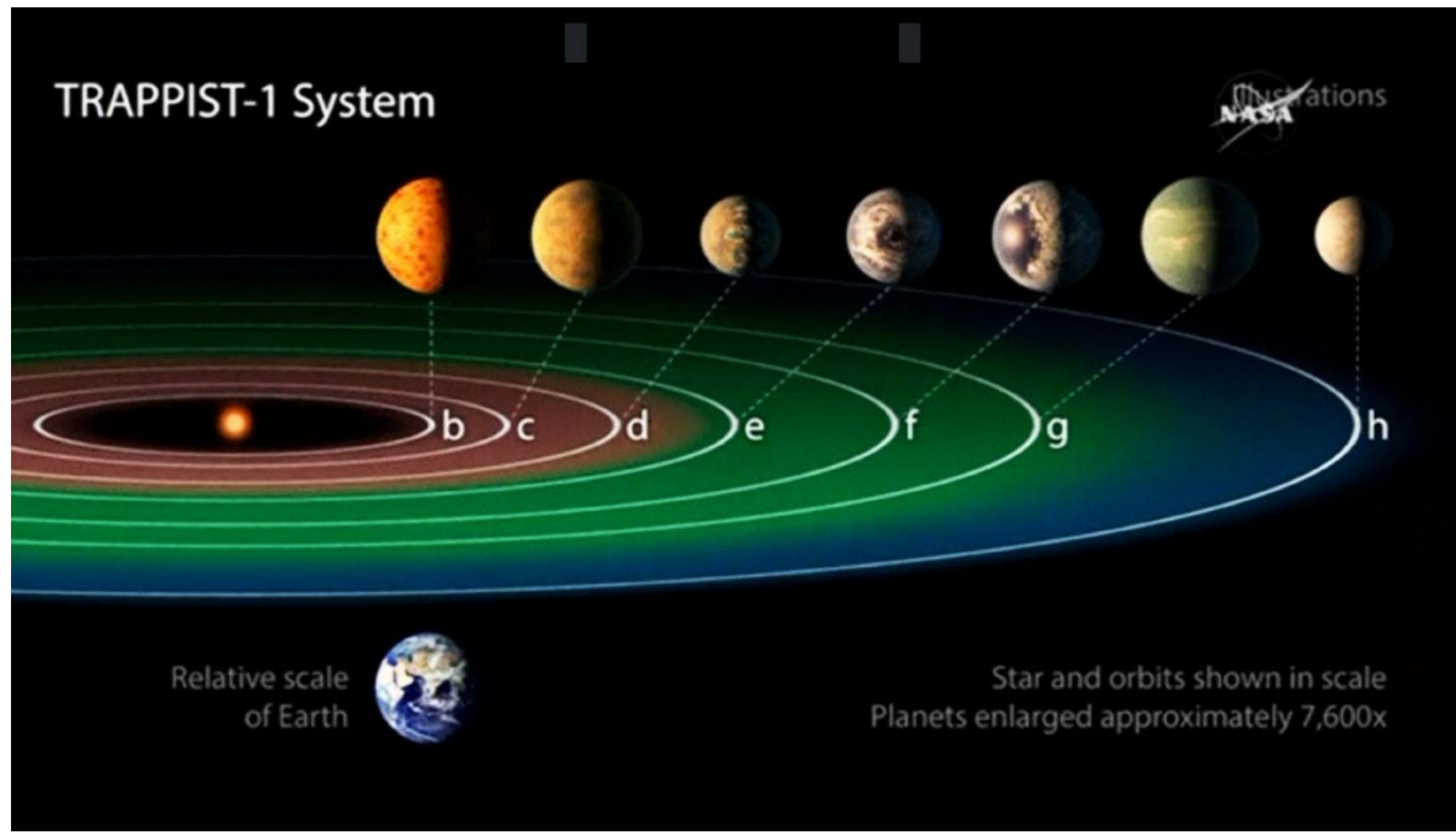
AST 296LB

Astronomy with Python

Exoplanets! (Also, a little about the Solar System)



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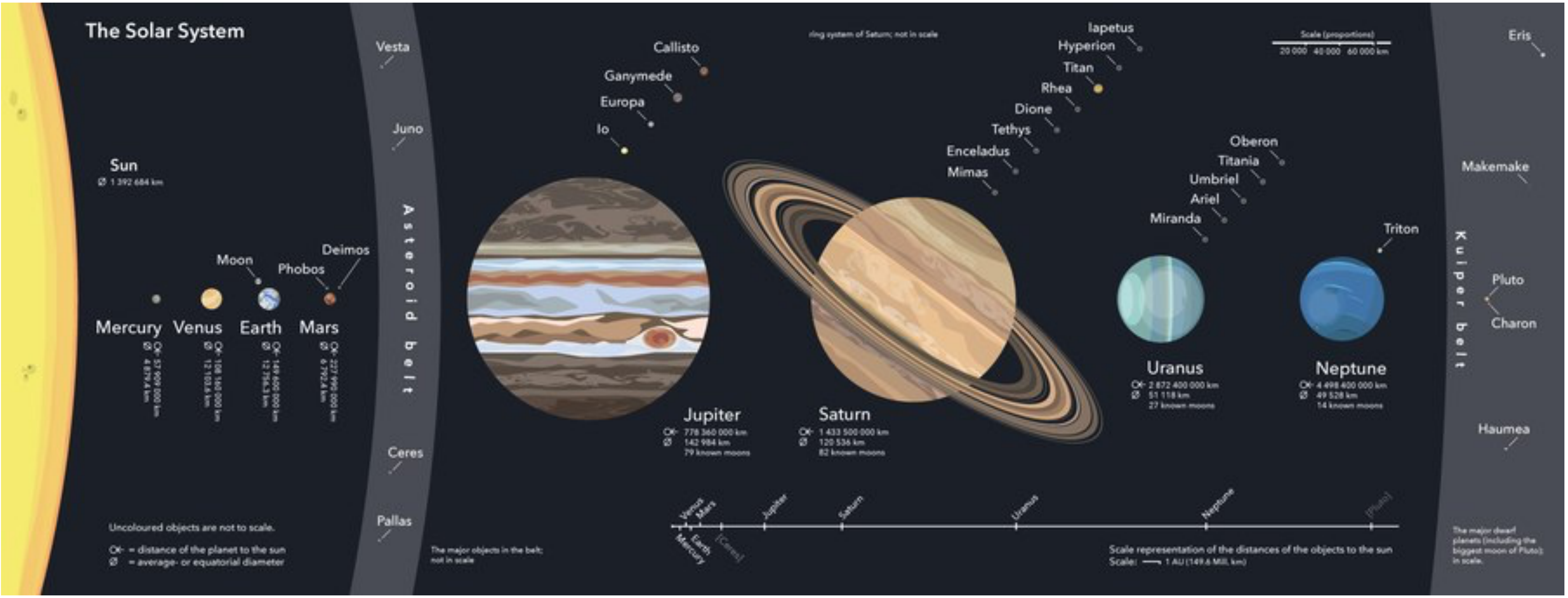
Our Solar System (in one or two slides)



High level

The Sun contains 99.8% of the mass in the solar system.
Most remaining mass is confined to a flattened disk.
All planets revolve in the same direction; most rotate in the same direction.
All objects seem to have a similar age of 4.6 billion years.

Two types of planets: Terrestrial and Jovian

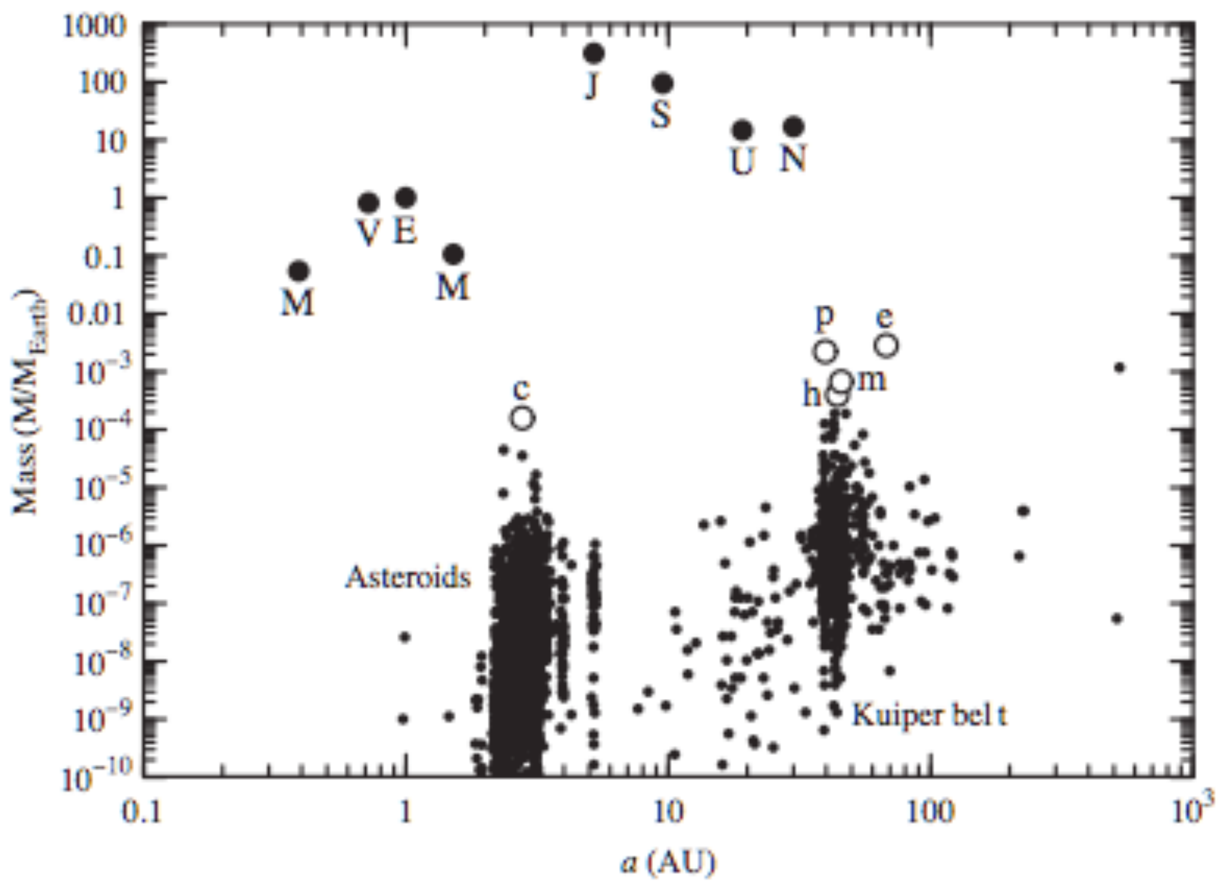
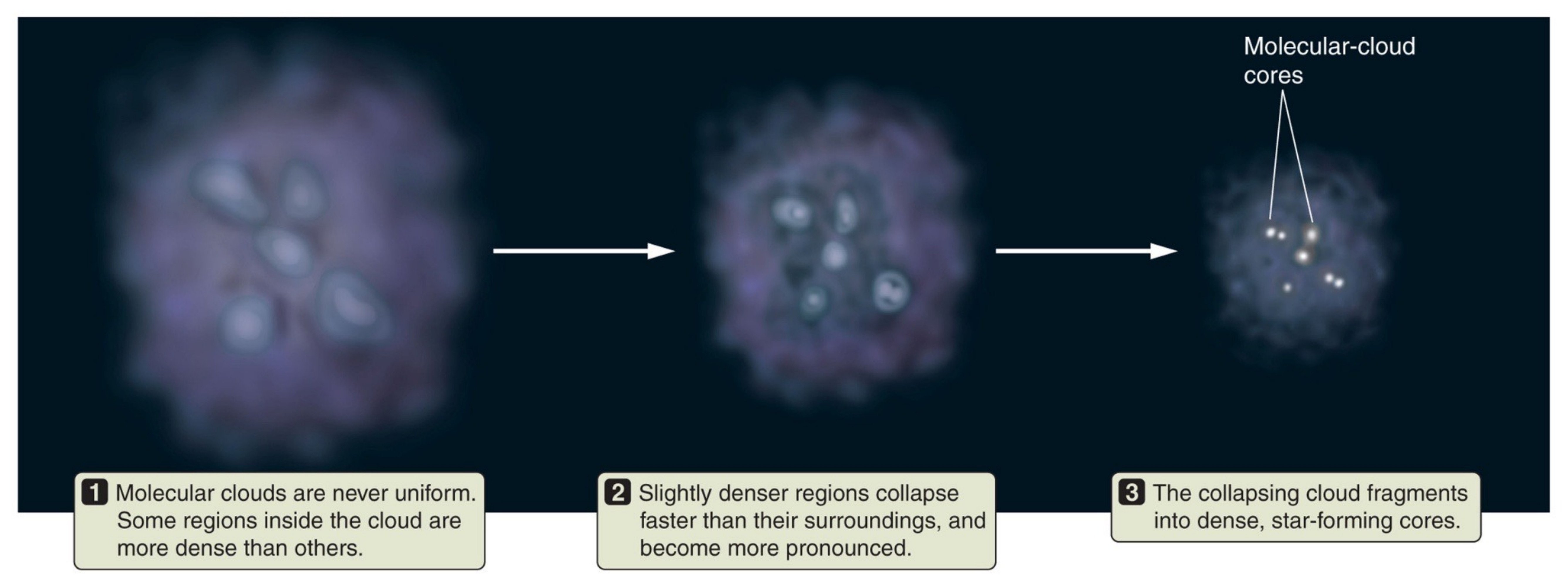


TABLE 8.1 Characteristics of Planetary Types

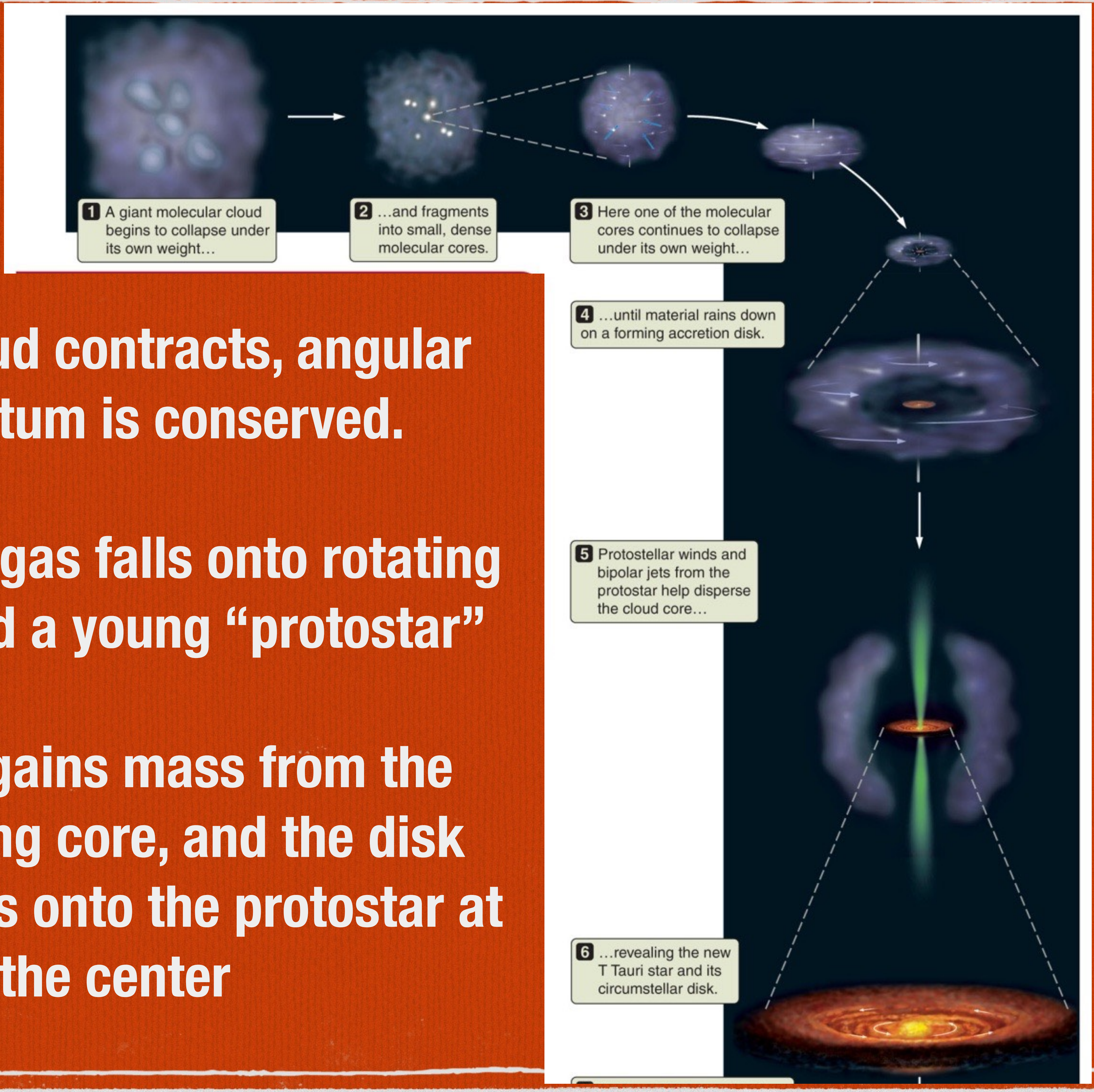
Characteristic	Terrestrial	Jovian
Mass	Low ($\leq 1\ M_\oplus$)	High ($> 10\ M_\oplus$)
Composition	Rocky/metallic ($\rho \gtrsim 3000$ kg m^{-3})	Gaseous/icy ($\rho \lesssim 2000$ kg m^{-3})
Rotation	Slow ($P \geq 24$ hr)	Fast ($P < 18$ hr)
Satellites	Few	Many
Distance from Sun	$a < 2$ AU	$a > 5$ AU

What explains the difference?

Star/Solar System formation



Core Collapse



As the cloud contracts, angular momentum is conserved.

Most of the gas falls onto rotating disk around a young "protostar"

The disk gains mass from the surrounding core, and the disk dumps mass onto the protostar at the center

Condensation

Gas disk from which planets form is hotter towards the center and cooler outside.

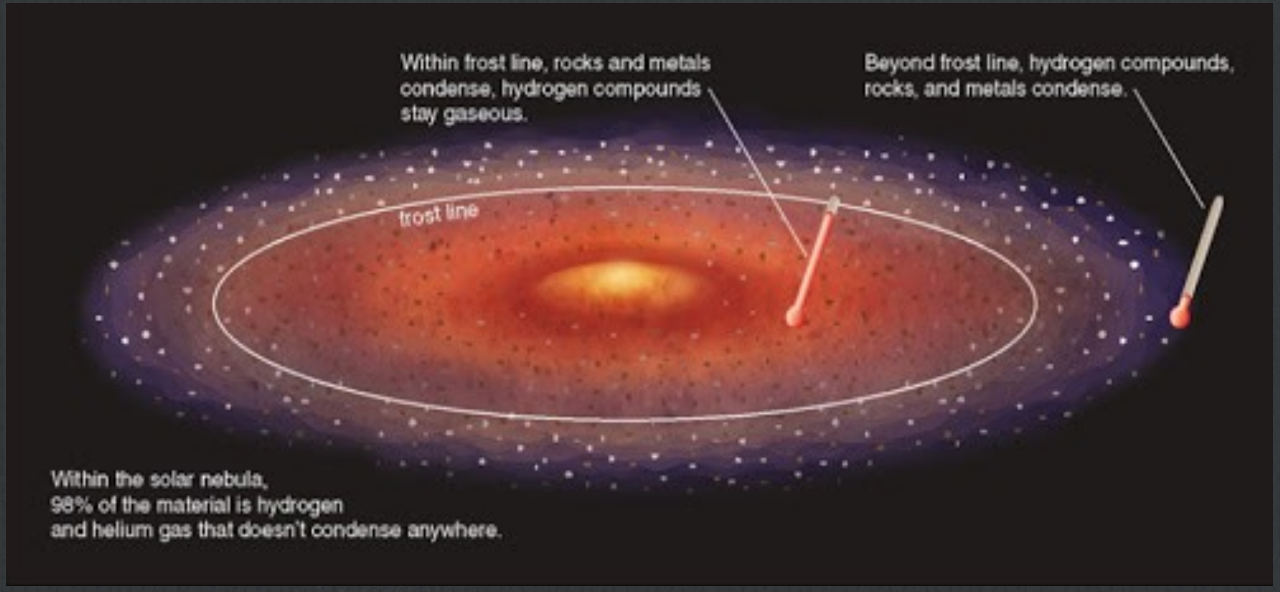
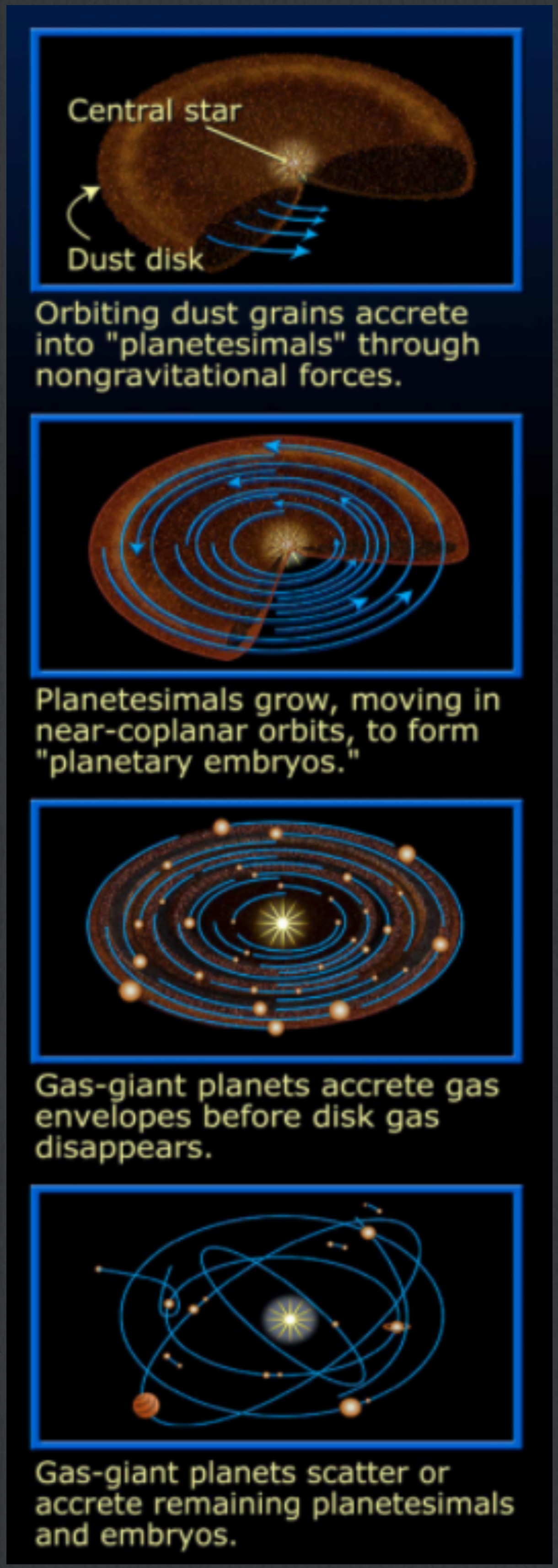


TABLE 8.4 Simplified Condensation Sequence

T (K)	Condensate	Planet
1500	Metal oxides	Mercury
1300	Fe, Ni	
1200	Silicates	
700	FeS (iron sulfide)	Venus
200	H_2O	Earth, Mars
150	NH_3	Jovian planets
120	CH_4	Pluto, Eris
65	Ar, Ne	



Very Schematic

Accretion of solid condensates

Planetesimals (~1+ km)

Planetesimals drawn together gravitationally - ‘coalescence’

Metal-rich, rocky materials coalesce near Sun; Rocky+Icy far from Sun

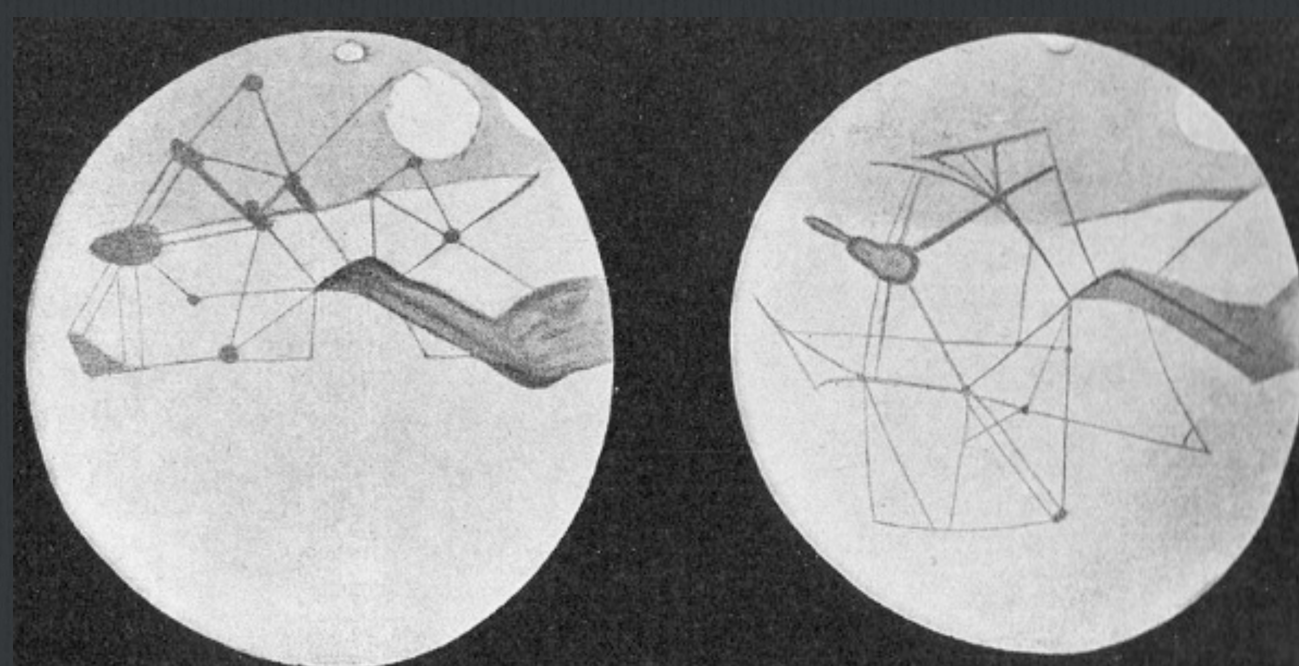
Outer planets, once >15 MEarth can retain H and He and groooowwww

Arizona History

Percival Lowell:
Two famous ideas

1. The Martian surface is covered with canals. Not true

This was debunked by the first Martian Orbiter in 1965



Arizona History

The original Clark Telescope in Flagstaff, AZ

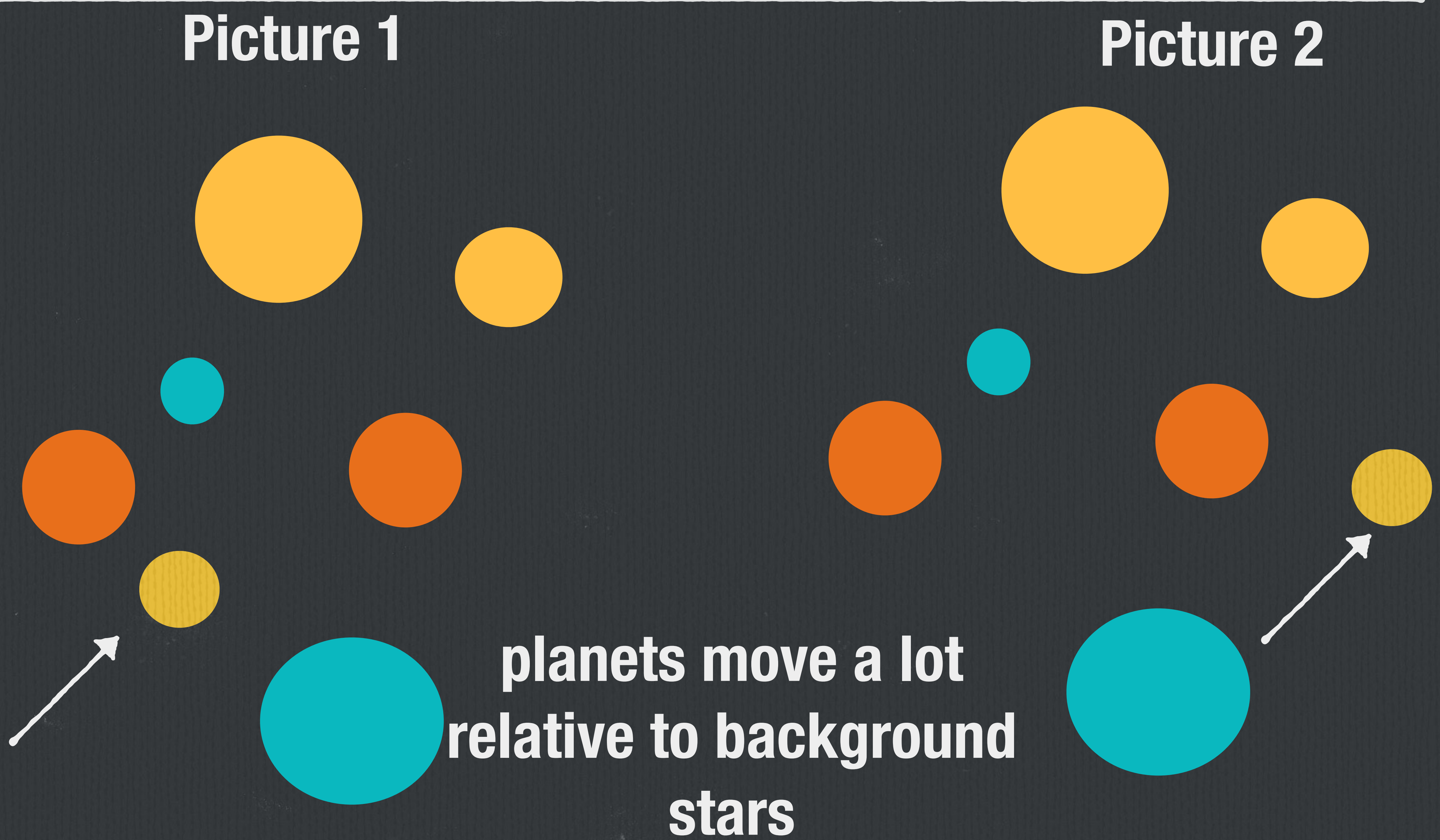
2. Planet X exists, pulling on Neptune like Neptune pulls on Uranus. True! sort of

Arizona History

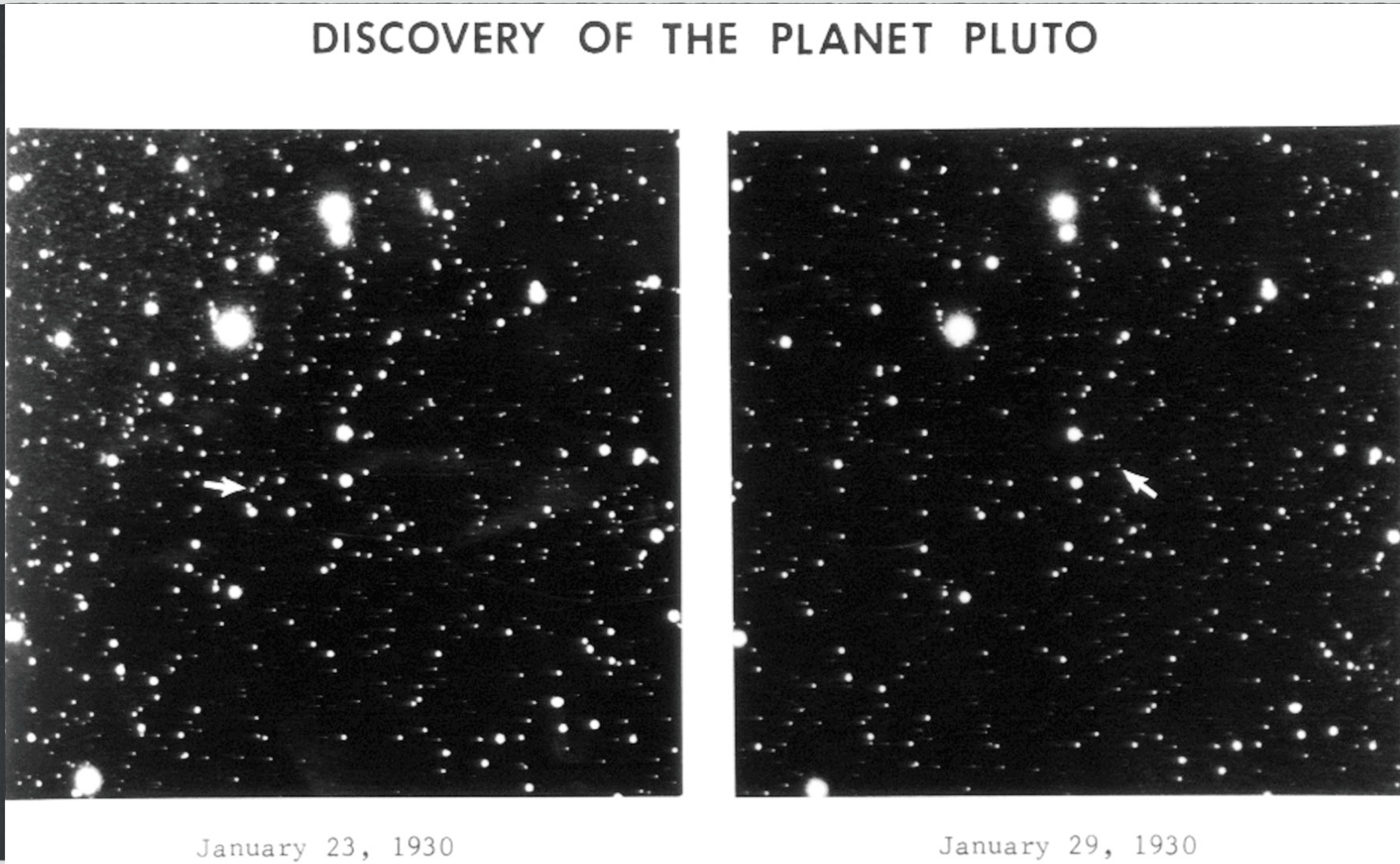
Lowell never found Pluto, but he left money in his will for someone to continue the search: Clyde Tombaugh was hired (w/o a degree) to scan the sky for another planet

How? Taking images night after night, looking for something that moved relative to the other stars

Finding planets (and asteroids)

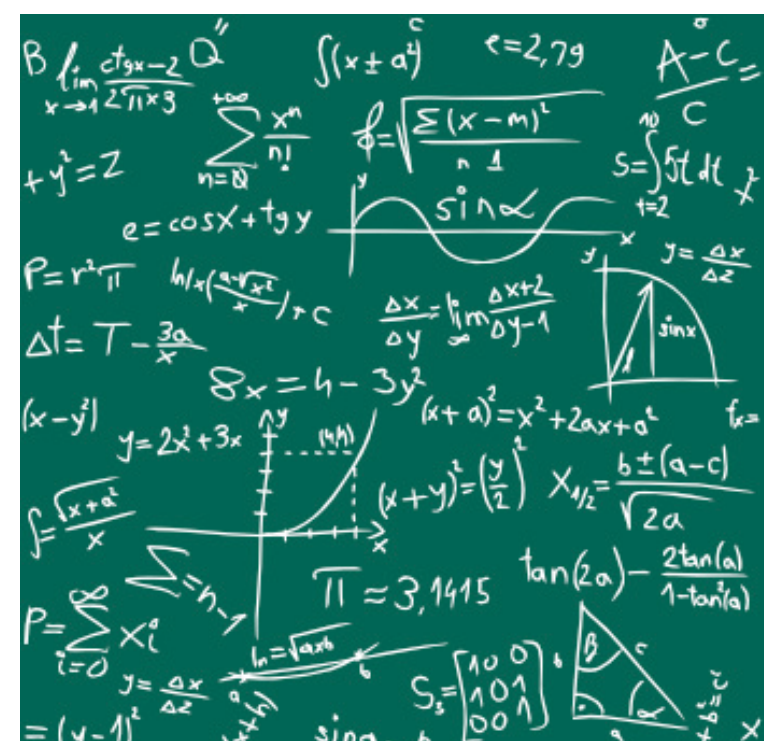


The discovery of Pluto: Arizona History



Planet Detection Methods

- Mercury-Saturn (Babylonians?)
- Uranus (Herschel) **1781**
- Neptune (Adams, Galle, Le Verrier*) **1840s**
- Minor Planets (Tombaugh, Brown, et al)



Exoplanet Detection Techniques

- **Direct Detection — Kind of obvious, but very difficult.**
- **Radial velocity Technique — Use the doppler shift to measure slight 'wobbles' in a star's motion.**
- **Transit — Literally see a mini-eclipse as the planet passes between us and the star.**

Venus is bright in the evening/morning sky when Earth blocks the Sun's light

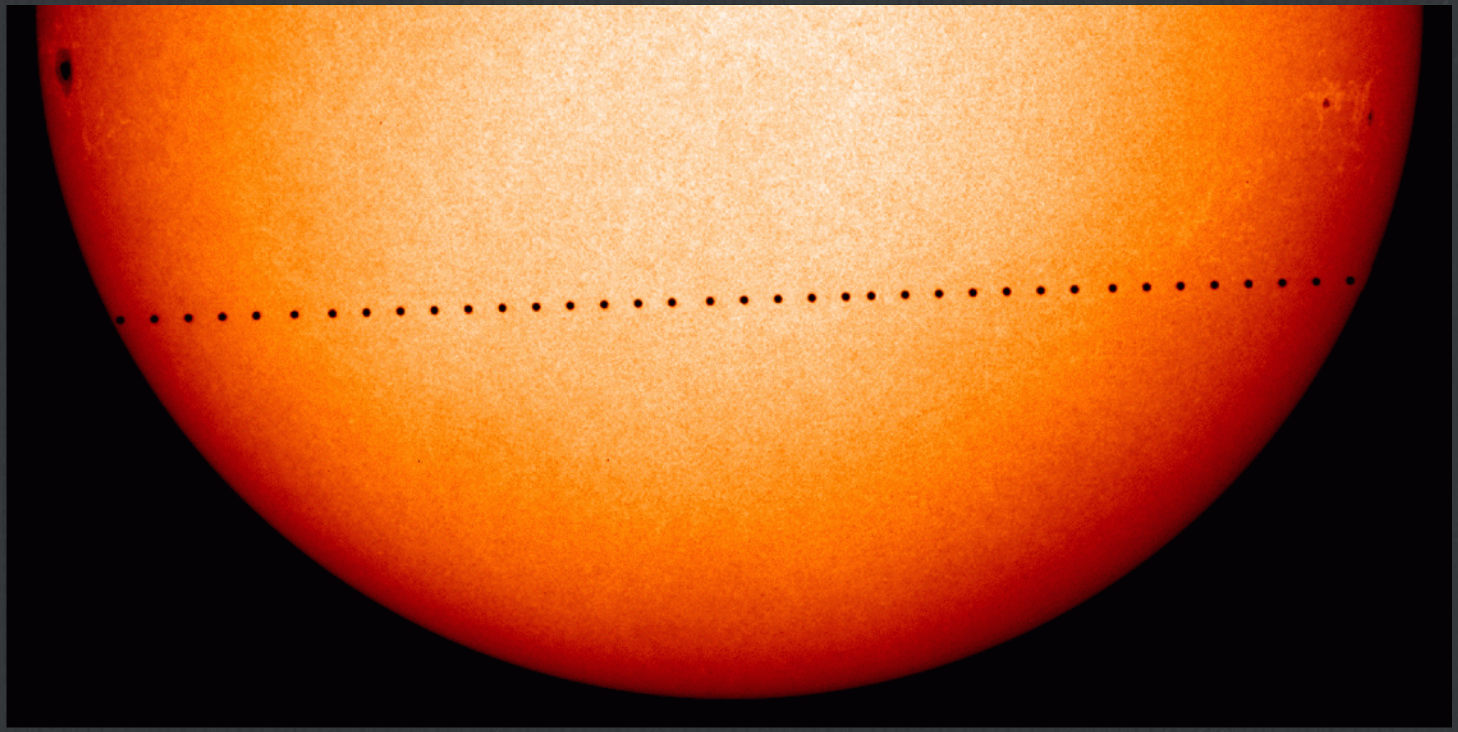
From outside the Solar System, Venus's brightness competes with glare from Sun – one billion times brighter!

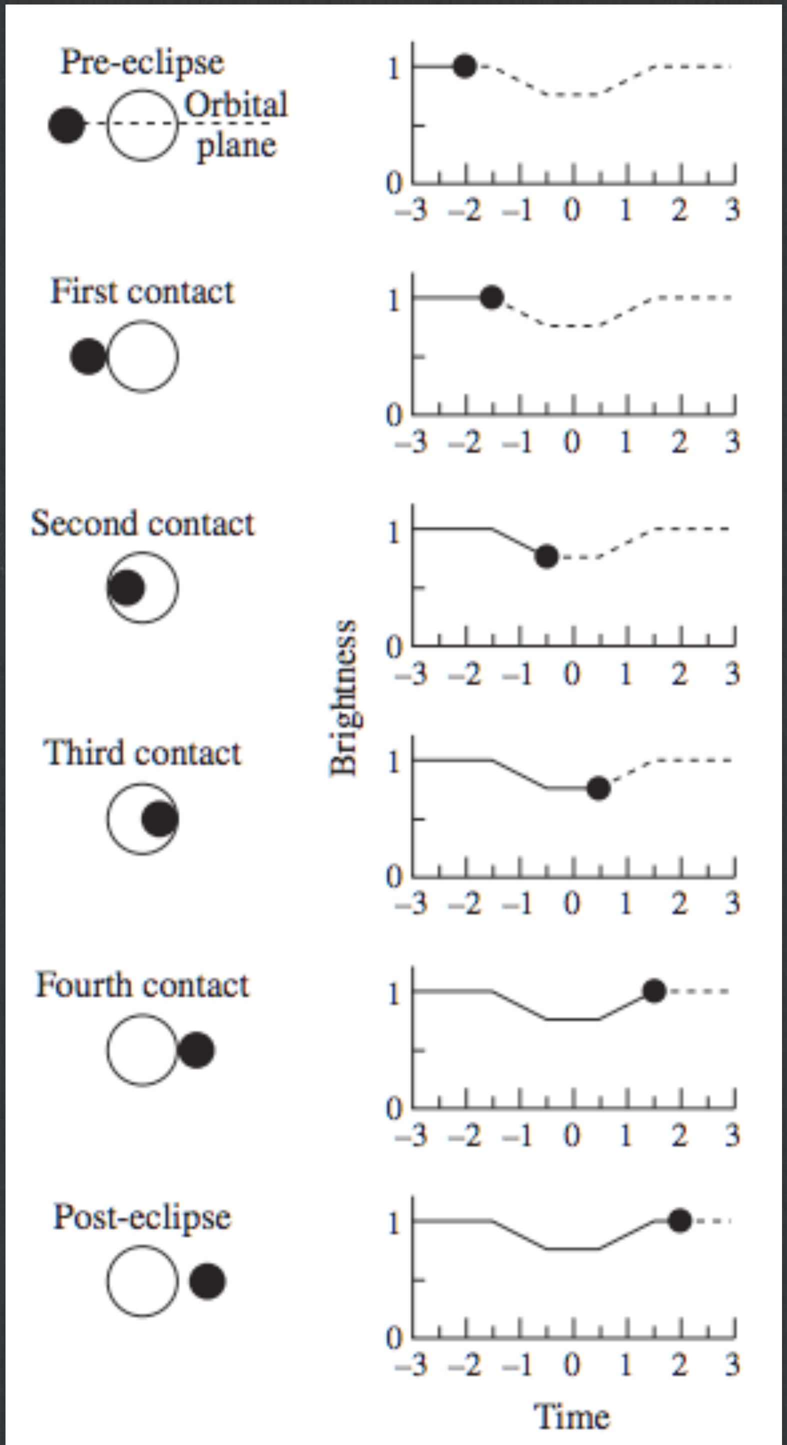
Transit Method

https://www.cfa.harvard.edu/~avanderb/tutorial/tutorial.html

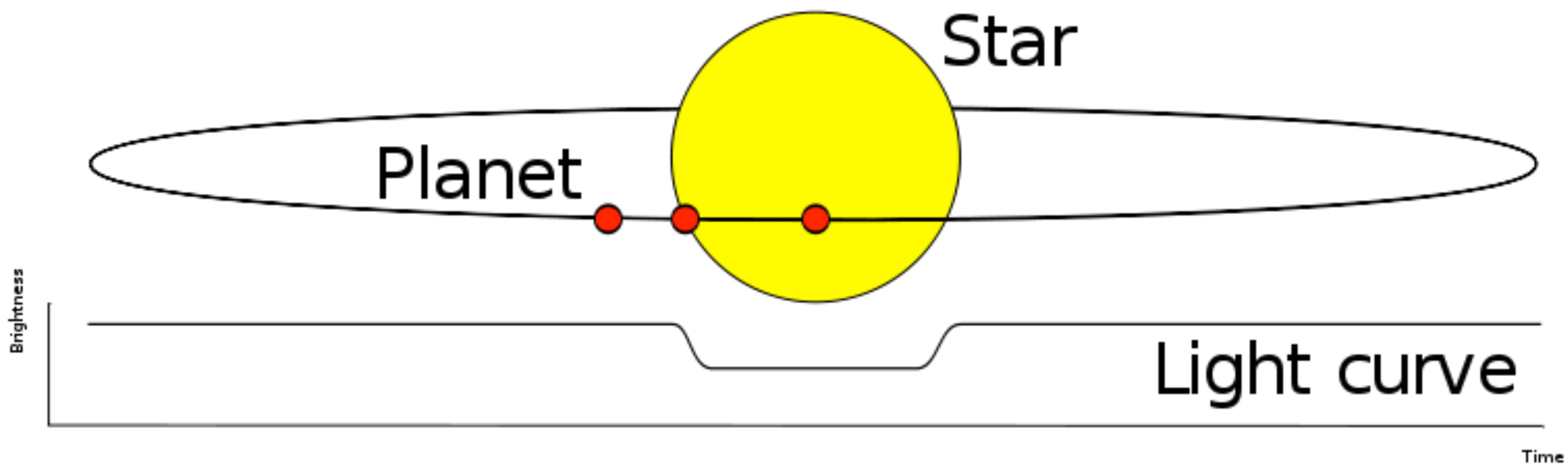
Witnessing the passage of a planet between its parent star and the observer.

Unlike observing a transit in the Solar System, neither the star nor the exoplanet can be resolved from Earth. But the exoplanet can be detected indirectly.



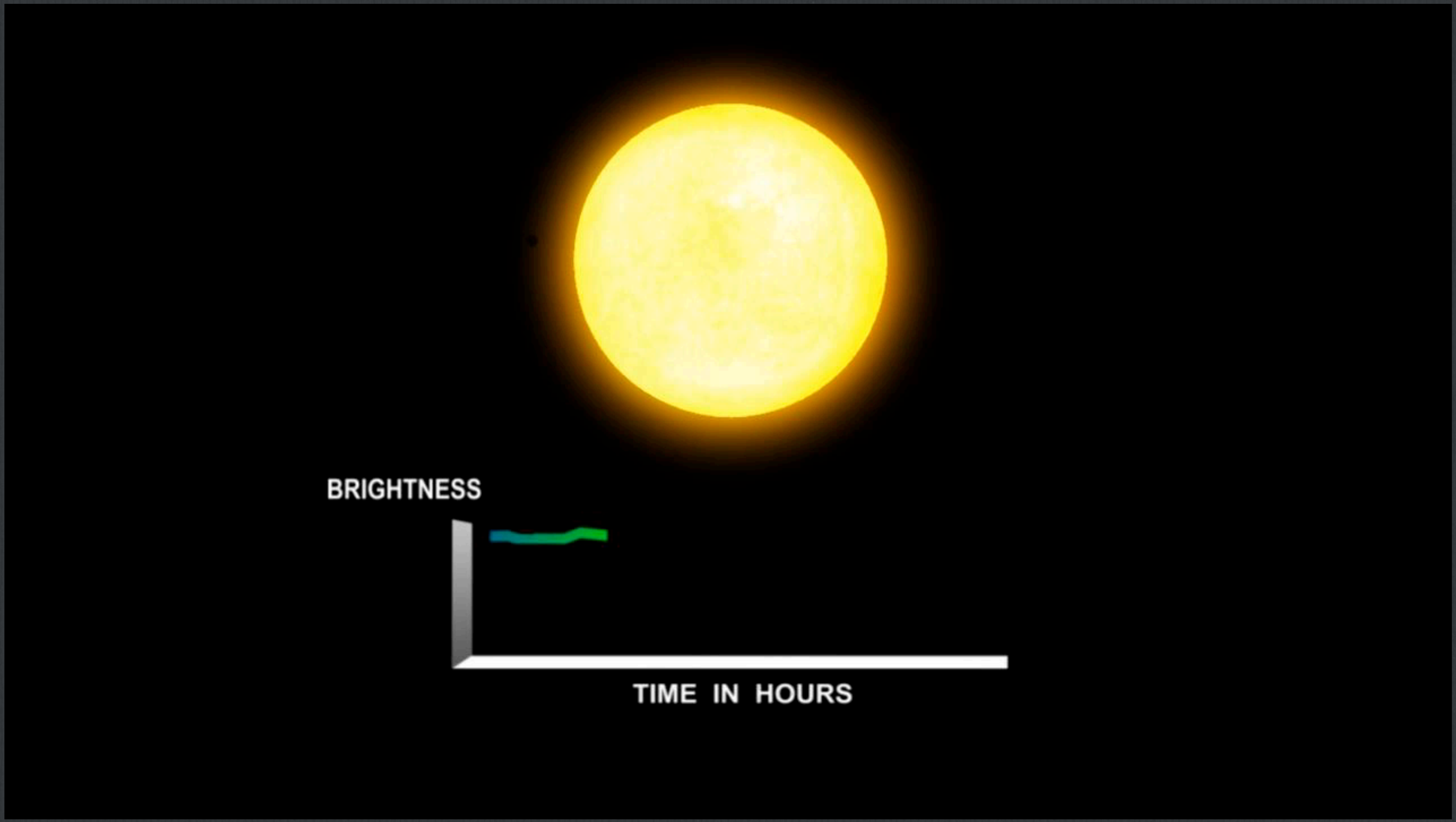


EXOPLANET DETECTION: TRANSITS

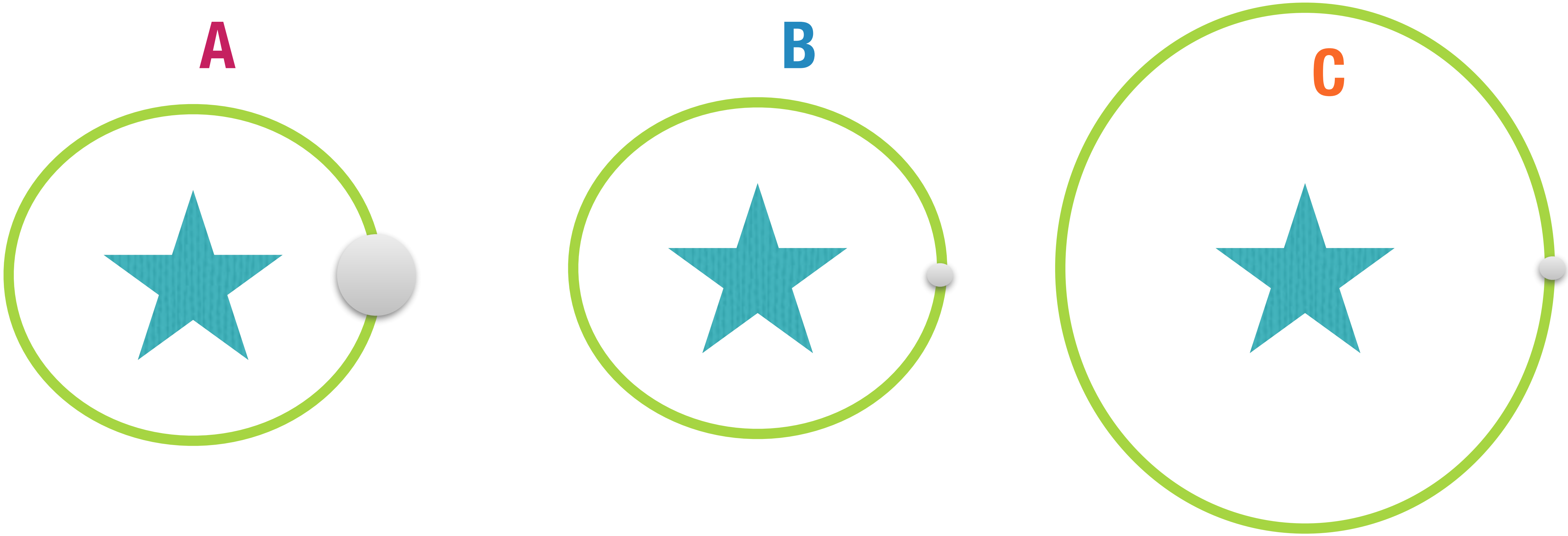


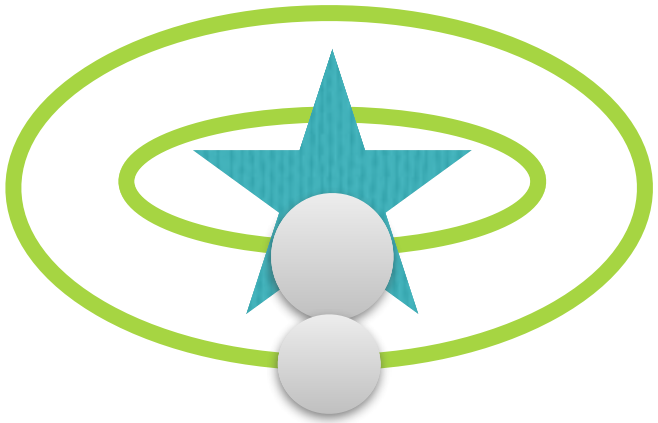
THIS *ONLY* WORKS WHEN THE PLANET AND STAR ARE LINED UP WITH OUR LINE OF SIGHT

Exoplanet Detection: Transits

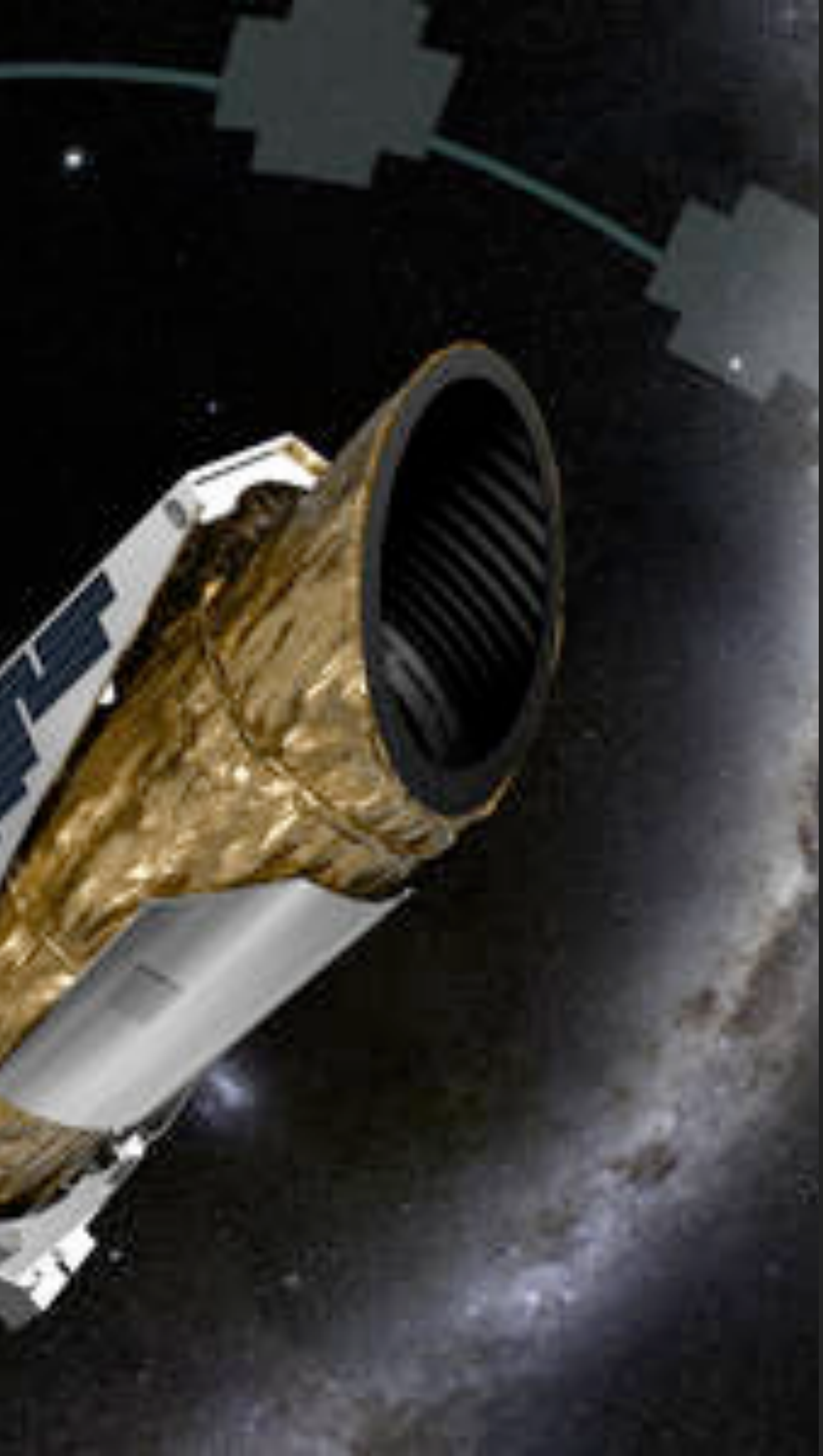


WHAT KIND OF PLANETS ARE EASIER TO SEE TRANSIT?





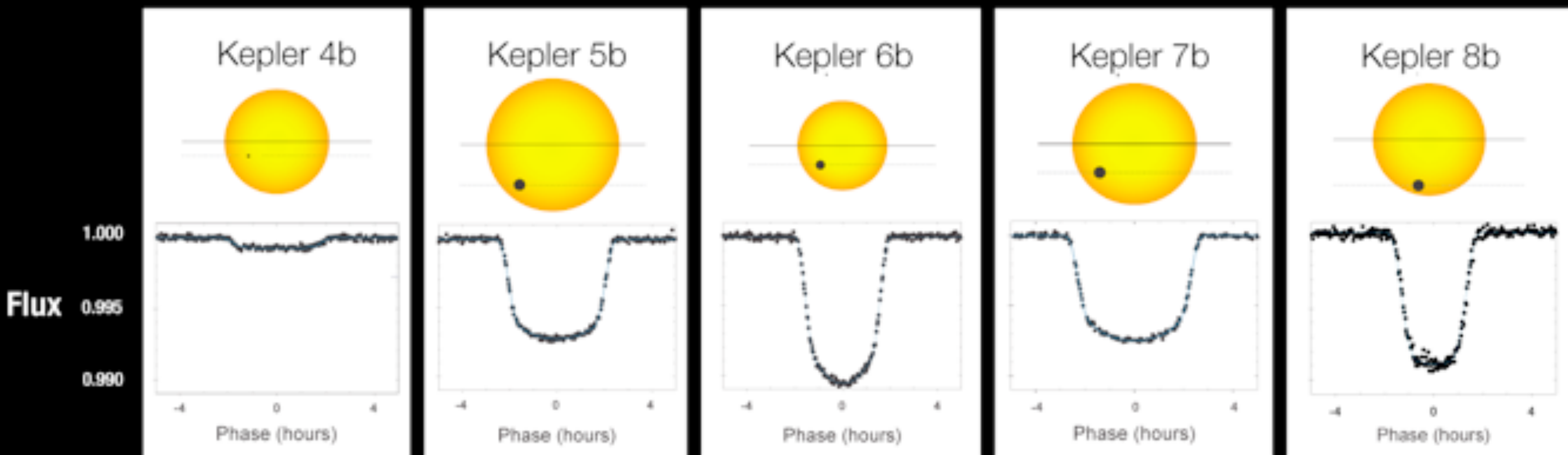
IF A PLANET REALLY CLOSE TO THE STAR IS A LITTLE BIT INCLINED TO OUR LINE OF SIGHT, WE CAN STILL SEE IT. BUT IF IT IS FAR AWAY FROM ITS STAR, IT WON'T TRANSIT



DESPITE SPECIAL ALIGNMENT, MOST PLANETS TO DATE WERE FOUND BY KEPLER. FOR 4 YEARS, IT STARED AT ONE TINY PATCH OF SKY AND WATCHED CHANGES IN THE BRIGHTNESS OF 100,000 STARS

KEPLER SPACE TELESCOPE

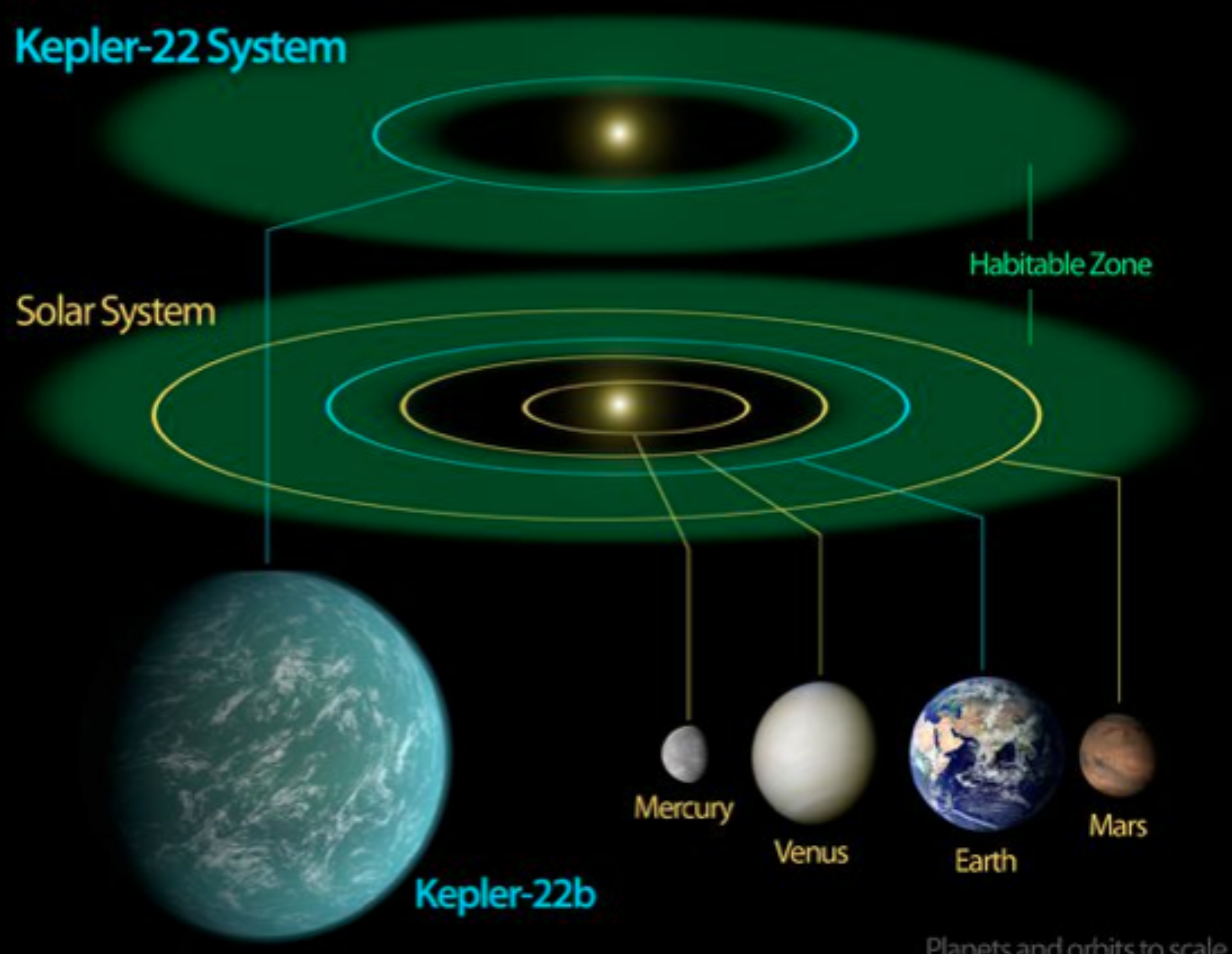
Transit Light Curves



Orbital Period (days)	*3.2 days*	*3.5 days*	*3.2 days*	*4.9 days*	*3.5 days*
Size (R_E)	*4.31*	*18.8*	*15.0*	*16.9*	*18.3*

Borucki et al 2010

Planets in the “habitable zone”



Kepler Orrery

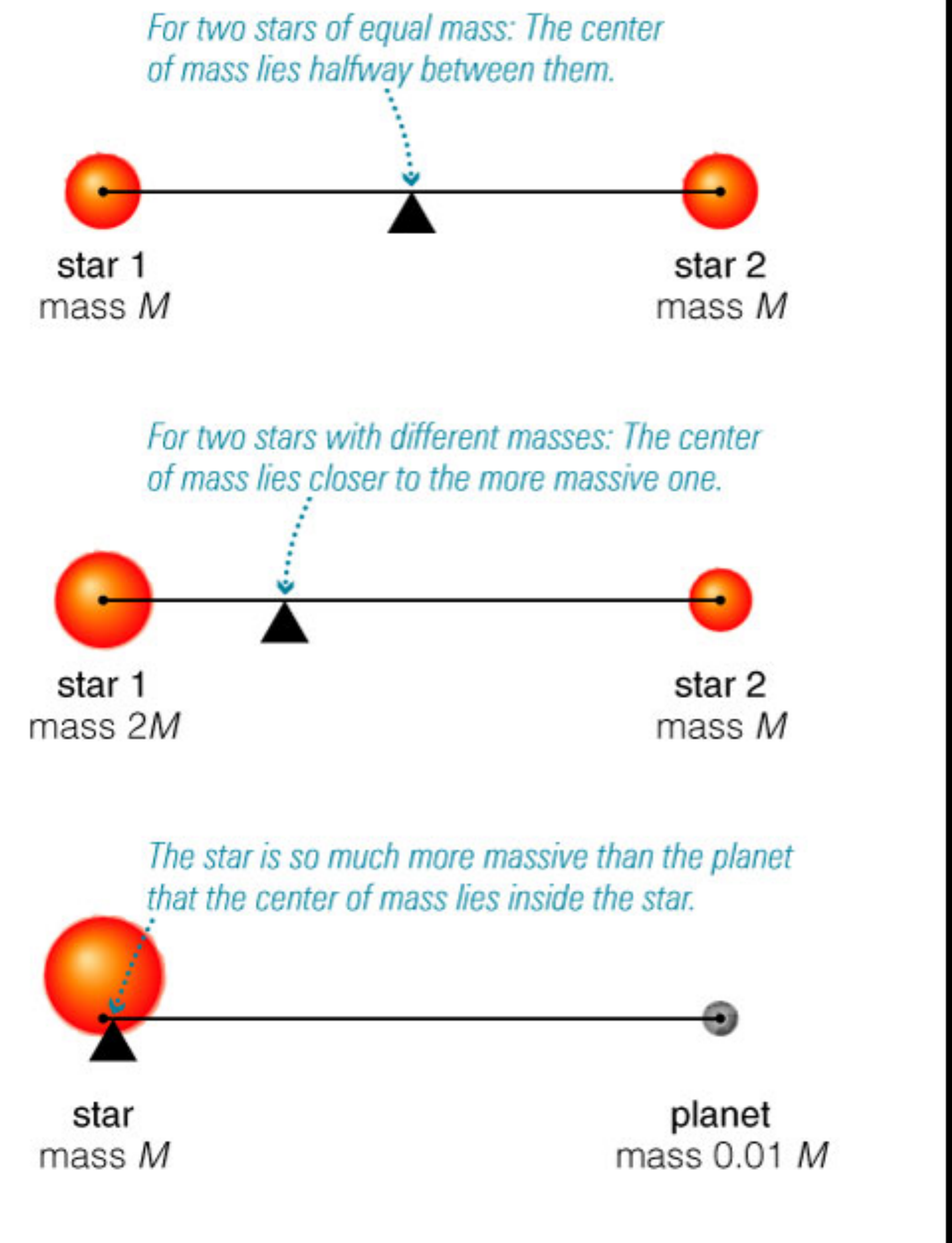
1815 planets in 726 systems

https://www.youtube.com/watch?v=Td_YeAdygJE#action=share

Remember: Newton's version of Kepler's Laws

Kepler's first law, revisted

– For a binary system, both objects move about the center of mass on ellipses, with the center of mass at one focus of each ellipse.



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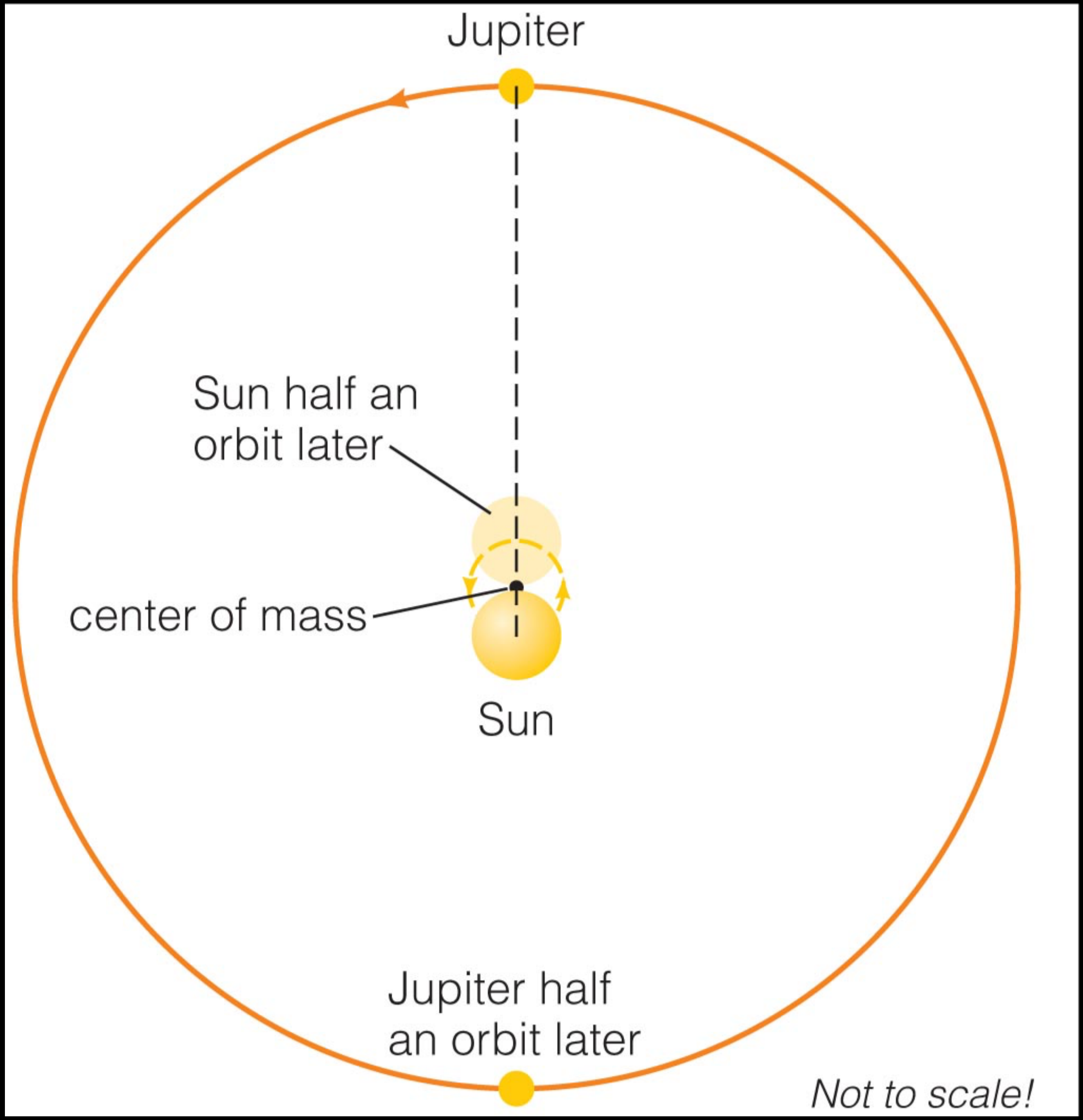
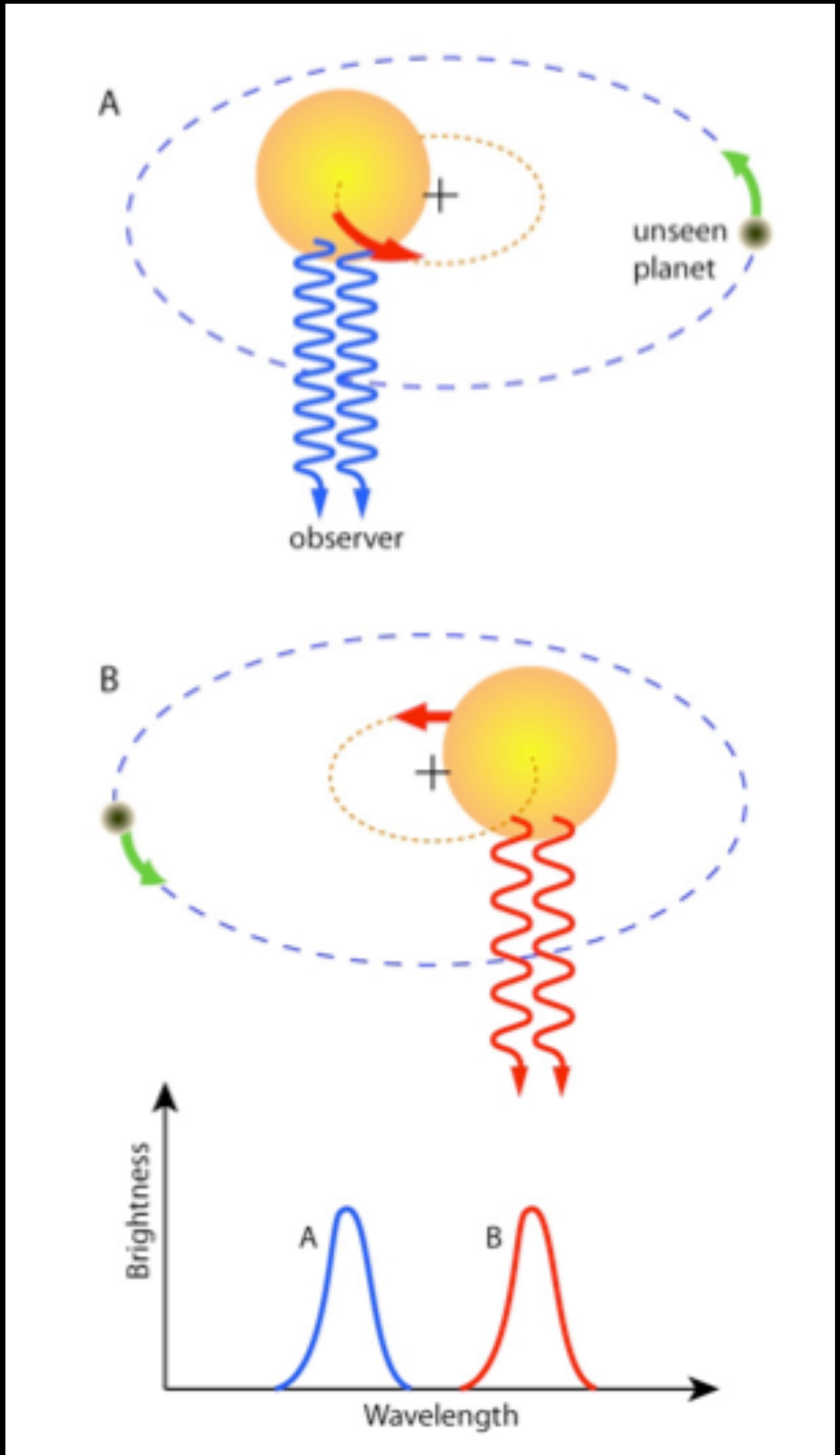
The Gravitational Effects of a Planet



- If the planet is massive enough, the center of mass is outside the star
- In these cases, it can be possible to see the motion of the star around the center of mass

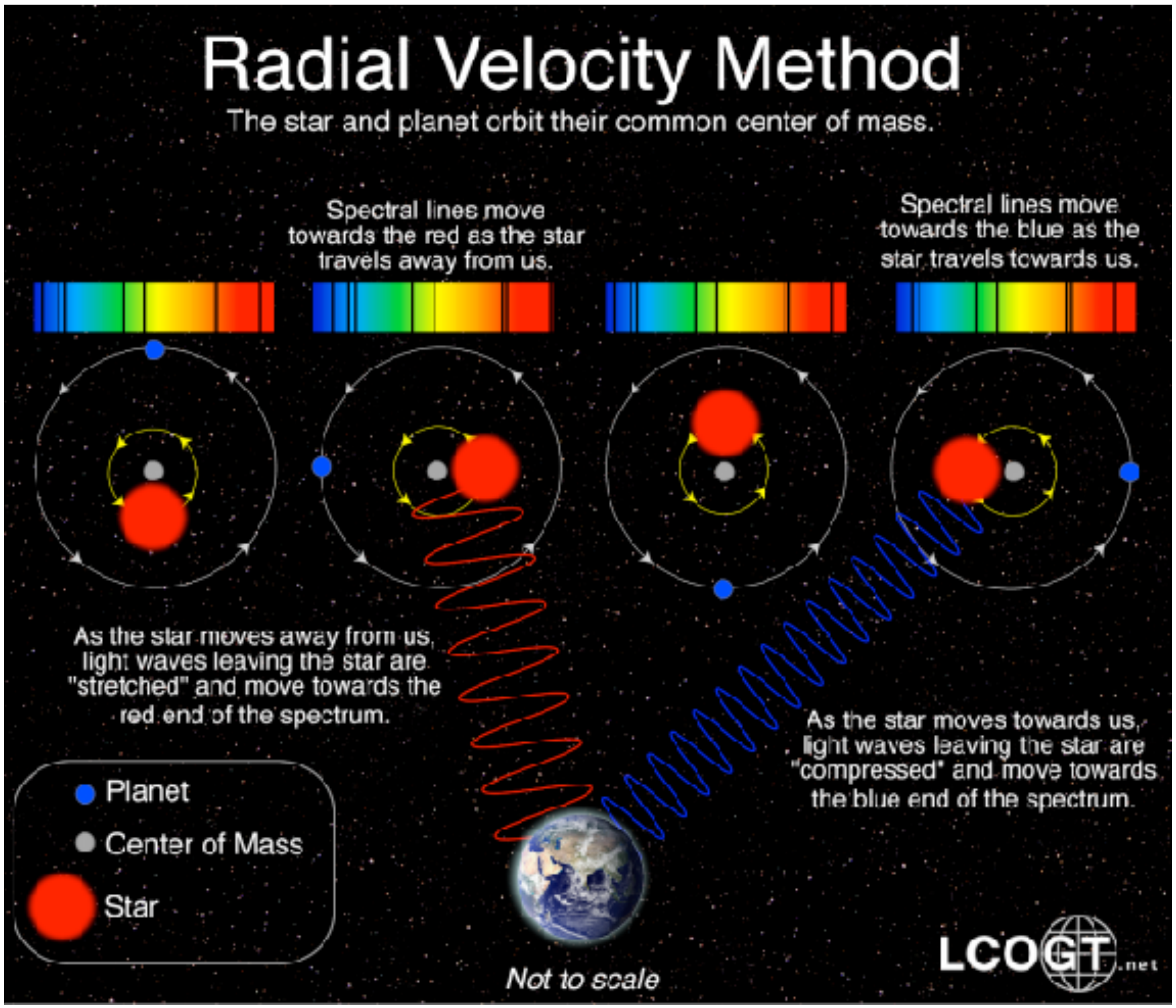
http://www.stefanom.org/spc/

The Gravitational Effects of a Planet

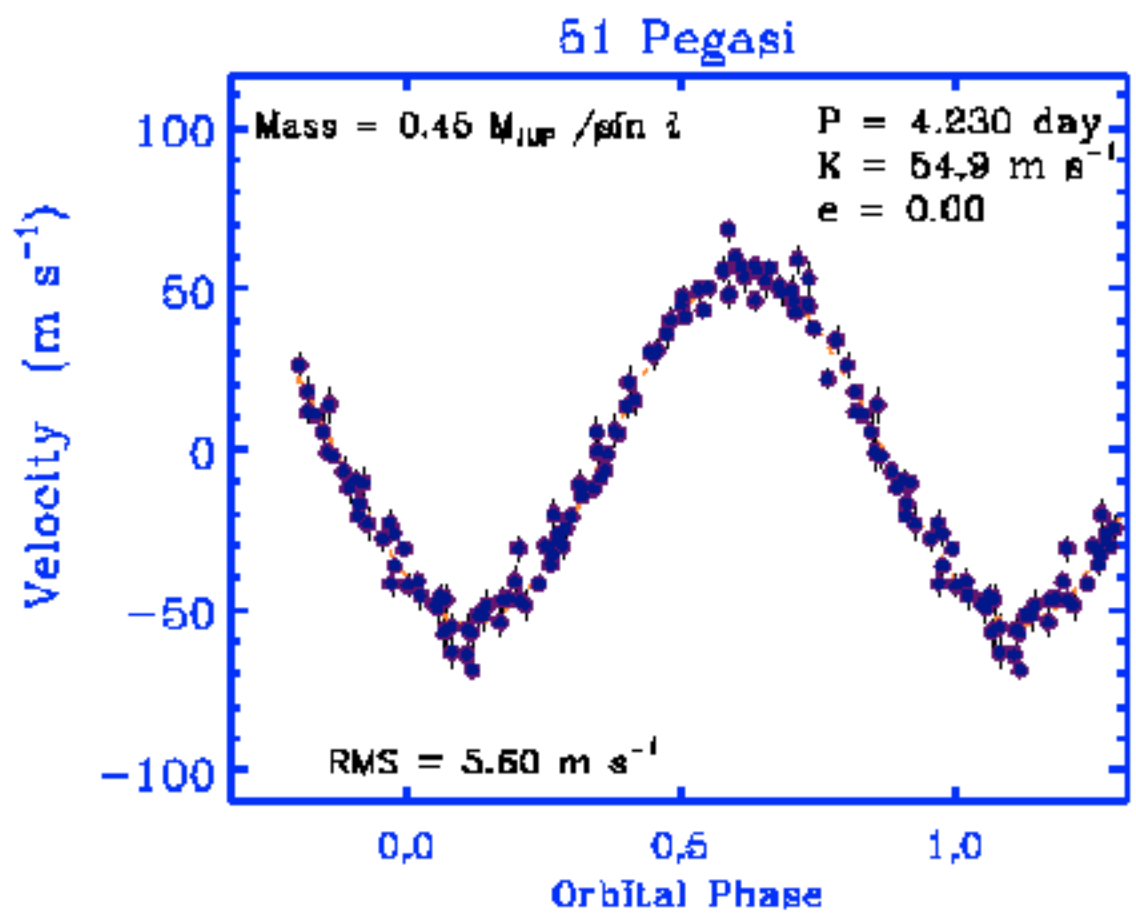


Doppler shift: radial motion of star back and forth along line of sight causes periodic shift in spectral lines

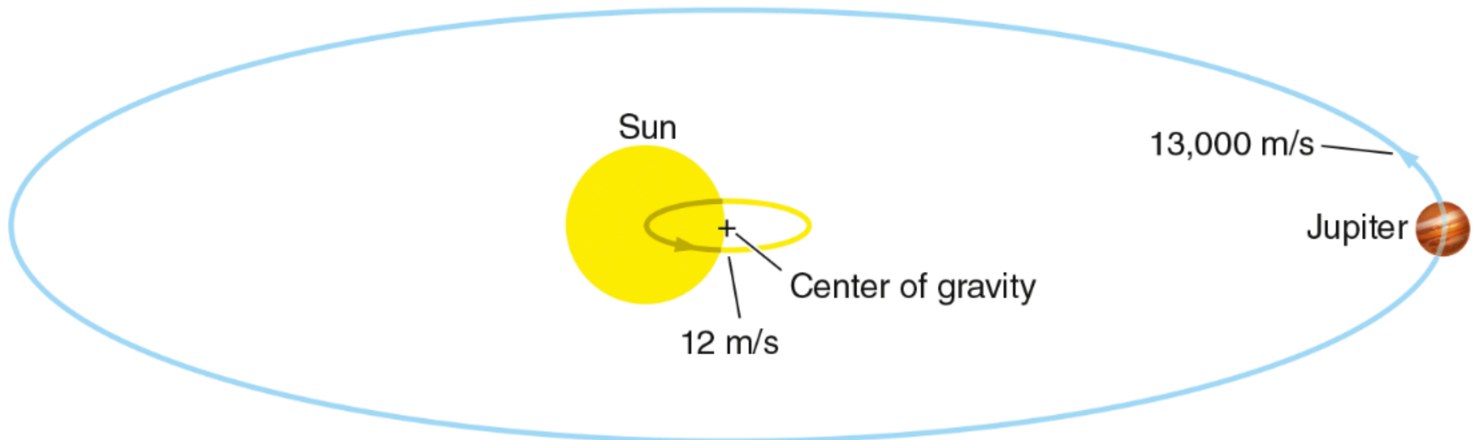
EXOPLANET DETECTION METHODS: RADIAL VELOCITY



BY MEASURING THE VELOCITIES OVER TIME, WE CAN GET AN INDICATION OF THE MASS AND THE ORBITAL PERIOD.



Could aliens like us detect planets in our solar system?



Current precision of radial velocity measurements, ~1 m/s

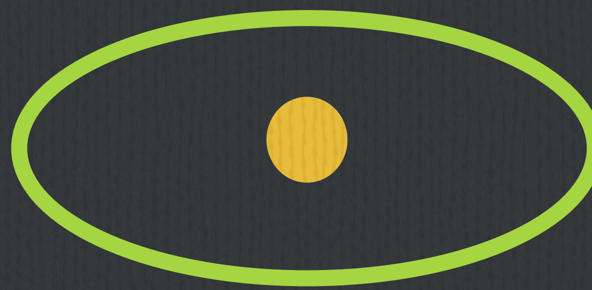
Saturn induces a radial velocity of 2.7 m/s
Earth induces a radial velocity of 0.09 m/s

Which system will have the largest measured velocity change?

Face on
A

Edge on
B

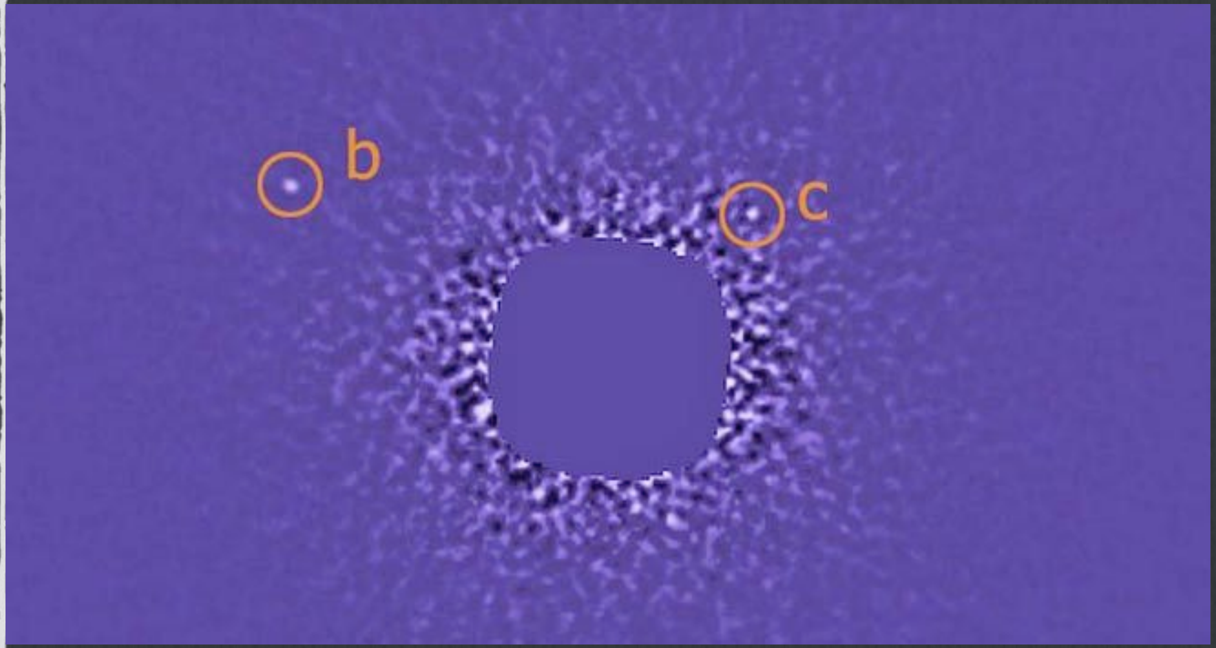
In the middle
C



All the same system, but how will their MEASURED radial velocities change?

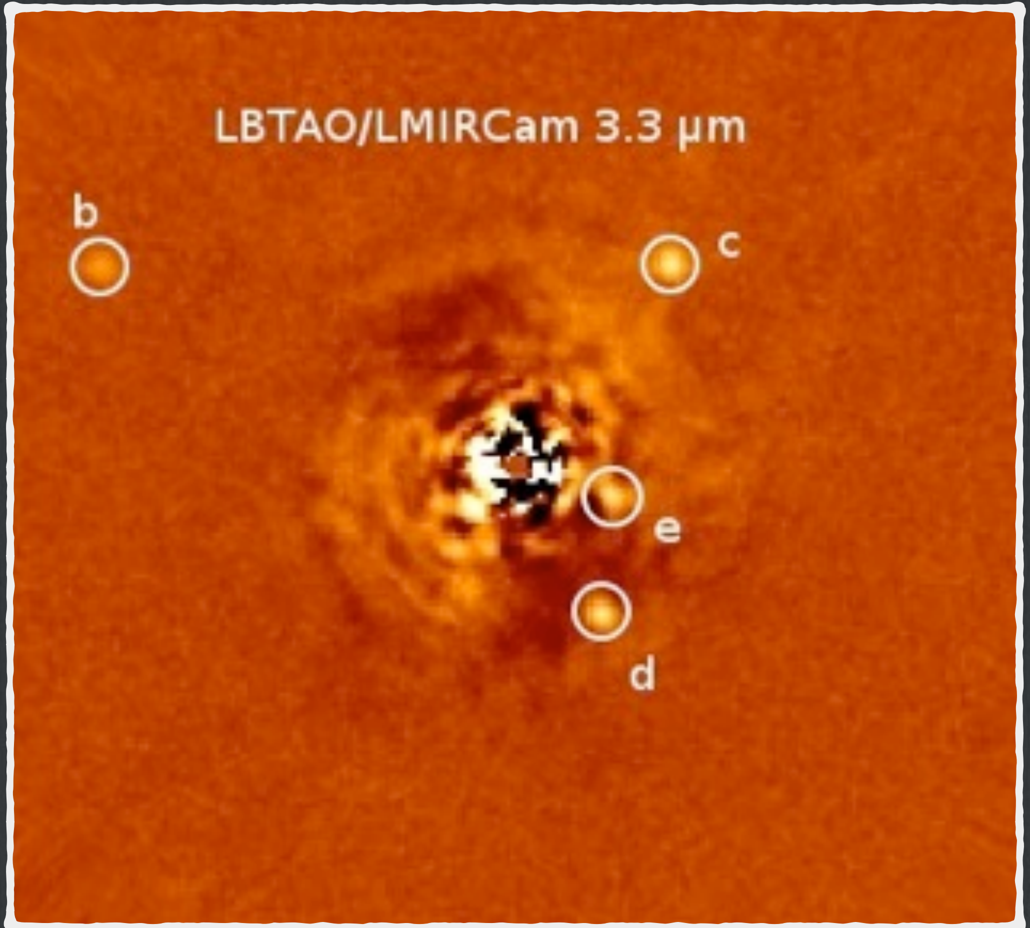
We can only know mass x sin(i) where i is the inclination

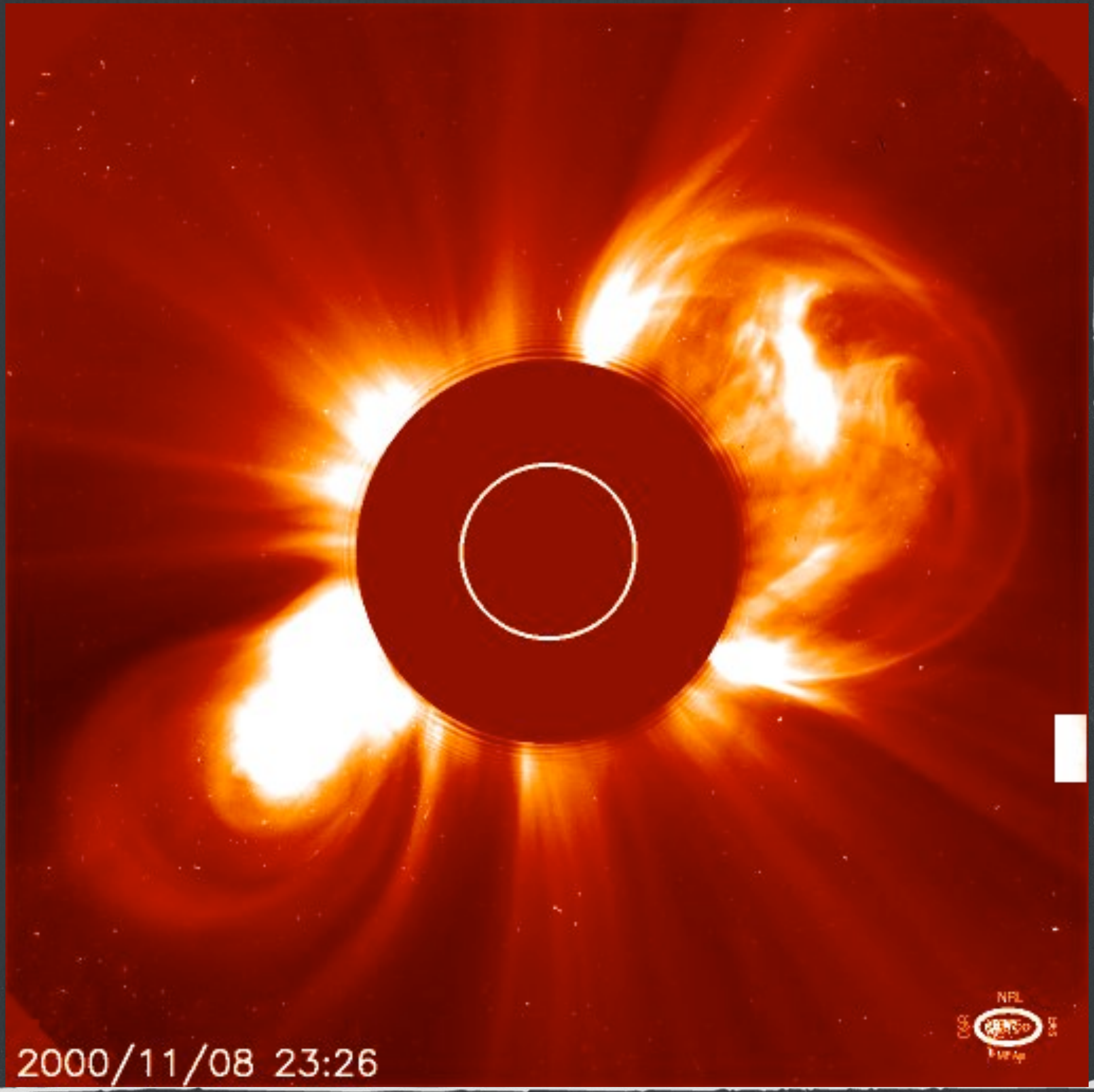
Exoplanet Detection: just take a picture!



uses a “coronagraph”

Hint: the name comes from …





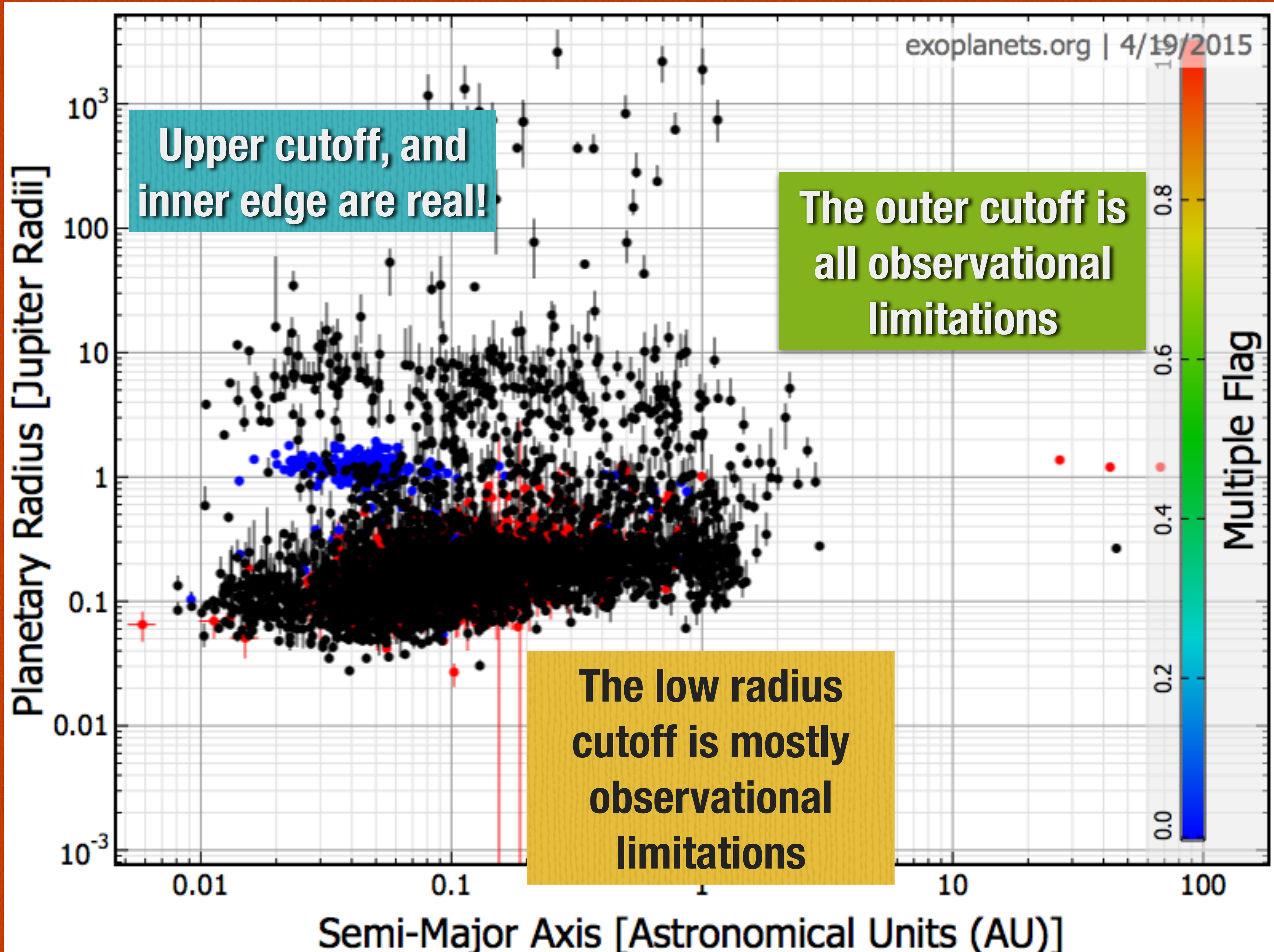
Selection Effects: What kinds of planets can we see?

Radial Velocity: more massive planet (or smaller star), close to the star

Transits: bigger planets (or smaller stars), close to the star

Imaging: brighter planets, far away from the star

The Diversity of Exoplanetary Systems



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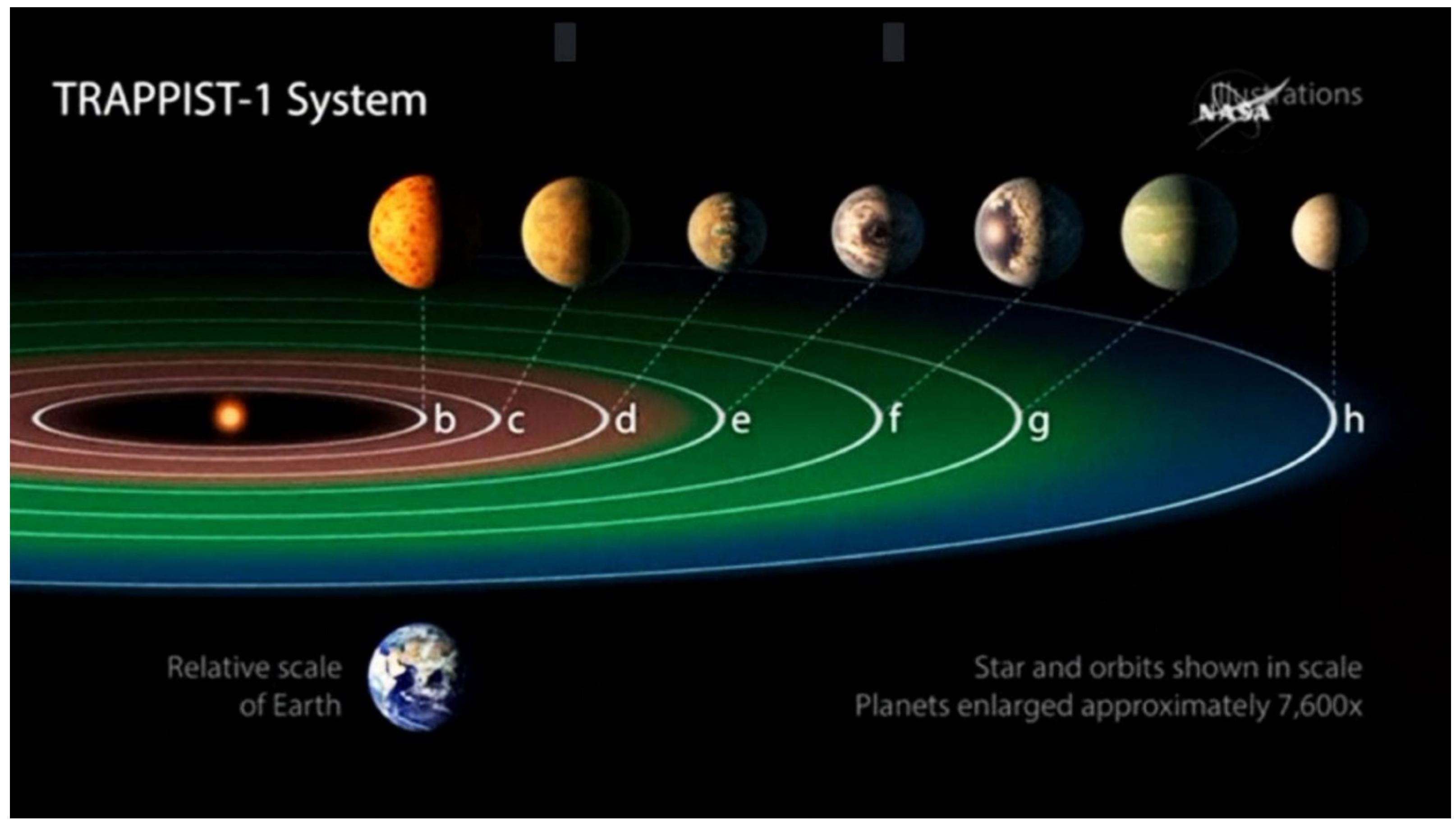
Thanks and see you next time!



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