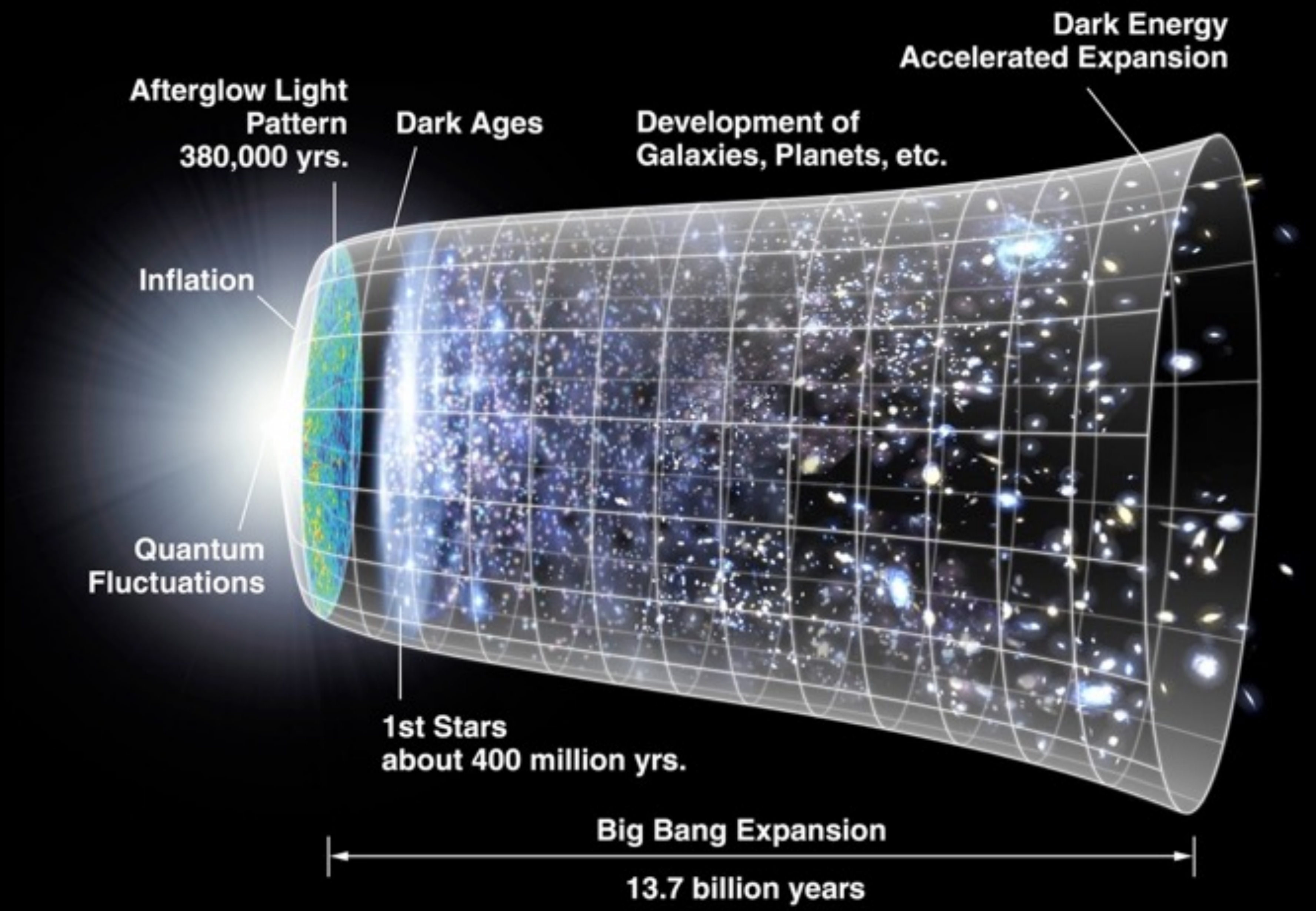
Testing Cosmological Models with Large-Scale Galaxy Surveys

Alvise Raccanelli

JOHNS HOPKINS
UNIVERSITY

with M. Kamionkowski, A. Szalay, J. Silk

The expansion of the Universe is accelerating



Why ?

The Dark Side

Dark Energy

$$G_{\mu\nu} = T_{\mu\nu} + T_{\mu\nu}^{\mathrm{de}}$$

Dark Energy

$$G_{\mu\nu} = T_{\mu\nu} + T^{\rm de}_{\mu\nu}$$

The Force

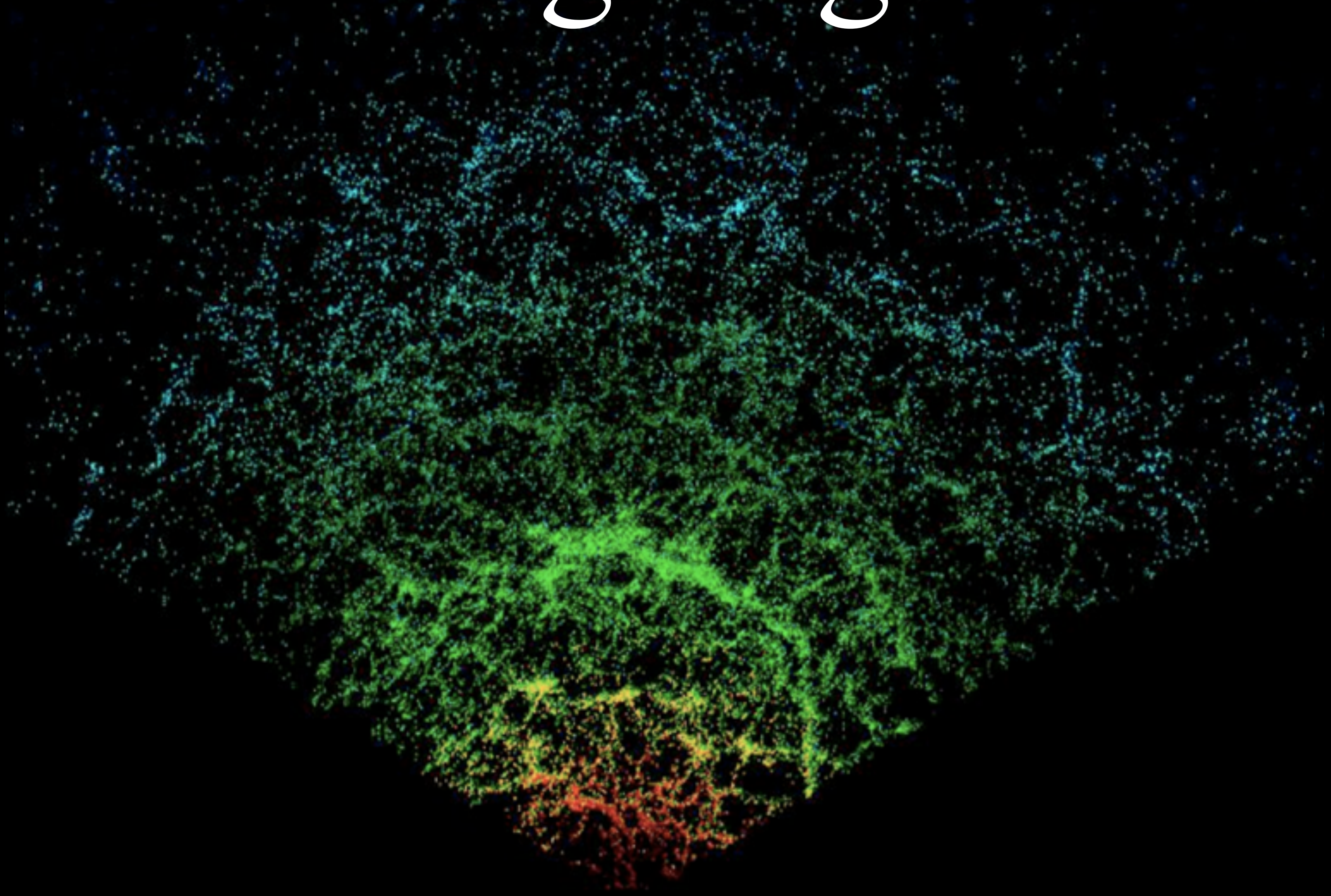
Dark Energy

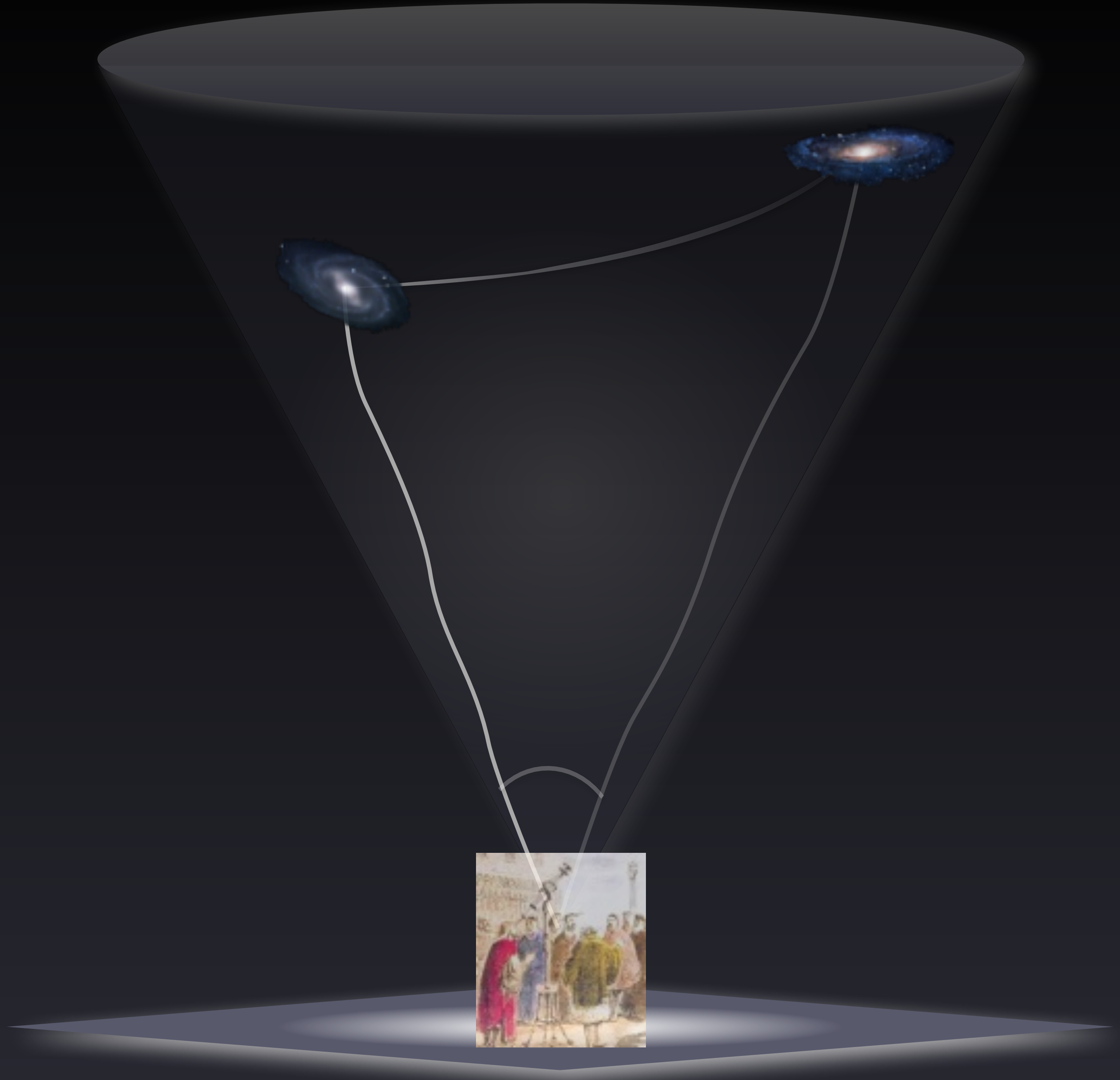
$$G_{\mu\nu} = T_{\mu\nu} + T_{\mu\nu}^{\rm de}$$

Modified Gravity

$$G_{\mu\nu} + G_{\mu\nu}^{\rm MG} = T_{\mu\nu}$$

We can look at the clustering of galaxies





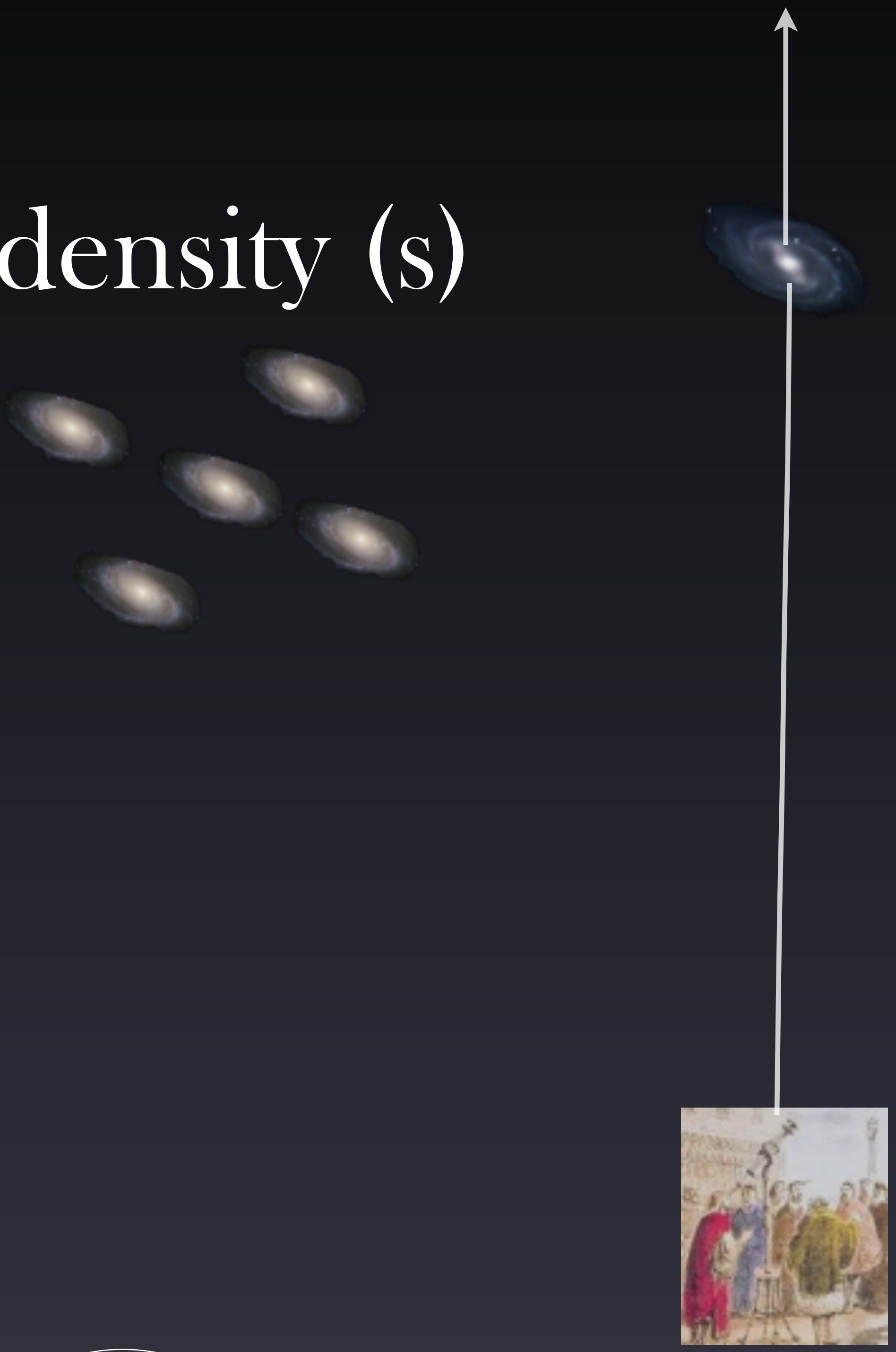
Real and Redshift Space in GR

Hubble expansion +

Real and Redshift Space in GR

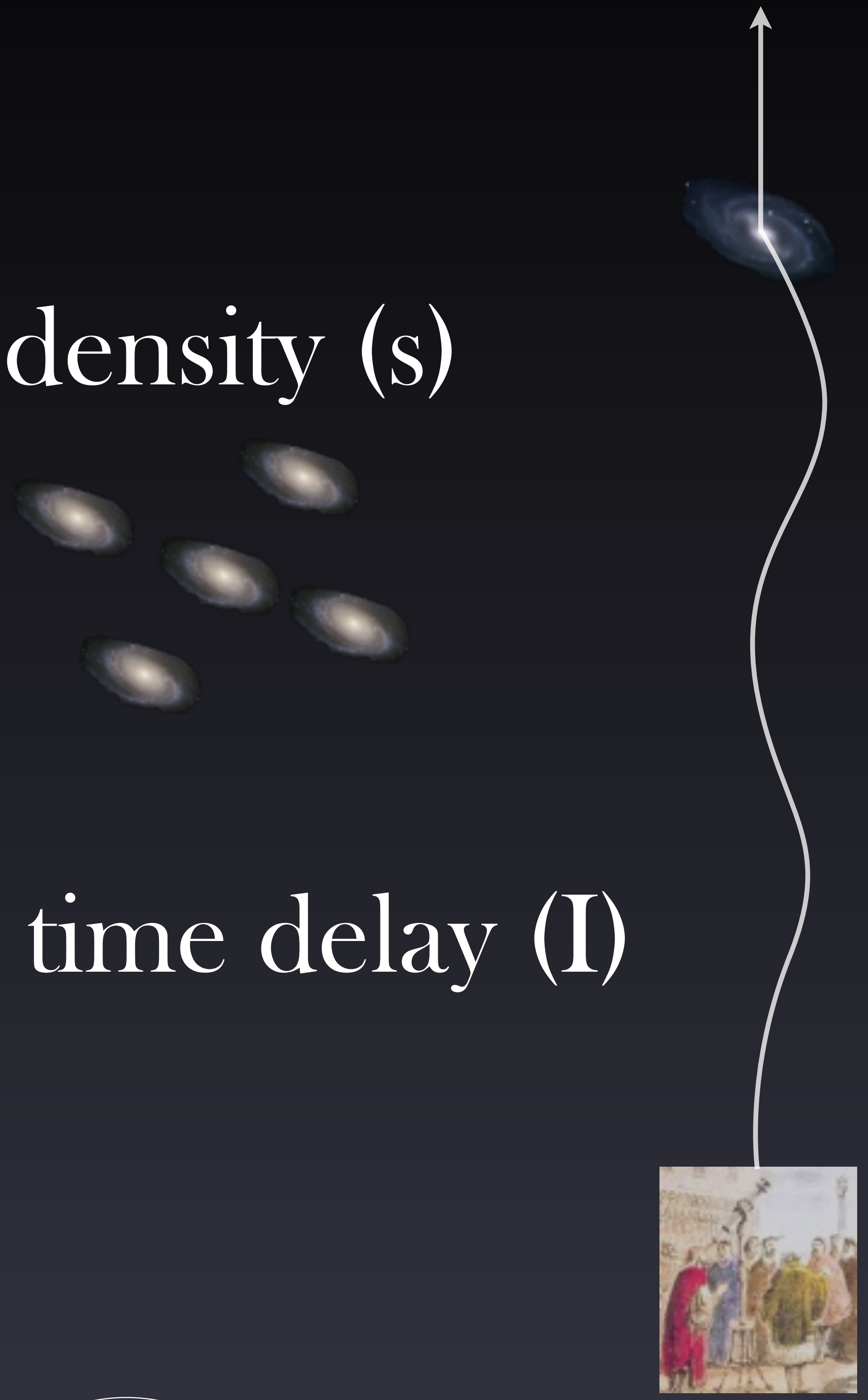
Hubble expansion +

local density (s)



Real and Redshift Space in GR

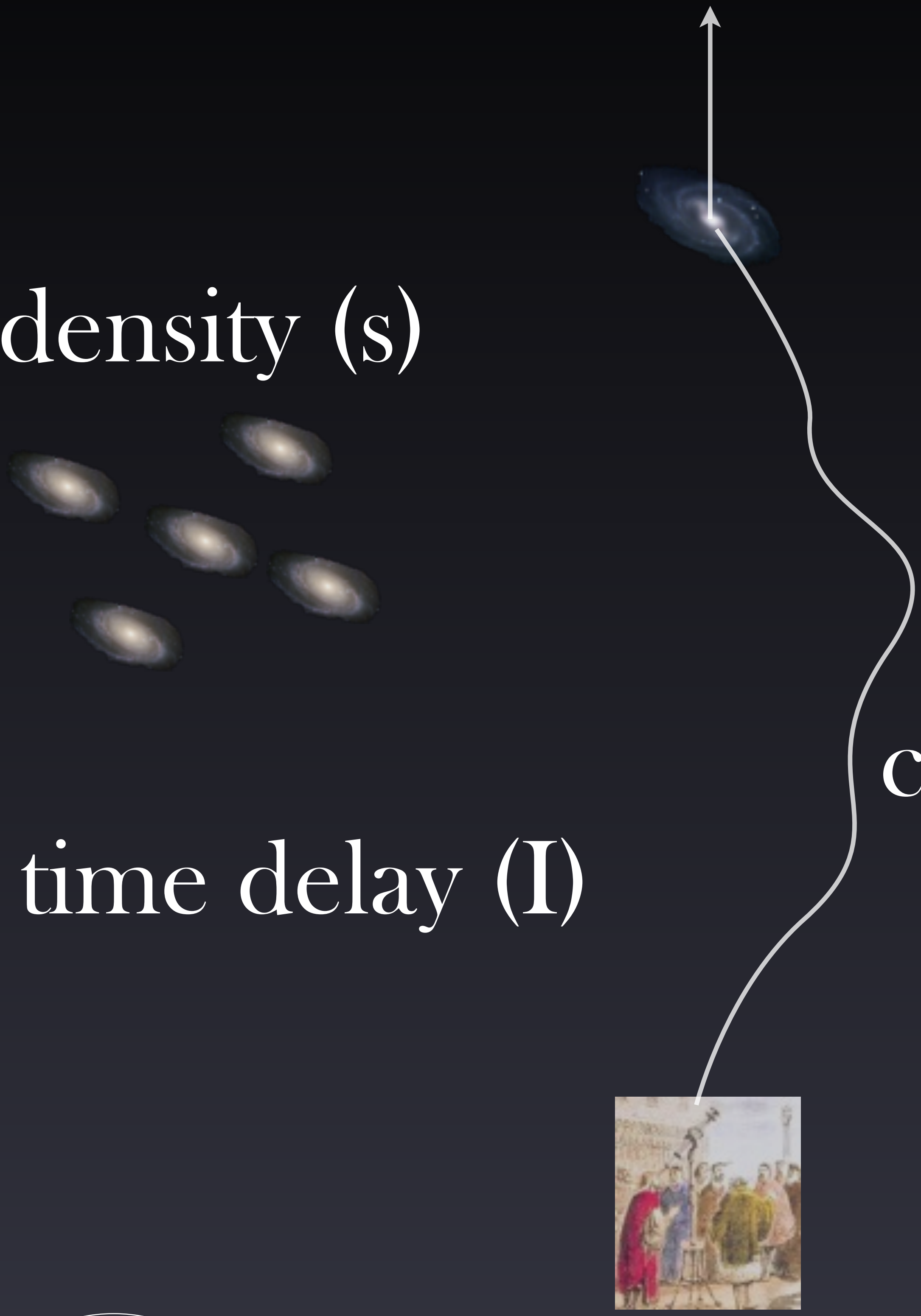
Hubble expansion +



local density (s)

time delay (I)

Real and Redshift Space in GR



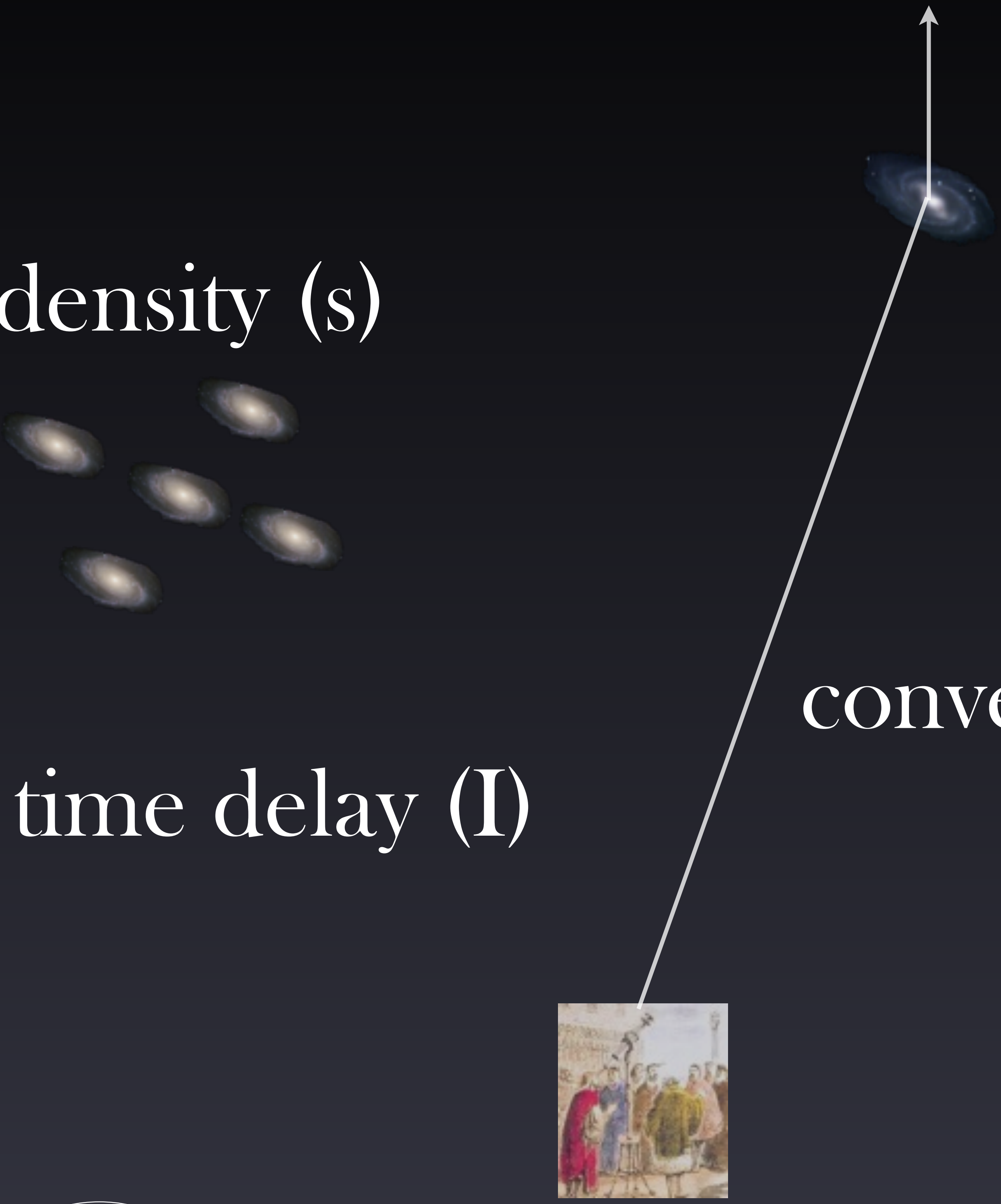
Hubble expansion +

local density (s)

convergence (κ)

time delay (I)

Real and Redshift Space in GR



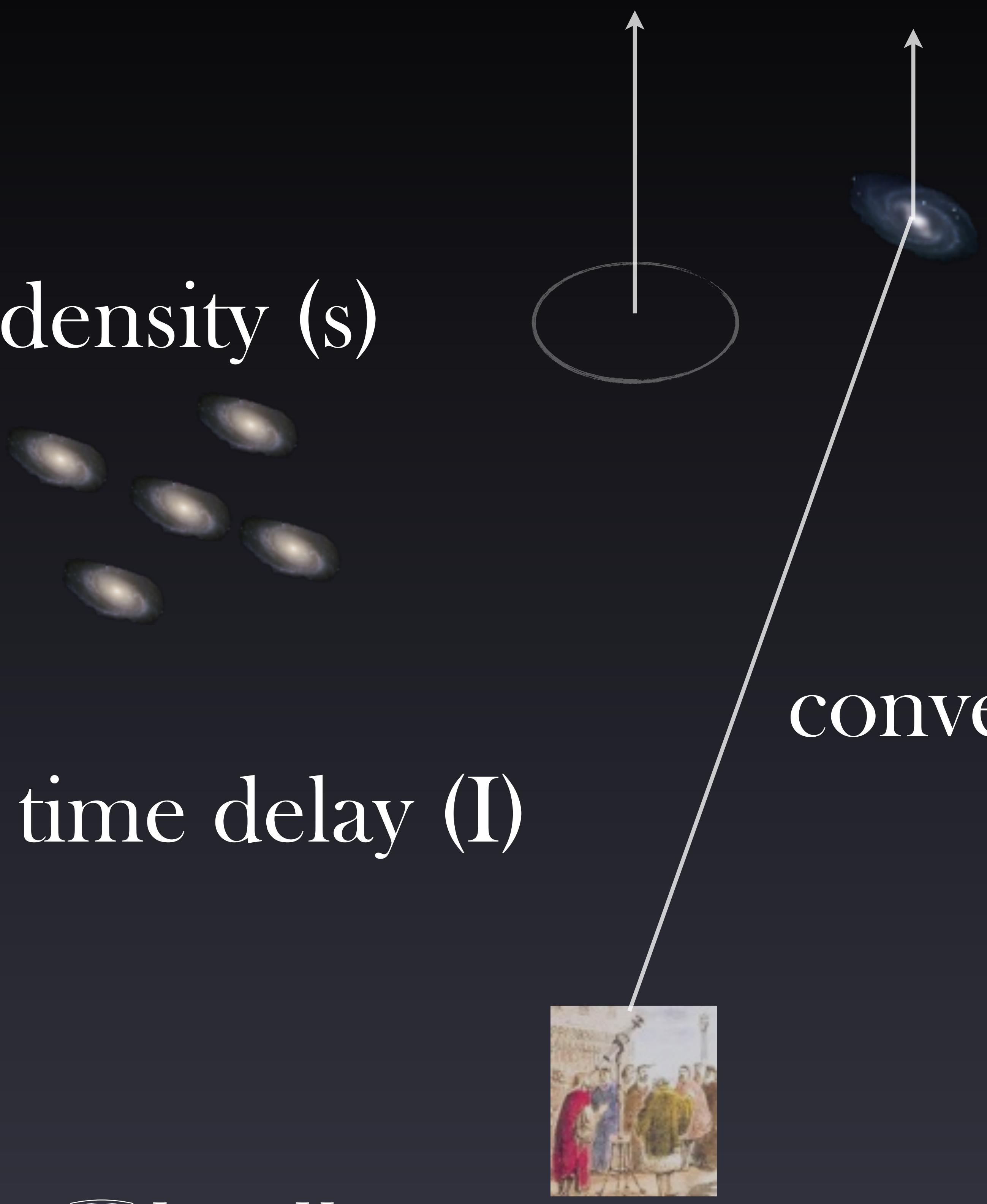
Hubble expansion +

local density (s)

convergence (κ)

time delay (I)

Real and Redshift Space in GR



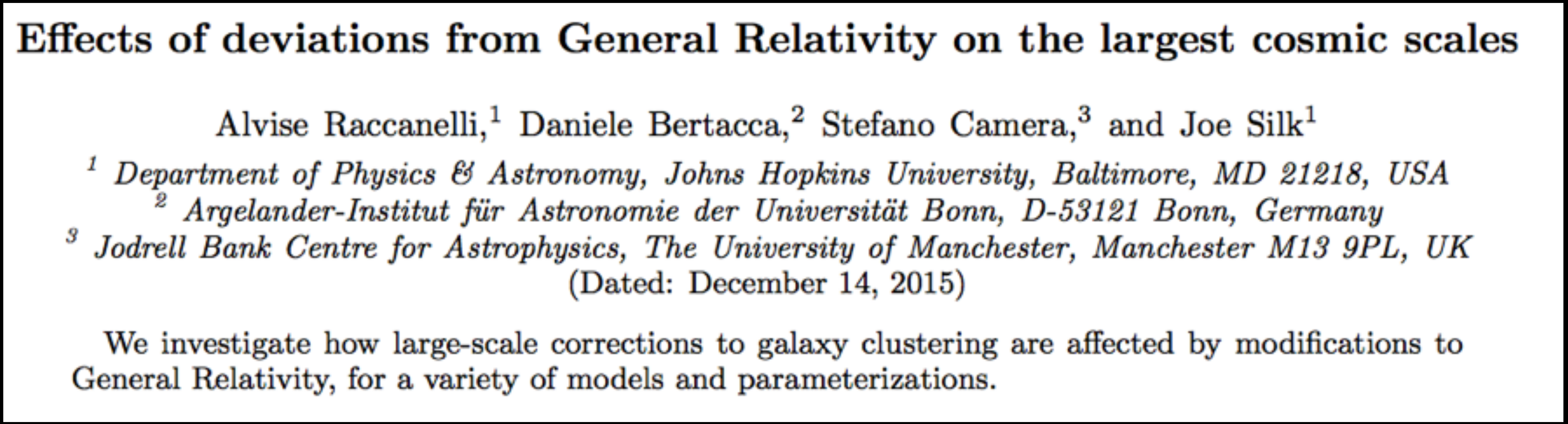
Hubble expansion +

local density (s)

convergence (κ)

time delay (I)

What if we modify GR?



Effects of deviations from General Relativity on the largest cosmic scales

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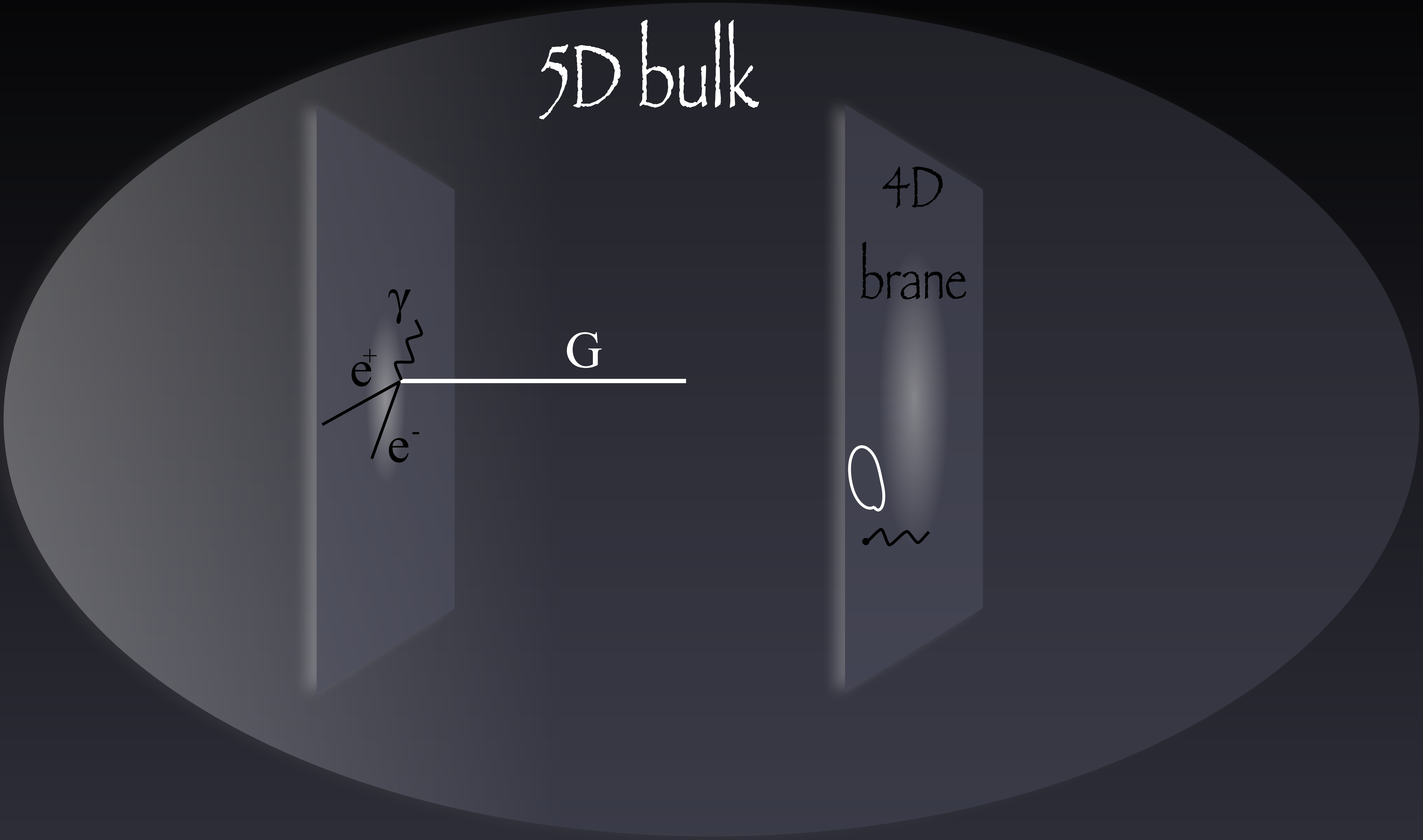
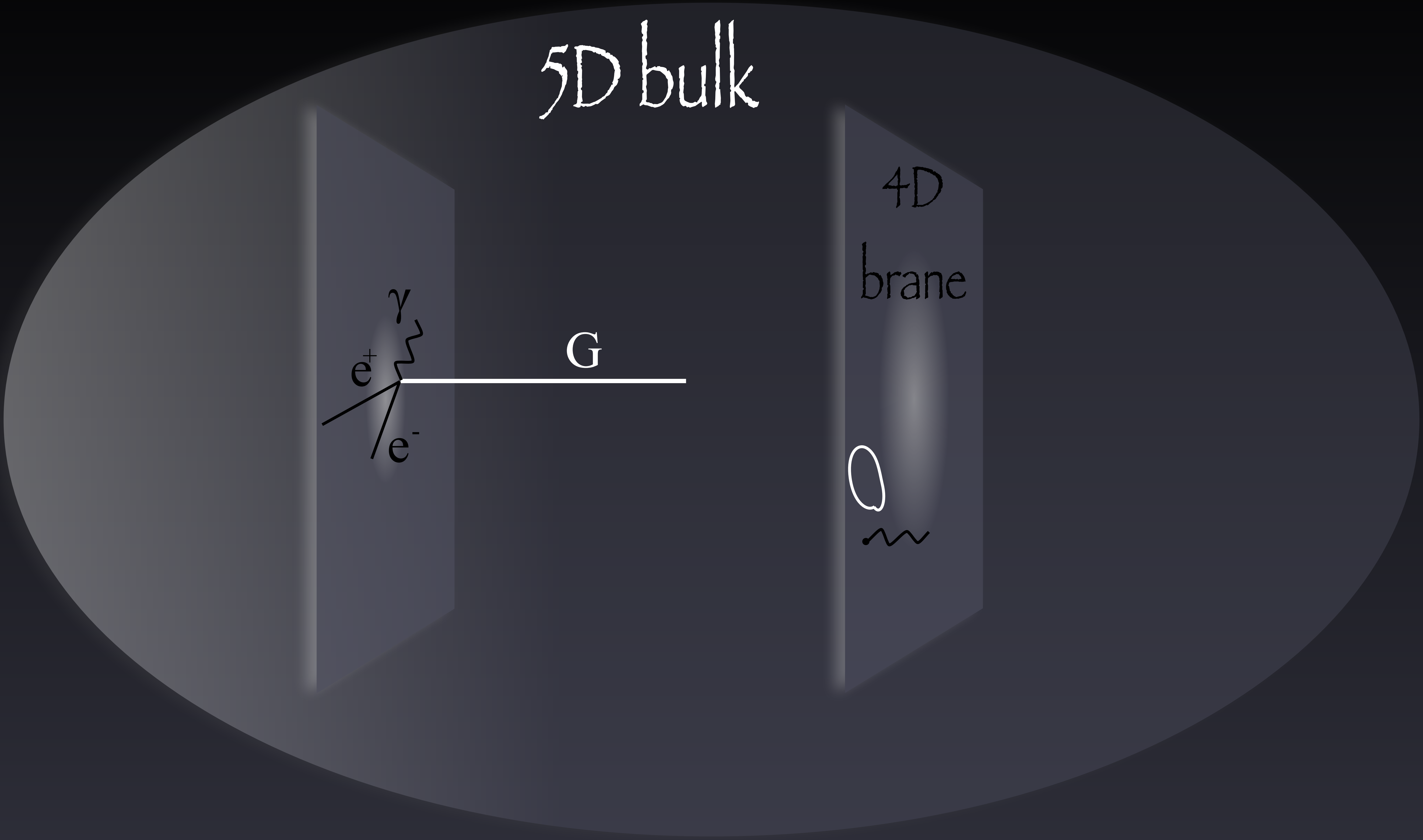
[2] *Argelander-Institut für Astronomie der Universität Bonn, D-53121 Bonn, Germany*
[3] *Jodrell Bank Centre for Astrophysics, The University of Manchester, Manchester M13 9PL, UK*
(Dated: December 14, 2015)

We investigate how large-scale corrections to galaxy clustering are affected by modifications to General Relativity, for a variety of models and parameterizations.

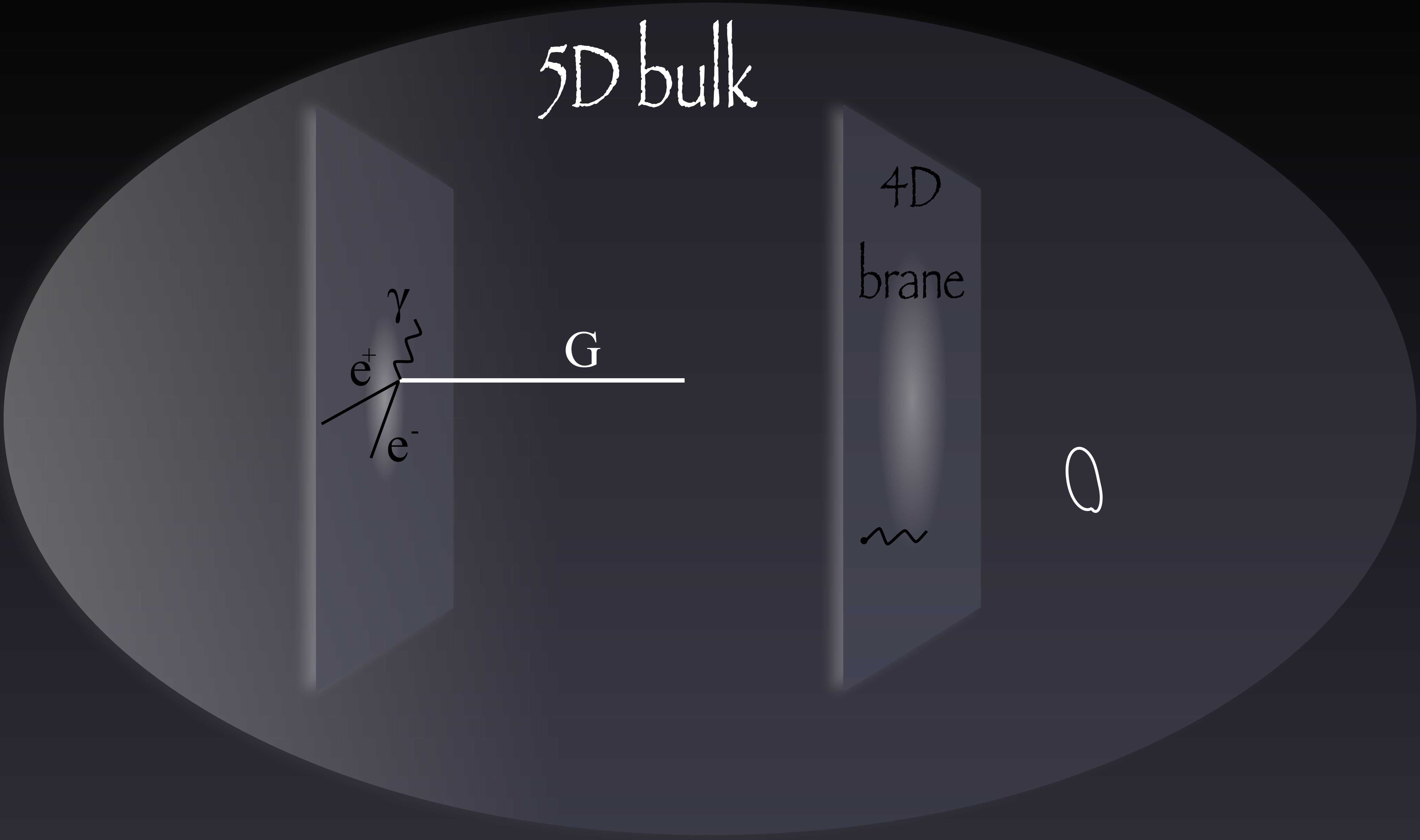
Braneworlds



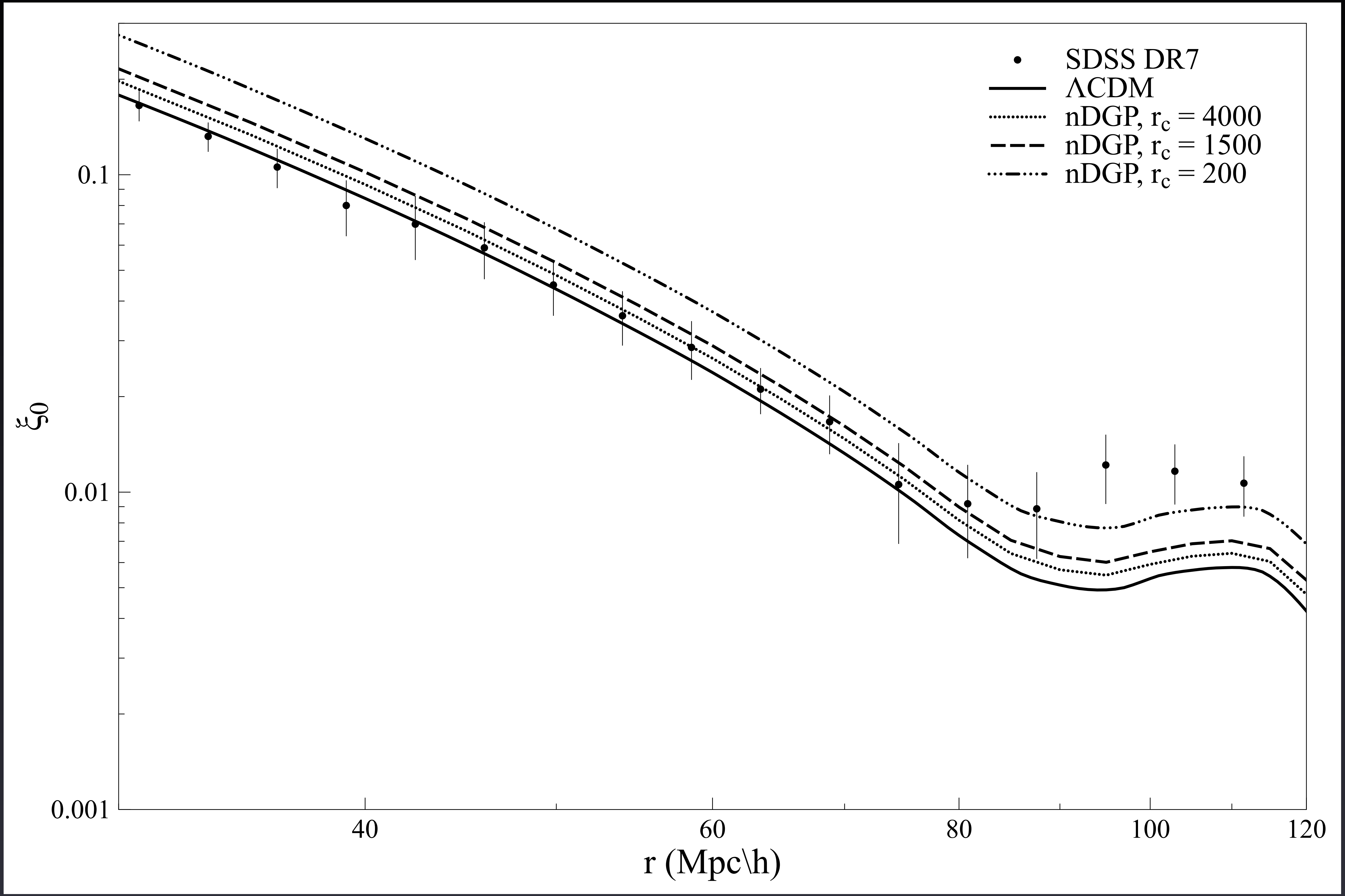
Braneworlds



Braneworlds



nDGP



Raccanelli et al. 2013

Dark Matter

Dark Matter

Cold Dark Matter

Dark Matter

Cold Dark Matter

Self-Interacting?

Dark Matter

Cold Dark Matter

Self-Interacting?

“Dark atoms”?

Dark Matter

NATURE | NEWS

Did dark matter kill the dinosaurs?

The Solar System's periodic passage through a 'dark disk' on the galactic plane could trigger comet bombardments that would cause mass extinctions.

Elizabeth Gibney

07 March 2014

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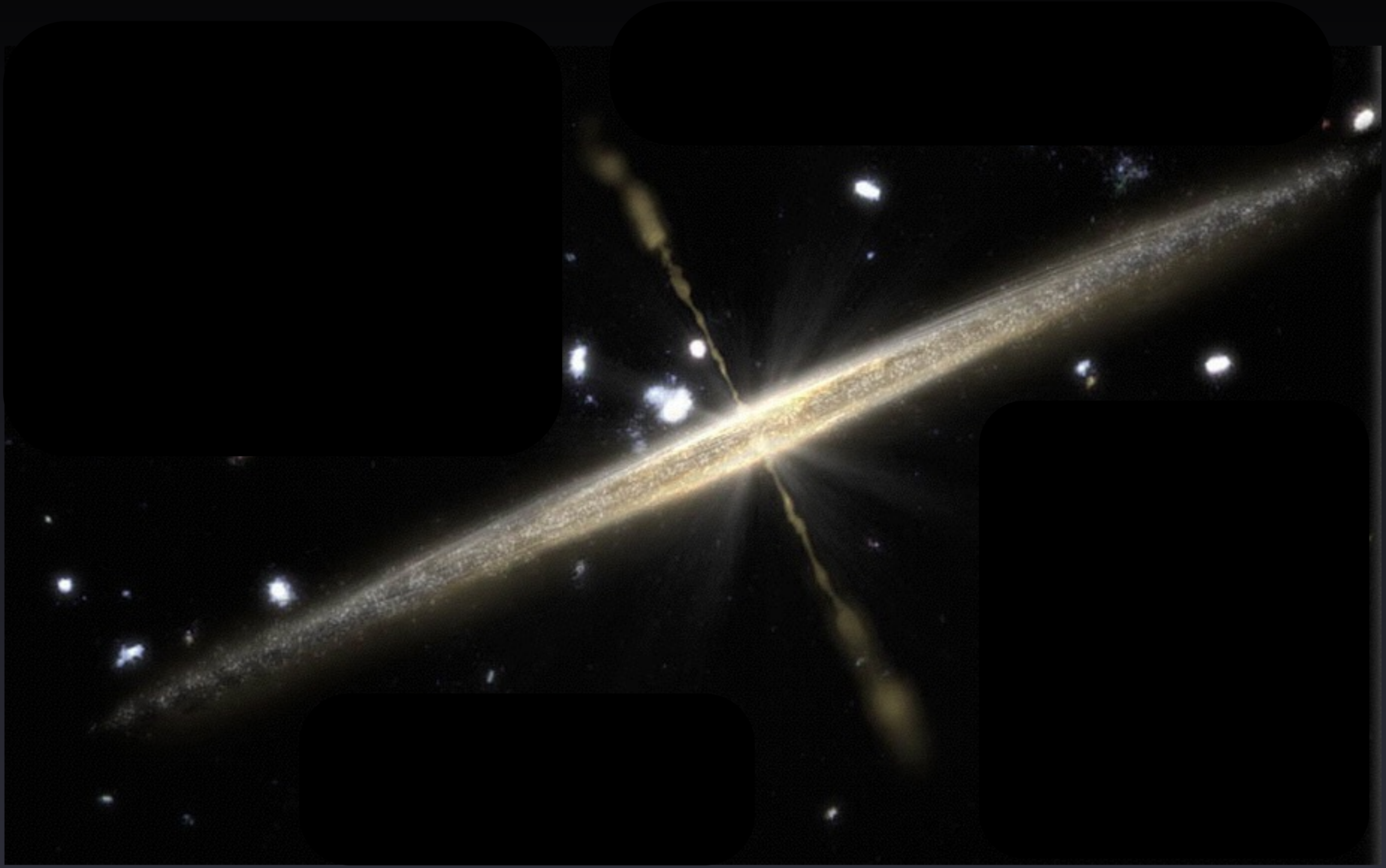
Mass extinctions such as the one that wiped out the dinosaurs seem to happen with regularity, pointing to possible cosmic causes.

Dark Matter



[redacted]

[redacted]

[redacted]

[redacted]

Dark Matter

Double disk

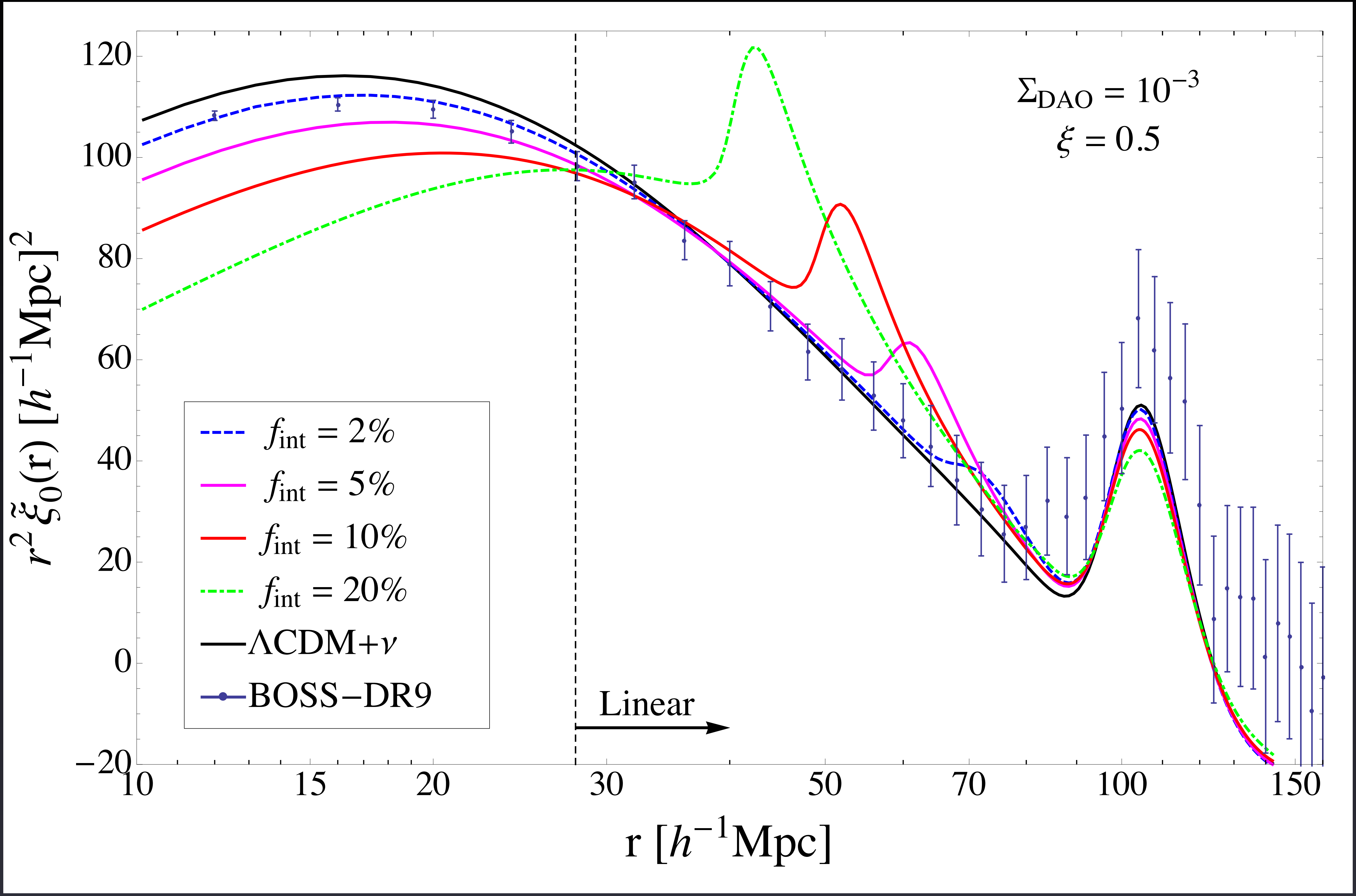
Dark Matter

Double disk

Dark Matter

Double disk

PIDM



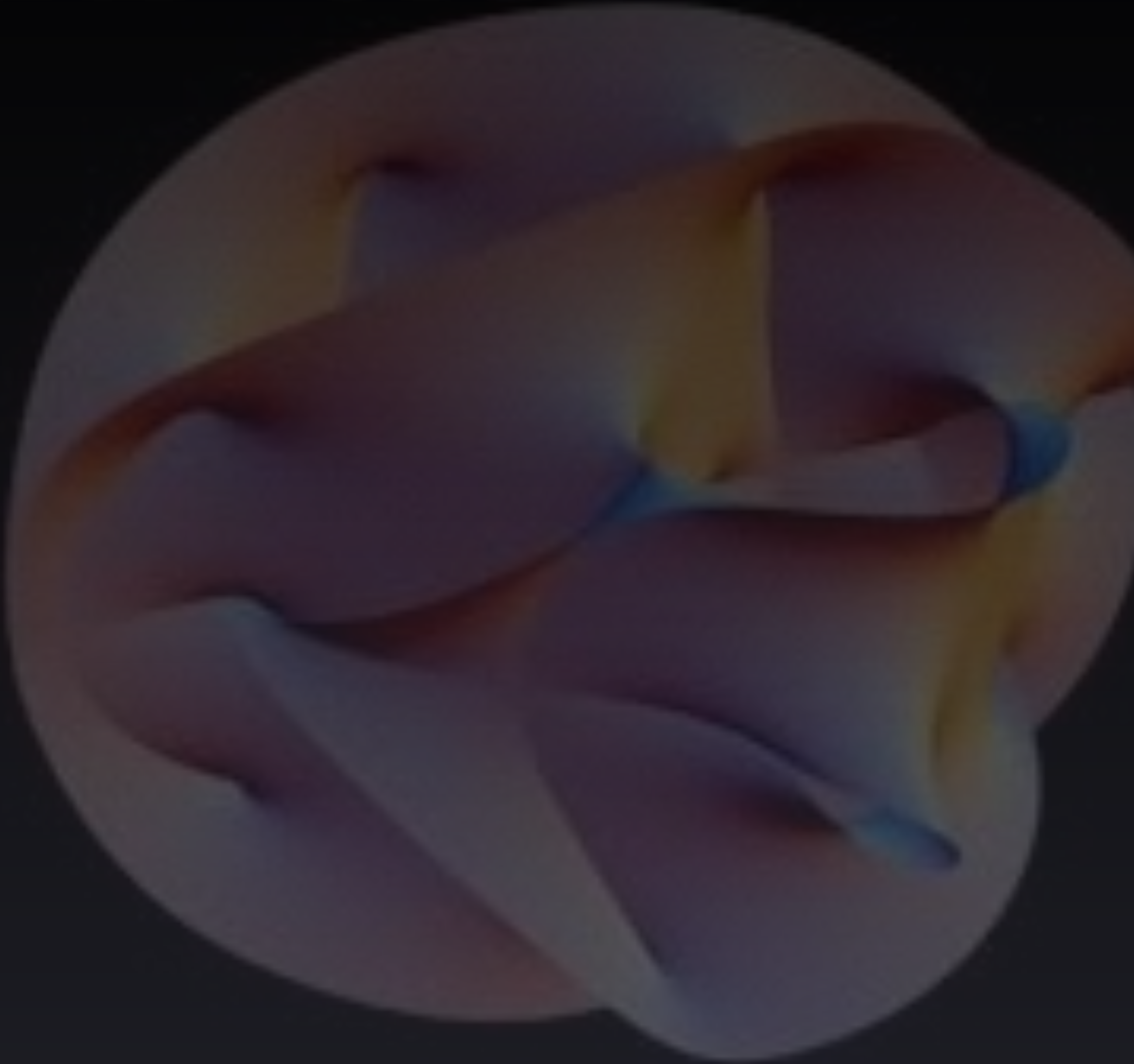
Cyr-Racine et al., 2013

Dark Matter

Did Dark Matter Kill the Dinosaurs? Probably Not. But It's a Fun idea.

By *Phil Plait*

String Axiverse



String Axiverse

Accelerated Cosmic expansion
driven by axion-like
quintessence field

String Axiverse

Accelerated Cosmic expansion
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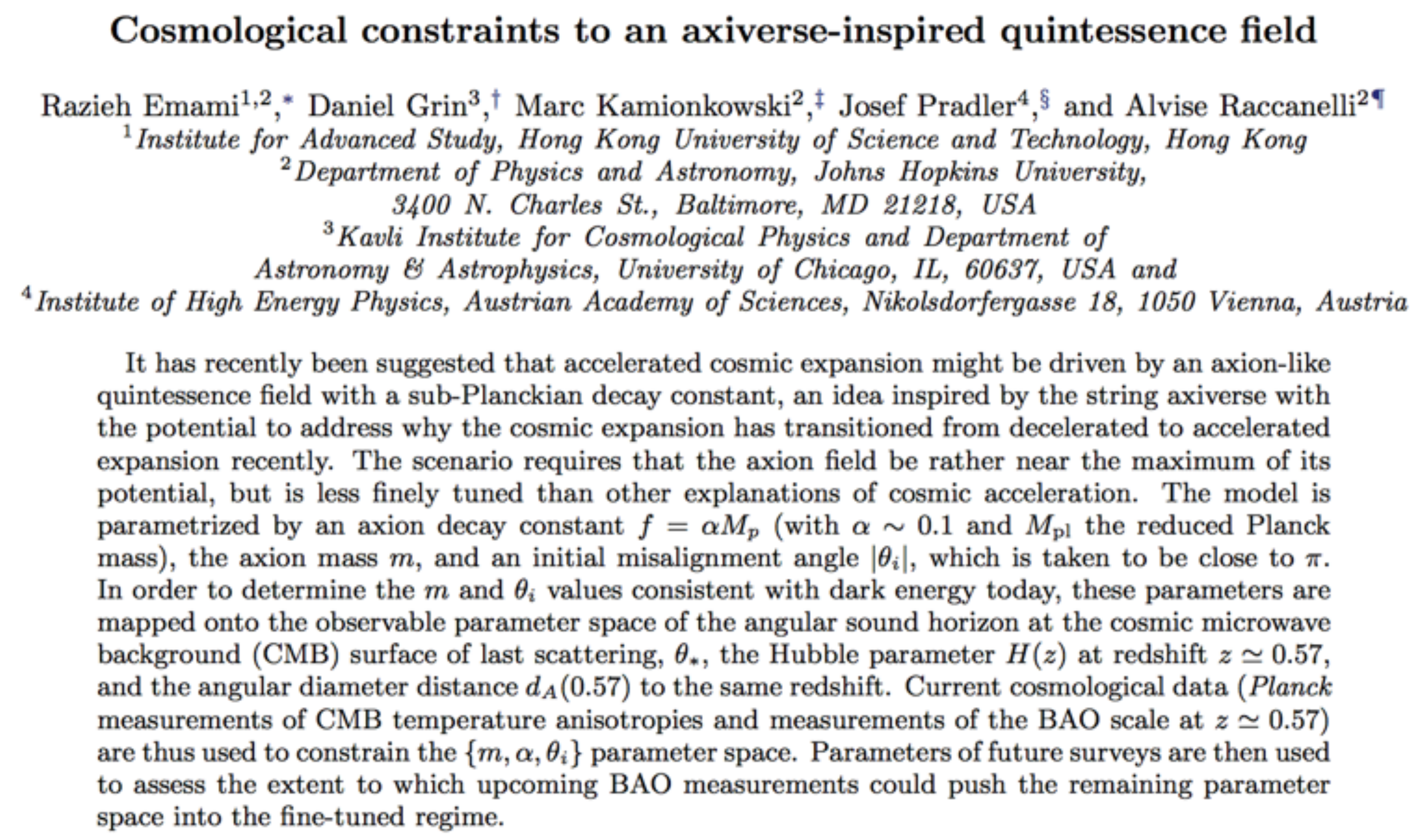
We can use measurements (D_A, H)
to test its parameters

String Axiverse



Cosmological constraints to an axiverse-inspired quintessence field

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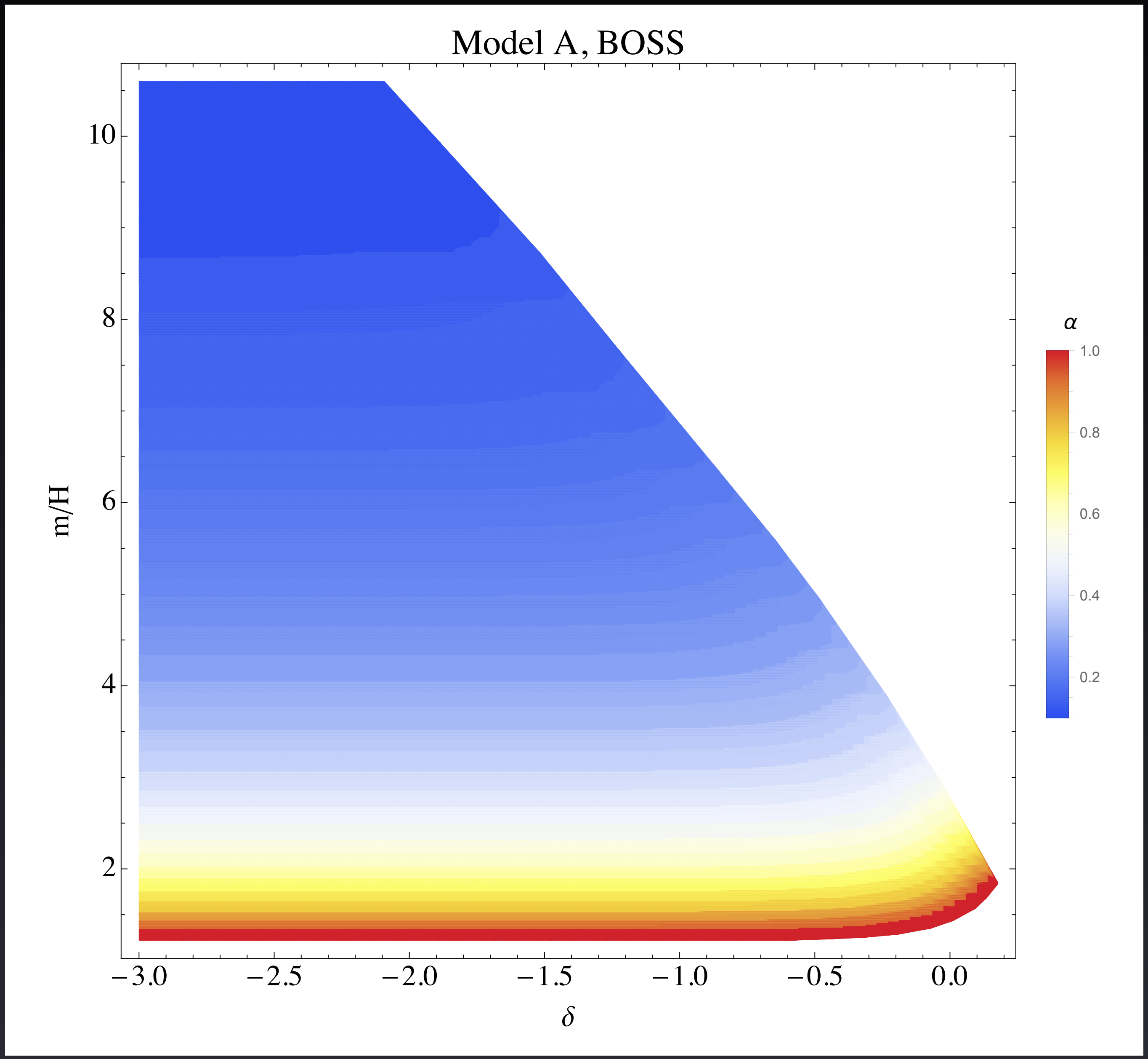
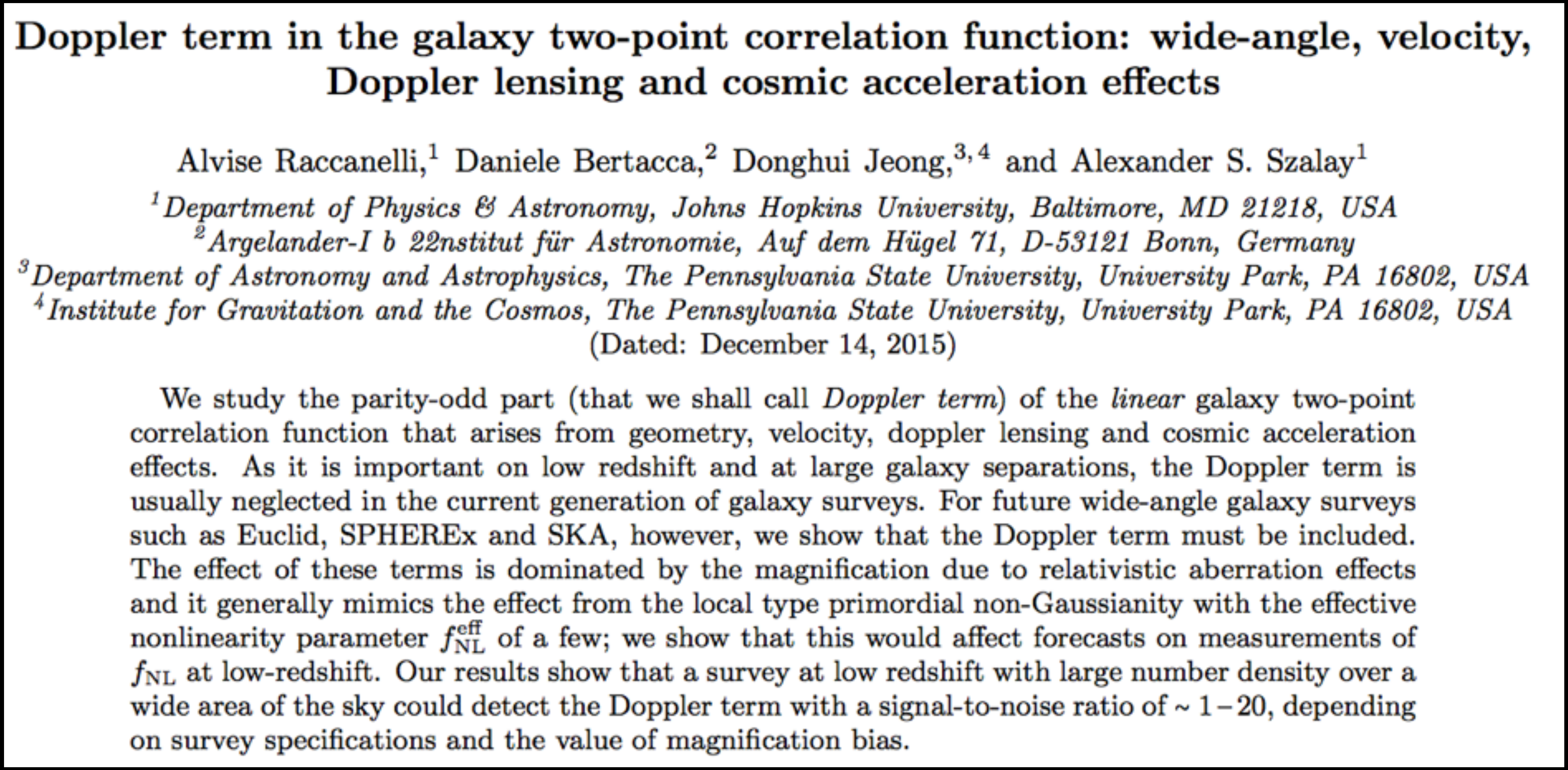
It has recently been suggested that accelerated cosmic expansion might be driven by an axion-like quintessence field with a sub-Planckian decay constant, an idea inspired by the string axiverse with the potential to address why the cosmic expansion has transitioned from decelerated to accelerated expansion recently. The scenario requires that the axion field be rather near the maximum of its potential, but is less finely tuned than other explanations of cosmic acceleration. The model is parametrized by an axion decay constant $f = \alpha M_p$ (with $\alpha \sim 0.1$ and $M_{\rm pl}$ the reduced Planck mass), the axion mass m, and an initial misalignment angle $|\theta_i|$, which is taken to be close to π. In order to determine the m and θ_i values consistent with dark energy today, these parameters are mapped onto the observable parameter space of the angular sound horizon at the cosmic microwave background (CMB) surface of last scattering, θ_*, the Hubble parameter $H(z)$ at redshift $z \simeq 0.57$, and the angular diameter distance $d_A(0.57)$ to the same redshift. Current cosmological data (*Planck* measurements of CMB temperature anisotropies and measurements of the BAO scale at $z \simeq 0.57$) are thus used to constrain the $\{m, \alpha, \theta_i\}$ parameter space. Parameters of future surveys are then used to assess the extent to which upcoming BAO measurements could push the remaining parameter space into the fine-tuned regime.

String Axiverse



Doppler



Doppler term in the galaxy two-point correlation function: wide-angle, velocity, Doppler lensing and cosmic acceleration effects

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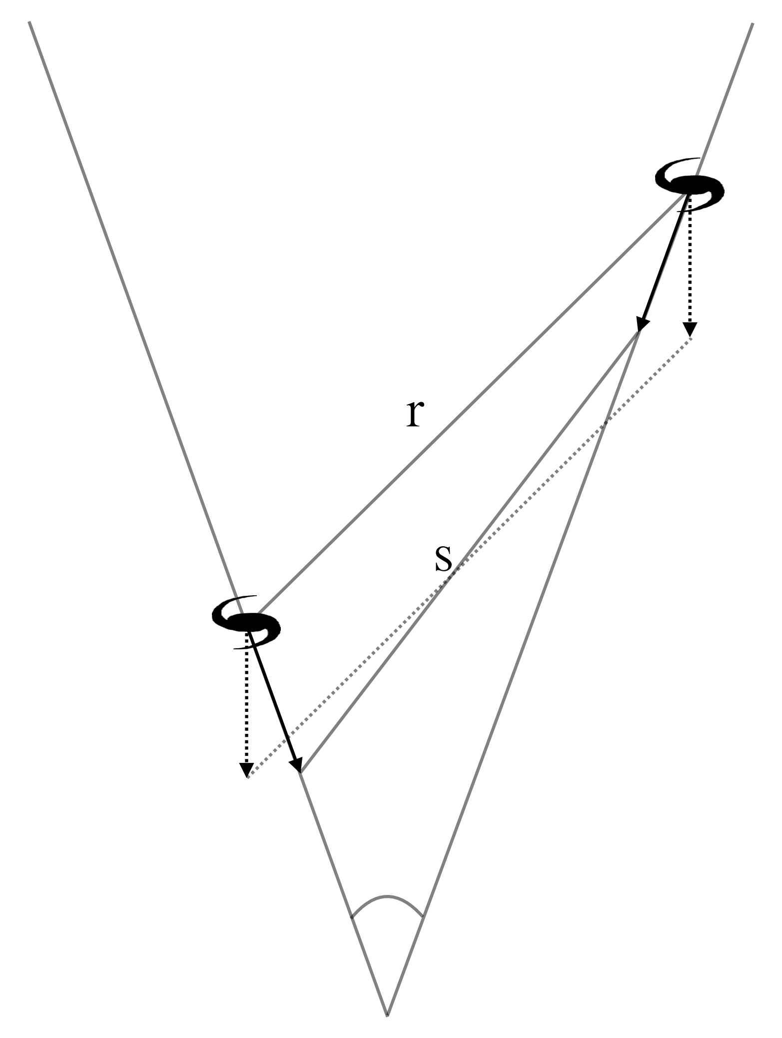
[3] *Department of Astronomy and Astrophysics, The Pennsylvania State University, University Park, PA 16802, USA*
[4] *Institute for Gravitation and the Cosmos, The Pennsylvania State University, University Park, PA 16802, USA*

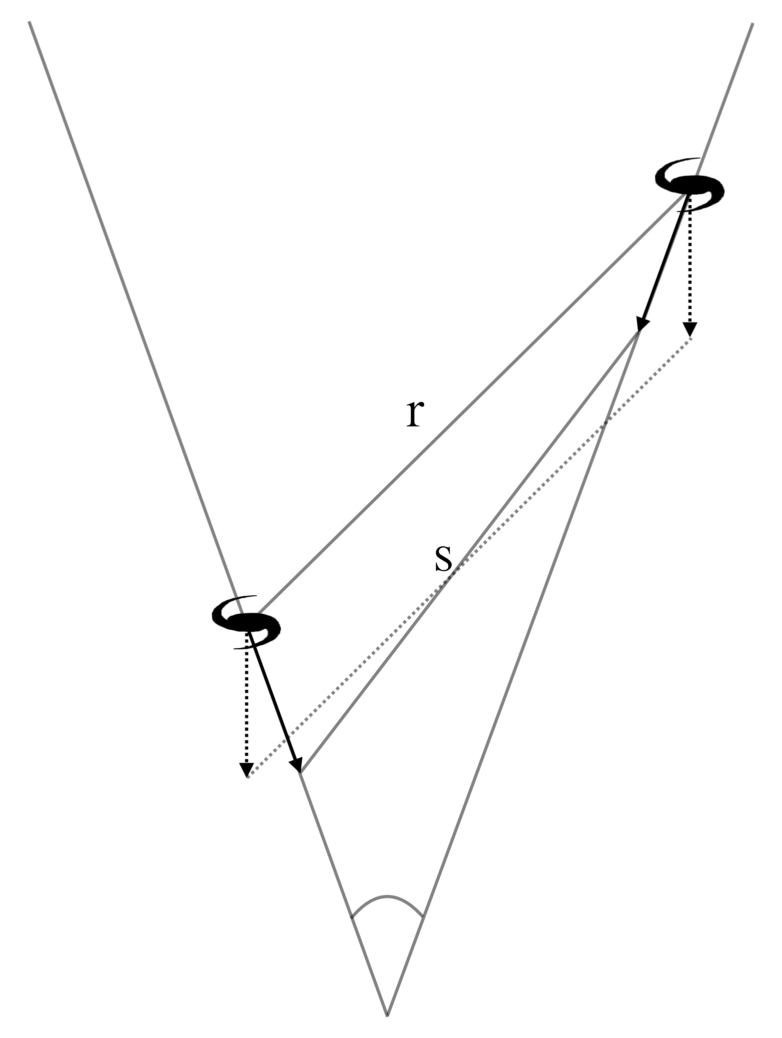
(Dated: December 14, 2015)

We study the parity-odd part (that we shall call *Doppler term*) of the *linear* galaxy two-point correlation function that arises from geometry, velocity, doppler lensing and cosmic acceleration effects. As it is important on low redshift and at large galaxy separations, the Doppler term is usually neglected in the current generation of galaxy surveys. For future wide-angle galaxy surveys such as Euclid, SPHEREx and SKA, however, we show that the Doppler term must be included. The effect of these terms is dominated by the magnification due to relativistic aberration effects and it generally mimics the effect from the local type primordial non-Gaussianity with the effective nonlinearity parameter $f_{\rm NL}^{\rm eff}$ of a few; we show that this would affect forecasts on measurements of $f_{\rm NL}$ at low-redshift. Our results show that a survey at low redshift with large number density over a wide area of the sky could detect the Doppler term with a signal-to-noise ratio of ~ 1 – 20, depending on survey specifications and the value of magnification bias.

Doppler



Doppler



wide angle!

Doppler

$$\delta^{\mathcal{S}}(\mathbf{r}) = \delta^{\mathcal{R}}(\mathbf{r}) - \left(\frac{\partial v_r}{\partial r} + \frac{\alpha(\mathbf{r}) v_r}{r}\right)$$

$$P^s(k,\mu) = \left[\left(1+\beta\mu^2\right)^2 + \left(\alpha\frac{\beta\mu}{k\chi}\right)^2\right] P^r(k)$$

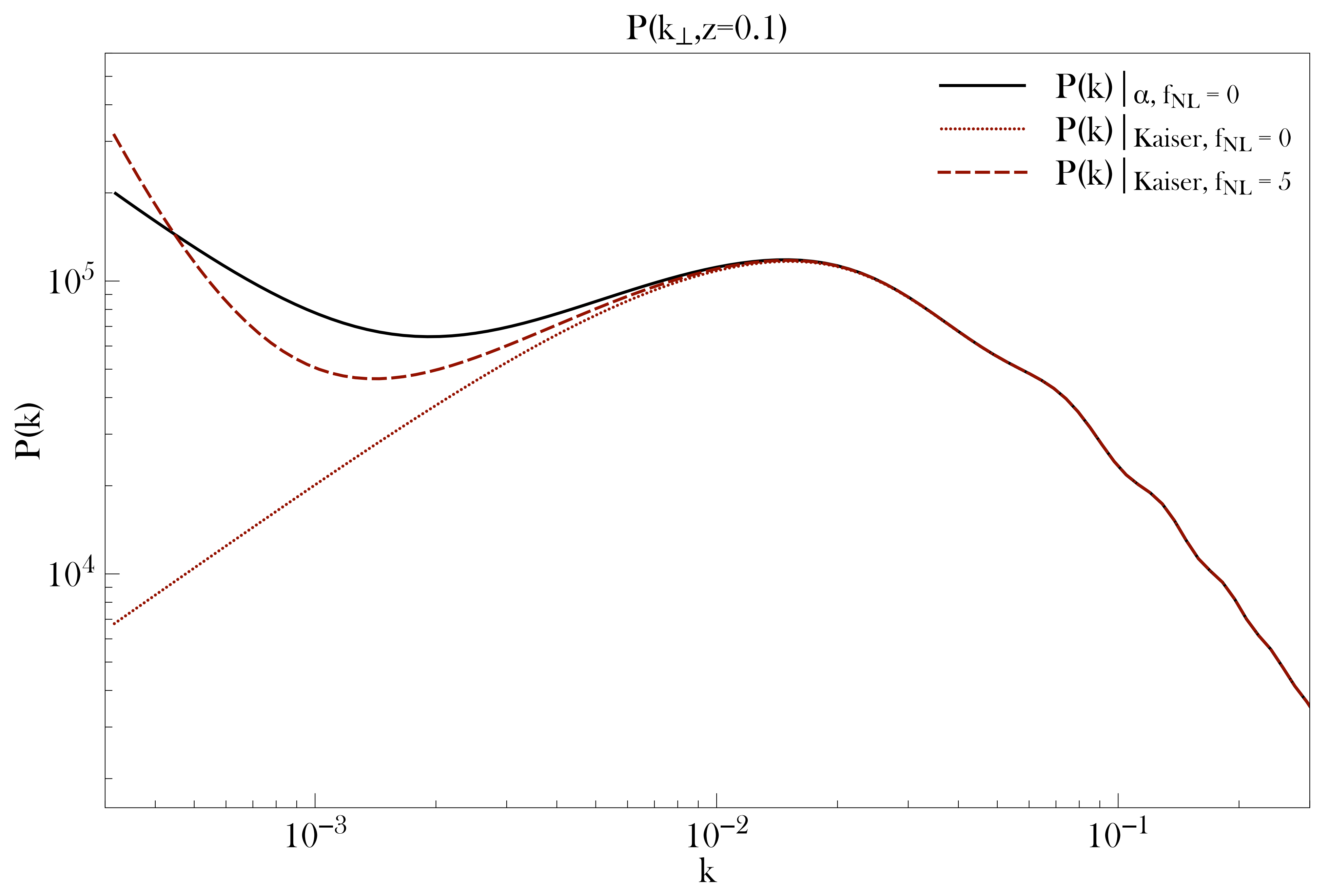
Doppler

$$\alpha_1 = 2 - b_e \frac{H(z)\chi(z)}{(1+z)}$$

$$\alpha_2 = 2\mathcal{Q}(z)\left[\frac{H(z)\chi(z)}{(1+z)} - 1\right]$$

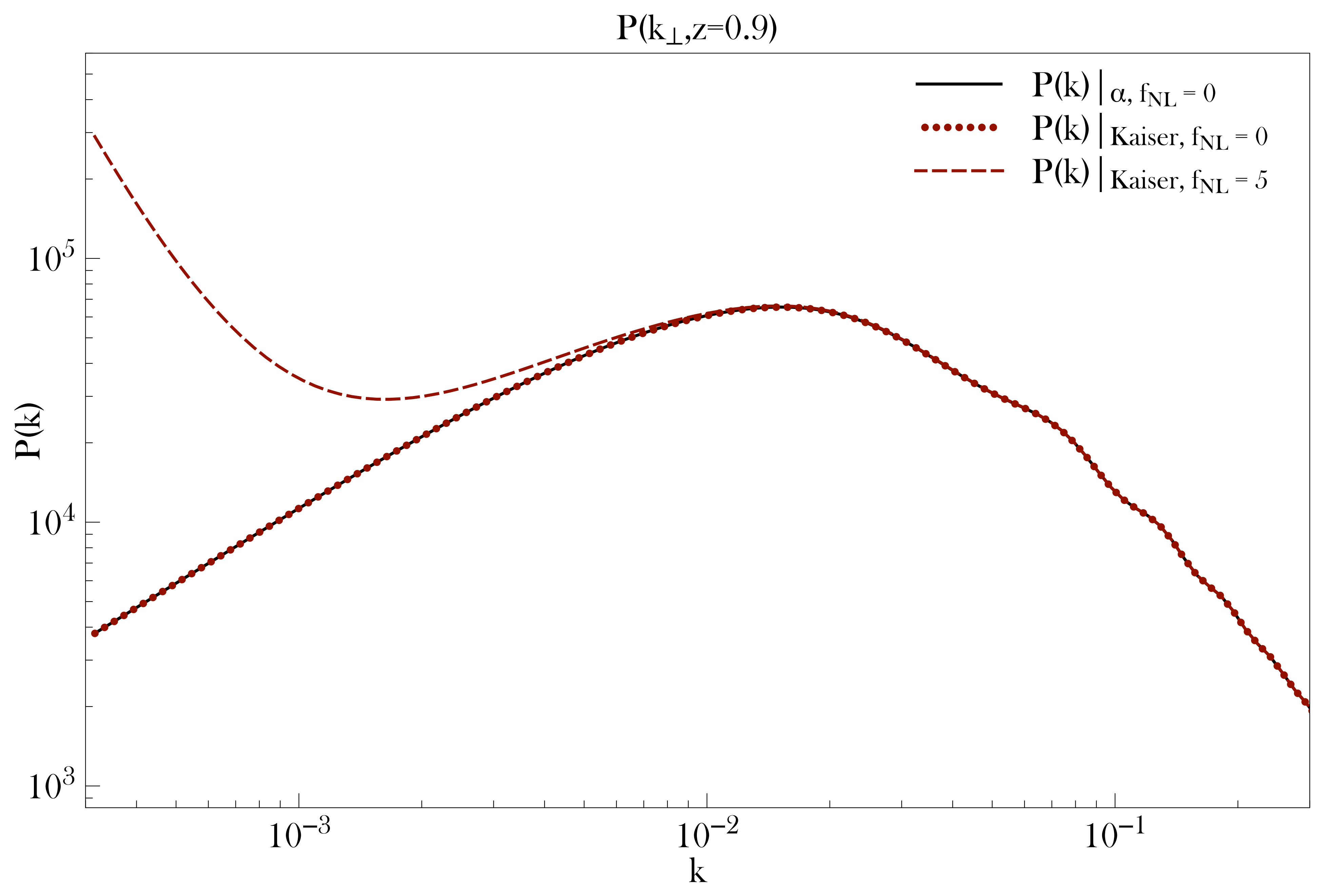
$$\alpha_3 = \frac{H(z)\chi(z)}{(1+z)}\left[1 - \frac{3}{2}\Omega_m(z)\right]$$

Doppler

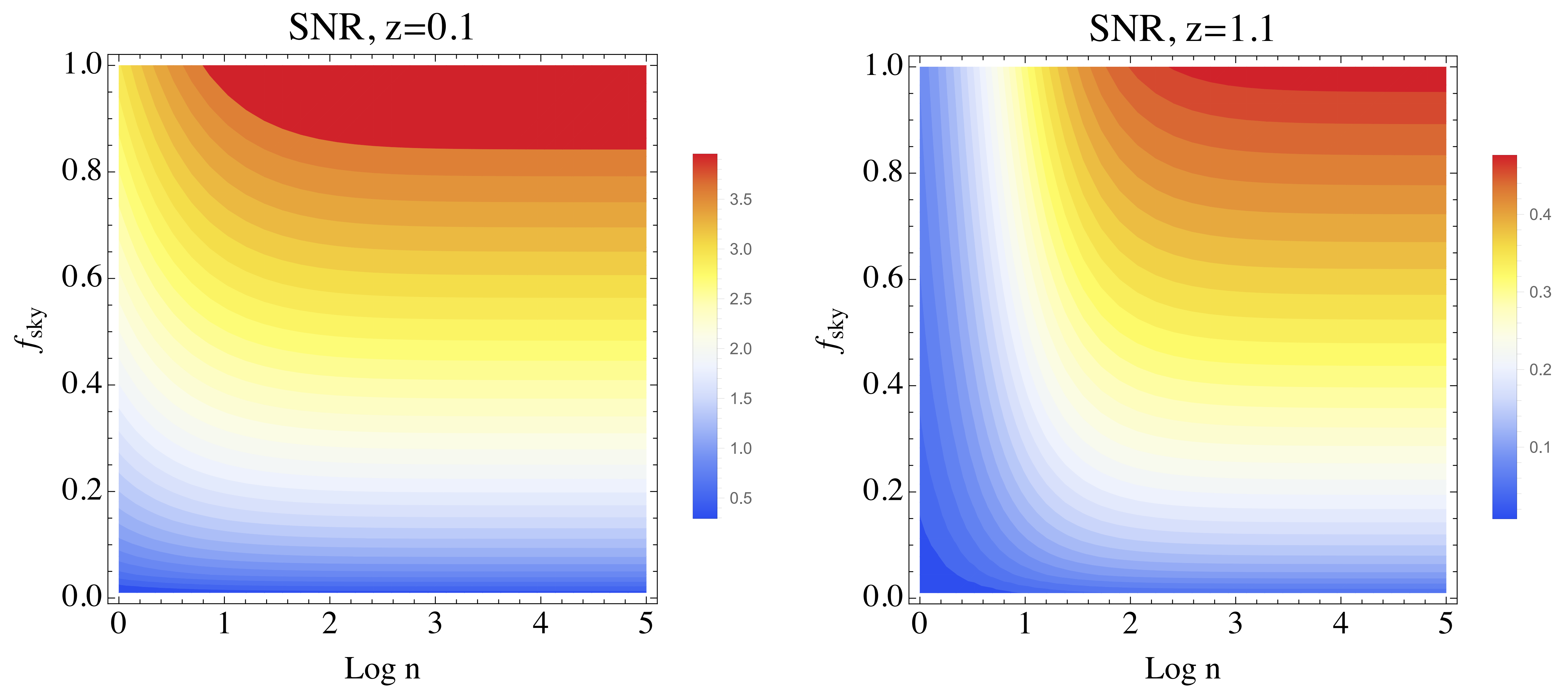

$P(k_\perp, z=0.1)$
$P(k)|_{\alpha,\, f_{NL}=0}$
$P(k)|_{\text{Kaiser},\, f_{NL}=0}$
$P(k)|_{\text{Kaiser},\, f_{NL}=5}$
P(k)
10^5
10^4
10^{-3}
10^{-2}
10^{-1}
k

Doppler

Doppler


P(k⊥,z=0.9)
P(k)
k
10^5
10^4
10^3
10^{-3}
10^{-2}
10^{-1}
$P(k)|_{\alpha,\, f_{NL}=0}$
$P(k)|_{\mathrm{Kaiser},\, f_{NL}=0}$
$P(k)|_{\mathrm{Kaiser},\, f_{NL}=5}$

Doppler


SNR, z=0.1
1.0
0.8
0.6
0.4
0.2
0.0
$f_{\rm sky}$
0
1
2
3
4
5
Log n
3.5
3.0
2.5
2.0
1.5
1.0
0.5
SNR, z=1.1
0.4
0.3
0.2
0.1

Future Surveys

Future Surveys

Deep: PFS, WFIRST

Future Surveys

Deep: PFS, WFIRST

Wide: SPHEREx

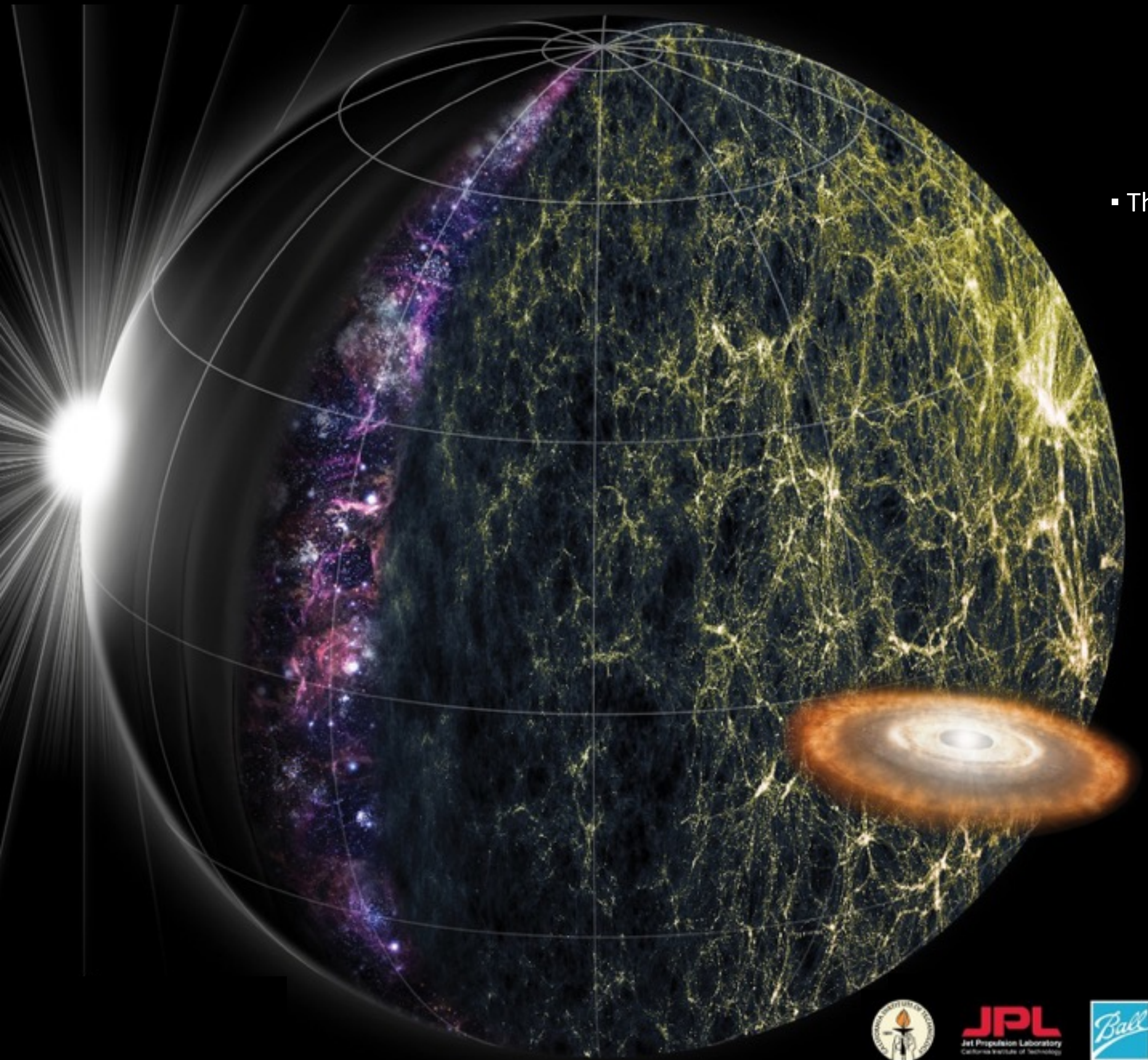
Future Surveys

Deep: PFS, WFIRST

Wide: SPHEREx

Deep and Wide: EMU, SKA

SPHEREx: An All-Sky Spectral Survey



Designed to Explore

- The Origin of the Universe
- The Origin and History of Galaxies
- The Origin of Water in Planetary Systems

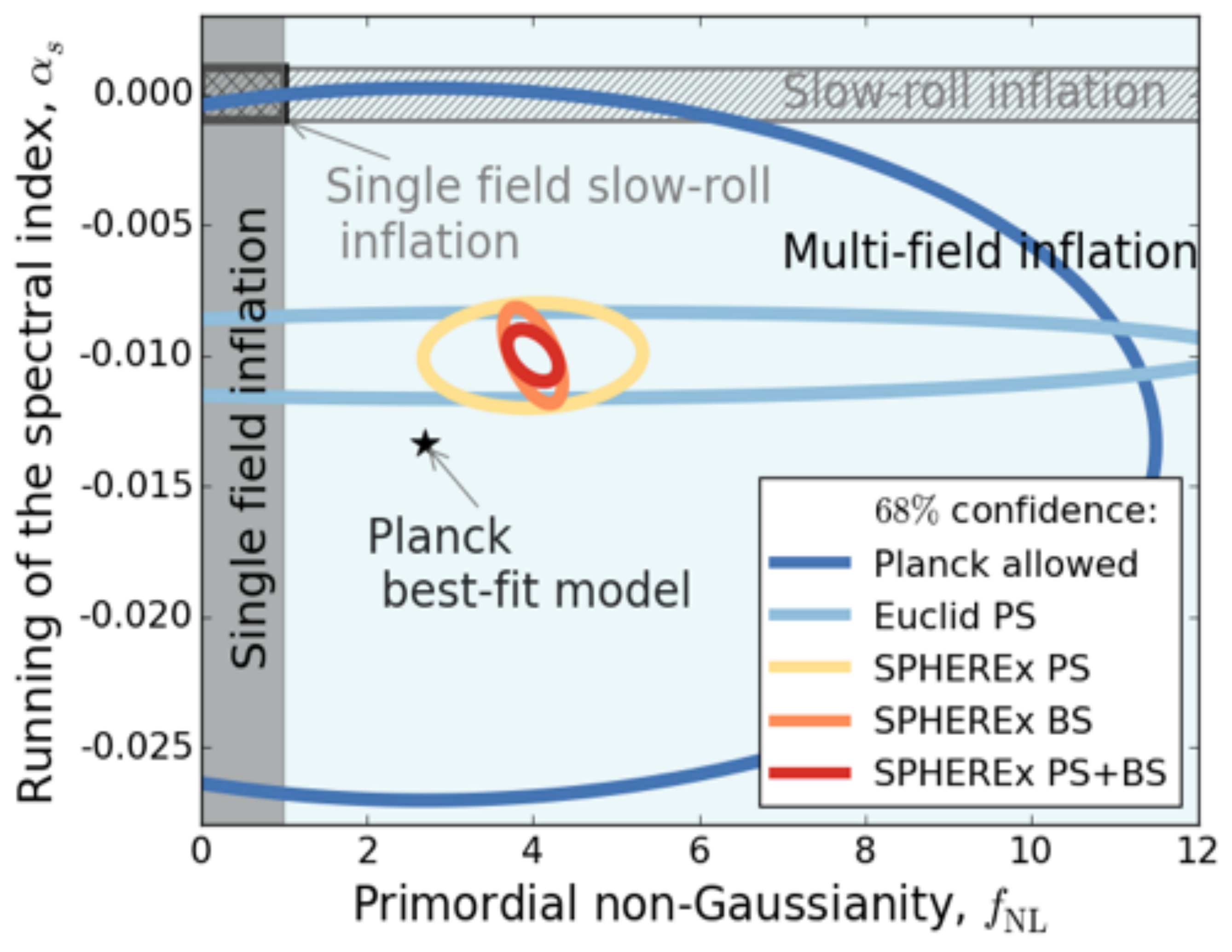
The First All-Sky Near-IR Spectral Survey

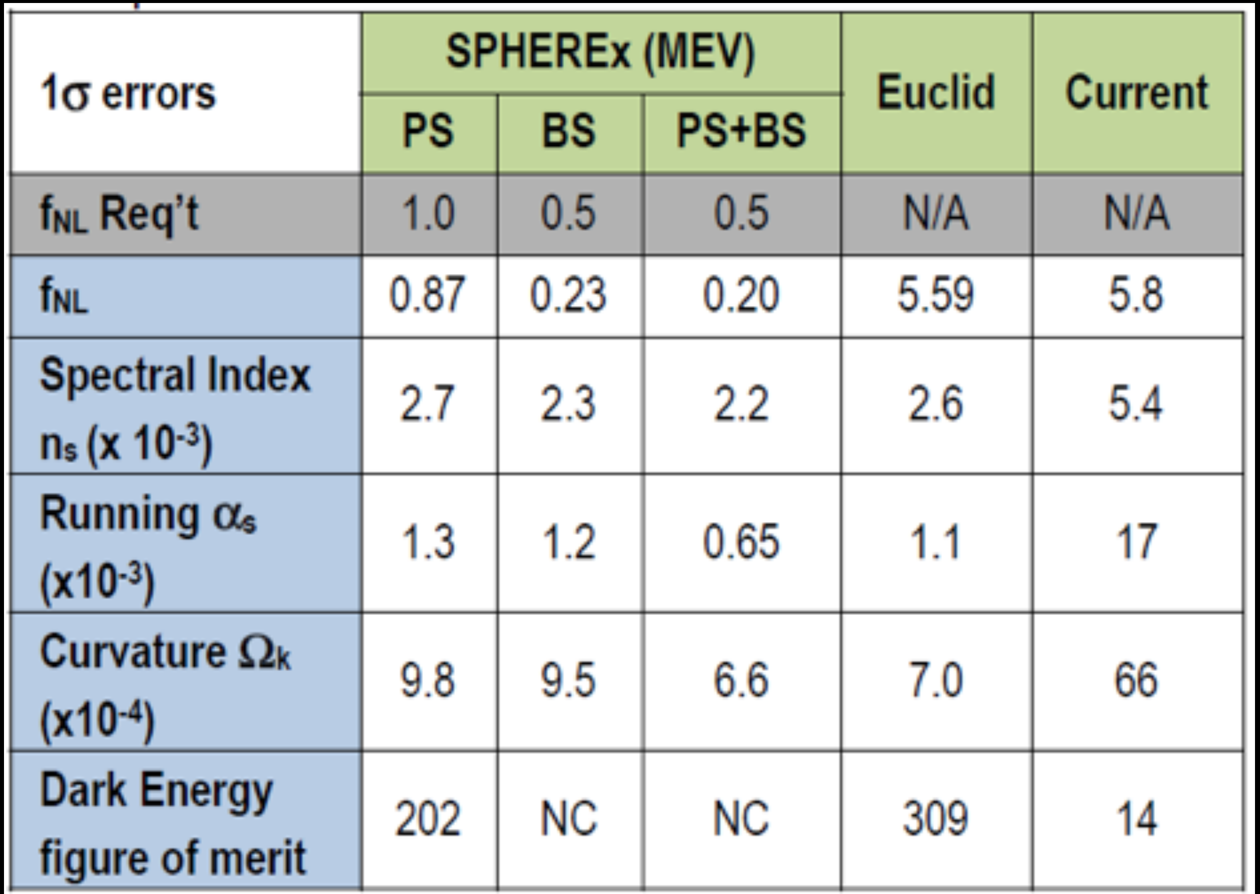
A Rich Legacy Archive for the Astronomy Community with 100s of Millions of Stars and Galaxies

Low-Risk Implementation

- Single Observing Mode
- No Moving Parts
- Large Technical & Scientific Margins

JPL Jet Propulsion Laboratory California Institute of Technology
Ball
ipac
CfA
UCI
THE OHIO STATE UNIVERSITY





1σ errors	SPHEREx (MEV)			Euclid	Current
	PS	BS	PS+BS		
f_{NL} Req't	1.0	0.5	0.5	N/A	N/A
f_{NL}	0.87	0.23	0.20	5.59	5.8
Spectral Index n_s (x 10^{-3})	2.7	2.3	2.2	2.6	5.4
Running α_s (x10^{-3})	1.3	1.2	0.65	1.1	17
Curvature Ω_k (x10^{-4})	9.8	9.5	6.6	7.0	66
Dark Energy figure of merit	202	NC	NC	309	14

- Non-Gaussianity distinguishes between multi- and single-field models
- Projected SPHEREx sensitivity is $\delta f_{NL} < 1$ (2σ)
    - Two independent tests via power spectrum and bispectrum
- Competitively tests running of the spectral index
- SPHEREx low-redshift catalog is complementary for dark energy

ASKAP - EMU

Name	**Telescope**	**Area (deg²)**	**Resolution**	**Sensitvity**	**No of gals**
ATLAS	ATCA	7	10″	15 uJy	6000
ATLAS-SPT	ATCA	100	10″	40 uJy	30,000
EMU (early)	ASKAP	1000	10″	30 uJy	500,000
EMU (full)	ASKAP	31,000	10″	10 uJy	70,000,000

- ATLAS is finished
- ATLAS-SPT is underway
- EMU-early will start late 2015/early2016
- EMU-full will start late 2016 ?

Thank

You