Detecting Planets in the Galactic Bulge

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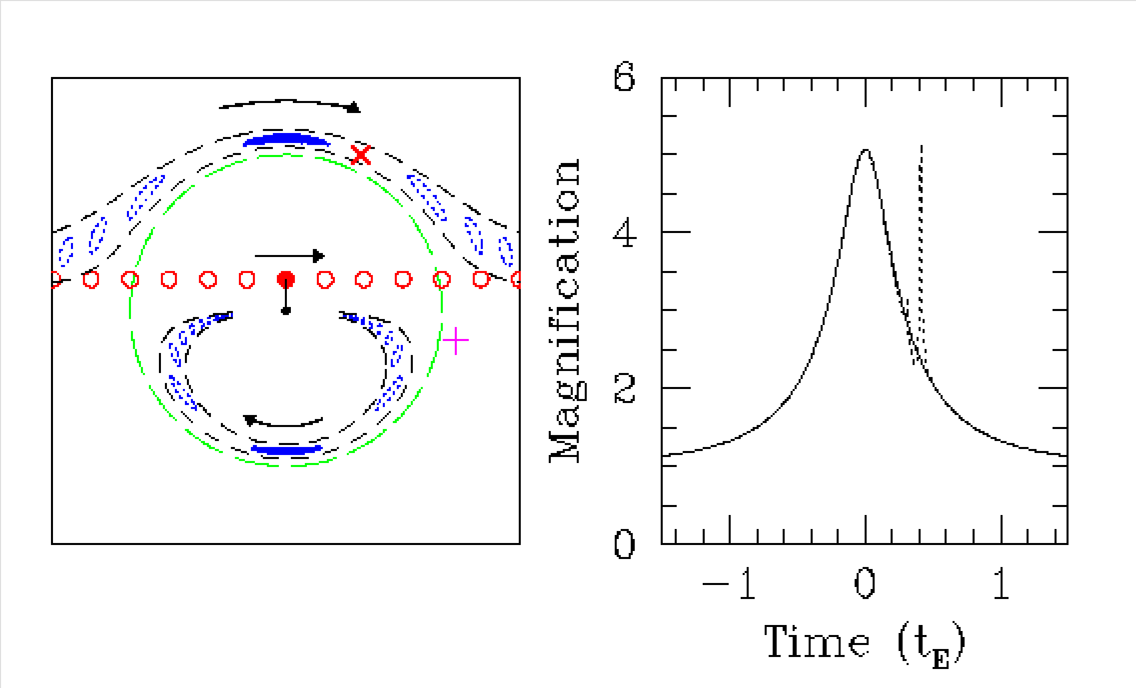
Abstract

Determination of the frequency of planets in environments different from the local neighborhood, such as the Galactic bulge, may provide clues to the formation mechanisms of planets. There are three currently feasible methods of detecting planetary companions to stars in the bulge: gravitational microlensing, transit, and "direct" detection. Microlensing searches for planets have been ongoing for six years, and have yielded interesting constraints on the frequency of Jupiter-mass planets around typical stars in the bulge (M-dwarfs) with separations of 1AU$<a<$5AU. If continued, such searches should eventually result in detections. Detection of planets in the bulge via transits requires a campaign of at least 10 nights on a 10m class telescope at an excellent site. Such a campaign would detect 5-50 Jupiter size planets with $a<0.1$ AU, if the frequency of planets in the bulge is similar to that locally. As a consistency check, close-in giant planetary companions can also be "directly" detected in caustic-crossing binary-lens events, where the reflected light of the planet can be magnified by two orders of magnitude. Direct detection requires a few hours of intensive monitoring per binary-lens microlensing light curve using a 10m class telescope. Combining these methods may eventually yield a complete census of Jovian companions to stars in the bulge with separations 0.01-10AU.

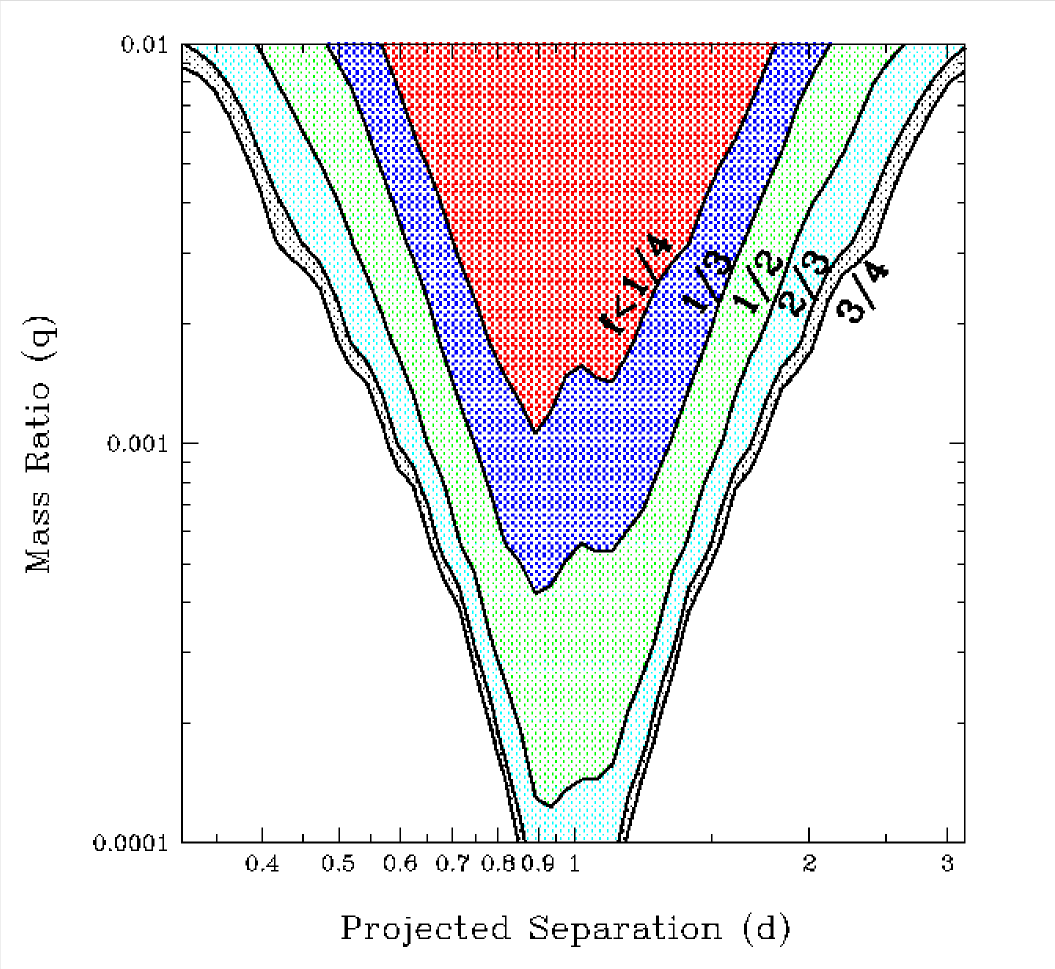
Gravitational Microlensing



Left: The images (blue ovals) are shown for several different positions of the source (red circles), along with the primary lens (black dot) and Einstein ring (green circle). If the primary lens has a planet near the path of one of the images, i.e. within the short-dashed lines, then the planet will perturb the light from the source, creating a deviation to the single lens curve.

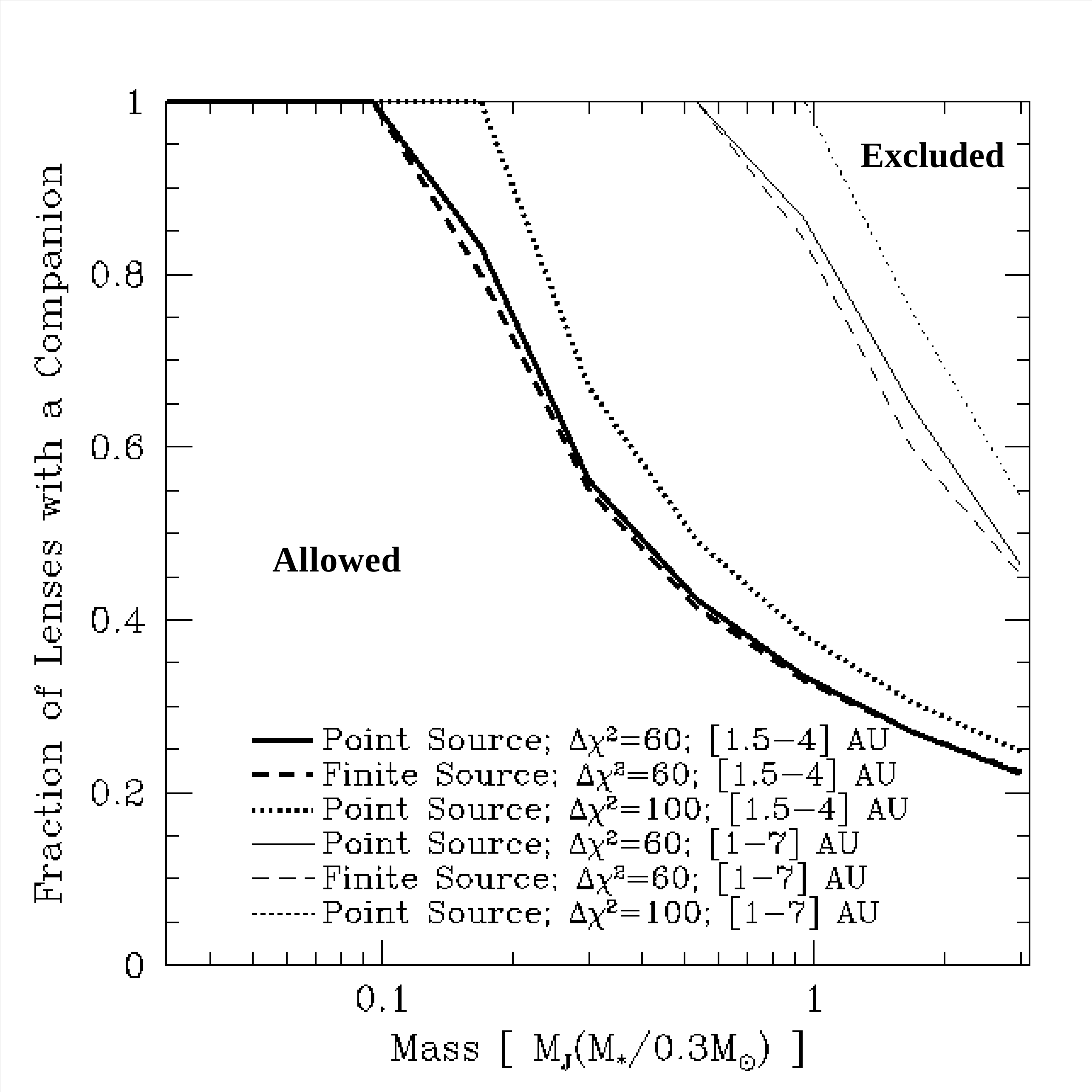
Right: The magnification as a function of time is shown for the case of a single lens (solid curve) and accompanying planet (dotted curve) located at the position of the red "X" in the top panel. If the planet was located at the magenta "+" instead, then there would be no detectable perturbation, and the resulting light curve would be identical to the black curve.

Limits from Five Years of PLANET Observations



Exclusion diagram for pairs of planet planet parameters (d,q), where d is the projected separation in units of the Einstein ring, and q is the planet-star mass ratio. The inner contour indicates the (d,q) for which the fraction of lenses with a planet is f<1/4 at 95% confidence (based on the analysis of 43 events). Other contours are for f<1/3, 1/2, 2/3, and 3/4. A mass ratio q=0.001 corresponds to approximately a 0.3 Jupiter-mass companion and a separation of d=1 corresponds to a physical separation of 2AU.

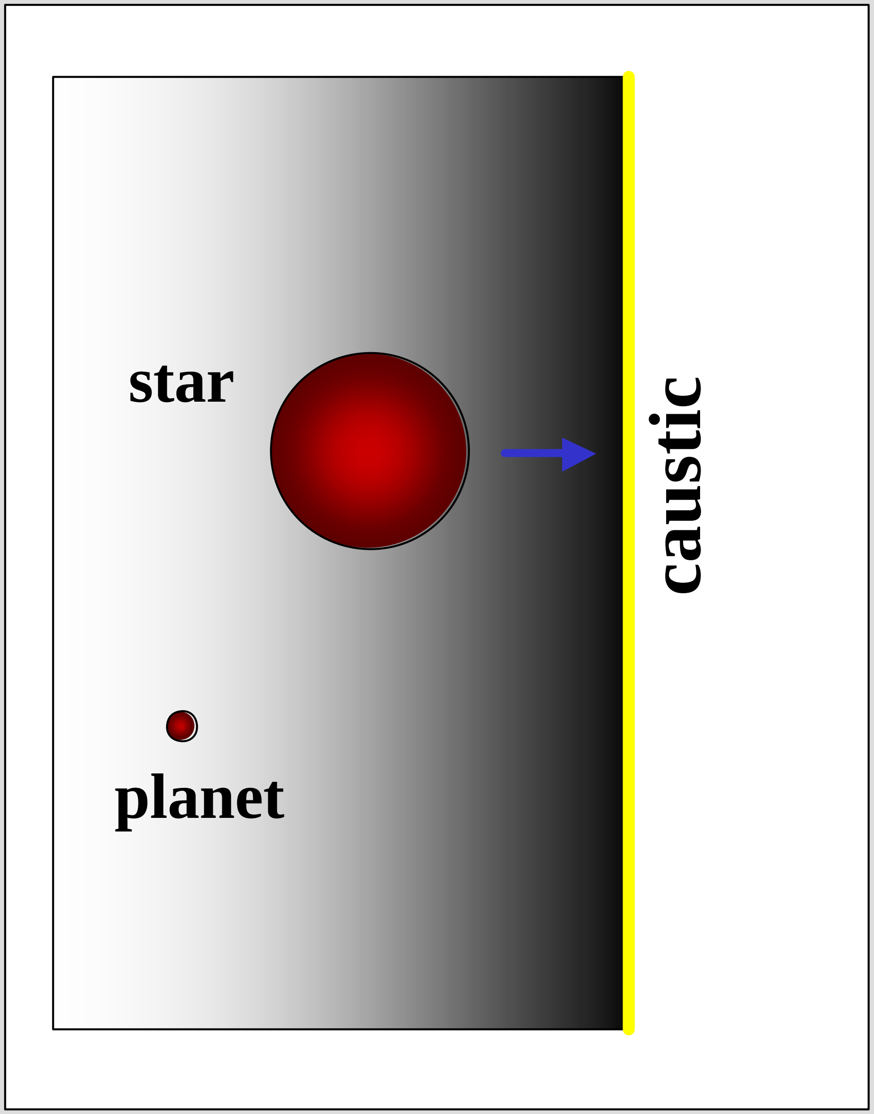
From Albrow et al. 2001, ApJL, submitted



Upper limits derived from 5 years of PLANET data for planets anywhere in a continuous range of semi-major axes centered on the Einstein ring. Bold curves show the excluded fraction (at 95% confidence) anywhere in the range 1.5AU < *a* < 4AU, while solid curves show the fraction for 1AU < *a* < 7AU, assuming a detection threshold of $\Delta\chi^2$=60, and that the primaries have Einstein ring radii of 2 AU. The dashed curves show the negligible effect of including the finite size of the source in the modelling. The dotted lines are for $\Delta\chi^2$=100.

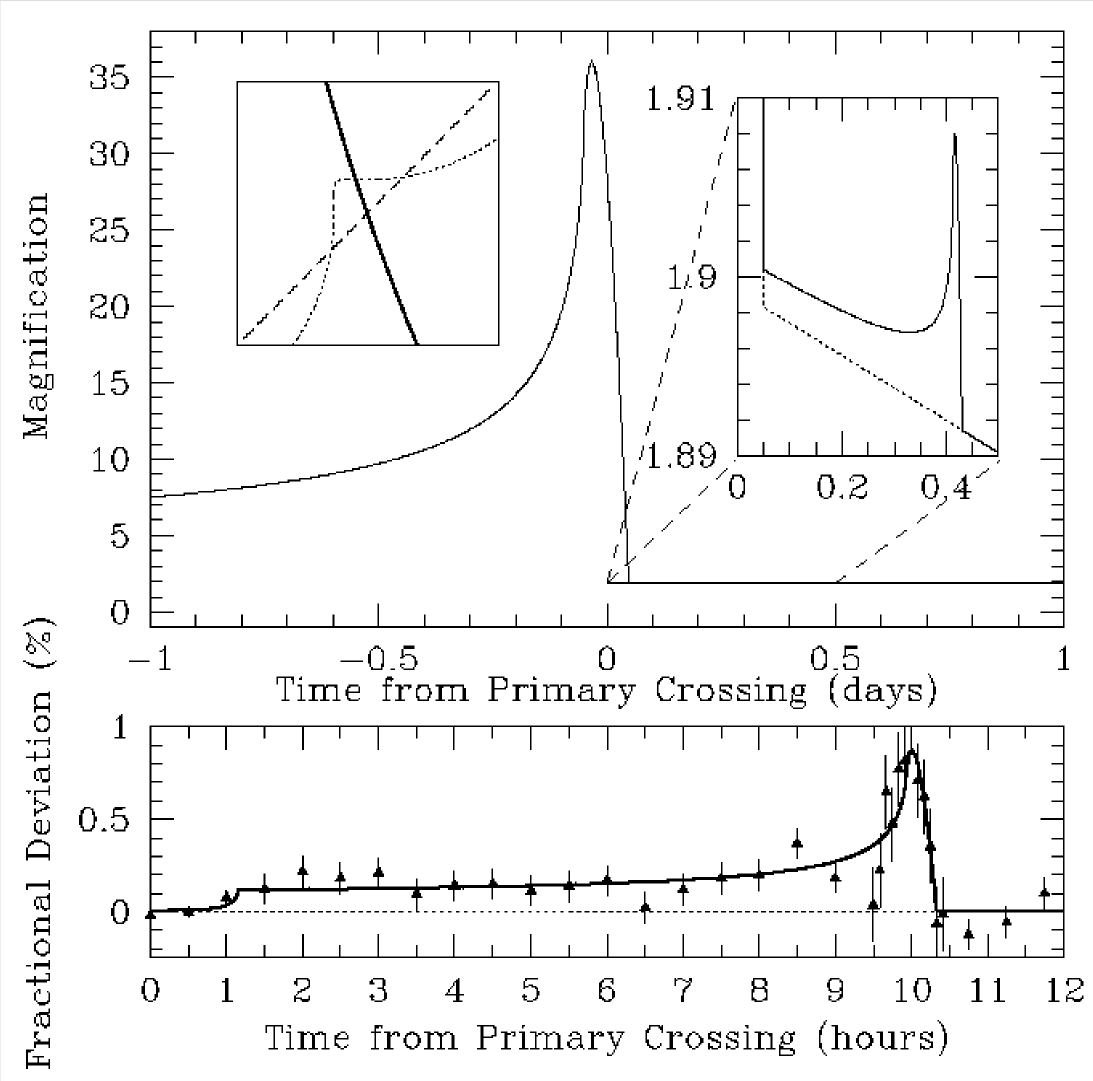
From Albrow et al. 2001, ApJL, submitted

“Direct” Detection



Close-in Jupiter-size planets orbiting stars in the bulge can be “directly” detected by using caustic-crossing binary microlensing events discovered by microlensing survey teams.

The cartoon to the left illustrates the concept. The black shaded region indicates the magnification due to the caustic of the binary-lens. The large and small circles indicate the parent star and planetary companion. When the planet crosses the caustic, it is more magnified than the source star: its light is magnified by 2 orders of magnitude for Jupiter-size planets. If the planet has a large radius and is close to the star, its magnified reflected light may make a significant deviation in the binary-lens light curve.

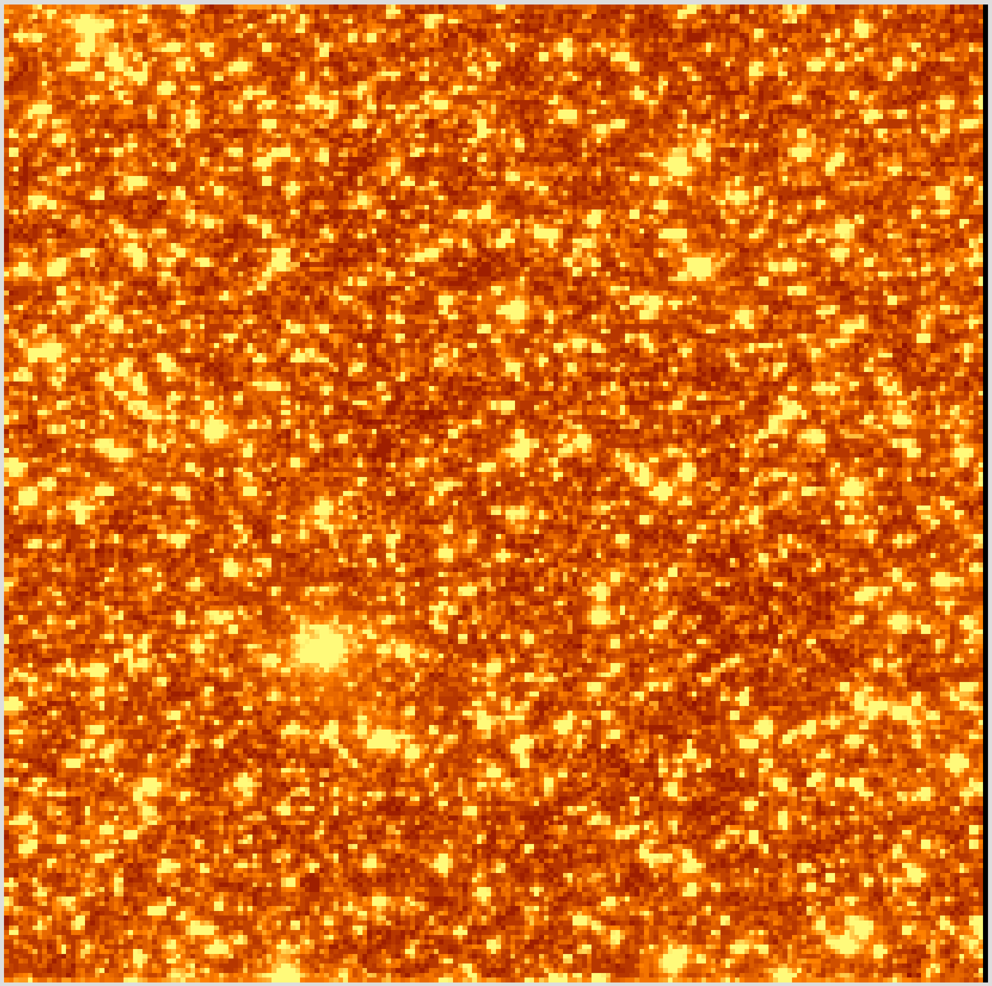


From Graff & Gaudi 2000, ApJL, 538, L133

Top: Magnification as a function of time from the primary caustic crossing. The lens is an equal-mass binary at 6 kpc with total mass of $1M_{\odot}$. The source system is an analog of HD 209458 at 8kpc: a G0V primary with a planet of radius 1.27 R_{jup} and a=0.0467 AU. The top-left inset shows the geometry of the source system trajectory: the dashed line shows the path of the primary, the dotted line the path of the secondary, and the solid line is the caustic. The right inset shows a blow-up of the light curve immediately after the primary caustic crossing both with (solid) and without (dotted) the planet.

Bottom: The fractional deviation from the single-source (no planet) light curve as a function of the time from the primary caustic crossing. The points with error bars are simulated photometric measurements from a 10m telescope for an I=20 mag star.

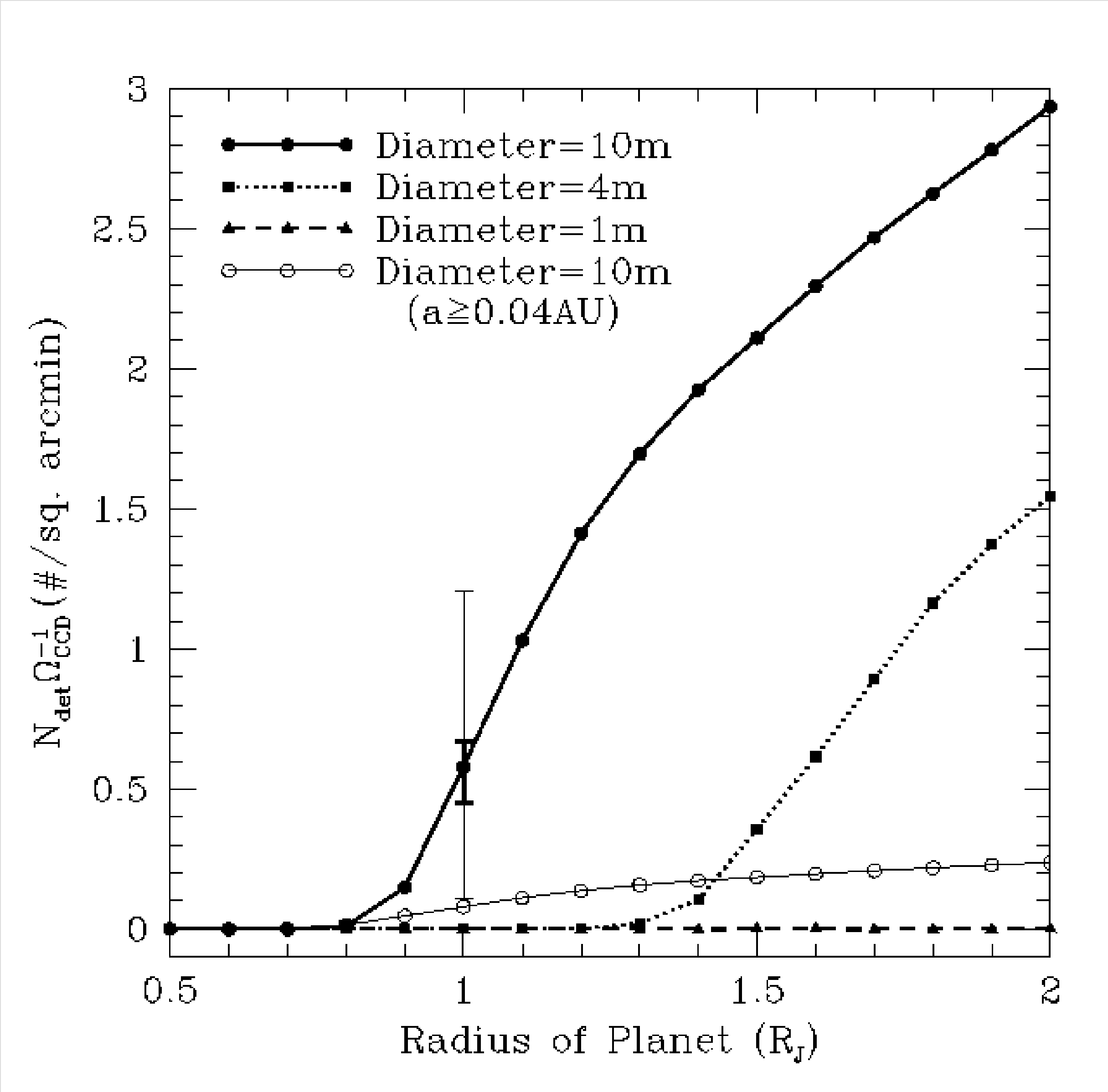
Planetary Transits Toward the Bulge



One difficulty with detecting planets via transits is the low probability a planet has of transiting its parent star. This can be overcome by searching for transits in dense stellar fields like the Galactic bulge.

The image to the left is a typical field toward Baade's window taken in the I-band with a 0.91m telescope in good seeing. The field-of-view is 4 arcminutes on a side. Many thousands of stars are visible.

By monitoring the bulge, a large number of stars can be monitored simultaneously. Due to the faintness of the stars, large telescope apertures are required to achieve the necessary photometric accuracy (<1%).



From Gaudi 2000, ApJL, 539, L59

Number of planets detected per square arcminute as a function of the radius of the planet for three different telescope apertures, assuming 10 nights of 8 hr per night, a seeing of 0.75” and that 1% of all stars have planets distributed uniformly in log *a* between 0.01 and 0.1 AU. The thick error bar on the point for D=10m, and R_p=1R_{Jup} corresponds to changing the number of nights from 20 to 5, and the thin errorbar corresponds to changing the seeing from 1-0.5”. The light solid line with open circles in the number of detected planets for D=10m, 10 nights, seeing of 0.75”, and assuming that 1% of all stars have planets distributed uniformly in log *a* between 0.04 and 0.15 AU.

Summary

- Gravitational microlensing searches toward the Galactic bulge are constraining the frequency of Jovian planets with separations of 1-10 AU.
- Jovian companions to stars in the bulge with separations of 0.01-0.1 can be detected via transits.
- Giant close-in planets can be “directly” detected using caustic-crossing binary-lens events.
- These methods can be extended and combined to obtain a census of Jovian companions to stars in the bulge with separations of 0.1-10AU.
- Such a census may provide clues to the formation mechanisms of planets, and would also serve as an important precursor for the proposed space-based survey GEST (see poster 11.08).

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