

Resource Letter: SEP-1: The Search for Extrasolar Planets

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This resource letter provides a guide to the literature on the methodologies employed in the search for extrasolar planets.

I. INTRODUCTION

The possibility of extra solar planets – and more importantly the possibility of intelligent life, has always intrigued humanity. As science continues its relentless march the possibility of high speed interstellar travel becomes more and more unfeasible; yet, we do not see a slacking of the basic human desire to discover that there is something else out there – space is indeed one of the last frontiers. As techniques are developed to systematically locate and catalog extra solar planets, in particular earthlike extra solar planets, our search at least becomes more methodical and better thought out.

Despite the incredible advances in telescope technology, it is still not feasible to search for extrasolar planets by means of visual observation with telescopes. Instead, we rely on the fact that a star's orbit is perturbed by the fact that another star is orbiting around it. By taking incredibly precise measurements of the orbit of a star, it is possible to determine whether or not a star has another body orbiting around it. With an accurate estimate of the mass of the star, we can go a bit further and describe the size and distance of the planet.

A. History

The desire to search for extrasolar planets surely dates back to the first time a human being pondered the heavens and considered the forbidden notion that the heavens might indeed contain other worlds, and not simply encompass the home of the gods. However, until recently, there was no way to act on such a desire, no way that would yield results in any case.

Beginning in the late 1800s claims were made that extrasolar planets had been discovered. However, these claims were all eventually proved to be either erroneous or binary star systems. In 1952 scientists moved one step closer to the day they would truly be able to say they had detected an extrasolar planet with a publication by Dr. Struve in *The Observatory*. He acknowledged that it would be possible to detect eclipsing systems by careful examination of their light curves. However, he strongly suggested that our best hope would lie in the direction of the study of Doppler shifting in the spectrum of a star due to its orbital perturbation due to a planet. With the benefit of having seen the future as he could not, it is now safe to say that this was an enlightening statement.

In the past years dramatic strides have been made in this area. There are now at least four techniques that have been employed with some success in searching for extrasolar planets.

These include techniques involving radial velocity measurement, astrometric wobbles, eclipses and gravitation lensing.

II. TECHNIQUES

A. RADIAL VELOCITY TECHNIQUE

The radial velocity technique operates by detecting perturbations in the radial velocity of the parent star through examination of the shifting in the stellar spectrum. However, this is easier said than done. The perturbation in the star's orbit due to Jupiter in our solar system is only 12.5 m s^{-1} .

$$v_{sun} = \frac{m_j}{M_{sun}} * v_j = 12.5 \frac{m}{s} \quad (\text{Eq. 1})$$

Yet in 1996 Marcy, Butler et al attained a precision of 3 m s^{-1} . By passing the incoming light through an iodide absorption cell before analysis they were able to have a precise scale against which they were able to measure the shifts in radial velocity. This technique requires a high signal to noise ratio and thus works better for planets closer to earth. It is also worth noting that for large, hot stars this technique is not effective as their spectra lack the structure required to perform this technique. Despite these limitations, this technique is by far the most predominant in current extrasolar planet searching.

B. ASTROMETRIC WOBBLES

Another technique works by searching for astrometric wobbles. Rather than searching for the perturbation in the star's orbit through the shifting of the spectra, this technique uses imaging to search for this effect visually. Unfortunately this technique requires extremely high powered telescopes and

observation periods on the order of months to years.

C. TRANSIT METHOD

A third technique involves looking for eclipses of the planet and its parent star. This method relies on searching for a change in the light reaching earth from a star due to the light being blocked by a planet. This technique has many limitations. To begin with, the orbit of the planet must be perfectly aligned with the line of sight of the observer for detection to occur; this precludes the discovery of most planets. Additionally, in order for the light output to change by an easily measured amount, planets that are large and close to a star as predisposed to being found.

About 20% of the planets found via the radial velocity technique have large masses and orbital periods of less than ten days. Of these "Hot Jupiters", about 10% of them are estimated to have orbital inclinations which will cause them to transit the star from our point of view. These planets are nothing like earths; however, for those interested in finding these planets, this method may prove effective. It has been proposed that large sky surveys can be performed to find numerous "Hot Jupiters" by this method in relatively short order.

D. GRAVITATIONAL MICROLENSING

The final and most exotic method currently in use takes advantage of the phenomenon of gravitational lensing. This method makes use of the fact that the gravitational field of a planet in effect creates a lens. When this gravitational lens is positioned correctly, it will cause the parent star to apparently shift with regard to the background of stars in the sky, implying the presence of a planet. This technique is most

useful for monitoring stars between Earth and the center of the Milky Way Galaxy, because the sky in that direction provides a multitude of potential background stars. It is interesting to note that this technique is the only one capable of detecting objects as small as .1 solar masses in earth like orbits. This requires continuous monitoring of the space between here and the center of the galaxy, however, as the chance alignment that produces micro-lensing is only likely to occur once. An earthlike planet of 5.5 solar masses was detected using this technique by Bennett, Beaulieu et al in 2006.

III. BOOKS

Books on the related subject, a good place to go for a more thorough discussion of the background and history of the search for extrasolar planets.

1. **Planet Quest: The Epic Discovery of Alien Solar Systems**, K. Croswell (Oxford University Press, Oxford 1997) {Absolutely recommended book. Tells a well rounded story of the search for Extrasolar Planets in a way that would make any author jealous, while managing to keep the book relevant to the aspiring Extrasolar planet astronomer}
2. **Extrasolar Planets**, P. Cassen (Springer, Berlin 2006)
3. **New Worlds in the Cosmos: the Discovery of Exoplanets**, M. Mayor (Cambridge University Press, Cambridge 2003)
4. **An Introduction to Modern Astrophysics – 2nd ed.**, B. Carroll and D. Ostlie (Pearson Education Press, San Francisco 2007) {This book is an introduction to all astrophysics but contains a good review of the details behind all of the above mentioned techniques}
5. **Extrasolar Planets: The Search for New Worlds**, S. Clark (Praxis, New York 1998)
6. **Infinite World : An Illustrated Journey to Planets Beyond our Sun**, R. Villard (University of California Press, Berkeley 2005) {An Illustrated Guide, but still a good introductory resource}

IV. JOURNALS

Peer reviews journal articles which go into great detail describing these techniques. A particular journal in which frequent articles are published on extrasolar planets is *Monthly Notices of the Royal Astronomical Society*. *The Observatory*, *Astrophysical Journal*, and the *Astronomical Society of the Pacific* are also worth consideration for review. Last, but far from least is the journal *Nature*, which thanks to its prestige and wide readership enjoys something of a feedback loop, maintaining it as one of the premier journals. *Nature* is always a good place to look for articles, especially when first starting out in a field as it prints both good reviews of recent research along with high quality normal journal articles.

V. SELECTED RESEARCH ARTICLES

Below are some selected research articles which should familiarize the reader more intimately with some of the specifics of the techniques employed in the field. The first article is of particular note as it represents the initial push for the use of Doppler Shifting to search for planets.

7. "The UNSW Extrasolar Planet Search: Methods and First Results from a Field Centred on NGC 6633," M.G. Hidas et al., *Monthly Notices of the Royal Astronomical Society* **360**, 703-717 (2005). {Paper detailing a massive survey of the sky, and how such a technique may allow more rapid discovery of extrasolar planets than the radial velocity technique}
8. "Upper limits on the hot Jupiter fraction in the field of NGC 7789," D.M. Bramich et al., *Monthly Notices of the Royal Astronomical Society* **367**, 1677-1685 (2006). {Using transit method upper limits are able to be placed on the fraction of hot Jupiters in a field}
9. "Discovery of a Cool Planet of 5.5 Earth Masses through Gravitation microlensing," Beaulieu, J.P. et al., *Nature* **439**, 437-440 (2006). {For those interested in a technical presentation of the

detection of planets through gravitational microlensing, this is a great place to start}

10. "Detection of an Extrasolar Planet Atmosphere," D. Charbonneau et al., *Astrophysical Journal* **568**, 377-384 (2002). {An innovative method to detect the atmosphere of an extrasolar planet}
11. "Observed properties of exoplanets: Masses, orbits, and metallicities," G. Marcy et al., *Progress of Theoretical Physics Supplement* **158**, 24-42 (2005).
12. "Detection of oxygen and carbon in the hydrodynamically escaping atmosphere of the extrasolar planet HD 209458b," A. Vidal-Madjar et al., *Astrophysical Journal* **604**, L69-L72 (2004).

(accessed March 25, 2007). {The Harvard Extrasolar Planet Detection Project}

20. "The Anglo-Australian Planet Search," <http://www.aao.gov.au/local/www/cgt/planet/at.html> (accessed April 10, 2007)
21. The Geneva Extrasolar Planet Search Programmes," <http://obswww.unige.ch/~udry/planet/planet.html> (accessed April 10, 2007)
22. "PlanetQuest: The Search for Another Earth" <http://planetquest.jpl.nasa.gov/index.cfm> (accessed April 10, 2007) {Nasa's webpage devoted to the search for "another earth"}

VI. GENERAL REVIEW ARTICLES

13. "Proposal for a project of high-precision stellar radial velocity work," O. Struve et al., *The Observatory* **72**, 199-200 (1952). {The first proposition to use Doppler Shifting to search for planets, an excellent introduction to the topic}
14. "Attaining Doppler Precision of 3 m s^{-1} ," R. P. Butler et al., *Astronomical Society of the Pacific* **724**, 500-509 (1996). {A discussion of an, at the time, novel technique to increase precision dramatically. Also a good article to read to gain an understanding of the field}
15. "Extrasolar Planets – Back in Focus," G. Marcy, *Nature* **391**, 127 (1998). {A slightly dated but still excellent review article}
16. "Extra-Solar Planets," M. Perryman, *Reports on Progress in Physics* **63**, 1209-1272 (2000). {A sweeping review}
17. "A Review of the Current Status of Follow-Up Techniques to Study Known Extrasolar Planets," D. Charbonneau, *IAU Symposium* **219**, 1-12 (2004). {A more recent overview}

VII. WEB RESOURCES

There are a number of websites on which you can view the progress of prominent research teams in this field. Some of the best are listed below.

18. "Exoplanets.org - Planet Search," <http://exoplanets.org/> (accessed March 25, 2007). {The California and Carnegie planet search - a forerunner in the field}
19. "Extrasolar Planet Detection with the AFOE," <http://cfa-www.harvard.edu/afoe/esp.html>