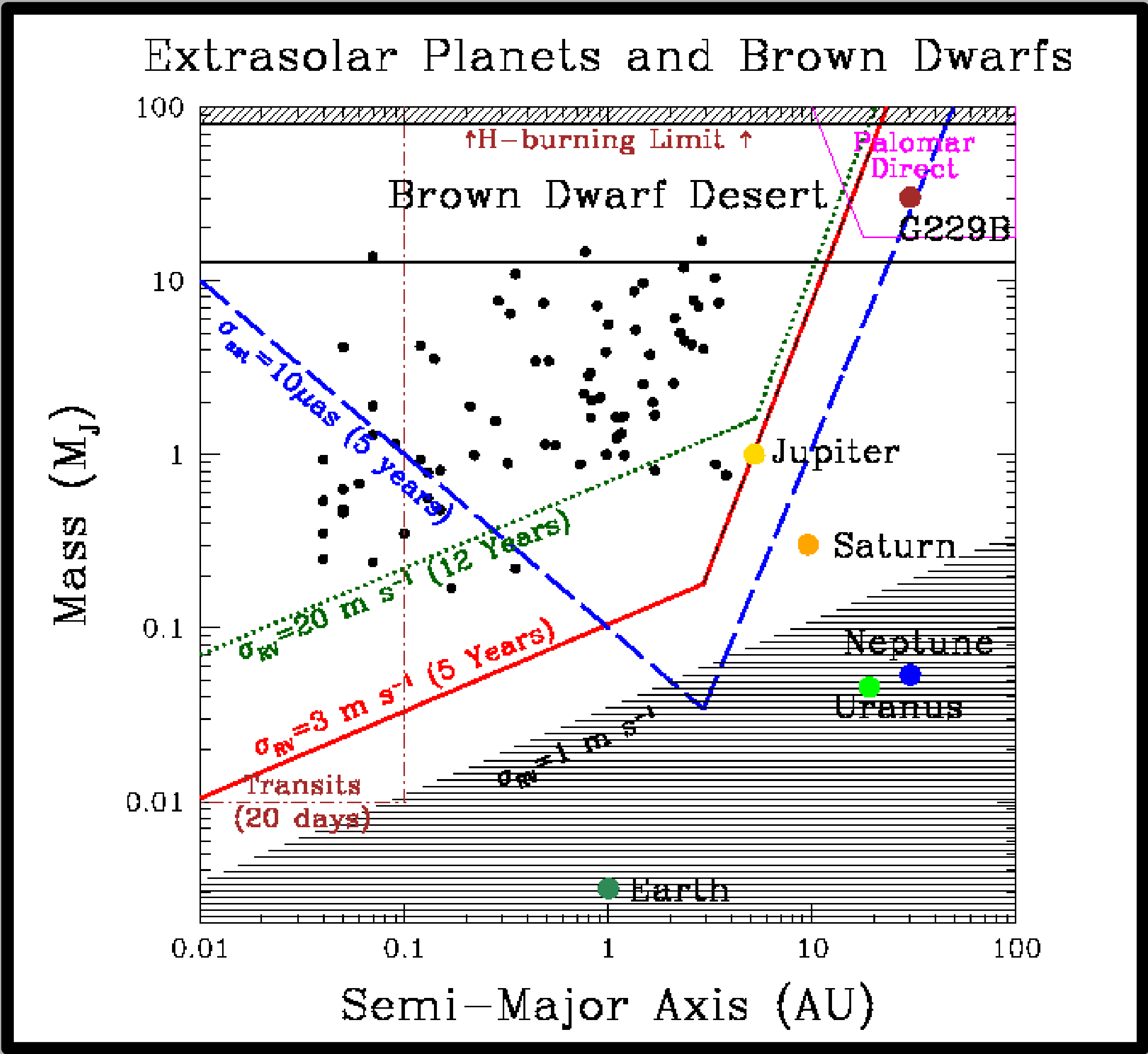
Microlensing Constraints on the Frequency of Low-mass Companions

B. Scott Gaudi, Institute for Advanced Study

Planetary and Brown Dwarf Companion Detection Methods



- Radial Velocity
- Astrometry
- Transits
- Direct Detection
- **Microlensing**

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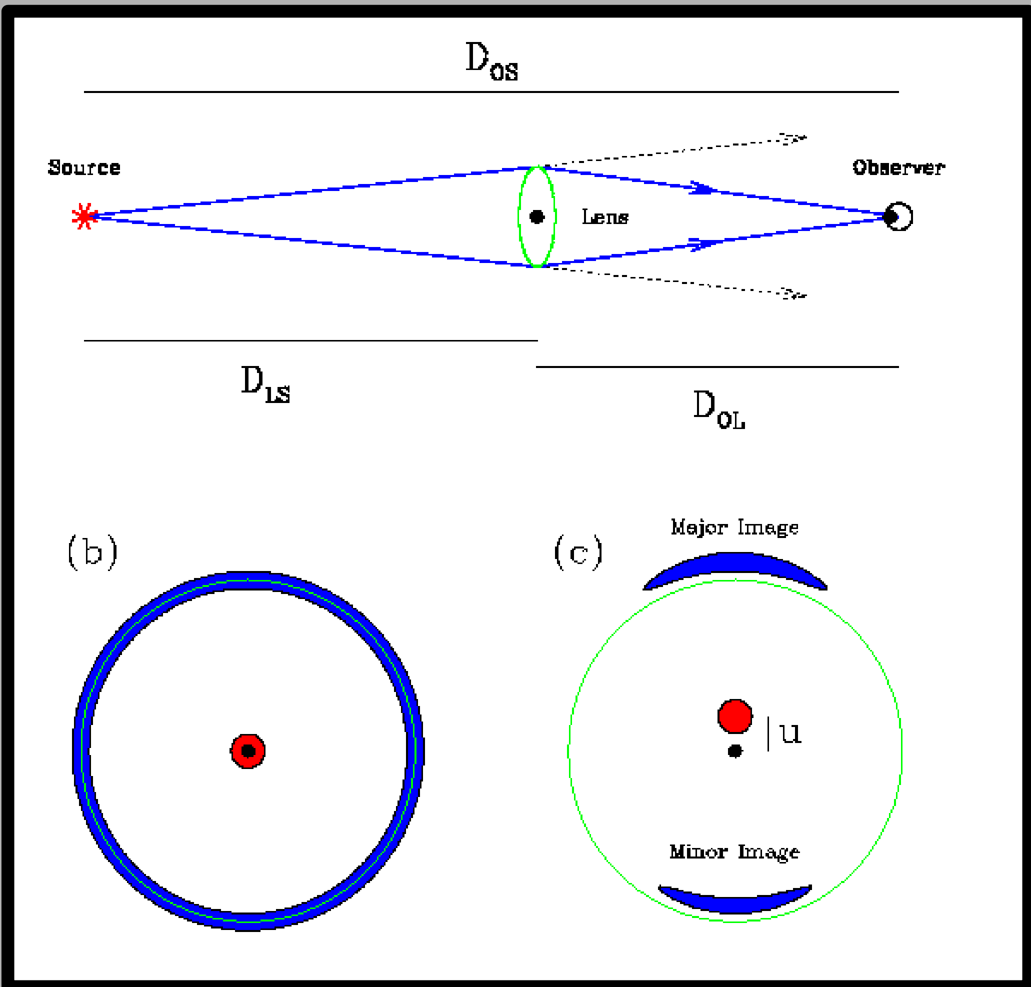
Microlensing Basics



Lens Equation:

$$\beta = \theta - \theta_E^2 / \theta$$

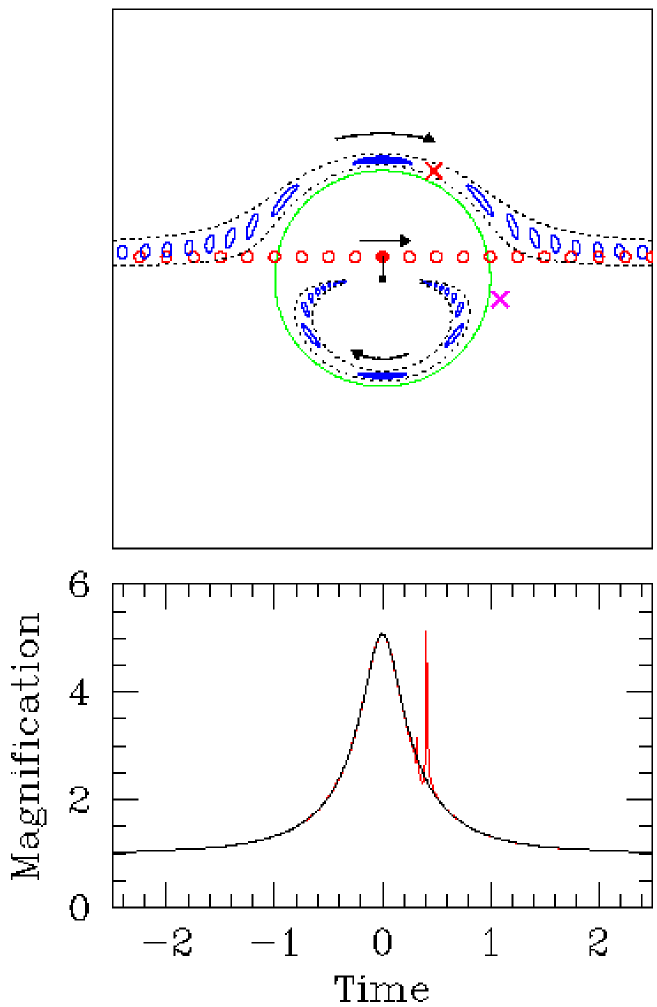
Angular Einstein Ring Radius

$$\theta_E = 300 mas \left(\frac{M}{0.3 M_*} \right)^{1/2}$$

Physical Radius

$$R_E = 2\mathrm{AU} \left(\frac{M}{0.3 M_*} \right)^{1/2}$$

Microlensing Basics



Single Lens Parameters:

- •Impact parameter
- •Time of Maximum Mag.
- •Timescale

$$t_E = 20\text{days}\left(\frac{M}{0.3M_*}\right)^{1/2}$$

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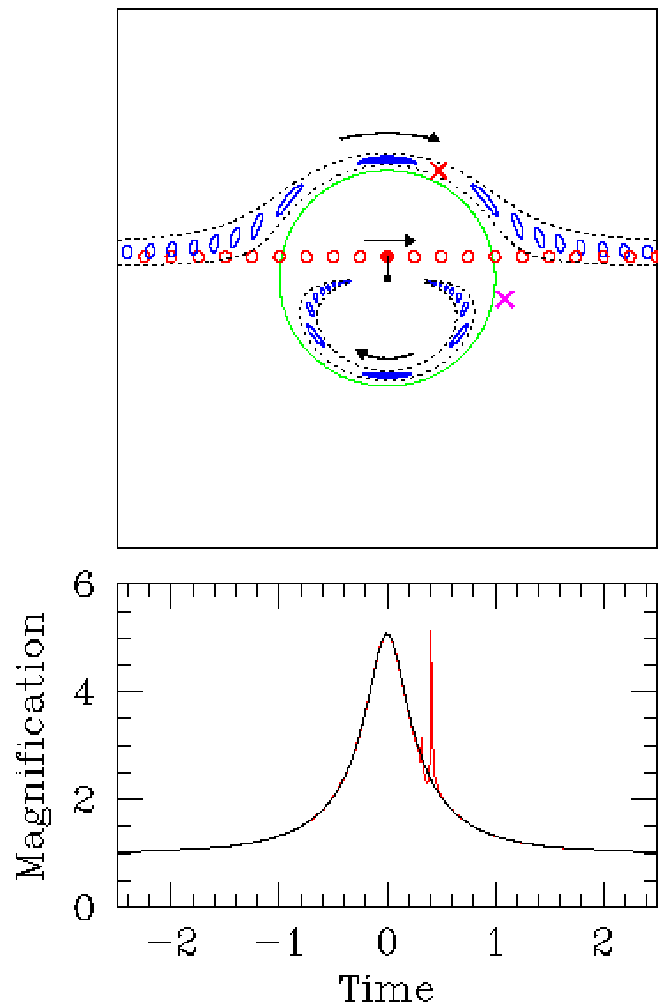
Planetary (Perturbative) Microlensing



Single Lens Parameters:

- Impact parameter
- Time of Maximum Mag.
- Timescale

$$t_E = 20\text{days}\left(\frac{M}{0.3M_*}\right)^{1/2}$$

Planet Parameters:

- Angle wrt Binary Axis
- Projected Separation
- Mass Ratio - q

$$t_p = \sqrt{q}\,t_E \approx 1\text{days}\left(\frac{M_p}{M_J}\right)^{1/2}$$

Planetary (Perturbative) Microlensing

Advantages:

- Sensitive to >Jupiters at 1-10 AU (immediately).
- No Flux Needed.

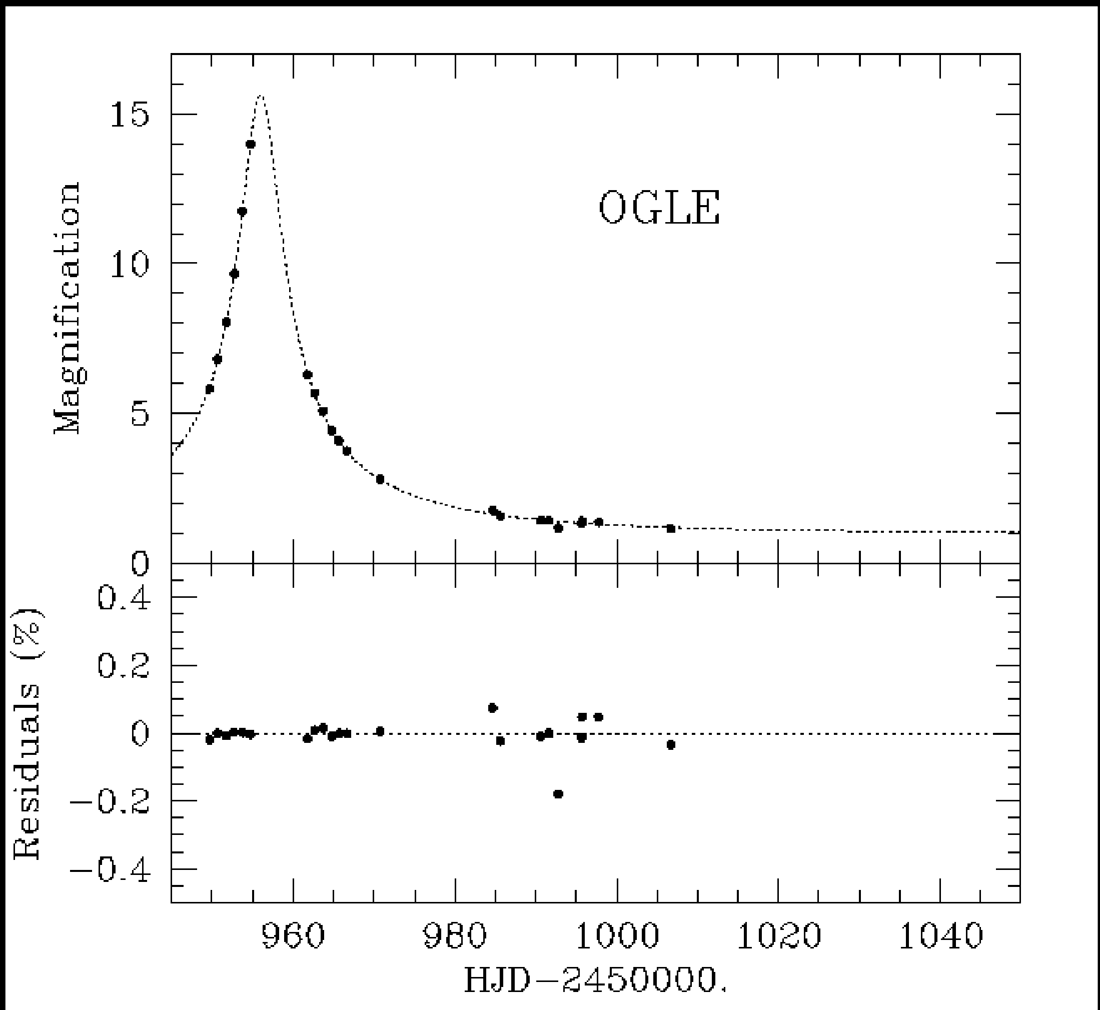
Disadvantages:

- Follow-up Difficult.
- Non-repeatable.
- Planetary Companions > Short Timescale Perturbations.

Basic Requirements:

- Nearly Continuous Sampling.
- Good Photometry for Detection.

Planetary (Perturbative) Microlensing



"Survey" Collaborations

- Insufficient Sampling
- Real-time Alerts

Current and Past Alerts

- EROS (5 per year)
- MACHO* (50 per year)
- MOA (50 per year)
- OGLE II* (75 per year)

Future Alerts

- OGLE III (~500 per year)

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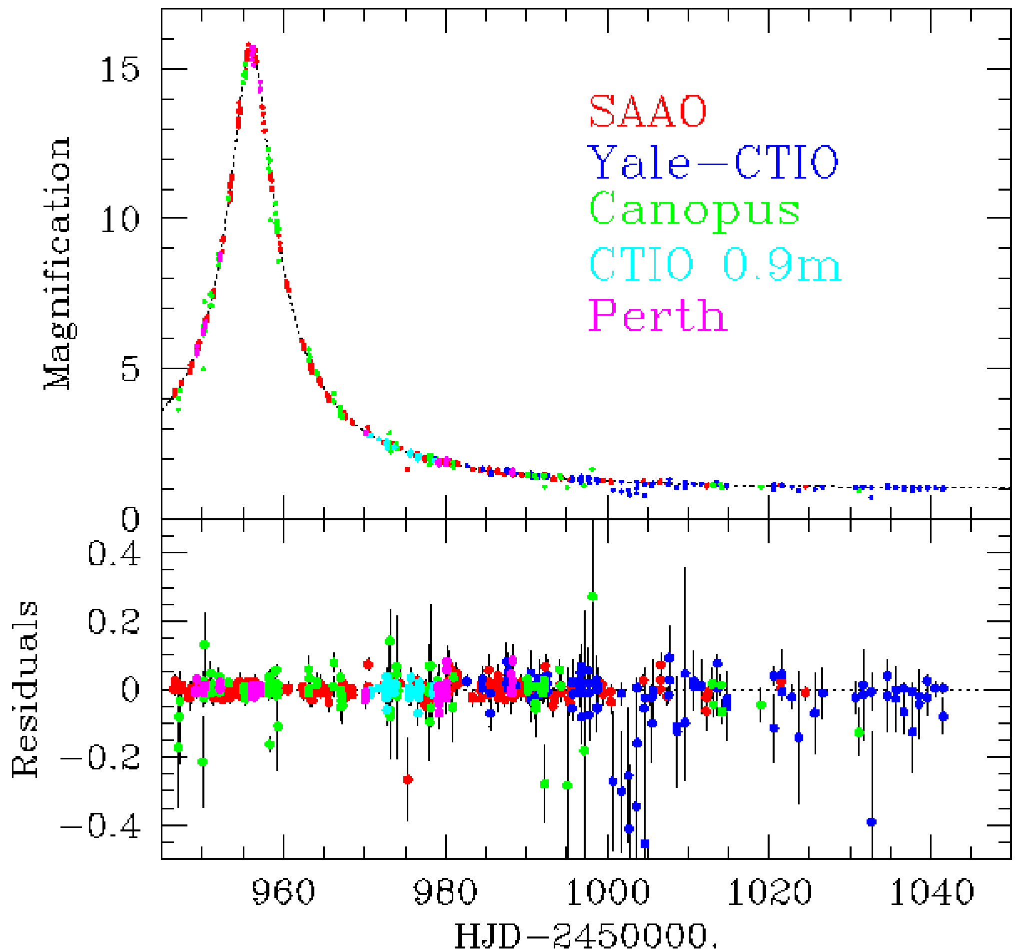


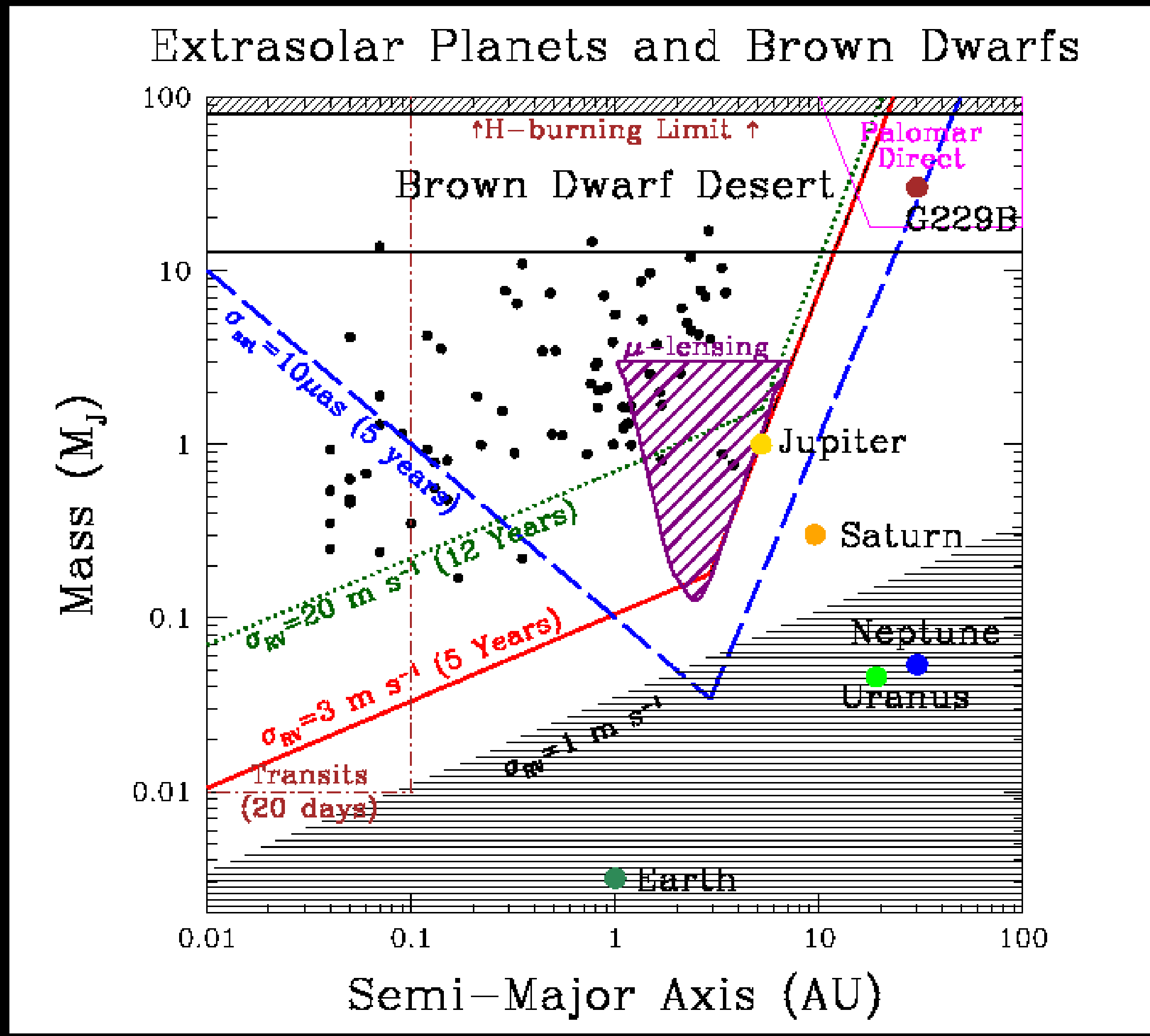
Follow-up Collaborations

- High Temporal Sampling
- Good Photometry

Current Collaborations

- EXPORT (12 events) (Tsapras et al. 2001)
- MOA (30 events) (Bond et al 2002
- MPS (50 events) (Rhie et al. 2000)
- PLANET (100+ events) (Albrow et al. 1998)

Planetary (Perturbative) Microlensing



95-99 PLANET Data

- 43 Events.
- No viable detections.
- <45% have $3M_J$ planets between 1-7AU
- Excluded $M > 3M_J$

(Albrow et al. 2001
Gaudi et al. 2002)

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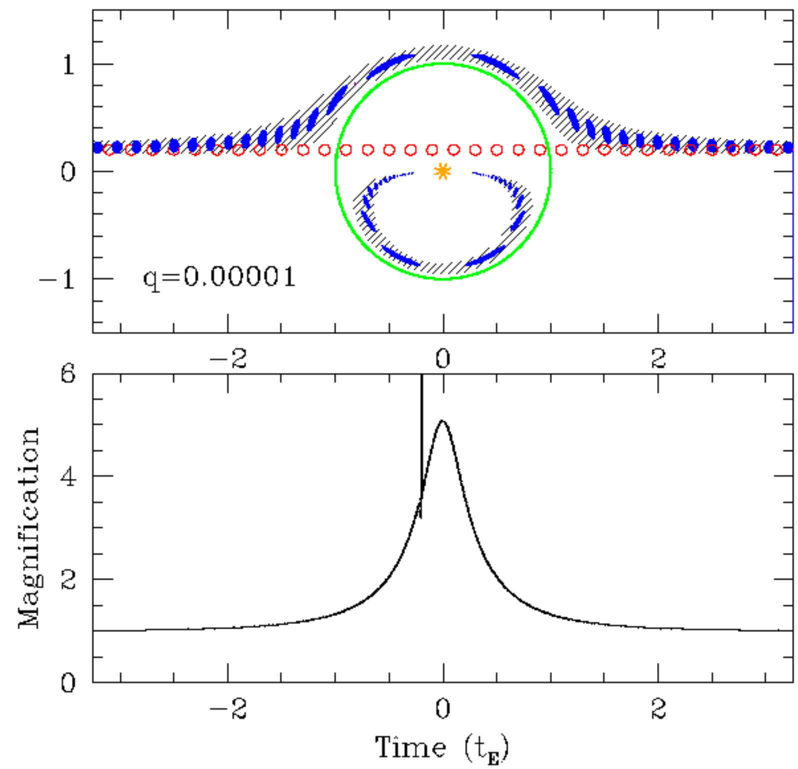
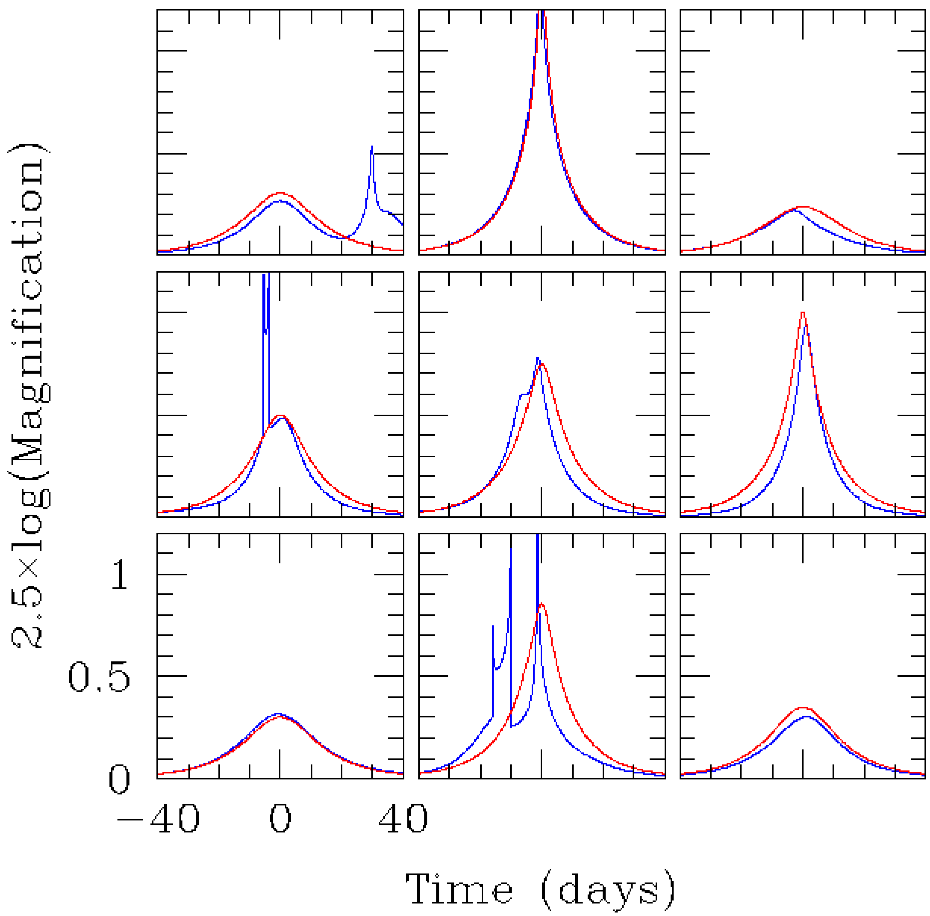
Binary (Non-Perturbative) Microlensing



•For $q > 0.01 (M > 3M_J)$ perturbative approach fails

- Large, long-duration deviations from single lens form.
- Easily recognizable.

Binary (Non-Perturbative) Microlensing



"Binaries"

$$0.1 < q < 1$$

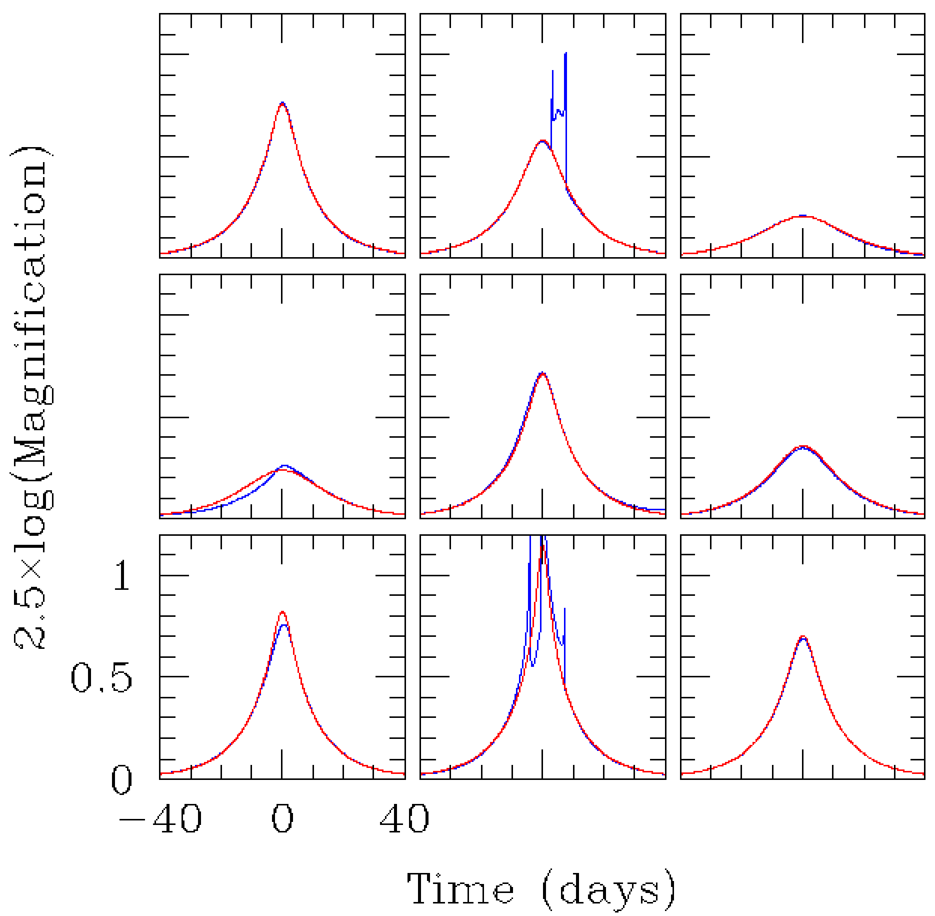
$$30M_J < M < 300M_J$$

Binary nature detectable for

$$0.1 < d < 10$$

$$0.2AU < a < 20AU$$

Binary (Non-Perturbative) Microlensing



"Brown Dwarfs"

$$0.01 < q < 0.1$$

$$3M_J < M < 30M_J$$

Lower probability
but still detectable.

Deviations have
- Long duration
- Large amplitude

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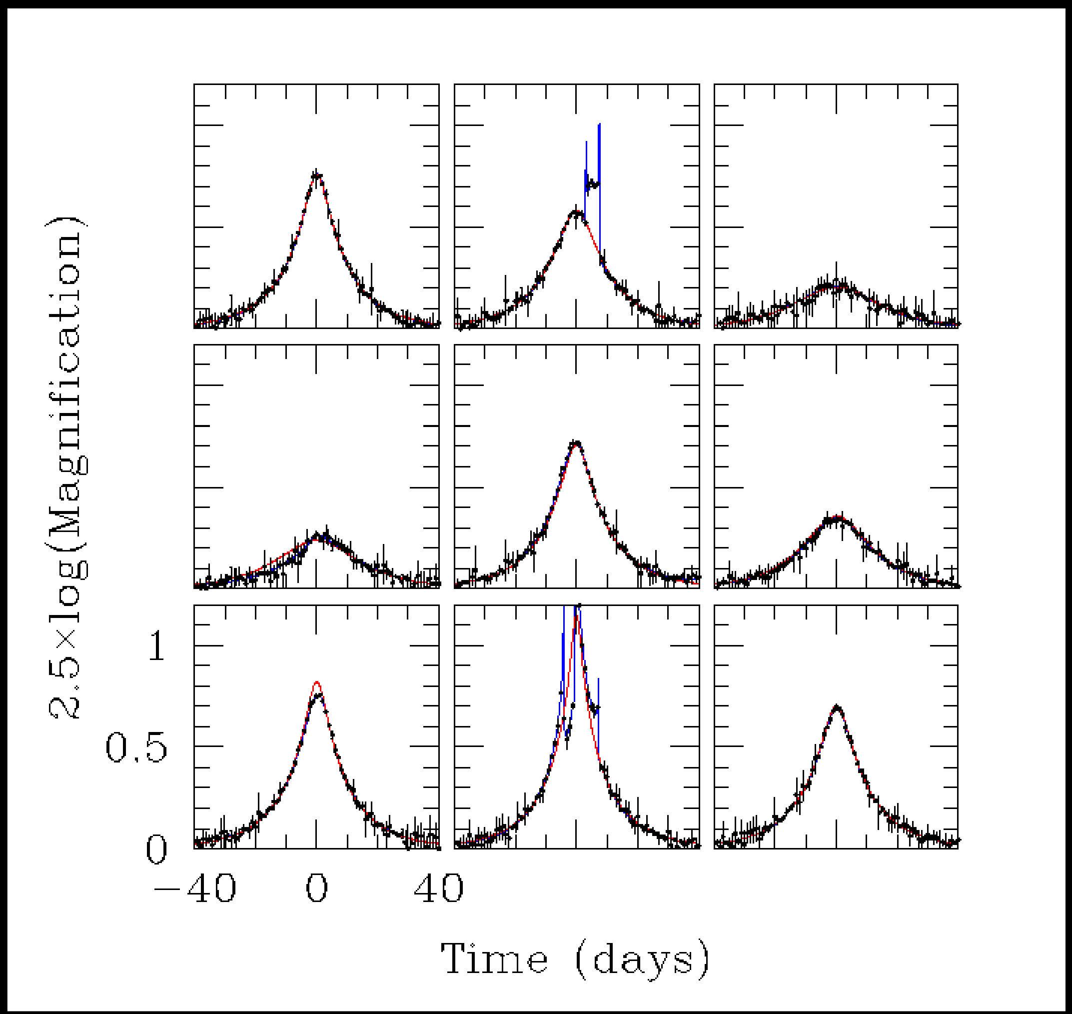
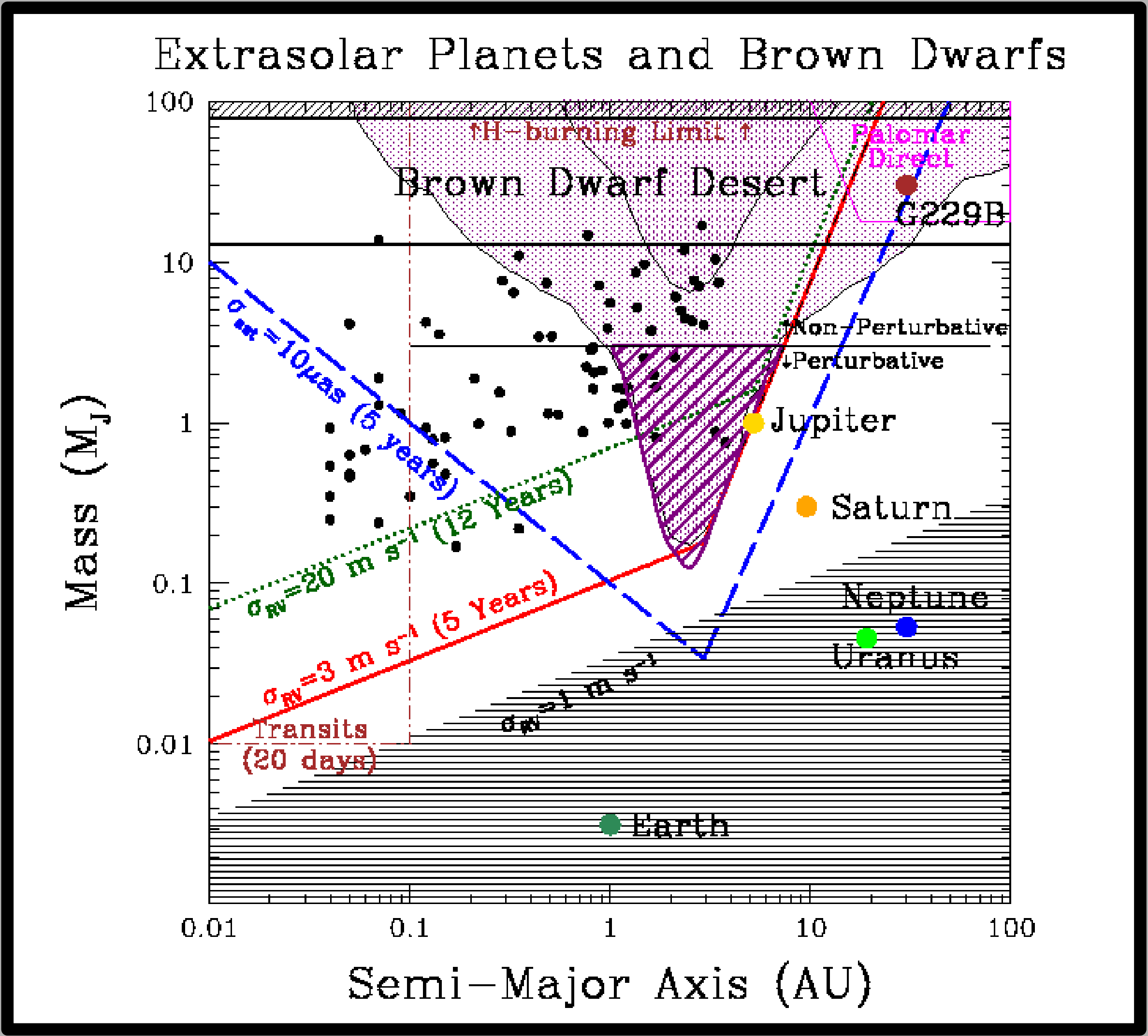
Binary (Non-Perturbative) Microlensing



Survey photometry

- <5 % accuracy
- ~daily sampling

Binary (Non-Perturbative) Microlensing



Survey photometry

- <5 % accuracy
- ~daily sampling

Sufficient to detect most companions.

Less prone to biases.

OGLE II image subtraction database is ideal.

- 512 events (Wozniak et al. 2001)

OGLE III coming soon!

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Conclusions

Microlensing is currently sensitive to companions with-

- Mass ratio: $q > 10^{-4} (M > 0.1 M_J)$
- Separations: $0.1 < d < 10 (0.2 AU < a < 20 AU)$

Two regimes-

- Planetary (Perturbative): $q < 10^{-2}$
- Brown-dwarf/Stellar (Non-perturbative): $q > 10^{-2}$

Planetary Constraints-

- PLANET 5yr Analysis
- <45% of M-dwarfs have 3 x Jupiter-mass Companions with 1AU<a<7AU.

Brown-dwarf Constraints-

- Complicated by non-perturbative nature
- Need homogeneous, unbiased dataset
- Analysis of OGLE-II dataset would provide interesting constraints.

Future Prospects-

- OGLE-III will provide better sampling and more events.