2nd World Summit on Exploring the Dark Side of the Universe
Guadeloupe islands, University of Antilles, Fouillole, 28 June 2018

Dark energy: Acceleration of the Universe with Variable Gravitational Mass

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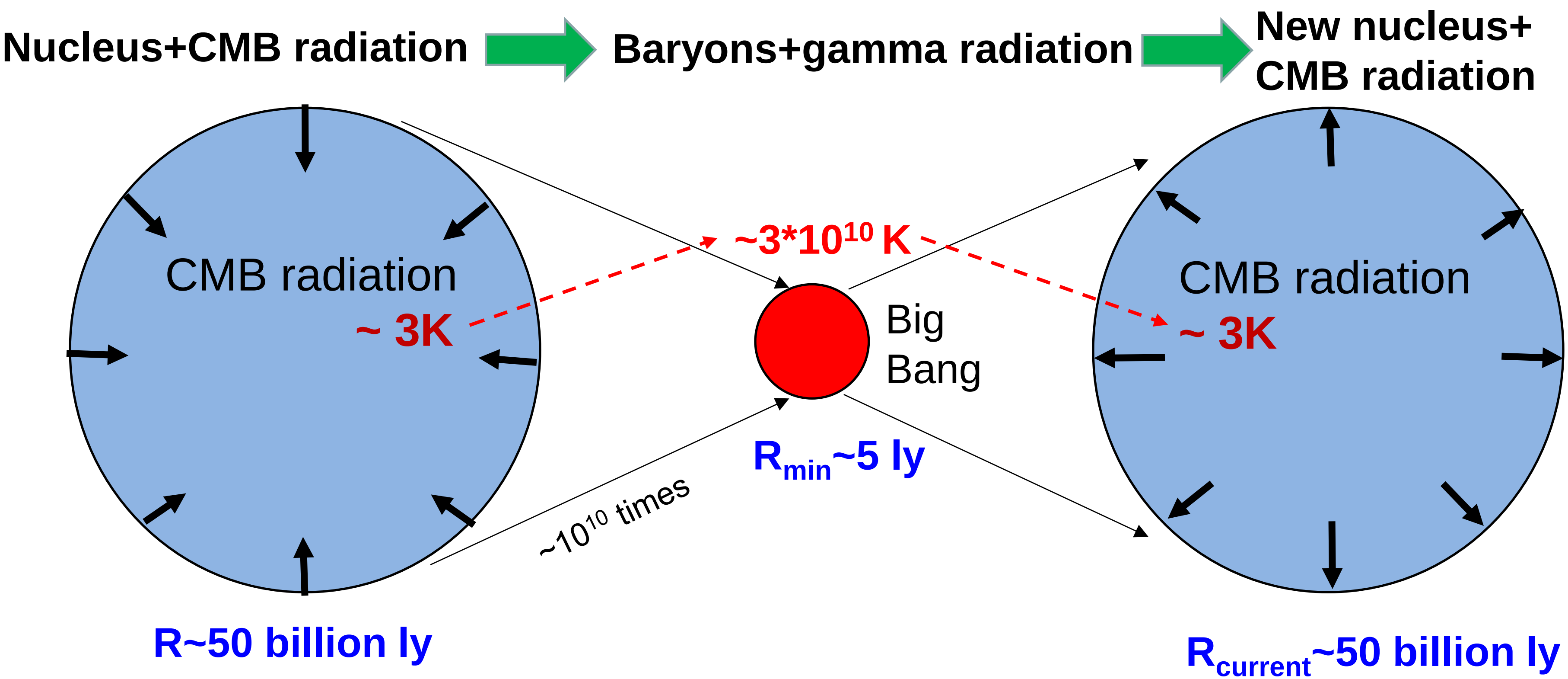
Gorkavyi, N. & Vasilkov, A. A repulsive force in the Einstein theory. *Mon.Not.Roy.Astron.Soc.* 461, 2929-2933 (2016)

Gorkavyi, N. & Vasilkov, A. A modified Friedman equation for a system with varying gravitational mass. *Mon.Not.Roy.Astron.Soc.* 476, 1384-1389 (2018)

Bouncing cosmology in the XX century (1946-1980)



Peebles P.J.E. “Principles of Physical Cosmology” 1993, p.141: “Let us extrapolate the expansion of the universe back to redshift $z \sim 10^{10}$, when the temperature was $T \sim 3*10^{10}$K, and the characteristic photon energy was ~ kT ~3Mev. At this epoch, the CBR photons are hard enough to photodissociate complex nuclei, leaving free neutrons and protons”.

$1+z=R_{current}/ R_{min}$ so $R_{min} \sim R_{current}*10^{-10}$

Bouncing cosmology in the XX century (1946-1980)

Gamow G. (1953):

"Why was our universe in such a highly compressed state, and why did it start expanding? The simplest… way of answering these questions would be to say that **the Big Squeeze which took place in the early history of our universe… and that the present expansion is simply an "elastic" rebound**".

Dicke R.H., Peebles P.J.E., Roll P.G., Wilkinson D.T. (1965):

"…for the matter we see about us now may represent the same baryon content of the previous expansion of a closed universe, oscillating for all time. …the temperature of the universe would exceed 10^{10} K, in order that **the ashes of the previous cycle would have been reprocessing back to the hydrogen**".

Bouncing cosmology was the mainstream (Misner, Weinberg et al)

Bouncing cosmology in the XX century (1946-1980)

3 problems of bouncing cosmology:

Problem A: The reason for the expansion of the universe (the Big Bang)
Problem B: Modern acceleration of the universe (the problem of Dark Energy)
Problem C: The nature and origin of Dark Matter

New data as a key to problems ABC

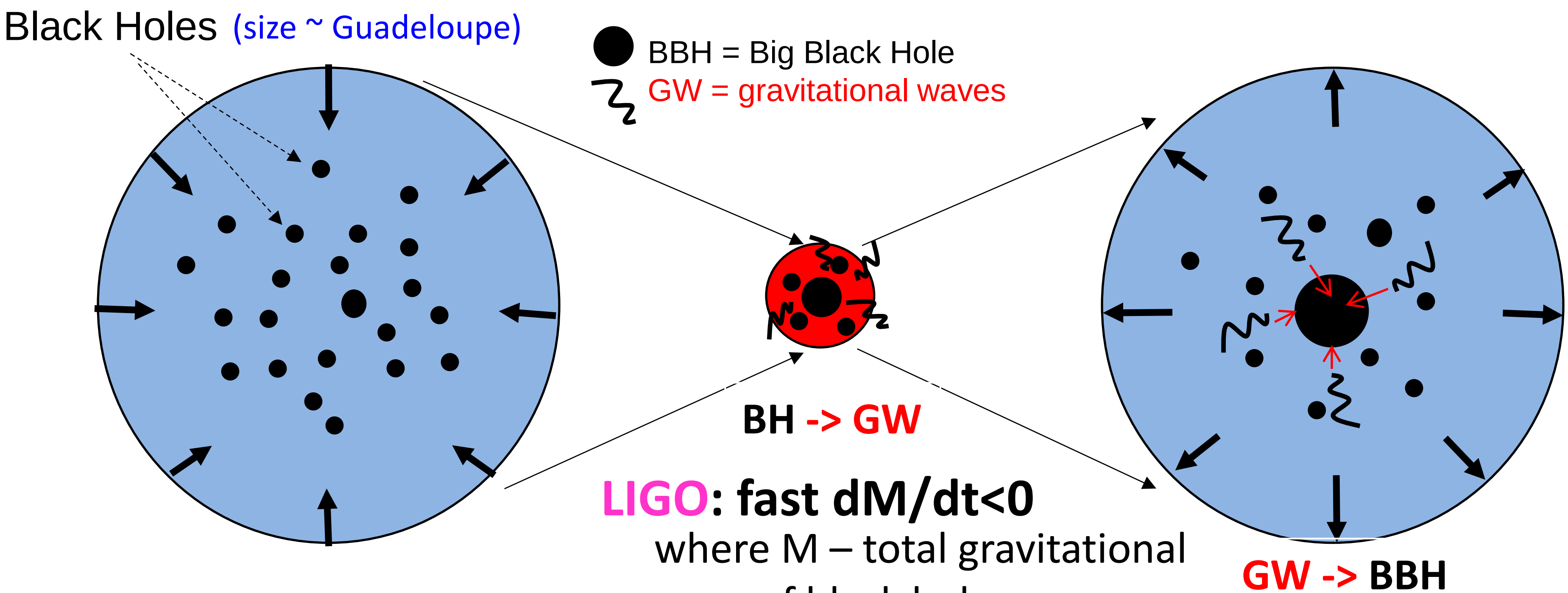
1. LIGO: discovery of gravitational waves and black holes of medium masses – 2016
2. BH with LIGO mass as a possible solution of **Problem C**:

Simeon Bird,…, Adam G. Riess. Did LIGO detect dark matter? *Phys.Rev.Letter*, 2016

3. A fraction of the black holes survives the stage of maximal contracting of the universe **(Clifton et al. 2017).** These relict black holes can produce the supermassive black holes in the galaxy centres and are responsible for the effects of 'dark matter'.

Bouncing cosmology with black holes and gravitational waves

Nucleus+CMB+BH → Baryons+gamma radiation +BBH+BH+GW → New nucleus+ CMB+BBH+BH



LIGO: fast dM/dt<0
where M – total gravitational mass of black holes

slow dM/dt>0

What's about total gravitational mass of Universe?

Different opinions about gravitational mass of gravitational waves:

Can gravitational waves be the source of the gravitational field?

Nobel Laureat tHooft (2010):

«I emphasize that any modification of Einstein's equations into something like

$$R_{\mu\nu} - 1/2\, R\, g_{\mu\nu} = \kappa(T_{\mu\nu}\, (\text{matter}) + t_{\mu\nu}\, (\text{grav}))$$

where $t_{\mu\nu}$ (grav) would be something like a "gravitational contribution" to the stress-energy-momentum tensor, is blatantly wrong. Writing such a proposal betrays a complete misunderstanding of what General Relativity is about».

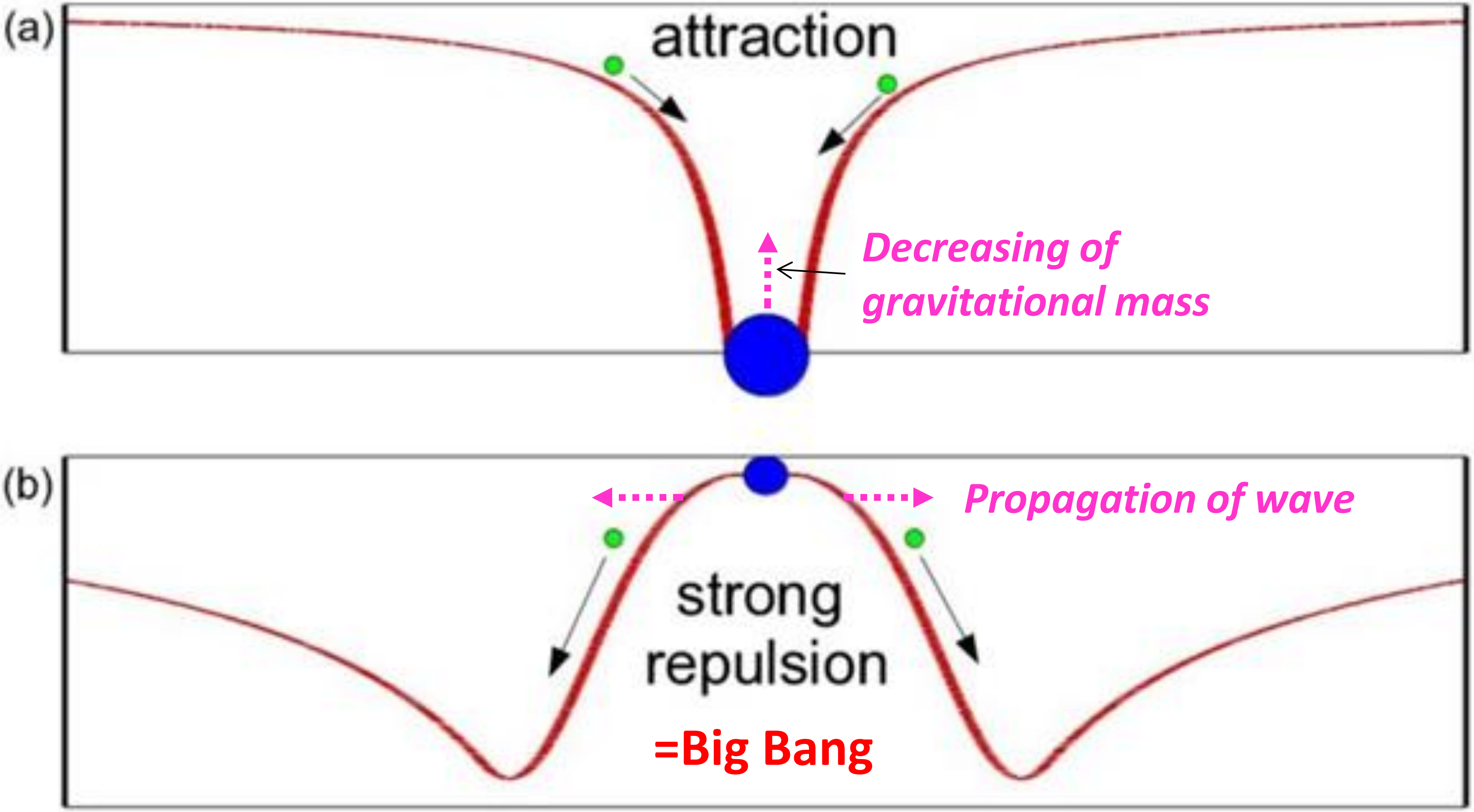
Sources of gravitational field:

$T_{\mu\nu}$ **(matter, em field) +** $t_{\mu\nu}$ **(grav)**	$T_{\mu\nu}$ **(matter, em field) +** ~~$t_{\mu\nu}$ **(grav)**~~
Einstein (1913-1916), Weinberg, Landau-Lifshitz, Misner-Thorne-Wheeler et al	Einstein (1918-1954), Schrodinger, Eddington, Chandracekhar, tHooft et al
Gravitational mass of the Universe is const ?	? ***Gravitational mass of the Universe is variable***

No conservation law for gravitational mass

Solution of Problem A: explanation of Big Bang

Why a question about variability of gravitational mass of the Universe is important?



Monopole gravitational wave??

Solution of Problem A: explanation of Big Bang

Ya.B. Zeldovich and I.D. Novikov "Stars and Relativity",
Univ. Chicago, 1971, p.40:
"lowest multipole of gravitational waves is the quadrupole. However, one should keep in mind the fact that quadrupole and higher-order waves can carry off mass and angular momentum; and as a result the longitudinal and the dipole stationary components of the field will change".

Monopole gravitational waves from relativistic fireballs driving gamma-ray bursts
M. Kutschera, MNRAS, 2003
"Whittaker's mass is not conserved, hence its changes can propagate as monopole gravitational waves. Such waves can be generated only by astrophysical sources with varying gravitational mass".

Minor matter before 2016. Key problem for cosmology after LIGO discovery of GW and 5% decreasing BH mass after merging

Solution of Problem A: explanation of Big Bang

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MNRAS **461,** 2929–2933 (2016)
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A repulsive force in the Einstein theory

Nick Gorkavyi★ and Alexander Vasilkov

Modification of Schwarzschild' metric for variable mass

$$R_{\mu\nu} = -\frac{8\pi G}{c^4}\left(T_{\mu\nu} - \frac{1}{2} g_{\mu\nu} T_\lambda^\lambda\right), \quad g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$$

$$\Box^2 h_{\mu\nu} = -\frac{16\pi G}{c^4} S_{\mu\nu},$$

where

$$S_{\mu\nu} \equiv T_{\mu\nu} - \frac{1}{2}\eta_{\mu\nu} T_\lambda^\lambda.$$

$$h_{\mu\nu}(r,t) = \frac{4G}{c^4}\int \frac{S_{\mu\nu}(t - r/c)}{r} \mathrm{d}V$$

(Weinberg 1972; Landau & Lifshitz 1975)

$$h_{00} = \frac{2GM(t - r/c)}{rc^2}$$

$$g_{00} = -\left[1 - \frac{2GM(t - r/c)}{rc^2}\right]$$

Similar solution for fireball:
Kutschera, MNRAS, 2003

Solution of Problem A: explanation of Big Bang

Gorkavyi, Vasilkov, 2016

Einstein

$$a \approx \frac{c^2}{2}\frac{\partial g_{00}}{\partial r} = \frac{\partial}{\partial r}\frac{GM(t - r/c)}{r}$$

or

$$a \approx -\frac{GM(t - r/c)}{r^2} + \frac{G}{r}\frac{\partial M(t - r/c)}{\partial r}$$

Newton

$$a = -\frac{\partial \phi}{\partial r},$$

where

$$\phi = -\frac{GM(t - r/c)}{r}.$$

If $\quad M = M_0 \exp[-\alpha(t - r/c)]$

then

$$a = -\frac{GM}{r^2} + \frac{\alpha}{c}\frac{GM}{r}$$

Newton

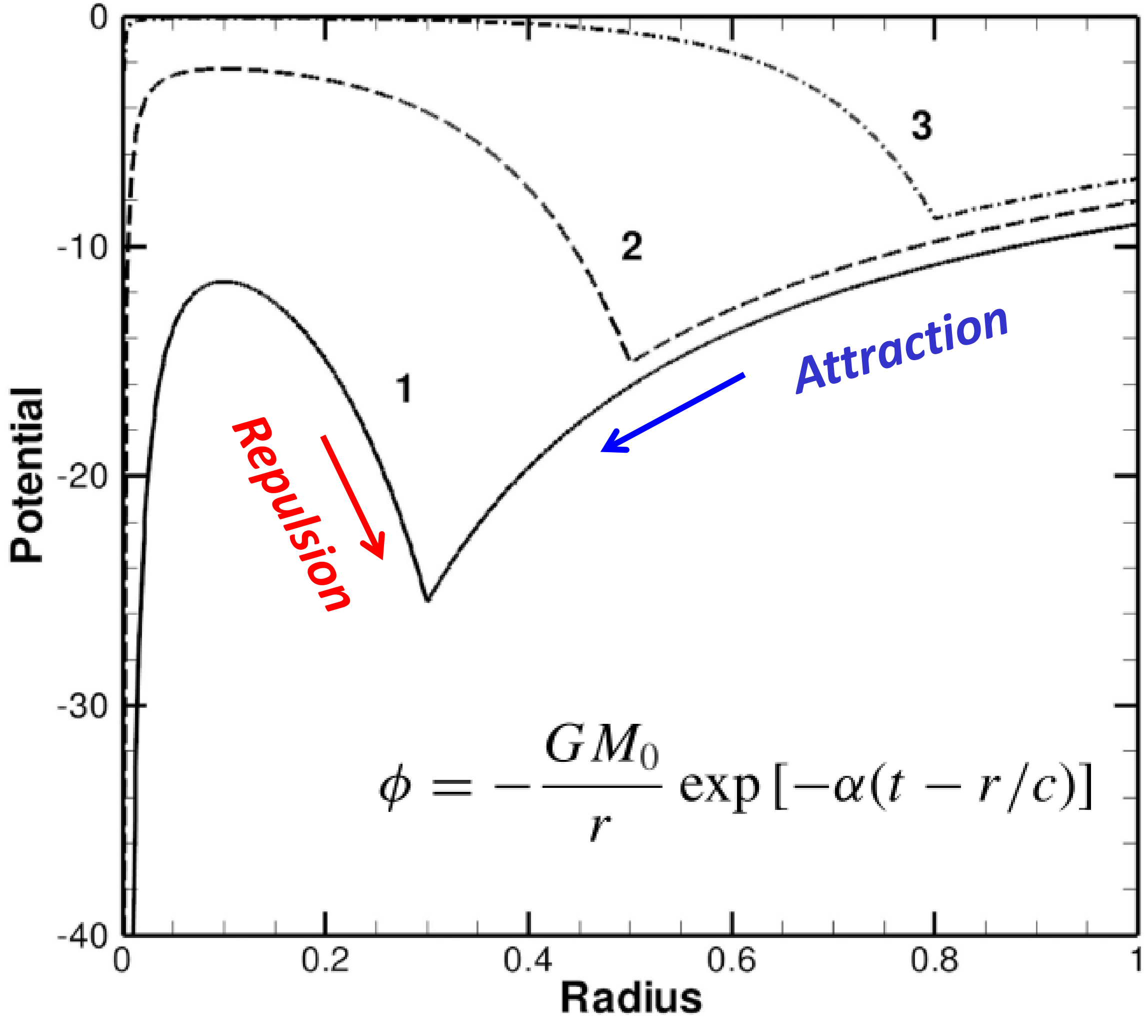
Monopole wave:

Alpha>0 – antigravitation

Alpha<0 - hypergravitation

It is NOT Hilbert (1917) antigravitation

Solution of Problem A: explanation of Big Bang



$$\phi = -\frac{GM_0}{r}\exp\left[-\alpha(t - r/c)\right]$$

Gorkavyi, Vasilkov, 2016

Figure 1. Gravitational potential (in 10^{-21} cm^2 s^{-2}) as a function of the radius (in billion light-years) for different times. The curves 1, 2, 3 correspond to times from the start of changing mass of the system: $t = 0.3, 0.5, 0.8$ billion years. For better visualization, the curve 2 shifted on 1 unit versus the curve 3; the curve 1 shifted on 2 units versus the curve 3.

Solution of Problem B: Dark Energy or enigma of Cosmological Constant

Schwarzschild metric

$$\mathrm{d}s^2 = (1-b_0)c^2\mathrm{d}t^2 - (1+b_0)\left(\mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2\right)$$

FRW metric

$$\mathrm{d}s^2 = c^2\mathrm{d}t^2 - a^2(t)\left(\mathrm{d}x_*^2 + \mathrm{d}y_*^2 + \mathrm{d}z_*^2\right)$$

Modified Schwarzschild metric

$$\mathrm{d}s^2 = [1-b(t,r)]c^2\mathrm{d}t^2 - [1+b(t,r)]\left(\mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2\right)$$

Modified FRW metric

$$\mathrm{d}s^2 = [1-b(t,r)]c^2\mathrm{d}t^2 - a^2(t,r)[1+b(t,r)]\left(\mathrm{d}x_*^2 + \mathrm{d}y_*^2 + \mathrm{d}z_*^2\right)$$

$$b(t,r) \ll 1$$

Solution of Problem B: Dark Energy or enigma of Cosmological Constant

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MNRAS **476,** 1384–1389 (2018)
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A modified Friedmann equation for a system with varying gravitational mass

Nick Gorkavyi★ and Alexander Vasilkov

$$R_{00} - \frac{1}{2} g_{00} R = -\frac{8\pi G}{c^4} T_{00}$$

$$R_{00} - \frac{1}{2} g_{00} R = -\left(\frac{1}{2g_{11}} \frac{\partial g_{11}}{c\partial t}\right)\left(\frac{1}{2g_{22}} \frac{\partial g_{22}}{c\partial t}\right)$$
$$-\left(\frac{1}{2g_{11}} \frac{\partial g_{11}}{c\partial t}\right)\left(\frac{1}{2g_{33}} \frac{\partial g_{33}}{c\partial t}\right) - \left(\frac{1}{2g_{22}} \frac{\partial g_{22}}{c\partial t}\right)\left(\frac{1}{2g_{33}} \frac{\partial g_{33}}{c\partial t}\right)$$

Terms of classical Friedmann equation

$$-g_{00}\left(\frac{1}{2g_{11}g_{22}} \frac{\partial^2 g_{22}}{\partial x_*^2} + \frac{1}{2g_{11}g_{33}} \frac{\partial^2 g_{33}}{\partial x_*^2} + \frac{1}{2g_{11}g_{22}} \frac{\partial^2 g_{11}}{\partial y_*^2}\right.$$
$$\left. + \frac{1}{2g_{22}g_{33}} \frac{\partial^2 g_{33}}{\partial y_*^2} + \frac{1}{2g_{11}g_{33}} \frac{\partial^2 g_{11}}{\partial z_*^2} + \frac{1}{2g_{22}g_{33}} \frac{\partial^2 g_{22}}{\partial z_*^2}\right).$$

Cosmological constant
(from left part of the Einstein equation)

Easy to show

APPENDIX B: DERIVATION OF THE MODIFIED FRIEDMANN EQUATIONS

Let us consider the Einstein equations (A1) without the cosmological constant and derive the Friedmann equations for the disturbed FRW metric (10) with a function $b(t,r)$ assumed to be small. In this case, there are additional to equations (A8)-(A10) non-zero Christoffel symbols:

$$\Gamma^0_{00} = \frac{1}{2g_{00}}\frac{\partial g_{00}}{\partial t}; \Gamma^1_{00} = -\frac{1}{2g_{11}}\frac{\partial g_{00}}{\partial x}; \tag{B1}$$

$$\Gamma^2_{00} = -\frac{1}{2g_{22}}\frac{\partial g_{00}}{\partial y}; \Gamma^3_{00} = -\frac{1}{2g_{33}}\frac{\partial g_{00}}{\partial z}; \tag{B2}$$

$$\Gamma^0_{10} = \frac{1}{2g_{00}}\frac{\partial g_{00}}{\partial x}; \Gamma^2_{12} = \frac{1}{2g_{22}}\frac{\partial g_{22}}{\partial x}; \tag{B3}$$

$$\Gamma^3_{13} = \frac{1}{2g_{33}}\frac{\partial g_{33}}{\partial x}; \Gamma^2_{11} = -\frac{1}{2g_{22}}\frac{\partial g_{11}}{\partial y}; \tag{B4}$$

$$\Gamma^3_{11} = -\frac{1}{2g_{33}}\frac{\partial g_{11}}{\partial z}; \Gamma^0_{20} = \frac{1}{2g_{00}}\frac{\partial g_{00}}{\partial y}; \tag{B5}$$

$$\Gamma^1_{21} = \frac{1}{2g_{11}}\frac{\partial g_{11}}{\partial y}; \Gamma^3_{23} = \frac{1}{2g_{33}}\frac{\partial g_{33}}{\partial y}; \tag{B6}$$

$$\Gamma^1_{22} = -\frac{1}{2g_{11}}\frac{\partial g_{22}}{\partial x}; \Gamma^3_{22} = -\frac{1}{2g_{33}}\frac{\partial g_{22}}{\partial z}; \tag{B7}$$

$$\Gamma^0_{30} = \frac{1}{2g_{00}}\frac{\partial g_{00}}{\partial z}; \Gamma^1_{31} = \frac{1}{2g_{11}}\frac{\partial g_{11}}{\partial z}; \tag{B8}$$

$$\Gamma^2_{32} = \frac{1}{2g_{22}}\frac{\partial g_{22}}{\partial z}; \Gamma^1_{33} = -\frac{1}{2g_{11}}\frac{\partial g_{33}}{\partial x}; \tag{B9}$$

$$\Gamma^2_{33} = -\frac{1}{2g_{22}}\frac{\partial g_{33}}{\partial y}. \tag{B10}$$

Let us write the components of the Ricci tensor from equation (A2):

$$\begin{aligned} R_{00} = {} & \Gamma^1_{01,0} + \Gamma^2_{02,0} + \Gamma^3_{03,0} - \Gamma^1_{00,1} - \Gamma^2_{00,2} - \Gamma^3_{00,3} + \\ & + (\Gamma^1_{01})^2 + (\Gamma^2_{02})^2 + (\Gamma^3_{03})^2 - \Gamma^0_{00}(\Gamma^1_{01} + \Gamma^2_{02} + \Gamma^3_{03}) \end{aligned} \tag{B11}$$

$$\begin{aligned} R_{11} = {} & \Gamma^0_{10,1} + \Gamma^2_{12,1} + \Gamma^3_{13,1} - \Gamma^0_{11,0} - \Gamma^2_{11,2} - \Gamma^3_{11,3} + \\ & - \Gamma^0_{11}(\Gamma^0_{00} - \Gamma^1_{01} + \Gamma^2_{02} + \Gamma^3_{03}) \end{aligned} \tag{B12}$$

$$\begin{aligned} R_{22} = {} & \Gamma^0_{20,2} + \Gamma^1_{21,2} + \Gamma^3_{23,2} - \Gamma^0_{22,0} - \Gamma^1_{22,1} - \Gamma^3_{22,3} + \\ & - \Gamma^0_{22}(\Gamma^0_{00} + \Gamma^1_{01} - \Gamma^2_{02} + \Gamma^3_{03}) \end{aligned} \tag{B13}$$

$$\begin{aligned} R_{33} = {} & \Gamma^0_{30,3} + \Gamma^1_{31,3} + \Gamma^2_{32,3} - \Gamma^0_{33,0} - \Gamma^1_{33,1} - \Gamma^2_{33,2} + \\ & - \Gamma^0_{33}(\Gamma^0_{00} + \Gamma^1_{01} + \Gamma^2_{02} - \Gamma^3_{03}) \end{aligned} \tag{B14}$$

In equations (B11)-(B14), we keep only those Christoffel symbols from (A8)-(A10) in the products, which contain non-zero index. Thus, we neglect all the products of the Christoffel symbols that are proportional to the squared function $b(t,r)$. Elsewhere we also neglect all terms that contain a non-linear combination of $b(t,r)$. Using equations (B1)-(B14), we can get the following expression for the zero-index component of the left side of the Einstein equations (A1):

$$\begin{aligned} R_{00} - \frac{1}{2}g_{00}R = {} & -(\frac{1}{2g_{11}}\frac{\partial g_{11}}{\partial t})(\frac{1}{2g_{22}}\frac{\partial g_{22}}{\partial t}) - \\ & - (\frac{1}{2g_{11}}\frac{\partial g_{11}}{\partial t})(\frac{1}{2g_{33}}\frac{\partial g_{33}}{\partial t}) - (\frac{1}{2g_{22}}\frac{\partial g_{22}}{\partial t})(\frac{1}{2g_{33}}\frac{\partial g_{33}}{\partial t}) - \\ & - g_{00}(\frac{1}{2g_{11}g_{22}}\frac{\partial^2 g_{22}}{\partial x^2} + \frac{1}{2g_{11}g_{33}}\frac{\partial^2 g_{33}}{\partial x^2} + \frac{1}{2g_{11}g_{22}}\frac{\partial^2 g_{11}}{\partial y^2} + \\ & + \frac{1}{2g_{22}g_{33}}\frac{\partial^2 g_{33}}{\partial y^2} + \frac{1}{2g_{11}g_{33}}\frac{\partial^2 g_{11}}{\partial z^2} + \frac{1}{2g_{22}g_{33}}\frac{\partial^2 g_{22}}{\partial z^2}) \end{aligned} \tag{B15}$$

Solution of Problem B: Dark Energy or enigma of Cosmological Constant

The first modified Friedmann equation:

$$\left(\frac{\dot{a}}{a}\right)^2 \underset{>>}{+} \left(\frac{\dot{a}}{a}\right)\dot{b} = \frac{\Lambda(t,r)c^2}{3} + \frac{8\pi G\rho}{3},$$

$$\boxed{\Lambda(t,r) = \left(\frac{\partial^2 b}{\partial x^2} + \frac{\partial^2 b}{\partial y^2} + \frac{\partial^2 b}{\partial z^2}\right)}$$

Solution of Problem B: Dark Energy or enigma of Cosmological Constant

(*The cosmological constant, calculated within the framework of quantum cosmology, is 40-120 orders of magnitude greater than the observed value.*)

$$\Lambda(t,r) \approx \frac{\alpha^2}{c^2} b(t,r) = \frac{\alpha^2}{c^2}\frac{2GM(t,r)}{rc^2} = \frac{\alpha^2}{c^2}\frac{r_0}{r},$$

Gorkavyi, Vasilkov, 2018

where the Schwarzschild radius $r_0 = 2GM(t,r)/c^2$ $\alpha = f/T,$

$$\Lambda(t,r) = \frac{f^2}{c^2T^2}\frac{r_0}{r} \approx 0.7 \times 10^{-56} f^2 \frac{r_0}{r}$$

(in cm^{-2}), where $T \approx 4 \times 10^{17}$ s.

similar order

Lambda from “Plank” observations: 1.1*10^{-56} cm^{-2}

The theoretical value of cosmological constant is equal to observed value, if

$$f^2\frac{r_0}{r} \approx 1.6$$

$$f \sim 10 \text{ and } r_0/r \sim 0.02$$

Radius of BBH ~ 1 billion ly, distance ~ 50 billion ly

Solution of Problem B: Dark Energy or enigma of Cosmological Constant

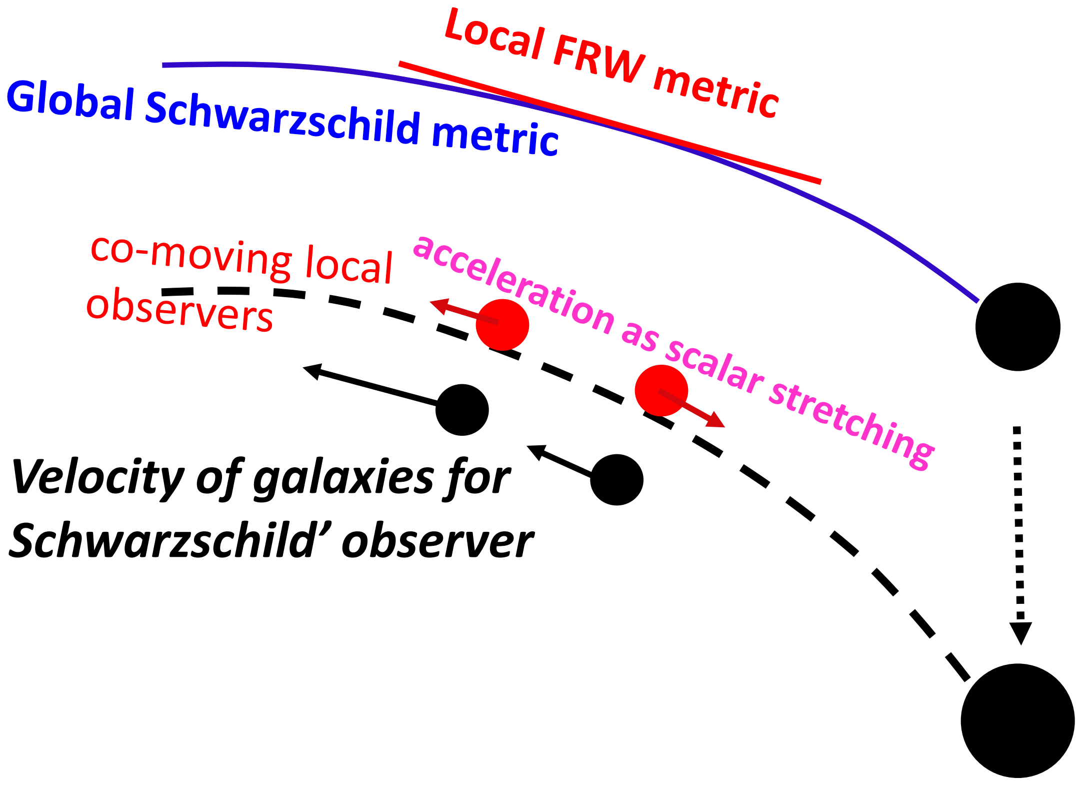
The second modified Friedmann equation:

$$\frac{\ddot{a}}{a} \approx -\frac{\alpha}{2}\sqrt{\frac{\Lambda(t,r)c^2}{3}}$$

>0 if Alpha<0

or dM/dt>0

- hypergravitation



GW -> BBH

BBH ~ 1 billion ly and growing by GW absorbing

Solution of Problem B: Dark Energy or enigma of Cosmological Constant

FOUR LAST "CONJECTURES"

Philip W. Anderson, Princeton University (emeritus)

March 23, 2018 https://arxiv.org/abs/1804.11186

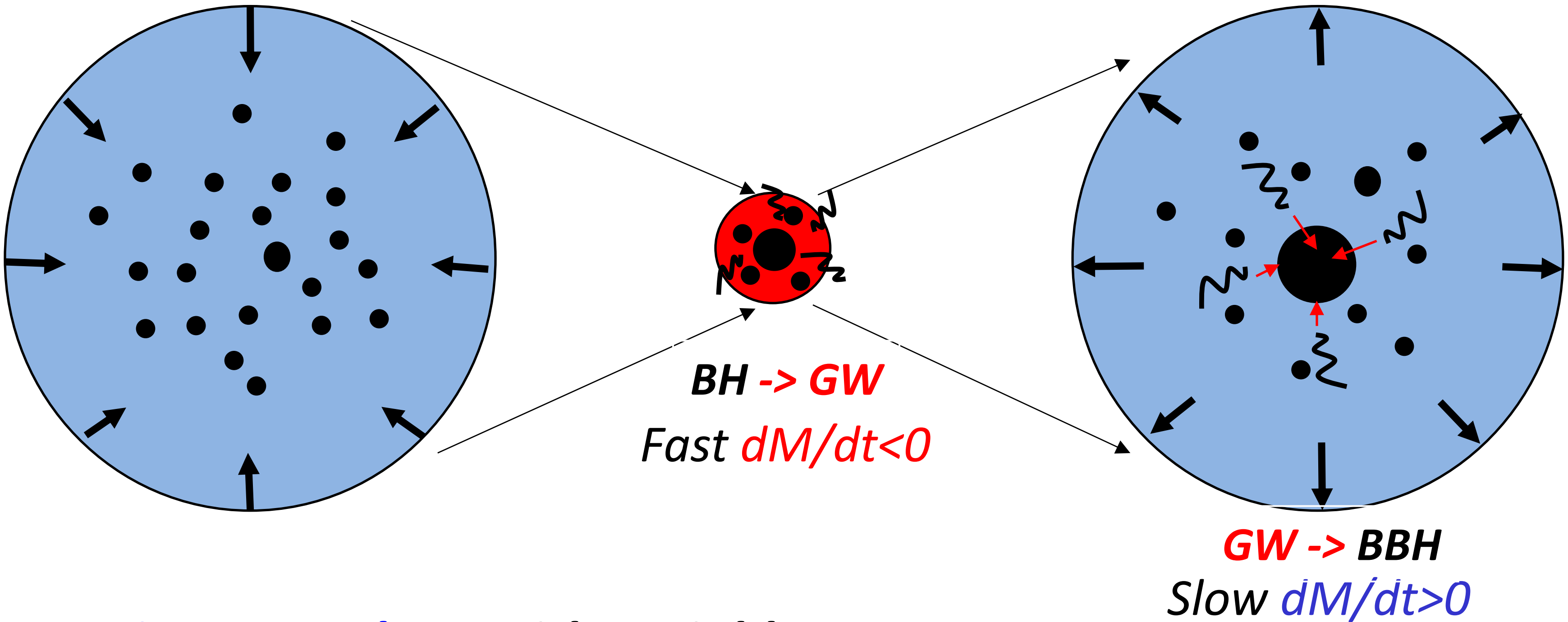
"The dark energy in cosmology models is the consequence at least in part of gravitational radiation carrying energy past us".

IV. Dark energy as gravitational radiation.

"...the radiation does not conserve total mass from our point of view… The observable universe is becoming lighter at some unknown rate, depending on how much is being irreversibly radiated away". "This does not seem to be accounted for in the present cosmology, and may be a part, or even the whole, of the "dark energy" that is now postulated".

John Mather (May 7, 2018) (from private letter to NG): "Yes indeed, just as you have been working out! I expect his paper will produce a lot of reaction (and back-reaction) since he is so well-known in so many areas of physics".

Solution of Problem AB: Big Bang and Dark Energy



Bouncing cosmology with variable mass can explain Big Bang and Dark Energy phenomena:

$$a = -\frac{GM}{r^2} + \frac{\alpha}{c}\frac{GM}{r}$$

Alpha>0 or fast dM/dt<0 – antigravitation

- explanation of Big Bang

Alpha<0 or slow dM/dt>0 – hypergravitation

- explanation of Dark Energy

Black Holes = dynamite for the Big Bang and an engine for acceleration of the Universe

Conclusions

1. A cosmic repulsive force for the Big Bang can be explained in the Einstein theory of relativity without additional hypotheses. The mergers of black holes, resulting in emissions of gravitational waves, generate a repulsive gravitational force.

2. The accelerated expansion of the Universe is described by the Friedmann equations with a varying gravitational mass. Hypotethical dark energy can be replaced by gravitational field of an object with growing gravitational mass.

3. An estimate of the effective cosmological constant is derived directly from the Einstein equations and agreed with observations. The Lambda depends on the speed of light, so we developed the fundamentally relativistic cosmology.

4. The cosmological principle for the Universe is not universal. The Universe is isotropic and homogeneous locally only. Possible effects of anisotropy and inhomogeneity of the Universe can be observable for distant objects.

New paradigm?

We believe that a cyclic model of the Universe can be developed on the basis of cyclic transformation of black holes, gravitation radiation, baryons and electromagnetic waves. The new cyclic model of the Universe will be based on periodic transformation of the mass of merging black holes into gravitational waves and absorption of the background gravitational radiation by black holes.