Determining the abundance of extragalactic planets

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Abstract. Gravitational microlensing provides a unique technique to reveal information about extragalactic planets. A network of at least four 2m-class telescopes distributed around the northern hemisphere could probe 15–35 jupiters and 4–10 saturns around M31 stars per year.

Planet detection by microlensing

By means of creating distortions to the gravitational field of their parent stars, unseen planets of mass \( m \) around unseen lens stars of mass \( M \) can cause deviations of 1–20\% (lasting days for jupiters to hours for earths) to the light curves of background stars undergoing a microlensing event which lasts \(~\sim\)1 month. The probability for a planetary signal varies with the projected orbital radius of the planet \( r_p \) reaching a maximum near \( r_p \sim r_E \), with the Einstein radius \( r_E = \sqrt{2R_S D} \), the Schwarzschild radius of the lens star \( R_S = (2GM)/c^2 \), \( D = D_L (D_S - D_L)/D_S \), and \( D_S \) and \( D_L \) being source or lens distances.

By achieving a galactic length scale \( D \sim 2.5 \text{ kpc} \left[ r_E/(2.5 \text{ AU}) \right]^2 \) for M-dwarf lens stars \( (M \sim 0.3 \, M_\odot) \), one becomes sensitive to planetary systems similar to our own. This condition is met not only for observations of Galactic bulge stars being lensed by stars in both the Galactic disk or the bulge itself \( (D_S \sim 8.5 \text{ kpc}, D_L \sim 6 \text{ kpc}) \), but also for observations of stars in other galaxies as M31 \( (D_S \gg D_S - D_L, D \approx D_L) \).

While the probability to detect a planetary deviation and its duration decreases with smaller mass ratios \( q = m/M \) (roughly as \( \sqrt{q} \)), the maximal deviation \( \delta_{\text{th}} \) is only limited by the radius of the source star \( R_\star \) \( (\text{Bennett & Rhie 1996}) \). For \( \delta_{\text{th}} = 10\% \) on observing M31 stars, a minimal mass ratio of \( q_{\text{min}} = 2 \times 10^{-3} [R_\star/(100 \, R_\odot)]^2 \) is required for \( r_E \sim 2.5 \text{ AU} \) and M-dwarf lens stars, corresponding to planets with twice the mass of Saturn for \( R_\star \sim 100 \, R_\odot \).

M31 microlensing observations

Due to its small angular size, the monitoring of M31 requires only a few fields and therefore only a fraction of telescope time during each night. A proposed network of at least four 2m-class telescopes distributed around the northern hemisphere \( (\text{Dominik 2002}) \) will provide a sampling interval of \(~\sim\)6 h. On-line data reduction based on difference-imaging will allow an increased sampling through target-of-opportunity observations in the case of ongoing anomalies.
Since M31 observations comprise *unresolved star fields*, only events with *high peak magnification* \( A_0 \) on *bright sources* are detectable, ruling out catching signatures of Earth-mass planets. The smaller fraction of useful events is partly compensated by the *large number of source stars* and an *increased planet detection efficiency* for larger peak magnifications (Griest & Safizadeh 1998).

The table compares the detection capabilities for Galactic and extragalactic planets with ground-based campaigns. Planet detection efficiencies follow Gould & Loeb (1992) and Covone et al. (2000) and are averaged over the lensing zone \( 0.6 \, r_E \leq r_p \leq 1.6 \, r_E \). The determination of planet parameters is not required for obtaining upper abundance limits based on the absence of deviations.

|                  | Galactic bulge | M31            |
|------------------|----------------|----------------|
| number of source stars | \( \sim 10^7 \) | \( \sim 10^{10} \) |
| resolution of source stars | resolved | unresolved |
| telescope time | dedicated | 0.5–2.5 h per night |
| field of view [sq deg] | 0.004–0.03 | 0.01–1 |
| number of fields | \( \sim 20 \) | 1–8 |
| monitored during night | 1.5–2.5 h | 4–6 h |
| mean sampling interval | \( \sim 300–600 \) | \( \sim 150–400 \) |
| useful types of source stars | giants | giants |
| useful peak magnifications | \( A_0 \gtrsim 2 \) | \( A_0 \gtrsim 10 \) |
| rate of useful events [yr\(^{-1}\)] | \( \sim 75 \) | \( \sim 35–100 \) |
| planet detection efficiency | \( \sim 20 \% \) (jupiters) | \( \sim 35 \% \) (jupiters) |
| planet probing rate [yr\(^{-1}\)] | \( \sim 1.5 \% \) (earths) | \( \sim 10 \% \) (saturns) |
| upper limit on planetary abundance within 3 years | \( 4–7 \% \) (jupiters) | \( 3–7 \% \) (jupiters) |
| location of parent stars | Galactic disk and bulge | M31 |
| extraction of planet parameters | fair in many cases | mostly difficult or even impossible |

References

Bennett, D. P., & Rhie, S. H. 1996, ApJ, 472, 660
Covone, G., de Ritis, R., Dominik, M., & Marino, A. A. 2000, A&A, 357, 816
Crotts, A. P. S. 1992, A&A, 399, L43
Dominik, M. 2002, in Napoli Series on Physics & Astrophysics, 6, General Relativity, Cosmology and Gravitational Lensing, ed. G. Marmo, C. Rubano & P. Scudellaro (Napoli: Bibliopolis), 87
Dominik, M., et al. 2002, P&SS, 50, 299
Gould, A., & Loeb, A. 1992, ApJ, 396, 104
Griest, K., & Safizadeh, N. 1998, ApJ, 500, 37
Jetzer, Ph. 1994, A&A, 286, 426