SAO Essay Cover Page

Essay Title Looking for Extrasolar Planets

Looking for Extrasolar Planets (1,965 words)

Introduction

What is an extrasolar planet, an exoplanet? Indeed, what is a planet? And why are we so interested in finding them? What are the various ways that scientists look for them? Is it a difficult task? Are some methods better than others? How many have we found to date, and what is the future of searches for these objects? These questions will be explored in this essay.

A massive definition

When is a planet not a planet? At what size does it become a star? In the past, these were considered questions with fairly straightforward answers. A star fuses Hydrogen into Helium and produces its own light. A planet (originally from the Greek phrase *asteres planetai,* for 'wandering star') is simply an object with insufficient mass to ignite the fusion process, and therefore is seen only by reflected light.

More recently, the category 'planet' was carefully re-defined by the IAU's Working Group on Extra-Solar Planets, as having three criteria: in orbit around the Sun, in hydrostatic equilibrium (spherical), and has cleared it's orbital neighbourhood. Pluto was thereby demoted. But this definition implies that only those qualifying bodies which orbit our Sun, are planets. Does this mean that worlds orbiting other stars are, strictly speaking, not planets?

In common parlance, even astronomers get caught up in terminology. Bailes et al (2011) recently described a binary pulsar system where the primary had stripped off nearly all of the mass of its partner, referring to the smaller body as a planet instead of a stellar remnant of planetary mass. So, where is the boundary, and is it only about mass? Current theory has it that anything less than about eighty Jupiter masses ($80M_j$) can't provide enough internal gravitational pressure to start fusing Hydrogen in the core, but, somewhat paradoxically, a body with more than about $13M_j$ can actually fuse a small amount of deuterium before cooling off like a planet. Is this then, a star that turns into a planet?

Brown Dwarfs, so named by Jill Tarter in the 1970s (Jayawardhana 2011), are objects that straddle the star/planet definitions. They're smaller than the lowest mass true Hydrogen-burning, stars (Red Dwarfs) and bigger than gas giants like Jupiter (Darlingweb). Now, Brown Dwarfs have been shown to have insufficient core temperatures to burn Lithium (D'Antona & Mazzitelli 1985), and Rebolo devised a 'Lithium test' for classifying such sub-stellar planets (Jayawardhana 2011) which was first used successfully in 1996 for a star in the Pleides called PPL 15 (Rebolo 2000, Basri et al 1996).

Perhaps I'm over-analysing. For the sake of the search for another world which may sustain life (which is the basic premise for exoplanet searches), all we need to find is a body which has some of the qualities of Earth. That is, a reasonable Earth facsimile in terms of size and composition, located in a Habitable Zone around another star. Easy!

In fact, it is actually quite difficult to gather sufficient data from such distant objects to comply with such a specific definition, so astronomers looking for exoplanets fall back on the limiting factor of 'Jupiter masses'. For current purposes, an object of less mass than $13M_j$ orbiting a star other than ours, is considered to be an exoplanet, and worthy of investigation.

Detecting Them

As of December, 2010 there were nearly 500 exoplanets discovered using a range of techniques from direct imaging to optical and radio astrometry, to transits, Doppler and pulsar timing (Exoplanetweb). But in 2009, banking on the transit method, NASA launched a photometer nearly 1m in diameter (Discoveryweb). This mission, named Kepler, as of September, 2011 had identified 1781 candidates and currently has 21 confirmed exoplanets, ranging from less than 0.06Mj to over 8 Mj, most with orbits similar in size to Jupiter (Keplerweb, SkyandTelescopeweb).

Jean Schneider, from the French Laboratory of the Universe and Theories, catalogues many of the current efforts (some successful), both ground and space-based, to find exoplanets, ranging from the XO Planet Project using photometric transit techniques, to Robonet looking for microlensing events towards the galactic bulge (Extrasolarweb). But let's first track a short history of some of the detection techniques (in bold) and their successes.

'Firsts' have an interesting etiology. The *proper* motion of a star (first described by Halley in 1718) is its apparent movement across the celestial sphere – a vector of real space motion. Using simple **astrometric techniques** to describe the 'wobbly' proper motion of the binary 70 Ophiuchi, Jacob (1855) may be regarded as the first to seriously suggest an exoplanet, as the cause of the wobble. To get clear results, astrometric techniques obviously work best for nearby, small stars with large planets in wide orbits, thereby, however, biasing the results towards these types of worlds. Wider orbits are slower orbits, so the determination of orbital parameters can take several years of observation by this technique. Nonetheless, radial velocity measurements taken over several years from 2003, eventually bore fruit (Setiawan et al 2007).

Jacob's result was incorrect though, and subsequent astrometric detection of exoplanets remained plagued with inaccuracies and errors for several decades (Jayawardhana 2011) until, in the 1980s, with the advent of digital technologies, the **Doppler method** was introduced by Walker (2008). Good for stars at any distance, and especially for short-period planets, the Doppler method detects the spectral shift induced in a star's light as its *radial* velocity is affected by an orbiting body. This method requires the observed system to be relatively 'edge on' with respect to Earth, and the closer we're looking along the orbital plane of the system, the greater the red- and blue-shifted signal, so this method also has obvious sampling limitations.

Almost as an aside, direct ground-based observation of exoplanets was continuing to develop also, but **direct observation** has an intrinsic drawback – the primary star's brightness. So development of quality coronagraphs in the late 1990s, which block the star light, allowed, for instance, the faint companion of Gliese 1229 (cleverly called Gliese 1229b!) to be found by direct observation, its status as an exoplanet confirmed with spectroscopic analysis of the atmosphere which revealed the existence of methane – not possible in the heat of stellar atmospheres (Jayawardhana 2011).

The Doppler method was used for what turned out to be a (self-declared) erroneous discovery of the first exoplanet by Bailes et al in 1991, the milestone subsequently being achieved in 1992 (Wolszczan & Frail 1992). After careful examination of their Arecibo radio signal from pulsar PSR B1257+12, it was concluded that slight, regular Doppler shifts (the **Pulsar timing** method) in the signal were due to two planets of at least three Earth-masses orbiting the pulsar.

Notwithstanding the poorly understood notion of a planet orbiting in the deadly vicinity of a pulsar, this highlights a disadvantage with the Doppler method – only the lower mass threshold can be determined. Since we don't know the angle of inclination of the planet's orbit, we can't know its orbit, and hence can't constrain it's mass. The Doppler method also suffers lack of precision if the primary is a giant star with a surging atmosphere – itself a source of red/blue shift (Jayawardhana 2011).

At about this point in our timeline (1995), improved spectrographic Doppler techniques resulted in an apparently astonishing discovery – a 1 M_j planet in a 4 day orbit around 51 Pegasi (Mayor & Queloz 1995, Nakajima et al 1995). Though contrary to the existing paradigm modelled on our Solar System, which describes rocky inner-system planets and gaseous outer-system planets, derived from a circumstellar debris disk, this may not have surprised Struve who, long before, speculated the existence of 10M_j planets with periods of one day (Struve 1952).

Astrometric results are biased towards finding large planets with long periods, but now Doppler methods were biasing towards 'hot Jupiters' – large planets with short periods. Theoreticians debated the 'natural' progress of solar system evolution. The discovery of retrograde and highly inclined hot-Jupiter orbits was suggesting that planets can be captured and/or migrate within their systems much more often than was previously thought.

1999 saw the first successful use of the **transit method** for exoplanet detection (Charbonneau et al 2000). Building on existing radial velocity results showing an exoplanet around HD 209458, they confirmed a gas giant of about 1.27Mj. As the name suggests, this method relies on a dip in the light curve of a star as an orbiting planet transits its disk, and can easily be demonstrated with an experiment appropriate for secondary school classes (George 2011).

Gravitational lensing is an effect caused by the light from a distant object bending around an intervening massive body, on its way to us, a la Einstein (Renn et al 1997). **Microlensing** is the name given to this event when it involves a star as the intervening body, and a blip in the expected light curve for the lensing star indicates the additional lensing effect of a planet in orbit around the star. It is especially useful for detecting smaller planets, not too close to their star, but otherwise in a range of orbital distances such that studies of galactic planetary demographics can be attempted (Gaudi 2010).

This technique was first successfully used to find a 1.5M_j in 2004 (Bond et al 2004), and corroborated a year later with the discovery of a similarly sized exoplanet (Udalski et al

2005). Several thousand microlensing events have been logged as of February, 2010 (Gaudi 2010).

Each of the various detection techniques requires follow-up verification using other astrophysical methods before a candidate can be considered to actually qualify as an exoplanet, and also, new procedures are constantly developing. One of several hybrid and interesting new techniques involves the detection of stellar, unpolarised light which is subsequently polarized by an exoplanet's atmosphere, and such **polarized light** projects as PlanetPol (Hough et al 2006) and SPICES (SPICESweb) have been developing these hopeful methods.

So, Where are we?

At the time of writing, the project receiving most public attention is NASA's Kepler mission, simply because of the sheer number of exoplanet candidates. Earlier this year Kepler found its first rocky planet named Kepler 10-b (Batalha et al 2011), and also a half dozen planets around Kepler-11 (Lissauer et al 2011) but other projects are adding to the list. The CoRoT project (a French collaboration space telescope launched in 2006) found ten transiting planets mid-year (Exoplanetarchiveweb), and possibly a habitable planet has been found orbiting a K5V star using radial velocity data from HARPS (Kaltenegger, et al 2011).

Fascinating outcomes are a byproduct of the hunt for extrasolar planets. Doyle et al (2011) have recently published (on Kepler data) details of an exoplanet dubbed Tatoinne or Kepler-16b (SkyandTelescopeweb) orbiting a binary of small stars, with an amazing level of definition of orbital parameters (Kepler16bweb). And even the public have contributed positively to the search: Fischer et al (2011) found the first exoplanet candidates from publicly available Kepler data, and to date, 69 candidates have been found by a public science online scheme called Planet Hunters (Zooniverseweb).

A most intriguing discovery is that of lone, orphan planets not gravitationally attached to any star. A NASA/Osaka University collaboration has recently discovered a handful of these wandering rogues, and suggest that there may be twice as many of them as there are stars (JPLNewsweb, Sumi et al 2011). This will clearly have ramifications for the theory of evolution of solar systems.

As evidenced from the contemporary nature of referenced material in this essay, it's obvious that this is a new, productive and exciting field of astronomy, engaging both the public and astronomers in the science and the speculation about if, where, and even how, exoplanets exist.

Star Date 30 Sep 2011: 474 stars orbited by a total of 688 confirmed planets, but none proven Earth-like (PlanetQuestweb, SkyandTelescopeweb, Exoplanetcatalogueweb). When will we strike pay dirt?

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