Primordial Black holes today and near redshift 10.

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Hot topics in Modern Cosmology
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During last several years there appear regularly (practically every week) new astronomical data which can be most naturally interpreted as a strong indication that the universe is abundantly populated by primordial black holes (PBHs):

massive, $M \sim (7-8)M_\odot$,

supermassive, $M \sim (10^6 - 10^9)M_\odot$, and

intermediate mass $M \sim (10^3 - 10^5)M_\odot$.

However, this interpretation encounters natural resistance from the astronomical establishment. Sometimes the authors of new discoveries admit that the observed phenomenon can be the naturally explained by massive BHs, which drives the effect, but immediately retreat, saying that there is no known way to create sufficiently large density of such BHs.

Here a review of old and recent observational data in favor of the rich population of PBHs in the universe is presented.

A mechanism of abundant formation of massive PBHs, suggested in 1993, is described.

The talk is partly based on the review:
"Massive and Supermassive Black Holes in the Contemporary and Early Universe and the Problems in Cosmology and Astrophysic Physics Uspekhi, Vol. 61, No. 2, 2018,
and on the papers with J. Silk (1993),
M. Kawasaki, N. Kevlishvili (2006),
and recent works with S. Blinnikov,
N. Porayjko, and K. Postnov

Astrophysical BH versus PBH.

Astrophysical BHs are results of stellar collapce after a star exhausted its nuclear fuel. Formed in sufficiently old universe. Masses are of the order of a few solar masses,

"Usual" supermassive black holes (SMBH), $M \sim (10^6 - 10^9) M_\odot$ are assumed to be the products of matter accretion to smaller BHs or matter accretion to matter excess in galactic centers. Not supported by calculations.

Primordial black holes (PBH) formed in the very early universe if the density excess at cosmological horizon is large, $\delta\rho/\rho \gtrsim 1$, at the horizon scale (Zeldovich, Novikov). Usually the masses of PBH are taken to be rather low and the spectrum is assumed to be close to delta-function.

Alternative mechanism of massive PBH formation with wide mass spectrum:
A. Dolgov and J.Silk, PRD 47 (1993) 4244 "Baryon isocurvature fluctuations at small scales and baryonic dark matter" and
A.Dolgov, M. Kawasaki, N. Kevlishvili, Nucl.Phys. B807 (2009) 229,
"Inhomogeneous baryogenesis, cosmic antimatter, and dark matter".
Heretic predictions of 1993 are turning into the accepted faith, since they became supported by the recent astronomical data.
Massive PBHs allow to cure emerging inconsistencies with the standard cosmolgy and astrophysics.

The model predicts an abundant formation of heavy PBHs with log-normal mass spectrum. An essential ingredient of the mechanism is the preparation of the PBH seeds during cosmological inflation. Similar mass spectrum is sometimes assumed for stars but physics is completely different. Log-normal mass spectrum of PBHs was rediscovered by S. Clesse, J. Garcia-Bellido, Phys. Rev. D92, 023524 (2015). Now in many works such spectrum is postulated without any justification.

Probably log-normal spectrum is a general feature of diffusion processes.

NB: not only PBHs can be created but also compact stellar-like objects.

Predictions, 25 year old and younger:

• Primordial BHs make all or dominant part of dark matter (DM).

• Black holes in the universe are mostly primordial (PBH).

• Early QSO formation.

• Early creation of metals and dust.

• Inverted picture of galaxy formation: seeding of galaxies by SMPBH or IMPBH, recently, AD & K. Postnov:
Seeding of globular clusters by $10^3 - 10^4$ BHs and dwarfs by $10^4 - 10^5$ BH.

• Clouds of matter with high baryon-to-photon ratio.

A possible by-product: plenty of (compact) anti-stars, even in the Galaxy.

10 billion year story in less than an hour. The observations of the last several years indicate that the young universe at $z \sim 10$ is grossly overpopulated with unexpetedly high amount:

1. Bright QSOs, alias supermassive BHs, up to $M \sim 10^{10} M_{\odot}$,
2. Superluminous young galaxies,
3. Supernovae, gamma-bursters,
4. Dust and heavy elements.

These facts are in good agreement with the predictions listed in the previous page, but in tension with the Standard Cosmological Model.

Mostly quotations from publications.
In any single case another interpretation is possible but as a whole the picture is very much in favor of massive PBHs.

1. Supermassive BH, or QSO.
About 40 quasars with $z > 6$ are known, with BH of $10^9 M_\odot$ and $L \sim 10^{13-14} L_\odot$. 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. Non-standard accretion physics and the formation of massive seeds seem to be necessary. Neither of them is observed in the present day universe.

Two years ago 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.

2. Galaxies observed at $z \sim 10$:
a galaxy at $z \approx 9.6$, which was created at $t_U < 0.5$ Gyr;
a galaxy at $z \approx 11$, born at $t_U \sim 0.4$ Gyr, three times more luminous in UV than other galaxies at $z = 6 - 8$. Unexpectedly early creation.
Not so young but extremely luminous galaxy $L = 3 \cdot 10^{14} L_{\odot}$; $t_U \sim 1.3$ Gyr.
Quoting the authors: The galactic seeds, or embryonic black holes, might be bigger than thought possible. Or another way to grow this big is to have gone on a sustained binge, consuming food faster than typically thought possible.
Low spin of the seed 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.

Very recently: M.A. Latif, M Volonteri, J.H. Wise, [1801.07685] ".. halo has a mass of $3 \times 10^{10}\ M_\odot$ at $z = 7.5$; MBH accretes only about 2200 $M_\odot$ during 320 Myr."

3. Dust, supernovae, gamma-bursters...

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.

Observations of high redshift gamma ray bursters (GRB) 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.

Problems of contemporary universe:

1. SMBH in every large galaxy; even 15 Gyr are not enough to make them

2. SMBH in small galaxies and in almost EMPTY space, $M \sim 10^9 M_\odot$.

3. Stars older than the Galaxy and even one 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 BHs: $M \sim 10^3 M_\odot$, in globular clusters and $M \sim 10^{4-5}$ in dwarf galaxies.

AND RECENTLY MORE PUZZLES:

Several (four?) binaries of SMBH.

Quasar quartet.

Plane concentration of galactic-satellites?

Massive BHs in dwarfs: ten IMBH, $M = 3 \times 10^4 - 2 \times 10^5 M_\odot$ and fourty found recently $10^7 < M < 3 \cdot 10^9$ [Chandra, 1802.01567].

$0.8 \cdot 10^9 M_\odot$ BH in NEUTRAL universe at $z = 7.5$ [1712.01860].

Triple SMBH [1712.03909].

Faint QSO, z=6, $M = 10^9 M_\odot$ needs either super-Eddington accretion or $10^5 M_\odot$ seed, 1802.02782.

Galaxies without or little dark matter.

Genzel, R., et al, "Strongly baryon-dominated disk galaxies at the peak of galaxy formation ten billion years ago". Nature 543 (2017), 397.

M. Swinbank, "Distant galaxies lack dark matter", Nature 543 (2017), 318-319.

P. van Dokkum et al, "An enigmatic population of luminous globular clusters in a galaxy lacking dark matter", Nature 555 (2018) no.7698, 629-632 arXiv:1803.10240, 27 Mar 2018

J.L. Bernal, et al "Cosmological implications of Primordial Black Holes", JCAP 1710 (2017) no.10, 052 arXiv:1709.07465.

Criticism: N.F. Martin, et al "Current velocity data on dwarf galaxy NGC1052-DF2 do not constrain it to lack dark matter", arXiv:1804.04136 11 Apr 2018.

High velocity stars in the Galaxy (thanks to K.A. Postnov).
"Old, Metal-Poor Extreme Velocity Stars in the Solar Neighborhood", Kohei Hattori et al.,arXiv:1805.03194, 8 May 2018.

"Gaia DR2 in 6D: Searching for the fastest stars in the Galaxy", T. Marchetti, E. M. Rossi and A. G. A. Brown arXiv:1804.10607 Date: Fri, 27 Apr 2018.
The origin of such stars is puzzling. They may be accelerated by interaction with IMBH but there are not enough IMBH in the conventional theory.

Igor V. Chilingarian, et al. "A Population of Bona Fide Intermediate Mass Black Holes Identified as Low Luminosity Active Galactic Nuclei" arXiv:1805.01467,
"...we identified a sample of 305 IMBH candidates having masses

$$3 \times 10^4 < M_{\rm BH} < 2 \times 10^5 M_\odot,$$

which reside in galaxy centers and are accreting gas that creates characteristic signatures of a type-I active galactic nucleus."

P.A. Christopher et al The Black Hole in the Most Massive Ultracompact Dwarf Gala M59-UCD3, arXiv:1804.02399.

A.V. Afanasiev, et al "A 3.5-million Solar Masses Black Hole in the Centre of the Ultracompact Dwarf Galaxy Fornax UCD3", arXiv:1804.02938.

He-Yang Liu, et al, A Uniformly Selected Sample of Low-Mass Black Holes in Seyfert 1 Galaxies. II. The SDSS DR7 Sample, arXiv:1803.04330, "A new sample of 204 low-mass black holes (LMBHs) in active galactic nuclei (AGNs) is presented with black hole masses in the range of $\mathbf{(1-20)\times 10^5 M_\odot}$."

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:

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

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

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 $\mathbf{m \neq 0}$, 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 $\mathbf{B \neq 0}$.

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.

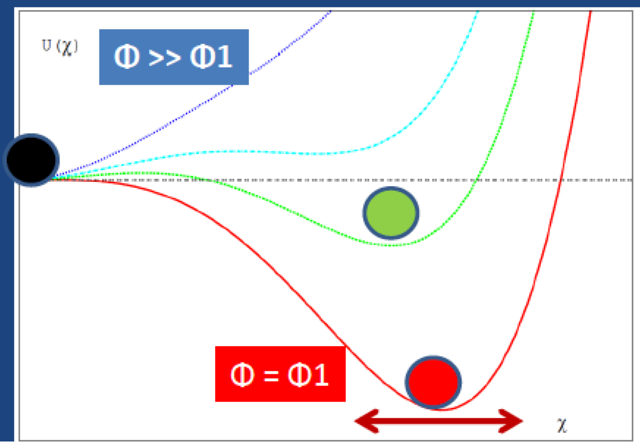
When the window to the flat direction is open, near $\Phi = \Phi_1$, the field χ slowly diffuse to large value, according to equation derived by Starobinsky, generalized to a complex field χ.

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.

Density perturbations are generated rather late after the QCF phase transition. The emerging universe looks like a piece of Swiss cheese, where holes are high baryonic density objects occupying a minor fraction of the universe volume.

Effective potential of χ for different values of the inflaton field Φ. The upper blue curve corresponds to a large value Φ >> Φ1 which gradually decreases down to Φ = Φ1, red curve. Then the potential returns back to the almost initial shape, as Φ drops down to zero. The evolution of χ in such a potential is similar to a motion of a point-like particle (shown as a black ball in the figure) in Newtonian mechanics. First, due to quantum initial fluctuations χ left the unstable extremum of the potential at χ = 0 and "tried" to keep pace with the moving potential minimum and later started to oscillate around it with decreasing amplitude. The decrease of the oscillation amplitude was induced by the cosmological expansion. In mechanical analogy the effect of the expansion is equivalent to the liquid friction term, $3H\dot{\chi}$. When Φ dropped below Φ1, the potential recovered its original form with the minimum at χ = 0 and χ ultimately returned to zero but before that it could give rise to a large baryon asymmetry

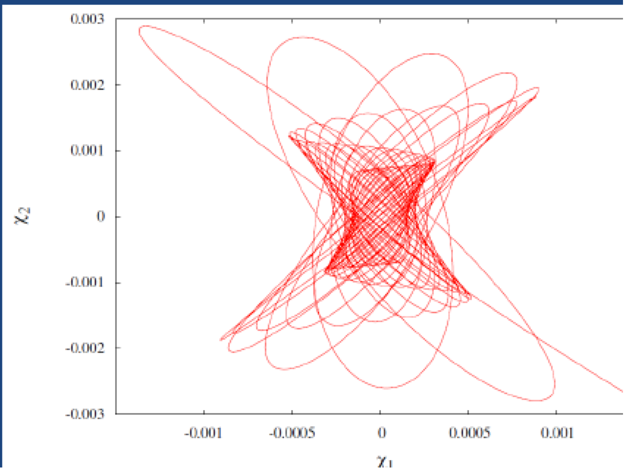
$$\ddot{\chi} + 3H\dot{\chi} + U'(\chi) = 0.$$



(Dolgov -Kawasaki-Kevlishvili)

Field χ "rotates" in this plane with quite large angular momentum, which exactly corresponds to the baryonic number density of χ. Later χ decayed into quarks and other particles creating a large cosmological baryon asymmetry.

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



The outcome, depending on $\beta = n_B/n_\gamma$.

- PBHs with log-normal mass spectrum.
- Compact stellar-like objects, as e.g. cores of red giants.
- Disperse hydrogen and helium clouds with (much) higher than average n_B density.
- β may be negative leading to compact antistars which could survive annihilation with the homogeneous baryonic background.

Sources of the "LIGO" (et al) GWs.

Several events of GW registration by LIGO and Virgo has proven that GR works perfectly, existence of BHs and GWs is established, but revealed essentially three problems of the SCM:

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.

See however, T.Broadhurst, J.M. Diego, G. Smoot. 1802.05273. Gravitational lensing of GW from log-normal BHs with central mass $8M_\odot$ - much smaller mass, mimicked by gravitational lensing of GWs.

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. Maybe the mirror matter progenitors will do(!?).

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, GW151 turned out to be closer to the standard binary BH system.

The other three demonstrate the same property.

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. Recall large pulsar velocites, $v \sim 1000$ km/s

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.

Recent news: BH with surprisingly high mass $M \approx 2000 M_\odot$ was observed in the core of the globular cluster 47 Tucanae.

Origin in standard model is 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 all globular clusters in galaxies.

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 usual 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 $\sim 0.5 M_\odot$.

"A Nearly Naked Supermassive Black Hole" J.J. Condon, et al arXiv:1606.04067. A compact symmetric radio source B3 1715+42 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, $\mathbf{3.63 \times 10^7} M_{\odot}$. (1709.06

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

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

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

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.

"Quasar quartet embedded in giant nebula reveals rare massive structure in distant universe", J.F. Hennawi et al, Science 15 May 2015, 348 p. 779,
discovered in a survey for emission at redshift $z \approx 2$.
Quasars are rare objects separated by cosmological distances, so the chance of finding a quadruple quasar is $\sim 10^{-7}$. It implies that the most massive structures in the distant universe have a tremendous supply ($\sim 10^{11} M_{\odot}$) of cool dense ($n \approx 1/\text{cm}^3$) gas, in conflict with current cosmological simulations.

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 $\mathbf{1.7 \times 10^{10}} M_{\odot}$, or **60%** of its bulge mass. This fact 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 looks more plausible, when first a supermassive black hole was formed and attracted matter serving as seed for subsequent galaxy formation.

AD, J. Silk, 1974;
AD, M. Kawasaki, N. Kevlishvili, 2008;
Bosch et al, Nature 491 (2012) 729.

More mysteries:

It was found that the BH masses are concentrated in the narrow range $(\mathbf{7.8 \pm 1.2}) M_\odot$ (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:1205.18

These features are not explained in the standard model of BH formation by stellar collapse, but nicely fit the hypothesis of primordial BH formation with log-normal spectrum and $M_0 \approx 8M_\odot$.

Very fresh news: J.D. Bowman, et al Nature, 1 March, 2018 : flattened absorption profile in the sky-averaged radio spectrum, at $\nu = 78$ MHz ($z = 1420/78 \approx 18$) and fullwidth at half-maximum of 19 MHz. It is consistent with the 21-cm signal induced by early stars; however, the best-fitting amplitude of the profile is more than twice greater than the predictions. The discrepancy suggests that either the primordial gas was much colder than expected or the background radiation temperature was hotter than expected.

Possible explanations (if the result is real):

I. Cooling of baryons by interactions with the millicharged (mirror) DM, advocated by Zurab Berezhiani.

II. Higher CMB temperature inside clouds with high N_B/N_γ, needed to be verified.

III. Could PBHs help?

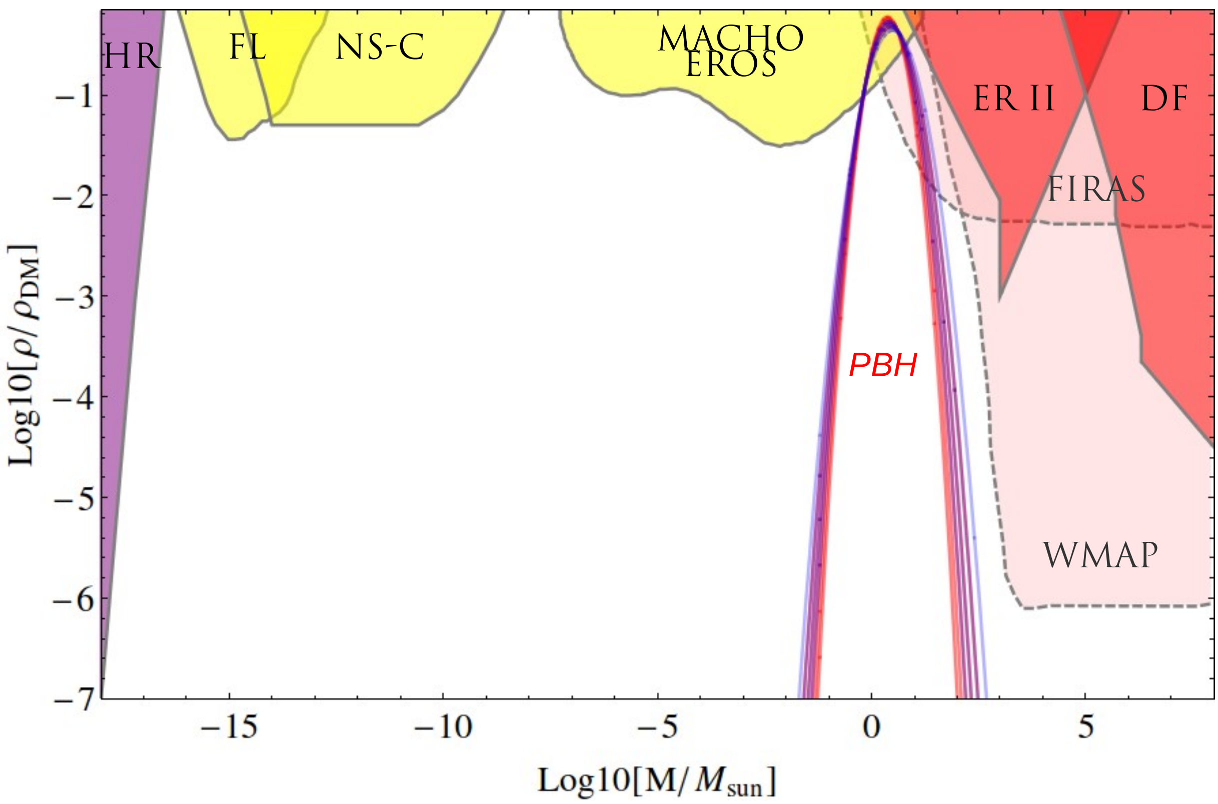


Figure 1: Constraints on PBH fraction in DM, $f = \rho_{\rm PBH}/\rho_{\rm DM}$, where the PBH mass distribution is taken as $\rho_{\rm PBH}(M) = M^2 dN/dM$ The existing constraints (extragalactic γ-rays from evaporation (HR), femtolensing of γ-ray bursts (F), neutron-star capture constraints (NS-C), 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 micro-lensing 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.

SUMMARY

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

2. Log-normal mass spectrum of these objects.

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.

E. Almost all galaxies must have a PBH seed, if it is not ejected form the galaxy later: a rare event.

THE (HAPPY?) END

More below for another 100 minutes

Куски из прежнiх докладов.

Перенести в текст рис. со стр. 50 и пояснение со стр. 51.

Статьи, указанные КАП недавно:

arXiv:1804.10607 Date: Fri, 27 Apr 2018 17:45:34 GMT (441kb,D)

Title: Gaia DR2 in 6D: Searching for the fastest stars in the Galaxy Authors: T. Marchetti, E. M. Rossi and A. G. A. Brown Categories: astro-ph.GA astro-ph.SR Comments: 12 pages, 11 figures, 2 tables, submitted to MNRAS. Comments are welcome! We search for the fastest stars in the subset of stars with radial velocity measurements of the second data release (DR2) of the European Space Agency mission Gaia. Starting from the observed positions, parallaxes, proper motions, and radial velocities, we construct the distance and total velocity distribution of more than 7 million stars in our Milky Way, deriving the full 6D phase space information in Galactocentric coordinates. These information are shared in a catalogue, publicly available at http://home.strw.leidenuniv.nl/ marchetti/ To search for unbound stars, we then focus on stars with a median total velocity in the Galactic rest frame > 450 km/s. This cut results in a clean sample of 165 sources with reliable astrometric parameters and radial velocities. Of these, 28 stars have probabilities greater than 50 % of being unbound from the Galaxy. On this latter sub-sample, we perform orbit integration to characterize the stars' orbital parameter distributions. We find 2 to 5 hypervelocity star candidates, stars that are moving on orbits consistent with coming from the Galactic Centre, and 9 hyper-runaway star candidates, coming from the Galactic disk. Surprisingly, the remaining unbound stars cannot be traced back to the Galaxy, including our two fastest stars (above 700

km/s). These may constitute the tip of the iceberg of a large extragalactic population or the extreme velocity tail of stellar streams.
(https://arxiv.org/abs/1804.10607 , 441kb)
————————————————————————

Ересь высказанная 35 лет назад, что темная материя в значительной степени или даже на все 100% состоит из первичных черных дыр, сейчас имеет хороший шанс стать общепринятой верой. Механизм

Two different but related subjects:
I. A mechanism of massive PBH formation much different from all others. The fundament of PBH creation is build at inflation by making large isocurvature fluctuations at relatively small scales, with practically vanishing density perturbations.
It is achieved by a simple modification of a popular scenario of baryogenesis. Density perturbations are generated rather late after the QCF phase transition. The emerging universe looks like a piece of Swiss cheese where holes are high baryonic density objects occupying a minor fraction of the universe volume.

II. A brief review of new (and not only new) astronomical data which are in strong tension with the accepted standard cosmological model.

The data nicely fits the suggested scenario of PBH formation.

More and more evidence in favor of massive and supermassive PBH

and other mysterious phenomena

in the universe appears practically every week.

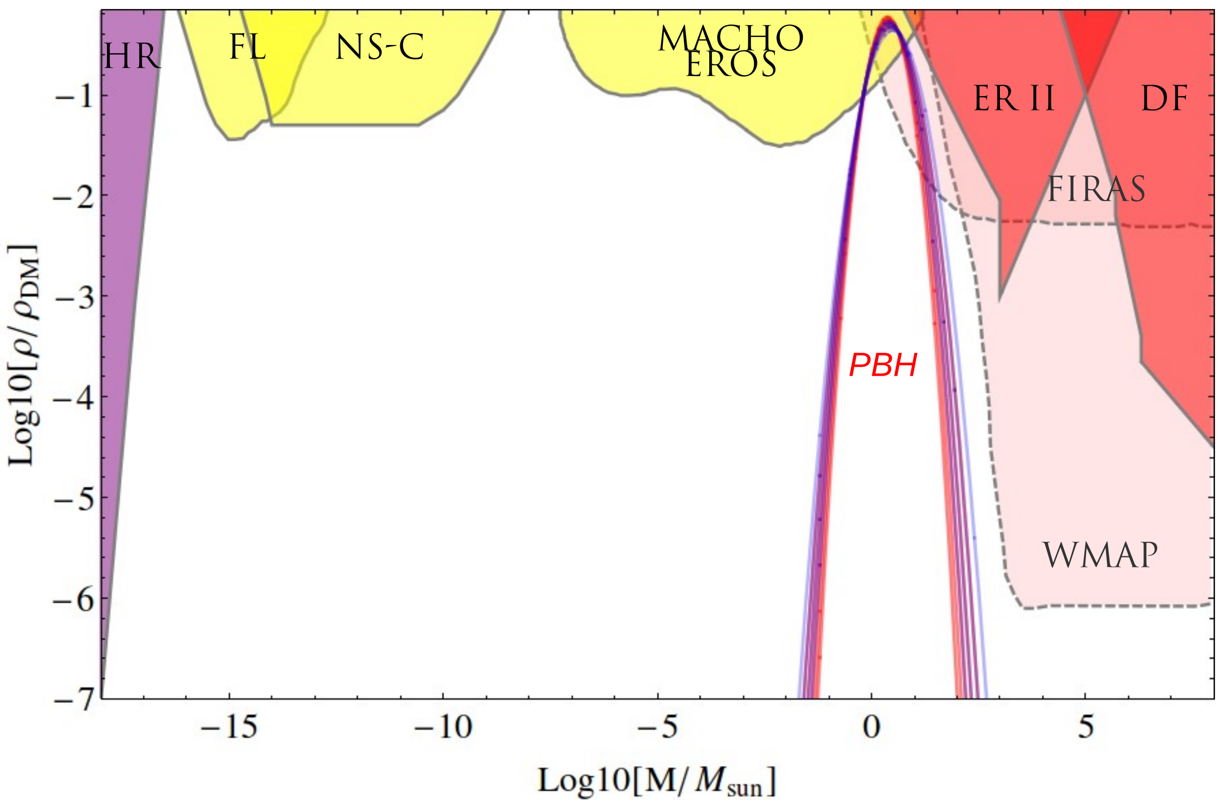


Figure 2: Constraints on PBH fraction in DM, $f = \rho_{\rm PBH}/\rho_{\rm DM}$, where the PBH mass distribution is taken as $\rho_{\rm PBH}(M) = M^2 dN/dM$ The existing constraints (extragalactic γ-rays from evaporation (HR), femtolensing of γ-ray bursts (F), neutron-star capture constraints (NS-C), 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.

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.

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 $\sim 0.5 M_\odot$.

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" (almost Shakespeare).

Heretic conclusions:

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 resolution of the observed tension with the standard cosmology is presented (in fact it was predicted 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, $\sim$ **20** times younger than t_U.

More details: "Beasts in Lambda-CDM Zoo"
Phys. Atom. Nucl., 80 (2017) 987; arXiv:160

"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.

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:

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

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 life-time, 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 $\mathbf{1.7 \times 10^{10}} \boldsymbol{M_\odot}$, 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.CLUSIO 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 over-sized 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:

$L_{AGN} = (5.3 \pm 0.4) \cdot 10^{45} \mathrm{erg/s} \approx 10^{12} L_\odot$. 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+42 is too bright (brightness temperature $\sim \mathbf{3 \times 10^{10}}$ K at observing frequency 7.6 GHz) and too luminous (1.4 GHz luminosity $\sim \mathbf{10^{25}}$ 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, $\mathbf{3.63 \times 10^7} \boldsymbol{M_\odot}$. (1709.06

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

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

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

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** $\pm$ 4 Gyr.

J.J. Cowan, *et al* Ap.J. 572 (2002) 861

The age of inner halo of the Galaxy **11.4** $\pm$ **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 $\mathbf{14.46 \pm 0.31}$ 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 $\boldsymbol{H = 67.3}$ and $\boldsymbol{t_U = 13.8}$; and if $\boldsymbol{H = 74}$, then $\boldsymbol{t_U = 12.5}$, more than 10 $\boldsymbol{\sigma}$
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, $\mathbf{10.6^{+1.5}_{-1.3}}$ 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 usual 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 $8 M_\odot$, a paucity of sources with masses below $5 M_\odot$, and a sharp drop-off above $10 M_\odot$ are observed, arXiv:1205.18

These features are not explained in the standard model of BH formation by stellar collapse, but nicely fit the hypothesis of primordial BH formation with log-normal spectrum and $M_0 \approx 8 M_\odot$.

Very fresh results: Lev Titarchuk, Elena Seifina, and Pascal Chardonnet, Astronomy and Astrophysics, submitted.

Measurement of BH masses through the X-ray spectra from the Galactic BH binaries:

GRS 1915+105: $(14 \pm 4) M_{\odot}$;

SS 433: $(4.30 \pm 0.8) M_{\odot}$;

V4641 Sgr: $(9.60 \pm 0.8) M_{\odot}$.

Very recent announcement

I. Zolotukhin, seminar GAISh, 10/10/17.

Discovery of several new IMBHs.

The X-ray accretion radiation registered by and XMM-Newton was analyzed. It led to registration of 10 IMBH, with 5 being new.

$$M = 3 \times 10^4 - 2 \times 10^5 M_\odot$$

The only possibility of the standard scenario is the coalescence of BH with solar mass. It meets serious difficulties. The observations nicely fit our scenario.

I. A brief review of high-z discoveries. In short, the young universe happened to be grossly overpopulated.

1. Several galaxies have been observed with natural gravitational lens “telescopes. A few examples:
a galaxy at $z \approx \mathbf{9.6}$ which was created at $t_U < \mathbf{0.5}$ Gyr;
a galaxy at $z \approx \mathbf{11}$ has been detected at $t_U \sim \mathbf{0.4}$ Gyr, three times more luminous in UV than other galaxies at $z = \mathbf{6-8}$. 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 reache

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.

Two years ago 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 $z = \mathbf{6.34}$ and in A1689-zD1 at $z = \mathbf{7.55}$.

Catalogue of the observed dusty sources indicates that their number is an order of magnitude larger than predicted by the cano ical 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, $z > 10$.

According to our model 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?

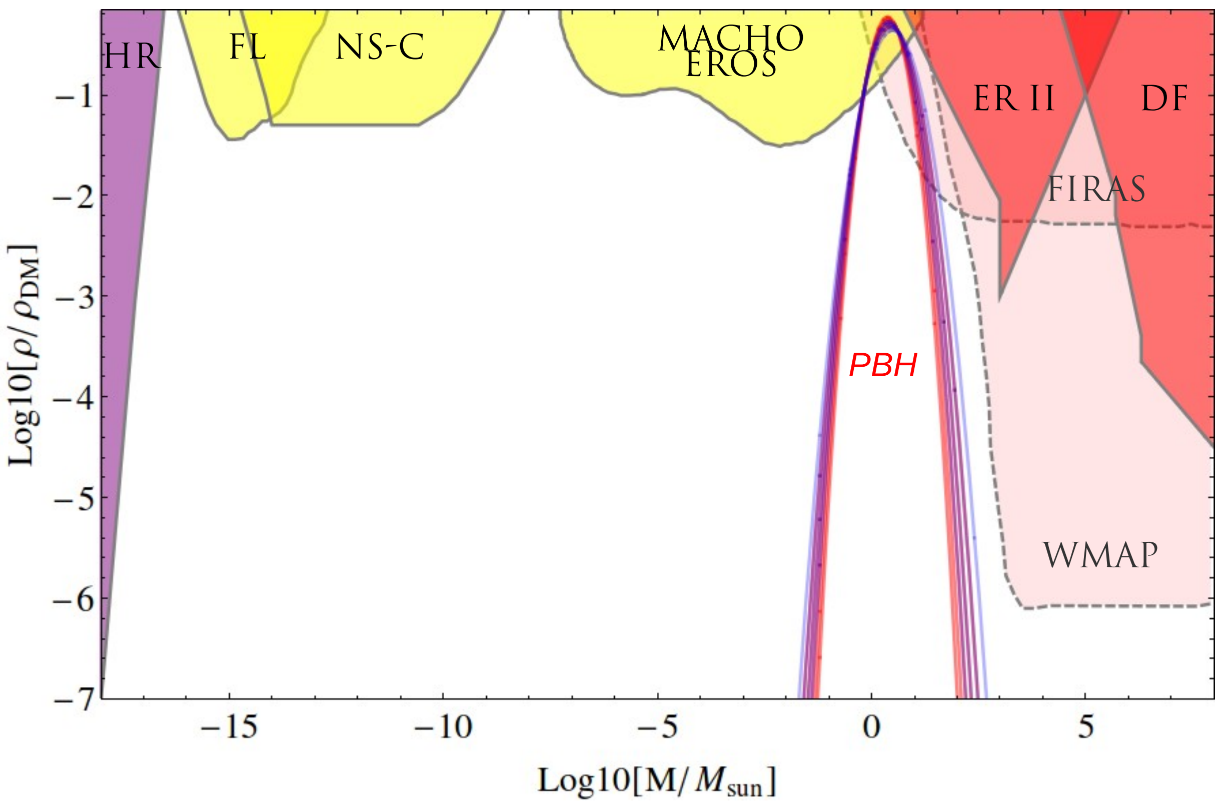


Figure 3: Constraints on PBH fraction in DM, $f = \rho_{\rm PBH}/\rho_{\rm DM}$, where the PBH mass distribution is taken as $\rho_{\rm PBH}(M) = M^2 dN/dM$ The existing constraints (extragalactic γ-rays from evaporation (HR), femtolensing of γ-ray bursts (F), neutron-star capture constraints (NS-C), 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.

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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 life-time, 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.

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 $\mathbf{m} \neq \mathbf{0}$, 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 $\mathbf{B} \neq \mathbf{0}$.

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

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

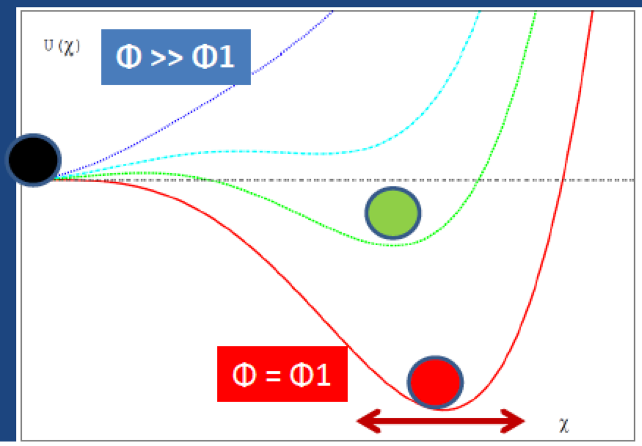
$$+\lambda_1\left(\chi^4 + h.c.\right) + (m^2\chi^2 + h.c.).$$

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.

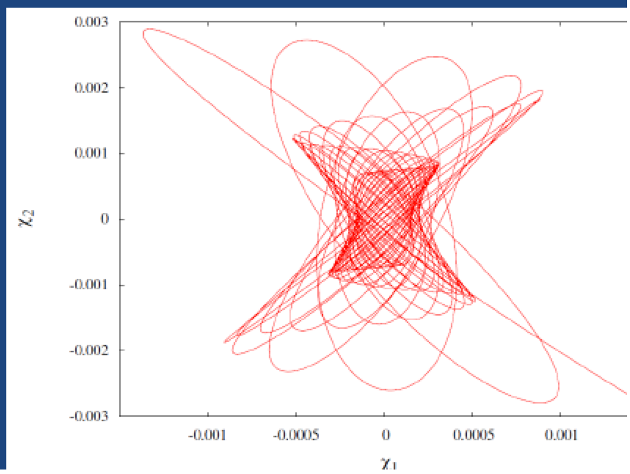
Effective potential of χ for different values of the inflaton field Φ. The upper blue curve corresponds to a large value Φ >> Φ1 which gradually decreases down to Φ = Φ1, red curve. Then the potential returns back to the almost initial shape, as Φ drops down to zero. The evolution of χ in such a potential is similar to a motion of a point-like particle (shown as a black ball in the figure) in Newtonian mechanics. First, due to quantum initial fluctuations χ left the unstable extremum of the potential at χ = 0 and ”tried” to keep pace with the moving potential minimum and later started to oscillate around it with decreasing amplitude. The decrease of the oscillation amplitude was induced by the cosmological expansion. In mechanical analogy the effect of the expansion is equivalent to the liquid friction term, $3H\dot{\chi}$. When Φ dropped below Φ1, the potential recovered its original form with the minimum at χ = 0 and χ ultimately returned to zero but before that it could give rise to a large baryon asymmetry

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



(Dolgov -Kawasaki-Kevlishvili)
Field χ "rotates" in this plane with quite large angular momentum, which exactly corresponds to the baryonic number density of χ. Later χ decayed into quarks and other particles creating a large cosmological baryon asymmetry.

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



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

Among the problems of contemporary universe: stars in the Milky Way, older than the Galaxy and even older than the universe (within two sigma);
and distant high redshift $(z = 5 - 10)$ population: early galaxies, QSO/SMBHs, and gamma-bursters. Moreover, the young universe is full of dust, which could not be created that early.

FACTS, quotations from publications: Observed high-z objects which could not be created in so short time.

There is a large "zoo" of astronomical objects formed in surprisingly short times. Several galaxies have been observed at high redshifts, with natural gravitational lens “telescopes, e.g. a galaxy at $z \approx 9.6$ which was created when the universe was about 0.5 Gyr old, (W. Zheng, *et al*, "A highly magnified candidate for a young galaxy seen when the Universe was 500 Myrs old" arXiv:

An observation of not so young but extremely luminous galaxy was recently reported: "The most luminous galaxies discovered by WISE" Chao-Wei Tsai, P.R.M. Eisenhardt *et al*,
arXiv:1410.1751, 8 Apr 2015.
$\boldsymbol{L = 3 \cdot 10^{14} L_\odot}$; age $\sim$ **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.

According to F. Melia (1403.0908), "The Premature Formation of High Redshift Galaxies", 1403.0908: "Rapid emergence of high-z galaxies so soon after big bang may actually be in conflict with current understanding of how they came to be. This problem is very reminiscent of the better known (and probably related) premature appearance of supermassive black holes at $z \sim 6$. It is difficult to understand how $10^9 M_\odot$ black holes appeared so quickly after the big bang without invoking non-standard accretion physics and the formation of massive seeds, both of which are not seen in the local Universe."

Another and even more striking example of early formed objects are high z quasars. A quasar with maximum $z = 7.085$ has been observed i.e. it was formed earlier than $t = 0.75$ Gyr.

Its luminosity and mass are:

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

D.J. Mortlock, *et al*, " A luminous quasar at a redshift of z = 7.085" Nature 474 (2011) 616, arXiv:1106.6088

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

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

Very recently another monster 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.

The medium around the observed early quas contains considerable amount of "metals" (elements heavier than He). According to the standard picture, only elements up to ^{4}He and traces of Li, Be, B were formed by BBN, while heavier elements were created by stellar nucleosynthesis and dispersed in the interstellar space by supernova explosions.

The universe at $z > 6$ is quite dusty, D.L. Clements et al "Dusty Galaxies at the Highest Redshifts", 1505.01841.
The highest redshift such object, HFLS3, lies at z=6.34 and numerous other sources have been found.
L. Mattsson, "The sudden appearance of dust in the early Universe",1505.04758: Dust galaxies show up at redshifts corresponding to a Universe which is only about 500 Myr old.

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 due to 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.

"Back to the future".
Quasar quartet embedded in giant nebula reveals rare massive structure in distant universe", J.F. Hennawi et al, Science 15 May 2015, 348 p. 779,
discovered in a survey for Lyman Quasars are rare objects separated by cosmological distances, so the chance of finding a quadruple quasar is $\sim 10^{-7}$. It implies that the most massive structures in the distant universe have a tremendous supply ($\sim 10^{11} M_{\odot}$) of cool dense ($n \approx 1/\mathrm{cm}^3$) gas, in conflict with current cosmological simulations.

Present days: it seems that every large galaxy and some smaller ones contain a central supermassive BH whose masses are 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 superheavy BHs is not understood.

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 fact 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 looks more plausible, when first a supermassive black hole was formed and attracted matter serving as seed for subsequent galaxy formation.

Bosch et al, Nature 491 (2012) 729; AD, J. Silk, 1974; AD, M. Kawasaki, N. Kevlishvili, 2008.