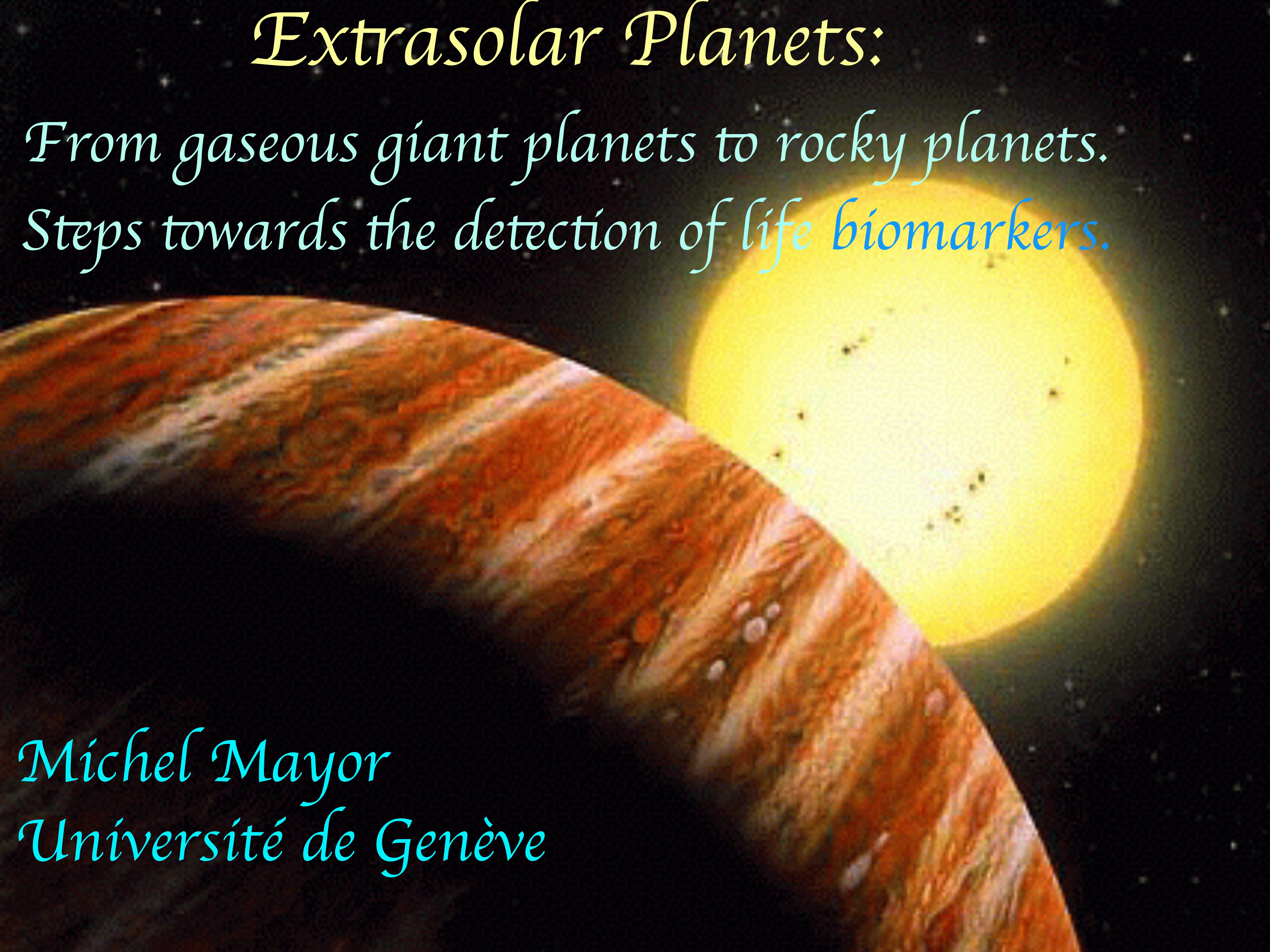
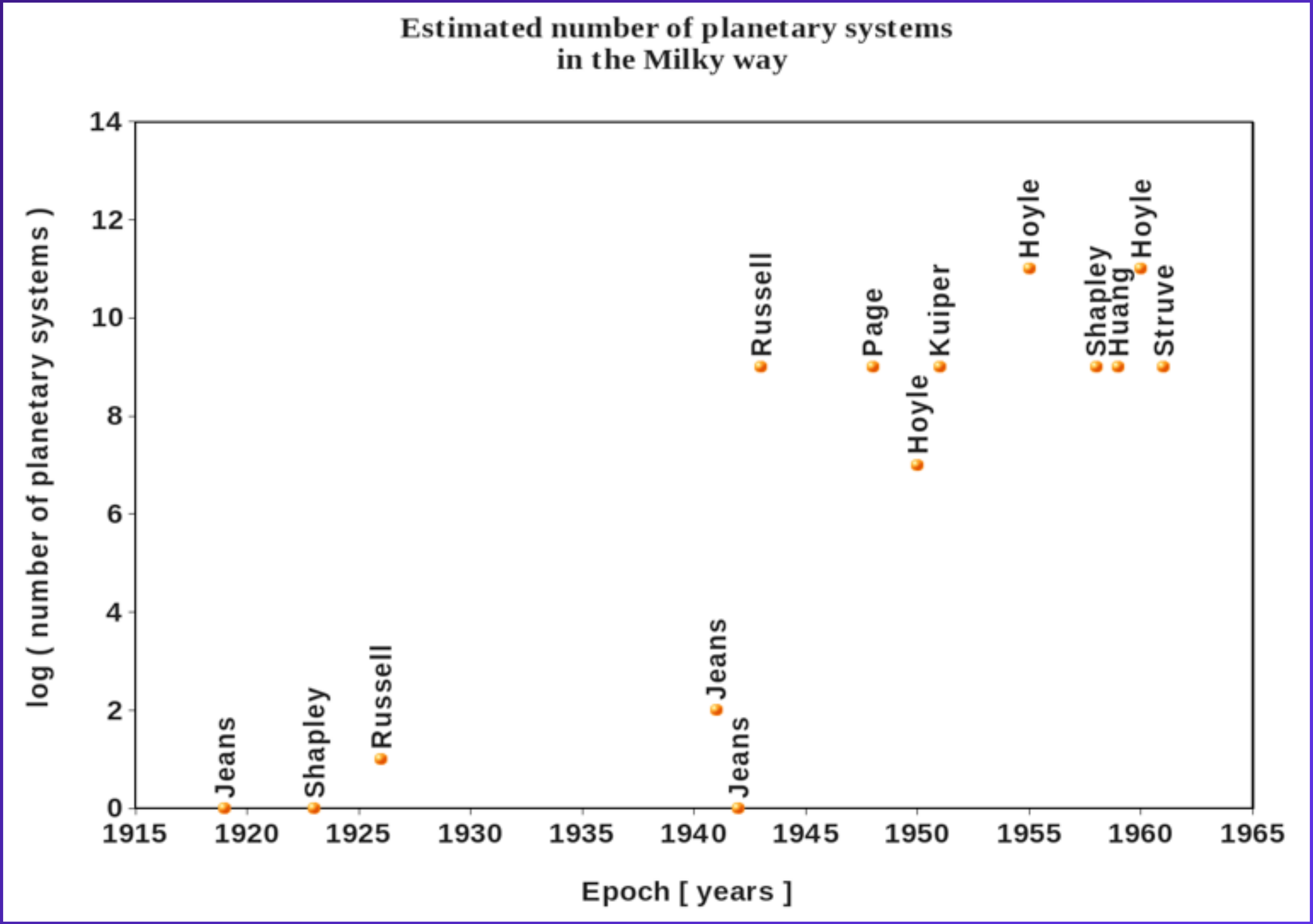
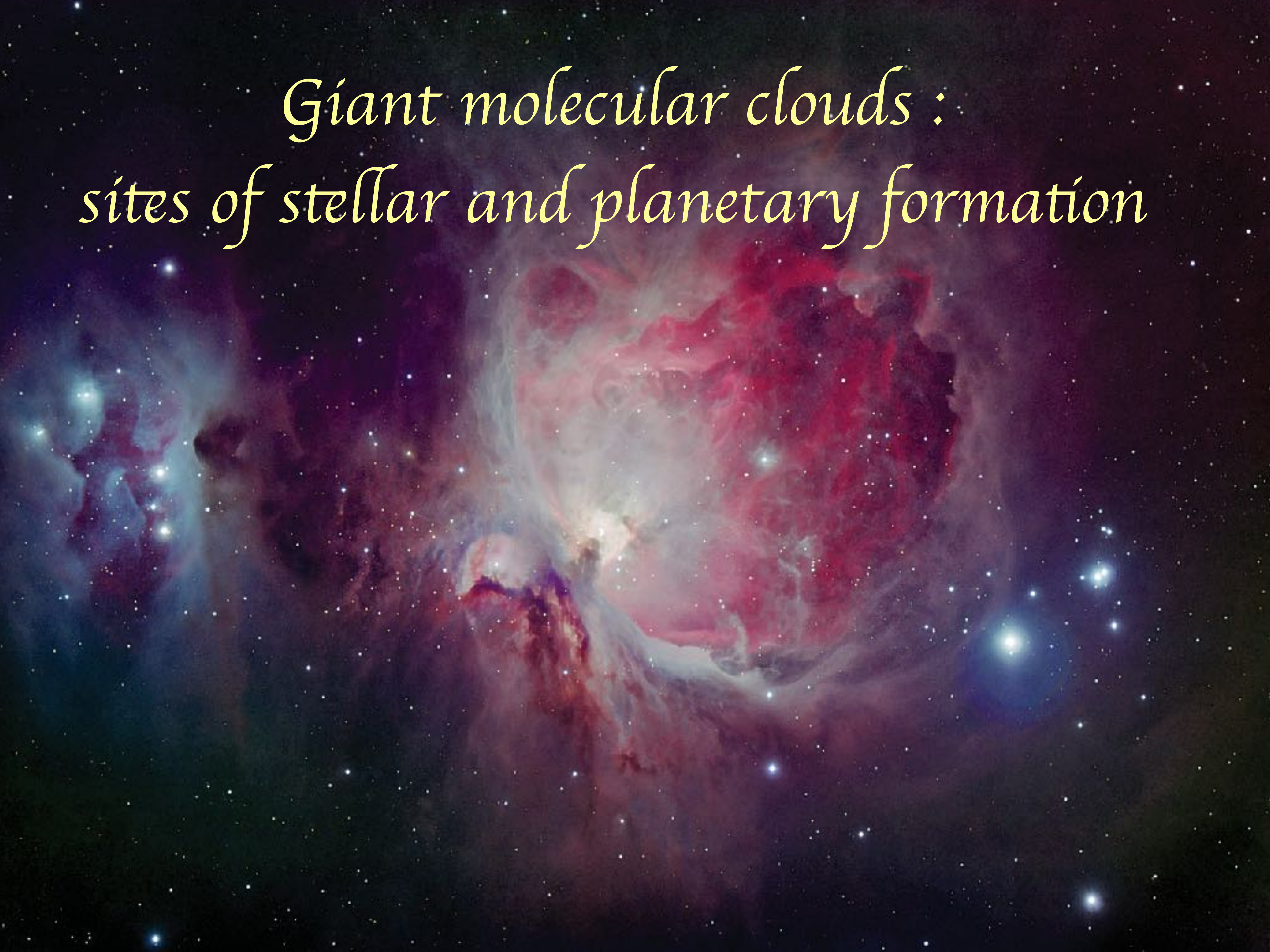


Extrasolar Planets:
From gaseous giant planets to rocky planets.
Steps towards the detection of life biomarkers.
Michel Mayor
Université de Genève



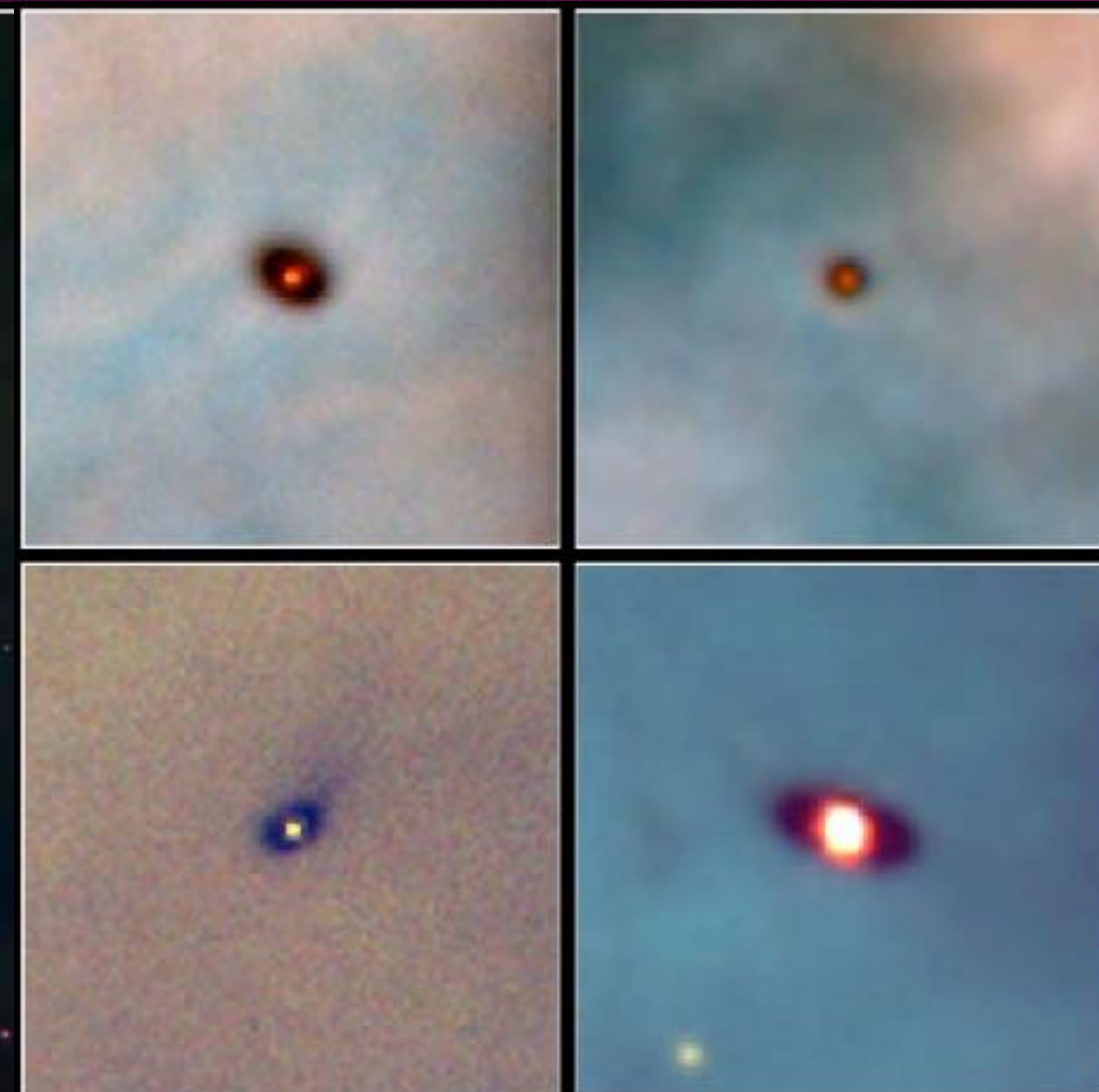
Adapted from S.J.Dick 1991

Giant molecular clouds :
sites of stellar and planetary formation



Protoplanetary discs observed by the HST

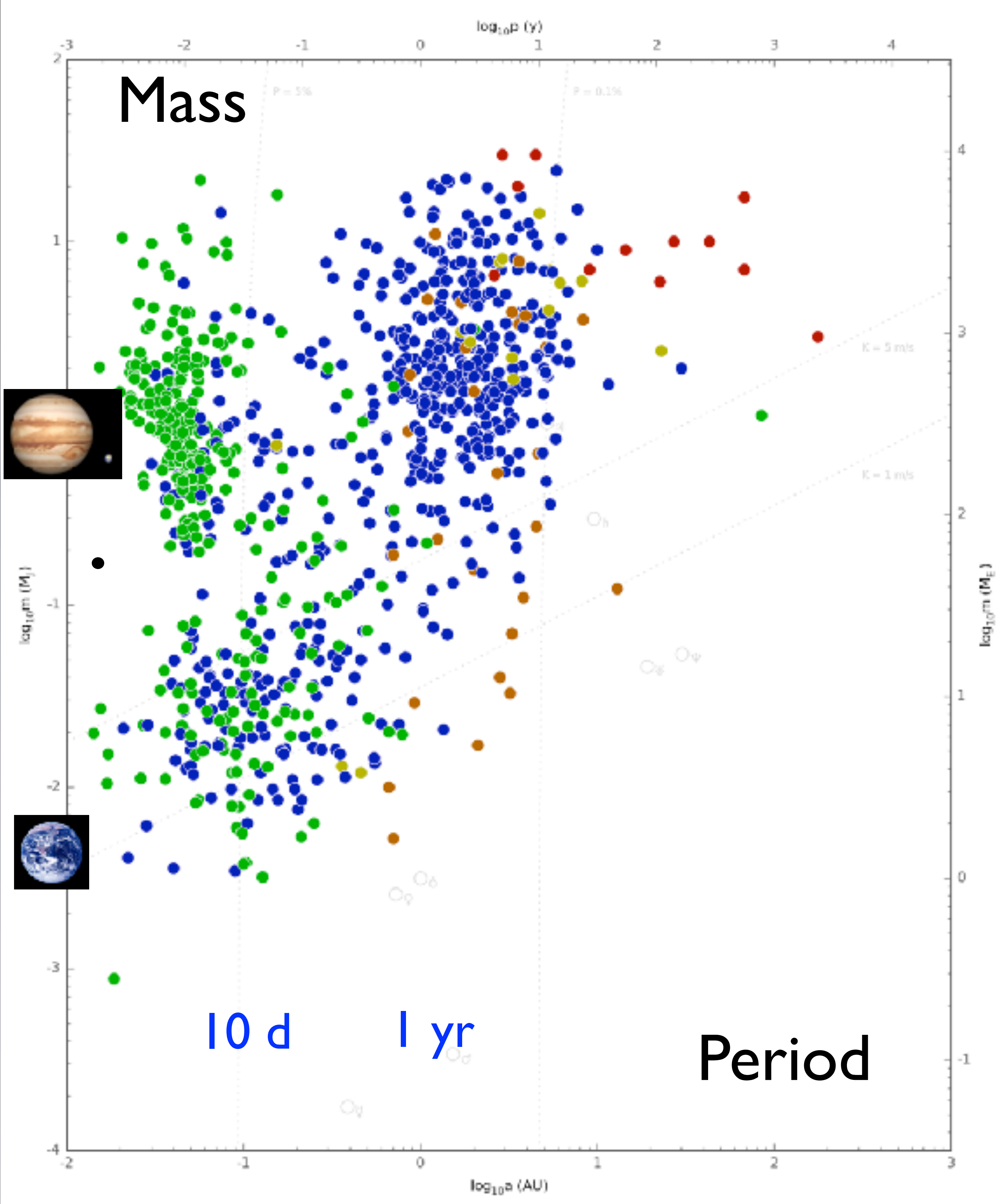
Orion Nebula Mosaic HST • WFPC2
PRC95-45a • ST ScI OPO • November 20, 1995
C. R. O'Dell and S. K. Wong (Rice University), NASA



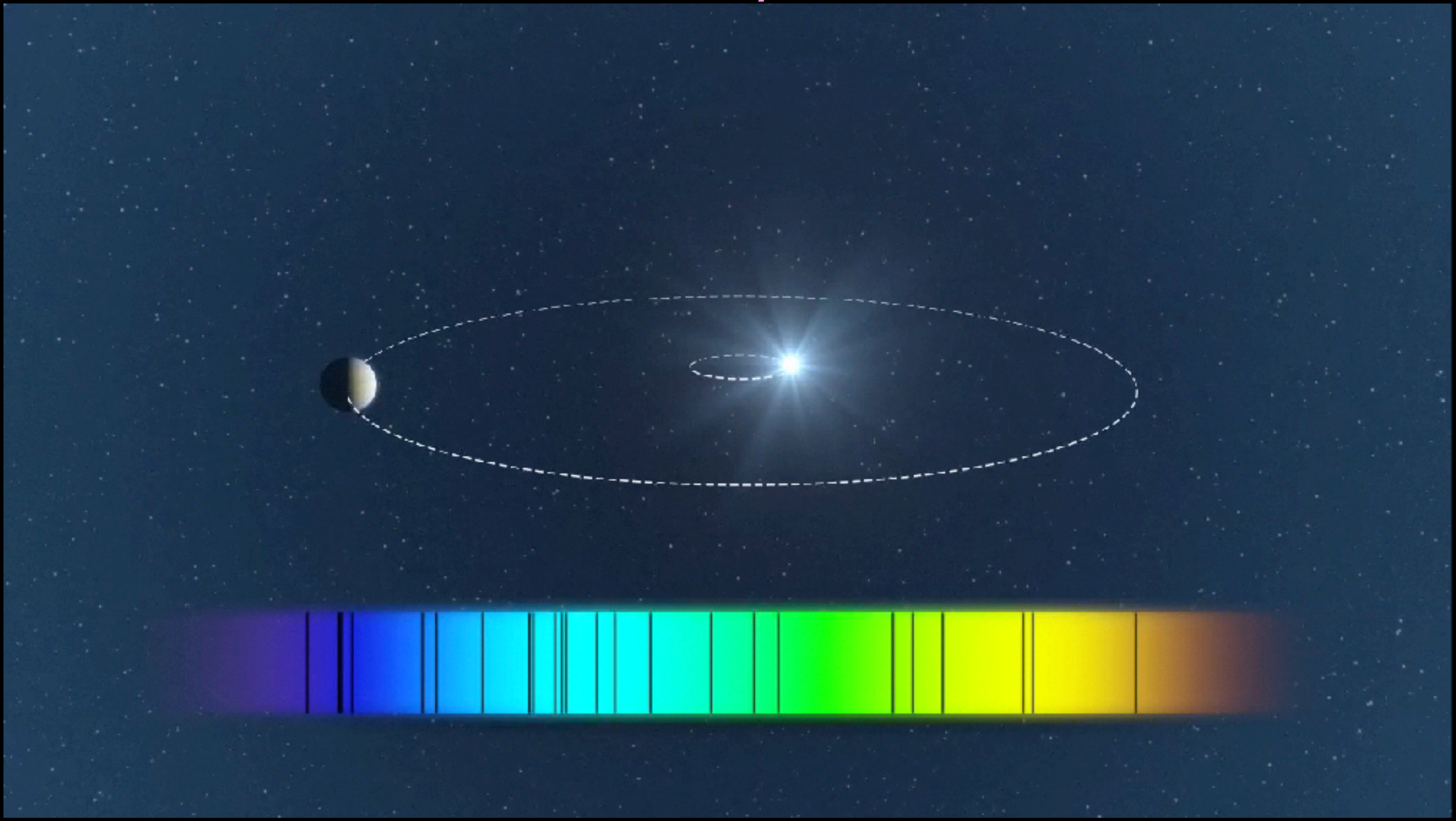
Protoplanetary Disks
Orion Nebula HST • WFPC2
PRC95-45b • ST ScI OPO • November 20, 1995
M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA

Most important techniques to detect exoplanets

* Doppler spectroscopy
* Planetary transits
* Direct imagery
* Astrometry
* Gravitational lenses
* Chronometry (cf planets hosted by a pulsar)


Mass
Period
10 d
1 yr
log10p (y)
log10a (AU)
log10m (MJ)
log10m (ME)
radial velocity
transit
timing
imaging
microlensing

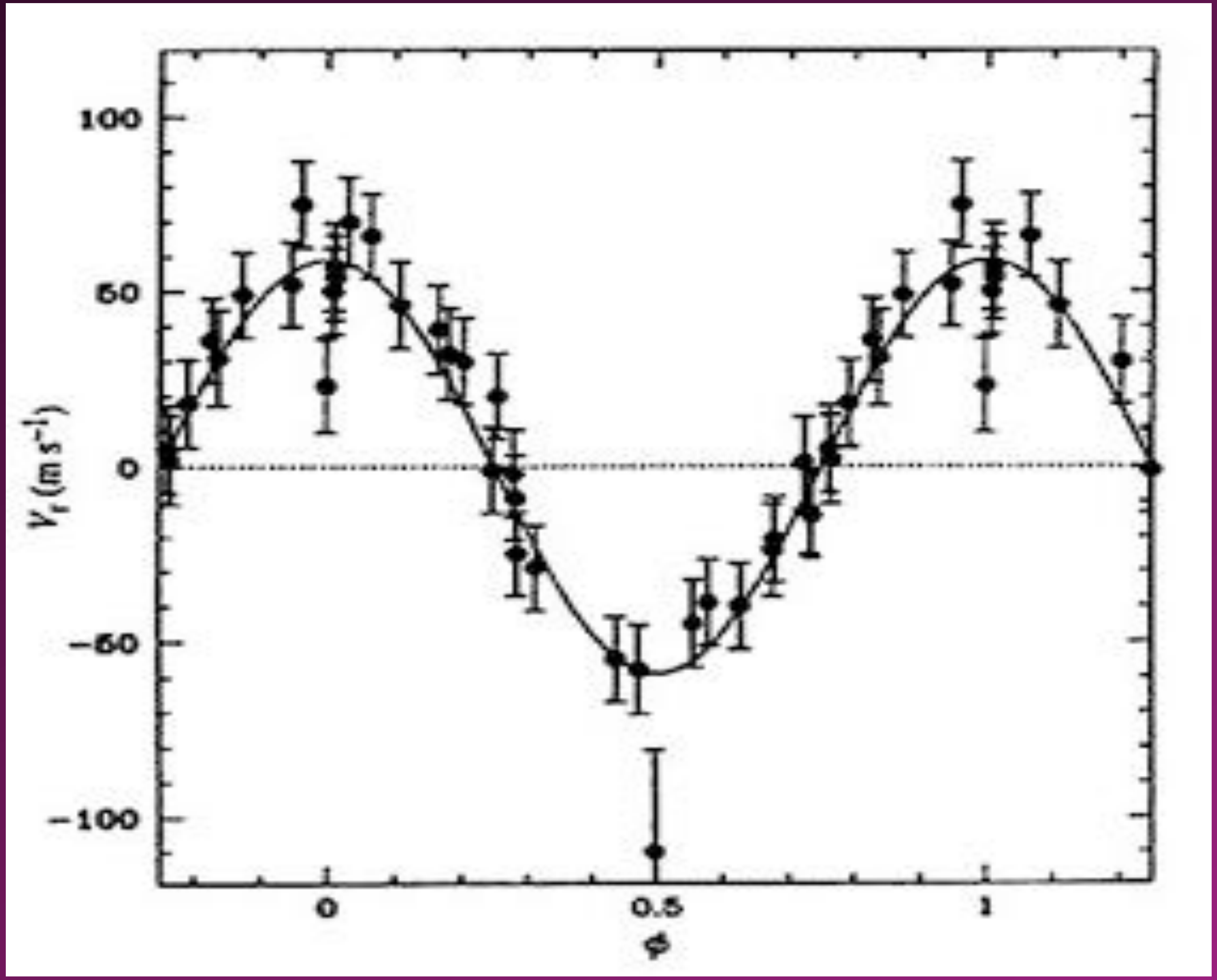
Detection of planets via Doppler spectroscopy
Present sensitivity $\delta\lambda/\lambda = 10^{-9}$



A first exoplanet :
51 Pegasi

Precision: 10 m/s

$M_{pl} = 0.5\ M_{Jup}$
P = 4.2 days <<<<<!!!!!
a = 0.04 AU



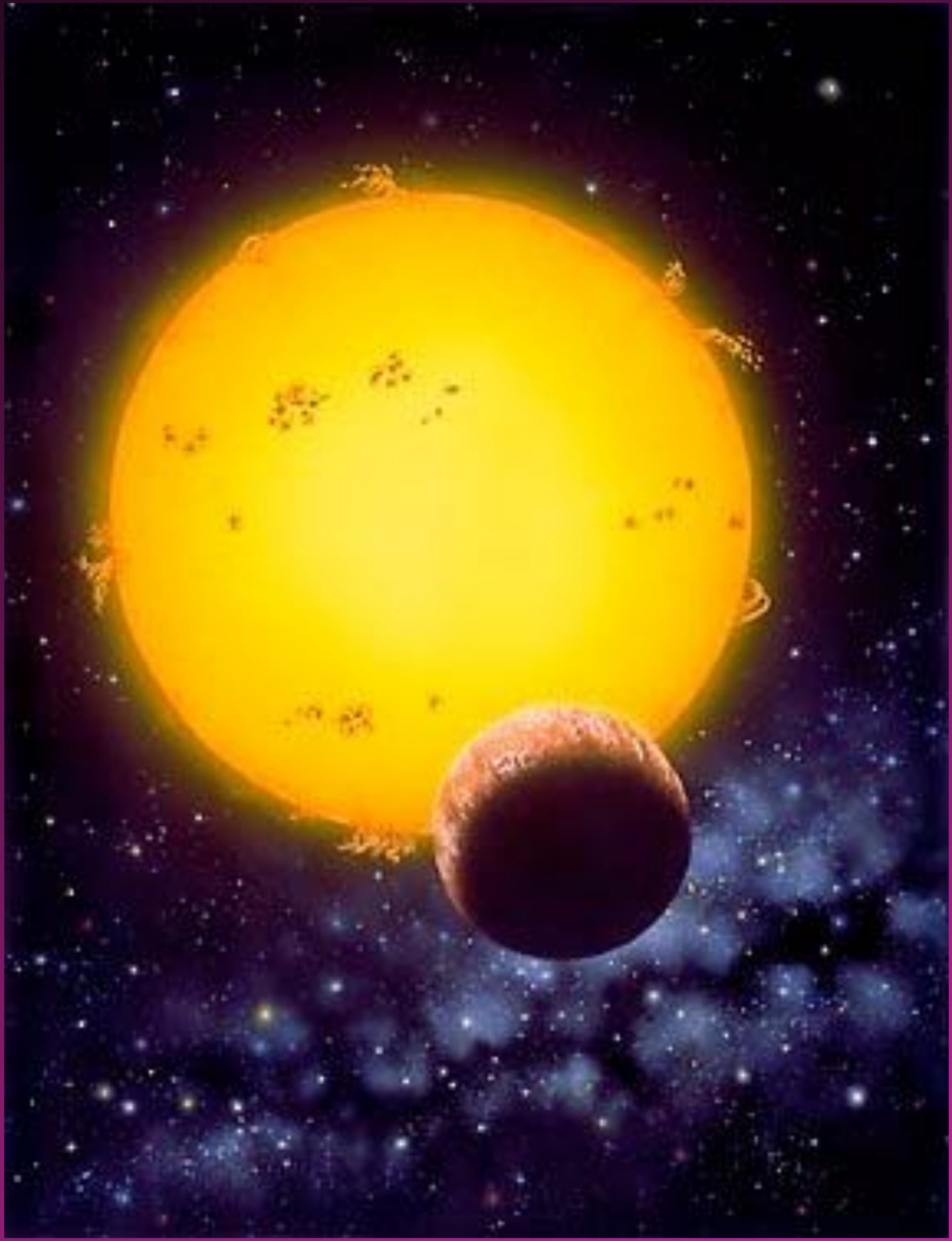
Observatoire de Haute-Provence 193 cm

Mayor & Queloz , Nature 1995

Pegasi 51 b

Prototype of
“Hot Jupiters”

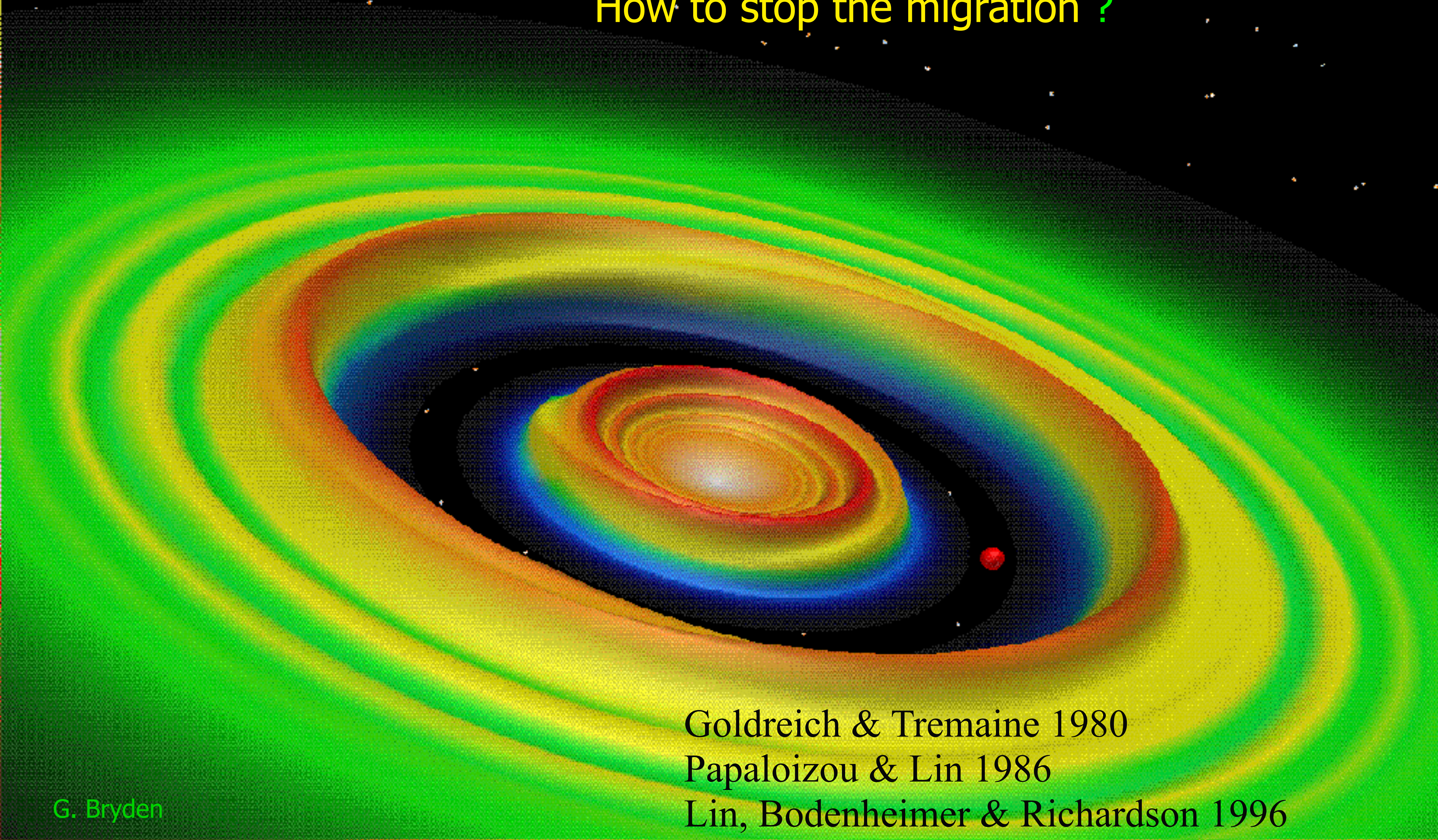
Formation?



Formation of short period gaseous planets : interaction disk - planet

Formation outside the "ice line" -> migration -> centre

How to stop the migration ?

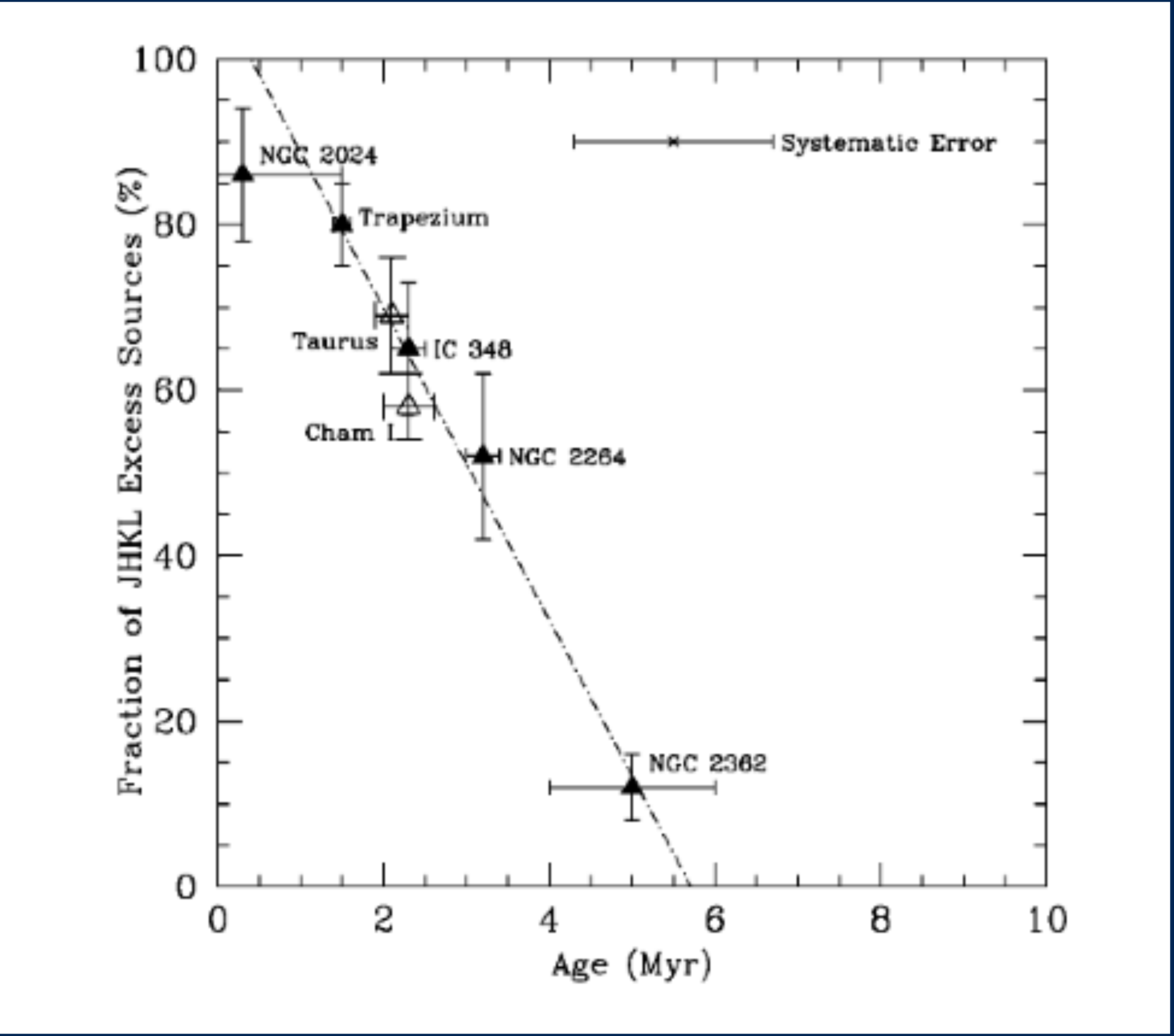


G. Bryden

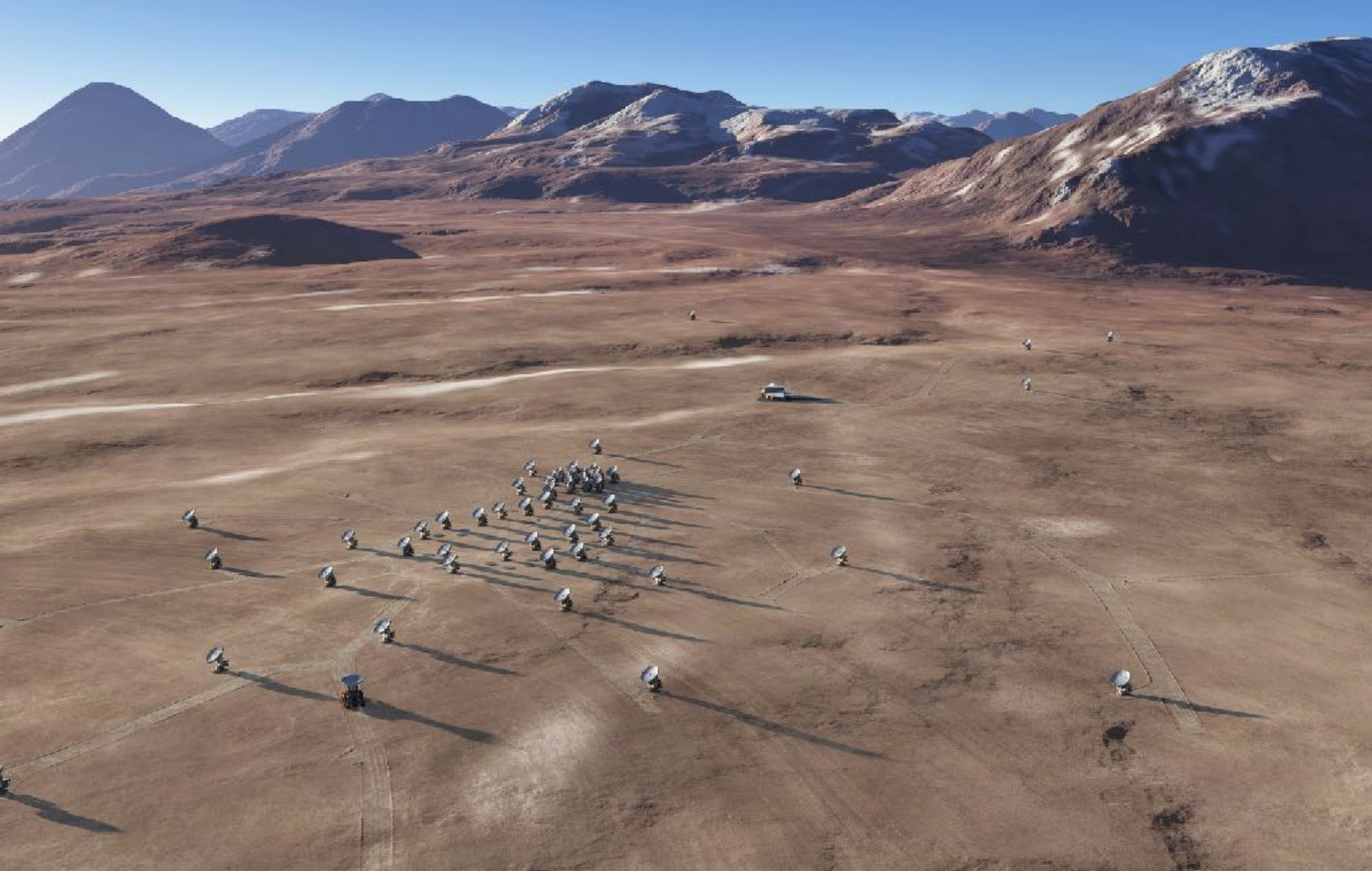
Goldreich & Tremaine 1980
Papaloizou & Lin 1986
Lin, Bodenheimer & Richardson 1996

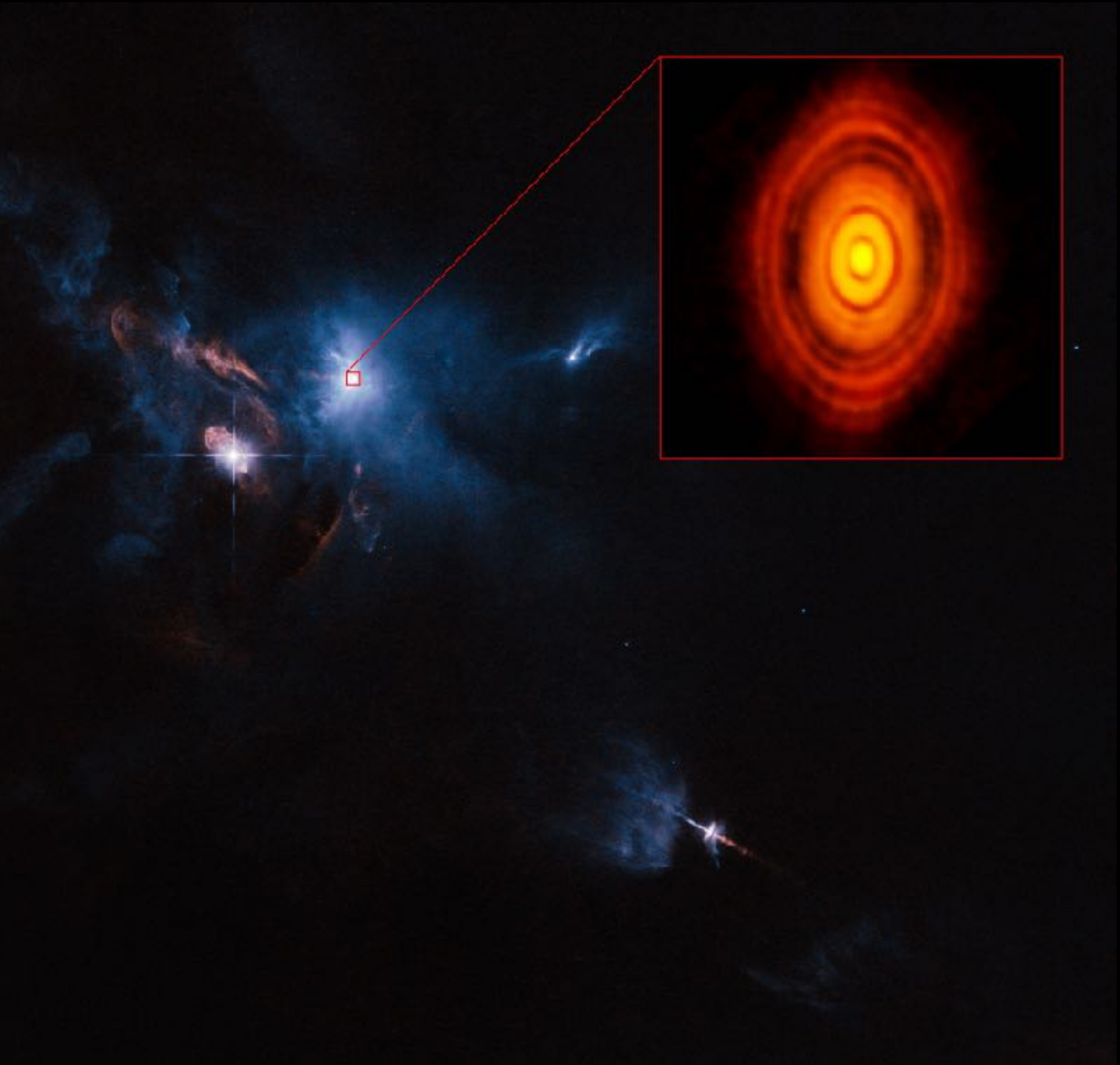
Life time of accretion discs

Haisch, Lada, Lada 2001



ALMA: A NIR interferometer at 5000 meters on the chilean altiplano (ESO, US, Japan)



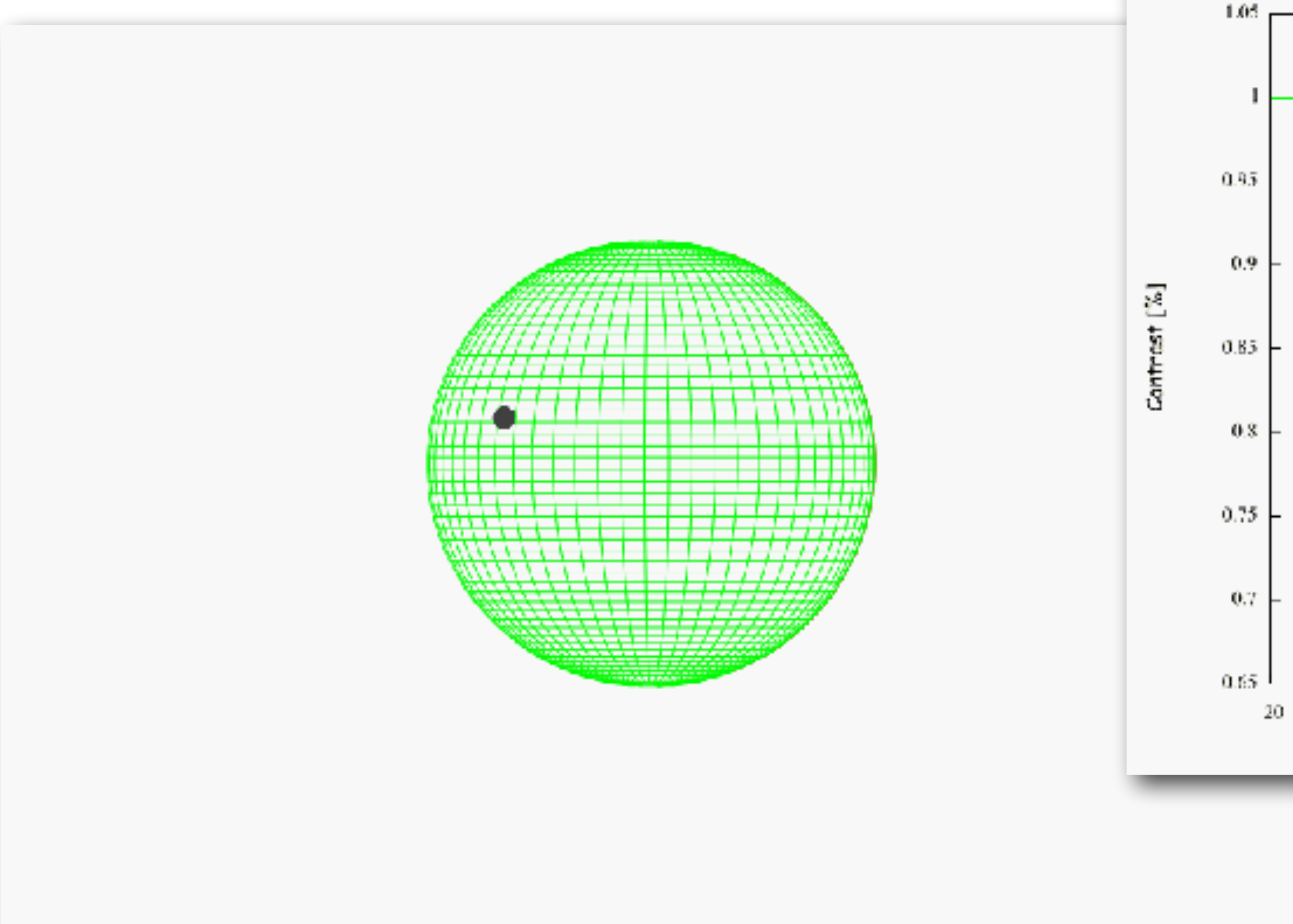


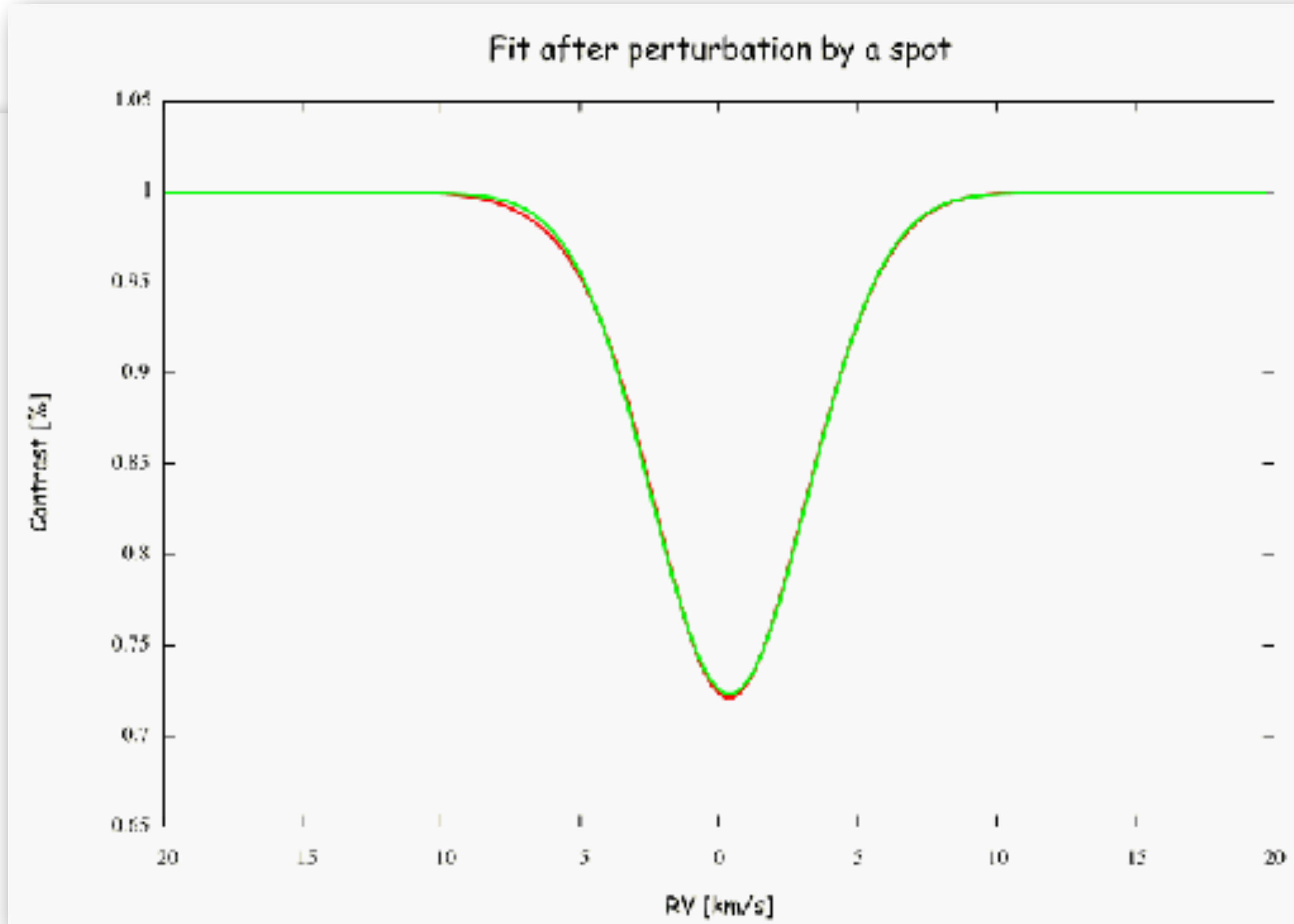
Planetary Transits

The relative inclination of orbital plane and stellar equatorial plane

... A new hint of complex dynamical interactions

The Rossiter - Mac Laughlin effect

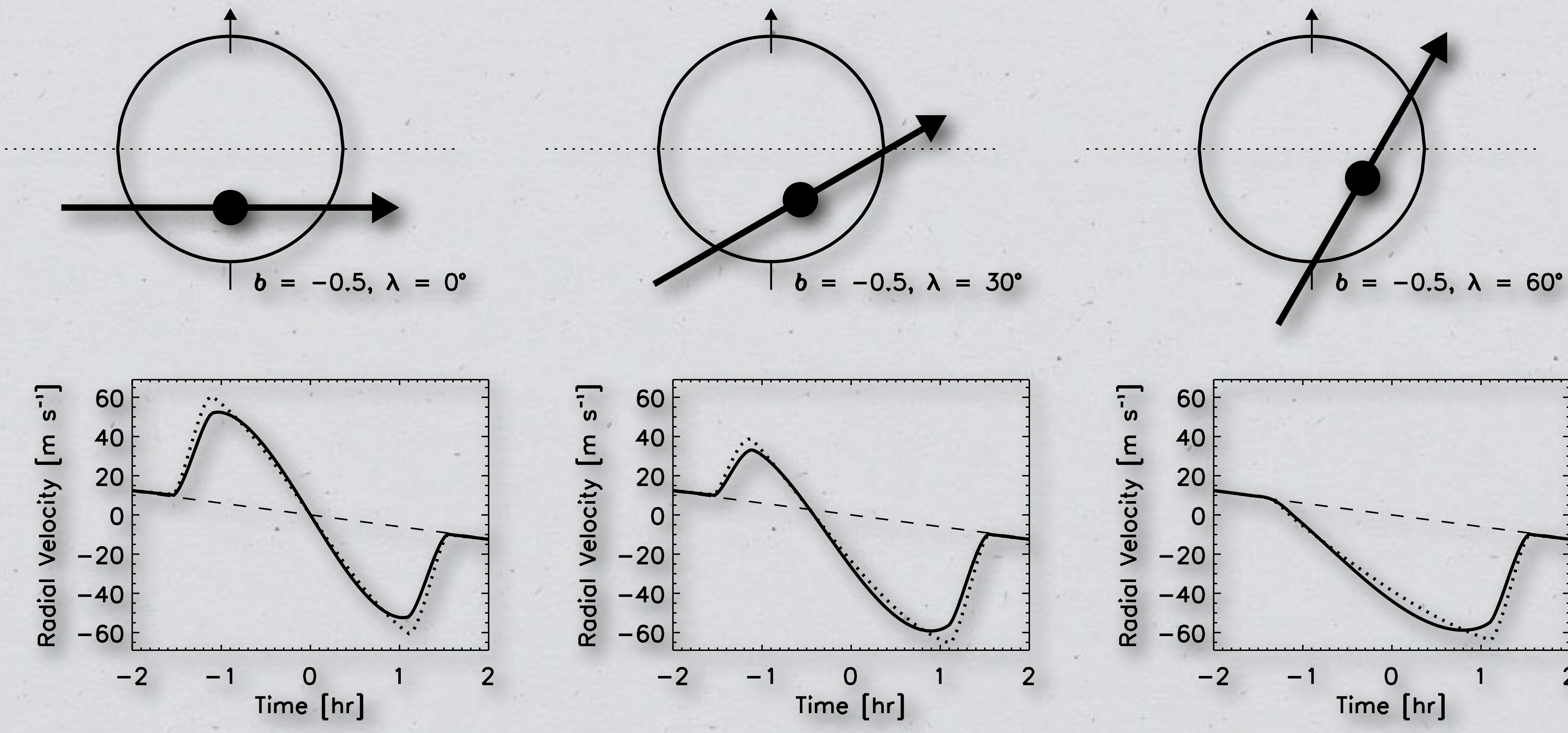




The transit of a planet in front of a rotating star creates a distorsion of stellar lines and an anomaly of the velocity curve

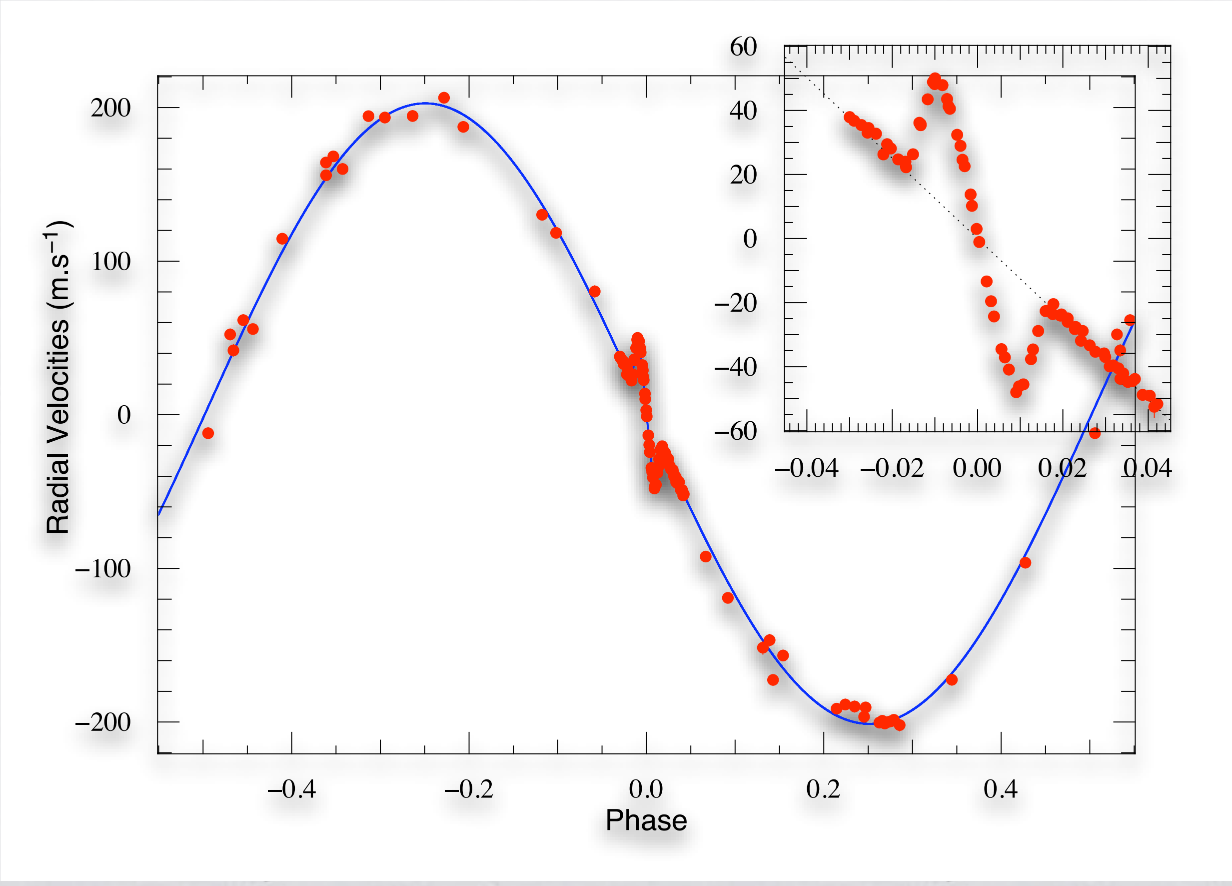
The Rossiter-McLaughlin effect

a spectroscopic transit



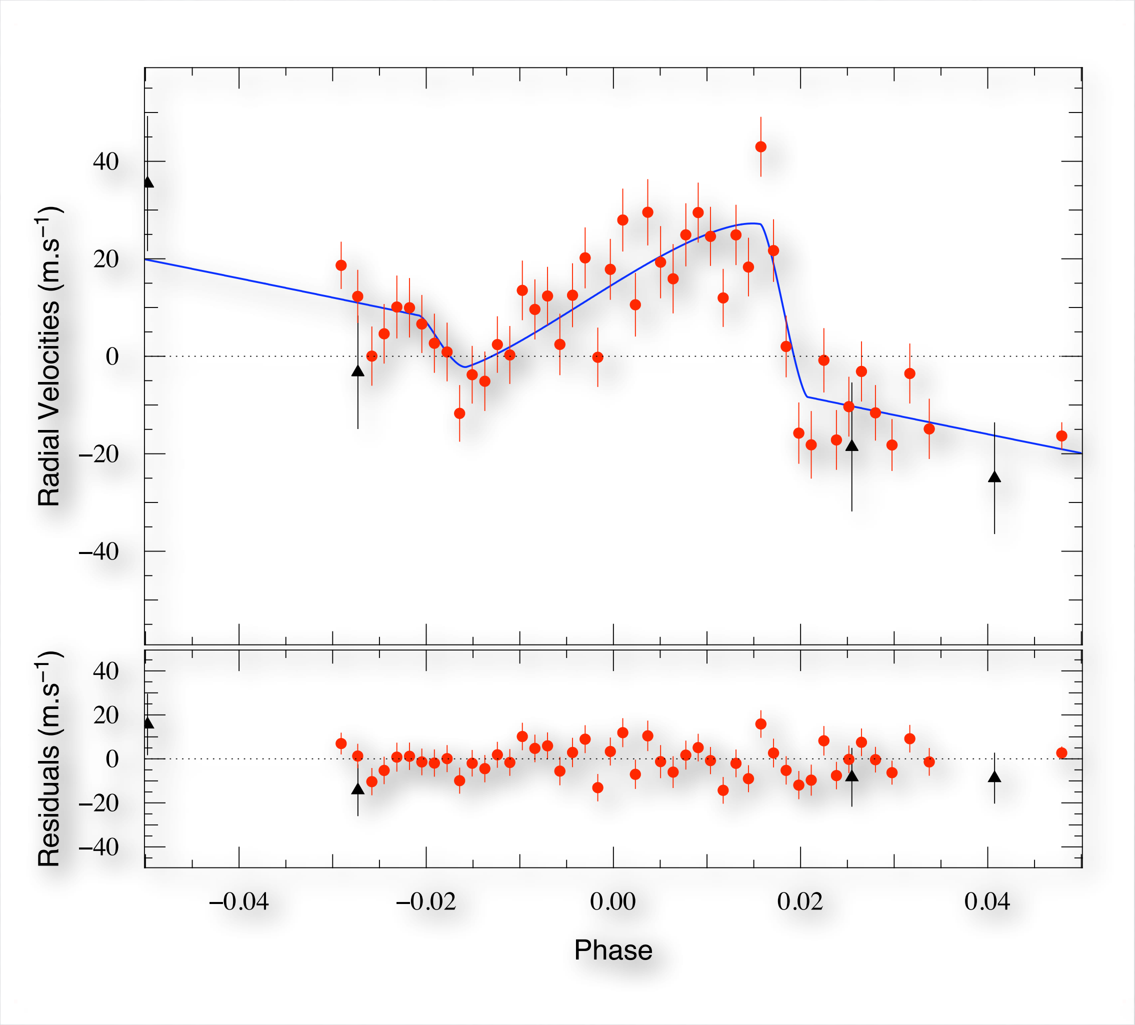
A coming diversity in spin-orbit angles: it allows to probe planetary formation

HD 189733b



Triaud et al. 2009

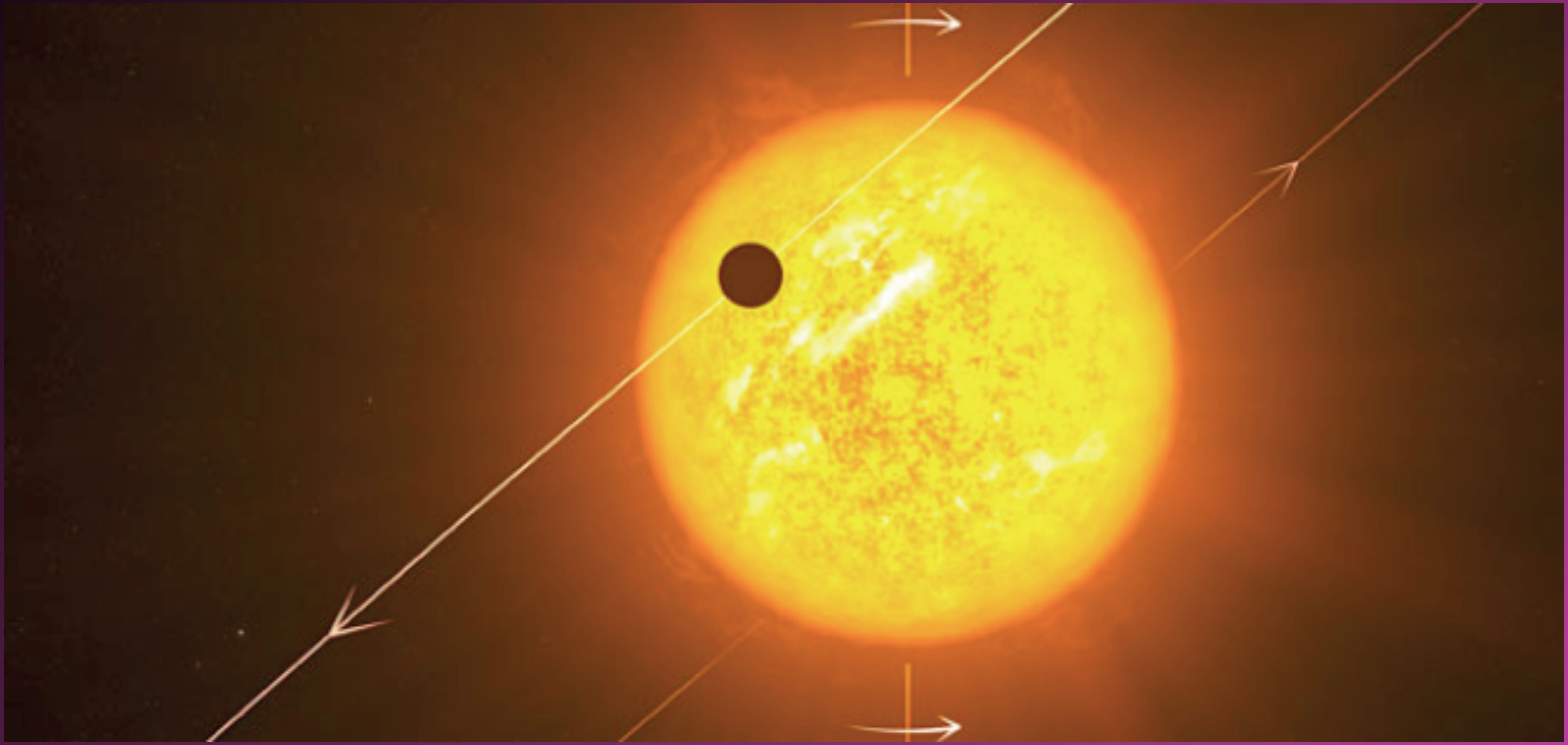
WASP-15b



Triaud et al. 2010

An example of retrograde and inclined orbit : WASP 8b

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

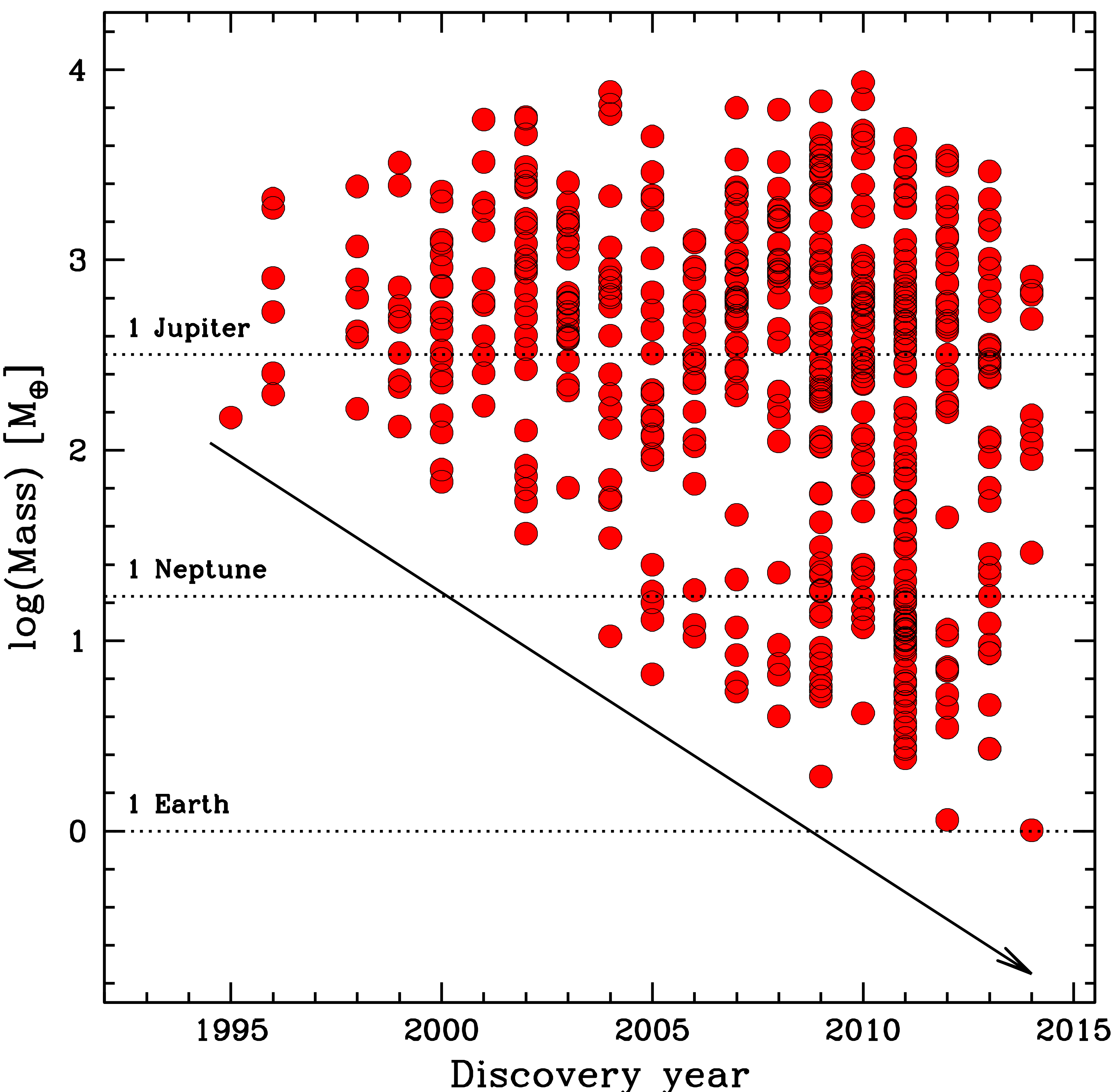


A survey with the HARPS spectrograph

- $\delta\lambda/\lambda$ = 10 (-9)   >>>>   0.3 m/s

HARPS

ESO-3.6m @ La Silla



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

HD10180 : a planetary system with 7 planets

P_1 = 1.18 day
e_1 = 0
m_1 sini = 1.5 $M_\oplus$

P_2 = 5.76 days
e_2 = 0.07
m_2 sini = 13.2 $M_\oplus$

P_3 = 16.4 days
e_3 = 0.16
m_3 sini = 11.8 $M_\oplus$

P_4 = 49.7 days
e_4 = 0.06
m_4 sini = 24.8 $M_\oplus$

P_5 = 122.7 days
e_5 = 0.13
m_5 sini = 23.4 $M_\oplus$

P_6 = 595 days
e_6 = 0.0
m_6 sini = 22 $M_\oplus$

P_7 = 2150 days
e_7 = 0.15
m_7 sini = 67 $M_\oplus$

Lovis et al. 2010

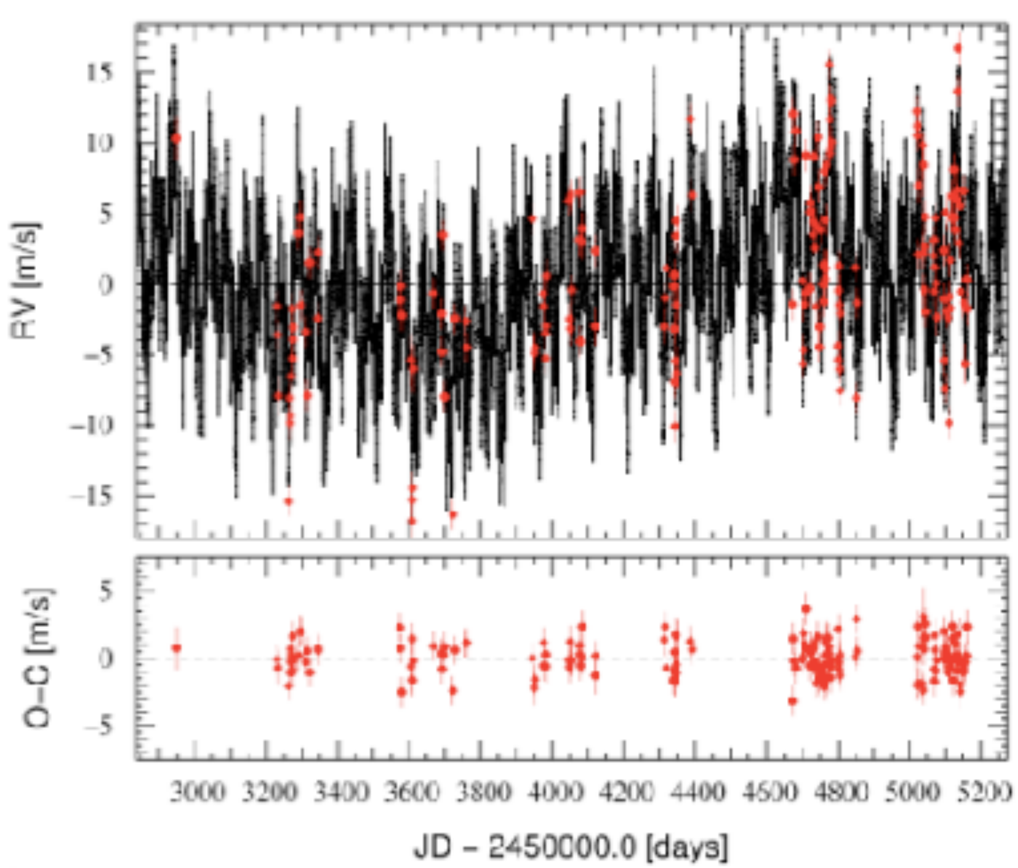
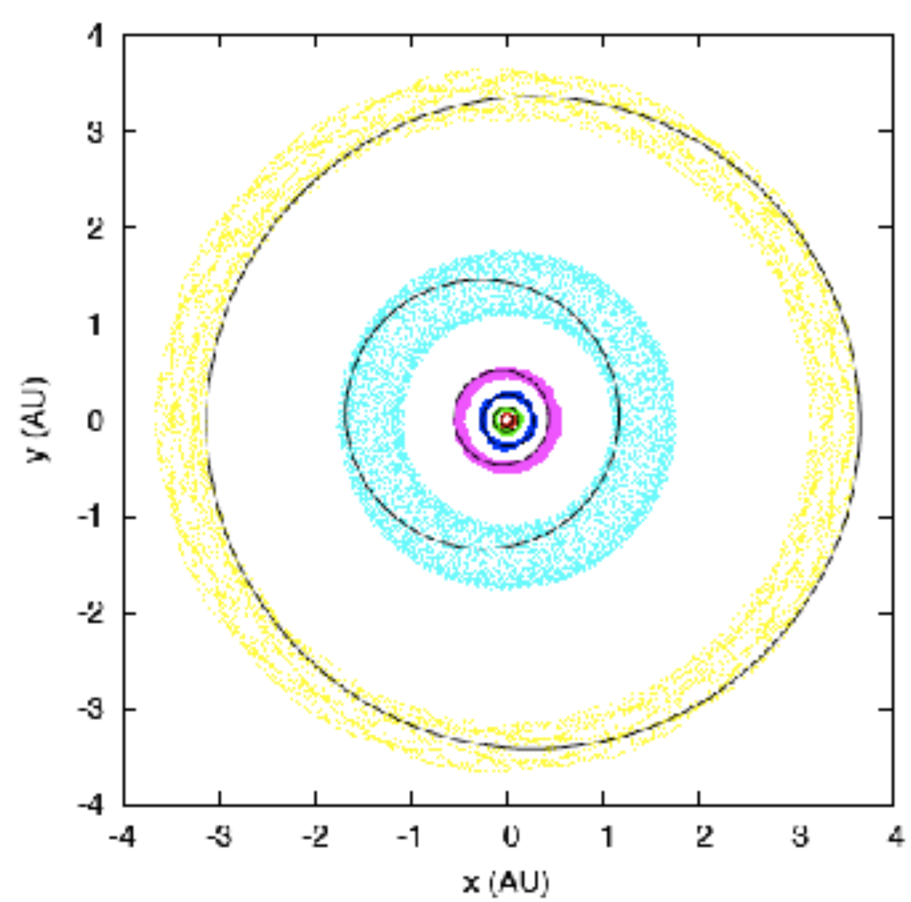
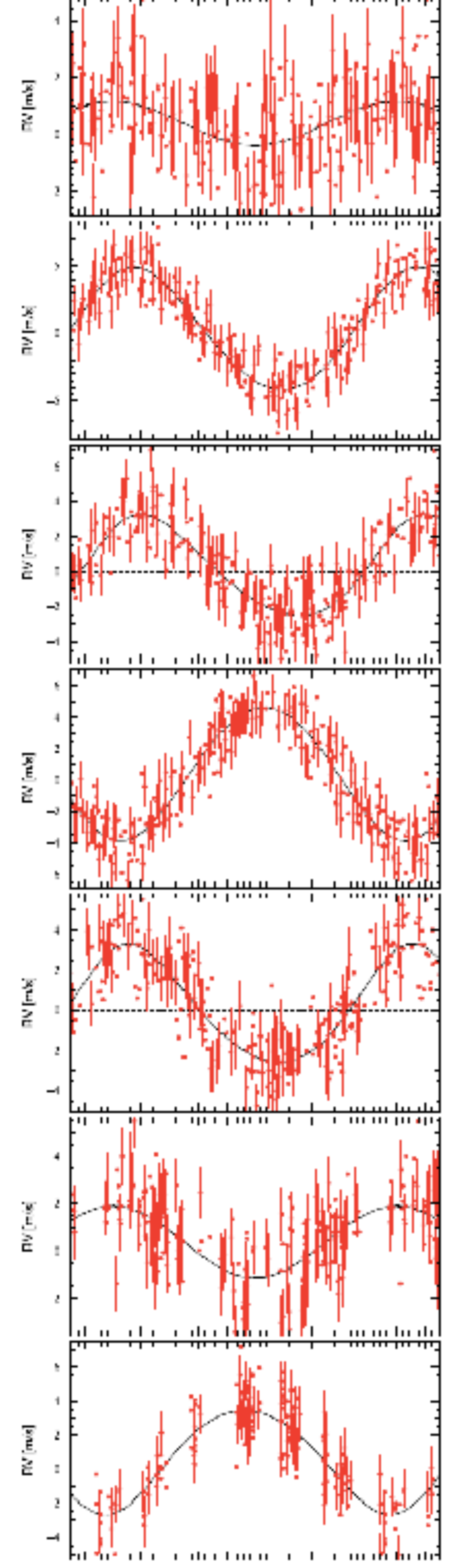


Fig. 5. Radial velocity time series with the 7-Keplerian model overplo





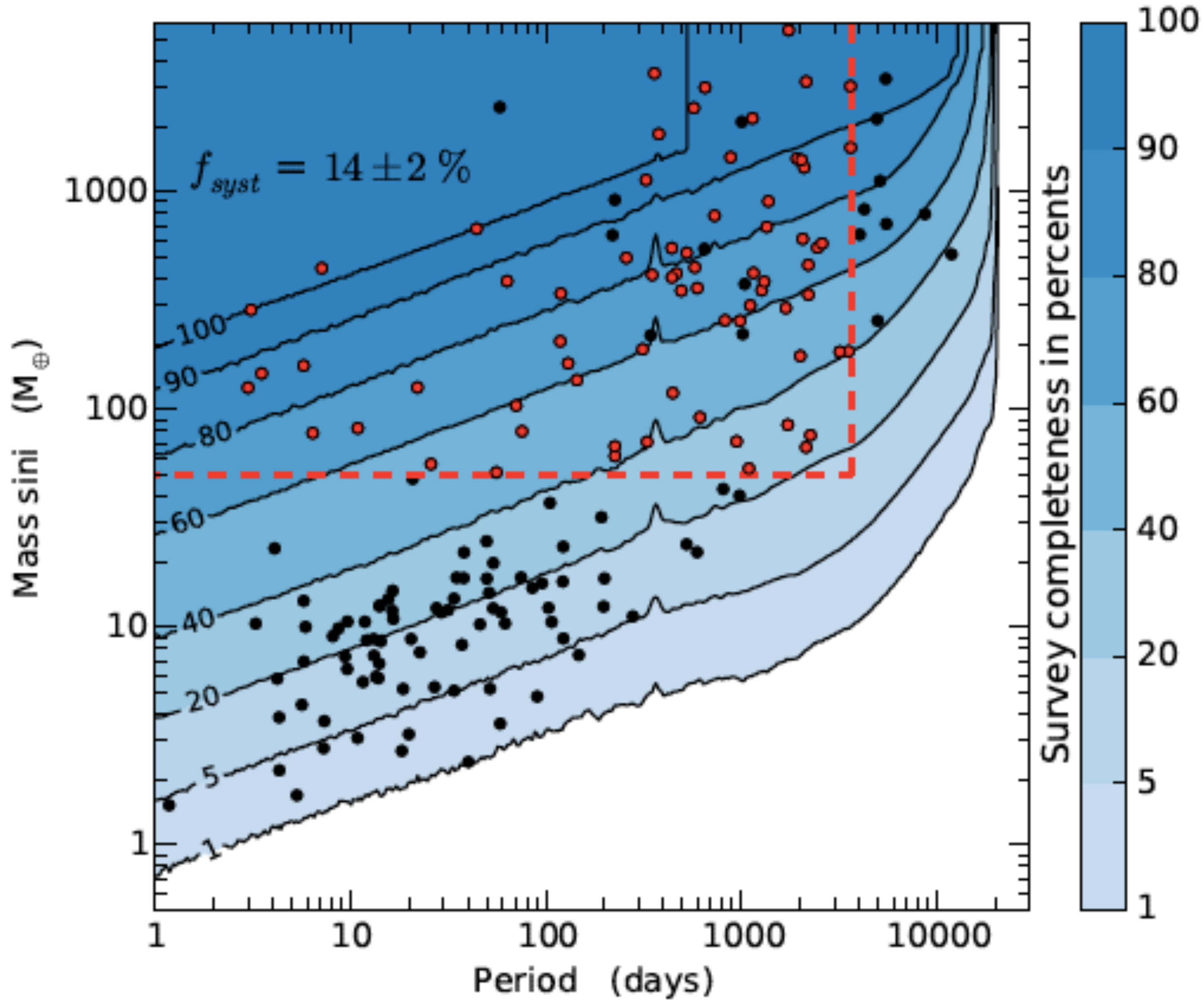


Fig. 5. Plot of the 169 planets of the considered HARPS+CORALIE sample in the $m_2 \sin i - \log P$ plane. The superimposed curves indicate the completeness of the survey. These detection probabilities are valid for the whole sample of 822 stars. After correcting for the detection bias, the fraction 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 ± 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.

(Mayor et al. 2011)

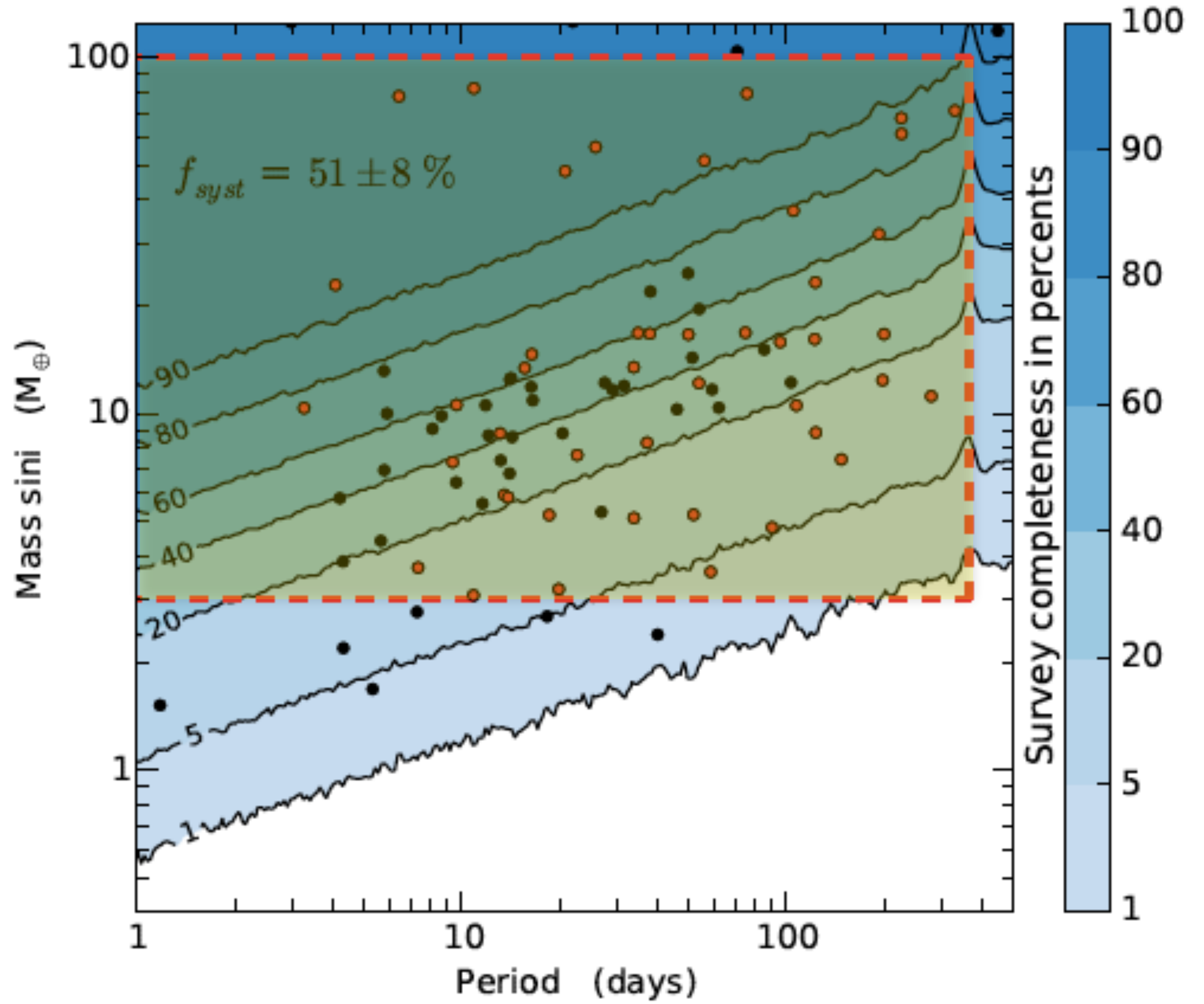


Fig. 6. Same as Fig. 5 but only for the HARPS subsample **of 376 stars.** The occurrence rate of planetary systems in the limited region between 3 and 100 $M_\oplus$, and with $P < 1$ year, is 51 ± 8 %. **Again, only one planet per system (represented by the red dots) have been considered for the computation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

Smaller-mass planets

$3 < M < 100\ M_\oplus$

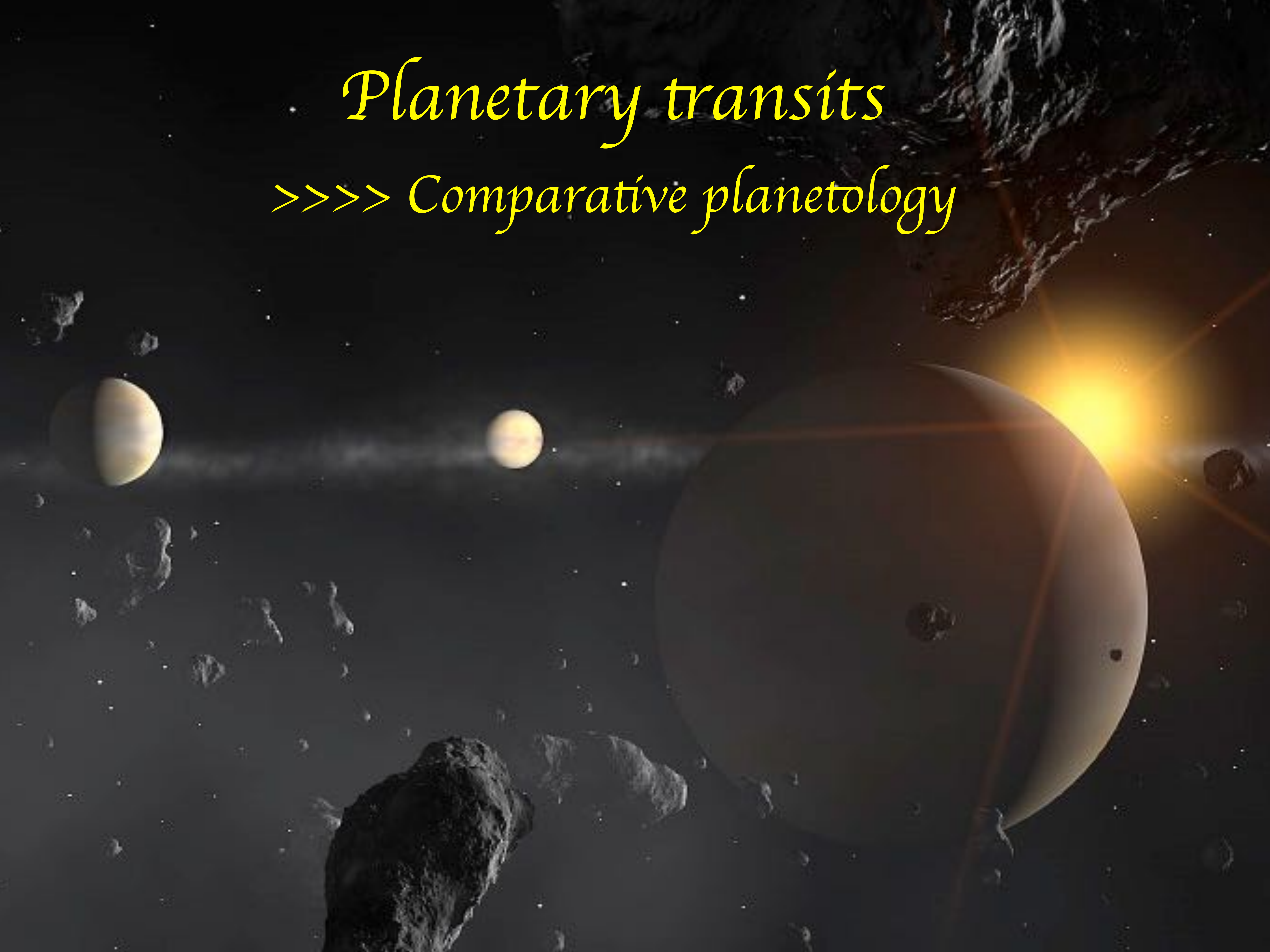
$P < 1yr$

$f_{syst} = 51 +/- 8\ \%$

(Mayor et al.2011)

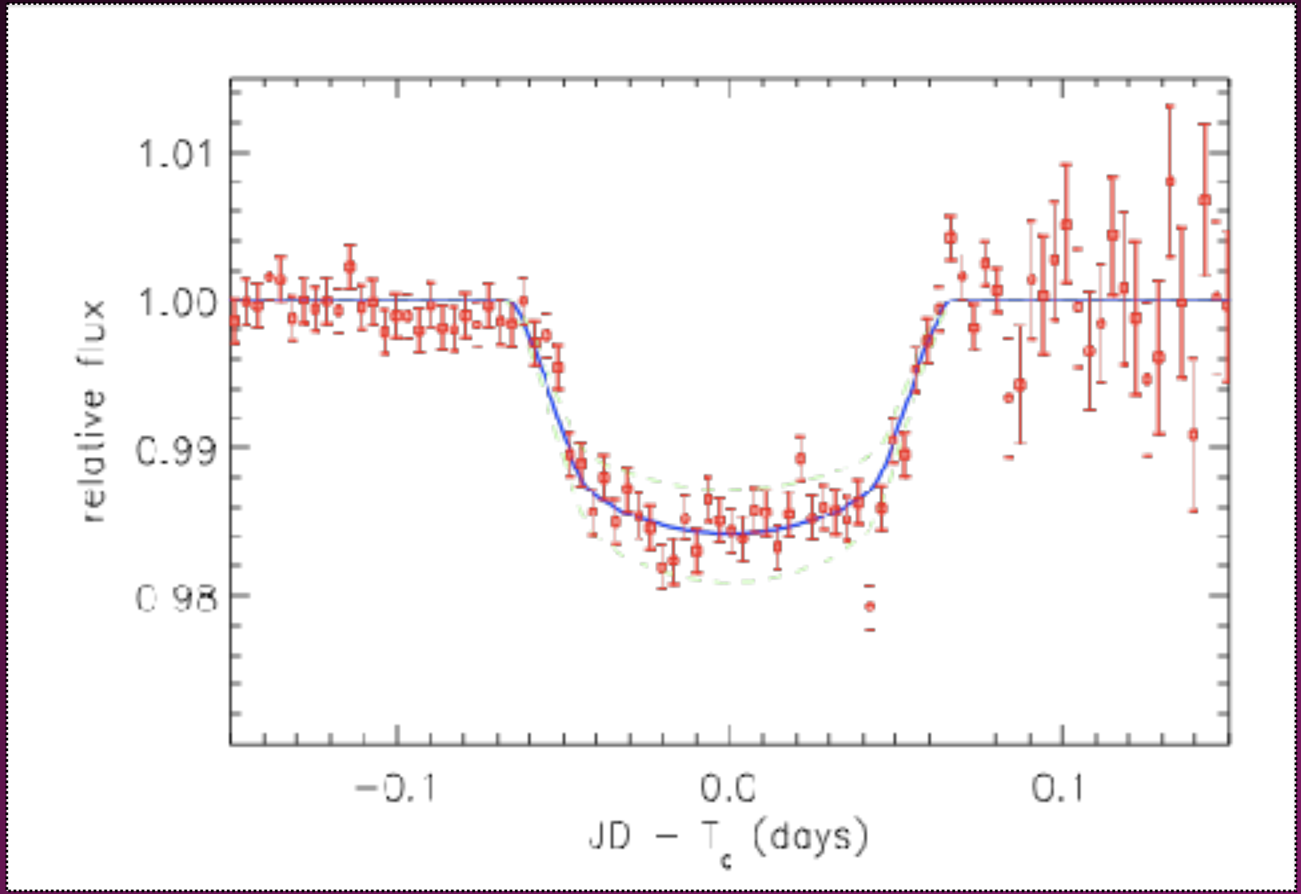
Planetary transits

>>>> Comparative planetology

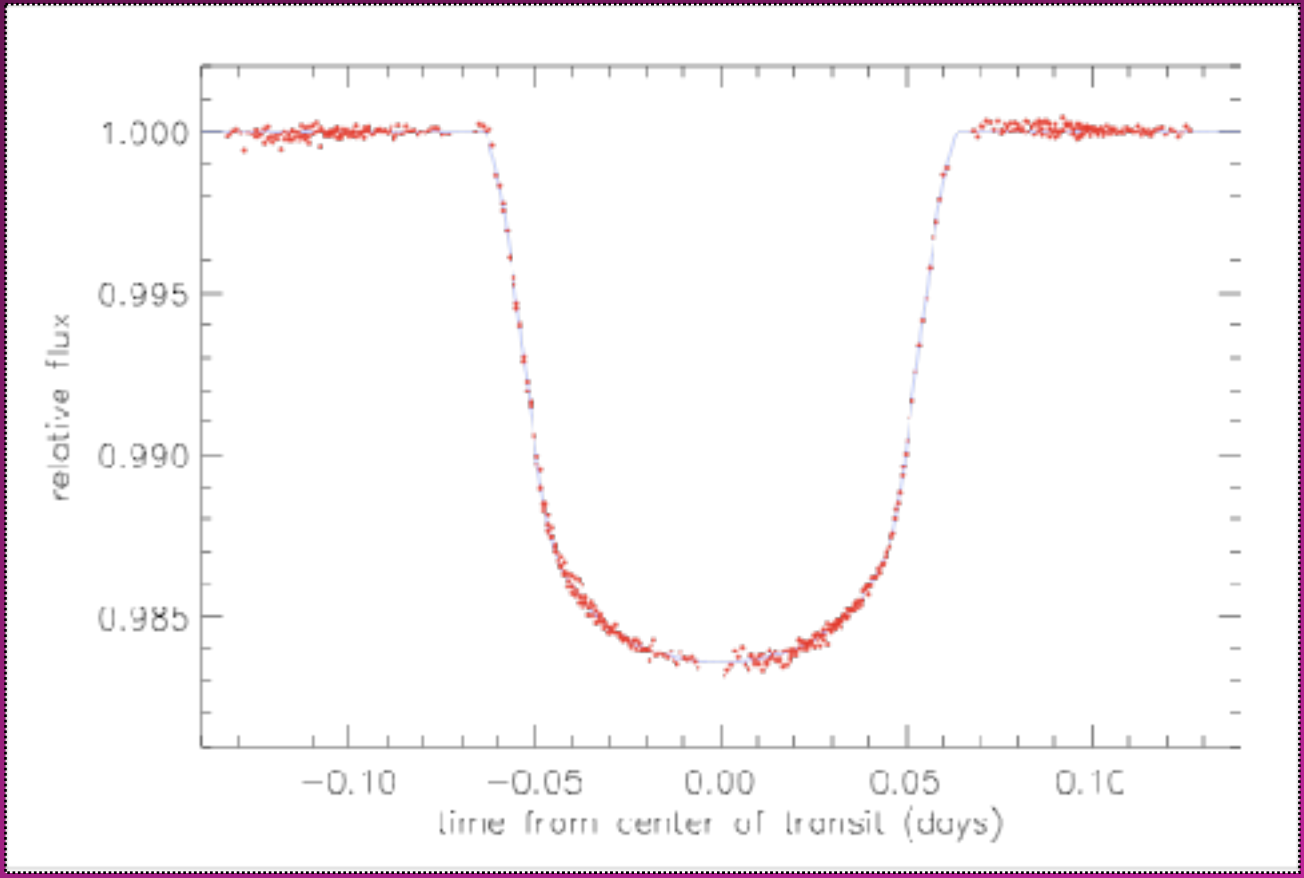


Ground based .. and from space.

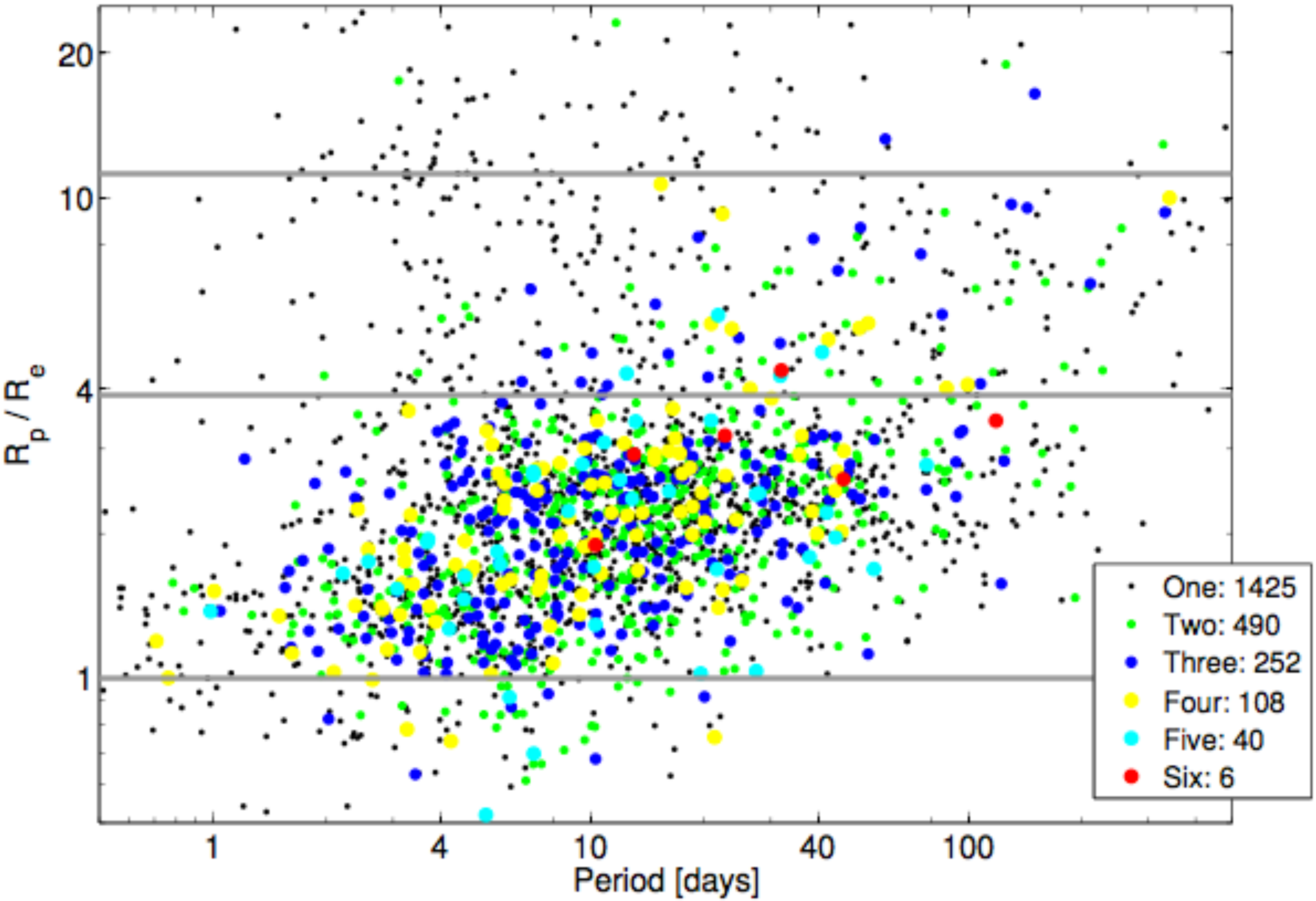
STARE



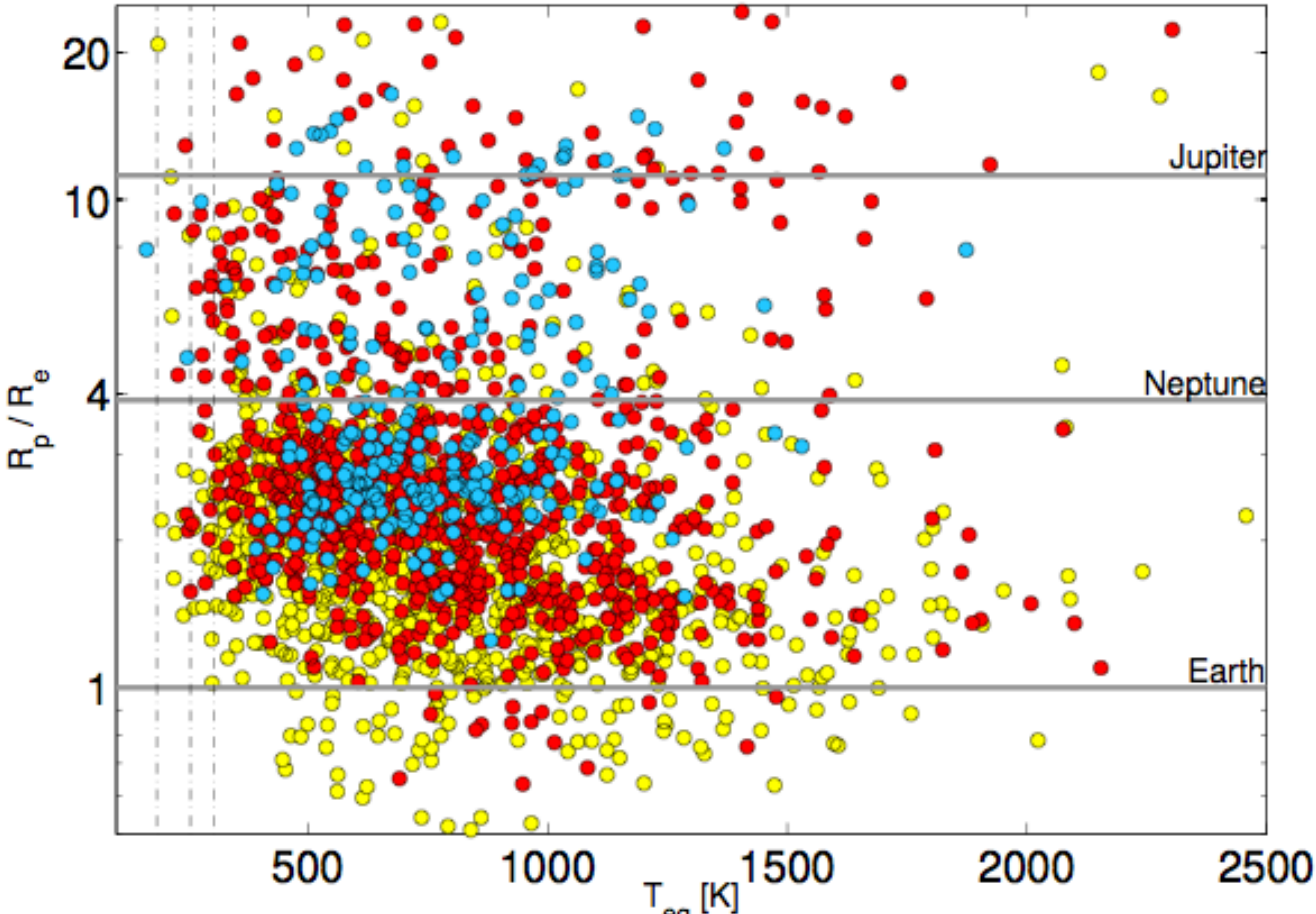
The Hubble space telescope



Kepler detections of planetary transits



Batalha et al. 2013



Batalha et al. 2013

HARPS programme at La Palma observatory (Canary Islands)

> Constraints on the composition of low-mass planets

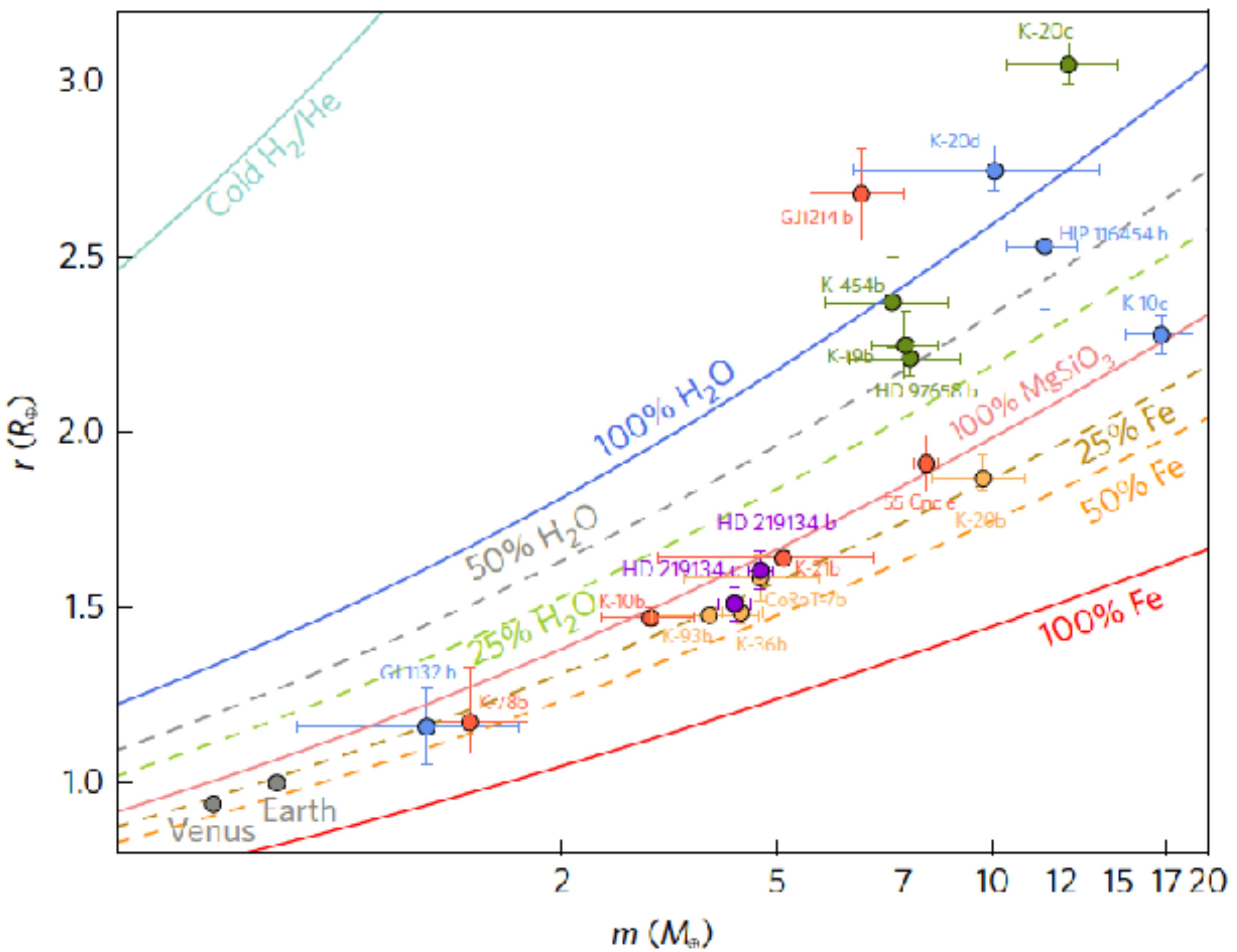


Figure 2 | Mass-radius relationship for small planets with precisions on the masses better than 20%. The solid lines are theoretical mass-radius curves from previous work[20].