Modern Astronomical Optics - Observing Exoplanets
2. Brief Introduction to Exoplanets

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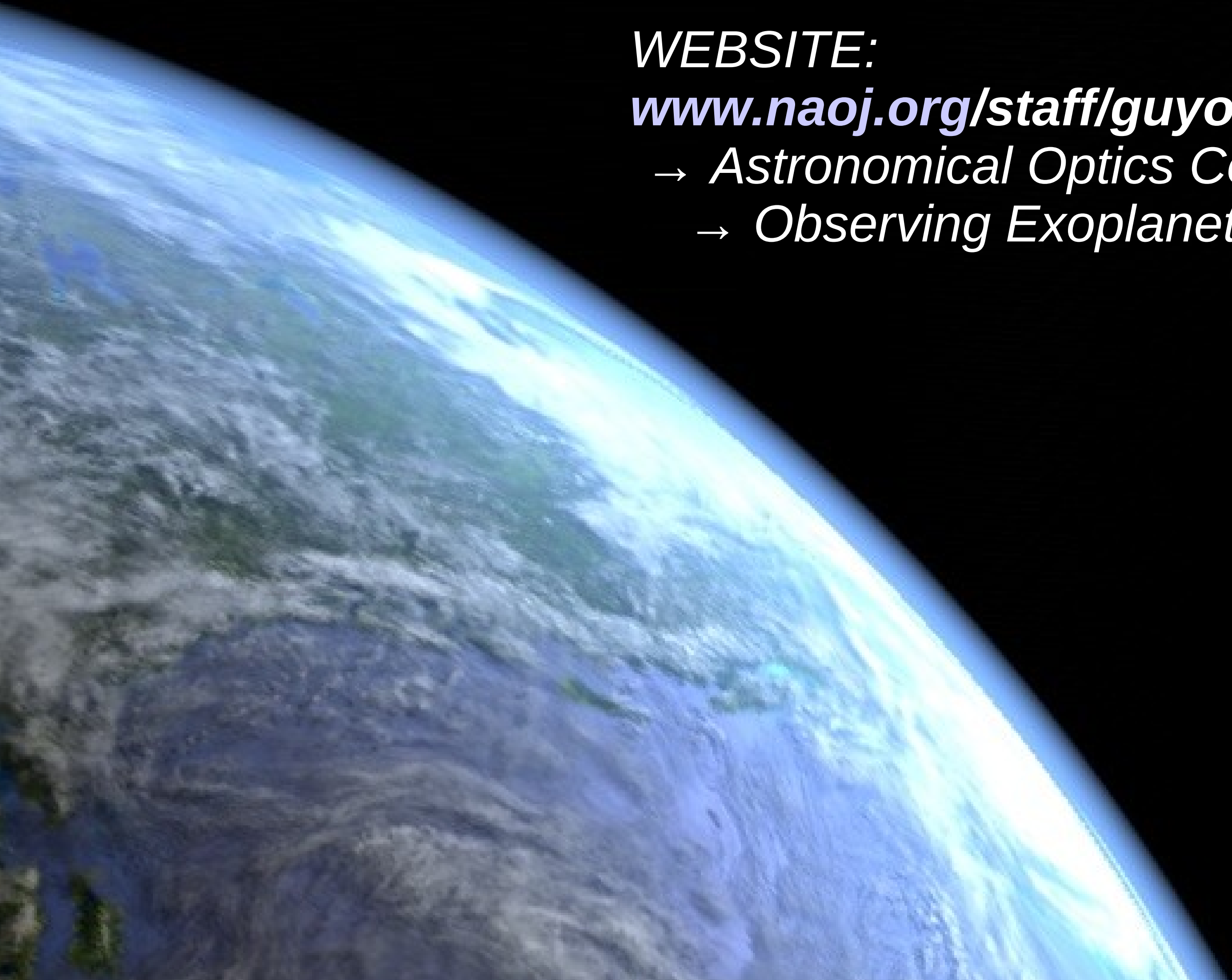
www.naoj.org/staff/guyon
→ *Astronomical Optics Course*
→ *Observing Exoplanets (2012)*



Definitions – types of exoplanets

Planet (& exoplanet) definitions are recent, as, prior to discoveries of exoplanets around other stars and dwarf planets in our solar system, there was no need to discuss lower and upper limits of planet masses.

Asteroid < dwarf planet < **planet** < brown dwarf < star

Upper limit defined by its mass: < 13 Jupiter mass
1 Jupiter mass = 317 Earth mass = 1/1000 Sun mass
Mass limit corresponds to deuterium limit: a planet is not sufficiently massive to start nuclear fusion reactions, of which deuterium burning is the easiest (lowest temperature)

Lower limit recently defined (now excludes Pluto) for our solar system:
has cleared the neighbourhood around its orbit

Distinction between **giant planets** (massive, large, mostly gas) and **rocky planets** also applies to exoplanets

Habitable planet: planet on which life as we know it (bacteria, planets or animals) could be sustained = rocky + surface temperature suitable for liquid water

Formation

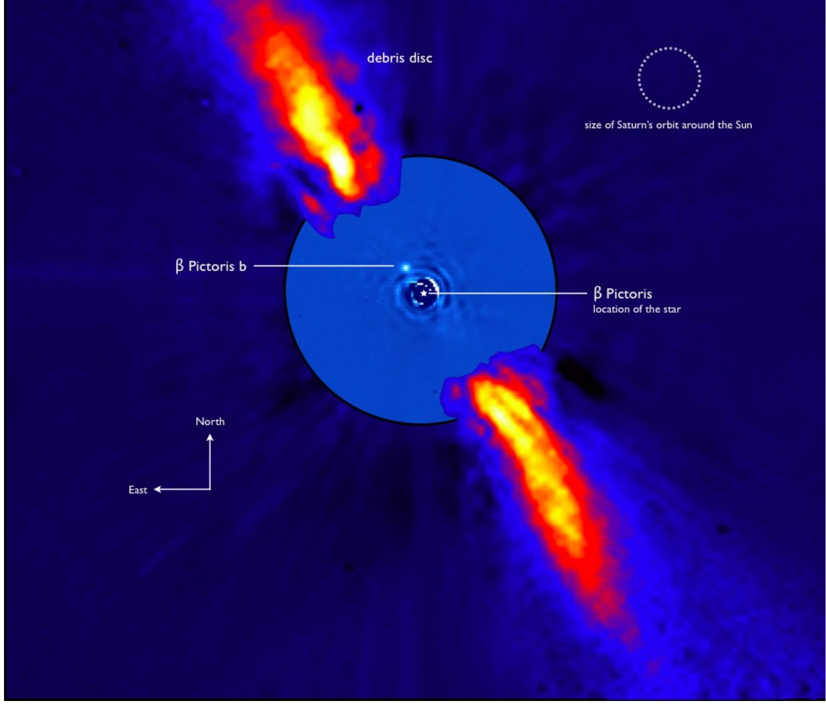
Planet and stars form (nearly) together,
within first few x10 Myr of system formation

Gravitational collapse of gas + dust cloud

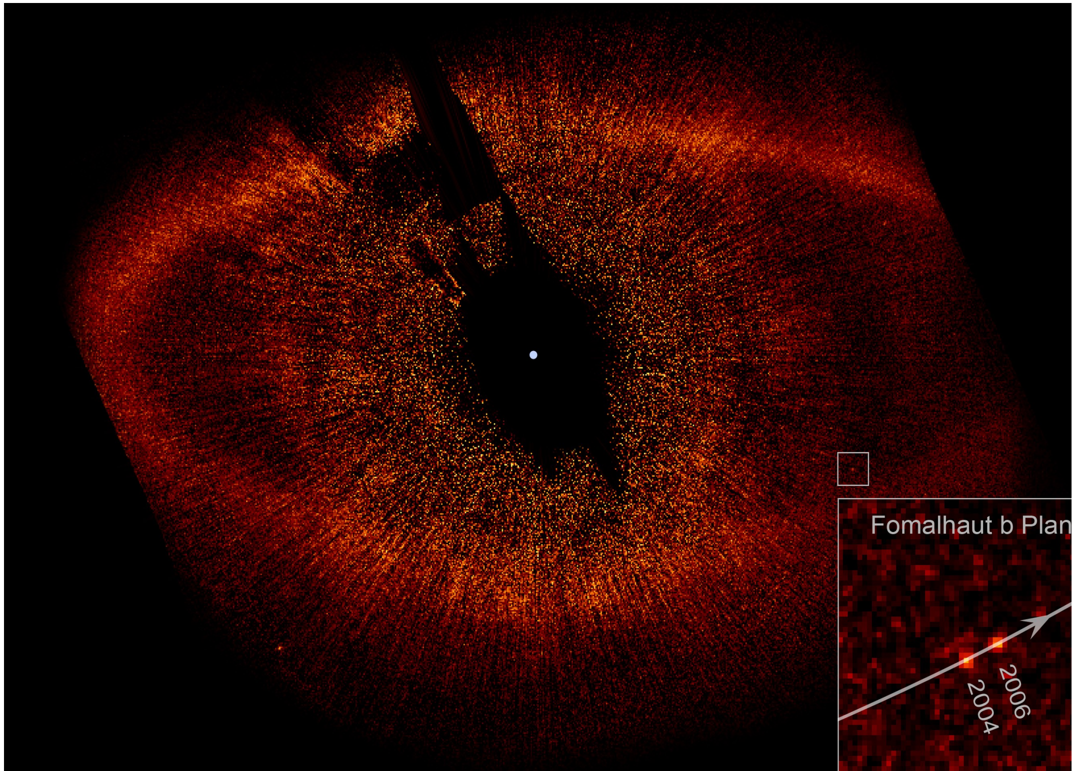
Star is formed at center of disk
Planets form in the protoplanetary disk

Planet embrios form first
Large embrios (> few Earth mass) can
accrete large quantity of gas in the first few
Myr, until gas is dissipated / depleted

Small rocky bodies grow through collisions
and form a debris disk around the star,
continuously replenished by collisions



Adaptive Optics image of Beta Pic
Shows planet + debris disk

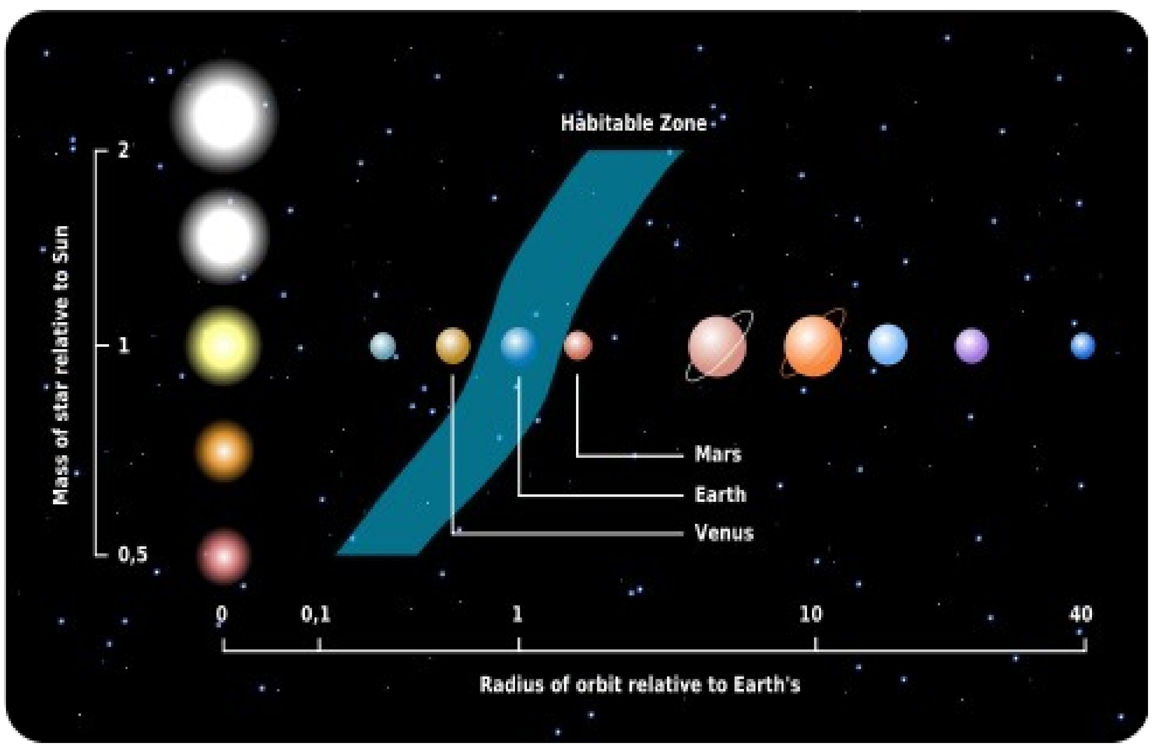


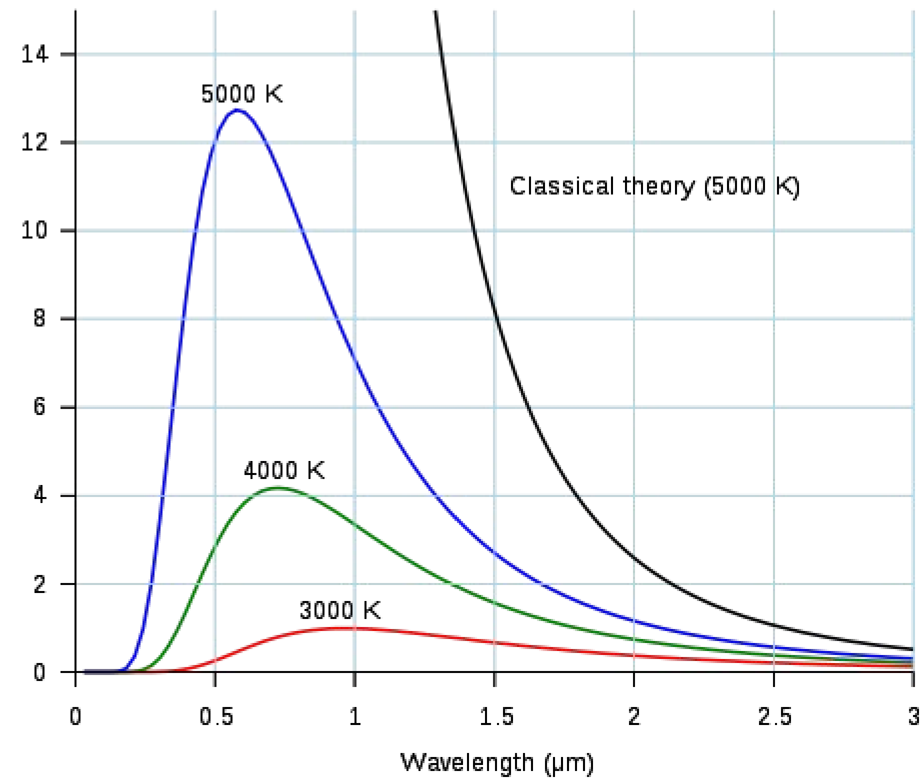
Bebris disk (+ planet?) imaged
Around Fomalhaut

What makes a planet habitable ?

WHERE ?
Habitable zone = range of distance around the host star for which liquid water can exist at the surface of a rocky planet

Its location is driven by stellar brightness, which is mostly function of mass (but also age → habitable zone moves with time)



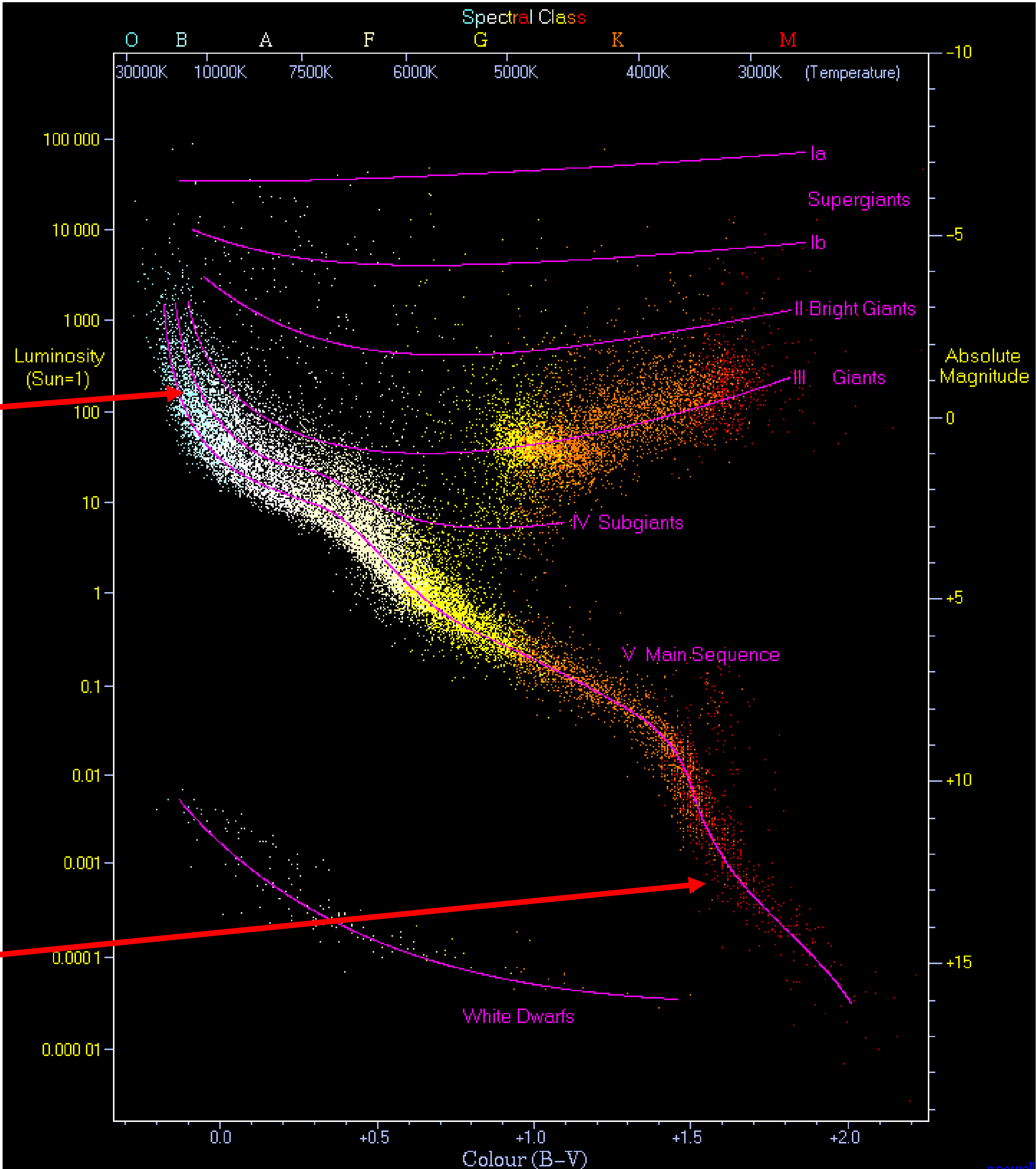


Habitability

Habitable zone
distance = sqrt(L)

Short lifetime
(down to few x10 Myr)
Strong UV flux

Stellar flares (UV)
Tidal locking

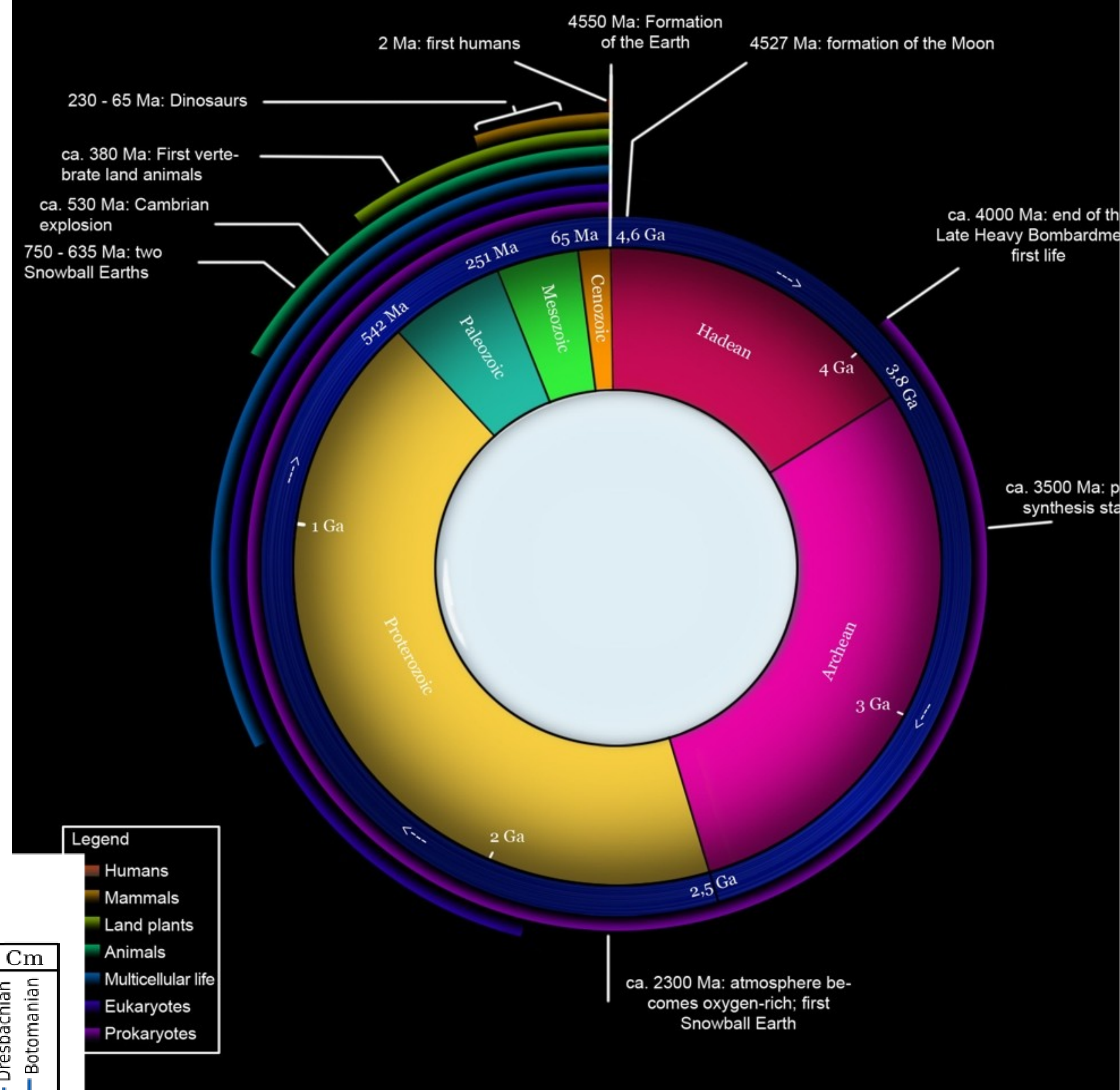


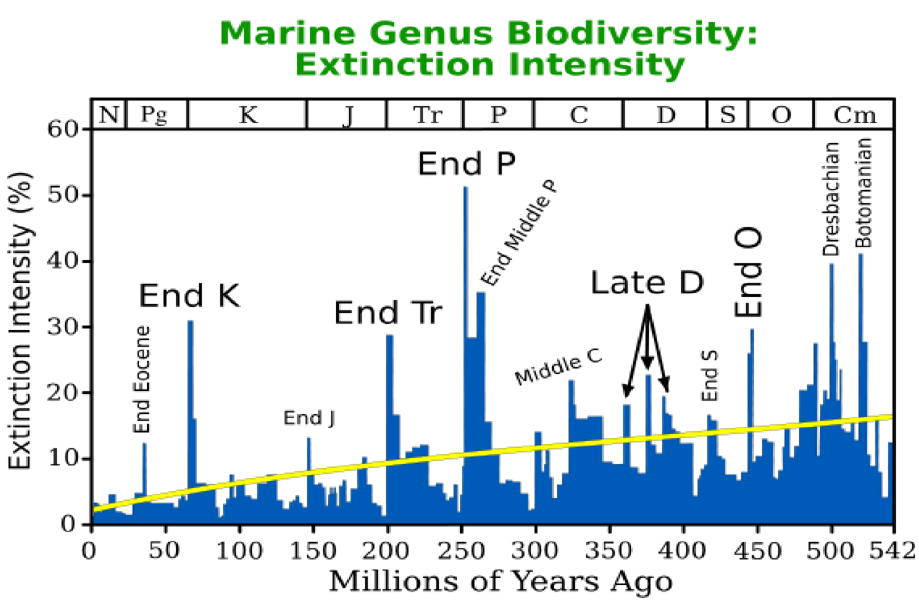
When ?

Planet atmospheres evolve with time, and a given planet only stays in the habitable zone for a limited amount of time

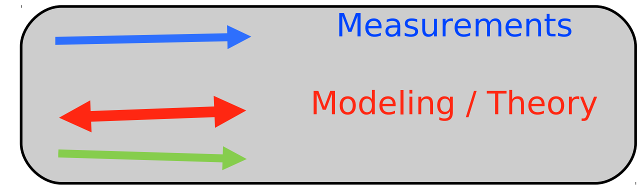
"Snowball Earth" episodes 2.3 Myr and 790 to 630 Myr ago

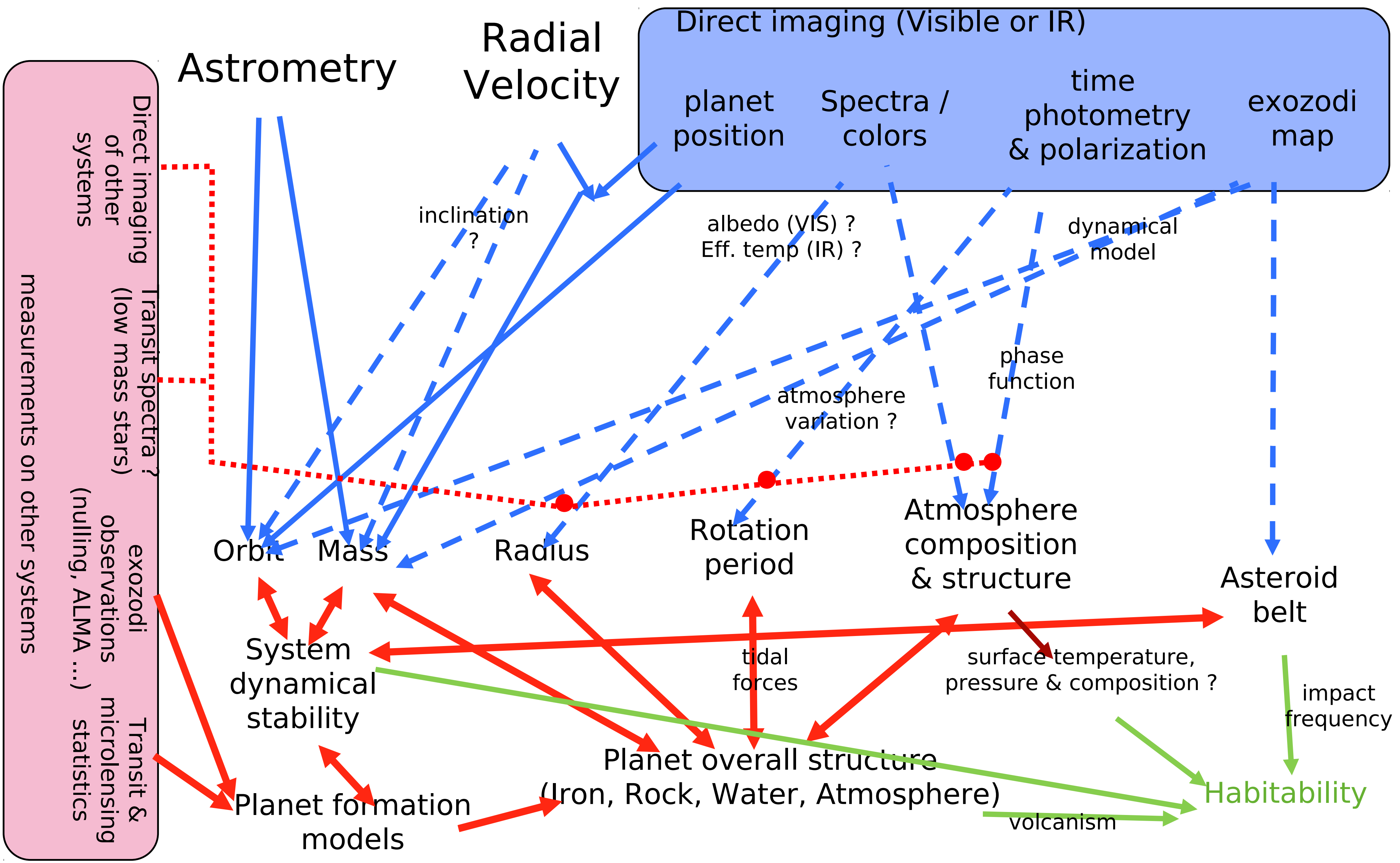
Several mass extinctions since Cambrian explosion (large impact, massive volcanic eruption...)





From observations to planet habitability





Observational challenges

Direct imaging of exoplanets is very challenging:
- exoplanets are faint
- high contrast between planets and stars (1e10 in visible light for Earth-Sun)
- small angular separation (1 AU = ~0.1” for nearby star at 10pc)

→ significant contributions from indirect detection techniques, which will also be covered in this course

- Radial velocity (the planet pulls the star in a small ellipse)
- Astrometry
- Transit (primary and secondary)
- Microlensing

Indirect detection techniques are often easier than direct imaging (depends of planet type)

Direct imaging is most promising long term strategy for detailed characterization of habitable exoplanets

Current status of exoplanet science

First exoplanet identified around Sun-like star in 1995: "Hot Jupiter" identified by radial velocity around star 51 Peg

Now (2012) ~1000 exoplanets identified, almost all of them indirectly observed

Important findings include:

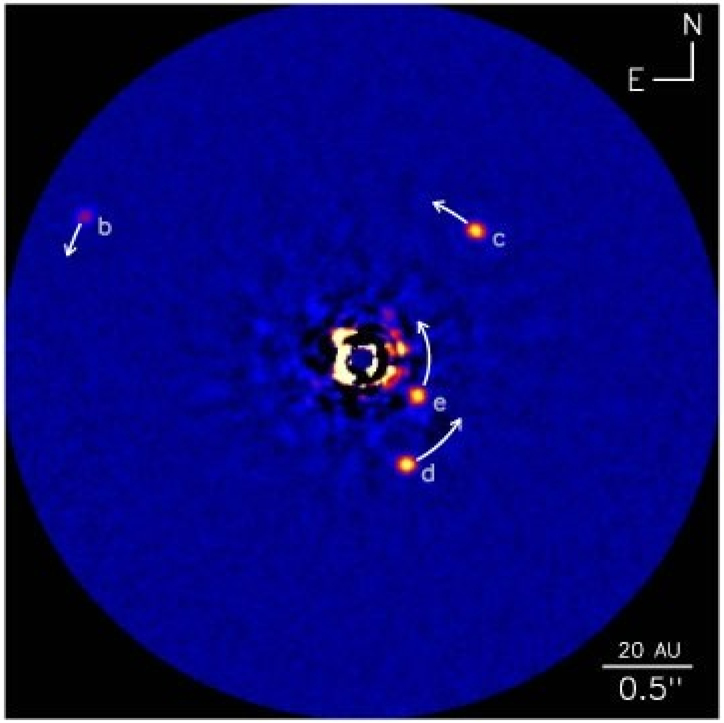
~1/3 of stars have massive giant planet in <~100 day period orbit

> 1/3 of planetary systems have multiple planets

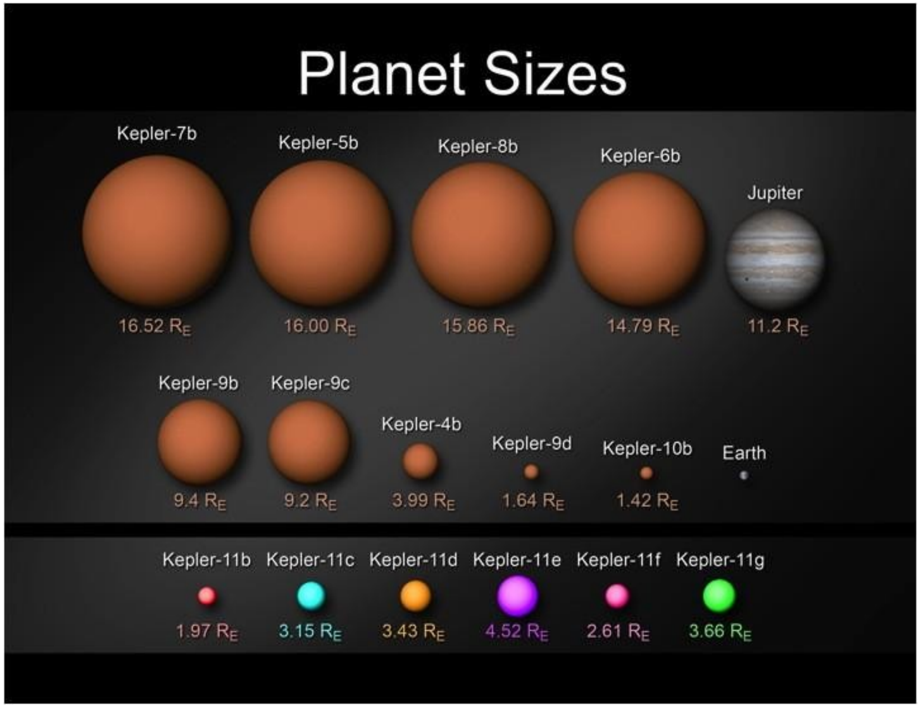
Extremely rich diversity in planet compositions and internal structures (our solar system is not typical)

- Superheated hot Jupiters, and rocky planets (easiest ones to find)
- Wide range of planet densities
- Wide range of orbital parameters

Massive stars seem to have more massive planets, low-mass stars seem to have more small rocky planets



HR8799 system, 4 planets



Some of the Kepler planets

Big questions

The Drake equation states that:

$$N = R^* \cdot f_p \cdot n_e \cdot f_\ell \cdot f_i \cdot f_c \cdot L$$

where:

N = the number of civilizations in our galaxy with which communication might be possible;

and

R^* = the average rate of star formation per year in our galaxy
f_p = the fraction of those stars that have planets
n_e = the average number of planets that can potentially support life per star that has planets
f_ℓ = the fraction of the above that actually go on to develop life at some point
f_i = the fraction of the above that actually go on to develop intelligent life
f_c = the fraction of civilizations that develop a technology that releases detectable signs of their existence into space
L = the length of time for which such civilizations release detectable signals into space[3]

(1) How do planets form ?

(2) How many Earth-mass planets in habitable zones ? Around which stars ? Architecture and evolution of planetary systems.

(3) Do conditions suitable for the emergence of life exist on other words ? How frequently ? (Drake equation)

(4) Detect and characterize life on other planets.

As of 2012....
Questions (1) and (2) are directly addressed by current research
Questions (3) and (4) will take longer...