Life on Other Planets? 1

Four hundred years ago a rebellious, independent Dominican monk, Giordano Bruno, advocated the idea that planets orbited stars other than our Sun. He infuriated religious leaders by asserting in the late 16th century that beings like humans inhabited these other worlds. He was burned at the stake in Rome's Campo de' Fiori in 1600.

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How Do We Find Extra-solar planets?

1. Look here first.

How Do We Find Extra-solar planets?

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2. Look here second.

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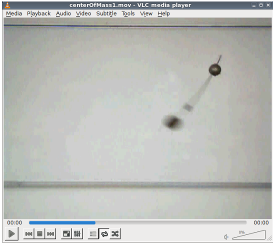

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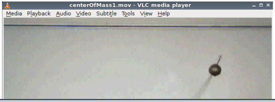
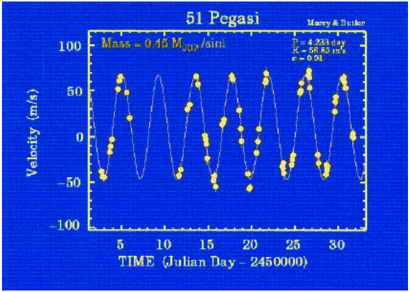
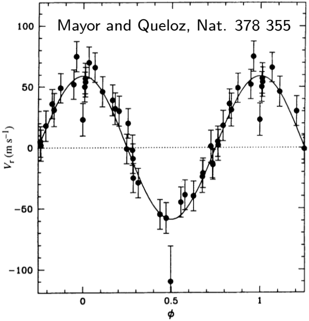


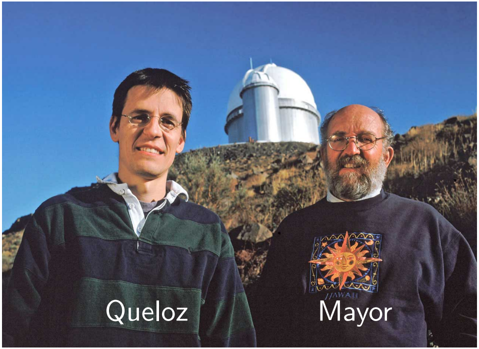
The data below show the oscillations in the speed of the star 51 Pegasus implying the existence of an unseen, orbiting companion. What is the period of the oscillation? How is this period related to the distance from 51 Pegasus to the unseen companion? What do these results imply about the maximum mass of the unseen companion? Assume the mass of 51 Pegasus is $m_s = 2.2 \times 10^{30}\ kg$ from its spectral type and that it is a distance $r_{peg} = 51 ly$ from Earth. The planet is now called Dimidium.





A Nobel Prize for 51 Pegasus

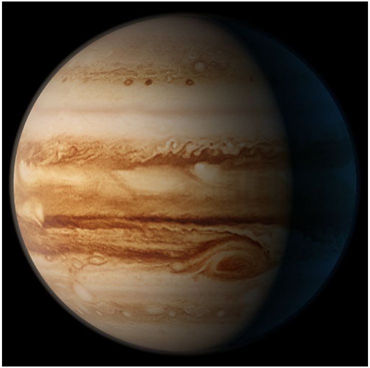
The Nobel Prize in Physics 2019 was awarded "for contributions to our understanding of the evolution of the universe and Earth's place in the cosmos" with one half to James Peebles "for theoretical discoveries in physical cosmology", the other half jointly to Michel Mayor and Didier Queloz "for the discovery of an exoplanet orbiting a solar-type star."



Consider a solar system consisting only of the Sun and Jupiter orbiting about their center of mass. What is the size of the Sun's 'wobble' as it orbits the center of mass? Compare the wobble with the radius of the Sun. If an alien species on a small planet (similar to Earth) orbiting 51 Pegasus tried to observe the Sun's wobble what would be the angular size of the wobble? The distance from 51 Pegasus to the Sun is 51 ly.

Jupiter's mass	1.90×10^{27} kg
Sun's mass	1.99×10^{30} kg
Sun-Jupiter distance	7.8×10^{11} m
Sun's radius	6.96×10^{8} m
1 light-year	9.46×10^{15} m

More on wobbling stars here.



What is the angular shift in position of 51 Peg orbiting the center-of-mass associated with a Jupiter-like planet?

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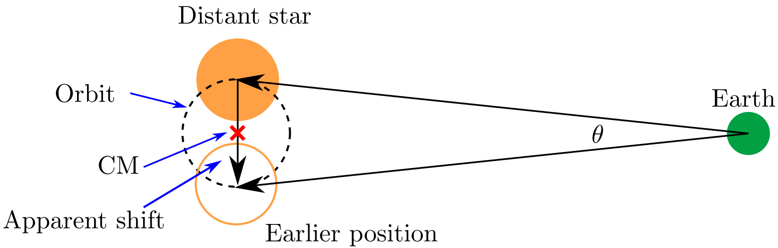

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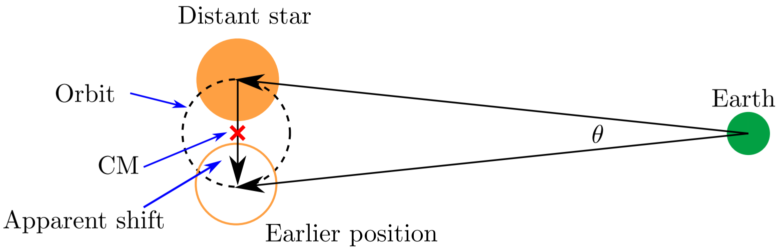
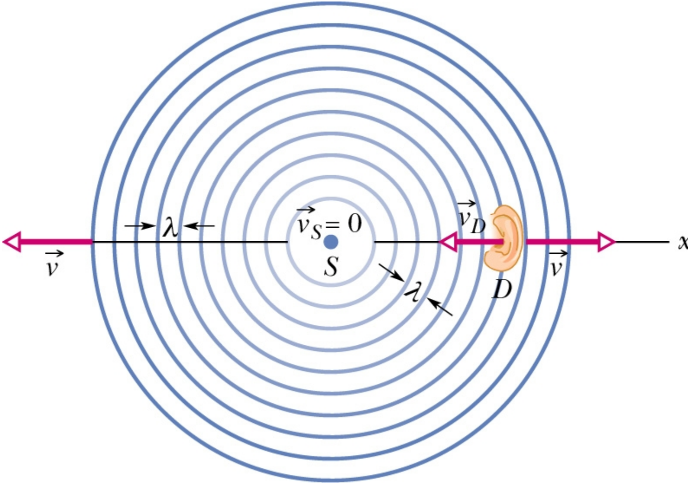
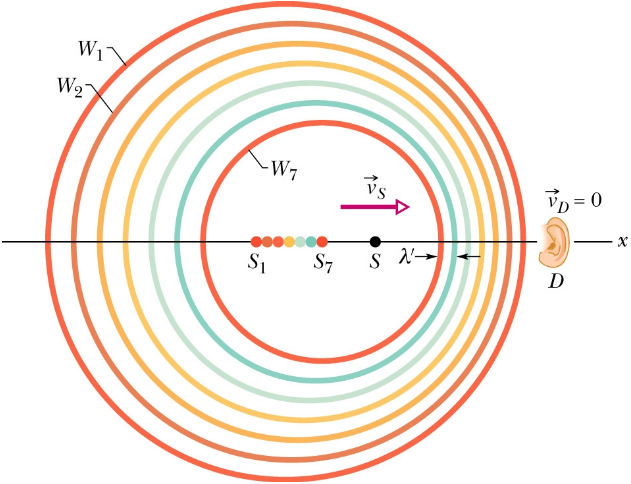


Telescope resolutions: VLBA (3×10^{-7} *deg*), Hubble (8×10^{-6} *deg*)

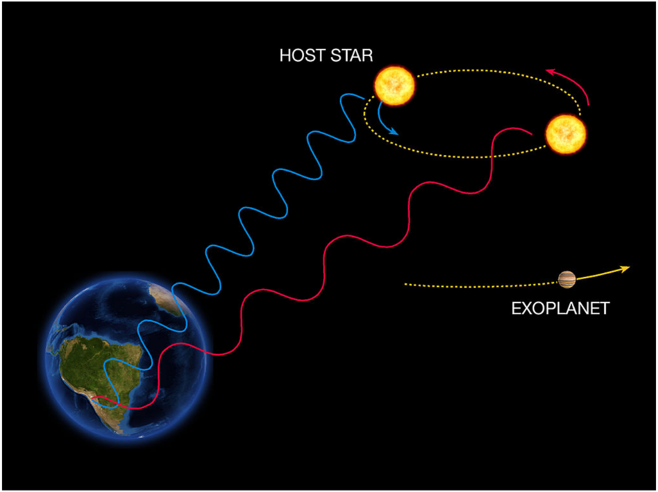


λ
$\vec{v}_S = 0$
S
$\vec{v}_D$
D
$\vec{v}$
$\vec{v}$
λ
x

The Doppler Effect



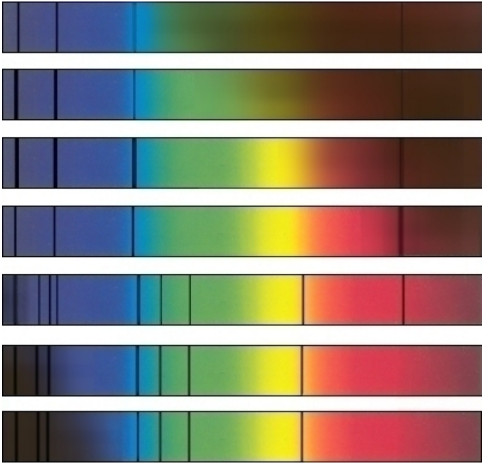
Wobbling Stars

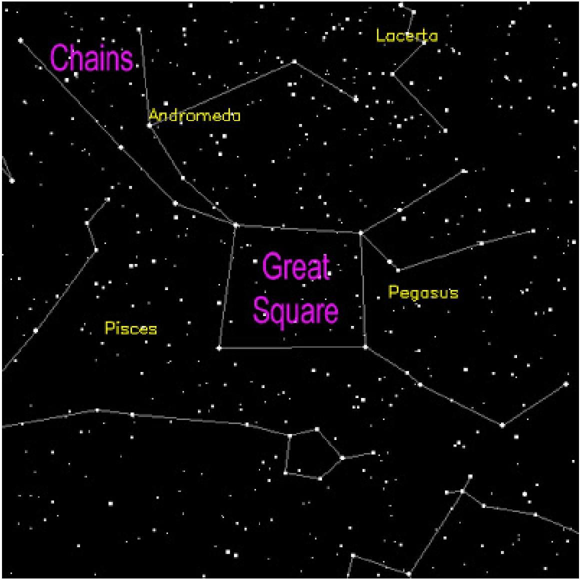


The Radial Velocity Method

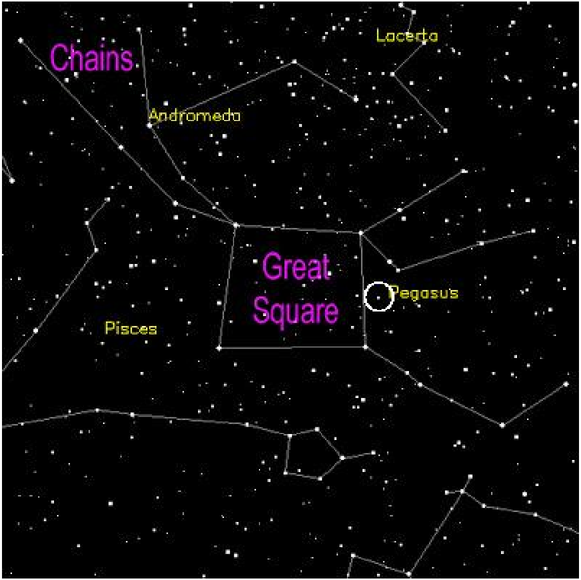
ESO Press Photo 22e/07 (25 April 2007)

The velocities of distant stars towards or away from the Earth are measured using small blue- or red-shirts of the absorption lines like those shown here in the spectra of a variety of stars. Several methods are used to keep the spectra precisely calibrated for the long periods needed to record the observations.

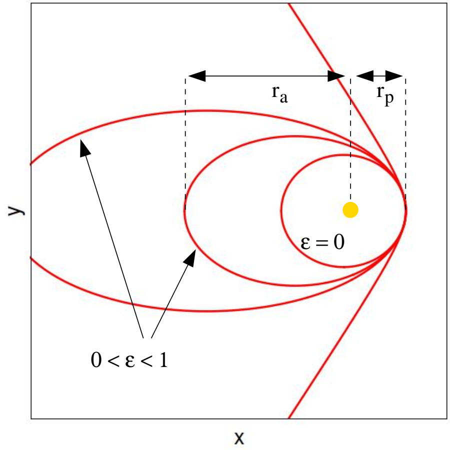



Chains
Lacerta
Andromeda
Great
Square
Pegasus
Pisces

51 Pegasus Location in the Sky

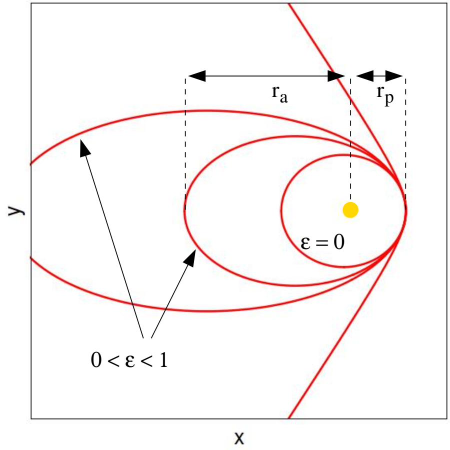


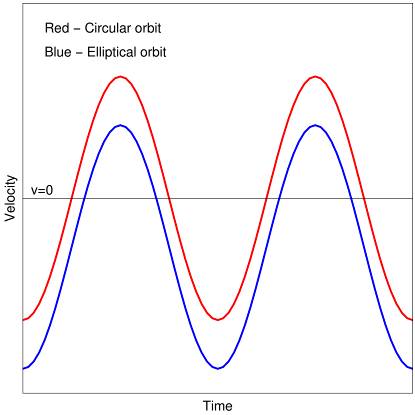
$$\epsilon = \sqrt{1 + \frac{2E\ell^2}{\mu\alpha^2}} = 1 - \frac{2}{\frac{r_a}{r_p} + 1}$$

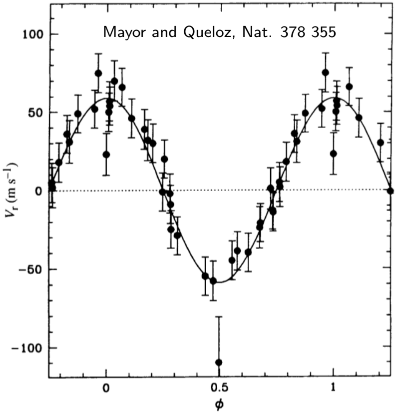


Is 51 Peg's Planet Eccentric?

$$\epsilon = \sqrt{1 + \frac{2E\ell^2}{\mu\alpha^2}} = 1 - \frac{2}{\frac{r_a}{r_p} + 1}$$



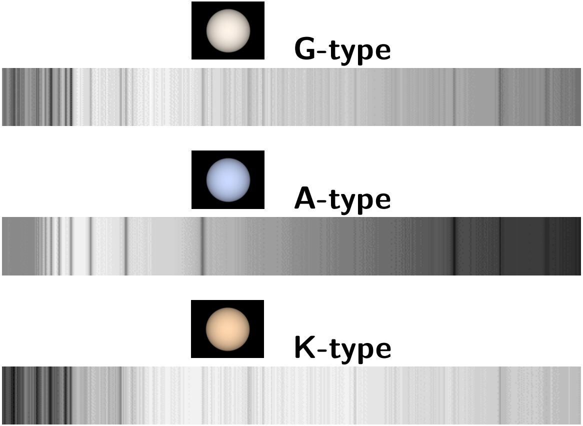




Orbital period: $4.2293 \pm 0.0011d$
Velocity resolution: 13 m/s

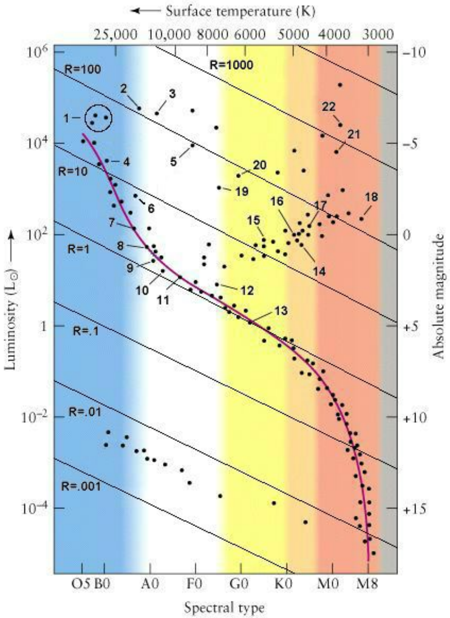
Stellar Spectra

The spectral class is a method for classifying stars based on the pattern of absorption lines (which reveal the elements in the star's photosphere) and their intensity (which reflects the abundance). These measurements can be translated into the temperature and density of the star's photosphere.

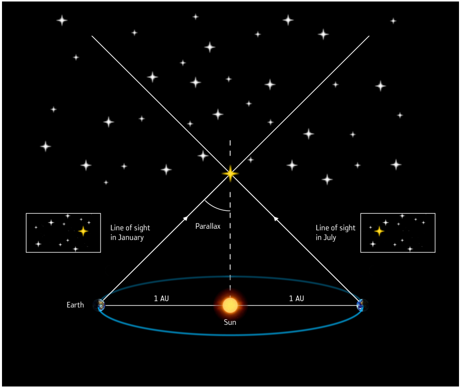


The Main Sequence

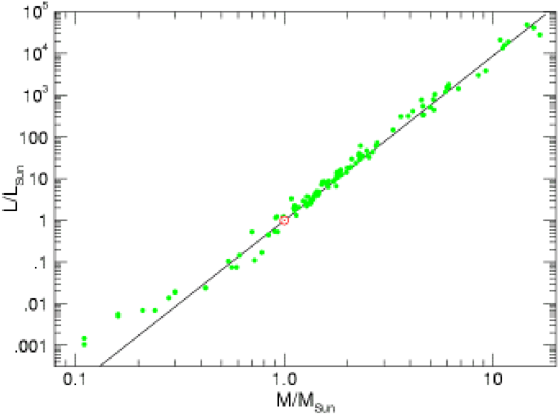
The main sequence of the Hertzsprung-Russell diagram is the curve where the majority of stars are located in this diagram. This line is so pronounced because both the spectral type and the luminosity depend on a star's mass only to zeroth order as long as it is fusing hydrogen.

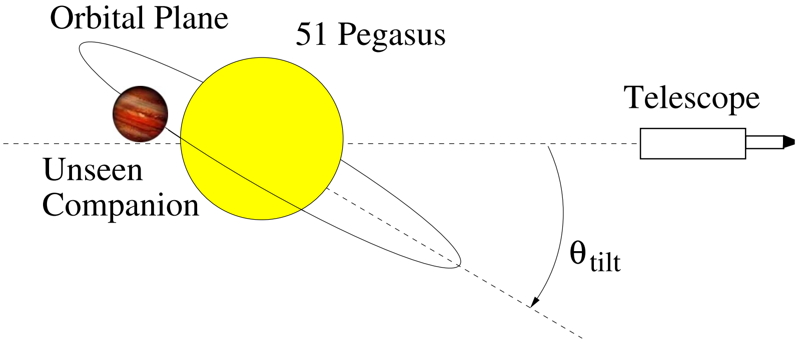


To place a star on the Hertzsprung-Russell diagram the absolute luminosity has to be determined. This step requires measuring the distance from the Earth to the star. Nearby stars appear to move with respect to more distant background stars due to the motion of the Earth around the Sun. This apparent motion (it is not "true" motion) is called Stellar Parallax.



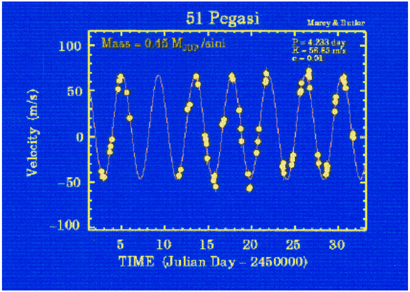
The luminosity of main sequence stars is proportional to their mass as shown in the plot below. Thus identifying the spectral type places the star on the main sequence and then measurments of its luminosity can be directly related to its mass.

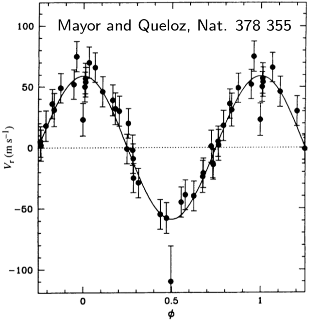


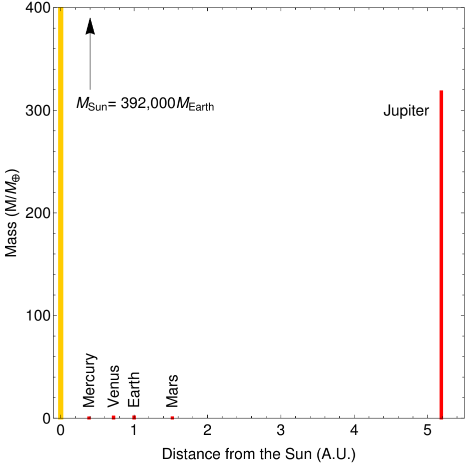

Orbital Plane
51 Pegasus
Telescope
Unseen
Companion
θ_{tilt}

A Planet Around 51 Pegasus

Consider the data below which shows the oscillations in the speed of the star 51 Pegasus implying the existence of an unseen, orbiting companion now called 51 Pegasus b. What is the period of the oscillation? How is this period related to the distance from 51 Pegasus to 51 Peg b? What do these results imply about the maximum mass of the unseen companion? Assume the mass of 51 Pegasus is $m_s = 2.2 \times 10^{30}\ kg$ from its spectral type and that it is a distance $r_{peg} = 51 ly$ from Earth.

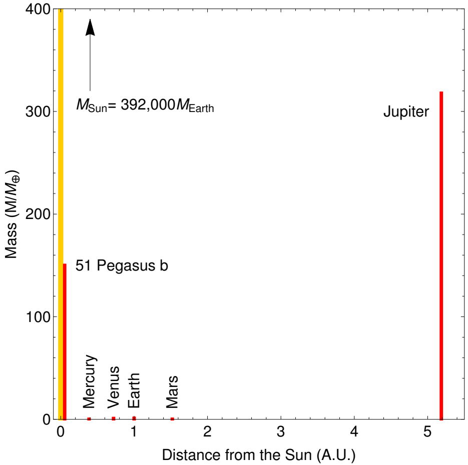


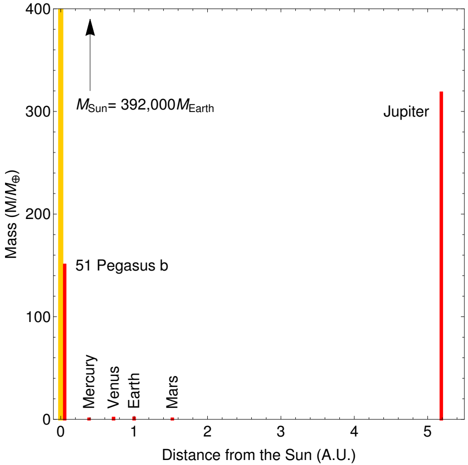


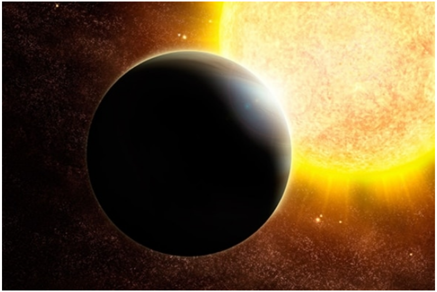


400
300
200
100
0
Mass (M/M⊕)
M_Sun = 392,000 M_Earth
Jupiter
Mercury
Venus
Earth
Mars
0
1
2
3
4
5
Distance from the Sun (A.U.)

Planet Comparison




400
300
200
100
0
M_{Sun}= 392,000M_{Earth}
Jupiter
51 Pegasus b
Mercury
Venus
Earth
Mars
0
1
2
3
4
5
Mass (M/M$_\oplus$)
Distance from the Sun (A.U.)



HOT JUPITER!