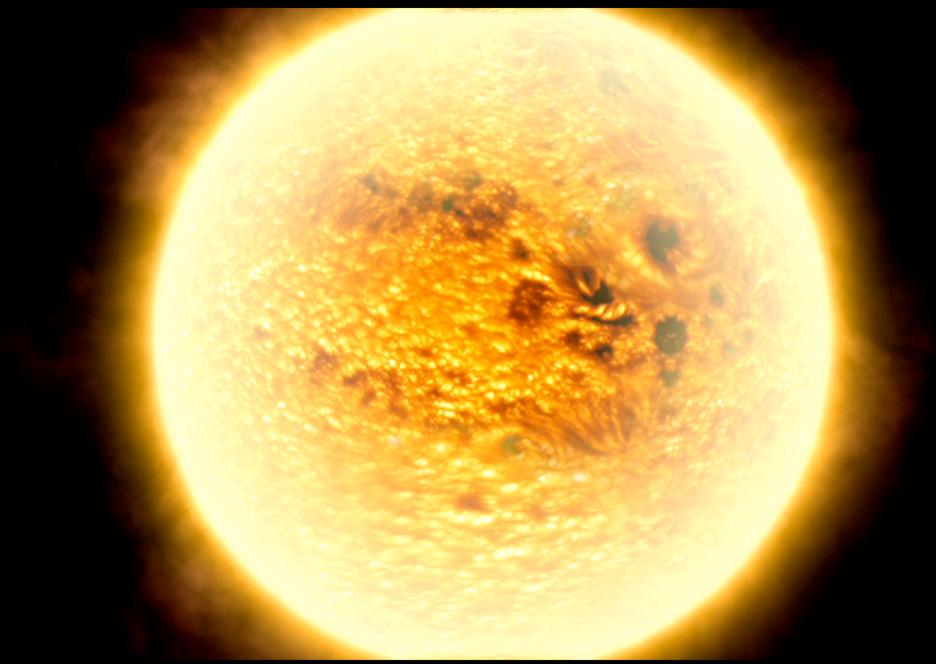
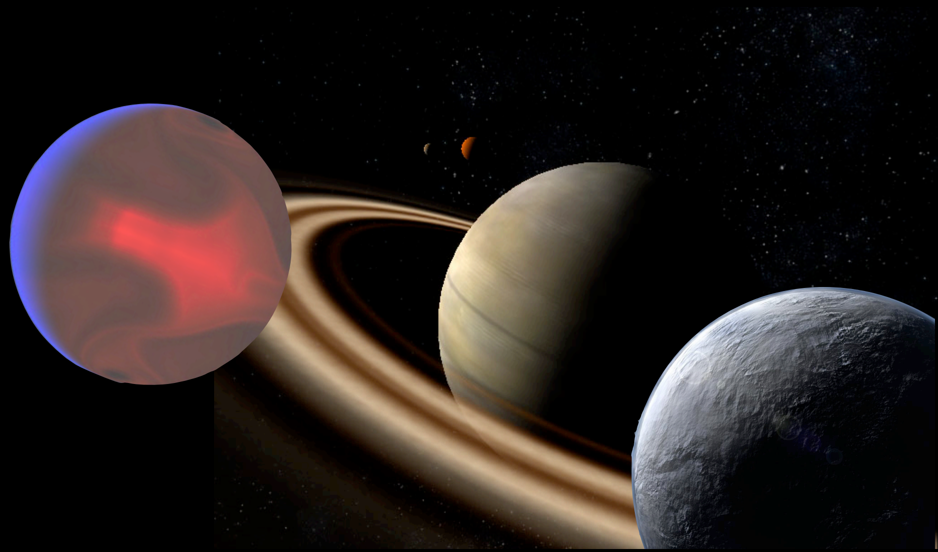
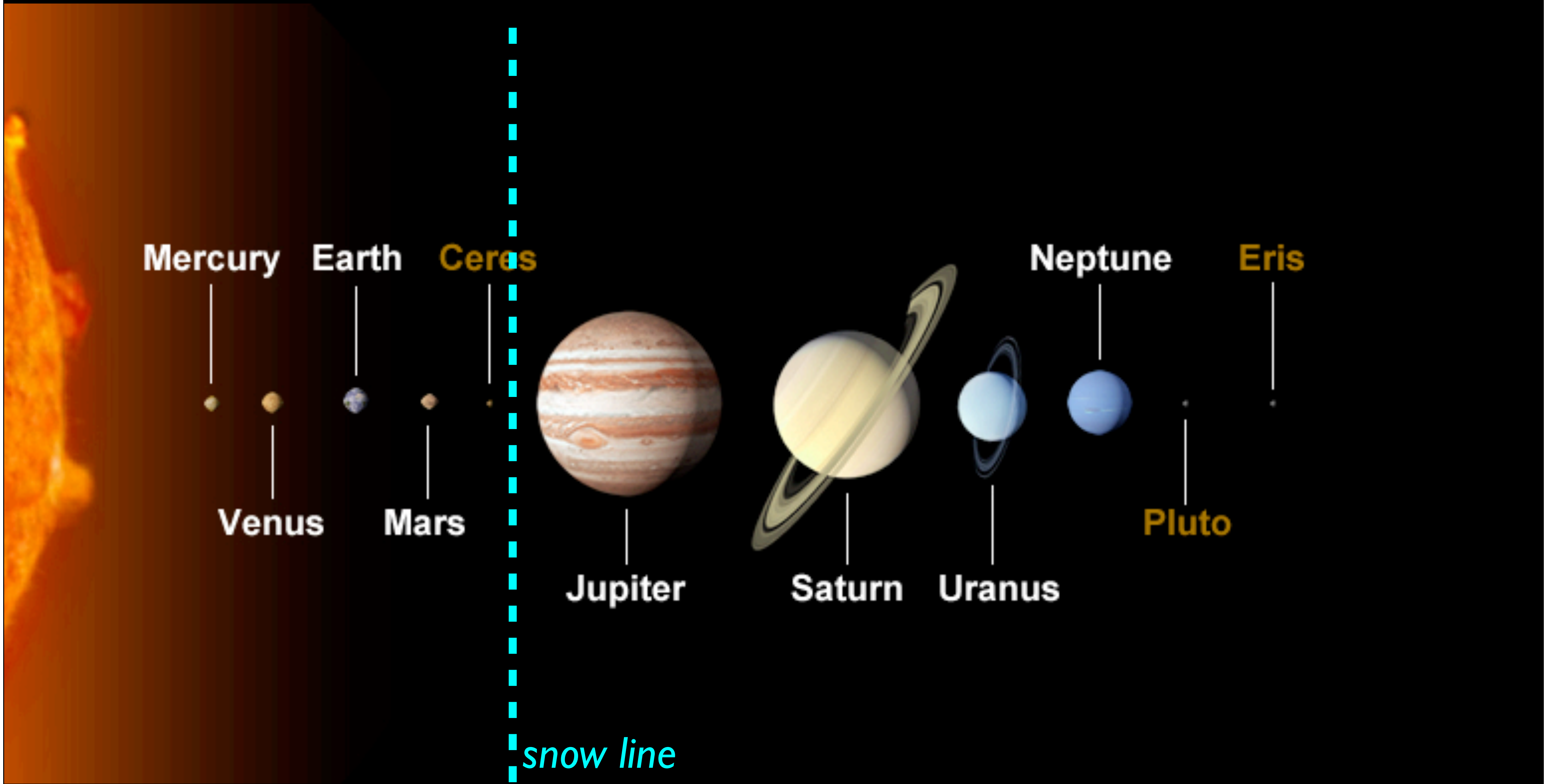
Extra-solar planets

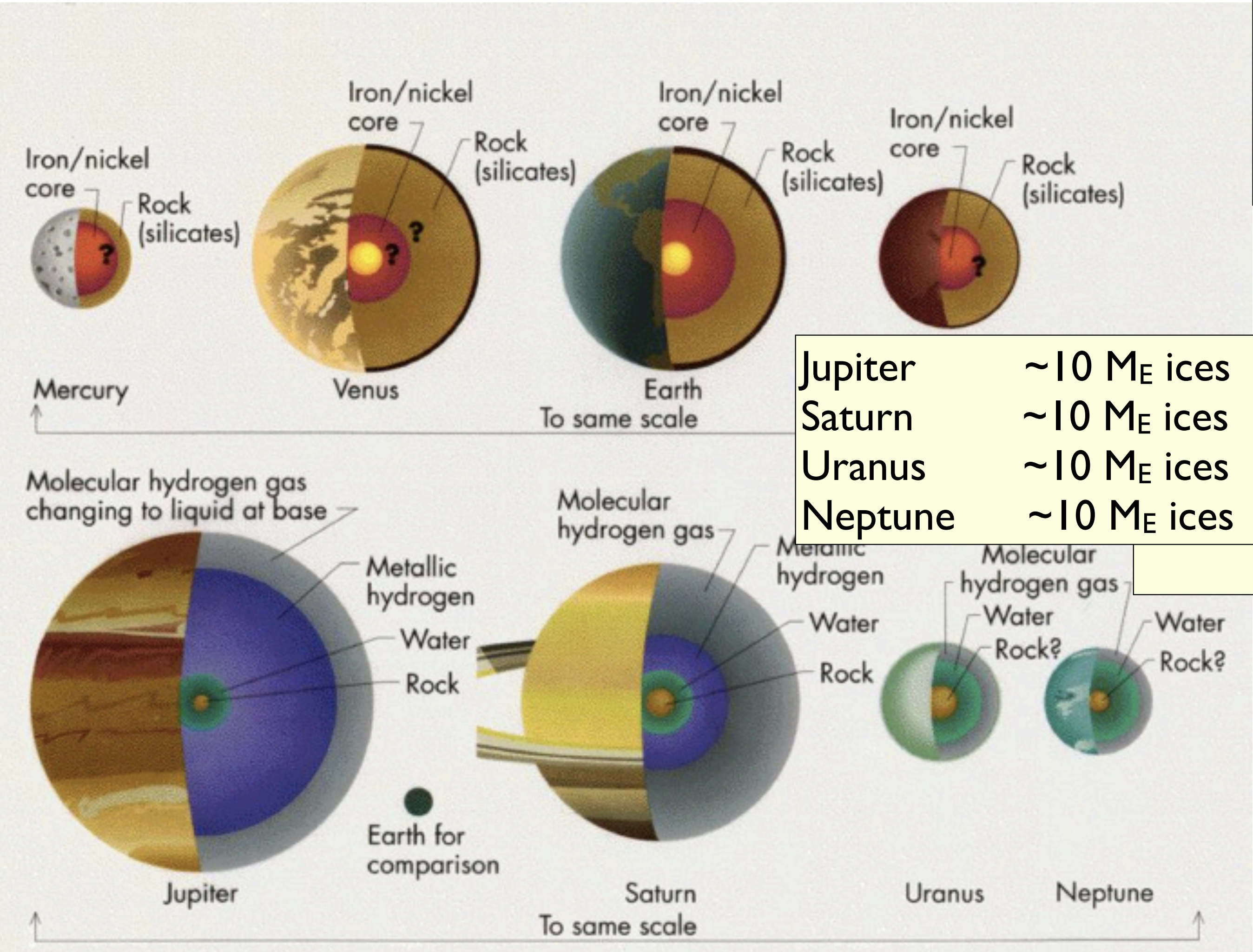




Frédéric Pont

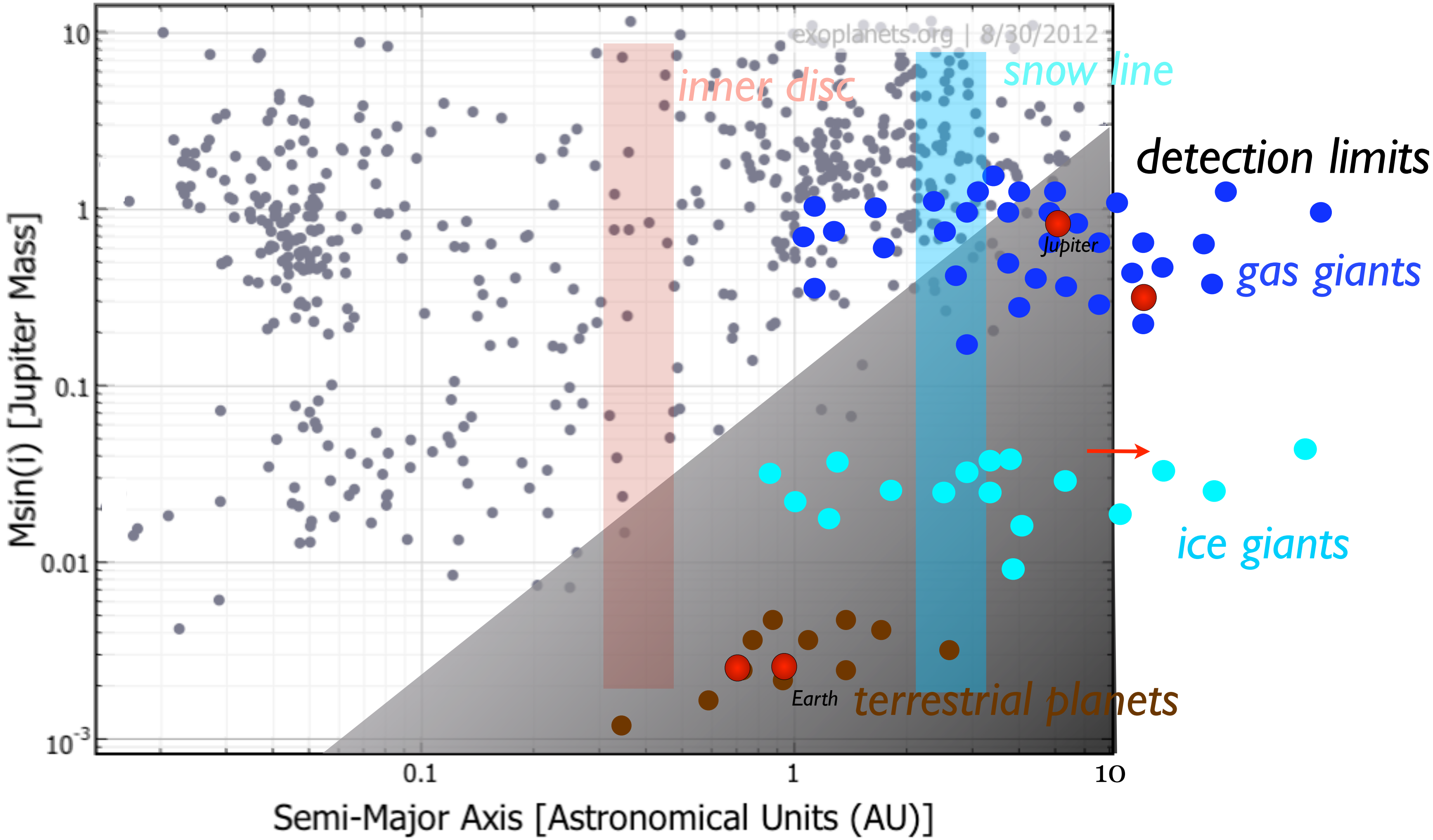
UNIVERSITY OF EXETER


Mercury
Earth
Ceres
Neptune
Eris
Venus
Mars
Pluto
Jupiter
Saturn
Uranus
snow line

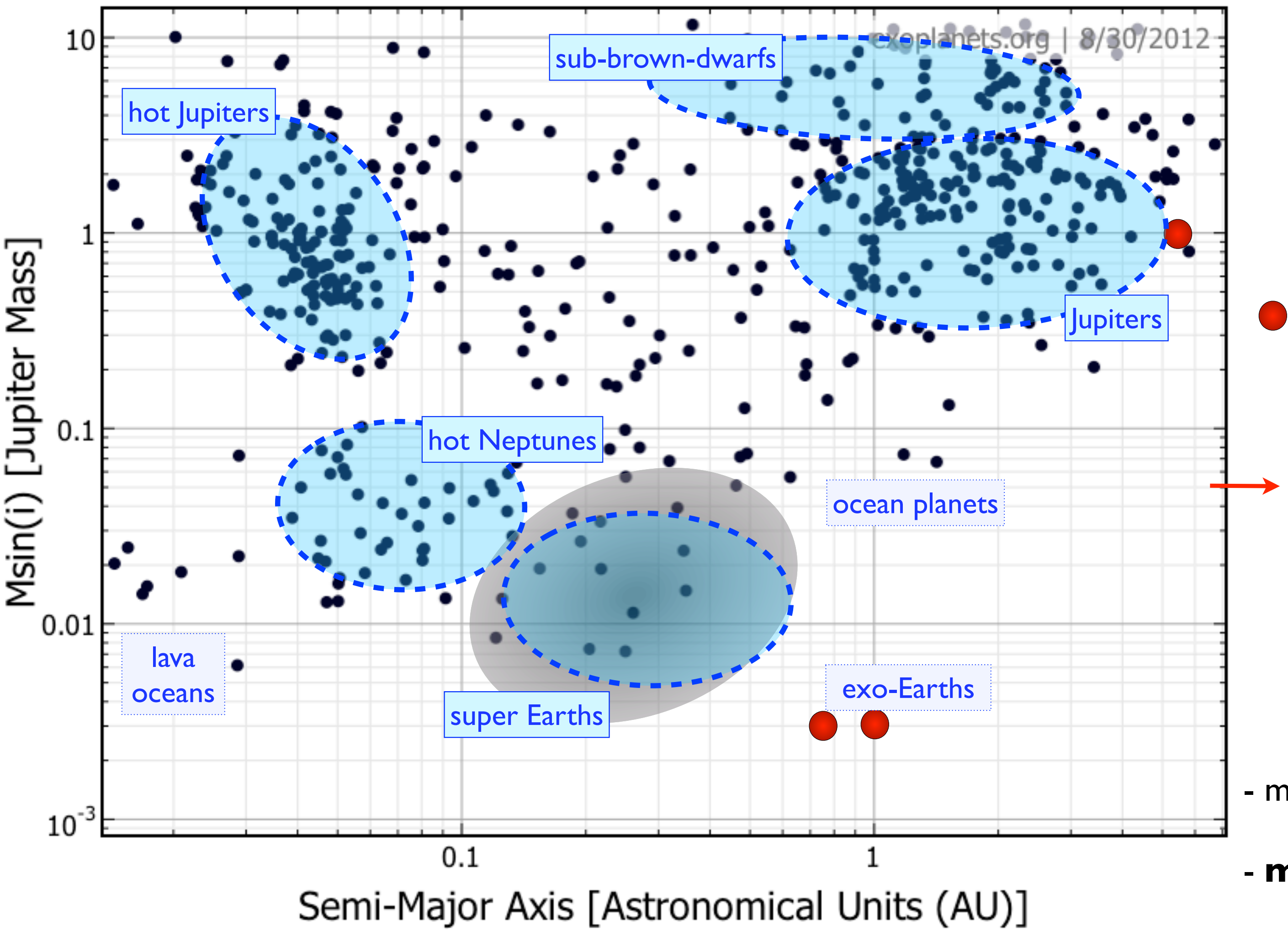


Mercury	~0.1 M_E rocks
Venus	~1 M_E rocks
Earth	~1 M_E rocks
Mars	~0.1 M_E rocks

Jupiter	~10 M_E ices	~1 M_E rocks	~100 M_E H/He
Saturn	~10 M_E ices	~1 M_E rocks	~100 M_E H/He
Uranus	~10 M_E ices	~1 M_E rocks	~1 M_E H/He
Neptune	~10 M_E ices	~1 M_E rocks	~1 M_E H/He



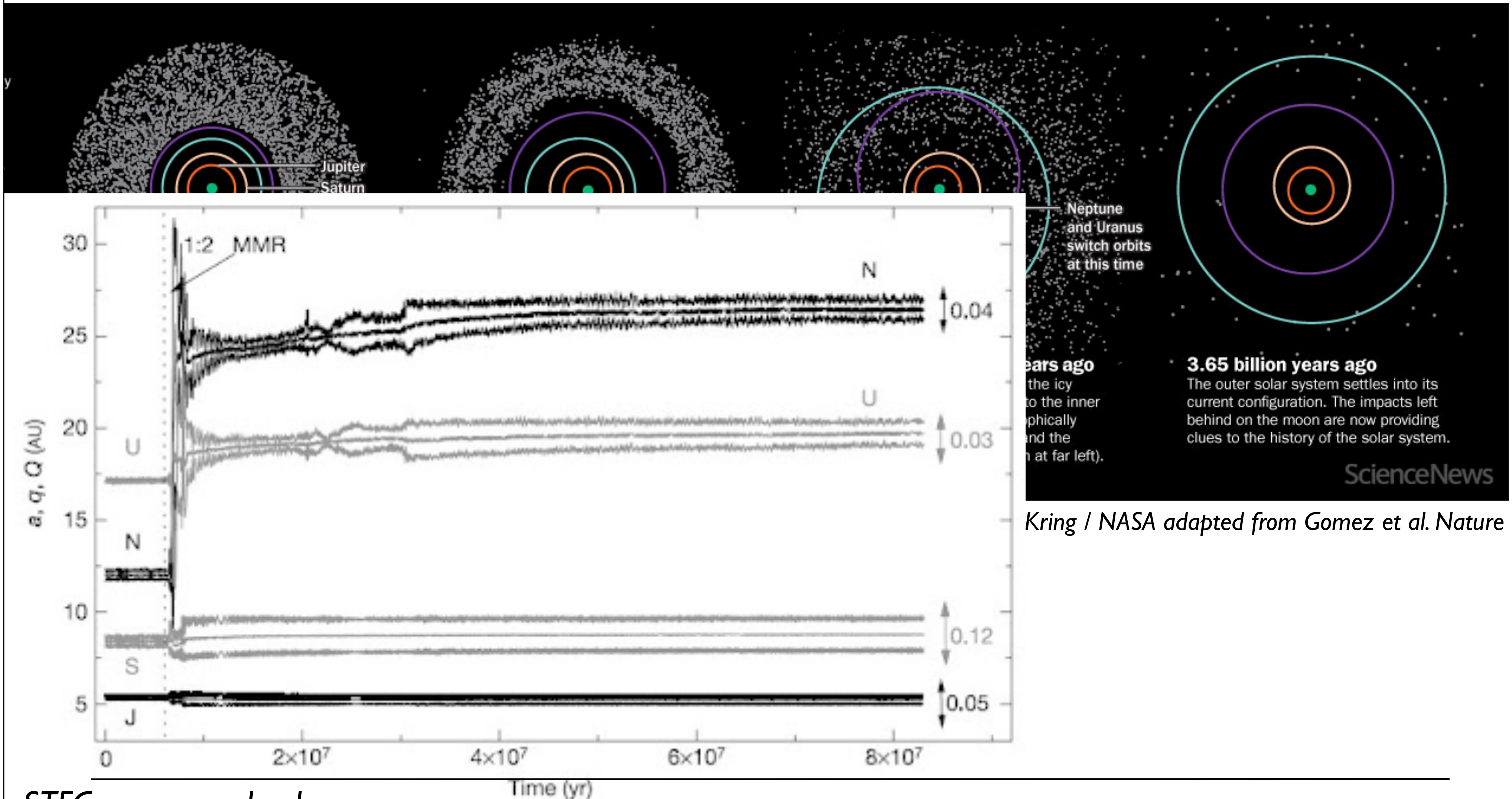
exoplanets.org | 8/30/2012
inner disc
snow line
detection limits
gas giants
Jupiter
ice giants
Earth
terrestrial planets
Msin(i) [Jupiter Mass]
Semi-Major Axis [Astronomical Units (AU)]
10
1
0.1
0.01
10^{-3}
0.1
1
10



- most orbits are **eccentric**

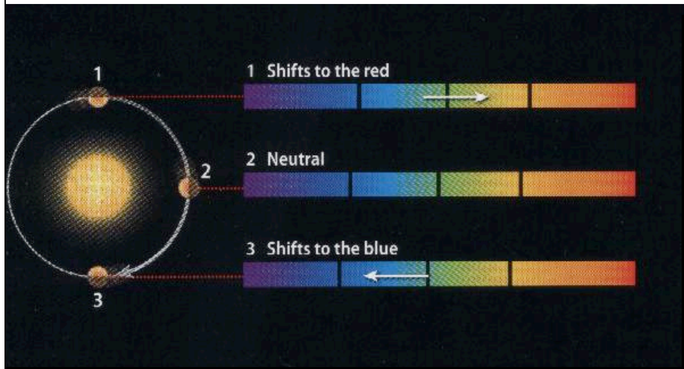
- **multi-planet systems** are common

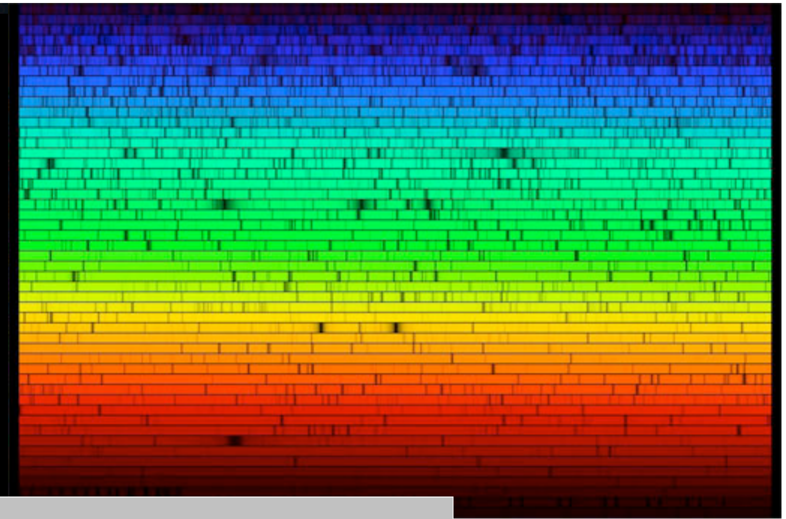
The Nice model of the Solar System



Kring / NASA adapted from Gomez et al. Nature

Measuring exoplanets : radial velocity & transits





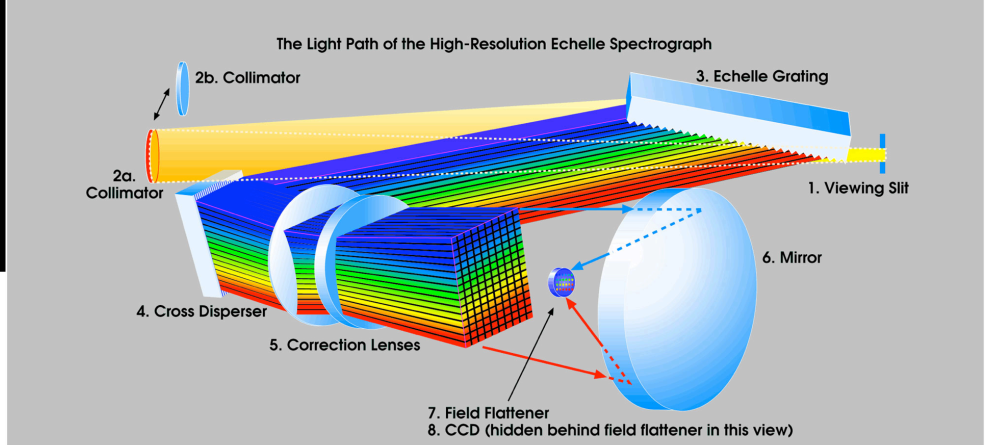
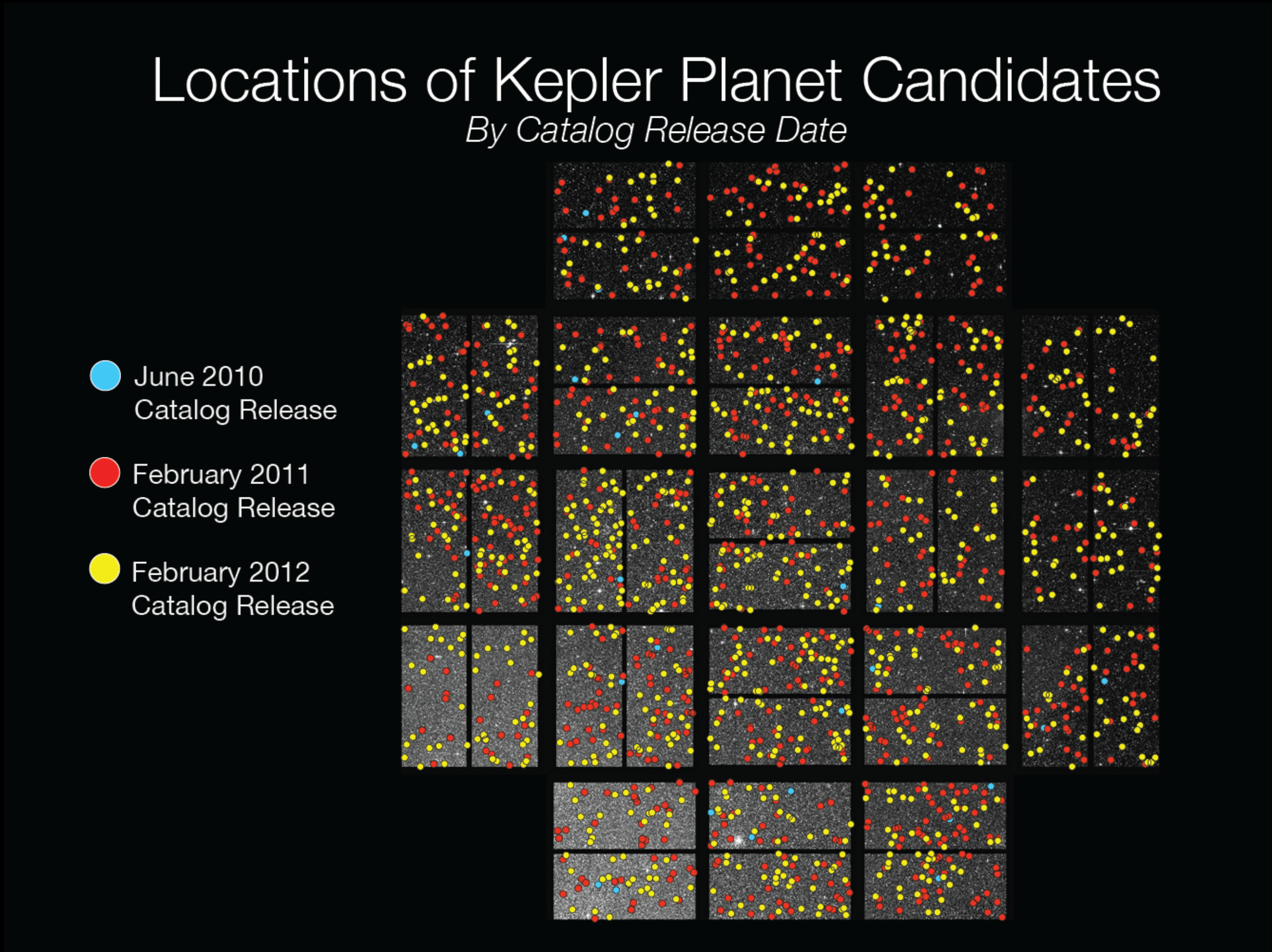


Image S. Vogt

→ size, mass, period


Locations of Kepler Planet Candidates
By Catalog Release Date
June 2010
Catalog Release
February 2011
Catalog Release
February 2012
Catalog Release

Statistics of exoplanets :

The occurence rate of giant planets rises sharply with the heavy-elements content of the parent star

1% of Sun-like stars have a close-in giant planet

The planet occurence rate keeps rising with orbital distance at least to 1 UA

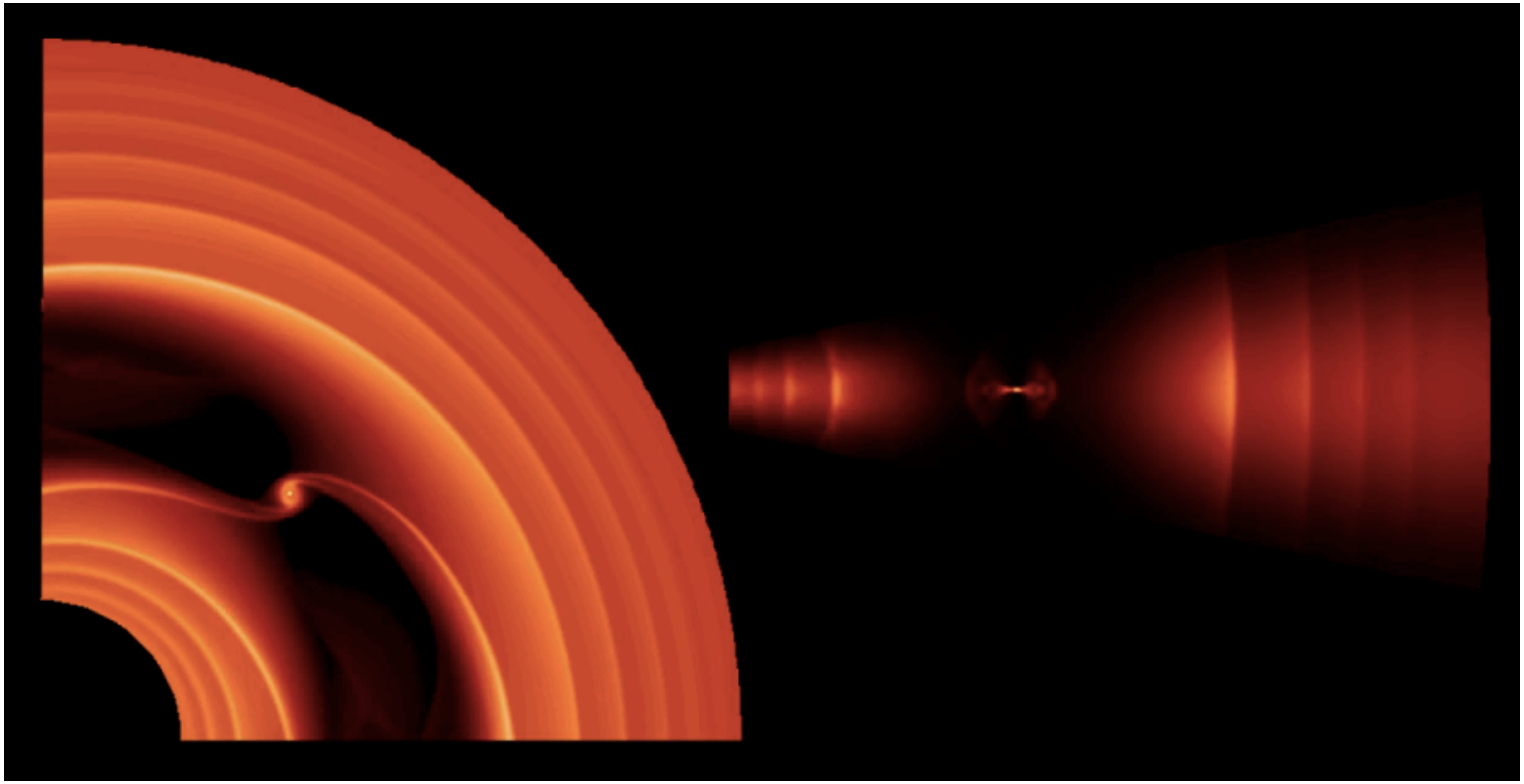
The planet occurence rate also rises for smaller masses at least to 2 R_E

With a slight extrapolation: Earth-like planets are very common

With a bit more extrapolation: Solar Systems analogues are also common, but “messier” systems are more common

How did close-in exoplanets get there?

Migration of planets by tidal interaction with disc



annualreviews.org/doi/abs/10.1146/annurev-astro-081811-125523.

How did close-in exoplanets get there?

The RM effect (Rossier, McLaughlin 1924 for eclipsing binaries) allows a measurement of the spin-orbit angle

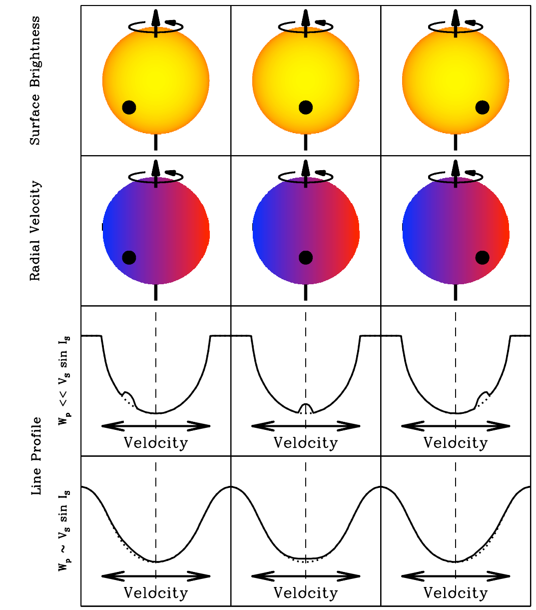


Fig. 5.— Illustration of the Rossiter-McLaughlin (RM) effect. The three columns show three successive phases of a transit. The first row shows the visible disk of the star. The second row shows the projected stellar rotation speed. The third row shows a stellar absorption line profile, assuming rotation is the dominant broadening mechanism; the "bump" occurs because the planet hides some of the velocity components that contribute to line broadening. The fourth row shows the case for which other line-broadening mechanisms are important; here the RM effect is manifested only as an "anomalous Doppler shift." From Gaudi & Winn (2007).

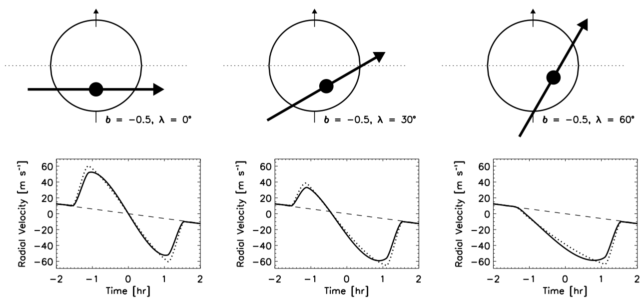
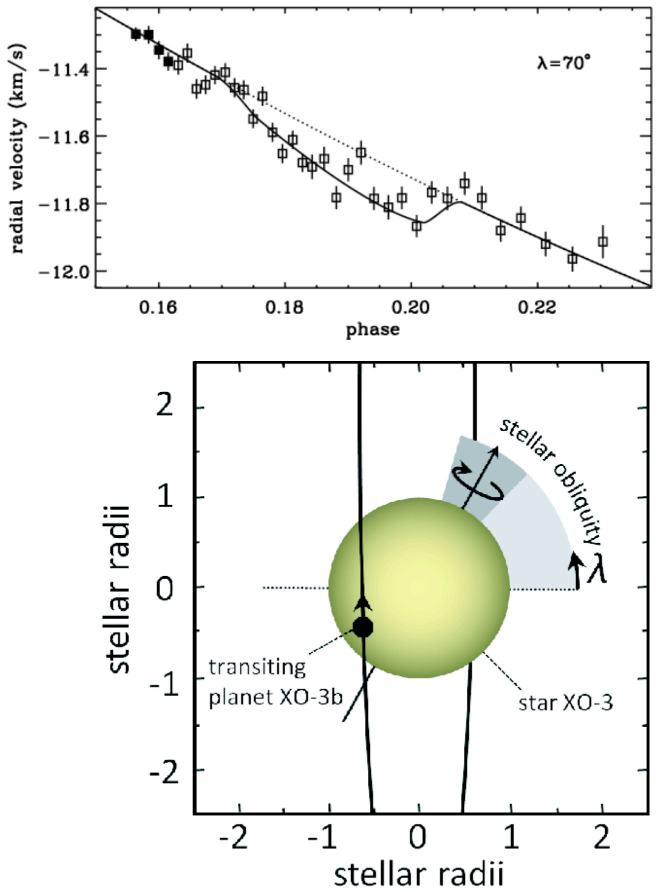


Fig. 6.— Using the RM effect to measure the angle λ between the sky projections of the orbital and stellar-rotational axes. Three different possible trajectories of a transiting planet are shown, along with the corresponding RM signal. The trajectories all have the same impact parameter and produce the same light curve, but they differ in λ and produce different RM curves. The dotted lines are for the case of no limb darkening, and the solid lines include limb darkening. From Gaudi & Winn (2007).

Spin-orbit misalignement from spectroscopic transits



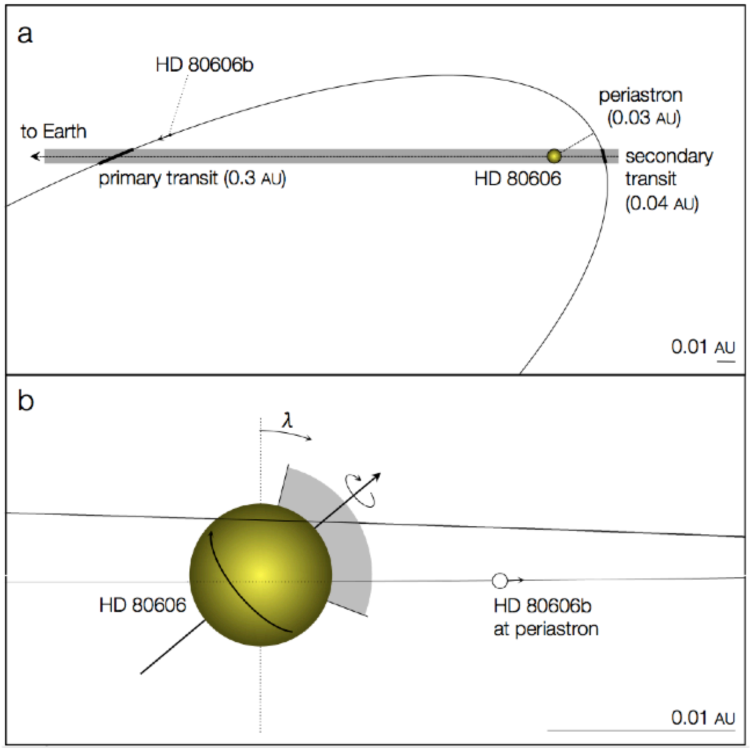
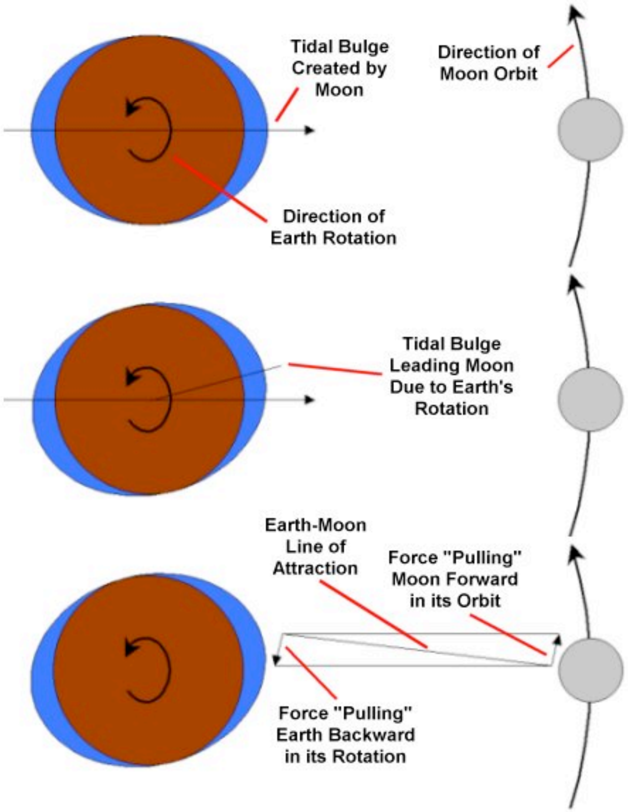


Fig. 4. Geometry of the HD 80606 system according to our best-fit solution, **(a)** from above the orbit, **(b)** seen from Earth.

Hebrard et al. (2008),
Pont et al. (2009)

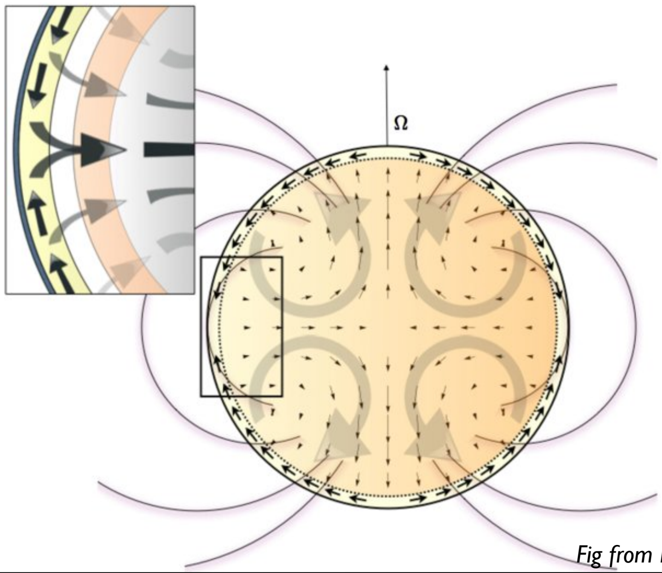
Tidal evolution : alignement, circularisation, synchronisation



Inflated gas giants

Flow dissipation

Ohmic dissipation



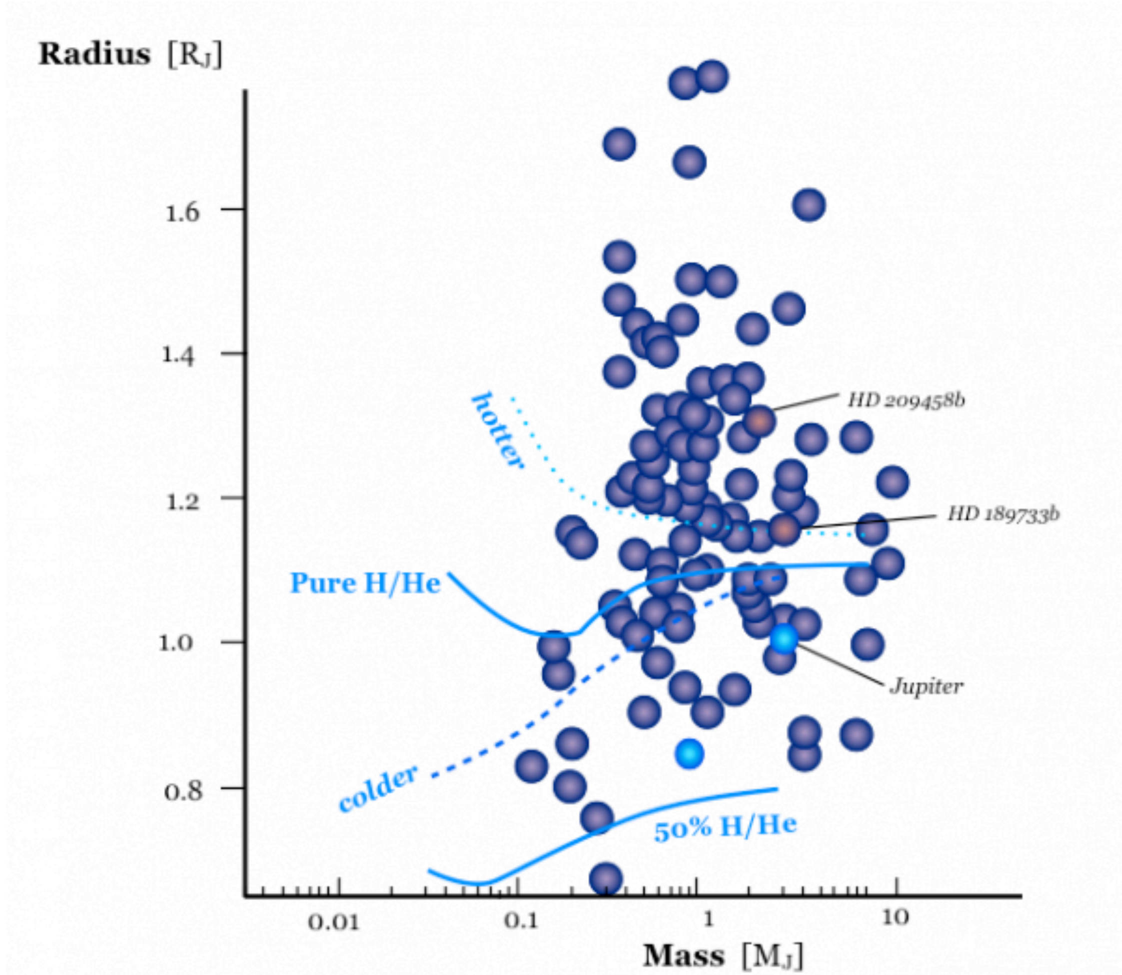
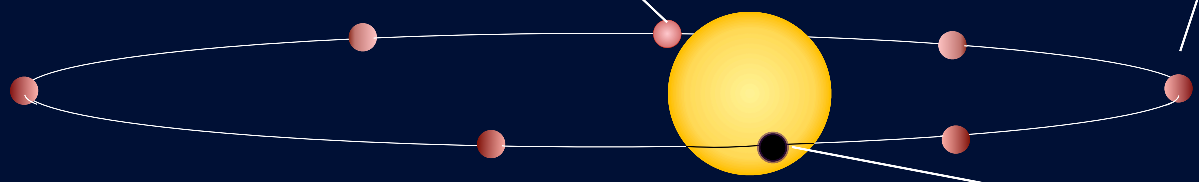


Fig from Batygin and Stevenson

Observing planetary atmosphere

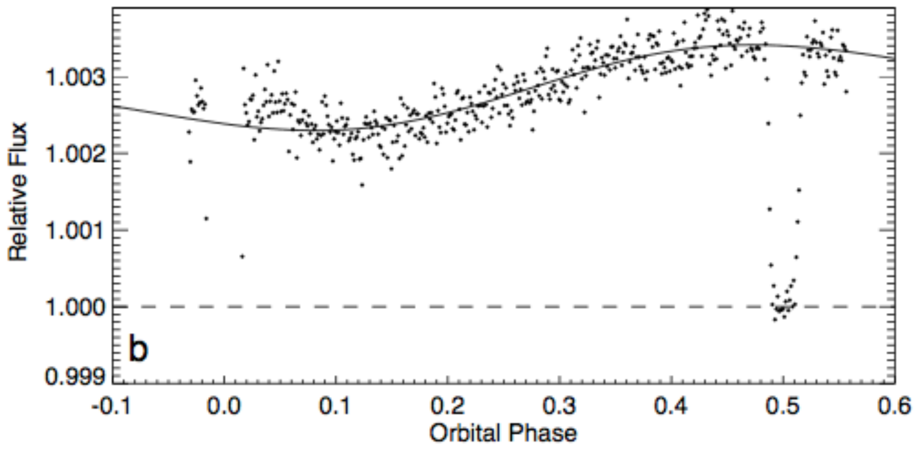
Secondary eclipse
$T_{pl}/T_* \,(R_{pl}/R_*)^2 \quad 10^{-3}$

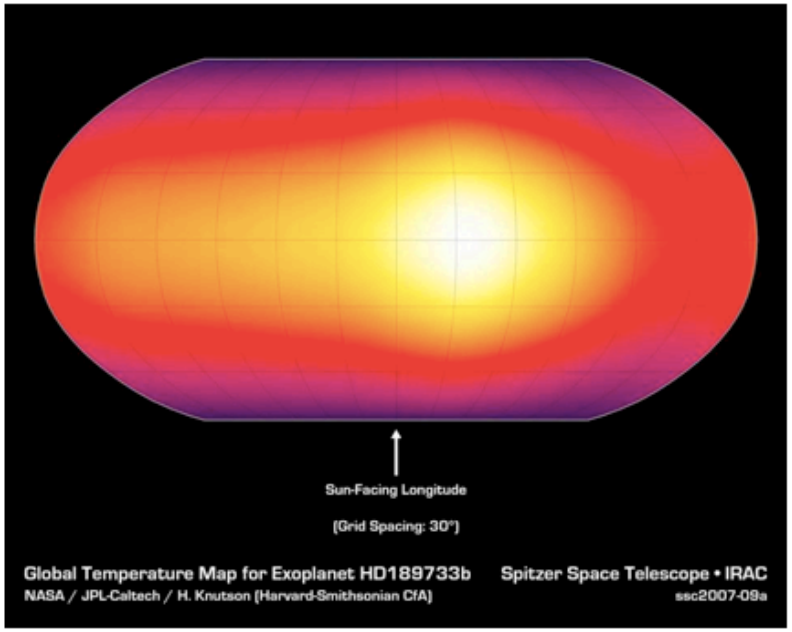
Phase curve
$T_{pl}/T_* \,(R_{pl}/R_*)^2 \quad 10^{-3}$



Transit
$(R_{pl}/R_*)^2 \quad 10^{-2}$
atmosphere $(R_{pl}/R_*)^2 \, (H/R_{pl})^2 \quad 10^{-4}$

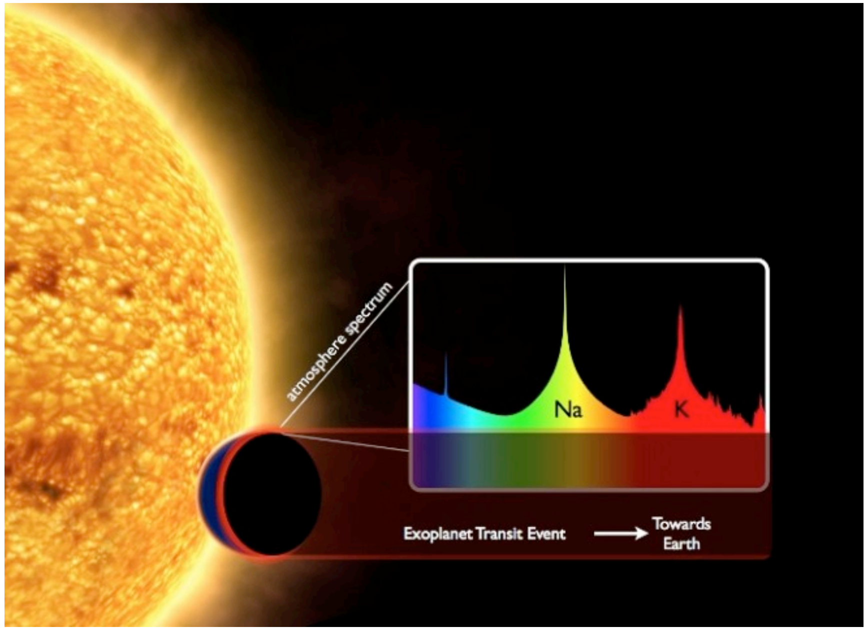
Temperature maps from eclipse and phase curve

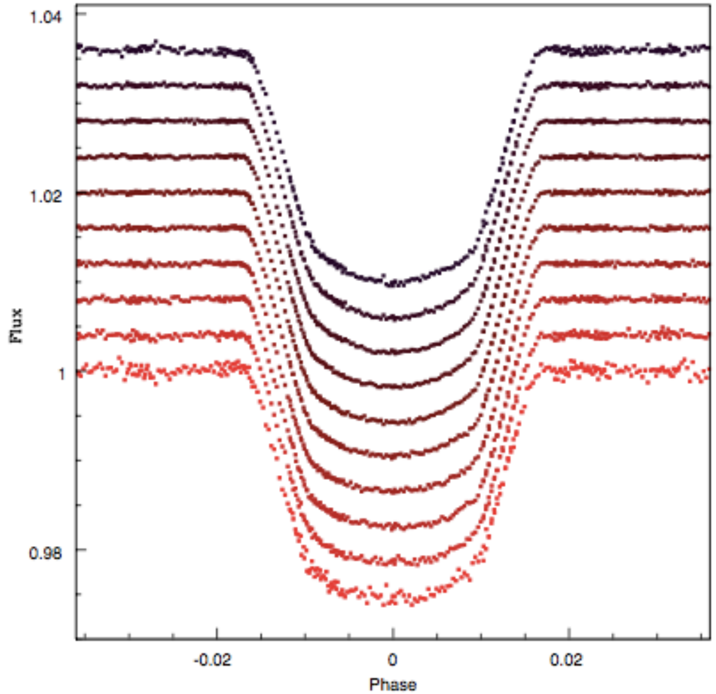




Knudson et al. 2008

Transit spectroscopy





9000 Å

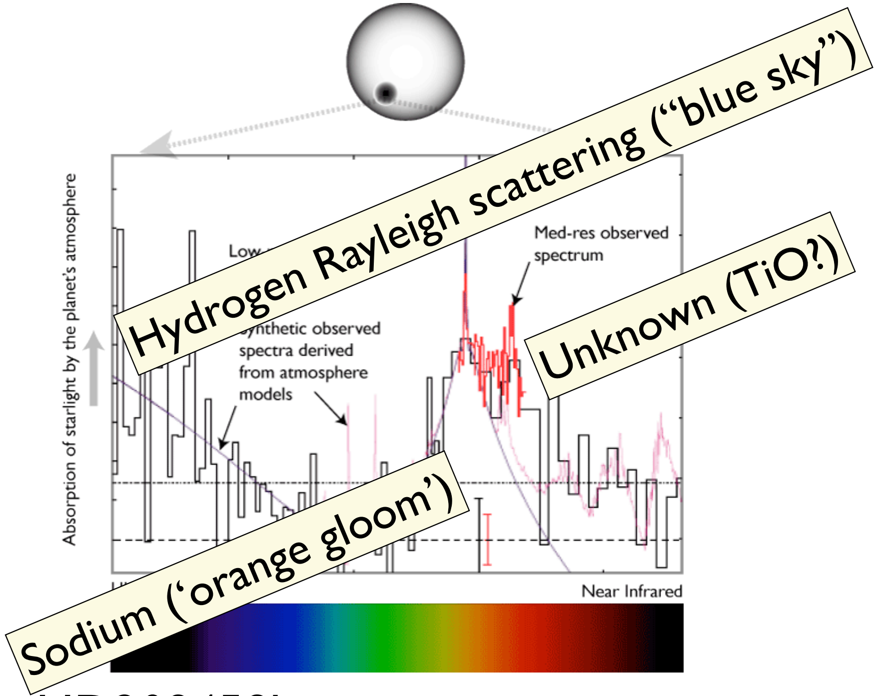
6000 Å

(HST/ACS, Pont et al. 2008)

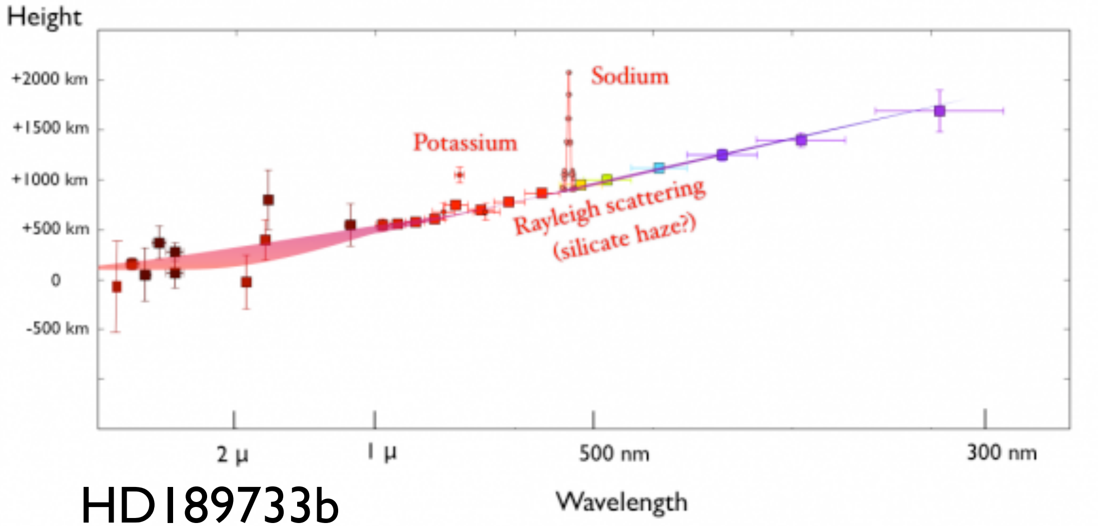
Deriving $R_{planet}(\lambda)$ by measuring the transit depth at many λ

Transmission spectrum of exoplanets

Two favourable cases measured with HST

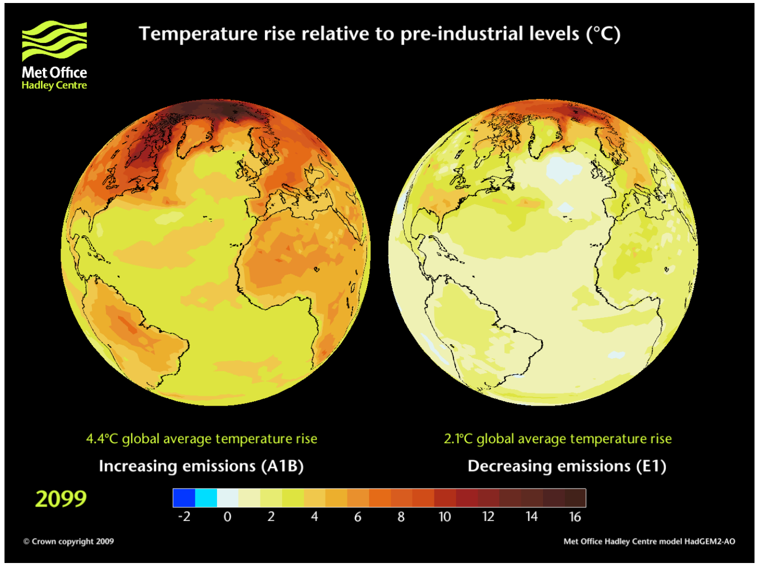


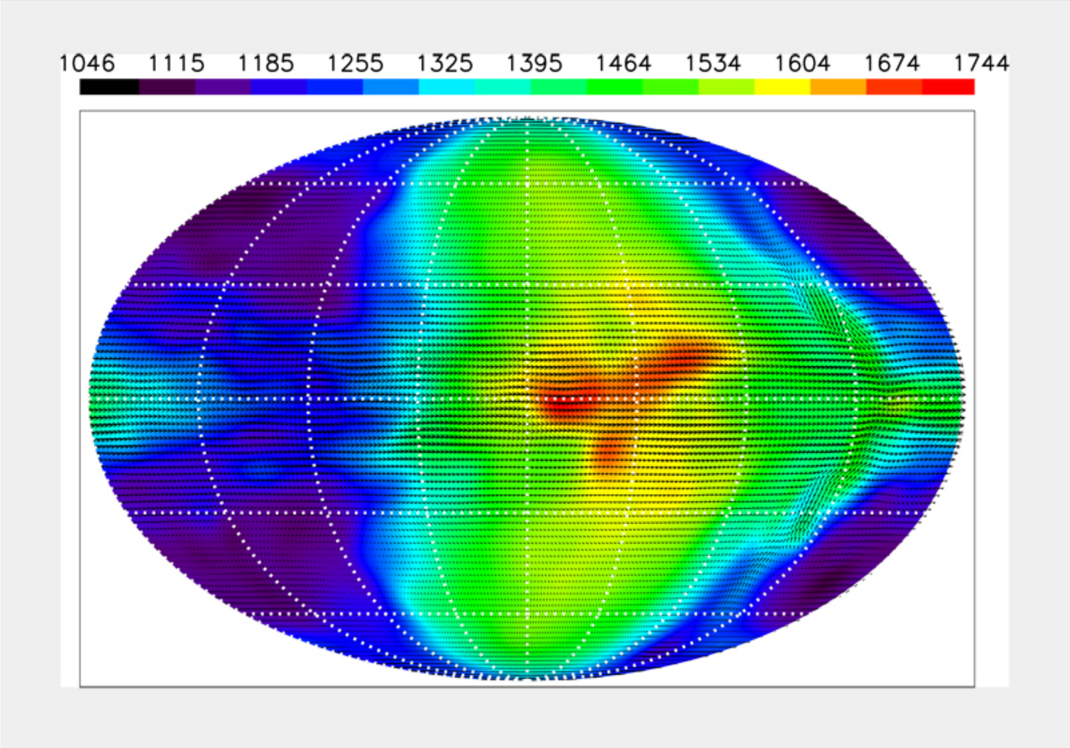
HD209458b



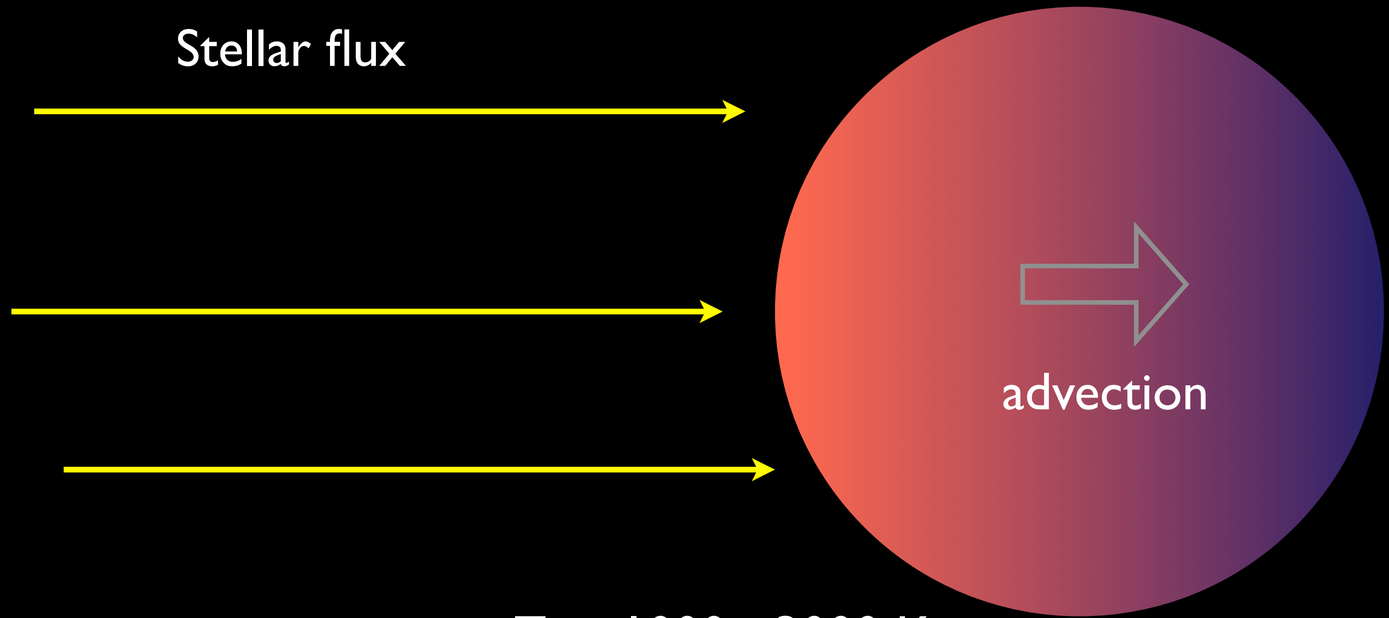
HD189733b

Circulation models:
like Earth climate models





Atmospheric circulation on hot gas giants



Teq <100 K

Teq 1000 - 3000 K

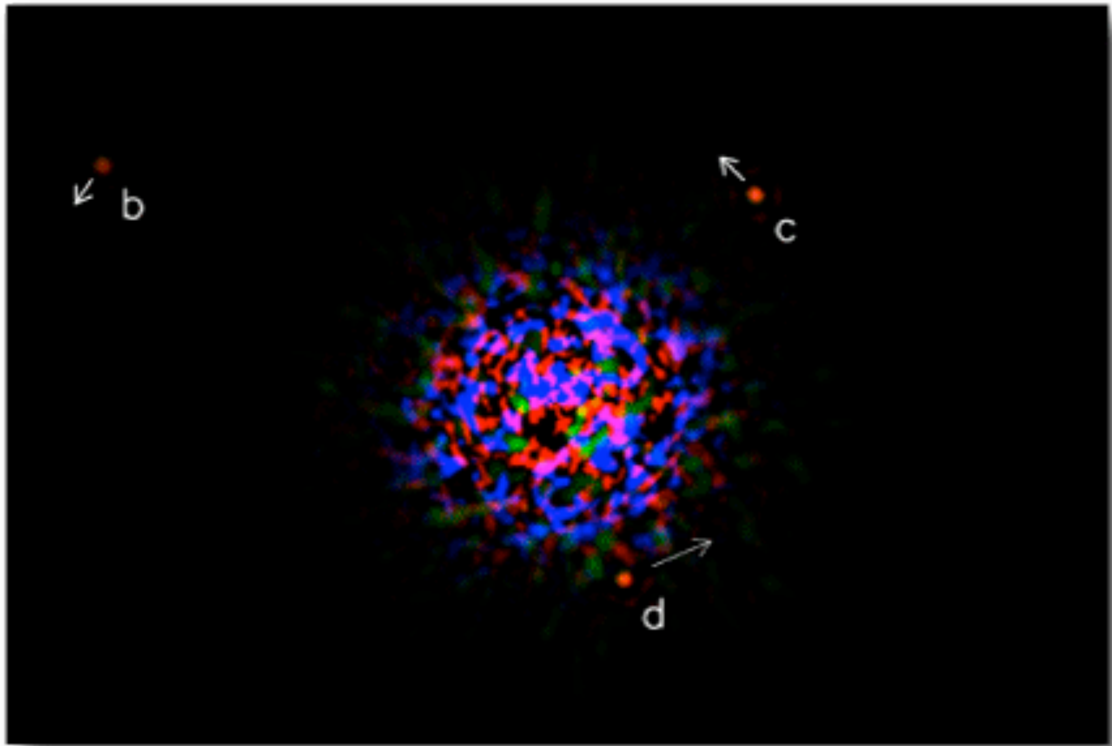
First-order understanding

τ_{avd} : timescale of heat transport

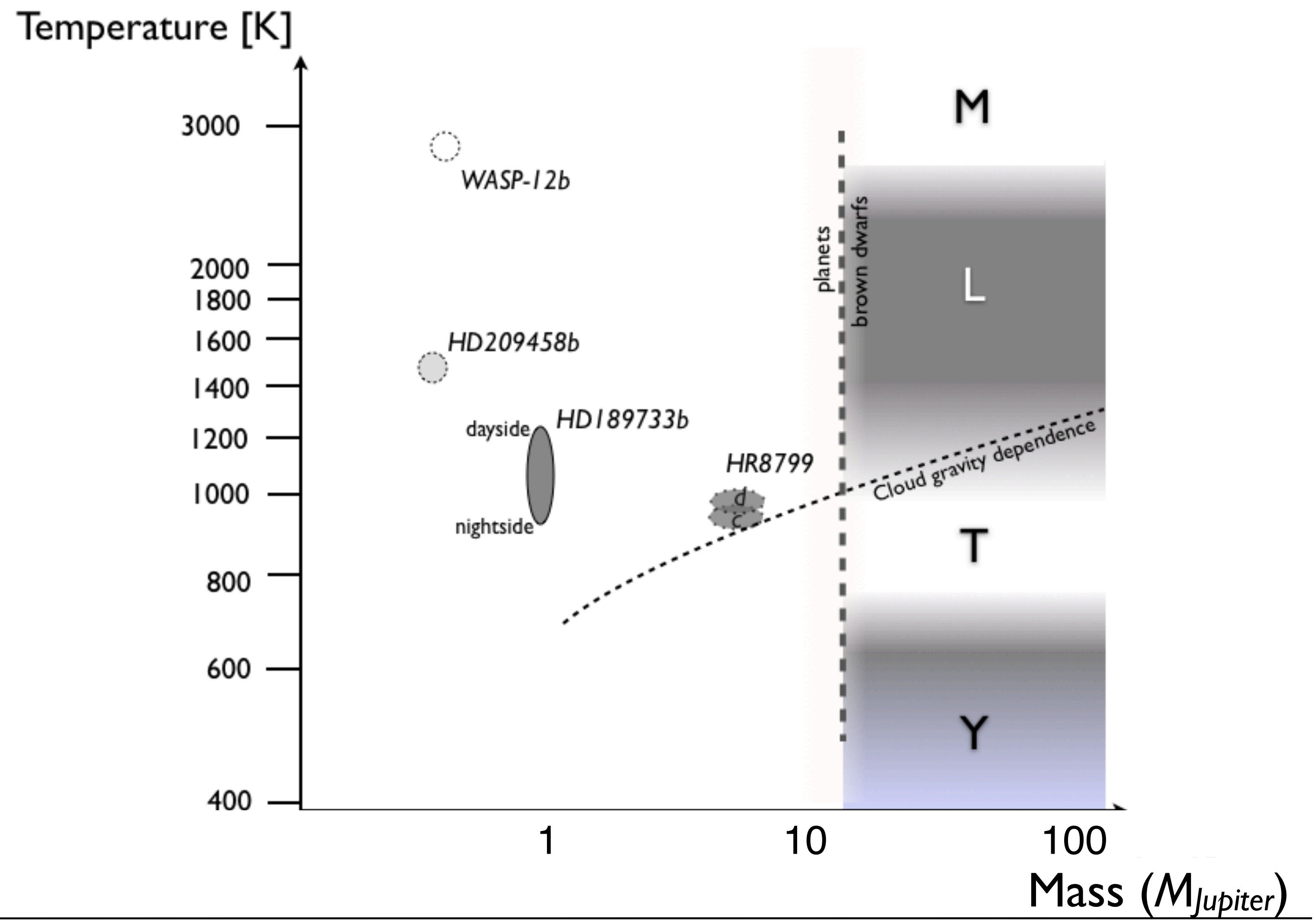
τ_{rad} : timescale of heat loss

$$T^{-1/2} \rightarrow \tau_{adv} \; / \; \tau_{rad} \leftarrow T^{-3}$$

Direct images of the HR8799 system



Clouds on hot Jupiters, young Jupiters, brown dwarfs

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