Weak Lensing with the Millennium Simulation

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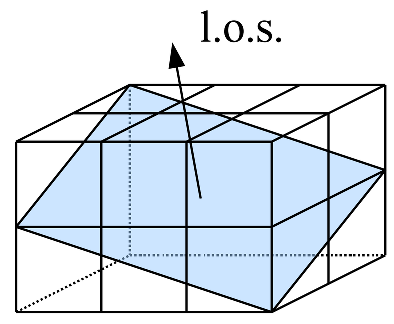
Abstract: The Millennium Simulation, by its large volume and dynamic range, is an unprecedented tool to study the growth of structure and the properties of the Dark Matter distribution in the ΛCDM model. We have developed a ray-tracing code which allows us to fully exploit the information contained within the Millennium Run. Here, we describe several novel features of our code, such as the accurate treatment of halos at slice boundaries, or the inclusion of galaxies from semi-analytic models (SAMs) of galaxy formation into the ray-tracing process. While previous work has focused mainly on cosmic shear studies, this extends the applicability of our code also to galaxy-galaxy lensing. Furthermore, a variant of the code has been used by Hilbert et al. (2007) to study strong lensing optical depths.

Algorithm Highlights

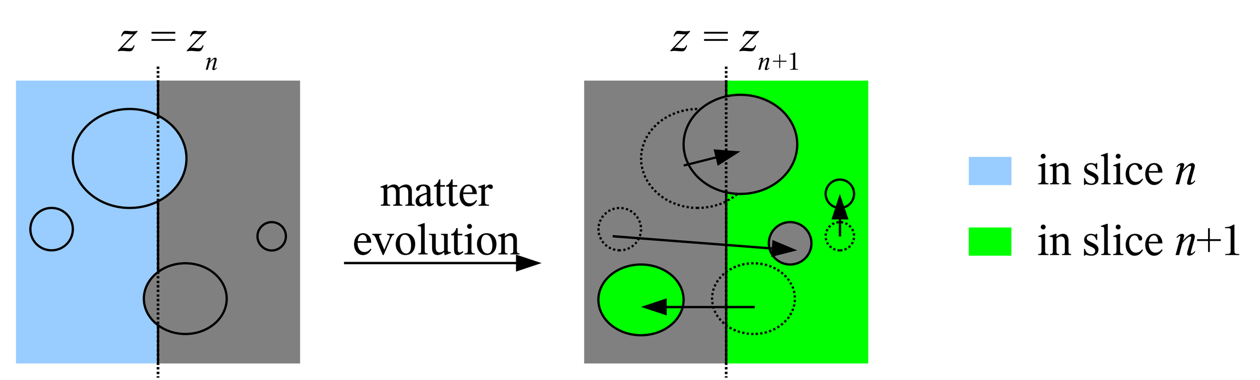
Avoid repetition of structure along l.o.s

- Can't project a full box onto one lens plane
  → *shoot rays at skewed angle*
- For FFT: can find l.o.s. such that tilted lens planes are still periodic and the mesh is rectangular!



Avoid truncation / double inclusion of halos

- One lens plane per snapshot, but:
- some halos might have crossed snapshot boundary in the time between two snapshots
- slice boundary might cut halo
  → *adaptive slice boundaries*

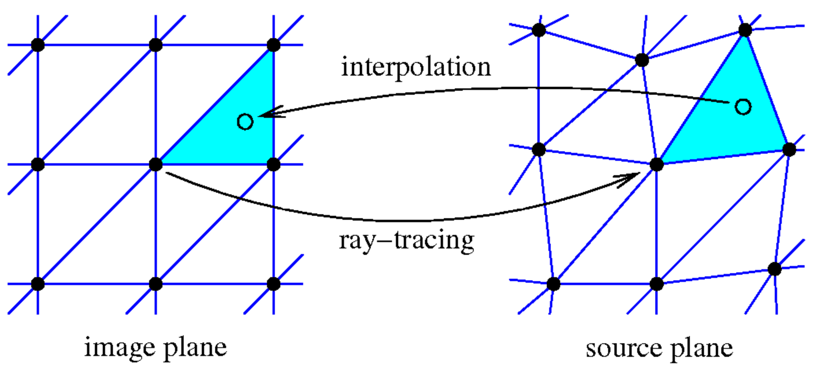


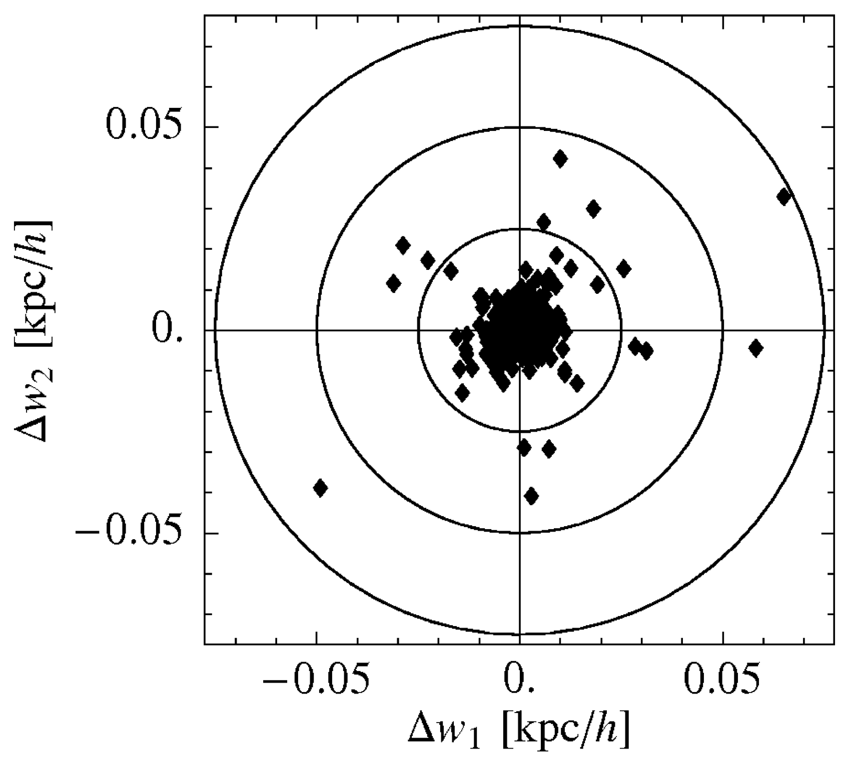
PMPM to compute the deflection potential

- Coarse mesh covering the whole lens plane for long range potential
- Short range potential computed on the fly where needed; grid spacing: 2.5 kpc/h
- Adaptive (SPH) smoothing to suppress shot noise

Inclusion of Galaxies

Need lensed positions of SAM galaxies for galaxy-galaxy-lensing!

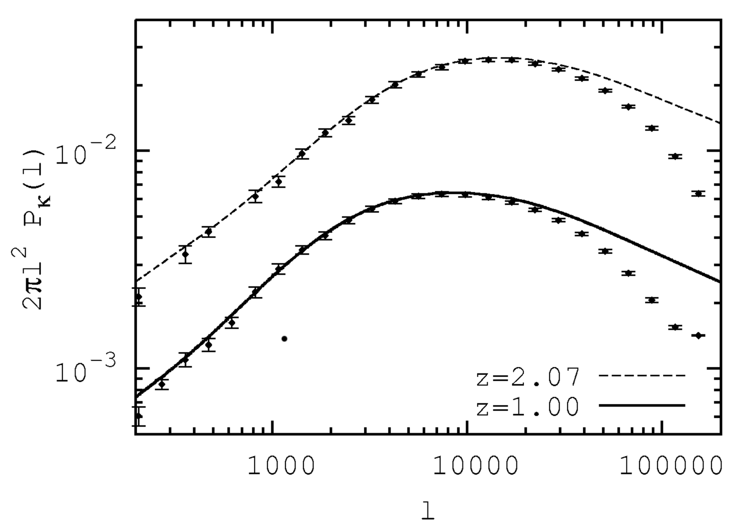




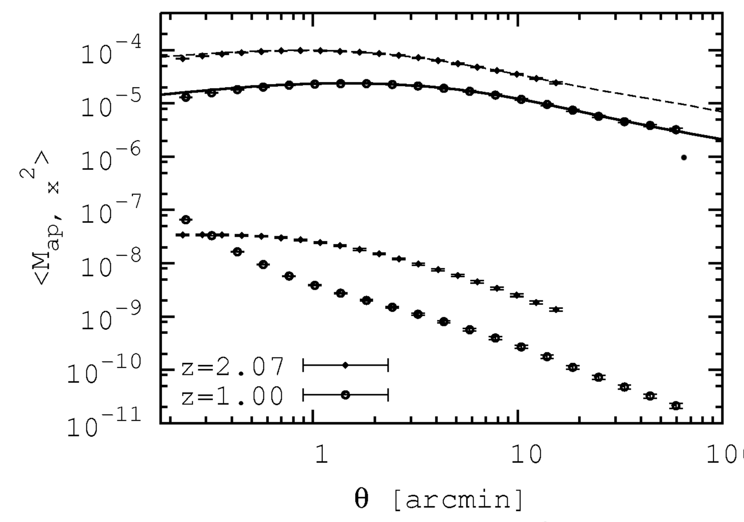
Deviations of the true source plane positions of galaxies to the positions obtained by shooting a light ray - starting from the ray-traced image position – back to the source plane. The source plane grid spacing is 2.5 kpc/h, the deviations are smaller than 2% of that.

- Light rays form grid on the image plane
- Divide each grid cell into two triangles
- Map these triangles to the source plane
- Find triangle containing the galaxy
- On the image plane, interpolate position, shear, etc. from the three light rays onto galaxy position
- SAMs use central particle in a halo as possible galaxy location
  → do this once for all central particles of halos; then use these positions for many different SAMs

First Results



Convergence power spectra for sources at *z=1* and *z=2*. Solid lines are predictions made by projecting the measured 3D power spectra of the Millennium Simulation

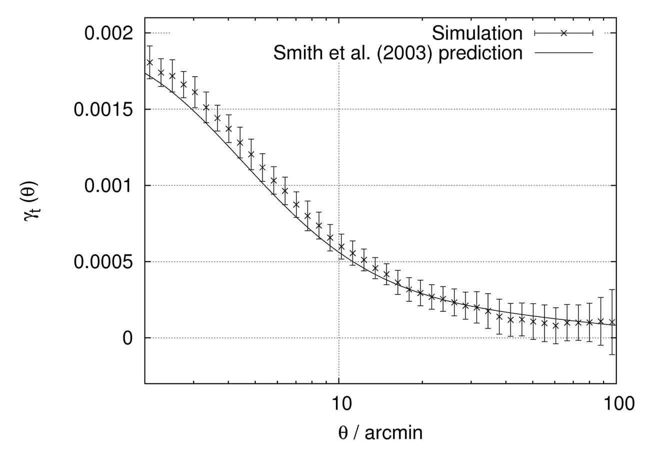


Aperture Mass Dispersion for sources at *z=1* and *z=2.* Points and solid lines give the E-modes, just points the B-modes. Predictions were obtained as in Fig.1

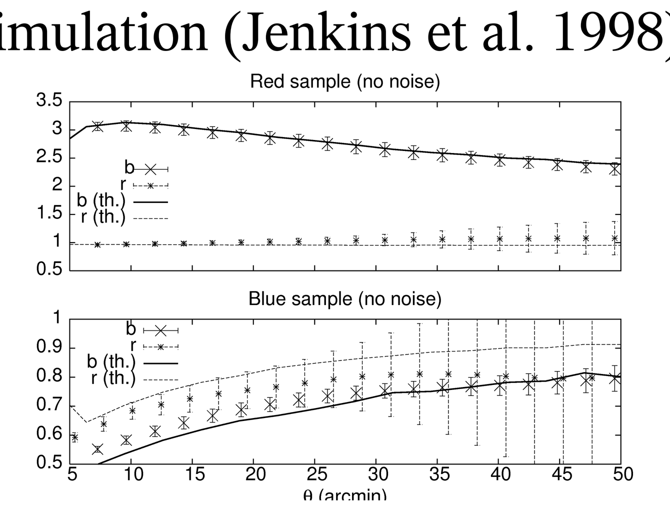
- Convergence power spectra agree with predictions up to $l \approx 2 \times 10^4 (\theta \approx 30$ arcsec$)$, where smoothing becomes important
- B-modes are at least 2-3 orders of magnitude smaller than the E-modes
- Origin of B-modes are lens-lens-coupling and deviations from the Born approximation
- B-mode from numerical artifacts is at least 6 orders of magnitude smaller than E-mode

Galaxy-Galaxy-Lensing

Results using the ΛCDM GIF-simulation (Jenkins et al. 1998)



GGL signal for unbiased galaxies from ray-tracing through the GIF simulation. The prediction is based on Smith et al. (2003).



Reconstruction of bias and correlation parameter using GGL, following Hoekstra et al. (2002), for blue and red galaxies. The galaxies are from the SAM by Kauffmann et al. (1999).

Outlook

Cosmic Shear

- Study B-modes from source clustering
- Obtain covariance matrices (in particular for tomography)
- Selection effects
- Produce large set of simulated sky maps

Galaxy-Galaxy-Lensing

- Make predictions based on SAMs
- How to interpret the GGL/GGGL signal
- Test halo-/HOD models
- Detectability of halo truncation in dense environments
- Can we measure halo ellipticities using GGL?
- What is gained by including flexion?

References

Hilbert et al. 2007, astro-ph/ 0703803
Hoekstra et al. 2002, ApJ 577, 604
Jenkins et al. 1998, AJ 499, 20
Kaufmann et al. 1999, MNRAS 303, 188
Smith et al. 2003, MNRAS 341, 1311