N-Body Simulations as Gravitational Lenses

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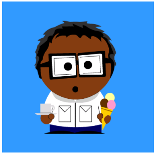
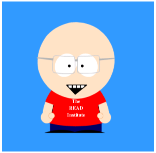
NBody2008 Turku, Finland



Prasenjit Saha

Jonathan Coles



Justin Read

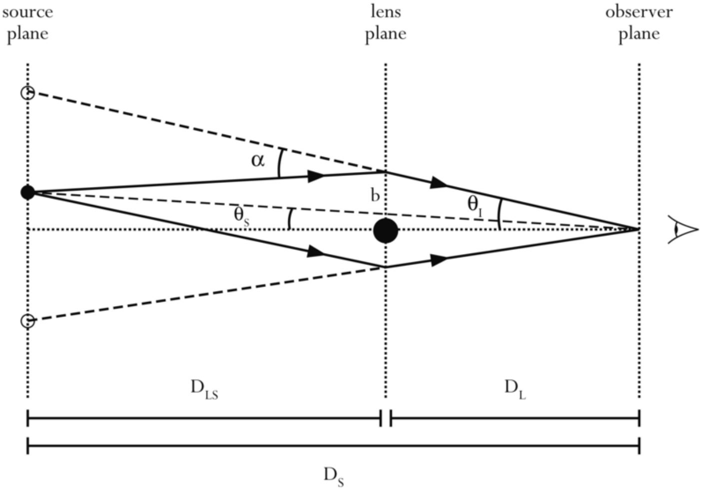
Andrea V. Maccò

Robert Feldmann

Liliya L.R. Williams

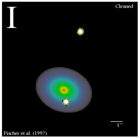
Outline

Schematic View of a Lens



(Wikipedia)

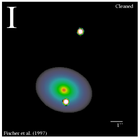
Lens Examples



Double Q0957

(Castles Database)

Lens Examples



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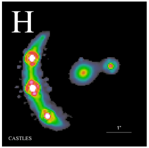

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Quad RXJ131

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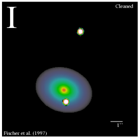

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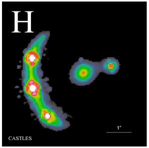

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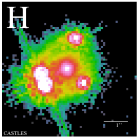
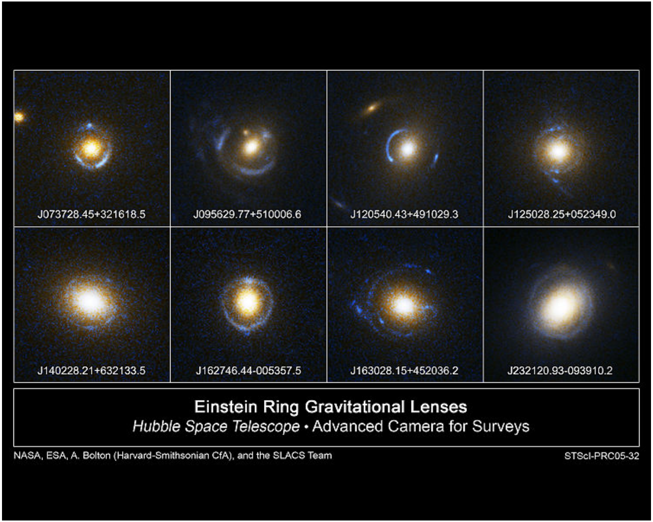


Quad PG1115

Einstein Rings



Abell 1689


Gravitational Lens in Galaxy Cluster Abell 1689
HUBBLESITE.org

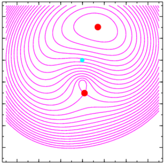
Lens Equation

The lens equation describes the arrival time of light at the observed position:

$$\tau(\theta) = \frac{1}{2}|\theta|^2 - \theta \cdot \beta - \int \ln|\theta - \theta'|\kappa(\theta')d^2\theta'$$

where θ is a position on the sky, β is the (unknown) source position, and κ is the mass at position θ'.

Images are at the minimum, maximum, and saddle points of this surface.



Uses

Knowing the mass distribution κ we can:

- Measure the dark halo profile of clusters and galaxies, particularly the inner profile: cusp or core?
- See dark matter substructure in clusters (Abell 1689)
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These degeneracies are well-known but not well-accepted.

Many still use parameterized models and find a 'best-fit'.

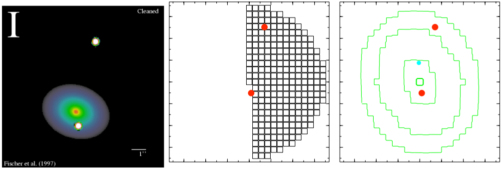
This is 20th century lensing!

21st Century Lensing

We discretize the sky into grid cells and rewrite the equation as

$$\tau(\theta) = \frac{1}{2}|\theta|^2 - \theta \cdot \beta - \sum_n \kappa_n Q_n(\theta) + \text{shear terms}$$

Need to solve for each grid cell mass κ_n.



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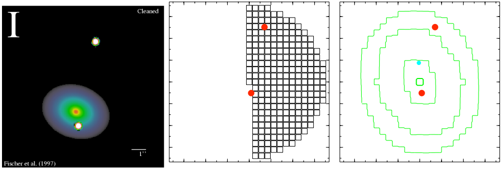

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Encapsulated into the program PixeLens. Easy to use, parallel, freely available, and can even run in a web browser!

Measuring the Hubble time

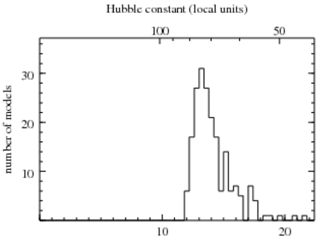
Simultaneous modeling of 11 lenses allowed us to constrain the Hubble Time

Hubble Time

$$H_0^{-1} = 13.7^{+1.8}_{-1.0}\mathrm{Gyr}$$

Hubble Constant

$$H_0 = 71^{+6}_{-8}\mathrm{km\ s^{-1}\ Mpc^{-1}}$$



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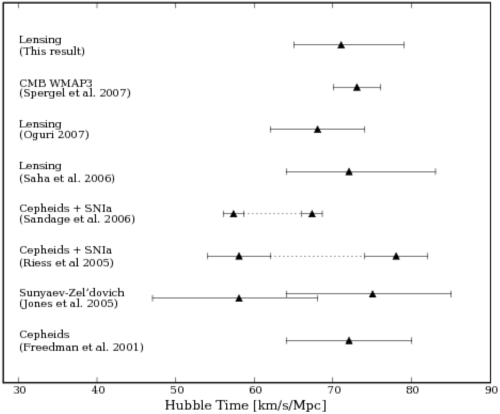

Testing with N-Body Simulations

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1. PKDGRAV – Treecode with Fast Multipole Method
2. A single initial galaxy has 2×10^6 DM particles, 2×10^6 gas particles
3. Two are merged to create the final lensing object

(Feldmann et al. 2008)

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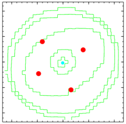
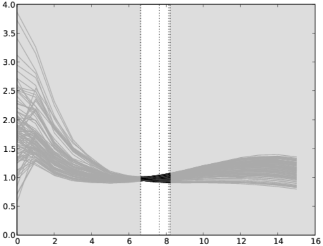
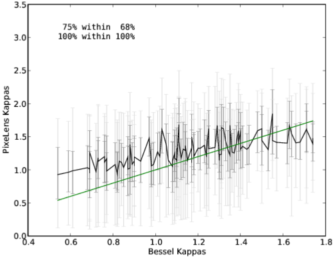
Single Quad



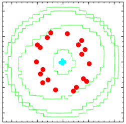


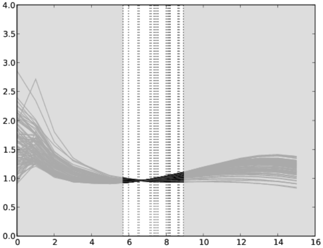
Enclosed mass comparison



Per pixel recovery

Einstein Ring





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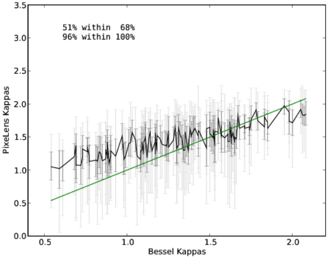
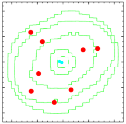
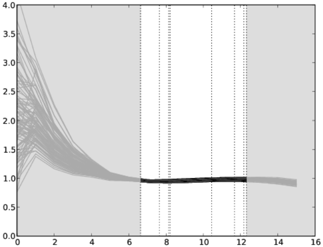


Per pixel recovery

2 Quads at different redshifts





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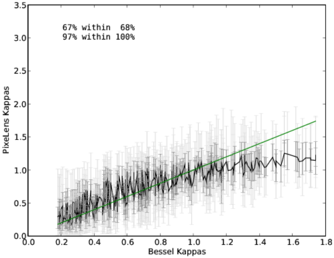

Per pixel recovery

Conclusions....But wait! There's more!

- Modern lensing *must* account for degeneracies.
- Studying N-Body simulations allows us to test our mass recovery.
- Lensing tells us nothing about the profile within the inner most image.
- Multiple sources at multiple redshifts break the steepness degeneracy and constrains the mass profile in the image region.

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StarSpray!