Paradoxes of the Cosmological Physics in the beginning of the 21-st century

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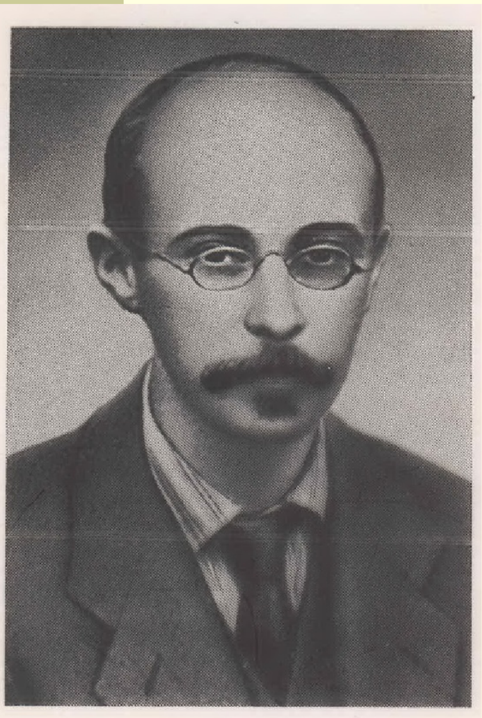
- The Standard Cosmological Model (SCM)
- Observational and conceptual problems of the SCM in the beginning of the 21-st century
- Perspectives for physical testing the basis and predictions of the SCM

The Standard Cosmological Model in the beginning of the 21-st century

Initial assumptions (the basis):

- ***Homogeneous*** *and isotropic matter distribution in the expanding Universe* $(\rho = \rho(t);\ \ p = p(t);\ \ g_{ik}(t)\ )$
- ***General Relativity*** *(geometrical gravity theory) is applicable to the whole Universe*
  $(g_{ik};\ \ R_{iklm};\ \ T^{ik}{}_{(m+de)})$
- ***Laboratory physics*** *in the expanding Universe (QFT)*
- ***Inflation*** *in the early Universe (flatness, isotropy, initial conditions for structure formation)*

Einstein-Friedmann expanding space paradigm



$$R^{ik} - \frac{1}{2} g^{ik} R = \frac{8\pi G}{c^4} \left(T^{ik}{}_{(m)} + T^{ik}{}_{(de)}\right)$$

$$\left(T^{ik}{}_{(m)} + T^{ik}{}_{(de)}\right)_{;k} \equiv 0$$

$$R_{ik} = \frac{\partial \Gamma^l{}_{ik}}{\partial x^l} - \frac{\partial \Gamma^l{}_{il}}{\partial x^k} + \Gamma^l{}_{ik}\Gamma^m{}_{lm} - \Gamma^m{}_{il}\Gamma^l{}_{km}$$

$$\Gamma^i{}_{kl} = \frac{1}{2}\, g^{im} \left(\frac{\partial g_{mk}}{\partial x^l} + \frac{\partial g_{ml}}{\partial x^k} - \frac{\partial g_{kl}}{\partial x^m}\right)$$

$$T^{ik}{}_{(m+de)} = diag\,(\rho c^2, p, p, p); \quad \rho = \rho(t); \quad p = p(t)$$

$ds^2 = g_{ik} dx^i dx^k$ RW homogeneous metric:

$$ds^2 = c^2 dt^2 - S(t)^2 [d\chi^2 + I_k(\chi)^2 d\omega^2]$$

$$I_k(\chi) = \sin\chi,\ \chi,\ \sinh\chi \qquad for \qquad k = 1, 0, -1$$

$r(t) = S(t) \times \chi$ - expanding space

(increasing distance between galaxies)

Friedmann's equations: derivation from Einstein's equations

$$T^i{}_k = diag(\varepsilon, -p, -p, -p) = T_{(m)}{}^i{}_k + T_{(de)}{}^i{}_k$$

$$\varepsilon = \varepsilon(t) = \varrho(t)c^2, \quad p = p(t) \qquad (\text{ no } T_{(g)}{}^i{}_k)$$

Einstein's eq. (0, 0) :

$$\boxed{\frac{\dot{S}^2}{S^2} + \frac{k c^2}{S^2} = \frac{8\pi G}{3c^2}\varepsilon}$$

$$\varepsilon = \varepsilon_m + \varepsilon_{de}$$

$$p = p_m + p_{de}$$

Einstein's eq. (1, 1) :

$$\boxed{2\frac{\ddot{S}}{S} + \frac{\dot{S}^2}{S^2} + \frac{k c^2}{S^2} = -\frac{8\pi G}{c^2}p}$$

Bianchi identity :

$$\boxed{3\frac{\dot{S}}{S} = -\frac{\dot{\varepsilon}}{\varepsilon + p}}$$

Fluid EoS $\quad p = \gamma\varepsilon$

Dust: $\gamma = 0$, Radiation: $\gamma = 1/3$,

Vacuum: $\gamma = -1$

Friedmann's equations: standard form for scale factor S(t)

$$\boxed{H^2 - \frac{8\pi G}{3}\rho = -\frac{k c^2}{S^2}}$$

$$\boxed{\ddot{S} = -\frac{4\pi G}{3}(\rho + \frac{3p}{c^2})\, S}$$

$$\boxed{1 - \Omega = -\Omega_k}$$

$$\boxed{q = \frac{1}{2}\Omega\ (1 + \frac{3p}{\rho c^2})}$$

Main parameters of the Friedmann model:

$$H(t) = \dot{S}/S$$

$$q = -\ddot{S}\,S/\dot{S}^2$$

$$\rho_{crit} = 3H^2/8\pi G$$

$$\Omega = \rho/\rho_{crit}$$

$$\Omega_k = kc^2/S^2H^2$$

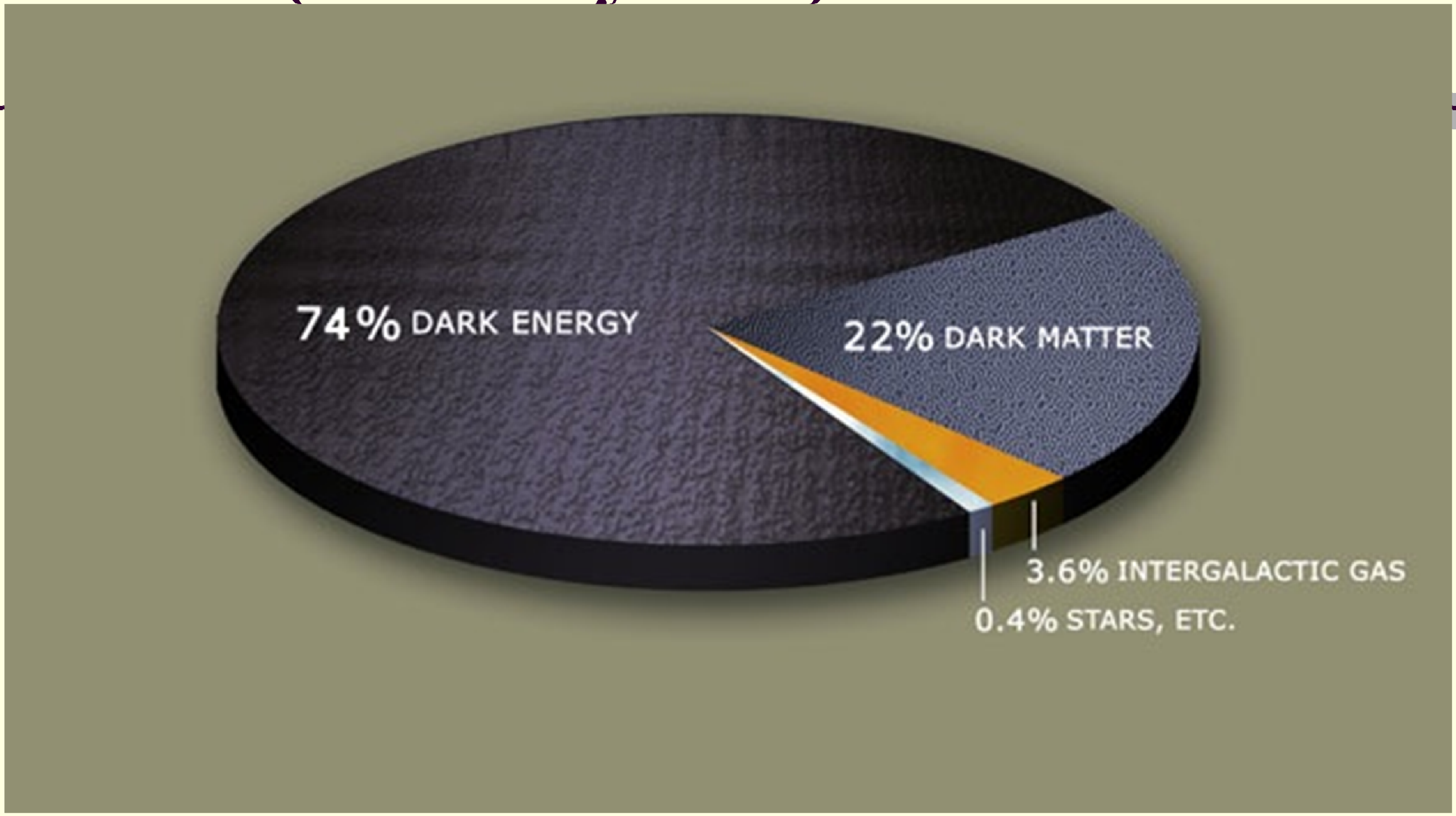
Solution for $p(t) = \gamma\varepsilon(t)$:

$$\boxed{\begin{array}{l} S(t) \propto t^{2/(3+3\gamma)},\ \ k = 0 \\ S(t) \propto \exp(\alpha t),\ \ \gamma = -1 \end{array}}$$

Fundamental conclusions of the LCDM SCM

- **Cosmological redshift** $z = d\lambda/\lambda$ and the linear Hubble Law $v_{exp} = Hr$ is the consequence of the homogeneous space expansion $r(t) = S(t) \times \chi$
- **Cosmic microwave background radiation** is the result of the photon gas cooling in the expanding space $T(z) = T_0(1+z)$
- **Small anisotropy** $\Delta T/T(\theta)$ of the CMBR is determined by the initial spectrum of density fluctuations which are the source of the large scale structure of the Universe
- **The expanding Universe is made of unobservable** in lab dark energy (70%), nonbaryonic dark matter (25%) plus ordinary matter (5%). Visible galaxies contribution is less than 0.5%.

Main mass-energy components in the LC(nonbaryonic)DM SCM



Planck 2013 (arXiv:1303.5076):
Minimal (flat) 6 parameters LCDM

$\Omega_i = \rho_i / \rho_{crit}$

$\rho_{crit} = \frac{3H^2}{8\pi G} = 0.853 \times 10^{-29}\ g/cm^3$

$\rho_{vac} \sim \rho_{Pl} = 10^{94}\ g/cm^3$

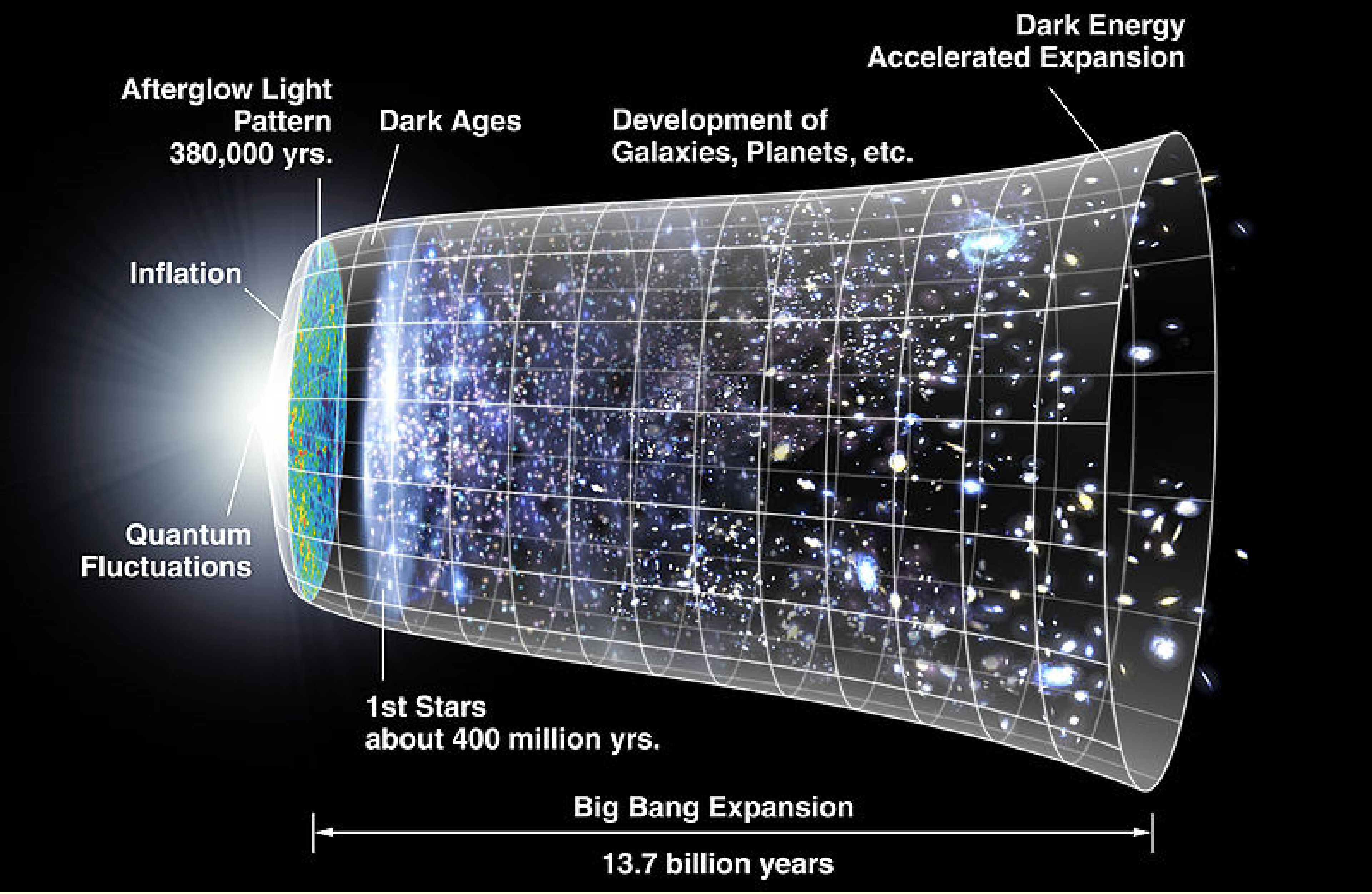
$H_0 = 67.4 \pm 1.4\ km\ s^{-1}\ Mpc^{-1}$

$\Omega_m = 0.314 \pm 0.020$

$\Omega_c = 0.263 \pm 0.0031$

$\Omega_b = 0.048 \pm 0.0003$

$\Omega_{de} = 0.686 \pm 0.020$



Cosmology is almost finished !

Examples of observational problems in the L(nonbaryonic)CDM SCM

- Tasitsiomi A., The Cold Dark Matter crisis on galactic and subgalactic scales, Int.J.Mod.Phys. D12 (2003) 11572002
- Perivolaropoulos L., LCDM: Triumphs, Puzzles and Remedies, (2011), Proc. Int. Conf. (arXiv:1104.0539)
- Kroupa P. et al., The Failures of the Standard Model of Cosmology Require a New Paradigm, Int.J.Mod.Phys. D21 (2012), 1230003
- Sylos Labini F., Inhomogeneous Universe, Class.Quant.Grav., 28, iss.16, 4003 (2011)

Problem of galaxy structure – dark matter relations

Problem of cusps and satellite galaxies

Problem of large scale correlations in 3d galaxy surveys

Problem of CMBR – ecliptic correlation

Is the SCM ultimate physical picture of the World? Is the basis of SCM firmly established?

Turner M.S., **Absurd universe**, Astronomy , Vol. 31, No. 11, p. 44 - 47 (2003) (visible matter <0.5%)

Steinhardt P., **Inflation debate: Is the theory at the heart of modern cosmology deeply flawed ?** , Sci. Am., April 2011 (+ arXiv: 1402.6980)

Francis M. et al., **Expanding Space: the Root of all Evil?** , Publ. Astron. Soc. Austr., 24, 95 (2007)

Clifton T. et al., **Modified gravity and cosmology**, Physics Reports, Volume 513, Issue 1, p. 1-189 (2012)

Hawking S., arXiv: 1401.5761 + Nature, 24 January 2014, **“there are no black holes - no event horizons and no firewalls”.**

Conceptual problems of the SCM

Gravitation theory

(GR is not a quantum theory, absence of the EMT of gravitational field in GR, **Hawking 2014:** need for unite gravity with the other fundamental forces of nature – "no black holes")

Physics of space expansion

(Continuous creation of vacuum, violation of energy conservation)

The nature of cosmological redshift

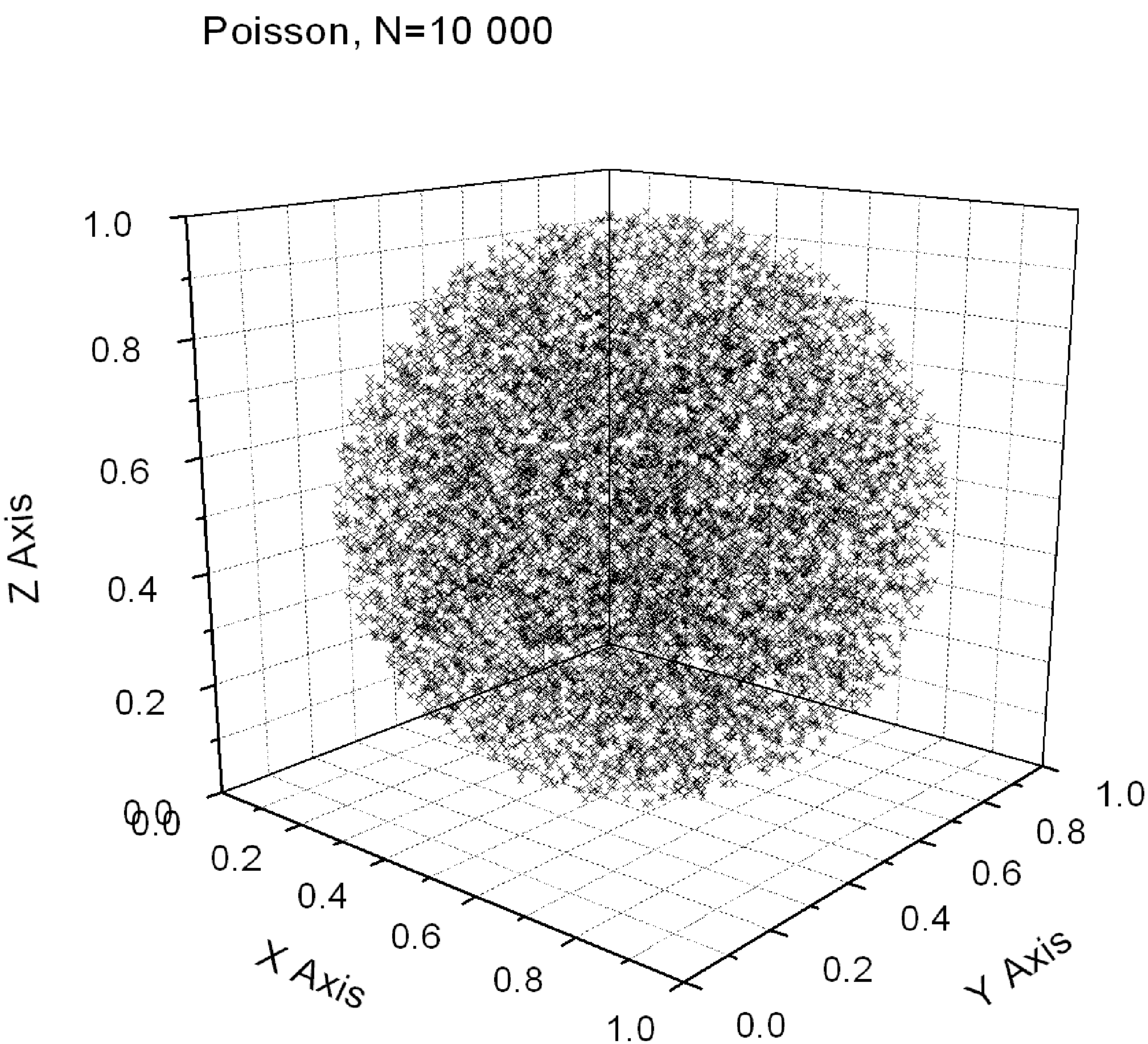
(It is not the Doppler effect, the global gravitational cosmological redshift should be taken into account)

Inhomogeneity of matter distribution

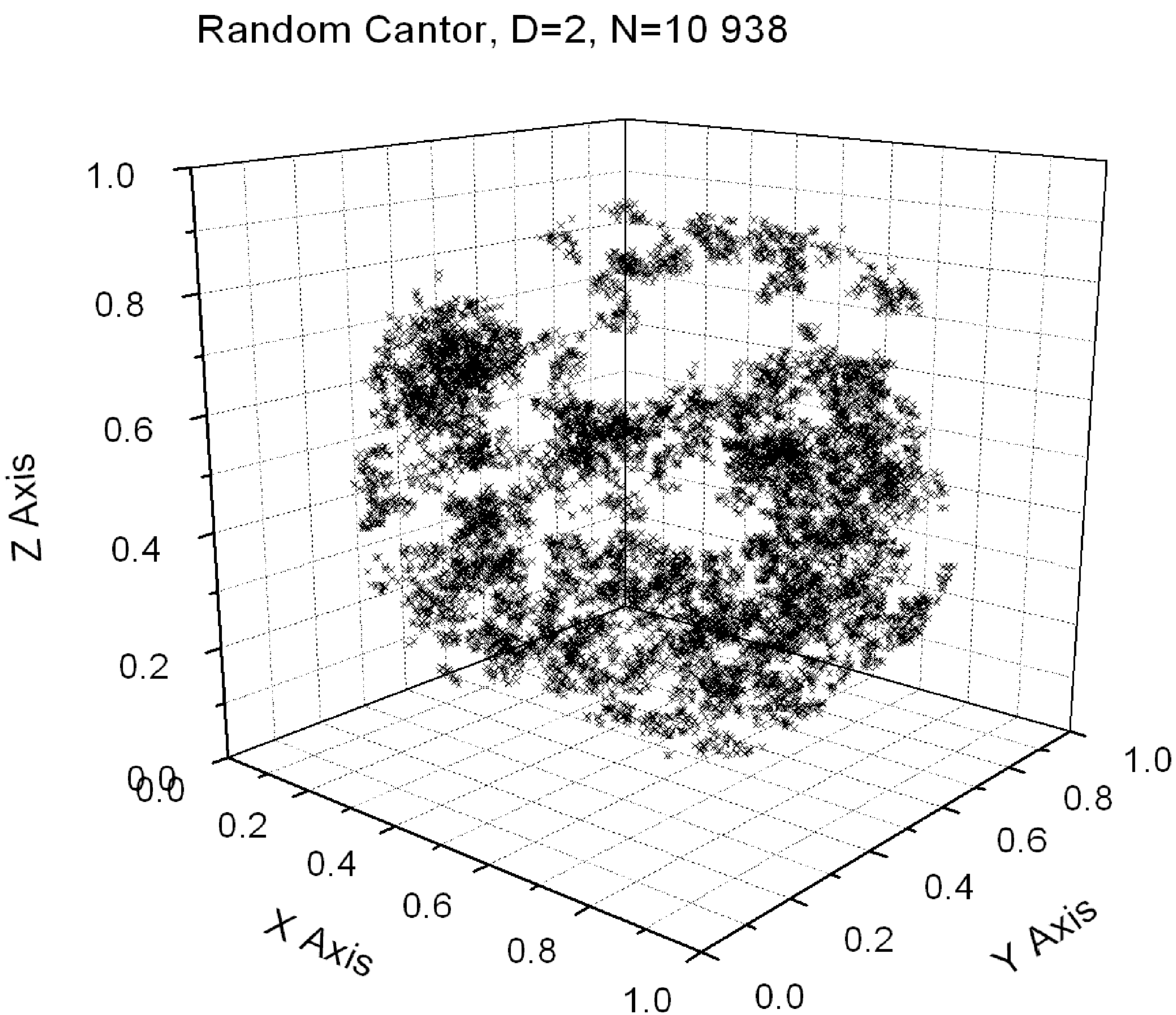
(Discreteness and **fractality** of spatial galaxy distribution)

Inhomogeneity of matter distribution

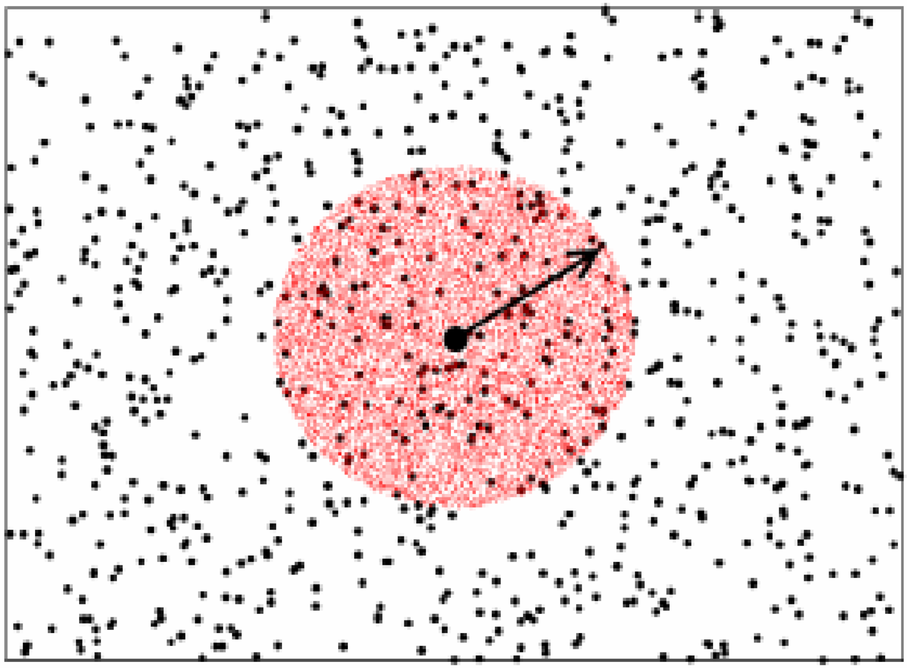
Homogeneous point distribution with D = 3



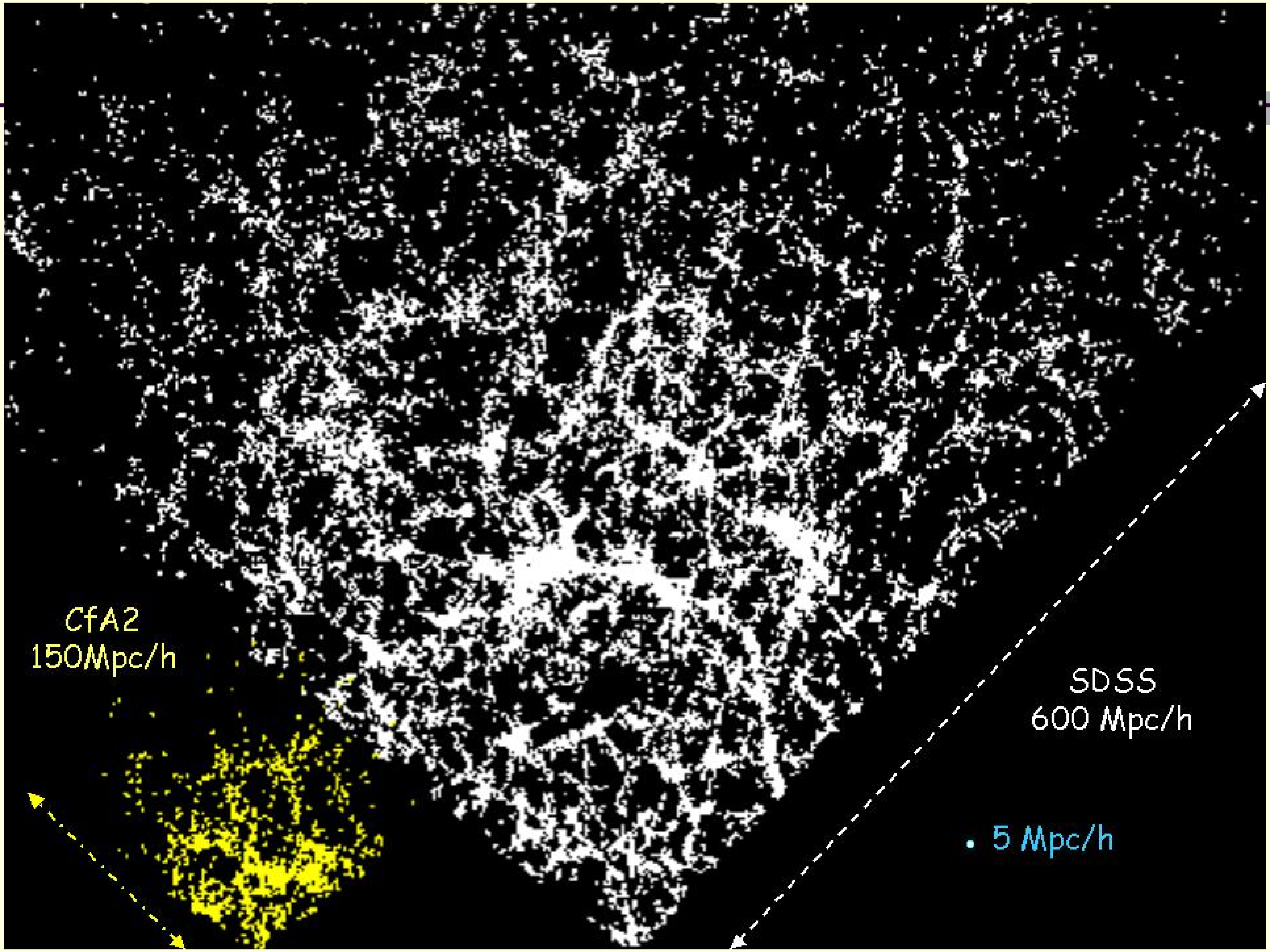
Inhomogeneous fractal point distribution with D = 2 (fractal dimension $N(r) \sim r^D$)



Conditional density <n(r)>_p :   estimation

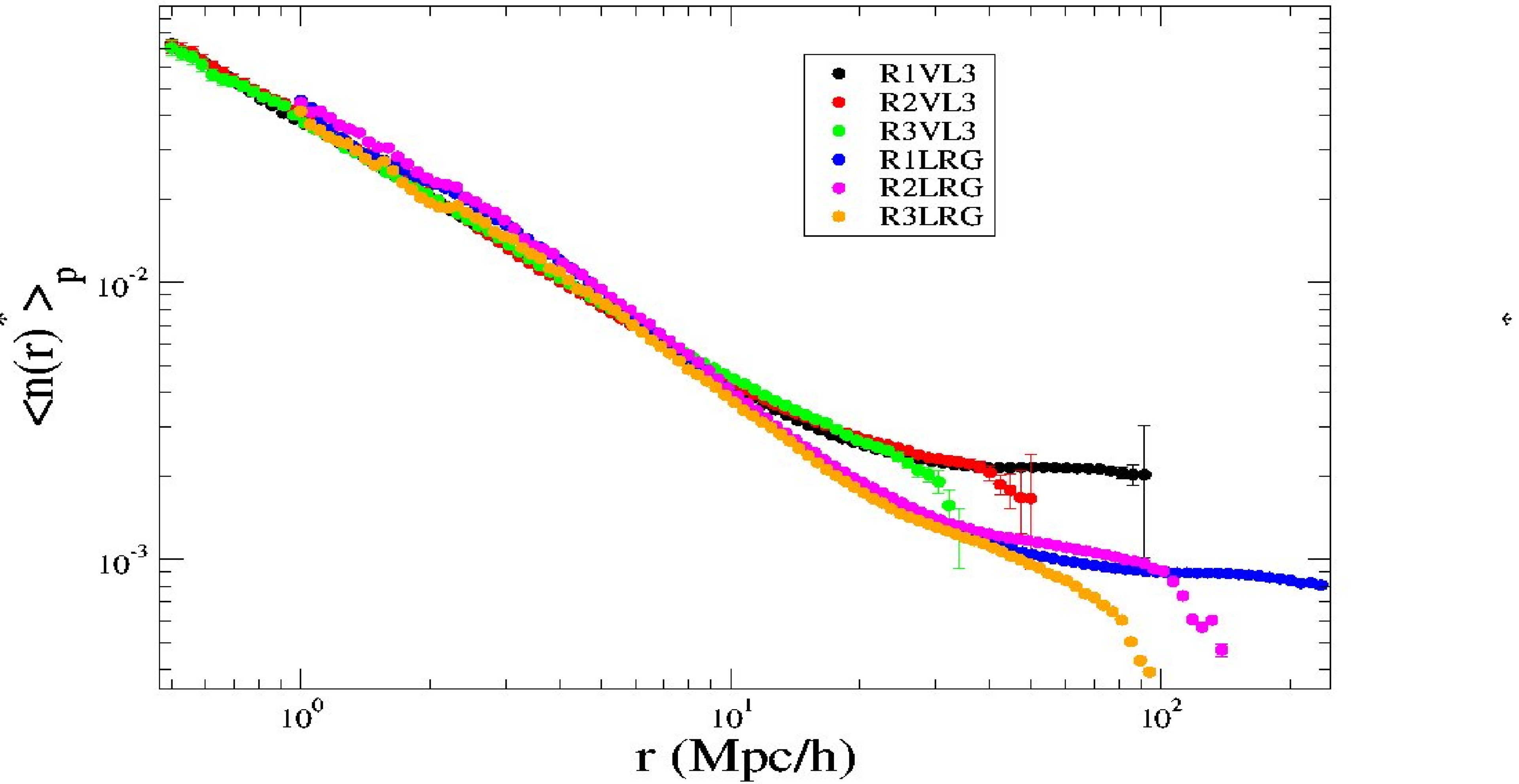
Integrated conditional density (in spheres) $\Gamma^*(r) = \langle n(r' < r) \rangle_P$	 $\Gamma^*_E(r) = \frac{1}{N_C(r)} \sum_{i=1}^{N_C(r)} \frac{N_i(r)}{\lVert C(r) \rVert}$

Inhomogeneous spatial galaxy distribution in SDSS sample (~100000 galaxies)



There are structures with sizes 400 Mpc , while LCDM predicts homogeneity scale 5 – 10 Mpc . Fractal dimension $D \sim N(r)^D$, D ~ 2 .

Conditional density of SDSS galaxy samples:
Sylos Labini F. et al., Astron.Astrophys.508:17-43,2009,
fractal dimension D ~ 2



The nature of cosmological redshift

Exact velocity – distance relation in the Friedmann model

$$\boxed{V_{\exp} = \frac{dr}{dt} = \frac{dS}{dt}\,\chi = \frac{dS}{dt}\,\frac{r}{S} = H(t)\,r = c\,\frac{r}{r_H}}$$

$\boxed{r(t) = S(t)\,\chi}$ $\boxed{H(t) = \dot{S}/S}$ $\boxed{r_H = c/H(t)}$ -- Hubble radius

Homogeneity implies the linear relation

$$\boxed{V_{\exp} = H\,r}$$

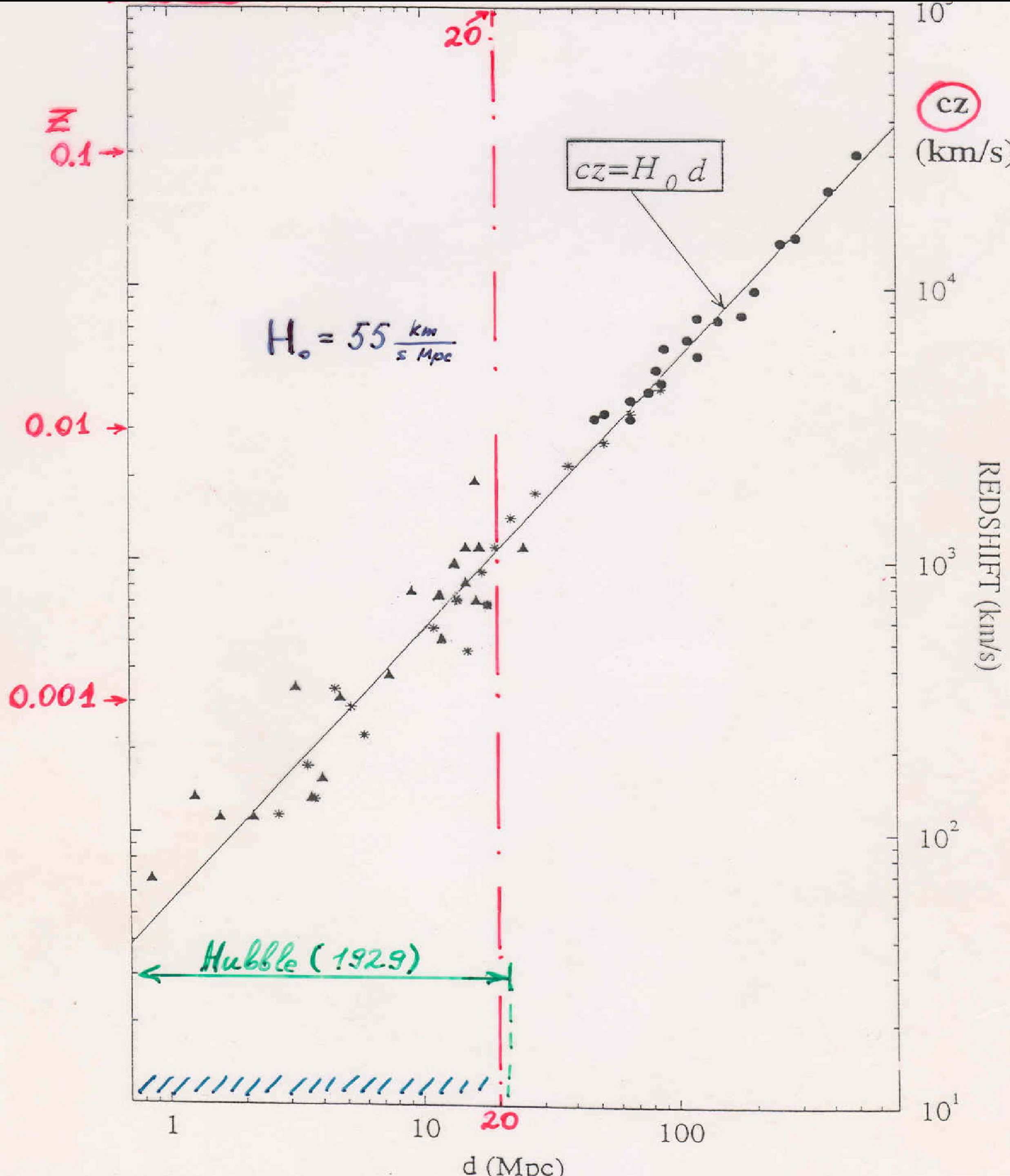
Exact GR relation between galaxy expansion velocity and distance to the galaxy (no relativistic effects)

Linear Hubble Law

Peebles P.J.E., Schramm D.N., Turner E.L., Kron R.,
"The case for the relativistic hot Big Bang cosmology",
Nature, 352, 769 (1991):

"The connection between
homogeneity and Hubble's law
was the first success
of the expanding world model."

$$\rho(r,t) = \rho(t) \quad \leftrightarrow \quad V_{exp} = H\, r$$

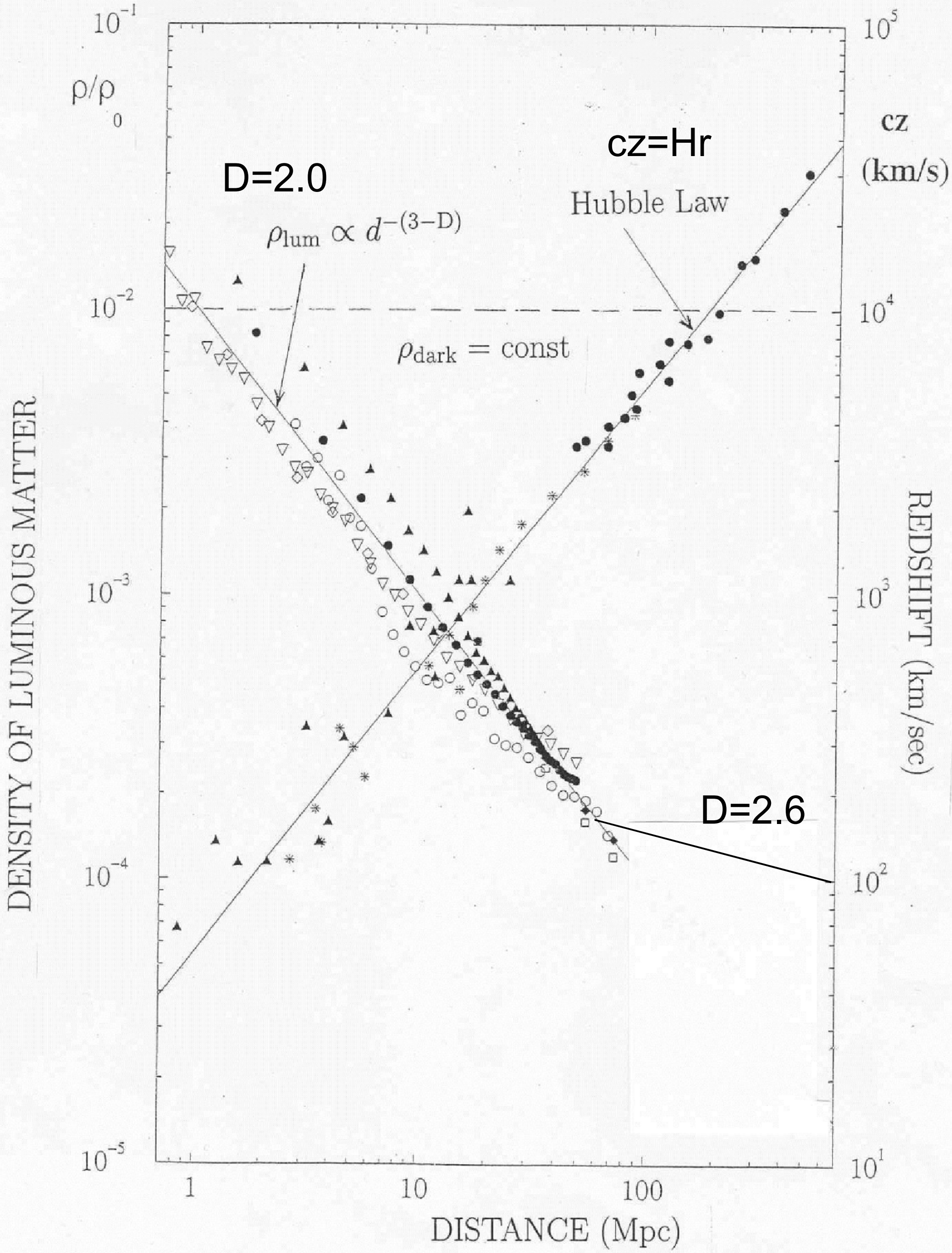


Linear Hubble Law

Teerikorpi P., Annu. Rev. Astron. Astrophys., 35, 101, (1997)

$$H_0 = (55 \div 75)\frac{km}{s\,Mpc}$$

$$2014 \rightarrow H_0 = 67\,\frac{km}{s\,Mpc}$$



Hubble – de Vaucouleurs (HdeV) paradox

The linear Hubble Law

$$cz = Hr$$

coexists with strong inhomogeneous Fractal Law – de Vaucouleurs Law of spatial galaxy distribution

$$\rho(r) = \rho_0 \left(\frac{r_0}{r}\right)^{\gamma}$$

$$\gamma = 3 - D$$

Global gravitational cosmological redshift

Fractal matter distribution: $M(r) \propto r^D$

Global gravitational cosmological redshift $z = d\lambda/\lambda$:

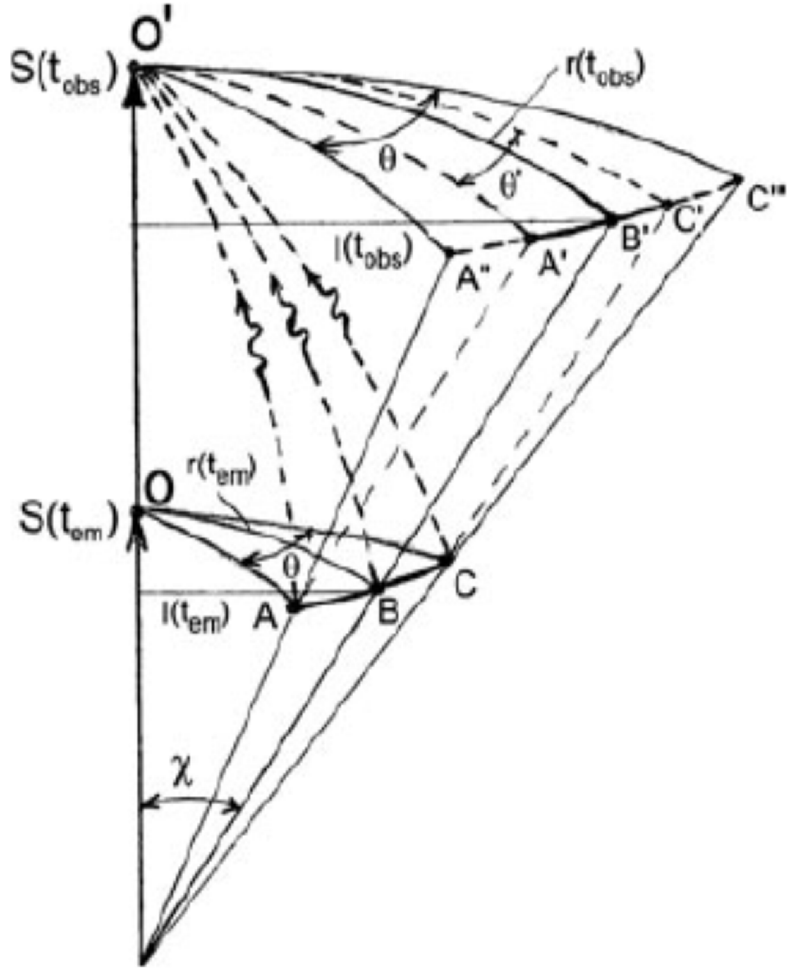
$$z_{\text{grav}} = \frac{\delta\phi(r)}{c^2} = \frac{1}{2}\frac{GM(r)}{c^2 r}$$

$$z_{\text{grav}}(r) = \frac{4\pi G\rho_0 r_0^2}{c^2 D(D-1)}\left(\frac{r}{r_0}\right)^{D-1} = \frac{2\pi G\rho_0 r_0}{c^2} r = \frac{H_g}{c} r \quad (D=2)$$

$$H_g = 2\pi\rho_0 r_0 \frac{G}{c} \approx 69\ \mathrm{km\,s^{-1}/Mpc}$$

$$\rho_0 = 5 \times 10^{-24}\ \mathrm{g/cm^3},\ r_0 = 10\ \mathrm{kpc}$$

Physics of space expansion



What is space expansion?

r(t) = S(t) χ

→ increasing distance between galaxies with violation of limiting velocity

→ continues space and vacuum creation

→ violation of energy conservation

Cosmological physics of the expanding space is essentially different from the lab physics

Newtonian physics of the relativistic Friedmann equations

$r(t) = S(t) \cdot \chi$ - distance to a galaxy

$$\boxed{\ddot{S} = -\frac{4\pi G}{3}\left(\rho + \frac{3p}{c^2}\right) S} \equiv \boxed{\frac{d^2 r}{dt^2} = -\frac{G\, M_g(r)}{r^2}}$$

Newtonian ball r(t) expansion

$$\boxed{H^2 - \frac{8\pi G}{3}\rho = -\frac{k c^2}{S^2}} \equiv \boxed{\frac{V^2{}_{exp}}{2} - \frac{GM}{r} = const}$$

Newtonian kinetic and potential energy

$$\boxed{M_g(r) = -\frac{4\pi}{3}\left(\rho + \frac{3p}{c^2}\right) r^3}$$

$$\boxed{p = \gamma \rho c^2} \qquad \boxed{M_g(r) = \frac{4\pi}{3}(1+3\gamma)\, \rho\, r^3 \quad \propto \quad S^{-3\gamma}(t)}$$

Cosmological redshift as the Lemaitre effect in the expanding Universe

$$\boxed{(1+z) = \lambda_0 / \lambda_1 = S_0 / S_1}$$

$$\boxed{V_{\exp}(r) = \frac{dr}{dt} = H\ r}$$

Velocity – distance relation (for receding galaxy)

$$\boxed{V_{\exp}(z) = H\ r(z)}$$

Velocity – redshift relation (for receding galaxy)

$$\boxed{r(t_0, z) = r(z) = \frac{c}{H_0} \int_0^z \frac{dz'}{h(z')}}$$

Distance – redshift relation

$$h(z) = [\,\Omega^0{}_{dm}(1+z)^3 + \Omega^0{}_{rad}(1+z)^4 +$$

$$+\,\Omega^0{}_{de}(1+z)^{3(1+w)} + (1-\Omega^0{}_{tot})(1+z)^2]^{1/2}$$

Comparison of the Lemaitre and the Doppler effects

$$\boxed{V_{\exp}(z) = c\,\frac{r(z)}{r_H}} \quad \Rightarrow \quad \boxed{\begin{array}{l} V_{\exp}(z) > c \qquad if \quad z > 3 \\ (q_0 = 0.5, \quad p = 0) \end{array}}$$

$$\boxed{V_{Dop}(z) = c\,\frac{2z + z^2}{2 + 2z + z^2}}$$

The expansion velocity of a galaxy in SCM

Models: **1**: ($\Omega_m = 1$, $\Omega_v = 0$); **2**: ($\Omega_m = 0$, $\Omega_v = 0$);
3: ($\Omega_m = 0$, $\Omega_v = 1$)

z	v_{dop}/c	v_{exp}/c, 1	v_{exp}/c, 2	v_{exp}/c, 3
1	0.6	0.6	0.75	1
2	0.8	0.84	1.33	2
6	0.96	1.25	3.43	6
10	0.98	1.4	5.45	10
1000	$1–2 \cdot 10^{-6}$	1.94	500	1000
∞	1	2	∞	∞

Gravitation theory

Energy paradox in the SCM

T.Davis, Scientific American, July 2010, p.39

Is the Universe Leaking Energy?

Total energy must be conserved. Every student of physics learns this fundamental law. The trouble is, it does not apply to the universe as a whole By Tamara M. Davis

The problem of energy conservation in the expanding Universe

Bianchi identity: $$\boxed{(T^{ik})_{;k} = (T_m^{ik} + T_{de}^{ik})_{;k} = 0}$$

$$\boxed{3\frac{\dot{S}}{S} = -\frac{\dot{\varepsilon}}{\varepsilon + p}} \equiv \boxed{dE + p\,dV = 0}$$

$$dE = d(\varepsilon V) = d(\rho c^2 V) \qquad \boxed{dE = -p\,dV}$$

$$V = const \times S^3$$

Change of energy in each local comoving volume during space expansion $r(t) = S(t) \cdot \chi$ (without performing work).
Continuity equation – no energy conservation (no gravity energy)

L.D.Landau & E.M.Lifshitz

"The Classical Theory of Fields", Oxford, 1971

$({T_{(m)}}^{ik} + {t_{(g)}}^{ik})$

§ 101. The energy-momentum pseudotensor

In the absence of a gravitational field, the law of conservation of energy and momentum of the material (and electromagnetic field) is expressed by the equation $\boxed{\partial T^{ik}/\partial x^k = 0.}$ The generalization of this equation to the case where a gravitational field is present is equation (94.7):

$$T^k_{i;k} = \frac{1}{\sqrt{-g}} \frac{\partial (T^k_i \sqrt{-g})}{\partial x^k} - \frac{1}{2} \frac{\partial g_{kl}}{\partial x^i} T^{kl} = 0. \tag{101.1}$$

In this form, however, this equation does not generally express any conservation law whatever.† This is related to the fact that in a gravitational field the four-momentum of the matter alone must not be conserved, but rather the four-momentum of matter plus gravitational field; the latter is not included in the expression for T^k_i.

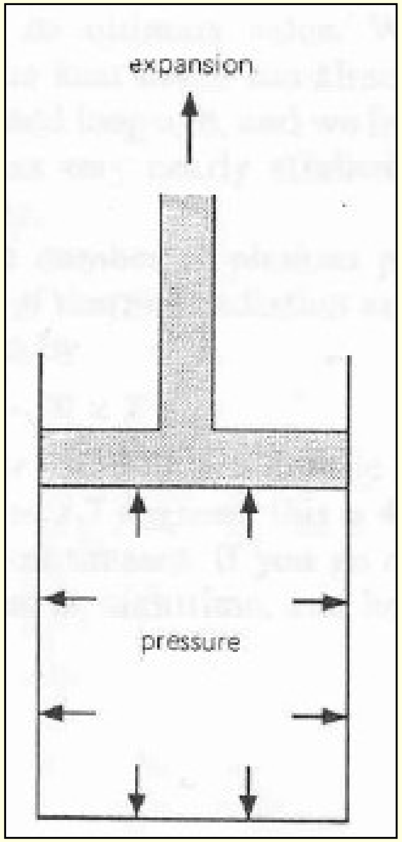
To determine the conserved total four-momentum for a gravitational field plus the matter located in it, we proceed as follows.‡ We choose a system of coordinates of such form that

† Because the integral $\int T^k_i \sqrt{-g}\, dS_k$ is conserved only if the condition

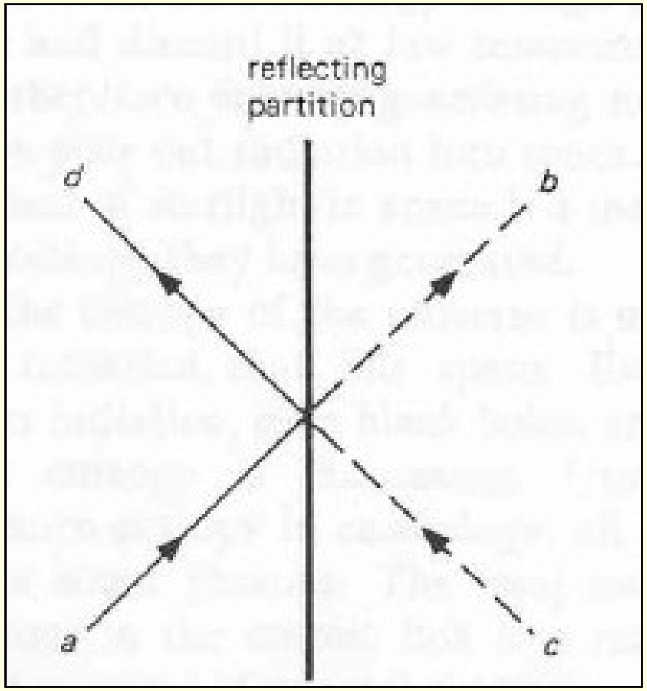
$$\frac{\partial (\sqrt{-g} T^k_i)}{\partial x^k} = 0$$

Edward Harrison, *"Cosmology: the science of the Universe", Cambridge Univ. Press, 2000*

Lab Physics



Cosmological Physics



"The conclusion, whether we like it or not, is obvious: energy in the Universe is not conserved."

dE = - p dV

Exact law for disappearance/creation of energy for each local comoving volume

Disappearance/creation of energy in each local comoving volume of a ball with radius

r(t) = S(t) χ for p = γε

$$E(r,t) = \int_0^r T_0^0 \, dV = \frac{4\pi}{3} \varepsilon(t)\, S^3(t)\, \chi^3\, \sigma_k(\chi)$$

$$E(r,t) = \frac{4\pi}{3} \rho(t) c^2\, r^3(t)\, \sigma_k(\chi) \quad \propto \quad S^{-3\gamma}(t)$$

$$\boxed{E_{dust}(t) \quad \propto \quad const}$$

=> the only Friedmann model (γ = 0), where the energy conserved (Lemaitre 1933; Mitra 2011)

$$\boxed{E_{rad}(t) \quad \propto \quad S^{-1}(t)}$$

=> cooling photon gas (CMBR) in the Friedmann model (γ = 1/3) is the result of continue disappearance of energy in a comoving volume

$$\boxed{E_{vac}(t) \quad \propto \quad S^{+3}(t)}$$

=> vacuum energy in the Freidmann model (γ = − 1) is continuously increases (created) in a comoving volume

Perspective for solution of paradoxes

- *Developing the theory of gravitational interaction, Ghc-theory, laboratory and astrophysical testing gravity theories predictions (Einstein's geometrical approach and Feynman's field approach, nearby SN explosions, RCO, neutrino detection)*

- *Galaxy properties and large scale structure at very high redshifts (wide-angle and pencil-beam very deep surveys of faint galaxies and QSO)*

- *Observational tests of the nature of the cosmological redshift (Сэндидж m(z, SN Ia) и dZ/dt ; Kopeikin dλ/λ<0 in the Solar system)*

Joseph Hooton Taylor, (born March 29, 1941)

Nobel Prize in Physics (1993)
with Russell Alan Hulse

"for the discovery of a new type of pulsar, a discovery that has opened up new possibilities for the study of gravitation"

PSR 1913+16 : Decreasing orbital energy via radiation of *positive energy of the gravitational waves*

Feynman Lectures on Gravitation

Richard P. Feynman

Fernando B. Morinigo · William G. Wagne

1995

Edited by Brian Hatfield

With a Foreword by
John Preskill and Kip S. Thorne

From Feynman to his wife:

"Remind me not to come to any more gravity conferences!"

Gravitation is just a next fundamental physical interaction: symmetric tensor field ψ^{ik}

"The geometric Interpretation is not really necessary or essential to physics." (p. 113)

"the situation is exactly analogous to electrodynamics - and in the quantum interpretation, every radiated graviton carries away an amount of energy ђω." (p.220)

Field Gravity and Geometry

Field Gravity		Geometry
$\eta^{ik}, \psi^{ik}(\vec{r},t), \ \vec{F}_g$	$g^{ik} \approx \eta^{ik} + \phi^{ik}$	$g^{ik}(\vec{r},t), \mathcal{R}_{iklm}$,
$\psi(\vec{r},t) = \eta_{ik}\psi^{ik}$	Spin 2	$g_{ik}\, g^{ik} = 4$
Spin 2 $\oplus$ Spin 0		
Poincare(1905)	Bronstein(1936)	Einstein(1915)
Thirring	Fierz, Pauli	Hilbert
Kalman	Gupta	Fock
Feynman	Deser	Landau, Lifshitz
Zakharov	Weinberg	MTW, …
$\Downarrow$	$\Downarrow$	$\Downarrow$
Sokolov, Baryshev(1980)	Straumann (2000)	Clifton et al. (2012)
	Padmanabhan(2008)	
“New Relativistic Astrophysics”	“no way to geometry”	“modifications of GR”
RCO (noBH), EMT, GW(T+S)		BH, noEMT, GW(T)

Theory of gravitational interaction

Field Gravity

- The **inertial** reference frames
- The **flat Minkowski** space

η^{ik} – conservation laws

- The concept of potential

$\psi^{ik}(\vec{r},t),\ \psi(\vec{r},t) = \eta_{ik}\psi^{ik}$

scalar part, **force**, **gravitons**

- The Energy-Momentum

Tensor of the gravity field $T_{(g)}{}^{ik}$

- The **universality** of gravitational interaction

$\Lambda_{(int)} = \psi_{ik}T^{ik}$, m_0

General Relativity

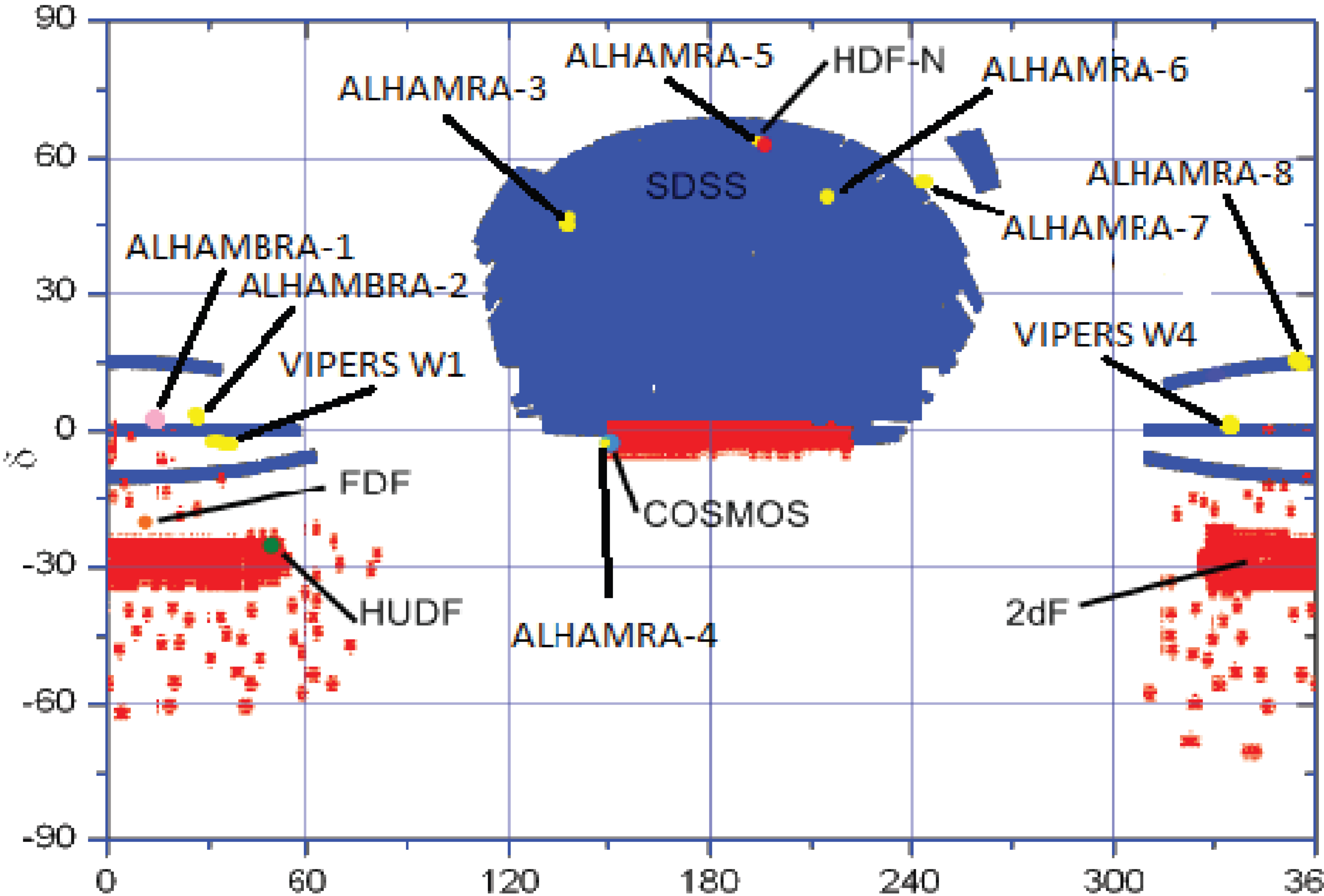
- The **non-inertial** reference frames
- The **curved Riemannian** space-time $g_{ik}\, g^{ik} = 4$
- The metric tensor $g^{ik}(\vec{r},t)$, the curvature tensor $\mathcal{R}_{iklm}$
- The **Pseudo-Tensor** of the gravity field $t_{(g)}{}^{ik}$
- The Equivalence Principle

$m_{inert} = m_{grav}$

free falling frames

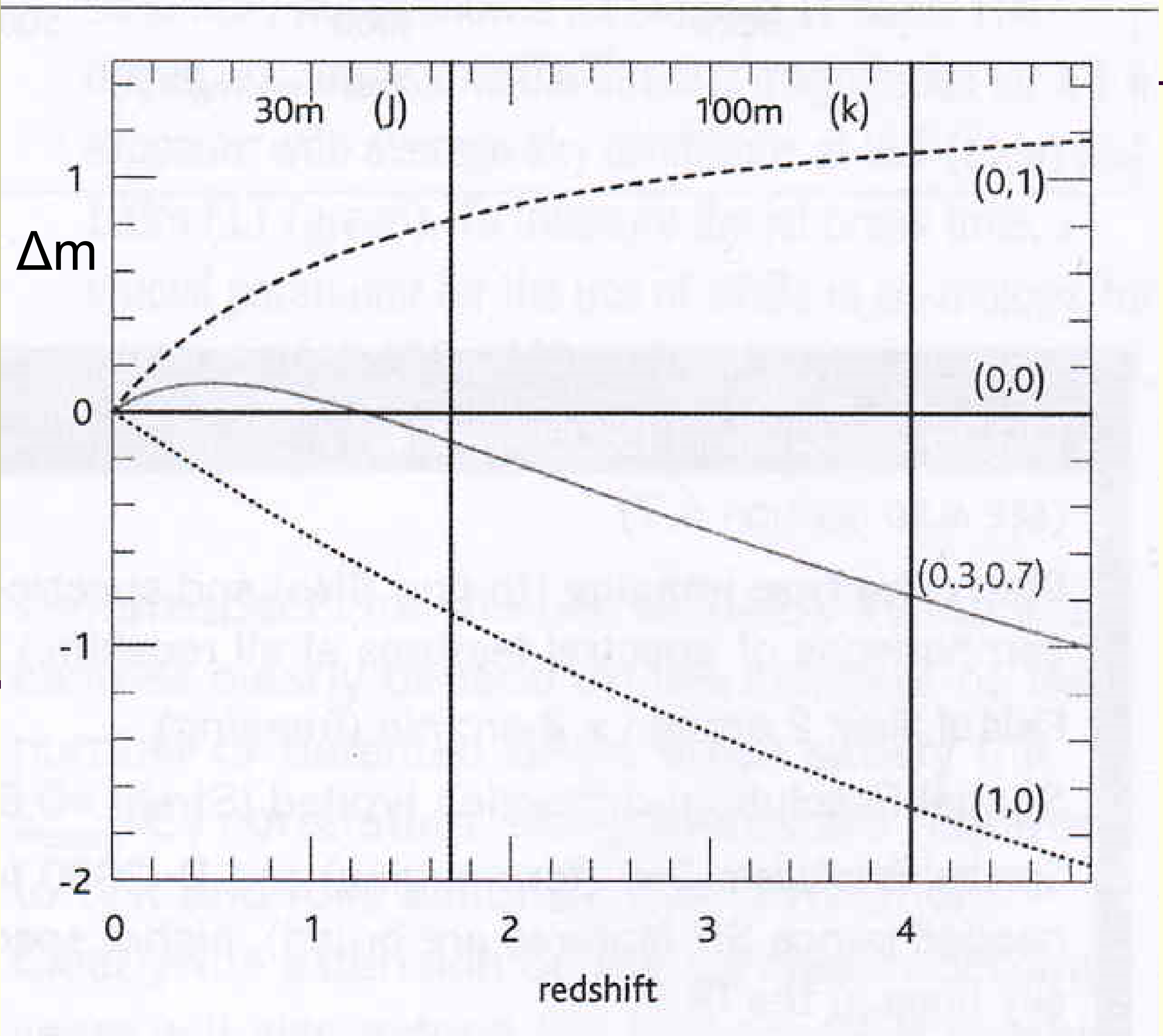
Relativistic Compact Objects, SN explosion, neutrino detection

Pencil-beam and wide-angle galaxy surveys for high redshift galaxies and large scale structures

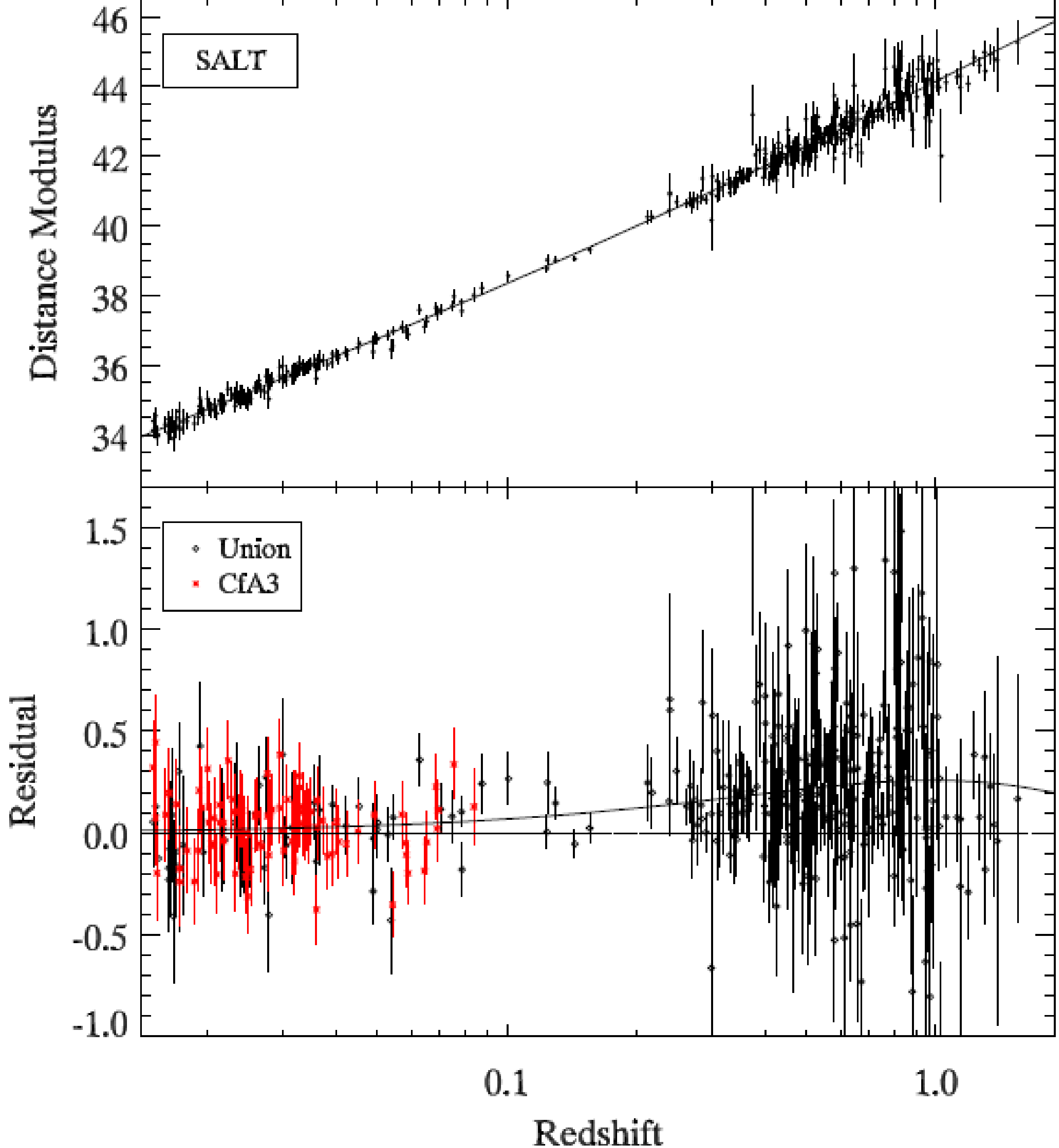


Observational test: stellar magnitude – redshift i.e. flux – distance relation

SN Ia



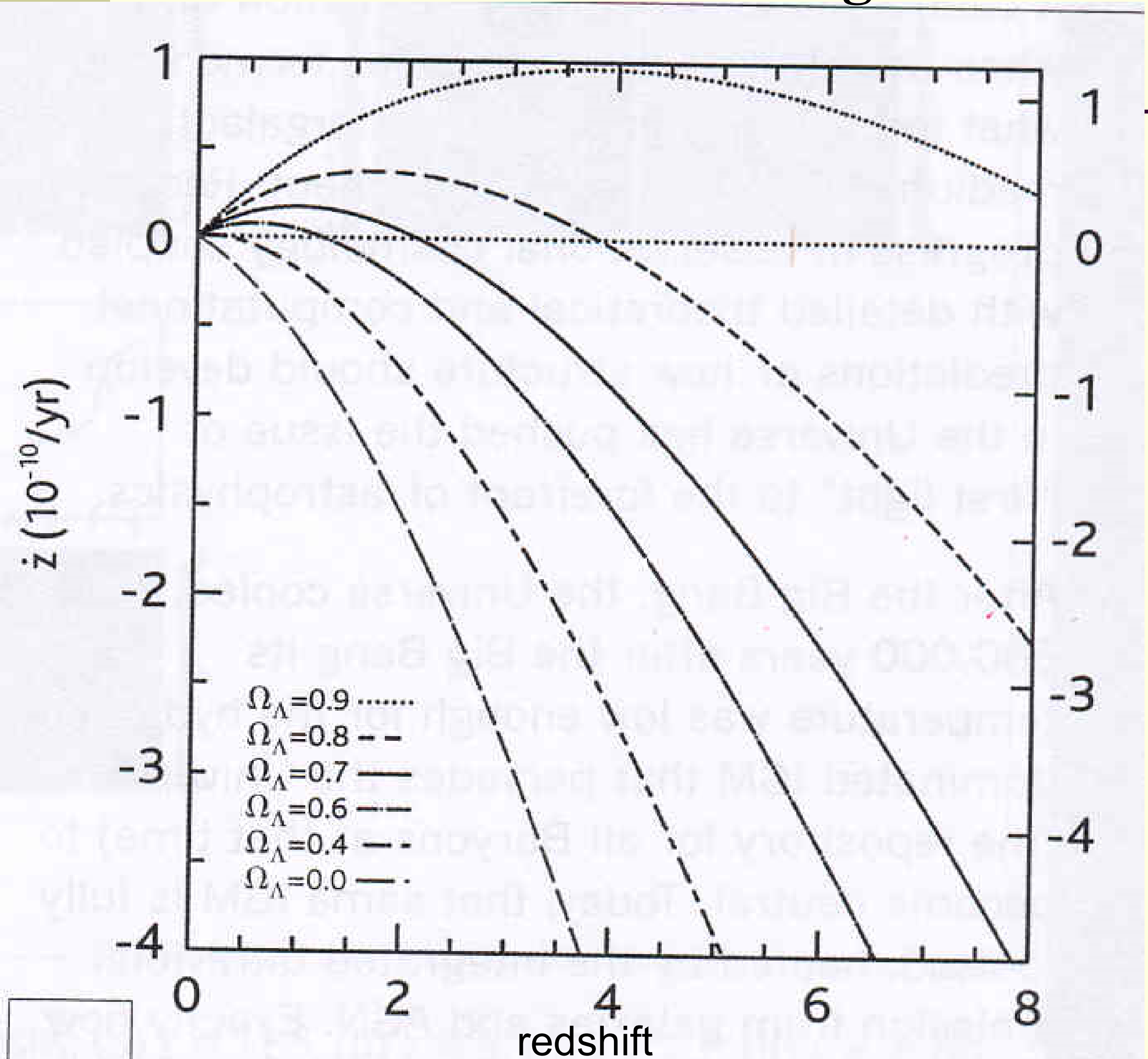
m(z, SN Ia)



SNIa Hubble Diagram

Hicken M. et al., Ap.J., 2009, 700, 1097

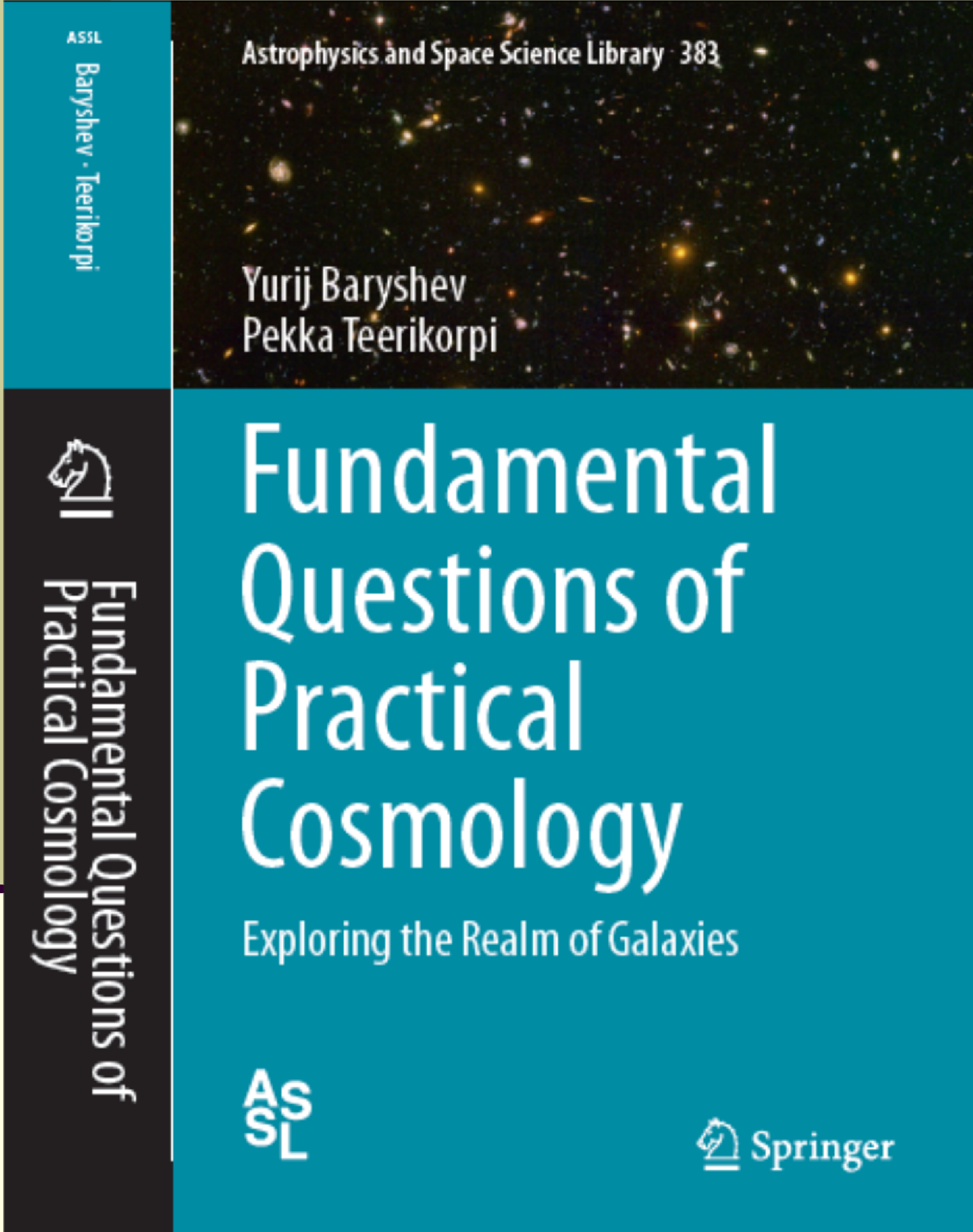
Observational test of the nature of the cosmological redshift



Sandage (1962)
ApJ, 136, 319
"the change of redshift with time"

$$\frac{dz}{dt}(z) \sim 1cm/s$$

Liske et al. (2008), MNRAS, 386, 1192



Yurij Baryshev,
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Thanks!