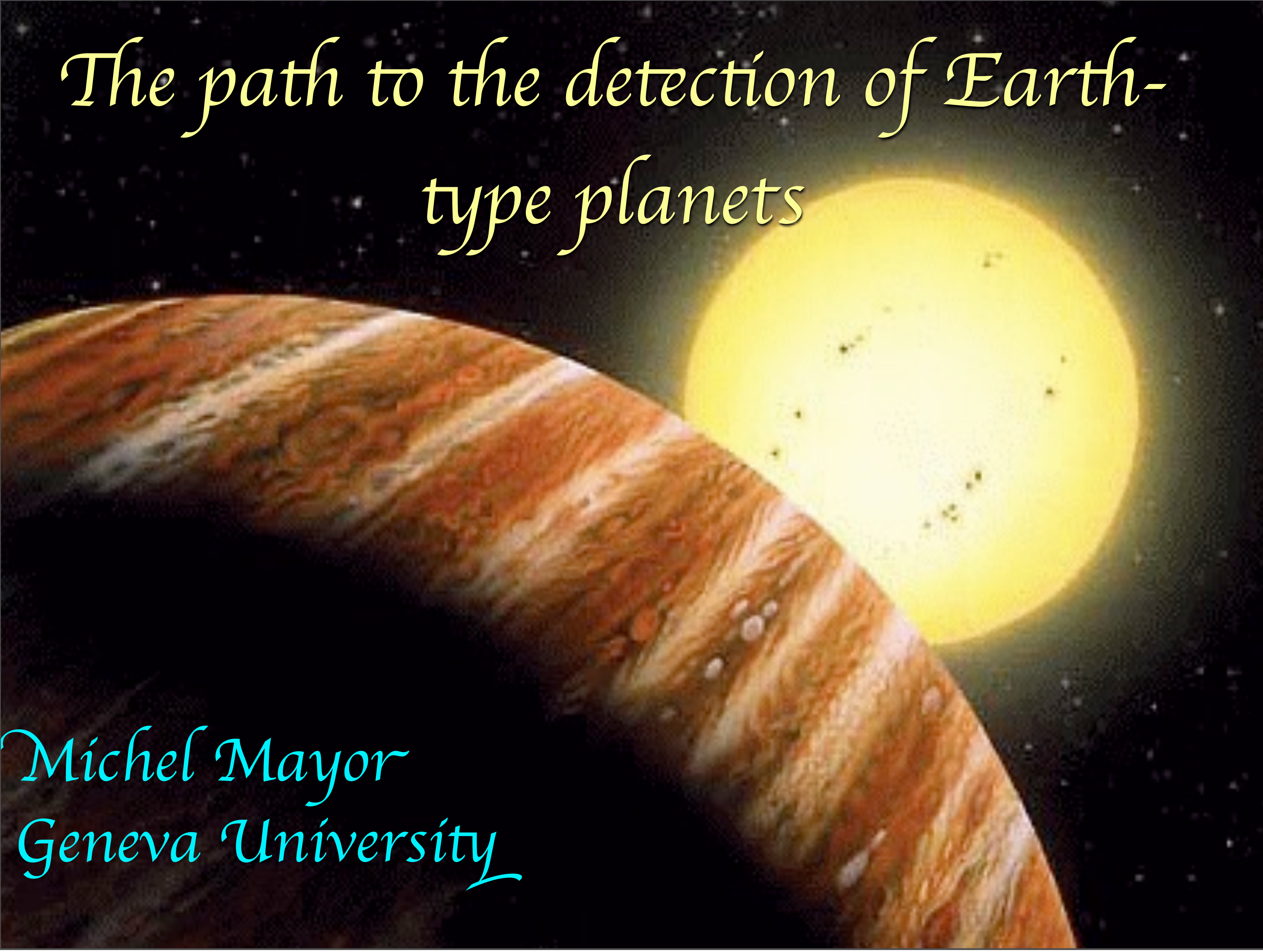
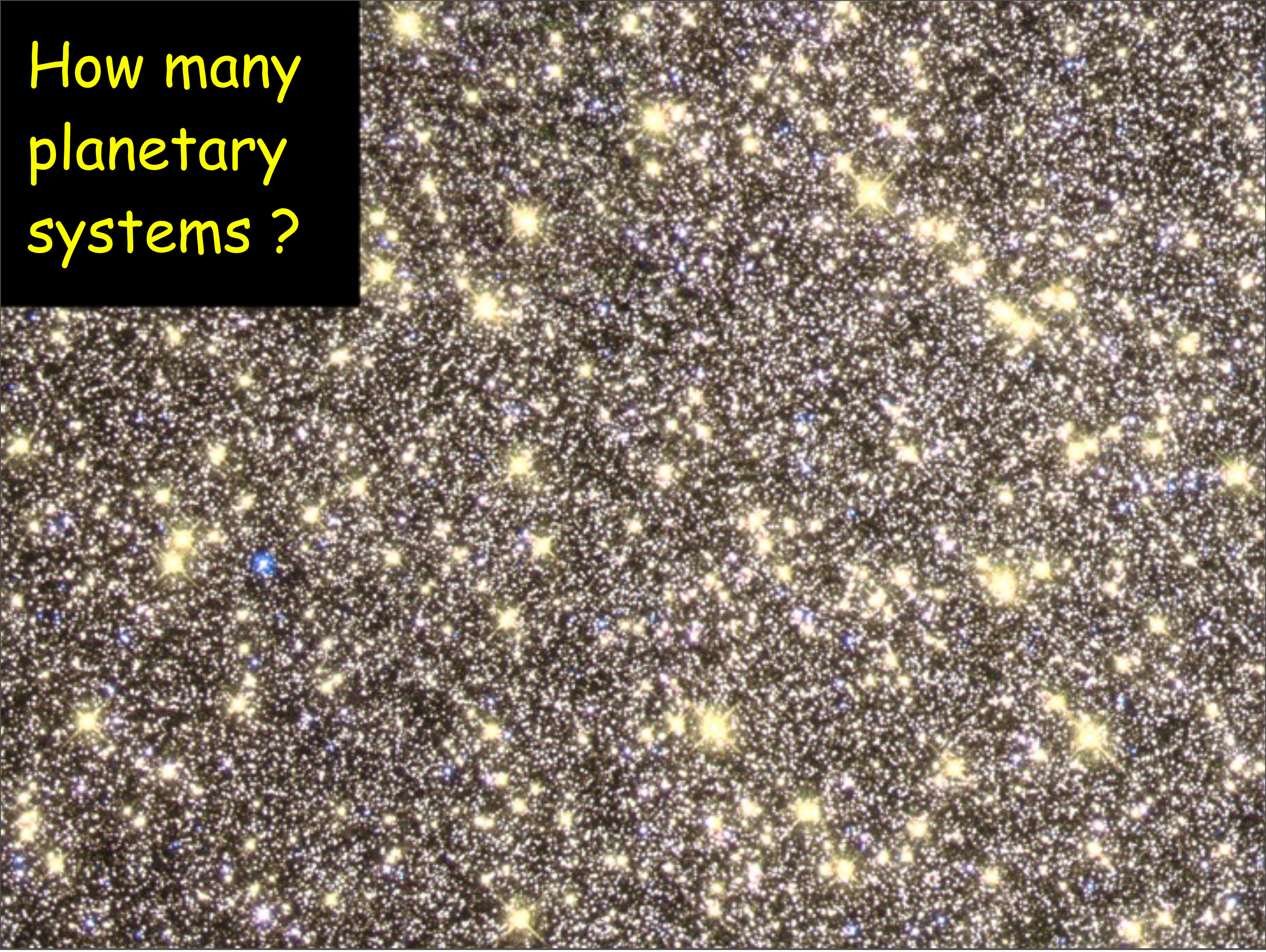
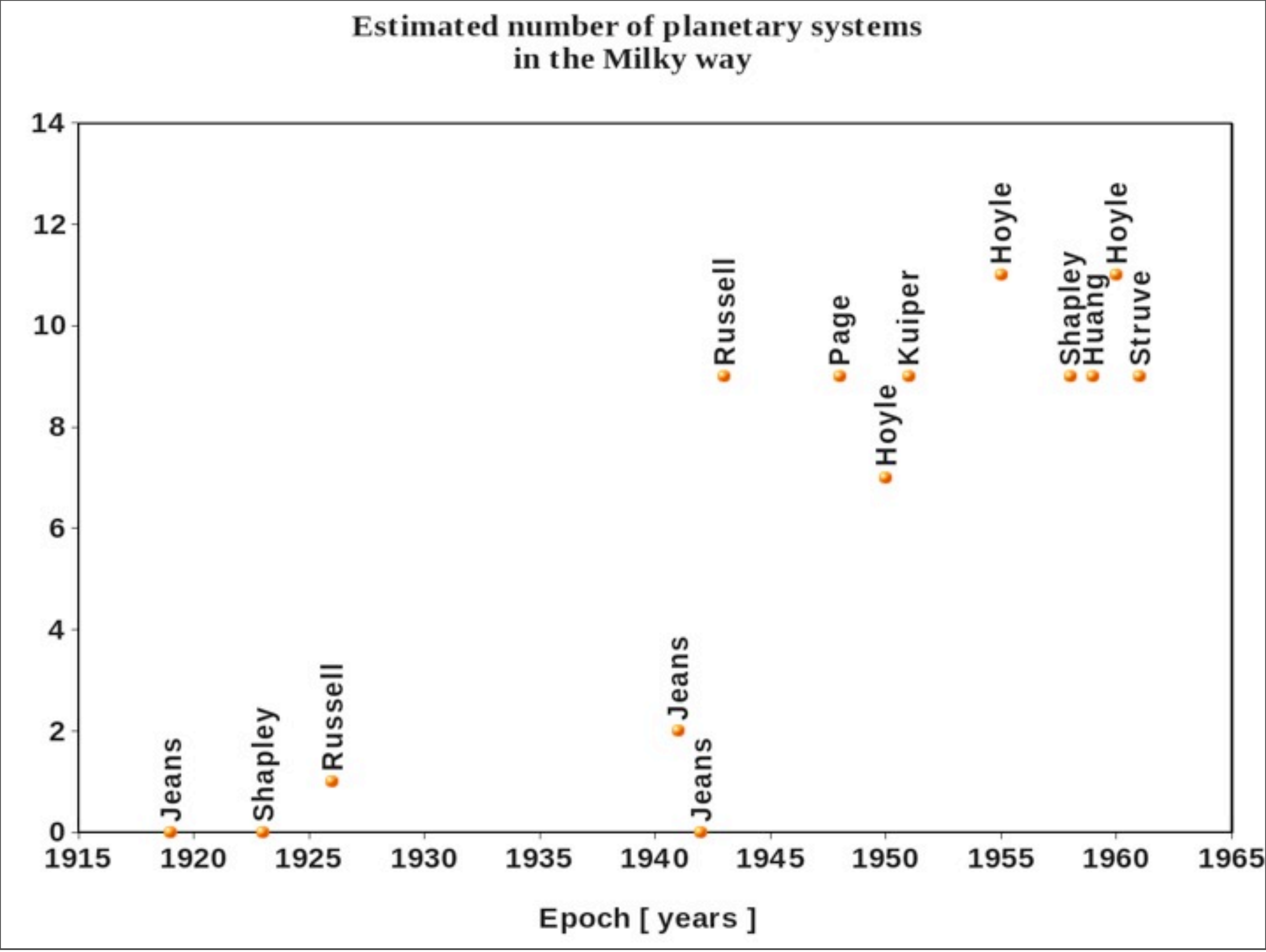
The path to the detection of Earth-type planets

Michel Mayor
Geneva University



How many planetary systems ?



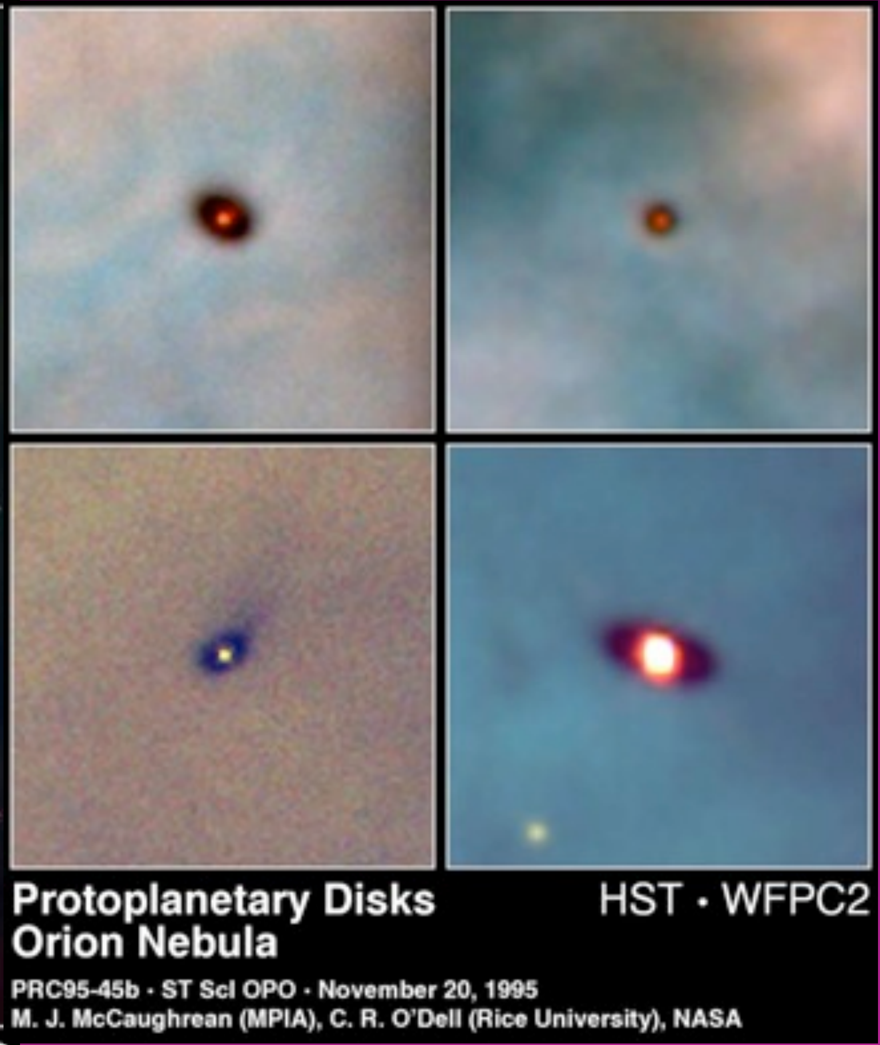


Estimated number of planetary systems in the Milky way
14
12
10
8
6
4
2
0
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
Epoch [years]
Jeans
Shapley
Russell
Jeans
Jeans
Russell
Page
Hoyle
Kuiper
Hoyle
Shapley
Huang
Hoyle
Struve

Victor Safronov 1969

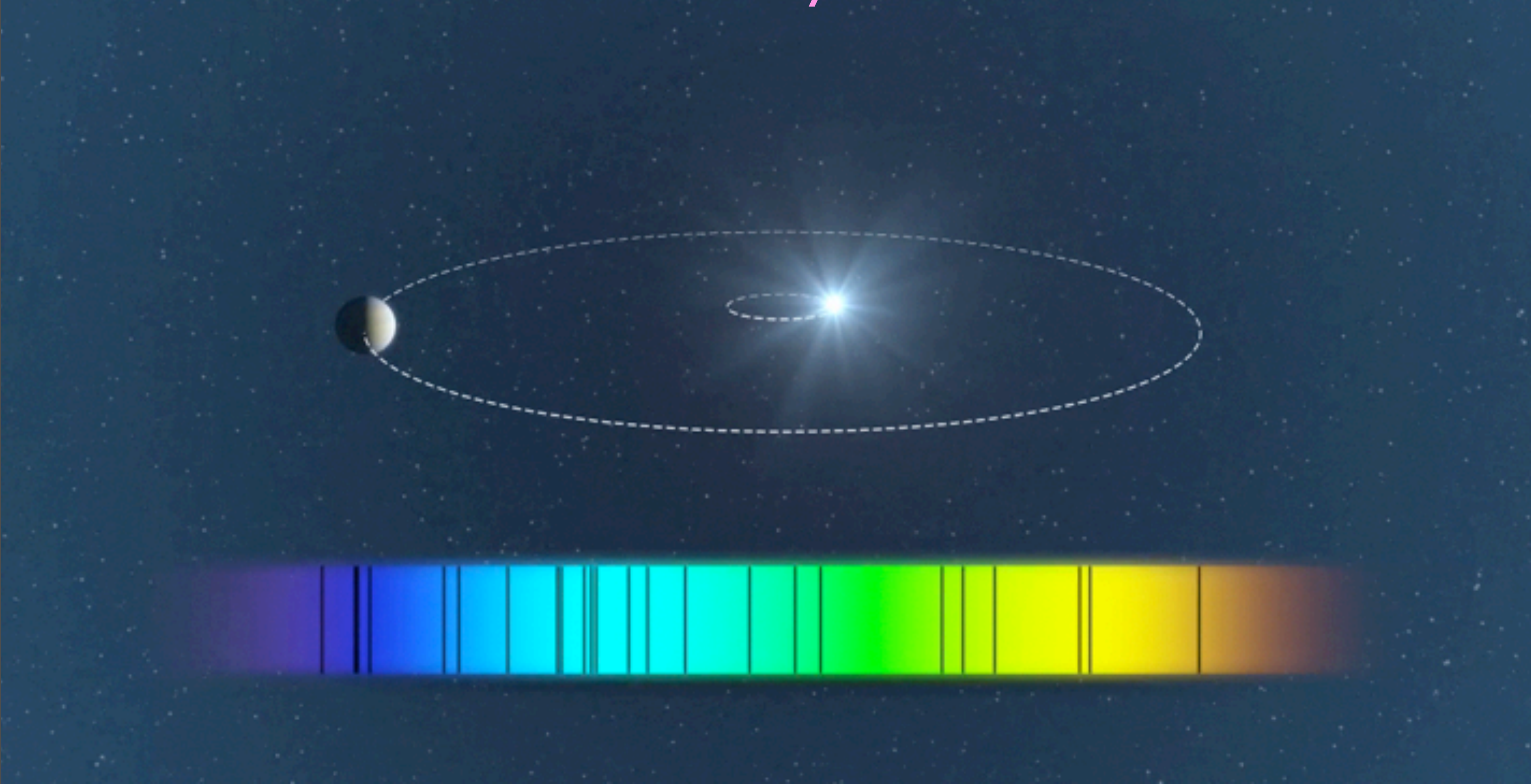
Proposes the scenario to explain the formation of planets in the accretion disk by agglomeration of planetesimals from dust grains to planets. The accretion disk is a by-product of the stellar formation .

Protoplanetary disks in the Orion nebula



Detection of planets via Doppler spectroscopy

Present sensitivity $\delta\lambda/\lambda = 10^{-9}$

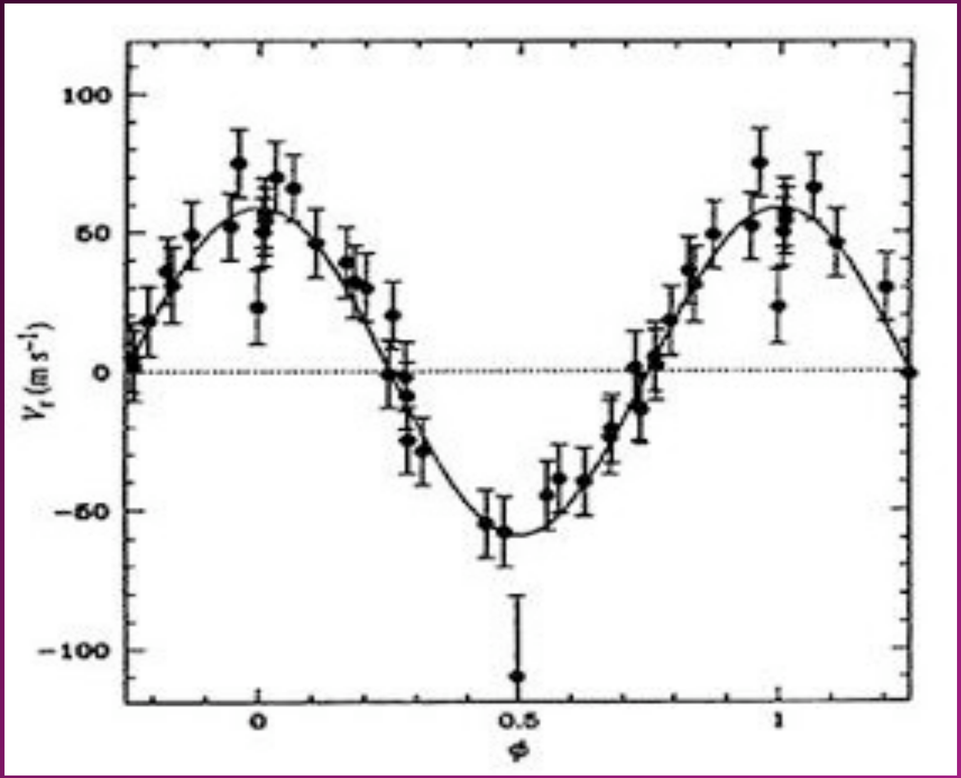


The spectrograph HARPS uses simultaneously 6000 spectral lines (cross-correlation technique)

A first planet : 51 Pegasi

Precision: 10 m/s

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



Haute-Provence Observatory 193 cm

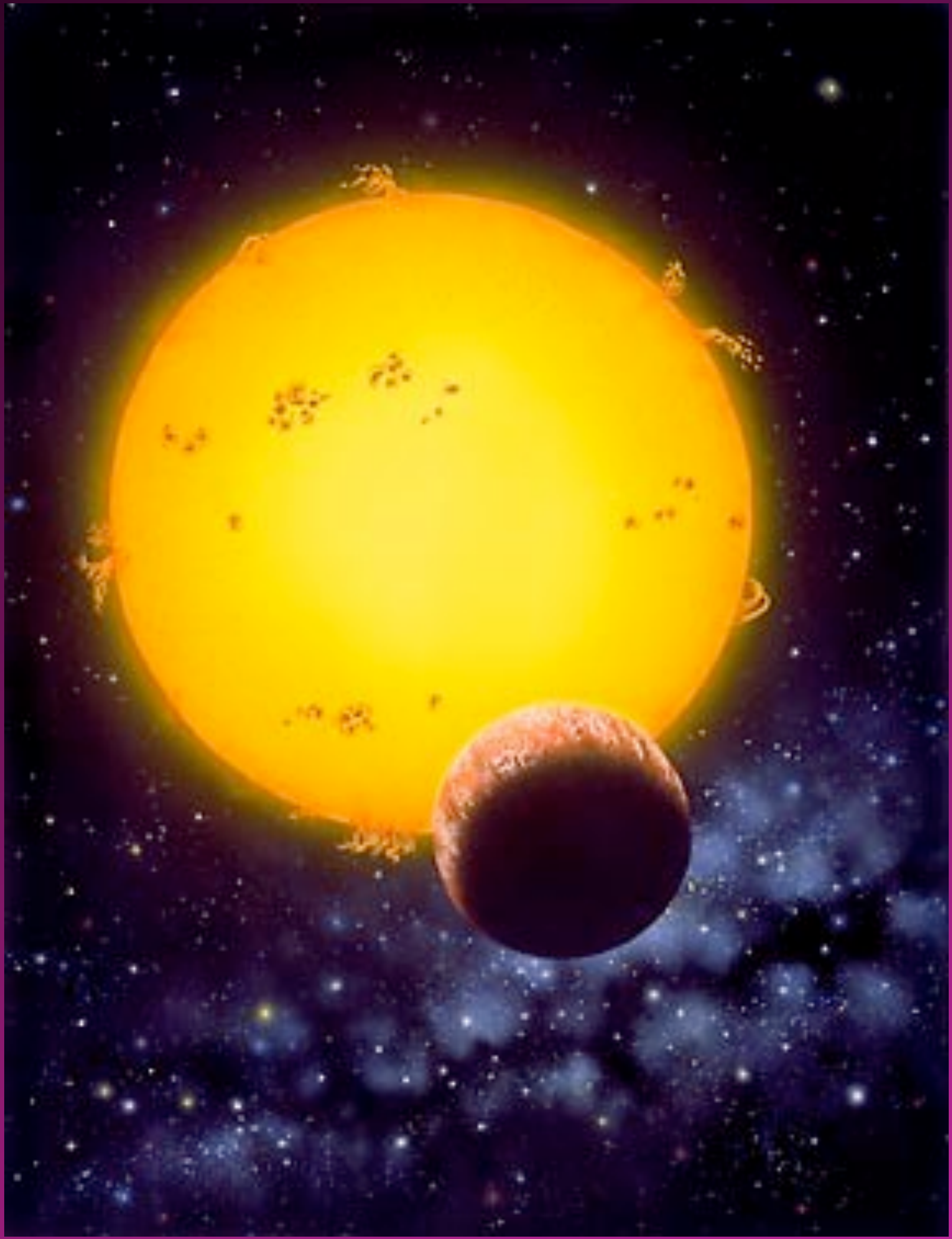
Mayor & Queloz , Nature 1995

Pegase 51 b

Surprise !!!

Prototype of
"Hot Jupiters"

First evidence of
orbital migration

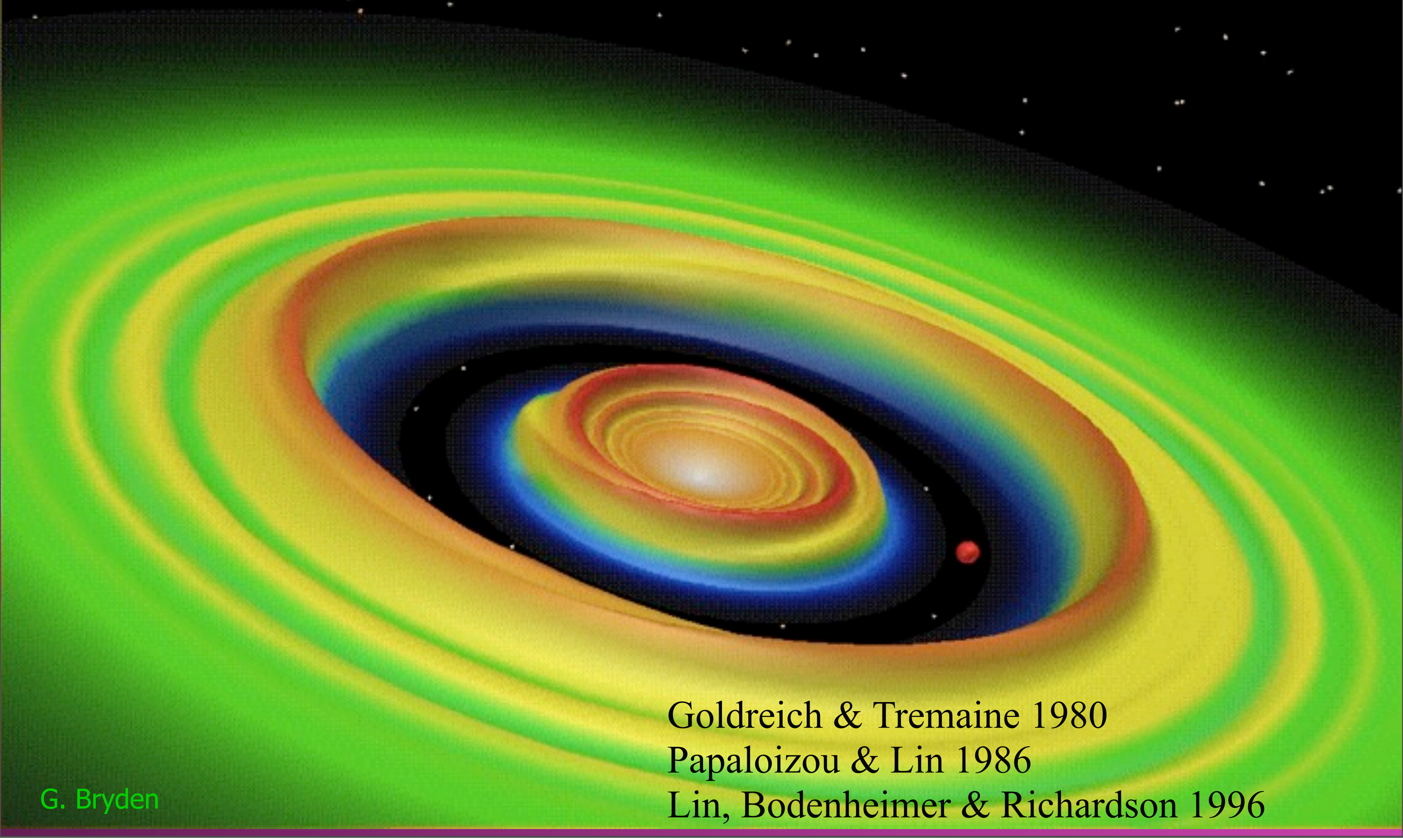


Lynette Cook

Formation of close-in planets : disk - planet interaction

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

How to stop the migration ?



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

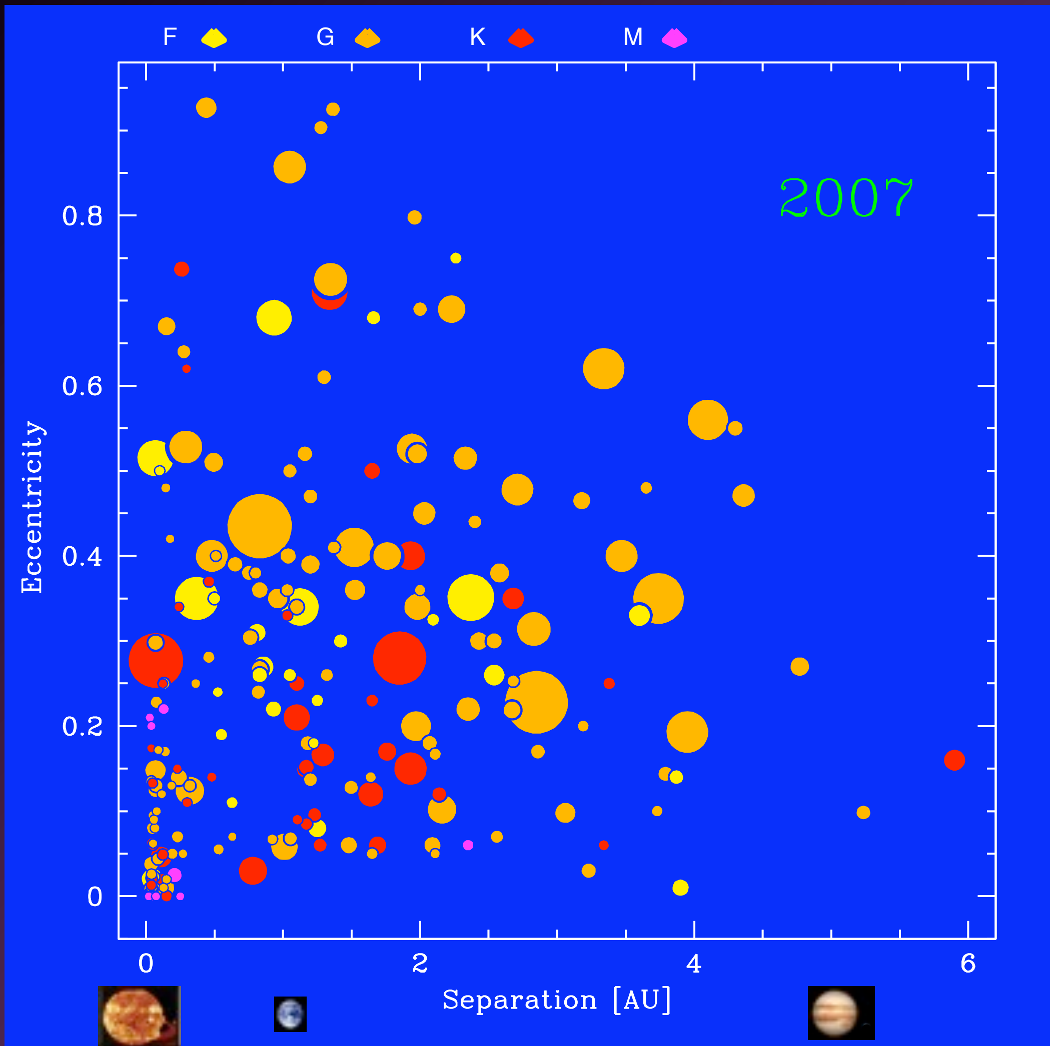
Planet detectability with radial velocities

$$k_1 = \frac{28.4\ \mathrm{m\ s^{-1}}}{\sqrt{1-e^2}} \frac{m_2 \sin i}{M_{\mathrm{Jup}}} \left(\frac{m_1 + m_2}{M_{\mathrm{Sun}}} \right)^{-2/3} \left(\frac{P}{1\ \mathrm{yr}} \right)^{-1/3}$$

Jupiter	@ 1 AU	: 28.4 m s^{-1}
Jupiter	@ 5 AU	: 12.7 m s^{-1}
Neptune	@ 0.1 AU	: 4.8 m s^{-1}
Neptune	@ 1 AU	: 1.5 m s^{-1}
Super-Earth (5 $M_{\oplus}$)	@ 0.1 AU	: 1.4 m s^{-1}
Super-Earth (5 $M_{\oplus}$)	@ 1 AU	: 0.45 m s^{-1}
Earth	@ 1 AU	: 0.09 m s^{-1}

The diversity of planetary systems

1995-2014: >1700 planets (+ several transit candidates)



Statistical properties

– Mass distribution

$1.0\ M_{Earth} < M_{pl} < 20\ M_{Jup}$

– Period

0.3 d < P < more than 10 years

– Eccentricity-period distribution

$0 < e < 0.93$

HD10180 : A system with more than 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

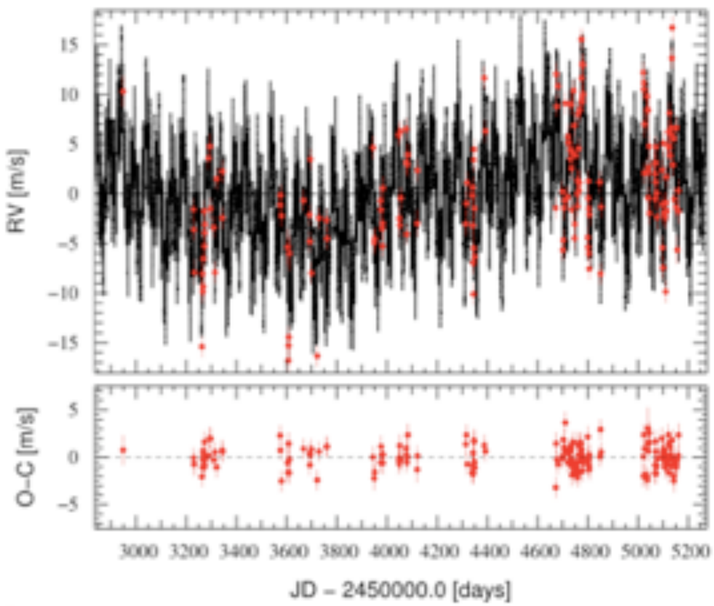
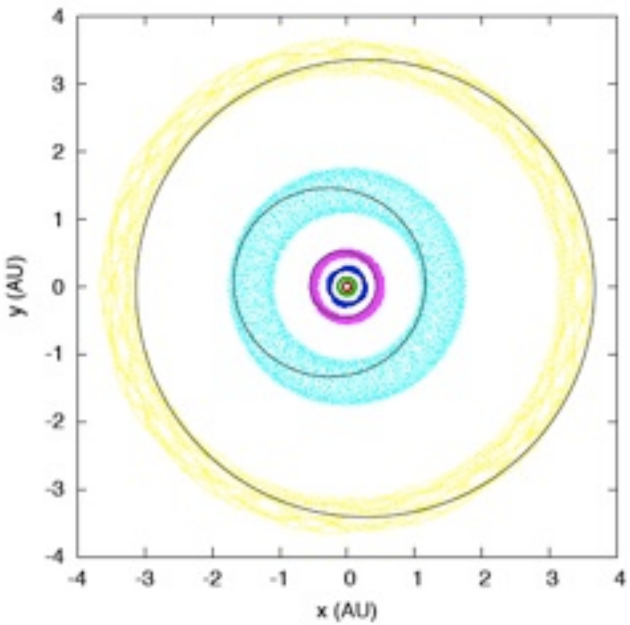
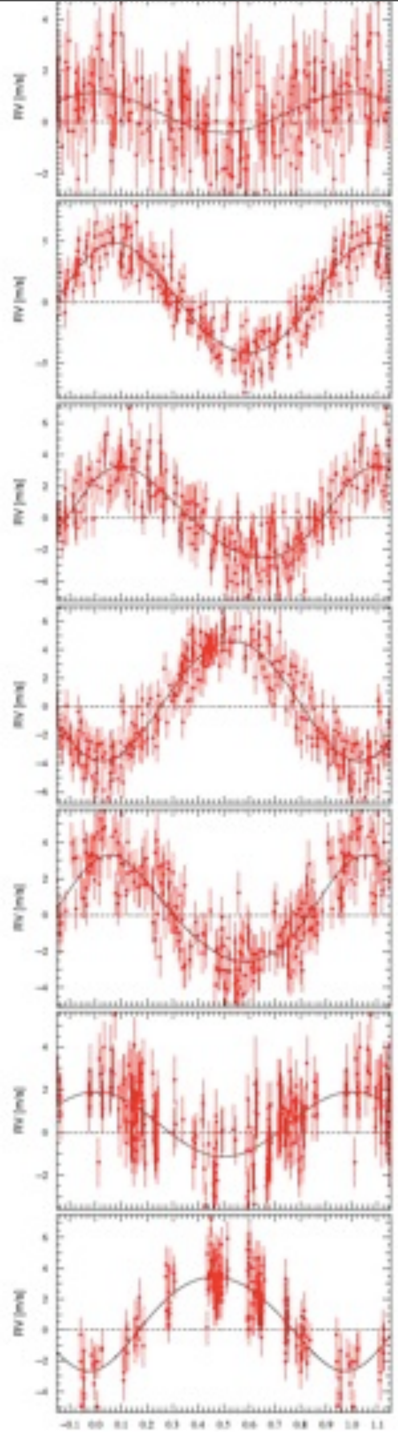
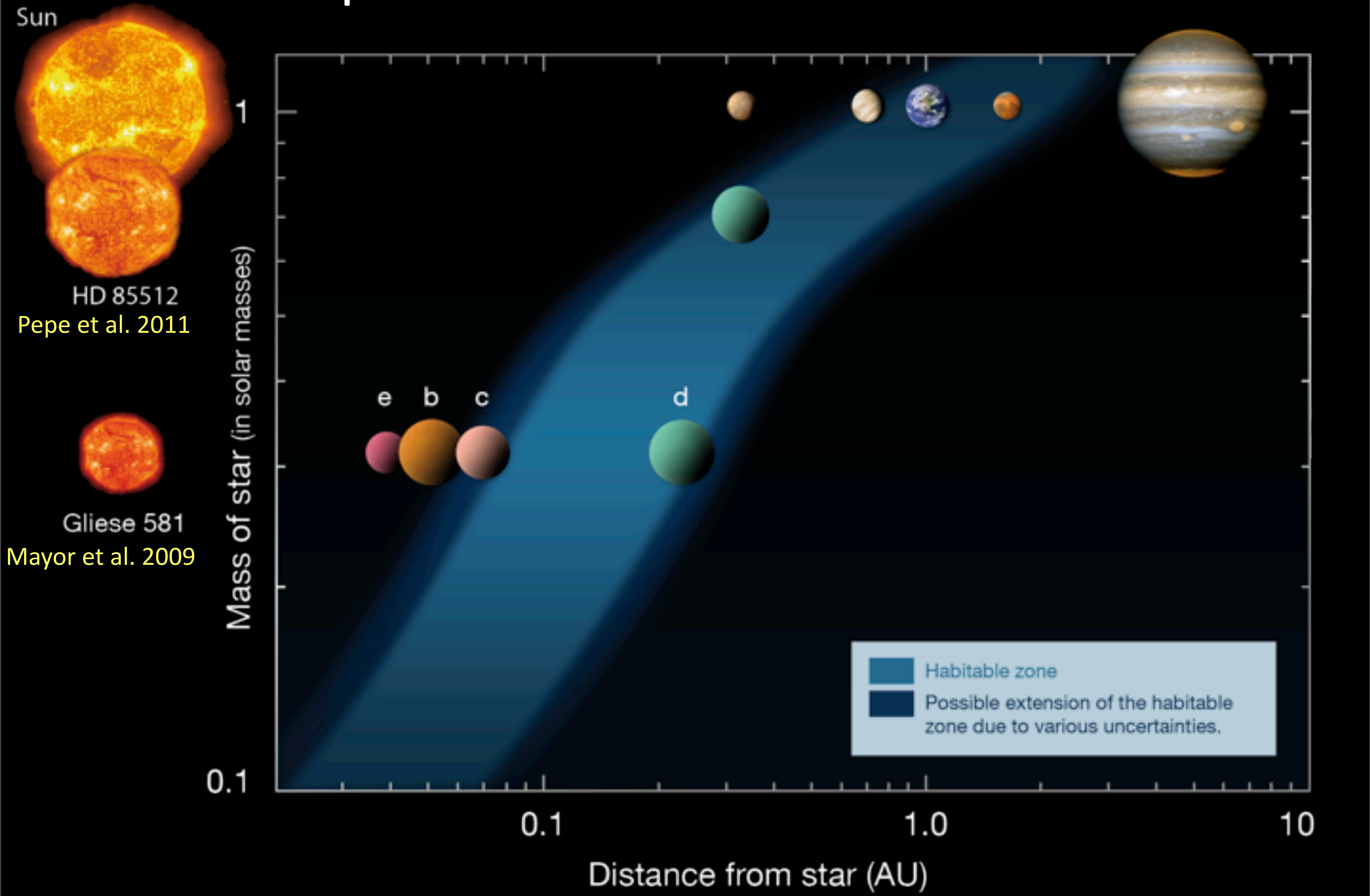


Fig. 5. Radial velocity time series with the 7-Keplerian model overplo





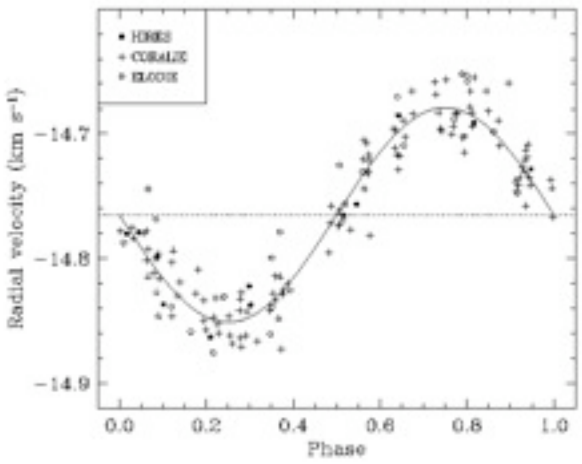
Super-Earths in the Habitable zone



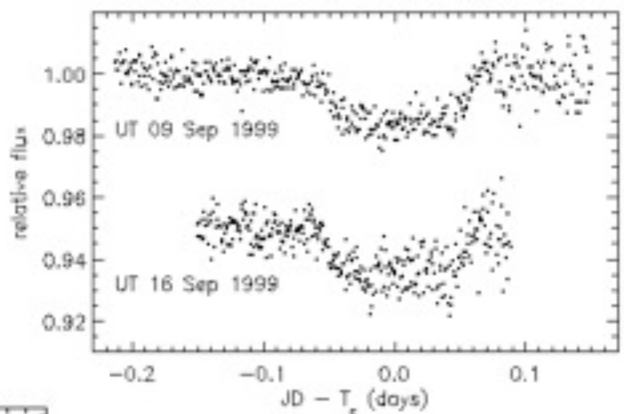
A first planetary transit : HD 209458

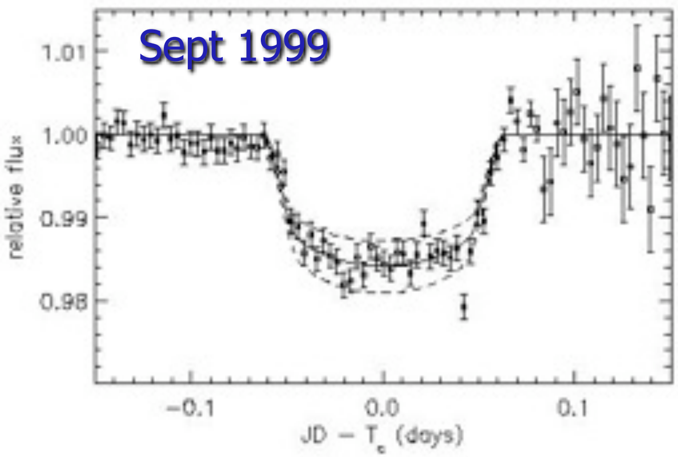
Mazeh et al 1999

P=3.5j



STARE





$R_{pl} = 1.4\ R_{Jup}$

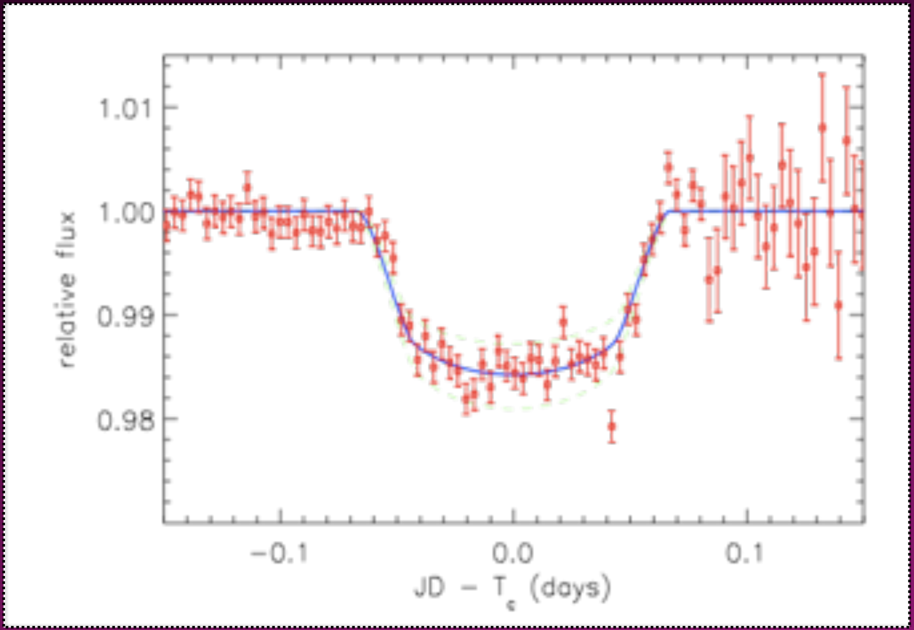
$M_{pl} = 0.69\ M_{Jup}$

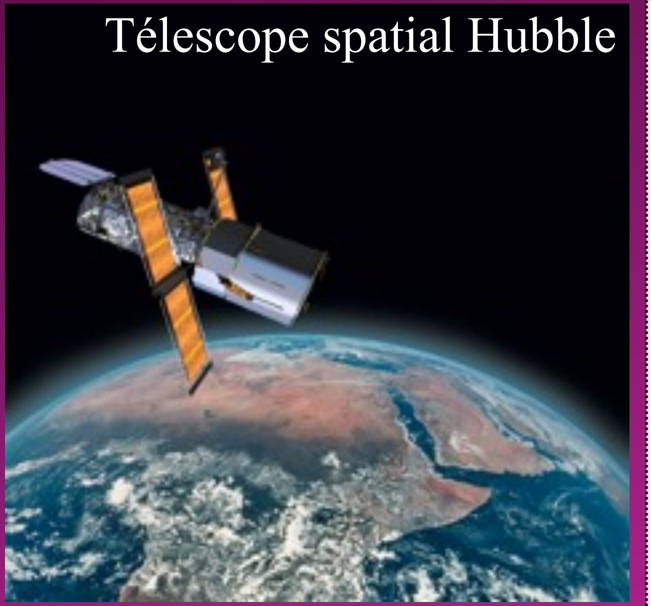
$\rho_{pl} = 0.31\ g/cm^3$

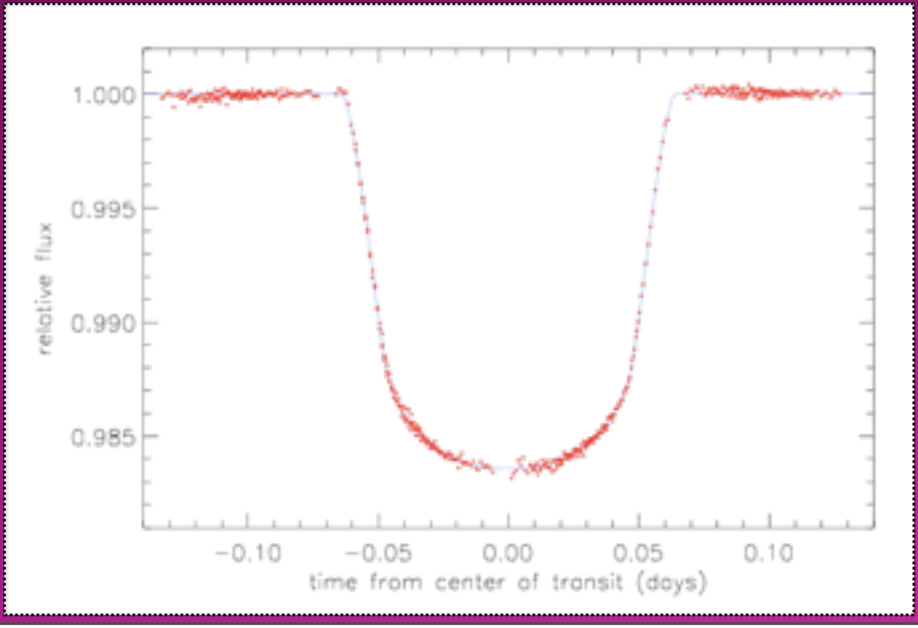
Charbonneau et al 2000

... transits from space

STARE

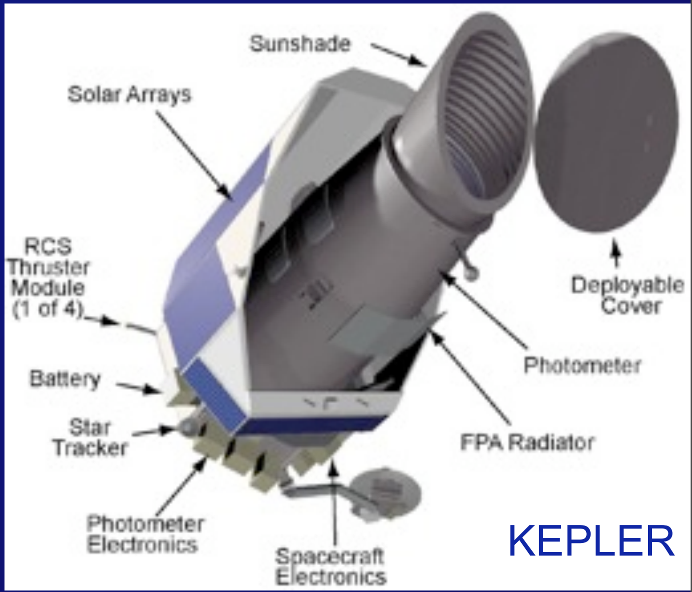


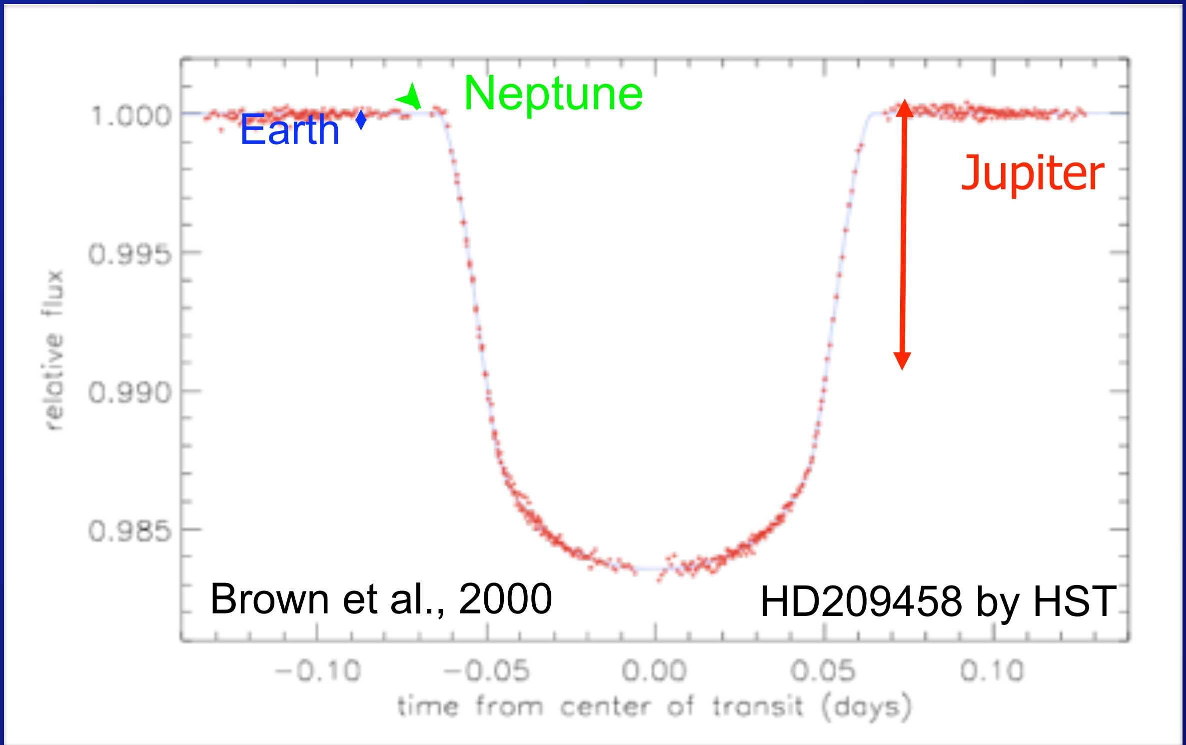




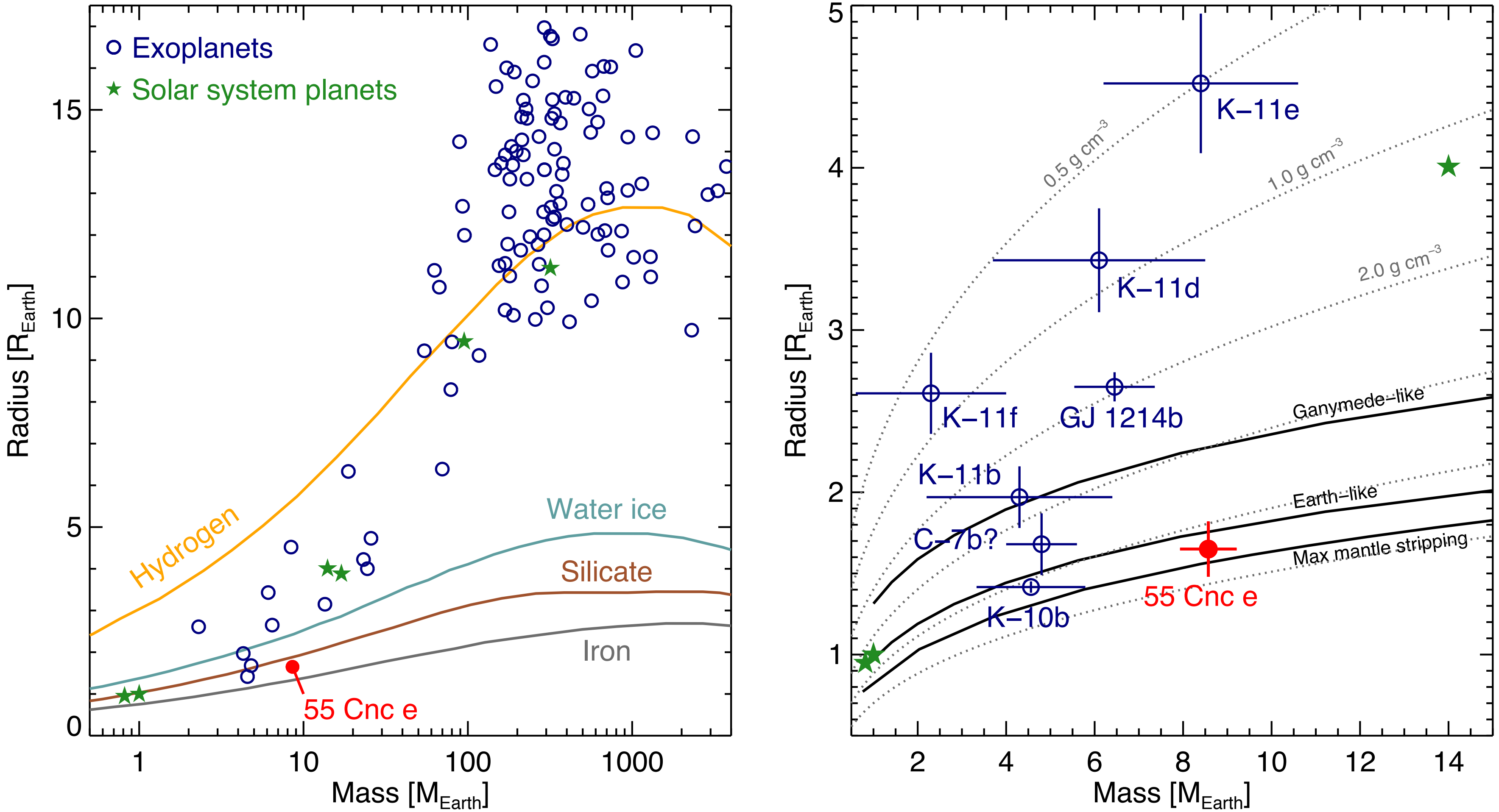
Transits of rocky planets !!

- Gaseous giant planets : 0.01 mag
- Rocky planets : 0.0001 mag



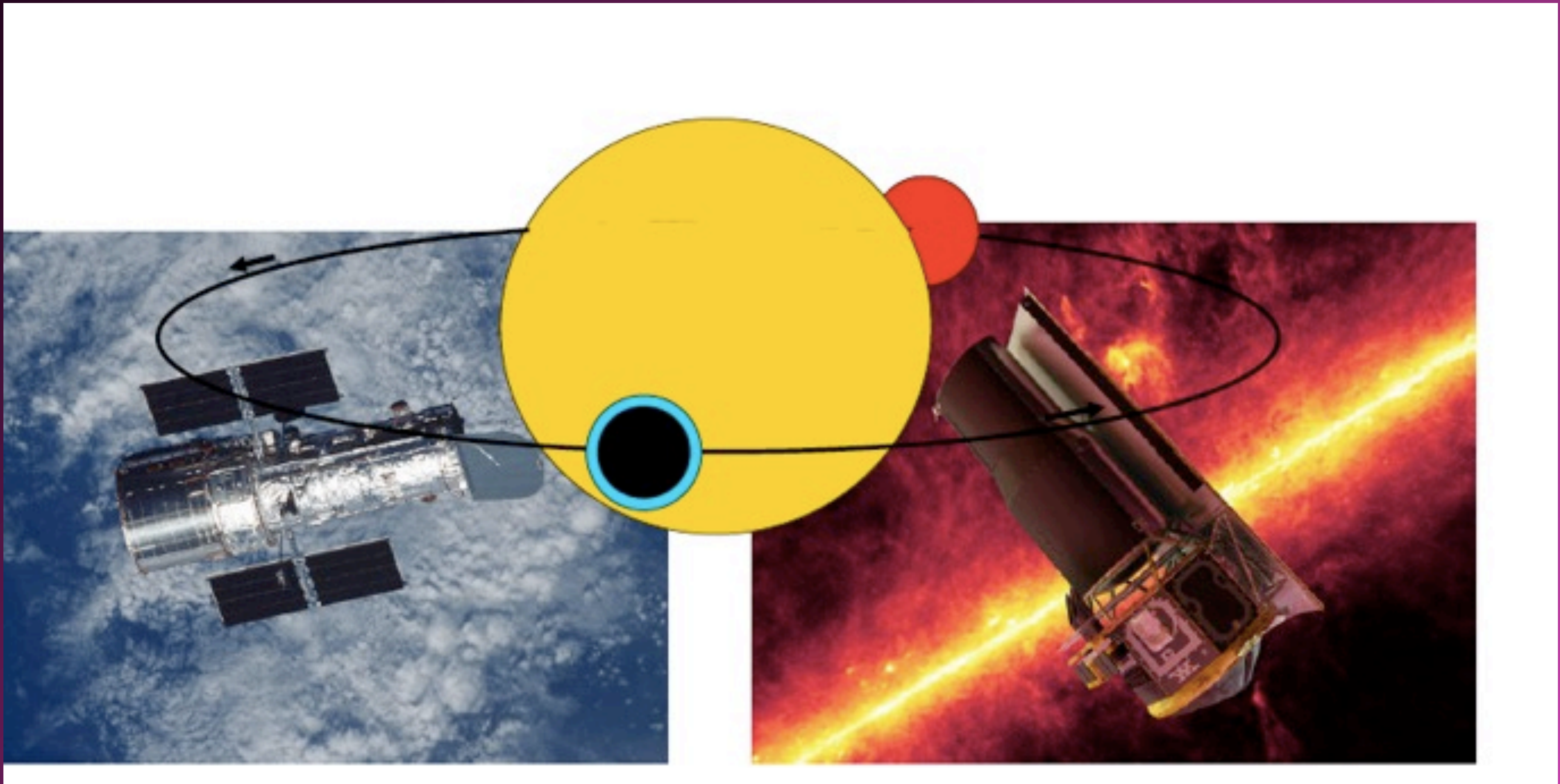


Radial velocities + transits give the planetary bulk density

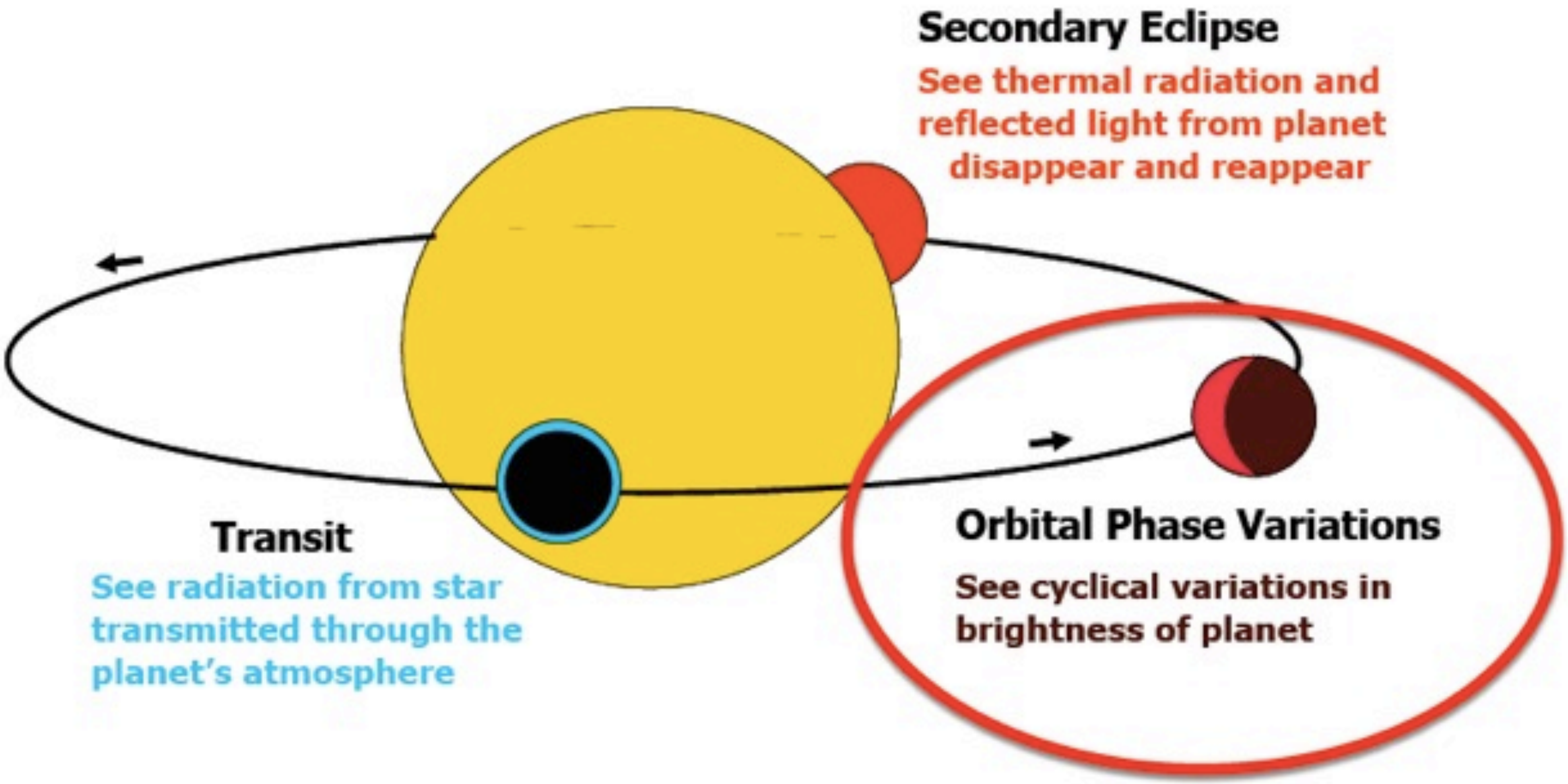


Transits allow the study of planetary atmospheres

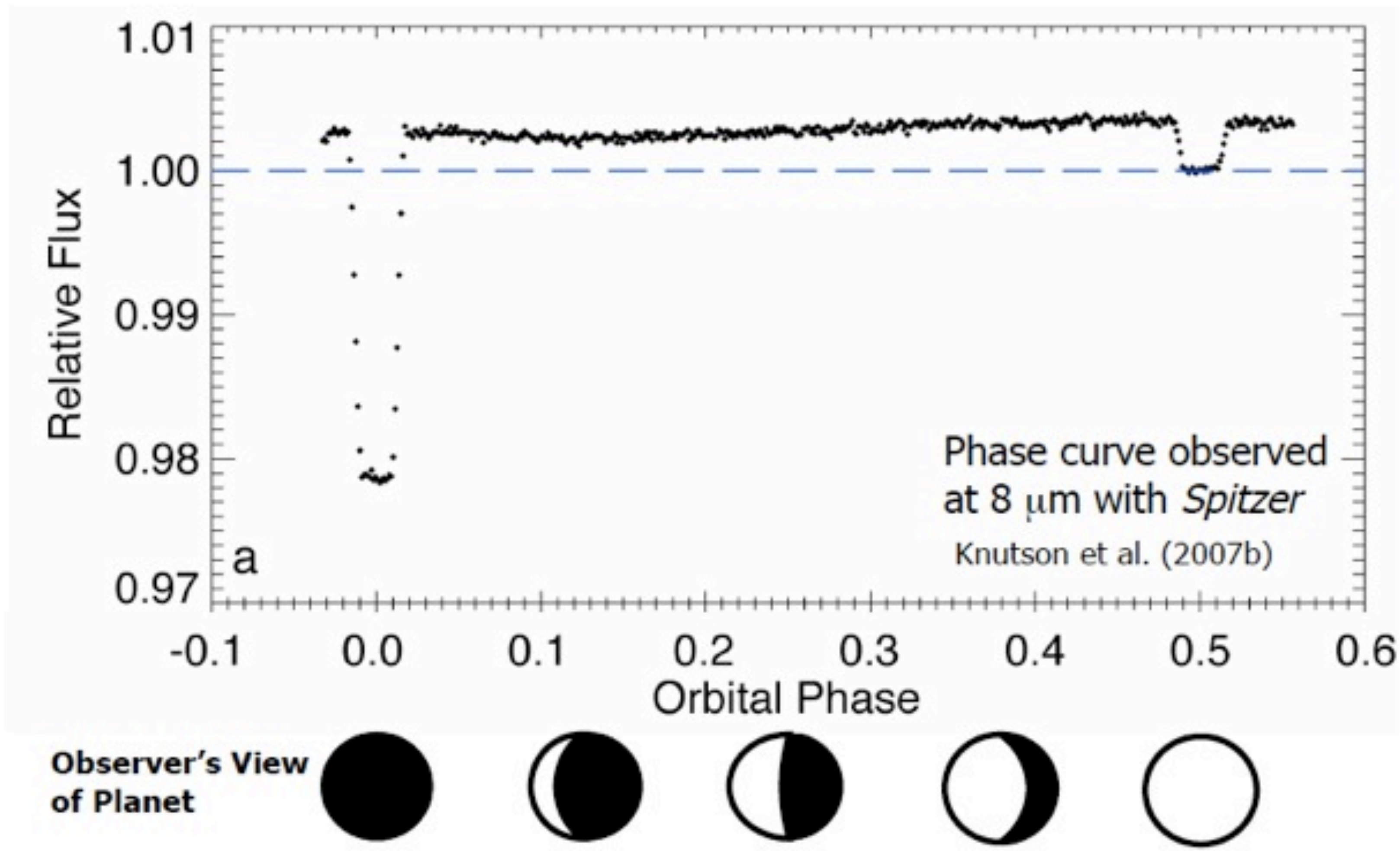
(day side... and night side)



Transiting Planets as a Tool for Studying Exoplanetary Atmospheres

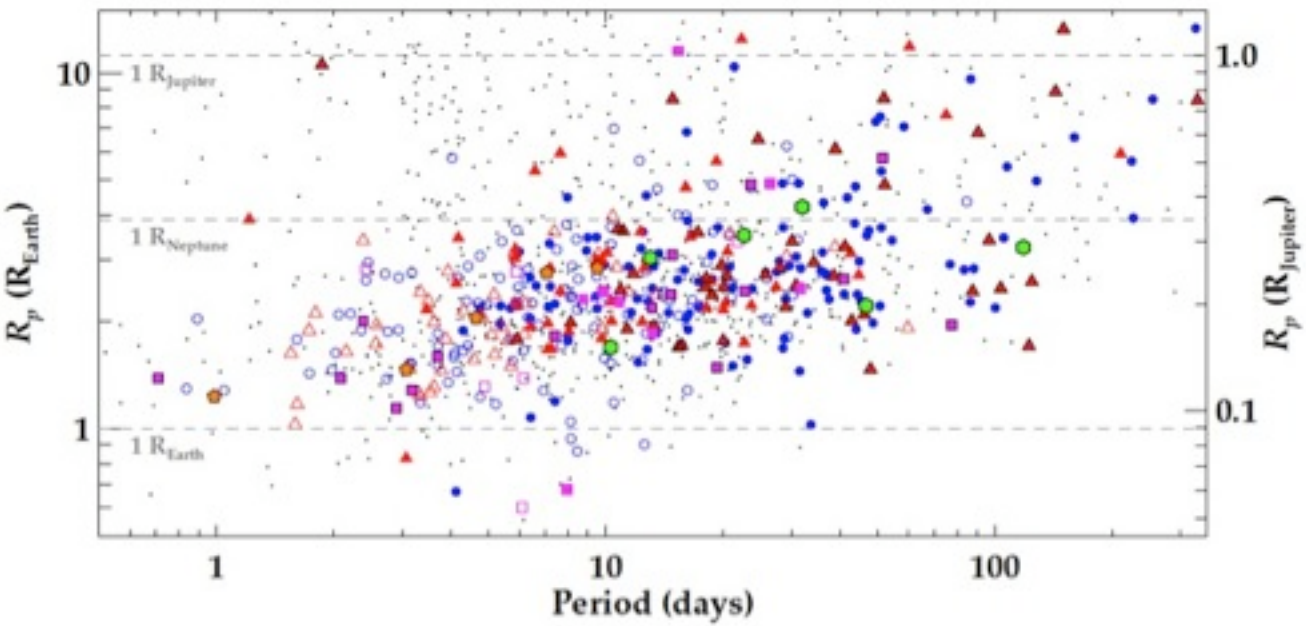


Orbit of HD 189333b



Multi-transiting KEPLER candidates

170/Feb 2011 --> 367/Sept 2011 -->



Numbers of multiplanets:

115 doubles, 45 triples, 8 quads,

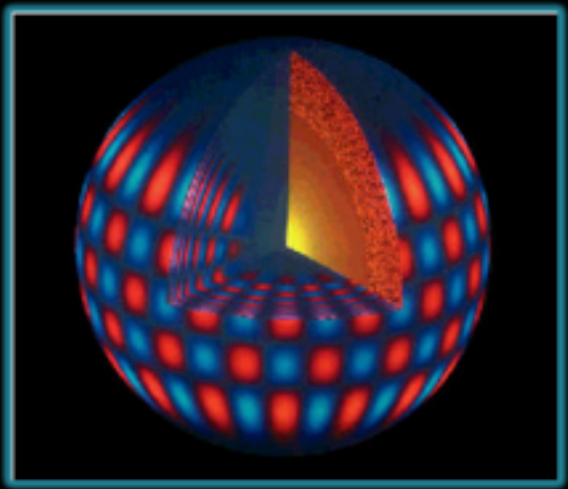
1 & 1 of five and six

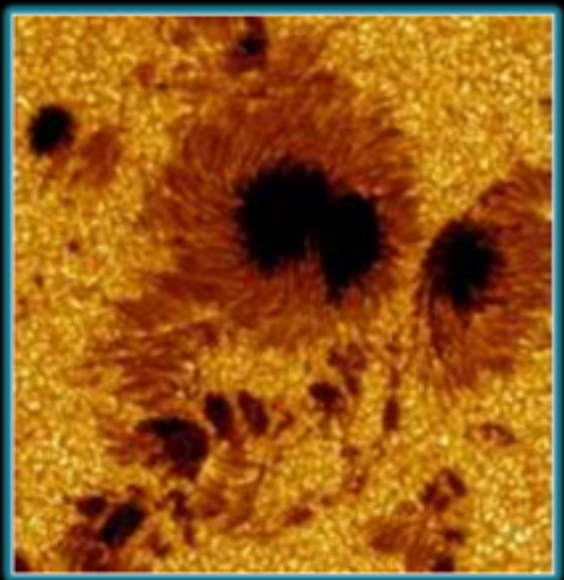
Borucki et al. 2011
Lissauer, Ragozzine, Fabrycky et al. 2011

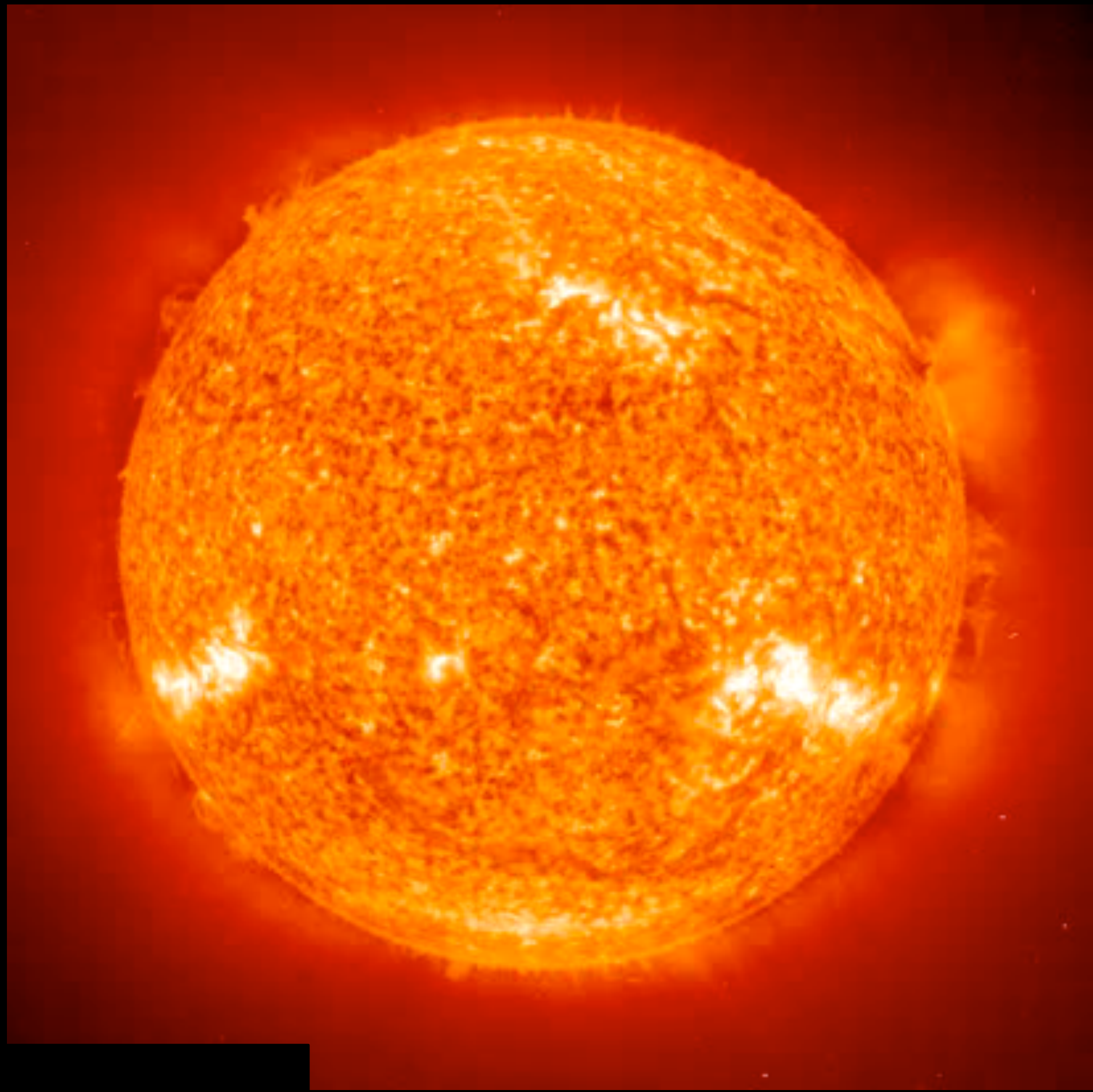
The orbital planes of systems with low mass planets are uncredibly coplanars : < 1 degree !

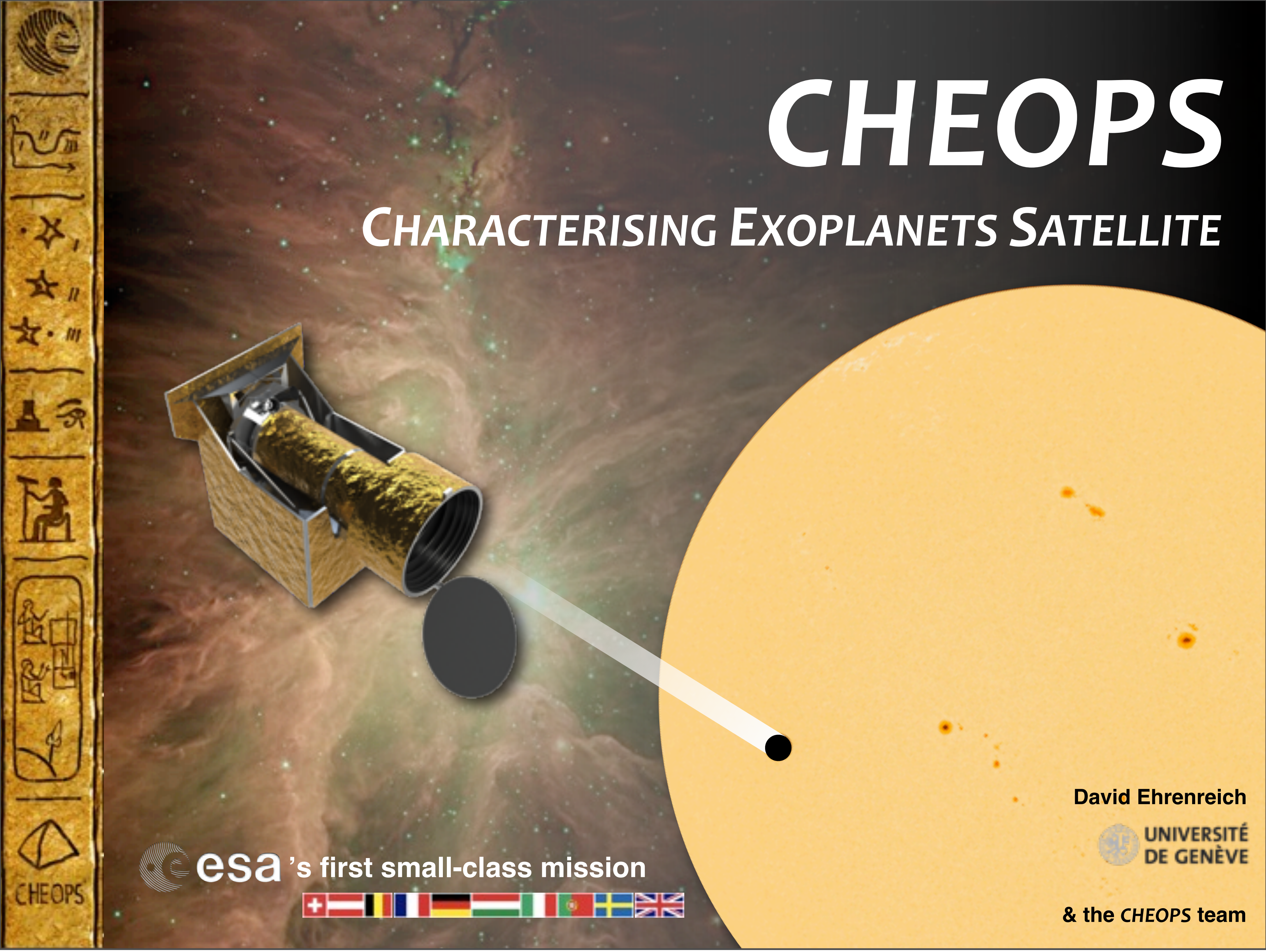

Earth-twins ?

Stellar intrinsic limitations

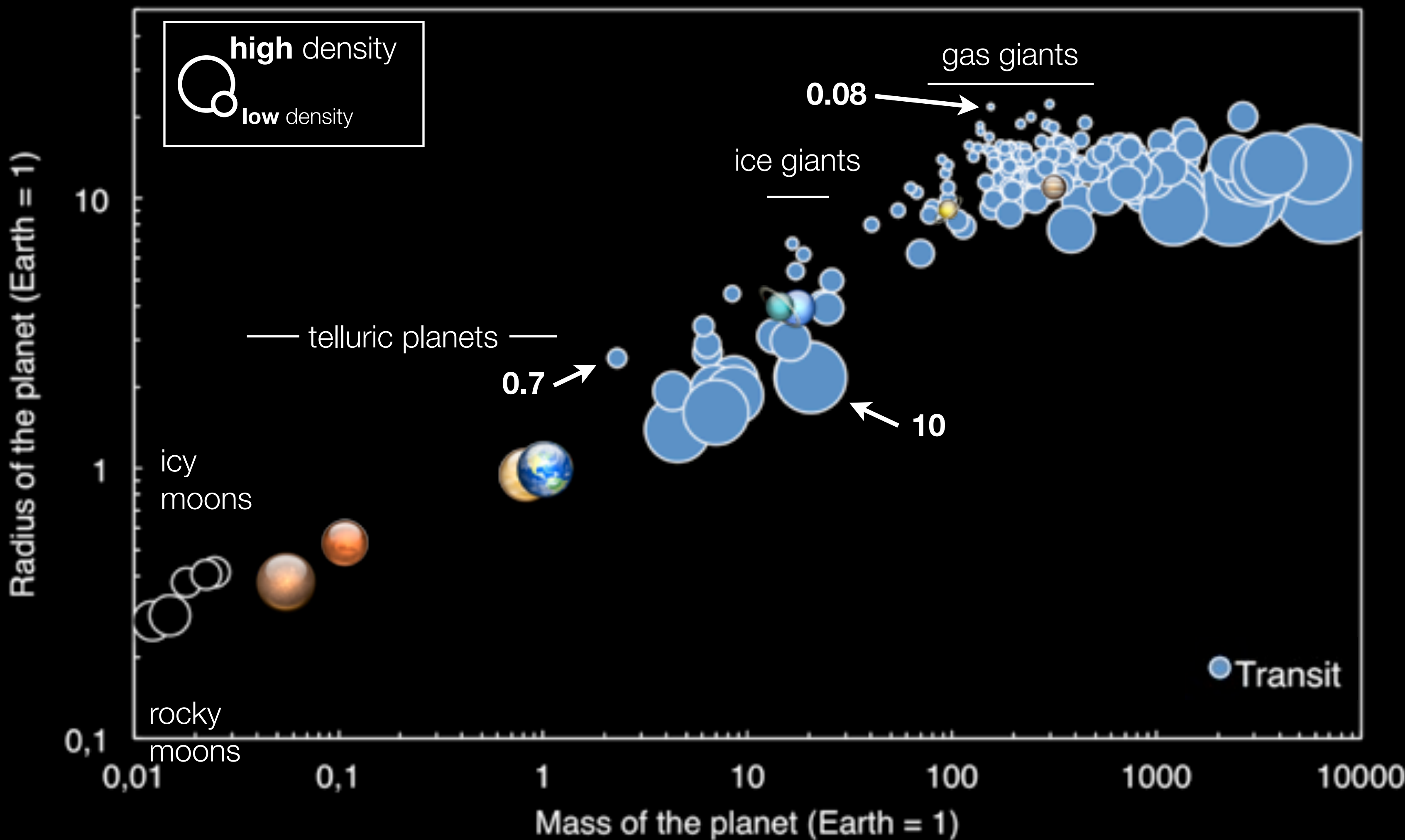




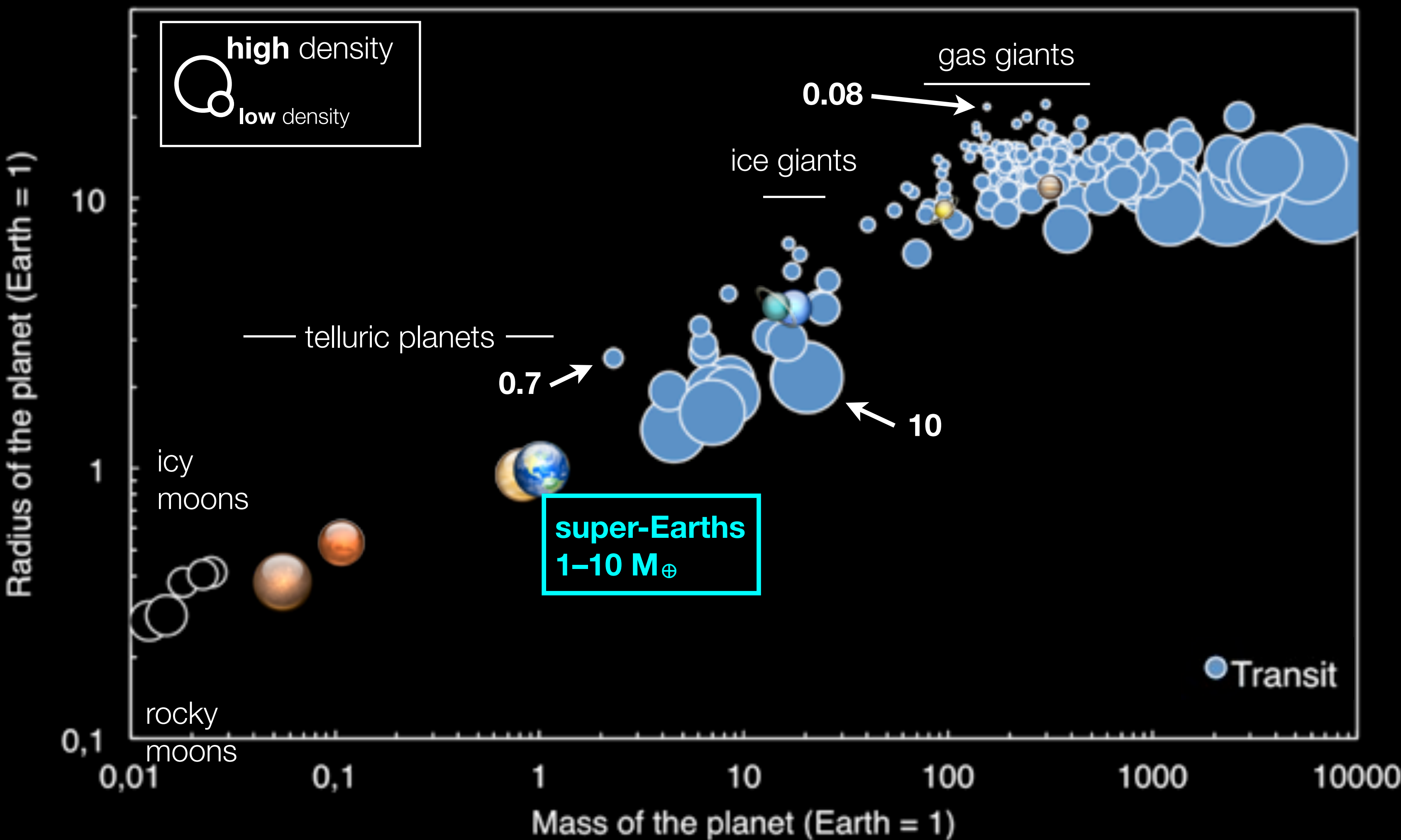



CHEOPS
CHARACTERISING EXOPLANETS SATELLITE
esa's first small-class mission
David Ehrenreich
UNIVERSITÉ DE GENÈVE
& the CHEOPS team
CHEOPS

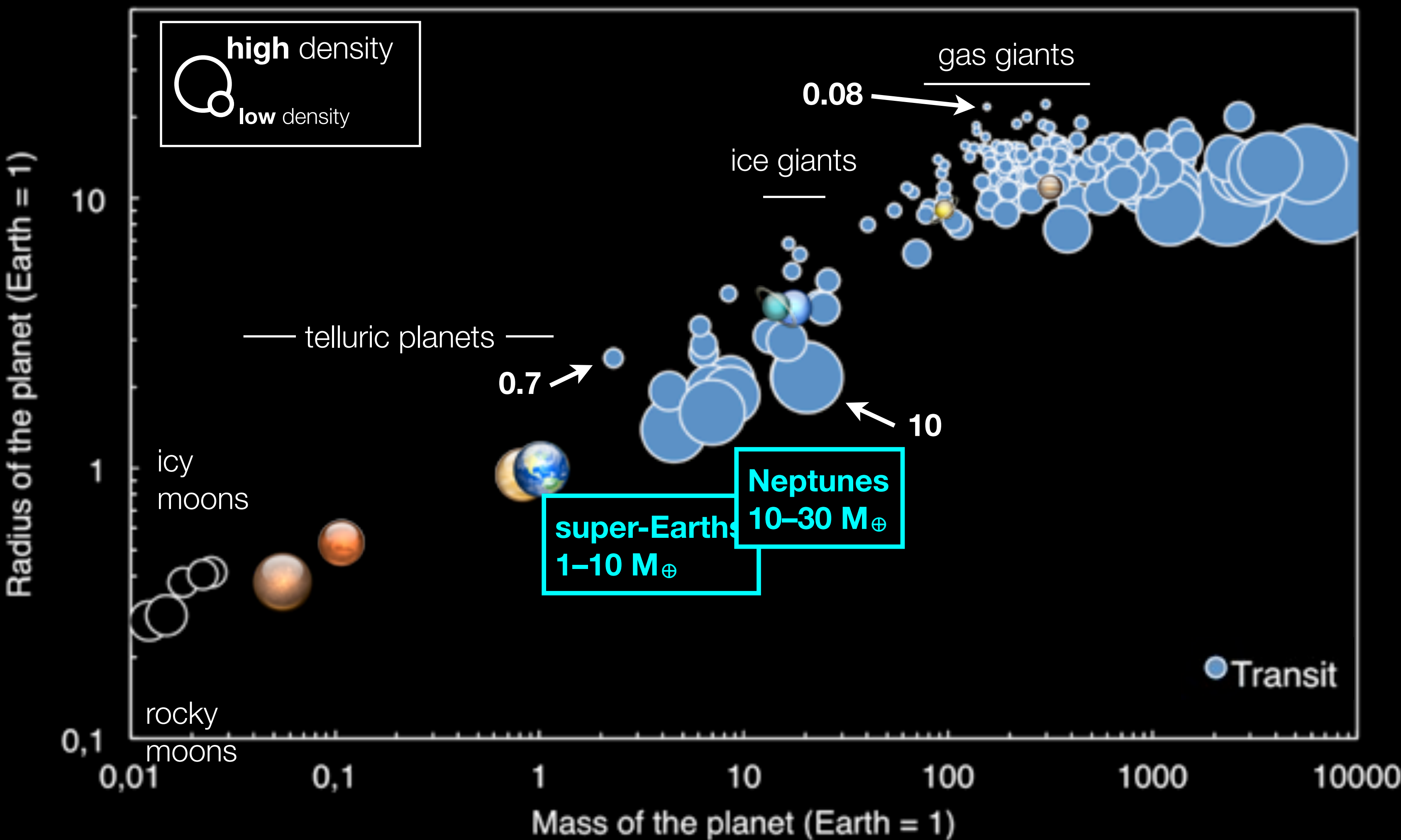
Mass continuity
& diversity of structures



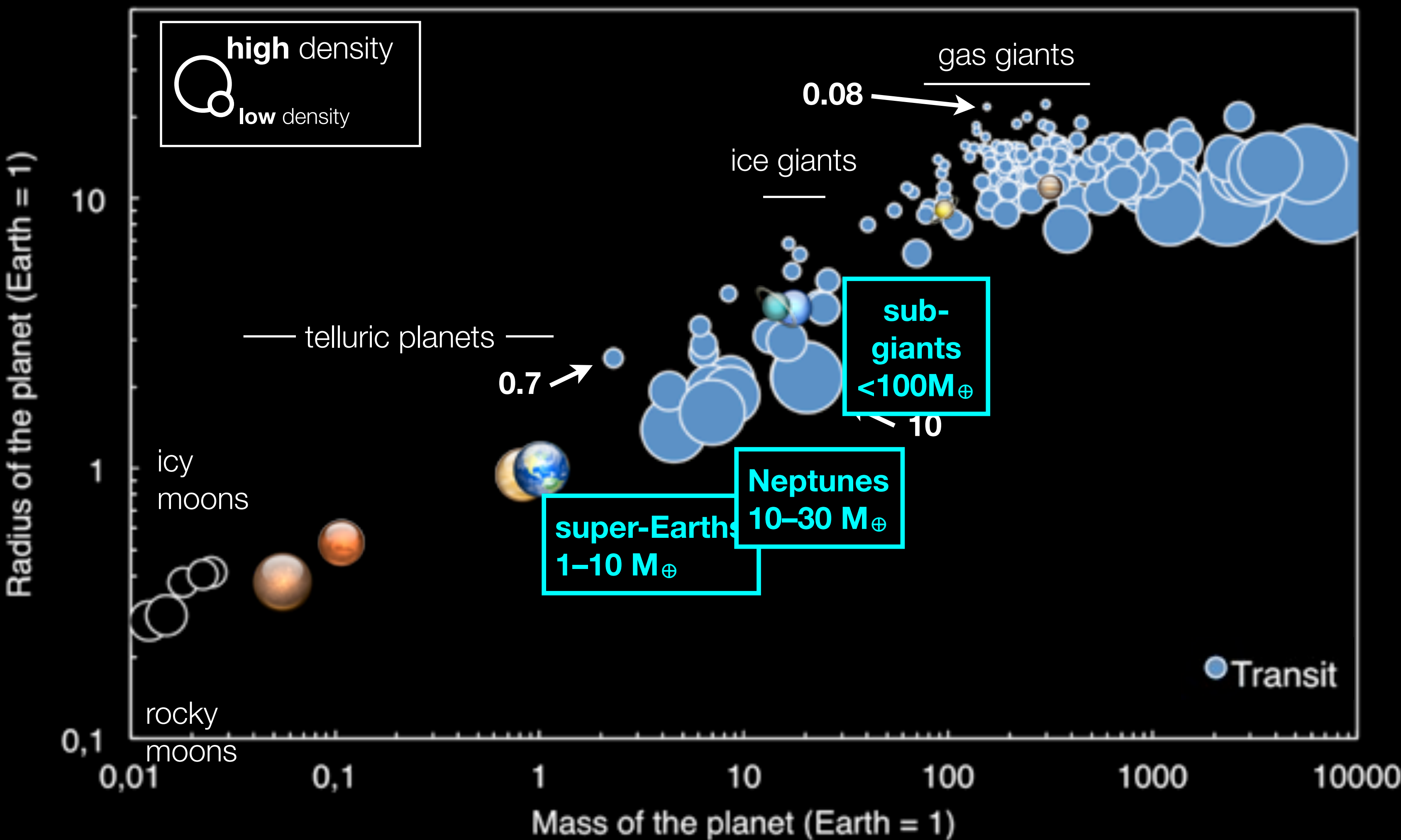
Mass continuity
& diversity of structures



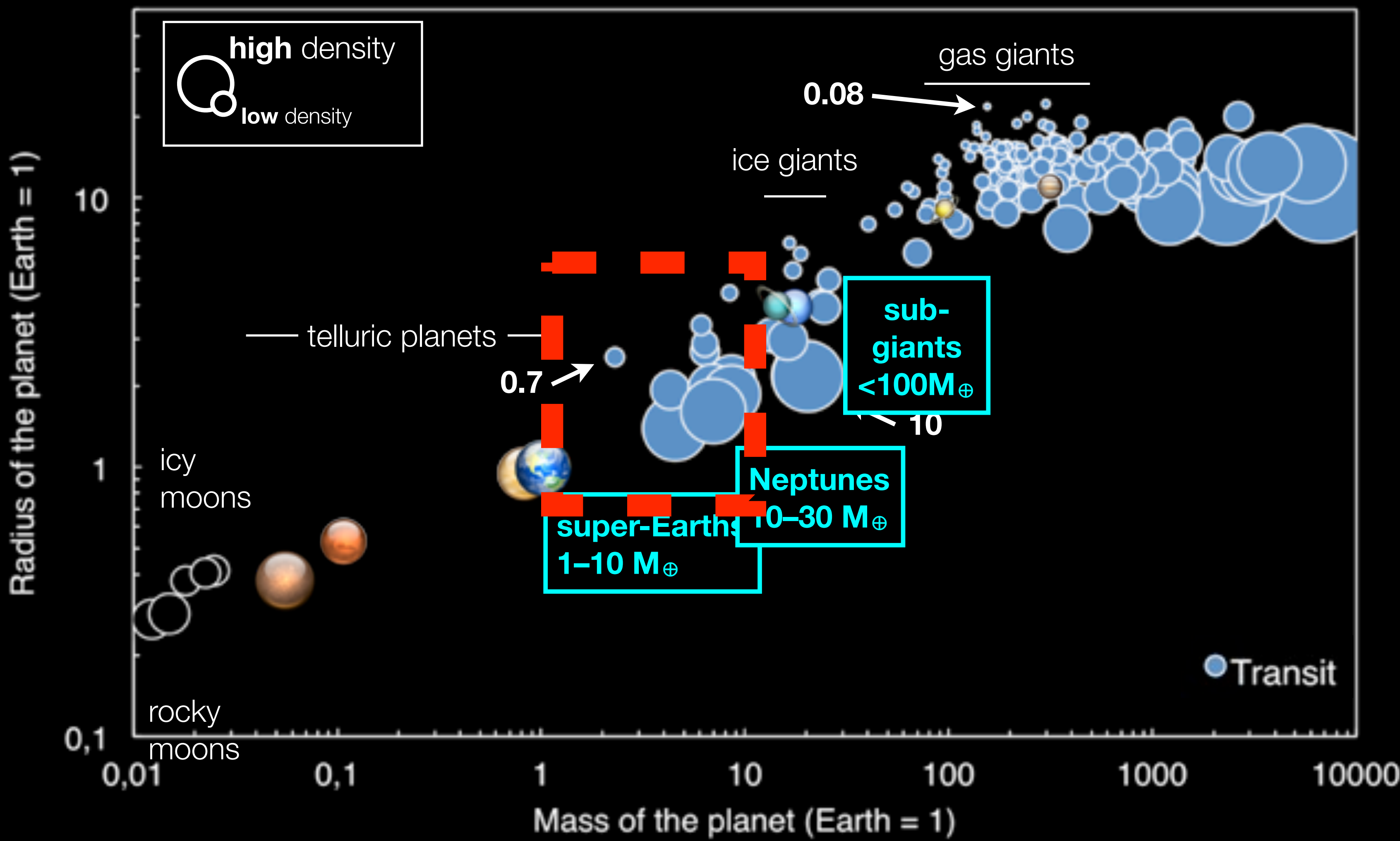
Mass continuity & diversity of structures



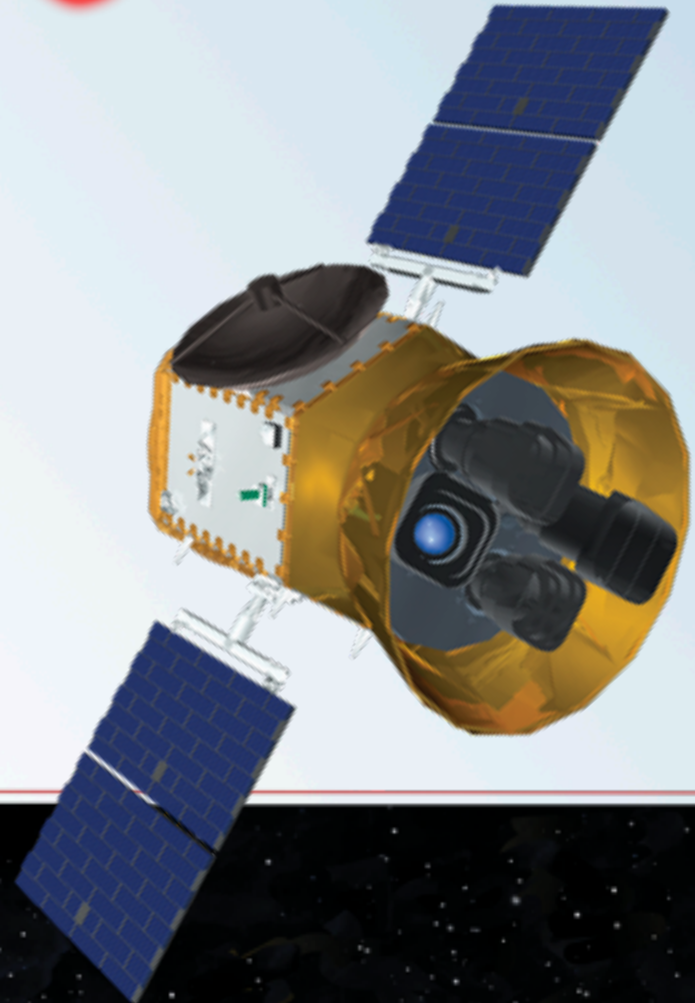
Mass continuity
& diversity of structures



Mass continuity
& diversity of structures



Transiting Exoplanet Survey Satellite

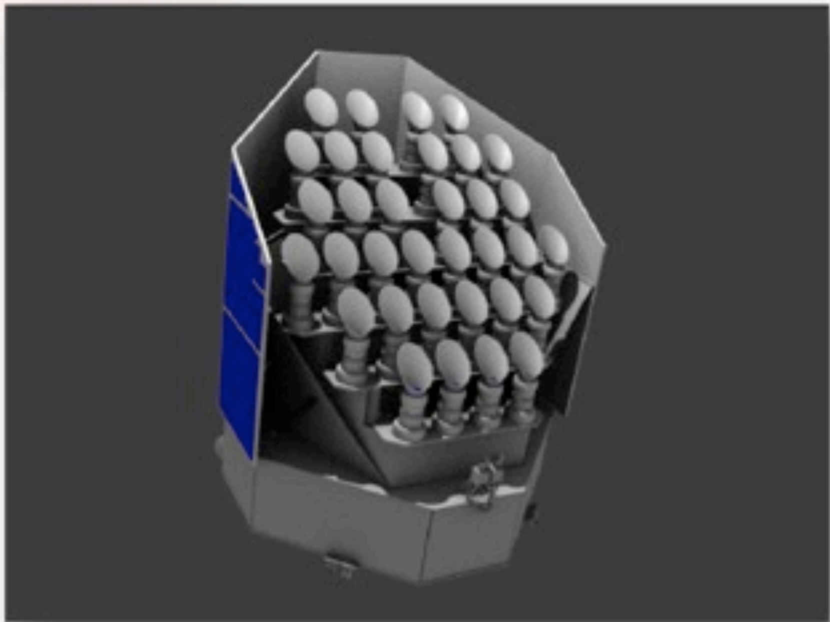


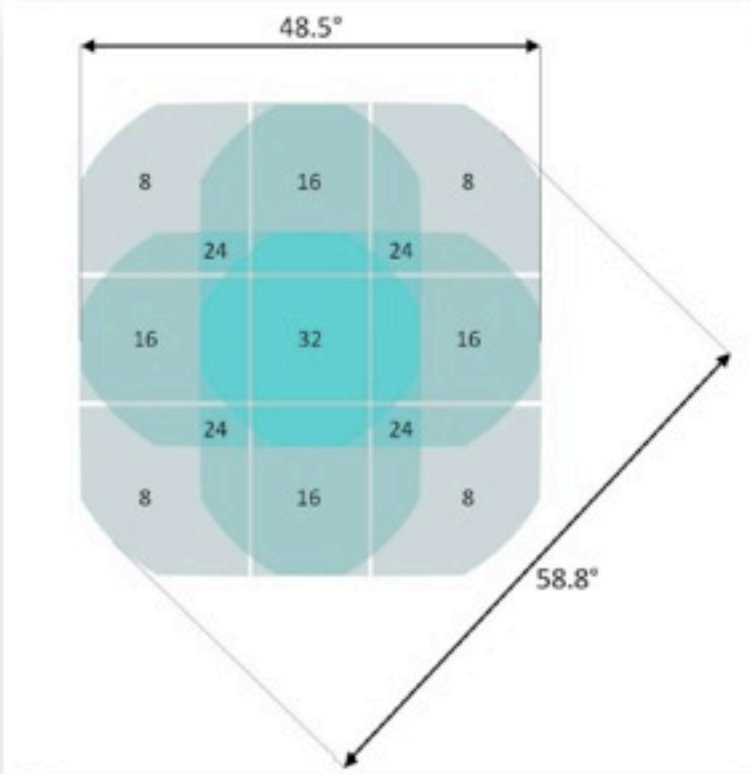
The TESS Mission:

Discovering New Earths and Super-Earths in the Solar Neighborhood

George Ricker (MIT)

PLATO instrument



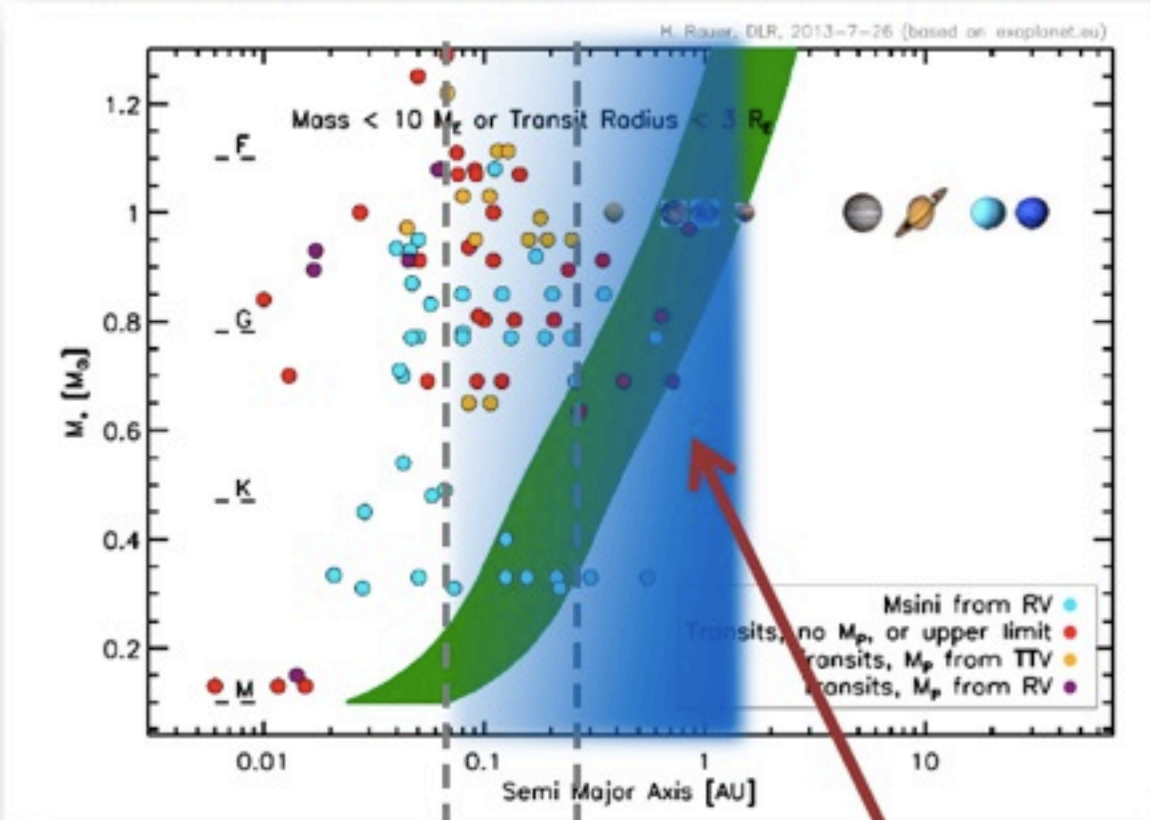


- 32 « normal » cameras, cadence 25 sec
- 2 « fast » cameras : cadence 2.5 sec, 2 colours
- dynamical range: $4 \leq m_V \leq 16$

- Cameras are in groups
- Offset to increase FoV

Bulk properties of Earth-like planets up to the HZ

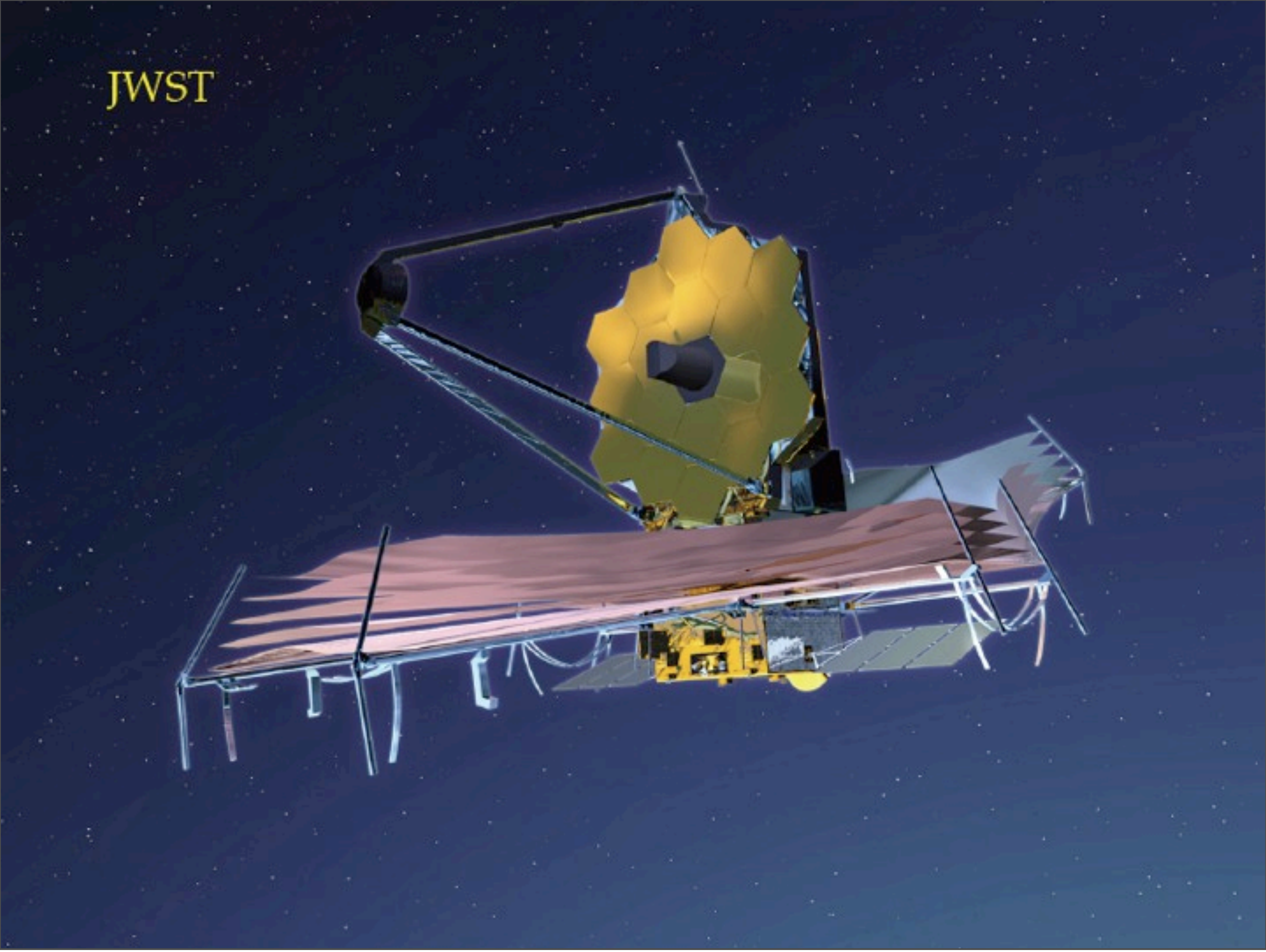
Status super-Earths detection and characterization

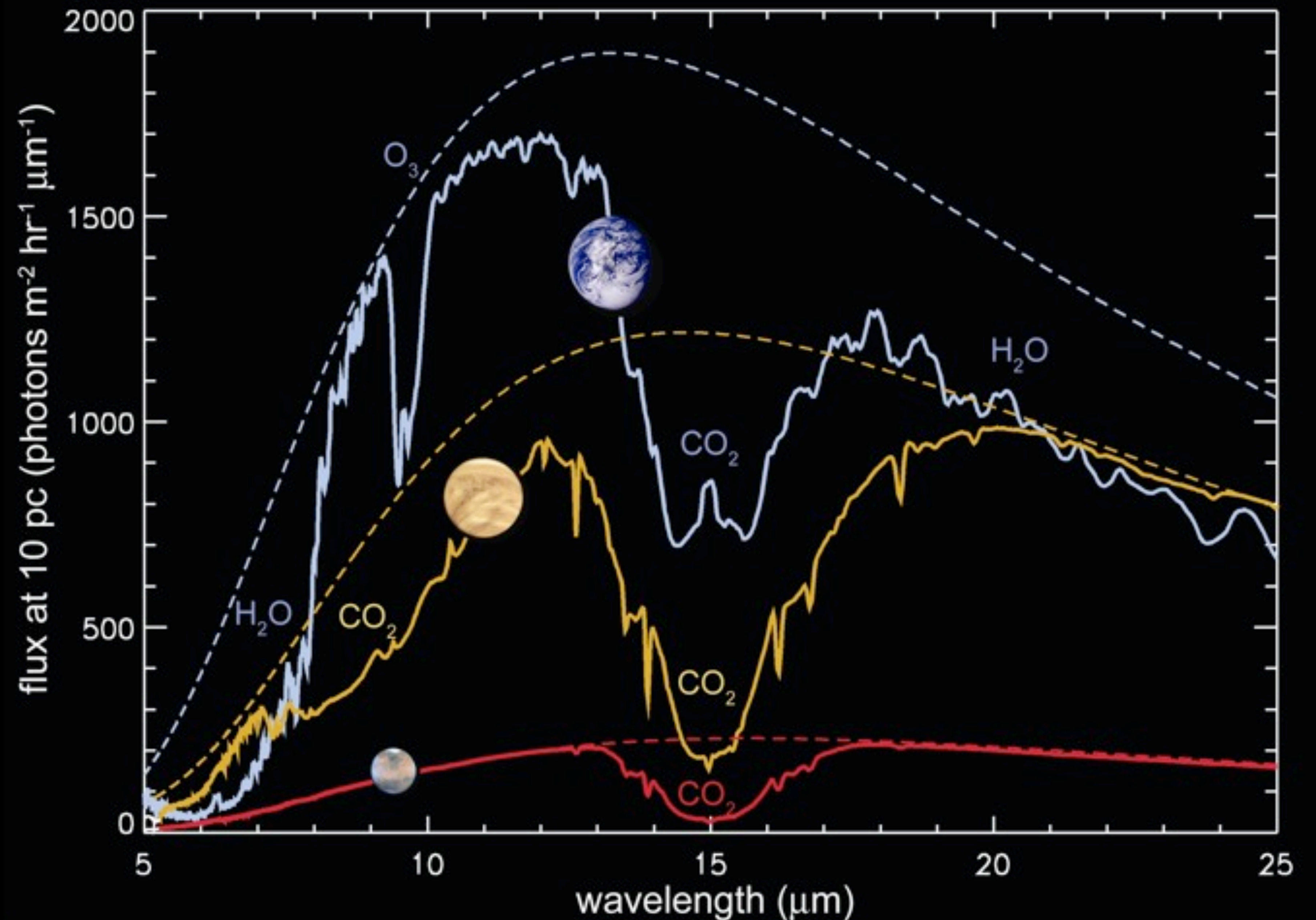


Transits and mass from RV

Mass from TTVs

Main target range for PLATO 2.0 characterization (transit + RV)


JWST

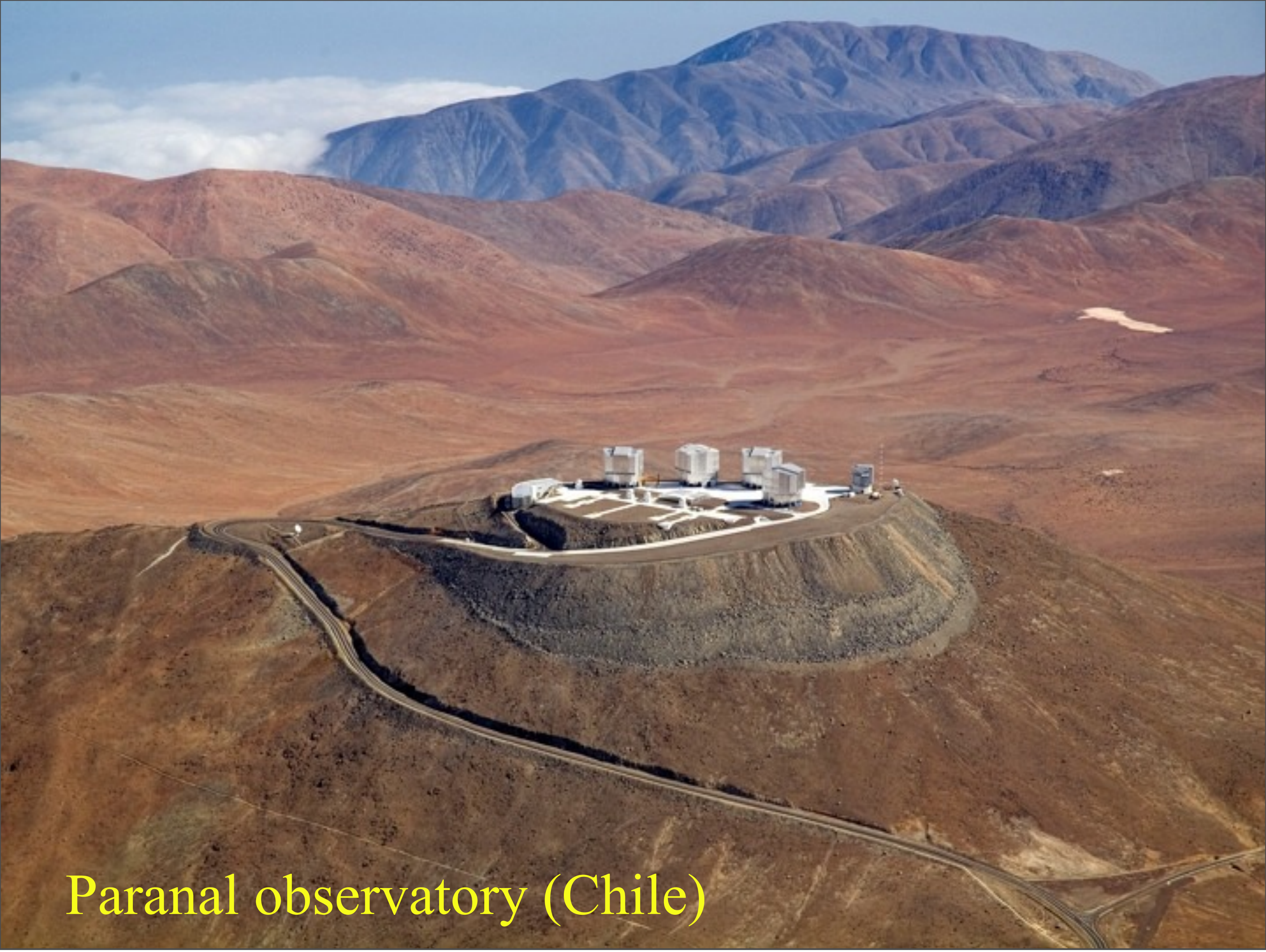


flux at 10 pc (photons m-2 hr-1 μm-1)
wavelength (μm)
2000
1500
1000
500
0
5
10
15
20
25
O3
H2O
CO2
CO2
CO2
CO2
H2O

Selsis 2007

Life *«a cosmic imperative» ?*

Christian de Duve

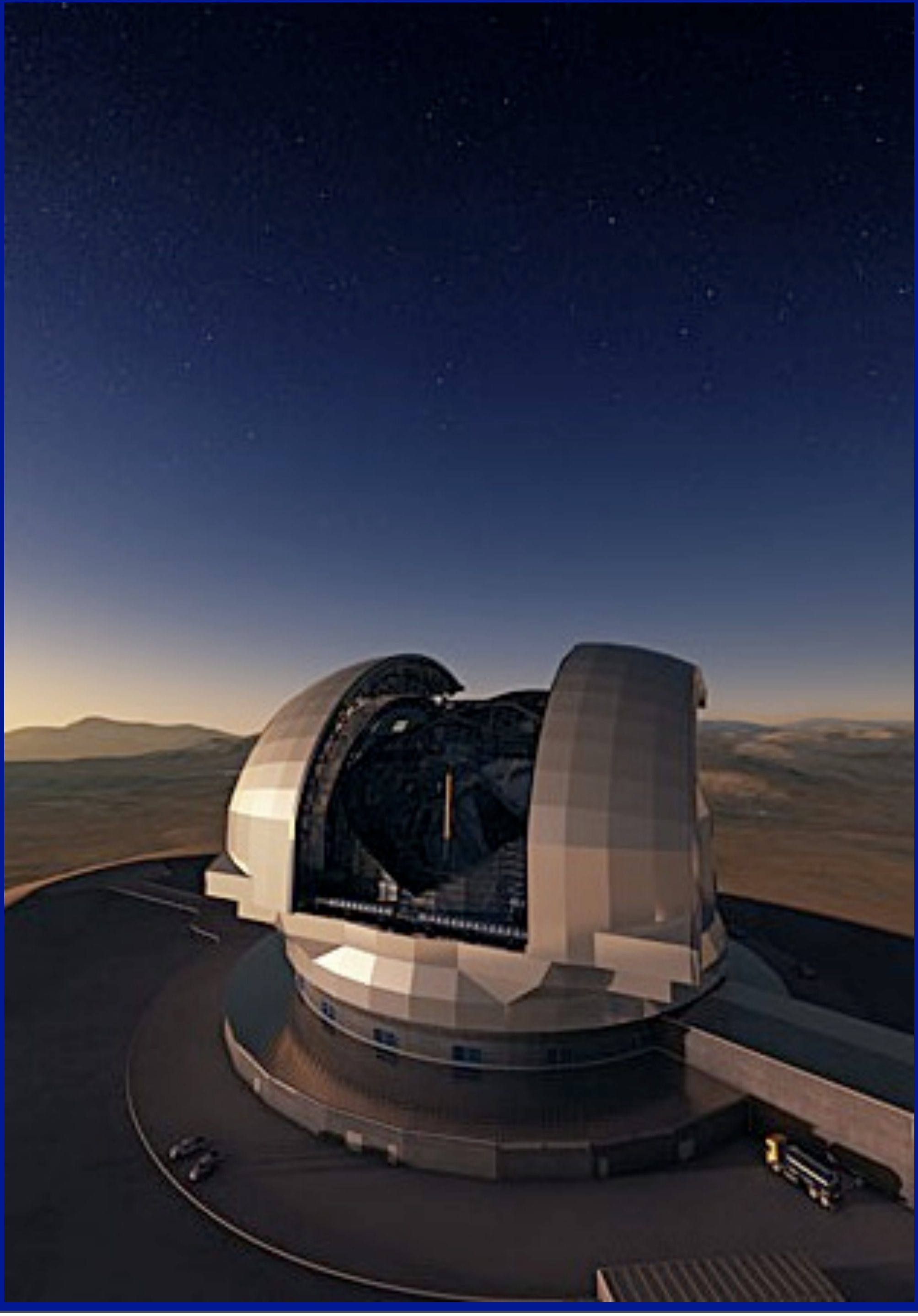

Paranal observatory (Chile)

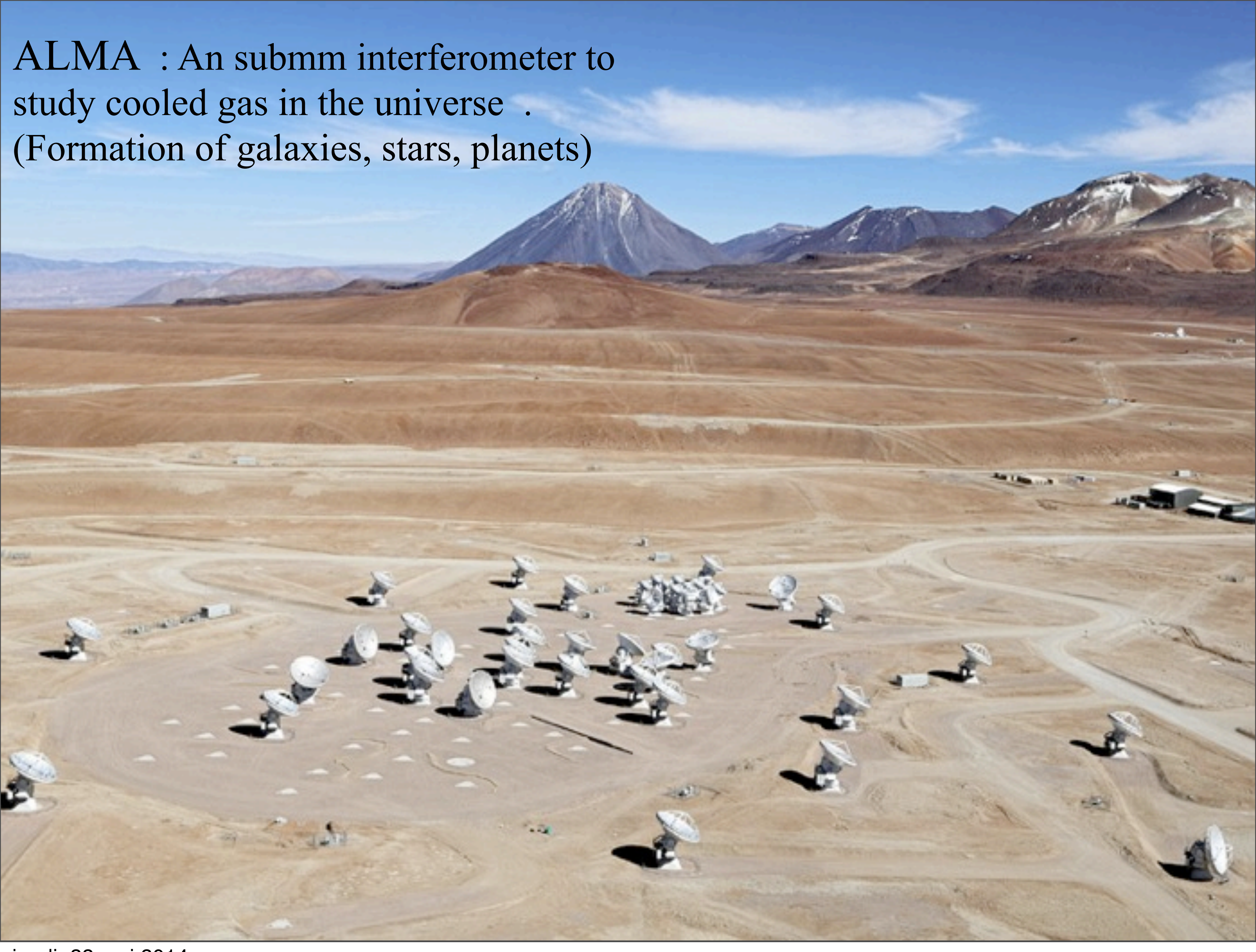
E-ELT

An ESO project of a 39 meter telescope.

2020

Cerro Armazones
Atacama desert
Chile




ALMA : An submm interferometer to
study cooled gas in the universe .
(Formation of galaxies, stars, planets)