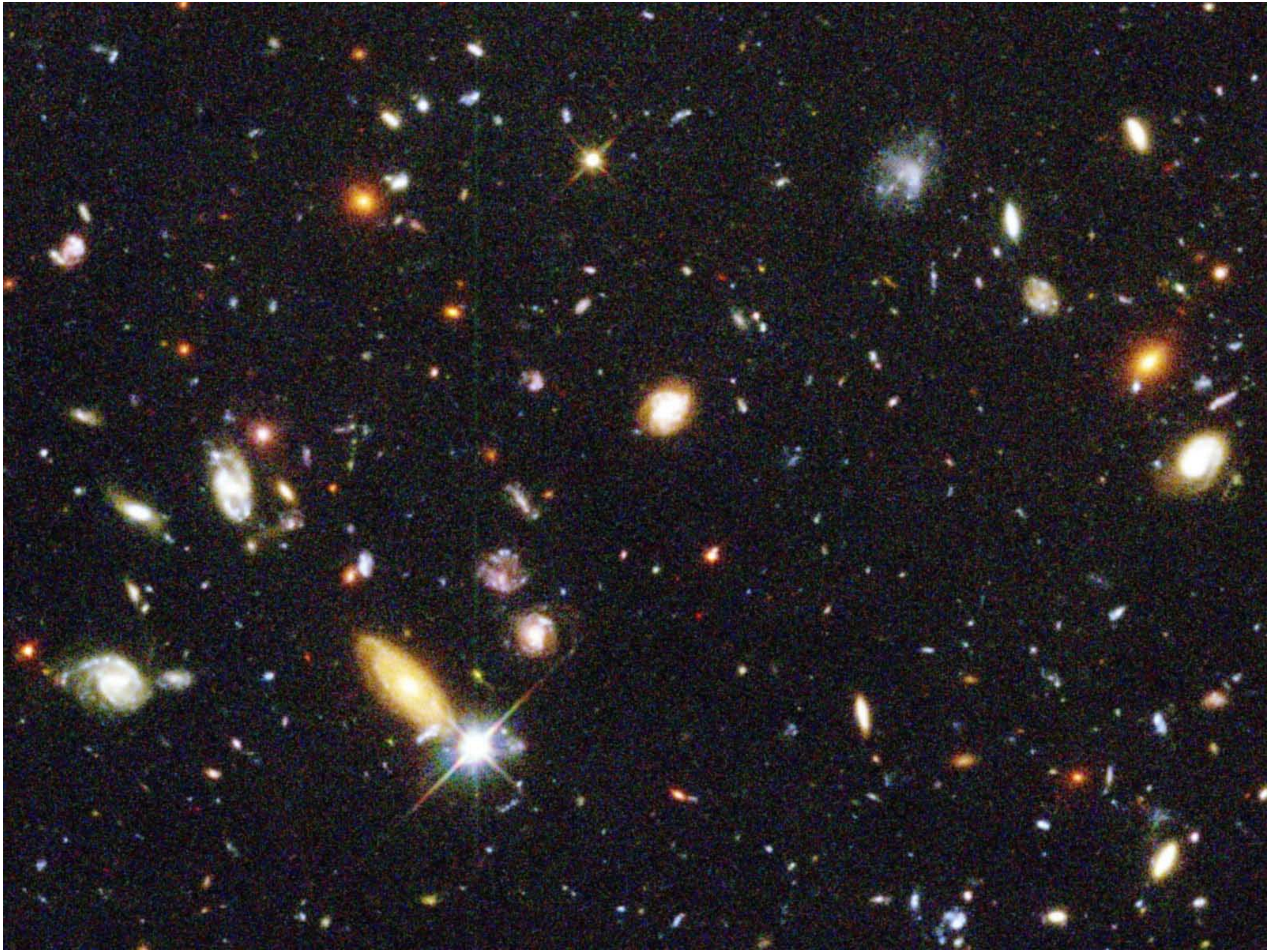
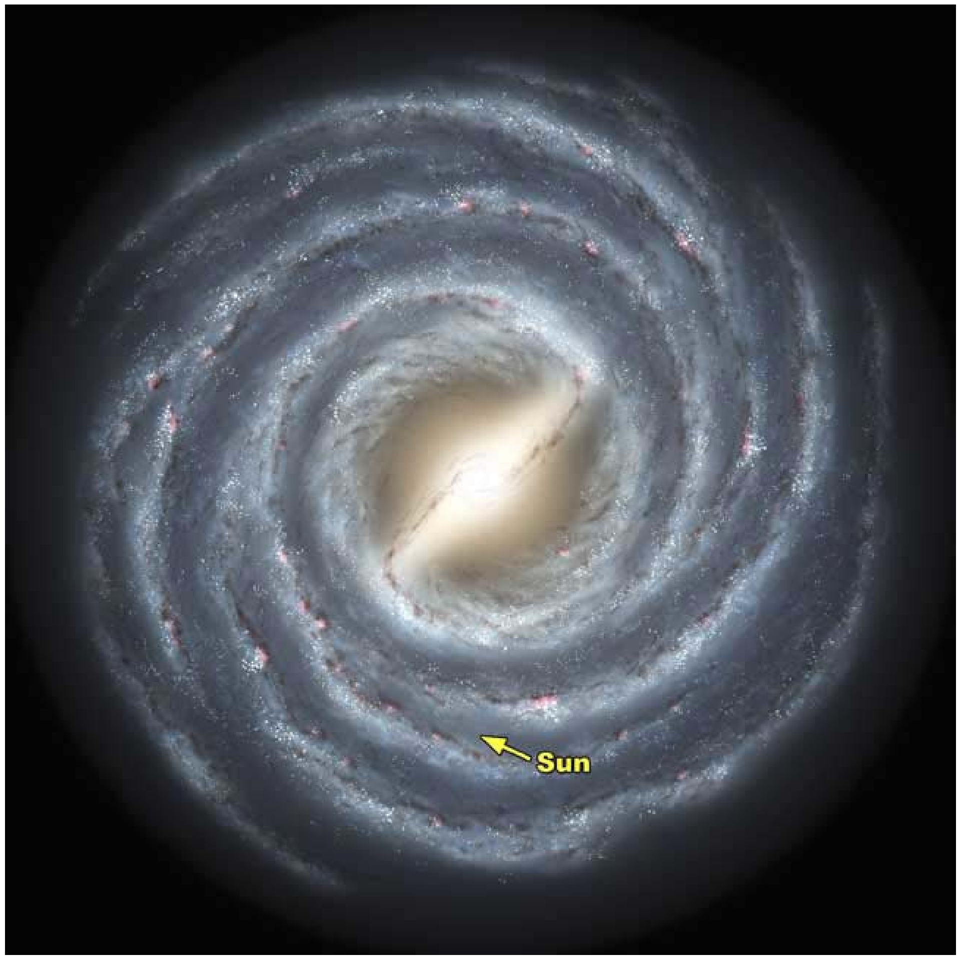
Exoplanets
– and the Search for the Second Earth

- Wing-Huen Ip/Institutes of Astronomy and Space Sciences, National Central University

- December 18, 2010



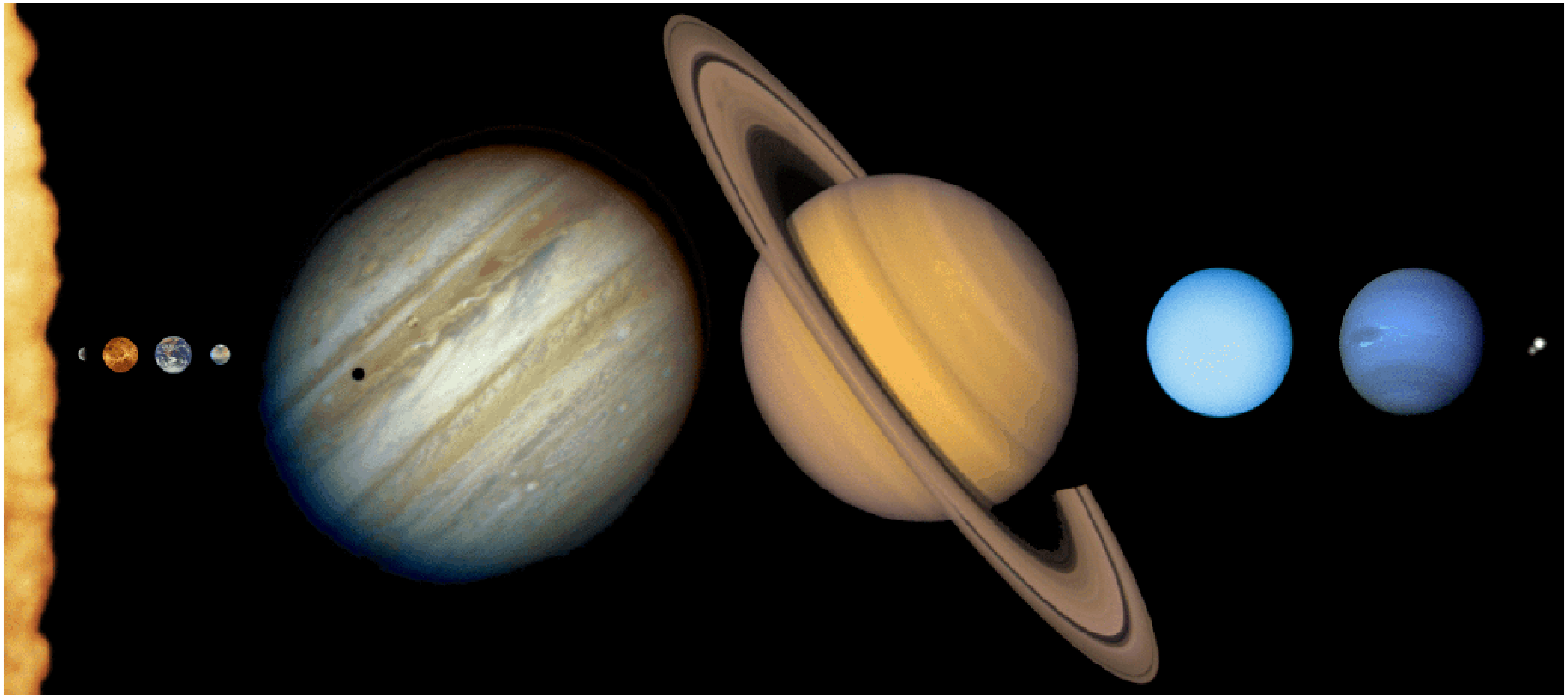
銀河系模型



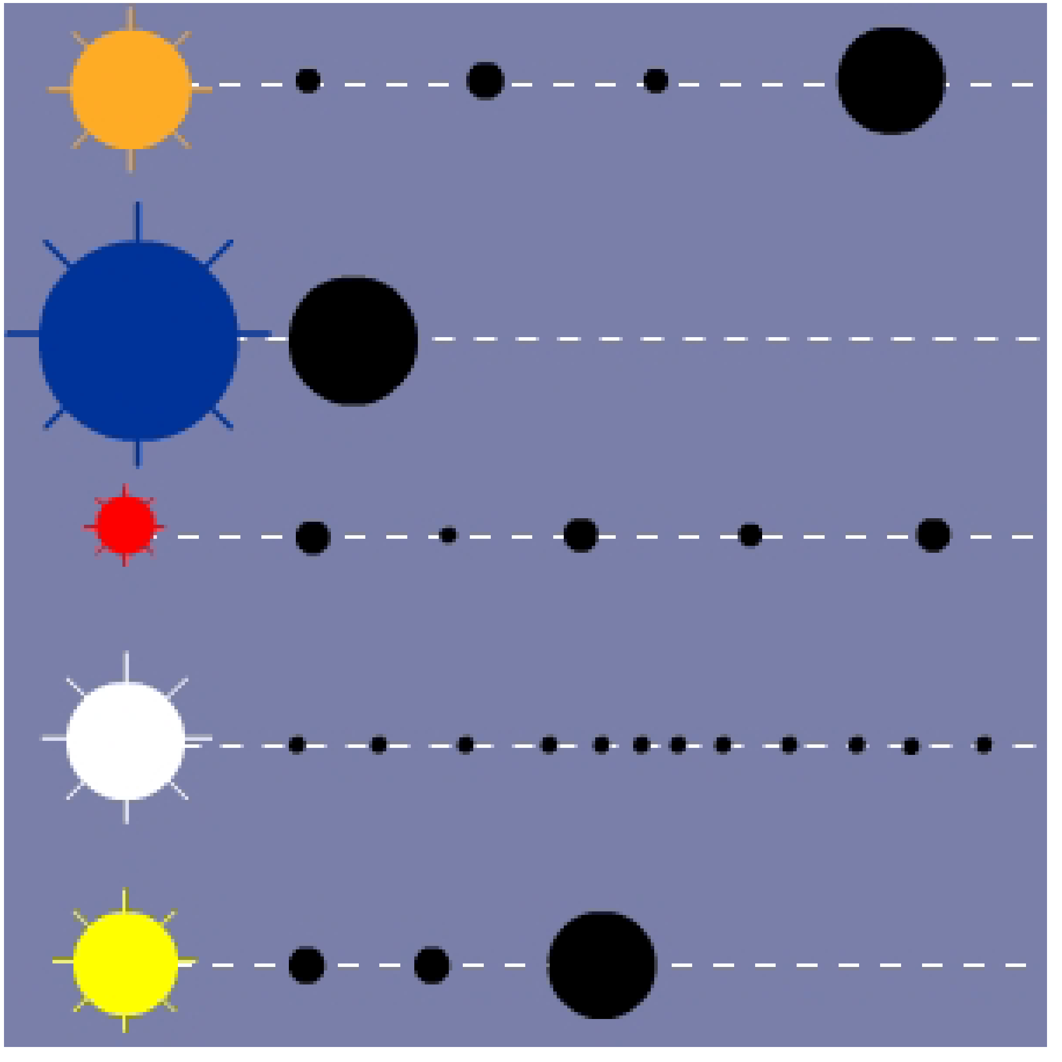
The Milkyway

Stars Like Dust

Our solar system



Exoplanets



ICARUS 18, 339–376 (1973)

Extrasolar Planetary Systems[1]

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Received May 11, 1972

The article deals with the occurrence of planetary systems in the Universe. In Section I, the terms "planet" and "planet-like objects" are defined. Two definitions proposed for the term "planetary system" are examined from the point of view (1) of the relation between planetary systems and binary and multiple star systems and (2) of planetary systems as abodes of intelligent beings. In Section II, the observational search for extrasolar planetary systems is described, as performable by earthbound optical telescopes, by space probes, by long baseline radio interferometry, and finally by inference from the reception of signals sent by intelligent beings in other worlds.

THE ASTROPHYSICAL JOURNAL, **187**:87–92, 1974 January 1

INTERPRETATION OF EPSILON AURIGAE. II. INFRARED EXCESS, SECONDARY LIGHT VARIATIONS, AND PLAUSIBLE FORMATION OF A PLANETARY SYSTEM

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Department of Astronomy, Northwestern University
Received 1973 April 20; revised 1973 July 30

ABSTRACT

Infrared excess based on the disk model proposed in a previous paper has been computed. It has been found that the disk alone will emit infrared radiation below the margin of detection. However, if individual condensations are present, the combined result of the disk proper and the condensations yields results of infrared excesses that are consistent with observations.

The presence of condensations also makes the secondary light variation understandable. An elementary theory has been developed that analyzes such light variations. The result of the analysis yields the size of the orbit of the condensation around the secondary component.

Subject headings: eclipsing binaries — infrared sources — stars, individual

THE ASTROPHYSICAL JOURNAL, 161:1033–1042, September 1970

LIGHT CURVE FOR ECLIPSING STARS WITH SCATTERING ENVELOPES AND ITS APPLICATION TO THE V444 CYGNI BINARY SYSTEM

SU-SHU HUANG
Department of Astronomy, Northwestern University
Received 1970 January 21; revised 1970 March 9

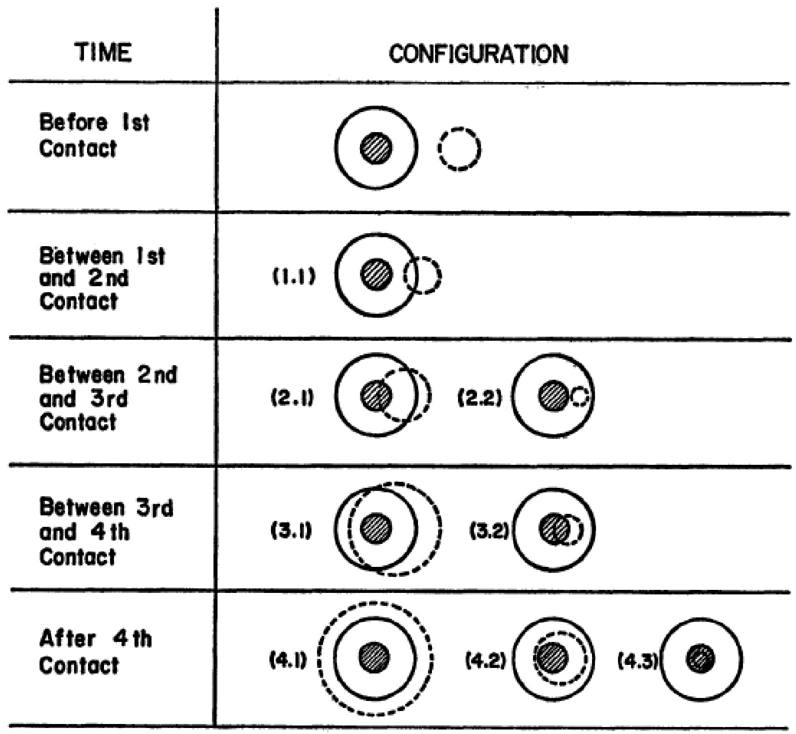
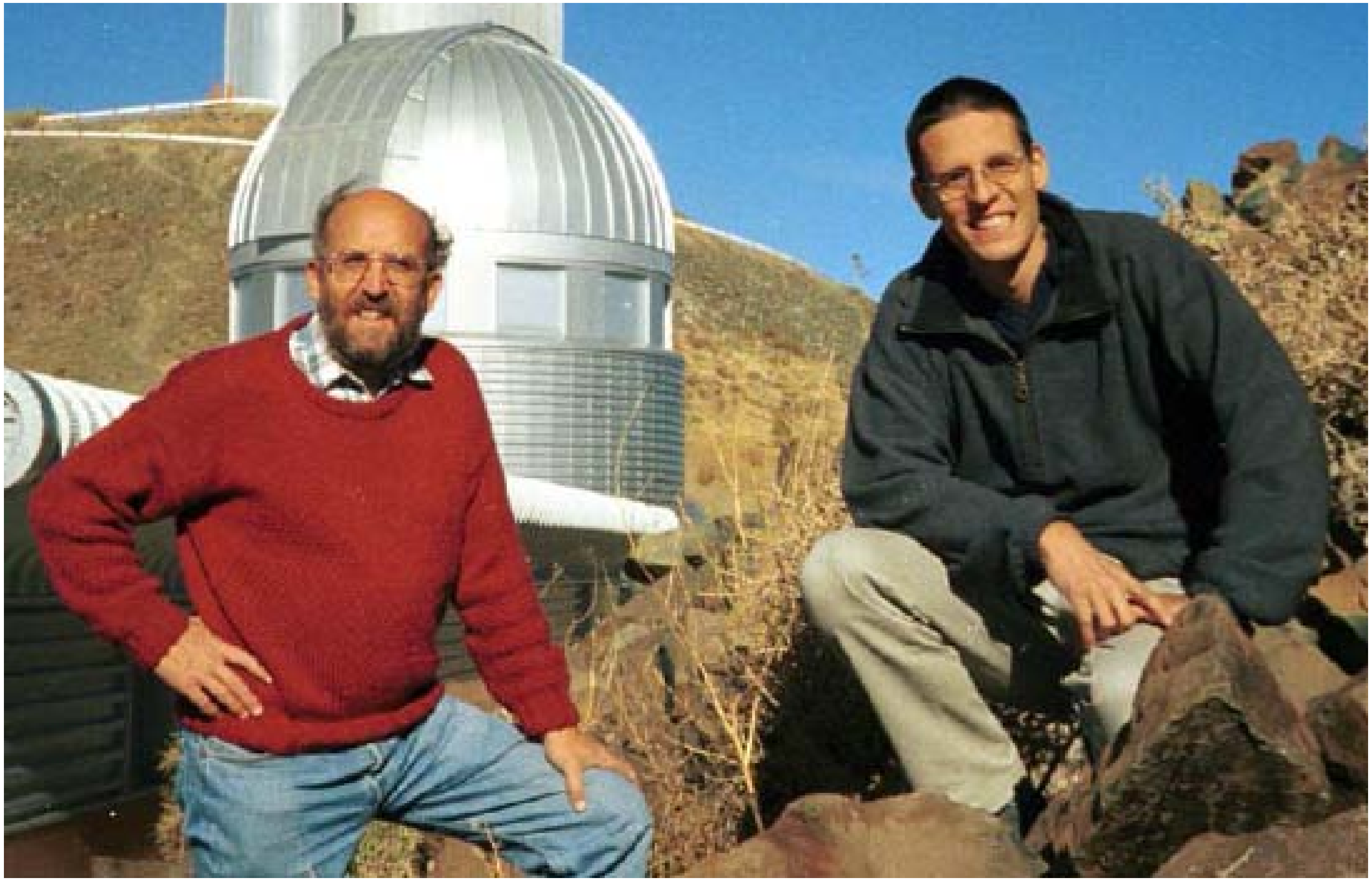


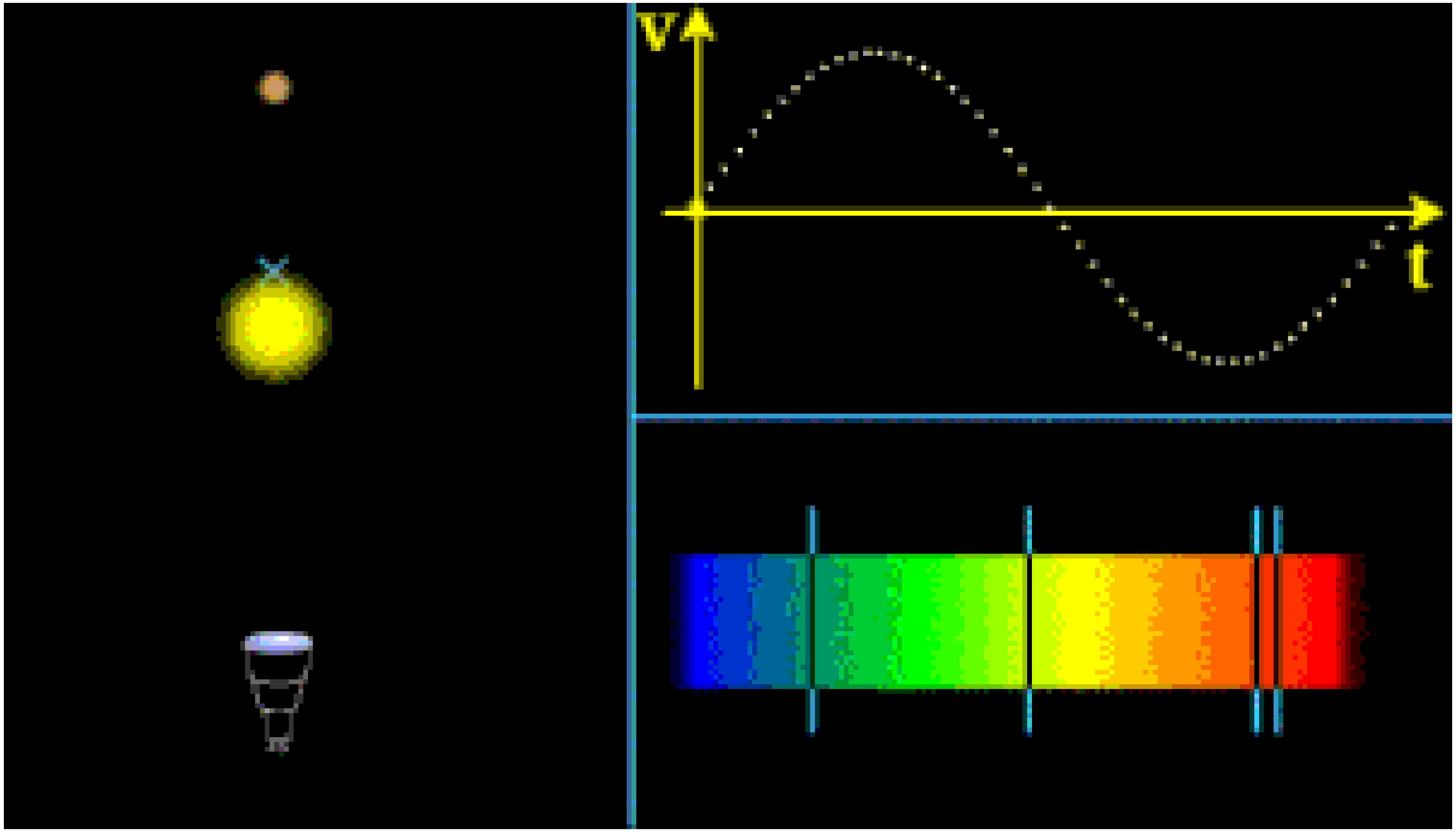
FIG. 1.—Nine configurations of the two stellar disks of a binary when the primary star (*hatched area*) has an extended envelope (between the hatched area and the outer solid circle) and is eclipsing the secondary star (*dotted circle*). The notation in parentheses for each configuration will be used elsewhere without further definition.

M Mayor and D Queloz

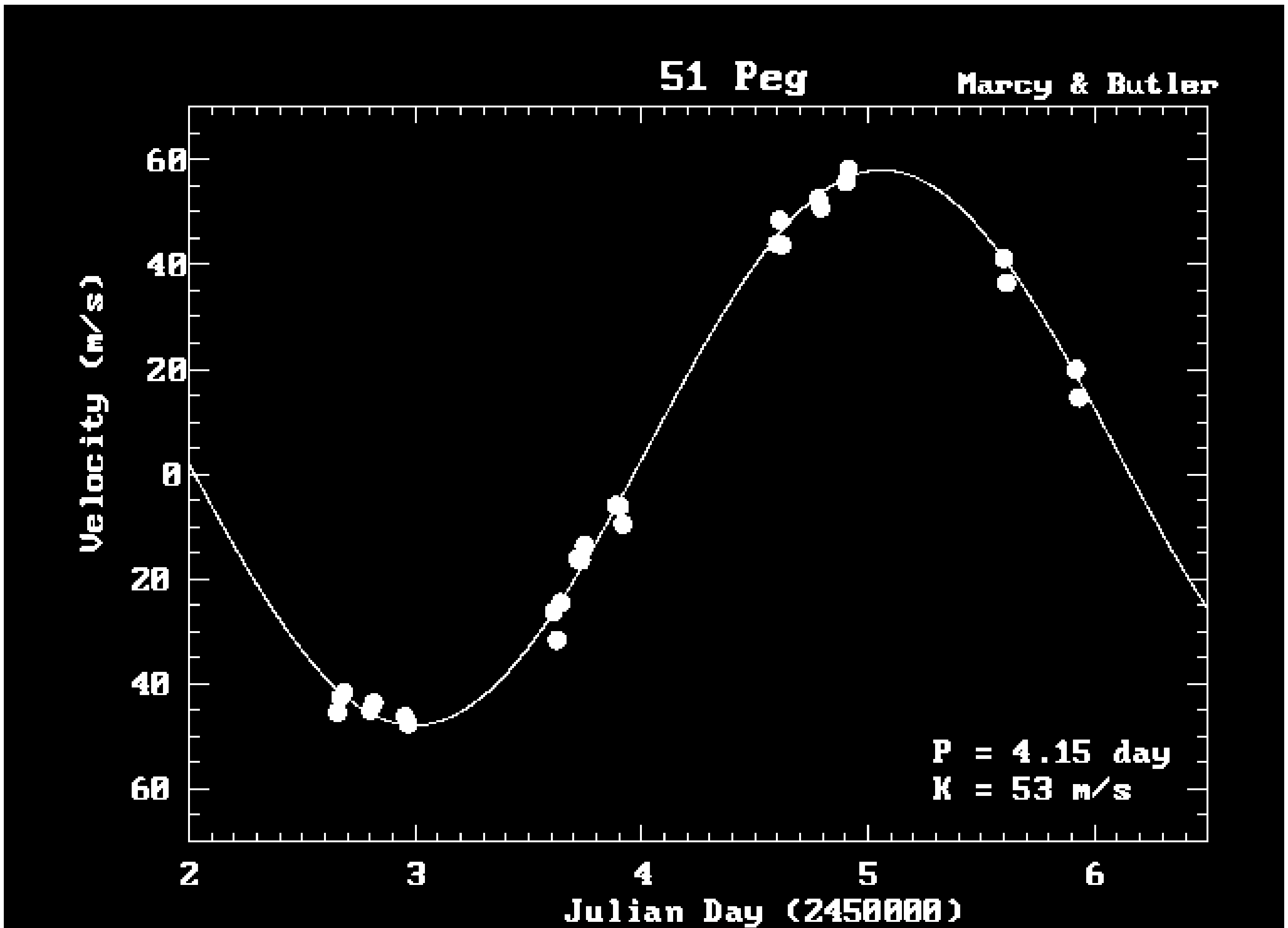


cosmicdiary.org/blogs/arif_solmaz/?p=468

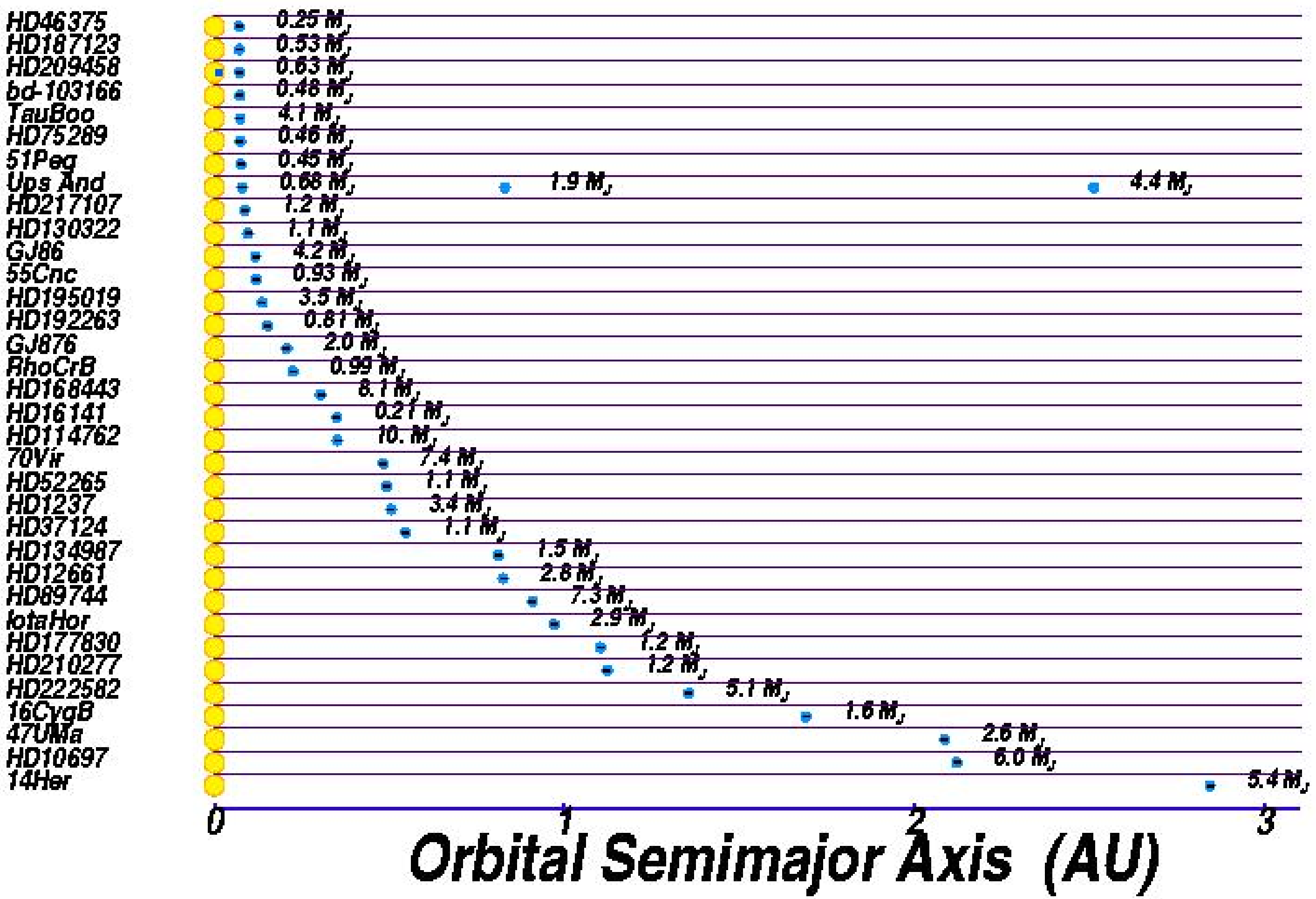
Radial Velocity Measurement



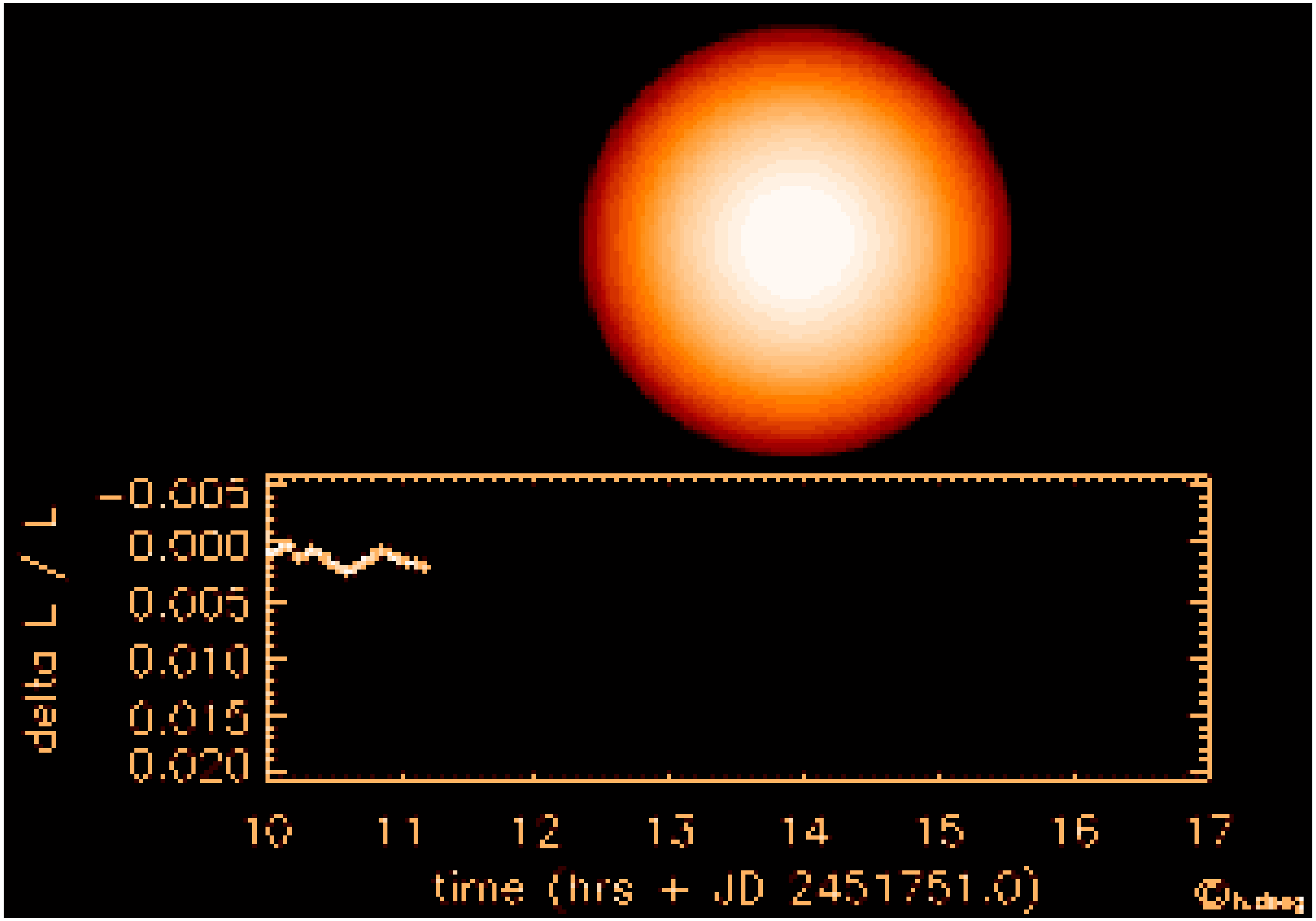
51 Pegasus (1995)



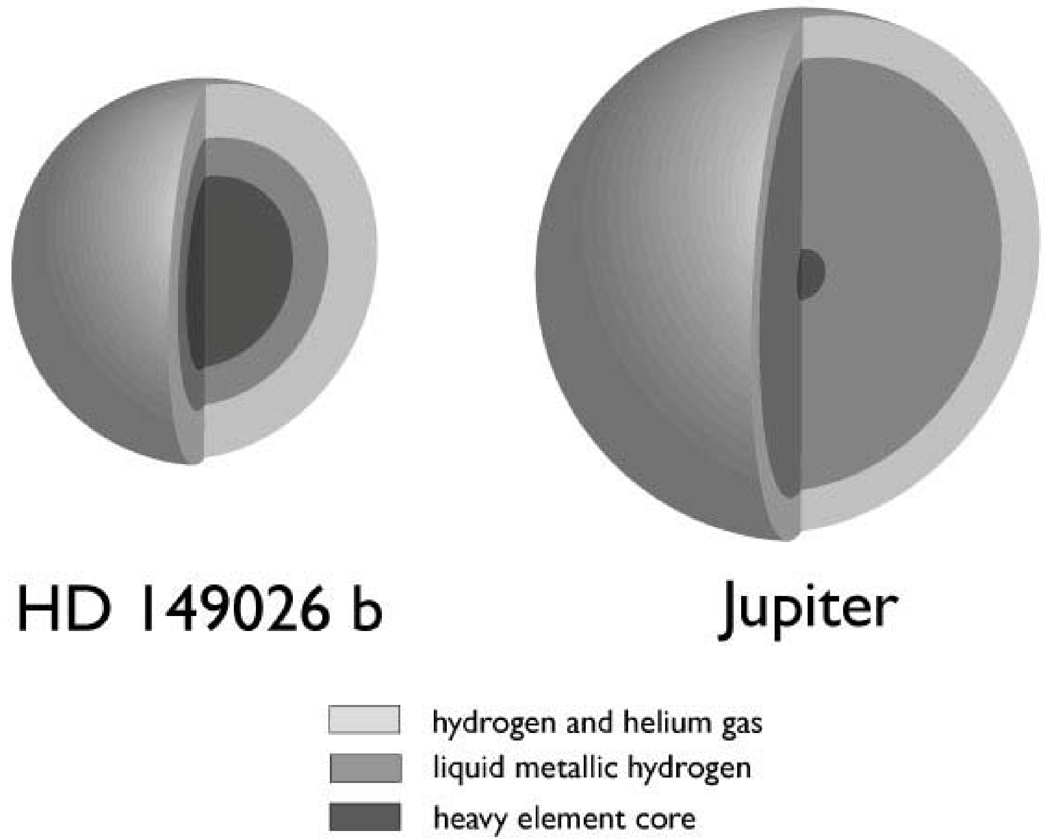
Orbital Distribution



Exoplanet Transit

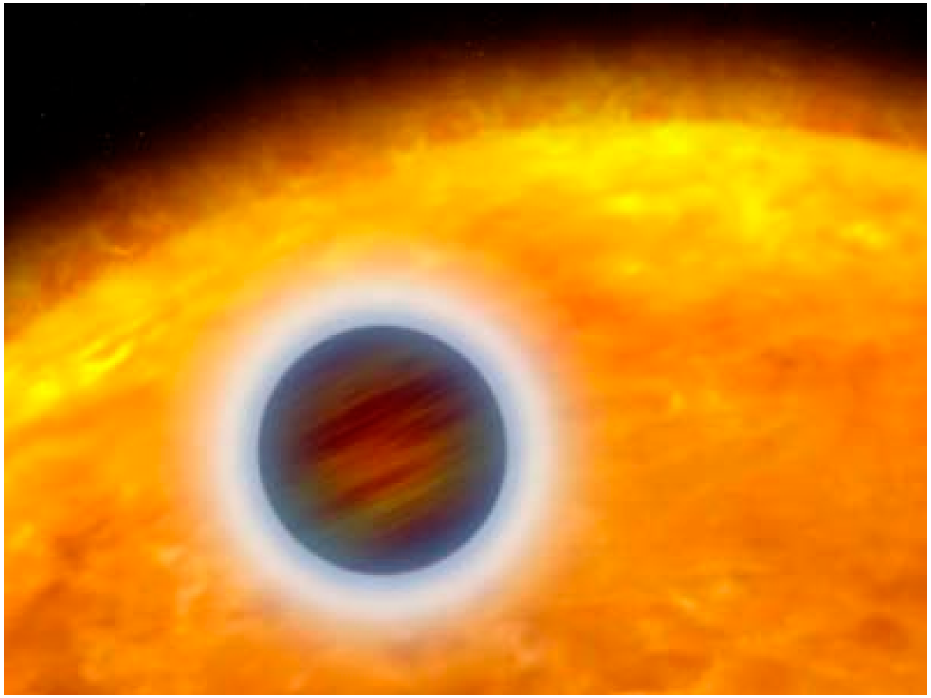


Interior Models of Hot Jupiters



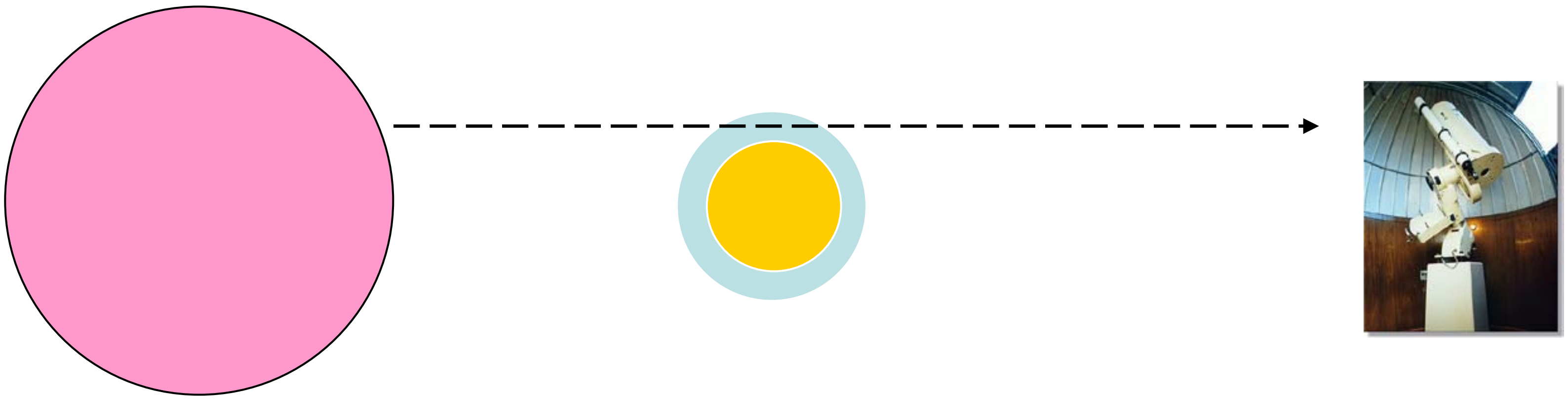
http://tauceti.sfsu.edu/n2k/hd149026/corecomparison.jpg

Hot Jupiters

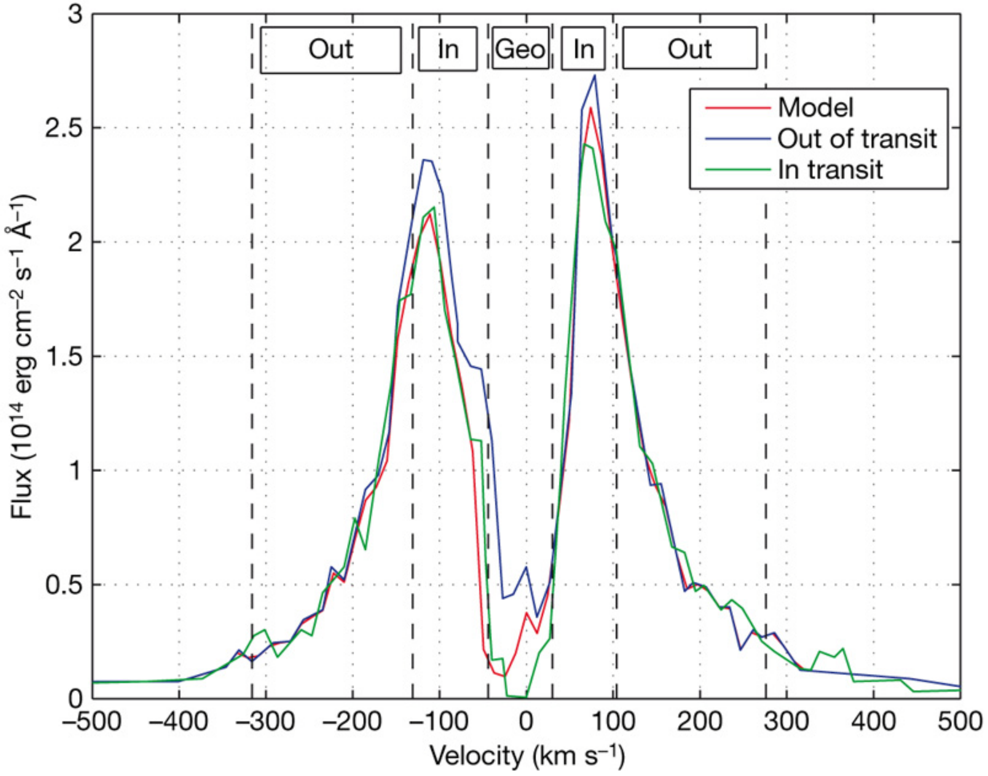


http://astronomyonline.org/aoblog/uploads/2007/01/hd209458b-puffed-atmosphere.jpg

Atmospheric Transmission Spectra

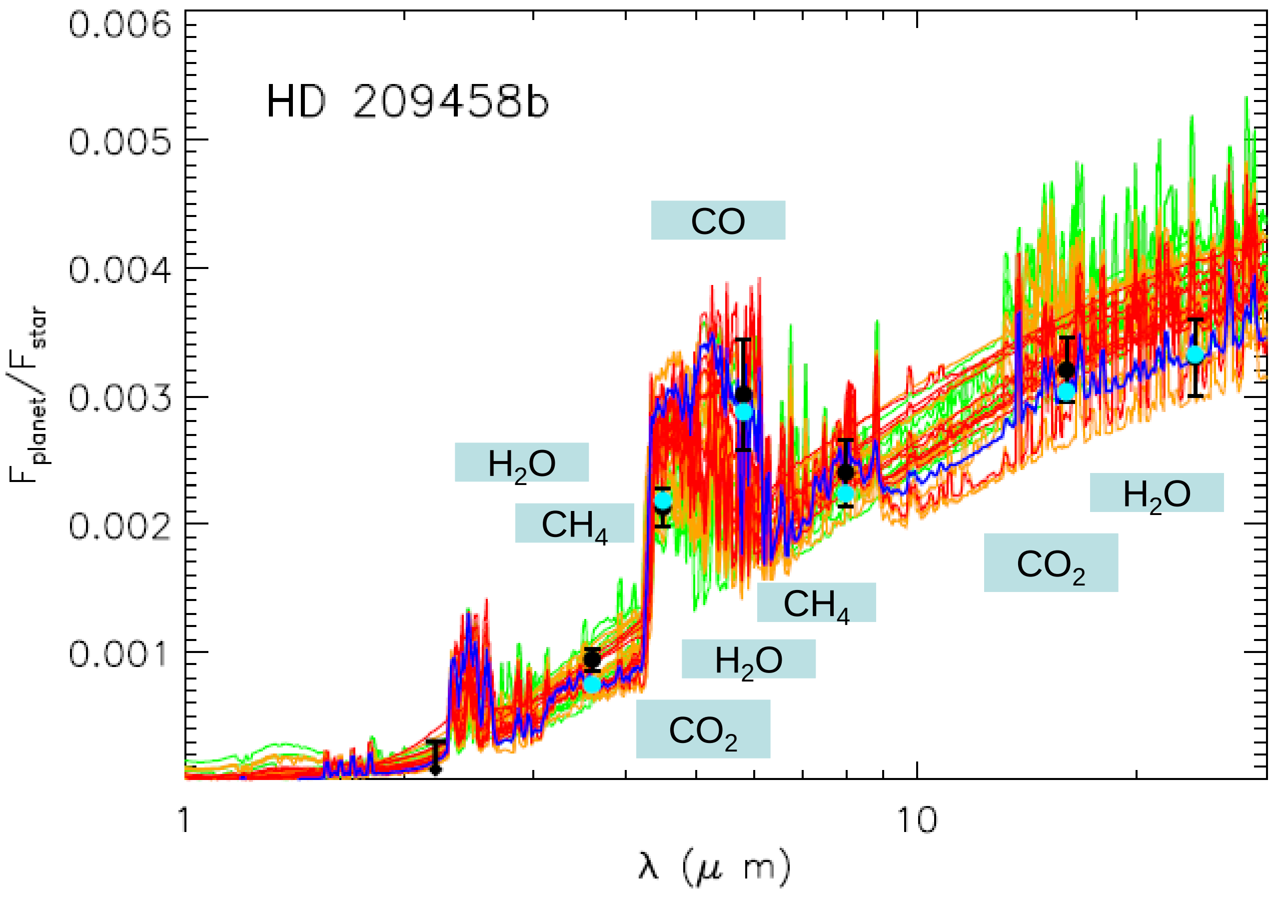


Absorption Spectral Feature of Atomic Hydrogen Corona of HD 209458b



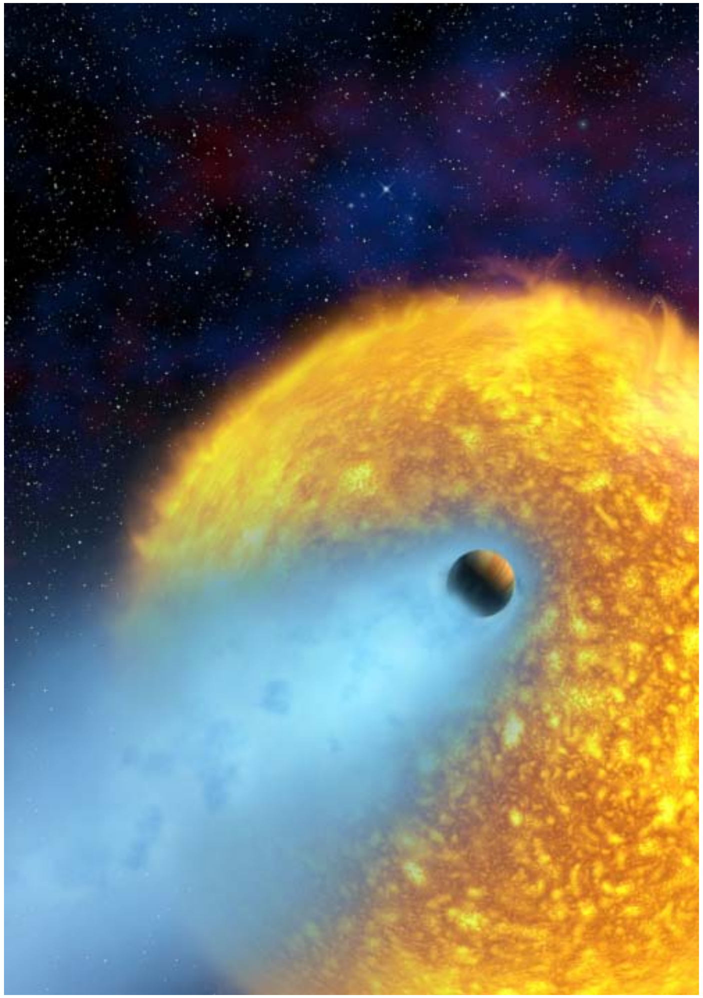
M. Holmstrom et al., Nature, 451, 970, 2008

Spitzer and Synthetic Infrared Spectra of HD 209458b

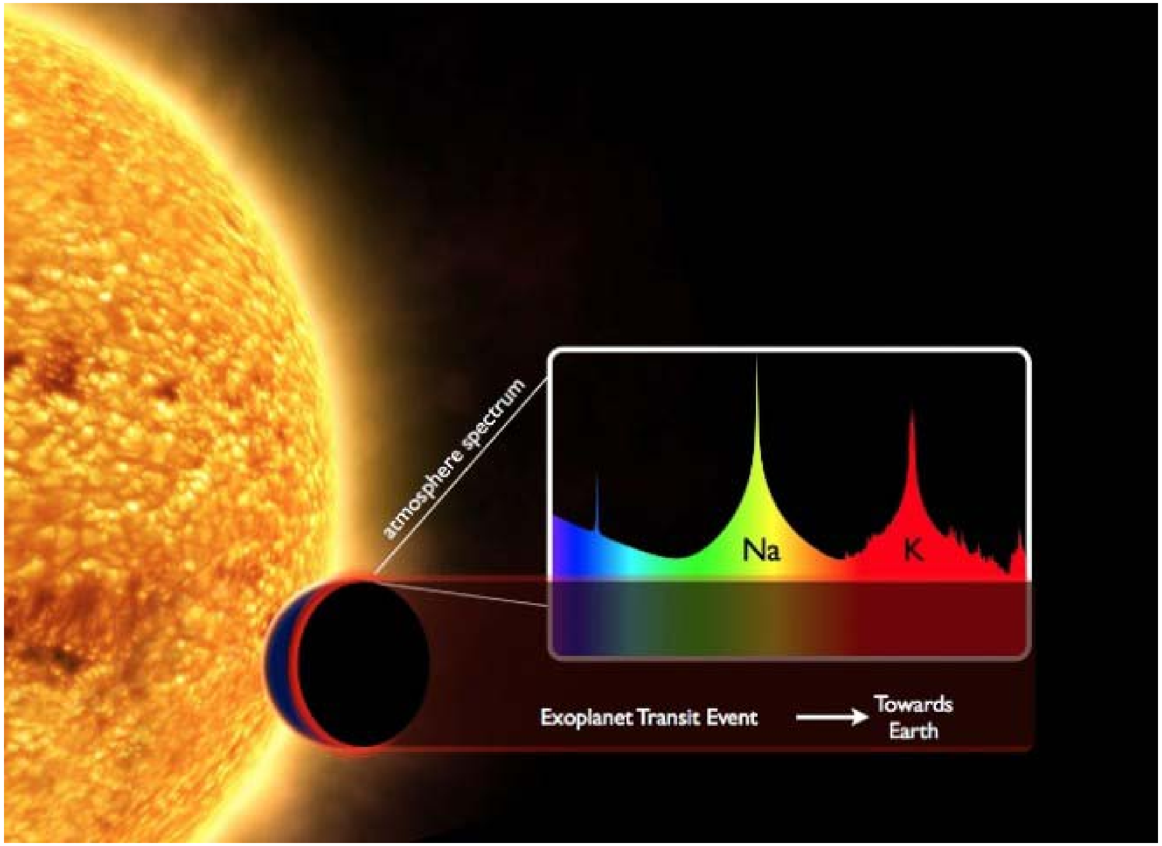


Sarah Seager (2010)

Extended Hydrogen Corona of HD 209458b



Detection of Na and K emissions in XO-2b and HD 80606b



http://www.wired.com/wiredscience/2010/08/potassium-exo-atmospheres/

Dayside temperatures

- HD209458b: T=1130+/-150K* (Deming et al. 2005)
- TrES-1: T=1060+/-50K** (Charbonneau et al. 2005)
- HD189733b: T=1117+/142K* (Deming et al. 2006)
- *Spitzer measurements: 16um & 24 um
- ** Spitzer measurements: 4.5um & 8 um.

A thermospheric circulation model

$$\frac{\partial \epsilon}{\partial t} + \boldsymbol{u} \cdot \nabla_P (\epsilon + \Phi) + \omega \frac{\partial (\epsilon + \Phi)}{\partial P} \approx \dot{Q}_{\mathrm{EUV}} + \dot{Q}_{\mathrm{IR}} + \frac{1}{\rho} K_m \nabla_P^2 T + \frac{g}{a^2} \frac{\partial}{\partial P} \left(a^2 K_m \rho g \frac{\partial T}{\partial P} \right) + \frac{g}{a^2} \frac{\partial}{\partial P} \left(a^2 u_\theta \mu_m \frac{\partial u_\theta}{\partial P} + a^2 u_\phi \mu_m \frac{\partial u_\phi}{\partial P} \right), \quad (4)$$

HD209458b

- Intense irradiation of the day-side drives strong thermal winds toward the night side.

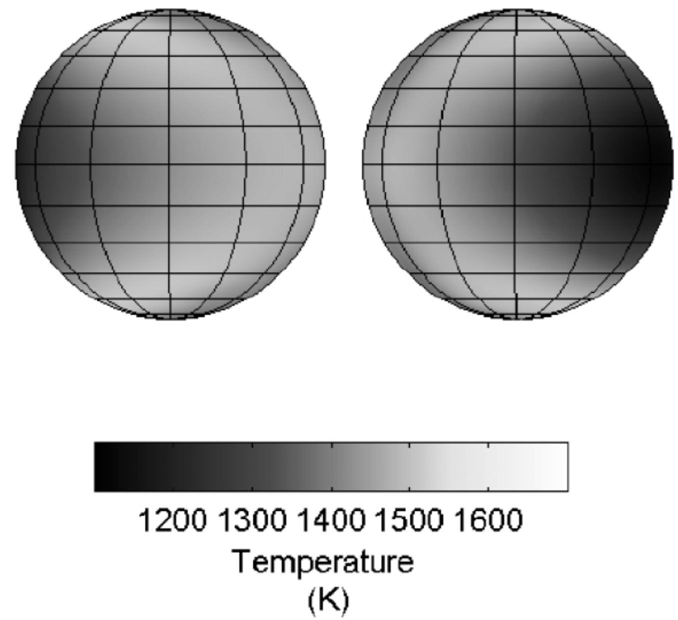


FIG. 1.—Steady state temperature of HD 209458b in the zero-obliquity case. Dayside temperature distribution is shown on the left; nightside on the right. [*See the electronic edition of the Journal for a color version of this figure.*]

Langton & Laughlin 2007

- Intense irradiation of the day-side drives strong thermal winds toward the night side.

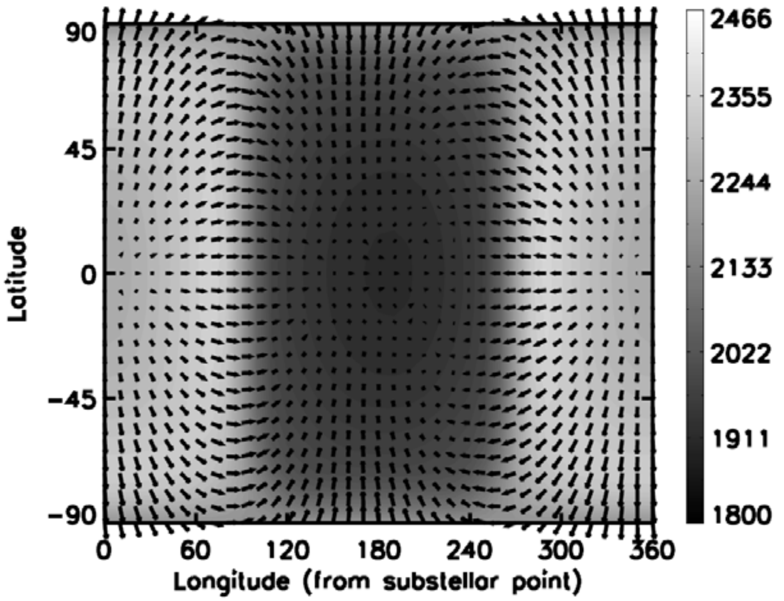


FIG. 2.—Temperatures and winds from Exo-114b (0.24 AU) at 0.04 nbar. The substellar temperature is 2340 K, while the nightside minimum temperature is 1950 K. The maximum zonal wind speed is $\sim$1 km s^{-1}. [*See the electronic edition of the Journal for a color version of this figure.*]

Koskinen et al. 2007

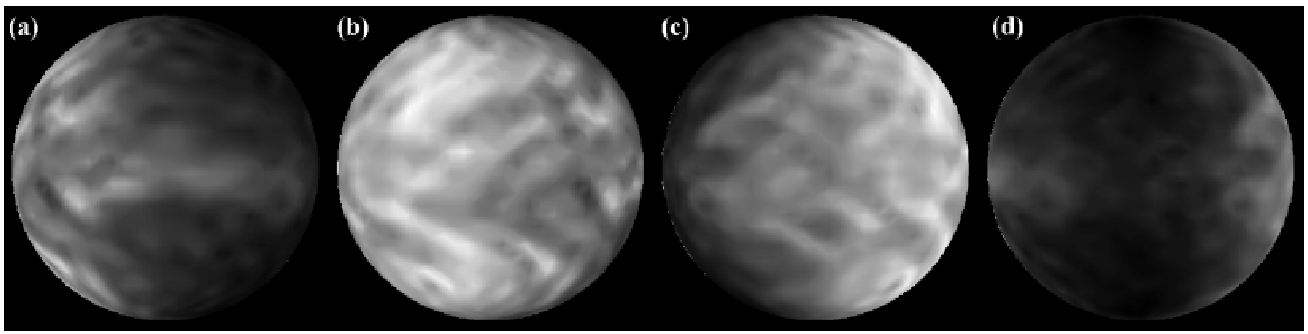


FIG. 2.—Flux from HD 209458b as it would appear from Earth at four orbital phases: (*a*) in transit, (*b*) one-quarter after the transit, (*c*) in secondary eclipse, and (*d*) one-quarter before the next transit. The planetary rotation axes are vertical, with the superrotating jet seen in Fig. 1 going from left to right in each panel. The temperature on this layer ranges from 1011 K (*dark*) to 1526 K (*bright*). In radiative equilibrium, panel *a* would be darkest and *c* would be brightest. The globes show that a difference in observed flux from the planet between the leading and trailing phases of its orbit—panels *b* and *d*—is a signature of winds.

Cooper & Showman 2005

Exoplanet Transits Around M Dwarfs

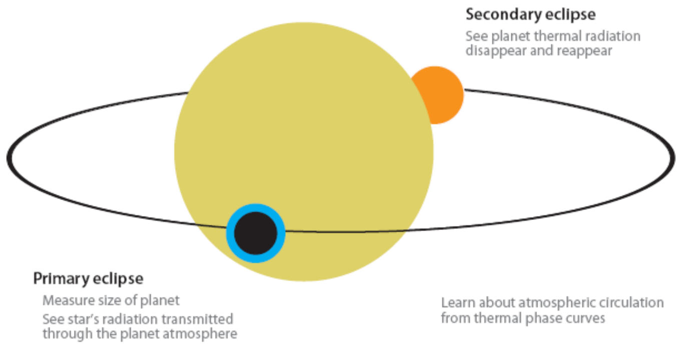
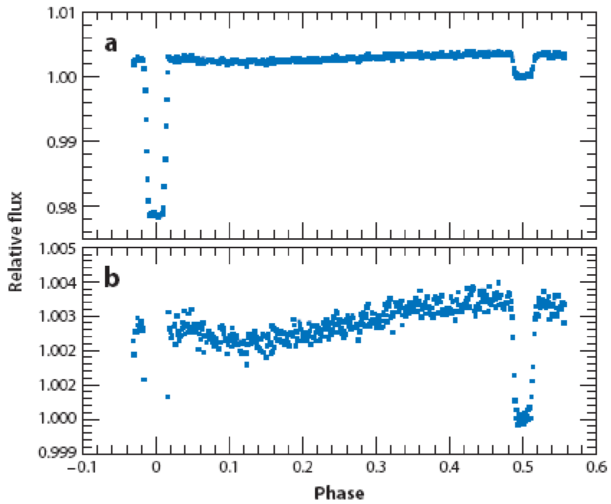


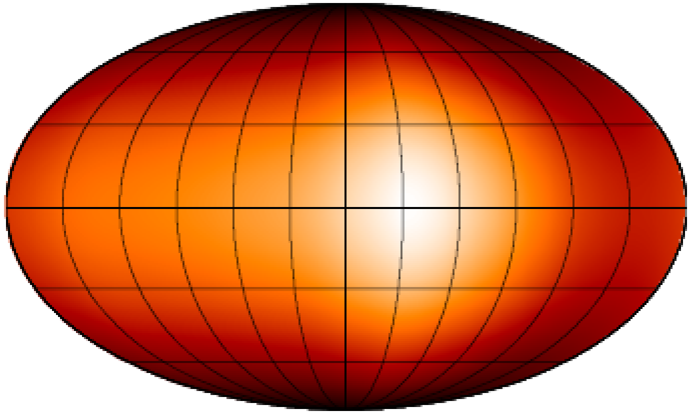
Figure 5

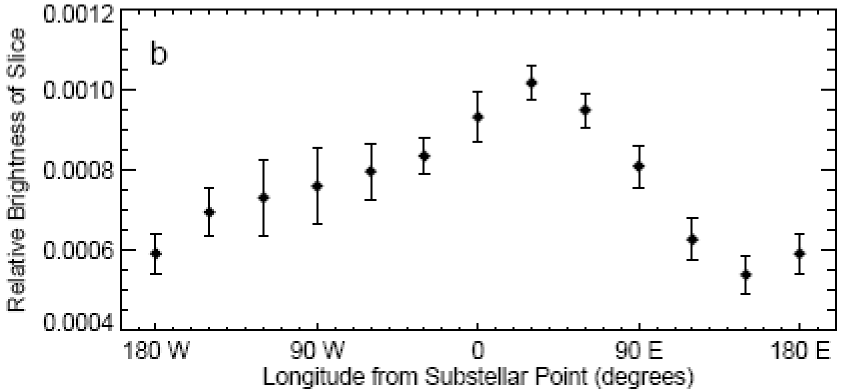
Schematic of a transiting exoplanet and potential follow-up measurements. Note that primary eclipse is also called a transit.



S. Saeger and D. Deming (2010)

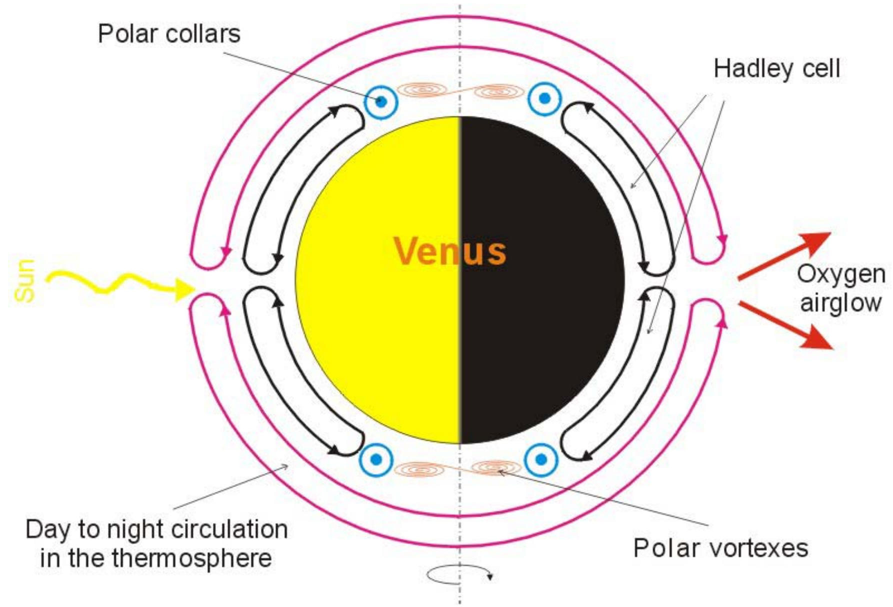
Measurements of Surface Temperatures on Both Hemispheres





Knutson et al. 2007

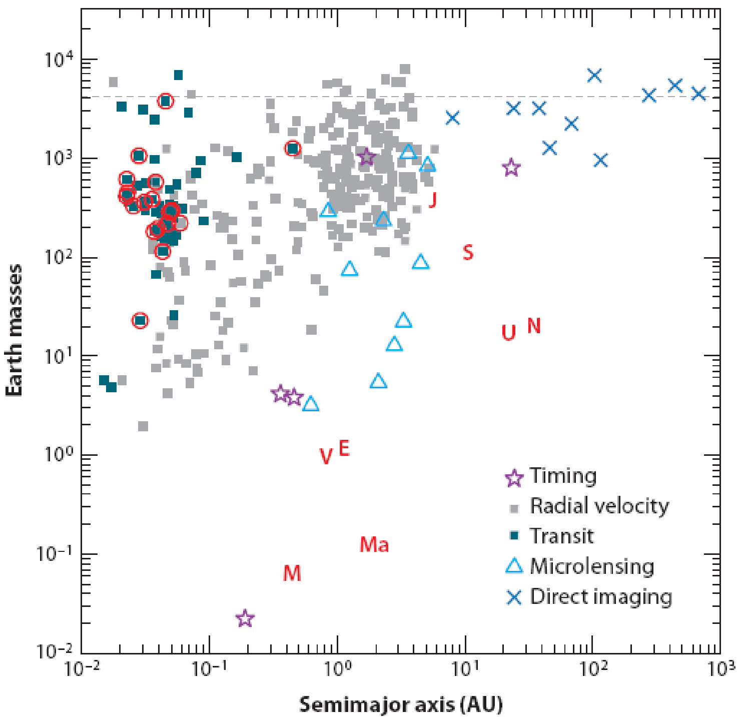
Venus-Like Zonal Wind System ?



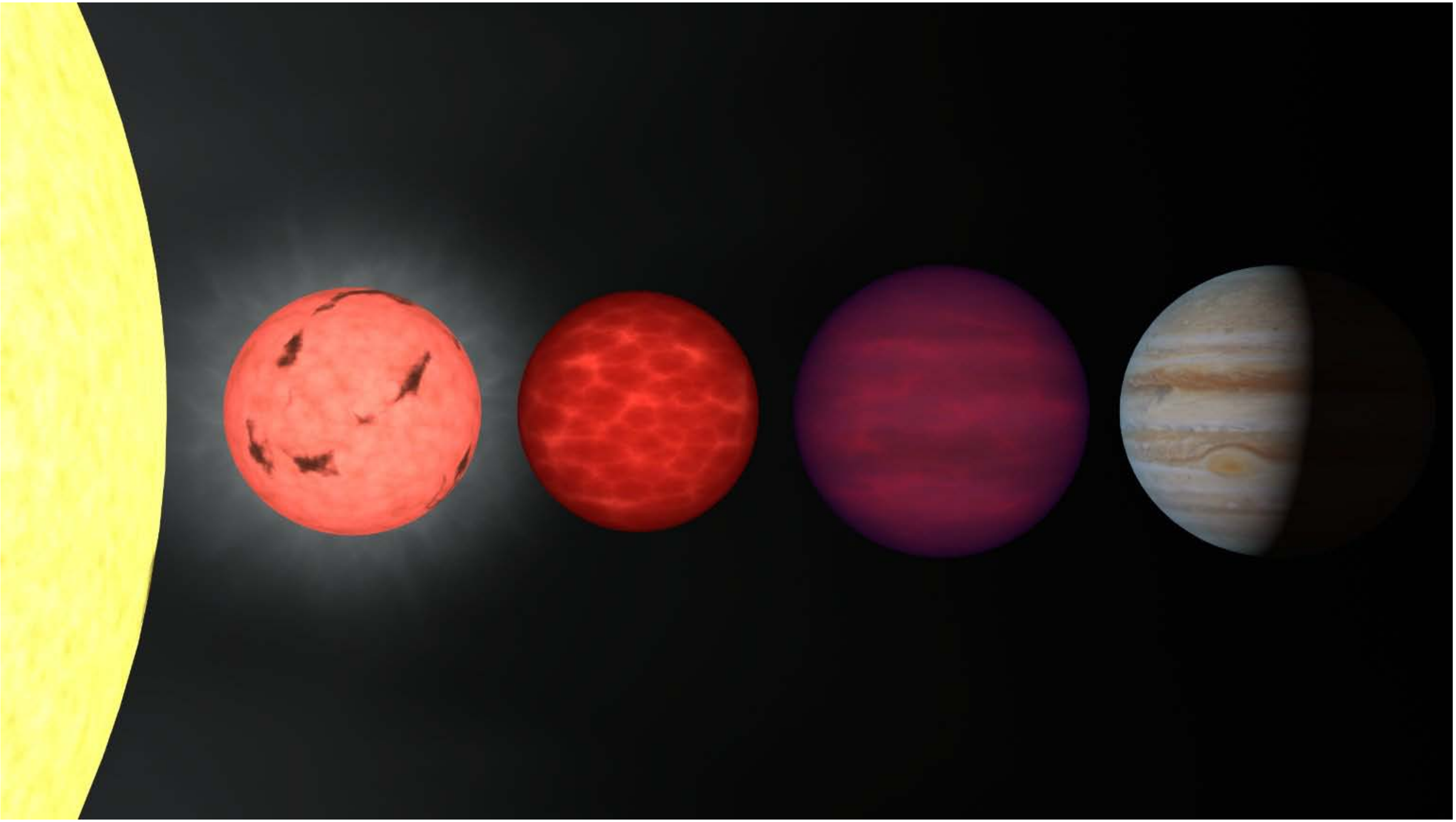
http://upload.wikimedia.org/wikipedia/commons/2/24/Venus_circulation.jpg

Mass and Distance Distribution

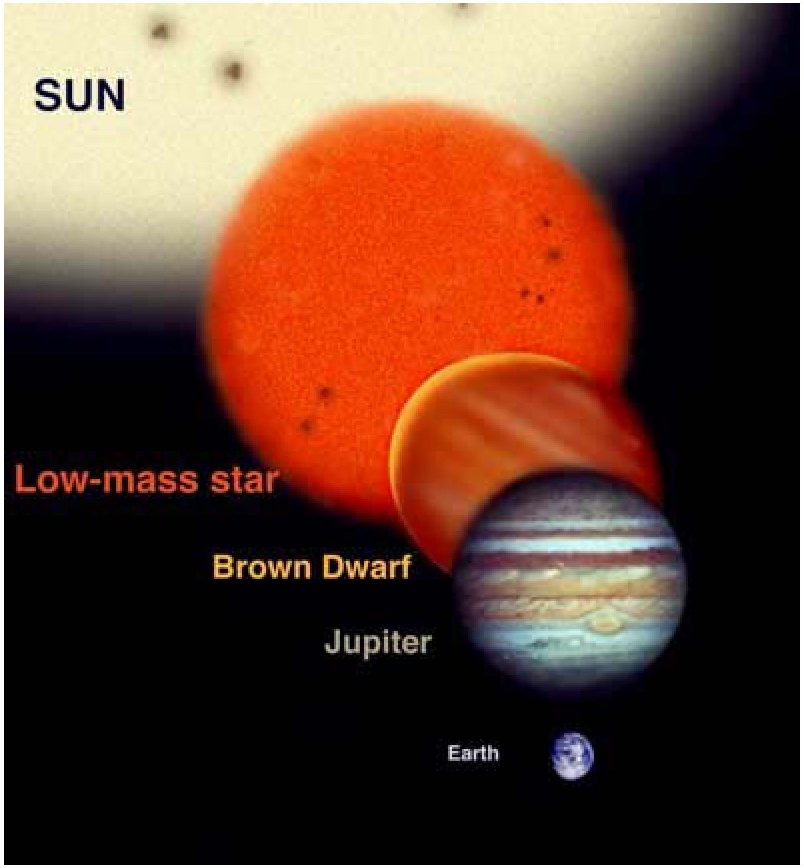
More and more Earth-like exoplanets have been discovered.



M Dwarfs



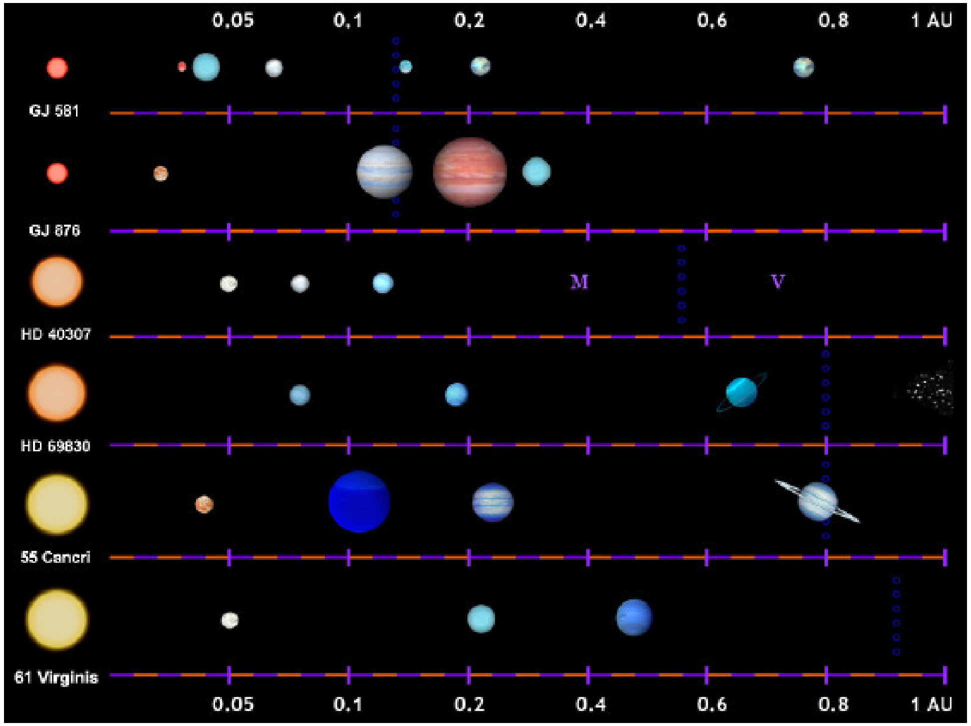
Earth-Analogs around Low-mass Stars



www.daviddarling.info/.../B/browndwarf.html

Extrasolar Planetary Systems

PACKED ORBITS

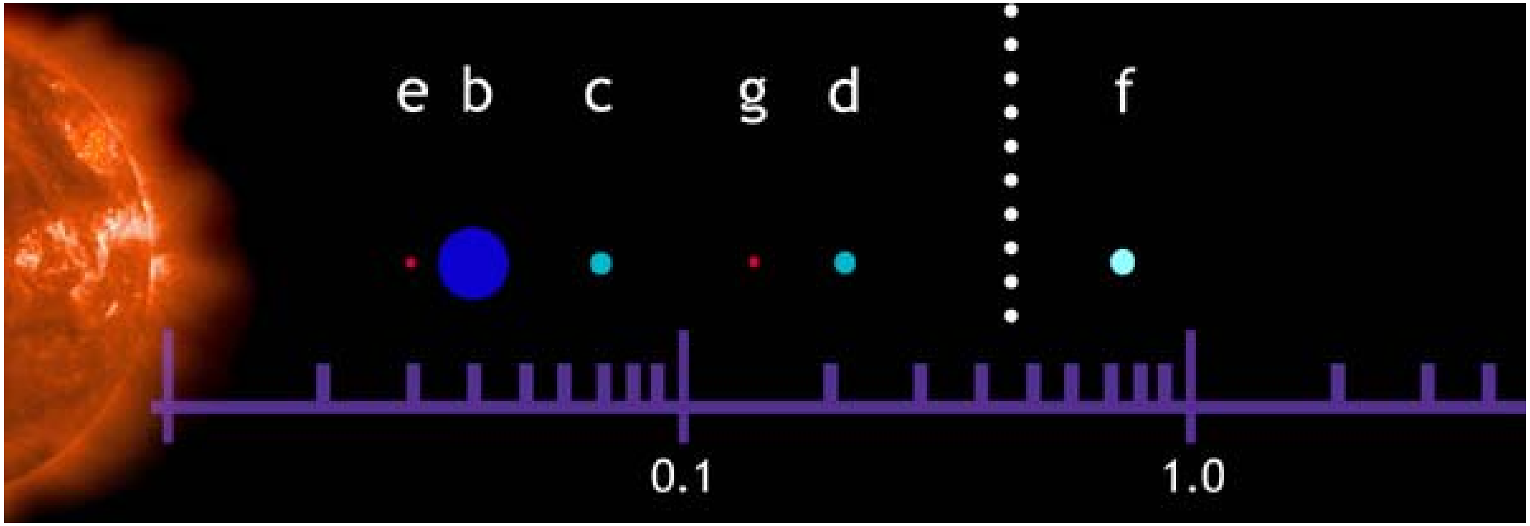


Inner system architectures of six nearby stars of sub-Solar mass. Star and planet icons express relative mass; star icons use a reduced scale because stars are much heavier, as well as much larger in radius, than planets. Distance is expressed in fractions of an astronomical unit (AU) by using a continuous linear scale beyond 0.2 AU and discontinuous scales (on account of packing) for smaller orbital radii. The approximate semimajor axes of Mercury and Venus are indicated by M and V, respectively. Blue bubbles mark the approximate center of each system's habitable or liquid-water zone. Around K- and G-type stars, this zone extends for a few tenths of an AU in either direction. Around M dwarfs, it extends for a few percent of an AU in either direction.

GJ 581

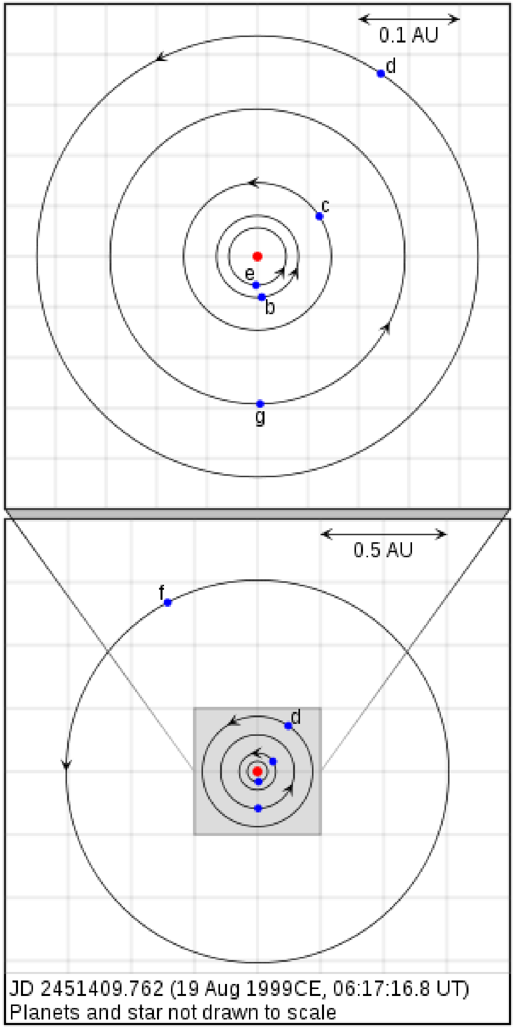
- Distance ~ 6.27 pc
- Type = M3
- Mass = 0.31 $M_\odot$
- Radius = 0.29 $R_\odot$
- Metallicity = -0.26
- Age ~ 4 Gyr

GJ 581



http://www.deepfly.org/TheNeighborhood/GJ581.html

Orbits of the GJ 581 Exoplanets

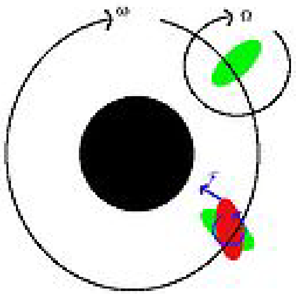


http://upload.wikimedia.org/wikipedia/commons/thumb/6/60/GJ581orbits_Vogt2010.svg/300px-GJ581orbits_Vogt2010.svg.png

GJ 581 e

(1.7-3.1 $M_{\odot}$/a=0.03 AU/P=3.1 days)

- Tidal locking configuration



- **GJ 581 e** is a terrestrial-mass object at the low end of the range for Super Earths. Its minimum mass is estimated at 1.7 to 1.94 MEA, while its maximum mass, determined on the basis of dynamical considerations, is only 3.1 MEA. With a semimajor axis of 0.03 AU and an orbital period of 3.1 days, the planet's surface temperature must exceed Mercury's. Michel Mayor and colleagues conclude that planet e "is almost certainly rocky," and that its temperature is too high to permit the survival of a significant atmosphere. Given its proximity to the host star, the planet's rotation must be tidally locked, with one hemisphere always in light and the opposite always in shadow. Such conditions may cause portions of its daylight surface to be molten, with a "magma pond" occupying the hottest point (Ganesan et al. 2008).

GJ 581 b

(15.6-30 $M_{\odot}$/a=0.041 AU/P=5.4 days)

- Hot Neptune
- Zonal wind like Venus?

- **GJ 581 b** is a classic Hot Neptune. In fact, its minimum mass of 15.6 MEA and maximum mass of 25 to 30 MEA make it a near-twin to our own cold Neptune. However, its orbital period and semimajor axis are only 5.4 days and 0.041 AU, respectively. Having assembled in the region beyond 1 AU around a cool, metal-poor star, GJ 581 b probably consists largely of ices, with a rocky core and a substantial hydrogen atmosphere. Such is the inferred composition of the Hot Neptune that transits GJ 436, an M dwarf very similar to GJ 581 (Gillon et al. 2007). Because GJ 581 b is hotter than Venus, its ices must subsist in a high-pressure, superheated environment unlike anywhere in the Solar System.

GJ 581 c

(5.6-9 $M_\odot$/a=0.07 AU/P=12.9 days)

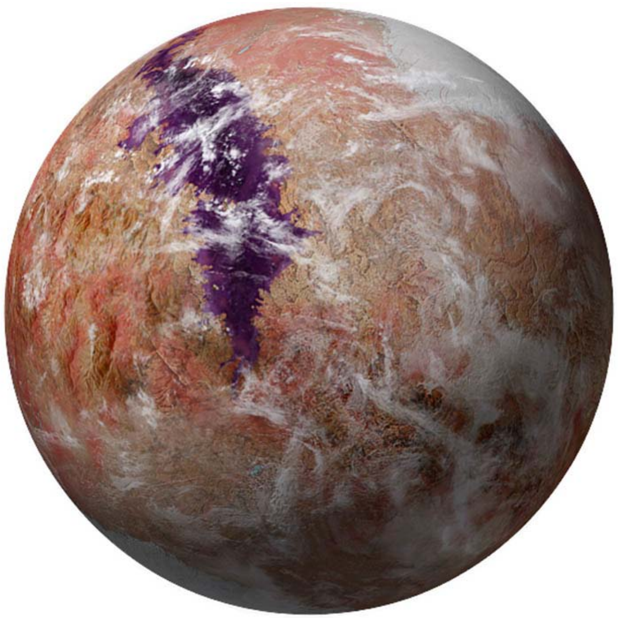
- Super-Venus?

- **GJ 581 c** has a minimum mass of 5.6 MEA (maximum ~9 MEA), a period of 12.9 days, and a semimajor axis of 0.07 AU. At this distance, planet c receives more irradiation from its host star than Venus receives from our Sun. Mayor and colleagues (2009) propose an orbital eccentricity of 0.17, a little less than Mercury's, but Vogt and colleagues (2010) argue that its eccentricity is poorly constrained and may be near zero. The bulk composition of planet c is unknown, and may remain so for the foreseeable future. If it includes a substantial quantity of ice, this material would be pressurized and superheated as in its inner neighbor, planet b.

GJ 581 g

(3-5 $M_{\odot}$/a=0.15 AU/P=37 days)

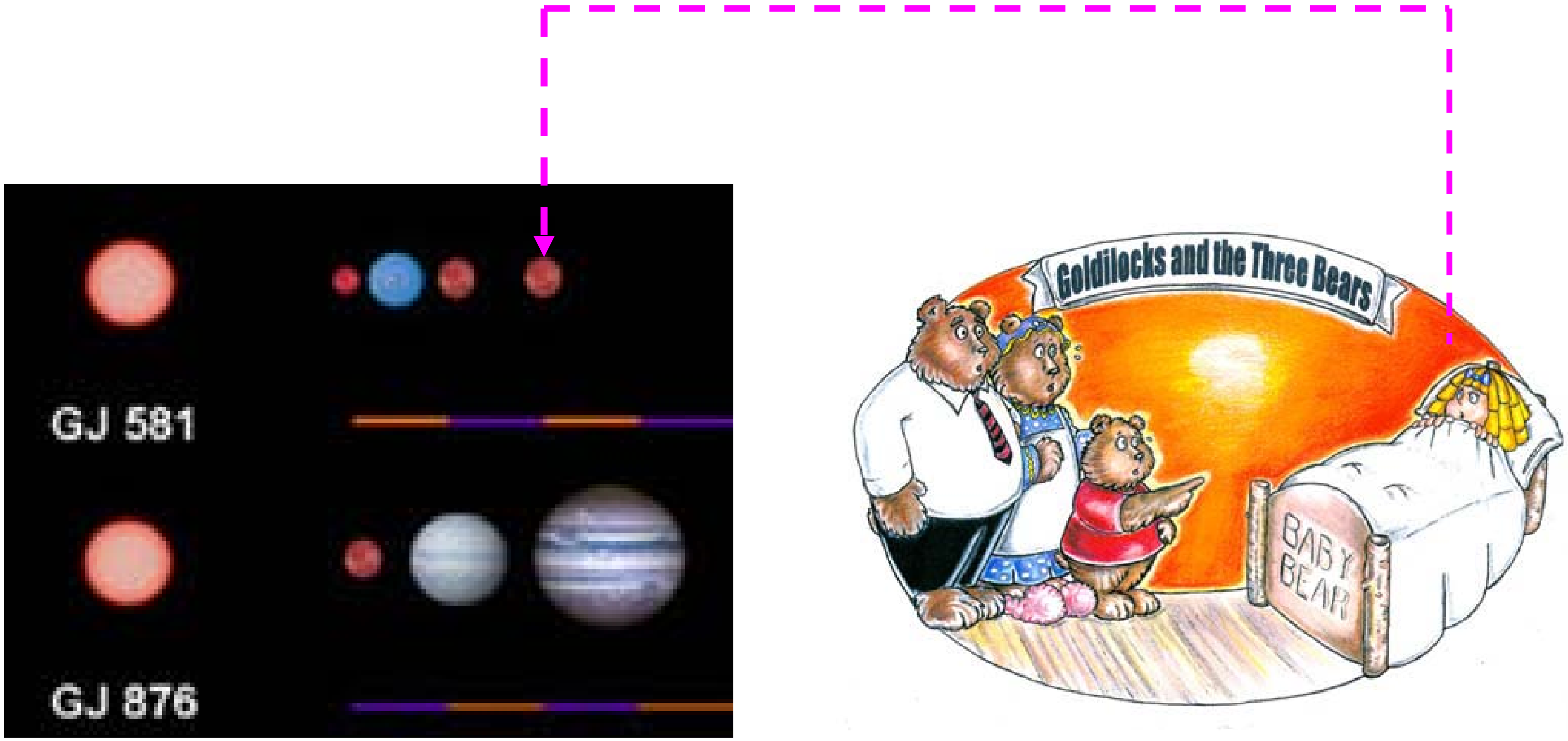
- Super-Earth!



- **GJ 581 g** is the most recently announced object in this system. Its discovery team, led by Steven Vogt, characterize it as a Super Earth that qualifies as a "Goldilocks" planet - not too hot, not too cold (Vogt et al. 2010). Its minimum mass is about 3 MEA, and even its maximum mass is only 5 MEA. It orbits at a semimajor axis of 0.15 AU in a period of 37 days. Given an appropriate bulk composition and surface conditions, this planet (nicknamed "Zarmina's World" by Vogt) could support bodies of open water, and might even be an abode of life (Vogt et al. 2010).

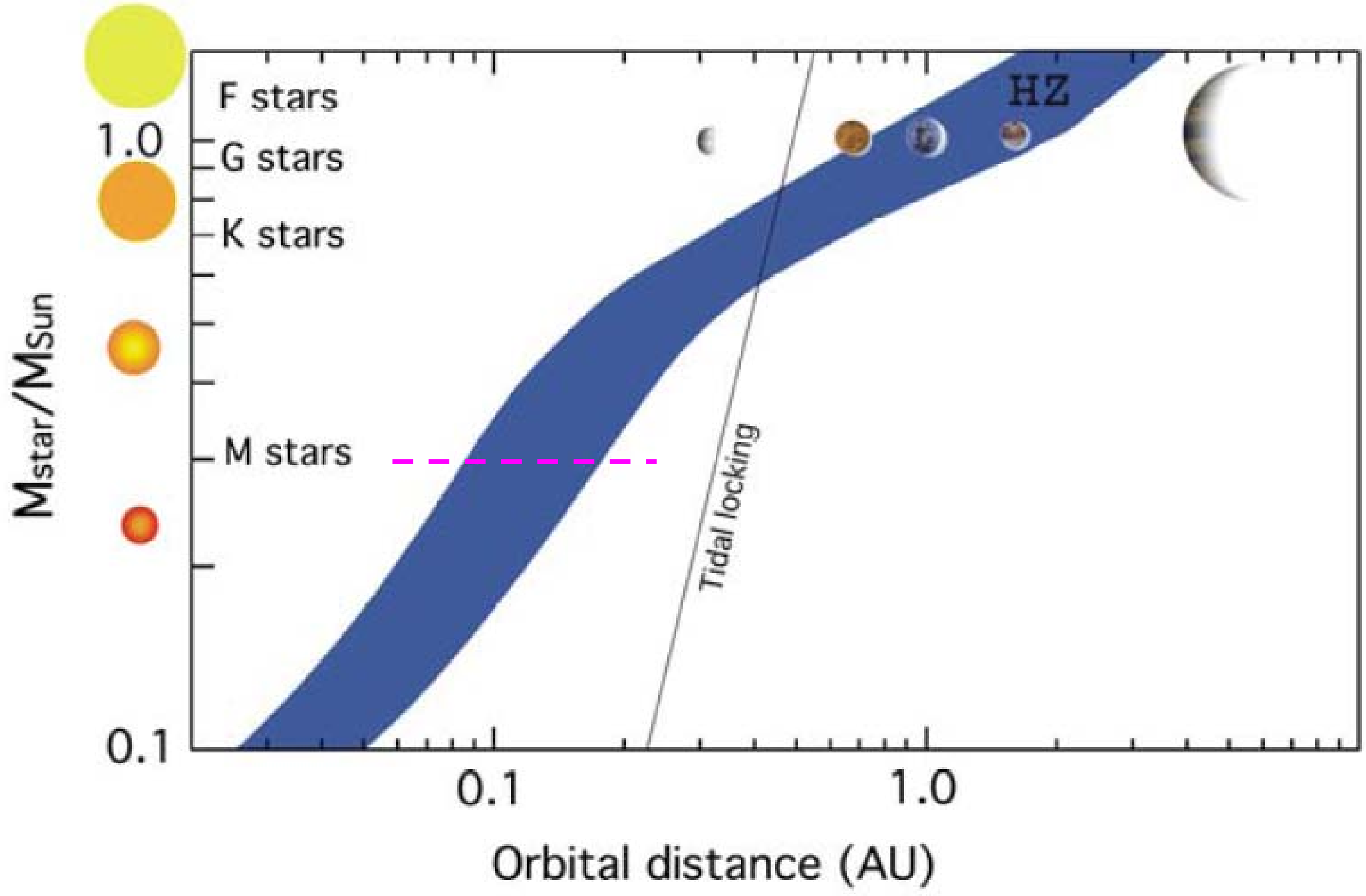
http://www.deepfly.org/TheNeighborhood/GJ581.html

Goldilocks Planets



http://www.deepfly.org/TheNeighborhood/GJ581.html

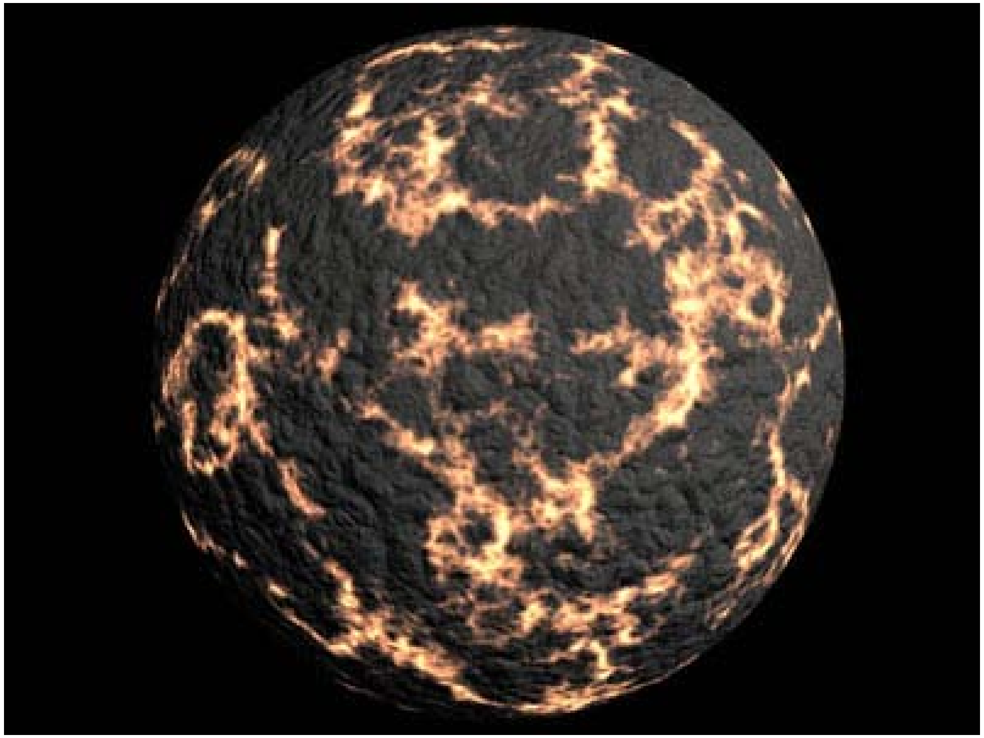
The Habitable Zones



Lammer et al. (2009)

Early Earth

Proto-biosphere



http://2.bp.blogspot.com/_rNMOlewSvvM/SkkZmh3IeZI/AAAAAAAACik/o2zV_CgaH2U/s400/hadean3.jpg

Extreme Thermophiles

ET Extremophiles

靠砷存活的細菌 改寫生命定義

美國加州摩諾湖 NASA發現新細菌 DNA中的磷被砷取 顛覆生命構成要素：原來可以這樣活！

【編譯李致翎／綜合報導】美國太空總署（NASA）二日公布一種只靠砷就能活的特殊細菌，可能改寫生命構成元素的鐵則，也顯示宇宙某處，甚至就在地球上，可能有生物靠人類從未想到的方式存活。

發現新砷命

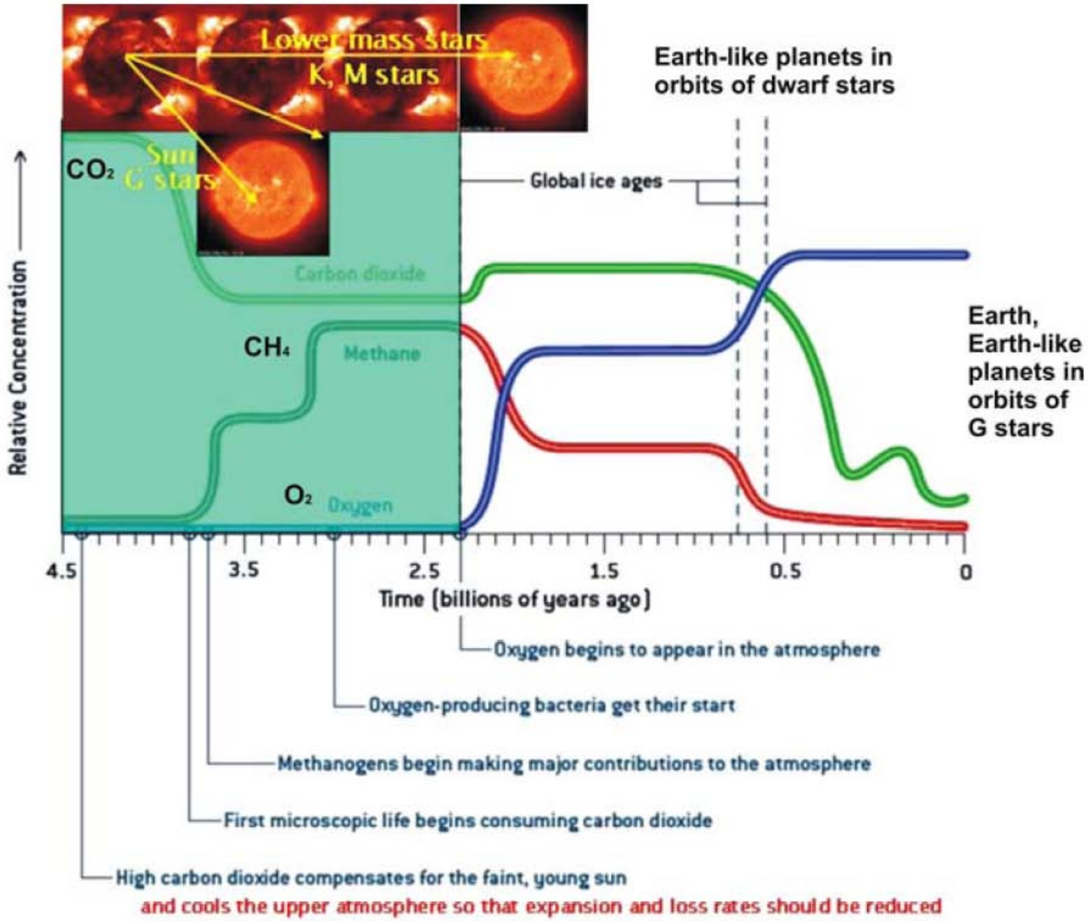
↑聯邦地質測量所太空生物學研究員菲麗莎・沃夫塞蒙在加州東部的摩諾湖發現以砷存活的細菌。（路透）

生命驚奇處

←科學家在美國加州東部的摩諾湖發現以砷維持生命的細菌，摩諾湖因鹽分多，砷和礦物含量很高，可能反映地球甚至太空生命演進初期的情形。（法新社）

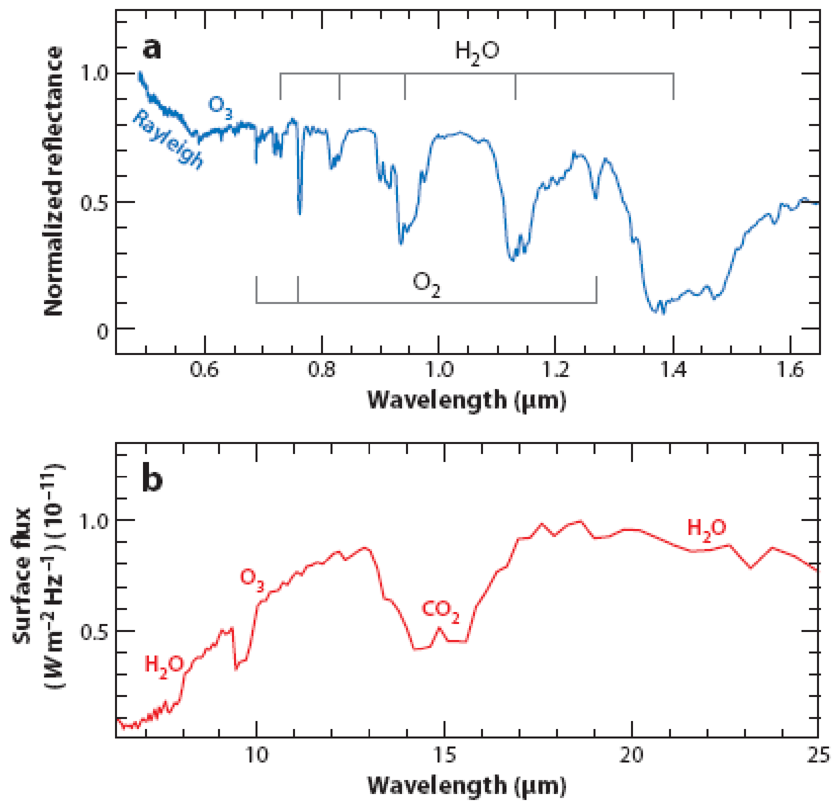
發現異形 地球生命起源 可能不只一次

Atmospheric Evolution of Terrestrial Exoplanets



Lammer et al. (2009)

Earth's Average Spectra from Space Observations



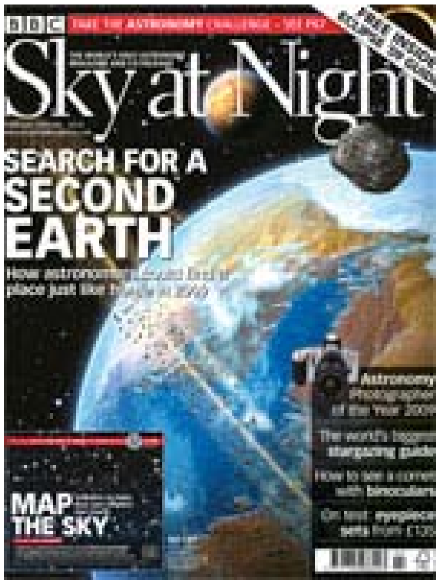
S. Seager and D. Deming (2010)

Non-green Plants

Caltech illustration by Doug Cumming

http://www.sciencedaily.com/releases/2007/04/070411091753.htm

Earth II



Thirty-Meter Telescope (TMT)