μFUN Planet Detections
2005-2008
Andy Gould (Ohio State)
A0 star GSC 3656-1328
A=40, V=7 at 1 kpc

How Microlensing Finds Planets
Mao & Paczynski
Microlens Planet Searches

GRAVITATIONAL MICROLENSING BY DOUBLE STARS AND PLANETARY SYSTEMS

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1. Geometry of microlensing by a binary, as seen in the sky. The primary of 1 \( M_\odot \) is located at the center of the figure, and the secondary of \( 0.001 M_\odot \) is located on the right, on the Einstein ring of the primary. The radius of the ring is 1.0 mas for a source located at a distance of 8 kpc from the lens at 4 kpc. The two complicated shapes around the primary arc the lens. The effect is strong even if the companion is a planet. A massive search for microlensing of the Galactic bulge stars may lead to a discovery of the first extrasolar planetary systems.
5. OBSERVATIONAL REQUIREMENTS

Two distinct steps are required to observe a planetary system by microlensing. First, one must single out a disk star which happens to be microlensing a bulge star. Second, one must observe this star often enough to catch the deviation in the light curve due to the planet. The first step involves the observation of millions of bulge stars on the order of once per day. The second step involves the observation of a handful of stars many times per day. In the following we give a rough outline of what is required for each of these steps.

While observations from one site would be useful, there are advantages to be gained by observing from several sites. First, two telescopes that were totally committed. Third, in view of the fleeting nature of the events, it would seem prudent to build in some redundancy in case of bad weather at a particular site. Thus, the optimal scheme would employ, say, a dozen telescopes. Each of these would be committed to carry out two observations per night. During the near-December season,
1995 PLANET Pilot Season

- Albrow et al. 1998
OGLE-2005-BLG-390
“Classical-Followup” Planetary Caustic

Beaulieu et al. 2006, Nature, 439, 437
OGLE-2005-BLG-071

1st $\mu$FUN Planet:

Super-Jupiter around M dwarf

Amateurs + Professionals
Grant, Ian, Jennie, Phil
OGLE-2005-BLG-169:

Second μFUN Planet: Cold Neptune
Deokkeun An
Tale of Two Planets

**OGLE-2005-BLG-390**
- $q = 8 \times 10^{-5}$
- $M_* = 0.2 \, M_{\odot}$
- $M_p = 5.5 \, M_{\oplus}$
- $D = 7 \, \text{kpc}$
- $a = 3 \, \text{AU}$
- $T = 50 \, \text{K}$
- Low-mag Event
- $(1 \, \text{det})/(4.4 \, \text{probed})$

**OGLE-2005-BLG-169**
- $q = 8 \times 10^{-5}$
- $M_* = 0.5 \, M_{\odot}$
- $M_p = 13 \, M_{\oplus}$
- $D = 3 \, \text{kpc}$
- $a = 4 \, \text{AU}$
- $T = 70 \, \text{K}$
- High-mag Event
- $(1 \, \text{det})/(2.25 \, \text{probed})$
OGLE-2006-BLG-109:
Without Followup Observations
OGLE-2006-BLG-109

µFUN Planets 3+4: Jupiter+Saturn System

Gaudi et al. 2008, Science, 319, 927
Five Lightcurve Features

1 + 2 + 3 + 5 = Saturn    4 = Jupiter
MOA-2007-BLG-400

Fifth μFUN Planet: “Buried” Jupiter
Microlensing vs. Other Methods
Microlensing and the “Snow Line”

Exoplanet Discoveries vs. Snow–Line

Mass (Earth masses)

(semi–major axis)/(snow–line)
Equilibrium Temperature

Transits

RV

\(\mu\)lensing

Liquid Water
CMD (Apparent Mags)
OB-03-235/MB-03-053: 5.5 kpc

Finite Source + Centroid Motion

OGLE-2005-BLG-071: 3.3 kpc
Parallax + Finite Source + Centroid Motion

Dong et al. 2009, astrophy/0804.1354
OGLE-2006-BLG-109: 1.5 kpc

Parallax + Finite Source + Blend

Gaudi et al. 2008, Science, 319, 927
MOA-2007-BLG-192: 1.5 kpc

Parallax + Finite Source

Conclusions

• $\mu$FUN has played a major role in the discovery of 9 extrasolar planets
  - 2005 (2), 2006 (2), 2007 (2), 2008 (3)

• Many planet distances are measured
  - Most in Disk

• Microlensing planets are cold
  - Great Probe Beyond the “Snow Line”