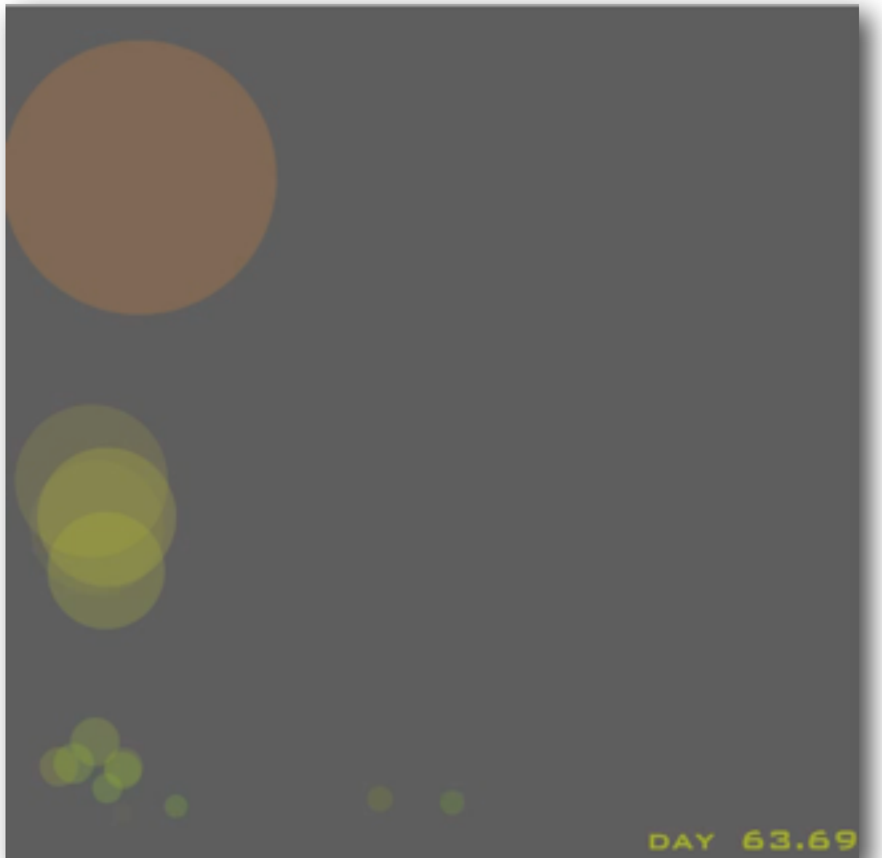

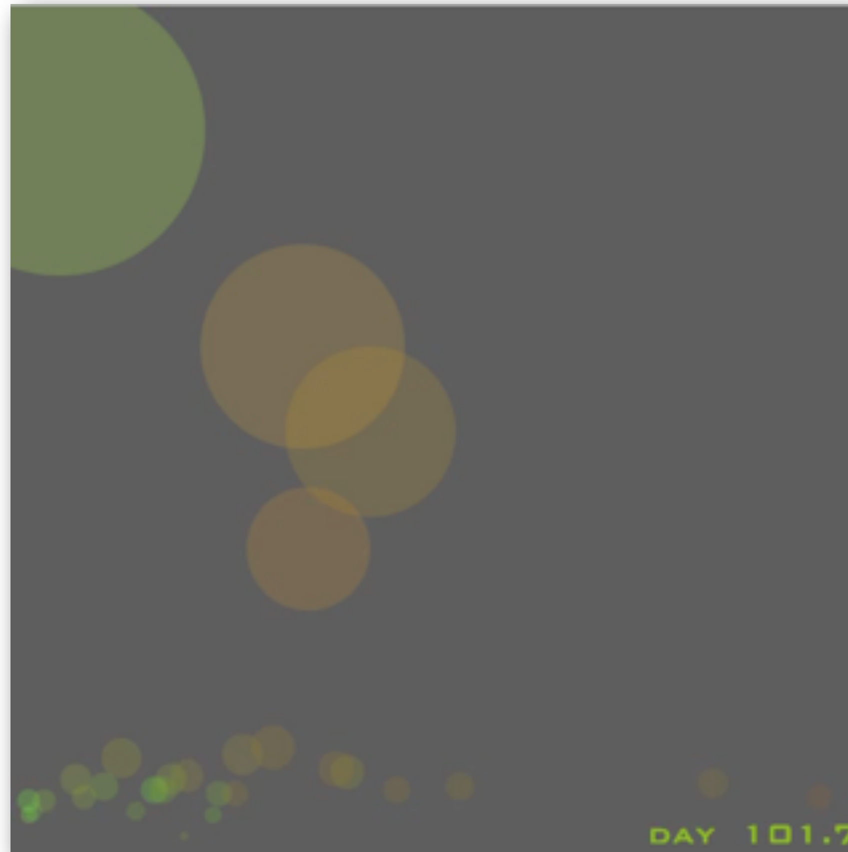

Probing the Galactic Planetary Census

Greg Laughlin -- UCSC Astronomy

Exoplanet News from the AAS meeting
(New York Times)

“The discovery of a planet, not much larger than Jupiter, outside the solar system was reported yesterday by a Swarthmore College scientist at an American Astronomical Society meeting.”

“The object is a dark companion of a dim star some 36,000,000,000,000 miles away. It is called Barnard’s star”

Another Solar System Is Found 36 Trillion Miles From the Sun

The discovery of a planet, not much larger than Jupiter, outside the solar system was reported yesterday by a Swarthmore College scientist at an American Astronomical Society meeting.

The object is a dark companion of a dim star some 36,000,000,000,000 miles away. It is called Barnard's Star.

Named Barnard's Star by its discoverer, Dr. Peter van de Kamp who directs Swarthmore's Sprout Observatory in Pennsylvania, the new planet is the third such body discovered outside the solar system but the most nearly planet-sized one of all.

This means that there are now three identified "solar systems" besides the one inhabited by earth. One, consisting of at least one planet and a sun named 61 Cygni, was discovered in 1943. Another, named Lalande 21185, was found in 1960. The planets in those two systems, however, are on the borderline between planetary bodies and stars, both having masses of about one one-hundredth that of the sun.

Barnard's Star is much smaller, only one seven-hundredth the sun's mass. It is one and a half times the mass of Jupiter, or nearly 500 times as massive as the earth, according to Dr. van de Kamp.

The Swarthmore scientist reported his discovery at the society's meeting at the University of Arizona in Tucson.

The finding was called "exciting" by Dr. Kenneth Franklin of the American Museum-Hayden Planetarium. He noted, however, that Barnard's Star B probably does not bear life as earth knows it because the new planet is too large and too cold.

According to Dr. van de Kamp's report, the new planet occupies an orbit four times farther from its parent star than the distance between earth and the sun. Also, the luminosity of Barnard's Star is only about forty-five hundred-thousandths that of the sun's.

This means, Dr. Franklin said that the new planet receives less than three hundred-thousandths as much energy over a square foot as the earth gets from the sun.

Despite its proximity to earth, Barnard's Star is invisible without a telescope because it is so dim. Likewise, the new planet is also invisible—even with a telescope. Dr van de Kamp discovered it through analyzing the wobbles its parent star makes in its movements across the heavens.

Those wobbles are created by the gravitational attraction between Barnard's Star and its planet, which orbits its sun once every twenty-four years.

So slight are the perturbations in Barnard's Star's trajectory, however, that they could be detected only through a painstaking study of thousands of photographs of the star over a period of nearly 50 years.

The new finding adds support to the conviction of astronomers that a great many solar systems exist, some of them possibly supporting life.

“The finding was called ‘exciting’ by Dr. Kenneth Franklin of the American Museum-Hayden Planetarium. He noted, however, that Barnard’s Star b probably does not bear life as Earth knows it because the new planet is too large and too cold.”

“The new finding adds support to the conviction of astronomers that a great many solar systems exist, some of them possibly supporting life.”

A Planetary System Orbiting Barnard's Star?

TimesSelect Archive

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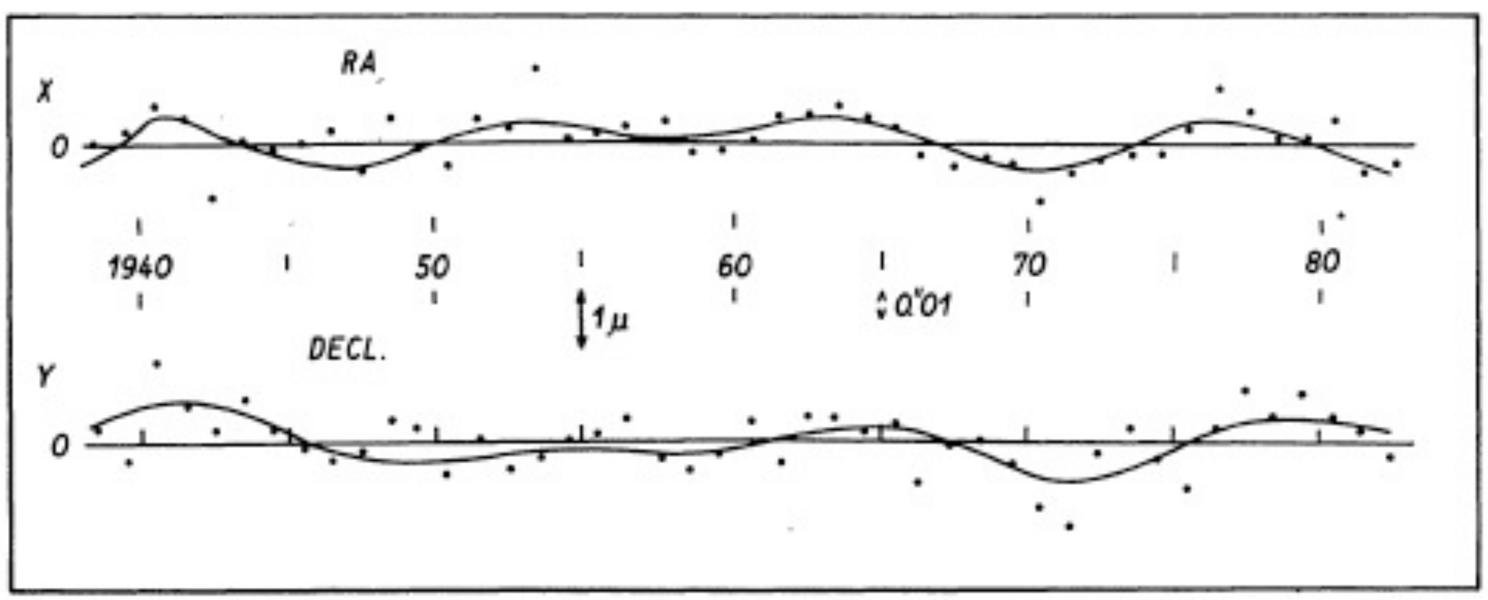
Another Solar System Is Found 36 Trillion Miles From the Sun

New York Times, April 19, 1963

*Please Note: Articles in The Archive from 1851-1980 will open in PDF format. Adobe Acrobat R… More information…

DISPLAYING FIRST PARAGRAPH - The discovery of a planet, not much larger than Jupiter, outside the solar system was reported yesterday by a Swarthmore College scientist at an American Astronomical Society meeting.



…ARDS Stern 1938—82, Sproul Observatory. Jährliche Störungen dargestellt durch zwei Kreisbahnen mit 12 und 20 Jahren.

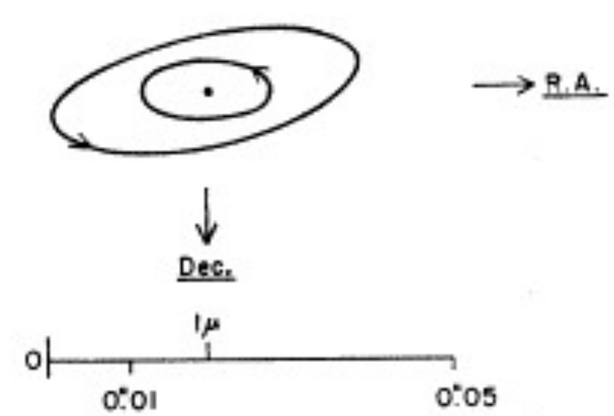


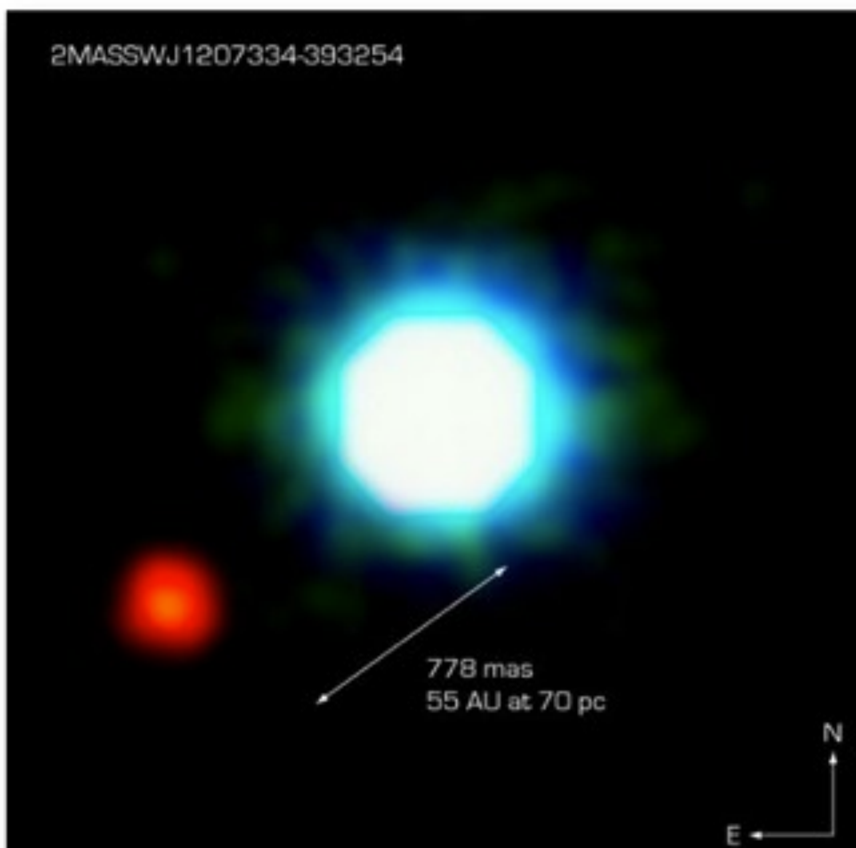
FIG. 3. Barnard's star: Apparent orbits of the two perturbations with circular orbits, and $P=26$ years and $P=12$ years.

IN SEARCH OF OTHER PLANETARY SYSTEMS

DAVID C. BLACK
Space Science Division, NASA-Ames Research Center, Moffett Field, Calif. 94035, U.S.A.

(Received 11 January, 1979)

Abstract. Numerous recent developments have led to an increasing awareness of and interest in the detection of other planetary systems. A brief review of the modern history of this subject is presented with emphasis on the status of data concerning Barnard's star. A discussion is given of plausible observable effects of other planetary systems with numerical examples to indicate the nature of the detection problem. Possible types of information (in addition to discovery) that observations of these effects might yield (e.g., planetary mass and temperature) are outlined. Also discussed are various candidate detection techniques (e.g., astrometric observations) which might be employed to conduct a search, the current state-of-the-art of these techniques in terms of measurement accuracy, and the capability of existing or planned facilities (e.g., space telescope) to perform a search. Finally, consideration is given to possible search strategies and the scope of a comprehensive search program.



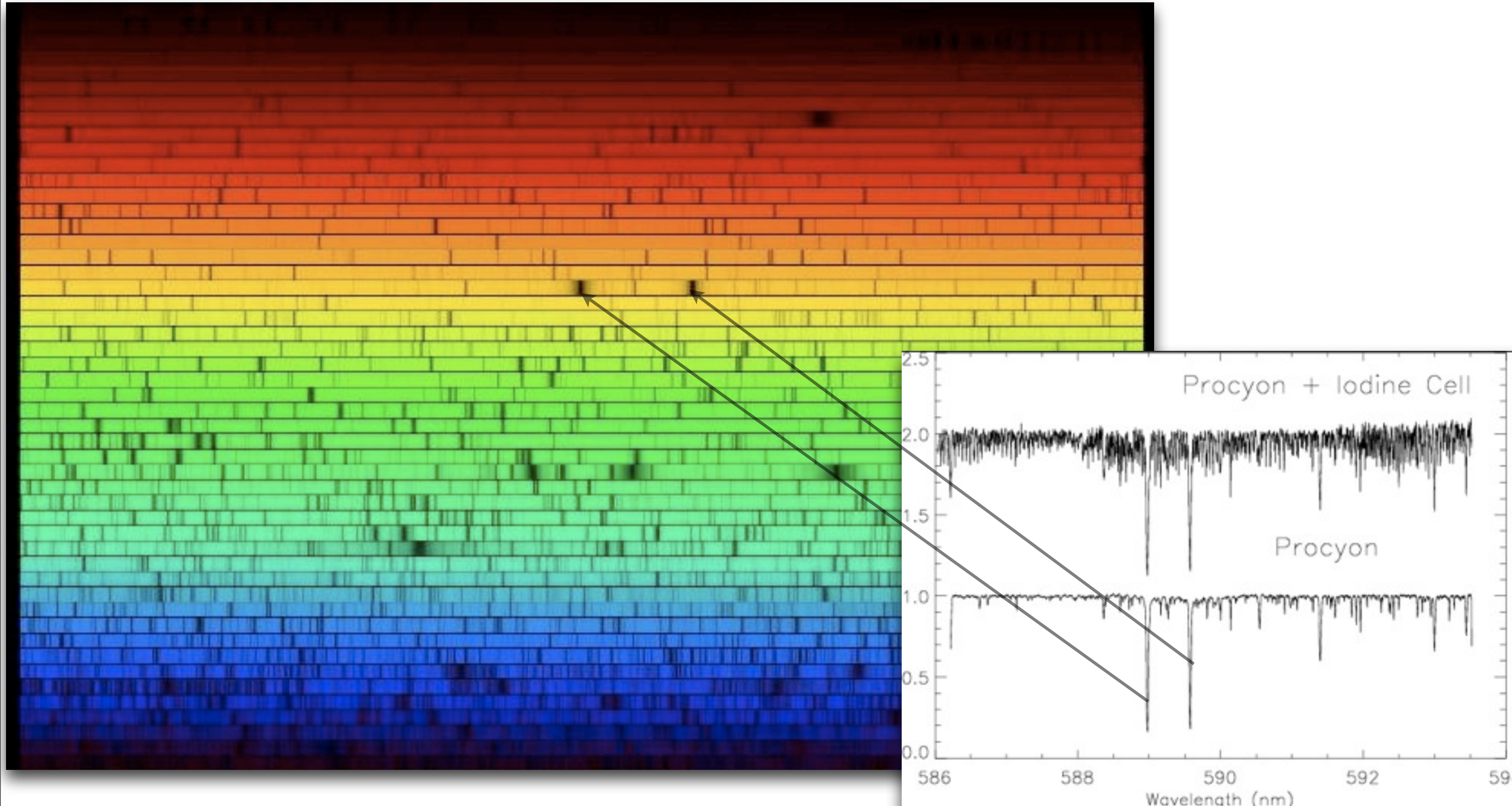
Credit: ESO (VLT/NACO)

2. Observable Manifestations of Extrasolar Planetary Systems

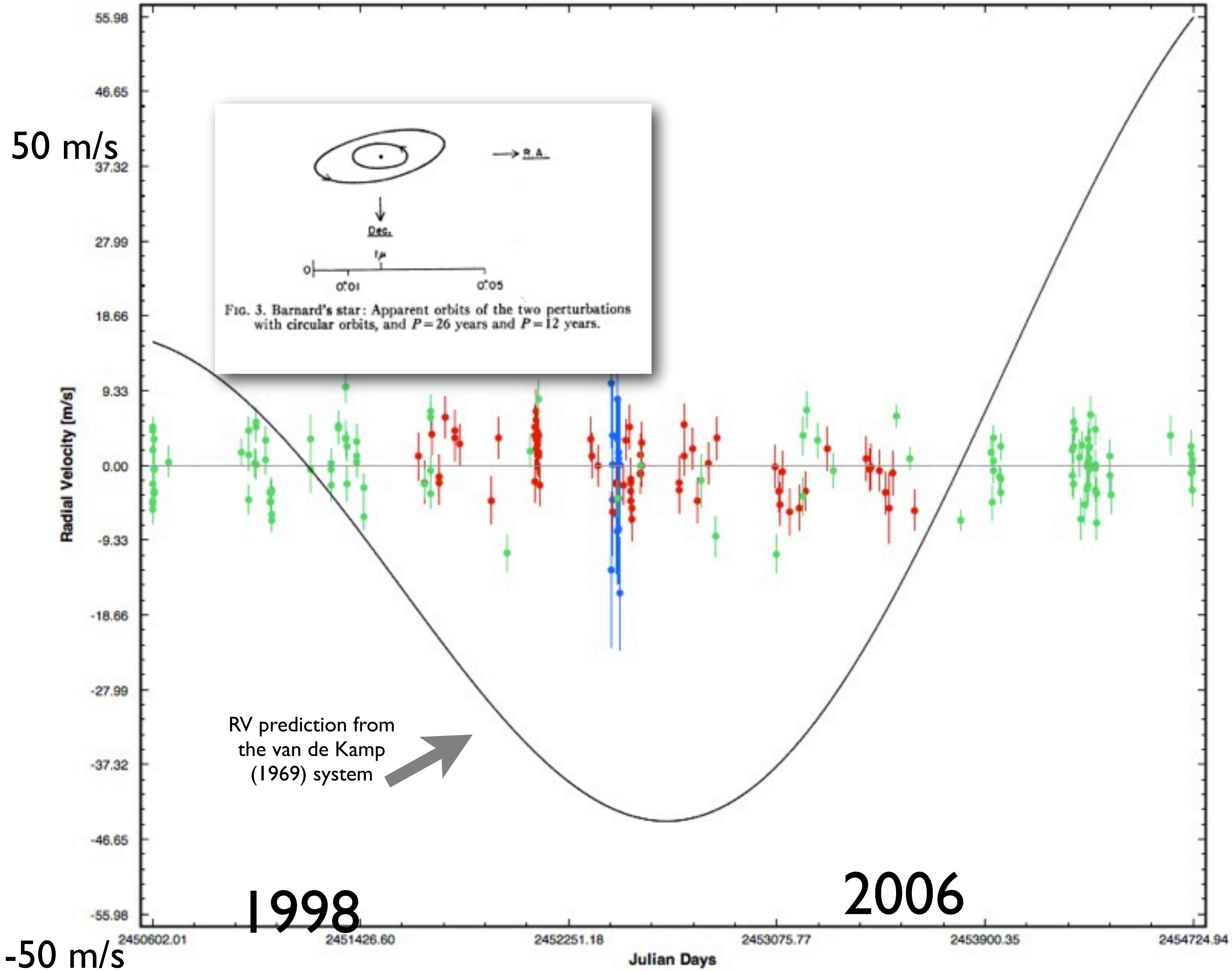
The task of detecting other PS is essentially that of detecting the planetary members of such systems. There are two general categories of effects by which these planets might be detected. One category involves radiation from a planet, while the other category involves effects that a planet has upon its central star. We shall refer to detection based on effects in the former category as *direct detection* (DD), whereas detection based on effects in the latter category will be termed *indirect detection* (ID).

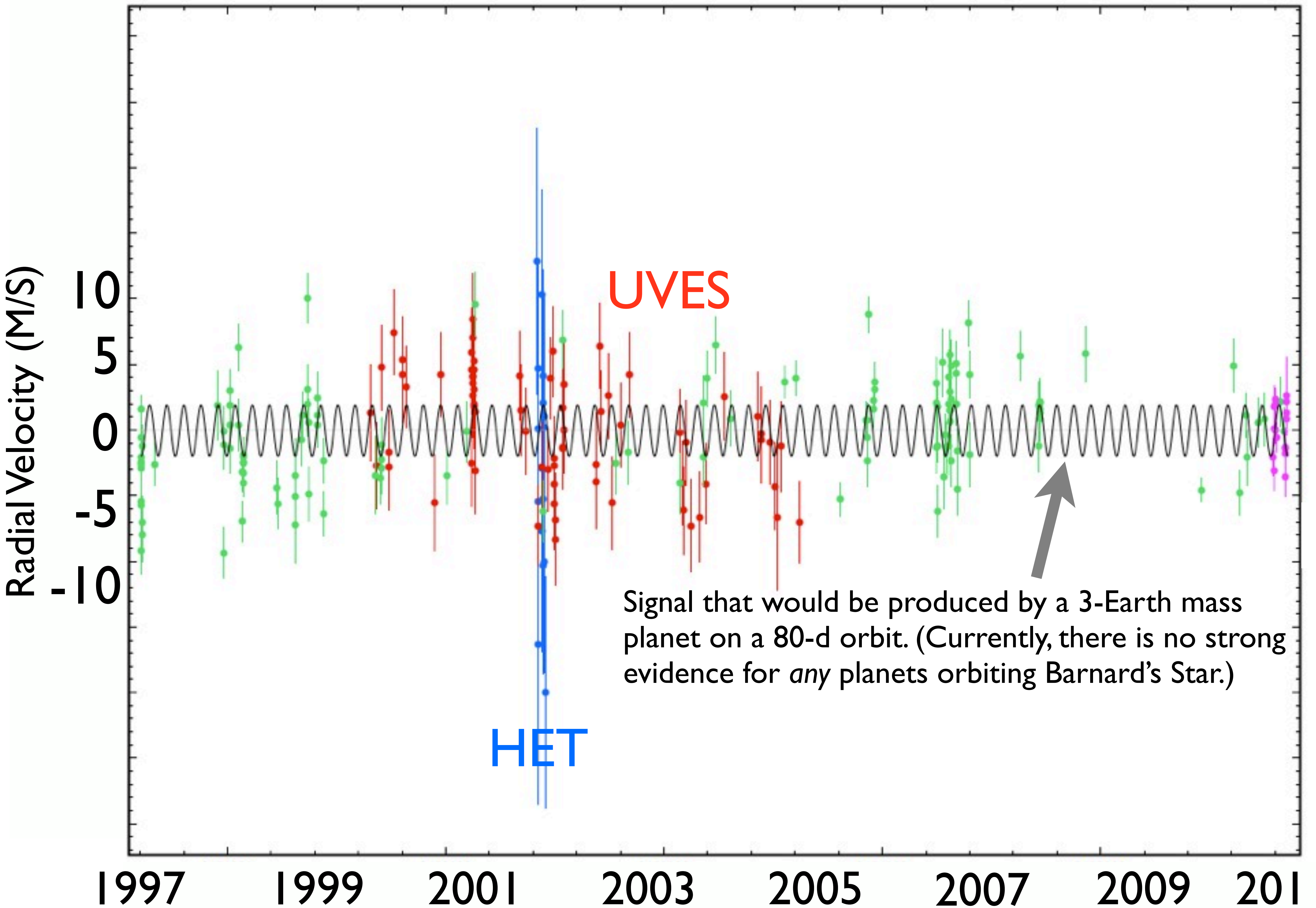
Planets can be sources of both thermal and non-thermal radiation. The temperature characterizing the thermal component of a planet's radiation is determined by a balance between energy input (e.g., internal radioactivity and external stellar radiation) and radiative loss from the planet. The non-thermal radiation component can arise from processes which are intrinsic to a planet, as well as from reflected radiation from the central star of a PS. Two potentially relevant examples of non-thermal planetary radiation are the Jovian decametric bursts (e.g., Carr and Desch, 1976) and the recently discovered CO_2 emission feature at $\lambda = 10.6$ µm in the spectrum of Venus (Townes, 1976).

Under the rubric of ID, one can identify at least three potentially observable effects, viz., perturbations in the proper motion of a star as it moves with respect to a reference frame defined by other stars, variations in the apparent wavelength of spectral features in a stellar spectrum, and dimming in the apparent luminosity of a star. If a star has a planetary companion, the star will revolve about the barycenter of the planet-star system with an orbital period equal to the orbital period of the planet. The projection of that orbital motion on the plane of the sky gives rise to the first effect mentioned above, whereas the projection of the orbital motion along the line-of-sight to the star gives rise to the second effect. The third effect derives not from dynamics but rather from a transit of the star as a planet moves between the star and an observer.



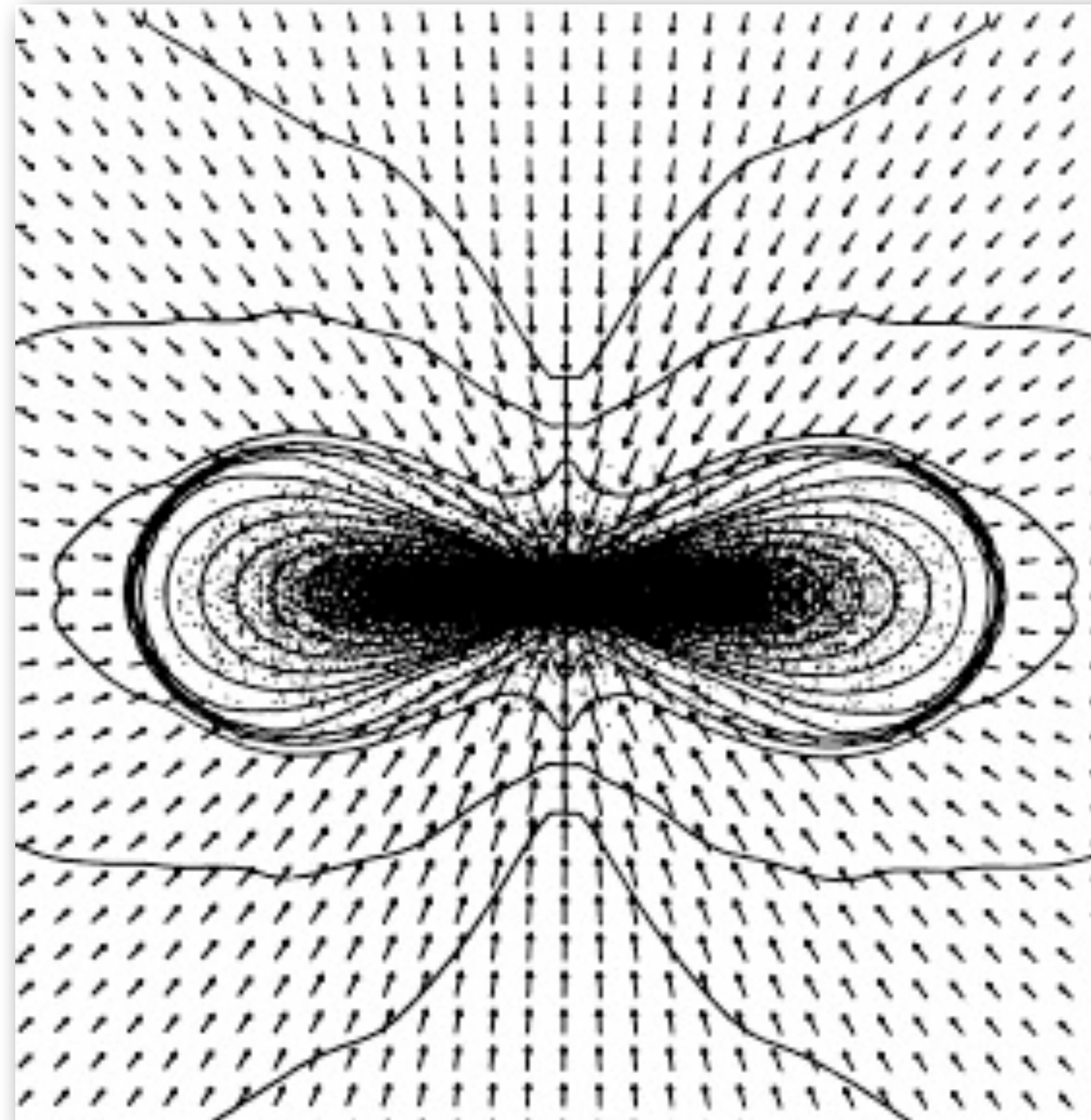
A stellar spectrum from The Keck Telescope. The velocity of the star along the line of sight is obtained by very accurately measuring the positions of the stellar absorption lines relative to a set of reference lines created by passing the light through an iodine cell which is at rest with respect to the telescope.


50 m/s
-50 m/s
55.98
46.65
37.32
27.99
18.66
9.33
0.00
-9.33
-18.66
-27.99
-37.32
-46.65
-55.98
Radial Velocity [m/s]
2450602.01
2451426.60
2452251.18
2453075.77
2453900.35
2454724.94
Julian Days
1998
2006
RV prediction from the van de Kamp (1969) system
R.A.
Dec.
0
0".01
0".05
FIG. 3. Barnard's star: Apparent orbits of the two perturbations with circular orbits, and P = 26 years and P = 12 years.

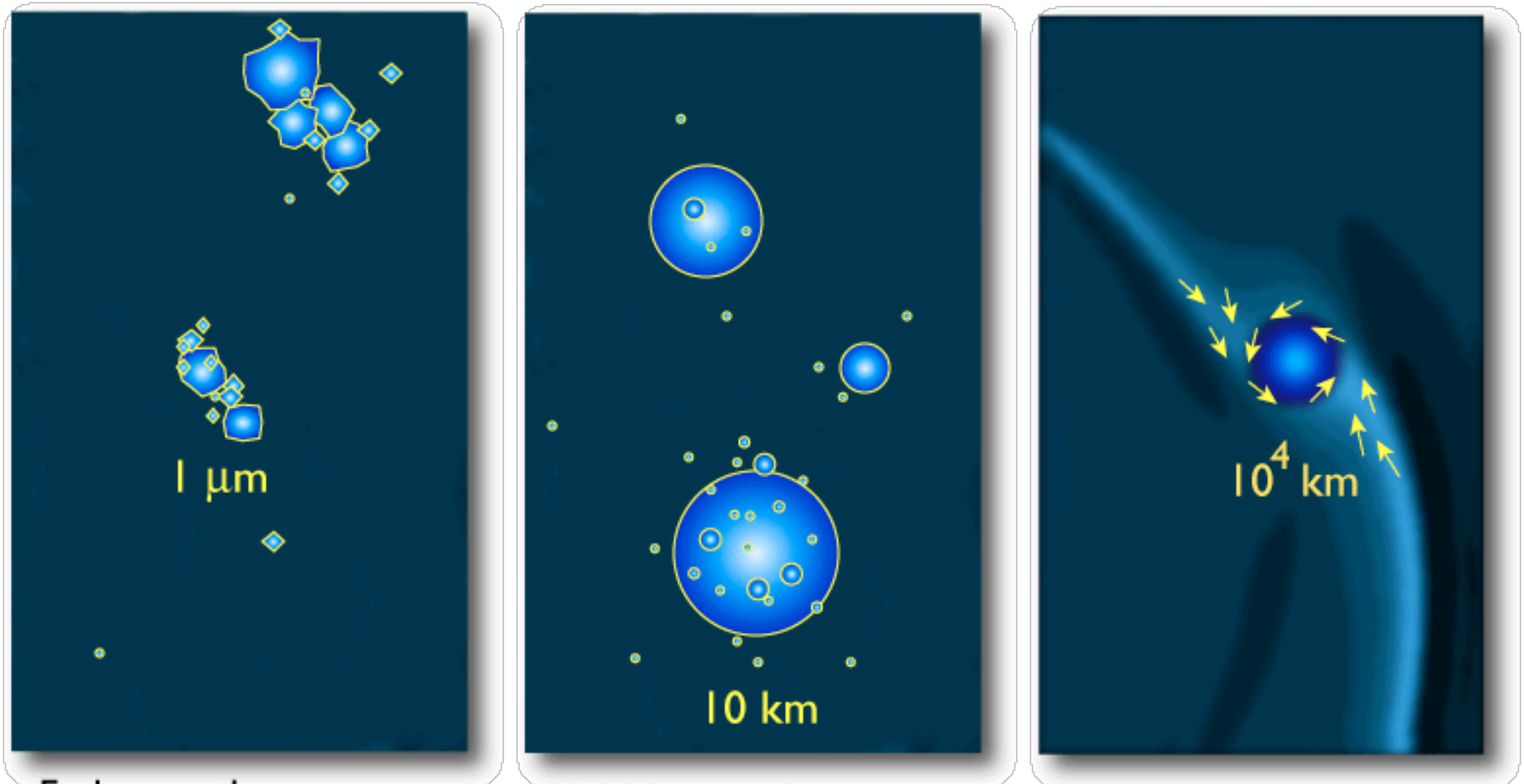

Radial Velocity (M/S)
10
5
0
-5
-10
UVES
HET
Signal that would be produced by a 3-Earth mass planet on a 80-d orbit. (Currently, there is no strong evidence for *any* planets orbiting Barnard's Star.)
1997
1999
2001
2003
2005
2007
2009
2011

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



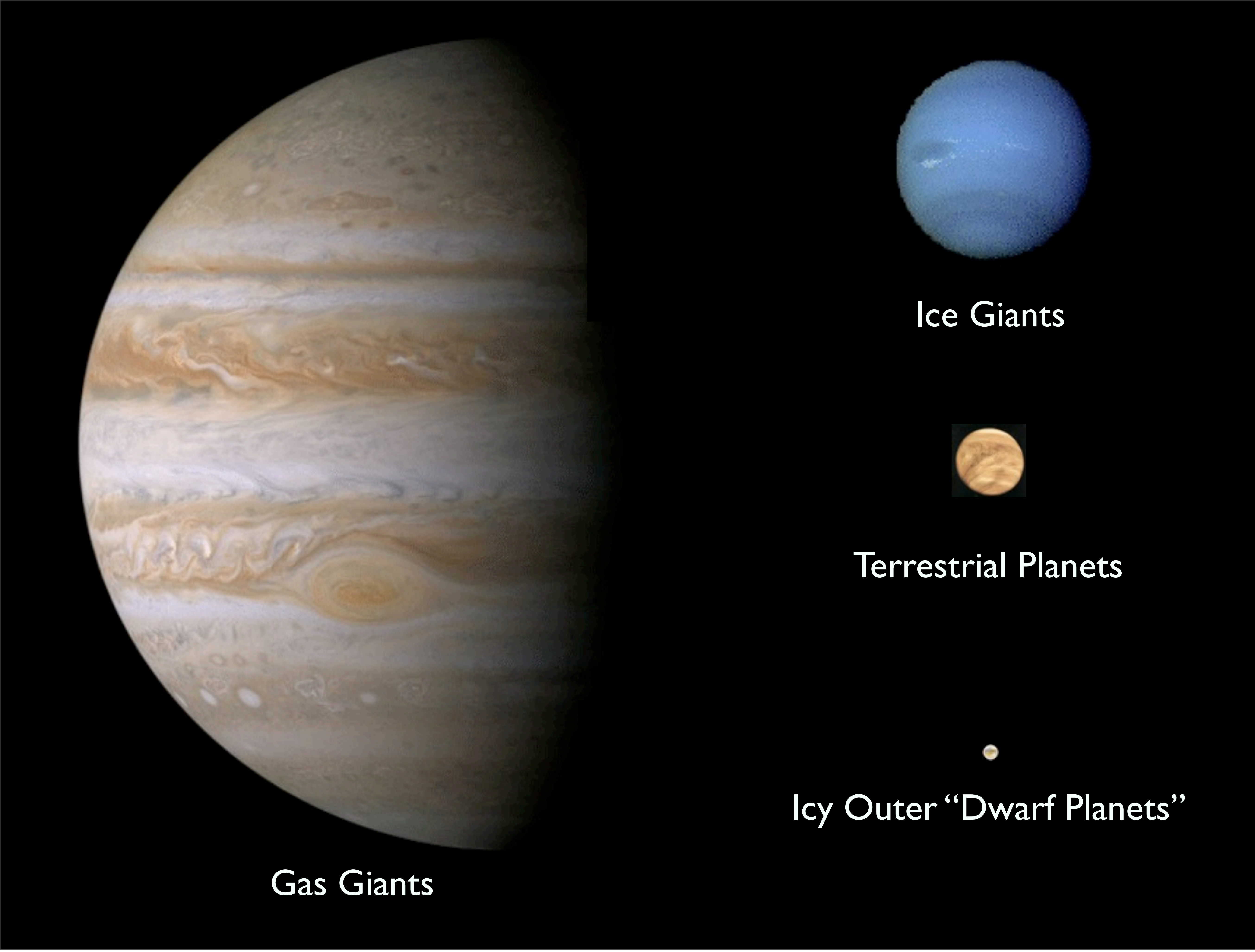
A computer simulation

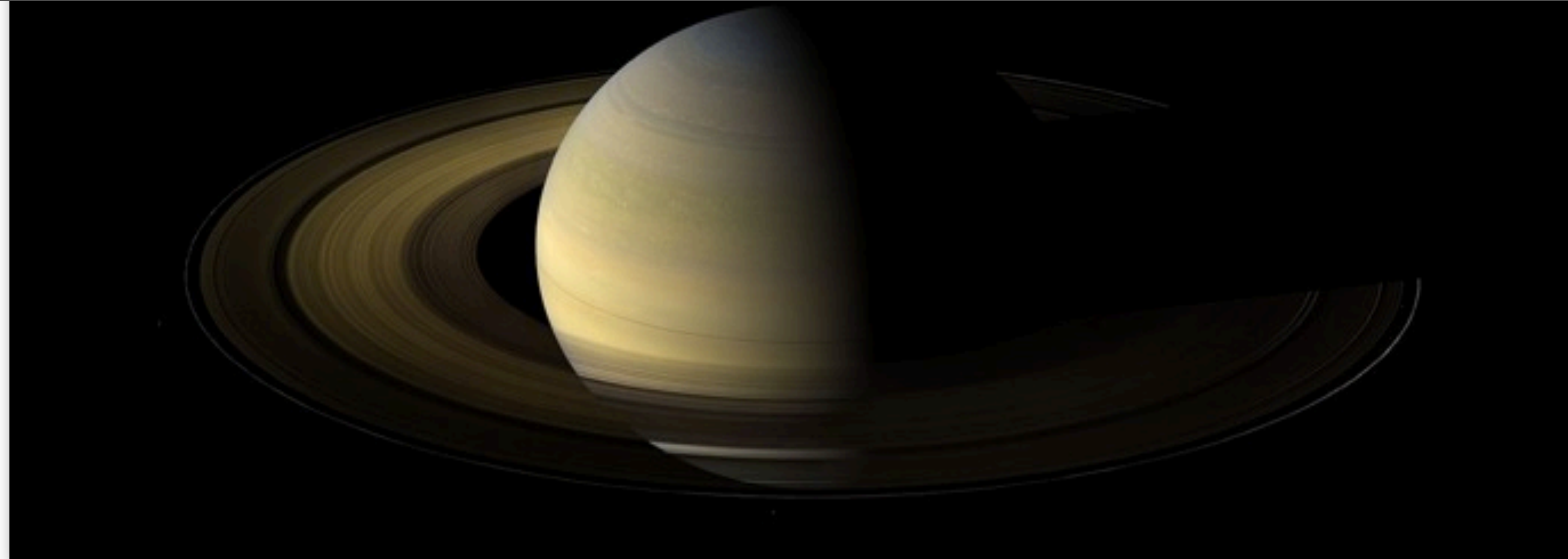


Early growth:
Sticking and Coagulation

Mid-life growth:
Gravitational Attraction

Late growth:
Gas Sweeping


Ice Giants
Terrestrial Planets
Icy Outer “Dwarf Planets”
Gas Giants



DISK-SATELLITE INTERACTIONS

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California Institute of Technology
and
Scott Tremaine
Institute for Advanced Study, Princeton, New Jersey

Received 1980 January 7; accepted 1980 April 9

ABSTRACT

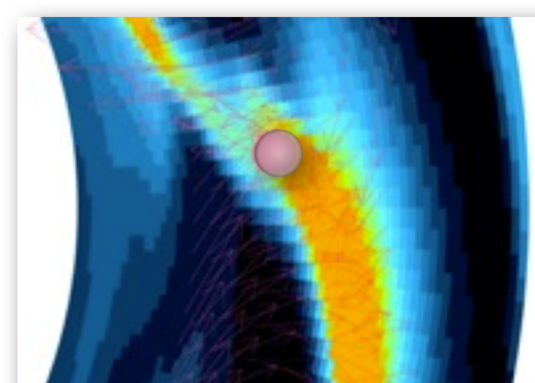
We calculate the rate at which angular momentum and energy are transferred between a disk and a satellite which orbit the same central mass. A satellite which moves on a circular orbit exerts a torque on the disk only in the immediate vicinity of its Lindblad resonances. The direction of angular momentum transport is outward, from disk material inside the satellite's orbit to the satellite and from the satellite to disk material outside its orbit. A satellite with an eccentric orbit exerts a torque on the disk at corotation resonances as well as at Lindblad resonances. The angular momentum and energy transfer at Lindblad resonances tends to increase the satellite's orbit eccentricity whereas the transfer at corotation resonances tends to decrease it. In a Keplerian disk, to lowest order in eccentricity and in the absence of nonlinear effects, the corotation resonances dominate by a slight margin and the eccentricity damps. However, if the strongest corotation resonances saturate due to particle trapping, then the eccentricity grows.

We present an illustrative application of our results to the interaction between Jupiter and the protoplanetary disk. The angular momentum transfer is shown to be so rapid that substantial changes in both the structure of the disk and the orbit of Jupiter must have taken place on a time scale of a few thousand years.

Subject headings: hydrodynamics — planets: Jupiter — planets: satellites — solar system: general

$$\frac{1}{a}\frac{da}{dt} = \pm 5.6\left(\frac{M_s}{M_p}\right)\left(\frac{\Sigma a^2}{M_p}\right)\Omega m_{\max}^3 .$$

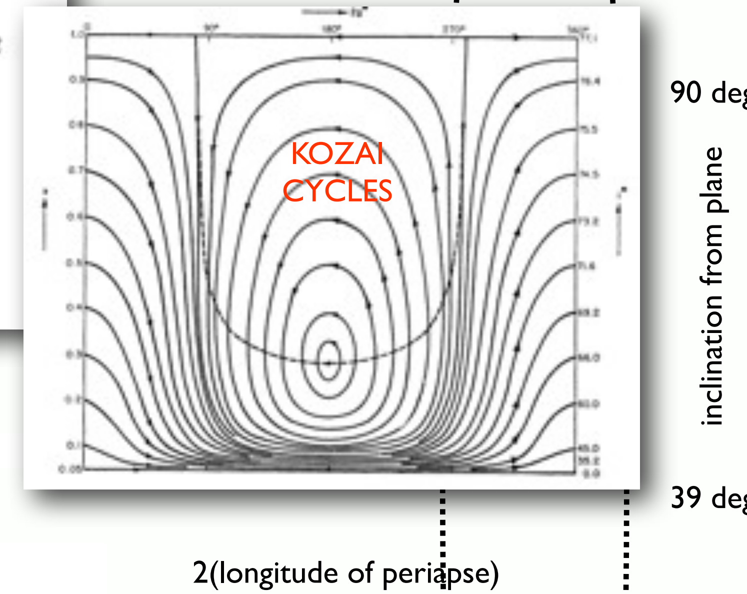
Migration



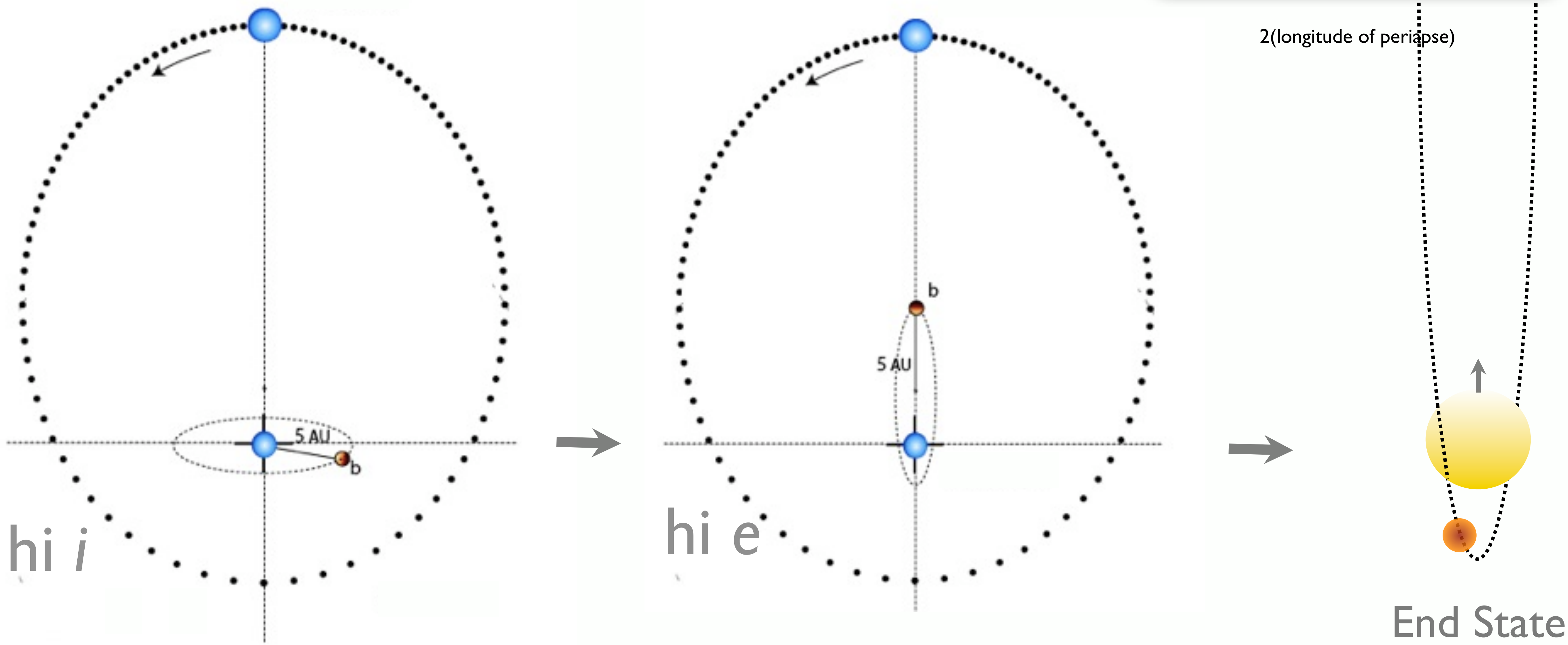
THE ASTRONOMICAL JOURNAL VOLUME 67, NUMBER 9 NOVEMBER 1962

Secular Perturbations of Asteroids with High Inclination and Eccentricity

YOSHIHIDE KOZAI*
Smithsonian Astrophysical Observatory, Cambridge, Massachusetts
(Received August 29, 1962)

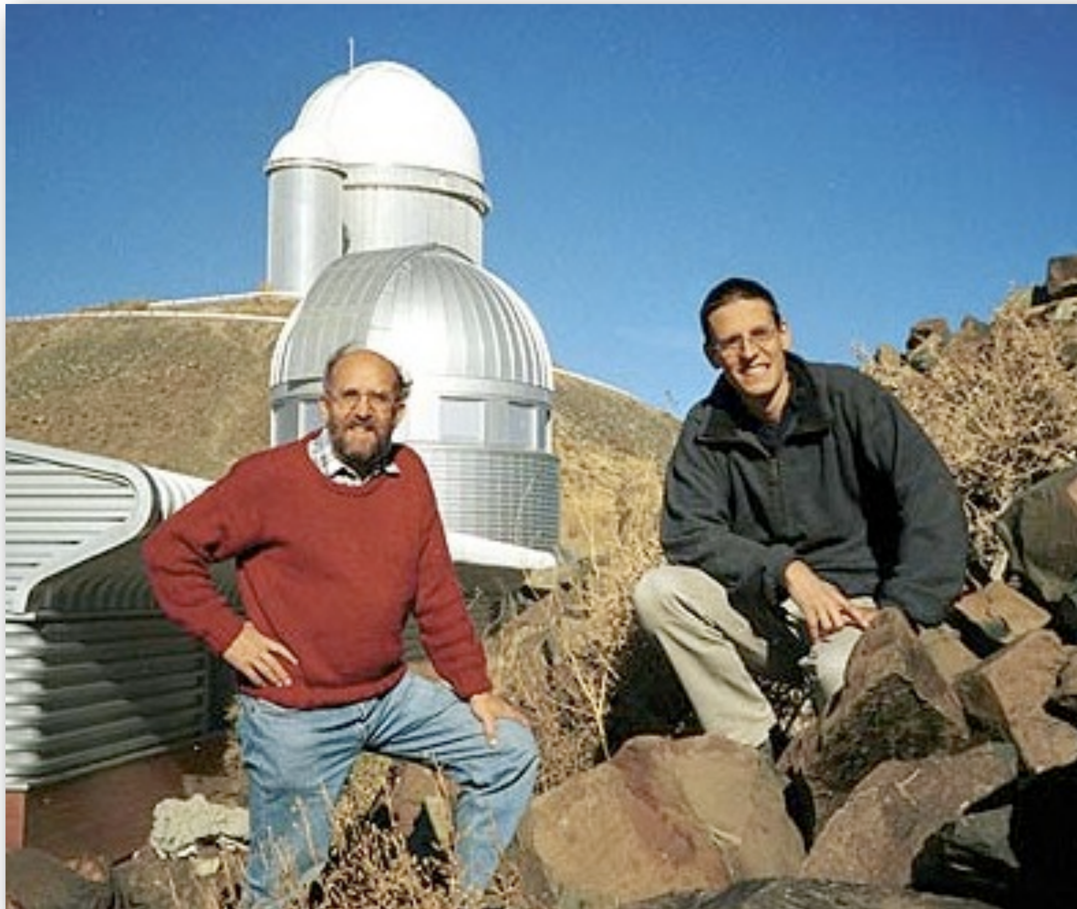


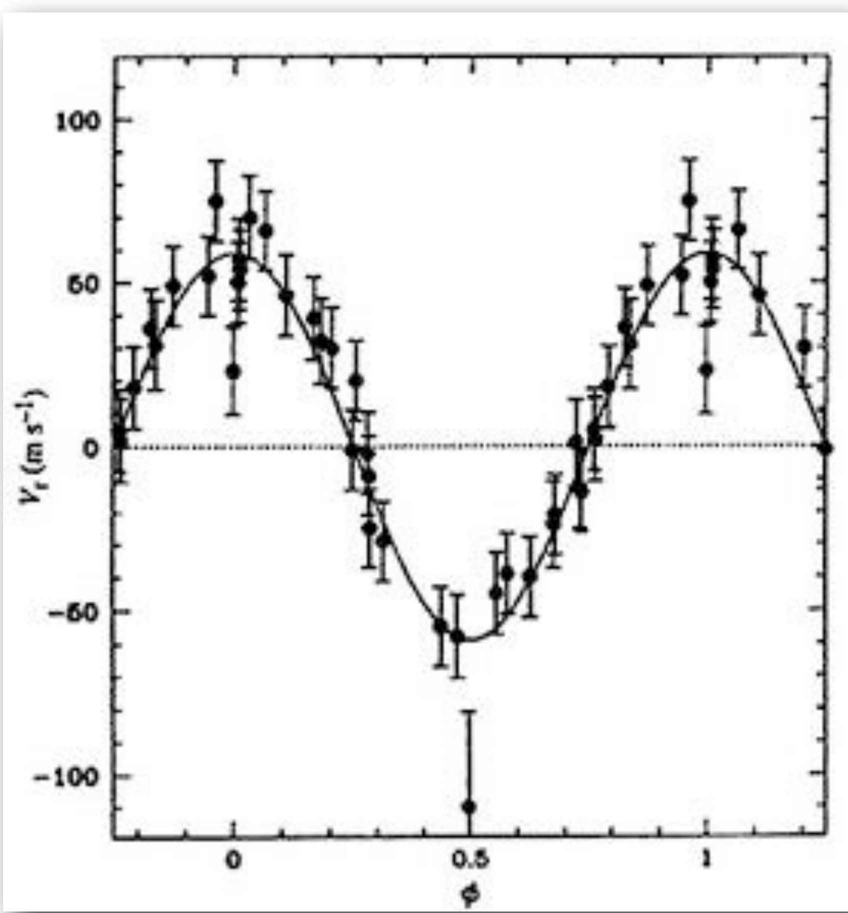
Kozai Cycles with Tidal Friction



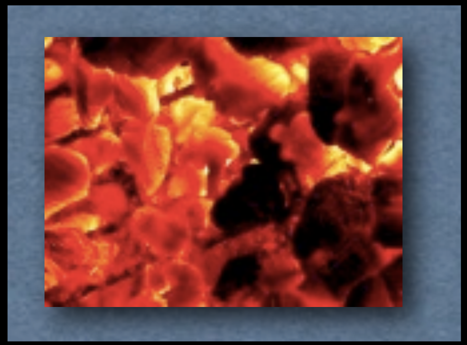
If we neglect the mass of the planet, then the planet conserves $\Theta = (1 - e_p^2)^{1/2} \cos I$ during its motion. (This *Kozai integral* is related to the Jacobi energy and the Tisserand relation in the circular restricted 3-body problem.)

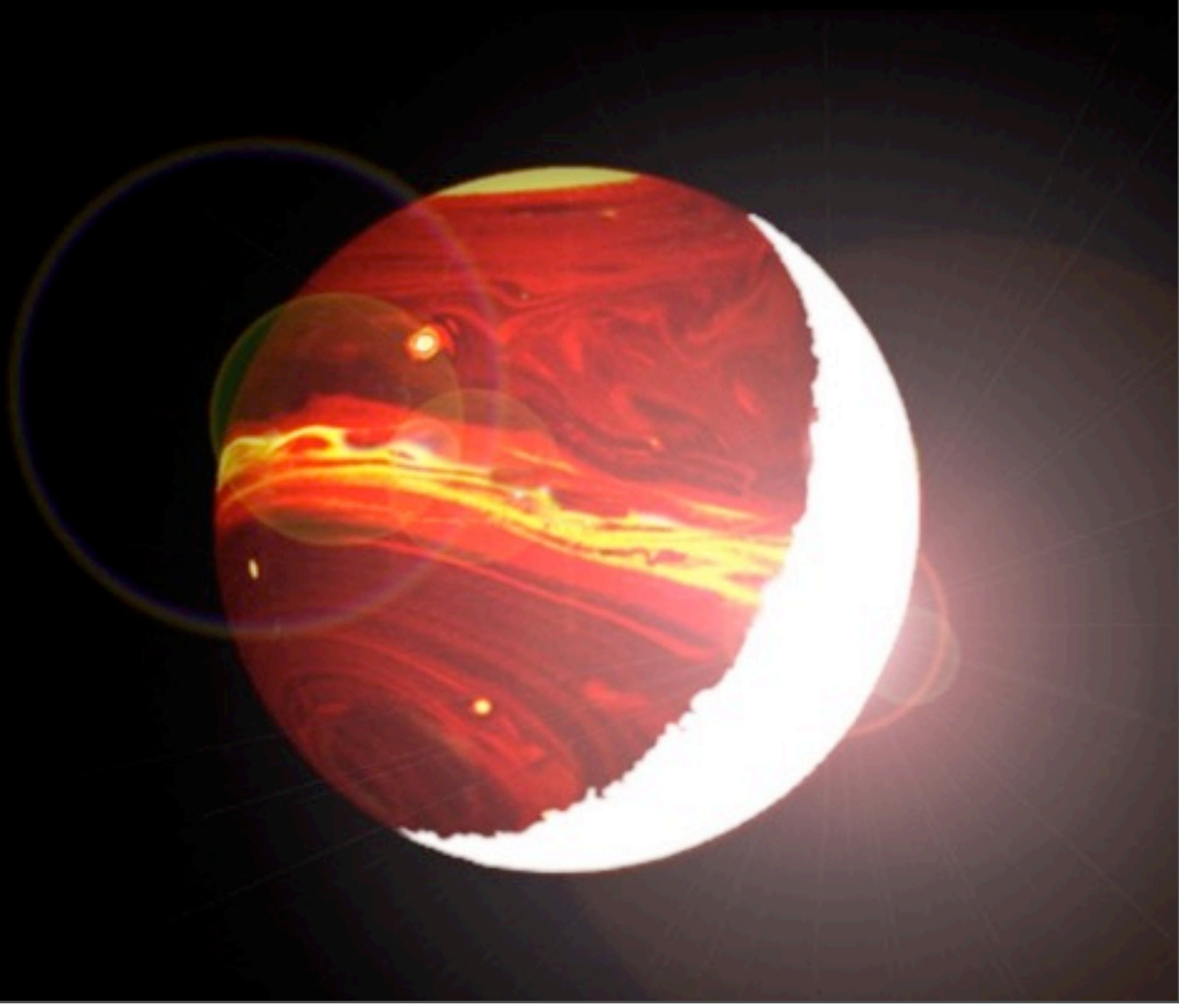
As the orbit shrinks, GR precession eventually destroys the Kozai oscillations, leaving the planet marooned in its high-e state. The orbit gradually circularizes, eventually leaving a hot Jupiter.



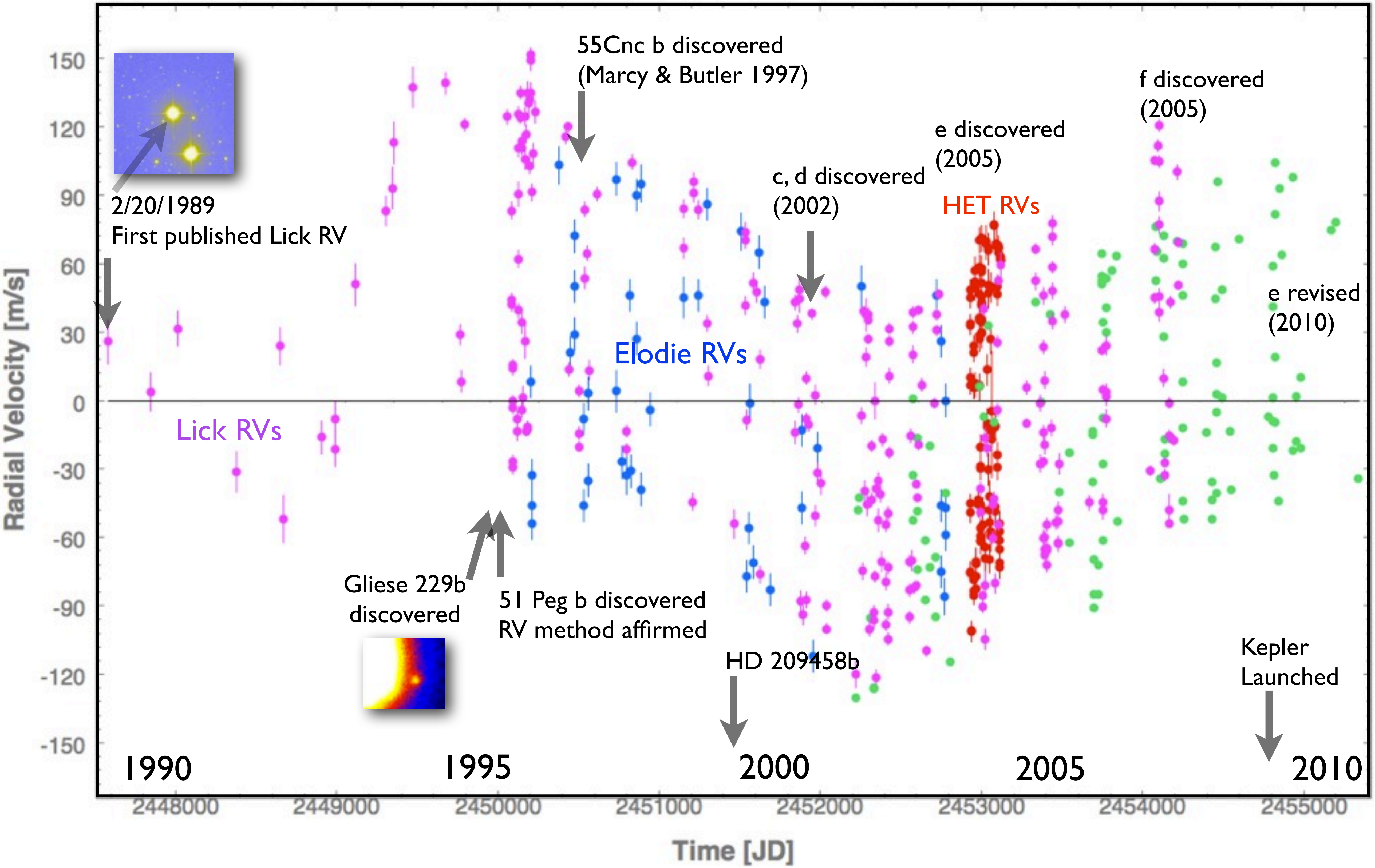


The first extrasolar planet around a sun-like star was discovered by Michel Mayor and Didier Queloz in 1995. They measured the *Doppler radial velocity* of the star.

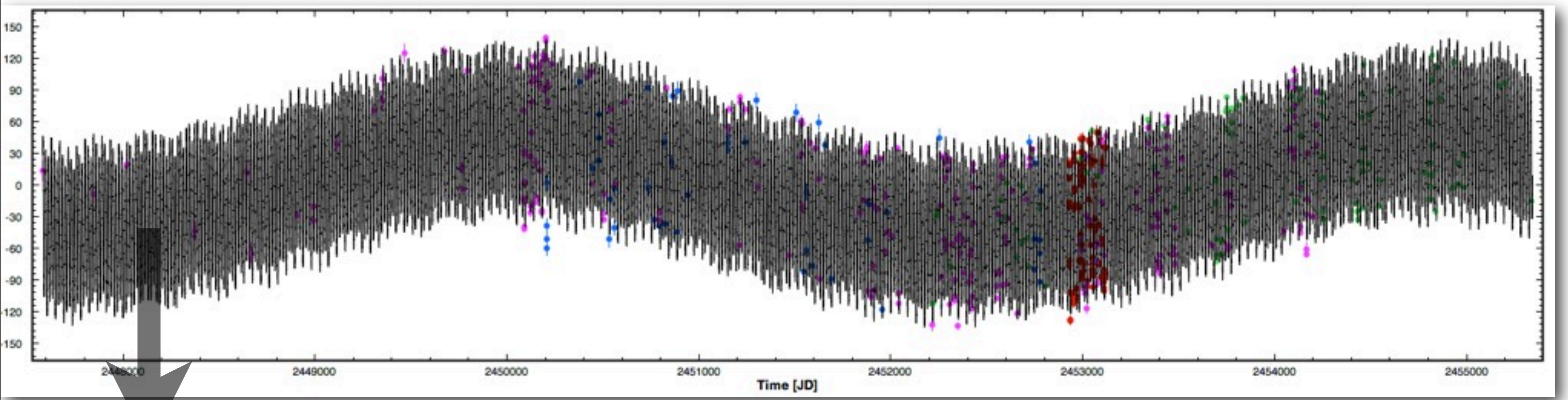


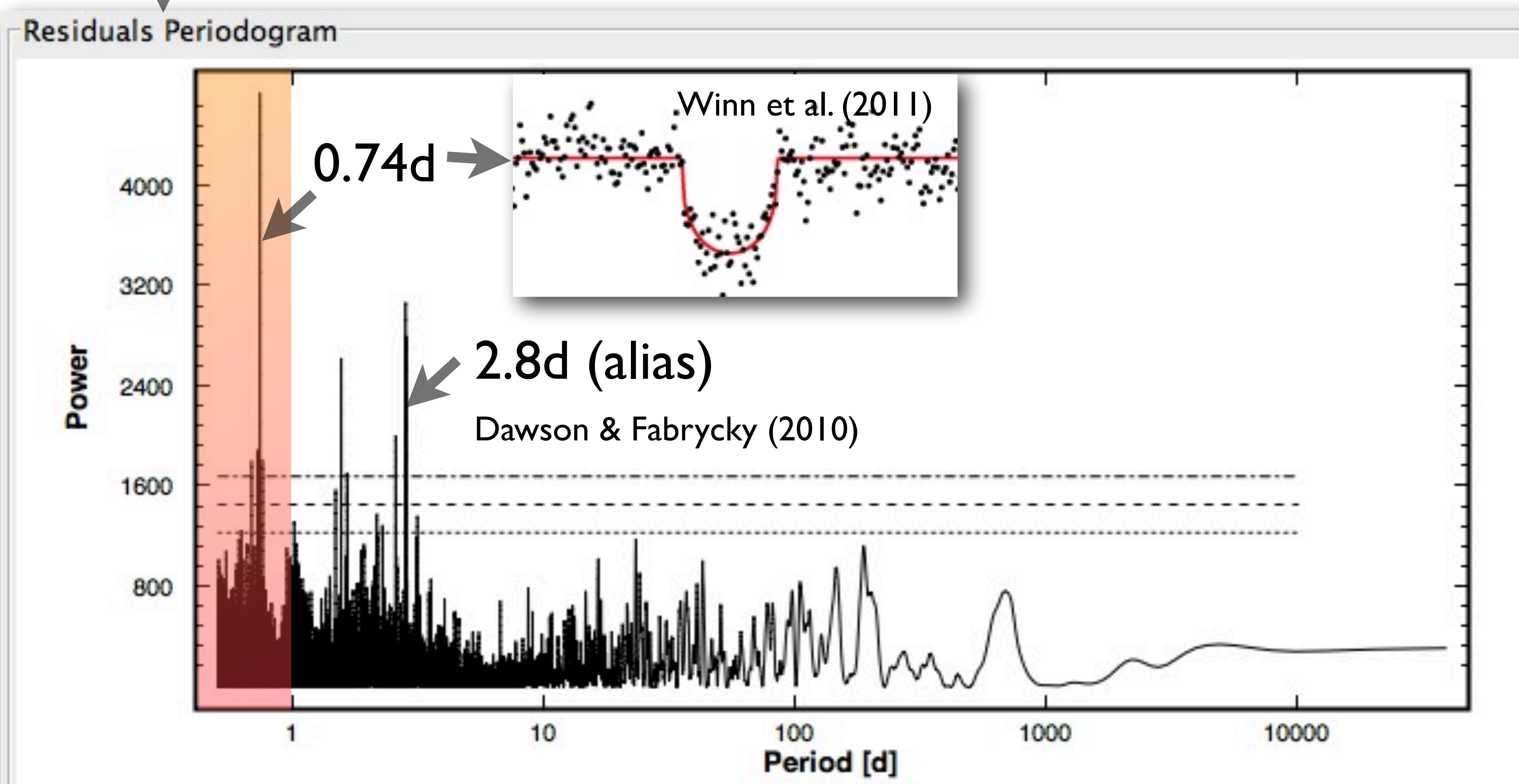


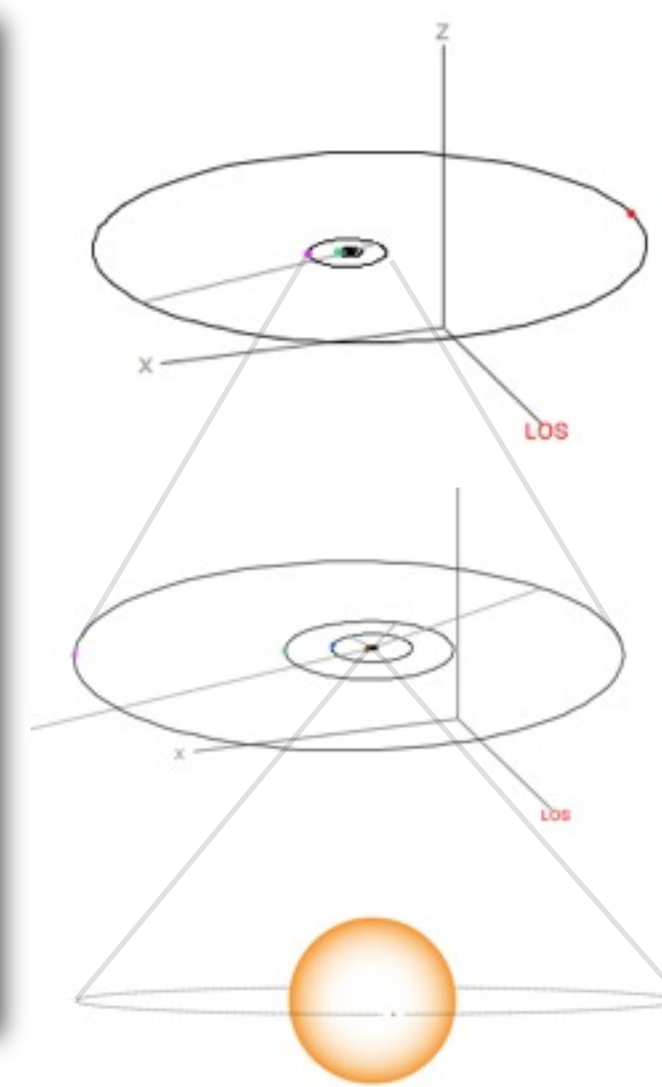
23-year Timeline of 55 Cancri RV Observations

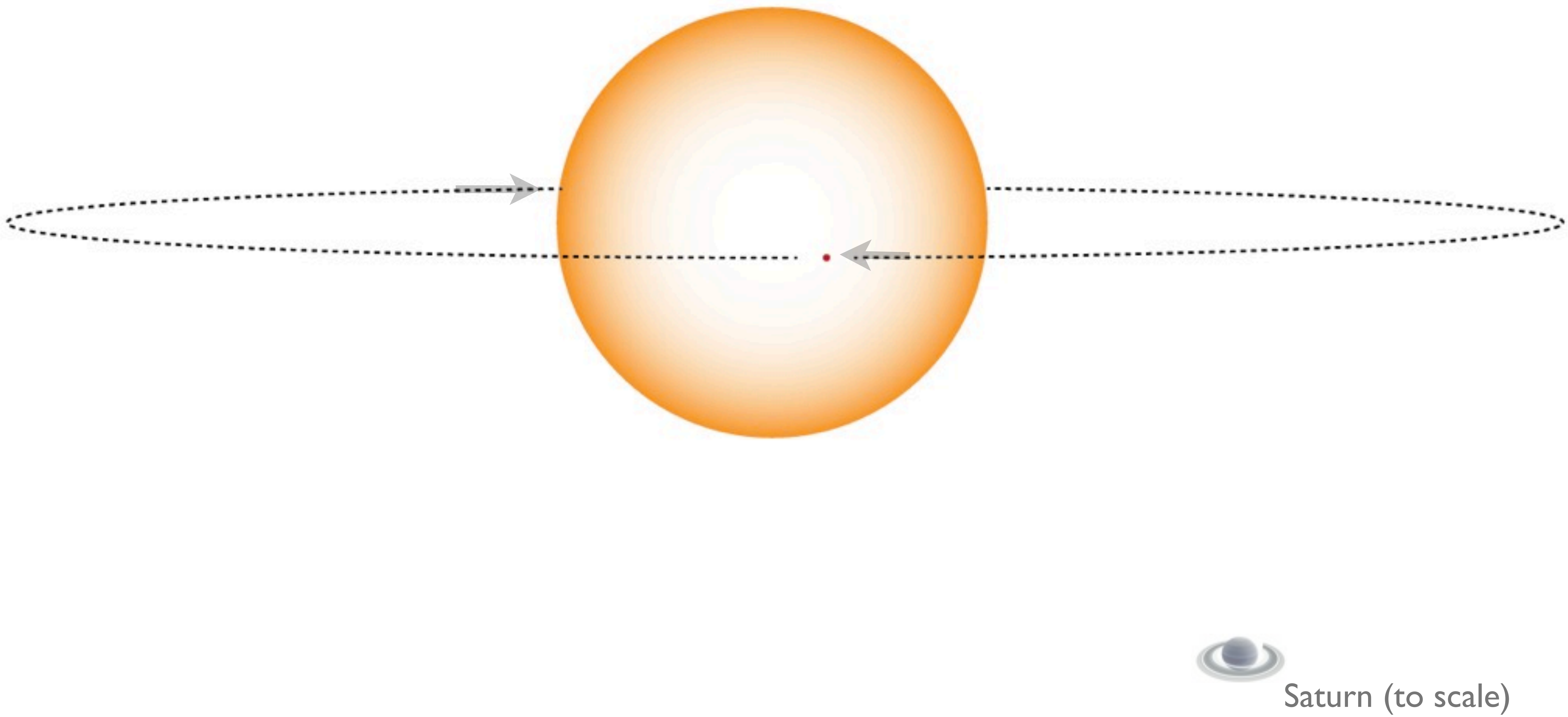


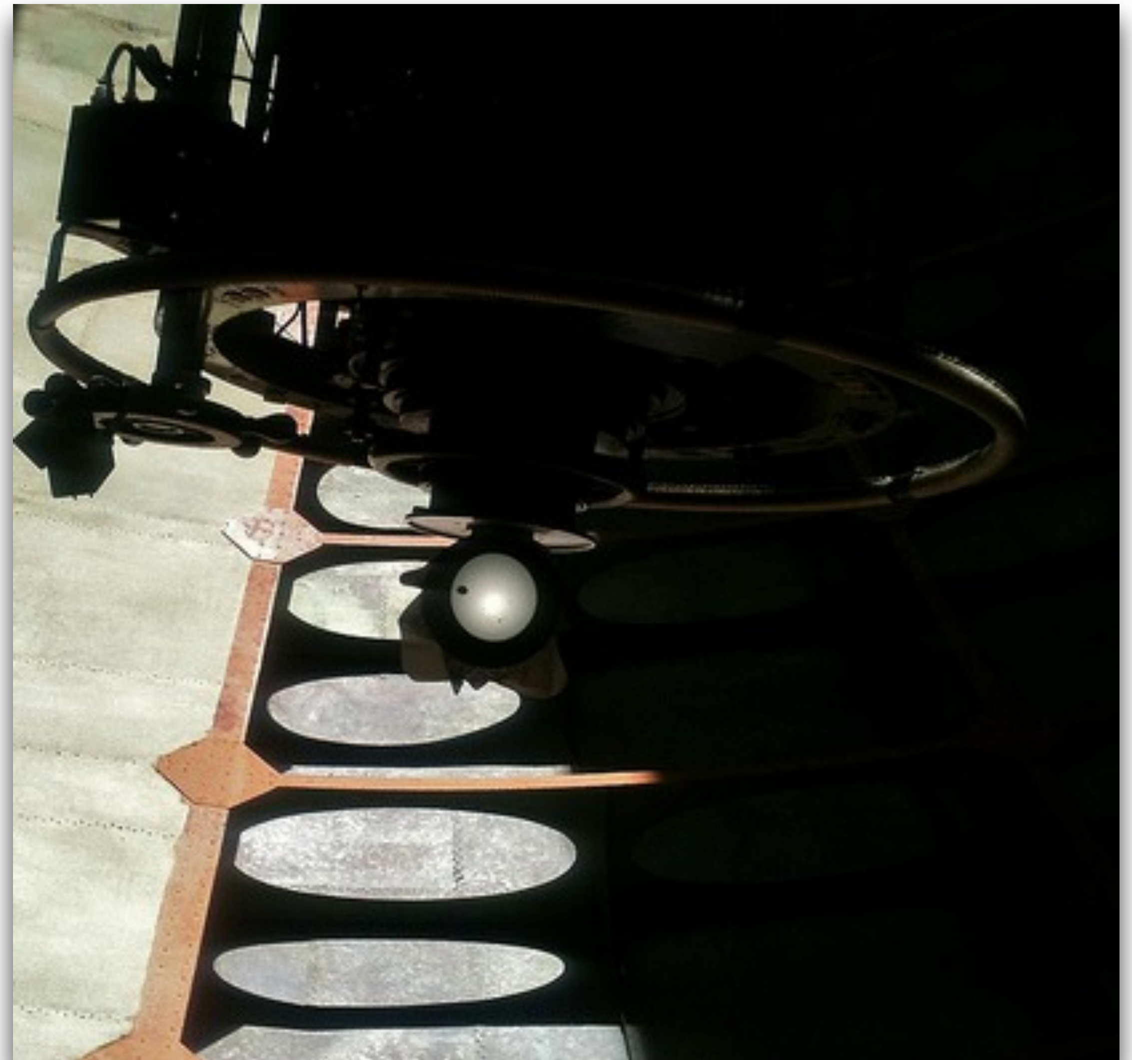
A 14d + 44d + 260d + 5200d fit to the 2+ decades of RV data for 55 Cancri



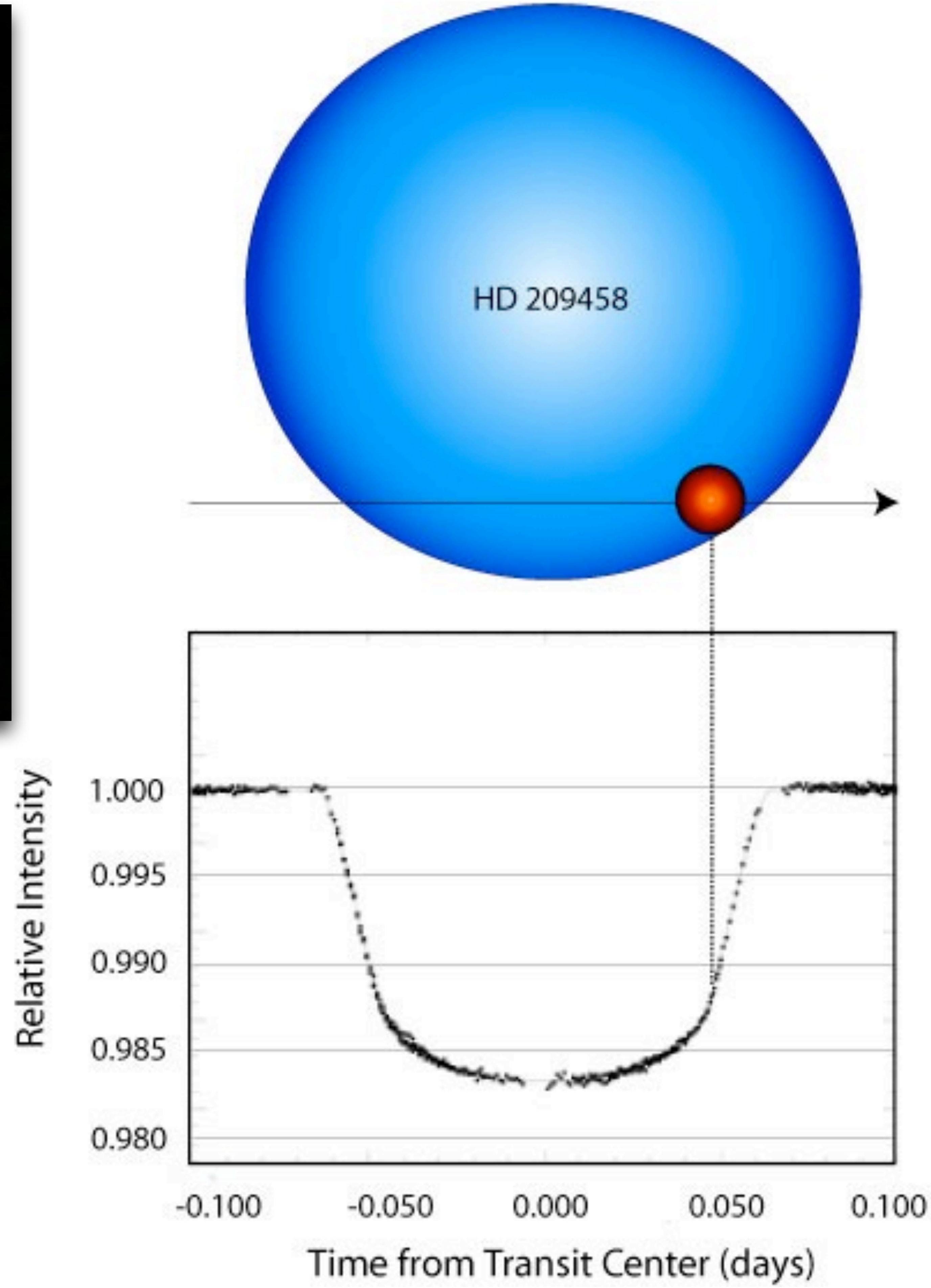





Saturn (to scale)



Transit of Venus



Planets detected via RV (including transiting planets)