## 4.2 Why Search for Extrasolar Planets with Microlensing? – Advantages and Disadvantages

Searching for extrasolar planets is a tough astrophysical enterprise. There are a number of different techniques being pursued: radial velocity variations or doppler wobble, transits, astrometric variations, pulsar timing, or direct detection. Each of those methods is used by a number of groups (more than 20 different teams, e.g., for transit searches alone, see review by Horne (2003)). So it is a fair question to ask: why bother applying yet another technique?

In this subsection, the microlensing method for planet searching is compared to the other indirect methods. It will be shown that microlensing is indeed a complementary method with different strengths, and that it is very worthwhile pursuing this search technique. As the starting point, here follows a list of commonly mentioned "disadvantages" of the microlensing planet searching technique (with a few comments added in parentheses):

1. The probability for an individual planet-lensing event is very small *(yes indeed, the chance for detecting a planet-microlensing event by monitoring an arbitrary background star in the galactic bulge is very roughly of order $10^{-8}$ or smaller)*.
2. The duration of the planet-induced deviation in the microlensing lightcurve is very short *(yes, estimated typical durations for planet deviations are of order hours to days)*.
3. The planets – once found – will be very distant *(true, most likely distance is a few kpc)*, and even worse: the exact distance determination will turn out to be very difficult or close to impossible *(true, unless we get additional information about the event)*.
4. It is close to impossible to do subsequently more detailed investigations of the planet *(fair enough)*.
5. The lightcurve shapes caused by extrasolar planets are diverse, occasionally there might be a parameter degeneracy when modeling the event, with no unique relation between lightcurve and planet parameters *(yes)*.
6. Even when unambiguously detected, what can be determined is not the *mass* of the planet, but only the mass ratio between host star and planet *(true)*.
7. No independent confirmation will be possible *after* the detection: it is a once-and-only event *(yes)*.

These are fair points of critique toward using microlensing as a planet search technique. So, why bother anyway? Firstly I would like to emphasize and recall that almost all these arguments were put forward already more than a decade ago, then used against the "normal" stellar/dark matter microlensing which had been proposed by Paczyński (1986b) and produced the first results a few years later (Alcock et al. 1993; Aubourg et al. 1993; Udalski et al. 1993). Today no one has any doubts any more about the reality of the many stellar microlensing events, despite, say, their non-repeatability. Secondly, I now try to present one by one good reasons why the above arguments – though true to a large degree – are not really arguments *against* using the microlensing technique for planet searching:

1. *Small probability:* The probability for "normal" microlensing events in the galactic halo or disk (i.e., directions to the LMC/SMC or the galactic bulge) is already very small (of order $10^{-6}...10^{-7}$). Nevertheless, more than a dozen microlensing events have been found toward the LMC/SMC (Alcock et al. 2000a,b) and more than 1000 events (!) have been detected in the direction of the galactic bulge (see, e.g., on the OGLE web page `http://www.astrouw.edu.pl/~ogle/ogle3/ews/ews.html`). This shows: small probability in itself is certainly not a strong argument against using this technique. It is just a matter of statistics: even today it is possible to monitor of order $10^7$ stars on a regular basis with sampling every few days on comparably small operational cost. Doubtlessly, this number will increase by an order of magnitude every few years.
2. *Short duration:* In the current "mode-of-operation", the planet-searching teams take advantage of the relatively coarse sampling in the time domain of the microlensing monitoring teams (in particular OGLE and MOA), they work "piggy-back": once a deviation indicative of a stellar microlensing event is detected by these monitoring teams, the planet-searching teams follow those alerted events with a very dense coverage in time. This can result in lightcurves with an average sampling of many data points per hour. A number of events with more than 1000 data points (An et al. 2002) with photometric accuracy of 1% or better have been observed. Due to a set-up of telescopes in Australia, South Africa and Chile, lightcurve coverage around the clock is possible, weather permitting (see 'The 24-Hour Night Shift', Sackett 2001). So even planetary deviations in the lightcurve lasting only a couple of hours can be covered very well with many data points.
3. *Large (and unknown) distance to the planet in general:* The distances to the microlensing planets will be larger by one or two orders of magnitude than those found with the conventional techniques. This is true, too, for the pulsar planets (Wolszczan 1994) and not a disadvantage in itself. The "not-well-determined" aspect can be treated in a statistical way for a sample of events. If there is additional information available (parallax, astrometric signatures), the distance can be determined for the individual events (cf. Alcock et al. 2001a; Gould 2001).
4. *More detailed investigation impossible:* Indeed, a more detailed study of the planet candidate will turn out to be very difficult. However, we may be able to get more information about the star which the planet is circling:

Alcock et al.,(2001a, b) show, that due to the relative proper motion, the projected positions of source star and lens star will move away from each other, so that we may be able to detect and measure the parent star and the relative proper motion of the star-plus-planet system, a few years after the event.

5. *Parameter degeneracy:* Lightcurves covering only the central caustic or only the outer caustic are likely to have two sets of solutions. However, there is a wide range of planetary lightcurves which will result in unique solutions/fits, if the data sampling and quality is good enough.
6. *Only mass ratios determinable:* Most stars in the disk of the Milky Way are low mass main sequence stars, M-dwarfs. Hence there is a relatively narrow range of absolute masses for most of the planets. Statistically, the planet mass distribution from microlensing can be determined to the same accuracy to which we know the mass function of the (host) stars. Furthermore, the most successful exoplanet search method to date – the radial velocity technique – also cannot determine the individual planet mass to better than a factor $1/\sin i$, due to the unknown inclination $i$ of the orbital plane of the planetary system relative to the line-of-sight.
7. *Once-and-only event, no independent* confirmation: Most star-plus-planet microlensing events will not repeat, this is true. But whether the event is "believable" or not is just a question of signal-to-noise: once there are enough data points with small enough error bars, this is convincing. A lightcurve consisting of more than 1000 data points with accuracy of order of 1% or better (cf. PLANET team caustic crossing data of event EROS-BLG 2000-005, An et al. 2002) is beyond any reasonable doubt. In addition, lightcurves are often collected by two or more separate teams, which is a good independent confirmation. Furthermore, supernovae or gamma-ray bursts also do not repeat; no one takes this as an argument against them being real.

So all the arguments commonly used against microlensing as a useful planet search technique can be refuted or weakened. If the sampling and the photometric accuracy are good enough, planet microlensing deviations will be believed by the astronomical community. Occasionally there might still be model degeneracies. The most significant ones, though, just concern the projected separation between planet and host star: for each solution with separation $d$ there is usually also one with separation $1/d$. We have to live with this, as well as we do with the unknown $\sin i$ of the radial velocity planets.

After having discussed in detail the potential or perceived disadvantages, let us now come to the positive aspects of planet searching with the microlensing technique, compared to the other methods:

- *No bias for nearby stars:* Almost all the conventional planet search techniques concentrate their efforts on nearby stars, mainly because the signals are stronger, the closer the host stars are. The solar neighborhood, however, might not be representative for the galactic planet population. Microlensing searches for planets are sensitive to stars anywhere along the line-of-sight to the source star in the galactic bulge at a distance of about 8.5 kpc, most sensitive for a lens position roughly half-way in between.

- *No bias for planets around solar-type stars/main sequence stars:* Almost all the conventional planet search techniques select and target the host stars. The very successful radial velocity technique cannot be applied to all stellar types, in particular not to active stars with broad and/or variable lines, so it has limited applications. Microlensing searches are "blind" for the characteristics of their host stars. Planet and host star will be found in proportion to their actual frequency in the Milky Way disk. The host stars of the microlensing planets will represent fair samples of the planet-carrying stars in the Milky Way. Planet microlensing is not constrained to any spectral type of host star, nor does it exclude any early type or active stars.
- *No strong bias for planets with large masses:* All conventional techniques are most sensitive to massive planets, with sensitivity strongly declining with decreasing planet mass. To first order, the microlensing signal – the amplitude of the lightcurve deviation – is independent of the planet mass. The duration and hence the probability for detection decreases, though, with decreasing planet mass. However, the size of the source star is important, and the lightcurve signal will be affected/smoothed by the finite source diameter, resulting in a lower amplitude signal (compared to a point source) and hence a lower detection probability.
- *Earth-bound method sensitive down to (almost) Earth-masses:* In principle, it is possible to detect even Earth-mass planets with ground based monitoring via microlensing. In practise, however, this would mean extremely high monitoring frequency and photometric accuracy. It is certainly true, though, that currently microlensing is able to reach down to lower planet masses than any other technique.
- *Most sensitive for planets in lensing zone, overlapping with habitable zone:* In the current mode-of-operation ("alerted" microlensing events being followed by dedicated planet-search groups), the most likely range of projected separations is the so-called lensing zone, roughly corresponding to a projected separation between 0.6 AU and 1.6 AU (Bennett and Rhie 1996). For low mass main sequence stars, this region overlaps with the habitable zone. This coincidence makes microlens-detected planets particularly interesting with regard to the question whether and how many planets exist in the habitable zone.
- *Multiple planet systems detectable:* There are two "channels", in which microlensing can even detect multiple planet systems: well sampled, very high magnification events have such small impact parameters that they pass the central caustic, which carries the signature of all the planets. Another channel would be the chance passage through two or more planet caustics, in case they happen to lie along the path of the background source star.

- *"Instantanous" detection of large semi-major axes:* The detection of long period planets is a long lasting process with the radial velocity or astrometry or transit techniques (years, decades?): ideally it takes at least one full period for confirmation, better two or three. Microlensing will find large-separation planets basically instantaneously. The measured (projected!) distance between planet and host-star is, though, only a lower limit to the real semi-major axis (statistically, the 3-dimensional distribution can be inferred under the assumption that there is no preferred direction of the planetary orbital planes in the Milky Way).
- *Detection of free-floating planets ("isolated bodies of planetary mass"):* The next generation of microlensing searches for planets most likely will not work in the two-step mode-of-operation described below, with one team sampling lightcurves coarsely and then follow-up teams sampling selected candidate frequently. Rather, they will do very massive photometry ground-based (cf. Sackett 1997), or potentially even continuously from space, as the satellite project "Microlensing Planet Finder" (MPF, formerly called GEST) promises to do (Bennett and Rhie 2002; Bennett et al. 2003). Once such an experiment is implemented, microlensing will also detect a potential population of free-floating planets, by the microlensing signature of single lenses with small mass, i.e. very short duration (Han and Kang 2003).
- *Ultimately best statistics of galactic population of planets:* Gravitational microlensing will ultimately provide the best statistics for planets in the Milky Way; it is not without biases, but the biases in the microlensing search technique are very different from those of all other methods and can easier be quantified.

So gravitational microlensing is a very powerful and promising method for the search for extrasolar planets. It is largely complementary to other planet search techniques and has relatively little sensitivity to the planet mass. It also has a number of not-so-favorable aspects, which, however, are more than balanced by the advantages listed above.