H_0 tension: shimmer of an unstable de Sitter cosmology?

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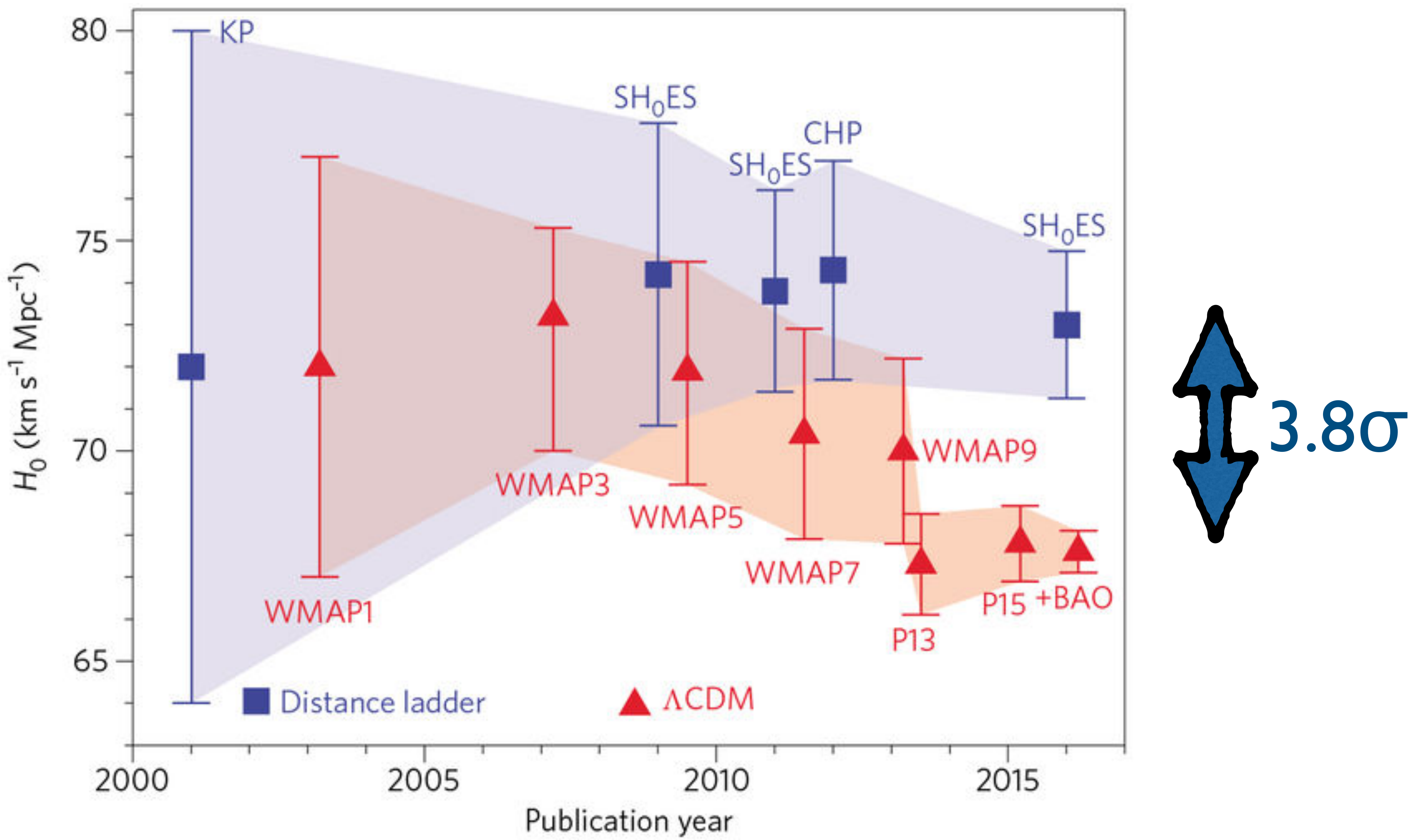
Ó Colgáin, van Putten, Yavartanoo, arXiv:1807.07451 (2018)

van Putten, 2017, ApJ **428**, 28

APCTP H0 tension and Swampland: theory confronts reality
Dec 29 2018

H_0 tension



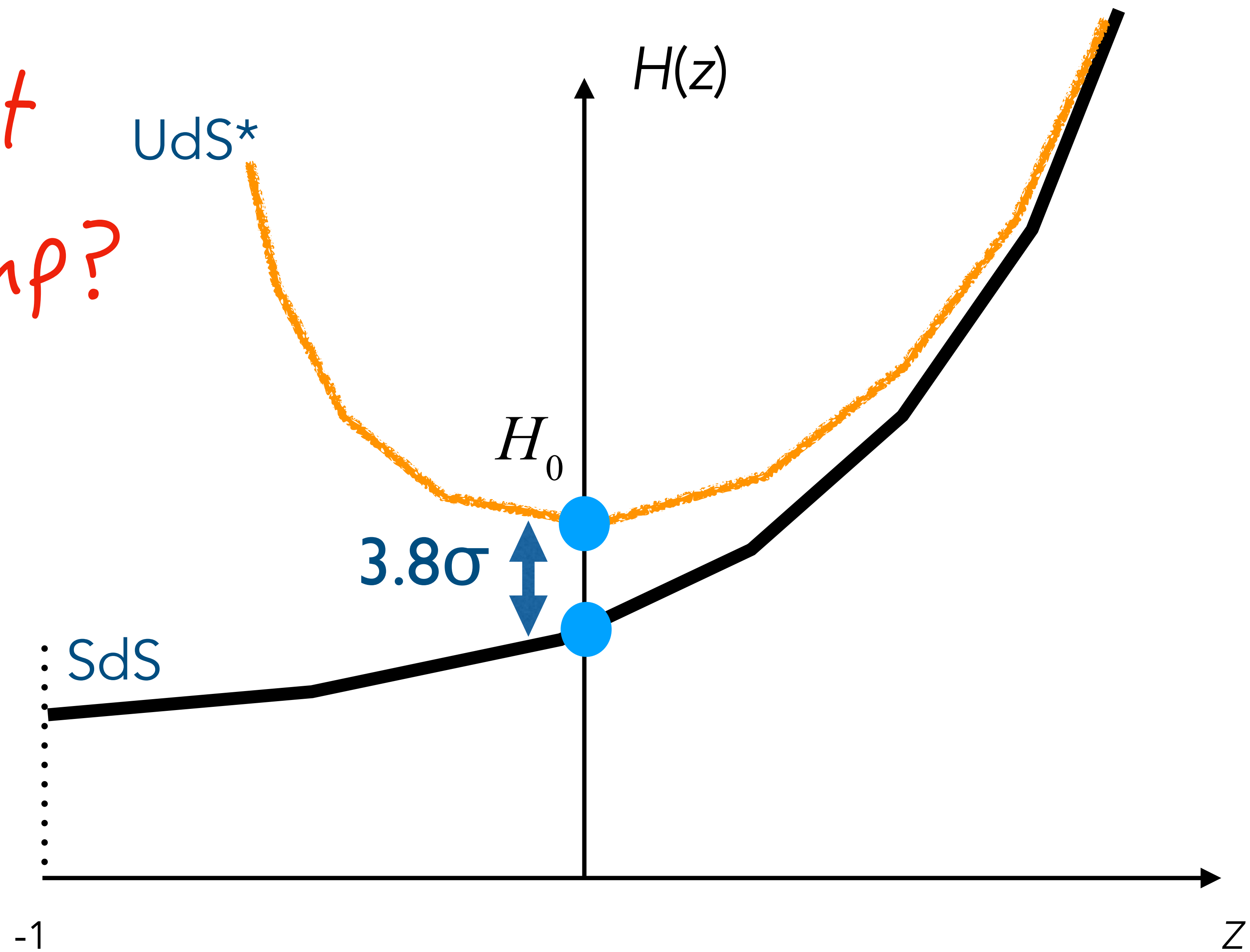
H_0 from surveys of the Local Universe (sans cosmological model)

H_0 from ΛCDM analysis of cosmological data (CMB, BAO, …)

W. L. Freedman, 2017, Nat. Astron., 1, 0169

H_0 tension: shimmer from the future?

Future is out of the Swamp?



UdS*: ΛCDM ruled out in the future (*Swampland conjecture*),
ΛCDM cannot hold to all orders today,
tensions today

*Vafa, C., 2005, hep-th/0509212
Brennan, T.D., Carta, F., and Vafa, C., 2017, arXiv:1711.00864;
Obied, Oooguri, Spodyneiko, Vafa, 2018
O'Colgain, E., van Putten, M.H.P.M., & Yavar, H., 2018, arXiv:1808.07451

Phase space BH spacetime is geometrically 2D (Bekenstein 1973 't Hooft 1993)

FRW-cosmologies have a cosmological horizon $\mathcal{H}$: an apparent horizon at Hubble radius $R_H = c/H$.

Turning this inside-out: phase space cosmological vacuum is 2D

This $\mathcal{H}$-constraint is woefully violated by Zel'dovich' UV-divergent dark energy **volume** density integral

Two polarizations:

$$M = 2\left(\tfrac{1}{2}T\right)S = \frac{H}{2\pi}\pi R_H^2 = \tfrac{1}{2}R_H$$

Gibbons & Hawking 1977
Verlinde 2011
Easson, Frampton & Smoot 2011

Dark energy density:

$$\rho_\Lambda = \frac{M}{V_H} = \frac{\frac{1}{2}R_H}{\frac{4\pi}{3}R_H^3} = \frac{3H^2}{8\pi} \equiv \rho_c$$

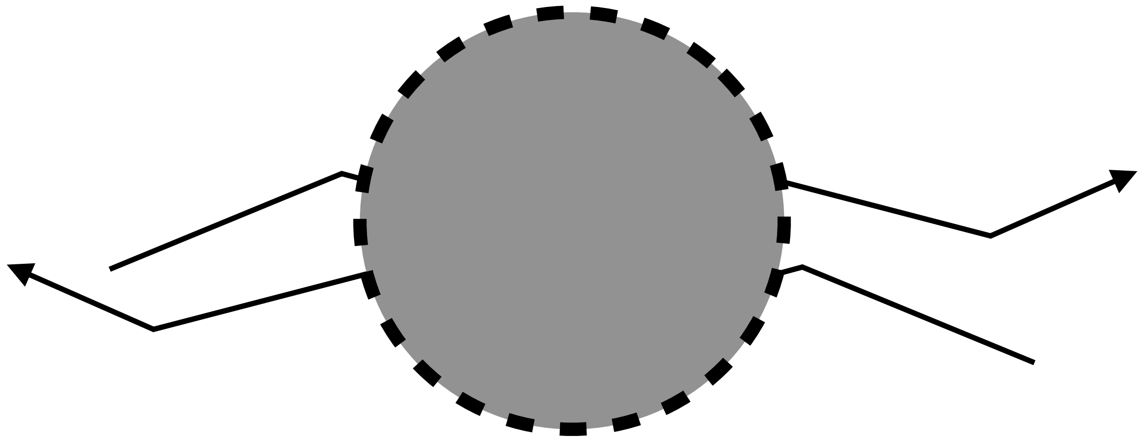
dS : residual of $\mathcal{H}$-constrained fluctuations

Is dS stable?

Apparent horizons: chromatic aberration

AH defined in the general relativity: geometric optics limit of gravitation

Subject to dispersion in IR:



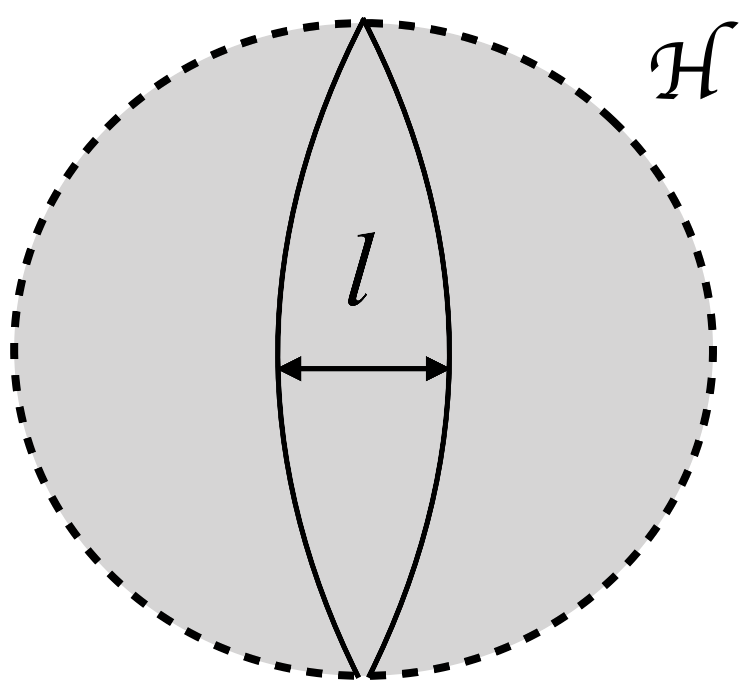
Hawking radiation, to null-infinity in Minkowski spacetime

On-shell

Super-horizon scale fluctuations *leaking out*

Super-horizon scale modes start leaking out at

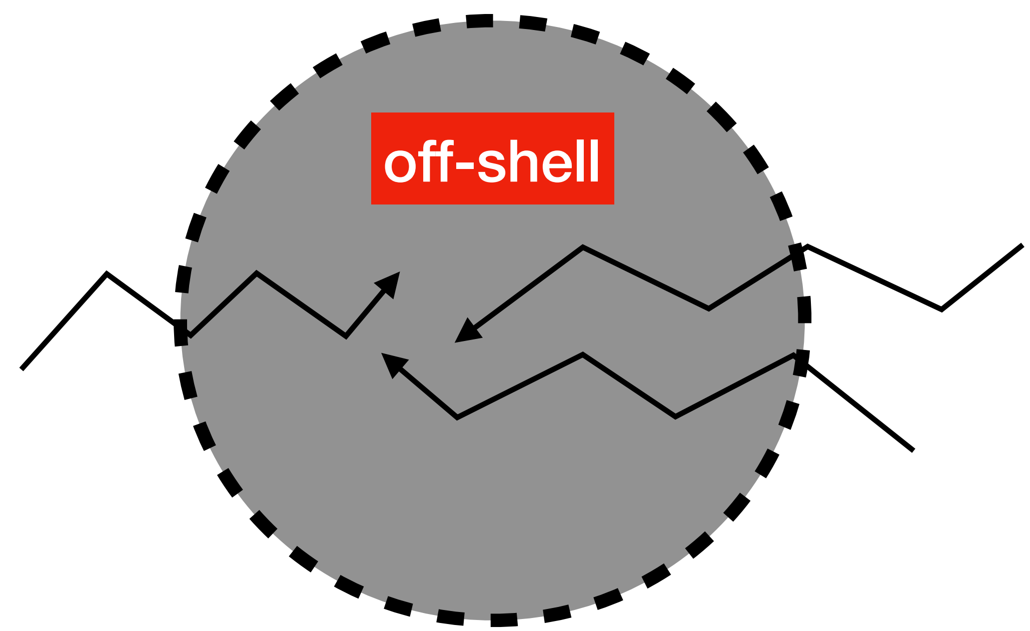
$$\omega_0 = \frac{1}{4\pi R_S}$$



Following Gauss-Bonnet: normal from tangential acceleration

Applied to $\mathcal{H}$ in FRW:

$$\omega_0 = \sqrt{1-q}\,H$$



Radiation dominated $(q=1)$: $\omega_0 = 0$

Pick up $p < 0$ by imaginary wave numbers at super-horizon scale fluctuations *leaking in*

van Putten 2017 ApJ 837 22

Cosmological vacuum: dispersion

$$\text{dS:} \quad \omega_0 = \sqrt{2}H \quad (q = -1)$$

Wave equations of EM/U(1) and GW/SO(3,1) in Lorenz gauge (van Putten & Eardley 1996): coupling to Ricci tension picks up sensitivity to Λ

Dispersion relation of linearized wave-motion: $\omega = \sqrt{k^2 + \Lambda}$

$$\Lambda = \omega_0^2 \quad \text{from } \mathcal{H}$$

Quadratic: inherently small and positive today

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Equations of motion

Three-flat FRW cosmology:

$$G_{ab} = 8\pi T_{ab} + (1-q)H^2 g_{ab}$$

Density parameters

$$\Omega_\Lambda = \frac{1}{3}(1-q)$$

$$\Omega_M = \frac{1}{3}(2+q)$$

Radiation picture

$$T_{ab} = (\rho + p)u_a u_b + p g_{ab} - \omega_0^2 g_{ab}$$

$$T_{ab} = \rho_c \left[(1-q)\pi^-_{ab} + q\pi^+_{ab} \right]$$

$$\pi^\pm_{ab} = \mathrm{dia}(1, \pm\tfrac{1}{3}, \pm\tfrac{1}{3}, \pm\tfrac{1}{3})$$

Dark "matter"

$$q = 3\Omega_p$$

$$w = \frac{2q-1}{1-q}$$

- Radiation dominated (q=1)
- Matter dominated (w=0,q=1/2)
- de Sitter (q=-1)

Analytic solution

$$H(z) = H_0\sqrt{1+\omega_m\left(6z+12z^2+12z^3+6z^4+\frac{6}{5}z^5\right)}\left(1+z\right)^{-1}$$

van Putten, 2017, ApJ, 848, 28

Analytic solution

$$H(z) = H_0 \sqrt{1 + \omega_m \left(6z + 12z^2 + 12z^3 + 6z^4 + \frac{6}{5} z^5 \right)} \left(1 + z\right)^{-1}$$

van Putten, 2017, ApJ, 848, 28

Same parameters of late-time ΛCDM cosmology:

$$H_0 = H(0), \quad \omega_m = \Omega_m(0)$$

Analytic solution

$$H(z) = H_0 \sqrt{1 + \omega_m \left(6z + 12z^2 + 12z^3 + 6z^4 + \frac{6}{5} z^5 \right)} \left(1 + z\right)^{-1}$$

van Putten, 2017, ApJ, 848, 28

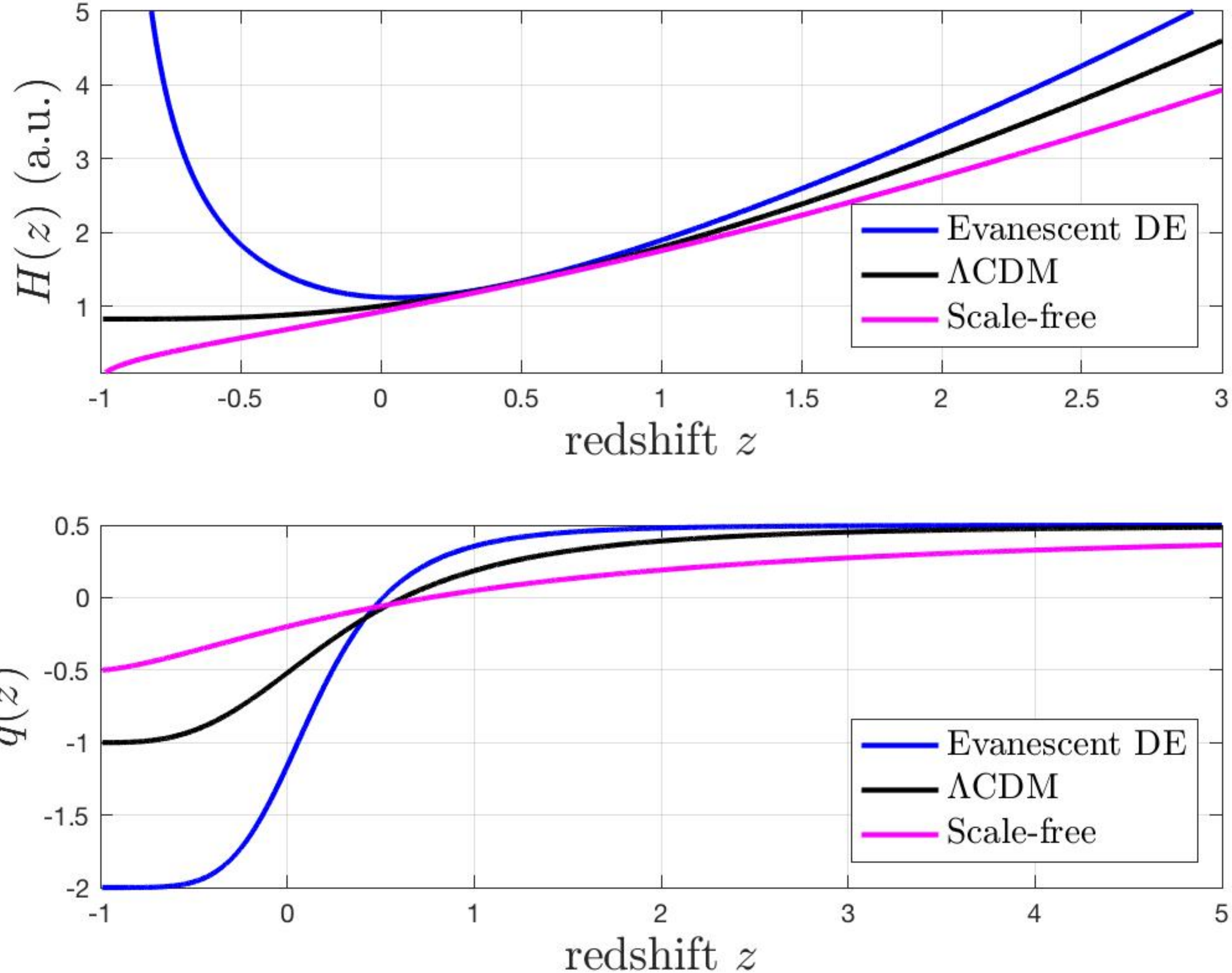
Same parameters of late-time ΛCDM cosmology:

$$H_0 = H(0), \quad \omega_m = \Omega_m(0)$$

Out-of-Swampland:

UdS: $H(z) \to \infty \quad \left(z \to -1\right)$

Analytic solution



H_0 tension: observational test

"Swampland escape" at nearby *turning point* in Hubble parameter

$$z_* = \left(\frac{5 - 6\omega_m}{9\omega_m} \right)^{\frac{1}{5}} - 1 \simeq 0.07 \quad (\omega_m = 0.28)$$

1 dimensionless parameter amenable to measurement by a single (homogeneous) survey of the Local Universe

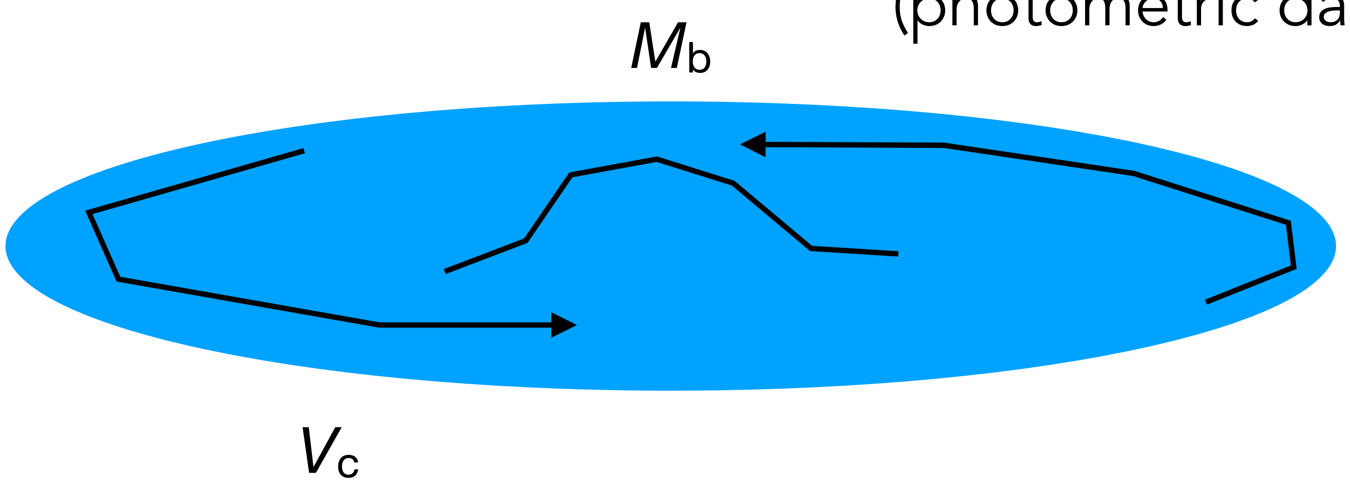
Ó Colgáin, van Putten, Yavartanoo, arXiv:1807.07451 (2018)

What about dark matter?

Three-flatness requires dark/phantom "stuff" on cosmological scales

On galactic scales, data tell a different story…

Baryonic mass distribution
(photometric data)

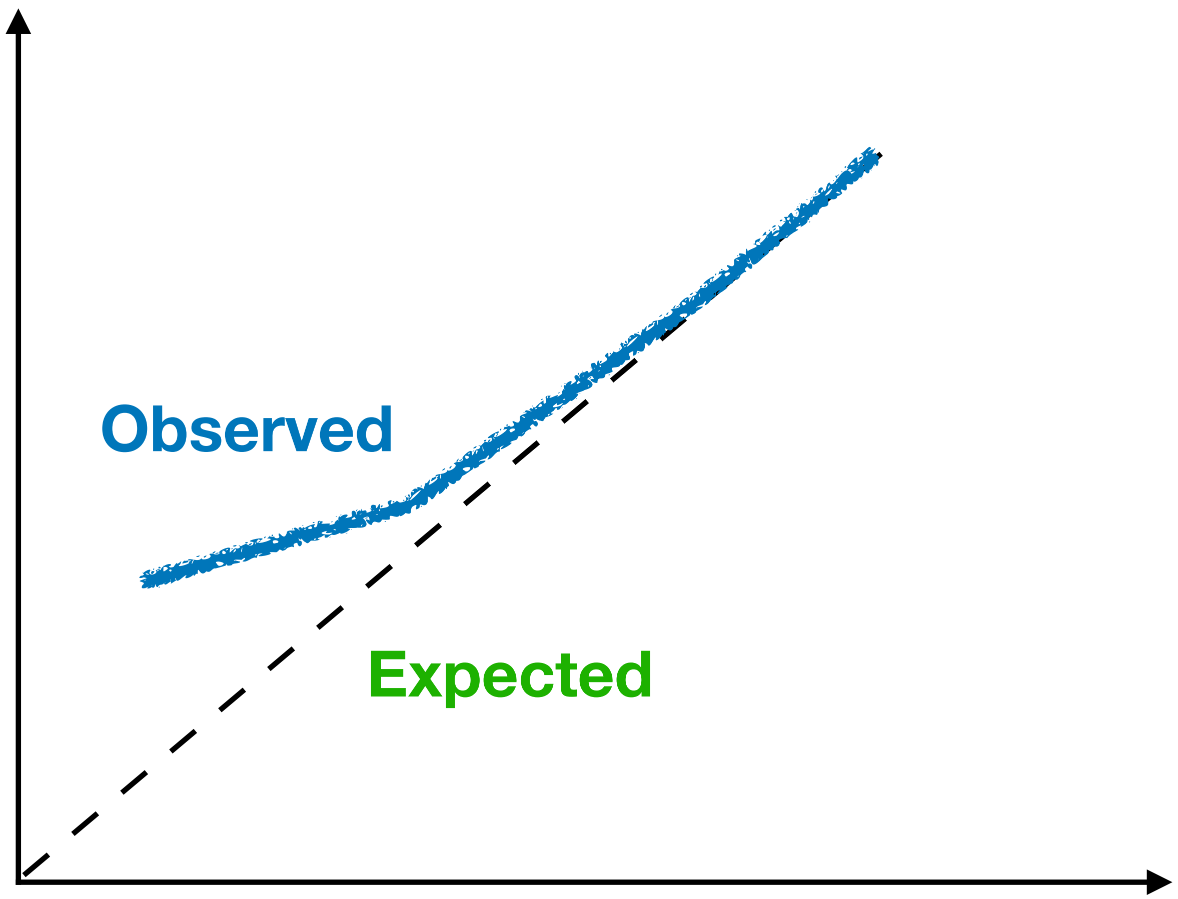


Galaxy rotation velocities
(spectroscopic data)

Galaxy rotation curves

Observed/Expected
radial acceleration

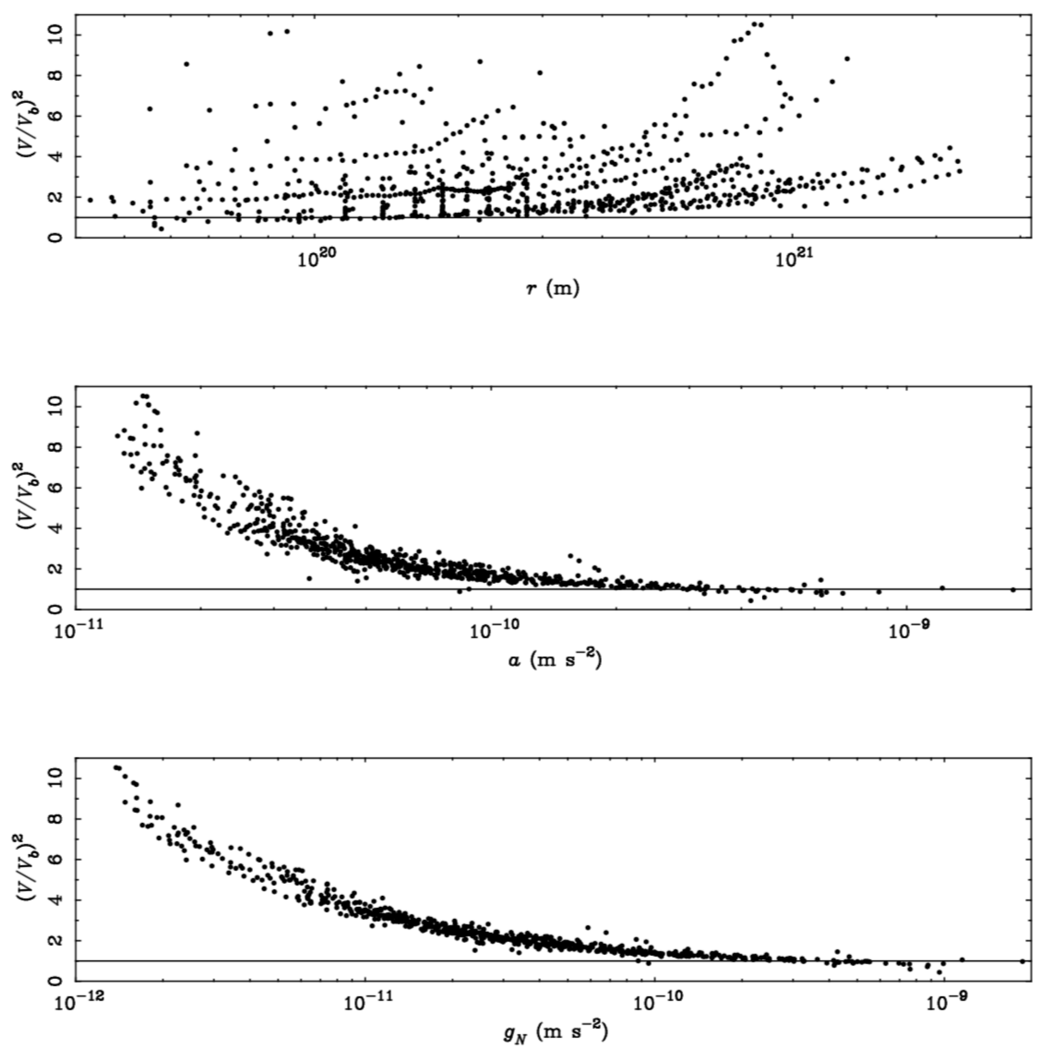
$$\frac{\alpha}{a_N} = \frac{V_c^2 / r}{V_b^2 / r}$$



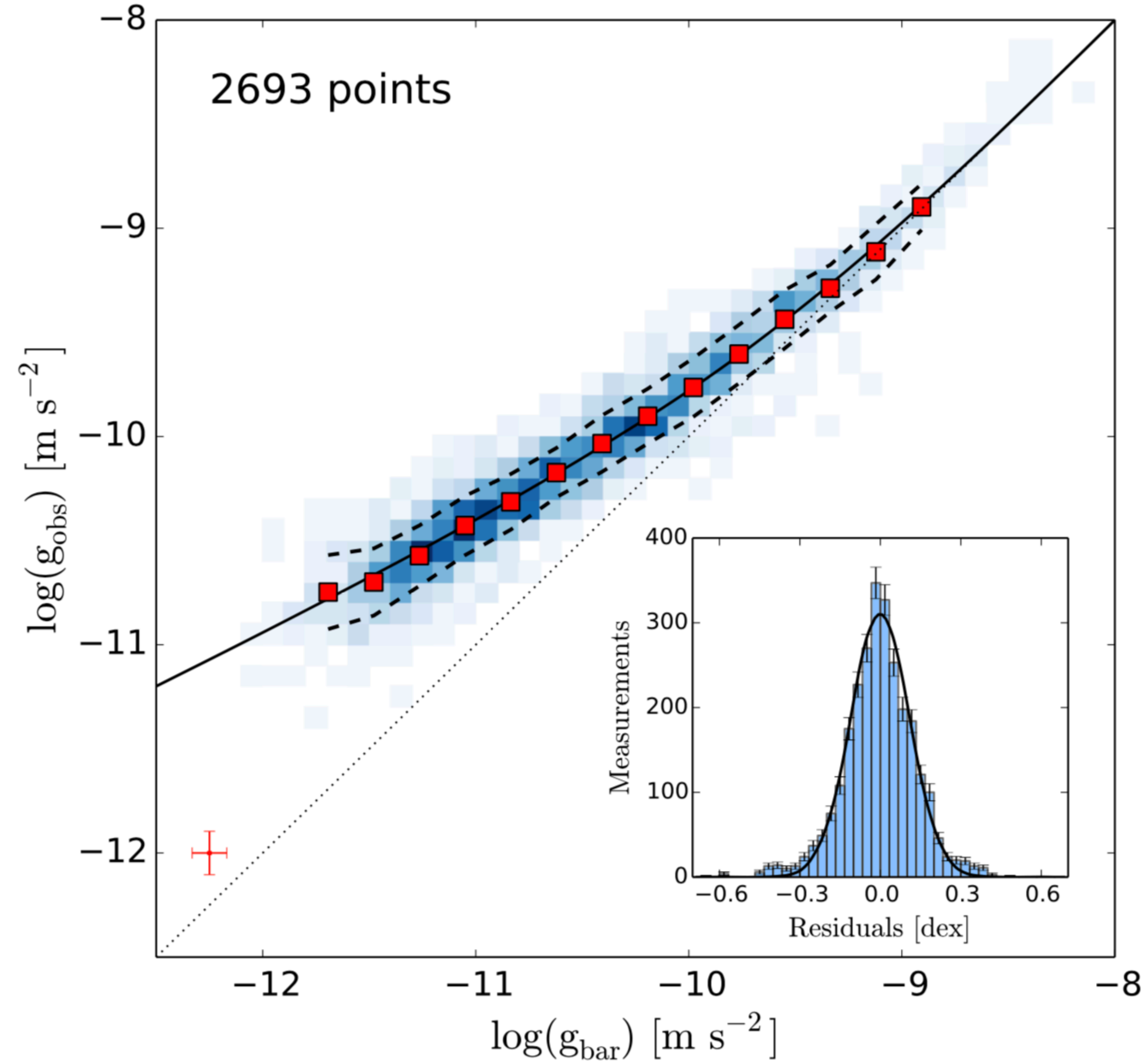
$$a_N \equiv -\frac{GM_b}{r^2}$$

Famae, B., & McGaugh, S.S., 2012, LRR, 15, 10 McGaugh, S.S., Lelli, F., & Shombert, J., 2016, PRL, 117, 201101

Galaxy rotation curves



SPARC: *Spitzer* Photometry and Accurate Rotation curves Catalogue (*z*=0)



Famae, B., & McGaugh, S.S., 2012, LRR, 15, 10

McGaugh, S.S., Lelli, F., & Shombert, J., 2016, PRL, 117, 201101

Galaxy rotation curves - normalized to a_{dS}

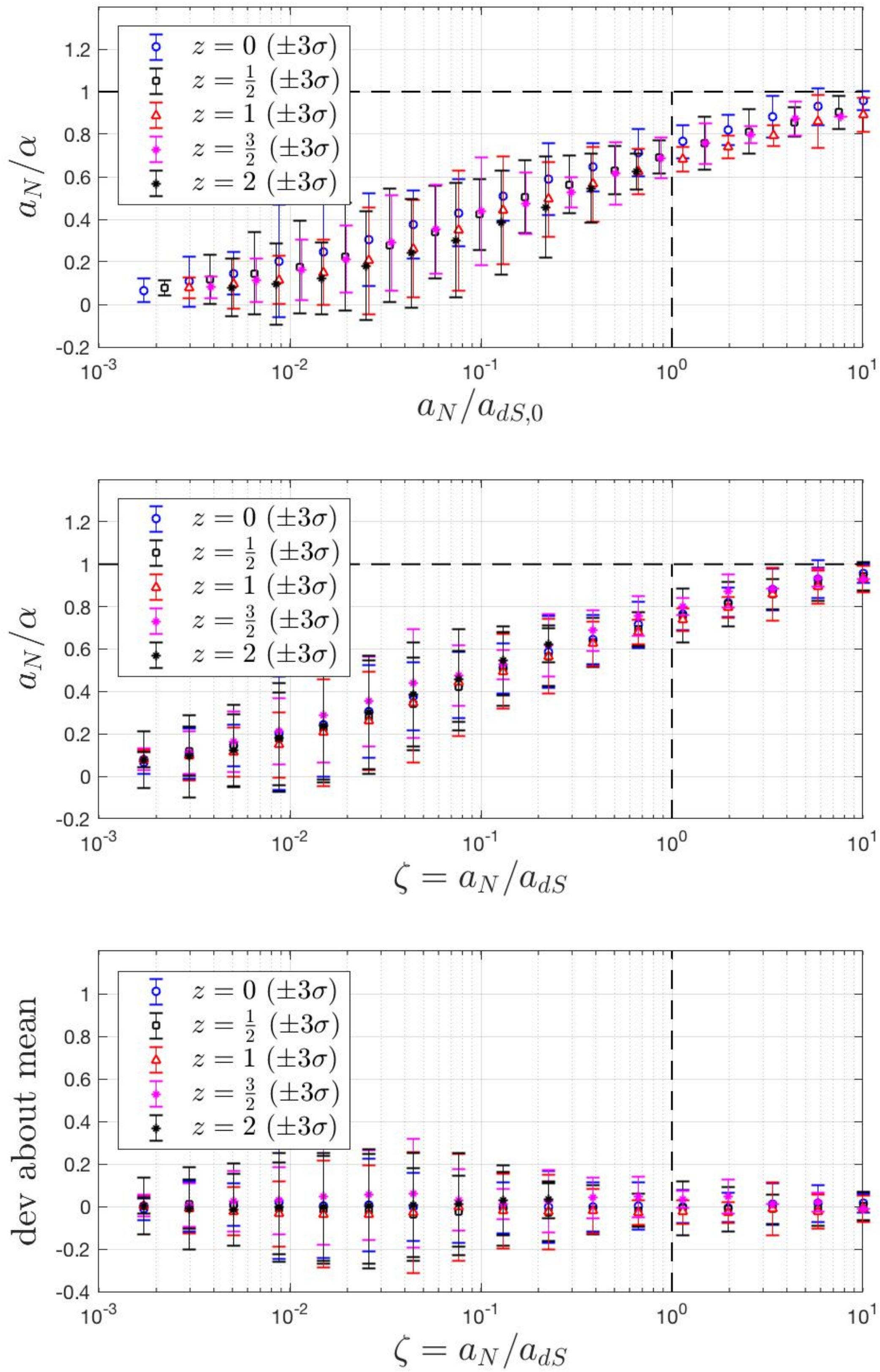
$$a_{dS} \equiv cH$$

Photometry $$\varsigma = \frac{a_N}{a_{dS}}, \quad a_{dS} \equiv cH$$

Spectroscopy Radial acceleration^{-1} $$\frac{a_N}{\alpha}$$

van Putten, 2018, MNRAS 481 L26

ΛCDM galaxy models in MUGS2



McMaster Unbiased Galaxy Simulations 2

Keller, B.W., Wadsley, J., Benincasa, S.M., & Couchmanm, H.M.P., 2014, MNRAS, 442, 3013

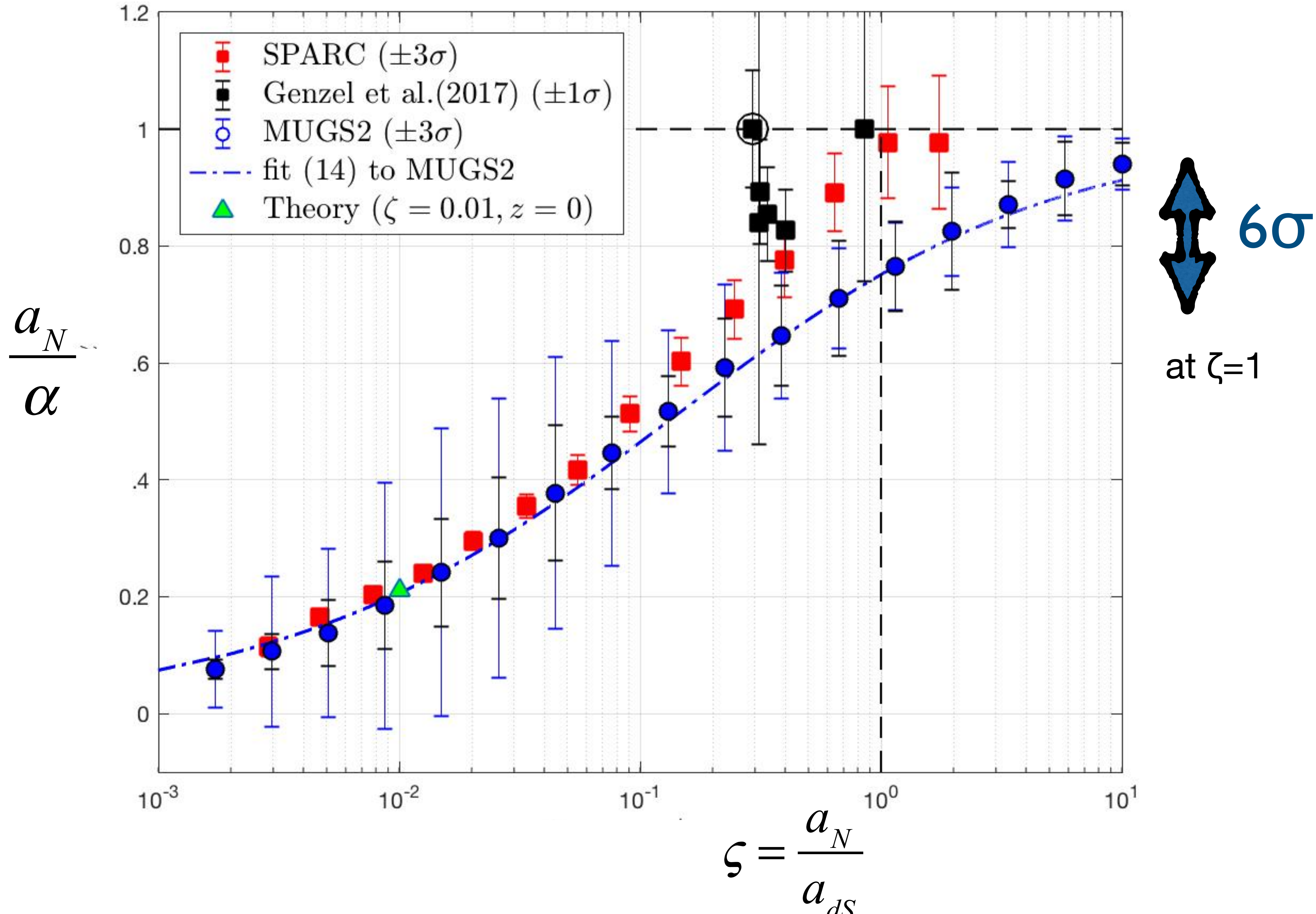
Keller, B.W., Wadsley, J., & Couchman, H.M.P., 2016, MNRAS, 463, 1431

Keller, B.W., & Wadsley, J.W., 2017, ApJ, 835, L17

Self-similar galaxy dynamics tracing background cosmology

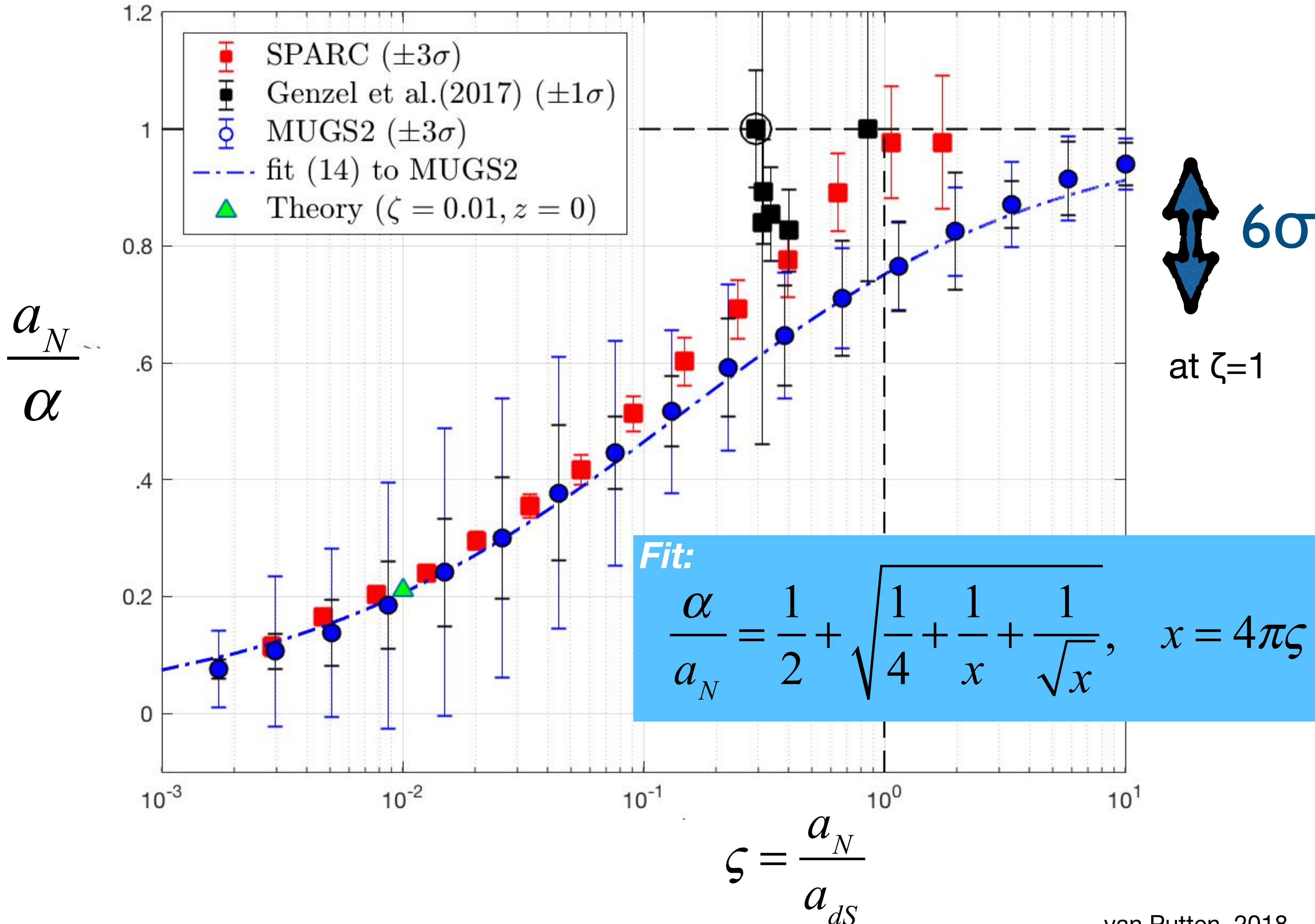
van Putten, 2018, MNRAS 481 L26

ΛCDM/MUGS2 vs MUGS2



van Putten, 2018, MNRAS, 481, L26

ΛCDM/MUGS2 vs MUGS2

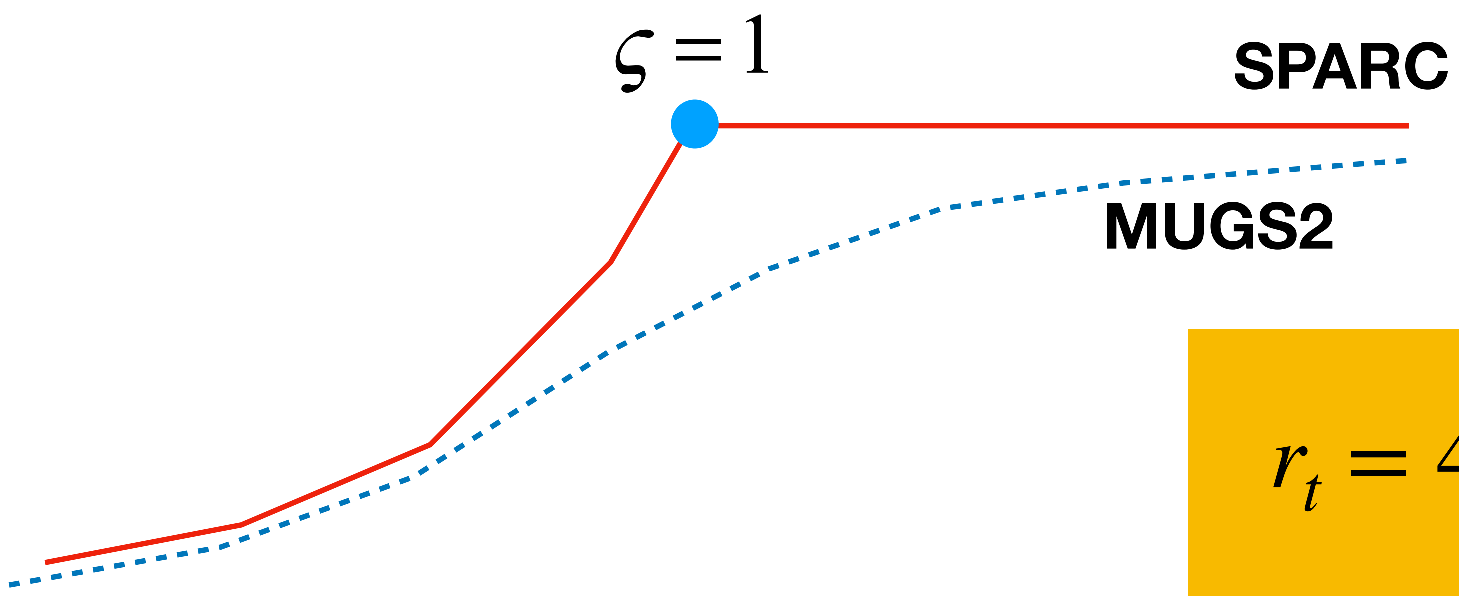


Fit:

$$\frac{\alpha}{a_N} = \frac{1}{2} + \sqrt{\frac{1}{4} + \frac{1}{x} + \frac{1}{\sqrt{x}}}, \quad x = 4\pi\varsigma$$

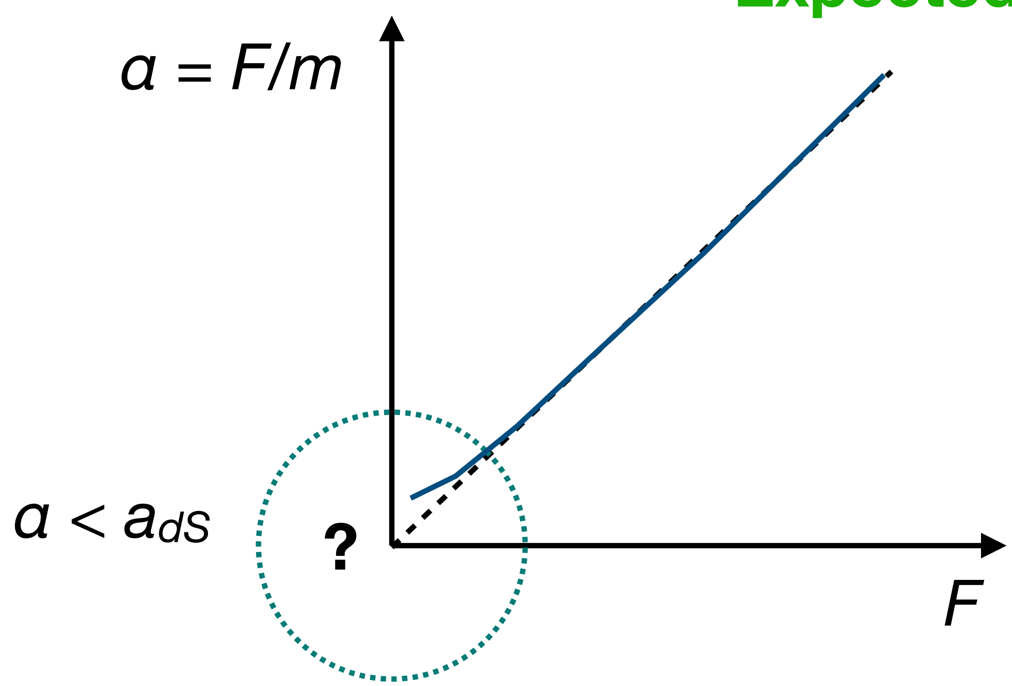
van Putten, 2018,
MNRAS, 481, L26

Approximate C^0 galaxy dynamics



$$r_t = 4.7 M_{11}^{1/2} (H_0/H)^{1/2} \mathbf{kpc}$$

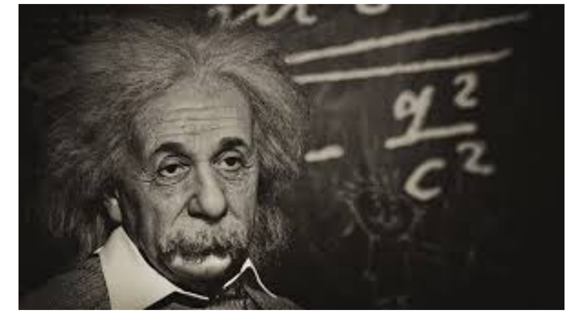
Expected (Newton's 2nd law)

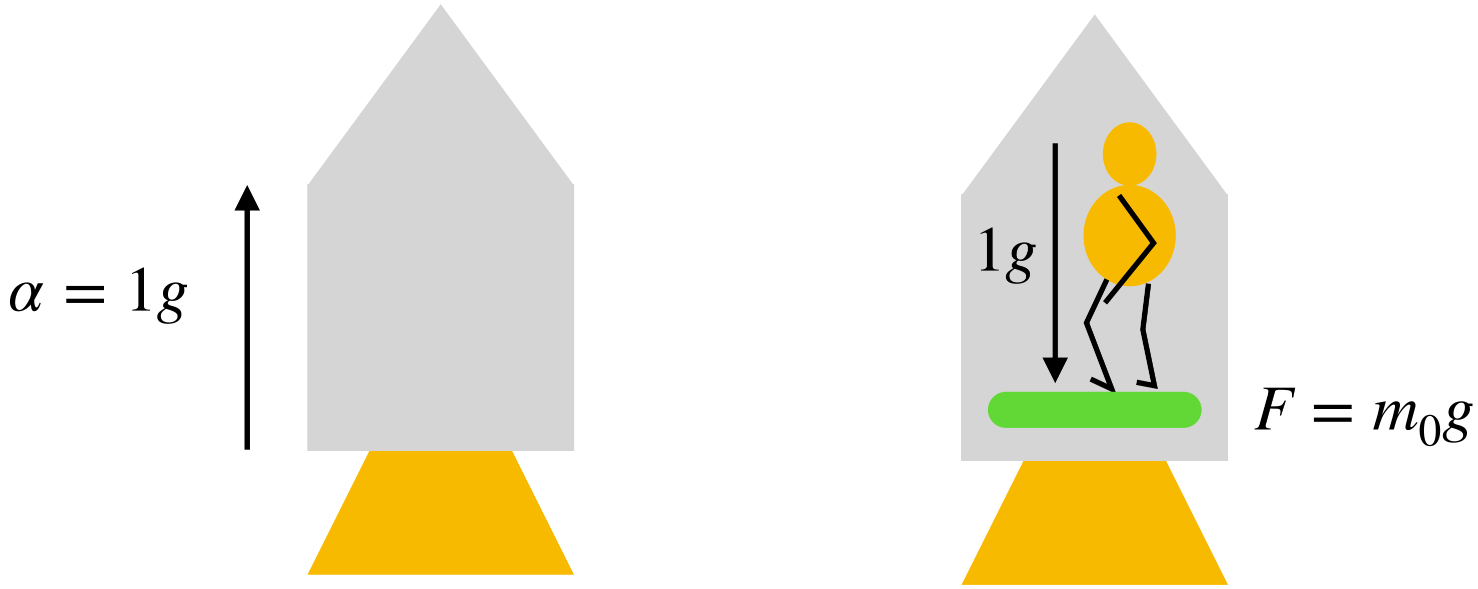


$a = F/m_0$

6σ gap: problem of inertia… ?

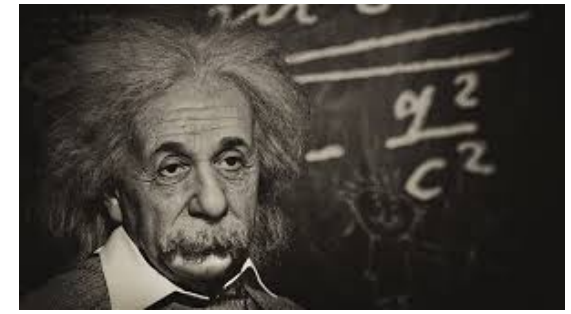
Equivalence Principle

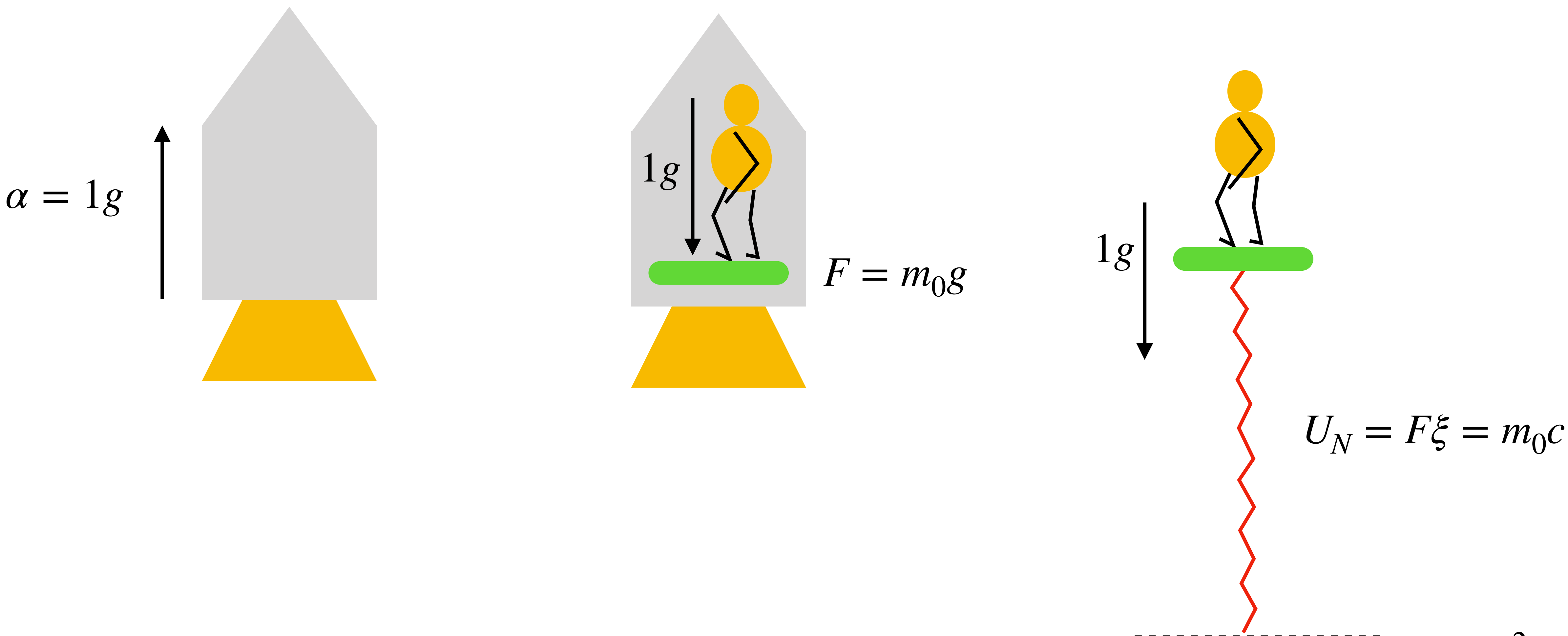




Apples fall, light is bend, … : gravitational field observed by the traveler inside

Extended Equivalence Principle





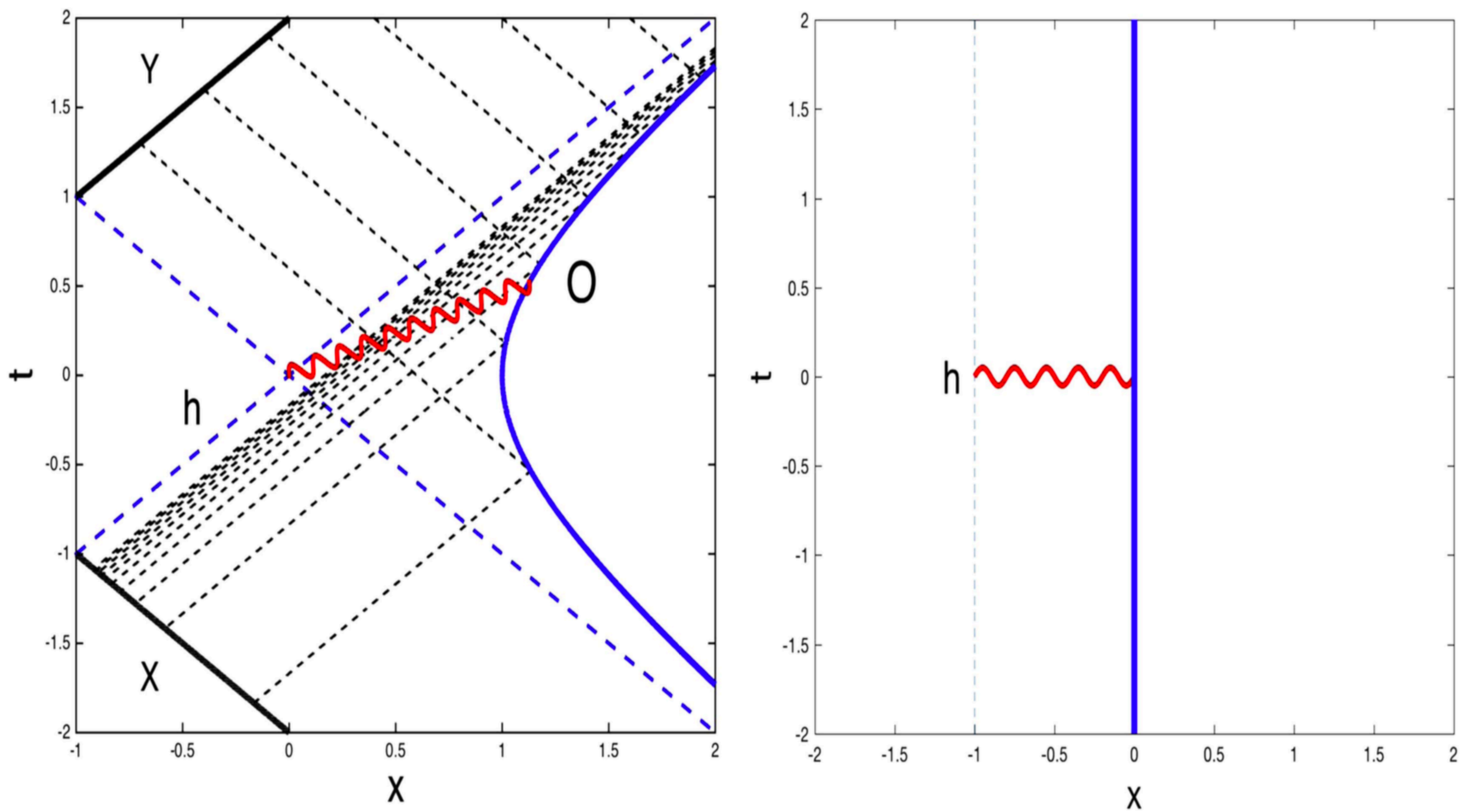
Boundary of Cauchy surface: Rindler horizon *h* at $\xi = \dfrac{c^2}{\alpha}$

Newtonian inertia = Gravitational binding energy to *h*

van Putten, 2017, ApJ, 837, 22; ApJ, 848, 28

Inertia from entanglement entropy with *h*

THE ASTROPHYSICAL JOURNAL, 837:22 (8pp), 2017 March 1 van Putten

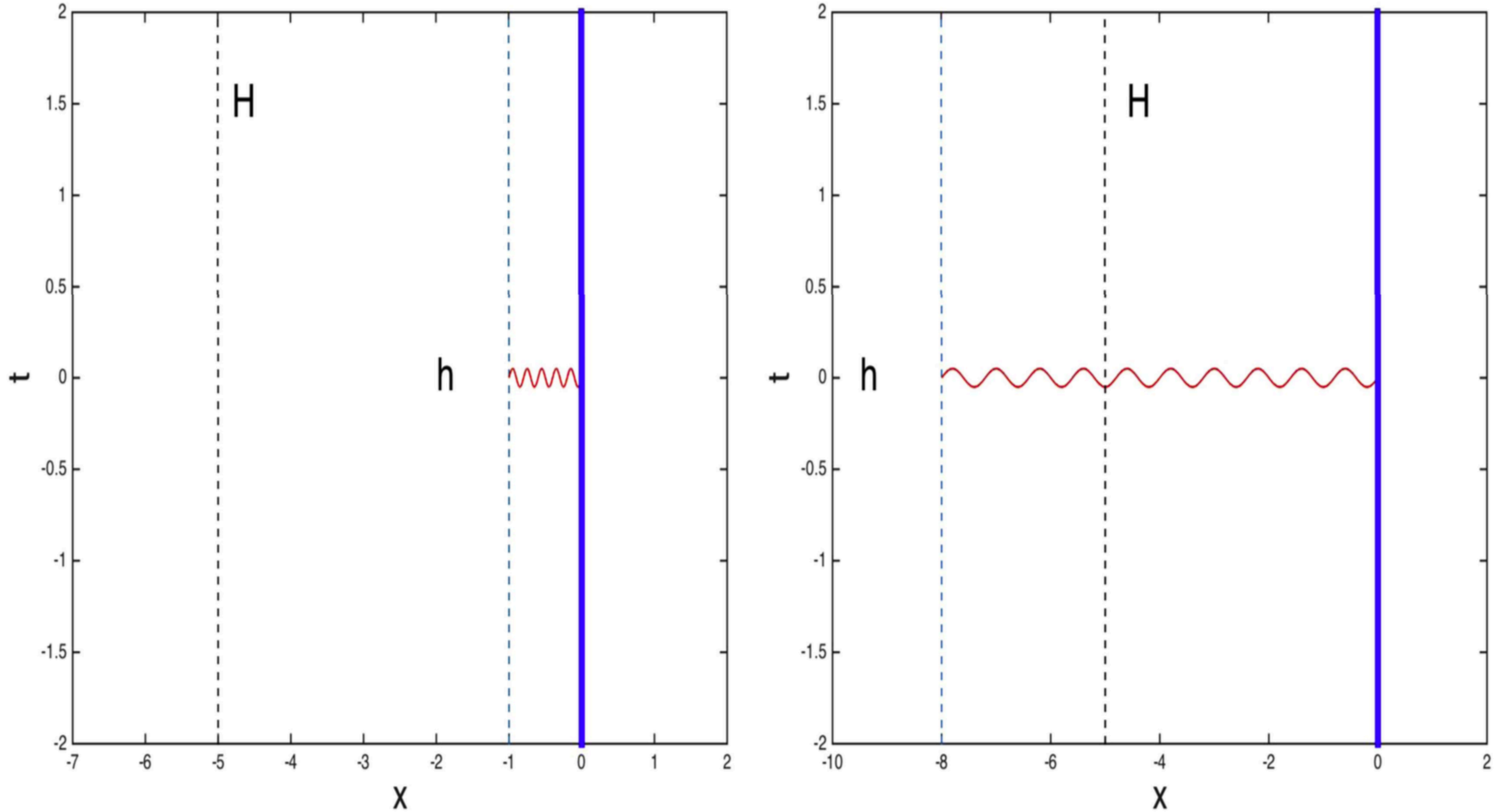


$$U_N = \int_0^{\xi} T_U dS = m_0 c^2, S = 2\pi m_0 \xi$$

van Putten, 2017, ApJ, 837, 22; ApJ, 848, 28

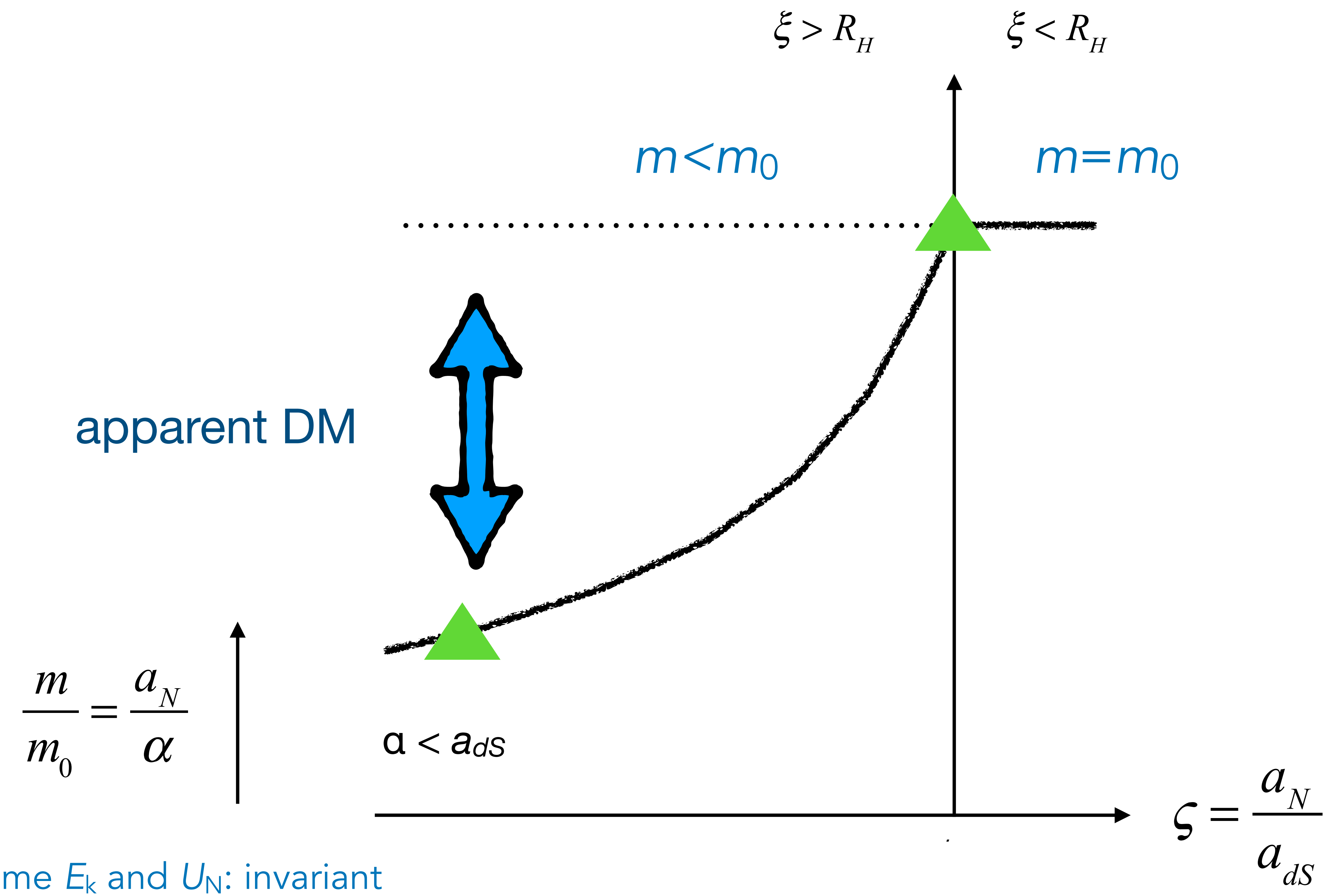
C^0 transition: entanglement to $\mathcal{H}$

$$R_H = \frac{c^2}{a_{dS}} = \frac{c}{H}$$



van Putten, 2017, ApJ, 837, 22; ApJ, 848, 28

C^0 galaxy dynamics across a_{dS}

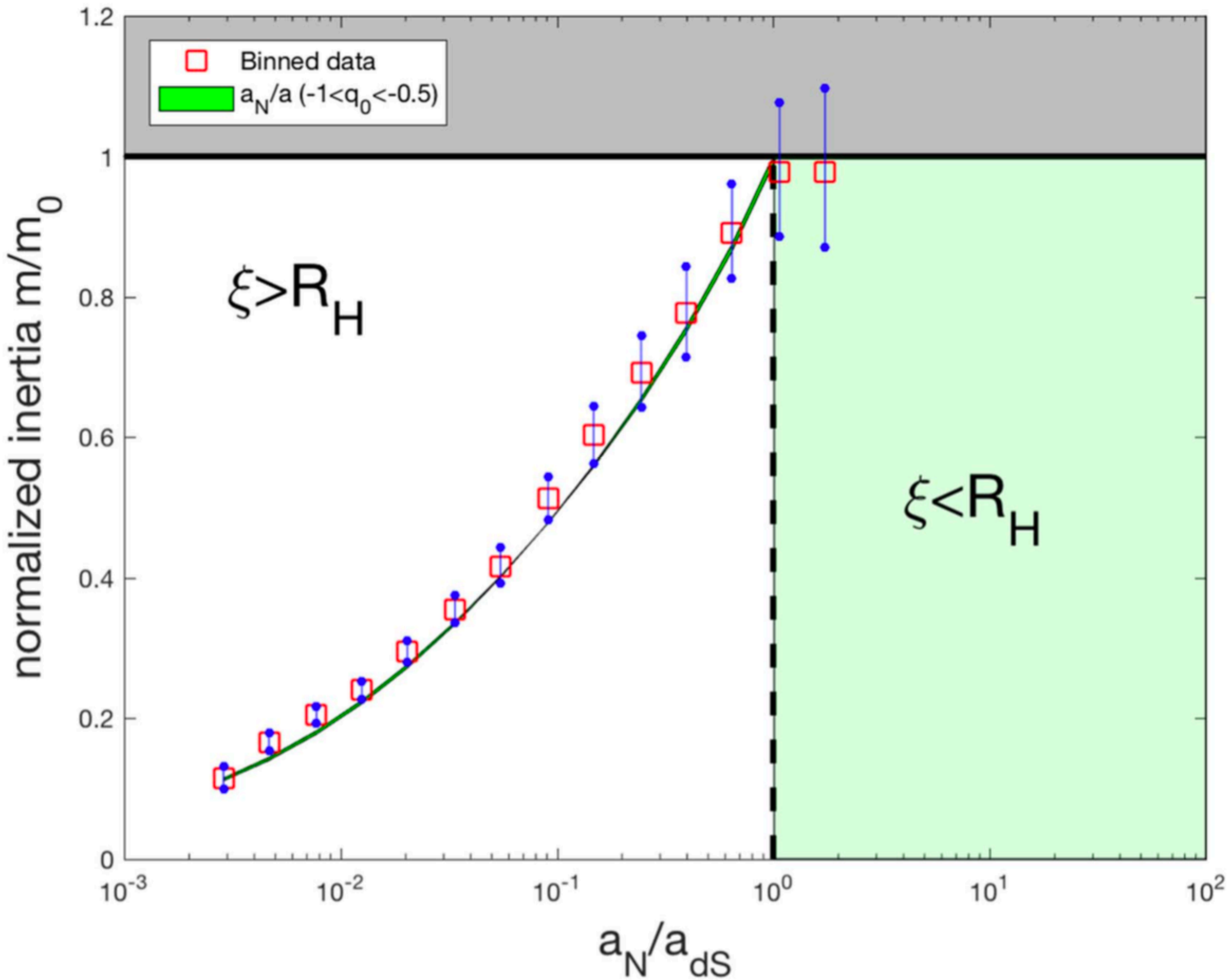


Same E_k and U_N: invariant Lagrangian and Hamiltonian

van Putten, 2017, ApJ, 848, 28

C^0 galaxy dynamics in SPARC

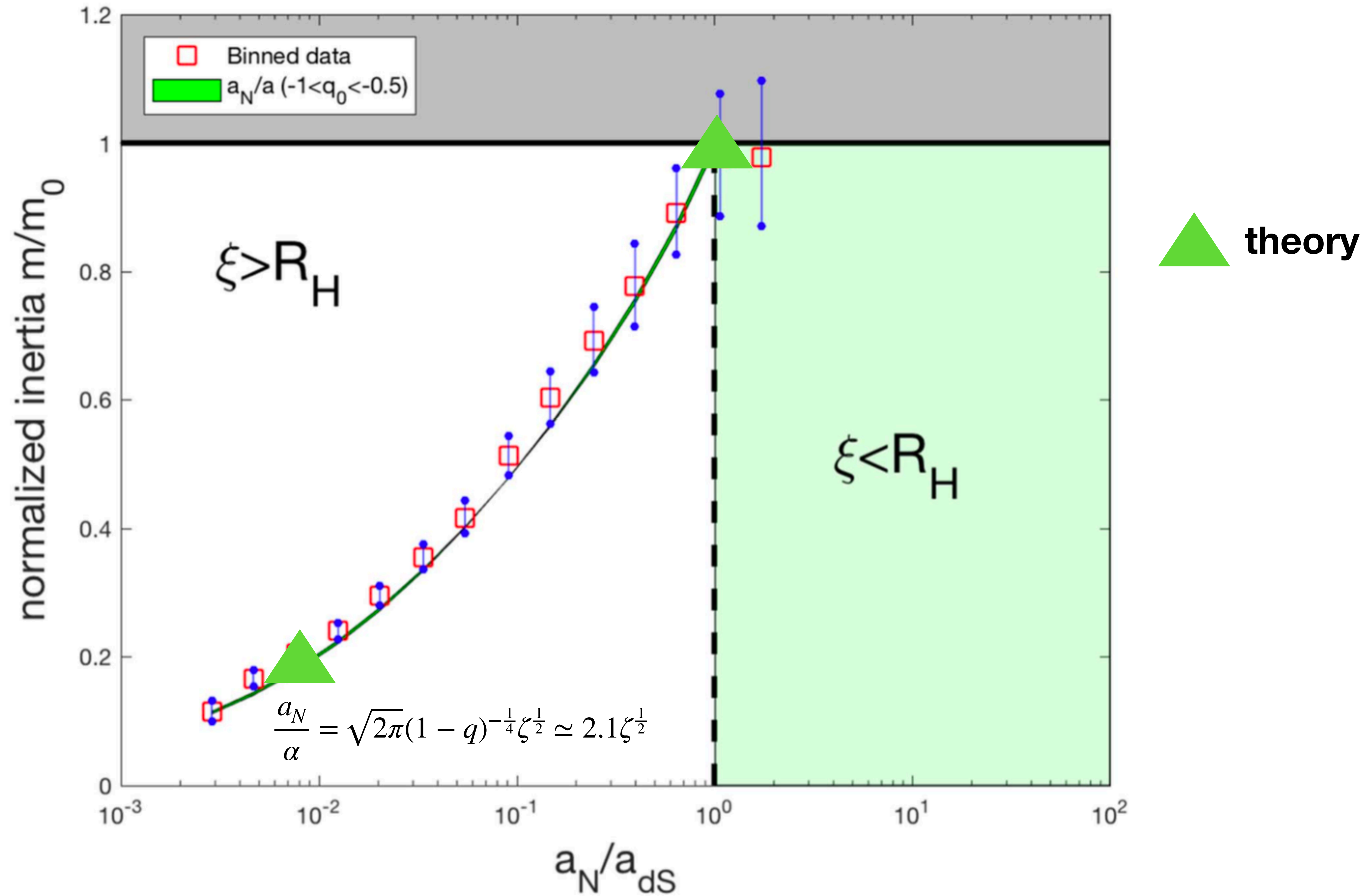
The Astrophysical Journal, 837:22 (8pp), 2017 March 1



van Putten, 2017, ApJ, 837, 22

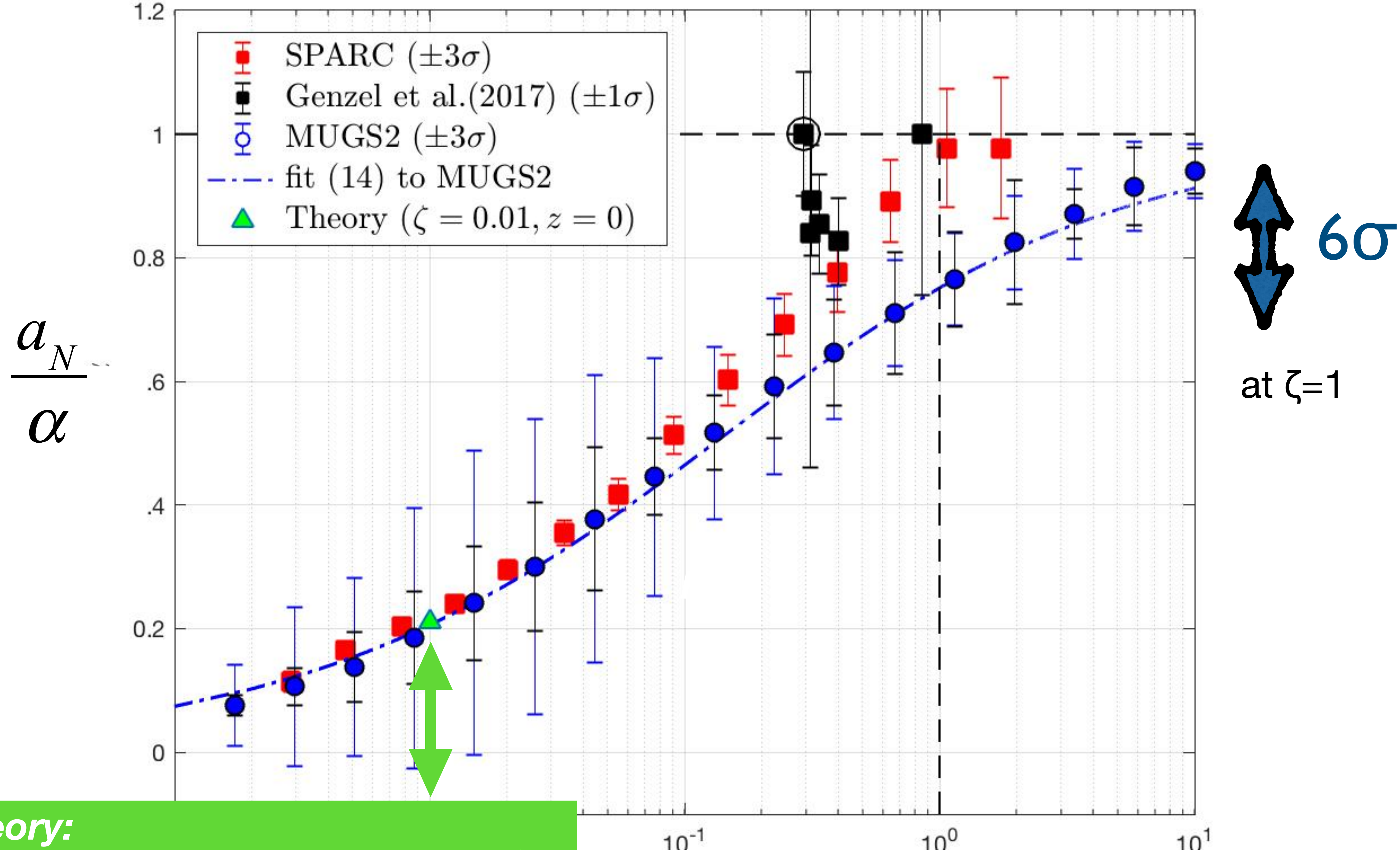
C^0 galaxy dynamics in SPARC

THE ASTROPHYSICAL JOURNAL, 837:22 (8pp), 2017 March 1



van Putten, 2017, ApJ, 837, 22

C^0 galaxy dynamics in SPARC



$$\varsigma = \frac{a_N}{a_{dS}}$$

Theory:

$$\frac{\alpha}{a_N} = \sqrt{2\pi\varsigma}\left(1-q\right)^{-\frac{1}{4}} \cong 2.1\varsigma^{\frac{1}{2}}$$

van Putten, 2018, MNRAS, 481, L26

Conclusions and observational outlook

In Bekenstein-'t Hooft 2D scaling of phase space, $\mathcal{H}$ protects vacuum against Zel'dovich UV catastrophe in Λ. **The residual is de Sitter.**

- $\mathcal{H}$ in FRW implies $\Lambda=(1-q)H^2$ with dS unstable. Future is *out of Swampland*, ΛCDM cannot hold true to all orders today, anticipating tension in H_0 - **3.8σ today**.
- For H_0~73.5 km/s/Mpc, it gives a test of "Swampland escape" by a **turning point** at

$$z_* = \left(\frac{5-6\omega_m}{9\omega_m}\right)^{\frac{1}{5}} - 1 \simeq 0.07 \quad (\omega_m = 0.28)$$

Dark "matter" is required for three-flatness but NOT for galaxies

- ~C^0 galaxy dynamics/SPARC is not accounted for by ΛCDM: **6σ failure.**
- May be due to Newton's 2nd law: inertia switching entanglement to $\mathcal{H}$ at $\alpha < a_{dS}$:

$\lambda_C >> r_t$: $m_{DM} << 10^{-27}$eV outside realm of lab experiments.