

Why modify gravity?

Explain

Tier I problems:

- Extra gravity in galaxies & clusters
 - Today
 - In growth of baryonic structure post-recombination
- Accelerating expansion

Why modify gravity?

Explain:

Tier I problems: (1) extra gravity; (2) acceleration

Tier II problems/mysteries/coincidences:

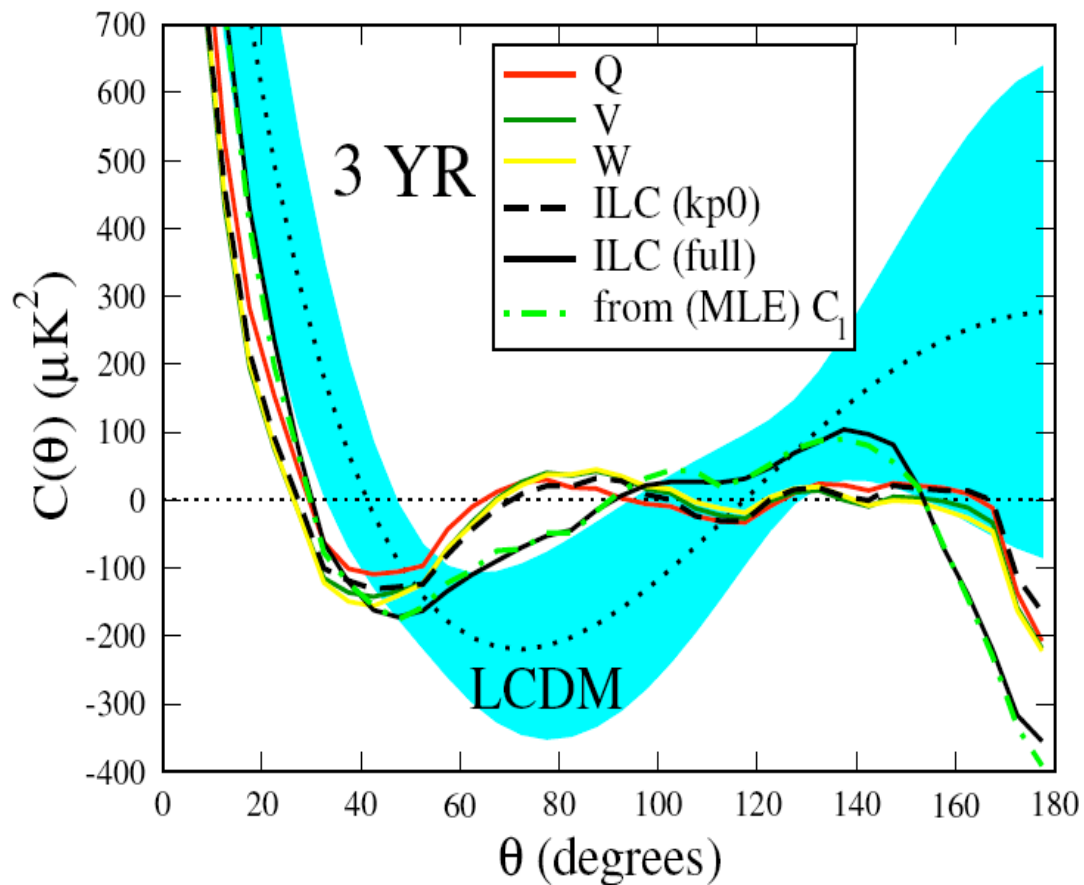
- Absence of large angle correlations in CMB ($C(\theta > \theta_c \approx 60^\circ) \approx 0$)
- Pioneer anomaly
- Coincidence of scales:

$$(v^2/r)_{\text{galaxies}} \approx H_0 c \approx (H_0 c) / \theta_c \approx \Delta a_{\text{Pioneer}}$$

Tier III vague musings:

- “inflationary” problems

Absence of large angle correlations



WMAP1:

$$S_{1/2} = \int_{-1}^{1/2} C(\theta)^2 d\cos\theta$$

C. Copi, D. Huterer,
D. Schwarz & G. Starkman

Dark matter
Dark energy
(Inflaton)

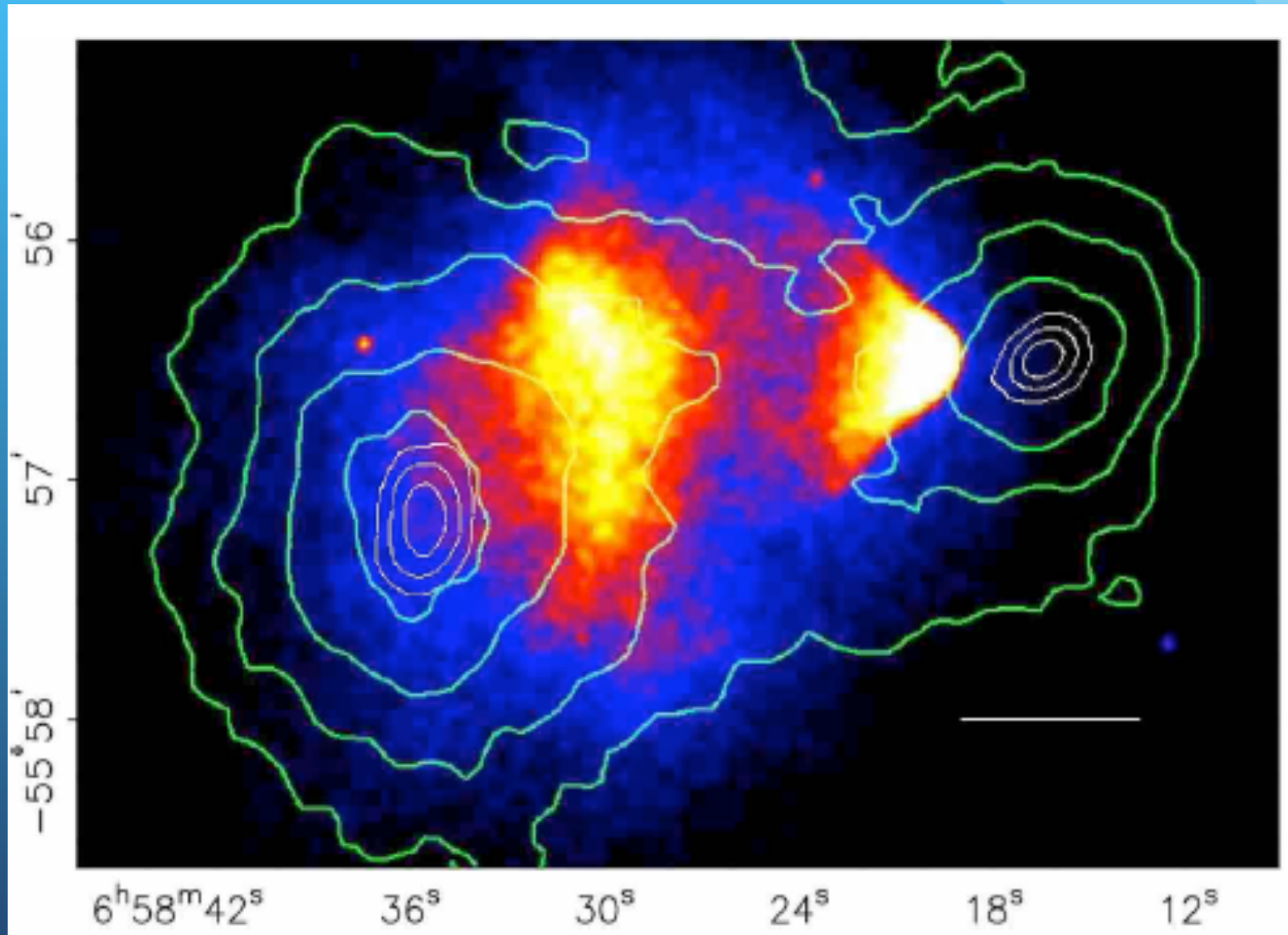


modified gravity



simple, unified, predictive, testable

gravitational “detection of dark matter”



Growth of structure

Any theory that respects Birkhoff's Law,
does not result in the observed growth of
structure

(Lue, Scoccimaro, Starkman *Phys.Rev.D*69:044005,2004.
e-Print: [astro-ph/0307034](https://arxiv.org/abs/astro-ph/0307034)).

Solution:

Break Birkhoff's law.

How:

Allow new fields to seed growth of structure

Modify Poisson equation (MOND)

Eg. TeVeS (Bekenstein [astro-ph/0403694](#)),

GEA (Zlosnik, Ferreira, GDS, [astro-ph/0607411](#))

Good news:

New gravitationally coupled fields that seed structure can cause weak lensing; could separate from baryons

→ “Bullet cluster”

(Dai, Matsuo, Starkman, Phys.Rev.D78:104004,2008.
arXiv:0806.4319)

Problem:

Without Birkhoff's law, the field here depends on the distribution of matter everywhere in some complicated way

$$\nabla \cdot \nabla \varphi = 0 \quad \Rightarrow \quad \nabla \varphi = 0 \quad \text{On interior of a spherical shell}$$

Good news:

MOND has a Birkhoff's law

$$\nabla \cdot (\mu(|\nabla\varphi|)\nabla\varphi) = 0 \implies \nabla\varphi = 0$$

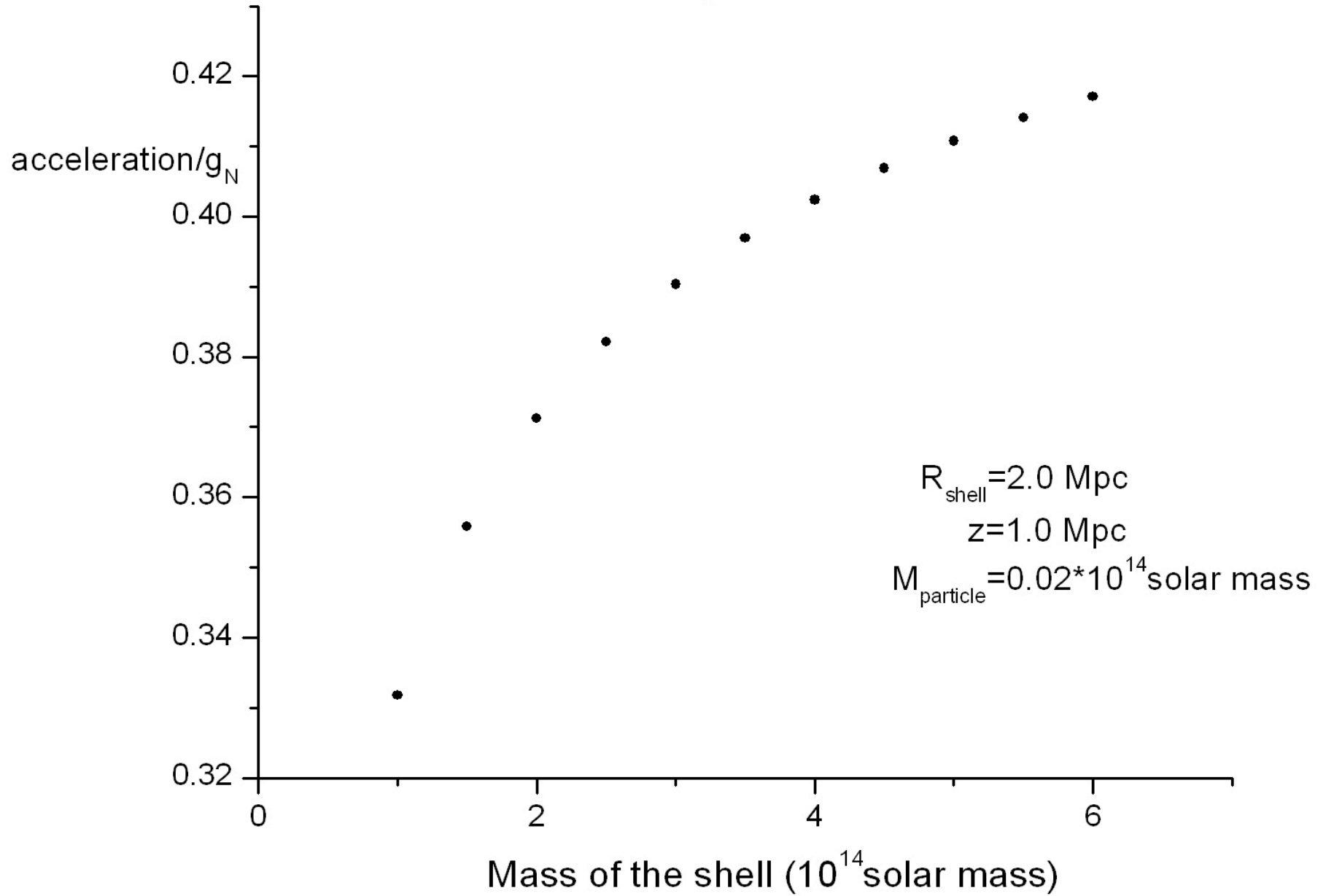
On interior of a spherical shell

Bad news:

This doesn't help

It is the $1/r^2$ of Newtonian gravity that counts

Acceleration on the particle as a function of the shell mass



Summary

Modified gravity theories could reproduce the successes of DM/DE, but at the expense of becoming like DM/DE theories -- wysiNwyg and with the possible loss of reliable calculability.

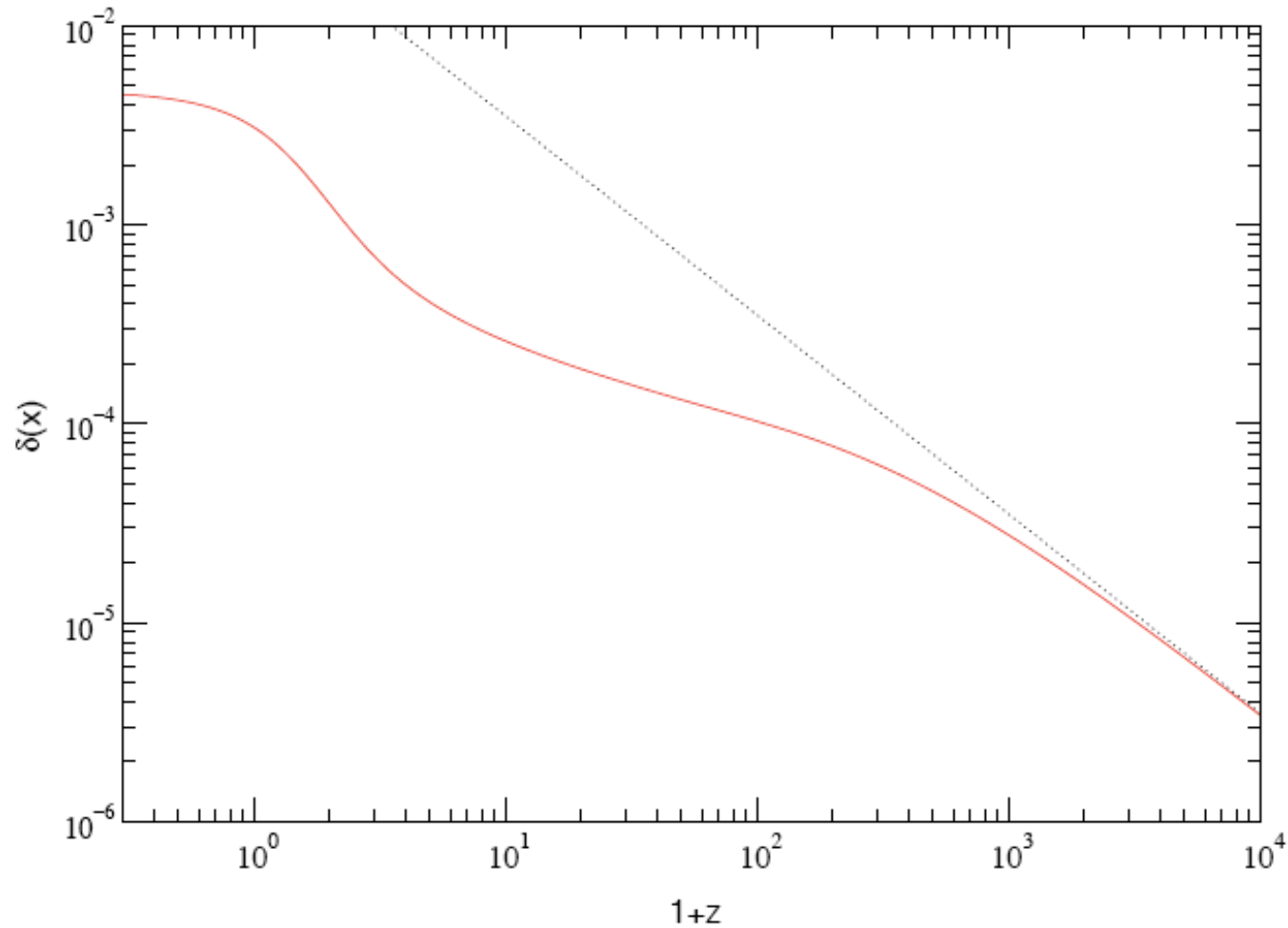


FIG. 2. Baryon density perturbation, $\delta(x)$ versus $1+z$ for the function $g(x)$ depicted in Fig. 1, normalized to be consistent with CMB anisotropy amplitude at recombination. The dotted line represents the growth in $\delta(x)$ if it were to follow Einstein gravity.

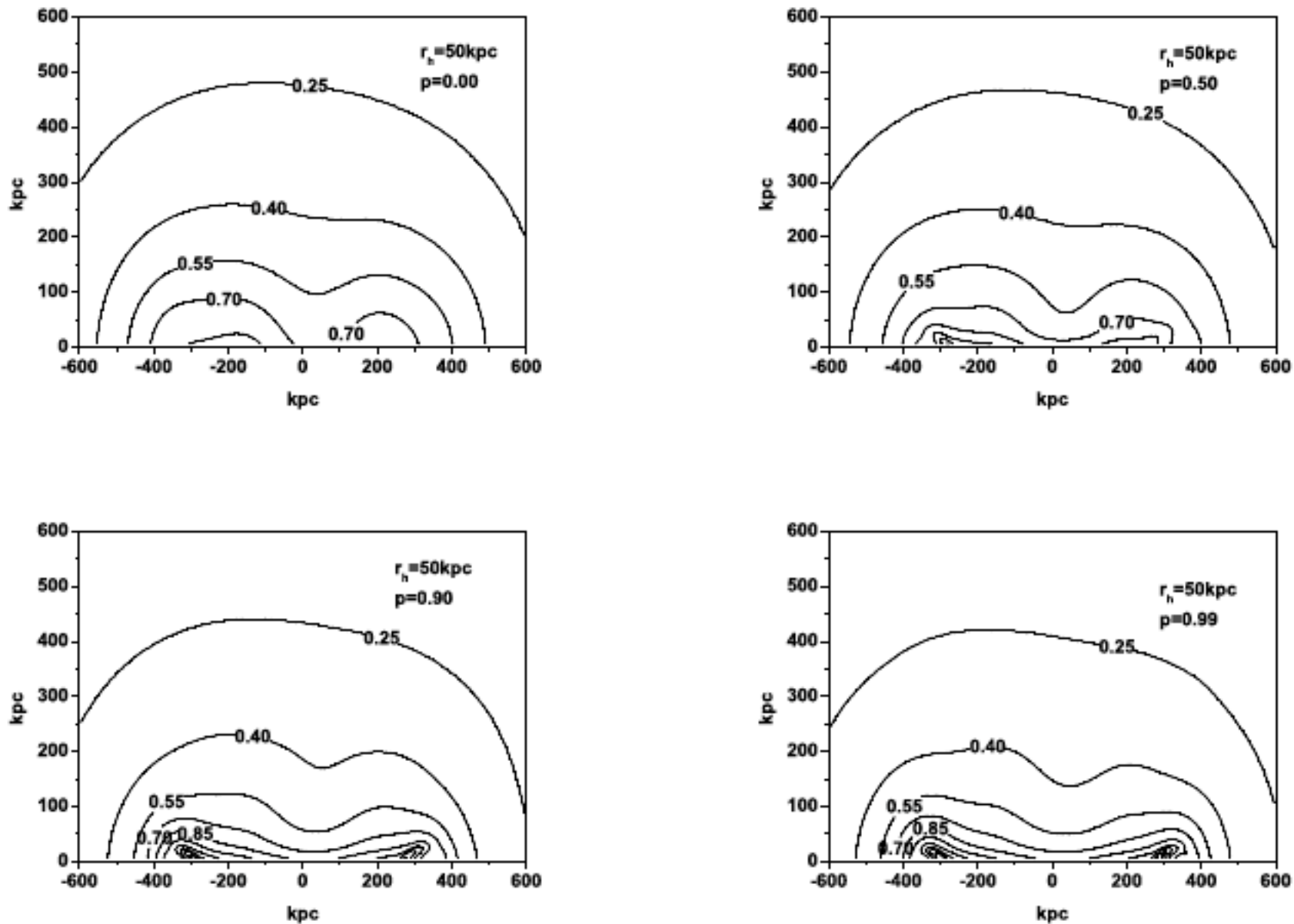


FIG. 2: The convergence map changing with different p : $r_h = 50$ kpc for the vector fields. $p = 0.00$, $p = 0.50$, $p = 0.9$, and $p = 0.99$ are corresponding to left up, right up, left bottom, and right bottom. The interval between each contour is 0.15. Left up figure shows the result of MOND. It does not show gravitational a lensing center at -350 kpc and 350 kpc. As the p increases, concentrated contours appears.

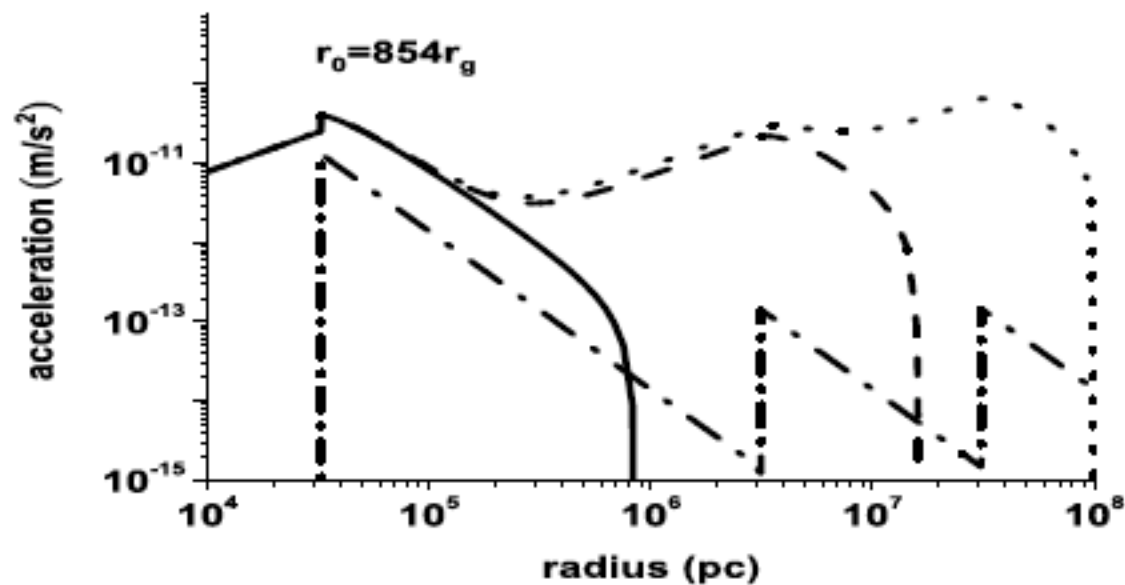


FIG. 1: Gravitational acceleration as a function of radius. g (solid) includes only the galaxy as a source, $g + c$ (dashed) adds the cluster, and $g + c + sc$ (dotted) adds the super-cluster. The Newtonian acceleration is g_n (dot-dashed). The crossover