# Estimating the weak lensing effect from ray-tracing in cosmological simulations

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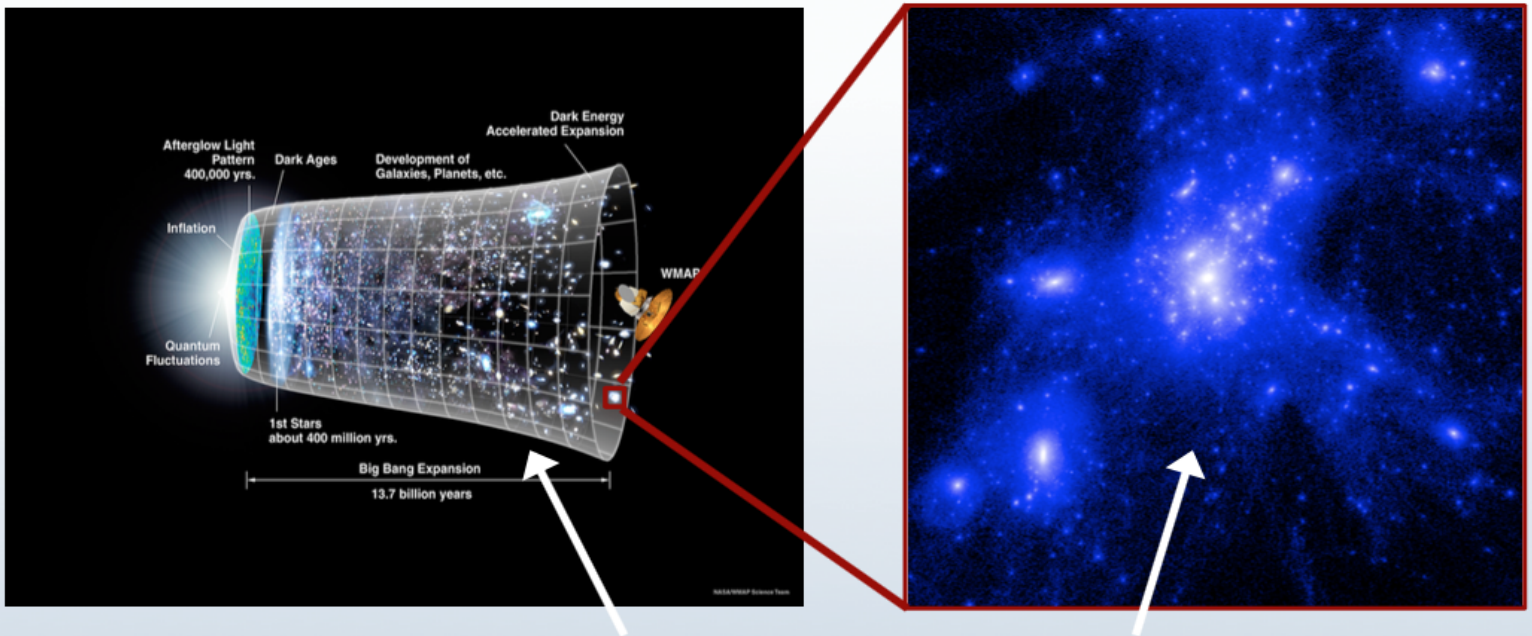
# Cosmology and structure formation

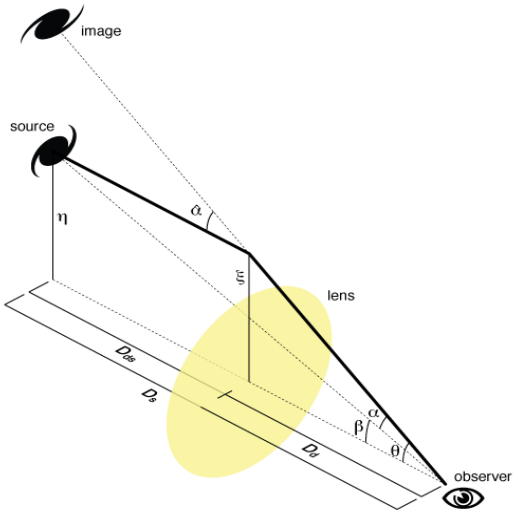
## Universe components

- *68% Dark Energy*
- *27% Dark Matter*
- *5% Ordinary Matter*




**Imprints of DARK ENERGY on COSMIC STRUCTURE FORMATION**

# Weak lensing and lens equation

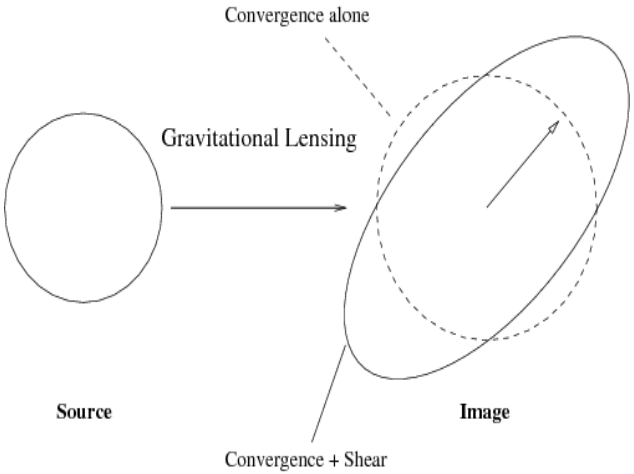



## Lens equation

$\vec{\beta} = \vec{\theta} - \vec{\alpha}(\vec{\theta})$

- $\vec{\beta}$ true angle
- $\vec{\theta}$ angle seen
- $\vec{\alpha}$ deflection angle

Approximation :
$\vec{\beta}, \vec{\theta}, \vec{\alpha} \ll 1$




## Distortion matrix

$$\frac{\partial \vec{\beta}}{\partial \vec{\theta}} = \textit{convergence} + \textit{shear}$$

$$\textit{convergence} : (1 - \kappa) \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

$$\textit{shear} : -\gamma \begin{pmatrix} \cos 2\phi & \sin 2\phi \\ \sin 2\phi & -\cos 2\phi \end{pmatrix}$$

# Cosmological N-Body simulation

*N-body simulations of interacting (dark matter) particles in an FLRW metric*

*Poisson equation :*

$$\Delta\Phi = 4\pi G\rho$$

*Evolution equations :*

$$\frac{d\vec{x}}{dt} = \vec{v}$$

$$\frac{d\vec{v}}{dt} = -\vec{\nabla}\Phi$$

*New ongoing simulations :*

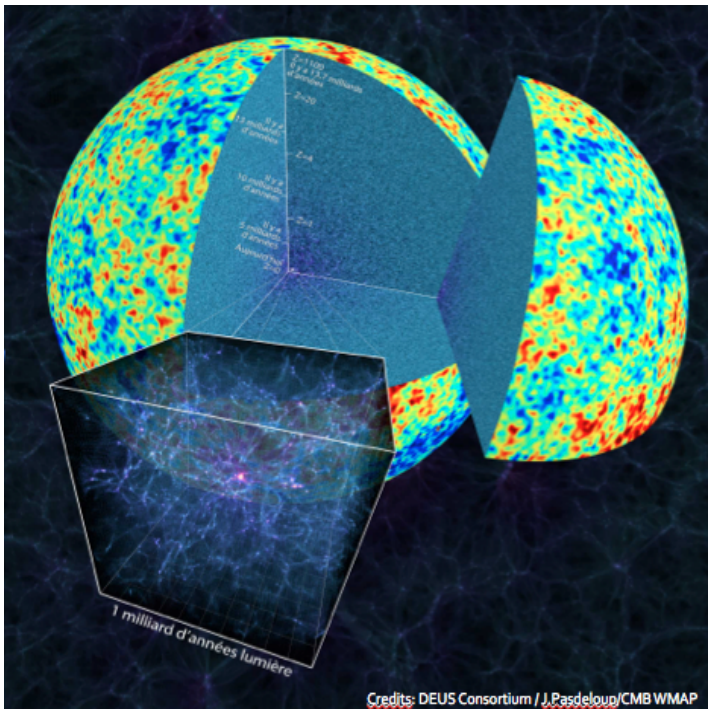
$4096^3$ *particles*

*box size :* $3Gpc$

*Ideal for groups*

*3 cosmologies :*

$\Lambda CDM - WCDM - RPCDM$

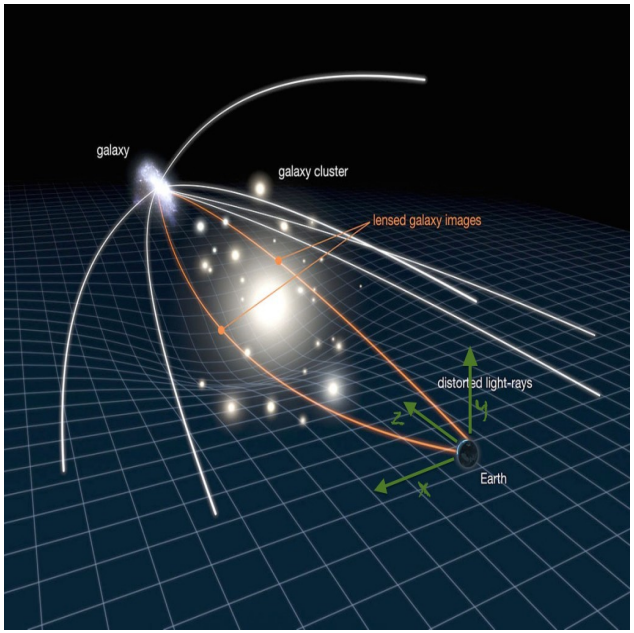


# A raytracing library : *Magrathea* (V. Reverdy)

*Compute propagation of photons in perturbed universe*

## Using C++11 template metaprogramming

- *Take action in the instanciation process*
- *MPI parallelized*




## Geodesic equation

$$\frac{d^2x^\alpha}{d^2v} = \Gamma^\alpha_{\beta\gamma}\frac{dx^\beta}{dv}\frac{dx^\gamma}{dv}$$

## Raytracing characteristics

- *RK4 integrator*
- *4 steps per cell*

# Light beam

## Definition

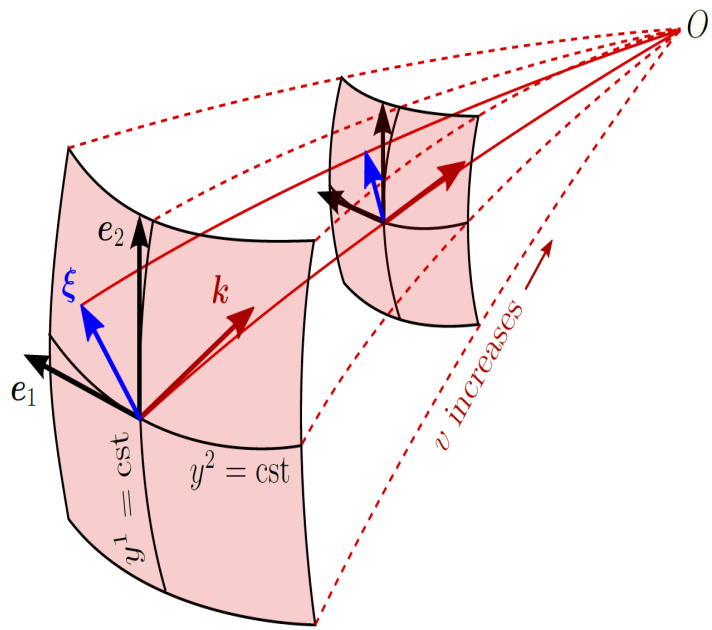
*set of light rays which all intersect at one event*

*affine parameter $v = cst$ – hypersurface*

## Stop conditions

*Different possibilities*

- *Affine parameter*
- *Comoving distance*
- *Scale factor*
- *Redshift*



# From the observer to sources (backward ray-tracing)

## Problematic

*How to get the position of sources as seen by an observer ?*
$\rightarrow$ *Find the null geodesic between the observer and a source*

## Method

- $x = (\varphi, \theta)$
- *Minimize* $F(x) \in \mathbb{R}^2$
- *Newton's method*

## Output

*« NEW » : Catalog of sources taking into account weak lensing effects*

# Conclusion

## Summary

- *Optimized raytracing library : metaprograming, MPI, HDF5 (new)*
- *Get shifted position (displaced galaxies) and deformation term (distorted galaxies)*

## Next step ?

- *Run the N-body simulations*
- *Investigate the effect of lensing on Large Scale Structure statistics*
- *Investigate the imprints of cosmology on weak-lensing*