Stars, Galaxies & the Universe Announcements

- **Reading Quiz #13**– retake today in class
- Reading Quiz #14 – Wednesday in class
- Error in HW #11 has been corrected (Dark Matter question)
- **HW #12 due on Friday (12-10) by 5 pm!**
- **Final Exam will be cumulative; Thursday 16 Dec @7:30 am in VAN LR 1; 150 points – 50 questions @3 pts each! We will have a review session sometime during Finals Week.**
- **Tuesday (12-14) evening @ 7 pm in LR70**

Stars, Galaxies & the Universe Lecture Outline

Life in the Universe (Chapter 27)

(1) What is life?
(2) Life on Earth – building blocks and extremophiles
(3) Life in the Solar System
(4) Planets around other stars ("exoplanets")
(5) Search for Intelligent Life – Wednesday!

Lecture Outline

Life in the Universe

-Life in the Solar System
- Life around other stars
-Radio signals: SETI
- scene from CONTACT

Lessons which have re-interested us in the search for life in the universe:

• life arose quite early in Earth's history suggesting the life could form quickly on other worlds in the right conditions

• lab experiments have shown chemical constituents common on young Earth combine quite readily into complex organic molecules – same chemistry on different worlds?

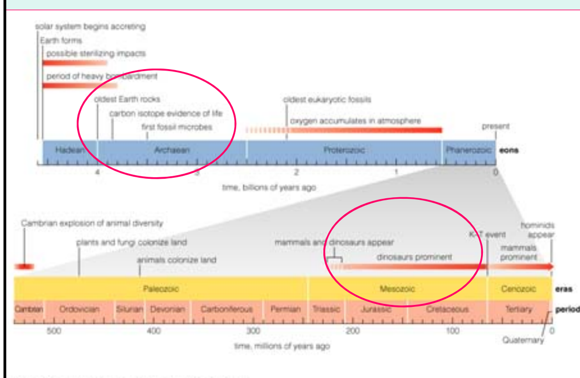
• we have discovered microscopic organisms which can survive conditions of extreme temperature (cold, hot, dry, wet, etc.)

When did life arise on Earth?

• would have been difficult during era of heavy bombardment (ended 3.9 billion years ago)

• some evidence for life (carbon isotope evidence & fossil microbes) as long ago as 3.8 billion years!

Grand Canyon
~2 billion years
Fossil Dinosaurs
100 million years



Liquid water appears to be a necessity for "life as we know it"

Earth organisms have been found in all types of LIQUID water
- boiling, highly acidic, and even ice cold "extremophiles"

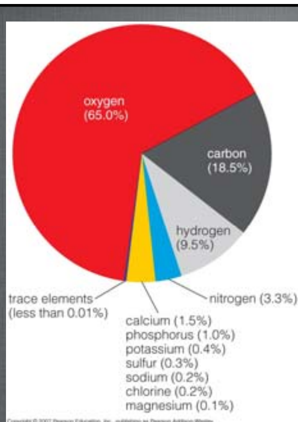
• temperature on a planet to sustain liquid water would need to be reasonable
  - no extreme temperature variations

• planet would likely need a thick atmosphere to keep temperatures constant and to prevent evaporation of liquid water

• picture of bottom of Gulf of Mexico
  - intense pressures and cold temperatures
  - methane forms into a solid
  - methane reefs teem with worms

Microscopic view of four types of Living Cells

Molecular components of cells:
Carbohydrates – source of energy
Lipids – store energy
Proteins – workhorses; enzymes & catlysts
And amino acids
Nucleic Acids – DNA, RNA (hereditary)



Earth Life is Carbon-Based

Pie chart showing what humans are made of

Four main elements:

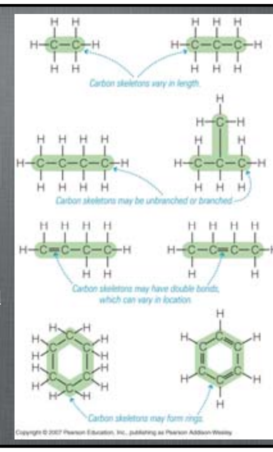
OXYGEN
CARBON
HYDROGEN
NITROGEN

Everything else is trace

Carbon combines with other elements in chemical bonds
- Very versatile

Carbon is very versatile and combines well with other atoms to make complex molecules which form the basic structures that underlie most living cells

However, is Carbon based life the only possibility?



How about Silicon?

Silicon often comes up a possibility – it is abundant on the Earth and probably on the other planets in our solar system

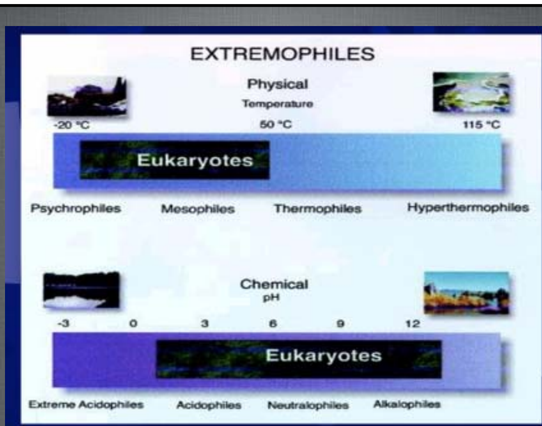
Why? Because it can have up to four bonds at once (although isn't as versatile as carbon)

However, Silicon has THREE STRIKES against it:
1. Bonds formed by silicon inherently weaker (fragile compounds)
2. Complex silicon-based molecules can't survive in liquid water
3. Silicon is only a solid (whereas carbon can be gaseous and therefore mobile)

Extremophiles

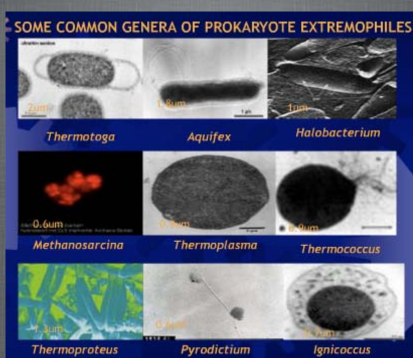
life forms (mostly bacteria)
that live in extreme[1] environments
[1]extreme for humans that is, not for the bacteria!

- Psychrophiles = cold loving
- thermophile = heat loving
- acidophile = acid loving
- alkalpphile = base loving
- radiophile = radiation loving
- hypolith = lives inside rocks
- xerophiles = lives in extremely dry envs. (actacama desert)
- halophile - lives in high salt concentrations



Extremophiles Can Survive:

- 113 to 200 °C
- - 15 °C
- pH < 0.0
- pH > 11
- 1200 atmospheres
- 0% oxygen
- 20-40 million years dormancy
- 2 1/2 years in space, etc.

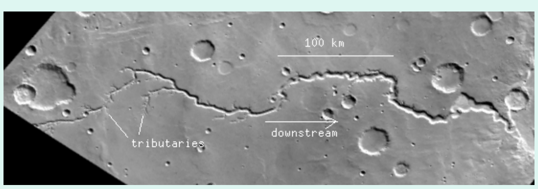


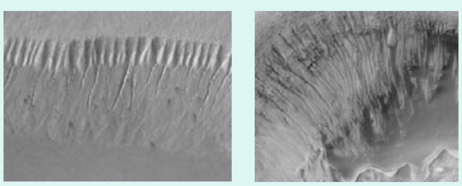
Life Elsewhere...

→ Life in our Solar System:
most of SS has been surveyed by spacecraft
we do have several good candidates

1. **Mars**
   -billions of years ago Mars may have had surface water
   both chemical, geological evidence for this
   -possible "microbial" evidence for past cellular life on Mars - meteorites
2. **Europa, Callisto and (satellite of Jupiter)**
   -surface texture, imaging of Europa suggests icy crust
   -underneath may be vast ocean of water
   -ideal place for life to be found in icy cracks
3. **Titan (satellite of Saturn)**
   -only satellite in Solar System with an atmosphere
   -methane atmosphere; ethane, hydrocarbon lakes, liquid water on surface
   -Huygens probe on Cassini reached Titan in early 2005 – surface!

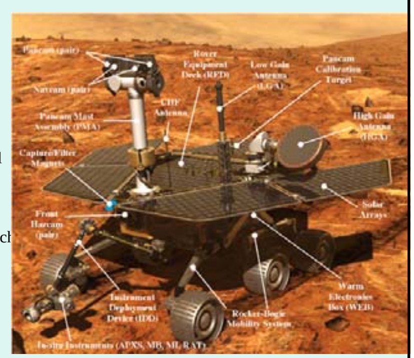
Geological Evidence on Mars:
Possible Ancient Streambeds and Erosion Channels





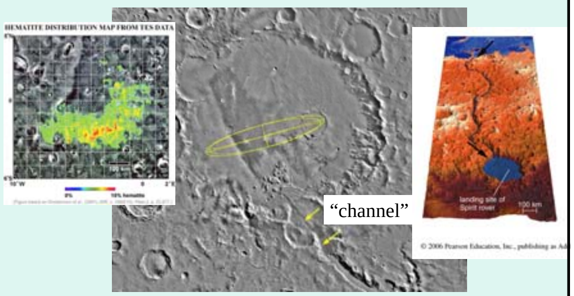
Mars Exploration Rover: Science Instruments

Pancam- Stereo camera
IR Spectrometer - rock composition
X-ray Spectrometer - soil and rock chemistry
RAT - rock abrasion tool
Microscopic imager (search for fossils?)



Landing Sites on Mars: 1. Gusev Crater - morphological

- 15 degrees **South** of Mars' equator
- large crater feature with several 'channels' leading into it
- water may have pooled in crater during first 2 billion years

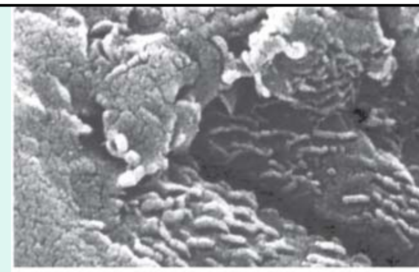


Landing Sites on Mars: 2. Meridiani Planum - mineralogical

- 2 degrees **South** of Mars' equator
- other side of planet from Landing Site 1
- place where hematite has been found (rust-like mineral) – indicates that it is a former dried lake bed

- rocks at this site contained "blueberries", size, shape suggests they formed in standing water!
- chemical analysis showed that they contained iron-rich mineral ***hematite*** & sulfur-rich ***jarosite***
- layering of rocks indicates sedimentary forms

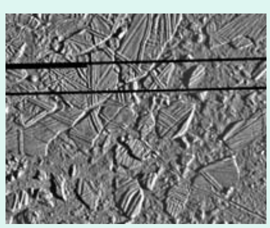
a The Martian meteorite ALH84001, before it was cut open for detailed study. The block on the right provides a sense of scale; it measures 1 cubic centimeter, about the size of a typical sugar cube.



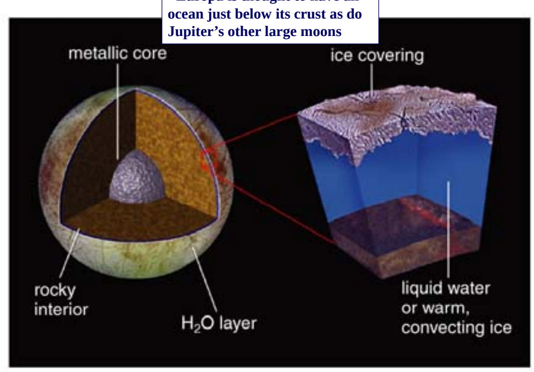
b This photo shows rod-shaped structures found in a highly magnified slice of ALH84001. They measure about 100 nanometers in length and are as small as 10–20 nanometers in width.

Life Elsewhere...

Europa's Icy Surface

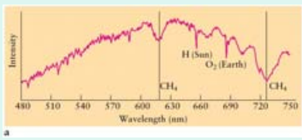


- **Europa is thought to have an ocean just below its crust as do Jupiter's other large moons**



Life Elsewhere...

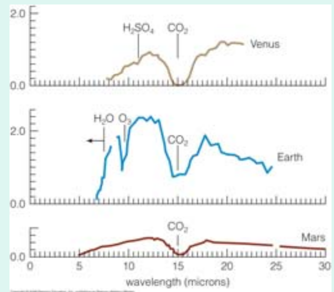
Titan's Methane Atmosphere



Spectral Signatures of Life:

-Future missions with spectrometers can get spectrum of individual planets

-Presence of absorption features can reveal gases in planets' atmospheres: CO_2, O_3, O_2!!



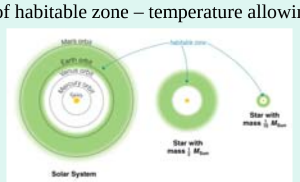
Venus

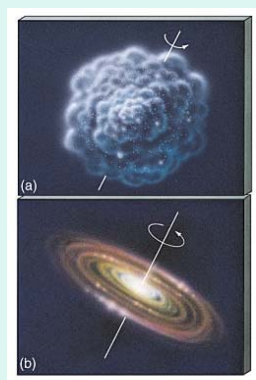
Earth

Mars

Life around other stars?

- Planets detected so far by Doppler method don't seem to be "habitable" – i.e., too hot (too close to star) and Jovian-like
- Terrestrial-type planets may be there, but undetectable now
- What properties must a star have to harbor a "habitable" planet?
  - → old enough to have life evolve on its planet (i.e. billions!)
  - → star must have stable orbits (not be binary or multiple)
  - → size of habitable zone – temperature allowing liquid water/ice



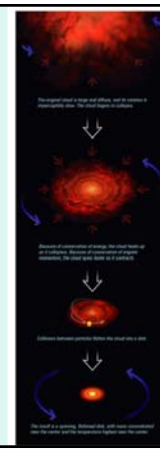


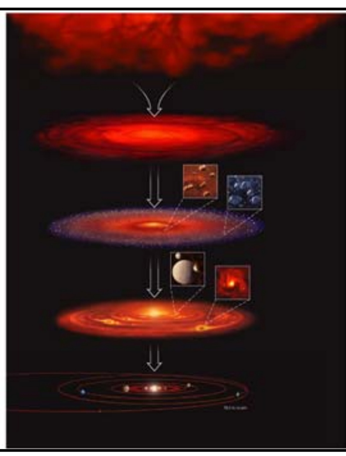
The collapse of an interstellar gas cloud:

-Heating
(temperature increases during collapse; gravitational potential)

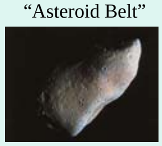
- Spinning
(cloud spins faster as it collapses – angular momentum)

-Flattening
(random motions become more orderly; i.e. material orbits in a flat disk)



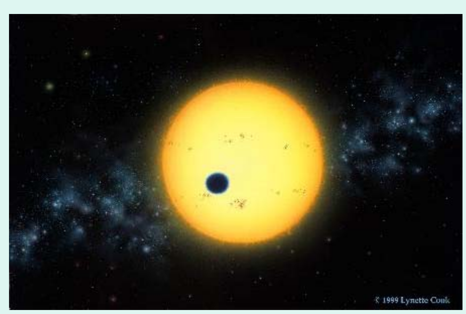


Leftover rocky planets – Asteroids – convene in the "Asteroid Belt"



Leftover Jovian planets – Comets– convene in the "Kuiper Belt" and "Oort Cloud"

"Extrasolar" Planets



Why is it so difficult to detect "extrasolar" planets?

• small relative size of planet and star
- -if Sun size of grapefruit, then Earth is pinhead, Jupiter is marble
- -Earth orbits 15m away, Jupiter 80m away
- -Same scale: nearest star is distance across the USA
- -To detect planet, like looking for pinhead/marble at distance of USA!

• large relative brightness of star and planet
- -stars are 1 billion times as bright as planets!
- -glow of the star would overshadow the planet

How do we detect planets around other stars?

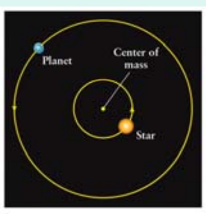
• very recent field in astronomy - 1995 (first discovery)

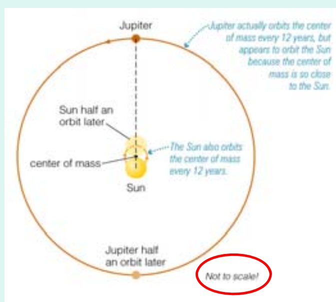
• two major ways we can detect "extrasolar" planets

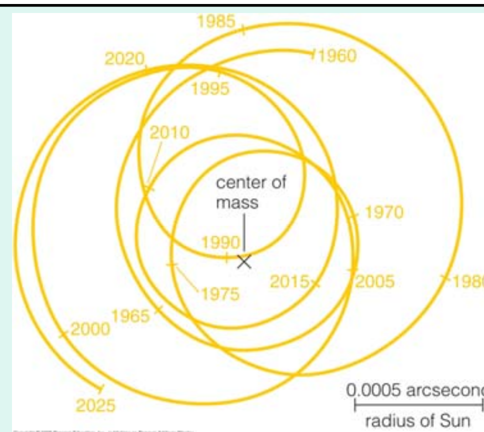
1. INDIRECTLY
   - "sense" that the planet is there in its position, brightness, spectrum
2. DIRECTLY
   - images of the planets themselves
   - spectrum from the planet itself

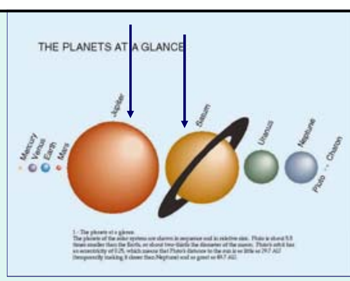
I. Gravitational Tugs: center of mass (Indirect)

In our Solar system, Sun & planets move around a center of mass
In any star system, both the star and planets will orbit a center of mass









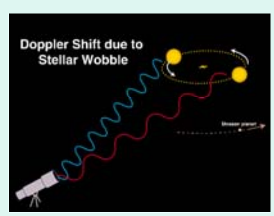
The magnitude of the gravitational tug will be proportional to:

-Mass of planet doing the tugging (more mass → bigger tug)

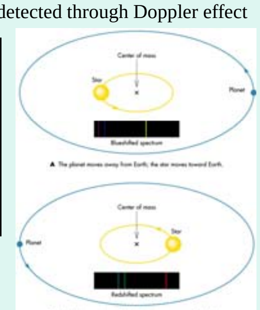
-Distance of the planet from the star (closer to star → bigger tug)

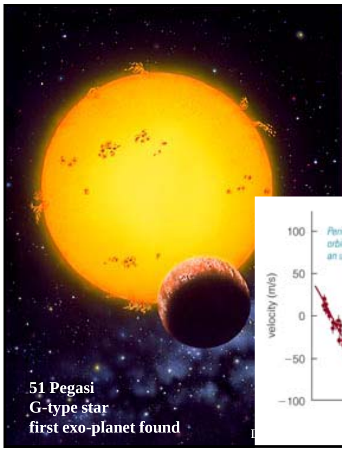
Gravitational Tugs: the Doppler technique of detection!

Doppler Technique
- "wobble" of star caused by unseen planet(s) - motion
- motion forward and back detected through Doppler effect



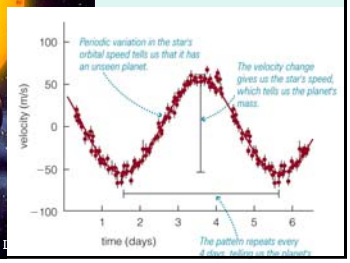
• "wobble" seen in spectral lines
• if star did not have a planet orbiting, we would not see the wobble

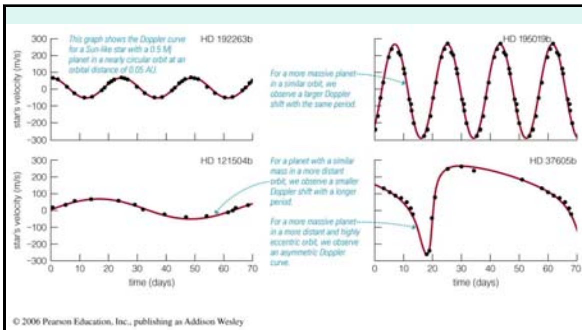




1995 - exoplanet found around 51 Pegasi

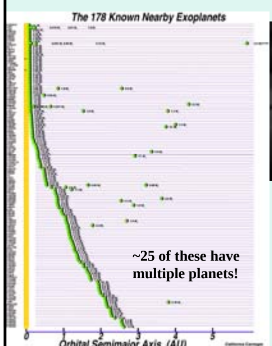
- "wobble" of 57 m/s
-4 day period





→ **Doppler profiles can tell you about mass of planet and how far it orbits from star**
→ **Occasionally, the Doppler profiles can reveal multiple planets around a star!**

Doppler method has been very successful:
identification of ~500+ planets around other stars!



~25 of these have multiple planets!

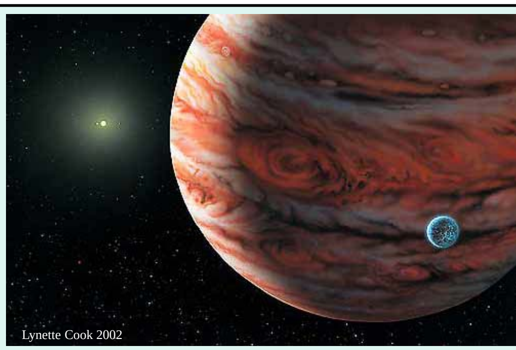


The Team
Dr. Geoff Marcy
Dr. Debra Fischer
Dr. Paul Butler
Dr. Chris McCarthy
and others in USA and Australia

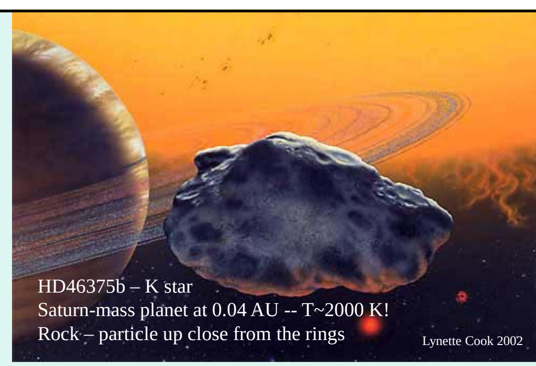
The Doppler Technique

Caveats of this method:

1. Planets of Jupiter mass and bigger are the most easily detectable
2. Planets closer to the star are easier to detect
   - gravity is stronger, "wobble" bigger
3. Planets less massive than Jupiter (like Earth, Mars) are very difficult to detect (undetectable)
   -mass, gravity weaker; "wobble" miniscule
4. If the plane of planet orbit is not aligned with our sight-line, then "wobble" not detected
   - Doppler effect for toward/away from motion
   - not side to side



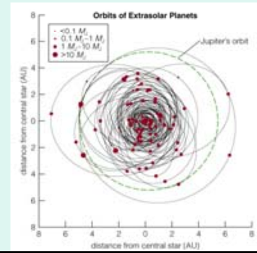
55 Cancri – triple planet system!
3x Jupiter mass at 5.5 AU from star
One of the most similar to our SS

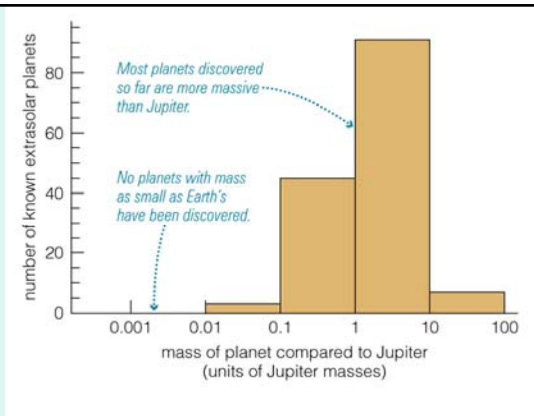


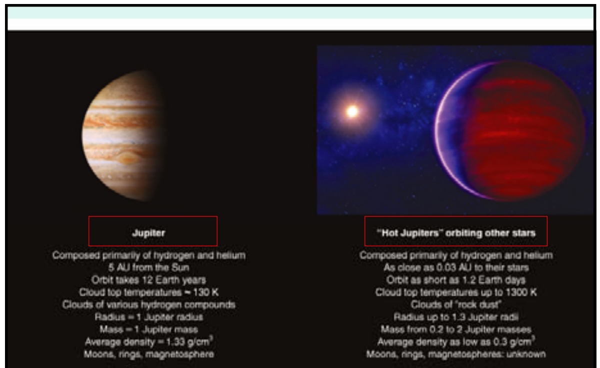
Upsilon Andromeda b
4 day orbital period
0.7 Jupiter masses – tidally locked to star

Most of the detected planets are ***not*** like our Solar system

- Most systems have planets within 0.2 AU of star and large mass
  These planets will have orbital periods of days, weeks
- Theoretical work shows that it is impossible for a gas giant like Jupiter to form so close to star
  Will have to have formed further out, drifted inwards

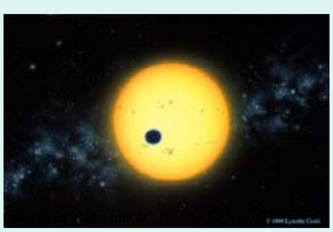




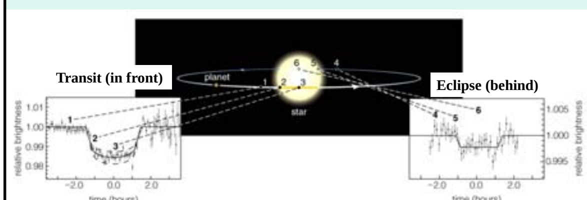


II. Planet Transits & Eclipses (Indirect)

planet crossing in front of star may cause brightness change
repeated observations b/c stars can vary their brightness
- can get direct measure of SIZE



- depends on parameters of how planet would be orbiting
- backyard astronomers are monitoring for such fluctuations

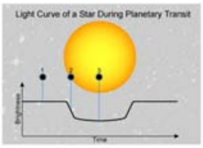


Visual light signal decreases when planet moves in front of star (b/c planet is blocking some of the visual light from star)

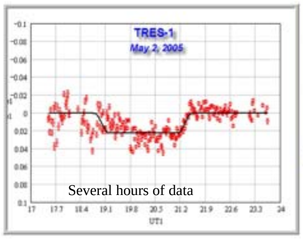
Infrared light signal decreases when planet moves behind star (b/c planet radiates mostly in IR)

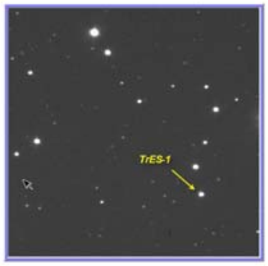
→Can figure out size by how much light decreases and for how long

→Can figure out thermal emission of planet by studying drop in IR light



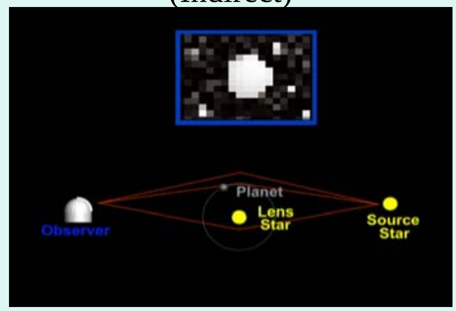
Data taken with the Iowa Robotic Telescope



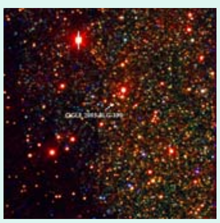


Star a little cooler than our Sun – K star

III. Extrasolar Microlensing (Indirect)



III. Extrasolar Microlensing



Distant star appears to change in brightness as star system with planet in the foreground bends the light around as it passes by

2005 and 2007 – first microlensed star-planet systems event were detected: 5-7 Earth masses

Indirect Methods of Extrasolar Planet Detection:

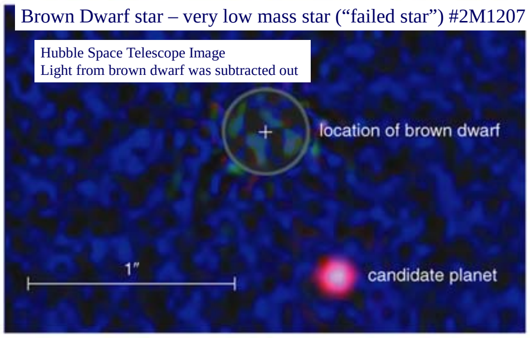
1. *Doppler Technique*
   - Looking for slight changes “wobbles” in star’s position
2. *Planet Transit*
   - Looking for slight changes in brightness of star due to planet crossing in front of star
3. *Microlensing*

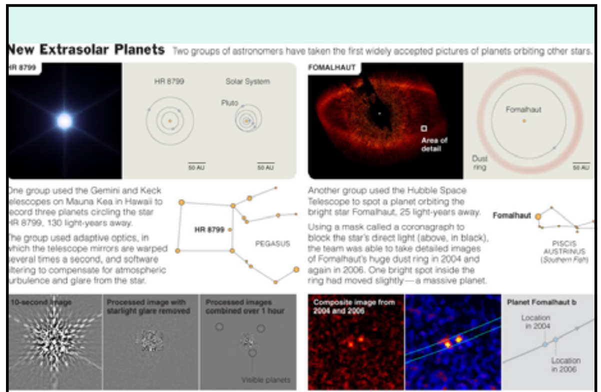
→ Learn orbital properties, size, mass

Direct Method of Extrasolar Planet Detection:

1. *Directly detecting the planet!*
   - emission from the star drowns out signal from planet
   - some hope if you look in IR, where planets are strong

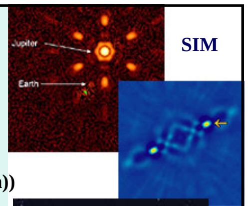
Brown Dwarf star – very low mass star (“failed star”) #2M1207





NASA is planning several new spacecraft missions to search for Earth-sized (!) planets:

-Space Interferometry Mission (SIM)
-Terrestrial Planet Finder (TPF-I (interferometry) or TPF-C (coronagraph))



SIM

Kepler Mission : to try to find Earth-like extrasolar planets

- telescope of 0.95 meter diameter
- 430-890 nm (visible)

- will monitor 100,000 solar type stars and measure very small changes in brightness (planet transits)

- ~ 85 days until launch!
- 6 March 2009