PBH, Antimatter, and HST/JWST Data

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Abstract

The data presented by Hubble Space Telescope and James Webb Space Telescope, are reviewed. It is argued that the declared contradiction of the data with the standard big bang cosmology is resolved if the universe is populated by very massive primordial black holes (PBH) that seed galaxy formation as it has been conjectured in 1993 in our paper with J. Silk (DS)
The statement that the galaxy formation might be seeded by PBH was recently **rediscovered** in several works aiming to explain the data of JWST on very early galaxy formation.
The log-normal mass spectrum of PBHs predicted by DS excellently fits the astronomical data on the chirp mass distribution of BH observed by LIGO/Virgo/Kagra.
It is argued that the PBH with log-normal mass spectrum could make 100% contribution to the density of the cosmological dark matter.
The striking byproduct of DS model predicting a noticeable antimatter population of the Milky Way seems to be true as well.

Outline

1. Recent discoveries made by HST and LWST.
2. Long standing cosmological problems.
3. PBH solution of new and old problems
4. Antimatter in the MIky Way: positrons, antinuclej, and antistars
5. Log-normal mass spectrum of PBHs, comparison to observations.
6. Black dark matter.
7. Gravitational waves and PBH.

Resolution of the problems by PBH envisaged long before they emerged:
A.Dolgov, J.Silk, PRD 47 (1993) 4244 (DS) "Baryon isocurvature fluctuations at small scale and baryonic **dark matter**".
A.Dolgov, M. Kawasaki, N. Kevlishvili (DKK), NPB807 (2009) 229, "Inhomogeneous baryogenesis, **cosmic antimatter**, and DM"
Prediction of well evolved early galaxies, quasars (SMBH), rich chemistry (heavy elements) and dust.

JWST and conventional cosmology

Recent few month discoveries made by JWST, in continuum infrared μm range, created strong doubts about validity of the accepted ΛCDM cosmology. It has been observed that the pretty young universe with the age about 200-300 million years is full of large and well developed bright galaxies which simply **couldt be there** according to the canonical faith or better to say to the standard cosmological model.

As is stated in the JWST publications: "an unexpectedly large density (stellar mass density $\varrho_* \gtrsim 10^6 M_\odot$ Mpc^{-3}) of massive galaxies (stellar masses $M_* \geq 10^{10.5} M_\odot$) are discovered at extremely high redshifts $z \gtrsim 10$."

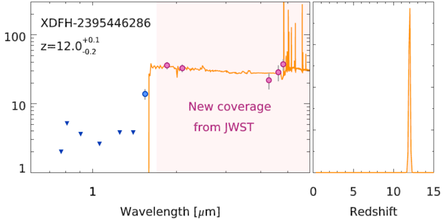
A few examples from CEERS = Cosmic Evolution Early Release Science:

Galaxies at: $z = 14.3 \pm 0.4$, $t_U = 264$ **Myr**; $z = 16.7$, $t_U = 235$ **Myr**

Still some doubts on the accuracy in the determination of the redshifts persisted because of lacking spectral analysis.

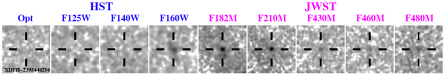
Confirmation by spectral line identifications was strongly demanded

JWST and HST agreement

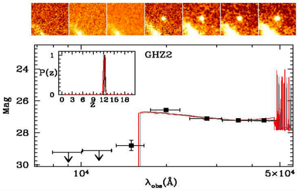


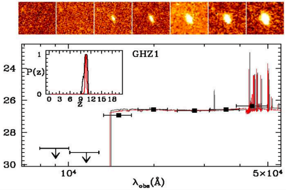
Rychard J.Bouwens et al, Evolution of the UV LF from Z~15 to z~8 Using New JWST NIRCam Medium-Band Observations over the HUDF/XDF. arXiv:2211.02607

Joint observation of object XDFH-2395446286 and measuring its redshift z=12 HST and JWST. This is the most distant galaxy ever discovered by HTS 30 years of observation.



Marco Castellano et al, Early results from GLASS-JWST.III: Galaxy candidates at z~9-15. arXiv:2207.09436

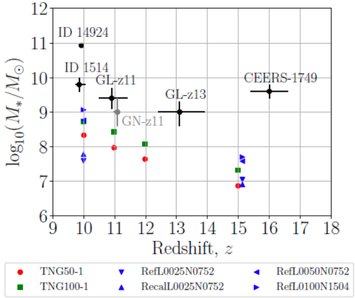




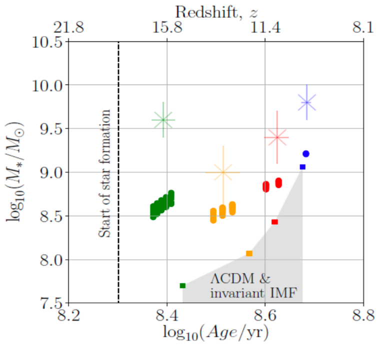
Two more examples of galaxies with z=10.62 and z=12.3 found JWST in a couple of months of observations.

JWST and ΛCDM cosmology

Moritz Haslbauer et al, Has JWST already falsified dark-matter-driven galaxy formation? arXiv:2210.14915



Comparison of the size of the most massive galaxies, obtained in models of formation and growth of galaxies based on LCDM (colored dots) with JWST observations (black dots with errors) depending on the redshift of the observed galaxies.



Early galaxies, spectroscopic confirmation

Several papers where spectral analsis has been performed are appearing starting from mid-February.

1. S. Tacchella, et al arXiv:2302.07234 14 Feb 2023
JADES Imaging of GN-z11: Revealing the Morphology and Environment of a Luminous Galaxy 430 Myr After the Big Bang. The JWST NIRCam 9-band near-infrared imaging of the luminous $z = 10.6$ galaxy GN-z11 from the JWST Advanced Deep Extragalactic Survey (JADES) of the GOODS-N field is made. **A spectral energy distribution (SED) is determined entirely consistent with the expected form of the high-redshift galaxy.**

2. A.J. Bunker, *et al* arXiv:2302.07256, 14 Feb 2023 JADES NIRSpec Spectroscopy of GN-z11: Lyman-α emission and possible enhanced **nitrogen** abundance in a $z = 10.60$ luminous galaxy, The spectroscopy of GN-z11, the most luminous candidate $z > 10$ Lyman break galaxy in the GOODS-North field with $M_{UV} = -21.5$ is presented. Redshift of $z = 10.603$ is derived (lower than previous determinations) based on multiple emission lines in low and medium resolution spectra over $0.8 - 5.3\,\mu$m. The spatially-extended Lyman-α in emission is observed. **The NIRSpec spectroscopy confirms that GN-z11 is a remarkable galaxy with extreme properties seen 430 Myr after the Big Bang.**

Early galaxies, spectroscopic confirmation

3. T. Bakx, *et al* MNRAS, 22.02,2023.
Age of Most Distant Galaxy is confirmed with Oxygen observation. The radio telescope array ALMA has pin-pointed the exact cosmic age of a distant JWST-identified galaxy, GHZ2/GLASS-z12, at 367 million years after the Big Bang. ALMA's deep spectroscopic observations revealed a spectral emission line associated with ionized Oxygen. It confirms the JWST ability to look out to record distances, and heralds a leap in our ability to understand the formation of the earliest galaxies in the Universe.
4. E. Curtis-Lake, *et al*, Spectroscopic confirmation of four metal-poor galaxies at $z = 10.3 - 13.2$,
Nat. Astron. (2023). https://doi.org/10.1038/s41550-023-01918-w. The galaxies are unambiguously detected at redshift $10.3 \leq z \leq 13.2$ previously selected from JWST Near Infrared Camera imaging. The spectra reveal that these primeval galaxies are metal poor, have masses on the order of about $10^7 - 10^8$ solar masses and young ages. These findings demonstrate the rapid emergence of the first generations of galaxies at cosmic dawn.

Early galaxies, spectroscopic confirmation

5. P. A. Haro, *et al* Spectroscopic verification of very luminous galaxy candidates in the early universe, arXiv:2303.15431.
The confirmation is made for the redshifts $z > 10$ of two galaxies, including one of the first bright JWST-discovered candidates with $z = 11.4$. It is shown that another galaxy with suggested $z \sim 16$ instead has $z = 4.9$, with strong emission lines that mimic the expected colours of more distant objects. These results reinforce the evidence for the rapid production of luminous galaxies in the very young Universe, while also highlighting the necessity of spectroscopic verification for remarkable candidates.

Spectroscopic observations confirm discoveries of very early galaxies by JWST beyond any doubts.

Seeding of galaxy formation by PBH

According to DS (1993) and DKK (2006), galaxy formation is seeded by supermassive primordial black holes both in the early and contemporary universe. This mechanism explains in particular how the galaxies observed by JWST in the very young universe might be created. This statement was rediscovered in some recent papers.

a) B. Liu, V. Bromm, "Accelerating early galaxy formation with primordial black holes", arXiv:2208.13178. "Very early formation of massive galaxies observed by JWST could be reconciled with standard $\Lambda\mathrm{CDM}$ predictions, if structure formation is accelerated by massive ($\gtrsim 10^9\ \mathrm{M}_\odot$) PBHs".

b) Guan-Wen Yuan, *et al* "Rapidly growing primordial black holes as **seeds** of the massive high-redshift JWST Galaxies", arXiv:2303.09391 relatively light PBH with masses about $50M_\odot$ gaining mass through **super-Eddington accretion** can explain observations of massive galaxies at redshifts of $z \geq 6.5$ by JWST. However, it seems that the seeding by supermassive PBH is much less cumbersome.

Early supermassive BH

The origin of the supermassive BHs is also hard to squeeze into narrow standard frameworks. But a great lot of them is observed.

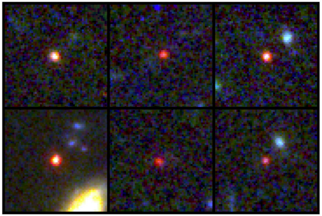
Recently an ultra-massive QSO at $z = 6.853$ was observed by ALMA:
R. Endsley *et al*, ALMA confirmation of an obscured hyper-luminous radio-loud AGN at z = 6.853 associated with a dusty starburst in the 1.5 deg2 COSMOS field. MNRAS, **520**, Issue 3, April 2023, Pages 4609-4620,
VIRCam and IRAC photometry perhaps suggests that COS-87259 is an extremely massive reionization-era galaxy with $M_* = 1.7 \times 10^{11} M_\odot$. Such a very high AGN luminosity suggests that this object is powered by $\sim 1.6 \times 10^9 M_\odot$ black hole if accreting near the Eddington limit.
This looks as nearly impossible, but if there is a **primordial supermassive black hole,** it could easily seed such monstrous galaxy and quasar.

Early supermassive BH

In paper R .L. Larson, *et al* A CEERS Discovery of an Accreting Supermassive Black Hole 570 Myr after the Big Bang: Identifying a Progenitor of Massive $z > 6$ Quasars, arXiv:2303.08918 the discovery of an accreting supermassive black hole at z=8.679 is announced in a galaxy previously observed via a Lyα-break by Hubble and with a Lyα redshift from Keck. The mass of the black hole is $\log(M_{BH}/M_{\odot}) = 6.95 \pm 0.37$, and it is estimated that it is accreting at 1.2 ($\pm$0.5) times of the Eddington limit. According to the authors: this presently highest-redshift AGN discovery is used to place constraints on black hole seeding models and find that a combination of either super-Eddington accretion from stellar seeds or Eddington accretion from massive black hole seeds is required to form this object by the observed epoch.

Impossible galaxies

I. Labbé et al, A population of red candidate massive galaxies 600 Myr after the Big Bang, Nature, published online 22.02.2023, Six candidate massive galaxies (stellar mass $> 10^{10}$ solar masses) at $7.4 \lesssim z \lesssim 9.1$ 500–700 Myr after the Big Bang, including one galaxy with a possible stellar mass of $\sim 10^{11} M_\odot$, too massive to be created in so early universe. According to the 'science' it is impossible to create so well developed galaxies. "May be they are **supermassive black holes** of the kind never seen before. That might mean a revision of our understanding of black holes." **Well agrees with our predictions of PBHs.**



The six candidate galaxies identified in the JWST data. (NASA, ESA, CSA, I. Labbe/Swinburne University of Technology)

Rich chemistry

B. Peng, et al, The Astrophysical Journal Letters, Volume 944, Issue 2, id.L36, 8 pp. 'Discovery of a Dusty, Chemically Mature Companion to $z \sim 4$ Starburst Galaxy in JWST Early Release Science Data,'
Most surprising about the companion galaxy, considering its age and mass, was its mature metallicity— amounts of elements heavier than helium and hydrogen, such as carbon, oxygen and nitrogen.
A.J. Cameron, et al, arXiv:2302.10142, 20.02.2023. Nitrogen enhancements 440 Myr after the Big Bang: super-solar N/O, a tidal disruption event or a dense stellar cluster in GN-z11? Observations of GN-z11 with JWST/NIRSpec revealed numerous oxygen, carbon, nitrogen, and helium emission lines at $z = 10.6$. Yields from runaway stellar collisions in a dense stellar cluster or a tidal disruption event provide promising solutions to give rise to these unusual emission lines at $z = 10.6$, and opened by JWST to constrain galactic enrichment and stellar evolution within 440 Myr of the Big Bang.
High abundances of heavy elements may be a result of BBN with large baryon-to-gamma ratio, as predicted in DS and DKK.

Problems prior to JWSP data

Similar serious problems are known already for many years. The Hubble space telescope (HST) discovered that the early universe, at $z = 6 - 7$ is too densely populated with quasars, alias SMBH, supernovae, gamma-bursters and it is very dusty. **No understanding how all these creature were given birth in such a short time is found in conventional cosmology.** Moreover great lots of phenomena in the **present day universe** are also in strong tension with canonical cosmological expectations.

A.D. "Massive and supermassive black holes in the contemporary and early Universe and problems in cosmology and astrophysics Phys. Usp. 61 (2018) 2, 115.

"Hubble"sees the universe up to $z = 6 - 7$, but accidentally a galaxy at $z \approx 12$ has been discovered for which both Hubble and Webb are in good agreement.

Still only after publications of JWST data astronomy establishment became seriously worried.

All the problems are neatly solved if the universe is populated by primordial black holes (PBH) and the astrophysically large bubbles with very high baryonic density

BH types by formation mechanisms

1. Astrophysical black holes,

created by the collapse of a star which exhausted its nuclear fuel. The expected masses should start immediately above the neutron star mass, i.e. about $3\boldsymbol{M_\odot}$, but noticeably below $100M_\odot$. Instead we observe that the BH mass spectrum in the galaxy has maximum at $\boldsymbol{M} \approx 8\boldsymbol{M_\odot}$ with the width $\sim (1-2)\boldsymbol{M_\odot}$. The result is somewhat unexpected but an explanations in the conventional astrophysical frameworks is possible.

Recently LIGO/Virgo discovered BHs with masses close to $100M_\odot$. Their astrophysical orrgin was considered **impossible.** Now some, quite exotic, formation mechanisms are suggested.

2. Formation by accretion on the mass excess in the galactic center.

In any large galaxy there exists a supermassive BH (SMBH) at the center, with masses varying from a few millions $M_\odot$ (e,g, Milky Way) up to almost hundred billions $M_\odot$. **However, the conventional accretion mechanisms are not efficient enough to create such monsters during the universe life-time, $t_U \approx 14.6$ Gyr. At least 10-fold longer time is necessary,** to say nothing about SMBH in 10 times younger universe.

BH types by formation mechanisms

3. Primordial black holes (PBH) created during pre-stellar epoch

The idea of the primordial black hole (PBH) i.e. of black holes which could be formed the early universe prior to star formation was first put forward by Zeldovich and Novikov: "The Hypothesis of Cores Retarded During Expansion and the Hot Cosmological Model Astronomicheskij Zhurnal, 43 (1966) 758, Soviet Astronomy, AJ.10(4):602–603;(1967).

According to their idea, the density contrast in the early universe inside the bubble with radius equal to the cosmological horizon might accidentally happen to be large, $\delta\varrho/\varrho \approx 1$, then that piece of volume would be inside its gravitational radius i.e. it became a PBH, which decoupled from the cosmological expansion.

Elaborated later in S. Hawking, "Gravitationally collapsed objects of **very low mass** Mon. Not. Roy. Astron. Soc. **152**, 75 (1971).

B. J. Carr and S. W. Hawking, "Black holes in the early Universe," Mon. Not. Roy. Astron. Soc. **168**, 399 (1974).

BH types by masses

There is the following conventional division of black holes by their masses:
1. Supermassive black holes (SMBH): $M = (10^6 - 10^{10}) M_\odot$.
2. Intermediate mass black holes (IMBH): $M = (10^2 - 10^5) M_\odot$.
3. Solar mass black holes: masses from a fraction of $M_\odot$ up to $100 M_\odot$.

The origin of most of these BHs is unclear, except maybe of the BHs with masses of a few solar masses, which may be astrophysical.
Highly unexpected was abundance of IMBH which are appearing during last few years in huge numbers.
The assumption that (almost) all black holes in the universe are primordial strongly reduce or even eliminate the tension.

Problems of the contemporary universe. Summary.

1. SMBH in all large galaxies. Too short time for their formation through the usual accretion mechanism.
2. SMBH in small galaxies and even in (almost) empty space. No material for their creation. Pushed out of large galaxies? Wandering BHs?
A striking example: the Hobby-Eberly Telescope at Texas's McDonald Observatory suggested the presence of a black hole with a mass of about 17 billion $M_\odot$ equivalent to 14% of the total stellar mass of the galaxy. Usually the mass of the central BH is about 0.1 % of the galaxy mass.
3. Too old stars, older than the Galaxy and maybe older that the universe?
4. MACHOs, non-luminous objects with masses $\sim 0.5 M_\odot$ obsserved through microlensing; origin unknown.
5. Problems with the BH mass spectrum in the Galaxy, masses are concentrated in the narrow interval $(7.8 \pm 1.2) M_\odot$.
6. Origin and properties of the sources of the observed gravitational waves.
7. IMBH, with $M \sim (10^3 - 10^5) M_\odot$, in dwarfs and globular clusters, discovered but unexpected..
8. Strange stars in the Galaxy, too fast and with unusual chemistry. Observed during the last decade..

Ultramassive BH

Y. Ni, *et al* , Ultramassive Black Holes Formed by Triple Quasar Mergers at $z \sim 2$, The Astrophysical Journal Letters, Volume 940, Number 2.
The origin of rare and elusive ultramassive black holes, UMBH; with $M_{BH} > 10^{10} M_\odot$ is an open question. Using the large volume cosmological hydrodynamic simulation ASTRID, we report on the formation of an extremely massive UMBH with $M_{BH} \sim 10^{11} M_\odot$ at $z \sim 2$.

Solution of all the problems by PBH

To summarise, a large amount of observational data are at odds with the conventional model but nicely fits the model of creation of primordial black holes and primordial stars proposed in DS and DKK The proposed mechanism is the first where inflation and Affleck-Dine baryogenesis are applied to PBH formation, repeated now in many works.

The striking feature of it is the **log-normal** mass spectrum which is the only known spectrum **tested by "experiment" in a good agreement.**

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

$M_0 \sim 10 M_\odot$, is predicted, A.Dolgov, K.Postnov, "Why the mean mass of primordial black hole distribution is close to $10 M_\odot$". JCAP 07 (2020) 063.
The horizon mass at QCD p.t. is $10 M_\odot$, for $\mu = 0$. At larger chemical potential the T_{pt} is smaller and M_{hor} is larger.

Seeding of galaxy formation by PBH in present-day universe

A large number of intermediate mass black holes, that were discovered during last decade, hardly fits the narrow frameworks of the standard cosmological model. However, if they are primordial with the determined above parameters of the log-normal mass spectrum, their number is just what is necessary to explain the data and in particular to understand the mechanism of the origin of dwarf galaxies and globular clusters which is not well understood in the conventional cosmology. The astrophysical origin of IMBH encounter serious problems for all mass values, while huge number of them are discovered recently. On the contrary, the described above model of PBH formation excellently resolves all the inconsistencies.

As argued in A. Dolgov, K. Postnov (AD-KP), Globular Cluster Seeding by Primordial Black Hole Population, JCAP 04 (2017) 036, e-Print: 1702.07621 [astro-ph.CO].

IMBHs with masses of a few thousand solar mass, or higher, can seed formation of globular clusters (GCs) and dwarf galaxies.

In the last several years such IMBH inside GSs are observed confirming this prediction. For example the BH with the mass $M \sim 10^5 M_\odot$ is discovered in the dwarf galaxy SDSS J1521+1404.

Seeding of dwarf formation by PBH

''Two Candidates for Dual AGN in Dwarf-Dwarf Galaxy Mergers,'' M. Mićić, et al, arXiv:2211.04609 [astro-ph.GA]. An evidence of a pair of dwarf galaxies featuring giant black holes on a collision course with each other.

Intermediate-mass black holes: finding of episodic, large-scale and powerful jet activity in a dwarf galaxy SDSS J090613.77+561015.2. Jun Yang et al, e-Print: 2302.06214 [astro-ph.GA,astro-ph.HE]. Discovery of an intermediate-mass black hole (IMBH) with a mass of $M_{BH} = 3.6^{+5.9}_{-2.3} \times 10^5 M_\odot$ which surely cannot be created by accretion but might seed the dwarf formation.

Recently possible discovery of SMBH in dwarf galaxy Leo 1 was announced: F. Pacucci, A. Loeb, "Accretion from Winds of Red Giant Branch Stars May Reveal the Supermassive Black Hole in Leo I ApJL 940 L33, 2022.

Such SMBH could not be created by the matter accretion to the galaxy centre.

Much more new data on several dwarfs are presented a few months ago: M. Mezcua, *et al,* "Overmassive black holes in dwarf galaxies out to $z \sim 0.9$ in the VIPERS survey arXiv:2212.14057. Six dwarf galaxies are identified that have X-ray AGN, powered by SMBHs of $M > 10^7 M_\odot$.

Most probably these dwarfs were seeded by primordial supermassive black holes in accordance with AD-KP prediction.

Problems solved by PBH

The origin of IMBH is unknown in all mass range, though plenty of them are discovered everywhere.
Moreover, BH with $M \approx 100 M_\odot$ **is strictly forbidden but nevertheless observed by LIGO/Virgo.**

The described above model of PBH formation excellently solves all the inconsistencies. **The inverted picture of galaxy formation is assumed: first SMPBH are created and later they seed galaxy formation.**

Gravitational waves from BH binaries

• GW discovery by LIGO strongly indicate that the sources of GW are PBHs. see e.g. S.Blinnkov, A.D., N.Porayko, K.Postnov, JCAP 1611 (2016), 036 "Solving puzzles of GW150914 by primordial black holes,"

1. Origin of heavy BHs ($\sim 30 M_\odot$); there appeared much more striking problem of BH with $M \sim 100 M_\odot$. See however, J. Ziegler, K. Freese, arXiv:2010.00254: DM annihilation inside stars

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

3. Low spins of the coalescing BHs .

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 observed in the necessary amount. PBHs with the observed by LIGO masses may be easily created with sufficient density.

Chirp mass

Two rotating gravitationally bound massive bodies are known to emit gravitational waves. In quasi-stationary inspiral regime, the radius of the orbit and the rotation frequency are approximately constant and the GW frequency is twice the rotation frequency. The luminosity of the GW radiation is:

$$L = \frac{32}{5}\, m_{Pl}^2 \left(\frac{M_c\, \omega_{orb}}{m_{Pl}^2} \right)^{10/3},$$

where M_1, M_2 are the masses of two bodies in the binary system and $\boldsymbol{M_c}$ is the so called chirp mass:

$$M_c = \frac{(M_1\, M_2)^{3/5}}{(M_1 + M_2)^{1/5}},$$

and

$$\omega_{orb}^2 = \frac{M_1 + M_2}{m_{Pl}^2 R^3}.$$

Chirp mass distribution

A.D. Dolgov, A.G. Kuranov, N.A. Mitichkin, S. Porey, K.A. Postnov, O.S. Sazhina, I.V. Simkine On mass distribution of coalescing black holes, JCAP 12 (2020) 017, e-Print: 2005.00892.

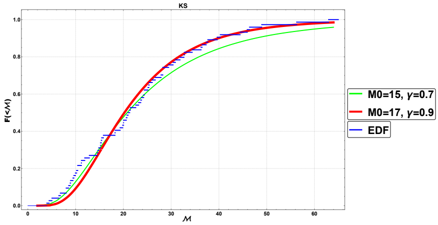
The available data on the chirp mass distribution of the black holes in the coalescing binaries in O1-O3 LIGO/Virgo runs are analyzed and compared with theoretical expectations based on the hypothesis that these black holes are primordial with log-normal mass spectrum.

The inferred best-fit mass spectrum parameters, $M_0 = 17 M_\odot$ and $\gamma = 0.9$, fall within the theoretically expected range and shows excellent agreement with observations.

On the opposite, binary black hole formation based **on massive binary star evolution** require additional adjustments to reproduce the observed chirp mass distribution.

Chirp mass distribution

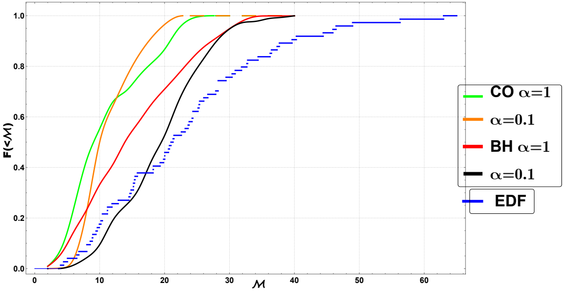
Model distribution $F_{PBH}(< M)$ with parameters $M_0 \approx 17 M_\odot$ and $\gamma \sim 1$ for two best Kolmogorov-Smirnov tests. EDF= empirical distribution function.



Similar value of the parameters are obtained in M. Raidal et al, JCAP.,2019. Feb. V. 2019, no. 2. P. 018. arXiv:1812.01930 and L. Liu, et al arXiv:2210.16094.
See also K. Postnov and N. Mitichkin, e-Print: 2302.06981.

Chirp mass distribution

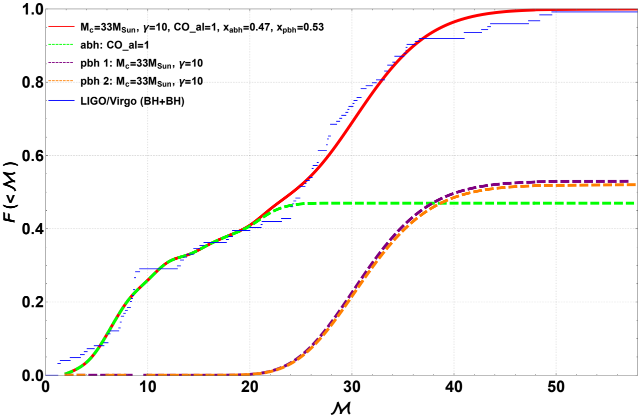
Cumulative distributions $F(< M)$ for several **astrophysical** models of binary BH coalescences.



Conclusion: PBHs with log-normal mass spectrum perfectly fit the data. Astrophysical BHs seem to be disfavoured.

Analysis of recent Ligo-Virgo-Kagra (LVK) data

A new analysis of the Ligo-Virgo-Kagra data was performed recently by K. Postnov and N. Mitichkin, "'On the primordial binary black hole mergings in LVK data', e-Print: 2302.06981 [astro-ph.CO]. They concluded that the chirp-mass distribution of LVK GWTC-3 BH+BH binaries with distinct two bumps can be explained by two different populations of BH+BH binaries:
1) the low-mass bump at $M_0 \sim 10 M_\odot$ due to the astrophysical BH+BH formed in the local Universe from the evolution of massive binaries
2) the PBH binaries with log-normal mass spectrum with $M_0 \simeq 10 M_\odot$ and $\gamma \simeq 10$. The central mass of the PBH distribution is larger than the expected PBH mass at the QCD phase transition ($\sim 8 M_\odot$) but still can be accommodated with the mass of the cosmological horizon provided that the temperature $T_{QCD} \sim 70$ MeV, possible for non-zero chemical potential at QCD p.t.



The observed (blue step-like curve) and model (red solid curve) distribution function of the chirp-masses of coalescing binary BHs from the LVK GWTC-3 catalogue. The model includes almost equal contributions from coalescences of astrophysical binary BHs (green dashed curve) and primordial BHs with the initial log-normal mass spectrum with parameters $M_0 = 33M_\odot$, $\gamma = 10$ - with such γ heavier PBH practically are not created.

PBH and inflation

Inflation allows for formation of PBH with very large masses. It was first applied to PBH production in DS paper, PRD 47 (1993) 4244,
a year later in: B.J. Carr, J.H. Hilbert, J.E. Lidsey, "Black hole relics and inflation: Limits on blue perturbation spectra'', Phys.Rev.D 50 (1994) 4853, astro-ph/9405027;
and soon after in P. Ivanov, P. Naselsky, I. Novikov (May 10, 1994), Inflation and primordial black holes as dark matter, PRD 50 (1994) 7173.
Presently inflationary mechanism of PBH production is commonly used. It allows to create PBH with very high masses, but the predicted spectrum is multi-parameter one and quite complicated
The only exception is the log-normal spectrum of DS and DKK tested by observatons.

Black Dark Matter

The first suggestion PBH might be dark matter "particles"was made by S. Hawking in 1971 "Gravitationally collapsed objects of very low mass Mon. Not. R. astr. Soc. (1971) 152, 75 and later by G. Chapline in 1975 who noticed that low mass PBHs might be abundant in the present-day universe with the density comparable to the density of dark matter. G.F. Chapline, Nature, 253, 251 (1975) "Cosmological effects of primordial black holes". Assumed flat mass spectrum in log interval:

$$dN = N_0 (dM/M)$$

with maximum mass $M_{max} \lesssim 10^{22}$ g, which hits the allowed mass range. The next one: A. Dolgov, J. Silk (Mar 13, 1992), Baryon isocurvature fluctuations at small scales and baryonic dark matter, PRD 47 (1993) 4244 with more realistic masses. **first paper with inflation applied to PBH formation, so PBH masses as high as $10^6 M_\odot$, and even higher can be created, log-normal mass spectrum was predicted.**

Black Dark Matter

Constraints on PBHs - B.Carr, F. Kuhnel "Primordial Black Holes as Dark Matter: Recent Developments arXiv:2006.02838, June 2020
Primordial black holes as dark matter candidates B. Carr, F. Kuhnel SciPost Phys.Lect.Notes 48 (2022), e-Print: 2110.02821 [astro-ph.CO]
For monochromatic mass spectrum of PBHs (caution, model-dependent).

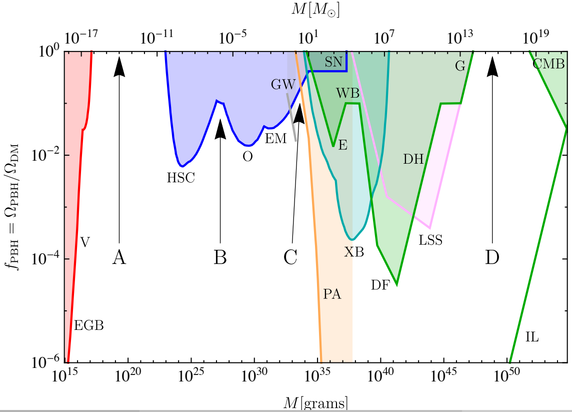


Figure caption

Constraints on $f(M)$ for a **monochromatic** mass function, from evaporations (red), lensing (blue), gravitational waves (GW) (gray), dynamical effects (green), accretion (light blue), CMB distortions (orange) and large-scale structure (purple). Evaporation limits from the extragalactic gamma-ray background (EGB), the Voyager positron flux (V) and annihilation-line radiation from the Galactic centre (GC). Lensing limits from microlensing of supernovae (SN) and of stars in M31 by Subaru (HSC), the Magellanic Clouds by EROS and MACHO (EM) and the Galactic bulge by OGLE (O). Dynamical limits from wide binaries (WB), star clusters in Eridanus II (E), halo dynamical friction (DF), galaxy tidal distortions (G), heating of stars in the Galactic disk (DH) and the CMB dipole (CMB). Large scale structure constraints(LSS). Accretion limits from X-ray binaries (XB) and Planck measurements of CMB distortions (PA). The incredulity limits (IL) correspond to one PBH per relevant environment (galaxy, cluster, Universe). There are four mass windows (A, B, C, D) in which PBHs could have an appreciable density.

Black Dark Matter

Carr, 2019: all limits are model dependent and have caveats.

Eliminating the LIGO bounds on primordial black hole dark matter,
C. Boehm, et al arXiv:2008.10743 .... reopens the possibility for dark matter in the form of LIGO-mass PBHs.
C. Corianò, P.H. Frampton, arXiv:2012.13821 [astro-ph.GA]
Does CMB Distortion Disfavour Intermediate Mass Dark Matter?
The most questionable step in this chain of arguments is the use of overly simplified accretion models. We compare how the same accretion models apply to X-ray observations from supermassive black holes SMBHs, M87 and Sgr A^*. The comparison of these two SMBHs with **intermediate mass MACHOs suggests that the latter could, after all, provide a significant constituent of all the dark matter.**

BH clustering and DM

As is argued by S.G. Rubin, A.S. Sakharov, M.Y. Khlopov, in "The Formation of Primary Galactic Nuclei during Phase Transitions in the Early Universe", Soviet Journal of Experimental and Theoretical Physics. 2001, V. 92, no. 6. 921. arXiv:hep-ph/0106187 PBHs can be formed in clusters. Dynamical interactions in PBH clusters offers additional channel for the orbital energy dissipation thus increasing the merging rate of PBH binaries, and the constraints on f_{PBH} obtained by assuming a homogeneous PBH space distribution can be weaker. A recent analysis by Y. Eroshenko, V. Stasenko, "Gravitational waves from the merger of two primordial black hole clusters" arXiv:2302.05167 based on the PBH formation model M. Sasaki et al "Primordial Black Hole Scenario for the Gravitational-Wave Event GW150914", PRL. 2016. V. 117, no. 6. P. 061101, arXiv:1603.08338 and T. Nakamura, et al "Gravitational Waves from Coalescing Black Hole MACHO Binaries", ApJL 1997, V. 487, no. 2, P. L139, arXiv:astro-ph/9708060. shows that even $f_{PBH} = 0.1 - 1$ is not excluded. Thanks to K. Postnov for these important references.

Intermediate summary and antimatter in the Galaxy

The mechanism of AD and DKK solves the problem of the observed dense population of the universe at high redshifts by SMBH (QSO), galaxies, SN, and of a large amount of dust.

The model allows for strange stars, too fast moving, too old (older than t_U), with unusual chemical content that probably exist.

The predicted log-normal spectrum of PBH is tested and confirmed by the observations (the only one existing in the literature).

The existence of IMBH in globular clusters is supported by observations.

The crazy by-product of AD and DKK mechanism, namely prediction of antimatter in the Galaxy, positrons, antinuclej, and especially antistars, seems to come true as well.

Anti-evidence: cosmic positrons

Observation of intense 0.511 line, a proof of abundant positron population in the Galaxy. In the central region of the Galaxy electron–positron annihilation proceeds **at a surprisingly high rate,** creating the flux:

$$\Phi_{511\ \mathbf{keV}} = 1.07 \pm 0.03 \cdot 10^{-3}\ \mathbf{photons\ cm^{-2}\ s^{-1}.}$$

The width of the line is about 3 keV. Emission mostly goes from the Galactic bulge and at much lower level from the disk,
"Great Annihihilator"in the Galactic bulge.
G. Weidenspointner *et al.*, Astron. Astrophys. **450**, 1013 (2006);
J. Knodlseder *et al.*, Astron. Astrophys. **441**, 513 (2005);
P. Jean *et al.*, Astron. Astrophys. **445**, 579 (2006).
Until recently the commonly accepted explanation was that e^+ are created in the strong magnetic fields of pulsars but the recent results of AMS probably exclude this mechanism, since the spectrum of $\bar{p}$ and e^+ at high energies are identical. L'Aquila Joint Astroparticle Colloquium, 10th November, 2021 by S. Ting.

Anti-evidence: cosmic antinuclei

Registration of anti-helium: **In 2018 AMS-02 announced possible observation of six $\overline{He}^3$ and two $\overline{He}^4$.**
A. Choutko, AMS-02 Collaboration, AMS Days at La Palma, La Palma, Canary Islands, Spain, (2018).
S. Ting, Latest Results from the AMS Experiment on the International Space Station. Colloquium at CERN, May, 2018.
Recent registration of more events
L'Aquila Joint Astroparticle Colloquium, 10th November by S. Ting; and COSPAR 2022, 16-24 July:
7 $\overline{D}$ ($\lesssim$ 15 GeV) and 9 $\overline{He}$, ($\sim$ 50 GeV). fraction $\overline{He}/He \sim 10^{-9}$, too high.
Secondary creation of $\overline{He}^4$ is negligibly weak.
Nevertheless Ting expressed hope to observe $\overline{Si}$!!!
It is not excluded that the flux of anti-helium is even much higher because low energy $\overline{He}$ may escape registration in AMS.

Antinuclei creation in cosmic rays

Expected secondary produced anti-nuclei:
Anti-deuterium can be created in the collisions $\bar{p}\,p$ or $\boldsymbol{\bar{p}\,He}$ (Duperray et al, 2005). which would produce the flux of $\bar{D}$ $\sim 10^{-7}/\mathrm{m}^2/\mathrm{s}^{-1}$**/steradian/GeV/neutron),**
i.e. 5 orders of magnitude below the observed flux of antiprotons.
The fluxes of $\overline{\boldsymbol{He}}^3$ and $\overline{\boldsymbol{He}}^4$, which could be created in cosmic rays are respectively 4 and 8 orders of magnitude smaller than the flux of anti-D.
After AMS announcement of observations of anti-He^4 there appeared theoretical attempts to create anti-He^4 through dark matter annihilation. Quite unnatural.

Deuterium/Helium problem

There is noticeable discrepancy between the large fraction of D with respect to He. In the case of the standard BBN this ratio should be smaller than unity, but the observed one is practically 1.
Too high ratio of anti-He^3 to anti-He^4.
It is assumed that the abundances of D and He are determined by BBN with large β (or η). However if $\beta \sim 1$ there is no primordial D. On the other hand in our scenario formation of primordial elements takes place inside non- expanding compact stellar-like objects with fixed temperature. If the temperature is sufficiently high, this so called BBN may stop before abundant He formation with almost equal abundances of D and He. One can see that looking at abundances of light elements at a function of temperature. Is it is so, antistars may have equal amount of $\overline{D}$ and $\overline{He}$!!!

Anti-evidence: antistars in the Galaxy

S. Dupourqué, L. Tibaldo and P. von Ballmoos, "Constraints on the antistar fraction in the Solar System neighbourhood from the 10-year Fermi Large Area Telescope gamma-ray source catalog",
Phys Rev D.103.083016 103 (2021) 083016
"We identify in the catalog 14 antistar candidates not associated with any objects belonging to established gamma-ray source classes and with a spectrum compatible with baryon-antibaryon annihilation."

Possible discovery of anti-stars in the Galaxy

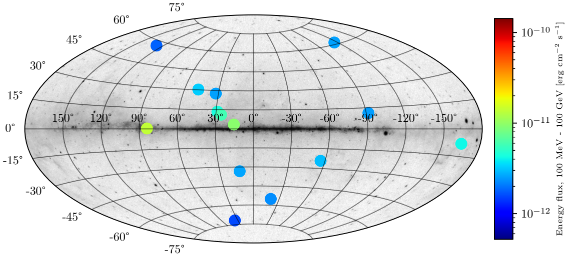


Рис.: Positions and energy flux in the 100 MeV - 100 GeV range of antistar candidates selected in 4FGL-DR2. Galactic coordinates. The background image shows the Fermi 5-year all-sky photon counts above 1 GeV

X-ray signatures of antistars

X-ray signature of antistars in the Galaxy A.E. Bondar, S.I. Blinnikov, A.M. Bykov, A.D. Dolgov, K.A. Postnov e-Print: 2109.12699 [astro-ph.HE], JCAP, Sep 26, 2021,

In astrophysically plausible cases of the interaction of neutral atmospheres or winds from antistars with ionised interstellar gas, the hadronic annihilation **will be preceded by the formation of excited $p\bar{p}$ and $He\bar{p}$ atoms.** These atoms rapidly cascade down to low levels prior to annihilation giving rise to a series of narrow lines which can be associated with the hadronic annihilation gamma-ray emission. The most significant are L (3p-2p) 1.73 keV line (yield more than 90%) from $p\bar{p}$ atoms, and M (4-3) 4.86 keV (yield $\sim$ 60%) and L (3-2) 11.13 keV (yield about 25%) lines from $He^4\bar{p}$ atoms. These lines can be probed in dedicated observations by forthcoming sensitive X-ray spectroscopic missions XRISM and Athena and in wide-field X-ray surveys like SRG/eROSITA all-sky survey.

Antistar prediction

The DS-DKK mechanism allows to solve multiple problems related to the observed BH population in the universe:

• PBHs formed according to this scenario explain the peculiar features of the sources of GWs observed by LIGO/Virgo.

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

Conventional models are short by two orders of magnitude.

SMBH and IMBH in contemporary and $z \sim 10$ universe Universe is full of supermassive black holes (SMBH), $M = (10^6 - 10^{10}) M_\odot$ and intermediate mass black holes (IMBH), $M = (10^2 - 10^5) M_\odot$.

Unexpectedly high amount in the present day and the early, $z = 5 - 15$ universe. Are they primordial?

Log-normal mass spectrum with the predicted value $M_0 \sim 10 M_\odot$ (A.D. and K. Postnov) very well describes the data. Thus the by-product of the mechanism, namely the prediction of antimatter may be true as well.

Bounds on antistars in the Galaxy

As argued in:

C. Bambi, A.D. Dolgov, **Antimatter in the Milky Way,** Nucl.Phys. B 784 (2007) 132-150 e-Print: astro-ph/0702350,

A.D. Dolgov, S.I. Blinnikov, **Stars and Black Holes from the very Early Universe,** Phys.Rev.D 89 (2014) 2, 021301 e-Print: 1309.3395,

S.I. Blinnikov, A.D. Dolgov, K.A. Postnov, **Antimatter and antistars in the universe and in the Galaxy,** Phys.Rev.D 92 (2015) 2, 023516 e-print: 1409.5736

an abundant density of compact anti-stars in the universe and even in the Galaxy does not violate existing observational limits. Surface annihilation on a compact object is much less efficient than volume annihilation, e.g. inside gas cloud of antimatter.

Anti-Creation 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, $U_m = m^2\chi^2 + m^{*\,2}\chi^{*\,2}$:

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

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.

Anti-Creation Mechanism

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}.

Anti-Creation Mechanism

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 domains might be formed with possible dominance of one of them.
Matter and antimatter objects may exist but globally $B \neq 0$.

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

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

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 diffuses to large value, according to quantum diffusion equation derived by Starobinsky, generalized to a complex field χ.

Anti-Creation Mechanism

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. The mechanism of massive PBH formation quite 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.

Initial isocurvature perturbations are in chemical content of massless quarks. Density perturbations are generated rather late after the QCD 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.

Results of (Anti-)Creation

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

- PBHs with log-normal mass spectrum - confirmed by the data!
- Compact stellar-like objects, as e.g. cores of red giants.
- Disperse hydrogen and helium clouds with (much) higher than average n_B density. Strange stars with unusual chemistry and velocity.
- **β may be negative leading to creation of (compact?) antistars which could survive annihilation with the homogeneous baryonic background.**
- Extremely old stars would exist even, "older than universe star"is found; the older age is mimicked by the unusual initial chemistry. Several such stars are observed.

Results

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The mechanism of PBH creation pretty well agrees with the data on the mass spectrum and on existence of antimatter in the Galaxy, especially of antistars. So we may expect that it indeed solves the problems created by HST and JWST.

More data are expected and coming, hopefully indicating the right way.