Simulating galaxy formation in $f(R)$-gravity

Full-physics simulations in modified gravity with AREPO

Christian Arnold

with Baojiu Li, Volker Springel

Cosmology in Dubrovnik, Oct 2018

ICC, Durham University

Why $f(R)$-gravity?

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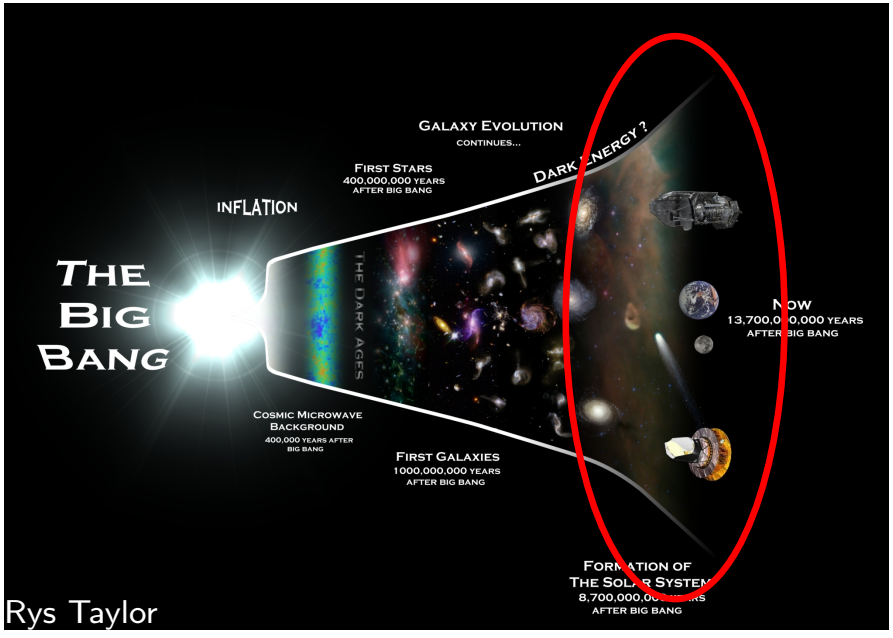

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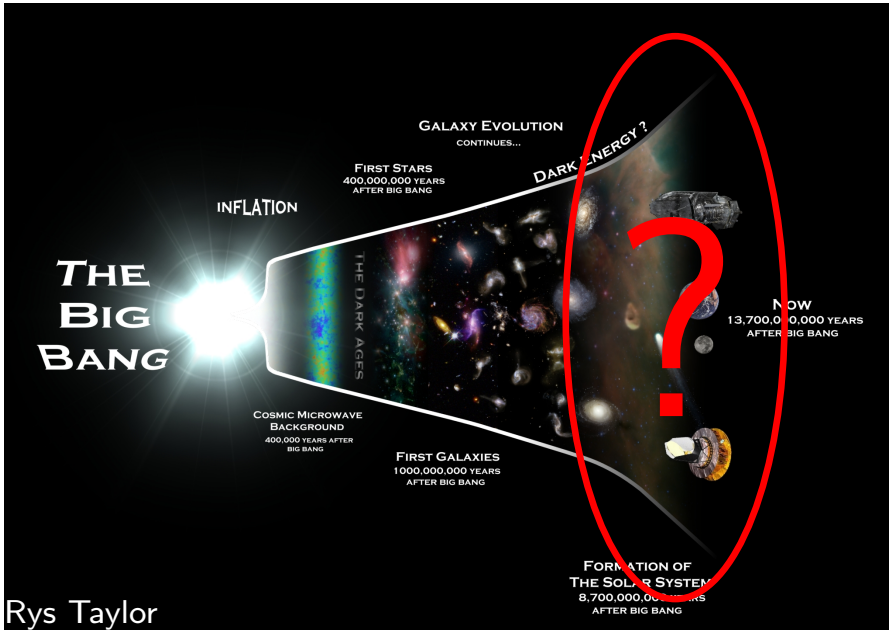

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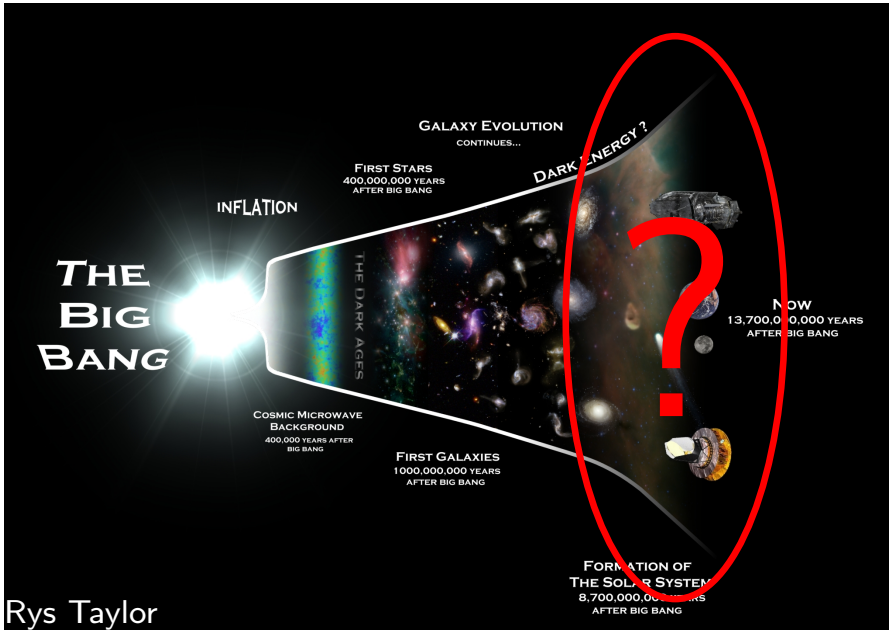

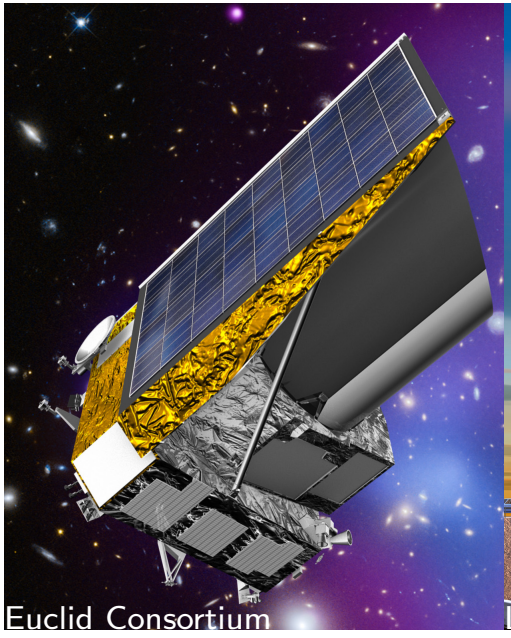

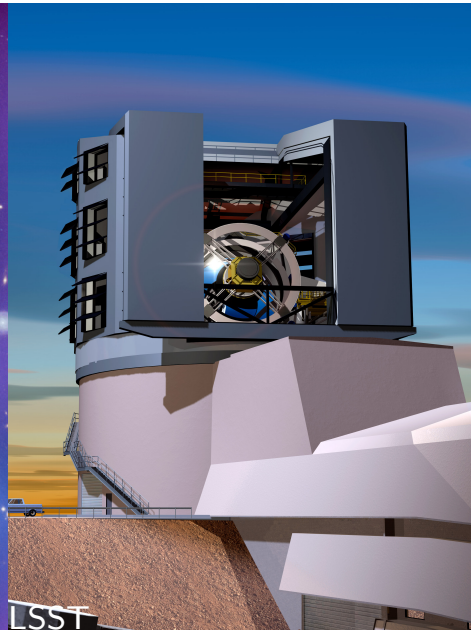

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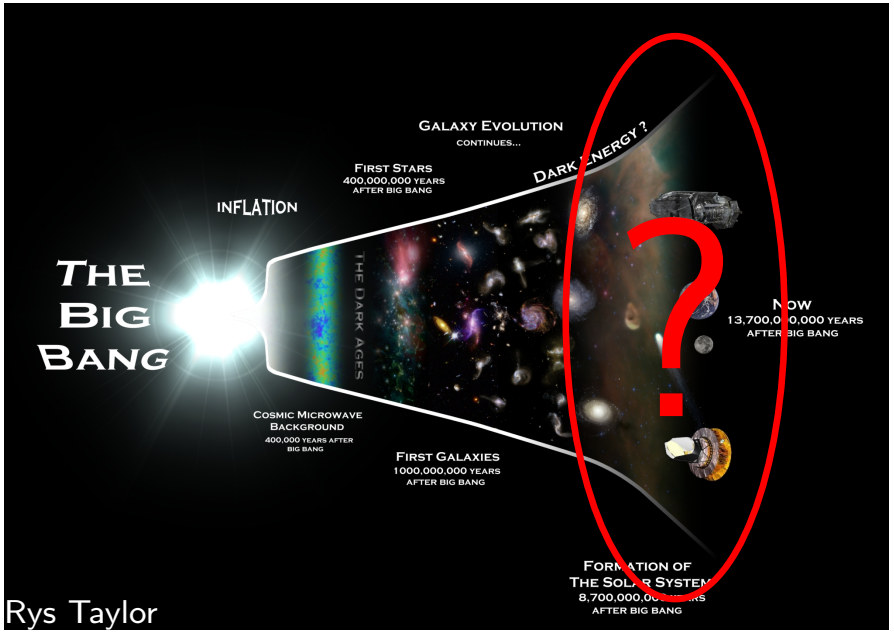
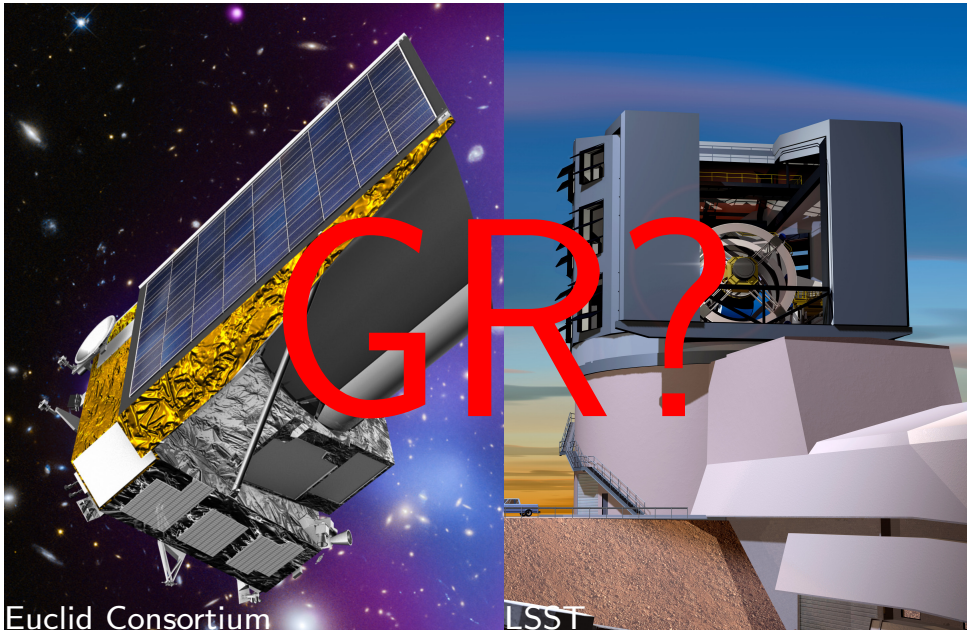


Rys Taylor



Euclid Consortium LSST

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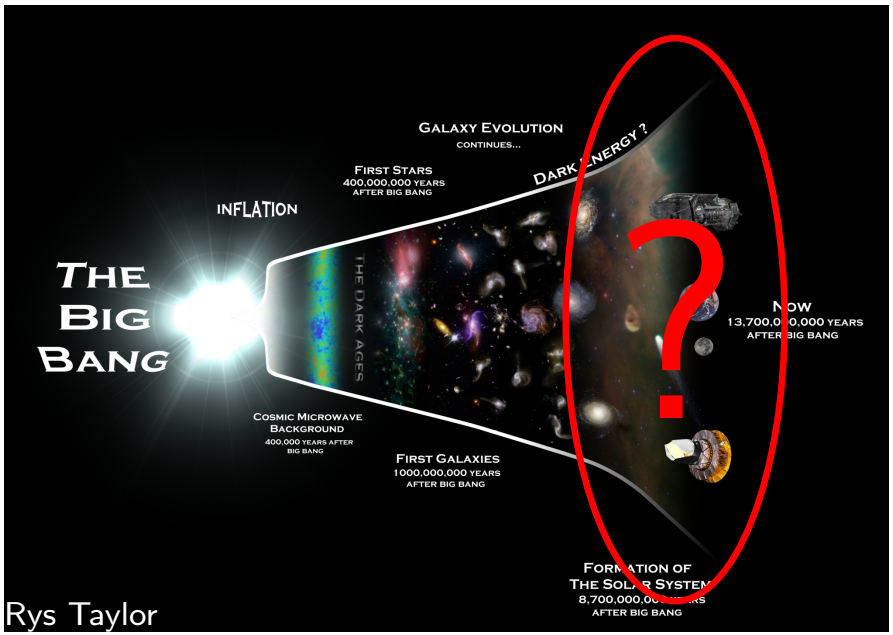

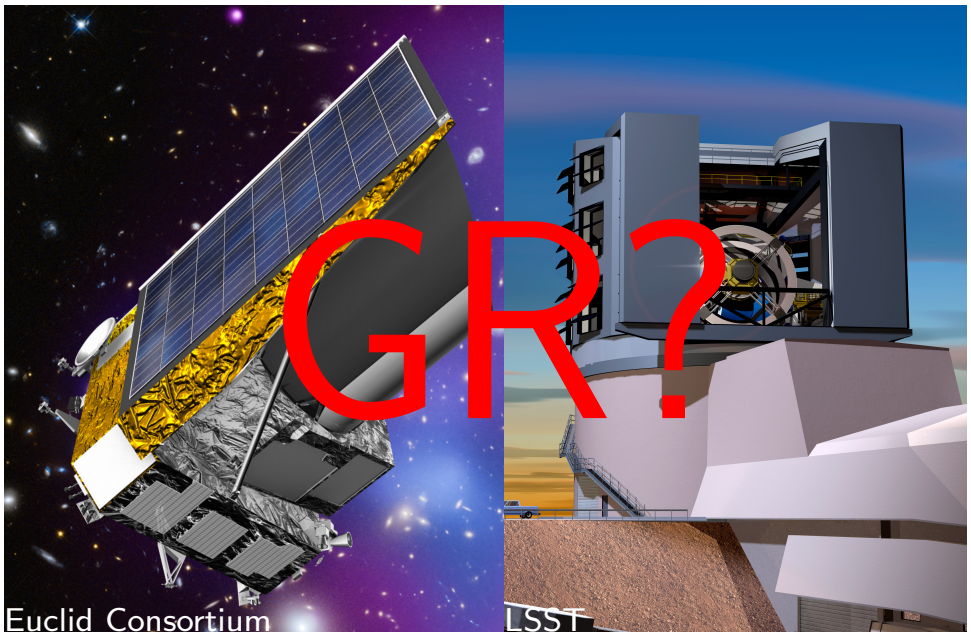

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Horndeski	General Relativity quintessence/k-essence [42] Brans-Dicke/$f(R)$ [43, 44] Kinetic Gravity Braiding [46]	quartic/quintic Galileons [13, 14] Fab Four [15, 16] de Sitter Horndeski [45] $G_{\mu\nu}\phi^\mu\phi^\nu$ [47], Gauss-Bonnet
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	Viable after GW170817	Non-viable after GW170817

Ezquiaga & Zumalacarregui (2017)

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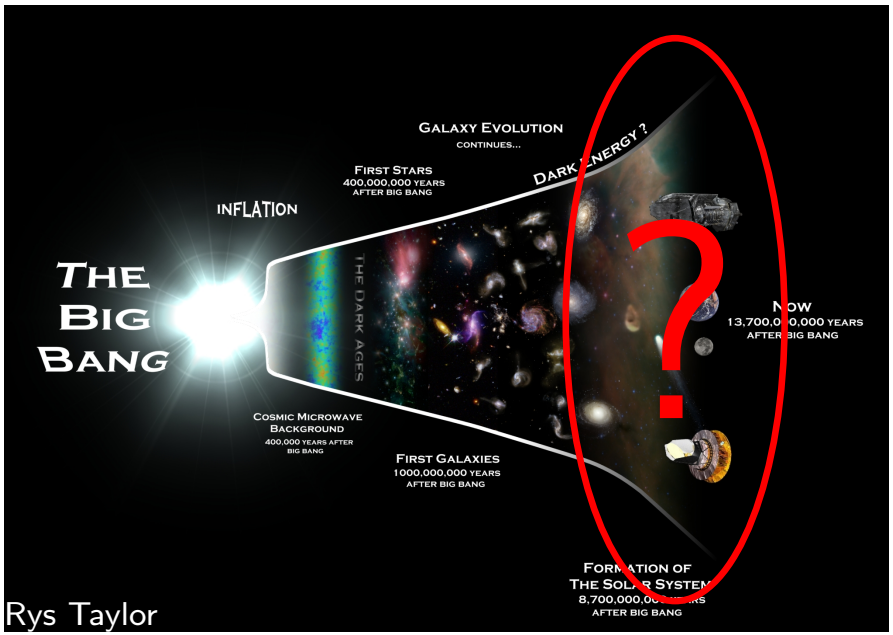

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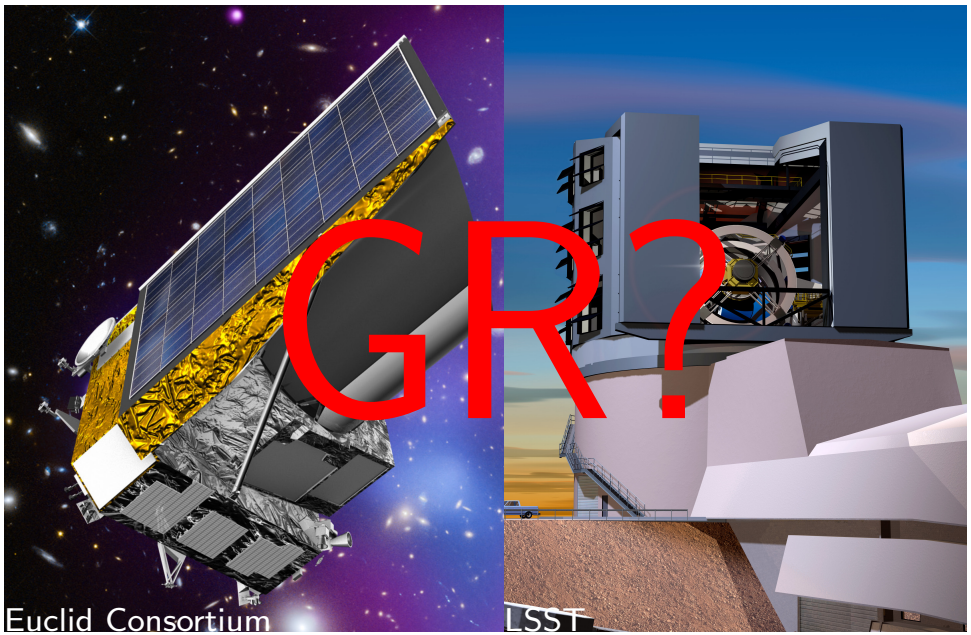

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Choice for $f(R)$?

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Model should reproduce

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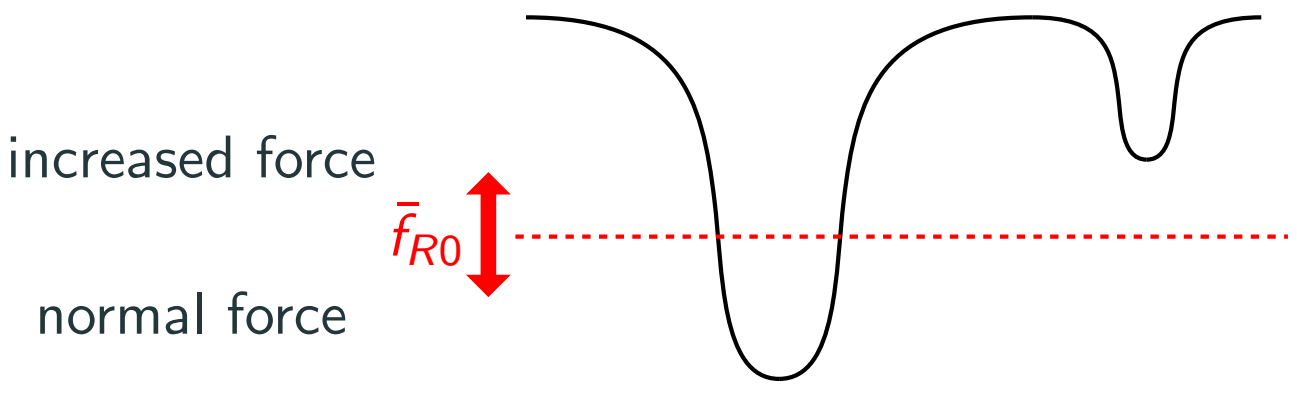
Chameleon screening:



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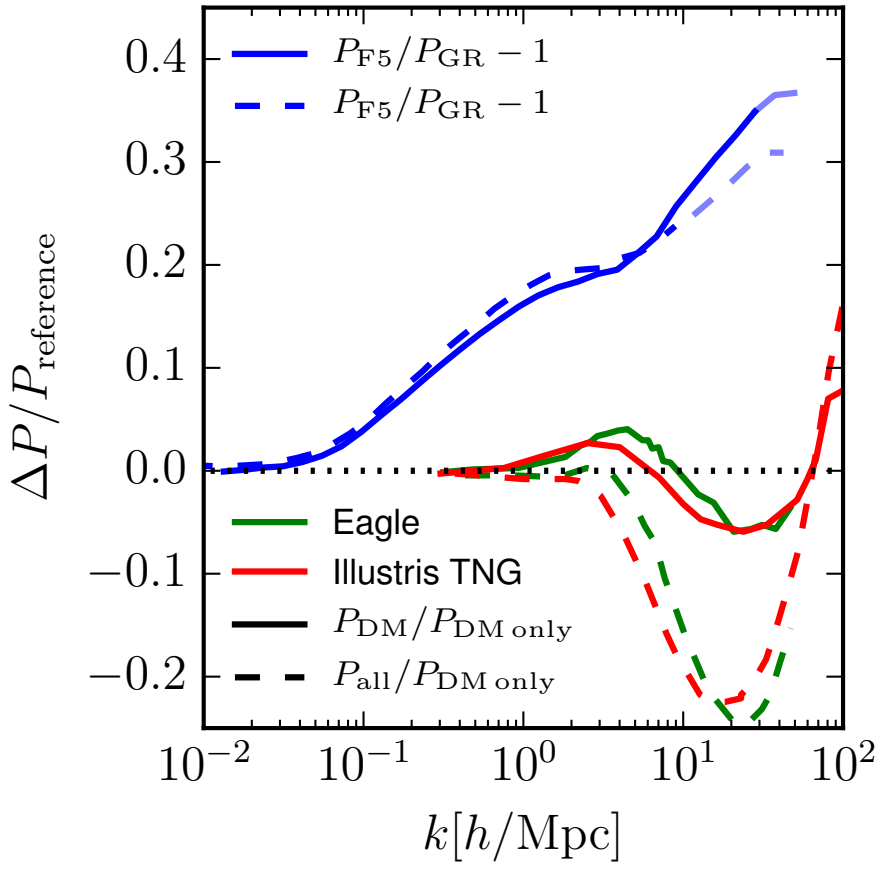

CA, Fosalba, Puchwein, Springel, Blot (2018)

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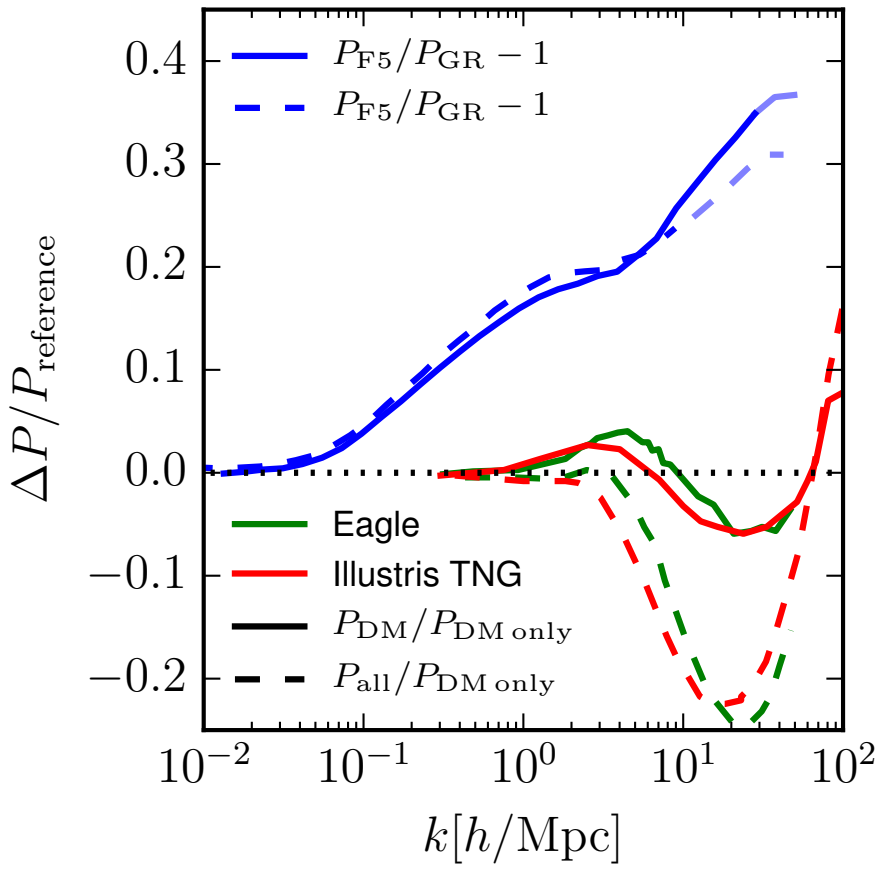

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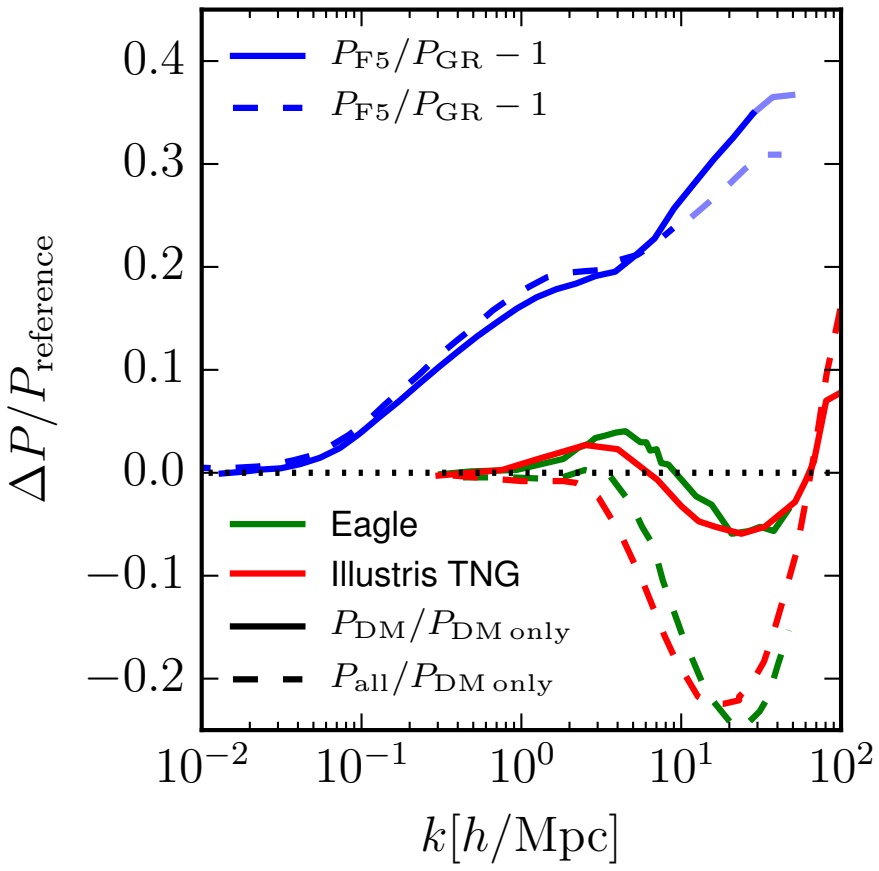

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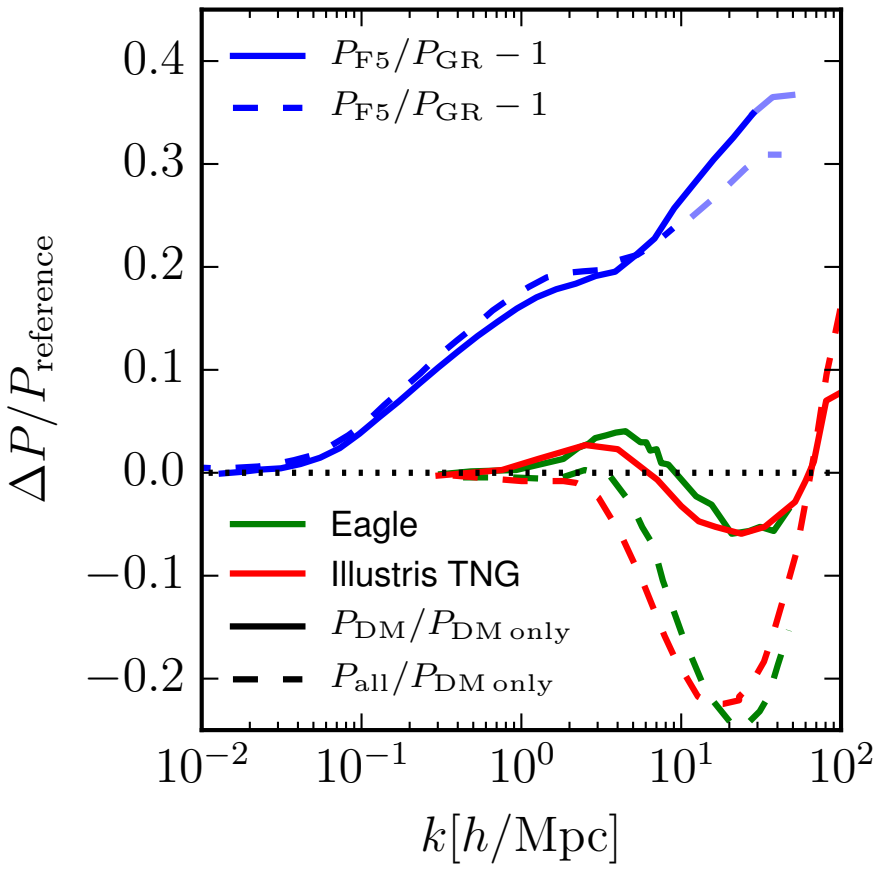
- What happens to the other galaxy properties?



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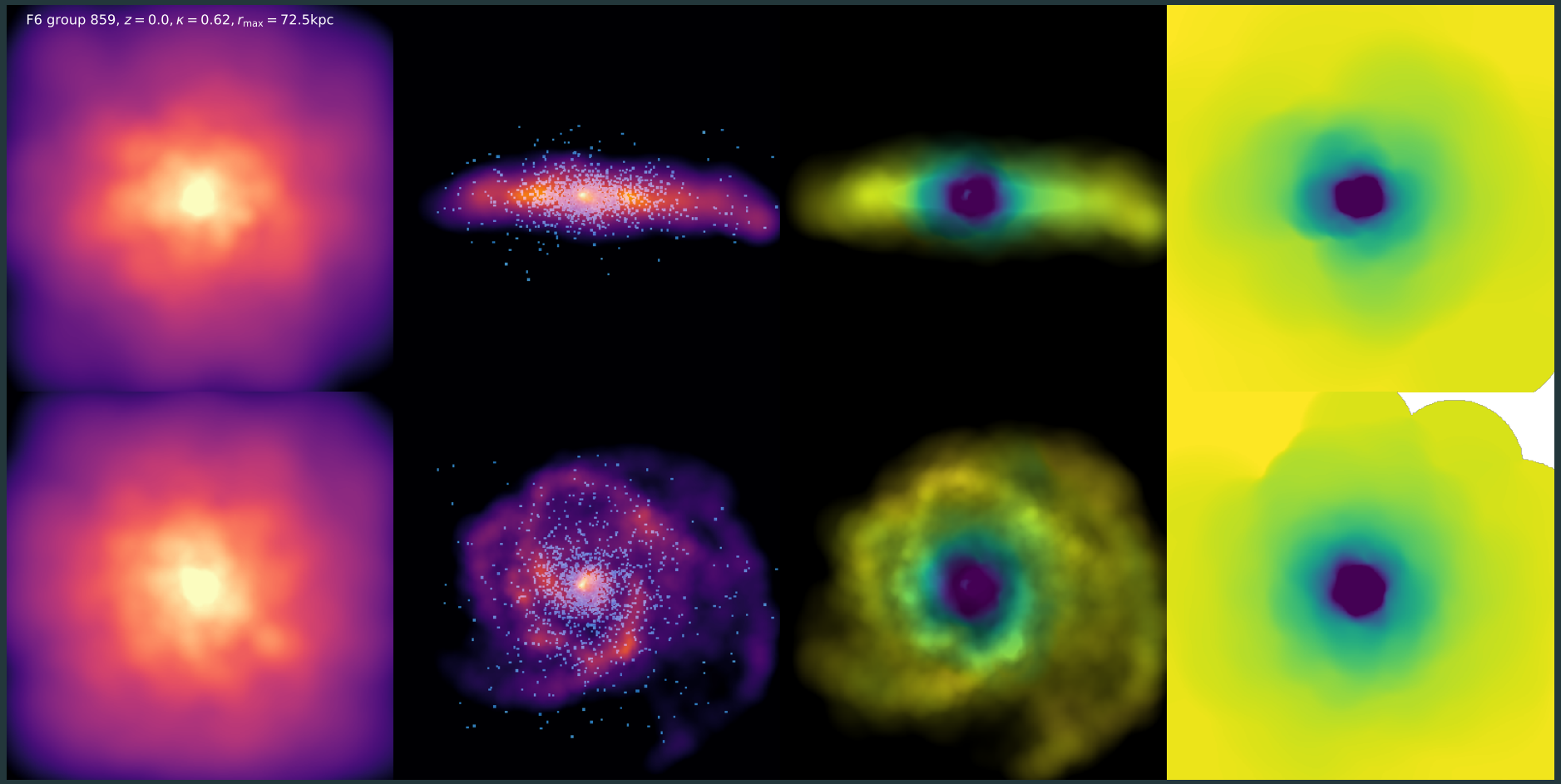
- dark matter only counterparts: ΛCDM, F6, F5, F4

Galaxies in $f(R)$-gravity

$M_{200} = 1.5 \times 10^{12} M_{\odot}$



DM density | Gas density + Stars | MG force within the gas | Scalar field

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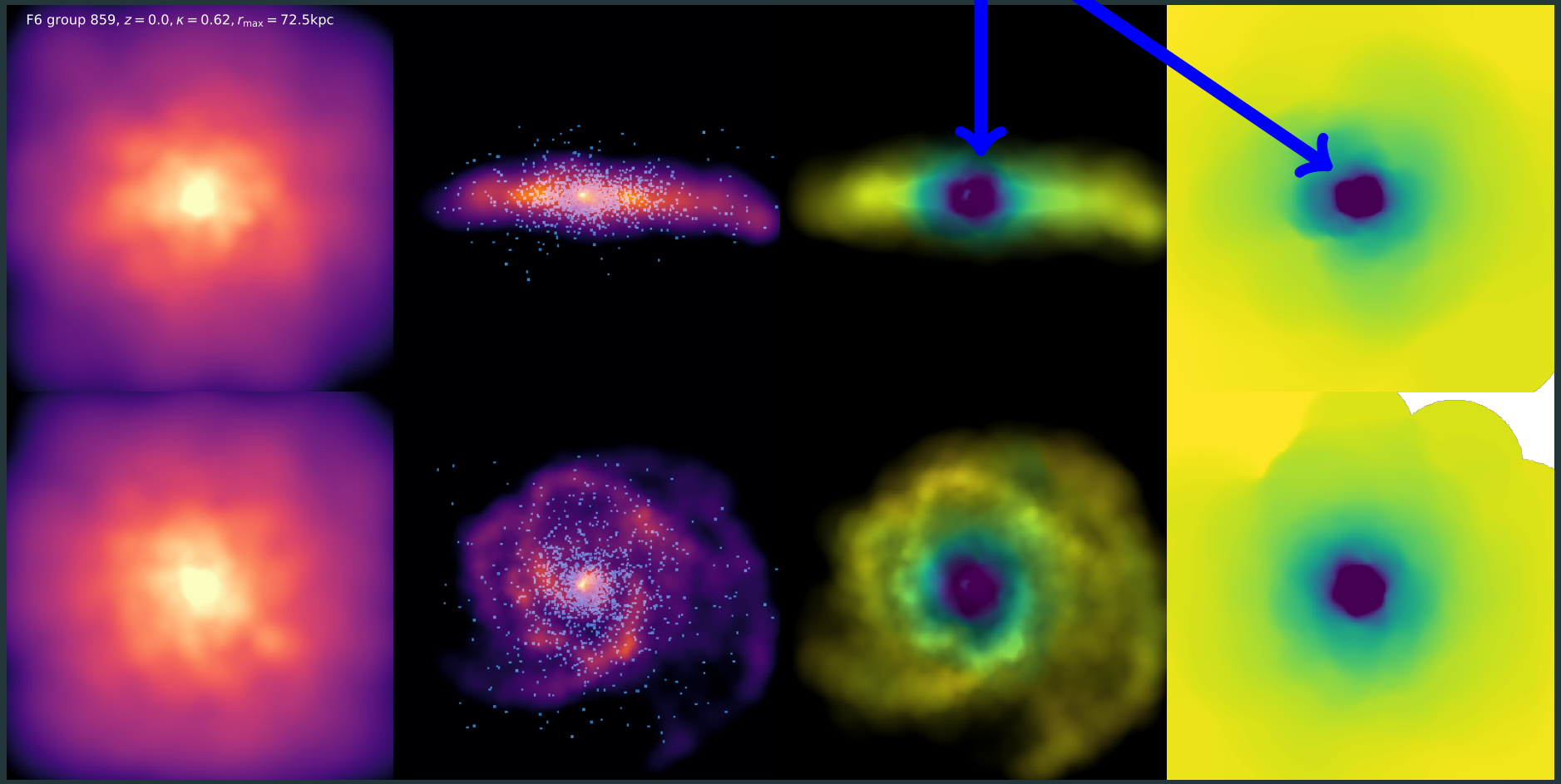
screened



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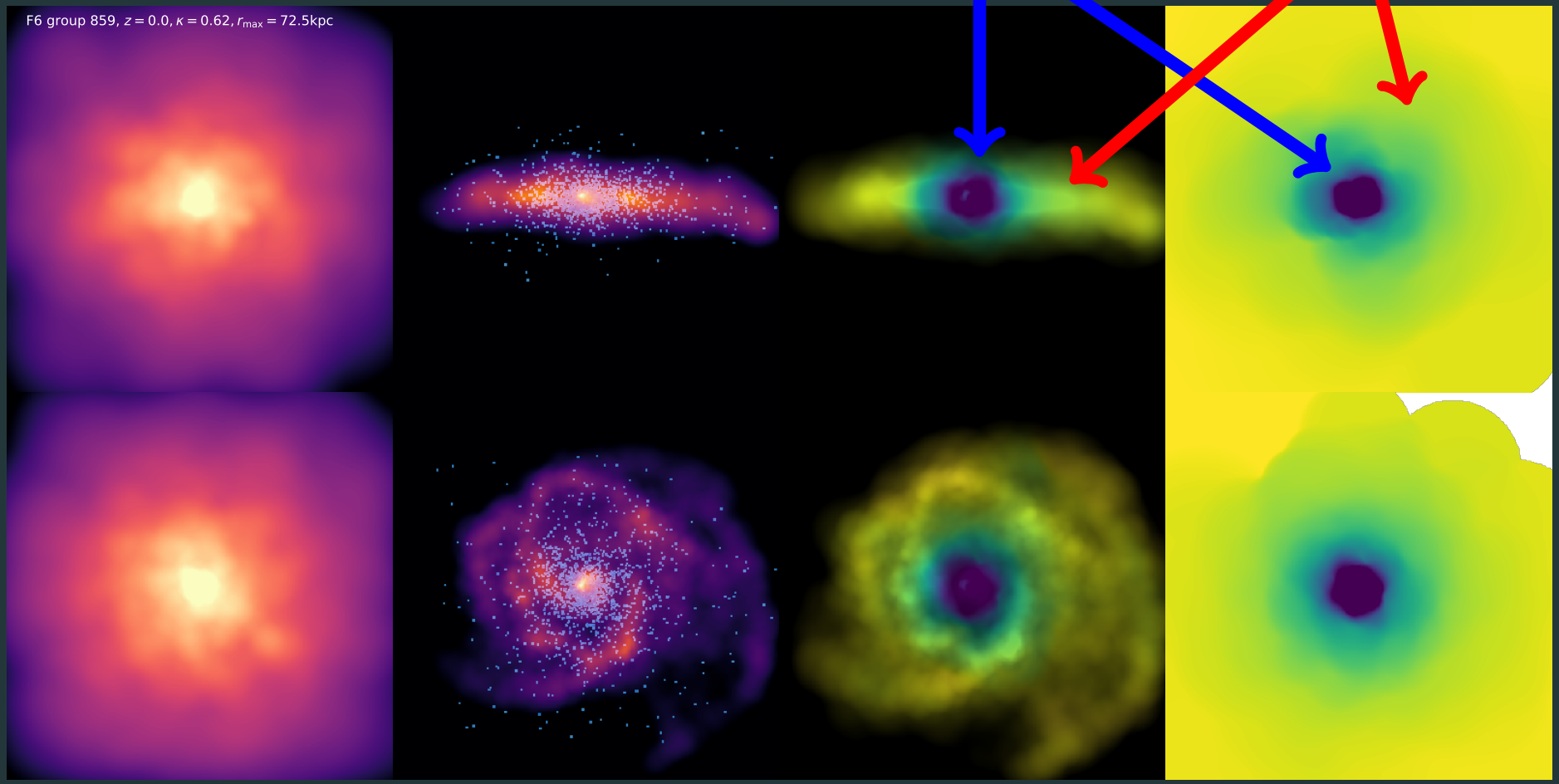

Galaxies in $f(R)$-gravity

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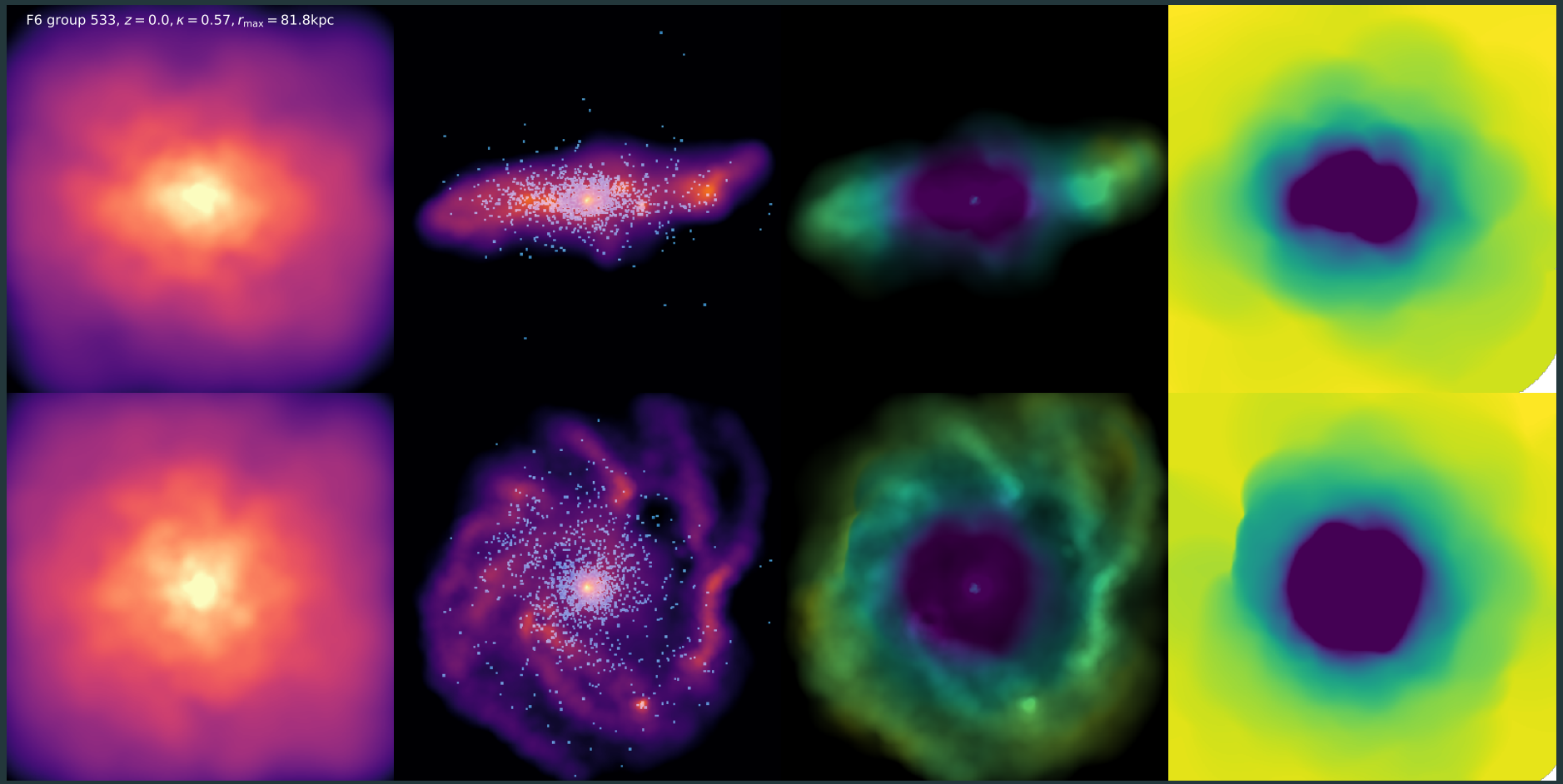

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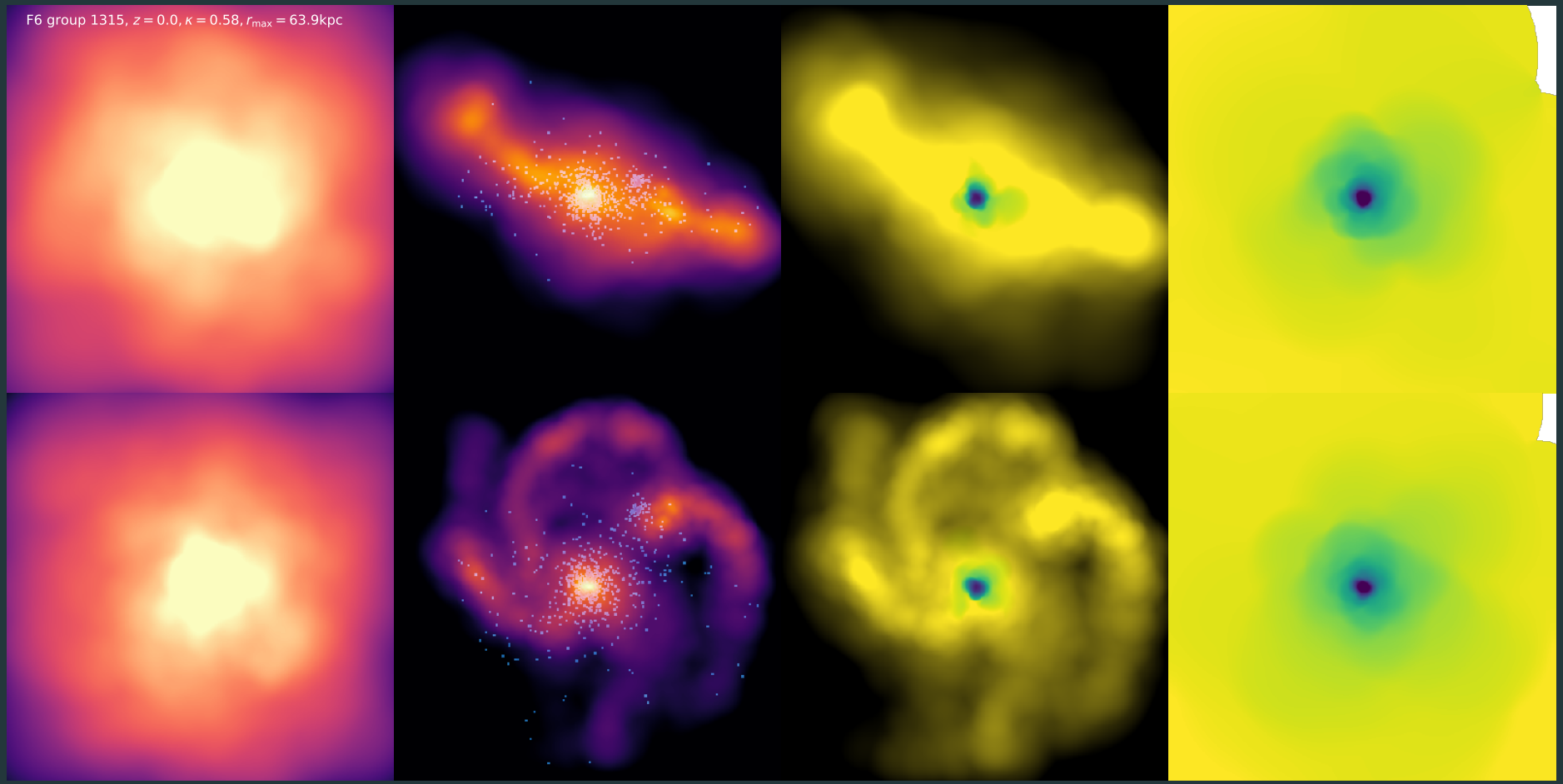

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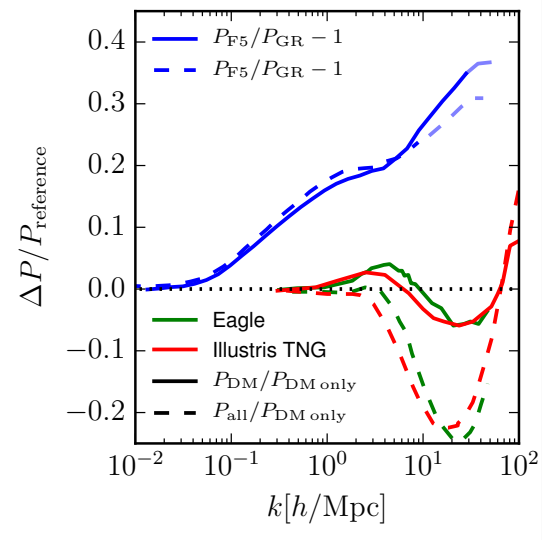
Matter power-spectrum



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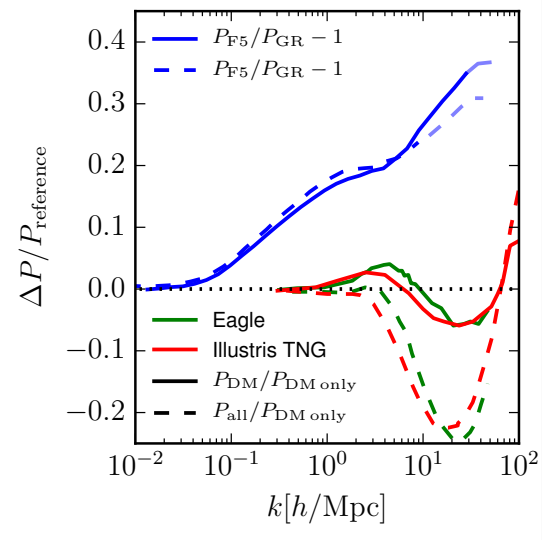

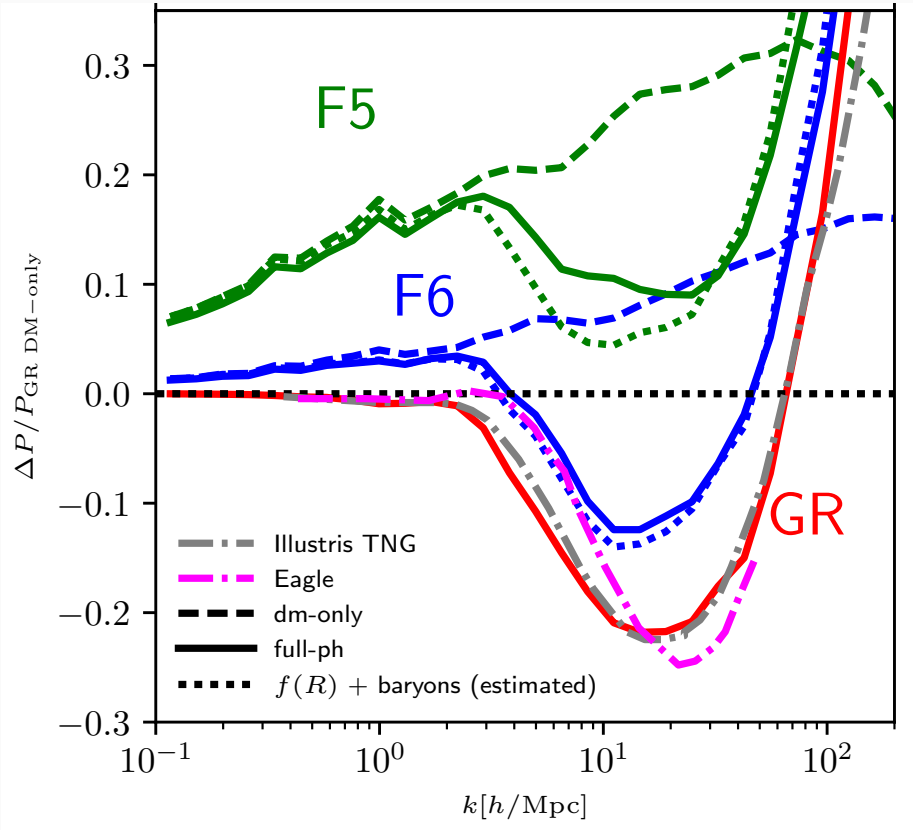

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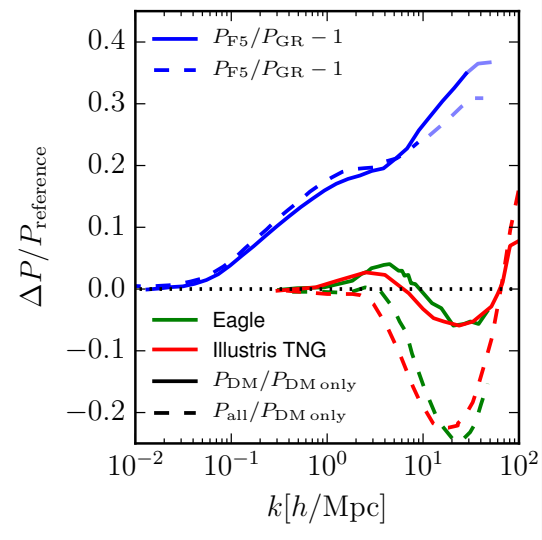
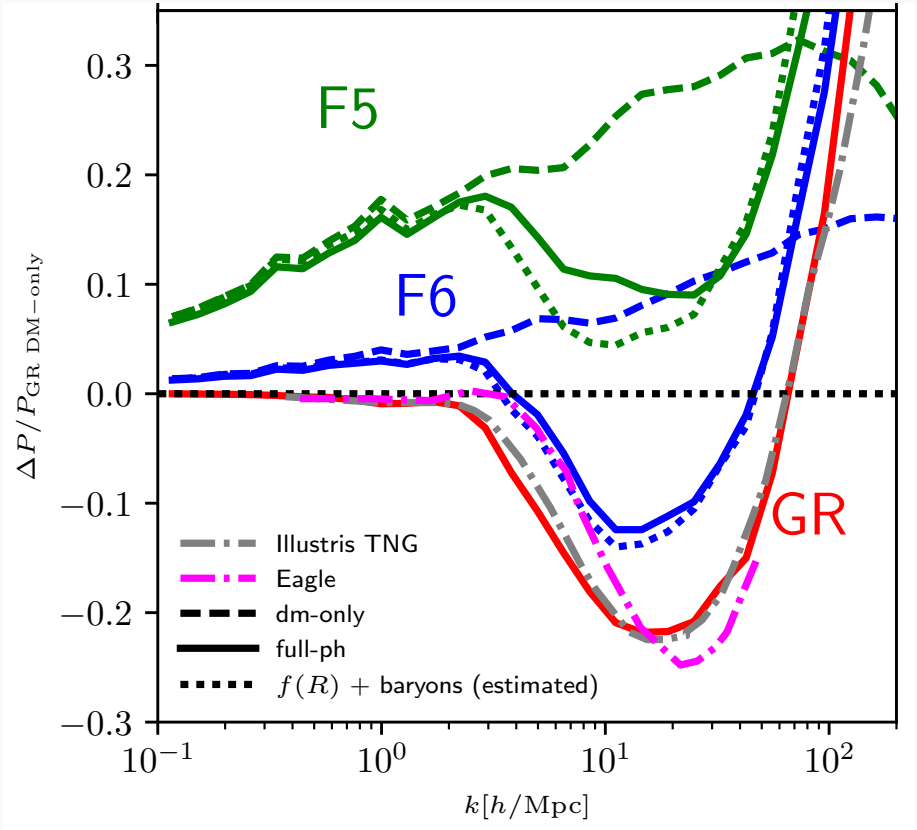


- GR predictions match Illustris-TNG and Eagle results



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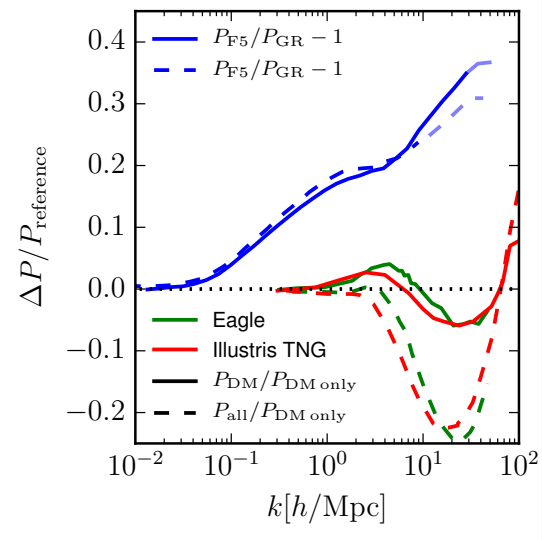

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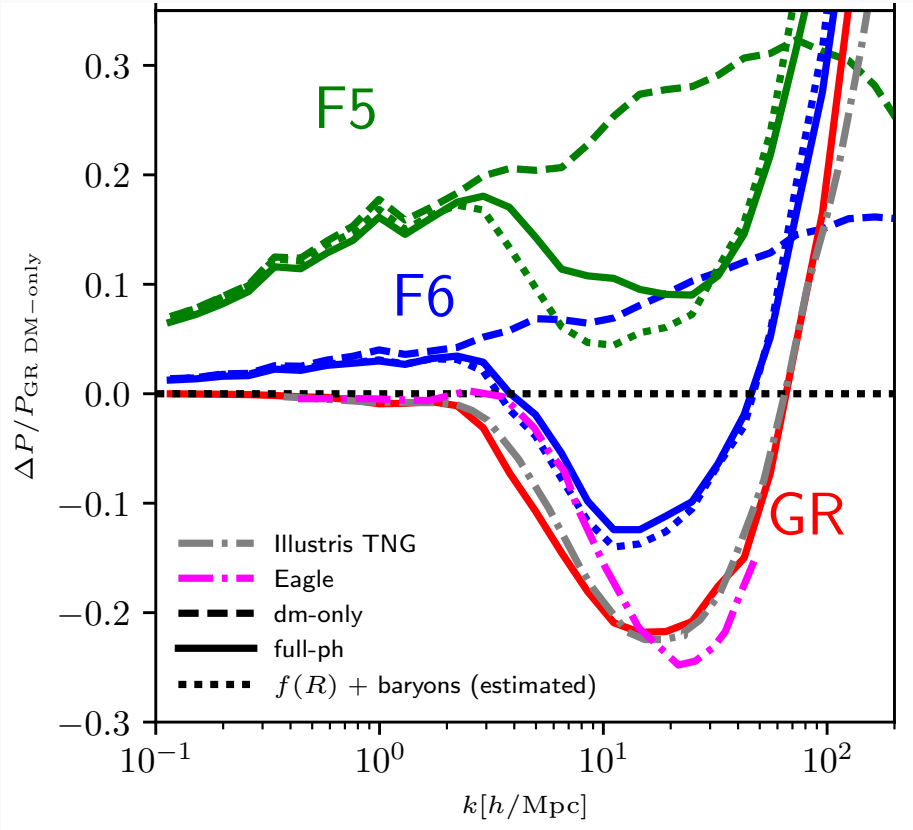
- back-reaction between BH-feedback and $f(R)$-gravity negligible for F6



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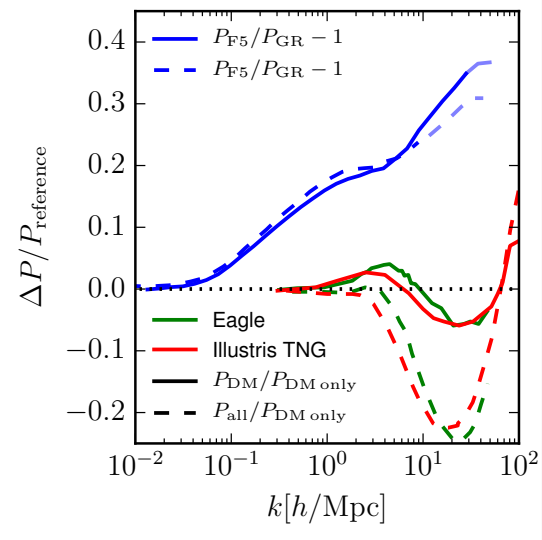

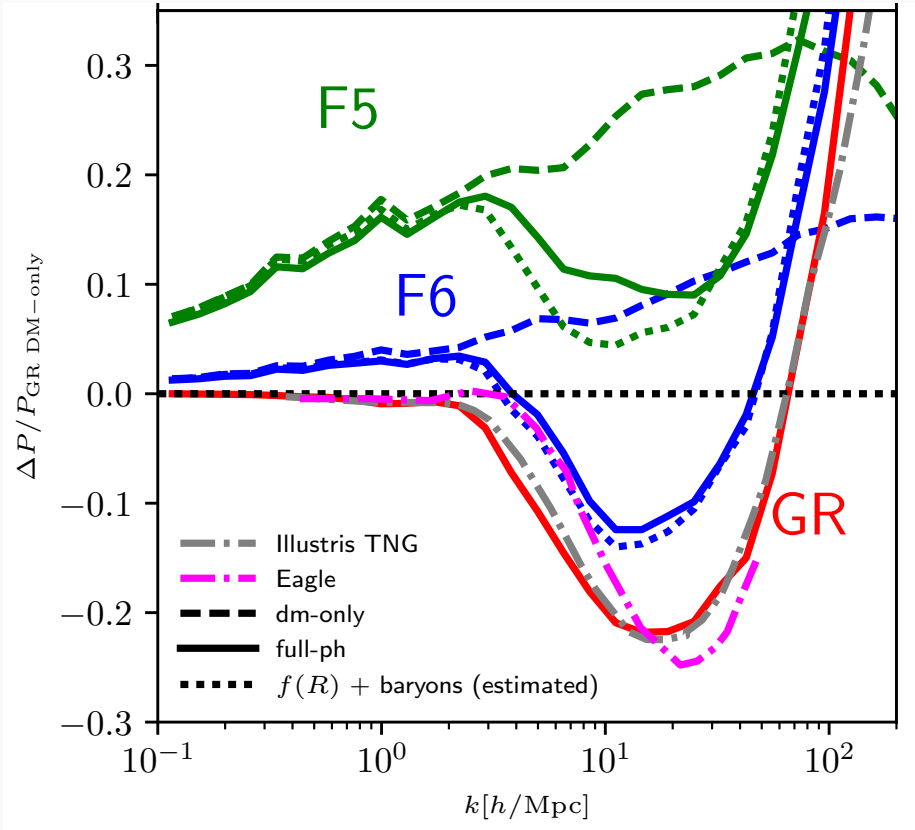

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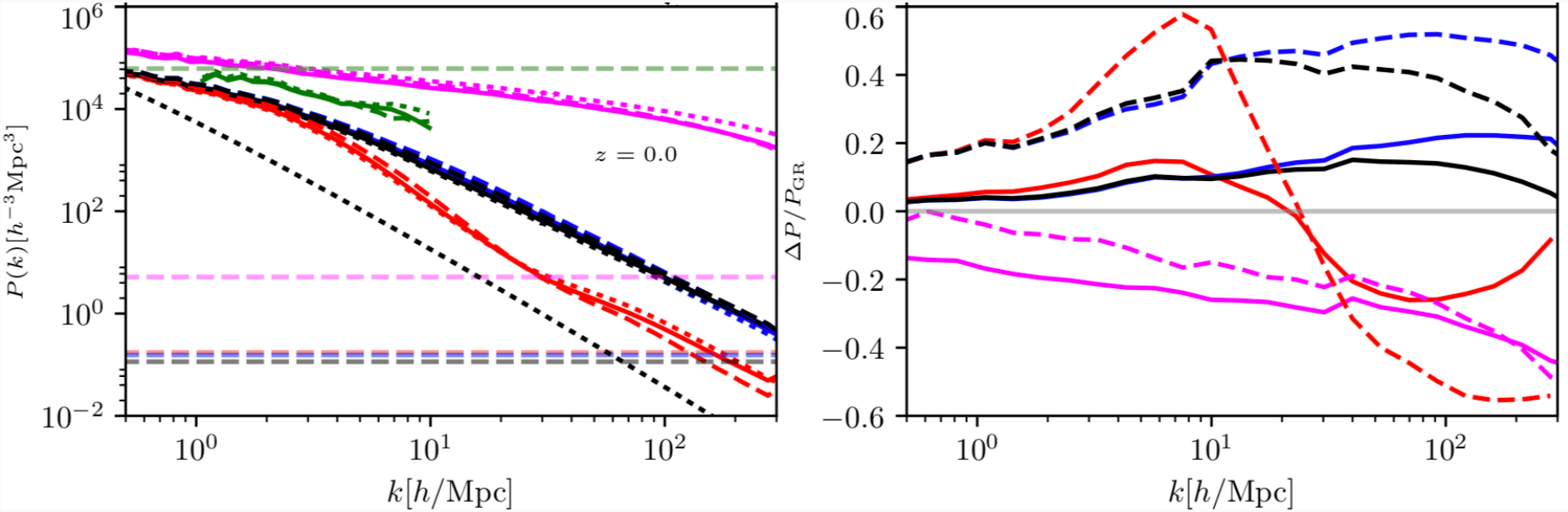
- sizeable back-reaction for F5

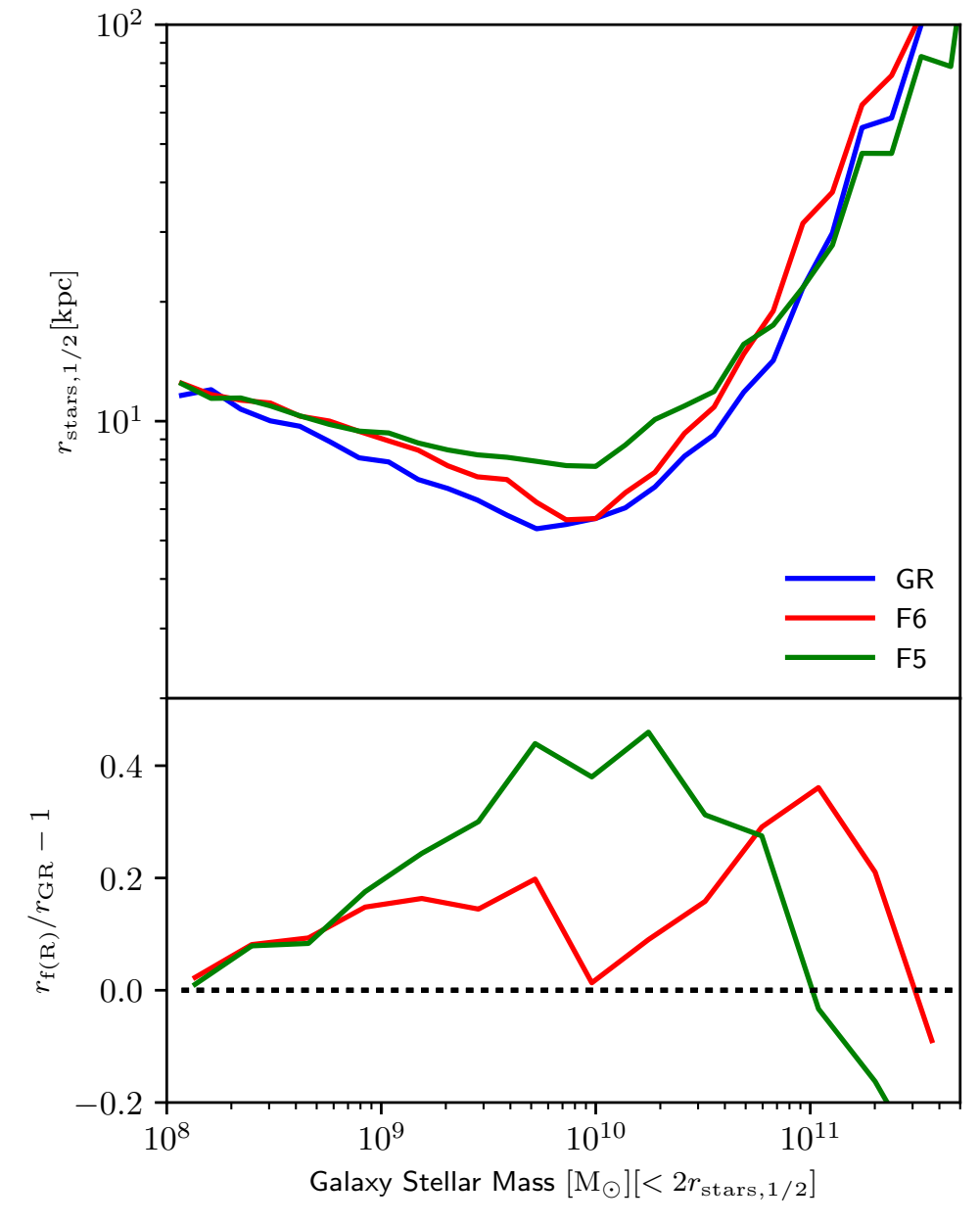
Matter power-spectrum of the components



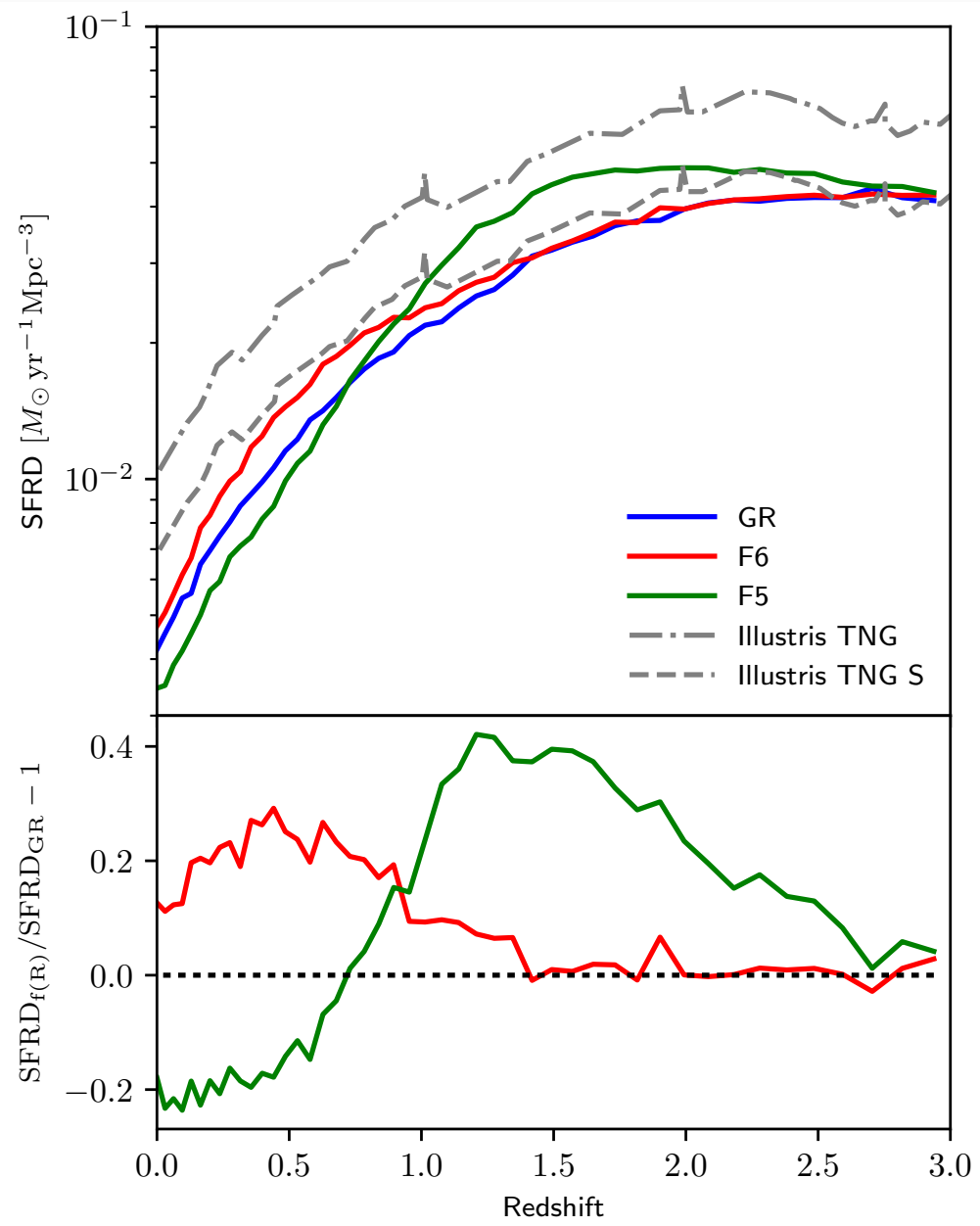
GR
F6
F5

gas
dark matter
stars
black holes
all matter

Galaxy size


10^2
10^1
$r_{\mathrm{stars},1/2}$[kpc]
GR
F6
F5
0.4
0.2
0.0
−0.2
$r_{\mathrm{f(R)}}/r_{\mathrm{GR}} - 1$
10^8
10^9
10^{10}
10^{11}
Galaxy Stellar Mass $[\mathrm{M}_\odot][< 2r_{\mathrm{stars},1/2}]$

Star formation rate density



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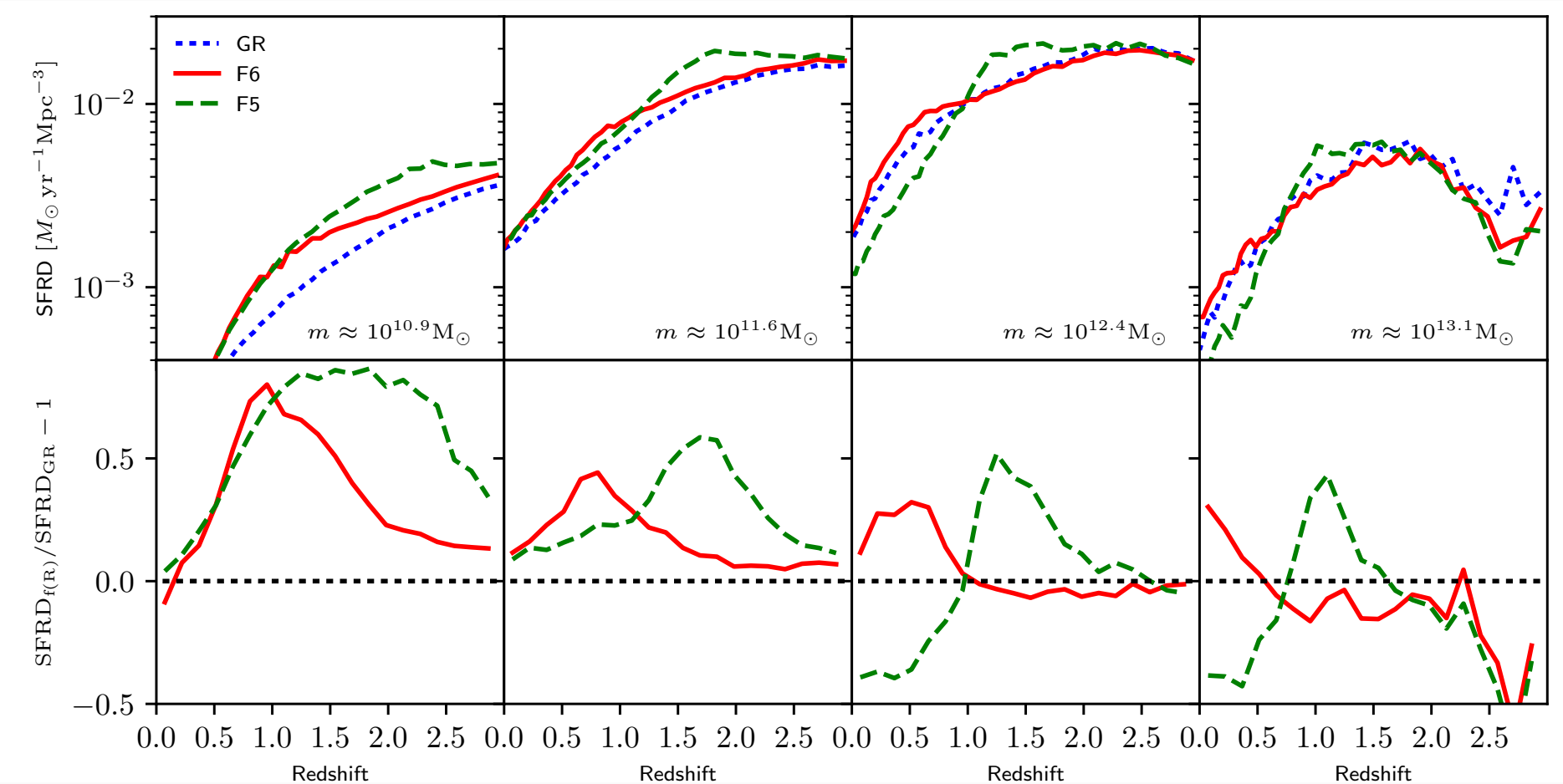
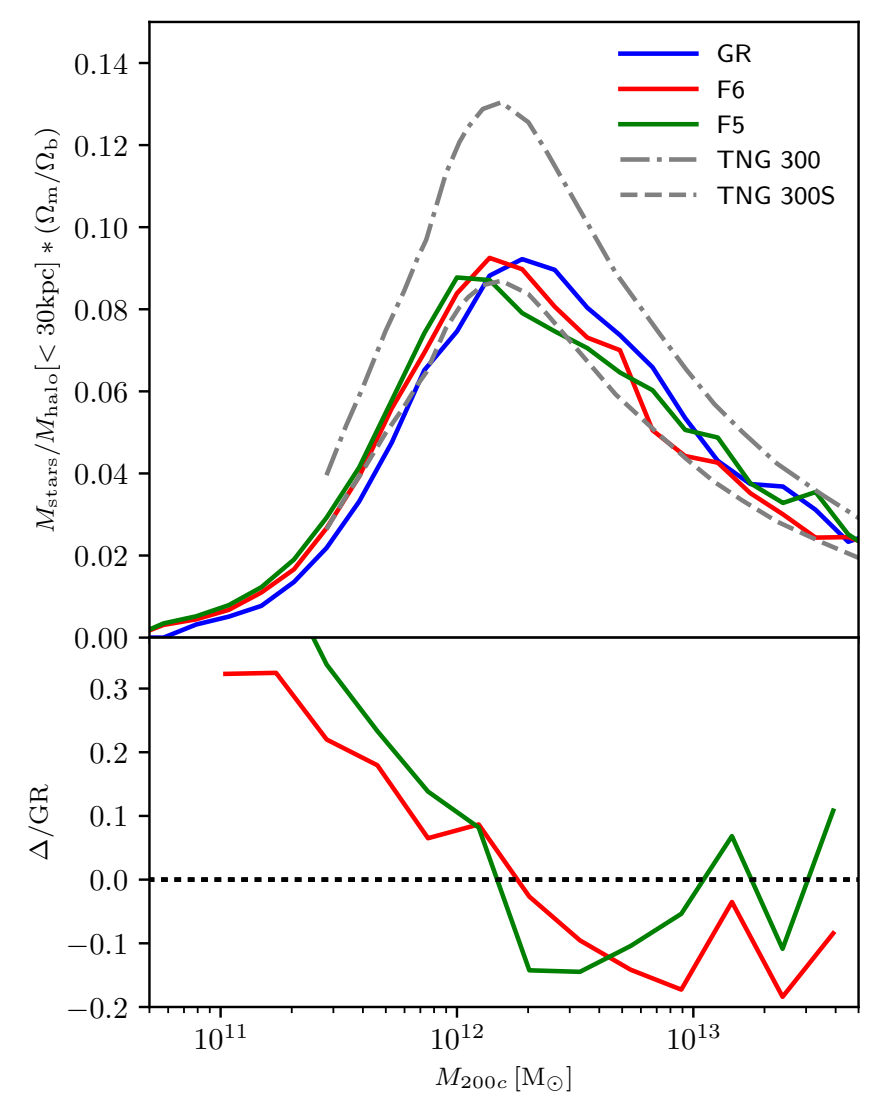


Galaxy stellar mass fraction



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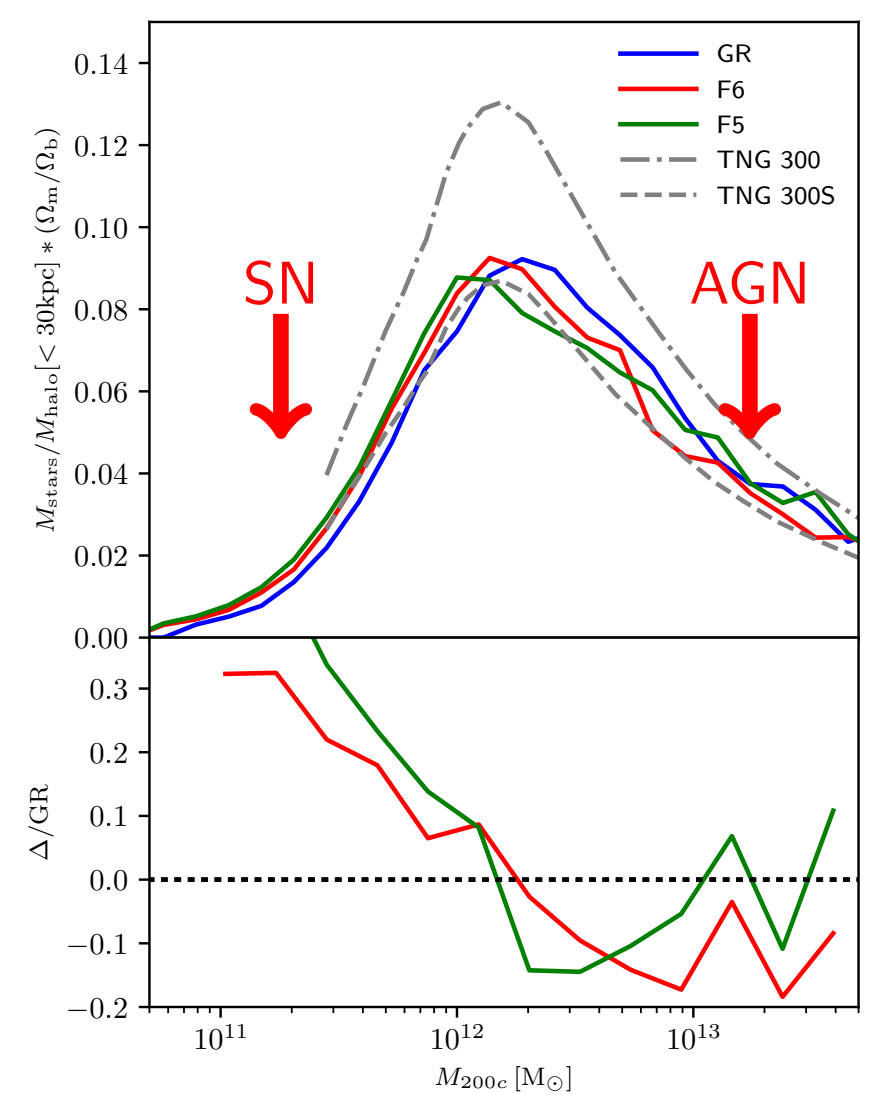

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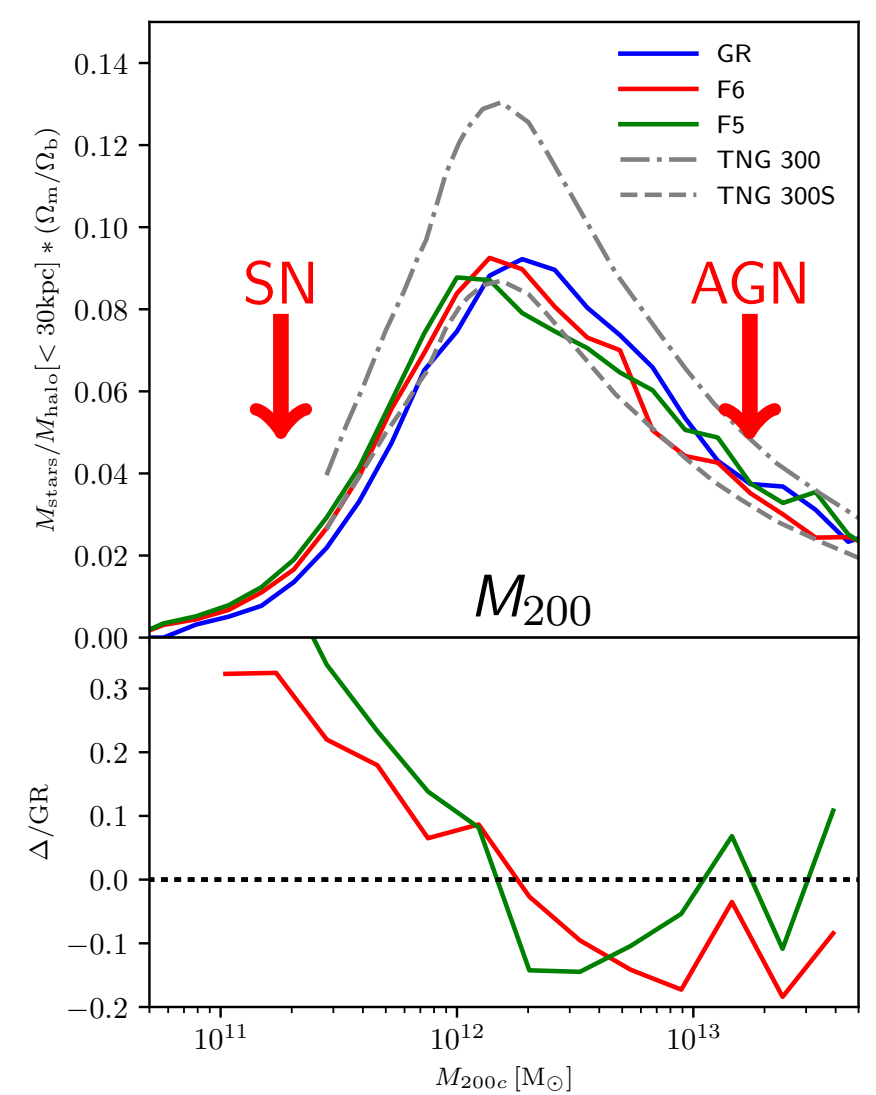
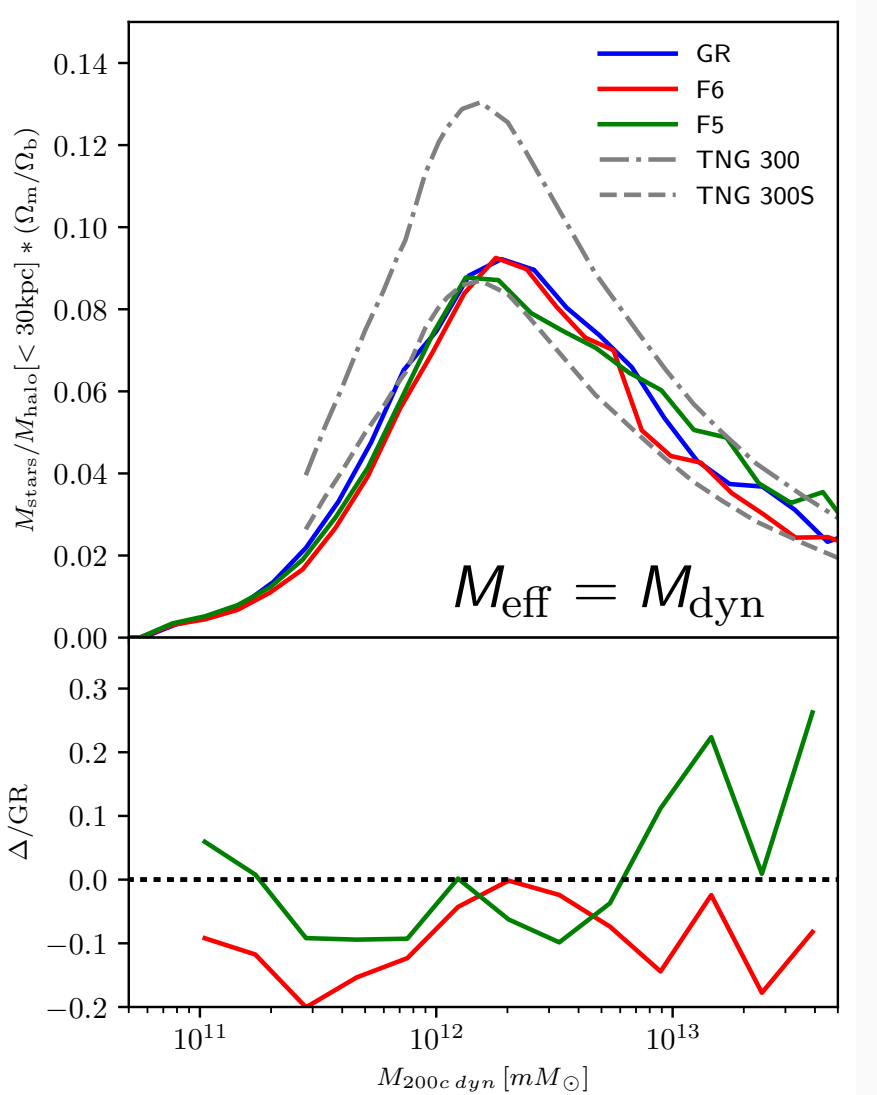
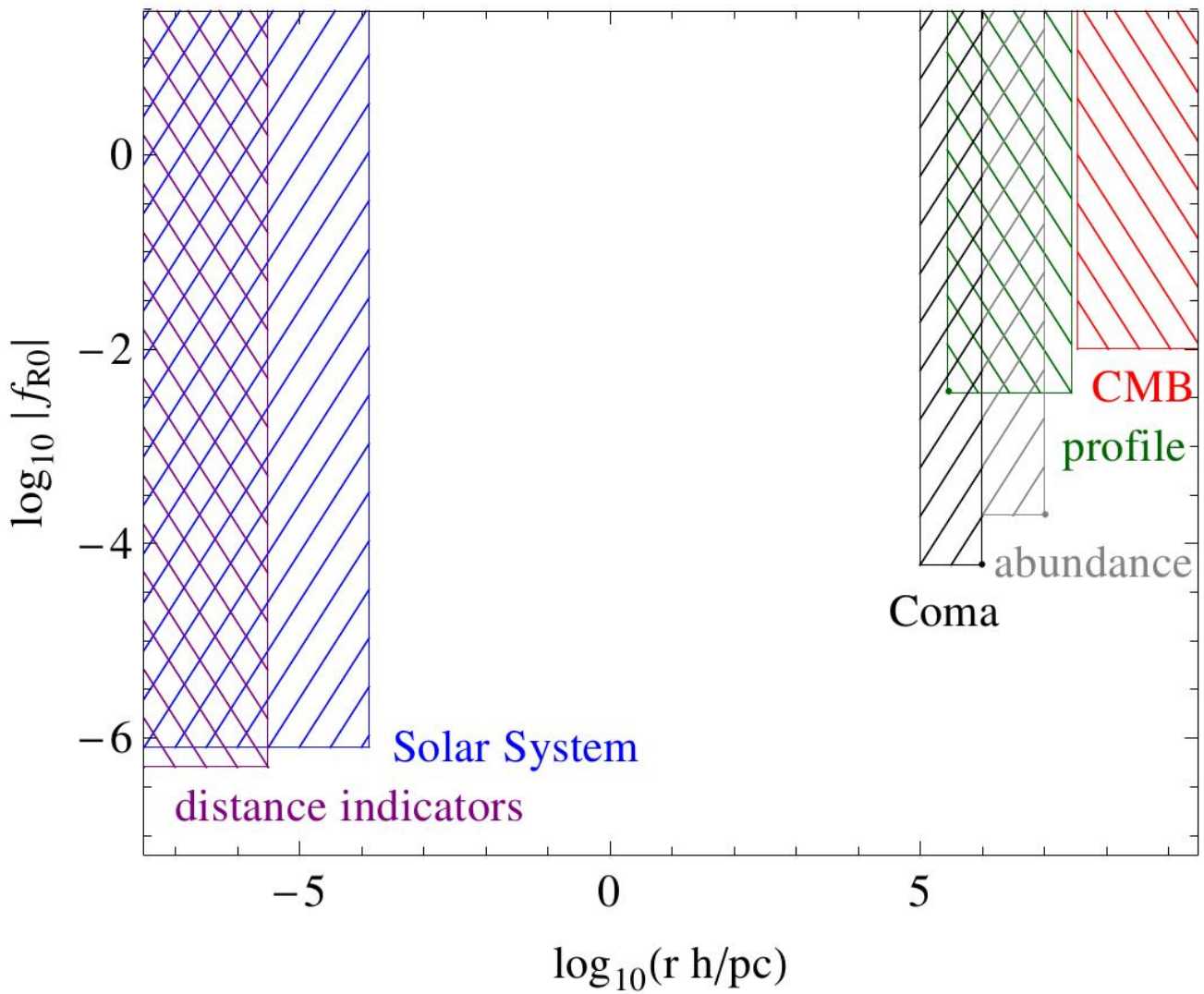




Conclusions

- $f(R)$-gravity can be used to test for deviations from GR
- Baryonic effects are important for many observables
- Back-reaction between baryonic feedback and $f(R)$-gravity is negligible for F6 but has sizeable effects for F5
- Disk-galaxies can form in $f(R)$-gravity
- Enhanced star formation affects galaxy formation

Current constraints on f_{R0}



Terukina et al. (2014)