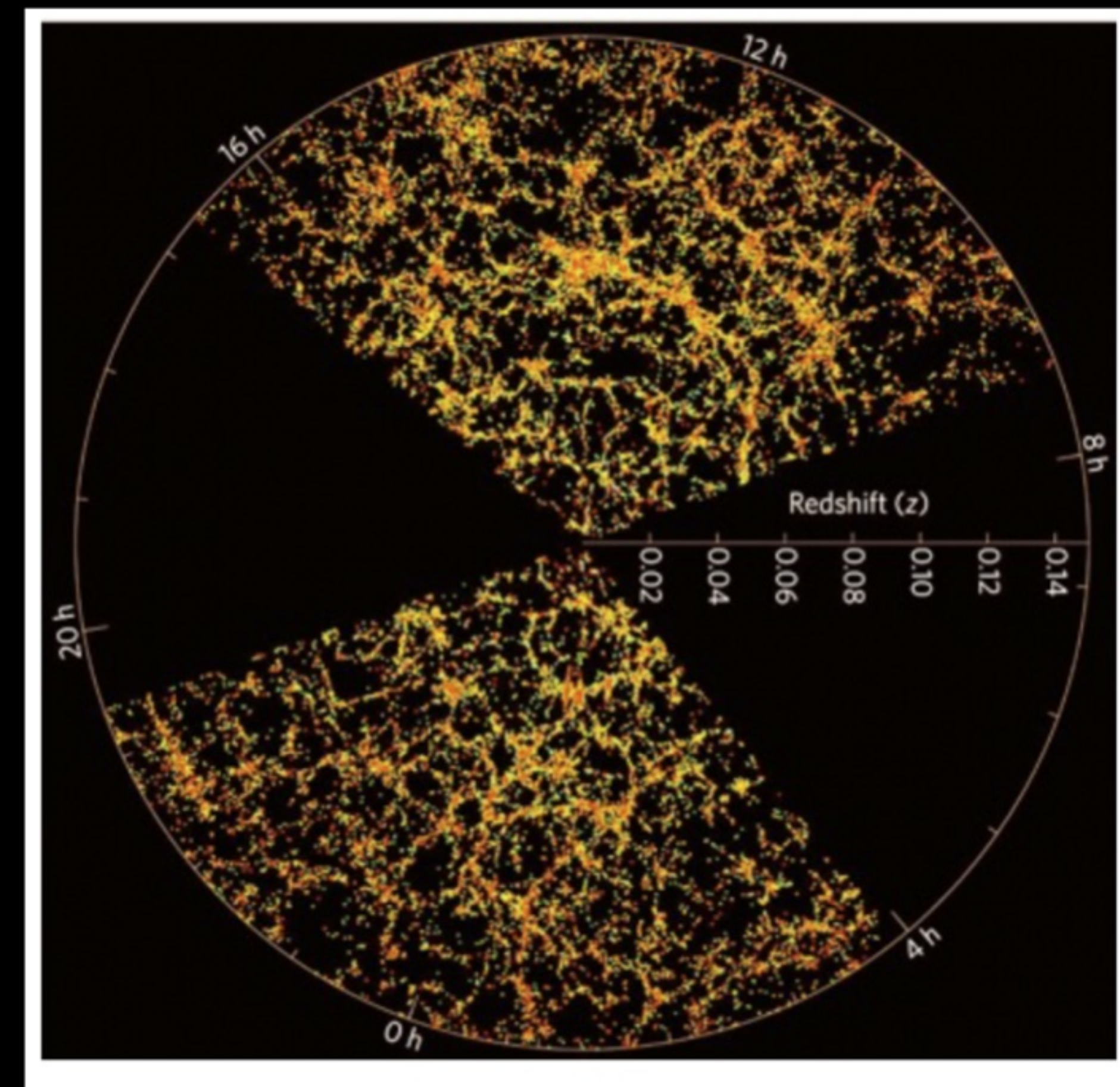
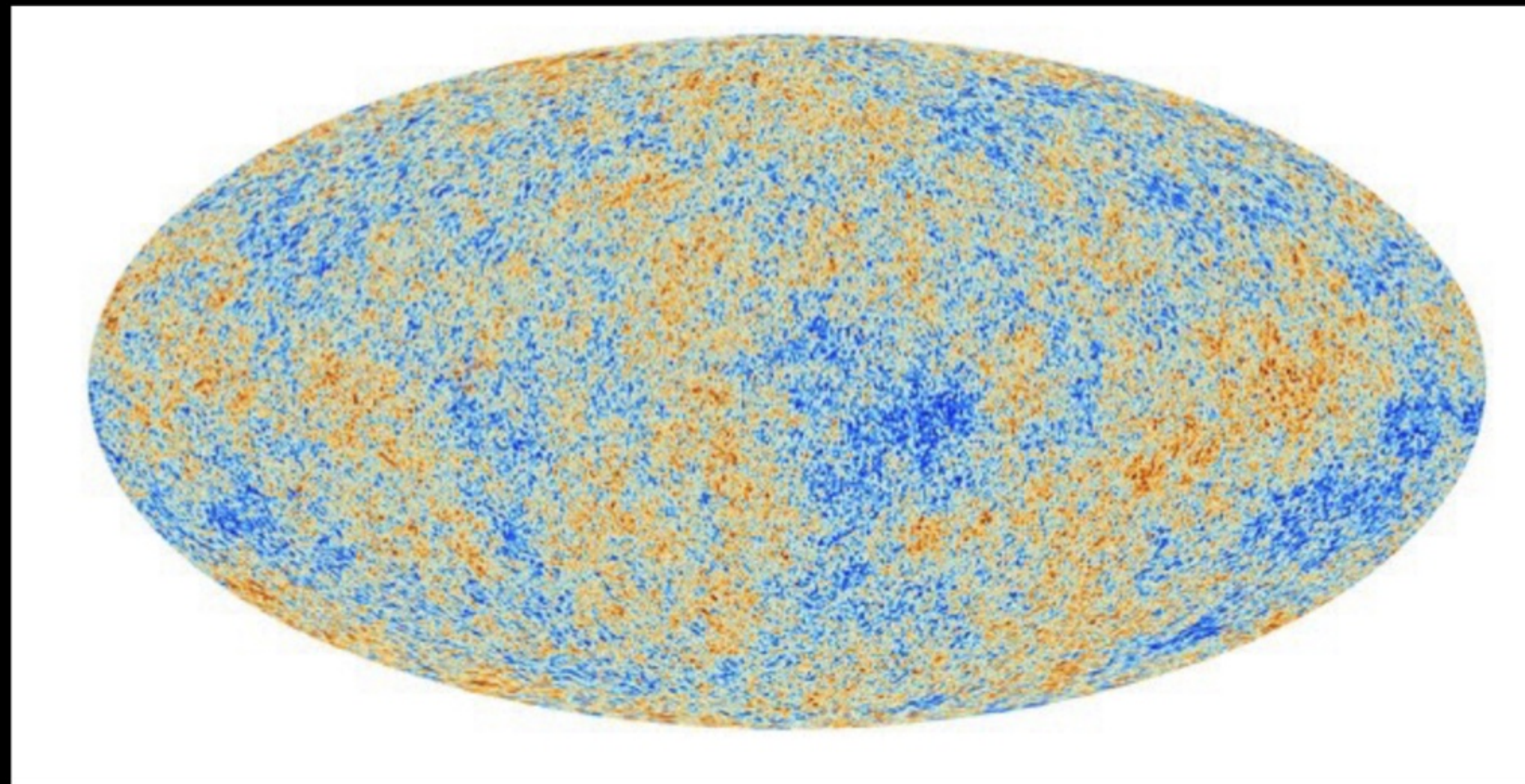


Galaxies as probes of fundamental physics

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

Planck



SDSS



Hubble Deep Field

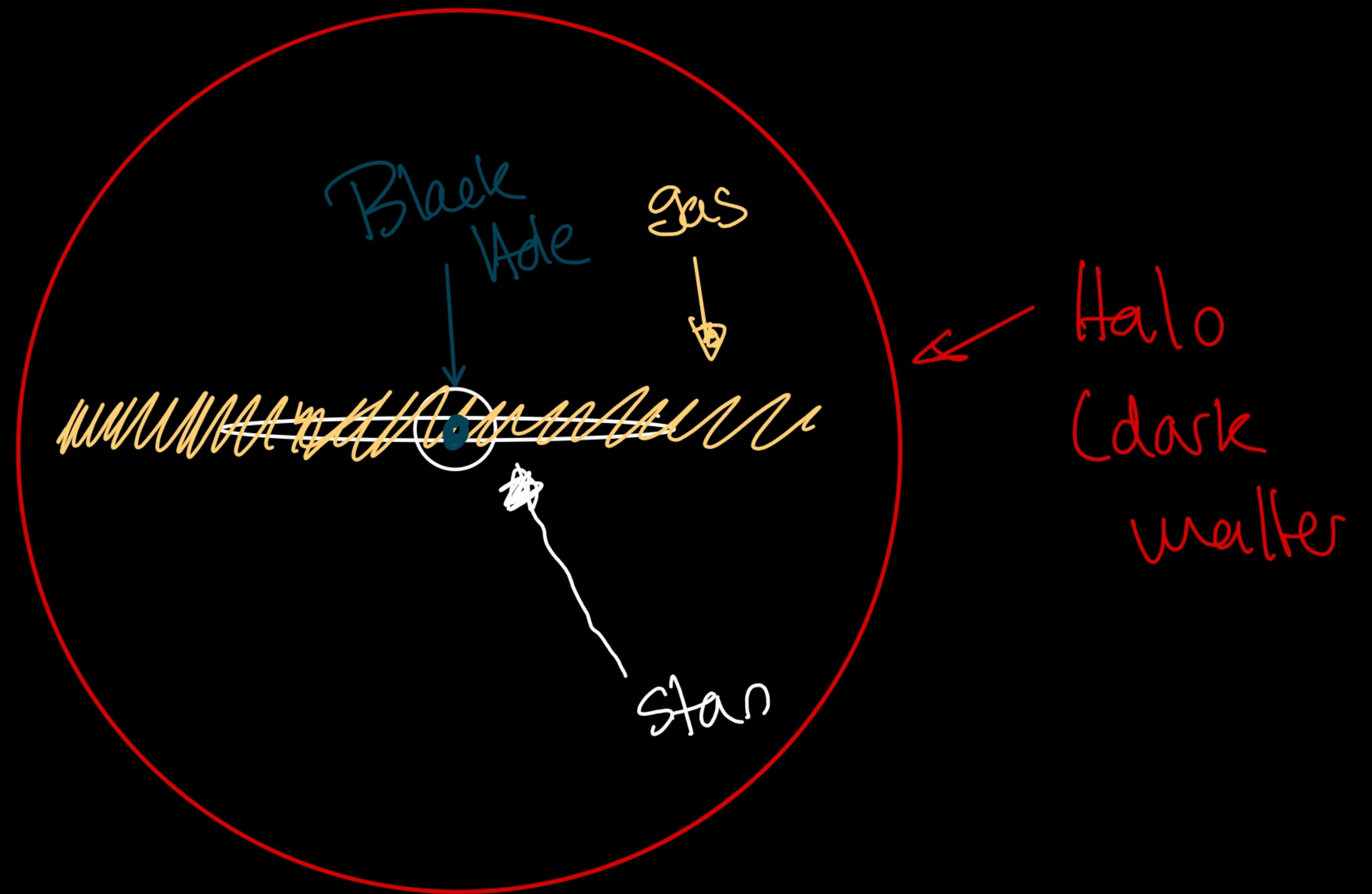
Galaxies as probes of fundamental physics

In large scale structure, galaxies are mere building blocks $\rightarrow$ "dots".

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

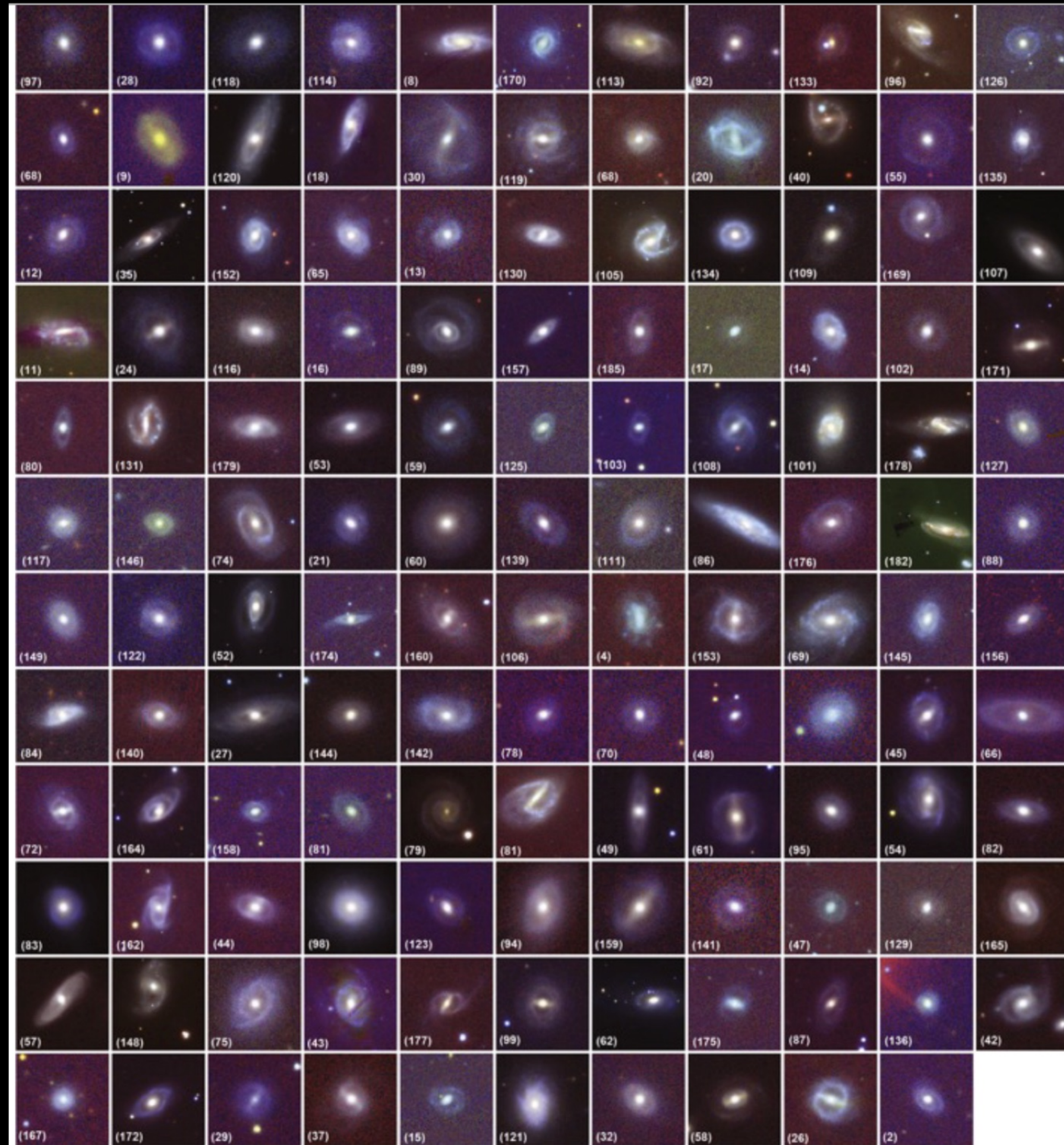
Search for fifth forces in Galaxies

Galaxies as probes of fundamental physics



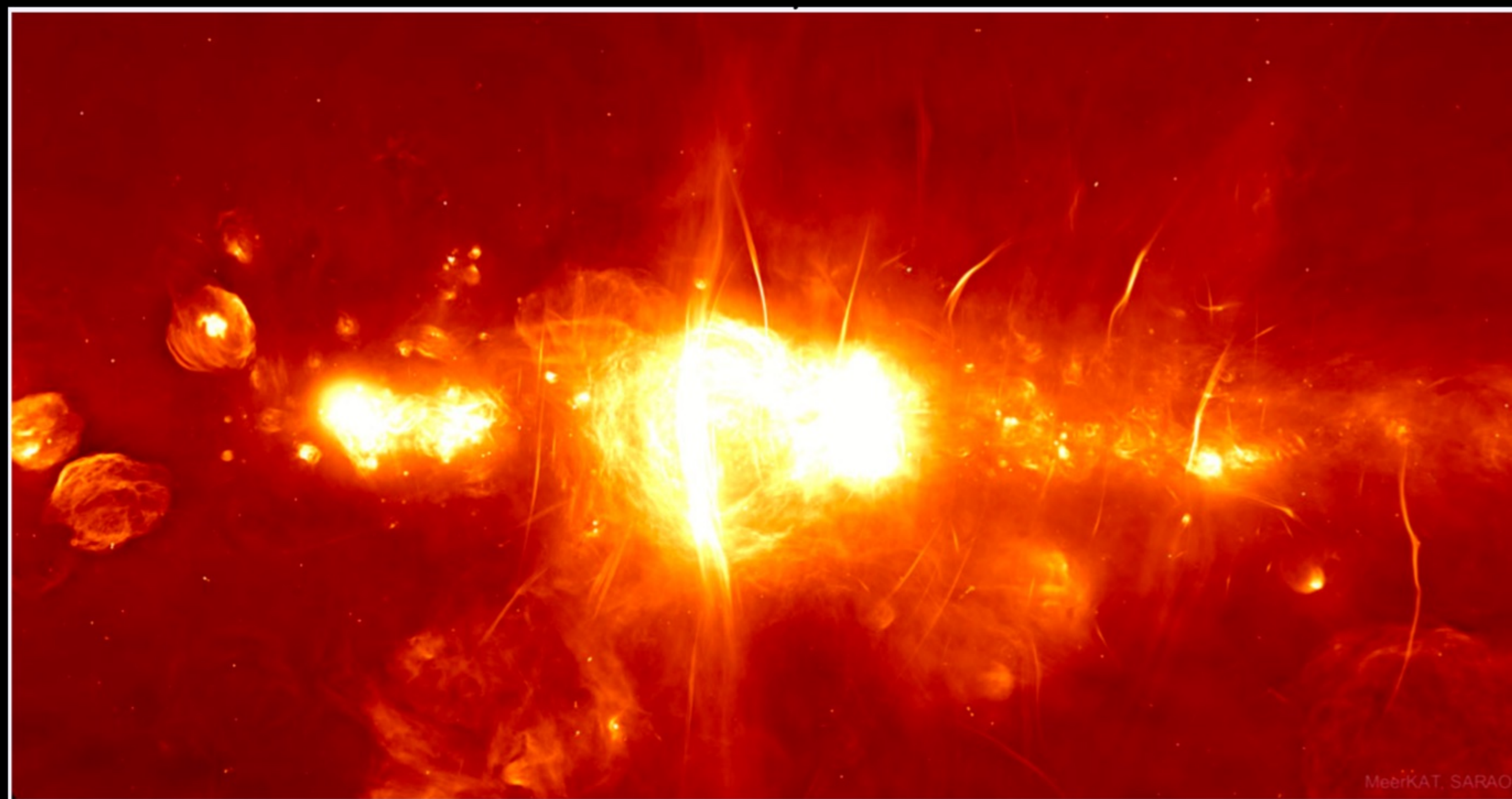
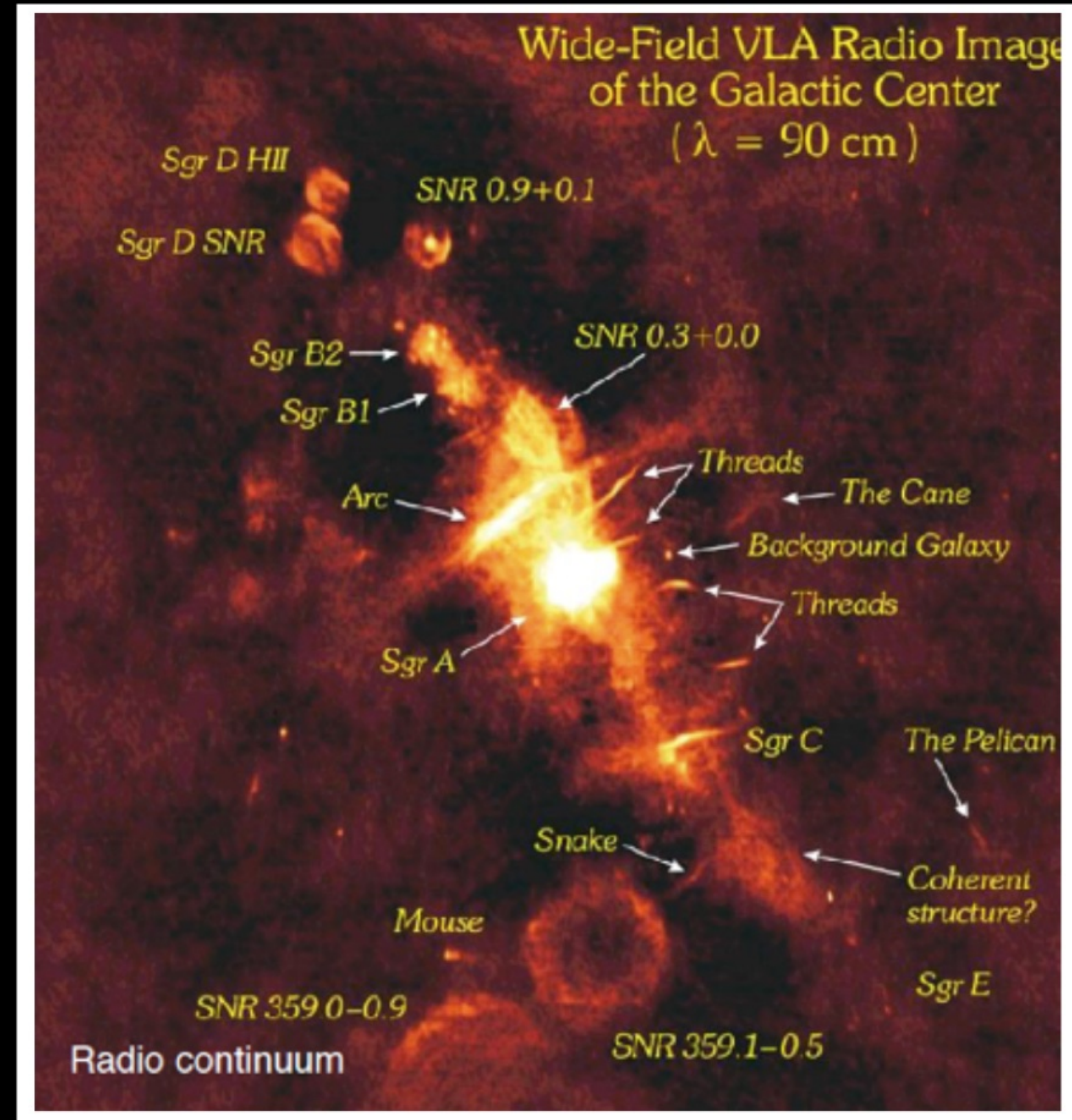
See Baker et al, 1908.03430

Galaxies as probes of fundamental physics



SDSS

Galaxies as probes of fundamental physics

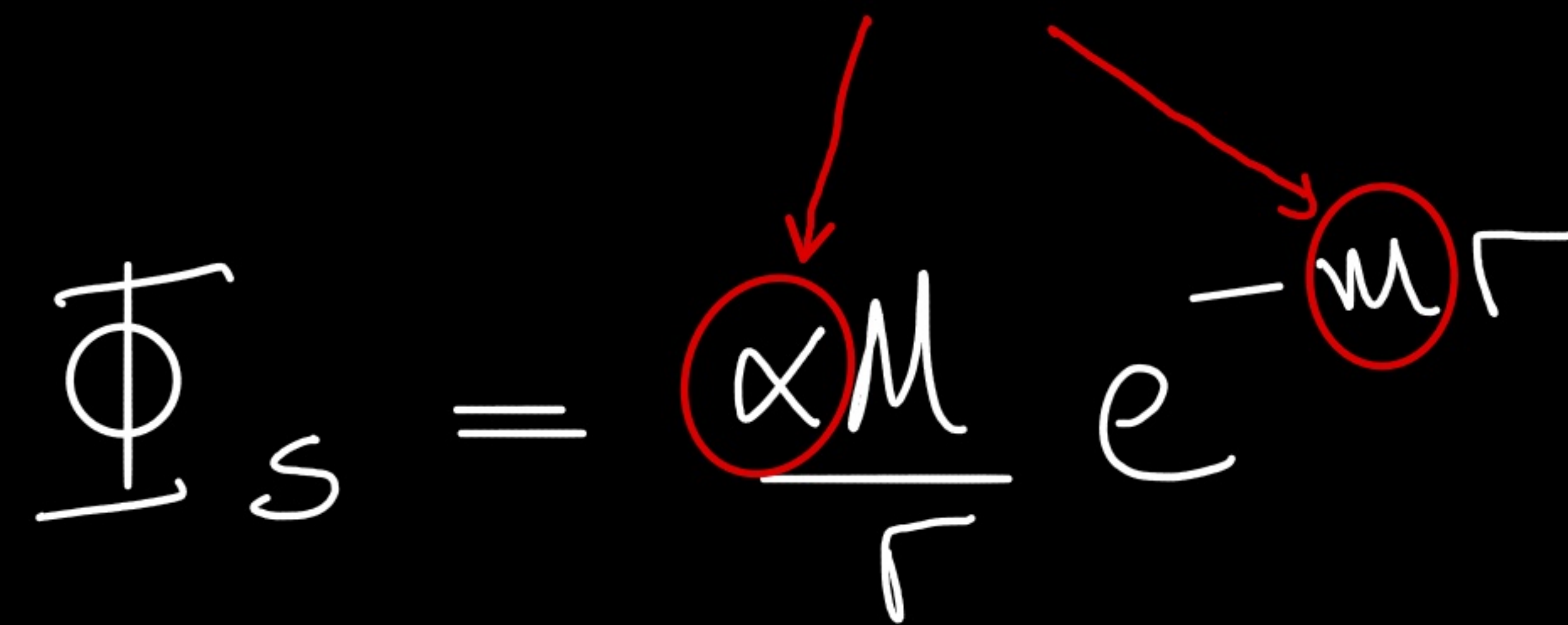


Meerkat
(Radio)
view of
centre of
our galaxy

Galaxies as probes of fundamental physics

Gravitational screening:

Depend on environment/mass ...

$$\Phi_s = \frac{\propto M}{r} e^{-m r}$$


Look at galaxies and constituents in different environments.

E.g. in voids versus clusters

• at stars versus gas and dark matter

• at black holes versus stars.

Galaxies as probes of fundamental physics

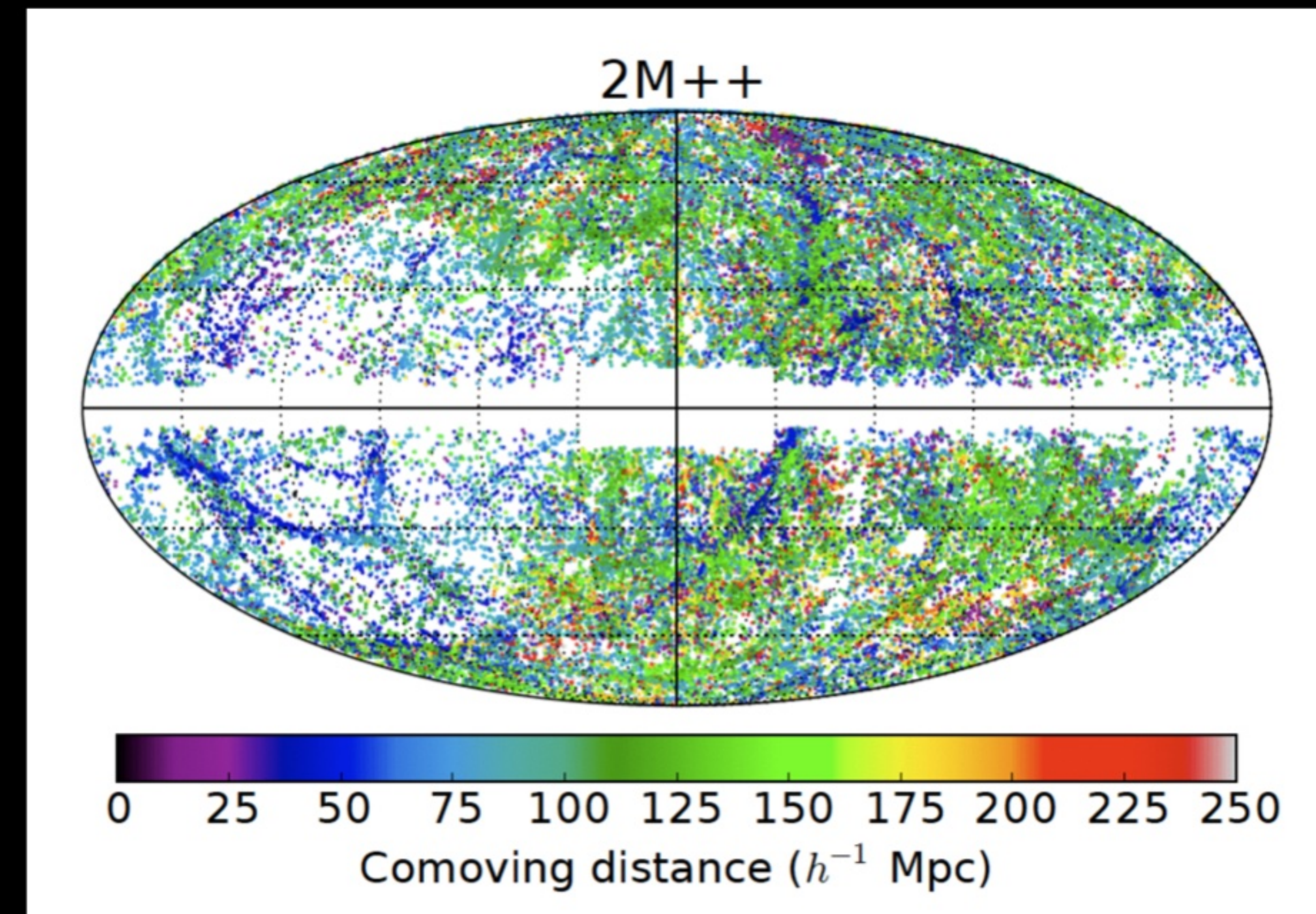
Environment: Build a "grand unified map" of the Universe

- Galaxy catalogue $\longrightarrow$

- Fill in long wavelength modes with BORG (Sims)

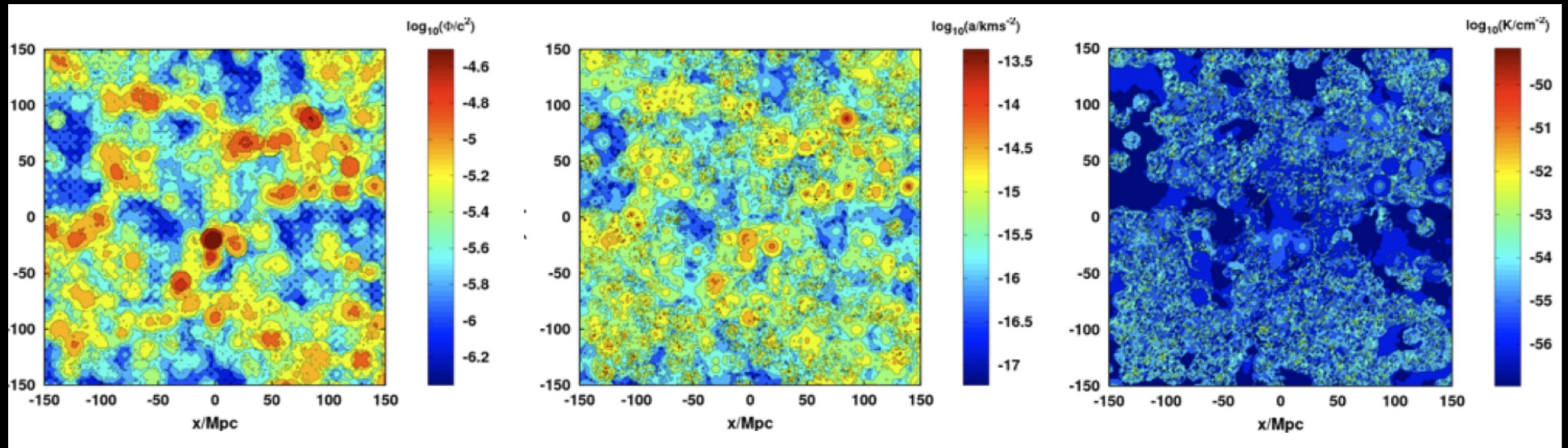
- Use abundance matching to associate halos to galaxies (short wavelengths).

Desmond et al, MNRAS 474, 3152
(2018)



Galaxies as probes of fundamental physics

2D slices of the Universe



Φ/c^2

(gravitational potential)

a

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

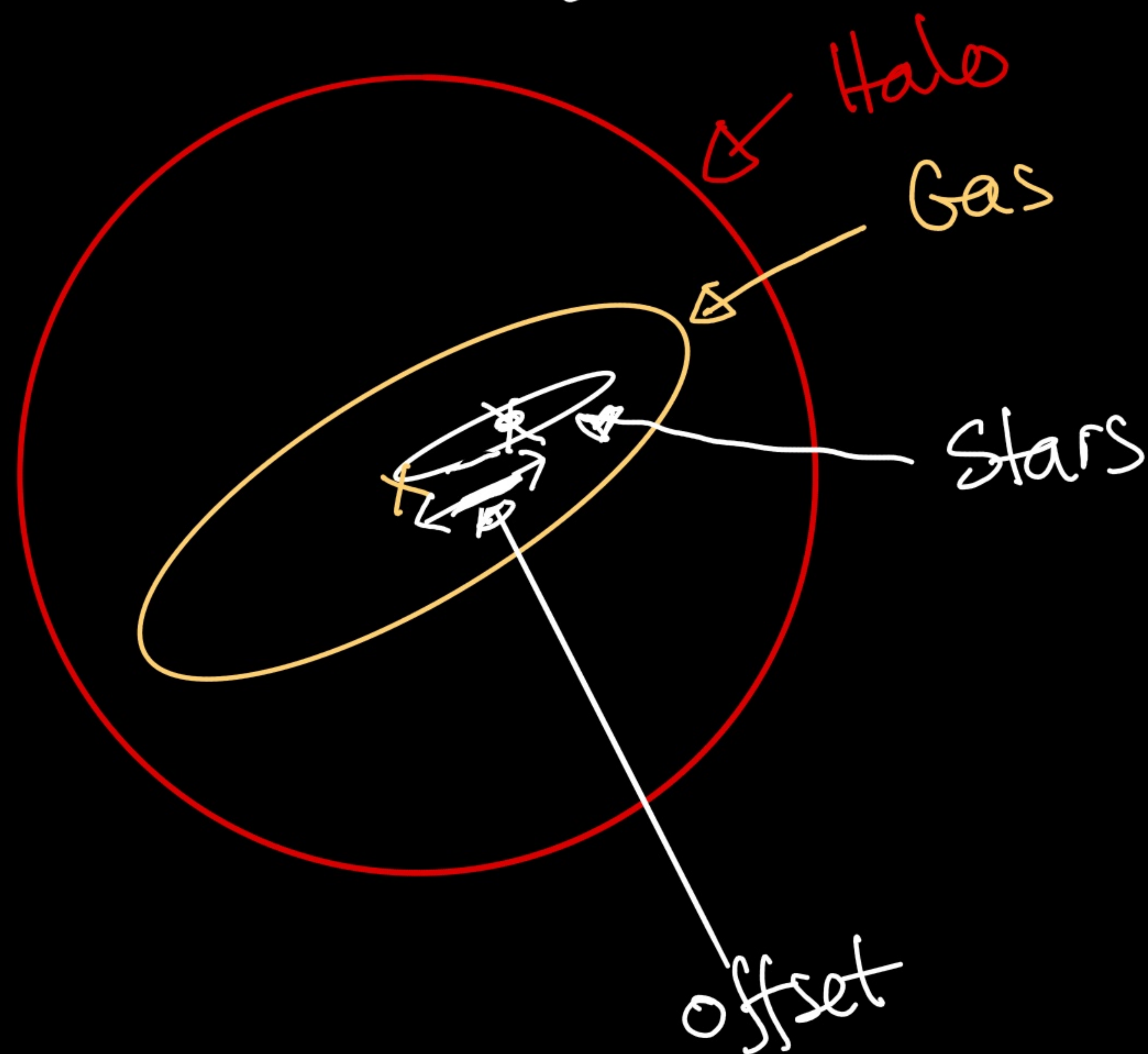
K

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

Galaxies as probes of fundamental physics

What do we look for?

Galactic offsets



$$\overset{\text{Gas Halo}}{\downarrow} a_{\text{unscreened}} = a_{\text{ext}} + \frac{\Delta G}{\Delta G} a_s$$

$$\overset{\text{Stars}}{\downarrow} a_{\text{screened}} = a_{\text{ext}} + G \frac{M(r_*)}{r_*}$$

So

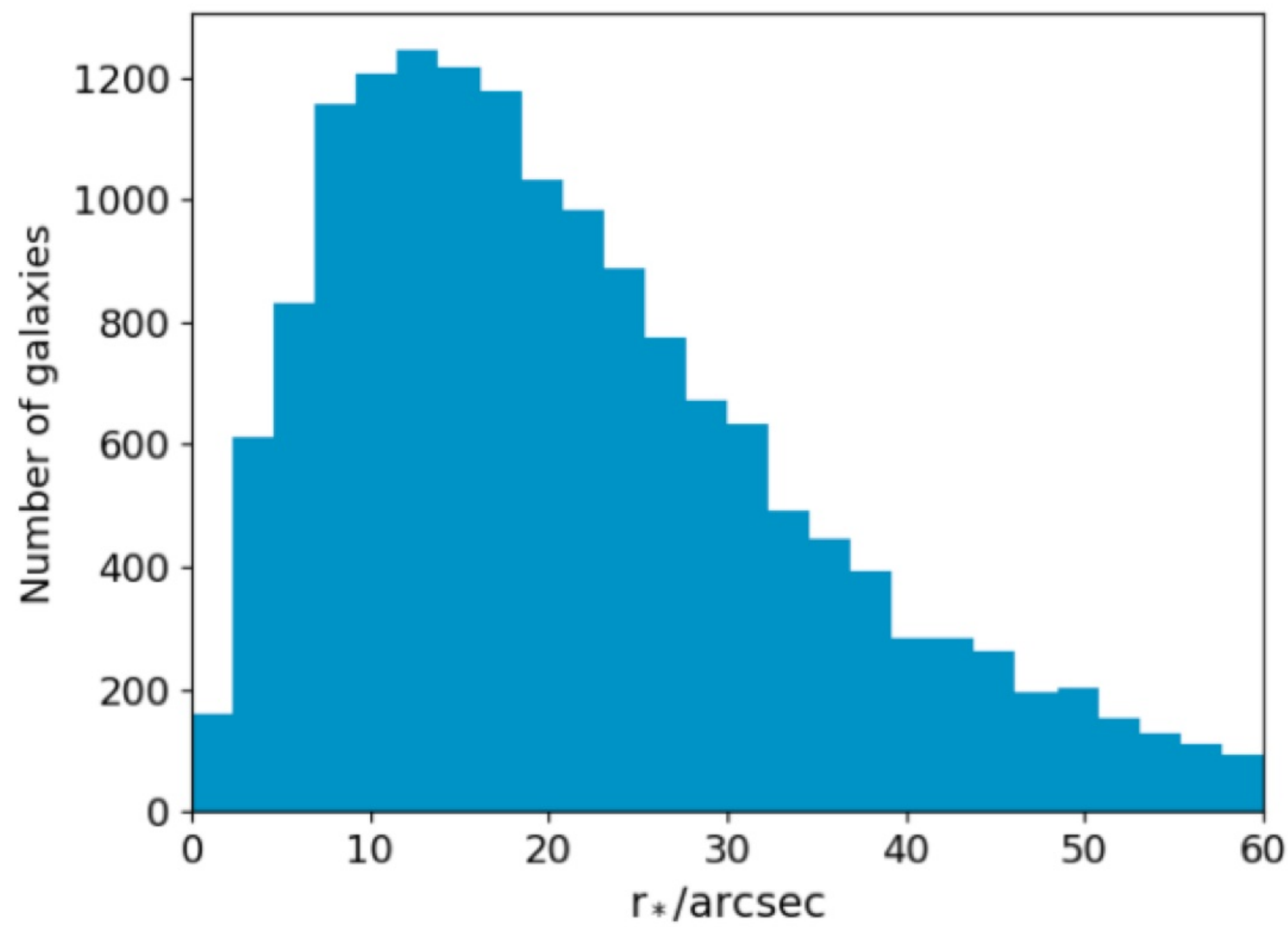
$$\frac{M(r_*)}{r_*^2} = a_s \frac{\Delta G}{G^2}$$

$$r_* = 0$$

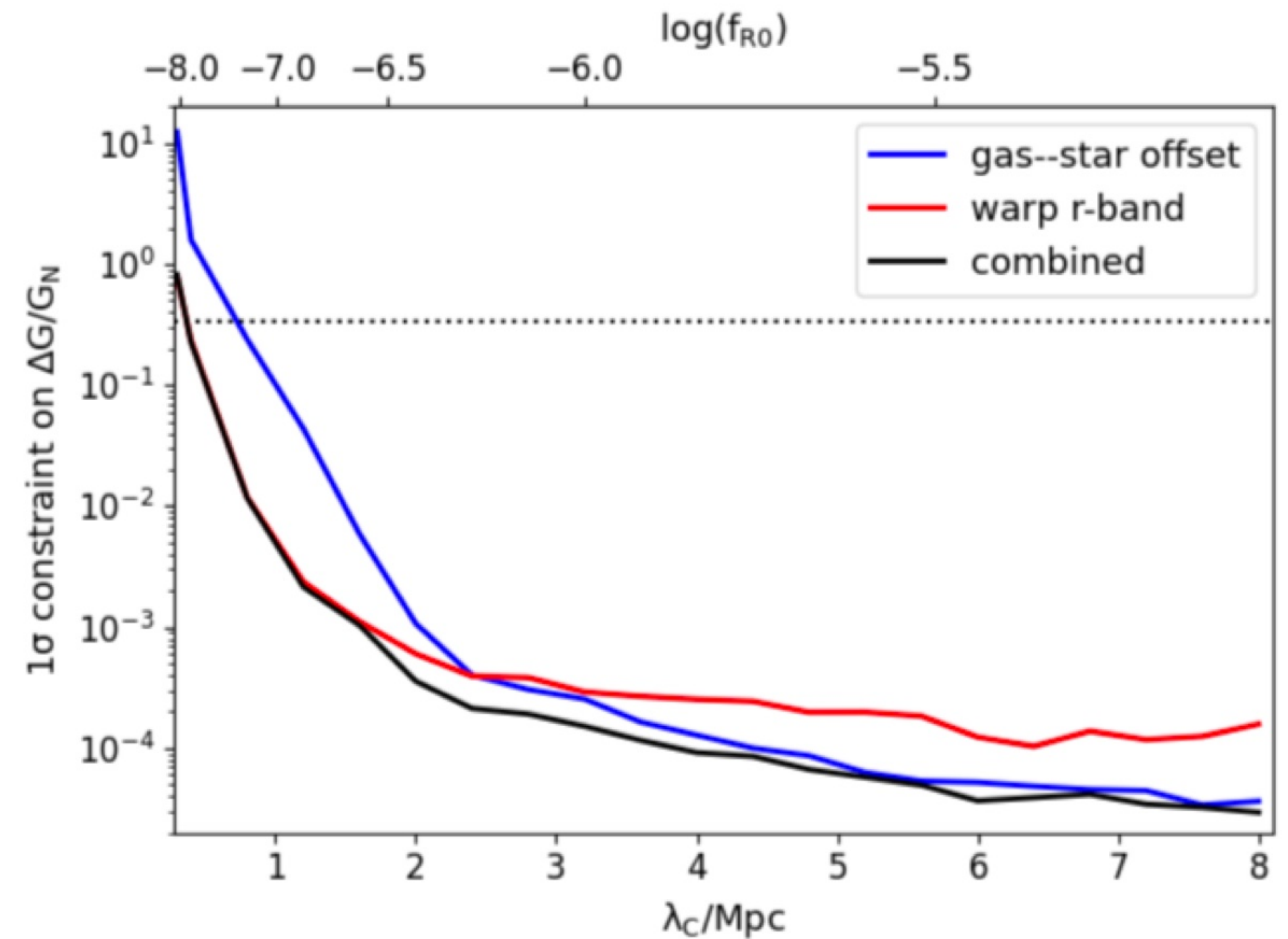
(screened)
if $|\Phi| < |\Phi_c|$

if $|\Phi| > |\Phi_c|$
(unscreened)

Galaxies as probes of fundamental physics



Offsets

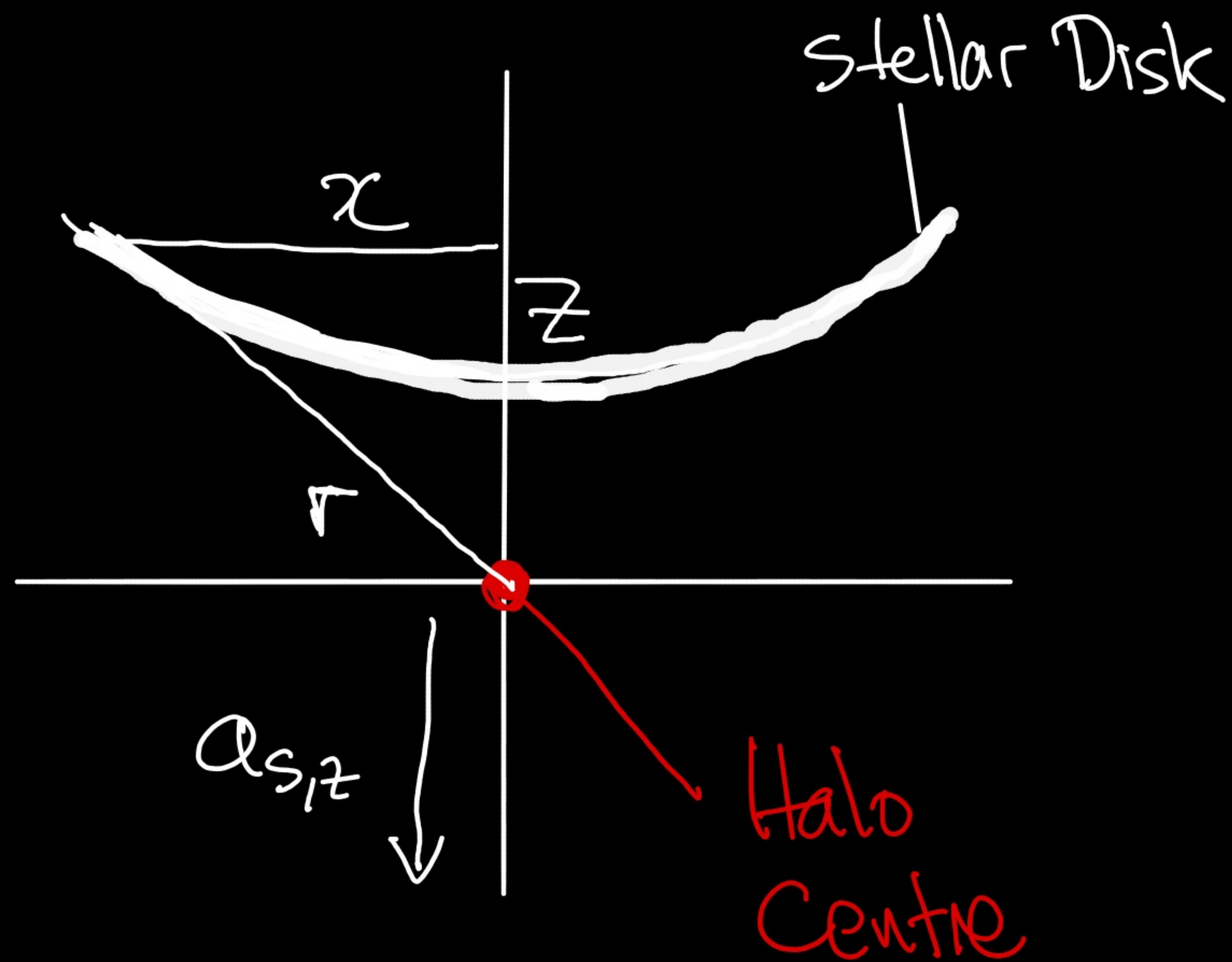


Screening Scale

Desmond & Ferreira, 2010.05811

Galaxies as probes of fundamental physics

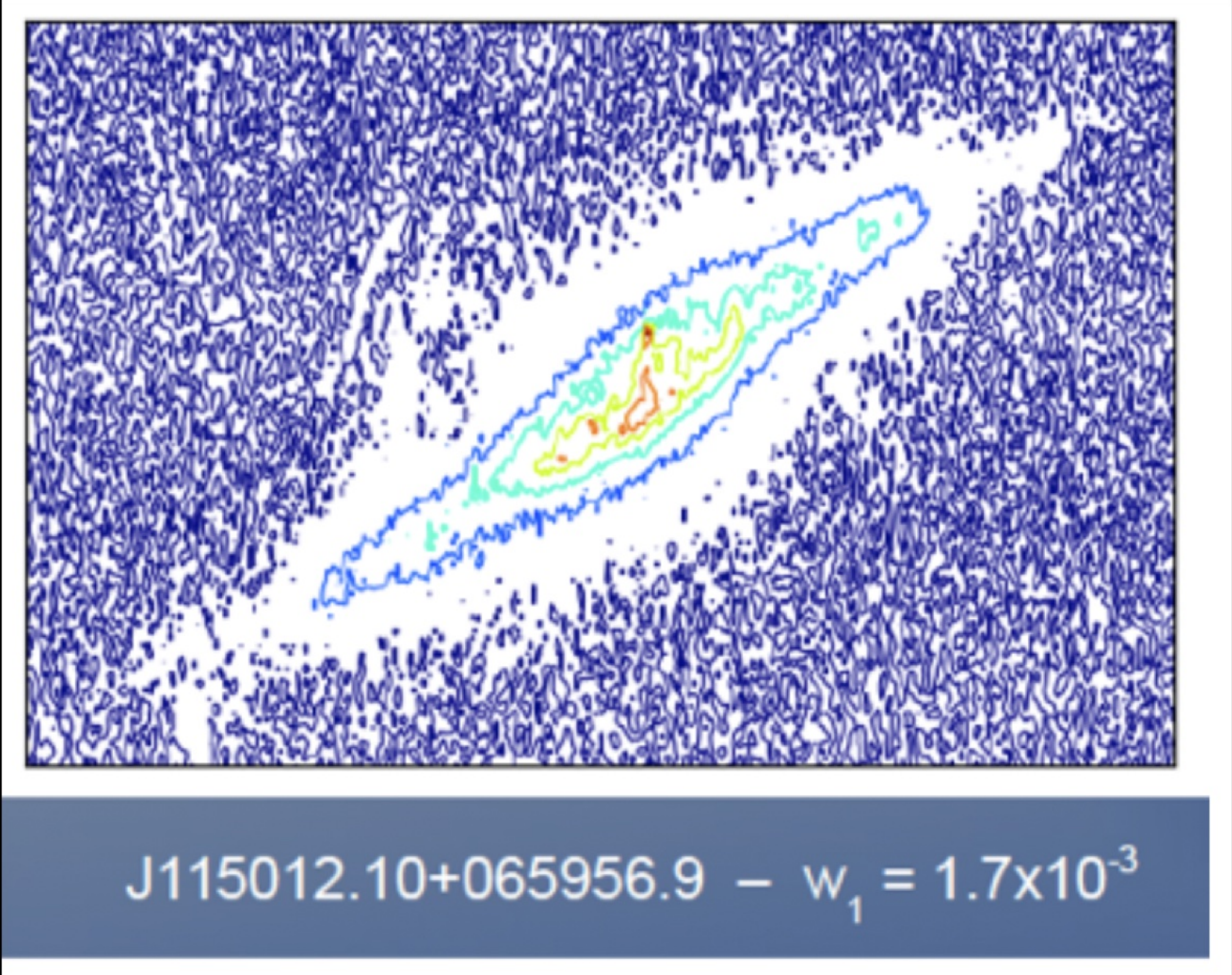
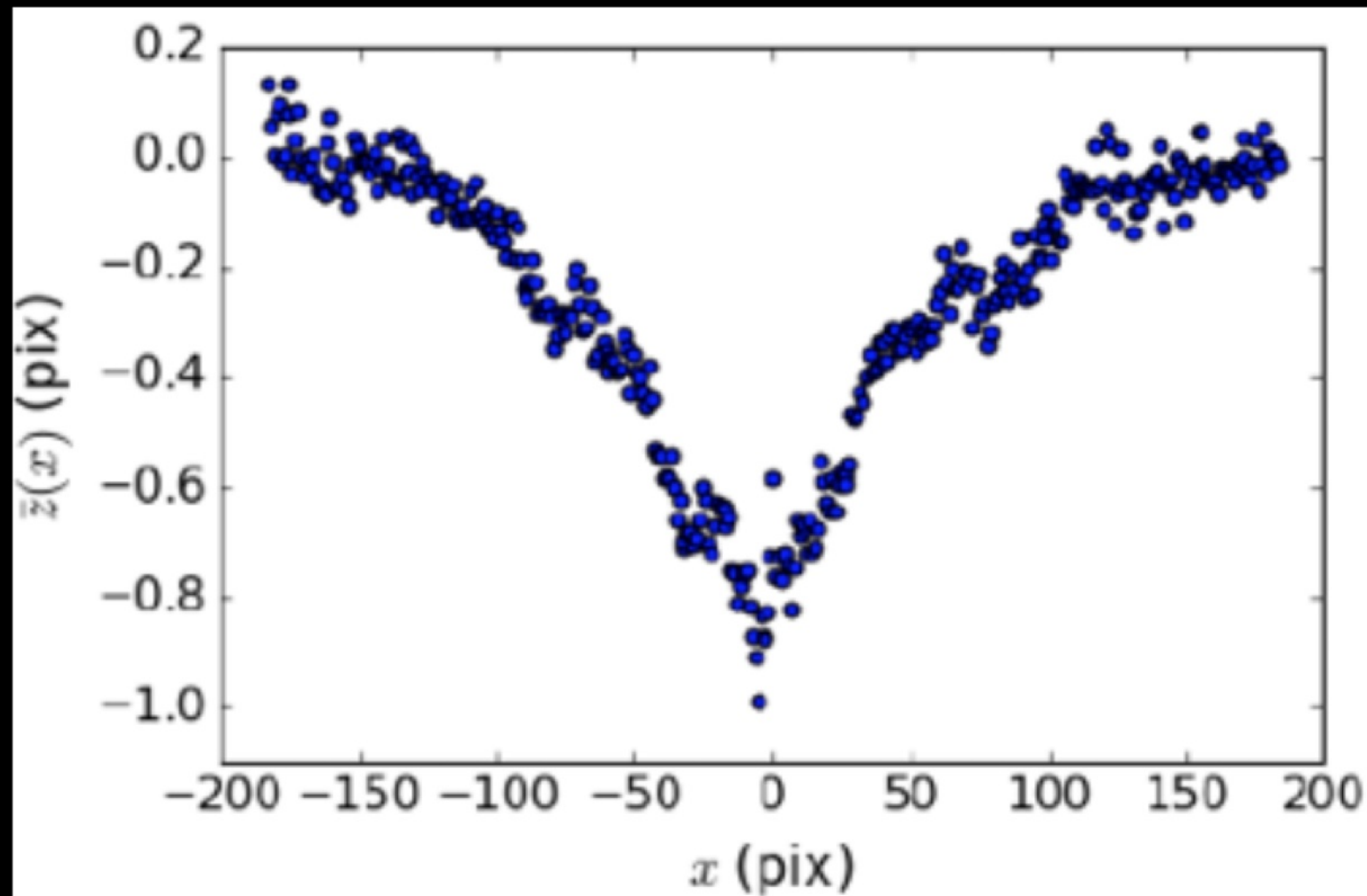
What do we look for? Warps



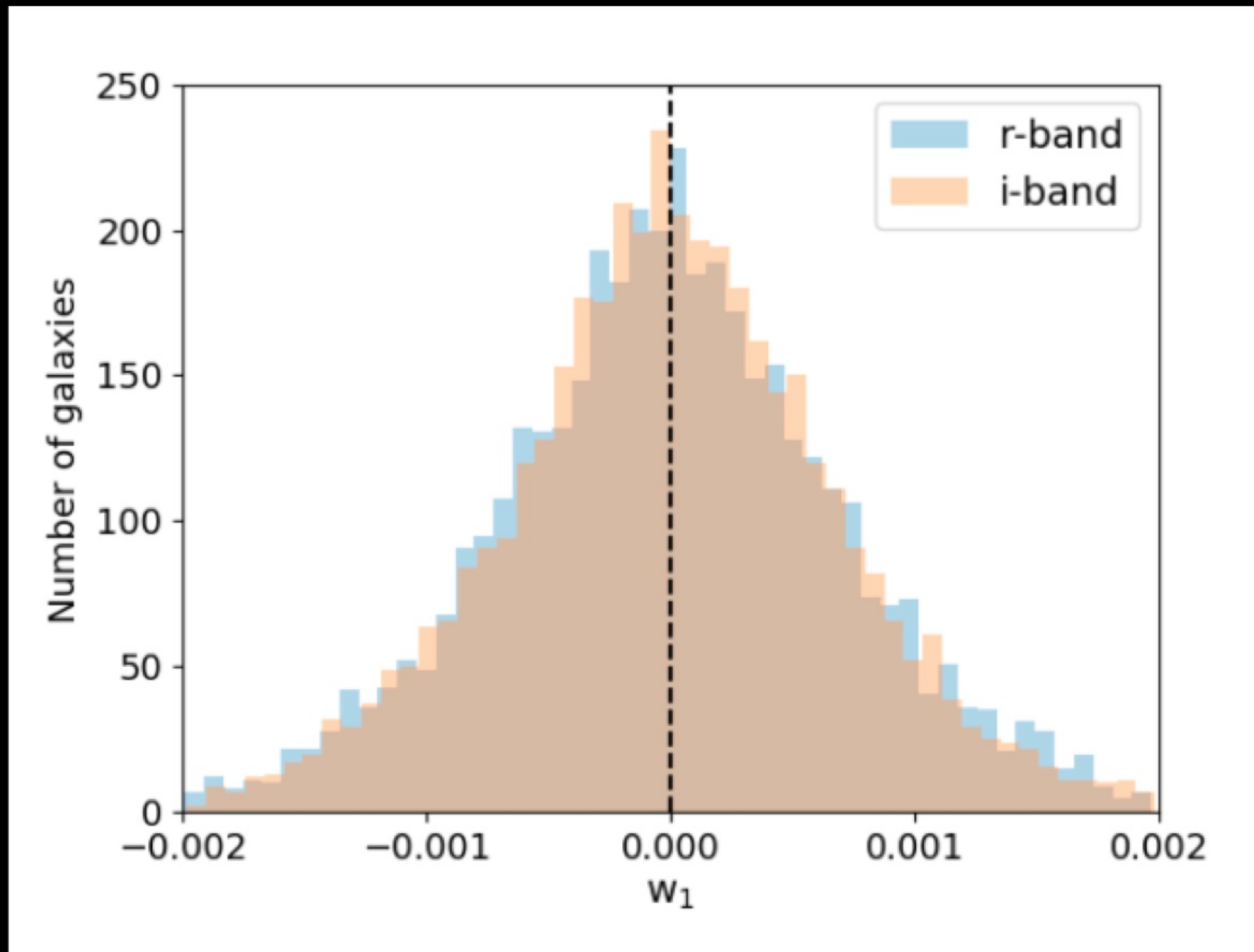
$$z(x) = -a_{s,z} \frac{\Delta G}{G_N^2} \frac{|x|^3}{M_{\text{halo}}(<x)}$$

$$w_1 = \frac{1}{L_x^3} \int_{-L_x}^{L_x} |x| z(x) dx$$

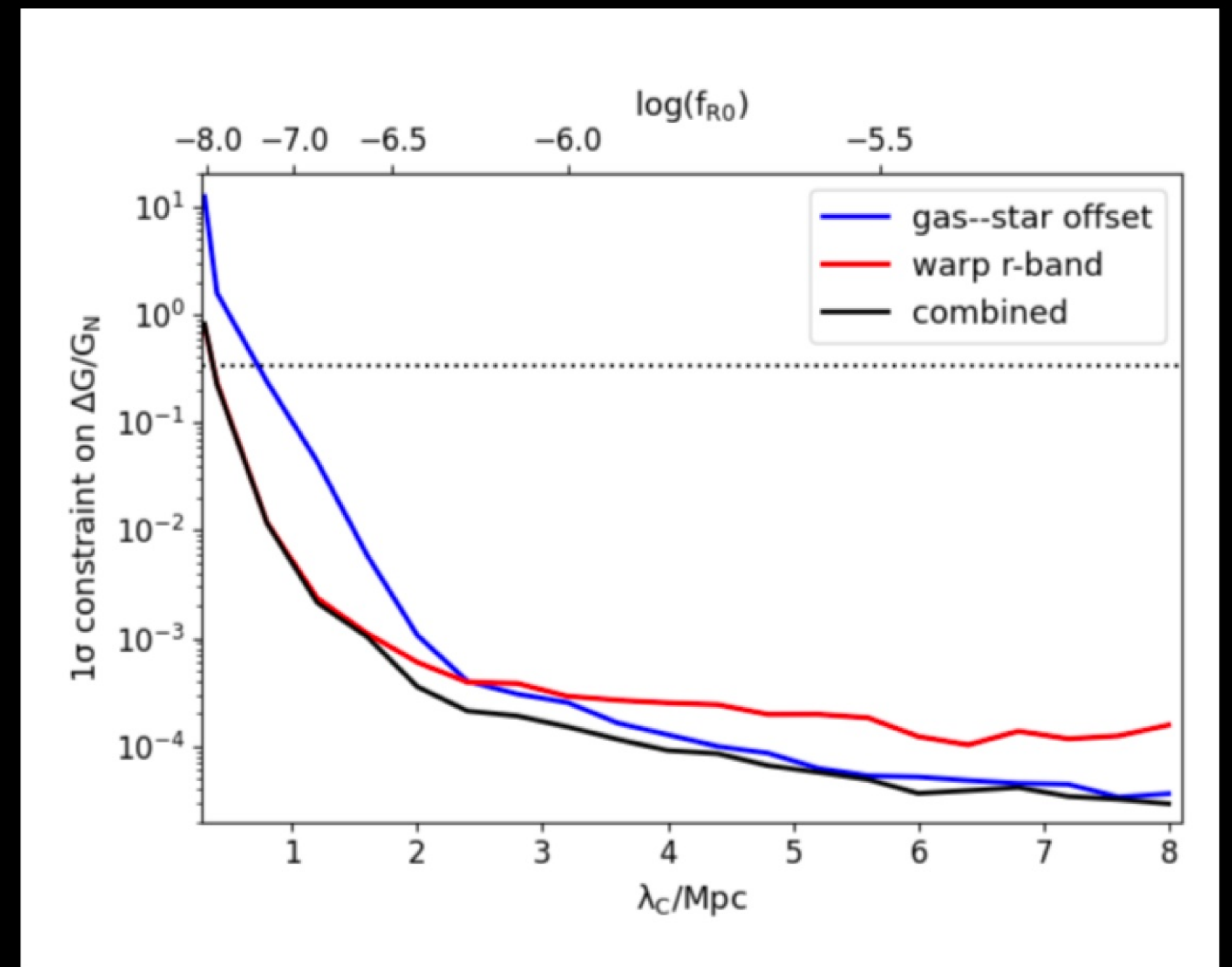
Galaxies as probes of fundamental physics



Galaxies as probes of fundamental physics



→
warp



→
Screening Scale

Desmond & Ferreira, 2010.05811

Galaxies as probes of fundamental physics

What does it mean?

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

$$f_{R_0} = \partial_R f|_{a=a_0}$$

Galaxy constraints: $f_{R_0} \lesssim 10^{-8}$

i.e. all objects are screened and so

no astrophysical significance!

Galaxies as probes of fundamental physics

Vainshtein Screening test.

Galilean models : invariant $\phi \rightarrow \phi + d_\mu x^\mu + c$

Have screening but Black holes are
unscreened

so

Star
Motion

$\neq$

Black Hole
Motion

Offset!

Galaxies as probes of fundamental physics

Vainshtein Screening test.

Fifth force has magnitude

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

Scalar charge

$$Q = \int T^0_0 d^3x$$

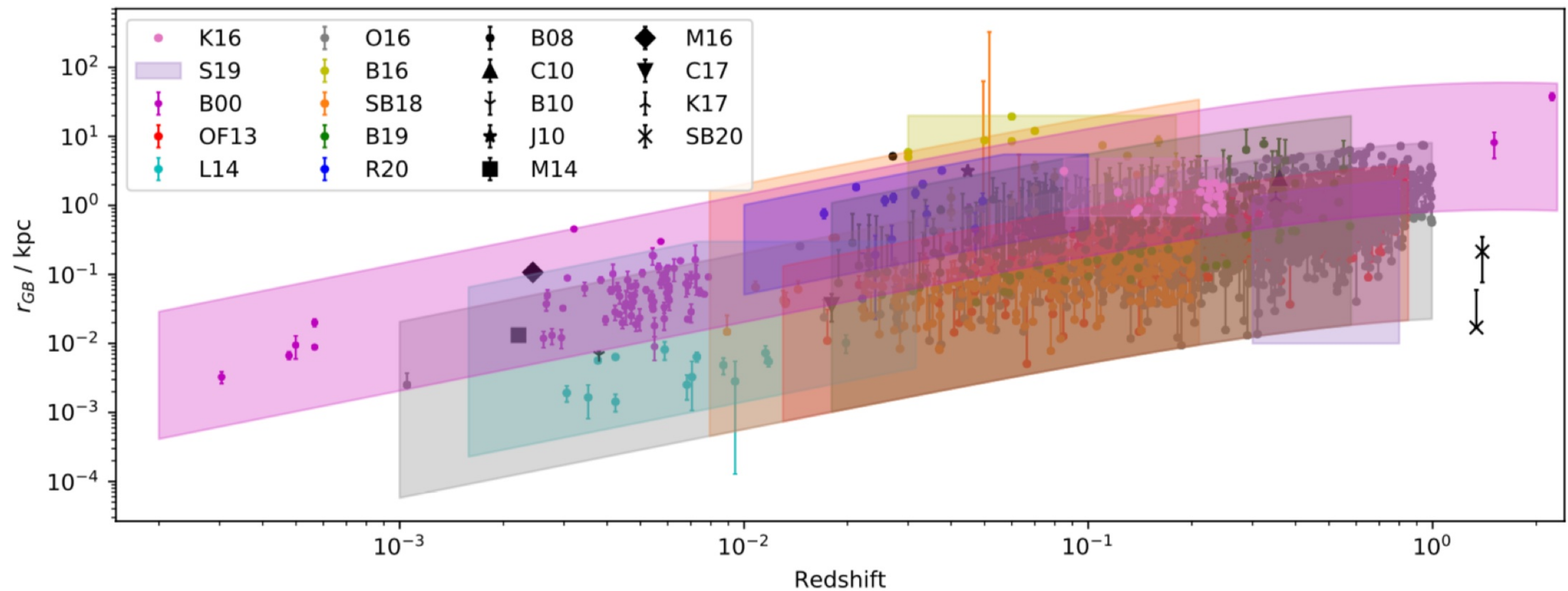
↑
density

Vainshtein
Radius

Galaxies as probes of fundamental physics

Vainshtein Screening test.

Black hole offsets $\rightarrow$ Data



Today

$z \approx 1$

Galaxies as probes of fundamental physics

Vainshtein Screening test.

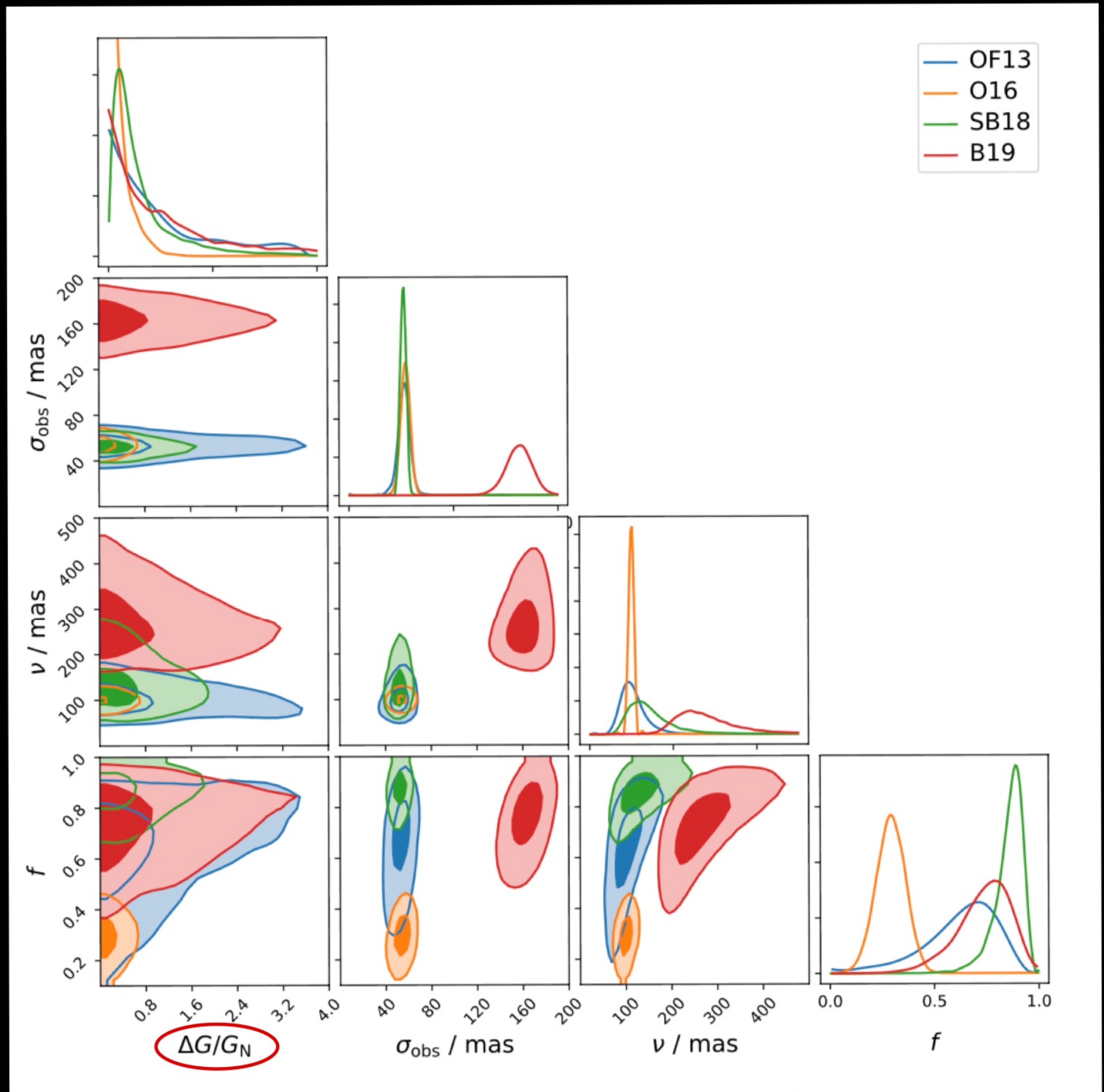
Model for offset distribution ($\Delta\theta$)

Gaussian

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

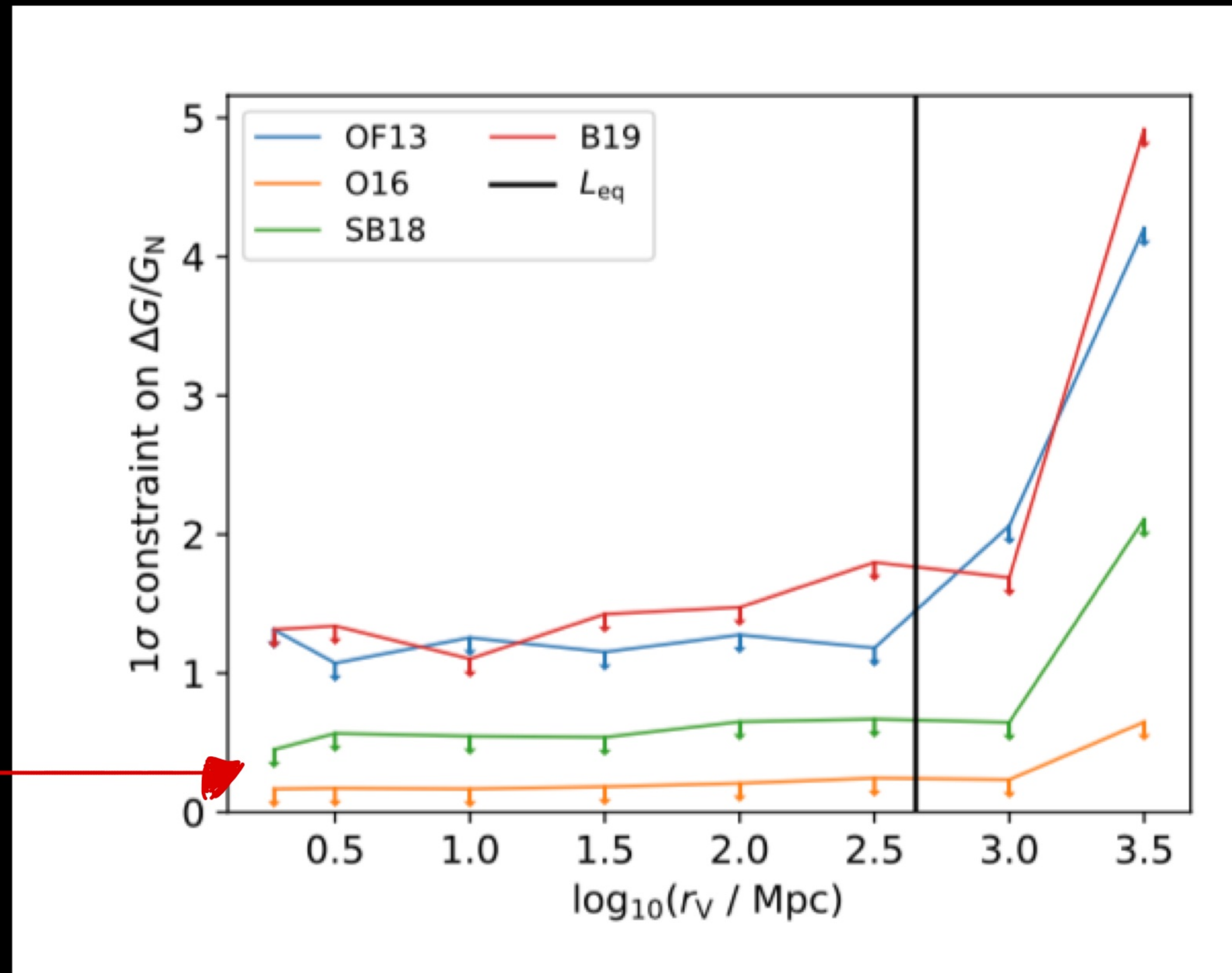
$$+ \frac{(1-f)}{2\nu} \exp\left(-\frac{|\Delta\theta|}{\nu}\right)$$

Laplace



Galaxies as probes of fundamental physics

Vainshtein Screening test.



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

Galaxies as probes of fundamental physics

Summary

- Galaxies have tremendous potential for constraining fundamental physics
- Very, very messy $\Rightarrow$ challenging
- "Messy" Bayesian Forward Modelling (The Future)
- Results $\Rightarrow$ Constraint on $f(R)$ is strong $f_R \sim 10^{-9}$
(the whole Universe is screened!)
- $\Rightarrow$ Constraint on Galileon $\frac{\Delta G}{G} \sim 0.1$