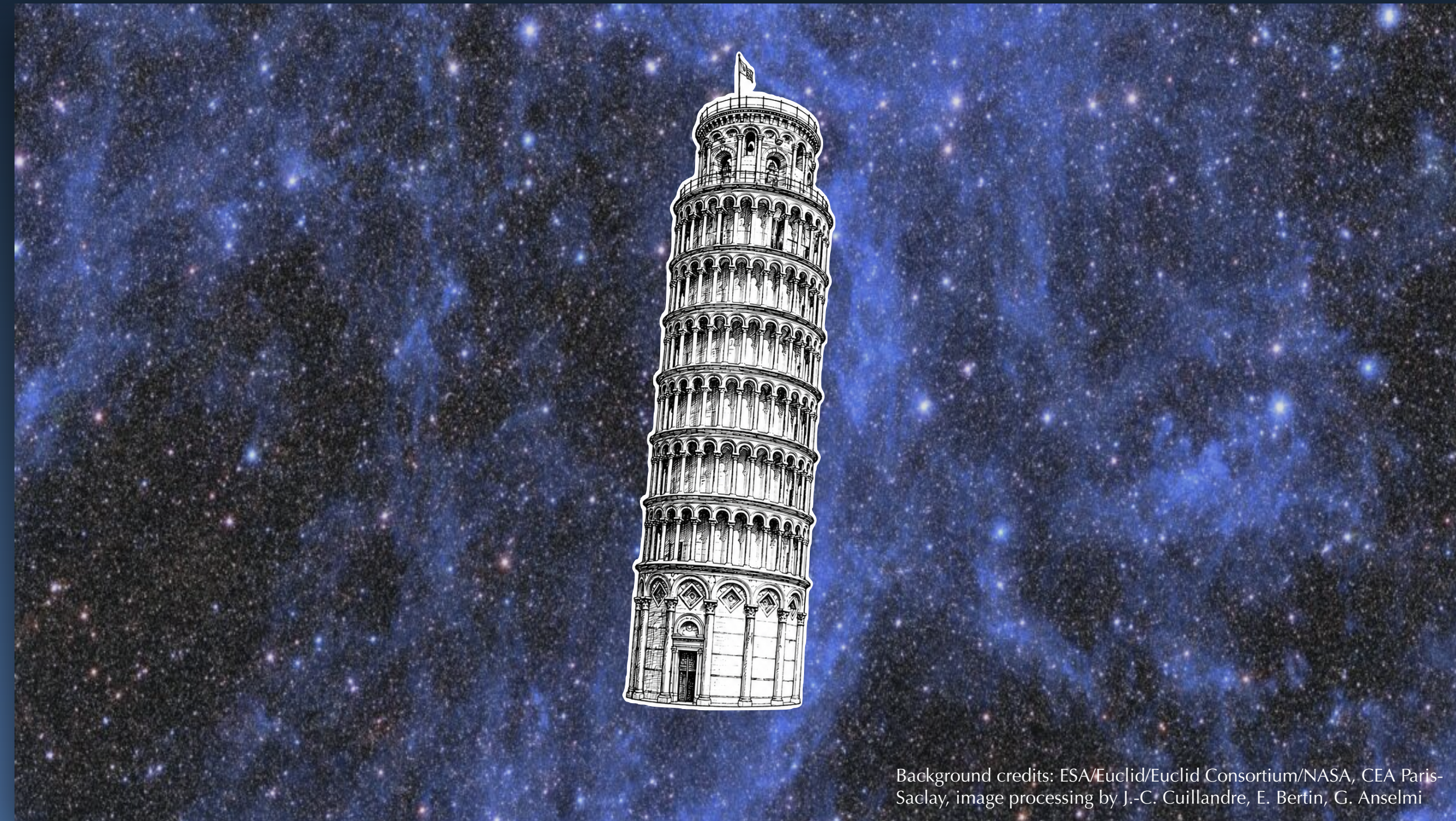
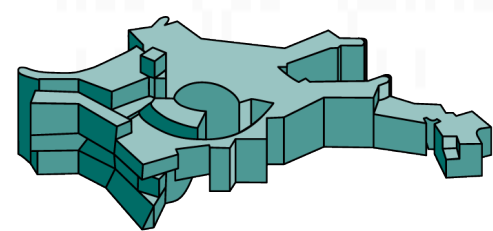


Testing the Equivalence Principle in Galaxy Surveys

A Matter of Time and Two Fluids



Sveva Castello

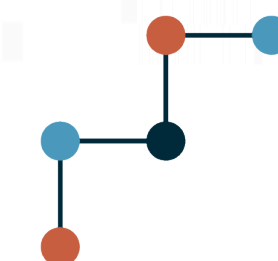


MAX-PLANCK-INSTITUT
FÜR ASTROPHYSIK



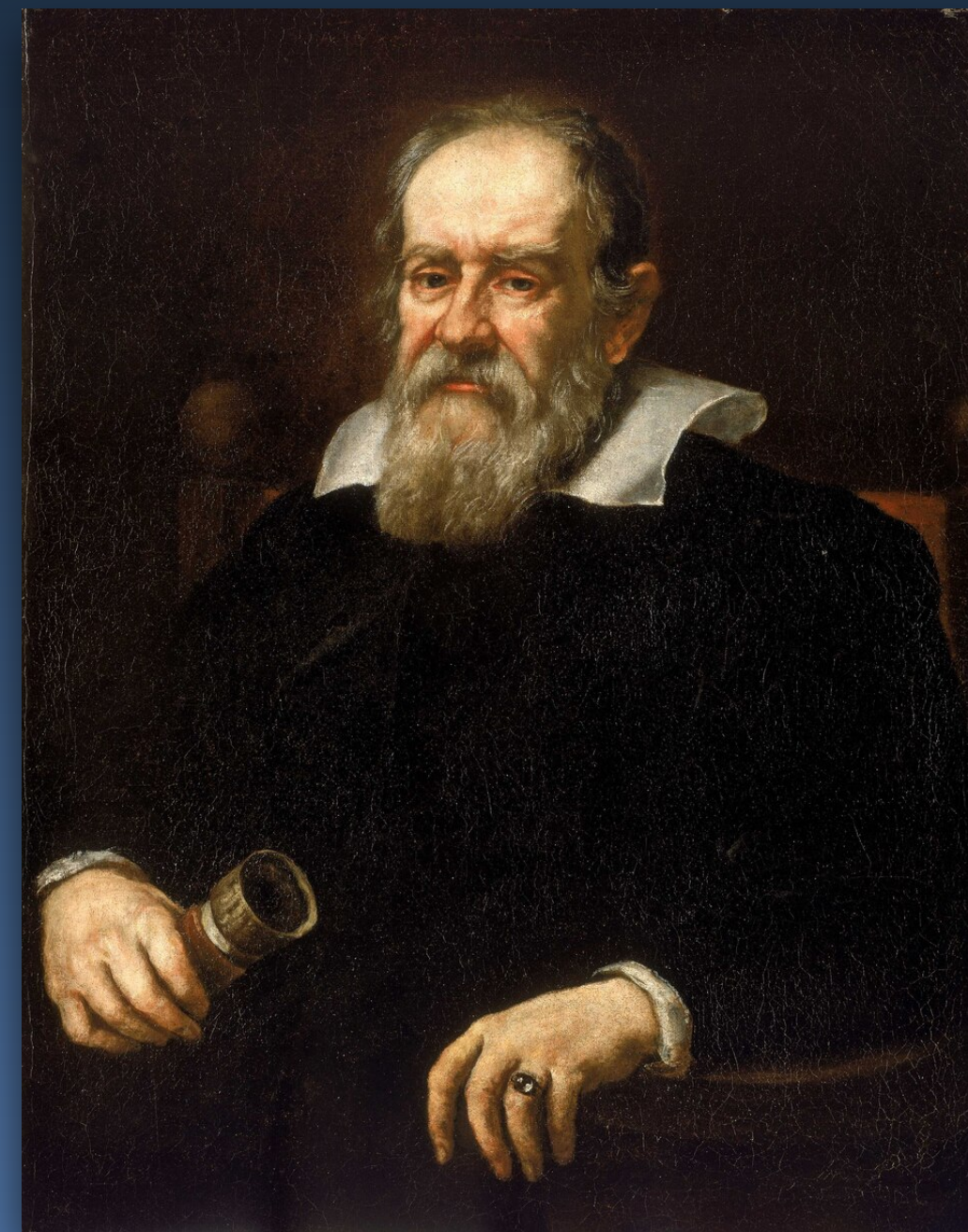
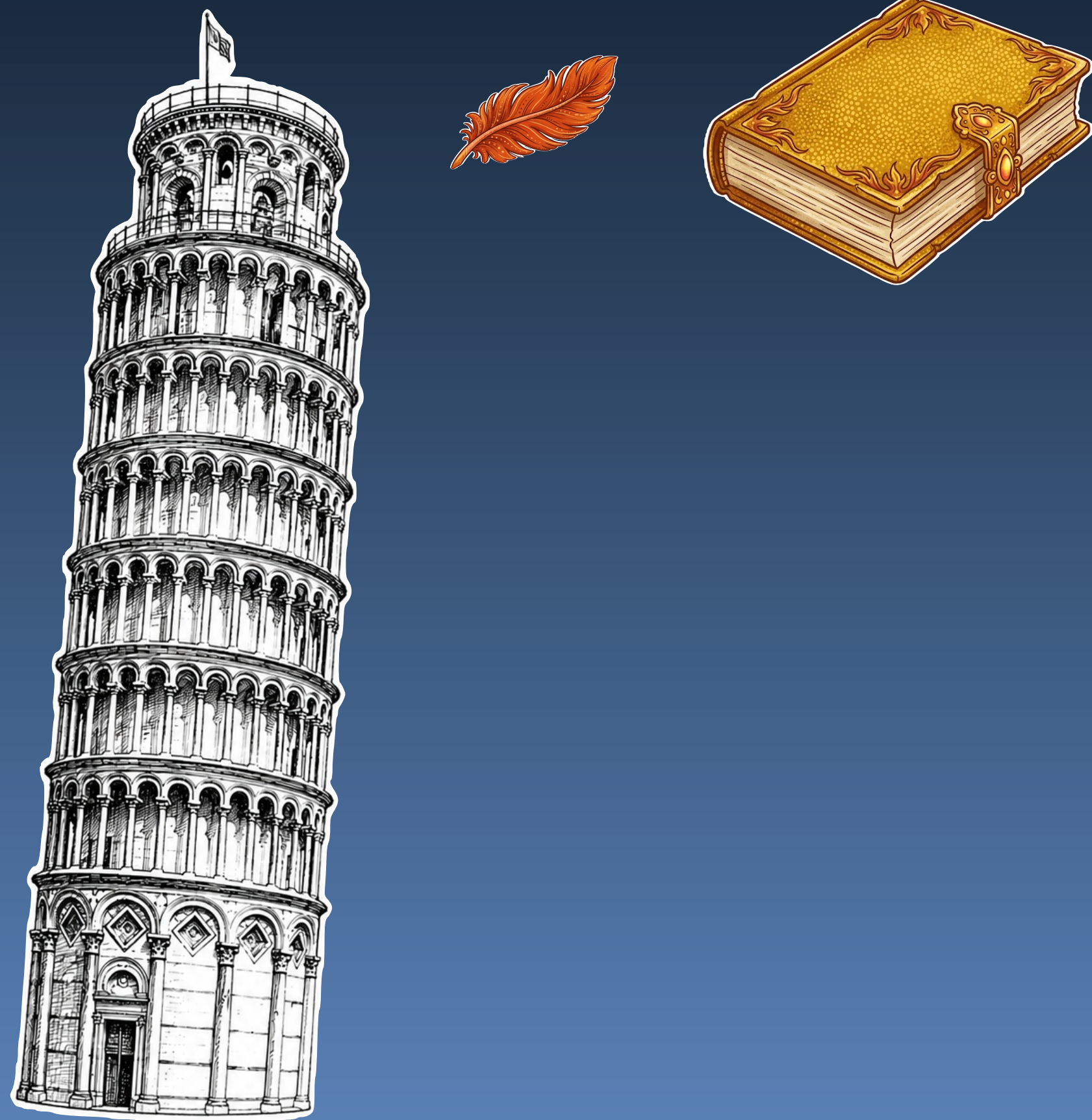
COSMO 26

Leiden, August 25th, 2026



Swiss National
Science Foundation

In the footsteps of Galileo



Credits: J. Sustermans, Royal Museums Greenwich

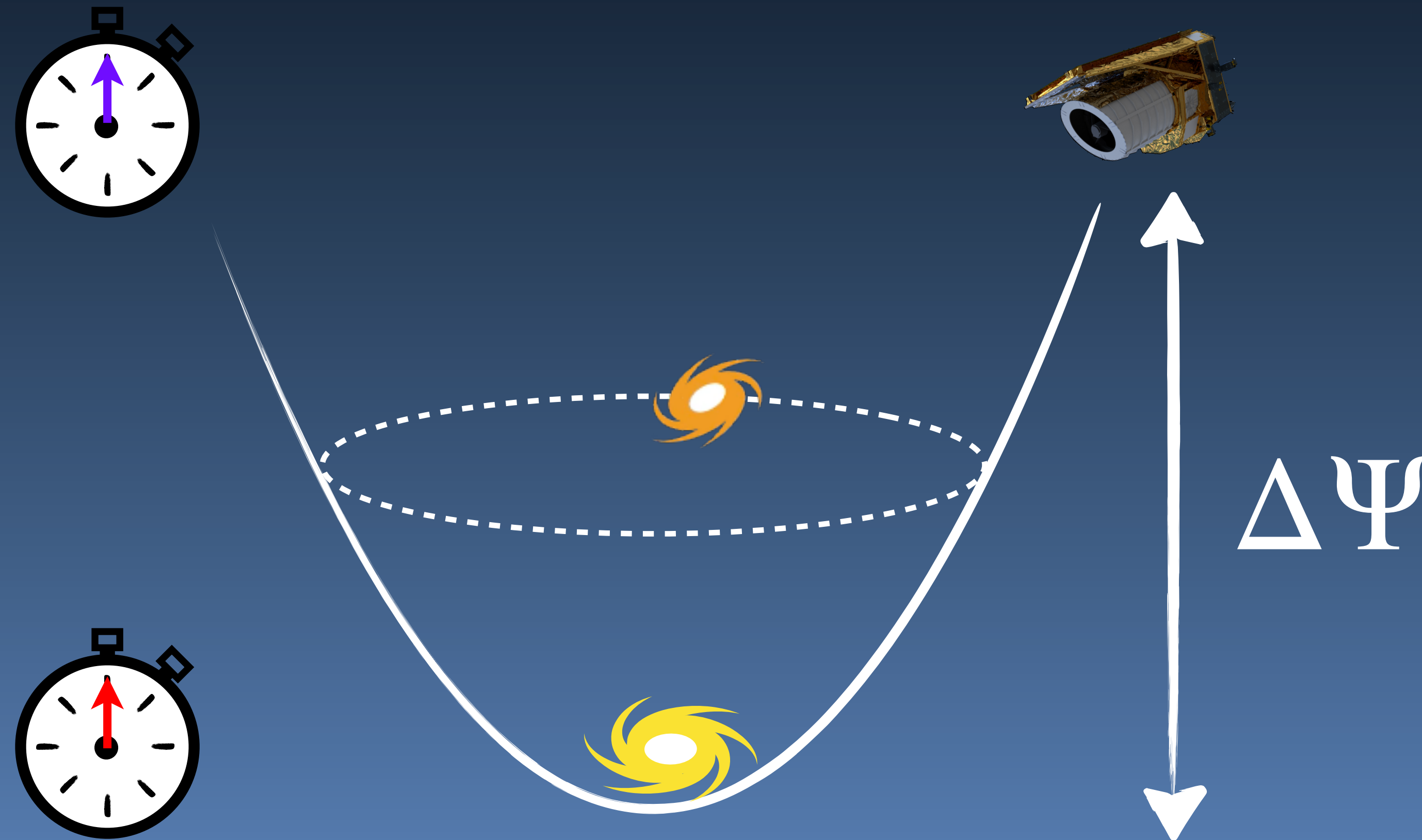


Credits: Rijksdienst voor het Cultureel Erfgoed

“A Matter of Time and Two Fluids”

A matter of time

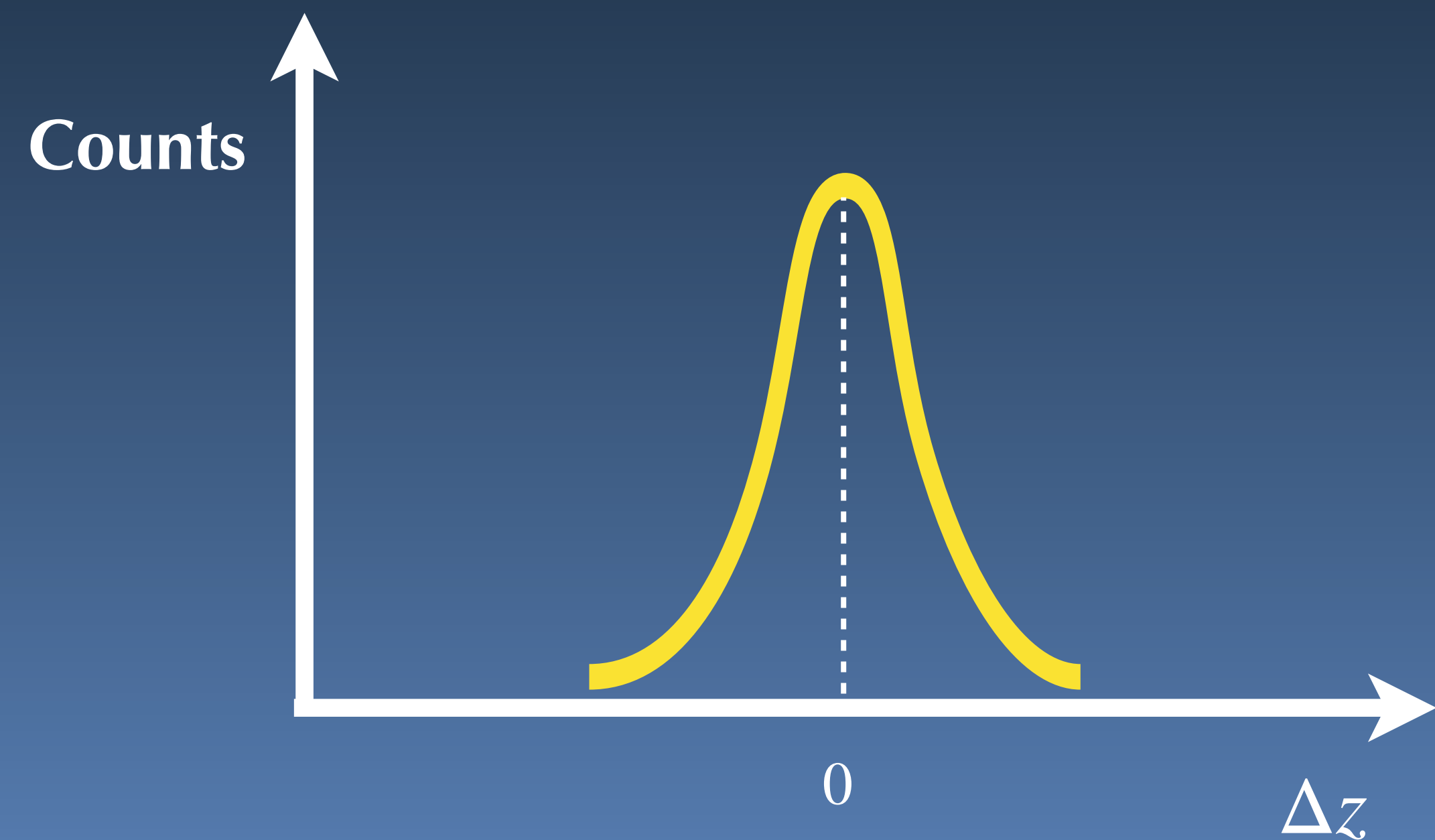
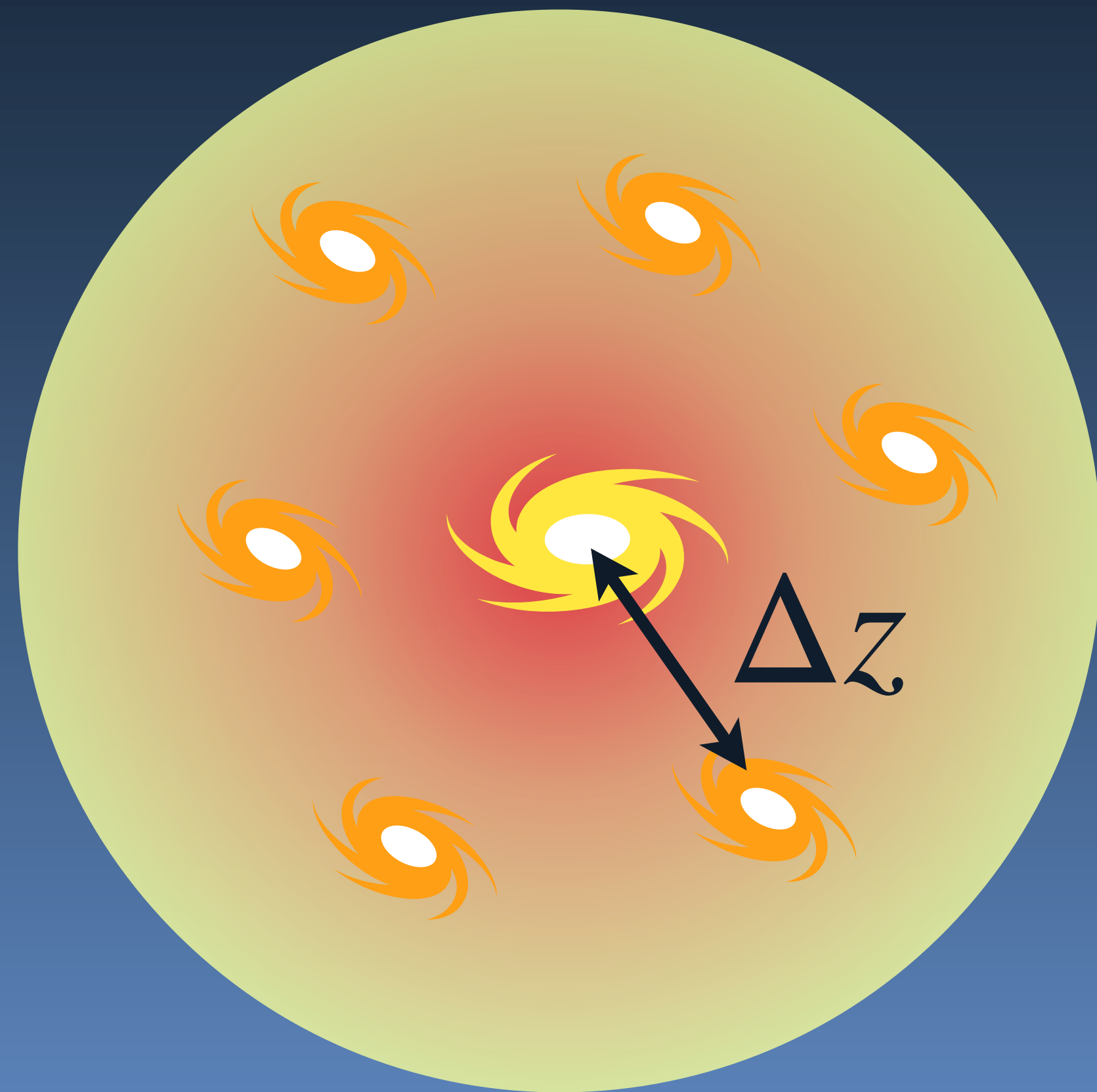
SC, Zheng, Bonvin, Amendola (2025)
Di Dio, SC & Bonvin (2026)



1. Galaxy velocities
2. Gravitational redshift

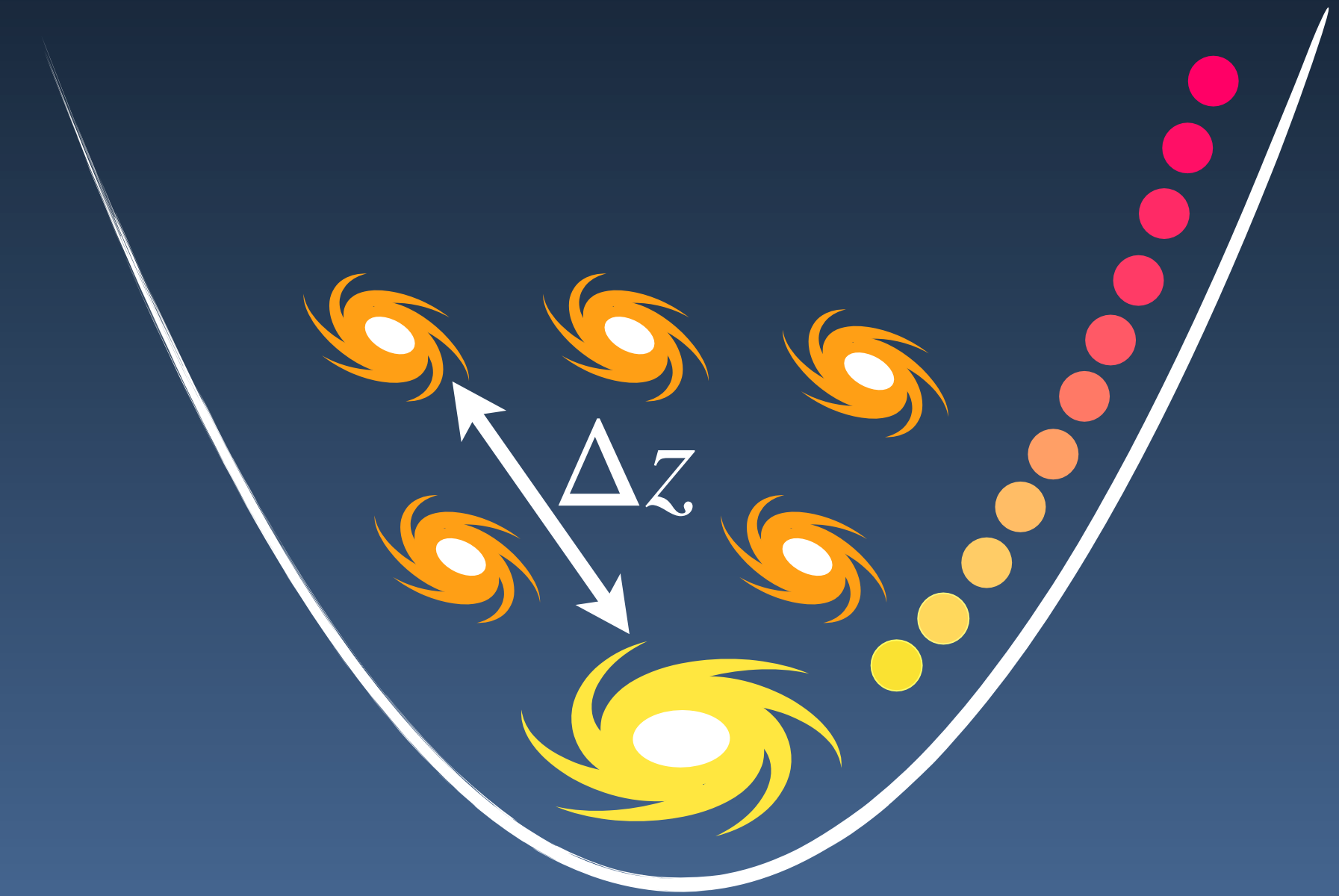
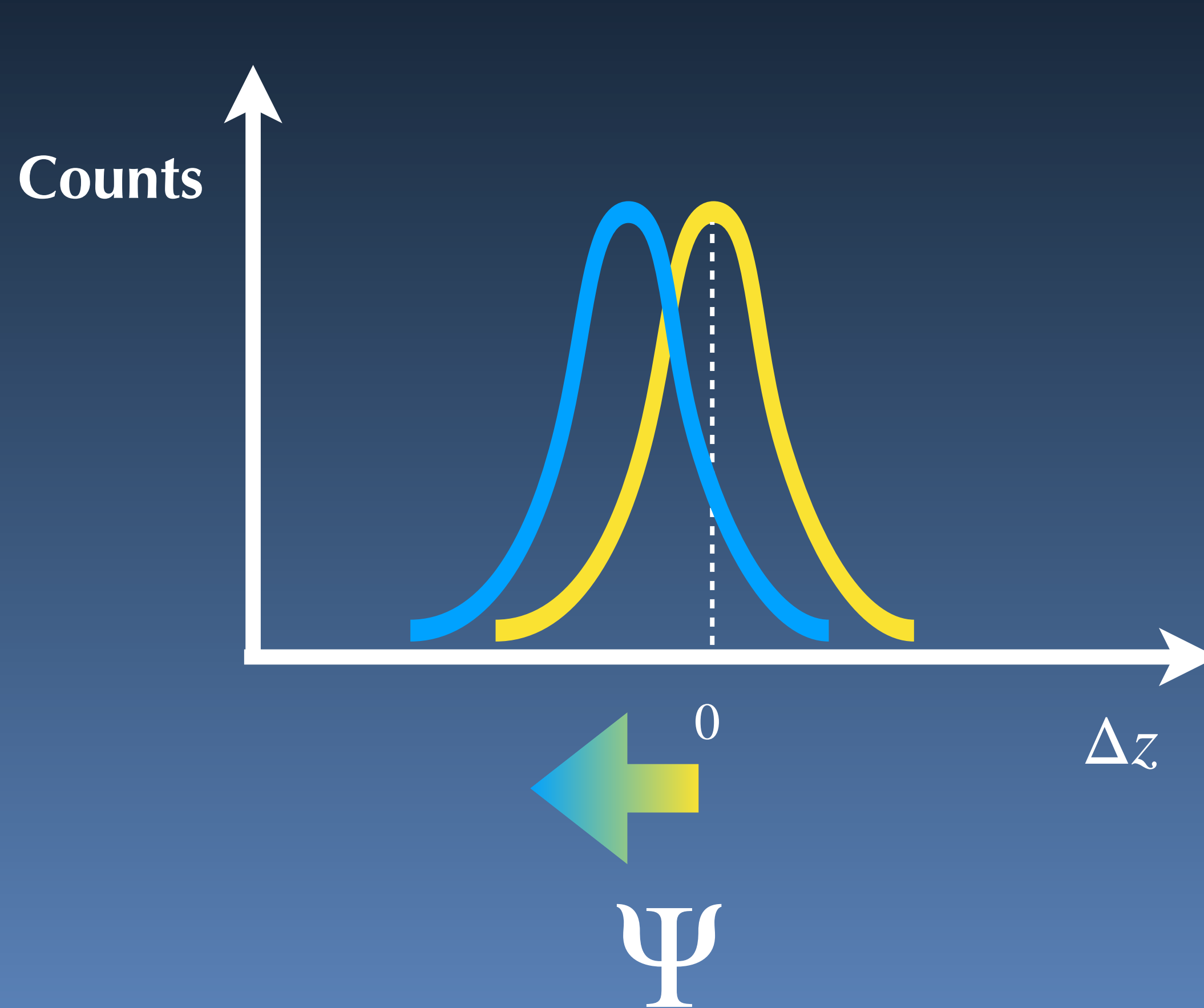
Gravitational redshift in galaxy clusters

Nottale (1990)
Cappi (1995)
Kim & Croft (2004)
Wojtak, Hans & Hjorth (2011)



Gravitational redshift in galaxy clusters

Nottale (1990)
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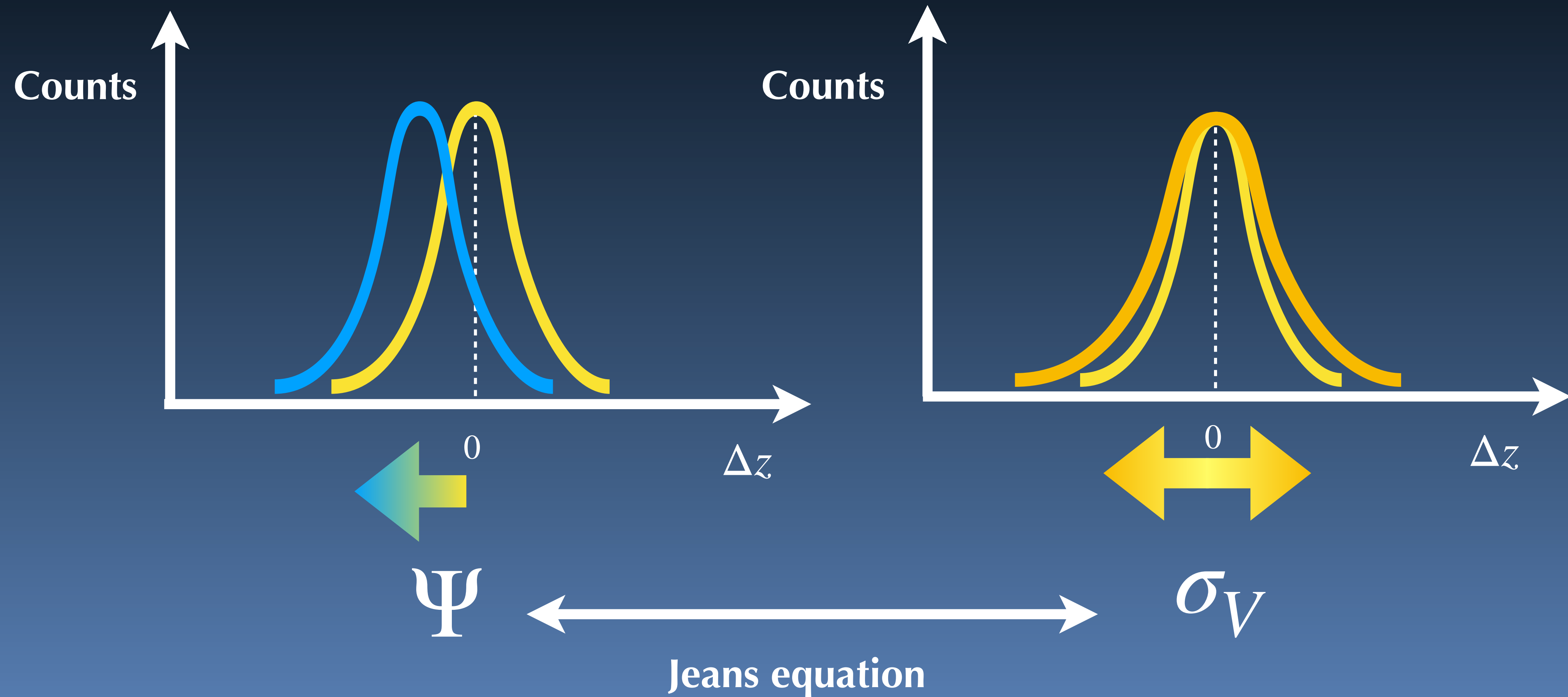
Di Dio, SC & Bonvin (2025)



Fully relativistic
modelling

Test of the weak equivalence principle

Di Dio, SC & Bonvin (2026)



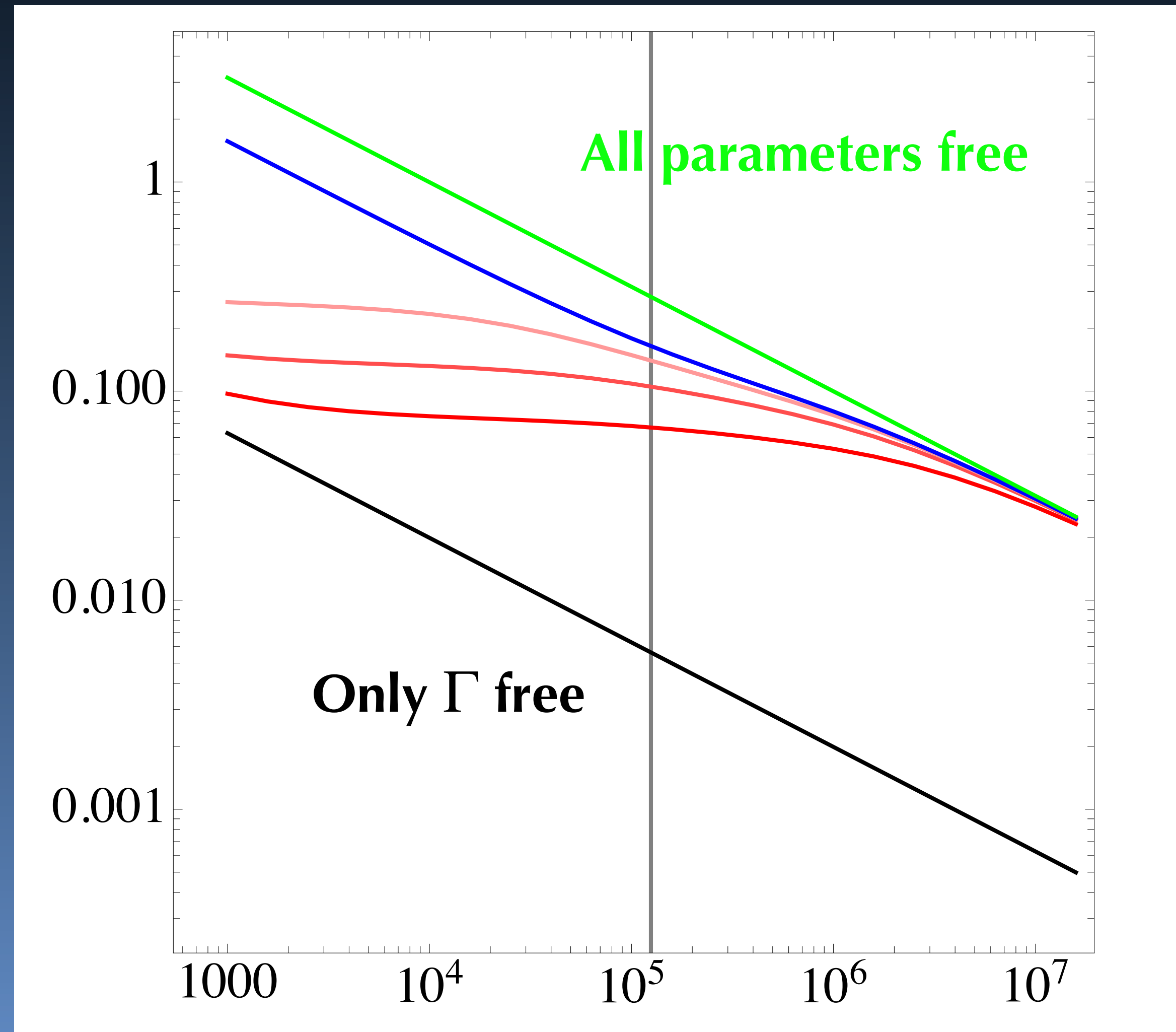
$$(1 + \Gamma) \rho \partial_Z \Psi + \partial_Z (\rho \sigma_v^2) = 0$$

Test of the weak equivalence principle

Di Dio, SC & Bonvin (2026)



1σ uncertainty
on Γ



Constraints of few %
from future surveys

- Current data
- Euclid standard project
- *with Charlie Mpetha*

What about larger scales?

Density fluctuation

Velocity

MATTER FIELD

δ

V

GRAVITATIONAL
POTENTIALS

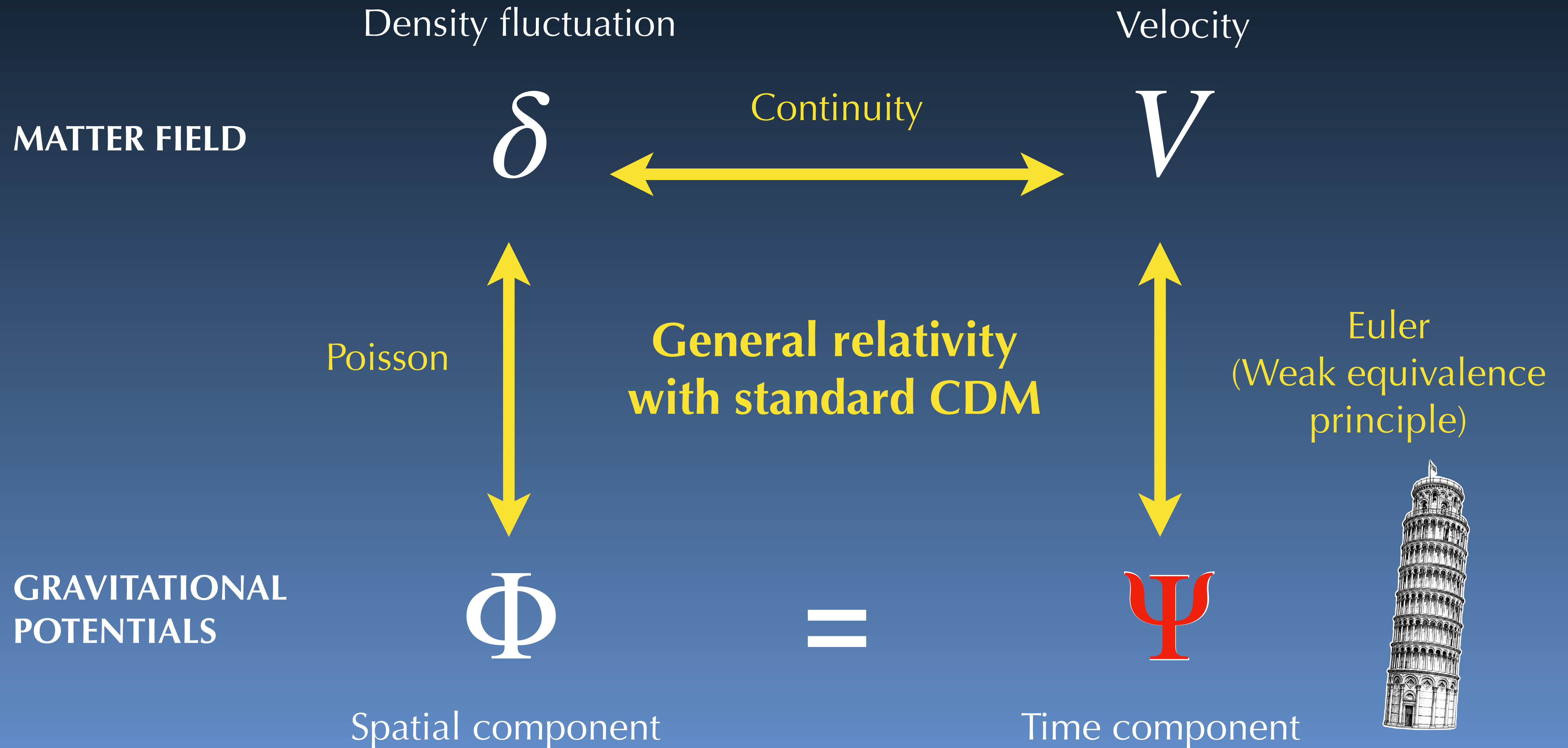
Φ

Ψ

Spatial component

Time component

What about larger scales?



Two scenarios

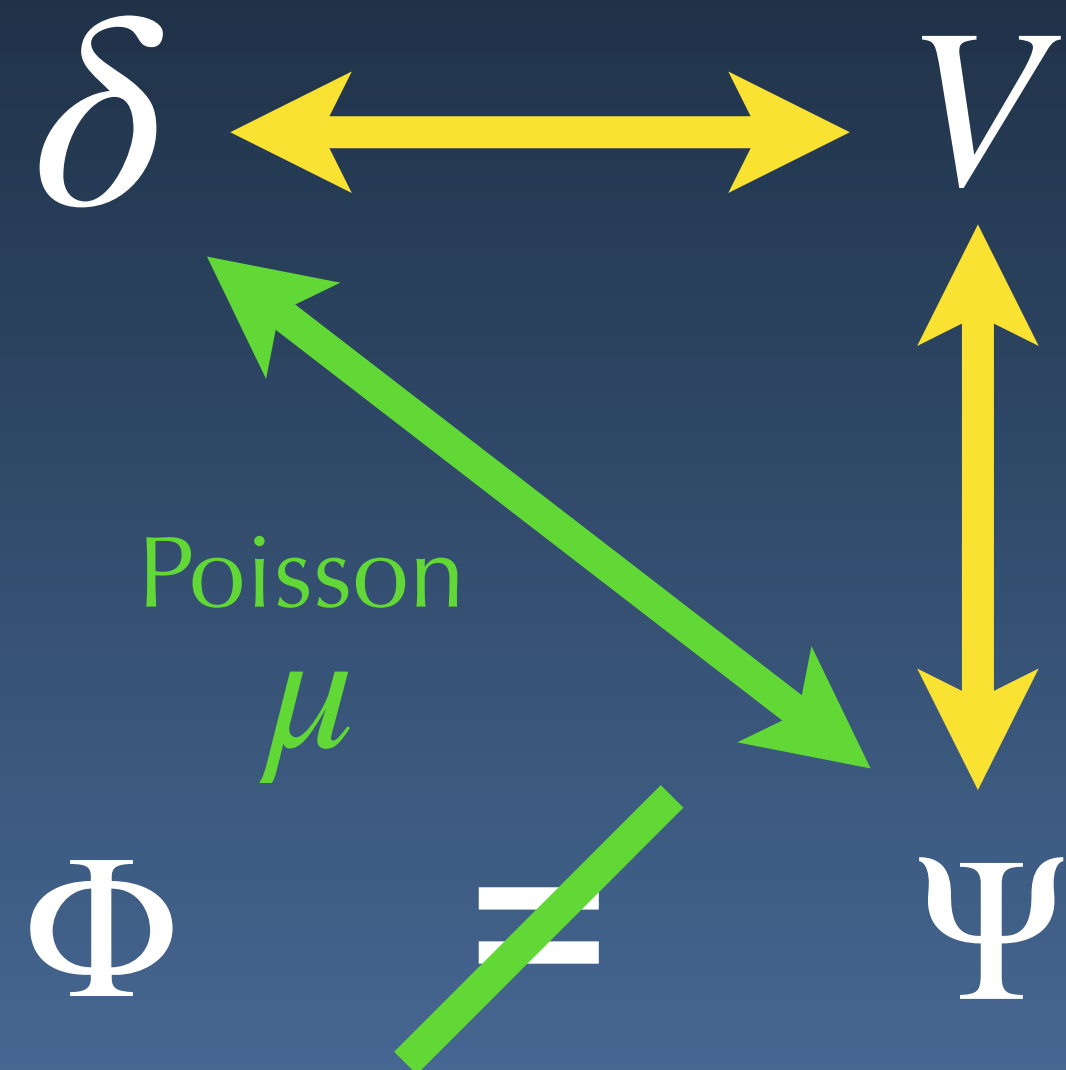
SC, Grimm and Bonvin (2022)

Bonvin & Pogosian (2022)

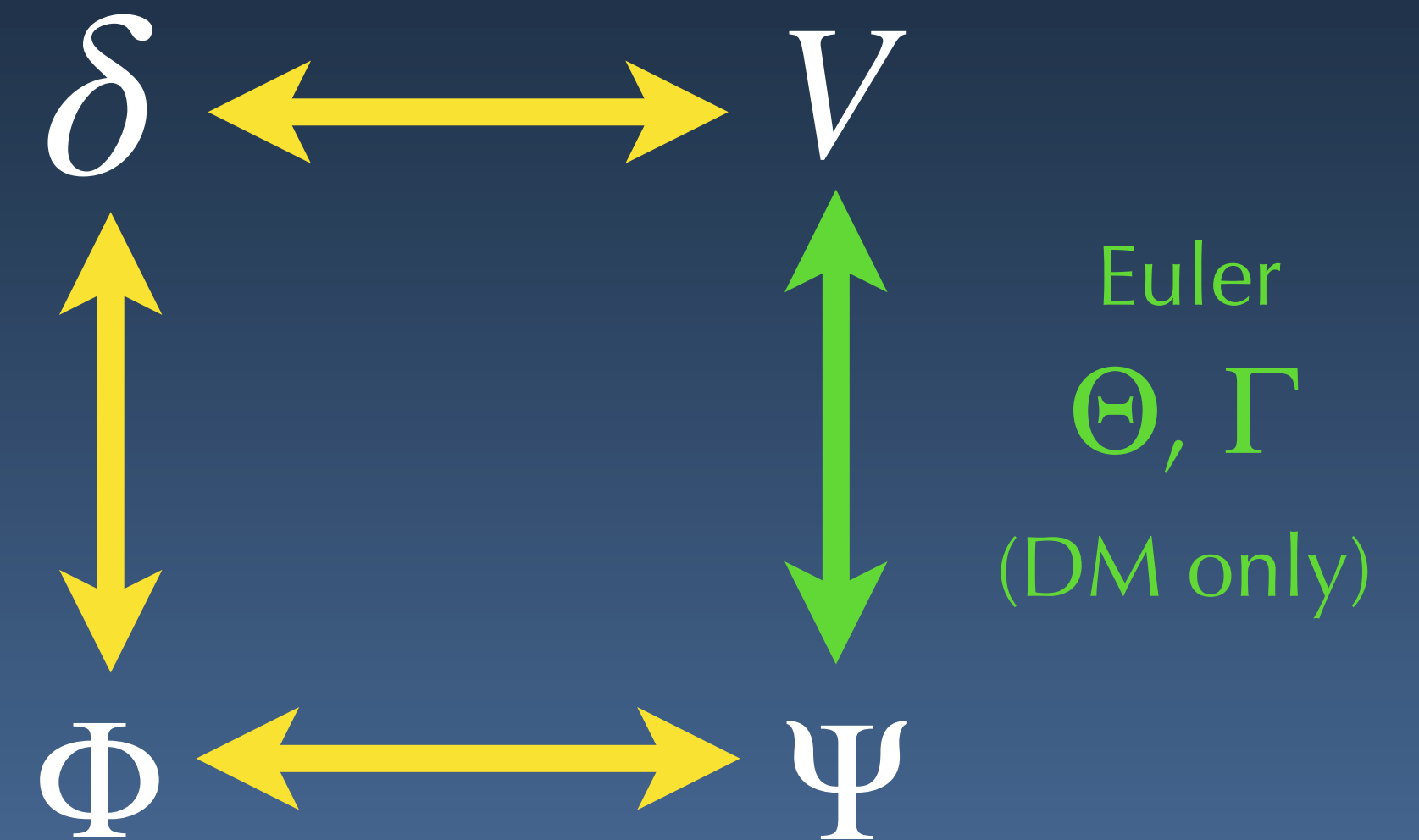
SC, Mancarella et al. (2024)

SC, Wang, Dam, Bonvin, Pogosian (2024)

Gravity modifications



Breaking of the WEP by DM



$$\delta'' + \left(1 + \frac{\mathcal{H}'}{\mathcal{H}}\right) \delta' - \frac{3}{2} \frac{\Omega_{m,0}}{a} \left(\frac{\mathcal{H}_0}{\mathcal{H}}\right)^2 \mu \delta = 0 \quad \delta'' + \left(1 + \frac{\mathcal{H}'}{\mathcal{H}} + \Theta\right) \delta' - \frac{3}{2} \frac{\Omega_{m,0}}{a} \left(\frac{\mathcal{H}_0}{\mathcal{H}}\right)^2 (\Gamma + 1) \delta = 0$$

DEGENERATE EFFECTS

Two scenarios

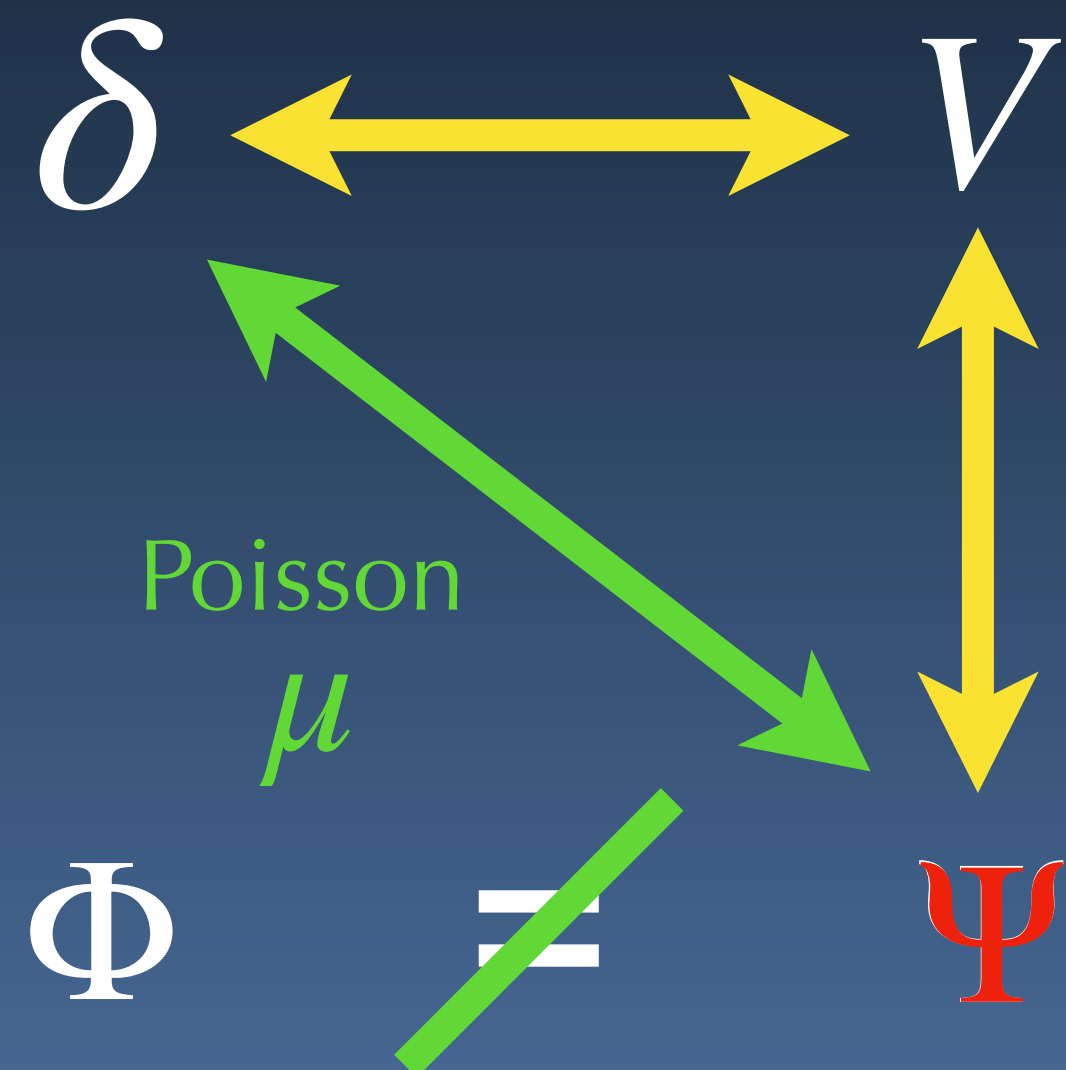
SC, Grimm and Bonvin (2022)

Bonvin & Pogosian (2022)

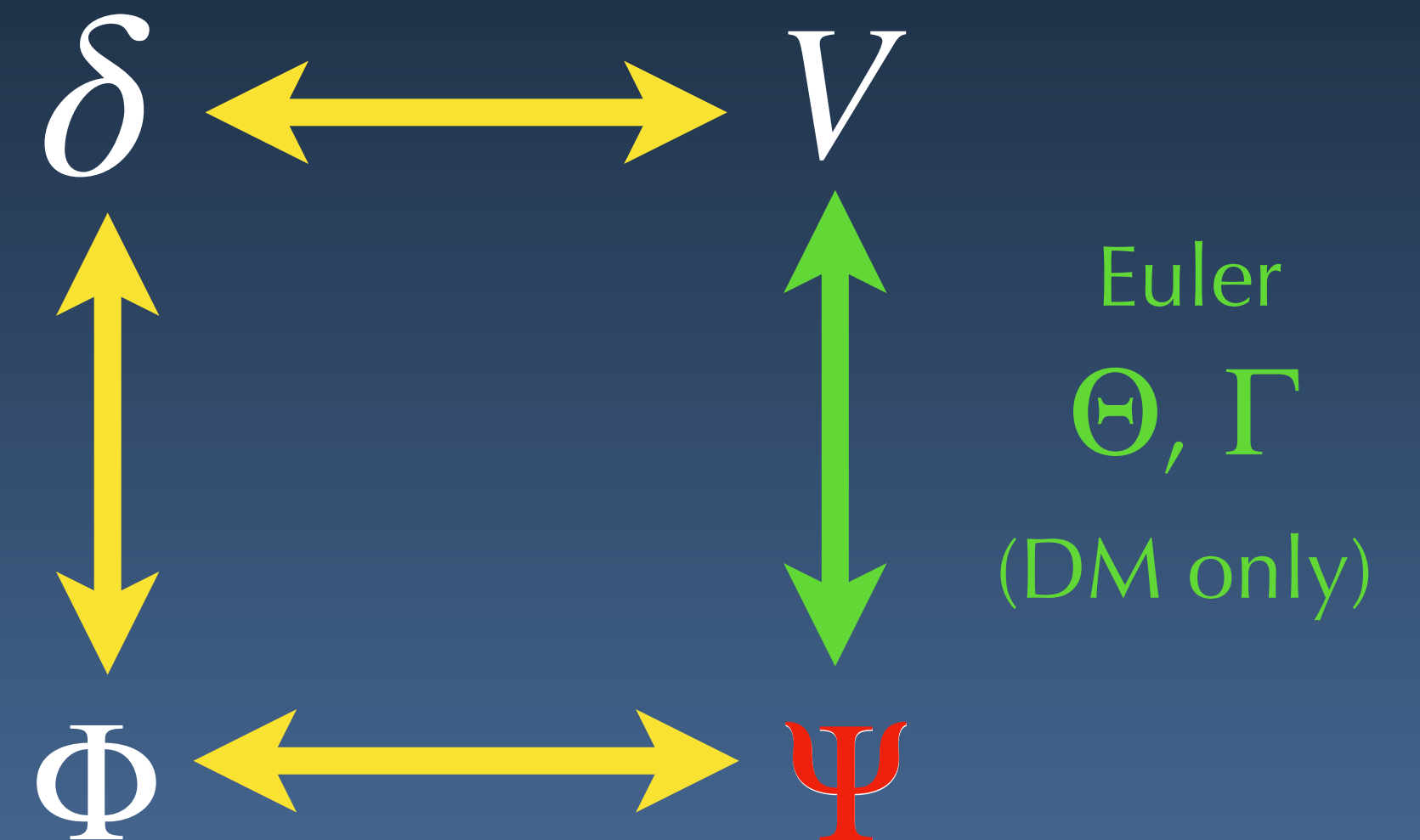
SC, Mancarella et al. (2024)

SC, Wang, Dam, Bonvin, Pogosian (2024)

Gravity modifications



Breaking of the WEP by DM



SC, Zheng, Bonvin, Amendola (2025)

10% constraints from SKA2!



A matter of two fluids

With Safak Celik, Toshiki Kurita, Fabian Schmidt



Dark matter

Baryons

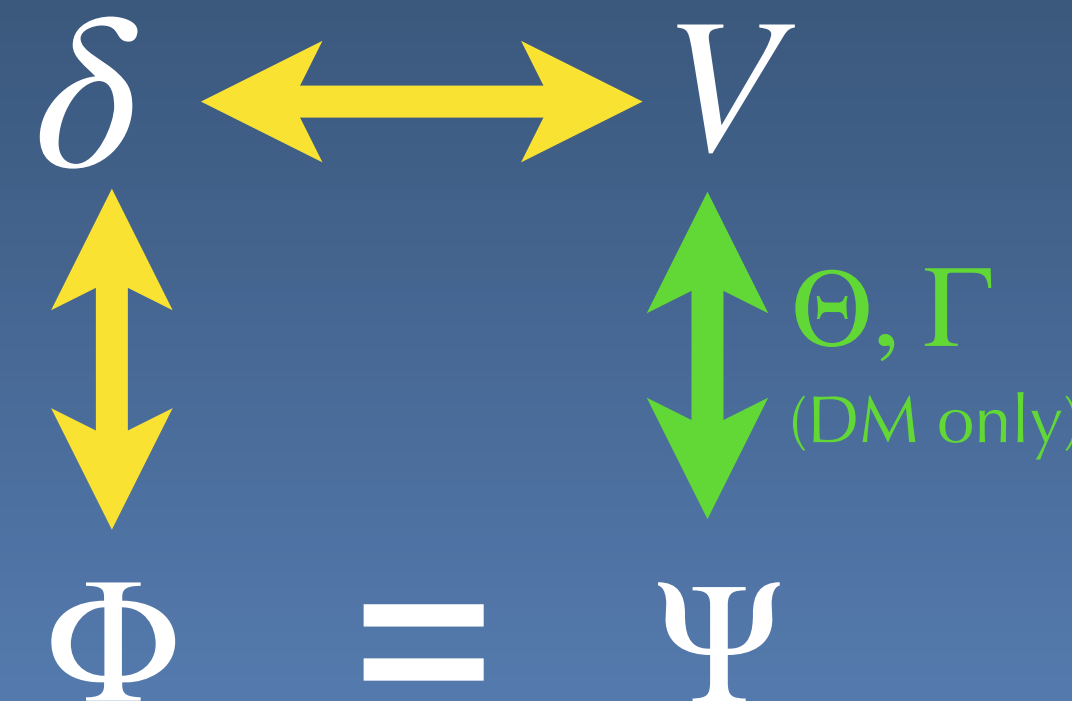
Relative perturbations

$$\delta_r \equiv \delta_c - \delta_b$$

Source term

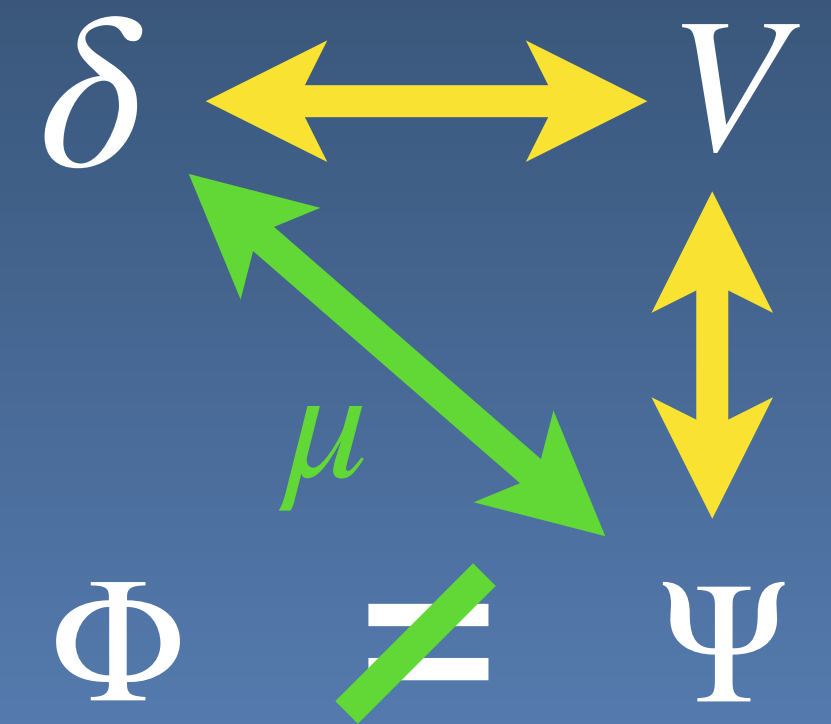
$$\delta_r'' + \left(1 + \frac{\mathcal{H}'}{\mathcal{H}}\right) \delta_r' + \Theta \delta_c' - \frac{3}{2} \Omega_m \delta_m \mu \Gamma = 0$$

Breaking of the WEP by DM



Source term $\neq 0$

Gravity modifications



Source term $= 0$

VS

A matter of two fluids

With Safak Celik, Toshiki Kurita, Fabian Schmidt



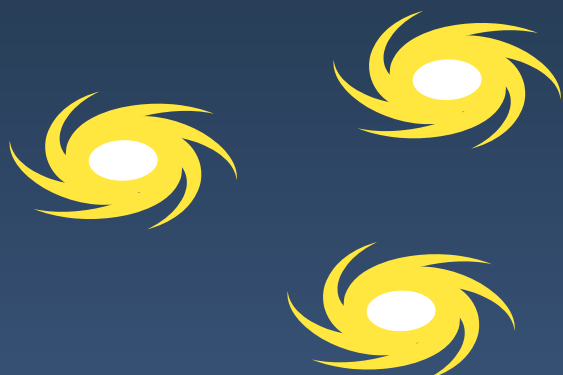
Dark matter

Baryons

Relative perturbations

$$\delta_r \equiv \delta_c - \delta_b$$

Galaxy density contrast = $b_1 \delta_m + b_\delta^r \delta_r + b_\theta^r \theta_r$

 $\underbrace{\hspace{1.5cm}}$ $\underbrace{\hspace{1.5cm}}$

Usual New contributions

Are these sufficient?

Dropping dark matter from the Pisa Tower



Gravitational redshift:
galaxy clusters and futuristic
clustering analyses

**Baryon-CDM relative
perturbations:**
large linear scales