Massive Primordial Black Holes, Dark Matter, and More...
(Old predictions and new data)

A.D. Dolgov

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

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Two different but related subjects:

I. A mechanism of massive PBH formation much different from all others. The basement 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 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 in the universe appears practically every week.

Heretic predictions of 1993

A.Dolgov, J.Silk PRD 47 (1993) 4244 "Baryon isocurvature fluctuations at small scales and baryonic dark matter" also A.D. Dolgov, M. Kawasaki, N. Kevlishvili, Nucl.Phys. B807 (2009) 229, "Inhomogeneous baryogenesis, cosmic antimatter, and dark matter"

turned into the accepted faith since they became supported by the recent astronomical data.

It allows to cure an avalanche of inconsistencies with the standard ΛCDM.

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 it is completely different physics. 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.

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

Quarter of century old predictions:

- **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.**
- **Seeding of large galaxies by supermassive PBH.**
- **Recently, AD & K. Postnov:**

Seeding of globular clusters by $10^3 - 10^4$ BHs and dwarfs by $10^4 - 10^5$ BH.

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

10 billion year story in 10 minutes. The observations of the last several years indicate that the young universe at $z \sim 10$ is grossly overpopulated with numerous:

1. Bright QSOs, alias supermassive BHs, up to $M \sim 10^{10} M_\odot$,

2. Superluminous young galaxies,

3. Supernovae, gamma-bursters,

and full of dust and heavy elements.

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

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 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 (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.

Problems of contemporary universe:

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

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.

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.

The model is based on the supersymmetric (Affleck-Dine) scenario for baryogenesis modified by introduction of a general renormalizable coupling of the scalar baryon to the inflaton field:

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

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

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 ($\sim 30 M_\odot$).

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 $8 M_\odot$.

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, 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.**

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.

Literature:

"Beasts in Lambda-CDM Zoo", Phys. Atom. Nucl., 80 (2017) 987; 1605.06749; "Massive and supermassive black holes in the contemporary and early universe ..." Physics Uspekhi, and several conference talks in the arXive.

THE (HAPPY?) END

More below for another 106 minutes

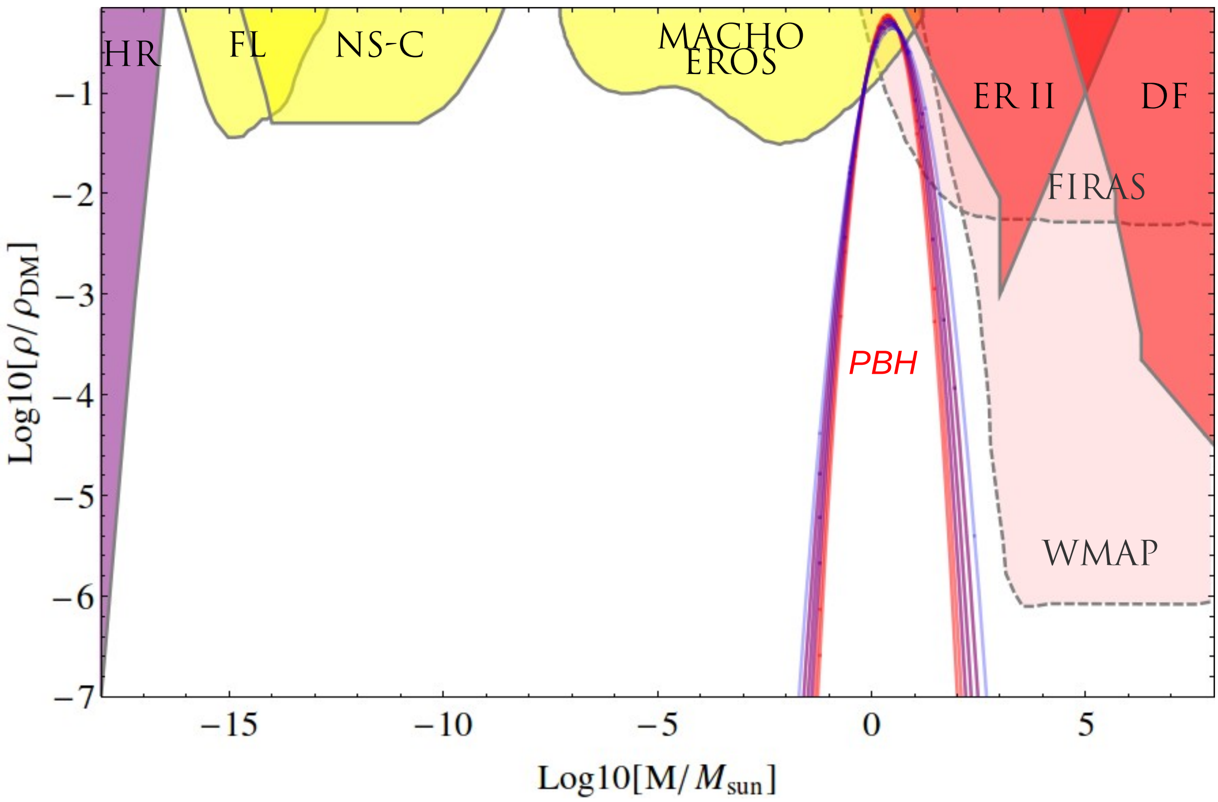

Figure 1: Constraints on PBH fraction in DM, $f = \rho_{\rm PBH}/\rho_{\rm DM}$, where the PBH mass distribution is taken as $\rho_{\rm PBH}(M) = M^2 dN/dM$ The existing constraints (extragalactic γ-rays from evaporation (HR), femtolensing of γ-ray bursts (F), neutron-star capture constraints (NS-C),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

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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 $\sim 0.5 M_\odot$.