Basic concepts of modern standard cosmology: The three cosmic scalars!

- The universe is a spacelike homgeneity
- Cosmic matter density varies inversely proportional to the spacelike volume!
- The universe is characterized by a globally isotropic curvature; i.e. K= 0; or = (+/-)1 !
- The cosmic vacuum energy density is constant!
- Then ---------->>>>

Present-day standard cosmology with **K=Lambda=const!**

Kosmologische Konstante

Die Einstein-Gleichung kann formal einen weiteren Term enthalten:

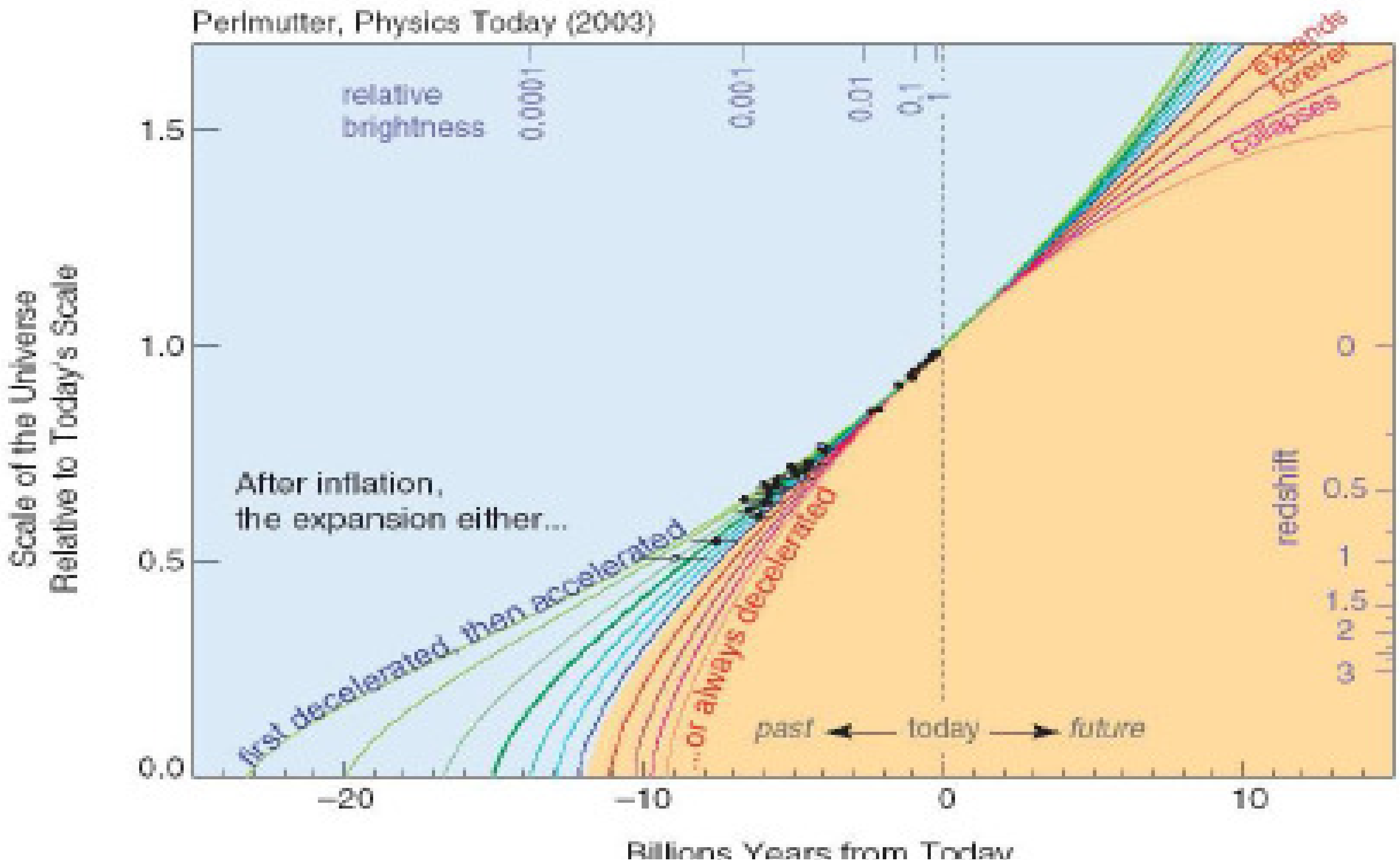
$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G_N}{c^4} T_{\mu\nu}$$

wobei die *kosmologische Konstante* Λ zeitlich konstant sein muss, damit die BIANCI-Identitäten erfüllt sind. Damit sehen dann die Gleichungen für $\dot{R}$ und $\ddot{R}$ folgendermaßen aus:

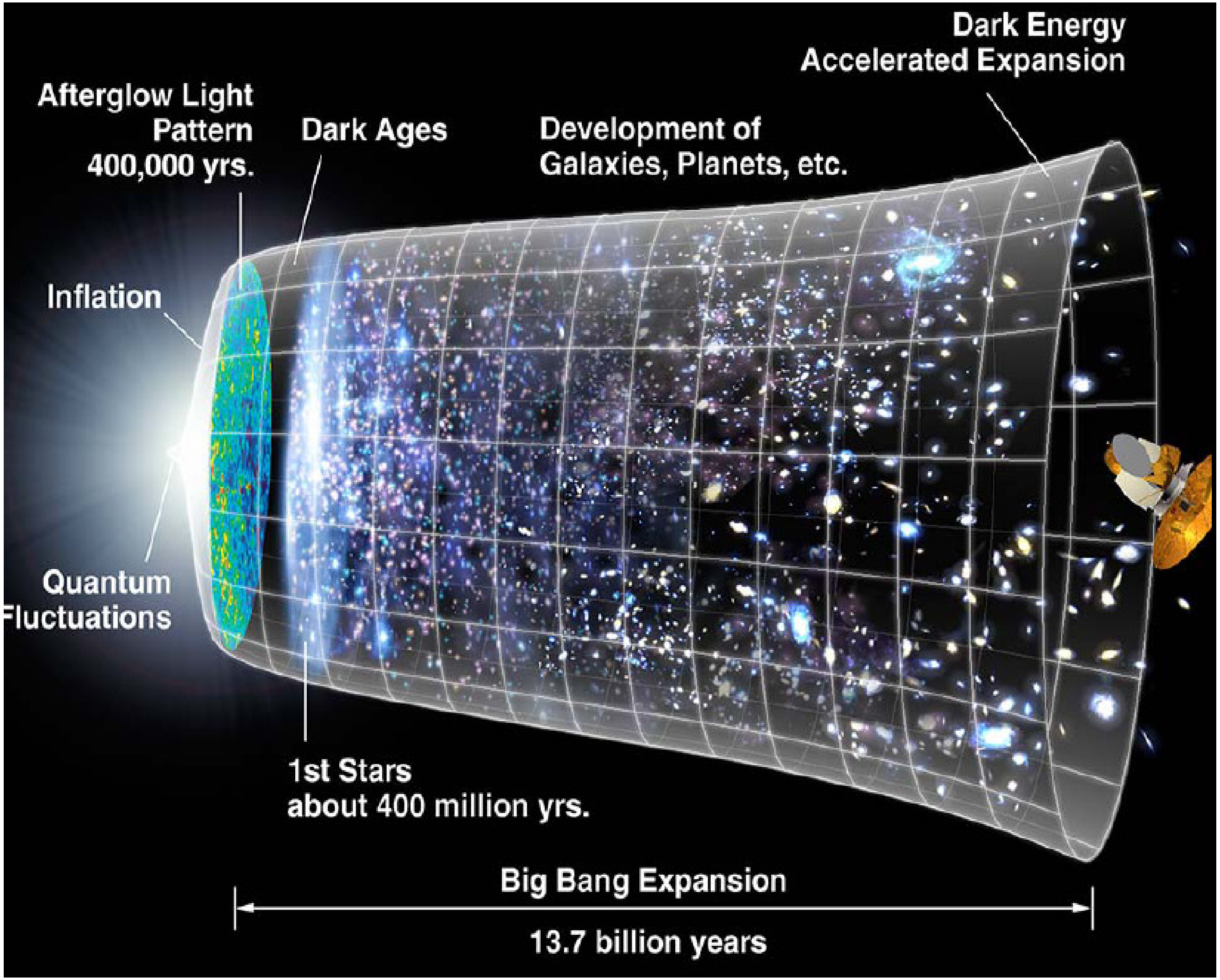
$$\left(\frac{\dot{R}(t)}{R(t)}\right)^2 = \frac{8\pi G_N}{3}\rho(t) - \frac{Kc^2}{R^2(t)} + \frac{\Lambda c^2}{3} \qquad (38)$$

$$\frac{\ddot{R}(t)}{R(t)} = -\frac{4\pi G_N}{3c^2}\left(3p(t) + \rho(t)c^2\right) + \frac{\Lambda c^2}{3} \qquad (39)$$

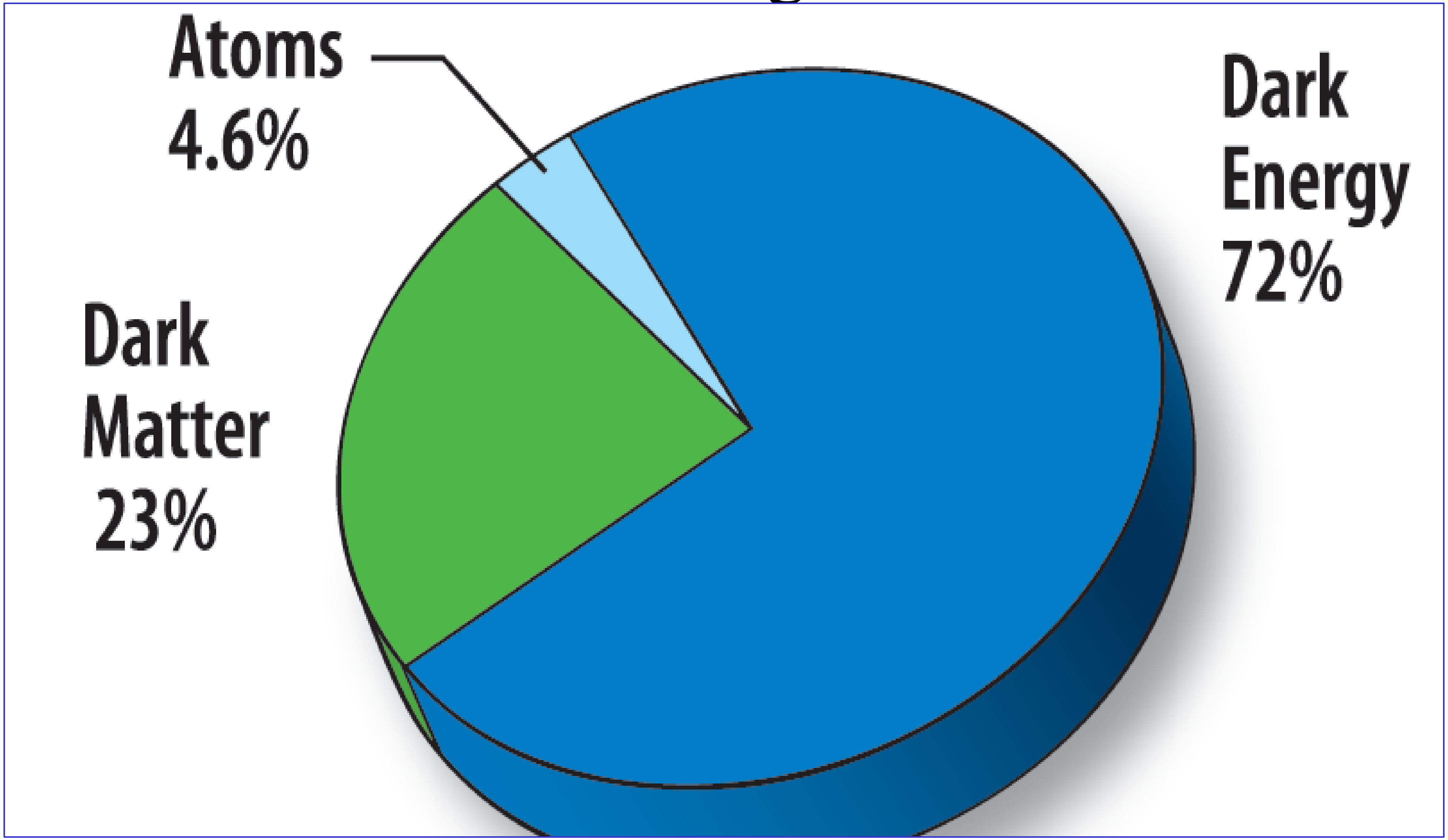
Alternative forms of cosmic expansion:



The Big-bang Universe with K=0!:



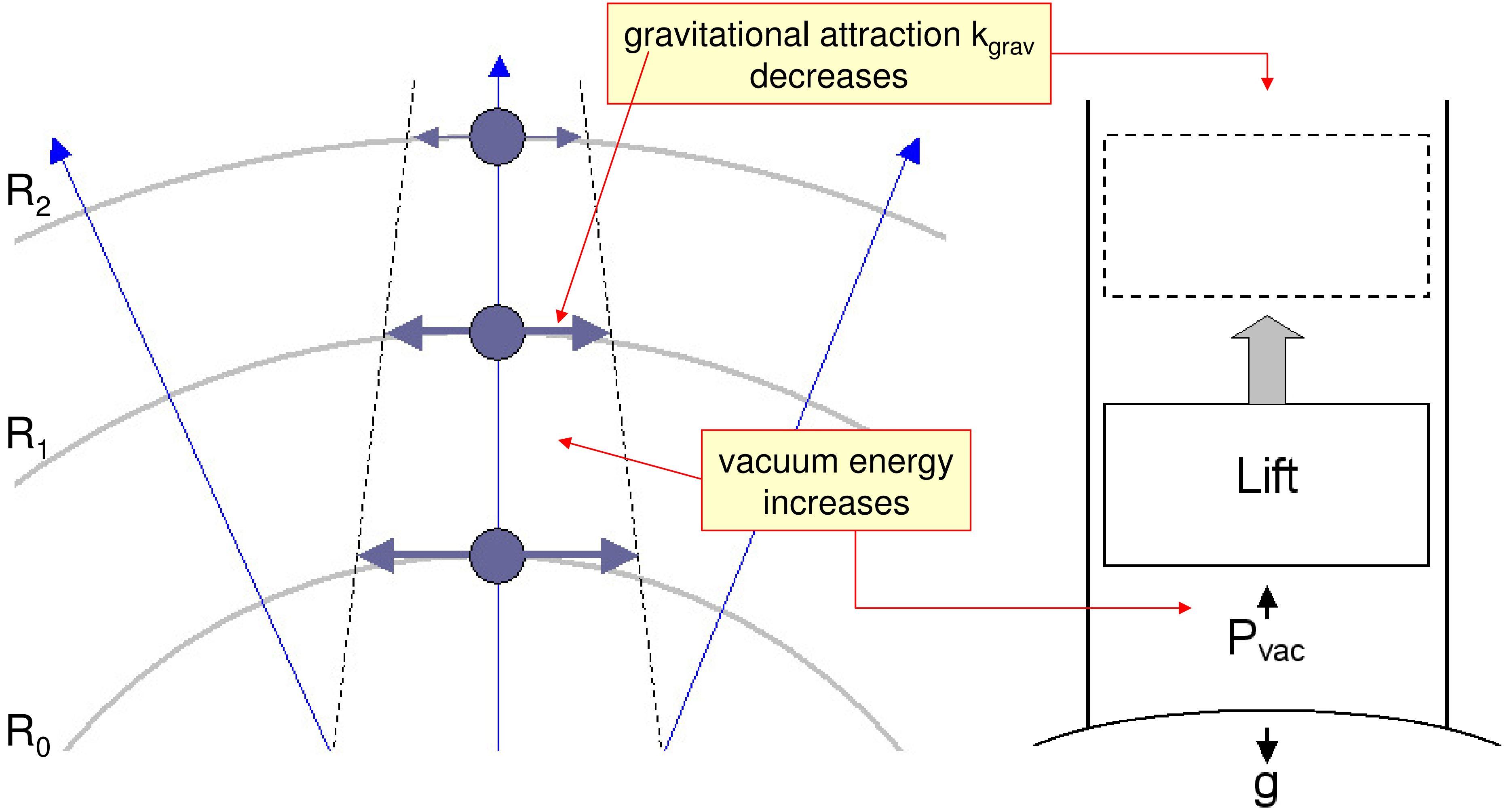
What constitutes the world in terms of Omega`s:



The problem with a constant vacuum energy density:

$$(\Lambda = const.)$$

$$k_{grav} = -\frac{8\pi G \rho_0 R_0}{3}\left(\frac{R_0}{R}\right)^2$$ = intermaterial gravitational force between co-moving masses



The anthropic Lambda-miracle:

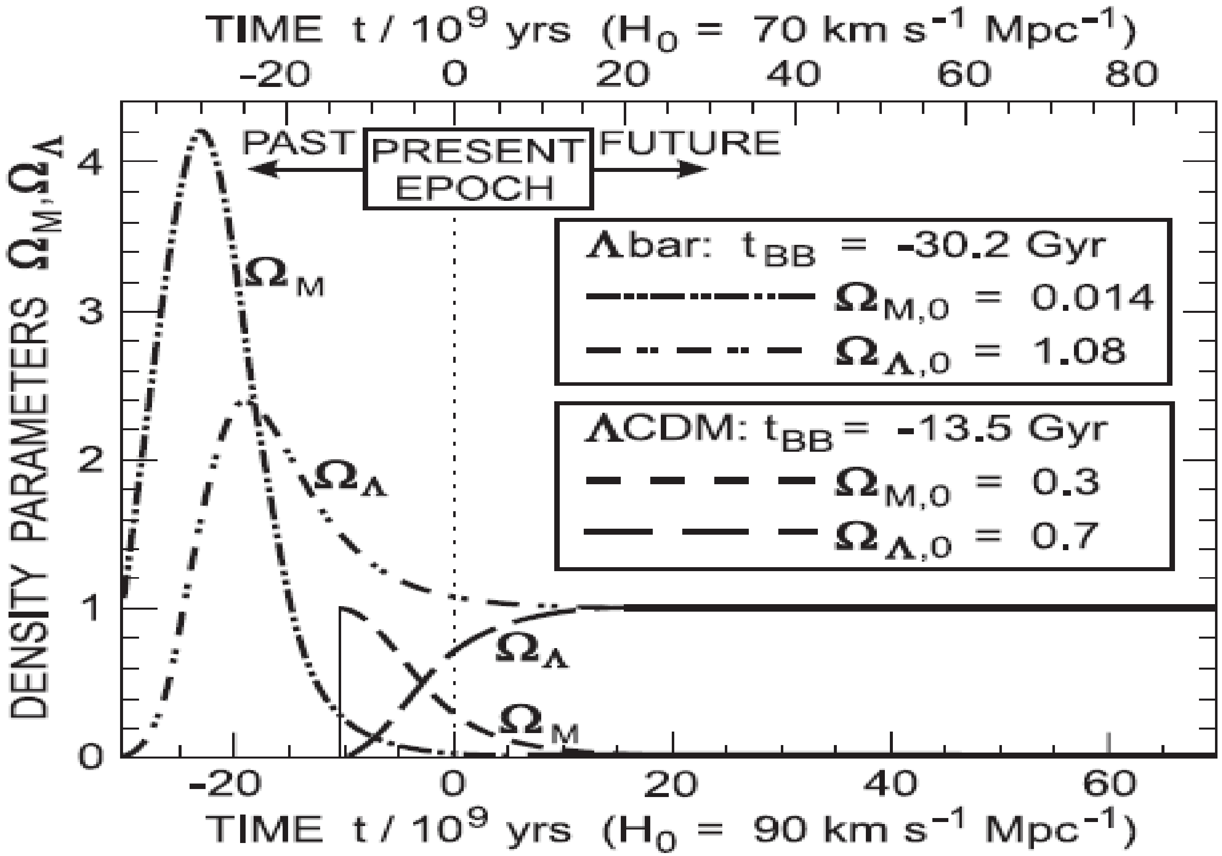


Fig. 7. Evolution of Ω_M and Ω_Λ in the Λbar and ΛCDM models (Models 1 and 6 in Figs. 2 and 3). Time is set to zero at the present epoch; t_{BB}, the time of the big bang, is calculated using $h_0 = 0.9$ for Λbar (bottom scale) and $h_0 = 0.7$ for ΛCDM (top scale). Compare Fig. 3.

Do we have the physical concepts right in FLRW-cosmologies?

- Is the mass of the universe conserved?
- What is the effective cosmic density?
- How is gravitational binding energy entering the ART field equations?
- Is isotropic cosmic curvature reasonable?
- How all of this is reflected in changes of the vacuum energy density?

What is the absolute reference system for centrifugal forces?

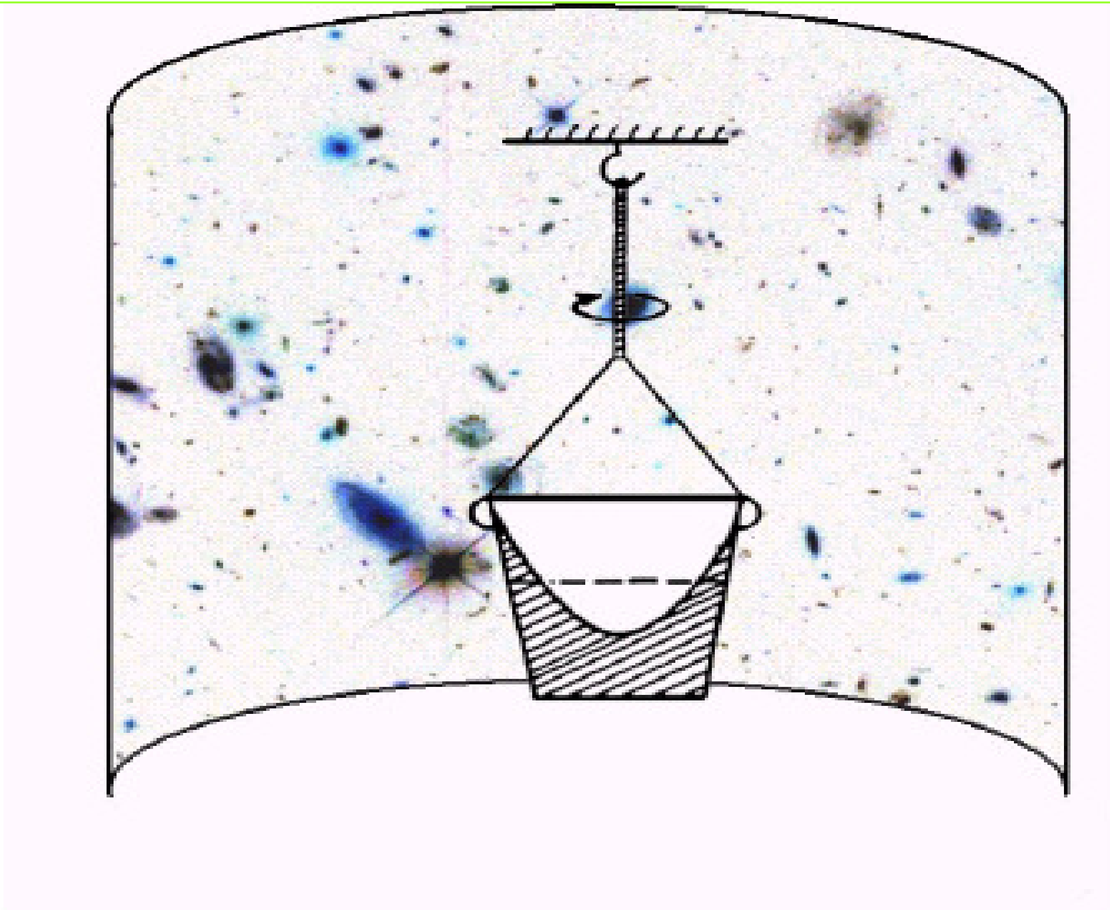


Fig. 1: Newton's Bucket in a rotating universe

The total universe as the cosmic reference system!

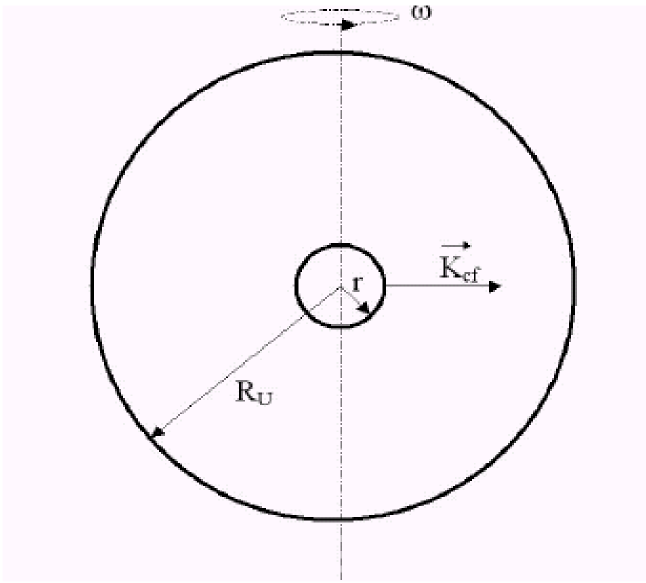


Fig 2.: Illustration of the earth at rest in a rotating universe

$$\vec{K}_{cf,a} = \psi \cdot \vec{K}_{cf,b}$$

ψ can be calculated as:

$$\psi = \frac{2GM_U}{c^2 R_U} = \frac{R_{S,U}}{R_U}$$

The instantaneous mass of the universe ?

$$M_{\mathrm{u}}(t)c^2 = 4\pi\rho_0(t)c^2 \int_0^{R_{\mathrm{u}}} \frac{\exp(\lambda(r)/2)r^2\mathrm{d}r}{\sqrt{1-(\frac{Hr}{c})^2}}$$

$$\exp[-\lambda(r)] = 1 - \frac{8\pi G}{rc^2}\rho_0 \int_0^r \gamma(x)x^2\mathrm{d}x$$

$$R_{\mathrm{u}} = \frac{1}{\pi}\sqrt{\frac{c^2}{2G\rho_0}}$$

$$\rho_0(R_{\mathrm{u}}) = \frac{c^2}{2\pi^2 G R_{\mathrm{u}}^2}$$

Hoyle`s creation theory

$$C_{\mu\nu} = \frac{\partial C_\mu}{\partial x^\nu} - \Gamma^\alpha_{\mu\nu} C_\alpha$$

$$C_{\mu\nu} = -3R\dot{R}\frac{\delta_{\mu\nu}}{cA}$$

$$G_{\mu\nu} - \frac{1}{2} g_{\mu\nu} G + C_{\mu\nu} = \frac{8\pi\gamma}{c^4} T_{\mu\nu}$$

$$R = \exp[ct/A]$$

$$\dot{\rho}_{\mathrm{H}} = \frac{c}{A}\rho_{\mathrm{H}} = \frac{3c^5}{8\pi\gamma A^3} = \frac{c^5 \Lambda_{\mathrm{H}}^{3/2}}{8\pi\gamma\sqrt{3}}$$

Vacuum energy and mass creation as analogous actions?

$$\Lambda^{3/2} = \frac{8\pi G\sqrt{3}}{c^5}\dot{\rho}$$

$$M_u = M_{u0}\exp[\frac{c(t-t_0)}{A}] = (\frac{M_{u0}}{R_0})R(t)$$

A curved universe with metrical reactions to potential energy density (E.Fischer,1993):

$$T^{p}_{\mu\nu} = -C\frac{\rho_c}{\Gamma}g_{\mu\nu}$$

$$\frac{c^2 k}{S^2} + \frac{\dot{S}^2}{S^2} + 2\frac{\ddot{S}}{S} = \frac{\kappa C \rho_c}{S}$$

$$-3(\frac{c^2 k}{S^2} + \frac{\dot{S}^2}{S^2}) = -\kappa\rho_c - \frac{\kappa C \rho_c}{S}$$

$$\frac{\ddot{S}}{S} = \frac{\kappa\rho_c}{6}(\frac{S_0}{S} - 1)$$

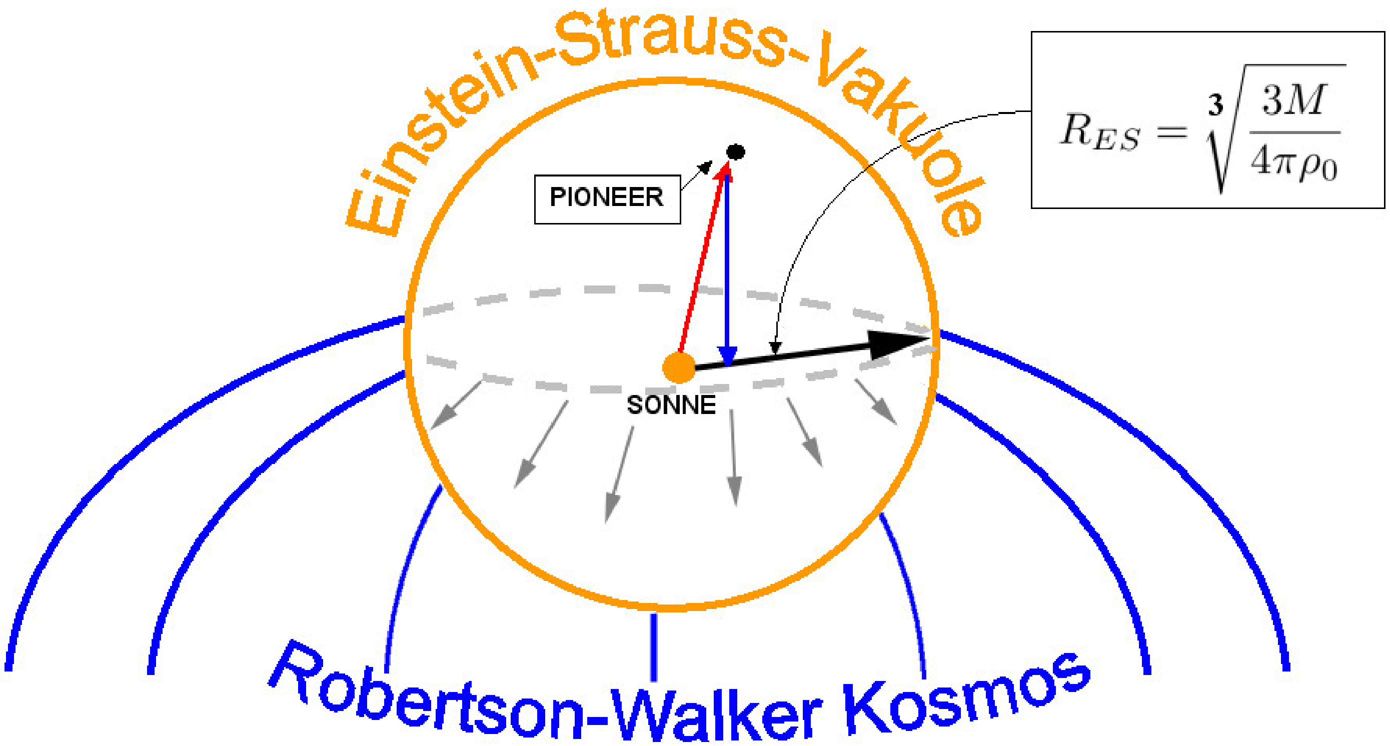
Curvature energy and mass creation:

$$\hat{T}_{00} = T_{00} + T^{p}_{00} = (\rho - C\frac{\rho}{\Gamma})g_{00}$$

$$\dot{\rho}^{*} = \frac{d}{dt}[\rho(1 - C\frac{1}{\Gamma})]$$

$$\dot{\rho}^{*} = \rho C \frac{1}{\Gamma^{2}}\dot{\Gamma}$$

Local masses in the global Universe?



What is the effective cosmic mass density?

$$\rho^* = \frac{M}{V_{\mathrm{ES}}^3} = \frac{\frac{4\pi}{3}\rho_{\mathrm{o}} R_{\mathrm{ES}}^3}{V_{\mathrm{ES}}^3}$$

$$\rho^* = \frac{\frac{4\pi}{3}\rho_{\mathrm{o}} R_{\mathrm{ES}}^3}{4\pi\left(\frac{3c^2}{8\pi G\rho_0}\right)^{3/2}\left[\frac{1}{2}\arcsin\xi_{\mathrm{ES}} - \frac{\xi_{\mathrm{ES}}}{2}\sqrt{1-\xi_{\mathrm{ES}}{}^2}\right]}$$

$$\rho^* = \rho_0 \frac{1}{1+\frac{3}{10}\ \xi_{\mathrm{ES}}^2} \simeq \rho_0 \cdot \left(1 - \frac{3}{10}\Psi^2 \rho_0^{1/3}\right)$$

The effective cosmic mass density (high density limit):

$$\rho^* = \frac{M}{V_{\mathrm{ES}}^3} = \frac{\frac{4\pi}{3}\rho_0 R_{\mathrm{ES}}^3}{V_{\mathrm{ES}}^3}$$

$$\xi_{\mathrm{ES}} = \sqrt{\frac{8\pi G\rho_0}{3c^2}} R_{\mathrm{ES}} = \frac{\dot{S}}{cS} R_{\mathrm{ES}} = \frac{S_{\mathrm{u}} H}{c} \frac{R_{\mathrm{ES}}}{S_{\mathrm{u}}} = \frac{R_{\mathrm{ES}}}{S_{\mathrm{u}}} \ll 1$$

$$\rho^* = \rho_0 \frac{\xi_{\mathrm{ES}}^3}{\frac{3}{2}\left[\arcsin \xi_{\mathrm{ES}} - \xi_{\mathrm{ES}} \sqrt{1 - {\xi_{\mathrm{ES}}}^2}\right]}$$

The local spacetime and the expansion of the Einstein-Straus vacuole

$$r_{ES} = \left(\frac{3M}{4\pi\rho_0} \right)^{1/3}$$

$$\frac{\dot{r}_{ES}}{r_{ES}} = \frac{\dot{R}_0}{R_0} = H_0$$

The local world embedded in a vacuum-energy-loaded universe

$$c^2 \dot{M}(t) = -(4\pi R_{\mathrm{ES}}^2 \dot{R}_{\mathrm{ES}}) p_{\mathrm{vac}}$$

$$p_{\mathrm{vac}} = -\frac{3-n}{3} \rho_{\mathrm{vac}} c^2$$

$$c^2 \dot{M}(t) = 3M \frac{\dot{R}_{\mathrm{ES}}}{R_{\mathrm{ES}}} \frac{3-n}{3} \frac{\rho_{\mathrm{vac}}}{\rho_{\mathrm{mat}}} c^2$$

$$\frac{\dot{M}(t)}{M} = 3 \frac{\dot{R}_{\mathrm{ES}}}{R_{\mathrm{ES}}} \frac{1}{3} \frac{\rho_{\mathrm{vac}}}{\rho_{\mathrm{mat}}}$$

Towards more realistic universes: The 2-phase structured universe

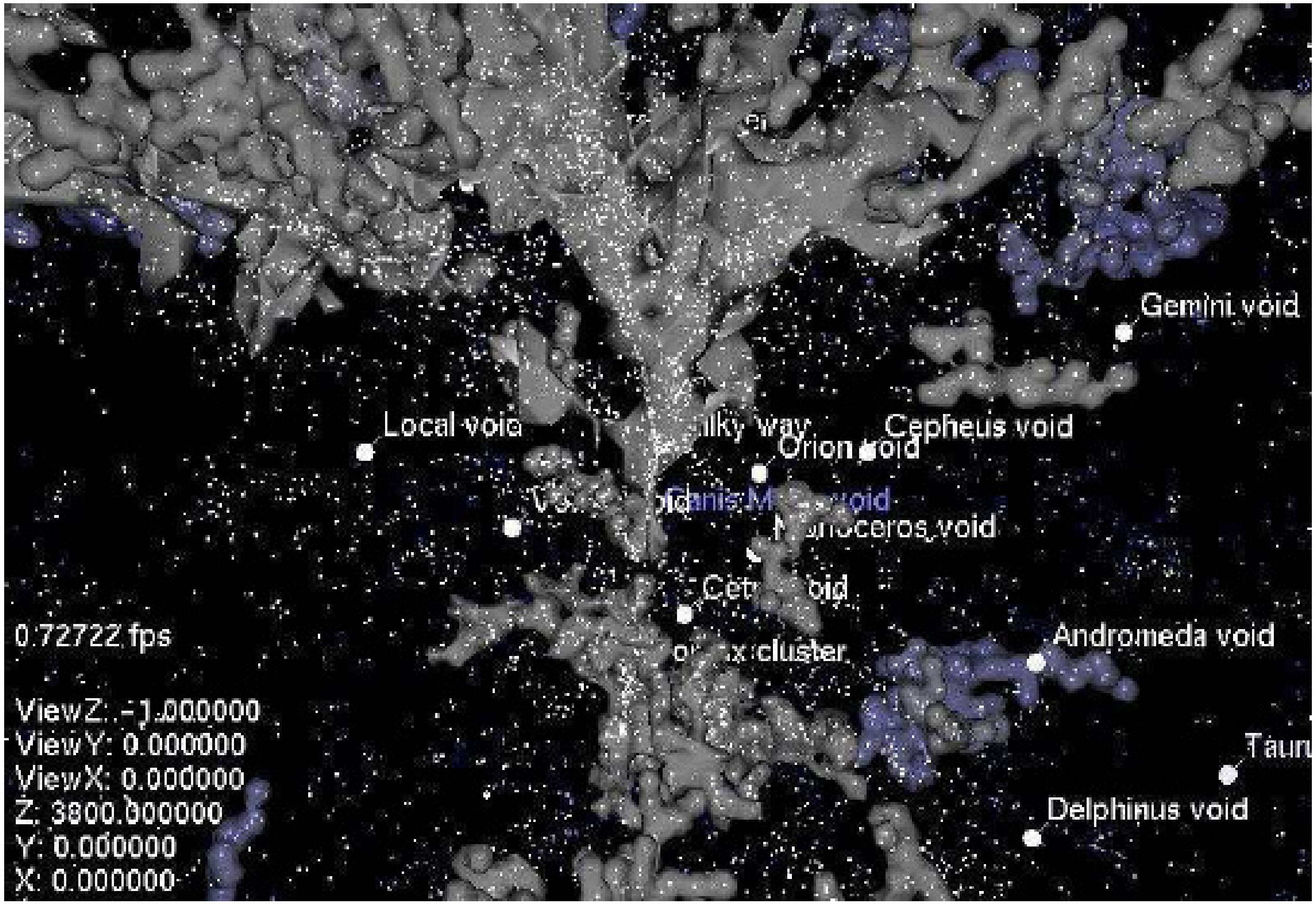
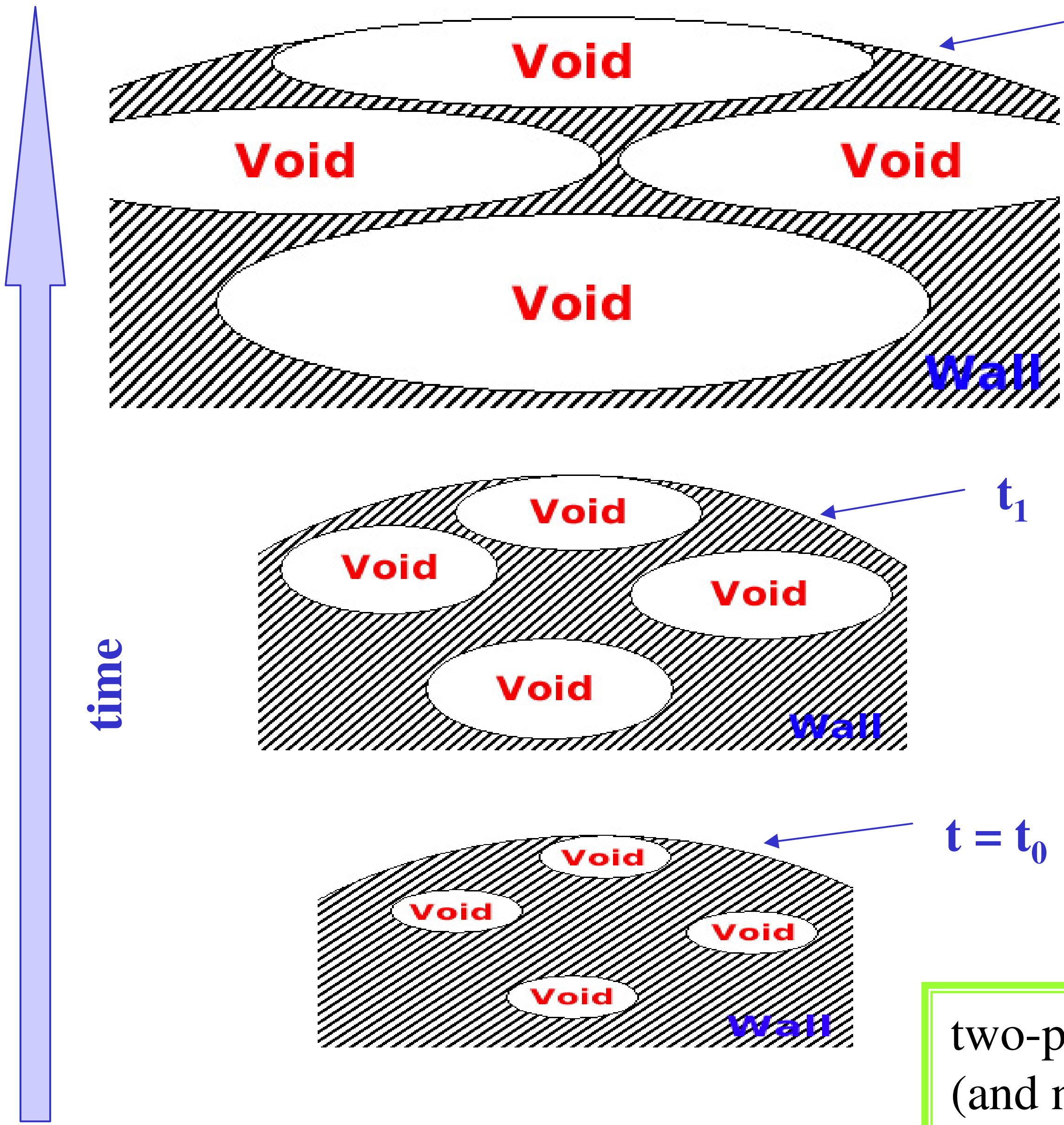


Fig. 1. Local voids and bubbles from the 6df survey. Courtesy of A. Fairall

Voids and Walls: !Non-homologous structure expansions!



t_2

$f_v = 0.8$

$f_w = 0.2$

t_1

$f_v = 0.6$

$f_w = 0.4$

$t = t_0$

$f_v = 0.5$

$f_w = (1 - f_v) = 0.5$

two-phase universe: Voids and Walls.
(and nothing else!)

General-Relativistic spacetime averages and GRT FRW equations

$$\langle \mathcal{R} \rangle \equiv \left(\int_{\mathcal{D}} \mathrm{d}^3 x \sqrt{\det {}^3 g} \mathcal{R}(t, \mathbf{x}) \right) / \mathcal{V}(t)$$

with $\mathcal{V}(t) \equiv \int_{\mathcal{D}} \mathrm{d}^3 x \sqrt{\det {}^3 g}$. The important lesson of Buchert averaging is that time evolution and averaging to do not commute.[5] Generally for any scalar Ψ,

$$\frac{\mathrm{d}}{\mathrm{d}t} \langle \Psi \rangle - \langle \frac{\mathrm{d}\Psi}{\mathrm{d}t} \rangle = \langle \Psi \vartheta \rangle - \langle \vartheta \rangle \langle \Psi \rangle \tag{1}$$

The fact that the r.h.s. of (1) does not vanish, as is the case for the FLRW cosmologies, is a manifestation of *backreaction*.

Applied to the equations of cosmic evolution one obtains the exact *Buchert equations*

$$3\frac{\dot{\bar{a}}^2}{\bar{a}^2} = 8\pi G \langle \rho \rangle - \tfrac{1}{2} \langle \mathcal{R} \rangle - \tfrac{1}{2} \mathcal{Q}, \tag{2}$$

$$3\frac{\ddot{\bar{a}}}{\bar{a}} = -4\pi G \langle \rho \rangle + \mathcal{Q}, \tag{3}$$

$$\partial_t \langle \rho \rangle + 3\frac{\dot{\bar{a}}}{\bar{a}} \langle \rho \rangle = 0, \tag{4}$$

The back-reaction of curvature averages

$$\mathcal{Q} \equiv \frac{2}{3}\left(\langle\vartheta^2\rangle - \langle\vartheta\rangle^2\right) - 2\langle\sigma\rangle^2$$

$$\bar{\Omega}_M = \frac{8\pi G\bar{\rho}_{M0}\bar{a}_0^3}{3\bar{H}^2\bar{a}^3}\,;\ \bar{\Omega}_k = \frac{-k_{\rm v} f_{\rm vi}{}^{2/3} f_{\rm v}{}^{1/3}}{\bar{a}^2\bar{H}^2}\,;\ \bar{\Omega}_{\mathcal{Q}} = \frac{-\dot{f}_{\rm v}{}^2}{9 f_{\rm v}(1-f_{\rm v})\bar{H}^2}$$

$$f_{\rm v} = \frac{3 f_{\rm v0}\bar{H}_0 t}{3 f_{\rm v0}\bar{H}_0 t + (1 - f_{\rm v0})(2 + f_{\rm v0})}$$

$$q = \frac{-\left(1 - f_{\rm v}\right)\left(8 f_{\rm v}{}^3 + 39 f_{\rm v}{}^2 - 12 f_{\rm v} - 8\right)}{\left(4 + f_{\rm v} + 4 f_{\rm v}{}^2\right)^2}$$

Redshift-magnitude relation in different universes

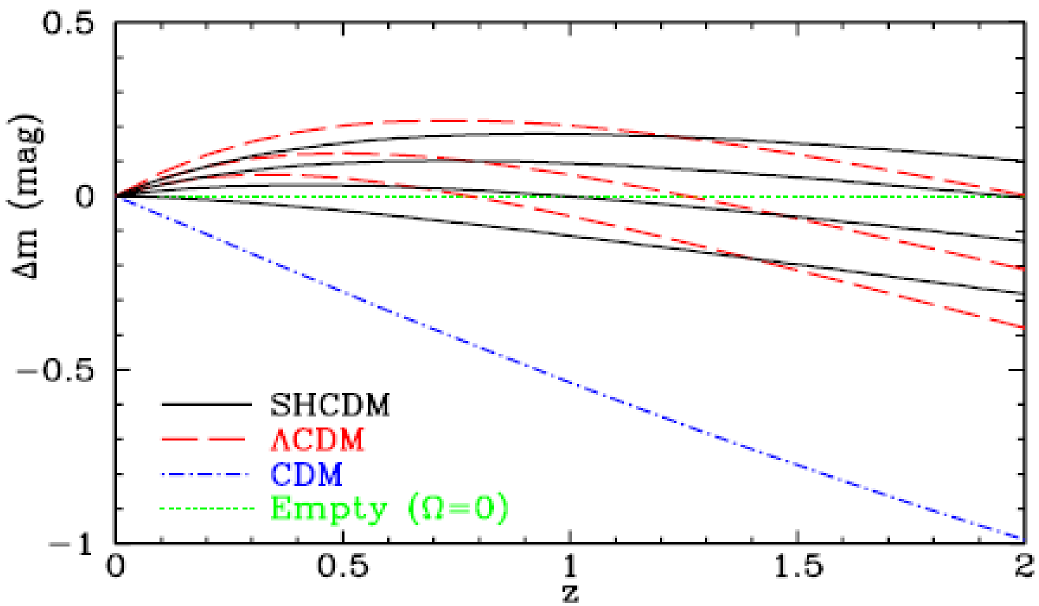


FIG. 1: The apparent magnitude difference as a function of redshift between SHCDM and ΛCDM models compared to a model empty universe. The SHCDM models from top to bottom are for $\Psi_{\ell 0} = -1.0, -0.75, -0.5,$ and -0.25, while the ΛCDM models from top to bottom are for $\Omega_\Lambda = 0.8, 0.7,$ and 0.6 (all with $w = -1$). Also indicated is the CDM model ($\Omega_\Lambda = 0$).

Structured cosmic matter in a 2-phase universe as analogy to vacuum energy

$$\bar{\rho}_2 = \rho_v f_v + \rho_w f_w = \rho_v f_v + \rho_w (1 - f_v)$$

$$\rho_{vac} = \frac{\bar{\rho}_2 (1 - 2\bar{q}_2)}{2(\bar{q}_2 + 1)}$$

$$\bar{\rho}_2(f_v \geq f_{vc}) = \bar{\rho}_2 - \bar{\rho}_{vac}(f_v \geq f_{vc}) = \bar{\rho}_2 (1 - \frac{1 - 2\bar{q}_2}{2(\bar{q}_2 + 1)})$$

$$f_v \geq f_{vc} = 0.57$$

Vacuum action in GRT?

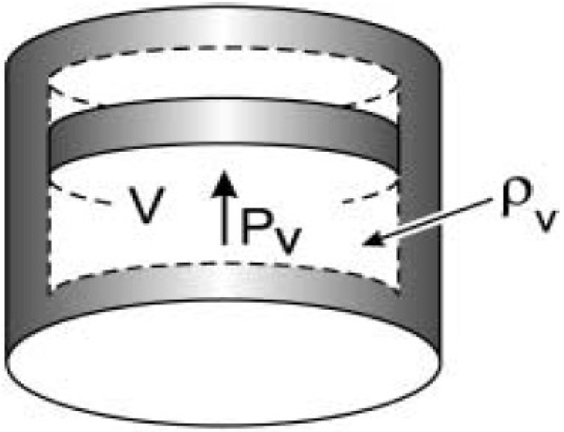


Fig. 6 Equation of state of the vacuum. As the vacuum does work to push out the piston, it creates *more* vacuum inside the chamber, increasing its internal energy. Ordinary intuition fails here if we imagine the piston in a typical laboratory environment, surrounded by high-pressure gas. In cosmology, there is no container, and no "outside" at all

$$dU = -p_{\mathrm{Vac}} dV$$

$$dU = \rho_{\mathrm{Vac}}\, c^2 dV$$

$$p_{\mathrm{Vac}} = -\rho_{\mathrm{Vac}} c^2$$

$$\begin{aligned} T_{\mu\nu}^{\mathrm{Vac}} &= \left(\rho_{\mathrm{Vac}} c^2 + p_{\mathrm{Vac}}\right) U_\mu U_\nu - p_{\mathrm{Vac}} g_{\mu\nu} \\ &= \rho_{\mathrm{Vac}} c^2 g_{\mu\nu} \end{aligned}$$

A rational concept of empty space

$$S_{\mathrm{GR}} = \frac{-1}{16\pi G} \int d^4x \sqrt{-g}\,(R + 2\Lambda) + S_{\mathrm{Mat}}$$

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} = \frac{-8\pi G}{c^4} \left(T_{\mu\nu}^{\mathrm{Mat}} + \frac{\Lambda c^4}{8\pi G} g_{\mu\nu} \right)$$

the spacetime of "nothing

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} = -\Lambda_{\mathrm{Eff}}\, g_{\mu\nu},$$

where the *effective* cosmological constant is

$$\Lambda_{\mathrm{Eff}} \equiv \Lambda + \frac{8\pi G \rho_{\mathrm{Vac}}}{c^2},$$

!No photon redshift in empty space!

$$ds^2 = c^2 dt^2 - R^2 \left[\frac{dr^2}{(1 - kr^2)} + r^2 \left(d\theta^2 + \sin^2\theta d\phi^2 \right) \right]$$

$$R(t) \propto \begin{cases} \cosh\left(\sqrt{\Lambda_{\mathrm{Eff}}/3}\, ct\right) & \text{if} \quad k = +1 \\ \exp\left(\sqrt{\Lambda_{\mathrm{Eff}}/3}\, ct\right) & \text{if} \quad k = 0 \\ \sinh\left(\sqrt{\Lambda_{\mathrm{Eff}}/3}\, ct\right) & \text{if} \quad k = -1 \end{cases}$$

A photon will thus experience contin
interaction with *empty space* at a rate

$$\frac{dz}{dt} = \sqrt{\frac{\Lambda_{\mathrm{Eff}}}{3}} c,$$

where $t \equiv t_O - t_E$, unless we set $\Lambda_{\mathrm{Eff}} = 0$

$$\Lambda_{eff} = \frac{8\pi G}{c^2} (\rho_{vac} - \rho_{vac,0})$$

The „zero energy“ universe:

$$E = \int^{V^3} (\rho c^2 + 3p)\sqrt{-g_3}\, d^3V = \frac{4\pi}{3} S^3 (\rho c^2 + 3p)$$

$$\rho = \rho_{\mathrm{b}} + \rho_{\mathrm{d}} + \rho_{\mathrm{vac}}$$

and the total pressure is given by

$$p = p_{\mathrm{b}} + p_{\mathrm{d}} + p_{\mathrm{vac}}$$

In the present phase of the evolution of the universe, baryonic and dark matter can be considered as cold and pressure-less, i.e., $p_{\mathrm{b}} + p_{\mathrm{d}} = 0$. Assuming, furthermore, a general dependence of $\rho_{\mathrm{vac}} \sim S^{-n}$ (see Fahr and Heyl 2006b), one then obtains $p = p_{\mathrm{vac}} = -\frac{3-n}{3}\rho_{\mathrm{vac}} c^2$ and finds

$$E = \frac{4\pi}{3} S^3 c^2 (\rho_{\mathrm{b}} + \rho_{\mathrm{d}} + (n-2)\rho_{\mathrm{vac}}) \qquad (15)$$

The „Zero-Energy“ universe

$$U = \int_0^S 4\pi r^2 (\rho_{\mathrm{b}} + \rho_{\mathrm{d}} + (n-2)\rho_{\mathrm{vac}})\Phi(r)dr$$

$$\Phi(r) = -\frac{2}{3}\pi G(\rho_{\mathrm{b}} + \rho_{\mathrm{d}} + (n-2)\rho_{\mathrm{vac}})r^2$$

$$U = -\frac{8\pi^2 G}{15}(\rho_{\mathrm{b}} + \rho_{\mathrm{d}} + (n-2)\rho_{\mathrm{vac}})^2 S^5$$

Now, the requirement that the total energy of the universe $T = E + U$ vanishes – with E and U given by

$$\frac{3c^2}{2\pi G S^2} = (\rho_{\mathrm{b}} + \rho_{\mathrm{d}} + (n-2)\rho_{\mathrm{vac}})$$

We could get the physical concepts right,...if....!

- Is the mass of the universe conserved?
- There is mass creation due to vacuum decay!
- What is the effective cosmic density?
- It is the metrically modulated proper density!
- How is gravitational binding energy entering the ART field equations?
- It reduces the effective density!
- How changes the vacuum energy density?
- It decays inversely proportional to the square of S !

All stories and books have a begin; the universe has none! unless we make a story out of it!

But all over the world doubts come up......