Searching for Exo-Earths through Gravitational Microlensing

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Outline

- Gravitational Lensing
- Gravitational Microlensing
- Exo-Planet Detections So Far...
- And Beyond...
- Review
Gravitational Lensing: History

- A. S. Eddington (1920) – Possibility of multiple star images...
- O. Chwolson (1924) – Ring-shaped image of a star...
- A. Einstein (1936)[¹] – Discussion of both effects in less than a page (which is comprehensible!)
- A. Einstein (1912) – Had done the calculations but not convinced it was observationally feasible (so back to GTR...)

- First confirmed gravitationally lensed object (1979): Twin Quasar (QSO 0957+561)
- First microlensing event (1993): towards Large Magellanic Cloud

[¹] J. Renn et al
Gravitational Lensing: Basics

• Lensing effect due to the gravitational field of a massive object (galaxy...) present between source object (quasar...) and observer (us...).

• ‘Numerous distorted’ images of the source object, and/or Amplification of intensity of the ‘image’.

• Types:
  2. Weak Lensing: Image Distortion at a weaker scale.
Gravitational Lensing: Theory

Light deflection angle, $\alpha$

$\theta_1 D_S = \alpha D_{LS} + \theta_S D_S$

$\Rightarrow \theta_1 - \theta_S = \left(\frac{4GM_L}{c^2} \theta_1 D_L\right) \left(\frac{D_{LS}}{D_S}\right)$

$\Rightarrow \theta_1^2 - \theta_S \theta_1 - \theta_E^2 = 0$

$\Rightarrow \theta_{} = \frac{1}{2} \left[\theta_S \pm (\theta_S^2 + 4\theta_E^2)^{1/2}\right]$

- Knowing $\theta_{}$ gives $M_L$...

- Einstein radius, $r_E = \theta_E D_L$

- Einstein ring crossing time, $t_E = r_E / v$
Examples-

- JVAS B1938+666
- Quad–image lensing of three sources!
- Two sources contributing to Einstein ring
- One source producing two offset images.
Gravitational μlensing: Theory-I

- $u \equiv \theta_s / \theta_E$
- $u_{\pm} \equiv \theta_{\pm} / \theta_E$
- $A_{\pm} = |u_{\pm} du_{\pm} / u du|$
- $A = A_+ + A_-$

- Intensity Amplification, $A(t) = (u^2 + 2) / [u(u^2 + 4)^{1/2}]$
- Impact parameter, $u(t) = [u_{\min}^2 + ((t-t_0)/t_E)^2]^{1/2}$
- $r_E = 4.42 \text{ AU} \left[ (M_L/0.3M_\odot)(D_S/8\text{Kpc})(x(1-x)) \right]^{1/2}$
- $t_E = 38.25d(200\text{Km.s}^{-1}/v_\perp)[...]$

Examples-II

Two lensed images of a single quasar source due to a galaxy. [Ref-4]

EINSTEIN CROSS at two different epochs. [Ref-5]
Gravitational μlensing: Theory-II

- Lens Eq: \( Y = X - \sum m_i (X - x_i)/|X - x_i|^2 \)
- Critical: \( X \) such that \( \det J = 0 \)
- Caustic: \( Y = f(X_{\text{critical}}) \)
- \( A = \sum A_j; A_j = |\det J(x_j)|^{-1} \)

\[ q = \frac{M_p}{M_L} = 10^{-3} \]
Projected radius, \( d = 1.4 \)
\( u_{\text{min}} = 0.01 \& 0.2 \)
\( \beta = 135^\circ \& 106^\circ \)

Gravitational μlensing: Theory-III

Low amplification caustic crossing event and corresponding microlensing light curve.

Gravitational μlensing: Theory-IV

High amplification caustic crossing event and corresponding microlensing light curve.

Exo-Planet Detection-I

Models:
- Cyan - Single lens model
- Magenta - $q > 0.03$
- Green - Early Caustic Crossing Model
- Black - Best Fit Model

Parameters:
- $u_{\text{min}}$, $t_E$, $t_0$, $q$, $d$, $R_s$, $\phi$.

Results:
$M_P = 1.5 M_J$ ($q = 3.9 \times 10^{-3}$) at 3.0AU ($d = 1.12$) from the star.

Exo-Planet Detection-II
OGLE-2005-BLG-071

High amplification caustic cusp crossing event.

Results:
$q=7.1 \times 10^{-3}$
$d=1.294$

[7] A. Gould
Exo-Planet Detection-III
OGLE-2006-BLG-109

Both high & low amplification events occur (5 times!)

Two Planets!
1, 2, 3 & 5: Saturn
4: Jupiter

[7] A. Gould
So What???

Comparing exo-planets discovered through Transits, Radial Velocity and micro-lensing:

- Small probability / Short event duration
- No Detailed investigations / Independent confirmations possible
- Only ‘q’ and ‘d’ determinable!

[7] A. Gould
Resolving Issues...

- Amplitude of planetary microlensing signals is large (>10%) and is approximately independent of the planet’s mass.
- Sensitive to low-mass planets down to 0.1 $M_\oplus$.
- Sensitive to planets at 1.5-4 AU from their host stars near the ‘snow line’.
  - Planets with large semi-major axes detectable ‘easily’!
- Not detecting light from either the planet or its host star, so planets orbiting unseen stars can be detected.
- Multiple planet systems are detectable.
- Even detecting free-floating planets is possible.
- No bias for nearby or main sequence stars.
- Best statistics for galactic population of planets.
Surveys: Present & Future-I

- **OGLE (Optical Gravitational Lensing Experiment)**
  - 1.3m telescope at La Silla, Chile
  - Field view 0.34(?) sq.deg.

- **MOA/MOA-II (Microlensing Observations in Astrophysics)**
  - 1.8m telescope at Mt. John, New Zealand
  - Field view 2.2 sq.deg.

- **Earth Hunter Network (EHN)**
  - Four 2m telescopes around the Earth
  - Field view 4 sq.deg.

Surveys: Present & Future-II

- Microlensing Planet Finder (MPF)
  - Space-based mission (1.1m telescope/1.5 deg FoV)
  - Sensitive to Earth-mass planets in habitable zone!
  - 10-100 events/year expected (<10 for ground-based!)
  - Feb. 2012 launch

Review

• Massive objects bend light and can act as lenses.
• Lensing by planets – Microlensing – a great tool to discover new solar systems.
• Such exo-planet detections complementary to other techniques...
• Parameters for these systems can be constrained very well!
• Various surveys & follow-up collaborations set up (even amateurs have a place!)
• Space-based missions also being designed.
• Future is bright!
References

11. For greater details: www.astro.uni-bonn.de/~peter/micro.ps.gz
THANK YOU

Have a GREAT Summer (Vacation?)