Gravitational Lensing with the Millennium Simulation

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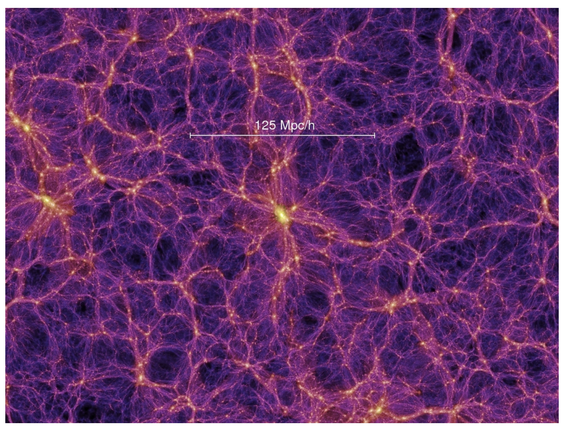
Abstract: We report on results for gravitational lensing from ray-tracing through the Millennium Simulation, a very large *N*-body simulation of cosmological structure formation in a ΛCDM universe. We have developed a new ray-tracing code in order to make optimal use of the information on the dark matter distribution in the simulation. First results obtained by this code include magnification distributions and strong lensing optical depths. One future aim of our work is to simulate galaxy-galaxy lensing using the dark matter distribution in conjunction with semianalytic galaxy models to gain more insight into the co-evolution of galaxies and their dark-matter environment.

The Millennium Simulation

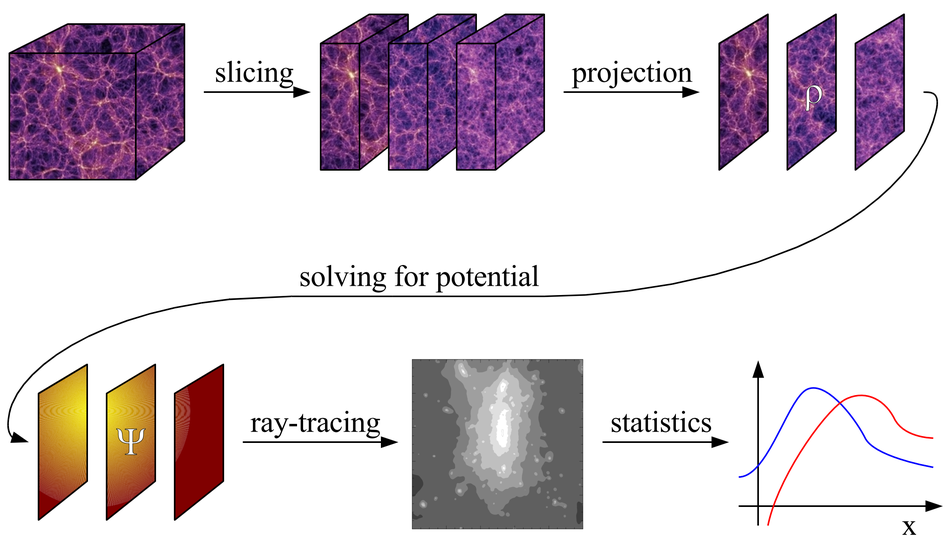


- cosmological parameters:
  - $\Omega_M = 0.25$
  - $\Omega_\Lambda = 0.75$
  - $h = 0.73$
  - $\sigma_8 = 0.9$
  - $n = 1$

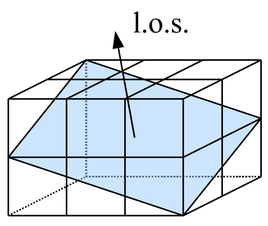
- $N = 2160^3$ particles in a cubic box of 500 Mpc/h comoving size
- 64 snapshots between $z = 127$ and $z = 0$
- semianalytic galaxy models with 2×10^6 galaxies at $z = 0$

Ray-Tracing

- **Outline:**

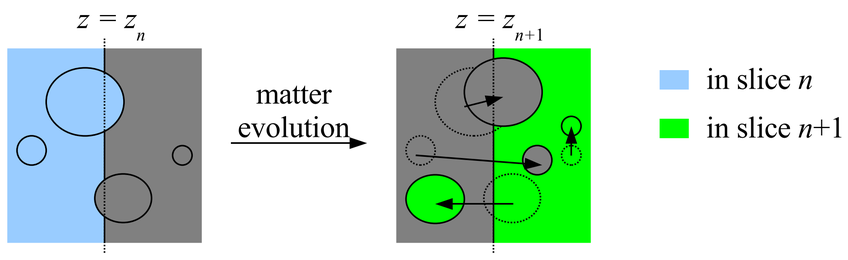


- **Some Details:**



- replicate simulation box to fill space
- line of sight, slices and planes tilted w.r.t. box
- one slice / plane per snapshot

- avoid truncation or double inclusion of halos at slice boundaries:



- PMPM method to obtain lensing potential, deflections etc.:
  - coarse mesh covering whole lens plane
  - fine mesh with 2.5kpc/h spacing
  - adaptive smoothing for projection of particles onto meshes

Results

- **Magnification Distribution:**

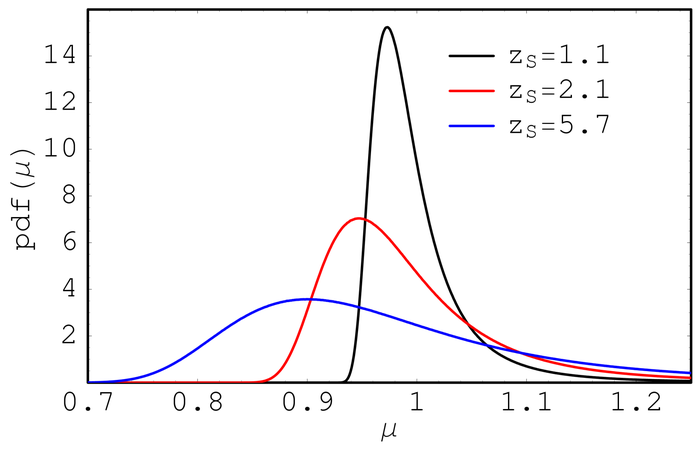


Figure 1: probability distribution function pdf(μ) of the image magnification μ of point-like sources for different source redshifts z_S

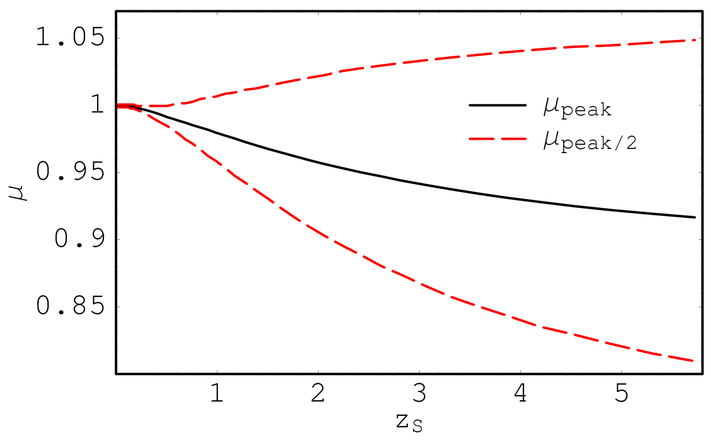


Figure 2: positions of the maximum μ_{peak} and the half maxima $\mu_{peak/2}$ of the magnification probability distribution function as a function of source redshift z_S

- **Optical Depths:**

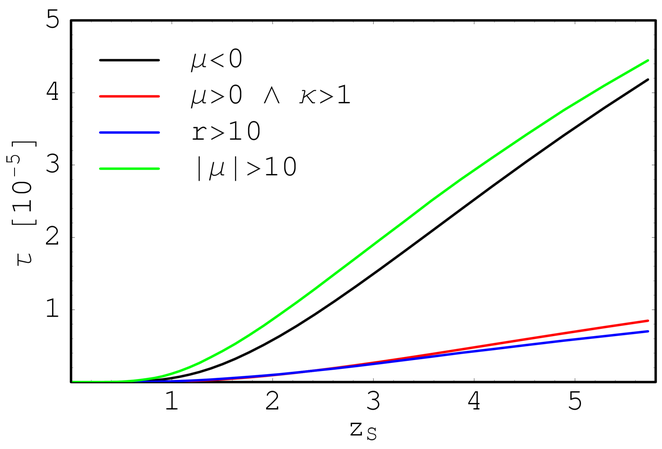


Figure 3: optical depths τ as a function of source redshift z_S for images with:
- magnification μ<0
- magnification μ>0 and convergence κ>1
- length-to-width ratio r>10
- magnification |μ|>10

Outlook

- study the effect of substructure for cluster lensing
- effects of additional matter along the line of sight
- cosmic shear simulations
- galaxy-galaxy lensing using semianalytic galaxy models
- *your suggestions*

Literature

- Springel, V. et al., 2005, Nature, 435, 629
- Hilbert, S. and White, S, *in preparation*