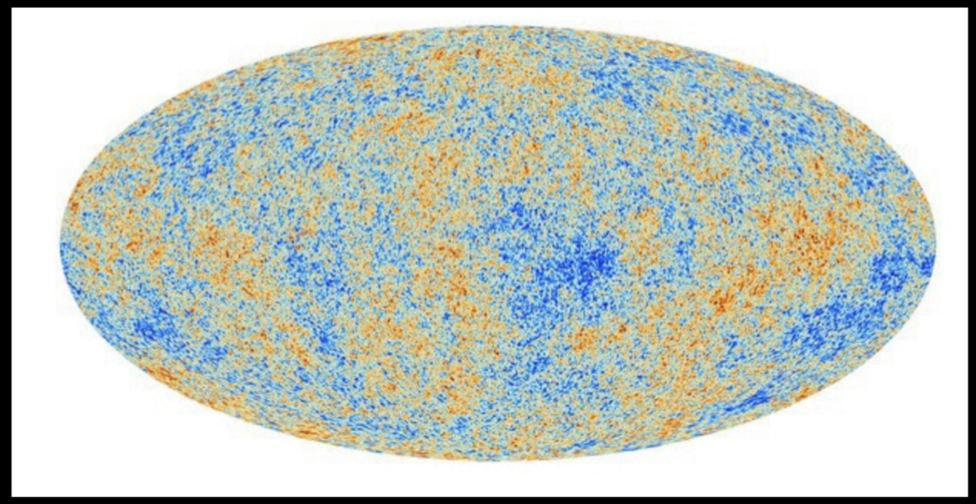
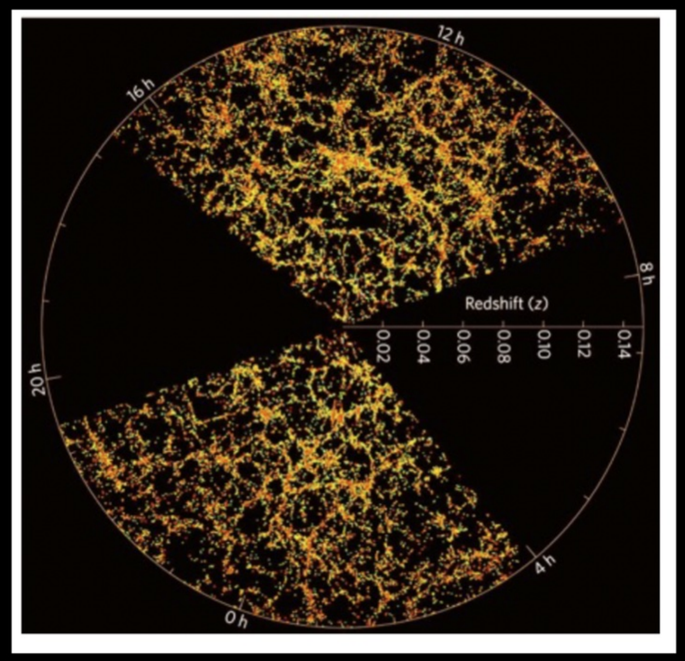
Galaxies as probes of fundamental physics

Focus has been on large scales and 'summary' statistics ⟶ power spectra, correlation functions, etc



Planck



SDSS

Hubble Deep Field

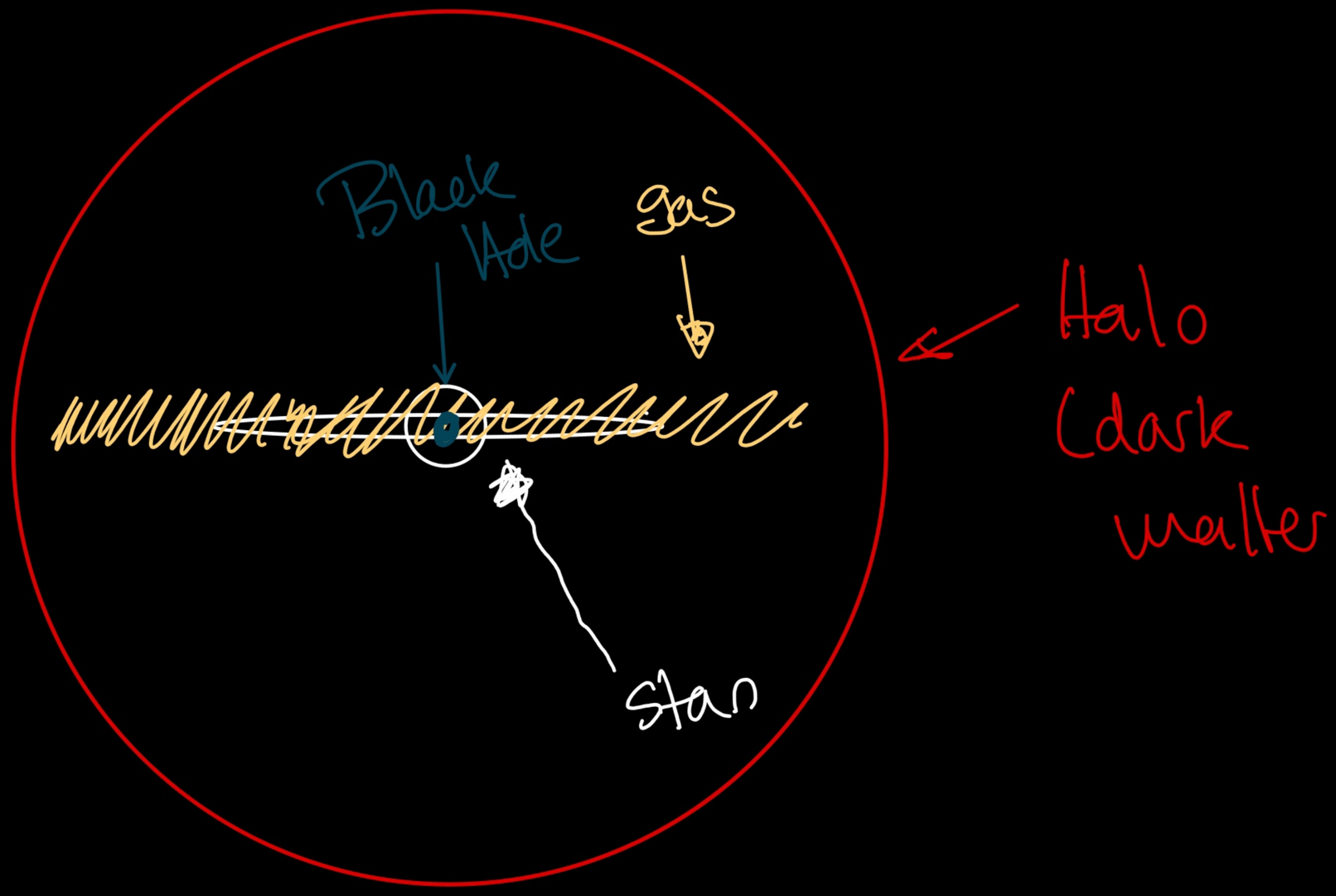
Galaxies as probes of fundamental physics

In large scale structure, galaxies are mere building blocks ⟶ "dots".

Different perspective: use individual galaxies as laboratories and look at how their structure depends on environment

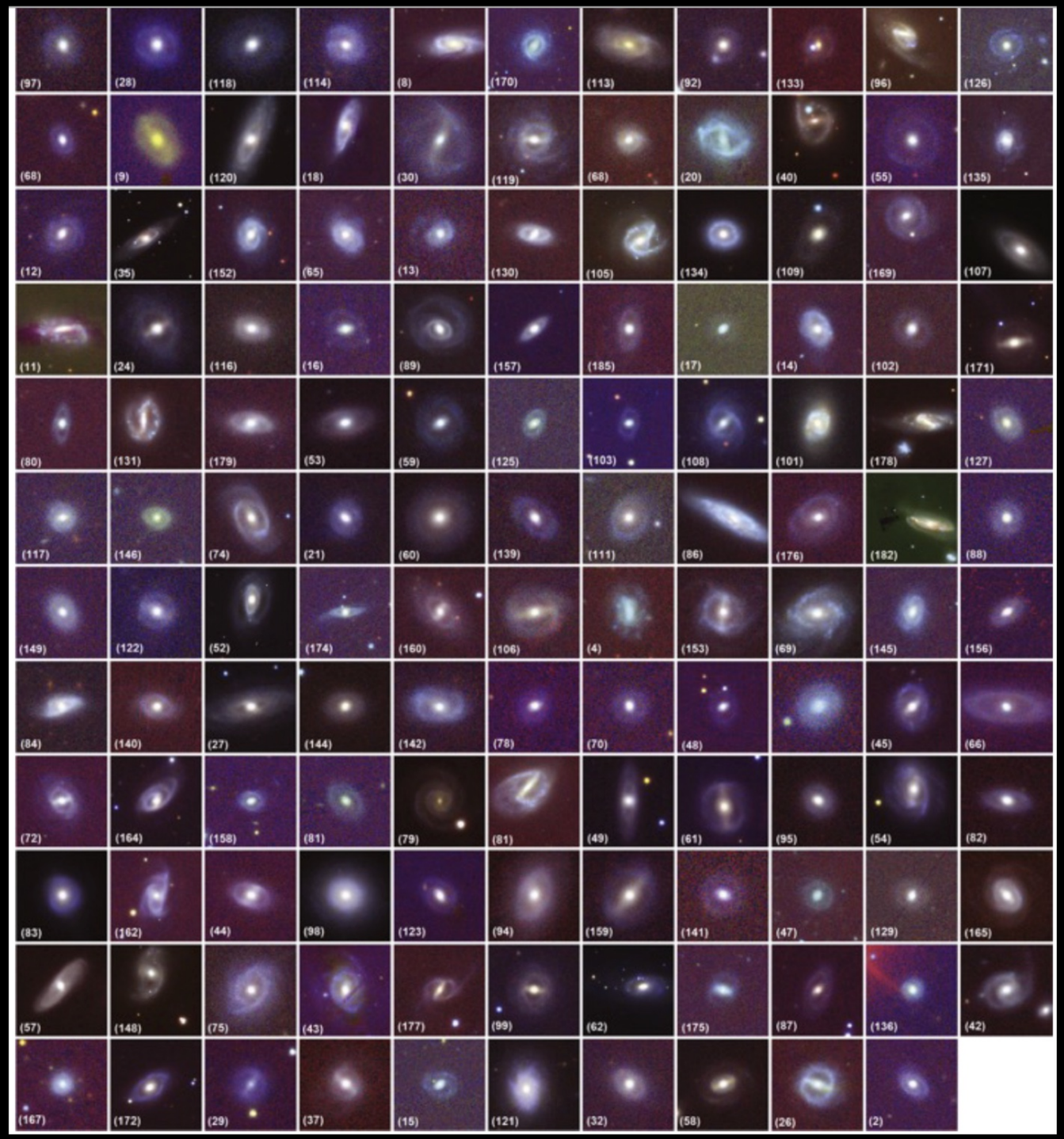
Search for fifth forces in Galaxies

Galaxies as probes of fundamental physics



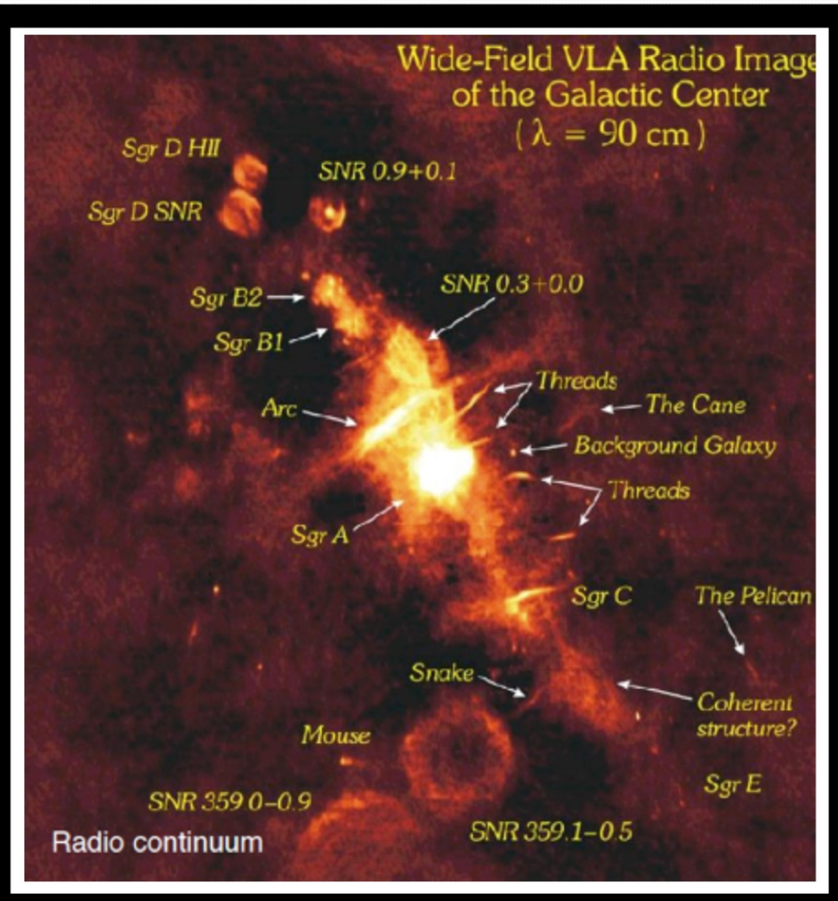
See Baker et al, 1908.03430

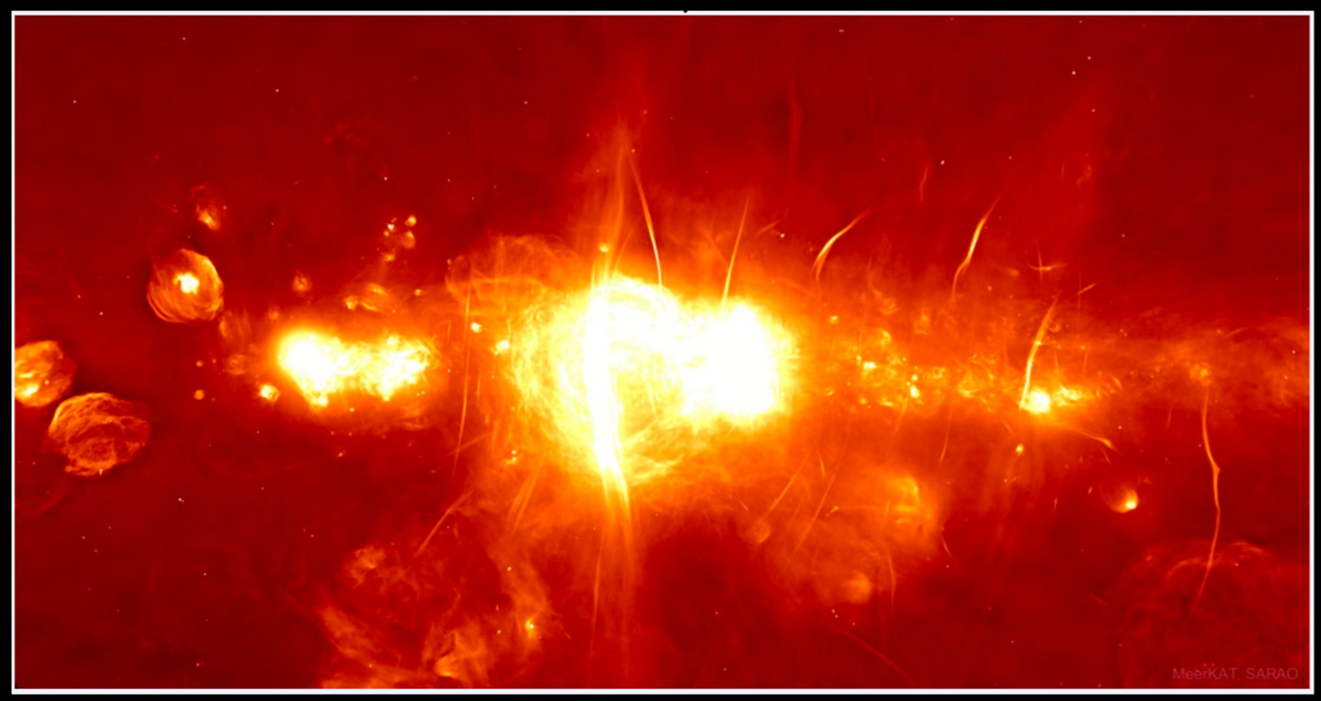
Galaxies as probes of fundamental physics



SDSS

Galaxies as probes of fundamental physics





Meerkat (Radio) view of centre of our galaxy

Galaxies as probes of fundamental physics

Gravitational screening:

Depend on enviroment/mass ...

$$\Phi_s = \frac{\alpha M}{r} e^{-mr}$$

Look at galaxies and constituents in different enviroments.

E.g.: - in voids versus clusters

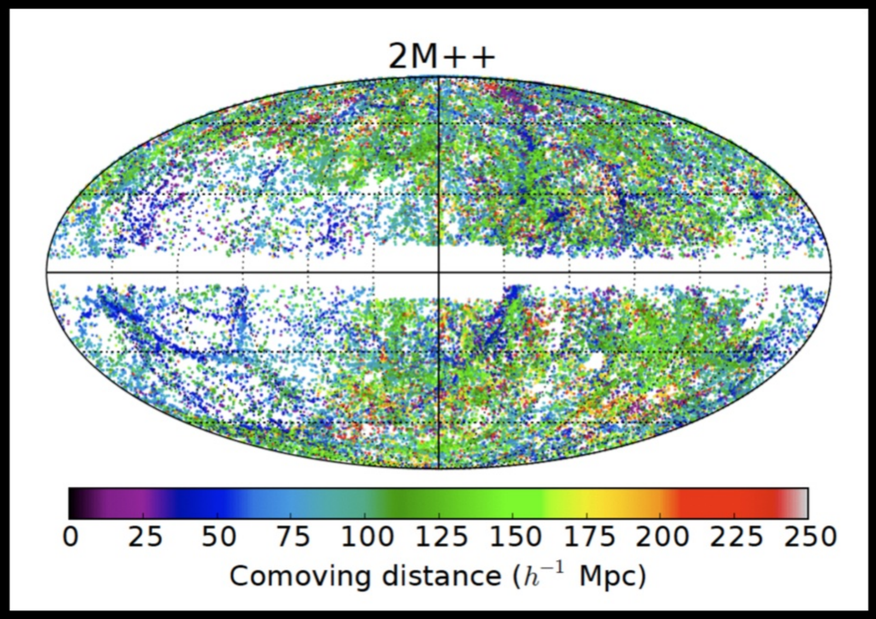
- at stars versus gas and dark matter

- at black holes versus stars.

Galaxies as probes of fundamental physics

Environment: Build a "gravitational map" of the Universe

- Galaxy catalogue ⟶



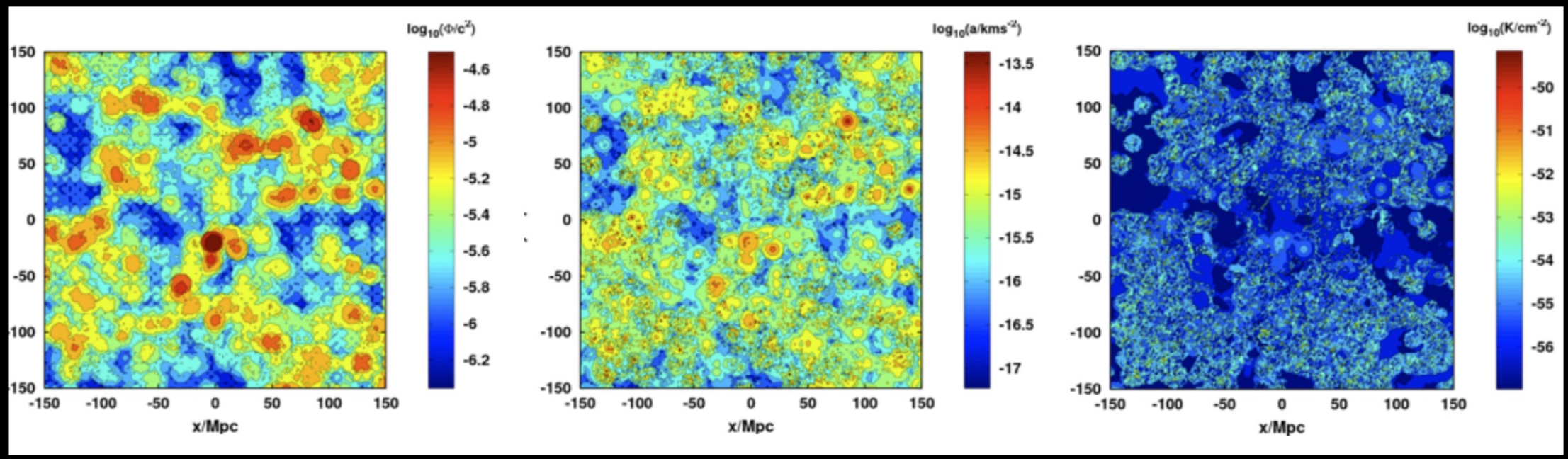
- Fill in long wavelength modes with BORG (Sims)

- Use abundance matching to associate halos to galaxies (short wavelengths).

Desmond et al, MNRAS 474, 3152 (2018)

Galaxies as probes of fundamental physics

2D slices of the Universe



Φ/c^2
(gravitational potential)

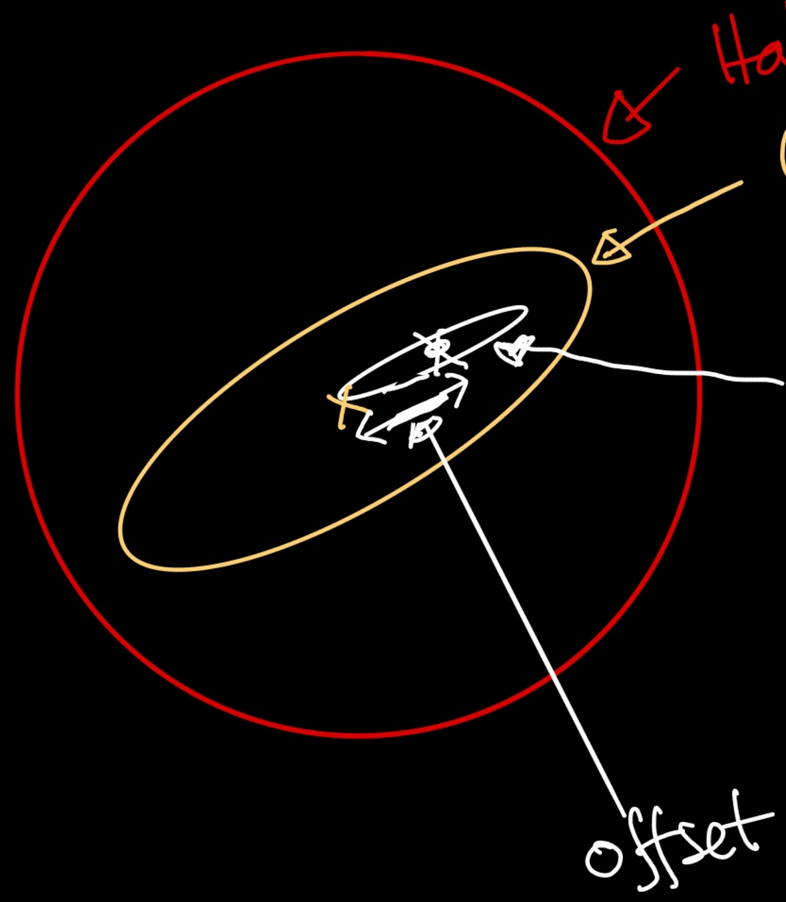
a
($\vec{a} = -\nabla\Phi$)

K
(curvature $\sim \nabla^2\Phi$)

Galaxies as probes of fundamental physics

What do we look for?

Galactic offsets



Gas Halo

$a_{unscreened} = a_{ext} + \frac{\Delta G}{G} a_s$

Stars

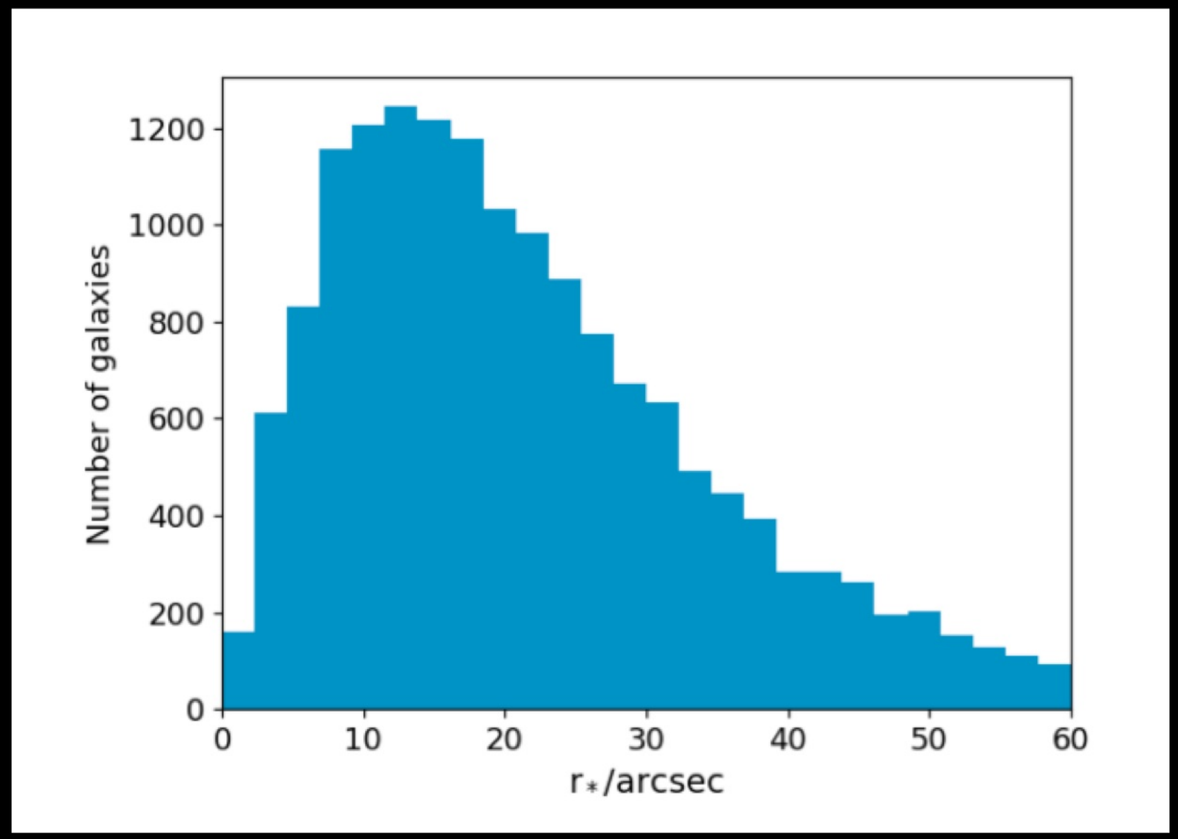
$a_{screened} = a_{ext} + G\frac{M(r_*)}{r_*^2}$

So

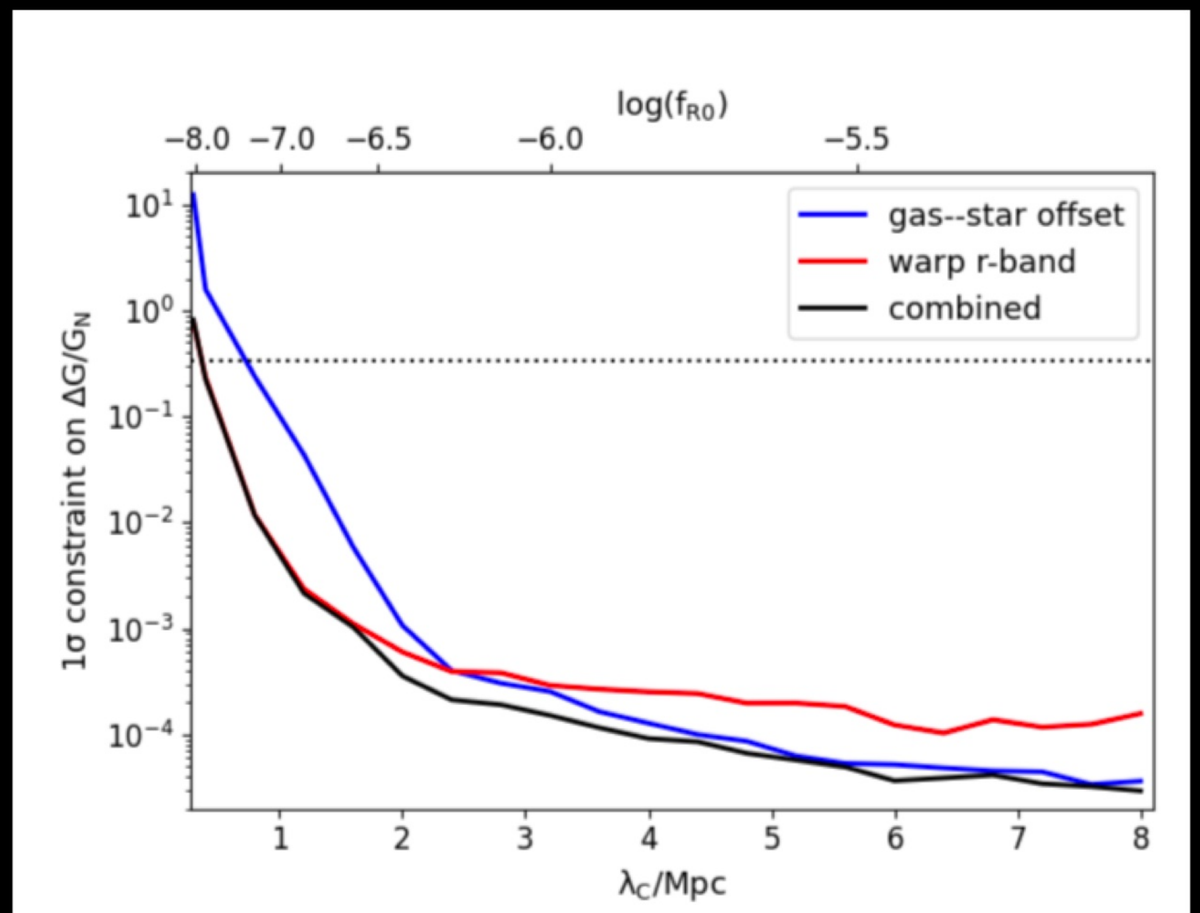
$\frac{M(r_*)}{r_*^2} = a_s \frac{\Delta G}{G^2}$ (screened) if $|\Phi| < |\Phi_c|$

$r_* = 0$ if $|\Phi| > |\Phi_c|$ (unscreened)

Galaxies as probes of fundamental physics



Offsets

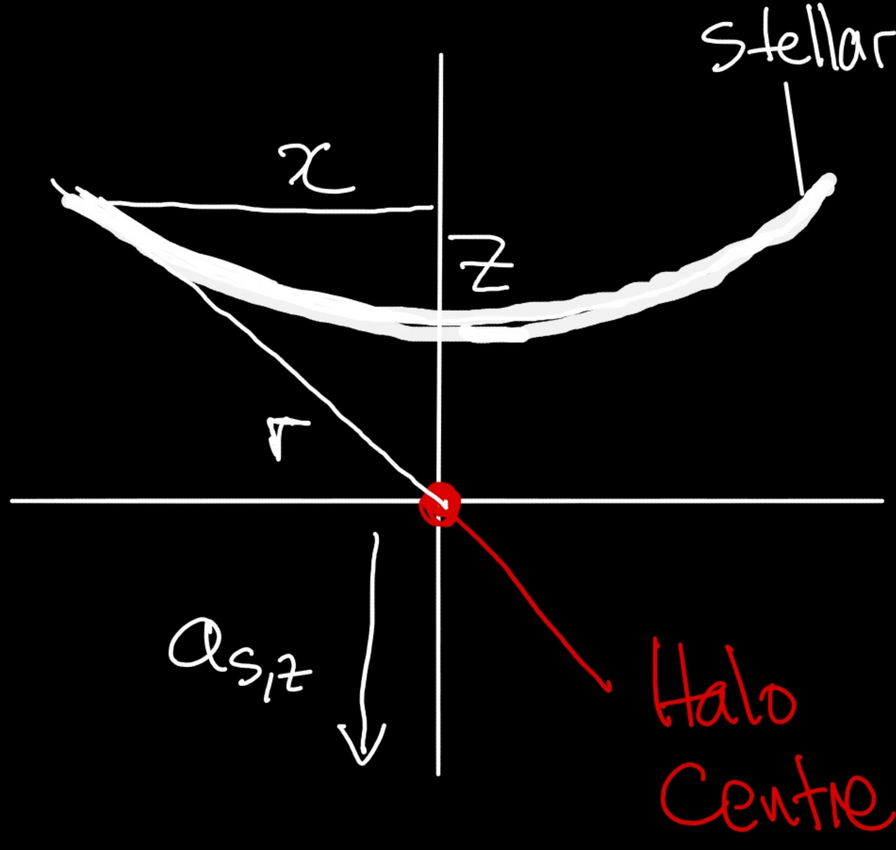


Screening Scale

Desmond & Ferreira, 2010.05877

Galaxies as probes of fundamental physics

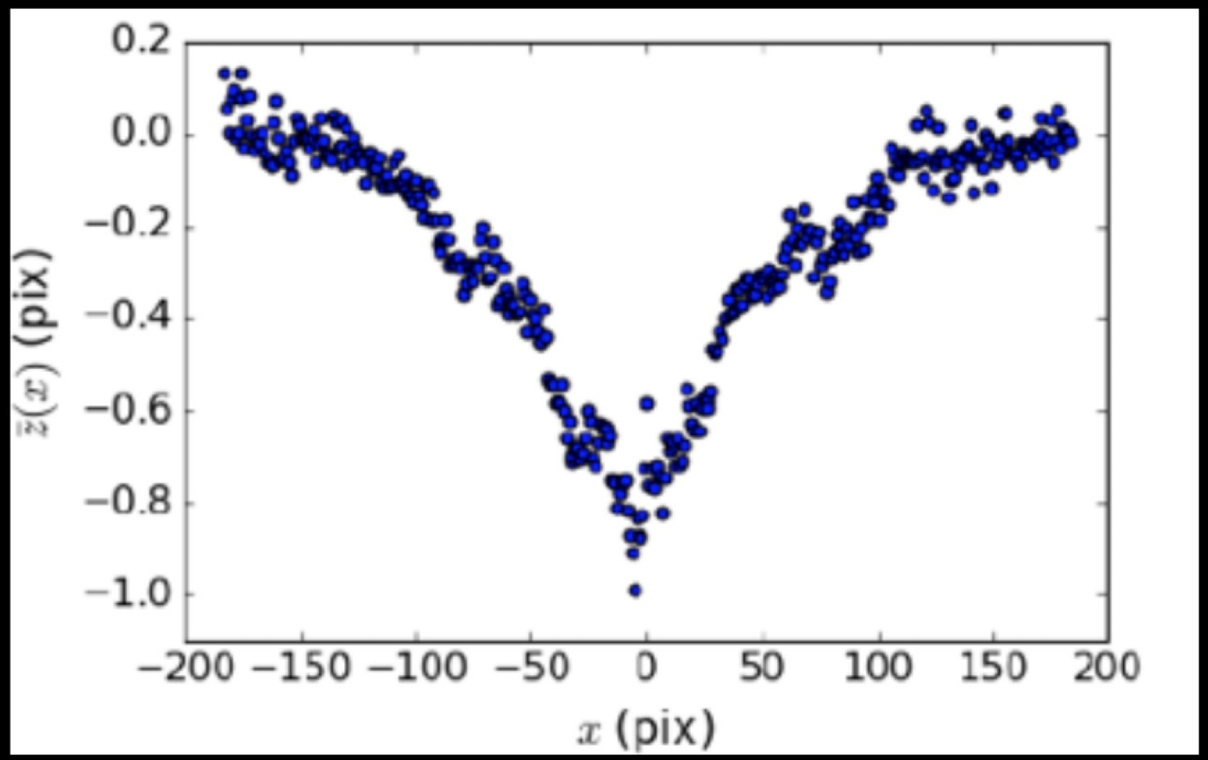
What do we look for? Warps

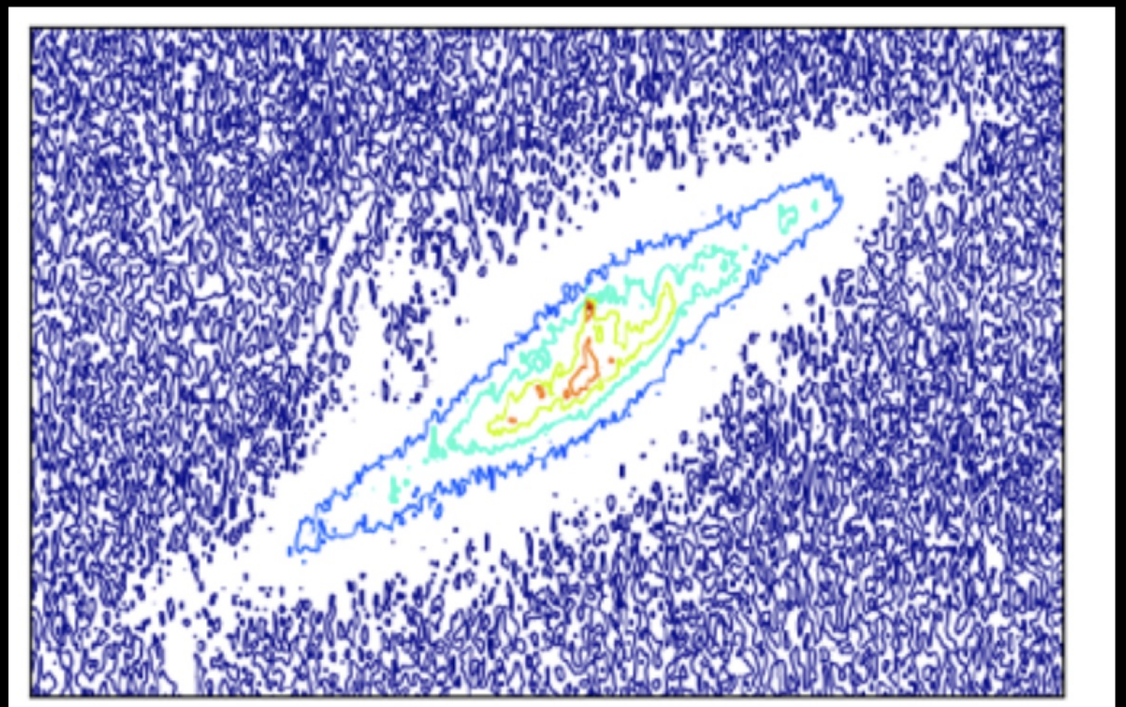


$$z(x) = -a_{s,z}\frac{\Delta G}{G_N^2}\frac{|x|^3}{M_{halo}(<x)}$$

$$\omega_1 = \frac{1}{L_x^3}\int_{-L_x}^{L_x} |x|\, z(x)\, dx$$

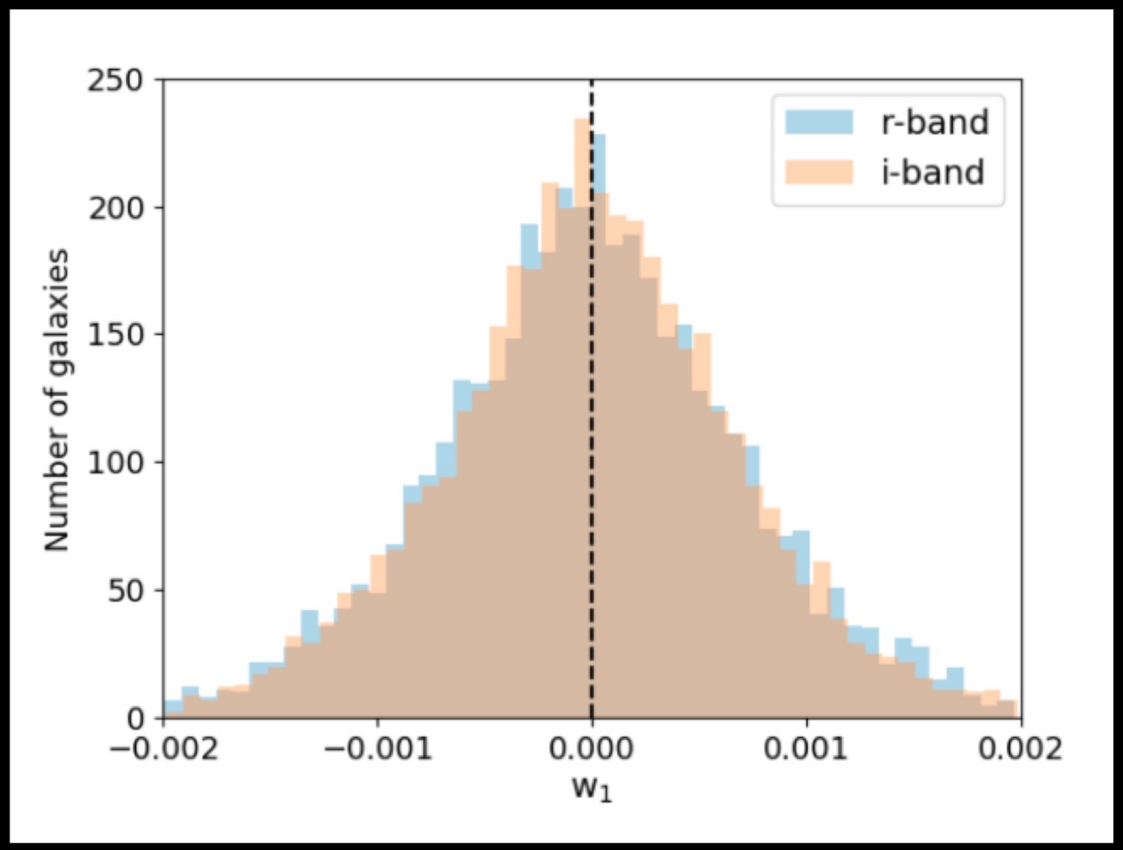
Galaxies as probes of fundamental physics

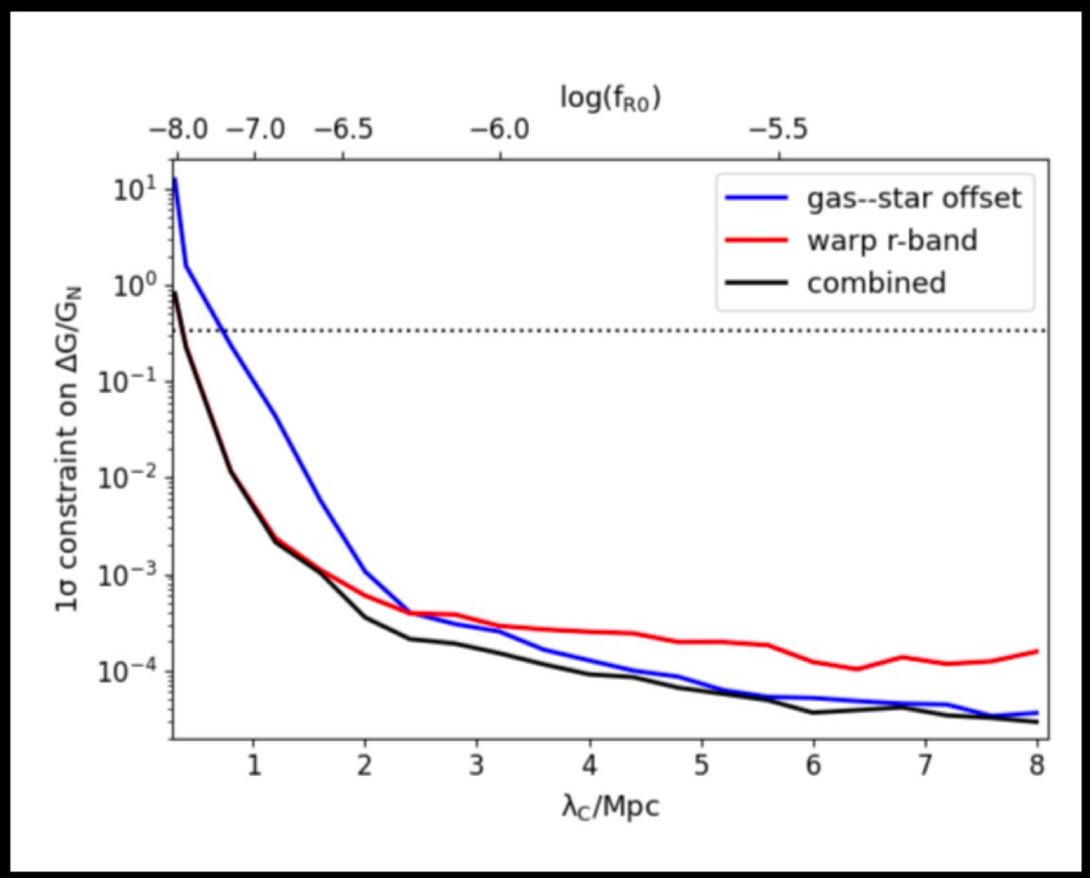




J115012.10+065956.9 – $w_1 = 1.7 \times 10^{-3}$

Galaxies as probes of fundamental physics





→ Warp

→ Screening Scale

Desmond & Ferreira, 2010.05877

Galaxies as probes of fundamental physics

What does it mean?

Example: $f(R)$ theory is screened.

$$f_{R0} = \partial_R f \big|_{a=a_0}$$

Galaxy constraints: $f_{R0} \leq 10^{-8}$

i.e all objects are screened and so

no astrophysical significance!

Galaxies as probes of fundamental physics

Vainshtain Screening test.

Galileon models : invariant $\phi \to \phi + d_\mu x^\mu + c$

Have screening but Black holes are unscreened

So

Star Motion $\neq$ Black Hole Motion

$\Leftarrow$ offset!

Galaxies as probes of fundamental physics

Vainshtain Screening test.

Fifth force has magnitude

Scalar charge

$$Q = \int T^{\circ}_{\circ} d^3x$$

density

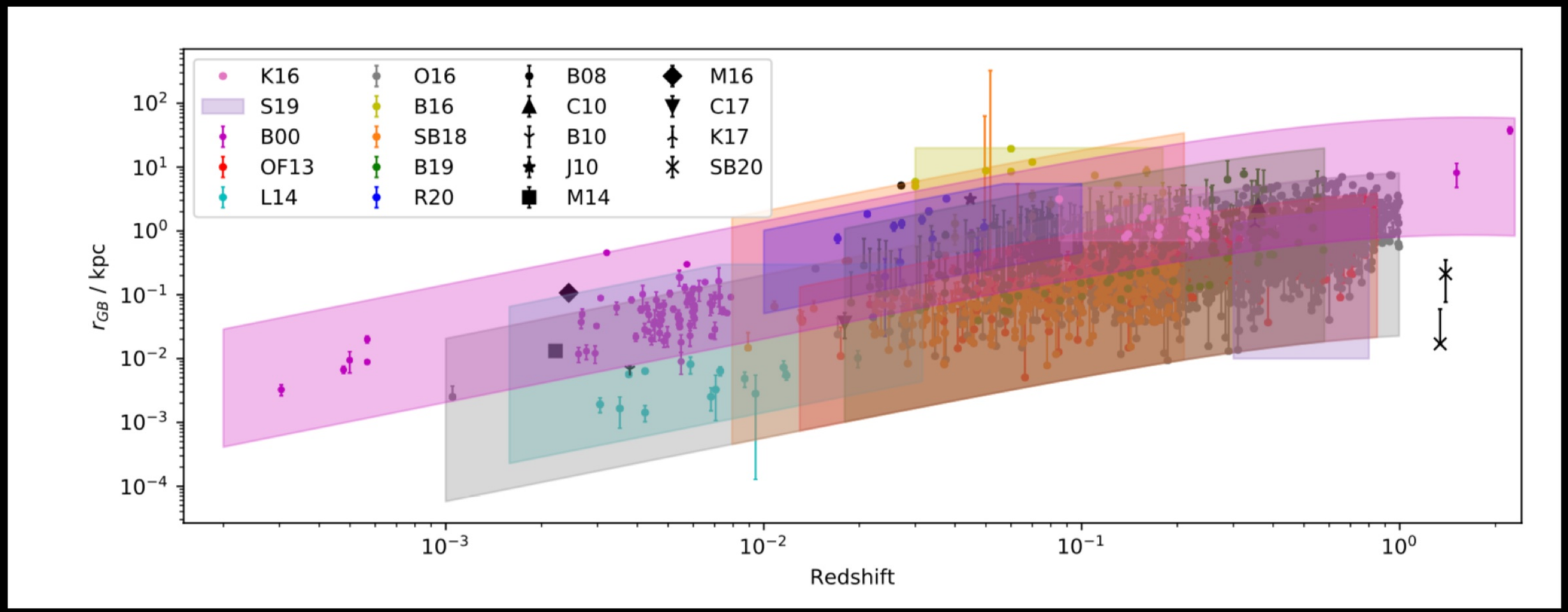
$$a_s = \frac{\Delta G}{G_N} \frac{G_N Q M}{r^2} \left(\frac{r}{r_V} \right)^{3/2}$$

Vainshtein Radius

Galaxies as probes of fundamental physics

Vainshtain Screening test.

Black hole offsets → Data



Today

$z \simeq 1$

Galaxies as probes of fundamental physics

Vainshtain Screening test.

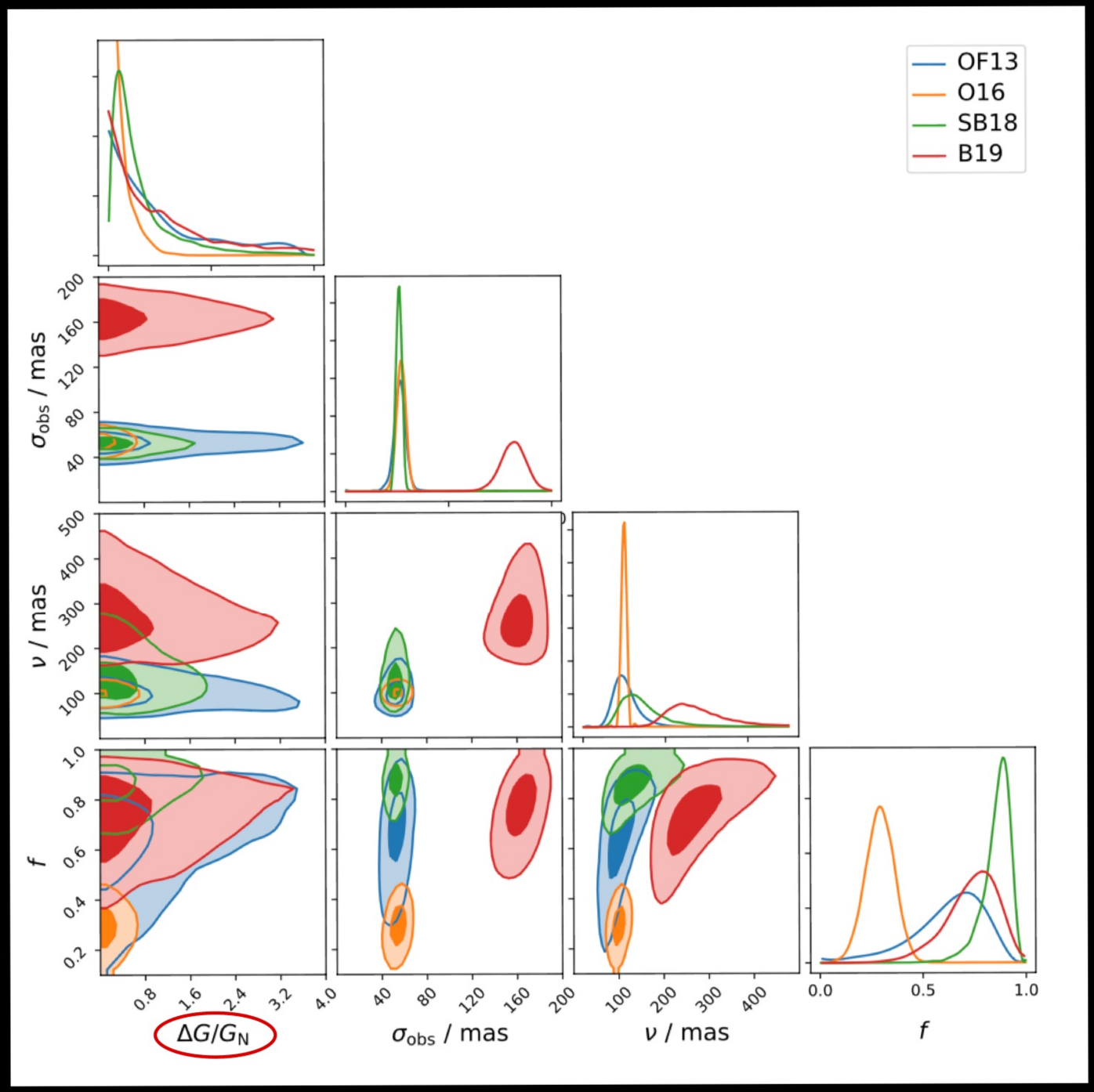
Model for offset distribution ($\Delta\theta$)

Gaussian

$$\frac{f}{\sqrt{2\pi}\,\sigma_{obs}} \exp\left[-\frac{\Delta\theta^2}{2\sigma_{obs}^2}\right]$$

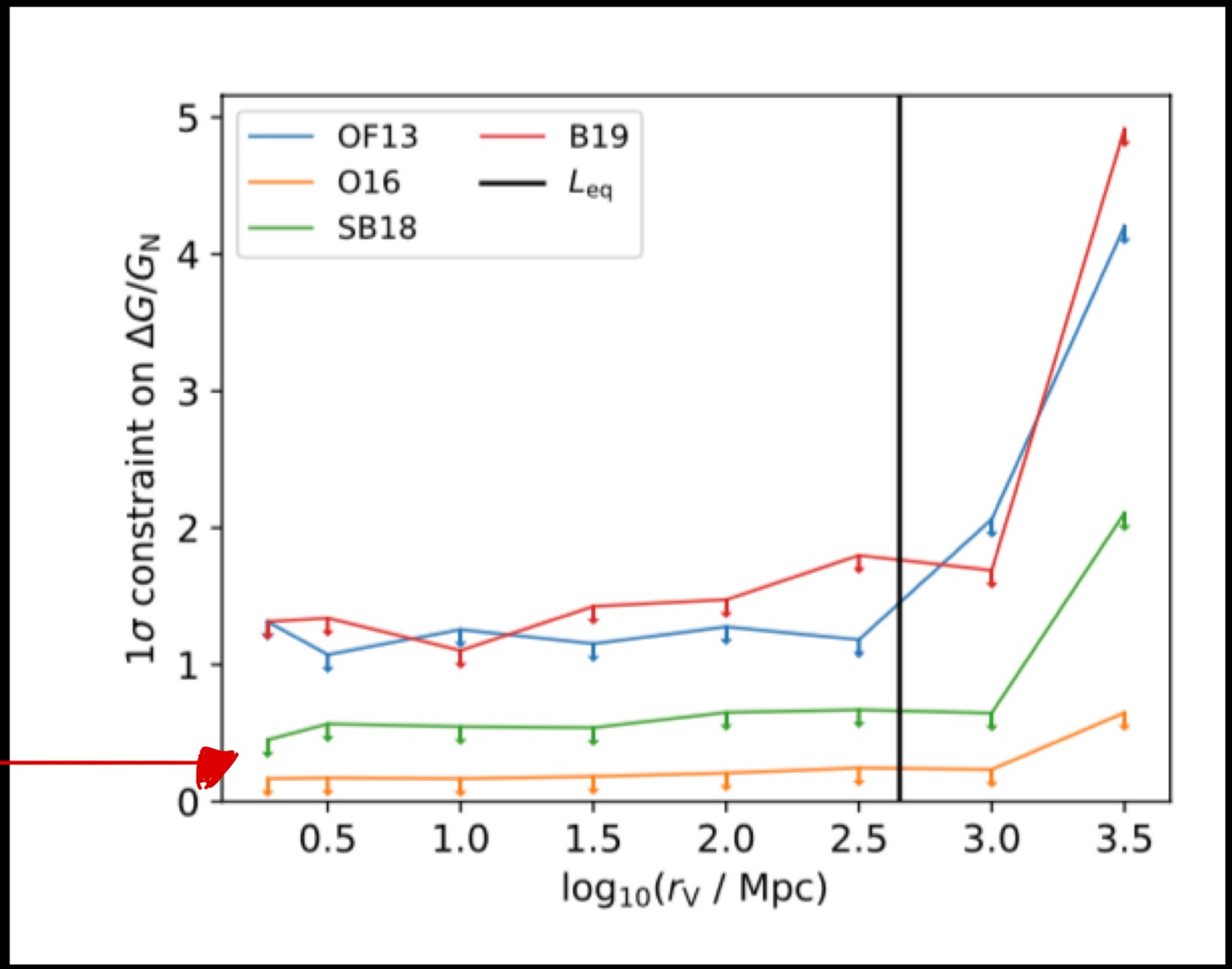
$$+\frac{(1-f)}{2v}\exp\left(-\frac{|\Delta\theta|}{v}\right)$$

Laplace



Galaxies as probes of fundamental physics

Vainshtain Screening test.



$\frac{\Delta G}{G} \gtrsim 0.1$

Galaxies as probes of fundamental physics

Summary

- Galaxies have tremendous potential for constraining fundamental physics
- Very, very messy $\Longrightarrow$ challenging
- "Messy" Bayesian Forward Modelling (the Future)
- Results $\longrightarrow$ Constraint on $f(R)$ is strong $f_R \sim 10^{-9}$ (the whole Universe is screened!)

$\longrightarrow$ Constraint on Galileon $\frac{\Delta G}{G} \sim 0.1$