



Observatoire
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PSL



The magnification bias in $w_0w_a\nu$ CDM from N -body simulations and relativistic ray-tracing

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General context

- ▶ Λ CDM : Conceptual problems
- Nature of dark energy still unknown
- H_0 and S_8 tensions : measurements in early and late universe not coherent together
- Motivate tests of **modified gravity and dark energy theories**
- ▶ Combine observables related to structure formation and relativistic effects (eg. gravitational lensing) to constrain the nature of gravity on cosmological scales
- ▶ Improve modeling of relativistic effects for ongoing cosmological surveys



The magnification bias

Weak lensing has two opposed effects on δ_{obs}

- ▶ Increase in solid angles: Dilution of the observed source density per unit area
- ▶ Galaxies that are normally too faint become detectable : Increase in source density

$$(1 + \delta)_{\text{obs}} = (1 + \delta)\mu^{2.5s-1} \quad (1)$$

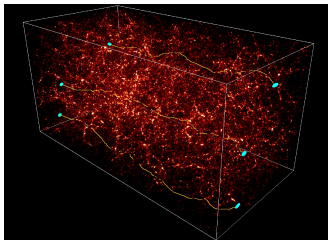
with the magnification $\mu = \frac{1}{(1-\kappa)^2 + |\gamma|^2}$, and s the logarithmic slope of the galaxy luminosity function.

- ▶ Poorly accounted for in current surveys



Methodology

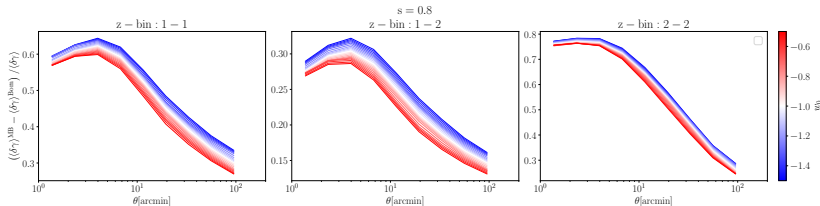
- ▶ N -body simulations with RAMSES (Teyssier 2002)
- ▶ Propagation of light rays in simulated structures with Magrathea-Pathfinder (Breton & Reverdy 2021)
- ▶ **Novelty** : Cosmological dependence of relativistic effects
- ▶ We progressively complexify Λ CDM (done, cf. Räsä 2022), dynamical dark energy (ongoing), modified gravity (future)



Credits : S. Colombi



Preliminary results



- ▶ All cosmological parameters modify the amplitude of relativistic effects
- ▶ Most important parameters are Ω_m and σ_8
- ▶ The amplitude of the magnification bias can be modified by w_0 by up to 10% for $\langle \delta\gamma \rangle$ and 5% for ξ_-

Future work : generalization to modified gravity

- Generalize ray-tracing to modified gravity : Unlike GR, $\Phi \neq \Psi$

$$\frac{d^2\eta}{d\lambda^2} = -\frac{2a'}{a} \frac{d\eta}{d\lambda} \frac{d\eta}{d\lambda} - \frac{2}{c^2} \frac{d\Psi}{d\lambda} \frac{d\eta}{d\lambda} + \frac{\partial(\Psi + \Phi)}{\partial\eta} \left(\frac{d\eta}{d\lambda}\right)^2$$
$$\frac{d^2x}{d\lambda^2} = -\frac{2a'}{a} \frac{d\eta}{d\lambda} \frac{dx}{d\lambda} + \frac{2}{c^2} \frac{d\Phi}{d\lambda} \frac{dx}{d\lambda} - \frac{\partial(\Psi + \Phi)}{\partial x} \left(\frac{d\eta}{d\lambda}\right)^2$$

- PySCo-EFT and ECOSMOG-EFT: New N -body codes for simulation of EFT of Dark energy (Ganjoo, Rasera, Bellini, Breton, **Castillo** et al 2026)
- Formalism with few free parameters that captures a wide range of modified gravity theories

Tests of pipeline ongoing, start new simulations this summer



Conclusions

- ▶ Improve modeling of relativistic effects crucial for ongoing cosmological surveys
- ▶ These relativistic effects can be used to test General Relativity on cosmological scales
- ▶ Emulator for magnification bias in $w_0w_a\nu$ CDM ongoing, need more simulations for better interpolation
- ▶ Extension to modified gravity theories planned for this summer
- ▶ Future : hydrodynamical simulations and higher order statistics

