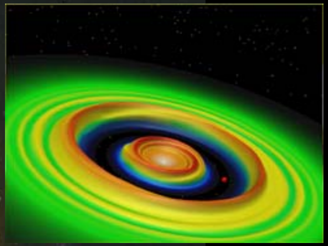
Actuality of Exoplanets Search



François Bouchy
OHP - IAP

How detect extrasolar planets ?

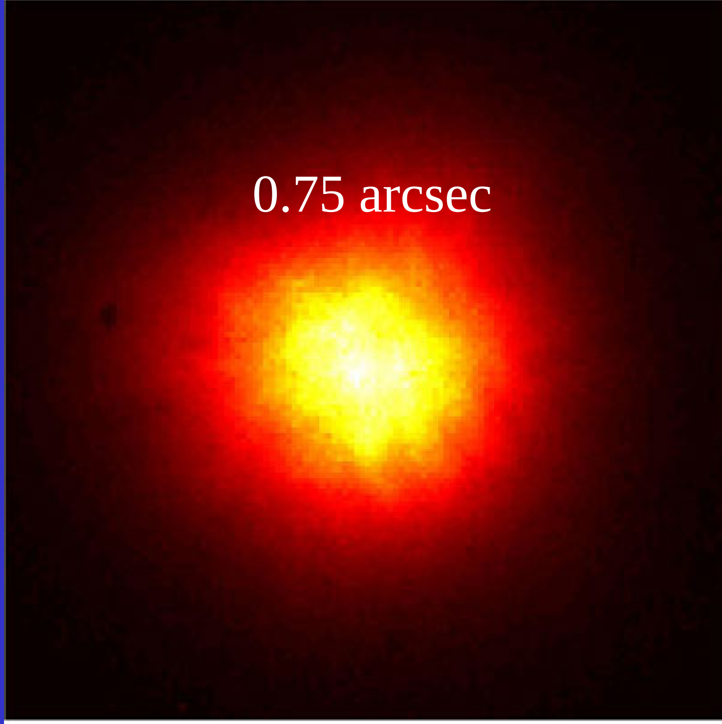
Two main difficulties :

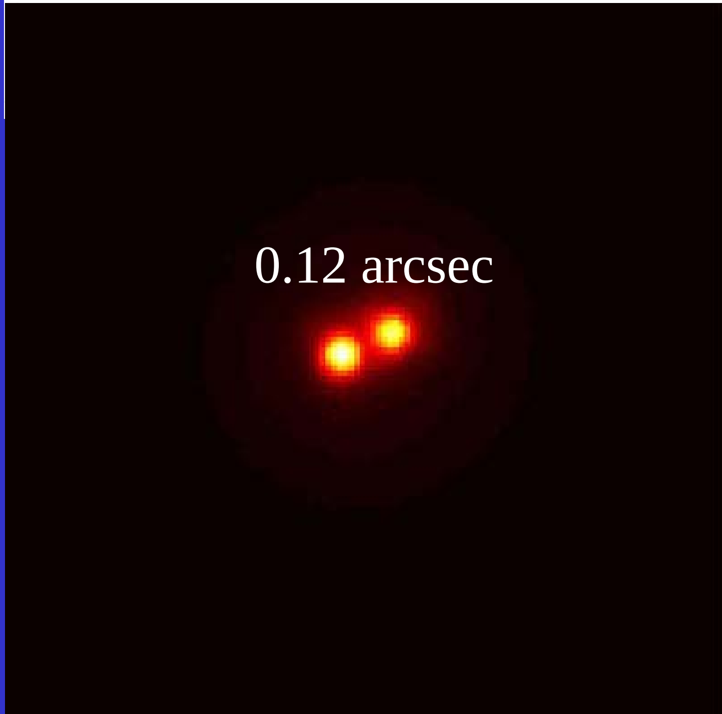
1 – A tiny angular separation

Sun – Jupiter at 4 light years
→ 4”

Sun – Jupiter at 100 light years
→ 0.15”

Sun – Earth at 100 light years
→ 0.03”





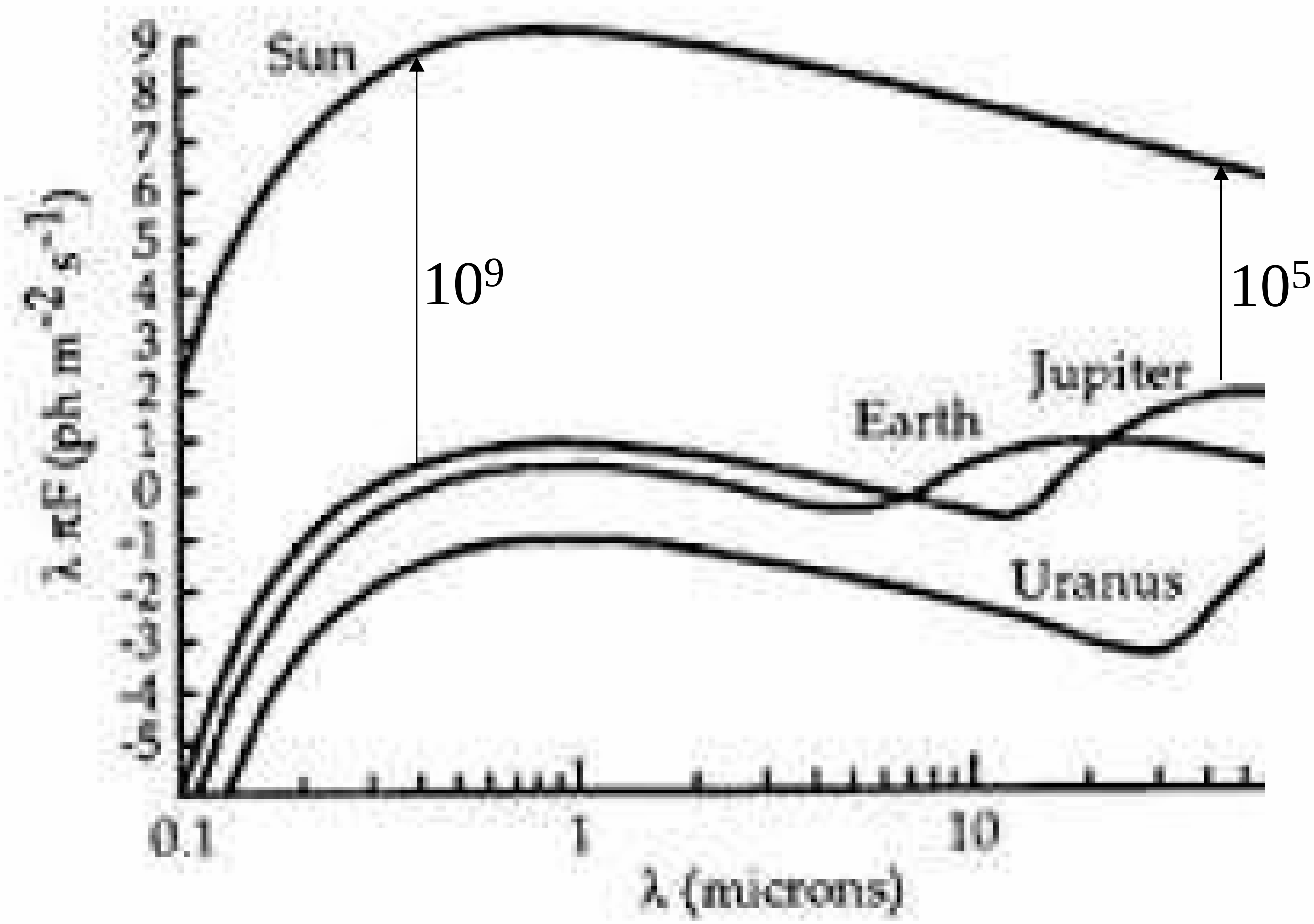
How detect extrasolar planets ?

Two main difficulties :

1 – A tiny angular separation

2 – A huge contrast in luminosity

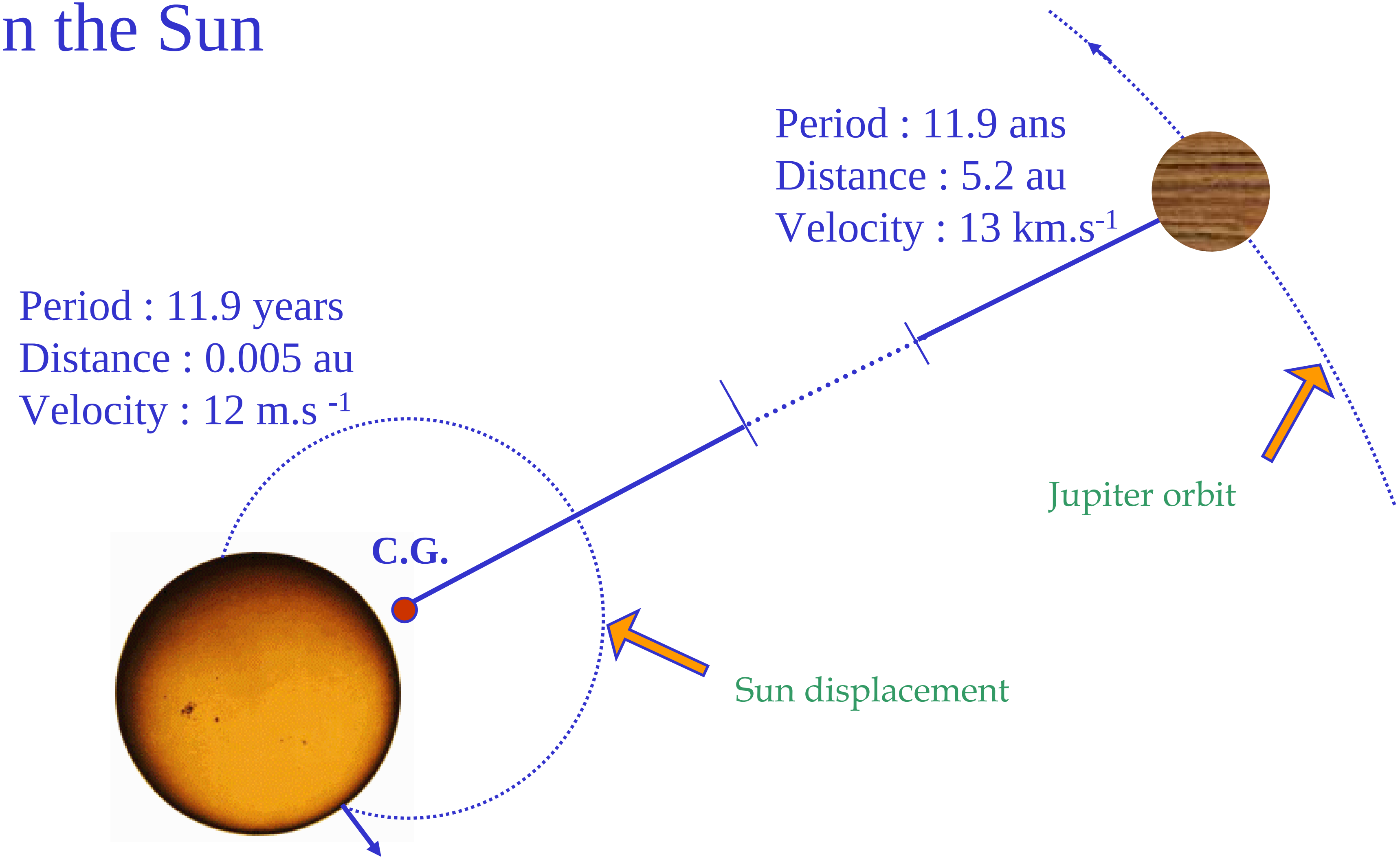

The star is up to 1 billion times
brighter than the planet



$$F_p/F_{star} \sim (R_p/a)^2$$

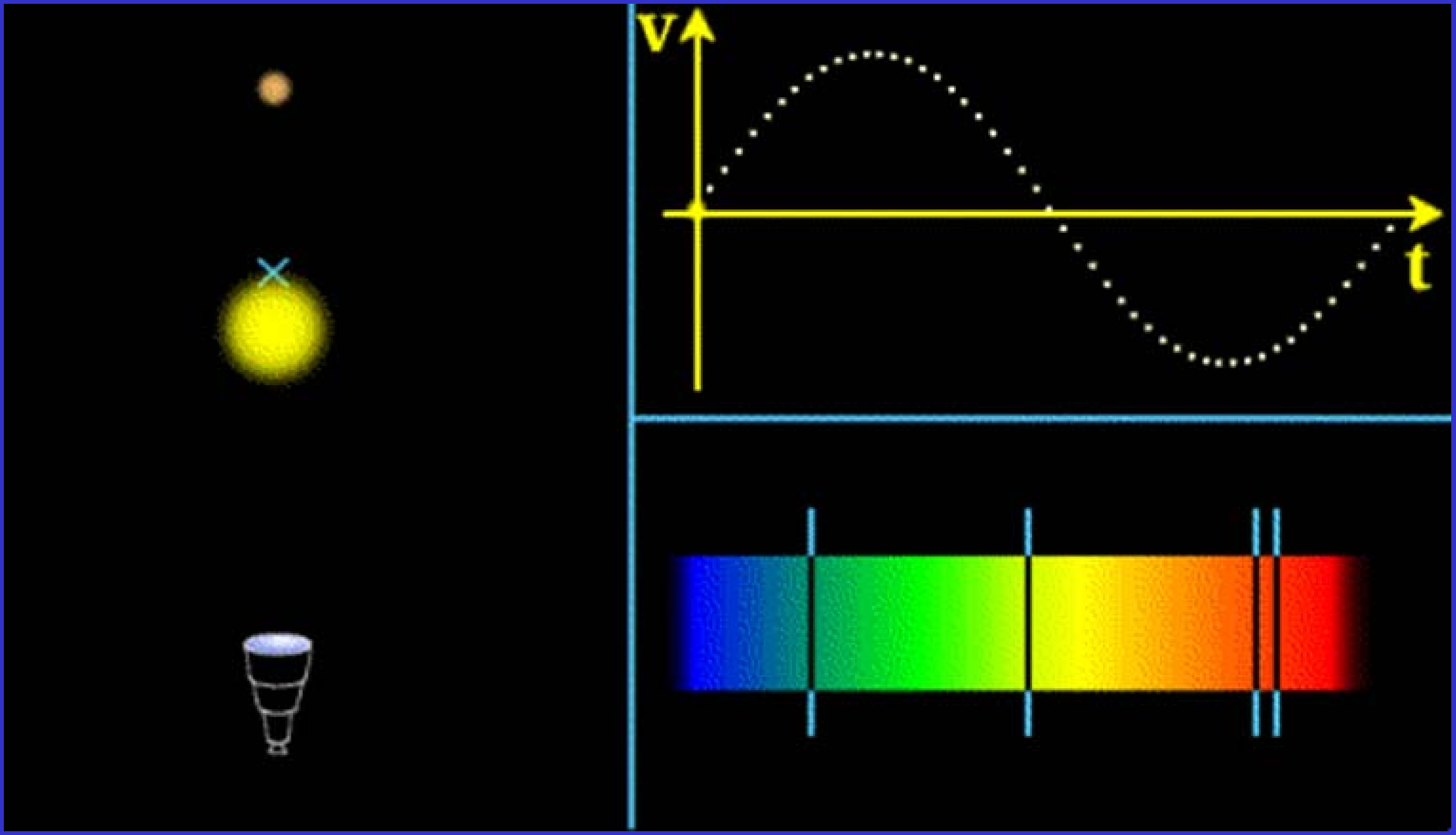
One solution : detect the dynamical perturbation induced of the star

Dynamical pertubation of Jupiter on the Sun

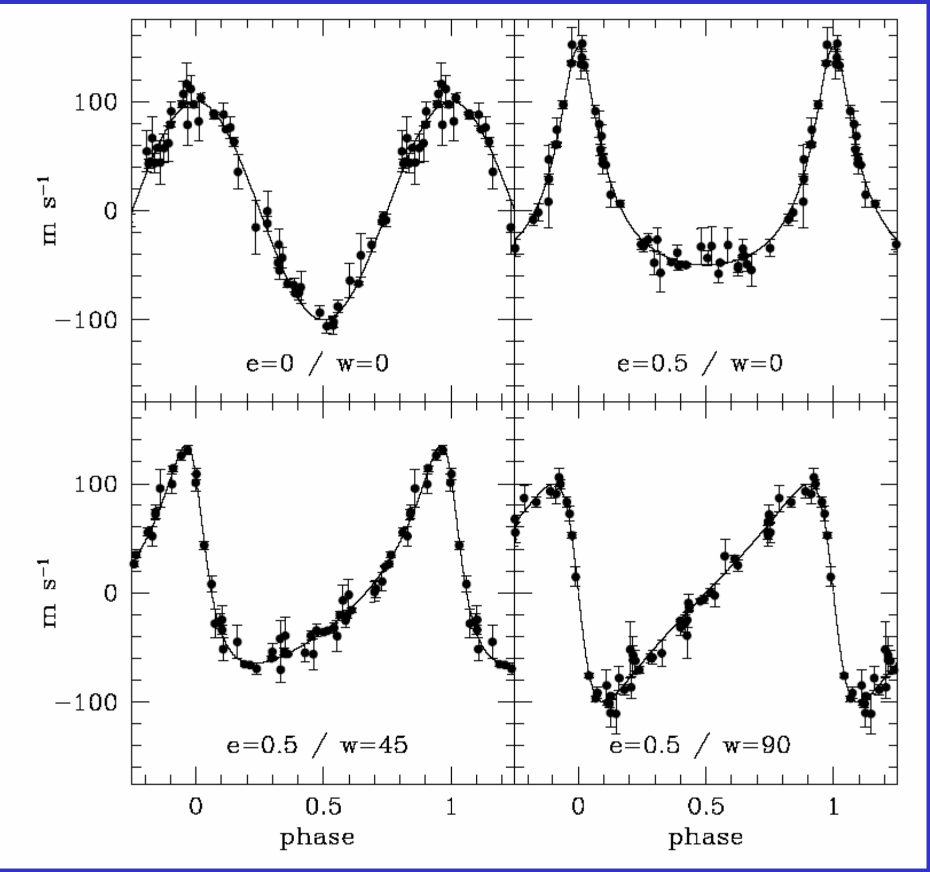


Detection by radial velocity

Based on the Doppler-Fizeau Effect



Keplerian orbit parameters



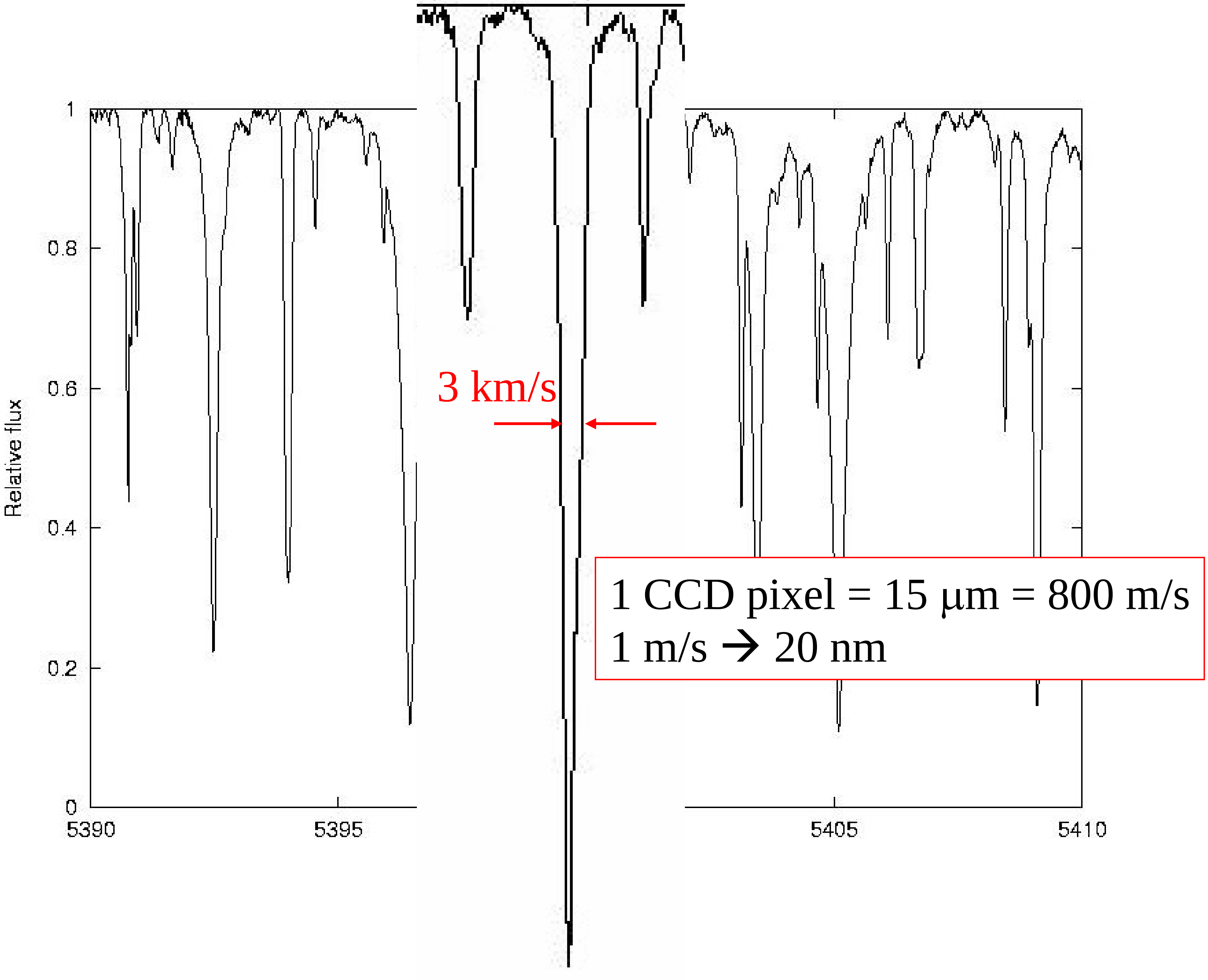
$$V_{rad} = \frac{m}{M_* + m} \cdot \frac{2\pi a \sin i}{P\sqrt{1-e^2}} \left[\cos(\nu(t) + w) + e\cos w\right]$$

$$V_{rad} = V_0 + K \cdot \left[\cos(\nu(t) + w) + e\cos w\right]$$

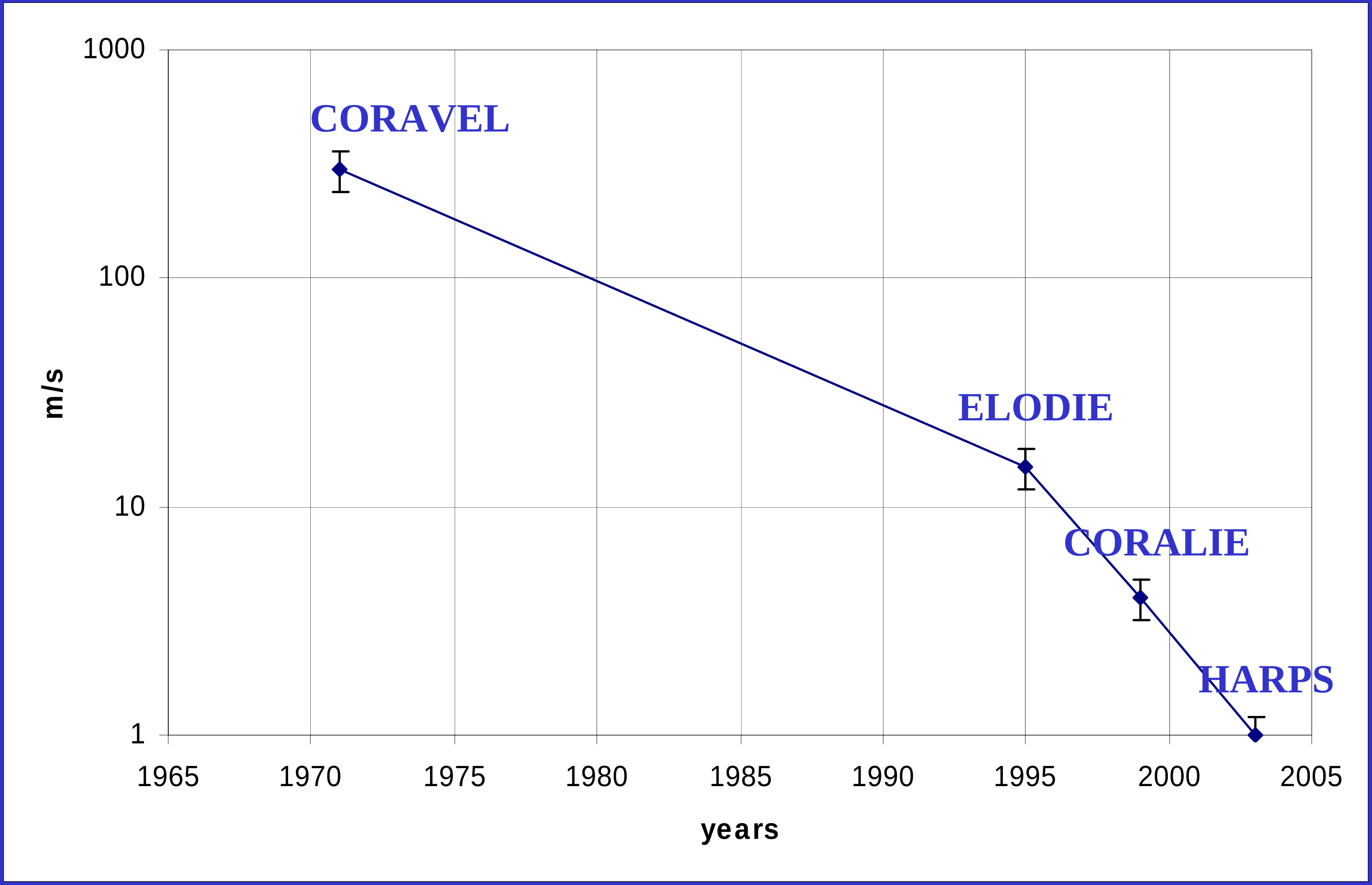
Orbital fit → 6 parameters of keplerian orbit :
V_0, K, P, e, T_p, w

$$K[m/s] = 28.45 \cdot \frac{m\ [\mathrm{M}_{Jup}]\sin i}{\sqrt{a[\mathrm{AU}] \cdot M_*[\mathrm{M}_{\mathrm{SUN}}]}}$$

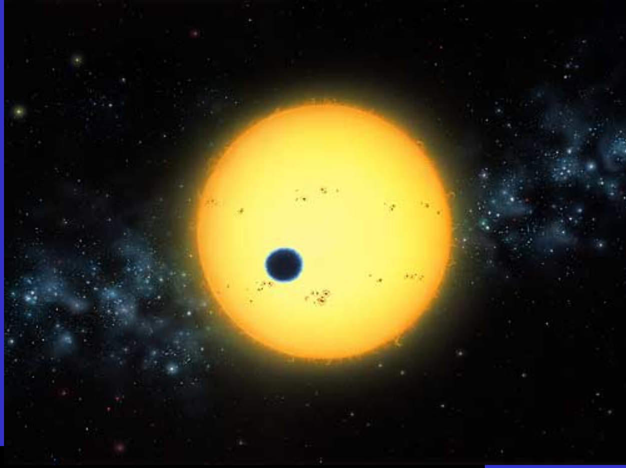
$$K[m/s] = 203 \cdot \frac{m\ [M_{Jup}]\sin i}{M_*[M_{SUN}]^{2/3} \cdot P[d]^{1/3}}$$

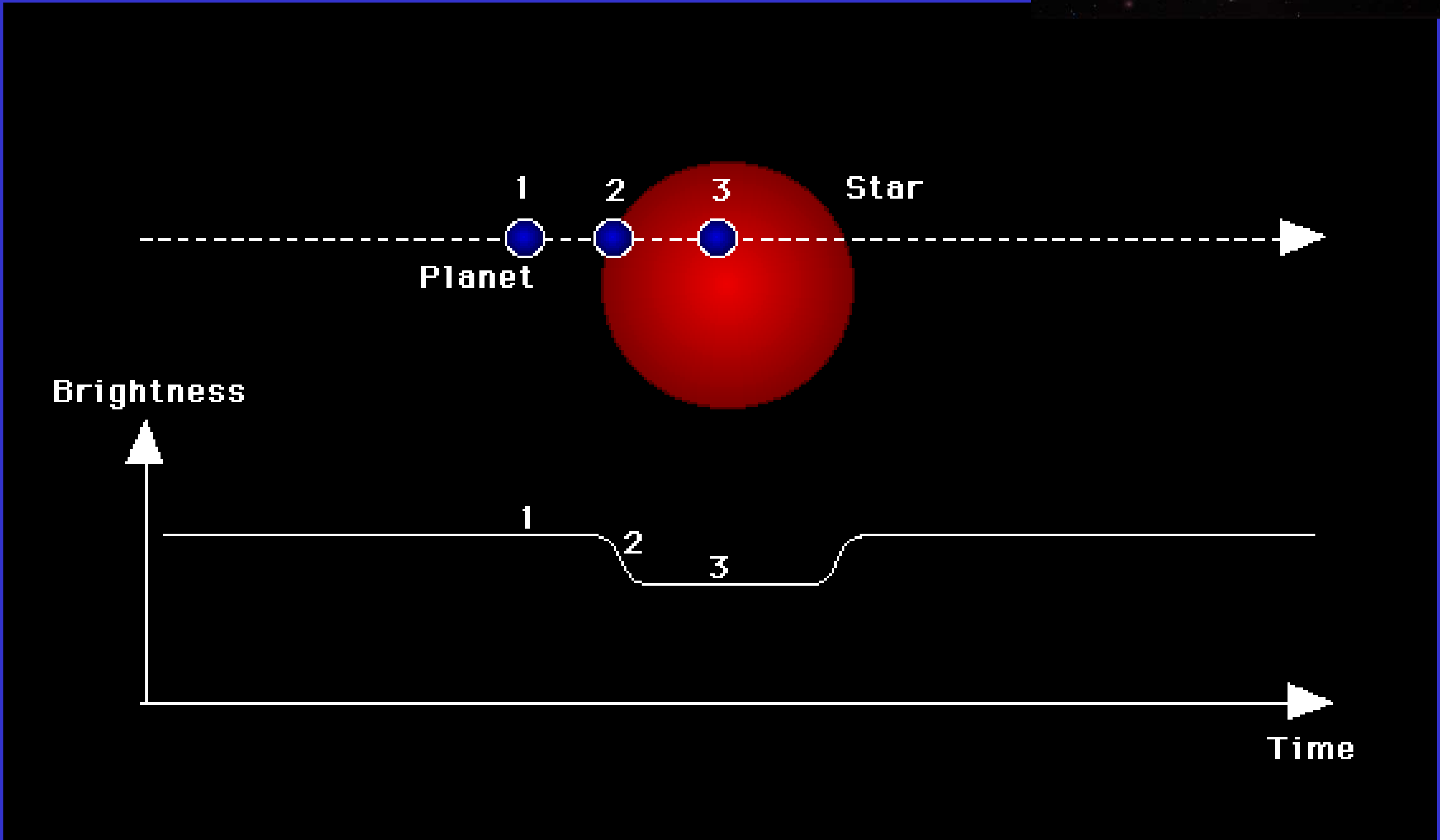

Relative flux
1
0.8
0.6
0.4
0.2
0
5390
5395
5405
5410
3 km/s
1 CCD pixel = 15 μm = 800 m/s
1 m/s → 20 nm

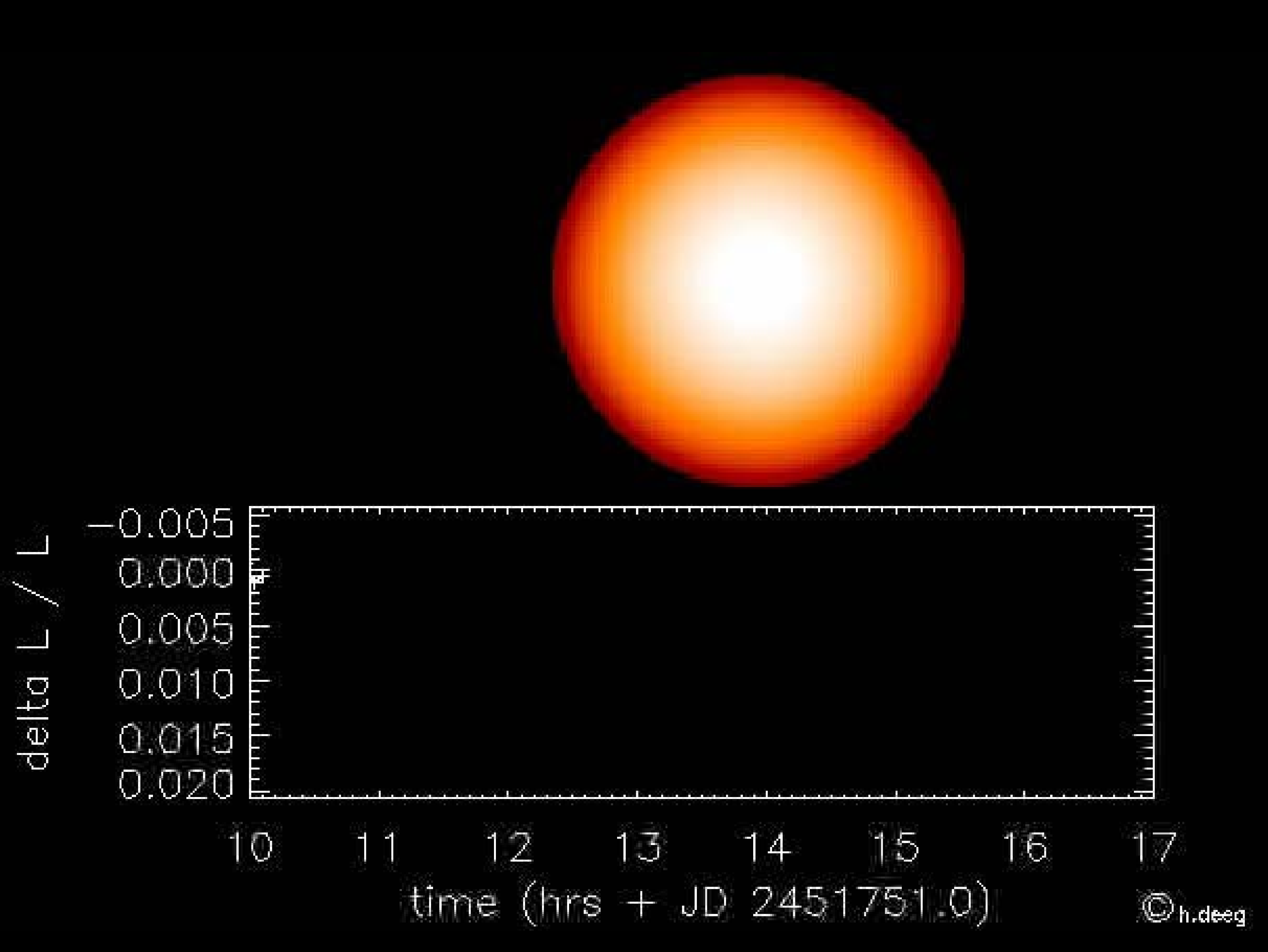
Improvement of Doppler techniques



Another solution :
Detect the shadow of the planet
- photometric transit -



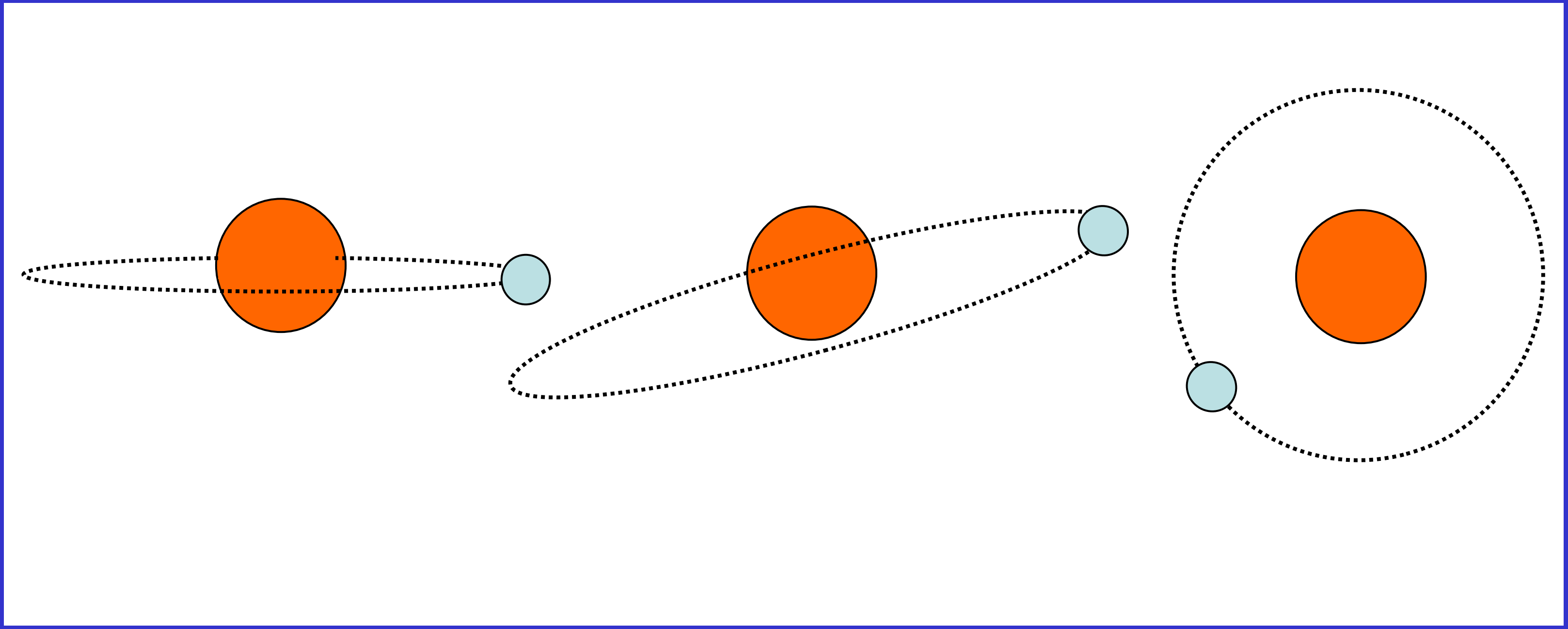




delta L / L
−0.005
0.000
0.005
0.010
0.015
0.020
10
11
12
13
14
15
16
17
time (hrs + JD 2451751.0)
© h.deeg

Transit Probability

$$p = \frac{R_*}{a}$$



For 1 R_{sun} and 1 M_{sun} →

$$p[\%] = \frac{24}{P^{2/3}[days]}$$

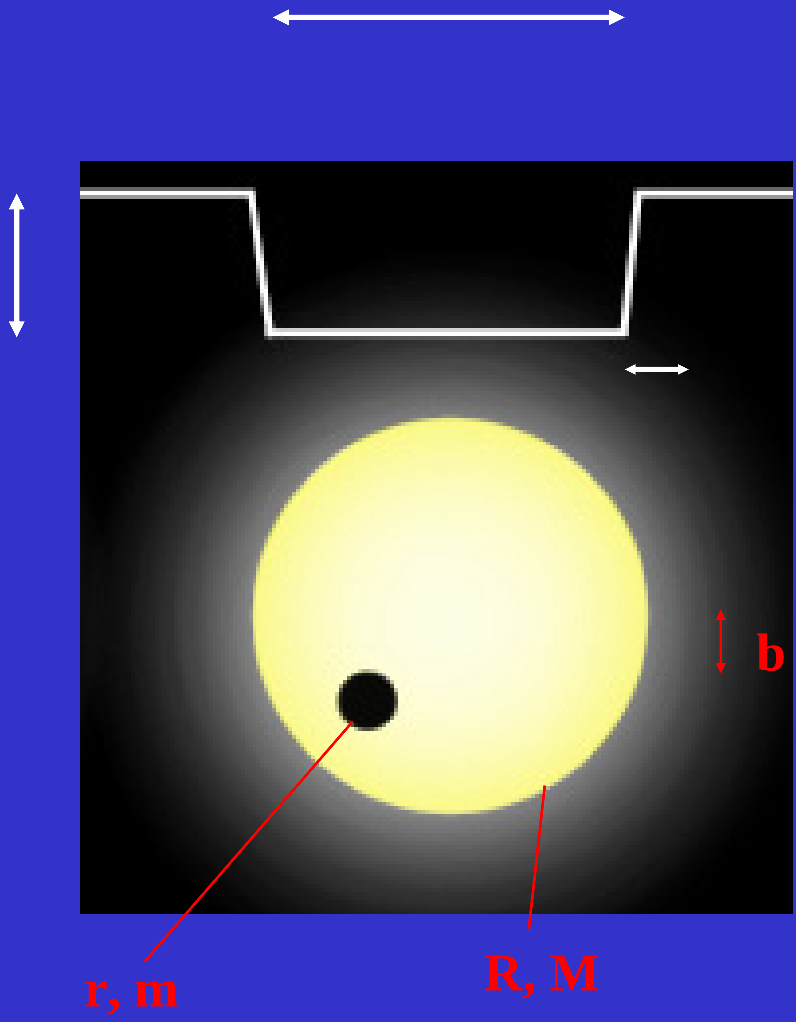
p = 3 days → 11 % p = 10 days → 5 %

p = 100 days → 1 % p = 365 days → 0.47 %

Duration $\Delta T \sim R\, P^{1/3} (m+M)^{-1/3} \sqrt{1-b^2}$

Depth

$d \sim (r/R)^2$



Ingress/Egress

$dt \sim \Delta T\ r / R \sqrt{1-b^2}$

3 relations :

$\Delta T \sim R\, P^{1/3}\, M^{-1/3} \sqrt{1-b^2}$

$d \sim (r/R)^2$

$dt \sim \Delta T \;\; r / R \sqrt{1-b^2}$

…. but 5 unknowns :

r, R, m, M, b

<u>Light curve fit:</u>

r/R

$R\, M^{-1/3}$

b

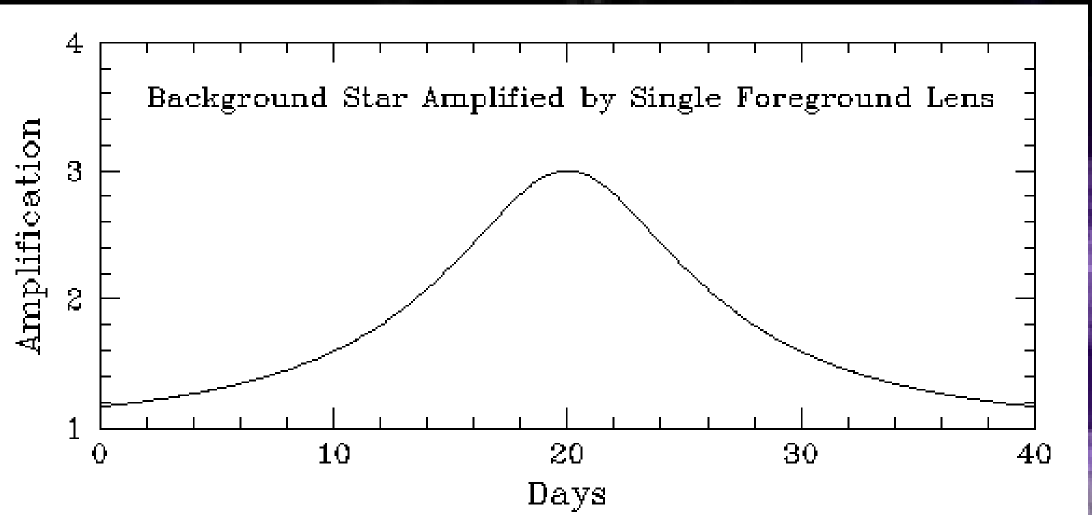
<u>Radial velocity</u>

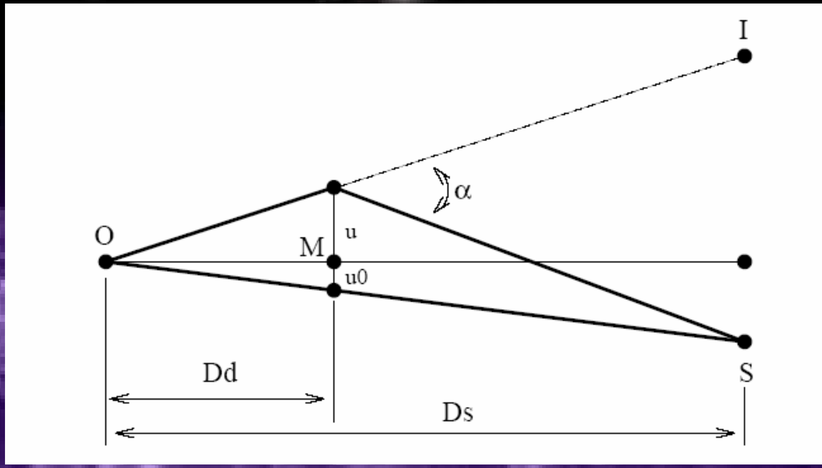
$m / M^{2/3}$

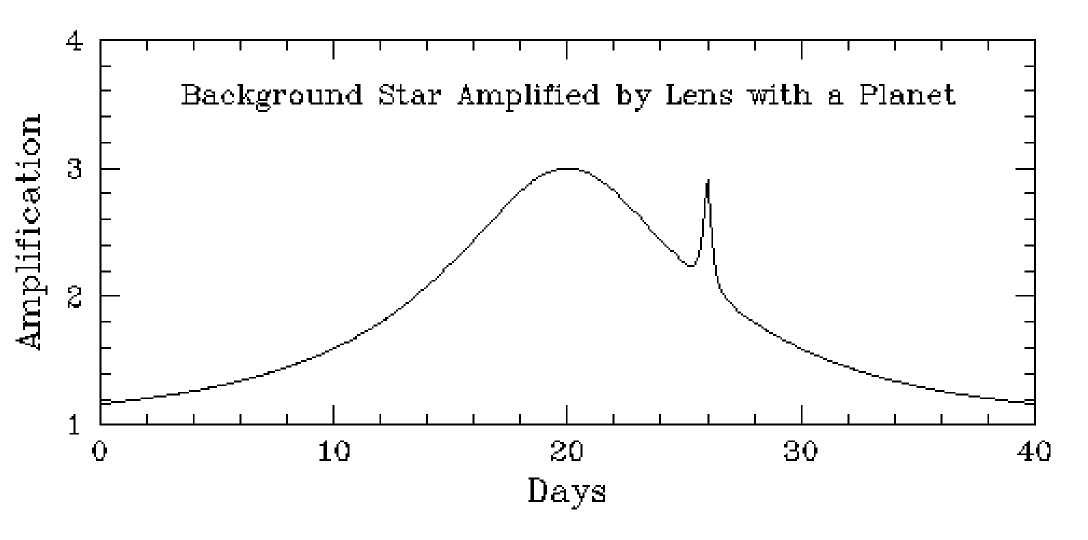
<u>Spectroscopy</u>

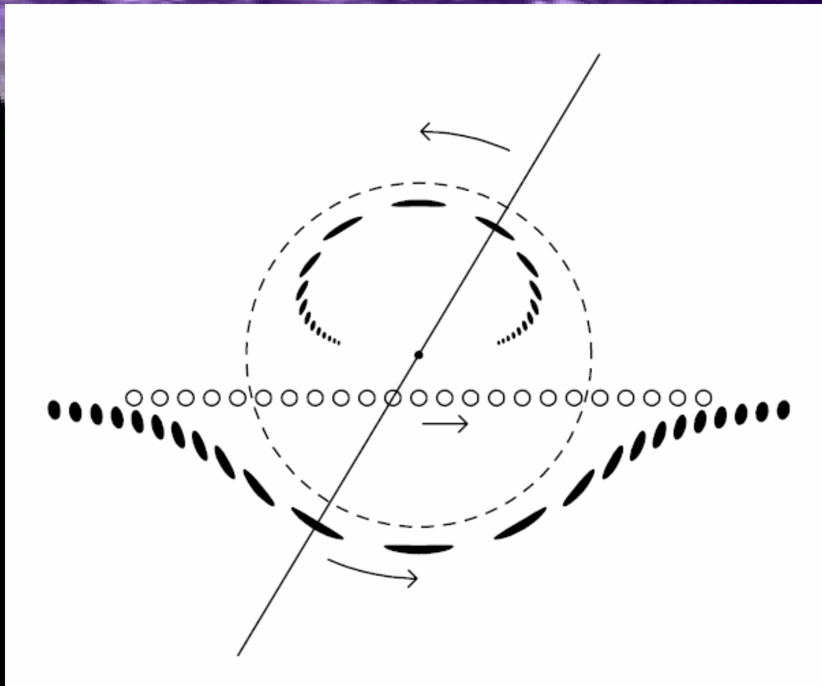
M, R

Gravitational microlensing

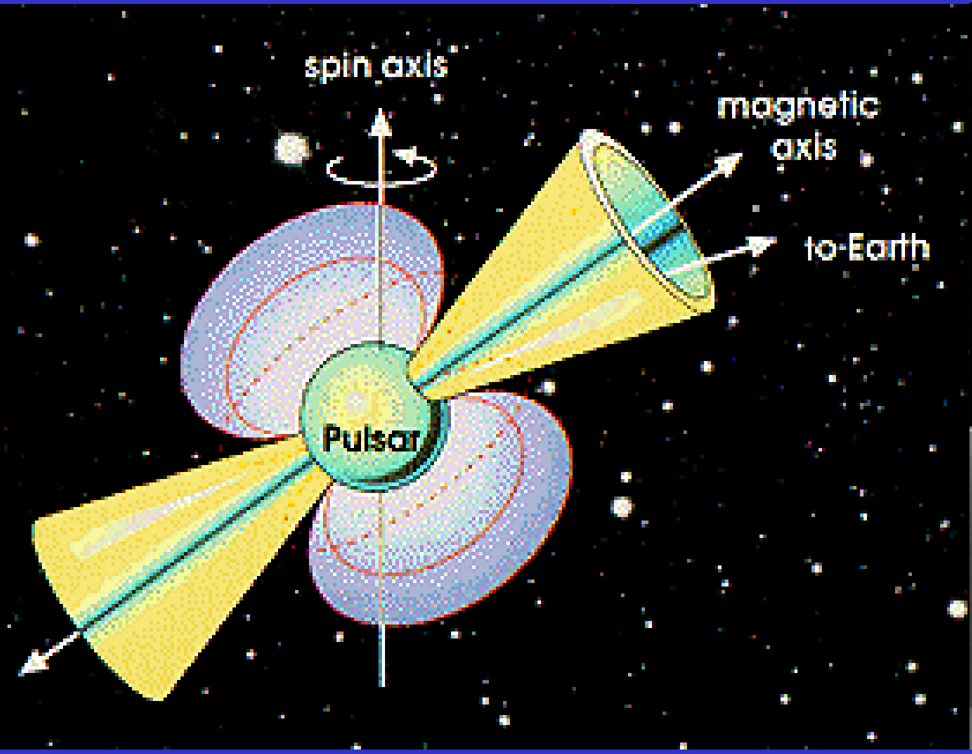


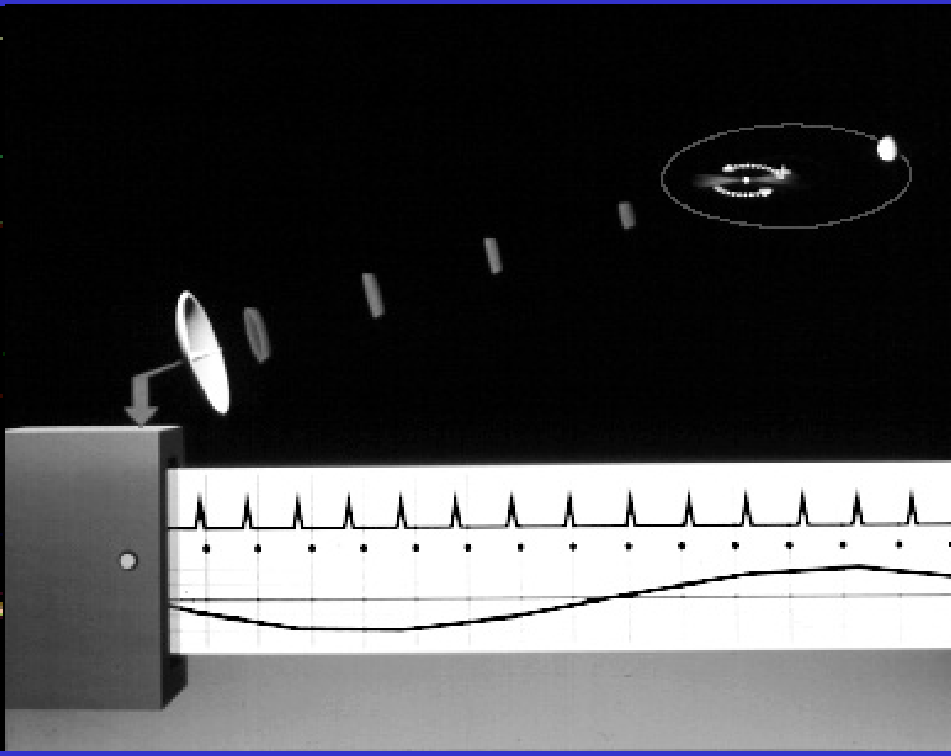






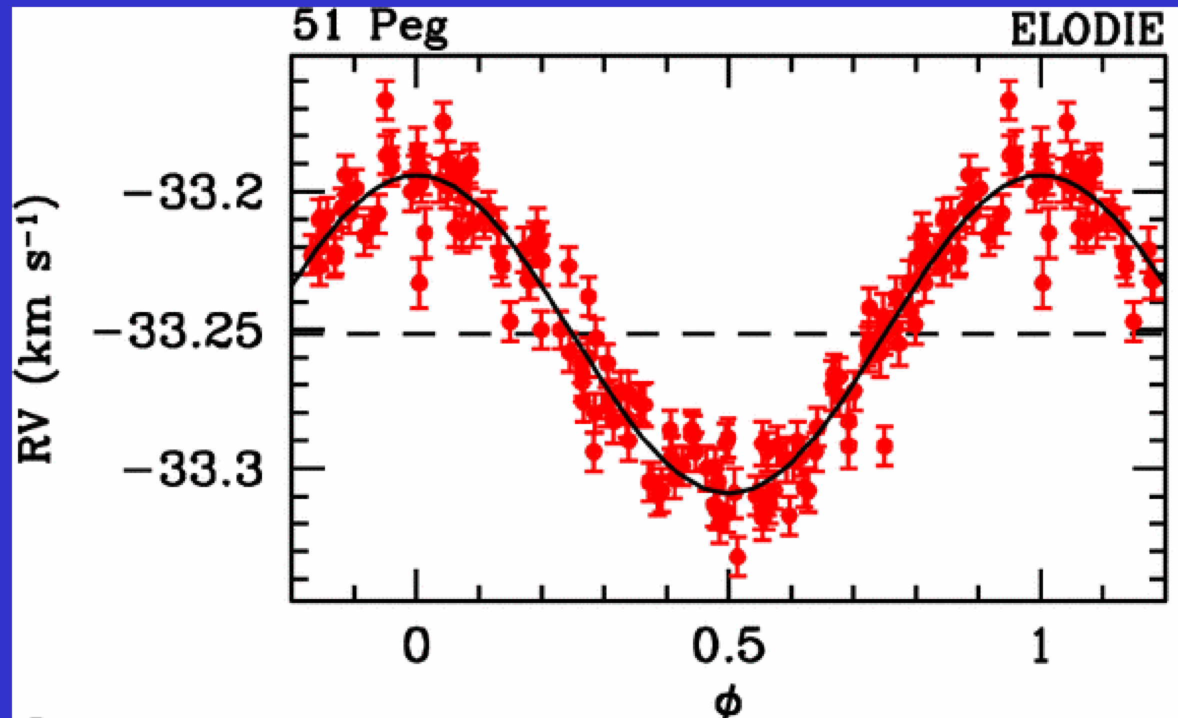
Pulsar timing





$$\tau[ms] = 1.6 \cdot \frac{M_p[M_{Earth}]}{M_{pulsar}^{4/3}[M_{Sun}]} \cdot P^{2/3}[year]$$

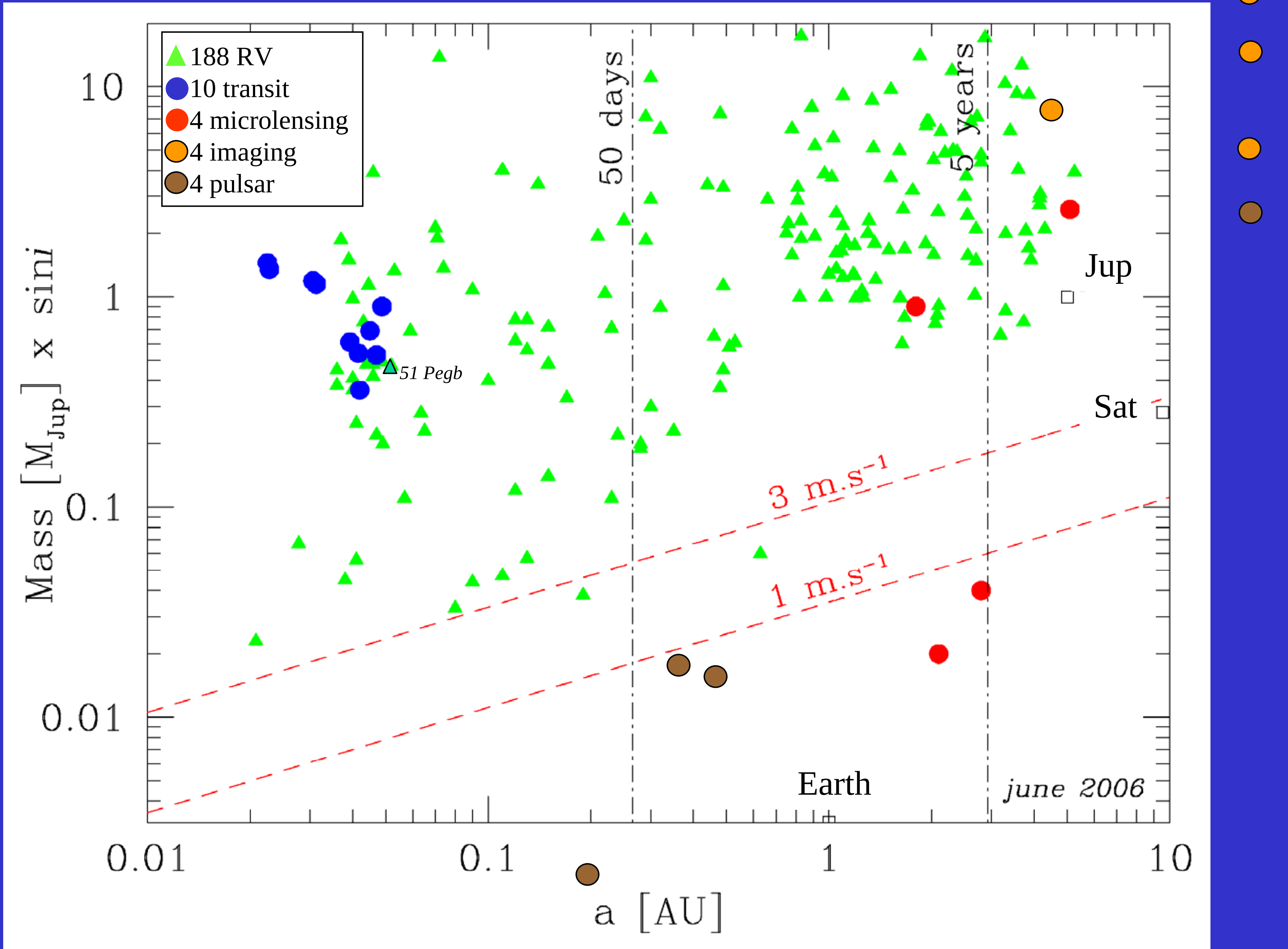
1995 : discovery of 51 Peg b
First extrasolar planet orbiting a solar-type star



K = 59 m.s^{-1}
P = 4.23 days

m_p.sin*i* = 0.47 M_J
a = 0.05 AU

Status : 200 known extrasolar planets



Main properties of orbital parameters

0) A huge diversity of orbital parameters (P, a, e)

1) no massive planets (> $2M_{Jup}$) with short period (P<100d)

2) maximum mass increases with orbital distance

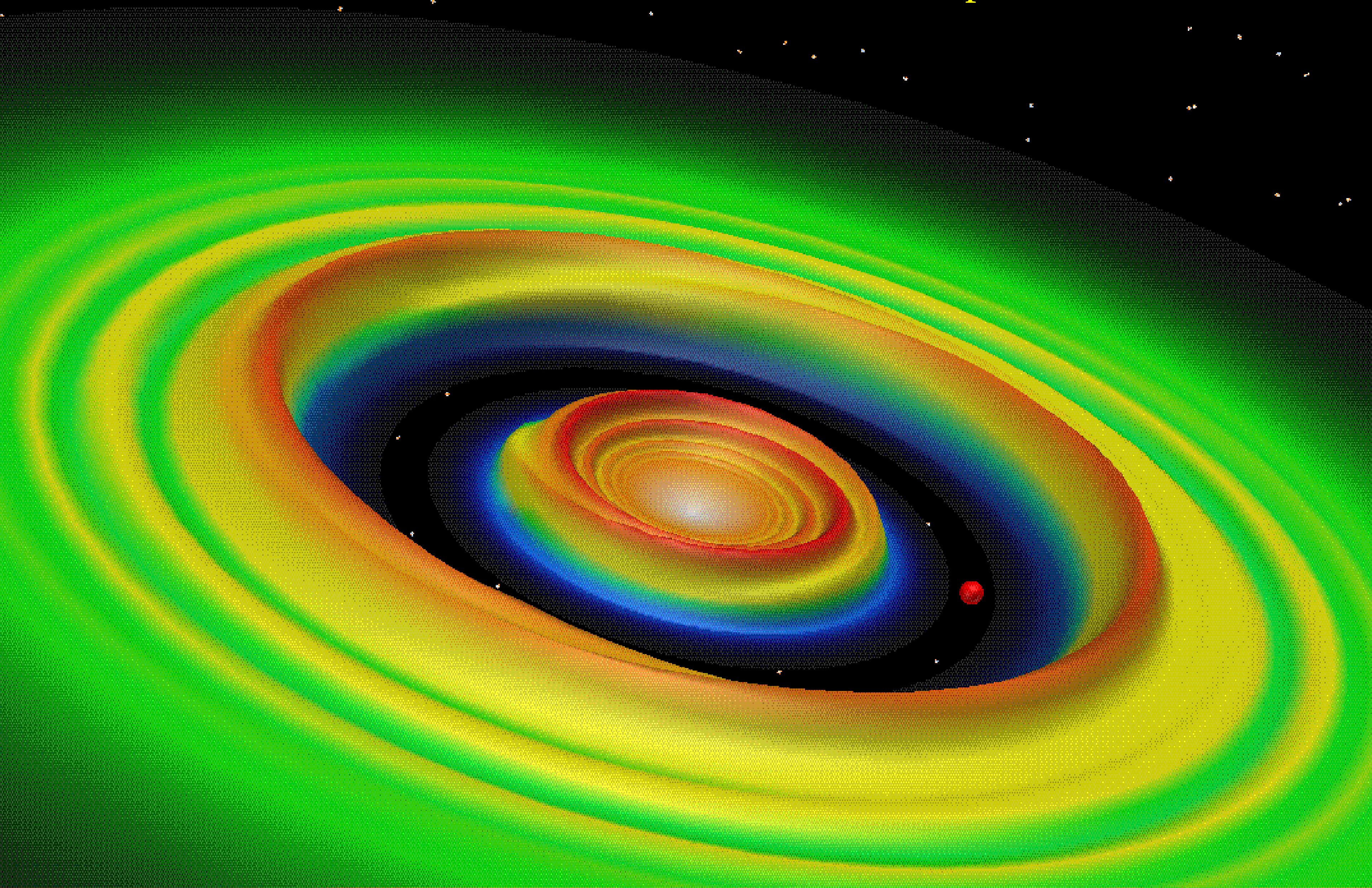
3) Lack of planets between 10 et 100 days

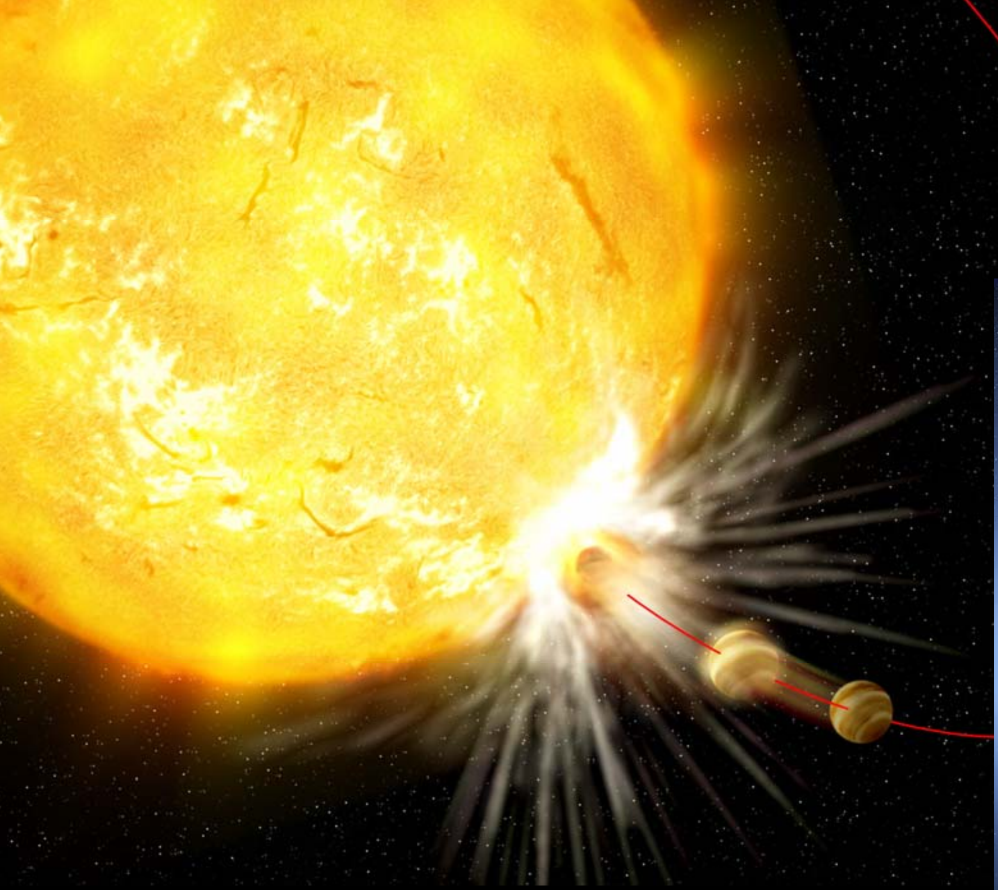
4) Lack of planets less massive than Jupiter with long period (P>100d)

5) Peak of planets with short period (3-10 d)

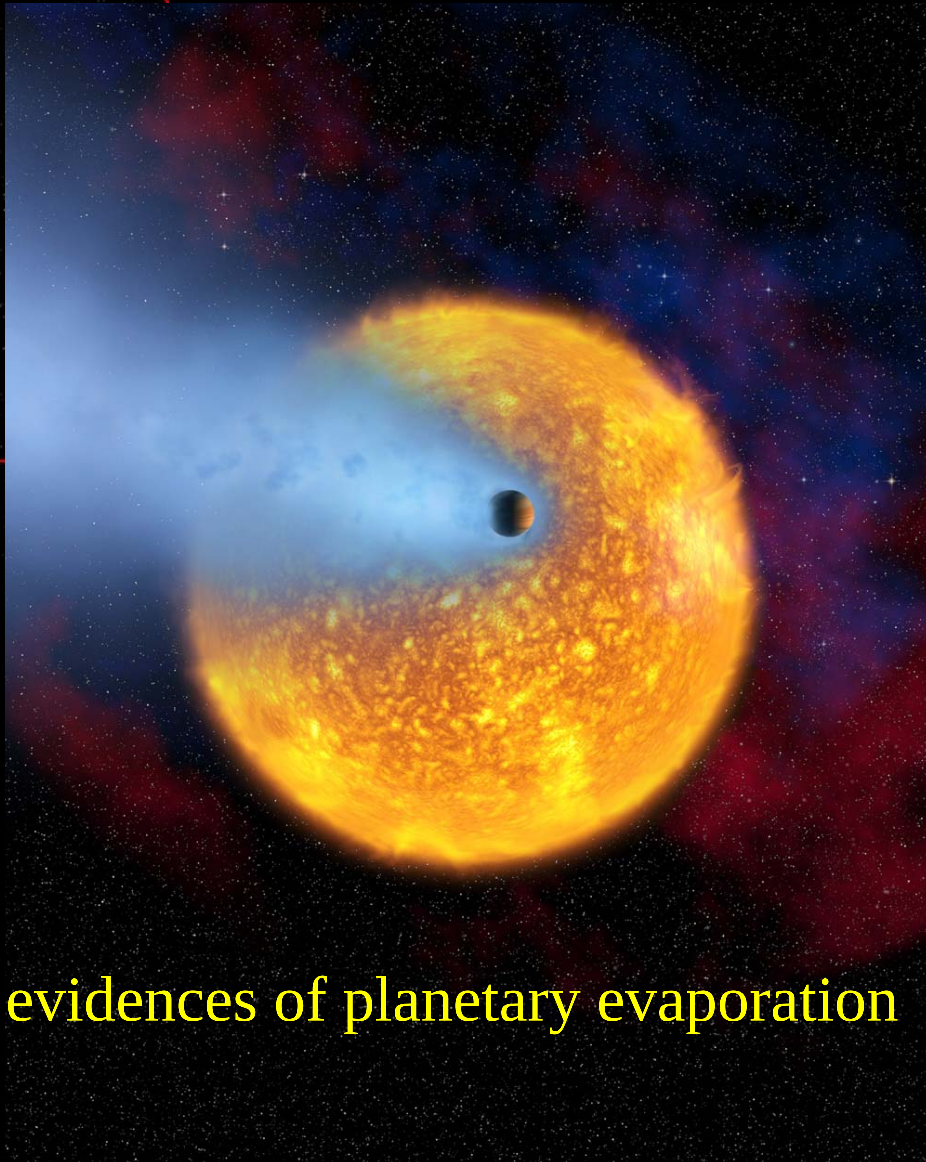
6) Nb of planets increases with period (for P>100 d)

Migration of HJ due to tidal interaction with disk
More efficient for low mass planets



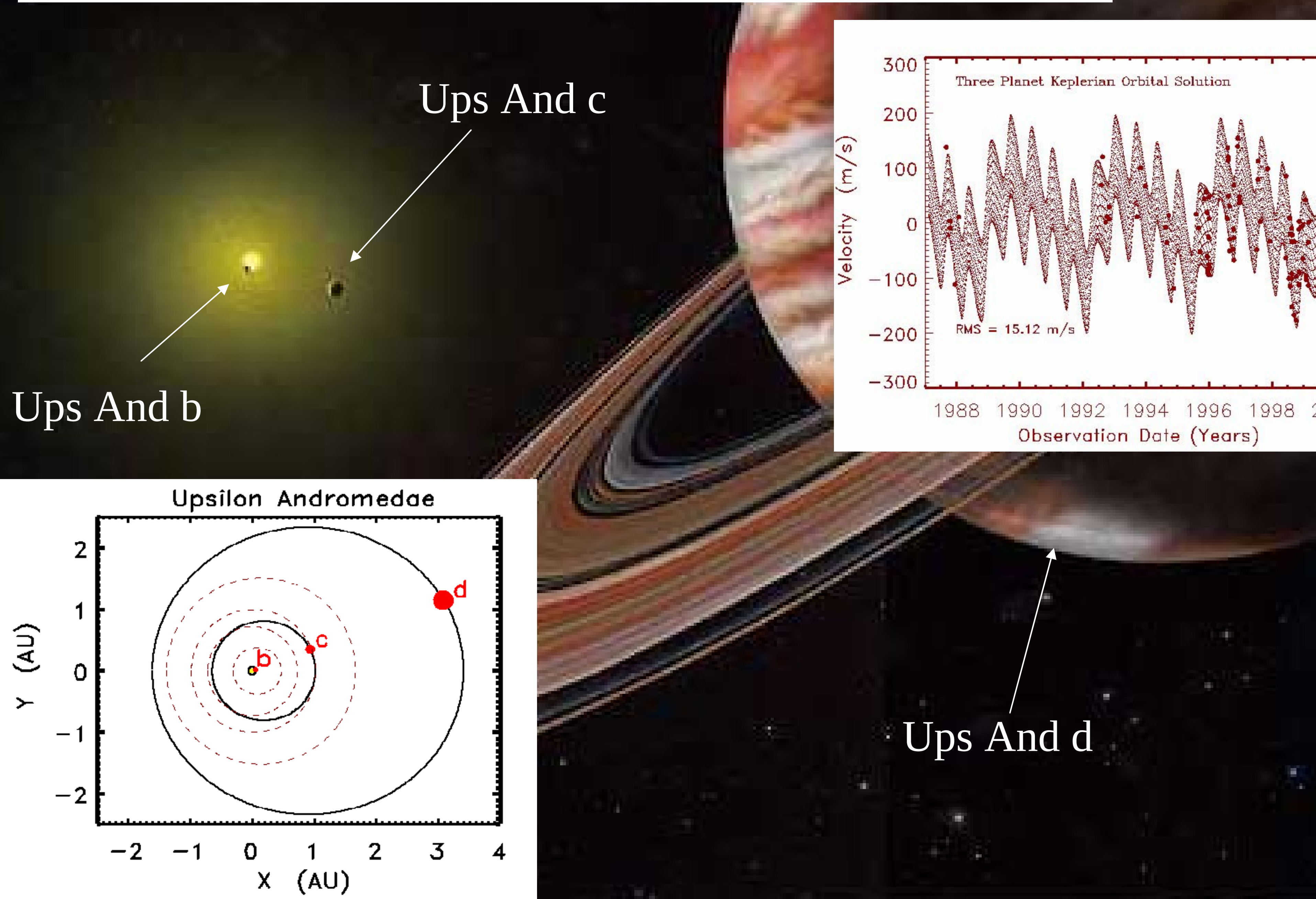


Some evidences of planetary fall

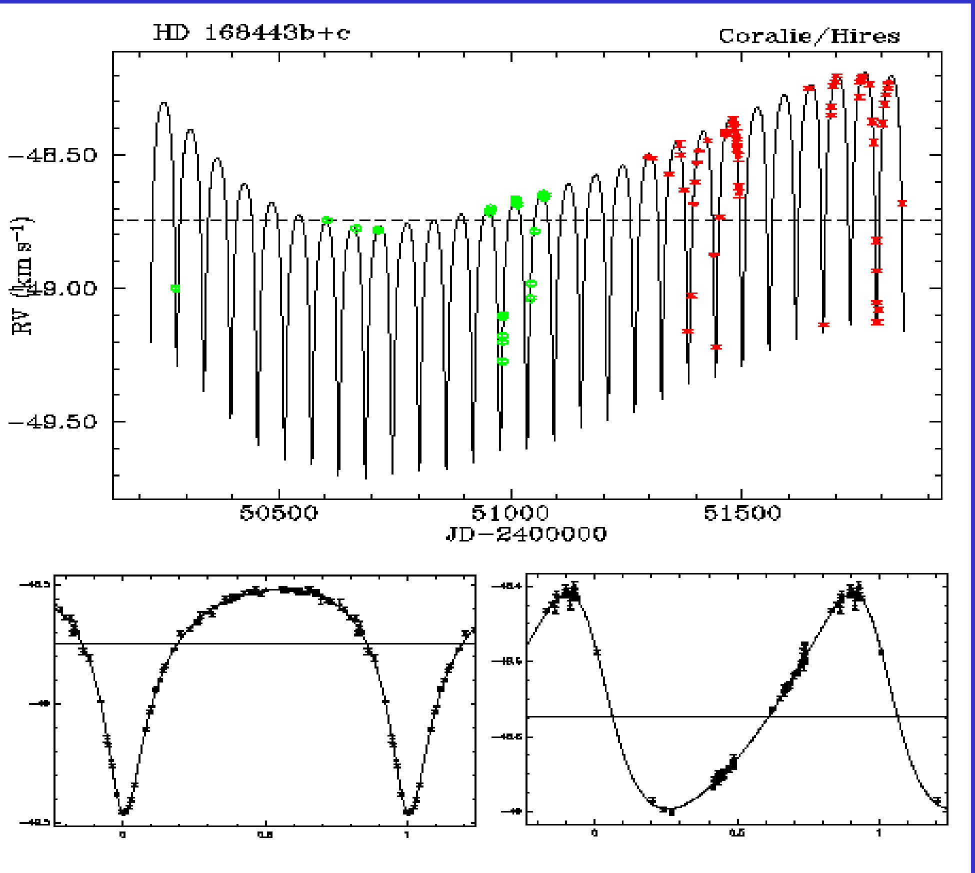


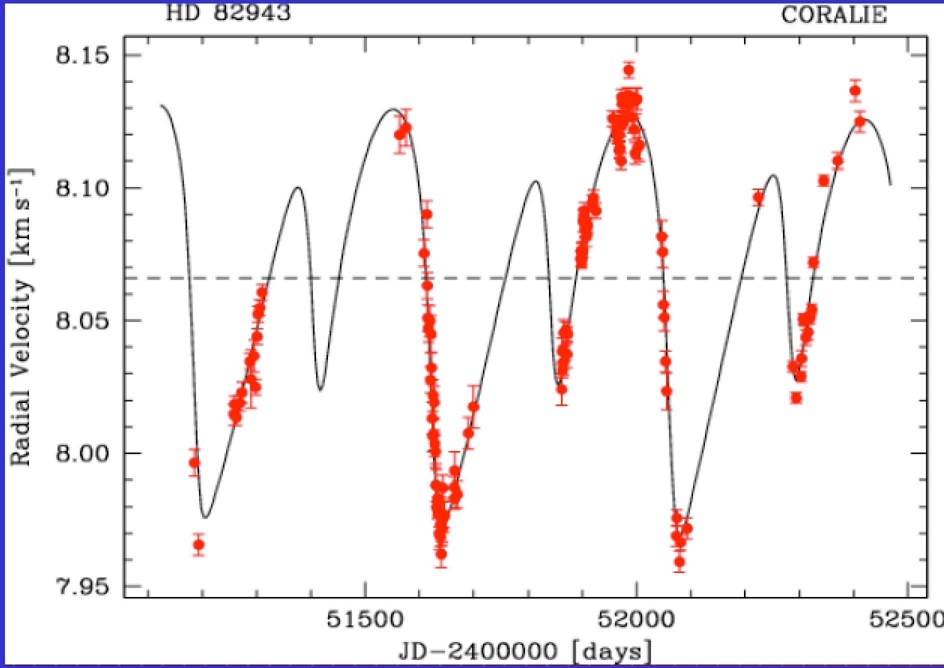
Some evidences of planetary evaporation

20 multiple systems ~ 25 % of the exoplanets



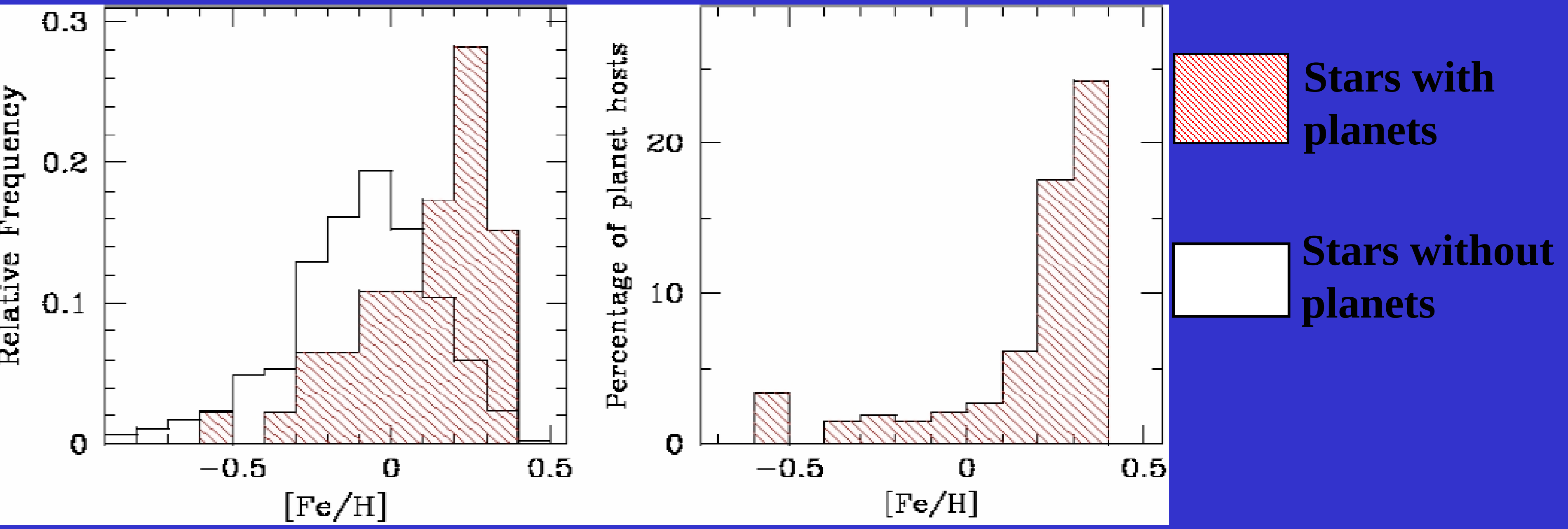
Seems to favor the eccentricity





Some resonant systems

Properties of exoplanet-host stars



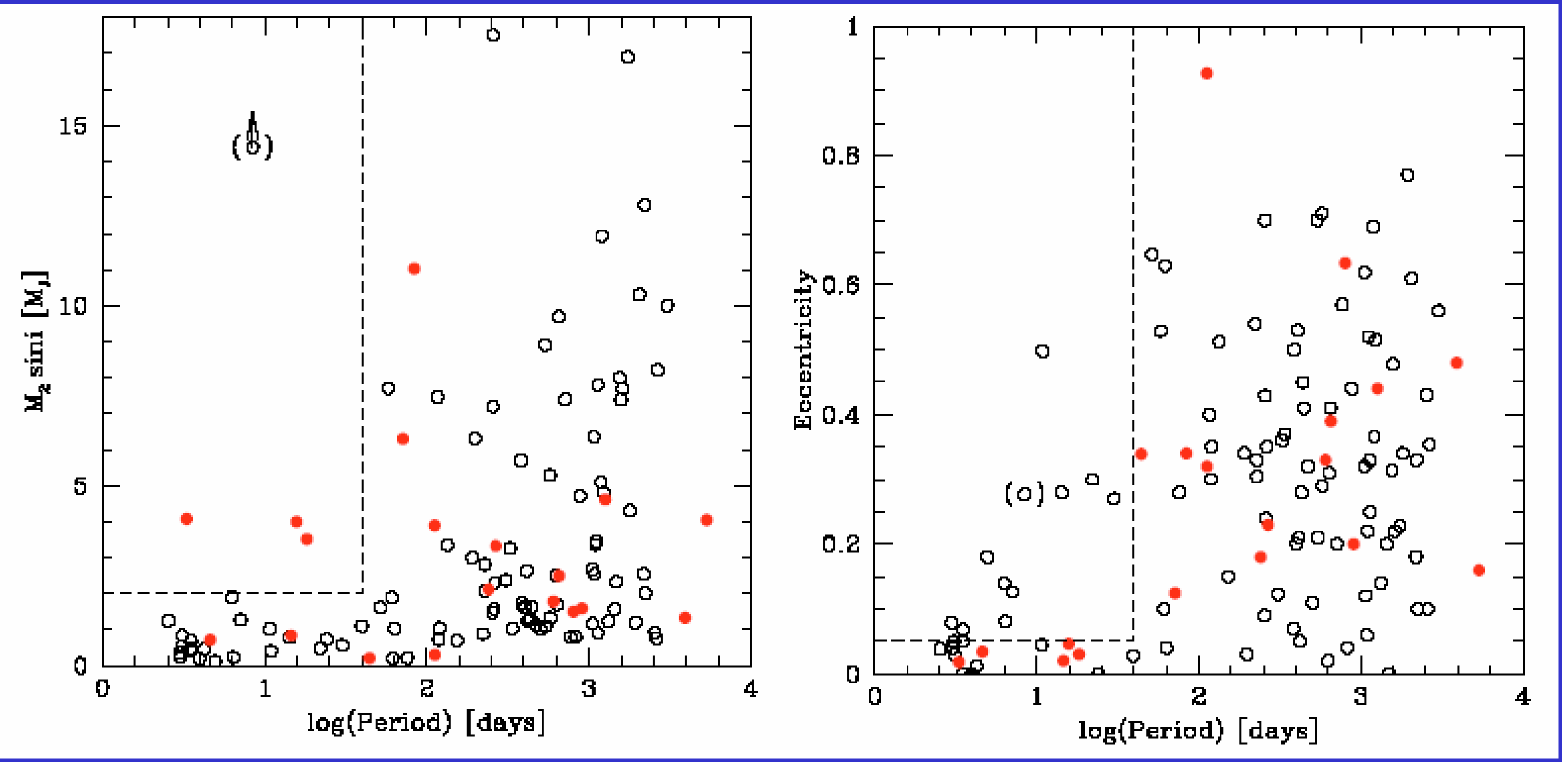
1) Planet host stars have higher metallicity

2) Probability to find a planete increase with metallicity

→ Over metallicity seems to favour the planetary formation

! This is not the case for Neptune and Big-Earth like planets

19 planets around binaries

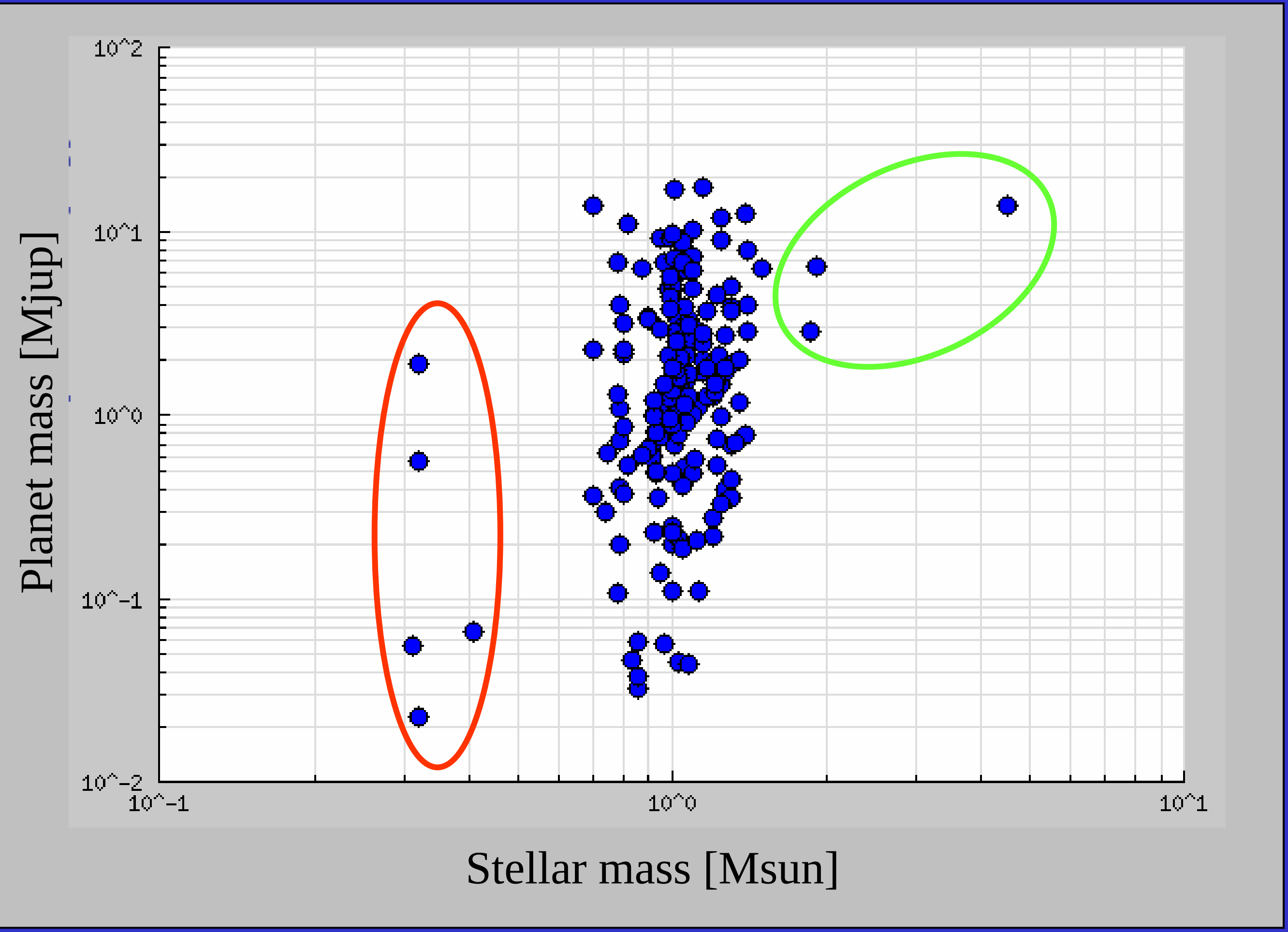


1) Massive planets (msini > 2 M_{Jup}) with short periods are around binaries

2) Short period planets orbiting binaries have low eccentricity

→ Migration process is different in binaries

Mass of the central star

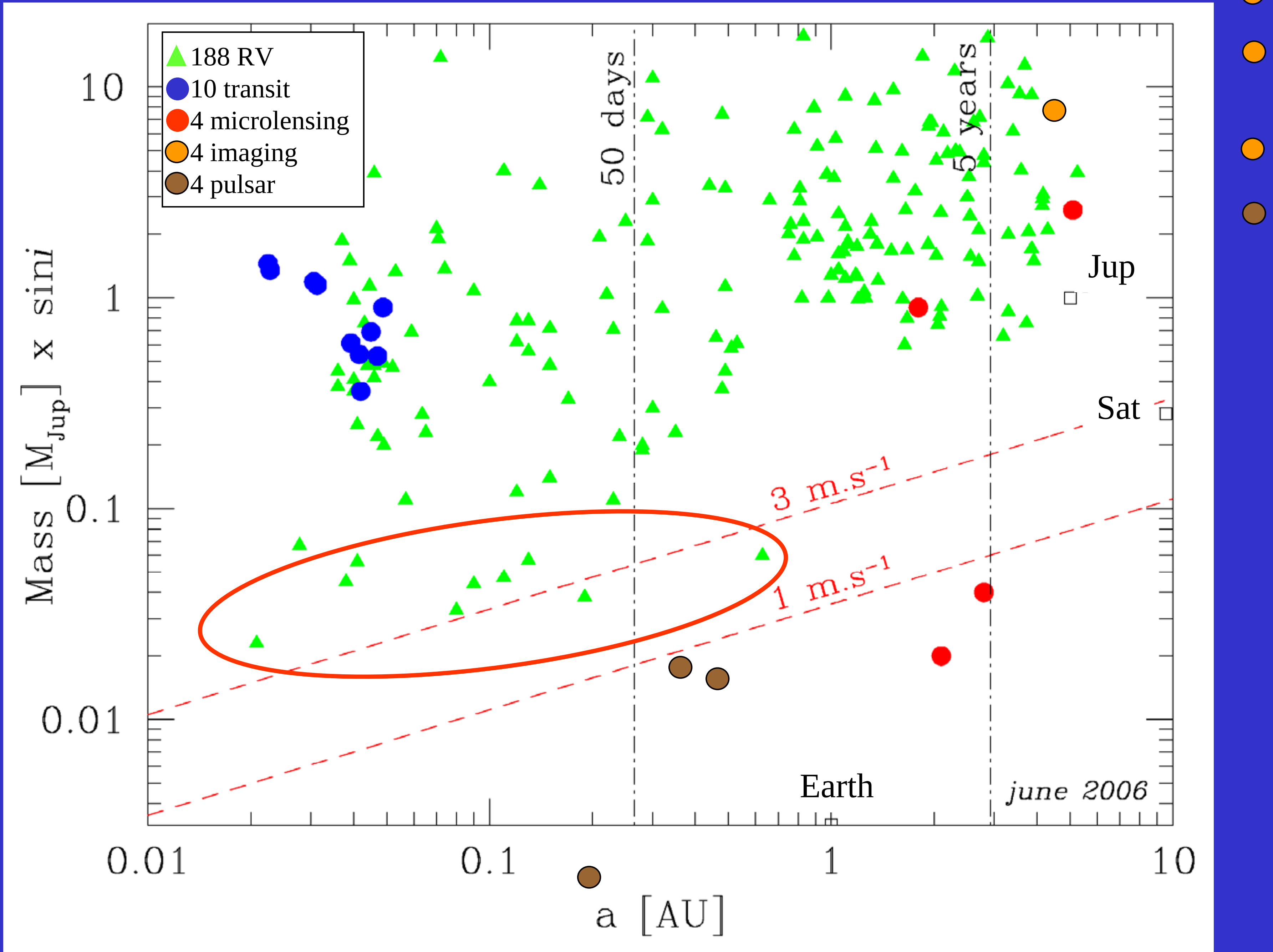


3 massive planets detected around F stars

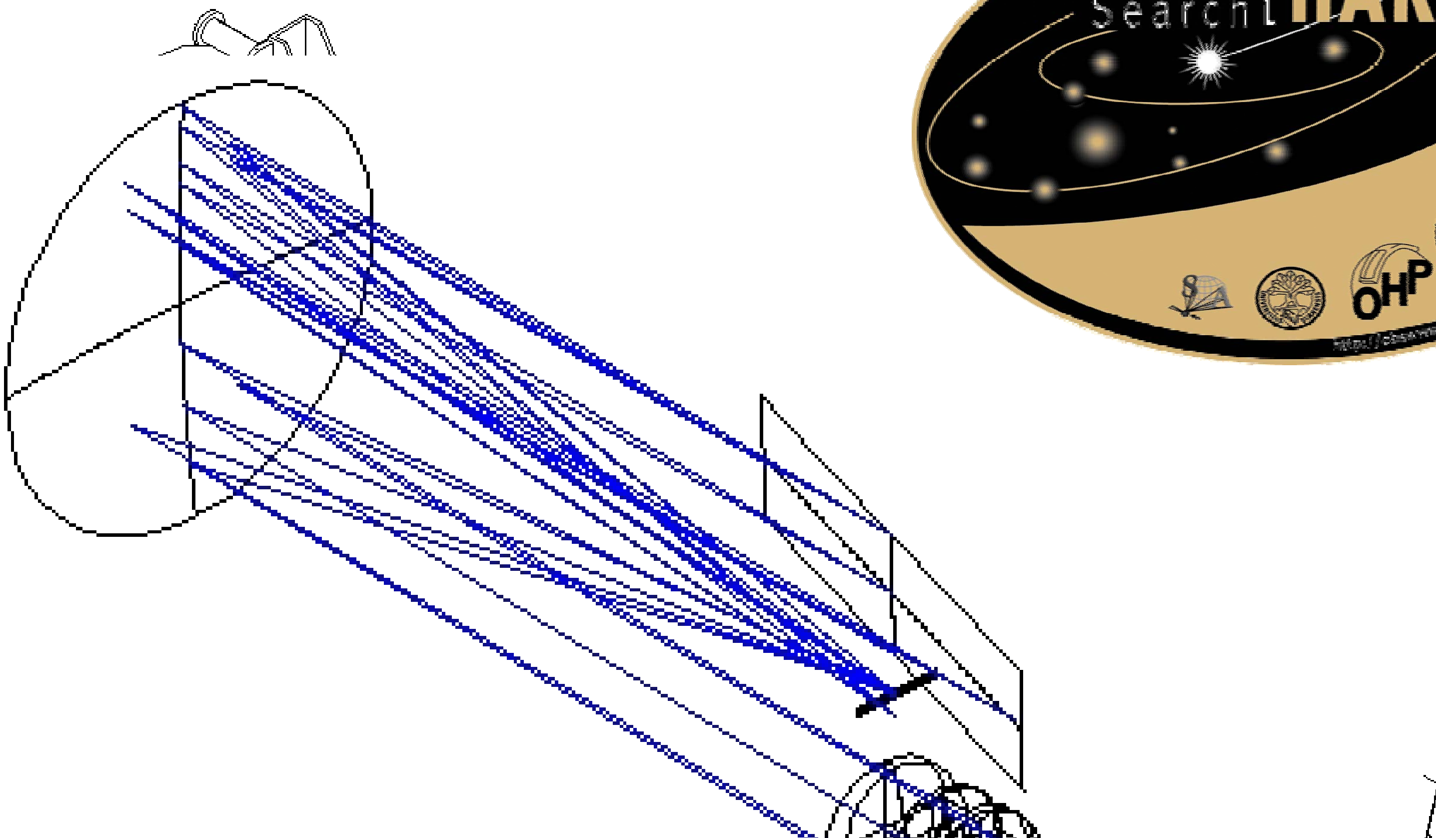
Only 5 planets detected around M dwarves (M < 0.6 Msun) including 3 Hot Neptunes.

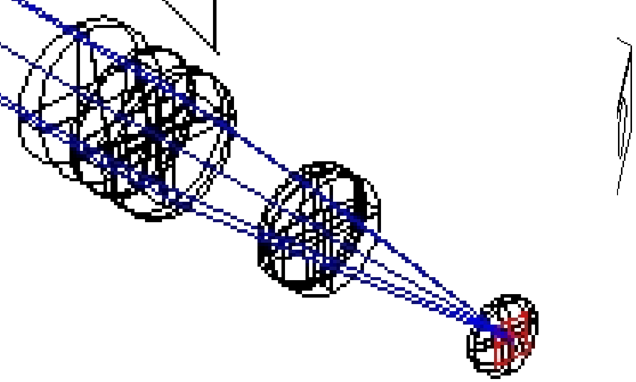
→Smaller disk around M dwarves do not favor the formation and the migration of giant planet

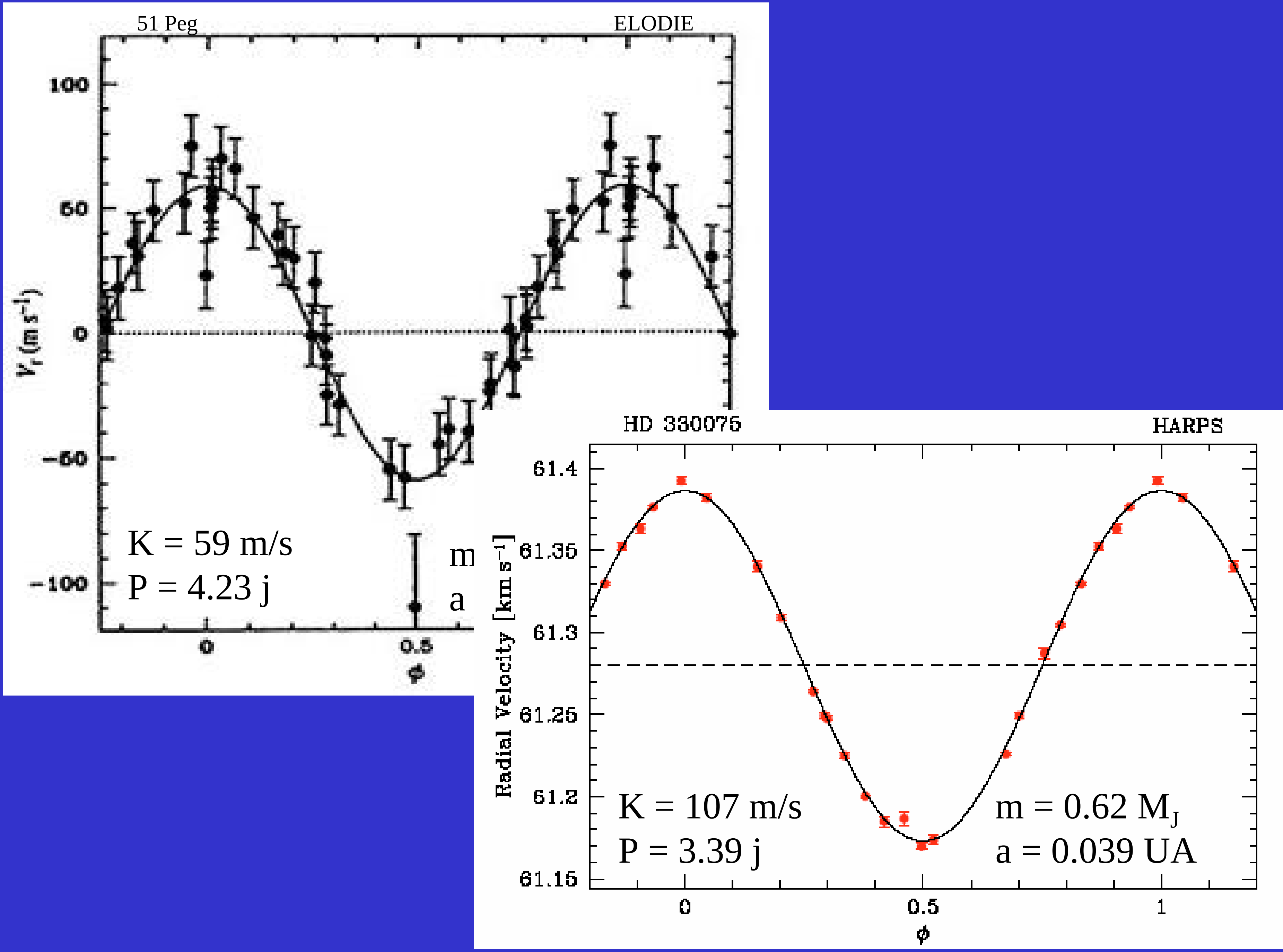
Toward the low-mass planets



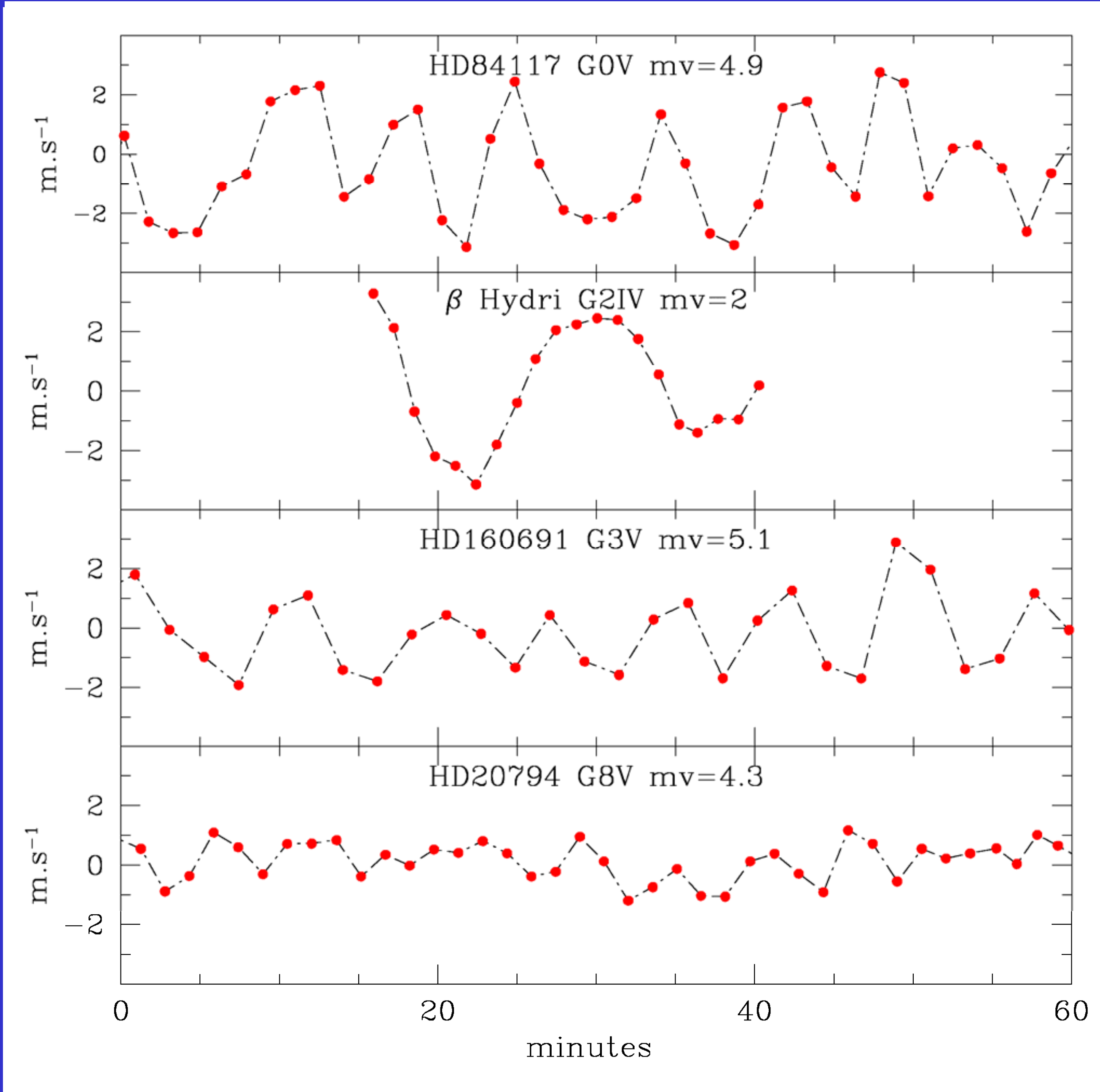
Planetary Search HARPS

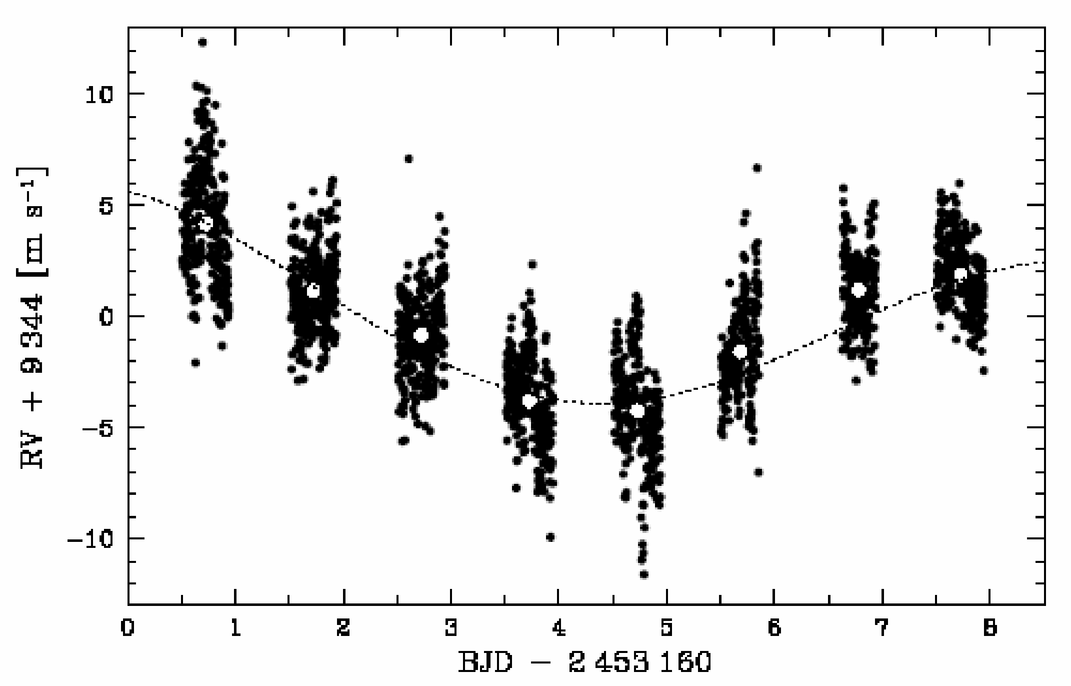





51 Peg
ELODIE
100
60
0
−60
−100
V_r (m s^{-1})
0
0.5
φ
K = 59 m/s
P = 4.23 j
HD 330075
HARPS
61.4
61.35
61.3
61.25
61.2
61.15
Radial Velocity [km s^{-1}]
0
0.5
1
φ
K = 107 m/s
P = 3.39 j
m = 0.62 M_J
a = 0.039 UA

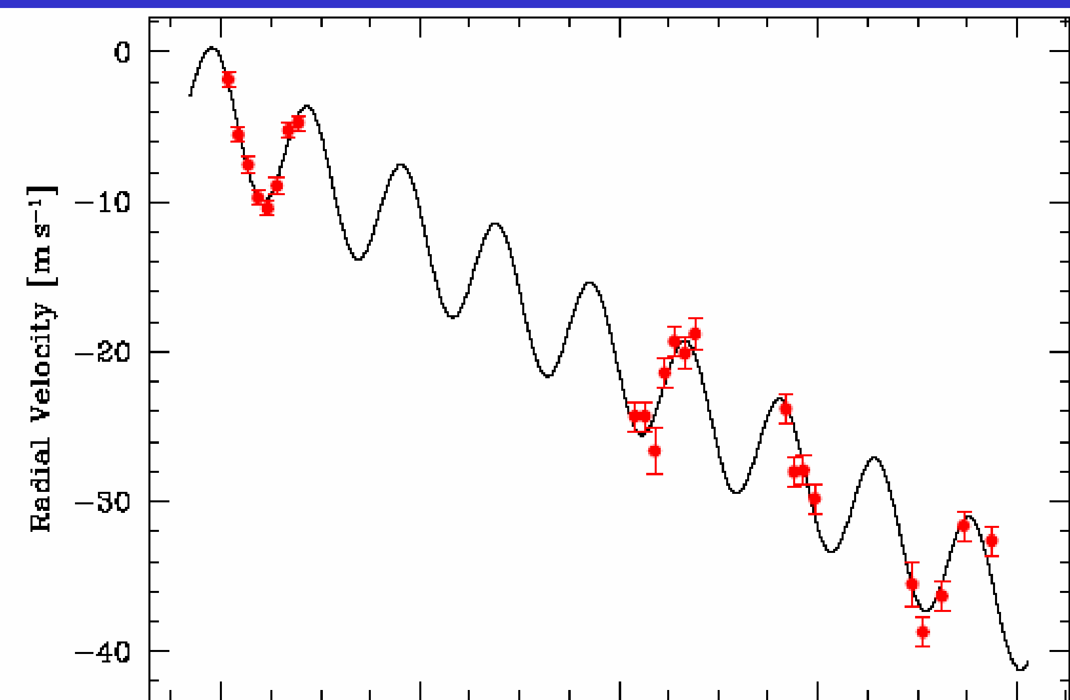
All stars are singing

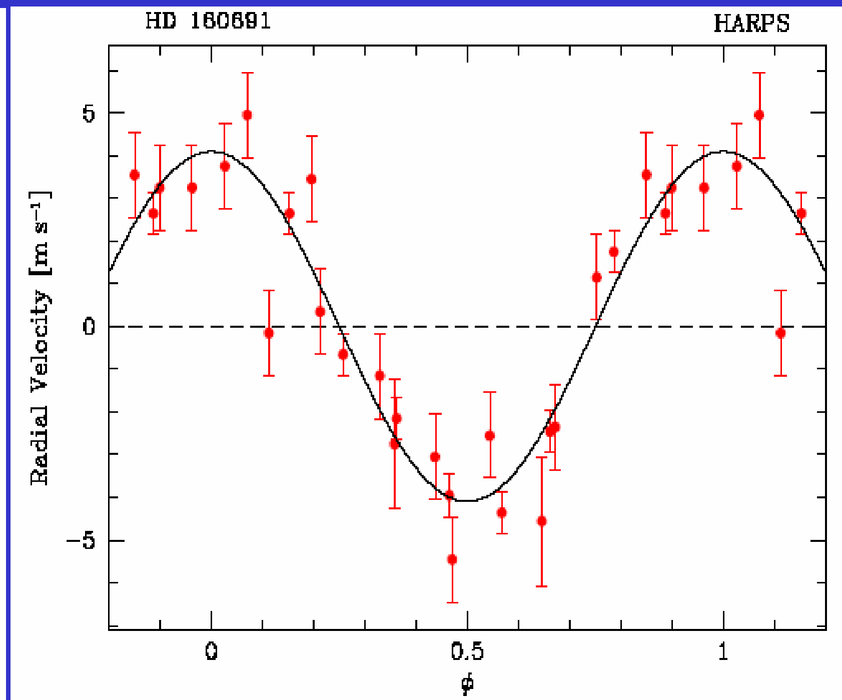




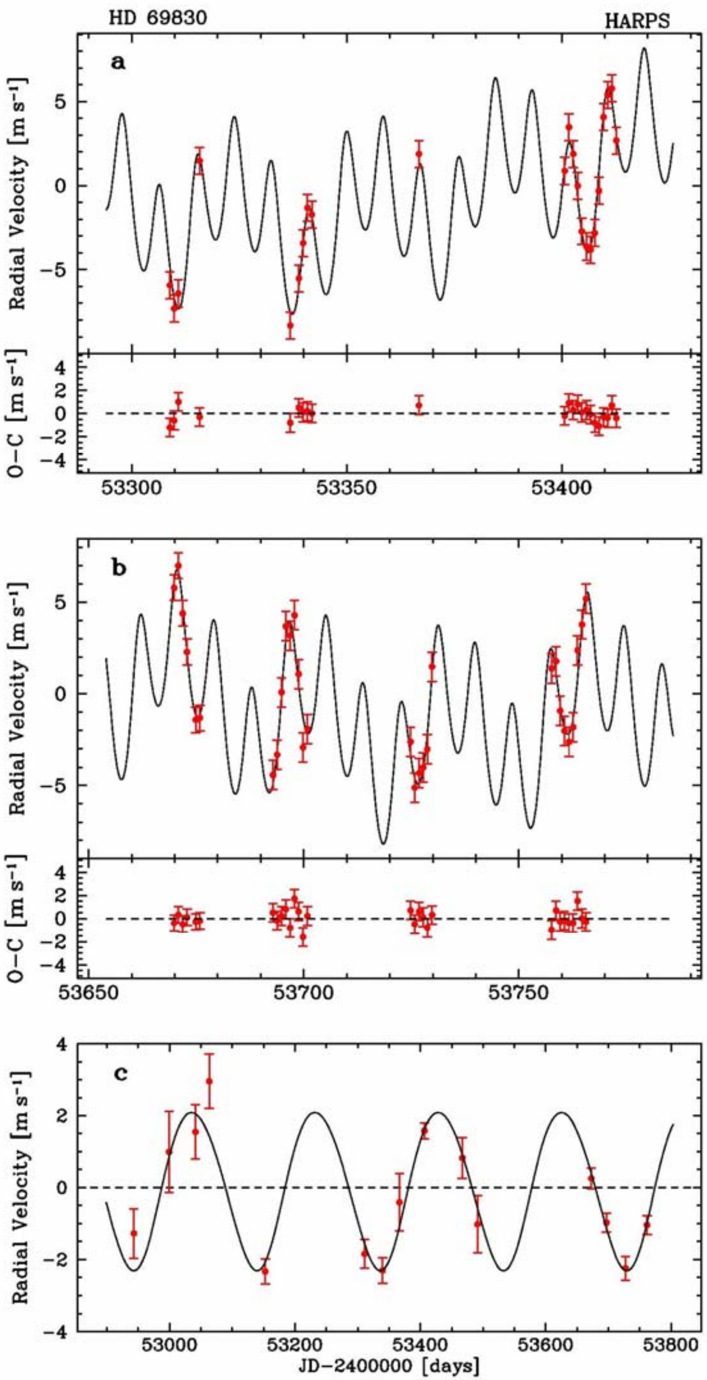
Venus of mu Arae

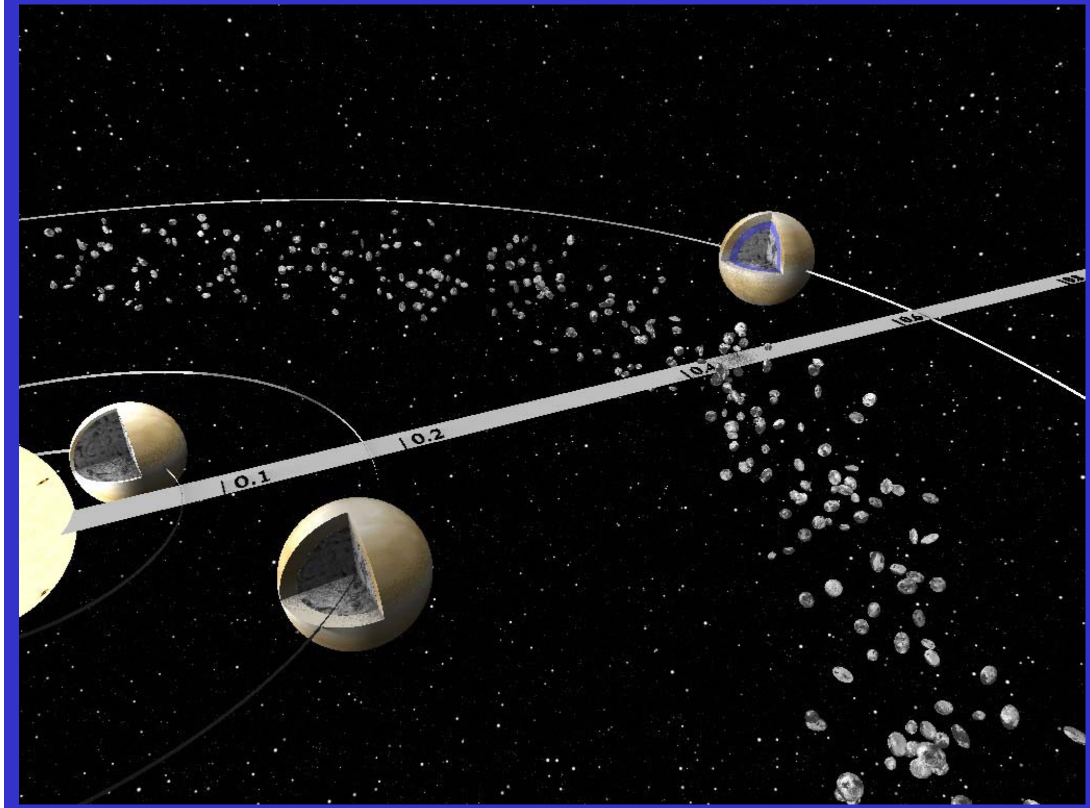
P = 9.55 d
K = 4.1 m/s
m.sini = 14 Mearth
a = 0.09 AU
O-C = 0.9 m/s





The trio of Neptunes





P = 8.7 / 31.6 / 197 days

a = 0.08 / 0.19 / 0.63 AU

m.sin$i$ = 10.2 / 11.8 / 18.1 M_{Earth}

Main limitations of RV method

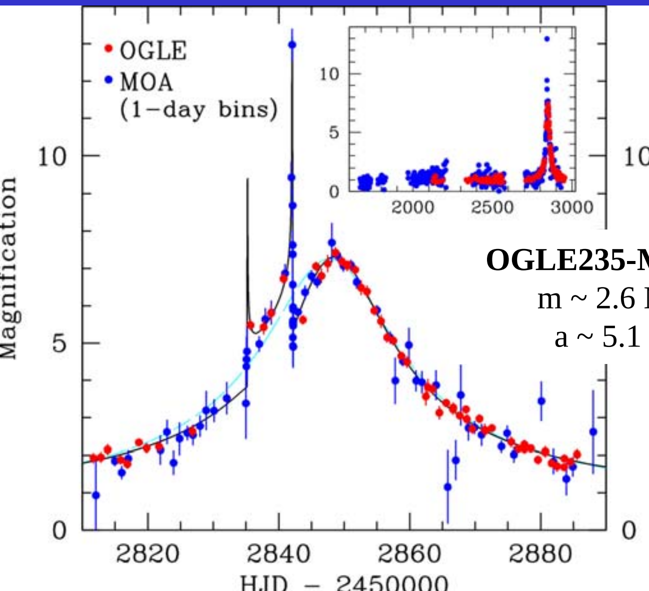
1. Instrumental limitations
   - Guiding noise
   - Wavelength calibration
   - CCD defaults

2. Stellar limitations
   - Seismic activity
   - Photospheric activity
   - Blend

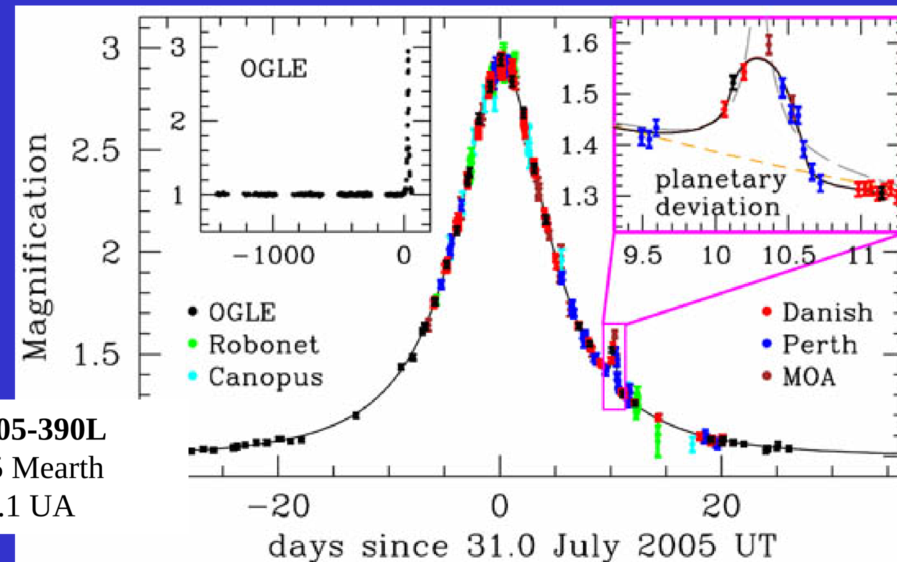
3. Photon noise limitations

Possibility to reach 30 cm/s these next years

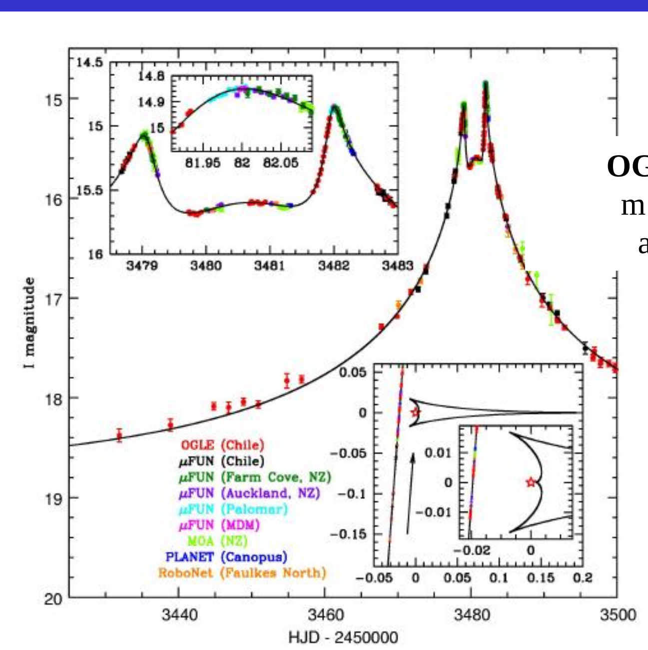
4 exoplanets found by microlensing including 2 big-earth planets



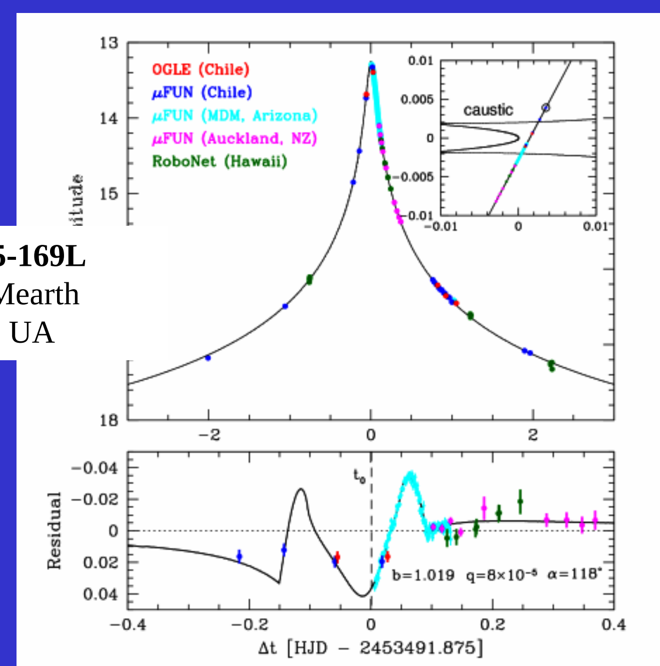
OGLE235-MOA53b
m ~ 2.6 Mjup
a ~ 5.1 UA



OGLE05-390L
m ~ 5.5 Mearth
a ~ 2.1 UA

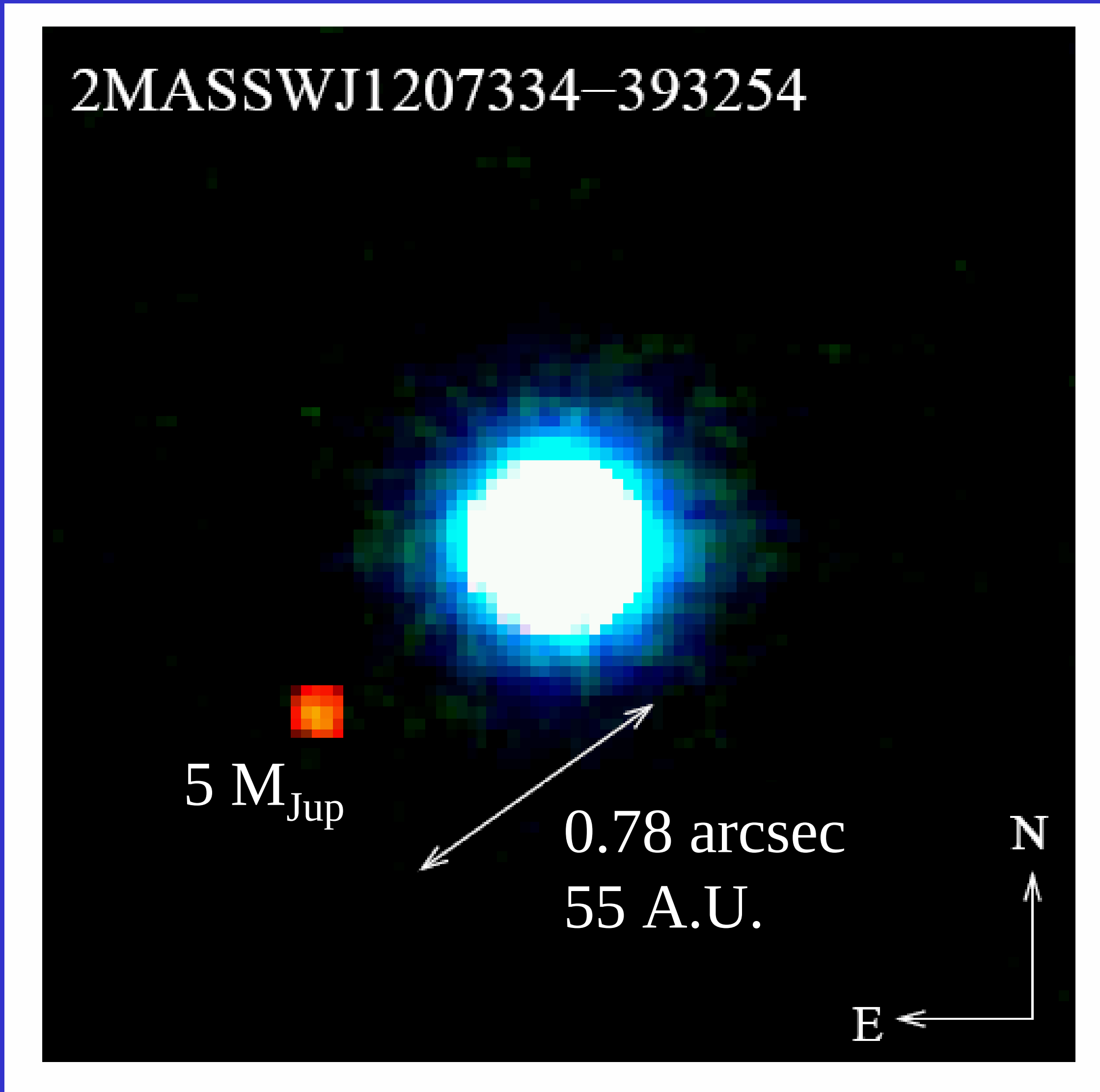


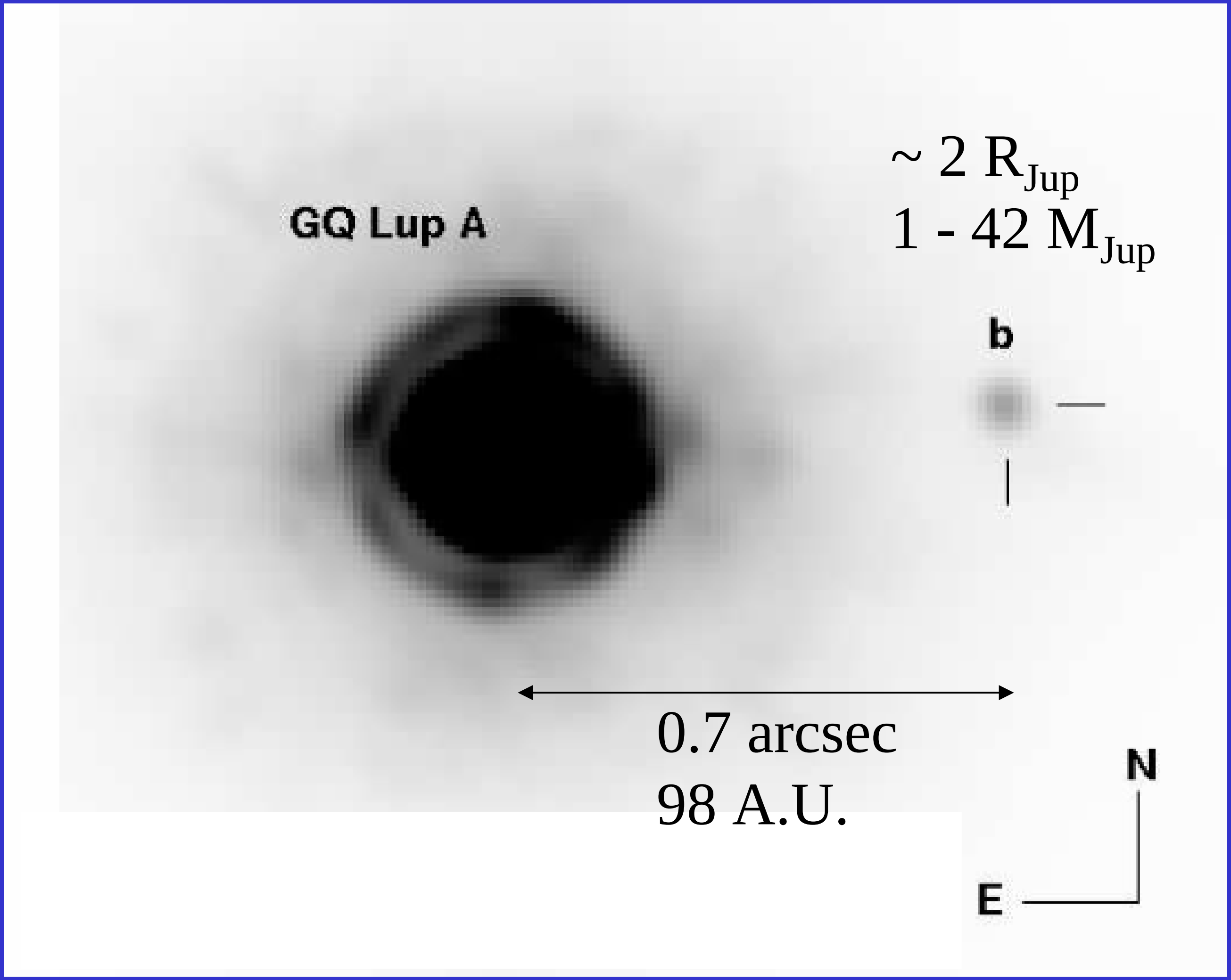
OGLE05-071L
m ~ 0.9 Mjup
a ~ 1.8 UA



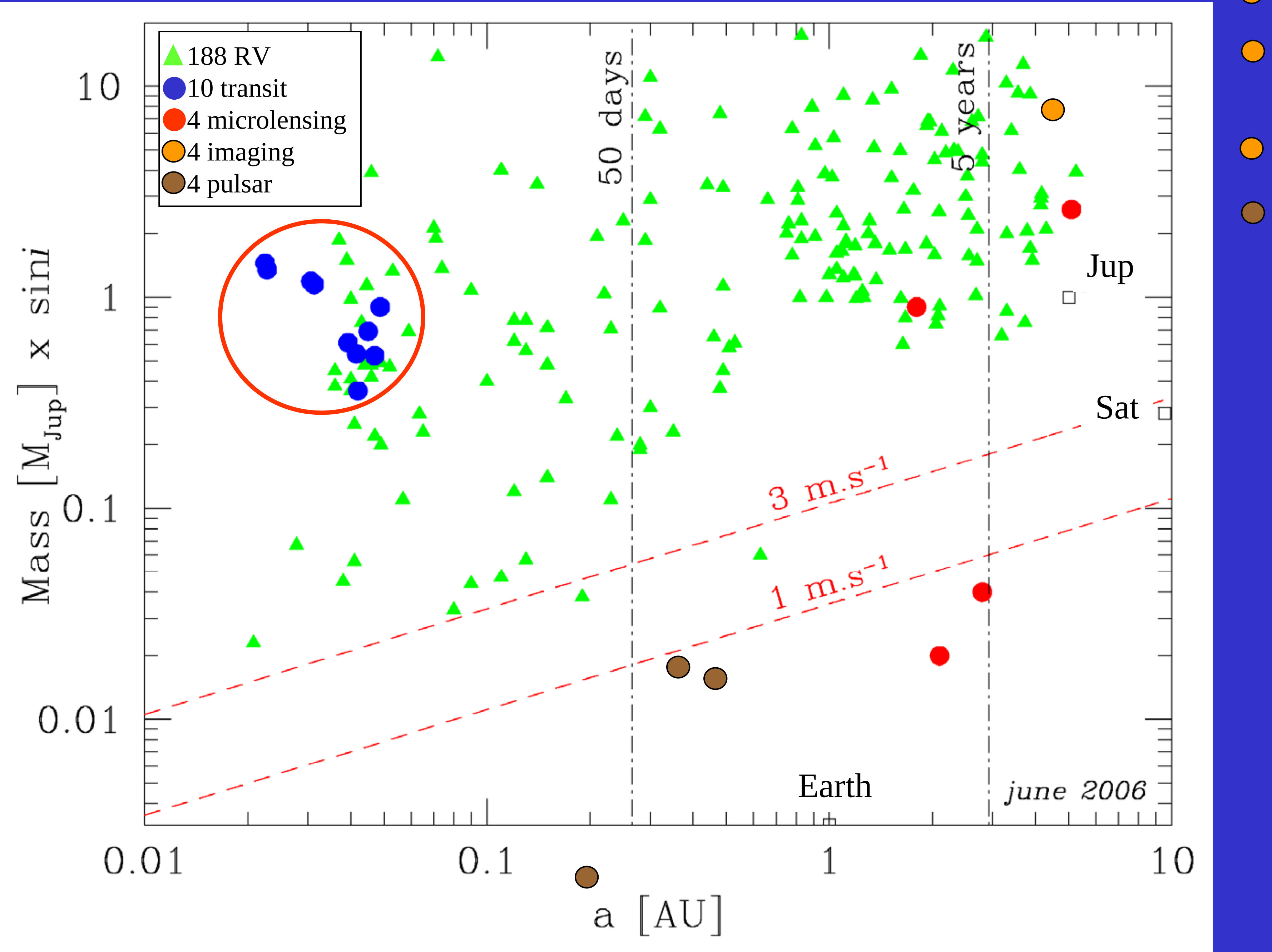
OGLE05-169L
m ~ 13 Mearth
a ~ 2.8 UA

First image of a young giant planet orbiting a brown dwarf

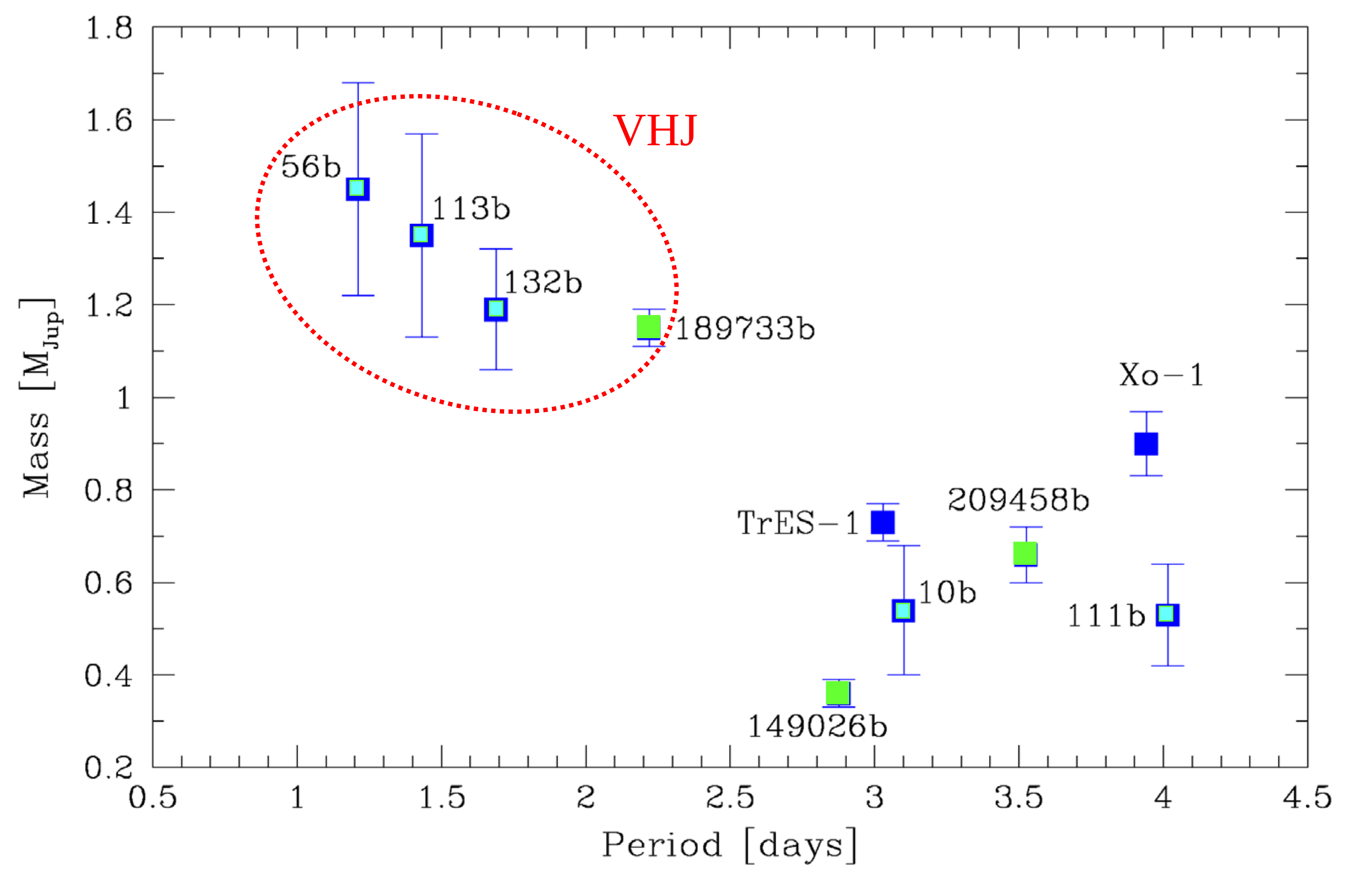



~ 2 R_{Jup}
1 - 42 M_{Jup}
GQ Lup A
b
0.7 arcsec
98 A.U.
N
E

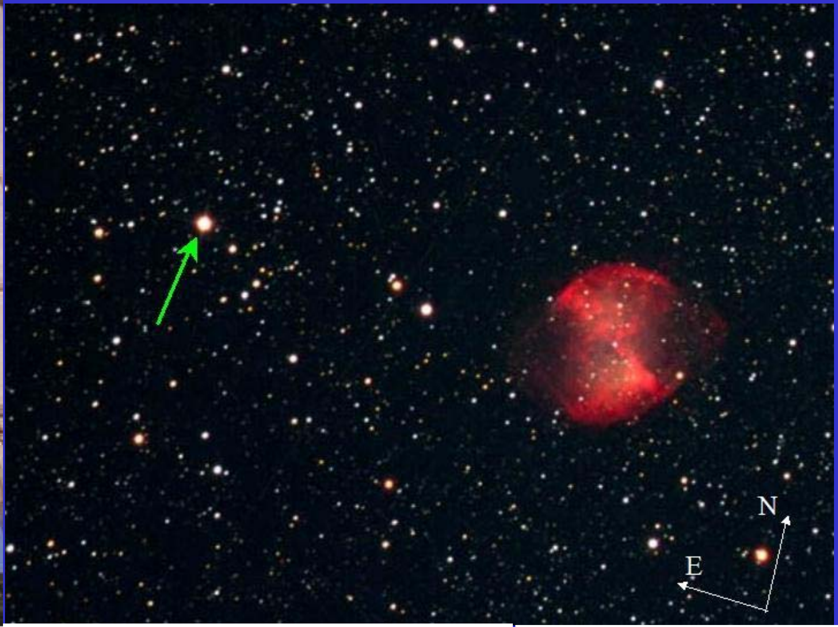
10 characterized planets



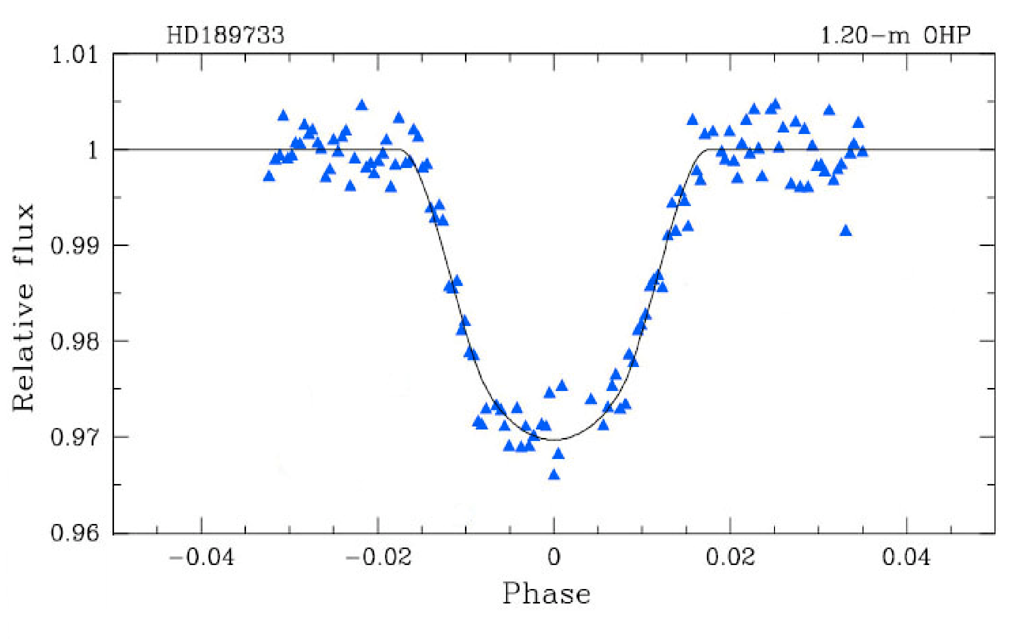
10 transiting extrasolar planets
Characterized by photometry and radial velocity

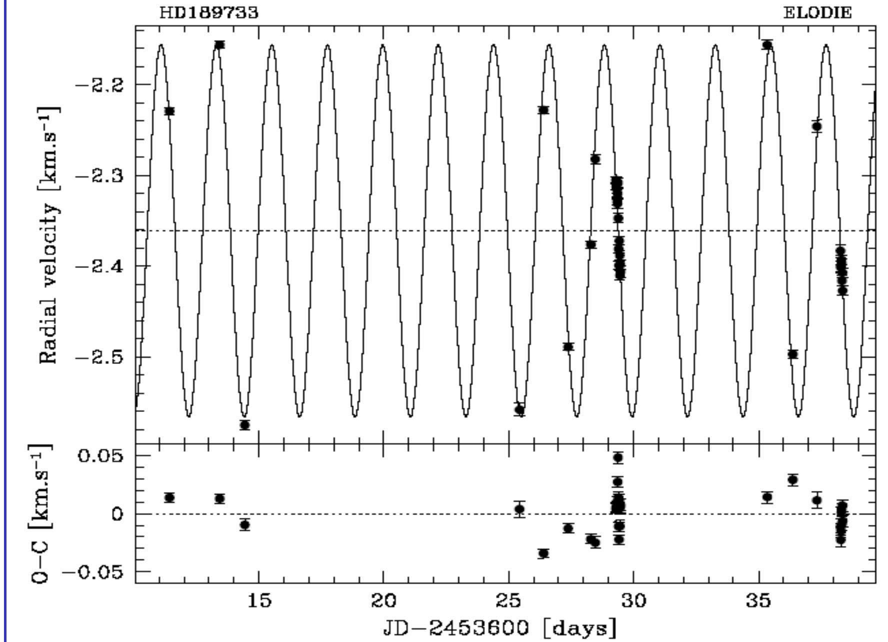


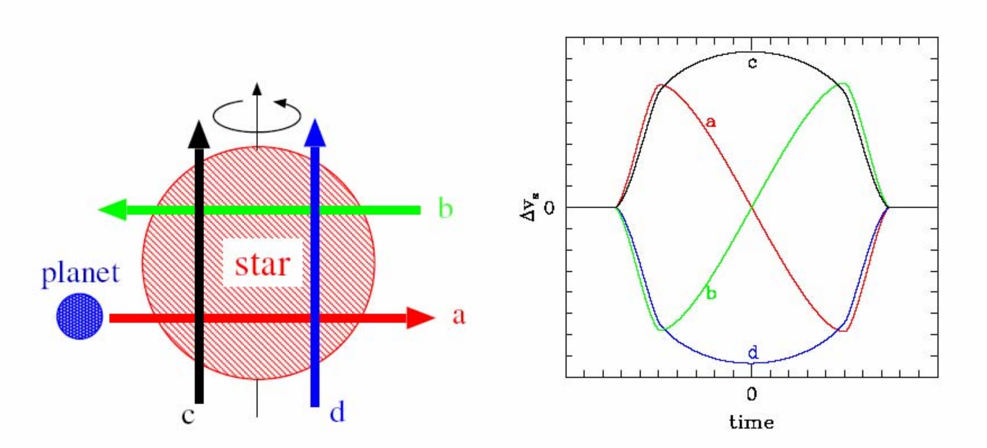
HD189733b detected and characterized at OHP



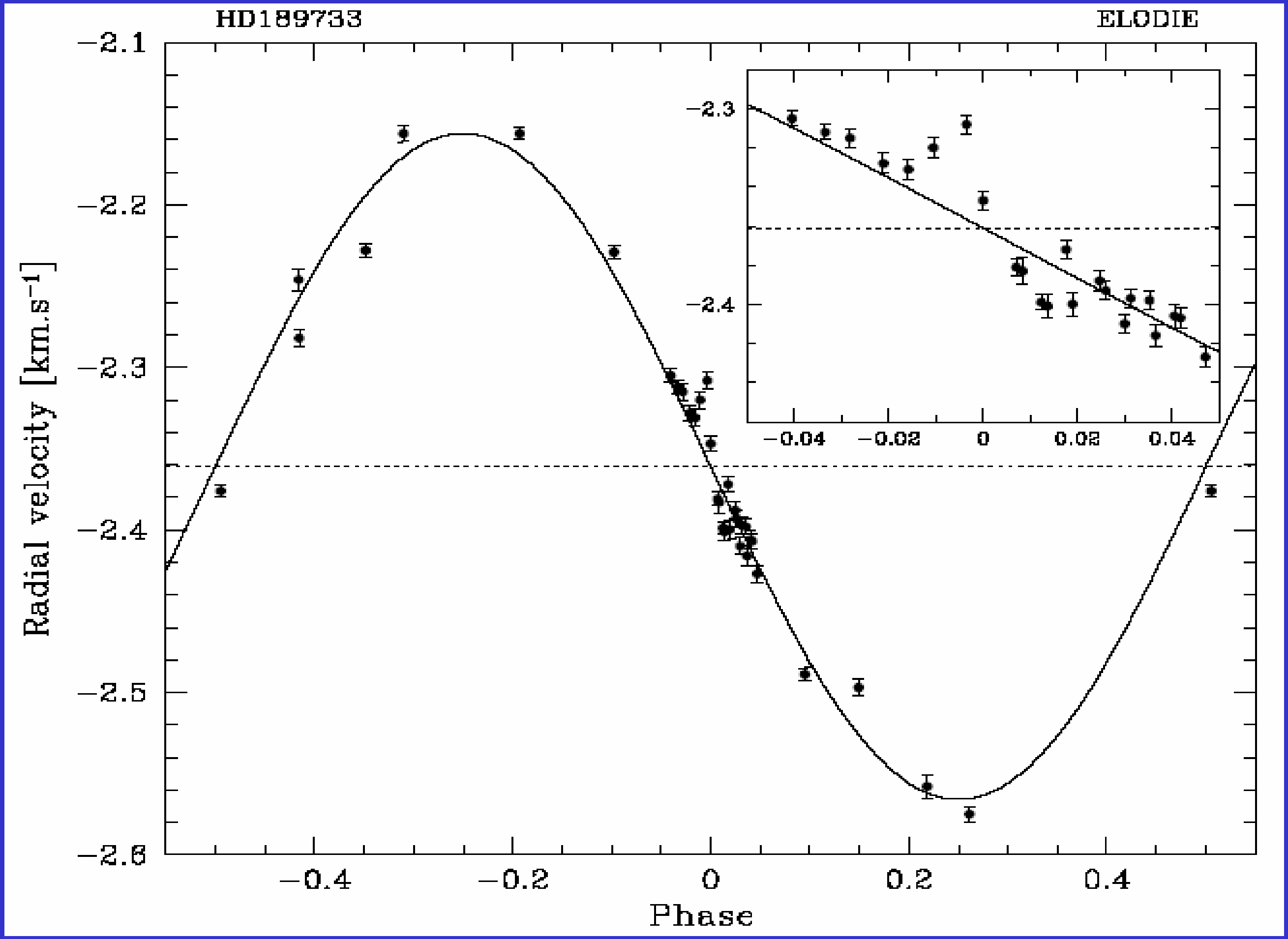
$P = 2.22$ days
$m = 1.15\ M_{Jup}$
$r = 1.2\ R_{Jup}$



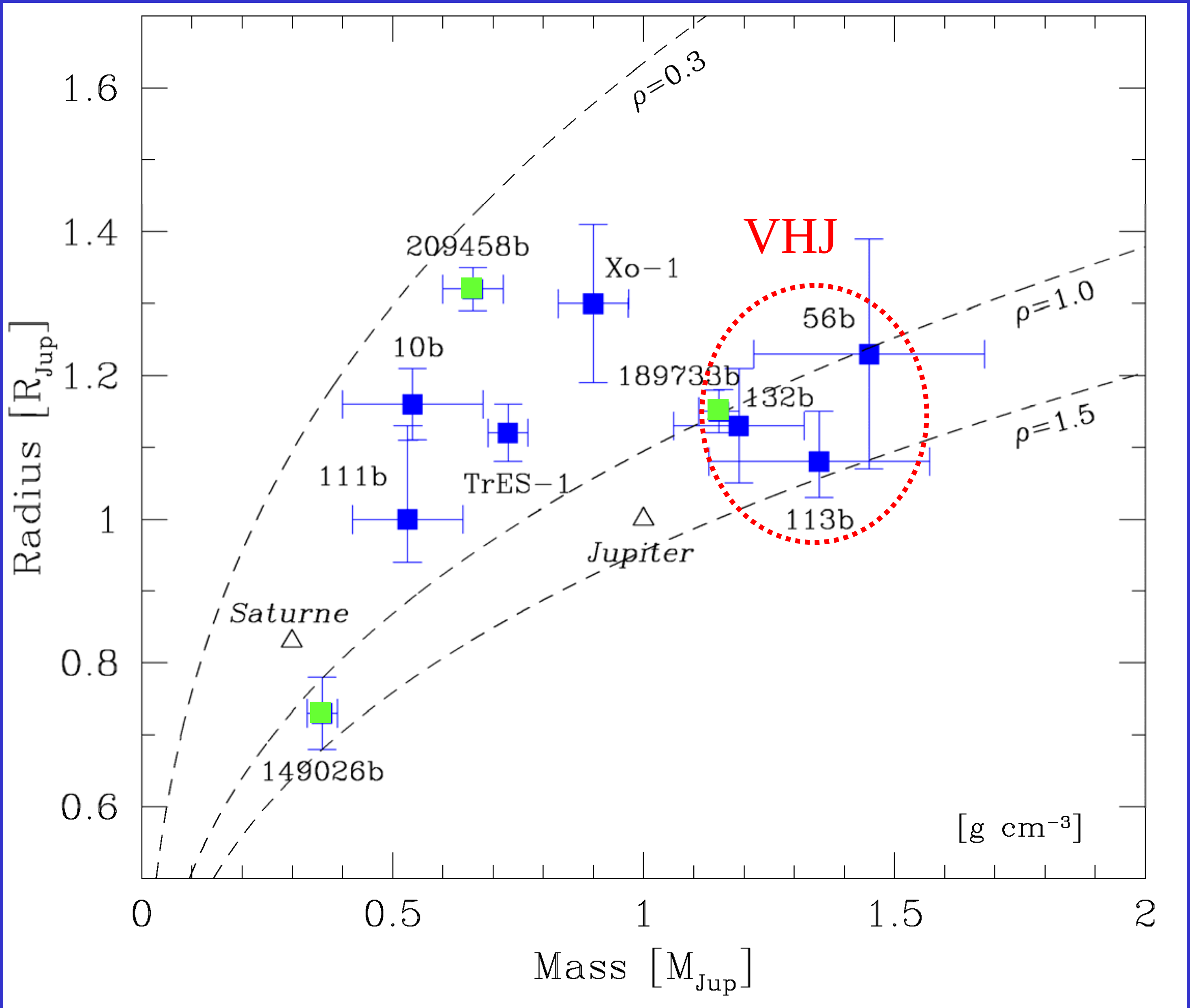




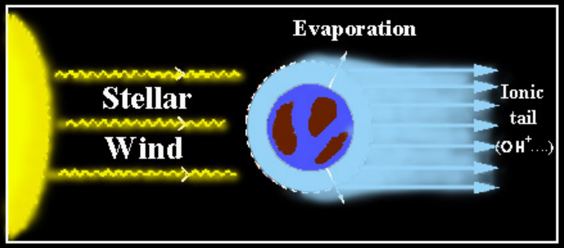
Spectroscopic transit of HD189733 (Rossiter - McLaughlin effect)

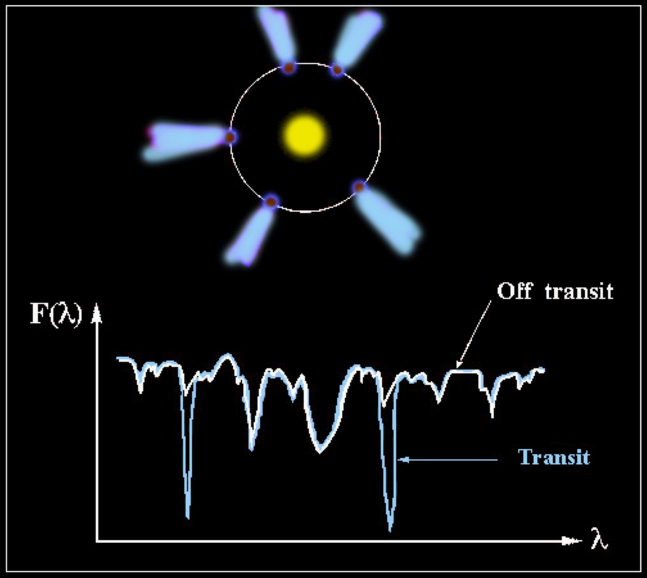


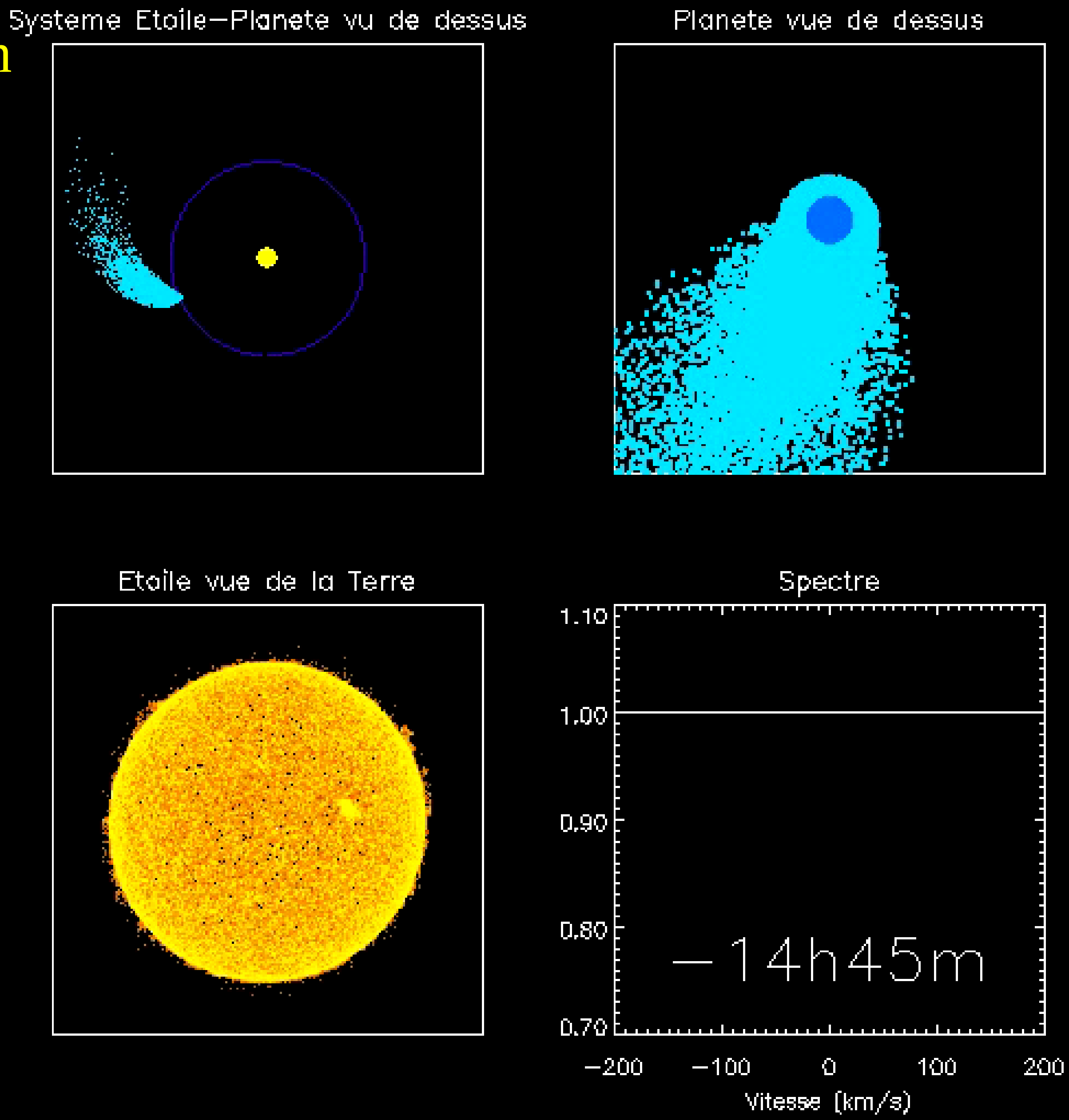
Mass – radius relation of the 10 transiting extrasolar planets



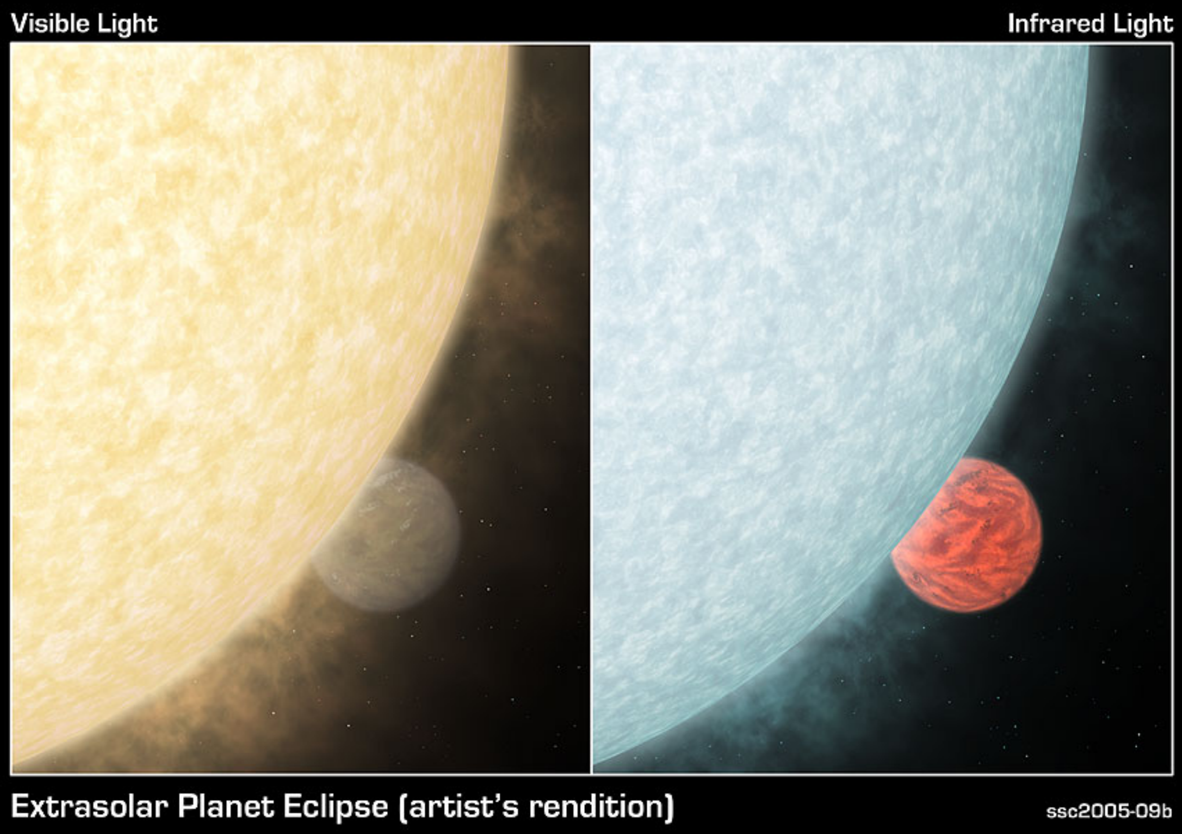
Atmosphere Evaporation of HD209458b

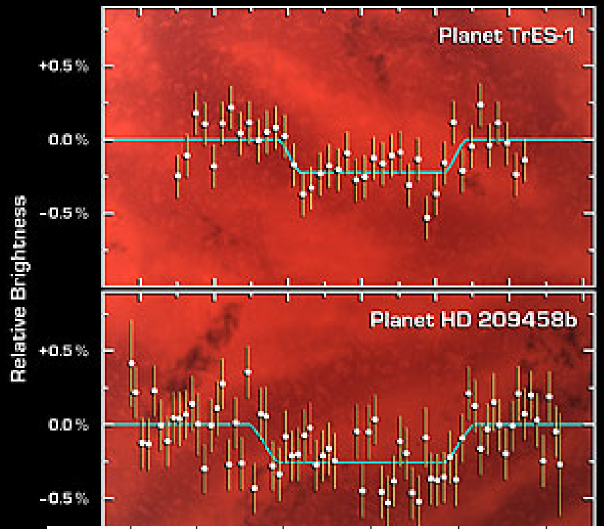


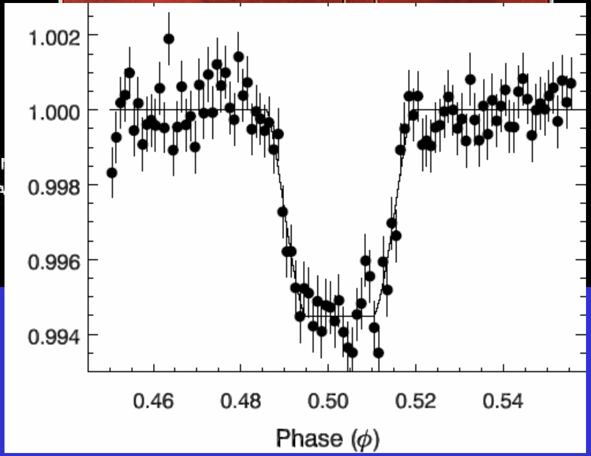




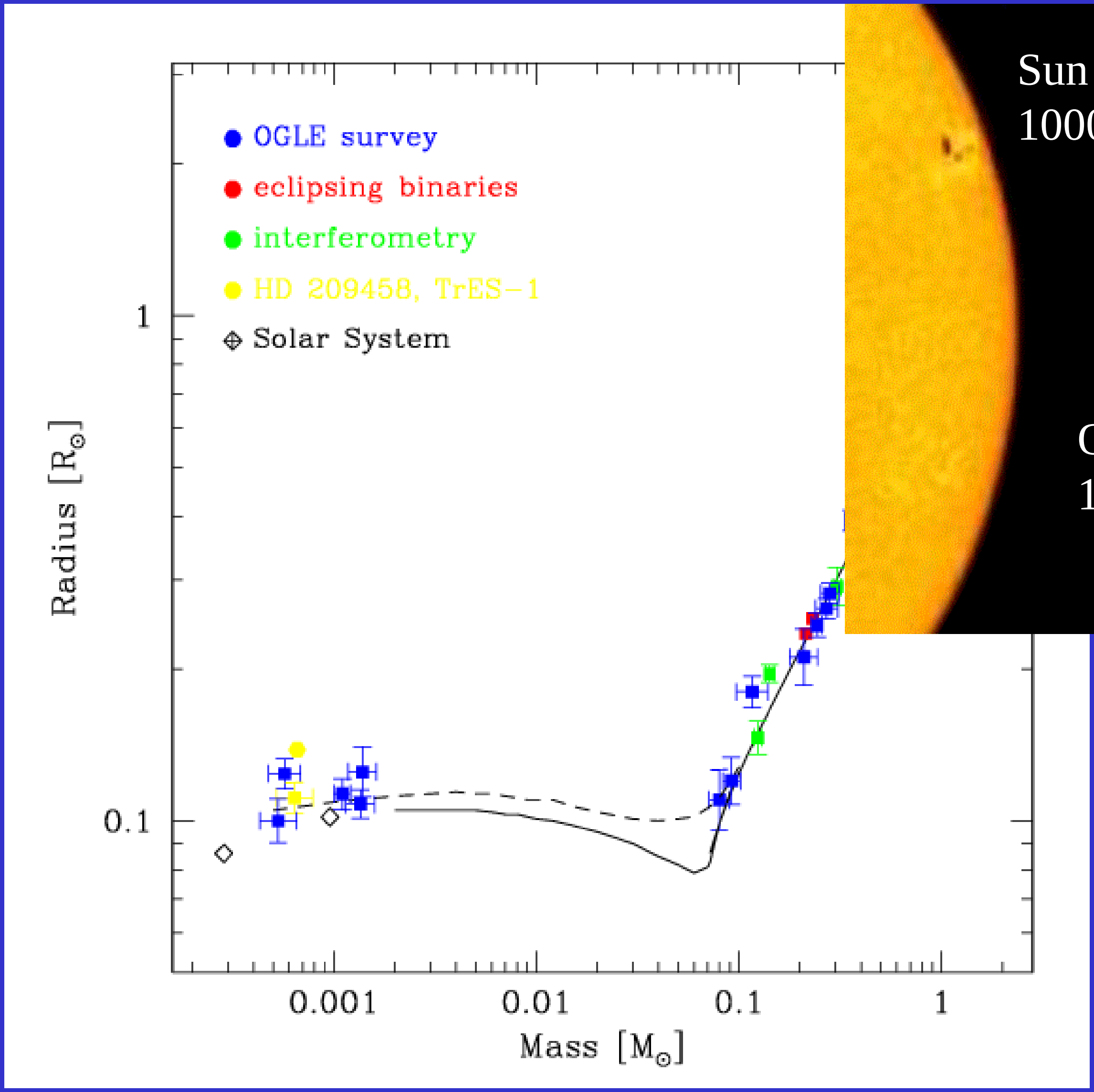
Spitzer IR anti-transits of HD209458b, Tres-1 and HD189733b

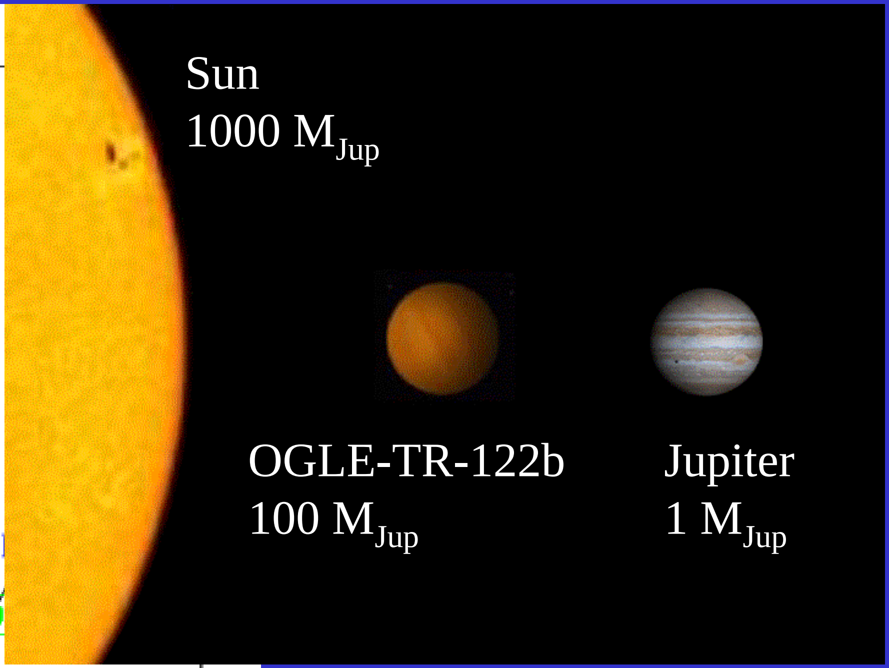






From planets to low-mass stars





OGLE-TR-122b :
A planet-size star

Photometry + Radial Velocity + Spectroscopy
Fully complementary methods

a, P, e, T_0, b, α

m_p, r_p, ρ, m_{core} , T, evap. , …

R_*, M_*, [Fe/H], $v\sin i$, R'_{HK} , …

→Constraints for processes of formation and evolution
→Constraints for composition and internal structure

Lack of efficiency of photometric surveys

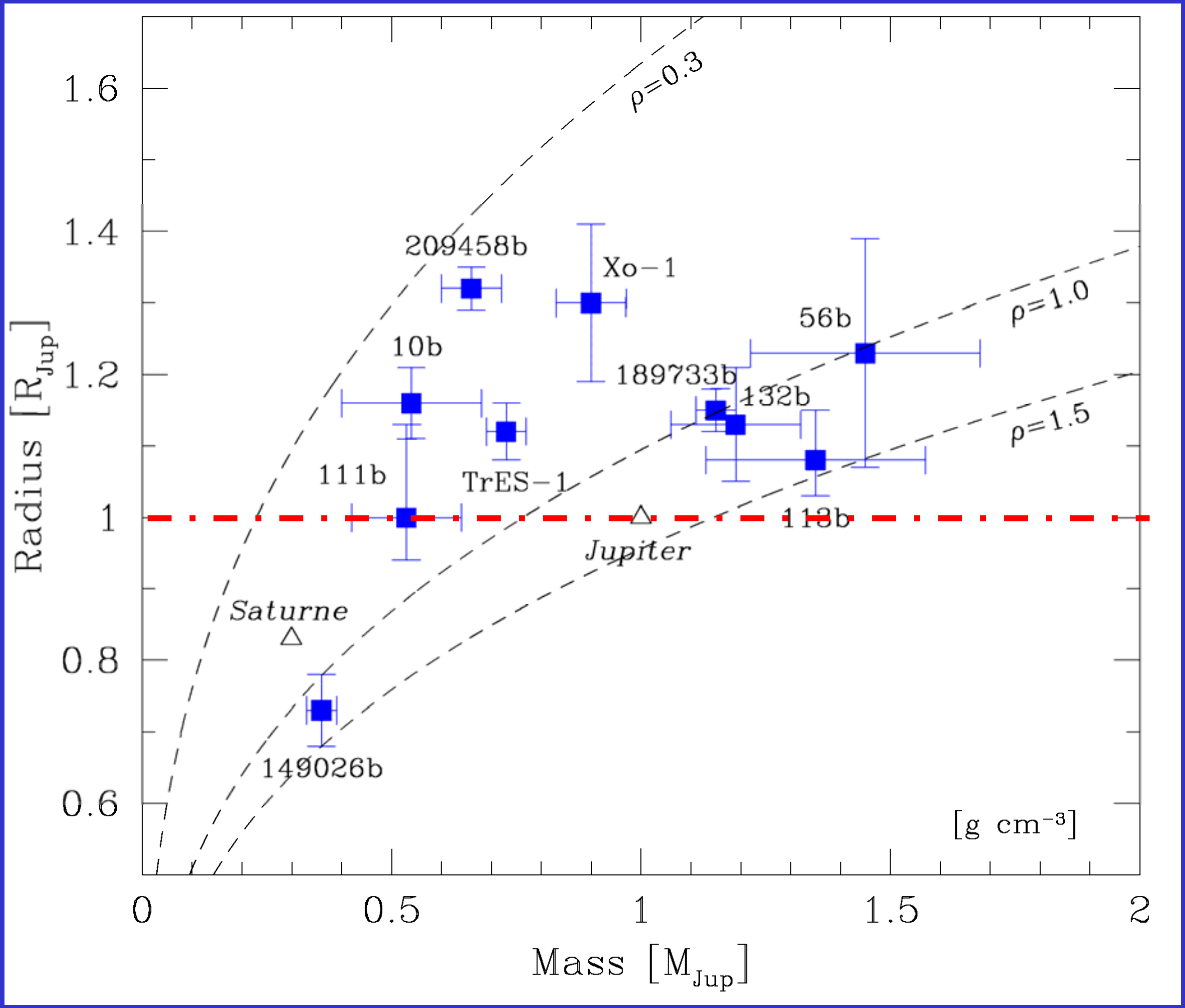
Transit Search Programmes

Programme		D (cm)	focal ratio	$W^{0.5}$ (deg)	N_x (kpix)	N_y (kpix)	no. of CCDs	pixel (arcsec)	sky mag	star mag	d (pc)	stars ($x10^3$)	planets /month
1	PASS	2.5	2.0	127.25	2.0	2.0	15	57.75	6.8	9.4	83	18	~~6.3~~ 0
2	WASP0	6.4	2.8	8.84	2.0	2.0	1	15.54	9.6	11.8	246	2	~~0.8~~ 0
3	ASAS-3	7.1	2.8	11.21	2.0	2.0	2	13.93	9.9	12.0	272	5	~~1.7~~ 0
4	RAPTOR	7.0	1.2	55.32	2.0	2.0	8	34.38	7.9	11.1	179	33	~~11.7~~ 0
5	TrES	10.0	2.9	10.51	2.0	2.0	3	10.67	10.5	12.7	362	10	~~3.5~~ 1
6	HATnet	11.1	1.8	19.42	2.0	2.0	6	13.94	9.9	12.5	338	28	~~9.7~~ 0
7	SWASP	11.1	1.8	31.71	2.0	2.0	16	13.94	9.9	12.5	338	74	~~26.0~~ 0
8	Vulcan	12.0	2.5	7.04	4.0	4.0	1	6.19	11.6	13.4	497	12	~~4.1~~ 0
9	RAPTOR-F	14.0	2.8	5.93	2.0	2.0	2	7.37	11.3	13.4	498	8	~~2.9~~ 0
10	BEST	19.5	2.7	3.01	2.0	2.0	1	5.29	12.0	14.2	668	5	~~1.8~~ 0
11	Vulcan-S	20.3	1.5	6.94	4.0	4.0	1	6.10	11.7	14.1	642	24	~~8.5~~ 0
12	SSO/APT	50.0	1.0	7.00	2.9	5.9	2	4.20	12.5	15.5	1103	126	~~43.8~~ 0
13	RATS	67.0	3.0	1.31	2.0	2.0	1	2.30	13.8	16.4	1548	12	~~4.2~~ 0
14	TeMPEST	76.0	3.0	0.77	2.0	2.0	1	1.35	15.0	17.1	1944	8	~~2.9~~ 0
15	EXPLORE-OC	101.6	7.0	0.32	2.0	3.3	1	0.44	17.1	18.4	2881	5	~~1.6~~ 0
16	PISCES	120.0	7.7	0.38	2.0	2.0	4	0.33	17.1	18.6	3045	8	~~2.7~~ 0
17	ASP	130.0	13.5	0.17	2.0	2.0	1	0.30	17.1	18.7	3125	2	~~0.6~~ 0
18	OGLE-III	130.0	9.2	0.59	2.0	4.0	8	0.26	17.1	18.7	3125	20	~~7.1~~ 5
19	STEPSS	240.0	0.0	0.41	4.0	2.0	8	0.18	17.1	19.5	3757	17	~~5.9~~ 0
20	INT	250.0	3.0	0.60	2.0	4.0	4	0.37	17.1	19.5	3800	37	~~13.1~~ 0
21	ONC	254.0	3.3	0.53	2.0	4.0	4	0.33	17.1	19.5	3817	30	~~10.5~~ 0
22	EXPLORE-N	360.0	4.2	0.57	2.0	4.0	12	0.21	17.1	19.9	4196	46	~~16.2~~ 0
23	EXPLORE-S	400.0	2.9	0.61	2.0	4.0	8	0.27	17.1	20.0	4313	58	~~20.1~~ 0
Total number of planets/month:													~~205~~ 6

More than 200 planets per month were expected

Up to day a total of only 7 detections

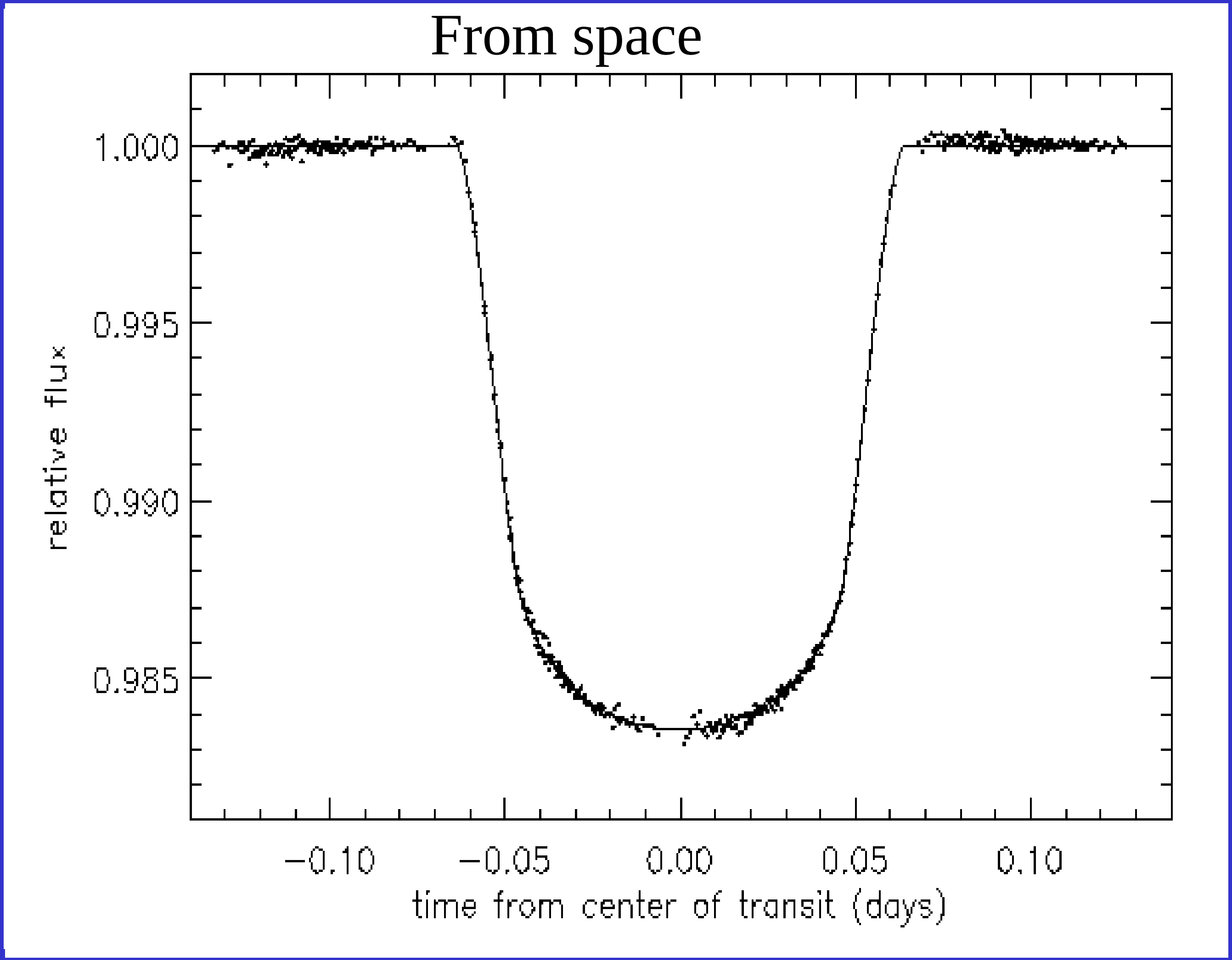
No transiting planet detected with a depth < 1.1%



Transit Depth	
OGLE-113	2.9%
Tres-1	2.3%
Xo-1	2.0%
OGLE-111	1.9%
OGLE-10	1.9%
OGLE-56	1.3 %
OGLE-132	1.1 %

1) Insufficient time coverage
2) Difficulties to reach the mmag precision

Photometric transit of HD209458b



$1.4\ R_{Jup}$
$0.69\ M_{Jup}$
$0.31\ g.cm^{-3}$

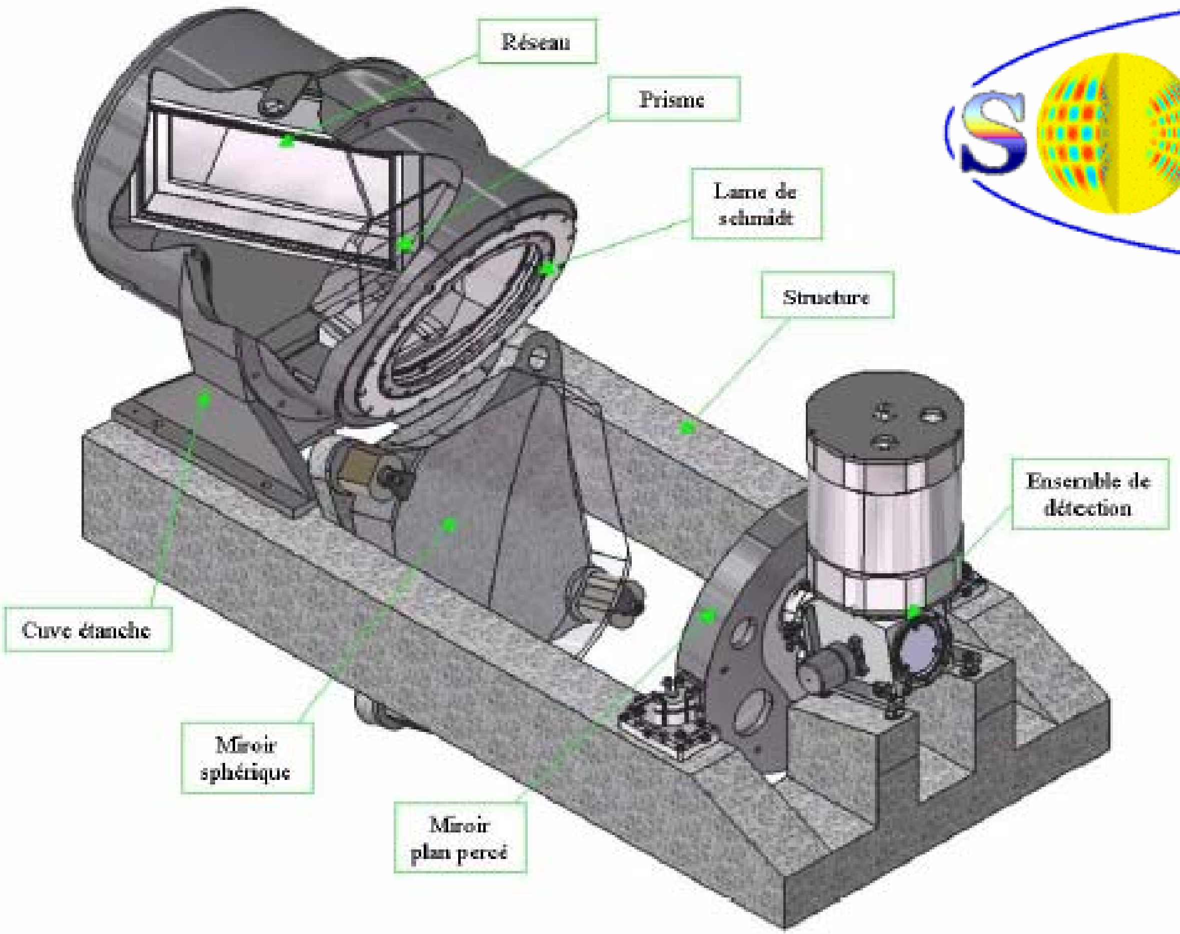
0.047 A.U.
3.524 days

COROT

Space photometric detection of planetary transiting candidates

~100’000 stars
observed during 150 days

~ 100 Hot Jupiters
~ 10 Hot Neptunes

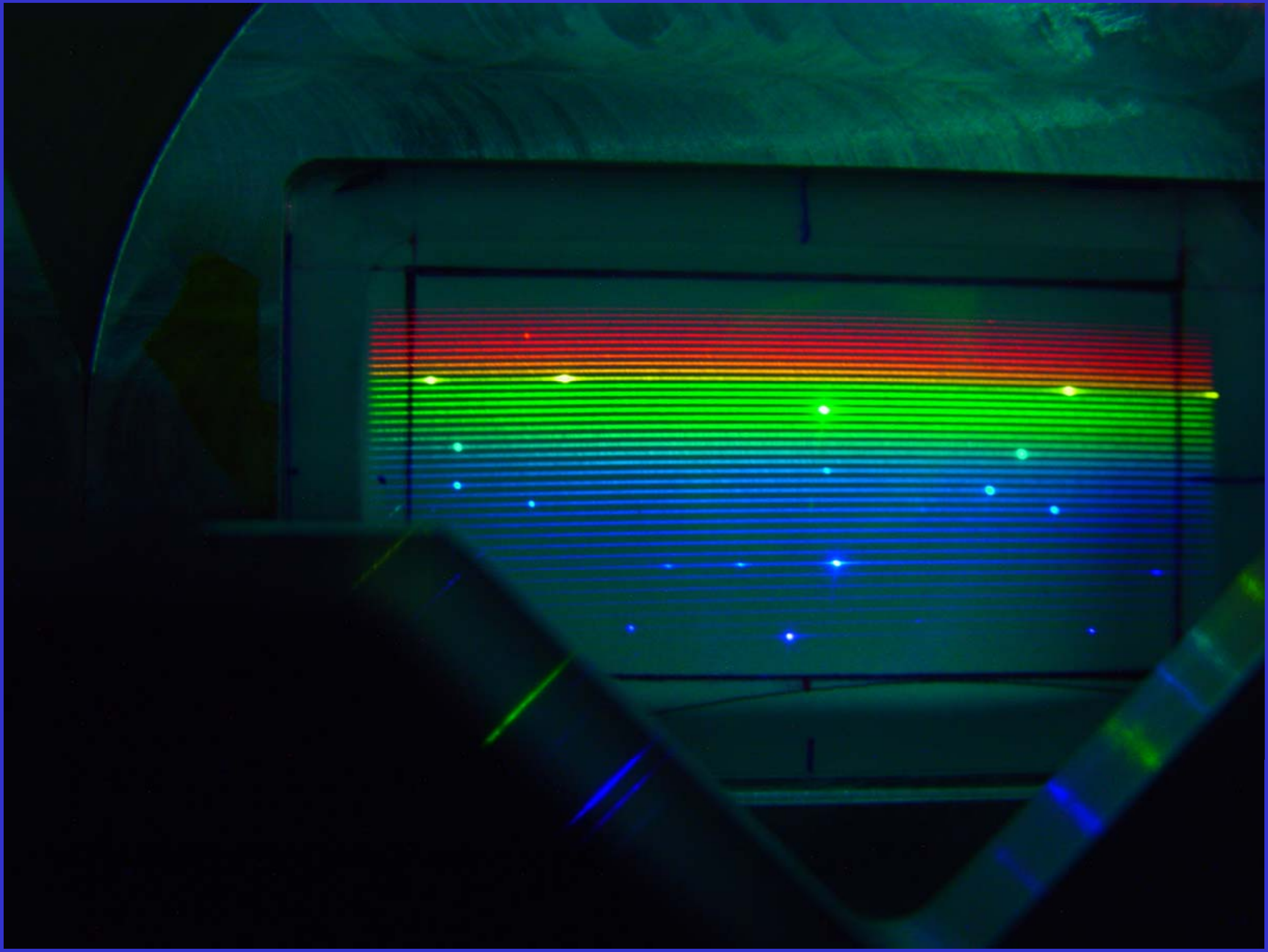


SOPHIE

New spectrograph on the 193-cm telescope

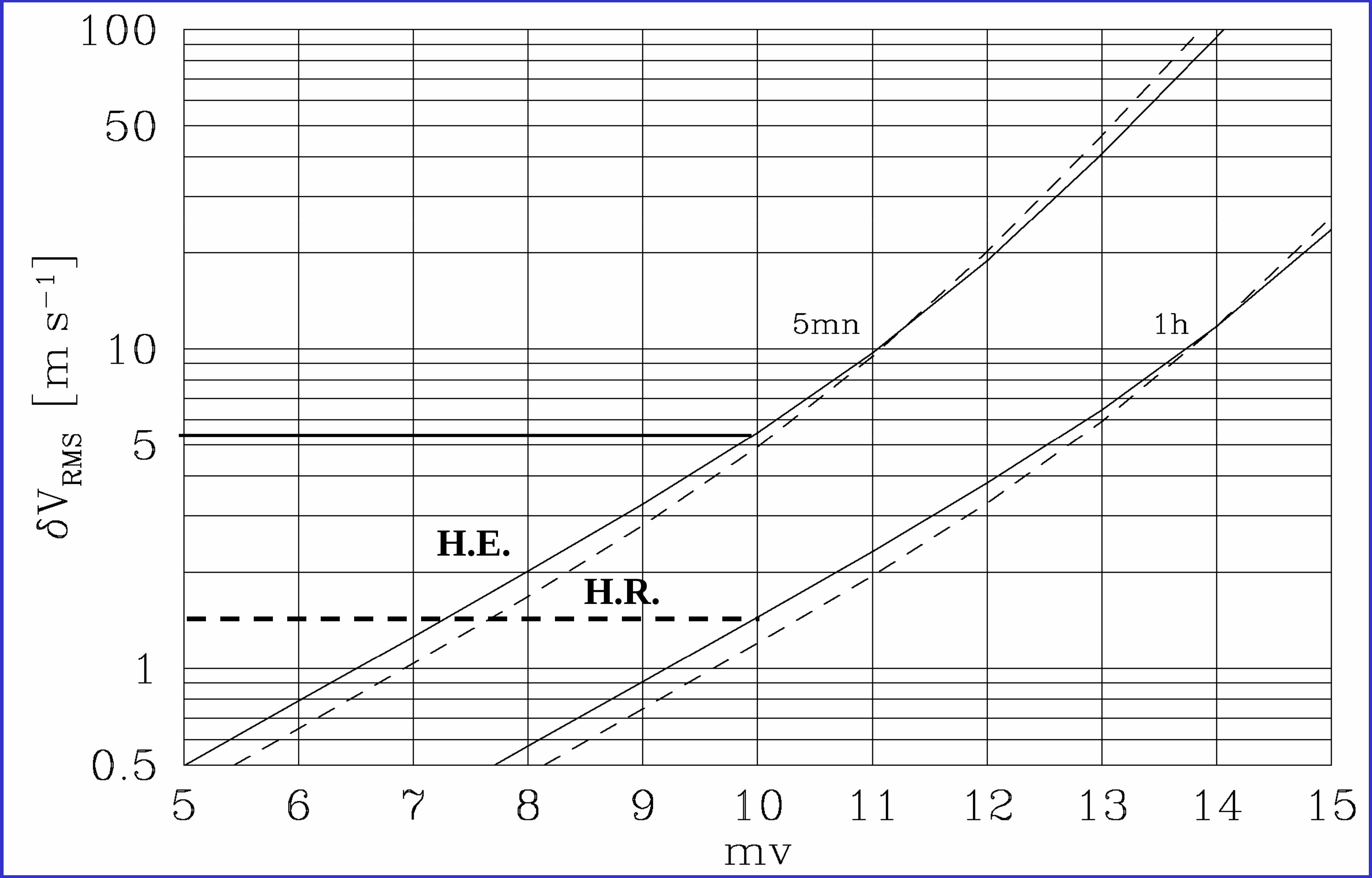
North Counter part of HARPS (R~70’000)
~ 2 mag more efficient than ELODIE
~ 1-2 m/s expected precision

First laboratory spectrum



First stellar spectrum
[51Peg]

Expected performances

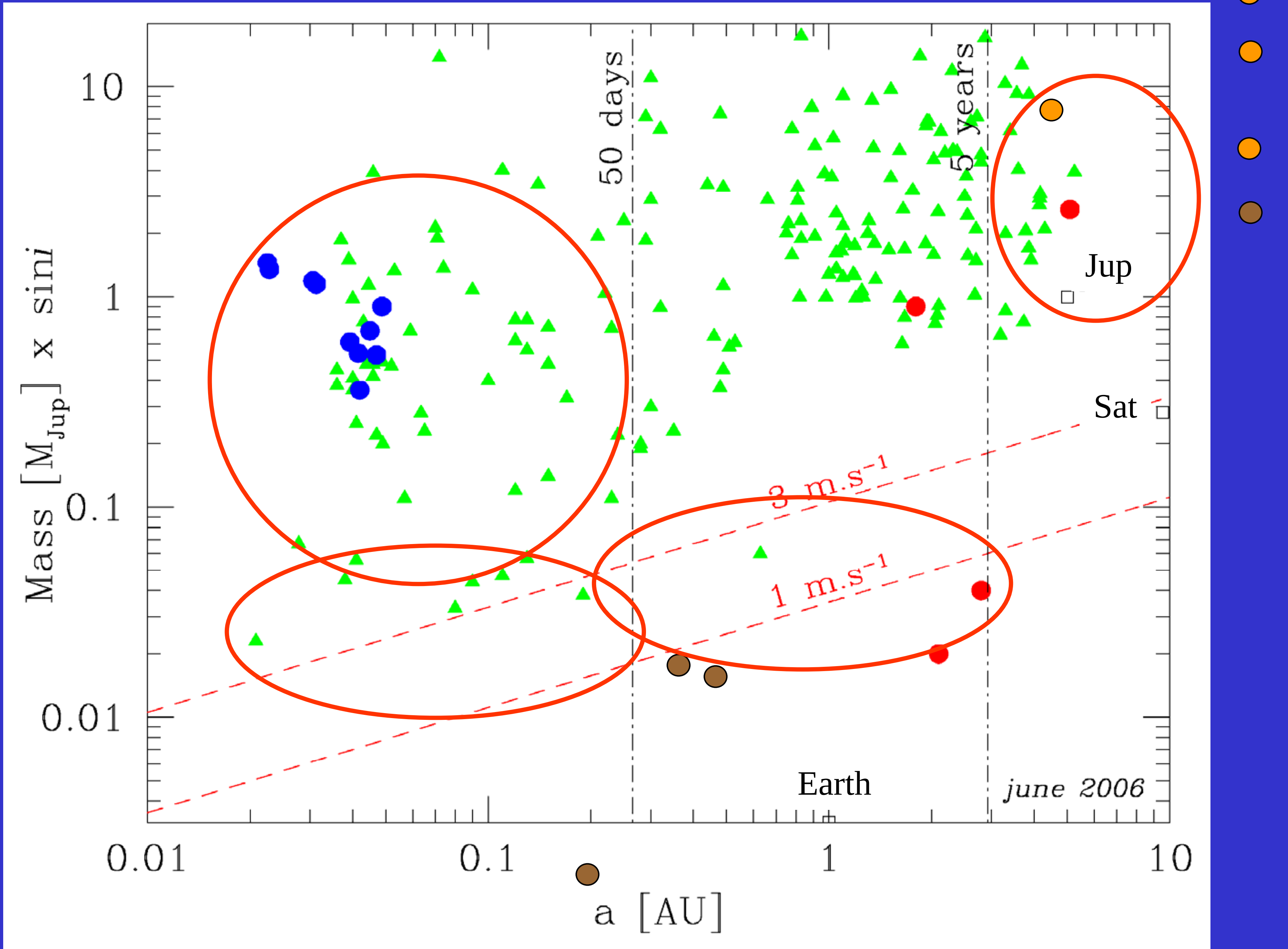


Schedule

31 July – 7 August	: 1th commissioning
21 – 28 August	: 2d commissioning
September – October	: Science verification
1th November	: Opening to community

Consortium Exoplanet Search in North Hemisphere
22 Co-Is from France and Switzerland
200 nights per years

Next steps


10
1
0.1
0.01
0.01
0.1
1
10
Mass [M_{Jup}] x sin*i*
a [AU]
50 days
5 years
3 m.s^{-1}
1 m.s^{-1}
Jup
Sat
Earth
june 2006