Hydrodynamical Simulations in $f(R)$ gravity

Galaxy Cluster Properties and the Lyman-α Forest

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Heidelberg Institute for Theoretical Studies HITS

TR 33 The Dark Universe Bonn München Heidelberg

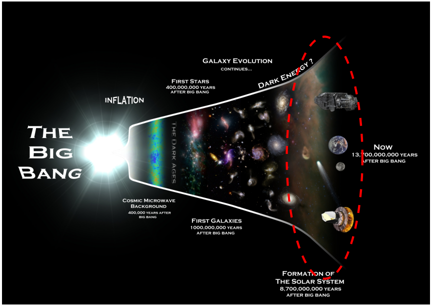
UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

Cosmological Simulations in $f(R)$ gravity

Outline

- $f(R)$ gravity
- The simulations: MG-GADGET
- Galaxy cluster scaling relations
- Galaxy cluster mass measures
- The Lyman-α forest in $f(R)$ gravity

What drives the accelerated expansion of the universe?



Rys Taylor, Cardiff University

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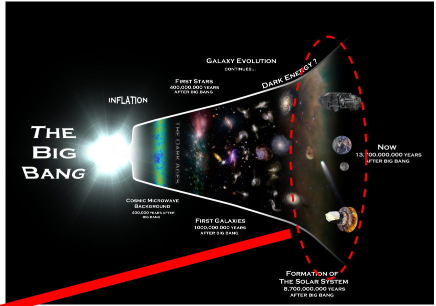

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Dark energy

- ΛCDM
- Quintessence
- k-essence
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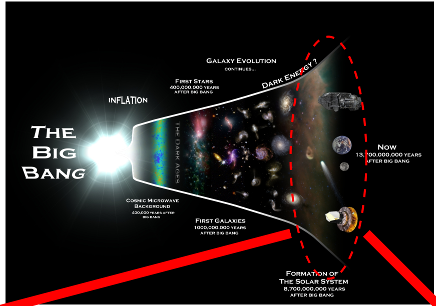

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Modified gravity

- $f(R)$
- $f(T)$
- DGP
- Galileon

$f(R)$ gravity

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$$S = \int \mathrm{d}^4x\sqrt{-g}\left[\frac{R + f(R)}{16\pi G} + \mathcal{L}_m\right]$$

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Newtonian limit:

$$\nabla^2\Phi = \frac{4}{3} \times 4\pi G\delta\rho - \frac{1}{6}\delta R \qquad \nabla^2 f_R = \frac{1}{3}\left(\delta R - 8\pi G\delta\rho\right)$$

$f(R)$: the *Hu & Sawicki* model

Model should reproduce

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Choice for $f(R)$ (*Hu & Sawicki* 2007):

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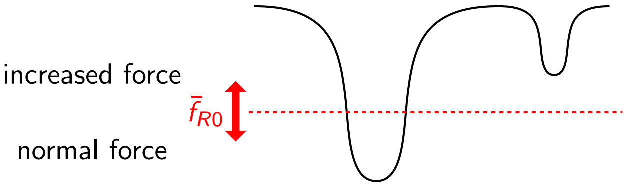
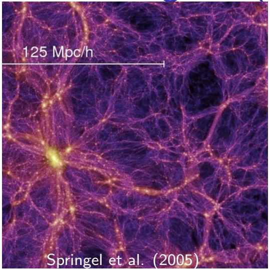
$\Rightarrow$ Chameleon screening:



Chameleon Screening in $f(R)$ gravity



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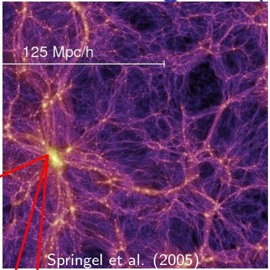
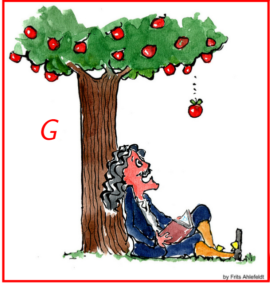


High density



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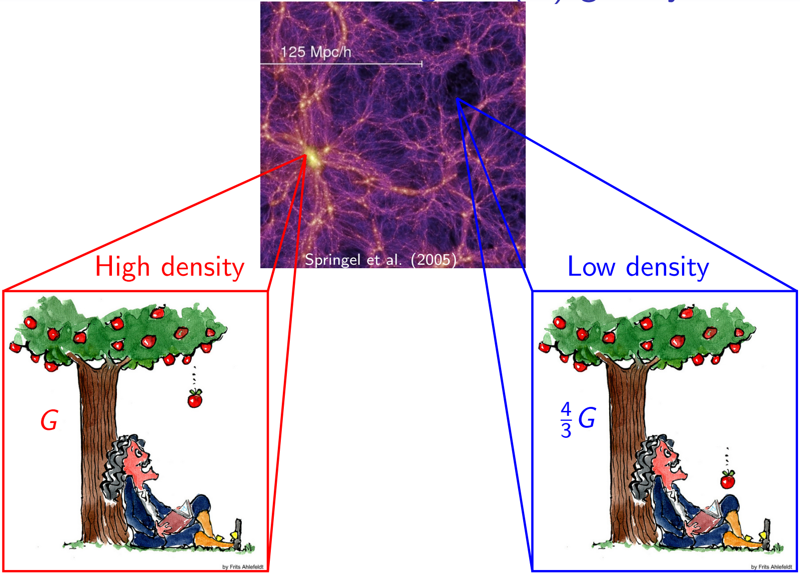

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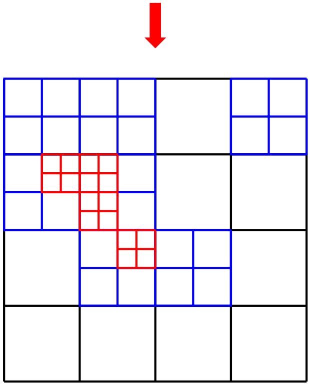

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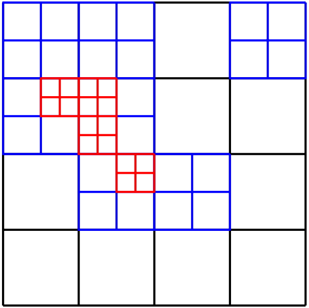

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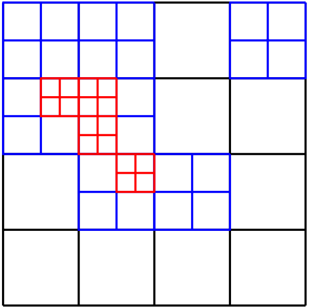
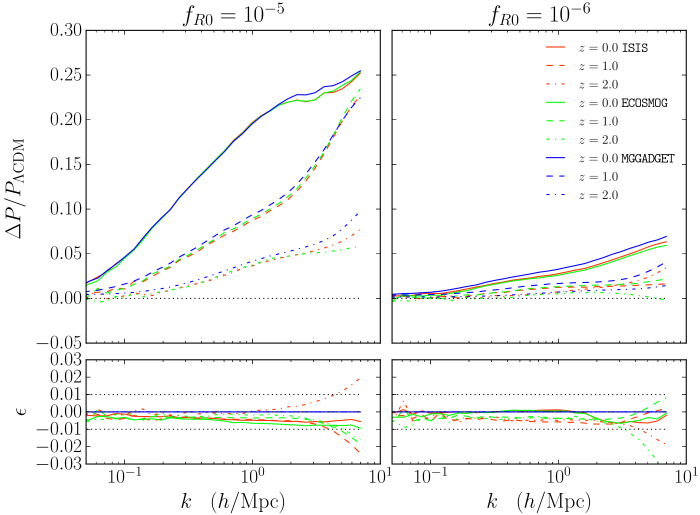
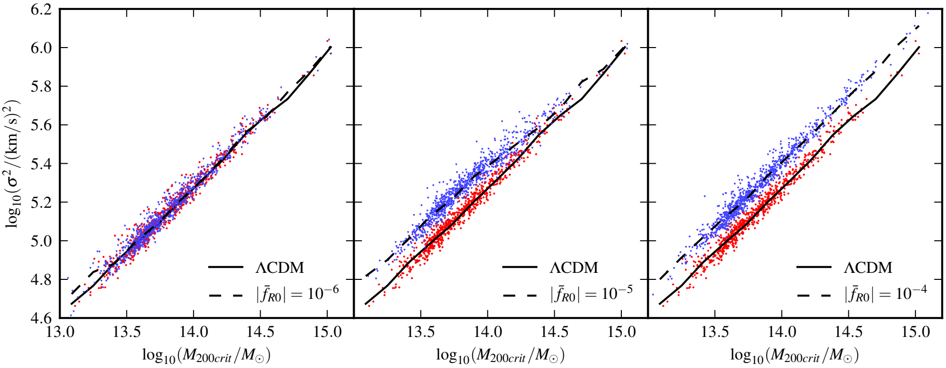


Comparison to other $f(R)$ codes



Winther et al. (2015)

Velocity dispersion



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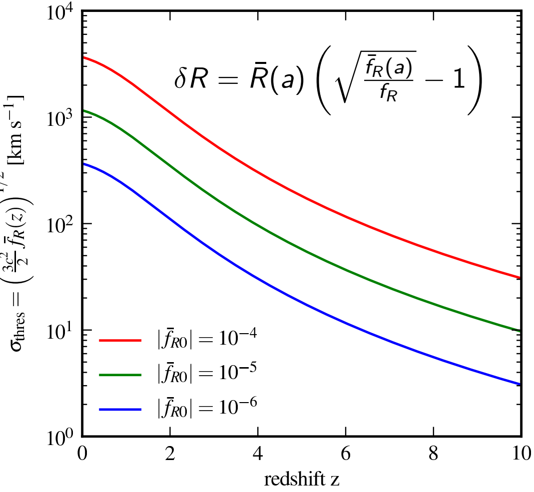

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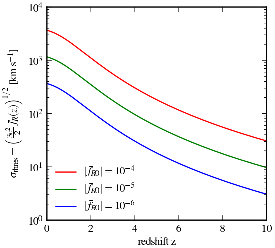
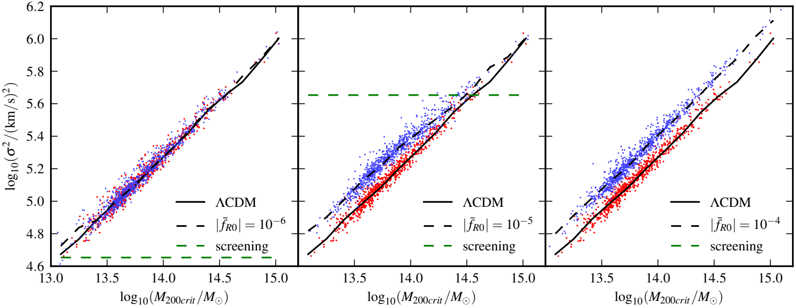
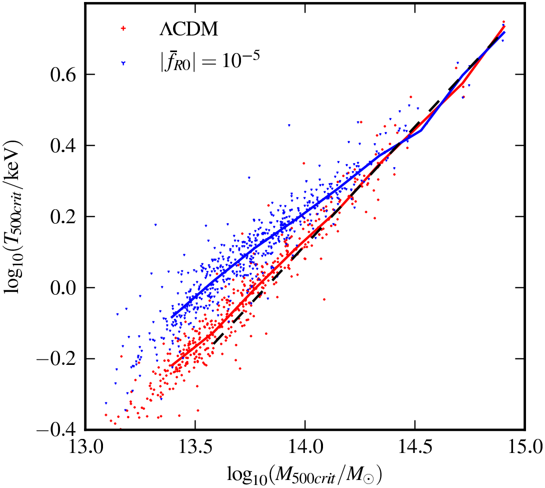
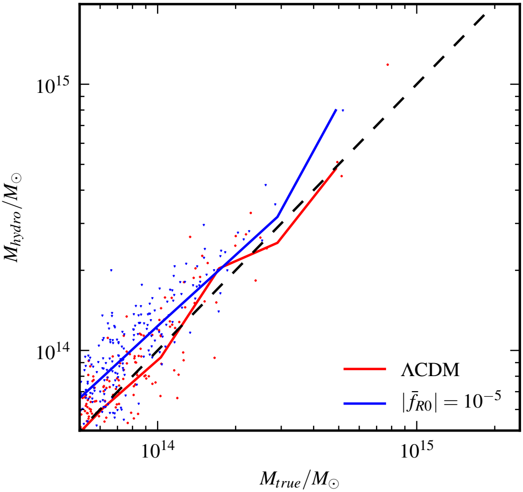




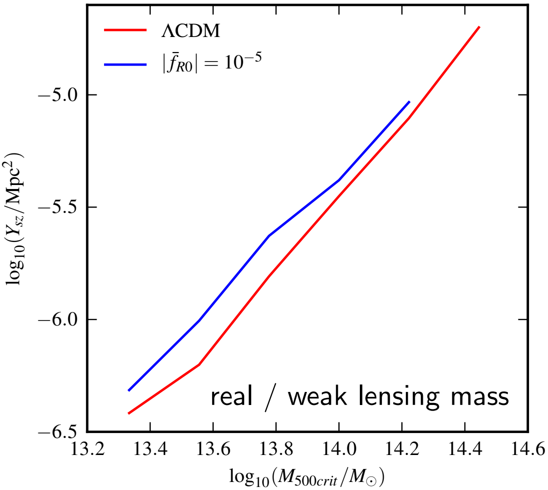
Intracluster and intragroup temperatures



Hydrostatic masses



Sunyaev-Zeldovich signal



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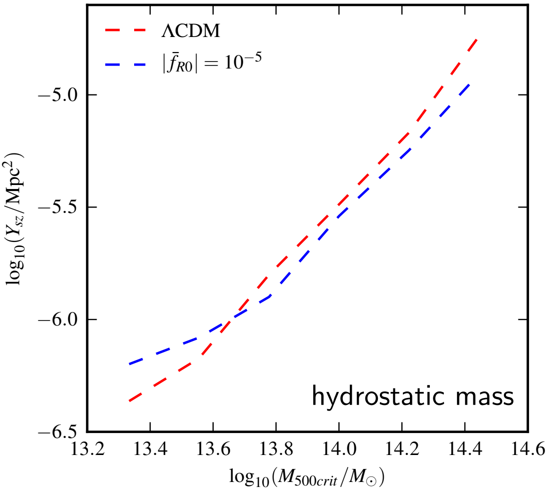

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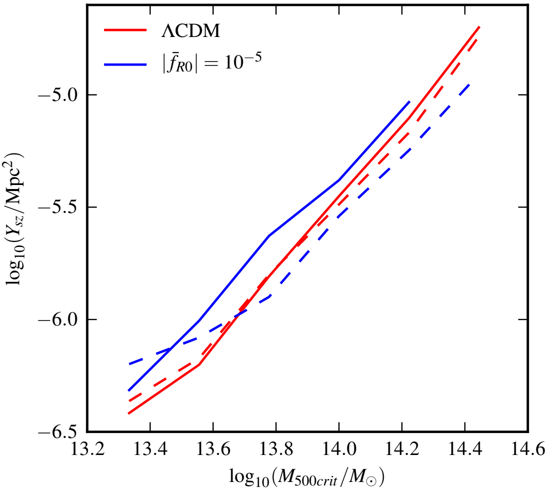
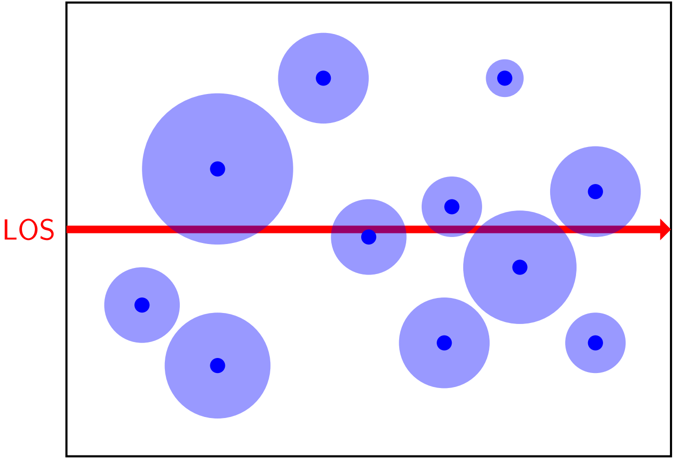


The Lyman-α forest in $f(R)$ gravity

- create synthetic Lyman-α absorption spectra from hydrodynamical simulations



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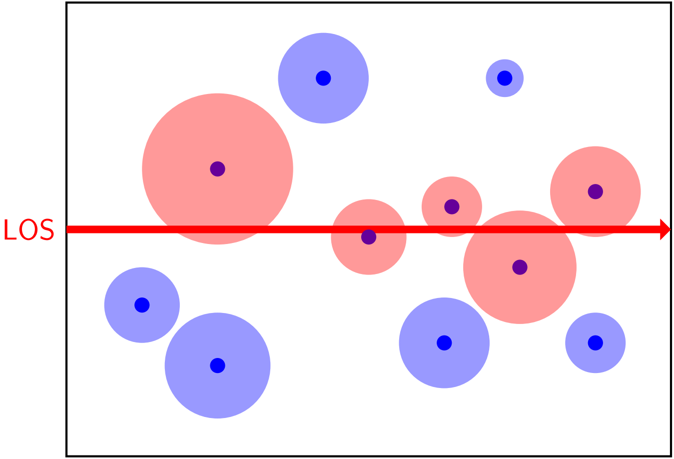

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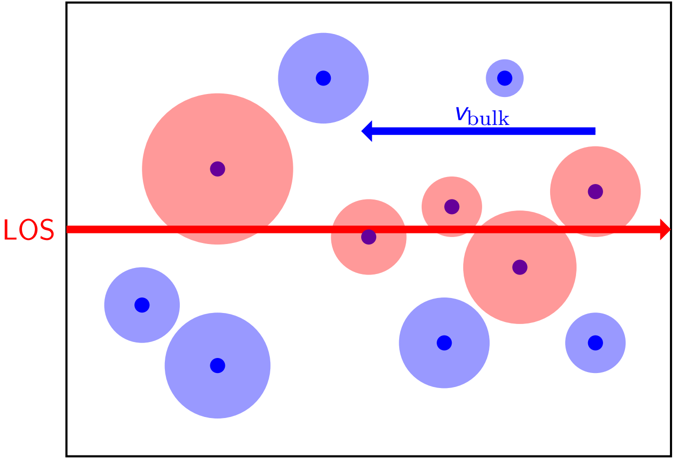

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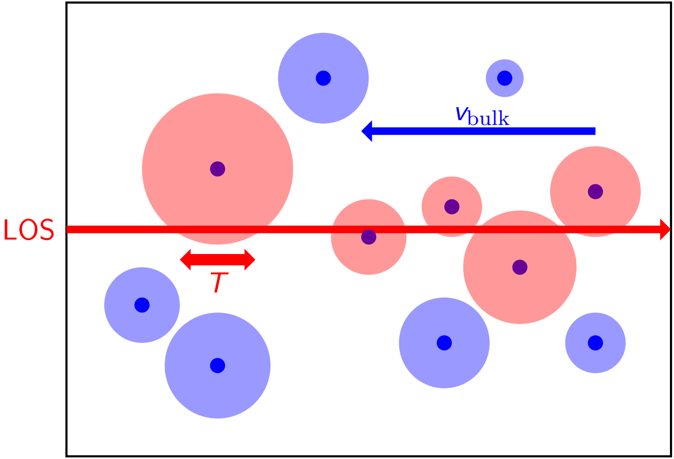
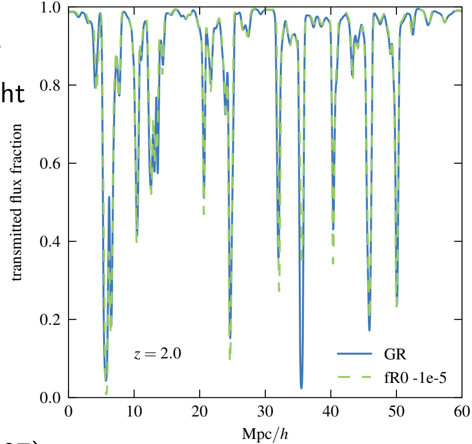


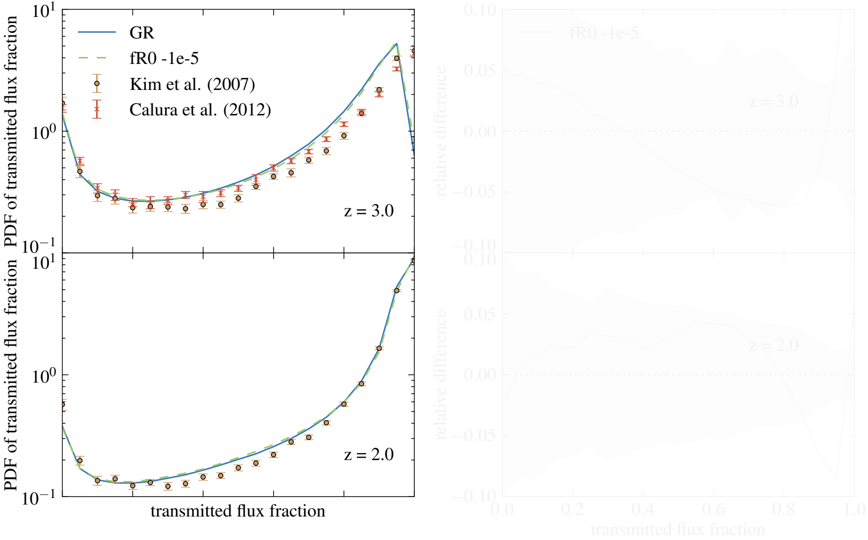
The Lyman-α forest in $f(R)$ gravity

$\Rightarrow$ absorption spectrum of an individual line of sight



$\Rightarrow$ tune $\bar{\tau}$ to Kim et al. (2007)

Lyman-α flux PDF



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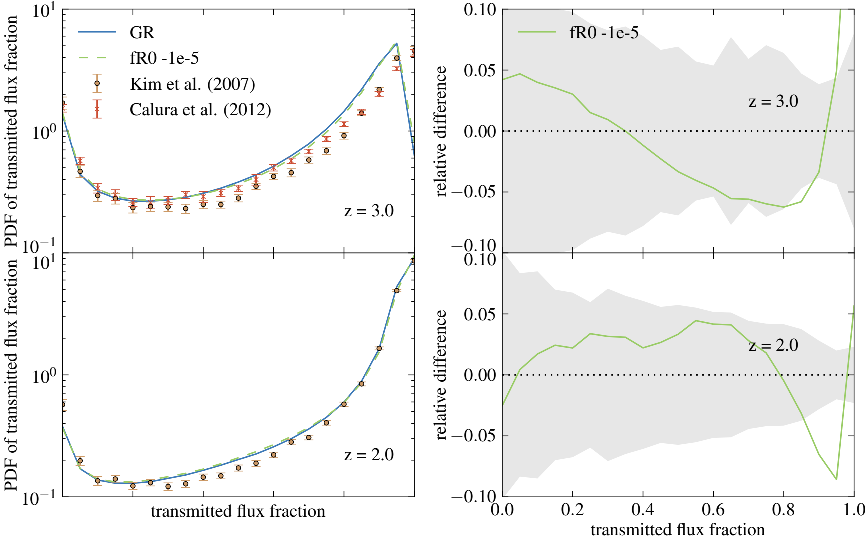
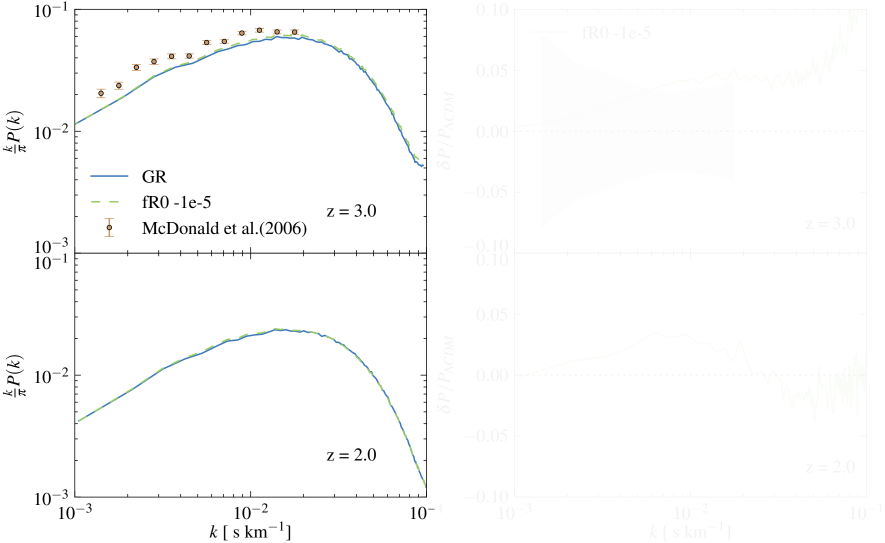


Lyman-α flux power-spectrum



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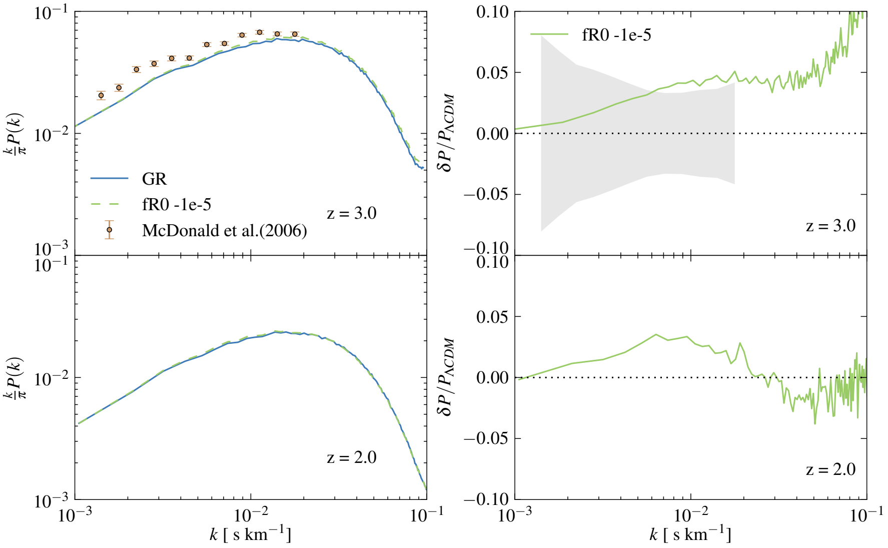

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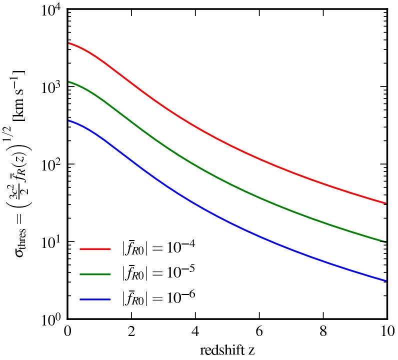
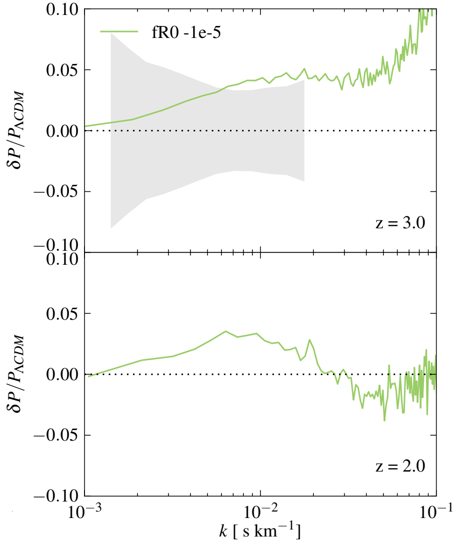
Screening





Conclusions

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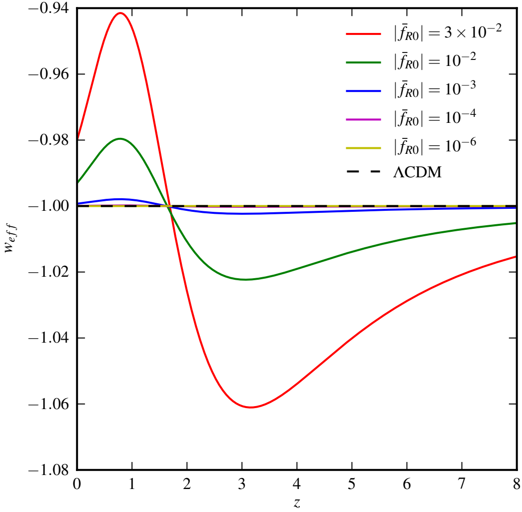
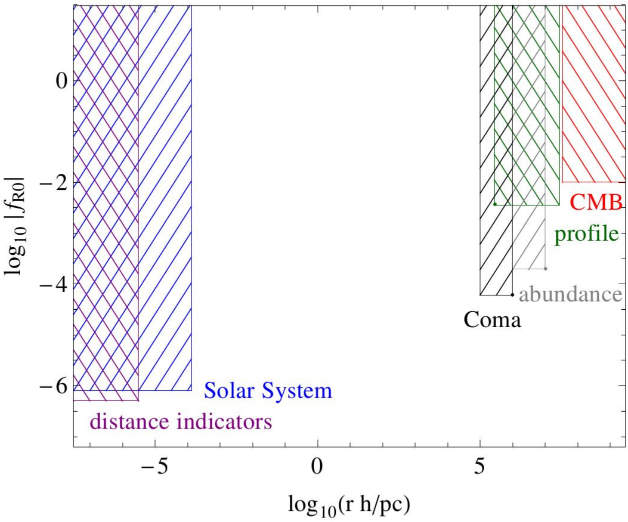
- Statistical properties of the Lyman-α forest only weakly influenced
- $f(R)$ gravity is still a valid theory to explain the accelerated expansion of the universe

Expansion history of a $f(R)$ universe

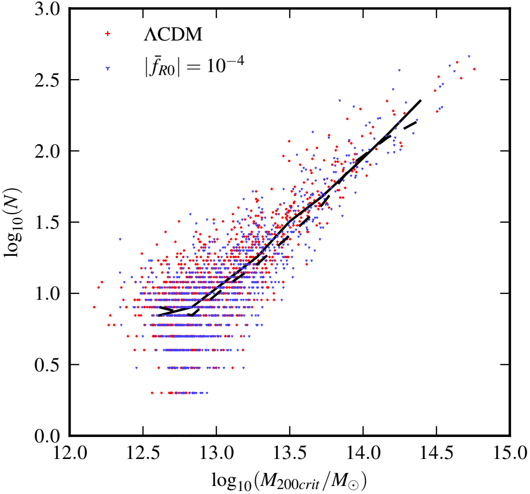


Current constraints on f_{R0}



Terukina et al. (2014)

Subhalo abundance



X-ray luminosities