A new estimator of the deceleration parameter from galaxy rotation curves

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Outline

Modern ideas on spacetime

Horizon surfaces and Rindler inertia

The accelerating Universe

Conclusions and outlook

We are just beginning to
probe the nature of
spacetime..

Attractive gravity on galactic scales

Repulsive gravity on cosmological scales

Gravitation governs
cosmological evolution
from the Big Bang to
the present and the
distant future..

$$\frac{V_{attr}}{V_{rep}} \cong 10^{-14}$$

WHO INFLATES THE BALL? WHAT MAKES THE
UNIVERSE EXPAND OR SWELL? THAT'S [BY]
LAMBDA, THERE IS NO ALTERNATIVE

Geometrical units

$$(G = c = 1)$$

Classical: $[\Lambda] = \frac{\text{energy}}{\text{volume}} = \frac{1}{\text{cm}^2}$

Holographic: $[\sqrt{\Lambda}] = \frac{\text{energy}}{\text{area}} = \frac{1}{\text{cm}}$

(van Putten, ApJ, 2016)

$$L_0 = \frac{c^5}{G} \rightarrow L_0 = 1$$

geometrical units

$$\rho_\Lambda = \frac{\Lambda}{8\pi} = -p_\Lambda$$

$$p_\Lambda = -\frac{L_0}{A} = -\frac{1}{4\pi R_H^3}$$

$$\rho_c = \frac{3}{8\pi R_H^2}$$

...WHAT MAKES THE UNIVERSE
EXPAND OR SWELL? THAT'S THE
COSMOLOGICAL HORIZON...

$$\Omega_\Lambda = \frac{2}{3}$$

Horizons of accelerating observers

totally “black screen” when
looking back

Excising a section of Minkowski spacetime

Invariant
distance

$$\xi = \frac{c^2}{a}$$

Light cone in Minkowski spacetime is a
Rindler horizon to an accelerating observer

Newtonian regime...

a const. along ξ

Holographic origin Rindler inertia

Unitary holography

$$I = 2\pi m\xi, \quad dS = -k_B dI$$

$$k_B T = \left(\frac{\partial S}{\partial mc^2} \right)^{-1} = \frac{a\hbar}{2\pi c} = k_B T_U$$

$$F = -T \left(\frac{\partial S}{\partial \xi} \right) = ma$$

O 's inertia originates in $h=h(a)$

(van Putten 2012, PRD, 85 064046; 2015 IJMPD 24 1550024; 2016, submitted)

Collision Rindler and cosmological horizons

$$\xi = \frac{c^2}{a}$$

$\sim$

$$R_H = \frac{c}{H_0}$$

Observed is h

Observed is H

Newtonian inertia

Perturbed inertia
(reduced)

(Photo by Cameron Spencer/Getty Images)

Out of sight, out
of luck:)

$$\xi = \frac{c^2}{a}$$

a

Perturbed Rindler inertia at small accelerations

Scale of all dark matter and dark energy observations:

$$a \sim cH_0 \sim 1 \text{ } \overset{\circ}{\text{A}} \text{ s}^{-2}$$

Relevant to most of the Universe:

$$\frac{V_{attr}}{V_{rep}} \cong 10^{-14}$$

Gravitational Potentials

Gravitational Potentials

Mobius transformation $u = \frac{1}{r}$:

$$H = m \left(\frac{1}{2} j^2 u'^2 + U_N(u) \right)$$

$$U_N = \frac{1}{2} (u - u_0)^2 + U_0$$

$$U_E = U_N - R_g u^3$$

Einstein's MOND

$$H = m \left(\frac{1}{2} j^2 u'^2 + U_E(u) \right)$$

Newton's inertia

perturbed in weak gravity

SC-SC accelerations

Clusters of 10^4 galaxies

Distances of 20 Mpc

$2.4 \times 10^{-12} \text{ m s}^{-2}$

Cosmological horizon

surface gravity

$$a_{\text{dS}} = cH_0 = \text{few } \text{\AA} \text{ s}^{-2}$$

LOCAL SUPERCLUSTERS

OBSERVABLE UNIVERSE

Weak gravity: 99.9999999999999999%
of the Universe

Weak gravity

Galaxy rotation curves

Holographic transition radius: $4\pi r^2 \sqrt{\Lambda} \cong M$

$$r_t = \sqrt{R_g R_H} = 4.7 \text{ kpc } M_{11}^{1/2}$$

Galaxy rotation curves

Weak gravity in cosmology

Dark energy:

$$\Omega_{\Lambda} = 0.692 \pm 0.010$$

$$H_0 = 67.80 \pm 0.77$$

Accelerated expansion (de Sitter when $q=-1$)

$$q = \frac{1}{2}\Omega_M - \Omega_{\Lambda} < 0 \quad (\text{three-flat FRW universe})$$

(GR on classical vacuum with no hidden low energy scales)

Intrinsic curvature of cosmological event horizon

$$a_H = \frac{1}{2}(1 - q)H \quad \text{Intrinsic surface gravity}$$

$$\omega_0^2 = (1 - q)H^2 \quad \text{Eigenfrequency on } H$$

Dynamical dark in four-dimensional spacetime within

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

Weak gravity

Galaxy rotation curves

$$r_t = \sqrt{R_g R_H} = 4.7 \text{kpc} M_{11}^{1/2}$$

Dynamical dark energy

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

Modified FRW equations

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

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

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

$$Q(z) = \frac{dq(z)}{dz} = 2(1 - q) \left(H^{-1} \frac{dH}{dz} - a_0^{-1}(z) \frac{da_0(z)}{dz} \right)$$

$$Q_0 = \left(\frac{dq(z)}{dz} \right)_{z=0}$$

van Putten 2015 MNRAS 450 L48

$$Q_0[\text{DDE}] > 2.5, \quad Q_0[\Lambda\text{CMD}] < 1$$

Tully-Fisher relation

Observed:

$$\alpha = \frac{1}{2}, \quad \frac{V_c^2}{r} = \frac{M_b^{\frac{1}{2}}}{r} \quad (a_c \ll a_{dS})$$

$$M_b = AV_c^4$$

$$A = 47 \pm 6 M_\odot \text{ km}^{-4} \text{ s}^{-4}$$

$$V_c^4 = a_0 GM_b$$

$$a_0 \sim a_{dS}$$

McGaugh, S.S., 2011, *Astron. J.*,
143, 40; *PRL*, 106, 121303

Equivalent Milgrom's scale of acceleration a_0

Dimensional reduction by Milgrom's square root:

$$a = \sqrt{a_0 a_N}, a_N = \frac{GM}{r^2}$$

$$a_0 = \frac{cH}{\sqrt{2}\pi} \left(\frac{1-q}{2} \right)^{\frac{1}{2}} \cong 1.2 h_0 \left(\frac{1-q}{1.8} \right)^{\frac{1}{2}} \text{Å s}^{-2}$$

van Putten 2016 ApJ 824 43; 2016, submitted

Galaxy rotation curves

Data from S.S. McGaugh <http://astroweb.case.edu/ssm/data/MDaccRgn-LR.dat>, rescaled to $H_0 = 70 \text{ km s Mpc}$

Weak gravity

Galaxy rotation curves

$$r_t = \sqrt{R_g R_H} = 4.7 \text{ kpc } M_{11}^{1/2}$$

Dynamical dark energy

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

Deceleration parameter

$$q = 1 - \left(\frac{4\pi a_0}{cH} \right)^{\frac{1}{2}}$$

van Putten 2015 MNRAS 450 L48; van Putten 2016 ApJ 824 43; van Putten 2016 submitted

Deceleration parameter $q_0 \sim -0.85$

- theoretical curve

- - Riess et al. 2016 ApJ 826 56

Deceleration parameter q_0

Galaxy rotation curves

$$q_0 = 1 - \left(\frac{4\pi a_0}{cH} \right)^{\frac{2}{3}} \cong -0.81$$

integrate accelerations out to cosmological horizon

Modified FRW equations

$$q_0 = -\frac{1}{2} - 3 \left(\frac{\Omega_b}{2\sqrt{\pi}} \right)^{\frac{1}{2}} \bigg|_{\Omega_b=0.048} \cong -0.85$$

van Putten 2016 ApJ 824 43; 2016, submitted

Q_0 from surveys of nearby spiral galaxies

$$Q(z) = \frac{dq(z)}{dz} = 2(1-q) \left(H^{-1} \frac{dH}{dz} - a_0^{-1}(z) \frac{da_0(z)}{dz} \right)$$

Galaxy rotation curves over, e.g., $z \approx 0 - 0.2$

Dynamical DE: $Q_0 > 2.5$

Λ CDM: $Q_0 < 1$

(van Putten, 2016, ApJ, 824, 43;
2016, submitted)

Conclusions

Weak gravity governs cosmological evolution and most of galaxy dynamics. In galaxies, $1/r$ law due to perturbed inertia by collusion of Rindler and cosmological horizons (inertia $U=mc^2$ falls below m_0c^2).

Current data: $q_0 \cong -0.83 \pm 0.02$

DM & DE of holographic origin

DM is extremely light, clustering down to galaxy clusters but not much smaller. Its mass scale at the de Sitter temperature $k_B T \sim 10^{-34}$ eV precludes direct detection. Instead, it can be probed in free fall Cavendish type experiments in space.

DE is dynamic. Can be identified in $Q_0 > 2.5$ in surveys of nearby spiral galaxies.