

# **Dark Matter From Modifications of General Relativity**

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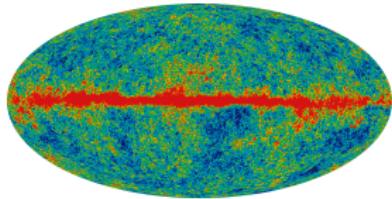
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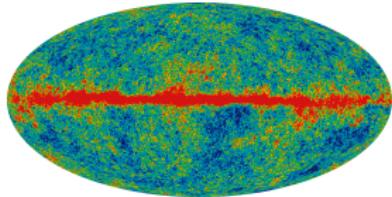
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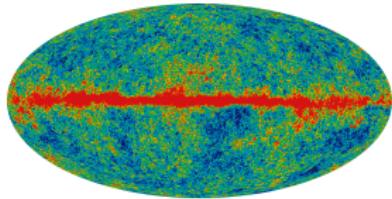
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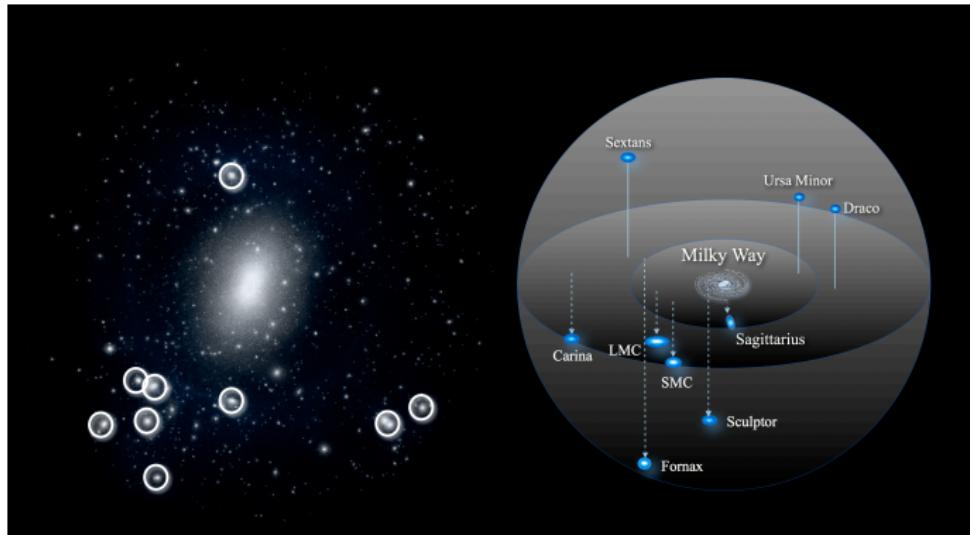
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Bullet cluster observations.

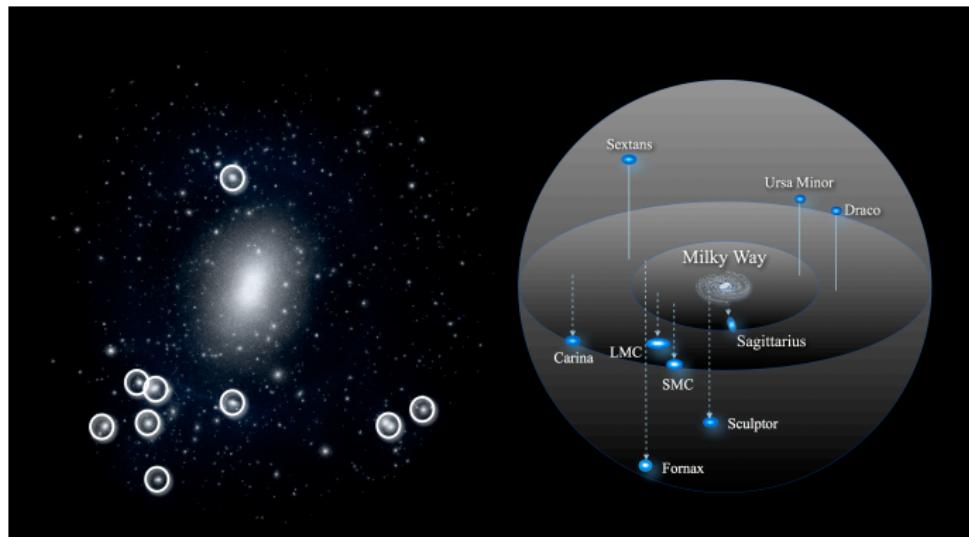
# Small scale crisis: Missing satellites

CDM overproduces dwarf galaxies    [Klypin et al.'99](#)    [Moore et al.'99](#)



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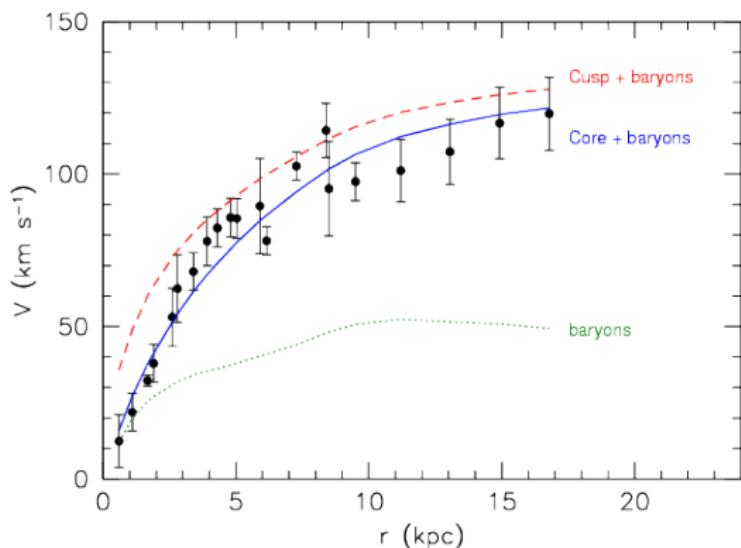
Star formation could be suppressed.    [Sawala et al.'14](#)    [Weinberg et al.'13](#)

# Small scale crisis: Cusp Vs. core

$$\text{CDM} \implies \rho_{DM} \propto 1/r^{1-1.5} \quad \text{NFW'96.}$$

Observations  $\implies \rho_{DM} \sim \text{const.}$

Supernovae feedback? [Governato et al.'12](#).

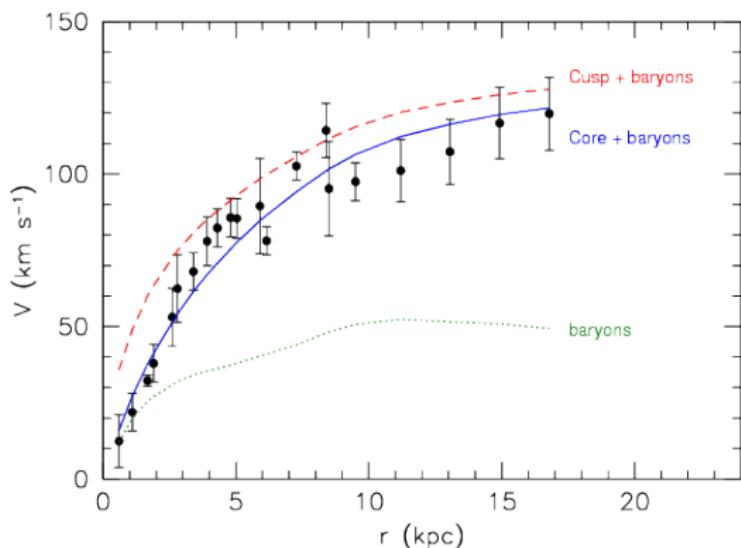


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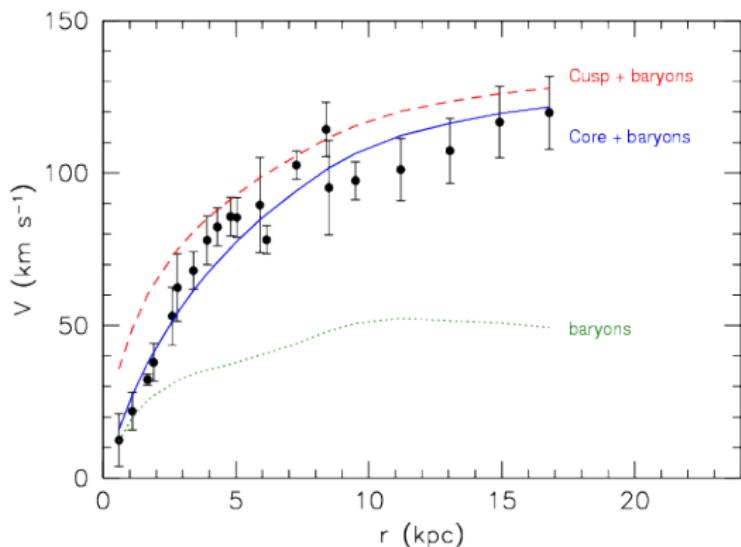
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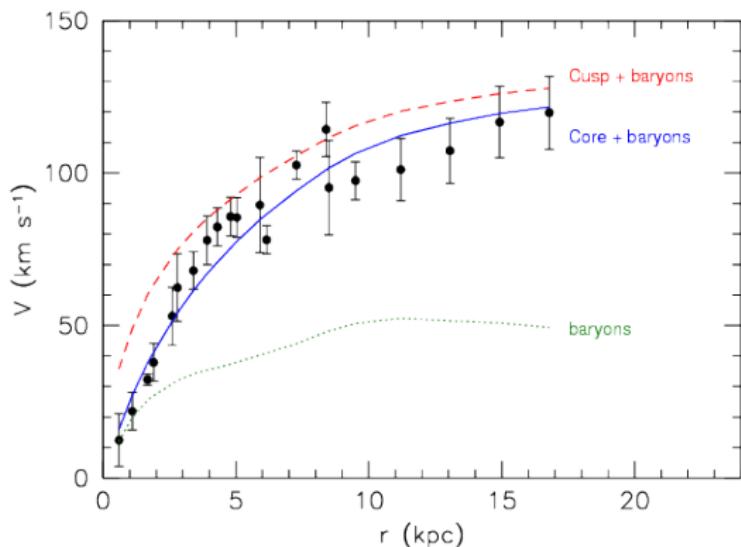
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Self-Interacting DM

$$\frac{\sigma_{DM}}{m} < 0.47 \frac{cm^2}{g} \quad 95\% \text{ C.L.}$$

[Harvey et al.'15](#)

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Fictitious  $\tilde{T}_{\mu\nu} = (G - T) \partial_\mu \varphi \partial_\nu \varphi$        $T_{\mu\nu} = (\rho + \mathcal{P}) u_\mu u_\nu - g_{\mu\nu} \mathcal{P}$

$$G - T \equiv \rho_{DM}$$

$$\mathcal{P}_{DM} = 0$$

Dark matter?

- $\mathcal{P} = 0 \implies \rho \propto -\partial v \rightarrow \infty$  at finite time.

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- How to set initial conditions?  $\rho = \frac{C}{a^3} \rightarrow 0$  during inflation.

Analogue of 'reheating+freeze-out mechanism'?

# Higher derivative extension

$$+ \frac{\gamma(\varphi)}{2} (\square\varphi)^2$$

HD terms: Chamseddine, Mukhanov, Vikman'14  
F. Capela, S. R.'14 / L. Mirzagholi and A. Vikman'14

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Non-zero sound speed  $c_s^2 \sim \gamma \implies$  promising for caustic problem

and small scale crisis.

Possibility to set natural initial conditions.

## Background level

$$\mathcal{P}_{DM} = \frac{3}{2}\gamma\mathcal{P}_{tot} : \quad \mathcal{P}_{DM} = \mathcal{P}_{tot} \implies \mathcal{P}_{DM} = 0$$

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Mimetic matter behaves as CDM independently of  $\gamma$ !

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$\gamma$ -terms lead to non-zero sound speed      Chamseddine et al.'14

$$c_s^2 \approx \frac{\gamma}{2} \quad \delta \mathcal{P}_{DM} = c_s^2 \delta \rho_{DM}$$

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Beyond sound horizon, perturbations grow as in CDM:  $\frac{\delta \rho_{DM}}{\rho_{DM}} \propto a(t)$ .

After crossing sound horizon, their growth stops:  $\frac{\delta \rho_{DM}}{\rho_{DM}} \propto e^{ic_s k}$ .

Picture is promising in a sense of missing satellites problem.

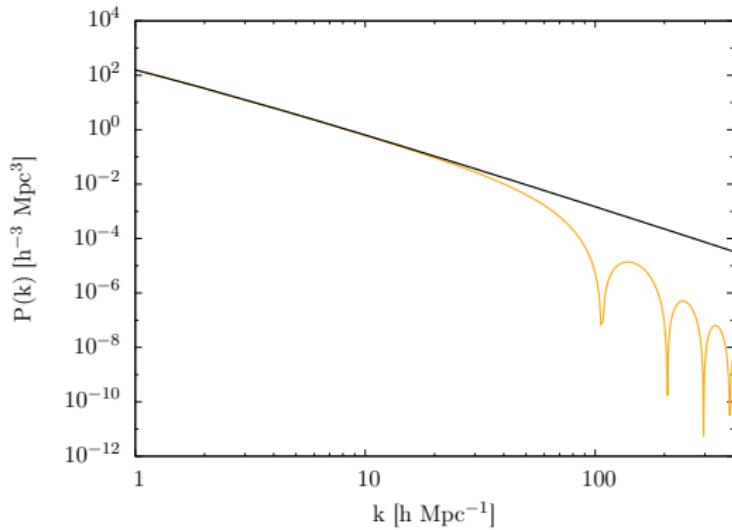


Figure: Linear power spectrum of DM perturbations,  $z = 3$ ,  $\gamma \sim 10^{-9}$

Novelty compared to WDM: oscillations at large momenta  $w \sim c_s k$ .

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$$\frac{d(\rho_{DM} \cdot a^3)}{dt} \propto \delta(t - t_*) \quad \rho_{DM}^0 = \frac{3}{2} \Delta\gamma z(t_*) \rho_{rad}^0$$

$$\Delta\gamma \lesssim \gamma \lesssim 10^{-9} \implies z(t_*) \gtrsim 10^{12-13}$$

Initial conditions for perturbations are adiabatic!

# Ghost instability?

after discussions with

S. Matarrese, L. Pilo, F. Arroja, M. Celoria, N. Bartolo, P. Karmakar

- Is there a way to handle a ghost?
- How to construct a ghost free fluid with large sound speed?
- Behaviour in the non-linear regime  $\Rightarrow$  stable DM haloes, flat Galaxy rotation curves etc.

GRAZZIE!