The Search for Exoplanets

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Formation of Solar Systems

• Our solar system is not unique.
• Similar processes most likely have occurred around other stars.
• Assuming similar events have happened around other stars, it is useful to mention current thinking regarding the formation of a solar system.
Interstellar Cloud
Interstellar Cloud Collapse

- Cloud begins to condense.
- Can be caused by the gravity of nearby galaxies or stars.
- Shock waves from supernovae can also contribute.
- Collapse is slow at first but accelerates rapidly.
Rotating Disk Formation

• If the cloud was rotating (has angular momentum), as it concentrates it will rotate faster.
• The rotation flattens the cloud and concentrates the mass in the center forming a disk.
Protostar

- The loss of gravitational potential energy causes heating.
- Gravity compresses gas and dust in the center.
- Pressure and heat increase.
Fusion Begins

• Heat and pressure increase.
• Fusion of hydrogen to helium begins.
• Solar radiation in the form of light and other EM radiation begins.
Planetesimals Form

- Substances condense to solid, liquid and gas depending on their proximity to the young star.
- Accretion occurs and forms planetesimals.
- Further growth occurs when they collide and merge.
Gas Giant Formation

- Usually the first planets to form.
- Icy planetesimals, gas and dust accrete to form the gas giants.
- Gas giants form equatorial disks which condense to form moons.
Inner Planet Formation

- Also formed by merging of planetesimals.
- Composed primarily of refractory elements and are rocky and dense.
- Most of the gas in this area accretes to the sun.
Terrestrial Planets

• Close to the size of Earth and have solid, rocky surfaces.
• Some of them may have atmospheres and might harbor the conditions for life (liquid water and moderate temperatures).
Asteroids and Comets

- Leftover debris from the formation of the solar system forms asteroids and comets.
- Asteroid belts contain the planetesimals which could not accrete because of gas giant’s gravitational pull.
The challenges of observing extrasolar planets

- Planets don't produce any light of their own, except when young.
- They are an enormous distance from us.
- They are lost in the blinding glare of their parent stars.
- Like trying to see a moth by a search light thousands of miles away.
Present methods of observing Exoplanets

- Radial Velocity Method (Doppler Shift).
- Astrometric Measurements.
- Transit Photometry Method.
- Gravitational Microlensing.
- Direct observation.
Radial Velocity Method

Looks for tiny shifts in the light spectrum of a star that indicate that it is moving ever so slightly. When it is moving towards Earth the star's spectrum shifts slightly towards the blue, and when it is moving away from Earth it shifts towards the red. If the spectrum shifts occur at fixed regular intervals it indicates that the star is WOBBLING back and forth at a fixed rate. This can mean that the star is moving to the tug of an invisible planet that pulls it back and forth as it orbits. The majority of exoplanets discovered to date were found by this method.
Doppler Shift due to Stellar Wobble
Advantages

• Very successful method for detecting exoplanets.
• Takes advantage of great strides in the sensitivity of astronomical spectroscopes, which can detect even very slight movement of a star.
Drawbacks

• Can only detect the movement of a star towards or away from the Earth.
• If the orbital plane of the distant planetary system appears "edge-on" when observed from the Earth the entire movement of the star will be towards or away from the Earth. The mass of the planet will be accurately measured.
• “Face-on” will yield no results.
• In between will yield highly inaccurate masses.
Astrometric Measurements

- Precision measurement of stars' locations in the sky. When planet hunters use astrometry, they look for a minute but regular WOBBLE in a star's position.
- If such a periodic shift is detected, it is almost certain that the star is being orbited by a companion planet.
Advantages

• The most sensitive method for detection of extrasolar planets.
• The future SIM mission is so sensitive that it has the potential of detecting an Earth-mass planet orbiting within its star's habitable zone.
• Astrometry does not depend on the distant planet being in near-perfect alignment with the line of site from the Earth, and it can therefore be applied to a far greater number of stars.
• Unlike the radial velocity method, astrometry provides an accurate estimate of a planet's mass, and not just a minimum figure.
Drawbacks

• Discovering extrasolar planets through astrometry is extremely hard to do.
• It requires a degree of precision that has seldom been achieved even with the largest and most advanced telescopes.
• SIM and Gaia will likely address many of the difficulties and produce measurements of unprecedented accuracy.
Transit Photometry Method

- Detects distant planets by measuring the minute dimming of a star as an orbiting planet passes between it and the Earth.
- The passage of a planet between a star and the Earth is called a "transit".
- If such a dimming is detected at regular intervals and lasts a fixed length of time, then it is very probable that a planet is orbiting the star and passing in front of it once every orbital period.
Transit Photometry

Diagram showing the transit of a planet across the face of a star, with a graph indicating the change in brightness over time.
Advantages

• One of the most sensitive methods for detecting extrasolar planets.
• The "Kepler" mission scheduled to launch early in 2009 uses photometry to search for extrasolar planets from space.
• The spacecraft's sensitivity will be such that it can detect Earth-sized planets orbiting at an Earth-like distance from their star.
• No other method currently proposed can match this sensitivity.
Drawbacks

• A transit must occur. This means that the distant planet must pass directly between its star and the Earth. Unfortunately, for most extrasolar planets this simply never happens.

• In order for a transit to occur the orbital plane must be almost exactly "edge-on" to the observer, and this is true only of a small minority of distant planets.
Gravitational Microlensing

- Microlensing is an astronomical effect predicted by Einstein's General Theory of Relativity. According to Einstein, when the light emanating from a star passes very close to another star on its way to an observer on Earth, the gravity of the intermediary star will slightly bend the light rays from the source star, causing the two stars to appear farther apart than they normally would.
Advantages

- Microlensing is capable of finding the furthest and the smallest planets.
- Is most sensitive to planets that orbit in moderate to large distances from their star.
- Microlensing searches are massive, targeting tens of thousands of planets simultaneously. If a microlensing event takes place anywhere within the observed starfield, it will be detected.
Drawbacks

• Planets detected by microlensing will never be observed again.
• Microlensing events are unique and do not repeat themselves.
• The distance of the detected planet from the Earth is known only by rough approximation.
• Dependent on rare and random events - the passage of one star precisely in front of another, as seen from Earth.
Direct Observation

Fomalhaut System

Hubble Space Telescope • ACS/HRC

NASA, ESA, and P. Kalas (University of California, Berkeley)
Advantages

• There is no substitute to actually seeing a faraway planet, and in this respect direct imaging is the holy grail of planet hunting.

• Works best for planets that orbit at a great distance from their stars, and for planetary systems that are positioned "face on" when observed from Earth.

• This makes it complimentary to the radial velocity method, which is most effective for planetary systems positioned "edge-on" to Earth and planets orbiting close to their parent star.
Drawbacks

- With current observation technology direct imaging is possible only on very rare occasions.
- It is most likely to succeed when conditions are just right, namely when a bright planet orbits at a great distance from a nearby star.
- Not a good candidate for large-scale surveys searching for new exoplanets.
Planetary Zoo

• Hot Jupiters
• Hot Neptunes
• Cool Giants
• Super Earths
Hot Jupiters

- Hot Jupiters are gas giants, meaning that they are at least 20% as massive as Jupiter, with a bulk composition that is typically at least 80% hydrogen. They have semimajor axes smaller than 0.1 AU and orbital periods of 10 days or less.
- The first exoplanet detected in orbit around a main sequence star was 51 Pegasi b.
A Transiting Hot Jupiter
Hot Neptunes

• Short-period planets consists of Neptune-mass objects on orbits that are typically smaller than Mercury's.

• The mass range of these planets begins at about 10 Earth masses (MEA), the minimum needed to accrete and sustain a substantial hydrogen atmosphere, and may rise to the vicinity of 60 MEA. Most are less massive than 35 MEA. They are somewhat heavyweight cousins to the ice giants in our Solar System. Given their warmish to hot orbits, this inevitably suggests the name Hot Neptunes.
Hot Neptune
Cool Giants

• Once a rarity, cooler gas giants with semimajor axes of 0.5 AU or more are now regularly reported.
• They currently constitute more than half of all detected exoplanets.
• Most of this population travel on orbits far more eccentric than those of the Solar planets.
Cool Giants
Super-Earths

- Super-Earths have masses between 2 and 10 times that of the Earth. There are well over a dozen candidates in this mass range.
- The term Super-Earth refers only to the mass of the planet, and does not imply anything about the surface conditions or habitability.
- An alternative term "Gas Dwarf" may be more accurate for some examples, especially higher mass ones.
Super Earths
Goldilocks Planets

- The Holy Grail of planet hunters is to find planets in habitable zones.
- Gliese 581c has a mass of at least 5 Earth masses and a distance from Gliese 581 of 0.073AU is on the "warm" edge of the habitable zone around Gliese 581 with an estimated mean temperature of 40 degrees Celsius.
- Gliese 581d does in fact lie within the star's habitable zone, with an orbit at 0.22 AU and a mass of 7.7 Earths.
How are We Doing? (as of December 2011)

- Stars with planets: 573
- Exoplanets found: 2326
- Earthlike exoplanets found: 0
In the Future

• Find terrestrial planets in the Goldilocks zone.
• Find some evidence of life on some planet.
• We might even find ...........
Suggested Websites

- [http://www.deepfly.org/TheNeighborhood/7b-ExoplanetaryOverview.html](http://www.deepfly.org/TheNeighborhood/7b-ExoplanetaryOverview.html)
- [http://www.public.asu.edu/~sciref/exopInt.htm](http://www.public.asu.edu/~sciref/exopInt.htm)