# Seeding of cosmic structures in contemporary and young universe

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# Crisis in cosmology at all times

Conventional ΛCDM cosmology encounters serious difficulties describing astronomical observations during **all the history** of the universe, **starting from our time with the universe age about 15 billion years, and back to the past down to $\sim 300$ million years discovered recently by HST, JWST, and ALMA at high redshifts** $z \sim 10$.

The problems known prior to HST, JWST and ALMA data are reviewed in 2018: A.Dolgov, "Massive and supermassive black holes in the contemporary and early Universe and problems in cosmology and astrophysics", Phys. Usp. 61, 115, 2018.

The tension that existed during all life-time of the universe between the canonical theory and observations is neatly solved if the universe is populated by primordial black holes (PBH) that **seeded** formation of cosmic structures, **as is suggested by A.Dolgov, J.Silk, PRD 47 (1993) 4244 (DS), "Baryon isocurvature fluctuations at small scale and baryonic dark matter"; and elaborated in A.Dolgov, M. Kawasaki, N. Kevlishvili (DKK), NPB807 (2009) 229, "Inhomogeneous baryogenesis, cosmic antimatter, and dark matter".**

# Problems of the contemporary universe. Summary.

1. Supermassive BH (SMBH) in all large galaxies. Too short time (15 billion year) for their formation through the conventional accretion mechanism.

2. Huge SMBH in small galaxies and even in (almost) EMPTY space. No material for their creation. Pushed out of large galaxies? Wandering BHs?

3. Too old stars, older than the Galaxy and maybe one **older** than the universe?

4. MACHOs, non-luminous objects, $M \sim 0.5 M_{\odot}$, observed through microlensing.

5. The BH mass spectrum in the Galaxy with ($M = 7.8 \pm 1.2) M_{\odot}$.

6. Origin and properties of the sources of the observed gravitational waves.

7. Origin of intermediate mass BH (IMBH) with masses $(10^3 - 10^5) M_{\odot}$. Plenty of them are observed everywhere in the universe, in particular in dwarfs and globular clusters, as predicted by AD & K. Postnov.

8. **Discovery of BH with $M \approx 100 M_{\odot}$, that is strictly forbidden but nevertheless observed by LIGO/Virgo.**

9. Strange stars in the Galaxy, too fast and with unusual chemistry.

# Inverted mechanism of galaxy formation

In DS and DKK an **inverted** formation mechanism of galaxies and their central black holes is proposed. Namely, a primordial SMBH was formed firstly and later it **seeded** the galaxy formation.

**Usually it is assumed that supermassive black holes (SMBHs) observed in large galaxies, are created by matter accretion to the galactic centres.**

However, the necessary time is much larger than the universe age, even for the contemporary universe, with the age about 15 billion years, to say nothing of the 20 times younger universe at $z \sim 10$.

Contradiction between observations and canonical theory is neatly solved if the universe is populated by primordial black holes (PBH) that **seeded** formation of cosmic structures, as is suggested 30 years ago: by DS and DKK.

# IMBH in tiny galaxies today

AD+K.Postnov prediction "Globular Cluster **Seeding** by Primordial Black Hole Population", JCAP 04 (2017) 036, e-Print: 1702.07621 [astro-ph.CO] is recently verified:

The observation of IMBH in Omega-Centauri (the most massive globular cluster of the Milky Way): M. Häberle, N. Neumayer, A. Seth *et al*, Nature, **631**, 285–288 (2024): $M_{IMBH} \gtrsim 8200 M_\odot$;

F. Pei$\beta$ker, M. Zajaček, M. Labaj, *et al*, "The Evaporating Massive Embedded Stellar Cluster IRS 13 Close to Sgr A*. II. Kinematic Structure".
Discovery of IMBH with $M \approx 3 \times 10^4 M_\odot$, 2024, ApJ **970** 74.

**The origin of IMBH is mysterious, if they are not primordial.**

# Huge black holes in tiny galaxies today

Primordial IMBHs with masses of a few thousand solar mass explain formation of globular clusters (GCs) and dwarf galaxies, otherwise the formation is not well understood, even mysterious.

In the last several years several such IMBH inside GSs are observed. Similar IMBHs are observed in dwarf galaxies.

A striking example: discovery by the Hobby-Eberly Telescope at Texas's McDonald Observatory of a SMBH with $M_{BH} \approx 1.7 \cdot 10^{10} M_{\odot}$ i.e. 14% of the stellar mass of the galaxy.

Usually the mass of the central BH is about 0.1 % of the galaxy mass.

# Huge BHs in dwarf galaxies today

The seeding of dwarfs by intermediate mass BHs is confirmed by the recent data, e.g. in the dwarf galaxy SDSS J1521+1404 the BH is discovered with the mass $M \sim 10^5 M_\odot$.

Two Candidates for Dual AGN in Dwarf-Dwarf Galaxy Mergers, M. Mićić, et al, arXiv:2211.04609 [astro-ph.GA]. For the first time, astronomers have spotted evidence of a pair of dwarf galaxies featuring GIANT black holes on a collision course with each other. In fact, they haven't just found just one pair – they've found two.

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 $M_{BH} = 3.6^{+5.9}_{-2.3} \times 10^5 M_\odot$, **that surely cannot be created by accretion but might seed the dwarf formation.**

# Unexpectedly light BH

"Observation of Gravitational Waves from the Coalescence of a $2.5 - 4.5 \, M_\odot$ Compact Object and a Neutron Star",
Authors: The LIGO Scientific Collaboration, the Virgo Collaboration, the KAGRA Collaboration Report-no: LIGO-P2300352, arXiv:2404.04248:
**(2.5-4.5) $M_\odot$ and (1.2-2.0) $M_\odot$**
The masses do not fit any conventional hypothesis, if they are not primordai.

# Problems of the early universe

**The 30 year old DS idea of seeding,** **but of different kind,** was rediscovered in several recent publications, under the pressure of the Hubble Space Telescope HST and the James Webb Telescope (JWST) observations of the early universe at redshifts $z = 5 - 15$.
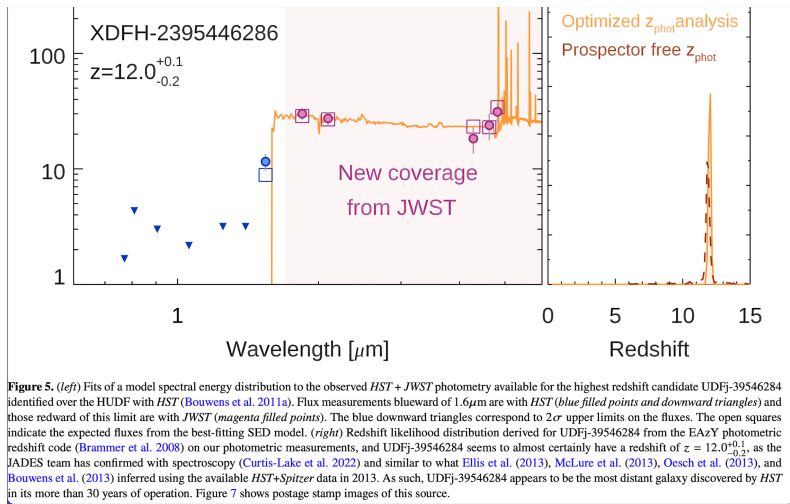
Serious problems, similar to those recently found by JWST, are known already for many years. HST discovered that the early universe, at $z = 6 - 7$ is too densely populated with quasars, alias SMBH, supernovae, gamma-bursters and it is very dusty. **No understanding how all these creature were given birth in such a short time exists in conventional cosmology.**
"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.

Huge BHs in small galaxies discovered in the early universe (as well as in the contemporary one). Such huge BHs could not be created by the accretion of matter to galactic center, since the amount of material is too small.

**All the problems are neatly solved if the universe is populated by primordial black holes (PBH) and the astrophysical large bubbles with very high baryonic density, according to DS and DKK.**

# JWST and HST common galaxy



XDFH-2395446286

$z = 12.0^{+0.1}_{-0.2}$

Optimized $z_{phot}$ analysis

Prospector free $z_{phot}$

New coverage from JWST

Wavelength [$\mu$m]

Redshift

**Figure 5.** (*left*) Fits of a model spectral energy distribution to the observed *HST + JWST* photometry available for the highest redshift candidate UDFj-39546284 identified over the HUDF with *HST* (Bouwens et al. 2011a). Flux measurements blueward of 1.6μm are with *HST* (*blue filled points and downward triangles*) and those redward of this limit are with *JWST* (*magenta filled points*). The blue downward triangles correspond to $2\sigma$ upper limits on the fluxes. The open squares indicate the expected fluxes from the best-fitting SED model. (*right*) Redshift likelihood distribution derived for UDFj-39546284 from the EAzY photometric redshift code (Brammer et al. 2008) on our photometric measurements, and UDFj-39546284 seems to almost certainly have a redshift of $z = 12.0^{+0.1}_{-0.2}$, as the JADES team has confirmed with spectroscopy (Curtis-Lake et al. 2022) and similar to what Ellis et al. (2013), McLure et al. (2013), Oesch et al. (2013), and Bouwens et al. (2013) inferred using the available *HST+Spitzer* data in 2013. As such, UDFj-39546284 appears to be the most distant galaxy discovered by *HST* in its more than 30 years of operation. Figure 7 shows postage stamp images of this source.

# JWST and the conventional ΛCDM cosmology

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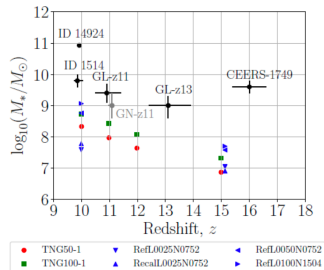


Comparison of the size of the most massive galaxies, obtained in models of formation and growth of galaxies based on LCDM (colored dots) with JWST observations (black dots with errors) depending on the redshift of the observed galaxies.
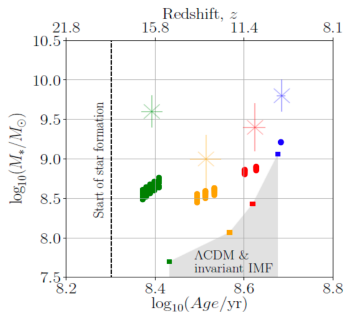


## Two orders of magnitude discrepancy.

# Impossible galaxies

I. Labbé, P. van Dokkum, E. Nelson, *et al*, "A population of red candidate massive galaxies 600 Myr after the Big Bang", Nature, 616, 7956, (2022), arXiv:2207.12446. 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, 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. NB: "May be they are supermassive black holes of the kind never seen before. That might mean a revision of usual 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)

# Ultra-massive early QSO observed by ALMA

ALMA (Atacama Large Millimeter Array) 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,

R. Endsley et al, "ALMA confirmation of an obscured hyperluminous radio-loud AGN at $z = 6.853$ associated with a dusty s tarburst in the 1.5 deg2 COSMOS field", MNRAS, 250, 4609 (2023).

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.**
**BH mass is about 1% of the stellar mass, 100 times larger than usually. Nearly impossible, but PBH could seed such monster.**

Summarising: recent observations have found a large number of supermassive black holes already in place in the first few hundred million years after Big Bang. **The channels of formation and growth of these early, massive black holes are not clear, with scenarios ranging from heavy seeds to light seeds** experiencing bursts of high accretion rate.

# Rediscovery of seeding of the galaxy by BH

Seeding was advocated also in A. Bogdan, A. Goulding, P. Natarajan, *et al*, "Evidence for heavy-seed origin of early supermassive black holes from a $z \approx 10$ X-ray quasar", Nature Astron. 8 (2024) 1, 126, 2305.15458 [astro-ph.GA] and A.D. Goulding, J.E. Greene, D. J. Setton, *et al*, "UNCOVER: The Growth of the First Massive Black Holes from JWST/NIRSpec—Spectroscopic Redshift Confirmation of an X-Ray Luminous AGN at $z = 10.1$", Astrophys. J. Lett. 955 (2023) 1, L24 • e-Print: 2308.02750 [astro-ph.GA].

It was postulated that seeds of the observed early galaxies and SMBHs could be either light BH with masses $(10 - 100)M_\odot$, or heavy ones, $M = (10^4 - 10^5)M_\odot$. According to the authors the light BHs could be remnants of the first stars and the heavy ones might be created by direct collapse of gas clouds, assuming accretion at the Edddington limit.

Observations of high-redshift quasars reveal that many supermassive black holes were in place less than 700 million years after the Big Bang.

However, the origin of the first BHs remains a mystery.

# Rediscovery of seeding of a quasar by BH

The same paper, A. Bogdan, et al Detection of an X-ray quasar in a gravitationally-lensed $z = 10.3$ galaxy suggests that early supermassive black holes originate from heavy seeds, 2305.15458 [astro-ph.GA]
The detection of an X-ray-luminous quasar powered by SMBH with the mass $\sim 4 \times 10^7 M_\odot$ in the galaxy identified by JWST at $z \approx 10.3$ is reported. This mass is comparable to the inferred stellar mass of its host galaxy, in contrast to the usual examples from the local universe where mostly the BH mass is $\sim 0.1\%$ of the host galaxy's stellar mass. The combination of such a high BH mass and large BH-to-galaxy stellar mass ratio $\sim 500$ Myrs after the Big Bang is consistent with a picture wherein **such BHs originated from heavy seeds, accreting near Eddington limit, as is stated in the previous slide.**

**Much simpler and easier if the seeds are primordial BH, suggested by DS and DKK.**

# Strong blow to the super-Eddington accretion

A dormant, overmassive black hole in the early Universe I. Juodzbalis, R. Maiolino, W.M. Baker, *et al*, 2403.03872: **Recent observations have found a large number of SMBHs already in place in the first few hundred million years after Big Bang. The channels of formation and growth of these early, massive black holes are not clear, with scenarios ranging from heavy seeds to light seeds experiencing bursts of high accretion rate.**

The detection, from the JADES survey, of broad Halpha emission in a galaxy at $z = 6.68$, which traces a black hole with mass of $\sim 4 \times 10^8 M_\odot$ and accreting at a rate of **only 0.02 times the Eddington limit. Sic!!!**

**The black hole to stellar mass ratio is 0.4, i.e. $10^3$ times above the local relation**. Huge BH in small galaxies, see more examples below.

This object is most likely the tip of the iceberg of a much larger population of dormant black holes around the epoch of reionization. Its properties are consistent with scenarios in which short bursts of **super-Eddington accretion have resulted in black hole overgrowth and massive gas expulsion from the accretion disk; in between bursts, black holes spend most of their life in a dormant(?!) state.**

# Huge black holes in tiny galaxies at high $z$

Black holes in high $z$ universe are too massive w.r.t. the expectations based on observations of BHs in contemporary large galaxies - PBHs solve the problem.

F. Pacucci, B. Nguyen, S. Carniani *et al* "JWST CEERS and JADES Active Galaxies at $z = 4 - 7$ Violate the Local $M_* - M_{BH}$ Relation at $> 3\sigma$: Implications for Low-mass Black Holes and Seeding Models", The Astrophysical Journal Letters, 957:L3 (10pp), 2023 November 1.
**Black holes are overmassive by factor 10-100 compared to their low-z counterparts in galactic hosts of the same stellar mass.**

M. Volonteri, M. Habouzit, M. Colpi. "What if young $z > 9$ JWST galaxies hosted massive black holes?" Monthly Notices of the Royal Astronomical Society, Volume 521, Issue 1, pp.241-250. Only MBHs overmassive relative to expected galaxy scaling relations, accreting at high Eddington rates, would be detectable. Their discovery would point to the presence of heavy MBH **seeds**, but care is needed to exclude the existence of lighter seeds as only overmassive MBHs.

**Possible resolution: primordial BH seeds operated too little time to create very massive galaxies as in the contemporary universe.**

# Huge Number of Early Quasars

M.J. Hayes, J.C. Tan, R.S. Ellis, *et al "Glimmers in the Cosmic Dawn: A Census of the Youngest Supermassive Black Holes by Photometric Variability",*
*The Astrophysical Journal Letters, Volume 971, Issue 1, id.L16.*

*The variability estimate of $n_{SMBH}$ at $z = (6-7) \geq 8 \times 10^{-3}$ $Mpc^{-3}$ places constraints on $d_{iso}$ to be $<< 100kpc$. It requires the halo mass threshold for SMBH formation to be $<< 3 \times 10^{10} M_{\odot}$. However, such models begin to have more severe tension by having significantly greater abundance than the $z = 0$ estimate of $n_{SMBH}$.*

*Finally, the estimate of $n_{SMBH}$ is about 100 times greater than the direct collapse prediction of Chon et al. (2016) and at least $10^4$ times greater than that of Wise et al. (2019).*

# Early Quasars in empty space

Final blow: six early quasars in empty space. Anna-Christina Eilers *et al*, *"EIGER. VI. The Correlation Function, Host Halo Mass, and Duty Cycle of Luminous Quasars at $z \gtrsim 6$", the Astrophysical Journal, Volume 974, Number 2. The data indicate that*
*(a) luminous quasars do not necessarily reside within the most overdense regions in the early Universe,*
*(b) the UV-luminous duty cycle of quasar activity at these redshifts is $f_{duty} \ll 1$. Such short quasar activity timescales challenge our understanding of early supermassive black hole growth.*

*Using the James Webb Space Telescope, astronomers have peered back 13 billion years to discover* **surprisingly lonely** *supermassive black hole-powered quasars.*
Eilers: **"Some of them seem to be sitting in the middle of nowhere**
*It's difficult to explain how these quasars could have grown so big if they appear to have nothing to feed from.*
**Contrary to previous belief, we find, on average, these quasars are not necessarily in those highest-density regions of the early universe."**
**Surely they are primordial SMBH.**

# "Experimental" confirmation of DS/DKK model

• The predicted form log-normal mass spectrum of PBH

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

and the value of $M_0$ is $\sim 10 M_\odot$, as calculated by A.Dolgov, K.Postnov, "Why the mean mass of primordial black hole distribution is close to $10 M_\odot$". JCAP 07 (2020) 063, nicely fits the data. At large chemical potential $M_0 = 17 M_\odot$.

• Moreover the striking prediction by DS and DKK mechanism of abundant population of antimatter in the galaxy by positrons, antinuclej, and antistars is confirmed by observations as well.

• Observation of record power gamma burster. Possibly: the star-antistar collision.

• The early galaxy formation observed by HST and JWST is explained if galaxies are SEEDED by BHs, as it is also rediscovered in several papers of the last years.

• Discovery of IMBH, with $M \sim (10^3 - 10^5) M_\odot$ in dwarfs and globular clusters, predicted in AD & K. Postnov. "Globular Cluster **Seeding** by Primordial Black Hole Population", JCAP 04 (2017) 036, e-Print: 1702.07621 [astro-ph.CO].

# 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 $3M_\odot$, but noticeably below $100M_\odot$. Instead we observe that the BH mass spectrum in the galaxy has maximum at $M \approx 8M_\odot$ with the width $\sim (1-2)M_\odot$. 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 origin was considered **impossible due to huge mass loss in the process of collapse.** To solve this conundrum some quite exotic formation mechanisms are specially invented.

**No problem if** $100M_\odot$ **BH is primordial.**

# BH created by accretion

**2. BH formed by accretion to 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 20 times younger universe, observed in impressive numbers by HST and JWST.

# Primordial Black Holes

**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 find itself inside its gravitational radius i.e. it became a PBH, 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).
PBHs are usually not accepted by astronomical establishment. Why?!

# PBH and inflation

**Inflation allows for early creation of very massive PBH.**
In earlier works the predicted masses of PBH were quite low.
Inflation was first applied to PBH production in DS paper: 30 years ago:
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 dark matter";
and subsequent publications by our group.
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.
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 confirmed by observations.**

# PBH Creation Mechanism by DS/DKK

Generic features of SUSY motivated baryogenesis, Affleck and Dine (AD).
SUSY predicts existence of scalars with $B \neq 0$. Such bosons may condense along
flat directions of AD field potential that generally exist in the model.
Quartic potential:

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

and 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.
AD baryogenesis could make baryon asymmetry of the universe of order
unity instead of normal $\beta = n_B / n_\gamma \sim 10^{-9}$.

# Creation Mechanism

Initially (after inflation) $\chi$ is normally away from origin and, when inflation is over, starts to evolve down to equilibrium point, $\chi = 0$, according to the equation of the Newtonian mechanics with Hubble friction:

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

Baryonic charge of $\chi$:

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

is analogous to mechanical angular momentum. Decays of $\chi$ ransferred baryonic charge to that of quarks in B-conserving process.

If $m \neq 0$, the angular momentum, B, is generated by a different direction of the quartic and quadratic valleys at low $\chi$.

If CP-odd phase $\alpha$ is small but non-vanishing, both baryonic and antibaryonic domains might be formed with possible dominance of one of them.

# Creation Mechanism

Matter and antimatter objects may exist but globally $\boldsymbol{B} \neq 0$.

Affleck-Dine field $\chi$ with CW potential coupled to inflaton $\Phi$ (AD and Silk; AD, Kawasaki, Kevlishvili):

$$\boldsymbol{U} = \boldsymbol{g}|\chi|^2 (\boldsymbol{\Phi} - \boldsymbol{\Phi}_1)^2 + \lambda |\chi|^4 \ln\left(\frac{|\chi|^2}{\sigma^2}\right)$$

$$+ \lambda_1 (\chi^4 + \boldsymbol{h.c.}) + (\boldsymbol{m}^2 \chi^2 + \boldsymbol{h.c.}).$$

Coupling to inflaton is the general renormalizable one.
When the window to the flat direction is open, near $\boldsymbol{\Phi} = \boldsymbol{\Phi}_1$, the field $\chi$ slowly diffuses to large value, according to quantum diffusion equation derived by Starobinsky, generalized to a complex field $\chi$.

# 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 $\beta$ 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 $\chi$. 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 which acquire mass after the QCD phase transition at temperatures near 100 MeV. Density perturbations are generated rather late after the QCD phase transition. **The mechanism is very much different from other conventional ones.**

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. Not massive enough bubbles could form stars with well evolved chemical content. In this way the "star older than the universe" has been created.

# 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.

# 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 $M \sim 100 M_\odot$.

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

3. Low spins of the coalescing BHs .

To form the so heavy BH, 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 $M_c$ 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.
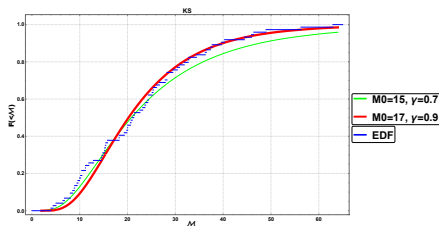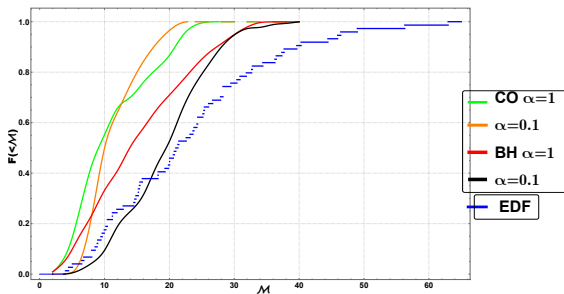


Similar value of the parameters are obtained in M. Raidal et al, JCAP.,2019. Feb. V. 2019, no. 2. P. 018. arXiv:1812.01930 and L. Liu, et al arXiv:2210.16094.
See also K. Postnov and N. Mitichkin, e-Print: 2302.06981.

# 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.

# 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 repeated by G. Chapline in 1975 who simply noticed that low mass PBHs might be abundant in the present-day universe with the density comparable to the density of dark matter.   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: DS (Mar 13, 1992), "Baryon isocurvature fluctuations at small scales and **baryonic dark matter",** 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 (model-dependent and have caveats).
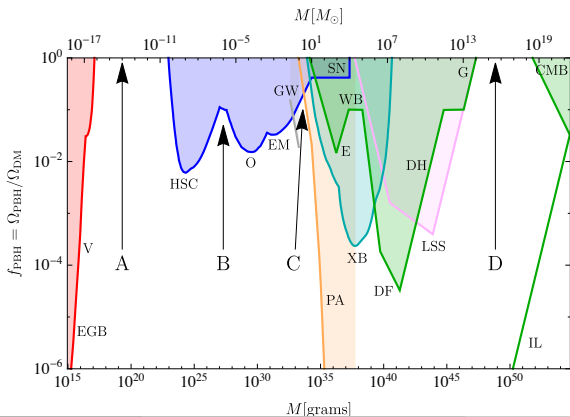
# BH clustering and DM

As is argued by S.G. Rubin, at al 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.

# BH clustering and DM

Surprisingly strong limits on BH number density in the Galaxy are presented in the paper P. Mroz, A. Udalski, M. K. Szymanski, *et al*, "No massive black holes in the Milky Way halo", Nature **632**, 749 (2024)

Based on the mirolensing analysis the authors conclude that the compact objects with masses from $1.8 \times 10^{-4} M_\odot$ to $6.3 M_\odot$ could make not more than 1% into dark matter density and those with masses in the range $1.3 \times 10^{-5} M_\odot - 860 M_\odot$ less than 10%.

The bounds are obtained for delta-function mass spectrum, while the model predicts the log-normal one. For the latter the bound are significantly weaker.

Moreover the clusterization of PBH, according to Y. Eroshenko, V. Stasenko, "Gravitational waves from the merger of two primordial black hole clusters", Symmetry 15, 637 (2023), arXiv:2302.05167 [astro-ph.CO], absolutely excludes the bound of Mroz et al.

# Intermediate summary and antimatter in the Galaxy

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

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 GCs is confirmed.

**The crazy by-product of AD and DKK mechanism, namely prediction of antimatter in the Galaxy comes true as well.**

Astronomical data of the several recent years present strong evidence in favour of noticeable antimatter population in our Galaxy including:

• Observation of gamma-rays with energy 0.511 MeV, which surely originate from electron-positron annihilation at rest.

• Very large flux of anti-helium nuclei, observed at AMS.

**• Several stars are found which produce excessive gamma-rays with energies of several hundred MeV which may be interpreted as indication that these stars consist of antimatter.**

# Antimatter history

**Search for galactic antimatter**
B.P. Konstantinov, et al Cosmic Research, 4, 66 (1968);
B.P. Konstantinov, et al Bulletin of the Academy of Sciences of the USSR.
Physical series, 33, No,11, 1820 (1969).

**Antimatter int the univerese:**
F. W. Stecker, et al Possible Evidence for the Existence of Antimatter on a
Cosmological Scale in the Universe, Phys. Rev. Letters 27, 1469 (1971);
F. W. Stecker, Grand Unification and possible matter-antimatter domain
structure in the the universe. Tenth Texas Symposium on Relativistic
Astrophysics, p. 69 (1981),

**Summary of the situation presented at 2002:**
F. W. Stecker, "The Matter-Antimatter Asymmetry of the Universe (keynote
address for XIVth Rencontres de Blois)" arXiv:hep-ph/0207323.
A.D. Dolgov, "Cosmological matter antimatter asymmetry and antimatter in the
universe", keynote lecture at 14th Rencontres de Blois on Matter - Anti-matter
Asymmetry • e-Print: hep- ph/0211260.

# Antimatter in the Galaxy

**Based on the conventional approach no antimatter object is expected to be in the Galaxy.**

However, it was predicted by DS in 1993 and elaborated by DKK in 2009 that antimatter, even antistars might be in the Galaxy and its halo.

Bounds on the density of galactic antistars are rather loose, because the annihilation proceeds only on the surface of antistars as analyzed in:

C.Bambi, A.D. Dolgov, **"Antimatter in the Milky Way",** Nucl.Phys.B 784 (2007) 132-150 • 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 • 1309.3395,

S.I.Blinnikov, A.D., K.A.Postnov, **"Antimatter and antistars in the universe and in the Galaxy",** Phys.Rev.D 92 (2015) 023516 • 1409.5736.

# 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:

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

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 S. 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.**

# 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.

It is assumed that the abundances of D and He are determined by BBN with large $\beta$ (or $\eta$). 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 $\overline{He}$!!!

# Possible discovery of anti-stars in the Galaxy

S. Dupourqué, L. Tibaldo and P. von Ballmoos, Constraints on the antistar fraction in the Solar System neighborhood 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.**

# 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.

# Antihelium and antistars

A.M. Bykov, K.A. Postnov, A.E. Bondar, S.I. Blinnikov, A.D. Dolgov, Antistars as possible sources of antihelium cosmic rays, 2304.04623.
Possible sources of antinuclei in cosmic rays from antistars which are predicted in a modified Affleck-Dine baryogenesis scenario by DS (1993) are discussed. The expected fluxes and isotopic content of antinuclei in the GeV cosmic rays produced in scenarios involving antistars are estimated. It is shown that the flux of antihelium cosmic rays reported by the AMS-02 experiment can be explained by Galactic anti-nova outbursts, thermonuclear anti-SN Ia explosions, a collection of flaring antistars, or an extragalactic source with abundances not violating existing gamma-ray and microlensing constraints on the antistar population.

# Gamma burster from star-antistar collision!?

Very powerful gamma-ray burster (GRB) was reported in M.E. Ravasio, O.S. Salafia, G. Oganesyan, *et al*, SCIENCE, 25 Jul 2024, **385**, Issue 6707, p. 452; 2303.16223 [astro-ph.HE].

This event got the nickname: the Brightest Of All Time or the bf BOAT This extremely strong GRB occurred in October 2022. A bright megaelectronvolt emission line was observed, that appeared 280 seconds after the GRB began and then rapidly faded away while shifting to lower energies.

Usually the gamma-ray spectra of GRBs consist of a smooth continuum without absorption or emission lines. The authors interpret this line as having been produced by the annihilation of electron-positron pairs within the relativistic jet produced by the GRB **possibly emerging from star-antistar annihilation !?**

Star-antistar collision, was briefly mentioned in: A.D. Dolgov arXiv:2301.01365. Plenary talk at 36th Rencontres de Physique de la Vallée d'Aoste on Results and Perspectives in Particle Physics. It may be a quasi-periodic process of a star-antistar direct contact, explosion forcing them apart, and possible, but not necessary return to each other by gravitational attraction.

# Results

- 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.

- $\beta$ **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.

**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.**

The DS/DKK model removes the tension between ΛCDM cosmology and astronomical data during all the history of the universe, it also predicts and explains the origin of the observed antimatter population of the Milky Way.