Primordial black holes: shining matter and dark matter
(heresy becoming accepted faith)

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Fest for Gianni and Dal Piaz^2

A workshop to mark the 70th birthday of Gianni Fiorentini
and the 80th birthday of Piero and Paola Dal Piaz
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Predictions of the old mechanism of PBH formation (AD, J. Silk, 1993) are now strongly supported by the newest astronomical observations:

- **Black holes in the universe are mostly primordial (PBH).**
- **Primordial BHs make all or a large part of dark matter.**
- **QSO are created in the very early universe.**
- **Metals and dust are made much earlier than expected.**
- **Inverted picture of galaxy formation is true: first supermassive BHs are formed and later galaxies are created around them. Seeding of galaxies by SMPBH or IMPBH;**
Seeding of globular clusters by $10^3 - 10^4$ BHs and dwarfs by $10^4 - 10^5$ BH. Plenty of such IMBH are observed recently.
- **Explanation of peculiar features of the sources of GWs registered by LIGO and Virgo,**
(S. Blinnikov, A.D., N. Porajko, and K. Postnov.)

Some other predictions:

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

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

The emerging from observations picture nicely fits all these striking statements, (not yet about antimatter).

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 Astrophysics", Physics Uspekhi, Vol. 61, No. 2, 2018 and the recent works with S. Blinnikov, N. Porajko, and K. Postnov and on a brief presentation of new published observational data.

Astrophysical BH versus PBH.

Astrophysical BHs are results of stellar collapse 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. But the universe age is not long enough for their formation. Serious problem of the standard theory.

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, J.Silk, PRD 47 (1993) 4244 "Baryon isocurvature fluctuations at small scaler and baryonic dark matter.

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. Dark matter made out of PBHs became a viable option.

During last several years there appear regularly (practically every week) new astronomical data strongly indicating that the the contemporary and young universe is abundantly populated by PBHs:
massive, $M \sim (7-8)M_\odot$,
supermassive, $M \sim (10^6 - 10^9)M_\odot$,
intermediate mass $M \sim (10^3 - 10^5)M_\odot$,
and a lot between and out of the intervals.
However, this interpretation encounters natural resistance from the astronomical establishment. Sometimes the authors of new discoveries admit that the observed phenomenon can be the explained by massive BHs, which drive the effect, but immediately retreat, saying that there is no known way to create sufficiently large density of such BHs.

Observational data about abundant PBHs, short review:
In any single case an alternative interpretation may be possible but as a whole the picture is very much in favor of massive PRIMORDIAL back holes.

Young universe, $z \sim 10$.
The data collected during last several years indicate that the young universe at $z \sim 10$ is grossly overpopulated with unexpectedly high amount of:

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

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

• 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.

Three 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.

Discovery of $0.8 \cdot 10^9 M_\odot$ BH in NEUTRAL universe at $z = 7.5$ [1712.01860]. Neutrality absence of accretion.
Existence of faint QSO, z=6, $M = 10^9 M_\odot$ needs either super-Eddington accretion or $10^5 M_\odot$ seed, 1802.02782.

Very recent data, not yet published:
Seminar talk by Yoshiki Matsuoka at Kashiwa, Univ. Tokyo:
Hunting for high-redshift (z > 6) quasars with Subaru Hyper Suprime-Cam.
The discovery of 80 new quasars at 5.8 < z < 7.1 and the establishment of the quasar luminosity function at z = 6.
The derived BH masses are systematically larger than allowed by the masses of the accompanying galaxies.
Supermassive black holes are created earlier than the galaxies which grow around them.
This is exactly our "crazy" statement of 1993.

• 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.
P. Eisenhardt: "How do you get an elephant? One way is start with a baby elephant." 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, [1801.0768 ".. halo has a mass of 3×10^{10} $M_\odot$ at $z = 7.5$; MBH accretes only about 2200 $M_\odot$ during [the universe age at this redshift,] $t_U = 320$ Myr." - by far insuffisient accretion rate.

T. Hashimoto et al, arXiv180505966H,
Nature, May, 17, 2018,
"The onset of star formation 250 million years after the Big Bang"
Oxygen line at $z = 9.1096 \pm 0.0006$.
"This precisely determined redshift indicates that the red rest-frame optical colour arises from a dominant stellar component that formed about 200 million years after the Big Bang, corresponding to a redshift of about 15."

• 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 the contemporary universe:

- SMBH in every large galaxy; even 15 Gyr are not enough to make them
- SMBH in small galaxies and in almost EMPTY space, $M \sim 10^9 M_\odot$.
- Stars older than the Galaxy and even one star older than the Universe (sic!).
- MACHOs (low luminosity 0.5 solar mass objects) - origin unknown.
- BH mass spectrum in the Galaxy: unexpected maximum at $M \sim 8 M_\odot$.
- Sources of the observed GWs.
- Intermediate mass BHs: $M \sim 10^3 M_\odot$, in globular clusters and $M \sim 10^4 - 10^5$ in dwarf galaxies.

AND MORE RECENT PUZZLES
(improbable systems in the standard model):

- **Several (four?) binaries of SMBH.**
- **Quasar quartet.**
- **Triple SMBH [1712.03909].**

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 SMBHs 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 ($n \approx 1/\mathrm{cm}^3$) gas, in conflict with current cosmological simulations.

Avalanche of IMBHs, $M = (10^3 - 10^5)M_\odot$

IMBHs in dwarfs: ten IMBH, two years ago,
$M = 3 \times 10^4 - 2 \times 10^5 M_\odot$
and 40 found recently $10^7 < M < 3{\cdot}10^9$ [Chandra, 1802.01567
More and more: 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 with

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

residing in galaxy centers and are accreting gas that creates characteristic signatures of a type-I active galactic nucleus."
He-Yang Liu, et al, A Uniformly Selected Sample of Low-Mass Black Holes in Seyfert 1 Galaxies. 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 $(1 - 20) \times 10^5 M_\odot$."

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.

Huge BH in small galaxies

• P.A. Christopher et al The Black Hole in the Most Massive Ultracompact Dwarf Galaxy 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.
• "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.

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.

AD, J. Silk, 1974;

AD, M. Kawasaki, N. Kevlishvili, 2008;

Bosch et al, Nature 491 (2012) 729.

High velocity stars in the Galaxy

• "Old, Metal-Poor Extreme Velocity Stars in the Solar Neighborhood", Kohei Hattori et al.,arXiv:1805.03194.

• "Gaia DR2 in 6D: Searching for the fastest stars in the Galaxy", T. Marchetti, E. Rossi, A. Brown arXiv:1804.10607. 20 stars have probabilities greater than 80 % of being unbound from the Galaxy. 7 hyper-runaway star candidates are coming from the Galactic disk. Surprisingly, the remaining 13 unbound stars cannot be traced back to the Galaxy, including two of the fastest stars around 700 km/s. These may constitute the tip of the iceberg of a large extragalactic population or the extreme velocity tail of stellar streams. 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.

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 the following problems:

1. Origin of heavy BHs ($\sim 30M_\odot$).
2. Low spins of the coalescing BHs.
3. Formation of BH binaries from original stellar binaries.

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

See however, T.Broadhurst, J.M. Diego, G. Smoot. 1802.0527

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 $M > 100M_\odot$ 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 GW15091
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 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).

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 $\sim 0.5 M_\odot$.

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, but nicely fit the hypothesis of primordial BH formation with log-normal spectrum and $M_0 \approx 8M_\odot$.

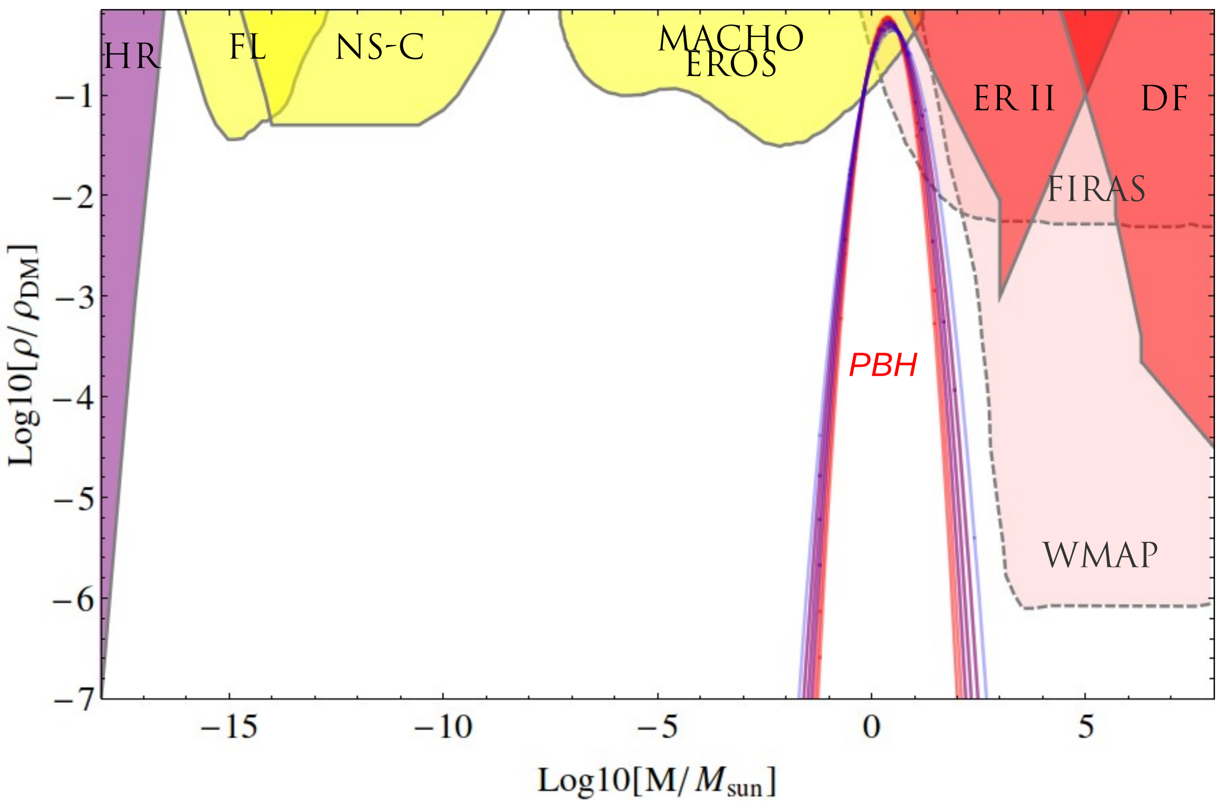


Figure 1: Constraints on PBH fraction in DM, $f = \rho_{\rm PBH}/\rho_{\rm DM}$, where the PBH mass distribution is taken as $\rho_{\rm PBH}(M) = M^2 dN/dM$ The existing constraints (extragalactic γ-rays from evaporation (HR), femtolensing of γ-ray bursts (F), neutron-star capture constraints (NS-C),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

Theoretical model, AD, J. Silk (1993), AD, M. Kawasaki, N. Kevlishvili (20060

The model predicts an abundant formation of heavy PBHs with log-normal mass spectrum:

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

with only 3 parameters: μ, γ, M_0.
This form is a result result of quantum diffusion of baryonic scalar field during inflation. Probably such spectrum is a general consequence of diffusion.
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.

Brief description of the mechanism.

SUSY motivated baryogenesis, 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 the observed 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):

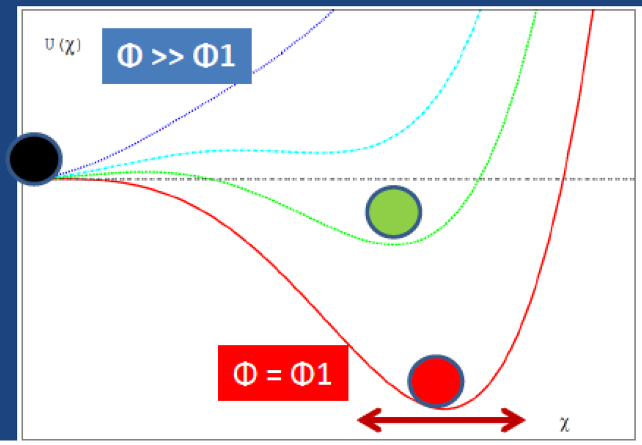
$$U = g|\chi|^2(\Phi - \Phi_1)^2 + \lambda|\chi|^4 \ln\left(\frac{|\chi|^2}{\sigma^2}\right)$$
$$+\lambda_1\left(\chi^4 + h.c.\right) + (m^2\chi^2 + h.c.).$$

Coupling to inflaton is the general renormalizable one.
When the window to the flat direction is open, near $\Phi = \Phi_1$, the field χ slowly diffuse to large value, according to quantum diffusion 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

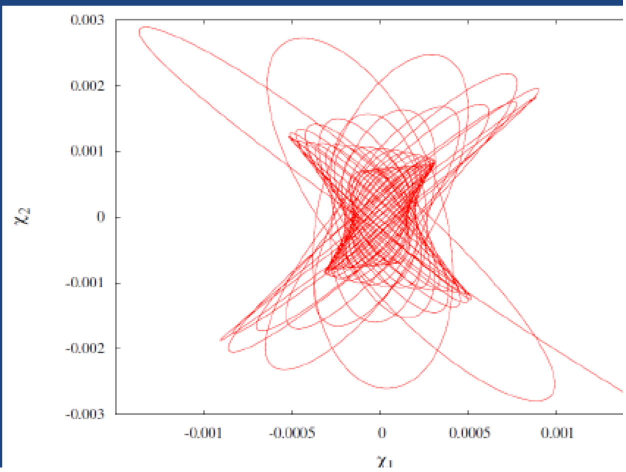
$$\ddot{\chi} + 3H\dot{\chi} + U'(\chi) = 0.$$



(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.**

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 large number of the recently observed IMBH was in fact predicted.

11. 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 from the galaxy later, a very rare event.

THE (HAPPY?) END