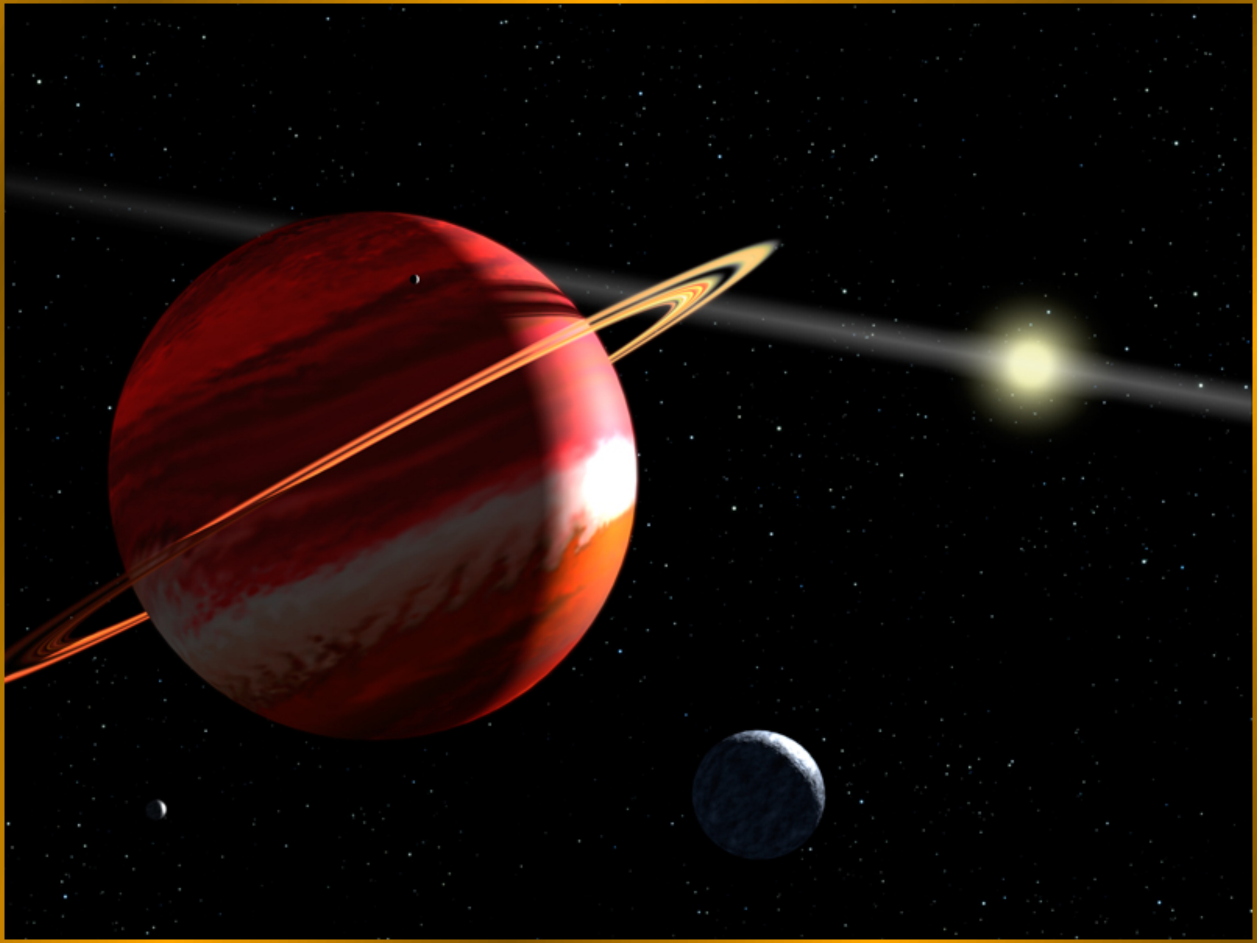
Using Spectropolarimetry to Study Extrasolar Planets.



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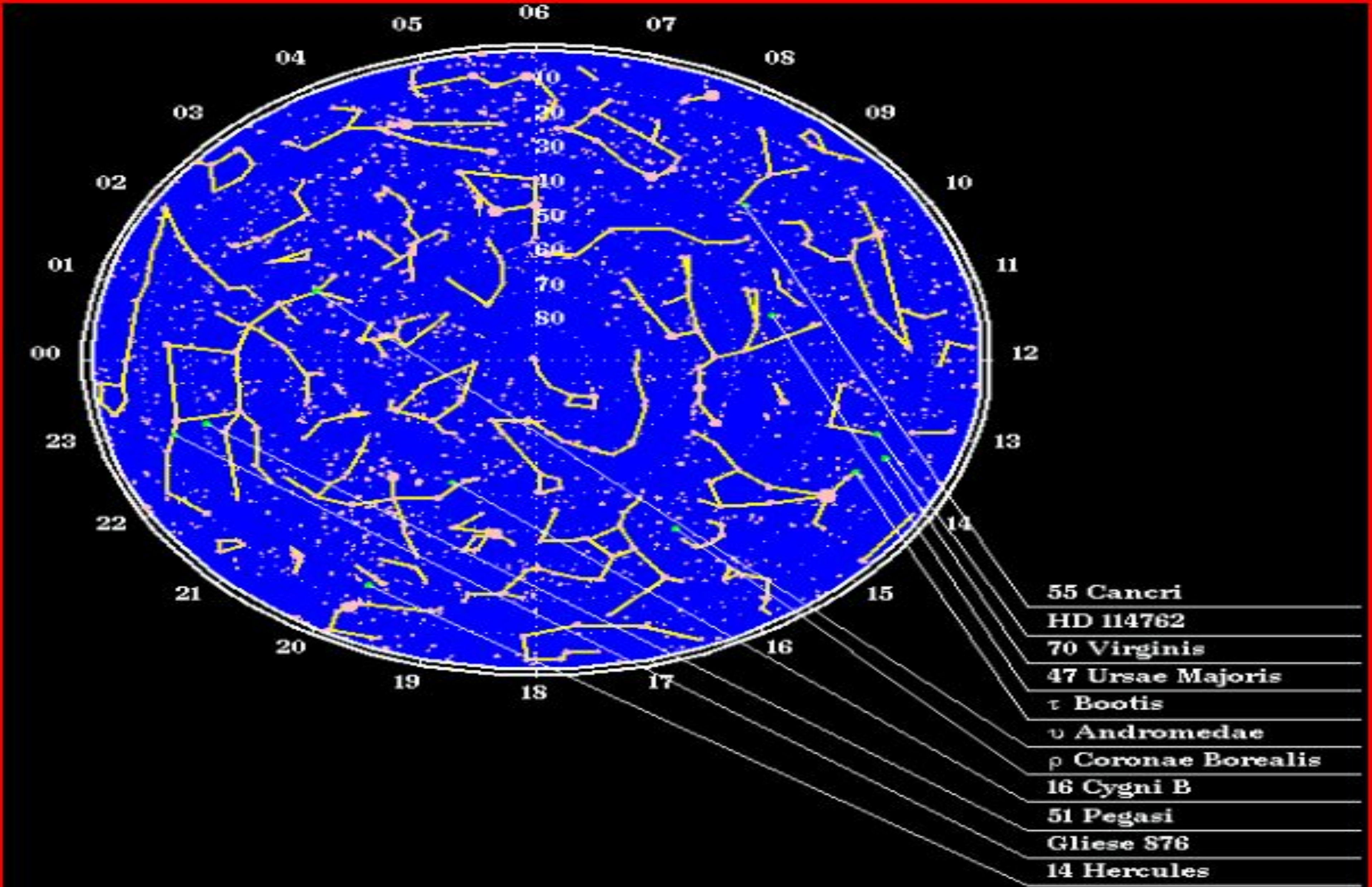
Introduction

- Hundreds of Extrasolar Planets (ESPs) have been discovered.
- Few have been directly imaged.
- Less have been studied spectroscopically.
- Polarized light was claimed to have been measured from one ESP.
- Measurement of polarized light scattering is key to understanding ESP atmospheres.
- This will not be easy.

ESPs

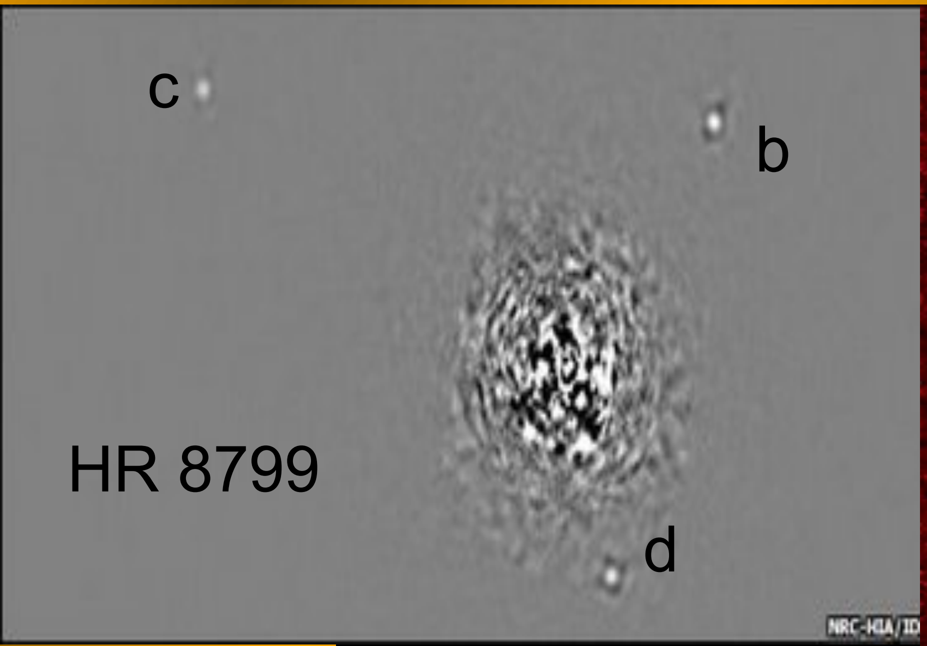
- An ESP is a planet that orbits a star outside of our solar system.
- The 1st ESP, 51 Pegasi b, was discovered in 1995.
- It is now known that a substantial fraction of stars have planets.
- This means there could potentially billions of ESP in our galaxy!!!
- Possibly one of these supports life.

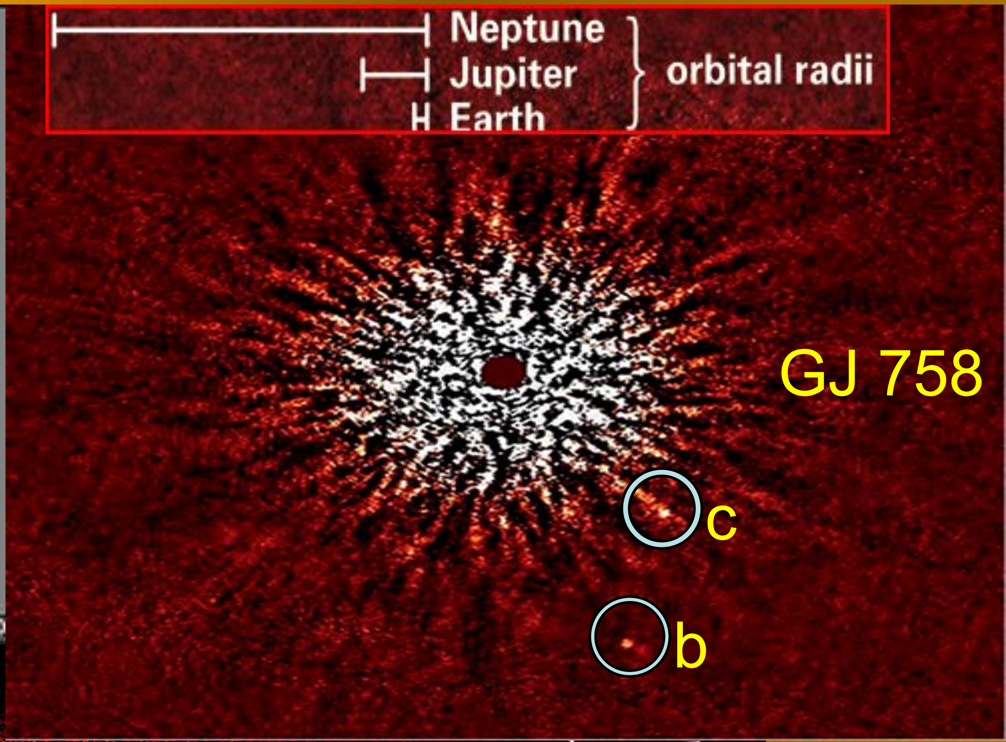
They are everywhere!

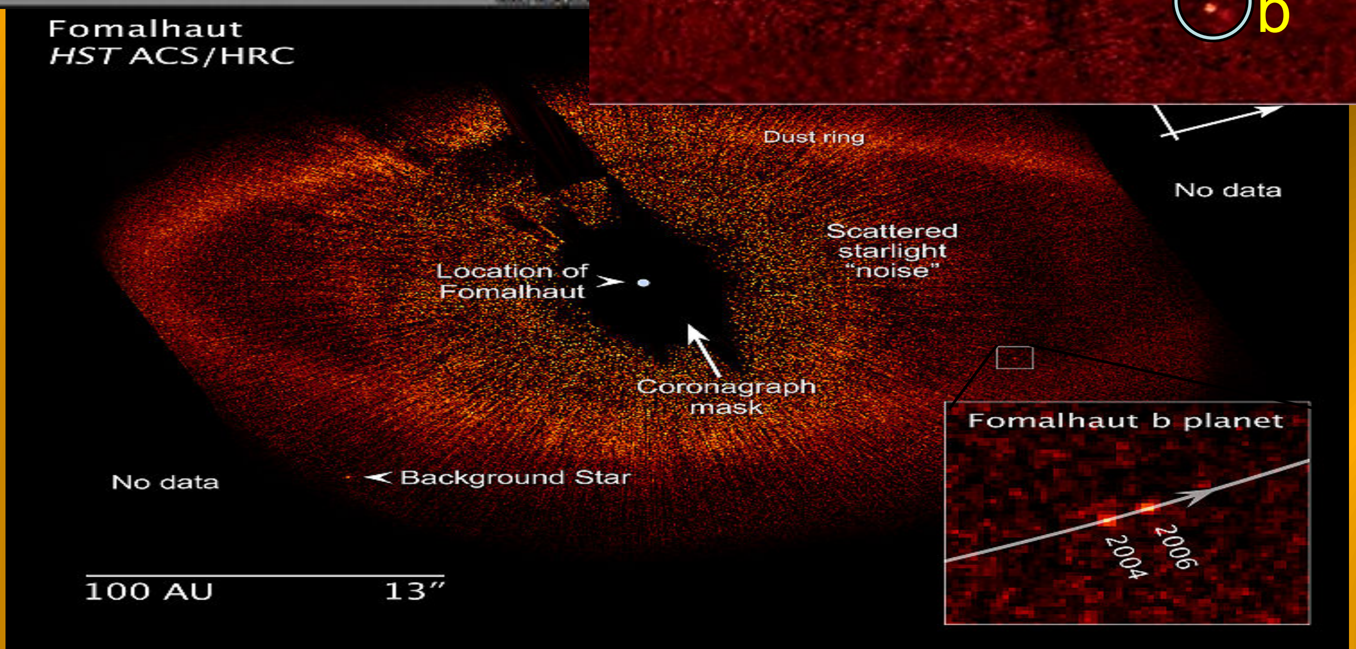


S.G. Korzennik (CfA, © 1997,1998)

Some Directly Imaged Companions







Understanding ESP Atmospheres

- We need spectral and polarized data.
- Spectral data can tell you about the composition of the atmosphere.
- Only polarization data tells you about the size and number of particles.

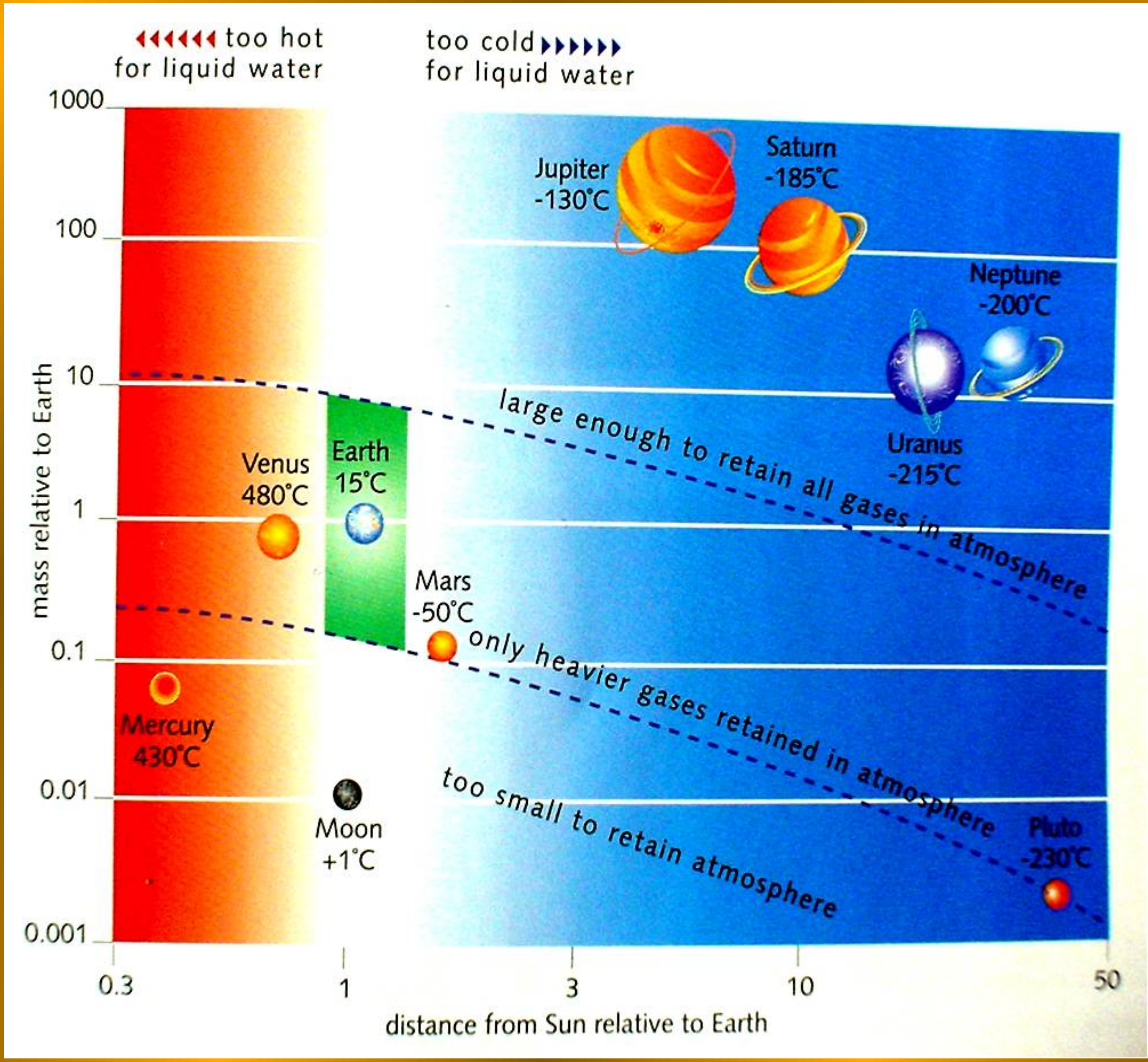
Types of ESPs

- The most common of ESPs are Hot Jupiters.
- Others are:
  - Super Earths
  - Rogue Planets
  - Cythonian planets aka shrinking planets
  - Recently Kepler discovered a planet with the density of Styrofoam!

The Habitable Zone

The Kepler missions are purposed to find Earth like planets in what is known as the habitable zone.

In order to find Earth-like planets or any planets for that matter, we need to have a better understanding of what atmospheres are composed of.



Scattering

- Scattering polarizes light.
- Scattering from a planetary atmosphere is a function of the atmospheric composition, number and size distribution of particles.
- Models of planetary atmospheres can be tested against real data.

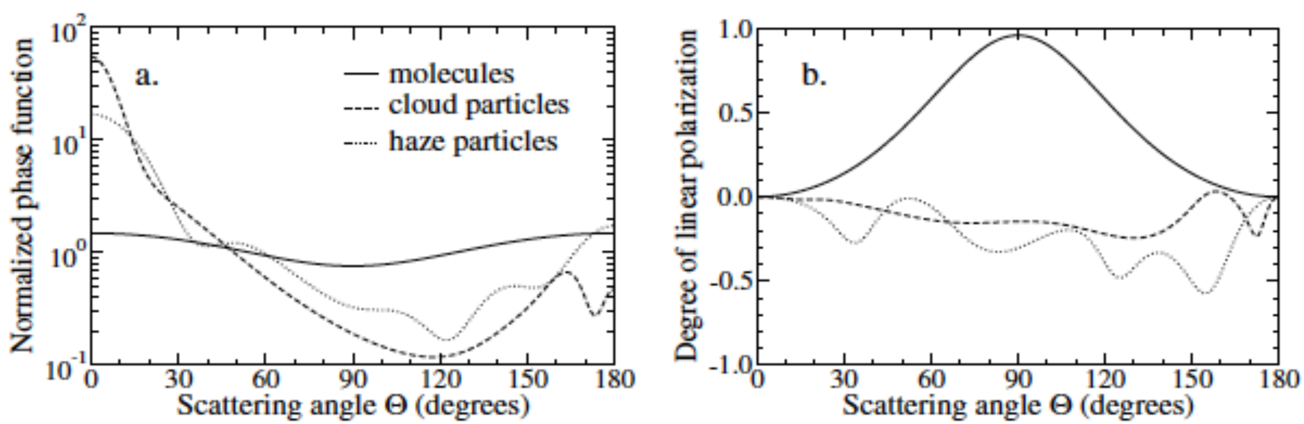


Fig. 3. The phase functions and the degree of linear polarization of light singly scattered by gaseous molecules (solid lines), the cloud particles (dashed lines), and the haze particles (dotted lines) at a wavelength $\lambda = 0.7\ \mu$m as functions of the scattering angle Θ (in degrees) (when $\Theta = 180°$, the light is scattered in the backward direction). The phase functions are normalized such that the average over all directions equals unity.

The Use of Polarimetry in our Own Solar System

- By comparing models and data, the presence of sulfuric acid was detected in Venus's atmosphere.
- Polarization studies of Jupiter from the Galileo spacecraft show evidence of non-spherical properties, which complicates any analysis.

Can we see similar signals from space?

Resolved system

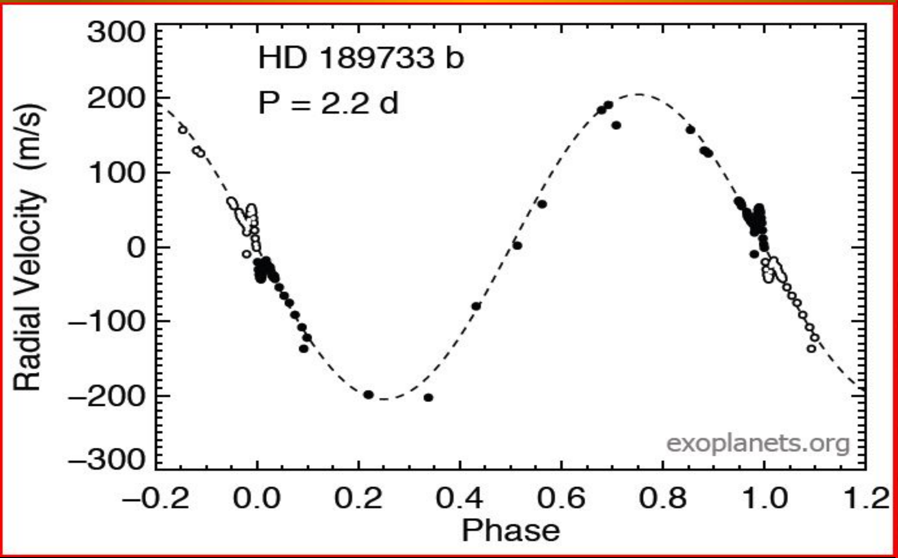
- Planet is farther from the host star.
- Smaller signal.
- Resolved images of exoplanets are not expected from the ground or space systems anytime soon.

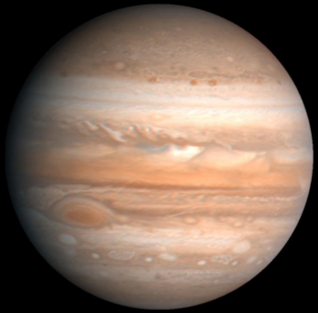
Unresolved system

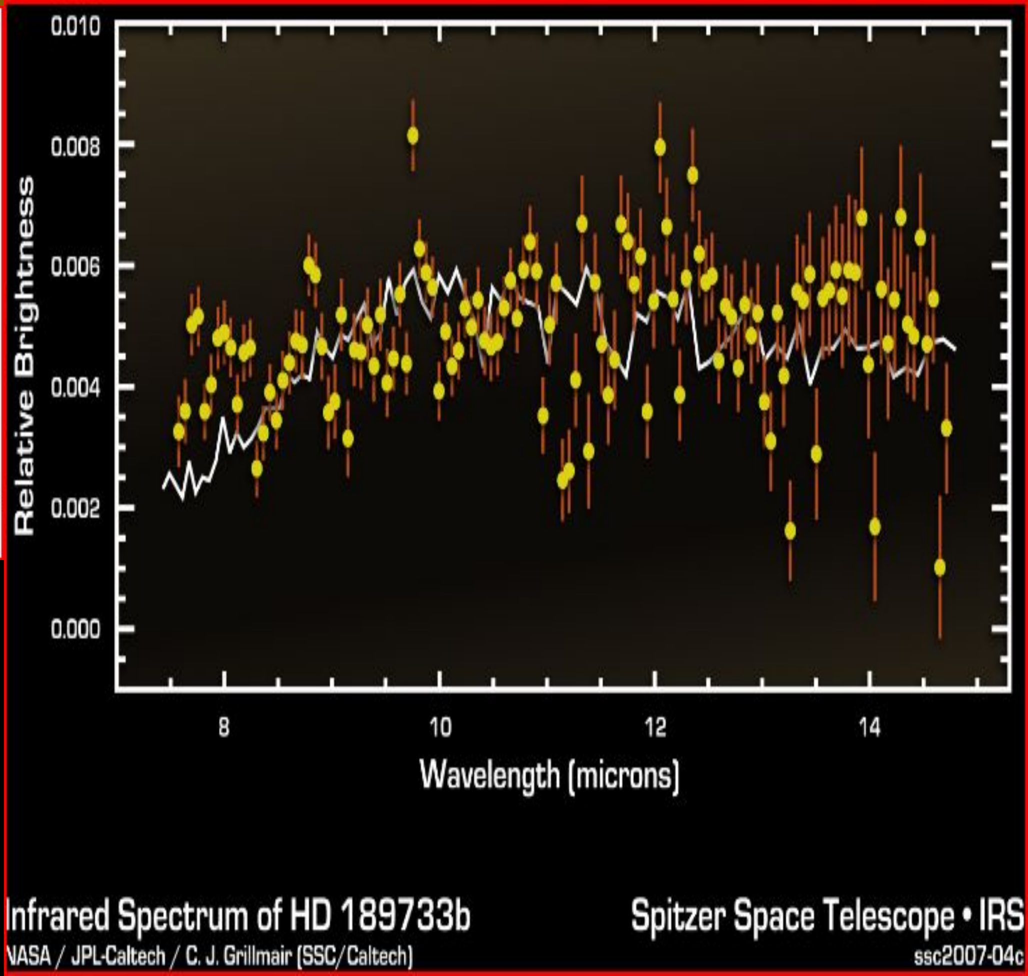
- Larger signal.
- Radiation from the star is greater than radiation from the planet.
- For an induced polarization of 0.1-1%, a dynamic range of 10^5 - 10^6 is required.
- This is doable as we will show.

HD189733b

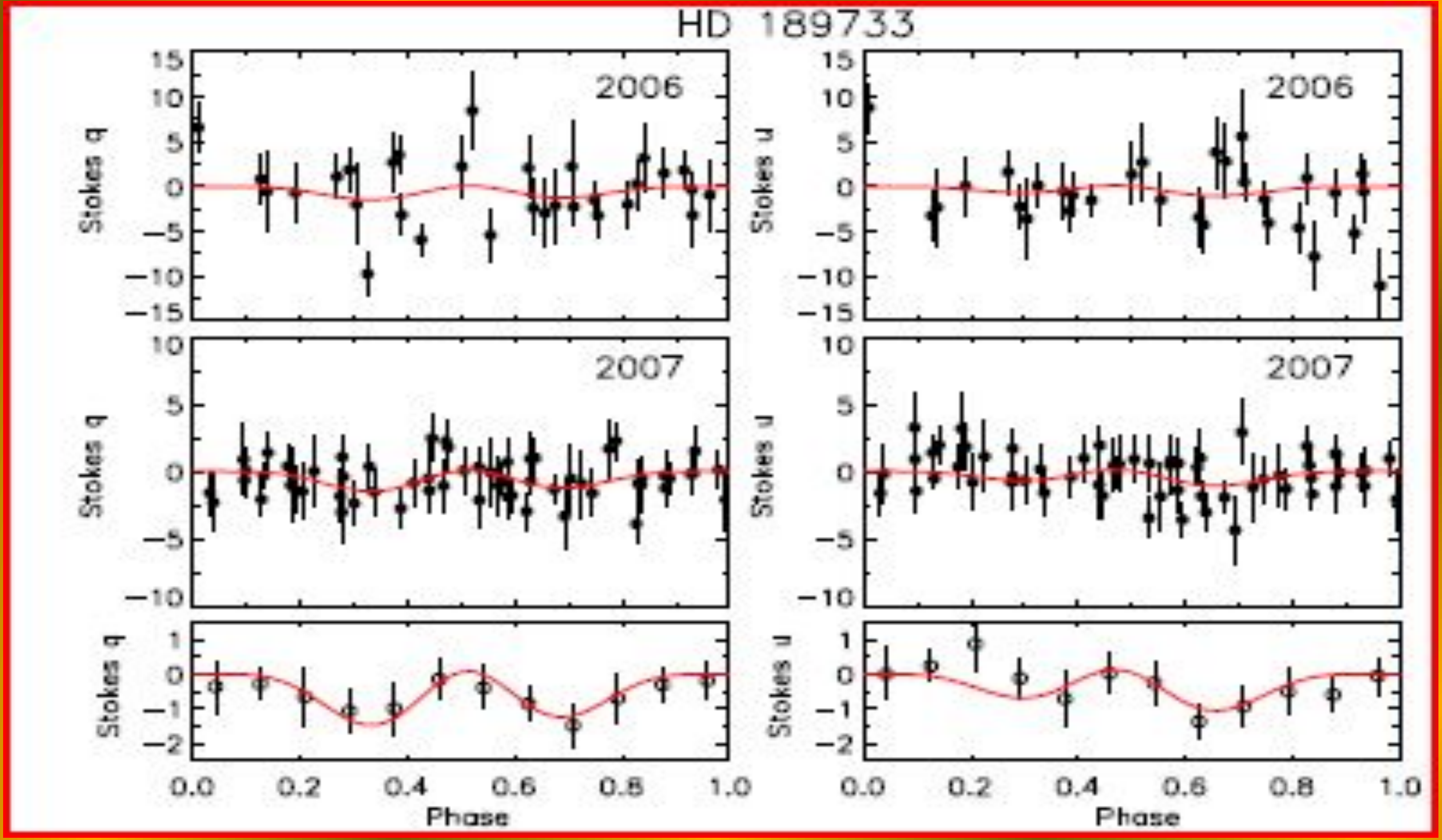
- Berdyugina et al. (2007) claims to have measured polarization in the visible from HD 189733b: a Hot Jupiter.







Data from HD 189733b



Calculations for HD189733

- Based on Hough et al (2003) we expect the exoplanet signal to be 150 μmag below the host star.
- This translates in 10^{-4} less mag.
- For a Polarization of 1 to 10%, we need to detect a signal 10^{-5} to10^{-6} down from the host star.
- At R Band HD189733 is a 7.1 magnitude star.

HD 189733

- This translates into about .8 to 8 polarized photons/sec at the detector.
  - ~ 2 meter telescope.
  - 50% optical efficiency.
  - 50% polarization
  - 100 nanometer bandwidth.

Can this be done?

- We want to detect approximately .8 to 8 photons/sec in a background of $8x10^6$ photons.
- Typical photomultiplier tubes have a shot noise of .3 photons/sec/$Hz^{1/2}$
- Dynamic Range of 10^5 or higher.
- For 10%P, the SNR for 8 photons/sec will be 26:1 and within the Dynamic Range of the detector.
- Signal averaging will allow us to see to the 1%P level and maybe higher.

Piece of Cake?

- A Photomultiplier tube can provide the necessary dynamic range and low noise level to detect polarized light from at least hot Jupiters.
- However, we did not look into other sources of noise atmospheric turbulence.

Conclusions

- Polarized signals from unresolved ESPs can be detected at levels sufficient to test models of ESP atmospheres.
- It is possible to study Hot Jupiters and maybe even Earth-like planets.

References

Images

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- http://en.wikipedia.org/wiki/File:Exoplanet_Comparison_HD_189733_b.png
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Information

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- "Spectra of Venus and Jupiter from 1800 angstroms to 3200 angstroms" by R.C. Anderson and J.G. Pipes.
- "Allen's Astrophysical Quantities" by Arthur N. Cox
- http://nssdc.gsfc.nasa.gov/planetary/factsheet/venusfact.html
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- "HST Detection of H_2 Raman Scattering in the Jovian Atmosphere" by Yan Bétremieux and Roger V. Yelle.
- http://www.spitzer.caltech.edu/images/1755-ssc2007-04c-Cracking-the-Code-of-Faraway-Worlds-An-Exoplanet-Atmosphere
- "Observed Properties of Exoplanets: Masses, Orbits, and Metallicities "by Geoffrey Marcy, R. Paul Butler, Debra Fischer, Steven Vogt, Jason T. Wright, Chris G. Tinney and Hugh R. A. Jones
- http://www.nasa.gov/mission_pages/kepler/main/index.html

In depth calculations

- At 7.1 E-6 in the R band, a 0 mag star has a flux of 1.75E-9 erg/Cm^2*sec*Å.
- At apparent magnitude of 7.1, the flux becomes (1.75E-9 ~~erg~~/~~Cm~~^{2}*sec*~~Å~~ divided by (2.51)$^{7.1}$) * 10^{-7} J/~~erg~~ * 10^4 ~~Cm~~^{2}/m^2 * 10^4 ~~Å~~/ µm = 2.54E-11 J/m^2*sec.
- E=h*c/λ = 6.626E-34 * 3E8 / .63E-6 = 3.15E-19.

In depth calculations continued

- (2.54E-11J/m^2*sec*~~µm~~)*(photons/3.15E-19 J)*(.1 ~~µm~~ bandwidth) =8.06E6 photons/sec*m^2.
- (8.06E6 photons/sec*m^2)*(3.8 m^2 which is area of telescope) =3.06E7 photons/sec
- Optical efficiency and polarization are both at 50%, so 3.06E7/2= 1.5E7/2 = 7.6E6 photons /sec

In depth calculations continued

- Mag of reflected signal from planet down by 10^{-4}
- Polarimetry will give 1%-10% or .76E5 - .76E4.
- Low noise Avalanche Photo Diode(APD) detects 25 photons/sec

Photomultiplier Tube

@ Anode

- Radian Sensitivity: 1.5E5 Amp/ Watt
- Dark Current: 10E-9 Amp
- 10E-9 Amp / 1.5E5 Amp/ Watt = 6.67E-14 Watt / 3E-19 J/sec = 2.12E5 photons/sec

@ Cathode

- Radian Sensitivity: 78E-3 Amp/Watt
- Dark Current: 10E-9 Amp
- 1.5E5 Amp/ Watt / 78E-3 Amp/Watt = 1.9E6 <= Gain of the system. Which translates to .1 photons/sec @ Cathode

In depth calculations continued

- $.1^{1/2}$ =.3 photons/sec. This is the Shot Noise.
- Signal to Noise Ratio = .8/.3 to 8/.3 = 2.67:1 to 26.67:1.