Outline

1. Black holes (BH), what's that? Different types of BH.
2. How we see "invisible".
3. BH by creation mechanisms.
4. Miracles in the sky. All BH = PBH?
5. Model of 1993 which predicted miracles observed now and led to extended mass spectrum of PBH. Claim: DM=PBH, all or a part?

ЧД, что это такое.

Это тела со столь сильным полем тяжести, что из них ничего вылететь не может. Сами не светятся и свет не отражают. **Абсолютно черные.**
Так считалось ранее, о.тсюда и название.
Митчел (1784): могут быть тела, для которых вторая космическая скорость больше скорости света. Наблюдению недоступны.
"Нет, ребята, все не так. Все не так, ребята!"(В. Высоцкий)

Свечение (от) черных дыр.
Согласно предсказанию Хокинга (Hawking) чёрные дыры испаряются и светятся. Правда, этого никто пока на видел: те что могли испариться, давно испарились а те, что есть сейчас, имеют фантастически долгое время жизни.
Черные дыры обнаруживают себя электромагнитным излучением (X rays) от притягиваемого вещества (аккреции), которое разогревается до миллионов градусов.
Самые мощные точечные источники излучения во Вселенной, квазары, каждый из которых светит, как тысячи галактик, генерируются сверхмассивными черными дырами. **Сияют, пока не съедят всё вокруг.**
Сверхмассивная, уже не столь хорошо видимая, ЧД остается в пустыне, как например, черная дыра в центре нашей Галактики,

General relativity predicts black hole existence.

Four possible types of BHs are described by 4 exact solutions of the General Relativity Equations:

BH are characterized by 3 and only 3 parameters (hairs): mass M, electric charge Q, and spin a, $0 < a < 1$.
If $m_\gamma \neq 0$, whatever tiny, electric hairs are absent, Coulomb field vanishes.
Schwarzschild (1916) $Q = a = 0$:
Reissner-Nordström (1916,1918), $Q \neq 0$:
Kerr (1963) $a \neq 0$:
Kerr-Newman (1965) $Q \neq 0,\ a \neq 0$.

Наблюдение черных дыр.

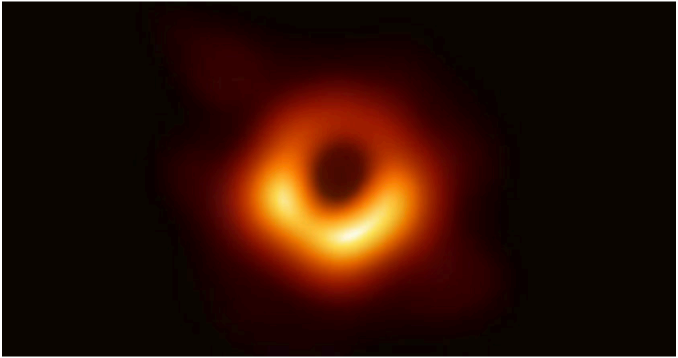
Теоретическая обработка наблюдатательных данных по аккреционному излучению. Аккреция на сверхмассивную ЧД - единственный известный способ объяснить излучение квазаров.
Оценка массы в центрах галактик по движению объектов вокруг предполагаемой ЧД, например, в центре нашей Галактики.
Гравитационное линзирование MACHO и возможных не очень массивных черных дыр, $M < M_{\odot}$.
Все эти методы являются косвенными, они позволяют определить лишь массу внутри небольшого объема. Согласно теории, ОТО, там должна быть ЧД. Но есть еще скептики (точнее были), которые в это не верят.
Сейчас получены прямые доказательства существования ЧД.

Прямые доказательства существование ЧД: грав. волны и "фото".

Регистрация гравитационных волн от слияния двойной системы ЧД.
Наилучшая подгонка к форме сигнала. прямо говорит, что сливаются именно шварцшильдовские черные дыры. Измерения позволяют определить массы обеих начальных ЧД, конечной ЧД и их спины.
Первая проверка ОТО для сильных полей и наблюдаемое доказательство существования метрики Шварцшильда!

Фотография ЧД. The Event Horizon Telescope Collaboration et al., First M87 Event Horizon Telescope Results. The Shadow of the Supermassive Black Hole. The Astrophysical Journal Letters. April 10, 2019.
BH mass $(\mathbf{6.5 \pm 0.7}) \cdot \mathbf{10^9} M_\odot$, giant elliptical galaxy M87, at 16.4 Mpc.

hole shadow.pdf



Типы черных дыр по механизму формирования

Три типа черных дыр: первичные, астрофизические и рожденные аккрецией.

1.Астрофизические ЧД.
Коллапс звезды, израсходовавшей свое ядерное горючее. Ожидаемые массы должны начинаться сразу после масс нейтронных звезд, т.е. около $3M_\odot$ и выше. Вместо этого видим, что: спектр масс ЧД в Галактике имеет максимум при $M \approx 8M_\odot$ с шириной $\sim (1-2)M_\odot$.
Результат неожиданный. Объяснение в обычной астрофизике найдены.

2. Аккреционный механизм, притяжение к массивному зародышу.
В каждой большой галактике имеется SMBH с массой в несколько миллионов масс Солнца в спиральных (Млечный Путь) и в несколько миллиардов $M_\odot$ в эллиптических и линзовидных.
Однако известные механизмы аккреции недостаточно эффективны для создания таких чудищ за время существования Вселенной, 14 гигалет.
Кроме того найдены SMBH в очень небольших галактиках и даже в почти пустом пространстве. Тут вещества для аккреции явно недостаточно.

3. Первичные черные дыры (ПЧД) могли возникнуть в ранней Вселенной в дозвездную эпоху. The canonical picture: the density excess might accidentally happen to be large $\delta\rho/\rho \sim 1$ at the cosmological horizon scale. Then this piece would be inside its gravitational radius i.e. it becomes a BH and decouples from the cosmological expansion. (Zeldovich and Novikov mechanism, elaborated later by Carr and Hawking).

Usually this mechanism is assumed to create PBH with rather low masses and with sharp almost delta-function mass spectrum.

A different mechanism (AD and J.Silk, 1993) could make PBH with masses exceeding millions solar masses and with extended mass spectrum (log-normal).

Such form of the mass spectrum and similar ones, the so called extended spectra, became quite popular nowadays.

PBH spins are normally very small, since vorticity perturbations in the early universe are negligible.

SUSY motivated baryogenesis, Affleck and Dine (AD). In our version AD baryogenesis could lead to baryon asymmetry of order of unity, much larger than the observed $\mathbf{10^{-9}}$, but only in cosmologically small but possibly astronomically large bubbles with high β occupying a small fraction of the universe volume, while the rest of the universe has normal $\beta \approx 6 \cdot 10^{-10}$. 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 at the QCD phase transition, when mass inside hotizon is close to $\mathbf{10M_\odot}$.

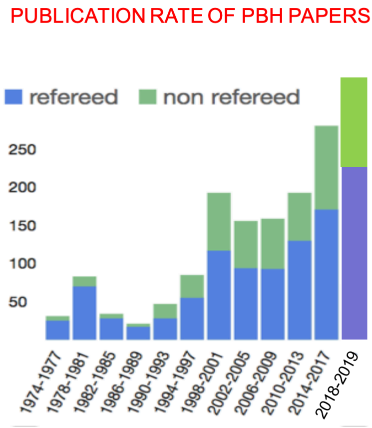
The emerging universe looks like a piece of Swiss cheese, where holes are high baryonic density objects occupying a minor fraction of the universe volume.

Log-normal mass spectrum with only 3 parameters: μ, γ, M_0:

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

where $\mathbf{M_0} \approx \mathbf{10M_\odot}$, as shown recently by A.D and K.Postnov, e-Print: 2004.11669 [astro-ph.CO], April 2020.

Publication about PBH per year from B. Carr, Kashiwa Dec. 2019



Gravitational waves from BH binaries

• Grav. waves from BH binaries, great discovery $\rightarrow$ great problems. GW discovery by LIGO has proven that the sources of GW are most probably 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 ($\sim \mathbf{30} M_\odot$); recently there appeared much more striking problem of BH with $M \sim \mathbf{100} M_\odot$
2. Formation of BH binaries from the original stellar binaries.
3. Low spins of the coalescing BHs .

1. Such BHs are believed to be created by massive star collapse, though a convincing theory is still lacking.
To form so heavy BHs, the progenitors should have $M > \mathbf{100} M_\odot$ 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.
Primordial BH with the observed by LIGO masses may be easily created with sufficient density.

2. Formation of BH binaries. Stellar binaries were formed from common interstellar gas clouds and are quite frequent in galaxies. If BH is created through stellar collapse, a small non-sphericity results in a huge velocity of the BH and the binary is destroyed. BH formation from PopIII stars and subsequent formation of BH binaries with $(36+29)M_\odot$ is analyzed and found to be negligible.

The problem of the binary formation is simply solved if the observed sources of GWs are the binaries of primordial black holes. They were at rest in the comoving volume, when inside horizon they are gravitationally attracted and and may loose energy due to dynamical friction in the early universe. The probability to become gravitationally bound is not small

Gravitational waves from BH binaries

3. The low value of the BH spins in GW150914 and in almost all (except for three) other events. It strongly constrains astrophysical BH formation from close binary systems. Astrophysical BHs are expected to have considerable angular momentum, nevertheless the dynamical formation of double massive low-spin BHs in dense stellar clusters is not excluded, though difficult. On the other hand, PBH practically do not rotate because vorticity perturbations in the early universe are vanishingly small.

However, individual PBH forming a binary initially rotating on elliptic orbit could gain COLLINEAR spins about 0.1 - 0.3, rising with the PBH masses and eccentricity (Postnov, Mitichkin, JCAP 1906 (2019) no.06, 044 arXiv:1904.00570; Postnov, Kuranov, Mitichkin, Physics-Uspekhi vol. 62, No. 11, (2019), arXiv:1907.04218) . This result is in agreement with the GW170729 LIGO event produced by the binary with masses $\mathbf{50}M_{\odot}$ and $\mathbf{30}M_{\odot}$ and and GW151216 (?). Earlier M. Mirbabayi, et al. (1901.05963) and V. De Luca et al. (1903.01179D) much weaker angular momentum gain was obtained.

To summarize: each of the mentioned problems may be solved in the conventional frameworks but it looks much simpler to assume that the LIGO sources are primordial.
Next: the observed chirp mass distribution strongly in favor of PBH.

Gravitational waves from BH binaries. Chirp mass

Two rotating gravitationally bound massive bodies are known to emit gravitational waves. If the back reaction is neglected, the radius of the orbit and the rotation frequency are 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

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

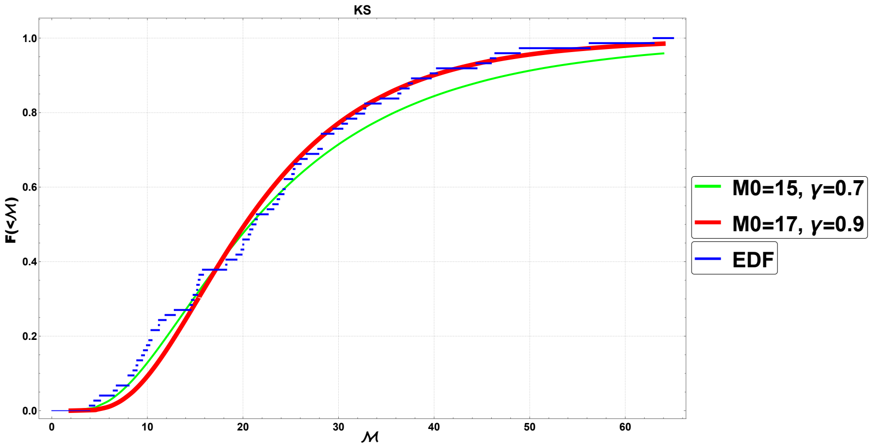
Chirp mass distribution

A.D. Dolgov, A.G. Kuranov, N.A. Mitichkin, S. Porey, K.A. Postnov, O.S. Sazhina, and I.V. Simkine On mass distribution of coalescing black holes, e-Print: 2005.00892 [astro-ph.CO], May, 2020.

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 models based on massive binary star evolution require additional adjustments to reproduce the observed chirp mass distribution.

Chirp mass distribution

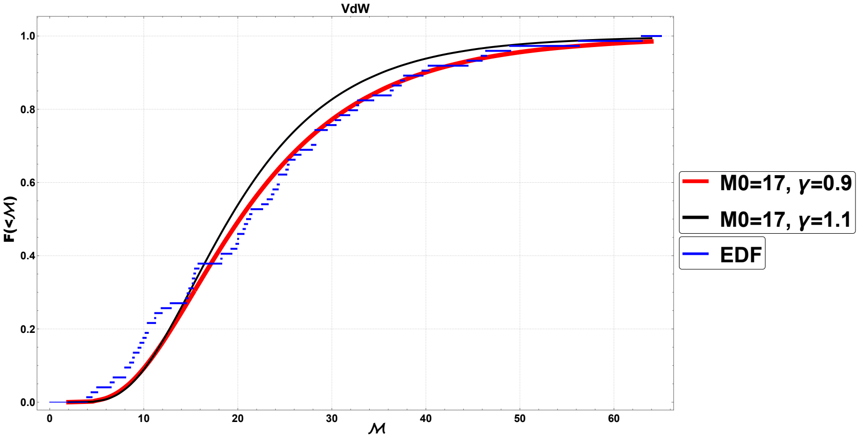
Model distribution $F_{PBH}(< M)$ with parameters M_0 and γ for two best Kolmogorov-Smirnov tests.



EDF= empirical distribution function.

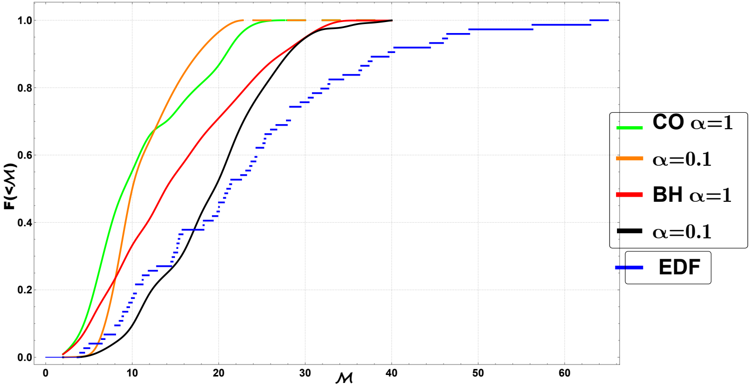
Chirp mass distribution

Model distribution $F_{PBH}(< M)$ with parameters M_0 and γ for two best Van der Waerden tests.



Chirp mass distribution

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



Bounds on PBHs-2017

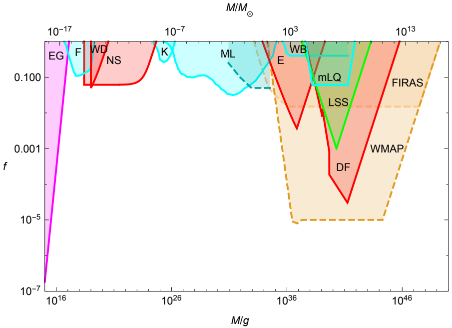


Рис.: Constraints on $f(M) = \rho_{PBH}/\rho_{DM}$ for a variety of evaporation (magenta), dynamical (red), lensing (cyan), large-scale structure (green) and accretion (orange) effects associated with PBHs; extragalactic γ-rays from evaporation (EG) femtolensing of γ-ray bursts (F), white-dwarf explosions (WD), neutron-star capture (NS), Kepler microlensing of stars (K), MACHO/EROS/OGLE microlensing of stars (ML), and quasar microlensing (broken line) (ML), survival of a star cluster in Eridanus II (E), wide-binary disruption (WB), dynamical friction on halo objects (DF), millilensing of quasars (mLQ), generation of large-scale structure through Poisson fluctuations (LSS), and accretion effects (WMAP, FIRAS), The accretion limits are shown with broken lines since they are are highly model-dependent. All bounds have caveats. [Carr et al, 2017.]

Bounds on PBHs - B.Carr, F. Kuhnel arXiv:2006.02838, June 2020

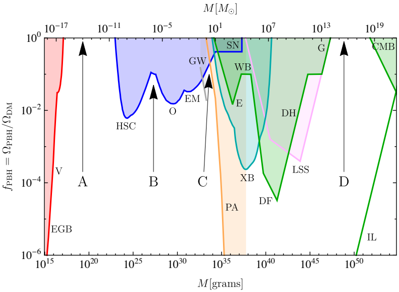


Рис.: Constraints on $f(M)$ for a **monochromatic** mass function, from evaporations (red), lensing (blue), gravitational waves (GW) (gray), dynamical effects (green), accretion (light blue), CMB distortions (orange) and large-scale structure (purple). Evaporation limits from the extragalactic gamma-ray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

ПЧД как темная материя

Review on PBH: Bernard Carr, Florian Kuhnel Primordial Black Holes as Dark Matter: Recent Developments arXiv:2006.02838 [astro-ph.CO] June, 2020

За последнее десятилетие, благодаря новым высокоточным астрономическим инструментам было сделано неожиданное открытие - во Вселенной "живет"великое множество массивных черных дыр, среди которых:
сверхмассивные черные дыры с массами в многие миллионы или даже в десять миллиардов масс Солнца (SMBH), $M \sim 10^{10} M_\odot$;
ЧД промежуточной массы (IMBH) с массами $(10^3 - 10^5) M_\odot$;
а также просто массивные черные дыры с массами в десятки $M_\odot$.
Происхождение таких ЧД неясно. В общепринятой теории их либо, вообще, не должно быть, либо они должны быть весьма редкими объектами во Вселенной. Кроме этих ЧД, обнаружен большой ряд астрофизических объектов, которых вообще не должно быть согласно нашим представлениям, в частности,

- слишком быстрые звезды в Галактике,
- очень старые звезды, одна из которых даже старше, чем Вселенная(!?),
- MACHOs = Massive Astrophysical Halo Objects - это невидимые компактные тела с массой около $0.5 M_\odot$, наблюдаемые как гравитационные микролинзы.

Обзор: АД, УФН, N^o 1000, 2018.

• MACHOs: discovered through gravitational microlensing by Macho and Eros groups. They are invisible (very weakly luminous or even non-luminous) objects with masses about a half of the solar mass in the Galactic halo, in the center of the Galaxy, and recently in the Andromeda (M31) galaxy. Their density is significantly greater than the density expected from the known low luminosity stars and the BH of similar mass.
f = mass ratio of MACHOS to DM.
Macho group: $0.08 < f < 0.50$ (95% CL) for $0.15M_\odot < M < 0.9M_\odot$;
EROS: $f < 0.2$, $0.15M_\odot < M < 0.9M_\odot$;
EROS2: $f < 0.1$, $10^{-6}M_\odot < M < M_\odot$;
AGAPE: $0.2 < f < 0.9$,
for $0.15M_\odot < M < 0.9M_\odot$;
EROS-2 and OGLE: $f < 0.1$ for $M \sim 10^{-2}M_\odot$ and
$f < 0.2$ for $\sim 0.5M_\odot$.
MACHOs surely exist but who are they is not known.

Данные противоречивы. Может быть, МАЧО образуют кластеры и их видят там где они есть?

Contemporary universe, $t_U = 14.6 \cdot 10^9$ years.

Every large galaxy contains a central supermassive BH with mass 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 origin of these BHs is not understood. Accepted belief is that these BHs are created by matter accretion to a central seed. But, the usual accretion efficiency is insufficient to create them during the Universe life-time, 14 Gyr.
Even more puzzling: SMHBs are observed in **very small galaxies** and even in almost EMPTY space, where no material to make a SMBH can be found.
Оценка темпа аккреции в современной Вселенной:. A Cool Accretion Disk around the Galactic Centre Black Hole, E.M. Murchikova, et al Nature 570, 83 (2019): Building up a supermassive black hole SgrA* with the mass $\sim 4 \times 10^6 M_\odot$ residing at the centre of our galaxy. within the $\sim 10^{10}$ year lifetime of our galaxy would require a mean accretion rate of $4 \times 10^{-4} M_\odot$ per year. At present, X-ray observations constrain the rate of hot gas accretion to $\dot{M} \sim 3 \times 10^{-6} M_\odot$ per year and polarization measurements constrain it near the event horizon to $\dot{M}_{horizon} \sim 10^{-8} M_\odot$/yr.
The universe age is short by two orders of magnitude.

Недавние открытия катастрофически усугубили кризис. Было обнаружено, что молодая Вселенная при красных смещениях порядка $z \sim 5 - 10$, т.е. будучи всего от сотни миллионов до миллиарда лет от роду, была плотно заселена яркими галактиками, квазарами, сверхновыми и ужасна пыльна. Было открыто множество (около 50) квазаров, светимость которых отвечает ЧД с массами в миллиарды масс Солнца и даже один квазар с массой в 12 миллиардов масс Солнца. Для их создания нужны тяжелые зародыши. "Чтобы получить слонов, нужны слонята."Но где же их взять?
Согласно недавним результатам, "слонята"должны быть громадными и их должно быть гораздо больше, чем мы видим (см. следующую страницу).

Оценка темпа аккреции при $\mathbf{z = 7.5}$: M.A. Latif, M Volonteri, J.H. Wise, [1801.07685] MBH accretes only about 2200 $M_\odot$ during 320 Myr.

Проблемы молодой Вселенной

Anna-Christina Eilers, *et al*, arXiv:2002.01811 [astro-ph.GA] and Aspen Colloquium June 23, "Multi-Wavelength Approach for Detecting and Characterizing Young Quasars I: Systemic Redshifts and Proximity Zones Measurements".
In a multi-wavelength survey of 13 quasars at $5.8 \leq z \leq 6.5$, we find five objects with extremely small proximity zone sizes that may imply UV-luminous lifetimes of $\leq 100,000$ years. Proximity zones are regions of enhanced transmitted flux in the vicinity of the quasars that are sensitive to the quasars' lifetimes because the intergalactic gas has a finite response time to their radiation.
Очень короткий период активности квазаров означает, что видна лишь небольшую их часть, $\mathbf{10^{-3} - 10^{-4}}$. Рождение столь большого количества квазаров во Вселенной, которая была лишь полмиллиарда лет от роду, многократно усугубляет проблему перенаселенности ранней Вселенной.
Eilers, private communication: "Primordial black holes are definitely an interesting potential solution, however, whether they can actually explain the black hole growth in very short times, depends on how massive these initial primordial black holes would be. To my knowledge, these primordial black holes are expected to be around $10^5 - 10^6$ solar masses, which is still not enough time, to grow a billion solar mass black hole in 10^6 years. The primordial black holes would need to be of the order of 10^8 to almost 10^9 solar masses in size, before accretion onto them starts happening."

Проблемы молодой Вселенной

Ранняя Вселенная, $\mathbf{z = 5 - 10}$ переобогащена гигантскими яркими галактиками.
Early galaxies (a few examples, many more are known):
Galaxy at $z \approx \mathbf{9.6}$ created earlier than $\sim \mathbf{0.5}$ Gyr, W. Zheng, *et al*
Galaxy at $z \approx \mathbf{11}$ formed earlier than the universe age was $t_U \sim \mathbf{0.4}$ Gyr, D. Coe *et al* Astrophys. J. 762 (2013) 32.
Not so young but extremely luminous galaxy Chao-Wei Tsai, P.R.M. Eisenhardt *et al*, arXiv:1410.1751, $L = 3 \cdot 10^{14} L_\odot$; $t_U \sim \mathbf{1.3}$ Gyr.
The galactic seeds, or embryonic black holes, might be bigger than thought possible. The BH was already billions of $M_\odot$, when our universe was only a tenth of its present age.
"Another way to grow this big is to have gone on a sustained binge, consuming food faster than typically thought possible. Low spin is needed!
According to D. Waters, et al, MNRAS 461 (2016), L51 density of galaxies at $z \approx \mathbf{11}$ is $\mathbf{10^{-6}}$ Mpc^{-3}, an order of magnitude higher than estimated from the data at lower z.
Origin of these galaxies is unclear. Inverted picture of galaxy formation can solve the problem: primordial SMBHs seeded galaxies but vice versa, and not only in young universe but also today.

Globular clusters and dwarf galaxies

Only one or two massive BH are observed in Globular clusters.
Definite evidence of BH with $M \approx 2000 M_\odot$ was found in the core of the globular cluster 47 Tucanae.
Origin in standard model is unknown.

Our prediction (AD, K.Postnov): if the parameters of the mass distribution of PBHs are chosen to fit the LIGO data and the density of SMBH, then the number of PBH with masses $(2-3) \times 10^3 M_\odot$ is about $10^4 - 10^5$ per one SMPBH with mass $> 10^4 M_\odot$. This allows all large galaxies to host their own SMBH, sometimes even two!.
This predicted density of IMBHs is sufficient to seed the formation of all globular clusters and dwarf galaxies.

PBH creation mechanism

The mechanism of massive PBH formation with wide mass spectrum:

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

Heretic predictions of 1993 are turning into the accepted faith, since they became supported by the recent astronomical data.
Massive PBHs allow to cure emerging inconsistencies of the standard cosmology and astrophysics with unexpectedly huge number of newly discovered massive BH
Dark matter made out of PBHs became a viable option.
Unusual stellar type compact objects could also be created.
The mechanism leads to Swiss cheese universe "upside down": small bubbles with high $\beta \equiv N_B/N_\gamma \sim 1$ and the under-dense low B background mostly turned into PBH and compact stellar-like objects.

The model predicts an abundant formation of heavy PBHs with log-normal mass spectrum:

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

with 3 constant parameters: μ, γ, M_0. The value of M_0 should be about $\mathbf{10 M_\odot}$.
Can be generalized to multi-maximum spectrum.
For high BH masses, $M_{BH} \gtrsim 10^4 M_\odot$ may be noticeably distorted due to subsequent accretion.
This form is a result result of quantum diffusion of baryonic scalar field during inflation (Starobinsky diffusion equation). Probably log-normal spectrum is a general consequence of diffusion.
Now in many works such spectrum is postulated without justification.

SUSY motivated baryogenesis, Affleck and Dine (AD).
SUSY predicts existence of scalars with $\mathbf{B \neq 0}$. Such bosons may condense along flat directions of the quartic potential:

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

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

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

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.

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}.

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 domains may exist but globally $B \neq 0$.
New input: Affleck-Dine field χ with coupling to inflaton Φ

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

An interaction between two scalar fields is Φ and χ must exist. This coupling is a general renormalizable one. The only mild tuning is that Φ reached and passed Φ_1 during inflation. Duration of inflation after that is a free parameter.
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.

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. Phase transition of 3/2 order.
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 variation of the asymmetry in number densities of massless quarks and antiquarks. Density perturbations are generated rather late after the QCD phase transition when quarks turn into massive baryons.

The emerging universe may be full of black holes occupying a minor fraction of the universe volume, where the total amount of baryons may be larger than that in the rest of the world.

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

- PBHs with log-normal mass spectrum.
- Compact stellar-like objects, similar e.g. to cores of red giants.
- Disperse hydrogen and helium clouds with (much) higher than average n_B density.
- β may be negative leading to compact antistars which could survive annihilation with the homogeneous baryonic background.

A modification of inflaton interaction with scalar baryons as e.g.

$$U \sim |\chi|^2(\Phi - \Phi_1)^2((\Phi - \Phi_2)^2$$

gives rise to a superposition of two log-normal spectra or multi-log.

Recently a torrent of new abundant BHs, has been observed presumably primordial. In any single case an alternative interpretation might be possible but the overall picture is very much in favor of massive PRIMORDIAL BHs.

SUMMARY

• 1. Natural baryogenesis model leads to abundant formation of PBHs and compact stellar-like objects in the early universe after QCD phase transition, $t \gtrsim 10^{-5}$ sec.

• 2. Log-normal mass spectrum of these objects.

• 3. PBHs formed at this scenario can explain the peculiar features of the sources of GWs observed by LIGO.

• 4. The considered mechanism solves the numerous mysteries of $z \sim 10$ universe: abundant population of supermassive black holes, early created gamma-bursters and supernovae, early bright galaxies, and evolved chemistry including dust.

• 5. There is persuasive data in favor of the inverted picture of galaxy formation, when first a supermassive BH seeds are formed and later they accrete matter forming galaxies.

• 6. An existence of supermassive black holes observed in all large and some small galaxies and even in almost empty environment is naturally explained.
• 7. "Older than t_U"stars may exist; the older age is mimicked by the unusual initial chemistry.
• 8. Existence of high density invisible "stars"(machos) may be possibly understood (?).
• 9. Explanation of origin of BHs with 2000 $M_\odot$ in the core of globular cluster and the observed density of GCs is presented.
• 10. A large number of the recently observed IMBH was predicted.
• 11. A large fraction of dark matter or 100% can be made of PBHs.
• 12. Clouds of matter with high baryon-to-photon ratio.
• 13. A possible by-product: plenty of (compact) anti-stars, even in the Galaxy, not yet excluded by observations (C. Bambi, S. Blinnikov, AD., K.Postnov).

- Black holes in the universe are mostly primordial (PBH).
- Primordial BHs make all or dominant part of dark matter (DM).
- QSO created much earlier than $z = 10$.
- Metals and dust are made much earlier than at $z = 10$.
- Inverted picture of galaxy formation: seeding of galaxies by SMPBH
- Seeding of globular clusters by $10^3 - 10^4$ BHs, dwarfs by $10^4 - 10^5$ BH.

Конец доклада, но не конец истории

Data about young universe, $z \sim 10$.

The data collected during last several years indicate that the young universe at $z \sim 10$ is grossly overpopulated with unexpectedly high amount of:

- Bright QSOs, alias supermassive BHs, up to $M \sim 10^{10} M_{\odot}$,
- Superluminous young galaxies,
- Supernovae, gamma-bursters,
- Dust and heavy elements.

These facts are in good agreement with the predictions mentioned above, but in tension with the Standard Cosmological Model.

To conclude on QSO or SMBH:
The quasars are supposed to be supermassive black holes and their formation in such short time by conventional mechanisms looks problematic. 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. Even the origin of SMBH in contemporary universe during 14 Gyr is difficult to explain.
It is difficult to understand how $10^9 M_\odot$ black holes (to say nothing about $\mathbf{10^{10} M_\odot}$) 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.

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 by BBN, while heavier elements were created by stellar nucleosynthesis and dispersed in the interstellar space by supernova explosions. Hence, an evident but not necessarily true conclusion was that prior to or simultaneously with the QSO formation a rapid star formation should take place. These stars should evolve to a large number of supernovae enriching interstellar space by metals through their explosions.
Demands very long time.
Another possibility is a non-standard BBN in bubbles with very high baryonic density, leading to formation of heavy elements.

The universe at $z > 6$ is quite dusty, D.L. Clements et al "Dusty Galaxies at the Highest Redshifts 1505.01841.
The highest redshift such object, HFLS3, lies at z=6.34 and numerous other sources have been found.

L. Mattsson, "The sudden appearance of dust in the early Universe 1505.04758:
Dusty galaxies show up at redshifts corresponding to a Universe which is only about 500 Myr old.
Abundant dust is observed in several early galaxies, e.g. in HFLS3 at $z = 6.34$ and in A1689-zD1 at $z = 7.55$.

Catalogue of the observed dusty sources indicates that their number is an order of magnitude larger than predicted by the canonical theory.

Young universe: chemistry, dust, supernovae, γ-bursters

To make dust a long succession of processes is necessary: first, supernovae explode to deliver heavy elements into space (metals), then metals cool and form molecules, and lastly molecules make dust which could form macroscopic pieces of matter, turning subsequently into early rocky planets.
We all are dust from SN explosions, at much later time but there also could be life in the early universe. Several hundred million years is enough for that.

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.

Universe today, $t_U = 14.6 \cdot 10^9$ years, SMBH

Every large galaxy contains a central supermassive BH with mass 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 origin of these BHs is not understood. Accepted faith is that these BHs are created by matter accretion to a central seed. But, the usual accretion efficiency is not sufficient to create them during the Universe life-time, 14 Gyr.
Even more puzzling: SMHBs are observed in small galaxies and even in almost EMPTY space, where is no material to make a SMBH.
A Nearly Naked Supermassive Black Hole J.J. Condon, et al arXiv:1606.04067. A compact symmetric radio source B3 1715+425 is too bright (brightness temperature $\sim 3 \times 10^{10}$ K at observing frequency 7.6 GHz) and too luminous (1.4 GHz luminosity $\sim 10^{25}$ W/Hz) to be powered by anything but a SMBH, but its host galaxy is much smaller.

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 $\mathbf{1.7 \times 10^{10} M_\odot}$, or $\mathbf{60\%}$ of its bulge mass. This creates serious problems for the scenario of formation of central supermassive BHs by accretion of matter in the central part of a galaxy.
More examples:

F. Khan, et al 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.
An inverted picture is more plausible, when first a supermassive BH was formed and attracted matter seeding the galaxy formation!!!
AD, J. Silk, 1993; AD, M. Kawasaki, N. Kevlishvili, 2008;
Bosch et al, Nature 491 (2012) 729.

Several binaries of SMBH observed:

P. Kharb, et al "A candidate sub-parsec binary black hole in the Seyfert galaxy NGC 7674 d=116 Mpc, $\mathbf{3.63 \times 10^7} M_\odot$. (1709.06258).

C. Rodriguez et al. A compact supermassive binary black hole system. Ap. J. 646, 49 (2006), $d \approx \mathbf{230}$ Mpc.

M.J.Valtonen,"New orbit solutions for the precessing binary black hole model of OJ 287 Ap.J. 659, 1074 (2007), $z \approx \mathbf{0.3}$.

M.J. Graham et al. "A possible close supermassive black-hole binary in a quasar with optical periodicity". Nature 518, 74 (2015), $z \approx \mathbf{0.3}$.

Triple Quasar.
E. Kalfountzou, M.S. Lleo, M. Trichas, SDSS J1056+5516: A Triple AGN or an SMBH Recoil Candidate? [1712.03909].
Discovery of a kiloparsec-scale supermassive black hole system at z=0.256. The system contains three strong emission-line nuclei, which are offset by $< \mathbf{250}$ km/s by 15-18 kpc in projected separation, suggesting that the nuclei belong to the same physical structure.
Such a structure can only satisfy one of the three scenarios: a triple supermasive black hole (SMBH) interacting system, a triple AGN, or a recoiling SMBH.

"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, Discovery of a a physical association of four quasars at $z \approx 2$. The probability of finding a quadruple quasar is $\sim 10^{-7}$. Our findings imply that the most massive structures in the distant universe have a tremendous supply ($\sim 10^{11}$ solar masses) of cool dense (volume density $\sim 1/\text{cm}^3$) gas, which is in conflict with current cosmological simulations.
Orthodox point of view: merging of two spiral galaxies creating an elliptical galaxy, leaving two or more SMBHs in the center of the merged elliptical. No other way in the traditional approach. However, even one SMBH is hard to create.

Heretic but simpler: primordial SMBH forming binaries in the very early universe and seeding galaxy formation.

• Intermediate mass black holes (MBH) $M = (10^3 - 10^5)M_\odot$
Nobody expected them in noticeable amount and now they came out as if from cornucopia (cornu copiae).
Intermediate mass BHs: $M \sim 10^3 M_\odot$, in globular clusters and $M \sim 10^4 - 10^5$ in dwarf galaxies.

10 IMBH, 3 years ago, $M = 3 \times 10^4 - 2 \times 10^5 M_\odot$
and 40 found recently $10^7 < M < 3 \cdot 10^9$ [Chandra, 1802.01567].

More and more: I.V. Chilingarian, et al. A Population of Bona Fide Intermediate Mass Black Holes Identified as Low Luminosity Active Galactic Nuclei arXiv:1805.01467, identified a sample of 305 IMBH candidates with $3 \times 10^4 < M_{\rm BH} < 2 \times 10^5 M_\odot$,

He-Yang Liu, et al, A Uniformly Selected Sample of Low-Mass Black Holes in Seyfert 1 Galaxies. arXiv:1803.04330, A new sample of 204 low-mass black holes (LMBHs) in active galactic nuclei is presented with black hole masses in the range of $(1 - 20) \times 10^5 M_\odot$.

"Indication of Another Intermediate-mass Black Hole in the Galactic Center" S. Takekawa, et al.,arXiv:1812.10733 [astro-ph.GA]
We report the discovery of molecular gas streams orbiting around an invisible massive object in the central region of our Galaxy, based on the high-resolution molecular line observations with the Atacama Large Millimeter/submillimeter Array (ALMA). The morphology and kinematics of these streams can be reproduced well through two Keplerian orbits around a single point mass of $\mathbf{(3.2 \pm 0.6) \times 10^4} M_\odot$. Our results provide new circumstantial evidences for a wandering intermediate-mass black hole in the Galactic center (tramp in the galaxy), suggesting also that high-velocity compact clouds can be probes of quiescent black holes abound in our Galaxy.
As an alternative: it could be nucleus of a globular cluster with stars stripped away by dense stellar population in the galactic center.

• Old 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 $\mathbf{13.8 \pm 4}$ Gyr. J.J. Cowan, et al Ap.J. 572 (2002) 861

The age of inner halo of the Galaxy $\mathbf{11.4 \pm 0.7}$ 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 $\mathbf{14.46 \pm 0.31}$ Gyr.

H. E. Bond, et al, Astrophys. J. Lett. 765, L12 (2013), arXiv:1302.3180.

The central value exceeds the universe age by two standard deviations, if $\boldsymbol{H = 67.3}$ and $\boldsymbol{t_U = 13.8}$; and if $\boldsymbol{H = 74}$, then $\boldsymbol{t_U = 12.5}$, more than 10 $\boldsymbol{\sigma}$.

Our model predicts unusual initial chemical content of the stars, so they may look older than they are.

X. Dumusque, *et al* "The Kepler-10 Planetary System Revisited by HARPS-N: A Hot Rocky World and a Solid Neptune-Mass Planet". arXiv:1405.7881; Ap J., 789, 154, (2014).

Very old planet, $\mathbf{10.6^{+1.5}_{-1.3}}$ Gyr. (Age of the Earth: 4.54 Gyr.)

A SN explosion must must precede formation of this planet.

Very recent observations: high velocity and "wrong"chemical content stars. We report the discovery of a high proper motion, low-mass white dwarf (LP 40-365) that travels at a velocity greater than the Galactic escape velocity and whose peculiar atmosphere is dominated by intermediate-mass elements. S. Vennes et al, Science, 2017, Vol. 357, p. 680; arXiv:1708.05568. Origin mysterious. Could it be compact primordial star?

Other high velocity stars in the Galaxy.
"Old, Metal-Poor Extreme Velocity Stars in the Solar Neighborhood Kohei Hattori et al., arXiv:1805.03194,.
Gaia DR2 in 6D: Searching for the fastest stars in the Galaxy, T. Marchetti, et al., arXiv:1804.10607.
They can be accelerated by a population of IMBH in Globular clusters, if there is sufficient number of IMBHs.

Universe today, strange stars

D.P. Bennett, A. Udalski, I.A. Bond, et al, "A Planetary Microlensing Event with an Unusually RED Source Star arXiv:1806.06106

We find host star and planet masses of $M_{\rm host} = 0.15^{+0.27}_{-0.10} M_\odot$ and $m_p = 18^{+34}_{-12} M_\oplus$.
The life-time of main sequence star with the solar chemical content is larger than t_U already for $M < 0.8 M_\odot$.
The origin is puzzling. May it be primordial helium star?
"A class of partly burnt runaway stellar remnants from peculiar thermonuclear supernovae arXiv:1902.05061, R. Raddi et al.
Discovery of three chemically peculiar runaway stars, survivors of thermonuclear explosions - according to the authors. "With masses and radii ranging between 0.20-0.28 $M_\odot$ and 0.16-0.60 $R_\odot$, respectively, we speculate these inflated white dwarfs are the partly burnt remnants of either peculiar Type SNIa or electron-capture supernovae".
Authors suggest that these stars are not completely burned down remnants of SNIa, but the probability for such events seems to be quite low.
They could be chemically peculiar primordial stars wandering in Galactic halo

- Mass spectrum of astrophysical (?) BH

It was found that the BH masses are concentrated in the narrow range $(\mathbf{7.8 \pm 1.2})M_\odot$ (1006.2834).
This result agrees with another paper where a peak around $\mathbf{8}M_\odot$, a paucity of sources with masses below $\mathbf{5}M_\odot$, and a sharp drop-off above $\mathbf{10}M_\odot$ are observed, arXiv:1205.1805.
These features are not easily explained in the standard model of BH formation by stellar collapse.

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Extreme conclusions

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