Lecture 7

The Search for Extrasolar Planets

Techniques used:

Wobbles of the central star due to planet's mass
- astrometry
- radial velocity (doppler shift) – **this is the main one at present**

Transits of the planet across the star

Gravitational lensing (microlensing)

Direct detection of the planet via imaging (in infrared or visible "light"

Planetary systems are believed to generally align in a plane (based on our models of planetary formation from a disk-shaped nebula).

Relative to our viewpoint, we may be viewing a system from directly above/below (top image), directly from the side (lower image) or somewhere in between.

Key point: Different detection methods work better or worse, depending on how we view the extrasolar system.

Stellar wobbles (astrometry) – works best if looking down on plane of planetary system, for planets with large orbits (need to watch for a long time) and for stars that are nearby

Until 2009, no exoplanets had been detected using astrometry. In 2009, it was announced that an exoplanet had been detected around a small star about 19 light years away using astrometry. As of July 2010 – not clear that VB 10 actually has an exoplanet – has been challenged – stay tuned …

In order to understand the radial velocity method (and the direct imaging methods), we need to review spectra briefly.

Because of its electric and magnetic properties, light is also called **electromagnetic radiation**

Visible light falls in the 400 to 700 nm rang

Experiments show that solids, liquids, and dense gases (like our sun) emit continuous spectra due to temperature – thermal or blackbody emission

Experiments with gases and prisms showed that substances can absorb parts of any light that shines on them. These substances can re-emit that absorbed light at a later time. An emission line spectrum is equivalent to thermal emission by the cloud of gas.

The photospheres of all stars are cooler than the stars' interiors and produce absorption lines, which we can identify

The wavelength of a spectral line is affected by the
relative motion between the source and the observer

Doppler Shift

Red Shift: The object is moving away from the observer
Blue Shift: The object is moving towards the observer

Stellar wobbles – radial velocity (doppler shift)
Looking at radial velocity – get best data if viewing system edge on – get no data if looking down on star's rotational axis

The radial velocity method can currently only find giant planets relatively close to their stars
Observe:

- the orbital period
- the average distance between the planet and its star
- the eccentricity (circularity) of the planet's orbit
- sometimes evidence for more than one planet
- a lower limit on the mass of the planet

First results – 51 Pegasi b discovered in 1995
51 Pegasi is a G star just a teensy bit brighter than our sun located about 51 light years away – note naming convention for planets (a reserved for sun, planets are b, c, etc.)

More examples – not important to know or write down specific ones

Radial velocity (doppler) technique was first way we discovered exoplanets.

Surprises: 1) massive planets close to their stars (hot Jupiters) – didn't fit models for forming planetary systems

Radial velocity (doppler) technique was first way we discovered exoplanets. Surprises:

Surprises: Many of the orbits are eccentric (fairly elliptical) – also didn't fit the model we had for forming our solar system.

But – This doesn't mean that these kinds of systems are the most common in our galaxy – this technique can only find "hot Jupiters".

But – we have found quite a few of them (hundreds).

Planetary transits – detect planets when a star's light dims because the planet passes in front of it – need to view planetary system close to edge on – more likely for "hot Jupiters" – amount of dimming depends on area of star covered (so bigger planet) and more likely to observe for a rapid orbit (close in).

The amount of dimming depends on ratios of areas of star and planet – for a distant viewer, would see about 1% dimming by transit of Jupiter; but only about 0.008% for Earth

HD209458b - 0.6 Jupiter mass – first planet discovered via transits

The Extrasolar Planets Encyclopedia lists 87 planets and 87 planetary systems as of July 2010 discovered by transits – it states that 4 are multiple planet systems – obviously there is a mistake – either 87 planets in 83 or less systems or more than 87 planets in 87 systems. The table of planets lists 87 planets, so it must be 87 planets in 83 or less systems. The diagram associated shows 86 planets.

Gravitational Lensing/microlensing

Einstein's theory of general relativity includes the idea that any object with mass bends or distorts space

When light from a distant object passes through the deformed space around a massive object, the light is bent and focused. This has been observed telescopically for light bent by nearby galaxies, which produces multiple deformed images of the distant object.

The idea behind microlensing that the deformed space around a star & its planets will focus or magify the light from a more distant

The Extrasolar Planets Encyclopedia lists 9 planets around 8 stars as of December 2009 discovered by micolensing.

When we look at this portion of spectrum for a planet, we call it the planet's "reflectance spectrum"

Another portion is planet's thermal emission -In reality, not close to a black body, due to surface composition

Direct Imaging - Seeing a planet's reflected sunlight or its own thermal emission

Direct detection
2M1207b
September 2004
Near infrared

Hubble Space Telescope launched in 1990 – not designed to look for extrasolar planets, but just (November 2008) gave us our first view in visible light of an extrasolar planet (Formalhaut b) – largest distance from star so far at ~115 AU

The results so far
So-called "hot Jupiters" (or "roasters") are relatively common – a few % of stars have them.

Temperatures of 1000K
Orbital periods of days

This is an old diagram when around 150 planets were known.

To date (July 2010) NASA's PlanetQuest site counts 453 exoplanets around 385 stars with ZERO earthlike planets. The Extrasolar Planets Encycolpedia site lists 464 planets. And more are being found every day. Last year I had a number from exoplanets.org, but they've revised their site and made it impossible to quickly obtain a number – but they do talk about their methodology

Discuss some recent press releases:
http://www.eso.org/public/news/eso1016/
http://hubblesite.org/newscenter/archive/releases/2010/15/full/

But what we want to find are Earth-like planets

For that, we need bigger or better telescopes

Planned or current missions to look for exoplanets:

Keck Interferometer and other ground-based telescopes

Hubble Space Telescope (NASA)

Spitzer Space Telescope (NASA)

JWST - James Webb Space Telescope (NASA)

COROT (ESA)

Kepler (NASA)

SIM – originally Space Interferometry Mission (NASA), now referred to as SIM PlanetQuest

HR 8799 planetary system – imaged in near infrared by Keck Observatory November 2008 – first image of multiple planetary system –shows 3 planets

10 Mj at 24 AU; 10Mj at 38AU and 7Mj @68AU
Star's spectra is complicated – considered both A and F

Spitzer Space Telescope launched 2003
Infrared telescope requiring that instruments be cryogenically cooled – ran out of coolant in May 2009 – reconfigured to act as "warm" telescope and is still finding neat things

Significant results:

February 2007 – took first spectra of atmospheres of two extrasolar planets

October 2008 – found two asteroid belts around the planetary system we've discovered closest to the Earth (around Epsilon Eridani)

HD 189733b is only slightly more massive than Jupiter (1.15x) and orbits its star every 2.2 days (semi-major axis is 0.03AU). Despite being tidally locked, the temperature varies only about 250K from the sun-facing side to the opposite side of the planet indicating atmosphere is moving rapidly to equalize pressure. Spectra of atmosphere indicates presence of methane and "significant amounts" of water vapor.

HD 209458b was the other planet whose infrared spectra was obtained by the Spitzer telescope. (This is the planet that was the first planet detected by the transit method using ground-based telescope). No water vapor was detected, but a peak at 9.65 micrometers was attributed to clouds of silicate dust in the planet's atmosphere. A more recent but controversial model based on Hubble Space telescope data suggests the presence of water vapor. In 2010, the European Southern Observatory announced the presence of carbon monoxide.

James Web Space Telescope:

large infrared-optimized space telescope scheduled for launch in 2014 (was 2013 in summer 2009)?

JWST will have a large mirror, 6.5 meters (20 ft) in diameter and a sunshield the size of a tennis court

JWST will reside in an L2 orbit about 1 million miles from the Earth

COROT
launched December 2006 – planned 2 ½ year mission
still operating

27 cm (10.6 inch) diameter telescope with spectroscopic instruments – placed in polar orbit

COROT has found four or six large planets (as of July 2010 was 6 last year) and has been first to see oscillations (sun quakes) around other stars – web site has been redesigned)

In Feb. 2009, COROT discovered the smallest exoplanet yet, which might be an "ocean planet" or one slightly smaller. It orbits at .017 AU around a K0 star, making one orbit every 20 hours. Its surface temperature is approx. 1800-2600 C? Rough estimates have a size 1.7 x Earth and mass ~5 x Earth

Kepler is basically a telescope with a 0.95 meter aperature designed to sit in an Earth-trailing heliocentric orbit - will survey a large number of stars for transits indicating planets - sensitive enough to detect terrestrial planets
launched March 2009
Will be able to find terrestrial-sized planets using transits, but has no spectral capabilities

http://planetquest.jpl.nasa.gov/missions/missions_index.cfm#

SIM - Space interferometry mission

to be launched in 2011 into Earth-trailing orbit

was supposed to make very precise measurements of positions of stars and thus will be making astrometric measurements capable of detecting planets ("down to a few Earth masses")

As of July 2010, on hold, may never be launched and has been scaled back and renamed SIM Planetquest or SIM ‘lite’

Detecting Life
NEED
(1) Small rocky planet
(2) Must be in the stellar habitable zone (HZ) - liquid water
(3) Not tidally locked (restricts location relative to star)
(4) Catch planet at the right time

If we can observe the spectra of an Earth-like planet, the things we want to look for are an atmosphere with molecules that aren’t in equilibrium with each other, and particularly evidence for free oxygen (ozone in this case).