Фундаментальная физика и астрономия: Почему всё больше астрофизиков получают Нобелевские премии по физике

Блинников С.И.
ИТЭФ и ЦФПИ ВНИИА

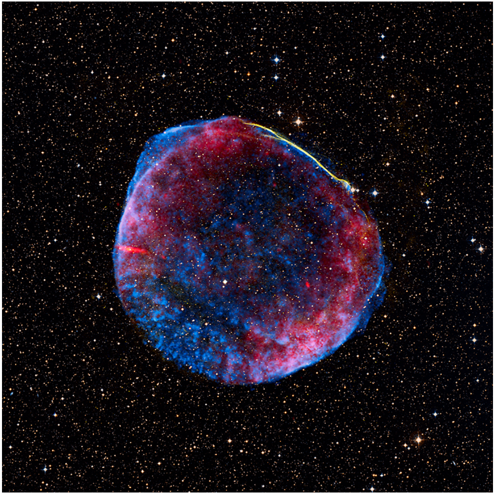
Нобелевские за космос-1

1936. За открытие космических лучей (CR, КЛ).
Victor Franz Hess.
1954. За метод совпадений для обнаружения космических лучей.
Walther Bothe.

Основатель ИТЭФа А.И.Алиханов – Арагац, наблюдения КЛ.

Сейчас нет сомнений, что основная доля КЛ производится в остатках сверхновых, SNR.

SNR 1006



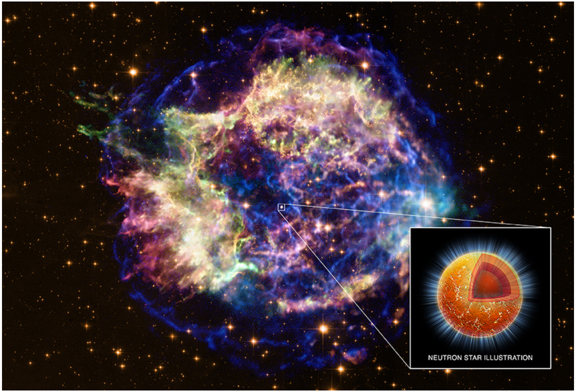
Важные числа о сверхновых:

Кинетическая энергия выброса $\sim 10^{51}$ эрг = 1 **foe**

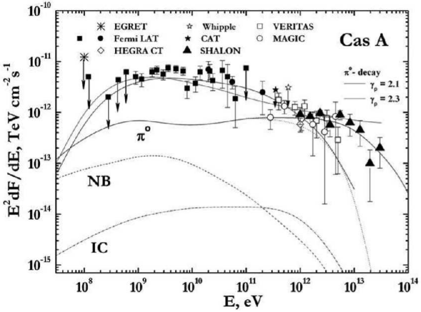
У обычных SN световая энергия за первый год ~ 0.01 foe

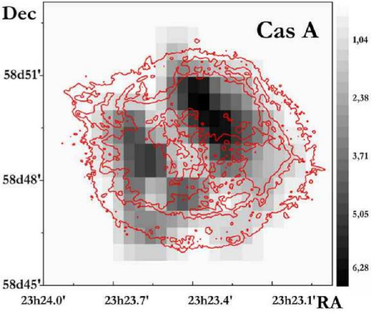
У сверхмощных SLSNe: ~ 1 foe и выше

Supernova Remnant (SNR) Cas A: Chandra X-ray observatory



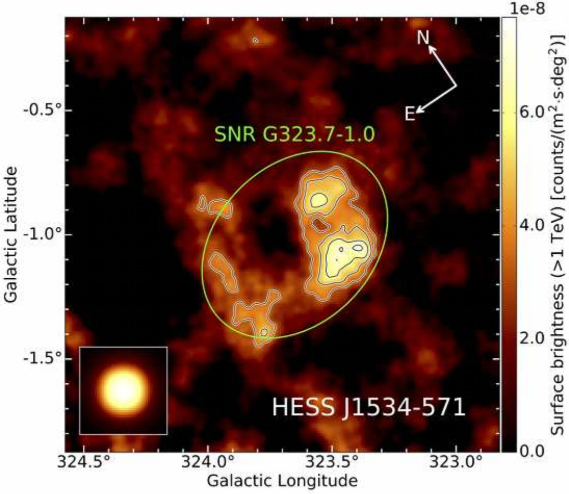
SNR Cassiopeia A: Fermi-LAT, SHALON, etc



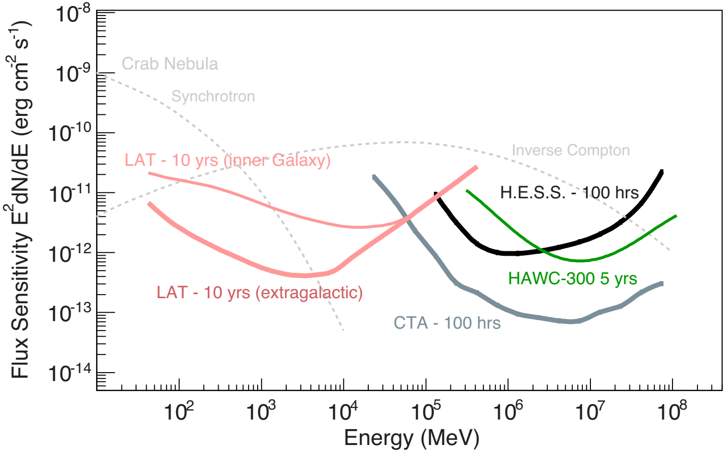


H.E.S.S. High Energy Stereoscopic System

H.E.S.S. is a system of Imaging Atmospheric Cherenkov Telescopes



"Differential" sensitivity Fermi-LAT, H.E.S.S., etc.



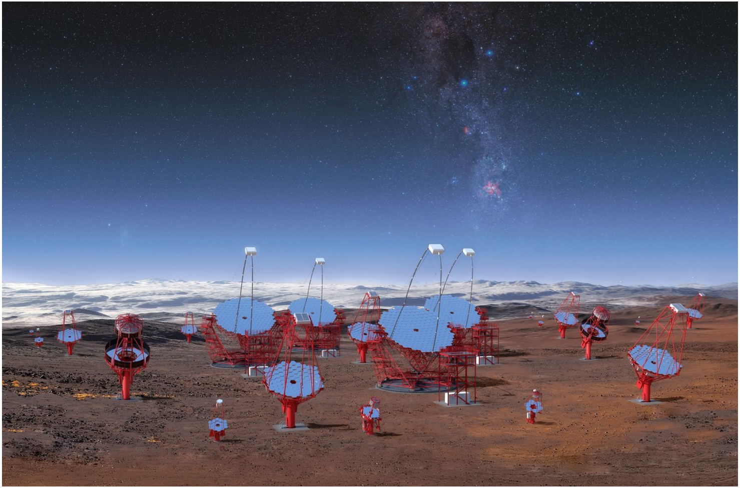
HAWC (High Altitude Water Cherenkov Gamma Ray Observatory)

CTA Cherenkov Telescope Array

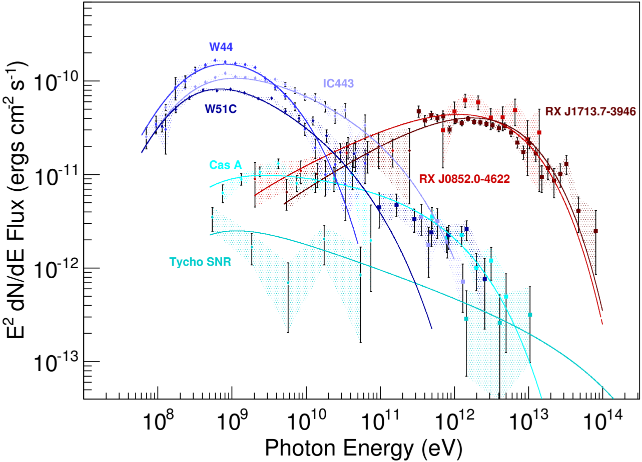
Dark Matter searches in the 2020s. At the crossroads of the WIMP

11-13 November 2019
The University of Tokyo, Kashiwa Campus
`https://indico.icrr.u-tokyo.ac.jp/event/259/overview`

Cherenkov Telescope Array



Typical γ-ray energy spectra for several of the most prominent SNRs



Нобелевские за космос-2

1967. Теория ядерных реакций, как источников энергии звёзд.
H.Bethe.
1974. Радиоастрономия, открытие пульсаров.
M. Ryle, A. Hewish, – J.Bell.
1978. Открытие микроволнового реликтового излучения CMB.
A.Penzias, R.Wilson.
1983. Строение и эволюция звёзд (**S.Chandrasekhar**) и образование химических элементов во Вселенной (**W.Fowler**) – **F.Hoyle** .
1993. Открытие нового типа пульсаров, давшее новые возможности в изучении гравитации (binary PSR, GW!).
R.Hulse, J.Taylor.

Нобелевские за космос-3

2002. Обнаружение космических нейтрино **R.Davis, M.Koshiba**, and X-ray sources **R.Giacconi**.

2006. CMB анизотропия **George Smoot, John C. Mather**

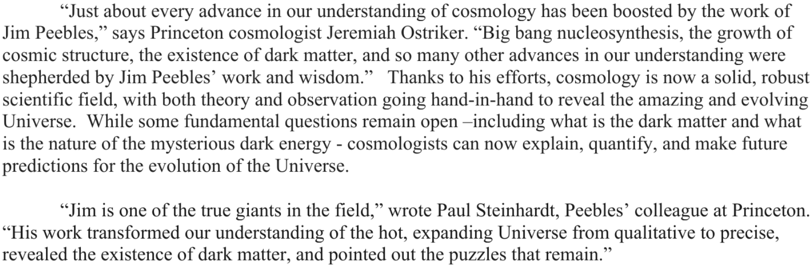
2011. Ускорение расширения Вселенной **Adam Riess, Brian Schmidt, Saul Perlmutter**

(см. обзор УФН, июнь 2019, Блинников и Долгов)

2017. LIGO – GWs, BH merging **Kip Thorne, Rainer Weiss, Barry Barish**

2019. Космология **Jim Peebles**, экзопланеты **Michel Mayor, Didier Queloz**.

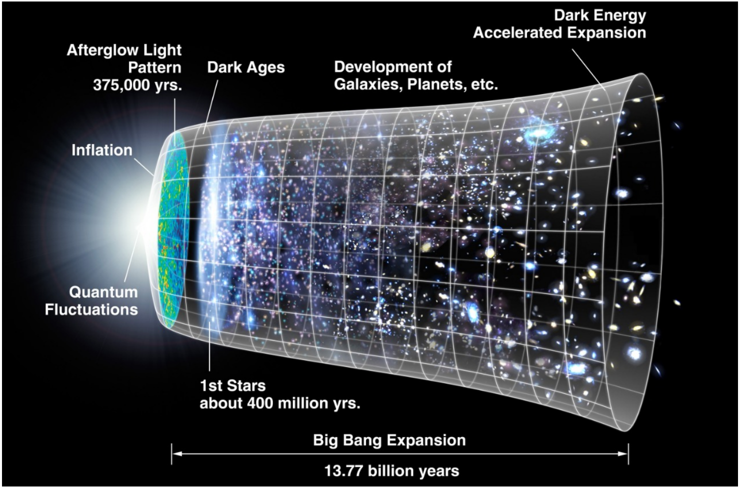
Космология и J.Peebles



“Just about every advance in our understanding of cosmology has been boosted by the work of Jim Peebles,” says Princeton cosmologist Jeremiah Ostriker. “Big bang nucleosynthesis, the growth of cosmic structure, the existence of dark matter, and so many other advances in our understanding were shepherded by Jim Peebles’ work and wisdom.” Thanks to his efforts, cosmology is now a solid, robust scientific field, with both theory and observation going hand-in-hand to reveal the amazing and evolving Universe. While some fundamental questions remain open –including what is the dark matter and what is the nature of the mysterious dark energy - cosmologists can now explain, quantify, and make future predictions for the evolution of the Universe.

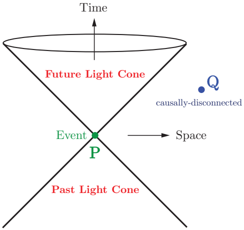
“Jim is one of the true giants in the field,” wrote Paul Steinhardt, Peebles’ colleague at Princeton. “His work transformed our understanding of the hot, expanding Universe from qualitative to precise, revealed the existence of dark matter, and pointed out the puzzles that remain.”

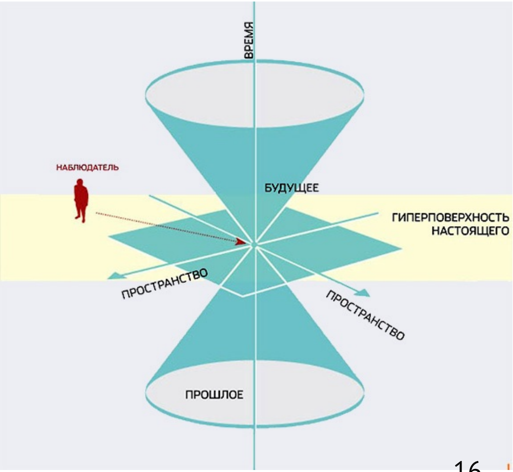
Инфляция – Big Bang – наша эпоха



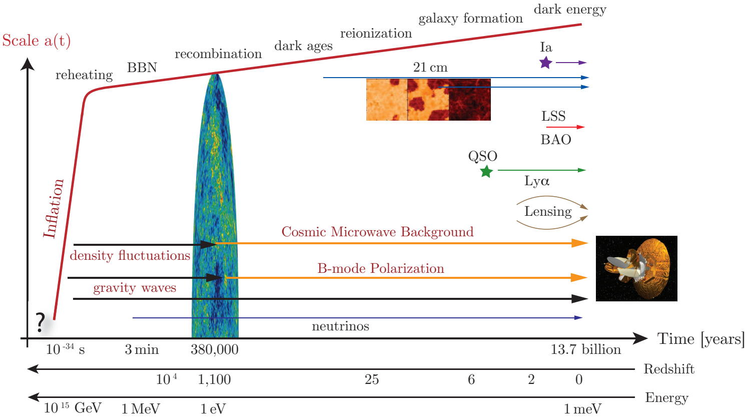
Отличие эксперимента в физике и в астрономии

В астрономии не эксперимент, а наблюдение.
Не только воспроизводимость: важно, что наблюдение почти исключительно **на световом конусе**.

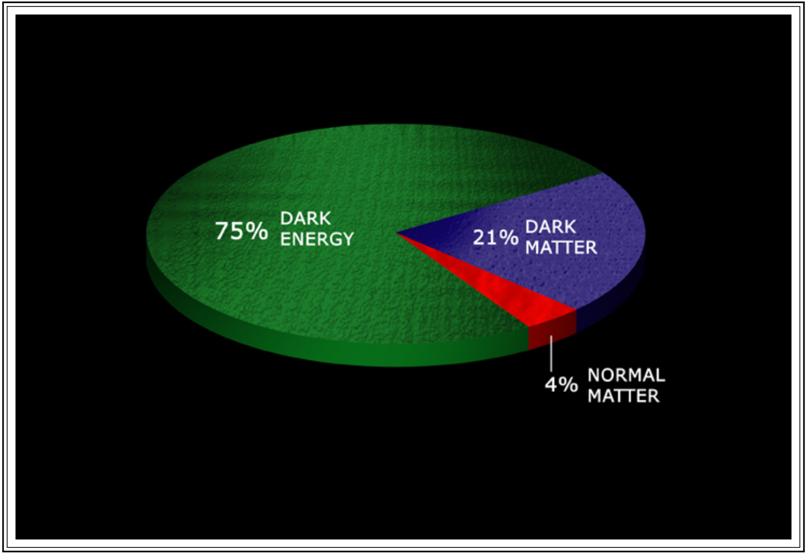




Схематично об истории Вселенной: Timeline



Dark Matter and Dark Energy pie



Проблемы

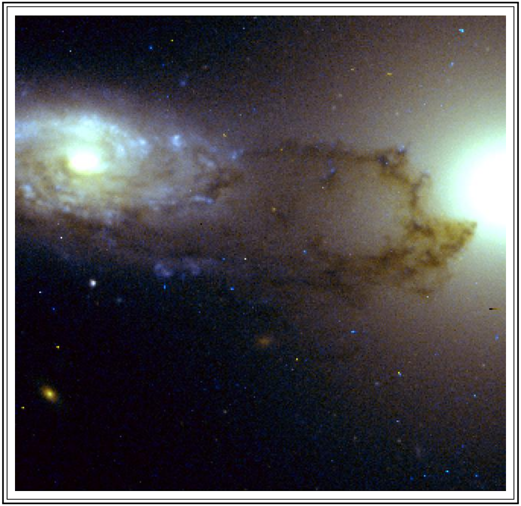
- Стандартная модель физики – несколько процентов Вселенной
- Стандартная модель космологии – нужны поля с “новой” физикой
- Что такое Тёмная энергия, **DE**?
- Что такое Тёмная Материя, **DM**?
- Образование структур, LSS, скопления, галактики, звёзды
- Квазары, чёрные дыры
- Гамма-всплески, сверхновые

Звёзды живут в галактиках

Галактика M51 “Водоворот”

Spiral NGC891 edge-on

Спиральные и эллиптические



Dark Matter

Сначала открыли Тёмную Материю (ТМ=DM), это не Тёмная Энергия (ТЭ=DE)!

Скопления как гравлинзы

Искаженные образы очень далеких галактик получаются из-за влияния гравитационного поля более близкого скопления галактик — эффект гравлинзы.

Оценки массы скоплений, полученных при такой интерпретации выявляют большое количество тёмной материи в неплохом согласии с вириальной оценкой массы.

Скопление галактик 0024+1654 – гравлинза

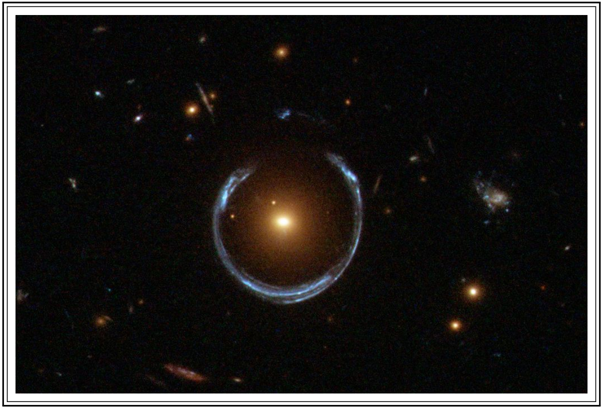
Gravitational Lens
Galaxy Cluster 0024+1654

HST • WFPC2

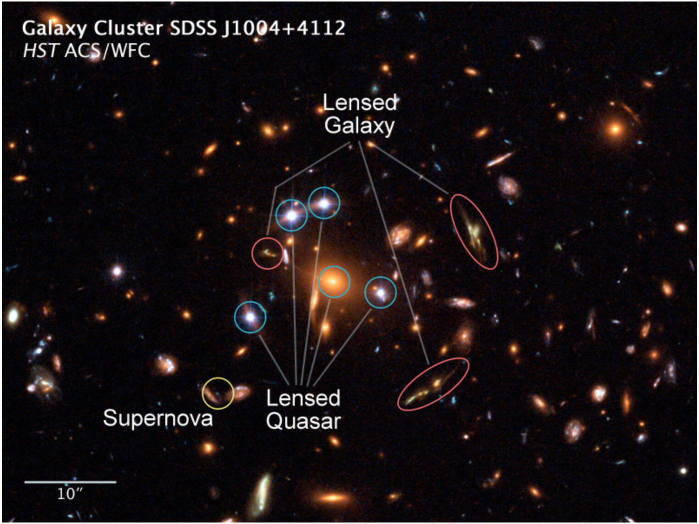
PRC96-10 • ST ScI OPO • April 24, 1996
W.N. Colley (Princeton University), E. Turner (Princeton University),
J.A. Tyson (AT&T Bell Labs) and NASA

Einstein Ring

Кольцо Эйнштейна

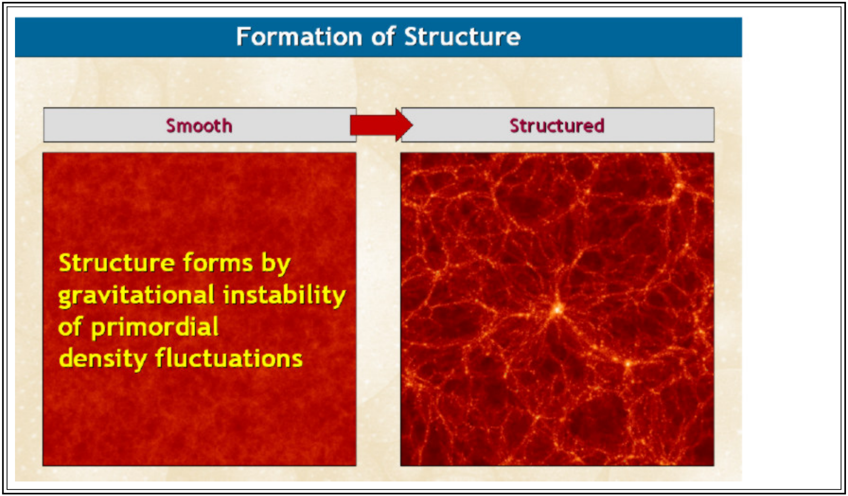


Lensing by SDSS J1004+4112



Крест Эйнштейна

Ещё один важнейший аргумент



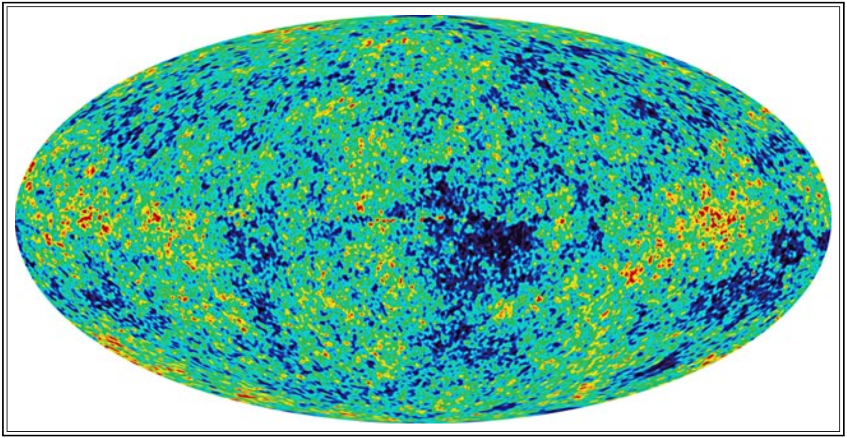
Formation of Structure

Smooth

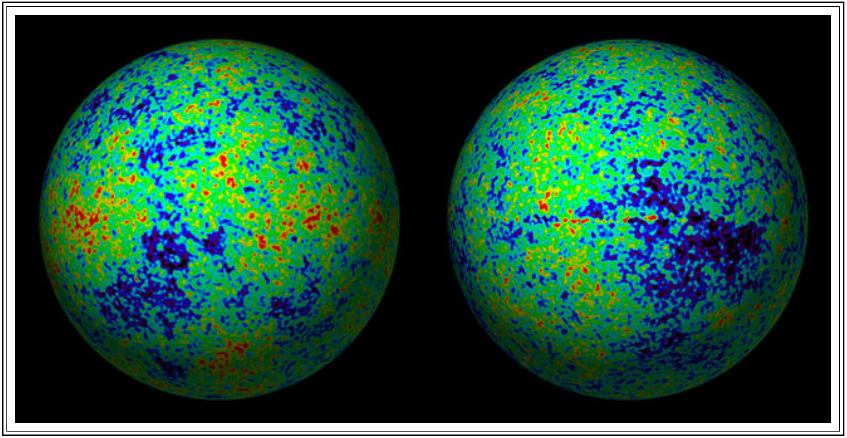
Structured

Structure forms by gravitational instability of primordial density fluctuations

CMB – WMAP sky

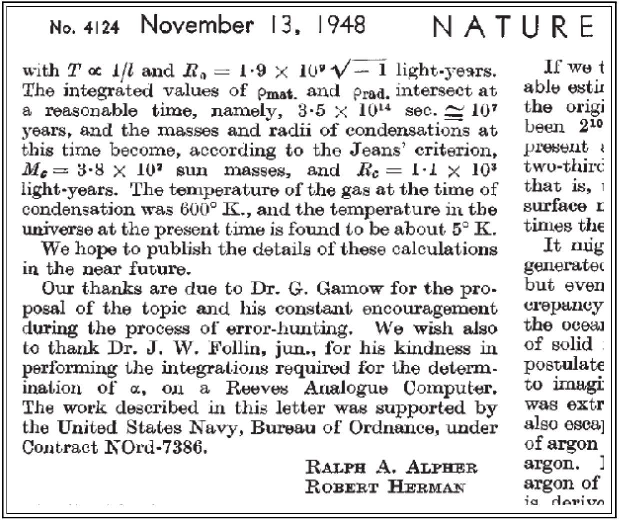


WMAP globes



Предсказания реликтового излучения

Дикке, **Пиблз** и др. искали, Пензиас, Вилсон нашли случайно



No. 4124 November 13, 1948 NATURE

with $T \propto 1/l$ and $R_0 = 1\cdot9 \times 10^9\sqrt{-1}$ light-years. The integrated values of $\rho_{\text{mat.}}$ and $\rho_{\text{rad.}}$ intersect at a reasonable time, namely, $3\cdot5 \times 10^{14}$ sec. $\cong 10^7$ years, and the masses and radii of condensations at this time become, according to the Jeans' criterion, $M_c = 3\cdot8 \times 10^7$ sun masses, and $R_c = 1\cdot1 \times 10^3$ light-years. The temperature of the gas at the time of condensation was 600° K., and the temperature in the universe at the present time is found to be about 5° K.

We hope to publish the details of these calculations in the near future.

Our thanks are due to Dr. G. Gamow for the proposal of the topic and his constant encouragement during the process of error-hunting. We wish also to thank Dr. J. W. Follin, jun., for his kindness in performing the integrations required for the determination of α, on a Reeves Analogue Computer. The work described in this letter was supported by the United States Navy, Bureau of Ordnance, under Contract NOrd-7386.

Ralph A. Alpher
Robert Herman

If we t
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Observed CMB

A primordial fluctuation spectrum in baryons consistent with the CMB fluctuations measurements does not allow the observed structure to form until today. Weakly interacting particles can begin to form structure earlier, while the baryonic matter is overwhelmed by photon pressure until the time of recombination (“**dark matter boost**”).

Реликтовое излучение настолько изотропно, что возмущения плотности в барионах не могли быть больше 10^{-5}, а вырасти они могли только в $(1+z)$ раз, где красное смещение $z = 3000$К$/3$К. Возмущения растут сначала в ТМ – поэтому она так нужна.

Важны работы Лифшица, Зельдовича, **Пиблза**.

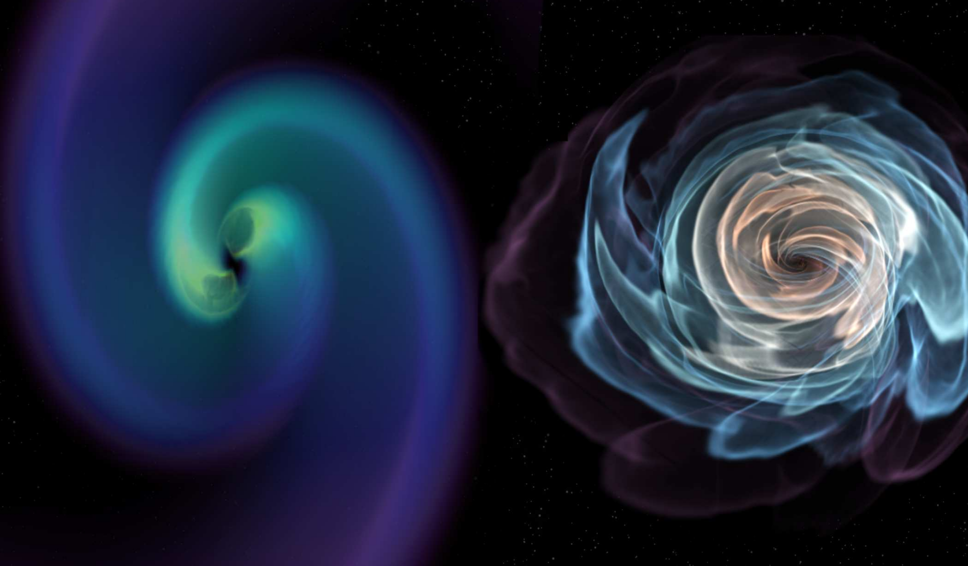
Ionization freeze-out: Зельдович, Курт, Сюняев; **Пиблз**.

Регистрация гравитационных волн
(Нобелевская премия 2017)
и гамма-всплеска от сливающихся нейтронных звёзд:
история, результаты и перспективы

С.Блинников (при помощи П.Бакланова, А.Юдина, ИТЭФ)

GW+γ

First Cosmic Event Observed in Gravitational Waves and Light



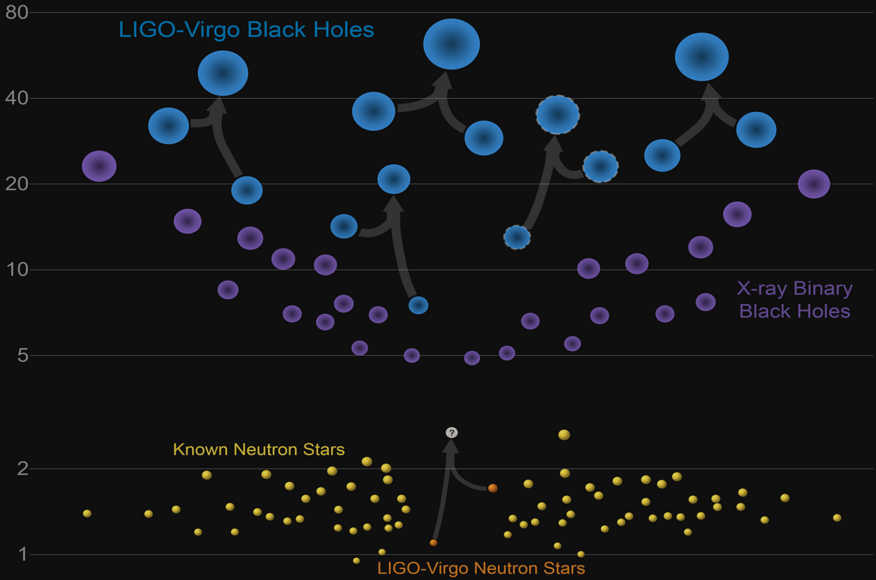
LIGO

Georgia Tech Center for Relativistic Astrophysics
College of Sciences

NSF

Masses in the Stellar Graveyard

in Solar Masses



Credit: LIGO-Virgo

FIRST COSMIC EVENT OBSERVED IN GRAVITATIONAL WAVES AND LIGHT

Colliding Neutron Stars Mark New Beginning of Discoveries

Collision creates light across the entire electromagnetic spectrum. Joint observations independently confirm Einstein's General Theory of Relativity, help measure the age of the Universe, and provide clues to the origins of heavy elements like gold and platinum

On August 17, 2017, 12:41 UTC, LIGO (US) and Virgo (Europe) detect gravitational waves from the merger of two neutron stars, each around 1.5 times the mass of our Sun. This is the first detection of spacetime ripples from neutron stars.

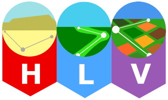
Within two seconds, NASA's Fermi Gamma-ray Space Telescope detects a short gamma-ray burst from a region of the sky overlapping the LIGO/Virgo position. Optical telescope observations pinpoint the origin of this signal to NGC 4993, a galaxy located 130 million light years distant.

LIGO
Georgia Tech Center for Relativistic Astrophysics

GW170817

Слияние двух нейтронных звезд

Наблюдалось детекторами гравитационных волн LIGO / Virgo и более 70 электромагнитными обсерваториями.



Росстояние
130 млн. световых лет

Произошло
17 Августа 2017

Тип
Слияние нейтронных звезд

12:41:04 UTC
Детектирована гравитационная волна от слияния нейтронных звезд

Гравитационная волна
Две нейтронные звезды, каждая размером с город, но с массой не меньше массы Солнца

Гамма излучение
Короткая вспышка гамма-излучения это яркий луч гамма излучения, генерируемый сразу после слияния звезд

+ 2 секунды
Детектирована выспышка гамма излучения.

+10 часов 52 минуты
Новый яркий источник оптического излучения обнаружен в галактике NGC 4993, в созвездии Гидры.

Килоновая
Эволюция богатого нейтронами вещества вызывает свечение килоновой, происходит синтез тяжелых элементов, таких как золото и платина

+11 часов 36 минут
Наблюдается инфракрасное излучение

+15 часов
Детектировано яркое ультрафиолетовое излучение.

+9 дней
Обнаружено рентгеновское излучение

Остаточное радио-излучение
Выброс материала из звезды приводит к ударной волне в межзвездной среде. Это создает радио-излучение, которое может продолжаться годами.

+16 дней
Обнаружено излучение радио-диапазона

GW170817 позволяет нам впервые измерить скорость расширения вселенной напрямую, используя гравитационные волны.

Регистрация гравитационного излучения от слияния нейтронных звезд позволяет нам узнать больше о строении этих необычных объектов

Регистрация этого события различными детекторами подтверждает, что слияние нейтронных звезд может порождать вспышки гамма излучения

Au

Полученные данные о килоновой позволили показать, что столкновения нейтронных звезд могут быть источником большинства тяжелых ядер, например золота, во вселенной.

Наблюдение гравитационных и электромагнитных волн от одного события позволяет уверенно утверждать что гравитационные волны распространяются со скоростью света

Важное о **GW170817**

- GW170817 — 6-е гравитационно-волновое событие и 1-ое наблюдение слияния объектов с массами нейтронных звезд.
- Гамма-всплеск GRB170817A наблюдался спустя 1.7 сек. после потери сигнала GW170817.
    - Подтверждена связь коротких GRB со сливающимися NS
    - Ограничения на гравитацию: скорость распространения ($\Delta v/c \lesssim 10^{-15}$), лоренц-инвариантность, принцип эквивалентности

Важное о **GW170817**

- Спустя 11 часов открыт источник в видимом свете в NGC 4993
  - Кривые блеска и спектры соответствуют килоновой
  - Синтез тяжелых элементов в r-процессе
  - Космология: независимое измерение расстояний, параметра Хаббла
- Впервые выполнены наблюдения одного объекта в грав.волновом и эл.-маг. (гамма, рентген, ультрафиолет, видимый и инфракрасный свет, радио) канале. Для нейтрино далеко

Начало эры многодиапазонной (многоканальной) астрономии – multi-messenger astronomy

Немного личного из 2017 года

Kip S Thorne
Sun, Sep 3, 2017 at 1:32 AM
To: Sergei Blinnikov
Dear Sergei,
How very nice to hear from you.
…
I remember well your old paper with Igor, Sasha, and Tanja on exploding neutron stars. It was very surprising to me at first, but then made sense when I read it. We can hope for a LIGO discovery of gravitational waves from merging neutron stars, with gamma ray burst, in the near future.
With warm best wishes,
Kip

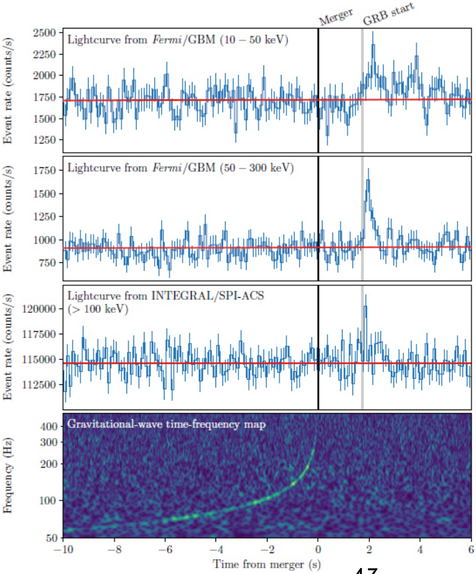
==

Kip S. Thorne: kip@tapir.caltech.edu
350-17 Caltech, Pasadena, CA 91125
Phone: +1 626 395-4598

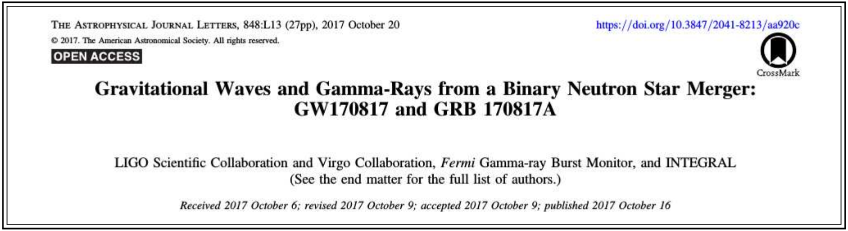
INTEGRAL and NASA's Fermi satellite

INTErnational
Gamma-Ray
Astrophysics
Laboratory
(INTEGRAL)

The Fermi
Gamma-ray
Space
Telescope



GW170817 and GRB170817A



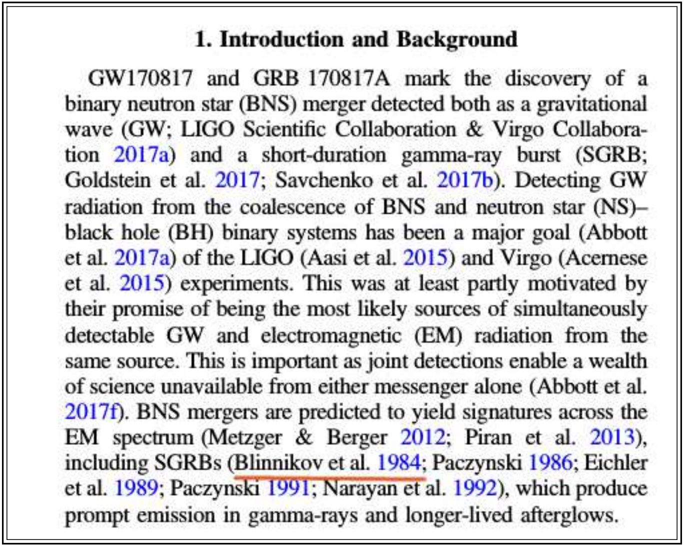
The Astrophysical Journal Letters, 848:L13 (27pp), 2017 October 20
https://doi.org/10.3847/2041-8213/aa920c

Gravitational Waves and Gamma-Rays from a Binary Neutron Star Merger: GW170817 and GRB 170817A

LIGO Scientific Collaboration and Virgo Collaboration, *Fermi* Gamma-ray Burst Monitor, and INTEGRAL
(See the end matter for the full list of authors.)

Received 2017 October 6; revised 2017 October 9; accepted 2017 October 9; published 2017 October 16

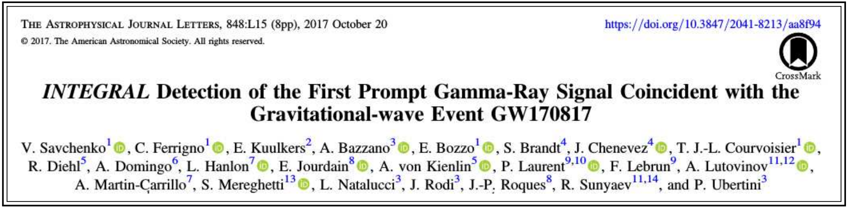
GW170817 and GRB170817A



1. Introduction and Background

GW170817 and GRB 170817A mark the discovery of a binary neutron star (BNS) merger detected both as a gravitational wave (GW; LIGO Scientific Collaboration & Virgo Collaboration 2017a) and a short-duration gamma-ray burst (SGRB; Goldstein et al. 2017; Savchenko et al. 2017b). Detecting GW radiation from the coalescence of BNS and neutron star (NS)–black hole (BH) binary systems has been a major goal (Abbott et al. 2017a) of the LIGO (Aasi et al. 2015) and Virgo (Acernese et al. 2015) experiments. This was at least partly motivated by their promise of being the most likely sources of simultaneously detectable GW and electromagnetic (EM) radiation from the same source. This is important as joint detections enable a wealth of science unavailable from either messenger alone (Abbott et al. 2017f). BNS mergers are predicted to yield signatures across the EM spectrum (Metzger & Berger 2012; Piran et al. 2013), including SGRBs (Blinnikov et al. 1984; Paczynski 1986; Eichler et al. 1989; Paczynski 1991; Narayan et al. 1992), which produce prompt emission in gamma-rays and longer-lived afterglows.

GW170817 and GRB170817A, INTEGRAL



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INTEGRAL Detection of the First Prompt Gamma-Ray Signal Coincident with the Gravitational-wave Event GW170817

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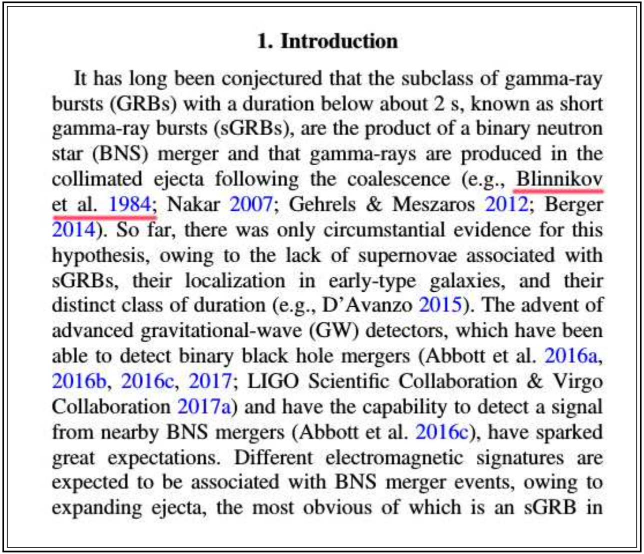
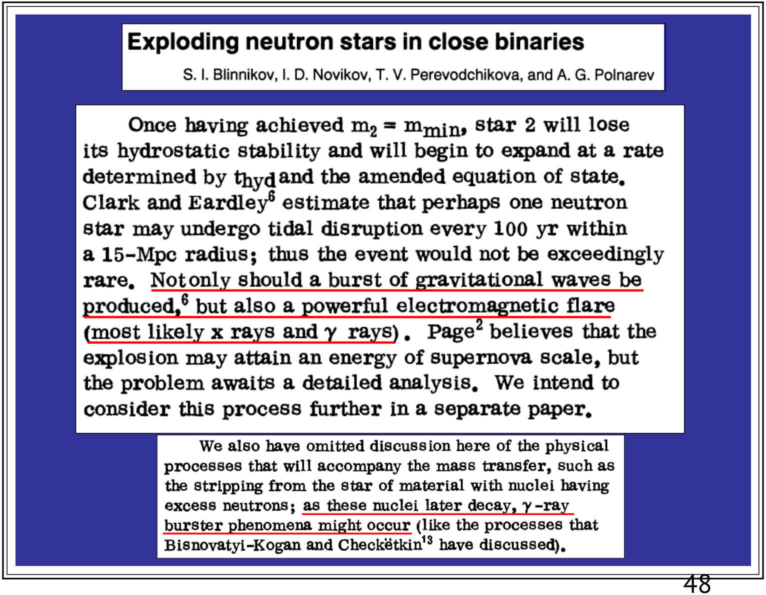
GW170817 and GRB170817A, INTEGRAL



1. Introduction

It has long been conjectured that the subclass of gamma-ray bursts (GRBs) with a duration below about 2 s, known as short gamma-ray bursts (sGRBs), are the product of a binary neutron star (BNS) merger and that gamma-rays are produced in the collimated ejecta following the coalescence (e.g., Blinnikov et al. 1984; Nakar 2007; Gehrels & Meszaros 2012; Berger 2014). So far, there was only circumstantial evidence for this hypothesis, owing to the lack of supernovae associated with sGRBs, their localization in early-type galaxies, and their distinct class of duration (e.g., D'Avanzo 2015). The advent of advanced gravitational-wave (GW) detectors, which have been able to detect binary black hole mergers (Abbott et al. 2016a, 2016b, 2016c, 2017; LIGO Scientific Collaboration & Virgo Collaboration 2017a) and have the capability to detect a signal from nearby BNS mergers (Abbott et al. 2016c), have sparked great expectations. Different electromagnetic signatures are expected to be associated with BNS merger events, owing to expanding ejecta, the most obvious of which is an sGRB in

NS+NS ⇒ GRB: предсказание 1984 и 1990

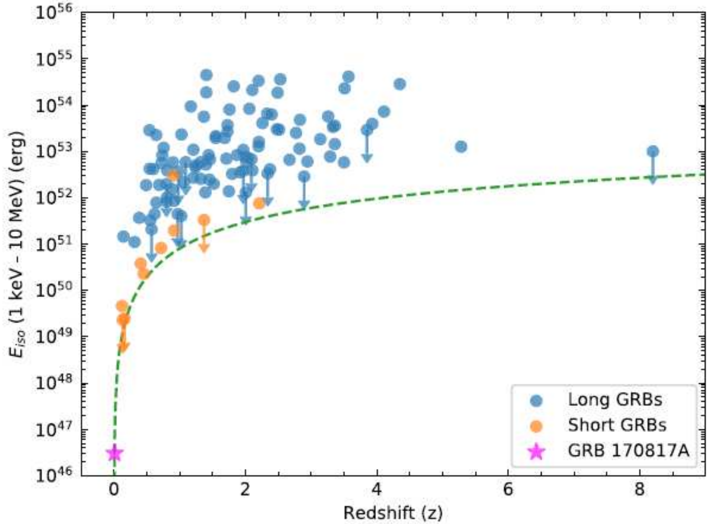


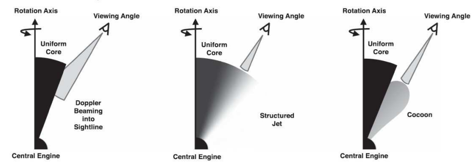
Exploding neutron stars in close binaries

S. I. Blinnikov, I. D. Novikov, T. V. Perevodchikova, and A. G. Polnarev

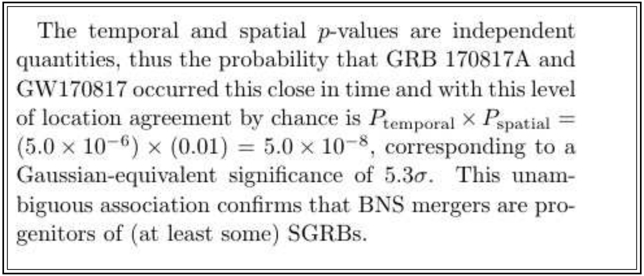
Once having achieved $m_2 = m_{min}$, star 2 will lose its hydrostatic stability and will begin to expand at a rate determined by t_{hyd} and the amended equation of state. Clark and Eardley[6] estimate that perhaps one neutron star may undergo tidal disruption every 100 yr within a 15-Mpc radius; thus the event would not be exceedingly rare. Not only should a burst of gravitational waves be produced,[6] but also a powerful electromagnetic flare (most likely x rays and γ rays). Page[2] believes that the explosion may attain an energy of supernova scale, but the problem awaits a detailed analysis. We intend to consider this process further in a separate paper.

We also have omitted discussion here of the physical processes that will accompany the mass transfer, such as the stripping from the star of material with nuclei having excess neutrons; as these nuclei later decay, γ-ray burster phenomena might occur (like the processes that Bisnovatyi-Kogan and Checkëtkin[13] have discussed).


10^{56}
10^{55}
10^{54}
10^{53}
10^{52}
10^{51}
10^{50}
10^{49}
10^{48}
10^{47}
10^{46}
E_{iso} (1 keV - 10 MeV) (erg)
0
2
4
6
8
Redshift (z)
● Long GRBs
● Short GRBs
★ GRB 170817A


Scenario i: Uniform Top-hat Jet
Rotation Axis
Viewing Angle
Uniform Core
Doppler Beaming into Sightline
Central Engine
Scenario ii: Structured Jet
Rotation Axis
Viewing Angle
Uniform Core
Structured Jet
Central Engine
Scenario iii: Uniform Jet + Cocoon
Rotation Axis
Viewing Angle
Uniform Core
Cocoon
Central Engine

UNAMBIGUOUS ASSOCIATION



The temporal and spatial p-values are independent quantities, thus the probability that GRB 170817A and GW170817 occurred this close in time and with this level of location agreement by chance is $P_{\mathrm{temporal}} \times P_{\mathrm{spatial}} = (5.0 \times 10^{-6}) \times (0.01) = 5.0 \times 10^{-8}$, corresponding to a Gaussian-equivalent significance of 5.3σ. This unambiguous association confirms that BNS mergers are progenitors of (at least some) SGRBs.

4.1. *Speed of Gravity*

Assuming a small difference in travel time Δt between photons and GWs, and the known travel distance D, the fractional speed difference during the trip can be written $\Delta v/v_{\mathrm{EM}} \approx v_{\mathrm{EM}}\Delta t/D$, where $\Delta v = v_{\mathrm{GW}} - v_{\mathrm{EM}}$ is the difference between the speed of gravity v_{GW} and the speed of light v_{EM}. This relation is less constraining for small distances, hence we conservatively use here $D = 26\,\mathrm{Mpc}$, the lower bound of the 90% credible interval on luminosity distance derived from the GW signal (Abbott et al. 2017a). If we conservatively assume that the peak of the GW signal and the first photons were emitted simultaneously, attributing the entire $(+1.74 \pm 0.05)\,\mathrm{s}$ lag to faster travel by the GW signal, this time difference provides an upper bound on Δv. To obtain a lower bound on Δv, one can assume that the two signals were emitted at times differing by more than $(+1.74 \pm 0.05)\,\mathrm{s}$ with the faster EM signal making up some of the difference. As a conservative bound relative to the few second delays discussed in Section 2.1, we assume the SGRB signal was emitted 10 s after the GW signal. The resulting constraint on the fractional speed difference is

$$-3 \times 10^{-15} \leq \frac{\Delta v}{v_{\mathrm{EM}}} \leq +7 \times 10^{-16}. \tag{1}$$

4.3. Test of the Equivalence Principle

Probing whether EM radiation and GWs are affected by background gravitational potentials in the same way is a test of the equivalence principle (Will 2014). One way to achieve this is to use the Shapiro effect (Shapiro 1964), which predicts that the propagation time of massless particles in curved spacetime, i.e., through gravitational fields, is slightly increased with respect to the flat spacetime case. We will consider the following simple parametrized form of the Shapiro delay (Krauss & Tremaine 1988; Longo 1988; Gao et al. 2015; Kahya & Desai 2016):

$$\delta t_{\rm S} = -\frac{1+\gamma}{c^3}\int_{r_e}^{r_o} U(\boldsymbol{r}(l))dl, \qquad (3)$$

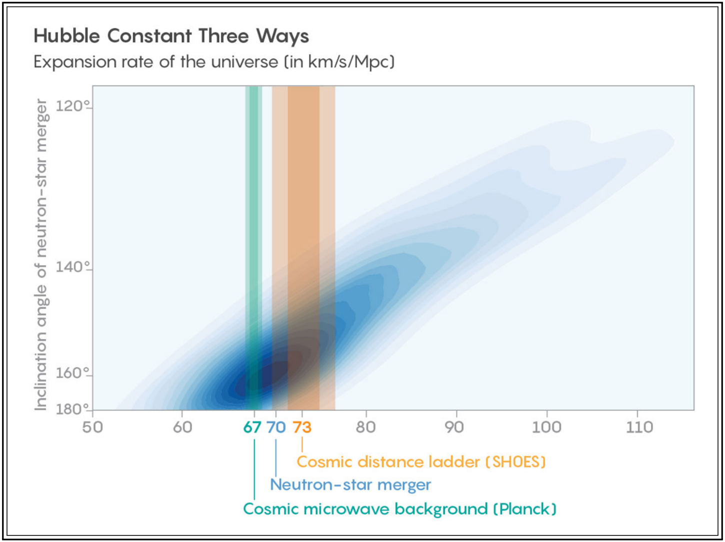
where $\boldsymbol{r}_e$ and $\boldsymbol{r}_o$ denote emission and observation positions, respectively, $U(\boldsymbol{r})$ is the gravitational potential, and the integral is computed along the wave path. γ parametrizes a deviation from the Einstein–Maxwell theory, which minimally couples classical electromagnetism to general relativity. We allow for different values of γ for the propagation of EM and GWs (γ_{EM} and γ_{GW}, respectively, with $\gamma_{\mathrm{EM}} = \gamma_{\mathrm{GW}} = 1$ in the Einstein–Maxwell theory).

While obtaining the best bound on the difference between the Shapiro time delays requires modeling the potential $U(\boldsymbol{r})$ along the entire line of sight, we determine a conservative bound on $\gamma_{\mathrm{GW}} - \gamma_{\mathrm{EM}}$ by considering only the effect of the Milky Way outside a sphere of 100 kpc, and by using a Keplerian potential with a mass of $2.5 \times 10^{11} M_\odot$ (the lowest total mass within a sphere of radius 100 kpc quoted in Bland-Hawthorn & Gerhard 2016, from Gibbons et al. 2014, taking the 95% confidence lower bound) (Krauss & Tremaine 1988; Longo 1988; Gao et al. 2015). Using the same time bounds as Equation (1) we find

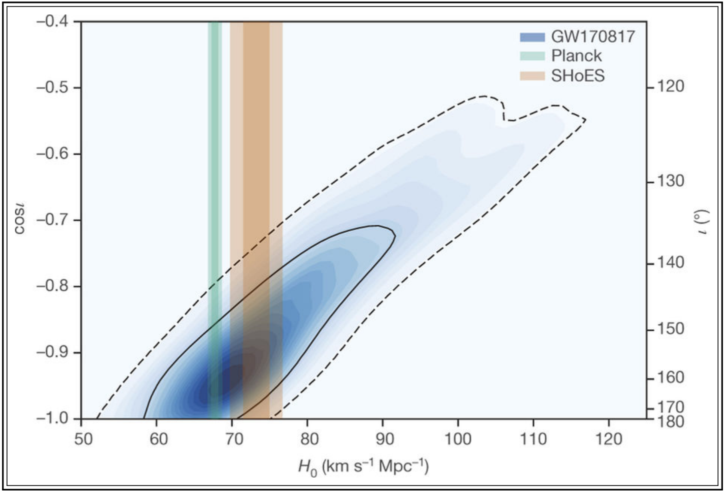
$$-2.6 \times 10^{-7} \leqslant \gamma_{\mathrm{GW}} - \gamma_{\mathrm{EM}} \leqslant 1.2 \times 10^{-6}. \qquad (4)$$

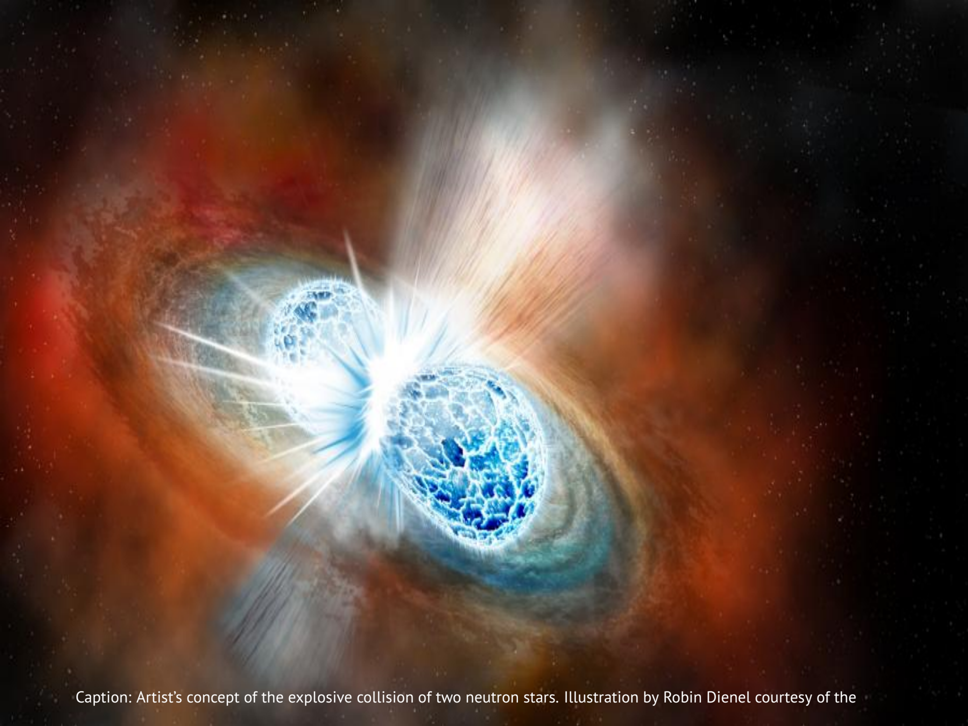
The best absolute bound on γ_{EM} is $\gamma_{\mathrm{EM}} - 1 = (2.1 \pm 2.3) \times 10^{-5}$, from the measurement of the Shapiro delay (at radio wavelengths) with the Cassini spacecraft (Bertotti et al. 2003).

Измерение параметра Хаббла из GW



Измерение параметра Хаббла из GW





Caption: Artist’s concept of the explosive collision of two neutron stars. Illustration by Robin Dienel courtesy of the

Спасибо за внимание!