Astronomy 122

<u>This Class (Lecture 15):</u>

Exoplanets

<u>Next Class:</u>

Midterm

Midterm on Thursday!

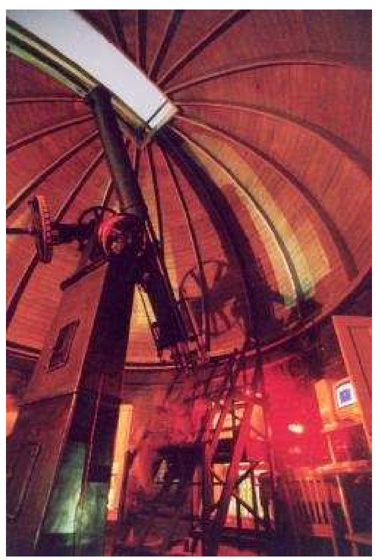
Music: *For Science* – They Might Be Giants

Midterm

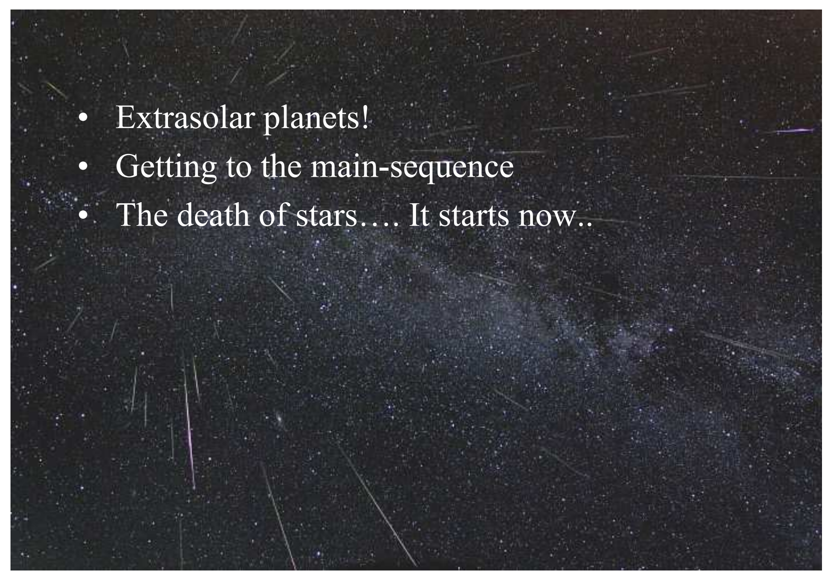
- 50 min exam in this classroom
- Will cover material up to and including star formation
- 40 multiple choice questions.
- Exam will have 105 points graded out of 100 (i.e. extra credit)
- You may bring normal-sized sheet with notes on each side.
- Study guide was posted on class webpage.
- Discussion will focus on your questions and perhaps a Jeopardy game.
- May want to bring a calculator, but don't really NEED one.

Night Observing

- Make-up dates added to list!
  - March 4-5th: Tuesday-Wednesday
- Bad semester!
- Observing sessions are from 7:30pm-9:30pm (allow 45 mins to complete)

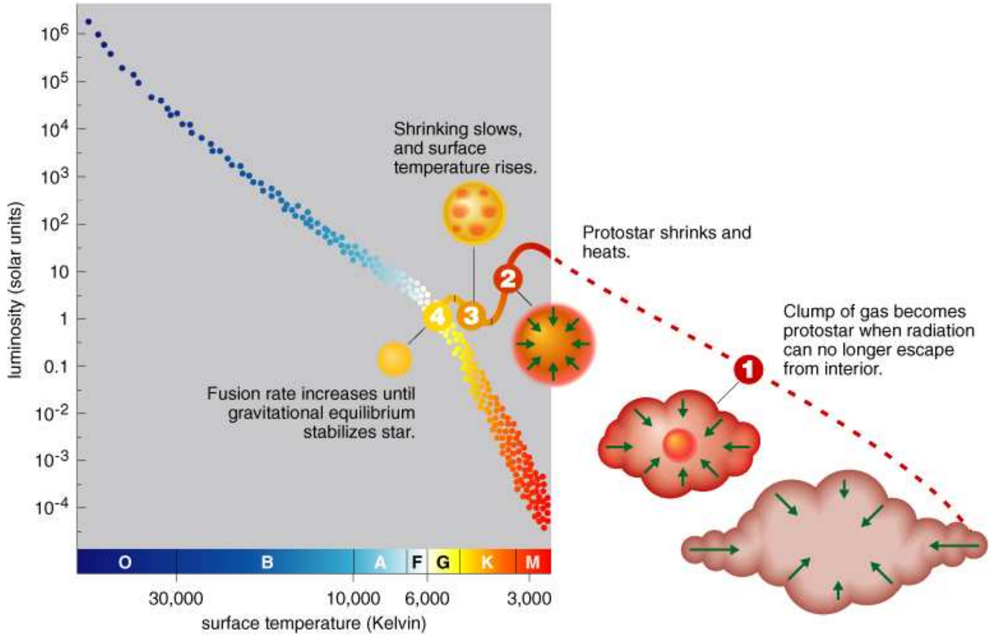


Outline



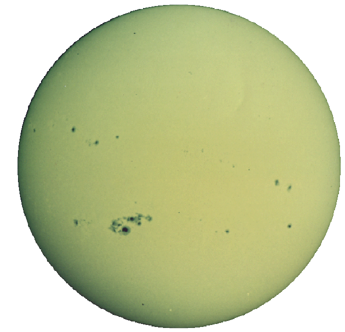
- Extrasolar planets!
- Getting to the main-sequence
- The death of stars…. It starts now..

A Star is Born!



Becoming a Star

- When the temperature in the pre-main-sequence star's core reaches about 10 million K, hydrogen fusion starts
- Gravitational collapse stops, pressure from fusion in the core halts contraction
- Now a main sequence star!



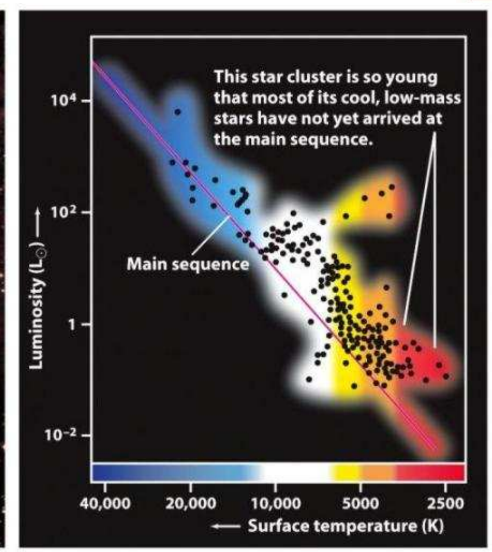
Question

A star was born and is now on the main sequence. Which of the following is **incorrect**?

a) It is now burning hydrogen into helium
b) It contracted from a molecular cloud
c) It is now in hydrostatic equilibrium
d) It will spend most of its life on the main sequence
e) It will live for as long as nuclear fission can occur in the core.

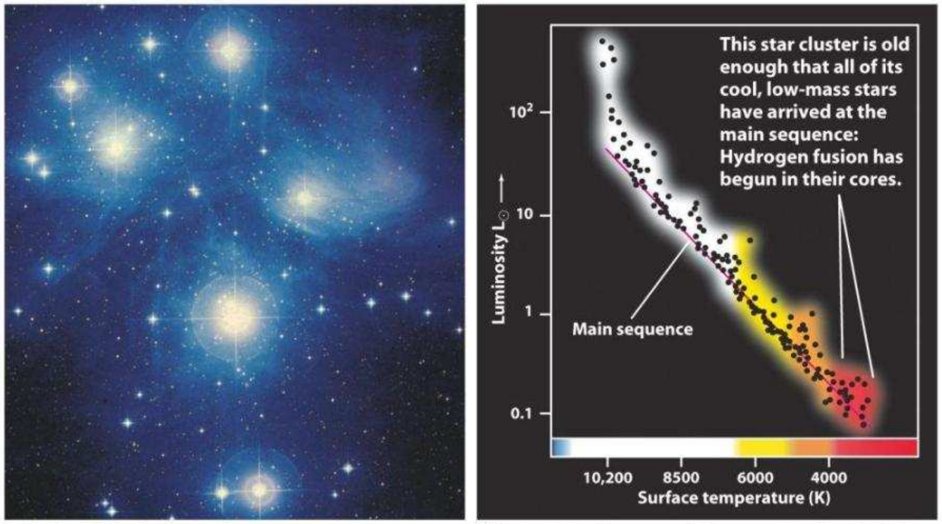
Very Young Cluster

(a) The star cluster NGC 2264



(b) An H-R diagram of the stars in NGC 2264

Older Cluster



(a) The Pleiades star cluster (b) An H-R diagram of the stars in the Pleiades

What Are We Looking For?

General Predictions of Solar Nebula Theory

- ☺ Are interstellar dust clouds common? ***Yes!***
- ☺ Do young stars have disks? ***Yes!***
- ? Are the smaller planets near the star?
- ? Are massive planets farther away?

Test Of Exoplanets

Planets around other stars

= extrasolar planets = "***exoplanets***"

Would our solar system nebula formation theory account for other solar systems around other stars?

Hard to find!

Reflected light from the Earth is 1 billion times fainter than the Sun!!!!!

Finding Planets

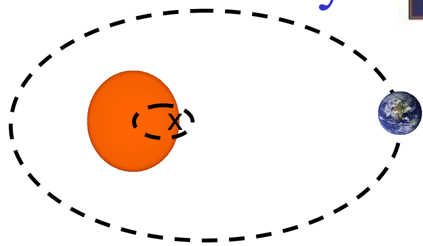
1. **Radial Velocity: Stars will wobble.**
2. Astrometry: See the stars move.
3. Transit Method: Occultation.
4. Optical Detection: Direct.

Arguable 2 extrasolar planets have been detected directly in the IR. Remember that planets in our Solar System seem bright because they reflect light from the Sun in the visible.

Star Wobble: Radial Velocity

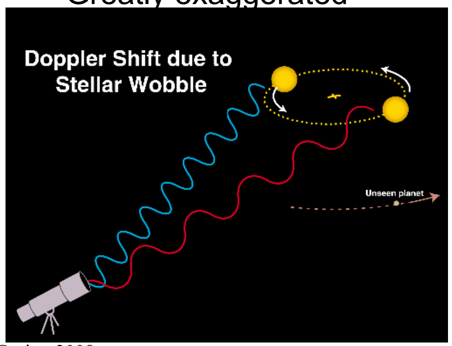
Newton's 3rd Law:

- *Both* planet *and star* move
- Both orbits fixed around the "center of gravity"



Greatly exaggerated

- Star's period? Place your bets…
  - Same as planet
- Star movement too small to see
  - Moves in small, tight circle
  - But "wobble" in star speed detected!

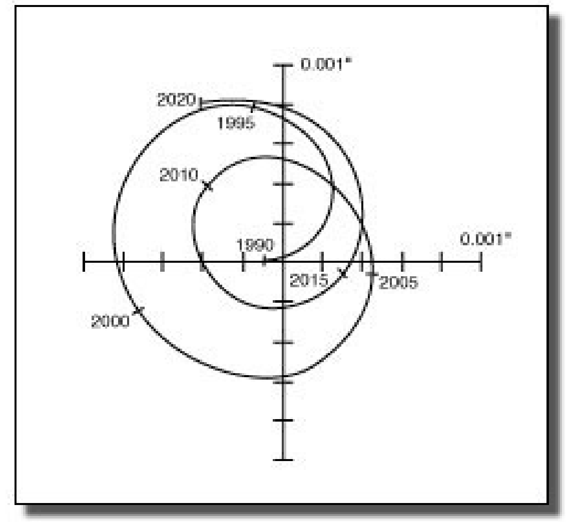


http://www.howstuffworks.com/planet-hunting2.htm

The Sun's Wobble

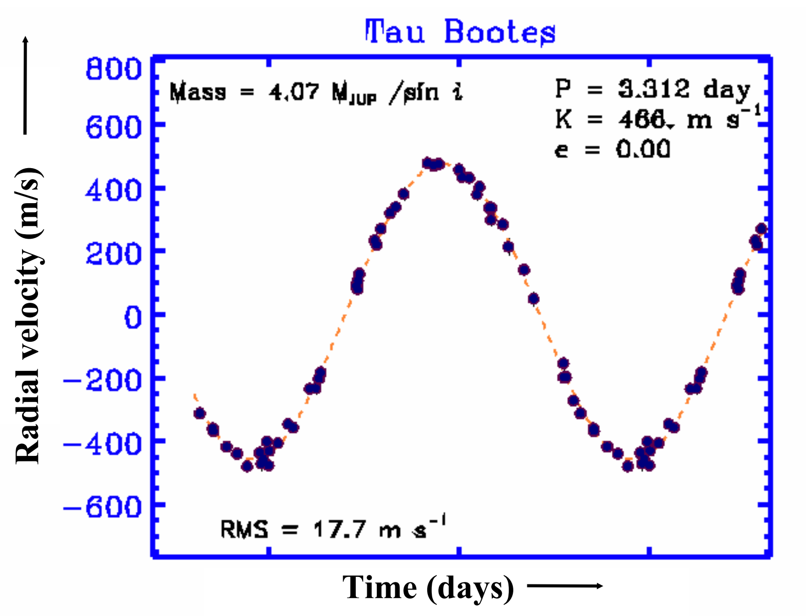
Astrometric displacement of the Sun due to Jupiter (and other planets) as at it would be observed from 10 parsecs, or about 33 light-years.

If we could observe this, we could derive the planetary systems– also called astrometry.



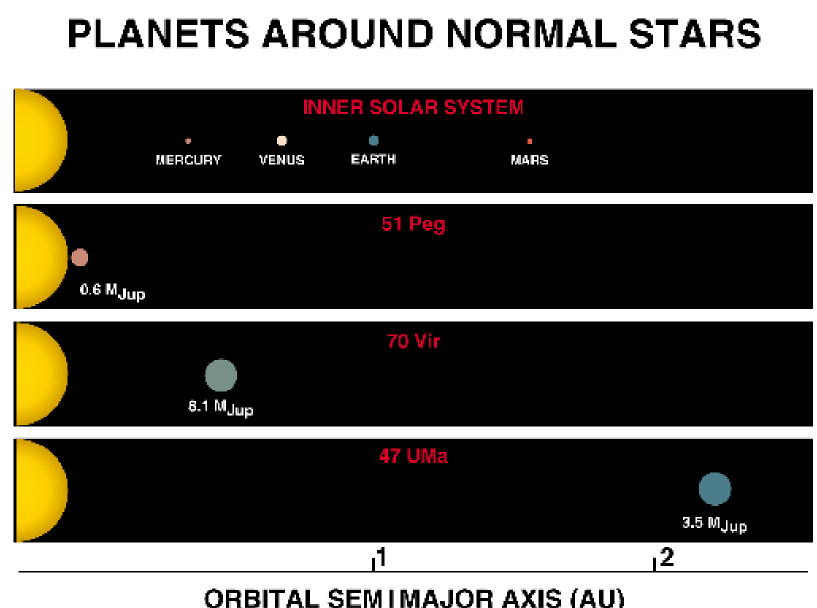
http://planetquest.jpl.nasa.gov/Keck/astro_tech.html

Radial Velocity Shifts: Planets around other Stars?

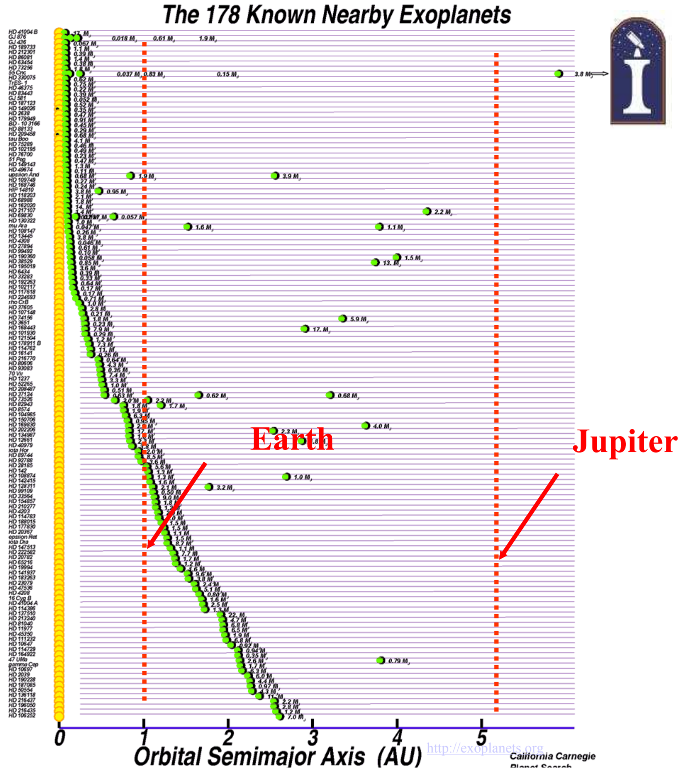


Early Discovery-- 1996

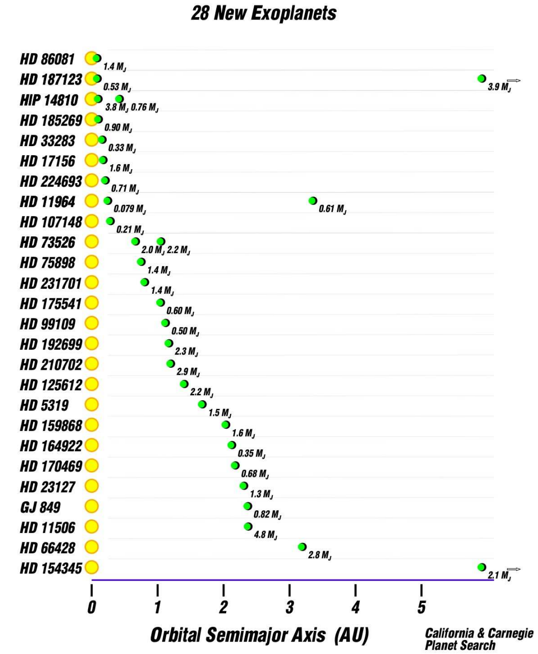
Hear all about it.



As of today, there are 228 planets known around nearby stars.



Recent Ones



Question

Most exoplanetary systems found so far are

a) Just like our own solar system.

b) Very different than our solar system.

c) It is hard to determine since we have only found a handful so far.

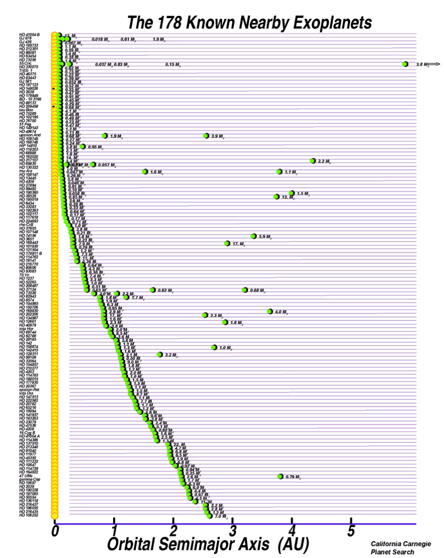
d) None of the above.

Exoplanets: Results to Date

Over 228 planets detected so far

- More than 25 times the number in our Solar System!

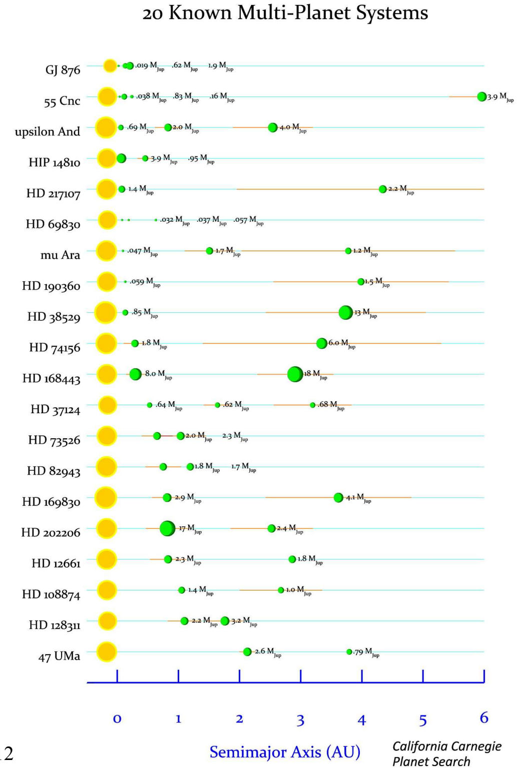
- By measuring the wobble variation:
  - With time, gives the planet distance: Kepler's 3rd law
  - The orbital speed of the star gives masses: the bigger the wobble amplitude, the heavier the planet



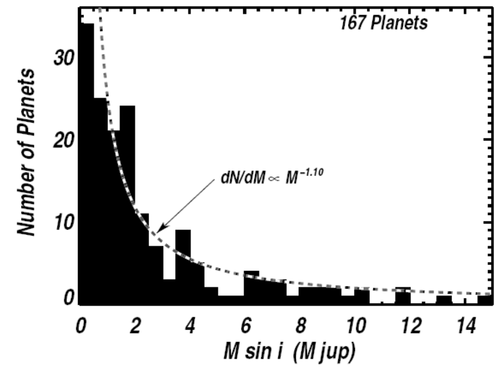
Exoplanets: Results to Date

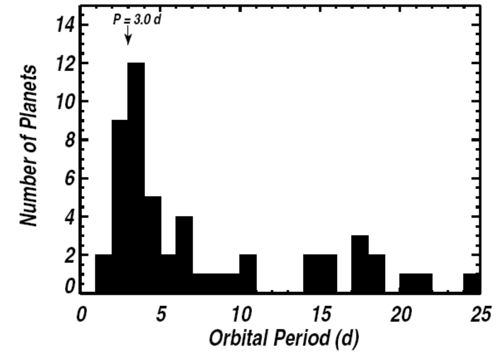
At least 20 multi-planet systems!

Note: Jupiter is 318 time the mass of Earth or
$M_E = 0.003\ M_J$
$M_J = 0.001\ M_{Sun}$
$M_{red\ dwarf} = 80\ M_J$
$M_{brown\ dwarf} = 18\ M_J$
$Period_J = 12\ years$



Masses/Periods of Extrasolar Planets





http://exoplanets.org

List

http://exoplanets.org/

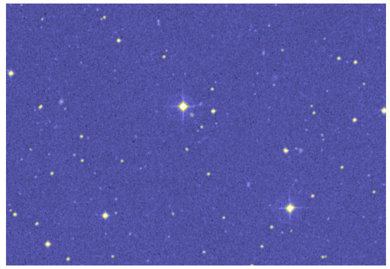
Other Planets, Other Stars

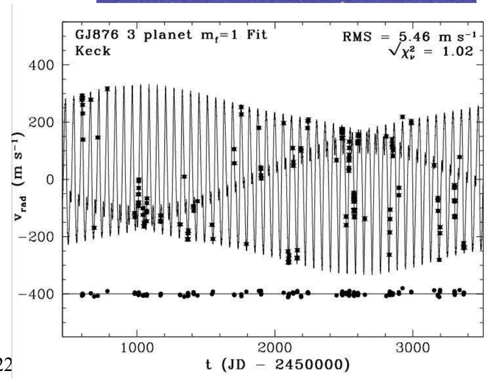
47 Ursae Majoris System– 51 light years away (near the Big Dipper). 13 years of data has shown 2 planets– 1 Jupiter like and 1 Saturn like.

Wow! Among the most similar to our own system

The Lowest Mass to Date

GJ 876 – a Red Dwarf that is 15 light years away (in Aquarius). Has three planets! 2 Jupiter-like and one that is 6-8 Earth masses! But all are inside 1 AU!





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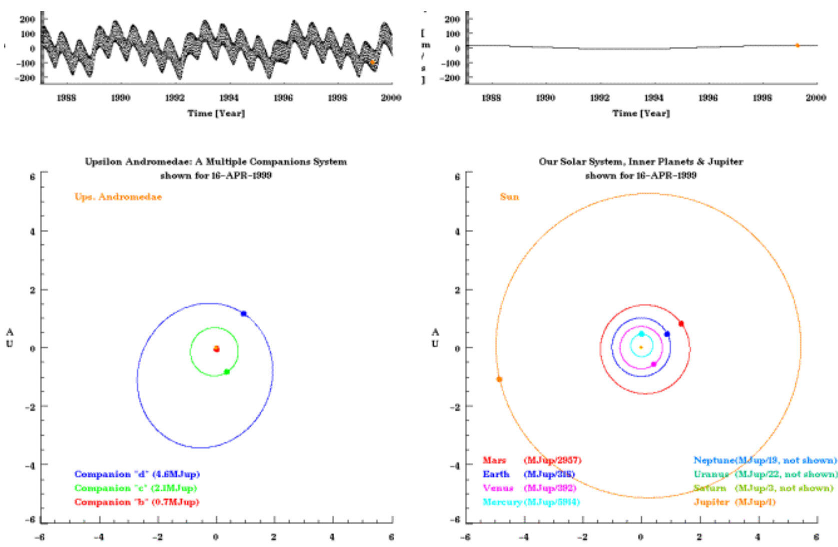
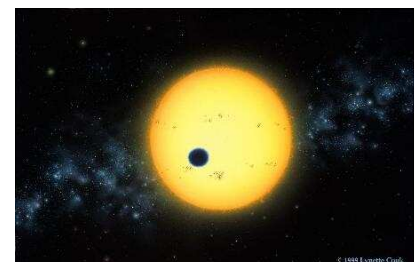
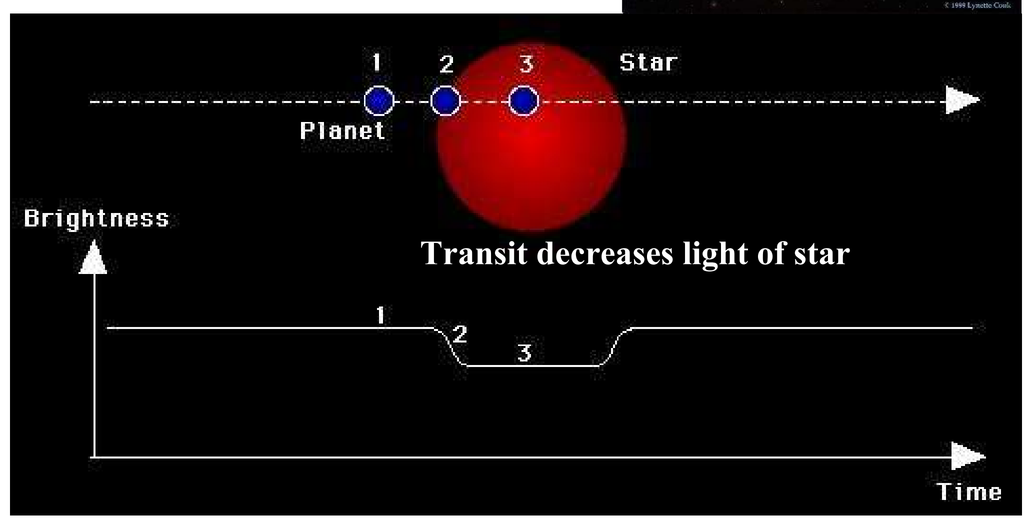
Detecting the Solar System



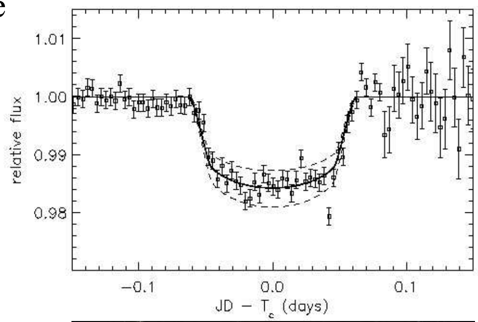
Planet Transits

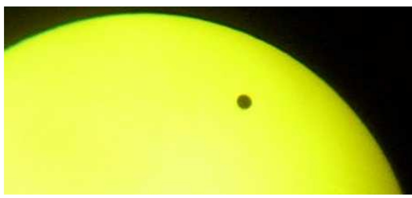


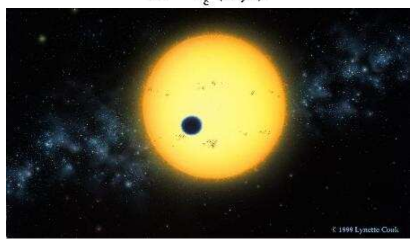


Transits

- The planet passes in front of the star– like Venus 2004.
- Can find planet radius
- Best chance of finding Earth-like planets
- Requires the extrasolar planet's orbital plane to be pointed at Earth
- http://www.howstuffworks.com/planet-hunting2.htm

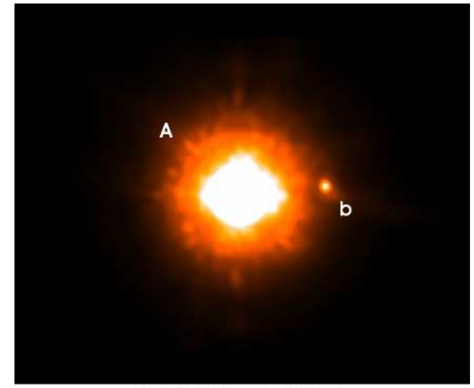






Direct Detection?

- The race is on to directly image a planet in the IR, it is still difficult to determine the stellar mass.
- Best example so far is an adaptive optic image from April, so planet or brown dwarf?

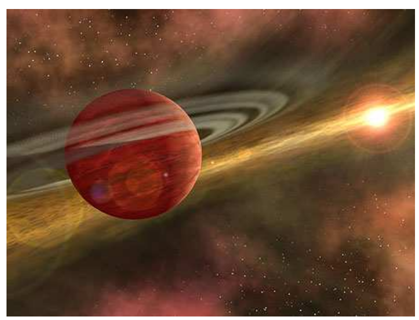


The Sub-Stellar Companion to GQ Lupi (NACO/VLT)

Results to Date

No surprise

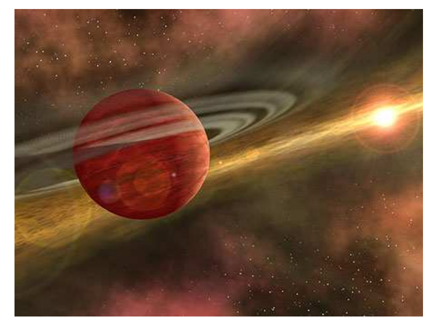
- ✓ New planets are massive
- ✓ Why? Big planets make a big wobble
- ✓ If not massive, we could not have found them
- ✓ About 3-5% of all stars have some type of planet.



Results to Date

Big surprises

- ? Most periods of only *a few days!*
- ? Most planets are very near their stars!
- ? τ Bootes' planet is 3.6 times Jupiter's mass, but it's orbit smaller than Mercury's!
- ? If a Jupiter-like planet formed close in, perhaps that prevents terrestrial planets from forming.



What Are We Looking For?
General Predictions of Solar Nebula Theory

☺ Are interstellar dust clouds common? ***Yes!***

☺ Do young stars have disks? ***Yes!***

? Are the smaller planets near the star?

Not the ones found so far! Haven't found smaller planets yet!

? Are massive planets farther away?

Not most of the ones found so far!

Important Caveat

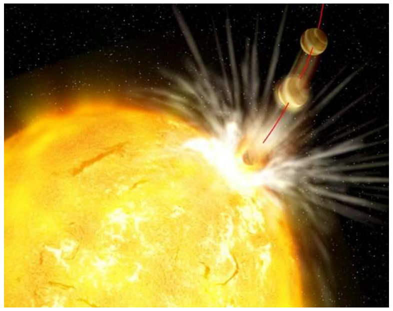
- Our current observations of extrasolar planets do **not** exclude planetary systems like our solar system
- Current instruments are most sensitive to large planets close to their stars
  - Big planet - big wobble
  - Close planet - fast wobble
- We only have a little over 10 years of data – 1 orbit's worth for Jupiter
- To find solar-type systems, we need more sensitive equipment

Exoplanets: Implications

Solar Nebula **Theory**:
- Giant planets born far from star

Exoplanet Data:
- Giant planets found very close

Theory is *incomplete/wrong*!



New questions:
? Who is normal: Them or us?
? Are giant planets born close in?
? Are some giant planets born far out, move in? "planet swallowing"!?!

Anyway: Planets are common!
✓ Good news in search for life elsewhere...maybe

Exo-Question

What do the exoplanets suggest about our idea of how planets form?

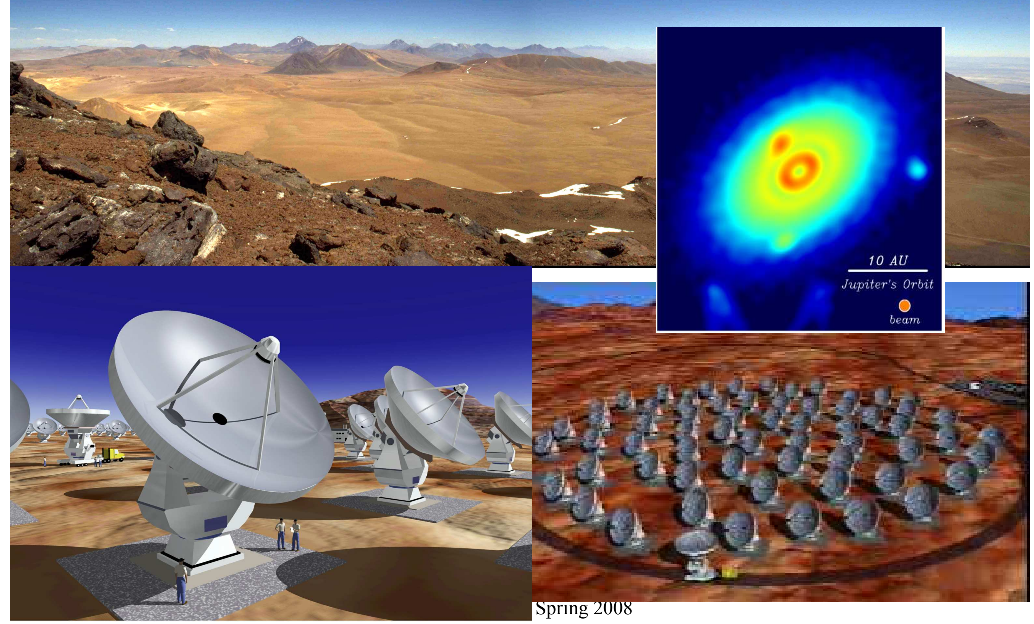
a) To date, the planets we have found, although in the wrong orbits, are similar to our Solar System.
b) Something is wrong with our picture of star formation.
c) Something may be wrong with our picture, we need more data.
d) Sometimes some planetary systems are formed that are different, but we don't yet know who is weird– us or them.
e) None of the above.

Future Projects

- Atacama Large Millimeter Array (ALMA): 2010
  - mm interferometer:
    direct detection of young gas giants
- Kepler: Feb 2009
  - Planet Transits
- Next Generation Space Telescope
  James Webb Space Telescope (JWST): 2013
  - Direct imaging of forming gas giants?
- Space Interferometry Mission (SIM): 2016?
  - Astrometry
- Terrestrial Planet Finder (TPF): Mission 1: deferred
  - Coronagraph
  - IR interferometer
- Terrestrial Planet Finder (TPF): Mission 2: deferred
  - A large-baseline infrared interferometer. Imaging extrasolar Earths!!!!

ALMA -- 2010

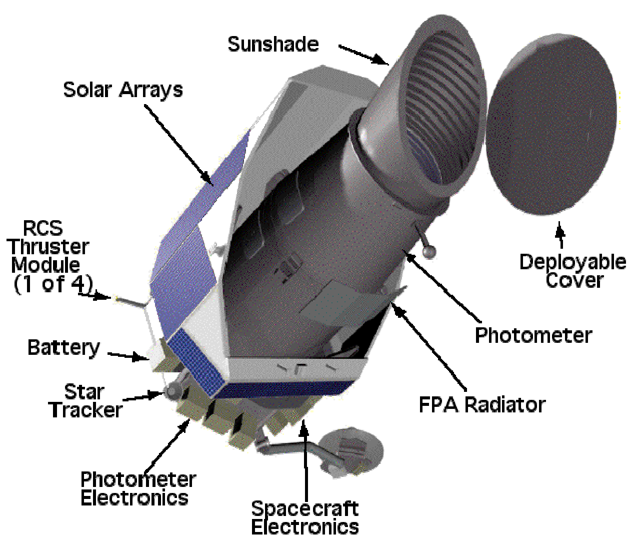
~~64~~ 50? x 12 m @ 16,400 ft Chajnantor Chile



Kepler

1.4 meter mirror, measuring accurate brightness of stars.

A terrestrial-sized Earth-like planet would dim the star's light by 1/10,000th – comparable to watching a gnat fly across the beam of a searchlight.

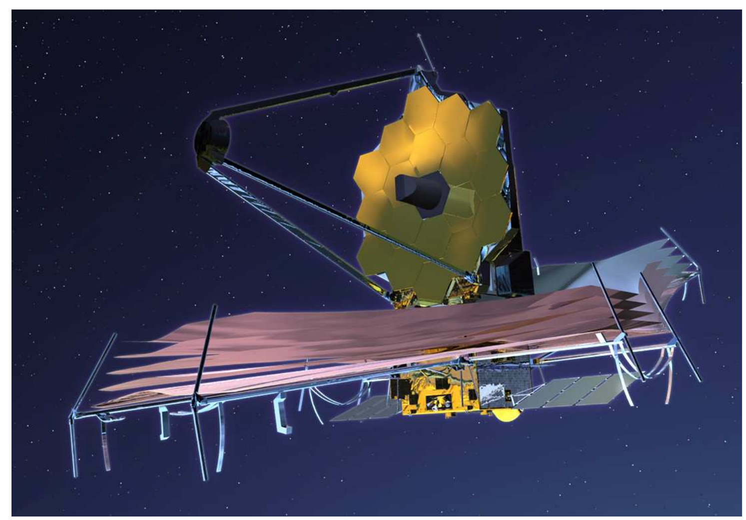


JWST

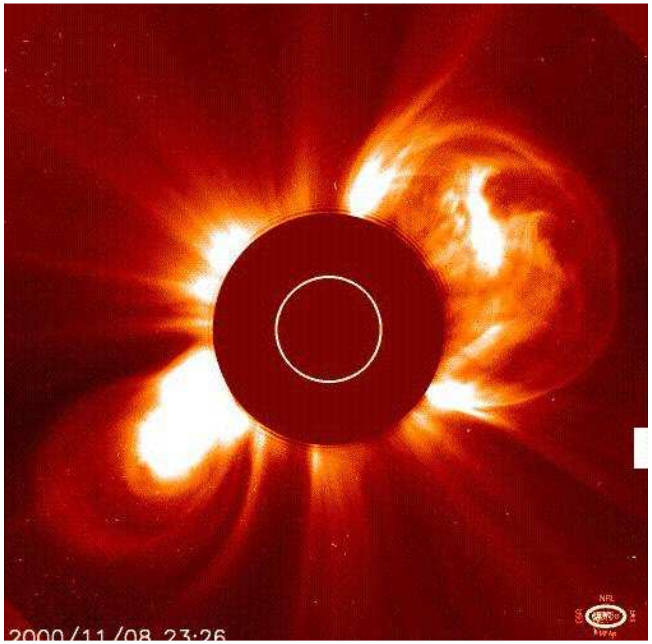
James Webb Space Telescope: Successor to HST

6.5 meter observatory

Working in the infrared with a coronagraph.



The Coronagraph Advantage



Space Interferometry Mission

Accurately measure location of stars to micro-arcseconds.

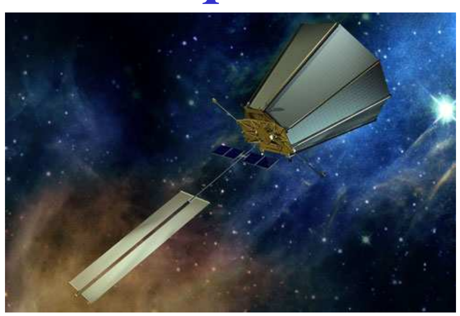
Need to know relative location of components to 50 pm.

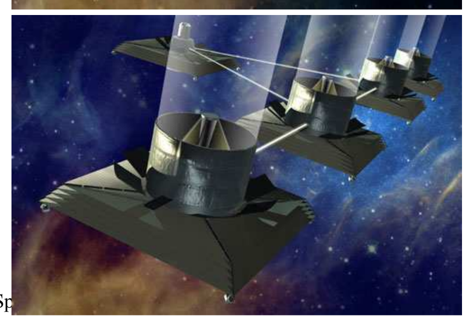
Funding in question.

http://planetquest.jpl.nasa.gov/SIM/sim_index.html

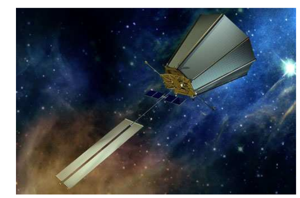
Terrestrial Planet Finder Mission: Two Telescopes

- Survey nearby stars looking for terrestrial-size planets in the "habitable zone"
- Follow up brightest candidates looking for atmospheric signatures, habitability, or life itself
- Then, the ultimate: image the little blue dots



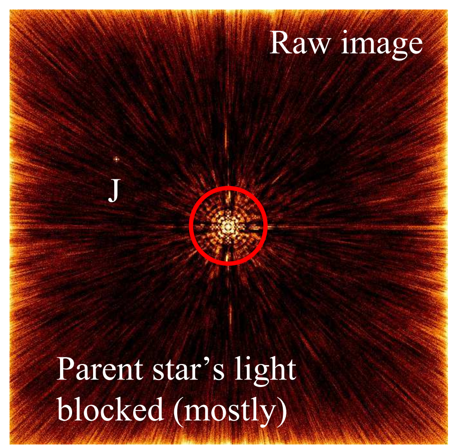


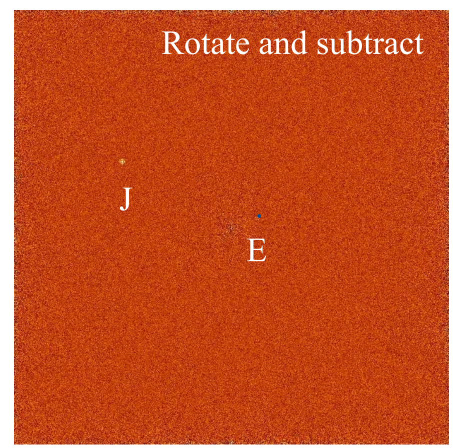
TPF



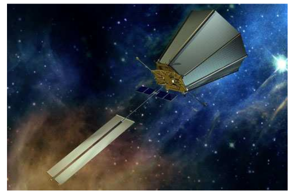
Visual wavelength `coronagraph'

- Find Earth-like planets
- Characterize their atmospheres, surfaces
- Search for bio-signatures of life (O_2, H_2O, etc)





TPF



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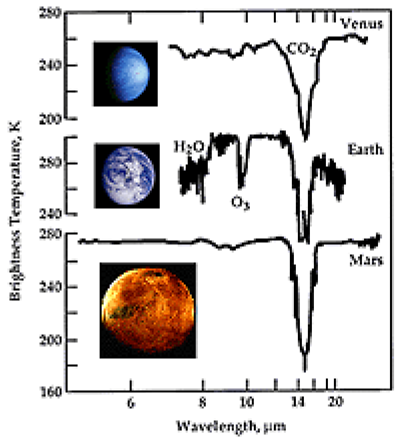
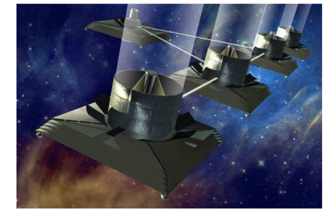


TPF: Step 2

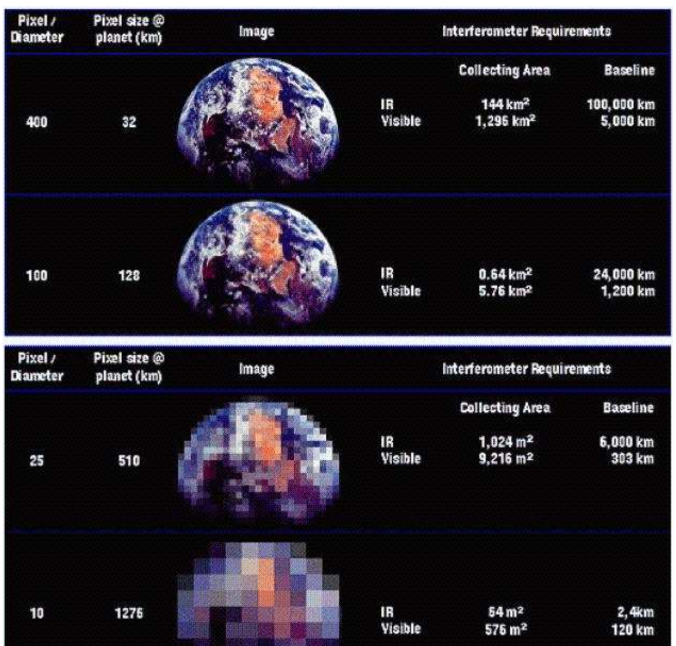


The goal of imaging an Earth-like planet.

5 platforms of 4 eight meter interferometer in space.

spider.ipac.caltech.edu/staff/jarrett/talks/LiU/origins/openhouse30.html

TPI -- Scales



Pixel / Diameter	Pixel size @ planet (km)	Image	Interferometer Requirements	Collecting Area	Baseline
400	32		IR Visible	144 km² 1,296 km²	100,000 km 5,000 km
100	128		IR Visible	0.64 km² 5.76 km²	24,000 km 1,200 km
25	510		IR Visible	1,024 m² 9,216 m²	6,000 km 303 km
10	1276		IR Visible	64 m² 576 m²	2,4km 120 km