Astro 1: Introductory Astronomy

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Class 19: Tuesday, April1

Spring 2014

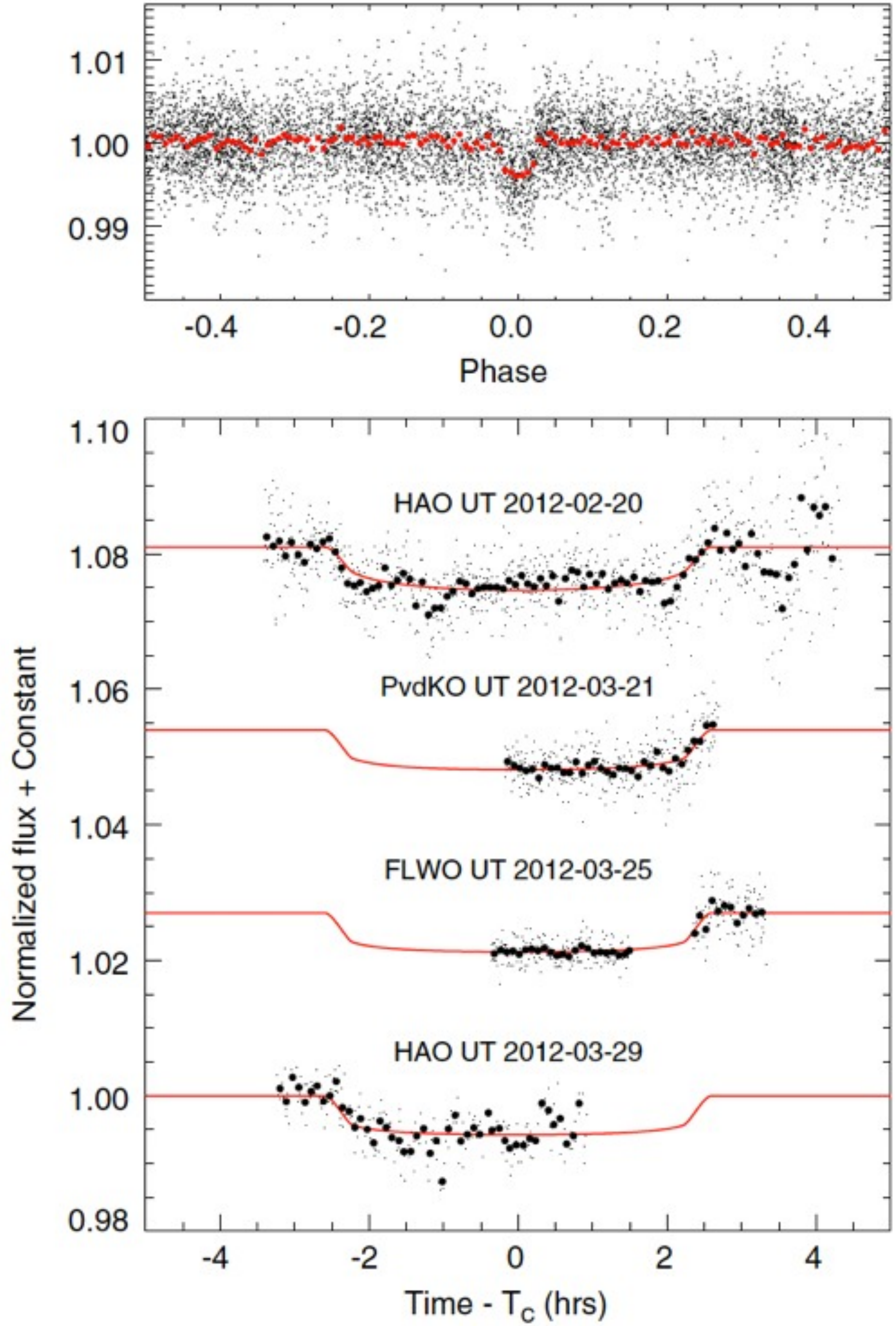


Figure 2. KELT-North discovery photometry (top panel), and then the follow-

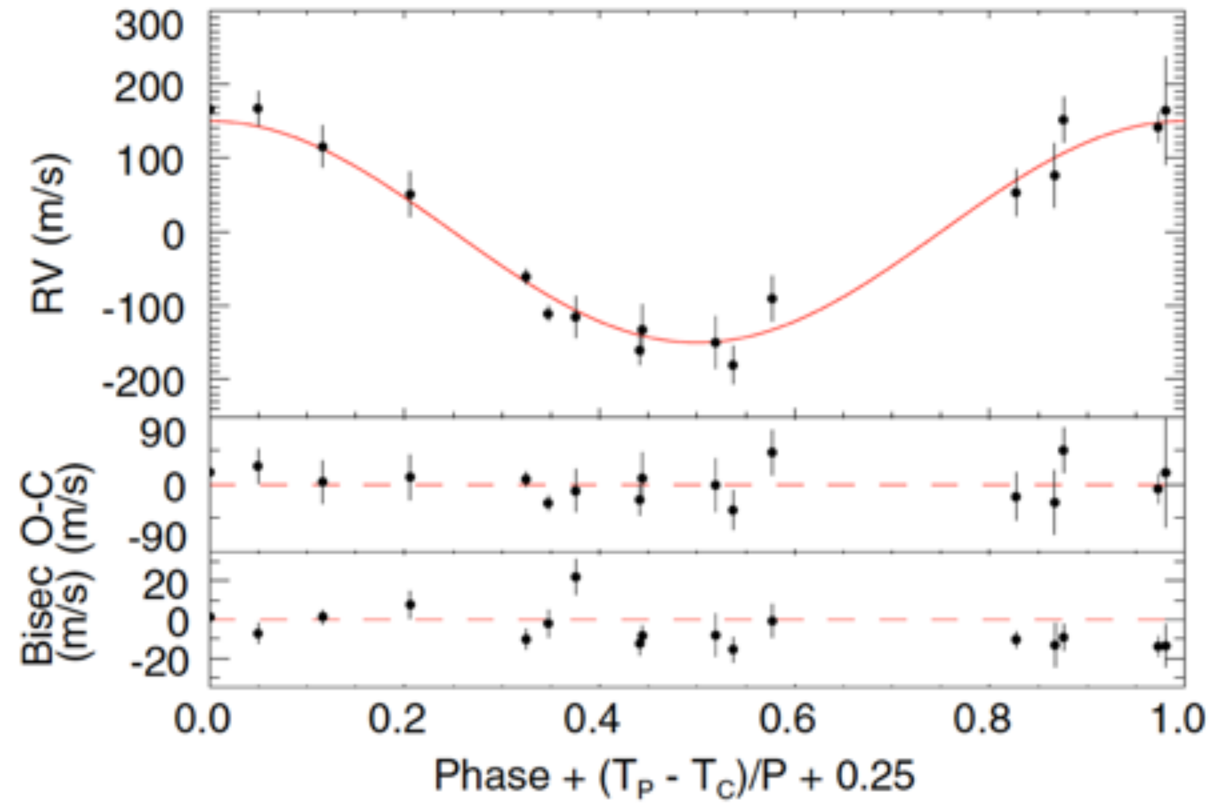
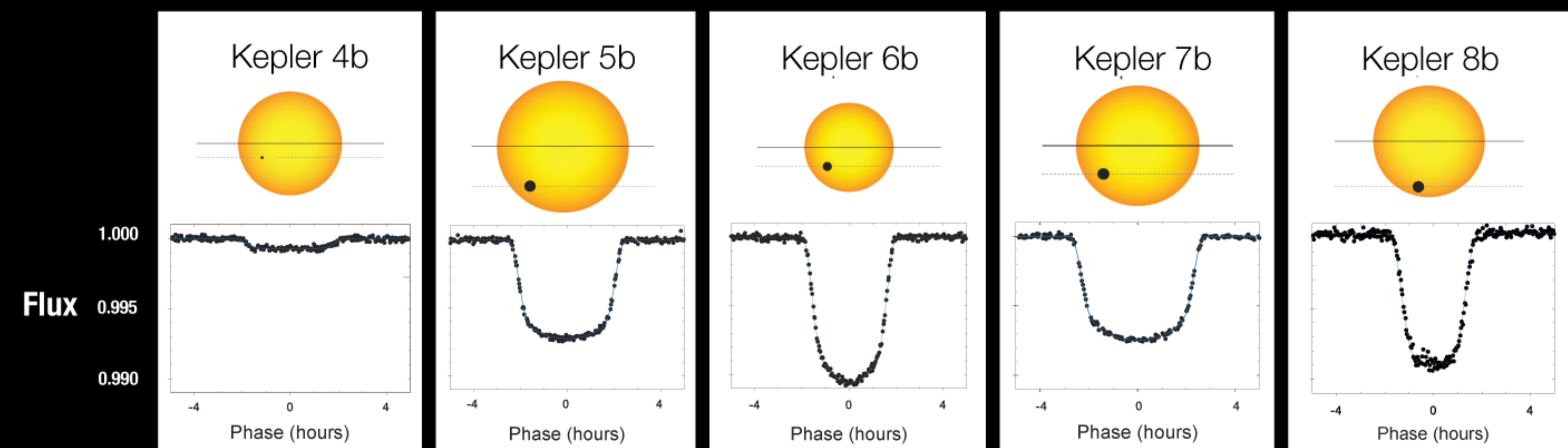


Figure 1. TRES radial velocity measurements of KELT-2A. The top panel shows the observations phased to our best orbital model, shown in red. We have removed the system's systemic velocity of 47.5 km s^{-1} and the best-fit slope. The middle panel shows the residuals of the radial velocity observations to our orbital fit, and the bottom panel shows the bisector span of each observation as a function of phase.

Transits (left) for the planet's radius and Doppler shift measurements (above) for the planet's mass

Kepler Mission (2009)

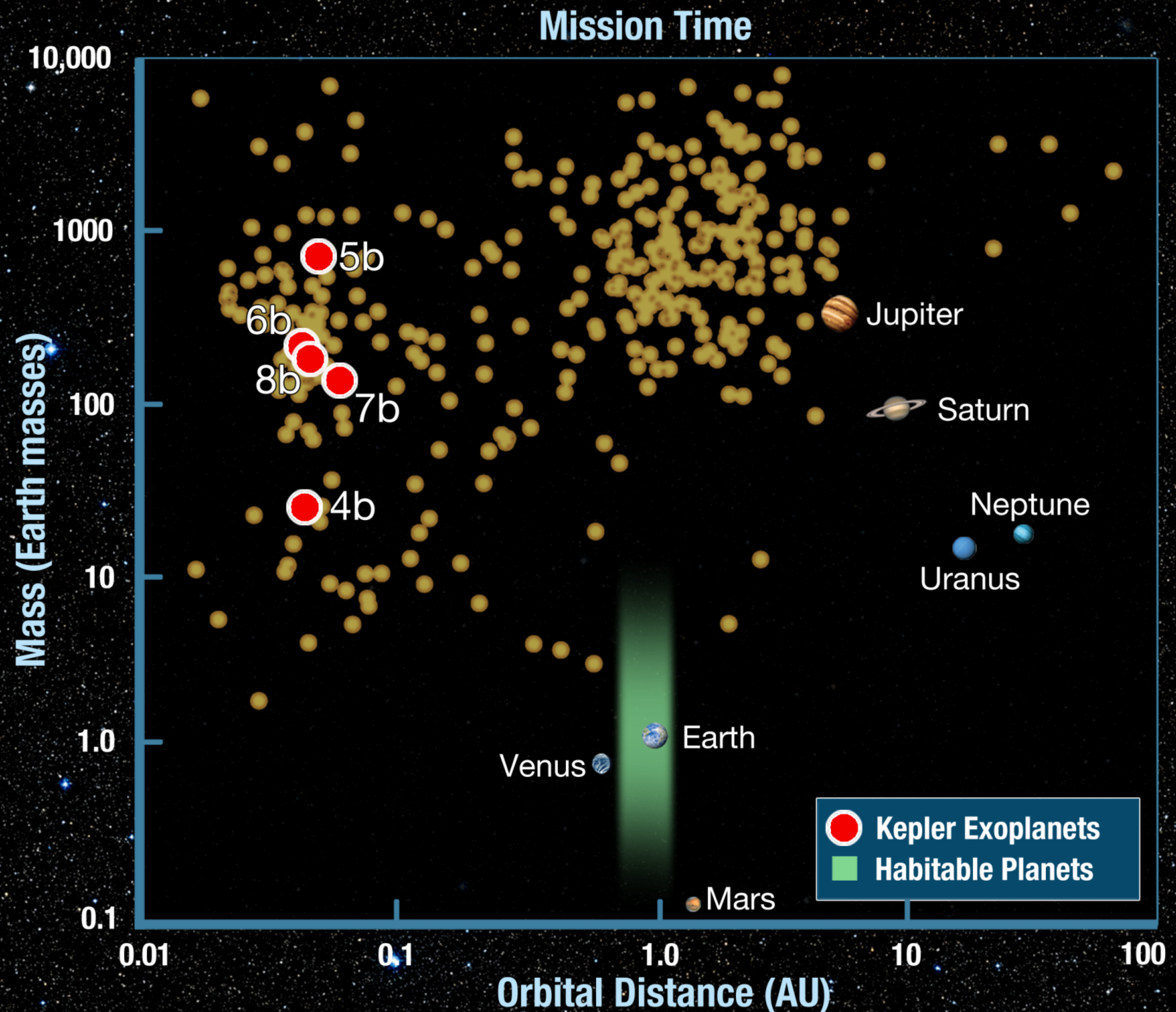
Transit Light Curves



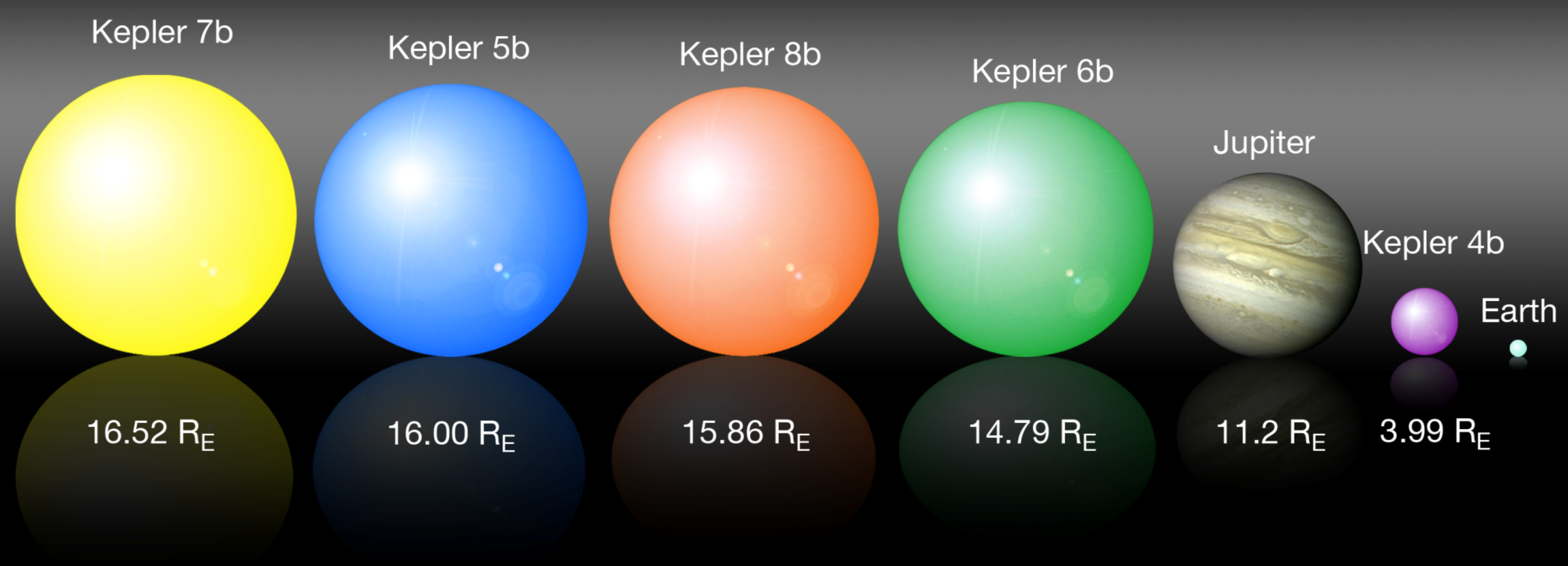
	Kepler 4b	Kepler 5b	Kepler 6b	Kepler 7b	Kepler 8b
Orbital Period (days)	*3.2 days*	*3.5 days*	*3.2 days*	*4.9 days*	*3.5 days*
Size (R_E)	*4.31*	*18.8*	*15.0*	*16.9*	*18.3*

First Five Planet Discoveries

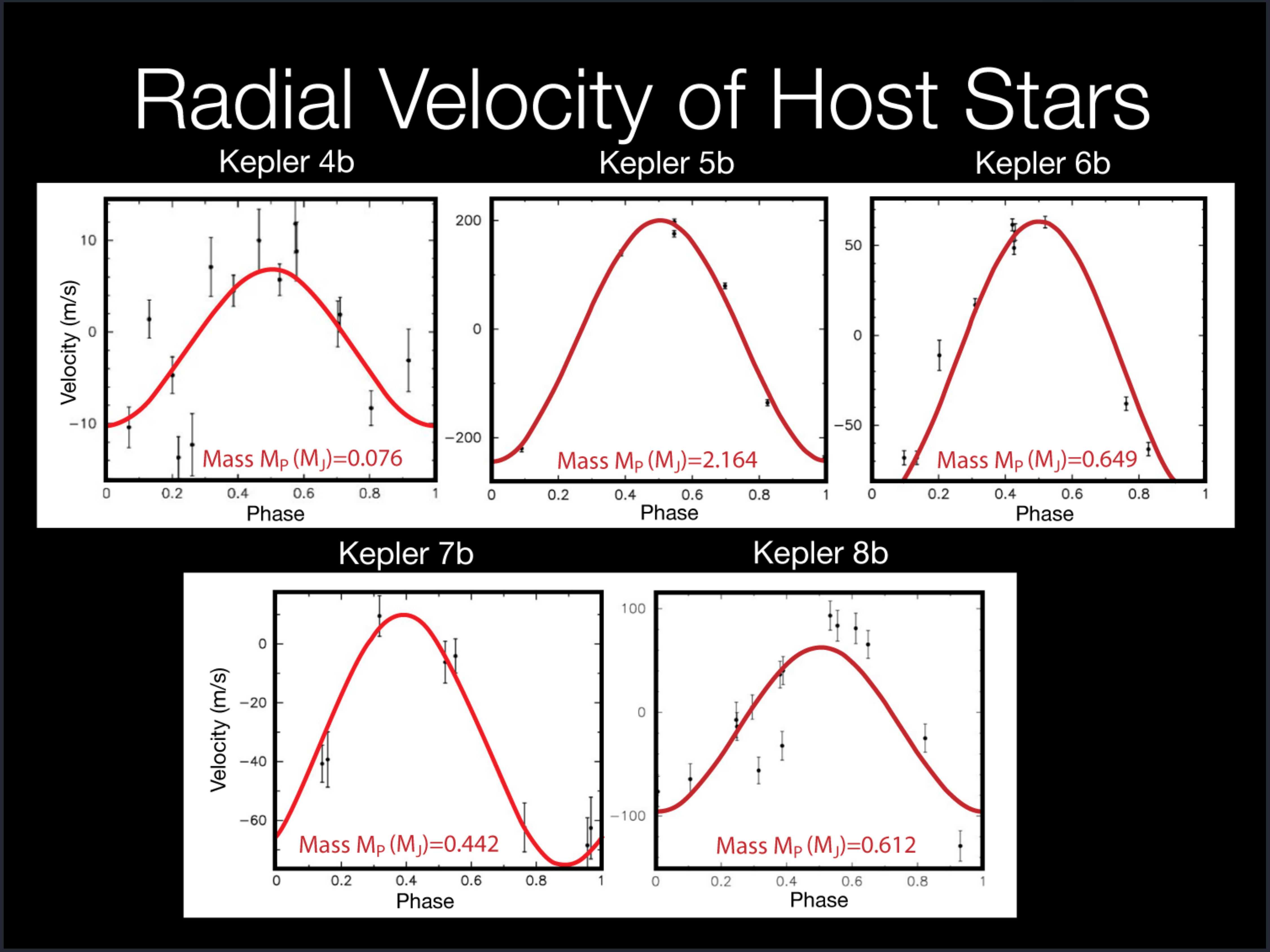
Made with First 43 Days of Data



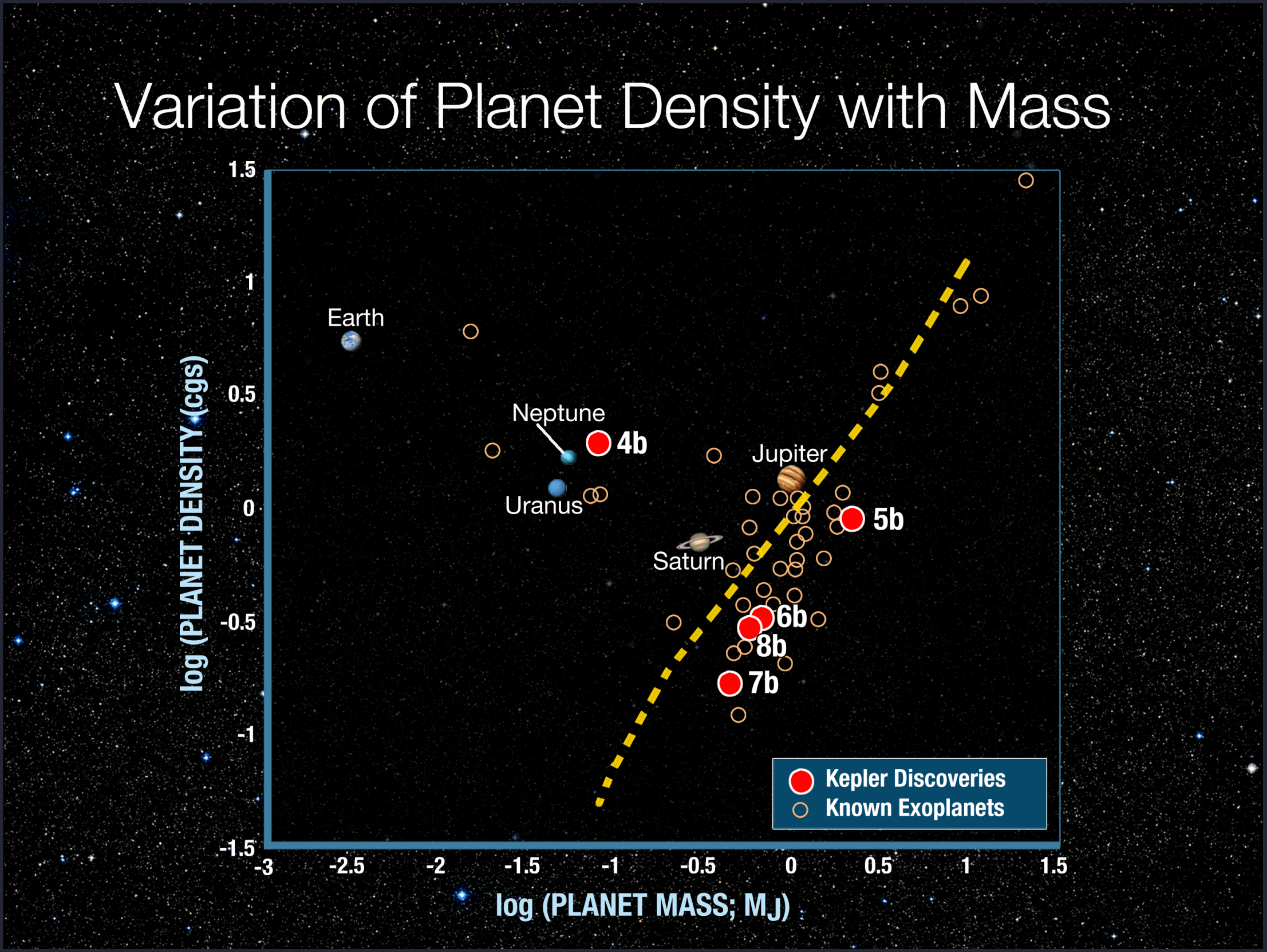
Planet Size

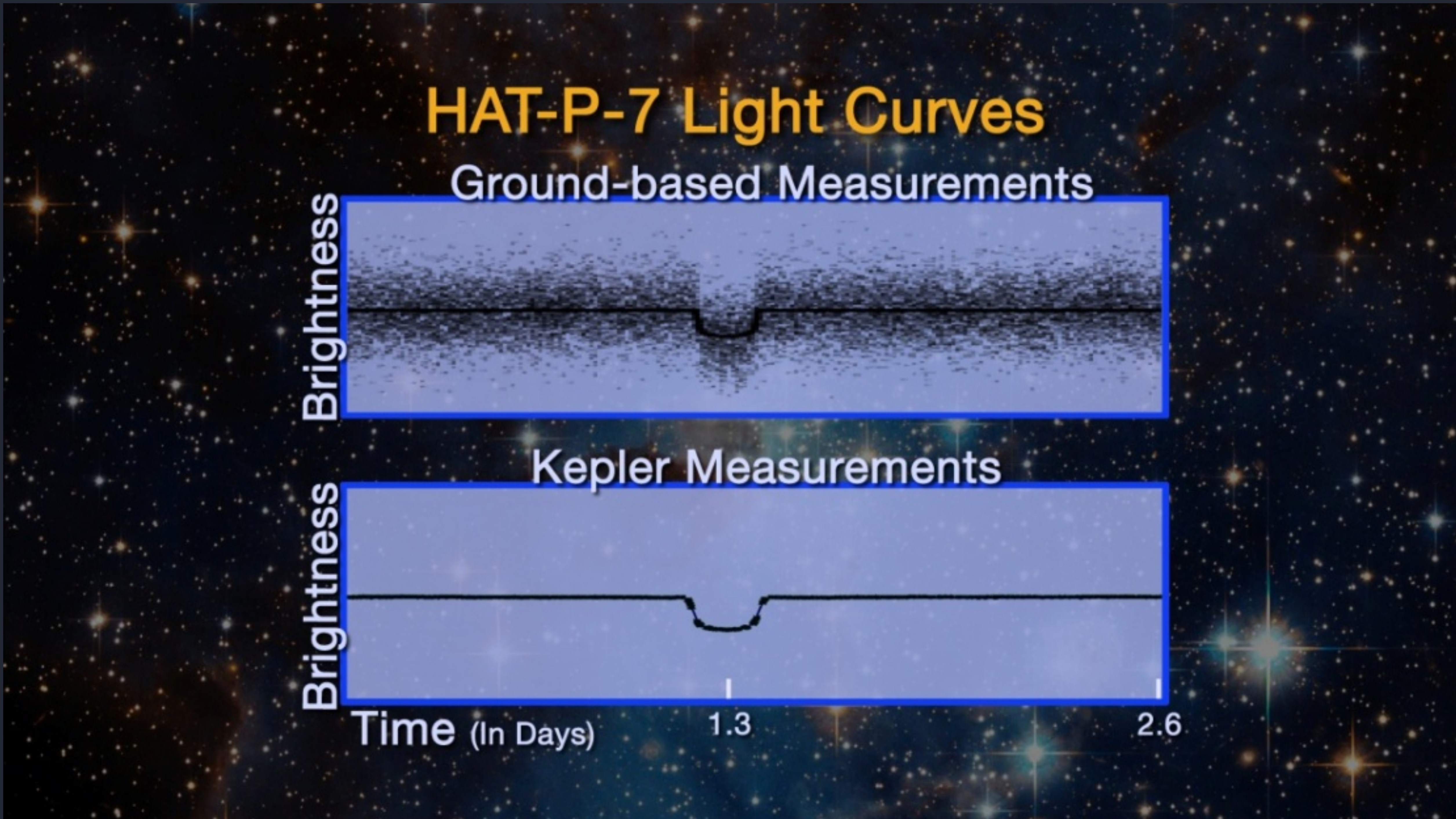

Kepler 7b
Kepler 5b
Kepler 8b
Kepler 6b
Jupiter
Kepler 4b
Earth
16.52 R_E
16.00 R_E
15.86 R_E
14.79 R_E
11.2 R_E
3.99 R_E

With the masses of these planets found from their radial velocities, their densities can be calculated (next slide)

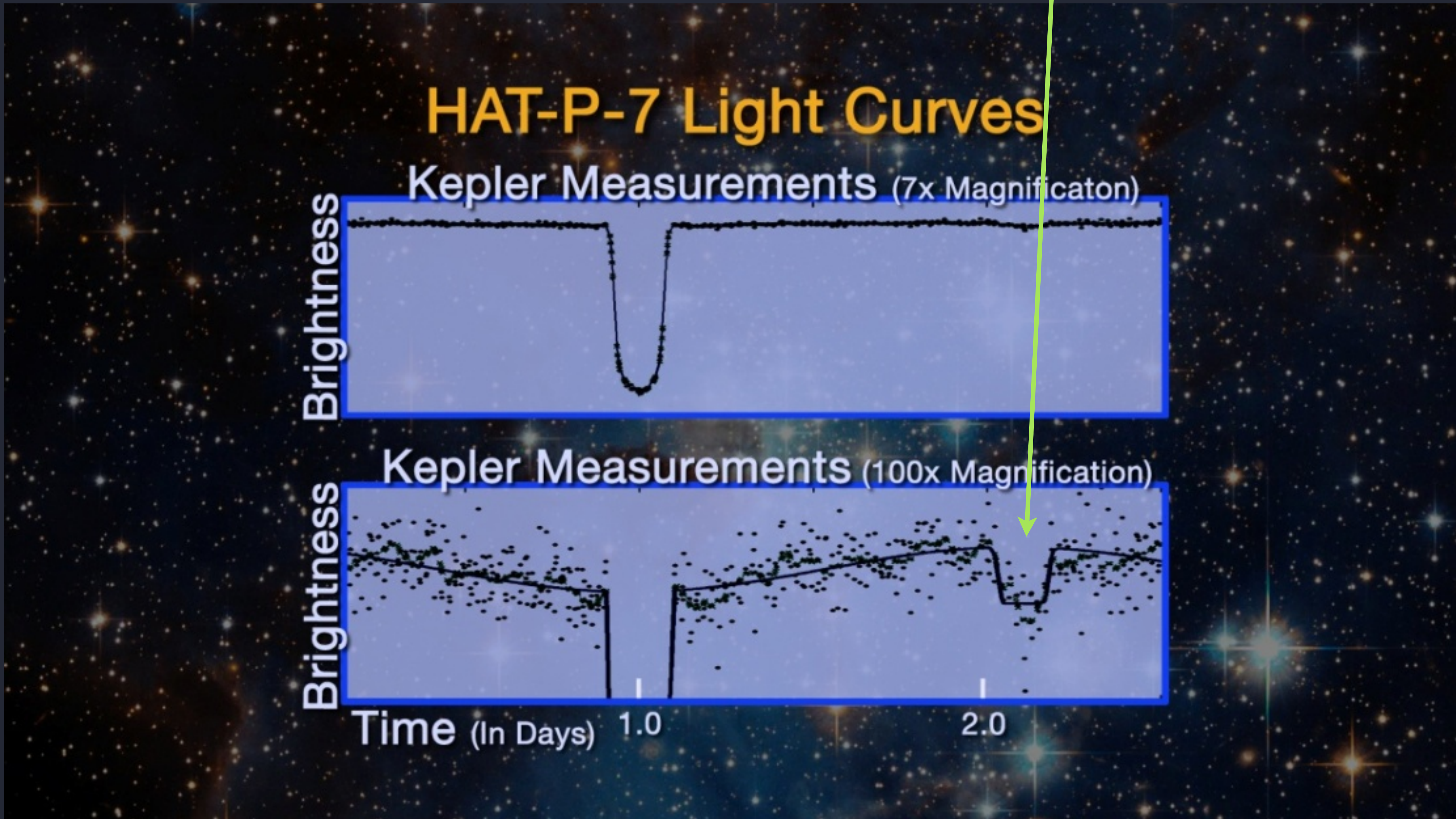


The density trends make sense, but note some low density Jupiter-mass planets - they're hot and bloated because they're near their host stars

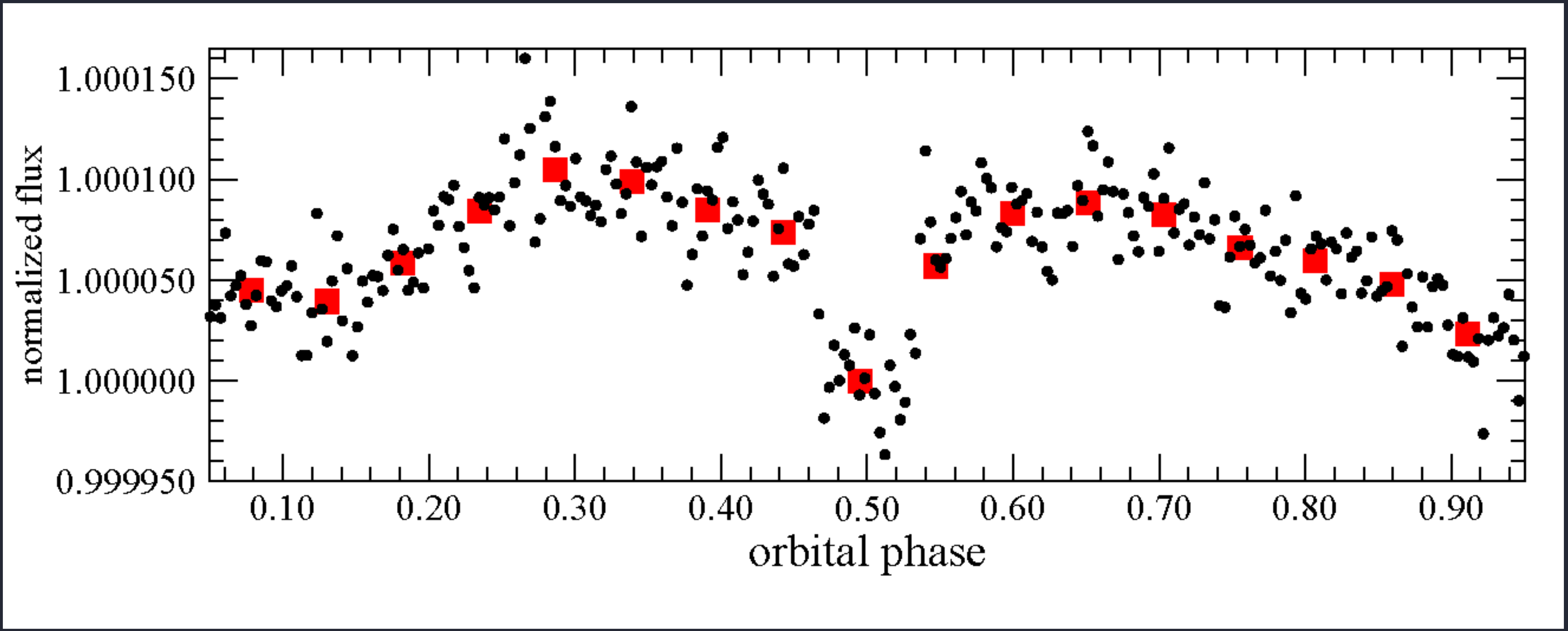



HAT-P-7 Light Curves
Ground-based Measurements
Brightness
Kepler Measurements
Brightness
Time (In Days)
1.3
2.6

secondary eclipse: the planet going behind its host star



secondary eclipse: zoom-in - see how the brightness goes up before the eclipse?



the planet is reflecting the most light right before the eclipse

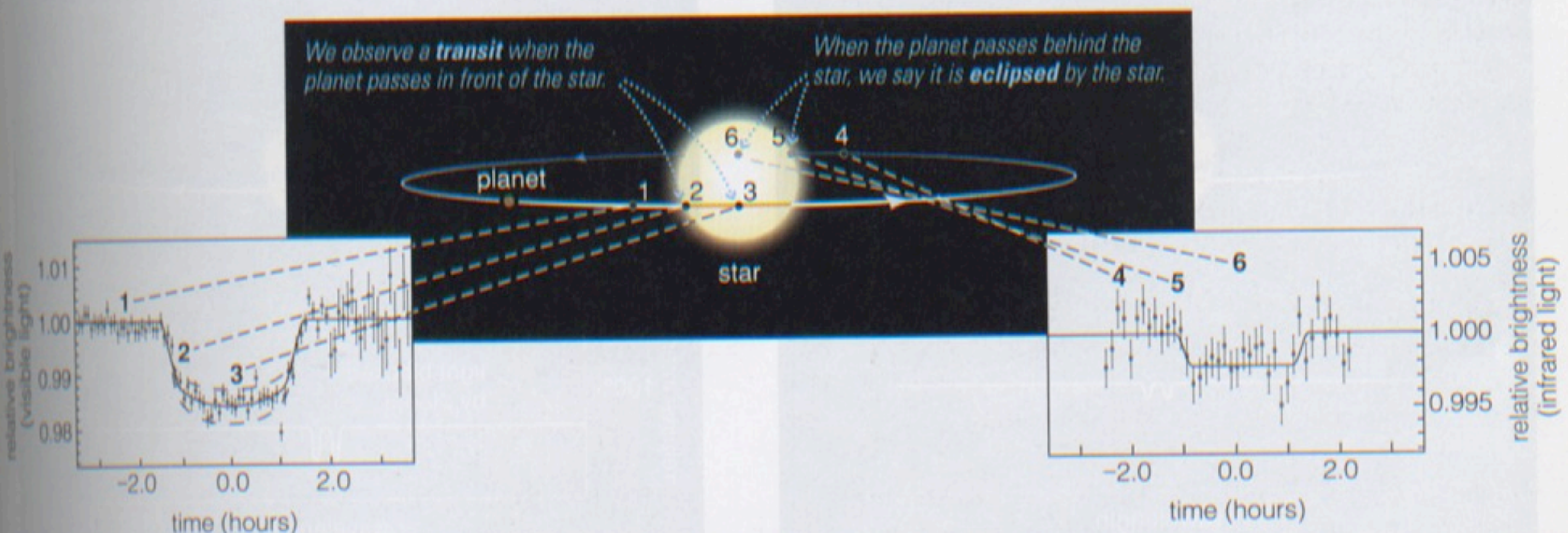


Figure 13.7 Interactive Figure The artist's conception (center) shows the planet orbiting the star HD209458. The graphs show how the star's brightness changes during transits and eclipses, which each occur once with every $3\frac{1}{2}$-day orbit. During a transit, the star's brightness drops for about 2 hours by 1.7%, which tells us how the planet's radius compares to the radius of its star. During an eclipse, the infrared signal drops by 0.25%, which tells us about the planet's thermal emission.

In our own Solar System, Venus reflects different amounts of light depending on its position in its orbit (too)

Summarizing

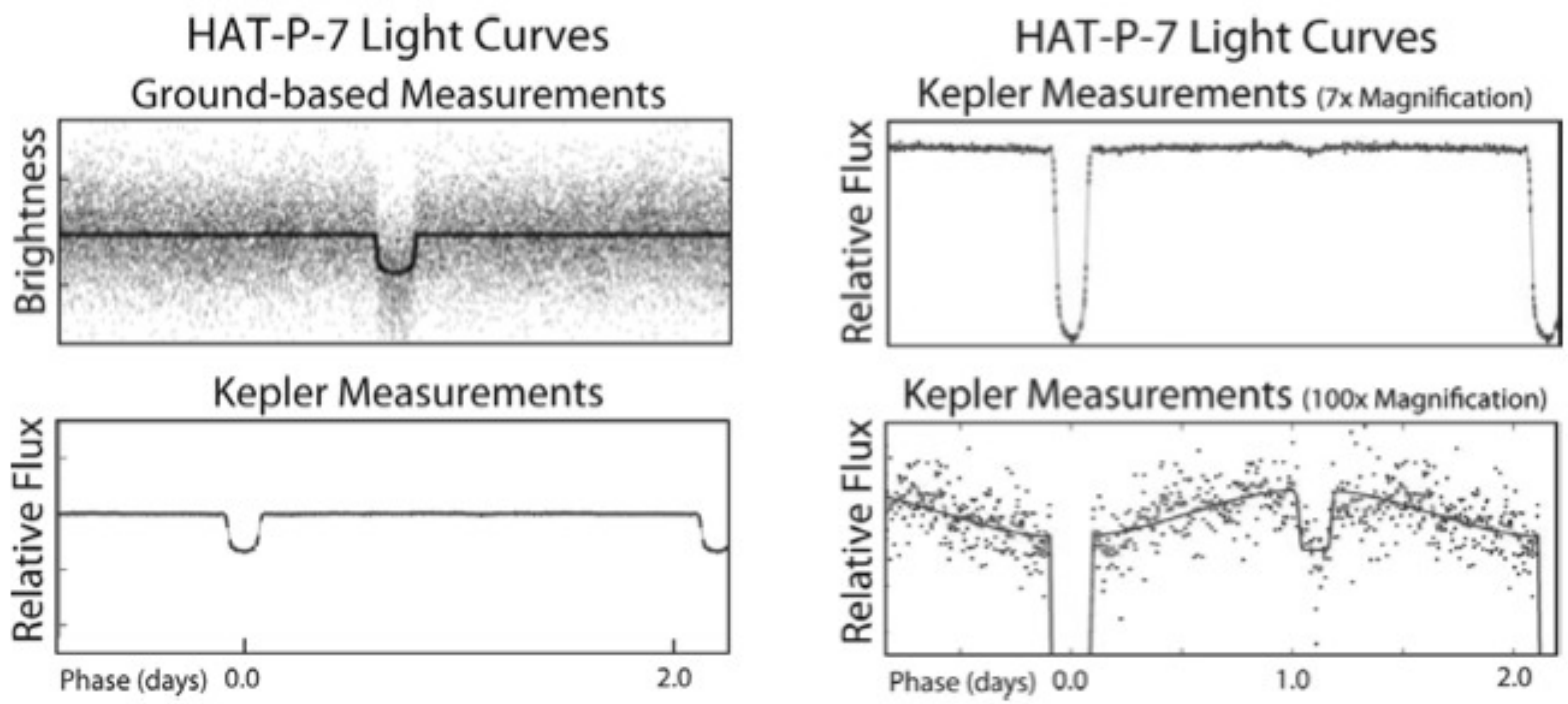


Figure 2. Kepler observations of exoplanet HAT-P-7b. Left panel upper: Ground based observations. Left panel lower: Scatter of the data points in the Kepler data is within the line thickness. Kepler precision is 100 times better than that from ground-based observations. Right panel; Scale expanded 7 and 100 times. The transit is off scale on the bottom half of the right panel, but the occultation and the variation of light from the combination of starlight and planet emission are clearly visible.

Exoplanet atmospheres can be detected during transits

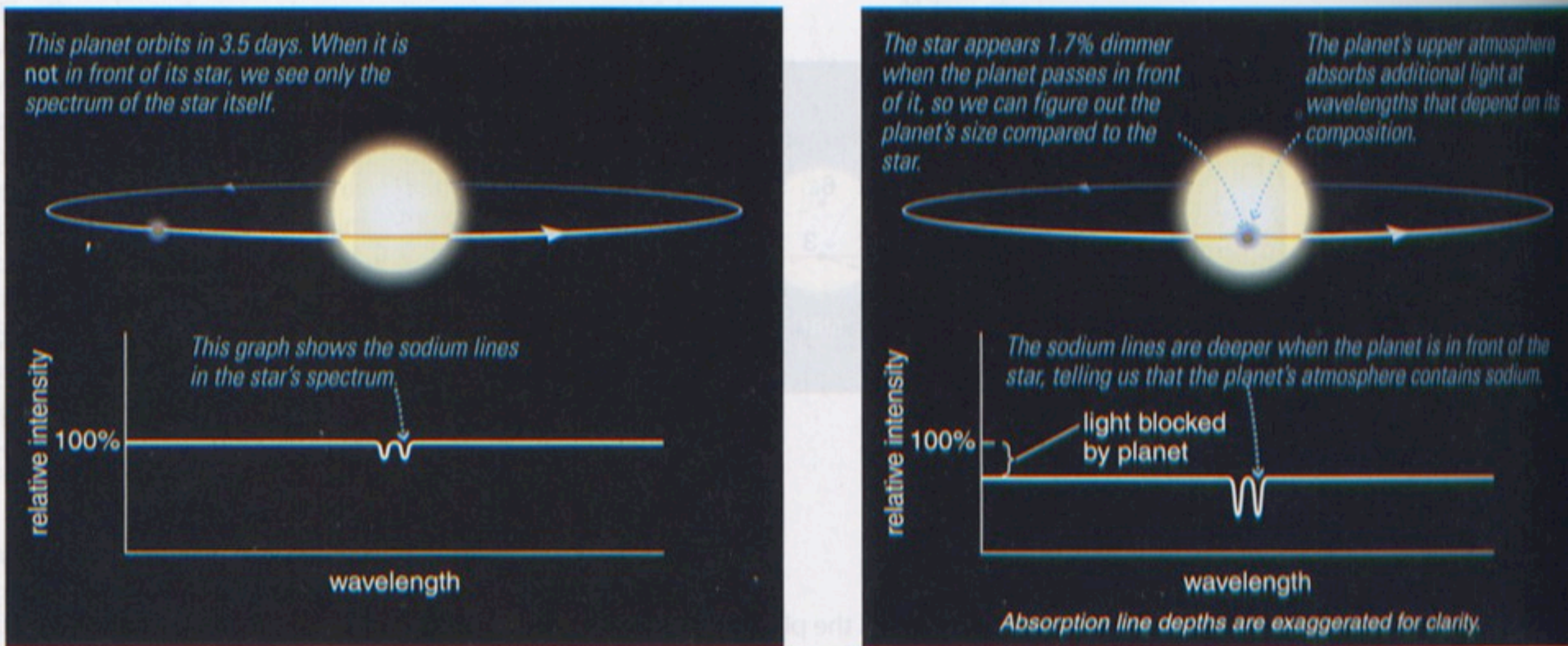
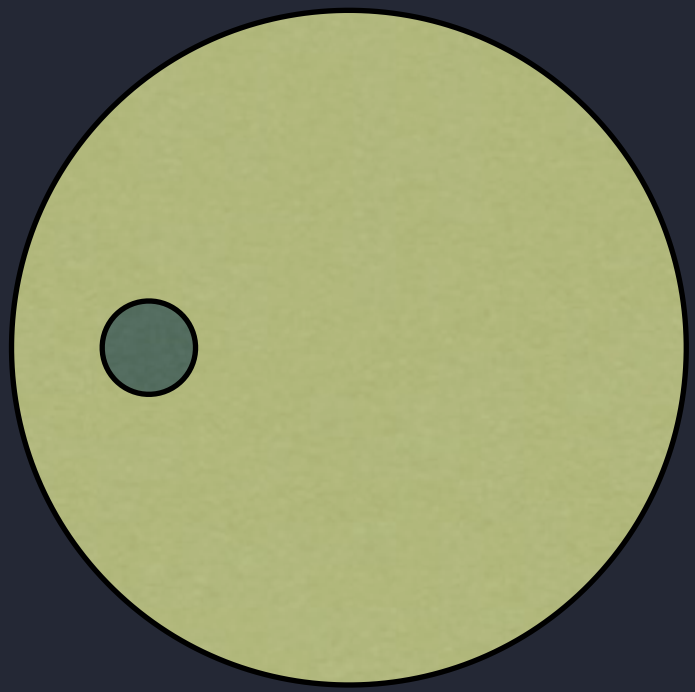


Figure 13.8 This diagram shows how transit observations can give us information about the composition of an extrasolar planet's extended upper atmosphere or exosphere.

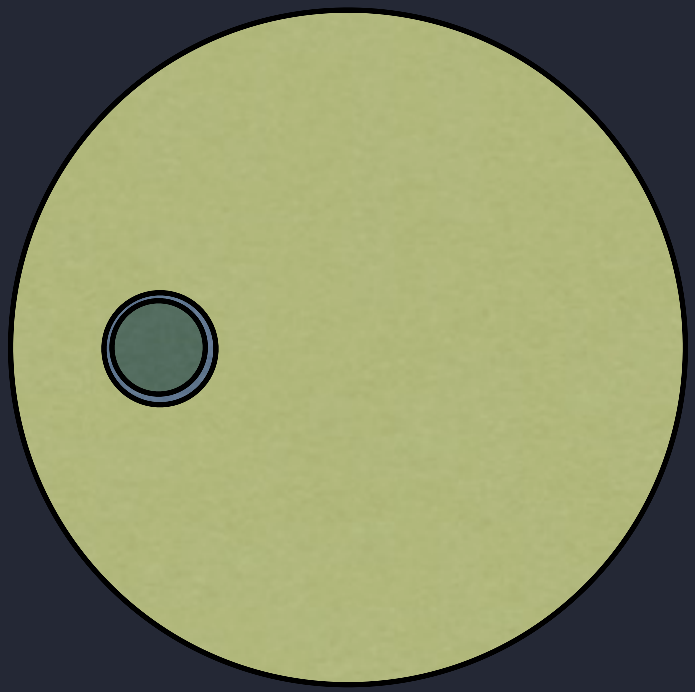
schematic of spectroscopy of the atmosphere, as the starlight shines through it during an eclipse

You can also think of this in terms of regular transit considerations

The planet effectively has a bigger radius when you look at wavelengths at which its atmosphere is opaque



vs.



multiplanet systems (left); Note (below) lighter planets are discovered as time goes on.

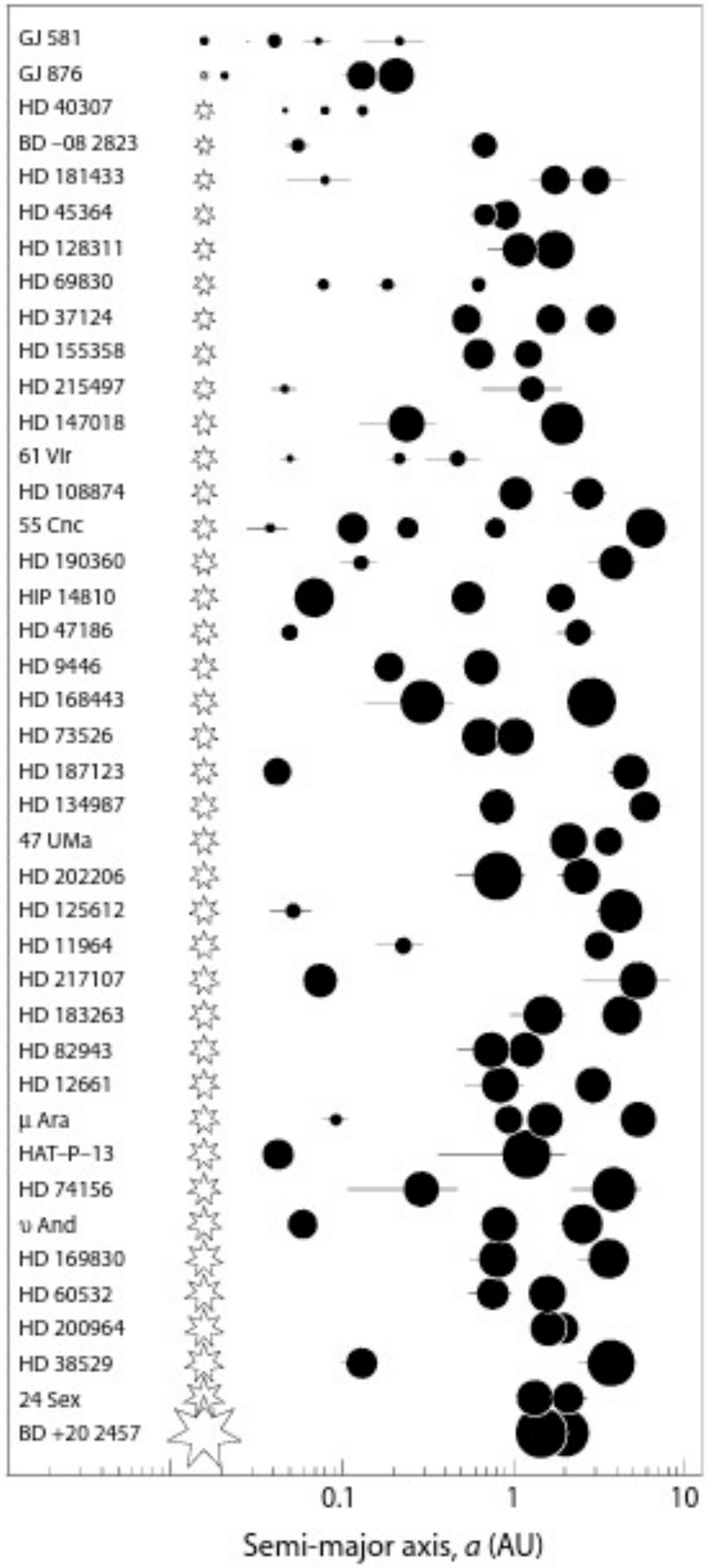


Figure 2.29: Multiple planet systems, ordered by host star mass (indicated at left with size proportional to $M_\star$, ranging from $0.31M_\odot$ for GJ 581 to $2.8M_\odot$ for BD +20° 2457). Each planet in the system is shown to the right, with sizes proportional to $\log M_\mathrm{p}$ (ranging from about $0.01 - 20M_\mathrm{J}$). Horizontal bars through the planets indicate maximum and minimum star–planet distance based on their eccentricities. Data are for 97 planets in 41 systems from `exoplanets.org`*, 2010–11–01. From a concept by Marcy et al. (2008, Figure 13).*

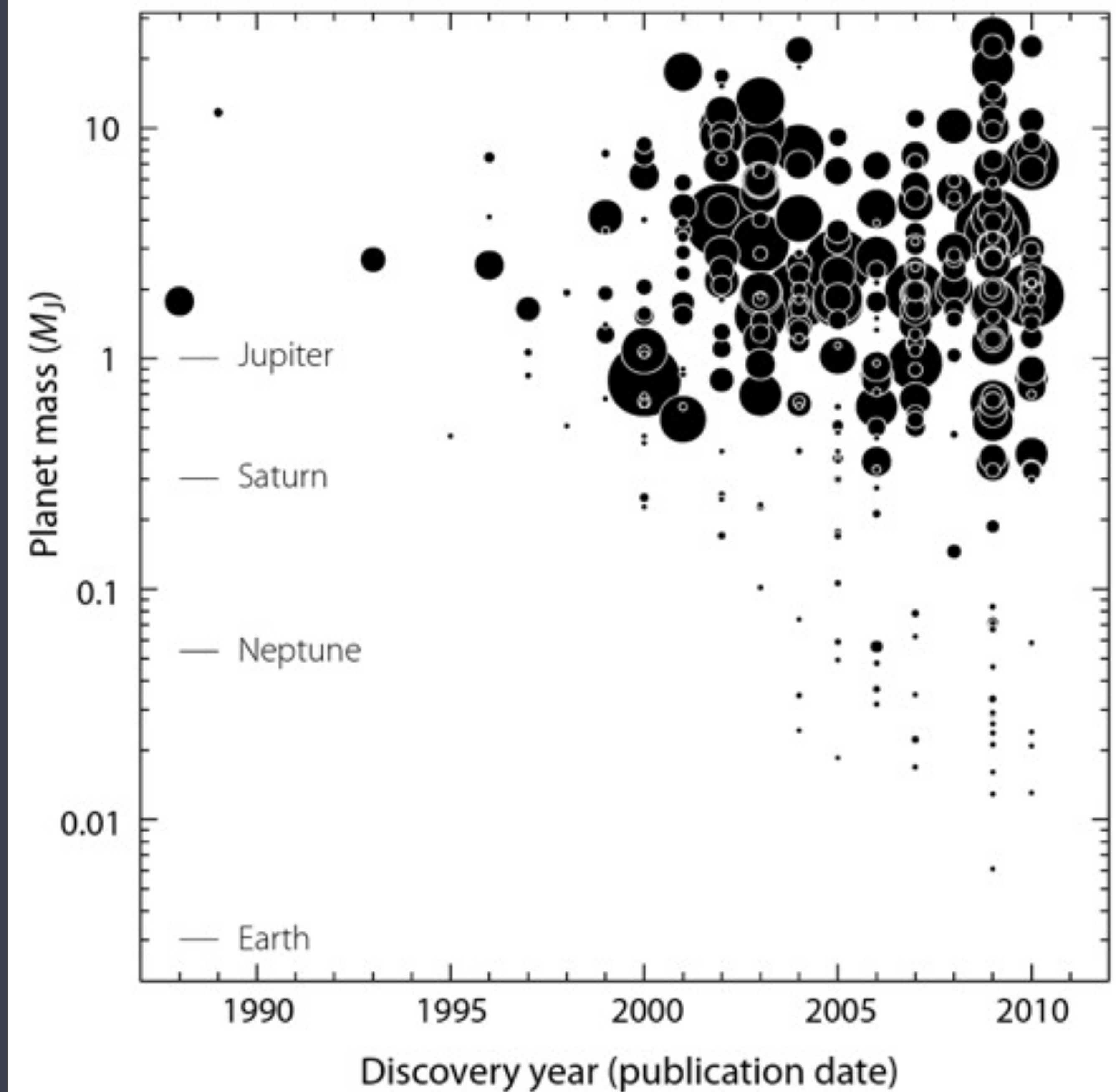
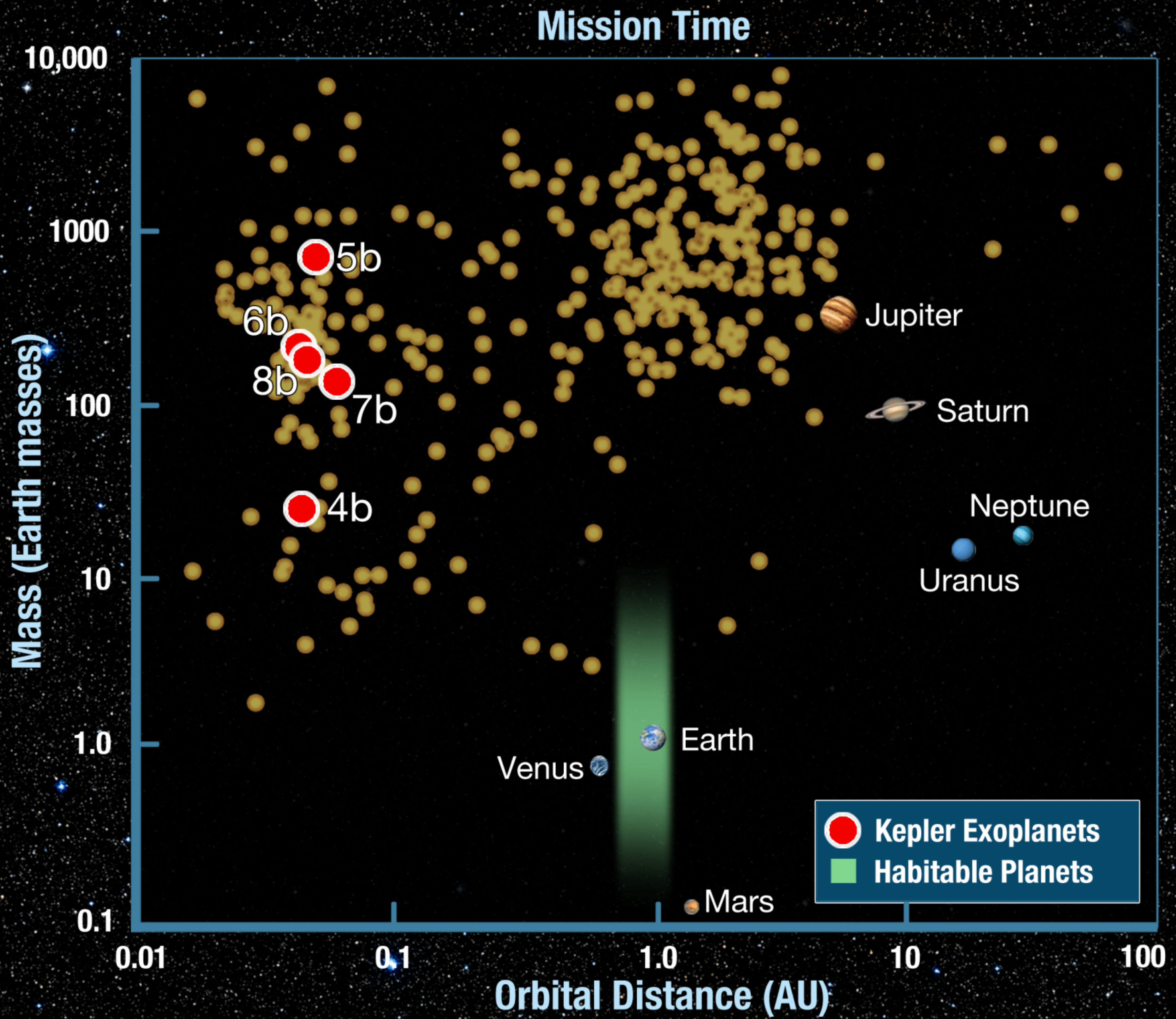


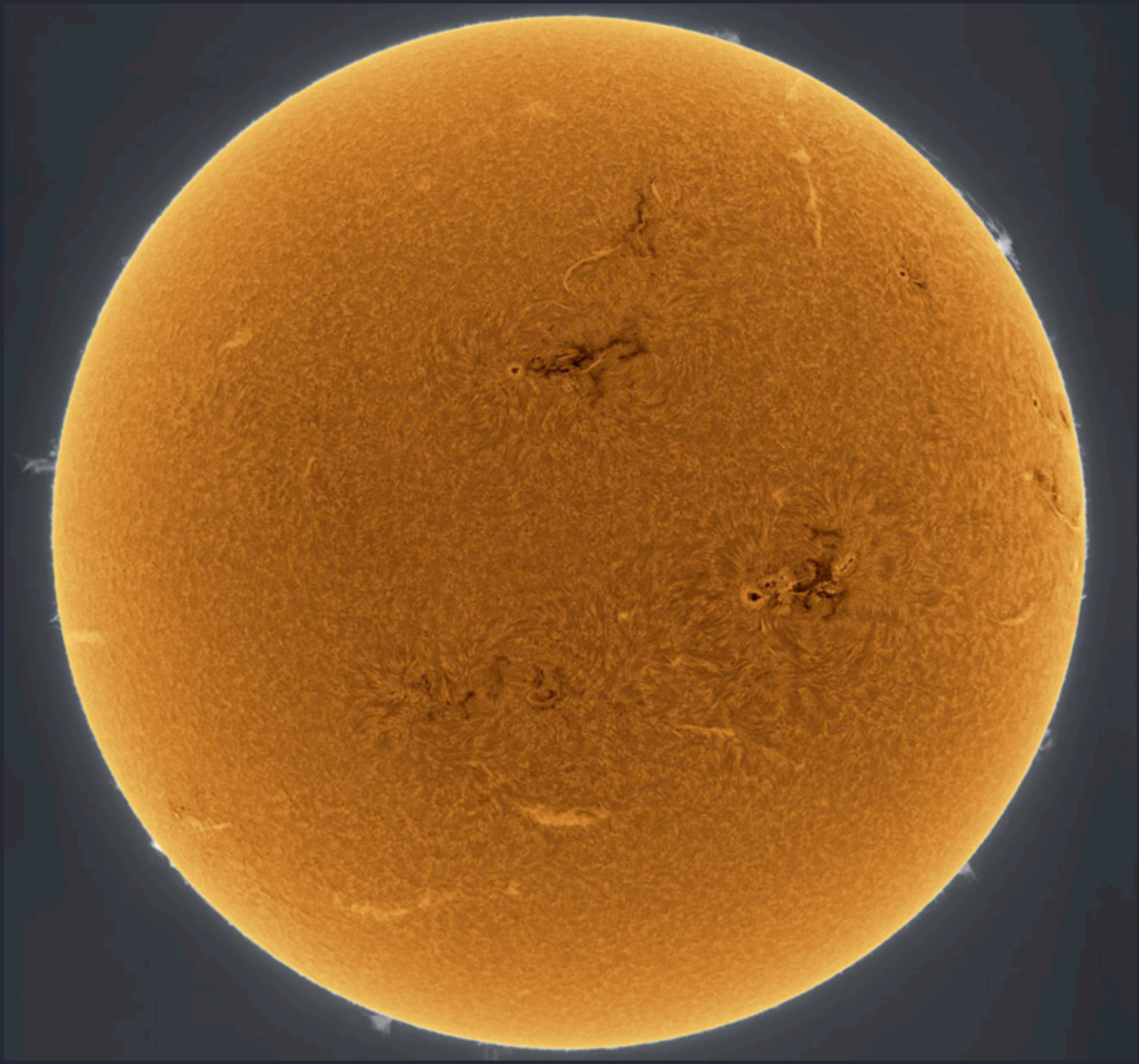
Figure 2.17: Planets discovered by radial velocity measurements, according to mass and year of discovery. Circle sizes are proportional to the semi-major axis a. Data are for 383 planets from `exoplanets.org`*, 2010–11–01.*

First Five Planet Discoveries

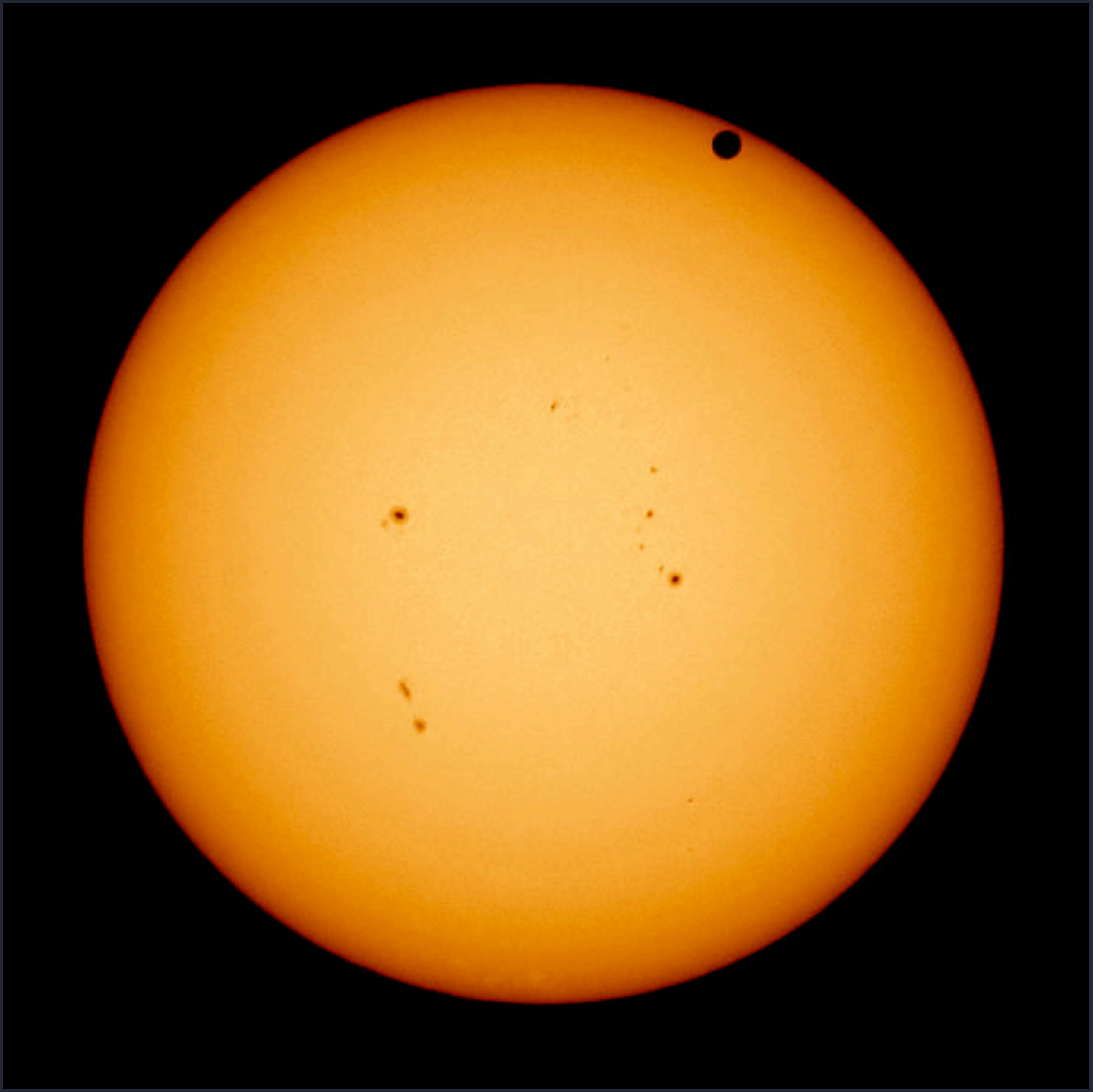
Made with First 43 Days of Data



The Sun: stars have surface brightness variations. This limits the precision with which transits and Doppler shifts can be measured.



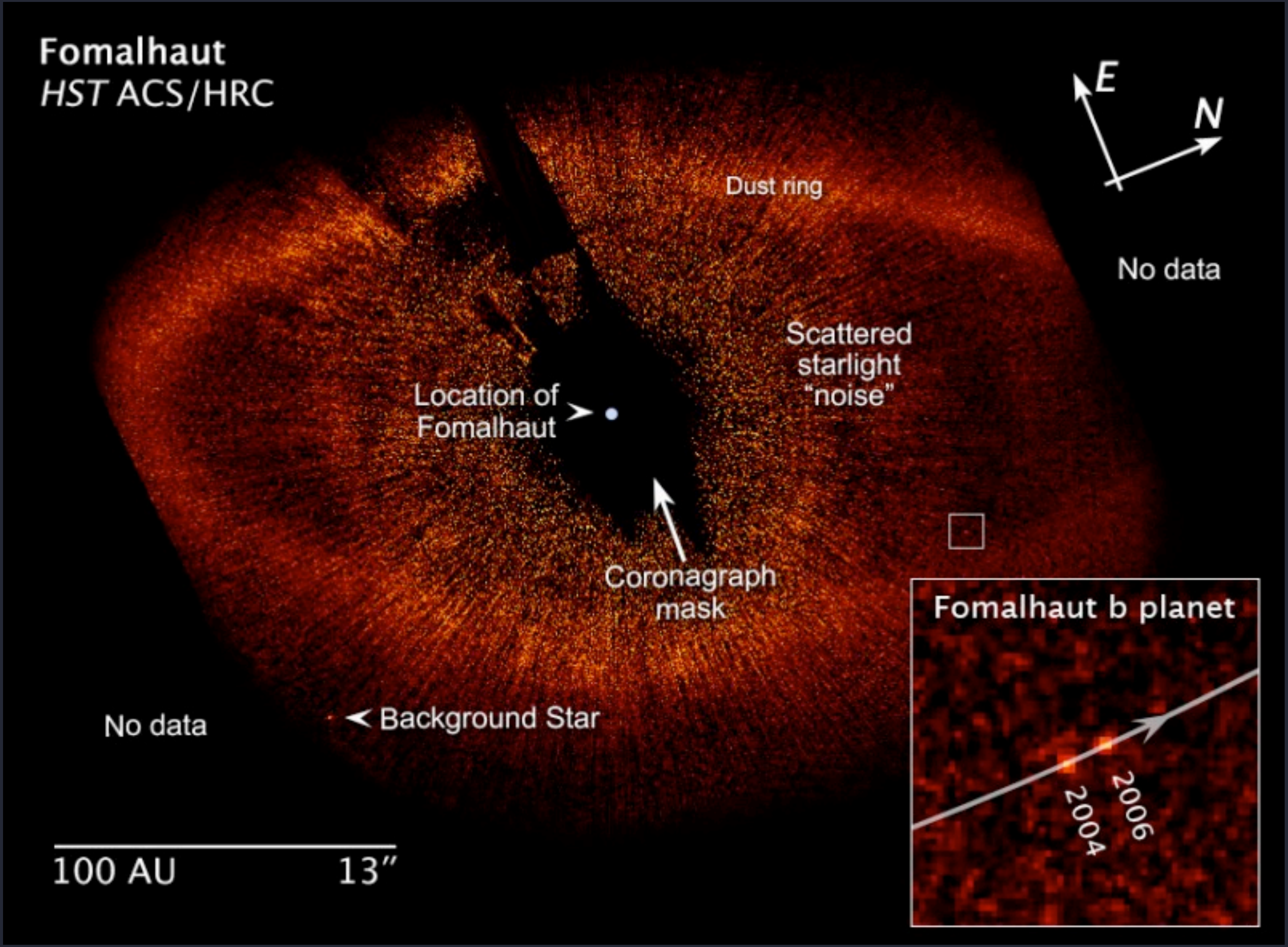
Limb darkening...plus sunspots and a transit of Venus



Exoplanet summary

Exoplanets are common
Many systems have planets very close to their host stars
These “hot Jupiters” seem to have formed farther from their stars and migrated inward

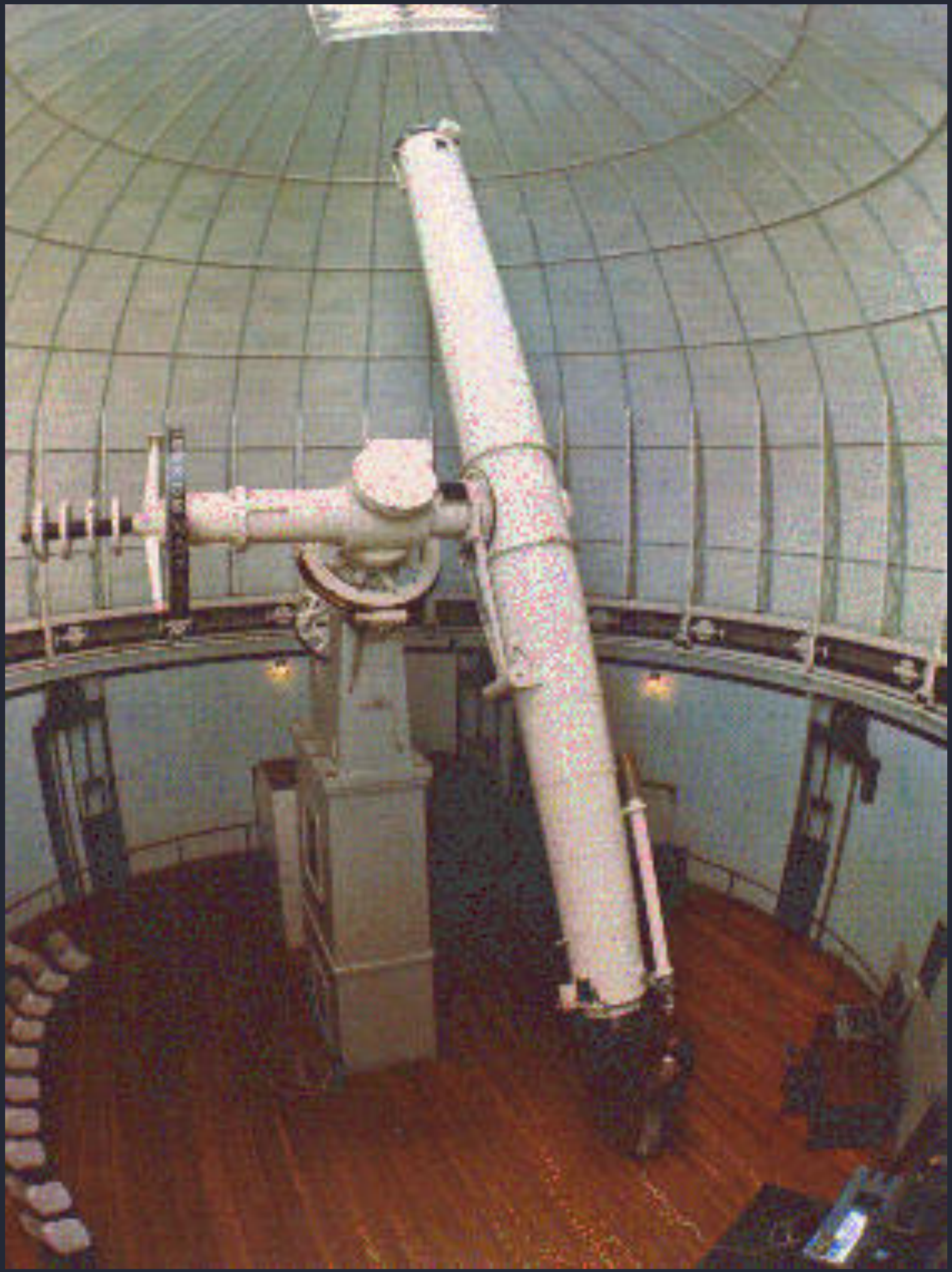
Direct imaging of exoplanets will be common someday (probably)



Now let’s start on telescopes

The Hubble Space Telescope – 200 km above the Earth, but it makes all the difference: above the distorting effects of the atmosphere

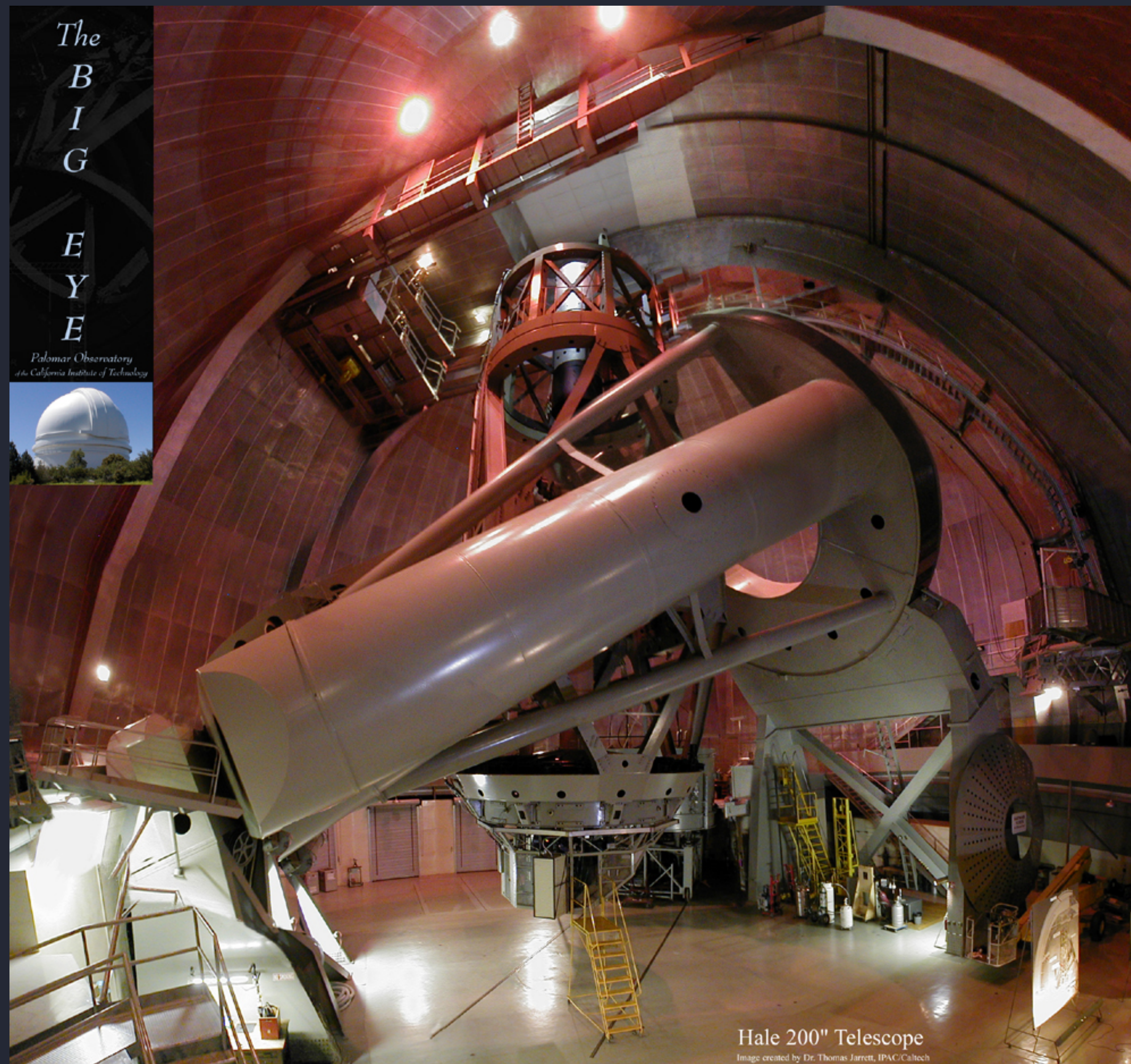
In the public imagination, telescopes are refractors (i.e. have lenses)
This tends to make them very long.



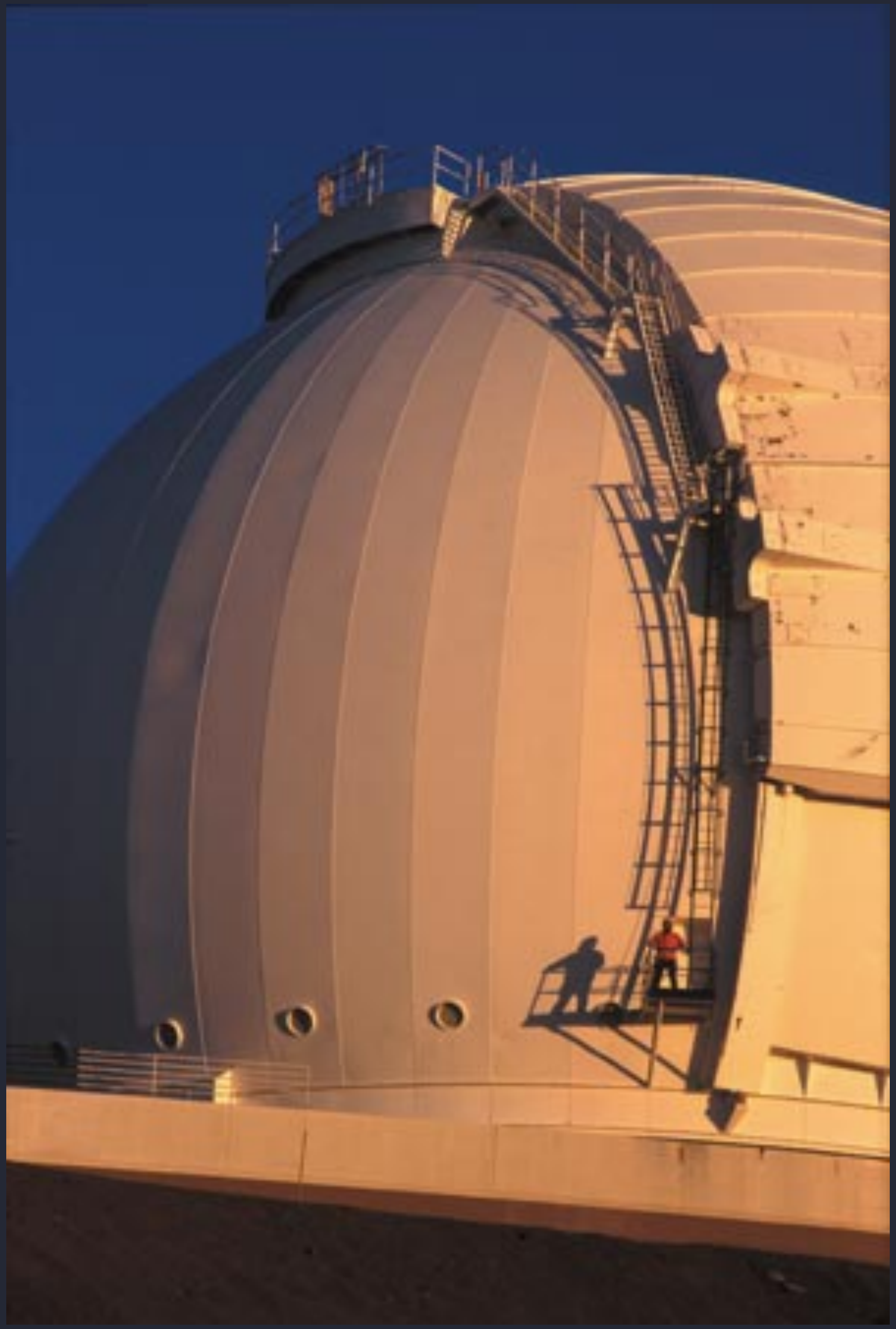
There's a physical limit to how big a telescope can get…without bending the tube or stressing the lens.

Yerkes refractor: world's biggest with a 40-inch lens

Biggest telescopes are all reflectors (mirrors, not lenses)



The light can bounce back and forth several times; they don't need to be as long

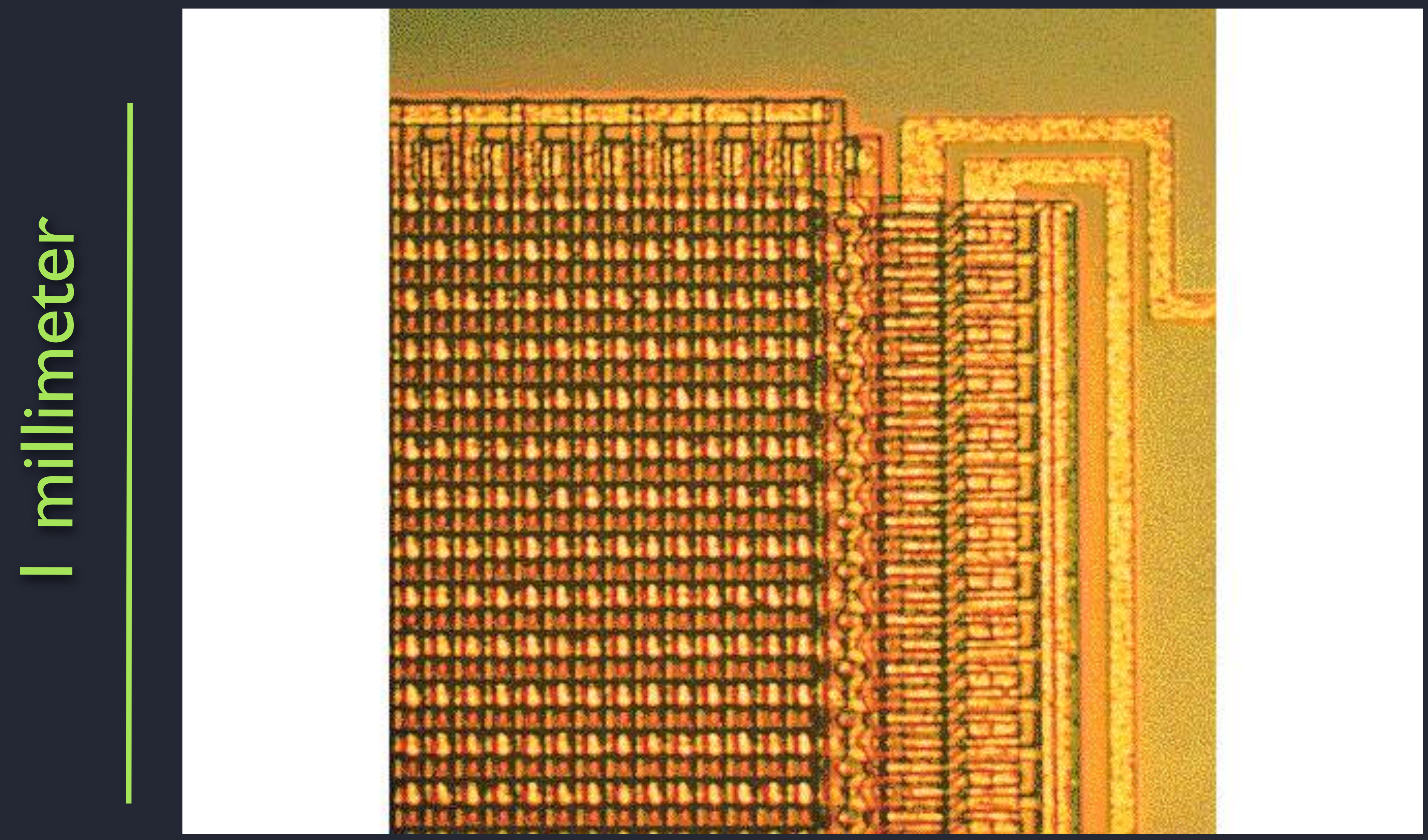


Huge telescopes are built only at the best sites: high altitude, dry air.

Also, images from two big scopes can be combined, effectively making one huge telescope (albeit with a strange-shaped mirror).

Kitt Peak in Arizona: More than ten telescopes, including the National Solar Observatory

No astronomers put their eye up to a research telescope these days… Collect data on electronic detectors, such as this charge-couple device (CCD) (same type of detector as those in commercial digital cameras).

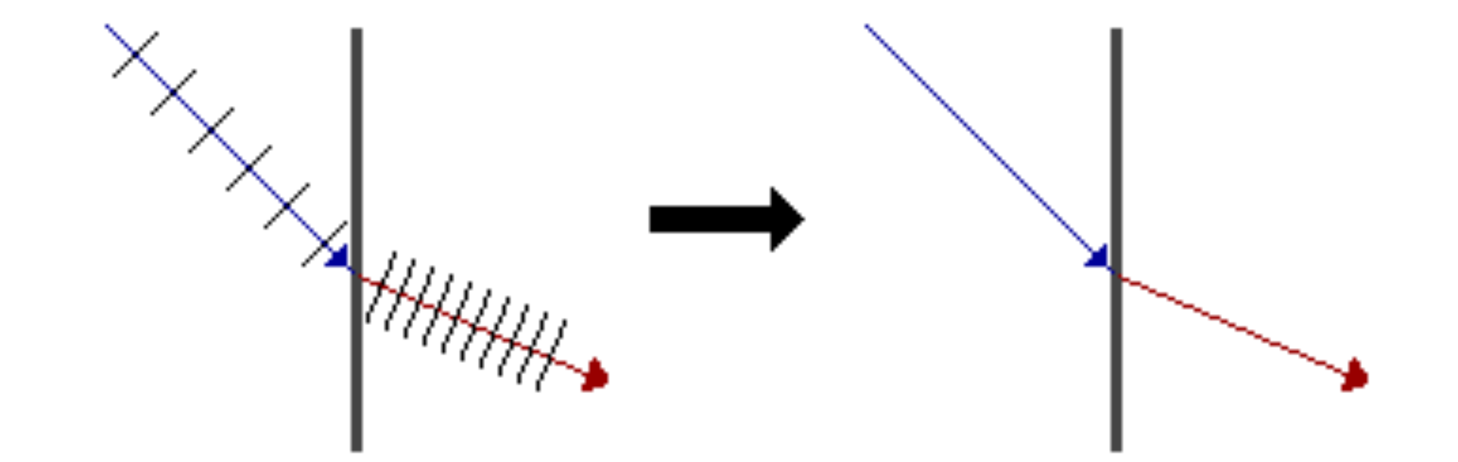


Magnified image of a CCD. Each little square is a pixel, in which photons get converted to electrons, which can be counted, or “read out”

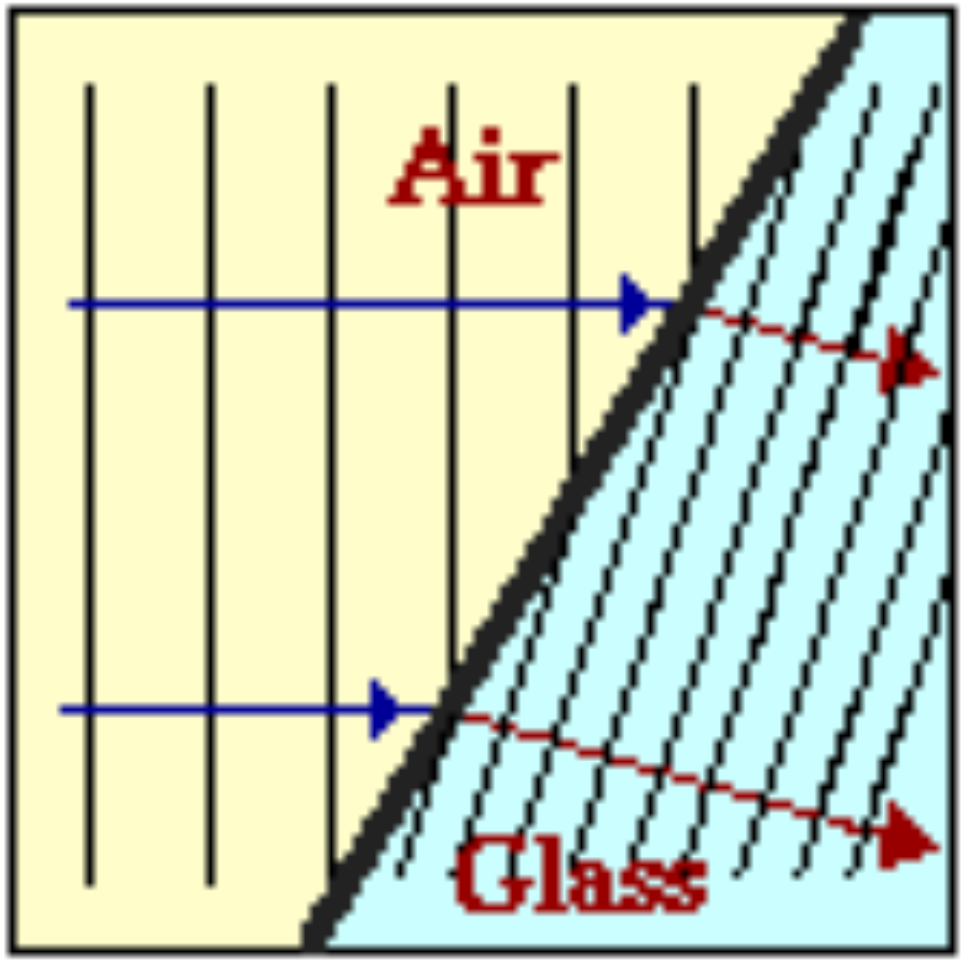
The Hubble Space Telescope – 200 km above the Earth, but it makes all the difference: above the distorting effects of the atmosphere

Also able to observe infrared (IR) and ultraviolet (UV) light, which is absorbed by the atmosphere.

Now for some slides on **refraction** which is the basis for how lenses and telescopes work

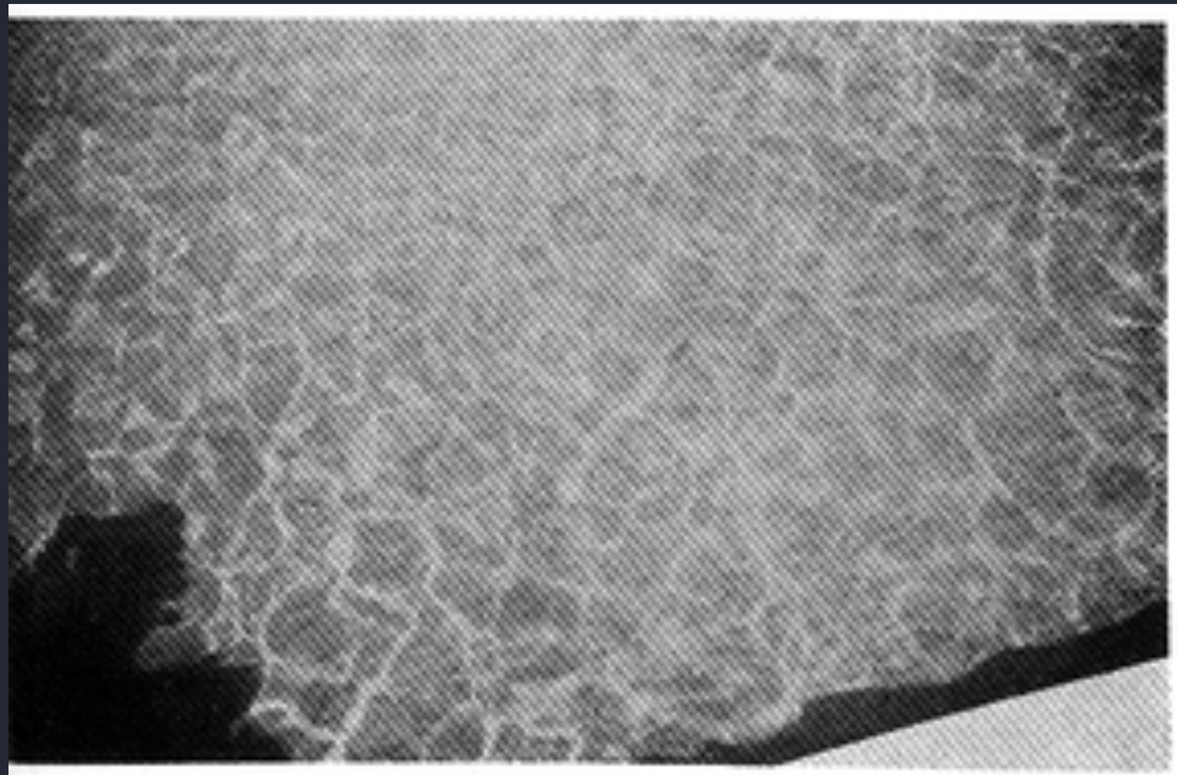


A ray will be used to depict the direction which a wavefront travels.



Refraction of light occurs at the air-glass boundary.

Since refraction bends light, but the total amount of light must be conserved, refraction by real objects tends to make patterns of light and dark…



(*b*) Sunlight, refracted by slightly undulating and shallow water, is concentrated on the bottom in lines of light

Where will the fisherman see the image of the fish?

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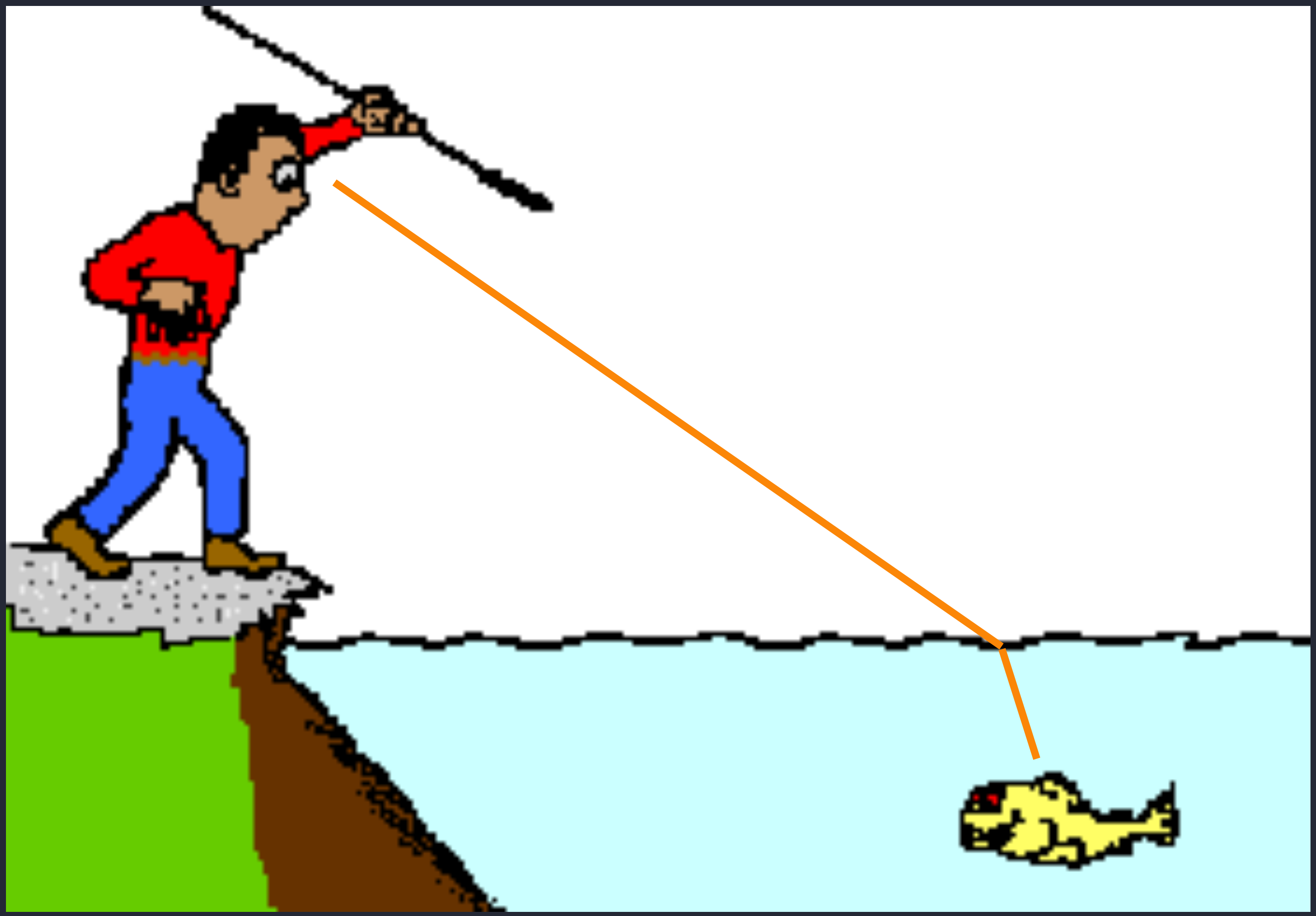
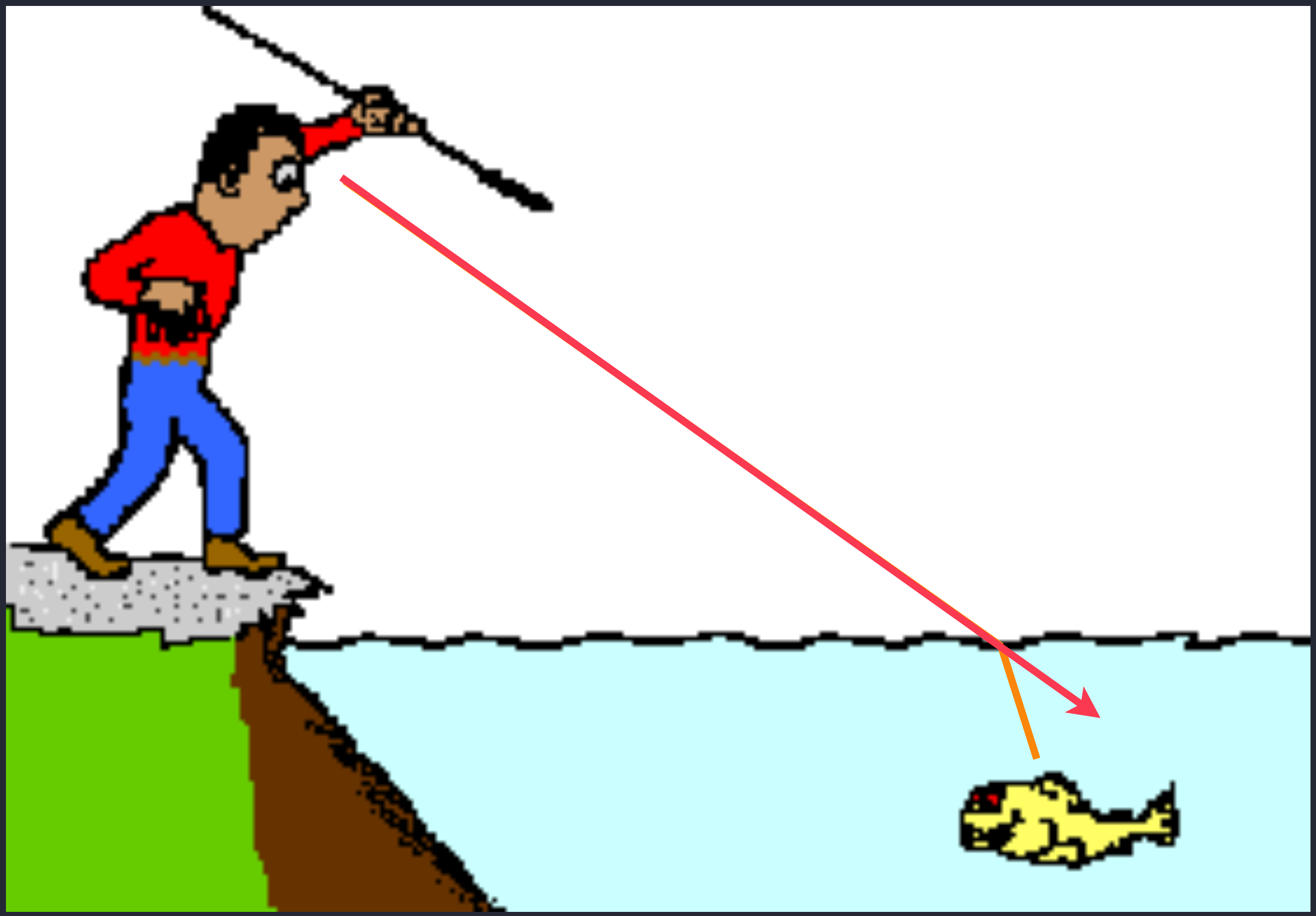


Where will the fisherman see the image of the fish?



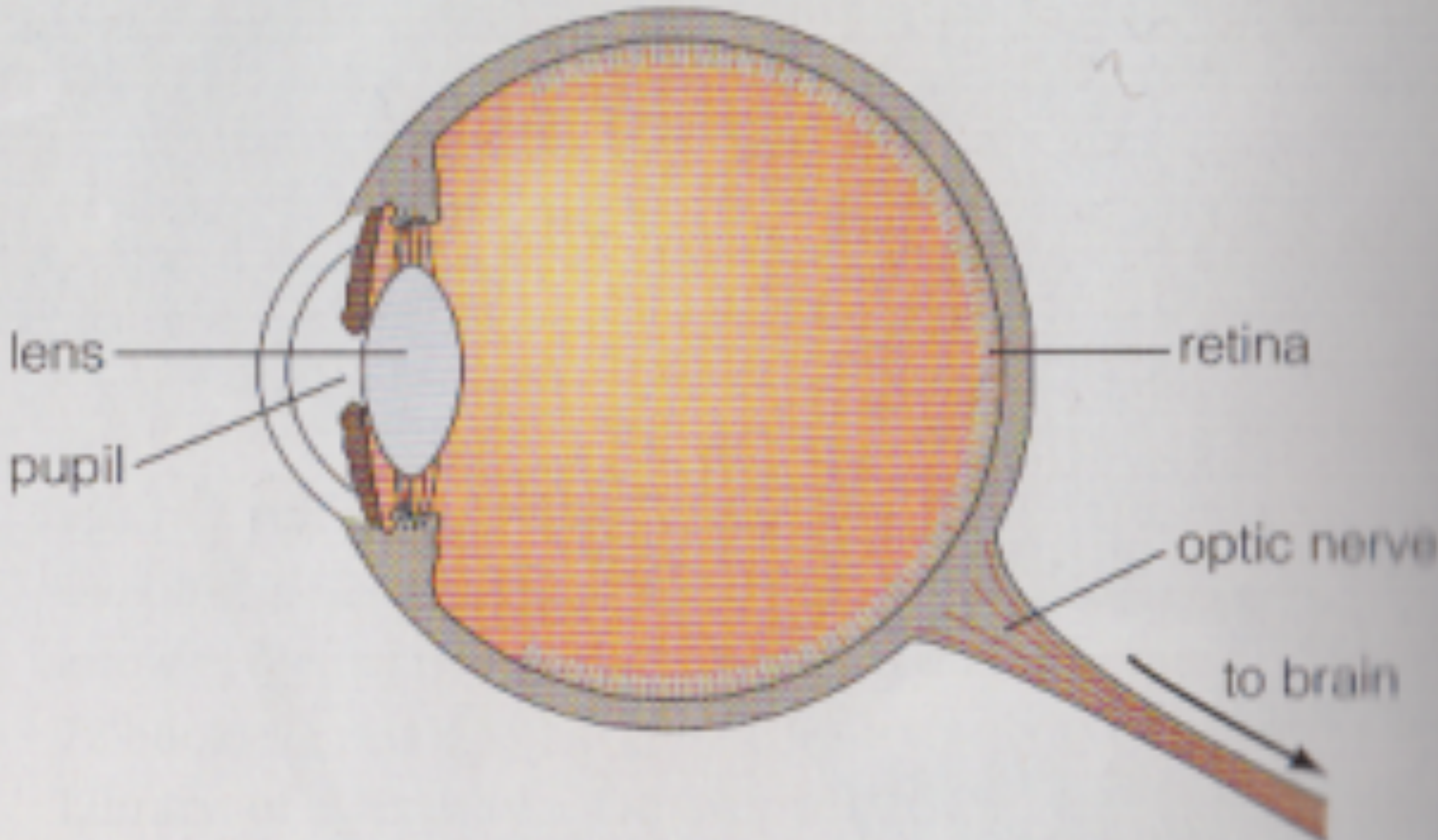


FIGURE 6.1 A simplified diagram of the human eye.

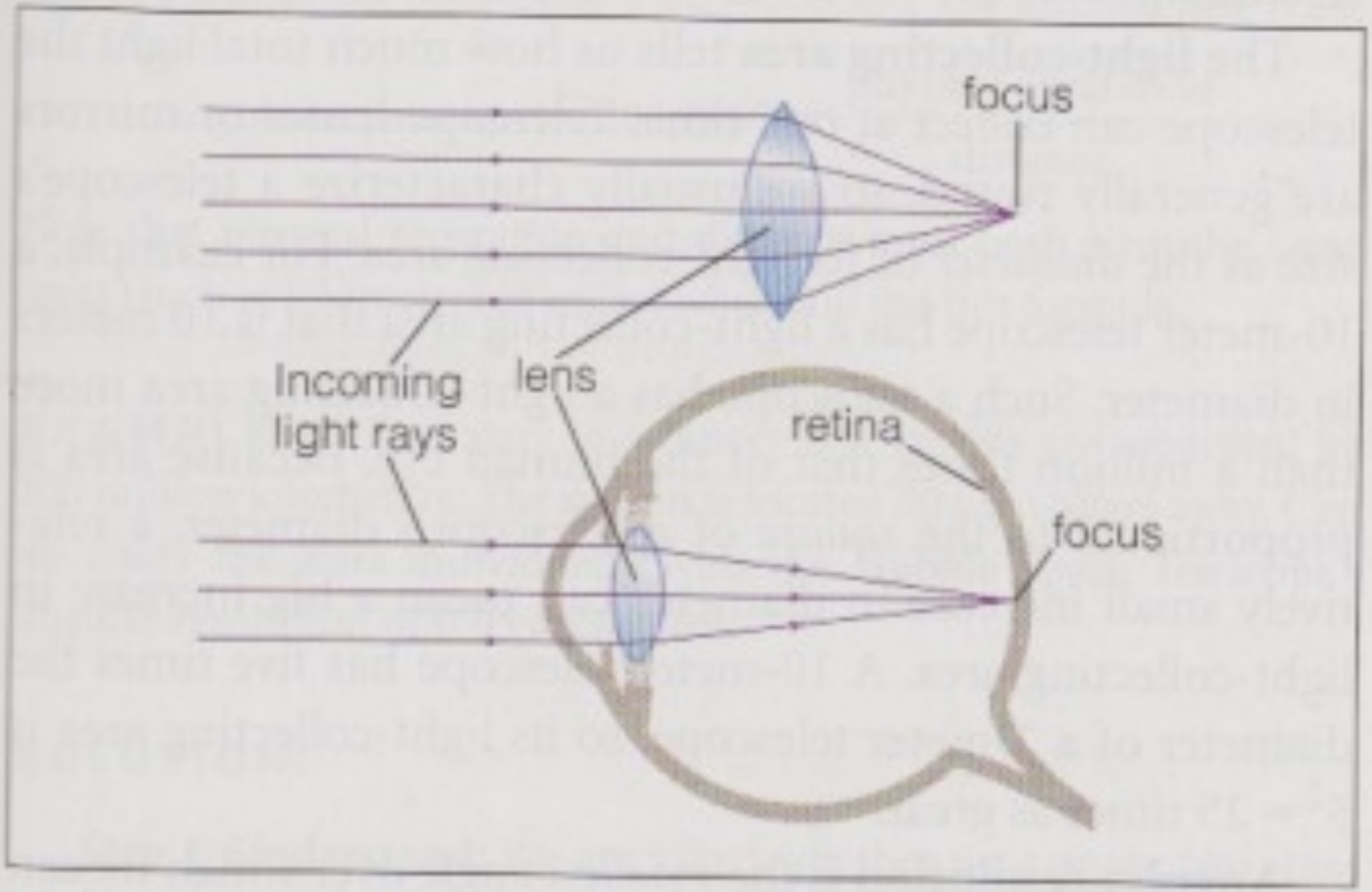


FIGURE 6.3 A glass lens bends parallel rays of light to a point called the *focus* of the lens. In an eye with perfect vision, rays of light are bent to a focus on the retina.