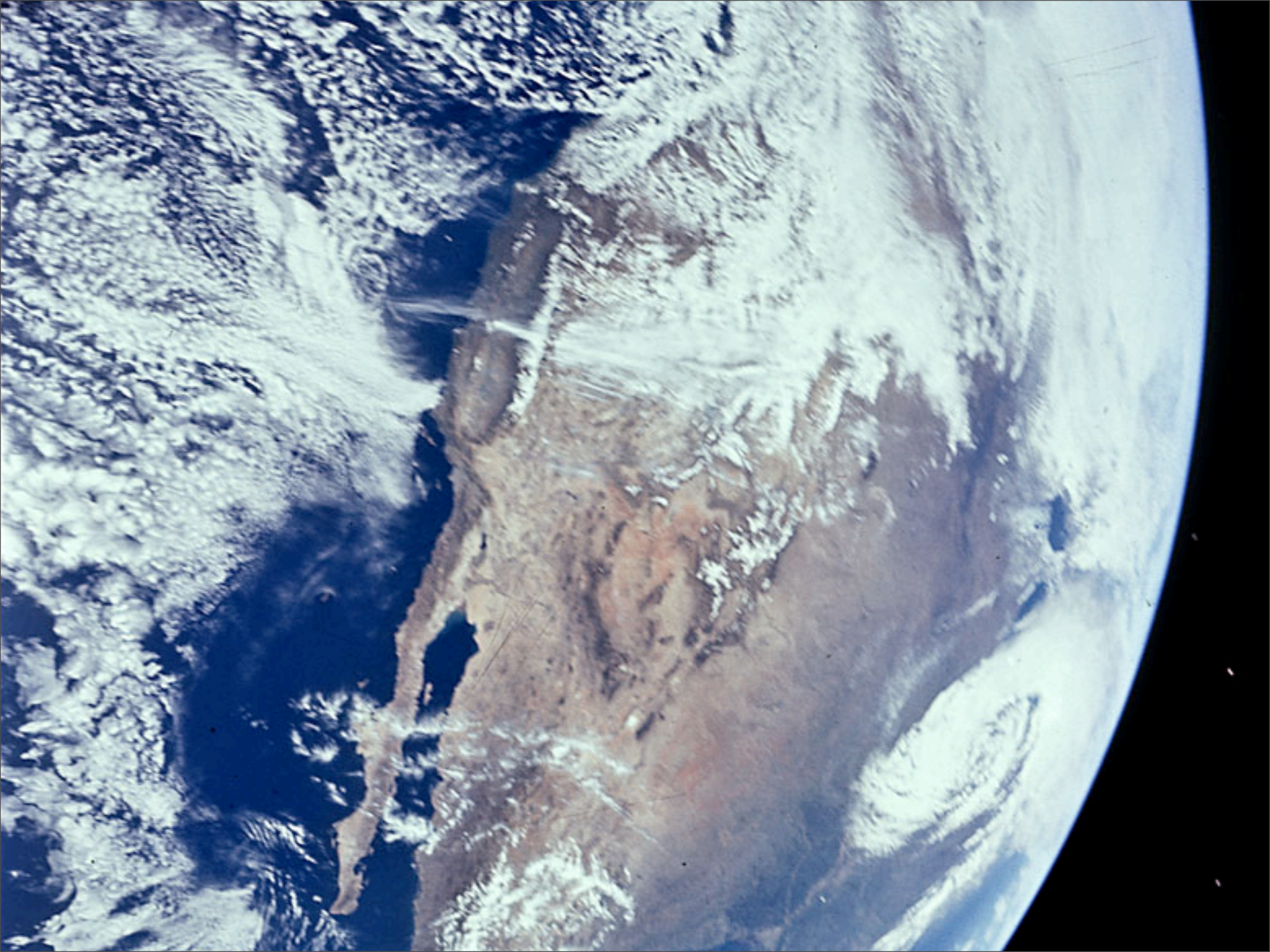
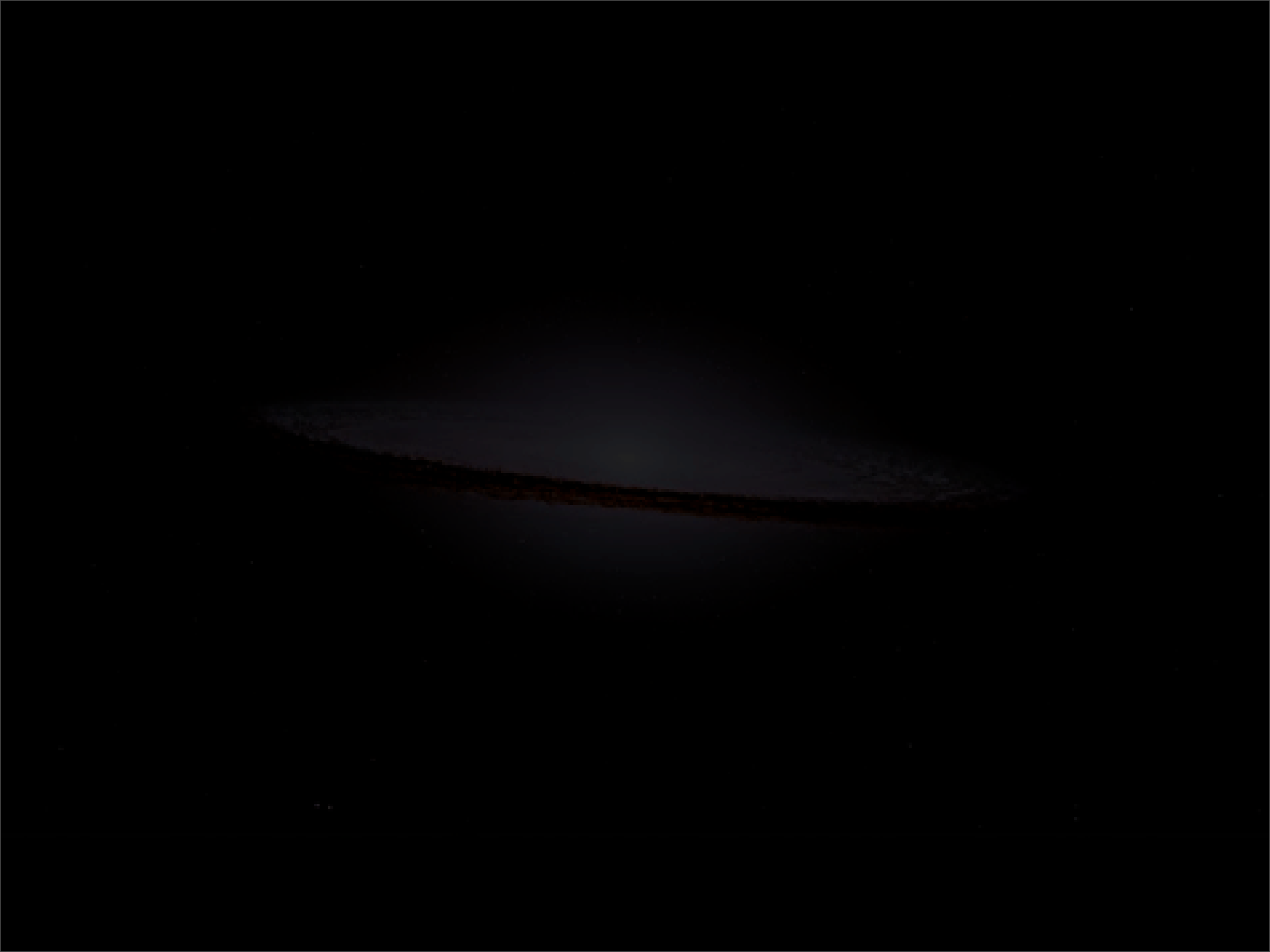
The Galactic Planetary Census

Gregory Laughlin
University of California at Santa Cruz





Formation by Natural Law

Physical *cosmogony*, the idea that the Earth and the other planets arose through natural processes, dates to the 18th century

- Buffon, in 1742, advanced the hypothesis that the planets in our solar system arose from the close encounter of another star, which pulled out a stream of material from the sun that later condensed to form the planets.

G.L.L.C. Buffon

The Nebular Hypothesis

Our current theory of how planets form can be traced directly back to the ideas of Immanuel Kant and Pierre Simon de Laplace

- In 1748, Kant suggested that the planets formed from a spinning disk of gas and dust.

- In 1782, Laplace independently developed a similar theory (with a much more mathematical basis).

P. S. de Laplace

"Dreams about the modes of creation, inquiries whether our globe has been formed by the agencies of fire or water, how many millions of years it has cost Vulcan or Neptune to produce what the fiat of the creator would effect by a single act of will are too idle to be worth a single hour of any man's life."

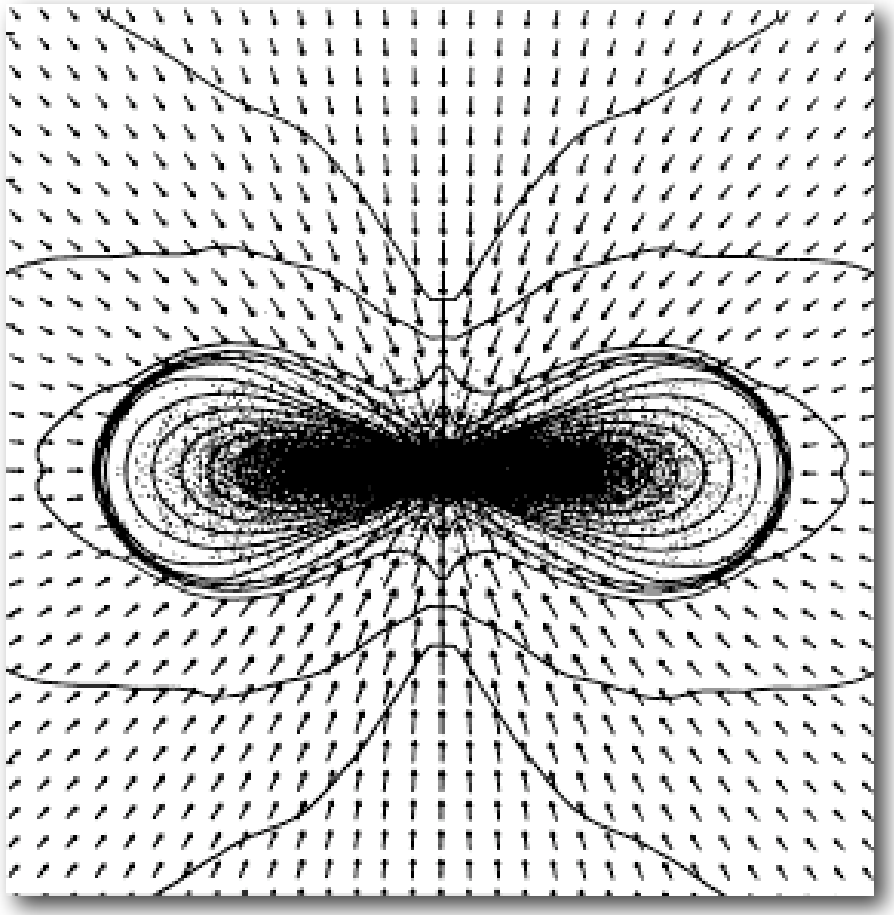
-Thomas Jefferson

(Writing on the topic of Laplace's Nebular Hypothesis for the formation of the Solar System.)

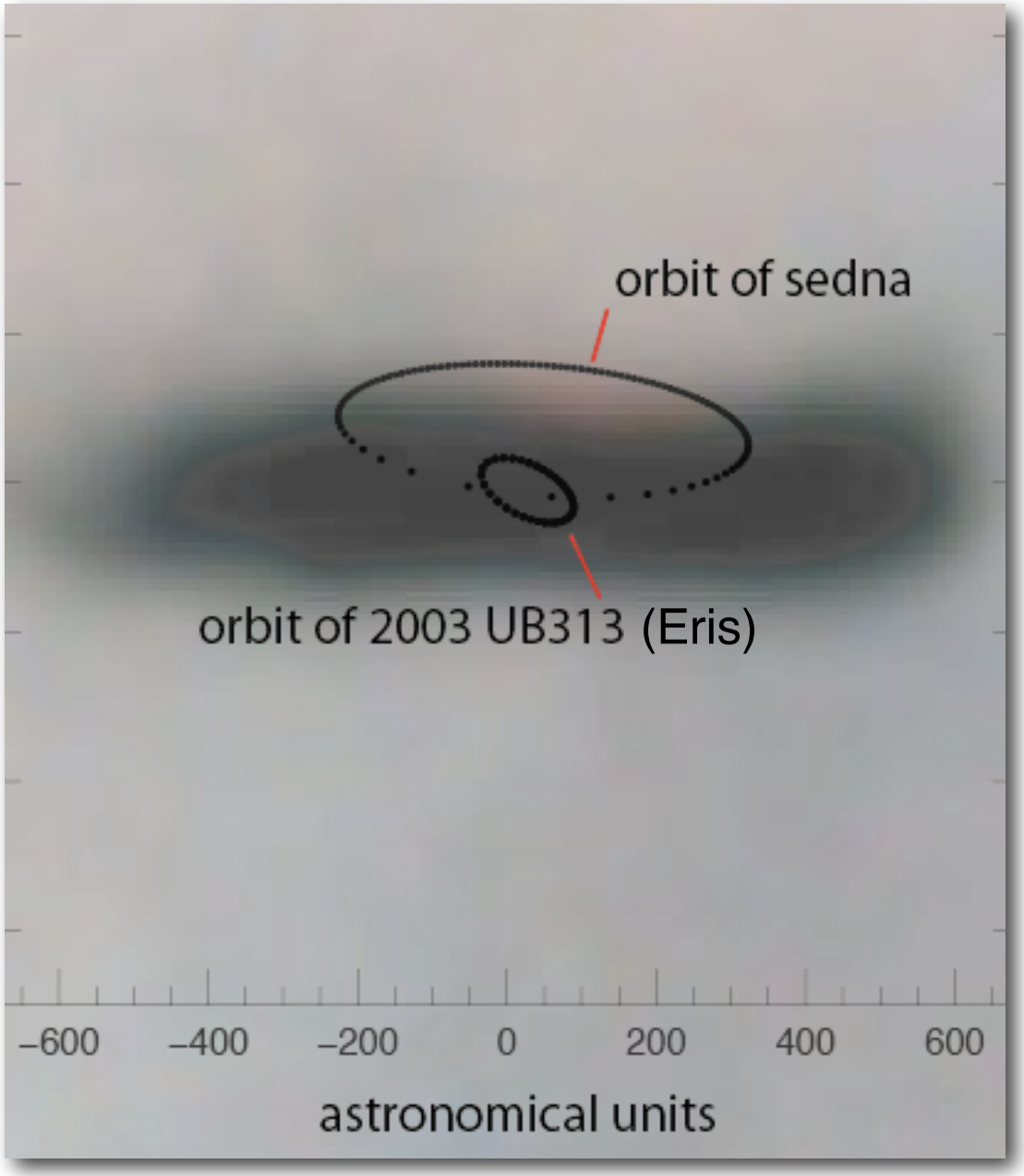
Source: Ronald Numbers, 1977, "Creation by Natural Law -- Laplace's Nebular Hypothesis in American Thought", University of Washington Press

A star and its planetary system forms when an interstellar cloud of gas and dust collapses under its own weight to form a "protostar" surrounded by a spinning disk.

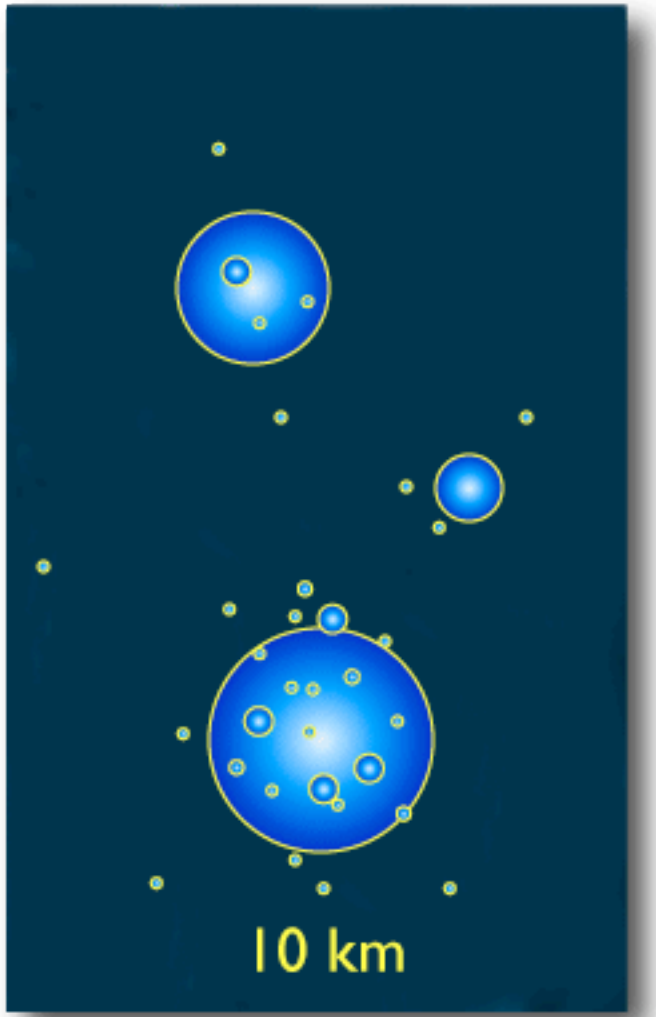
Hubble Space
Telescope image



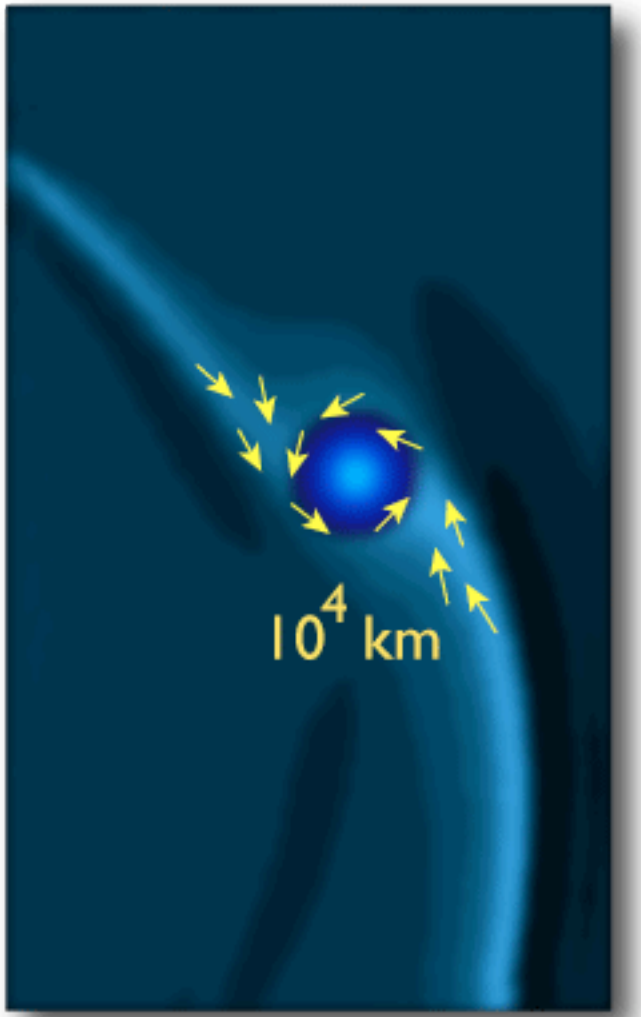
A computer simulation


orbit of sedna
orbit of 2003 UB313 (Eris)
–600
–400
–200
0
200
400
600
astronomical units

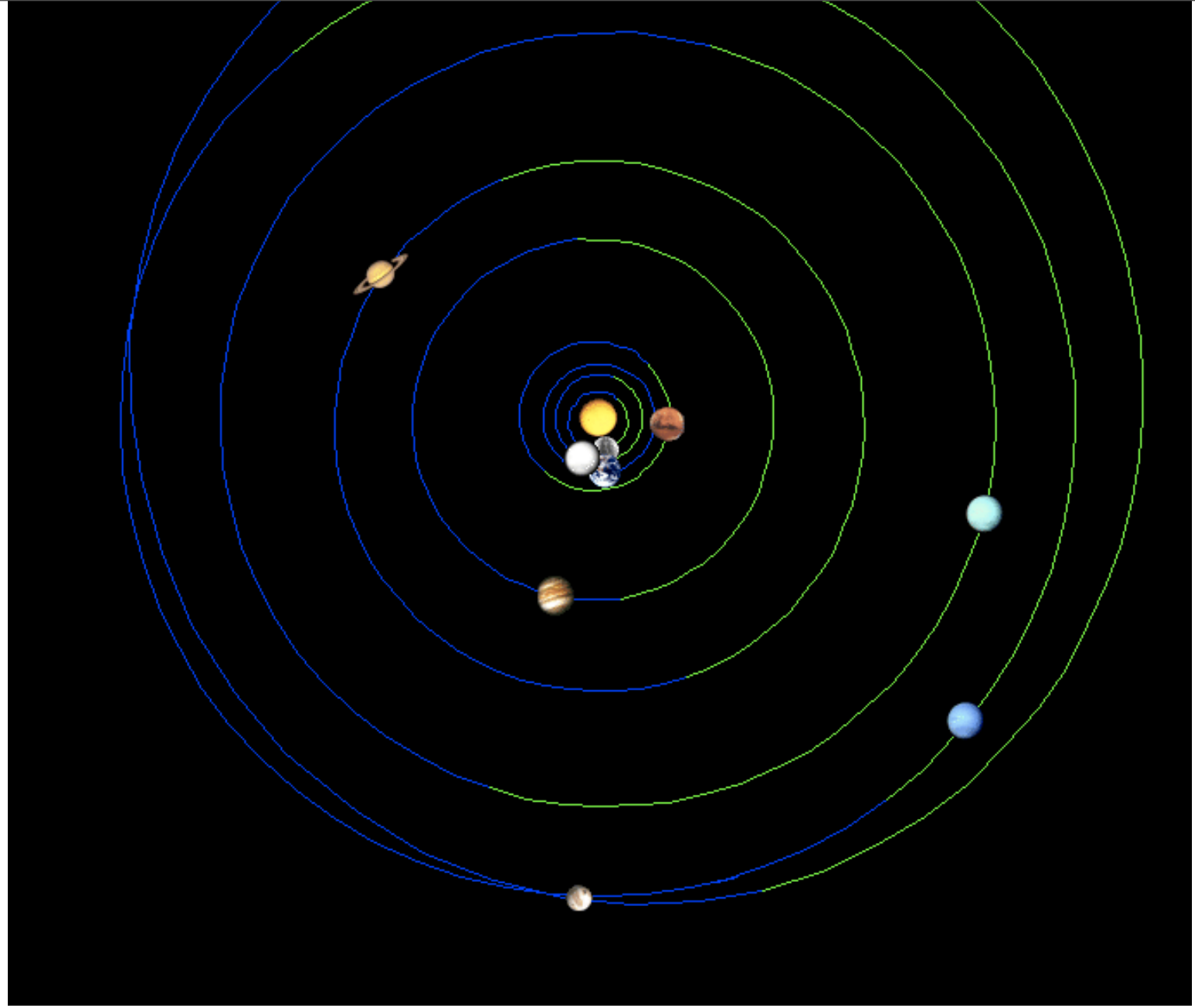
Early growth:
Sticking and Coagulation



Mid-life growth:
Gravitational Attraction

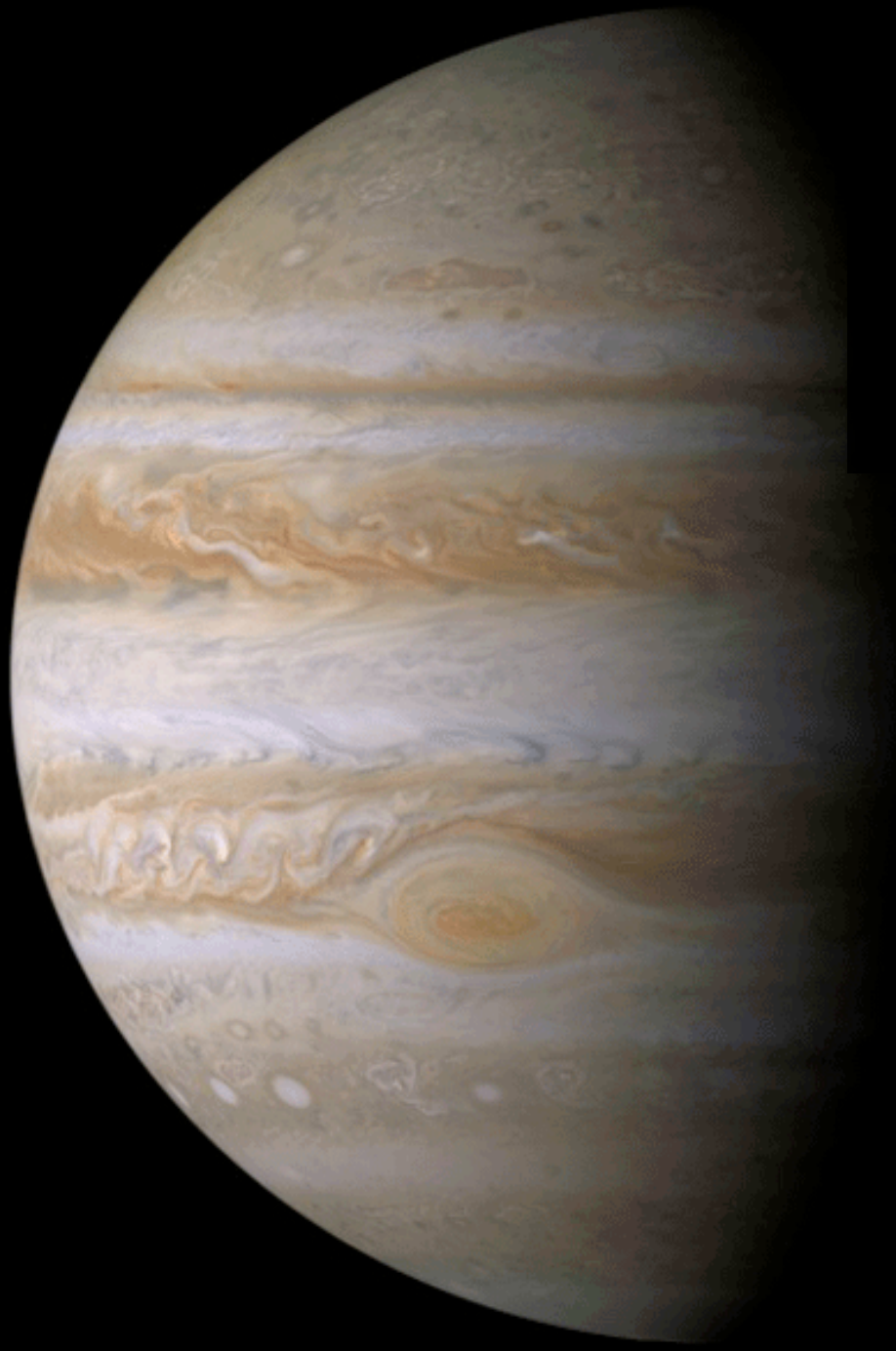


Late growth:
Gas Sweeping

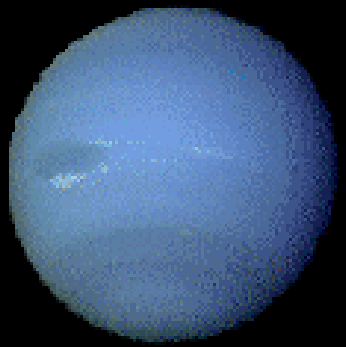


The positions of the planets (and Pluto!) at 9:00 AM, June 30, 2007, PDT
(Julian Day 2454282.16667)

http://www.fourmilab.ch/cgi-bin/uncgi/Solar



Gas Giants



Ice Giants

Terrestrial Planets

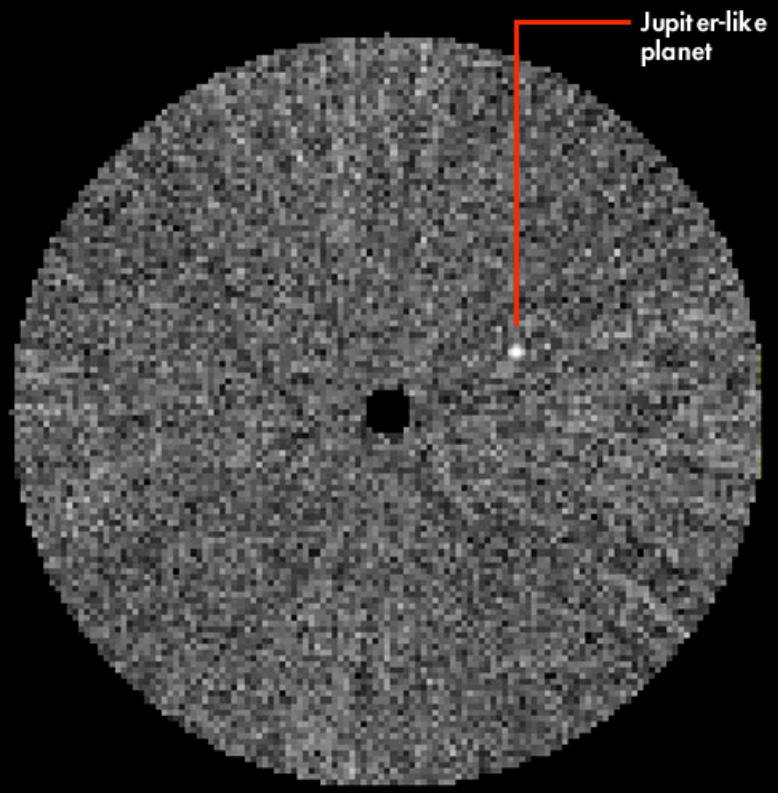
Icy Outer “Dwarf Planets”


Planets are readily lost in
the glare.

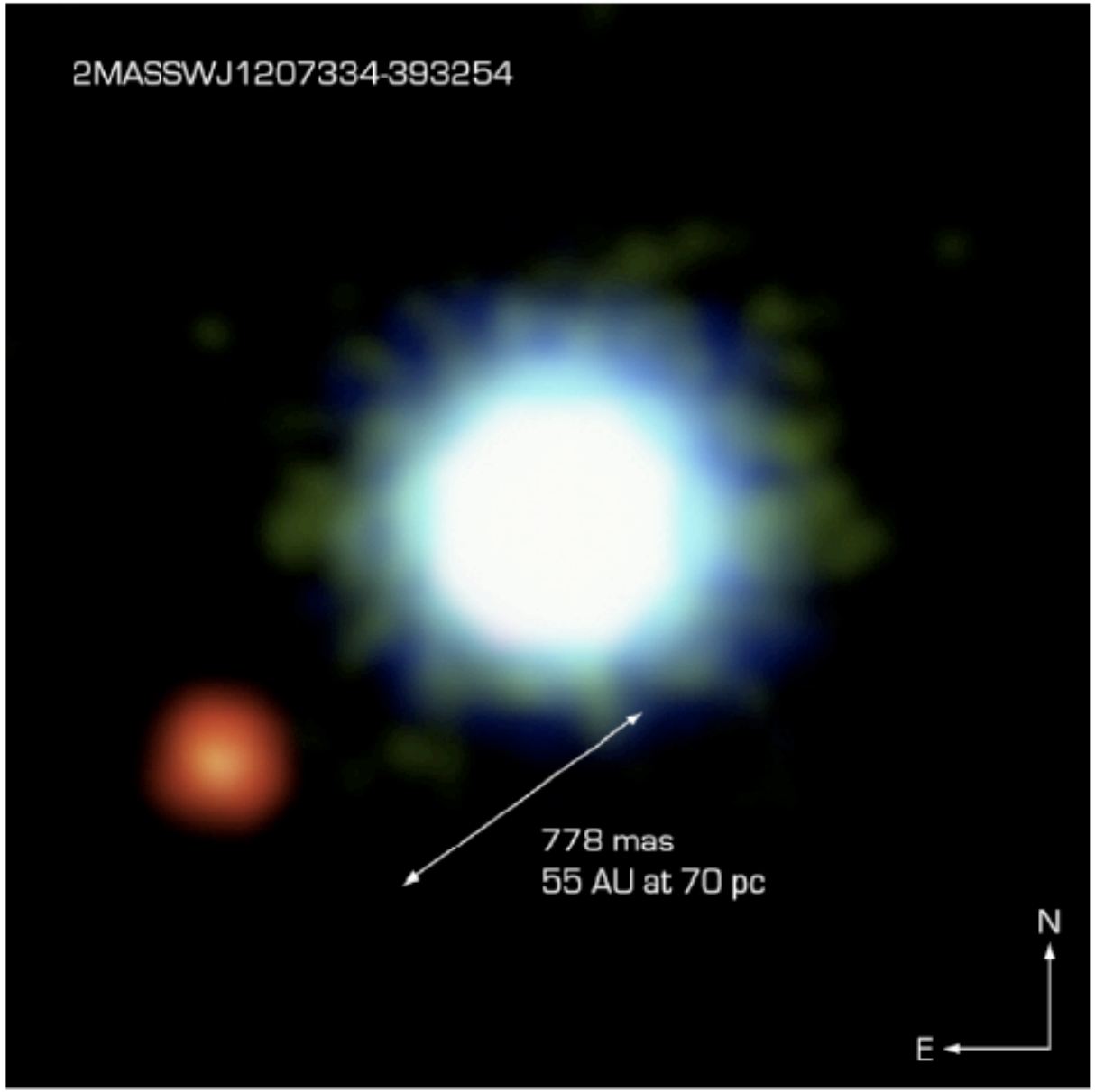
How Can We Detect Extrasolar Planets?

The most straightforward approach to finding extrasolar planets is direct imaging. The first known search for extrasolar planets using this method was carried out by Huygens in 1698.

This HST image was initially thought to show a young Jupiter-like planet at ~40 Pluto distances from a young star. It was later discovered to be a background star.

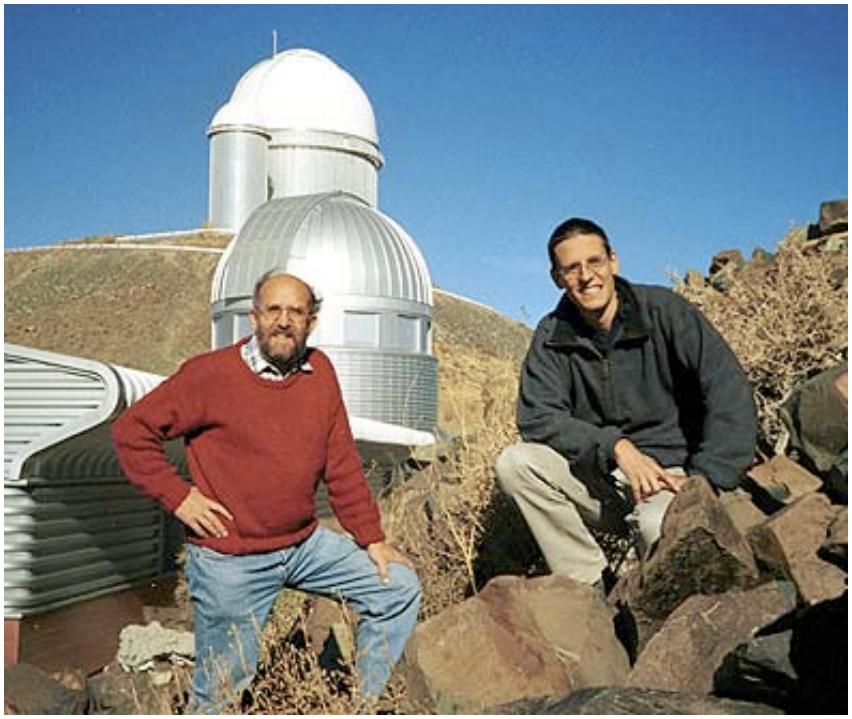


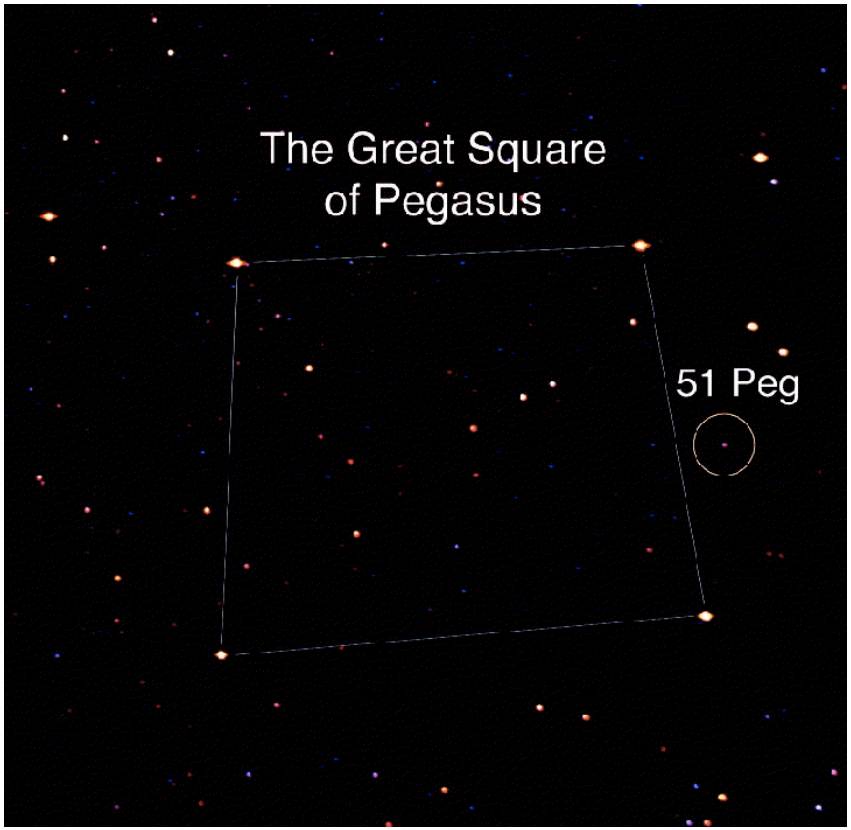
Simulated image from a super-Adaptive Optics system on an 24-foot telescope.

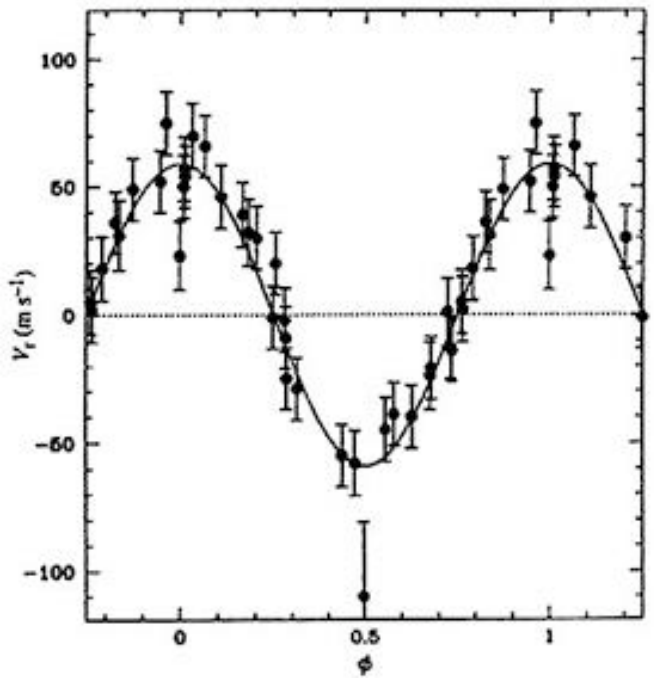


The Brown Dwarf 2M1207 and its Planetary Companion
(VLT/NACO)

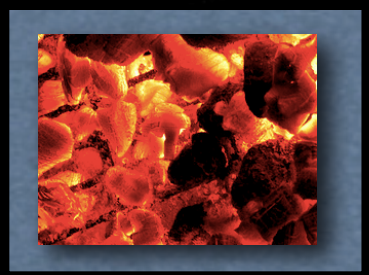
ESO PR Photo 14a/05 (30 April 2005)

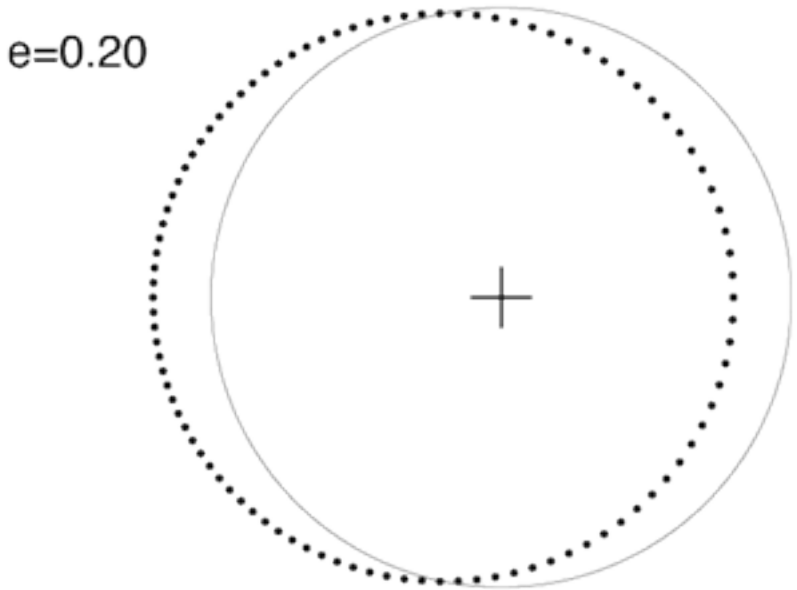


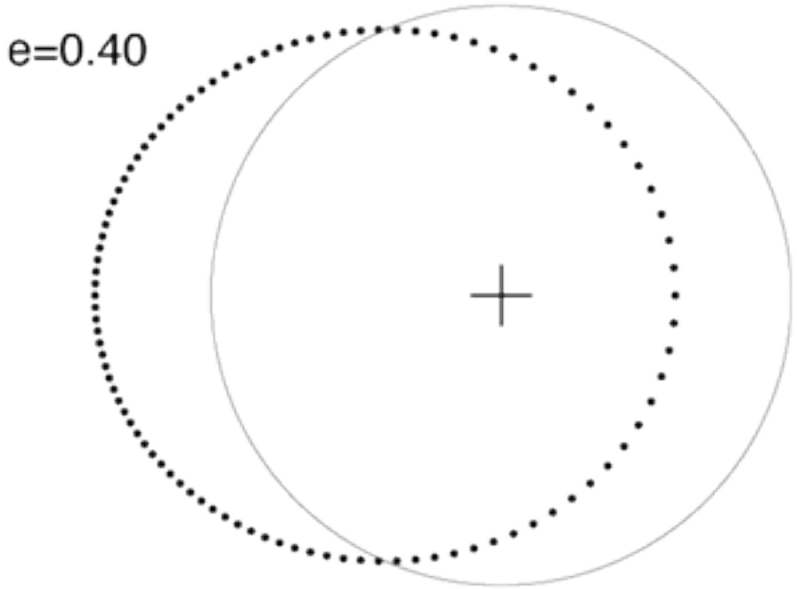




The first extrasolar planet around a sun-like star was discovered by Mayor and Queloz in 1996




e=0.20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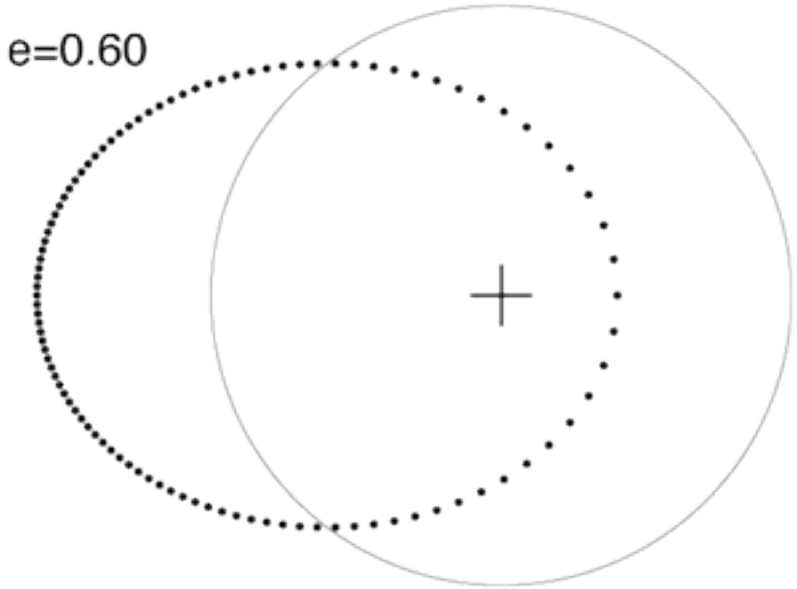
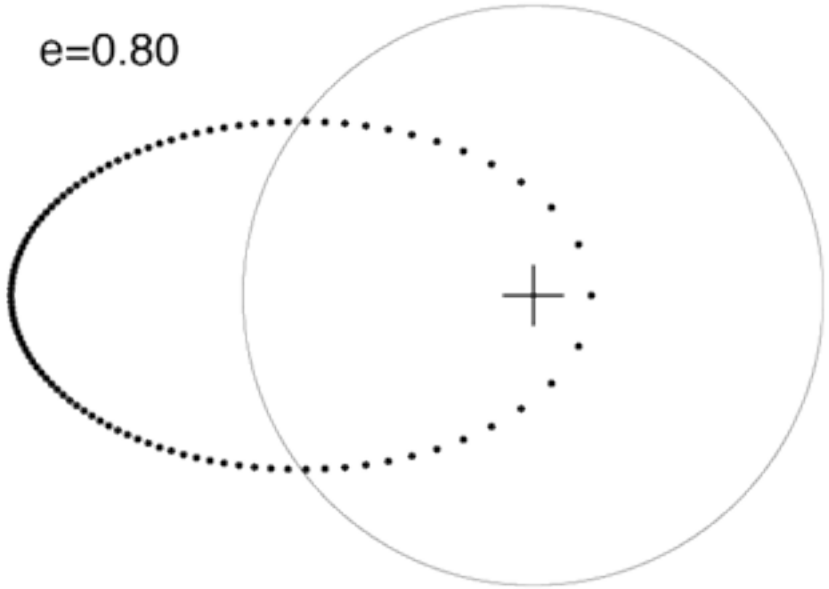
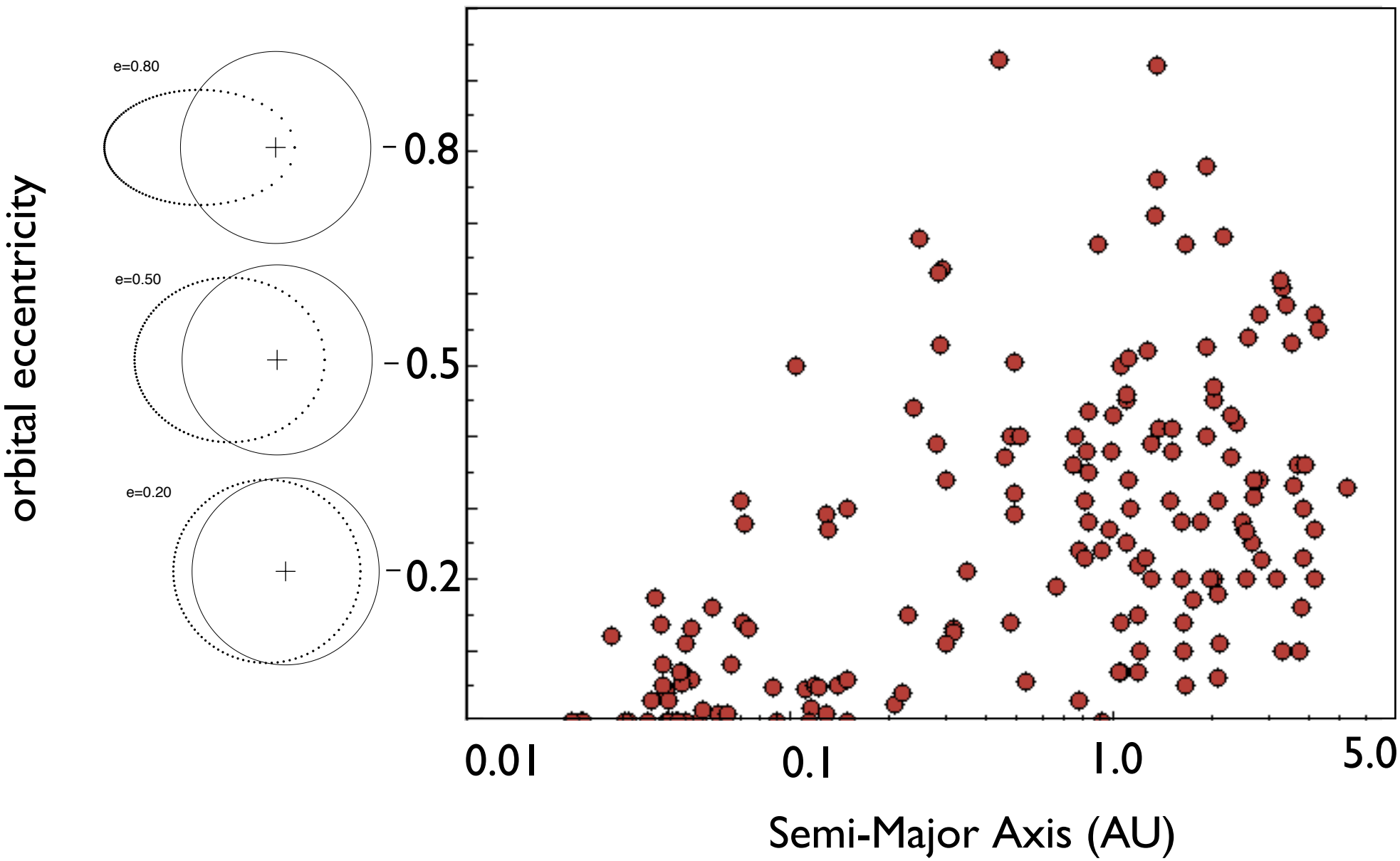
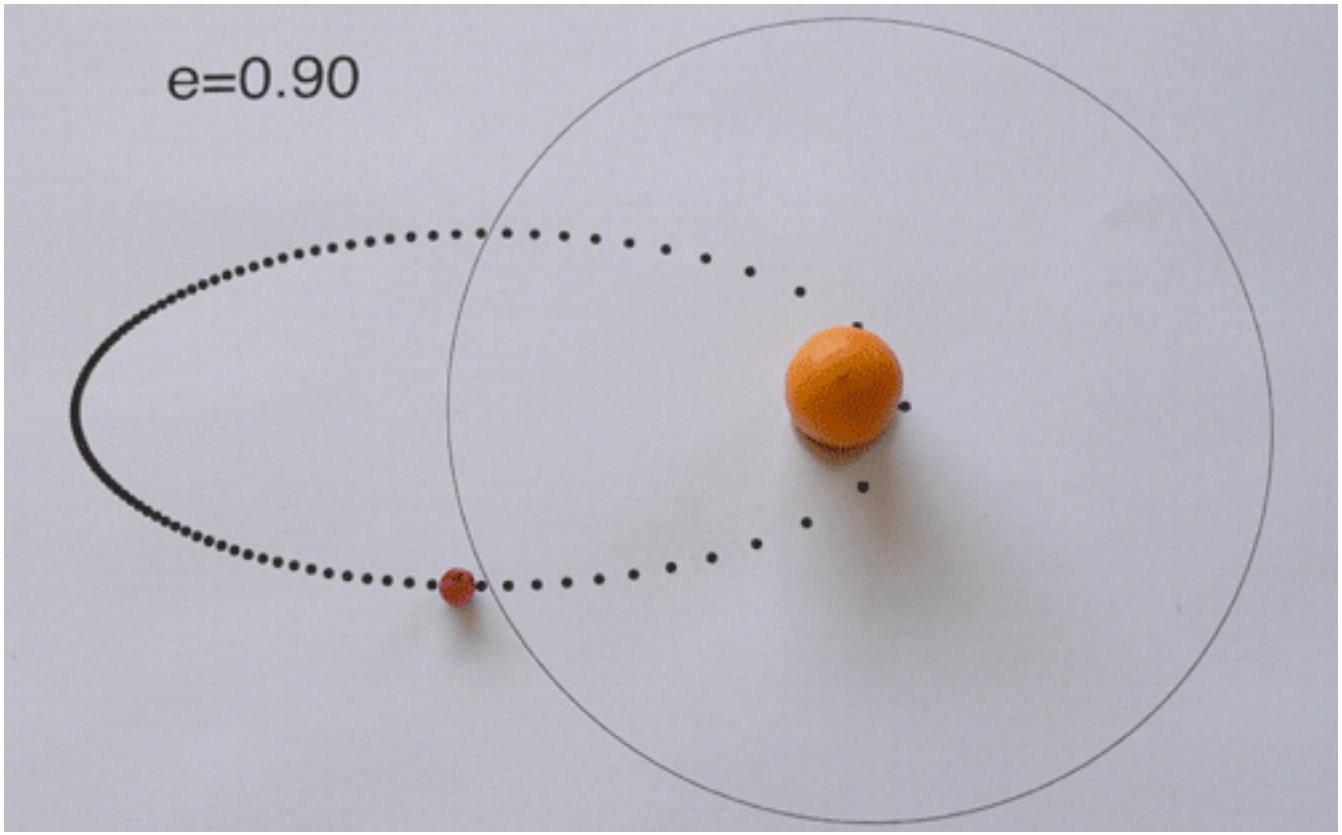
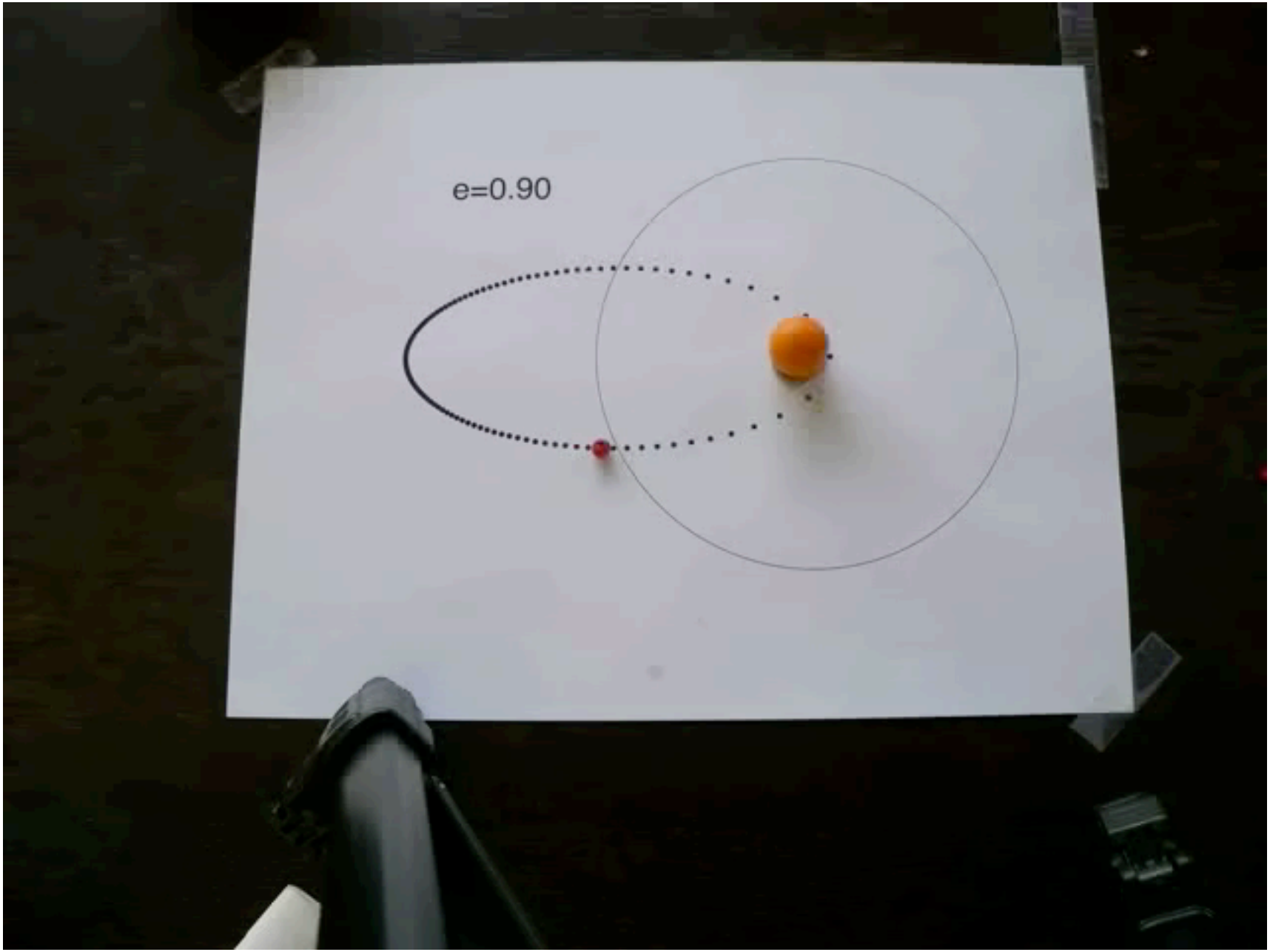

e=0.60

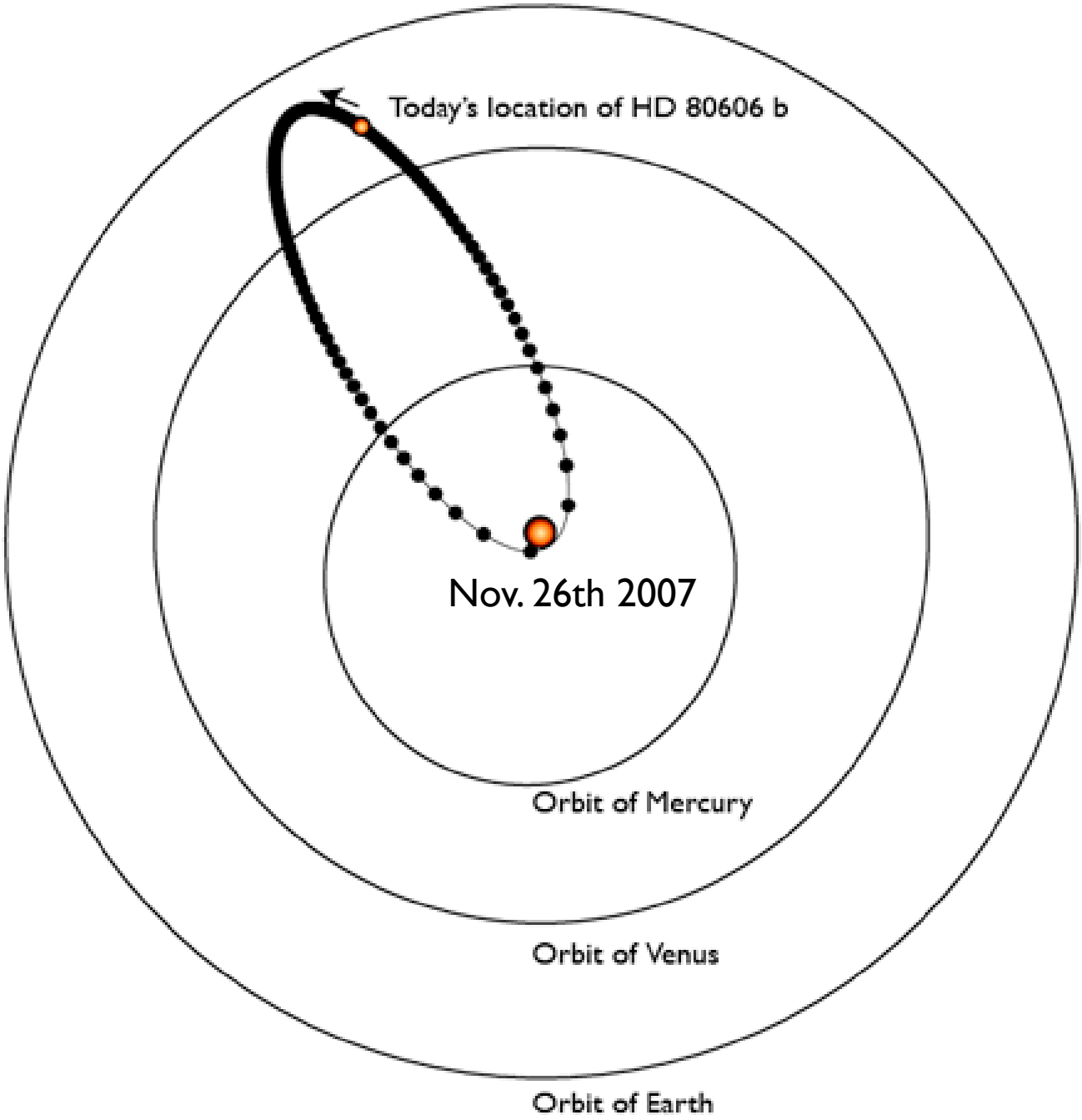

e=0.80

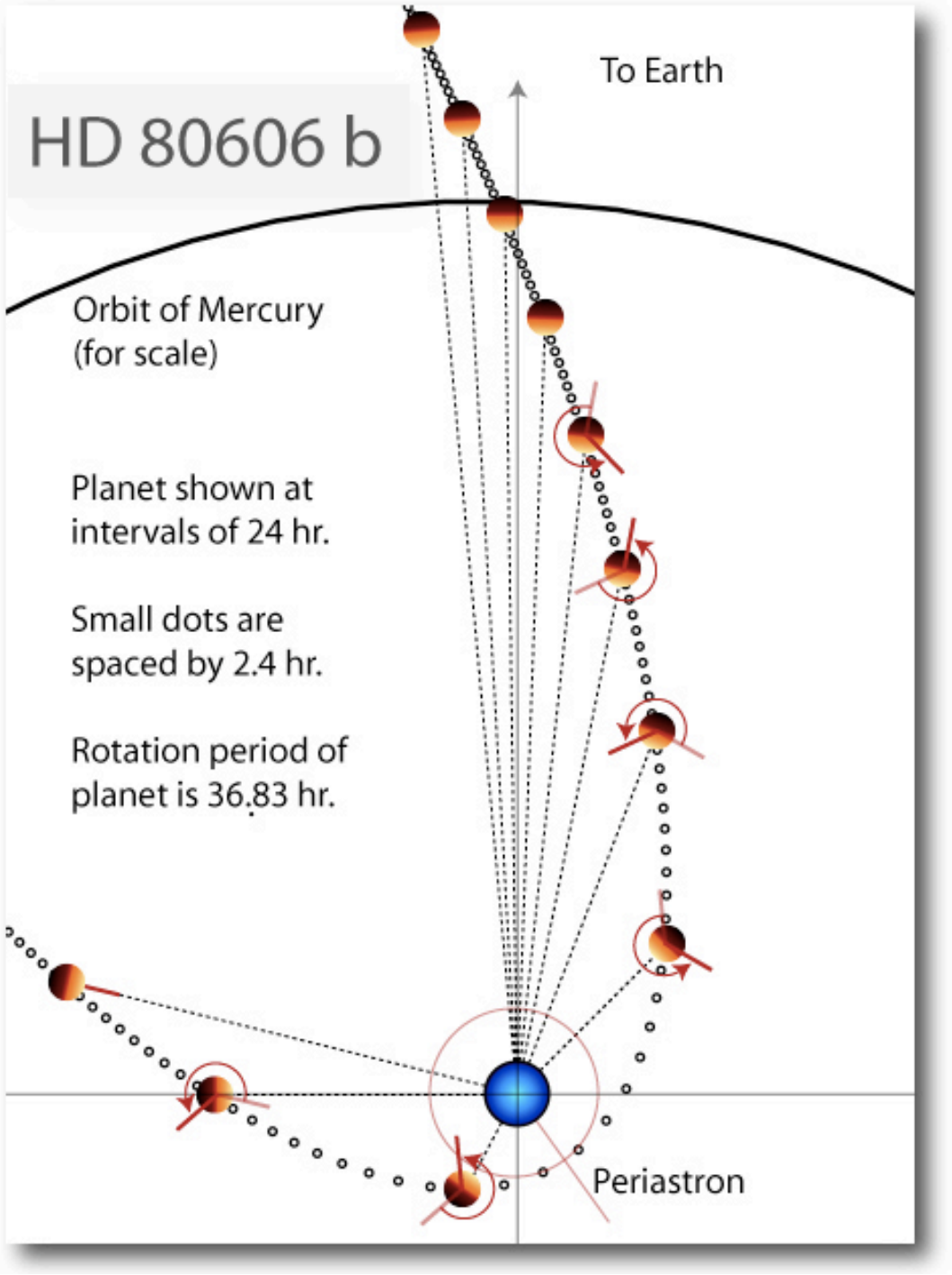

orbital eccentricity
e=0.80
e=0.50
e=0.20
0.8
0.5
0.2
0.01
0.1
1.0
5.0
Semi-Major Axis (AU)

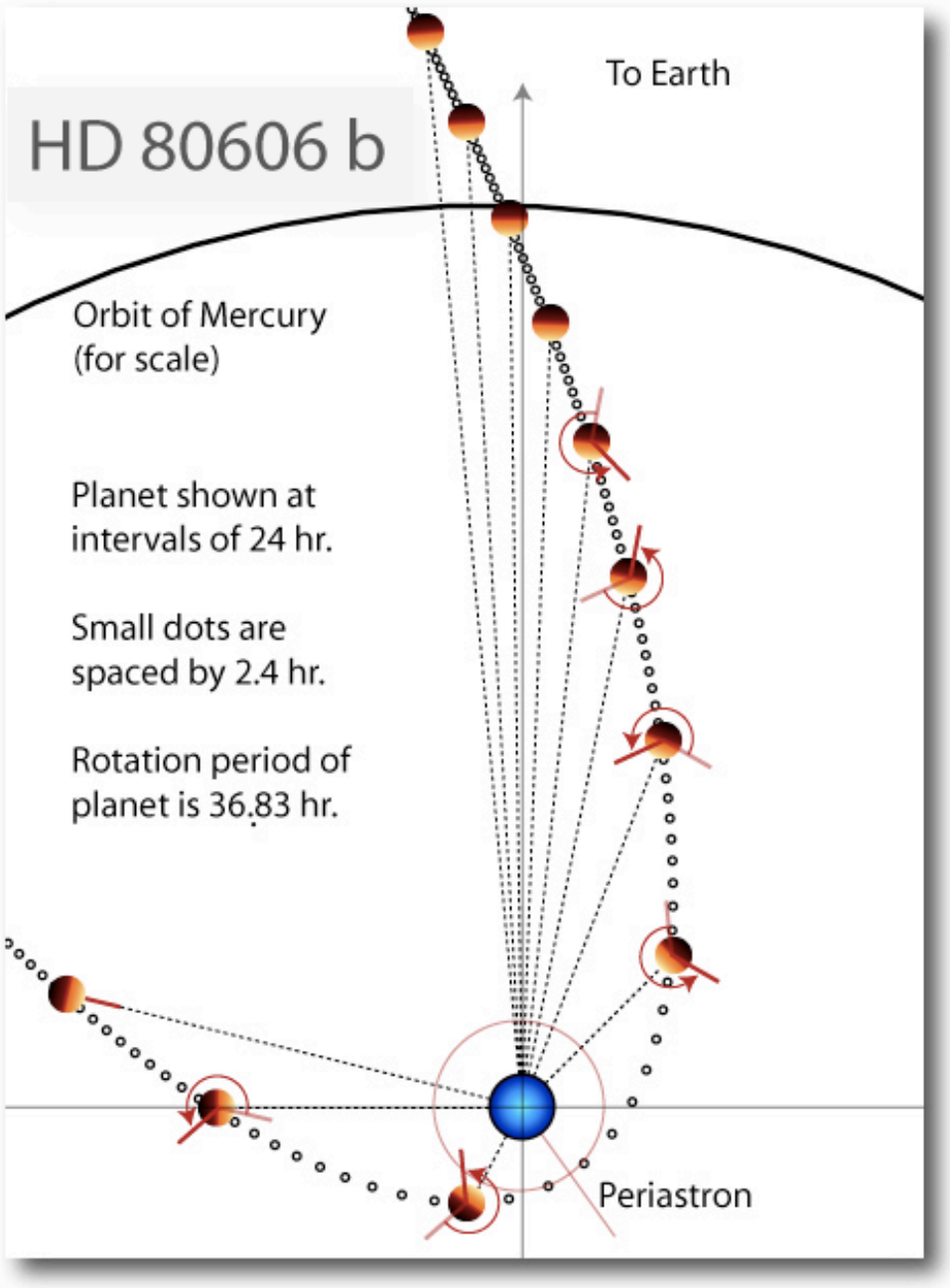

e=0.90


e=0.90

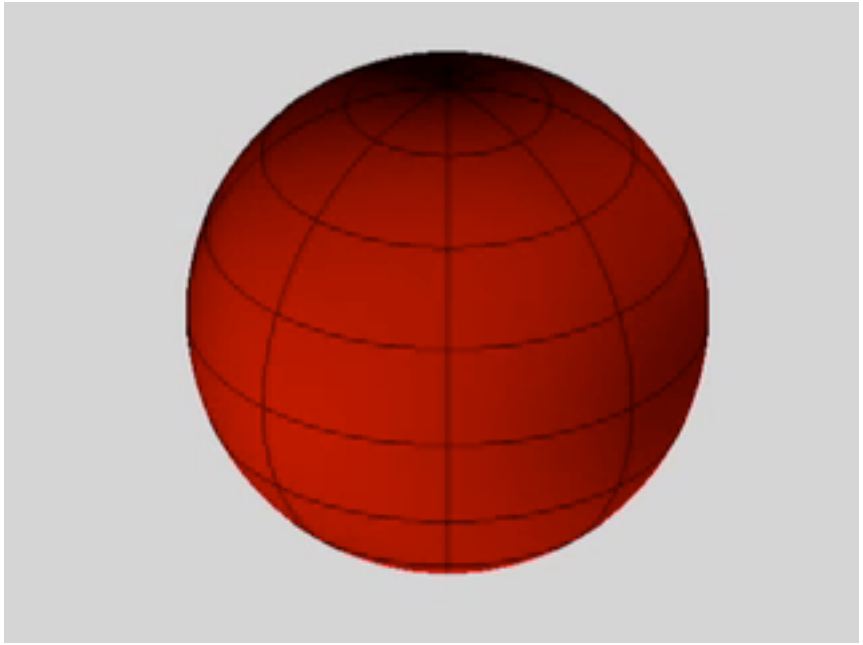
HD 80606 b has the most eccentric orbit known



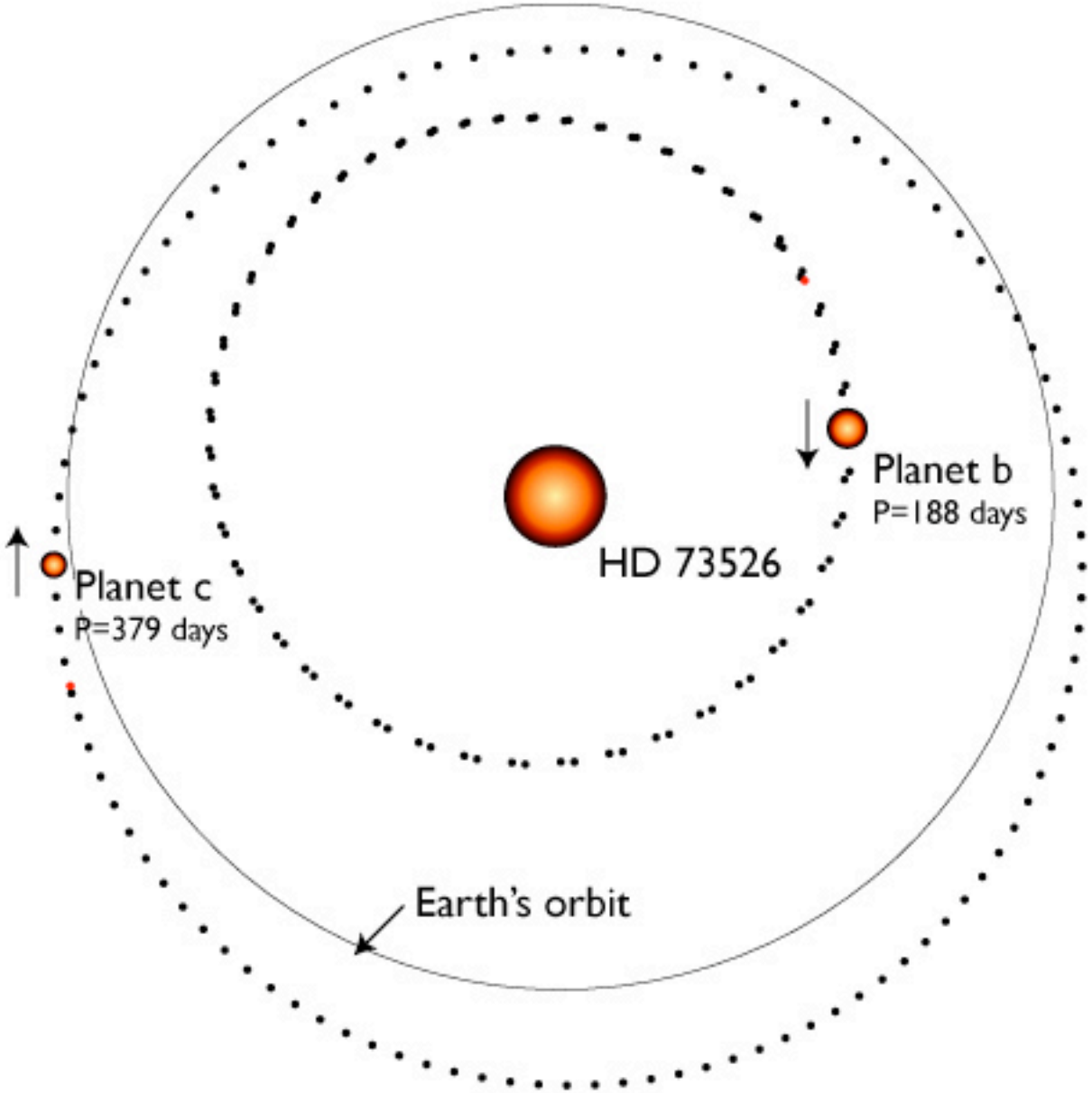

HD 80606 b
To Earth
Orbit of Mercury
(for scale)
Planet shown at
intervals of 24 hr.
Small dots are
spaced by 2.4 hr.
Rotation period of
planet is 36.83 hr.
Periastron

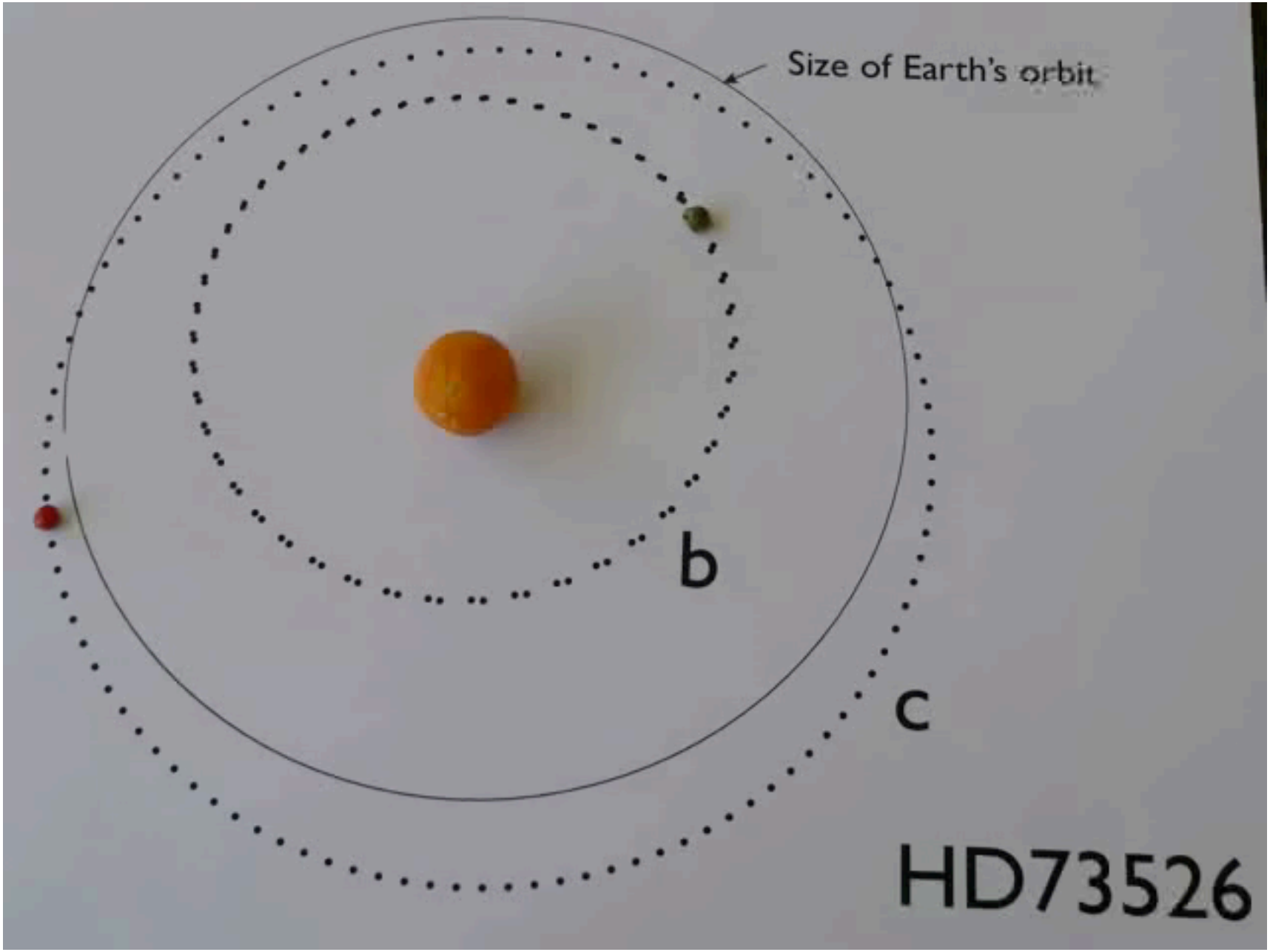


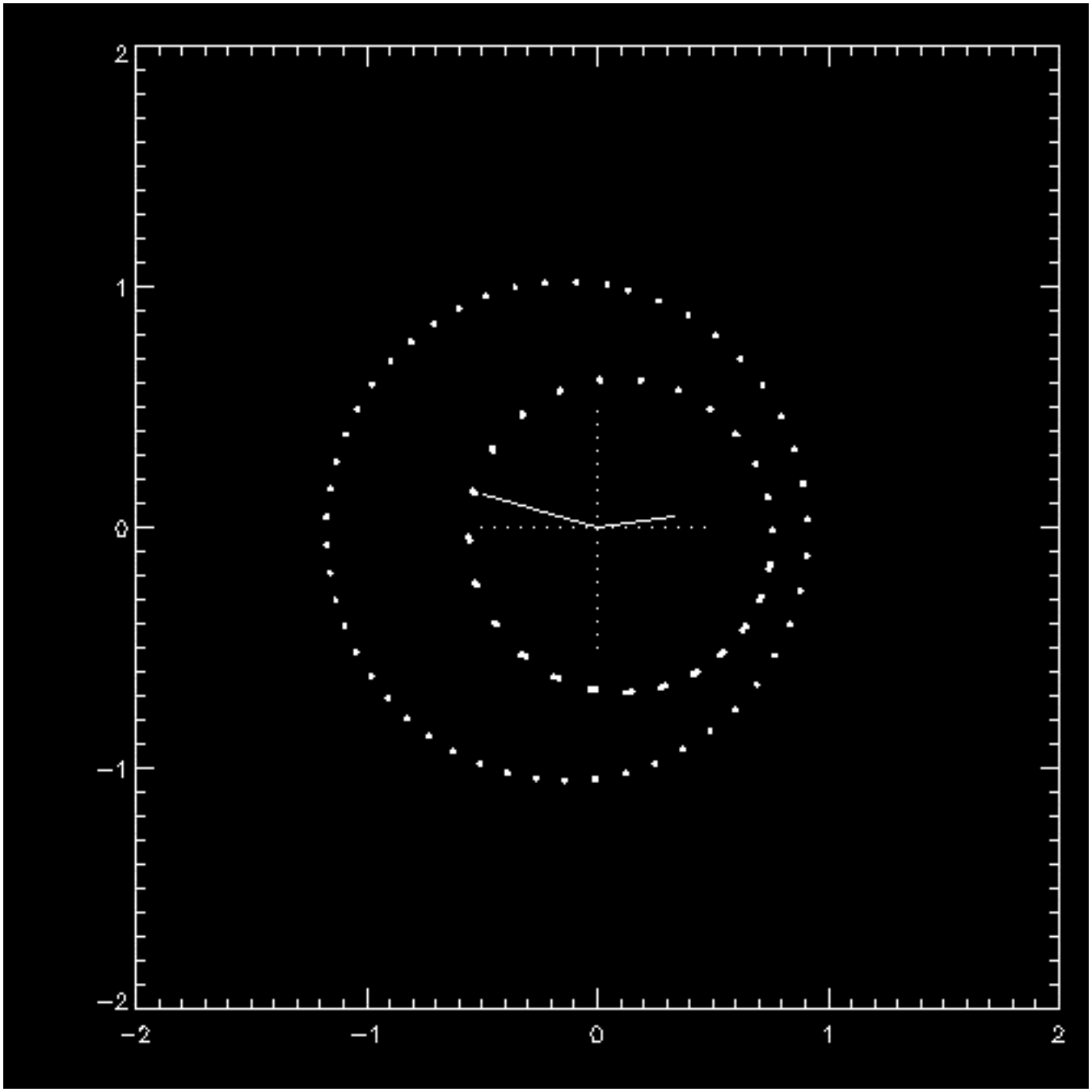
Global Warming



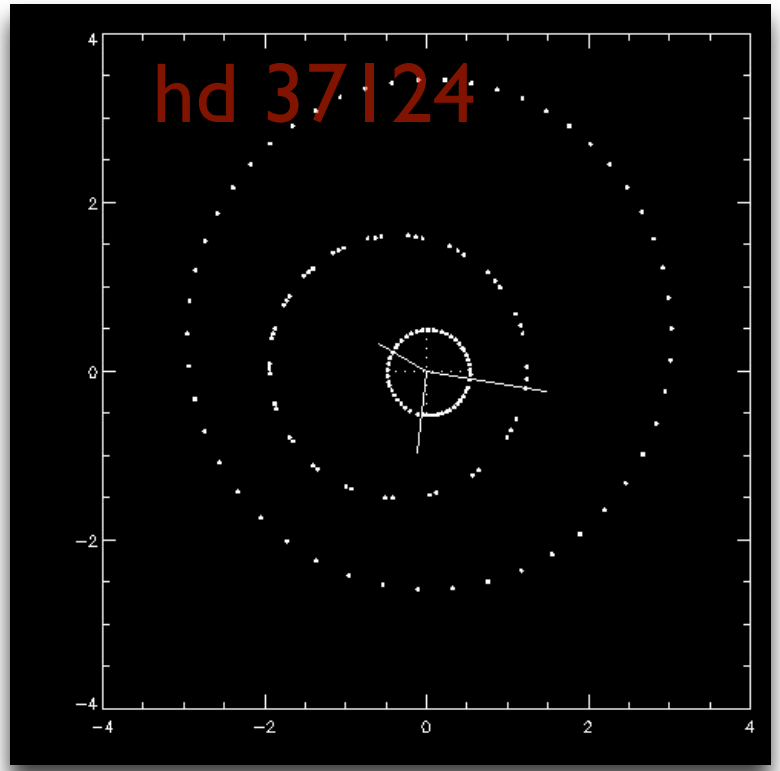
Weather prediction for HD 80606b Nov. 24th, 2007 through Nov. 28th, 2007
Lo 260 F Hi 1500 F

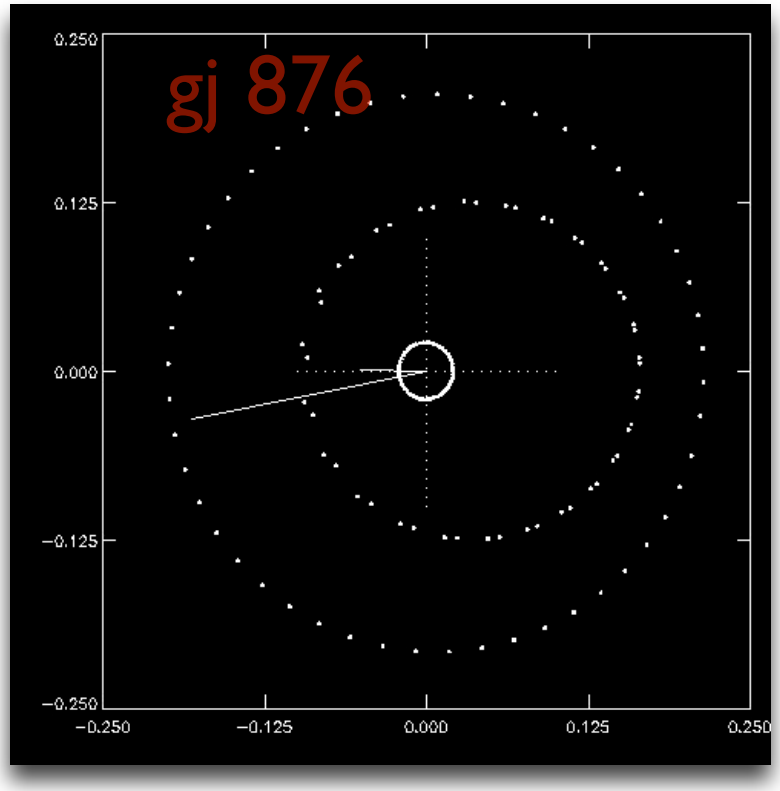

Planet b
P=188 days
HD 73526
Planet c
P=379 days
Earth's orbit

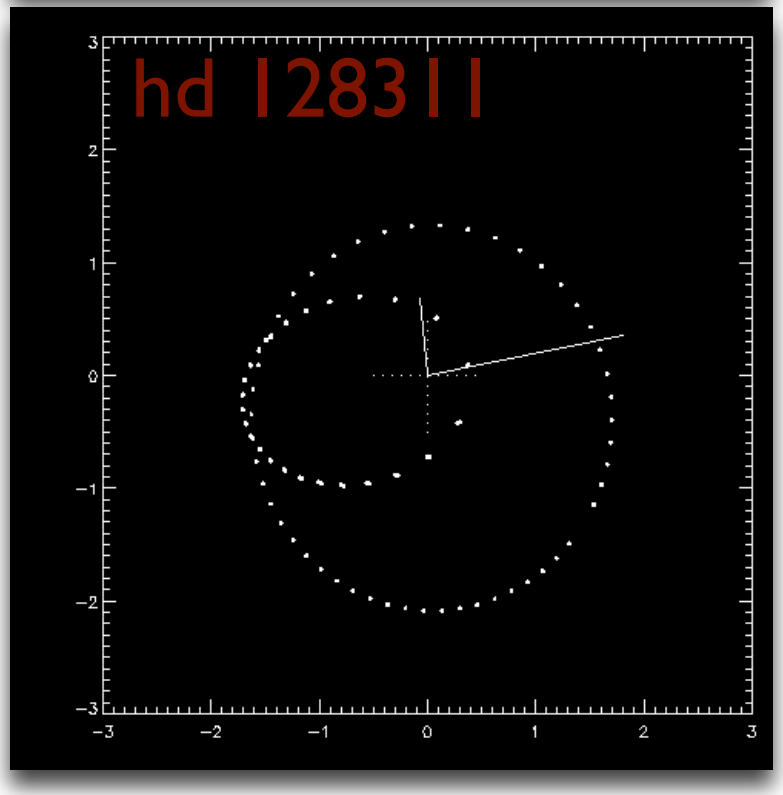

Size of Earth's orbit
b
c
HD73526


2
1
0
−1
−2
−2
−1
0
1
2

The multiple planetary systems that have been discovered often show strong gravitational pulls between the planets, which causes the orbits to evolve with time

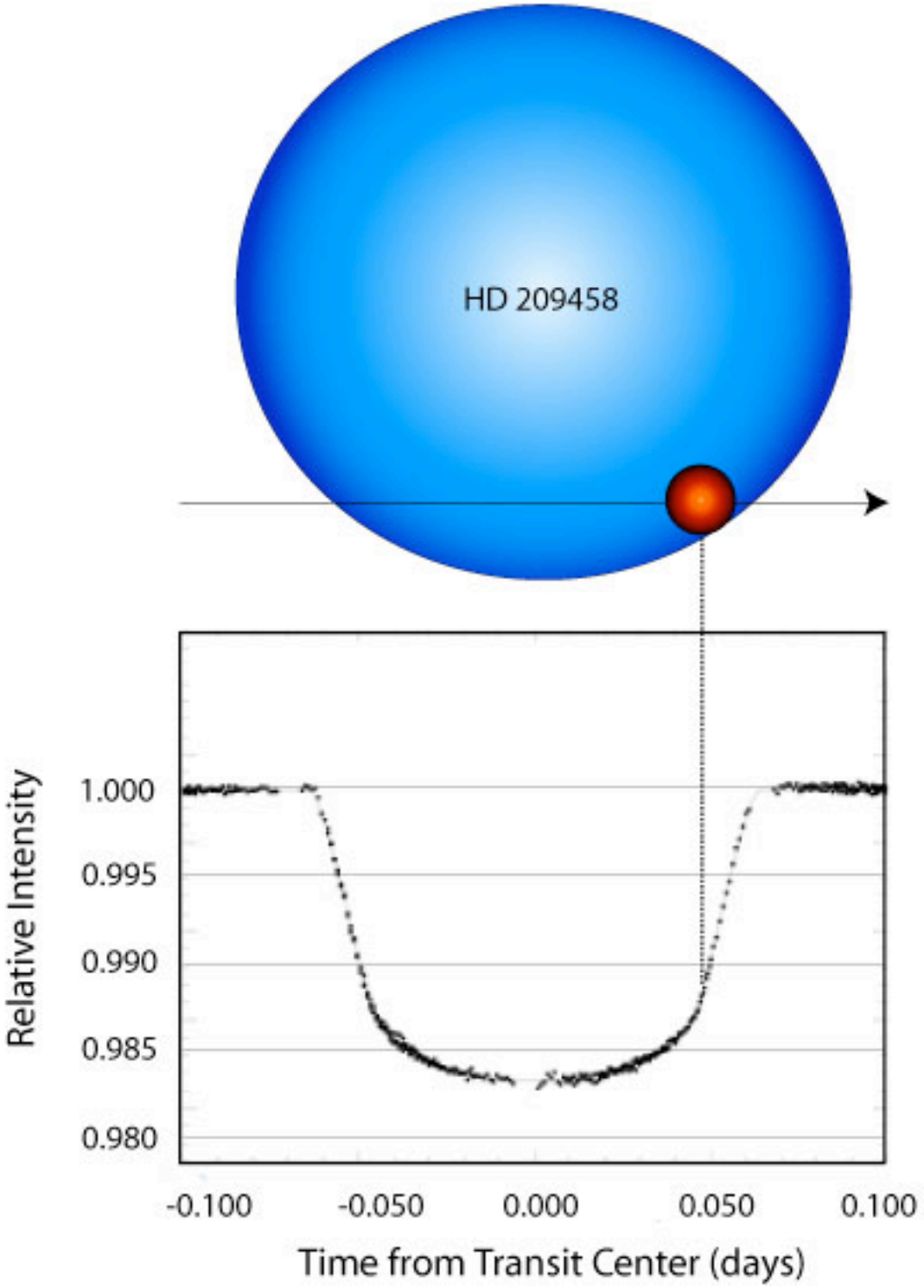


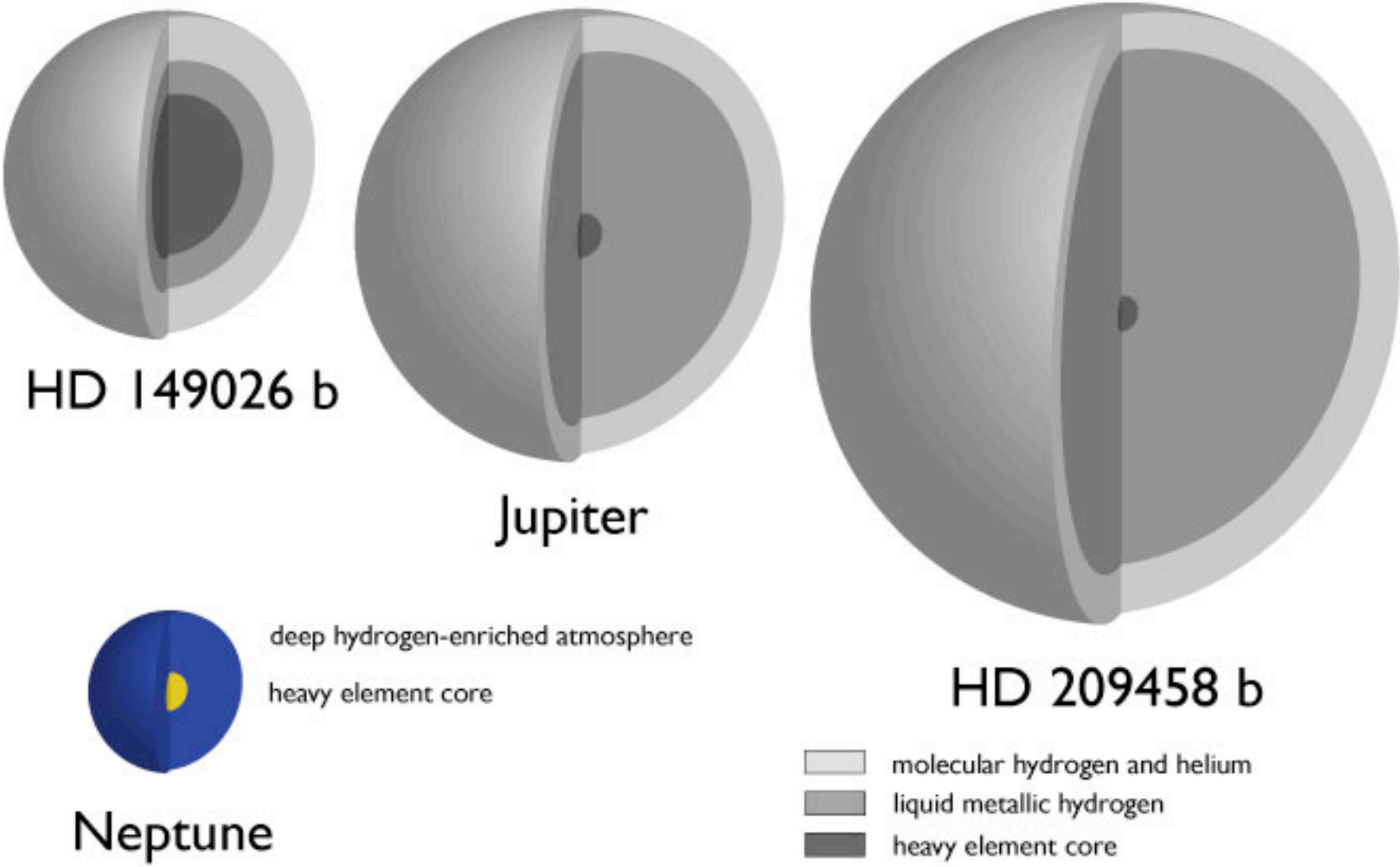


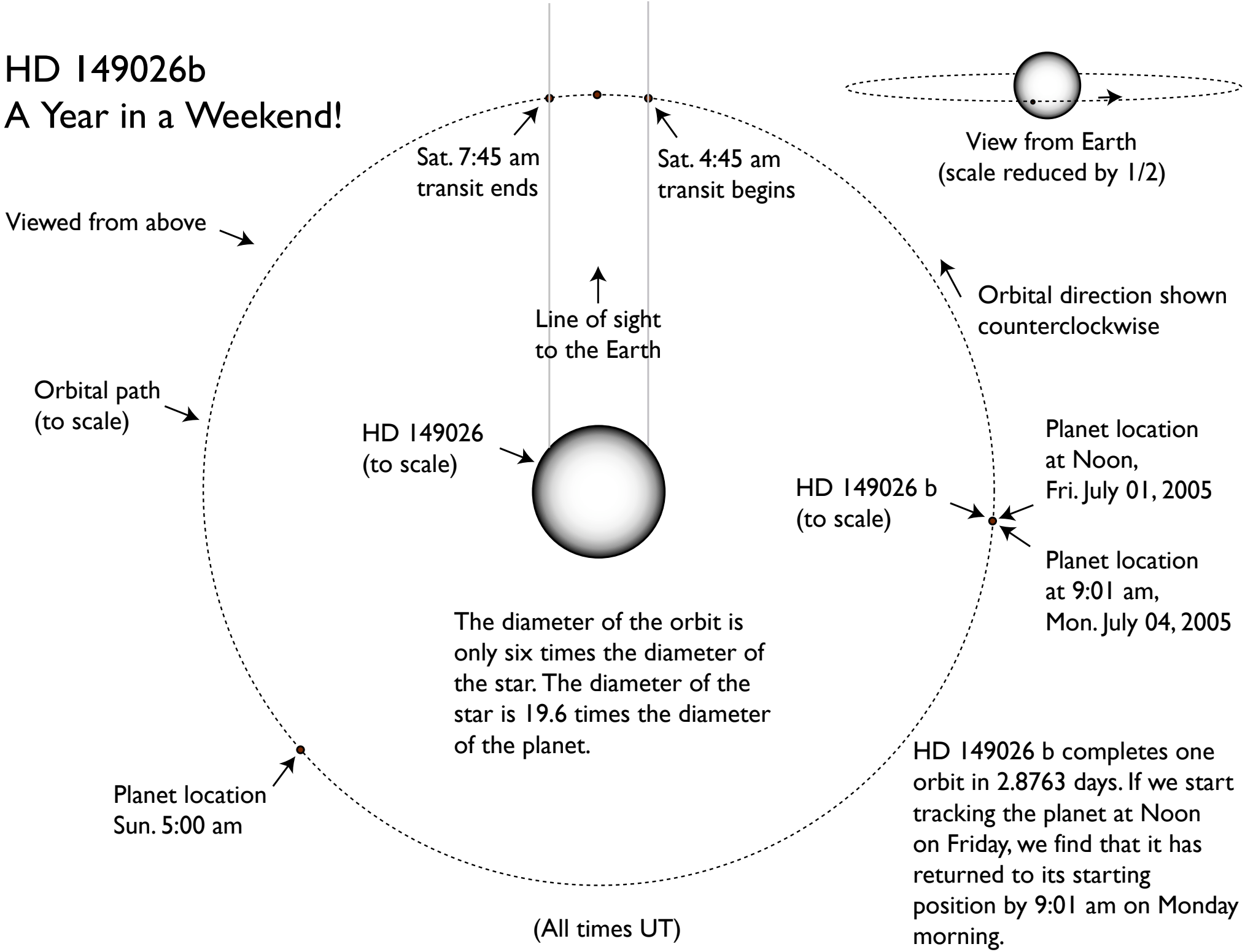


Transits have also been used to discover extrasolar planets.

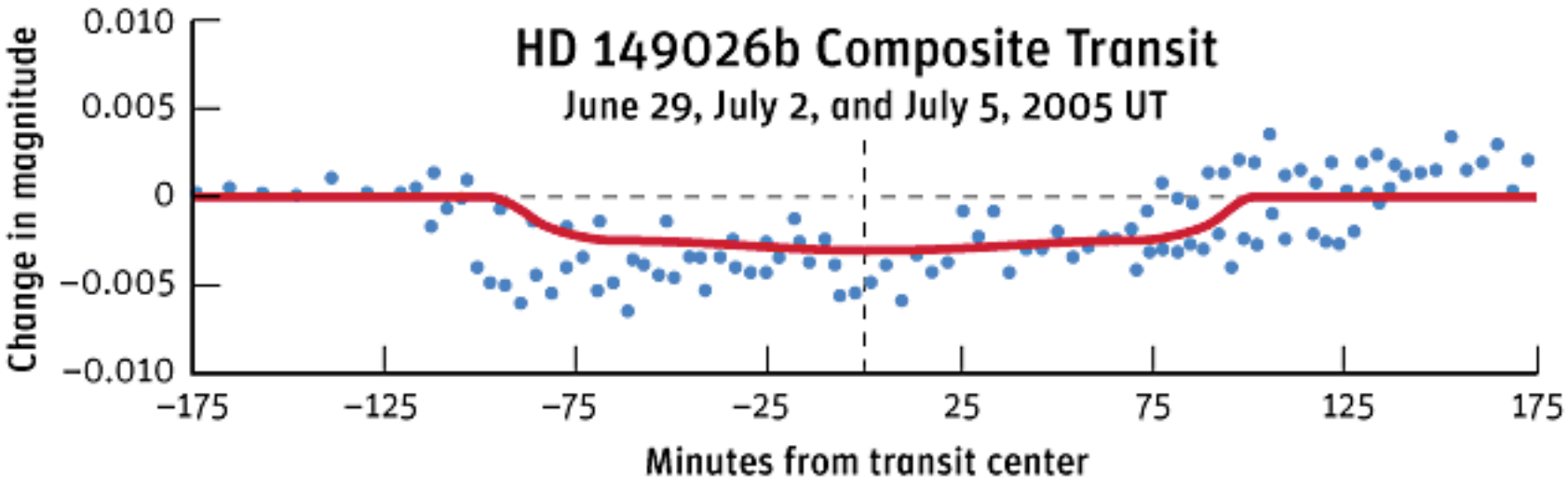
Transit of Venus
June 2004



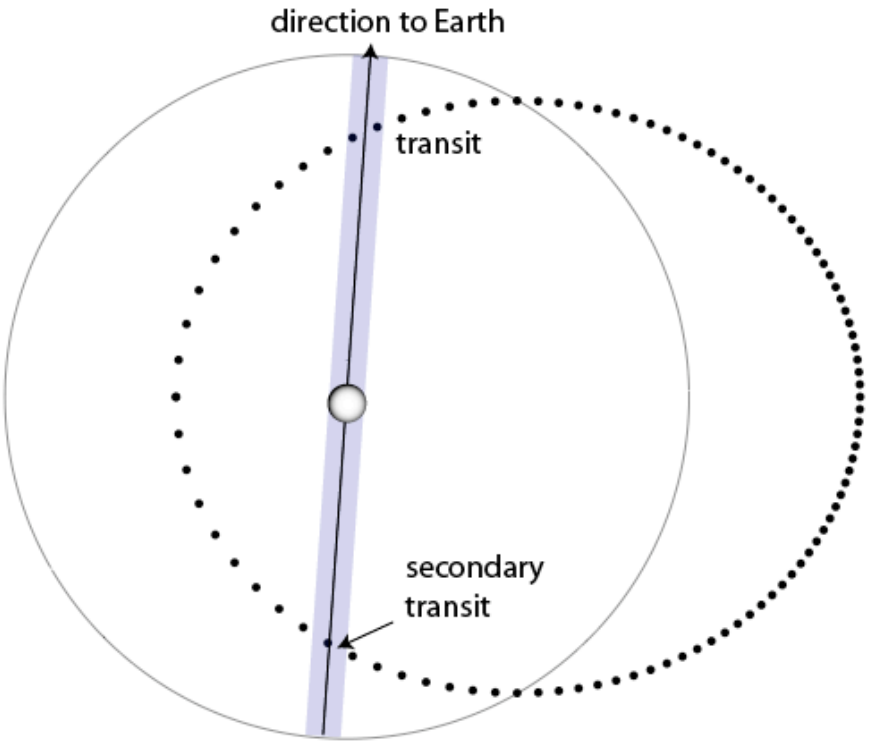

HD 149026 b
Jupiter
HD 209458 b
deep hydrogen-enriched atmosphere
heavy element core
Neptune
molecular hydrogen and helium
liquid metallic hydrogen
heavy element core

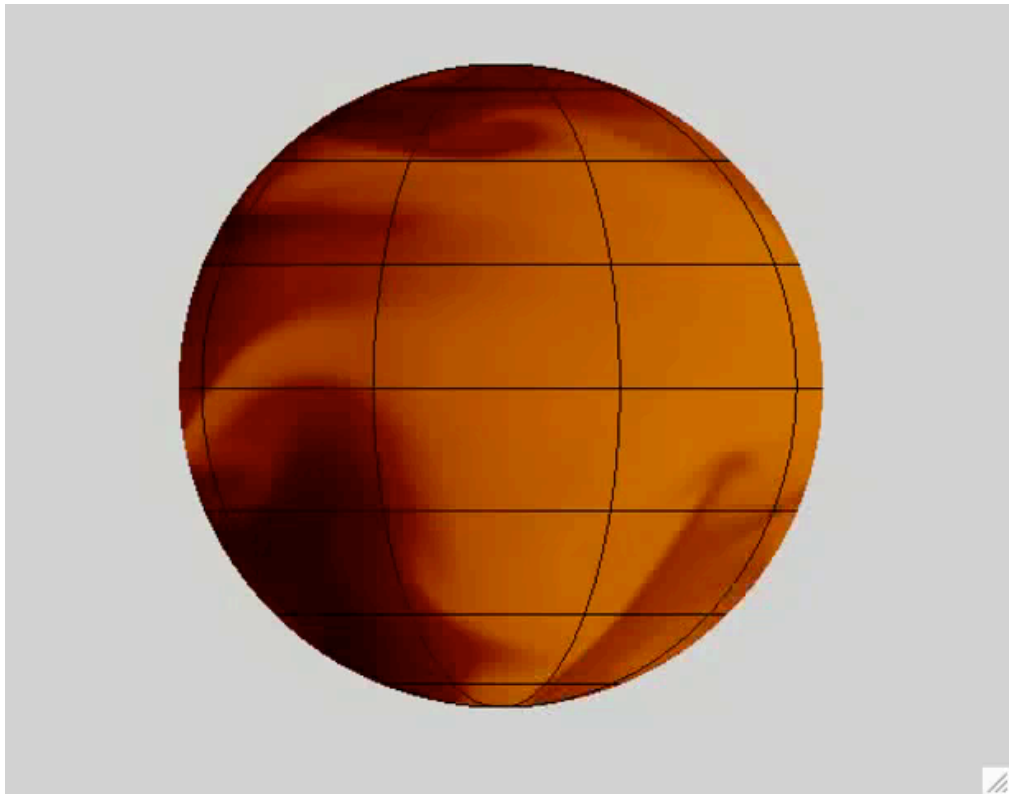

HD 149026b
A Year in a Weekend!
Sat. 7:45 am
transit ends
Sat. 4:45 am
transit begins
View from Earth
(scale reduced by 1/2)
Viewed from above
Line of sight
to the Earth
Orbital direction shown
counterclockwise
Orbital path
(to scale)
HD 149026
(to scale)
HD 149026 b
(to scale)
Planet location
at Noon,
Fri. July 01, 2005
Planet location
at 9:01 am,
Mon. July 04, 2005
The diameter of the orbit is only six times the diameter of the star. The diameter of the star is 19.6 times the diameter of the planet.
Planet location
Sun. 5:00 am
HD 149026 b completes one orbit in 2.8763 days. If we start tracking the planet at Noon on Friday, we find that it has returned to its starting position by 9:01 am on Monday morning.
(All times UT)

Amateur astronomer Ron Bissinger observed the transit from his backyard in Pleasanton California starting only hours after we announced the discovery

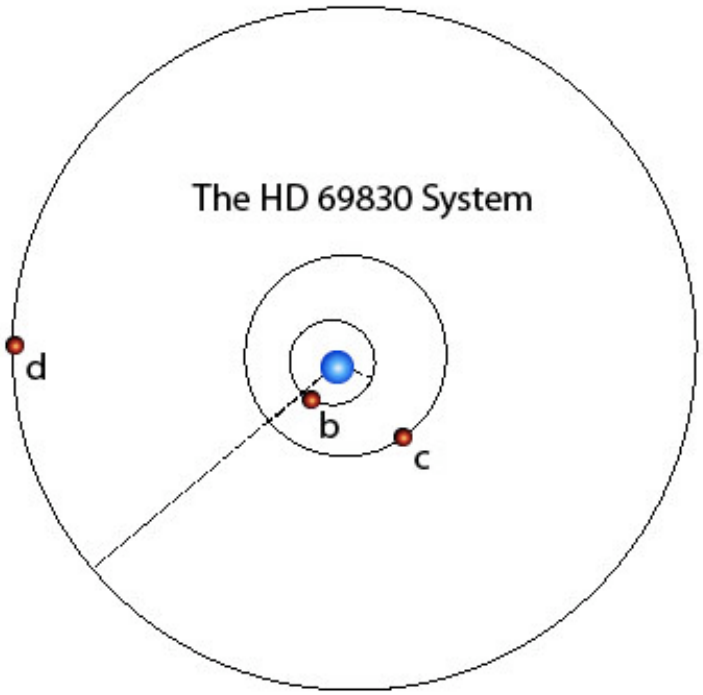


Global Roasting



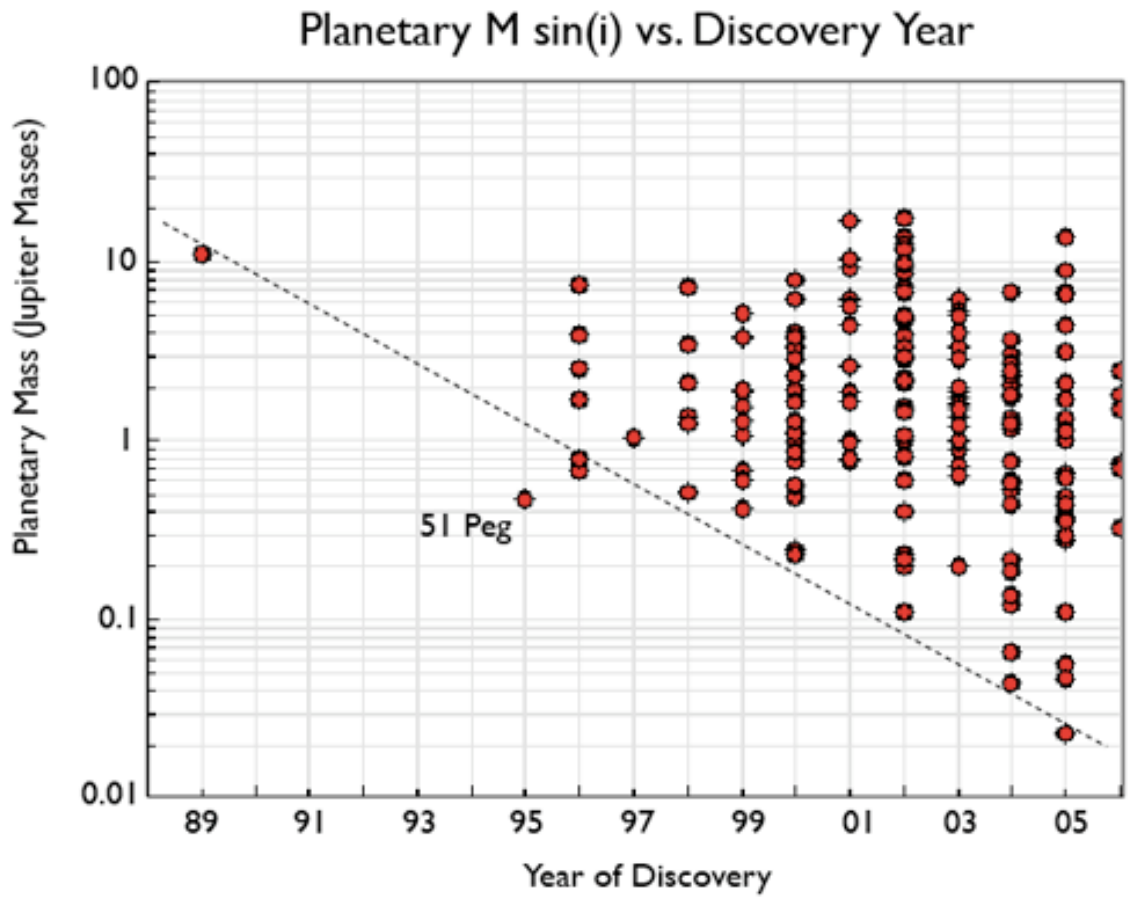


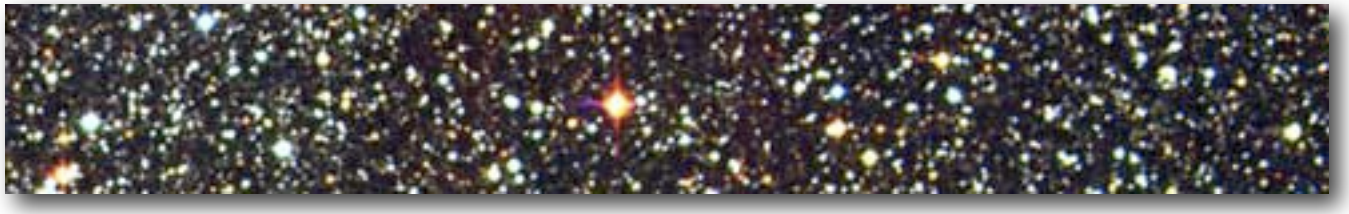
The weather on HAT-P-2b makes HD 80606b look like Ann Arbor by comparison. Lo: 1130 F, Hi: 2390F



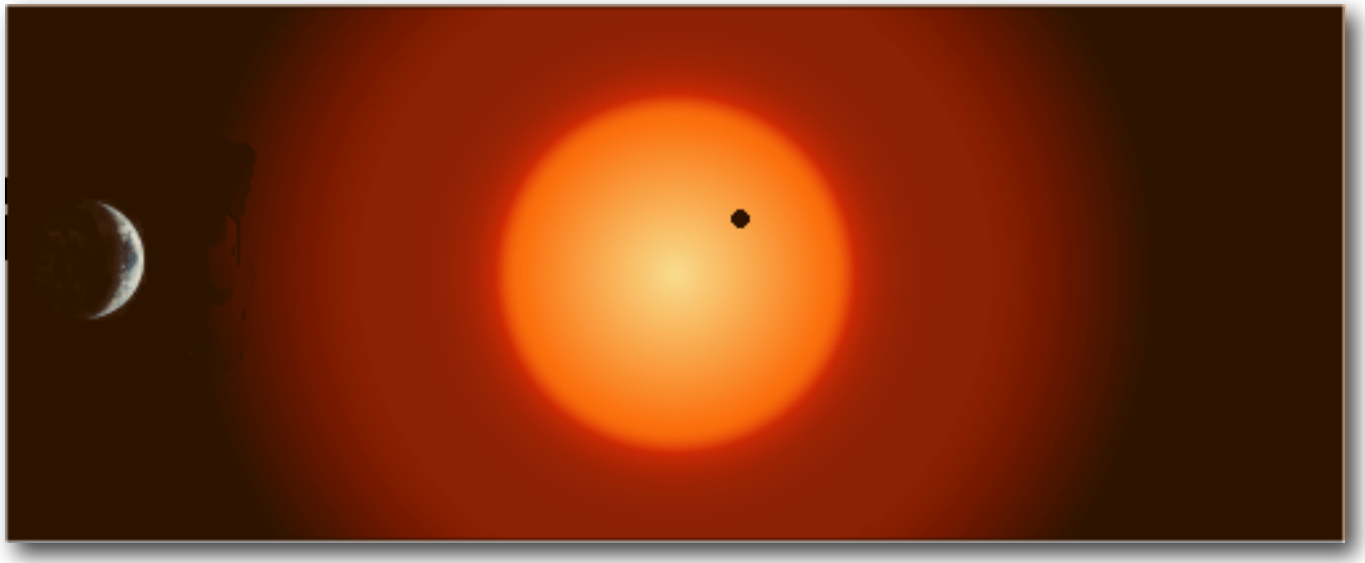
10.2 Earth Masses
11.8 Earth Masses
18.1 Earth Masses

The error on the half-amplitude, K, for planet b *is 0.2 m/s*

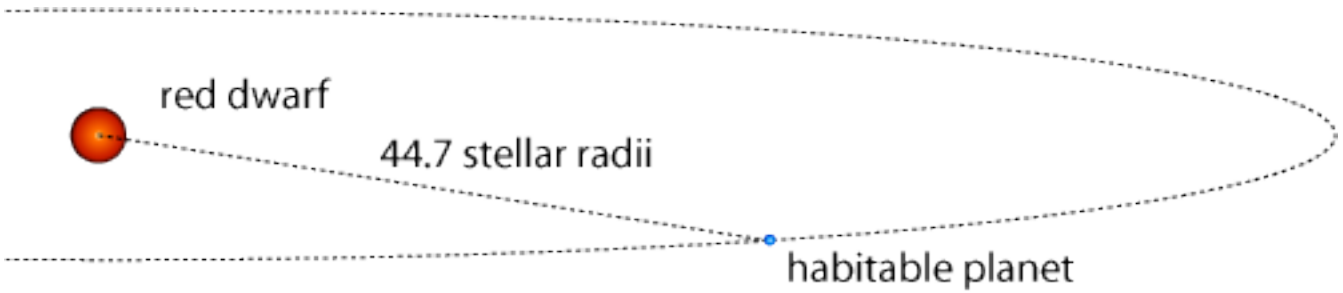




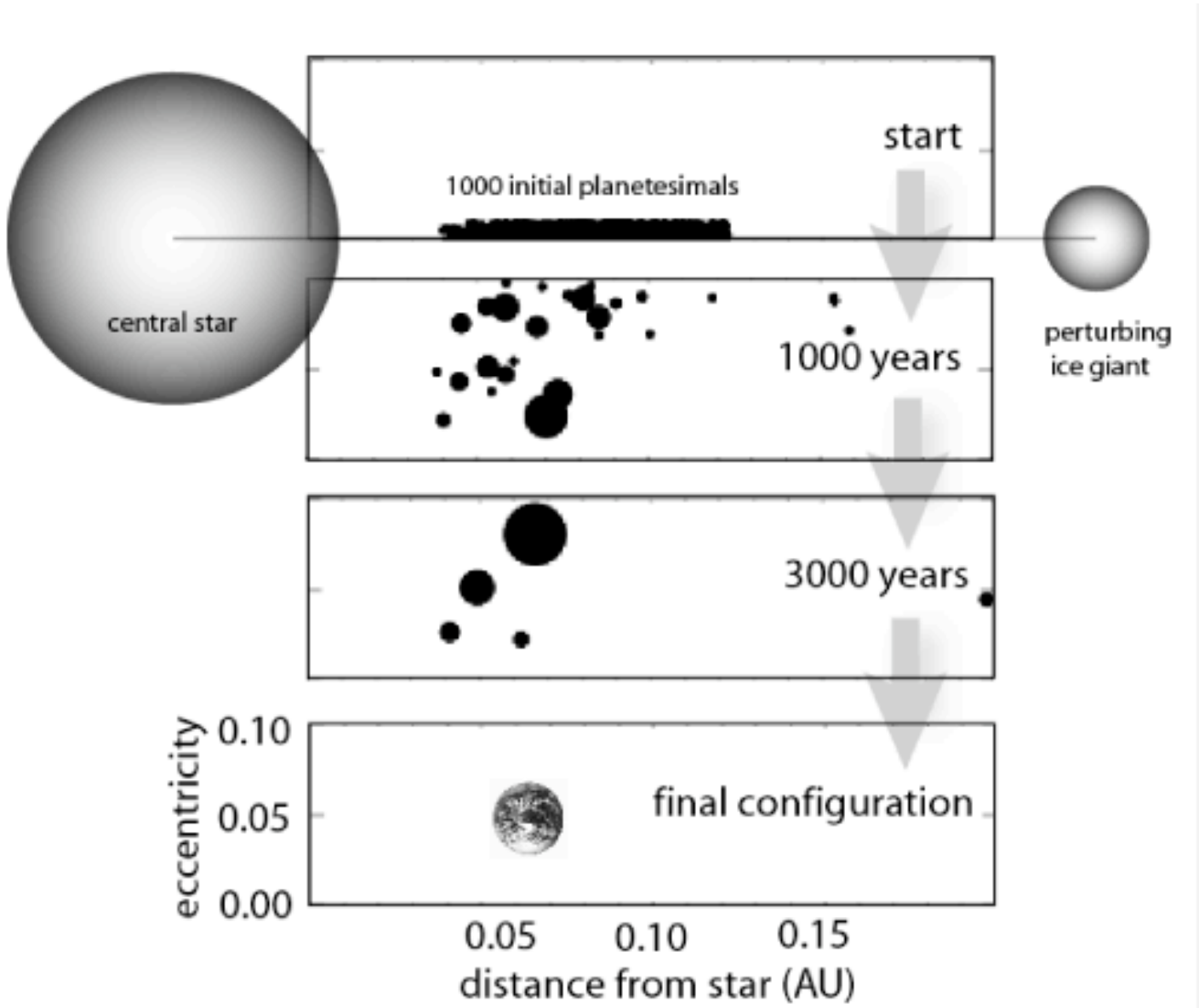
Red dwarf stars are the most numerous type of star in the Galaxy



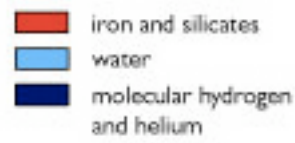
A habitable planet orbiting a red dwarf has a ~12 day orbit

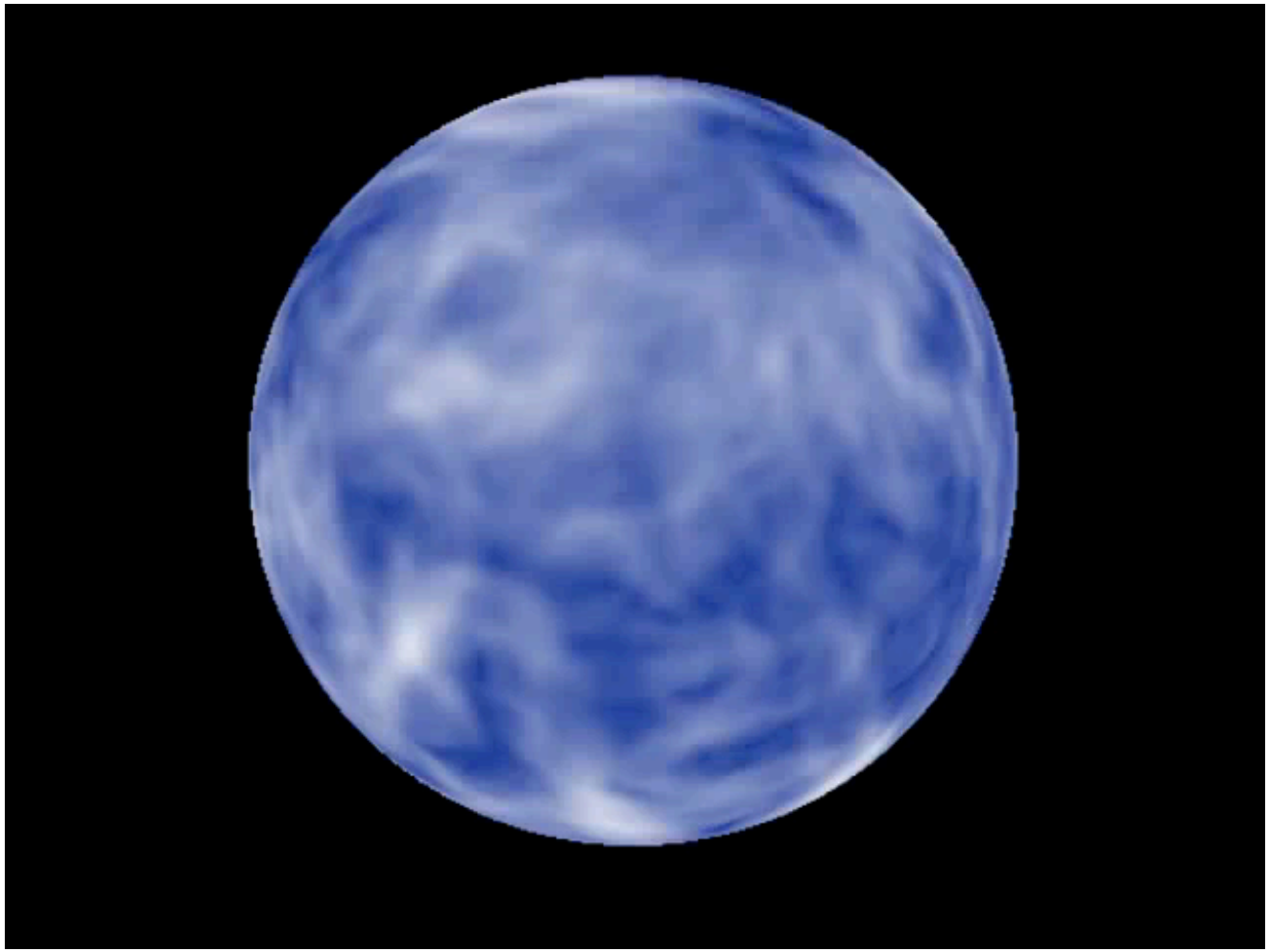


If such planets exist around a nearby red dwarf, they will be detected soon.



Our simulations of planet formation are indicating that it's quite likely that such planets exist.



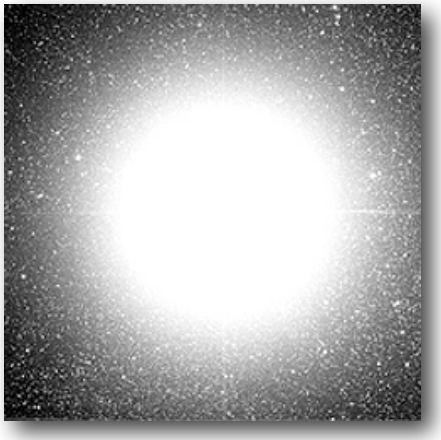


Our computer simulation of Gl 581c's atmosphere

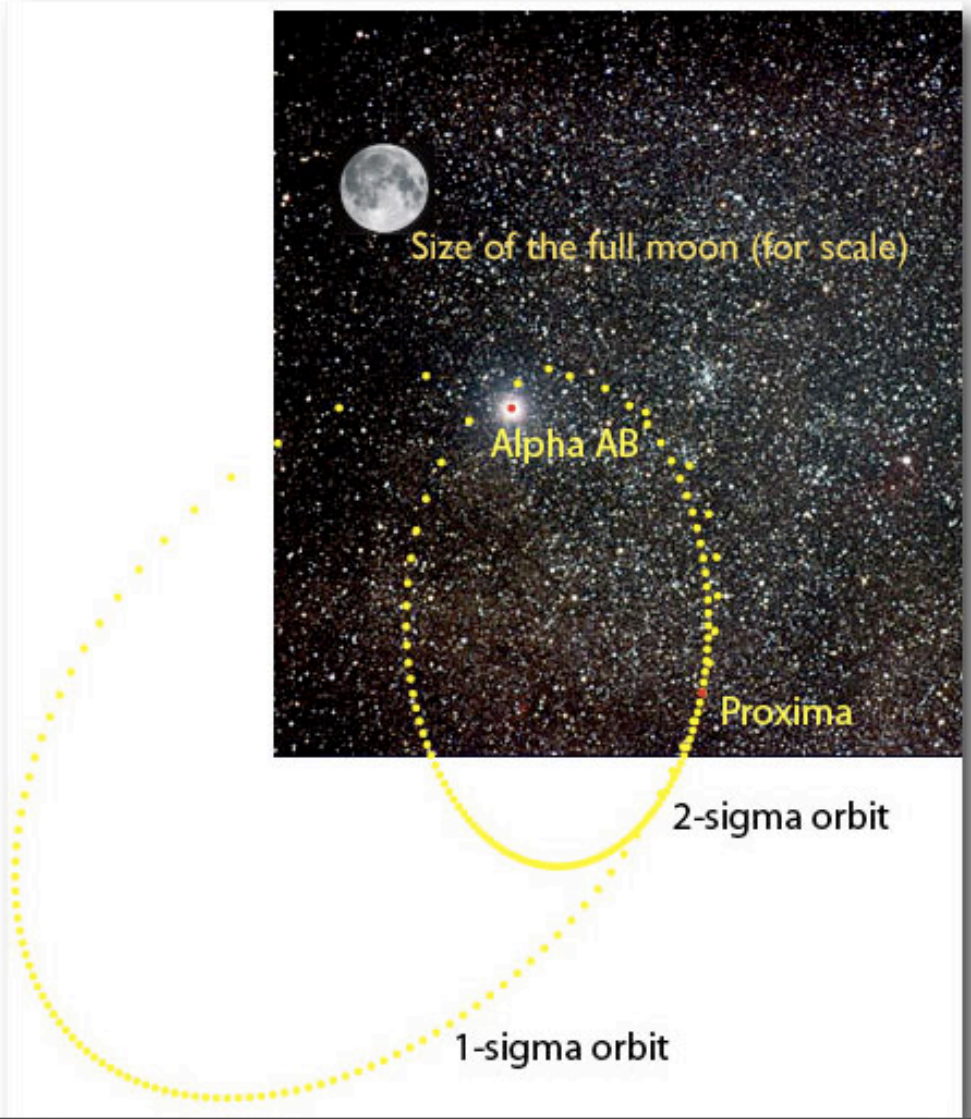
Gliese 581 "c" (which made headlines several weeks ago) orbits a nearby red dwarf (20 light years away). It likely has a mass of ~7 Earth masses and an orbital period of 12.8 days. It is only slightly too close to the star for habitability, and it probably has a very deep and steamy ocean. It points, however, toward the discovery of potentially Earthlike worlds within only a year or two.

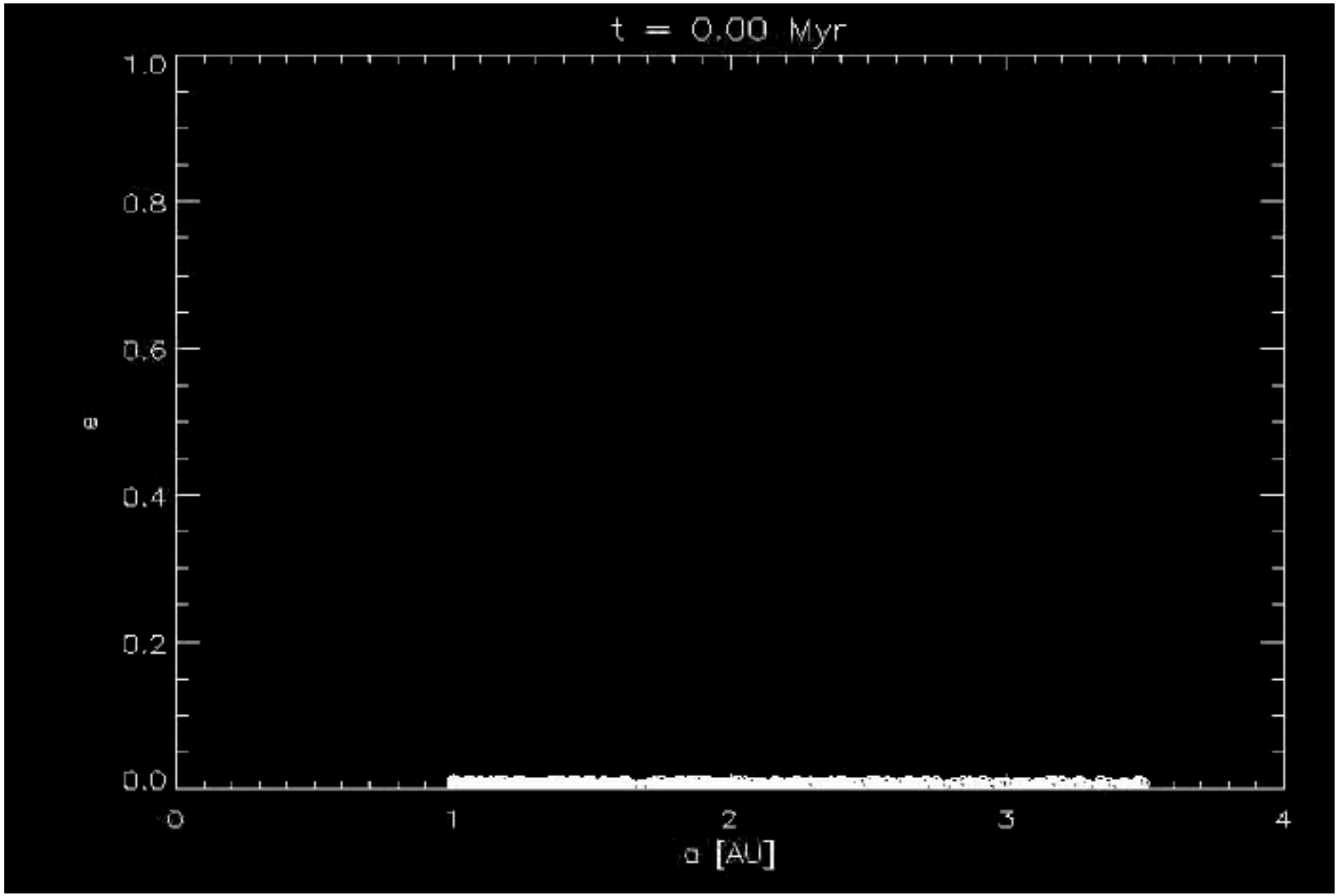
The Kepler Mission is scheduled to launch in 2008. It will look for transits of Earth-sized planets, using a 30-inch telescope in space.

WANTED: High Quality RV Candidate star. A successful applicant should be old (6-8 Gyr) MS Dwarf, Med. to wide binary w/ orbital Plane: inclined by 11 degrees to line of sight or less pref.; Metallicity: >0.2 dex (plenty of planet-forming material); HZ: 0.7 AU, K=20 cm/sec for an Earth-mass planet; V mag=0.8 (100x brighter than typical high quality applicant) Spectral type K0. Dead quiet photosphere. No variables please. Near-twin of HD 69830 pref. No gas giants. Circumpolar in SH (Dec=-60), must be available nearly year round. Send HD or HIP number to: oklo@mac.com



Alpha Centauri B





If our basic understanding of how our own solar system formed is correct, then terrestrial planets should exist in orbit around Alpha Centauri B.

Simulated results for 3 m/s RV precision observations of Alpha Cen B.
Realistic weather, 200 sec cadence, 5 years of observations.