Astronomy 210

This Class (Lecture 27):

Birth of the Solar System II

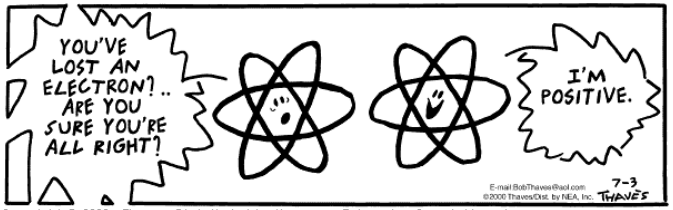
Next Class:

Exam!!!!

2nd Hour Exam on Friday!!!

Review Session on Thursday 12-1:30 in room 236

Solar Observing starts on Monday



Midterm #2

- 1 hour exam in this classroom.
- It will cover material including Blackbody up to, but not including, extrasolar planets
- Will consist of a few short-answers and a few problems + extra credit.
- That means 105 possible points graded out of 100.
- You can bring a normal-sized sheet of paper with notes on both sides.

Outline

- Daddy, where did the Solar System come from?
  - A rotating cloud of collapse dust and gas
- Extrasolar planets
  - Good news?

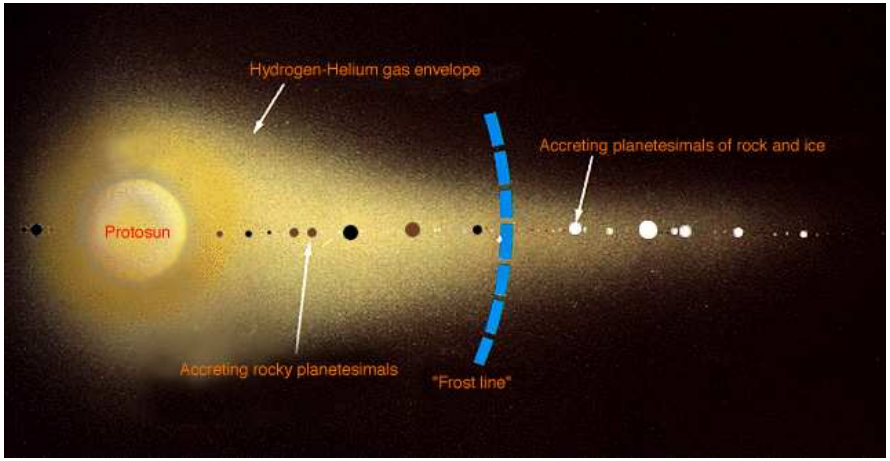
Formation of the Solar System 4.6 billion years ago

Planet Formation in the Disk

Heavy elements clump and then

1. *Dust grains* collide, stick, and form planetesimals– about 10^{12} of them, sort of like asteroids! All orbit in the same direction and in the same plane.
2. Gravity Effects: Big planetesimals attract the smaller planetesimals. So, fewer and fewer of large objects (100's). Collisions build-up inner planets and outer planet cores.
3. Collisions can also account for odd motions of Venus (backwards), Uranus (rotates on its side), and Pluto (high inclination of orbit). Proof of period of high collision evident on moon

Why are the Planets so Different?



Temperature is the key factor!

Why are the Planets so Different?

- Temperature is the key factor
- Inner Solar System: Hot
  - Light gasses (H, He) and "ices" vaporized
  - Blown out of the inner solar system by the solar wind
  - Only heavy elements (iron & rock) left
- Outer Solar System: Cold
  - Too cold to evaporate ices to space
  - Rock & ice "seeds" grew large enough to pull gasses (H, He) onto themselves

Heavy Bombardment

- There were billions of planetesimals in the early solar system
- Many collided with the young planets
  - Look at the Moon & Mercury!
  - Period of **heavy bombardment**
  - Lasted for about the first 800 million years of the Solar System
- Others were ejected from the solar system…

Earth's Water Source?

- There are two ideas on where Earth's water came from:
  - Released from within by volcanic vents
  - Brought to Earth by comets during the heavy bombardment

Fates of the Planetesimals

- Between Mars and Jupiter
  - Remain as the asteroids
- Near Jupiter & Saturn
  - Ejected from the solar system
- Near Uranus & Neptune
  - Ejected to the Oort Cloud
- Beyond Neptune
  - Remain in the Kuiper Belt

Results

- Most disk matter goes into the planets
- Asteroids and comets are left-over planetesimals
  - "Fossils" of solar system birth!
- The Solar System continues to evolve, but slower
  - Outer planets still contracting
  - Earth and Venus are still volcanically active
  - Impacts from left-over planetesimals continue

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?

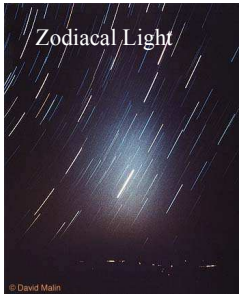
Test of Exoplanets

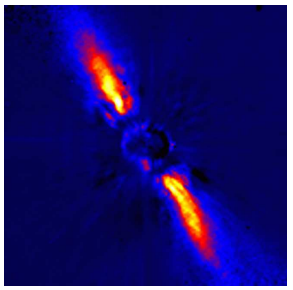
Planets around other stars
= extrasolar planets = **"*exoplanets*"**

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

Do Fossil Disks Exist around other Stars?

- We see old disks around other stars (e.g. Vega and Beta Pictoris) as well as our own.
- Many (more than half!) of newborn stars surrounded by a disk of material!
- Disks are thick and dusty
  - Enough material to make planets
  - Agrees with the Solar Nebula theory!





http://www.eso.org/outreach/press-rel/pr-1997/phot-16-97.html
http://antwrp.gsfc.nasa.gov/apod/ap970826.html

Test Of Exoplanets

Planets around other stars
= extrasolar planets = **"*exoplanets*"**

Hard to find!

Cannot just look at star
- Planet lost in glare

The Earth is 1 billion times fainter than the Sun!!!!!

Can use effect of gravity.
- Star pulls on planet,
- Newton 3rd Law: But planet pulls on star with equal & opposite force
- Planet lighter, wobbles a lot (called orbits)
- But star must wobble too!

Finding Planets

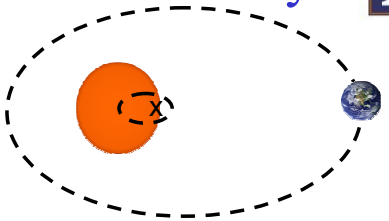
1. Radial Velocity: Stars will wobble.
2. Astrometry: See the stars move.
3. Transit Method: Occultation.
4. Optical Detection: Direct.

To date no extrasolar planet has been detected directly (but wait for new observations). Remember that planets in our Solar System are bright because they reflect light from the Sun.

Star Wobble: Radial Velocity

Newton's 3rd Law:

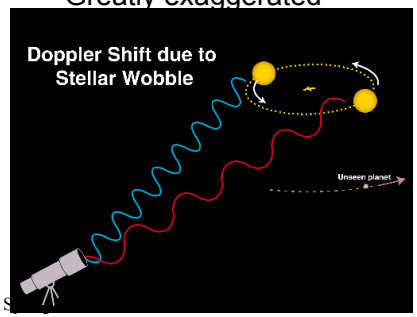
- *Both* planet *and star* move
- Both orbits fixed around the "center of gravity"



- Star's period? Place your bets…
  - Same as planet

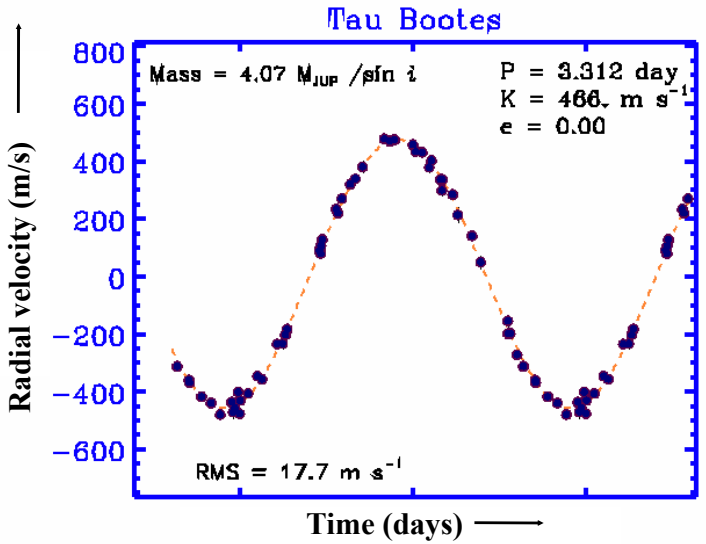
- Star movement too small to see
  - Moves in small, tight circle
  - But "wobble" in star speed detected!

Greatly exaggerated

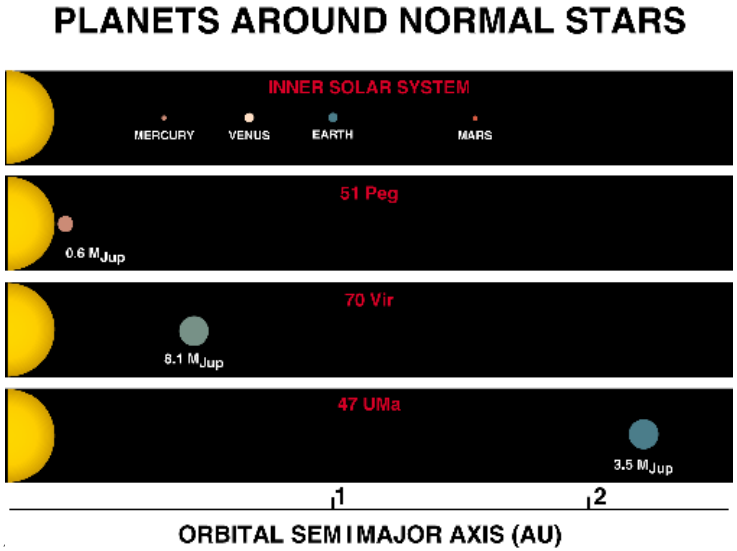


http://www.howstuffworks.com/planet-hunting2.htm

Radial Velocity Shifts: Planets around other Stars?

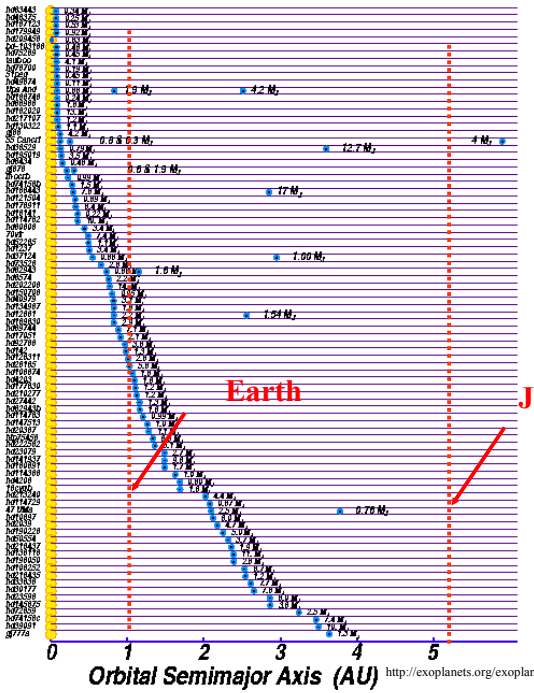


Early Discovery-- 1996



Hear all about it.

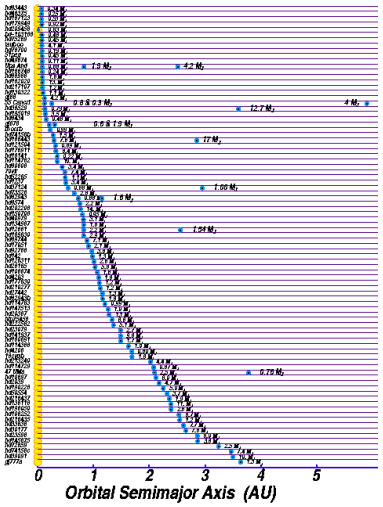
As of Feb, there are at least 136 planets around other nearby Stars.



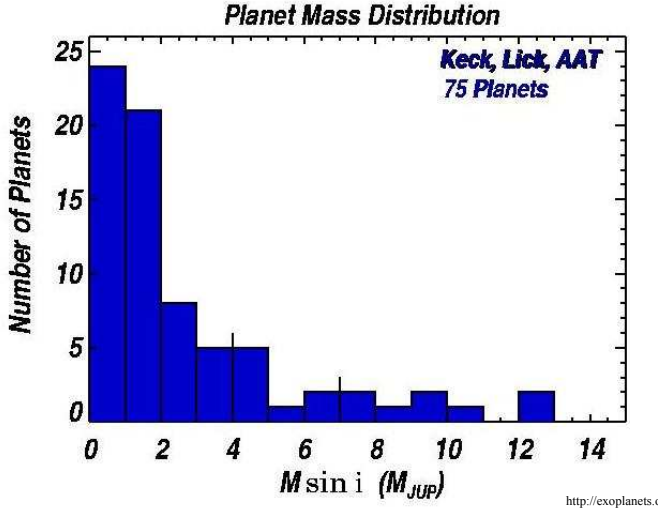
Exoplanets: Results to Date

Over 136 planets detected so far
- More than 10 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
- At least 13 are multi-planet systems



Masses of Extrasolar Planets

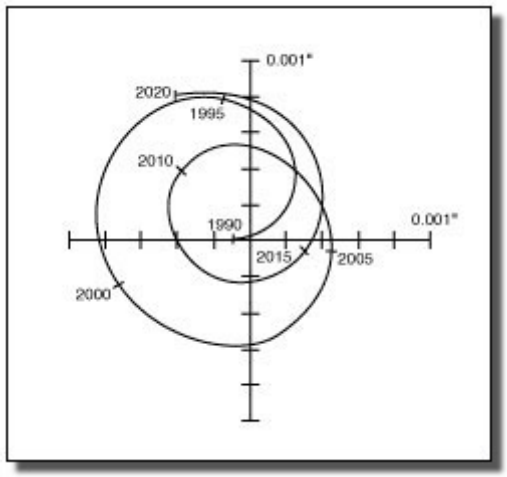


http://exoplanets.org

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.

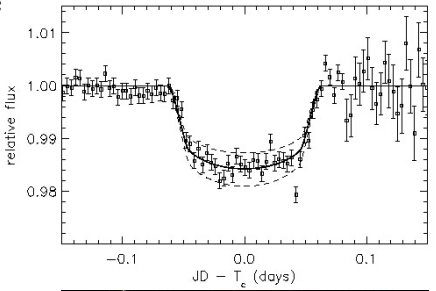
If we could observe this, we could derive the planetary systems– also called astrometry.

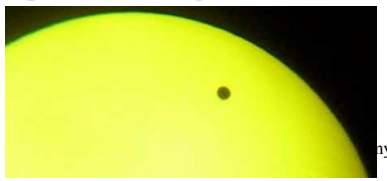


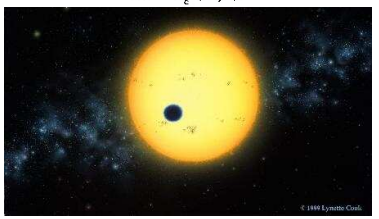
http://planetquest.jpl.nasa.gov/Keck/astro_tech.html

Transits

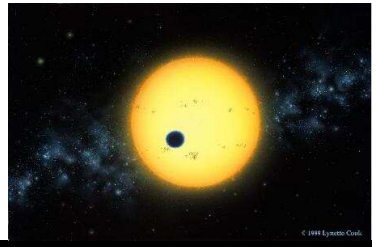
- The planet passes in front of the star– like Venus last year.
- Can find planet radius
- Best chance of finding Earth-like planets
- Requires the extrasolar planet's orbital plane to be pointed at Earth
- http://www.howstuffworks.com/planet-hunting2.htm

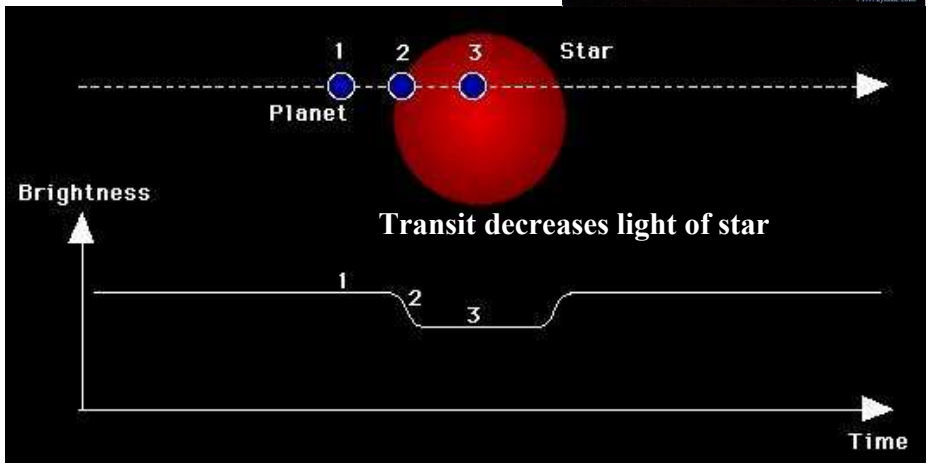






Planet Transits





Other Planets, Other Stars

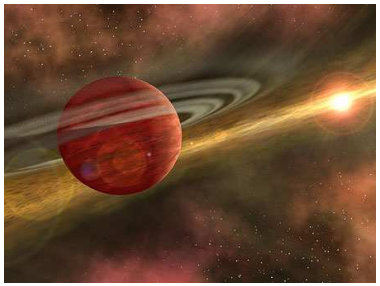
47 Ursae Majoris System– 51 light years away (near the Big Dipper). 13 years of data has shown 2 planets– 1 Jupiter like and 1 Saturn like.

Wow! Among the most similar to our own system

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



Big surprises

- ? Some 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?

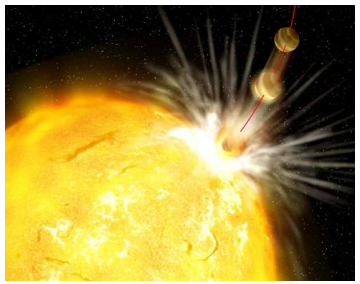
General Predictions of Solar Nebula Theory

- ☺ 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!

Exoplanets: Implications



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

Exoplanet Data:
- Giant planets found very close

Theory is *incomplete/wrong*!

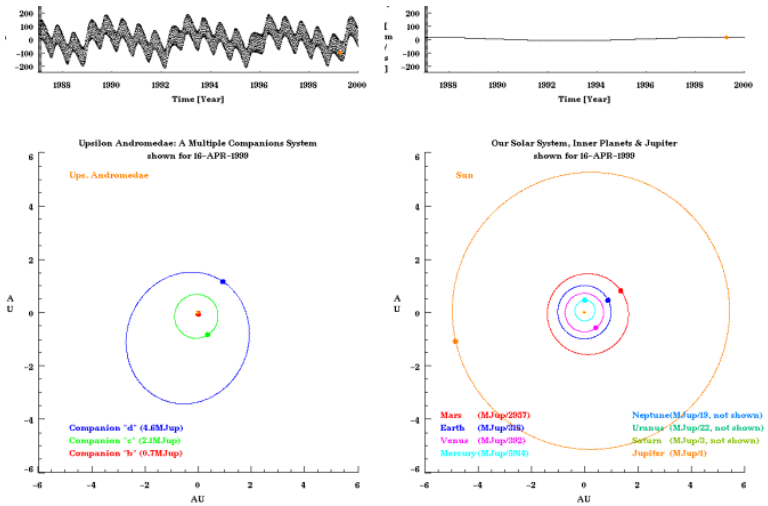
New questions:
? Who is normal: Them or us?
? Are giant planets born close in?
? Are some giant planets born far out, move in?
"planet swallowing"!?!

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

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

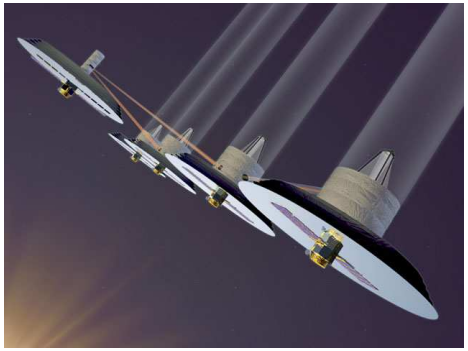
Detecting the Solar System



Future Projects

- Atacama Large Millimeter Array (ALMA): 2010
  - mm interferometer:
    direct detection of young gas giants
- Kepler: 2007
  - Planet Transits
- Next Generation Space Telescope
  James Webb Space Telescope (JWST): 2011
  - Direct imaging of forming gas giants?
- Space Interferometry Mission (SIM): 2009
  - Astrometry
- Terrestrial Planet Finder (TPF): 2012
  - Coronagraph
  - IR interferometer
- Terrestrial Planet Imager (TPI): 2015
  - Either a visible band coronagraph or a large-baseline infrared interferometer. Imaging extrasolar Earths!!!!

Terrestrial Planet Finder Mission

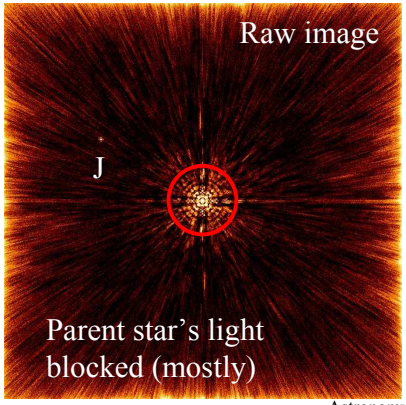


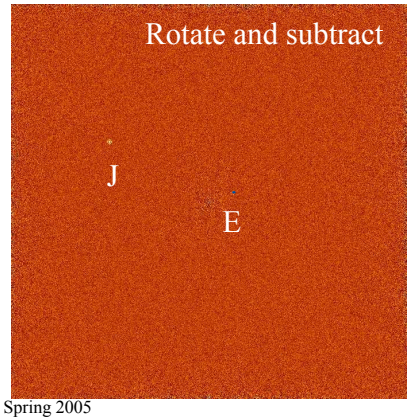
- Survey nearby stars looking for terrestrial-size planets in the "habitable zone"
- Follow up brightest candidates looking for atmospheric signatures, habitability, or life itself
- Launch is anticipated between 2012-2015

TPF

Visual wavelength `coronagraph'

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





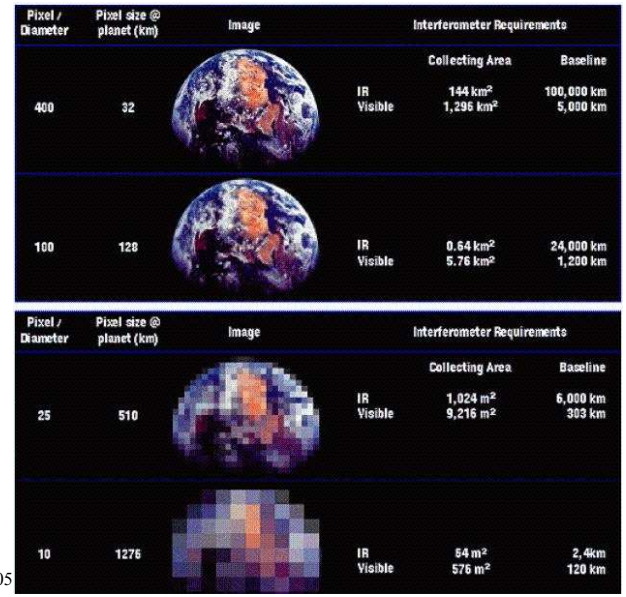
Terrestrial Planet Imager

The goal of imaging an Earth-like planet.

5 platforms of 4 eight meter interferometer in space.

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

TPI -- Scales



List

http://exoplanets.org/planet_table.shtml