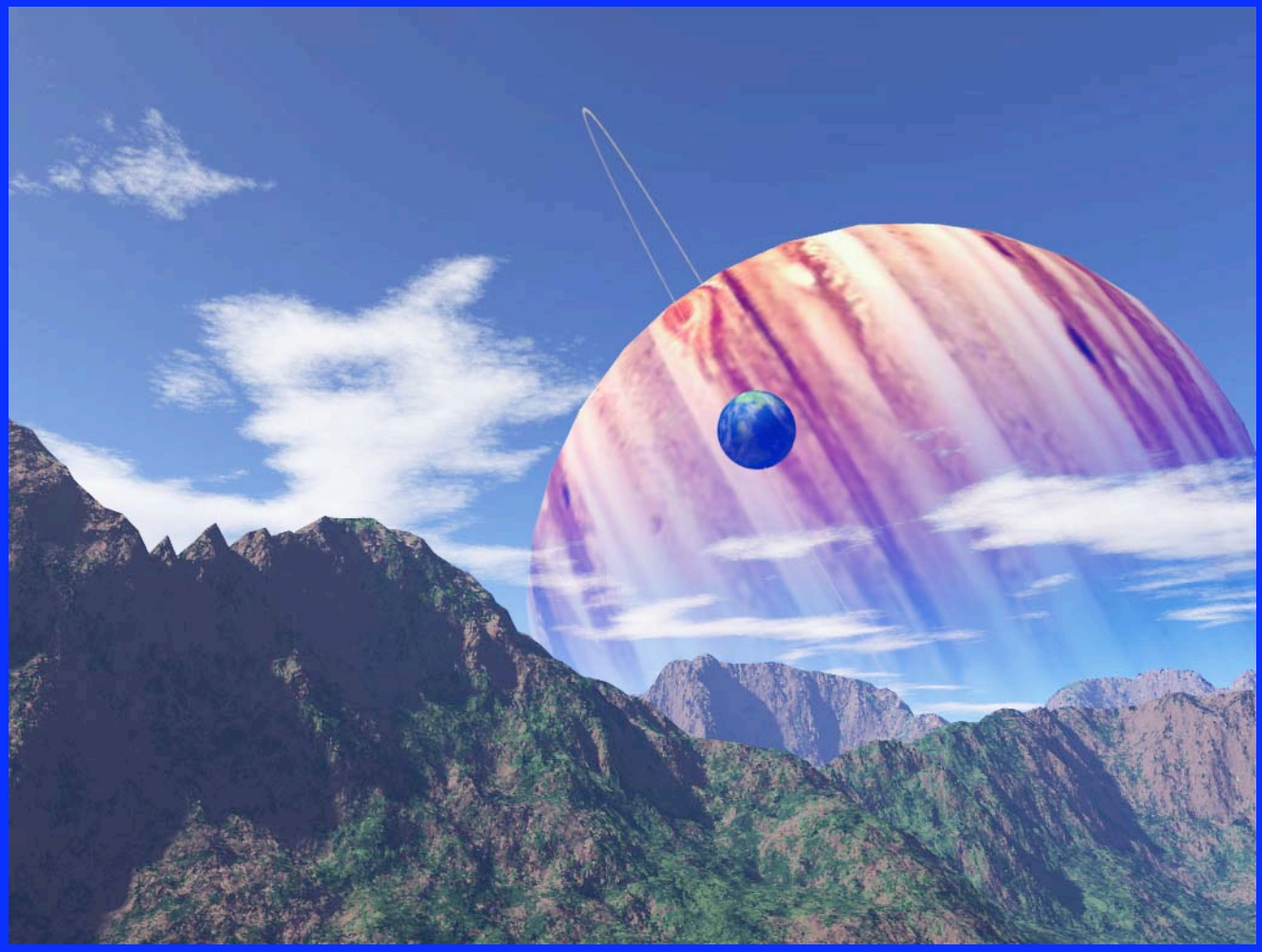
ASTR 380
Extrasolar Planets

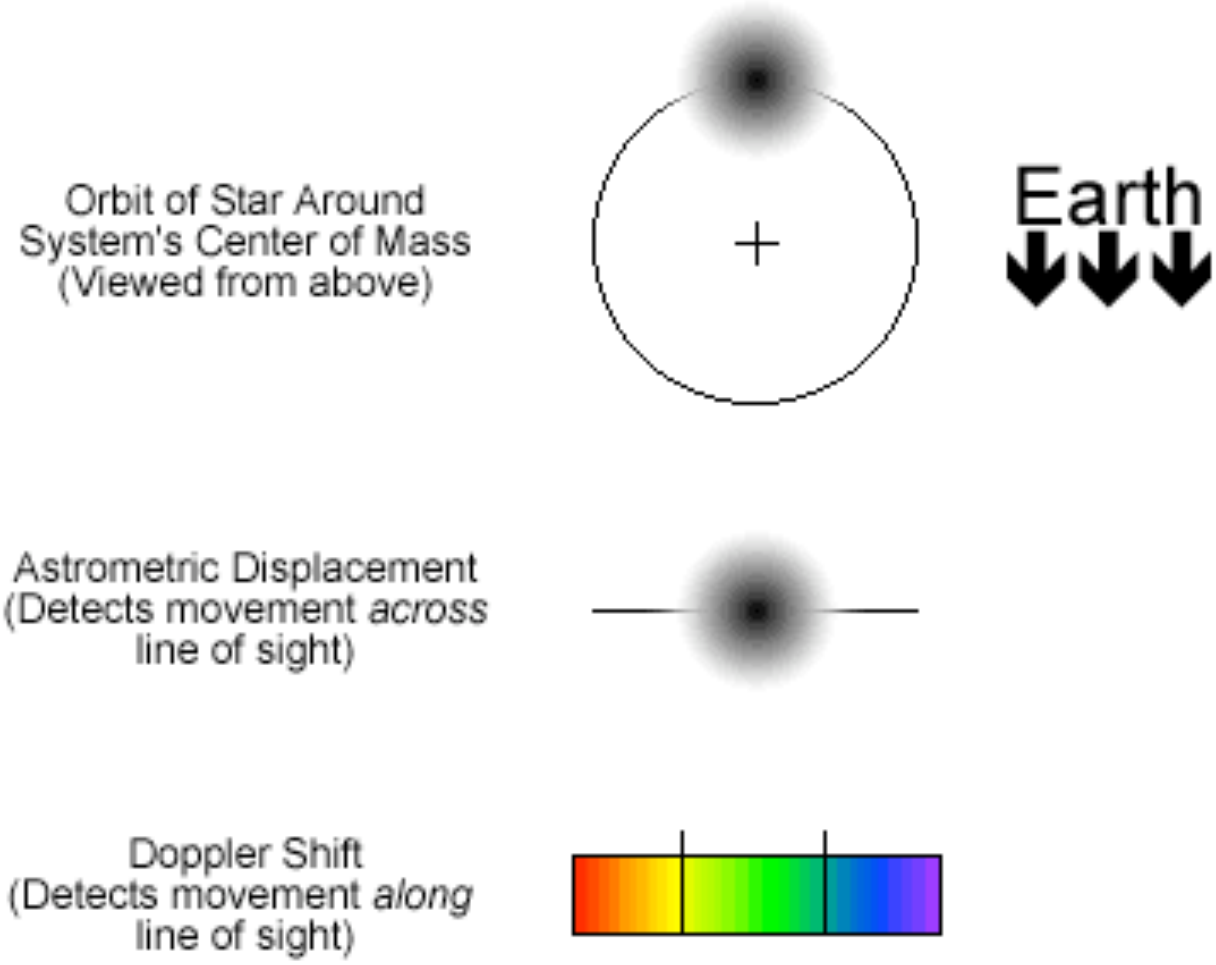


http://www.astro.keele.ac.uk/~rdj/planets/images/TauGruisHydra2.jpg

Outline

- Detection of extrasolar planets
- Selection biases
- Properties of extrasolar systems
- Future missions

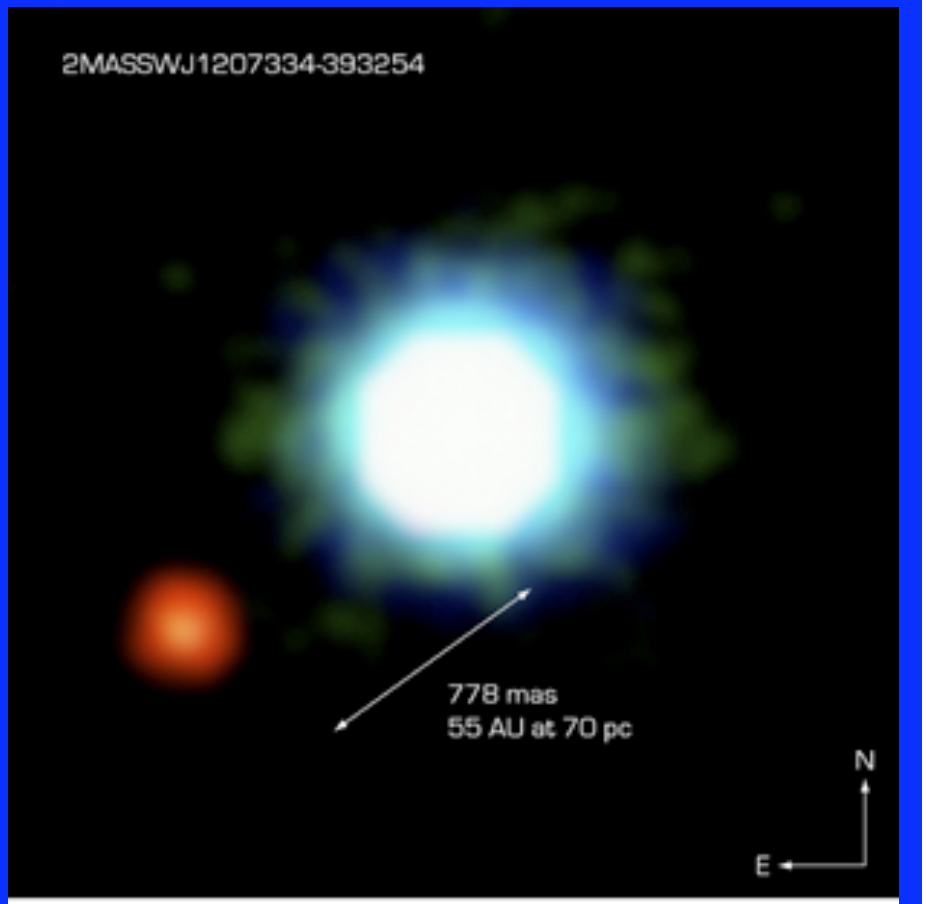
Observation of Stellar Motions Due to Presence of Extra-Solar Planet



http://eo.ucar.edu/staff/dward/sao/exoplanets/images/method4.gif

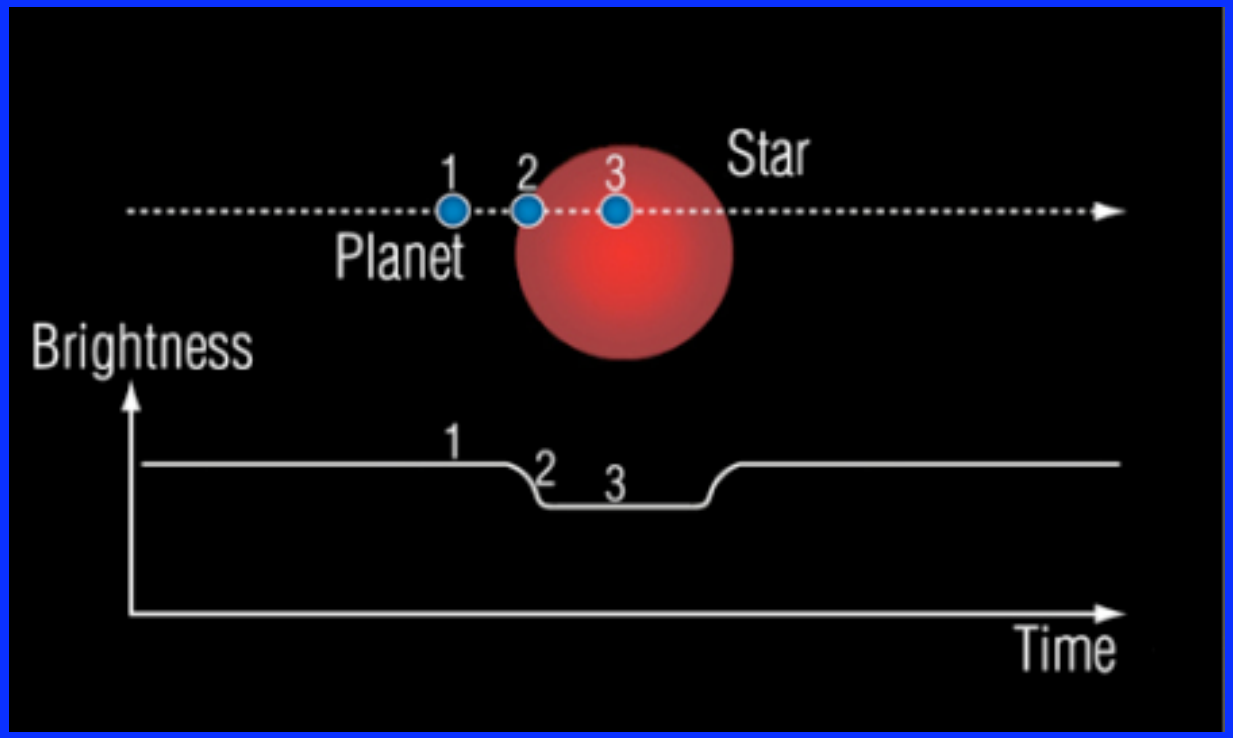
Detection of Extrasolar Planets

- How can we see them? Really far away!
- First thought: just get a picture
- But angle is tiny and star is much brighter
- Image at right: "star" is brown dwarf, 100,000 times dimmer than Sun

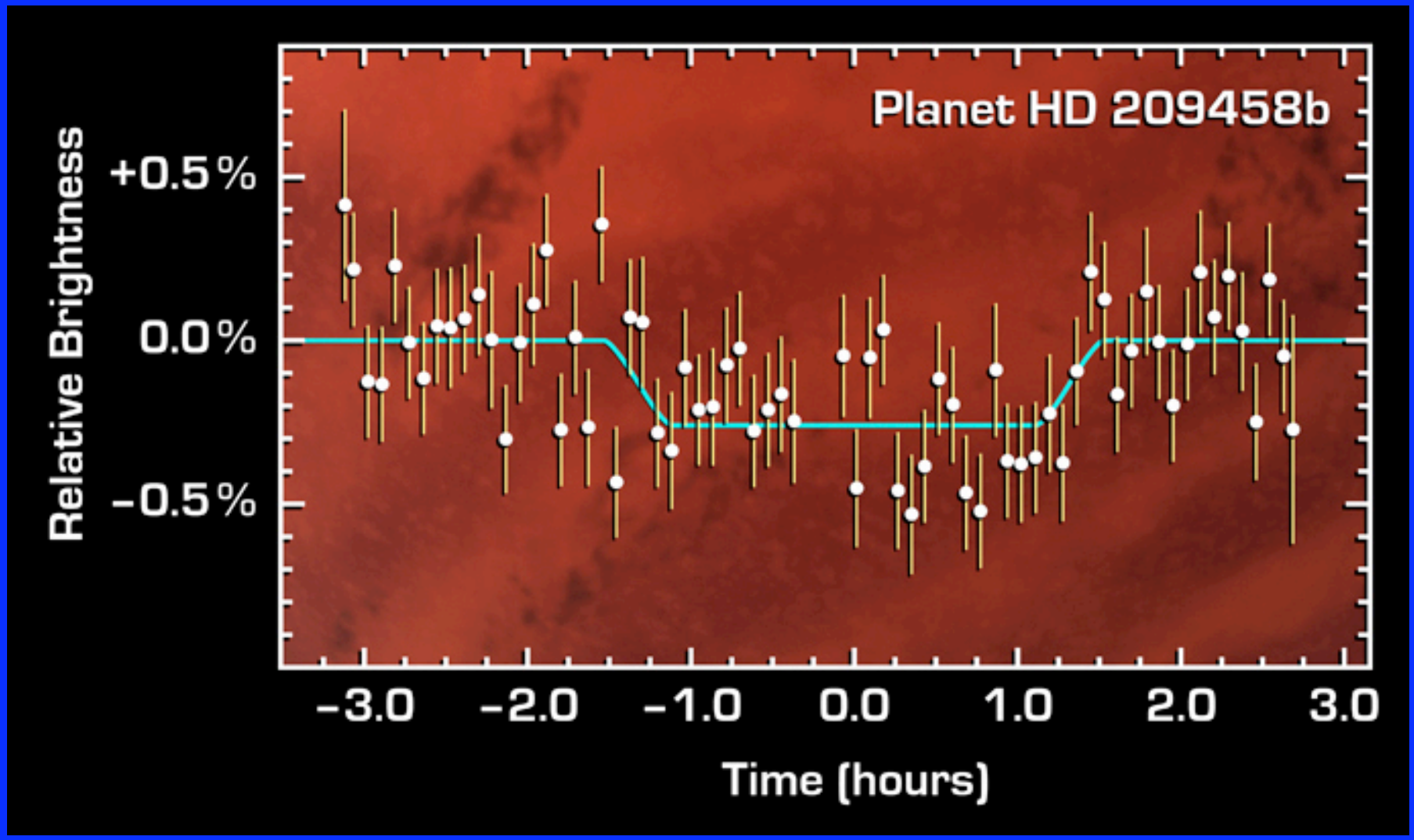


Eclipses?

- Next possibility: maybe planet passes in front
  Partial eclipse: reduces light during transit
- Has worked, but need special orientation



http://www.centauri-dreams.org/wp-content/uploads/2008/05/planetary_eclipse-md.jpg



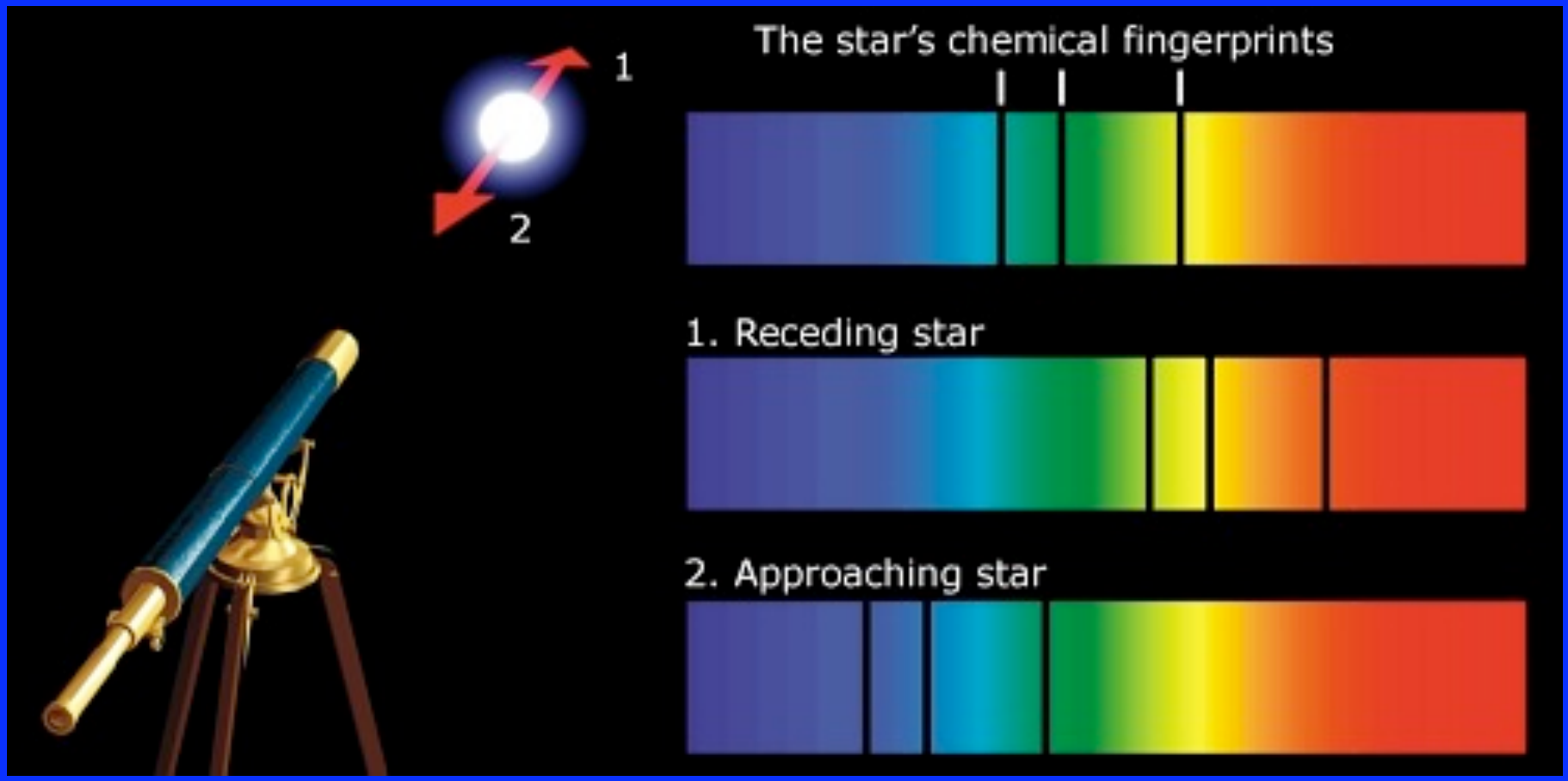
Spitzer Space Telescope

Note the data: not easy to see eclipse!

Some Numbers

- To give you an idea of difficulties...
- Light reflected from Earth is only about a billionth the light from the Sun
- If Earth appeared to pass in front of Sun, it would block out 10^{-4} of the light
- Tough measurements. Need other methods.

Line of Sight Motion

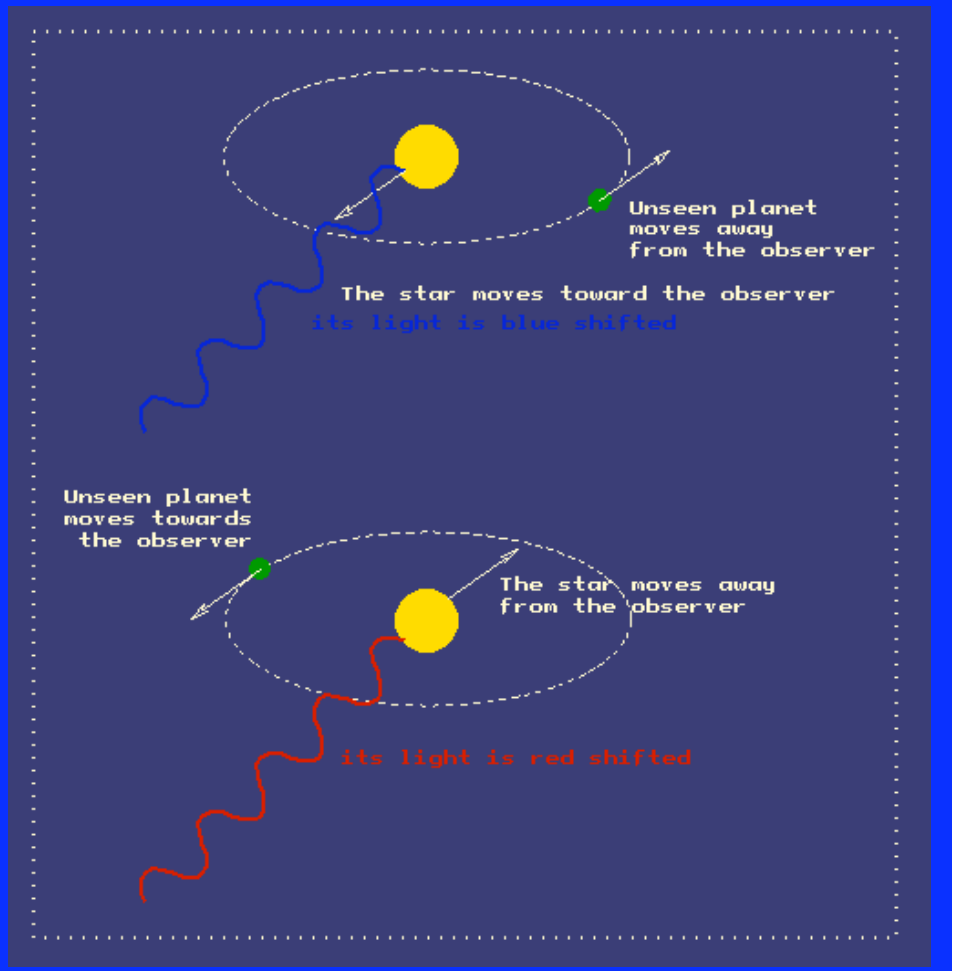


http://ast.phys.au.dk/SONG/BOOKLET-WWW/pictures/spectroscopy.jpg

We know spectrum if we were at rest relative to the source.
Shift tells us how fast it is moving towards or away from us.

Planet Detection: Doppler Shifts

- Planet orbits star
- But by Newton's third law, star must move
- We observe *star*, not planet
- Tiny motion shifts spectra back and forth
- If we see period, can infer unseen planet!



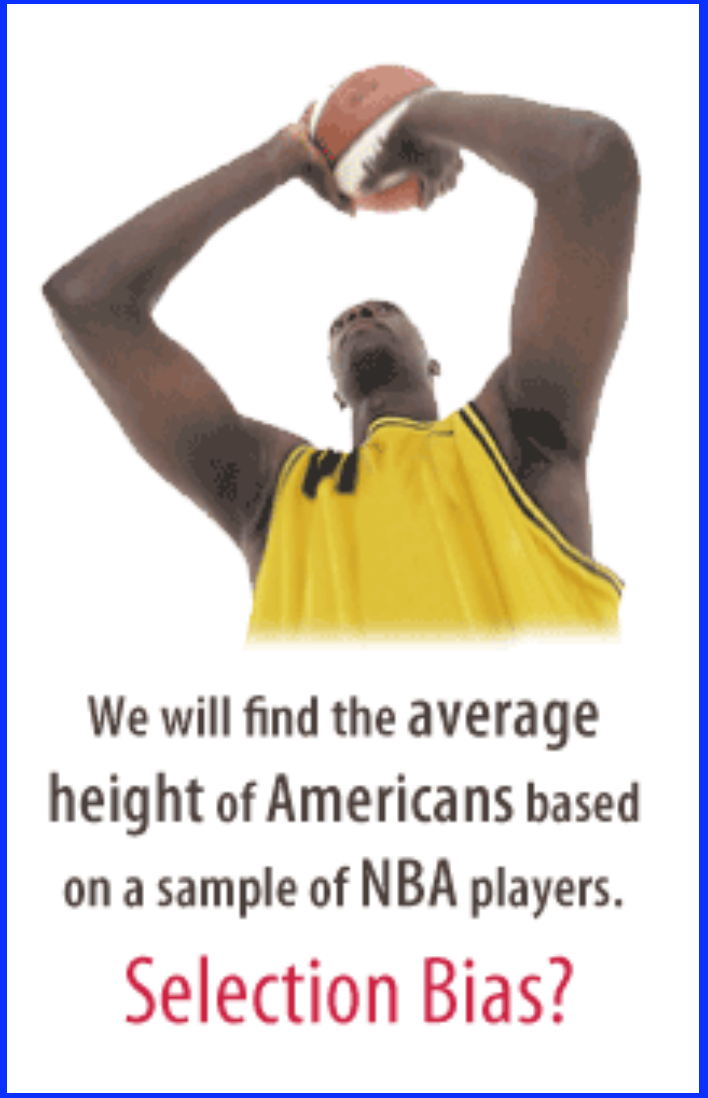
http://cfa-www.harvard.edu/afoe/doppler-shift.gif

Some More Numbers

- Could we detect Earth this way?
- Earth moves at about 30 km/s
- Sun is 300,000 times more massive
- So Sun moves (30 km/s)/300,000=10 cm/s!
- Can't detect this currently
- But *could* detect for more massive planet or closer, hence faster-moving, planet

Selection Bias

- When collecting data, need to realize that you will see some things more easily than others
- This is selection bias
- Must take into account when evaluating information
- Examples?



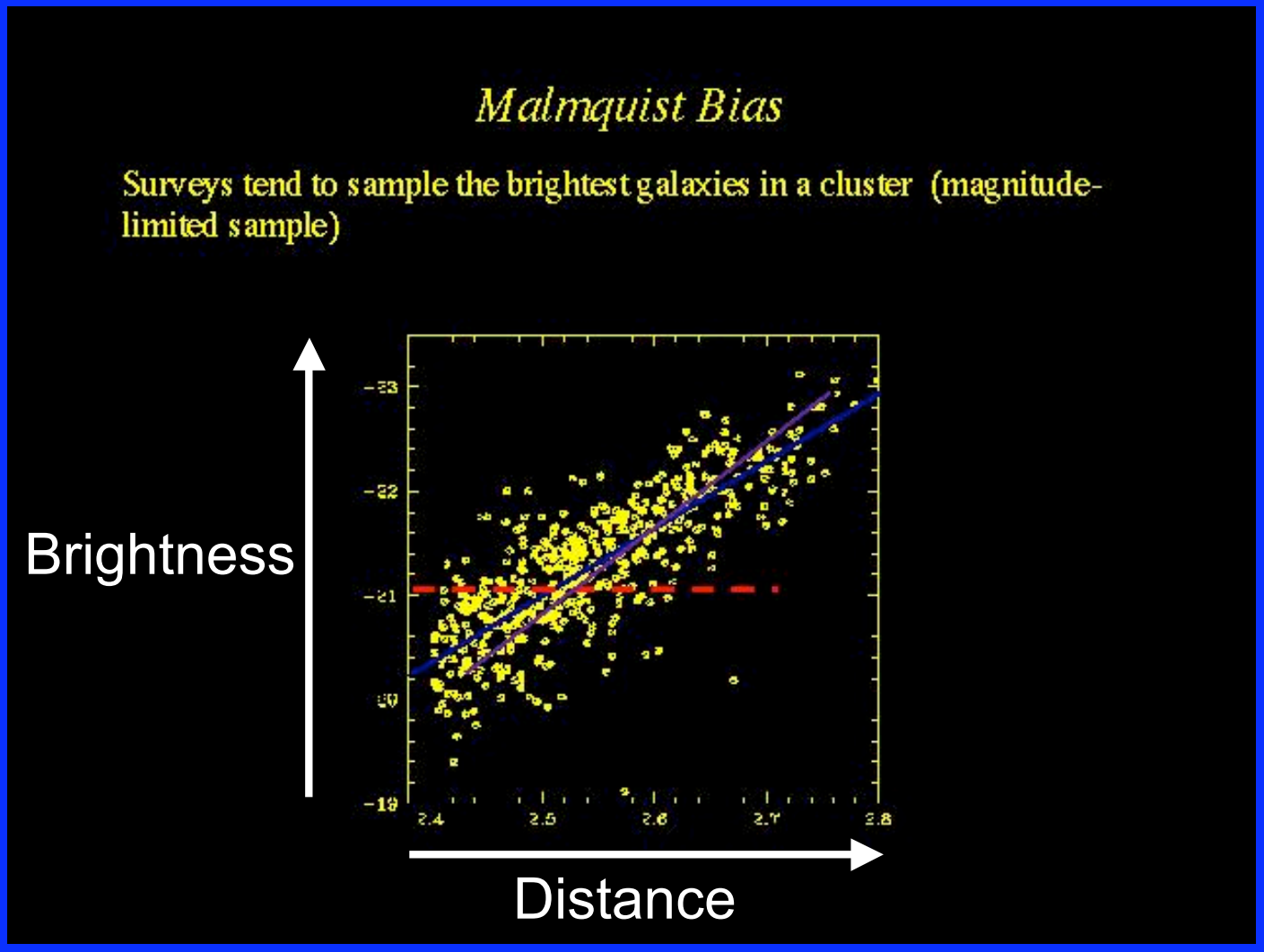
http://www.nedarc.org/nedarc/collectingData/eliminatingBias/images/selectionBias.gif

Landon Defeats Roosevelt?

- 1936 pres. election
- Literary Digest: 10 million polls sent, 2.3 million responded
  57%-43% for Landon
- Actual result:
  Roosevelt 27 million votes, Landon 16 mill!
- Prob: car, phone owners, and self-selected responses

Alf Landon campaign poster, 1936

Brightness Bias



http://www.astro.ucla.edu/~malkan/astro278/img34.jpg

Biases For Planets

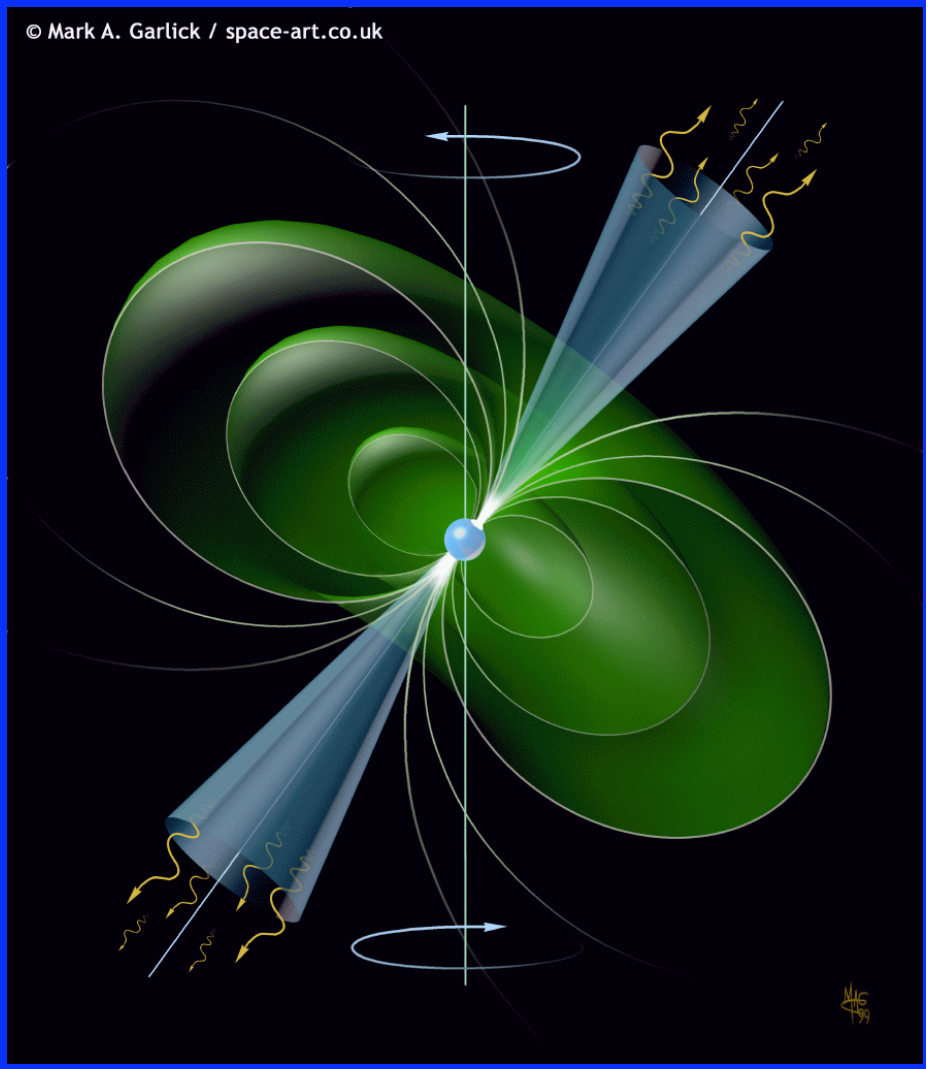
- Using Doppler shift method
- Larger shifts seen more easily
- Therefore, bias towards massive planets
- Also bias towards close planets
- Less obvious: bias towards stars with many heavy elements
- Why? More lines in spectrum, easier to see!

Keep in Mind:

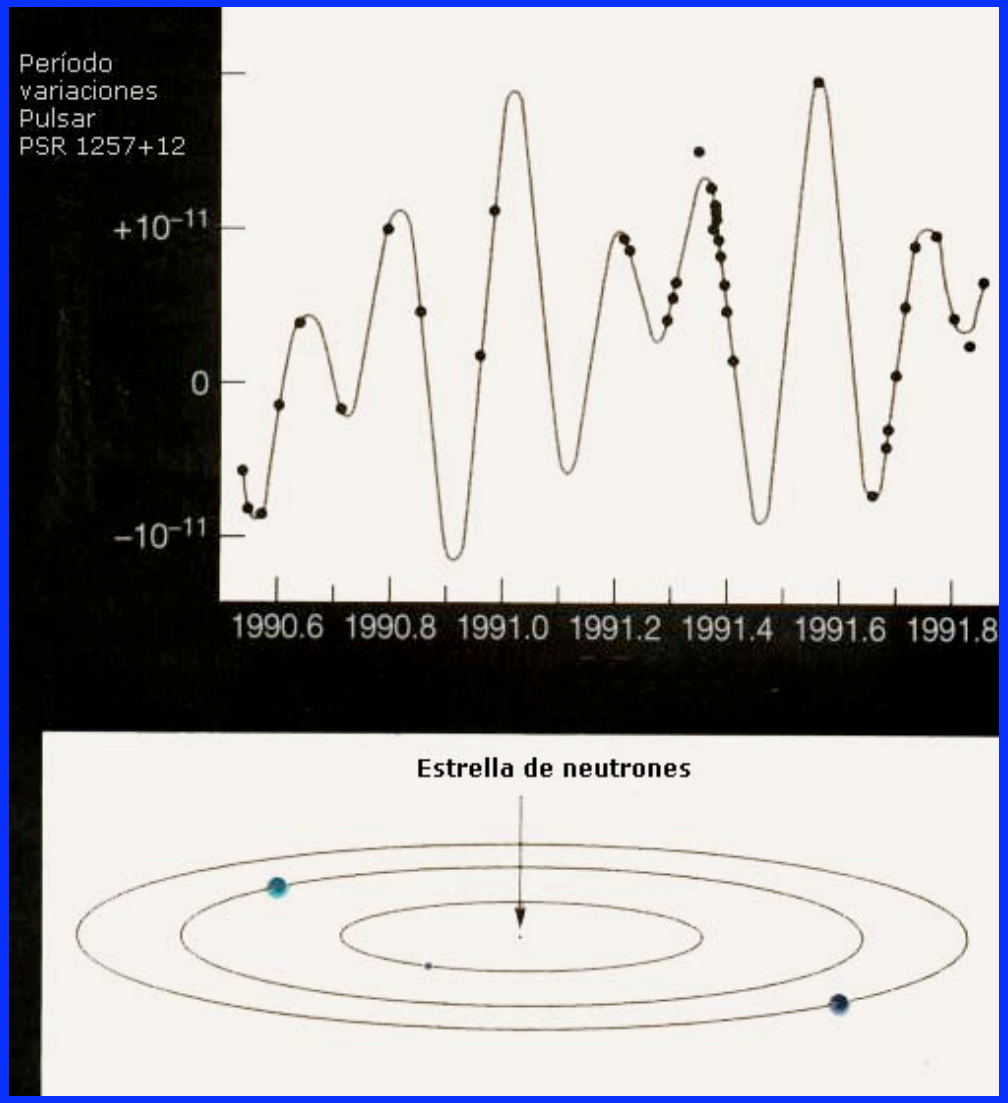
- Biases in astronomy and elsewhere mean that what you see does ***not*** have to represent the actual distribution
- Average NBA height is not average height!
- Extremely tempting to forget this
  Has led to many social problems
  Can also lead to astronomical problems

First Detection: Around Neutron Star!

- Collapsed core of massive star
- 10 km radius, 1.5x mass of Sun
- Rotate, have strong magnetic fields, so emit radio waves
- Extremely regular rotators: great clocks!
- Doppler shifts change timing of pulses



PSR 1257+12



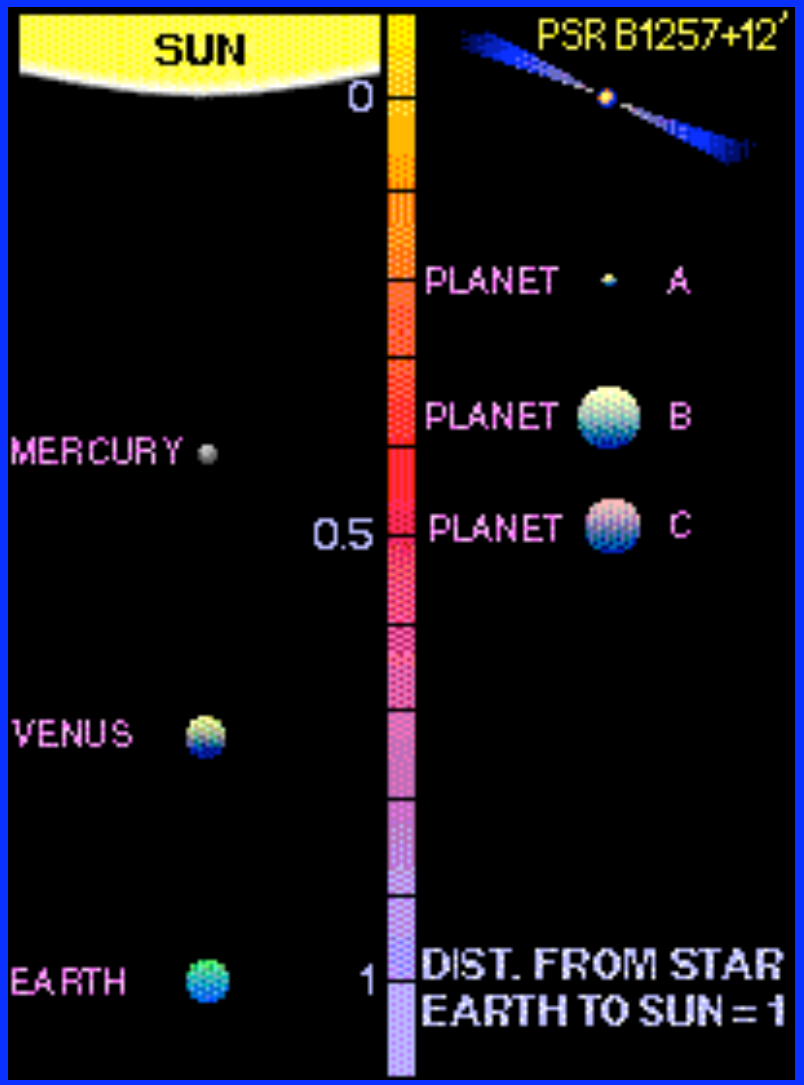
Detected 1992

Variations are small, but definitely there. But they are also rather complicated. What might be going on?

http://www.cielosur.com/imagenes/i_planetasextra2/PSR1257-2B12.jpg

Multiple Planets Around Pulsar!

- Complexity of data and previous false reports led to disbelief
- But complexity was real: two major planets, 3x Earth mass
- Inner planet discovered later: mass of Moon!
- Still the three smallest detected



http://www.daviddarling.info/images/pulsar_planets.gif

How Did Pulsar System Emerge?

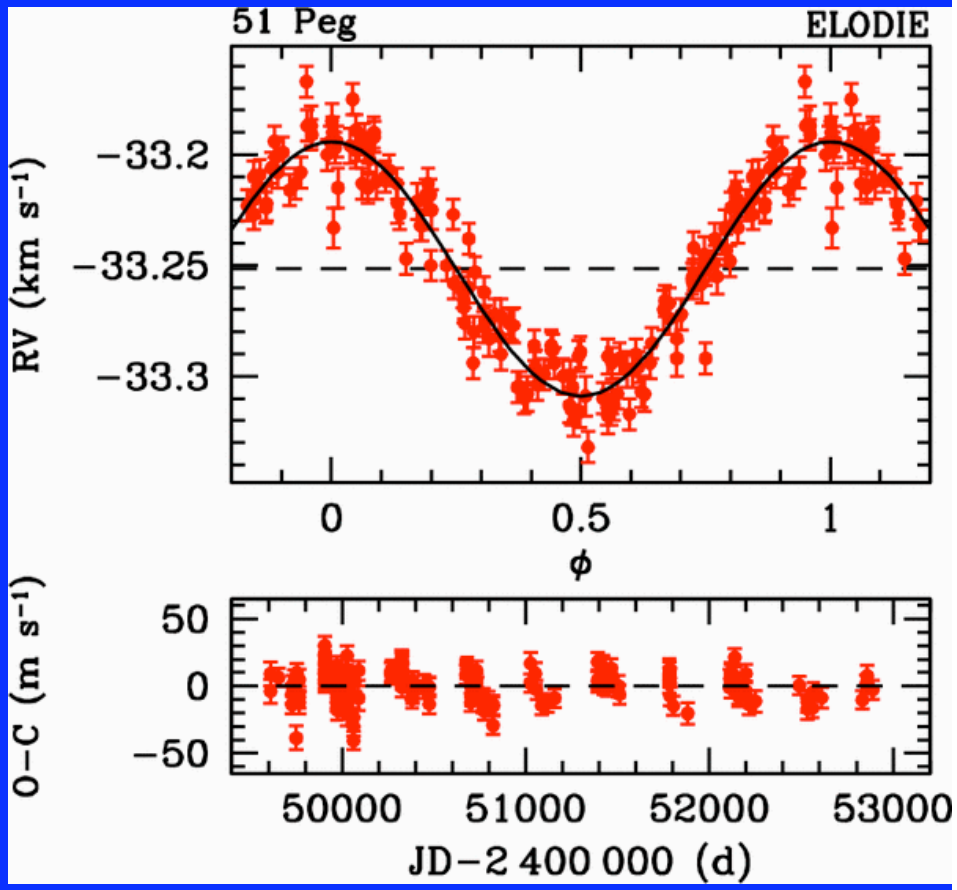
- Prof. Doug Hamilton (UMd astro) and I surveyed models, and the only survivor was:
  Supernova occurs in binary star system
  Recoil kicks neutron star through companion
  NS picks up matter in disk as a result
  Disk cools, moves out, makes planets
- Pretty cool!

Systems Around Other Pulsars?

- Only one other, but in globular cluster where binary-binary interactions could have led to swapping of planets between systems
- Interesting, because pulsars are such great clocks that even big asteroids would be easily detectable
- Okay, fine. What about normal stars?

First Around Normal Star

- Radial velocity of 50 m/s. Detected 1995
- Half mass of Jupiter
- But surprise: orbital period of 4 days!!!
- Very strong detection



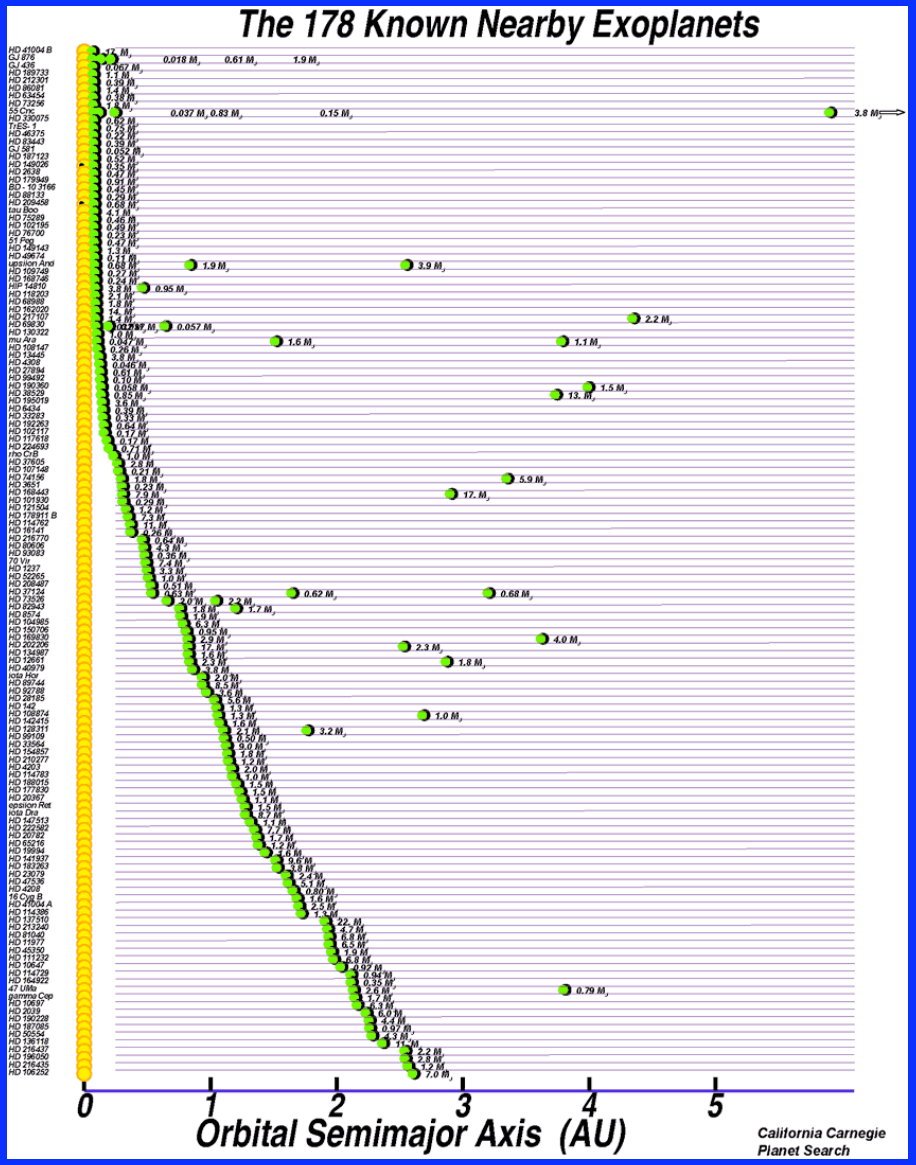
M. Mayor, D. Queloz, 1995

Extrasolar Planets: Examples

http://www.physics.sfsu.edu/~gmarcy/planetsearch/graphics/planets.gif

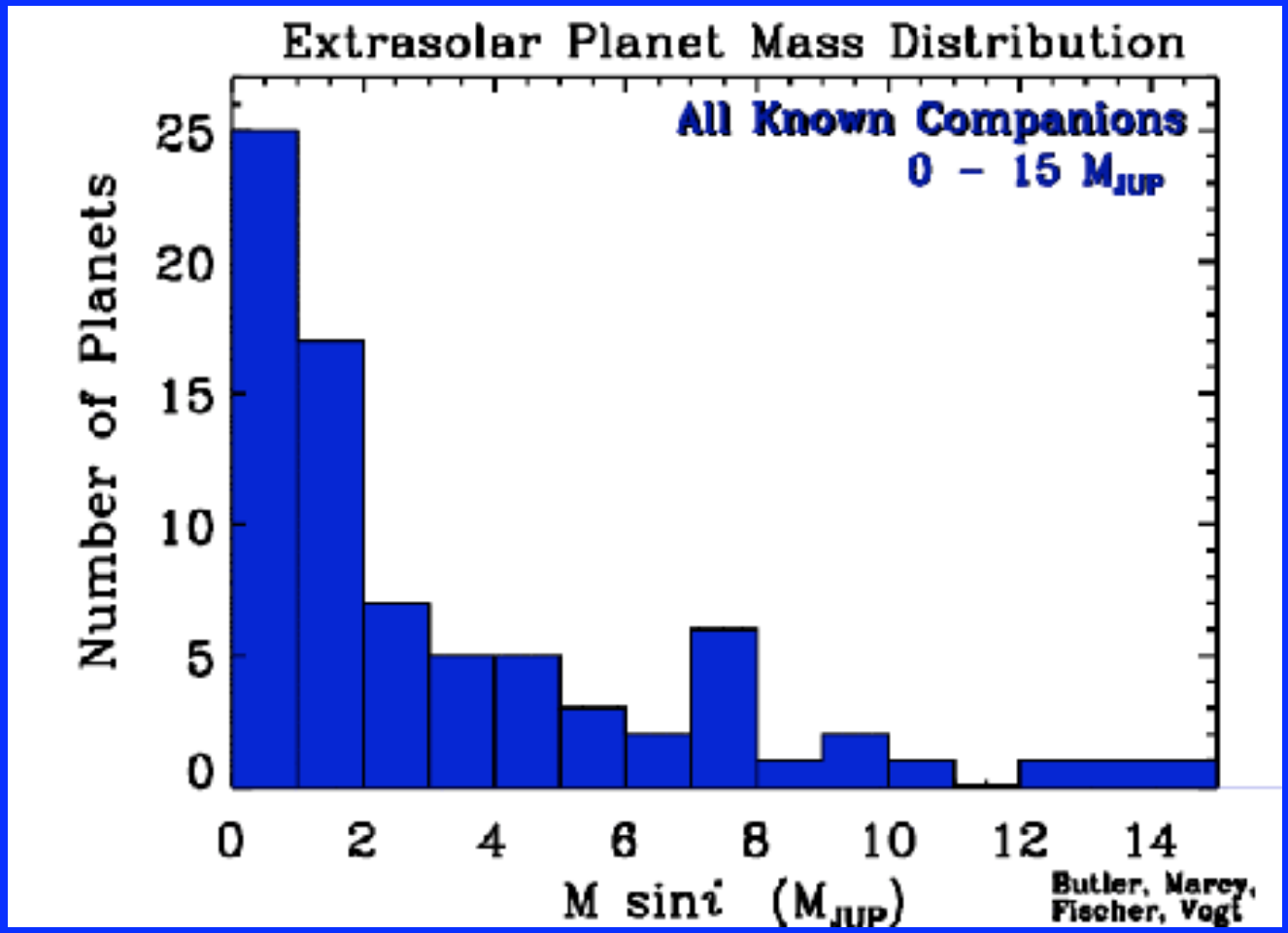
Properties: Orbital Distance

- Now >300 known
- Remember: 1 AU is average Earth-Sun dist
- But most extrasolar planets much closer
- Real, or bias?



Masses

- Many more massive than Jupiter
- More at low mass than high. Real, or bias?

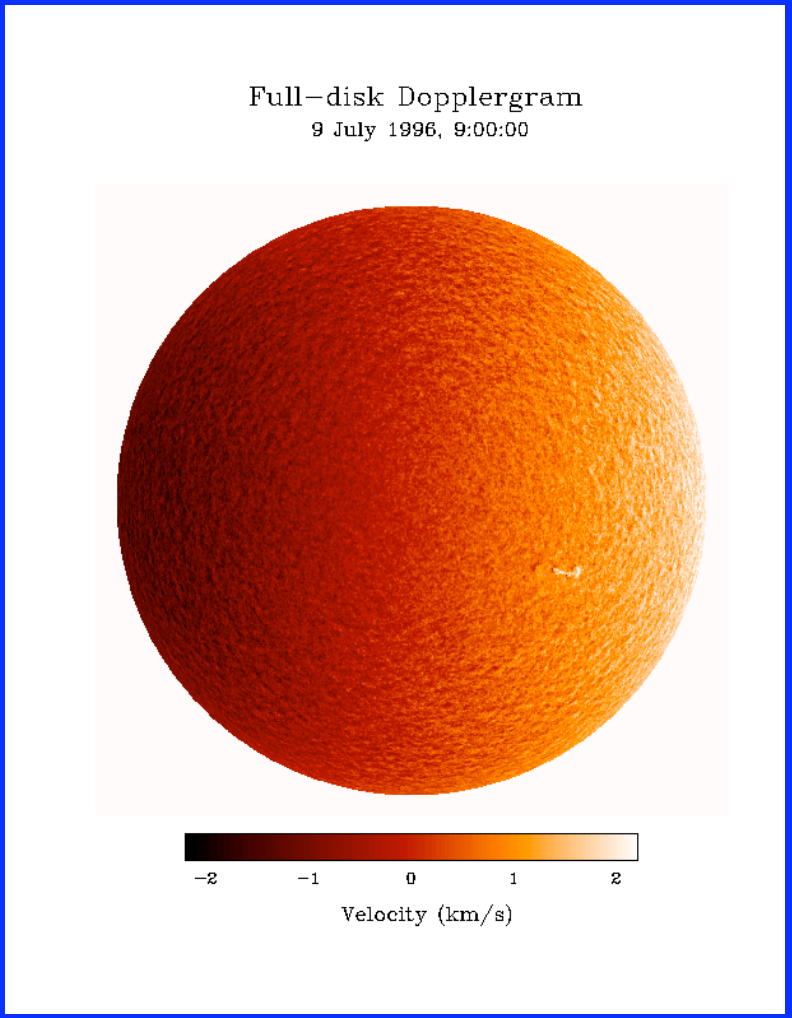


Masses, Part 2

- Lower and lower mass planets are being found around ordinary stars
- Some a few times the mass of Earth
- Improved techniques could do better in the future
- Are there any limits?

Limits on Detectable Mass?

- One problem: stars wiggle
- Like seismology, but surfaces not solid
- Motions are often meters per second, similar to what is induced by planets
- People are finding clever work-arounds, but more and more difficult...



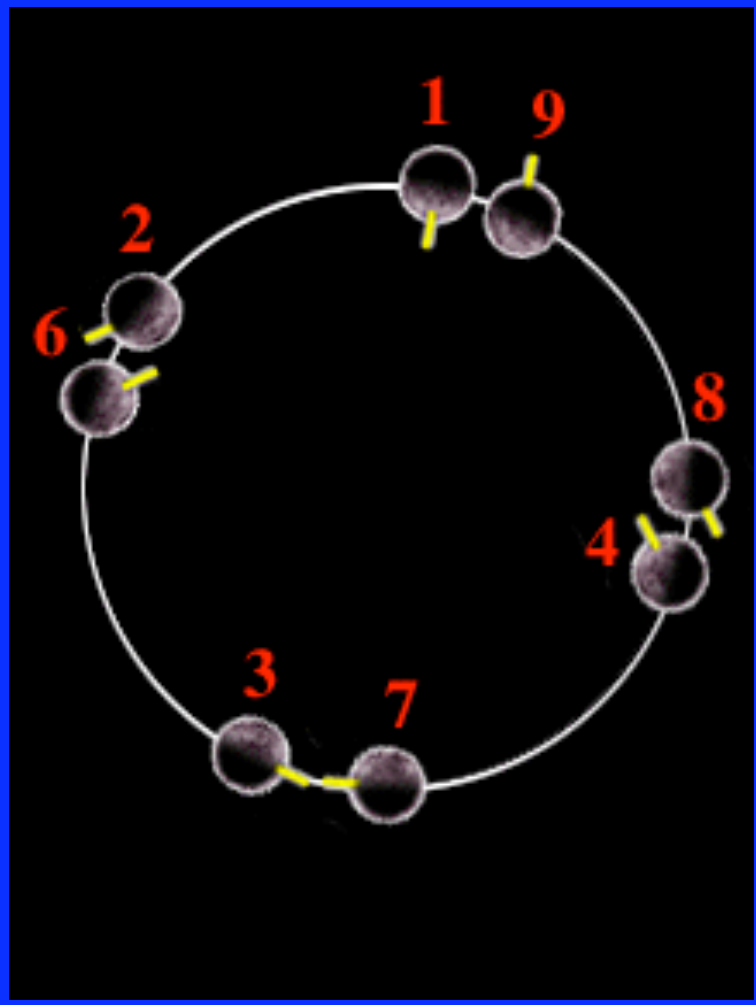
http://solar-center.stanford.edu/images/dopplergram1.gif

Properties of Host Stars

- Almost all have between 0.7 and 1.5 times the mass of our Sun.
- Wow! Does that mean that we are in a special system, with a favored mass?
- Not so fast...
- This is where searches have concentrated
- Now finding around more massive, less massive stars

Solar System Eccentricities

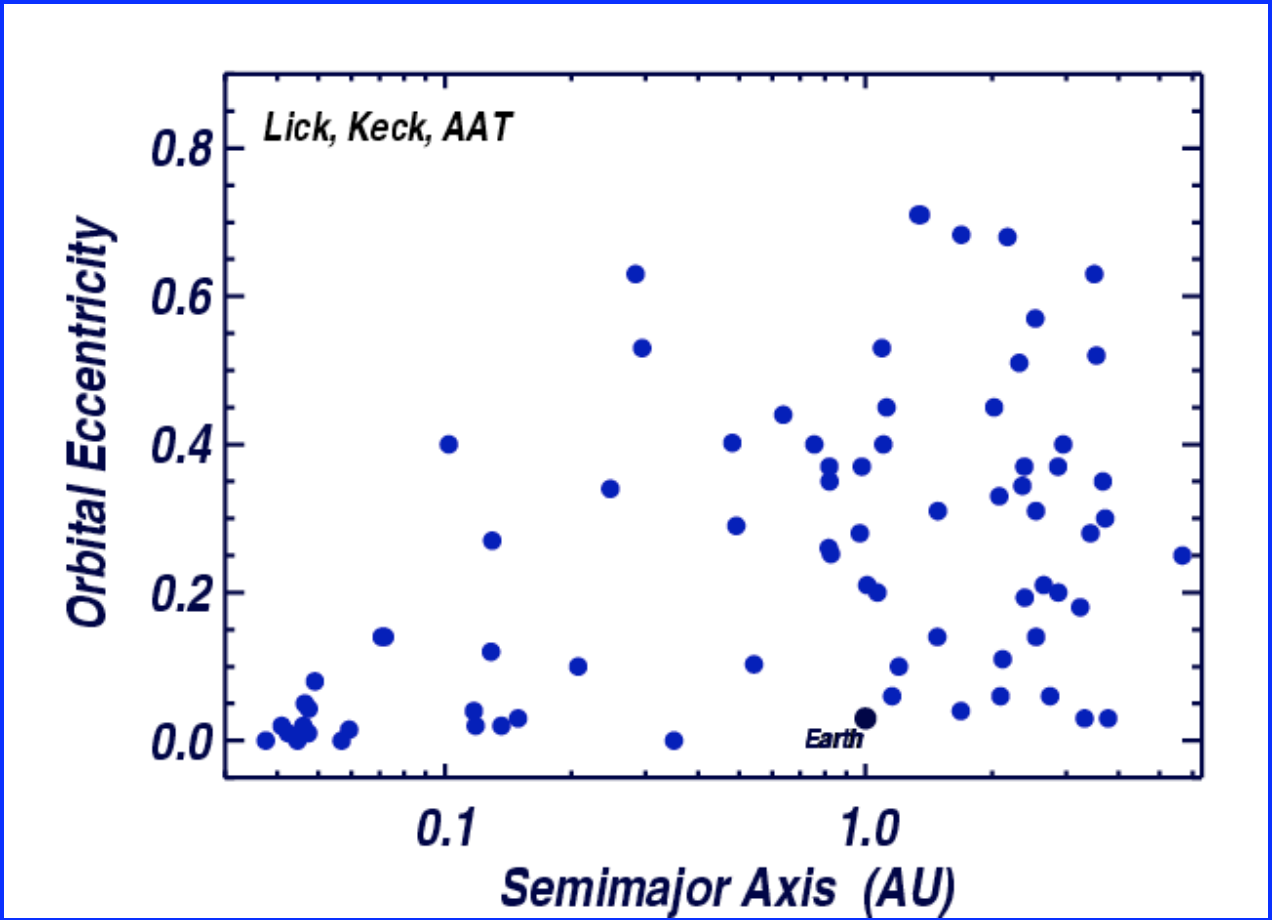
- Planetary orbits are very close to circular
- Most eccentric is Mercury, with eccentricity of 0.21
- Most much less; look like circles to the eye



http://www.windows.ucar.edu/mercury/images/mercury_orbit.gif

Eccentricities

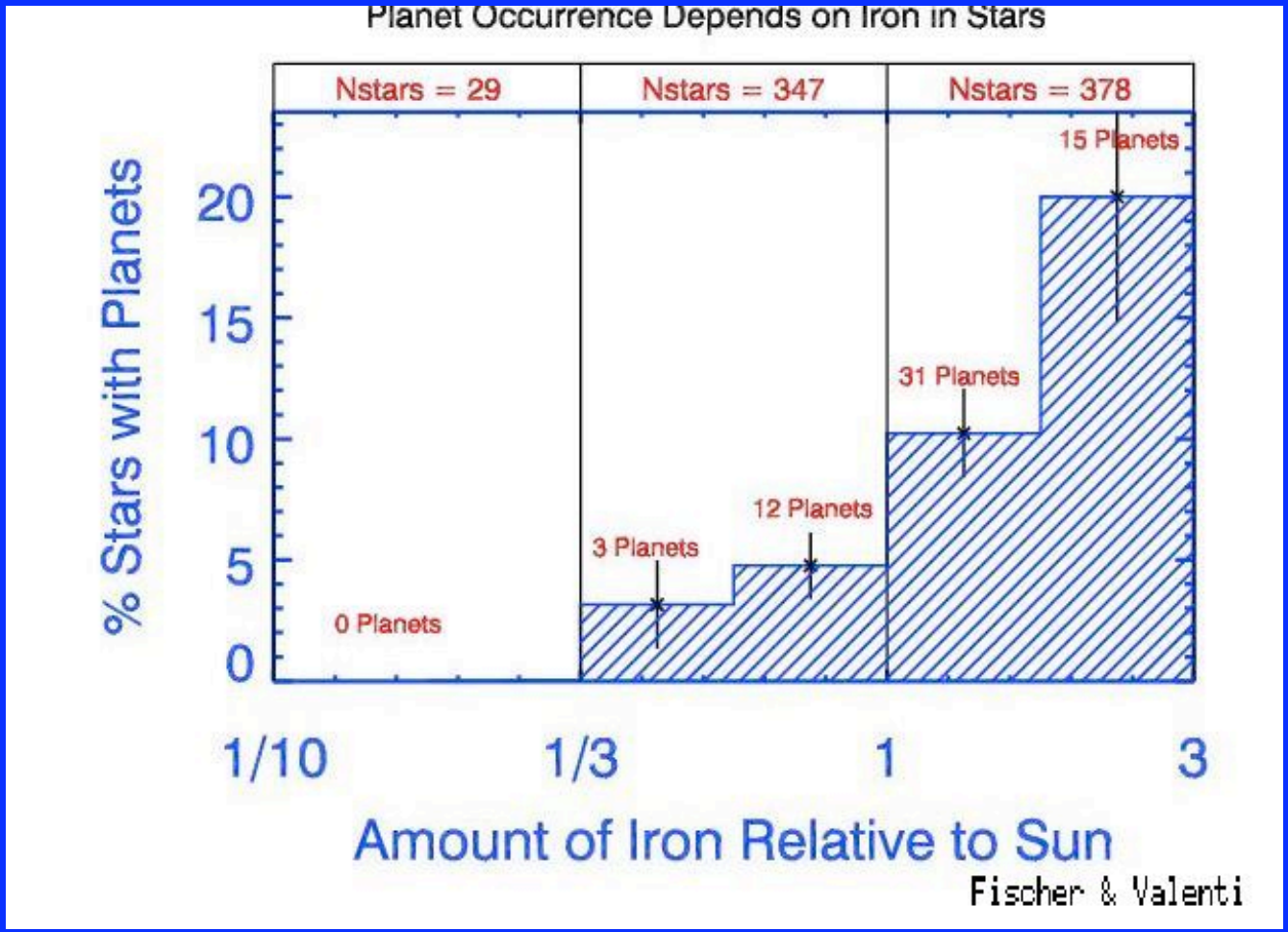
- Most are way higher than Solar System max
  Real, or bias?



http://exoplanets.org/ecc_vs_a_col.html

Properties: Heavy Elements

- More likely to see planets when star has more heavy elements. Real, or bias?



Properties: Heavy Elements

- Another data point: Gilliland et al. (2000) pointed Hubble at the globular cluster 47 Tuc; has small fraction of heavy elements
- Expected 17 planets if similar fraction
- Found none
- Does this confirm that high fraction of heavy elements is needed, or might there be other reasons for lack of detection?

Big and Close-In

- All but one of 14 with periods <1 day have masses greater than Jupiter
- Doesn't this contradict our picture that high masses form outside of frost line???

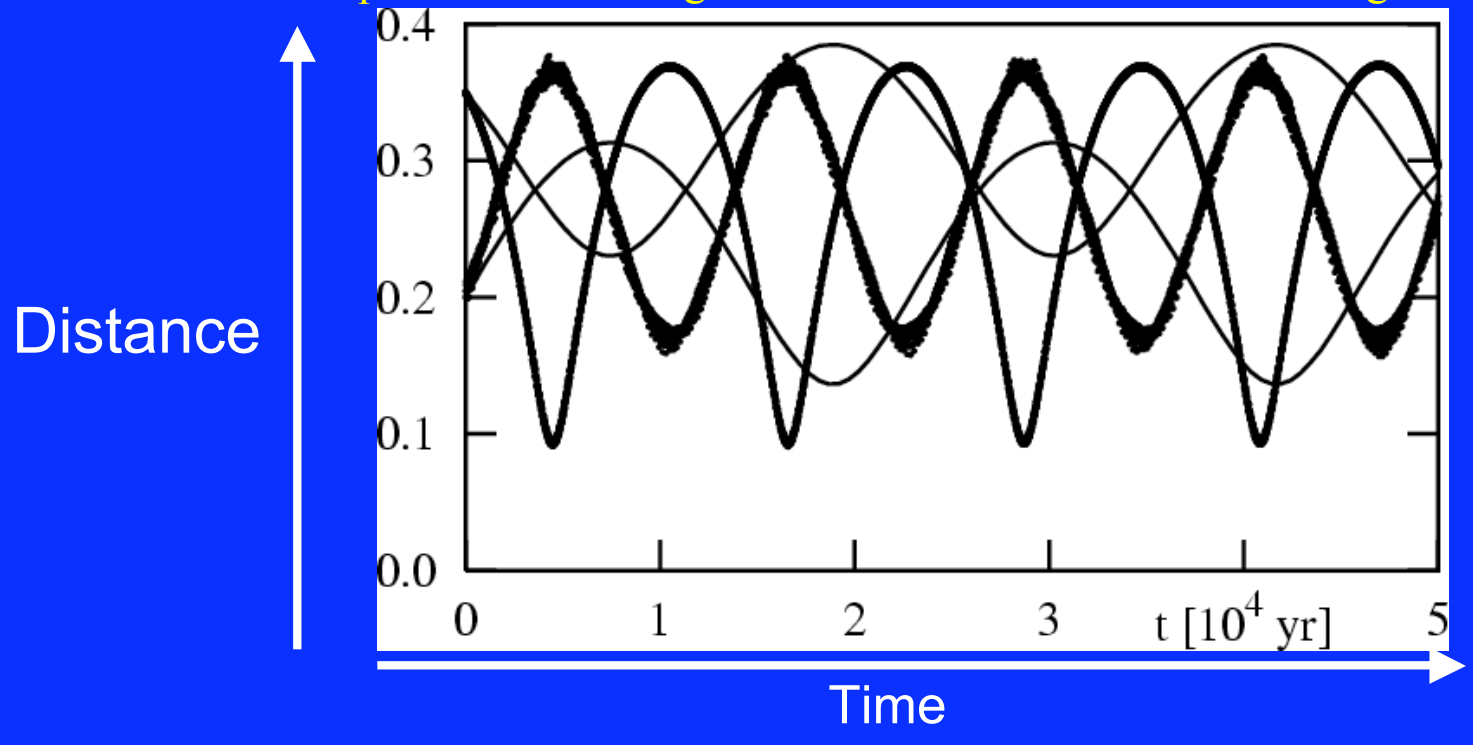
Big and Close-In

- All but one of 14 with periods <1 day have masses greater than Jupiter
- Doesn't this contradict our picture that high masses form outside of frost line???
- No!
- *Formation* still happens there, but drift in
- We don't know whether drift stops, or whether we see only last few survivors...

Planet-Planet Scattering

- High eccentricities consistent with simulations
- Last few protoplanets scatter with gravity
- Is our Solar System very unusual with circularity?

http://www.aanda.org/articles/aa/full/2003/06/aah3945/img95



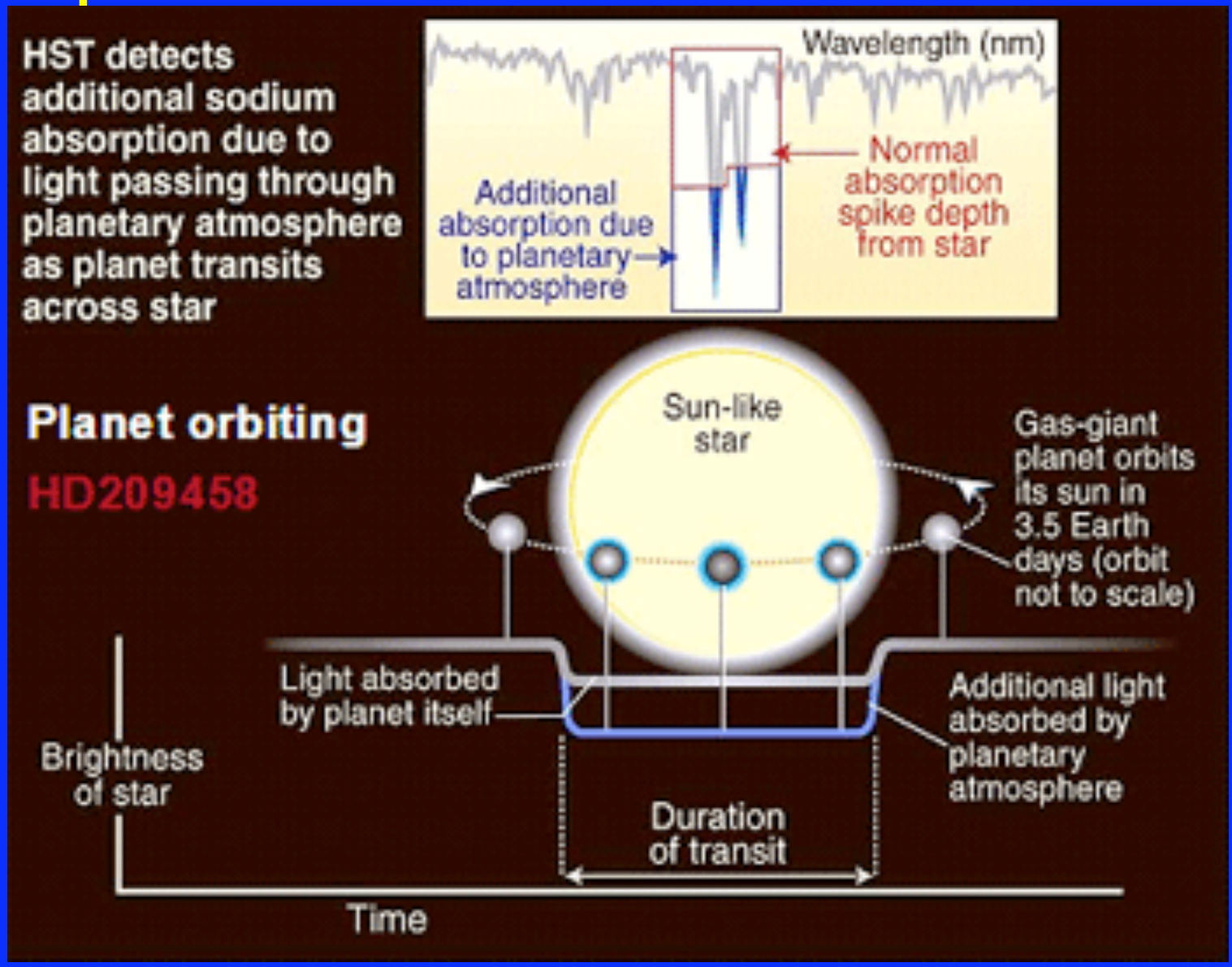
Perspective: Solar System

- Looking at us, could only detect Jupiter
  Inner planets too low-mass
  Saturn etc.: period too long, haven't observed for enough time
- No Earth-mass planet at any radius could be seen around normal star
- Therefore, lingering uncertainty

Perspective: Planet Frequency

- At least 5% of Sun-type stars have planets
  Fraction going up with better searches
  Current best estimate: 15-45%
- But how many could host life?
  Most are large, close-in, and/or eccentric
- Don’t forget possibility of life on moons!

Spectrum of Extrasolar Planet



http://www.scitizen.com/stories/Extrasolar-Planets/2006/01/Methods-to-search-for-extrasolar-planets/Hubble.gif

Plant Diagnostic?

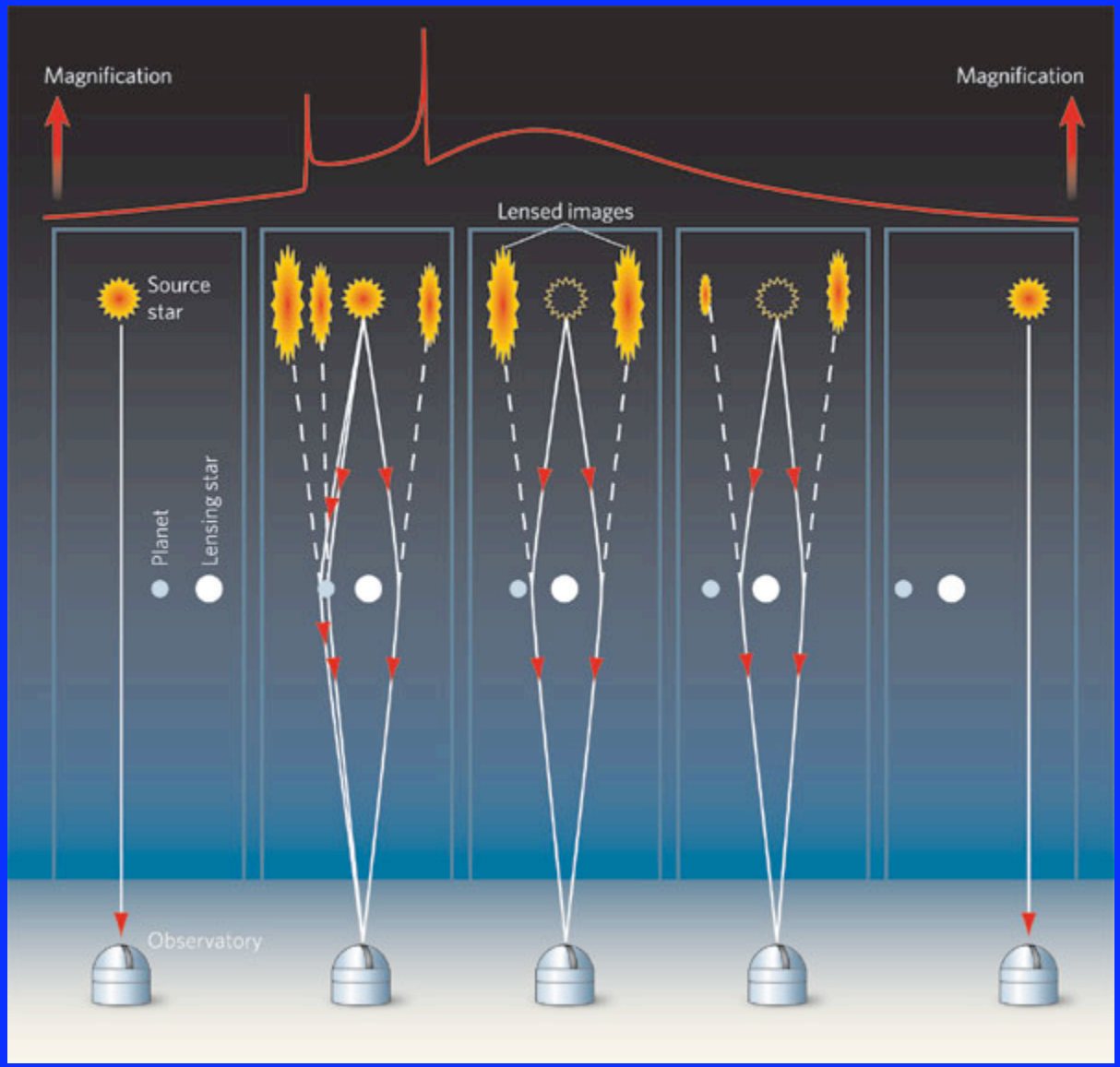
- Living plants reflect brightly in near-infrared
  Needed to release heat
- Would unusual IR brightness be a diagnostic of plants?

http://www.nelsontan.com/reviews/eir/ir7.jpg

Prospects for Spectra?

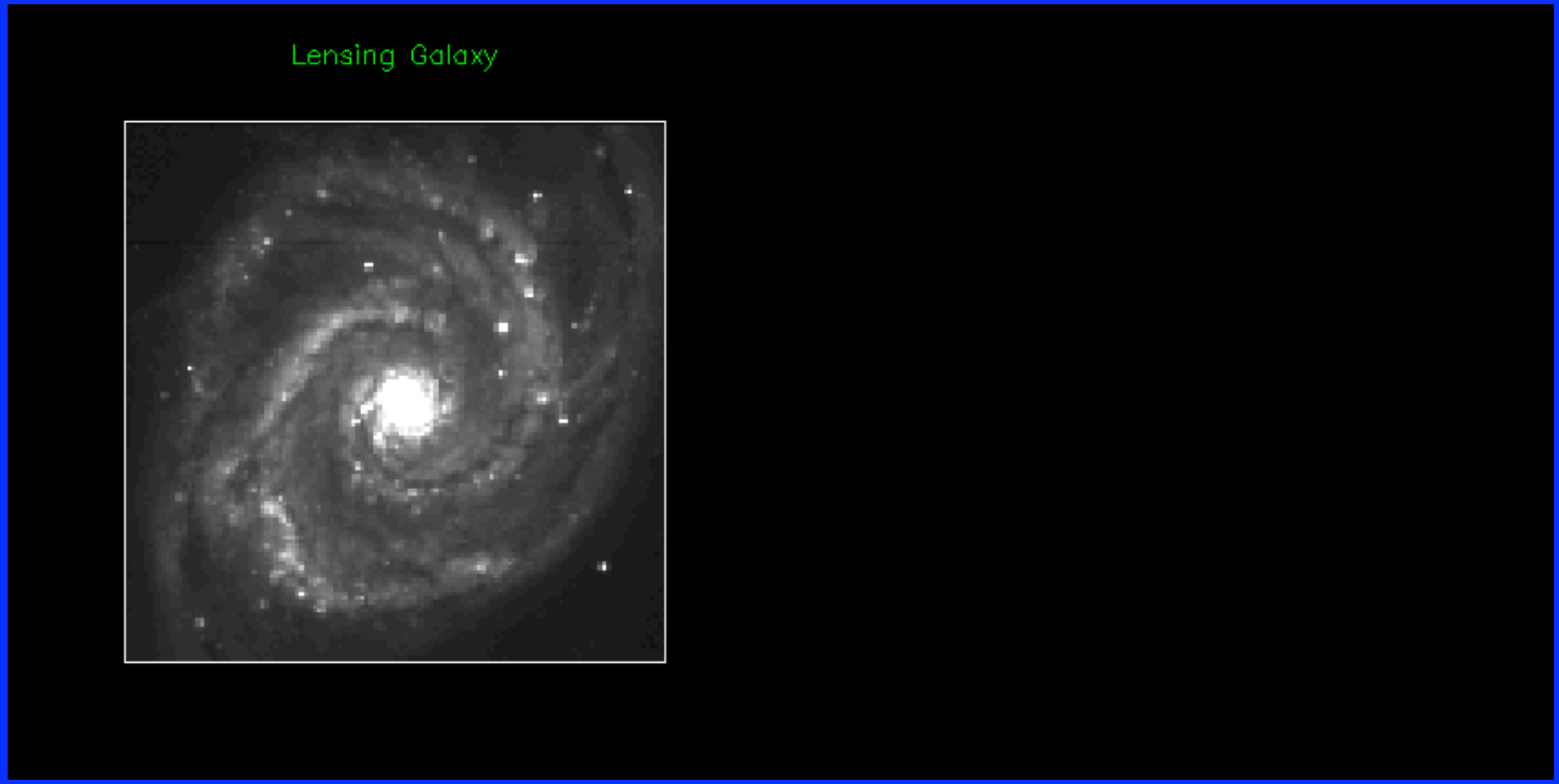
- Can we do even better?
  If saw oxygen, might indicate life
- Same would be true for any molecules that are short-lived in atmosphere without life to sustain them
- Maybe, but probably very difficult at present

Ongoing Method: Grav. Lensing



http://www.nature.com/nature/journal/v439/n7075/images/439400a-f2.2.jpg

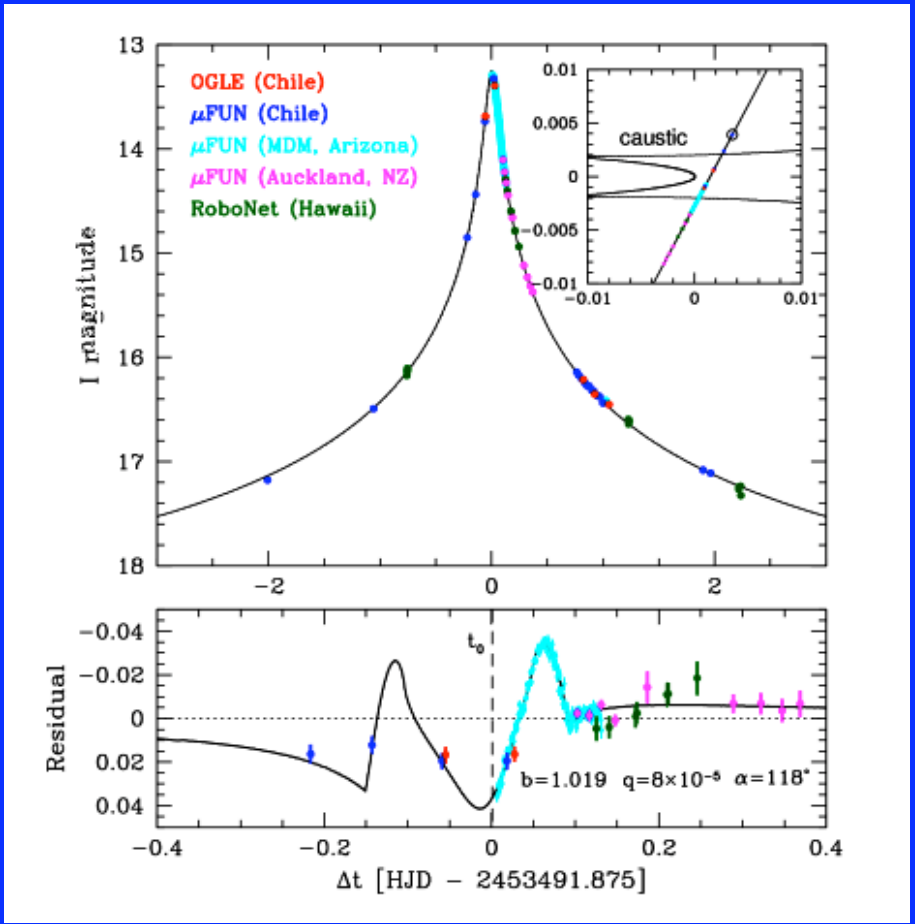
Lensing of Galaxy



Jim Lovell, University of Tasmania

Example Lensing Detection

- Can potentially see very low-mass planets this way
- Also, can see very far away



http://bulge.princeton.edu/~ogle/ogle3/blg169.png

Low-Mass Planets, and the Benefits of Periodicity

- For other methods (radial velocity variation or eclipses), note that even weak signal can add up over time
- If you see 1,000 cycles of a 4 day period, this might show up even if weak
- But then you have to look for many periods; computer power limited

The Future: Dedicated Surveys

- Some space-based missions, or dedicated missions on Earth, could increase the number of extrasolar planets by a lot
- Large area, multi-fiber spectroscopy, excellent detection of the apparent motion of stars
- Get better statistics, but also expect rare types of planets that can tell us a lot

Summary

- Since 1992, more than 300 planets have been detected outside our Solar System
- Many surprising properties; different enough to rule out life? Not sure
- But note that Earth, or our Solar System, would not have been detected
- Discovery pace is picking up...