Hubble expansion beyond ΛCDM in Big Bang quantum cosmology

Maurice H.P.M. van Putten

Sejong University, Seoul, South Korea

INAF-OAS, Bologna, Italy

The Dark Side of the Universe

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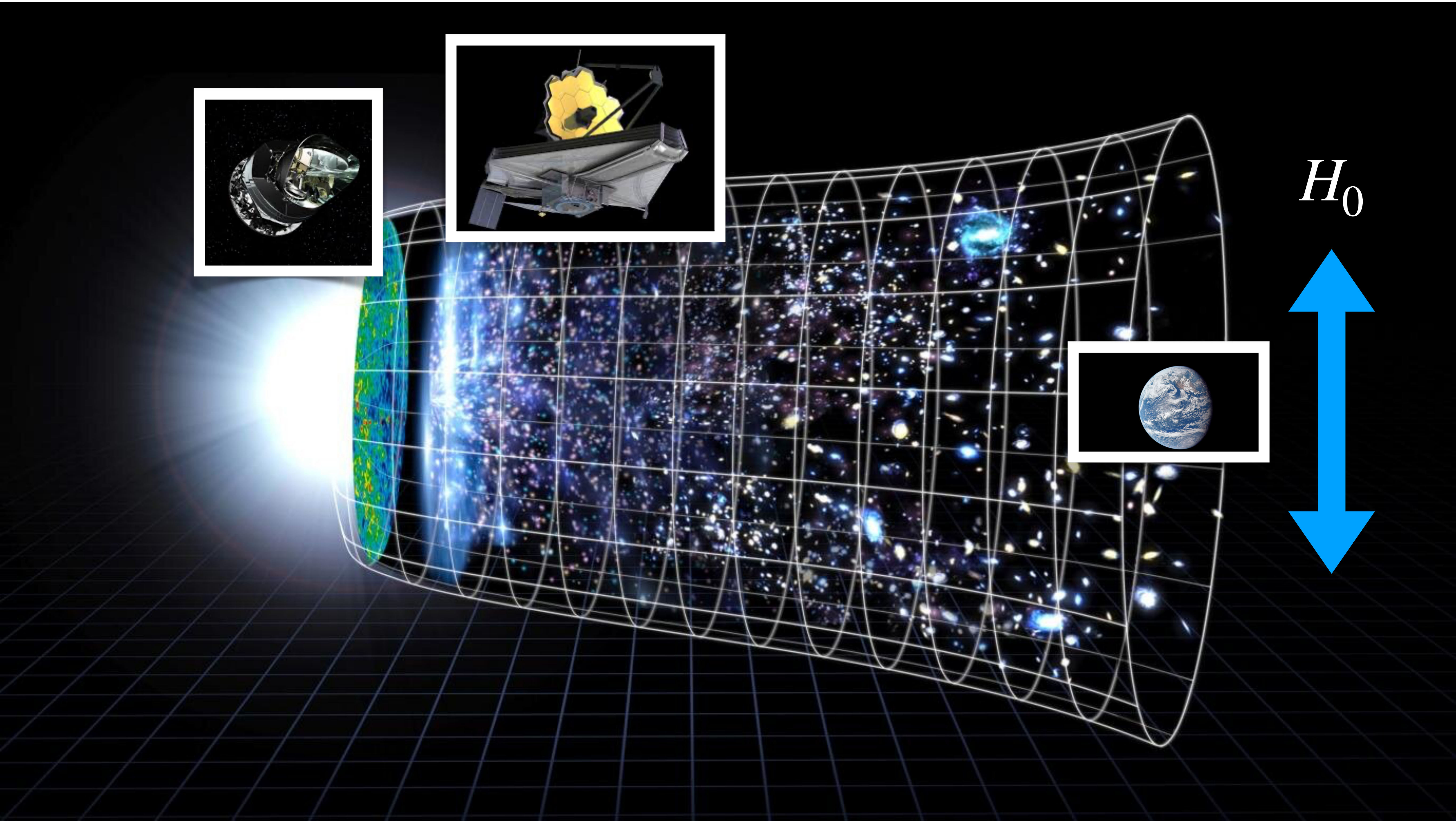
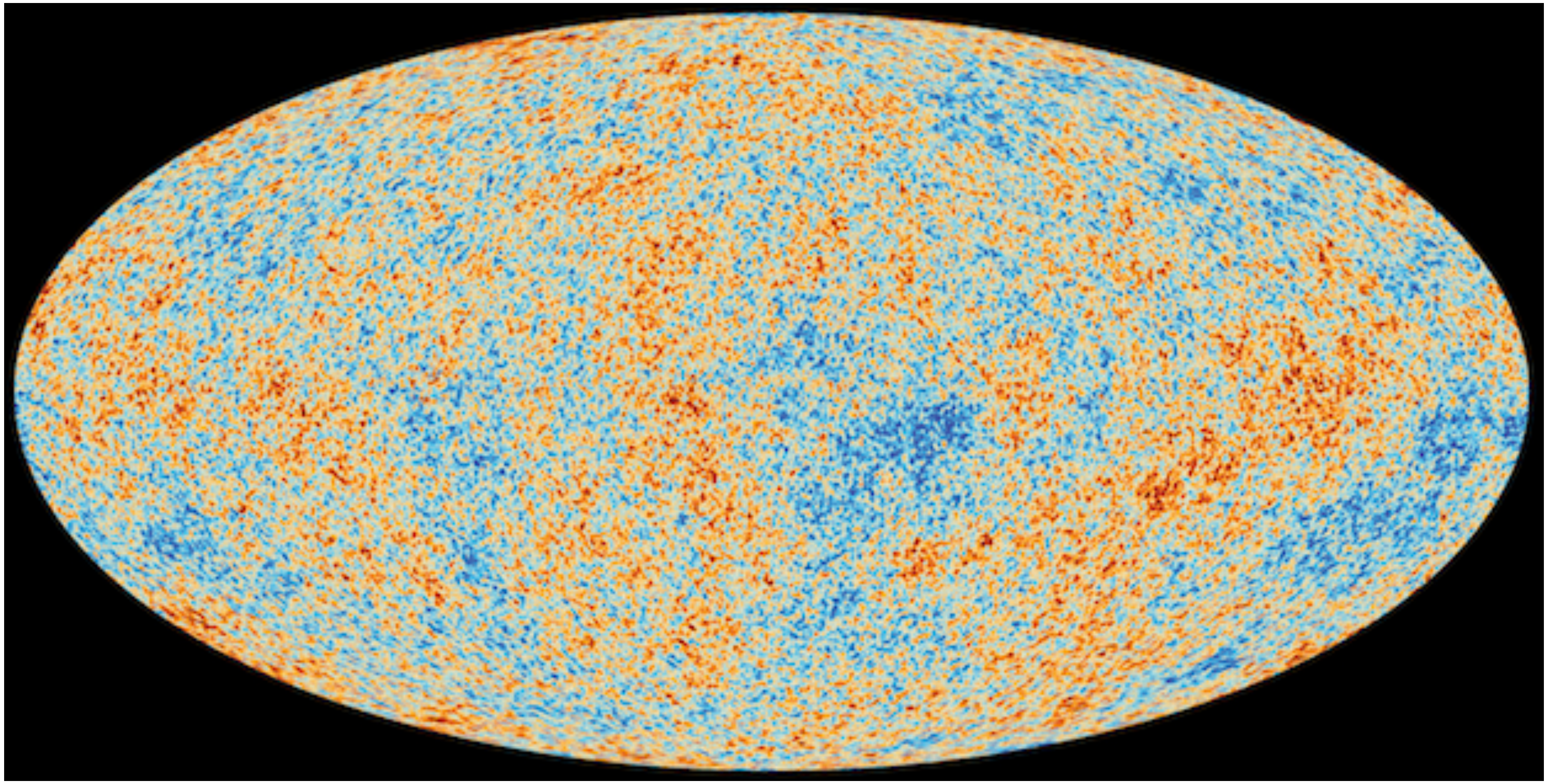
A Big Bang Universe



https://skyandtelescope.org/astronomy-news/loosening-the-hubble-tension/

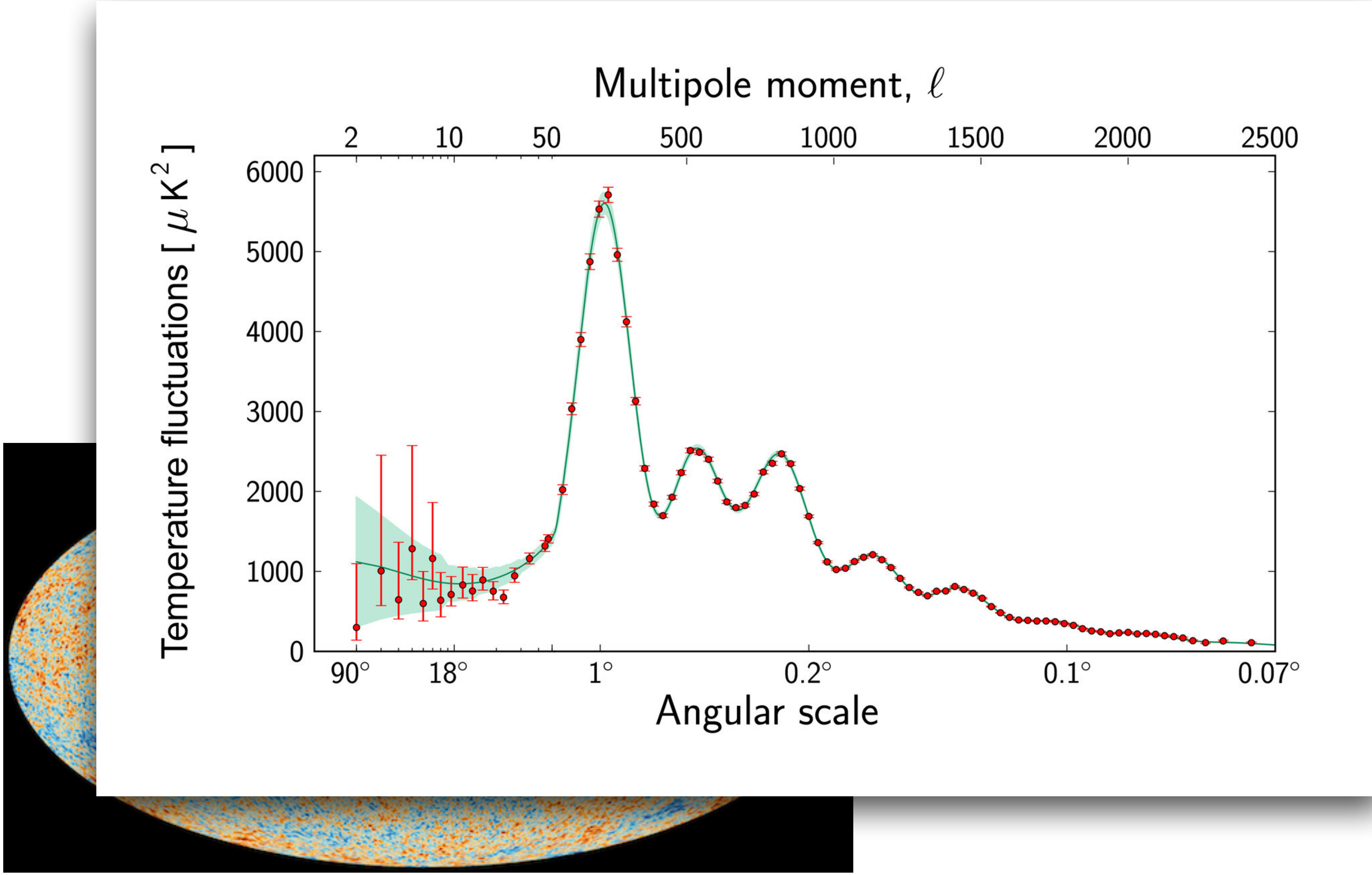
Bright side of $\hbar$

PLANCK'S VIEW OF THE COSMIC MICROWAVE BACKGROUND



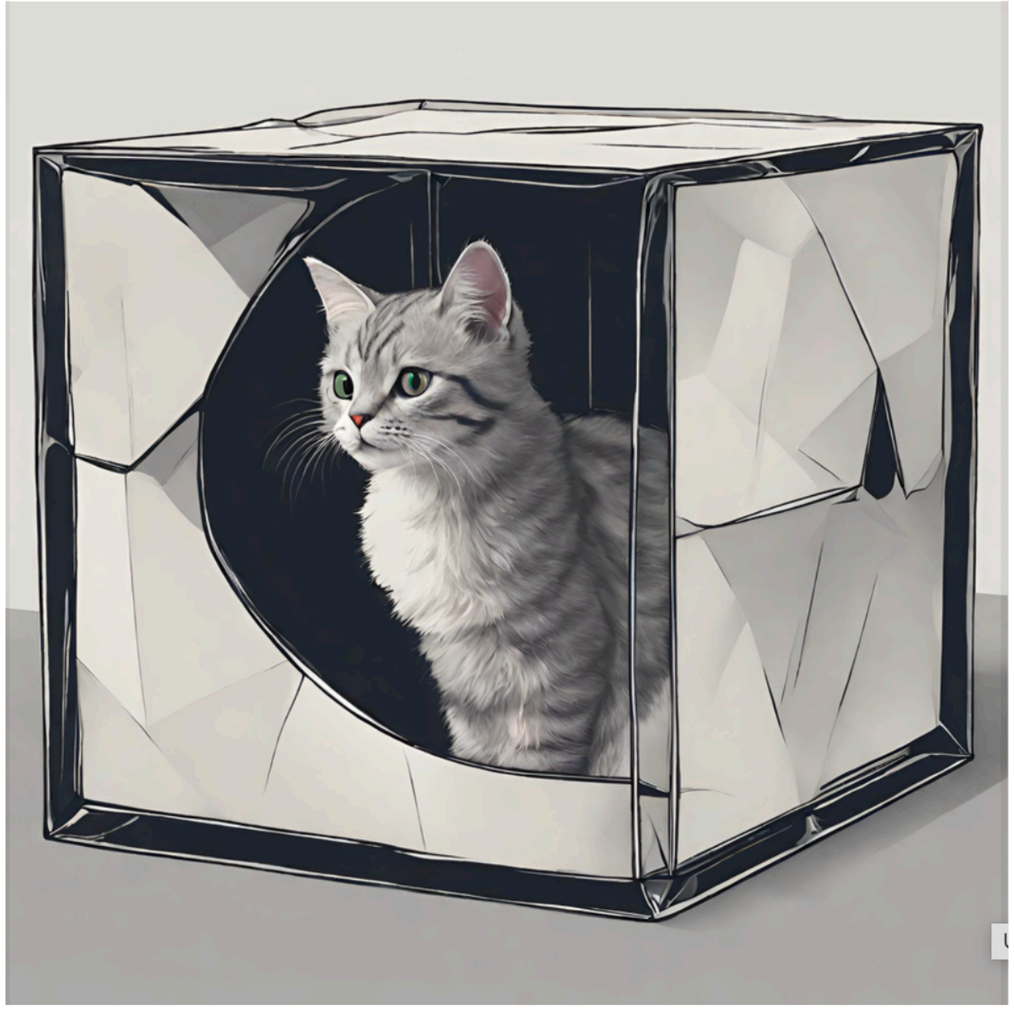
ESA/Planck Collaboration

Bright side of $\hbar$



ESA/Planck Collaboration

Unitarity



Unitarity

$$P_{IN} + P_{OUT} = 1$$

is strict:

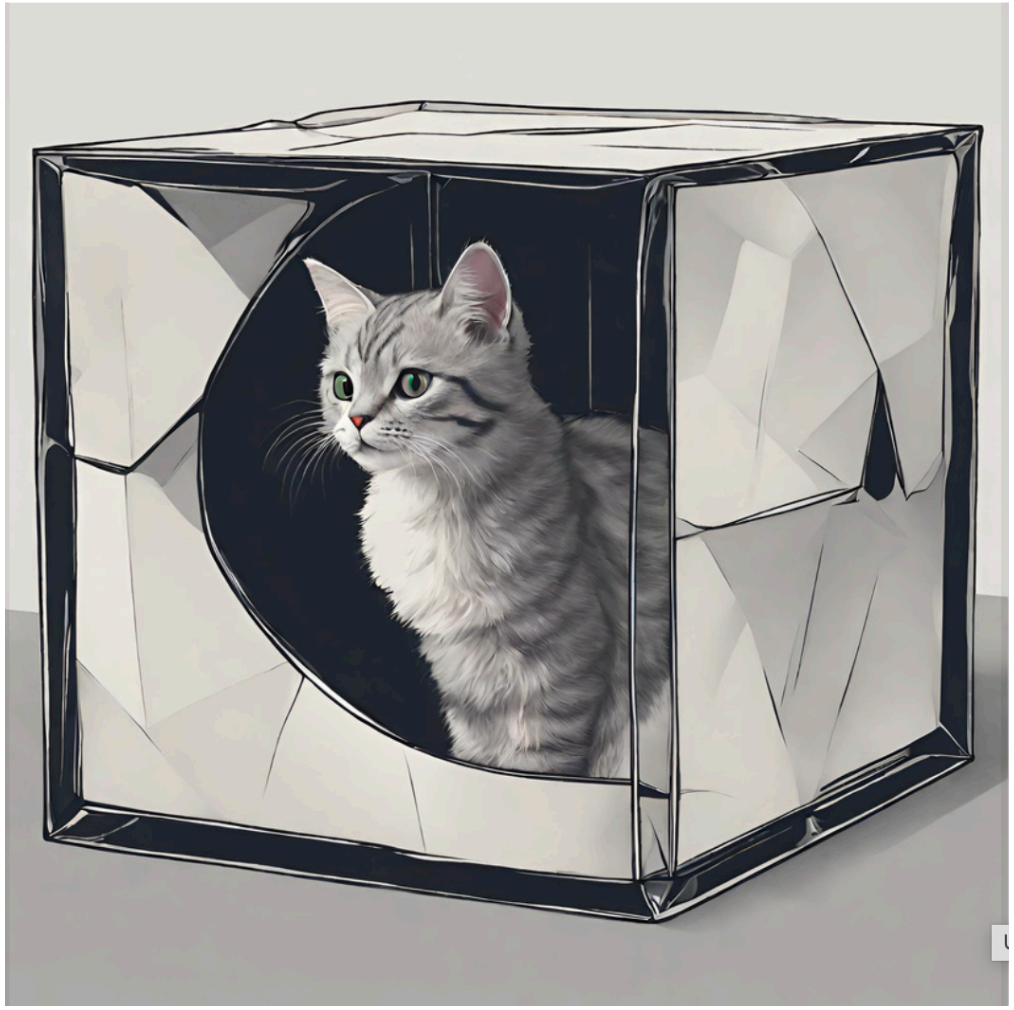
no round-off error

- *encoding is discrete*.

van Putten, IJMPD, 24, 1550024 (2015)

Fuzzy side of $\hbar$

Compton phase
$\varphi = k_C s \; k_C = mc/\hbar$



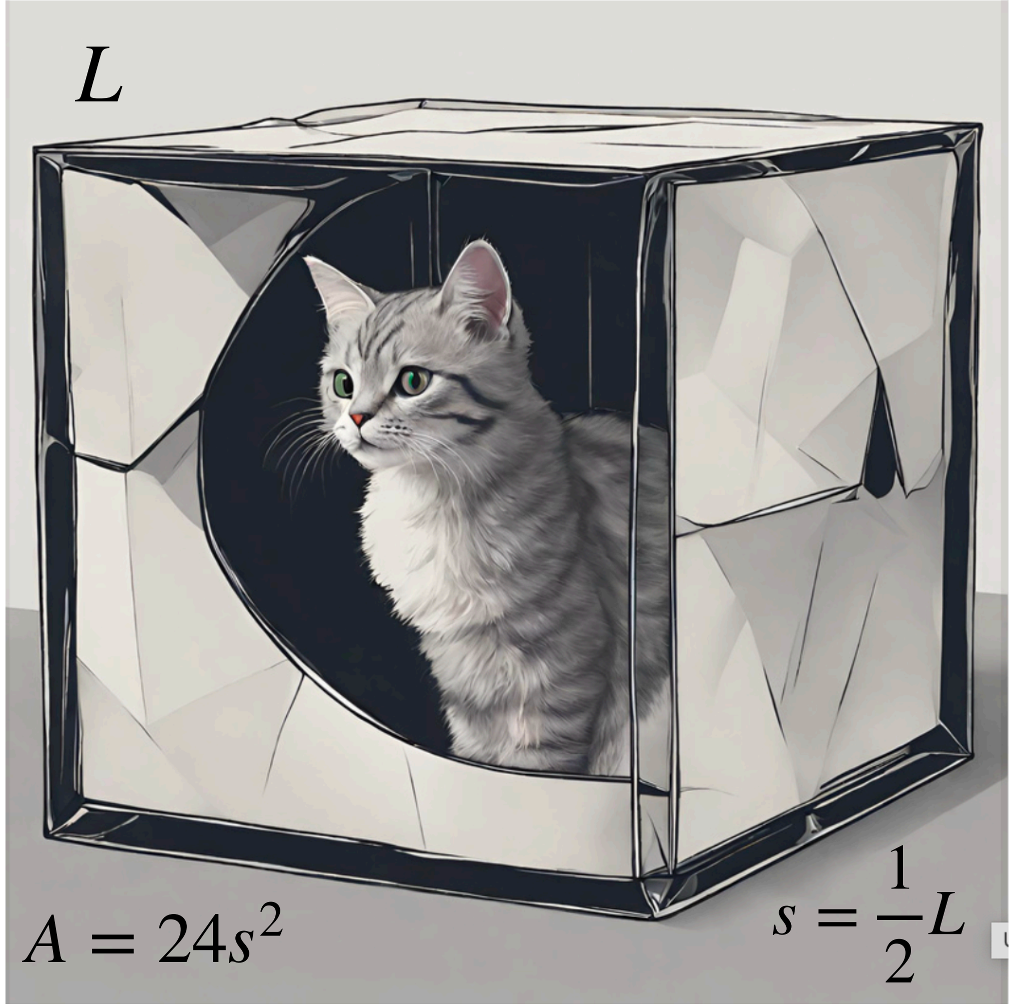
linear size s

van Putten, IJMPD, 24, 1550024 (2015)

… position information

$I \simeq (\log P_{IN}/P_{OUT})$ to be IN

van Putten, IJMPD, 24, 1550024 (2015)
APS April Meeting 2024; PoS Corfu2023
463:208 (2024); arXiv:2408.13121v1

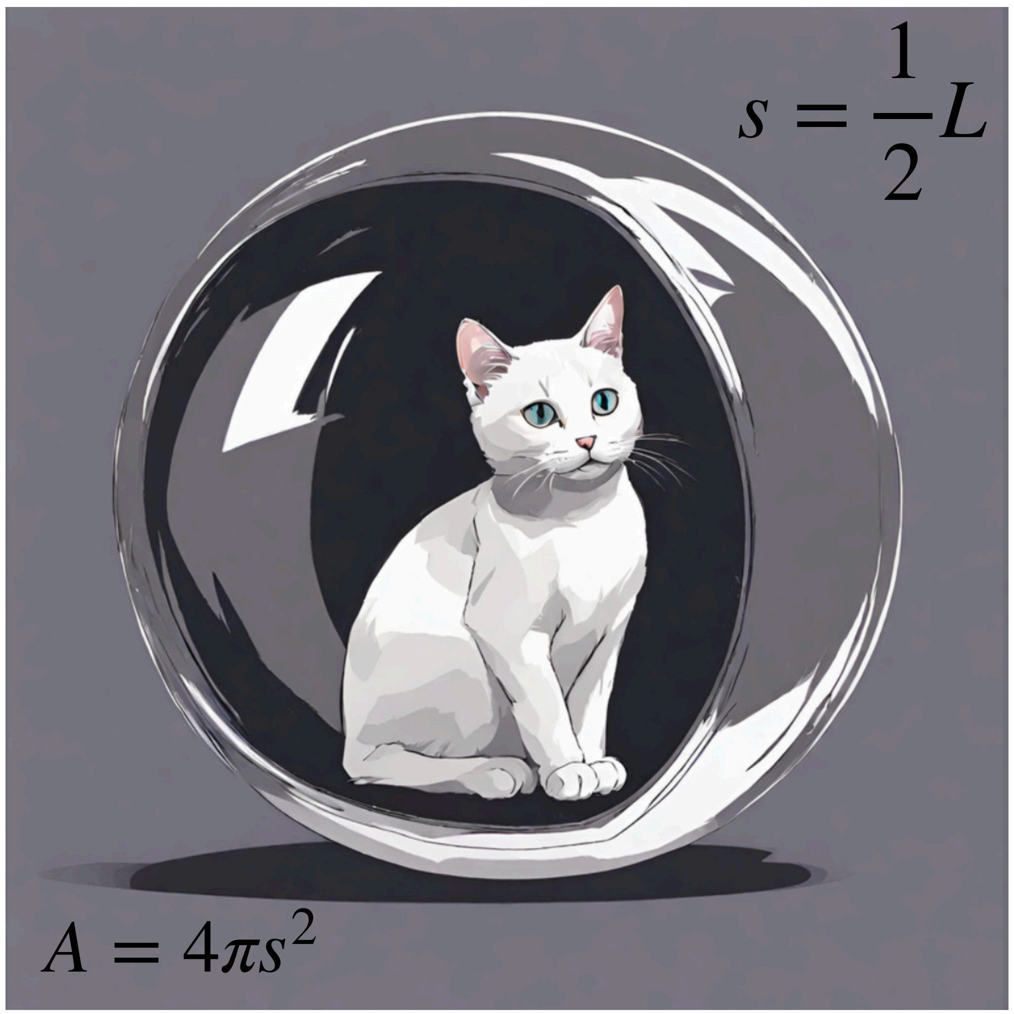


$I_0 = 12\varphi$

$P_{OUT} \sim e^{-12\varphi}$

… for a sphere

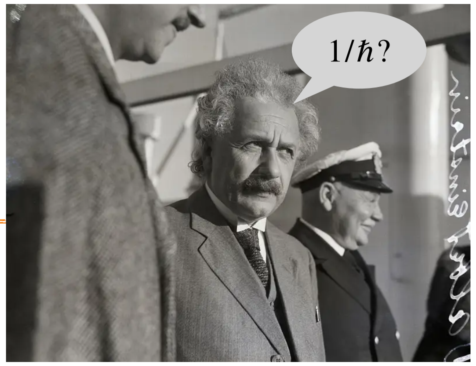
van Putten, IJMPD, 24, 1550024 (2015)
APS April Meeting 2024; PoS Corfu2023
463:208 (2024); arXiv:2408.13121v1



$$I = \left(\frac{A}{A_0}\right) I_0 = \frac{\pi}{6} I_0 = 2\pi\varphi$$

$$P_{OUT} \sim e^{-2\pi\varphi}$$

IR-consistent coupling to spacetime



For massive particles, the Compton phase $\varphi = k_C s$ is UV-divergent in $\hbar$:

$$\varphi \sim 1/\hbar.$$

Coupled to classical spacetime in (G, c), Compton phase is a primitive, that requires an IR-consistent limit for small $\hbar$, i.e., coupling by

$$\alpha_p \propto \hbar.$$

Classical spacetime has no intrinsic length scale, calling for a running coupling $\propto \hbar$

van Putten, 2024, ChJPh, 91, 377
2024, PoS 463 arXiv:2408.13121

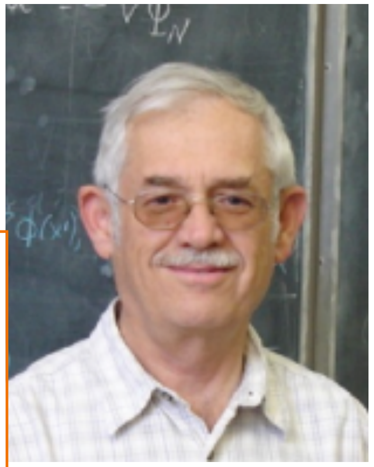
Running coupling $\propto \hbar$ derives from

$$\alpha_p A_p = 1,$$

based on the area of concentric spheres of radius r about a massive particle,

$$A_p = 4\pi r^2 / l_p^2,$$

In Planck units $l_p = \sqrt{G\hbar/c^3}$.



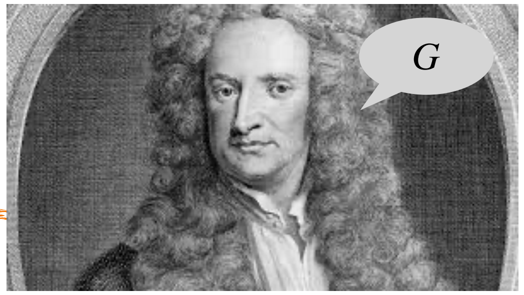
Recall the Bekenstein bound

$$I \leq S/k_B,$$

$S = A_p/4$ with equivalent *Einstein area* $A_E = 4Il_p^2$.

van Putten, 2024, ChJPh, 91, 377
2024, PoS 463 arXiv:2408.13121

Gravitation from IR-consistency



The Einstein area A_E presents a density of I with equivalent probability

$$p = \frac{A_E}{4\pi r^2} = 4I\alpha_p,$$

satisfying $0 \leq p \leq 1$ ($p = 1$: black hole event horizon).

While A_E is used for encoding position, the remainder is free for wave propagation: p causes attenuation (Huygens): $\beta \equiv v/c = 1 - p$ (Huygens).

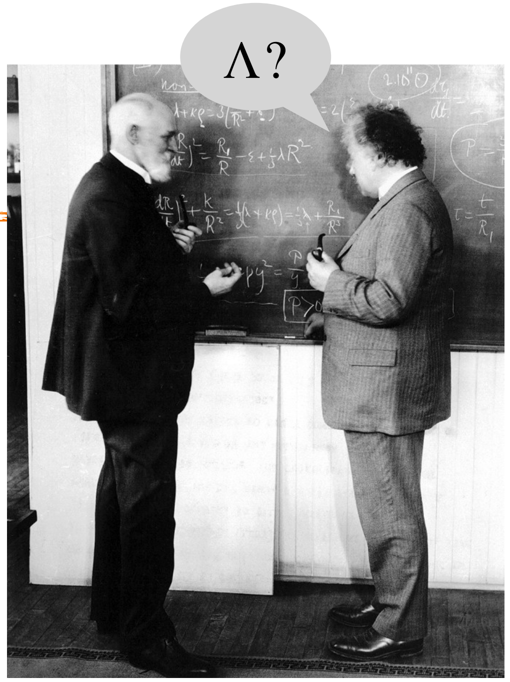
Embedded in curvature (GR), $ds^2 = -\beta c^2 dt^2 + \beta^{-1} dr^2 + r^2 d\Omega$, $\beta = dr/cdt$, the Newtonian limit derives from $\sqrt{\beta} \simeq 1 + u$,

$$u = -2I\alpha_p = -\frac{R_g}{r}.$$

Newton's law in p-induced curvature

van Putten, 2024, ChJPh, 91, 377
2024, PoS 463 arXiv:2408.13121

Dark side of $\hbar$



QFT predicts a a bare energy density:

$$\rho_0 = \frac{\hbar c}{l_p^4}:\ \Lambda_0 = 8\pi G c^{-4} \rho_0.$$

Since $\Lambda_0 \simeq 1/\hbar$, Λ_0 is a second primitive.

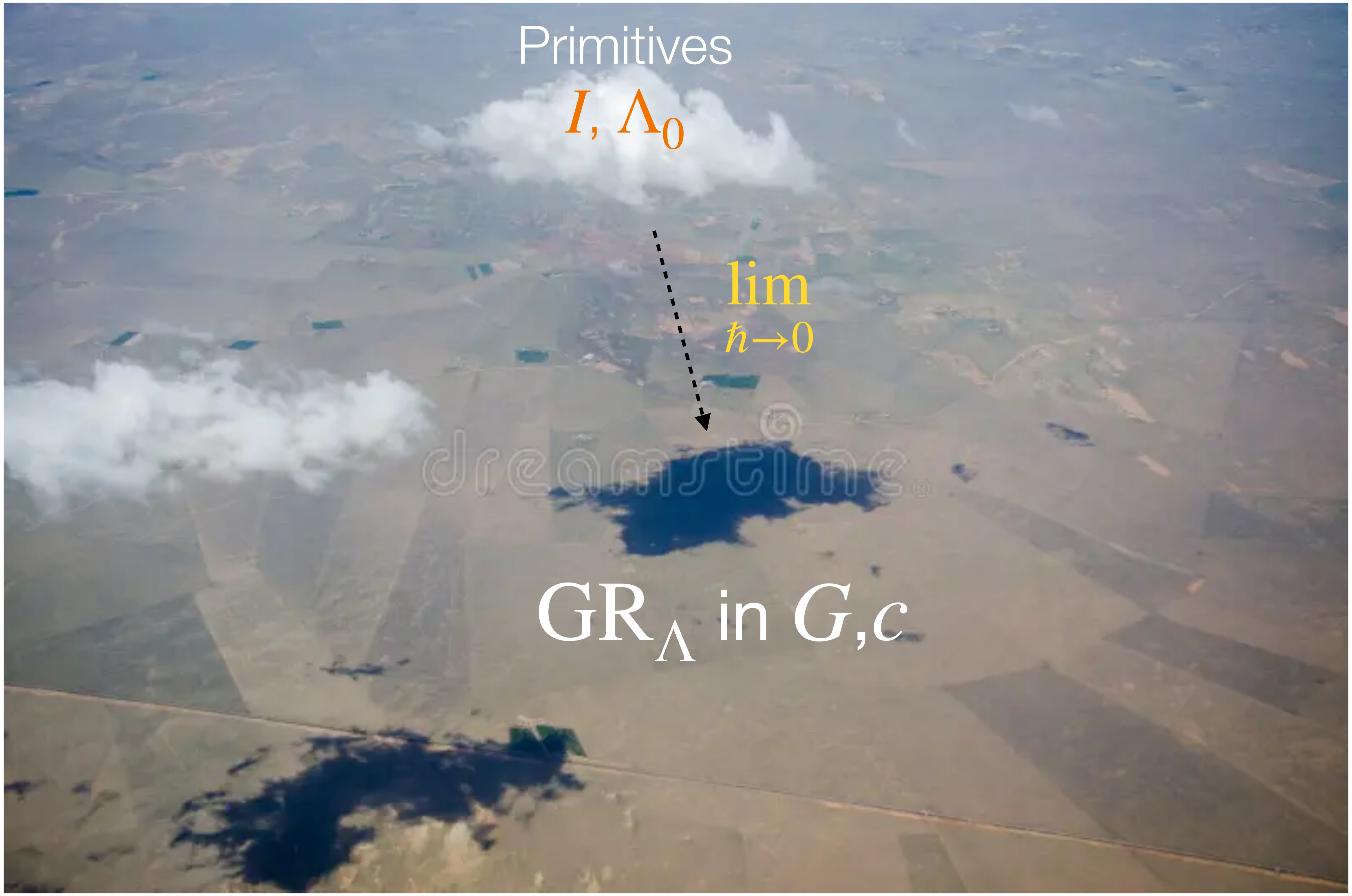
IR-consistency with classical spacetime once more requires a coupling $\alpha_p \propto \hbar$.

Extending $A_p = 4\pi R_H^2 / l_p^2$ to the Hubble scale $R_H = c/H$,

$$\Lambda \equiv \alpha_p \Lambda_0 = 2H^2/c^2.$$

Dynamical Λ consistent with the swampland conjectures

UV-shadows of $\hbar$



IR consistent completion outside the Swampland

In the shadow of $\hbar$

Sub-Hubble scale variations define the Einstein equations.

Super-Hubble scale variations $(k \sim 0)$ require a global phase reference $\Phi_0 = \Phi_0\left[\mathscr{H}\right]$, i.e., a *normalized propagator:*

$$e^{i\left(\Phi - \Phi_0\right)} = \frac{e^{i\Phi}}{e^{i\Phi_0}}.$$

With no asymptotically flat Minkowski spacetime in FLRW: $\Phi_0 \not\equiv 0$. Write

$$\Phi_0\left[\mathscr{H}\right] = \int 2\Lambda\sqrt{-g}\,d^4x,$$

where $\Lambda = \lambda R$ - nonlocal by the Friedmann scale factor a.

van Putten, 2020, MNRAS, 491, L6

… trace of the Schouten tensor

Jan A. Schouten
(1883-1971)

Global phase reference for super-Hubble scale variations:

$$\Lambda = \frac{1}{6}R \equiv J$$

on an FRLW cosmology of dimension four, supported by

- Confrontation with data (H_0, BAO, age): $\lambda \simeq 1/6$ within 1%
- Entropic forcing with $a_H = \dfrac{1-q}{2}a_{dS}$, $a_{dS} = cH$: $\lambda = 1/6$

It follows that

$$\Lambda = (1-q)H^2,$$

where q is the deceleration parameter.

van Putten, 2015, MNRAS, 450, L48;
2020, MNRAS 491, L6;
2021, PLB, 823, 136737

JCDM

$\Lambda = J$:

$$H(z) = H_0 \frac{\sqrt{1 + \frac{6}{5}\Omega_{M,0} Z_5(z) + \Omega_{r,0} Z_6(z)}}{1+z}.$$

van Putten 2021 PLB 823 136737

O'Colgain, van Putten & Yavartanoo 2019 PLB 793 121

Subject to Planck BAO data:

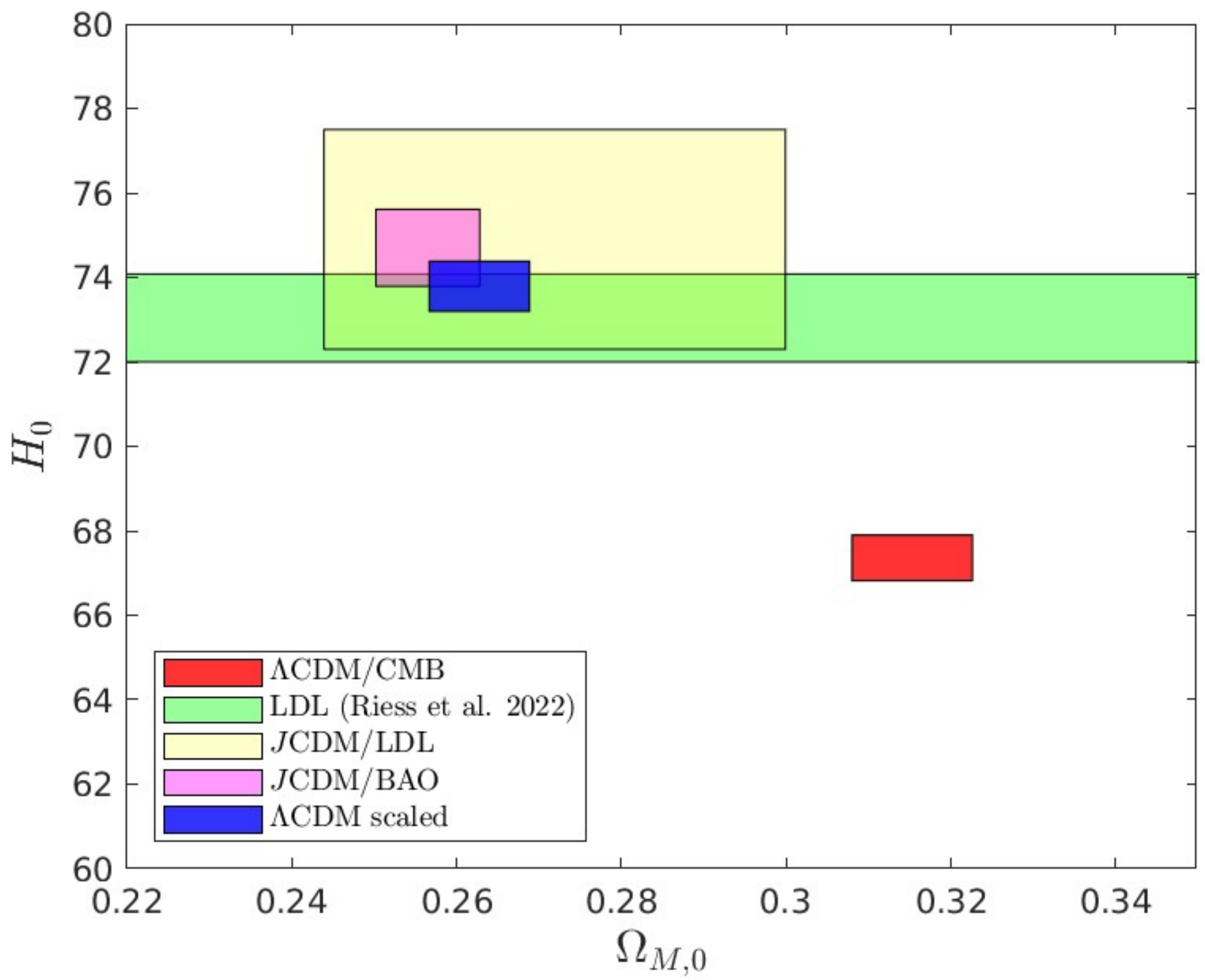
$$H_0 \simeq \sqrt{\frac{6}{5}} H_0^{\rm Planck} \simeq 73\,{\rm km\,s^{-1}Mpc^{-1}}.$$

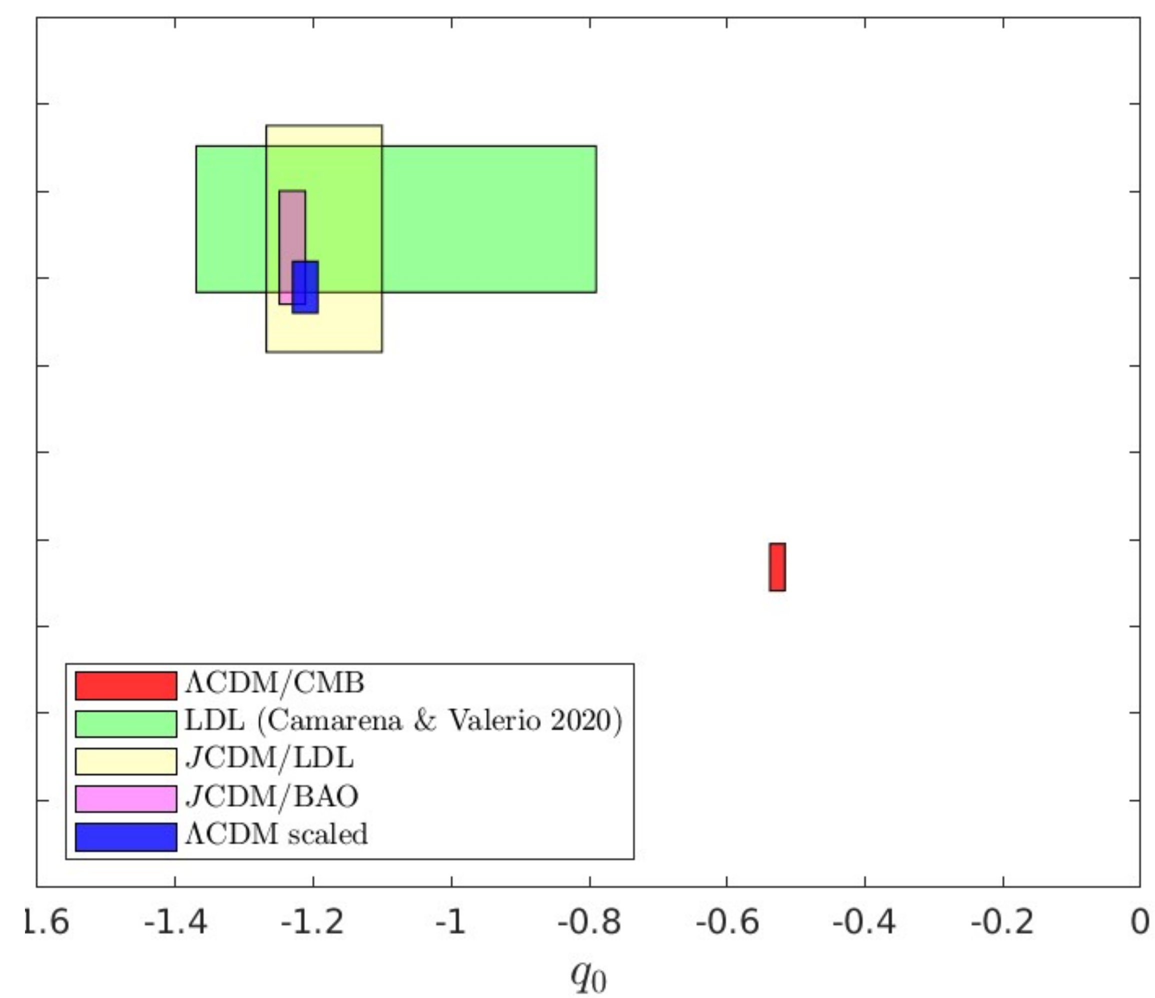
van Putten 2024 arXiv:2403.10865;

2024, PoS 463 arXiv:2408.13121

JCDM versus ΛCDM

van Putten 2024 arXiv:2403.10865;
2024, PoS 463 arXiv:2408.13121

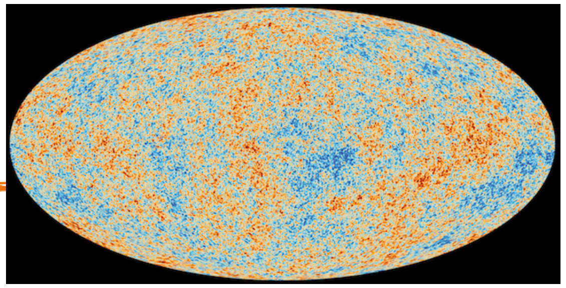


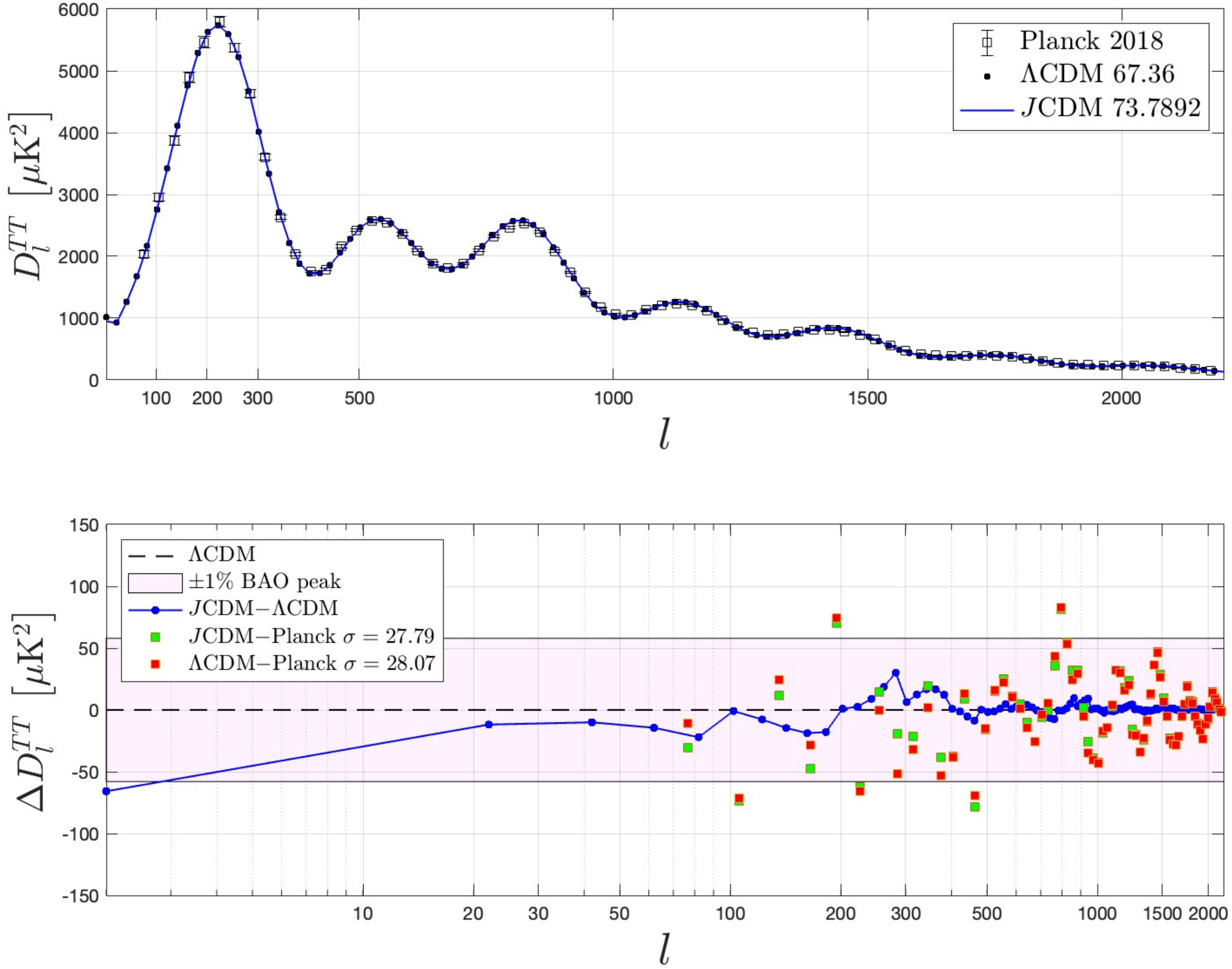


$q_0 \simeq -1$ represents enhanced curvature in $H(z)$ today

Signals unstable de Sitter: ΛCDM ruled out in distant future

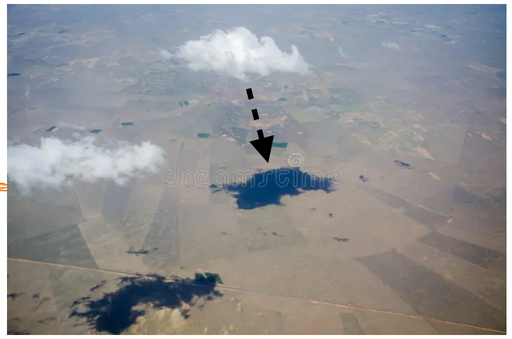
*J*CDM facing *Planck* power spectrum CMB





van Putten, 2024, arXiv:2403.10865v2

Conclusions



- Shadows of quantum gravity from primitives: UV-divergences in $1/\hbar$ with IR-consistent coupling to

  (a) Position information recovers classical gravitation.

  (b) Bare cosmological constant leads to $\Lambda = J$.

- With no free parameters, JCDM is tension-free in H_0 with matter density Ω_M reduced by $5/6$ relative to *Planck* and $q_0 \simeq -1$ (dS is unstable), distinct from $q_0 \simeq -0.55$ in ΛCDM (assumes dS is stable).

van Putten 2024, CJPh, 91, 377;
2024, PDU, 43, 101417

EXTRA SLIDES

Two scales of spacetime

The Hubble radius of FRLW cosmologies

$$R_H = \frac{c}{H} = 3\,\mathrm{Gpc}\,h^{-1}\left(h = H_0/\left[100\mathrm{km\,s^{-1}Mpc}\right]\right).$$

Gravitational radius of general relativity (GR) on sub-horizon scales

$$R_G = \frac{GM_b}{c^2} = 1.5 \times 10^{16}\mathrm{cm}\left(\frac{M}{10^{11}M_\odot}\right).$$

… with a transition radius across

Between GR and the Hubble scale, expect a transition radius

$$r_t = \sqrt{R_G R_H} \simeq 4.7\,\mathrm{kpc}\,M_{11}^{1/2}$$

(Roughly the size of the bulge in a spiral galaxy)

at the de Sitter scale of acceleration

$$a_{dS} = cH \simeq 7\,\mathrm{Å cm\,s^{-2}}.$$

van Putten 2017 ApJ 848 28
2018 MNRAS 480 L48
2024, PDU, 43, 101417

… between weak and strong gravitation

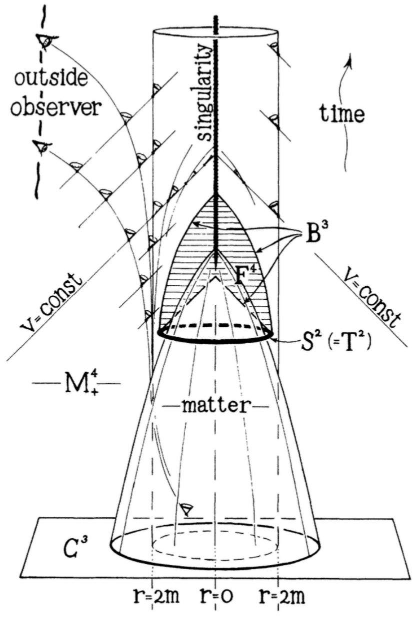
Weak gravitation

Baryonic Tully-Fisher relation

JWST ‘Impossible galaxies’ at cosmic dawn

a_{dS}

Newtonian/strong gravitation

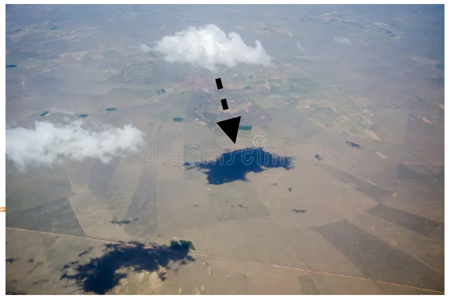


Sensitive to background cosmology

Insensitive to background cosmology

van Putten 2017 ApJ 848 28
2018 MNRAS 480 L48
2024, PDU, 43, 101417

Conclusions



Galaxy dynamics' sensitivity to a_{dS}:

A C^0-transition to anomalous dynamics across $a_{dS} = cH$.

Unification of the baryonic Tully-Fisher relation with the JWST 'Impossible galaxies' by the Milgrom parameter

$$a_0 = c^2\sqrt{J}/2\pi.$$

DM is excluded on scales $r_t = \sqrt{R_H R_G} \simeq 4.7\,\mathrm{kpc}M_{11}^{1/2}$: DM is ultra-light:

$$m_D < 10^{-21}\mathrm{eV}.$$

van Putten 2024, CJPh, 91, 377;
2024, PDU, 43, 101417