Universal predictions of screened modified gravity in galaxy clusters

David F. Mota

UiO : Institute of Theoretical Astrophysics
University of Oslo

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Mass of clusters inferred via lensing, kinematics and thermal observations are different!

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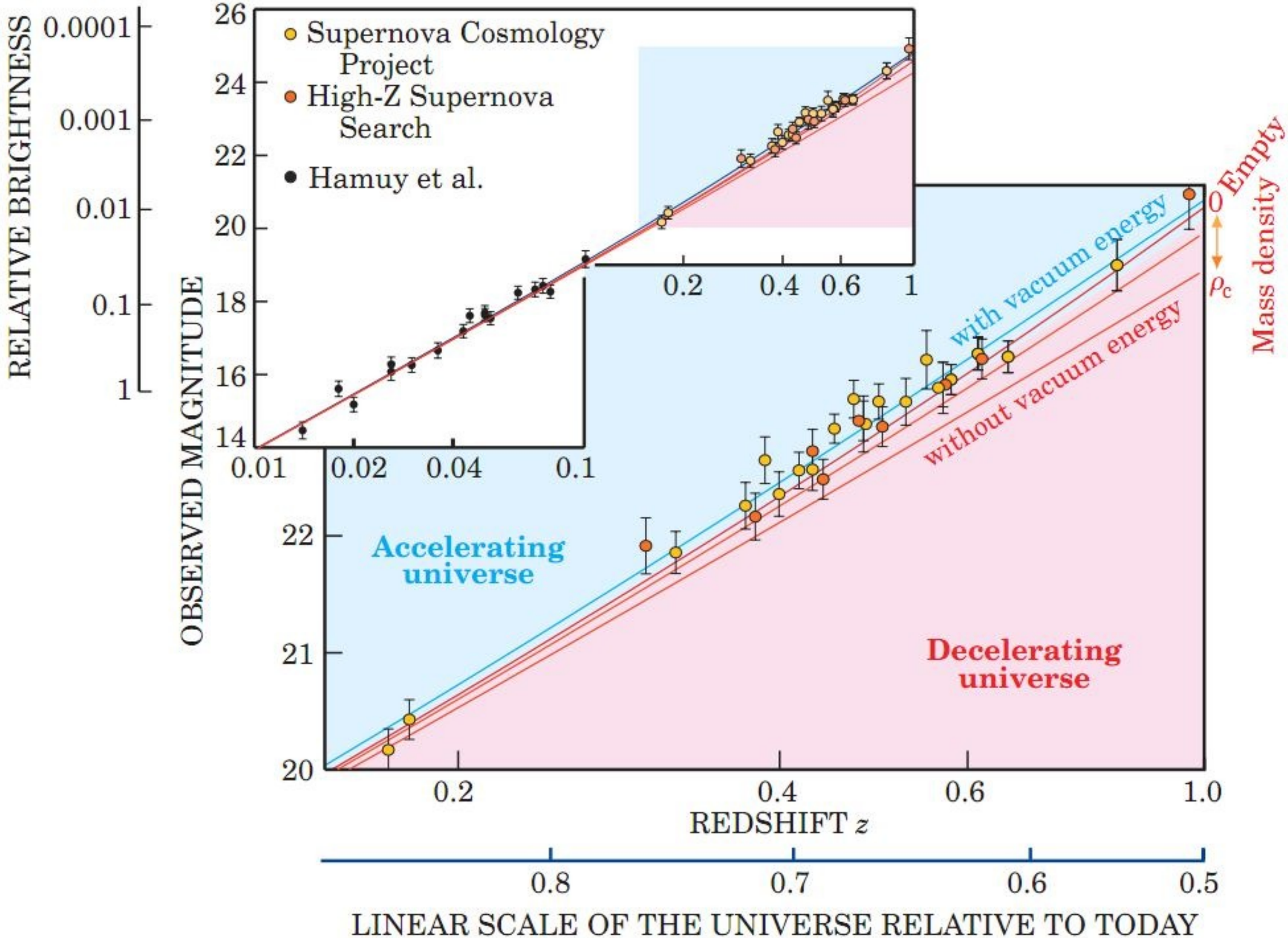
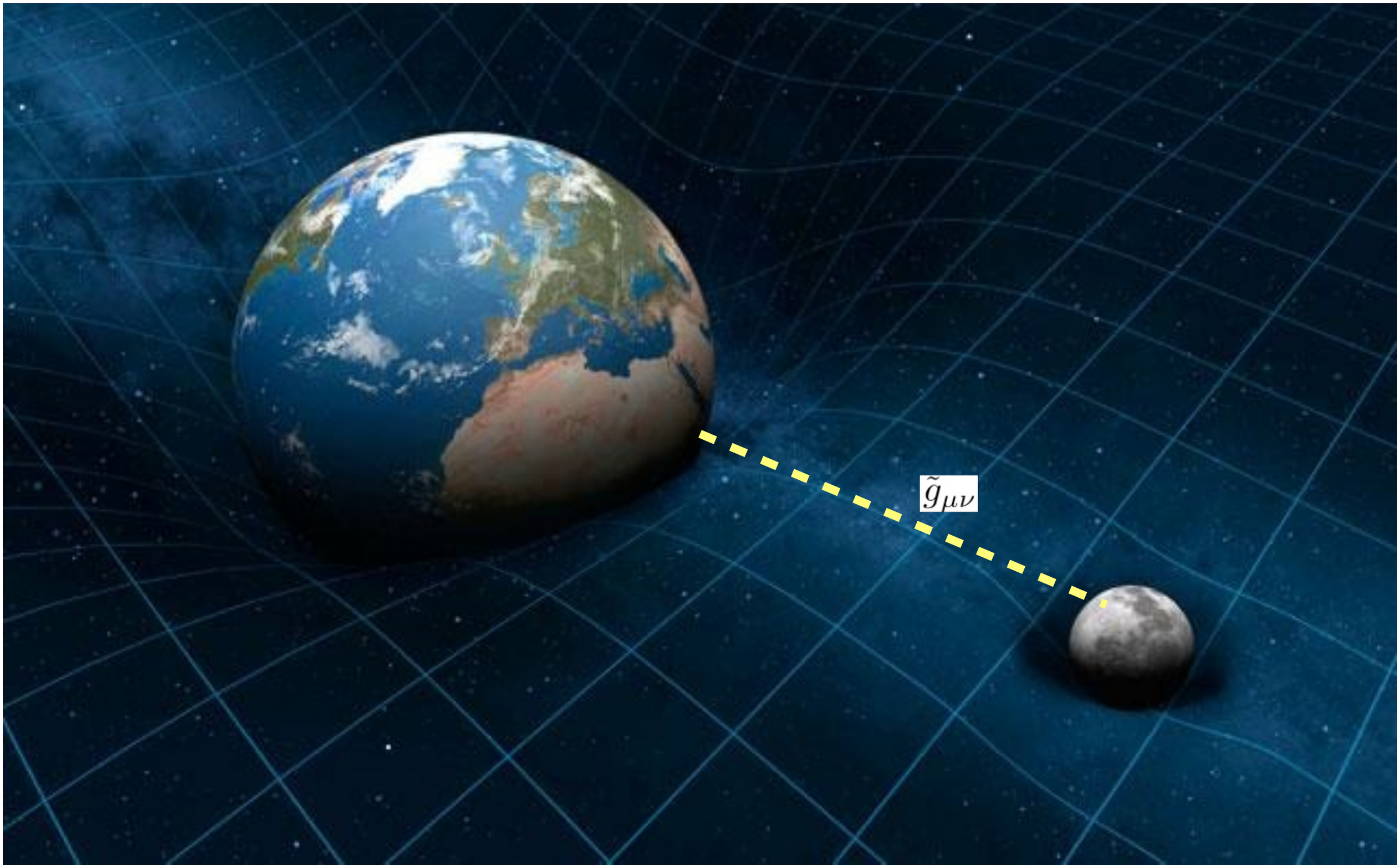
Modified Gravity: Universe Acceleration



Extending General Relativity

extra degree of freedom driving acceleration



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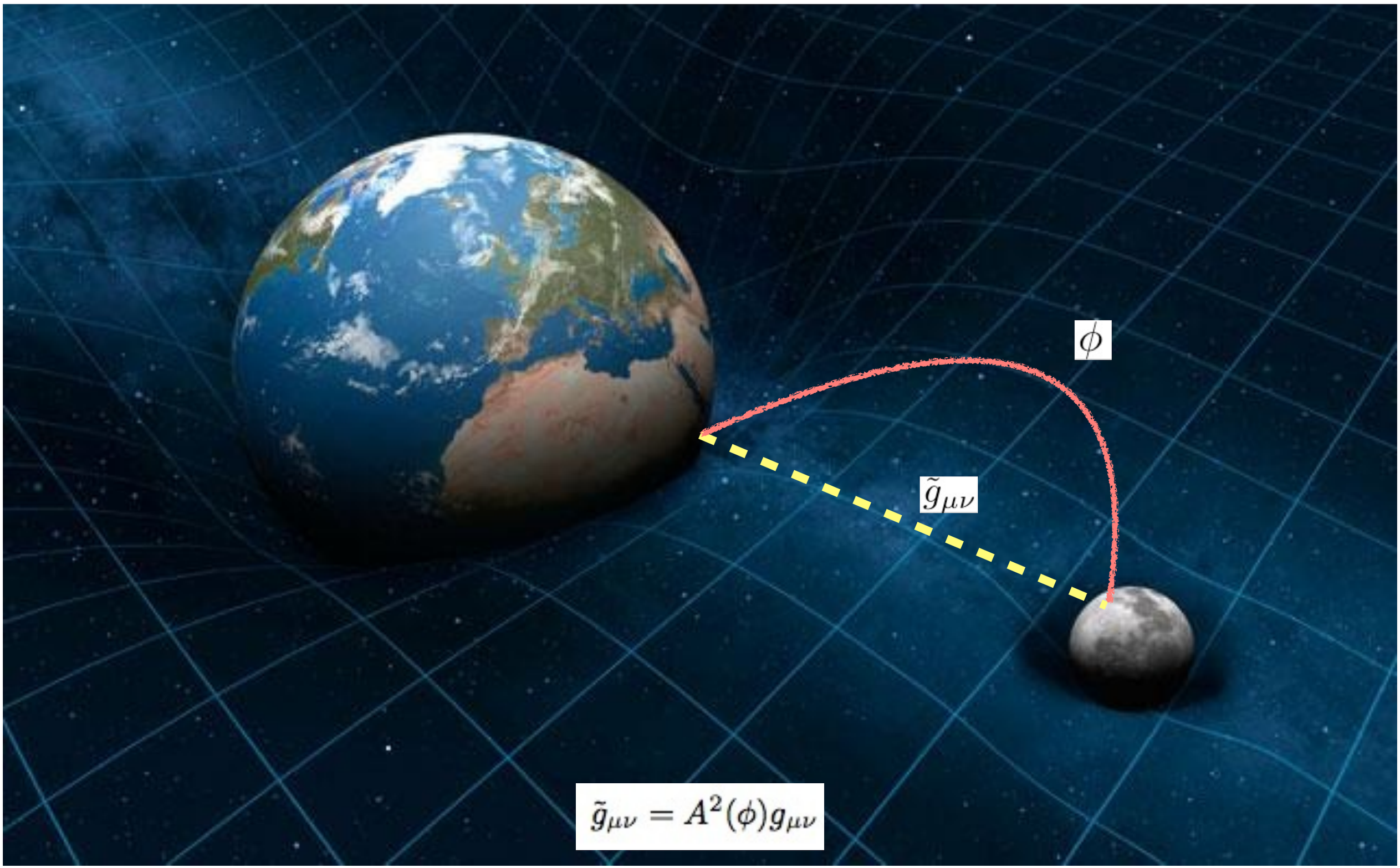

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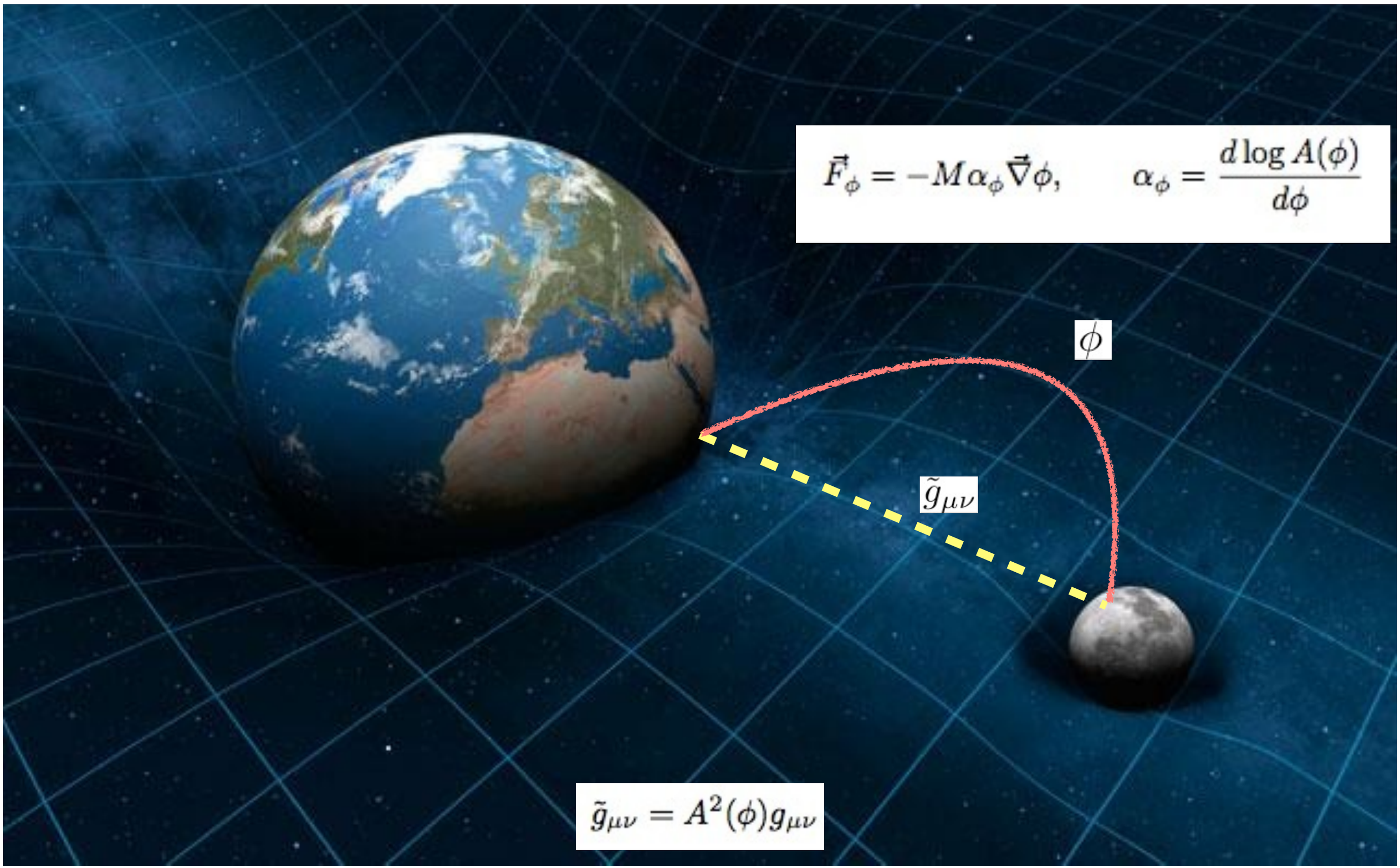
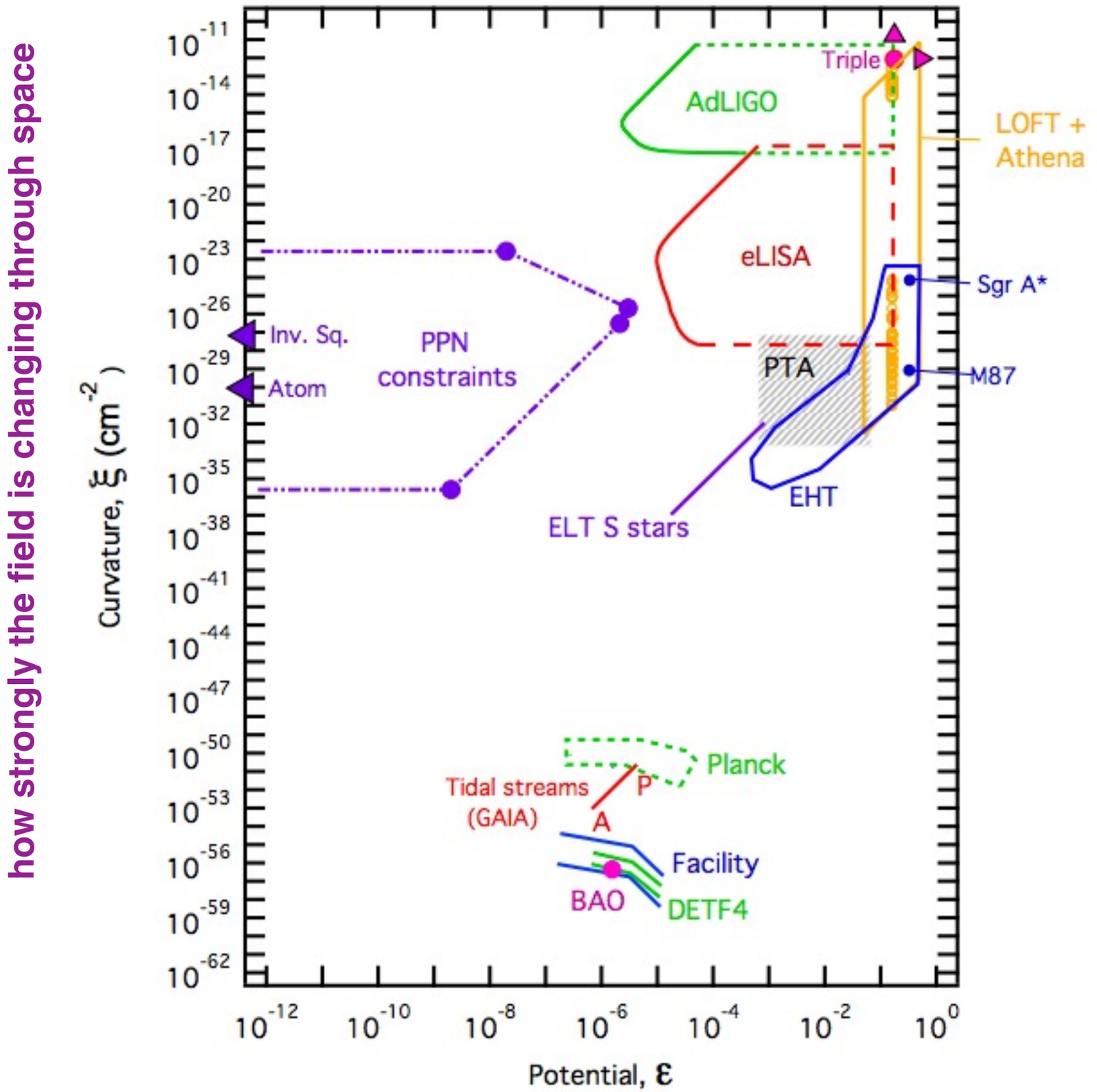


Tight constraints on Modified Gravity but all in very small or large scales/regimes!



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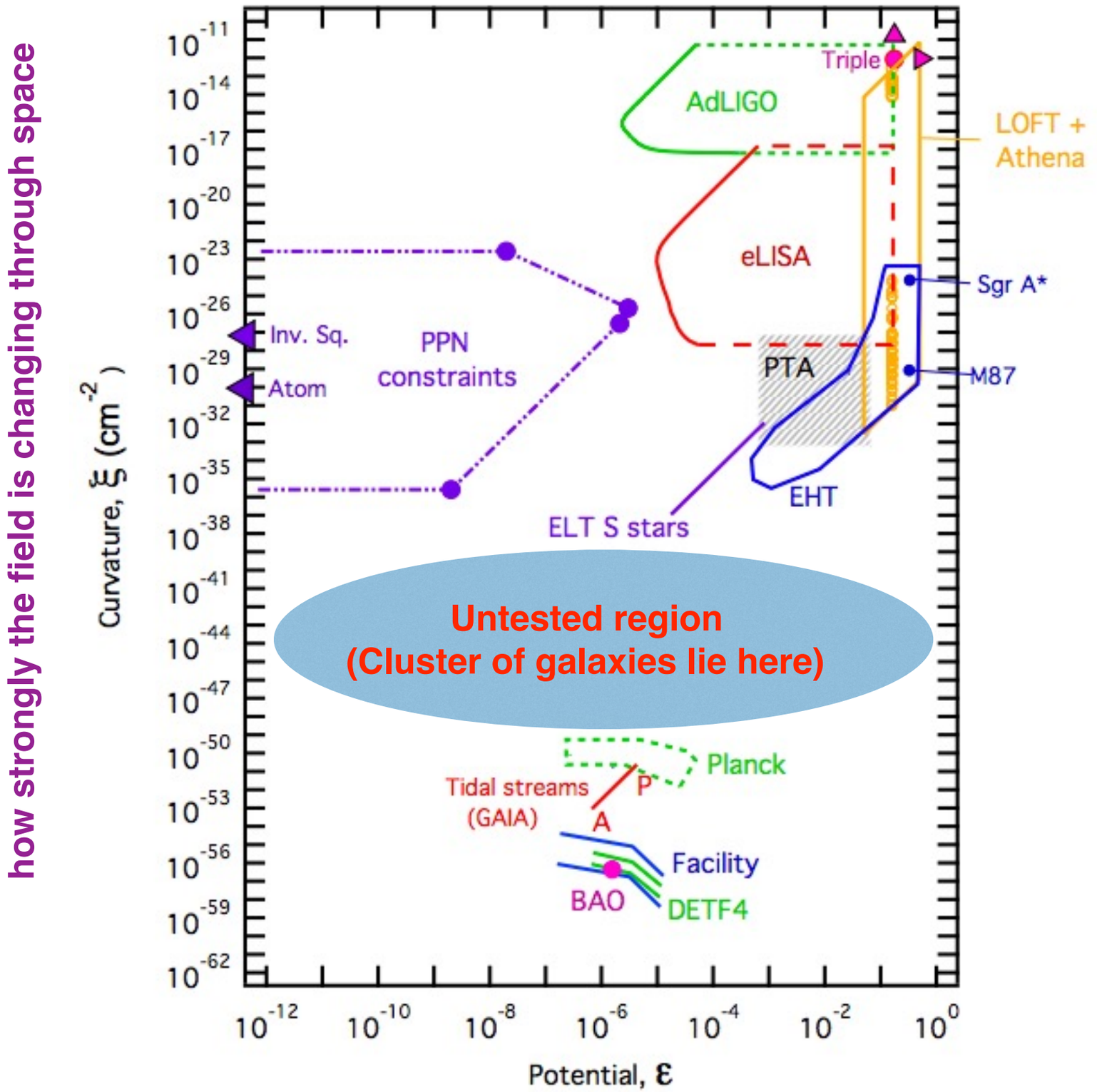
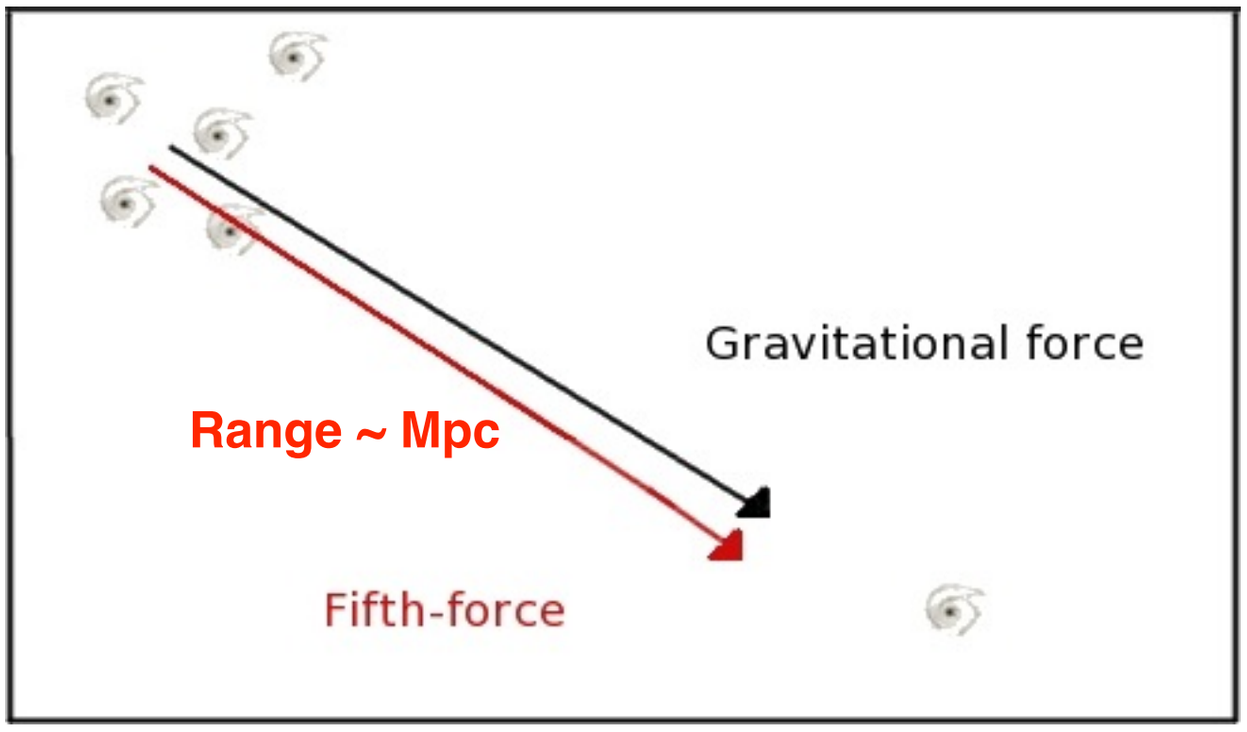


Modified Gravity with Screening Mechanisms:
Fifth force short ranged and disappears in high density



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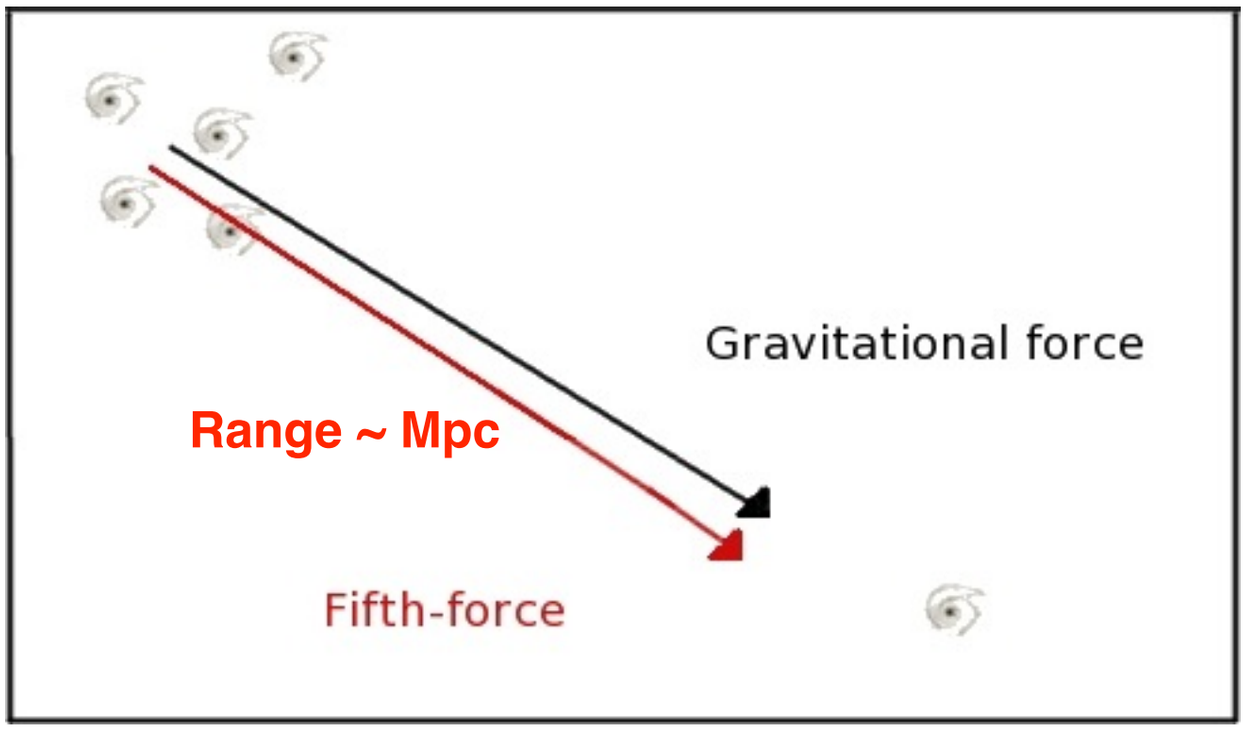

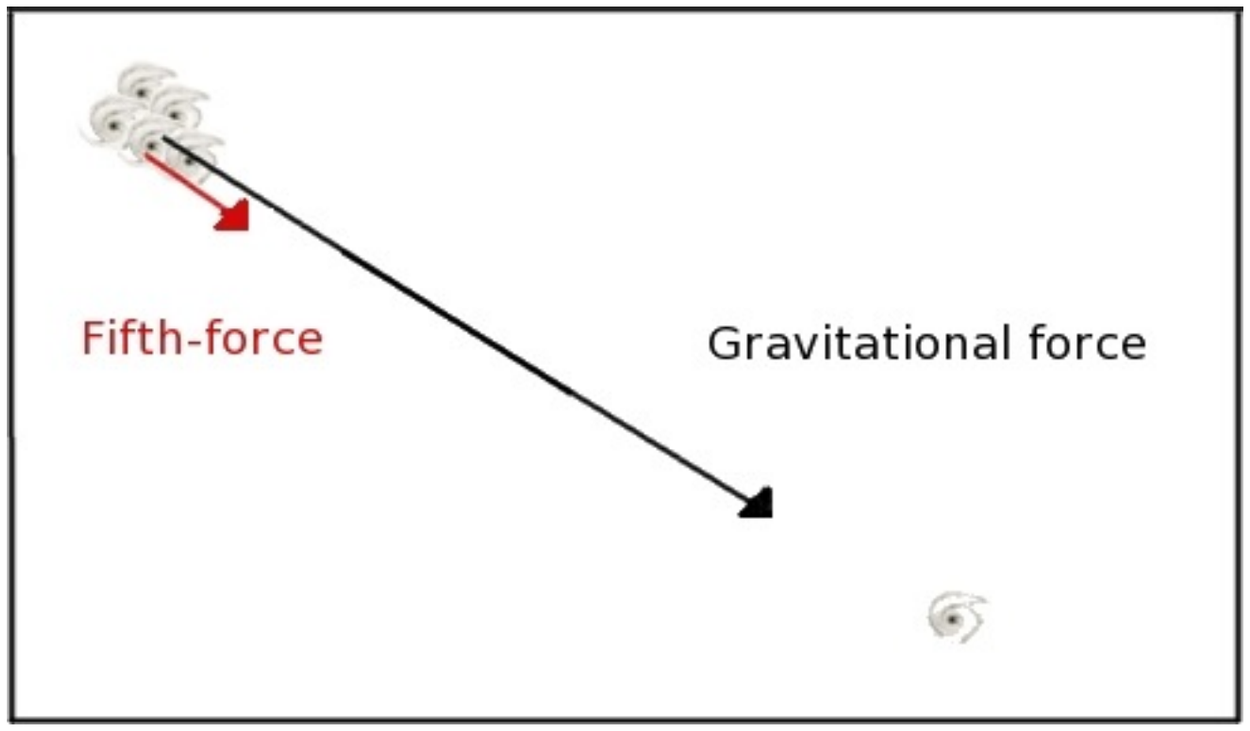

Low density => deviations from GR

High Density => GR recovered

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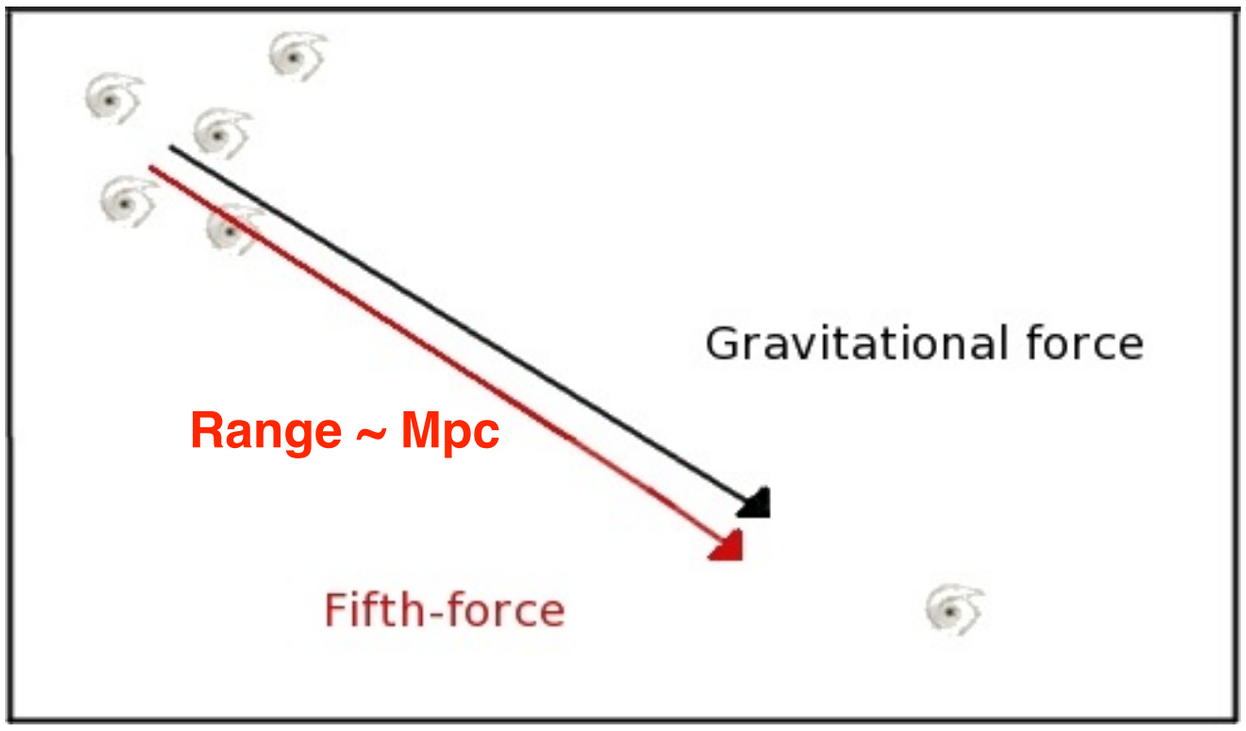
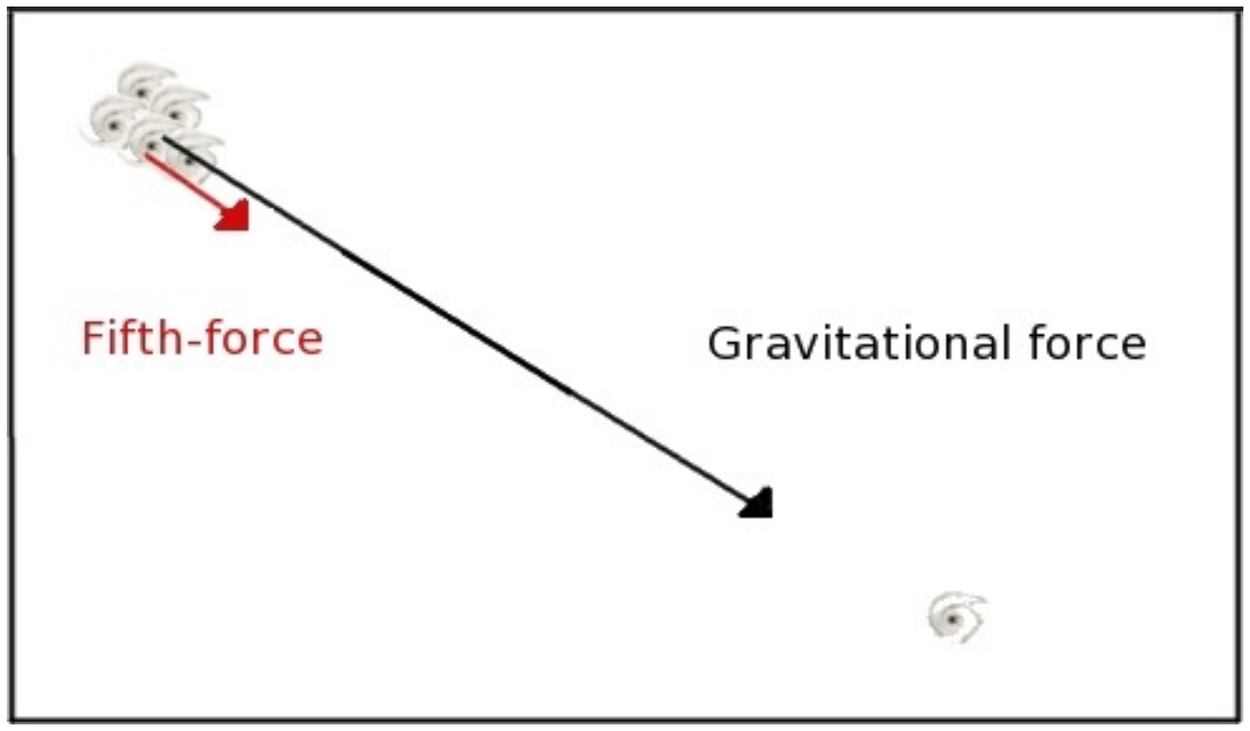




Low density => deviations from GR

High Density => GR recovered

Looking for smoking guns of screening mechanisms?

Search in Clusters!

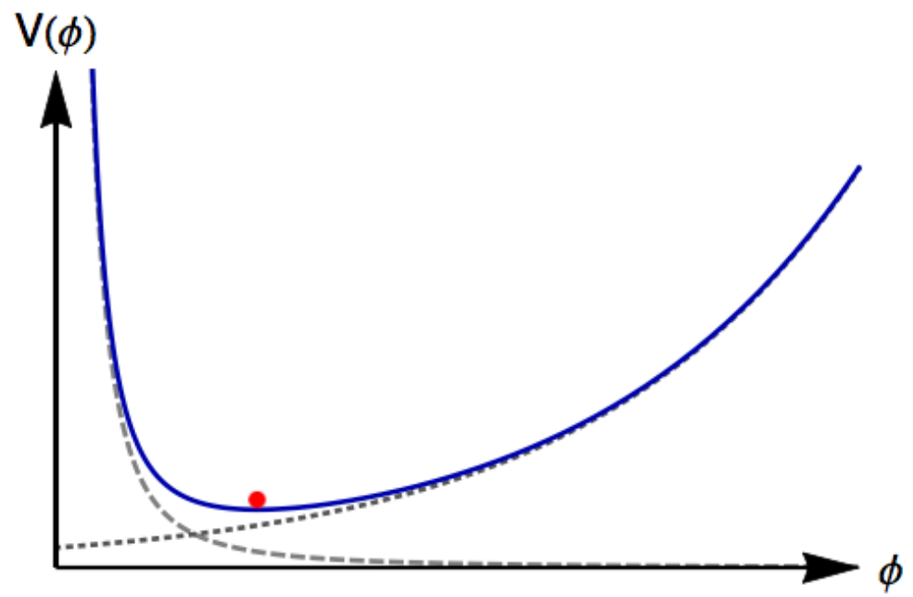
Chameleon f(R)-gravity

Hu & Sawicki (2007)

$$\int dx^4 \sqrt{g}\left[f(R)+L_{matter}\right]$$

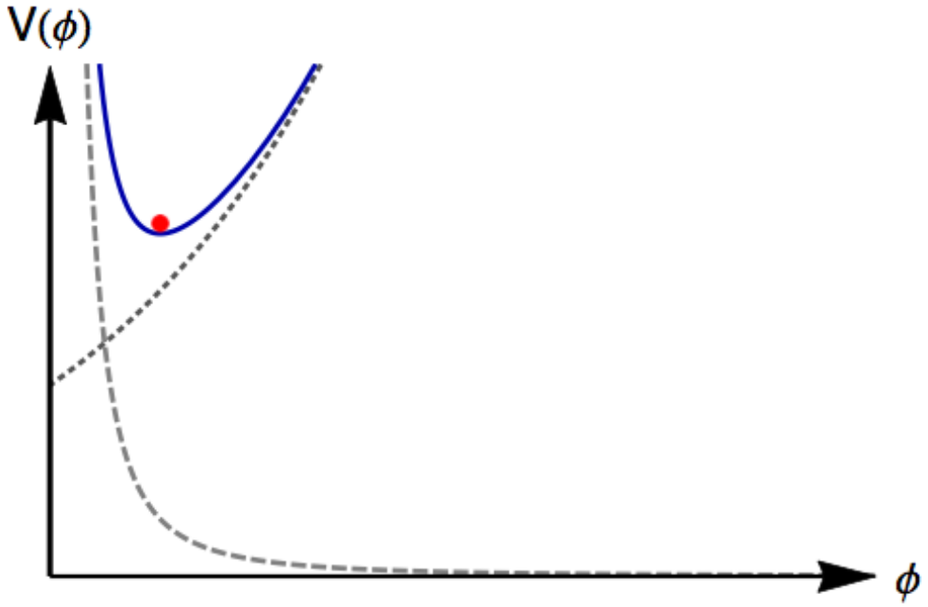
$$f(\tilde{R}) = -m^2 \frac{c_1(\tilde{R}/m^2)^n}{1+c_2(\tilde{R}/m^2)^n} \approx -16\pi G\rho_\Lambda - \frac{f_{R0}}{n}\frac{\tilde{R}_0^{n+1}}{\tilde{R}^n}$$

Low density region



$V''(\phi) \ll 1 \rightarrow$ Unscreened

High density region

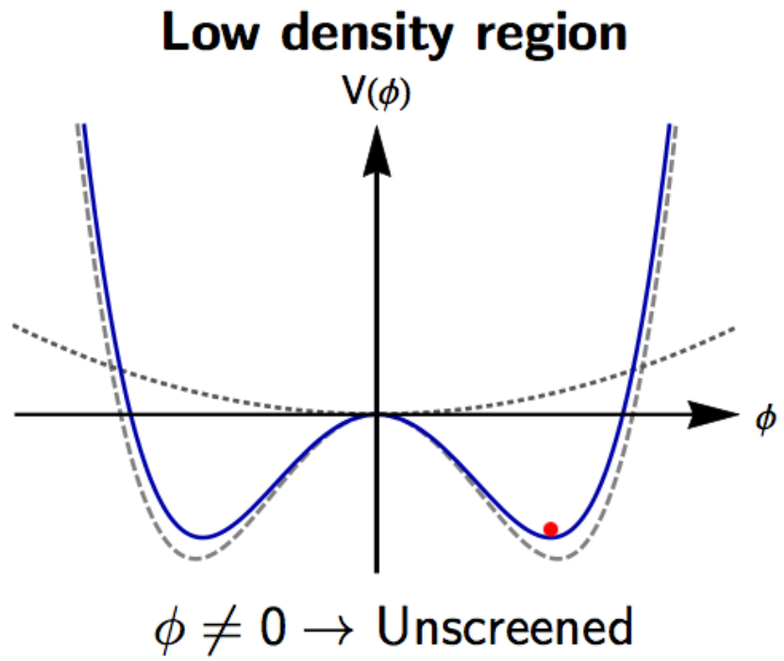


$V''(\phi) \gg 1 \rightarrow$ Screened

Hinterbichler & Khoury (2010)

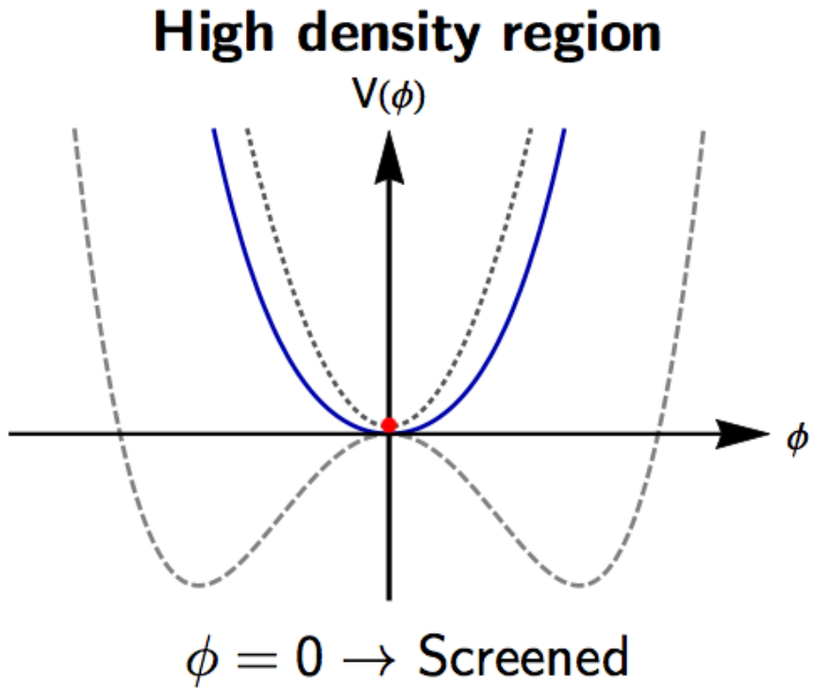
The Symmetron

$$S = \int \mathrm{d}^4x\sqrt{-g}\left[\frac{R}{16\pi G} - \frac{1}{2}(\partial\varphi)^2 - V(\varphi)\right] + S_m(\tilde{g}_{\mu\nu}, \psi)$$

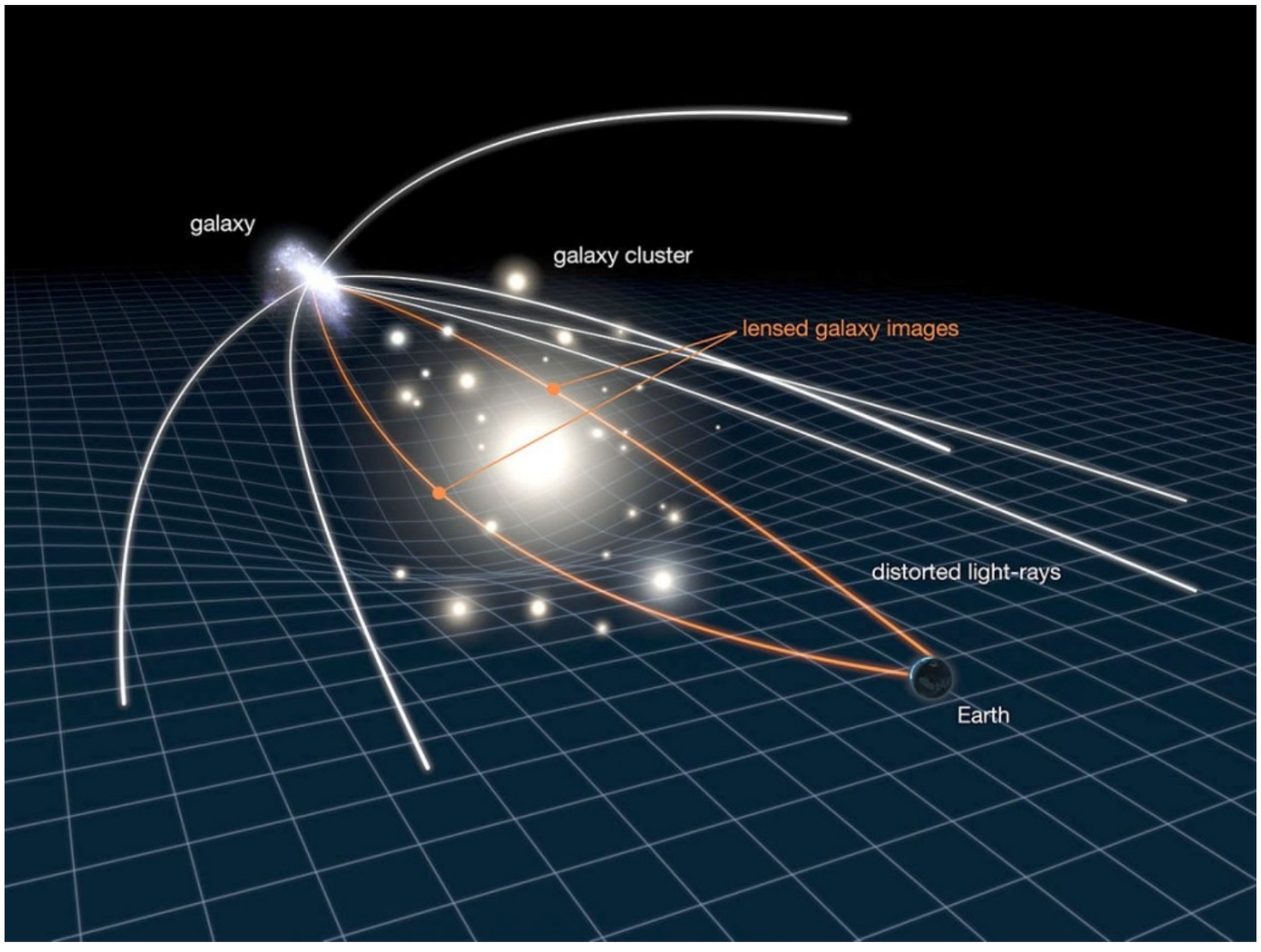


- Effective potential

$$V_{\text{eff}} = \frac{1}{2}\left(\frac{\rho_m}{M^2} - \mu^2\right)\varphi^2 + \frac{1}{4}\varphi^4$$



Lensing Mass
measured via gravitational lensing



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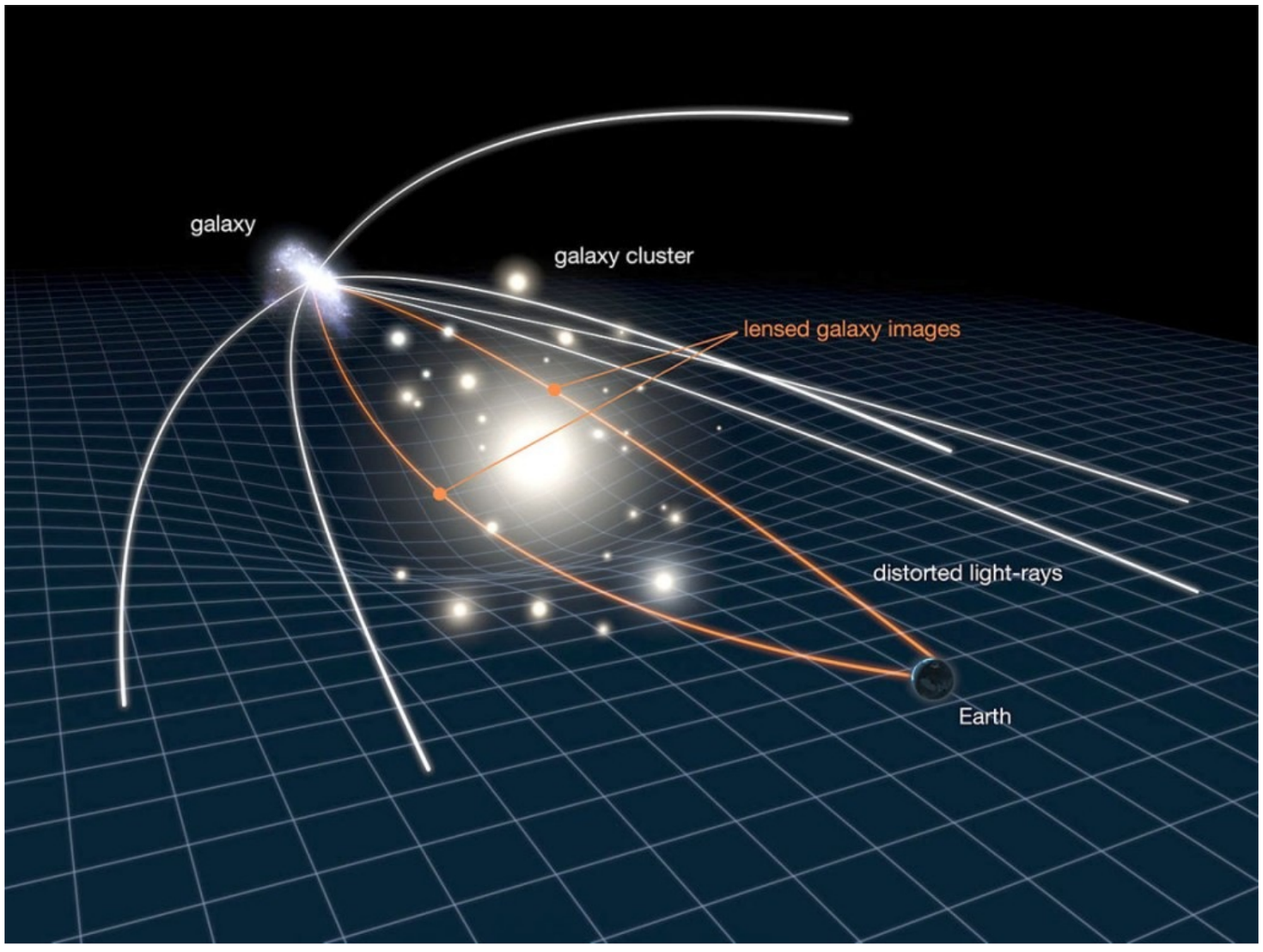

Conformal Invariance: photons not affected by Modified Gravity

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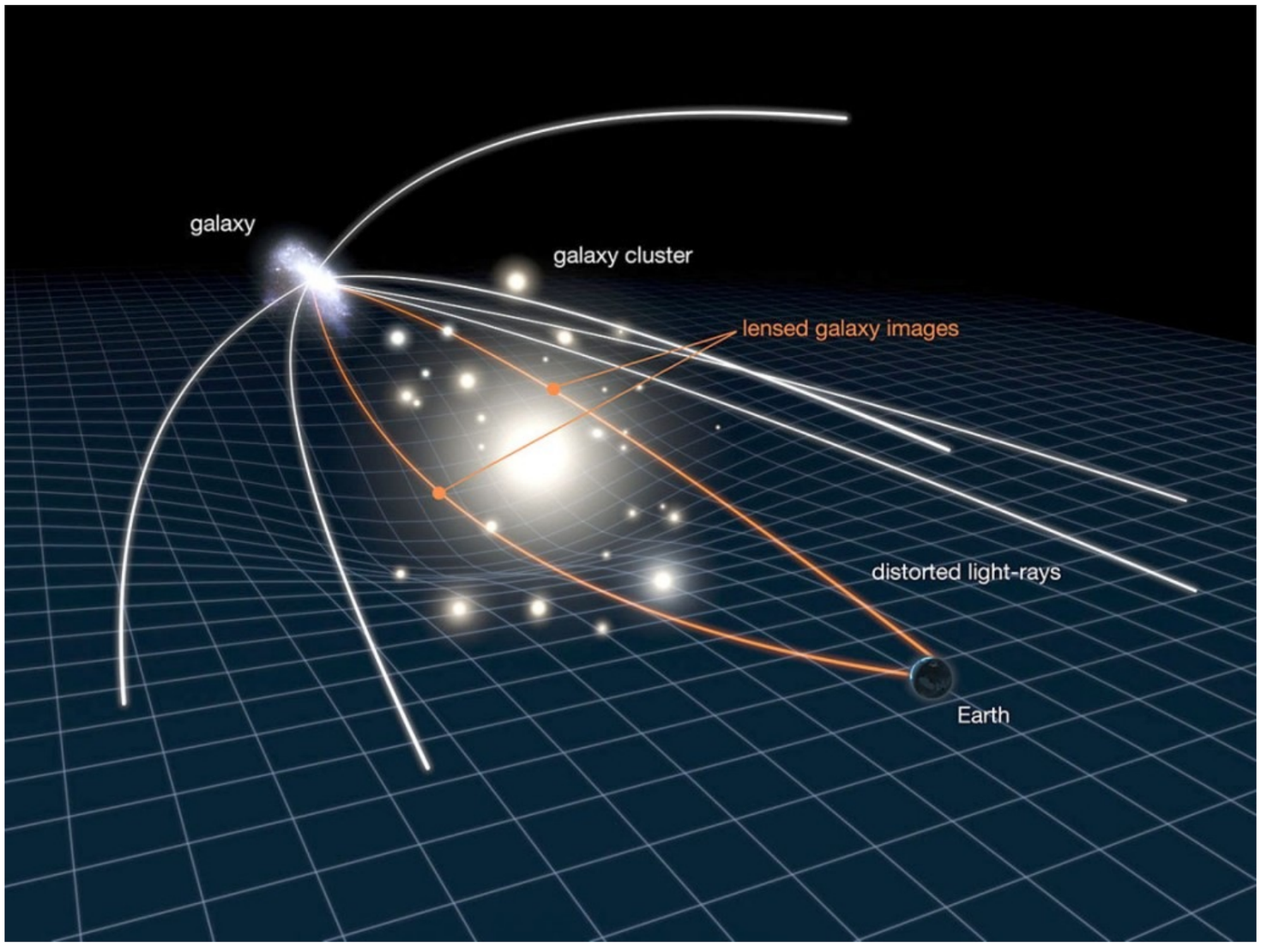
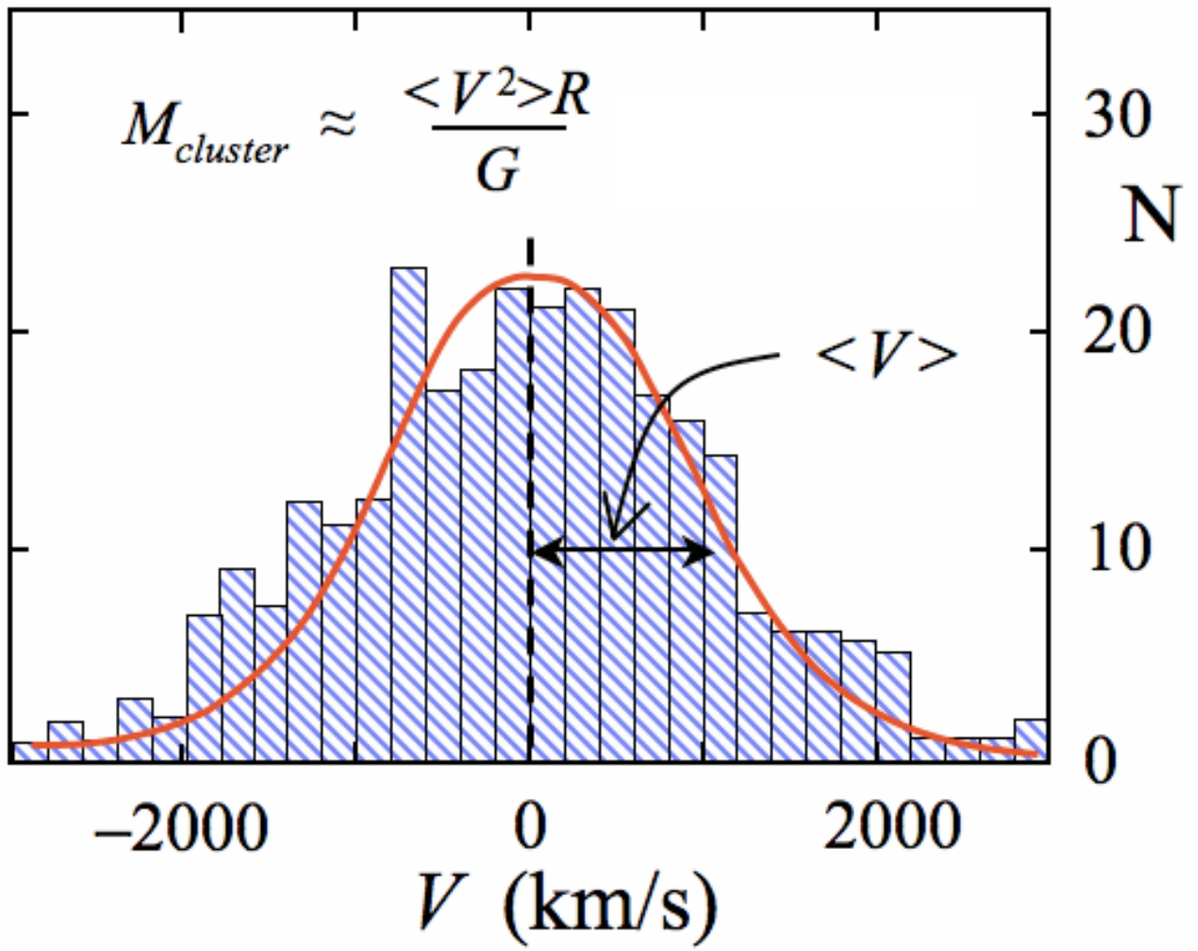


Conformal Invariance: photons not affected by Modified Gravity

Lensing Mass in (conformal) Modified Gravity same as GR

Kinematical Mass: from velocity dispersions

Coma cluster (central part)



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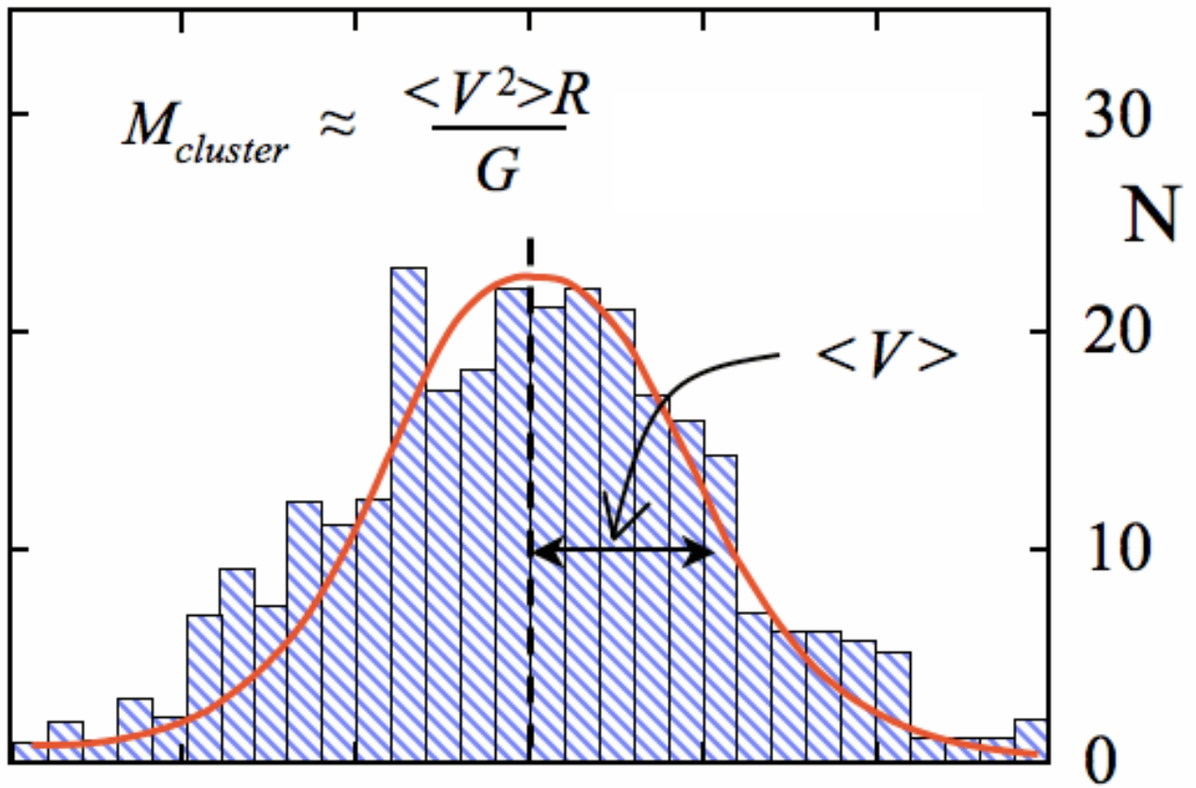

Coma cluster (central part)

$$M_{kinematic}\frac{< V^2 >}{R} = F_N$$

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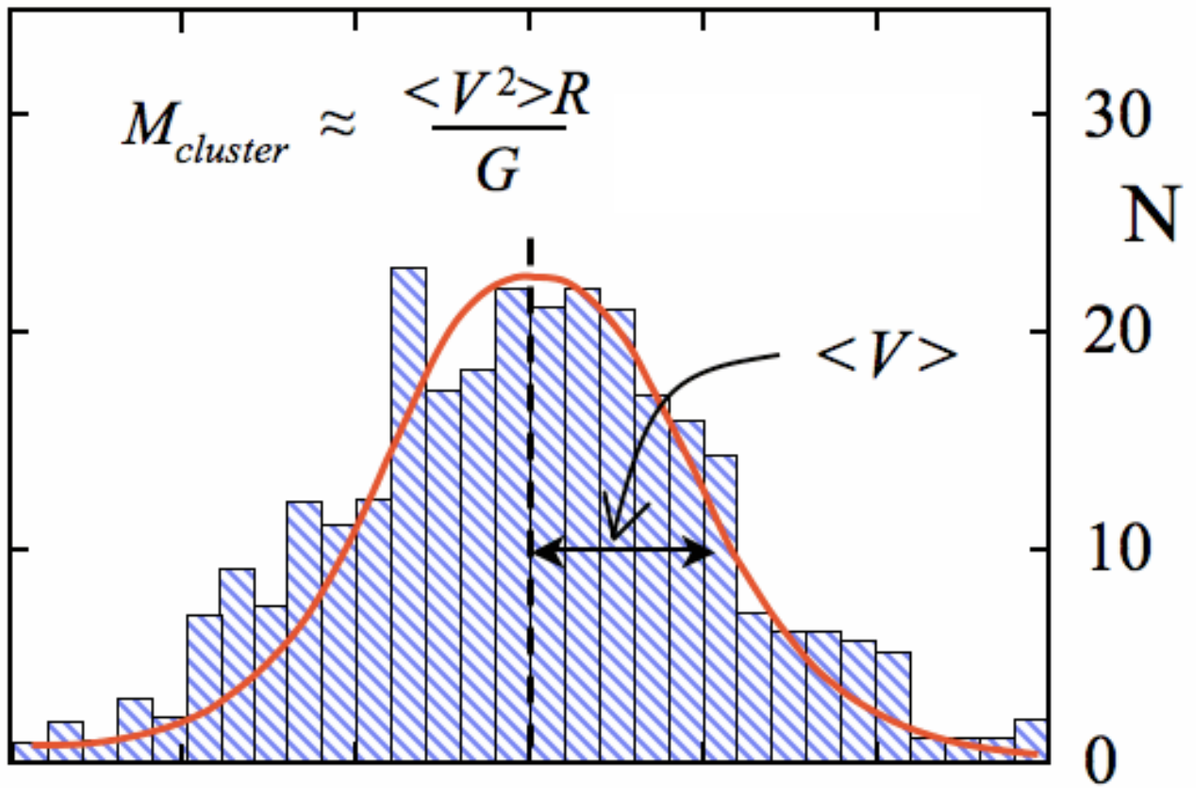

$$M_{kinematic}\frac{< V^2 >}{R} = F_N + \mathbf{F}_\phi$$

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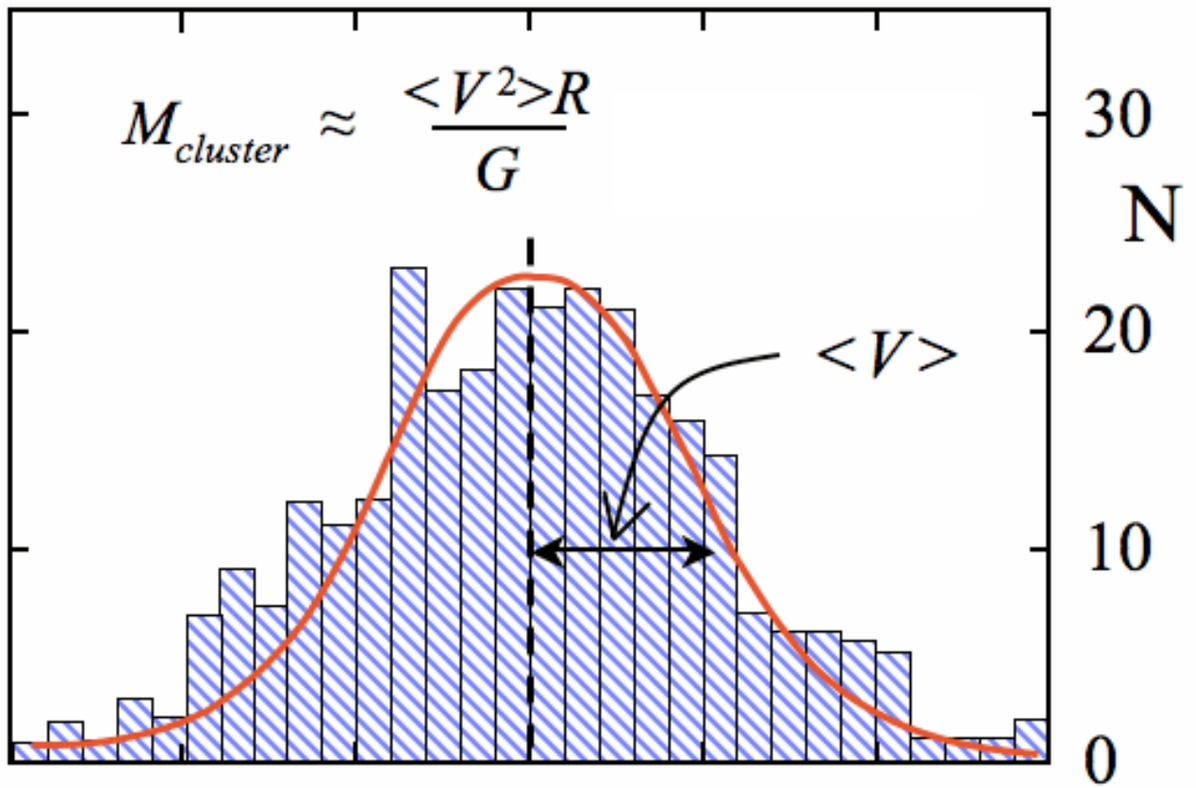
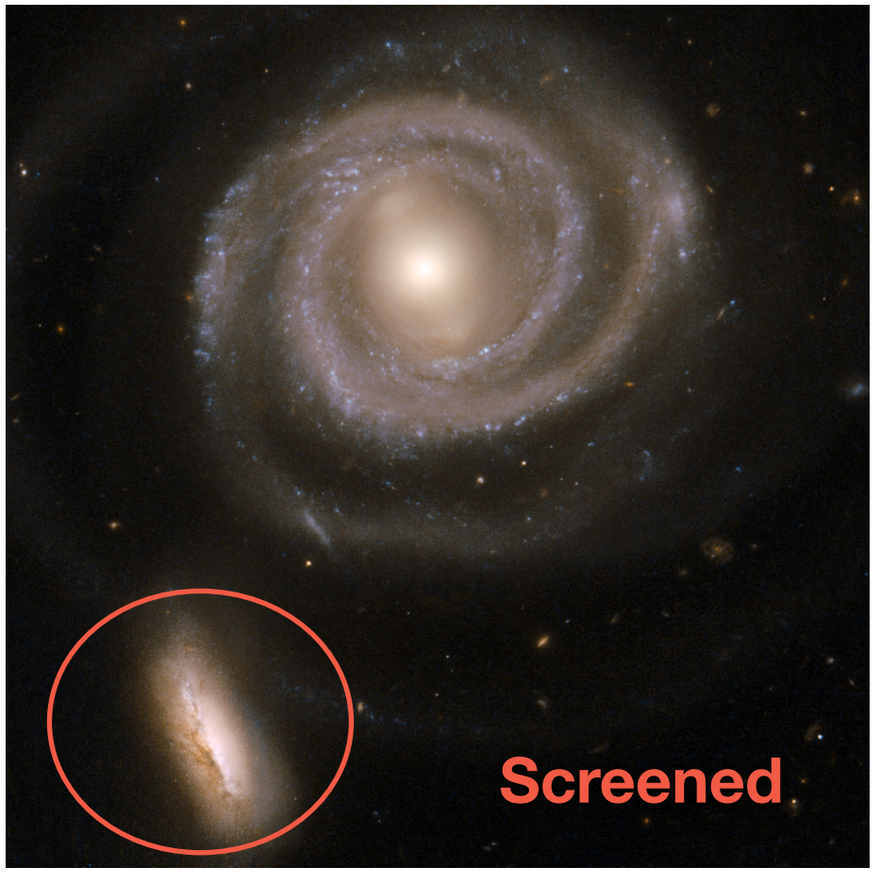


$$M_{kinematic}\frac{< V^2 >}{R} = F_N + \mathbf{F}_\phi$$

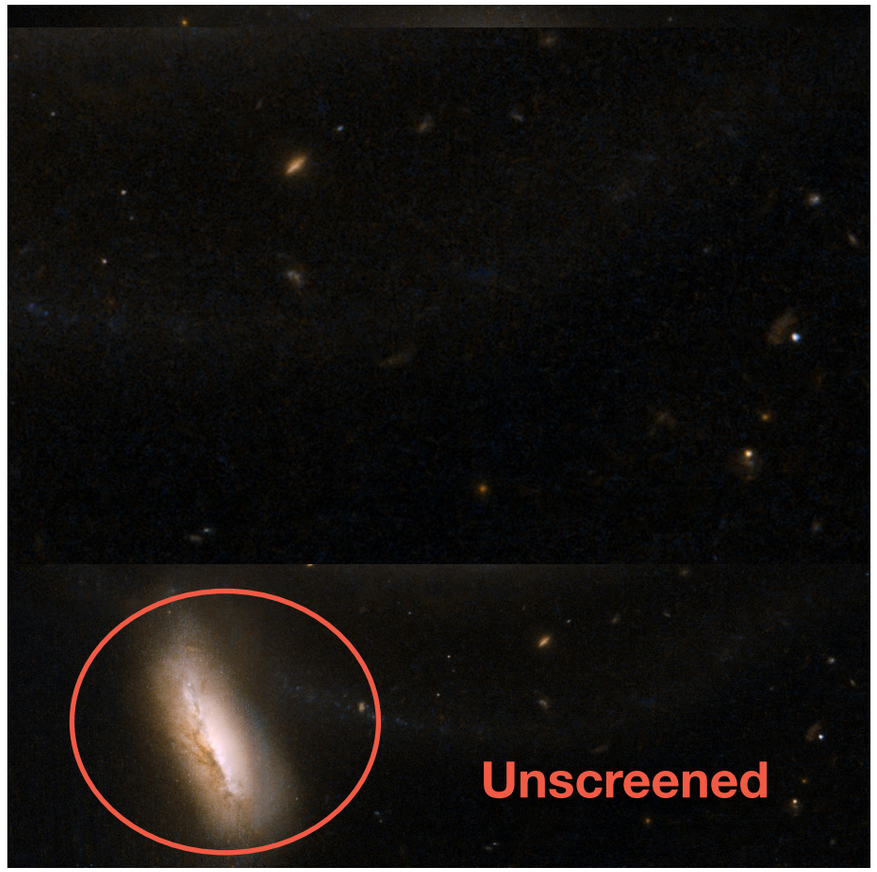
Modified Gravity enhances kinematical mass

Modified Gravity with Screening Mechanisms:

Fifth force depends on environmental density



Kinematic mass is same in GR



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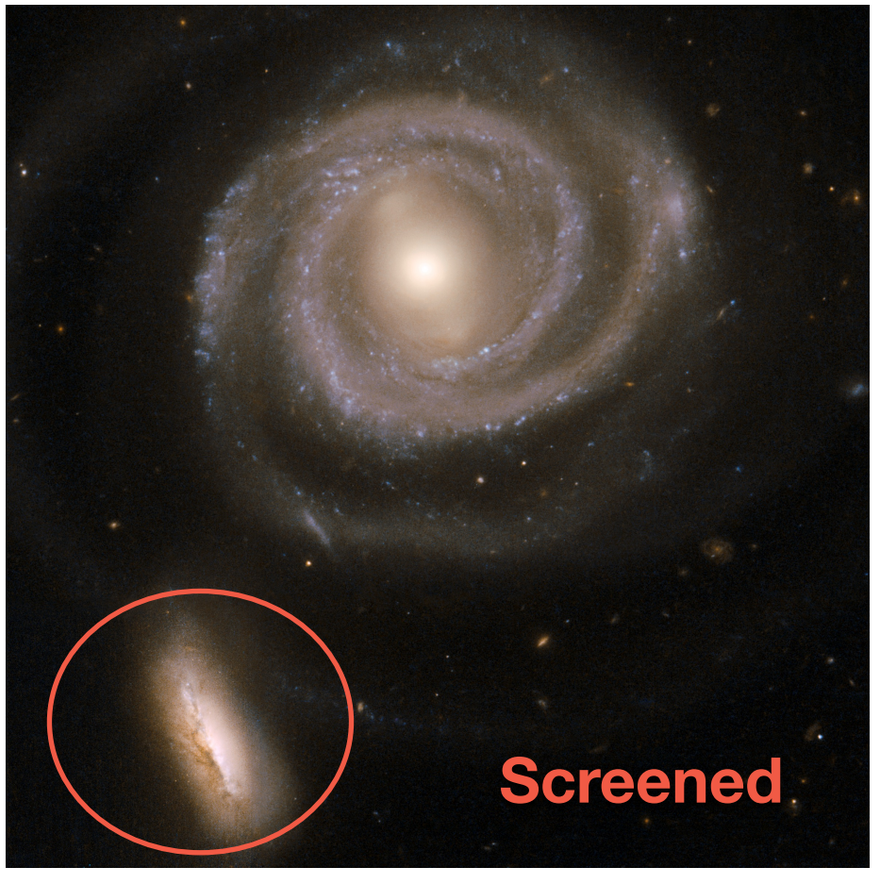

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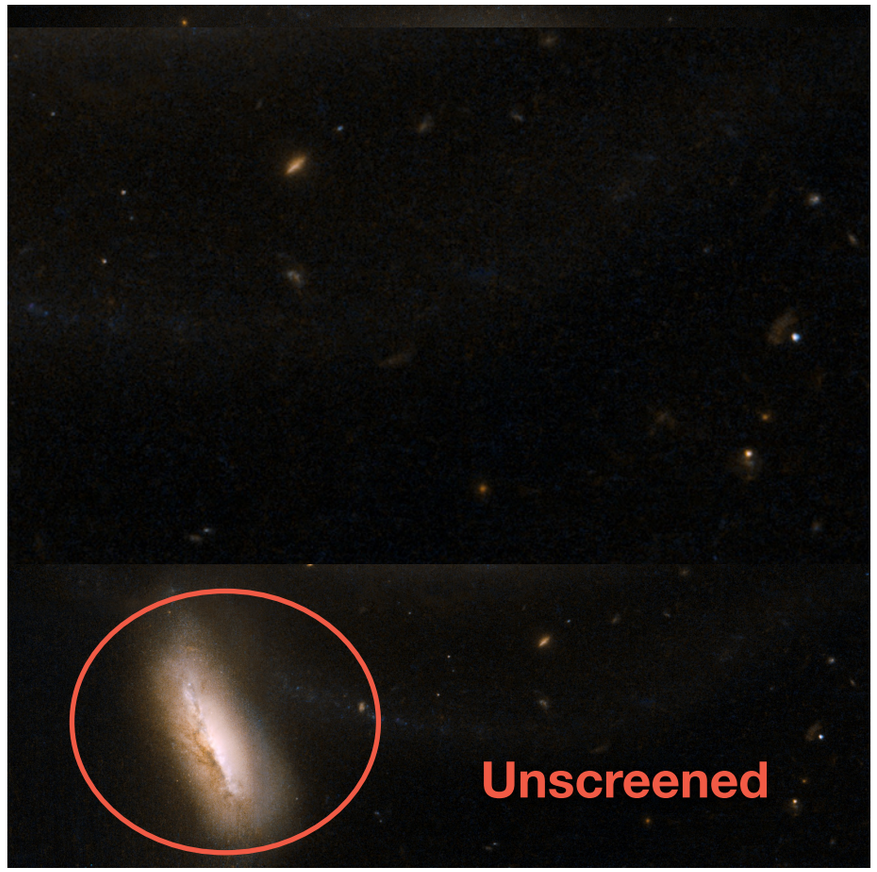


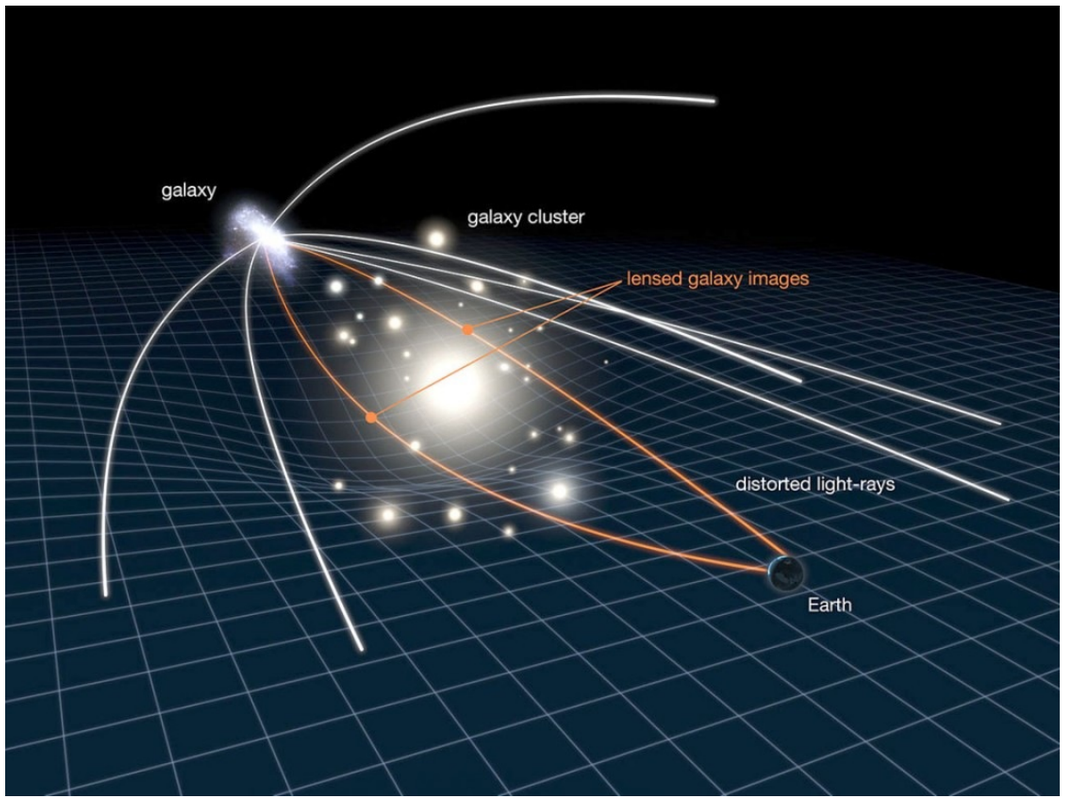
Kinematic mass differs from GR

Kinematic Mass depends on location in a high/low dense environment (size of cluster)

Smoking gun for Screening Mechanisms

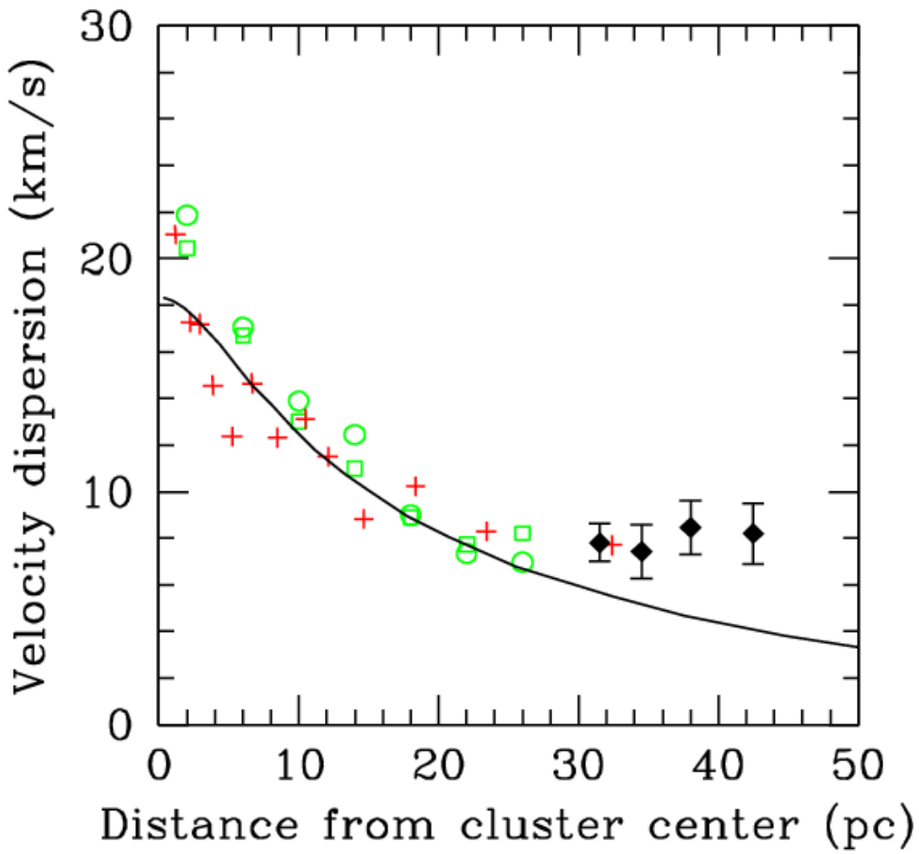
Lensing Mass vs. Environmental dependent Kinematic Mass

Lensing Mass same as in GR



$$\Delta_M \equiv \frac{M_D}{M_L} - 1$$

Kinematic Mass depends on environment



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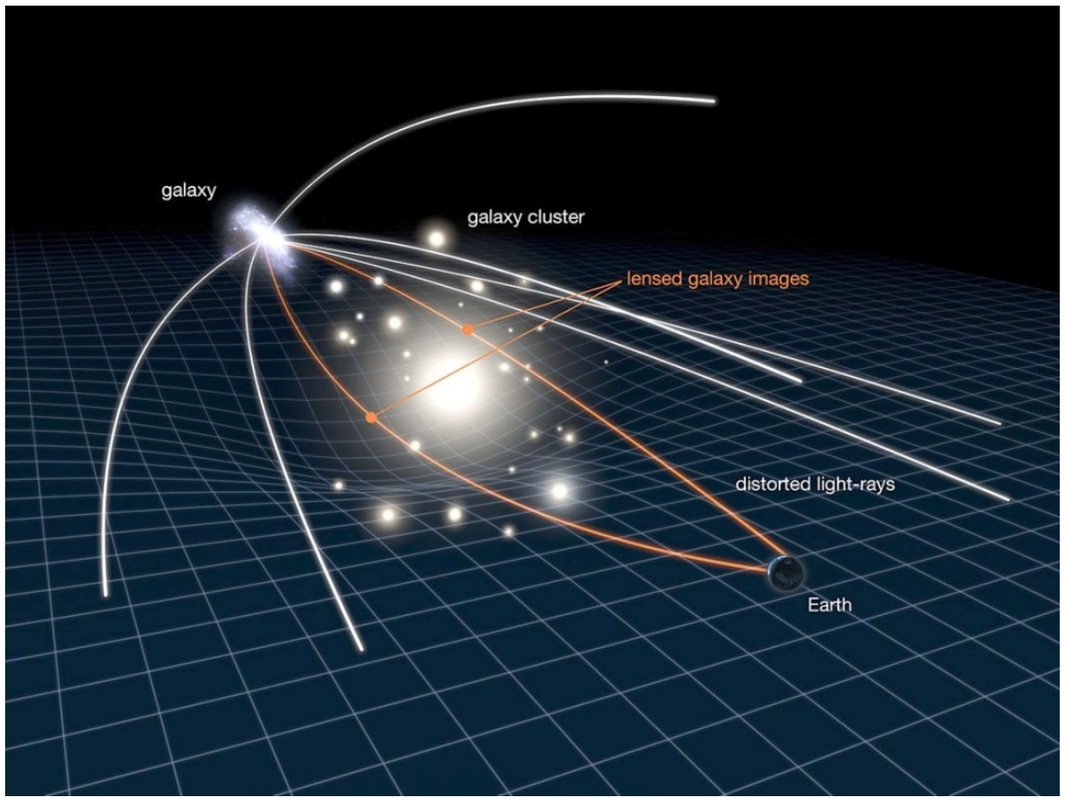

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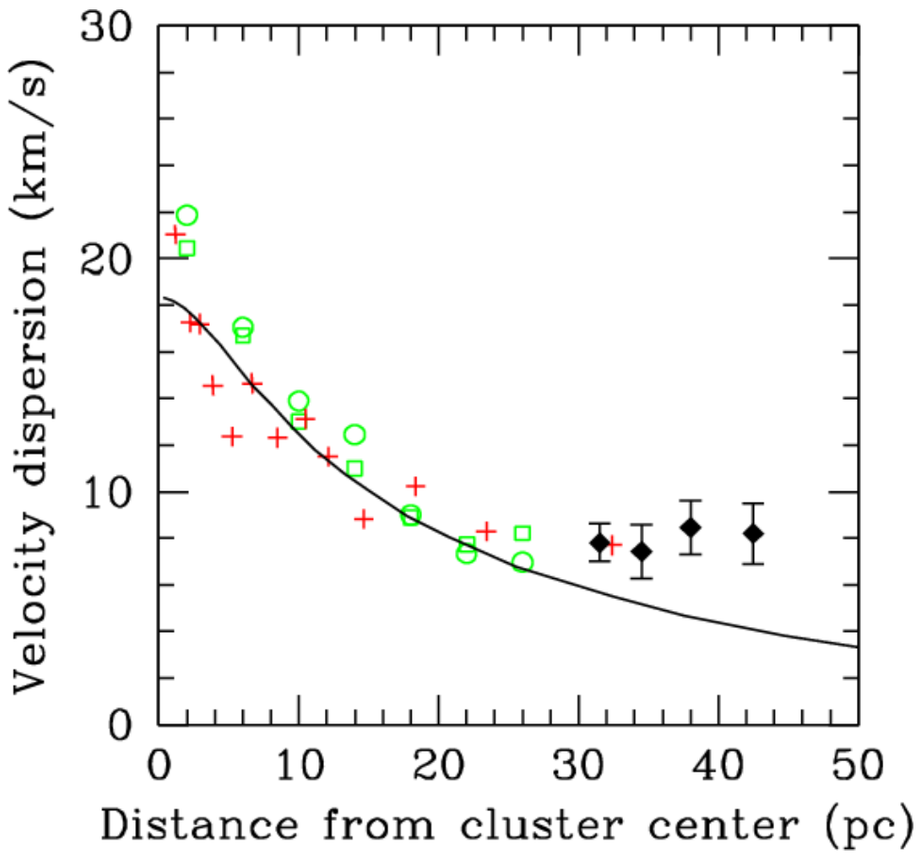


$$\Delta_M \equiv \frac{M_D}{M_L} - 1$$

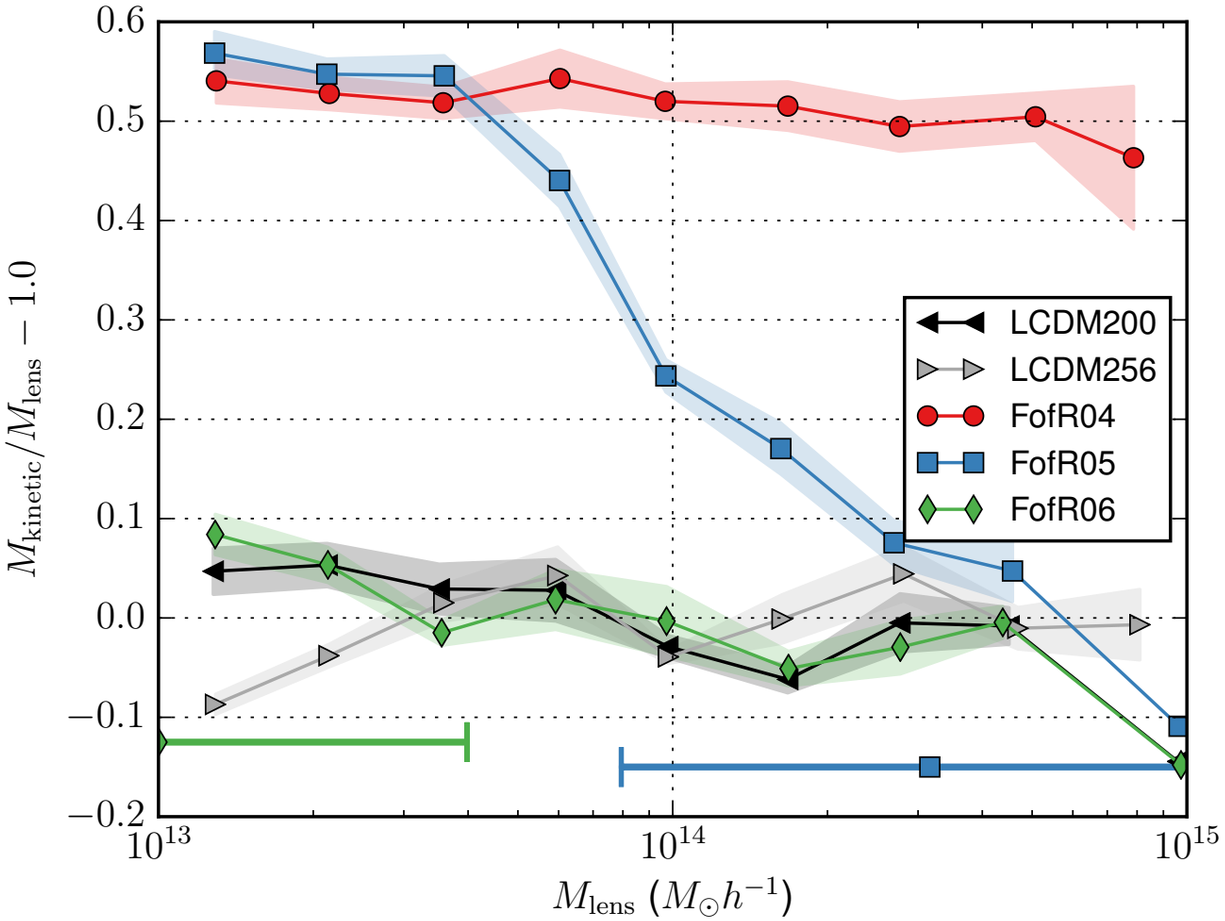
$$GR: \quad \Delta_M = 0$$

$$F(R): \quad \Delta_M \in [0, \frac{1}{3}]$$

$$Chameleon/Symmetron: \quad \Delta_M \in [0, 2\beta^2]$$

Smoking gun for Screening Mechanisms

Lensing Mass vs. Kinematic Mass



fofr4~24 Mpc

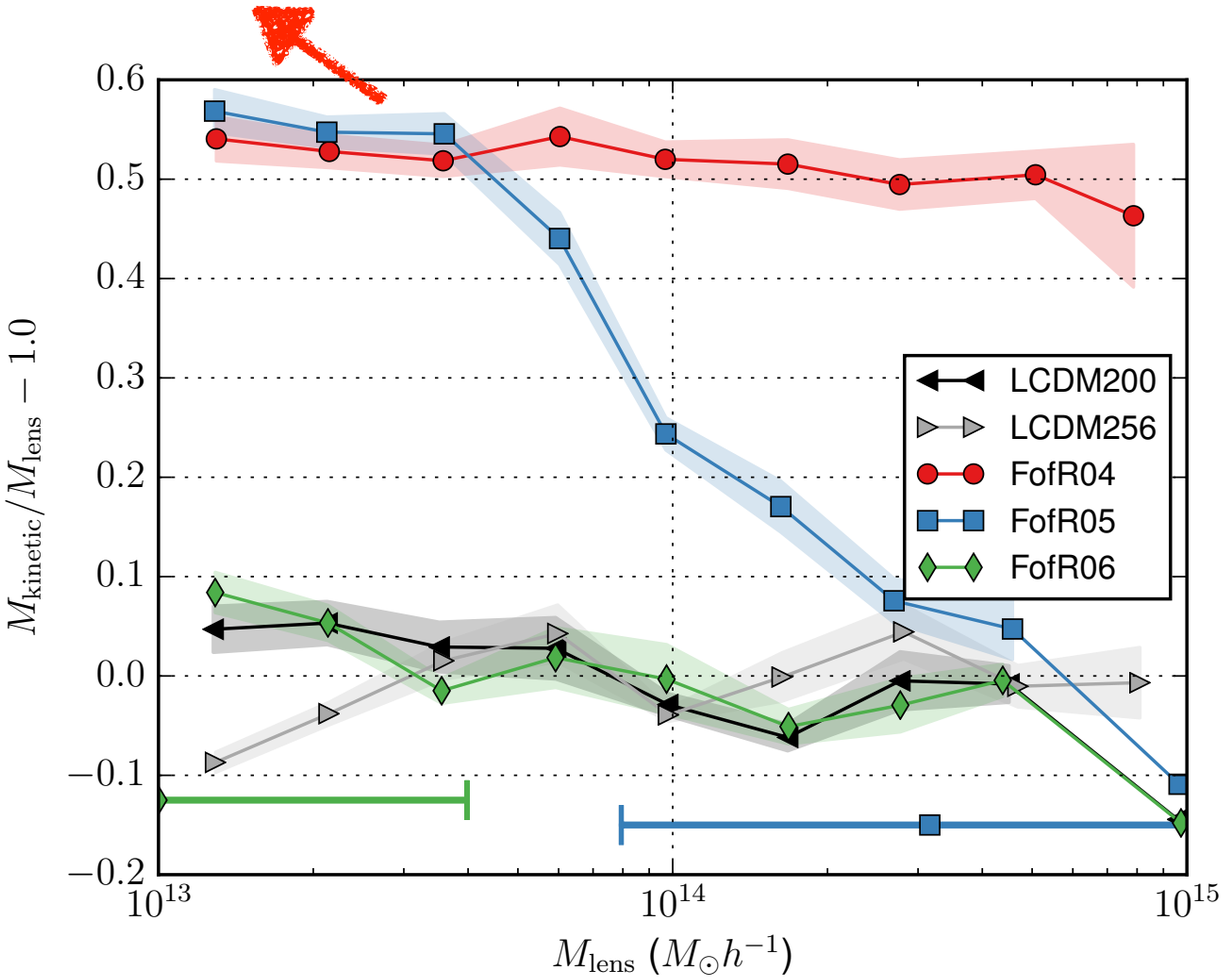
fofr5~7 Mpc

fofr6~2 Mpc

Smoking gun for Screening Mechanisms

Lensing Mass vs. Kinematic Mass

Unscreened Modified Gravity



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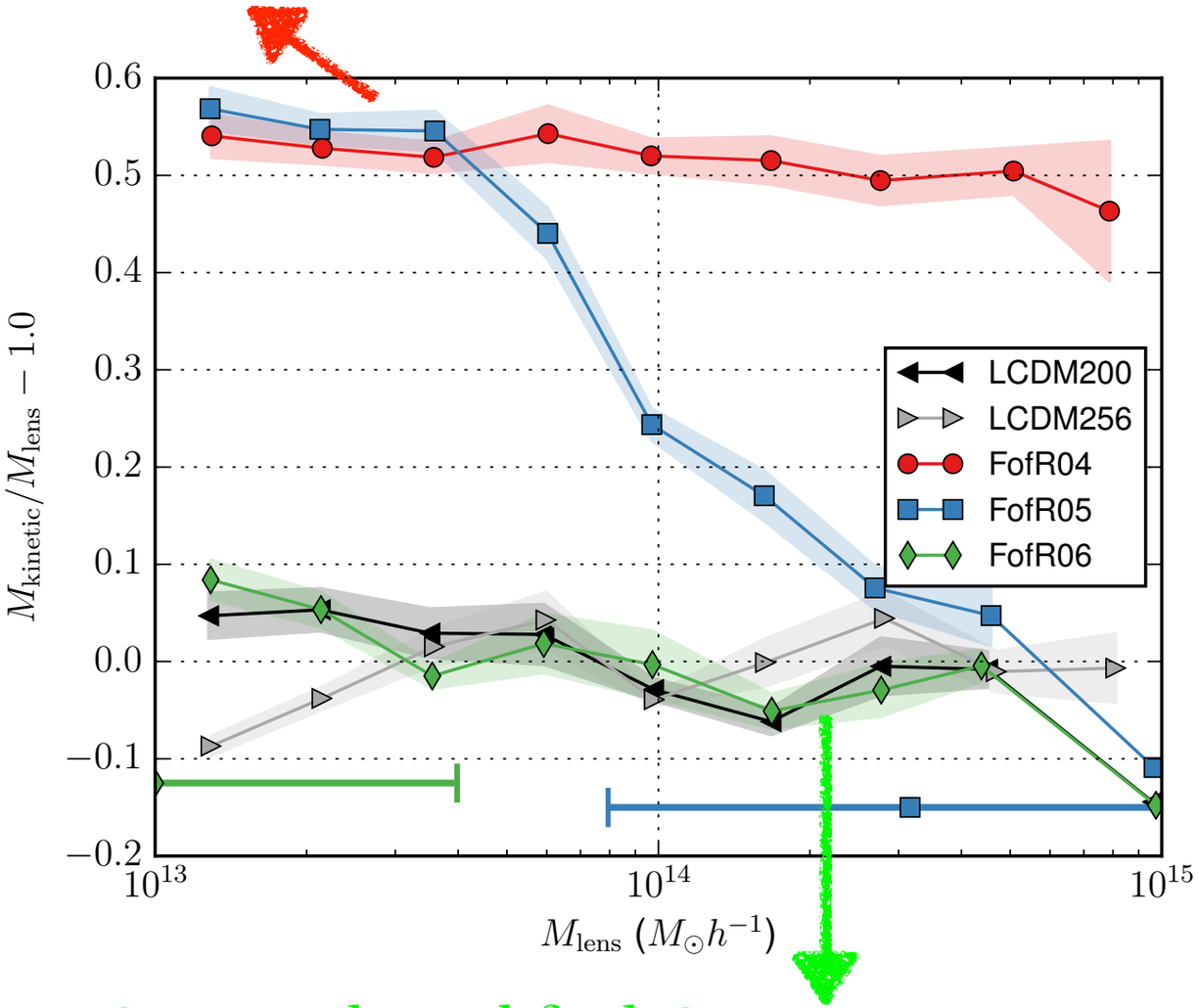

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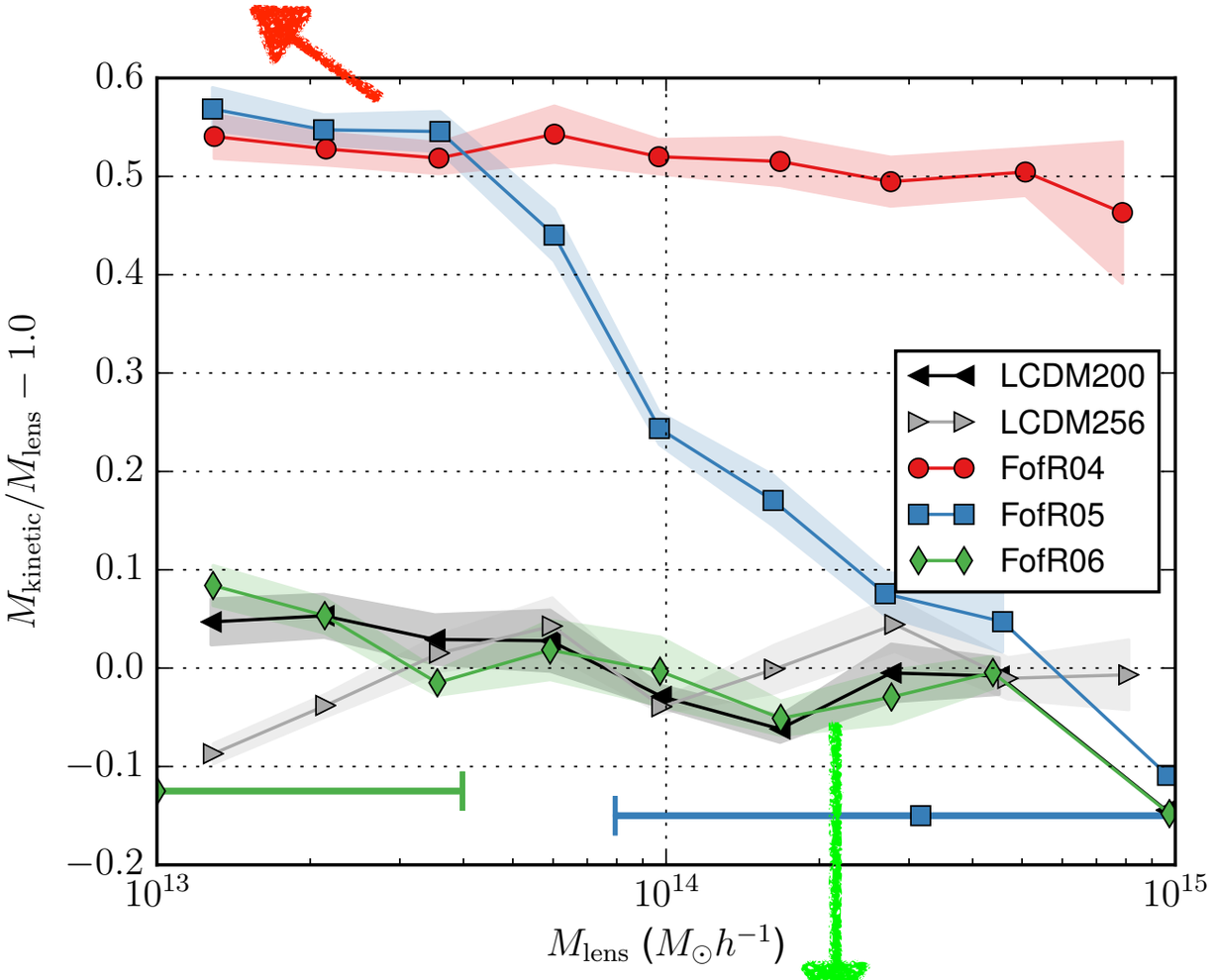

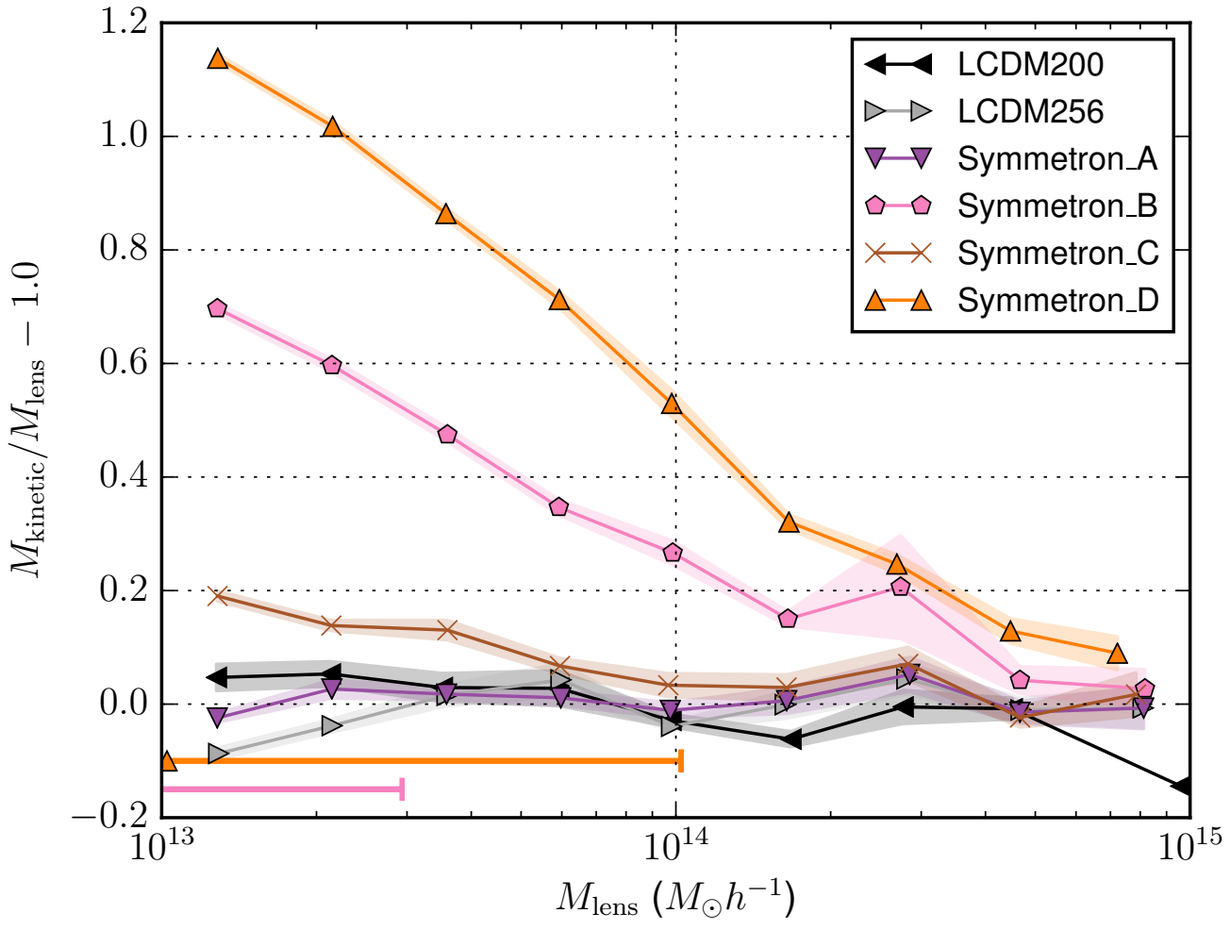

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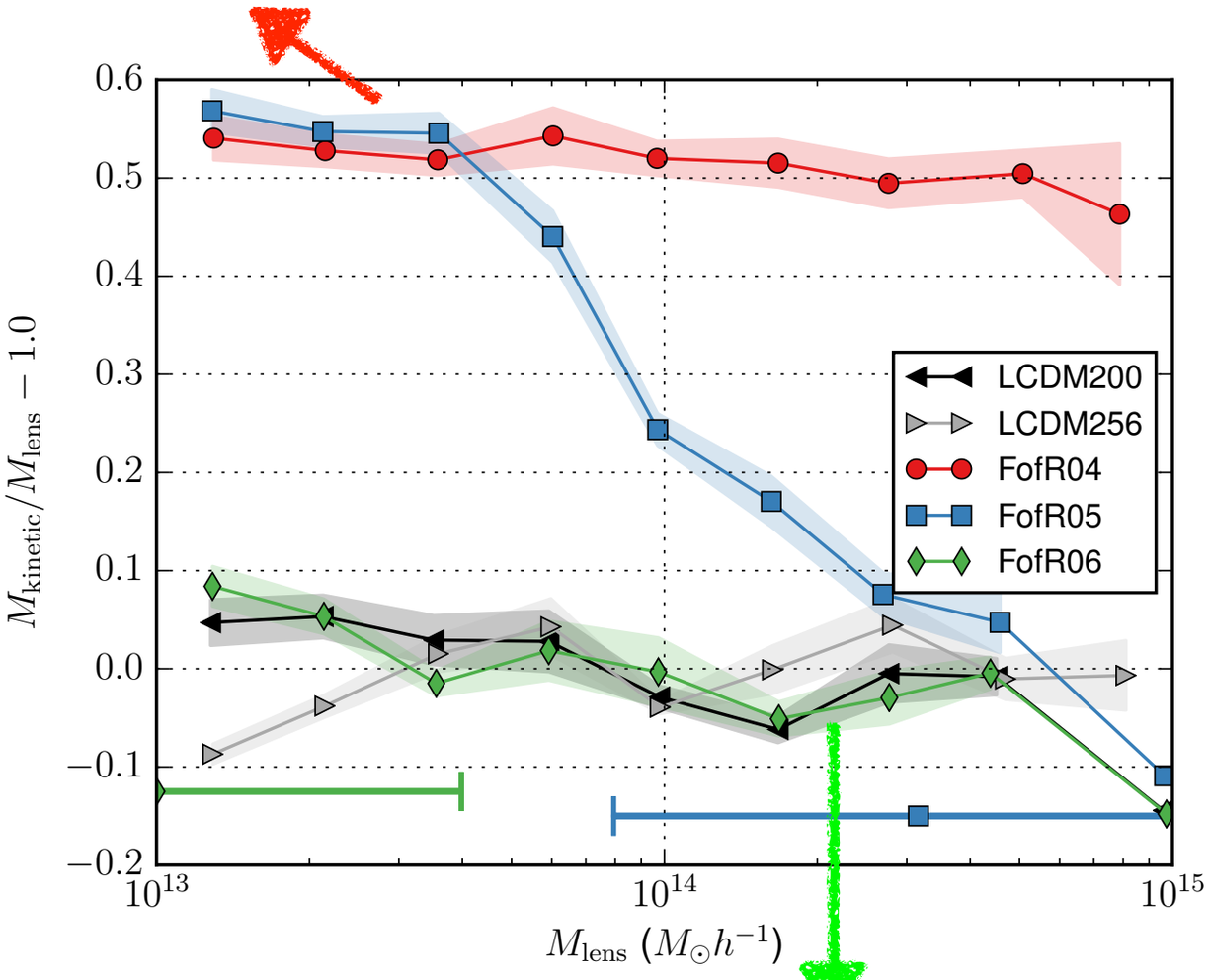
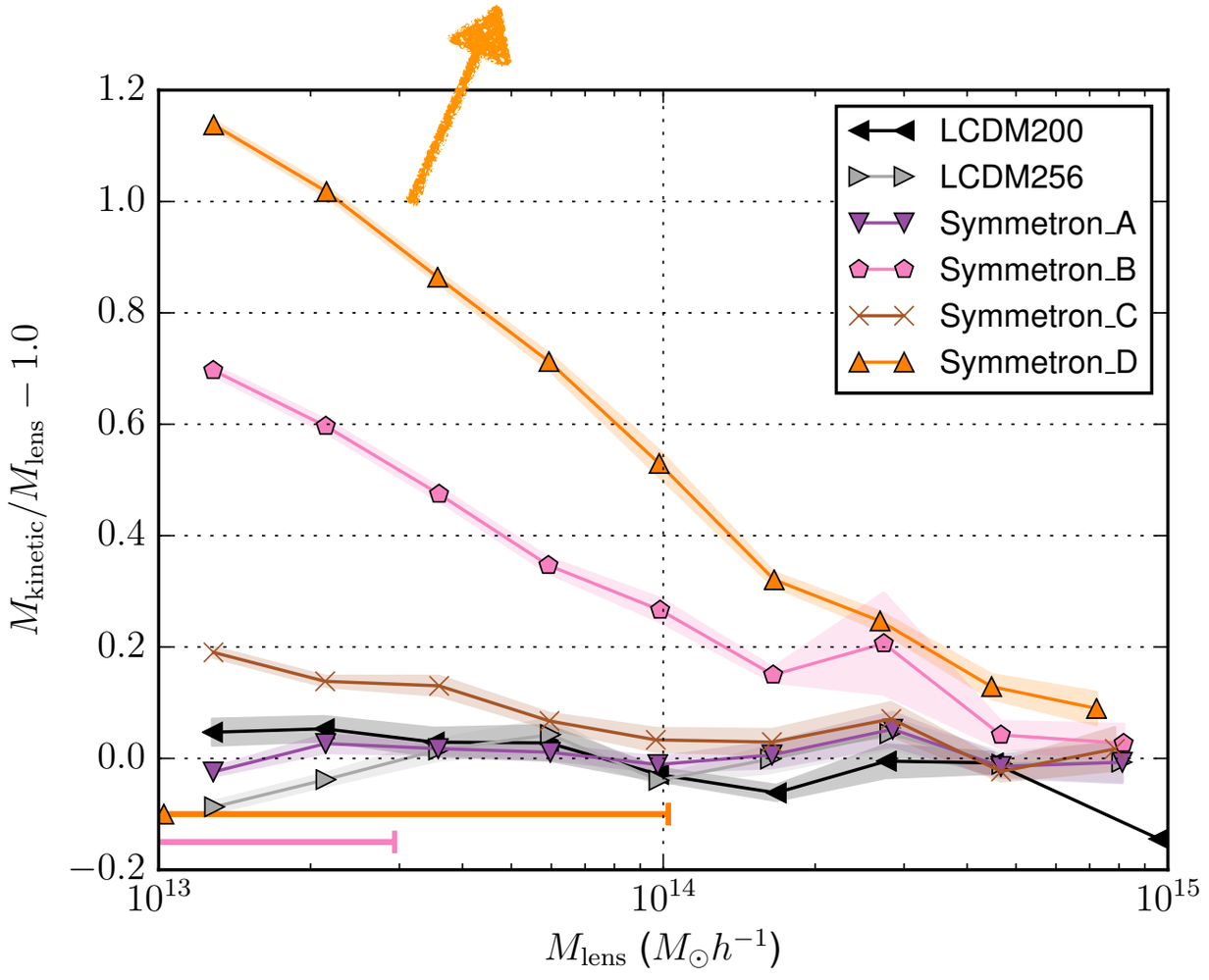


Screened Modified Gravity

Large coupling/small scale screening



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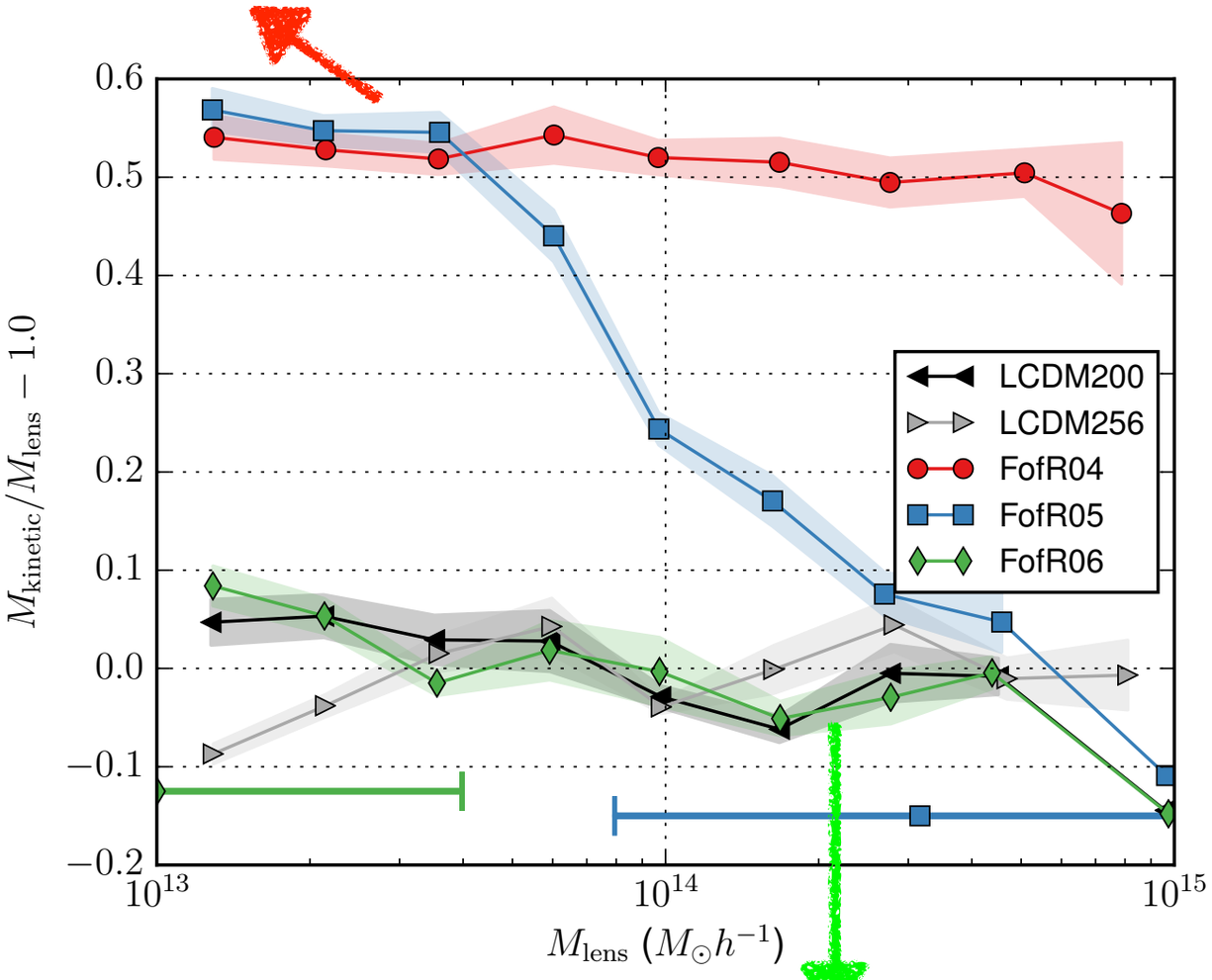

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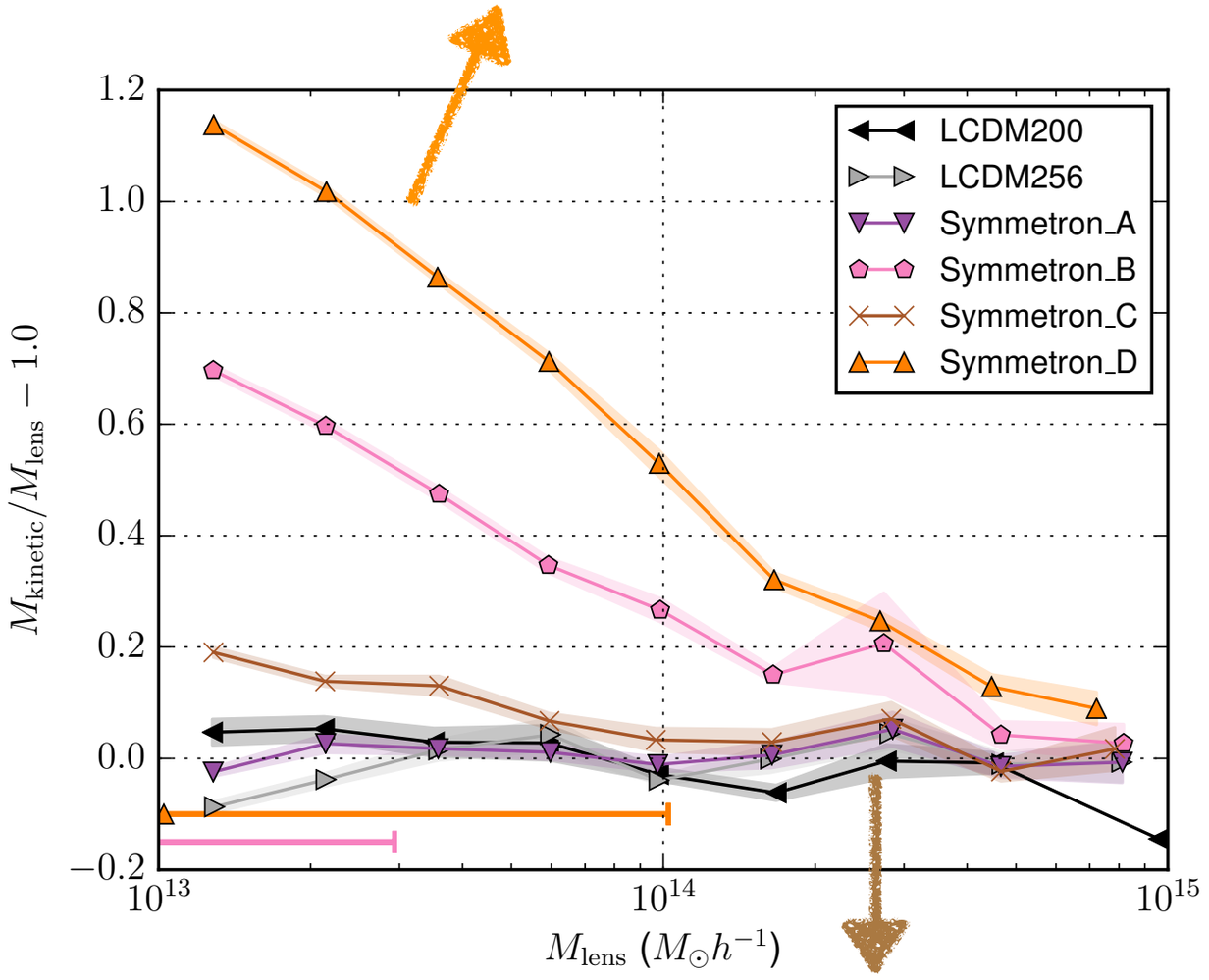

small coupling/large scale screening

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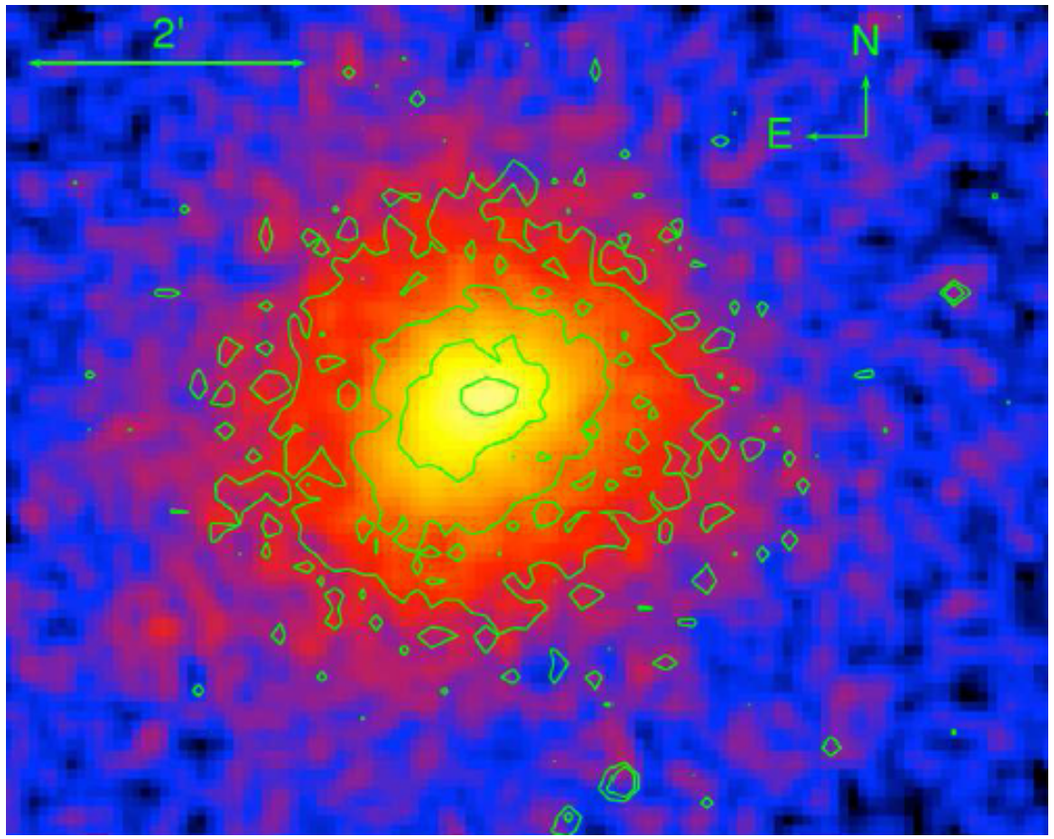
Thermal Mass: from x-ray measurements of temperature and density profiles of baryons

Umetsu et al., ApJ 755, 56 (2012)



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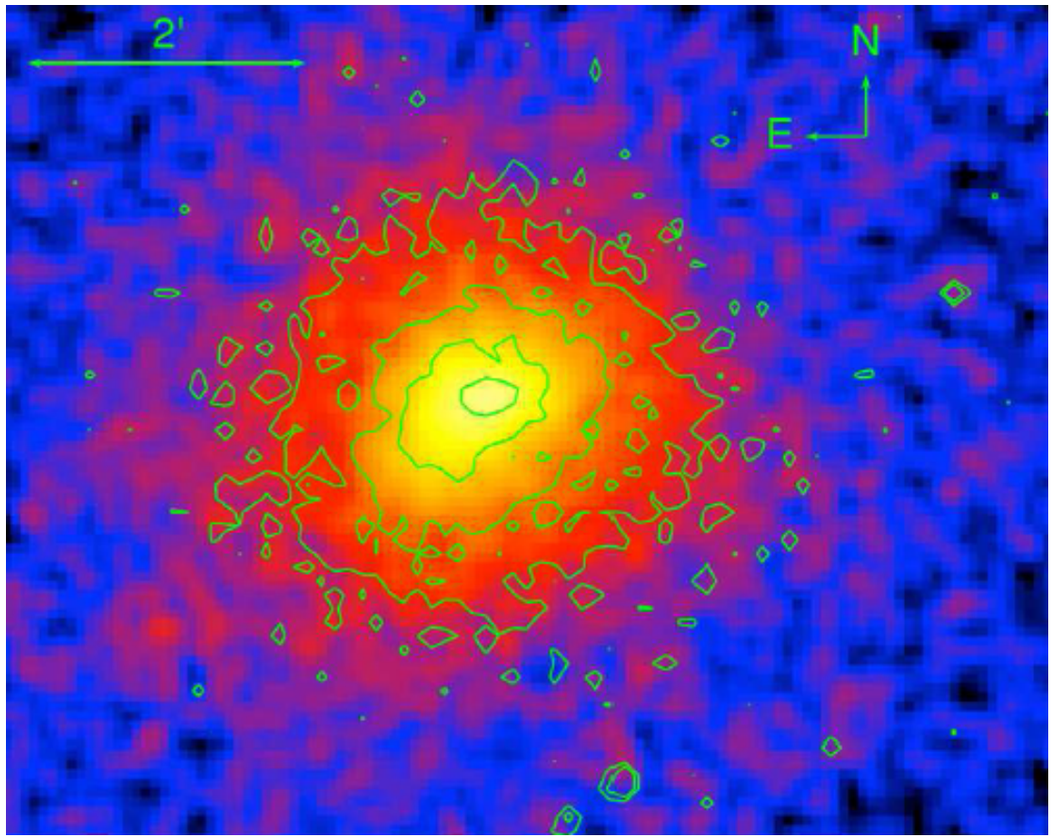

Mass holds hydrostatic equilibrium: $\frac{dP}{dr} = -\frac{GM(r)\rho(r)}{r^2}$

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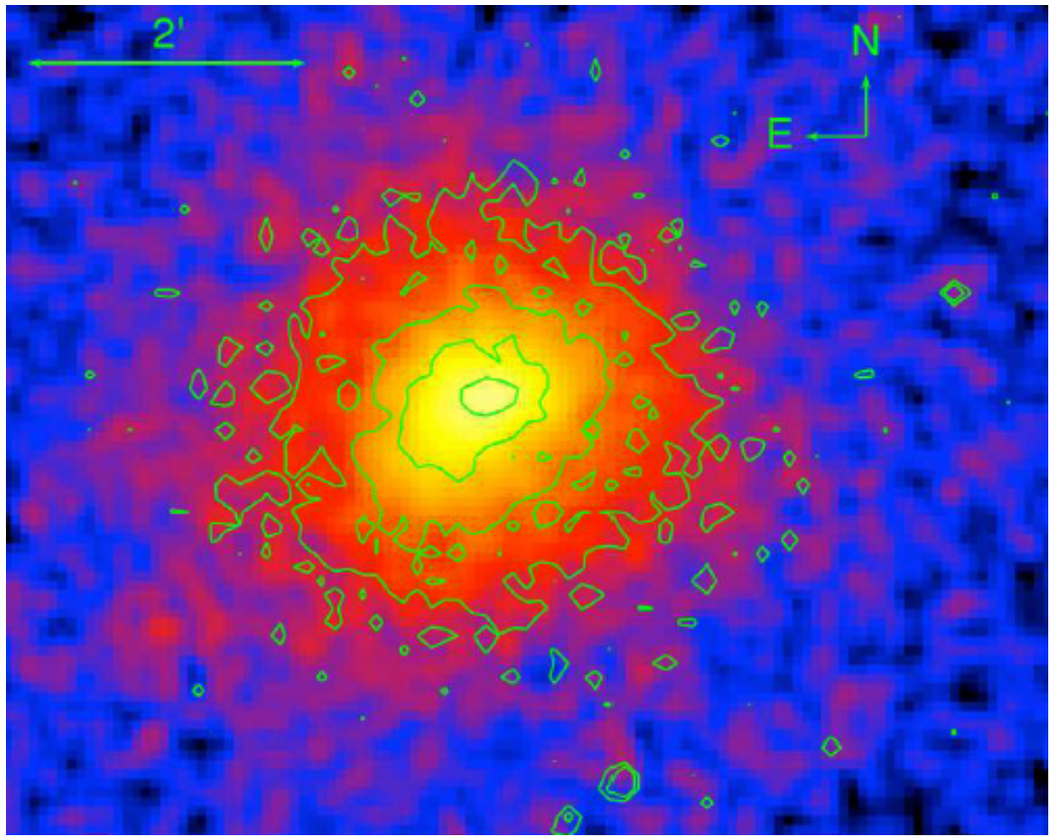

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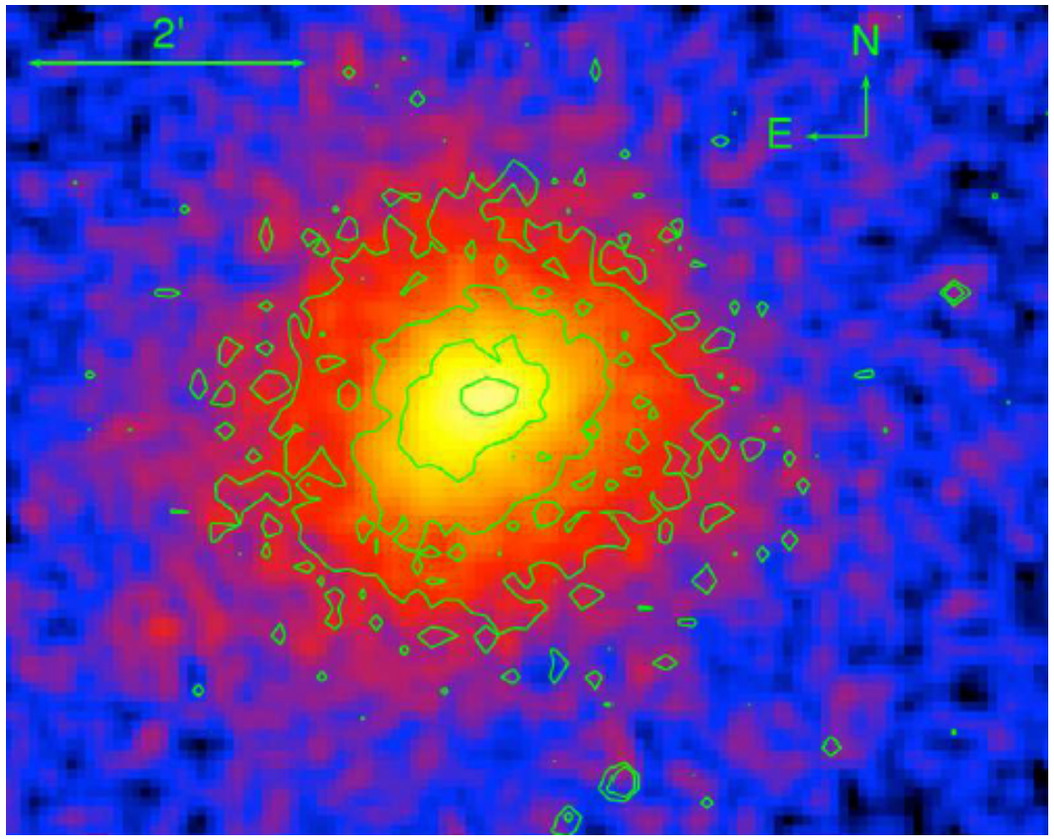

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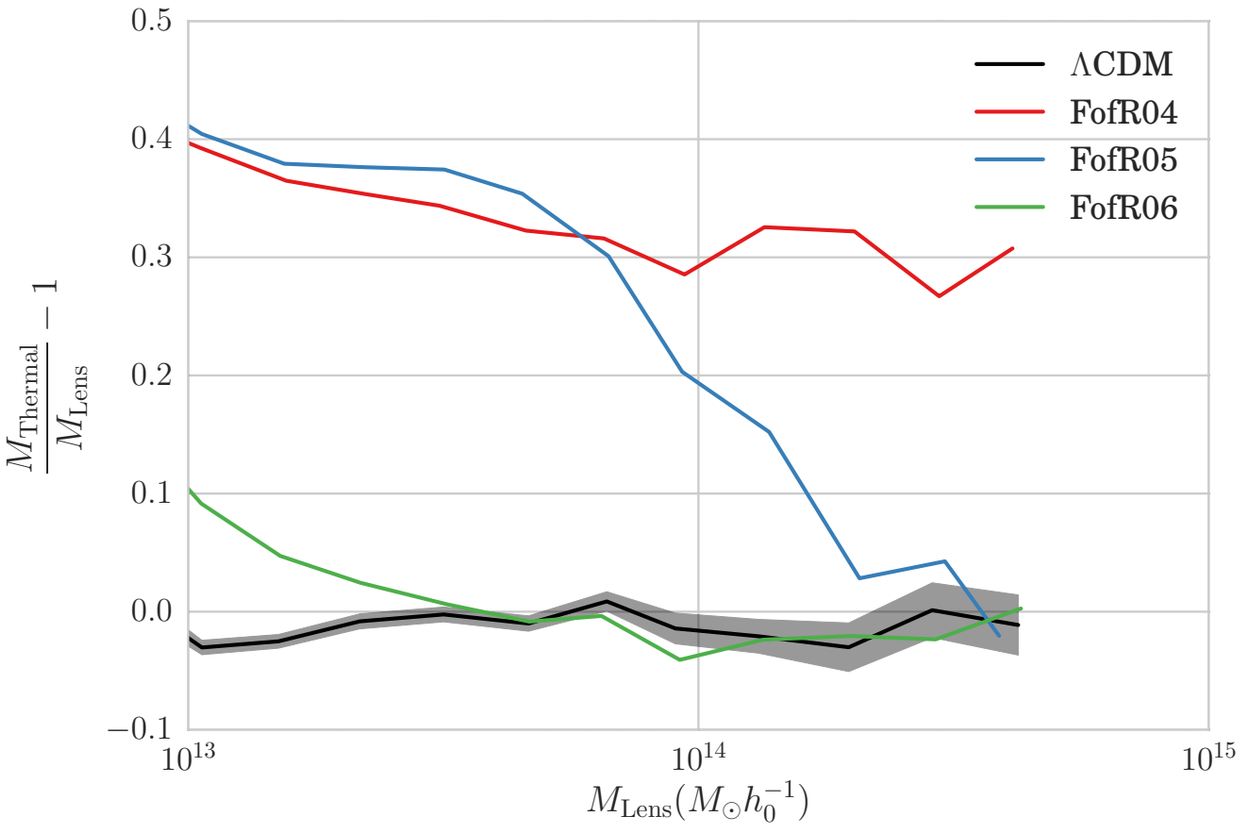
Thermal mass in Modified Gravity depends on the fifth force (which is environmental dependent!)

Smoking gun for Screening Mechanisms

Lensing Mass vs. Environmental dependent Thermal Mass



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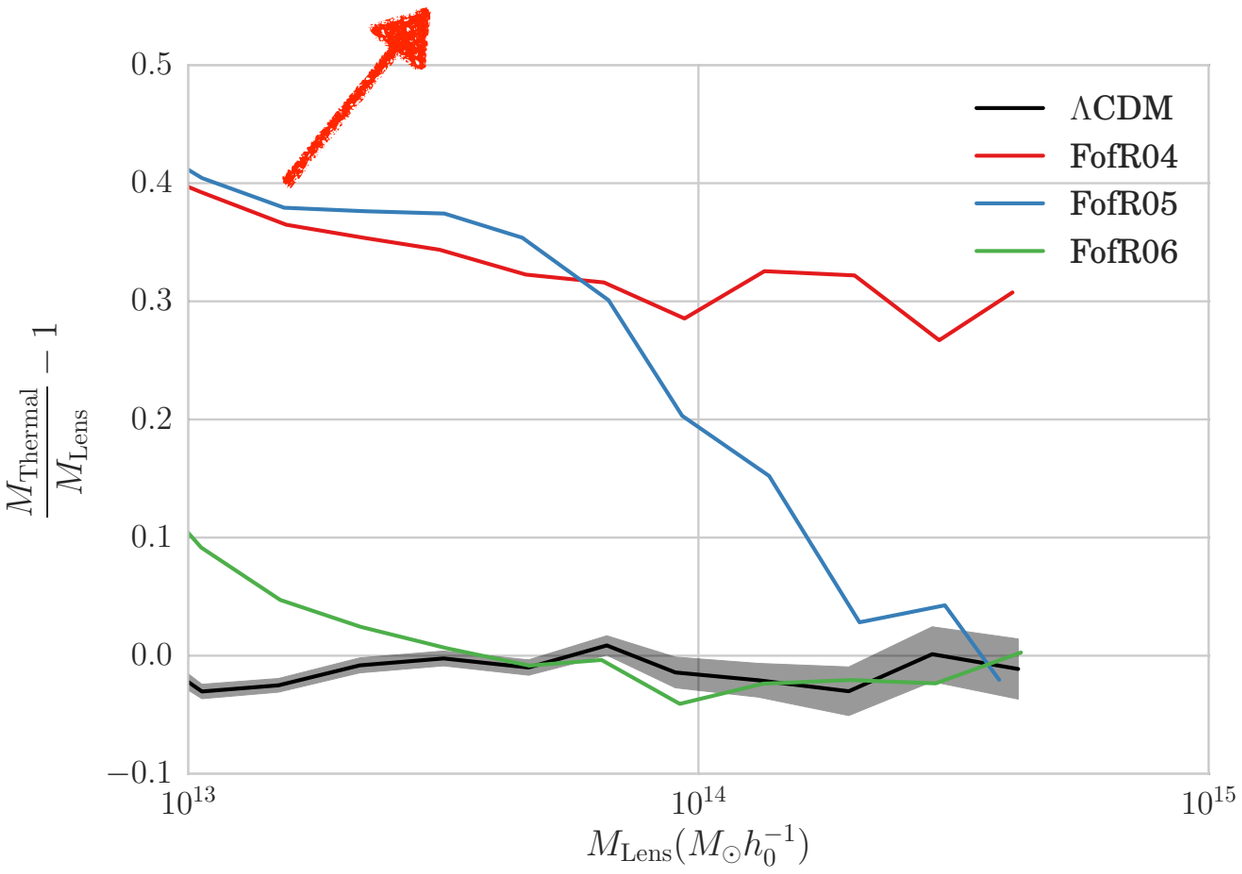

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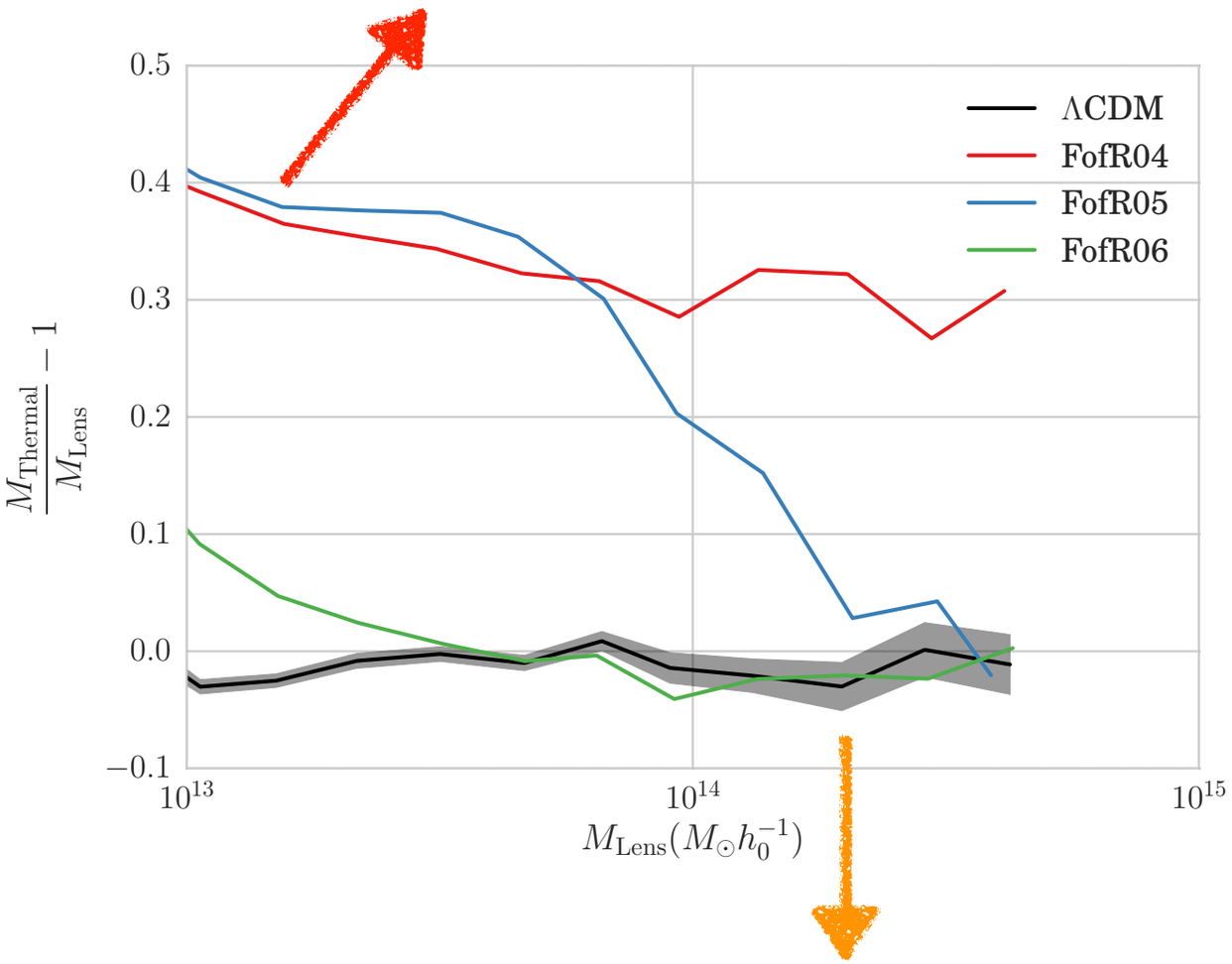
Lensing Mass vs. Environmental dependent Thermal Mass

Unscreened Modified Gravity



Screened Modified Gravity

fofr4~24 Mpc

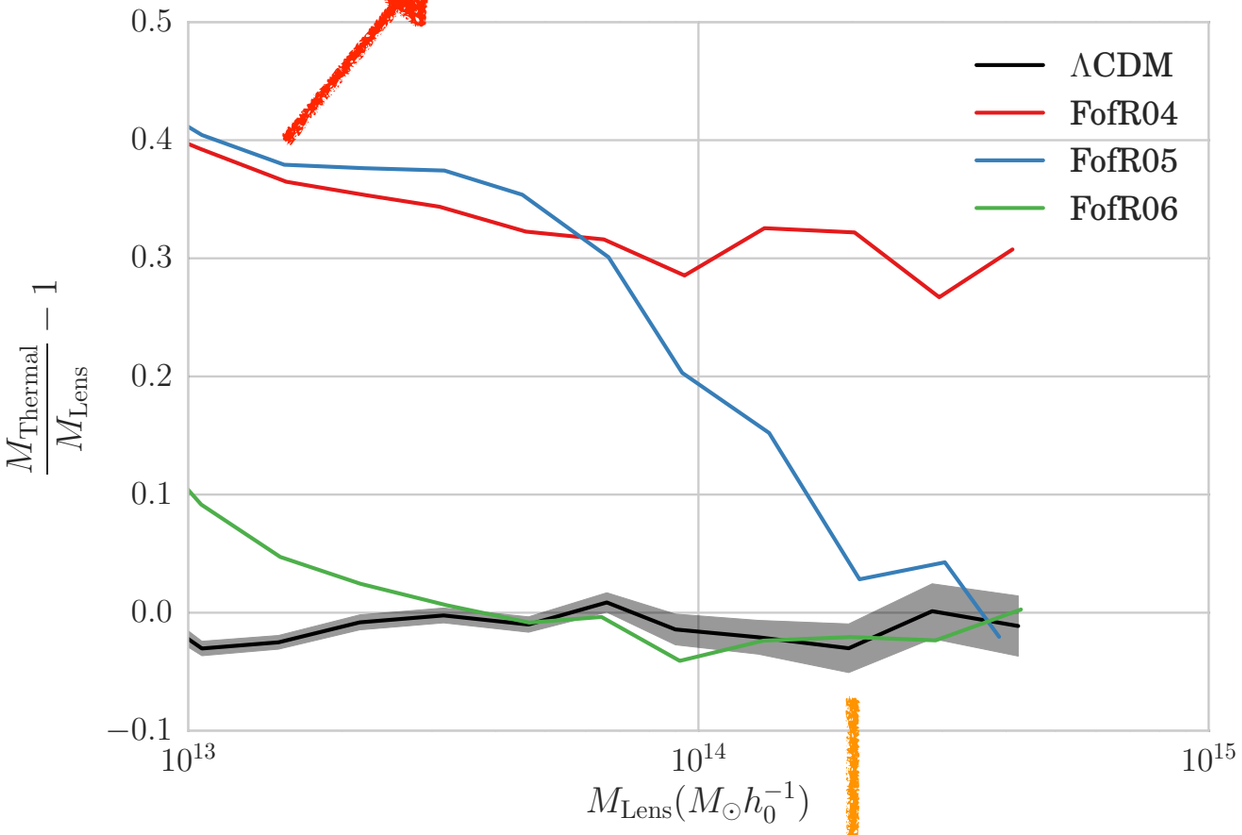
fofr5~7 Mpc

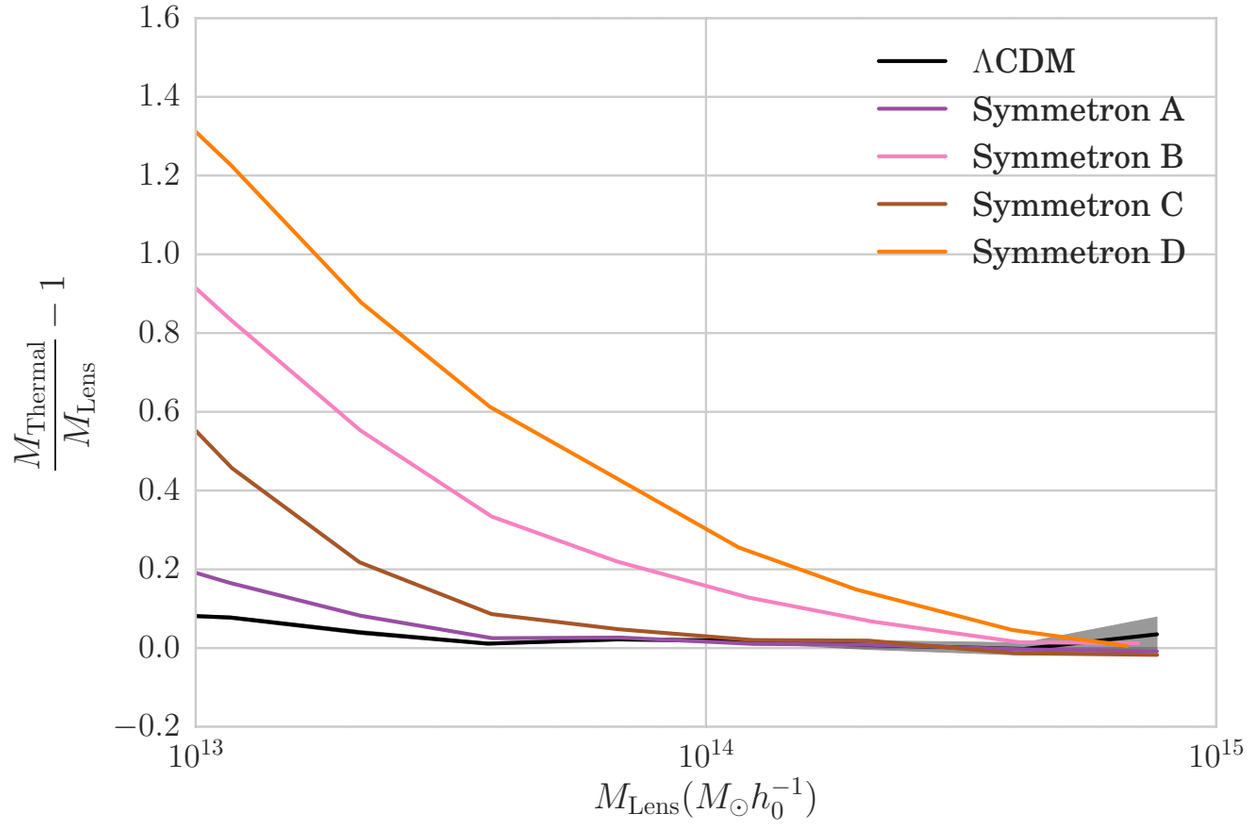
fofr6~2 Mpc

Smoking gun for Screening Mechanisms

Lensing Mass vs. Environmental dependent Thermal Mass

Unscreened Modified Gravity





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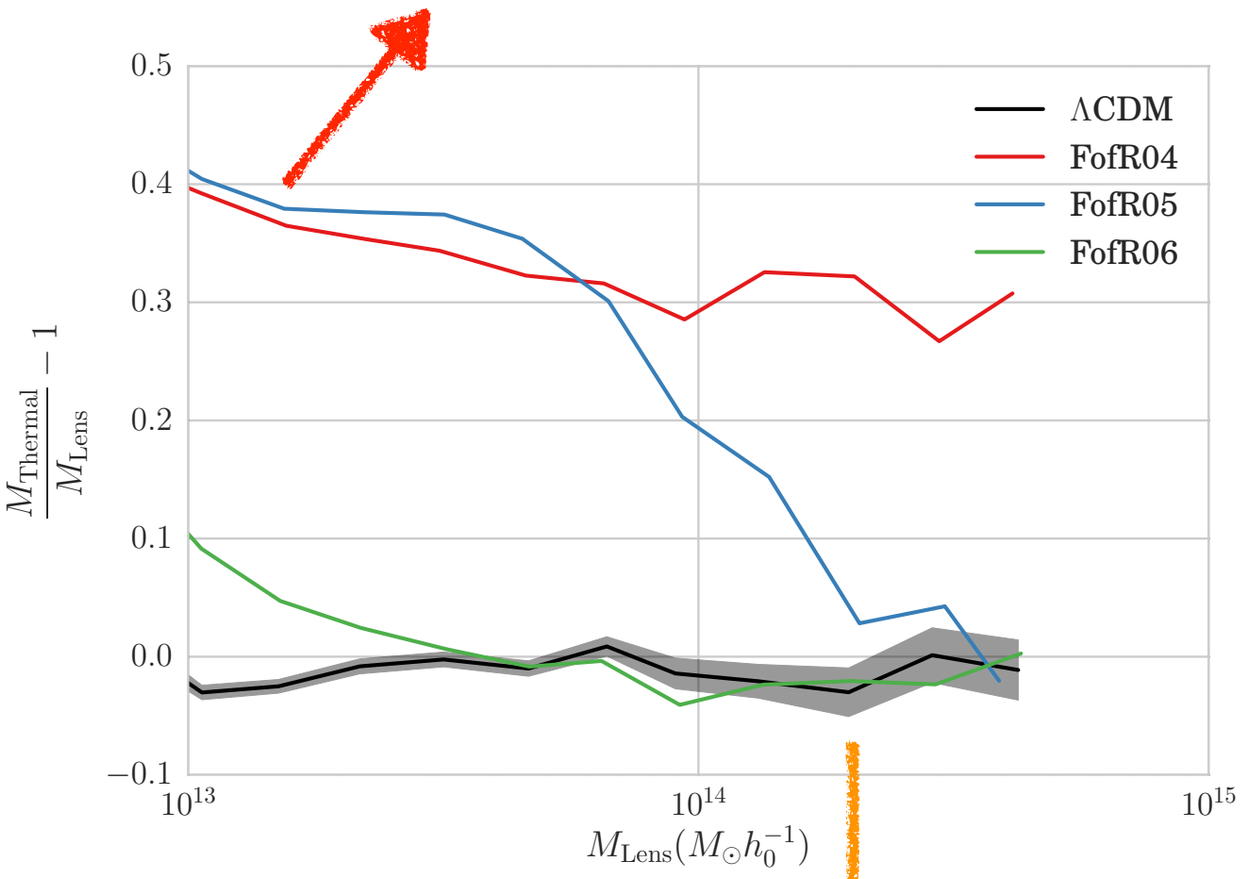
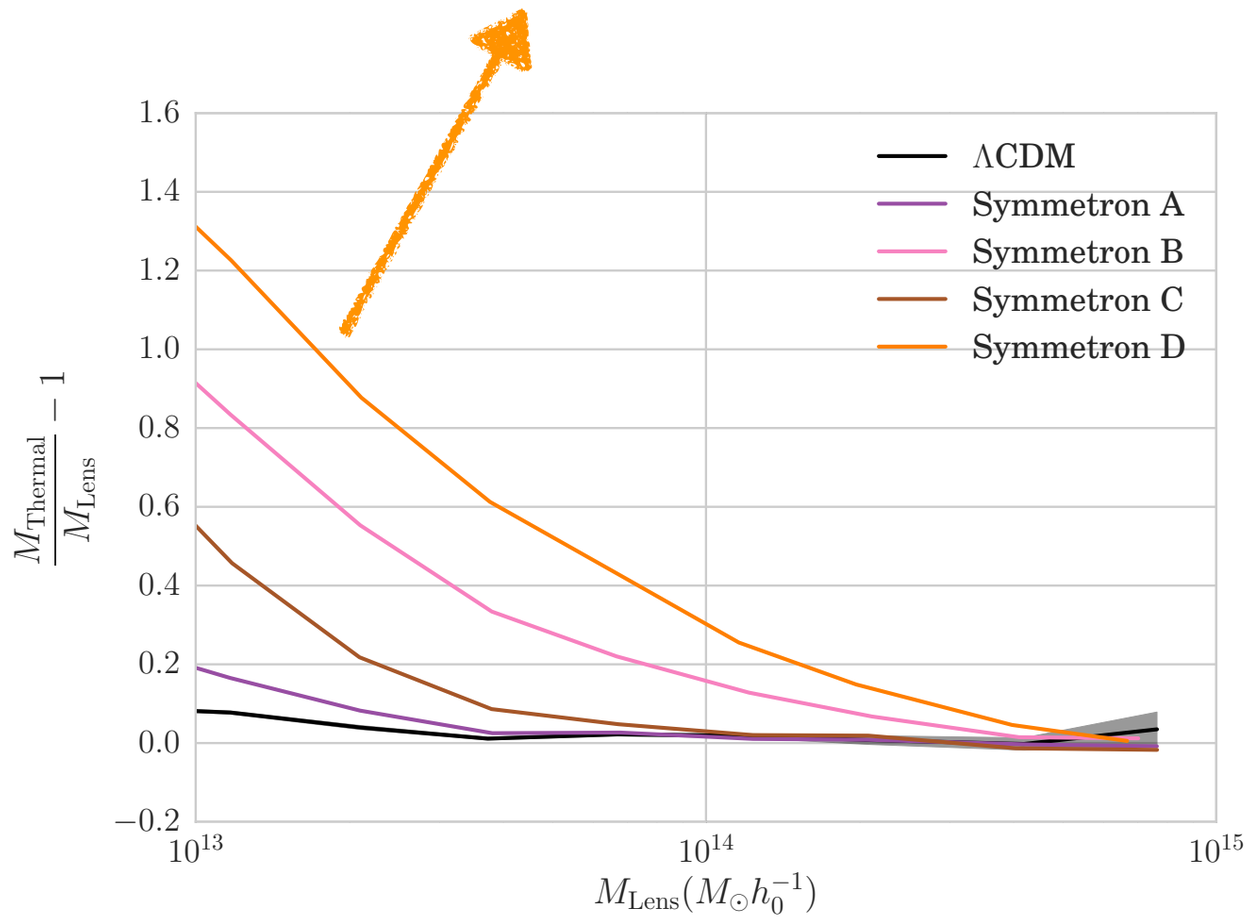


Large coupling/small scale screening



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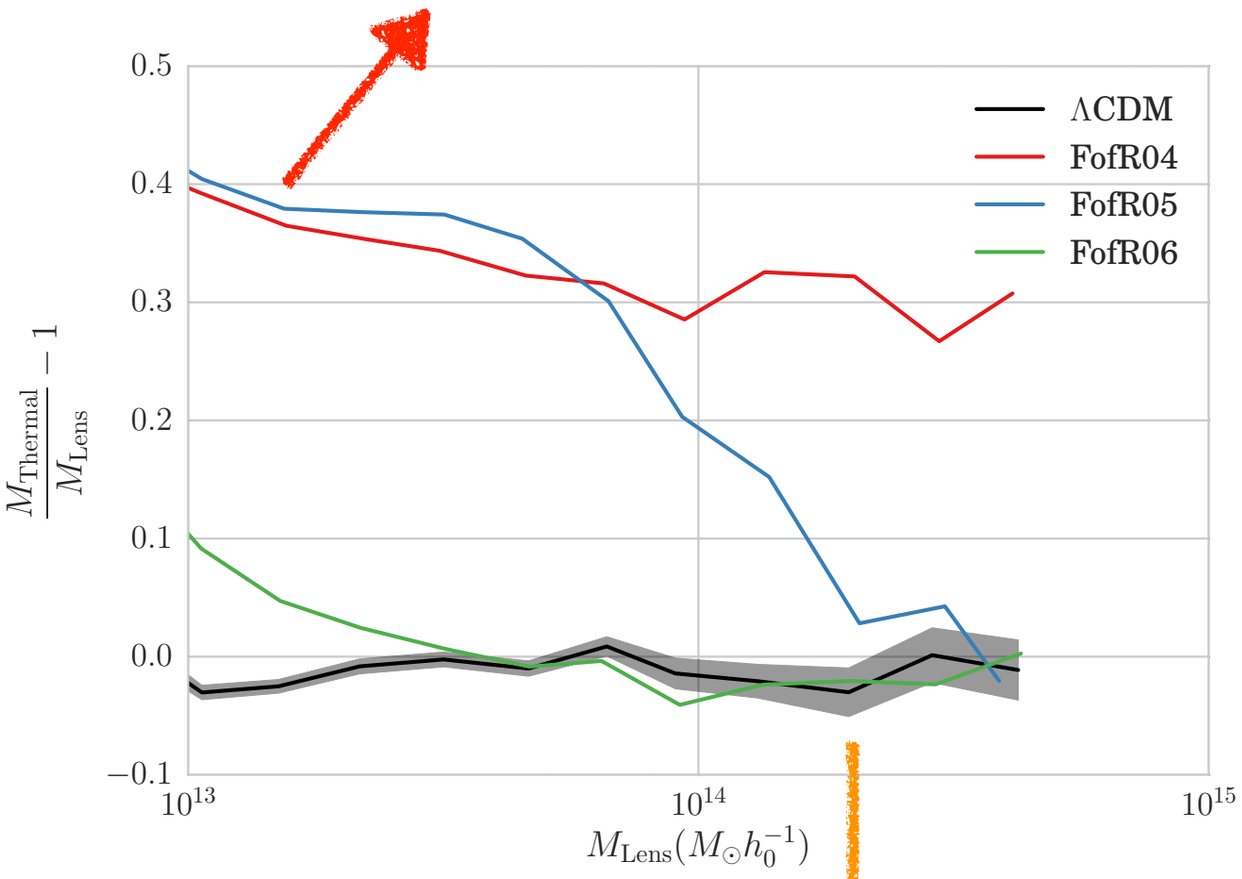
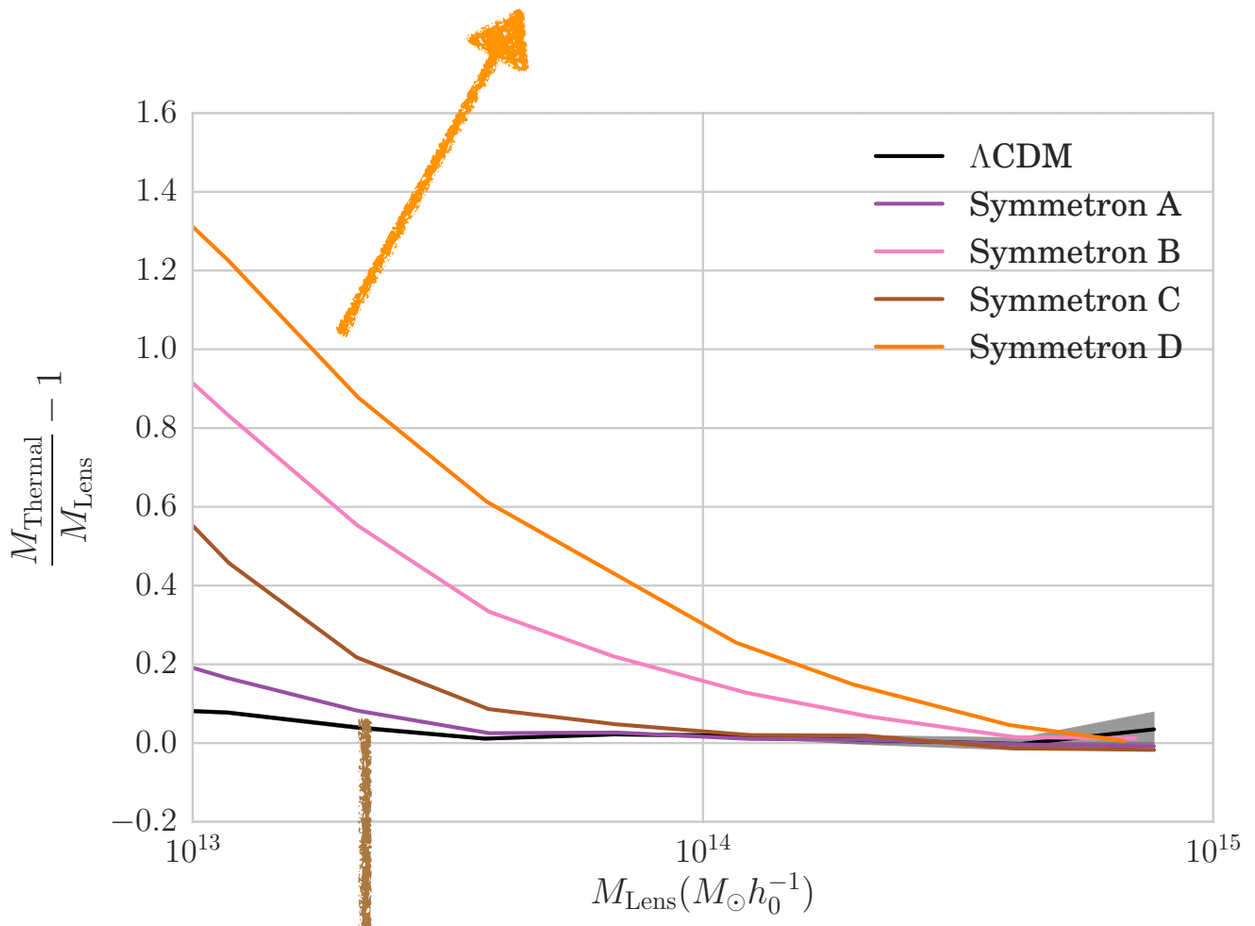


Screened Modified Gravity

Large coupling/small scale screening



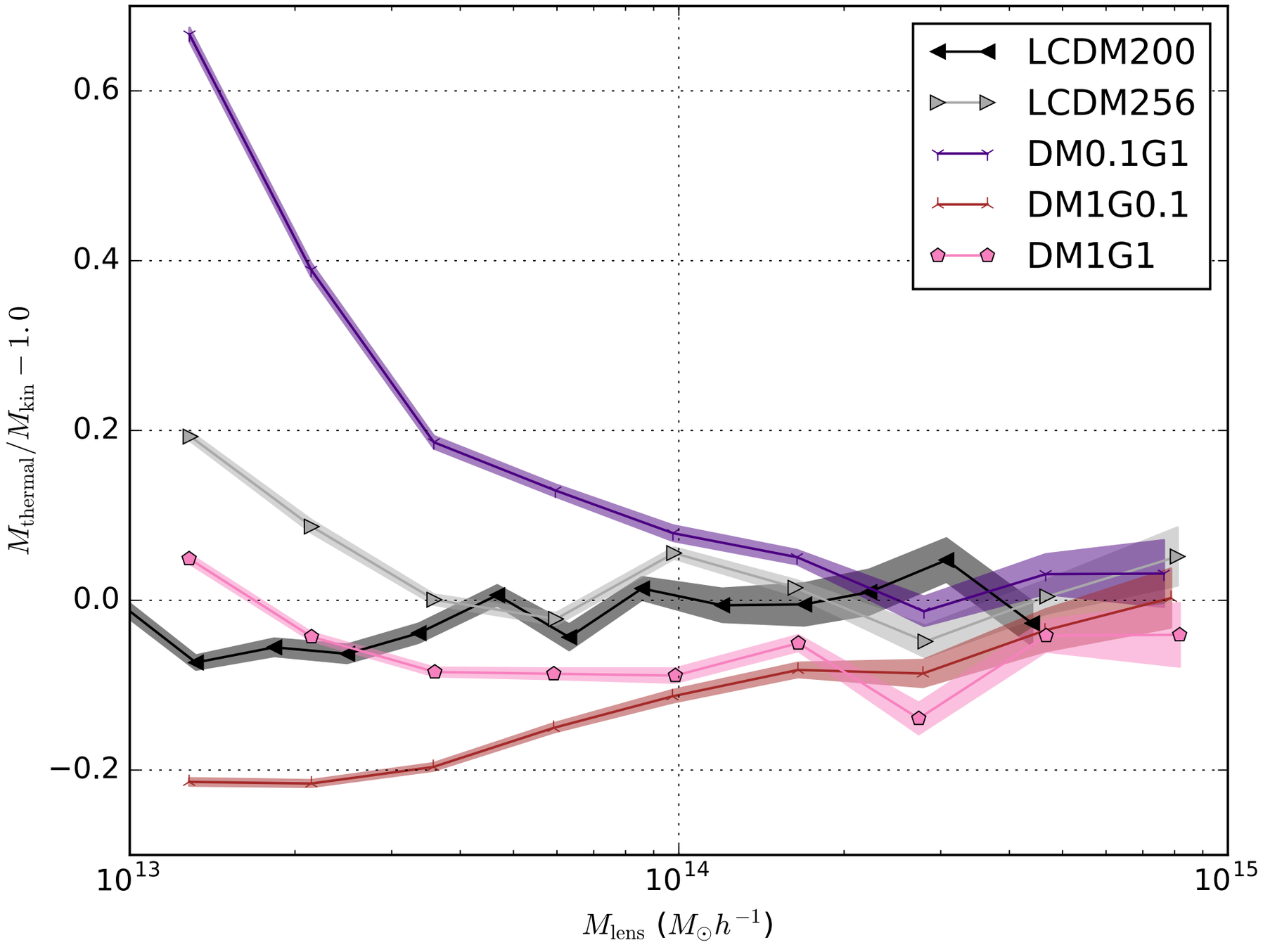
small coupling/large scale screening

fofr4~24 Mpc

fofr5~7 Mpc

fofr6~2 Mpc

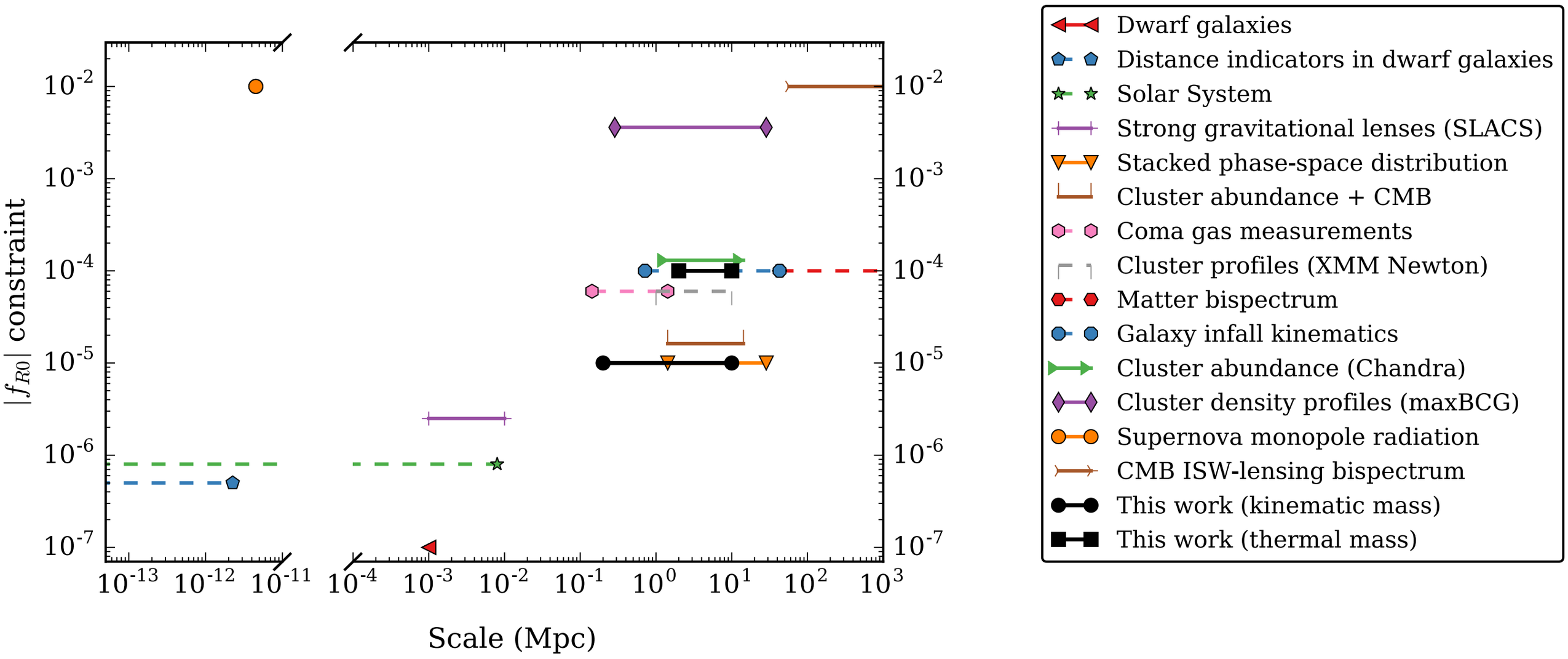
Thermal + Lense + Kinematic Mass
Probe non-universal couplings



Kinematic Mass probes couplings to dark matter

Thermal Mass probes couplings to baryons

Observational Constraints



Summary

- Measuring the mass of galaxy clusters can probe equivalence principle violations
  - In modified gravity the mass inferred via lensing differs from the mass inferred via kinematical methods and thermal methods
    - The differences between the observed masses are environmental dependent

- Non-universally coupled models can be differentiated by combining lensing, kinematic and thermal mass
  - Lensing mass probes gravity
  - Kinematic mass probes coupling to dark matter
  - Thermal mass probes coupling to baryons