Summary of GR effects in ΛSS Conference

NAREI LORENZO MARTINEZ - LSST GROUP MEETING - JUNE 23RD 2026

Introduction

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- 3 main topics : non-homogeneous universe, non-Gaussianities, weak/strong lensing



Lockers and More
RENT BIKES

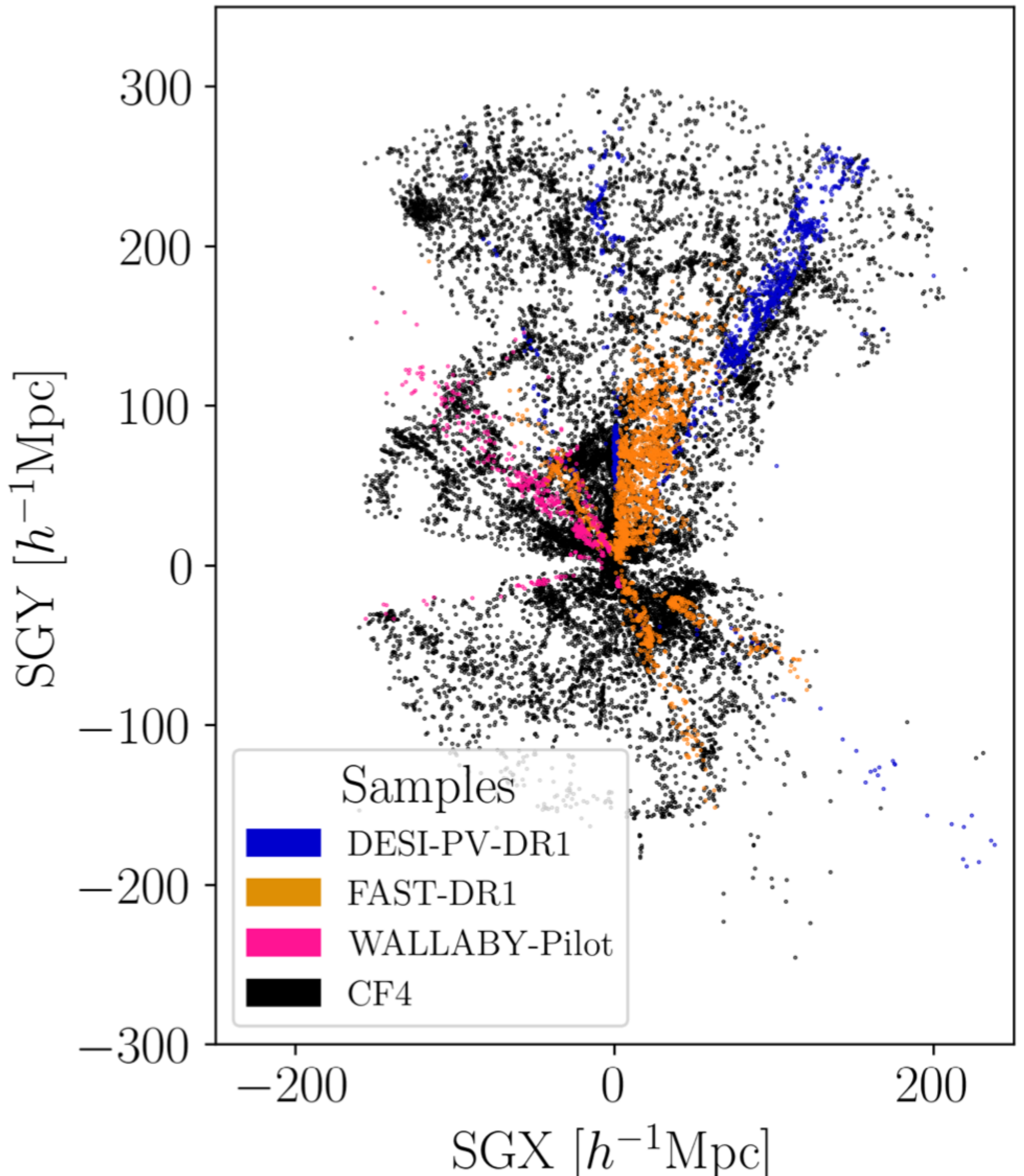
Backreaction and the Role of Spatial Curvature in the Cosmic Neighborhood

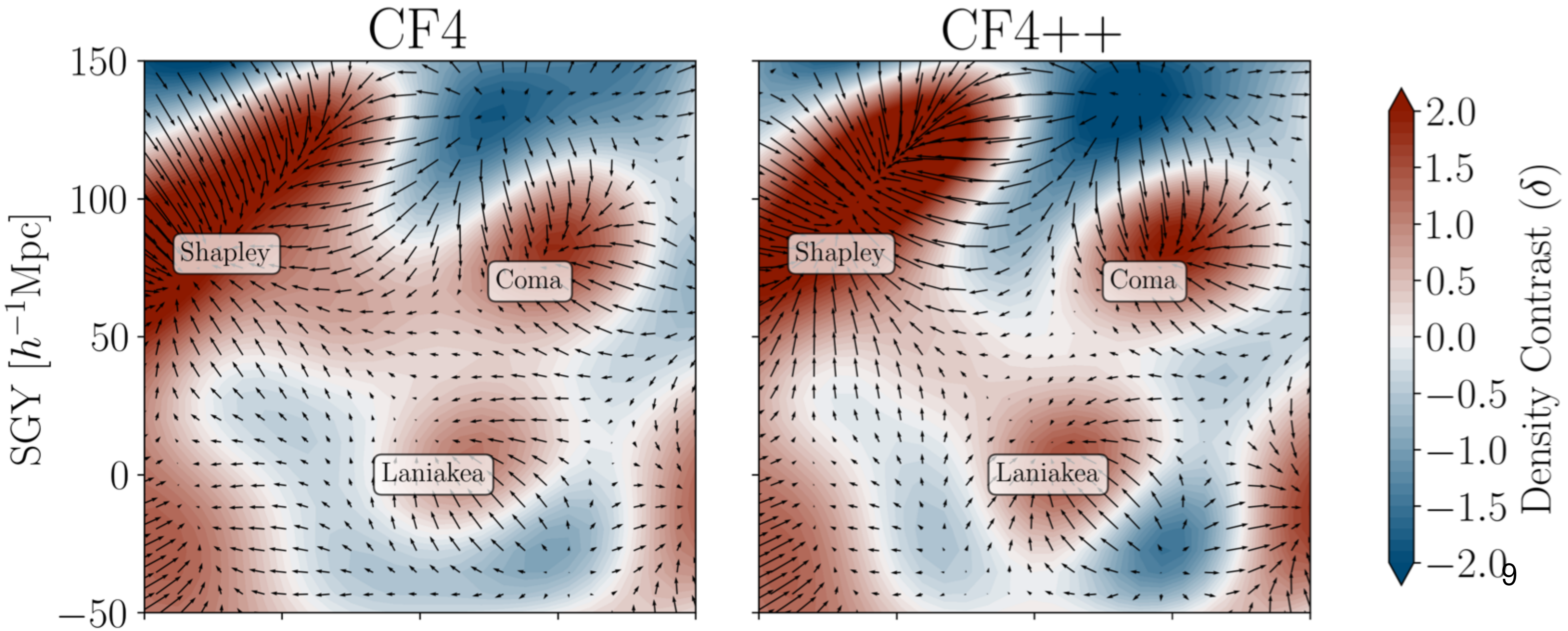
- https://iopscience.iop.org/article/10.3847/2041-8213/ae5f73 (Marco Galoppo, Thomas Buchert, and Pierre Mourier)
- CosmicFlow4++ dataset (300 Mpc, z~0.1), newtonian reconstruction

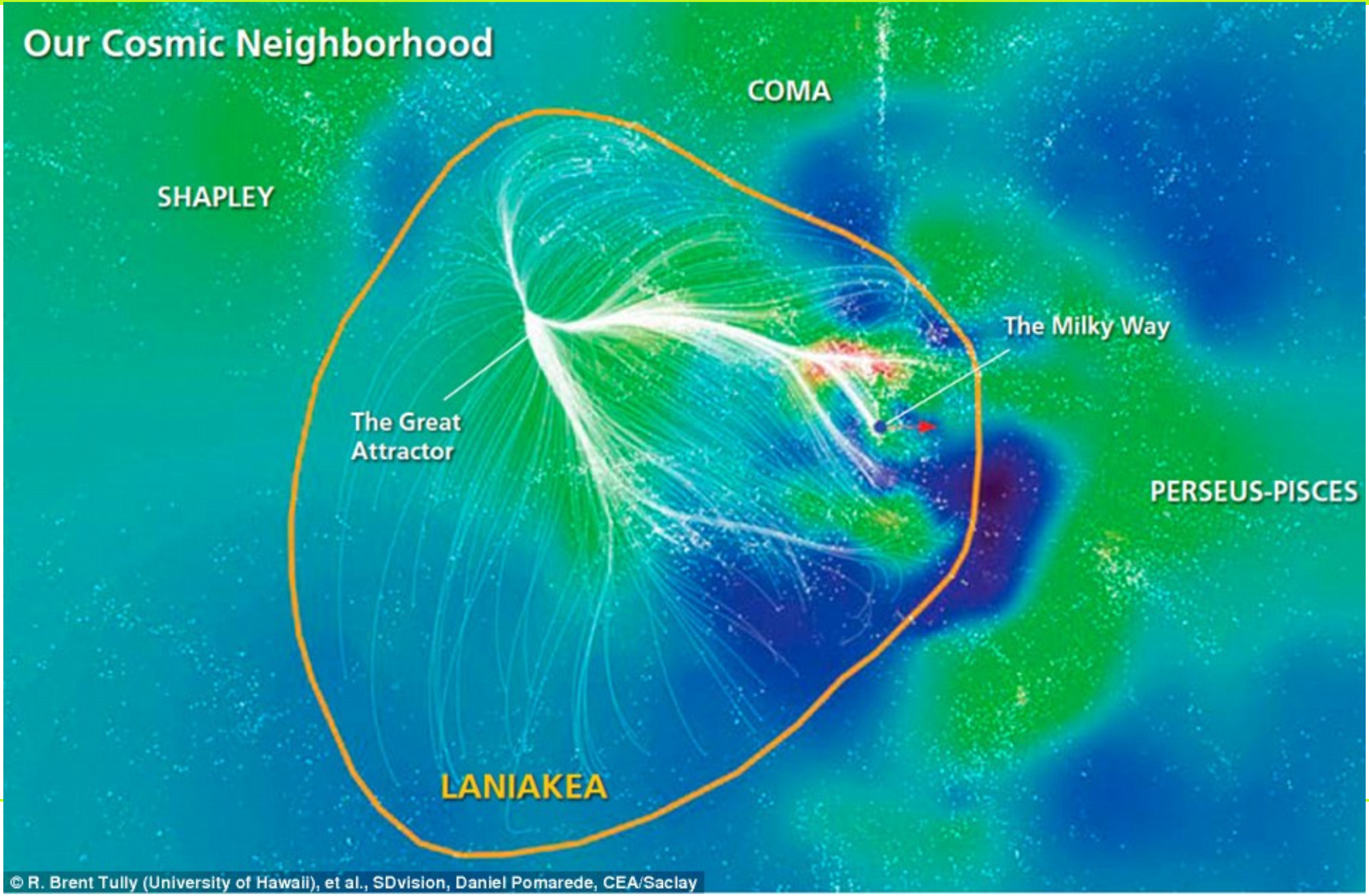
CosmicFlow4 ++

- CF4 + WALLABY, FAST, and DESI surveys (peculiar velocities)
  - Great Attractor (Laniakea) and Coma superclusters
  - https://arxiv.org/pdf/2502.01308

- « dynamical scale of homogeneity is not yet reached within the interval [200-300] h^{-1}Mpc from the observer, exhibiting a **2.28σ** tension with ΛCDM, indicating that the local Universe still exhibits significant fluctuations in the distribution of mass and dynamics of galaxy motions. »






Our Cosmic Neighborhood
COMA
SHAPLEY
The Milky Way
The Great
Attractor
PERSEUS-PISCES
LANIAKEA
© R. Brent Tully (University of Hawaii), et al., SDvision, Daniel Pomarede, CEA/Saclay

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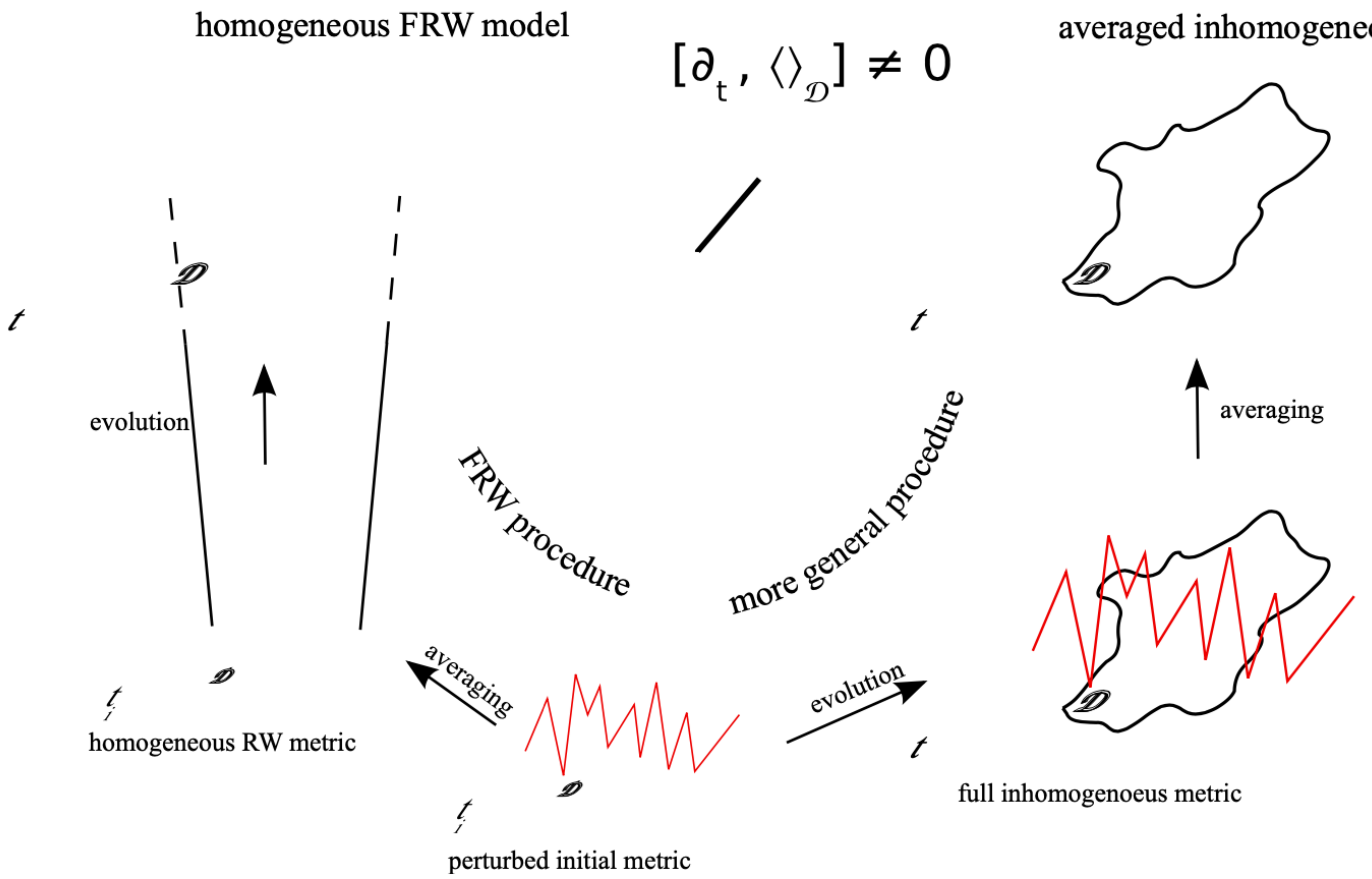
- GR scalar averaging framework for irrotational dust
  - cosmological principal : Universe homogeneous at large scales
  - what happens if universe is in fact lumpy and we average Einstein equation on large region ?
  - -> averaging and time evolution do not commute !! (non-linear equations) (https://arxiv.org/pdf/gr-qc/0102049 Buchert 2001)
    - voids expands faster than matter field.

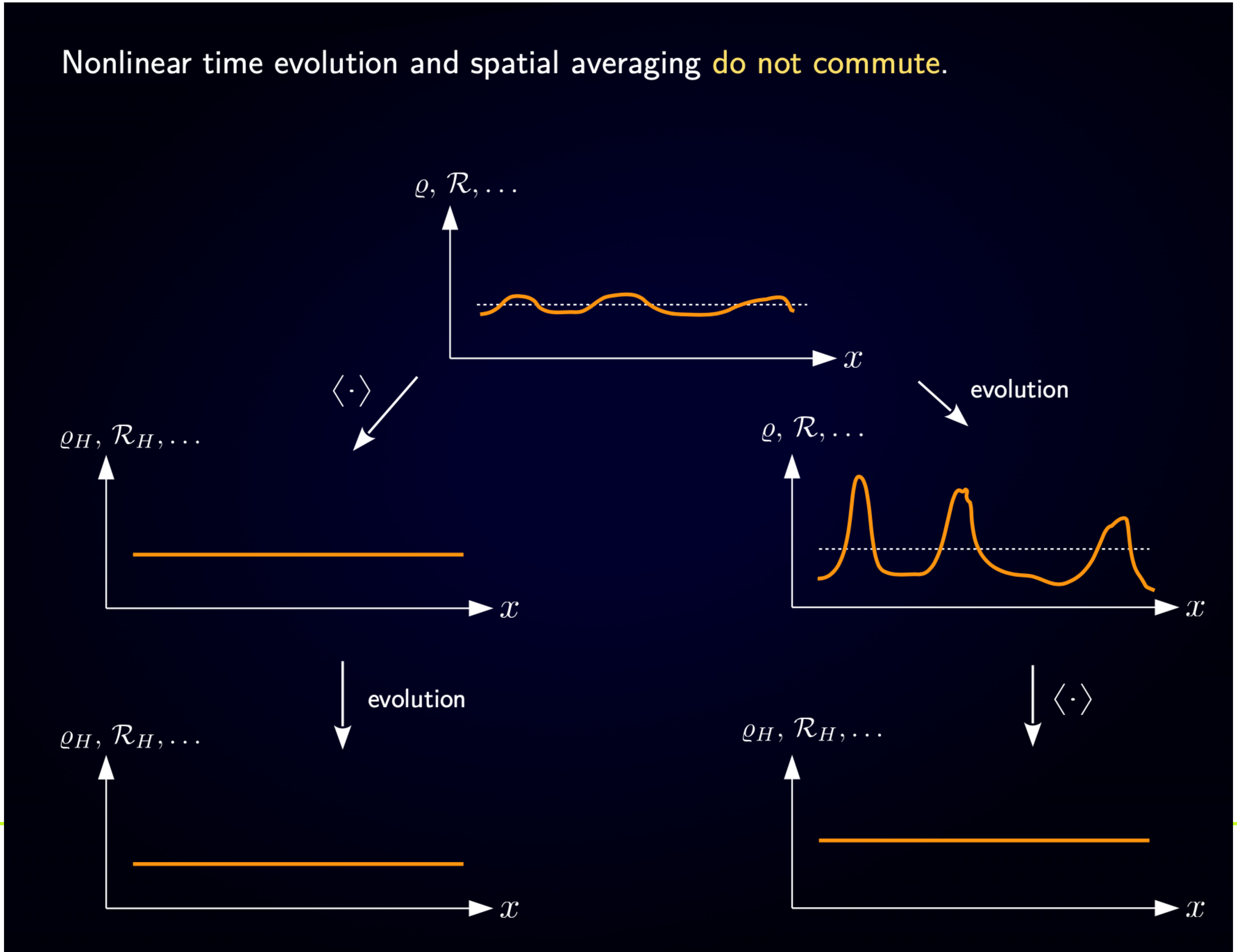
- Need to introduce correction terms :
  - backreaction and spatial curvature

Averaging and evolution do not commute

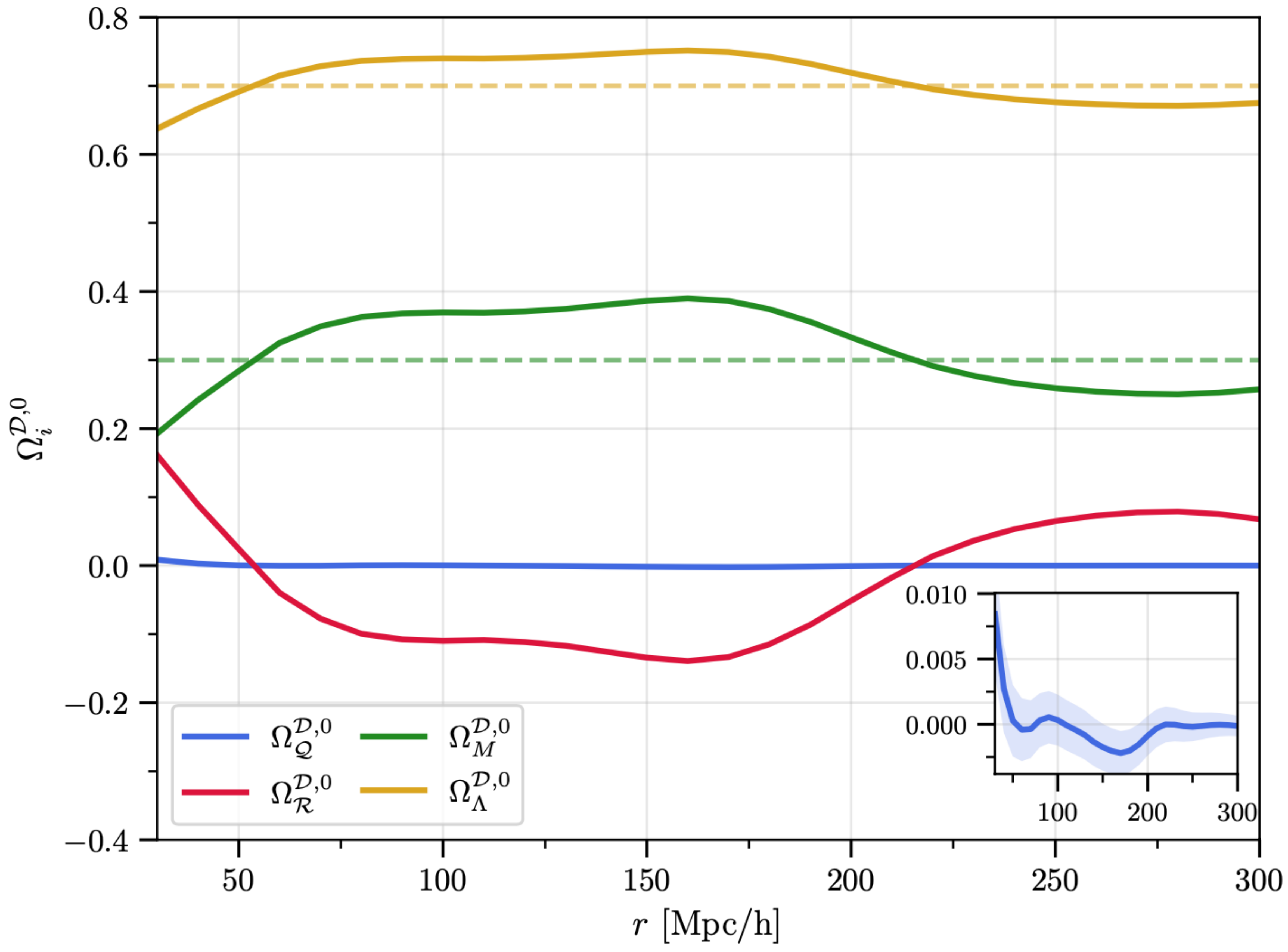


Multiscale approach to inhomogeneous cosmologies
Alexander Wiegand, Thomas Buchert https://arxiv.org/abs/1103.1531

Averaging and evolution do not commute



Non-convergence to LCDM



$$\Omega_M^{\mathcal{D}} + \Omega_\Lambda^{\mathcal{D}} + \Omega_\mathcal{R}^{\mathcal{D}} + \Omega_\mathcal{Q}^{\mathcal{D}} = 1,$$

where we have defined

$$\Omega_M^{\mathcal{D}} := \frac{8\pi G\, \langle \rho \rangle_\mathcal{D}}{3H_\mathcal{D}^2}; \quad \Omega_\Lambda^{\mathcal{D}} := \frac{\Lambda}{3H_\mathcal{D}^2};$$

$$\Omega_\mathcal{R}^{\mathcal{D}} := -\frac{\langle \mathcal{R} \rangle_\mathcal{D}}{6H_\mathcal{D}^2}; \quad \Omega_\mathcal{Q}^{\mathcal{D}} := -\frac{\mathcal{Q}_\mathcal{D}}{6H_\mathcal{D}^2}.$$

- backreaction (inhomogeneity and anisotropy of fluid volume deformation

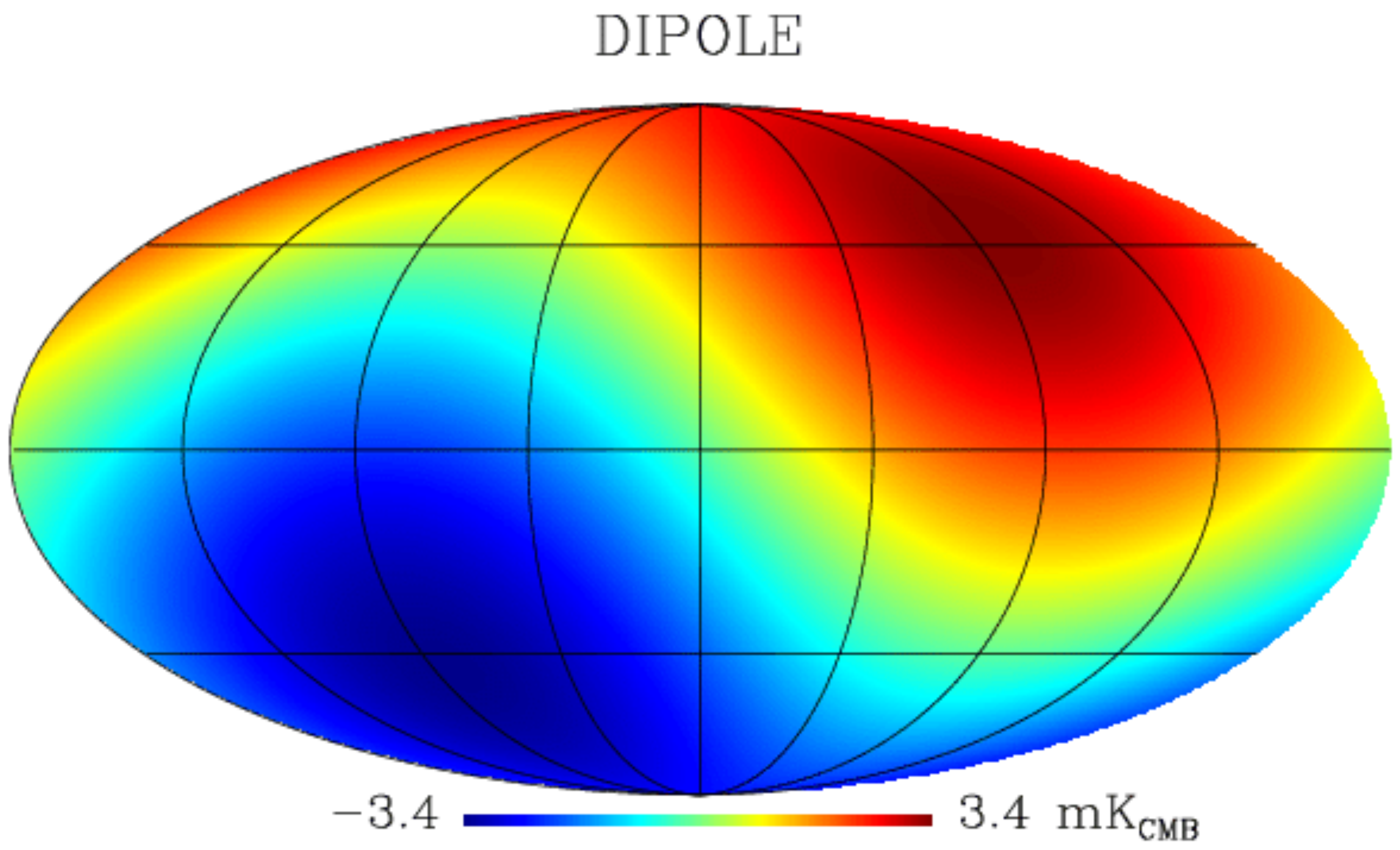
- fluid spatial intrinsic curvature

Local environment dominated by voids -> small but non-negligible spatial curvature + small backreaction contribution

Cosmic Dipole

Cosmic Dipole and test of cosmological principle

- CMB temperature dipole (dT ~3.3 mK) -> we are moving relatively to the CMB rest frame , v~369 km/s



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- But studying matter dipole :
  - direction is same than CMB dipole
  - but size is 2-3 times larger than the CMB one
  - Same anomaly seen with Radio survey and Quasars
  - +5σ significance now ! https://arxiv.org/pdf/2505.23526
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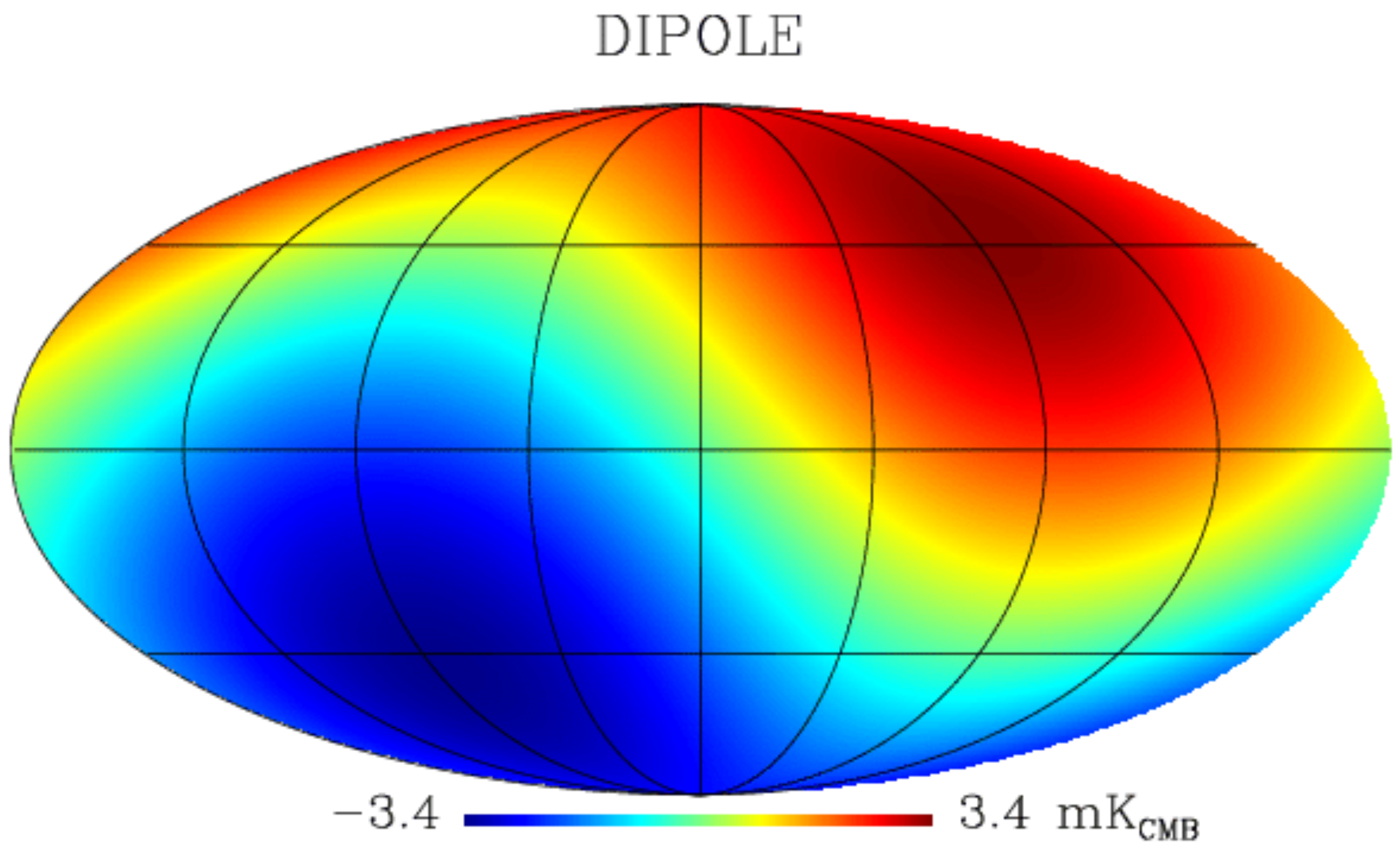
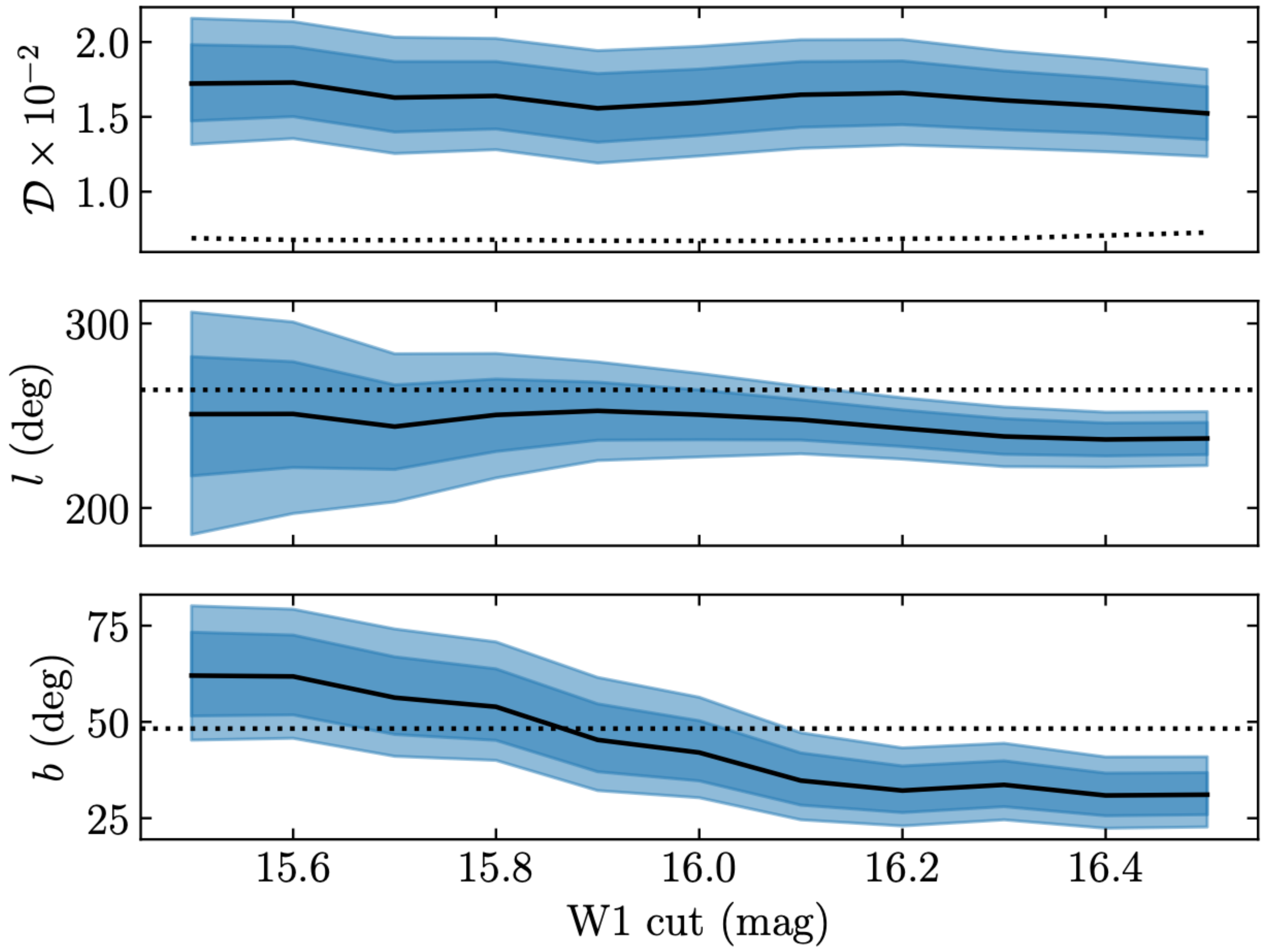
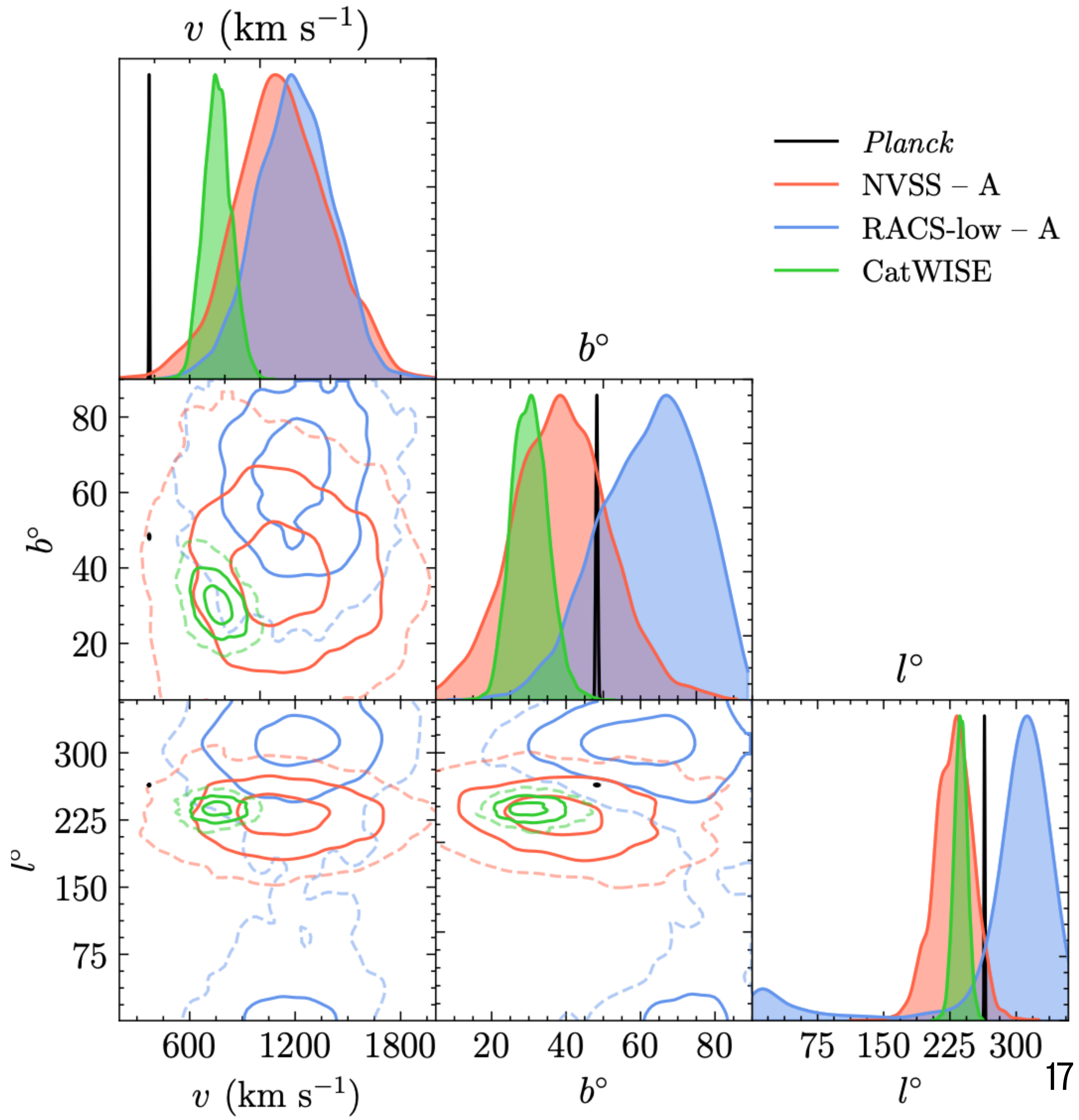
https://arxiv.org/pdf/2509.18689







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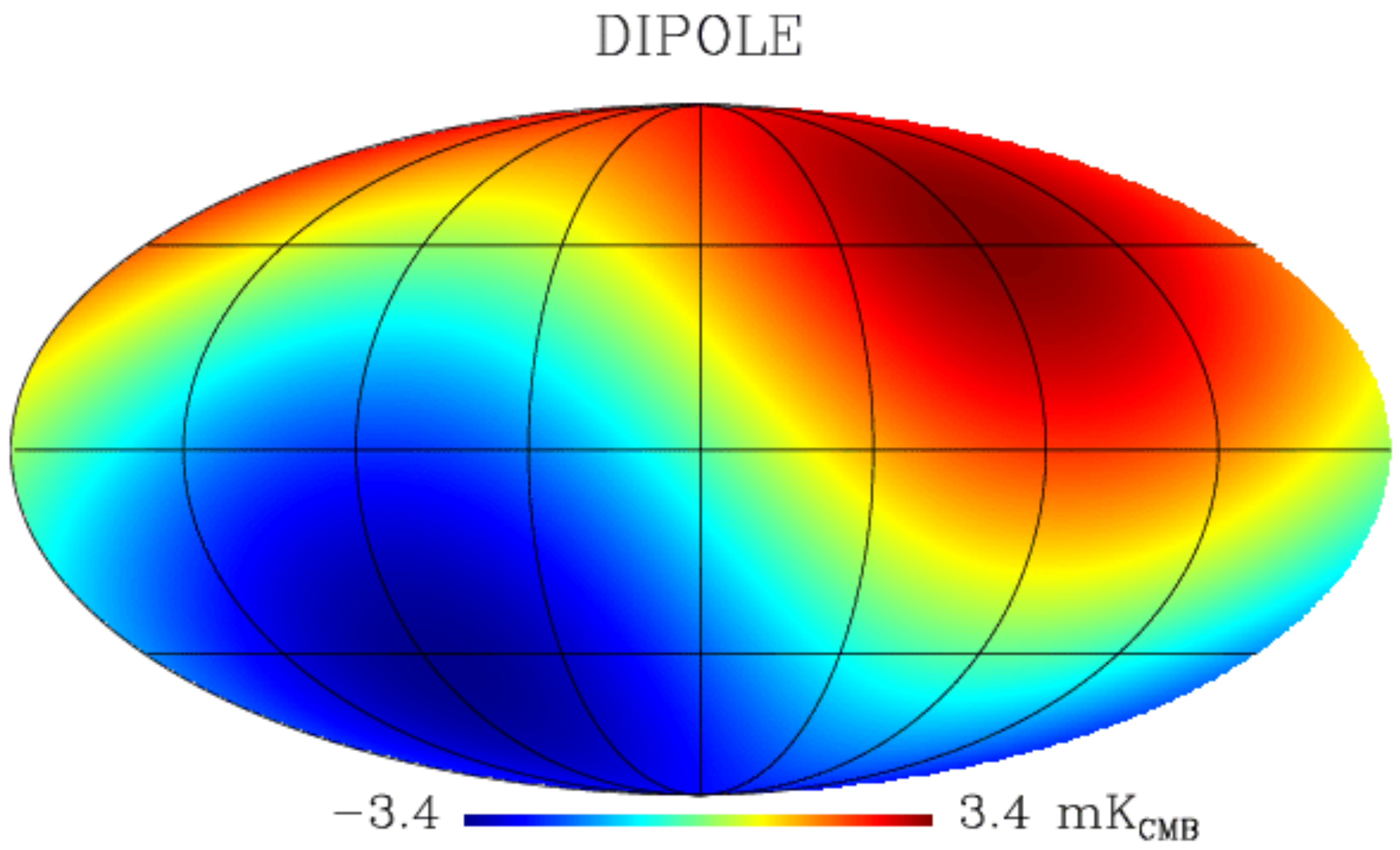
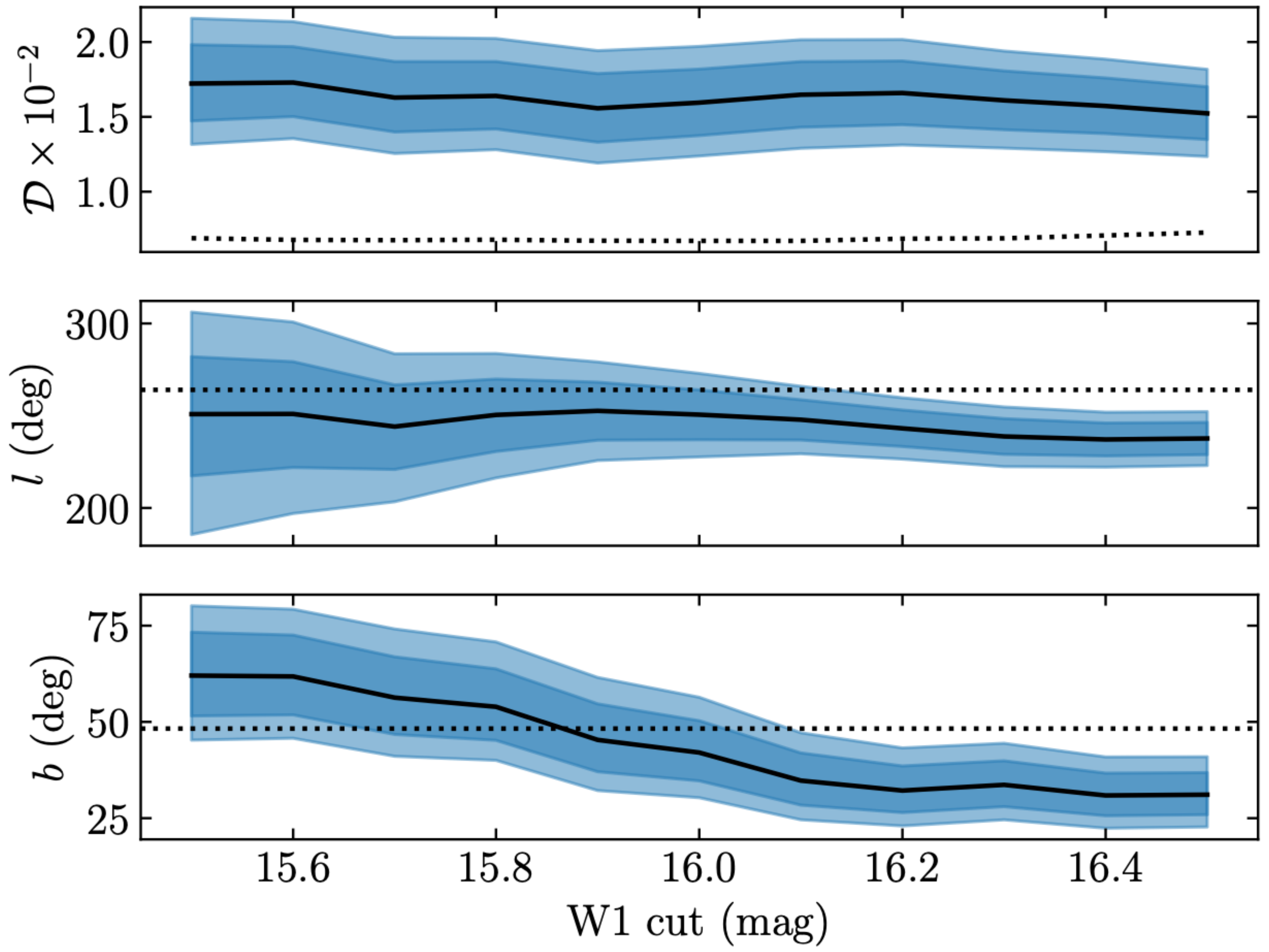
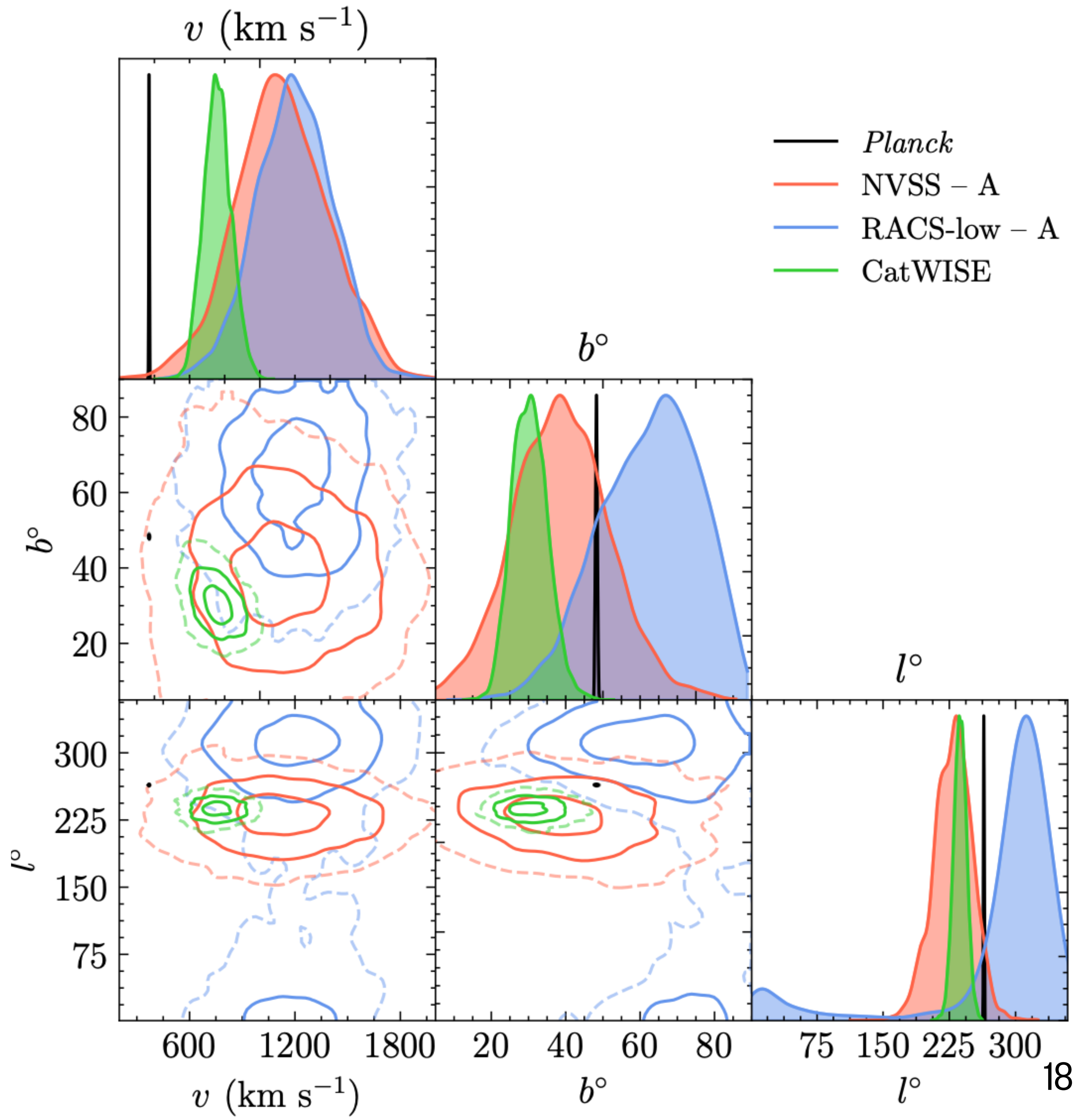
- Two different rest frames ? Inhomogeneous universe ?
- If confirmed clearest observational cracks in the cosmological principle !

https://arxiv.org/pdf/2509.18689



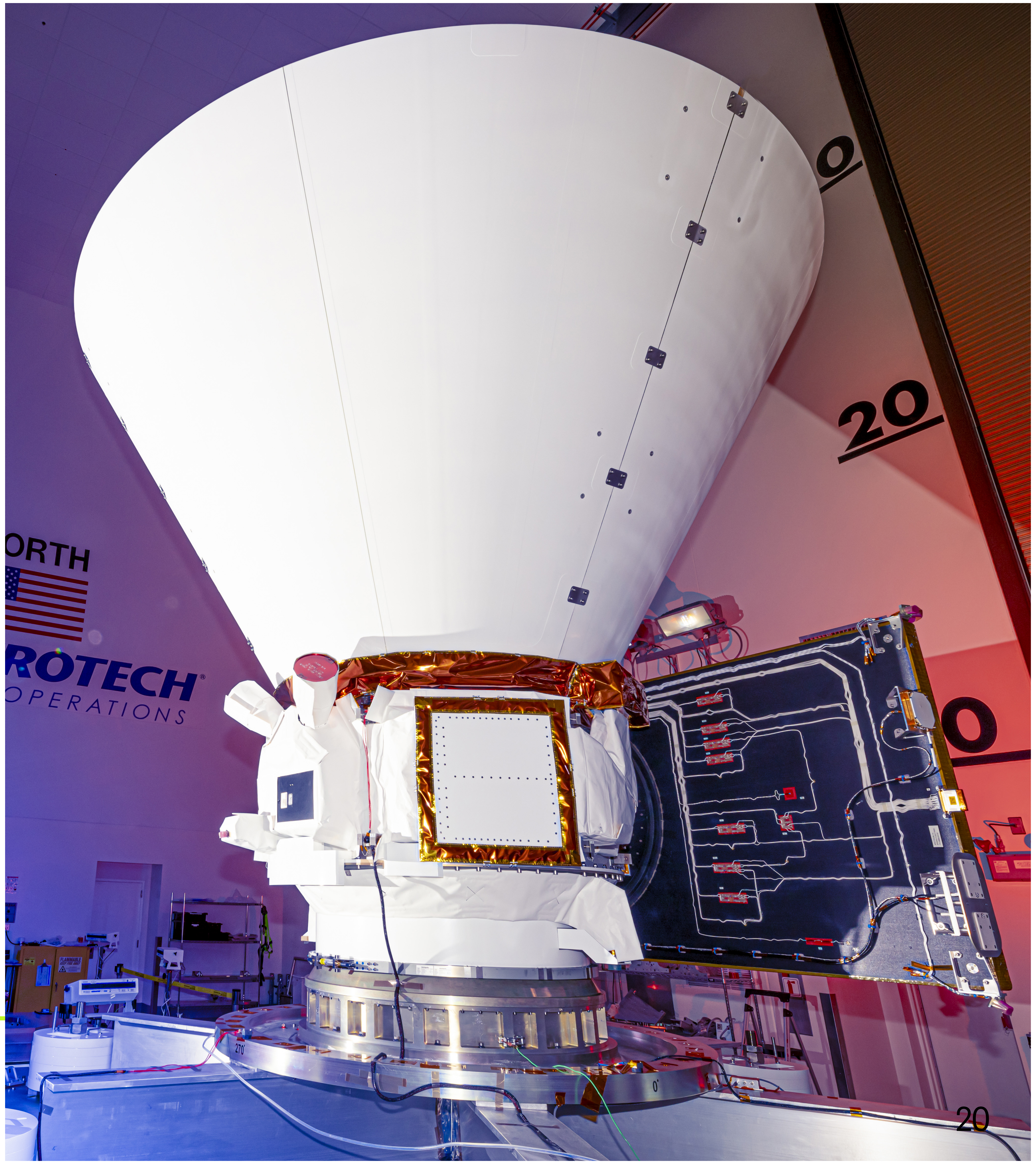


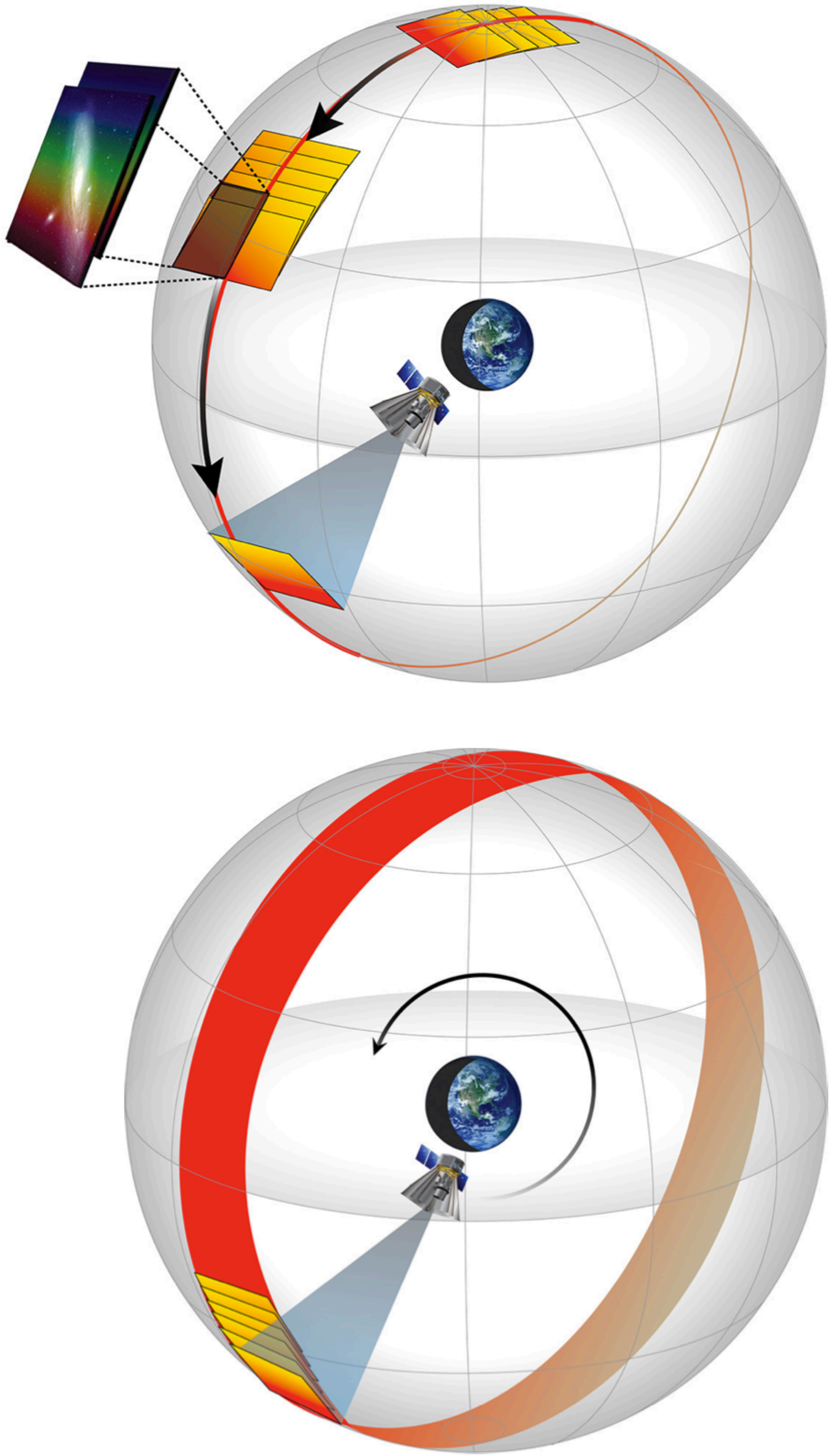


Primordial Non Gaussianities

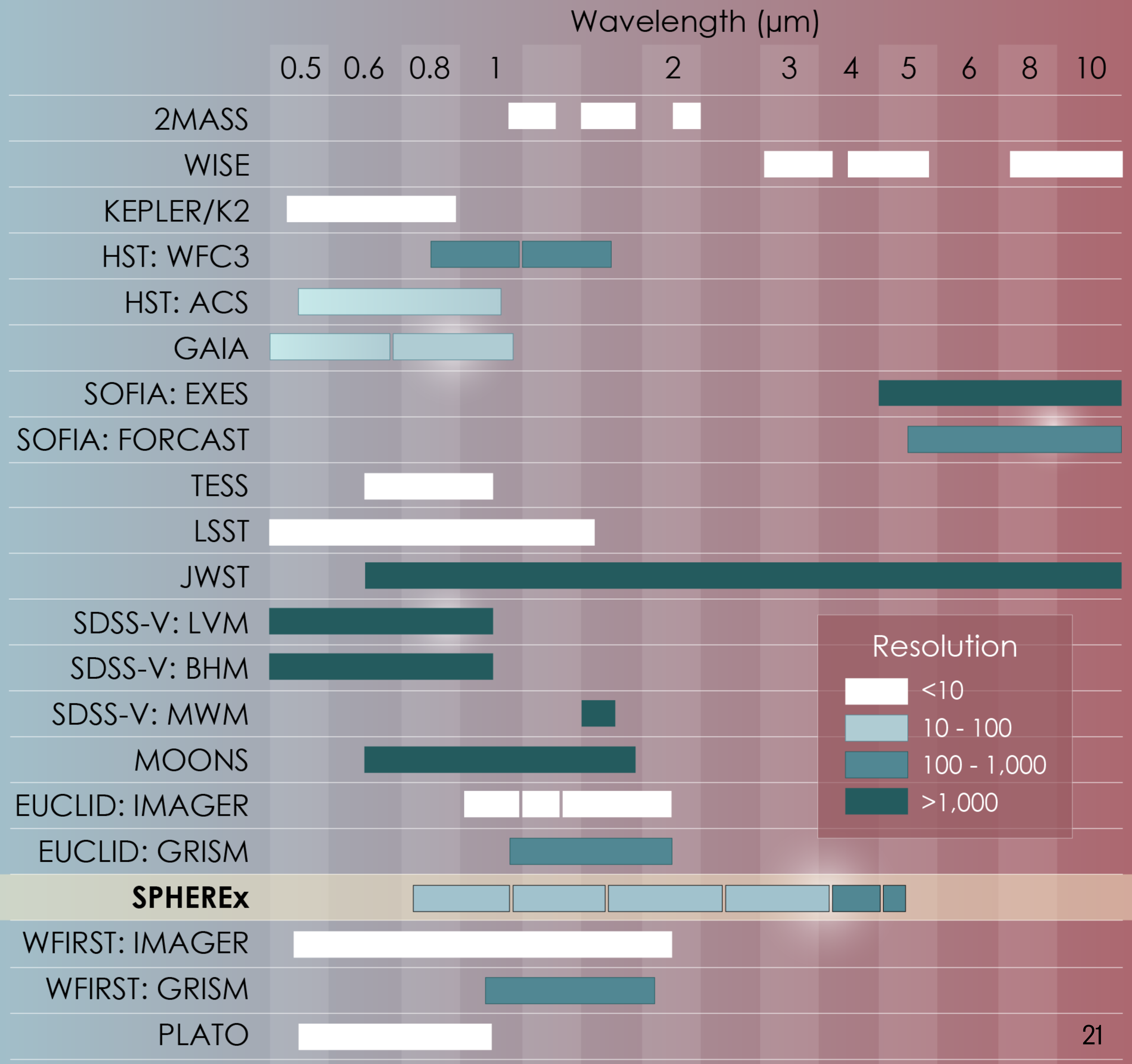
Large-Scale Structure and Primordial Non-Gaussianity with SPHEREx

- SPHEREx : Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer
- Small NASA IR spatial telescope equipped with a spectro-photometer (102 bands within 0,75-5 um)
  - precisely the range absorbed by atmosphere !
  - provide accurate redshifts for ~ 100 million galaxies out to $z < 1$
- 2 years mission, launched March 11th 2025 (Full sky in 6 months)
- Will allow to constrain primordial non-Gaussianities





Mission Wavelengths and Resolving Power



Primordial non-gaussianity

- Gaussian field -> statistical properties fully determined by power spectrum (2pt corr. function)
  - arises from a free linear quantum field.
- non-Gaussianity -> additional information beyond Power Spectrum
  - 3pt function (bispectrum), 4pt function (trispectrum)
  - fNL is a term that measure this non-Gaussianity (proportional to bispectrum)
- if non-Gaussianities -> gives information about inflation !

$$\zeta(\mathbf{x}) = \zeta_G(\mathbf{x}) + \frac{3}{5} f_{\mathrm{NL}} \left(\zeta_G^2(\mathbf{x}) - \langle \zeta_G^2 \rangle \right)$$

Magnification bias

Magnification bias in 3x2 pts

- Fabien Castillo (ANR ProGraceRay) : https://indico.cern.ch/event/1634832/contributions/7104863/attachments/3294900/5892456/GR_effects_LSS_castillo.pdf

The magnification bias

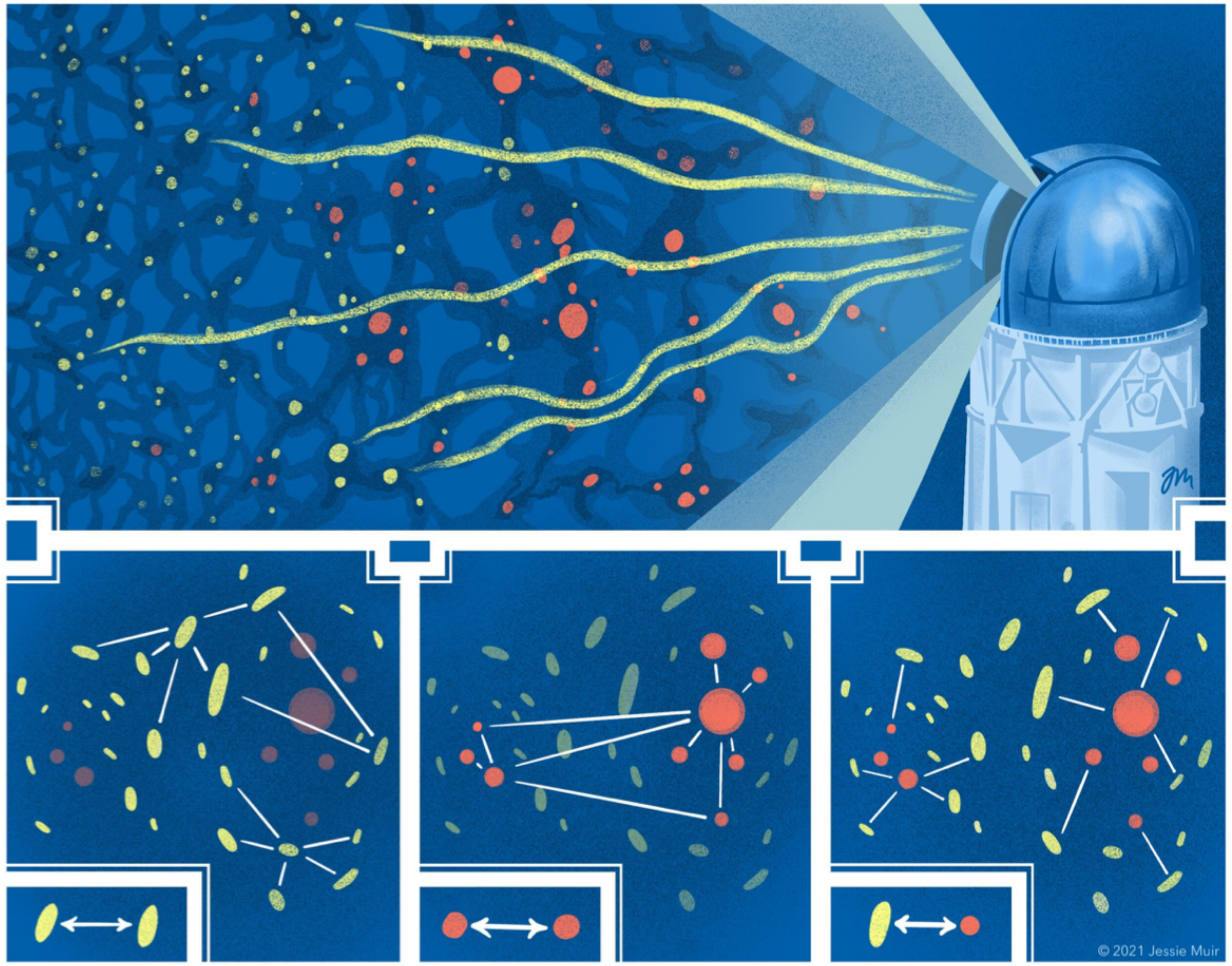
Weak lensing has two opposed effects on δ_{obs}

- Increase in solid angles: Dilution of the observed source density per unit area
- Galaxies that are normally too faint become detectable : Increase in source density

$$(1+\delta)_{\mathrm{obs}} = (1+\delta)\mu^{2.5s-1} \tag{3}$$

with the magnification $\mu = \frac{1}{(1-\kappa)^2+|\gamma|^2}$, and s the logarithmic slope of the galaxy luminosity function.

- Also biases γ, since magnified regions will be assigned a different weight
- Poorly accounted for in current surveys



Relativistic effects

Other relativistic effects that can affect the 3×2 pts correlation functions :

$$z = \frac{a_0}{a}\left(1 - \Psi + \frac{\boldsymbol{v}\cdot\boldsymbol{n}}{c} + \frac{1}{2}\frac{v^2}{c^2} - \int_{\eta}^{\eta_0} \frac{\partial\left(\Phi + \Psi\right)}{\partial \eta'} \mathrm{d}\eta'\right), \tag{4}$$

$$\boldsymbol{\theta} = \boldsymbol{\beta} + \boldsymbol{\alpha}, \tag{5}$$

$$n_{\mathrm{obs}} = n\mu^{2.5s-1}. \tag{6}$$

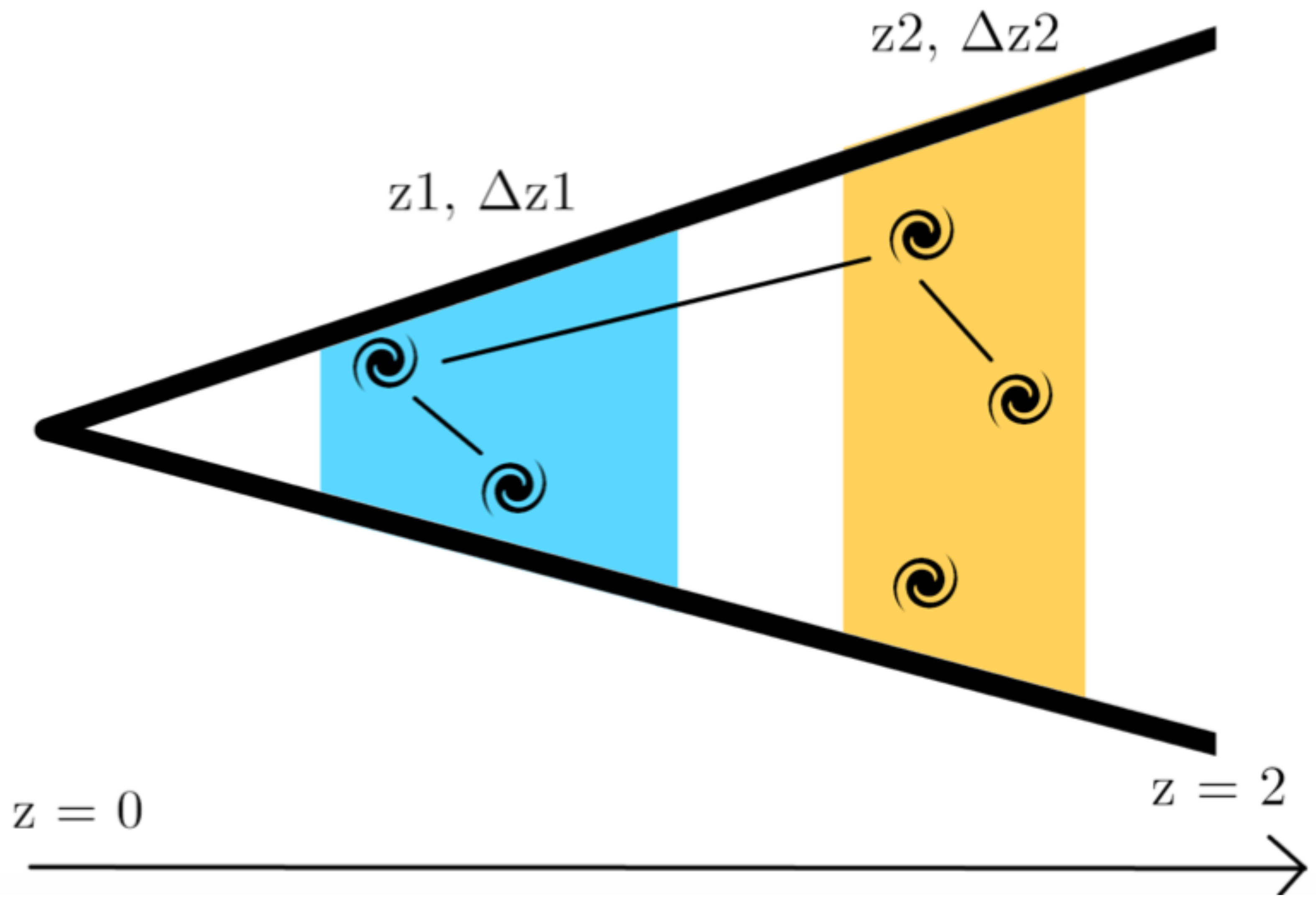
Redshift : Comoving + Gravitational redshift + RSD + Transverse Doppler + ISW

Apparent position of sources changed by weak lensing

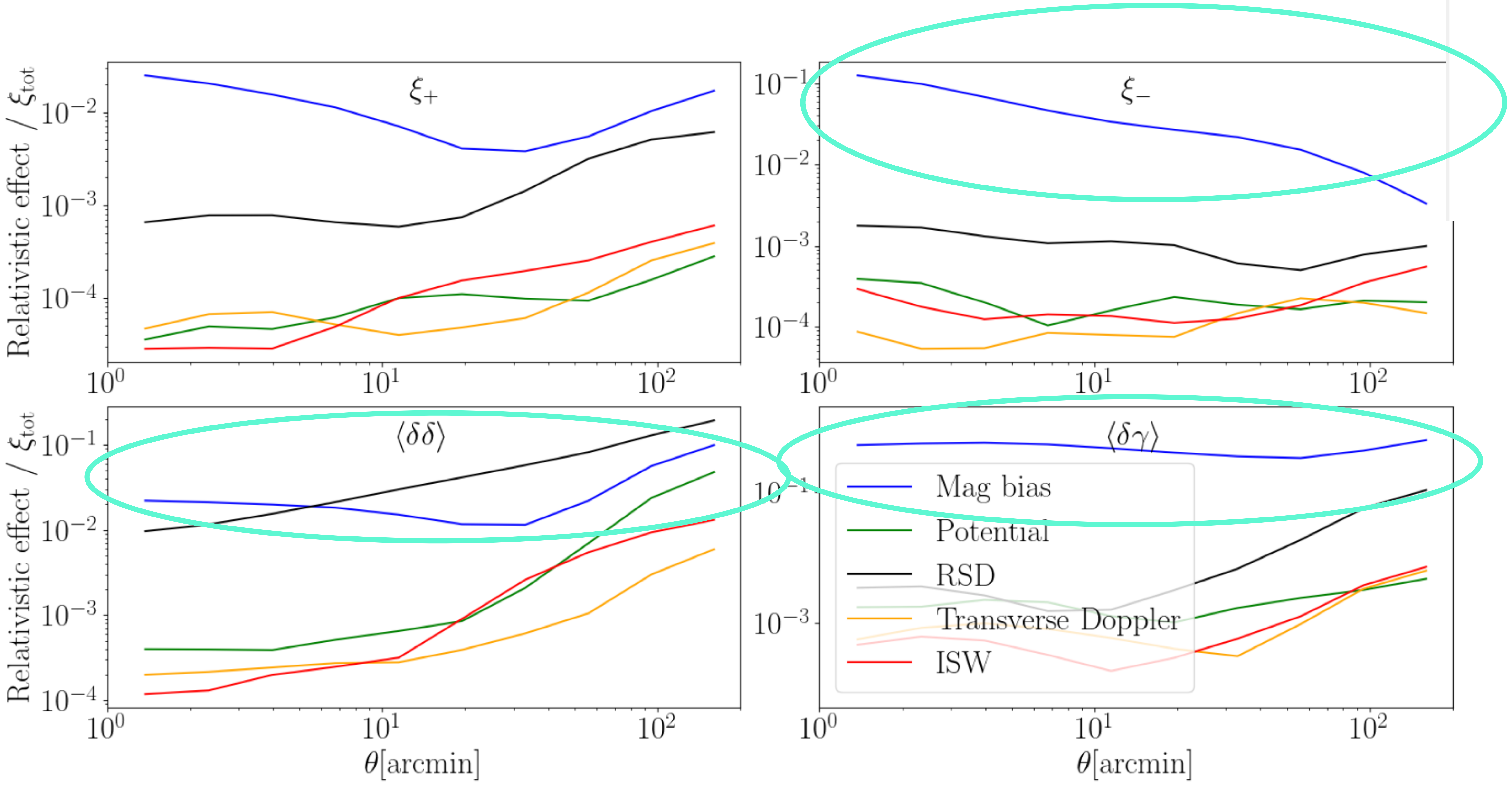
Magnification bias : change of source density by weak lensing

Methodology

- With the raytracing, we can study the impact of the different relativistic effects separately
- Comparison of Born and relativistic 3×2 pts correlation functions
- Amplitude of the relativistic effects will depend on the configuration of the two redshift bins
- Plots in this talk : $z_1 = 1.1,\ z_2 = 1.5,\ \Delta z = 0.2$



Relativistic effects in ΛCDM



- Born approximation good for ξ_+, magnification bias important for ξ_-, $\langle\delta\delta\rangle$ and $\langle\delta\gamma\rangle$
- RSD important for $\langle\delta\delta\rangle$, other effects negligible for 3×2 pts

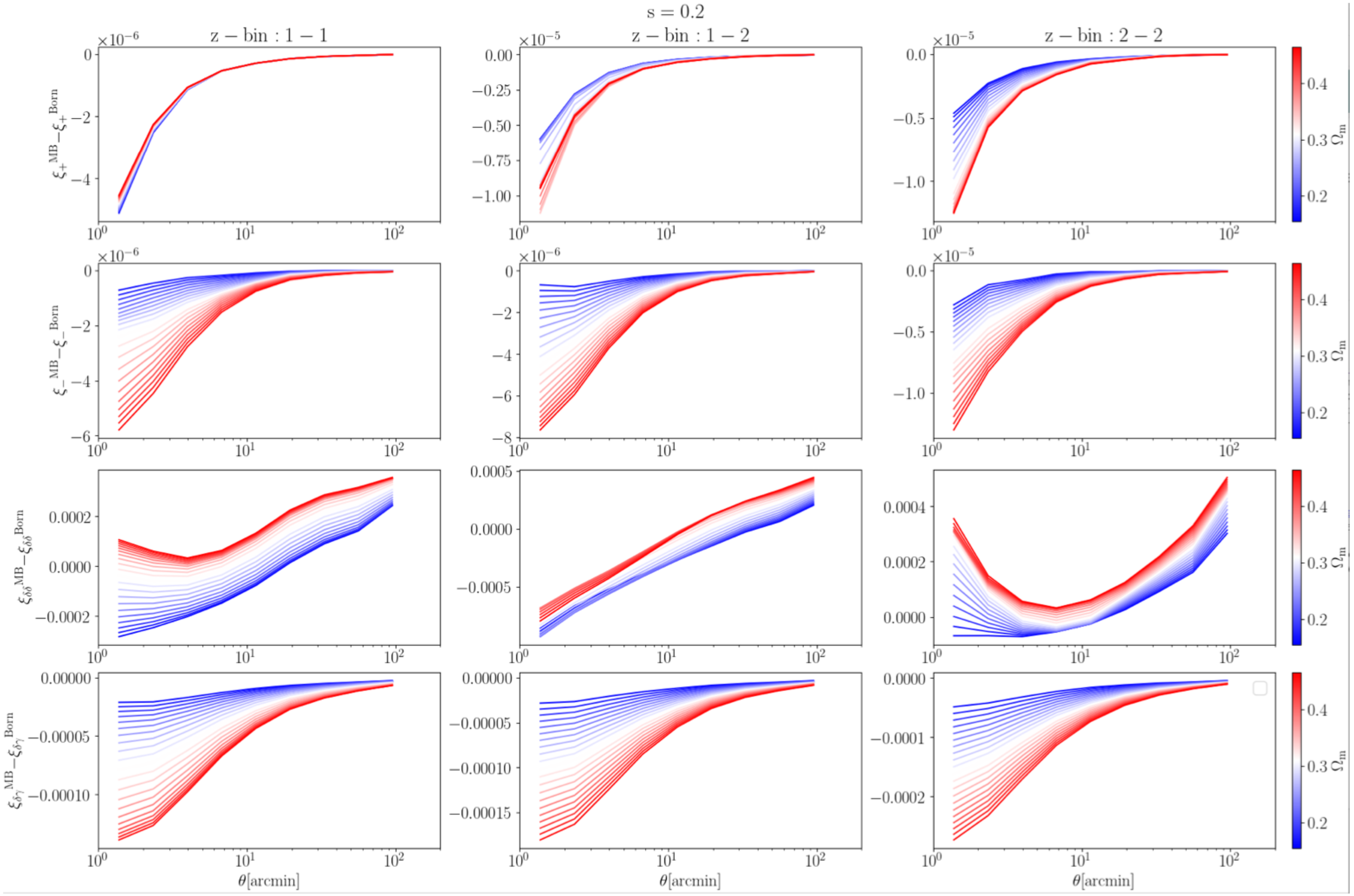
3x2 pts correlation functions

Cosmic shear surveys (KiDs, DES, Euclid, LSST...) : measure 4 correlation functions

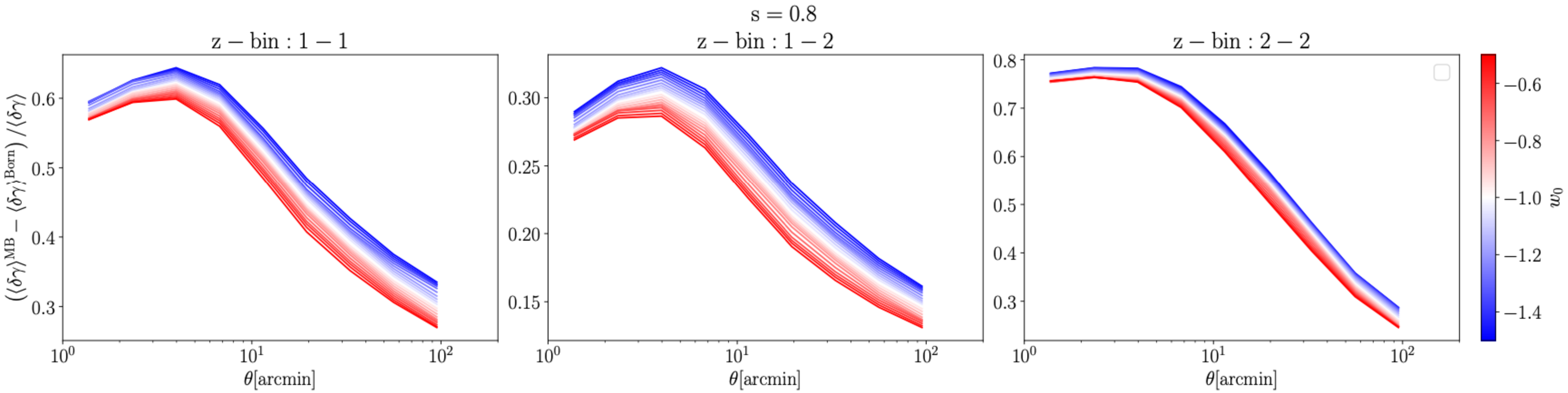
- $\langle\delta\delta\rangle$: Position of galaxies in two different redshift bins
- $\langle\delta\gamma\rangle$: Position of galaxies in a bin and shear in another bin
- ξ_+, ξ_- : shear in two reshift bins (γ has two components)

Predictions : Ω_{m} (preliminary)

- Effect of Ω_m on the amplitude of the magnification bias



Predictions : w_0 (preliminary)



- The amplitude of the magnification bias can be modified compared to ΛCDM by up to 10% for $\langle\delta\gamma\rangle$ and 5% for ξ_-
- Negligible effect on ξ_+ and $\langle\delta\delta\rangle$
- Negligible effect of Ω_ν

Thank you !