Lifting the tension of HST and JWST data with conventional cosmology by PBHs

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Crisis in cosmology

Crisis in cosmology, is it real?

Dense population of the early universe, noticeably younger than one billion years at redshifts $z \gtrsim 10$, discovered by Hubble Space Telescope (HST) and James Webb Space Telescope (JWST), was taken as a strong blow to the conventional ΛCDM cosmology.
However, the resolution of the problems by primordial black holes (PBH) was suggested **long before these problems 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 dark matter"
It was conjectured there that the galaxy formation is SEEDED by supermassive primordial black holes (PBH) and not vice versa,
inverted model of galaxy formation.
The idea is gaining increasing support in recent publications under the pressure of HST and JWST data.

"Experimental"support

• The predicted log-normal mass spectrum of PBH perfectly agrees with the data.
• Noticeable antimatter population of the Galaxy is predicted and confirmed by the observations of **positrons, antinuclei, and antistars.**
• **The early and the present day universes are overfilled with massive black holes, presumably primordial.**
• great number of SMBH binaries creating pulsar humming are observed.

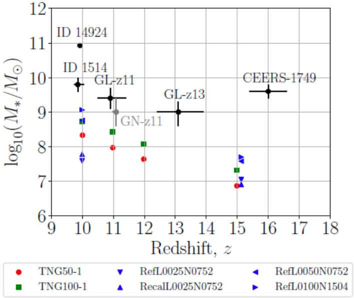
Comparison of JWST and HST

HST: Distance: 570 km
Mirror 2.4 m
Wave length: optical, e.g. blue 450 nm and UV,
some IR: 0.8-2.5 microns;

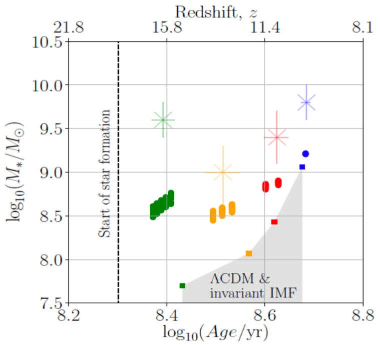
JWST: Distance 1.5×10^6 km
Mirror: 6.5 m
Wave length: 0.6 - 28,5 micron.

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.

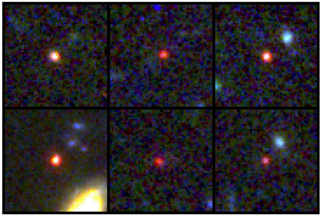


Early galaxies, spectroscopic confirmation

Only continuum in micron range was measured till February. That raised doubts on determination of the redshifts of the observed galaxies.
Now numerous spectral observations excellently confirm the early data.
S. Tacchella, et al arXiv:2302.07234 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). **A spectral energy distribution (SED) is entirely consistent with the expected form of the high-redshift galaxy.**
A.J. Bunker, *et al* arXiv:2302.07256, JADES NIRSpec Spectroscopy of GN-z11: Lyman-α emission and possible enhanced **nitrogen** abundance in a $z = 10.60$ luminous galaxy, The spectroscopy confirms that GN-z11 is a remarkable galaxy with extreme properties seen 430 Myr after the Big Bang.
T. Bakx, MNRAS, **519**, 4, pp.5076, arXiv:2208.13642,
Age of Most Distant Galaxy is confirmed with Oxygen observation.
ALMA determined the cosmic age of a distant JWST-identified galaxy, GHZ2/GLASS-z12, **at 367 million years after the Big Bang** through ionized Oxygen observation that **heralds a leap in our ability to understand the formation of the earliest galaxies in the Universe.**

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. **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)

Rich chemistry

Unexpectedly high abundances of heavy elements (high metallicity, heavier He).
B. Peng, et al, APJL **944**, 2, L36, 8. '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— large amounts of elements heavier than helium carbon, oxygen and nitrogen. The amount is comparable to the sun, which is more than 4 billion years old and inherited most of its metals from previous generations of stars that had 8 billion years to build them up.

One more example: Nitrogen enhancements 440 Myr after the Big Bang: super-solar N/O, a tidal disruption event or a dense stellar cluster in GN-z11?
A.J. Cameron, et al, arXiv:2302.10142, 20.02.2023.
Observations of GN-z11 with JWST/NIRSpec revealed numerous oxygen, carbon, nitrogen, and helium emission lines at $z = 10.6$.
The data prefers (N/O), greater than 4 times solar. The derived $C/O \approx 30$ solar.
Nitrogen enhancement in GN-z11 cannot be explained by enrichment from metal-free Population III stars.
High abundances of heavy elements may be a result of BBN inside bubbles with large baryon-to-gamma ratio, as predicted by DS&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.

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 origin was considered **impossible due to huge mass loss in the process of collapce.** Now some, quite exotic, formation mechanisms are suggested.

2. BH formed 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, 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).

Problems of the contemporary universe. Summary.

1. SMBH in all large galaxies. Too short time for their formation
2. SMBH in small galaxies and even in (almost) empty space. No material for their creation. Pushed out of large galaxies? Wandering BHs? Or PBH!
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.
3. Strange stars in the Galaxy, too fast and with unusual chemistry.
4. Too old stars, older than the Galaxy and maybe **older** than the universe?
5. MACHOs, non-luminous objects with masses $\sim 0.5 \boldsymbol{M_\odot}$ origin unknown.
6. Problems with the BH mass spectrum in the Galaxy, masses are concentrated in the narrow interval $(7.8 \pm 1.2) \boldsymbol{M_\odot}$.
7. Origin and properties of the sources of the observed gravitational waves.
8. IMBH, with $\boldsymbol{M} \sim (10^3 - 10^5) \boldsymbol{M_\odot}$, in dwarfs and globular clusters, unexpectedly discovered, despite being predicted by AD & K. Postnov.
9. Antistars in the Milky Way, maybe have not survived to the present time in large numbers.

Seeding of galaxy formation by PBH

The hypothesis by DS (1993) and DKK (2006), that SMBH seeded galaxy formation allows to understand the presence of SMBH in all large and several small galaxies accessible to observation. This mechanism explains how the galaxies observed by JWST in the very young universe might be created.
The idea is rediscovered in several recent works.

B. Liu, V. Bromm, "Accelerating early galaxy formation with primordial black holes", arXiv:2208.13178, 28 Aug 2022: Recent observations with JWST have identified several bright galaxy candidates at $z \gtrsim 10$, some of which appear unusually massive (up to $\sim 10^{11}\ \mathrm{M}_\odot$). Such early formation of massive galaxies is difficult to reconcile with standard $\Lambda\mathrm{CDM}$ predictions.
The observed massive galaxy candidates can be explained, if structure formation is accelerated by massive ($\gtrsim 10^9\ \mathrm{M}_\odot$) PBHs that enhance primordial density fluctuations.

Seeding of galaxy formation by PBH

A. Bogdan, *et al*, 2305.15458 [astro-ph.GA], Observations of high-redshift quasars reveal that many supermassive black holes were in place less than 700 Million years after the Big Bang. The detection of an X-ray-luminous quasar in a gravitationally-lensed galaxy, identified by JWST at $z \approx 10.3$, powered by SMBH with the mass $\sim 4 \times 10^7 M_\odot$ in the galaxy is reported.
(See also A.D. Goulding, et al, arXiv:2308.02750).
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 ~ 500 Myrs after the Big Bang is consistent with a picture wherein **such BHs originated from heavy seeds.**
However, the origin of the first BHs remains a mystery.
Seeds of the first BHs are postulated that could be either light i.e., $(10-100)M_\odot$ remnants of the first stars or heavy i.e., $(10^4-10^5)M_\odot$, originating from direct collapse of gas clouds, according to the authors. Questionable!

Much simpler and easier if the seeds are primordial BH, as predicted by DS and DKK.

Remnants of the early universe today

Primordial stars in the Galaxy

Jiaqi Martin Ying, *et al*, The Absolute Age of M92, Ap.J. 166 (2023) 1, 18, e-Print: 2306.02180 [astro-ph.SR]

Absolute age of the globular cluster M92 is evaluated and found to be practically equal to the universe age, $t_{M92} = 13.8 \pm 0.75$ Gyr.

Pristine stars in the Galaxy

An international team of researchers, Pristine Inner Galaxy Survey (PIGS) team, has obtained the largest set of detailed observations yet of the oldest stars in the center of our Galaxy, the Milky Way. Some of the stars that were born in the first billion years after the Big Bang are still around today, A. Arentsen, the University of Cambridge presented at the National Astronomy Meeting 2023 at the University of Cardiff.

BHs in dwarf galaxies and globular clusters

Primordial IMBHs with masses of a few thousand solar mass explain formation of globular clusters (GCs), otherwise mysterious.
In the last several years several such IMBH inside GSs are observed. Similar features are predicted for dwarf galaxies: A. Dolgov, K. Postnov, "Globular Cluster **Seeding** by Primordial Black Hole Population JCAP 04 (2017) 036, e-Print: 1702.07621 [astro-ph.CO].

- The seeding of dwarfs by intermediate mass BHs might be possibly confirmed by the recent data, 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. 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, 2302.06214 Discovery of an intermediate-mass black hole (IMBH) with $M_{BH} = 3.6^{+5.9}_{-2.3} \times 10^5 M_\odot$, **that surely cannot be created by accretion but, other way around, might seed the dwarf formation.**

Intermediate summary

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 suggested by DS and DKK.
The proposed mechanism is the first one 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" with very 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} could be smaller and M_{hor} would be larger.
The origin of IMBH is unknown, though a large lot of them are observed .
Moreover, BH with $\mathrm{M} \approx 100\mathrm{M}_\odot$ is strictly forbidden but nevertheless observed by LIGO/Virgo. Is it primordial?

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.

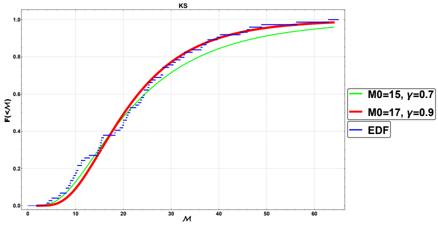
The available data on the chirp mass distribution of the black holes in the coalescing binaries in O1-O3 LIGO/Virgo runs are analyzed and compared with theoretical expectations based on the hypothesis that these black holes are primordial with log-normal mass spectrum.

The inferred best-fit mass spectrum parameters, $M_0 = 17M_\odot$ 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

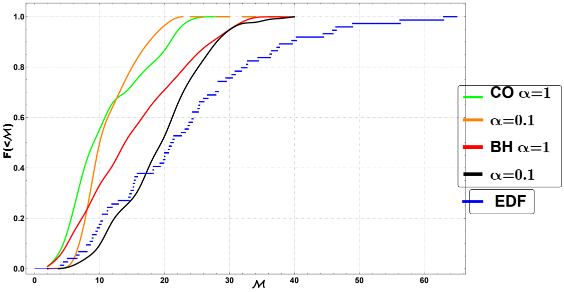
Model distribution $F_{PBH}(< M)$ with parameters $M_0 \approx 17 M_\odot$ and $\gamma \sim 1$ for two best Kolmogorov-Smirnov tests. EDF= empirical distribution function.



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.

PBH and inflation

In earlier works the predicted masses of PBH were quite low.

Inflation allows for formation of PBH with very large masses.

It was first applied to PBH production in DS paper,

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.

An avalanche of papers on inflationary formation of PBH nowadays.

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.

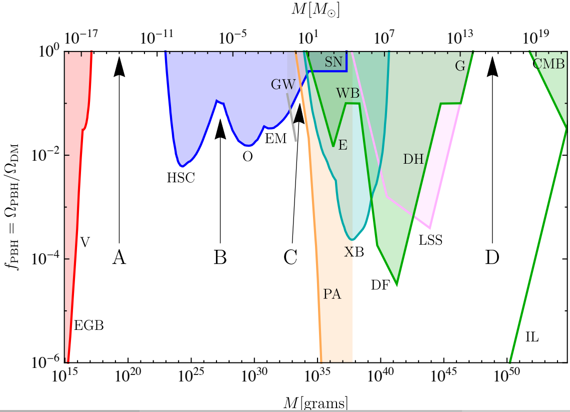
Black Dark Matter (BDM)

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: 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.**

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).



Black Dark Matter

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

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.

Pulsar humming

If a pulsar moves in any way, such as orbiting a star, the relative motion of the pulsar causes the pulses to shift slightly. These shifts can be measured with high accuracy. The observations are so precise, pulsars were used to measure the orbital decay of binary systems as indirect evidence of gravitational waves long before they are observed directly.

Unexpectedly high number of SMBH binaries are presumably observed through distortion of the pulsar timing by emission of gravitational waves.
G. Agazie et al, The NANOGrav 15 yr Data Set: Constraints on Supermassive Black Hole Binaries from the Gravitational- wave Background, The Astrophysical Journal Letters (2023). DOI: 10.3847/2041-8213/ace18b The NANOGrav 15 yr data set shows evidence for the presence of a low-frequency gravitational-wave background. The signal is analyzed as coming from a population of supermassive black hole (SMBH) binaries distributed throughout the Universe.
Such binaries are naturally expected if these SMBHs are primordial.

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).

Strongly criticised by Ya.B. Zeldovich, despite very friendly relations.

Antimatter in the universe:

F. W. Stecker, D. L. Morgan, Jr., J. Bredekamp, 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 history

Paul A.M. Dirac: "Theory of electrons and positrons", Nobel Lecture, December 12, 1933: "It is quite possible that... these stars being built up mainly of positrons and negative protons. In fact, there may be half the stars of each kind. The two kinds of stars would both show exactly the same spectra, and there would be no way of distinguishing them by present astronomical methods."

It seems that now we know ways to distinguish stars from an antistars by observations from the Earth. A.D. Dolgov, V.A. Novikov, M.I. Vysotsky, "How to see an antistar" JETP Lett. 98 (2013) 519, e-Print: 1309.2746

The spectra are not exactly the same, even if CPT is unbroken and the polarisation of radiation form weak decays could be a good indicator or the type of emitted neutrinos/antineutrinos from supernovae.

Antimatter in the Galaxy

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

However, it was predicted in 1993 and elaborated in 2009 that noticeable amount of antimatter, even antistars might be in the Galaxy and in its halo:

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

A.Dolgov, M. Kawasaki, N. Kevlishvili, Nucl.Phys. B807 (2009) 229, "Inhomogeneous baryogenesis, **cosmic antimatter,** and dark matter".

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:

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

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 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

Normal BBN gives 25% of ^4He and $\sim (10^{-5} - 10^{-4})$ of deuterium and about the same fraction of ^3He.

There is noticeable discrepancy of these results with the large observed fraction of $\overline{D}$ with respect to $\overline{He}$, and, what's more, with the observed $\overline{He^3} > \overline{He^4}$

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 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.

Possible discovery of anti-stars in the Galaxy

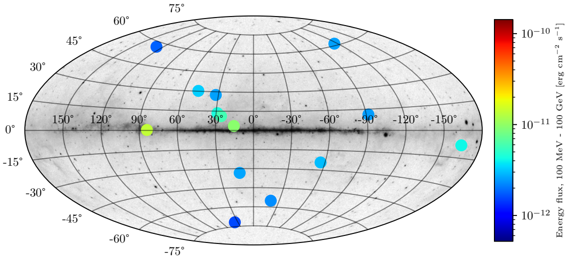


Рис.: Positions and energy flux in the 100 MeV - 100 GeV range of antistar candidates selected in 4FGL-DR2. Galactic coordinates. The background image shows the Fermi 5-year all-sky photon counts above 1 GeV

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.

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, JCAP08(2023), 2304.04623 [astro-ph.HE]

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.

PBH 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:

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

and of the mass term, $U_m = m^2\chi^2 + m^{*\,2}\chi^{*\,2}$:

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

where $\chi = |\chi| \exp\left(i\theta\right)$ 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.

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}.

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 interaction of two scalars.
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.

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 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 mechanism is very much different from other conventionl 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.

Results

- PBHs with log-normal mass spectrum - confirmed by the data!
- Compact stellar-like objects, similar to 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.

The mechanism of PBH creation pretty well agrees with the data on the BH 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.

PBHs save life of the canonical ΛCDM cosmology

Antimatter in the Milky Way is predicted and found