New Astronomical Data and Problems of Modern Cosmology and Astrophysics

A.D. Dolgov

NSU, Novosibirsk, 630090, Russia,
ITEP, Moscow, 117218, Russia

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Astronomical data accumulated mostly during several recent years are in striking disagreement with the standard cosmology and astrophysics.

"Something is rotten in the cosmological kingdom"

Heretic outcome:

1) Black holes in the universe are mostly primordial (PBH);

2) Primordial BHs makes all or dominant part of dark matter (DM).

Simple mechanism of explanation is presented (in fact it was a prediction a quarter of century ago, AD, J.Silk 1993.)

The usual black holes observed in contemporary universe are assumed to be created in the process of the star collapse of stars with the masses $\gtrsim 3M_\odot$.
Supermassive BHs (SMBH) with masses $(10^6 - 10^9)M_\odot$, "living" in galactic centers, might be formed by matter accretion to the center, (not supported by calculations).
PBH are formed at prestellar epoch if $\delta\rho/\rho \sim 1$ at horizon (Zeldovich, Novikov) Their masses can vary from a fraction of gram up to supermassive BH mass.

The observations of several recent years revealed multitude of objects which, according to the standard approach, could not exist in our universe: they are either much younger or much older than allowed by the theory.

The problems persist both in the present day universe and in the young universe, ~ 20 times younger than t_U.

More details: "Beasts in Lambda-CDM Zoo", Phys. Atom. Nucl., 80 (2017) 987; arXiv:1605.06749:

"Massive and supermassive black holes in the contemporary and early universe ..." Physics Uspekhi,

DOI 10.3367/UFNe.2017.06.038153.

The list of the problems:

I. CONTEMPORARY UNIVERSE

1. SMBH in every large galaxy.
2. SMBH in small galaxies and in almost EMPTY space, $M \sim 10^9 M_\odot$.
3. Stars older than the Galaxy and even older than the Universe.
4. MACHOs (low luminosity 0.5 solar mass objects) - origin unknown.
5. BH mass spectrum in the Galaxy: unexpected maximum at $M \sim 8 M_\odot$.
6. Sources of the observed GWs.
7. Intermediate mass, $\sim 10^3 M_\odot$, BHs in globular clusters.

II. EARLY, $Z = 5 - 10$, UNIVERSE is surprisingly overpopulated:

1. Bright QSO, super-superheavy BH.
2. Superluminous young galaxies.
3. Supernovae and gamma-bursters.
4. Very high level of dust.

All these problems are uniquely and simply solved by the mechanism of creation in the early universe of massive PBHs and compact stellar-like objects suggested in 1993 (A.D. and J.Silk).
Log-normal mass spectrum was predicted, which became very popular during last year or two:

$$\frac{dN}{dM} = \mu^2 \exp{[-\gamma \ln^2 (M/M_0)]},$$

with only 3 parameters: μ, γ, M_0.
Spectrum is practically model independent, it is determined by inflation. and stochastic process of BH creation.

MYSTERIES IN THE SKY TODAY AND IN THE NEAREST PAST.

Every large galaxy contains a central supermassive BH with mass larger than $10^9 M_\odot$ in giant elliptical and compact lenticular galaxies and $\sim 10^6 M_\odot$ in spiral galaxies like Milky Way.

The origin of these BHs is not understood. Accepted faith is that these BHs are created by matter accretion to a central seed. But, the usual accretion efficiency is insufficient to create them during the Universe lifetime, 14 Gyr.

Even more puzzling: SMHBs are observed in small galaxies and even in almost EMPTY space, where no material to make a SMBH can be found.

Some examples of the data:

The mass of BH is typically 0.1% of the mass of the stellar bulge of galaxy but some galaxies may have huge BH: e.g. NGC 1277 has the central BH of $1.7 \times 10^{10} M_\odot$, or 60% of its bulge mass. This creates serious problems for the standard scenario of formation of central supermassive BHs by accretion of matter in the central part of a galaxy.

An inverted picture is more plausible, when first a supermassive BH was formed and attracted matter being a seed for subsequent galaxy formation!!!

More examples:

F. Khan, et al arXiv:1405.6425. Although supermassive black holes correlate well with their host galaxies, there is an emerging view that outliers exist. Henize 2-10, NGC 4889, and NGC1277 are examples of SMBHs at least AN ORDER OF MAGNITUDE MORE MASSIVE than their host galaxy suggests. The dynamical effects of such ultramassive central black holes is unclear.

A recent discovery of an ultra-compact dwarf galaxy older than 10 Gyr, enriched with metals, and probably with a massive black in its center seems to be at odds with the standard model **J. Strader,** *et al* **Ap. J. Lett. 775, L6 (2013).**

The dynamical mass is $2 \times 10^8 M_\odot$ and $R \sim 24$ pc - very high density.

Chandra: variable central X-ray source with $L_X \sim 10^{38}$ erg/s, which may be an AGN associated with a massive black hole or a low-mass X-ray binary.

"An evolutionary missing link? A modest mass early-type galaxy hosting an oversized nuclear black hole", J. Th. van Loon, A.E. Sansom, Xiv:1508.00698v1
BH mass, $M_{BH} = (3.5 \pm 0.8) \cdot 10^8 M_\odot$,
host galaxy $M_{stars} = 2.5^{+2.5}_{-1.2} \cdot 10^{10} M_\odot$,
and accretion luminosity:
$L_{AGN} = (5.3 \pm 0.4) \cdot 10^{45}$erg/s $\approx 10^{12} L_\odot$.
The AGN is more prominent than expected for a host galaxy of this modest size. The data are in tension with the accepted picture in which this galaxy would recently have transformed from a star-forming disc galaxy into an early-type, passively evolving galaxy.

"A Nearly Naked Supermassive Black Hole" J.J. Condon, et al arXiv:1606.04067
A compact symmetric radio source B3 1715+425 is too bright (brightness temperature $\sim 3 \times 10^{10}$ K at observing frequency 7.6 GHz) and too luminous (1.4 GHz luminosity $\sim 10^{25}$ W/Hz) to be powered by anything but a SMBH, but its host galaxy is much smaller.

Several binaries of SMBH observed:

P. Kharb, et al "A candidate sub-parsec binary black hole in the Seyfert galaxy NGC 7674", d=116 Mpc, $3.63\times 10^7 M_\odot$. (1709.06258).

C. Rodriguez et al. A compact supermassive binary black hole system. Ap. J. 646, 49 (2006), $d \approx 230$ Mpc.

M.J. Valtonen, "New orbit solutions for the precessing binary black hole model of OJ 287", Ap.J. 659, 1074 (2007), $z \approx 0.3$.

M.J. Graham et al. "A possible close supermassive black-hole binary in a quasar with optical periodicity". Nature 518, 74 (2015), $z \approx 0.3$.

Orthodox point of view: merging of two spiral galaxies creating an elliptical galaxy, leaving two or more SBHs in the center of the merged elliptical. No other way in the traditional approach. Even one SMBH is hard to create.

Heretic but simpler: primordial SMBH forming binaries in the very early universe and seeding galaxy formation.

Old stars in the Milky Way:

Employing thorium and uranium in comparison with each other and with several stable elements the age of metal-poor, halo star BD+17^{o} 3248 was estimated as 13.8 ± 4 Gyr.
J.J. Cowan, *et al* Ap.J. 572 (2002) 861

The age of inner halo of the Galaxy 11.4 ± 0.7 Gyr, J. Kalirai, "The Age of the Milky Way Inner Halo" Nature 486 (2012) 90, arXiv:1205.6802.

The age of a star in the galactic halo, HE 1523-0901, was estimated to be about 13.2 Gyr. First time many different chronometers, such as the U/Th, U/Ir, Th/Eu and Th/Os ratios to measure the star age have been employed.

"Discovery of HE 1523-0901: A Strongly r-Process Enhanced Metal-Poor Star with Detected Uranium", A. Frebe, N. Christlieb, J.E. Norris, C. Thom Astrophys.J. 660 (2007) L117; astro-ph/0703414.

Metal deficient high velocity subgiant in the solar neighborhood HD 140283 has the age 14.46 ± 0.31 Gyr.
H. E. Bond, et al, Astrophys. J. Lett. 765, L12 (2013), arXiv:1302.3180.
The central value exceeds the universe age by two standard deviations, if $H = 67.3$ and $t_U = 13.8$; and if $H = 74$, then $t_U = 12.5$, more than 10 σ
Our model predicts unusual initial chemical content of the stars, so they may look older than they are.

X. Dumusque, *et al* **"The Kepler-10 Planetary System Revisited by HARPS-N: A Hot Rocky World and a Solid Neptune-Mass Planet". arXiv:1405.7881; Ap J., 789, 154, (2014).**

Very old planet, $10.6^{+1.5}_{-1.3}$ Gyr.

(Age of the Earth: 4.54 Gyr.)

A SN explosion must must precede formation of this planet.

MACHOs: discovered through gravitational microlensing by Macho and Eros groups. They are invisible (very weakly luminous or even non-luminous) objects with masses about a half of the solar mass in the Galactic halo, in the center of the Galaxy, and recently in the Andromeda (M31) galaxy.
Their density is significantly greater than the density expected from the known low luminosity stars and the BH of similar mass.

Summary of limits on MACHOs

f = mass ratio of MACHOS to DM.
Macho group: $0.08 < f < 0.50$ (95% CL) for $0.15 M_\odot < M < 0.9 M_\odot$;
EROS: $f < 0.2$, $0.15 M_\odot < M < 0.9 M_\odot$;
EROS2: $f < 0.1$, $10^{-6} M_\odot < M < M_\odot$;
AGAPE: $0.2 < f < 0.9$,
for $0.15 M_\odot < M < 0.9 M_\odot$;
EROS-2 and OGLE: $f < 0.1$ for $M \sim 10^{-2} M_\odot$ and $f < 0.2$ for $\sim 0.5 M_\odot$.

Thus MACHOs for sure exist.
Their density is comparable to the density of the halo dark matter but their nature is unknown.
They could be brown dwarfs, dead stars, or primordial black holes.
The first two options are in conflict with the accepted theory of stellar evolution, if MACHOs were created in the conventional way.

More mysteries:
It was found that the BH masses are concentrated in the narrow range $(7.8 \pm 1.2)M_{\odot}$ (1006.2834)
This result agrees with another paper where a peak around $8M_{\odot}$, a paucity of sources with masses below $5M_{\odot}$, and a sharp drop-off above $10M_{\odot}$ are observed, arXiv:1205.1805. These features are not explained in the standard model of BH formation by stellar collapse.

GW discovery by LIGO has proven thar GR works perfectly, existence of BHs and GWs is established, but "in much wisdom is much grief", mostly created by GW150914.

There are essentially three problems in the standard theory:

1. Origin of heavy BHs ($\sim 30M_\odot$).

2. Low spins of the coalescing BHs.

3. Formation of BH binaries from the original stellar binaries.

S.Blinnkov, A.D., N.Porayko, K.Postnov.

**The first problem is a heavy BH origin. Such BHs are believed to be created by massive star collapse, though a convincing theory is still lacking.
To form so heavy BHs, the progenitors should have $M > 100 M_{\odot}$ and a low metal abundance to avoid too much mass loss during the evolution. Such heavy stars might be present in young star-forming galaxies but they are not yet observed in sufficiently high number.**

Another problem is the low value of the BH spins in GW150914. It strongly constrains astrophysical BH formation from close binary systems. However, the dynamical formation of double massive low-spin BHs in dense stellar clusters is not excluded, but difficult.

The second reliable LIGO detection, GW151226, turned out to be closer to the standard binary BH system.

The other two demonstrate the same problem.

Last but not the least, formation of BH binaries. **Stellar binaries were formed from common interstellar gas clouds and are quite frequent in galaxies.** **If BH is created through stellar collapse,** **a small non-sphericity results in a huge velocity of the BH and the binary is destroyed.**
BH formation from PopIII stars and subsequent formation of BH binaries with (36+29)$M_{\odot}$ is analyzed and found to be negligible.
All these problems are solved if the observed sources of GWs are the binaries of primordial black holes (PBH).

Globular clusters and massive BHs.

Very recent news: BH with $M \approx 2000 M_\odot$ observed in the core of the globular cluster 47 Tucanae.

Origin unknown.

Our prediction (AD, K.Postnov): if the parameters of the mass distribution of PBHs are chosen to fit the LIGO data and the density of SMBH, then the number of PBH with masses $(2-3)\times 10^3 M_\odot$ is about $10^4 - 10^5$ per one SMPBH with mass $> 10^4 M_\odot$.

This density of IMBHs is sufficient to seed the formation of globular clusters in galaxies.

I. A brief review of high-z discoveries.

1. Several galaxies have been observed with natural gravitational lens "telescopes. A few examples:

a galaxy at $z \approx 9.6$ which was created at $t_U < 0.5$ Gyr;

a galaxy at $z \approx 11$ has been detected at $t_U \sim 0.4$ Gyr, three times more luminous in UV than other galaxies at $z = 6 - 8$. D. Coe *et al* "CLASH: Three Strongly Lensed Images of a Candidate $z \sim 11$ Galaxy", Astrophys. J. 762 (2013) 32.

Unexpectedly early creation.

Not so young but extremely luminous galaxy $L = 3 \cdot 10^{14} L_{\odot}$; $t_U \sim 1.3$ Gyr. The galactic seeds, or embryonic black holes, might be bigger than thought possible. P. Eisenhardt: "How do you get an elephant? One way is start with a baby elephant." The BH was already billions of $M_{\odot}$, when our universe was only a tenth of its present age of 13.8 billion years. "Another way to grow this big is to have gone on a sustained binge, consuming food faster than typically thought possible." Low spin is necessary!

According to the paper "Monsters in the Dark" D. Waters, et al, Mon. Not. Roy. Astron. Soc. 461 (2016), L51 density of galaxies at $z \approx 11$ is 10^{-6} Mpc^{-3}, an order of magnitude higher than estimated from the data at lower z.

Origin of these galaxies is unclear.

2. Supermassive BH and/or QSO.

About 40 quasars with $z > 6$ are already known, each quasar containing BH with $M \sim 10^9 M_\odot$.

The maximum z is $z = 7.085$ i.e. the quasar was formed before the universe reached 0.75 Gyr with

$L = 6.3 \cdot 10^{13} L_\odot$, $M = 2 \cdot 10^9 M_\odot$,

Similar situation with the others.

The quasars are supposed to be supermassive black holes and their formation in such short time by conventional mechanisms looks problematic.

Such black holes, when the Universe was less than one billion years old, present substantial challenges to theories of the formation and growth of black holes and the coevolution of black holes and galaxies. Even the origin of SMBH in contemporary universe during 14 Gyr is difficult to explain. Non-standard accretion physics and the formation of massive seeds seem to be necessary. Neither of them is observed in the present day universe.

Very recently another huge QSO was discovered "An ultraluminous quasar with a twelve billion solar mass black hole at redshift 6.30". Xue-BingWu et al, Nature 518, 512 (2015).
There is already a serious problem with formation of lighter and less luminous quasars which is multifold deepened with this new "creature". The new one with $M \approx 10^{10} M_\odot$ makes the formation absolutely impossible in the standard approach.

3. Dust, supernovae, gamma-bursters...
To make dust a long succession of processes is necessary: first, supernovae explode to deliver heavy elements into space (metals), then metals cool and form molecules, and lastly molecules make macroscopic pieces of matter.
Abundant dust is observed in several early galaxies, e.g. in HFLS3 at $z = 6.34$ and in A1689-zD1 at $z = 7.55$.
Catalogue of the observed dusty sources indicates that their number is an order of magnitude larger than predicted by the canonical theory.

Hence, prior to or simultaneously with the QSO formation a rapid star formation should take place. These stars should evolve to a large number of supernovae enriching interstellar space by metals through their explosions which later make molecules and dust. (We all are dust from SN explosions, but probably at much later time.) Another possibility is a non-standard BBN in bubbles with very high baryonic density, which allows for formation of heavy elements beyond lithium.

Observations of high redshift gamma ray bursters (GBR) also indicate a high abundance of supernova at large redshifts. The highest redshift of the observed GBR is 9.4 and there are a few more GBRs with smaller but still high redshifts.

The necessary star formation rate for explanation of these early GBRs is at odds with the canonical star formation theory.

All these problems are solved if the BHs in the universe and stellar-like objects are primordial, created at the very early stage, $z > 10$.
The formation took place at very high z after the QCD phase transition at $T \sim 100$ MeV down to $T \sim$ keV.
The mechanism explains an avalanche of mysteries discovered recently, may provide all or a large fraction of cosmological DM, and possibly a a lot of antimatter nearby in the Galaxy.

This August announcement: **"We report the discovery of a high proper motion, low-mass white dwarf (LP 40-365) that travels at a velocity greater than the Galactic escape velocity and whose peculiar atmosphere is dominated by intermediate-mass elements."**
S. Vennes et al, Science, 2017, Vol. 357, p. 680; arXiv:1708.05568.
The origin is puzzling.
Can it be a compact primordial star?

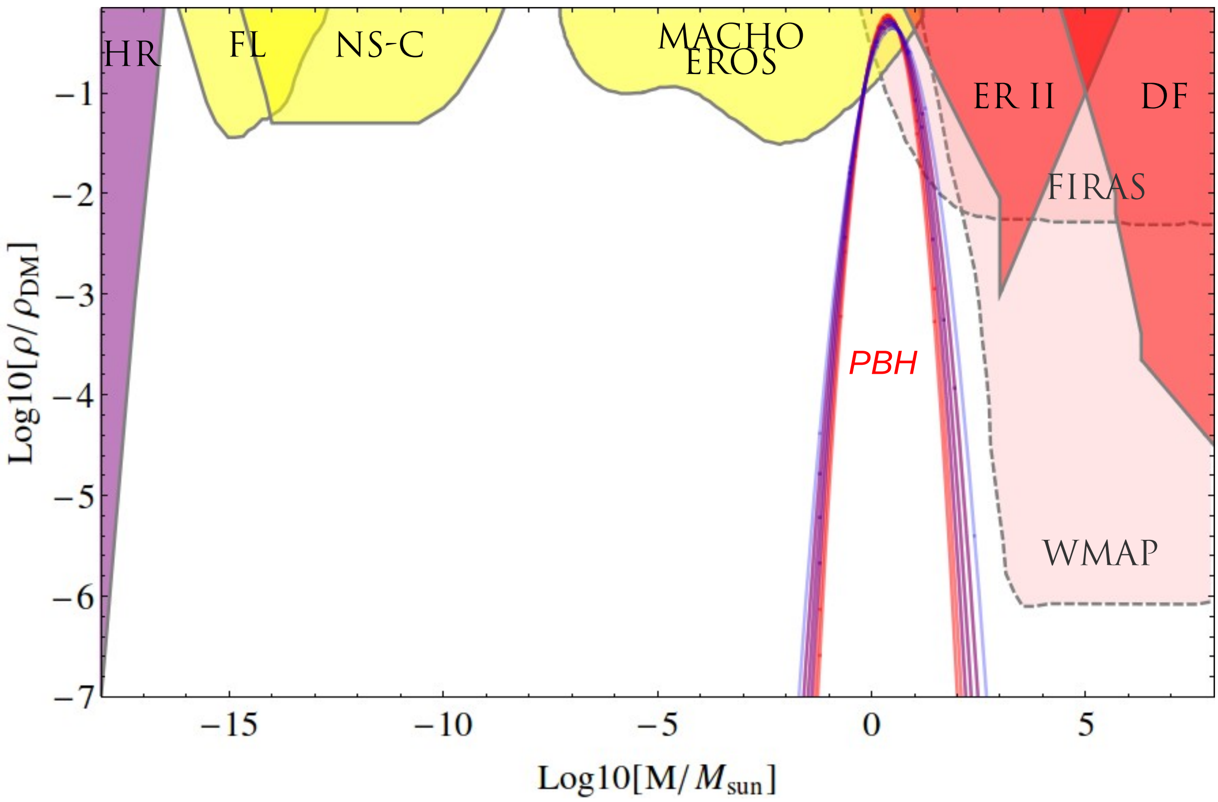

Figure 1: Constraints on PBH fraction in DM, $f = \rho_{\rm PBH}/\rho_{\rm DM}$, where the PBH mass distribution is taken as $\rho_{\rm PBH}(M) = M^2 dN/dM$ The existing constraints (extragalactic γ-rays from evaporation (HR), femtolensing of γ-ray bursts (F), neutron-star capture constraints (NS-C), MACHO, EROS, OGLE microlensing (MACHO, EROS) survival of star cluster in Eridanus II (E), dynamical friction on halo objects (DF), and accretion effects (WMAP, FIRAS)) The PBH distribution is shown for ADBD parameters $\mu = 10^{-43}$ Mpc^{-1}, $M_0 = \gamma + 0.1 \times \gamma^2 - 0.2 \times \gamma^3$ with $\gamma = 0.75 - 1.1$ (red solid lines), and $\gamma = 0.6 - 0.9$ (blue solid lines).

The effects are extragalactic γ-rays from evaporation (EG), femtolensing of γ-ray bursts (F), neutron-star capture constraints (NS), Kepler microlensing and millilensing (K), MACHO, EROS, OGLE microlensing (ML), survival of star cluster in Eridanus II (E), wide binary disruption (WB), dynamical friction on halo objects (DF), millilensing of quasars (mLQ), generation of large-scale structure through Poisson fluctuations (LSS), and accretion effects (WMAP, FIRAS); the accretion limits are shown with broken lines since they are highly model-dependent.

The model, which explains all that, is based on the supersymmetric (Affleck-Dine) scenario for baryogenesis modified by introduction of a general renormalizable coupling to the inflaton field, see below. It is discussed in more details in several our papers applied to an explanation of existence of the observed "old" objects in the young universe and all mentioned above puzzles in the contemporary Universe.
As a byproduct it may predict abundant antimatter objects in the Galaxy.

Baryogenesis with SUSY condensate, Affleck and Dine (AD). SUSY predicts existence of scalars with $B \neq 0$. Such bosons may condense along flat directions of the quartic potential:

$$U_\lambda(\chi) = \lambda |\chi|^4 (1 - \cos 4\theta),$$

and of the mass term, $m^2\chi^2 + m^{*\,2}\chi^{*\,2}$:

$$U_m(\chi) = m^2 |\chi|^2 [1 - \cos(2\theta + 2\alpha)],$$

where $\chi = |\chi| \exp(i\theta)$ and $m = |m| e^\alpha$. If $\alpha \neq 0$, C and CP are broken.
In GUT SUSY baryonic number is naturally non-conserved - non-invariance of $U(\chi)$ w.r.t. phase rotation.

Initially (after inflation) χ is away from origin and, when inflation is over, starts to evolve down to equilibrium point, $\chi = 0$, according to Newtonian mechanics:

$$\ddot{\chi} + 3H\dot{\chi} + U'(\chi) = 0.$$

Baryonic charge of χ:

$$B_\chi = \dot{\theta}|\chi|^2$$

is analogous to mechanical angular momentum. χ decays transferred baryonic charge to that of quarks in B-conserving process. AD baryogenesis could lead to baryon asymmetry of order of unity, much larger than 10^{-9}.

If m $\neq 0$, the angular momentum, B, is generated by a different direction of the quartic and quadratic valleys at low χ. If CP-odd phase α is small but non-vanishing, both baryonic and antibaryonic regions are possible with dominance of one of them.
Matter and antimatter domain may exist but globally B $\neq 0$.

Affleck-Dine field χ with CW potential coupled to inflaton Φ (AD and Silk; AD, Kawasaki, Kevlishvili):

$$U = g|\chi|^2(\Phi - \Phi_1)^2 + \lambda|\chi|^4 \ln\left(\frac{|\chi|^2}{\sigma^2}\right)$$
$$+\lambda_1\left(\chi^4 + h.c.\right) + (m^2\chi^2 + h.c.).$$

Coupling to inflaton is the general renormalizable one.

If the window to flat direction, when $\Phi \approx \Phi_1$ is open only during a short period, cosmologically small but possibly astronomically large bubbles with high β could be created, occupying a small fraction of the universe, while the rest of the universe has normal $\beta \approx 6 \cdot 10^{-10}$, created by small χ.

Phase transition of 3/2 order.

This baryogenesis scenario could lead to an early formation of PBH or compact stellar-type objects and possibly (naturally?) to a comparable amount of anti-objects, such that the bulk of baryons and maybe antibaryons are contained in compact stellar-like objects or PBH, plus the sub-dominant observed homogeneous baryonic background. The amount of antimatter may be comparable or even larger than of KNOWN baryons, but such "compact" (anti)baryonic objects would not contradict any existing observations. Bambi C., A.D., Nucl. Phys., B 784 (2007), 132; A.D., Blinnikov S.I., Phys. Rev., D89 (1014), 2, 021301; Blinnikov S.I., A.D., Postnov K.A., Phys. Rev., D92 (2015), 2, 023516;

SUMMARY

1. A natural baryogenesis model leads to abundant fomation of PBHs and compact stellar-like objects in the early universe after the QCD phase transition, $t \gtrsim 10^{-5}$ sec.

2. These objects have log-normal mass spectrum.

3. PBHs formed at this scenario can explain the peculiar features of the sources of GWs observed by LIGO.

4. The considered mechanism solves the numerous mysteries of $z \sim 10$ universe: abundant population of supermassive black holes, early created gamma-bursters and supernovae, early bright galaxies, and evolved chemistry including dust.

5. There is persuasive data in favor of the inverted picture of galaxy formation, when first a supermassive BH seeds are formed and later they accrete matter forming galaxies.

6. An existence of supermassive black holes observed in all large and some small galaxies and even in almost empty environment is naturally explained.

7. "Older than t_U" stars may exist; the older age is mimicked by the unusual initial chemistry.
8. Existence of high density invisible "stars" (machos) is understood.
9. Explanation of origin of BHs with 2000 $M_\odot$ in the core of globular cluster and the observed density of GCs is presented
10. A noticeable fraction of dark matter or all of it can be made of PBHs.

Conclusion

Large amount of astronomical data very strongly demand abundant cosmological population of PBH with wide mass spectrum. Such PBH nicely explain the mysteries accumulated during a few last years.

Testable predictions:

A. Rate and masses of new GW events.
B. Possible existence of antimatter in our neighborhood, even in the Galaxy.
C. PBH with $M = 2000 - 3000\, M_\odot$ in the cores of globular clusters.
D. Number of PBH binaries as a function of mass, to be calculated.

THE END