Puzzles of objects created very early in the Universe

or

Stars older than the universe

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General trend: many objects in the universe were formed much earlier than expected by theory.

Among them:

stars in the Milky Way, older than the Galaxy and even older than the universe (within two sigma);

distant high redshift ($z \sim 10$) staff: galaxies, QSO/supermassive BHs, and gamma-bursters.

If no explanation is found in the frameworks of the standard cosmology, there are a few possible ways (maybe more):

1. Faster universe expansion earlier, (AD, V.Halenka, I.Tkachev) "Power-law cosmology and SN Ia" (in progress).

2. A novel mechanism of formation of stellar-mass object in very early universe, (AD, S.Blinnikov) "Stars and Black Holes from the very Early Universe", Phys.Rev. D89 (2014) 021301.

D. Spolyar, K. Freese, P. Gondolo. Dark Matter and the First Stars: A New Phase of Stellar Evolution. PRL, 100(5), 051101.

K.Freese,T. Rindler-Daller, D. Spolyar, Dark Stars: A Review. arXiv:1501.02394. Explains chemistry, origin of PBH.

Universe age as a function of redshift:

$$t(z) = \frac{1}{H}\int_0^{\frac{1}{z+1}} \frac{dx}{\sqrt{1-\Omega_{tot}+\frac{\Omega_m}{x}+x^2\Omega_v}},$$

Parameters:

$\Omega_{tot} = 1$, $\Omega_m = 0.317$, $\Omega_v = 0.683$;

$H = 67.3$ **km/sec/Mpc (Planck);**

$H = 74$ **km/sec/Mpc (direct).**

Origin of the tension?

Universe age (in Gyr):

$t_U \equiv t(0) = 13.8;\ 12.5.$

$t(12) = 0.37;\ 0.33;\quad t(10) = 0.47;\ 0.43$

$t(6.3) = 0.87;\ 0.79;\quad t(3) = 2.14;\ 1.94.$

Stars in the Milky Way:

Employing thorium and uranium in comparison with each other and with several stable elements the age of metal-poor, halo star BD+17^o 3248 was estimated as 13.8 ± 4 Gyr.
J.J. Cowan, C. Sneden, S. Burles, *et al* **Ap.J. 572 (2002) 861, astro-ph/0202429.**

The age of inner halo of the Galaxy 11.4 ± 0.7 Gyr, J. Kalirai, "The Age of the Milky Way Inner Halo" Nature 486 (2012) 90, arXiv:1205.6802.

The age of a star in the galactic halo, HE 1523-0901, was estimated to be about 13.2 Gyr. First time many different chronometers, such as the U/Th, U/Ir, Th/Eu and Th/Os ratios to measure the star age have been employed.

"Discovery of HE 1523-0901: A Strongly r-Process Enhanced Metal-Poor Star with Detected Uranium", A. Frebe, N. Christlieb, J.E. Norris, C. Thom Astrophys.J. 660 (2007) L117; astro-ph/0703414.

Metal deficient high velocity subgiant in the solar neighborhood HD 140283 has the age 14.46 ± 0.31 Gyr.
H. E. Bond, E. P. Nelan, D. A. VandenBerg, G. H. Schaefer, D. Harmer, Astrophys. J. Lett. 765, L12 (2013), arXiv:1302.3180.
The central value exceeds the universe age by two standard deviations,
if $H = 67.3$ and $t_U = 13.8$;
if $H = 74$, then $t_U = 12.5$.

High redshift distant objects.

Galaxies observed at high redshifts, with natural gravitational lens "telescopes". There is a galaxy at $z \approx 9.6$ which was formed when the universe was approximately 0.5 Gyr old (W. Zheng, M. Postman, A. Zitrin, *et al*, "A highly magnified candidate for a young galaxy seen when the Universe was 500 Myrs old" arXiv:1204.2305).

Moreover a galaxy at $z \approx 11$ has been observed which was formed eariler than the universe age was 0.41 Gyr (or even shorter with larger H).
D. Coe, A. Zitrin, M. Carrasco, *et al* **"CLASH: Three Strongly Lensed Images of a Candidate $z \sim 11$ Galaxy", Astrophys. J. 762 (2013) 32; e-Print: arXiv:1211.3663.**

Another example of early formed objects are quasars observed at high z. A quasar with maximum $z = 7.085$ has been observed i.e. it was formed at $t < 0.75$ Gyr. Its luminosity is $6.3 \cdot 10^{13} L_\odot$ and mass $2 \cdot 10^9 M_\odot$.

Daniel J. Mortlock, *et al*, " A luminous quasar at a redshift of z = 7.085" Nature 474 (2011) 616, arXiv:1106.6088

The quasars are supposed to be supermassive black holes (BH) and their formation in such short time looks problematic by conventional mechanisms.

"rapid emergence of high-z galaxies may actually be in conflict with current understanding of how they came to be. This problem is very reminiscent of the better known (and probably related) premature appearance of supermassive black holes at $z \sim 6$. It is difficult to understand how $10^9 M_\odot$ black holes appeared so quickly after the big bang without invoking non-standard accretion physics and the formation of massive seeds, both of which are not seen in the local Universe."
F. Melia, "The Premature Formation of High Redshift Galaxies", 1403.0908.

Very recently: "An ultraluminous quasar with a twelve billion solar mass black hole at redshift 6.30". Xue-BingWu et al, Nature 518, 512 (2015)
About 40 quasars with $z > 6$ are known, each quasar containing BH with $M \sim 10^9 M_\odot$. Such black holes, when the Universe was less than one billion years old, present substantial challenges to theories of the formation and growth of black holes and the coevolution of black holes and galaxies.
Now we have $10^{10}\mathrm{M}_\odot$!!!

THE MOST LUMINOUS GALAXIES DISCOVERED BY WISE,
Chao-Wei Tsai, P.R.M. Eisenhardt et al, arXiv:1410.1751, 8 Apr 2015.
$L = 3 \cdot 10^{14} L_{\odot}$; **age** $\sim$ **1.3 Gyr.**
The galactic seeds, or embryonic black holes, might be bigger than thought possible. P. Eisenhardt: "How do you get an elephant? One way is start with a baby elephant." The BH was already billions of $M_{\odot}$ **, when our universe was only a tenth of its present age of 13.8 billion years.**

”Quasar quartet embedded in giant nebula reveals rare massive structure in distant universe”, J.F. Hennawi et al, Science 15 May 2015, 348 p. 779, discovered in a survey for Lyman- emission at redshift $z \approx 2$.

Quasars are rare objects separated by cosmological distances, so the chance of finding a quadruple quasar is $\sim 10^{-7}$. It implies that the most massive structures in the distant universe have a tremendous supply ($\sim 10^{11} M_{\odot}$) of cool dense ($n \approx 1/\mathrm{cm}^3$) gas, in conflict with current cosmological simulations.

Back to the present days: it seems that every large galaxy and some smaller ones contain a central supermassive BH whose masses are larger than $10^9 M_\odot$ in giant elliptical and compact lenticular galaxies and $\sim 10^6 M_\odot$ in spiral galaxies like Milky Way.

The mass of BH is typically 0.1% of the mass of the stellar bulge of galaxy but some galaxies may have huge BH: e.g. NGC 1277 has the central BH of $1.7 \times 10^{10} M_\odot$, or 60% of its bulge mass. This fact creates serious problems for the standard scenario of formation of central supermassive BHs by accretion of matter in the central part of a galaxy. An inverted picture looks more plausible, when first a supermassive black hole was formed and attracted matter serving as seed for subsequent galaxy formation.

Bosch et al, Nature 491 (2012) 729.

More examples: F. Khan, K. Holley-Bockelmann, P. Berczik arXiv:1405.6425. Although supermassive black holes correlate well with their host galaxies, there is an emerging view that outliers exist. Henize 2-10, NGC 4889, and NGC1277 are examples of SMBHs at least an order of magnitude more massive than their host galaxy suggests. The dynamical effects of such ultramassive central black holes is unclear.

Early SN are needed:

The medium around the observed early quasars contains considerable amount of "metals" (elements heavier than He). According to the standard picture, only elements up to ^{4}He and traces of Li, Be, B were formed in the early universe by BBN, while heavier elements were created by stellar nucleosynthesis and dispersed in the interstellar space by supernova explosions. If so, prior to QSO creation a rapid star formation should take place. These stars produced plenty of supernovae which enriched interstellar space by metals.

Observations of high redshift gamma ray bursters (GBR) also indicate a high abundance of supernova at large redshifts. The highest redshift of the observed GBR is 9.4 and there are a few more GBRs with smaller but still high redshifts. The necessary star formation rate for explanation of these early GBRs is at odds with the canonical star formation theory.

A recent discovery of an ultra-compact dwarf galaxy older than 10 Gyr, enriched with metals, and probably with a massive black in its center seems to be at odds with the standard model
J. Strader, *et al* Astrophys. J. Lett. 775, L6 (2013), arXiv:1307.7707.
The dynamical mass is $2 \times 10^8 M_\odot$ and $R \sim 24$ pc - very high density.
Chandra: variable central X-ray source with $L_X \sim 10^{38}$ erg/s, which may be an AGN associated with a massive black hole or a low-mass X-ray binary.

Model of early formation of compact stellar-like objects and heavy PBH
(AD, J.Silk, 1993;
AD, M.Kawasaki, N.Kevlishvili, 2009).
Modified Affleck-Dine scenario of baryogenesis where the general renormalizable coupling of the scalar baryon, χ, to the inflaton field, Φ, is introduced:

$$U(\chi, \Phi) = U_\chi(\chi) + U_\Phi(\Phi) + U_{\rm int}(\chi, \Phi).$$

Here $U_\Phi(\Phi)$ is the inflaton potential, $U_\chi(\chi)$ is the quartic Affleck-Dine potential, which generically has some flat directions (valleys).

Classical AD-scenario: field χ acquires a large expectation value along a flat direction, e.g. during inflation and evolves down later, when $m_\chi > H$. The potential:

$$U_\chi(\chi) = [m_\chi^2 \chi^2 + \lambda_\chi(\chi^4 + |\chi|^4] + h.c.$$

If flat directions in quadratic and quartic parts of the potential do not coincide, then at the approach to the minimum χ starts to "rotate". Rotation means that χ gets (a large) average baryonic number.

Coleman-Weinberg correction:

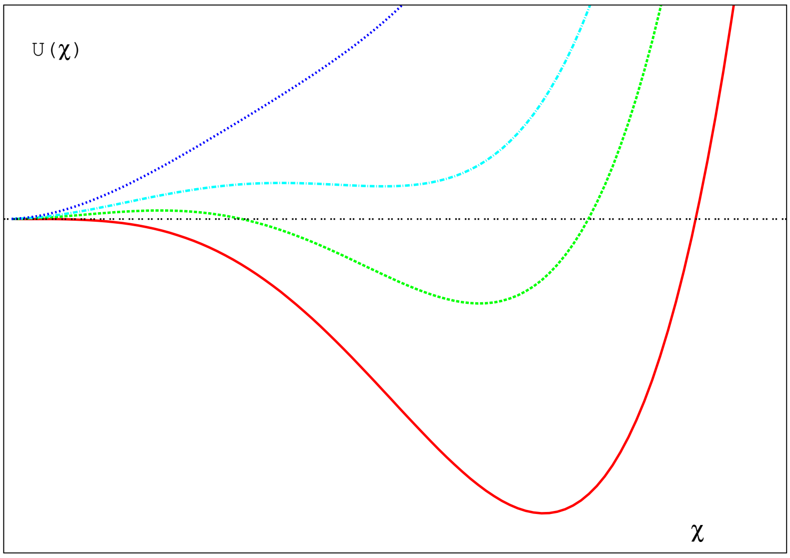
$$\delta U_{\chi}(\chi) = \lambda_2 |\chi|^4 \ln \frac{|\chi|^2}{\sigma^2}\,.$$

The additional interaction term is:

$$U_{\text{int}}(\chi, \Phi) = \lambda_1 |\chi|^2 (\Phi - \Phi_1)^2 \,,$$

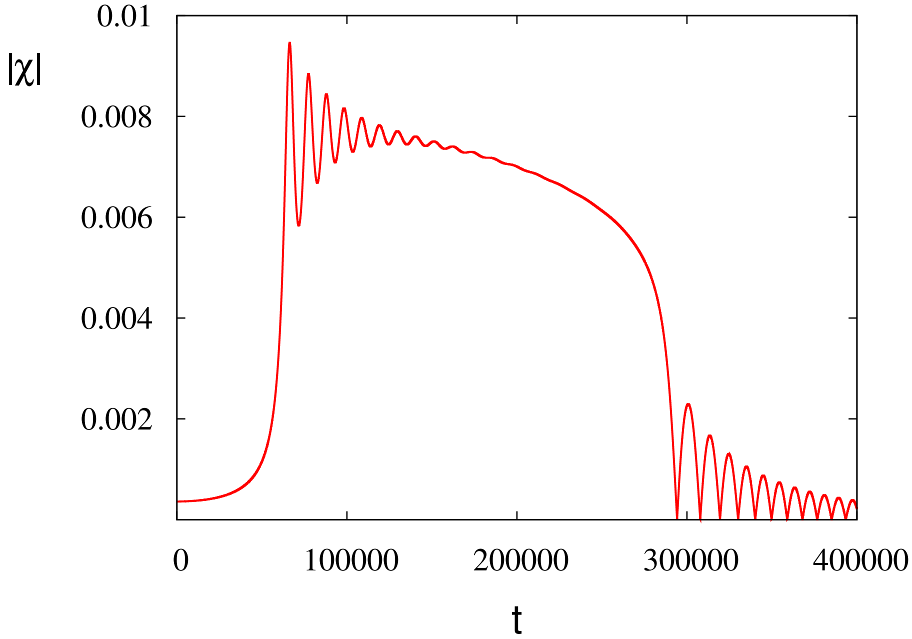
where Φ_1 is some value of the inflaton field which it passes during inflation and λ_1 is a constant.
This terms acts as a positive time-dependent mass and thus gates to the valleys are open only when Φ is near Φ_1. So there is a chance for χ to reach a high value and to create a large baryon asymmetry.

The probability for χ to reach high value is low, so in most of space baryogenesis creates normal tiny baryon asymmetry, but in some bubbles which occupy a small fraction of the whole volume, baryon asymmetry may be huge.



Behavior of $U_{\chi}(\chi)$ for different values of $m^2_{eff}(t)$.

Evolution of $|\chi|$ in time.



After the QCD phase transition, the contrast in baryonic charge density transformed into perturbations of the energy/mass density andthe bubbles with high B formed PBH's or compact stellar-like objects. The mass distribution of these high-B bubbles has practically model independent form:

$$\frac{dN}{dM} = C_M \exp\left[-\gamma \, \ln^2 \frac{(M - M_1)^2}{M_0^2}\right].$$

The values of the parameters can be adjusted in such a way that superheavy BHs formed at the tail of this distribution would be abundant enough to be present in every large galaxy and in some small ones.
Moreover such heavy PBHs could be seeds for the galaxy formation.

This mass distribution naturally explains some features of stellar mass black holes in the Galaxy. It was found that their masses are concentrated in narrow range $(7.8 \pm 1.2)M_\odot$ (1006.2834) This result agrees with another paper where a peak around $8M_\odot$, a paucity of sources with masses below $5M_\odot$, and a sharp drop-off above $10M_\odot$ are observed, arXiv:1205.1805. These features are not explained in the standard model.

A modifications of U_{int} leads to a more interesting spectrum of the early formed stellar type objects, e.g., if:

$$U_{\text{int}} = \lambda_1 |\chi|^2 (\Phi - \Phi_1)^2 (\Phi - \Phi_2)^2 ,$$

we come to a two-peak mass distribution of the PBHs and compact stars, which is probably observed, but not explained up to now.
ArXive: 1011.1459: "sample of black hole masses provides strong evidence of a gap between the maximum neutron star mass and the lower bound on black hole masses."

Evolved chemistry in the so early formed QSOs can be explained, at least to some extend, by more efficient production of metals during BBN due to much larger ratio $\beta = N_B/N_\gamma$. The standard BBN essentially stops at ^{4}He due to very small β. However, in the model considered here β is much larger than the canonical value, even being close or exceeding unity.

The model naturally predicts an existence of compact antimatter objects which could be abundant in the Galaxy.

Observations and bounds.

$\bar{p}/p \sim 10^{-5} - 10^{-4}$, observed, can be explained by secondary production;

$He/p \sim 0.1$;

Upper limit: $\bar{H}e/He < 3 \times 10^{-7}$;

Theoretical predictions: $\bar{d} \sim 10^{-5}\bar{p}$, $^3\bar{H}e \sim 10^{-9}\bar{p}$, $^4\bar{H}e \sim 10^{-13}\bar{p}$.

From the upper limit on $\bar{H}e$: the nearest single antigalaxy should be further than 10 Mpc (very crudely).

From cosmic gamma rays:

Nearest anti-galaxy could not be closer than at ∼10 Mpc (Steigman, 1976), from annihilation with p in common intergalactic cloud.
Fraction of antimatter Bullet Cluster $< 3 \times 10^{-6}$ (Steigman, 2008).

CMB excludes LARGE isocurvature fluctuations at $d > 10$ Mpc.
BBN excludes large "chemistry" fluctuations at $d > 1$ Mpc.

Review: P.v. Ballmoos, arXiv:1401.7258
Bondi accretion of interstellar gas to the surface of an antistar:

$$L_\gamma \sim 3 \cdot 10^{35} (M/M_\odot)^2 v_6^{-3}$$

put a limit $N_{\bar{*}}/N_* < 4 \cdot 10^{-5}$ inside 150 pc from the Sun.
The presented bounds are true if antimatter makes the same type objects as the OBSERVED matter. E.g., compact fast objects made of antimatter may be abundant in the Galaxy but still escape observations. (C. Bambi, AD, Nucl.Phys. B784 (2007) 132; Blinnikov, AD, Postnov, arXiv:1409.5736

CONCLUSION.

The scenario may be speculative but not too unnatural and explains a lot:

1. Superheavy BH and early quasar formation with plenty of metals around.

2. High abundance of supenovae and gamma-bursters at $z \gg 1$.

3. Existence very old stars in the Galaxy and very old galaxies.

New types of stellar-like objects from the very early universe and probably abundant cosmic antimatter are predicted. A study of astrophysics of such new kind of stars is in order.

LAST BUT NOT THE LEAST:

GREAT THANKS TO THE ORGANIZERS

OF THIS EXCELLENT CONFERENCE IN ONE OF THE MOST BEAUTIFUL TOWNS IN THE WORLD,

ESPECIALLY TO KATIE F.

THE END