Testing Galileon Gravity Using Supermassive Black Holes

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Why modified gravity?

- Quantum gravity
- Dark energy
- Cosmological constant problem
- Need alternative theories to test GR

Galileons

Newtonian gravity:

$$\nabla^2 \Phi_N = 4\pi G\rho \qquad F_N = \frac{GM}{r^2}$$

New scalar graviton:

$$\nabla^2\phi + \frac{r_c^2}{3}\left[(\nabla^2\phi)^2 - \nabla_i\nabla_j\phi\nabla^i\nabla^j\phi\right] = 8\pi\alpha G\rho$$

Poisson term

galileon term

coupling to matter

Galileons - Vainshtein screening

$$\left(\frac{F_5}{F_N}\right) + \frac{1}{2\alpha^2}\left(\frac{r_V}{r}\right)^3\left(\frac{F_5}{F_N}\right)^2 = 2\alpha^2$$

Poisson term

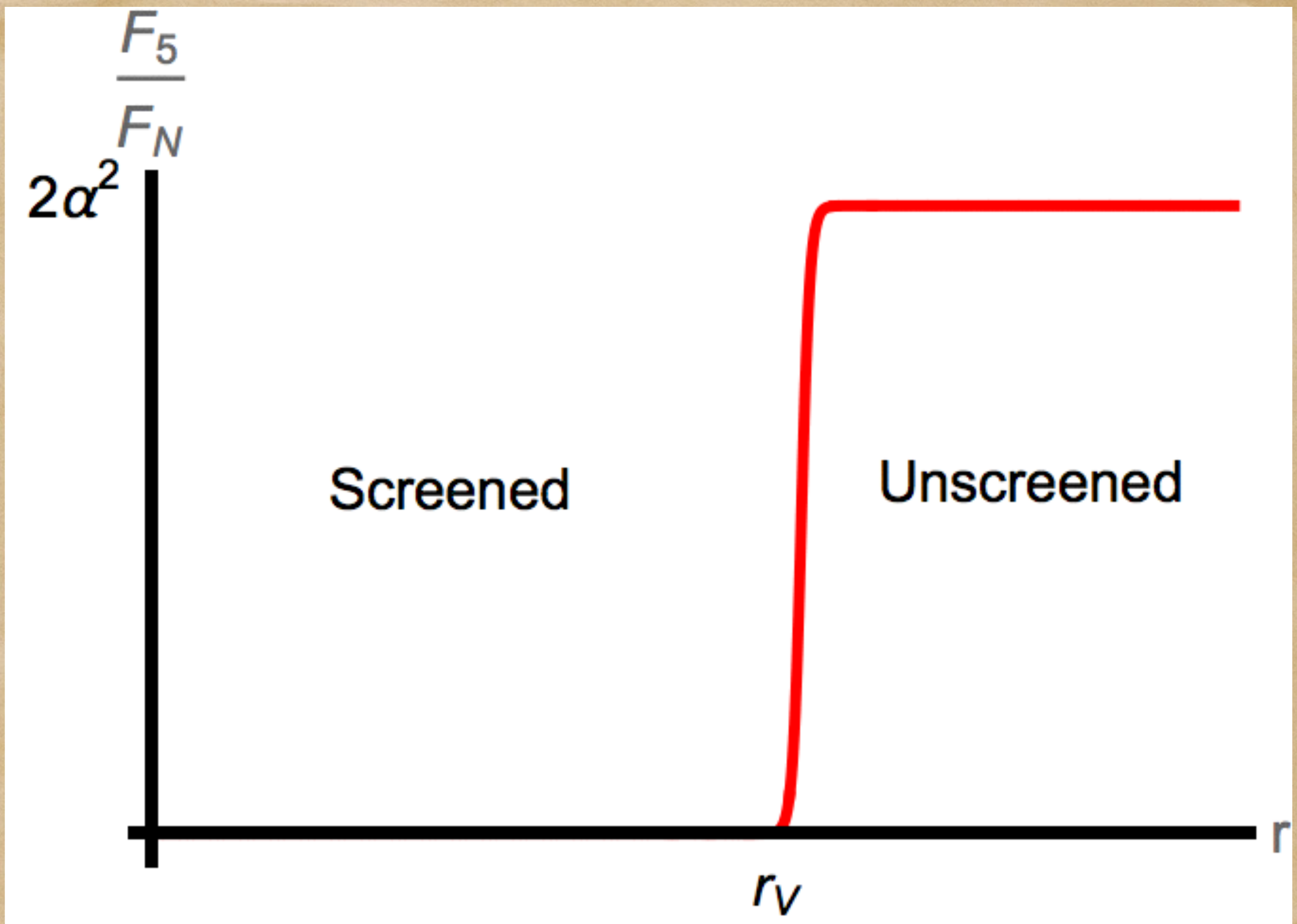
galileon term

coupling to matter

$$\frac{F_5}{F_N} = 2\alpha^2 \qquad r \gg r_V$$

$$\frac{F_5}{F_N} = 2\alpha^2\left(\frac{r}{r_V}\right)^{\frac{3}{2}} \qquad r \ll r_V$$

$$r_V^3 = \frac{4}{3}\alpha G M r_c^2$$


$\frac{F_5}{F_N}$
$2\alpha^2$
Screened
Unscreened
r
r_V

Galileons

- Self-acceleration (DE but does not solve CC)
- Nice UV properties
- Massive gravity
- Braneworld models
- Hard to test due to Vainshtein screening

Hui & Nicolis '12

No hair theorem

Black holes described by mass and spin only!

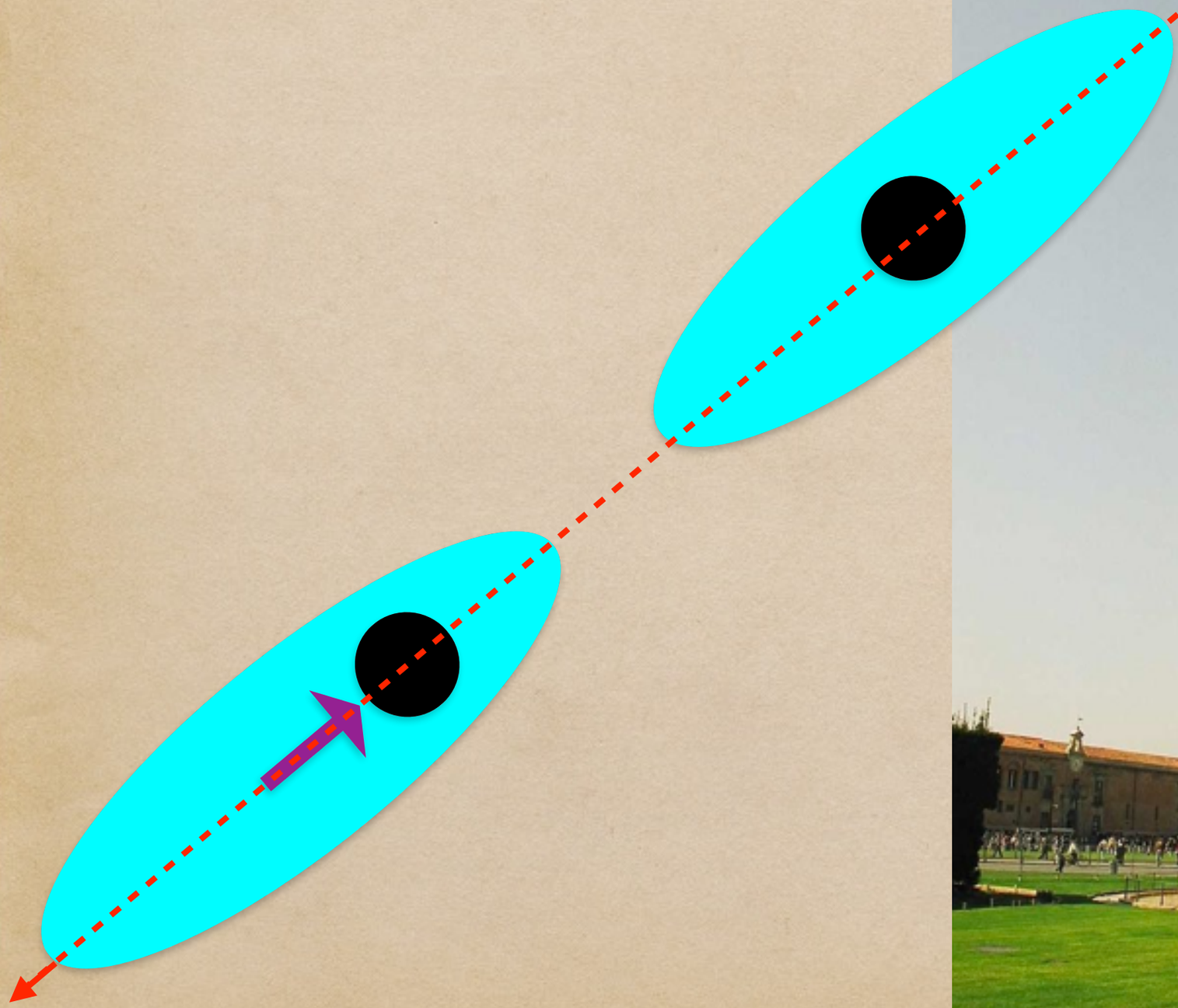
No galileon charge Q so BH does not feel galileon force

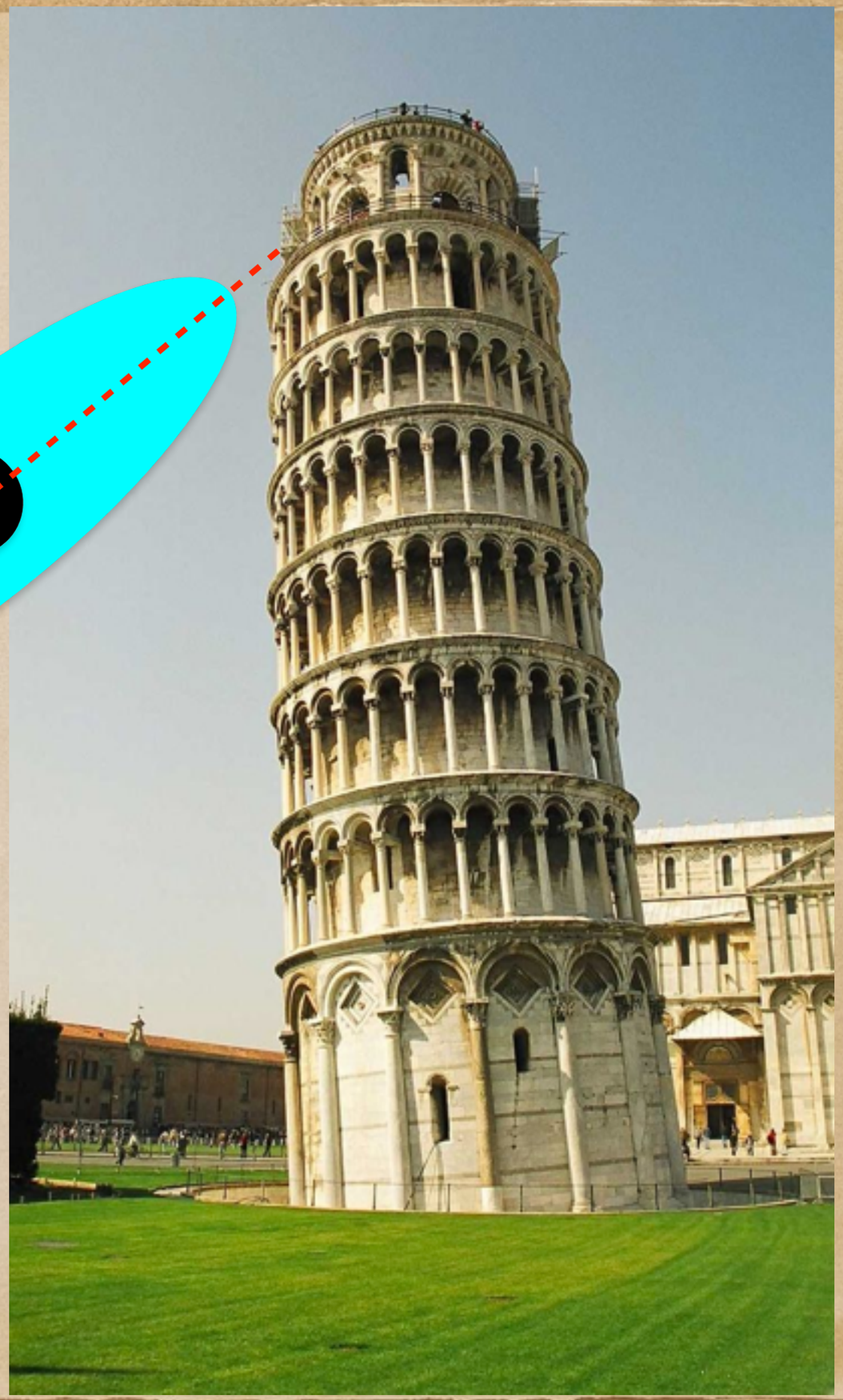
Matter has $Q = M$

Matter and BH fall at different rates

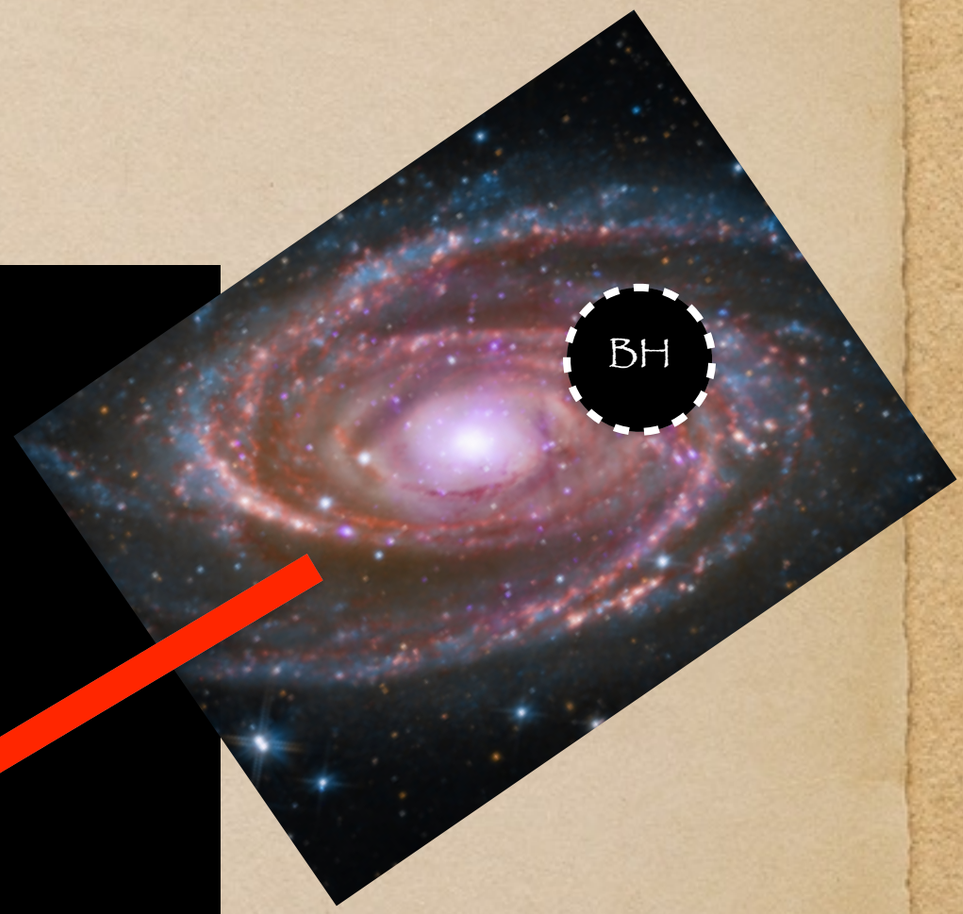
Violation of the strong equivalence principle

Hui & Nicolis '12





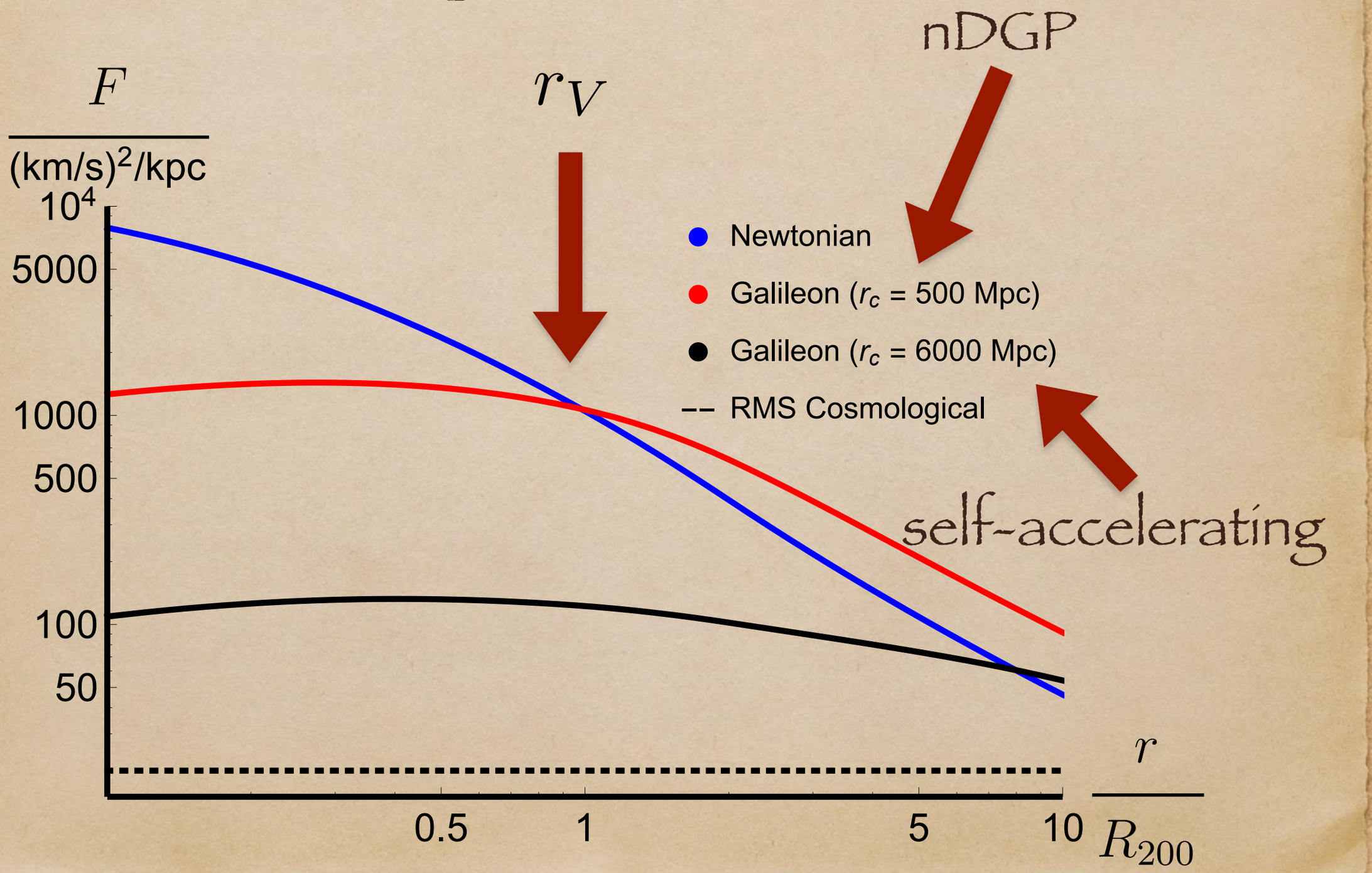
Galaxy clusters: nature's leaning towers



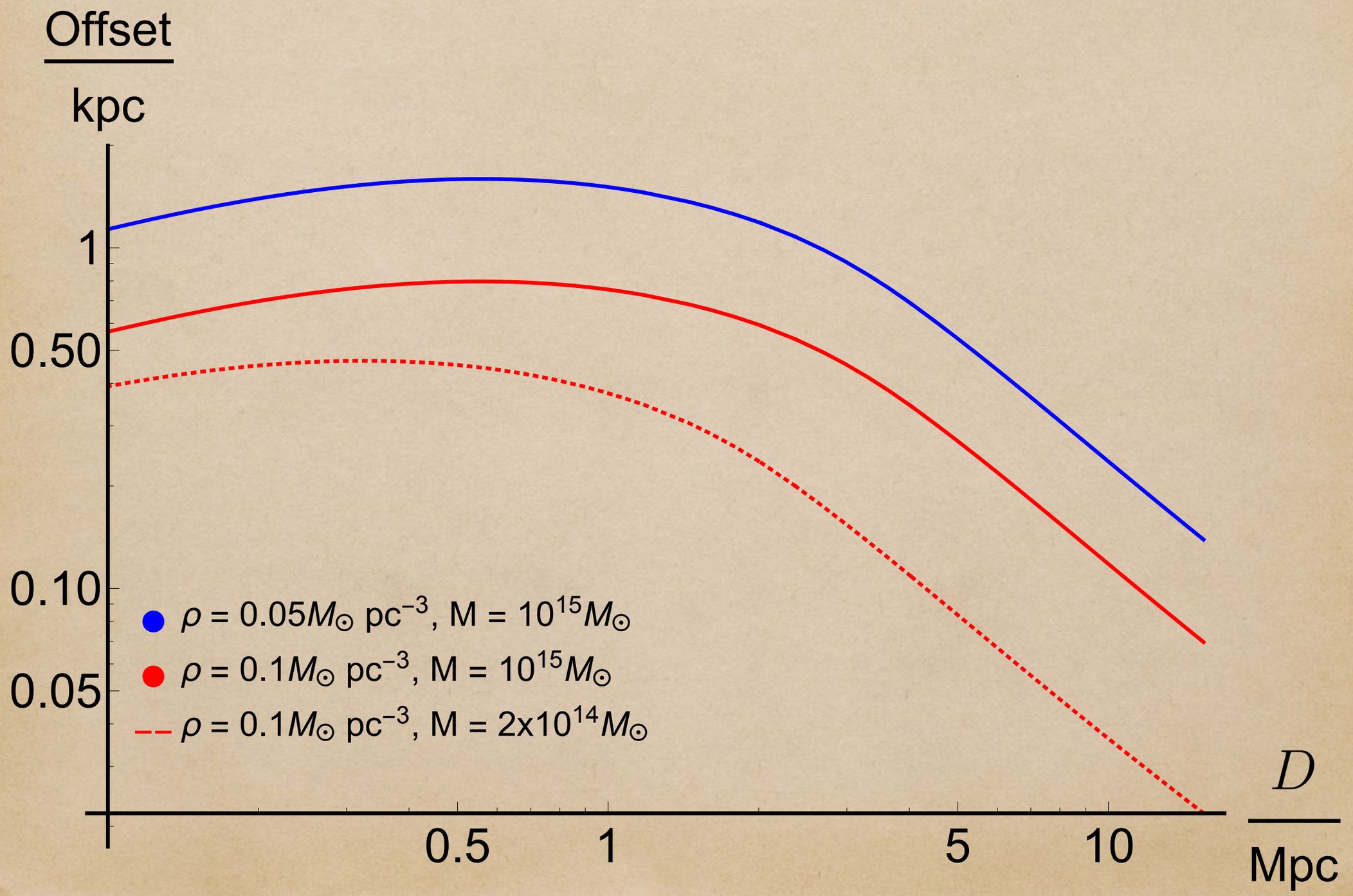
NFW, c=5

$M = 10^{15} M_\odot$

Virgo Cluster

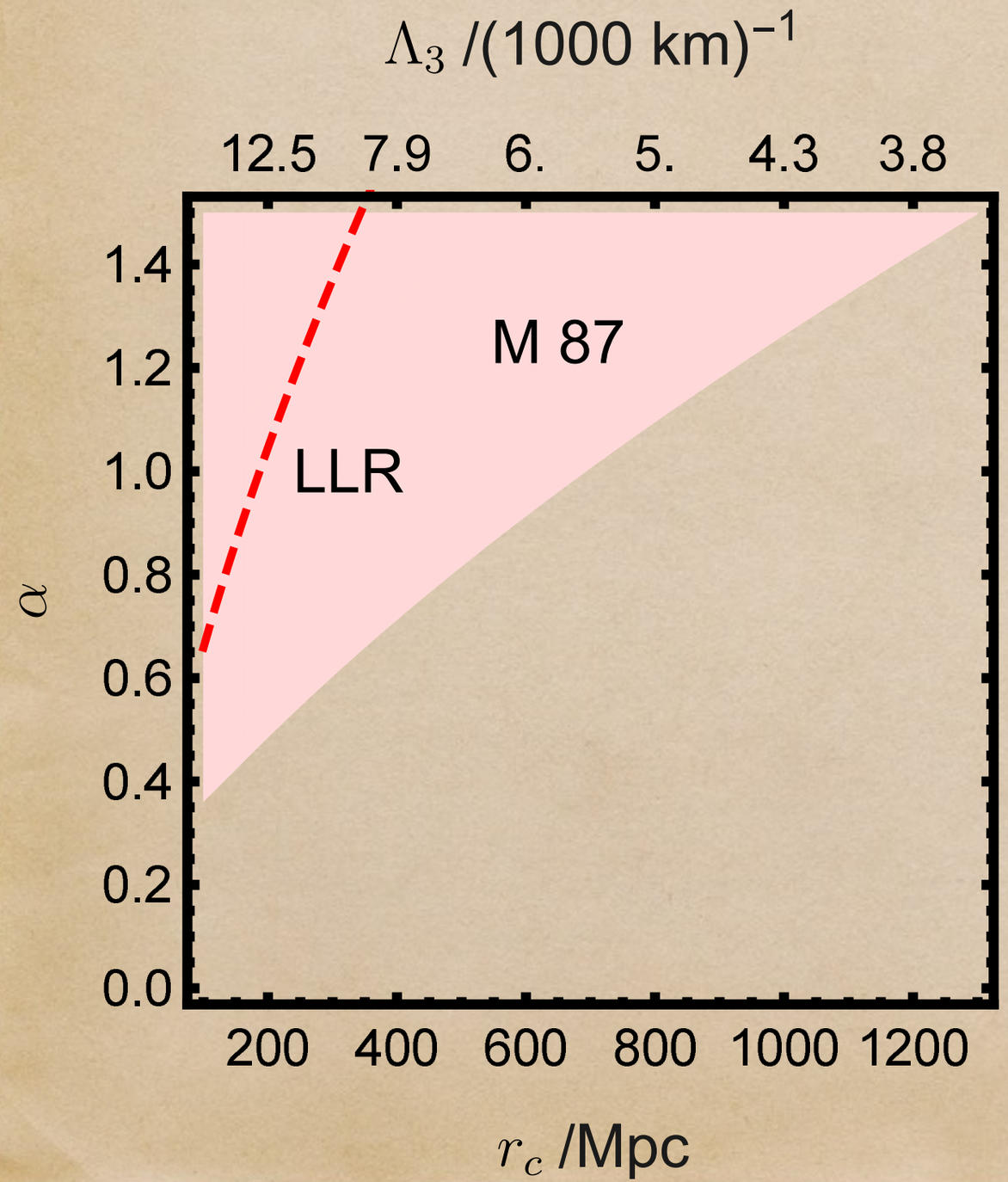


Offset


Offset
kpc
1
0.50
0.10
0.05
$\rho = 0.05 M_\odot$ pc^{-3}, M = $10^{15} M_\odot$
$\rho = 0.1 M_\odot$ pc^{-3}, M = $10^{15} M_\odot$
$\rho = 0.1 M_\odot$ pc^{-3}, M = $2 \times 10^{14} M_\odot$
0.5
1
5
10
D
Mpc

M 87

self-acceleration



$$\Lambda_3 = (6M_{\rm pl}/r_c)^{1/3}$$

Future tests

This is one galaxy!

- More galaxies — SDSS, DES, Euclid + X-ray/Radio
- Morphological distortions
- Missing SMBHs!

Summary

- Can test Vainshtein using SEP violation
- Expect offset black holes in cluster satellite galaxies
- New constraints from Virgo cluster/M 87
- Expect improvements with imaging survey data