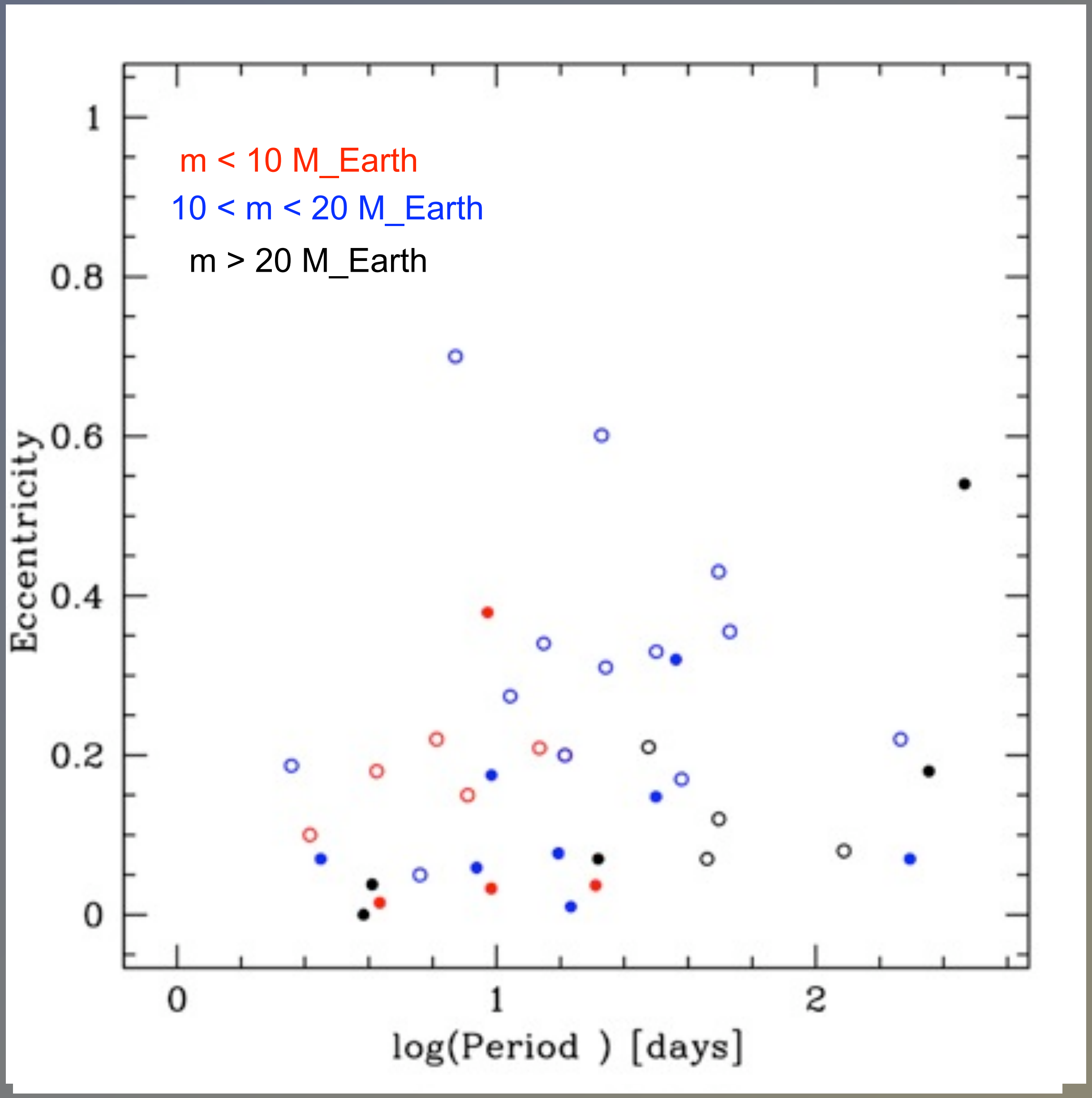
Some properties of close-in low-mass planets

3) eccentricity

- High eccentricities seem common, as for gas giants



Warning: Highly uncertain



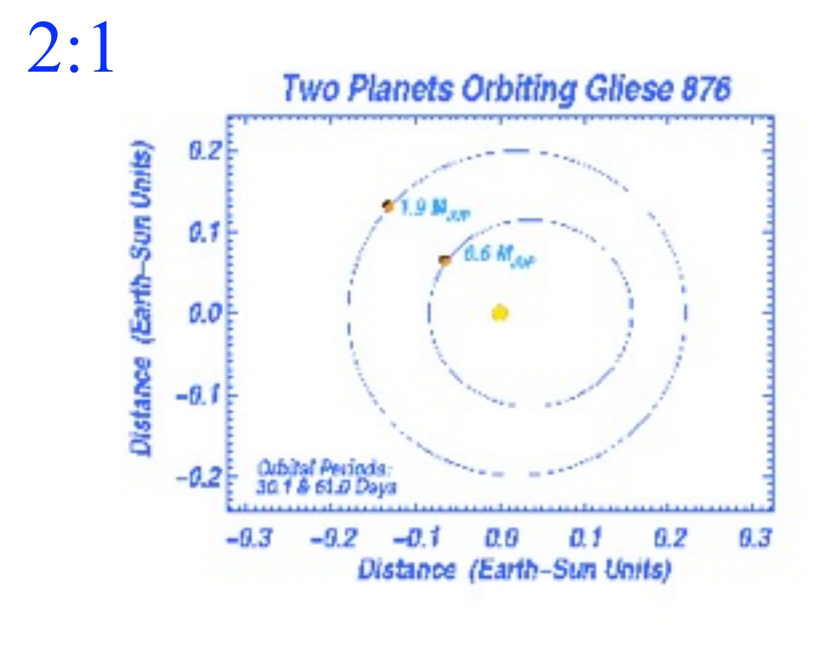
- System with several giant planets: many resonances

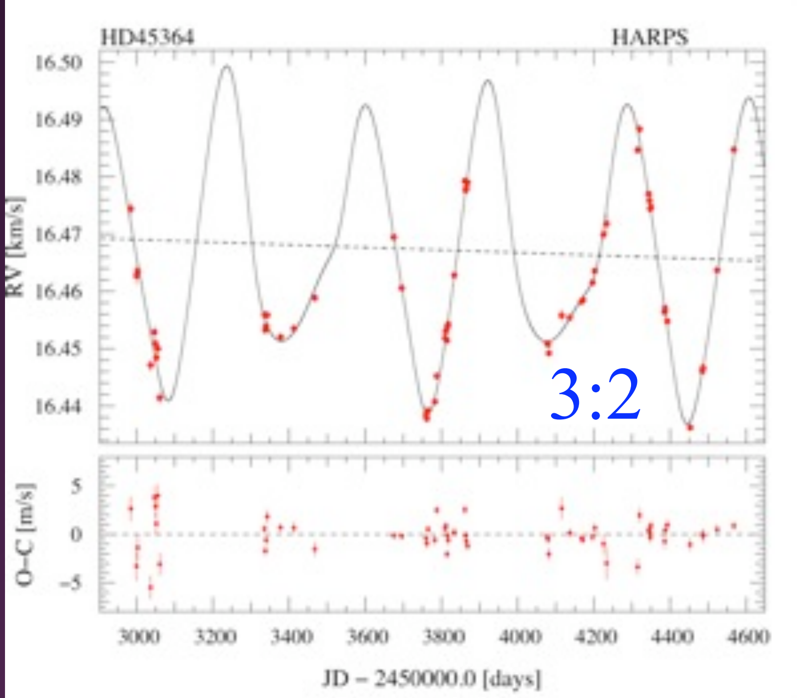
Desort et al. 2009

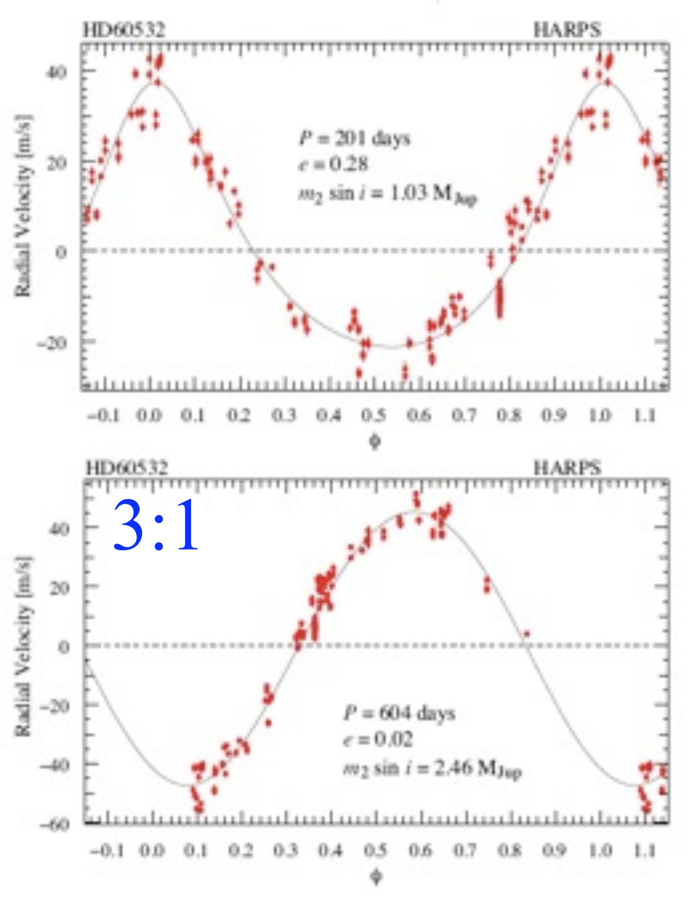
Correia et al. 2008

P1= 226 d   P2 = 334 d

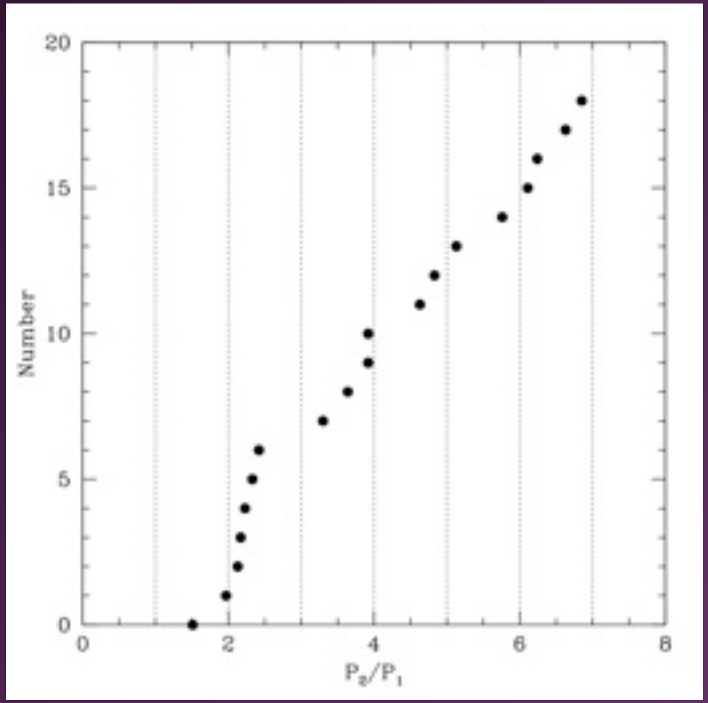
Marcy et al. 2001


2:1


3:2


3:1

- Planetary multiplicity for systems with at least one Neptune/Super-Earth



resonances are not the rule!

Systems with Neptunes and super-Earths

An emerging new population

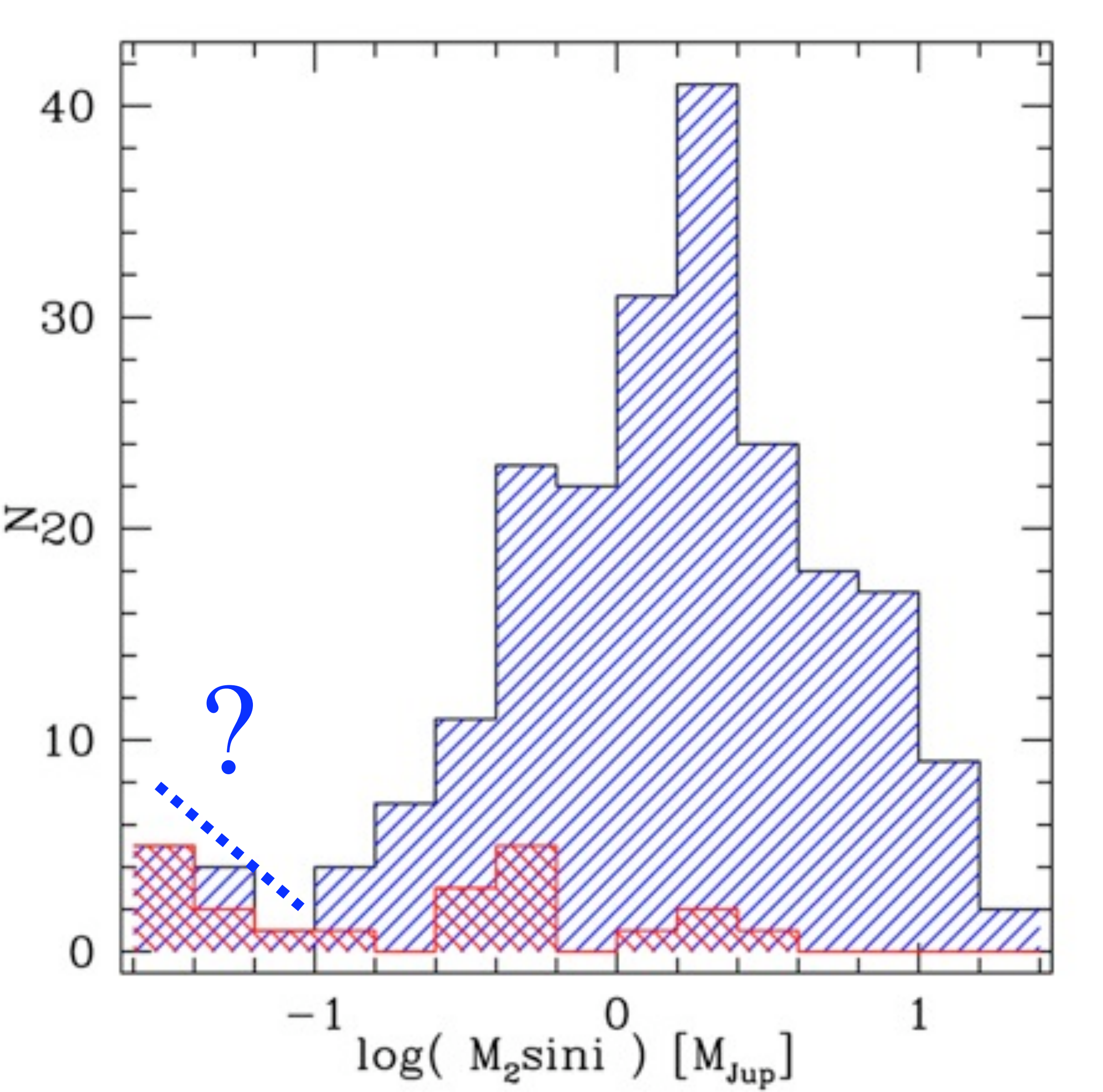
Properties?

comparison with giant panets?

Some properties of close-in low-mass planets

1) Mass distribution

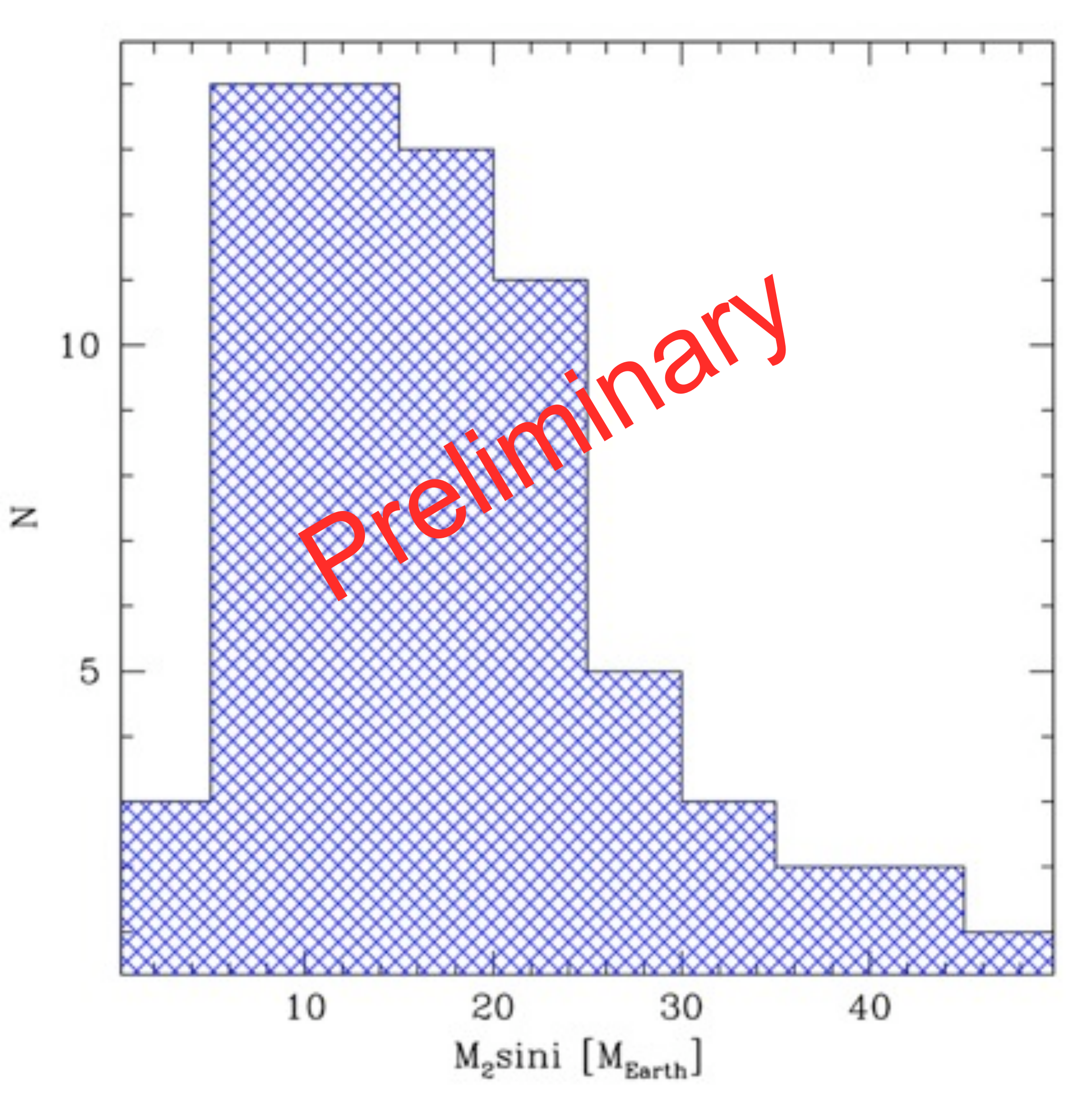
Preliminary

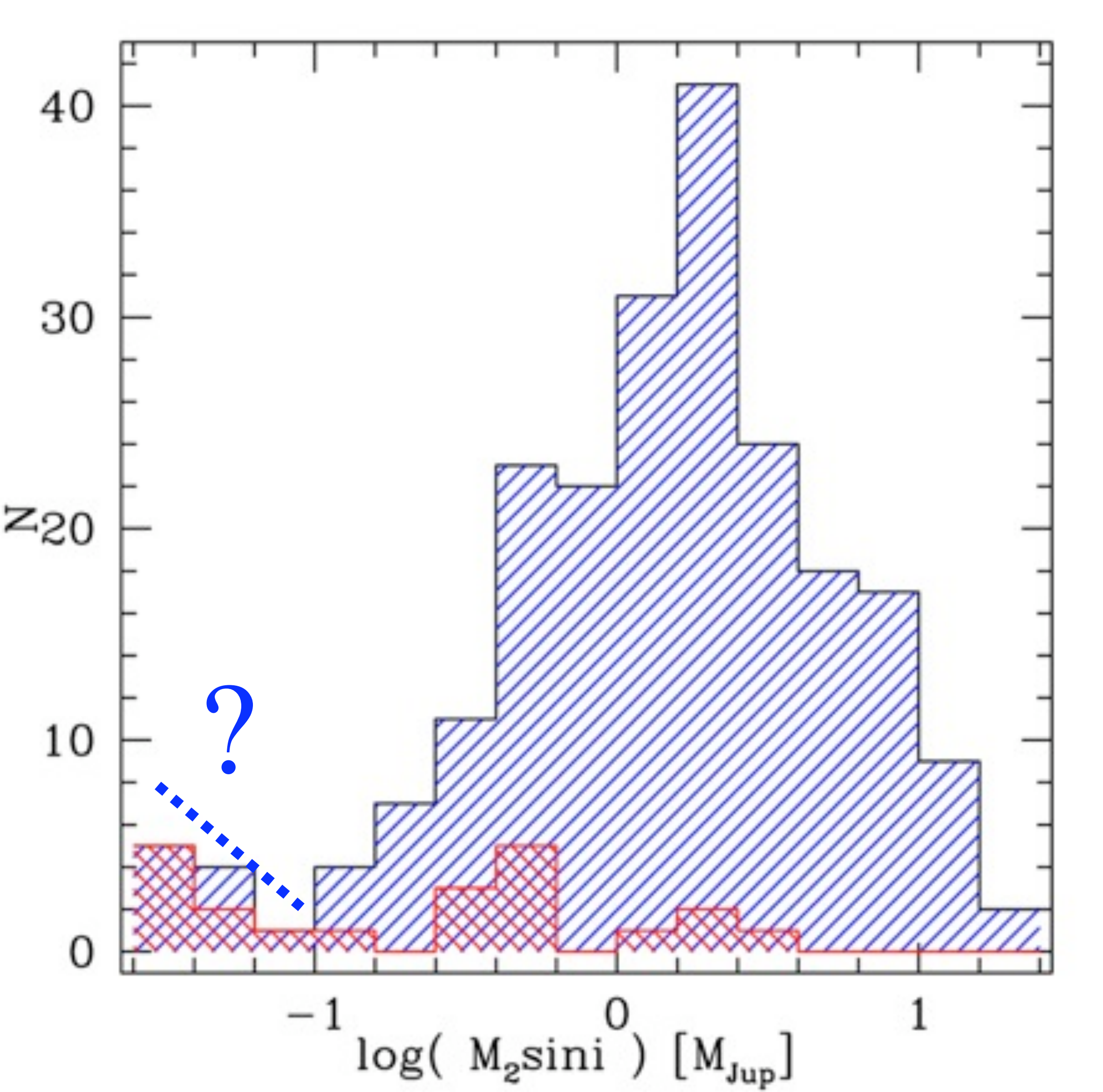


Some properties of close-in low-mass planets

1) Mass distribution

- Mass distribution grows towards lower masses, as predicted by core accretion (   )





Some properties of close-in low-mass planets

1) Mass distribution

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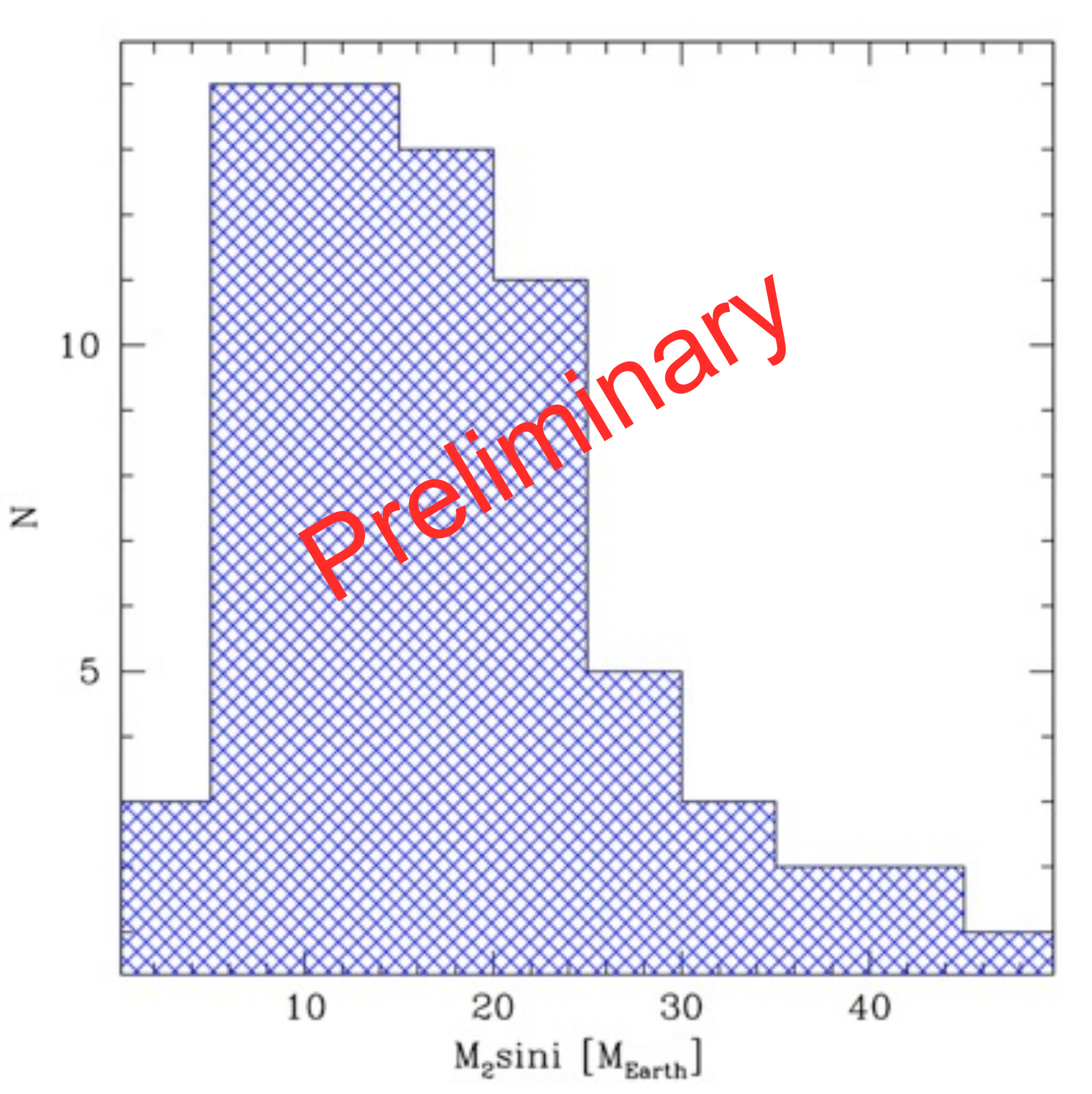
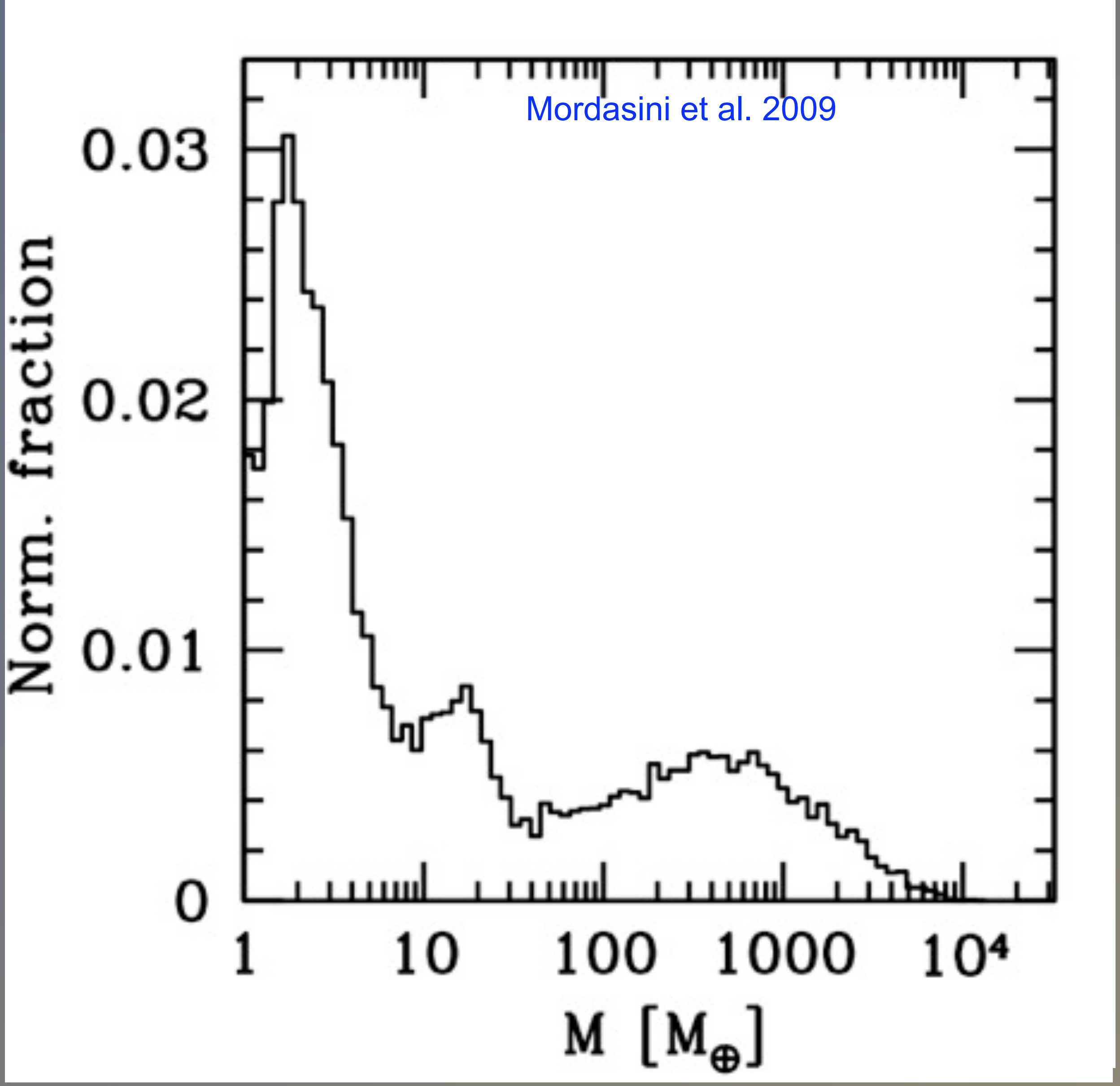
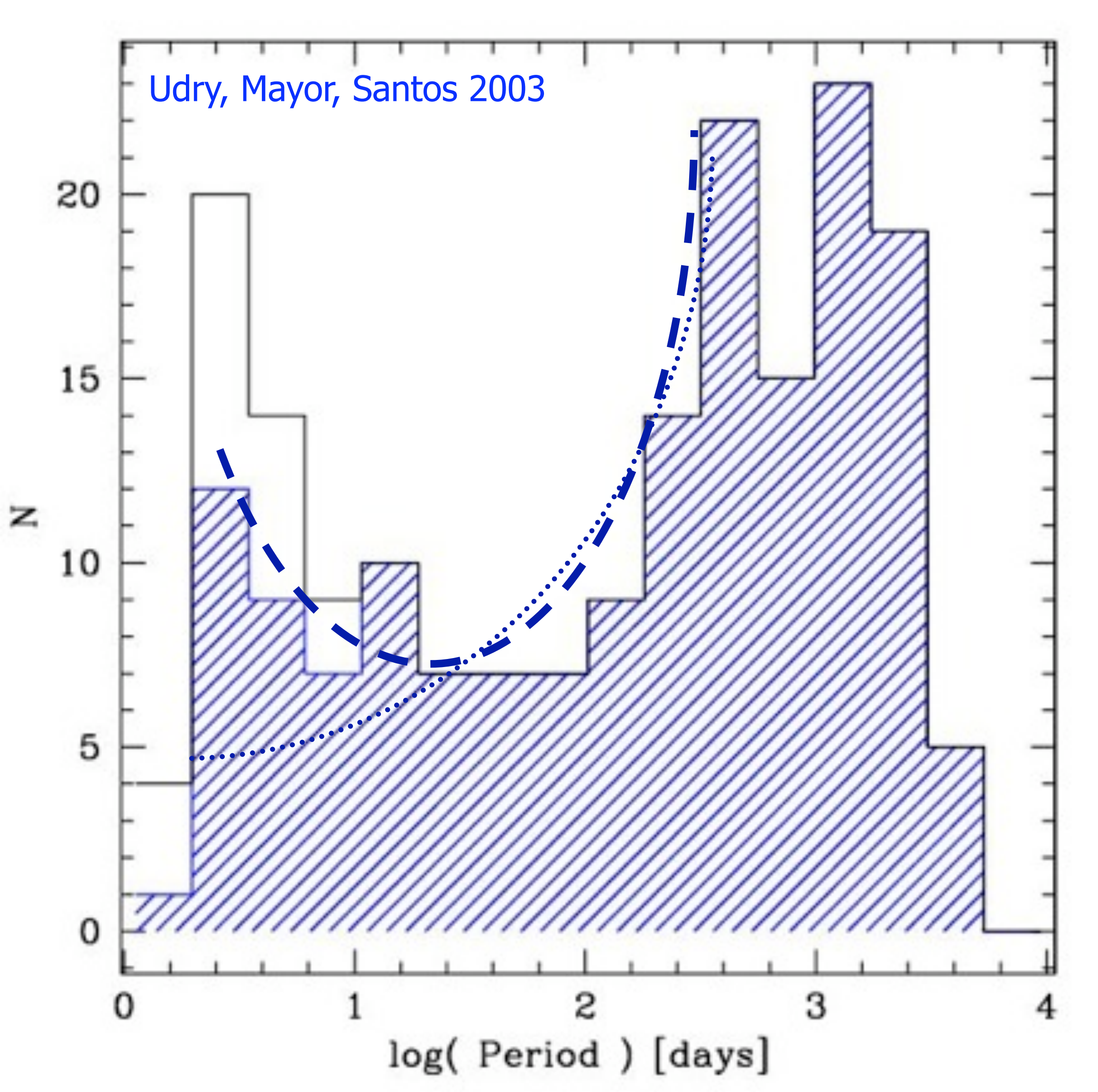




Some properties of close-in low-mass planets

2) Period distribution

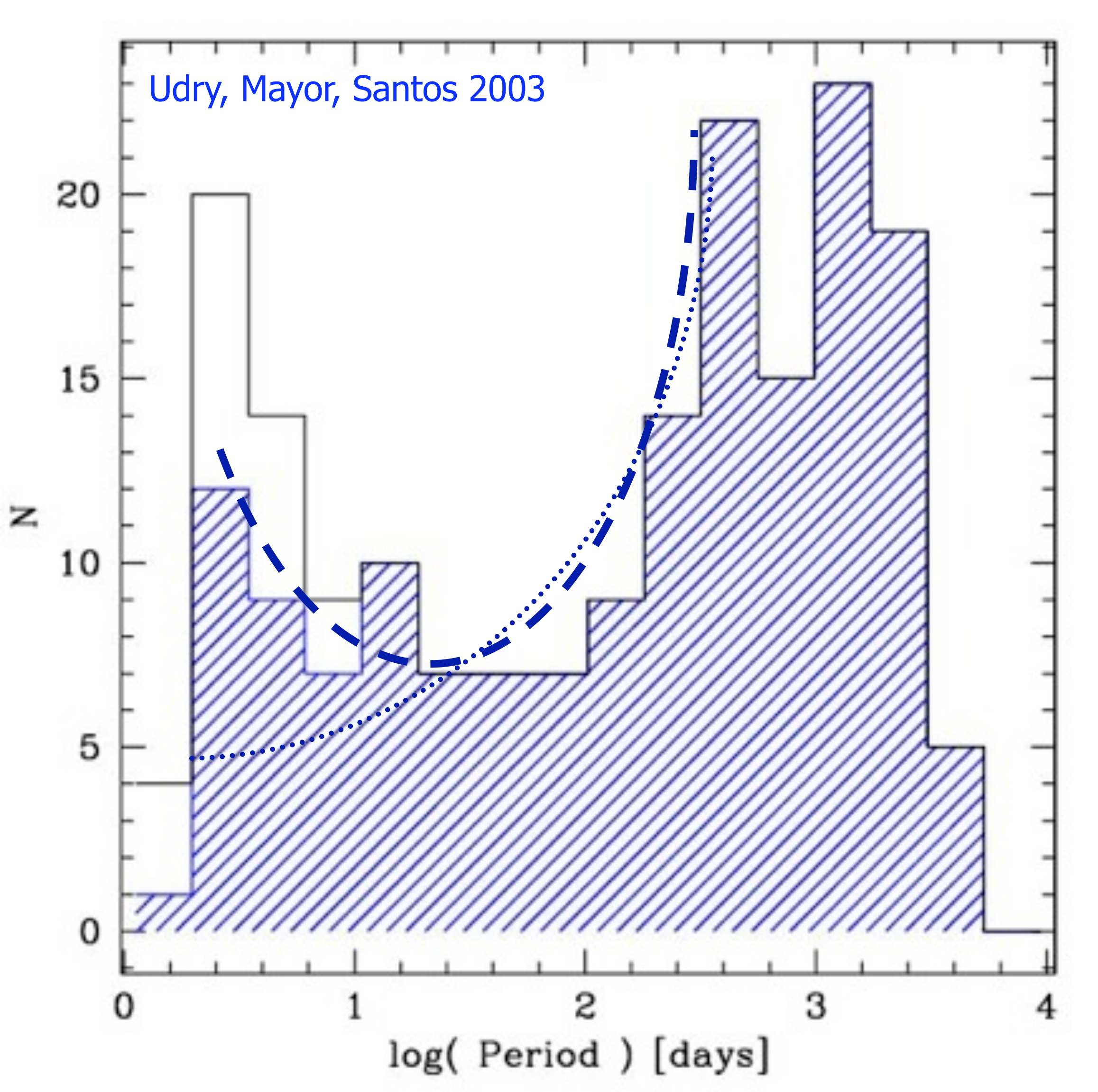


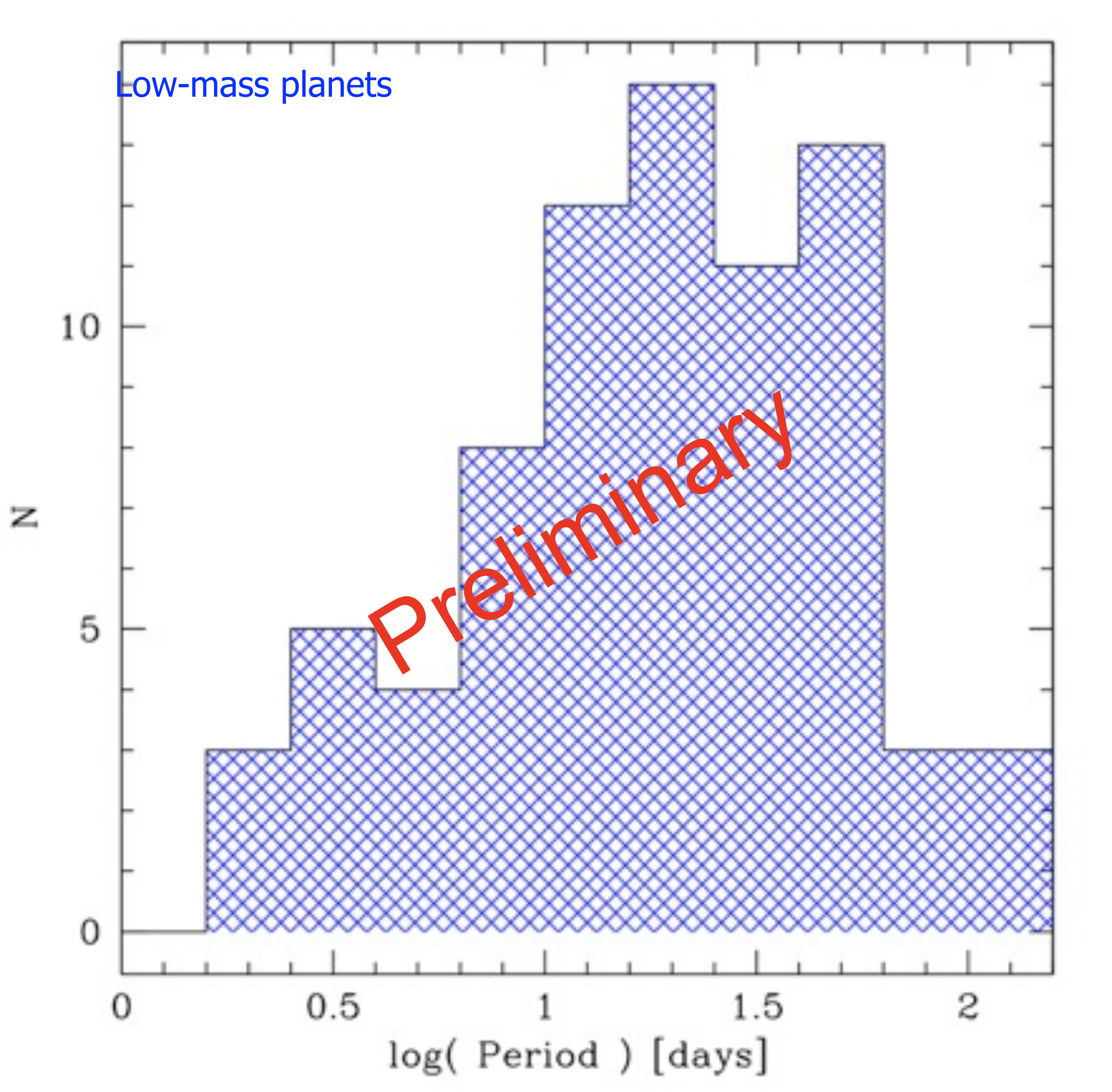
Preliminary

Some properties of close-in low-mass planets

2) Period distribution

- For small-mass planets, no peak at ~3 days. Rise to >10 days? -> different formation mechanism?

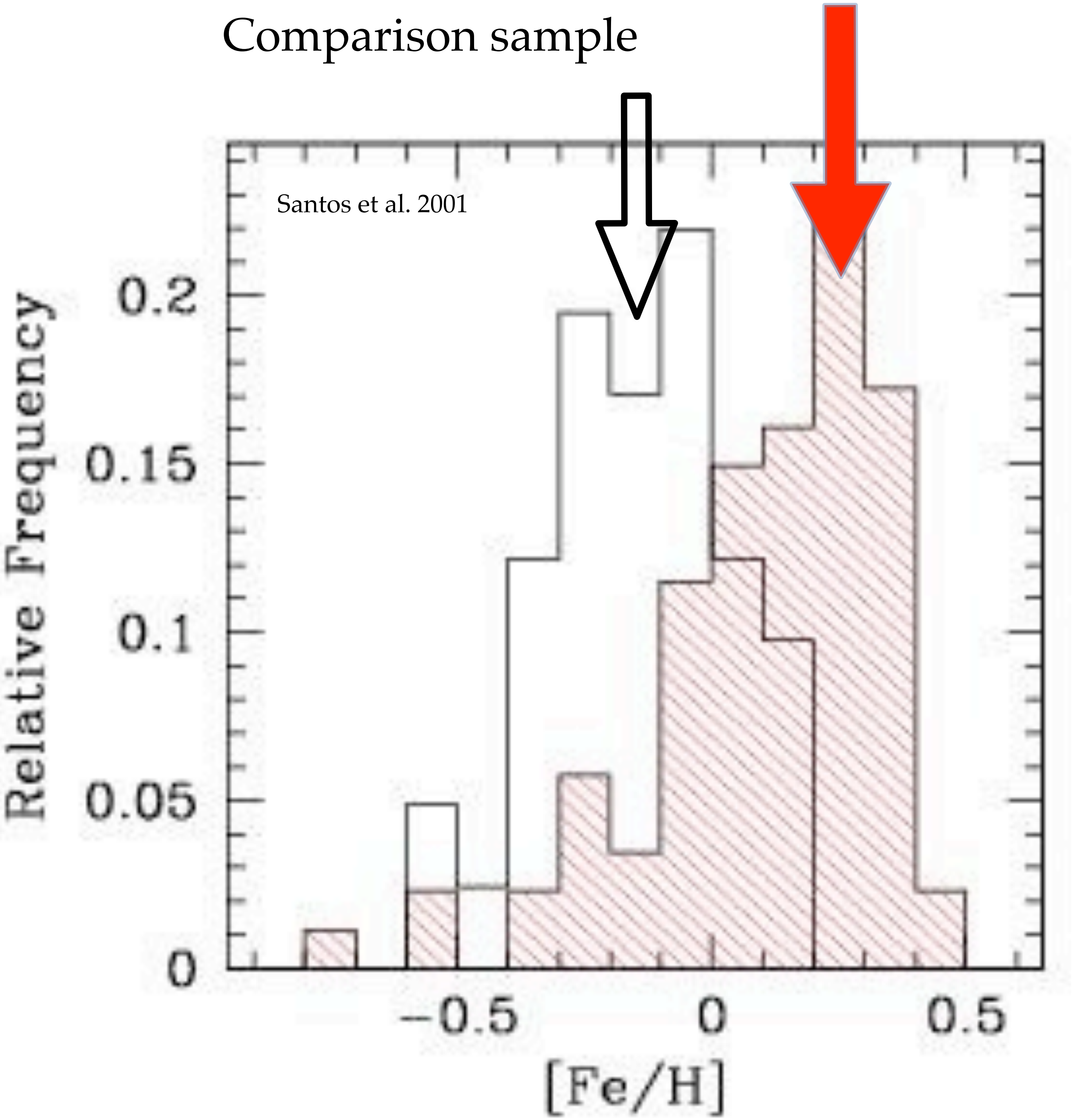




No host star metallicity correlation for low-mass planets ?

CORALIE giant planets

Comparison sample

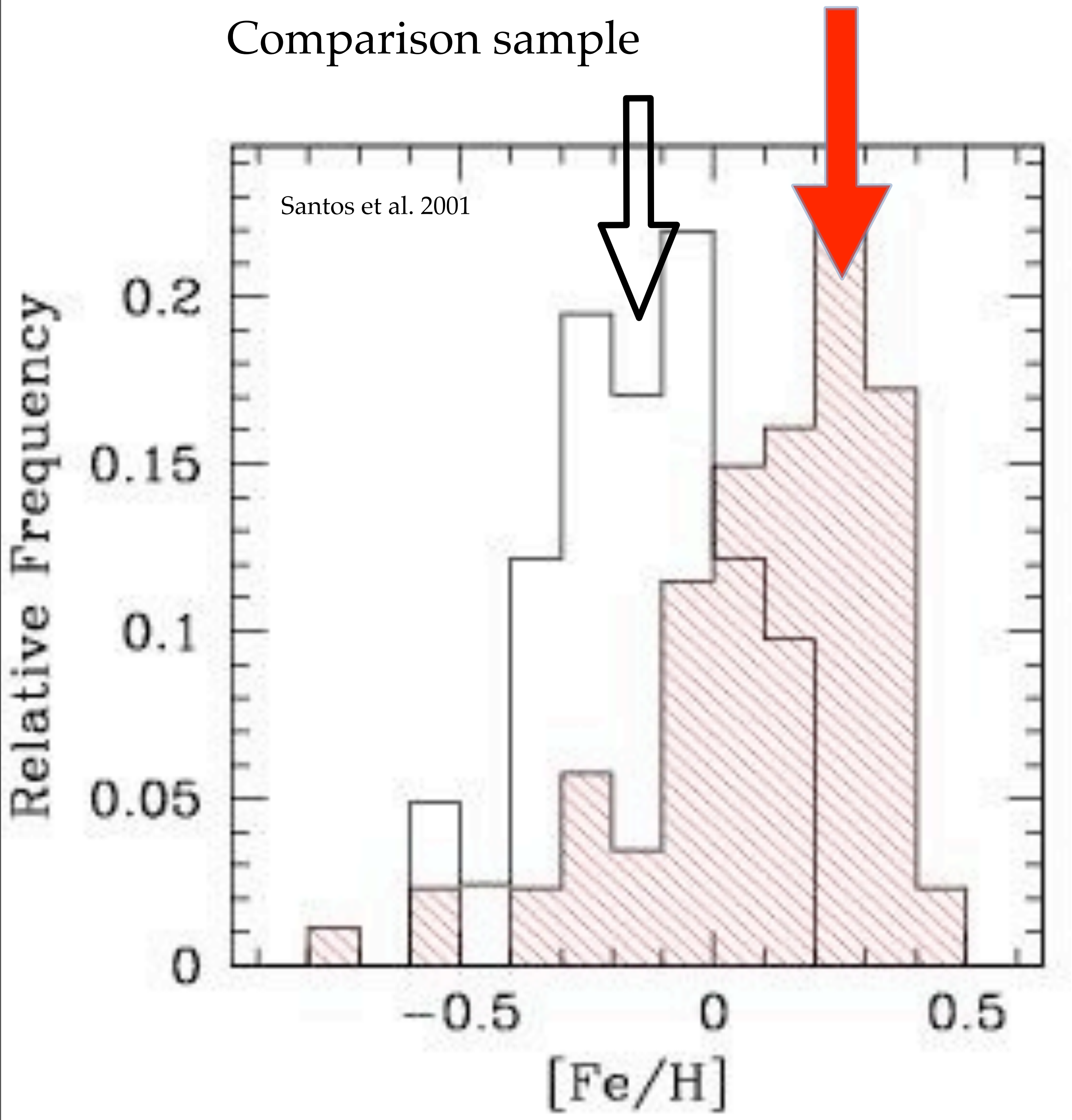


Santos et al. 2001

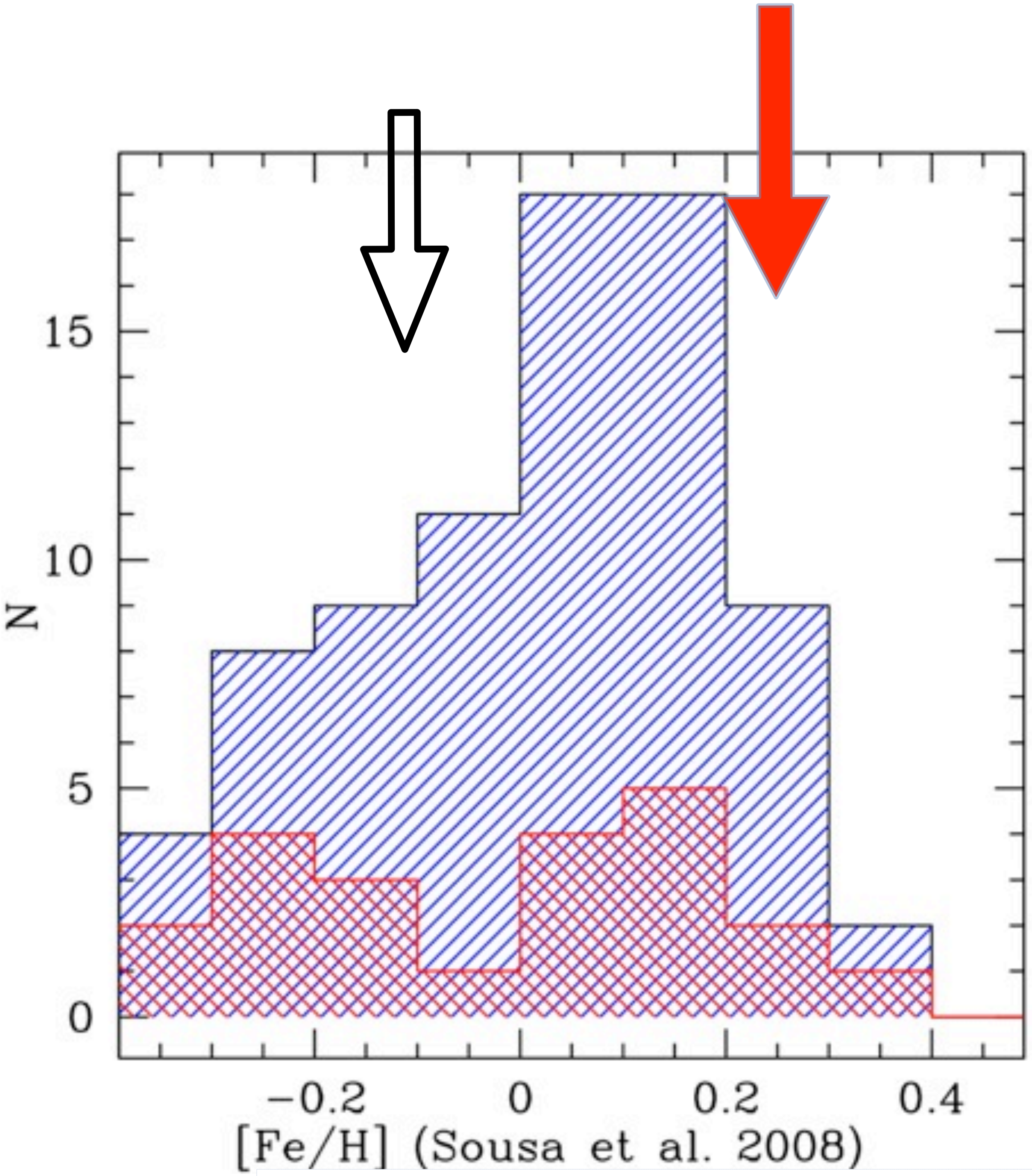
No host star metallicity correlation for low-mass planets ?

CORALIE giant planets

Comparison sample



HARPS low-mass planets



No host star metallicity correlation for low-mass planets ?

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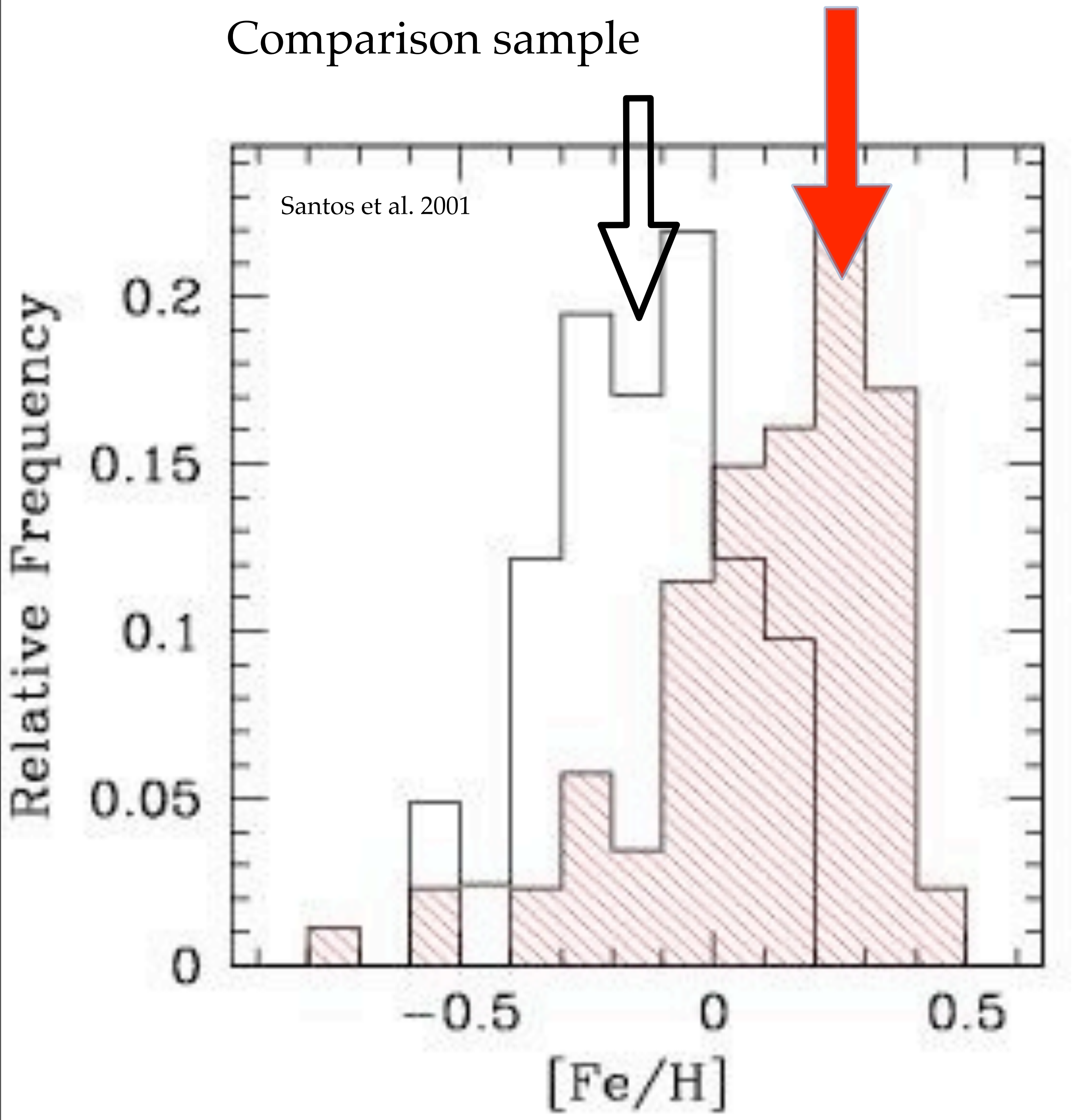
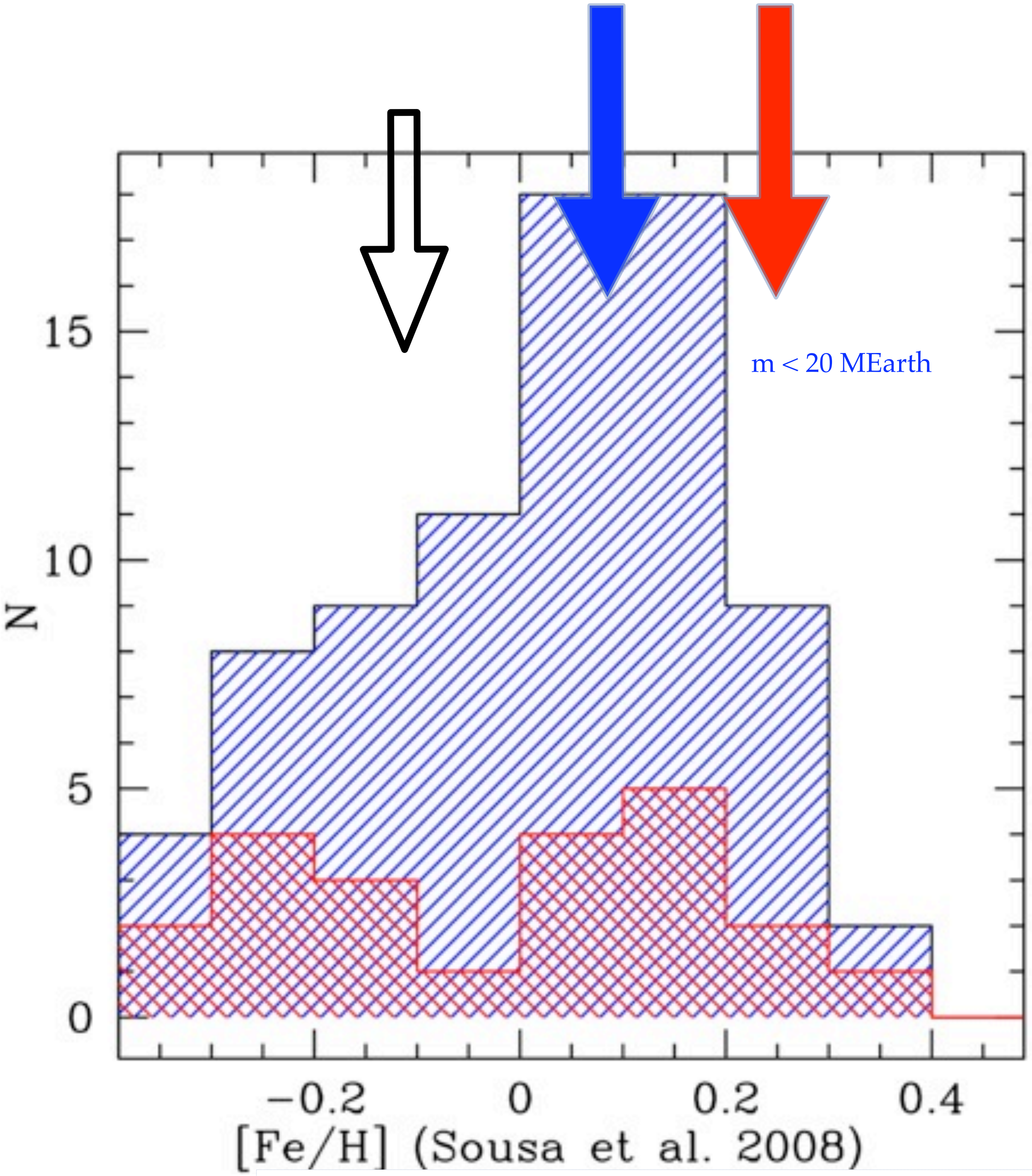


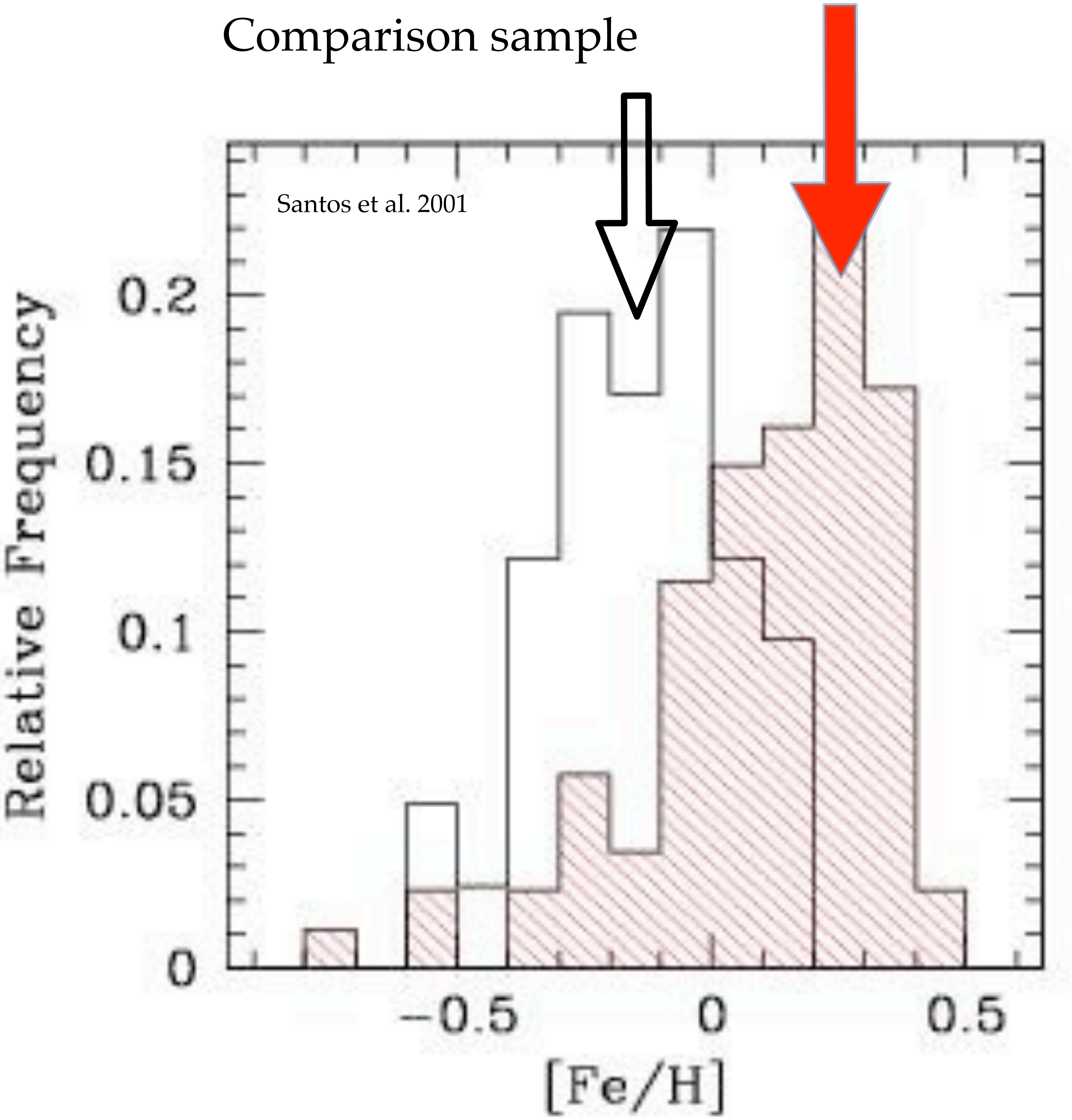
HARPS low-mass planets



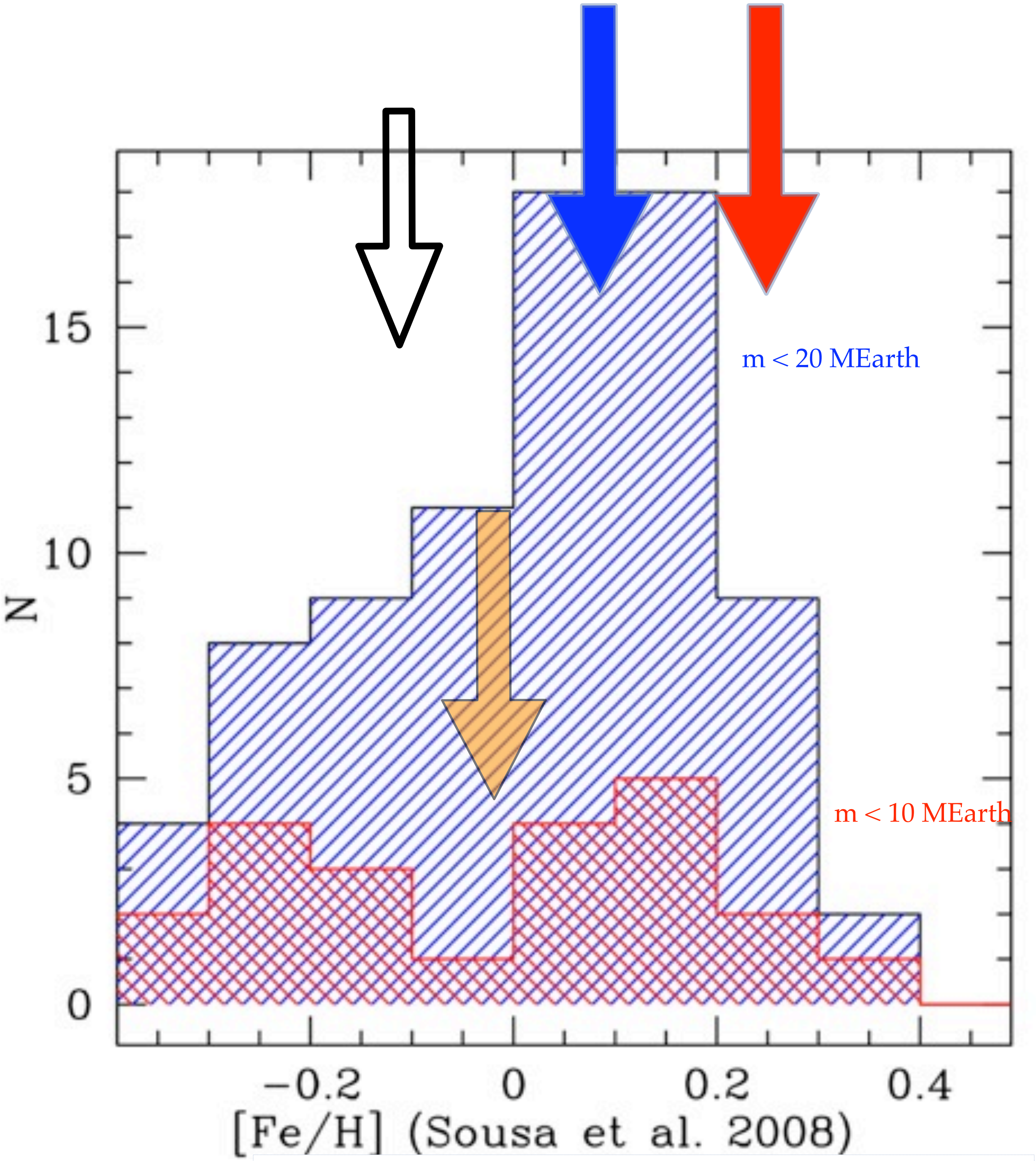
No host star metallicity correlation for low-mass planets ?

CORALIE giant planets

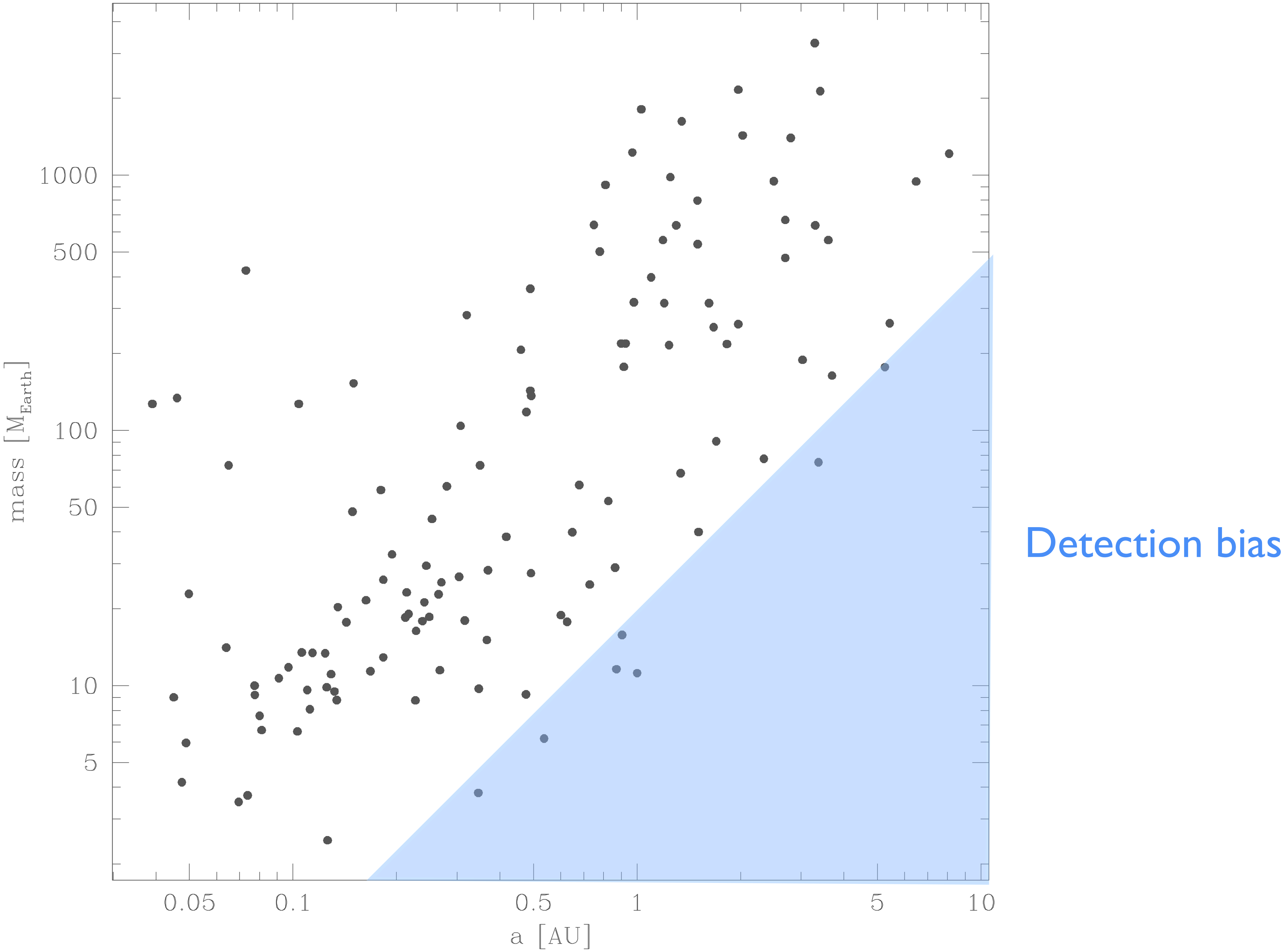
Comparison sample



HARPS low-mass planets



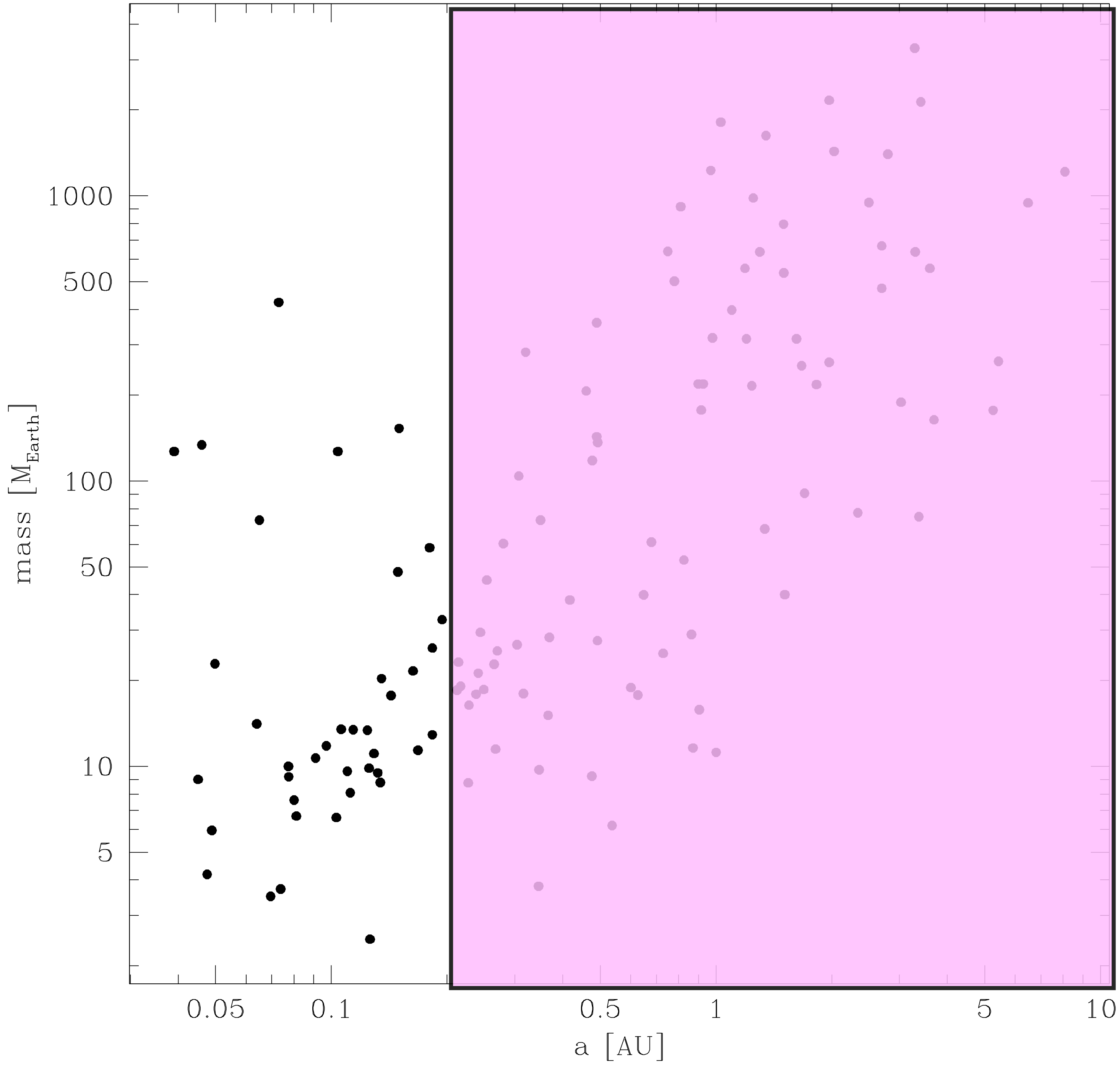
Observed (M2sini - a) distribution



HARPS survey : Preliminary results

Systematic search for planets in a sample of non-active stars .

S/N and integration time choosen to decrease photon noise and acoustic noise to a global error smaller than about 0.5 m/s



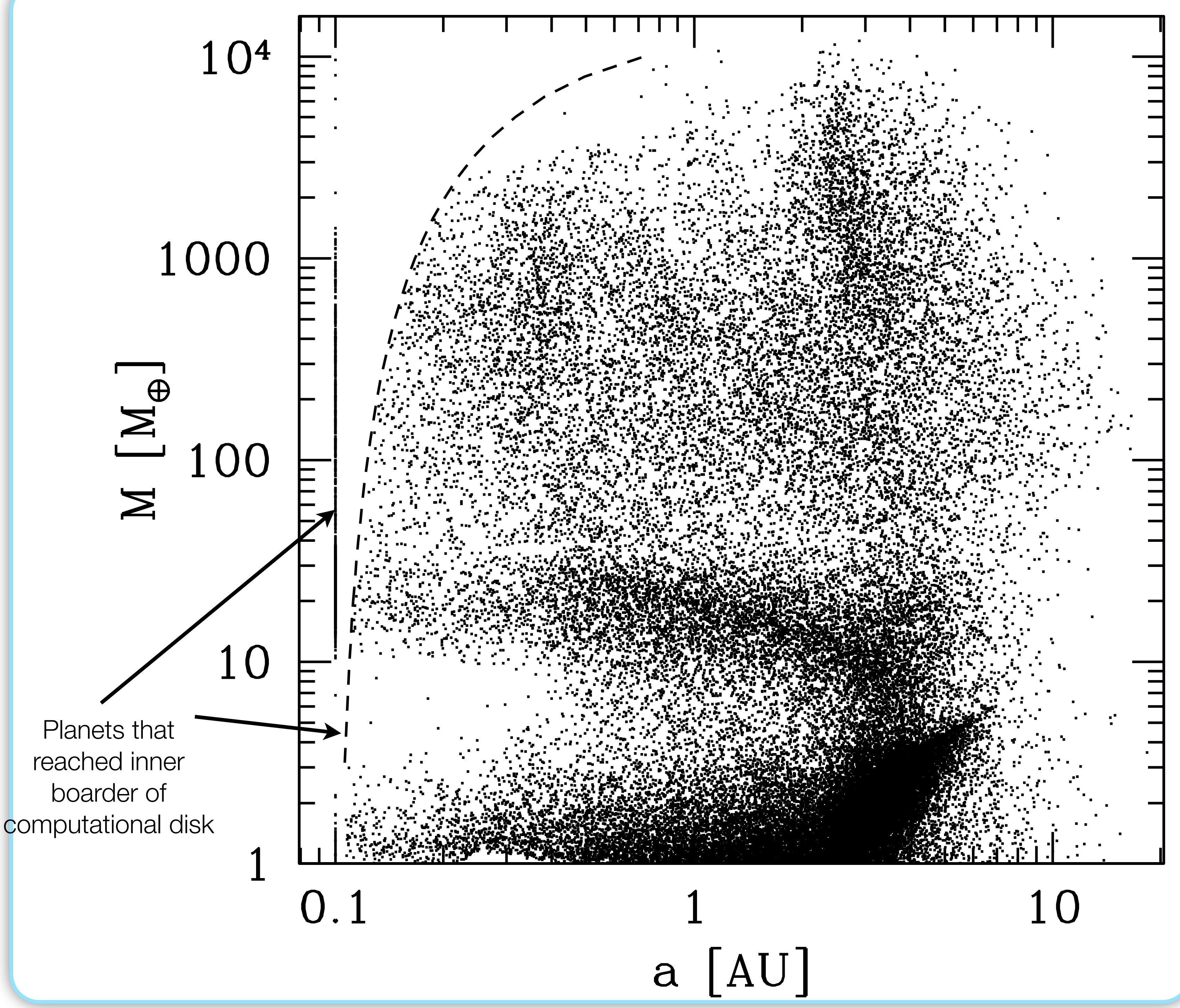
June 2009

HARPS survey : Preliminary M_2sini-a distribution

A not too biased view below 0.2 AU

Synthetic planet population

Nominal Model: alpha= 7×10^{-3}, $f_1=0.001$, $M=1\ M_\odot$

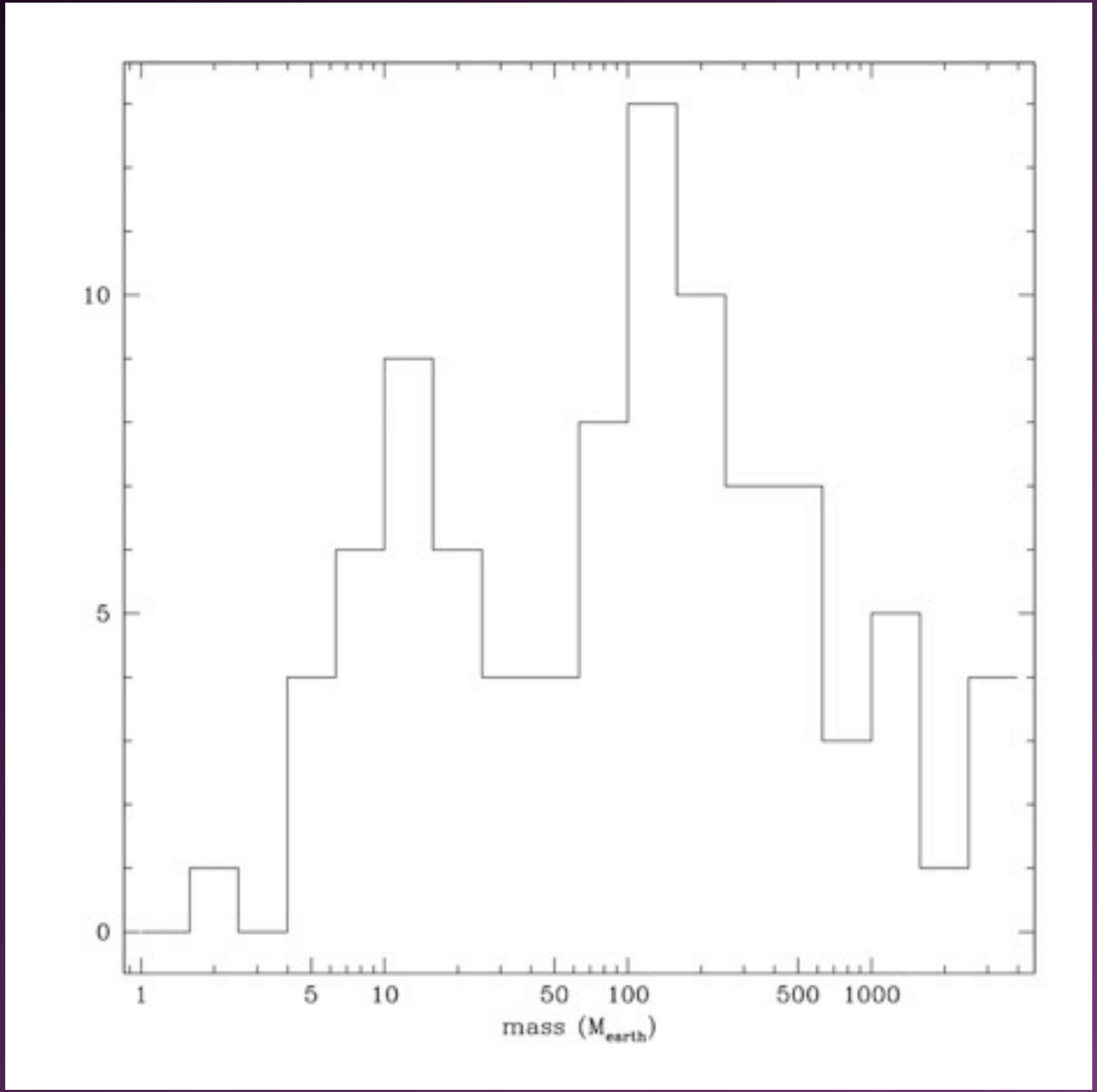


The variation of the initial conditions within the observed limits (protoplanetary disk properties) produces synthetic planets of a very large diversity.

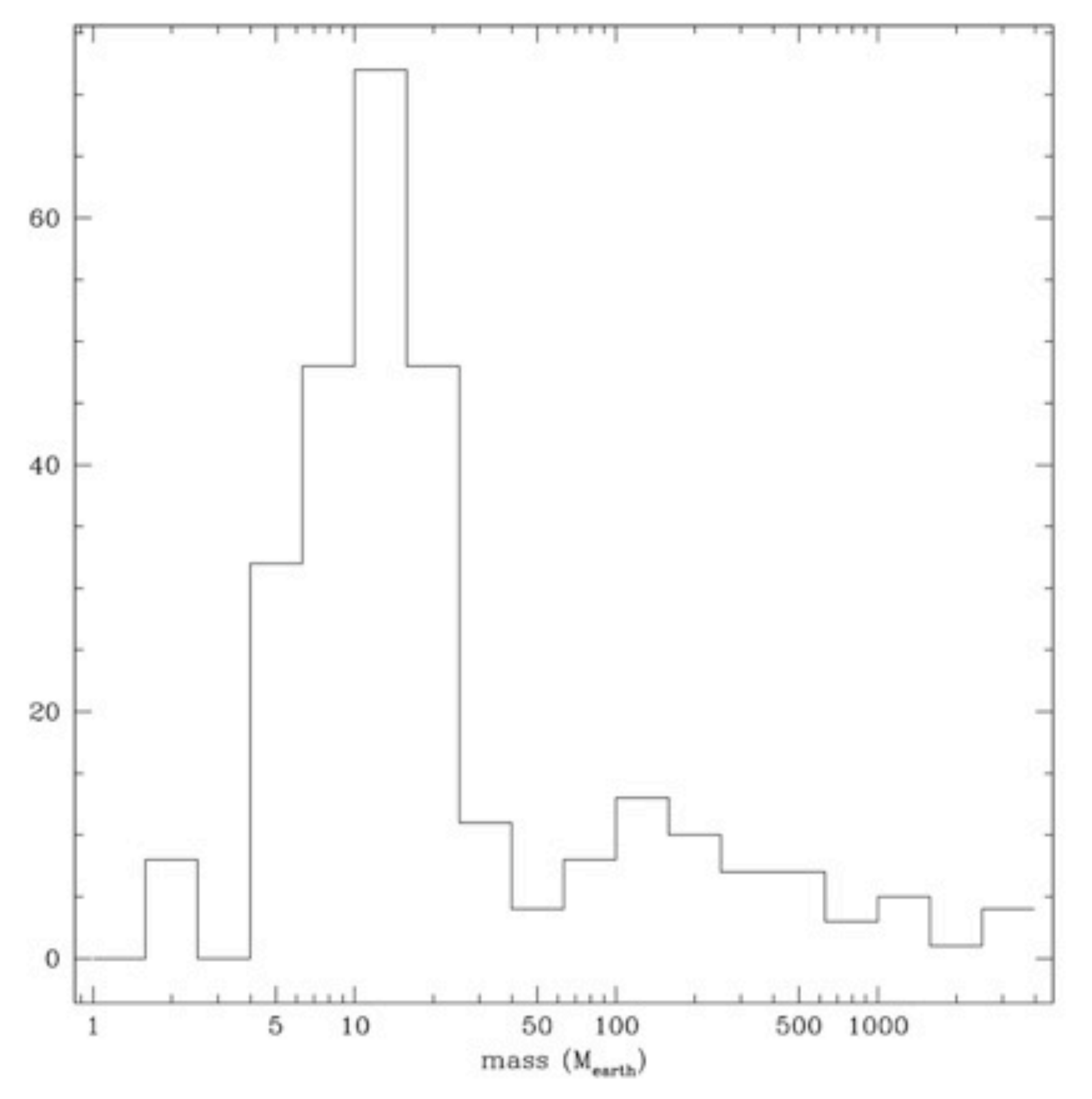
- Mass: More than four orders of magnitude
- Distance: More than two orders of magnitude.

Harps: exploration of small-mass domain

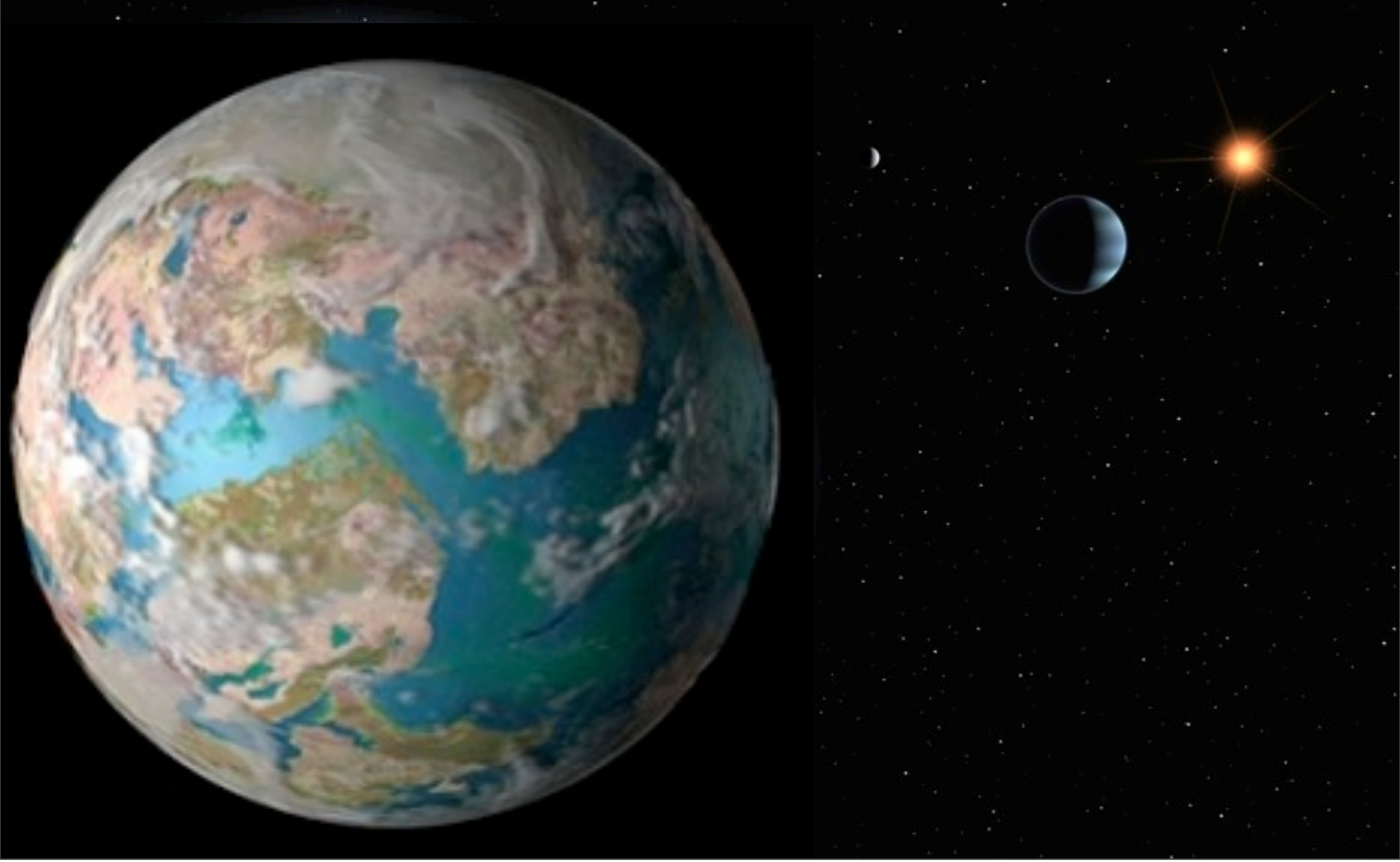
“Completeness”
(P<100 d)

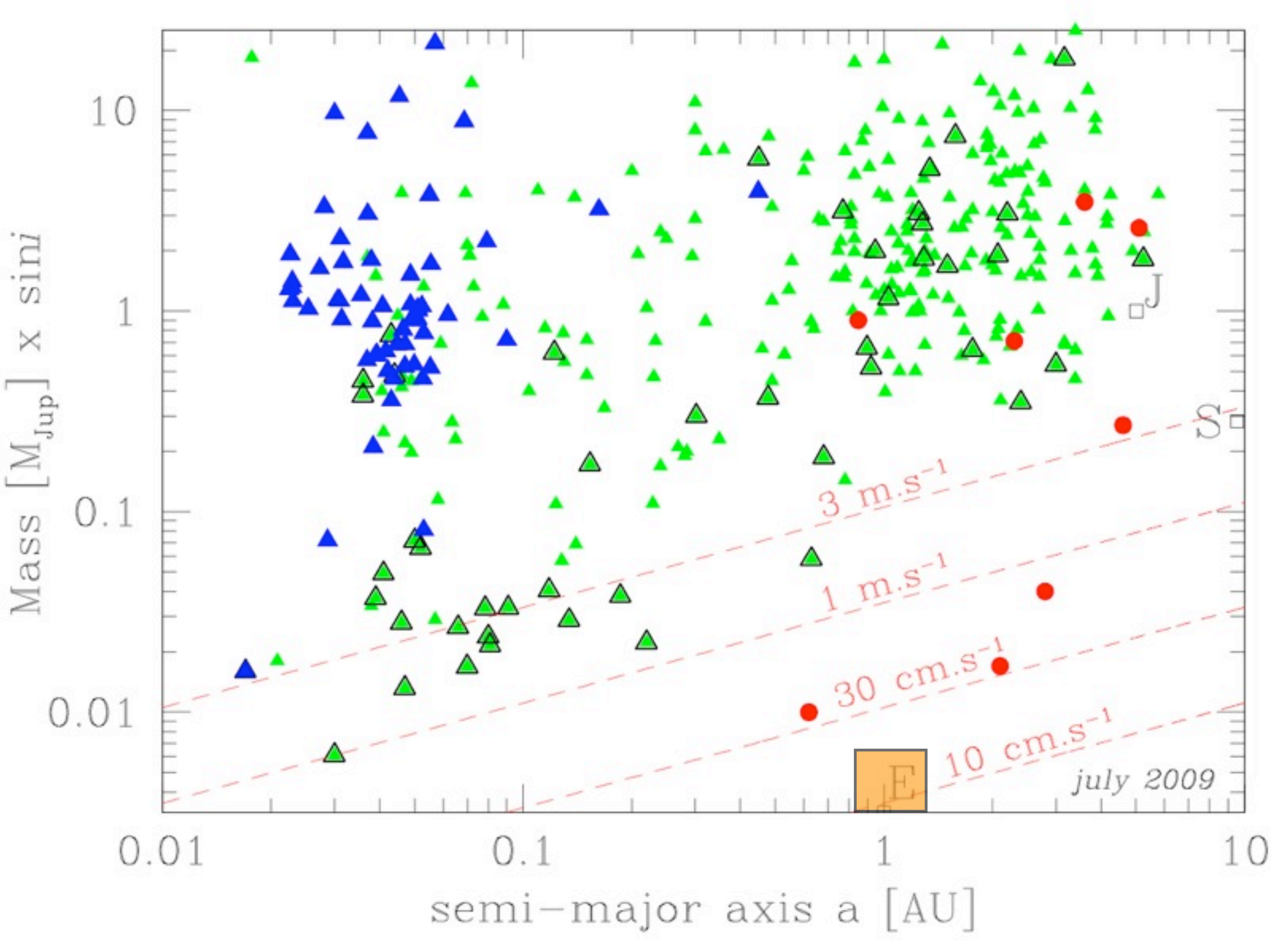


Normalization
(factor 8)

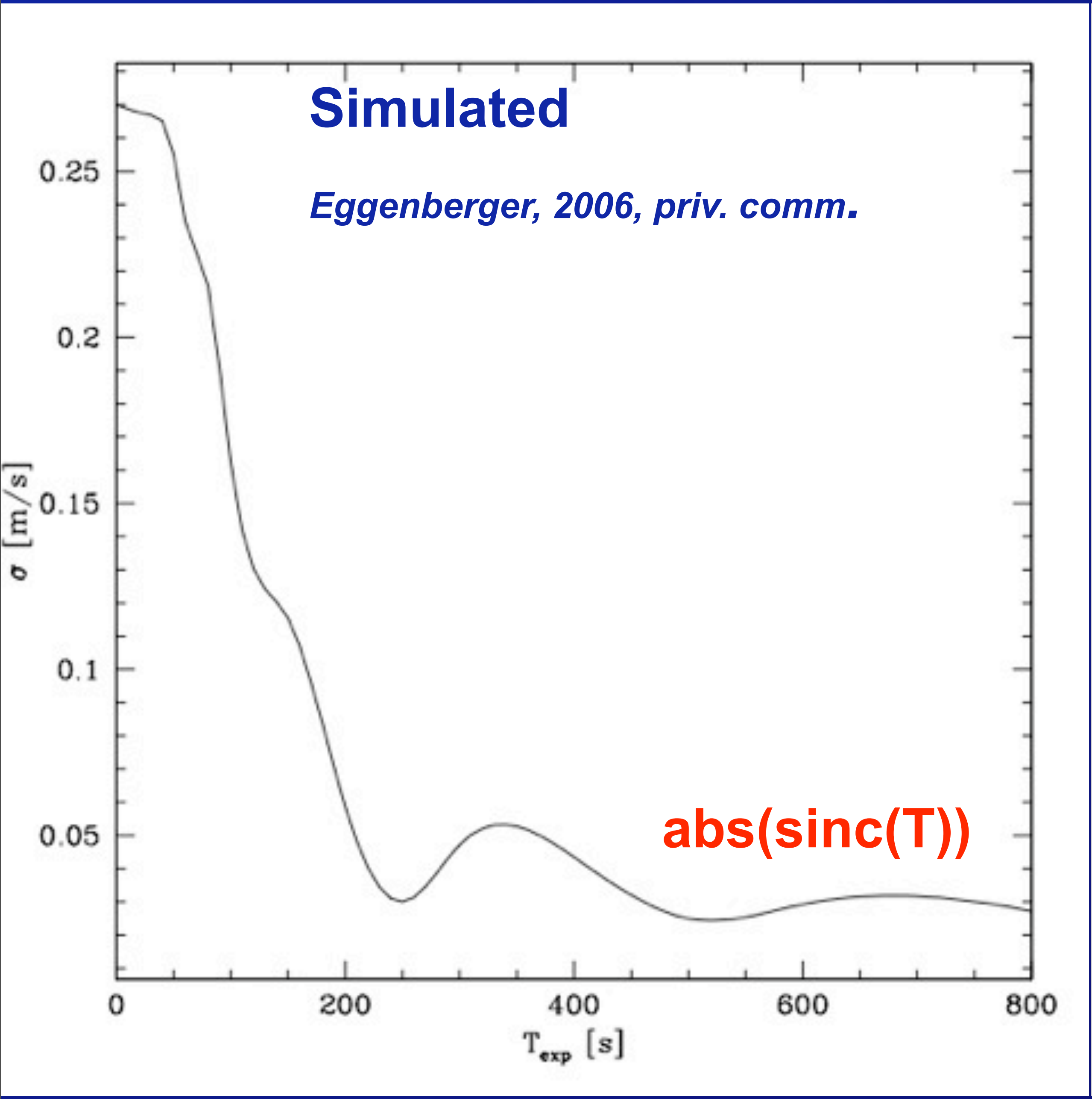


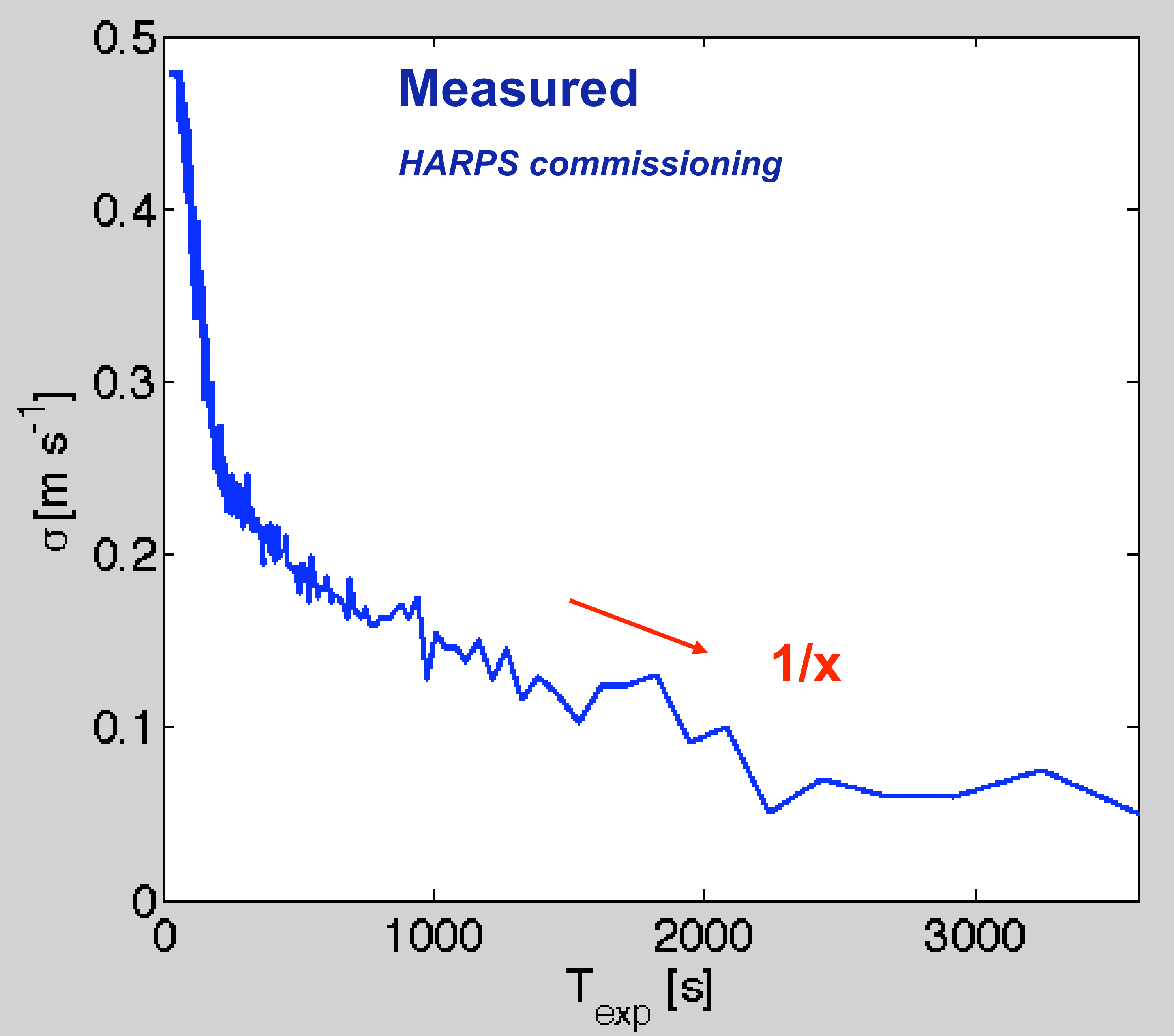
Detection of Earth twins in the HZ of solar-type stars ?




Mass [M_Jup] x sini
10
1
0.1
0.01
0.01
0.1
1
10
semi−major axis a [AU]
J
S
E
3 m.s-1
1 m.s-1
30 cm.s-1
10 cm.s-1
july 2009

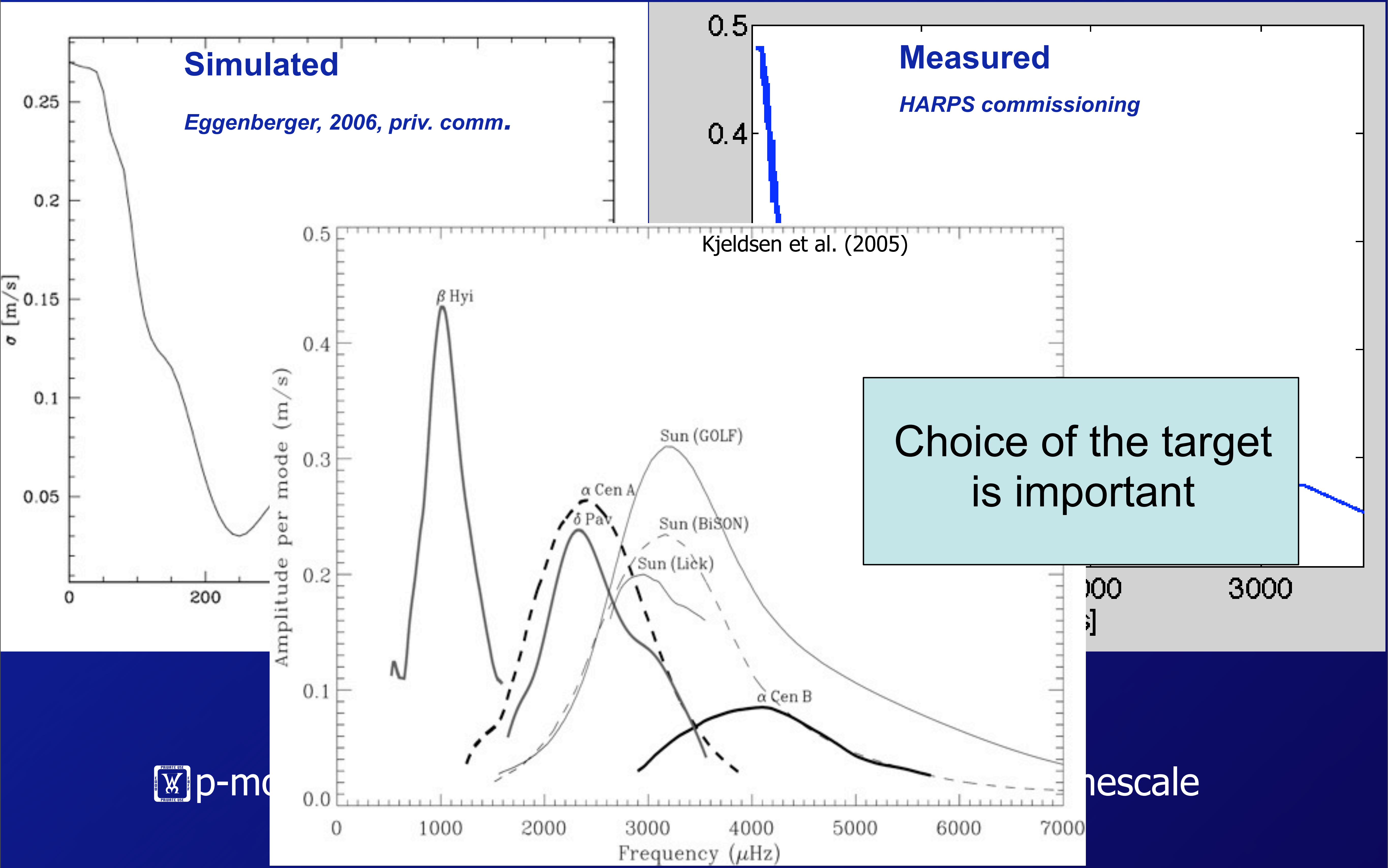
Pulsation noise on α Cen B and other stars





- p-modes average well on time > ~1 characteristic timescale

Pulsation noise on α Cen B and other stars



Simulated

Eggenberger, 2006, priv. comm.

Measured

HARPS commissioning

Kjeldsen et al. (2005)

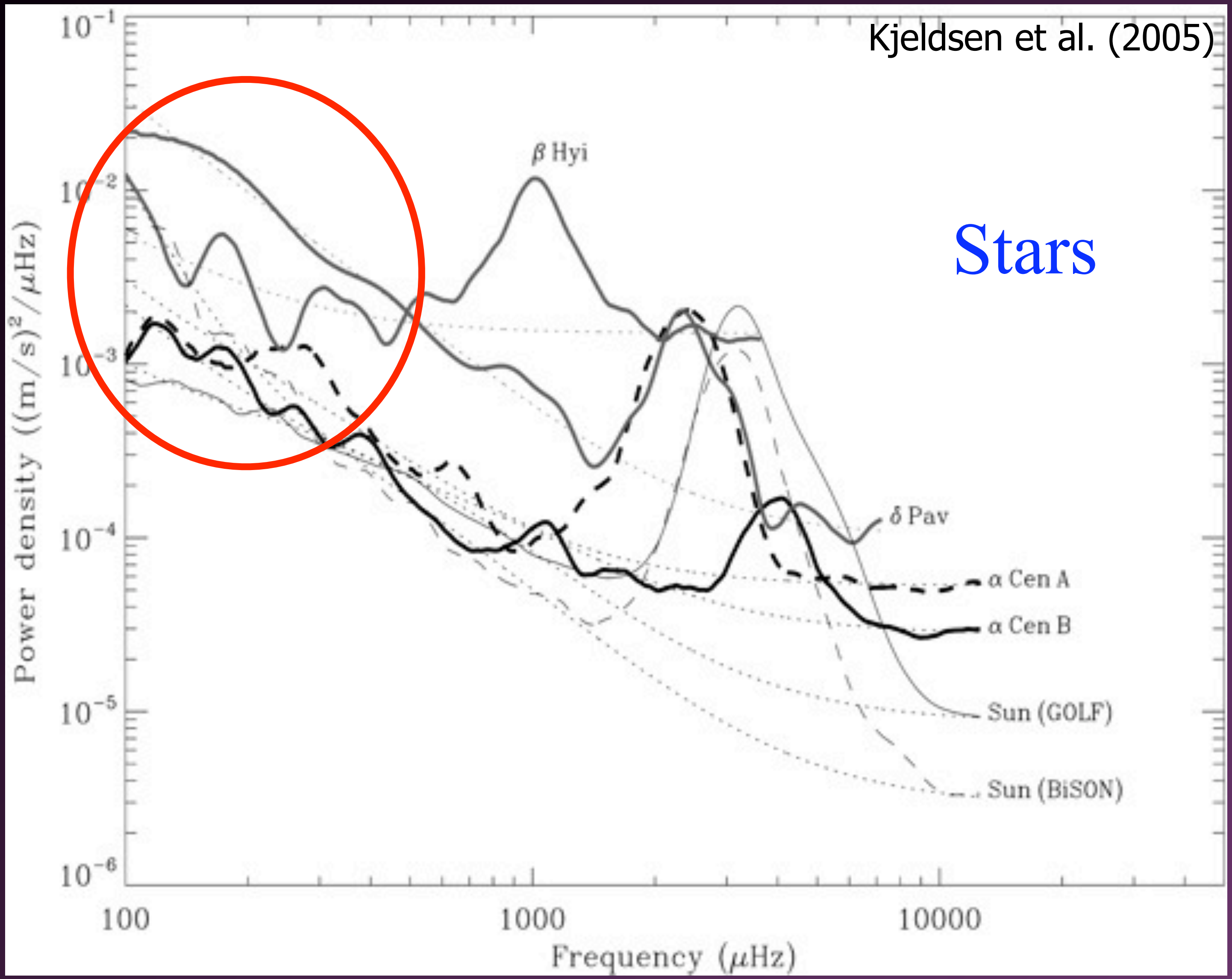
Choice of the target is important

p-m

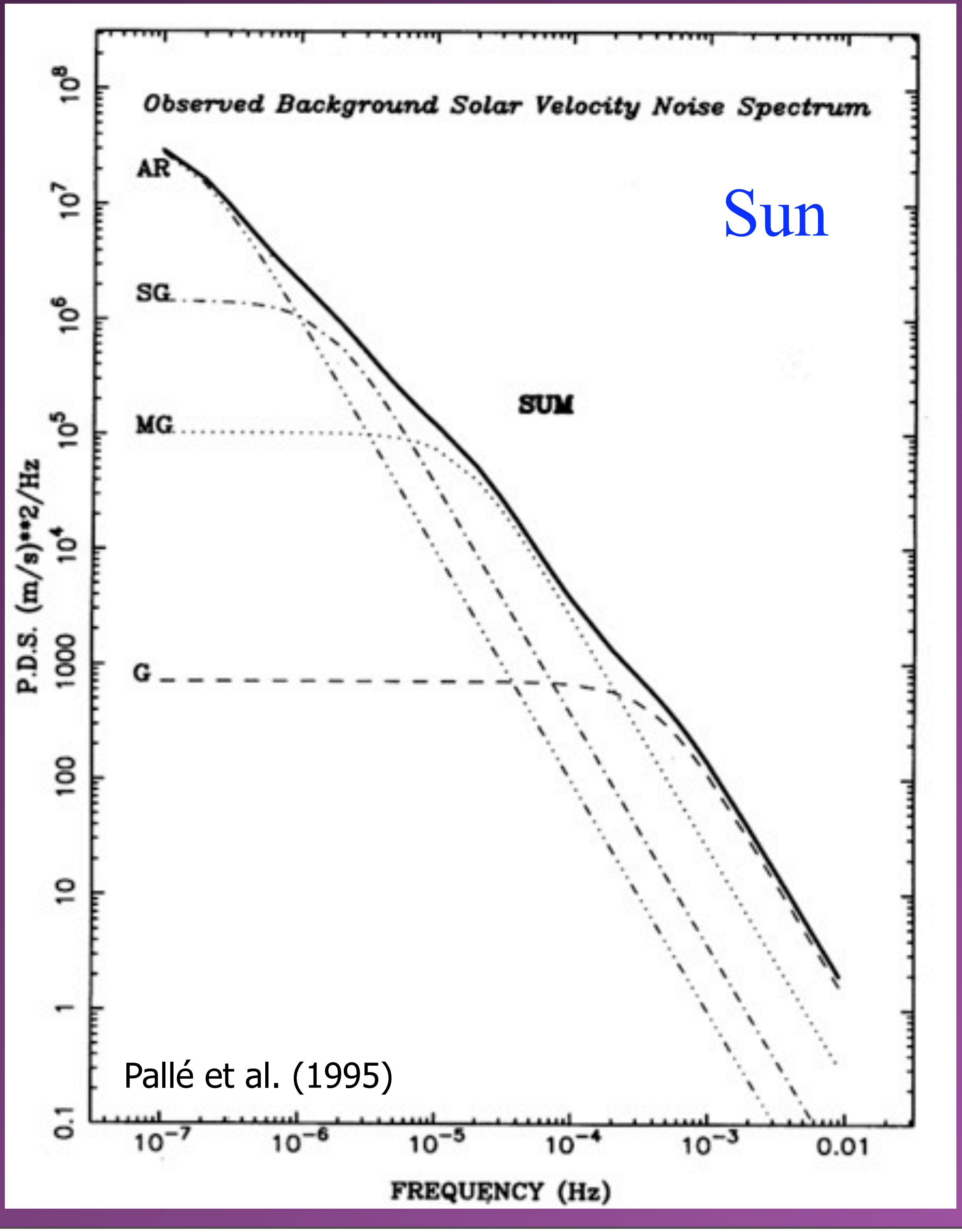
mescale

Granulation?

- Granulation (τ ~ 6 min)
- Mesogranulation (τ ~ 3h)
- Supergranulation (τ ~ 1 day)
- Active regions (τ ~ 10 days)



Kjeldsen et al. (2005)

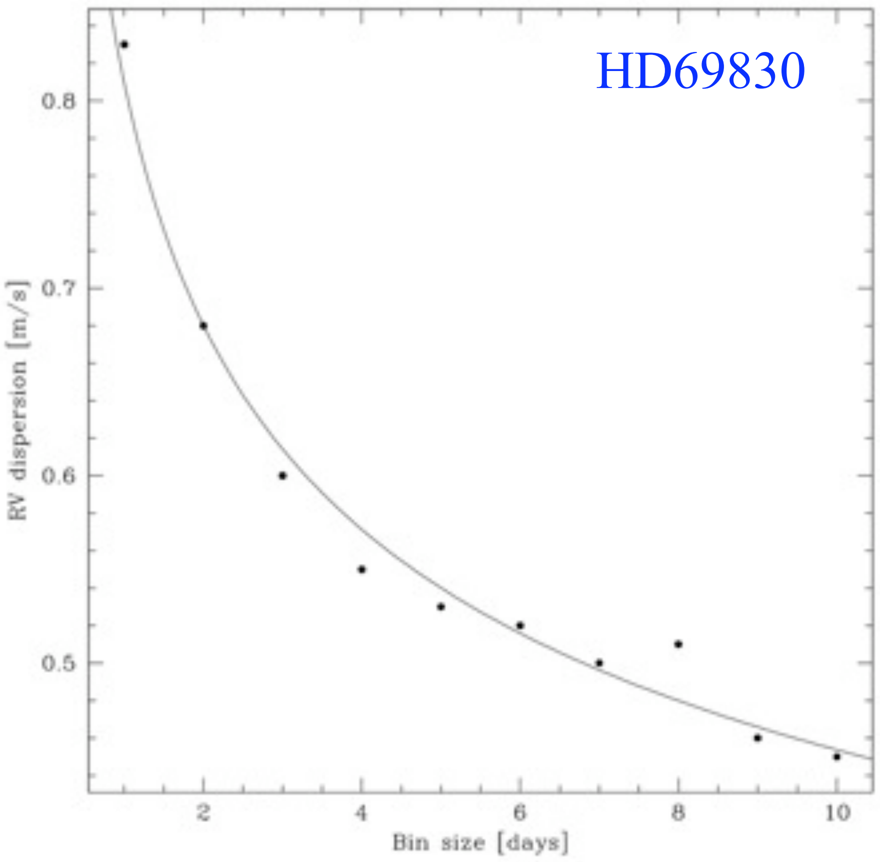


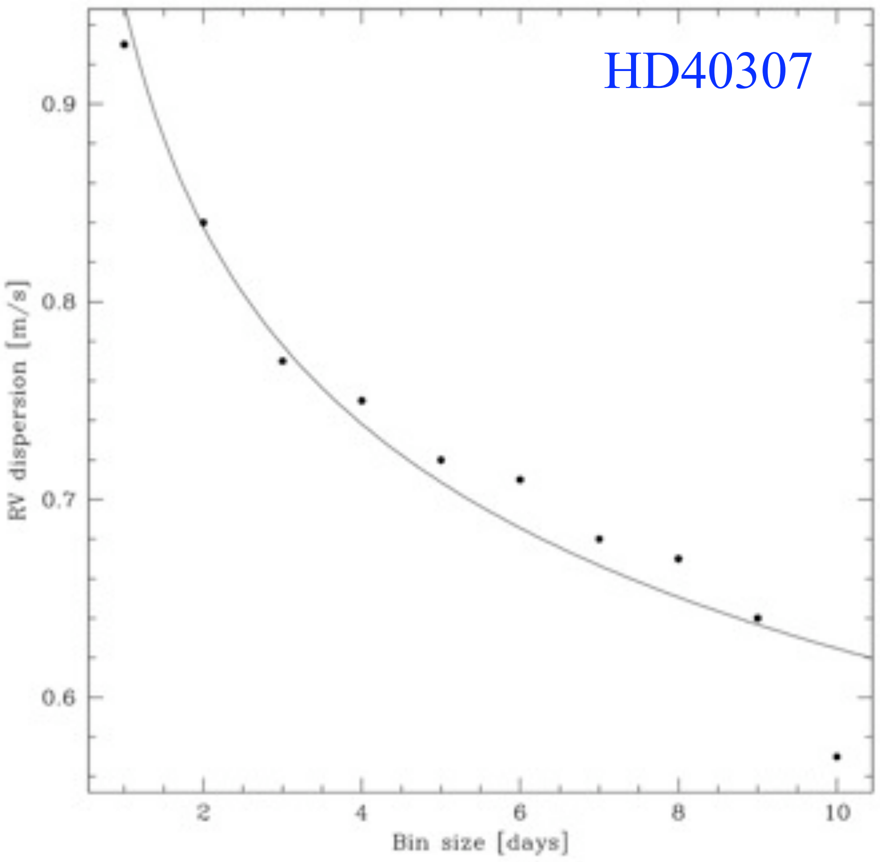
Pallé et al. (1995)

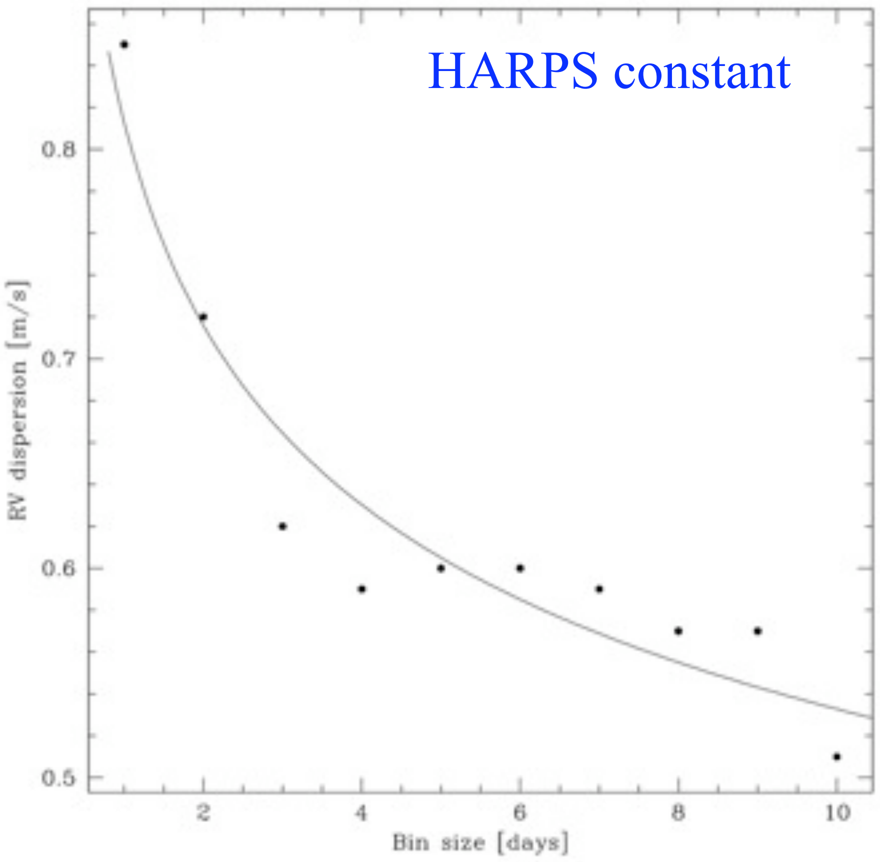
- Other sources of noise at lower frequencies
- requires simulations

Encouraging results....

Binning effect calculated on several HARPS stars

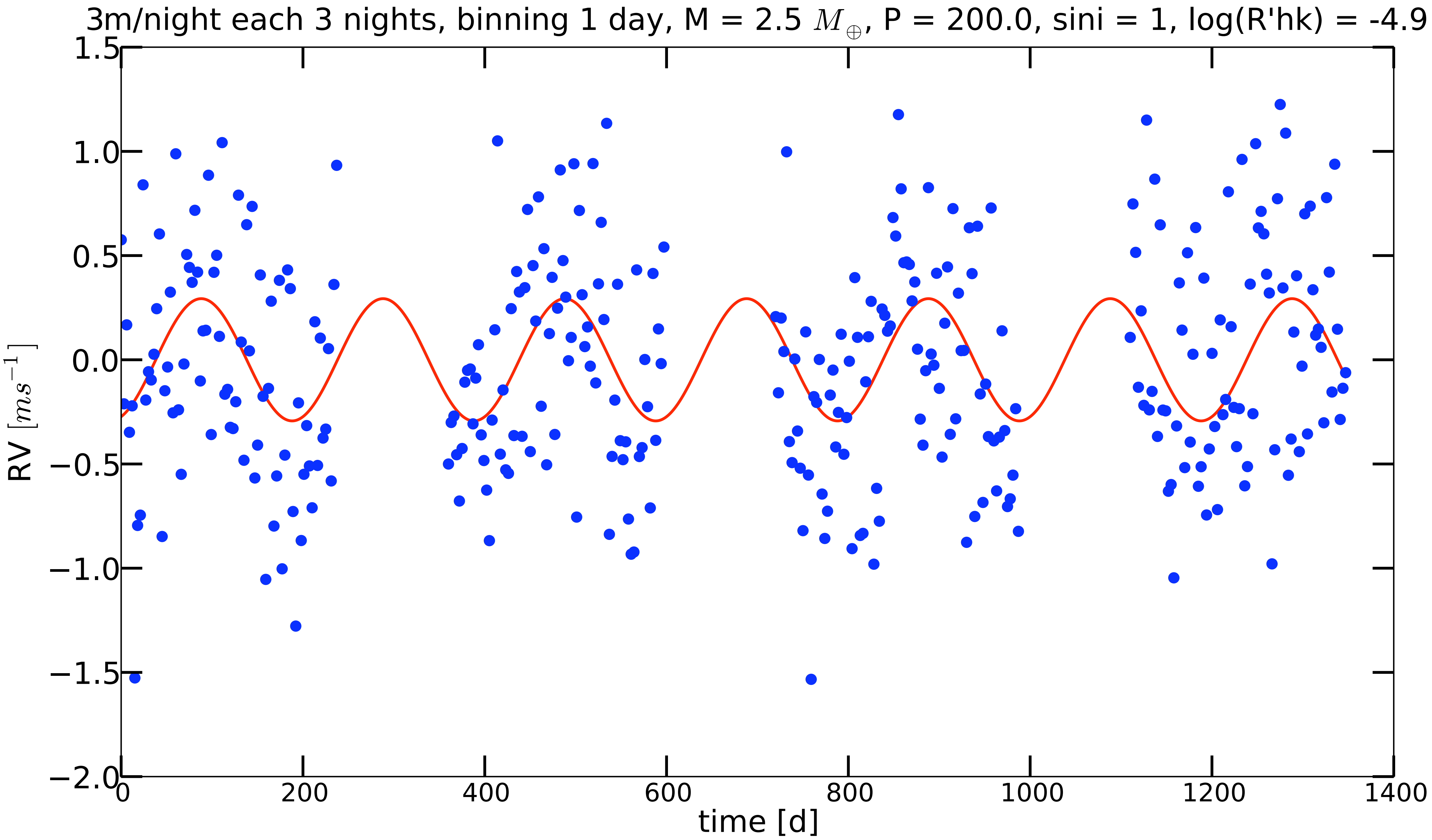




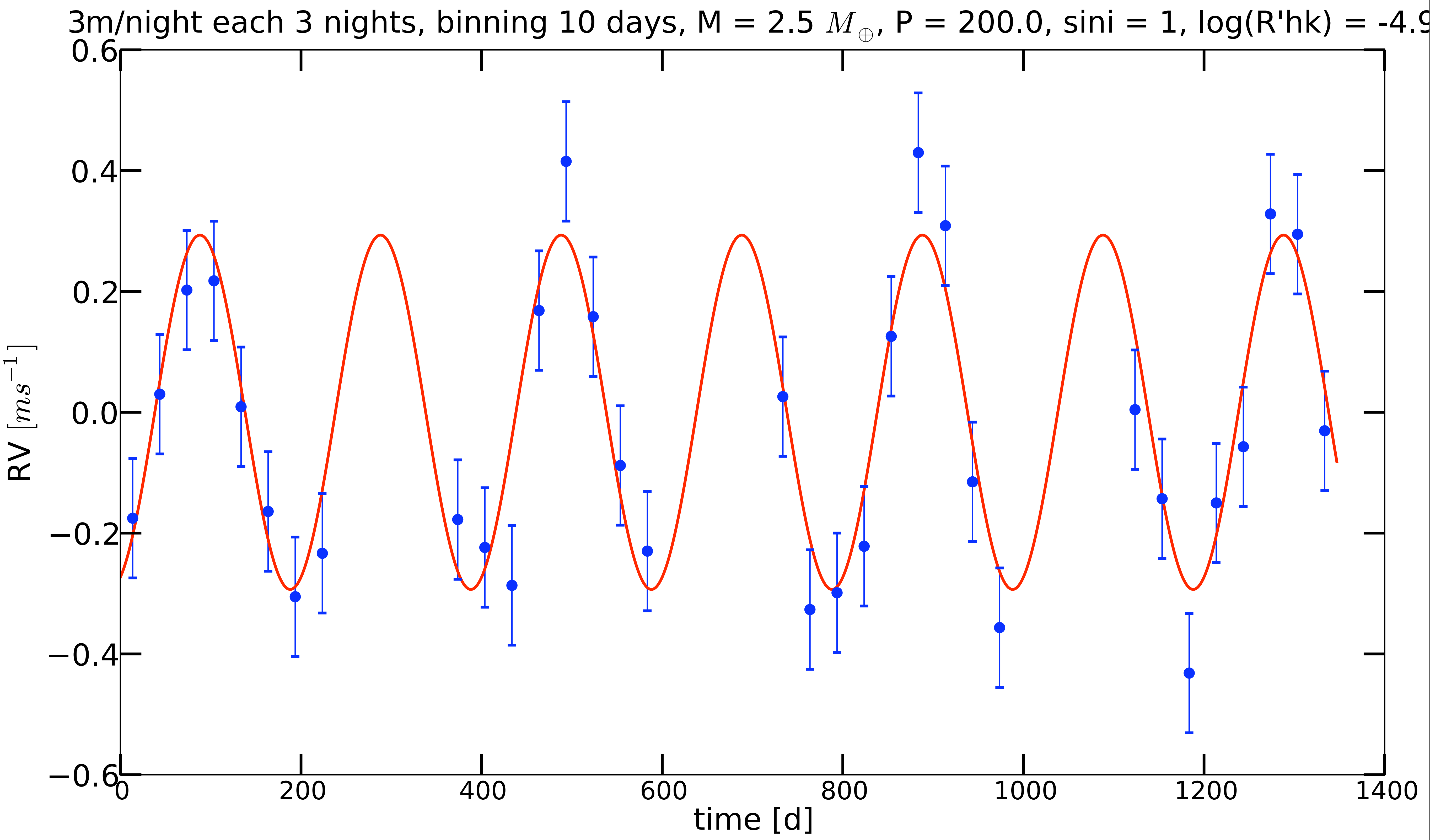


Warning: observation strategy not optimum + instrumental effect + photon noise

- only 1 observation per night
- sparse sampling (not every night)

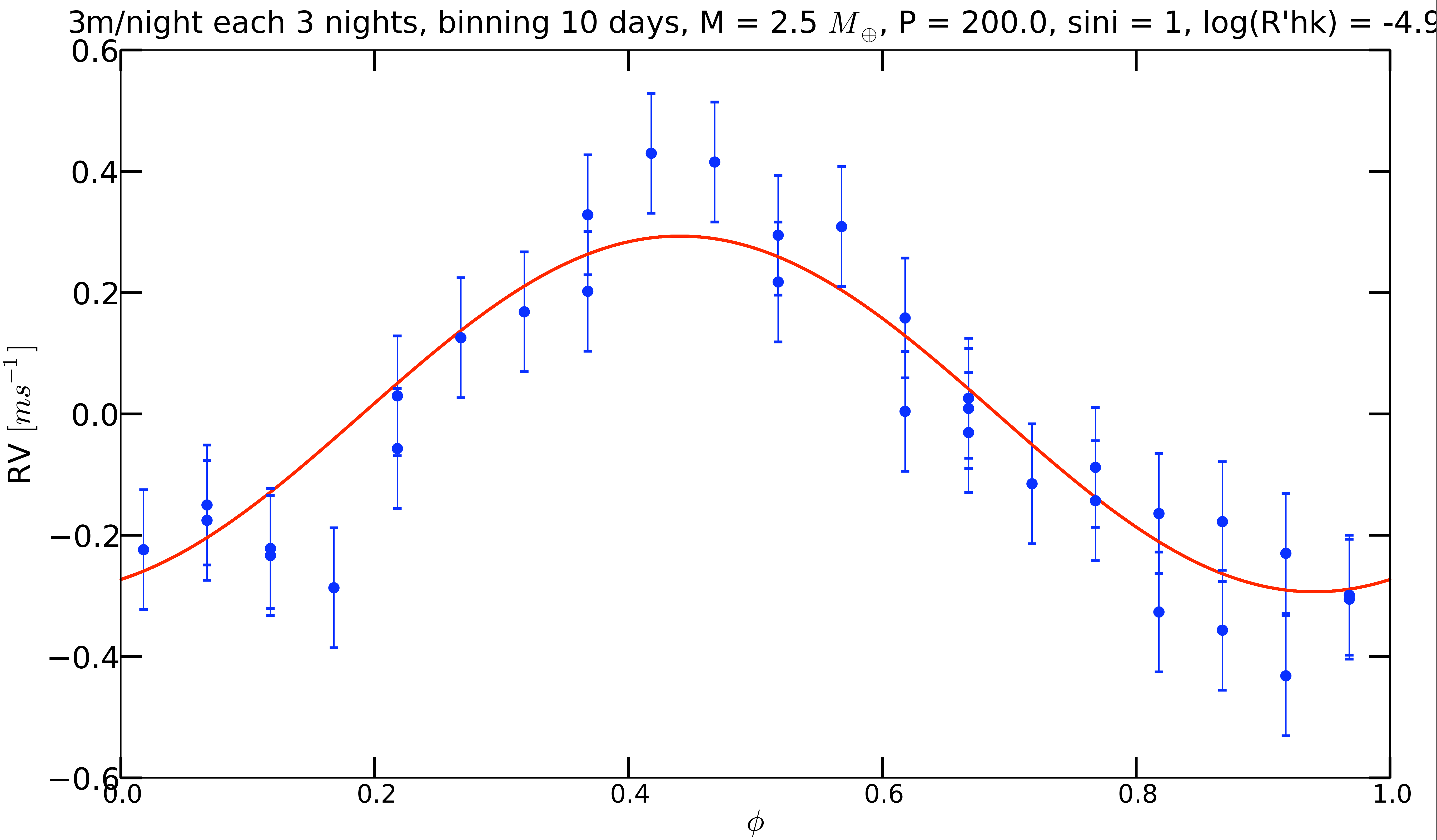


Dumusque et al. 2010



3m/night each 3 nights, binning 10 days, M = 2.5 $M_\oplus$, P = 200.0, sini = 1, log(R'hk) = -4.9

Dumusque et al. 2010



3m/night each 3 nights, binning 10 days, M = 2.5 $M_\oplus$, P = 200.0, sini = 1, log(R'hk) = -4.9

Dumusque et al. 2010

The HARPS Search for Southern Extra-Solar Planets

Search for Earth-analogs around nearby stars

PI: F. Pepe Cols: W. Benz, F. Bouchy, C. Lovis, M. Mayor, D. Queloz, N. C. Santos, S. Udry

Sample

10 nearby, quiet, non-rotating, stars

Goal

Find a planet similar to the Earth in m and P

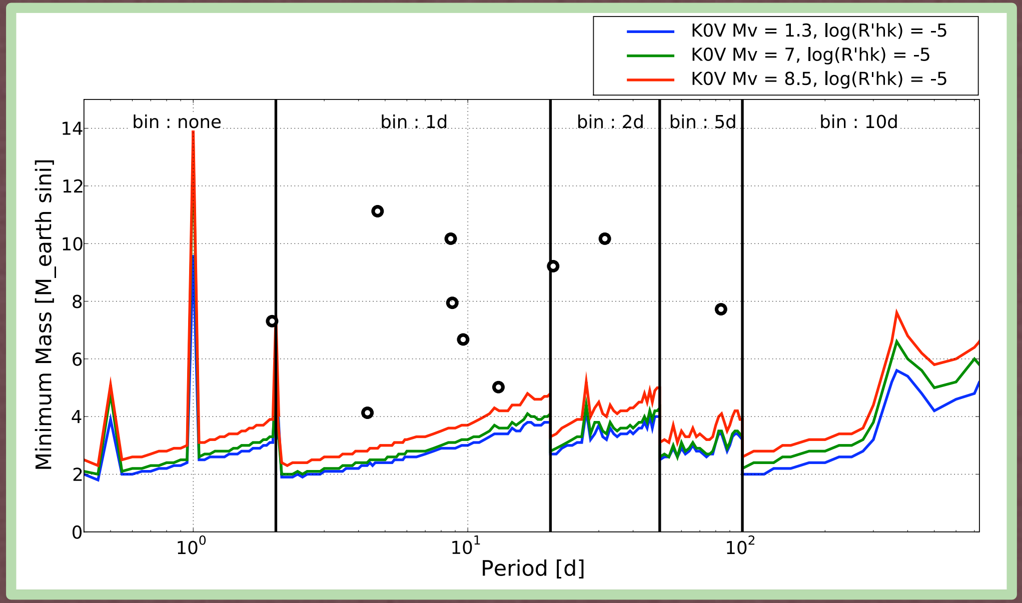
Strategy

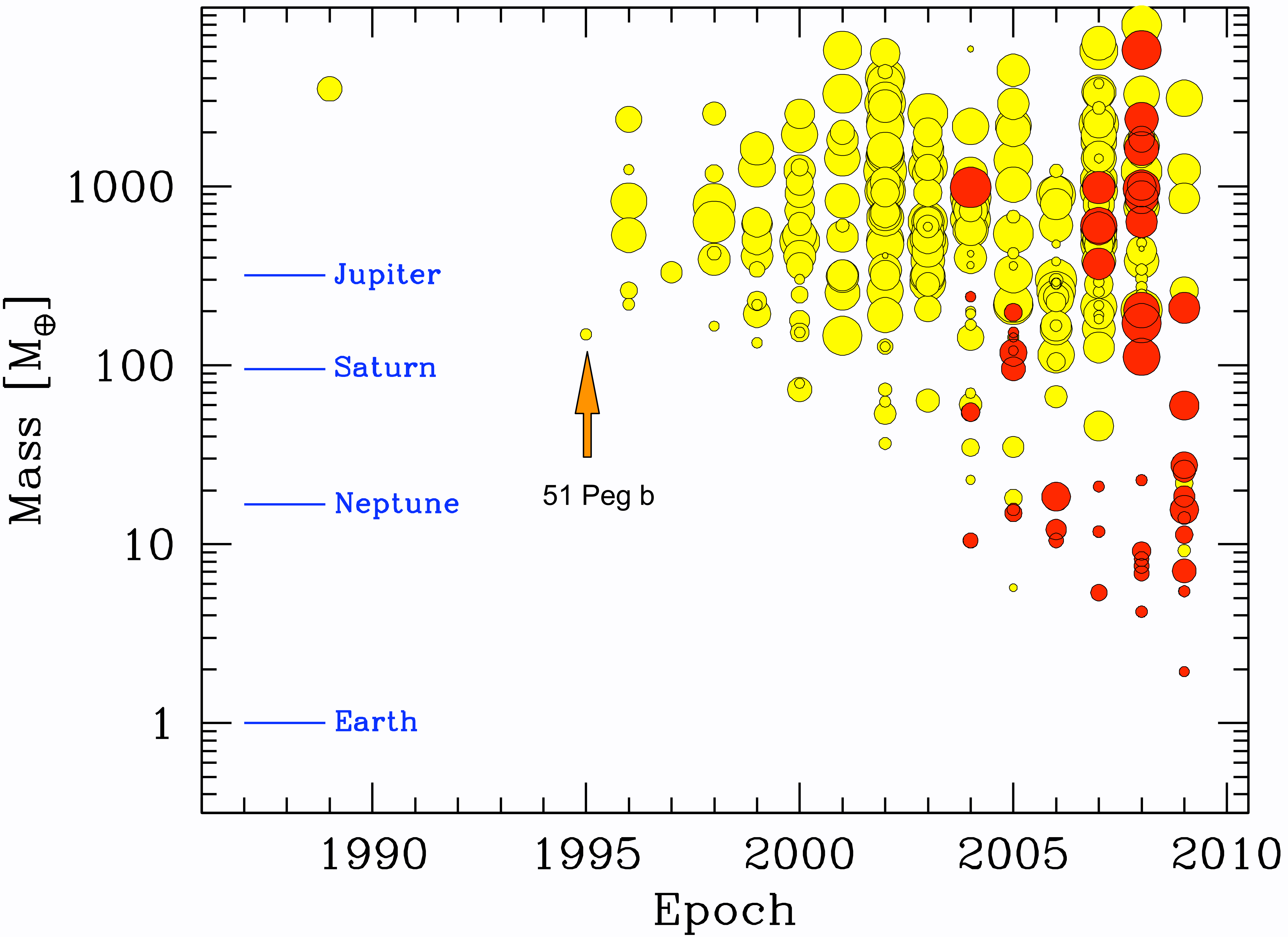
- Observe with high time sampling (3x per night) and long exposures (15 min.) to average oscillations and granulation
- Obtain at least 50 data points per season
- Observe at least 2 - 3 seasons

High expected and measured frequency of low-mass planets

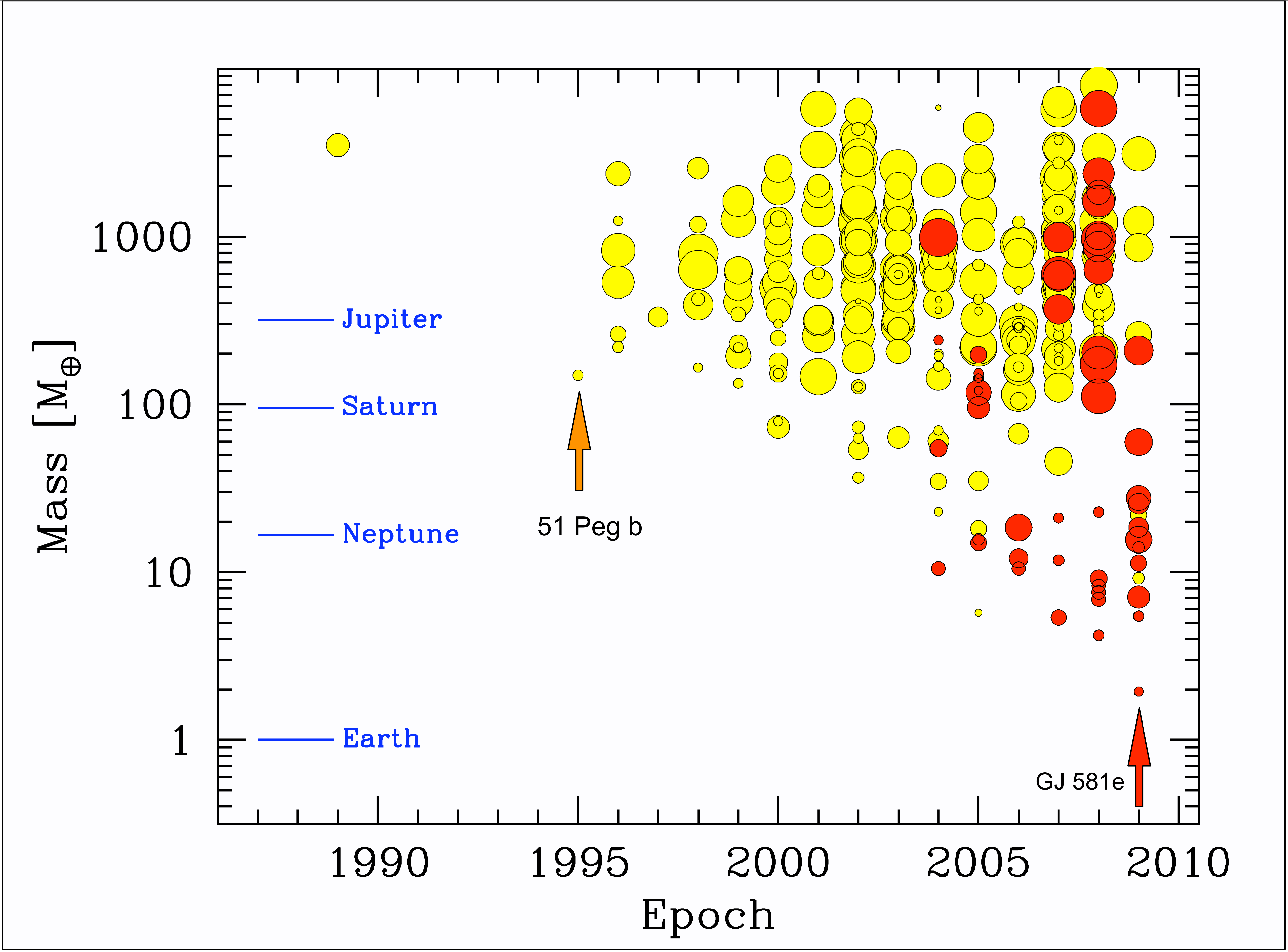
Detectability

Detectable minimum planetary mass assuming $\epsilon = 0$ and aiming at K/rms > 2.5 (for varying stellar magnitude and activity):





Planet discovered by Doppler spectroscopy



Planet discovered by Doppler spectroscopy