Finding extraterrestrial sites for thermophiles

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Abstract
Virtually our entire knowledge of the universe comes from two sorts of measurement of the electromagnetic radiation from the stars and galaxies within it; either their flux through relatively wide bandpasses (photometry), or measurements of the shape and wavelength of relatively narrow lines via spectroscopy. These techniques are now being used to discover planets outside our solar system, and perhaps in the next 10 years will begin to characterize them. If a serious search is to be made for extraterrestrial thermophiles, we need predictions for the effects of thermophiles on their host planets that are observable with these techniques. In this paper I shall outline what sorts of observation are likely to be used in the next 15 years for extra-solar planet work. All of the journal articles quoted here can be found through http://adsabs.harvard.edu/abstractservice.html, and often also accessed as preprints at http://uk.arxiv.org/form/astro%20ph?MULTI=form%20±%20interface.

Doppler wobble
Consider a binary system consisting of two equal-mass stars. One does not orbit the other, they actually orbit their common centre of mass. If one imagines reducing the mass of one of the stars until it has an Earth-like mass the centre of mass will move towards the other star, until it lies essentially at its centre, and the planet appears to orbit around the star. But for more massive planets the difference between the position of the common centre of mass and the centre of the star is not negligible. For example, the Sun and Jupiter orbit about a point roughly on the surface of the Sun. Thus if one studied the motion of the Sun, it would appear to orbit around this point. More specifically, if one measured its velocity using Doppler shift, for roughly half of Jupiter’s orbit the Sun appears to move towards an observer, and for half away from them. This motion is known as the Doppler wobble, and has been used to detect over a hundred planets orbiting other stars (see, for example, http://obswww.unige.ch/exoplanets/). For each planet one obtains a mass and an orbital radius (as a function of the unknown inclination of the plane of the orbit to the line of sight), and an orbital period.

The problem here is that the Doppler wobble has to be large enough to detect. This introduces a strong selection effect, since large Doppler wobbles are caused by massive planets close to their parent stars. Unsurprisingly, therefore, the results from this technique have been the discovery of Jupiter-mass planets in orbits with a radius a few times the Earth–Sun distance or less. With time, it is likely that Jupiter-mass planets at larger orbital radii will be discovered (simply because the orbits are of the order of 10 years), but the technique will ultimately be limited by the accuracy of the velocity measurements obtainable. It is likely that both astrophysical limits (such as atmospheric motions in the star) and instrumental limits will mean that this technique can never discover terrestrial planets.

The transit method
When a planet orbiting a star moves between the star and the observer it will occult part of the surface of the star, an event known as a planetary transit. (In our own solar system it is possible to see such transits of Mercury and Venus.) Since the planet is dark compared with the star, it is essentially a black occulting disc, and so blocks a portion of the light from the star from reaching the observer. Thus the experiment here is straightforward. Monitor the brightness of the star, and if it dims and then re-brightens this might be due to a planet in orbit around it. Observationally there are two major problems with this technique. First, if you were to view our own solar system from above, no such occultations would occur. The orbital plane of the planetary system has to
co-incide with the line of sight from the observer to within $\approx 0.01^\circ$ for a planet in an Earth-like orbit around a solar-type star, implying that only 1 in $\approx 10^4$ stars that have such planets would have occultations visible from Earth. Second, the dips in brightness are very small, about $1\%$ for planets the diameter of Jupiter, and much smaller for Earth-size planets. Thus the observational requirement is for the very precise photometry ($1\%$ is straightforward, $0.1\%$ is getting hard in astronomical terms) of very many stars.

To date, there has been no certain discovery of a planet by the transit method (see [1] for an attempt and [2] for what may turn out to be the first discovery), although planetary transits have been observed in the case of one system originally discovered by the Doppler method [3]. Since the apparent change in brightness is a function of how much of the star’s disc is occulted, the transit method gives the radius of the planet. But one also can estimate its distance from the star using its orbital period.

**Direct detection**

The very simplest experiment one could conceive is to image a star and see the planet in orbit around it. The problem with such an experiment is that the glare from the host star will drown out the planet. For even the closest stars (1 parsec away) an Earth-like planet appears to be a 1 second of arc from the star. Turbulence in the Earth’s atmosphere typically smears out a star to these sizes. There are now instruments which compensate for the effects of the Earth’s atmosphere, at which point the size of the star is limited by diffraction about the telescope aperture. Even with the current generation of large telescopes (10 m in diameter), the image of the star is not small enough to reveal the planet.

There are several ways around this problem. In the short term the simplest is to look at stars which are fainter with respect to their planets. White dwarfs are the small (Earth-radius) degenerate objects left after stars have gone through their giant phase. If the planets around them survive this, then they should soon be found by programmes such as that reported in [4].

Another possibility is to use interferometry to combine the light from two or more telescopes to obtain an effective aperture (and hence diffraction limit) much larger than the current telescopes. The problem here is that interferometers, unless they have a very large number of telescopes, produce interference fringes, not images, and an interference fringe pattern can normally be fitted with many physical models, only one of which might be a star and a planet.

The contrast between star and planet is improved if one can work at wavelengths longer than about $10\ \mu m$. This means going into space, and perhaps the most ambitious plan at the moment is the European Space Agency’s Darwin mission. This is a plan to fly several space-based infrared telescopes whose beams will be combined to make an interferometer. Of course, to combine the beams the spacecraft distances must be kept stable (or compensated for) to a fraction of the operating wavelength. The main advantage of such a scheme, though, is that it would be able to collect light from any planet discovered, and spectroscopy would then tell us about the composition of the atmosphere. Unfortunately such a mission is not scheduled to fly before 2010.

The European Southern Observatory has plans for an Overwhelmingly Large Telescope (OWL), which at 100 m in diameter would probably concentrate the light well enough that it too could obtain the spectra of any planets it discovered. Again this is an ambitious plan, unlikely to come to fruition before 2015, and (like Darwin) relies on as yet unproven technology.
The future
I do not see extra-solar planet astronomy having a large impact on the thinking of those involved in thermophile work in the next few years, although there is a chance that we will obtain spectra of a few extra-solar giant planets [5]. The Doppler wobble technique is likely to provide an expanding set of measurements of the masses of giant planets. However, relatively little is likely to be discovered about these planets other than their mass, and in the case of those that show transits, their density. The great hope for the immediate future (the next 4 years or so) is microlensing. It will only yield the mass of the planet, but does have the potential to discover Earth-like planets. The only problem is that it is restricted to discovering planets around stars in the regions of the Galaxy mainly inhabited by older stars, and we already know from the Doppler wobble discoveries that older stars are less likely to harbour planets [6]. If it works, though, the first discoveries of Earth-mass planets will be of great interest.

Beyond microlensing, the transit method should prove to be the next significant step. While tied to the ground, photometric precision will probably limit it to the discovery of giant planets, but there are plans for space-based experiments which could yield the precision required to discover Earth-like planets. Since transits determine the radius of the planet, combined with microlensing this will give us masses and radii for planets, so we will at least then know their gravity (in a statistical sense, since we can probably never use transits and microlensing for the same star).

I think it is in the stage beyond this that the field could have an interesting interaction with thermophiles. Once astronomers begin to obtain spectra of the planets, we can then pin down, in addition to gravity, chemical abundances, temperature and pressure.

Initially the pressure will be on astronomers to take spectra of those planets most likely to be analogues of the Earth, especially as each spectrum taken is likely to cost millions of pounds to collect. There are already discussions of which chemical signatures in the atmospheres of these planets would be sure signs of biological activity. Taking such a blinkered view is probably bad. In biasing our sample towards Earth-like planets we might well miss those planets which are the most common habitats for life. So, can you persuade the astronomers to look at a wider range of planets? Are there chemical signatures for the existence of thermophiles (or other extremophiles) that you can ask the astronomers to look for on planets that they would traditionally have said cannot support life?

References

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