Dark matter halo profiles in modified gravity simulations

Irène Balmès

IFUSP

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Observational cosmology workshop

MODIFIED GRAVITY

- alternative to general relativity
- small scales: gives back standard gravity
- large scales: compatible with current constraints
- expansion history similar to ΛCDM

Collaborators: Marcos Lima, Claudio Llinares, David Mota, Leonardo Duarte, Rodrigo Voivodic

ISIS simulations

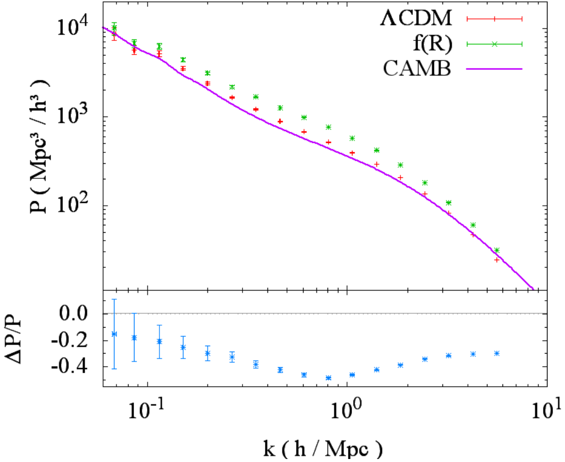
ISIS code

Llinares, Mota & Winther, 2014
DM only. 128 Mpc/h, 512^3 particles
ΛCDM, $f(R)$, Symmetron

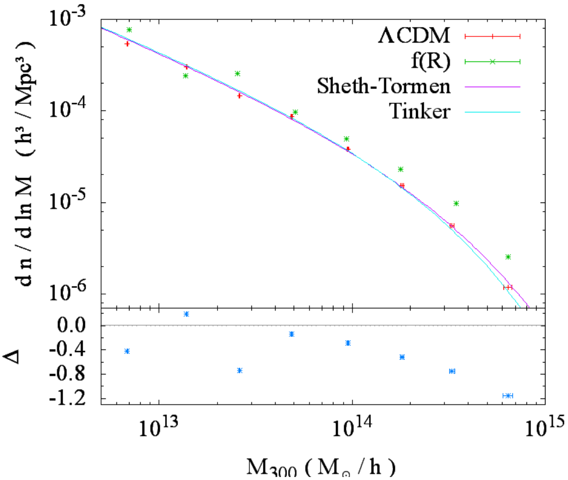
Model	λ_0	z_{SSB}	β
Symm A	1	1	1
Symm B	1	2	1
Symm C	1	1	2
Symm D	1	3	1

Model	n	$\lvert f_{R0}\rvert$	λ_0
fofr4	1	10^{-4}	23.7
fofr5	1	10^{-5}	7.5
fofr6	1	10^{-6}	2.4

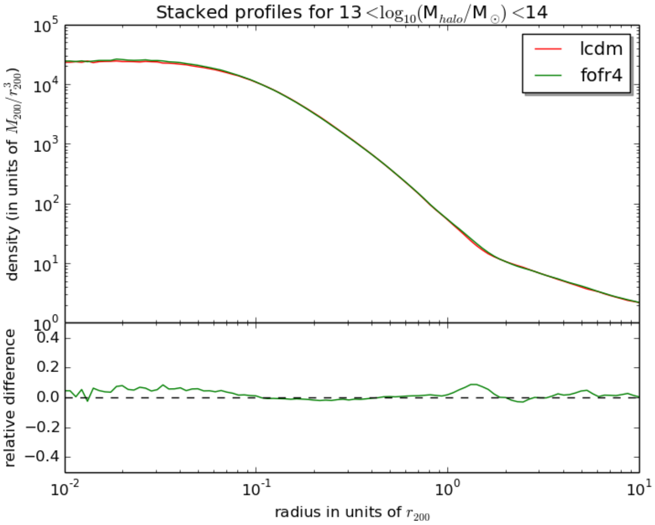
Power spectrum



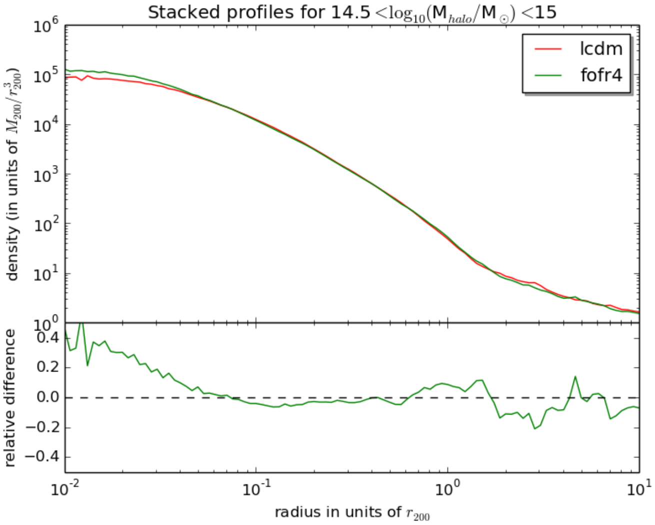
Halo mass function



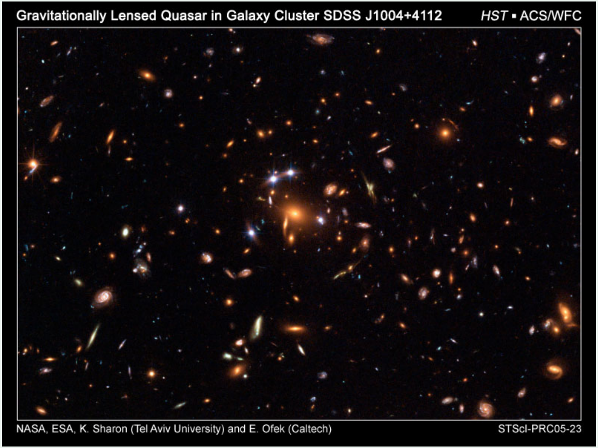
Halo profiles



HALO PROFILES

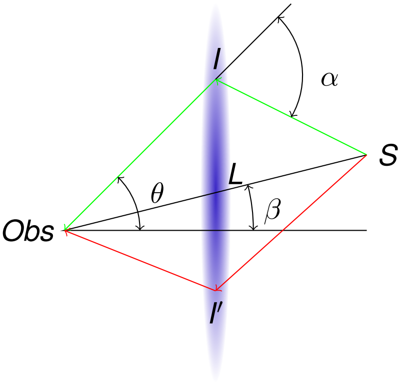


What is a gravitational lens?



Denomination

2 images : double lens
4 images : quadruple lens



FERMAT'S PRINCIPLE

Images are formed at extremum of the arrival time.

β: source position
θ: image position on the sky
α: light deviation

$$t = (1 + z_l)\frac{d_l d_s}{d_{ls}}\left[\frac{1}{2}(\theta - \beta)^2 - \psi(\theta)\right]$$

Time delay expression

$$\Delta t_{A,B} = (1+z_l)\frac{d_l d_s}{d_{ls}}\left\{\frac{1}{2}\left[(\theta_A-\beta)^2-(\theta_B-\beta)^2\right] + \psi(\theta_A)-\psi(\theta_B)\right\}$$

with

$$\frac{d_l d_s}{d_{ls}} \propto H_0^{-1}$$

- Δt_{AB}: measured when the source is variable (quasar)
- mass distribution: reconstructed through a model

Lens models

Spherical model

$$\rho(r) \propto r^{-n}$$

$$\psi(\vec{\theta}) = \frac{\theta_E^2}{3-n}\left(\frac{\theta}{\theta_E}\right)^{3-n}$$

Elliptical model

$$\psi(\vec{\theta}) = \frac{\theta_E^2}{3-n}\left(\frac{\sqrt{(1-\epsilon)\theta_1^2+(1+\epsilon)\theta_2^2}}{\theta_E}\right)^{3-n}$$

Influence of the environment

Several components

$$\psi(\vec{\theta}) = \psi_0(\vec{\theta}) + \psi_1(\vec{\theta}) + ...$$

or

Global shear term

$$\psi(\vec{\theta}) = \psi_0(\vec{\theta}) - \frac{1}{2}\gamma\theta^2 \cos 2(\phi - \phi_\gamma)$$

High number of parameters (θ_E, n, ϵ, ϕ_ϵ, γ, ϕ_γ...): models underconstrained.

Two competing models

Spherical model $\mathcal{M}_0$

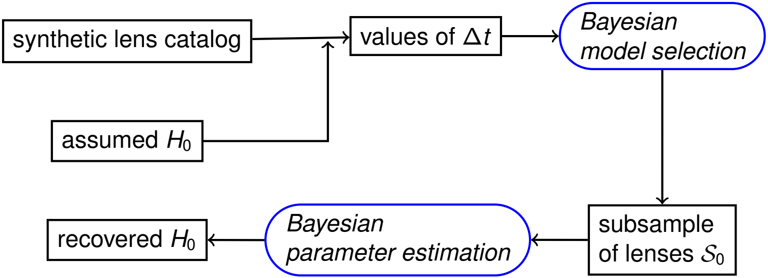
$$\psi(\vec{\theta}) = \frac{\theta_E^2}{3-n}\left(\frac{\theta}{\theta_E}\right)^{3-n}$$

Model including angular structure $\mathcal{M}_1$

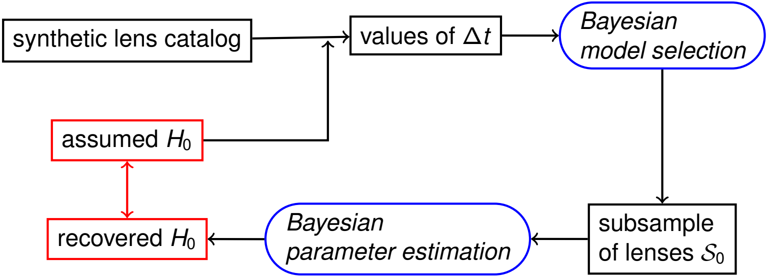
$$\psi(\vec{\theta}) = \frac{\theta_E^2}{3-n}\left(\frac{\theta}{\theta_E}\right)^{3-n} - \frac{1}{2}\gamma\theta^2\cos 2(\phi - \phi_\gamma)$$

Use of Bayesian evidence to determine whether the data requires model $\mathcal{M}_1$.

Testing our method



Testing our method



Catalog with shear

500 lenses simulated using `gravlens` (Keeton, 2011) with model $\mathcal{M}_1$:

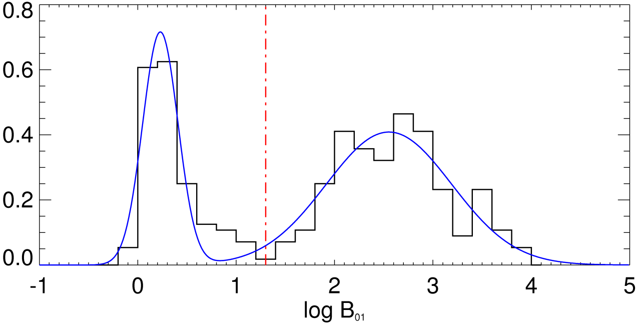
$$\psi(\vec{\theta}) = \frac{\theta_E^2}{3-n}\left(\frac{\theta}{\theta_E}\right)^{3-n} - \frac{1}{2}\gamma\theta^2\cos 2(\phi - \phi_\gamma)$$

Randomly generated parameters

- $\theta_E = 1$
- $n = 2 \pm 0.3$
- $\gamma = 0.2 \pm 0.1$
- $\phi_\gamma = 0$
- source position: $-1 < x, y < 1$

$\rightarrow$ 280 double lenses

COMPARISON OF THE EVIDENCES

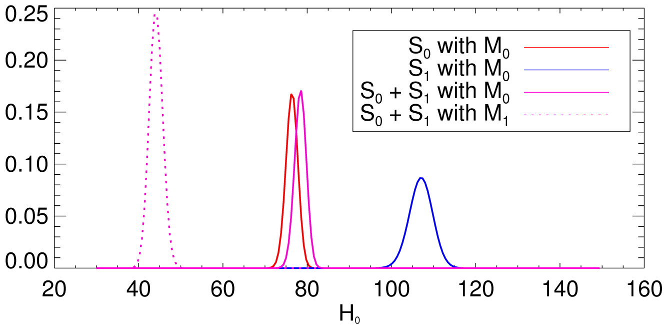


favors $\mathcal{M}_1$ ← model with shear

favors $\mathcal{M}_0$ → spherical model

Recovered value of H_0

Starting value for $h = H_0/100$ km/s/Mpc: 0.72



Result from the analysis of $\mathcal{S}_0$

$h = 0.76^{+0.016}_{-0.015}$: compatible within 3σ with the starting value.

Observational data

Lenses with measured Δt

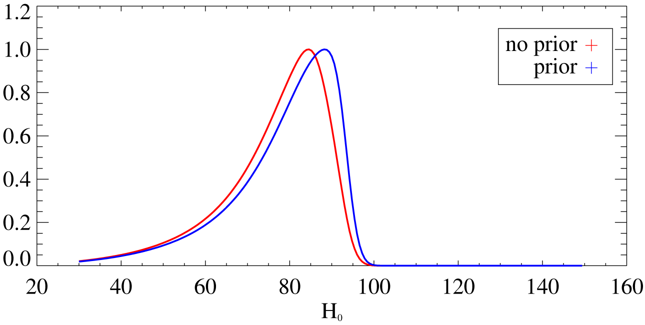
- 12 doubles
- 8 quads

Bayes factor selection

3 lenses favor model $\mathcal{M}_0$:

- B1600+434
- SBS 1520+530
- SDSS J1650+4251

Results on H_0



$$H_0 = 76^{+15}_{-5} \text{ km/s/Mpc}$$

results published in Balmès & Corasaniti, 2013

Conclusion

- Modified gravity differs from ΛCDM at transition scales, creating differences in structure formation.
- Bayesian statistics can help select homogeneous data samples.
- Time-delays give additional constraint on H_0.