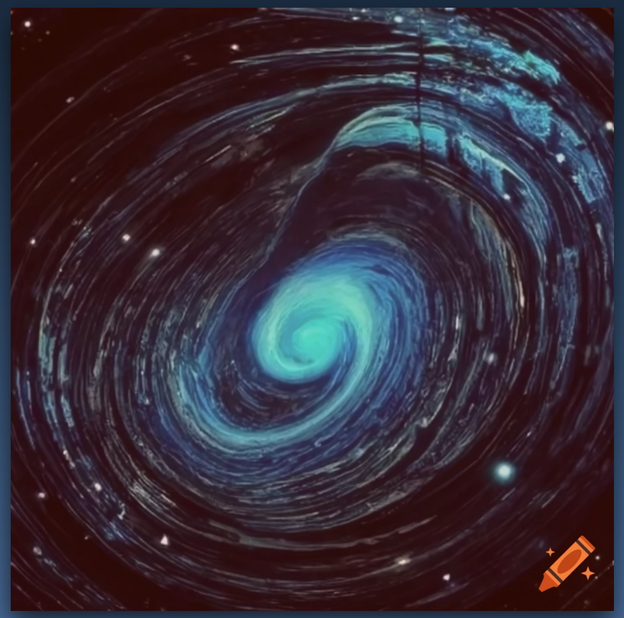
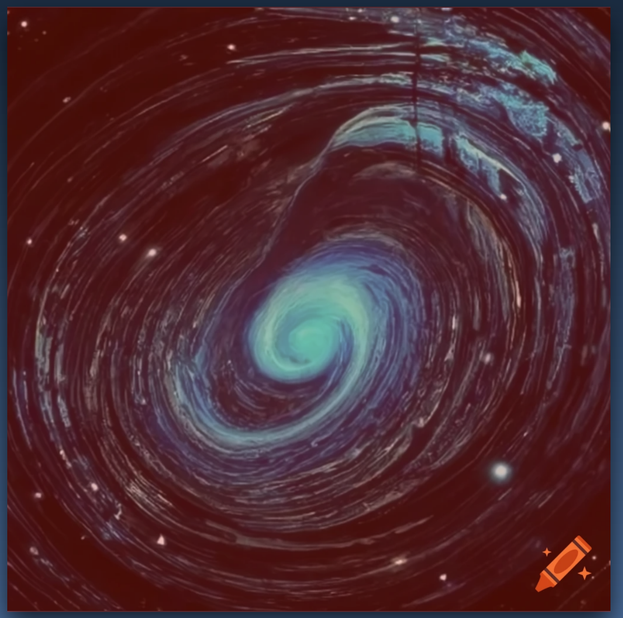
Testing Gravity through the Distortion of Time

Sveva Castello

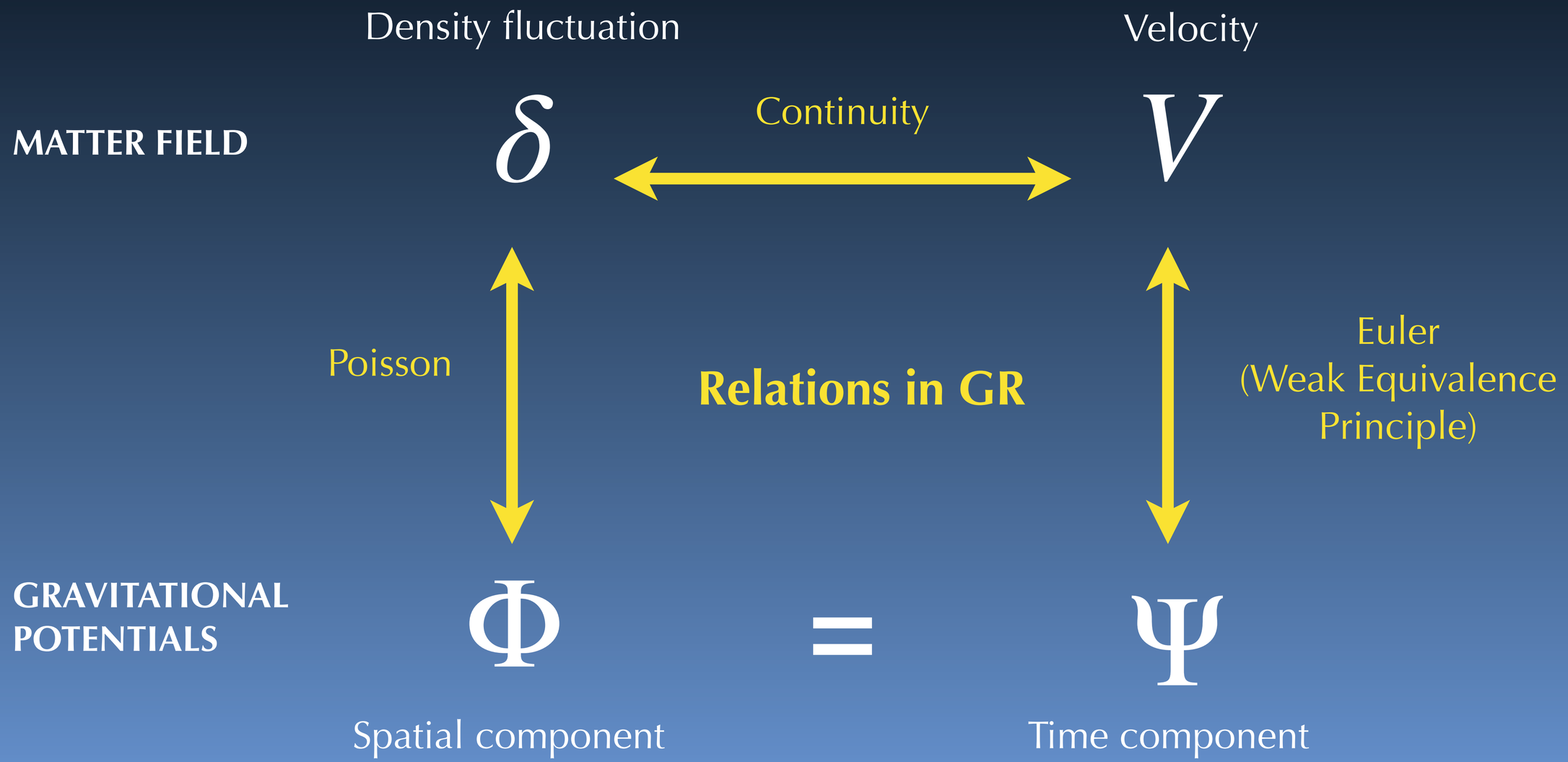
UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

CASTLE 2024

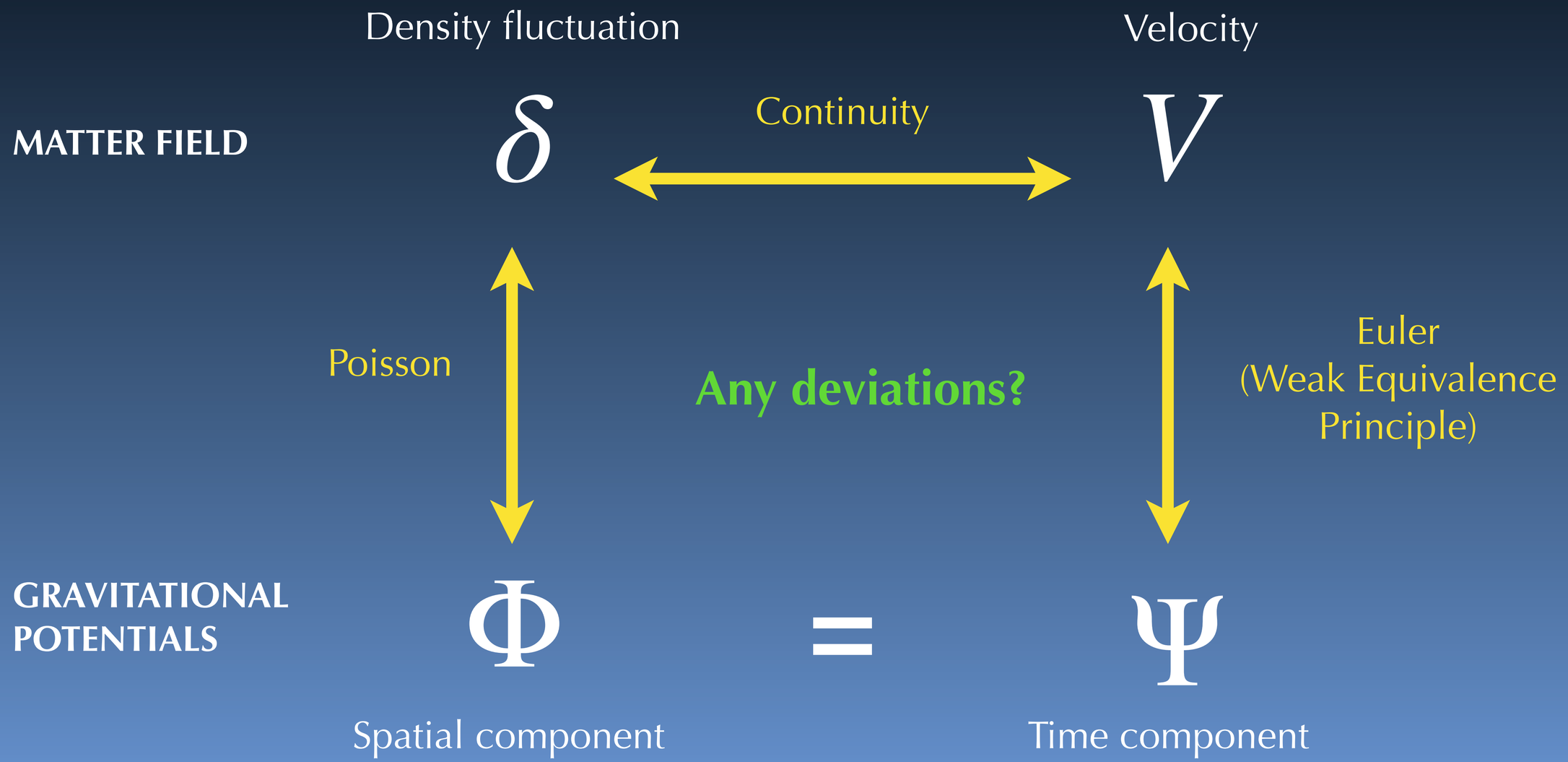
Tagliolo Monferrato, September 19th, 2024

European Research Council
Established by the European Commission

Describing the Universe with four fields

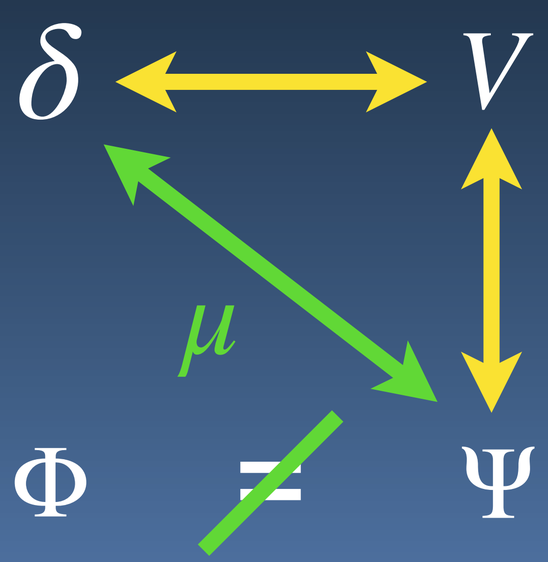


Describing the Universe with four fields



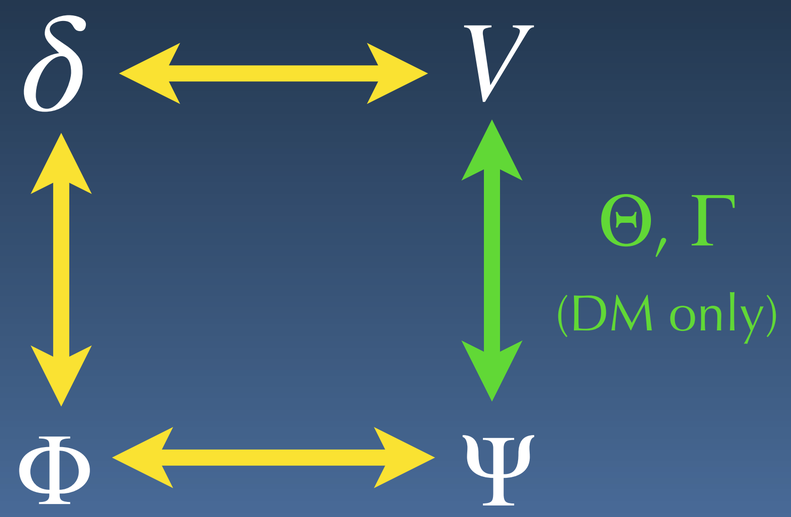
Two scenarios

Gravity modifications



vs

Dark sector interactions



Can we distinguish between the two?

Galaxy clustering

Fluctuations in galaxy number counts

$$\Delta(z, \mathbf{n}) = b\,\delta_{\rm DM} - \frac{1}{\mathscr{H}}\partial_r(\mathbf{V}\cdot\mathbf{n})$$

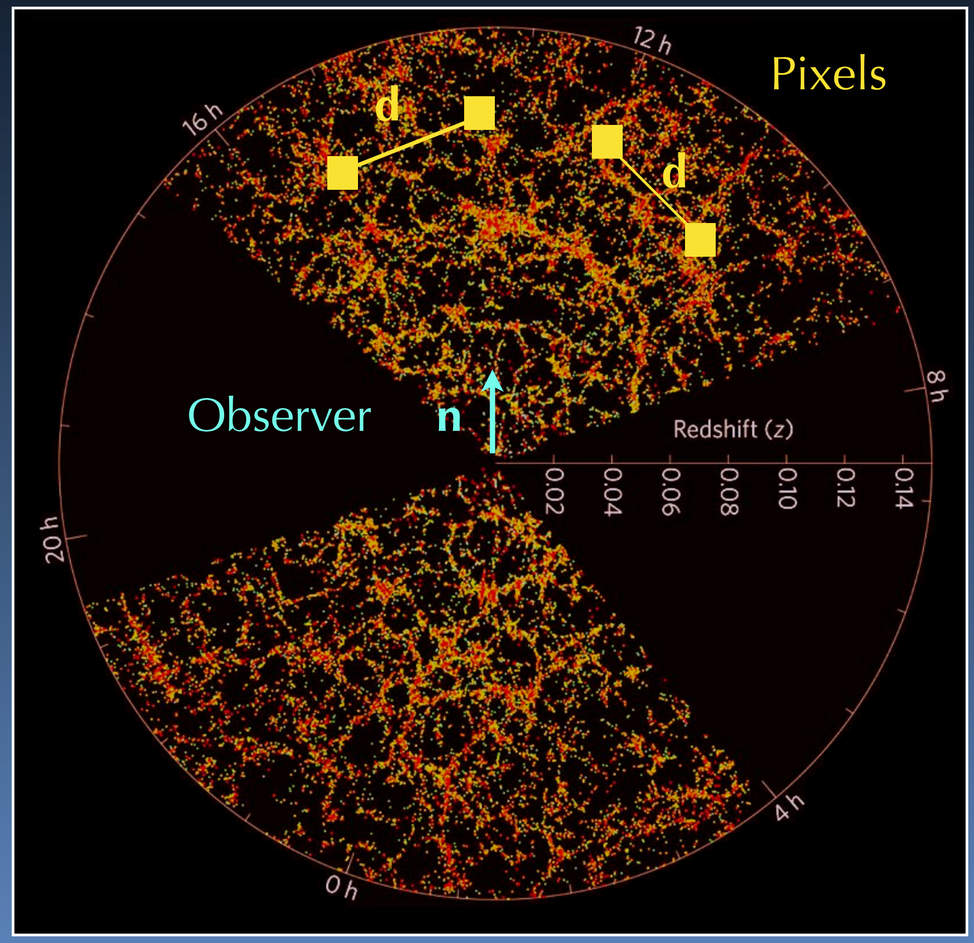
DM density x galaxy bias

Redshift-space distortions (RSD)

Two-point correlation function

$$\xi \equiv \langle \Delta(z, \mathbf{n})\Delta(z', \mathbf{n}')\rangle$$

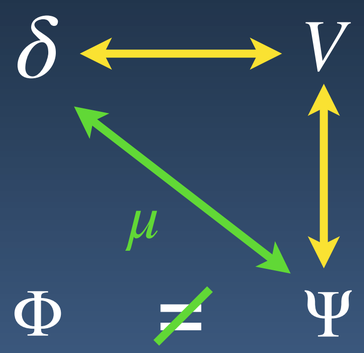
→ Extracted from observations and compared with theoretical predictions



Credits: M.Blanton, SDSS

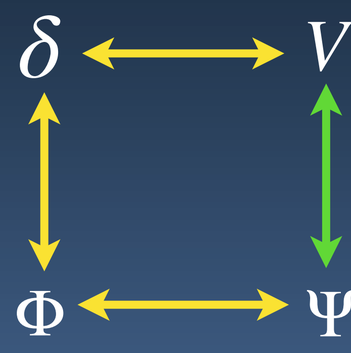
Impact of the modifications

Gravity modifications



VS

Dark sector interactions



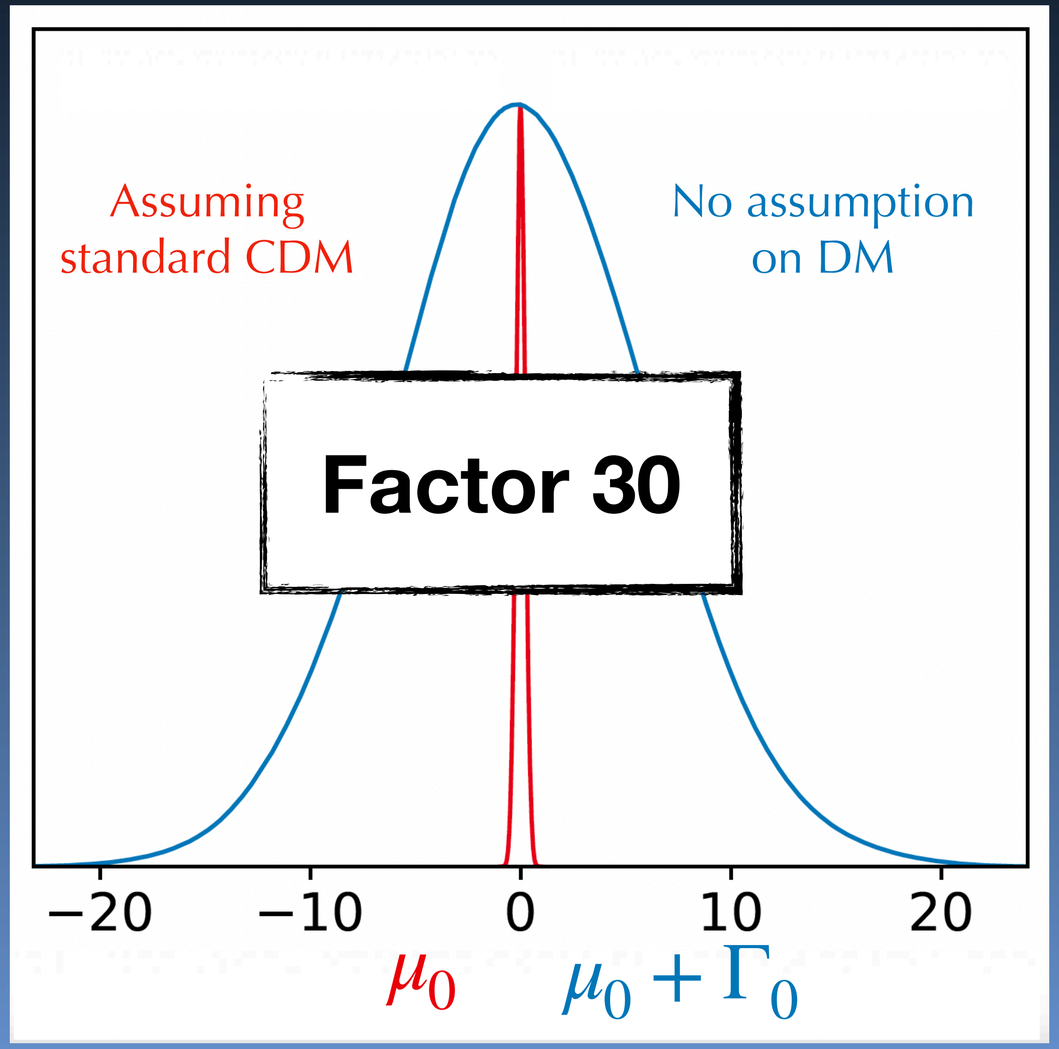
$$\delta'' + \left(1 + \frac{\mathcal{H}}{\mathcal{H}'}\right)\delta' - \frac{3}{2}\frac{\Omega_{m,0}}{a}\left(\frac{\mathcal{H}_0}{\mathcal{H}}\right)^2 \mu\,\delta = 0$$

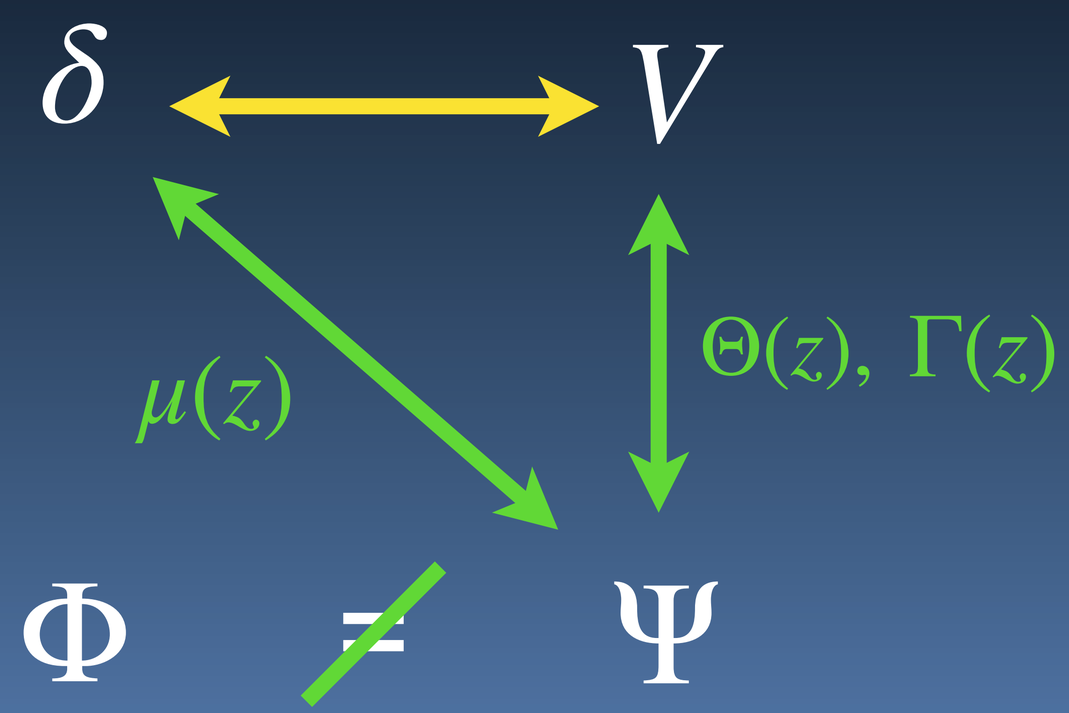
$$\delta'' + \left(1 + \frac{\mathcal{H}}{\mathcal{H}'} + \Theta\right)\delta' - \frac{3}{2}\frac{\Omega_{m,0}}{a}\left(\frac{\mathcal{H}_0}{\mathcal{H}}\right)^2 (\Gamma + 1)\,\delta = 0$$

DEGENERATE EFFECTS

Precision with SDSS data

SC, Grimm and Bonvin (2022)





Precision with SDSS data

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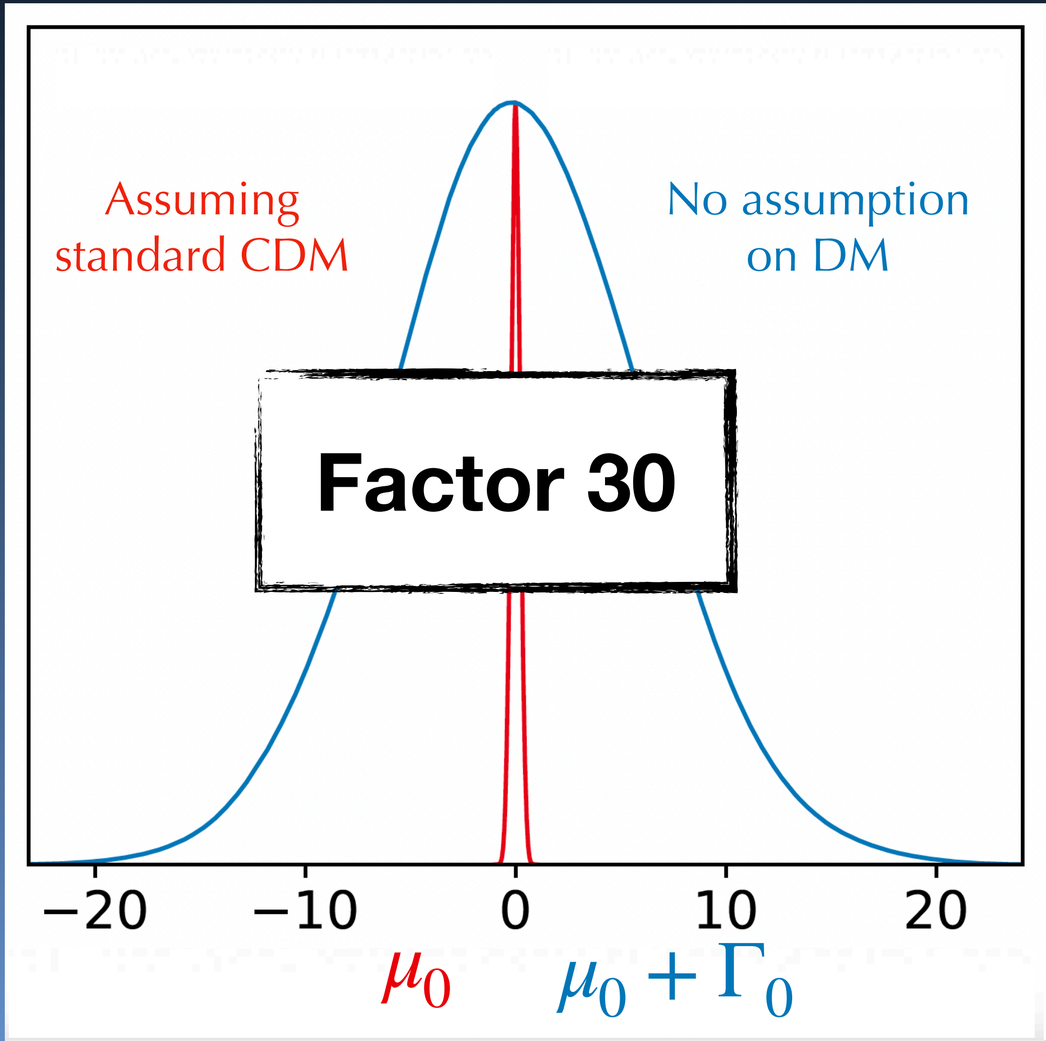

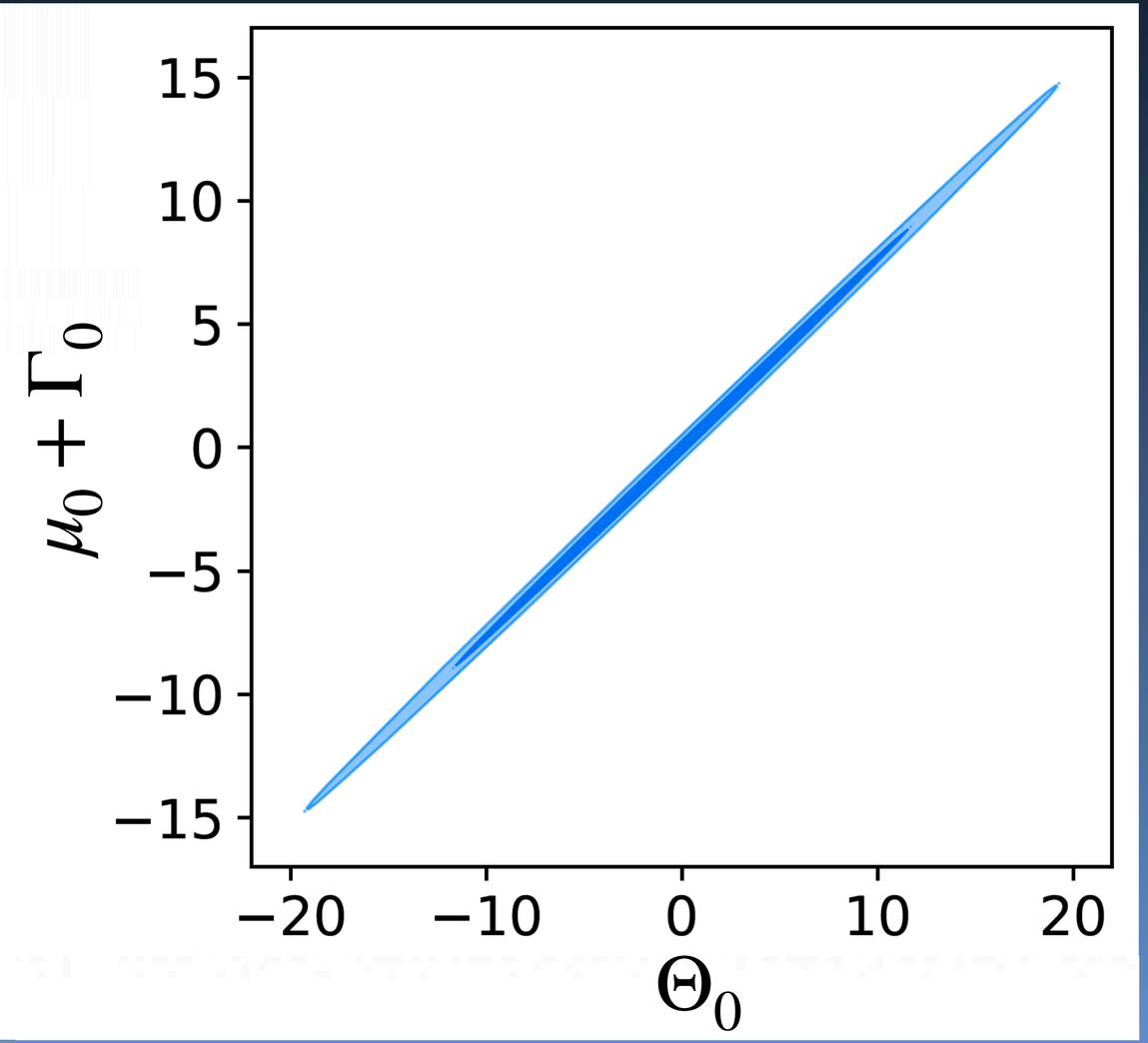

Precision with SDSS data

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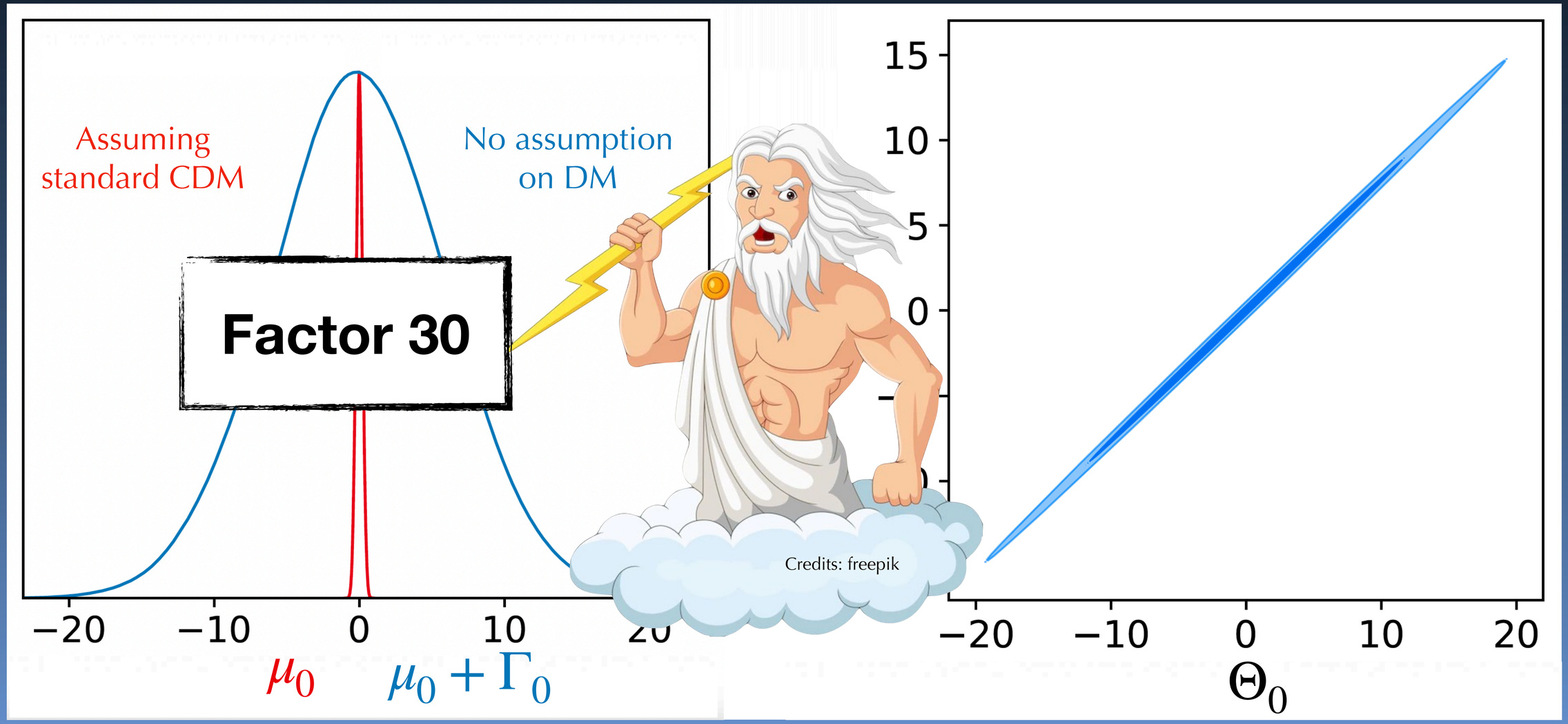


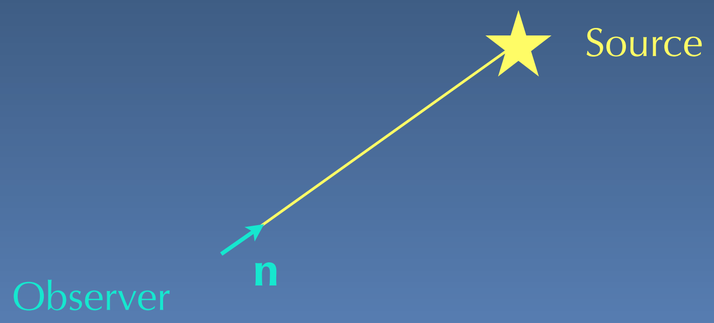
What we really observe

Yoo et al. (2010)
Bonvin and Durrer (2011)
Challinor and Lewis (2011)

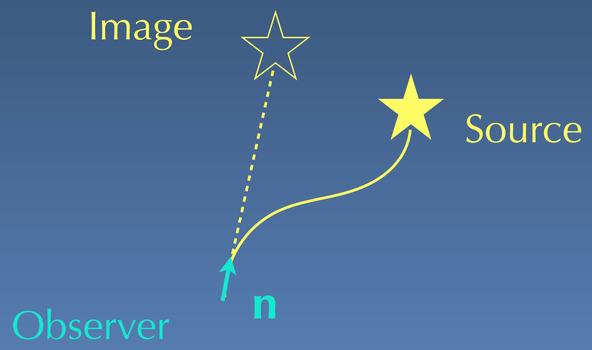
$$\Delta(\mathbf{n}, z) = b\,\delta_{\rm DM} - \frac{1}{\mathcal{H}}\partial_r(\mathbf{V}\cdot\mathbf{n})$$

+ relativistic corrections

Homogeneous Universe



Inhomogeneous Universe

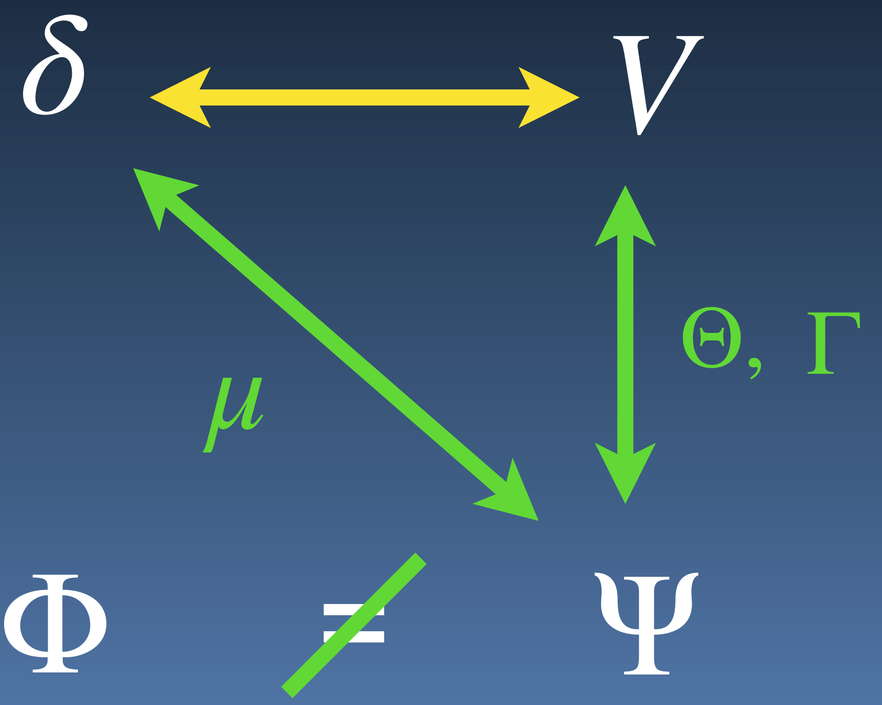


Calculate effects within linear perturbation theory

Deus ex machina: gravitational redshift

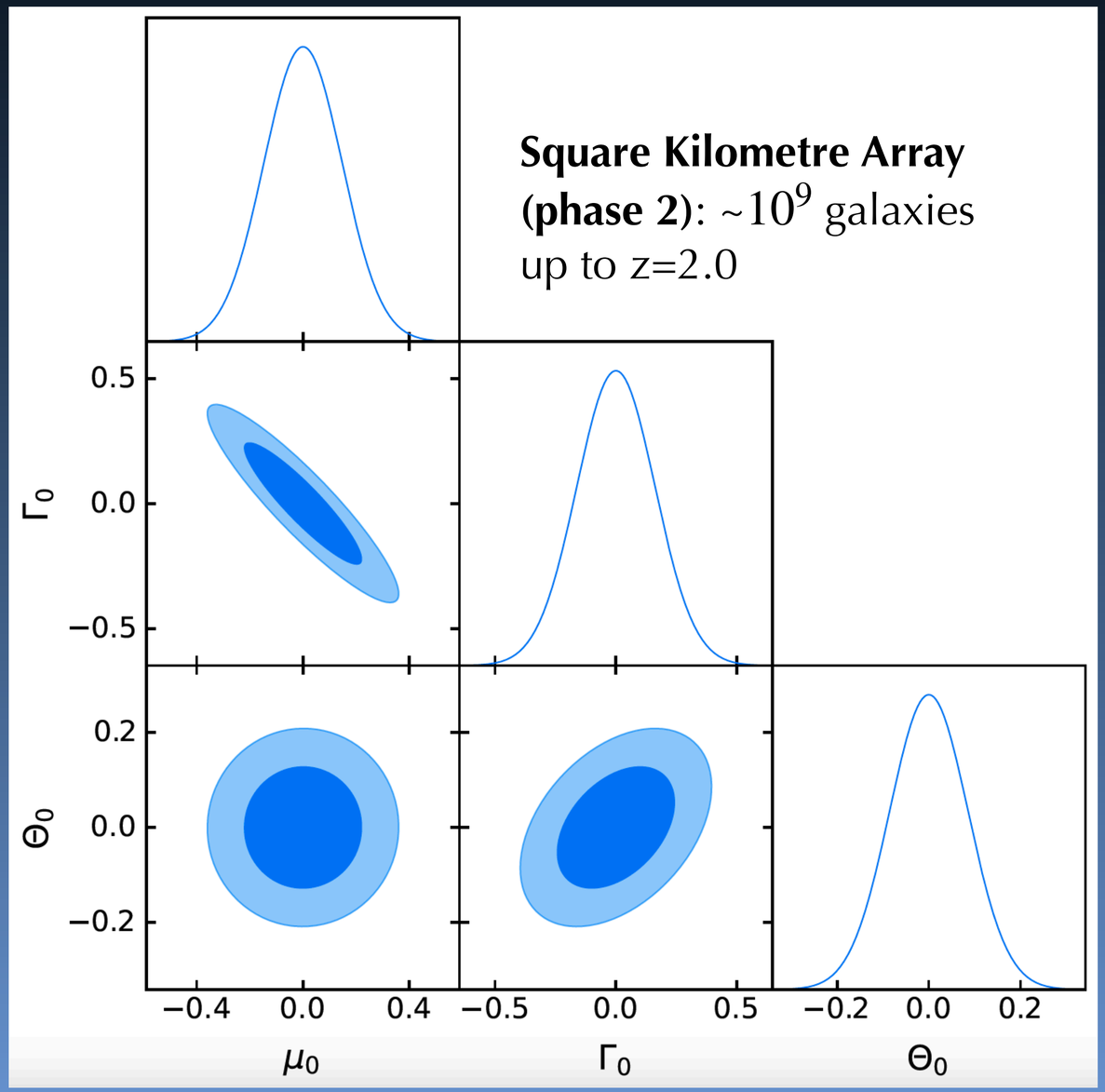
SC, Grimm and Bonvin (2022)

$$\Delta_{\rm gr} = \frac{1}{\mathscr{H}}\partial_r \Psi$$

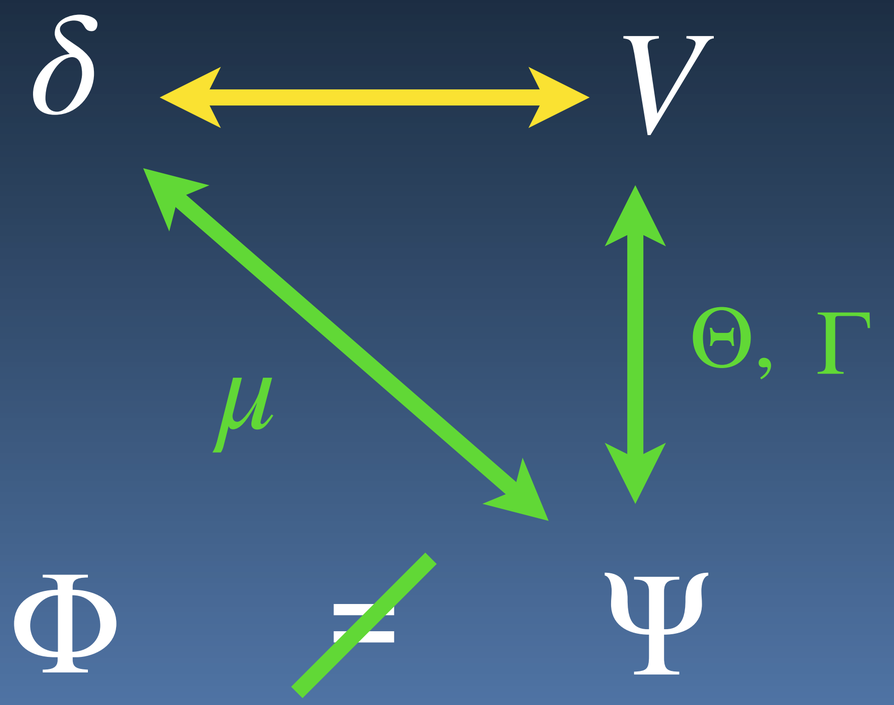


- Much smaller than RSD
- Observable by upcoming surveys
- Extracted by correlating two populations

Deus ex machina: gravitational redshift



SC, Grimm and Bonvin (2022)



Effective theory of interacting dark energy

SC, Mancarella et al. (2024)

Gravity modifications

α_M, α_B

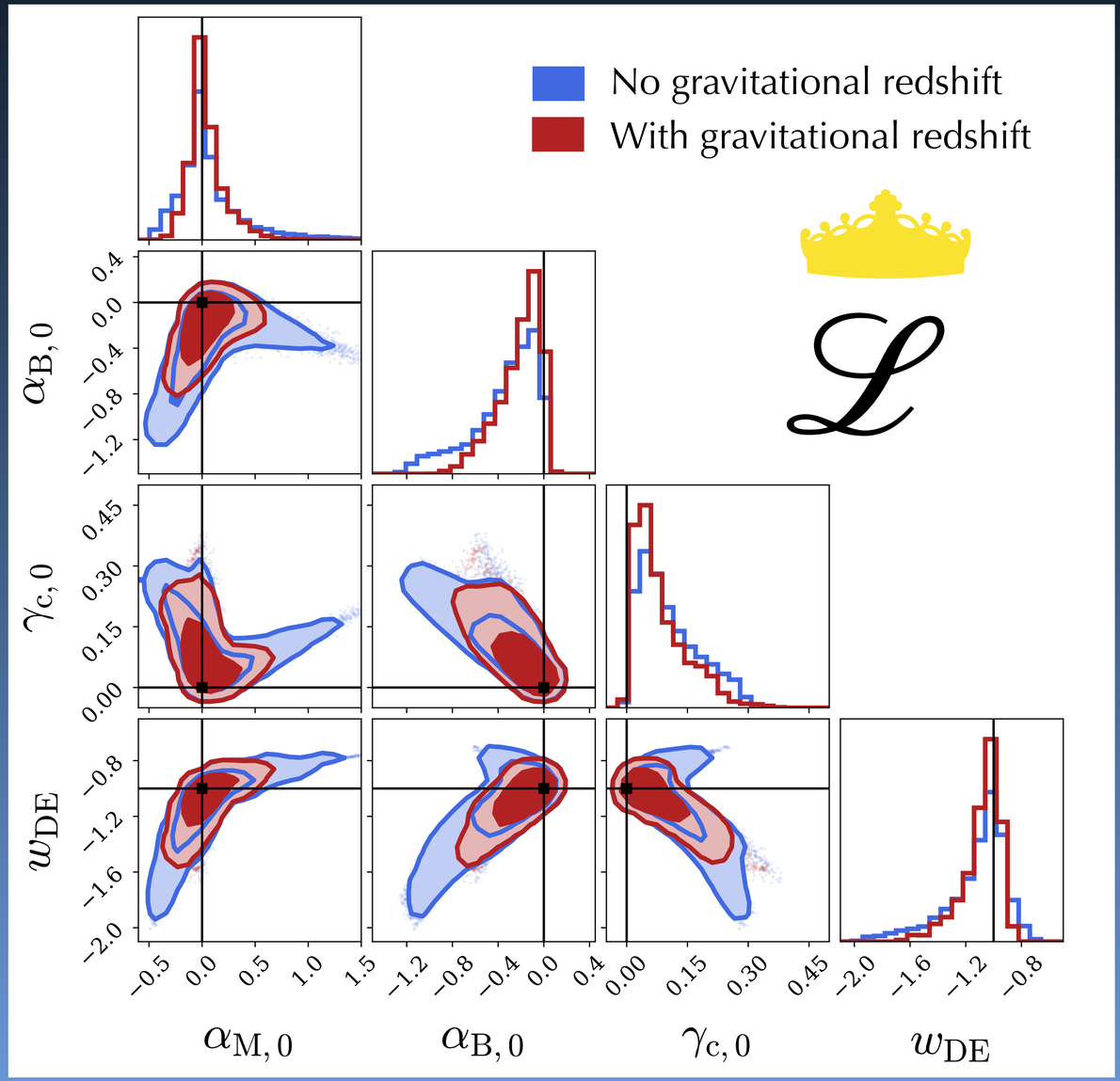
WEP breaking

γ_c

Equation of state of DE

$w_{\rm DE}$

EF-TIGRE package

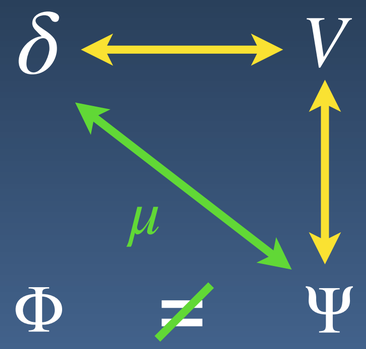


Two example models

Bonvin & Pogosian (2022)

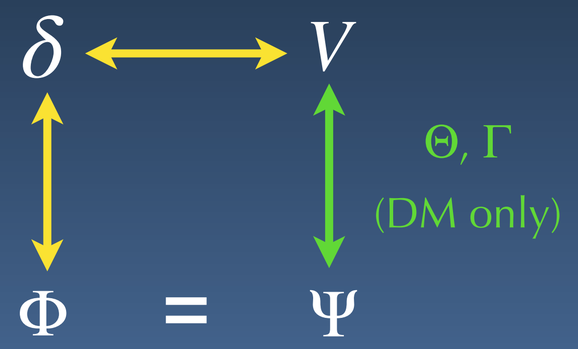
SC, Wang, Dam, Bonvin, Pogosian (2024)

Gravity modifications affecting all constituents



VS

Breaking of the WEP for DM only



→ Generalised Brans-Dicke

Universal coupling β_1

→ Coupled quintessence

DM-only coupling β_2

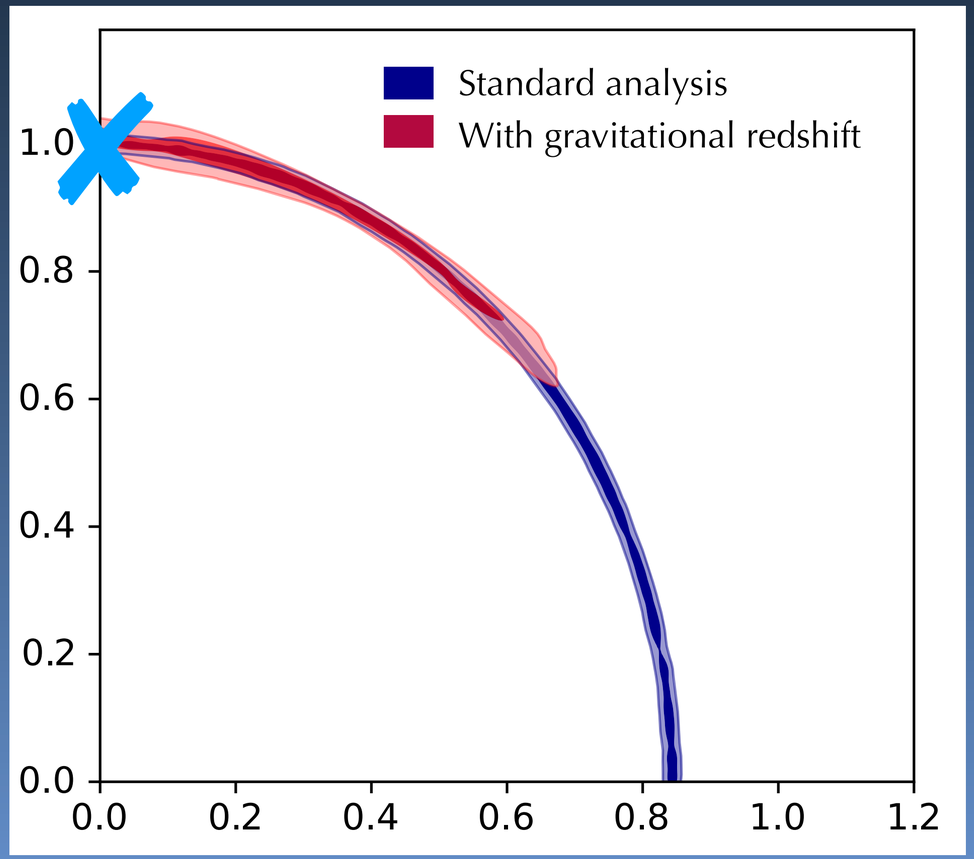
Forecasts for SKA2

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

→ Generate mock data with one type of modification (e.g. $\beta_1 = 0$, $\beta_2 = 1$)

→ Fit with both models (galaxy clustering + CMB + weak lensing)

Fiducial model



δ + RSD give a constraint on
$\beta_1^2 + X_c\beta_2^2 = X_c$

Gravitational redshift isolates one of the two modifications

Forecasts for SKA2

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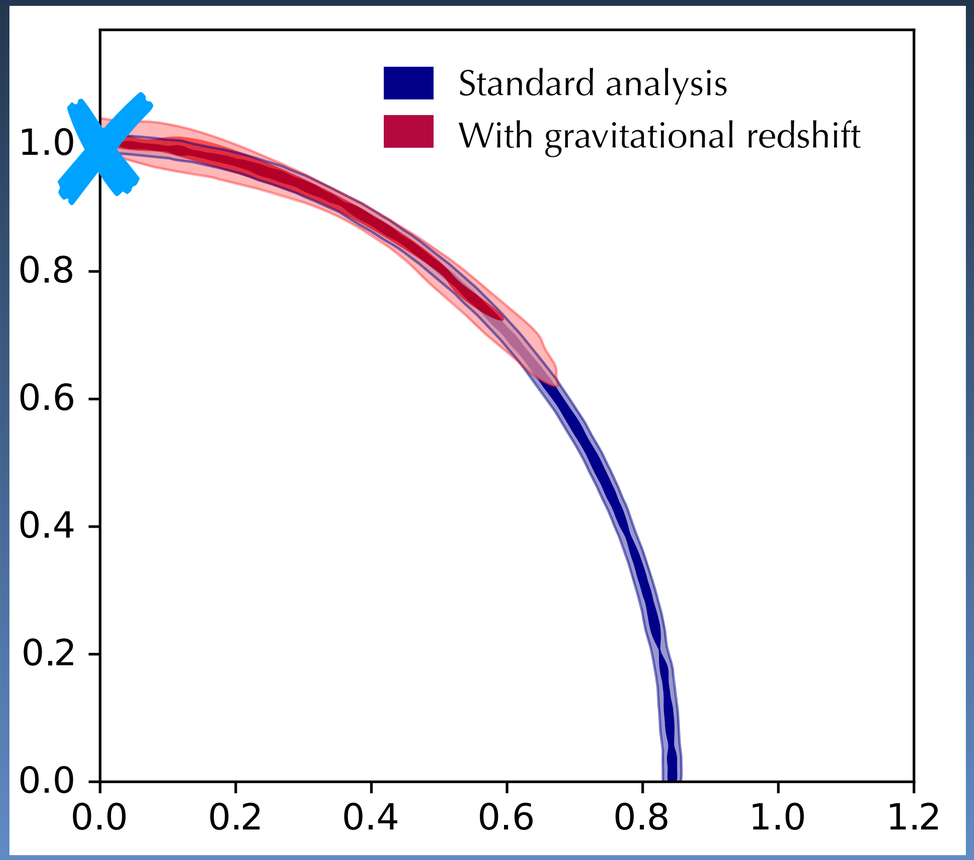


What is the threshold for gravitational redshift to help?

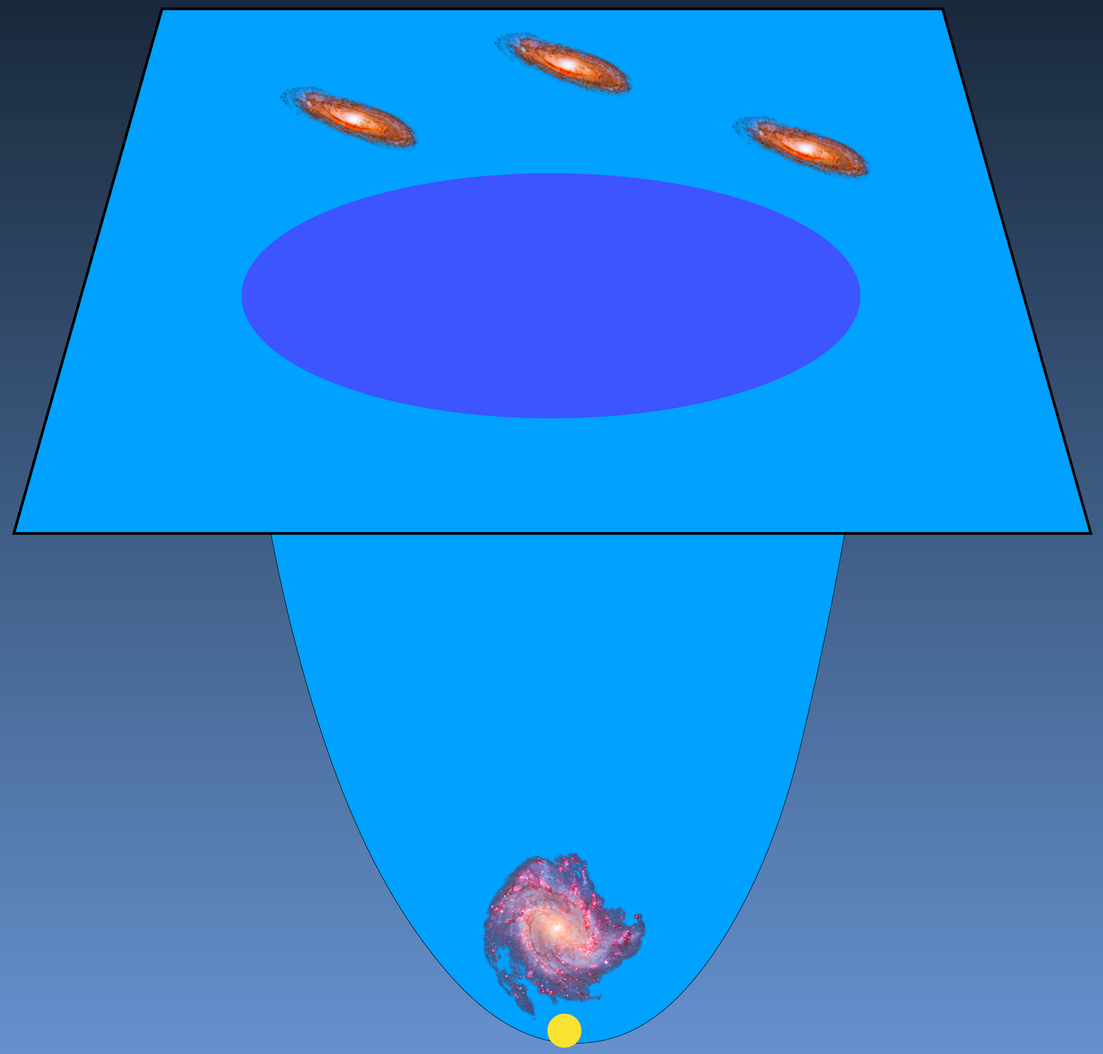
$\beta_2 = 0.7$ for $m = 0.1$ Mpc^{-1}

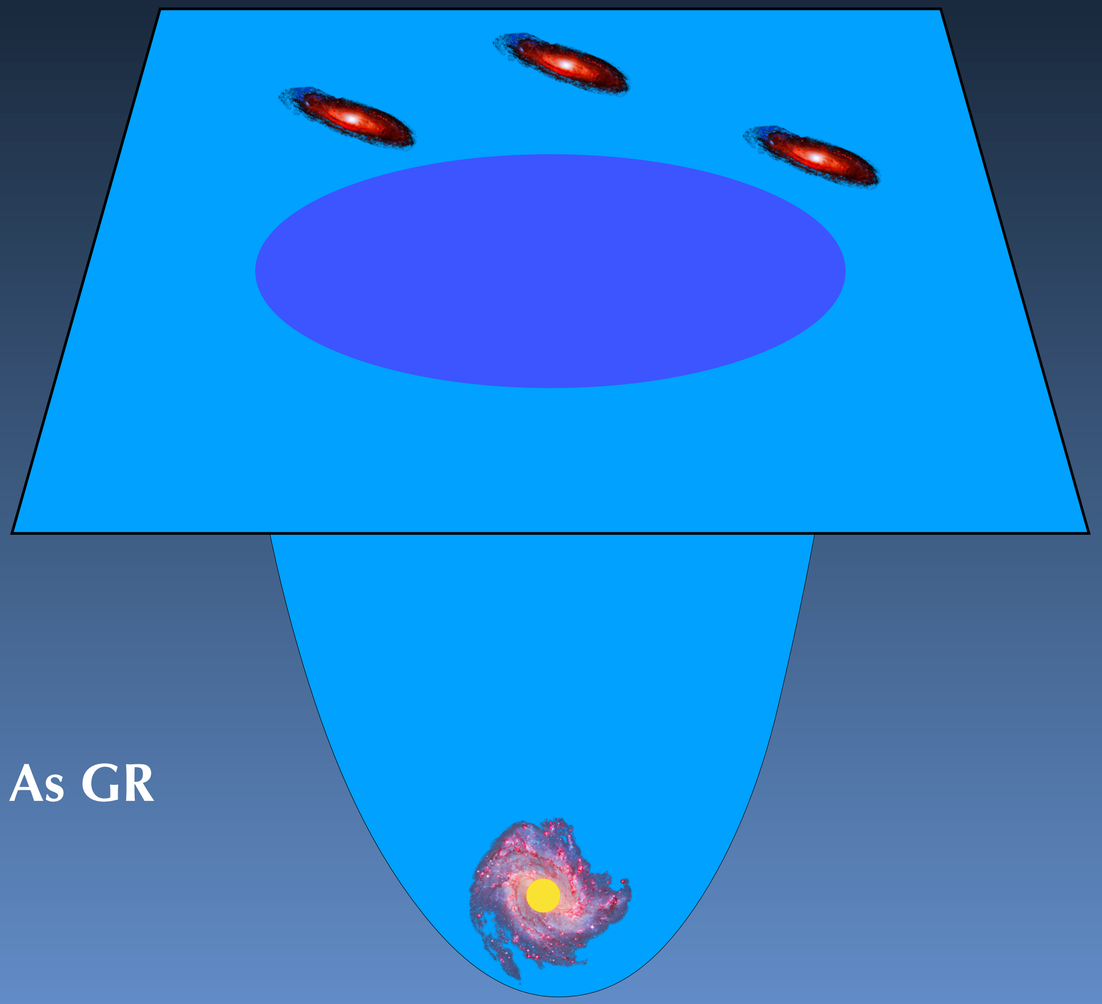
$\beta_2 = 0.4$ for $m = 0.01$ Mpc^{-1}

Some physical intuition

Modified gravity

Dark interactions





As GR

Some ongoing work…

Small scales: Gravitational redshift from galaxy clusters

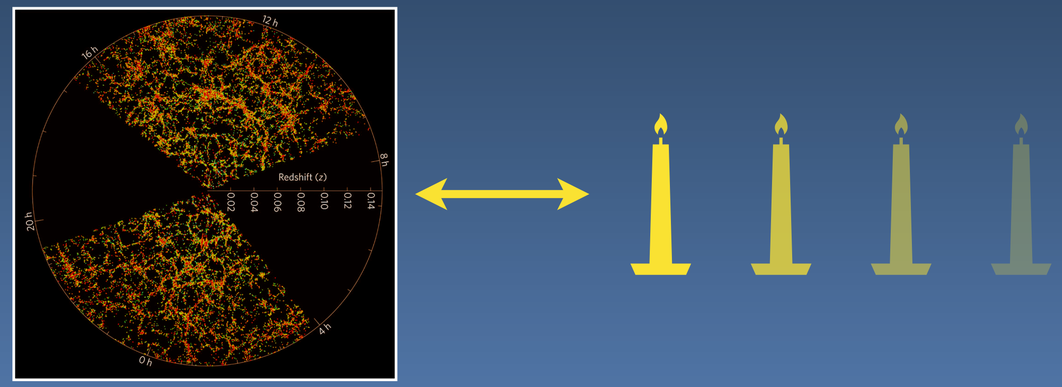
With C. Bonvin, Ø. Christiansen, E. Di Dio, D. Mota, H. Winther

→ Fully relativistic modelling of the signal

→ Test of the equivalence principle

Cross-correlation: luminosity distance fluctuations

With L. Amendola, C. Bonvin, Z. Zheng



→ Model-independent approach

→ Maximal set of observable quantities

Take-home message

Credits: freepik

Gravitational redshift can break the degeneracy between modified gravity and a dark fifth force!

Happy to chat live or at sveva.castello@unige.ch :)