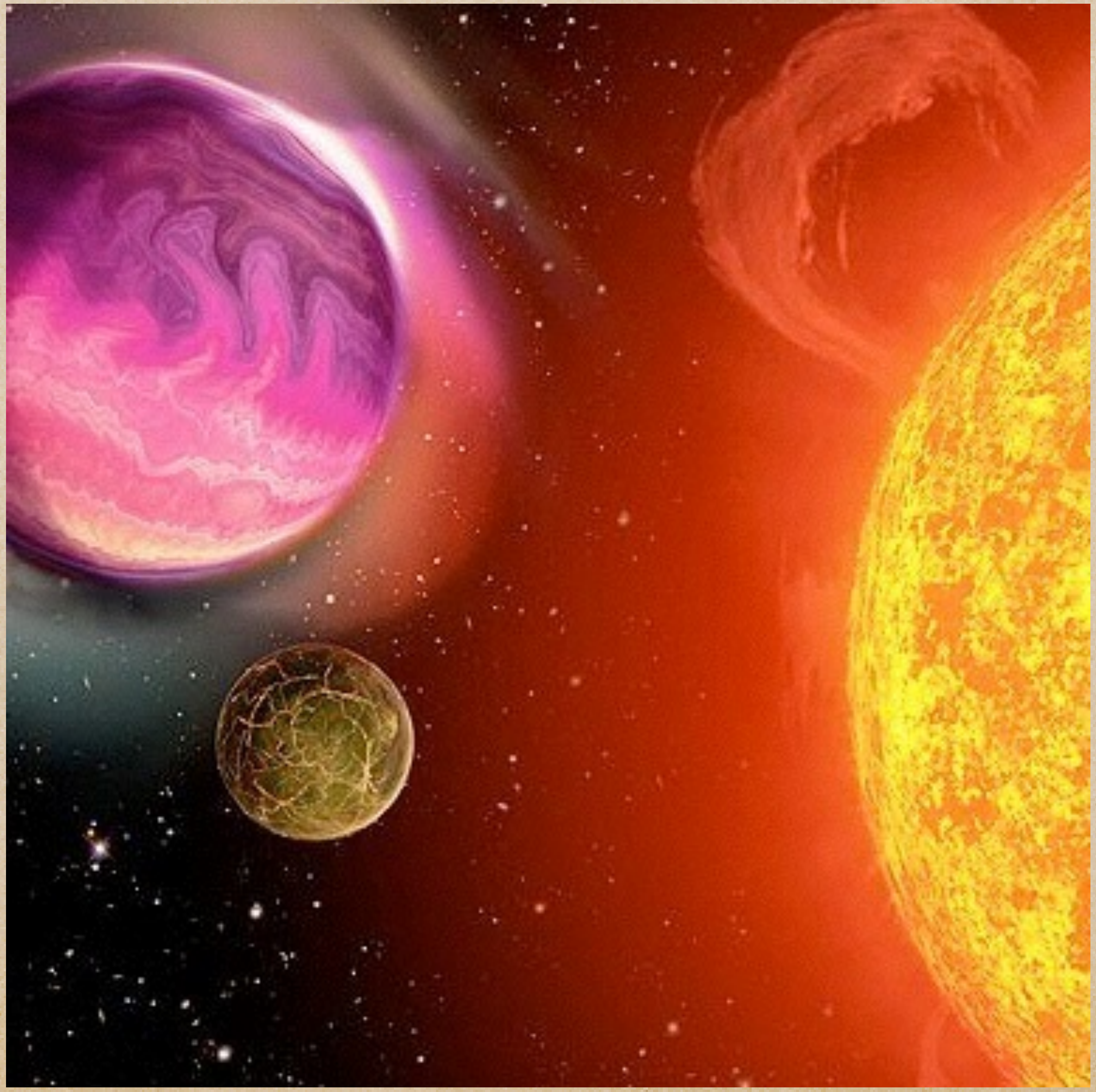
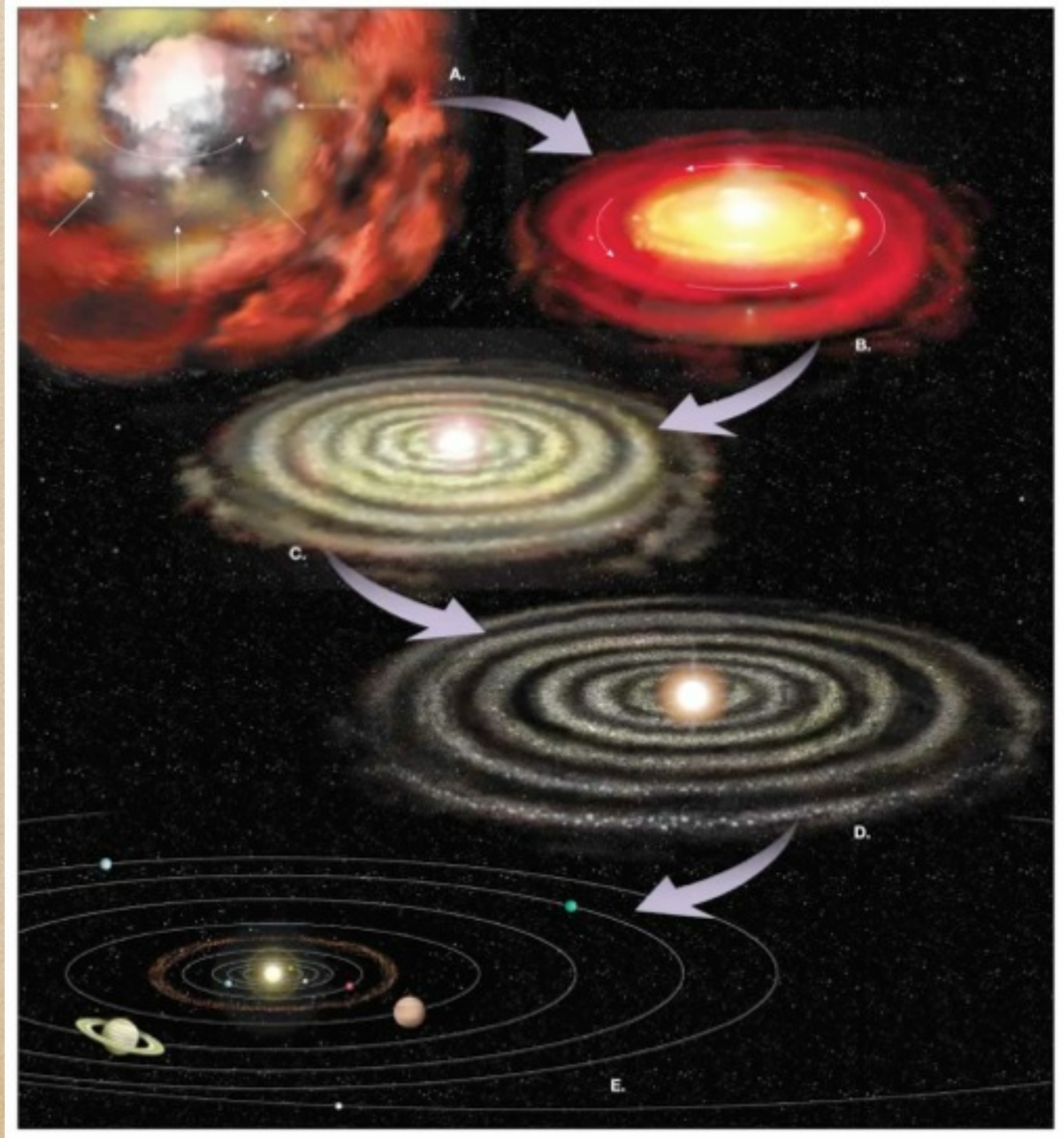
Exoplanets and the potential for life in the Universe

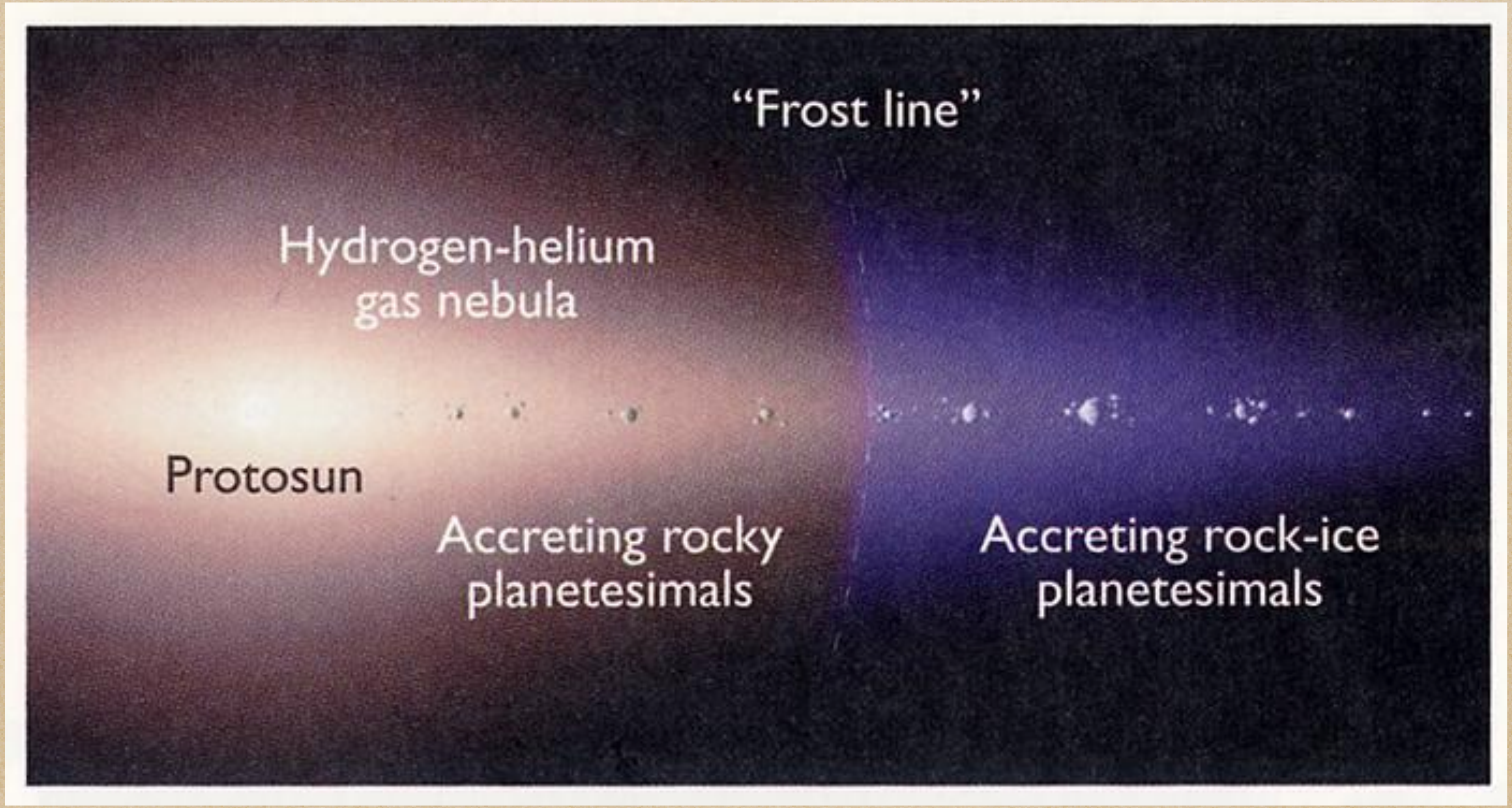


Outline of the talk

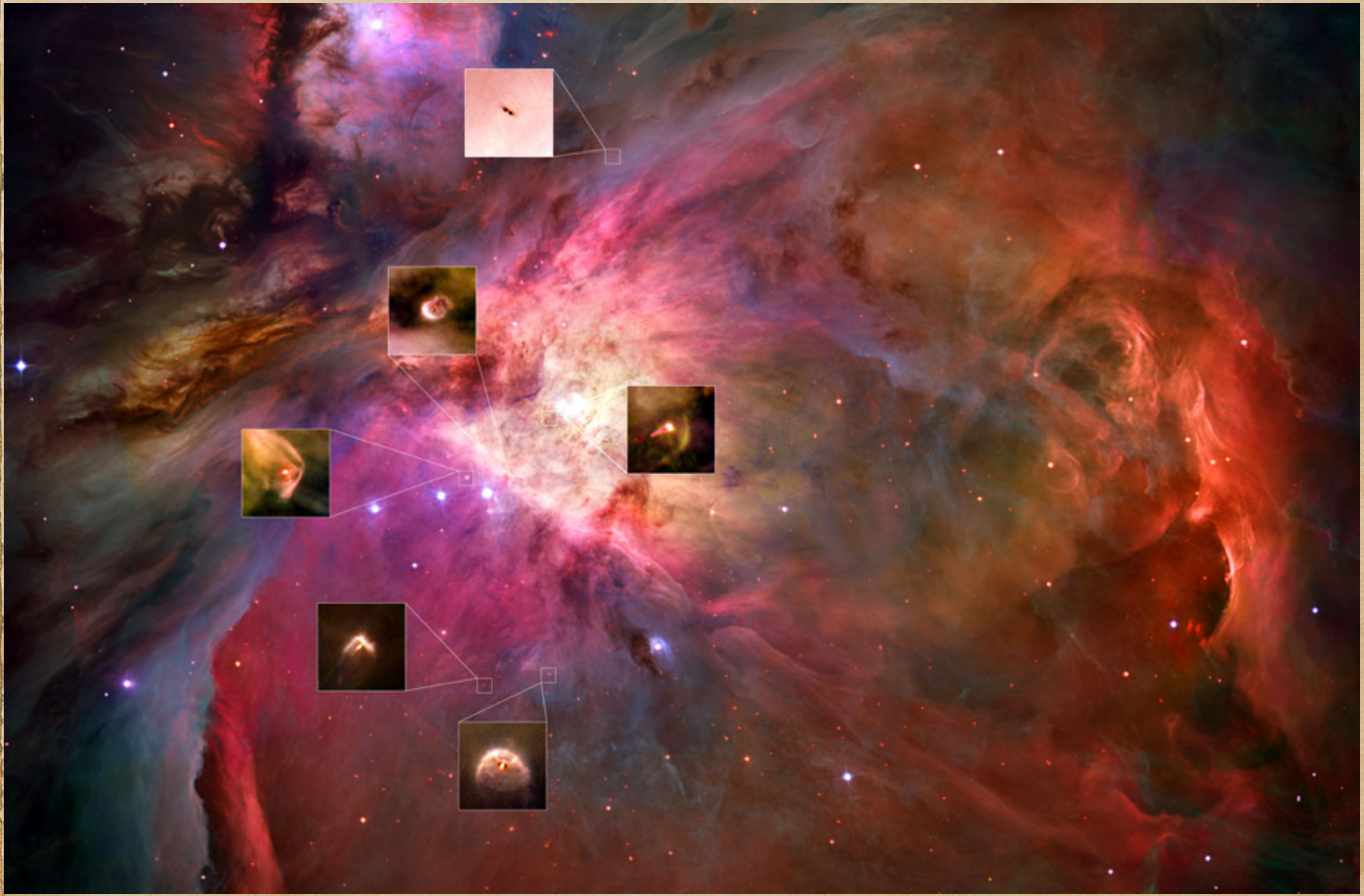
- Solar System Formation
- Exoplanets
  - Definition
  - Detection Methods
  - What we Found
- Modified Theory of Formation
- Properties Of Exoplanets
- What's The Point of all This?
- LIFE IN THE UNIVERSE
  - Habitability/Kepler/Life

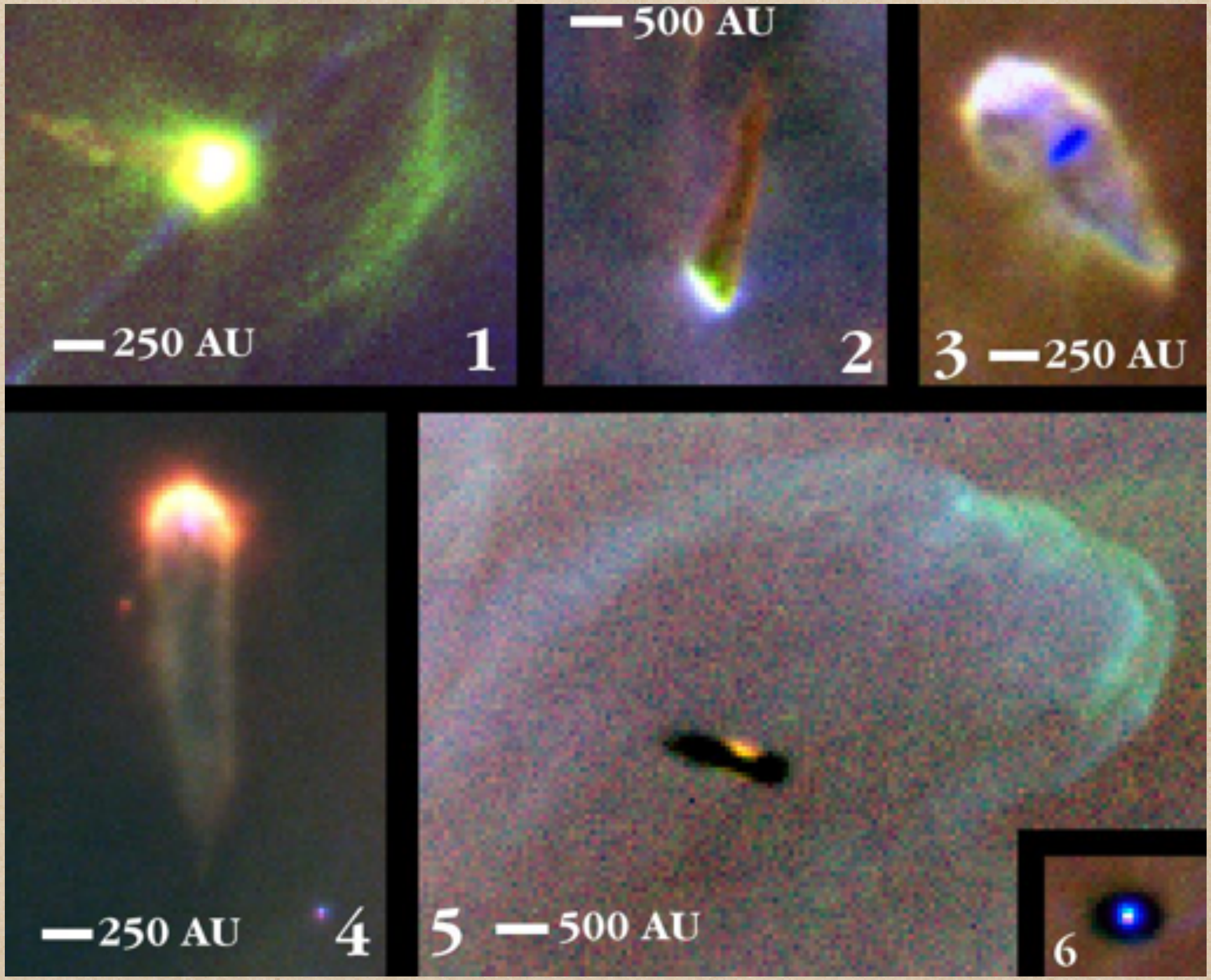
Nebular Theory

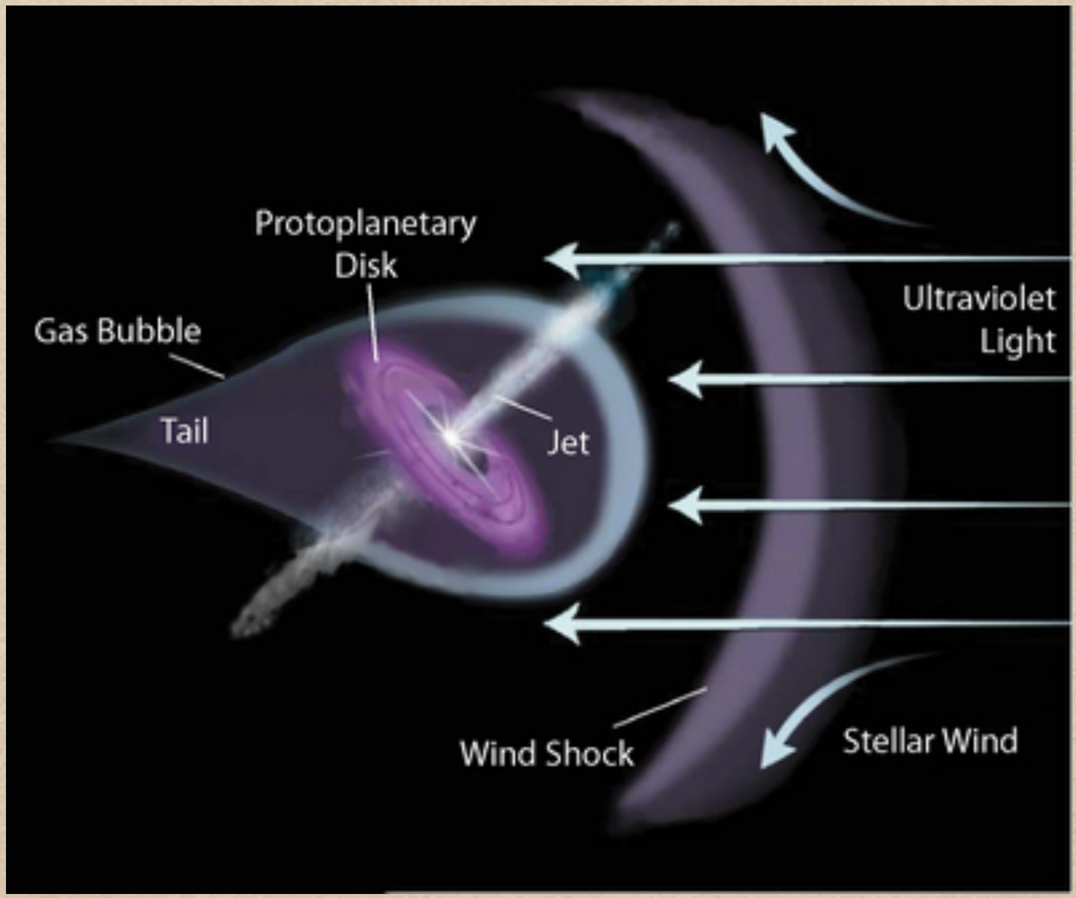



"Frost line"
Hydrogen-helium gas nebula
Protosun
Accreting rocky planetesimals
Accreting rock-ice planetesimals

-
- tem



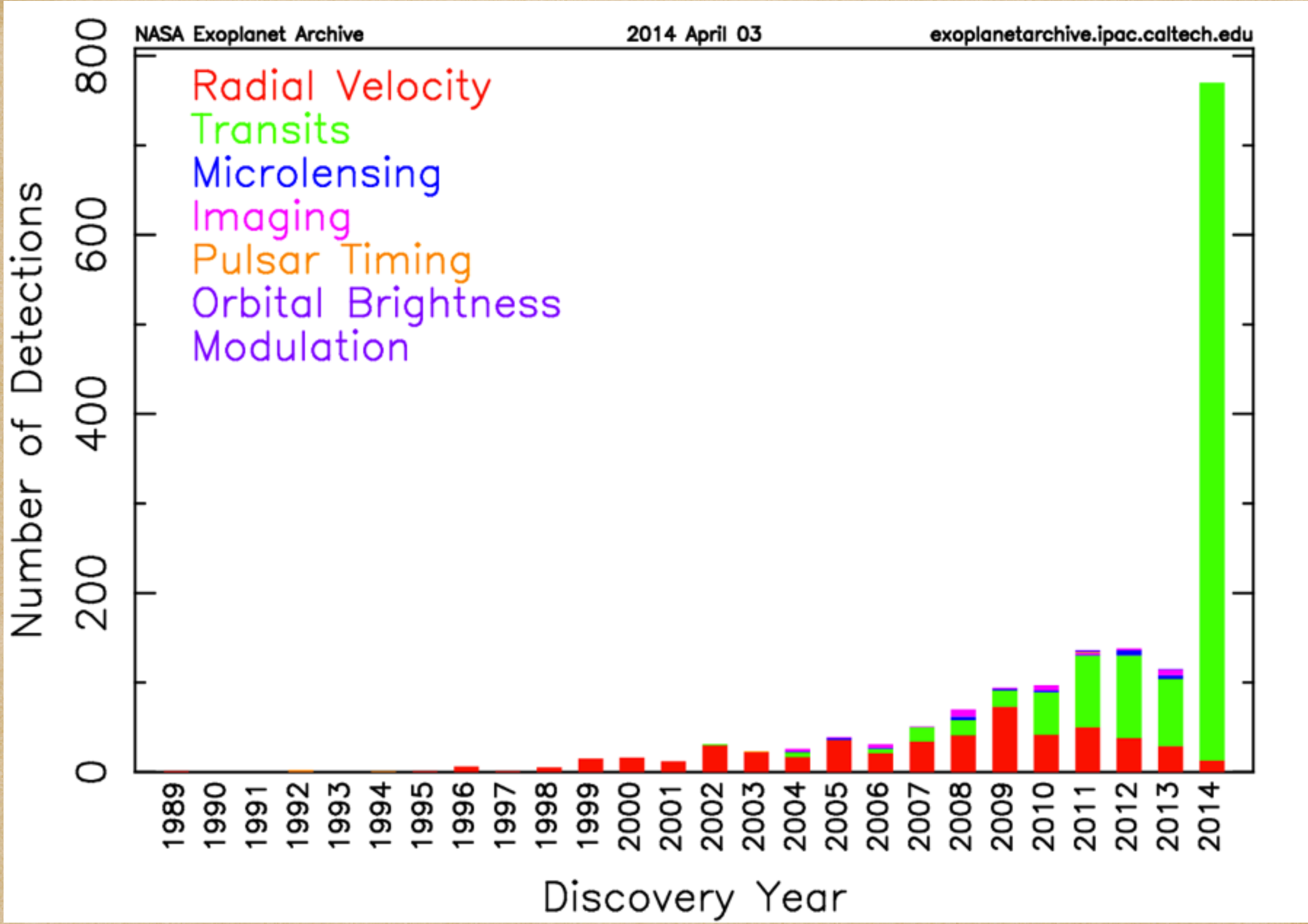

500 AU
250 AU
1
2
3
250 AU
250 AU
4
5
500 AU
6



Protoplanetary
Disk
Gas Bubble
Tail
Jet
Ultraviolet
Light
Wind Shock
Stellar Wind

First Exoplanet

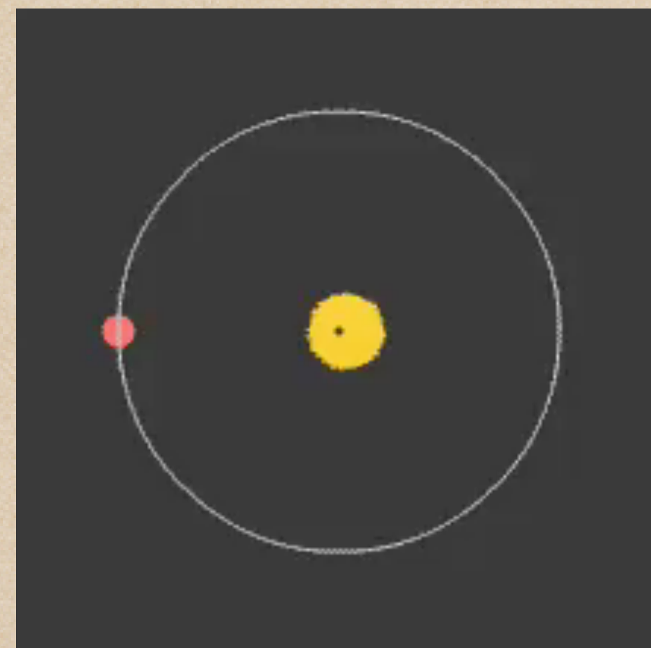
- First - 1988 Bruce Campbell, G. A. H. Walker, and Stephenson Yang but Not Confirmed until 2003
- From Wikipedia
  - In early 1992, radio astronomers Aleksander Wolszczan and Dale Frail announced the discovery of two planets orbiting the pulsar PSR 1257+12.[6] This discovery was confirmed, and is generally considered to be the first definitive detection of exoplanets. These pulsar planets are believed to have formed from the unusual remnants of the supernova that produced the pulsar, in a second round of planet formation, or else to be the remaining rocky cores of gas giants that somehow survived the supernova and then decayed into their current orbits.

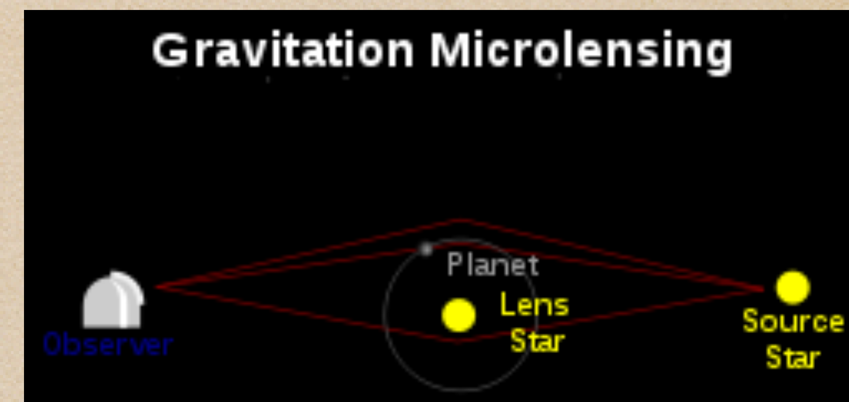


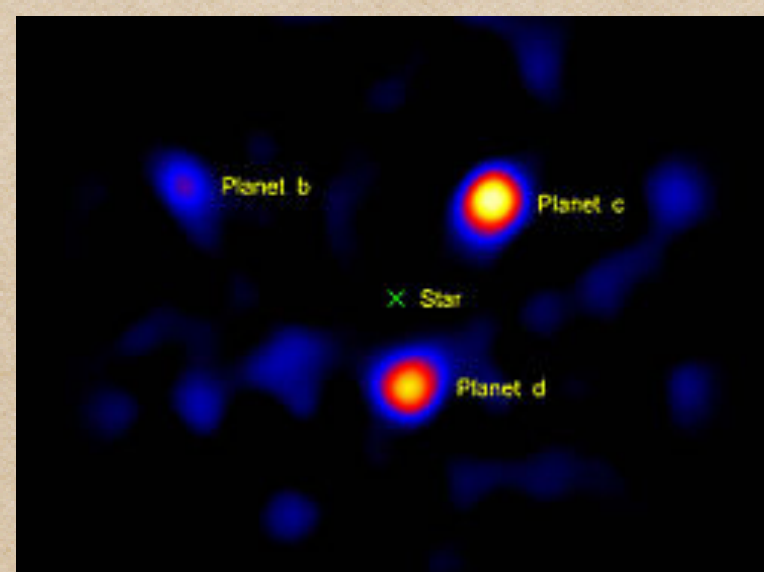
NASA Exoplanet Archive
2014 April 03
exoplanetarchive.ipac.caltech.edu
Radial Velocity
Transits
Microlensing
Imaging
Pulsar Timing
Orbital Brightness
Modulation
Number of Detections
0
200
400
600
800
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
Discovery Year

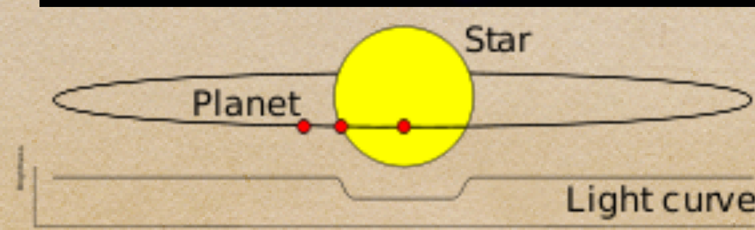
How Do We Find Them?

- Radial Velocity
- Pulsar Timing
- Transits
- Gravitational Microlensing
- Direct Imaging
- Astrometry

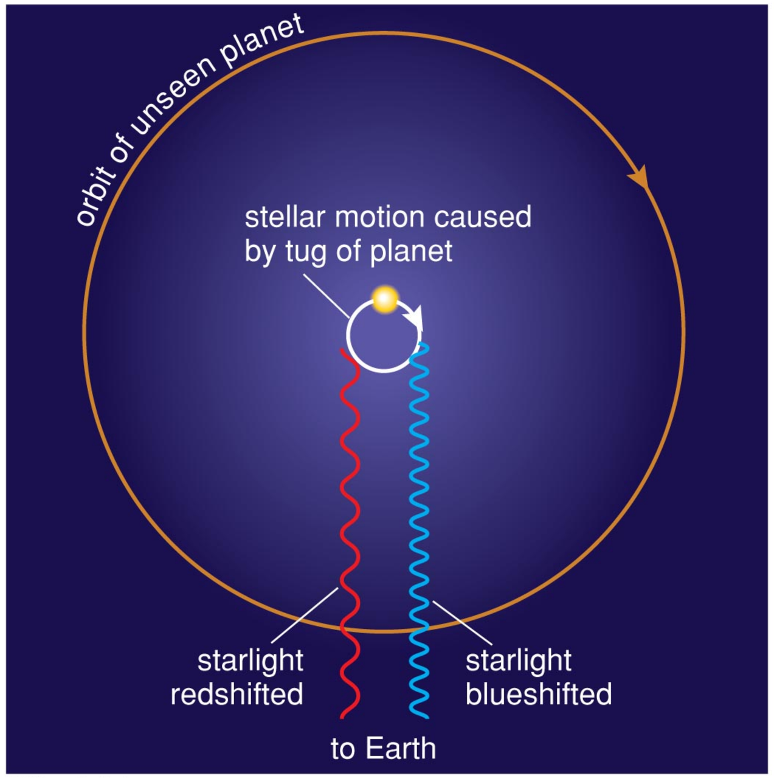




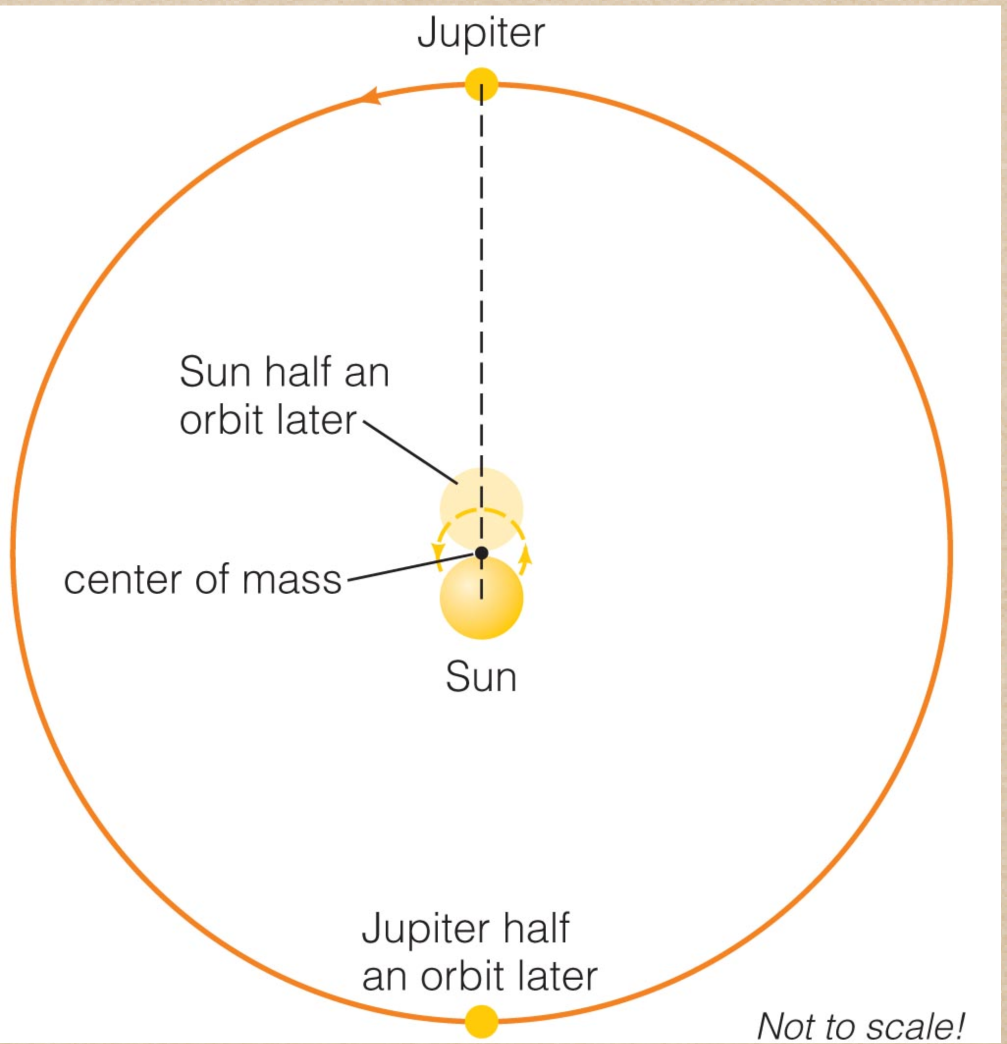




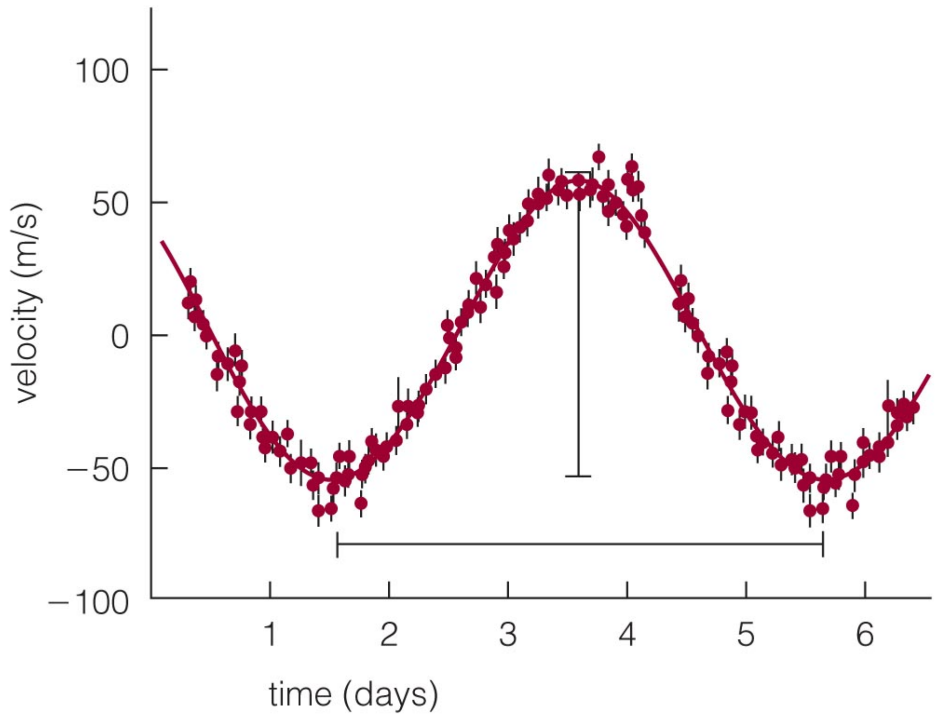
Doppler Technique



- Measuring a star's Doppler shift can tell us its motion toward and away from us.
- Current techniques can measure motions as small as 1 m/s (walking speed!).


Jupiter
Sun half an
orbit later
center of mass
Sun
Jupiter half
an orbit later
Not to scale!

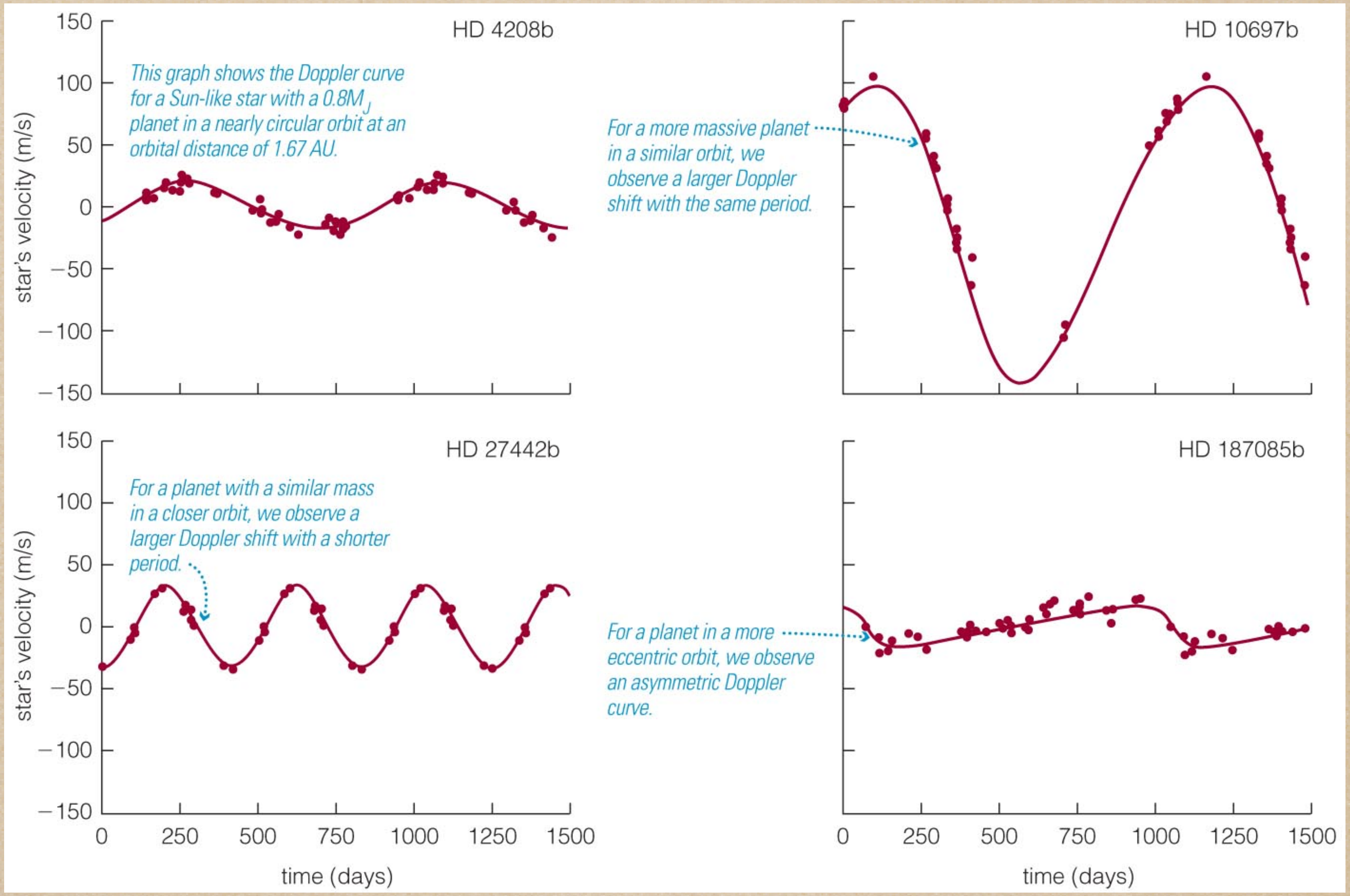
First Extrasolar Planet



a A periodic Doppler shift in the spectrum of the star 51 Pegasi shows the presence of a large planet with an orbital period of about 4 days. Dots are actual data points; bars through dots represent measurement uncertainty.

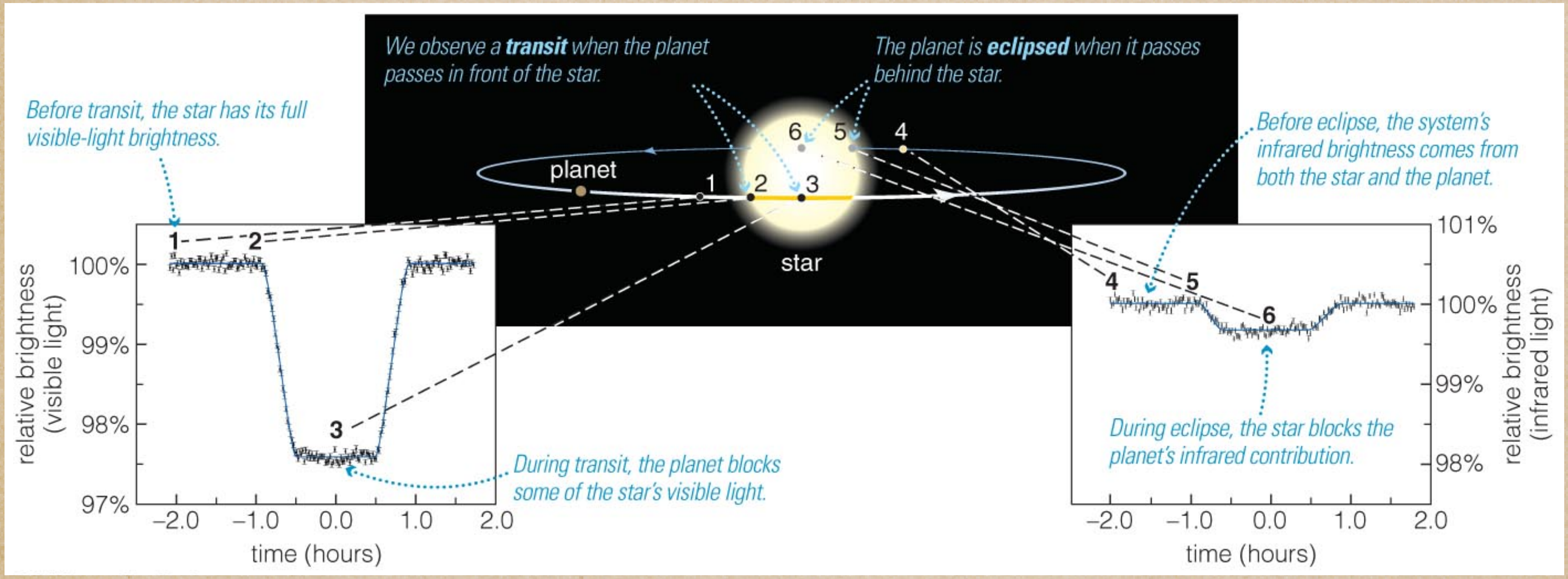
- Doppler shifts of the star 51 Pegasi indirectly revealed a planet with 4-day orbital period.
- This short period means that the planet has a small orbital distance.
- This was the first extrasolar planet to be discovered around a Sun-like star (1995).

What can Doppler shifts tell us?

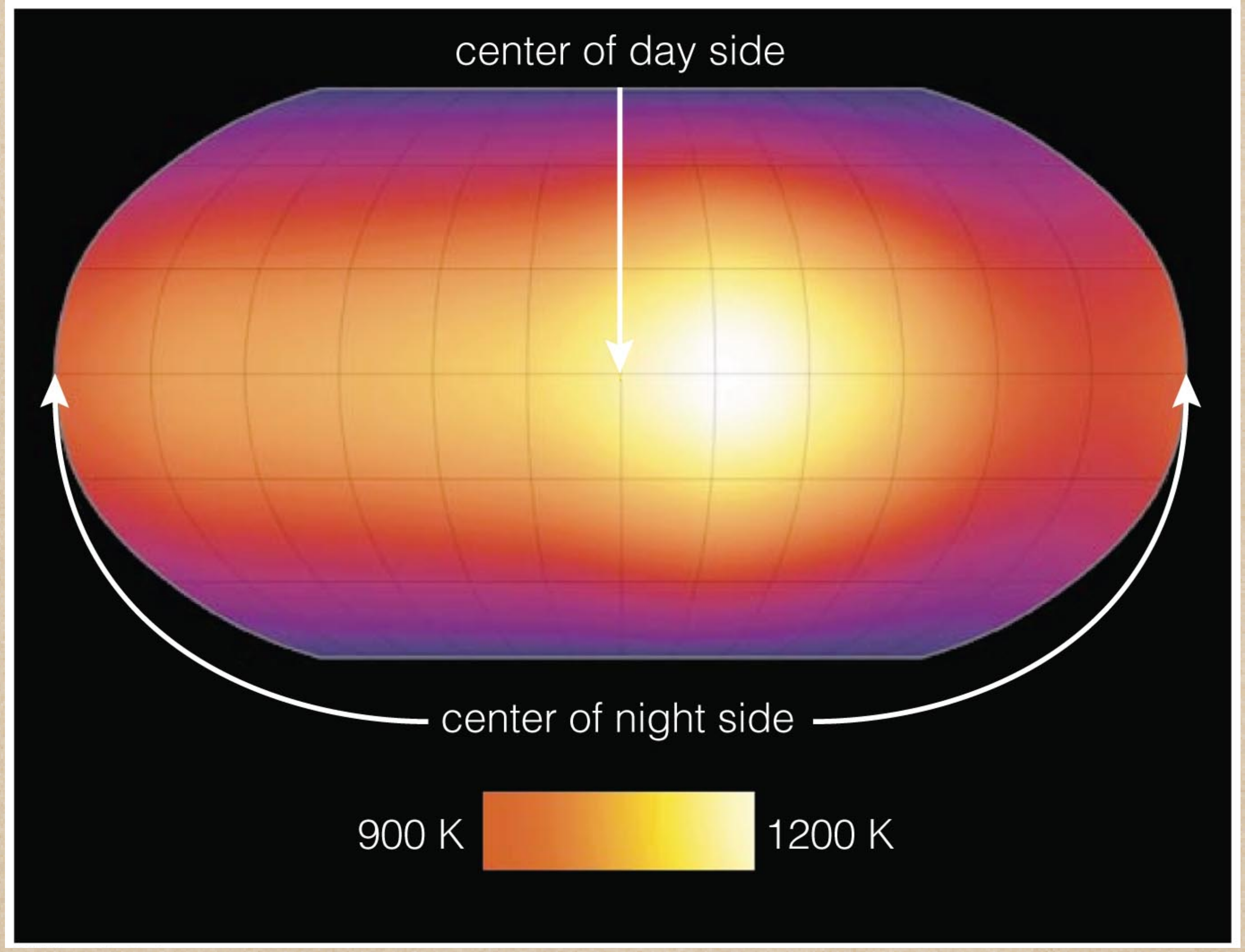


- Doppler shift data tell us about a planet's mass and the shape of its orbit.

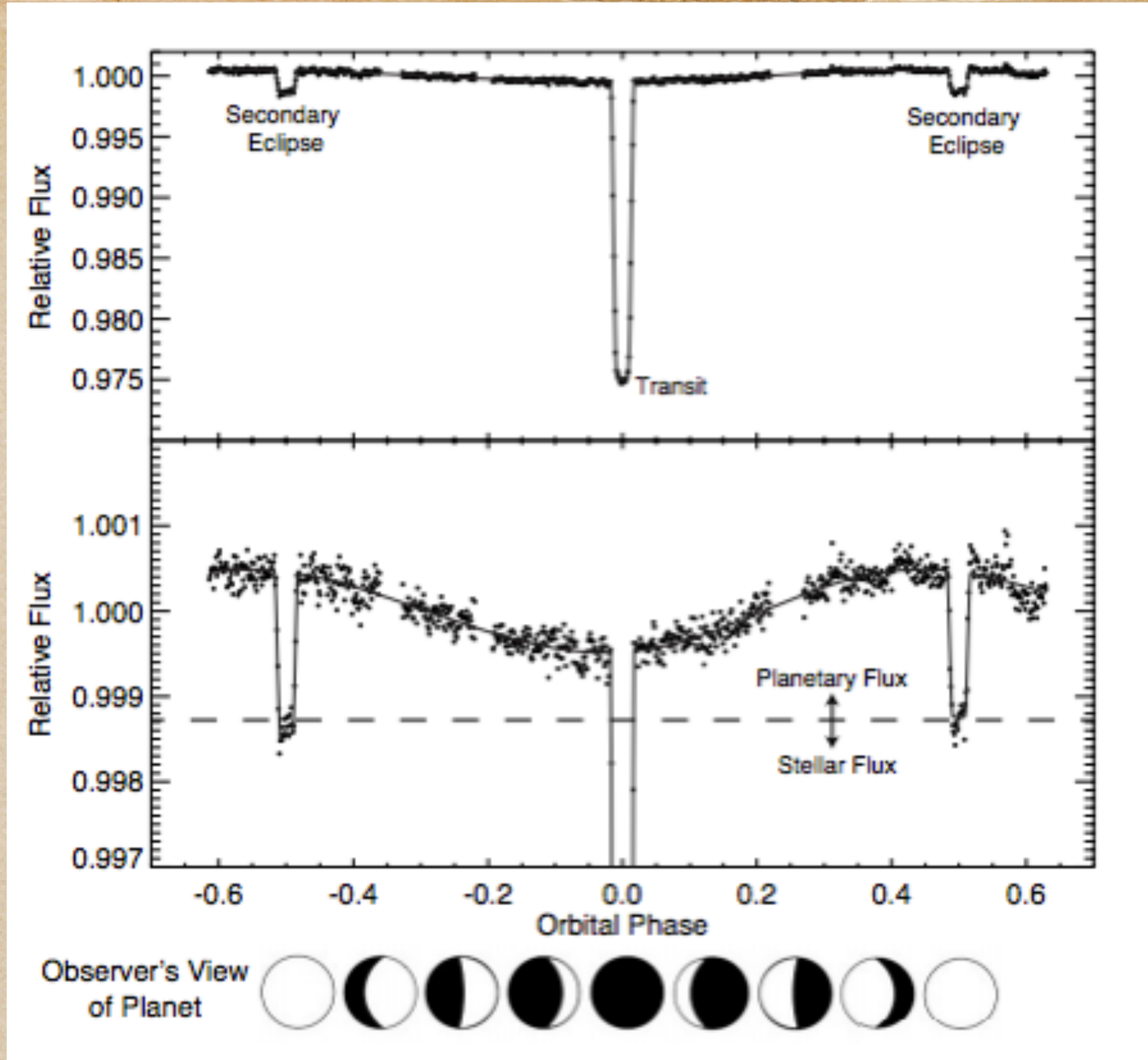
How can changes in a star's brightness reveal the presence of planets ?



Surface Temperature Map



- Measuring the change in infrared brightness during an eclipse enables us to map a planet's surface temperature.



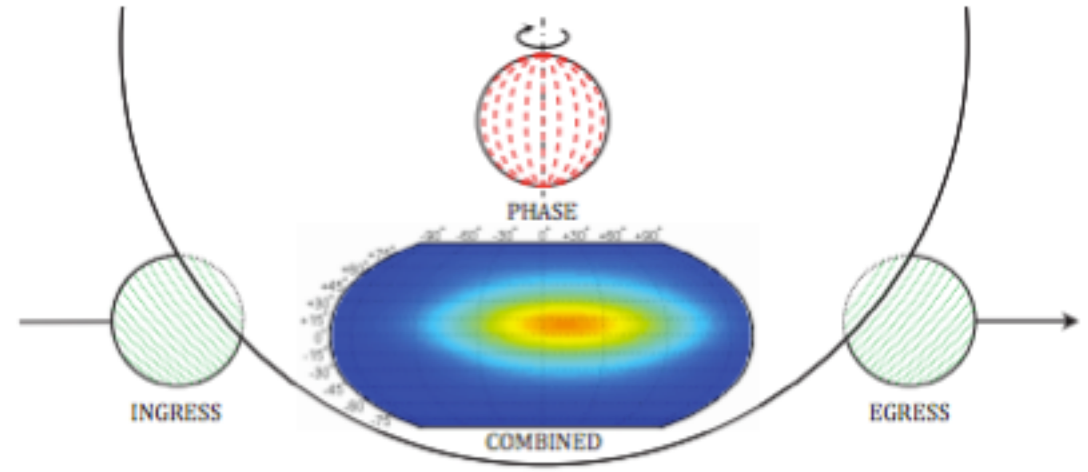
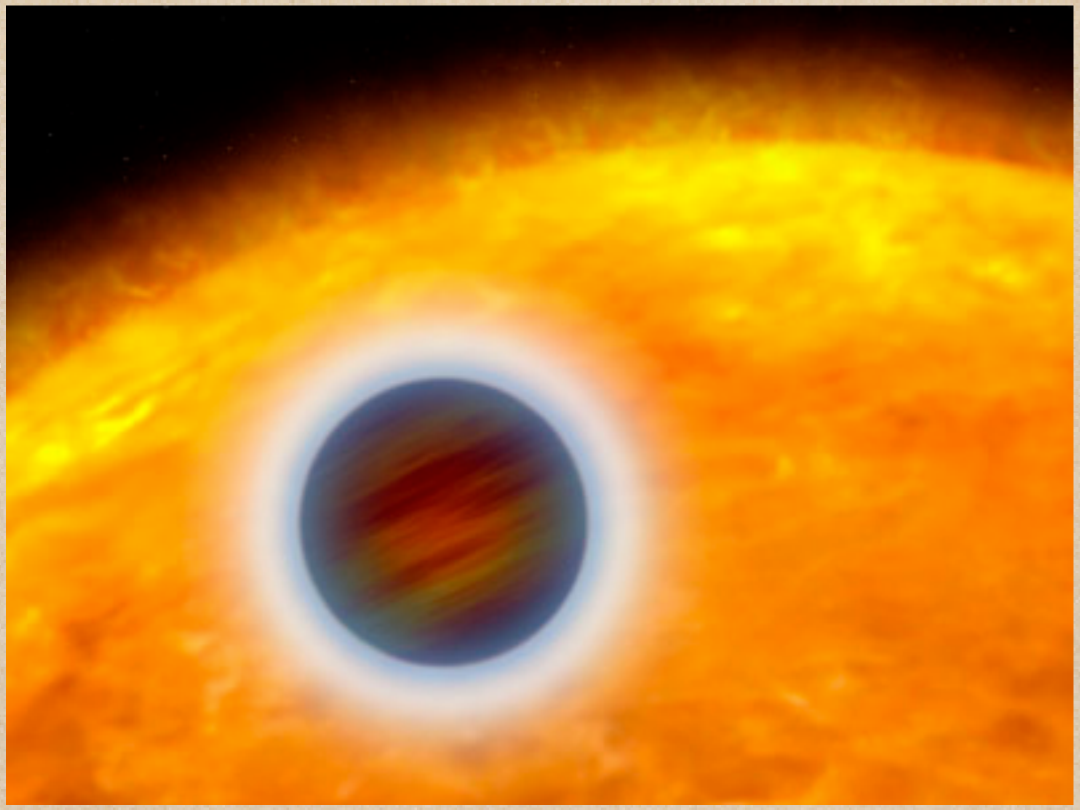
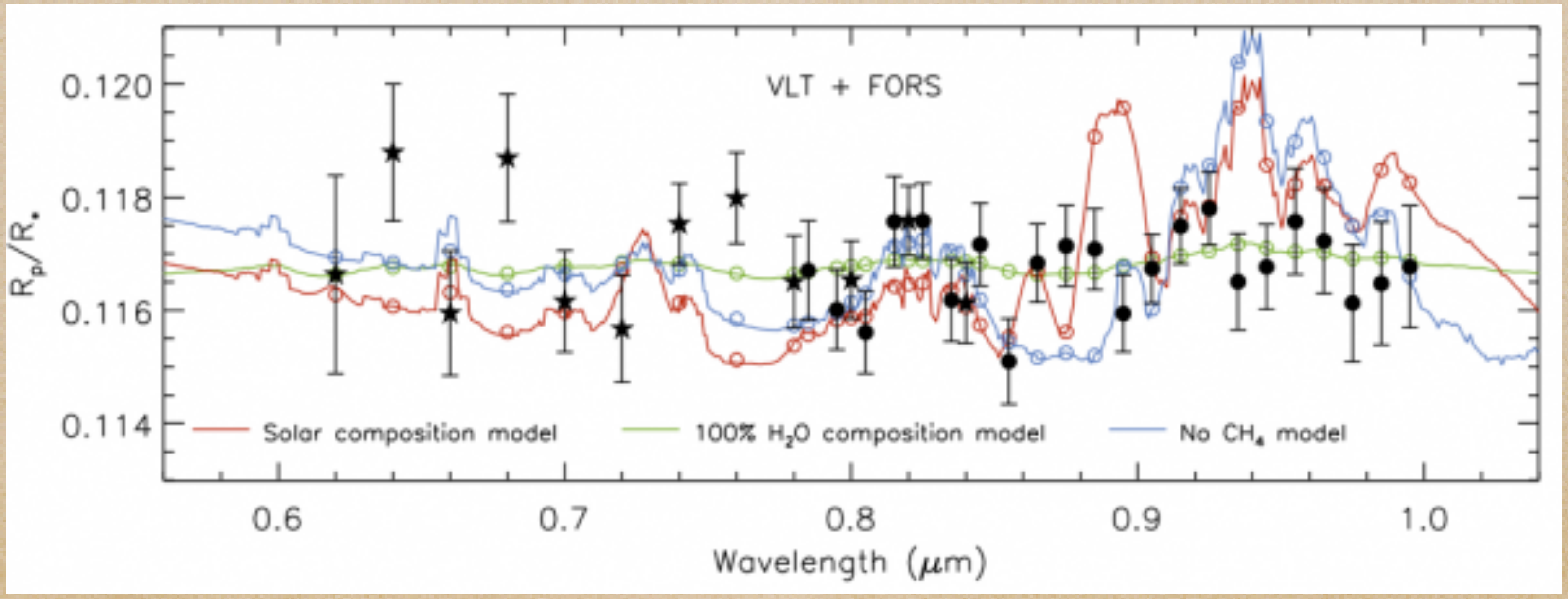


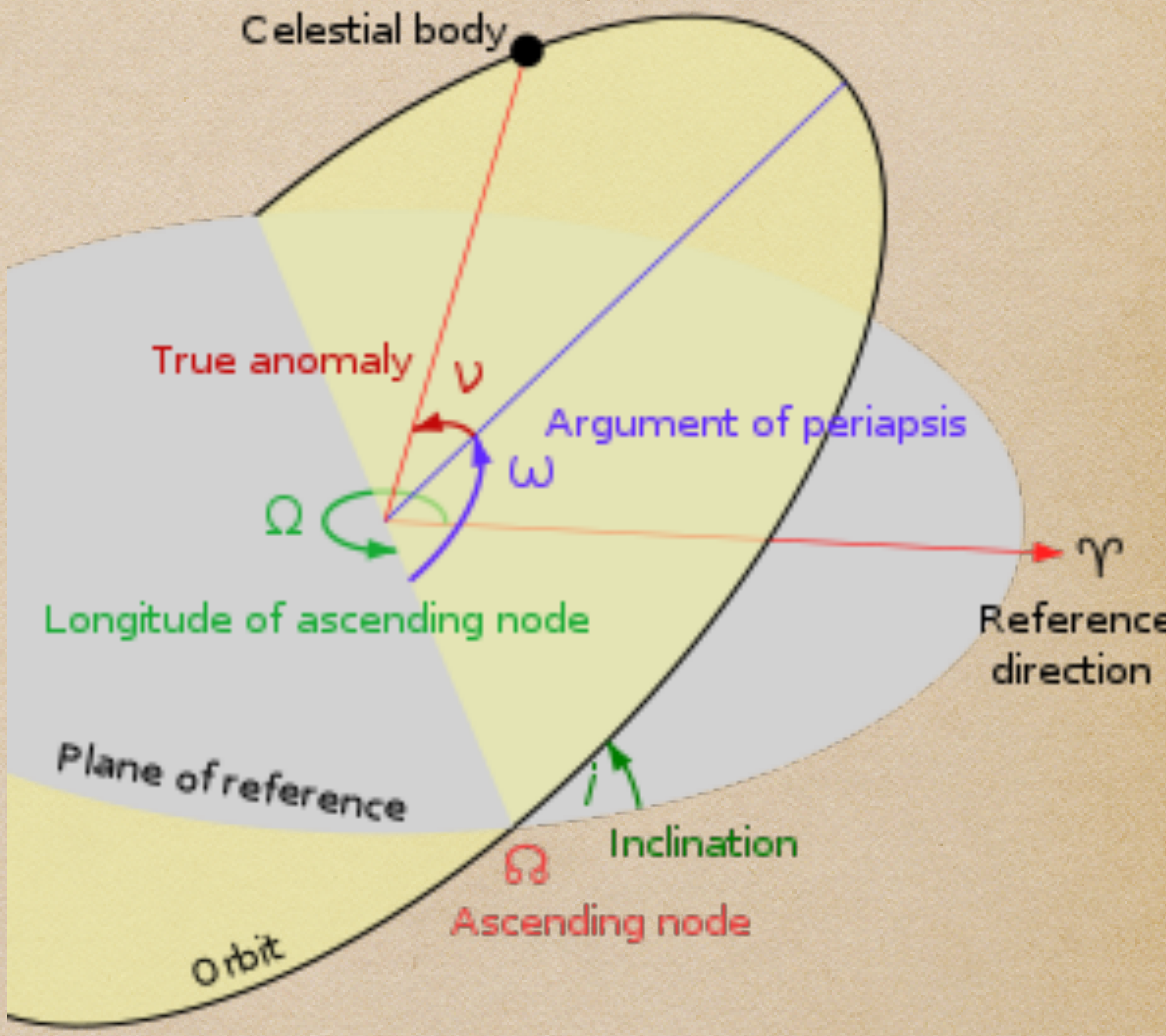
Figure 4: Combined eclipse and phase map of the hot Jupiter HD 189733b. Courtesy of Julien de Wit [40].

Also starting to get chemistry

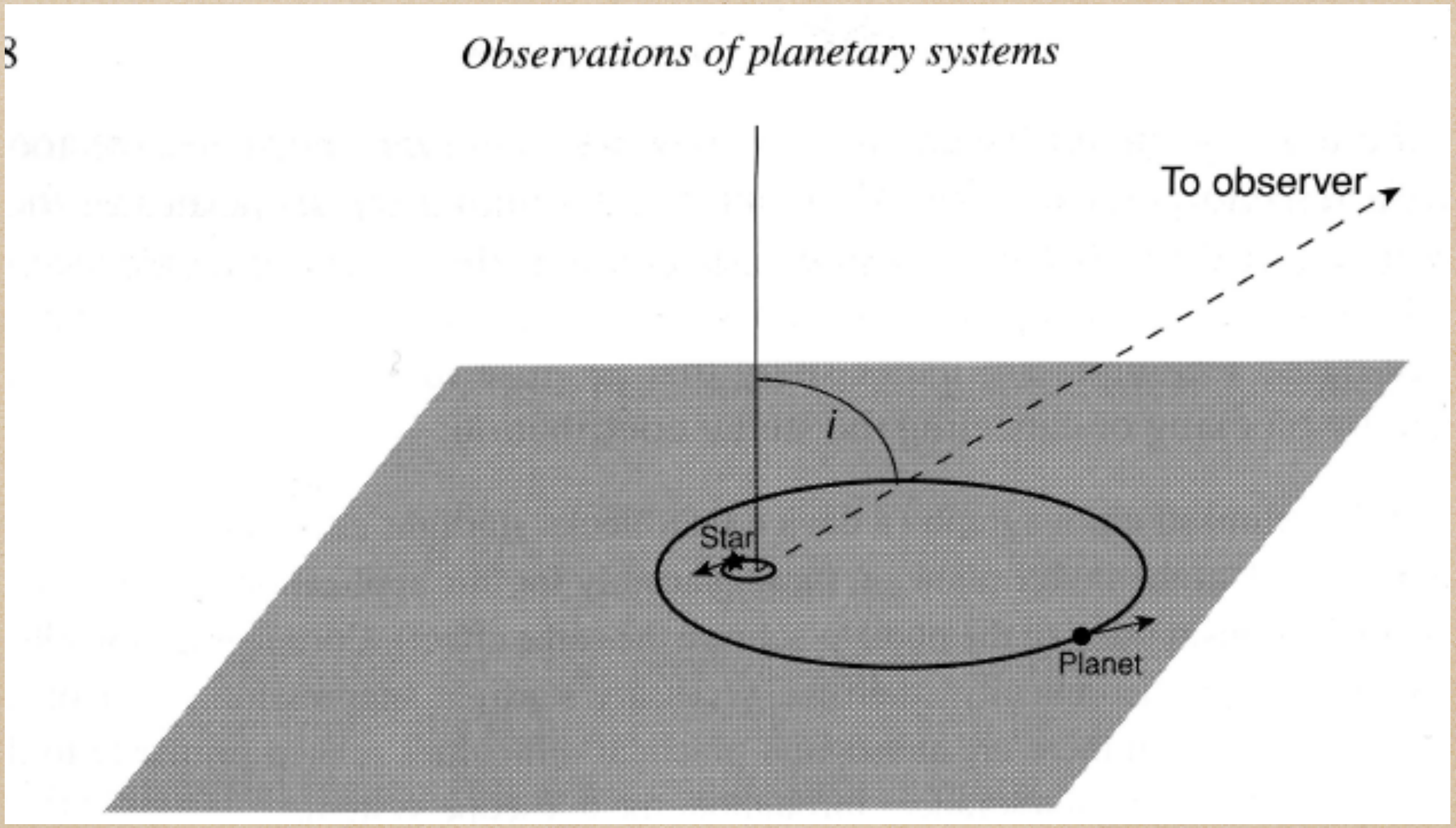




- What We Get
  - Semi Major Axis
  - Eccentricity
  - Longitude of Periastron
  - Time Of Periastron
- What We Don't
  - Inclination (unless via transit method)
  - Longitude of the Ascending Node



Only M Sin(i) For Radial Velocity

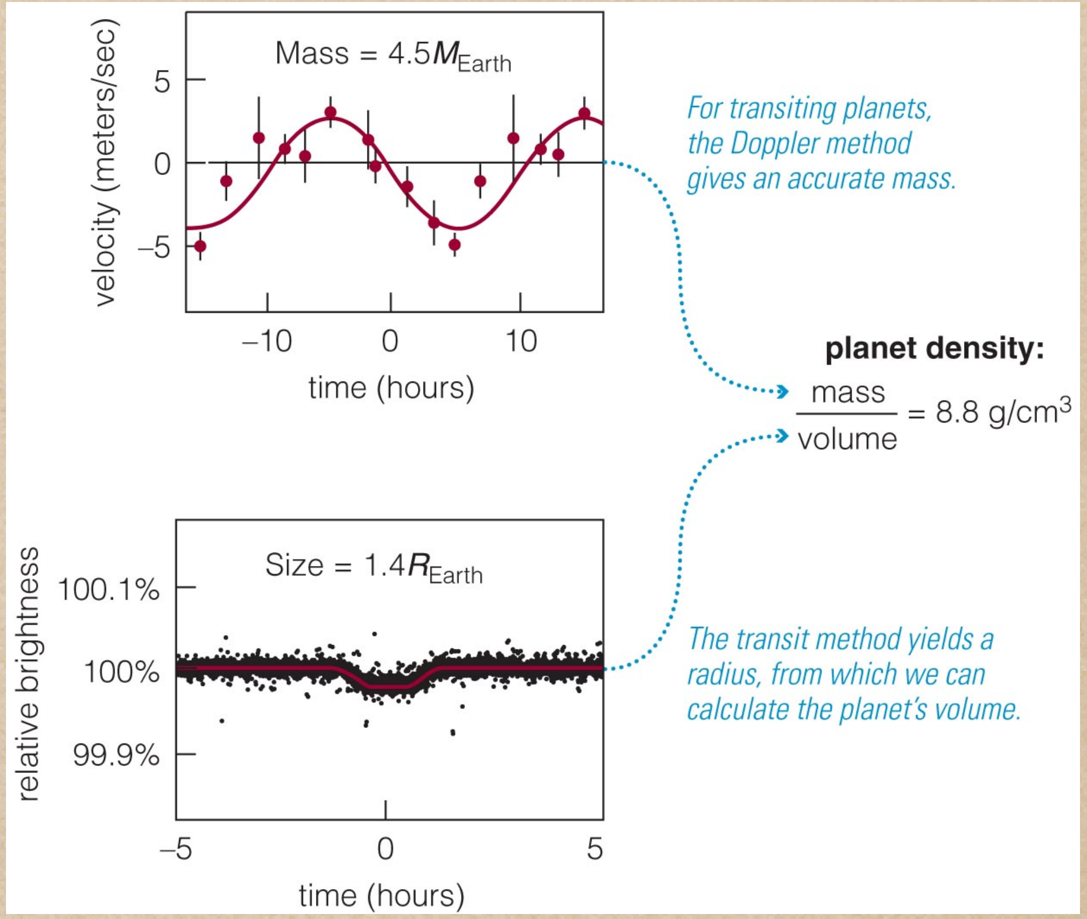


Lower Limit Only

Also

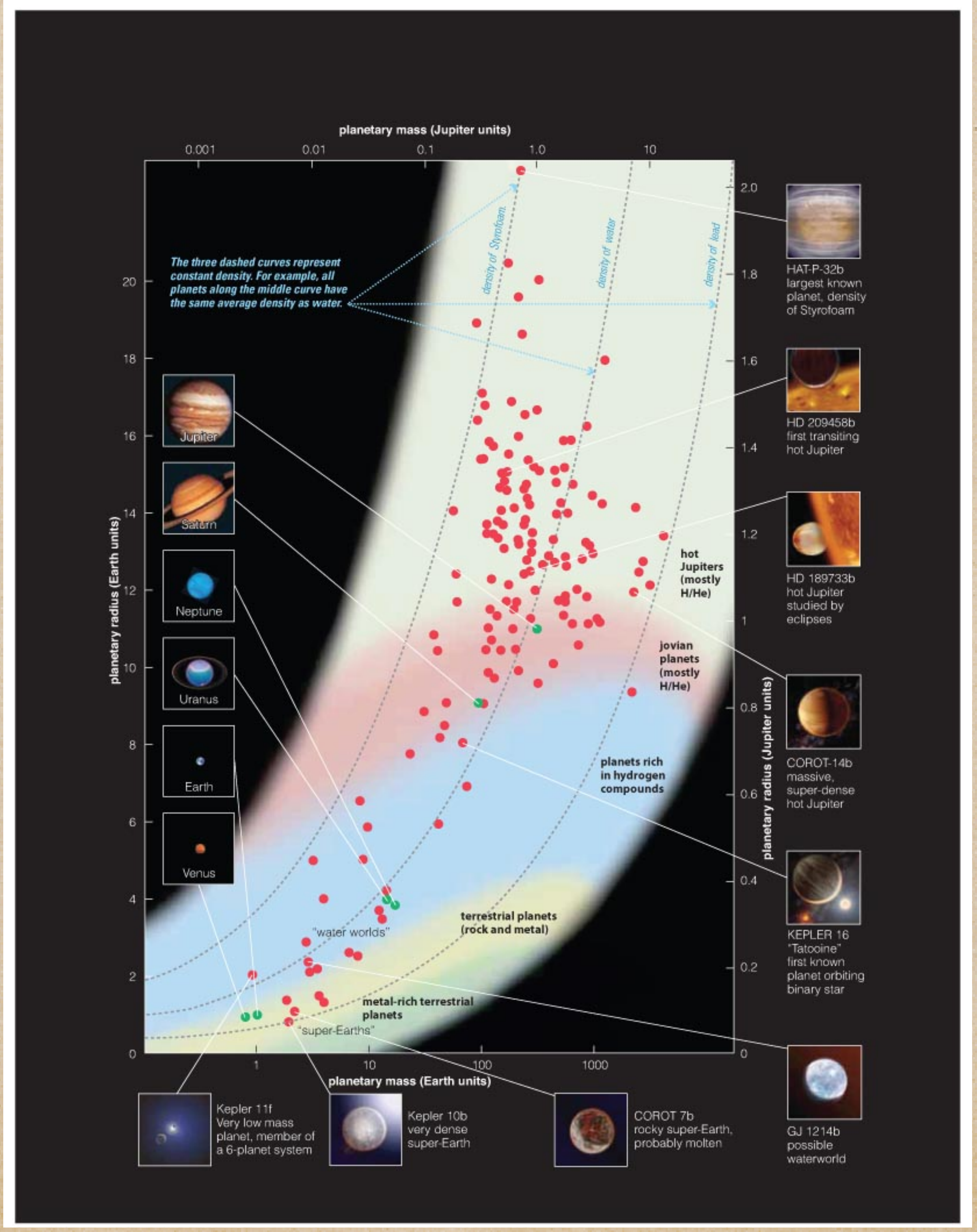
Calculating density

- Using mass, determined using the Doppler technique, and size, determined using the transit technique, density can be calculated.

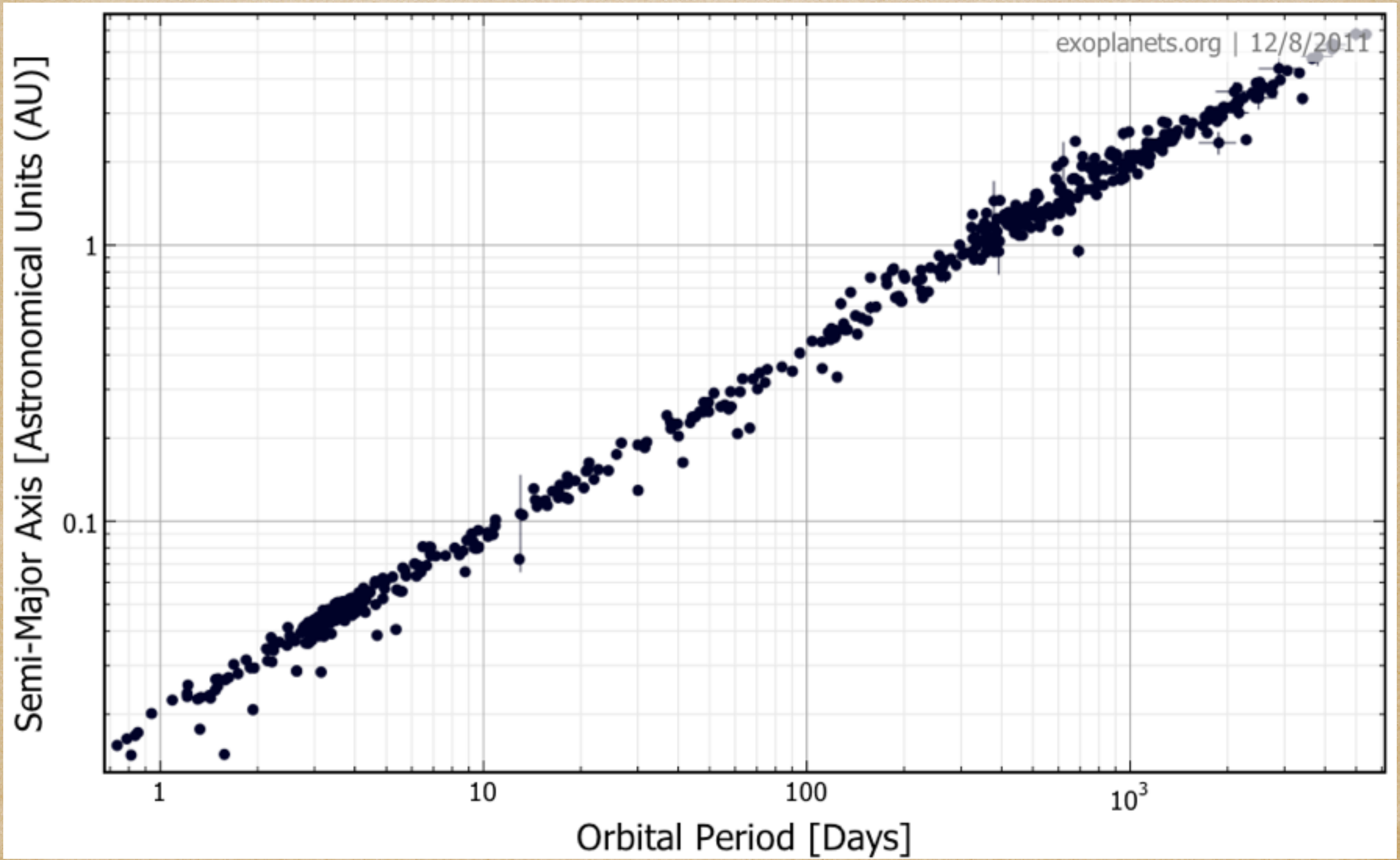


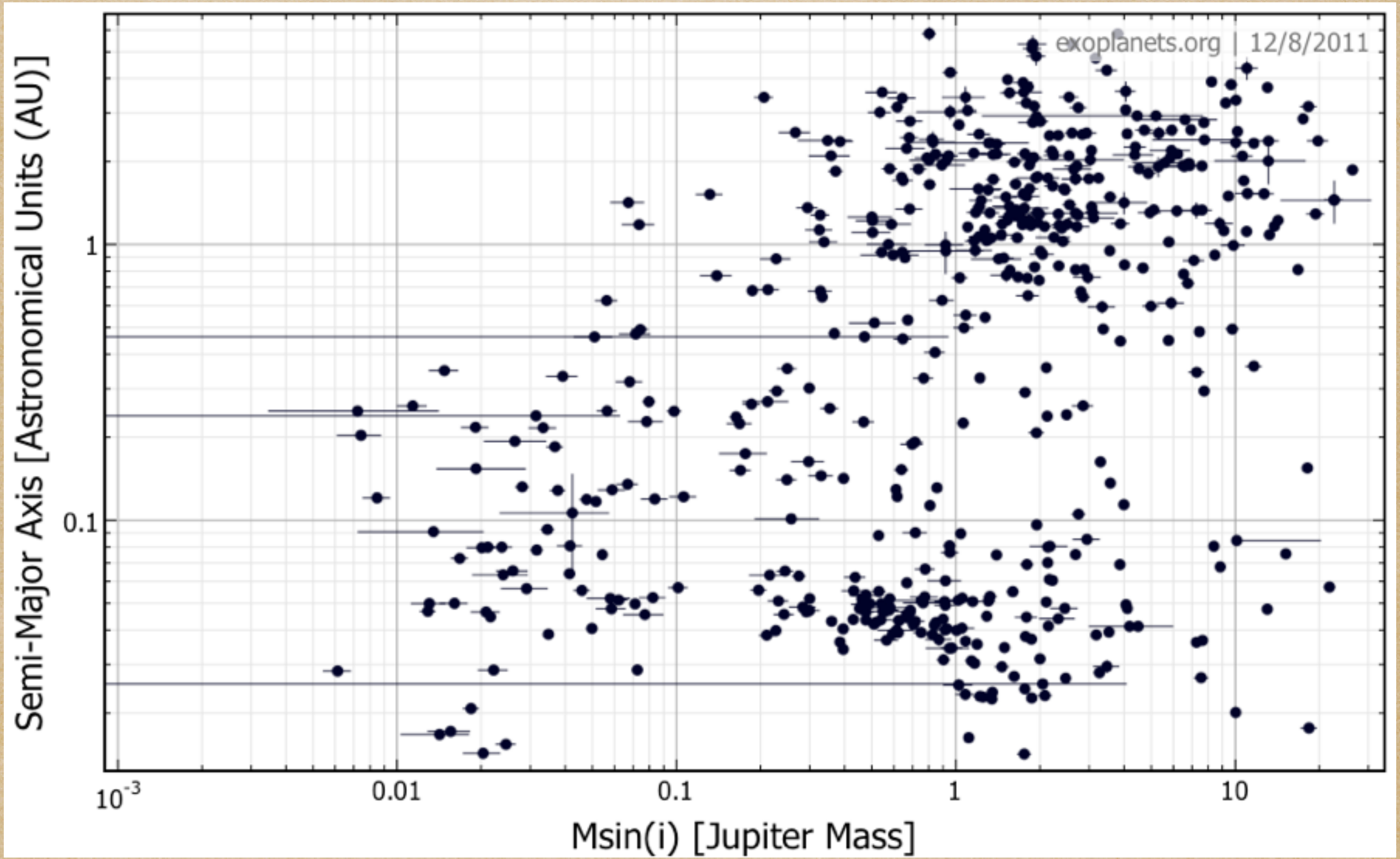
Some Properties Of the 1800 (and increasing weekly) Discovered Planets

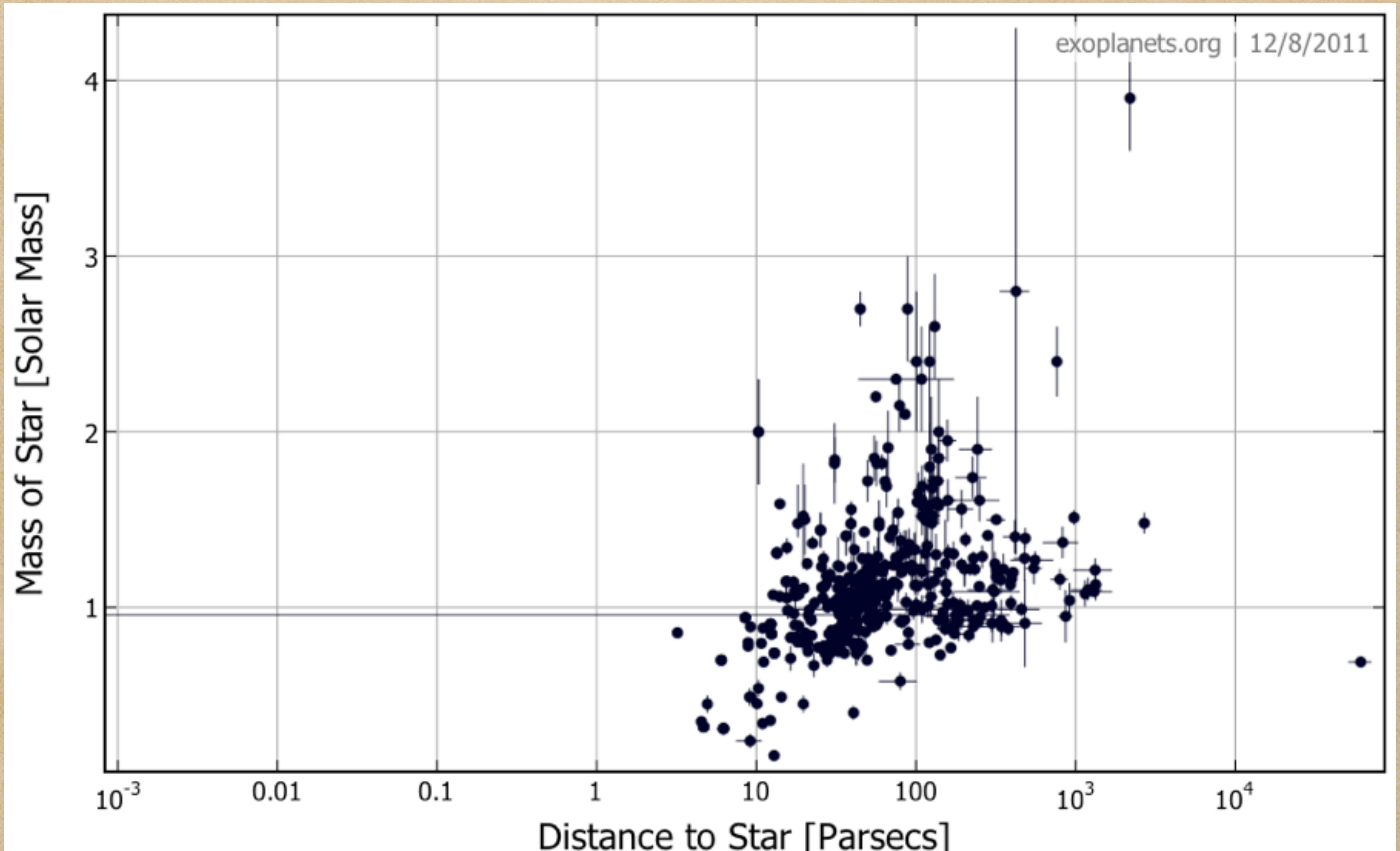
How do extrasolar planets compare with planets in our solar system?



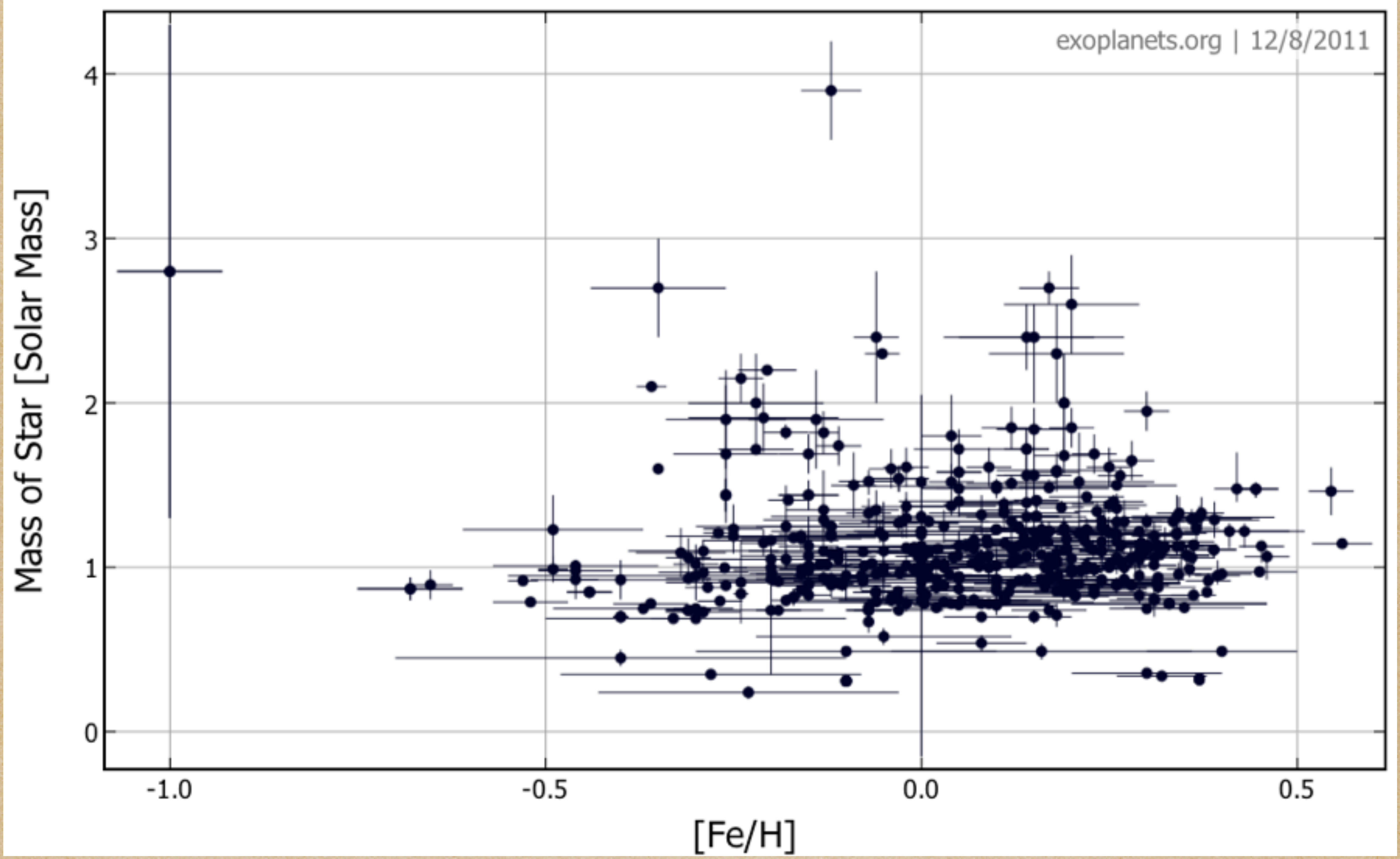
Following Plots From exoplanets.org



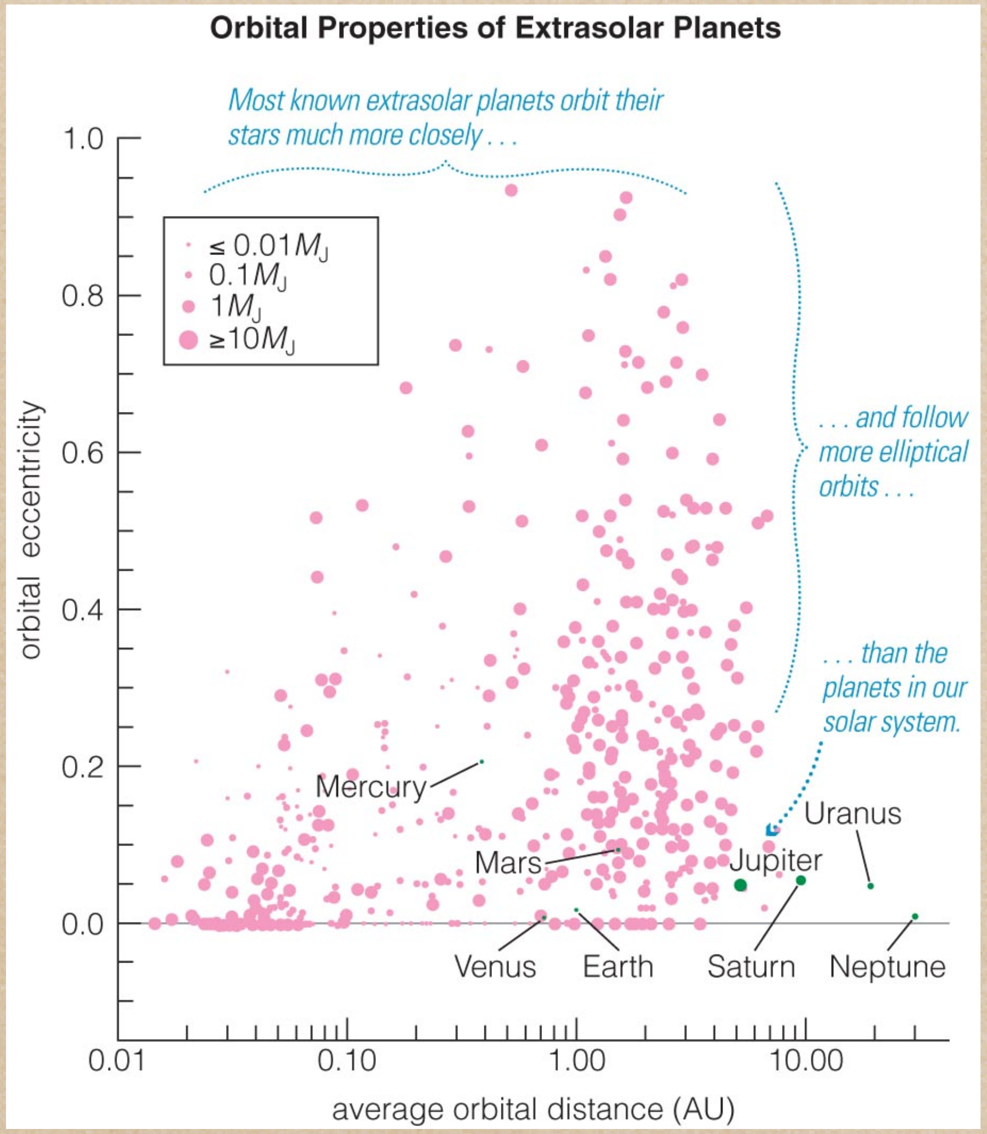

exoplanets.org | 12/8/2011
Semi-Major Axis [Astronomical Units (AU)]
1
0.1
Msin(i) [Jupiter Mass]
10^{-3}
0.01
0.1
1
10



exoplanets.org | 12/8/2011
Mass of Star [Solar Mass]
4
3
2
1
10^-3
0.01
0.1
1
10
100
10^3
10^4
Distance to Star [Parsecs]

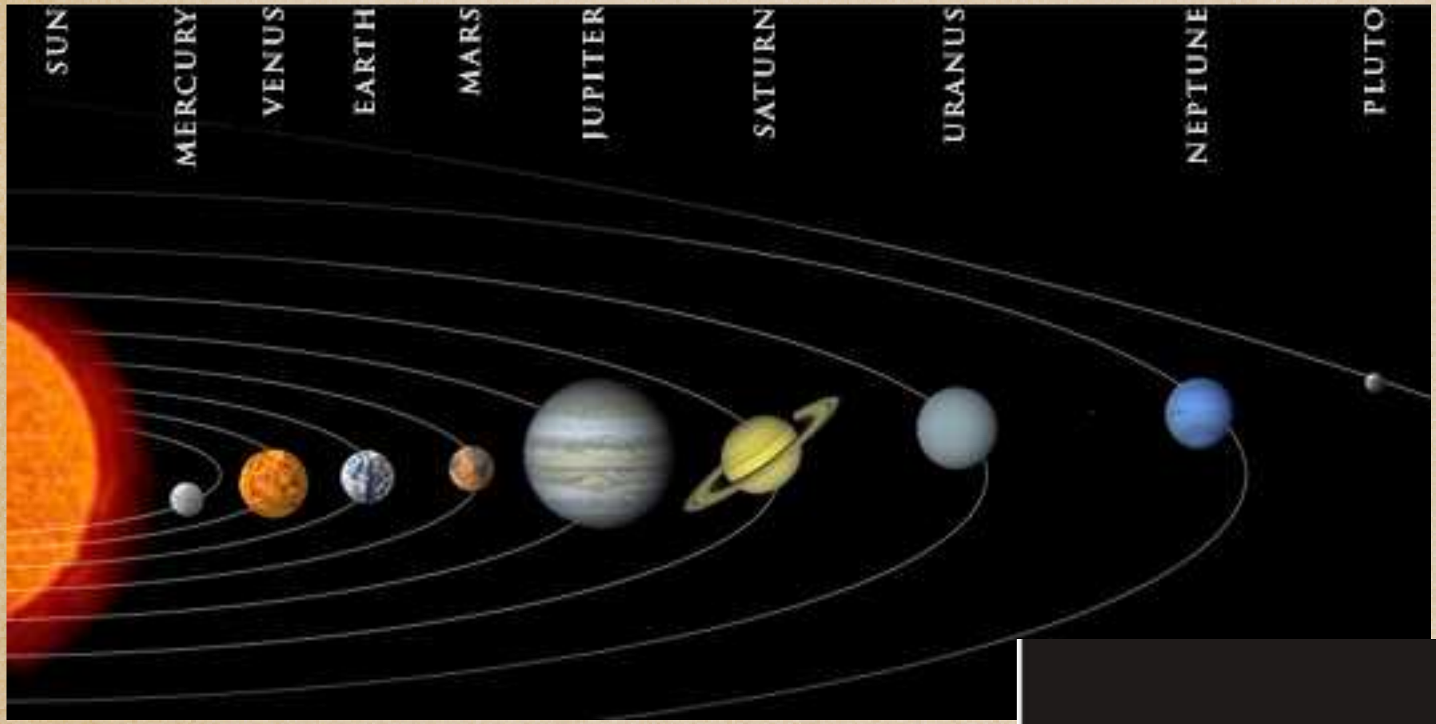

exoplanets.org | 12/8/2011
Mass of Star [Solar Mass]
[Fe/H]
0
1
2
3
4
-1.0
-0.5
0.0
0.5

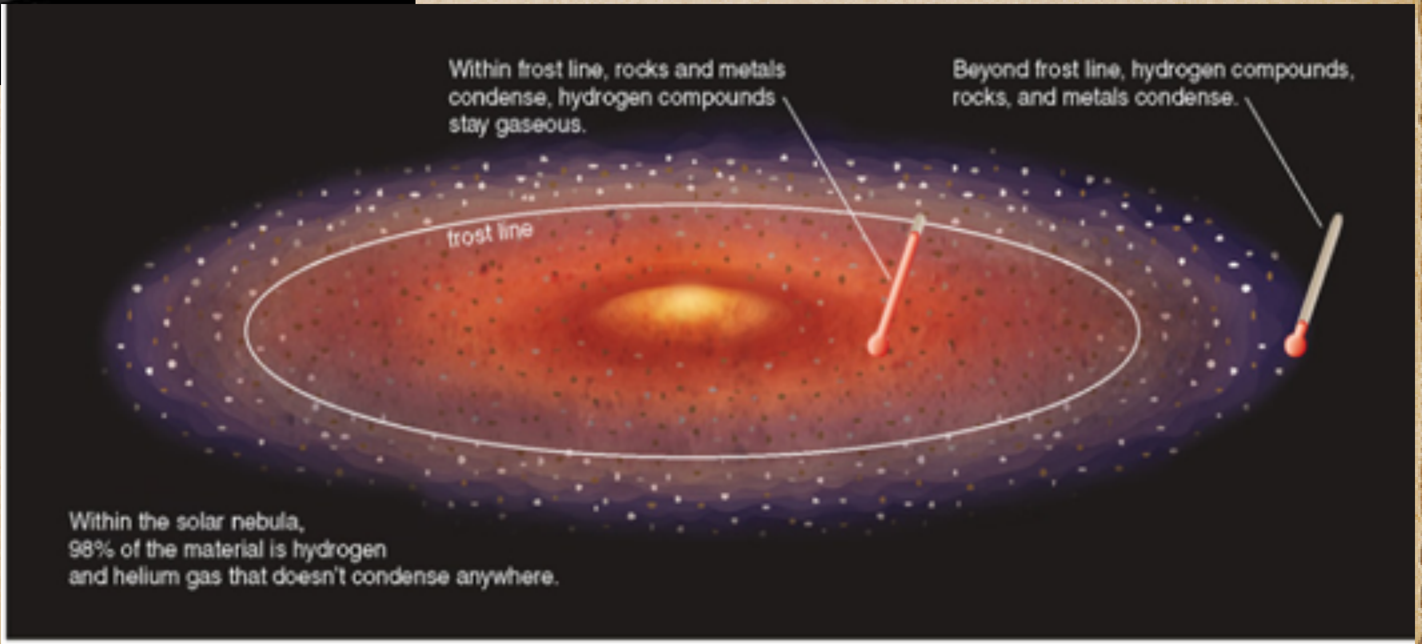
Orbits of Extrasolar Planets



- Most of the detected planets have orbits smaller than Jupiter's.
- Planets at greater distances are harder to detect with the Doppler technique.

What Are They Like?
Paradigm





THEY ARE NOT WHAT WE EXPECTED

What We Found

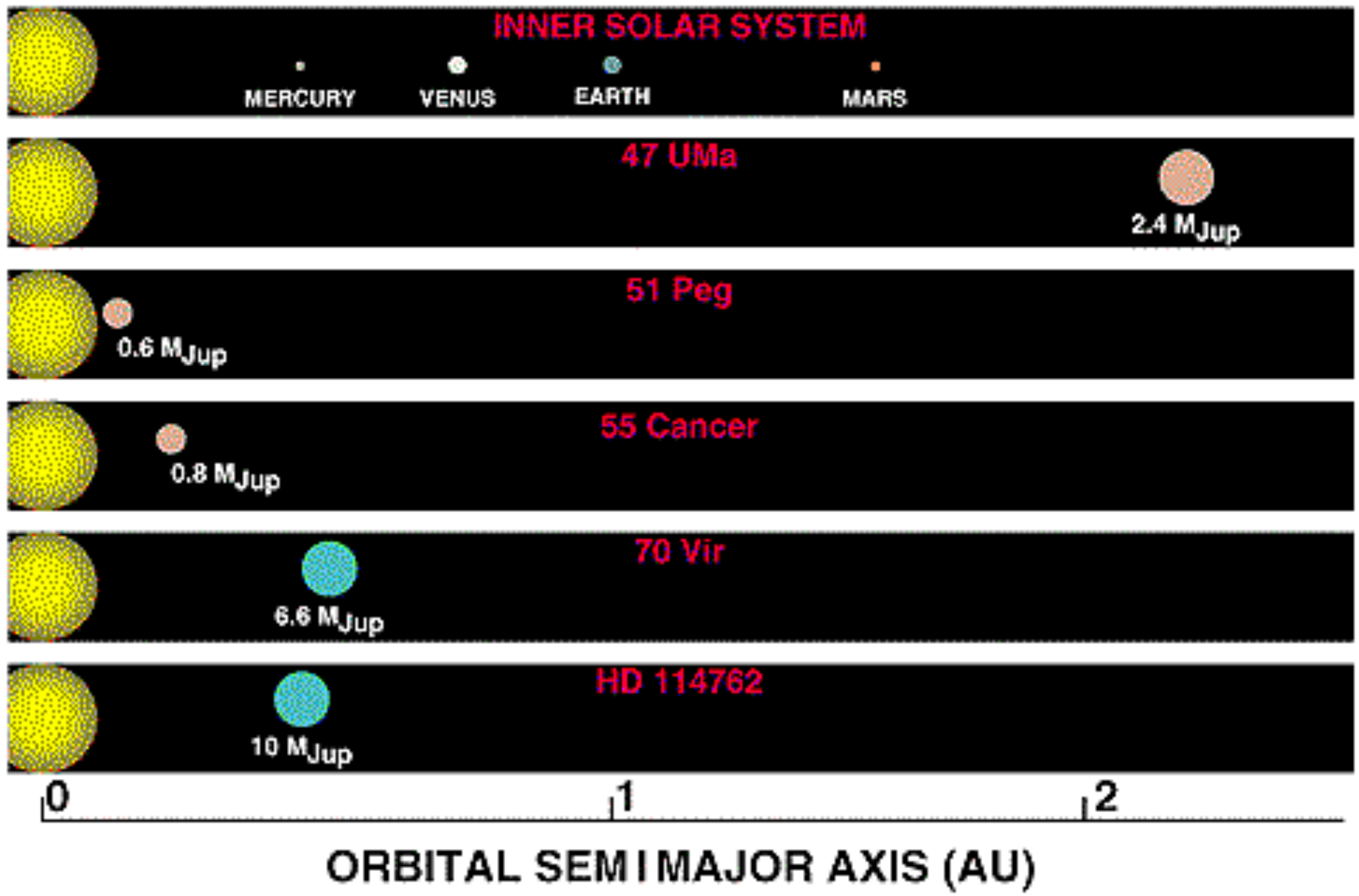
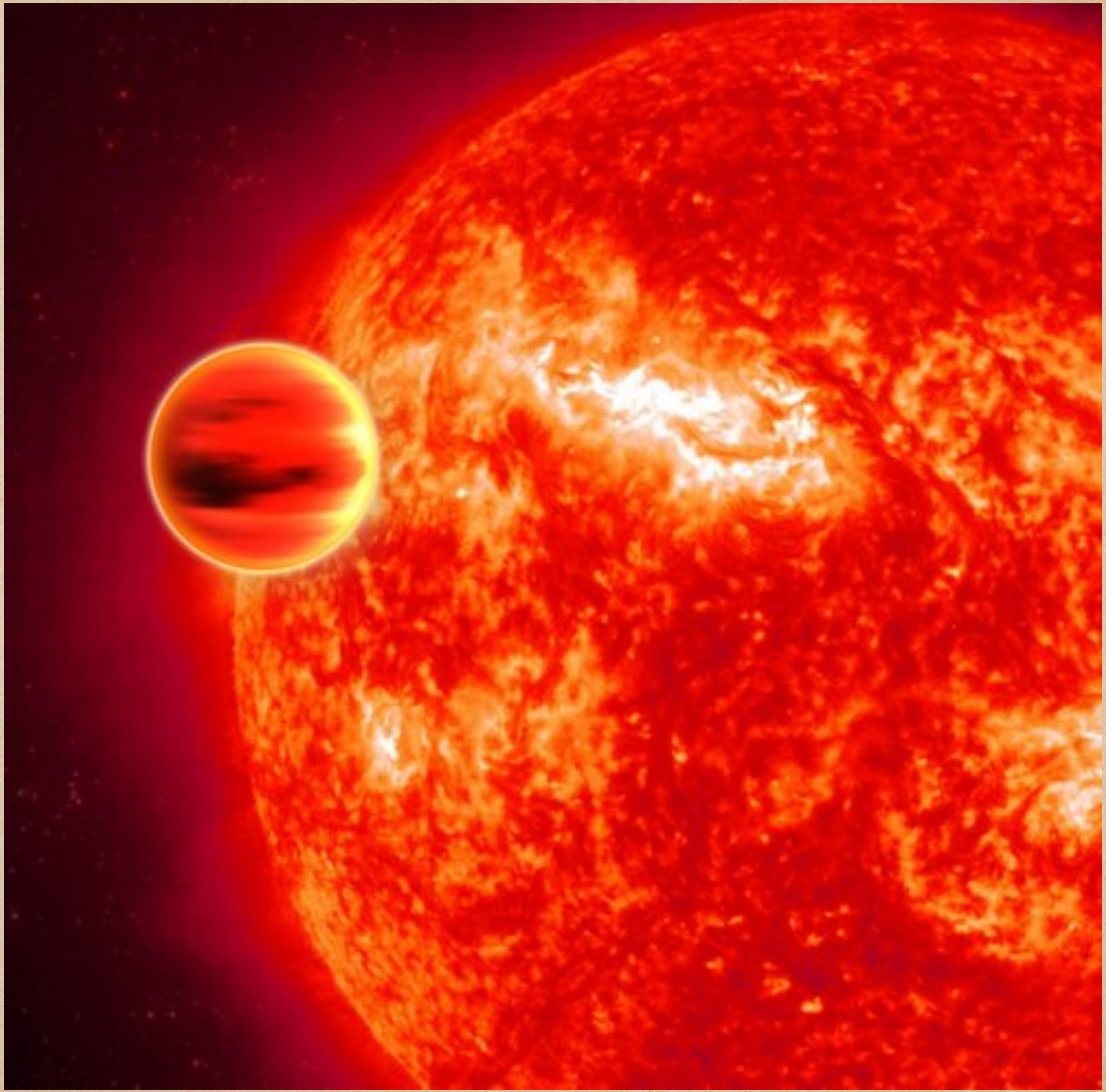


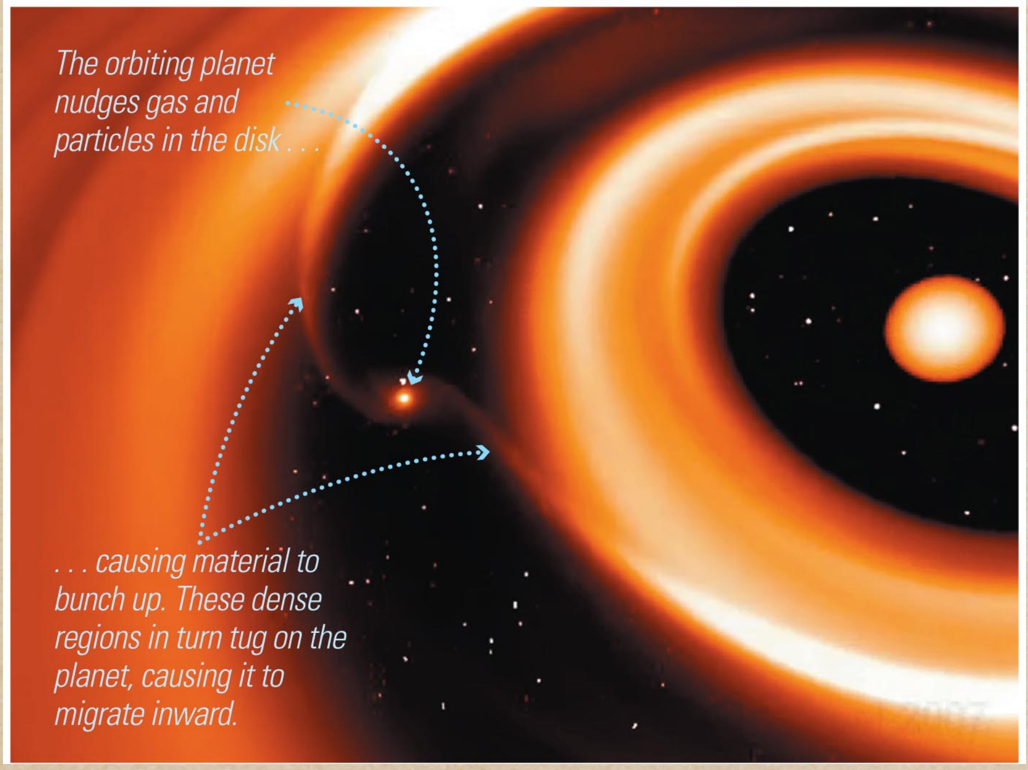
Image courtesy of Geoffrey Marcy, San Francisco State University



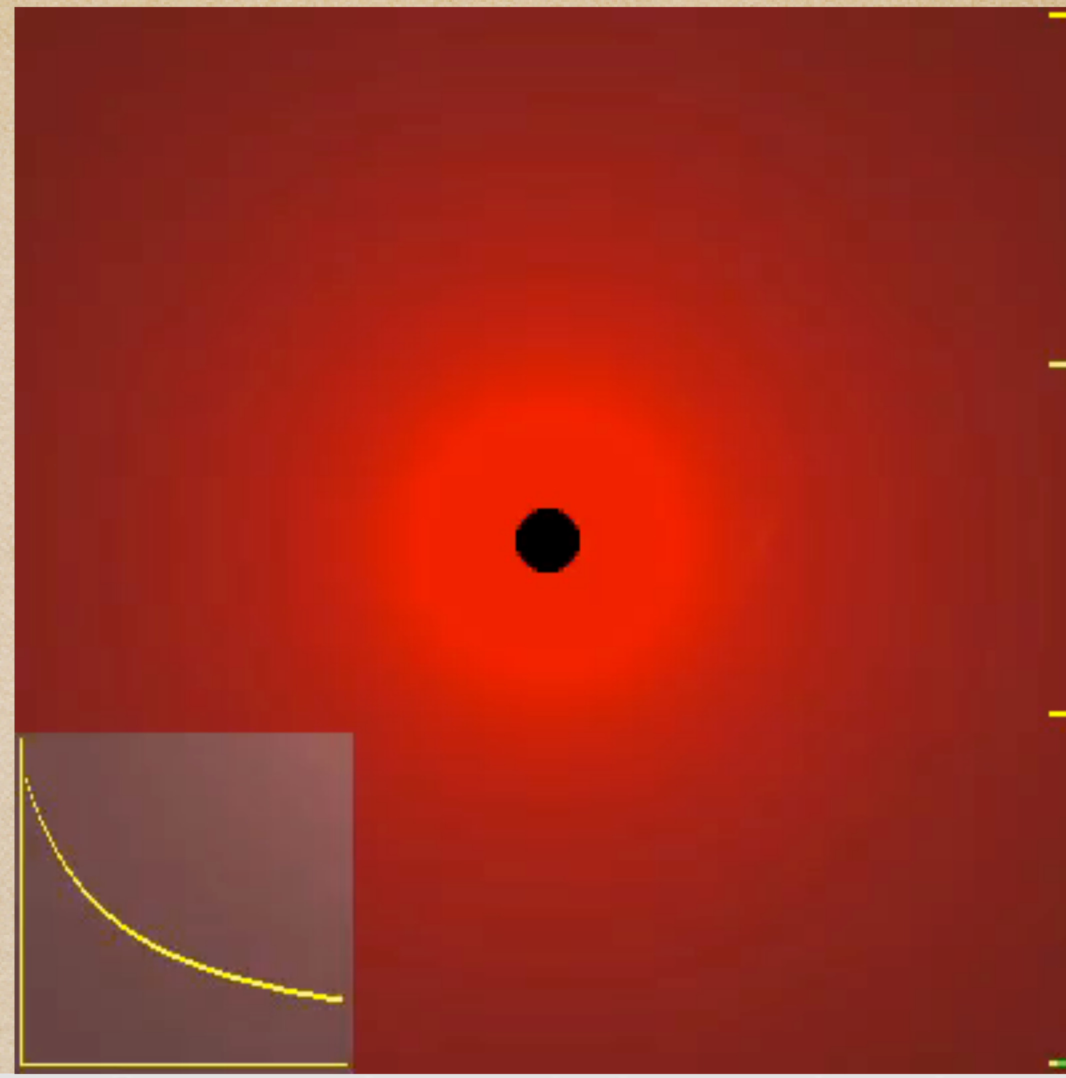
This Can't Happen With The Conventional Theory Of Planet Formation

- So We Change It
- Planets MUST move when they form
- Type 1 Migration
  - Smaller planets moved by torques from disk
- Type 2 Migration
  - Bigger planets effect disk, move inward
  - Gravitational scattering

Planetary Migration

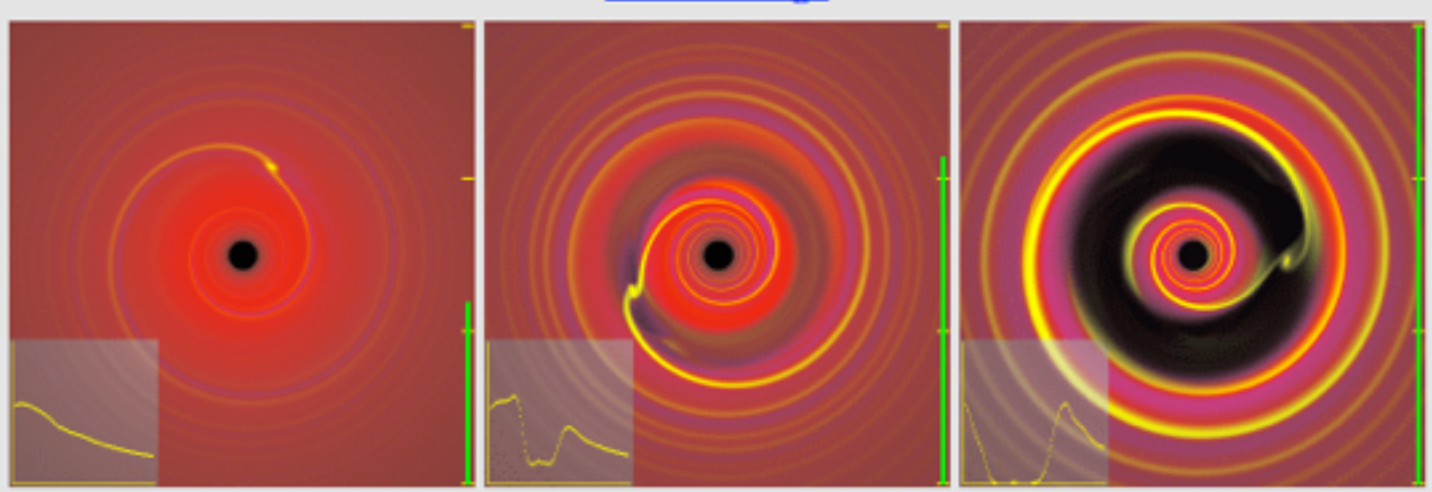


- A young planet's motion can create waves in a planet-forming disk.
- Models show that matter in these waves can tug on a planet, causing its orbit to migrate inward.



Gap opening and planet migration

[Phil Armitage]

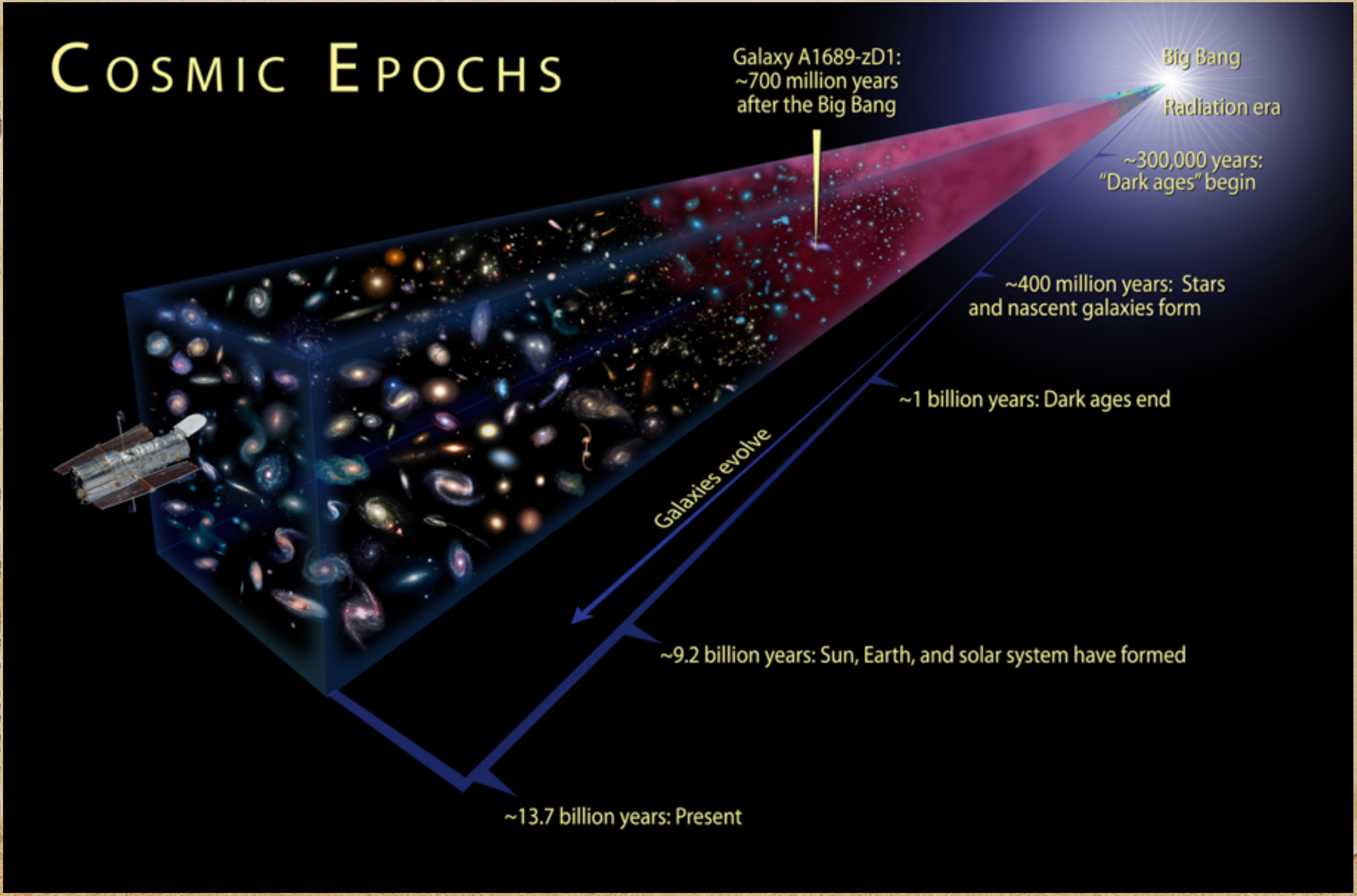


Low mass planets: Type I migration	Gap formation: Type II migration	Suppression of accretion at high planet masses

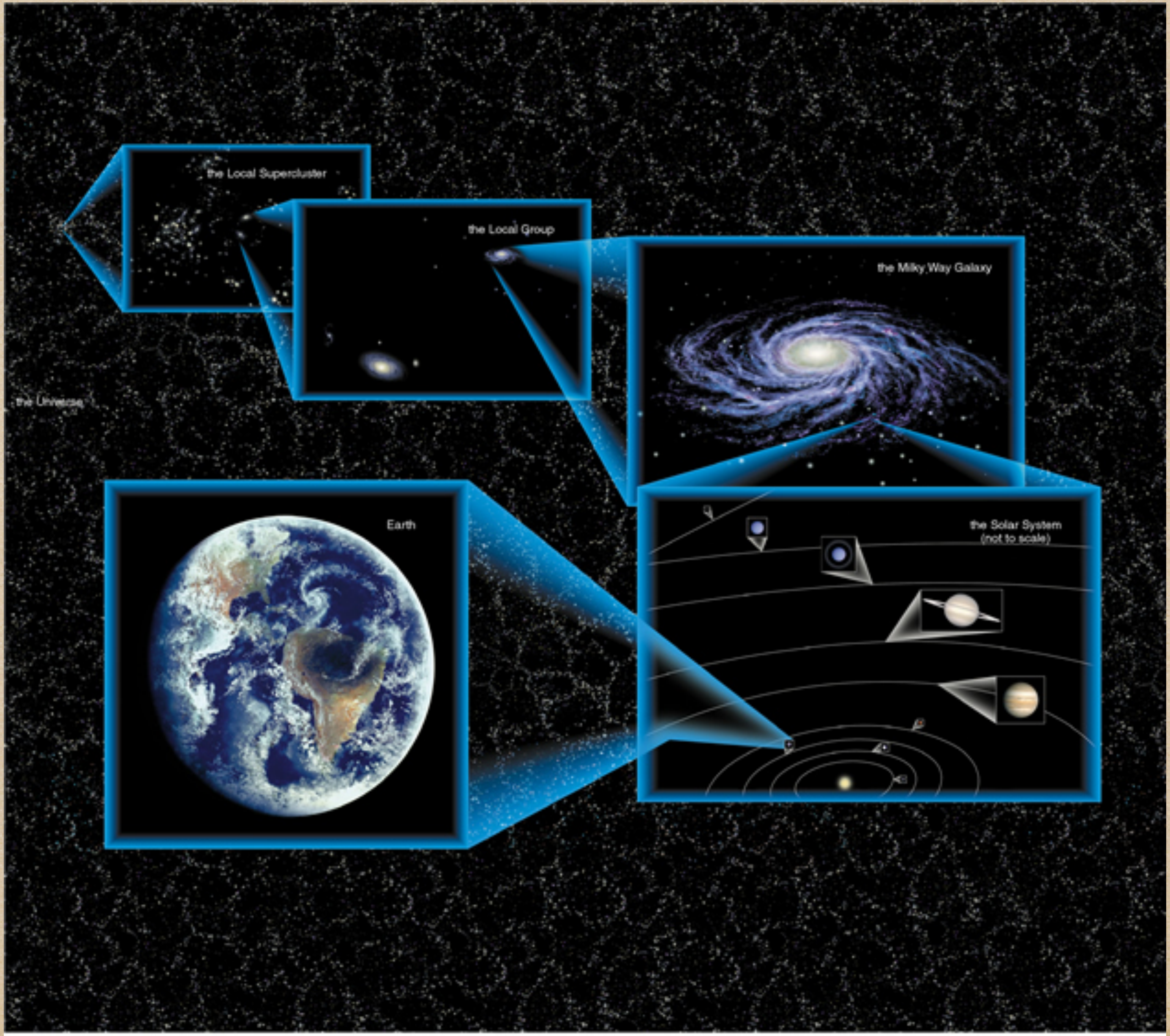
So What's The Point?

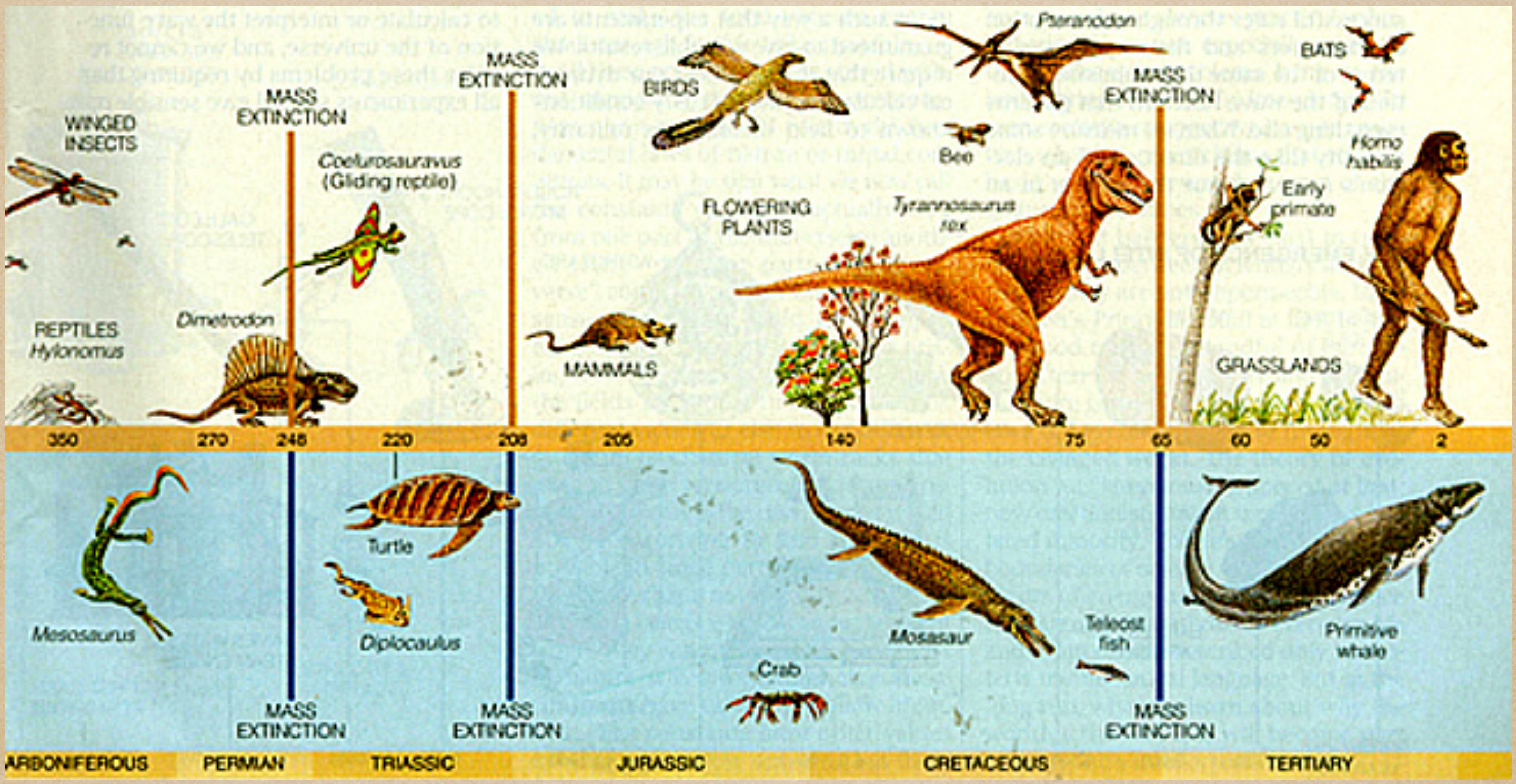
- Are We Alone?
- We aren't the center of the universe
- We aren't the center of our galaxy
- We aren't the center of our solar sytem
- We aren't even the center of the Earth
- Star formation is ubiquitous
- Planet formation is ubiquitous
- We see H2O, NH3, CH4, and complex organic molecules all through space
- There's no reason to conclude our formation is unique
- BUT, planet formation and (probably) evolutionary processes are stochastic
- BUT There are ~10^{11} stars in each of the ~ 10^{11} galaxies in the observable universe
    - That's a lot of times to roll the dice

LIFE?

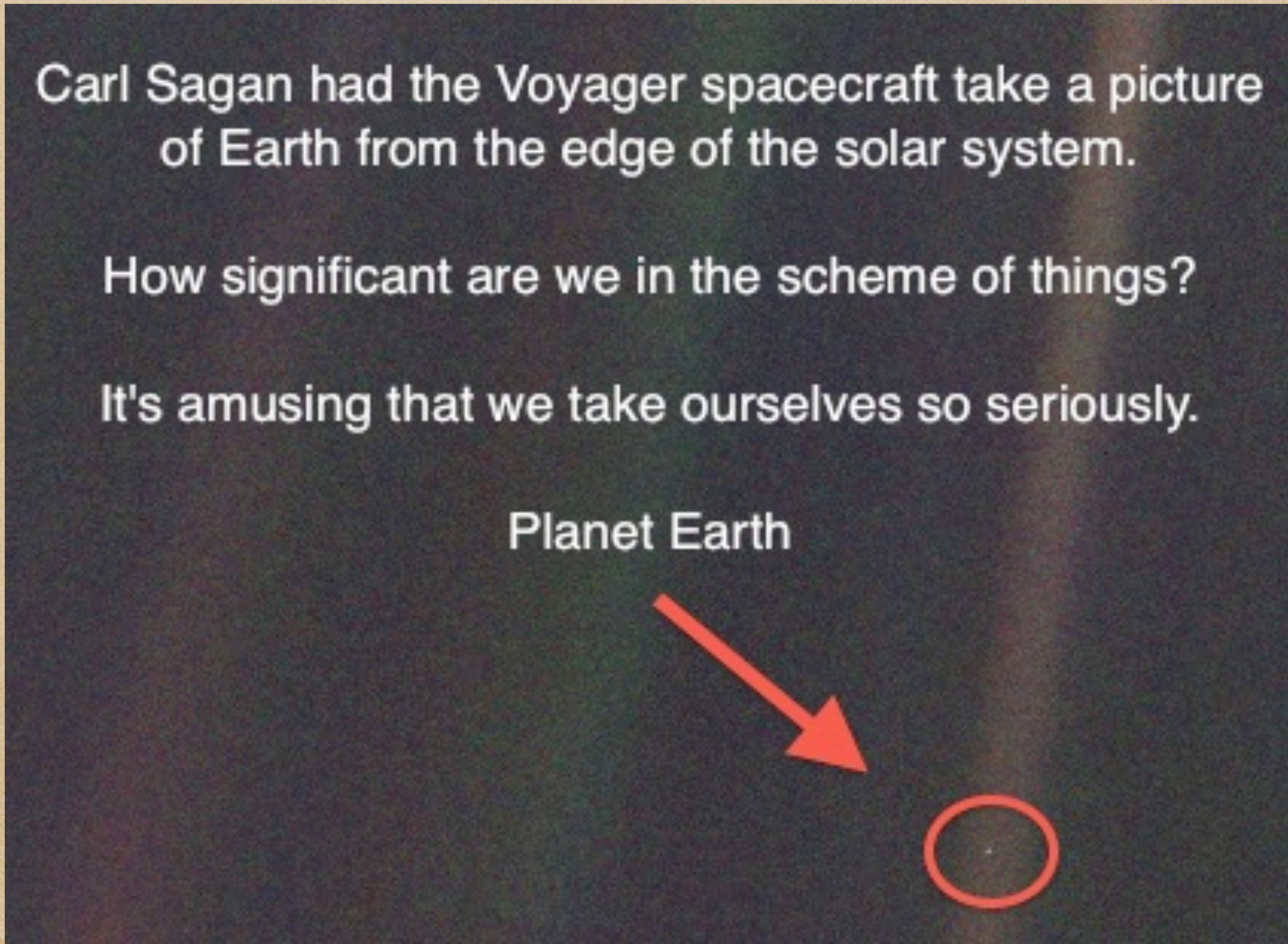


Cosmic Epochs
Galaxy A1689-zD1:
~700 million years
after the Big Bang
Big Bang
Radiation era
~300,000 years:
"Dark ages" begin
~400 million years: Stars
and nascent galaxies form
~1 billion years: Dark ages end
Galaxies evolve
~9.2 billion years: Sun, Earth, and solar system have formed
~13.7 billion years: Present

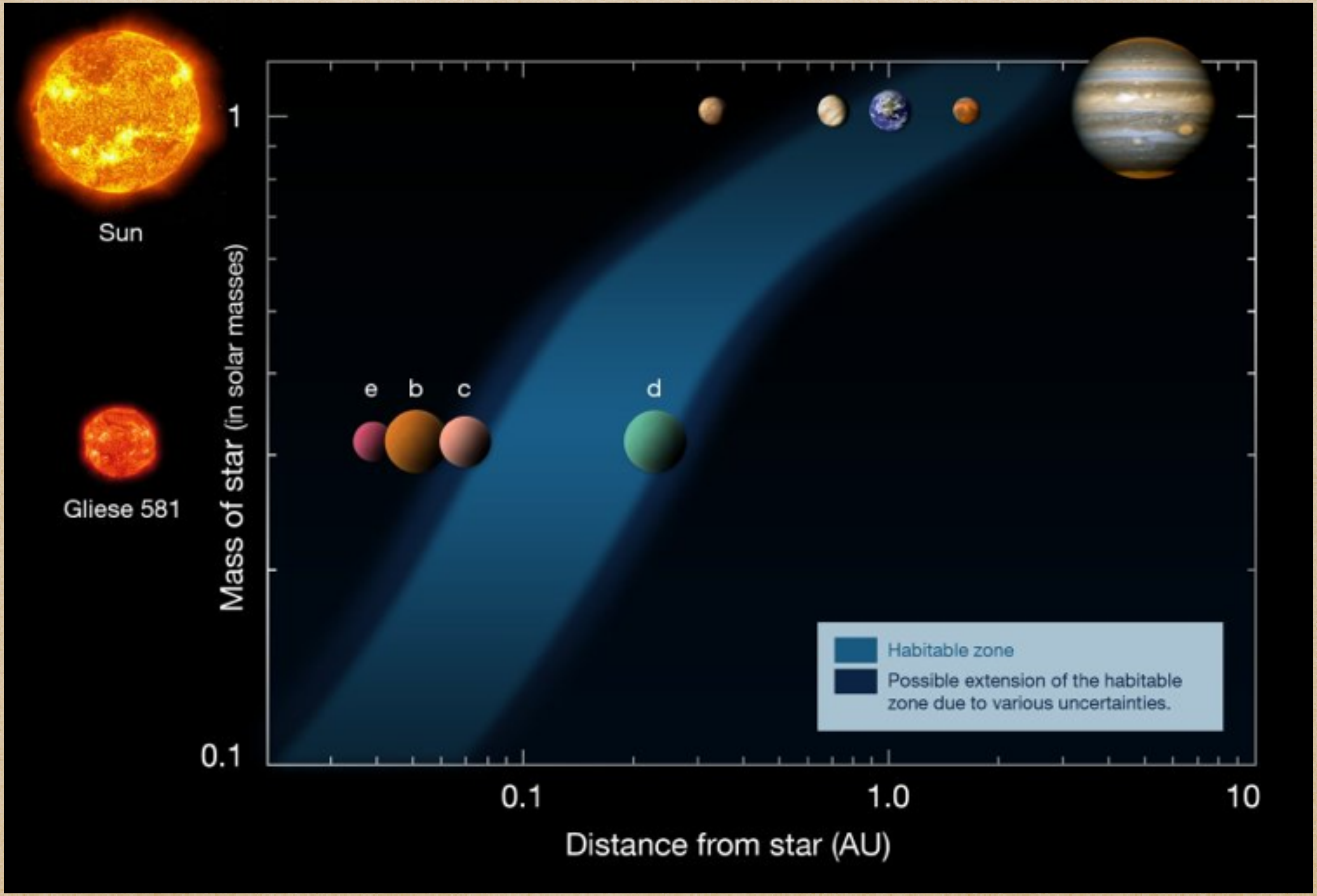

the Local Supercluster
the Local Group
the Milky Way Galaxy
the Universe
Earth
the Solar System
(not to scale)



WINGED INSECTS
MASS EXTINCTION
Coelurosauravus (Gliding reptile)
MASS EXTINCTION
BIRDS
Pteranodon
BATS
MASS EXTINCTION
Bee
Homo habilis
Early primate
FLOWERING PLANTS
Tyrannosaurus rex
REPTILES Hylonomus
Dimetrodon
MAMMALS
GRASSLANDS
350 270 248 220 208 205 140 75 65 60 50 2
Turtle
Mesosaurus
Diplocaulus
Mosasaur
Teleost fish
Primitive whale
Crab
MASS EXTINCTION
MASS EXTINCTION
MASS EXTINCTION
ARBONIFEROUS PERMIAN TRIASSIC JURASSIC CRETACEOUS TERTIARY


Carl Sagan had the Voyager spacecraft take a picture of Earth from the edge of the solar system.
How significant are we in the scheme of things?
It's amusing that we take ourselves so seriously.
Planet Earth

TheHoly Grail - Habitable Planets



Habitability

- We mean habitable by US!!!
- Suitable Star
  - F,G,M stars
    - Long Lives
    - Long Term Stability
    - High Metallicity
    - Energy to Warm The Planet
- Planet Characteristics
  - Rocky (water?)
  - Massive but not too massive
  - Low eccentricity
  - Slower rotation
  - Suitable Atmosphere
  - Small Axial wobble

Maybe we also need a moon and a Jupiter

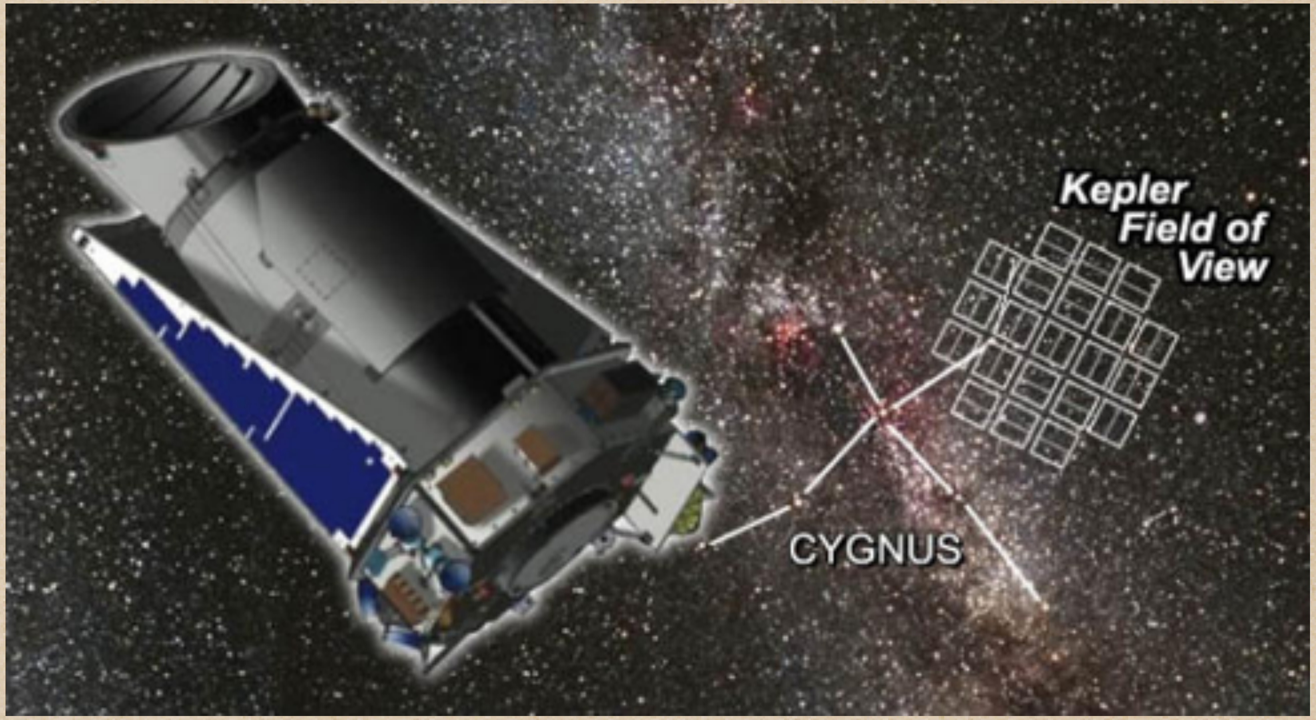
Lets Define Life

- Life is a self replicating chemical system capable of evolving such that its offspring might be better suited for survival

Ingredients for Life

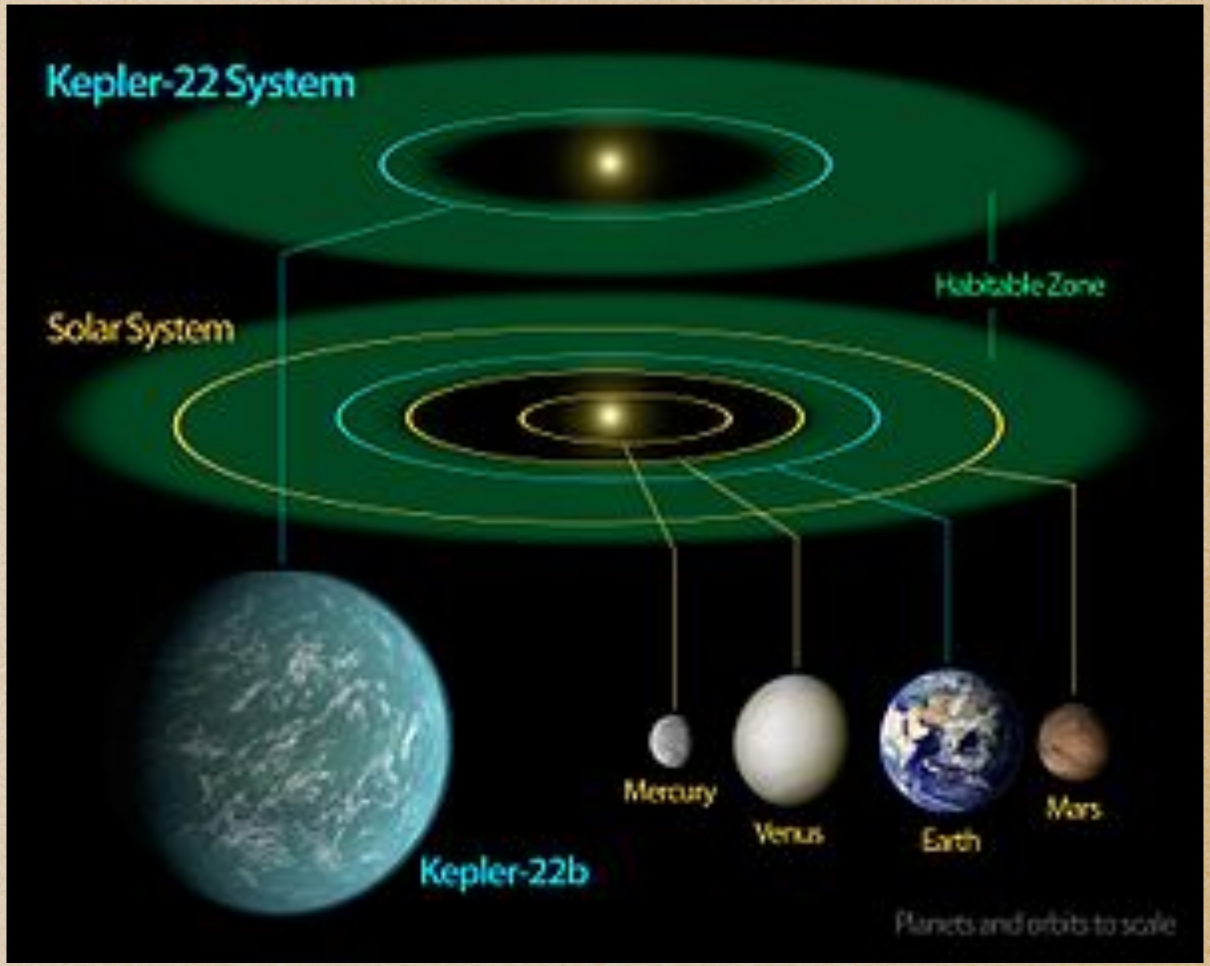
- Life Requires Chemistry
  - Bonding elements only no noble elements
  - Strong Bonds
    - Carbon, 4th most abundant element
    - Silicon too weak, no complex silicon chains
  - Solvent
    - high liquid range in temperature
    - High heat capacity
    - High dielectric constant
    - High molar density
      - Water!!!!
        - Floats when ice
      - Second - Hydrogen Flouride 1/100,000th as abundant as oxygen

Enter Kepler - kepler.nasa.gov

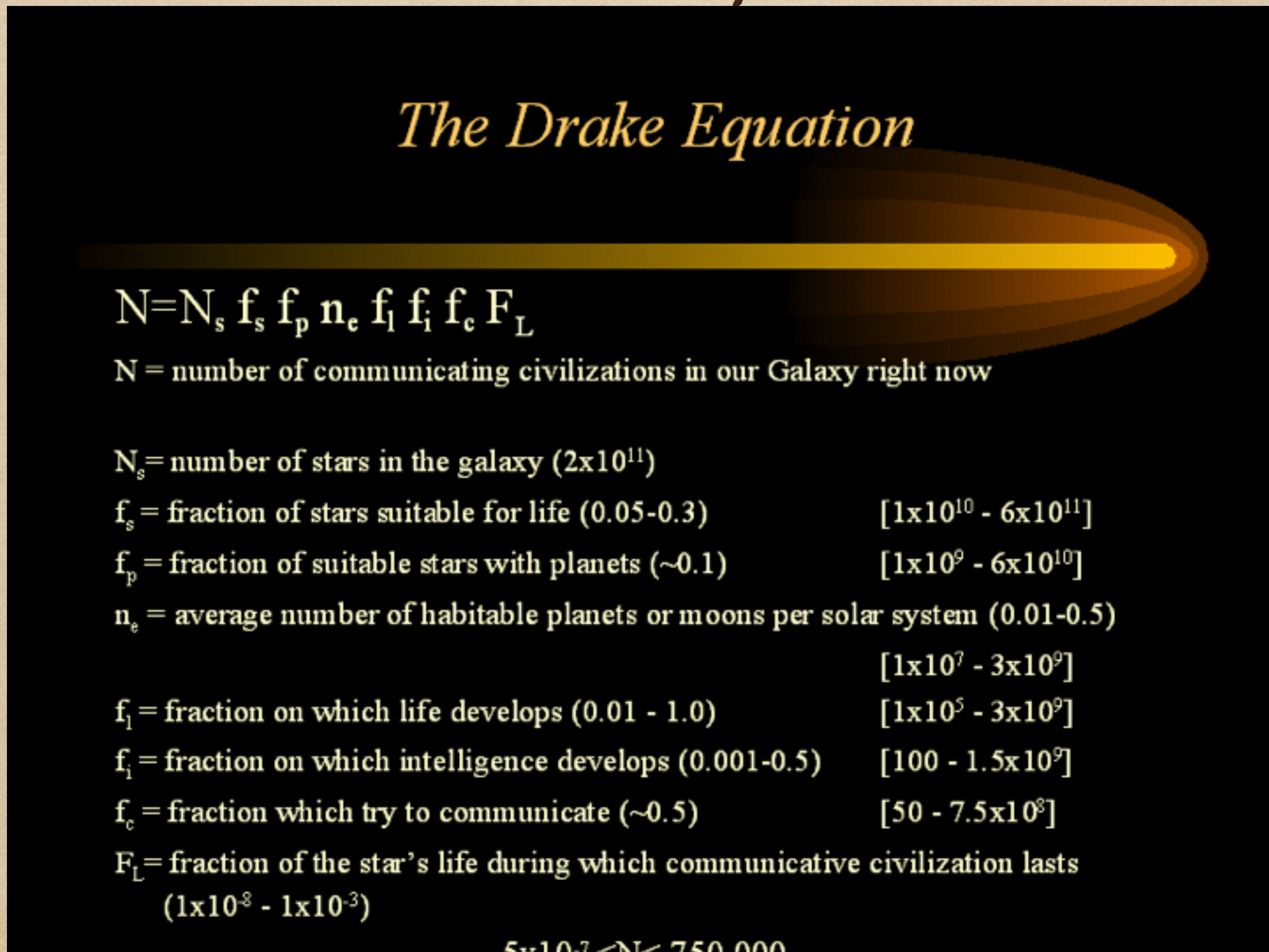


Kepler 22-B

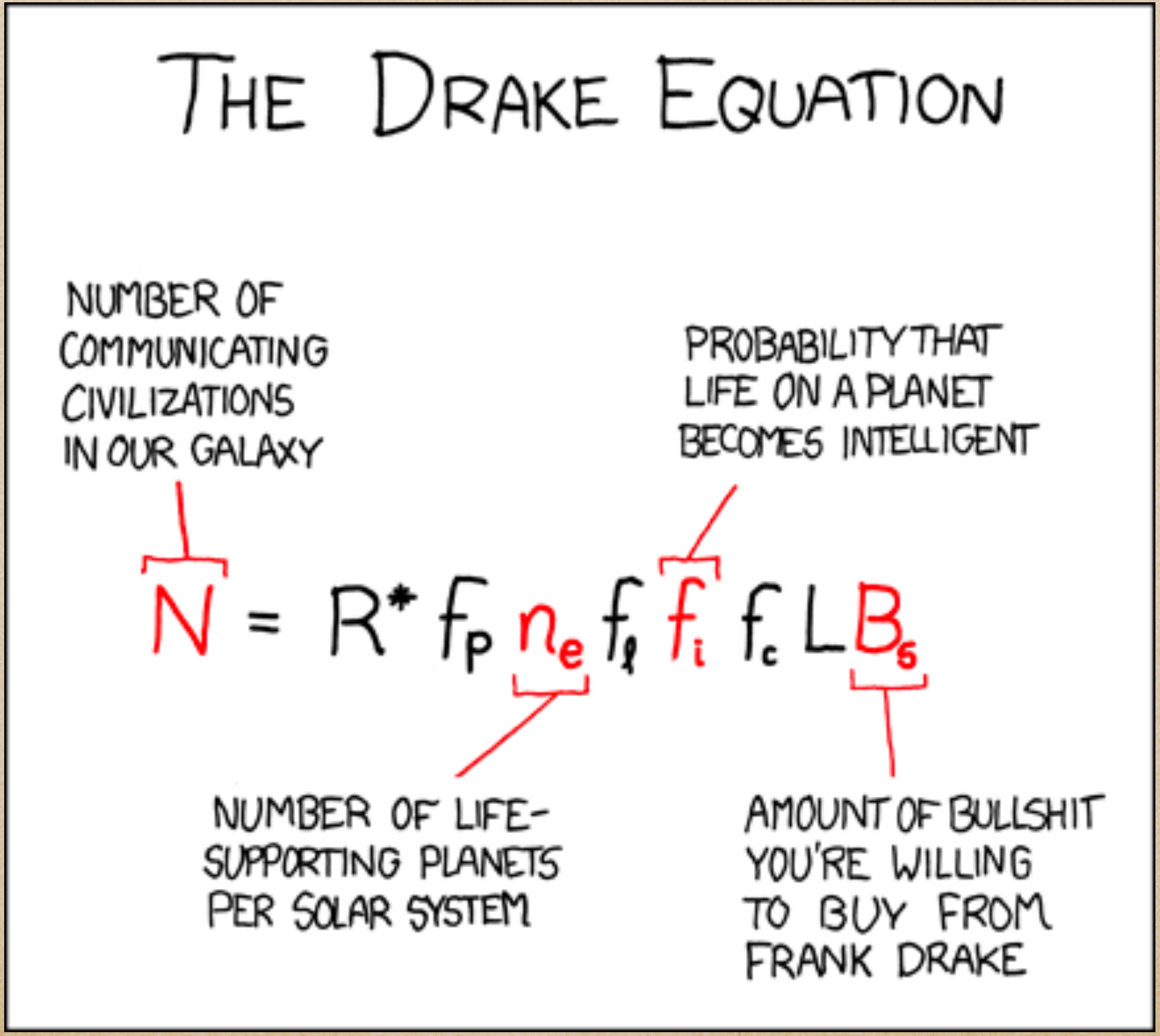
- Kepler.nasa.gov
- We may have found one
- Kepler 22-B
    - 2.5 x Earth Radius
    - 10-35 Earth Mass
    - Surface Temperature ~ 72F
    - Surface Gravity ~ 2-7 x Earth's
    - Either ice planet or watery Earth



How Likely Is Life?



My Version Of The Drake Equation



We See Evidence For Atmospheres On Exoplanets

So lets go see if we can see evidence for life

SO WHERE ARE WE?

We see

- Winds
- Carbon Dioxide
- Hot Spots
- More To Come

We want to see

Biosignatures In Spectra

- Water
- OZONE!!!!

But this is very hard, you are subtracting spectra during secondary eclipses looking for evidence of molecular absorption

We Aren't Where We Can See The Atmospheres On Other Earths

- But we didn't know other planets existed 20 years ago
- Now we are finding several a month!!!
- We are characterizing the numbers of planets as we speak
  - We are getting statistics for habitable planets in the Milky Way
- While we aren't there yet I firmly believe we will be in your lifetime

Unfortunately Kepler is dead and so is a purely exoplanetary atmospheric satellite mission

What's on the horizon?

Future Missions

- Tess - Transiting Exoplanetary Survey Satellite (NASA)
  - 2017
  - 400 times sky coverage of Kepler
  - Transit survey
- CHEOPS - (CHaracterising ExOPlanets Satellite) (ESA)
  - 2017 (University of Bern)
- PLATO - Planetary Transits and Oscillations of stars (ESA)
  - 2024
  - Looking at 1 million stars

Keep your eyes peeled

- We're characterizing the statistics of exoplanets and potentially habitable planets
- We're taking rudimentary atmospheric spectra
- We're putting looking for ET on firm scientific footing

Thanks for your time