The Search For Extra-Solar Planets

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Why search for planets?

- Find Earth-like planets in order to possibly discover life on exoplanets
- How common are planetary systems like our own solar system?
- To discover new planet systems and types

Plan

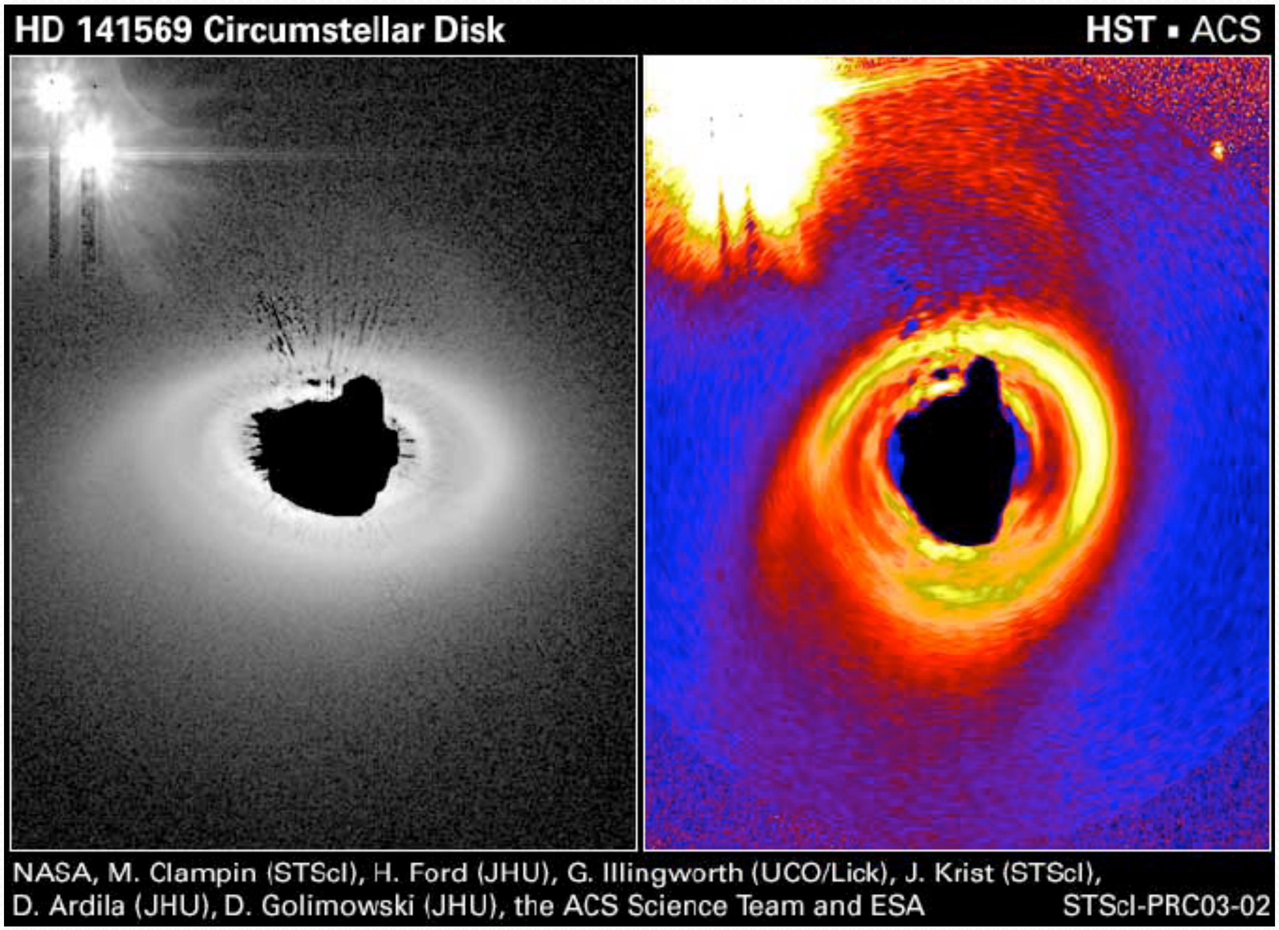
- Protoplanetary Disks
- Planet Formation Theories
- Planet Detection Techniques
- Future Missions

Protoplanetary Disks

Definition: A disk like configuration of natal gas and dust surrounding a protostar. (Wisniewski 2009)

- Mostly gas (99 percent)
- Guide star formation
- Birthplace for planets

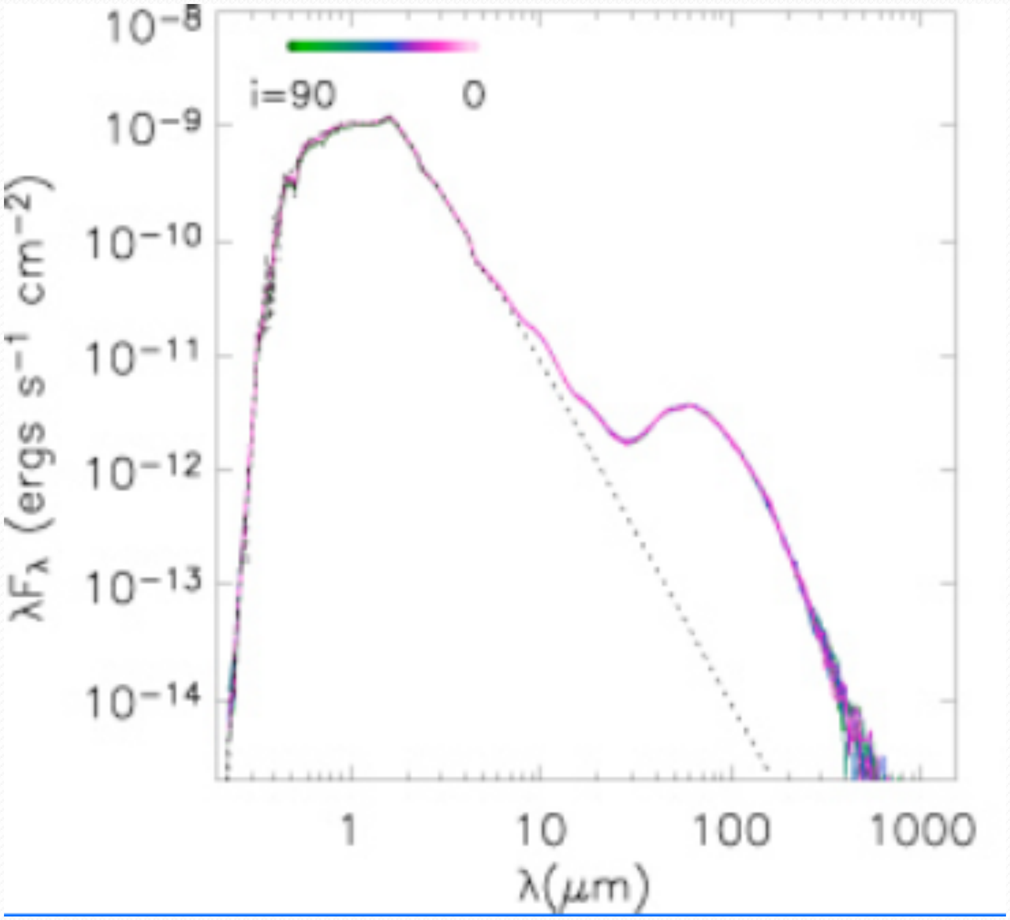
Protoplanetary Disks: HD 141569



Protoplantary Disks (PPD): Observational Methods

- Measure the Star's SED (Spectral Energy Distribution)
  - Determines if a star has a PPD through the presence of an Infrared Excess (IE)
    - The IE is additional light emitted in the IR above that which is predicted for a normal star.
  - A quick easy way to view many stars

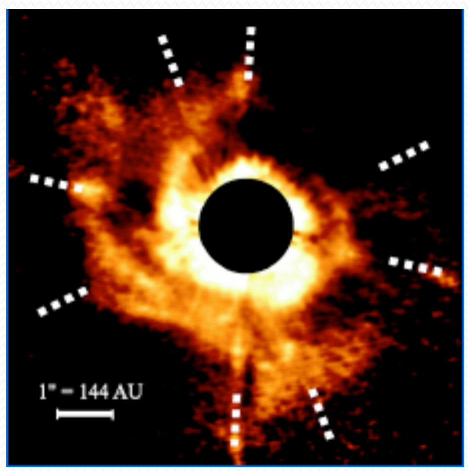
Protoplanetary Disks: Infrared Excess



Denzmore and Whitney

Protoplanetary Disks: Observational Method

- Direct imaging
  - Taking images of the disk itself can help you see the geometry of the PPD
  - Clumps, warps, spiral structures infer presence of planets



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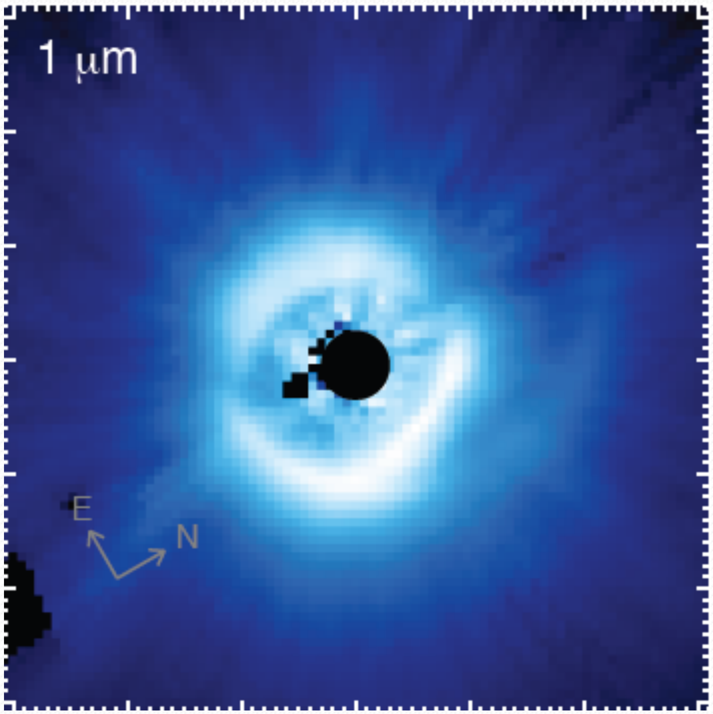
Fukugawa et al. (2004)

Protoplanetary Disks: HD 142527



Perrin, Schneider, Wisniewski, Hines and the HST/GO 11155 team (2009 AAS – Long Beach)

Planet Formation

- Planets form inside protoplanetary disks
- Many different theories
  - Core Accretion Theory ("The Standard Model")
  - Disk Instability Theory

Core Accretion Theory

- Small particles constructively collide forming larger and larger particles until they get large enough to become a planetesimal and then a planet embryo.
- "bottom-up" scenario
- Probability of collisions for smaller bodies is determined by the geometric cross section
- For larger bodies, gravitational focusing increases the cross sections
- Time scale: 1 – 100 million years

Core Accretion: Concern

- Lifetime for most of the material in protoplanetary disks is between 6 and 10 million years
- Can you form large enough cores to actually form gas giants around the systems that are known to harbor such planets (before your gas disk disappears)?
  - GJ 876 has a Jupiter mass planet, but the time scale for the core accretion of a 10 earth mass planet core is >> 10 million years

Planet Formation: Disk Instability Theory

- Top-down formation scenario
- Protoplanetary gas disk is gravitationally unstable and the instability leads to collapse of a section of the disk
- Entire mass of planet is formed at once
- Time-scale: several hundred years
- Problem:
  - Formation of gas giants requires extremely fast cooling, otherwise you'll just produce spiral arm structures in the disk

Planet Detection Techniques

- Many different techniques with varying success rates:
  - Radial Velocity Technique
  - Transit Photometry
  - Microlensing
  - Astrometry
  - Direct Imaging

Radial Velocity Technique

- Most successful technique: approx. 320 planets detected thus far
- Gravitational interactions between host star and an exoplanet will cause the star to move about the systems center of mass.
- What is measured?
  - Speed variations at which the star moves toward and away from our vantage point on earth
- Cannot determine the mass of the planet detected unless the inclination of the orbit is known.

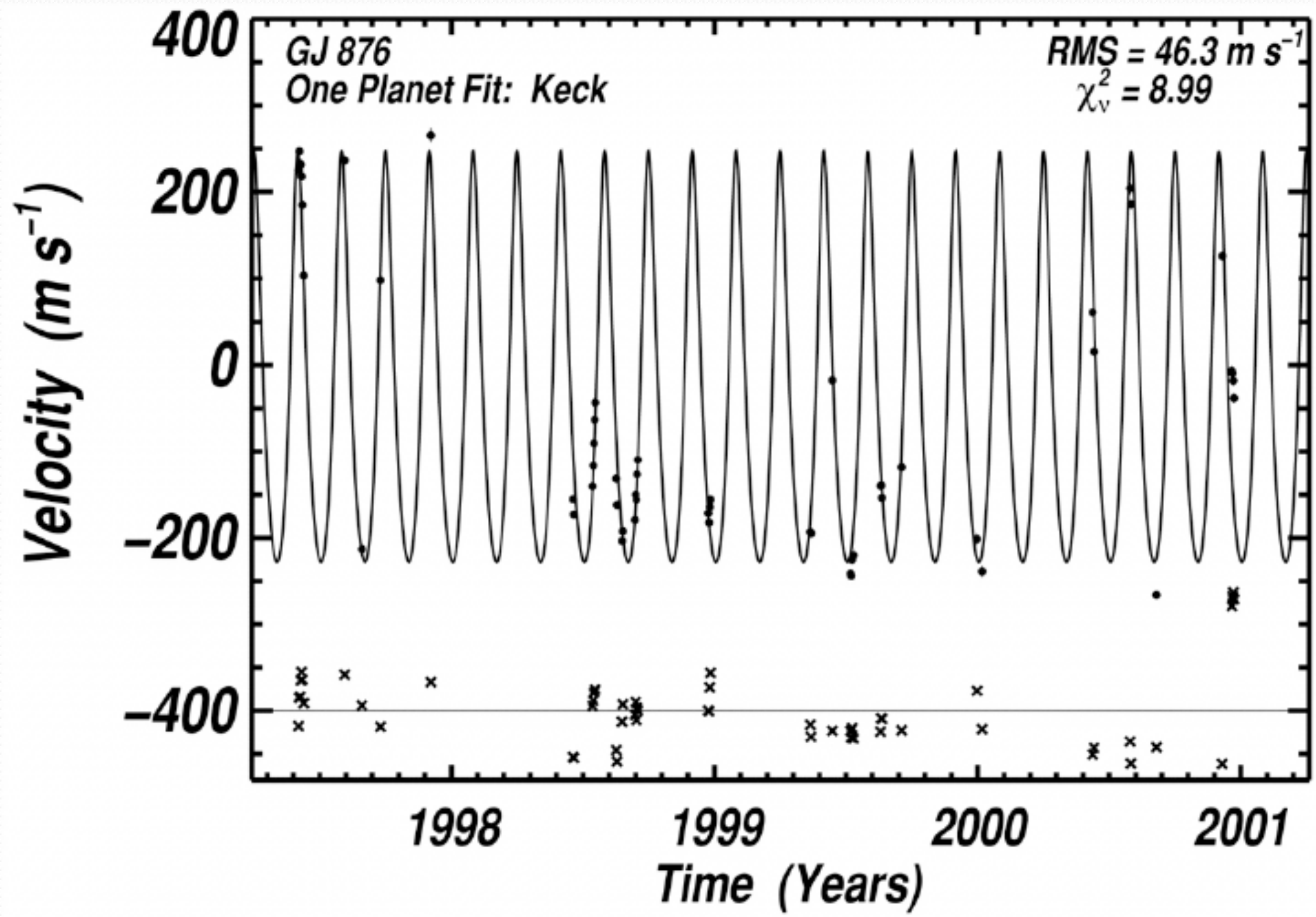
Radial Velocity Technique

- Advantages:
  - Clearly effective at identifying new exoplanets
  - Can find exoplanets oriented at many inclination angles and at a wide range of orbital distances from the central host star
- Disadvantages
  - Restricted to observing host stars which are: slow rotators, have low activity levels, and are single stars

Radial Velocity Technique: Instruments

- HARPS (High Accuracy Radial Velocity Planet Searcher spectrograph)
  - Very high precision (precision ~ 1 m/s)
- MARVELS (Multi-Object APO Radial Velocity Exoplanet Large-area Survey)
  - 6 year survey designed to monitor radial velocities of 11,000 stars
  - Can observe 60 stars simultaneously
  - Less precise than HARPS (precision ~ 25 m/s)

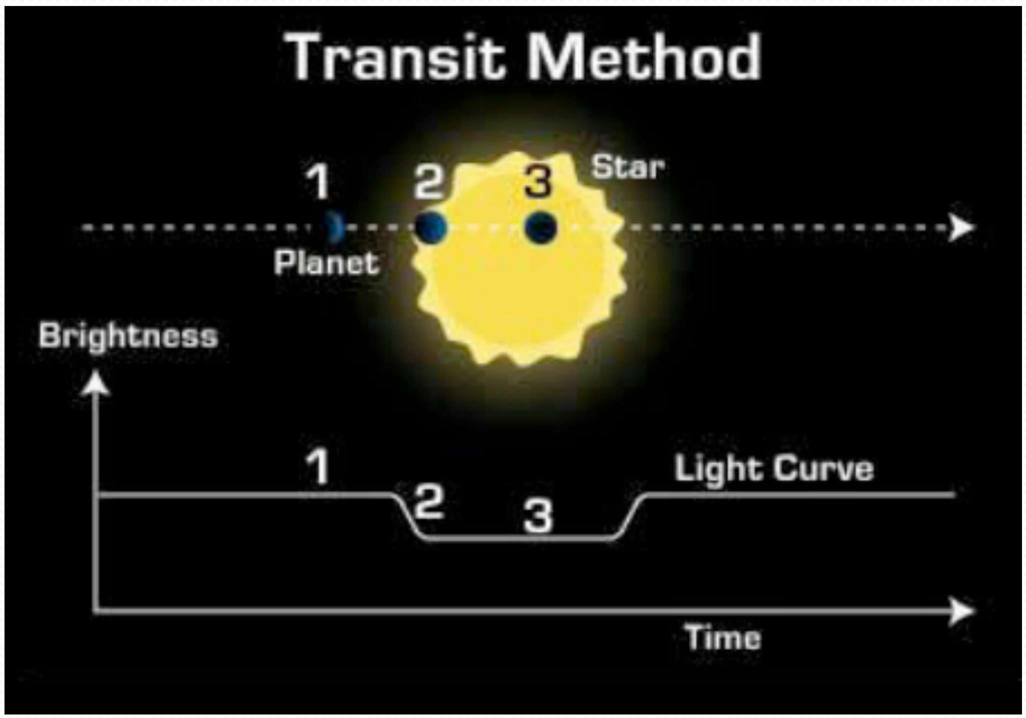
Radial Velocity Example: GJ 876



Marcy et al 2001

Planet Detection Techniques: Transit Photometry

- An exoplanet which occults its parent star will block out a small amount of light emitted by the central star in a repeatable fashion

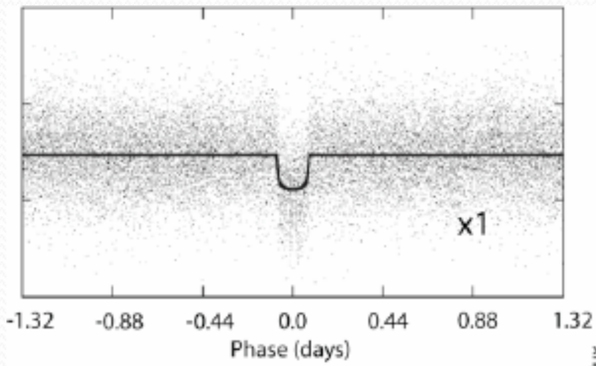


http://enersec.org/db3/00265/enersec.org/_uimages/transit-JPL.jpg

Transit Photometry

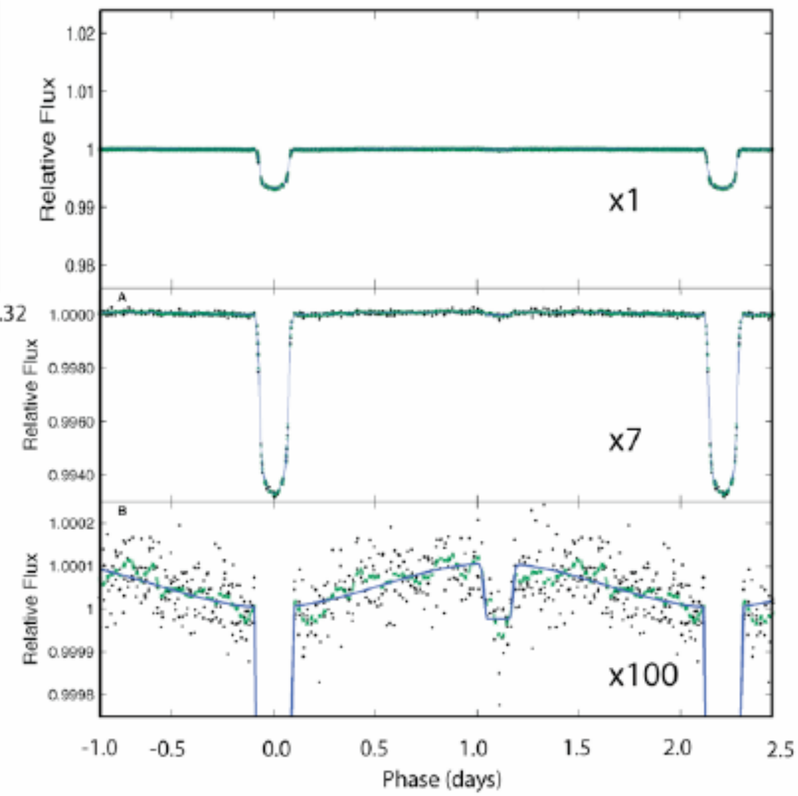
- Advantages
  - Using transit depth, duration and period, one can accurately determine the mass and radius of the transiting planet
  - Knowing the radius of the planet we can determine the density as well as the composition
  - Detects earth size planets (or smaller)
- Disadvantage
  - Requires a near edge on geometry

Transit Data



16,620 HATNet data points (57.7 days of data)

HAT-P-7b data from the ground
A. Pal et al., 2008

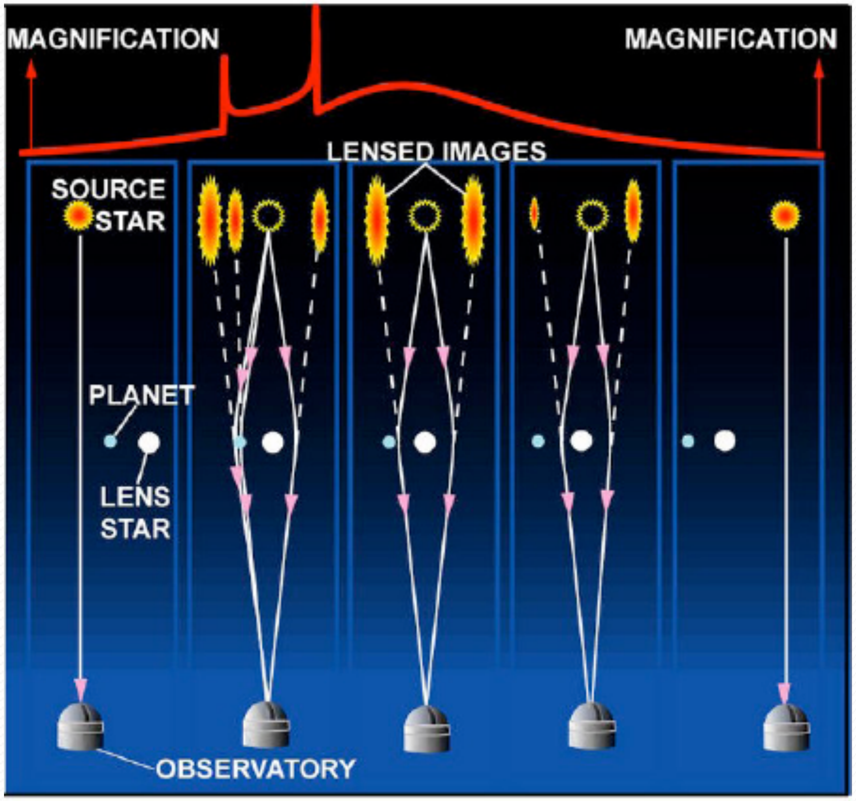


Kepler Commissioning data (10 days)
W. Borucki et al., 2009

http://kepler.nasa.gov/about/1stlight/ffi-inverted.html

Extrasolar Planet Detection Techniques: Microlensing

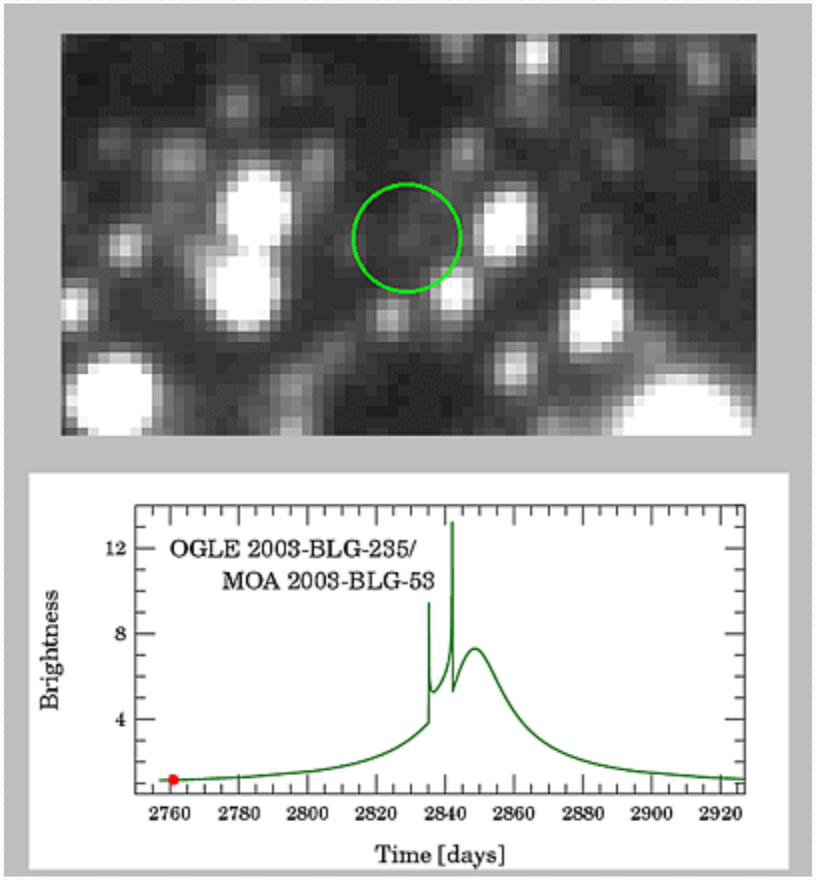
- Light from a distant source is bent around a lensing object
    - Causes light from a distant source to be magnified
    - If lensing object has a planet the planet will induce a smaller secondary magnification of distant source



http://ogle.astrouw.edu.pl/cont/4_main/epl/blg235/sch_23553.jpg

Microlensing: OGLE 2003-BLG-235

- First exoplanet detected via microlensing.
  - Mass = 1.5 to 2.5 Jupiter masses
  - 3 AU from host star
  - Located around 30,000 light years away
- 8 exoplanets found via microlensing to date



http://web.ipac.caltech.edu/staff/skane/teaching/as3012/lecture04_ani3.gif

Microlensing: strengths and weaknesses

- Advantages
  - The method can detect earth mass planets at small orbital separations from host star
    - A large microlensing survey could yield the frequency of exo-earth's
- Disadvantages
  - Frequency of observing a lensing event is low
  - Extracting fundamental parameters for exoplanets can be tricky (mass, distance from host star)

Extrasolar Planet Detection Techniques: Astrometry

- Exoplanets gravitationally interact with their host stars inducing a wobble in the host stars motion on the sky
  - Involves accurately measuring the position of the star on the sky to record this wobble
- Method
  - First measure a host star's proper motion, then search for deviations from this proper motion (need to observe long enough to record 2-3 orbits of any exoplanet residing in the system).

Astrometry

- Advantages
  - Can yield accurate exoplanet masses
- Disadvantages
  - Need to use Hubble Space Telescope or Hipparcos
  - Observationally Expensive

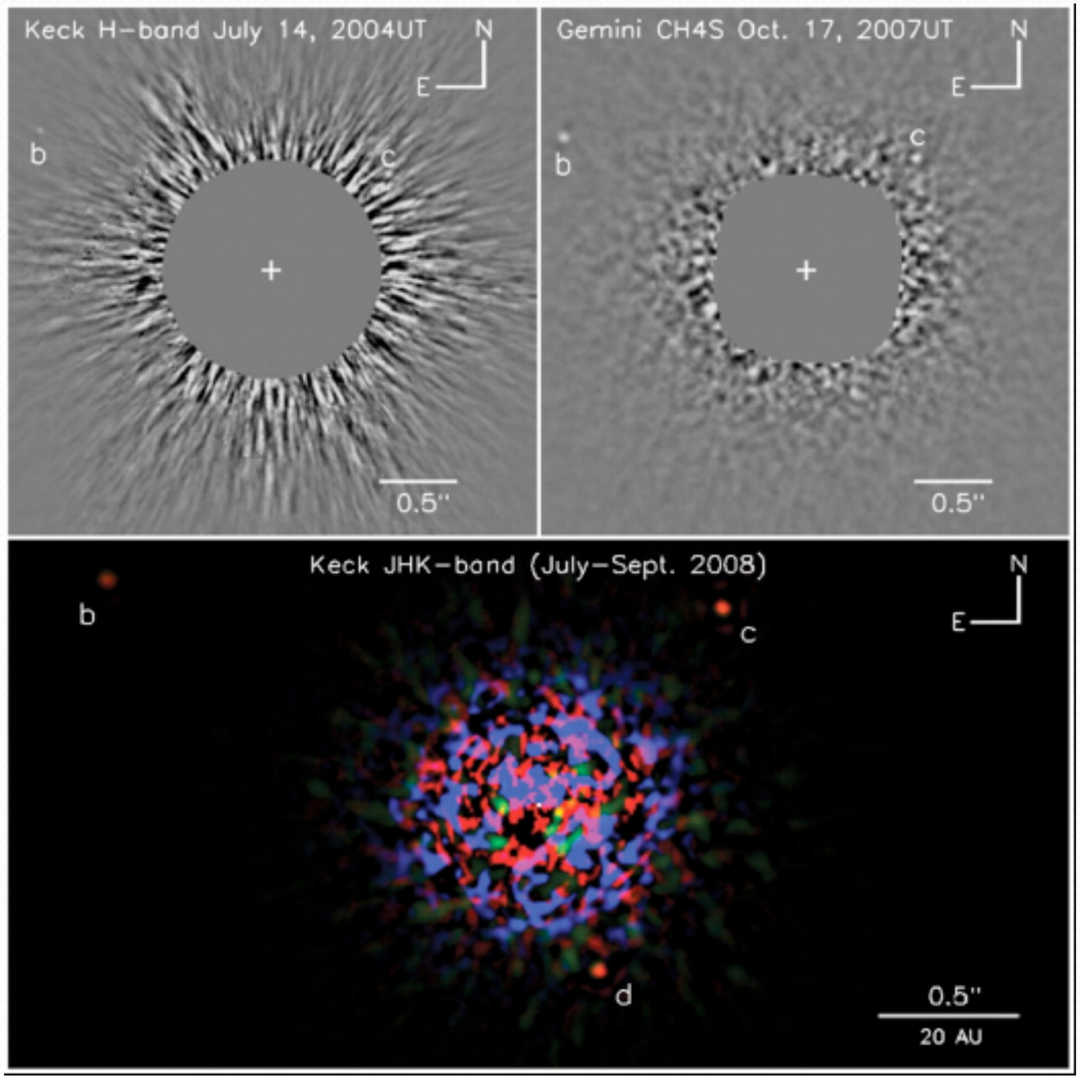
Extrasolar Planet Detection Techniques: Direct Imaging

- Obtaining an image of an exoplanet's thermal emission or light scattered off the exoplanet's atmosphere
- Requirements
  - 2 or more detections, to confirm suspected exoplanet is orbiting host star
  - High contrast imaging, coronagraphy

Direct Imaging Results HR 8799

- First imaged exoplanetary system in 2008
- Exoplanets imaged with near-IR Adaptive Optics instruments at Gemini and Keck observatories

HR 8799

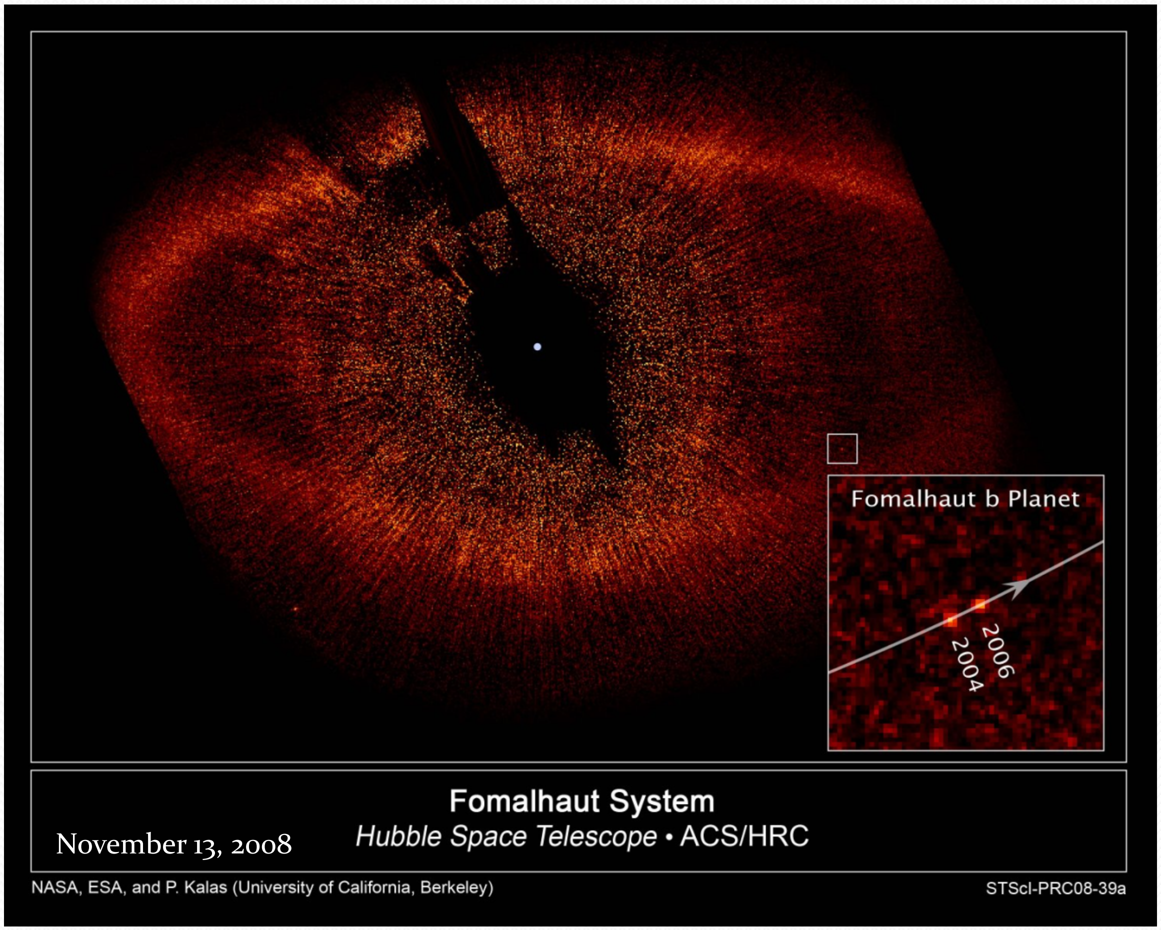


Marois et al 2008

HR 8799

- 3 imaged planets:
  - HR 8799b: 7 Jupiter masses; 68 AU from star
  - HR 8799c: 10 Jupiter masses; 38 AU from star
  - HR 8799d: 10 Jupiter masses; 24 AU from star

Direct Imaging Results: Fomalhaut b



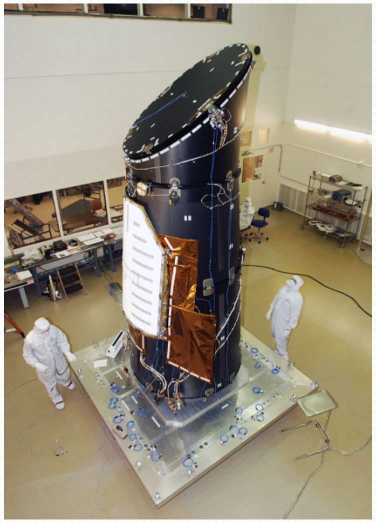
http://science.nasa.gov/headlines/y2008/images/fomalhaut/289899main_fomalhaut_actual_HI.jpg

Fomalhaut b

- Observed with Hubble Space Telescope imaged with a coronagraph
- Mass < 3 Jupiter masses
- Period of orbit: 872 years
- Unexpected features
  - Planet is 100x brighter than a gas giant should be
  - Planet's color is bluer than expected
  - Interpretation: Fomalhaut b might have a circum-planetary disk, extending 30 times the radius of Jupiter

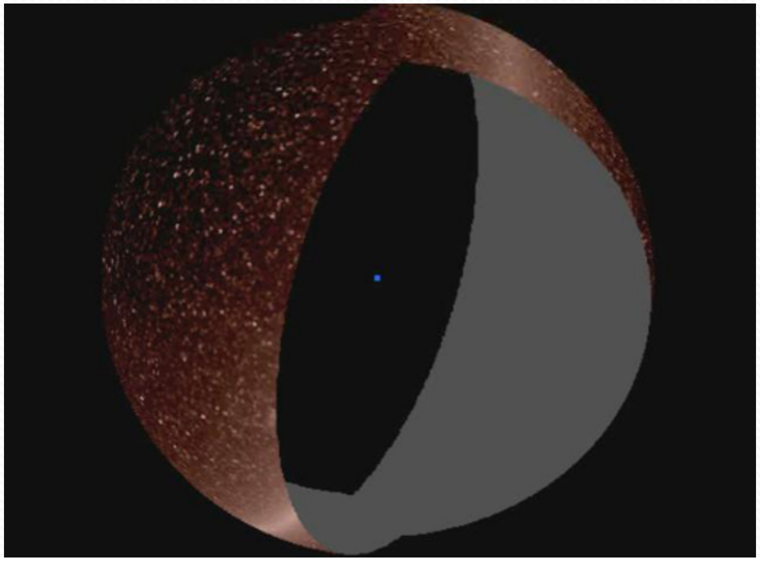
Future Missions: Kepler

- NASA space telescope launched March 6, 2009
- First light image takes April 8, 2009
- Staring at a region in the sky near Cygnus continuously for 3-5 years
- Wide field survey for transiting exoplanets
  - Will be able to detect earth size planets



Future Missions: WISE

- Wide Field Infrared Survey Explorer (WISE)
  - Will survey the entire sky in the infrared
  - Acquire large amounts of images to be studied by scientists for years to come
  - To launch on December 9, 2009
  - Survey Strategy:



Conclusion

- Over 400 planets have been detected thus far
- With advances in technology and newer missions, this number will increase rapidly over the next couple years
- The more exoplanets we discover, the more better we come to understand our solar system and the universe itself.