Релятивистская астрофизика:

современное состояние и перспективы

Ю. В. Барышев

Санкт-Петербургский государственный университет

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- **50 years of Relativistic Astrophysics:**
  - ***Relativistic Compact Objects (BHC, SN, AGN)***
  - ***Gravitational Radiation (GW)***
  - ***Cosmology (Hubble Law, LSS, CM)***
- **Gravity physics** as the basis of Relativistic Astrophysics ***(geometry*** g^{ik}***, material field*** ψ^{ik} ***)***
- **Crucial observational/experimental tests** of the fundamental and gravitational physics **(multi-messenger astronomy: γ, GW, ν …)**

50 years of Relativistic Astrophysics:

from 3C273 to GW150914

3C 273: A STAR-LIKE OBJECT WITH LARGE RED-SHIFT

By Dr. M. SCHMIDT
Mount Wilson and Palomar Observatories, Carnegie Institution of Washington, California Institute of Technology, Pasadena

THE only objects seen on a 200-in. plate near the positions of the components of the radio source 3C 273 reported by Hazard, Mackey and Shimmins in the preceding article are a star of about thirteenth magnitude and a faint wisp or jet. The jet has a width of 1″–2″ and extends away from the star in position angle 43°. It is not visible within 11″ from the star and ends abruptly at 20″ from the star. The position of the

Table 1. Wave-lengths and Identifications

λ	$\lambda/1{\cdot}158$	λ_0	
3239	2797	2798	Mg II
4595	3968	3970	$H\varepsilon$
4753	4104	4102	$H\delta$
5032	4345	4340	$H\gamma$
5200–5415	4490–4675		
5632	4864	4861	$H\beta$
5792	5002	5007	[O III]
6005–6190	5186–5345		
6400–6510	5527–5622		

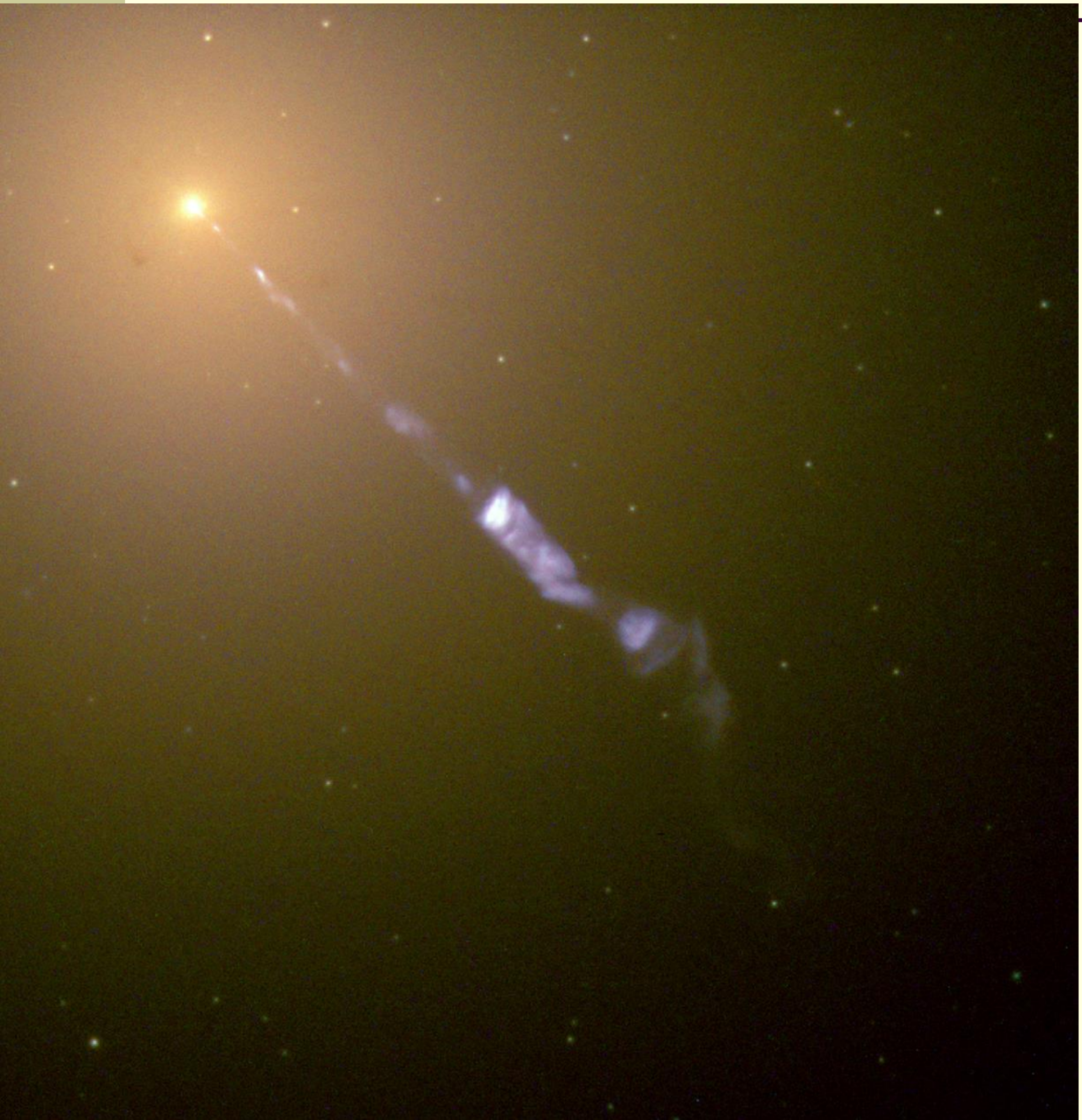
The beginning of Relativistic Astrophysics

3C 273 : Z = 0.158, jet ~ 100 kpc, L ~ 10^{47} erg/sec, $E_{rad} \approx 10^6\, M_{\odot} c^2$, Discovery of extremal (variable)

Relativistic Compact Objects (RCO) M=? R = ?

Modern RA: central energy machine + jet

R_g = GM/c^2 , M87: HST , EHT



HST

z = 0.00436

D=16.7 Mpc

Jet 10" - 770 pc

M_RCO = 6.2×10^9 $M_\odot$

R_Sch = 2×10^15 cm

Θ_Sch = 7.3 μas

EHT 1.3 mm

Θ_obs = 40 ± 1.8 μas =>

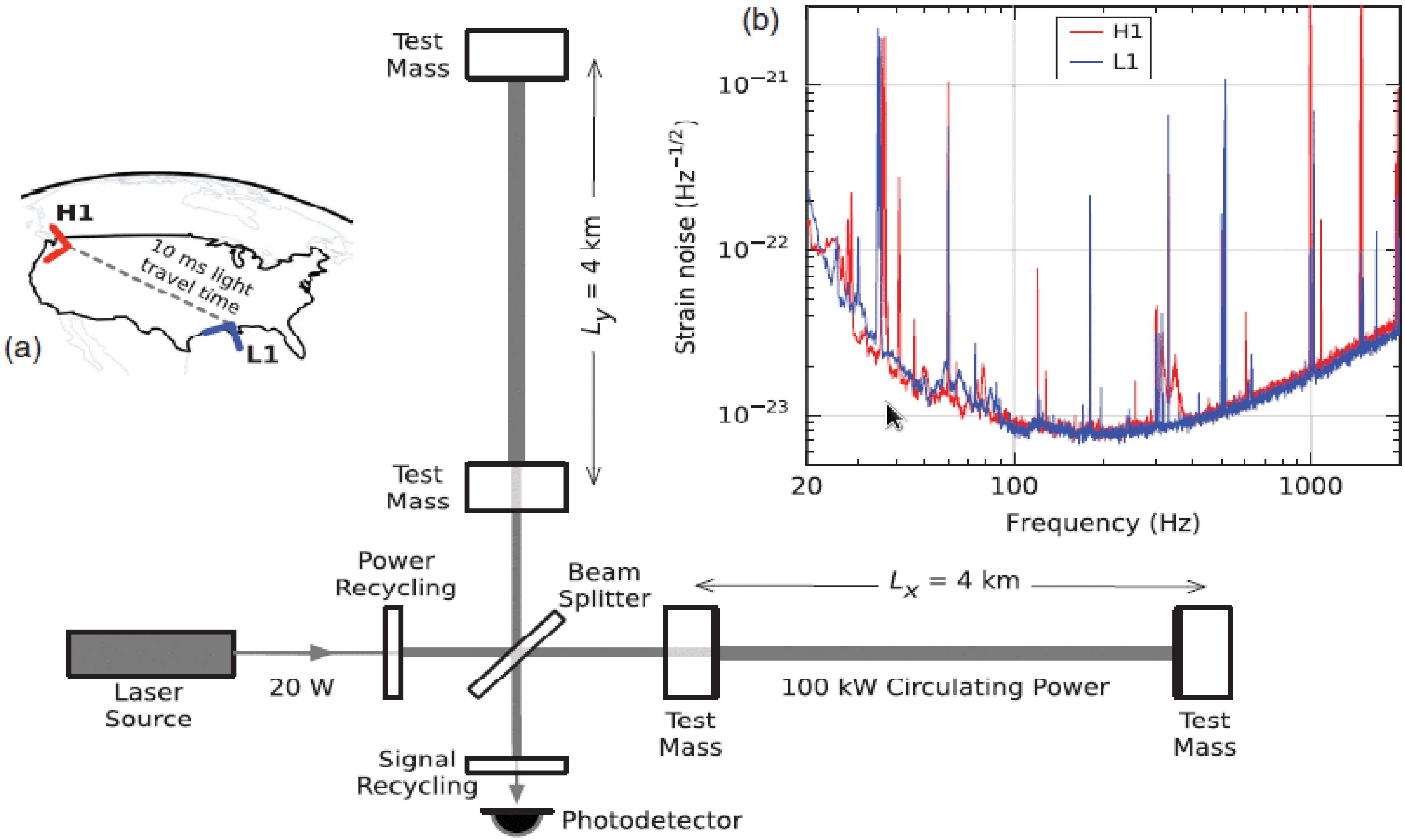
D = 5.5 R_Sch (R = 2.7_Sch)

Θ_ring = 38 μas =>

D = 5.2 R_Sch (R = 2.6_Sch)

R_Sch = 2R_g = 2GM/c^2

Abbott B. et al., Phys.Rev.Lett., 116, 061102 (2016)
(~ 1013 authors) GW 150914 $\Delta\tau(L1, H1) = 7ms$



ON RELATIVISTIC ASTROPHYSICS

F. Hoyle
St. John's College, Cambridge, England, and
California Institute of Technology, Pasadena, California

William A. Fowler
California Institute of Technology, Pasadena, California

G. R. Burbidge and E. Margaret Burbidge
University of California, San Diego, La Jolla, California

Received October 5, 1963

Astrophys. J., 139, 909 – 928 (1964)

In this paper we have attempted to discuss the relation of massive highly condensed objects to astrophysics in general, rather than only to the radio-source problem. Because situations in which general relativistic effects play a dominant role have not received much attention in astrophysics, a brief review of the relativistic properties of collapsed objects is given in Section I of the paper.

The first papers on Relativistic Astrophysics

- **Hoyle F., Fowler W., Burbidge G., Burbidge E.,**
 On relativistic astrophysics, **Ap. J., 139, 909, 1964** .
 (**GRT** and **alternative gravitation theory - C-field with negative energy to prevent Black Hole formation**)

- **Зельдович Я. Б., Новиков И. Д.**
 Релятивистская астрофизика I, II,
 УФН, 84, 377, Ноябрь **1964**, **УФН, 86, 447**, Июль **1965**.

Зельдович Я.Б., Новиков И.Д., ***Релятивистская астрофизика,*** **М.: Наука, 1967.** (Неизбежность ОТО и Черных Дыр – **no alternative gravitation theory)**.

Modern Relativistic Astrophysics (multi-messenger astronomy: γ, GW, ν …)

> ***Relativistic Compact Objects:*** **black hole candidates $3 \div 10^{10}$ M_{sun} ,** **Energy Sources and Origin of Jets (GRB**, **CCSN** (SN1987A)**, AGN, Blazars** (EHT, Fe K_α)**)**

> ***Gravitational Radiation:*** **binary RCO and massive SN explosions (PSR1913+16, SN1987A, LIGO GW events)**

> ***Cosmology:*** **cosmological models**, **Hubble law, large scale structure, fractals, dark matter, deep fields**

Common basis is *relativistic gravity theory* (quantum field theory of the fundamental interactions)

Modern questions discussed in the literature on Relativistic Astrophysics

Does General Relativity hold in the strong field regime?

Does General Relativity hold on cosmological scales?

Are there alternative gravity theories which predicts testable crucial experiments/observations?

General Theory of Relativity: Will it survive the next decade?

Search for General Relativity limits

and

to resolve the gravitational energy problem

Modern reviews of
relativistic* metric *gravity theories

Will C., *The Confrontation between General Relativity and Experiment*, Living Rev. Rel., 17, 113pp., (2014) – (415 ref.) includes discussion of 6 alternative **metric** gravity theories (modifications of GRT).

Clifton T. et al., *Modified gravity and cosmology*, Physics Reports, Vol. 513, Iss. 1, 189pp. (2012) - **review** of 13 alternative **metric** gravity theories (*1316 ref.*).

Main motivation is an extension of geometrical GRT including addition of extra fields (scalar, vector, …)

Modern review of
the field non-metric gravity theories

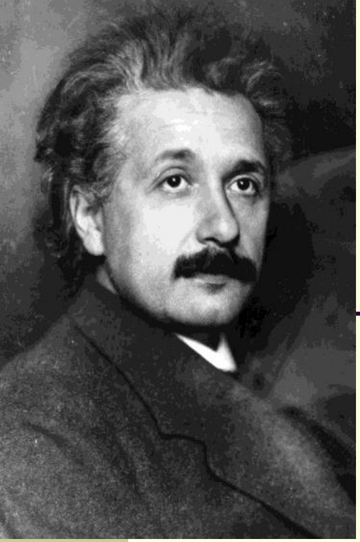
Comparison of **Feynman's non-metric** field approach to gravity physics with **Einstein's metric** gravity theory:

Baryshev Y., *Foundation of Relativistic Astrophysics: Curvature of Riemannian Space versus Relativistic Quantum Field in Minkowski space*, arXiv:1702.02020 (2017), 88 pp., 224 references, including my 28 papers in: **G&C, A&A, ApJ, JCAP, Аф, ПАЖ, АЖ …**

Main motivations is :

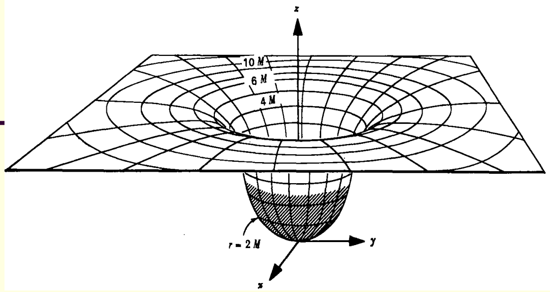
*** unification of fundamental physical interactions**

*** resolution of the gravitational energy problem**



Two ways in gravity theory

Einstein's Geometrical Gravity



(General Relativity Theory,

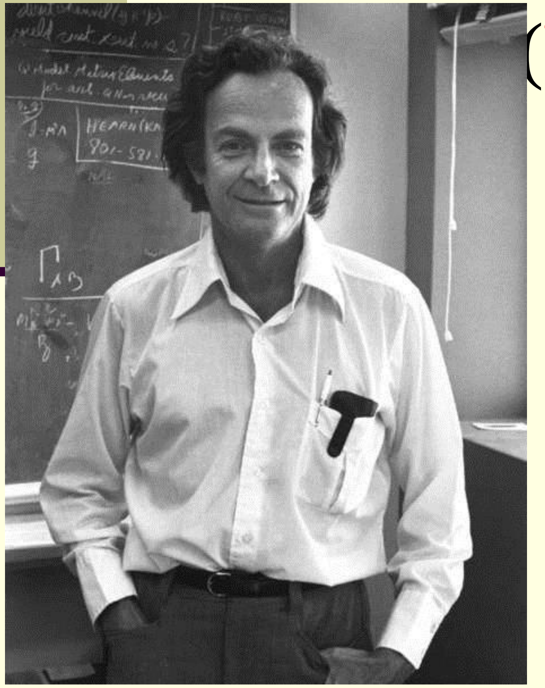
Geometrodynamics - GRT)

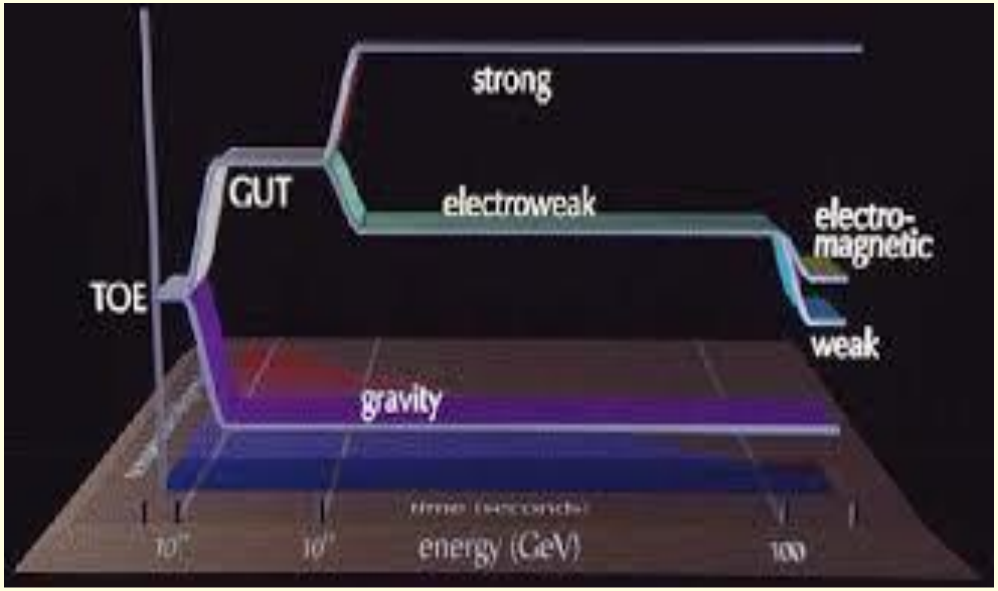
and

Feynman's Field Gravity Approach

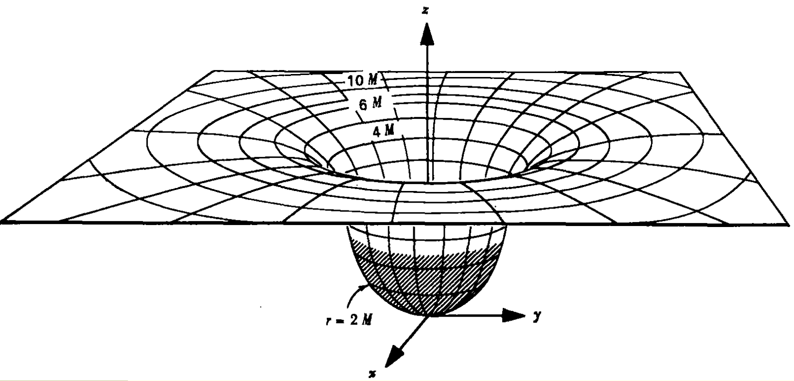
(Field Gravitation Theory, Gravidynamics

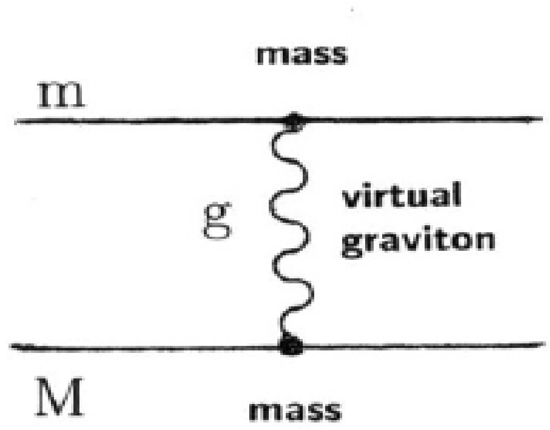
- FGT)





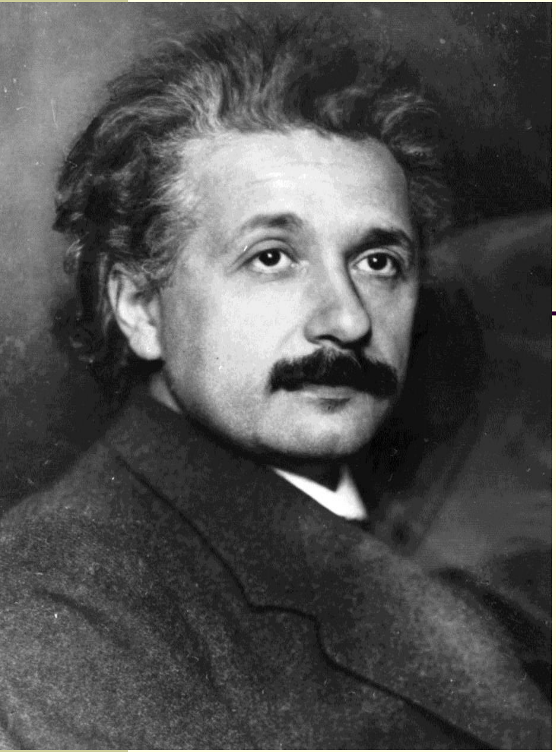
Metric and nonmetric gravity physics





- Einstein's geometrical general relativity theory of curved Riemannian space (GRT and its modifications) $g^{ik}(\vec{r},t),\ \mathcal{R}_{iklm}$
- Feynman's relativistic quantum field theory in Minkowski space (FGT) $\eta^{ik},\quad \psi^{ik}(\vec{r},t),\quad \vec{F}_g,$

$$T^{00}(t,x) = \varepsilon_g\left(\frac{erg}{cm^3}\right),\ \ E_{(g)} = h\nu$$

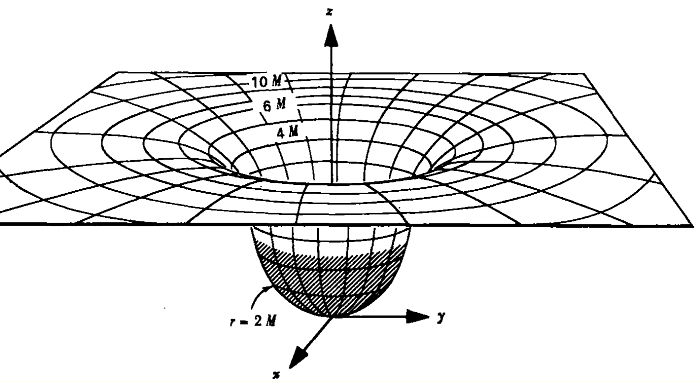


Albert Einstein
(1879 – 1955)

Nobel Prize in Physics (1921) :

"for his services to theoretical physics, and especially for his discovery of the law of the photoelectric effect”

General Relativity Theory (GRT)



Gravity is R-Geometry, g^{ik} is metric

Einstein A., Sitzungsber. K. Preuss. Akad. Wiss. 1, 844 (**1915**) (gravity is not a matter)

Einstein A., Sitzungsber. K. Preuss. Akad. Wiss. 1, 688 (**1916**) ; 154 (**1918**) GW

Gravitational Waves : $g^{ik} \approx \eta^{ik} + h^{ik}$ => $\Box h^{ik} = 0$

Richard Phillips Feynman (1918 – 1988)

Nobel Prize in Physics (1965) :
"for his fundamental work in
quantum electrodynamics "

"Lectures on Gravitation"(1962), CIT

Feynman's Field Gravity approach:

$\eta^{ik}, \quad \psi^{ik}(\vec{r},t), \quad \vec{F}_g, \quad \varepsilon_g\ (erg/cm^3)$

(Gravity is relativistic quantum field in Minkowski space)

"The **geometric interpretation** is **not really necessary or essential to physics**" Gravitational Waves: $\boldsymbol{\Box\psi^{ik} = 0}$

"the situation is exactly **analogous to electrodynamics** - and in the **quantum interpretation**, every radiated **graviton** carries away an amount of **energy ђω**." (A^i - ED, ψ^{ik}- GD)

Field and Geometrical approaches to gravitation

Field Gravitation Theory

$\eta^{ik}, \psi^{ik}(\vec{r},t), \vec{F}_g$

$\mathbf{Trace}(\boldsymbol{\psi}^{ik}) = \boldsymbol{\eta}_{ik}\boldsymbol{\psi}^{ik}(\vec{\boldsymbol{r}},\boldsymbol{t}) =$
$= \boldsymbol{\psi}(\vec{\boldsymbol{r}},\boldsymbol{t})$ **– fuction of spacetime**

$f^{ik} = \eta^{ik} + \psi^{ik}$

$f_{ik} = \eta_{ik} + \psi_{ik}$

$\boldsymbol{f^i}_{\boldsymbol{k}}(\vec{\boldsymbol{r}},\boldsymbol{t}) = \boldsymbol{\eta^i}_{\boldsymbol{k}} + \boldsymbol{\psi^i}_{\boldsymbol{k}}(\vec{\boldsymbol{r}},\boldsymbol{t})$

non-metric Spin 2 $\oplus$ Spin 0

"New Relativistic Astrophysics"

RCO (**noBH**), EMT, GW(T+S)

Positive Localizable Gravity Energy, Cosmological models with Evolution in Static Space

General Relativity

$g^{ik}(\vec{r},t), \mathcal{R}_{iklm}$

$\mathbf{Trace}(\boldsymbol{g}^{ik}) = \boldsymbol{g}_{ik}\,\boldsymbol{g}^{ik} =$
$= \mathbf{4}$ **- costant**

$g^{ik} \approx \eta^{ik} + h^{ik}$

$g_{ik} \approx \eta_{ik} - h_{ik}$

$\boldsymbol{g^i}_{\boldsymbol{k}} = \boldsymbol{\delta^i}_{\boldsymbol{k}} = \boldsymbol{const}$

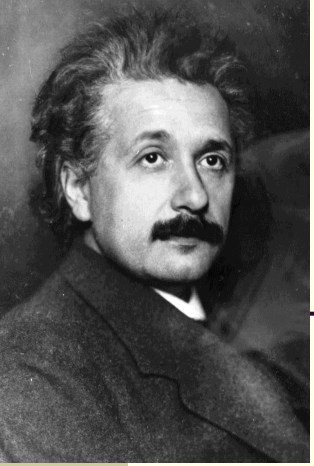
"modifications of GR and other **metric theories**"

BH, **no EMT**, GW(T),

no Localization of Gravity Energy, Cosmological models with Expanding Space

General Relativity Theory:

basic principles, main equations and predictions



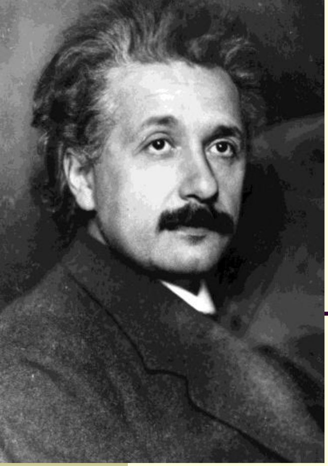
GRT basic principles

- The **Equivalence Principle:** free falling frames equivalent inertial reference frames , $m_{inert} = m_{grav}$(WEP), …

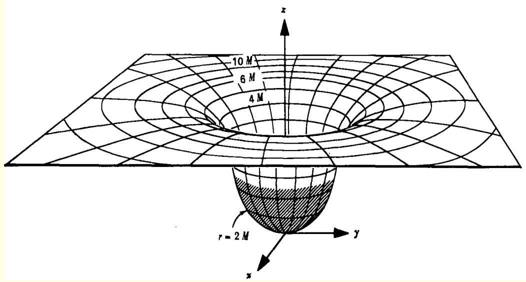
- The **Geometrization Principe:** gravitational potentials are described by the metric tensor $g^{ik}(\vec{r}, t)$ of the Riemannian space-time

- The **Stationary Action Principle** (geometrical extension of)

$$\delta S = \delta(S\_m + S\_g) = 0 \quad \text{for} \quad \delta g^{ik}$$



GRT main equations



$$ds^2 = g_{ik}dx^i dx^k$$

$g^{ik}(\vec{r},t)$; $\mathcal{R}_{iklm}$; $\boldsymbol{g_{ik}\, g^{ik} = 4;}$ δg^{ik}, $\delta S = 0$

$$S = S_{(\mathrm{m})} + S_{(\mathrm{g})} = \frac{1}{c}\int \left(\Lambda_{(\mathrm{m})} + \Lambda_{(\mathrm{g})}\right)\sqrt{-g}\,d\Omega$$

$$\Re^{ik} - \frac{1}{2}g^{ik}\,\Re = \frac{8\pi G}{c^4}\,T^{ik}_{(m)} \qquad T^{ik}_{(\mathrm{m})\,;\,i} = 0 \qquad \frac{du^i}{ds} = -\Gamma^i_{kl}u^k u^l$$

$$\frac{\partial}{\partial x^k}(\sqrt{-g})(T^{ik}_{(\mathrm{m})} + t^{ik}_{(\mathrm{g})}) = 0$$

${T_{(m)}}^{ik} = {T_{(p)}}^{ik} + {T_{(vac)}}^{ik}$ which includes matter and vacuum (*dark energy*) ${T_{(v)}}^{ik} = g^{ik}\Lambda$ but **does not includes the gravity field**

EMT : gravity field is not a matter in GR (no ${T_{(g)}}^{ik}$),

$\boldsymbol{t^{ik}}_{(g)}(\boldsymbol{t},\boldsymbol{x})$ is the gravity **Energy-Momentum Pseudo-Tensor**

The energy problem in GRT: $t^{ik}{}_{(g)}(t, x)$ is Pseudo-Tensor

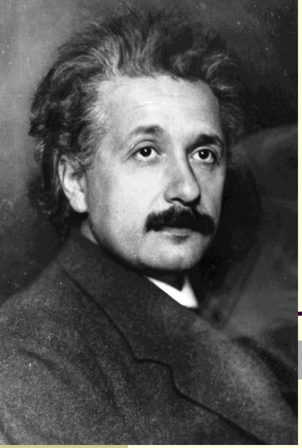
L.D.Landau & E.M.Lifshitz "The Classical Theory of Fields", Oxford (1971)

$$T^{00}{}_{(e)}(r) = +\frac{(\nabla\varphi_e)^2}{8\pi}$$

Misner, C., Thorne, K., Wheeler, J. "Gravitation", Freeman, San Francisco (1973)

$$t^{00}{}_{(gLL)}(r) = -\frac{7\,(\nabla\varphi)^2}{8\pi G}$$

- "It has no meaning to speak of a definite localization of the energy $t^{ik}{}_{(g)}(t, x)$ of the gravitational field in space" (§101, p.307)
- (§20.4,p.467) "..gravitational energy... is not localizable. The equivalence principle forbids", and (§35.7, p.955): "the stress-energy carried by gravitational waves cannot be localized inside a wavelength".

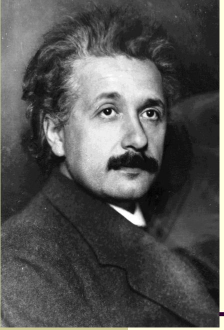


GRT predictions in the weak field approximation

- *Universality of free fall for any bodies,*
- *The deflection of light by massive bodies,*
- *The gravitational frequency-shift,*
- *The time delay of light signals,*
- *The perihelion shift of planets,*
- *The Lense-Thirring effect,*
- *The geodetic precession of a gyroscope,*

+ *Phenomena based on Pseudo-Tensor calculations:*

- *The emission of quadrupole gravitational waves,*
- *The detection of the gravitational waves .*



GRT open questions

- Existence and localization of GW energy (according to MTW 1973 (§20.4, p.467): *"...gravitational energy... is not localizable. The equivalence principle forbids"*

  $g^{ik} \approx \eta^{ik} + h^{ik} \;\; => \;\; \square h^{ik} = 0 \;\; <=> \; \boldsymbol{t^{ik}}_{(\boldsymbol{g})}(\boldsymbol{t}, \boldsymbol{x}) = ?$

- Existence of Black Holes event horizon and singularity

  $r_{Sch} = 2GM/c^2 \quad => \quad \boldsymbol{t^{ik}}_{(\boldsymbol{g})}(\boldsymbol{t}, \boldsymbol{x}) = ?$

$$ds^2 = (1 - \frac{r_{\text{Sch}}}{r})c^2dt^2 - \frac{dr^2}{1 - \frac{r_{\text{Sch}}}{r}} - r^2(\sin^2\theta\, d\phi^2 + d\theta^2)$$

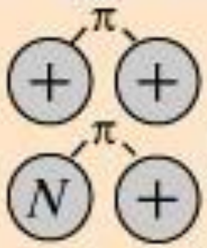
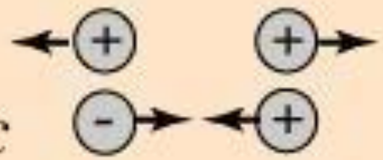
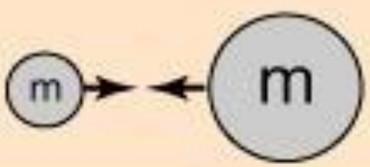
- Existence of continuous space creation with vacuum in Friedmann's cosmological model $r(t) = S(t) \cdot \chi$,

$$ds^2 = c^2dt^2 - S^2(t)d\chi^2 - S^2(t)I_k^2(\chi)(d\theta^2 + sin^2\theta d\phi^2) \quad \boldsymbol{t^{ik}}_{(\boldsymbol{g})}(\boldsymbol{t}, \boldsymbol{x}) = ?$$

Relativistic Quantum Field Gravitation Theory:

basic principles, main equations and predictions

Fundamental Forces

Force	Diagram	Strength	Range (m)	Particle
Strong	 Force which holds nucleus togeher	1	10^{-15} (diameter of a medium sized nucleus)	gluons, π(nucleons)
Electro-magnetic		$\frac{1}{137}$	Infinite	photon mass = 0 spin = 1
Weak	 neutrino interaction induces beta decay	10^{-6}	10^{-18} (0.1% of the diameter of a proton)	Intermediate vector bosons W^+, W^-, Z_0, mass > 80 GeV spin =1
Gravity		6×10^{-39}	Infinite	graviton ? mass = 0 spin = 2

History of the Field Gravitation Theory

Poincare(1905), Fierz & Pauli(1939), Birkhoff(1944), Moshinsky(1950), Thirring (1961), Kalman (1961)…

Minkowski space η^{ik} : $A^i(\vec{r},t)$- ED, $\psi^{ik}(\vec{r},t)$ - GD

Richard Feynman (1962,1971,1995), *Lectures on Gravitation,* Caltech (Spin 2 gravitons)

V. V. Sokolov, Yu. V. Baryshev(1980),

Field-theoretical approach to gravitation: Energy Momentum Tensor of the field, Gravitation and Relativity Theory, Kazan State University, vyp.17, 34 (1980):

$$\mathrm{Tr}\,\psi^{ik} = \eta_{ik}\psi^{ik} = \psi(\vec{r},t) \rightarrow \text{Spin 2 + Spin 0}$$

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:

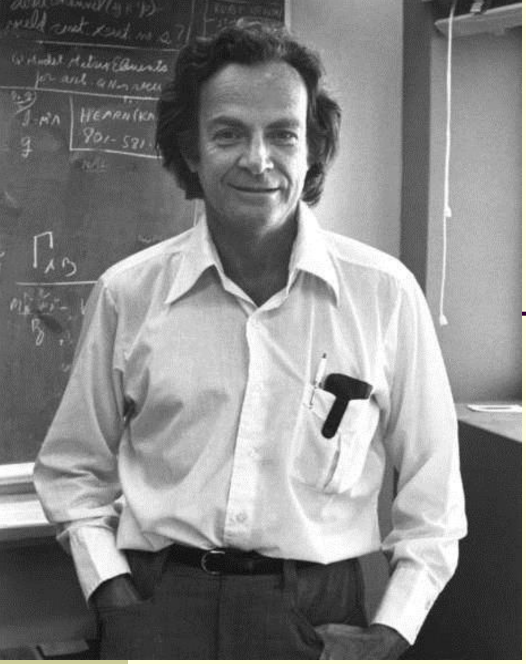
"Remind me not to come to any more gravity conferences!"

Feynman's Field Gravity approach:

ψ^{ik} - symmetric tensor field in Minkowski space

(A^i - ED, ψ^{ik} - GD)

$T_{(fg)}{}^{ik}$ - true EMT of the gravitational field with positive energy density



Feynman Lectures on Gravitation

(1962-1963 course at Caltech)

Lecture 1

1.1 A Field Approach to Gravitation

1.3 Quantum Effects in Gravitation

Lecture 3

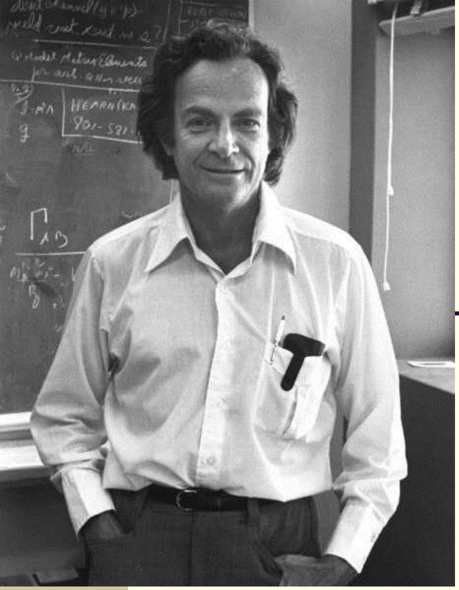
3.1 The Spin of the Graviton

3.5 The Lagrangian for the Gravitational Field

Lecture 16

16.4 Radiation of Gravitons

16.5 The Sources of Classical Gravitational Waves



from Feynman's book :

- "The geometric interpretation is not really necessary or essential to physics." (p.113) (A^i - ED, ψ^{ik}- GD)
- "the situation is exactly analogous to electrodynamics - and in the quantum interpretation, every radiated graviton carries away an amount of energy ђω." (p.220)

From letter to his wife: **"Remind me not to come to any more gravity conferences!"** (Warsaw 1962)

Physical basis for theory of gravitational interaction

Field approach

- 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

Geometry

- 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 EM **Pseudo-Tensor** of the gravity field $t_{(g)}{}^{ik}$
- The Equivalence Principle

$m_{inert} = m_{grav}$

free falling frames

Relativistic Compact Objects, GW, Cosmological models

Comparison of FG and GR: field equations

Field Gravity	General Relativity
$\eta^{ik},\ \psi^{ik}(\vec{r},t),\ \psi(\vec{r},t), T_{(g)}{}^{ik}$	$g^{ik},\quad g_{ik}\, g^{ik} = 4,\quad \mathcal{R}_{iklm}\,,$
$\Lambda_{(int)} = \psi_{ik} T^{ik}$	

$$S = S_{(g)} + S_{(int)} + S_{(m)}$$

$$-\psi^{ik,l}{}_{l} + \psi^{il,k}{}_{l} + \psi^{kl,i}{}_{l} - \psi^{,ik} -$$

$$- \eta^{ik}\psi^{lm}{}_{,lm} + \eta^{ik}\psi_{,}{}^{l}{}_{l} = \frac{8\pi G}{c^2} T^{ik}$$

$$\psi^{ik} \Rightarrow \psi^{ik} + \lambda^{i,k} + \lambda^{k,i} \qquad \psi^{ik}{}_{,k} = \frac{1}{2}\psi^{\,,i}$$

$$\left(\Delta - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)\psi^{ik} = \frac{8\pi G}{c^2}\left[T^{ik} - \frac{1}{2}\eta^{ik} T\right]$$

$$\left(T^{ik}_{(p/m)} + T^{ik}_{(int)} + T^{ik}_{(g)}\right)_{,\,i} = 0$$

gravity EM Tensor $\boldsymbol{T_{(g)}{}^{ik}}$

$$S = S_{(m)} + S_{(g)}$$

$$\Re^{ik} - \frac{1}{2} g^{ik}\, \Re = \frac{8\,\pi\, G}{c^4}\, T^{ik}_{(m)}$$

$$T^{ik}_{(m)\ ;\ i} = 0$$

$$\frac{\partial}{\partial x^k}(-g)(T^{ik}_{(m)} + t^{ik}_{(g)}) = 0$$

gravity EM Pseudo-Tensor
$\boldsymbol{t_{(g)}{}^{ik}}$

Comparison of FGT and GRT: P-N gravitational potentials of SSS body

Field Gravity | General Relativity

Weak field approximation

$$\left(\triangle - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)\psi^{ik} = \frac{8\pi G}{c^2}\left[T^{ik} - \frac{1}{2}\eta^{ik}T\right]$$

$$T^{ik} = T^{ik}_{(p/m)} + T^{ik}_{(int)} + T^{ik}_{(g)}$$

$$(\psi^{ik}) = \mathrm{diag}(\Phi, \varphi_{\mathrm{N}}, \varphi_{\mathrm{N}}, \varphi_{\mathrm{N}})$$

$$\hat{g}_{ik} = \eta_{ik} + \psi_{ik}/c^2$$

$$\hat{g}^{ik} = \eta^{ik} + \psi^{ik}/c^2$$

$$\hat{g}^i_k = \delta^i_k + \psi^k_i/c^2$$

$$\hat{g}_{ik}\cdot\hat{g}^{ik} \approx 4 + 2\psi/c^2$$

$$\varphi_N(r) = -\frac{GM}{r} \quad \text{for} \quad r > R_0$$

Weak gravity approximation

$$g_{ik} = \eta_{ik} + h_{ik} \qquad |h_{ik}| << 1$$

$$\left(\triangle - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)h^{ik} = \frac{16\pi G}{c^4}\left[T^{ik}_{(m)} - \frac{1}{2}\eta^{ik}T_{(m)}\right]$$

$$g_{ik} = \eta_{ik} + \frac{2\varphi_N}{c^2}diag(1,1,1,1)$$

$$g^{ik} = \eta^{ik} - \frac{2\varphi_N}{c^2}diag(1,1,1,1)$$

$$g^i_k = \delta^i_k$$

$$g_{ik}\cdot g^{ik} = 4$$

Repulsive force of the scalar part of the gravitational potential in the Field Gravity Theory for SSS body with mass M

Birkhoff's $\psi^{ik}(r) = \varphi_N diag(1,1,1,1), \quad \varphi_N(r) = -GM/r$

can be presented as a sum $\psi^{ik} = \psi^{ik}_{\{2\}} + \psi^{ik}_{\{0\}}$

$$\psi^{ik} = \frac{3}{2}\varphi_{\rm N}\,{\rm diag}(1,\,\frac{1}{3},\,\frac{1}{3},\,\frac{1}{3}) \;-\; \frac{1}{2}\varphi_{\rm N}\,{\rm diag}(1,\,-1,\,-1,\,-1)$$

then from the equation of motion (Poincare force) we get the expression for Newtonian force $\overrightarrow{F_N} = m_0 d\vec{v}/dt$

$$F_{\rm N} = F_{\{2\}} + F_{\{0\}} = -\frac{3}{2}m_0\nabla\varphi_{\rm N} + \frac{1}{2}m_0\nabla\varphi_{\rm N} = -m_0\nabla\varphi_{\rm N}$$

Hence the Newton force of gravity is the sum of attraction due to the spin 2 tensor field and repulsion due to the spin 0 scalar field. Thus FGT is, strictly speaking, a scalar-tensor theory. But in contrast to the Brans-Dicke theory that introduces additional scalar field with coupling constant ω, in FGT the scalar field is the trace $\psi = \eta_{ik}\psi^{ik}$ of the tensor potential ψ^{ik} and has the same coupling constant G.

Field equations for spin 2 and spin 0 parts

Field Gravity

For spin 2 and spin 0 parts we can rewrite the field equation as

$$\left(\triangle - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)\phi^{ik} = \frac{8\pi G}{c^2}\left[T^{ik} - \frac{1}{4}\eta^{ik}T\right]$$

$\phi^{ik}(\vec{r},t) = \psi_{\{2\}}{}^{ik}$

$$\left(\triangle - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)\psi\frac{1}{4}\eta^{ik} = -\frac{8\pi G}{c^2}T\frac{1}{4}\eta^{ik}$$

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

where $\psi_{\{2\}}^{ik} = \phi^{ik}$ and $\eta_{ik}\phi^{ik} = 0.$ For tensor and scalar parts in the case of free field we get ordinary wave equations

Lagrangians : $\Lambda_{\{2\}} = \frac{1}{16\pi G}\phi_{lm,n}\phi^{lm,n}, \quad \text{and} \quad \Lambda_{\{0\}} = \frac{1}{64\pi G}\psi_{,n}\psi^{,n}$

Corresponding EMT: $T_{\{2\}}^{ik} = \frac{1}{8\pi G}\phi_{lm}{}^{,i}\phi^{lm,k}, \quad \text{and} \quad T_{\{0\}}^{ik} = \frac{1}{32\pi G}\psi^{,i}\psi^{,k}$

1) $T_{(g)}{}^{ik} = T_{(g)}{}^{ki}$; 2) $T_{(g)}{}^{00} > 0$; 3) $T = \eta_{ik}T_{(g)}{}^{ik} = 0$

FGT predictions in the weak field approximation

The universality of free fall for non-rotating bodies

The deflection of light by massive bodies

The gravitational frequency-shift

The time delay of light signals

The perihelion shift of planets (17% due to $T_{(g)}{}^{00}$)

The Lense-Thirring effect

The geodetic precession of a gyroscope

PLUS

The additional acceleration of rotating bodies (V^2/c^2)

The emission of spin2 and spin 0 gravitational waves,

The localization of the energy of the gravitational waves.

Existence of Gravitational Waves which carry positive energy and its localization by GW detector

A historical remark on Gravitational Waves prediction

Jules Henri Poincaré (1854–1912)

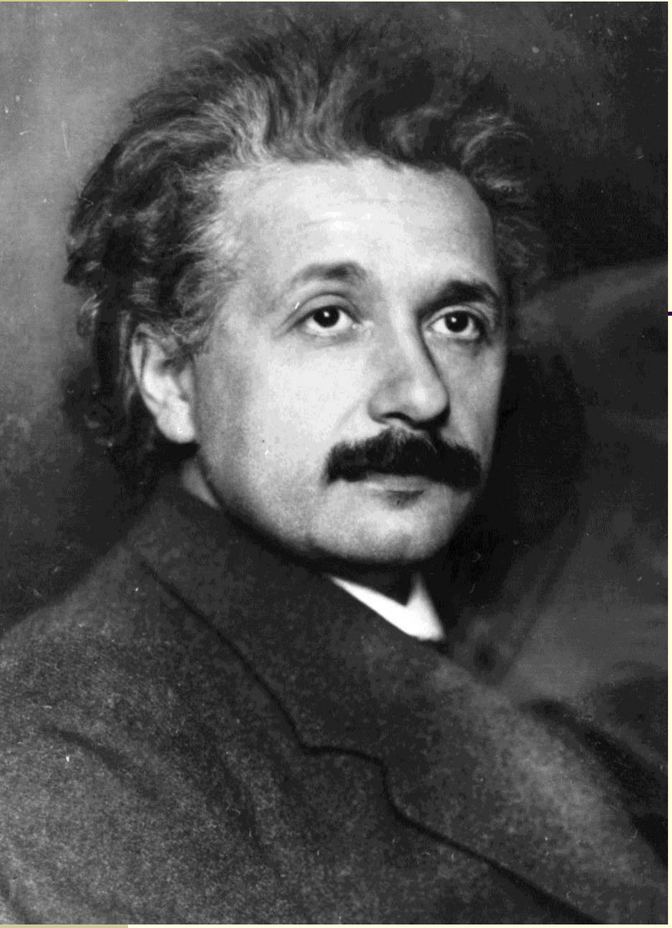
Poincare H., *Sur la dynamique de l'electron*, Compt. Rend. l'Acad. Sci., 140, p.1504 (**1905**);

Poincare H., *Sur la dynamique de l'electron*, Rend. Circolo matem. di Palermo, 21, p.129 (**1906**).

Gravitation as a fundamental force in relativistic 4d space-time

In 1905, Poincaré first predicted existence of the **gravitational waves** (*"ondes gravifiques"*) from a variable source and **propagating at the speed of light** as being required by the Lorentz transformations:

$$\left(\Delta - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)\Phi = \Box\Phi = 0$$ (instead of $\Delta\Phi$)



Albert Einstein (1879 – 1955)

General Relativity Theory (GRT)

Gravity is R-Geometry, g^{ik} is metric

Einstein A., Sitzungsber. K. Preuss. Akad. Wiss. 1, 844 (**1915**) (gravity is not a matter)

Einstein A., Sitzungsber. K. Preuss. Akad. Wiss. 1, 688 (**1916**) ; 154 (**1918**) GW as weak deflection **h**^ik from Minkowski metric

Einstein A., Rosen N. (**1936**) , (**1937**) *no GW in GRT → cylindrical GW exist*

Modern view on

Gravitational Waves : $g^{ik} \approx \eta^{ik} + h^{ik}$ => $\square h^{ik} = 0$

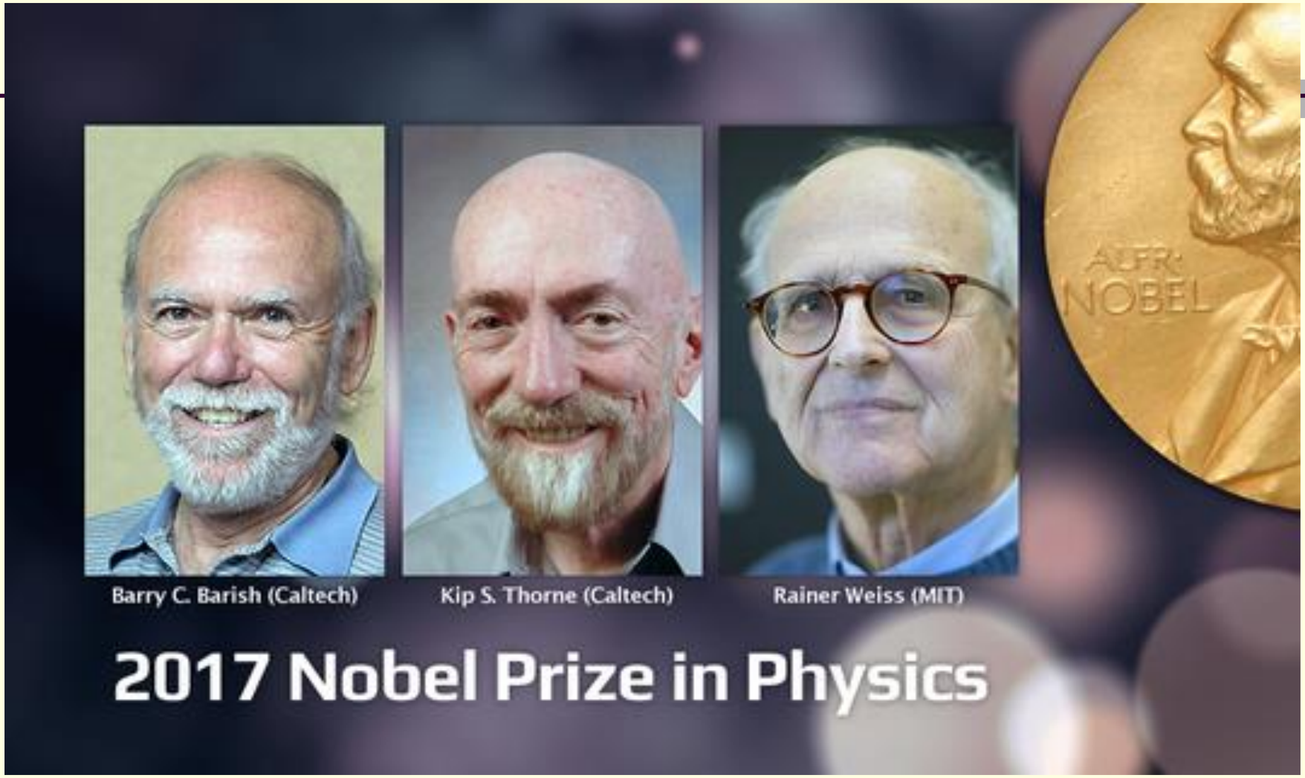
Joseph Hooton Taylor, (born March 29, 1941)

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

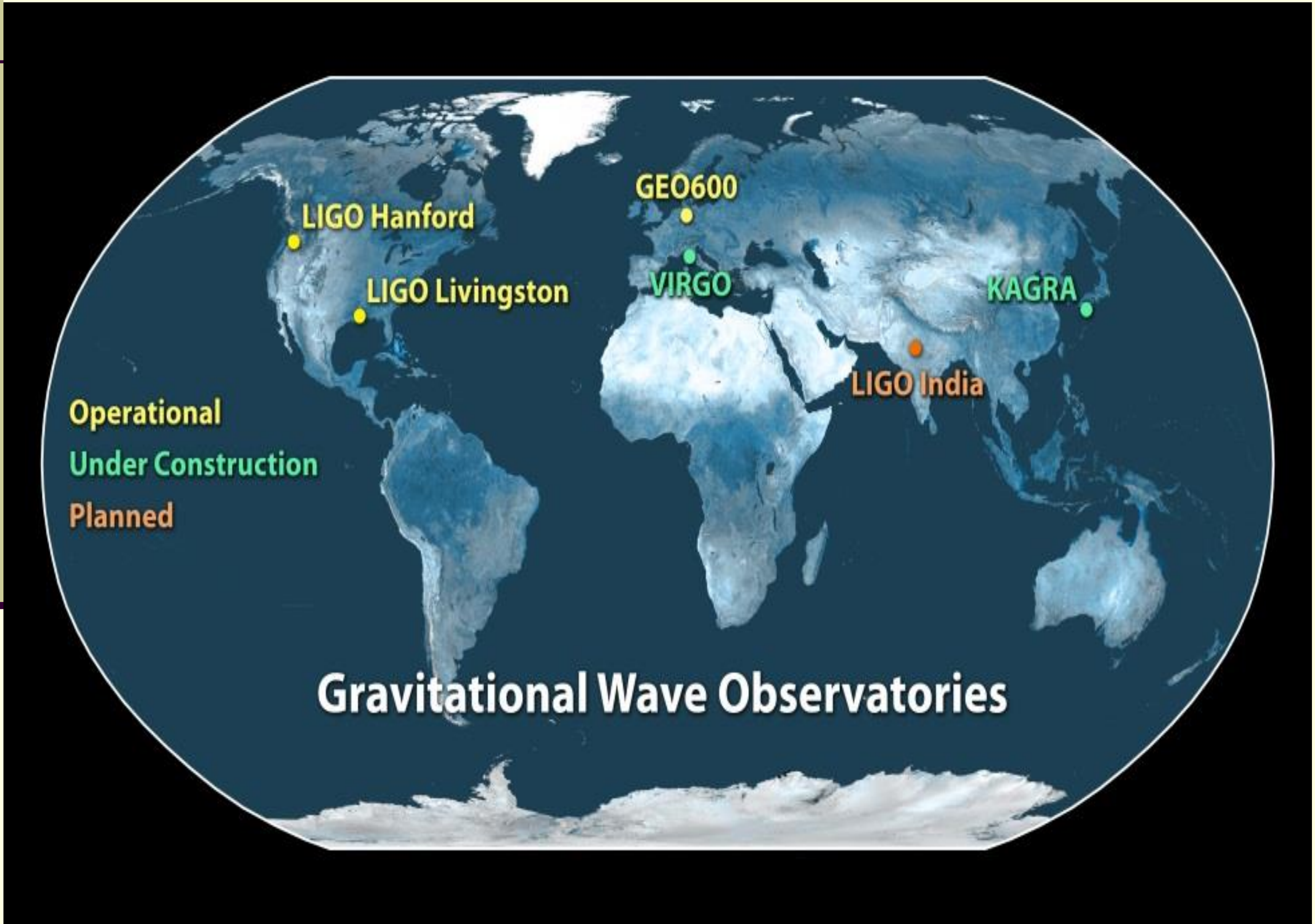
Nobel Prize awarded to LIGO Founders News Release • October 3, 2017



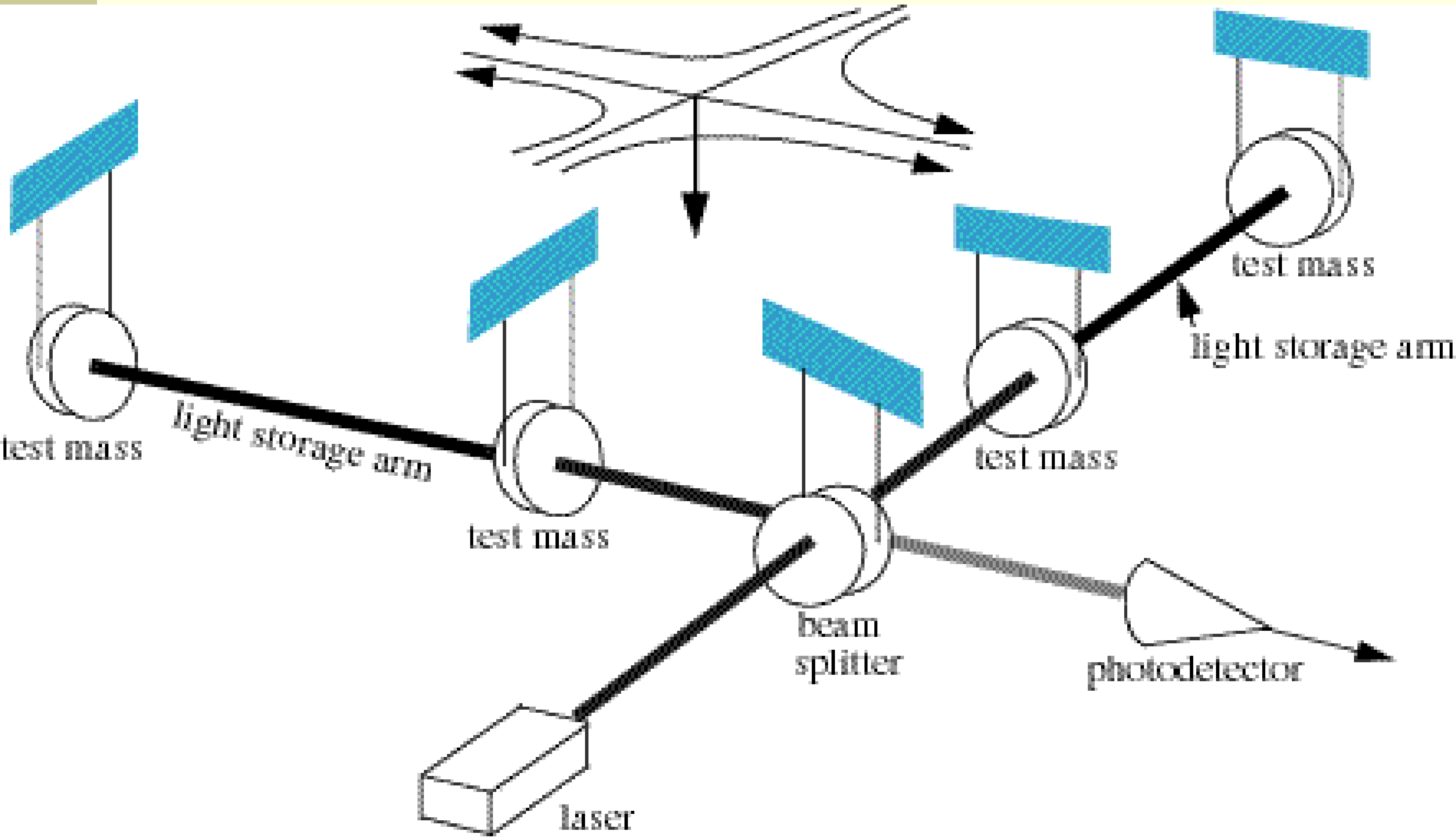
the 2017 Nobel Prize in Physics:
Barry Barish **and** ***Kip Thorne*** **of Caltech**
and ***Rainer Weiss*** **of MIT**

"for decisive contributions to the LIGO detector and the observation of gravitational waves"

Gravitational Waves detection

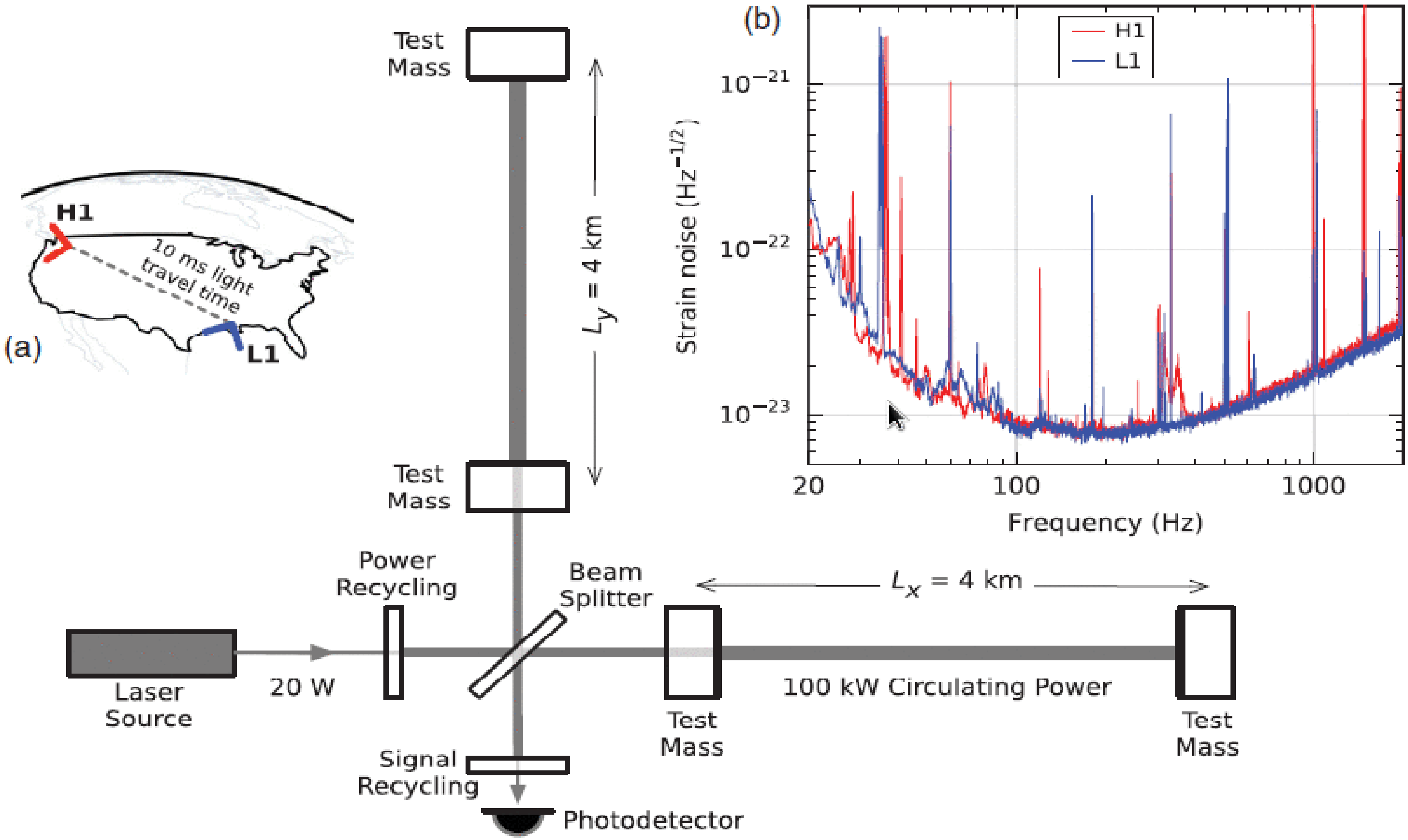


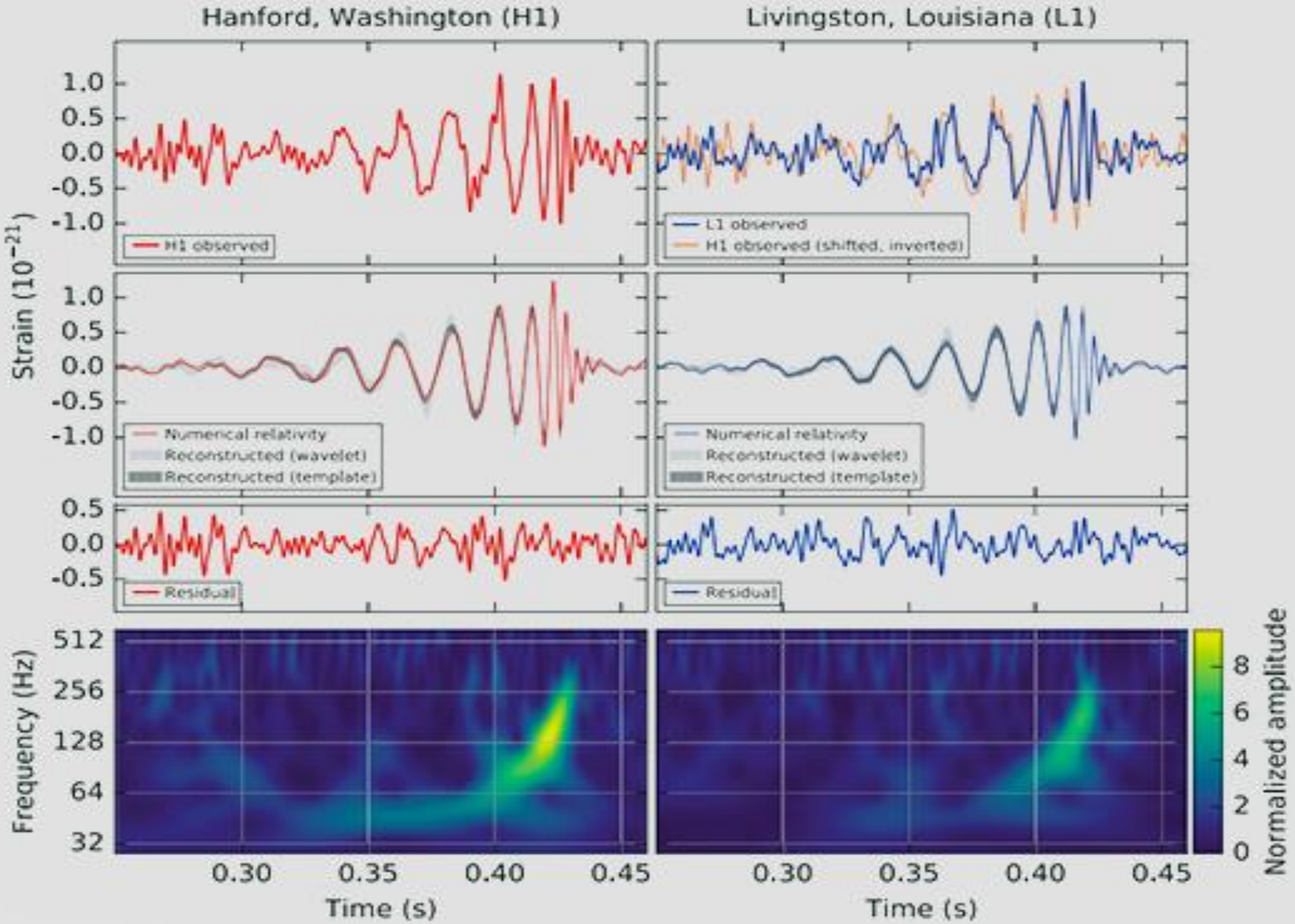
Feynman (1957), Bondi (1957), Gertsenstein & Pustovoit (1962),
LIGO design: Drever (Caltech), Thorne (Caltech), Weiss (MIT)
Nobel Prize in Physics 2017: Barry Barish, Kip Thorne, RainerWeiss



Laser Interferometer Gravitational-Wave Observatory (LIGO)

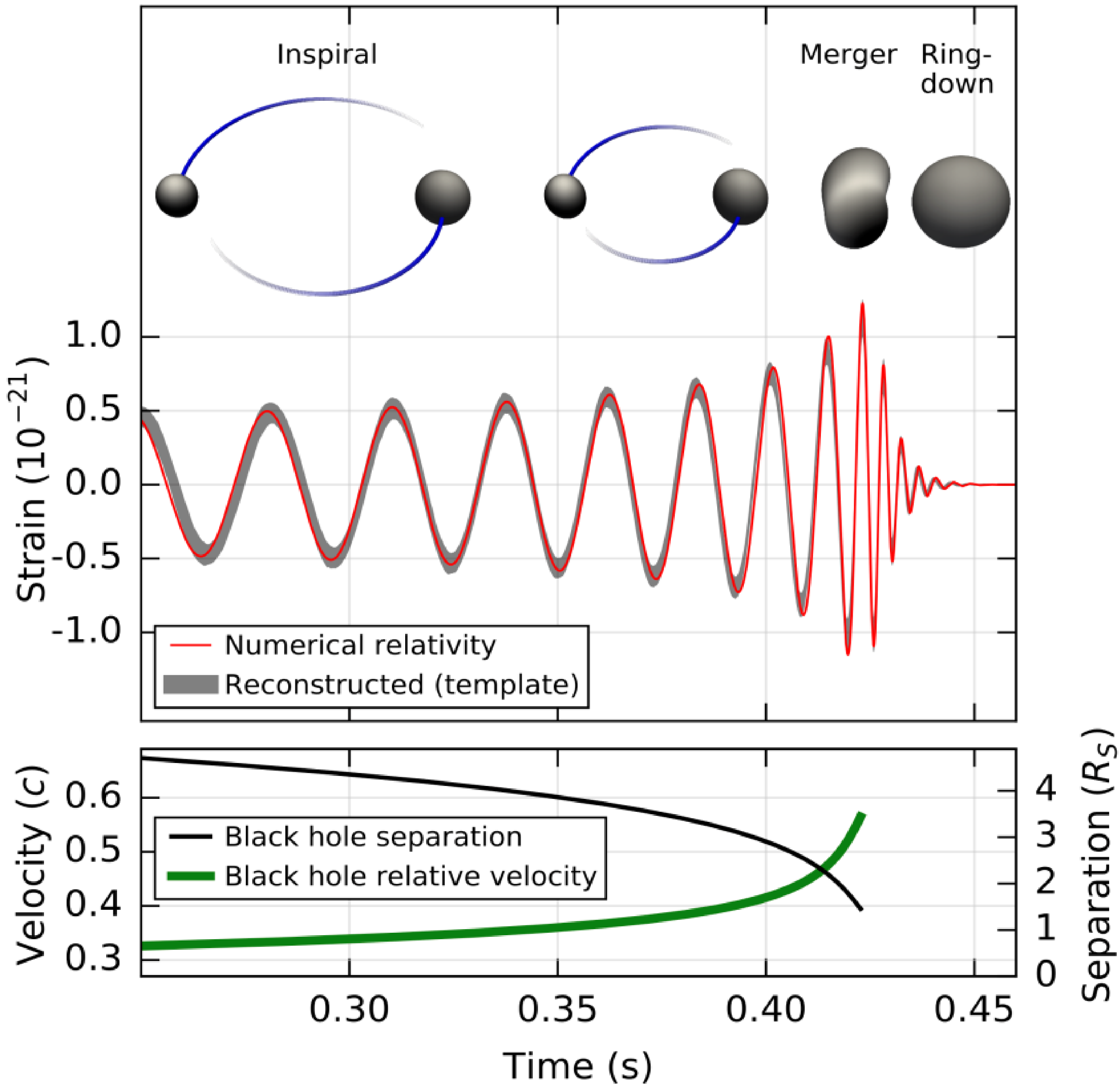
Abbott B. et al., Phys.Rev.Lett., 116, 061102 (2016) (~ 1013 authors) GW 150914 $\Delta\tau(L1, H1) = 7ms$





$$h = \frac{\Delta l}{l} = 10^{-21}, \qquad \Delta l = 4\ km \times h = 4 \times 10^{-16}\ \text{cm}$$

$$M_1 = 36\ M_\odot, \quad M_2 = 29\ M_\odot, \quad 410\ Mpc, \quad M_{1\cup 2} = 62\ M_\odot$$



GRT: BH
FGT: RCO

Binding
Energy ?

$$E_{rad} = 3M_{\odot}c^2$$

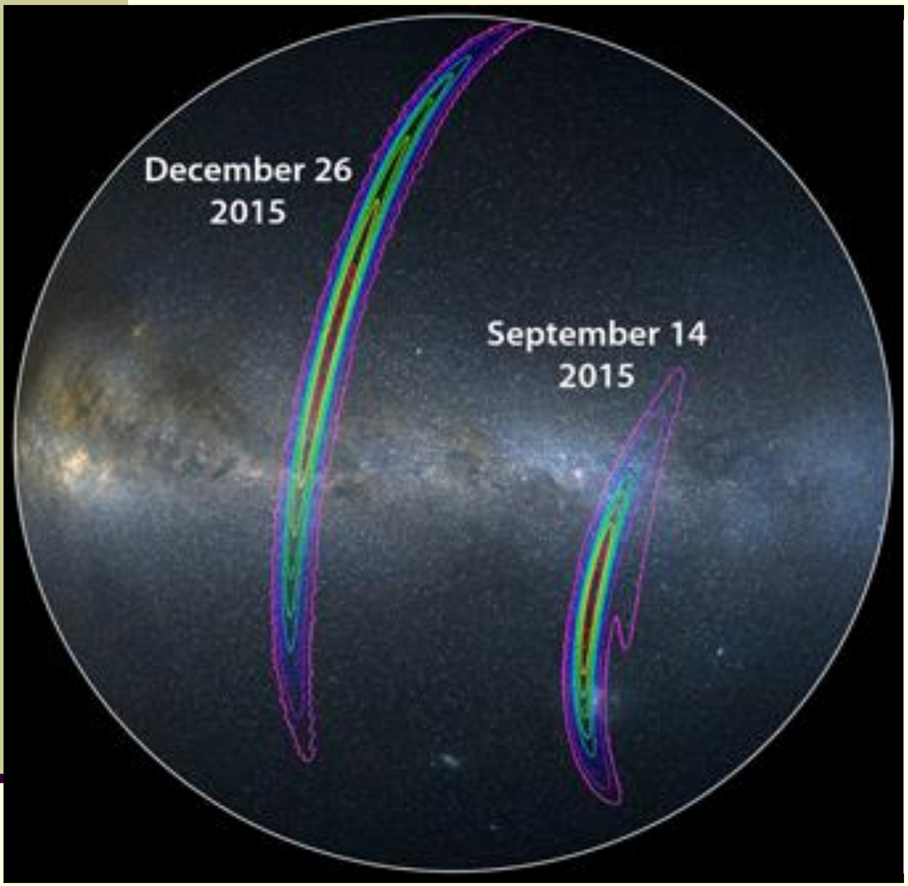
$$F_g \rightarrow \infty \ (?)$$

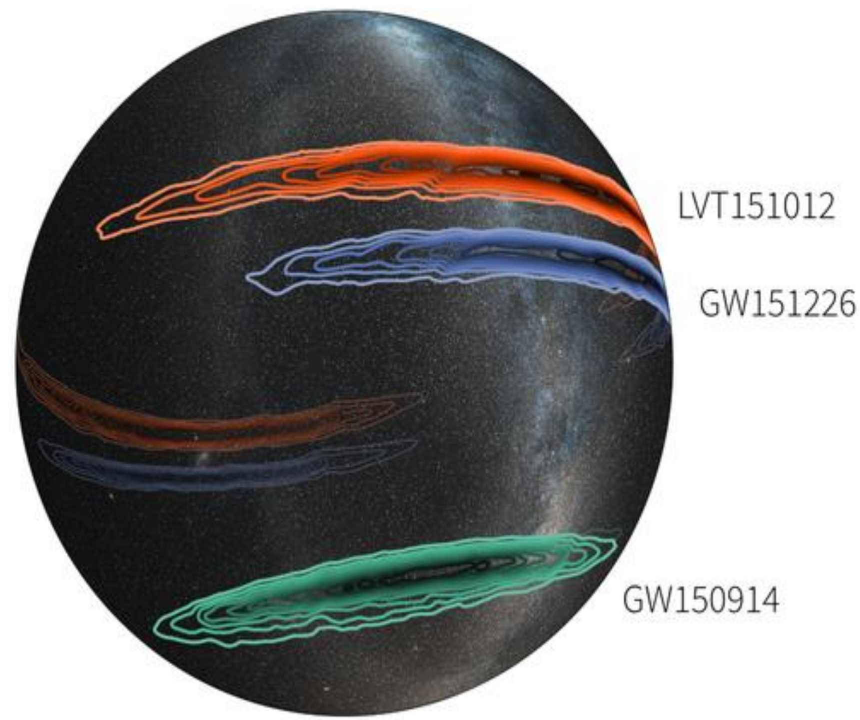
Localization of the GW
Energy ?

$$\boldsymbol{t^{ik}}_{(\boldsymbol{g})}(\boldsymbol{t}, \boldsymbol{x}) = ?$$

pseudotensor

LIGO: 3 GW events sky positions
GW150914, GW151226 and LVT151012





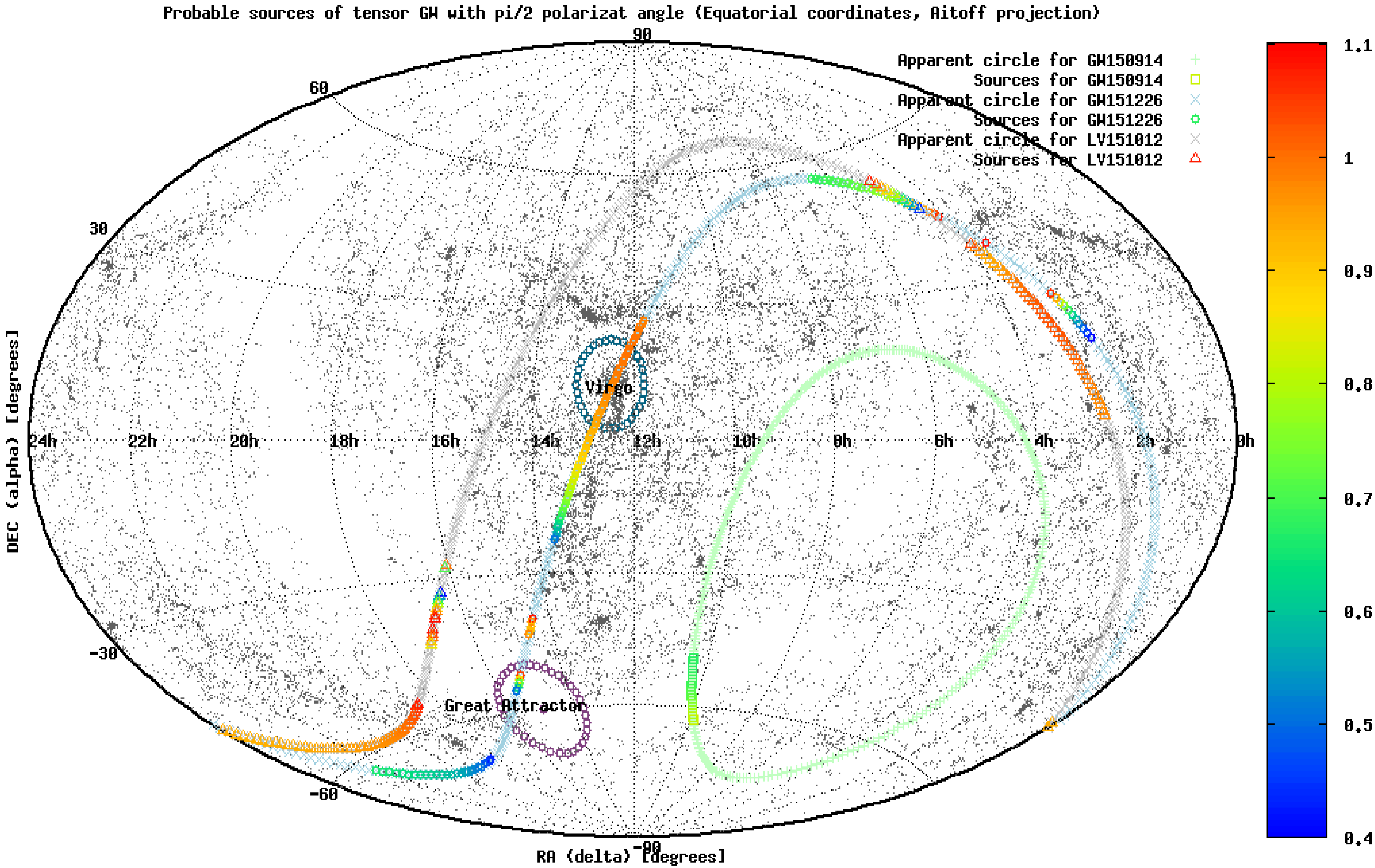
GW150914 : $M_1 = 36\, M_\odot$, $M_2 = 29\, M_\odot$, $420\, Mpc$

GW151226 : $M_1 = 14\, M_\odot$, $M_2 = 7.5\, M_\odot$, $440\, Mpc$

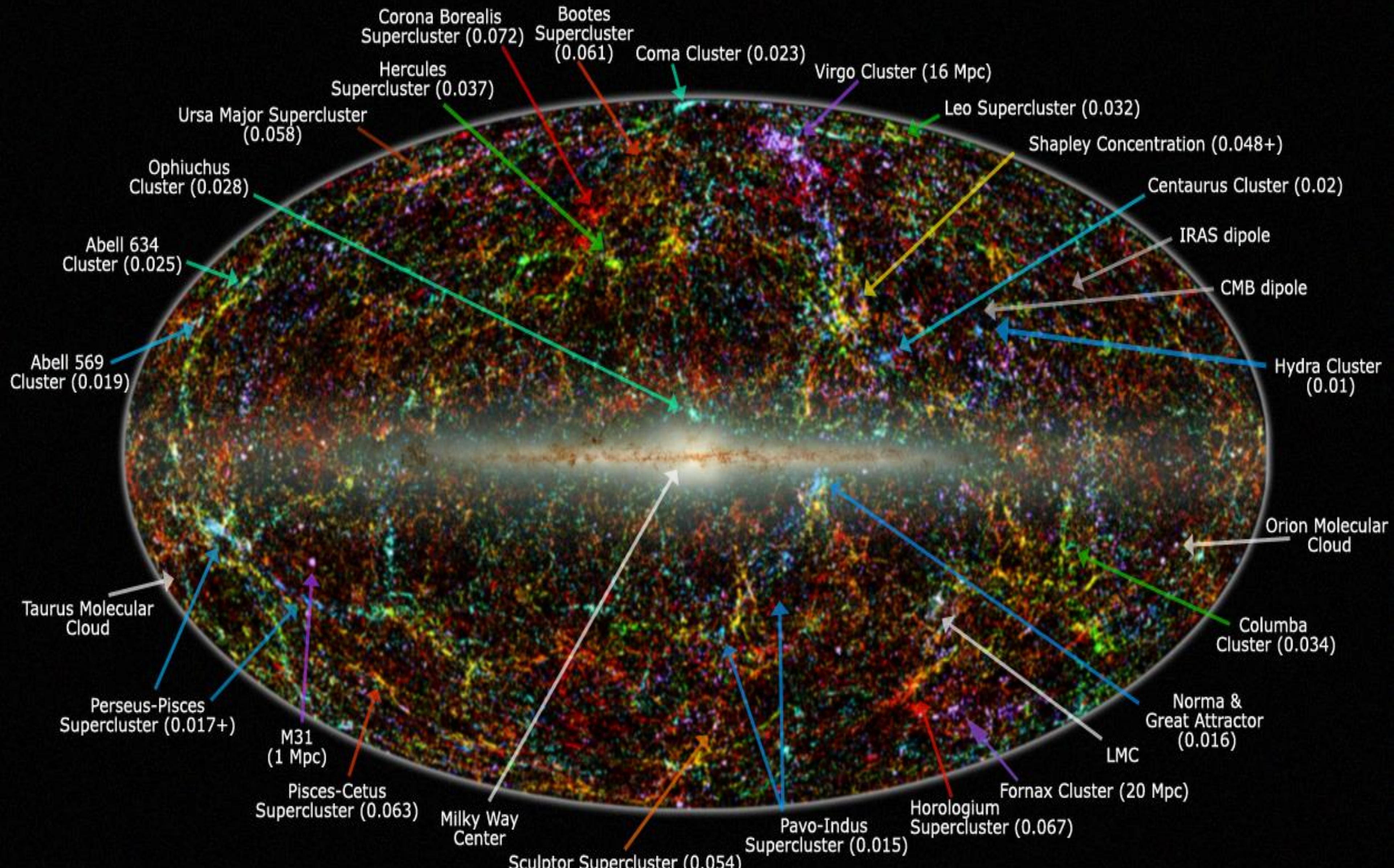
LVT151012: $M_1 = 23\, M_\odot$, $M_2 = 13\, M_\odot$, $1000\, Mpc$

LIGO: 3 GW events sky positions

GW150914, GW151226, LVT151012 (Fesik et al., arXiv:1702.03440)



Large Scale Structure in the Local Universe

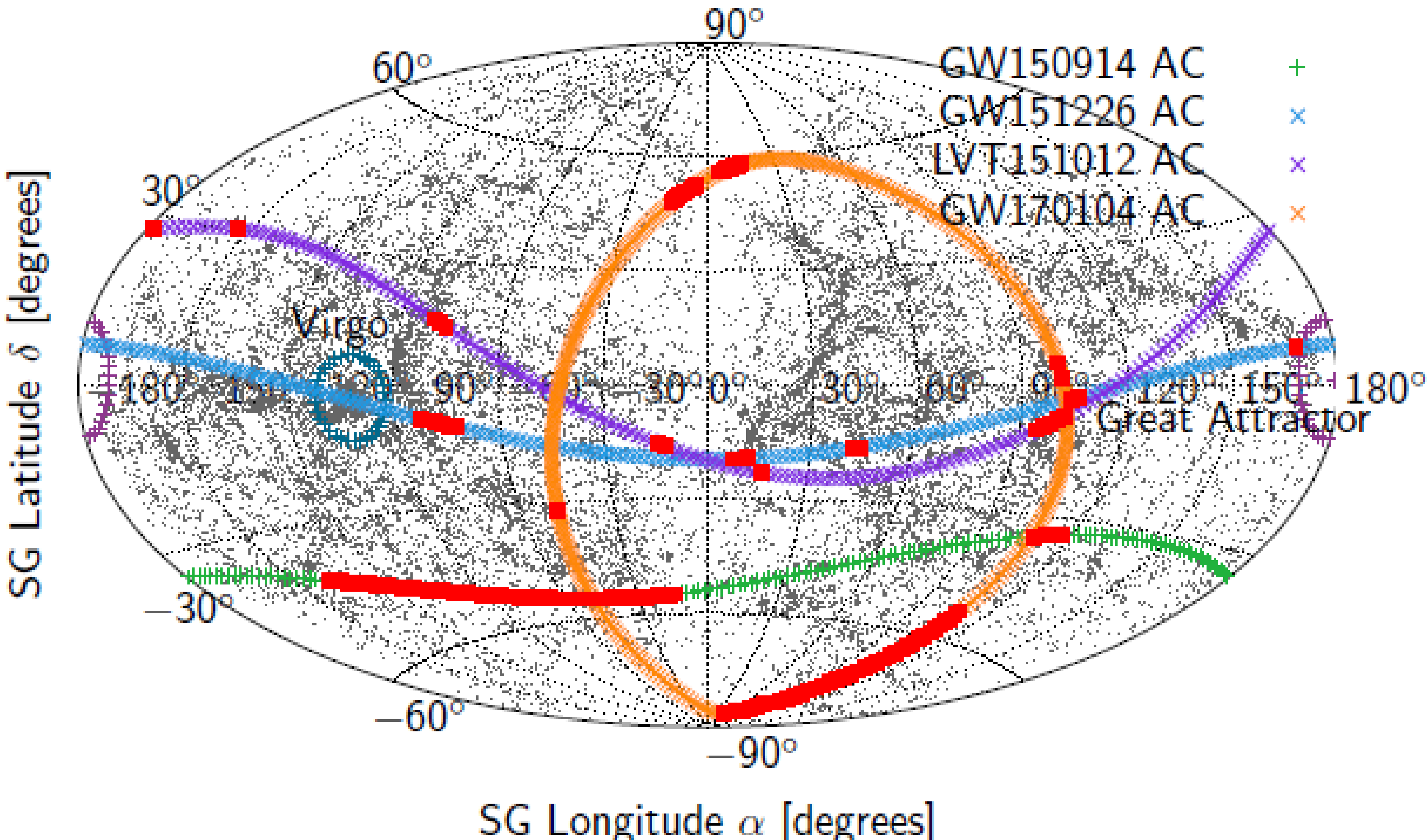


Legend: image shows 2MASS galaxies color coded by redshift (Jarrett 2004); familiar galaxy clusters/superclusters are labeled (numbers in parenthesis represent redshift). Graphic created by T. Jarrett (IPAC/Caltech)

LIGO: 4 GW events sky positions

GW150914, GW151226, LVT151012, GW170104

(Fesik et al., arXiv:1702.03440)



Existence of Black Holes event horizon and singularity

“The reluctant Father of Black Holes”, Sci. Am., June 1996: discussed the paper by Einstein (1939) where he clamed that “Schwarzschild singularity cannot exist in physical reality”

A. Einstein, *On a stationary system with spherical symmetry consisting of many gravitating masses*, Ann. Math., 40, 922 (1939)

Why Black Holes physically impossible:

$V_{ff} < c \rightarrow R > R_{Sch}$

+ New argument:

$E_{fg} < mc^2 \rightarrow R > R_g$

$$T^{00}{}_{(fg)} = \varepsilon_{(fg)} = + \frac{(\nabla \varphi_N)^2}{8\pi G}$$

Albert Einstein and Robert Oppenheimer in Princeton University (1949)

“Stephen Hawking: There are no black holes”

Z. Merali, Nature, 24 January 2014 (arXiv: 1401.5761)

Notion of an 'event horizon', from which nothing can escape, is incompatible with quantum theory.

A full explanation of the process would require a theory that successfully ***merges gravity with the other fundamental forces of nature.***

But that is a goal that has eluded physicists for nearly a century.

However Feynman’s nonmetric field gravitation theory is just such a unification of gravity with other fundamental forces: (A^i - ED, ψ^{ik}- GD)

Hawking Evaporation is Inconsistent with a Classical Event Horizon at r = 2M

B. Chowdhury and L. Krauss **arXiv: 1409.0187**

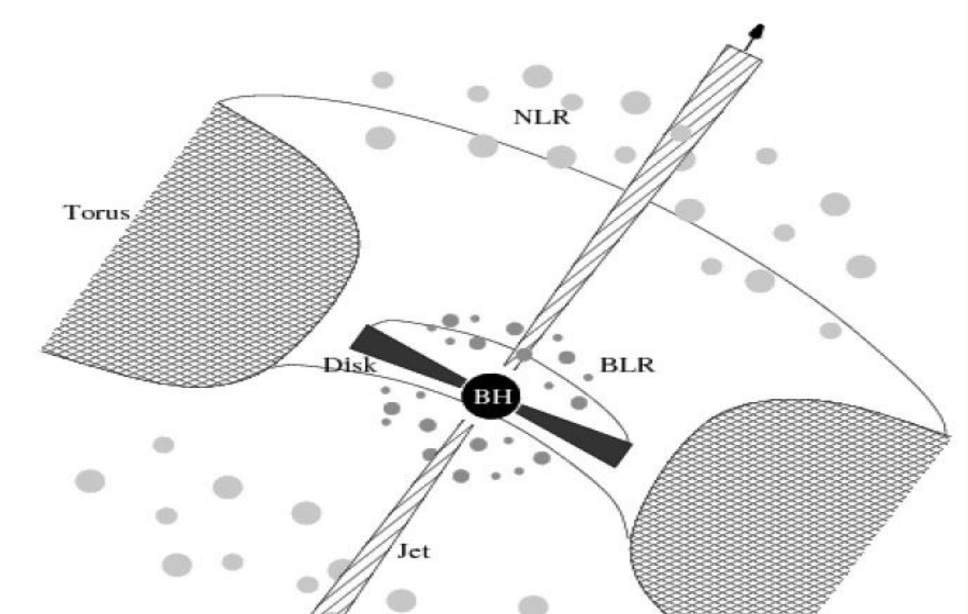
Department of Physics, Arizona State University, Tempe, AZ 85287

In the frame of a distant observer an infall cutoff outside the event horizon of a black hole must be imposed in order for the formation time of a black hole event horizon to not exceed its evaporation time.

$$\tau_{(infall)} = \infty \; > \; \tau_{(evap)} \approx 5 \cdot 10^3 \sec \left(\frac{\mathrm{M}}{10^{10} g}\right)^3$$

Observational testing existence of Black Hole Event Horizon

- S. Doeleman et al., *Imaging an Event Horizon : VLBI EHT* , arXiv: 0906.3899 (VLBI observations)
- King A., et al., *What is on tap? The role of spin in compact objects and relativistic jets*, arXiv: 1305.3230 (K_alpha Fe line profile X-ray observations)



VLBI imaging of Black Hole Candidates

S. Doeleman et al., arXiv: 0906.3899

Imaging an Event Horizon: submm-VLBI of a Super Massive Black Hole

VLBI EHT Event Horizon Telescope:

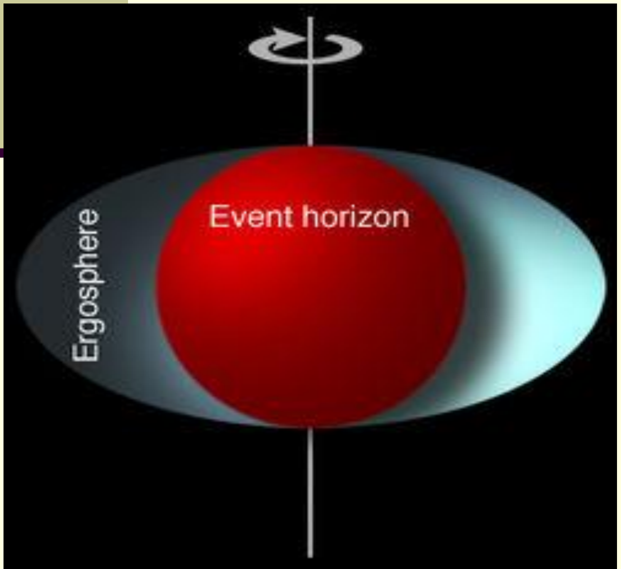
- Does General Relativity hold in the strong field regime?
- Is there an Event Horizon? $R_{hor} = ?$
- Is there an Ergosphere? $R_{ergo} \Rightarrow d\tau = 0\ ?$

Kerr BH : $R_{hor} = R_g\left(1 + \sqrt{1 - a^2}\,\right),$

$$a = J/J_{max} \qquad J_{max} = McR_g$$

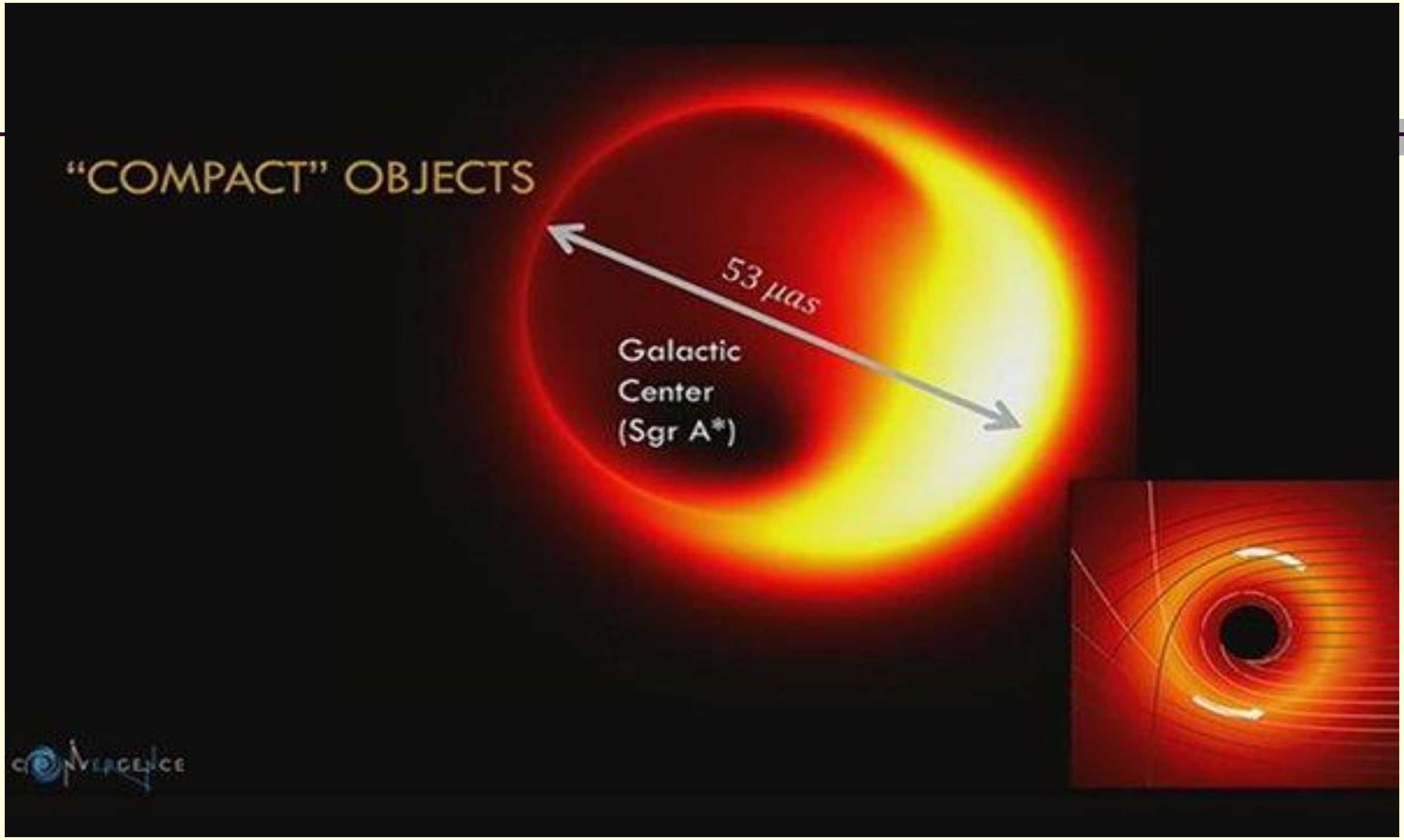
$$R_{hor} = R_g = \frac{GM}{c^2}\ \ (\,a = 1)\ ;$$

$$R_{hor} = R_{Sch} = \frac{2GM}{c^2}\,(\,a = 0)$$



How do Black Holes accrete matter and create powerful jets?

Expected SgrA* image in GRT



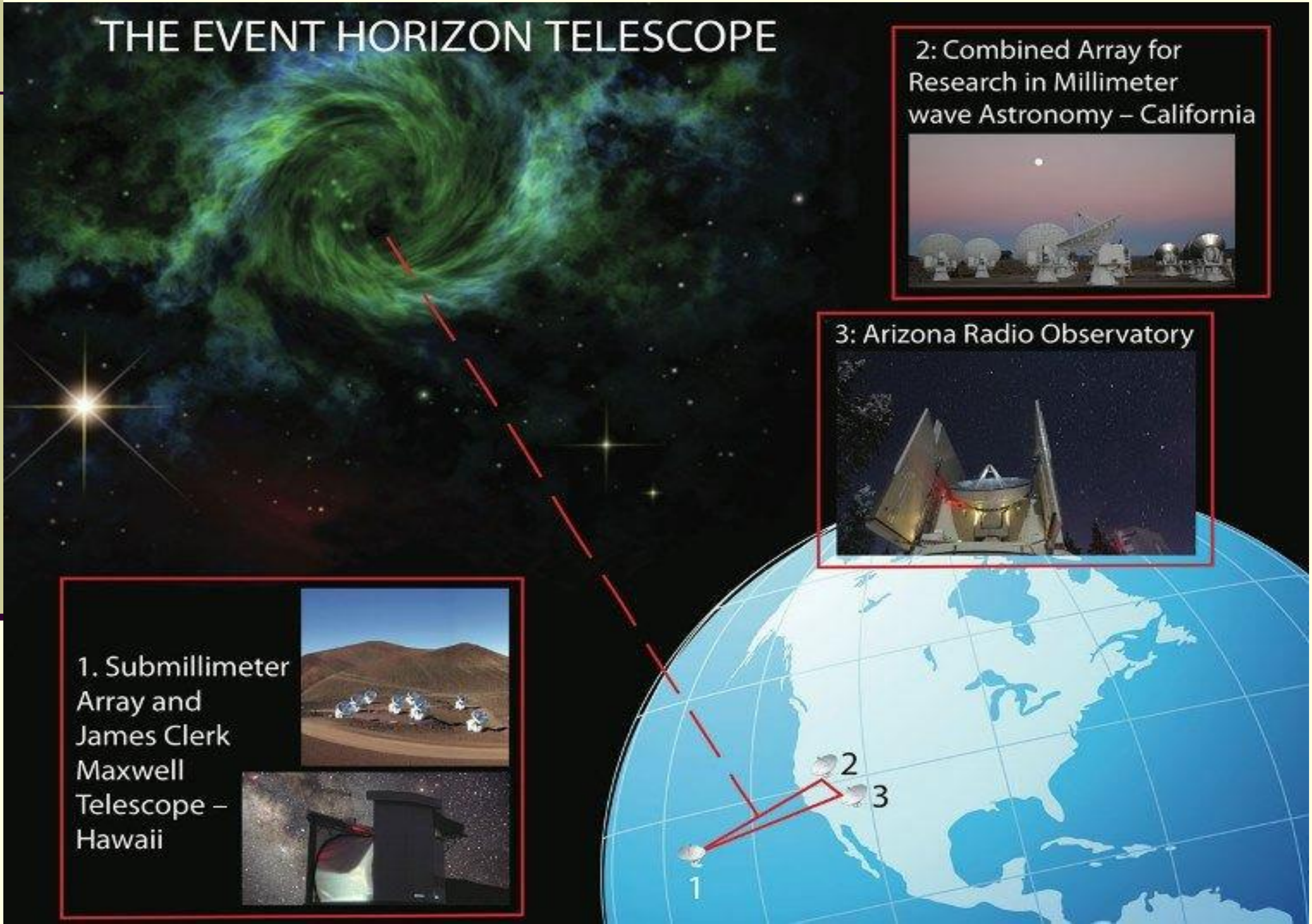
$M_{RCO} = 4.3 \cdot 10^6 M_\odot$, $D = 8.3\, kpc$

$R_{Sch} = 1.3 \cdot 10^{12} cm$ $\theta_{R_{Sch}} = 10.2\, \mu as$

$\theta_{ring} = 5.2\theta_{R_{Sch}} = 53\, \mu as$ (light ring diameter)

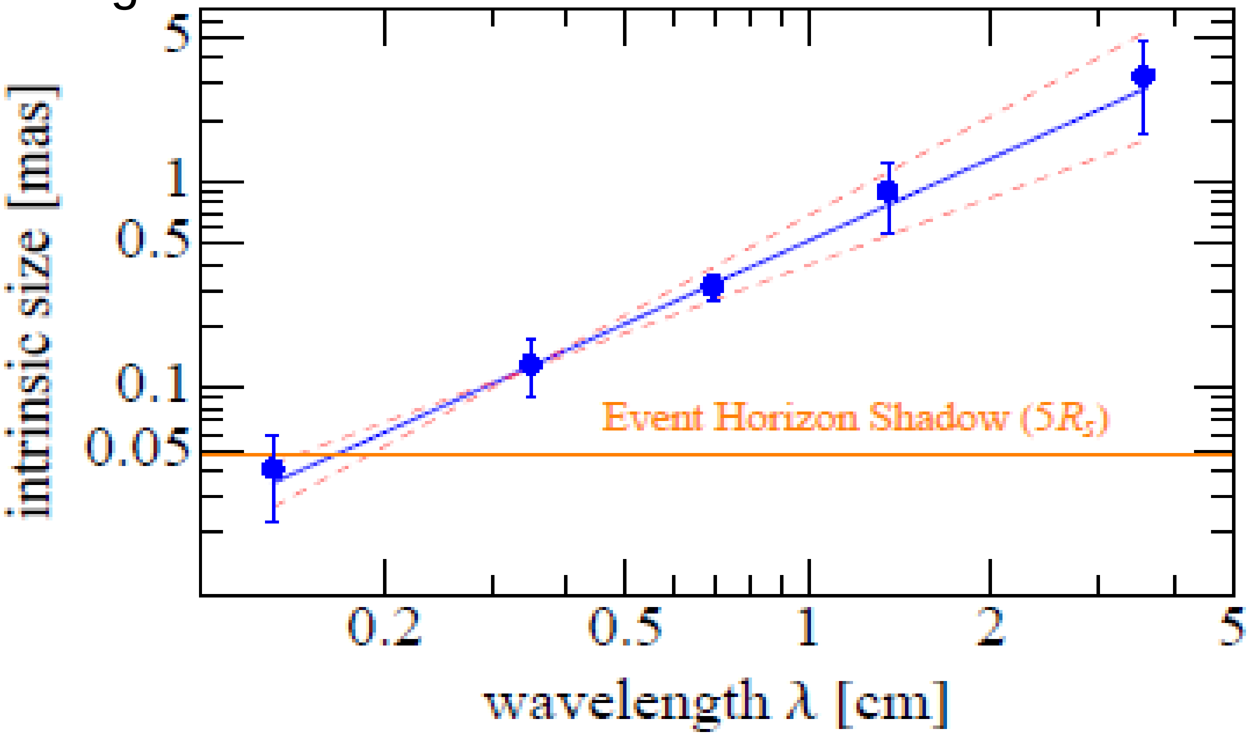
The EHT first results at 1.35 mm

Doeleman, S. S., et al. 2008, Nature, 455, 78



Falcke H., Markoff S., Towards the event horizon – the supermassive black hole in the Galactic Center, Class. Quant. Grav., 30, iss. 24, id. 244003 (2013)

Sgr A* VLBI EHT λ=1.35 мм



Existence of BH horizon?

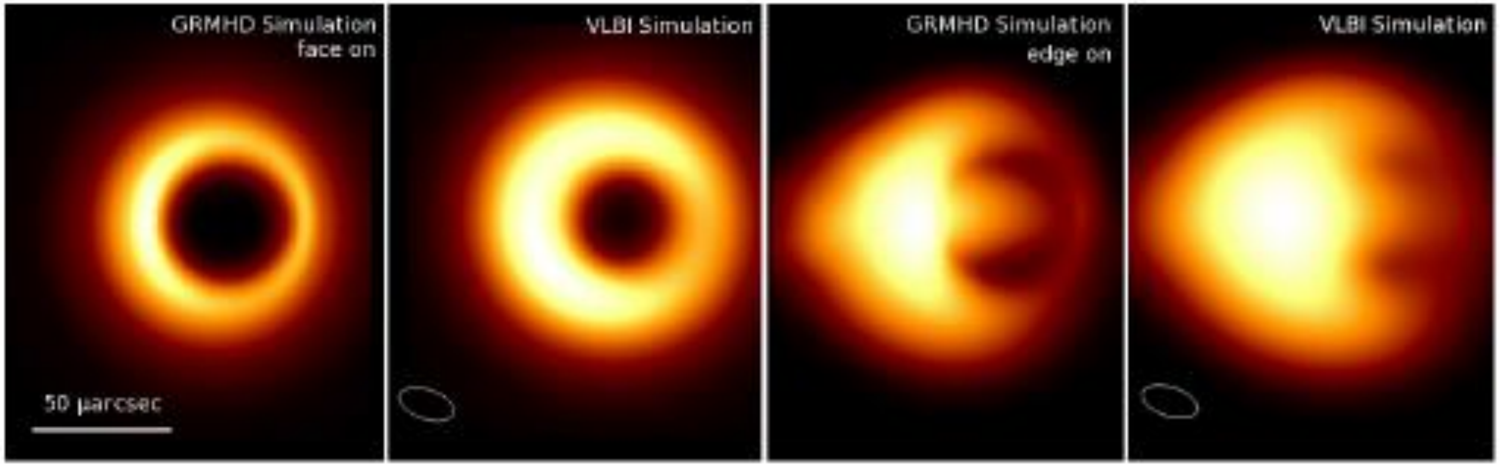
Intrinsic sizes of black hole candidates as crucial observational tests for gravitation theories

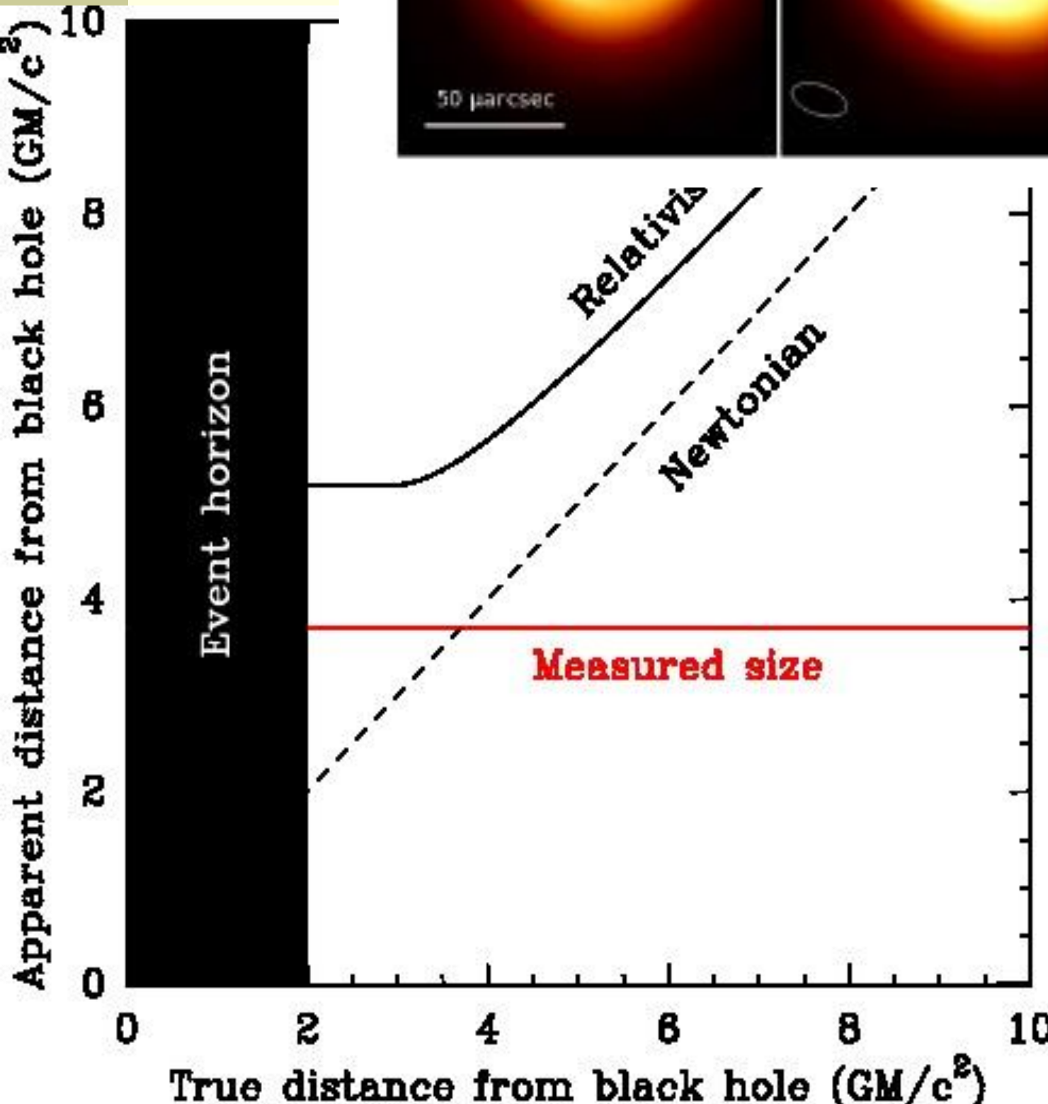
Universal light ring around BH:

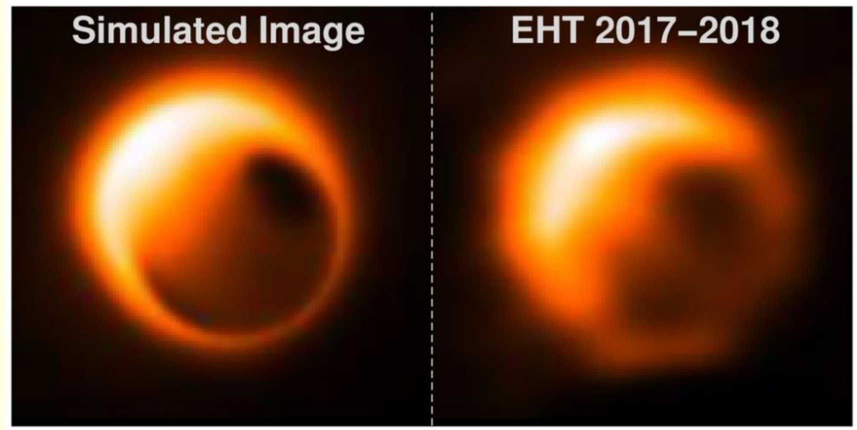
$D_{ring} = 5.2 R_{Sch}$

Observed size SgrA* : $\theta_{obs} \approx 37 \mu as \quad (4\, R_{Sch})$

(Doeleman, S. S., et al. 2008, Nature, 455, 78)







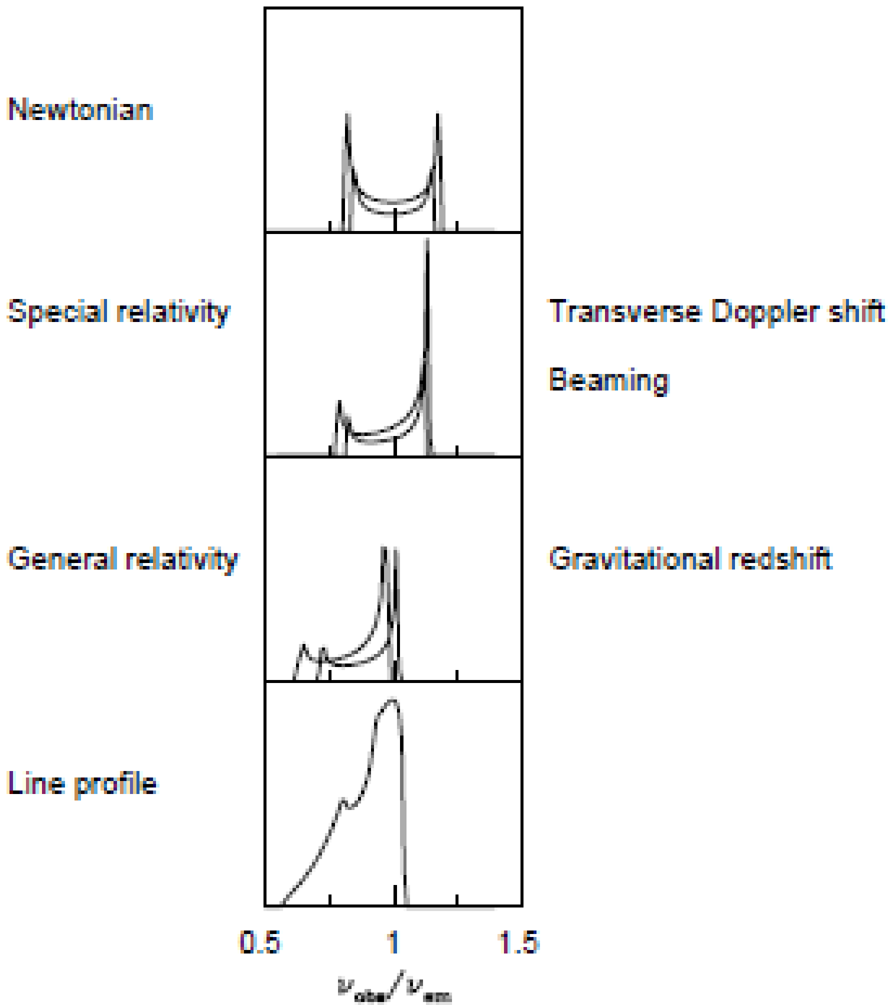
$$r \sim R_g = \frac{GM}{c^2} = R_{Sch}/2$$

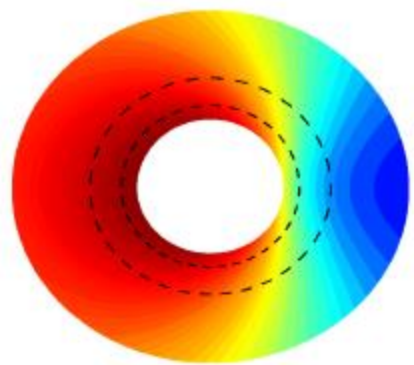
Universal light ring around BH: $53\ \mu as$?

X-ray spectroscopy of

Fe K_alfa line

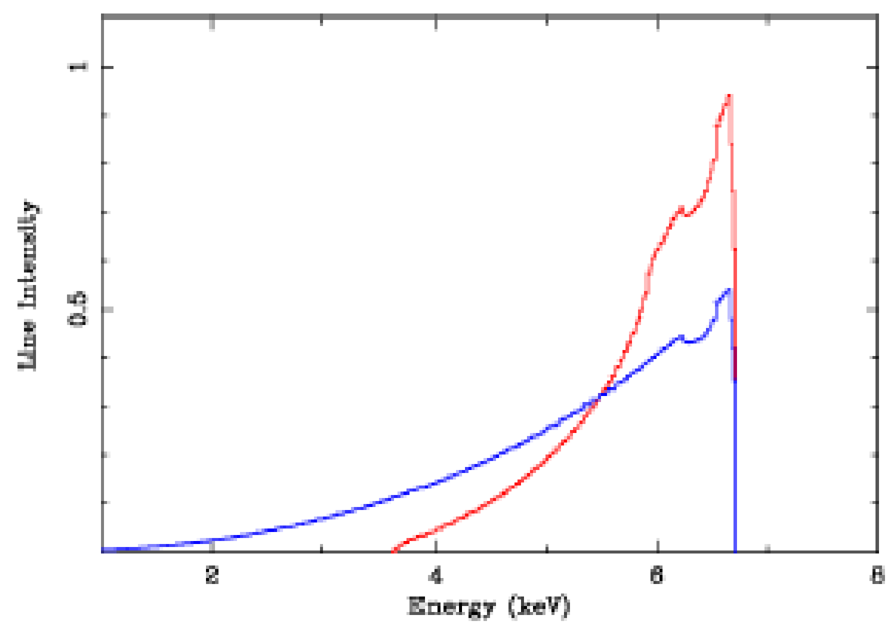
A.C. Fabian, Probing General Relativity with Accreting Black Holes, arXiv:1211.2146 (2012)



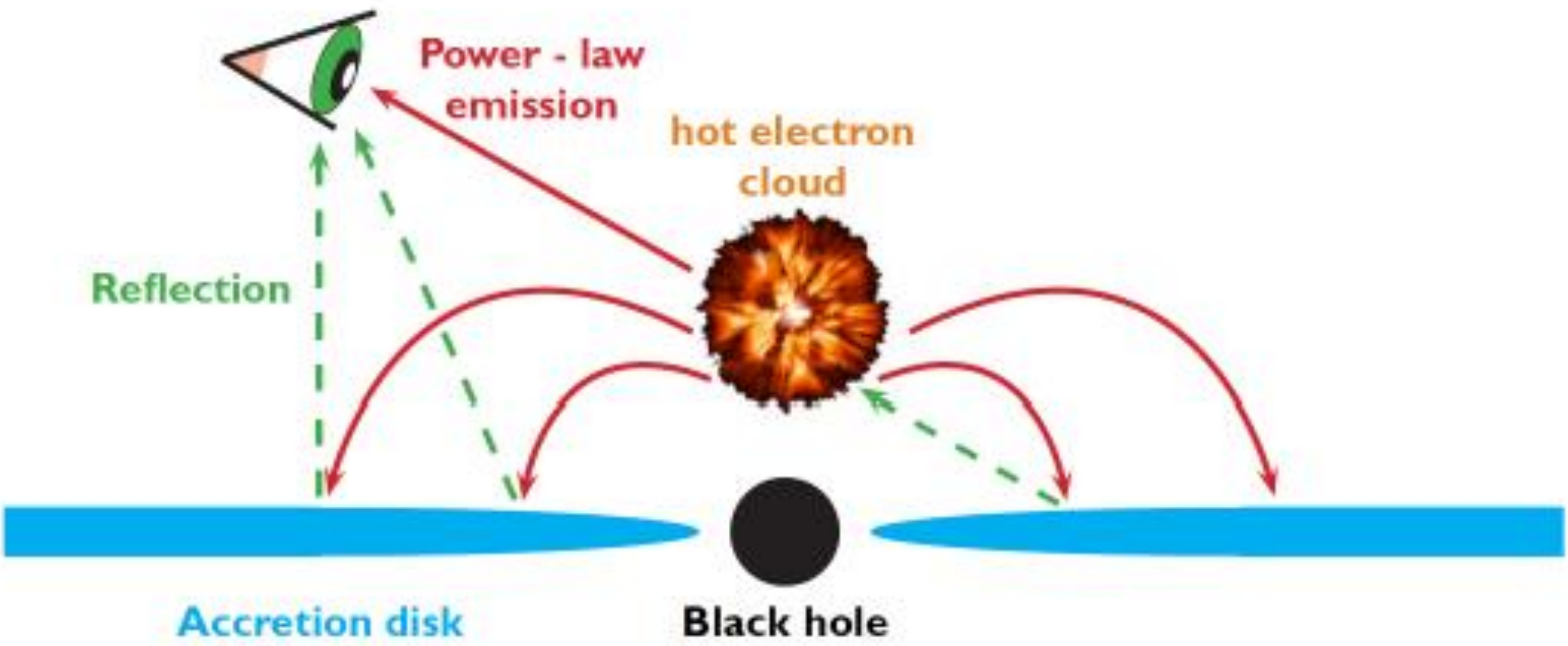


$r_{in} = 3R_{Sch}$

$r_{in} = 0.6R_{Sch}$



Fe K_alfa X-ray spectral observations of Seyfert-1 galaxies: model of BH/RCO jets and accretion disc



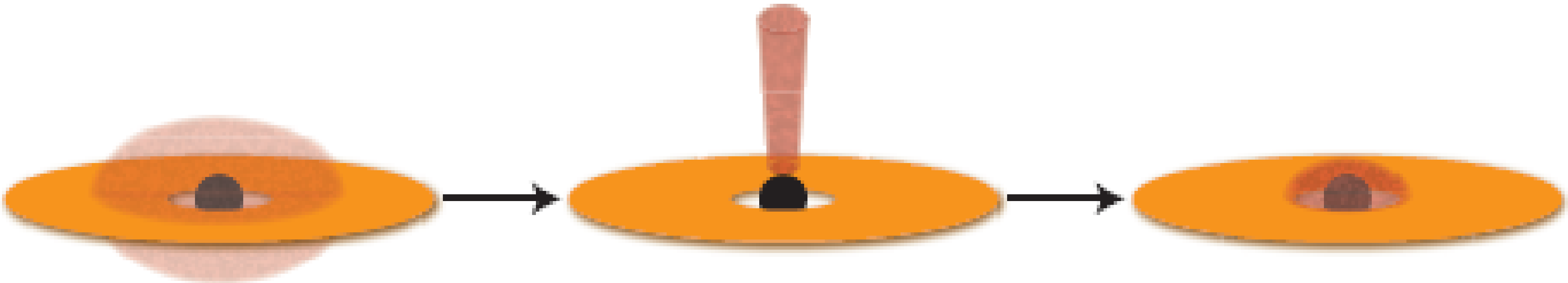
$r \sim R_g = GM/c^2 = R_{Sch}/2$ (MCG-6-30-15 $r_{in} = 0.615R_{Sch}$)

GRT : Kerr Black Hole (Mrk 335 $r_{in} = 0.62R_{Sch}$)

FGT : Relativistic Compact Object (RCO)

Driving extreme variability: The evolving corona and evidence for jet launching in Markarian 335

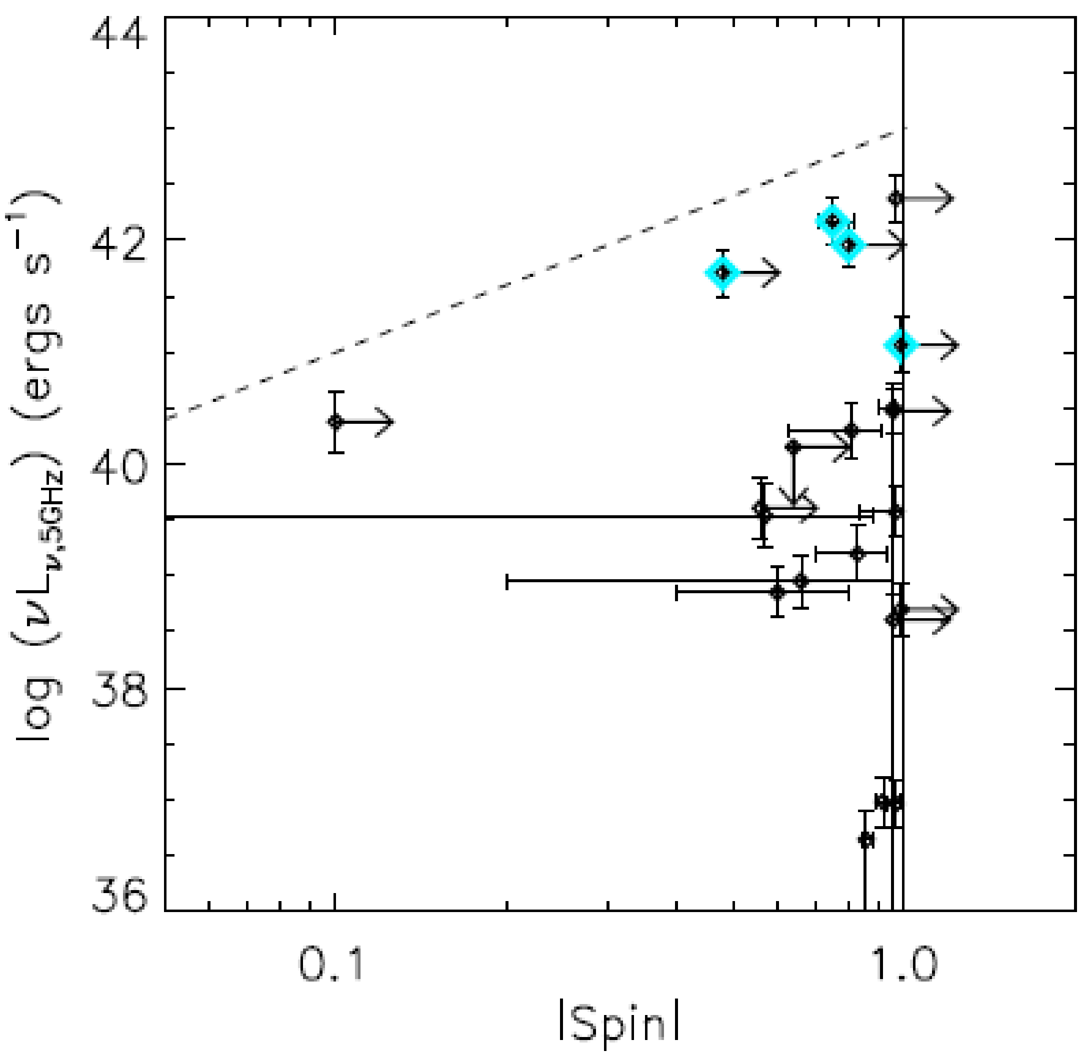
D.Wilkins, L.Gallo, MNRAS,449,129 (2015)



During all epochs, we find that the maximum measured redshift in the wing of the relativistically broadened iron K_alfa emission line is statistically consistent with the accretion disc extending as far in as the innermost stable circular orbit of a maximally rotating black hole at

r_{in} = 1.235 R_g supporting findings that the black hole spin, $a > 0.9$. There is no evidence for truncation of the accretion disc between the high and low flux epochs.

King A., et al., What is on tap? The role of spin in compact objects and relativistic jets, Ap.J., 771, 84 (2013)



37 Seyfert-1

K_alfa Fe line

Disc intrinsic size

$r_{in} \sim R_g = GM/c^2$

Kerr BH model:

$$|Spin| = a = \frac{J}{J_{max}}$$

$R_{hor} = R_g(1 + \sqrt{1 - a^2}\ )$

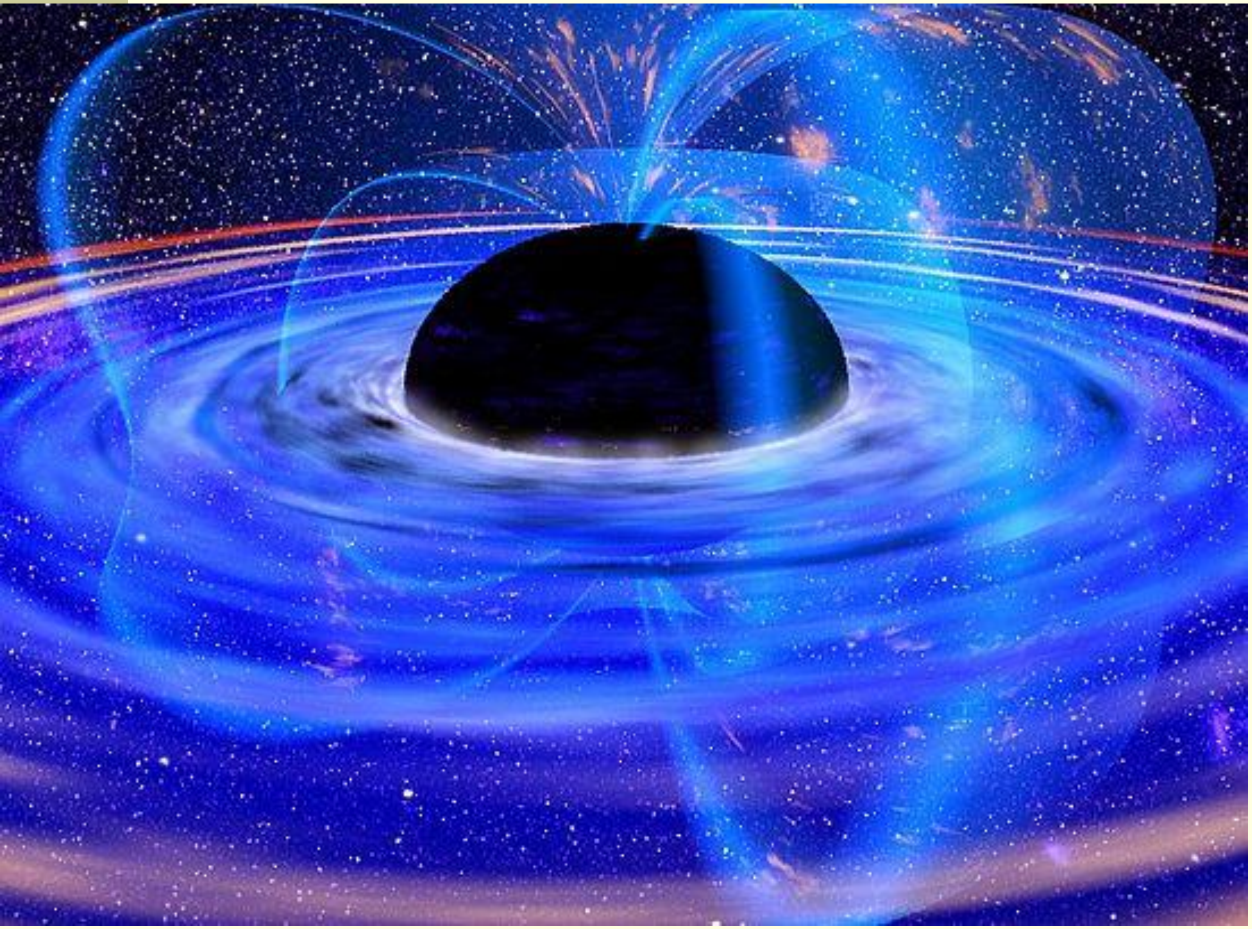
For a = 1:

$R_{hor} = R_g = GM/c^2$

For a = 0:

$R_{hor} = 2R_g = R_{Sch} = 2GM/c^2$

Modern view on the Central Energy Source in AGN



Jet begins very close to gravitational radius

$r \sim R_g < R_{Sch}$

BH or RCO (?)

Strongly binded material object (?)

+ accretion disc

and jet

Crucial tests for comparison FGT and GRT predictions

- *The universality of free fall for rotating bodies (additional acceleration of rotating bodies (V^2/c^2))*
- *The scalar-tensor nature of the symmetric tensor potentials* $\psi^{ik}(\vec{r},t)$, $\psi(\vec{r},t) = \eta_{ik}\psi^{ik}$ *(repulsion by the trace part of the symmetric tensor)*
- *The structure, masses and sizes of RCO (Quark stars, SMRCO having* $\boldsymbol{r \sim R_g = GM/c^2 = R_{Sch}/2}$)
- *The emission and detection of spin2 and spin 0 gravitational waves (EMT of GW :* $T_{\{2\}}{}^{00}$ *and* $T_{\{0\}}{}^{00}$)

Near perspectives
of Relativistic Astrophysics

The Event Horizon Telescope (EHT) is finally ready to take a picture **of SgrA***

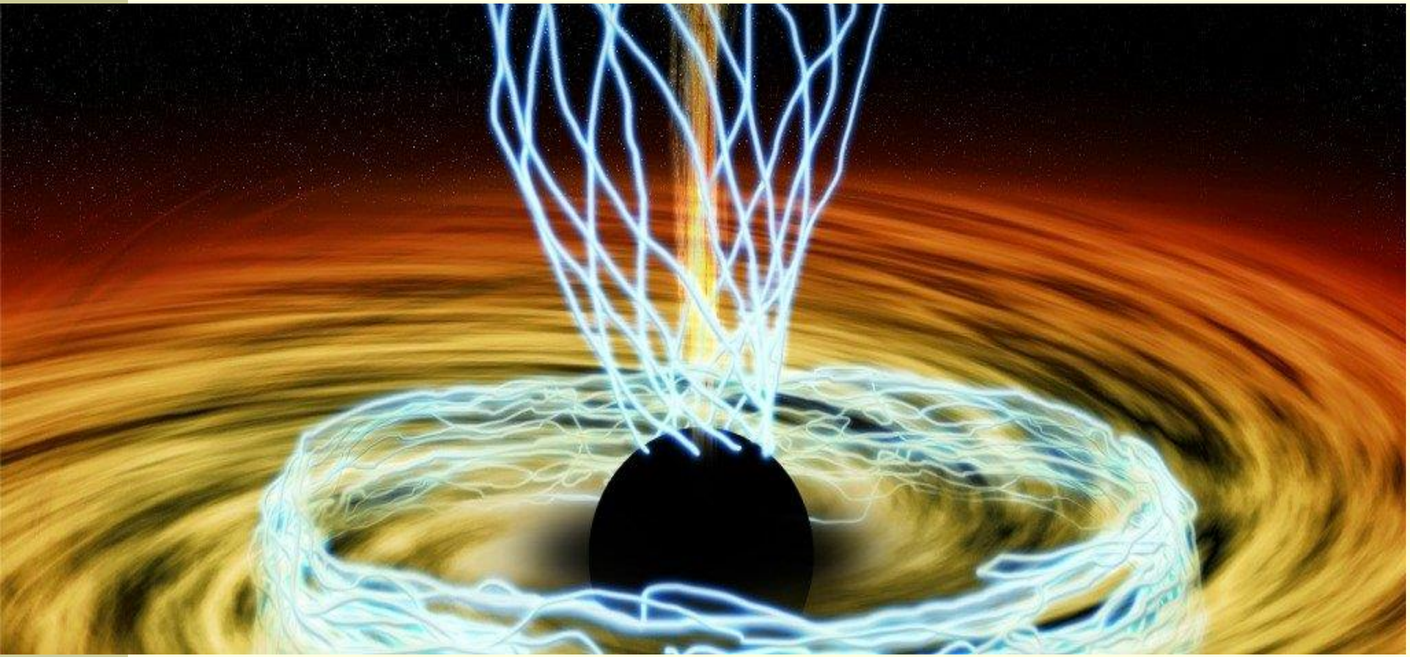
From April 5 to 14th (2017)

with linear resolution $l \sim R_{Sch} = \frac{2GM}{c^2}$

$\lambda \sim 0.6\,mm$

1. South Pole Telescope **2.** Atacama Large Millimeter/submillimeter Array and Atacama Pathfinder Experiment (Chile) **3.** Large Millimeter Telescope (Mexico) **4.** Submillimeter Telescope (Arizona) **5.** James Clerk Maxwell Telescope and Submillimeter Array (Hawaii) **6.** IRAM 30-meter (Spain)

Michael D. Johnson et al. (EHT), Science 04 Dec 2015: Vol. 350, Issue 6265, pp. 1242-1245



"Resolved magnetic-field structure and variability near the event horizon of Sagittarius A* "

$$r \sim R_g = GM/c^2 = R_{Sch}/2$$

GRT : Kerr Black Hole

FGT : Relativistic Compact Object (RCO)

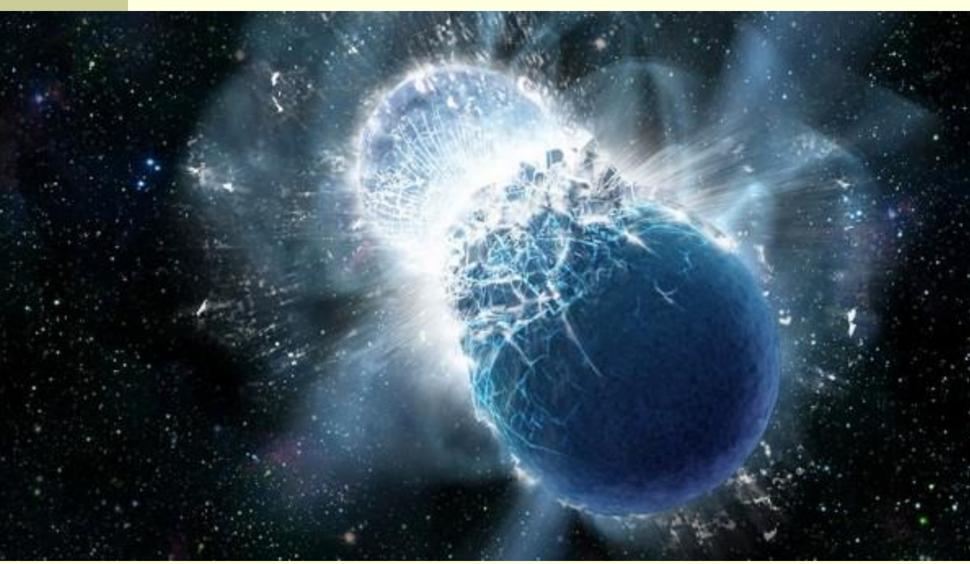
massive material object

Virgo + LIGO GW detectors

- **Nature / News 24.08.2017 doi:10.1038/nature.2017.22482**

NGC4993, d = 40 Mpc

GRB 170817A, new type of signal (not published yet)



+

- Second GW signal arXiv: 1709.09660

GW170814, d = 540 Mpc

Binary BH => 31 + 25 MΘ

Perspectives for Relativistic Astrophysics

Developing the theory of gravitational interaction:

Ghc-theory,

Einstein's geometrical approach and Feynman's field approach,

Multi-messenger observational astrophysics:

nearby SN explosions,

RCO images,

AGN jets origin,

neutrino and GW detection

Thank for attention

Founders of Relativistic Astrophysics
1958 Solvay conference

F. HOYLE H. C. van de HULST A. R. SANDAGE J. A. WHEELER H. ZANSTRA L. LEDOUX

S. KLEIN W. W. MORGAN B. V. KUKARKIN M. FIERZ W. BAADE H. BONDI T. GOLD L. ROSENFELD A. C. B. LOVELL J. GÉHÉNIAU

V. A. AMBARZUMIAN E. SCHATZMAN

. McCREA J. H. OORT G. LEMAÎTRE C. J. GORTER W. PAULI W. L. BRAGG J. R. OPPENHEIMER C. MØLLER H. SHAPLEY O. HECKMA

Gravitational origin of jets in the Field Gravitation Theory

From equations of motion of test particles:

$$\left(\frac{d\vec{v}}{dt}\right)_{FGT} = -\left(1+\frac{v^2}{c^2}+4\frac{\varphi_N}{c^2}\right)\vec{\nabla}\varphi_N + 4\frac{\vec{v}}{c}\left(\frac{\vec{v}}{c}\cdot\vec{\nabla}\varphi_N\right)$$

For circular motion $v \perp \boldsymbol{\nabla}\varphi_N$ $a_g \to 2\,a_N$

$$\left(\frac{dv}{dt}\right)^{\perp}_{FGT} = -\left(1+\frac{v^2}{c^2}+4\frac{\varphi_N}{c^2}\right)\boldsymbol{\nabla}\varphi_N$$

For radial motion $v \uparrow\downarrow \boldsymbol{\nabla}\varphi_N$ $a_g \to 0$

$$\left(\frac{dv}{dt}\right)^{\parallel}_{FGT} = -\left(1-3\frac{v^2}{c^2}+4\frac{\varphi_N}{c^2}\right)\boldsymbol{\nabla}\varphi_N$$

Comparison of FG and GR: hydrostatic equilibrium

Field Gravity | **General Relativity**

$$\frac{dp}{dr} = -\frac{G(\varrho_0 + \delta\varrho)\ M_r^*}{r^2}$$

$$\delta\varrho = \frac{e+p}{c^2} + 2\varrho_0 \frac{\Phi}{c^2}$$

$$\Phi = \psi^{00}, \ \ M_0^r = \int_0^r 4\pi r^2 \rho_0 dr$$

$$M_r^* = \int_0^r 4\pi r'^2 (\varrho_0 + \frac{e+3p}{c^2} + 2\frac{\varrho_0 \Phi}{c^2}$$

$$+ 2\frac{(d\Phi/dr)^2}{8\pi G c^2})dr'$$

so $\frac{dp}{dr} = const$ for $r = r_g$

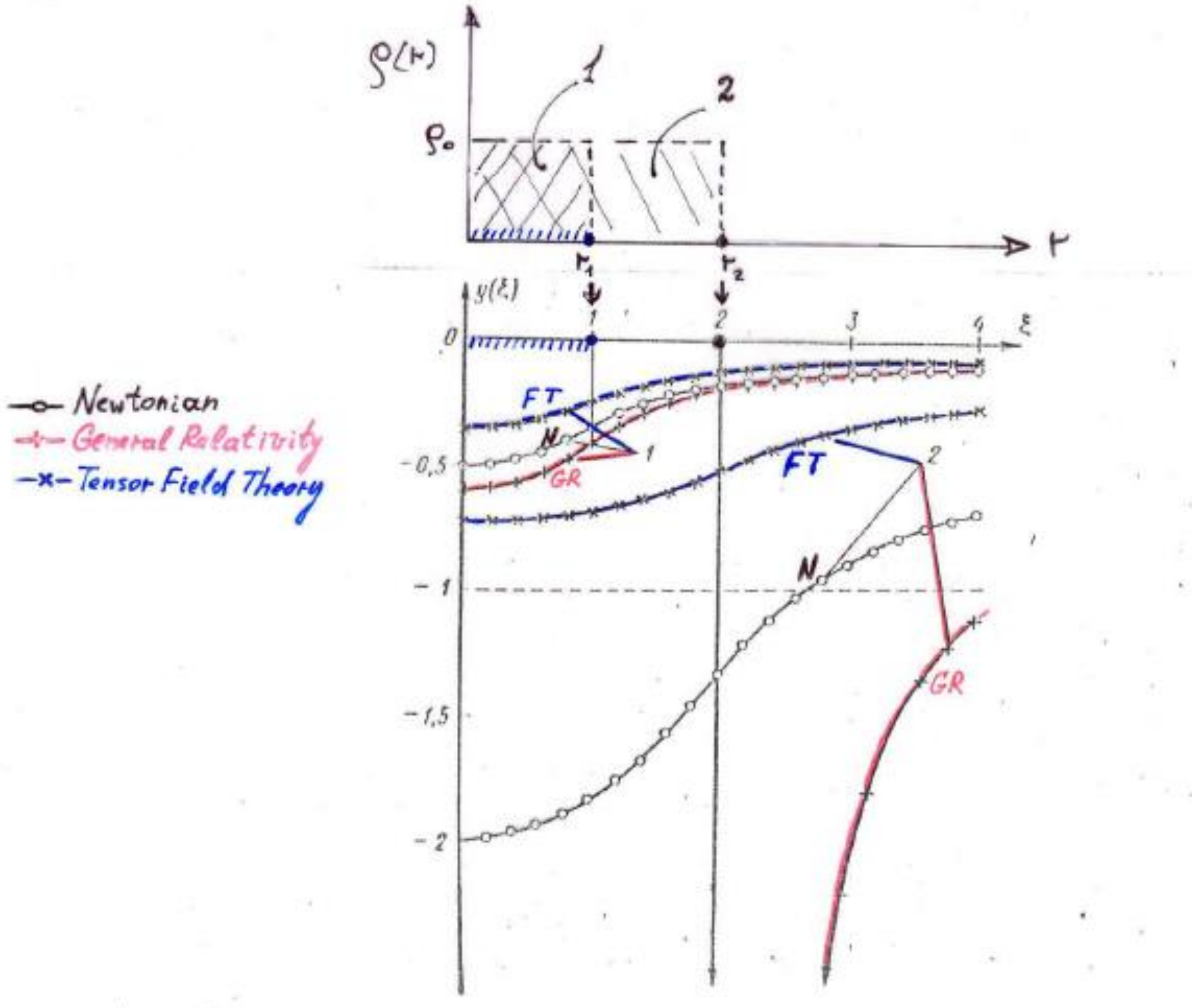
TOV equation

$$\frac{dp}{dr} = -\frac{G(\rho + p/c^2)(M + 4\pi p r^3/c^2)}{r^2(1 - r_{\rm Sch}/r)}$$

for $r \rightarrow r_{Sch}$

$$\frac{dp}{dr} \rightarrow \infty$$

GRT-Newton-FGT:
Relativistic Compact Objects



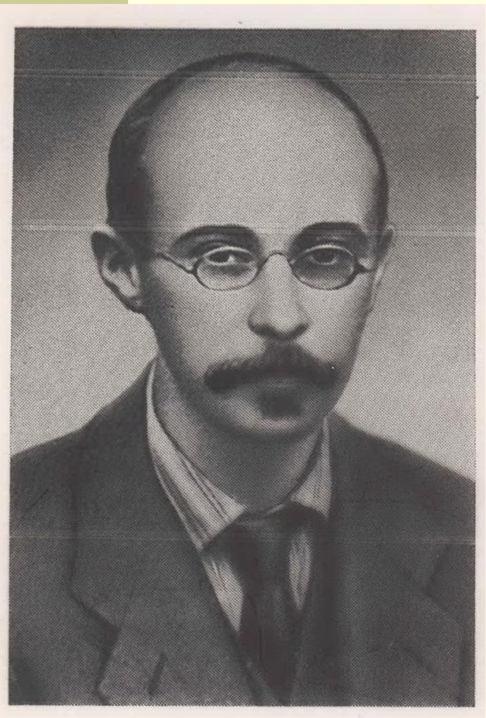
Strongly Binded Objects

Cosmological models in relativistic astrophysics

Einstein-Friedmann SCM: 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:

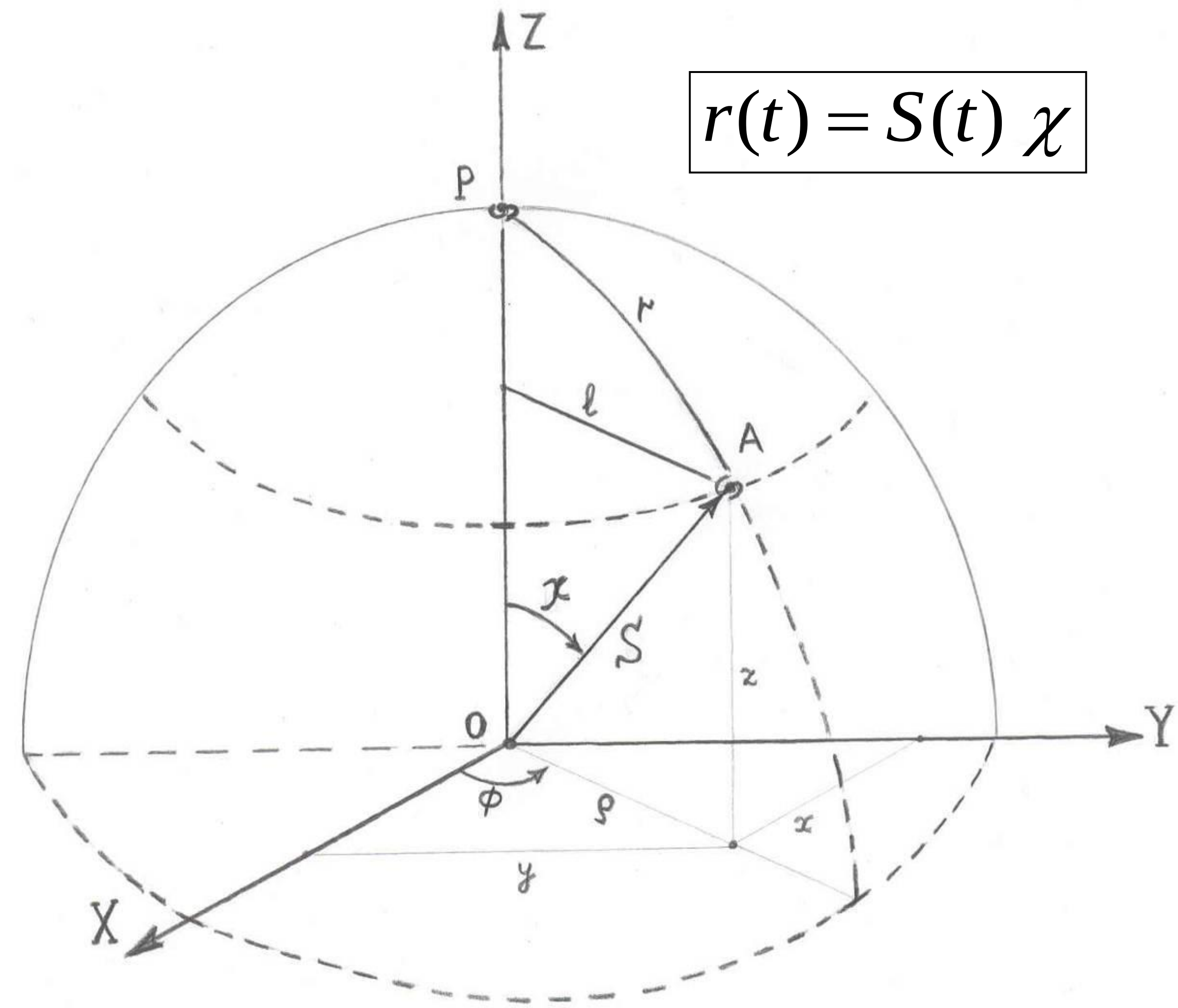
$$ds^2 = c^2 dt^2 - S(t)^2 [d\chi^2 + I_k(\chi)^2 d\omega^2]$$

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

$r(t) = S(t) \times \chi$ - expanding space (increasing distance between galaxies)

Coordinates and distances in SCM

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



$$ds^2 = g_{ik} dx^i dx^k$$

$$g_{ik} = g_{ik}(t)$$

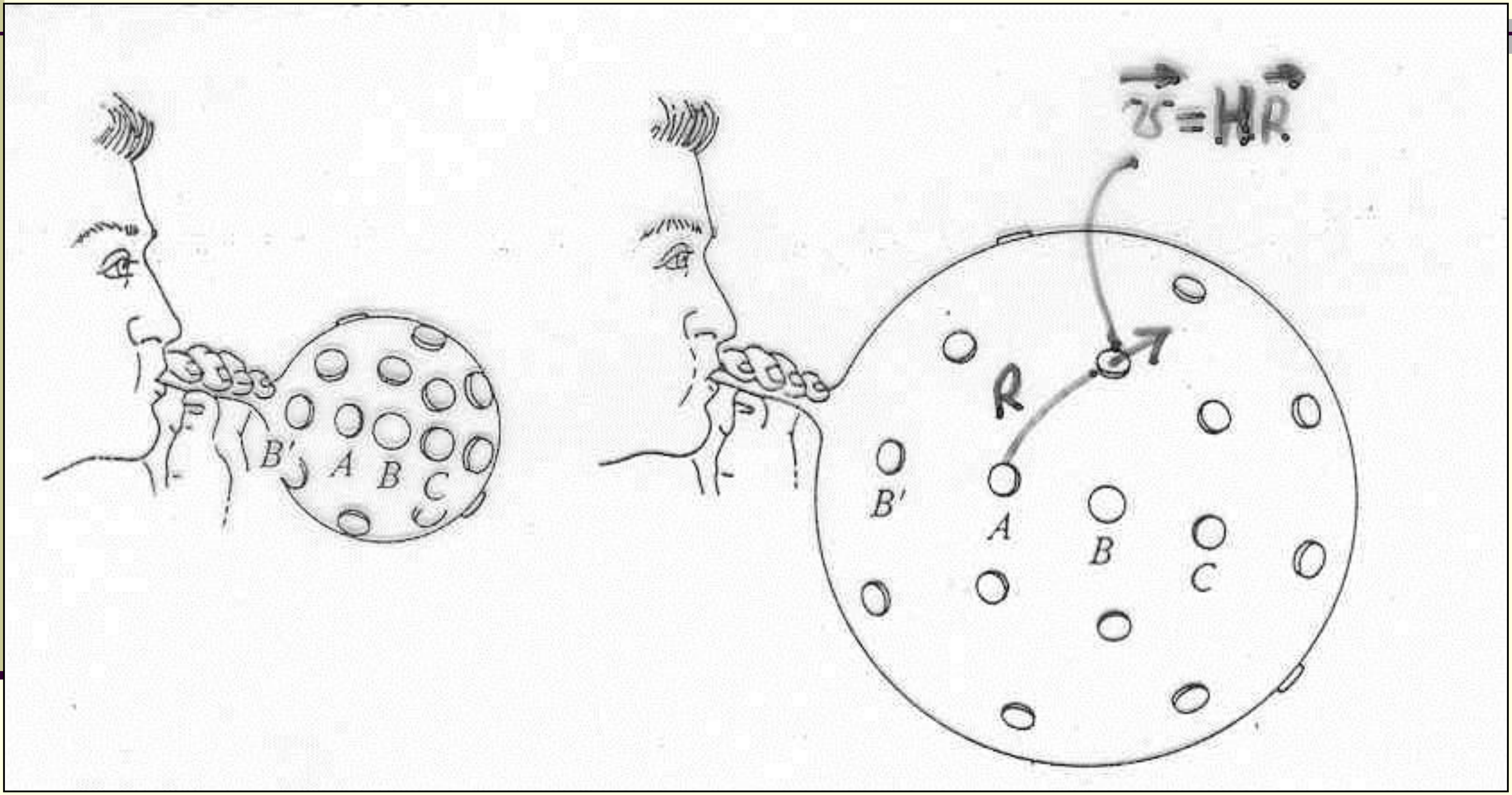
$$x^i = (ct, x^\alpha)$$

What is space expansion ?

$$r(t) = S(t) \times \chi$$

[cm] [cm]

The expanding space having fixed measuring rods



Misner, Thorne, Wheeler: Gravitation, 1973 (Fig. 27.2)

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

E(0, 0):

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

$$1 - \Omega = -\Omega_k$$

E(1,1):

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

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

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

$$S(t) \propto t^{2/(3+3\gamma)},\ \ k = 0$$

$$S(t) \propto \exp(\alpha t),\ \ \gamma = -1$$

Homogeneity of matter distribution: *Einstein's Cosmological Principle*

$$\varepsilon(\vec{r},t) = \varepsilon(t) = \rho(t)\,c^2$$

$$p(\vec{r},t) = p(t)$$

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

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

Equation of state

$$p = \gamma\,\rho\,c^2$$

Hydrodynamic approximation

Ordinary matter:

$$p_m = \gamma\,\varepsilon_m$$

$$0 \le \gamma \le 1/3$$

"Dust": $\gamma = 0$

"Radiation": $\gamma = 1/3$

Dark energy:

$$p_{de} = \gamma\,\varepsilon_{de}$$

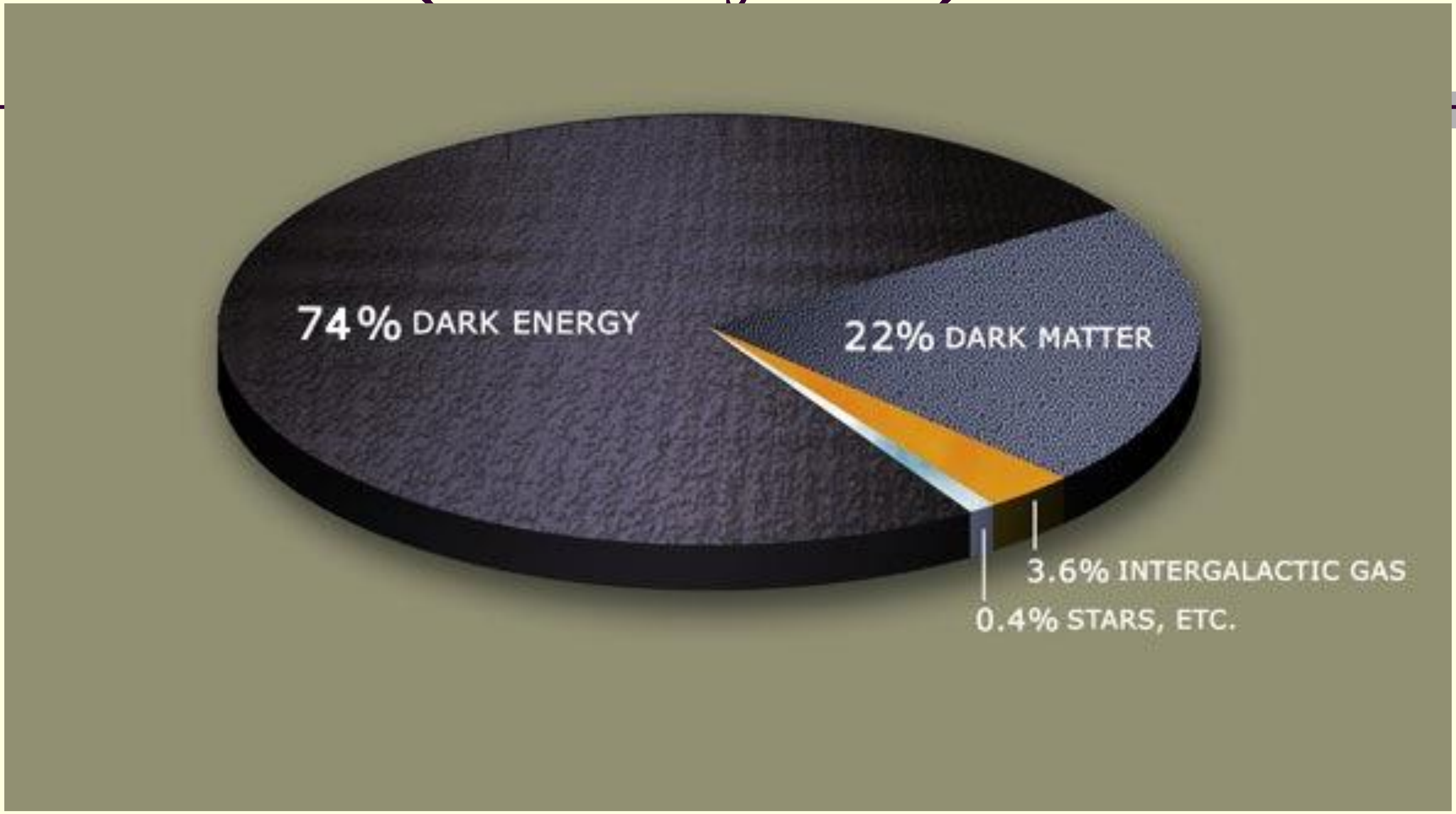
$$\gamma < 0$$

"Vacuum": $\gamma = -1$

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 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%),ordinary matter (5%). **Visible galaxies** contribution is less than 0.5%.

Main mass-energy components in the LCDM(nonbaryonic) SCM



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

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

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

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

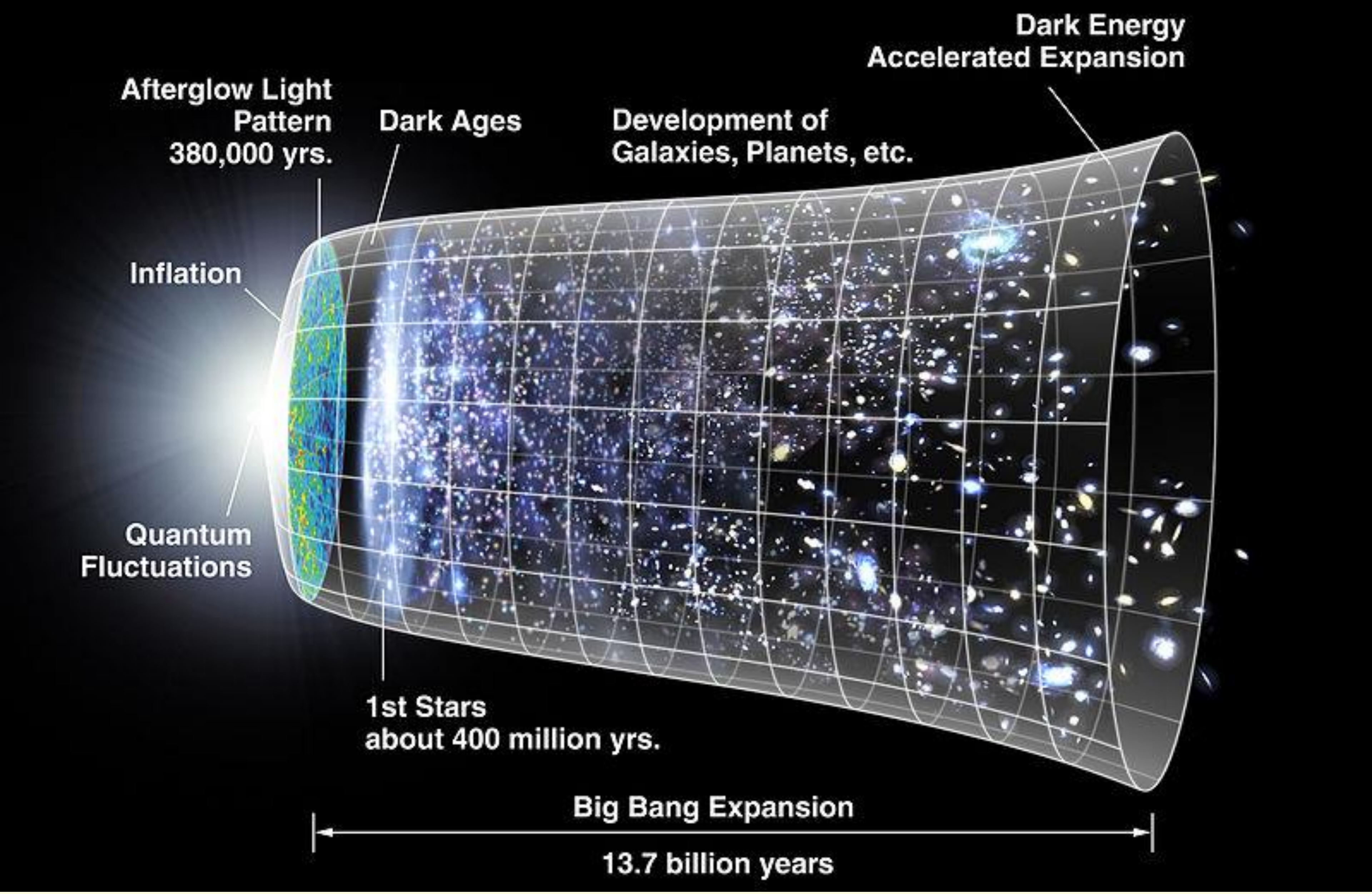
$H_0 = 67.4 \pm 1.4\ km\ s^{-1}\ Mpc^{-1}$

$\Omega_m = 0.314 \pm 0.020$

$\Omega_c = 0.263 \pm 0.0031$

$\Omega_b = 0.048 \pm 0.0003$

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



LCDM SCM: Cosmology is almost finished !

Conceptual problems of the SCM

Gravitation theory

(GR is not a quantum theory, absence of the EMT of gravitational field in GR, need for unite gravity with the other fundamental forces of nature, Geometrical and Field gravitation physics)

Physics of space expansion

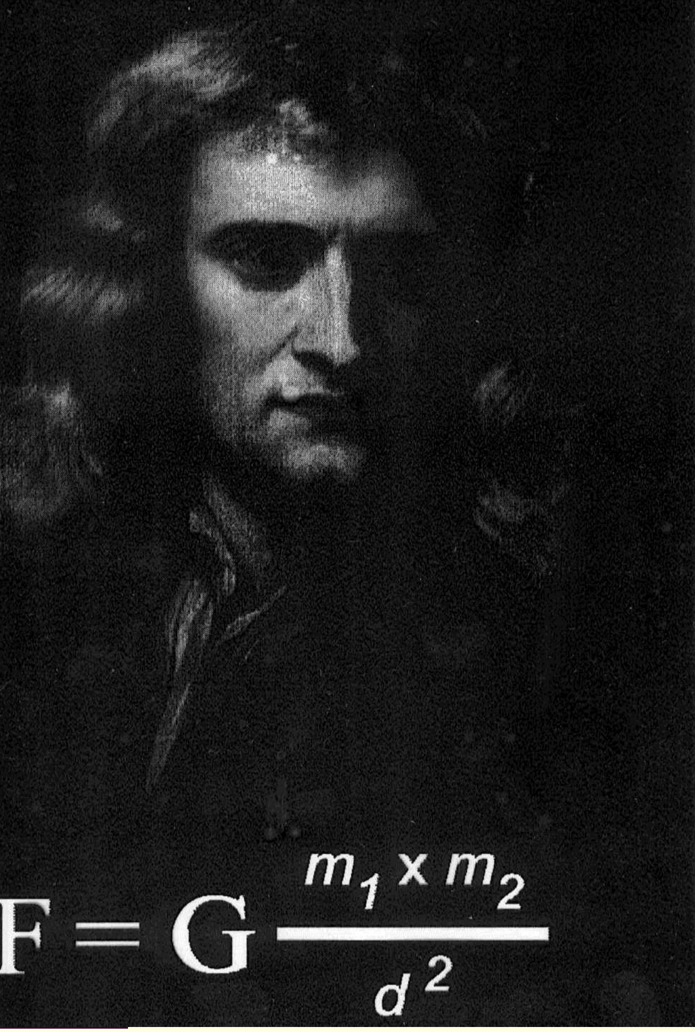
(Continuous creation of vacuum, violation of energy conservation, receding velocity more than light velocity c)

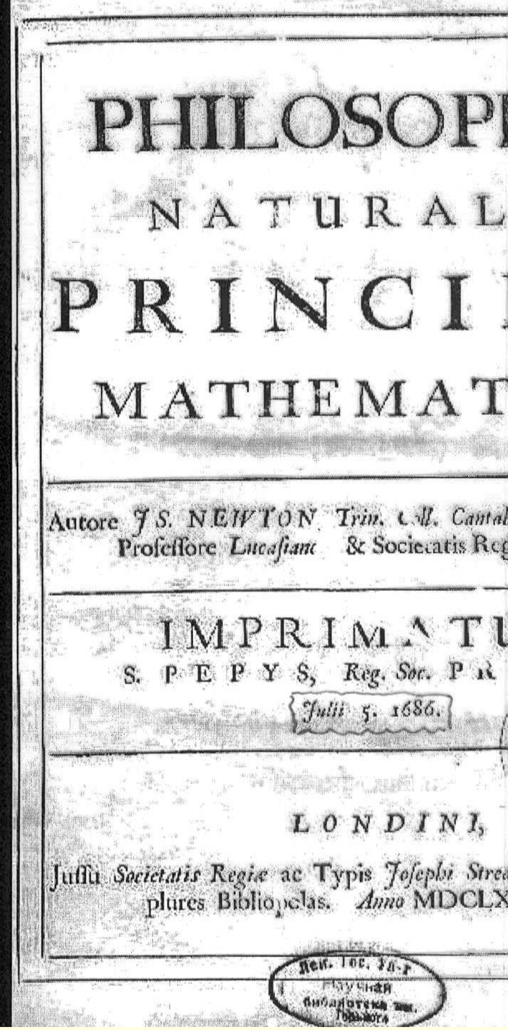
Inhomogeneity of matter distribution

(Discreteness and fractality of spatial galaxy distribution)

The nature of cosmological redshift

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





Космология 19-го века

Основные уравнения:

$$\Delta\varphi = 4\pi G\,\rho$$

$$\vec{F} = m_I \frac{d\vec{v}}{dt} = -m_G \vec{\nabla}\varphi$$

$$m_I = m_G$$

$$\frac{d^2 r}{dt^2} = -\frac{G\,M(r)}{r^2}$$

Исходные принципы:

однородное распределение звезд в евклидовом пространстве

\+

ньютоновская физика

Парадоксы:

гравитационный,

фотометрический,

термодинамический

Exact Newtonian equation of motion for the exact relativistic Friedmann equation

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

(1,1): $\ddot{S} = -\frac{4\pi G}{3}(\rho + \frac{3p}{c^2})\, S \equiv \frac{d^2 r}{dt^2} = -\frac{G\, M_g(r)}{r^2}$ **Newtonian ball r(t) expansion**

(0,0): $H^2 - \frac{8\pi G}{3}\rho = -\frac{k c^2}{S^2} \equiv \frac{V^2{}_{exp}}{2} - \frac{GM}{r} = const$ **Newtonian kinetic and potential energy**

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

$$p = \gamma\, \rho\, c^2$$

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

Violation of energy conservation in each local comoving volume of the Friedmann model

for any ball with radius $r(t) = S(t)\,\chi$ **(for** $p = \gamma\varepsilon$**)**

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

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

=> the only model ($\gamma = 0$), where the energy is conserved (Lemaitre 1933)

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

=> cooling photon gas (CMBR) in the Friedmann model ($\gamma = 1/3$) is the result of continuous disappearance of photons energy

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

=> vacuum energy in the Freidmann model ($\gamma = -1$) is continuously increases (created) in any comoving volume

Космологическое красное смещение - эффект Леметра в расширяющемся пространстве

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

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

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

Соотношение скорость – красное смещение

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

Соотношение расстояние – красное смещение:

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

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

Сравнение эффекта Леметра и эффекта Доплера

$$V_{\exp}(z) = c\,\frac{r(z)}{r_H}$$

$$V_{\exp}(z) > c \qquad if \quad z > 3$$

$$q_0 = 0.5, \quad p = 0$$

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

Скорость удаления галактик в СКМ

Модели: **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	$1{-}2\cdot10^{-6}$	1.94	500	1000
∞	1	2	∞	∞

The nature of cosmological redshift

A RELATION BETWEEN DISTANCE AND RADIAL VELOCITY AMONG EXTRA-GALACTIC NEBULAE

By Edwin Hubble

Mount Wilson Observatory, Carnegie Institution of Washington

Communicated January 17, 1929

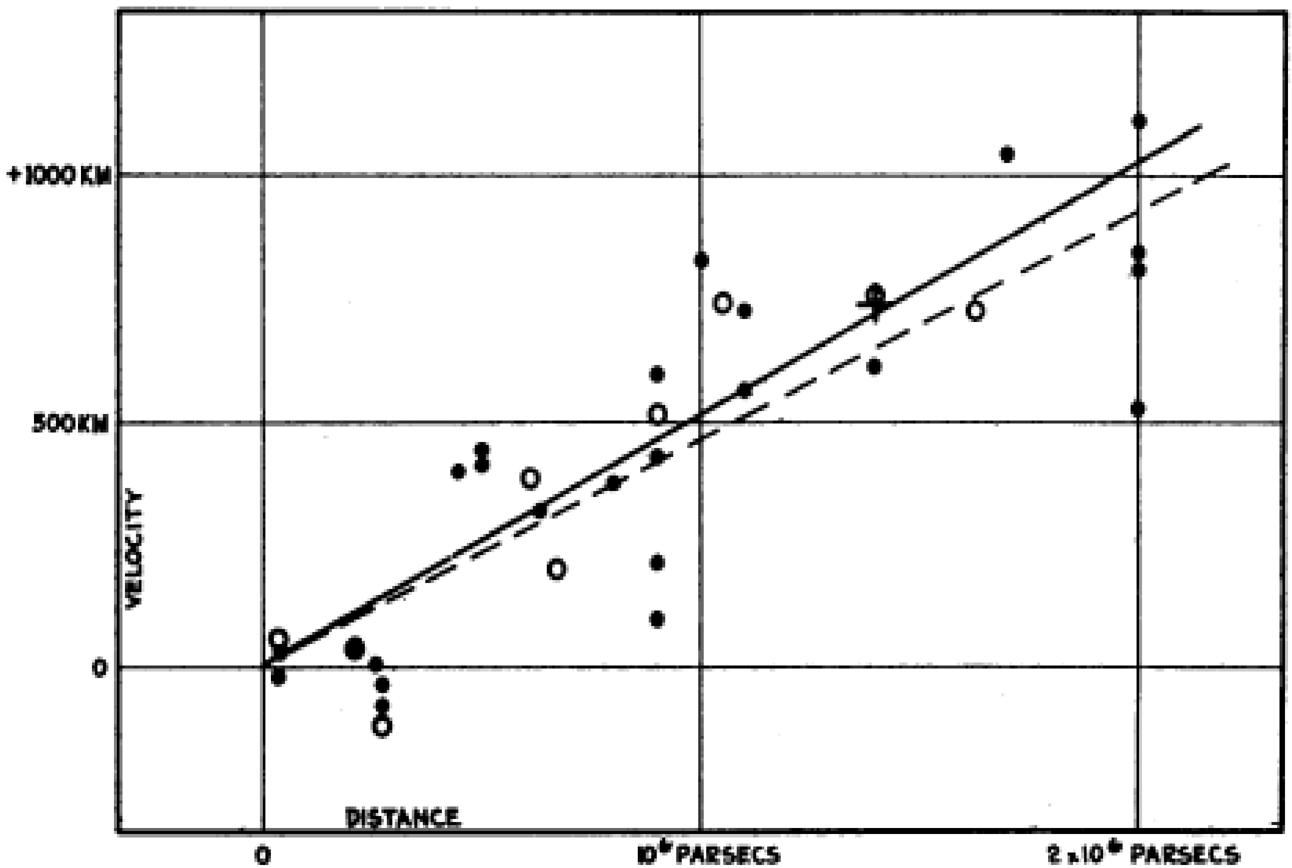


FIGURE 1

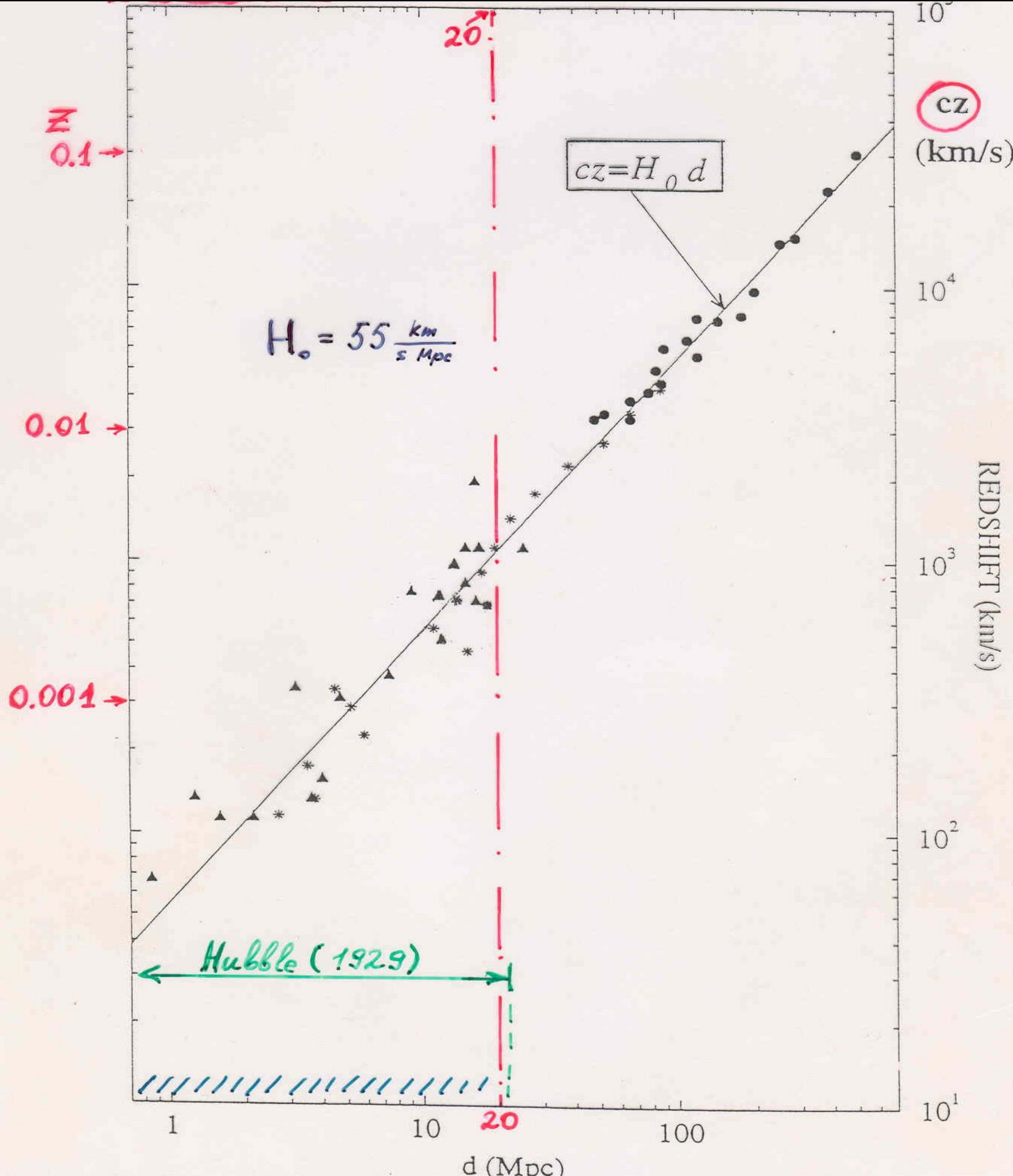
Edwin Hubble, PNAS USA, 15, 168, (1929):

“The outstanding feature, however, is the possibility that the velocity - distance relation may represent the de Sitter effect”

“displacements of the spectra arise from … an apparent slowing down of atomic vibrations… “

V=cz =Hd “apparent velocity” at distances

d < 20 Mpc



Linear Hubble Law

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

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

$$2014 \rightarrow H_{0Pl} = 67\ \frac{km}{s\,Mpc}$$

$$2016 \rightarrow H_{0loc} = 73\ \frac{km}{s\,Mpc}$$

De Sitter effect of cosmological gravitational redshift

De Sitter (1917), MNRAS, 78, 3 - static cosmological solution of Einstein's equations:

$$ds^2 = \left(1 - \frac{r^2}{R_\Lambda^2}\right)c^2dt^2 - \frac{dr^2}{1 - r^2/R_\Lambda^2} - r^2(d\theta^2 + \sin^2\theta d\phi^2).$$

Here *r* is the distance from the source to the observer, and $(R_\Lambda)^2 = {}^3/_\Lambda$ is the characteristic radius corresponding to the cosmological constant Λ .

The de Sitter effect is caused by the *g*_00 component of the metric and from the definition 1+*z*_g = 1/ (*g*_00)^1/2 it is the cosmological gravitational redshift for a homogeneously distributed substance with positive mass density $\rho = \Lambda c^2 / 8\pi G$.

Sandage (1989) : "De Sitter effect was due to a scandalous space-dependent factor in the metric coefficient of the time dimension "

Cosmological gravitational redshift: Bondi effect

Bondi H., *Spherically symmetrical models in general relativity*
MNRAS, 107, 410 (1947)

для z << 1 , x = r / r_H = v / c

$$z_{\cos} \approx z_{Dop} + z_{grav} = x + \frac{1+q_0}{2}\, x^2 = \left(\frac{v}{c} + \frac{v^2}{2\,c^2}\right) + \frac{q_0}{2}\, x^2$$

$$z_{grav} = \frac{\delta\,\phi(r)}{c^2} = \frac{1}{2}\,\frac{G\,M(r)}{c^2\,r} = \frac{1}{4}\,\Omega_0\, x^2$$

Global Gravitational Redshift

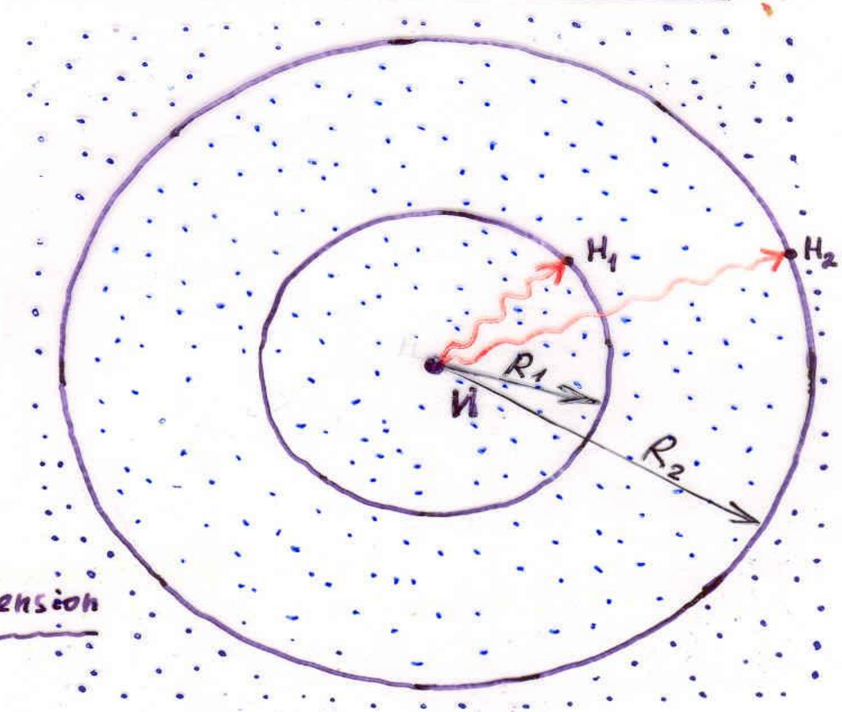
Bondi, 1947, MNRAS, 107, 410.

$$\varphi \sim \frac{GM}{R}$$

$$M \sim R^{D_F}$$

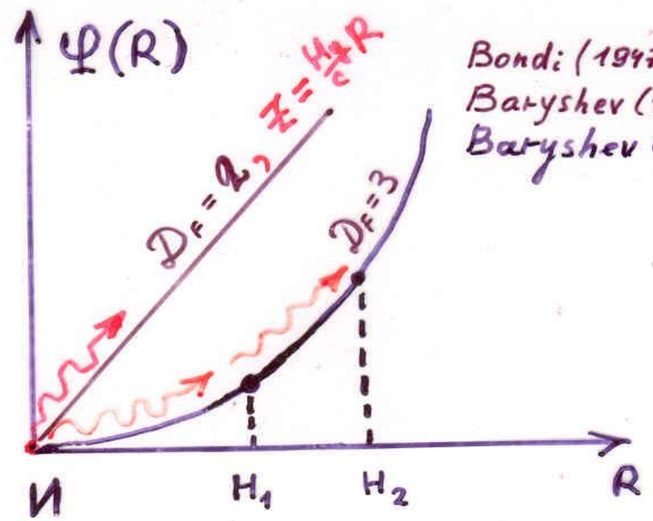
$$\varphi \sim R^{D_F - 1}$$

D_F is fractal dimension



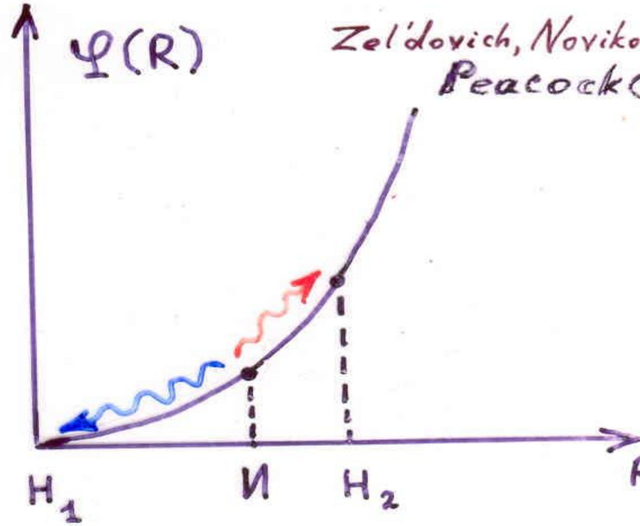
$$Z_{cos}(R) \approx$$

$$\approx \underbrace{\frac{v(R)}{c} + \frac{1}{2}\frac{v^2(R)}{c^2}}_{\text{velocity}} + \underbrace{\frac{\delta\Phi_N(R)}{c^2}}_{\text{mass}}$$



Bondi (1947)
Baryshev (1981)
Baryshev et al. (1994)

Zel'dovich, Novikov, "RA"
Peacock (1999)



Comparison of FG and GR: cosmological redshift

Field Gravity

Fractal matter distribution:

$$M(r) \propto r^D$$

Global gravitational cosmological redshift:

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

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

$$= \frac{2\pi G\rho_0 r_0}{c^2} r = \frac{H_g}{c} r \quad (D=2)$$

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

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

General Relativity

Lemaitre effect in expanding space:

$$(1+z) = \frac{\lambda_0}{\lambda_1} = \frac{S_0}{S_1}.$$

Cooling-down of particles velocities:

energy-momentum non-conservation

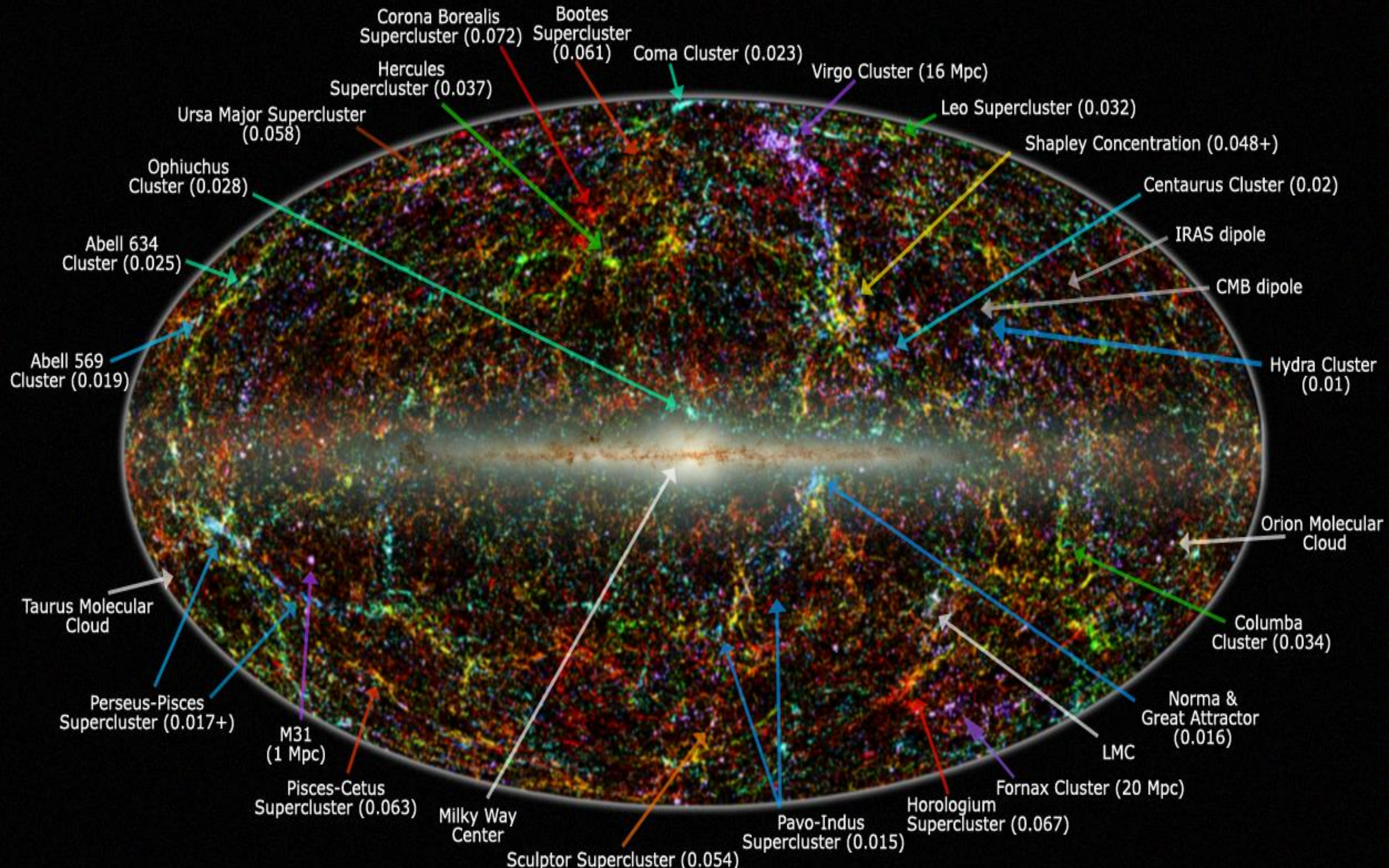
$$v(t) \propto 1/S(t)$$

Velocity-distance-redshift relations:

$$v_{\rm exp}(z) = r(z)H_0 = c\frac{r(z)}{R_{H_0}}.$$ (> c for $r > R_{H_0}$)

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

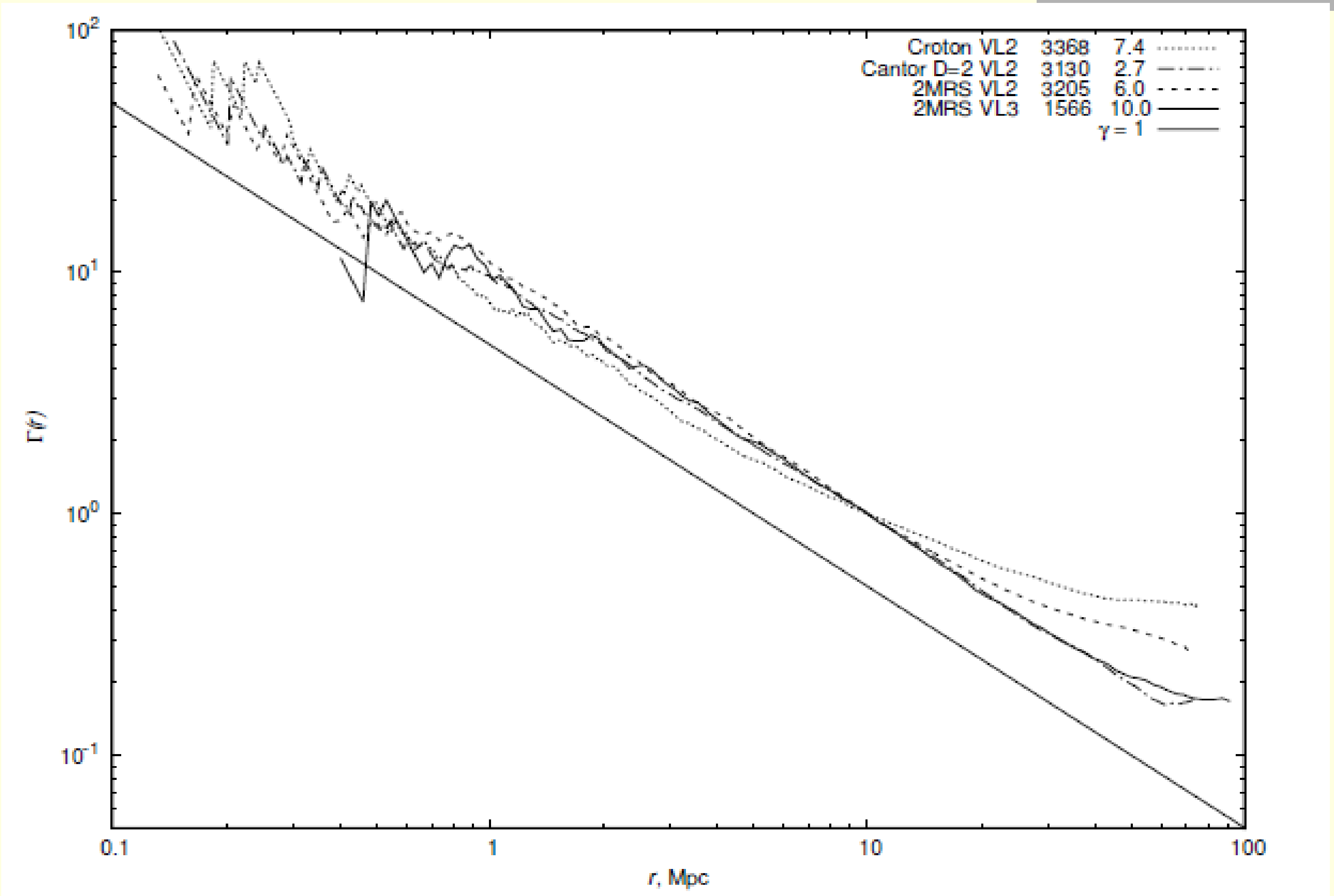
Large Scale Structure in the Local Universe



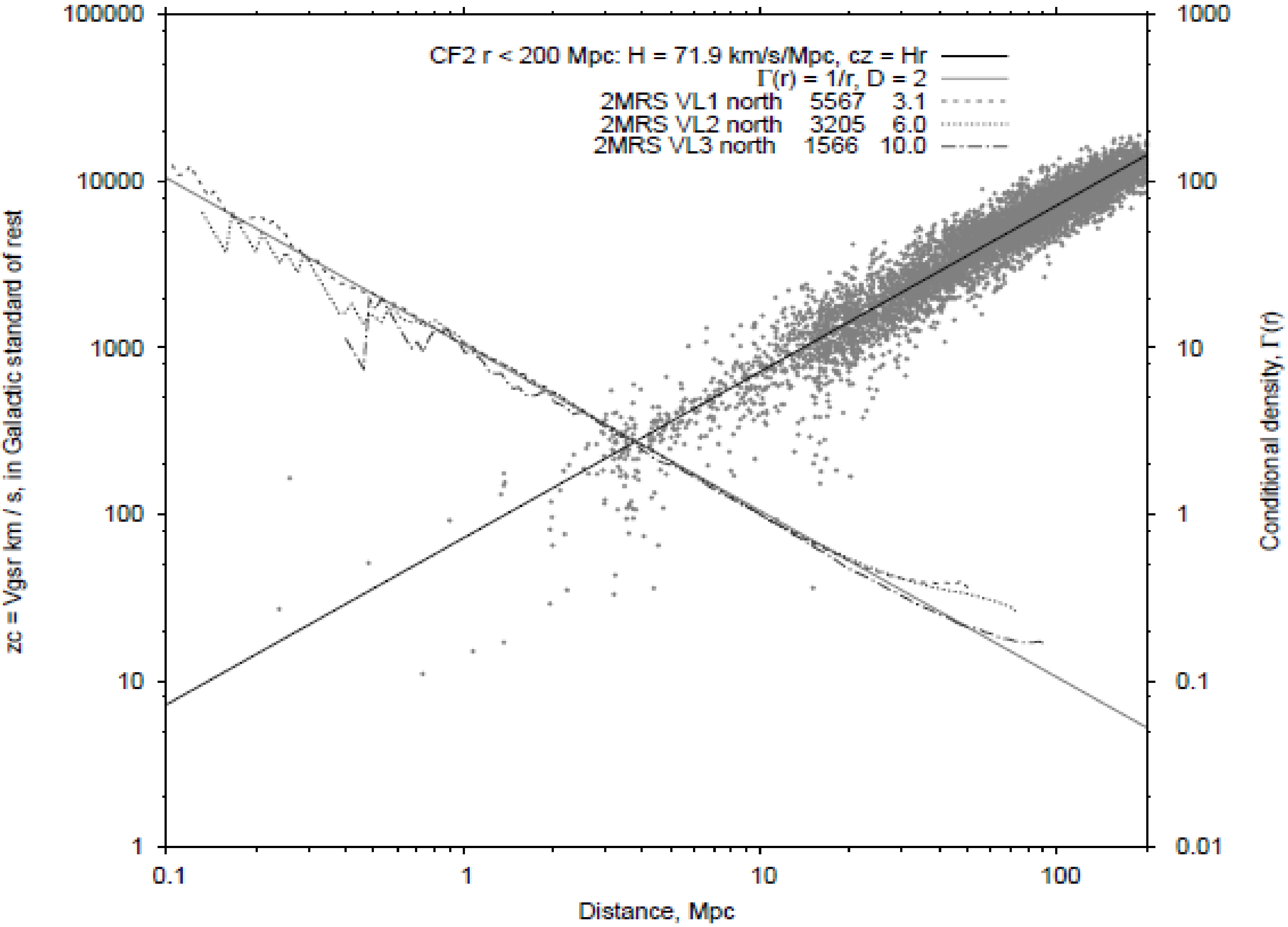
Legend: image shows 2MASS galaxies color coded by redshift (Jarrett 2004); familiar galaxy clusters/superclusters are labeled (numbers in parenthesis represent redshift). Graphic created by T. Jarrett (IPAC/Caltech)

Conditional density for 2MRS samples

Tekhanovich D., Baryshev Y., Astr.Bull., 71, 155 (2016)



Z(r) CosmicFlows-2 vs 2MRS Γ(r)



Hubble – de Vaucouleurs paradox

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

(Peebles P.J.E. et al., 1991, Nature, 352, 769)

According to SCM:

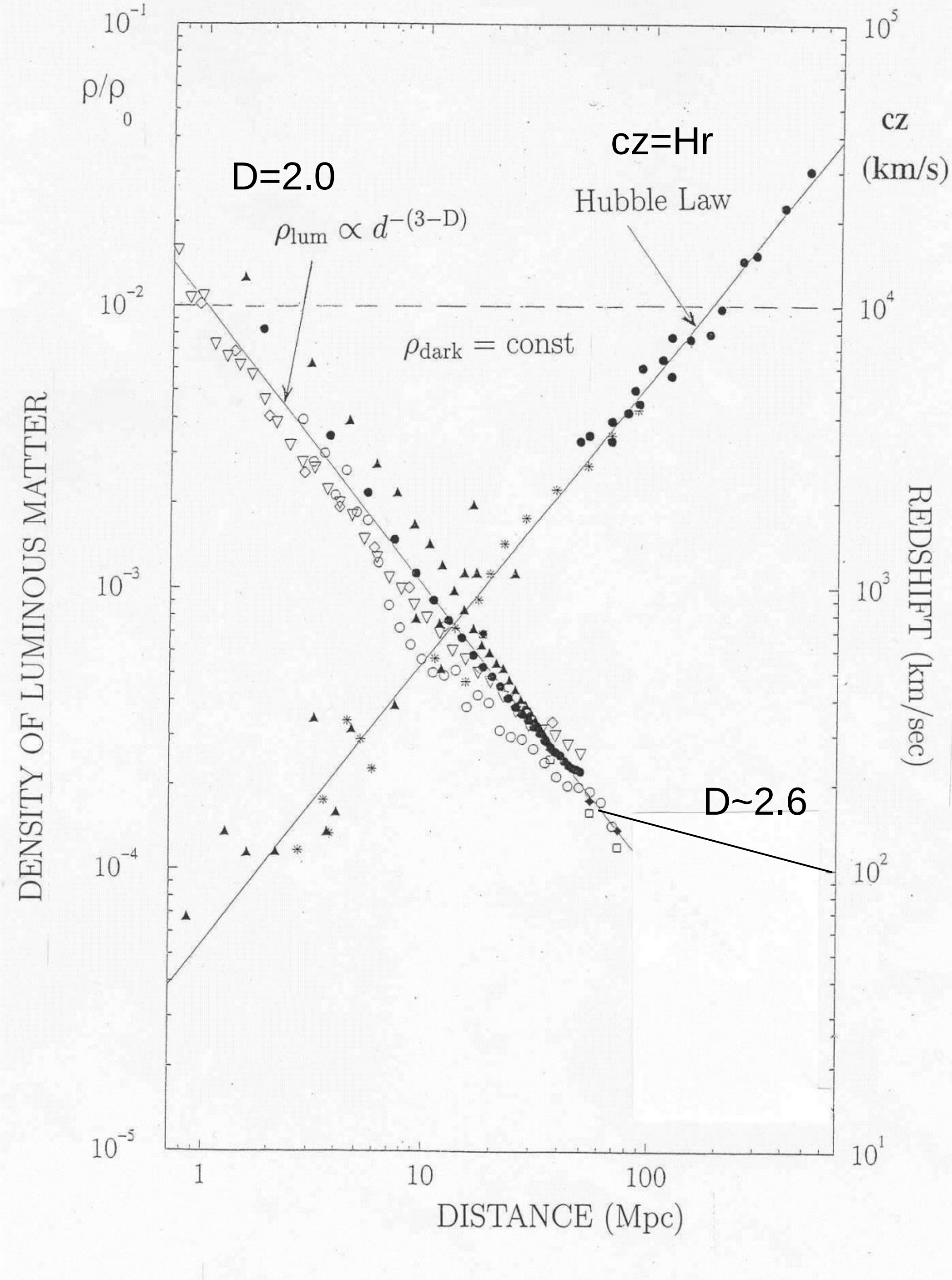
Linear Hubble Law <=> Homogeneity

However:

From observations Linear Hubble Law coexists with strong inhomogeneous spatial galaxy distribution

$$(\quad r < r_{\mathrm{hom}} \quad) \quad \& \quad (\quad cz = H_0 \, r \quad)$$

Hubble – de Vaucouleurs (HdeV) paradox



The linear Hubble Law

$$cz = Hr$$

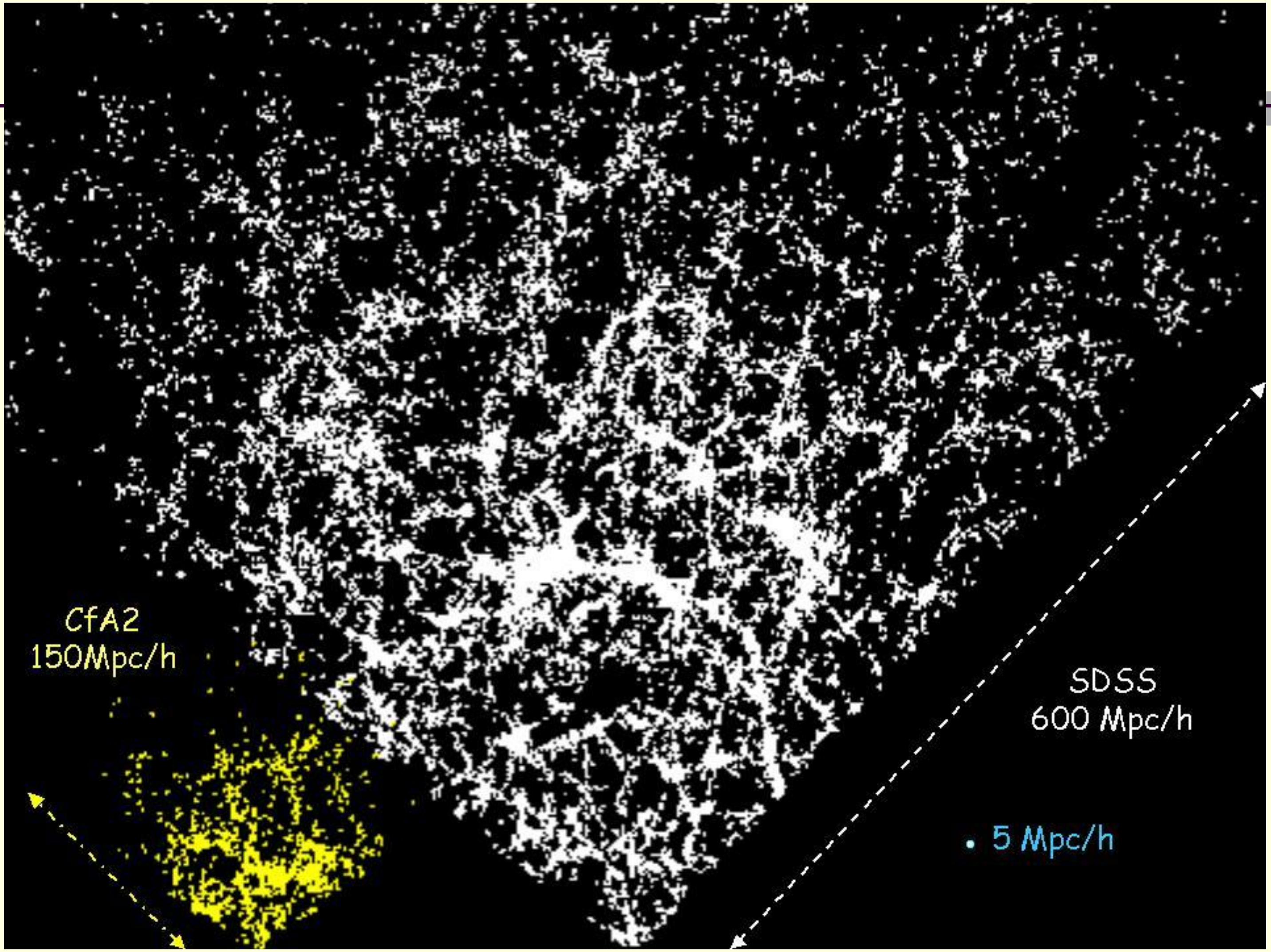
coexists with strong inhomogeneous Fractal Law – de Vaucouleurs Law of spatial galaxy distribution

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

$$\gamma = 3 - D$$

$$D = 2$$

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

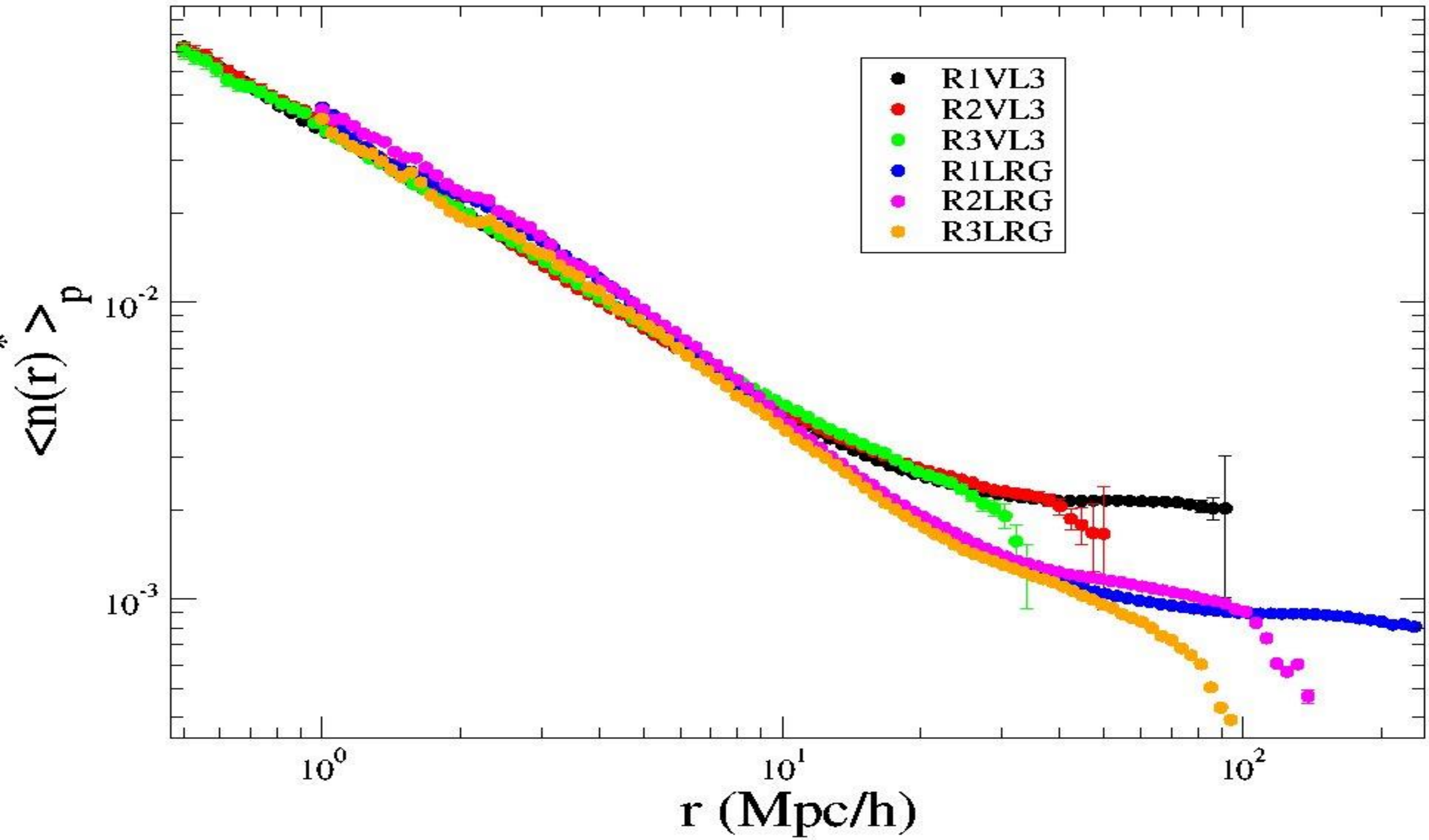


There are structures with sizes 400 Mpc , while LCDM predicts homogeneity scale 5 – 10 Mpc . Fractal dimension $D \sim N(r)^D$, D ~ 2 .

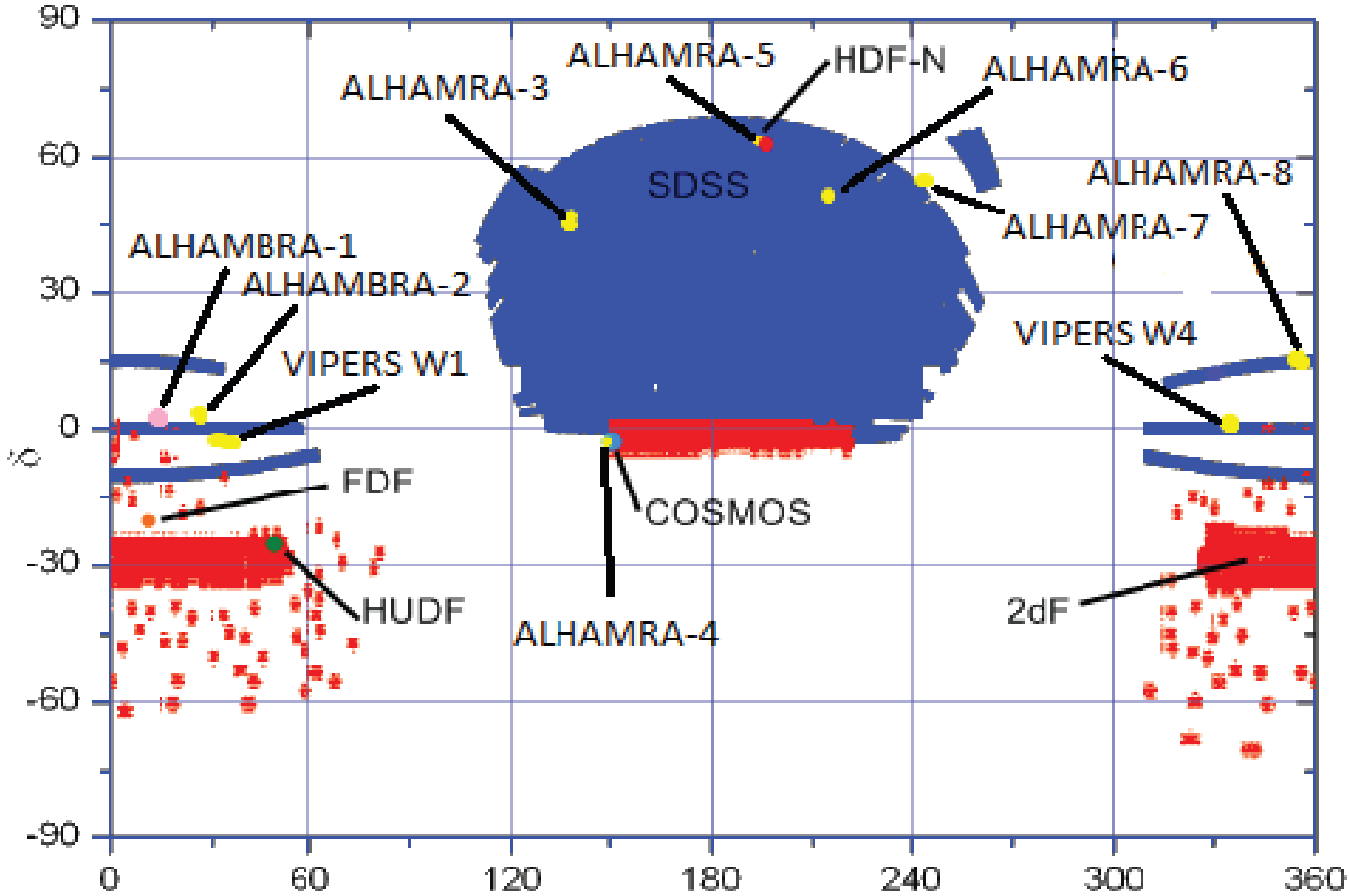
Conditional density of SDSS galaxy samples:

Sylos Labini F. et al., Astron.Astrophys.508:17-43,2009,

fractal dimension D ~ 2

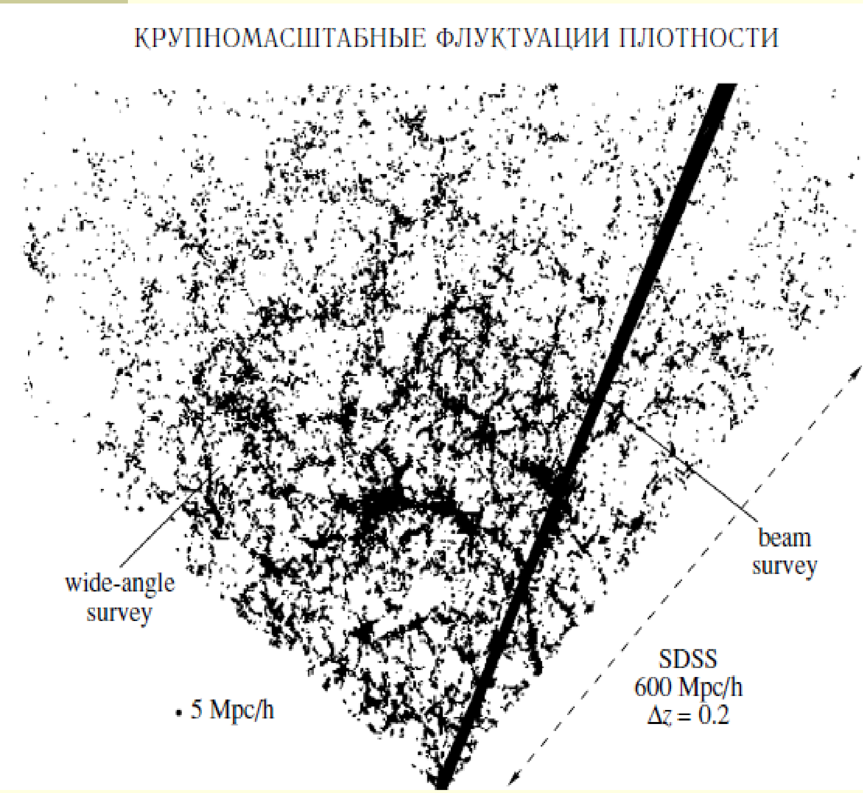


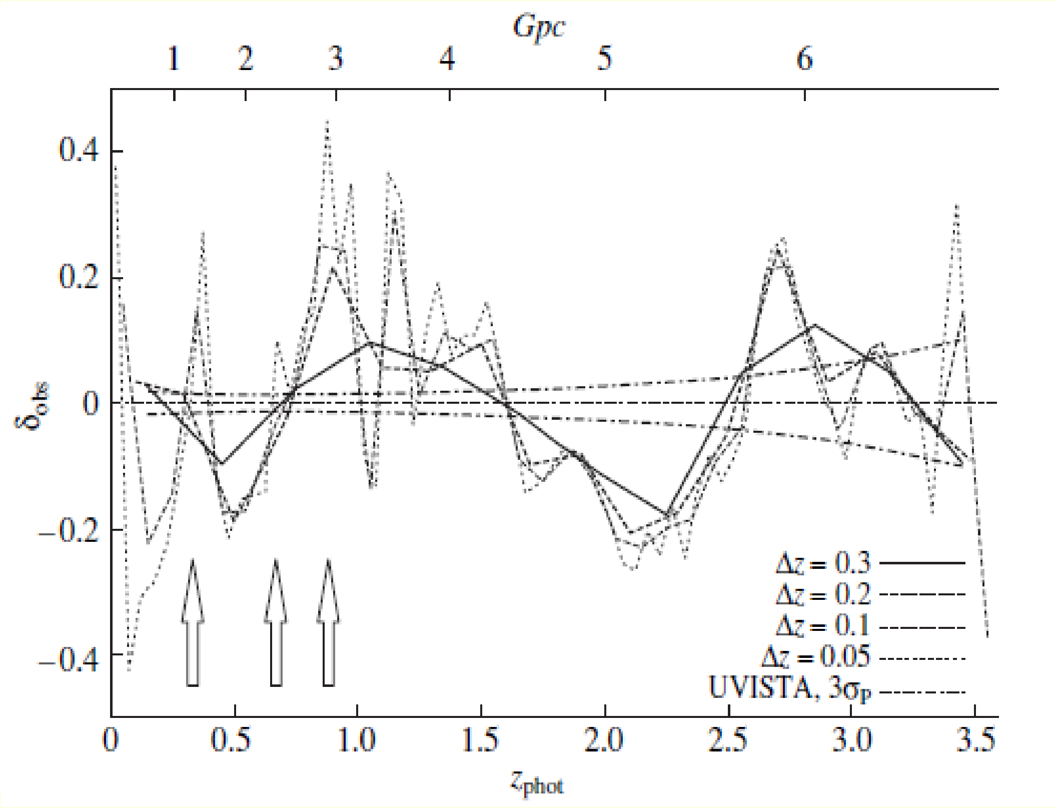
Pencil-beam and wide-angle galaxy surveys for high redshift galaxies and large scale structures



Large-Scale Fluctuations in the Number Density of Galaxies in Independent Surveys of Deep Fields

S. I. Shirokov et al., Astron. Rep., Vol.60, No. 6, 565 (2016)





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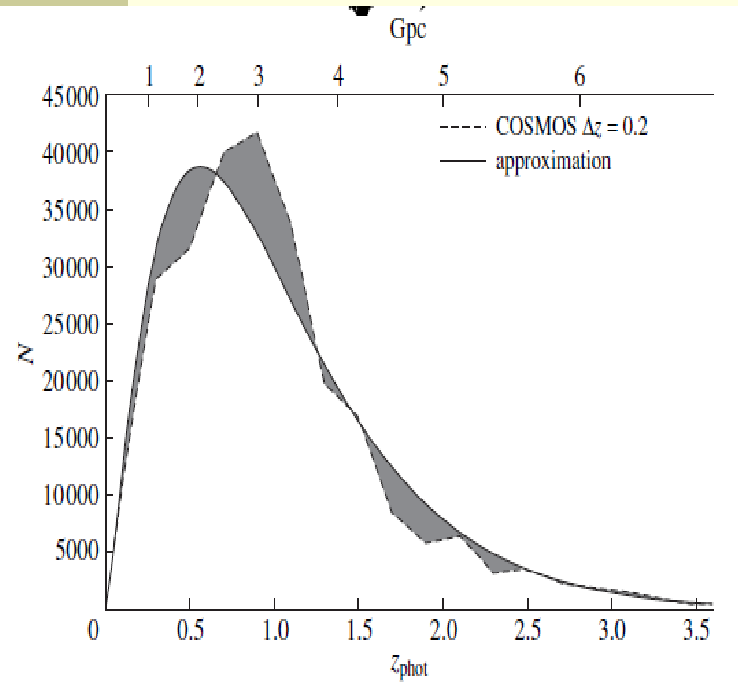
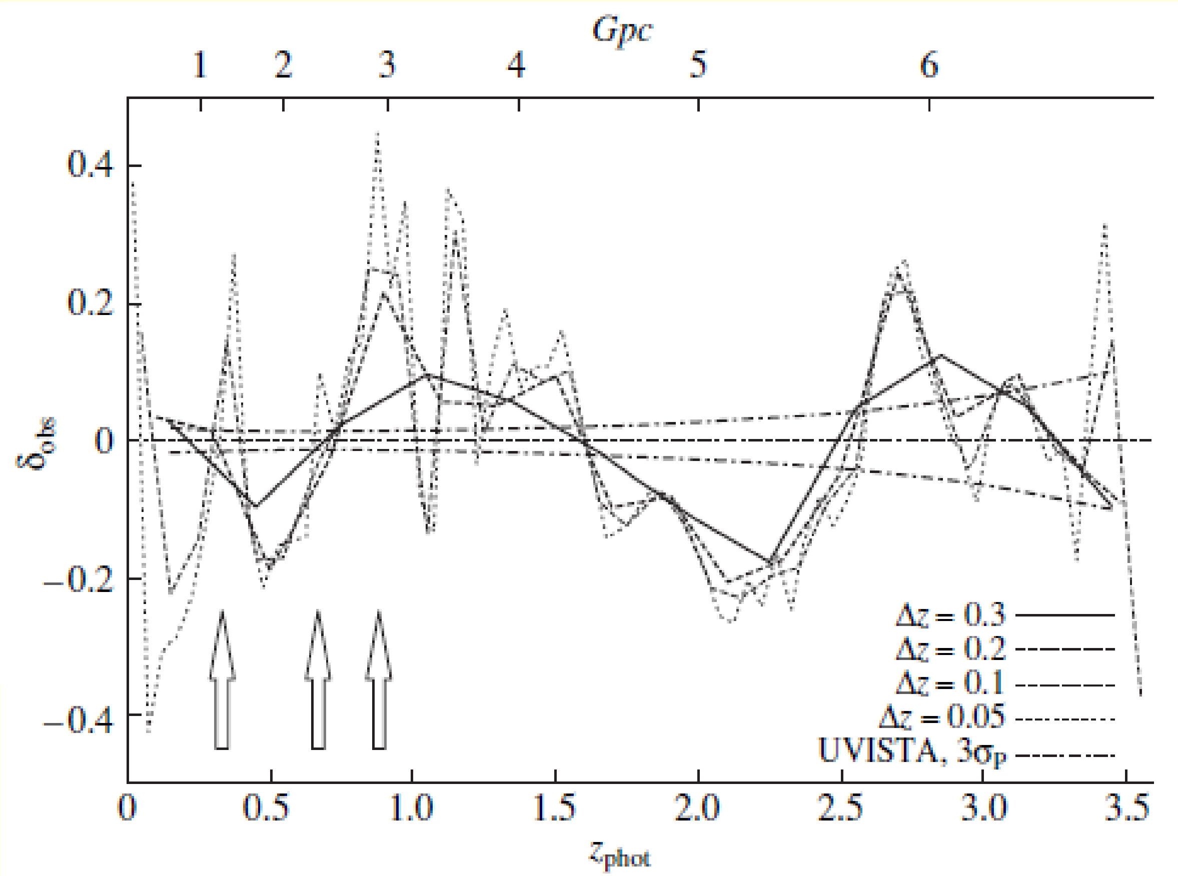




Perspectives for Relativistic Astrophysics

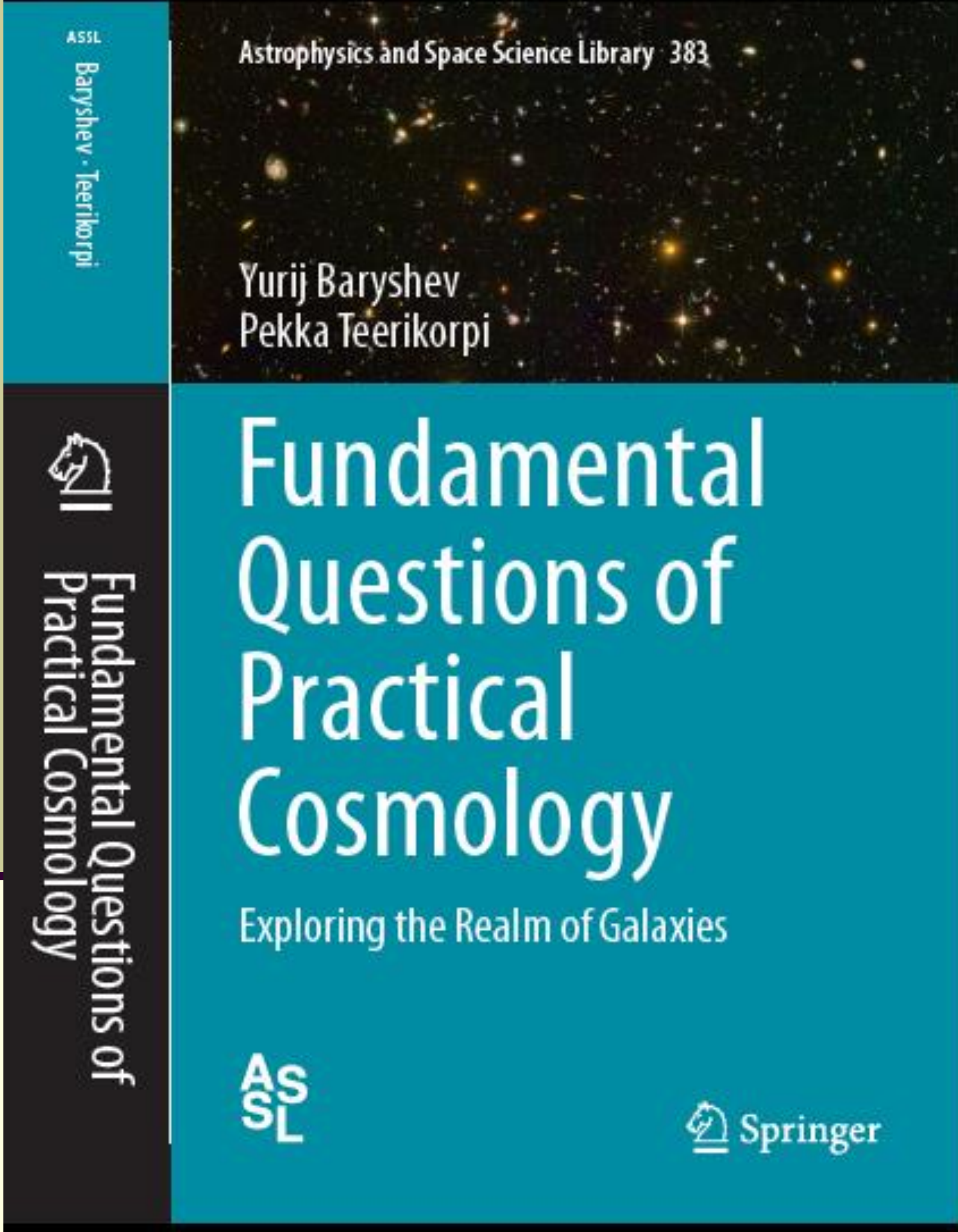
- *Developing the theory of gravitational interaction, Ghc-theory, laboratory and astrophysical testing gravity theories predictions (Einstein's geometrical approach and Feynman's field approach, nearby SN explosions, RCO images, AGN jets, neutrino and GW detection)*

- *Galaxy properties and large scale structure at small and high redshifts (wide-angle and pencil-beam 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)*

Review of modern problems in Relativistic Astrophysics

Baryshev Yu. V., *Foundation of relativistic astrophysics: Curvature of Riemannian Space versus Relativistic Quantum Field in Minkowski Space*, https://arxiv.org/abs/1702.02020



Yurij Baryshev,
Pekka Teerikorpi

***"Fundamental Questions of Practical Cosmology"*,**

Springer, Dordrecht Heidelberg London New York, 2012, 332p.

(Introduction to foundations and problems of modern cosmology)

BT2012

Richard Phillips Feynman
(1918 – 1988)

Nobel Prize in Physics (1965) :
for his fundamental work in
quantum electrodynamics

Strategy and Philosophy of science:

«Science is a culture of doubt»

«Knowledge can progress only if people have open minds and test their ideas. So far so good.»