Режимы слияния и обдирания в тесных парах релятивистских звёзд: перспективы для моделей коротких гамма-всплесков

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совместно с:
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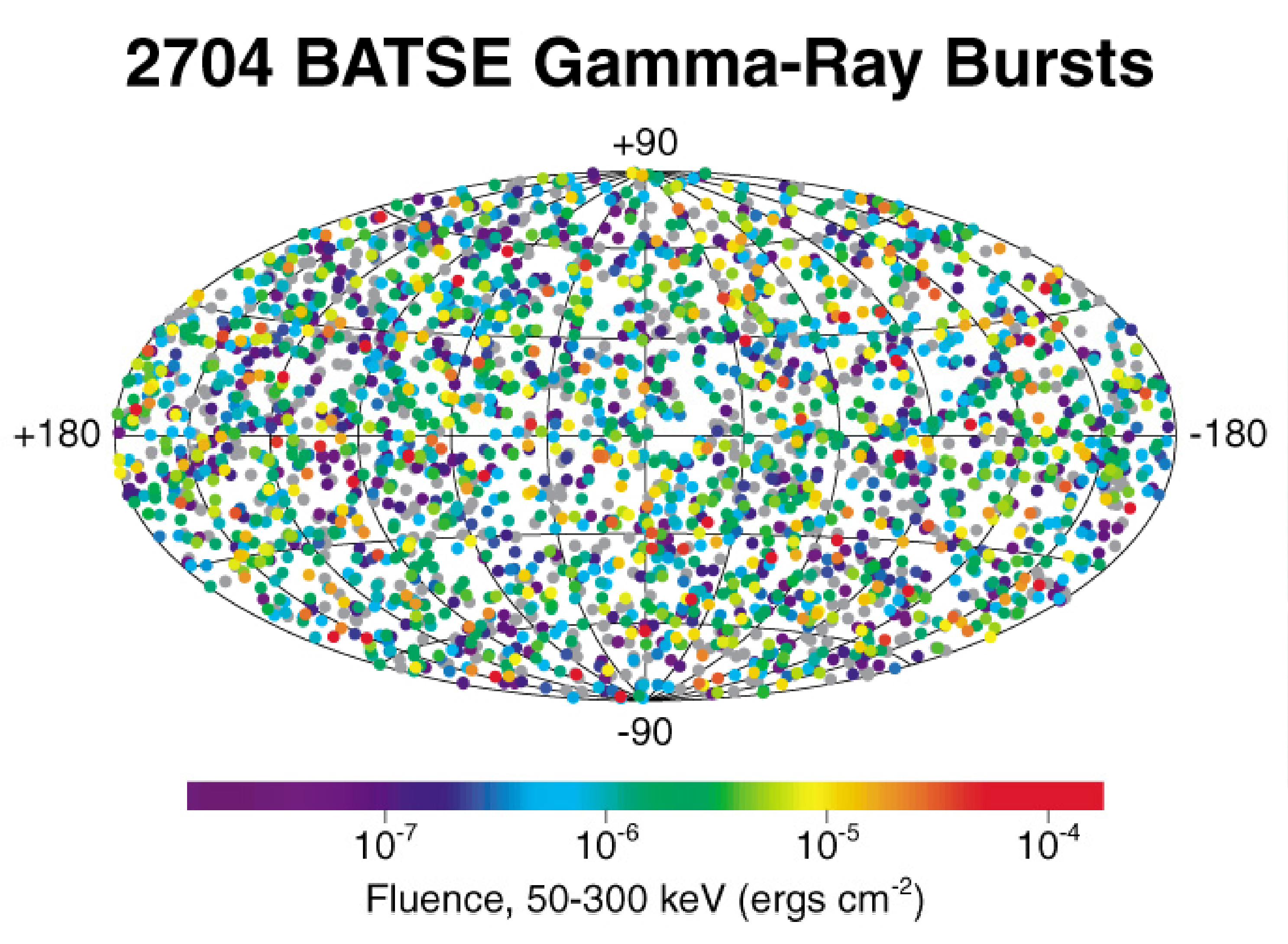
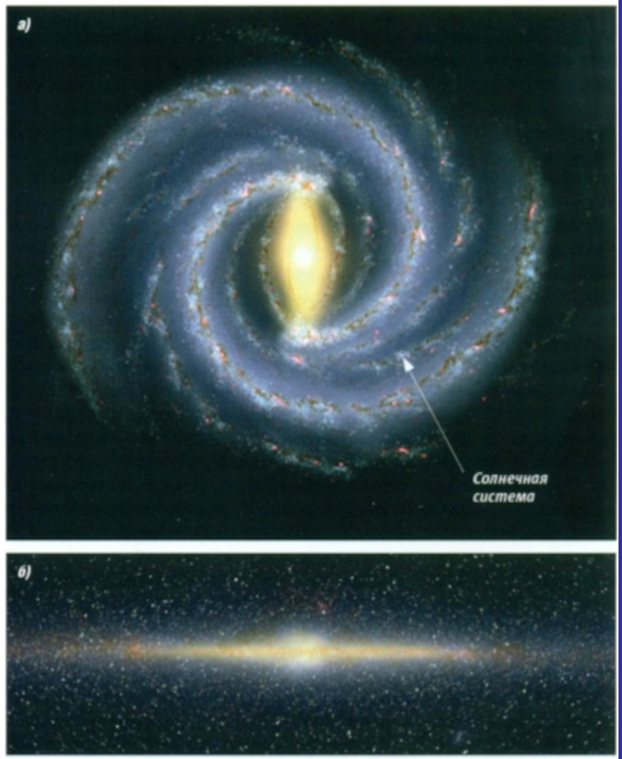
Курчатовский комплекс теоретической и экспериментальной физики,
НИЦ "Курчатовский Институт", Москва

НЕЛИНЕЙНЫЕ ВОЛНЫ – 2022

Gamma-Ray Bursts





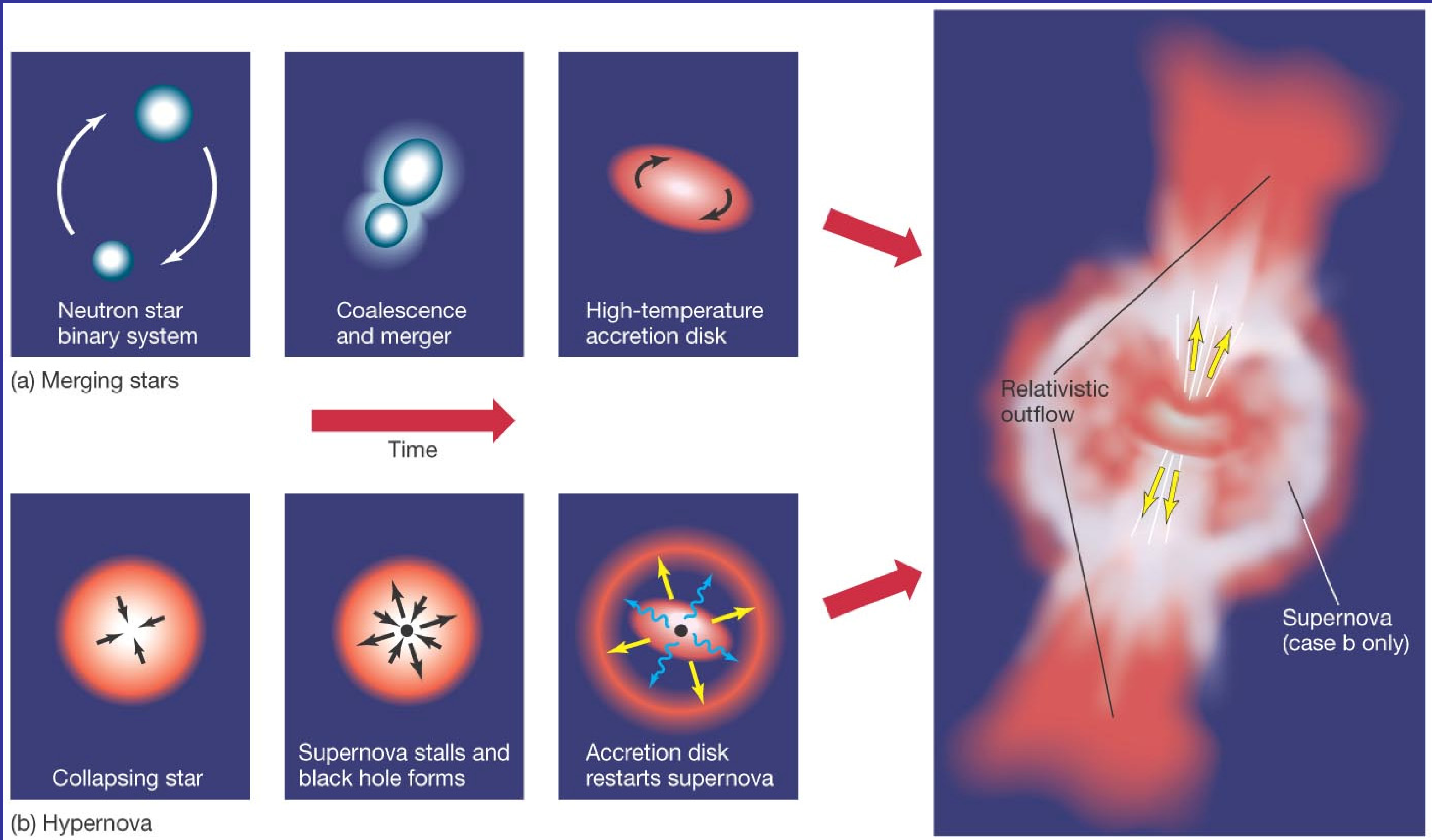
GRB (гамма-всплески): вспышки с энергией от нескольких десятков кэВ до МэВ (иногда и более жесткие). Вспышки длятся от нескольких долей секунд до минут, а иногда и часов.

<u>Короткие гамма-всплески</u> (меньше 2 сек) – слияние нейтронных звёзд.

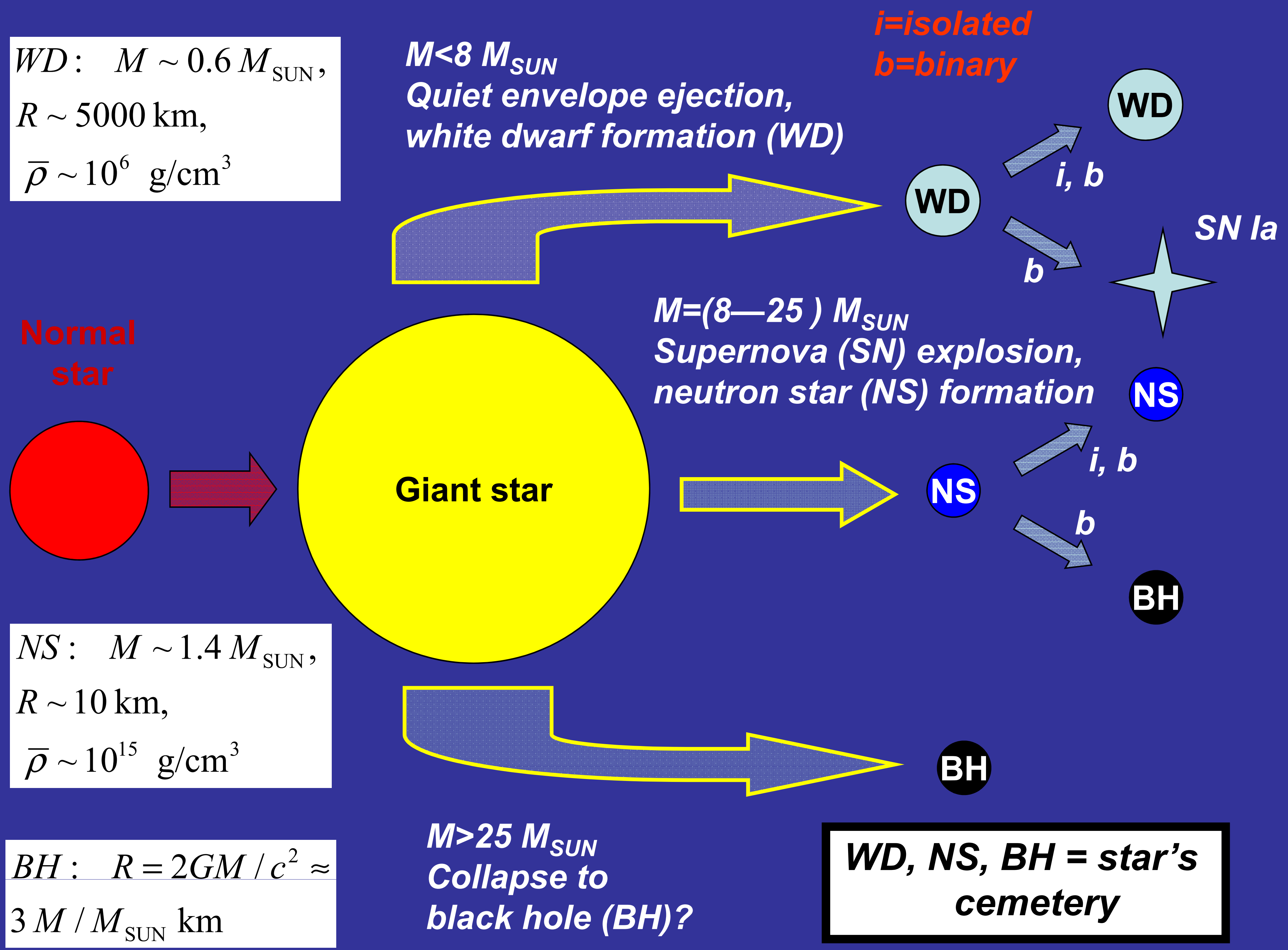
<u>Длинные</u> – Гипернова.

Gamma-Ray Bursts

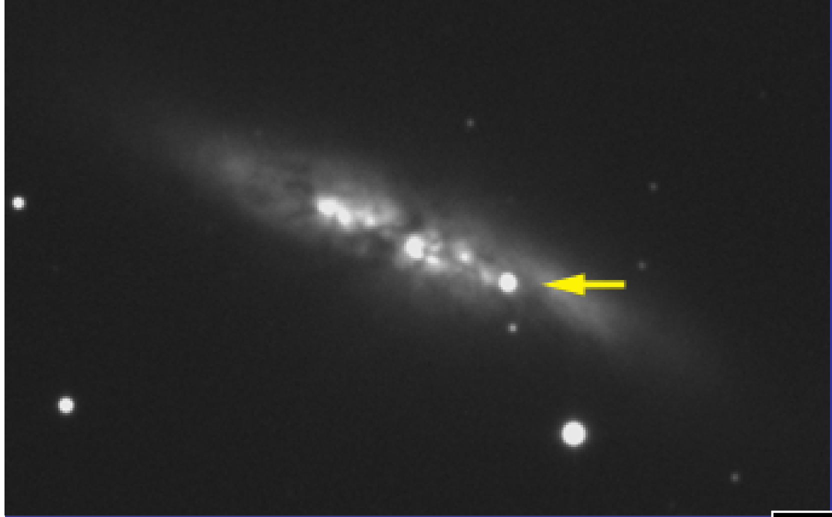
Two models—merging Neutron Stars or a "Hypernova" – have been proposed as the source of Gamma-Ray Bursts ("GRB's"):



Краткий экскурс в теорию звёздной эволюции

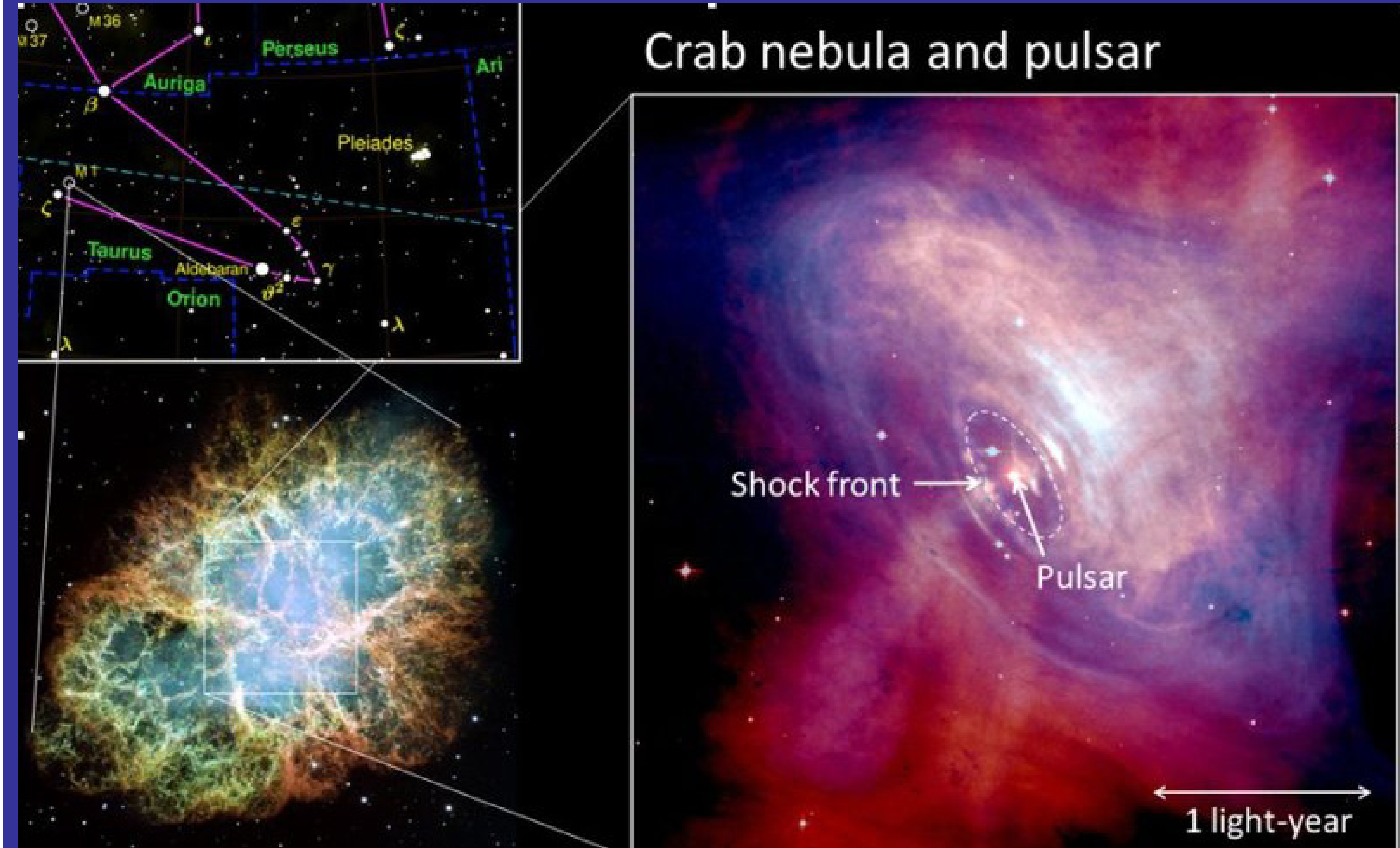


Adapted from D.G. Yakovlev, "Nuclear burning in superdense matter", Pushino (2010)

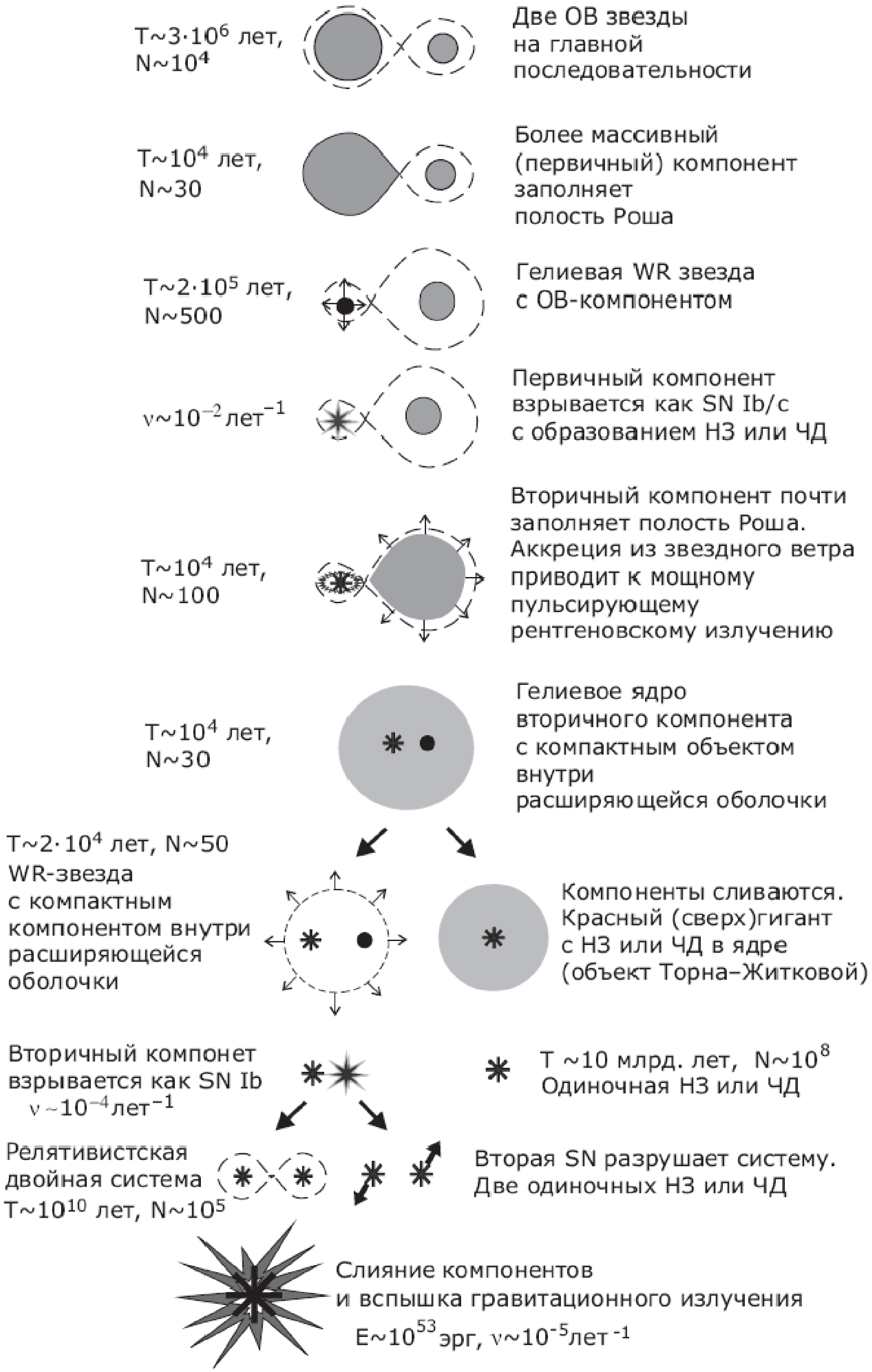


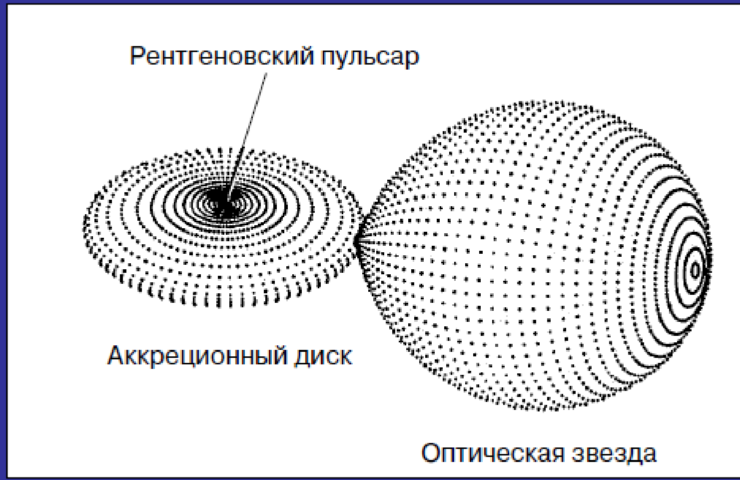
Supernova 1994D in Galaxy NGC 4526


Neutron Star
Vancouver
www.kindaroomy.com



Crab nebula and pulsar
M 36
M 37
Perseus
Ari
Auriga
Pleiades
Taurus
Aldebaran
Orion
Shock front
Pulsar
1 light-year





А.В. Тутуков и Л.Р. Юнгельсон, Научные информ. Астросовета АН СССР. Т. 27. 1973

Двойной радиопульсар PSR 1913+16 Халса и Тейлора Нобелевская премия 1993 г.

$$M_{1,2} \approx 1.4 M_{\odot}$$

$$T = 7.75\, h$$

$$e = 0.617$$

$$a_{min} = 1.1 R_{\odot}$$

$$a_{max} = 4.8 R_{\odot}$$

$$t_{life} \approx 3 \times 10^{8}\ y$$

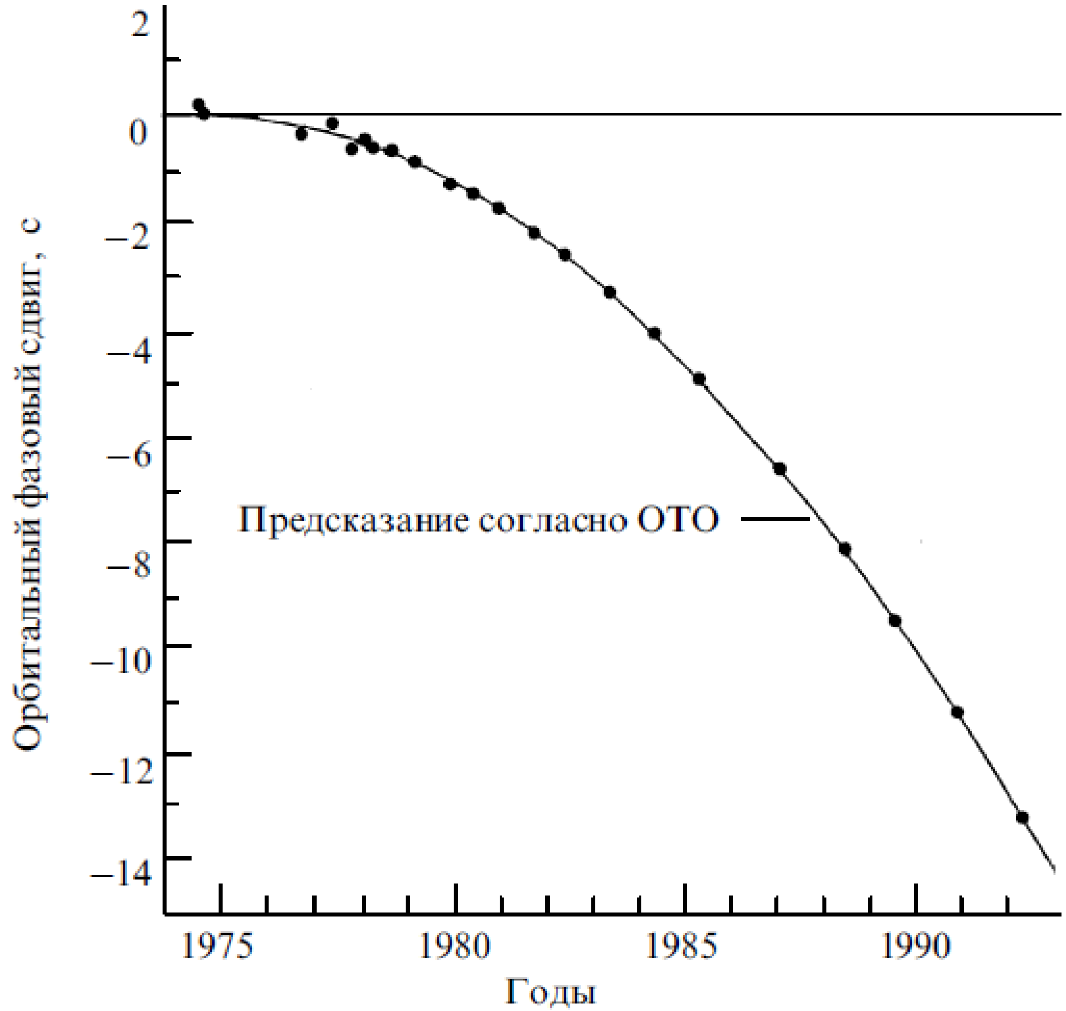
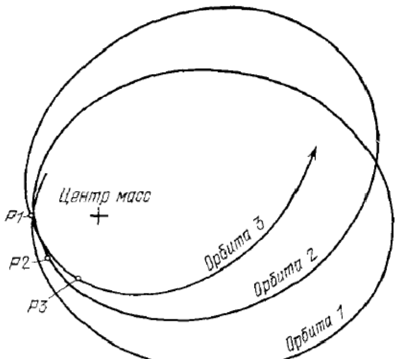


Рис. 4. Влияние уменьшения орбитального периода на фазу двойного пульсара. Пульсар проходит через периастр все раньше и раньше по мере уменьшения периода. Сплошная линия соответствует предсказанию общей теории относительности для измеренных значений масс компонент двойного пульсара. Точками нанесены данные наблюдений. Экспериментальные ошибки меньше размера точек (любезно предоставлено Дж.Х. Тэйлором)

Рис. 7. Движение периастра орбиты пульсара PSR 1913 + 16 — первое наблюдение эффектов общей теории относительности за пределами Солнечной системы.

Движение периастра, т. е. вращение эллиптической орбиты пульсара в своей плоскости, связано с кривизной пространства-времени вблизи массивного компаньона. Согласно общей теории относительности скорость движения периастра должна составлять около 4 градусов в год, причем эта величина зависит от массы пульсара и его компаньона. Измерения, проведенные авторами статьи, показали, что периастр вращается со скоростью 4,2 градуса в год, что находится в хорошем согласии с предсказанием теории.



Стандартный взгляд на короткие гамма-всплески: модель слияния (merging) и формирование выброса вещества (jet)

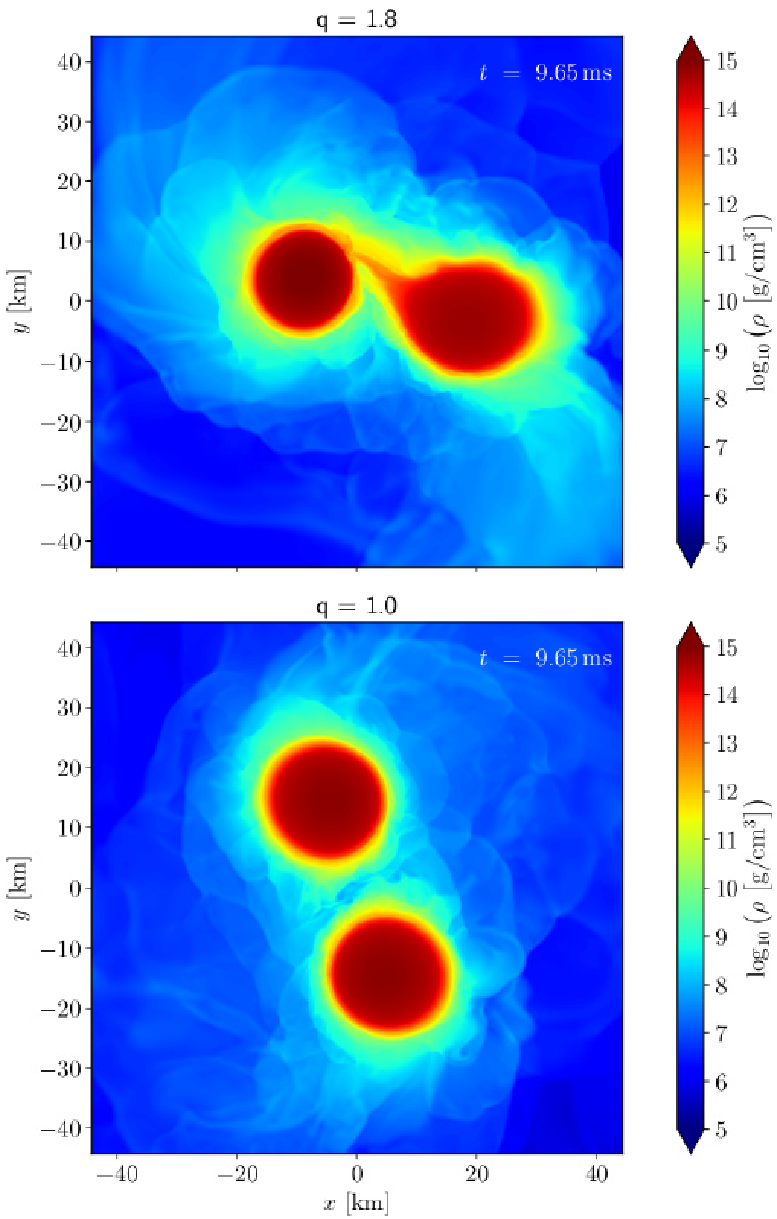


Figure 3. Snapshots of premerger dynamics for BLh $q = 1.8$ (top) and $q = 1.0$ (bottom) simulations. Shown is the rest-mass density in the orbital plane at ∼9 ms corresponding to the third orbit from the beginning of the simulations and 2 orbits to the moment of merger. The companion in the $q = 1.8$ BNS is tidally disrupted and a significant accretion onto the primary is taking place. Accretion starts approximately after one orbits from the beginning of the simulations.

8 *S. Bernuzzi et al.*

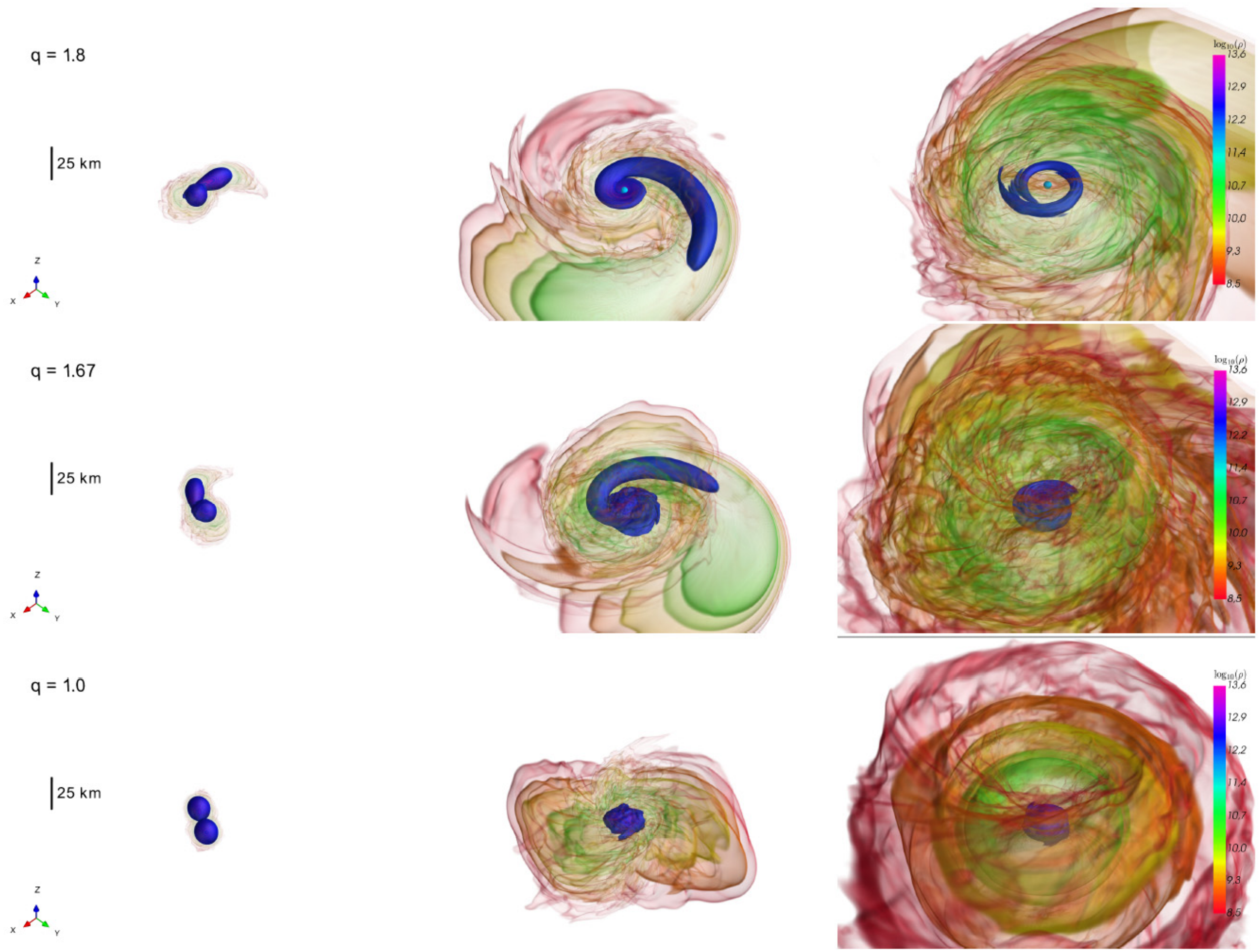


Figure 4. 3D volume rendering of the rest mass density ρ in g cm^{-3} expressed in logarithmic scale for the BLh models. Each column represer time inside the simulation: merger time (left), early postmerger (~ 2ms, middle) and later stages (~ 10ms, right). In each row we show a differe $q = M_A/M_B$: $q = 1.8$ (top), $q = 1.67$ (middle) and $q = 1.0$ (bottom). The BH apparent horizon is shown as a bright green isosurface of the l $\alpha = \alpha_{\rm AH}$.

S.Bernuzzi et al.,
arXiv:2003.06015v1

D.Radice, F. Galeazzi, J. Lippuner, L.F. Roberts, C. D. Ott, L. Rezzolla
MNRAS **460, 3255–3271 (2016)**

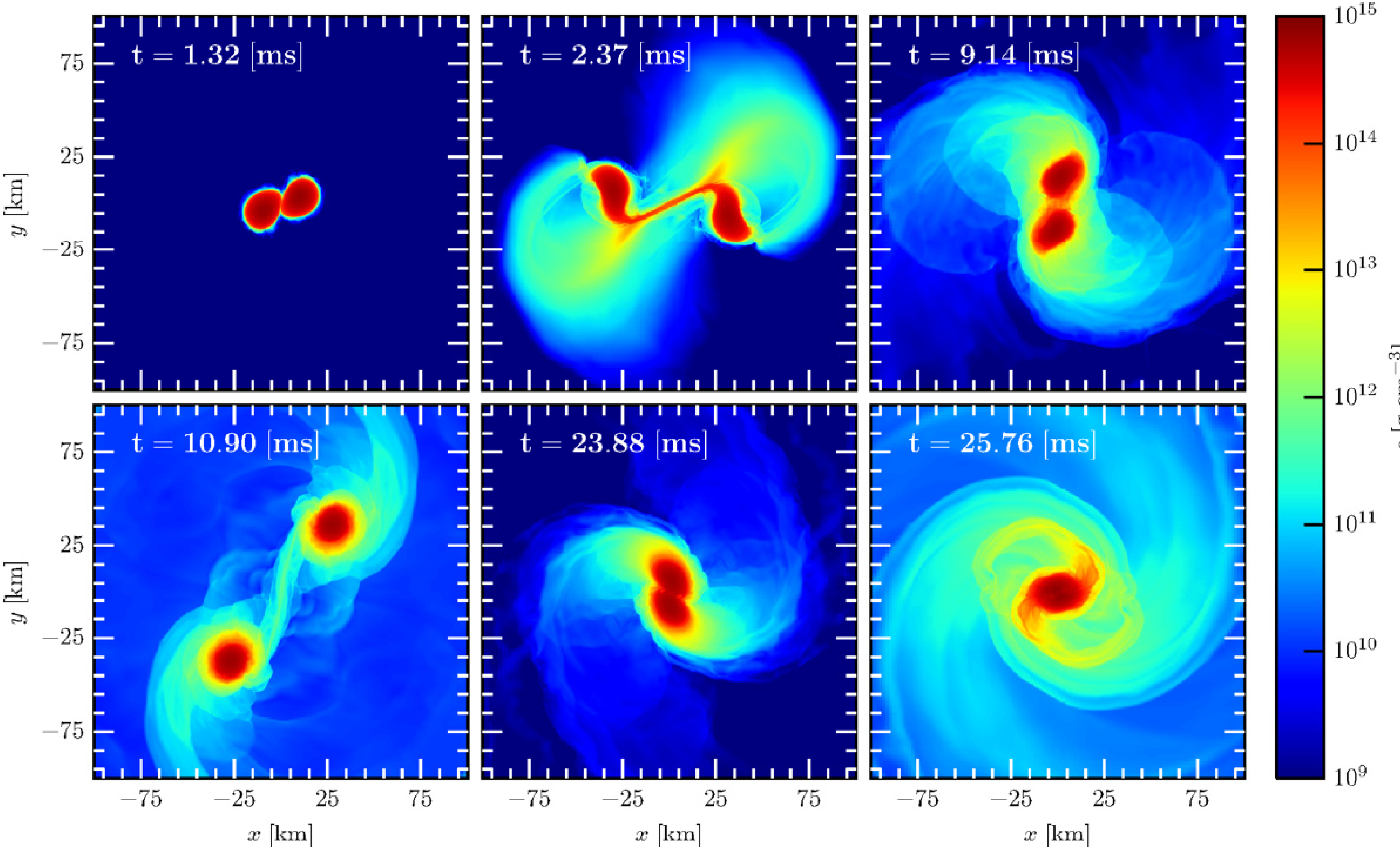


Figure 1. Rest-mass density (equation 4) in the orbital plane for the parabolic encounter simulation LK_RP10 at six different times. The NSs undergo three close encounters before merging. The panels show snapshots of the two stars immediately before and after each encounter. Tidal torques at the periastron result in large mass ejection and trigger oscillations in the NSs, cf. Fig. 2.

4

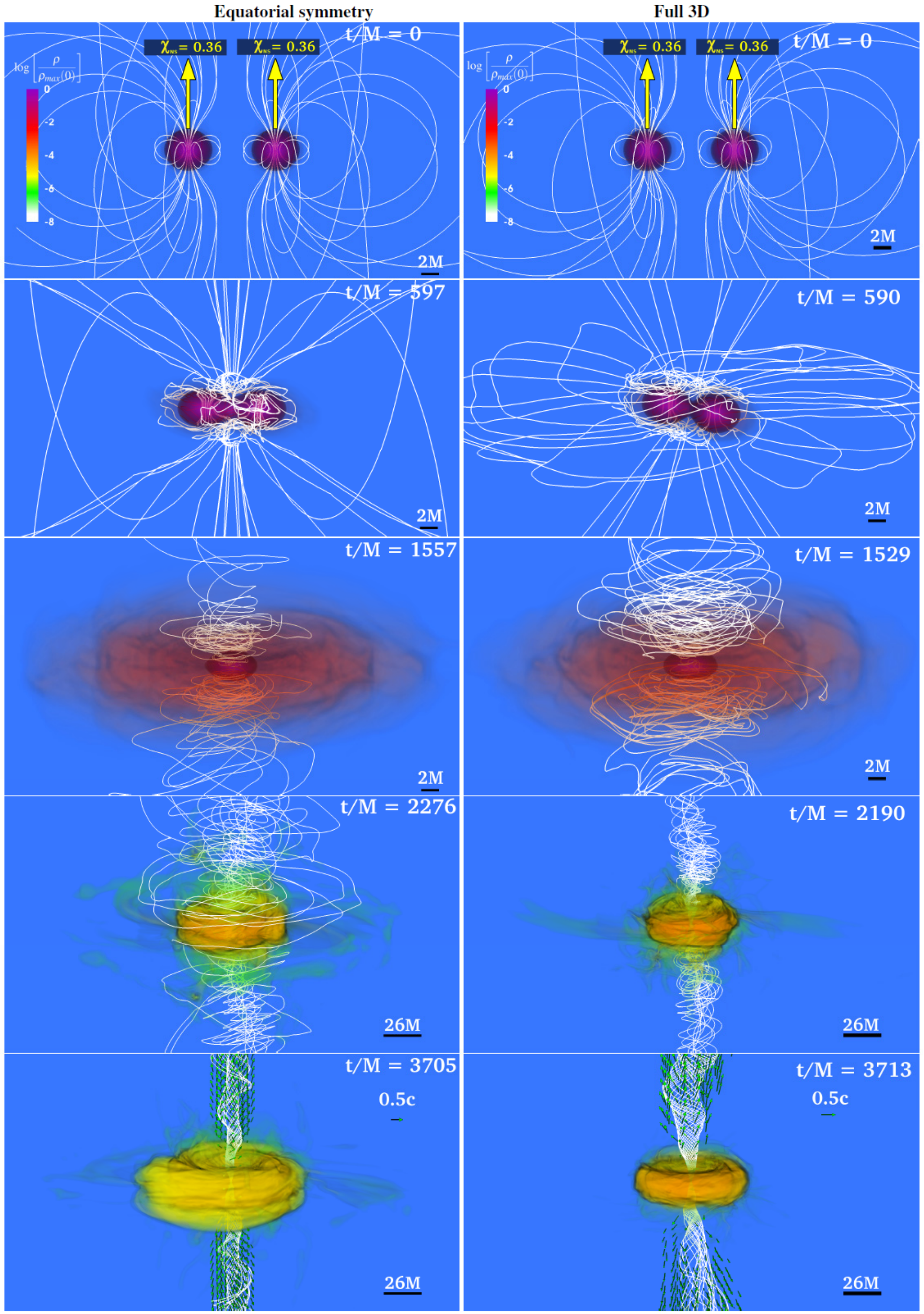
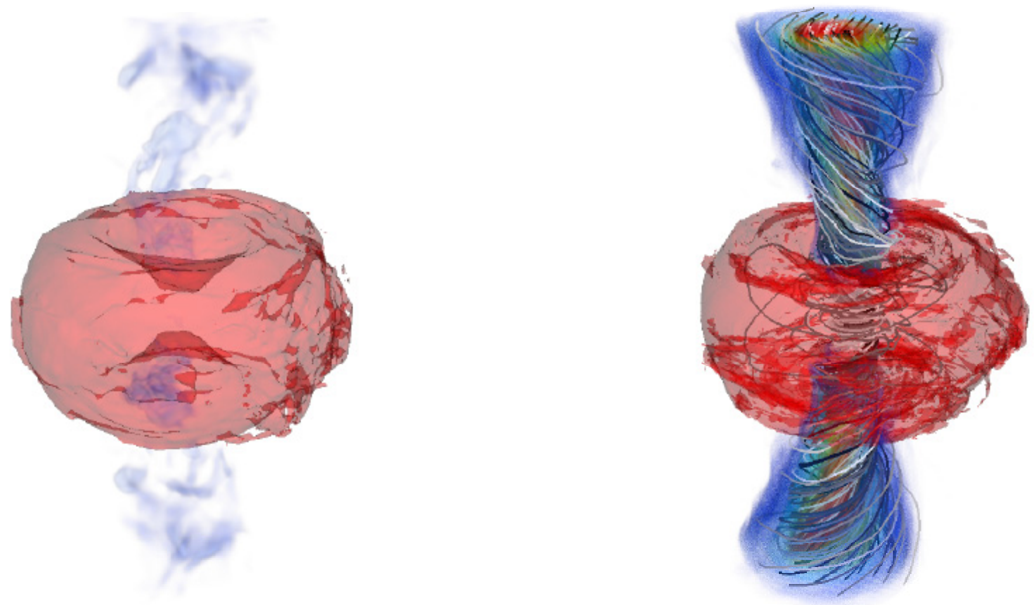


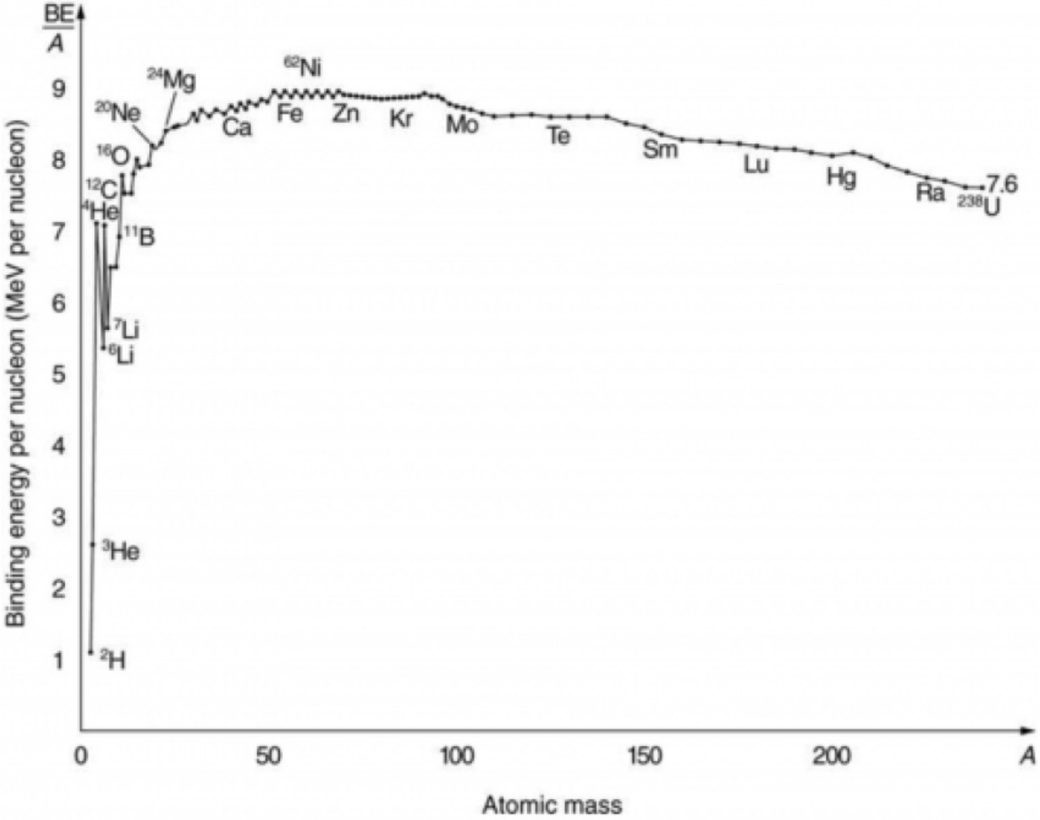
FIG. 1. Volume rendering of rest-mass density ρ_0, normalized to the initial maximum value $\rho_0^{\max} = 10^{14.78}(1.625\,M_\odot/M_{\rm NS})^2 {\rm g/cm}^3$ (log scale), at selected times for the Ali-Ali (Eq) case (left column) and the Ali-Ali case (right column). White lines represent the magnetic field lines, while arrows indicate plasma velocities. Bottom panels highlight the final configuration of the BH + disk remnant after an incipient jet has been launched. Here $M = 1.47 \times 10^{-2}(M_{\rm NS}/1.625M_\odot)$ms= $4.4288(M_{\rm NS}/1.625M_\odot)$km.

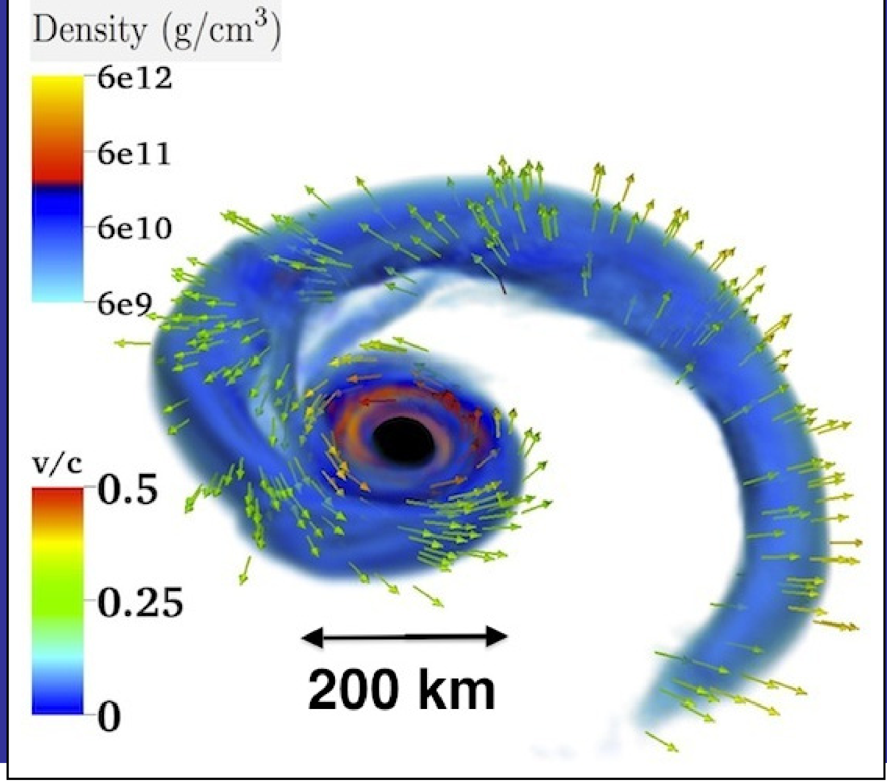
M. Ruiz, A. Tsokaros, S. L. Shapiro
arXiv:2001.09153v1

A MAGNETAR ENGINE FOR SHORT GRBS AND KILONOVAE

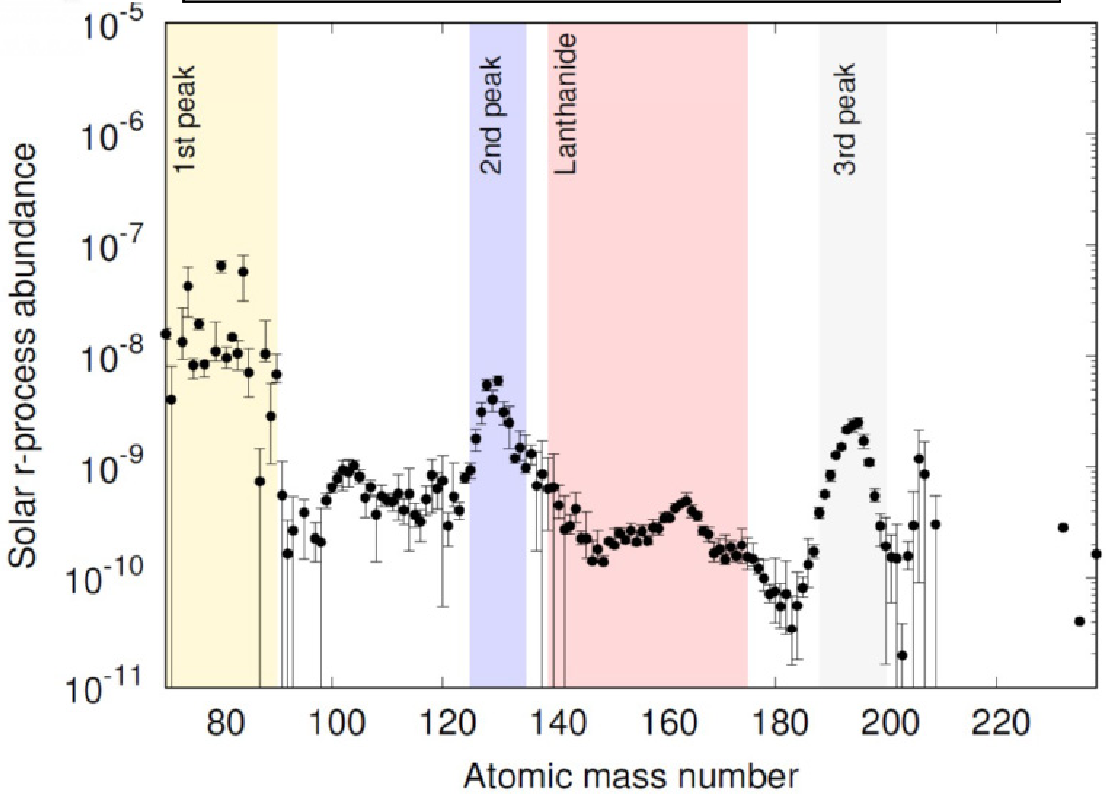


P. Mosta, D. Radice, R. Haas,
E. Schnetter, S. Bernuzzi
ApJL, 901, L37 (2020)

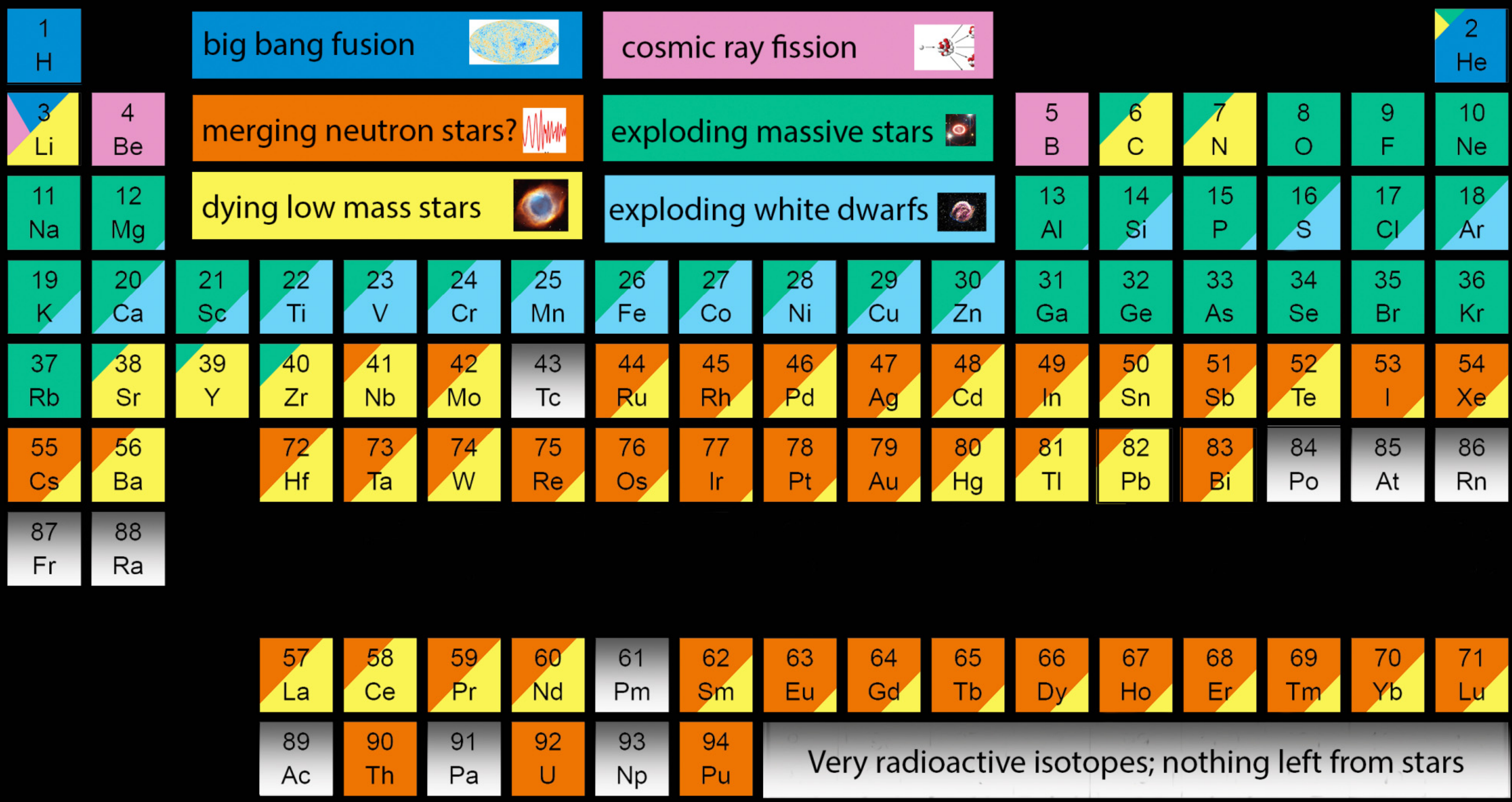




JOHN L. FRIEDMAN
International Journal of Modern Physics D
Foucart et al

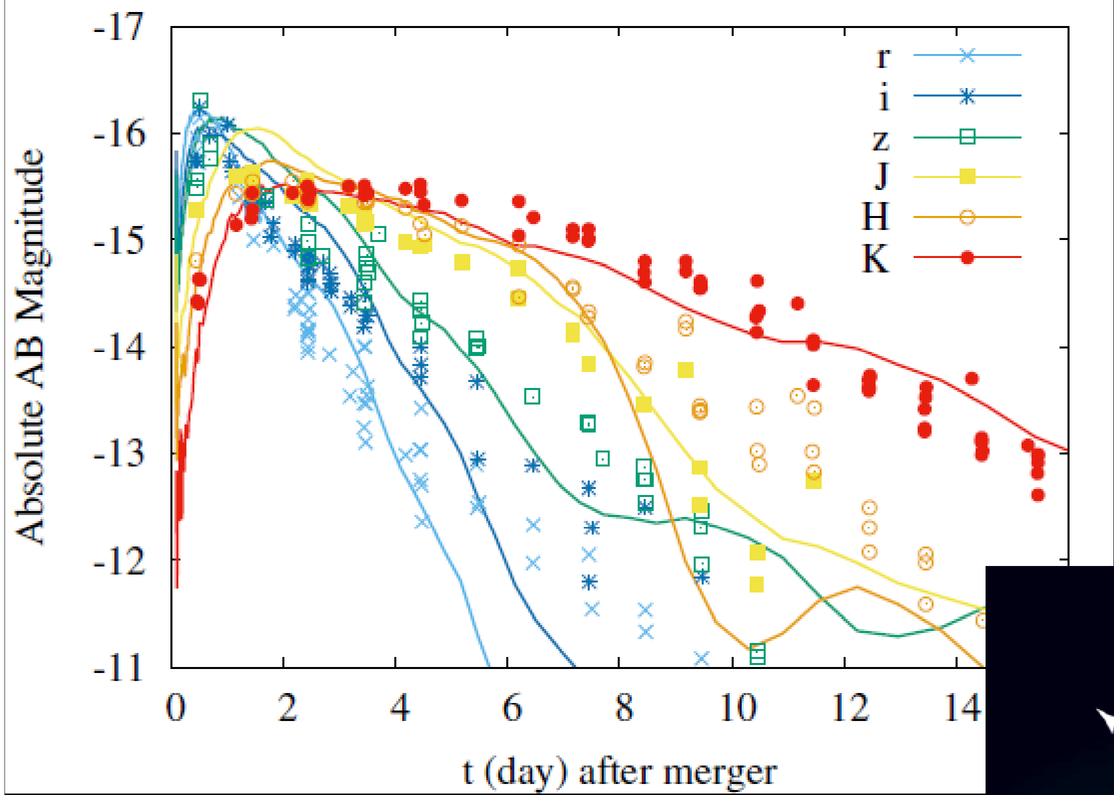


The Origin of the Solar System Elements



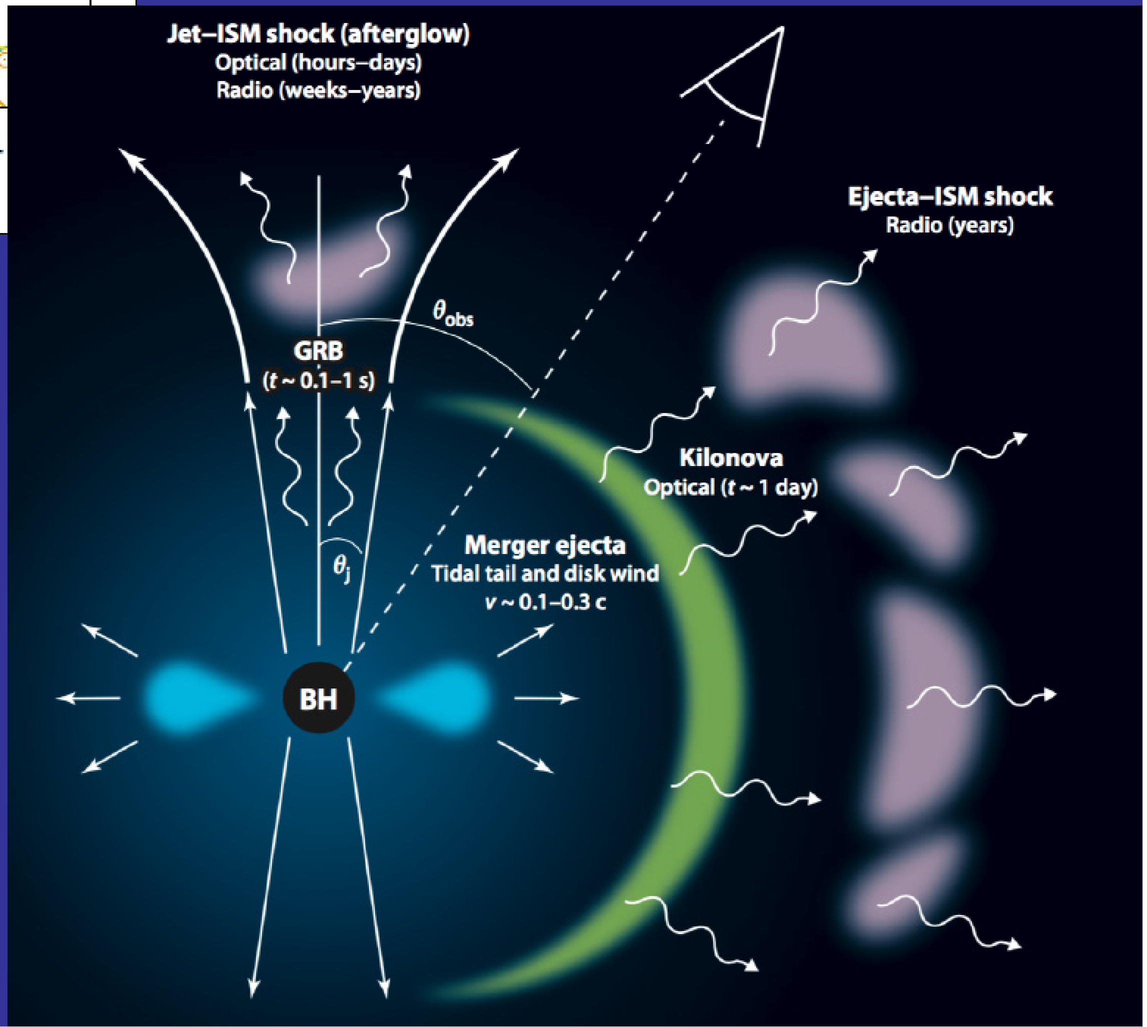
Graphic created by Jennifer Johnson
http://www.astronomy.ohio-state.edu/~jaj/nucleo/

Astronomical Image Credits:
ESA/NASA/AASNova

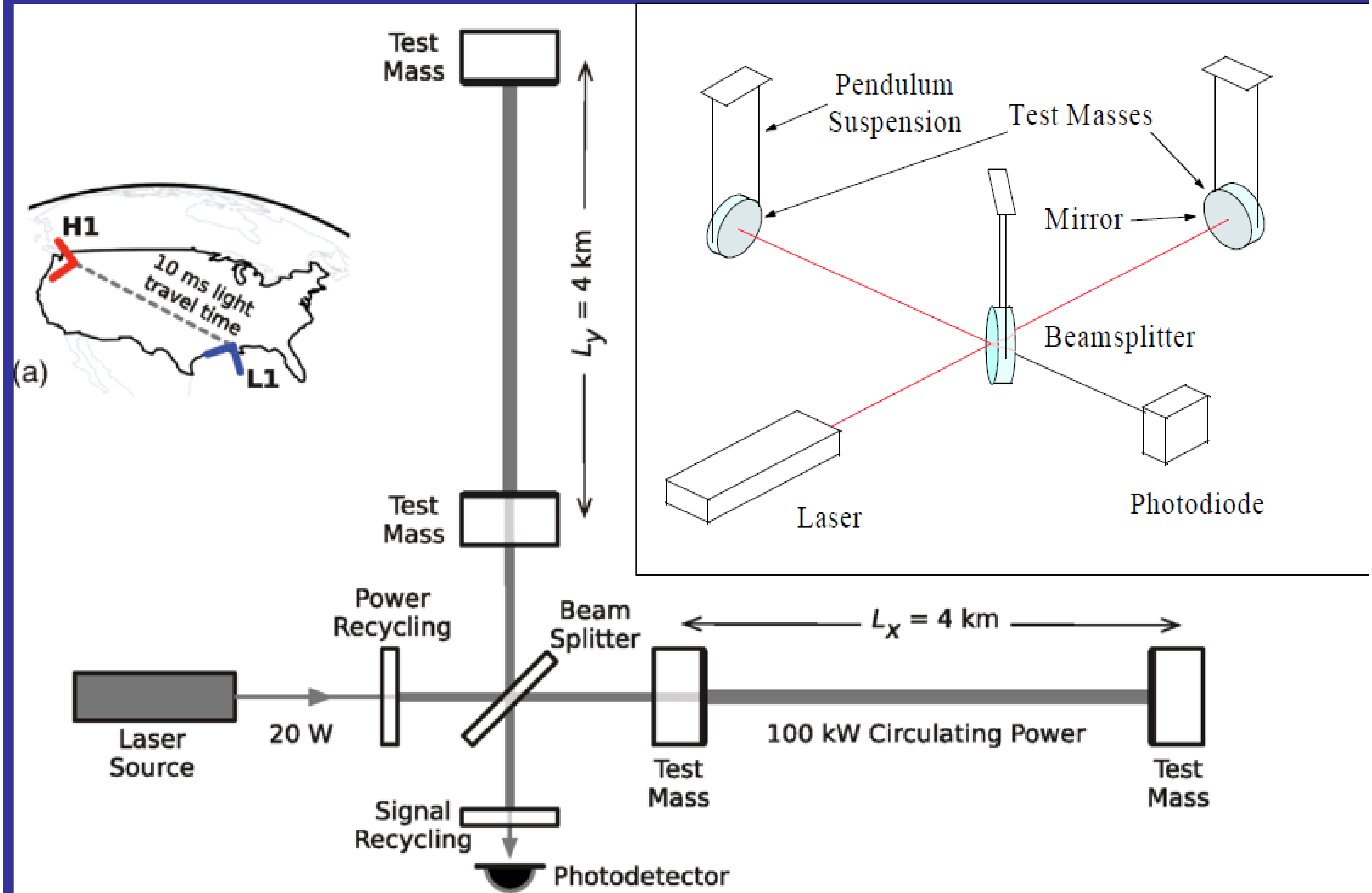


Living Rev. Relativ.
Kilonovae
Brian D. Metzger

Annu. Rev. Nucl. Part. Sci. 2019. 69:126
M. Shibata and K. Hotokezaka



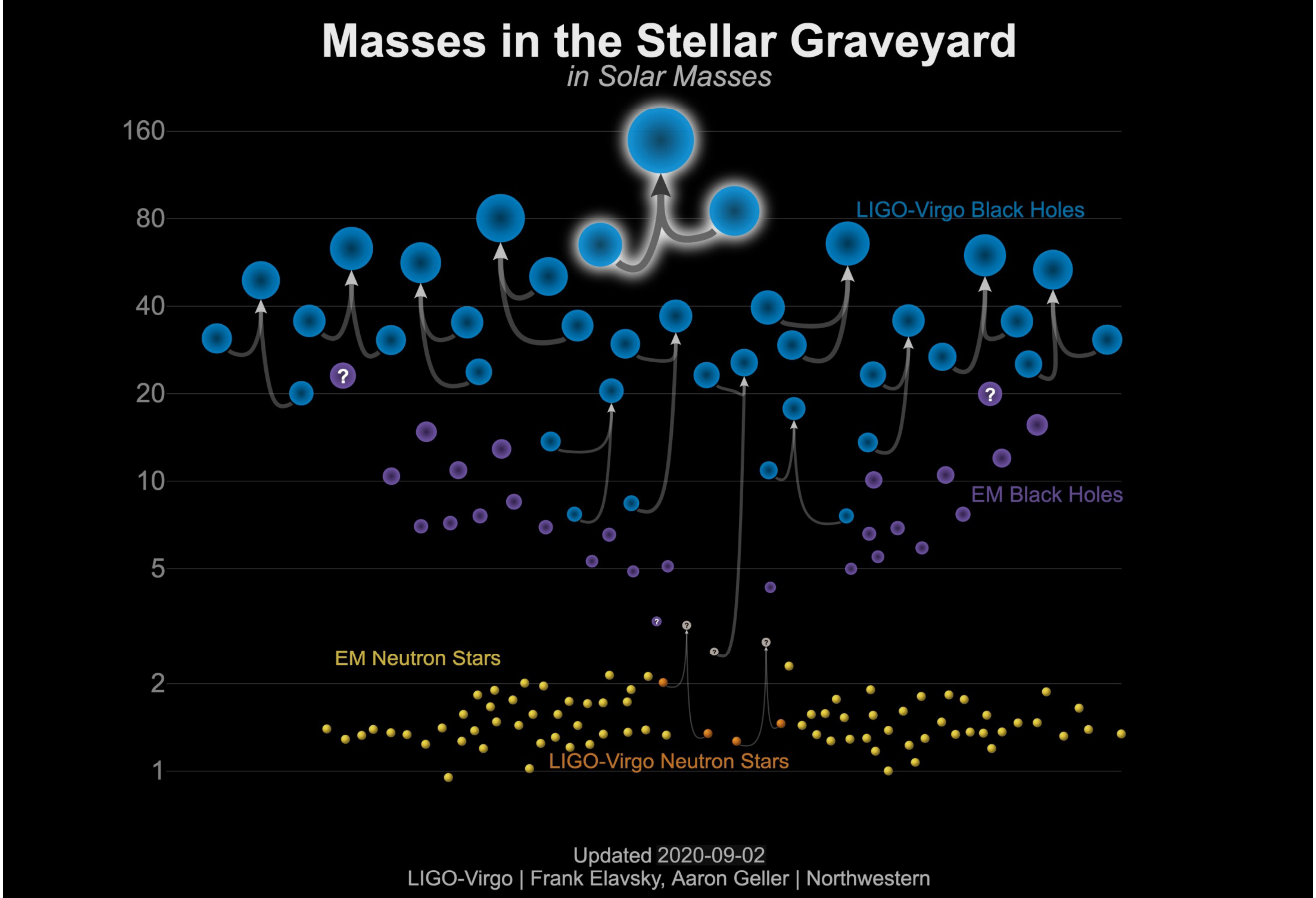
Гравитационные антенны LIGO-Virgo и событие 17.08.17



H1
10 ms light travel time
L1
(a)
Test Mass
Test Mass
L_y = 4 km
Power Recycling
Beam Splitter
L_x = 4 km
Laser Source
20 W
Test Mass
100 kW Circulating Power
Test Mass
Signal Recycling
Photodetector
Pendulum Suspension
Test Masses
Mirror
Beamsplitter
Laser
Photodiode


Virgo


LIGO



14 сентября 2015 года - первое детектирование ГВ: слияние черных дыр по 30 Ms

https://www.nature.com/news/rumours-swell-over-new-kind-of-gravitational-wave-sighting-1.22482

NATURE | EXPLAINER

Rumours swell over new kind of gravitational-wave sighting

Gossip over potential detection of colliding neutron stars has astronomers in a tizzy.

Davide Castelvecchi

24 August 2017 | Updated: 25 August 2017, 25 August 2017

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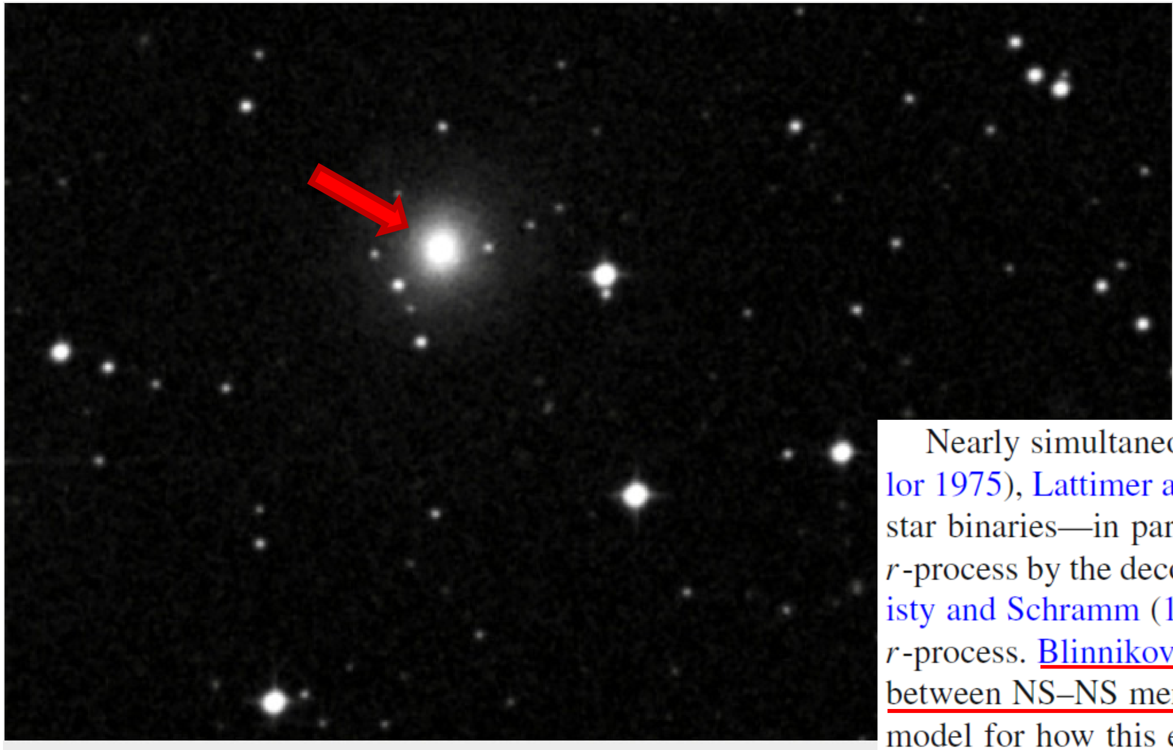


The galaxy NGC 4993 (fuzzy bright spot) in the constellation Hydra, where dete
have spotted gravitational waves from a neutron star merger.

Событие GW170817

Галактика NGC 4993
Расстояние 40 млн пс

Гамма-всплеск
GRB 170817A

Living Rev Relativ (2017) 20:3
DOI 10.1007/s41114-017-0006-z

REVIEW ARTICLE

Kilonovae

Brian D. Metzger[1]

Nearly simultaneous with the discovery of the first binary pulsar (Hulse and Taylor 1975), Lattimer and Schramm (1974, 1976) proposed that the merger of compact star binaries—in particular the collision of BH–NS systems—could give rise to the r-process by the decompression of highly neutron-rich ejecta (Meyer 1989). Symbalisty and Schramm (1982) were the first to suggest NS–NS mergers as the site of the r-process. Blinnikov et al. (1984) and Paczyński (1986) first suggested a connection between NS–NS mergers and GRBs. Eichler et al. (1989) presented a more detailed model for how this environment could give rise to a GRB (albeit one which differs significantly from the current view). Davies et al. (1994) performed the first numerical simulations of mass ejection from merging neutron stars, finding that ∼2% of the binary mass was unbound during the process. Freiburghaus et al. (1999) presented the first explicit calculations showing that the ejecta properties extracted from a hydro-

GW170817

Слияние двух нейтронных звезд

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

H L V

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.

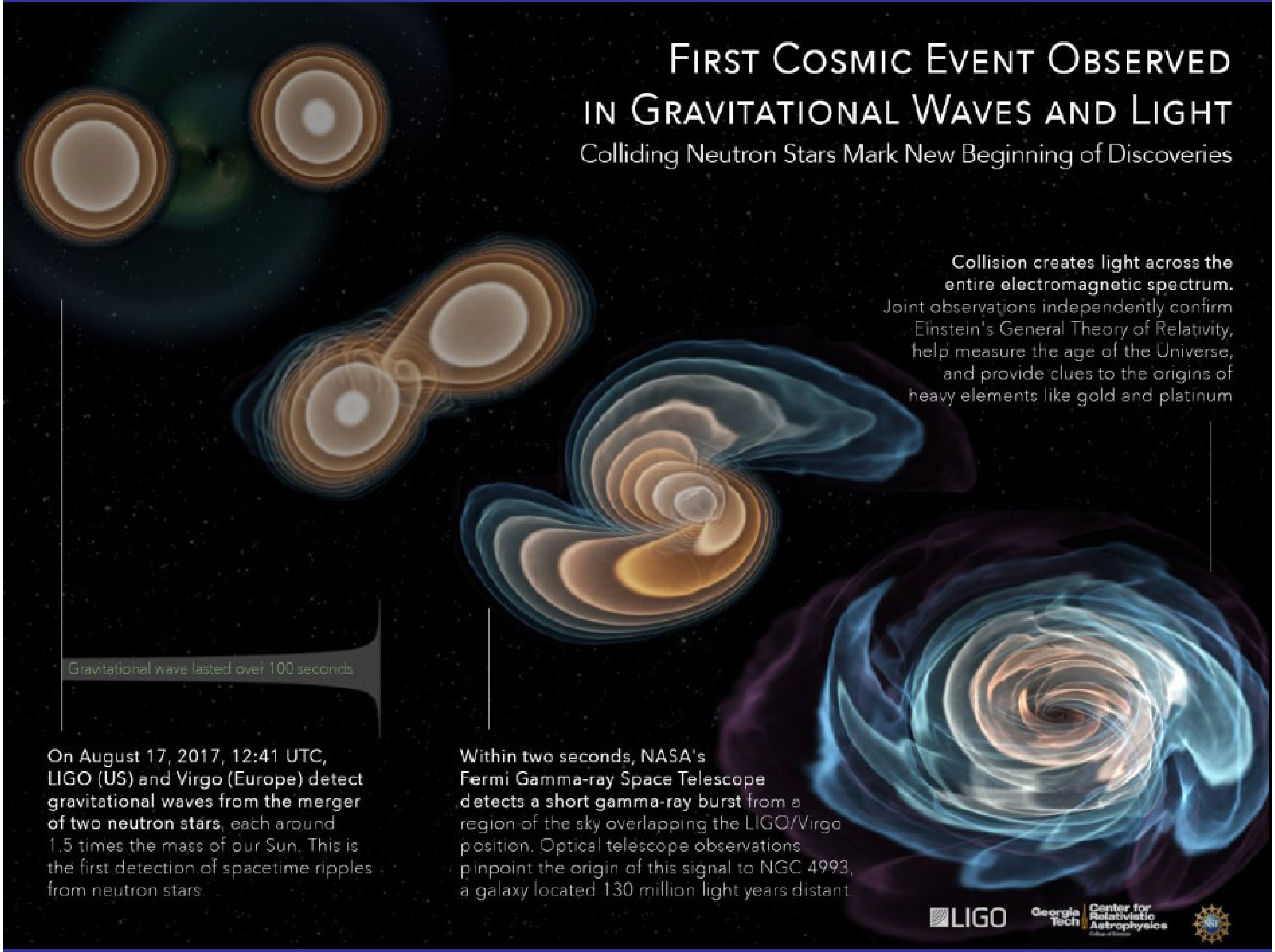
Регистрация гравитационного излучения от слияния нейтронных звезд позволяет нам узнать больше о строении этих необычных объектов

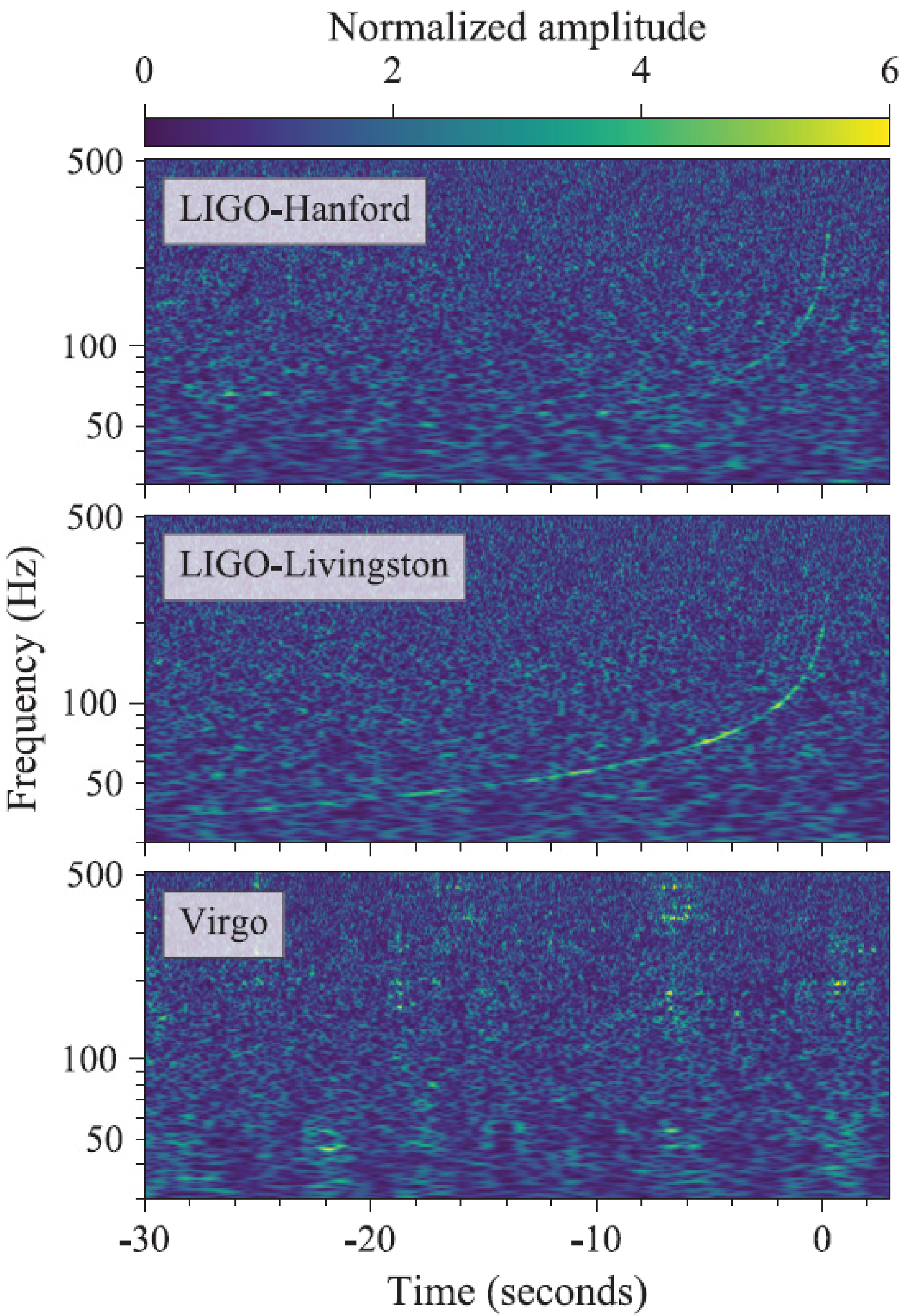
Регистрация этого события различными детекторами подтверждает, что слияние нейтронных звезд может порождать вспышки гамма излучения

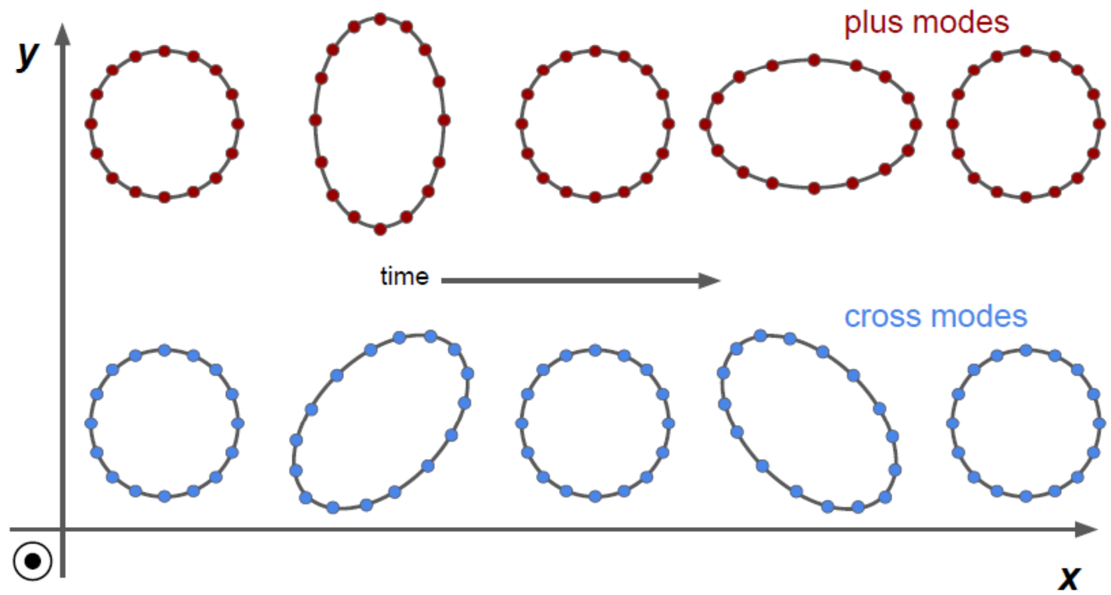
Au

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


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
Gravitational wave lasted over 100 seconds
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





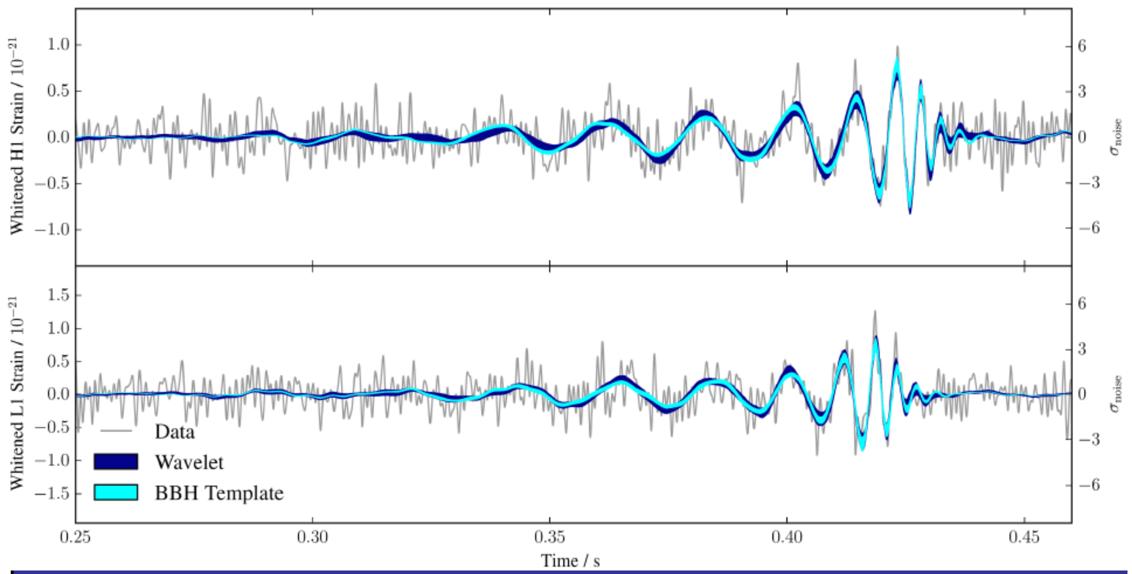
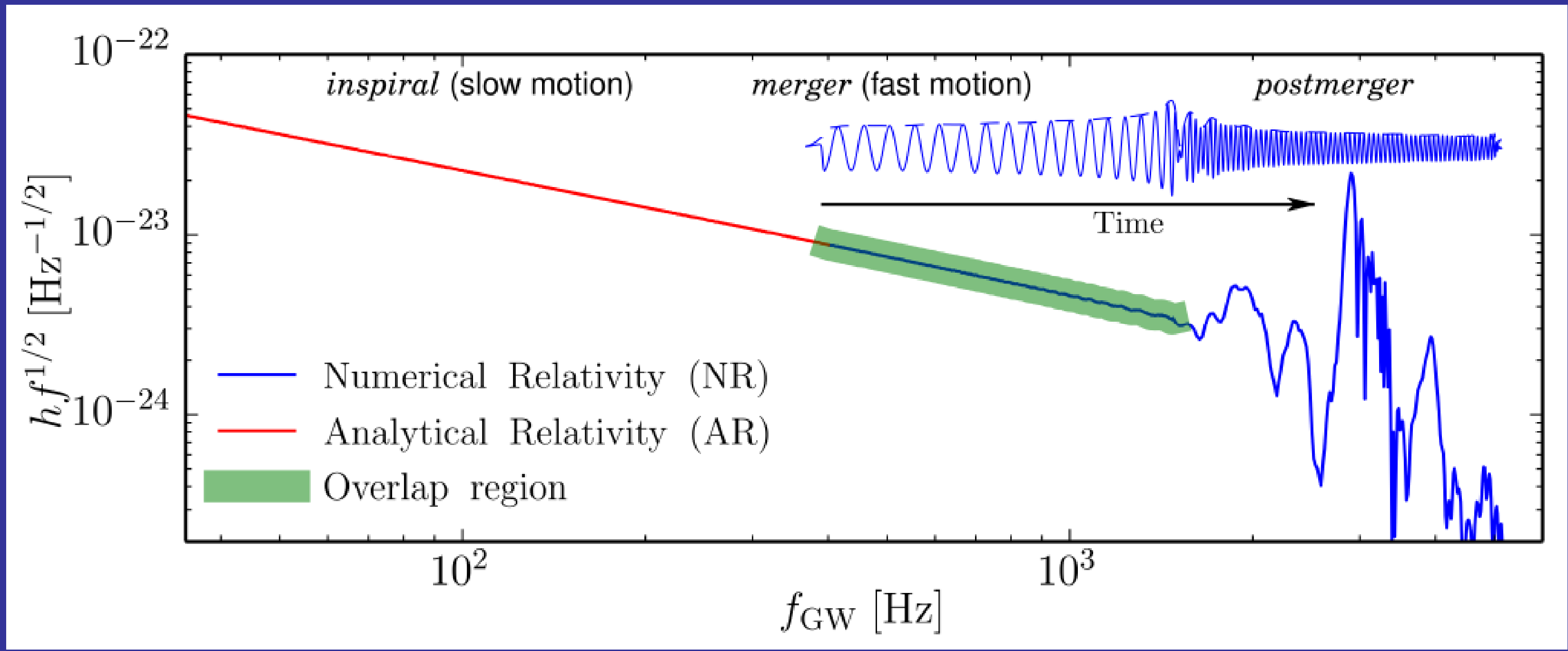
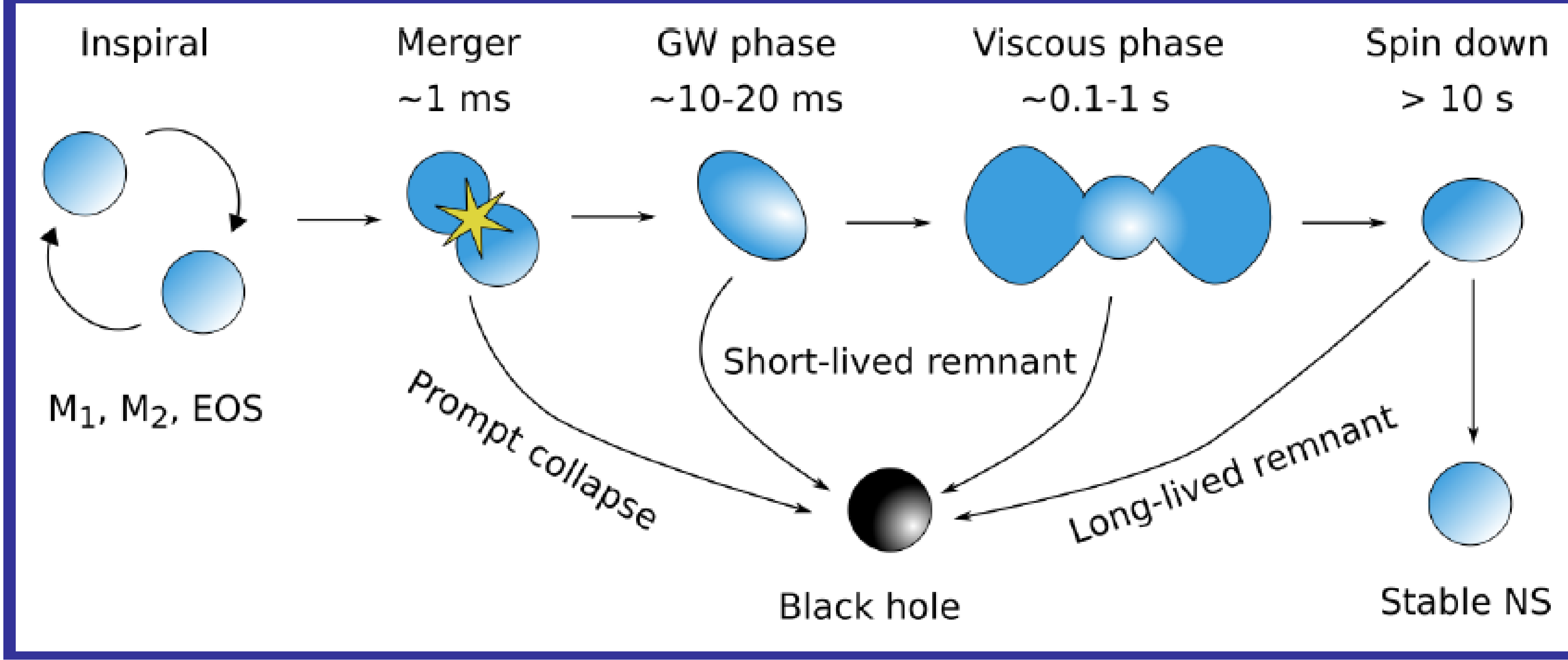
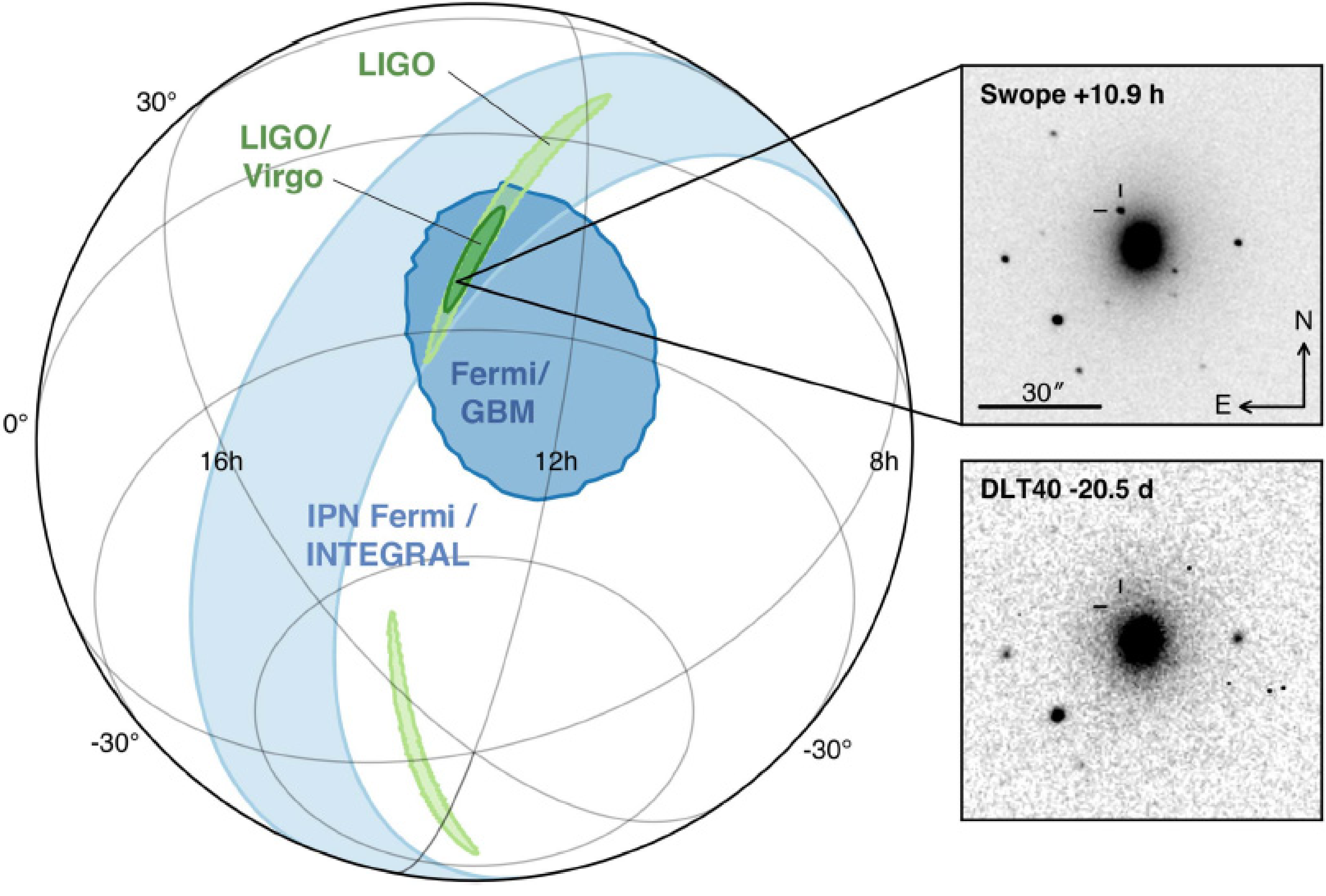


FIG. 1. Time-frequency representations [65] of data containing the gravitational-wave event GW170817, observed by the LIGO-Hanford (top), LIGO-Livingston (middle), and Virgo (bottom) detectors. Times are shown relative to August 17, 2017 12:41:04

D.Radice, S. Bernuzzi, A. Perego
Annual Reviews of Nuclear and Particle Science





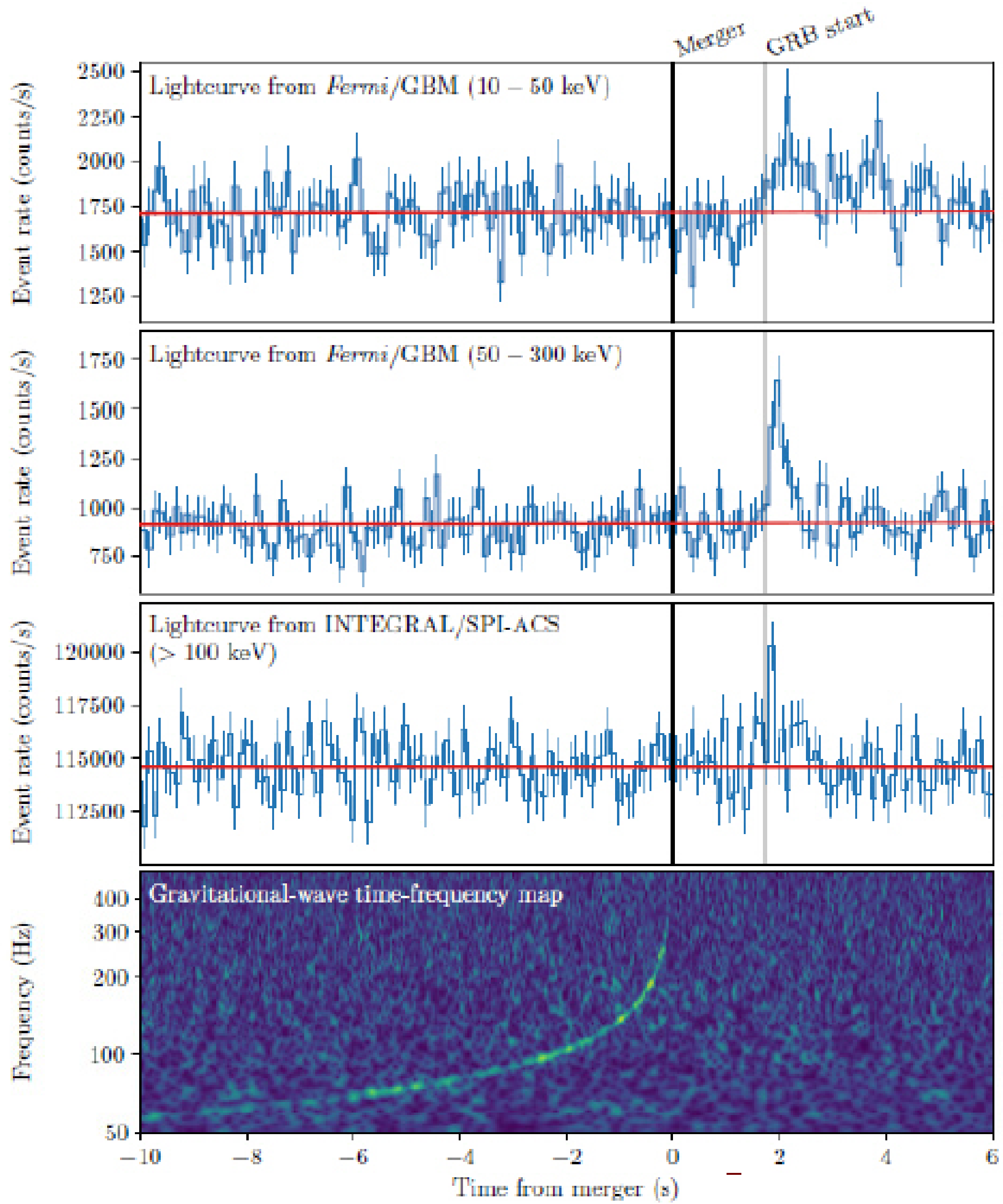


LIGO
LIGO/
Virgo
30°
0°
16h
12h
8h
-30°
-30°
Fermi/
GBM
IPN Fermi /
INTEGRAL
Swope +10.9 h
30″
N
E
DLT40 -20.5 d

INTEGRAL and NASA's Fermi satellite

INTErnational
Gamma-Ray
Astrophysics
Laboratory
(INTEGRAL)

The Fermi
Gamma-ray
Space
Telescope



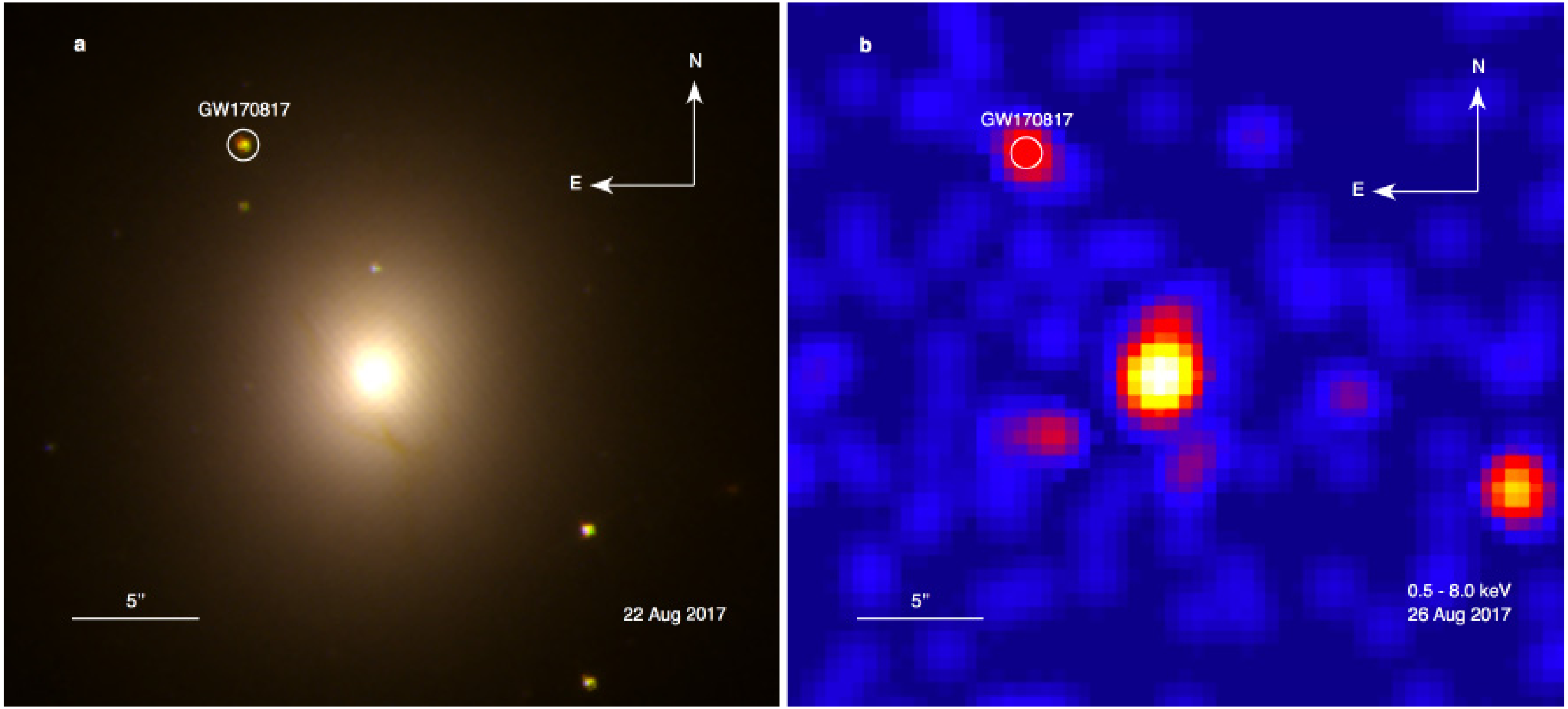
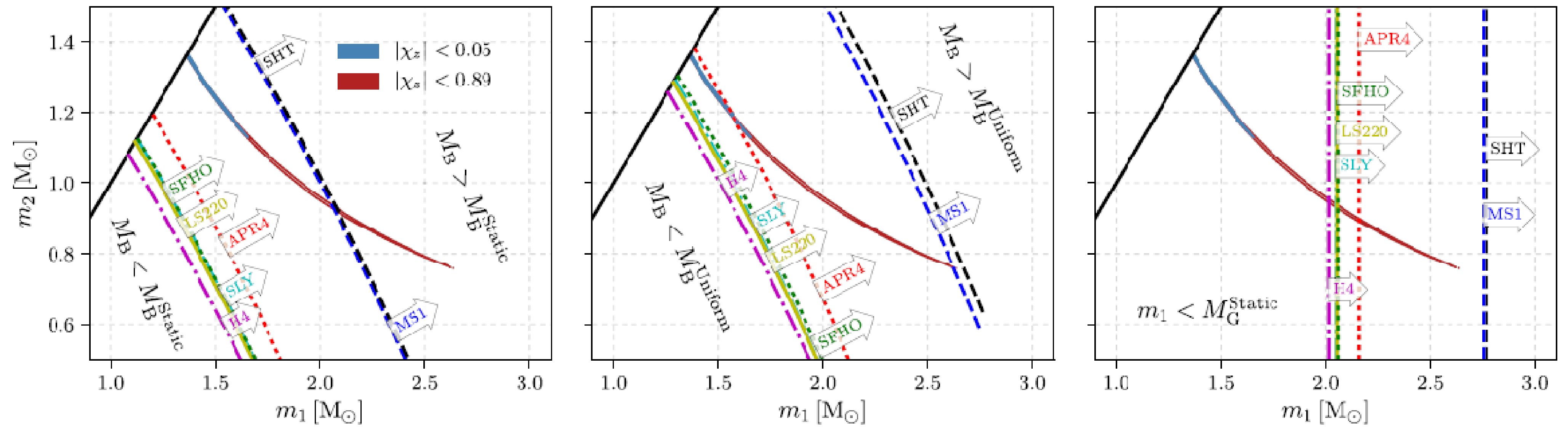


Figure 1: Optical/Infrared and X-ray images of the counterpart of GW170817

a *Hubble Space Telescope* observations show a bright and red transient in the early-type galaxy NGC 4993, at a projected physical offset of ~2 kpc from its nucleus. A similar small offset is observed in some (~25%) short GRBs[5]. Dust lanes are visible in the inner regions, suggestive of a past merger activity (see Methods). **b** *Chandra* observations revealed a faint X-ray source at the position of the optical/IR transient. X-ray emission from the galaxy nucleus is also visible.



$$\mathrm{M} = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}$$

Chirp mass

high-spin:

$m_1 \in (1.36 \div 2.26) M_\odot$

$m_2 \in (0.86 \div 1.36) M_\odot$

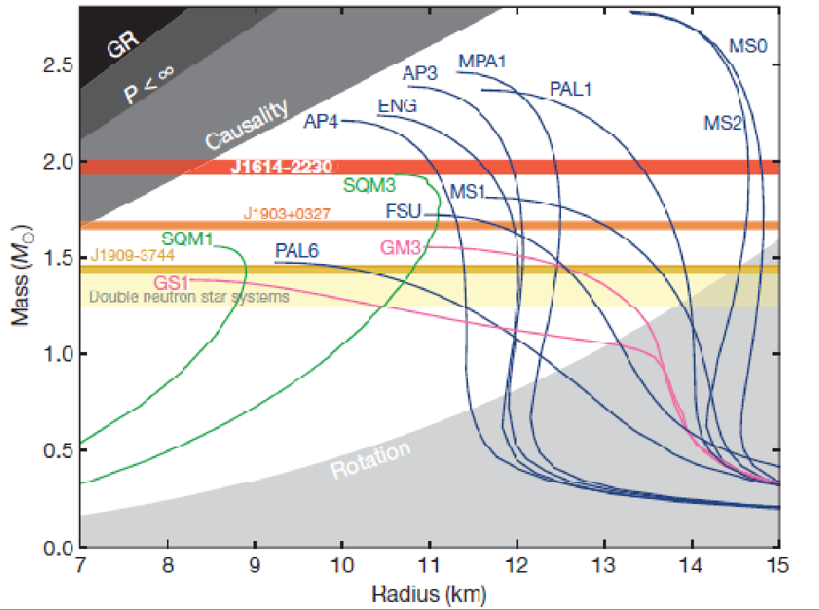
$m_{tot} = 2.82^{+0.47}_{-0.09} M_\odot$

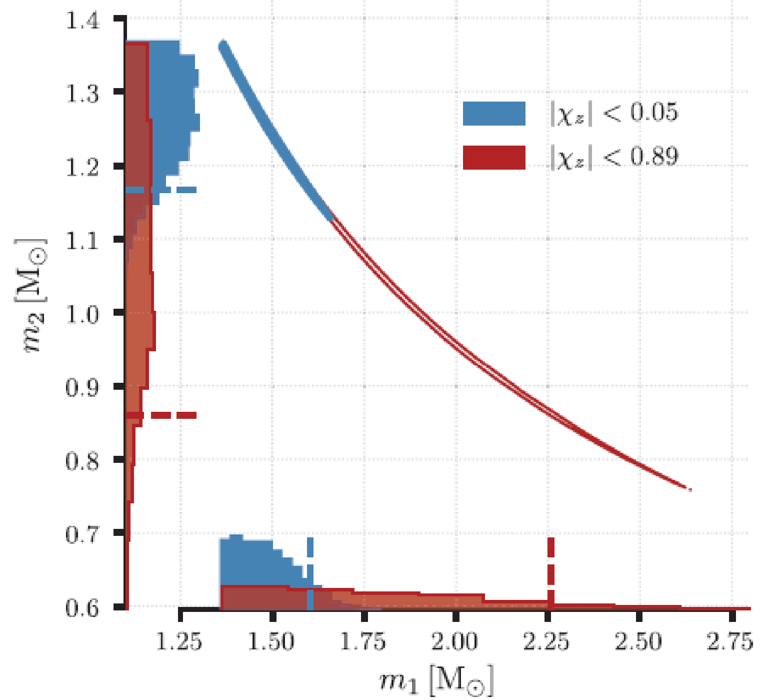
low-spin:

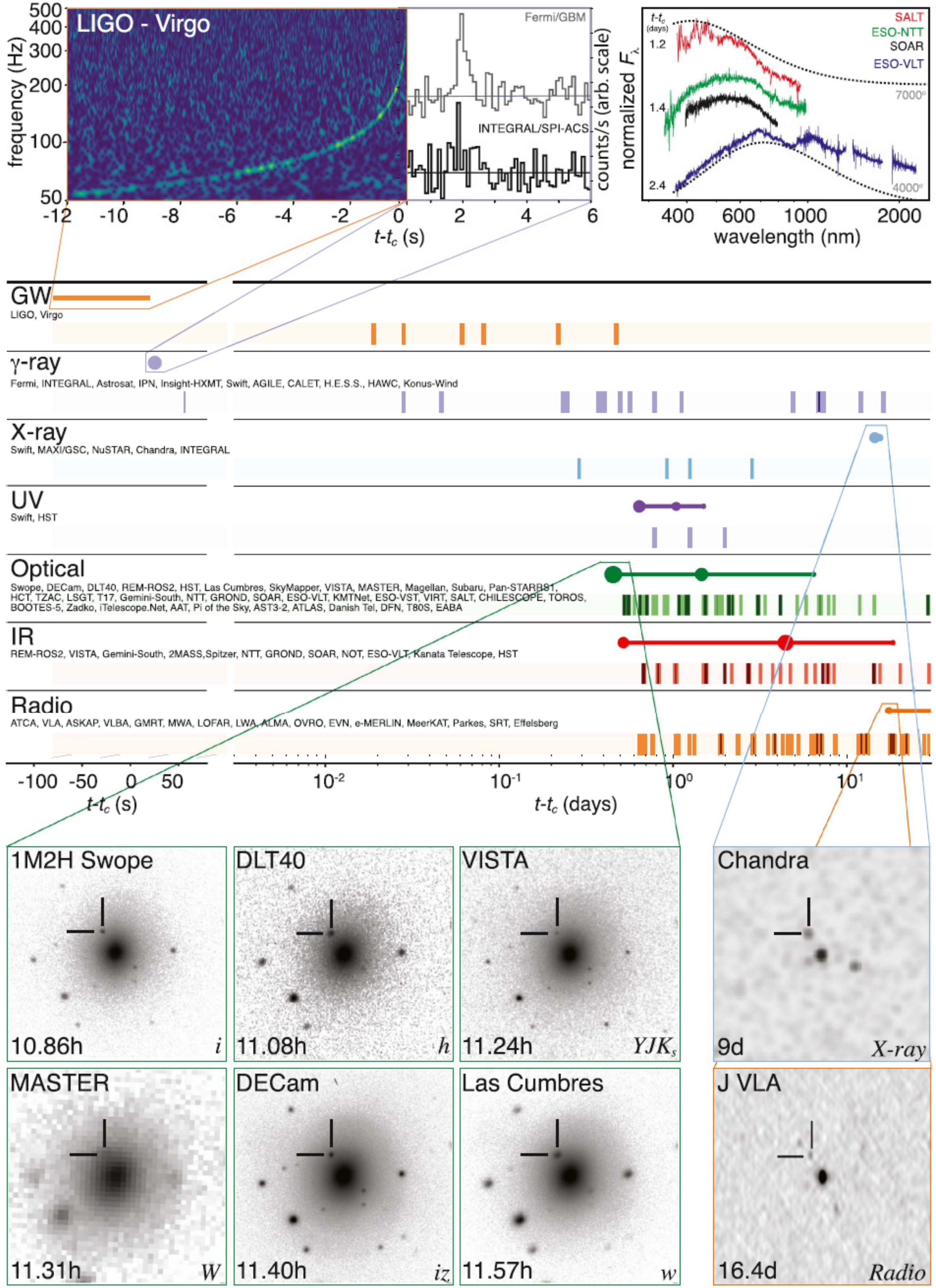
$m_1 \in (1.36 \div 1.60) M_\odot$

$m_2 \in (1.17 \div 1.36) M_\odot$

$m_{tot} = 2.74^{+0.04}_{-0.01} M_\odot$







LIGO - Virgo
frequency (Hz)
500
400
300
200
100
50
-12
-10
-8
-6
-4
-2
0
2
4
6
t-tc (s)
Fermi/GBM
INTEGRAL/SPI-ACS
counts/s (arb. scale)
normalized Fλ
t-tc (days)
1.2
1.4
2.4
SALT
ESO-NTT
SOAR
ESO-VLT
7000°
4000°
400
600
1000
2000
wavelength (nm)
GW
LIGO, Virgo
γ-ray
Fermi, INTEGRAL, Astrosat, IPN, Insight-HXMT, Swift, AGILE, CALET, H.E.S.S., HAWC, Konus-Wind
X-ray
Swift, MAXI/GSC, NuSTAR, Chandra, INTEGRAL
UV
Swift, HST
Optical
Swope, DECam, DLT40, REM-ROS2, HST, Las Cumbres, SkyMapper, VISTA, MASTER, Magellan, Subaru, Pan-STARRS1, HCT, TZAC, LSGT, T17, Gemini-South, NTT, GROND, SOAR, ESO-VLT, KMTNet, ESO-VST, VIRT, SALT, CHILESCOPE, TOROS, BOOTES-5, Zadko, iTelescope.Net, AAT, Pi of the Sky, AST3-2, ATLAS, Danish Tel, DFN, T80S, EABA
IR
REM-ROS2, VISTA, Gemini-South, 2MASS,Spitzer, NTT, GROND, SOAR, NOT, ESO-VLT, Kanata Telescope, HST
Radio
ATCA, VLA, ASKAP, VLBA, GMRT, MWA, LOFAR, LWA, ALMA, OVRO, EVN, e-MERLIN, MeerKAT, Parkes, SRT, Effelsberg
-100
-50
0
50
t-tc (s)
10^-2
10^-1
10^0
10^1
t-tc (days)
1M2H Swope
10.86h
i
DLT40
11.08h
h
VISTA
11.24h
YJKs
Chandra
9d
X-ray
MASTER
11.31h
W
DECam
11.40h
iz
Las Cumbres
11.57h
w
J VLA
16.4d
Radio

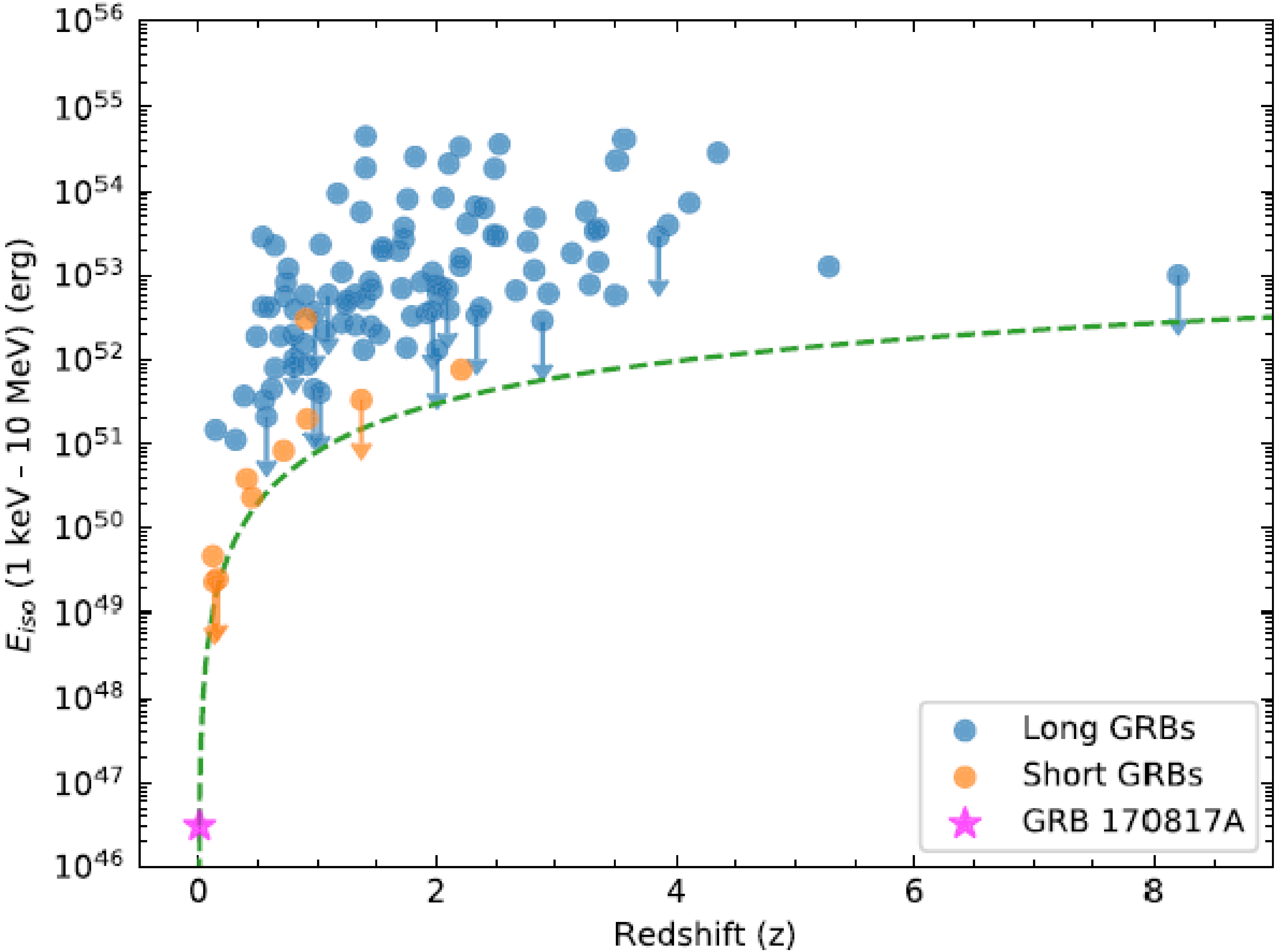
Важное о GW170817

- 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
- 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

Пекулярность

GRB170817A



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

GW170817–the first observed neutron star merger and its kilonova: implications for the astrophysical site of the r-process

Daniel M. Siegel[1,2]

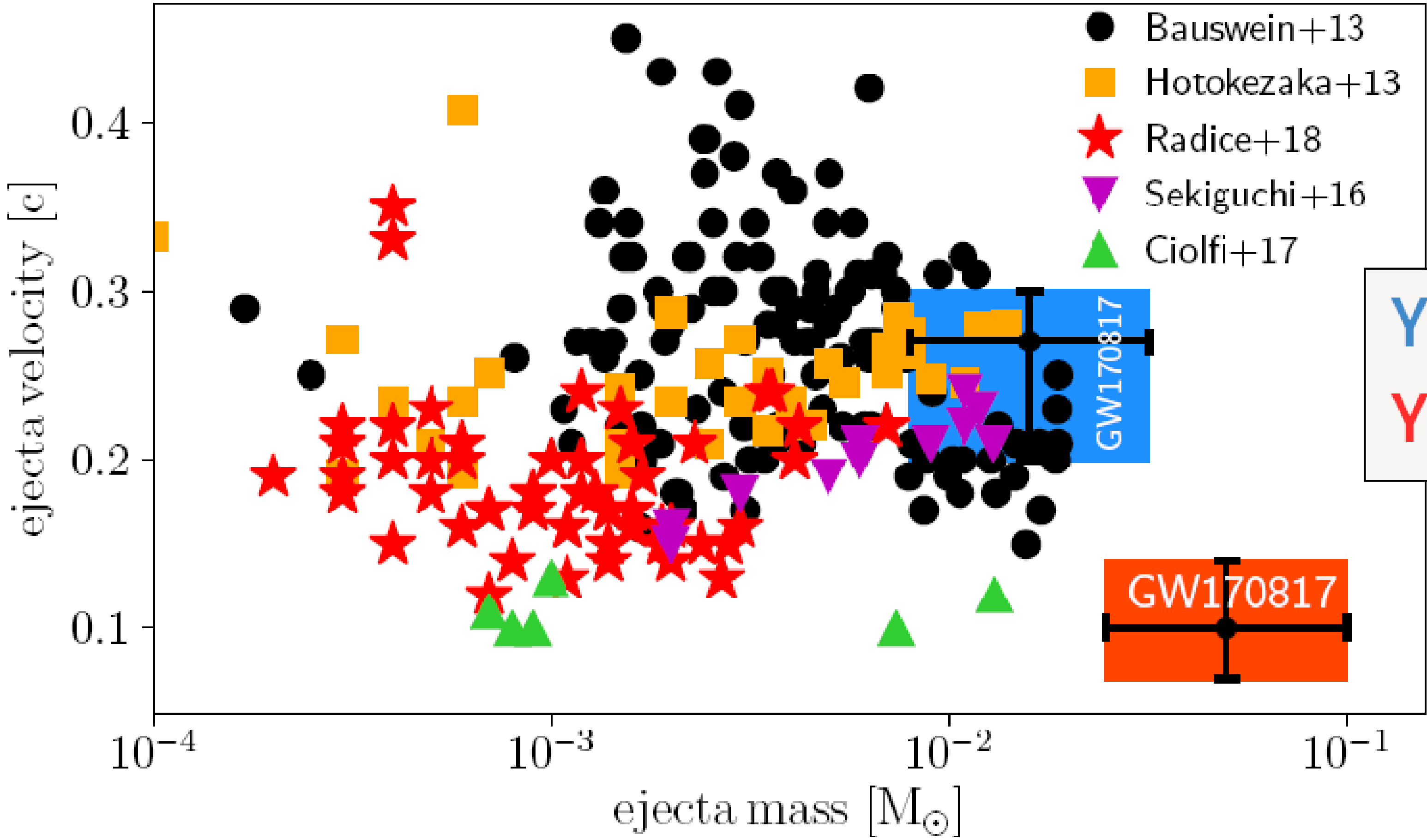
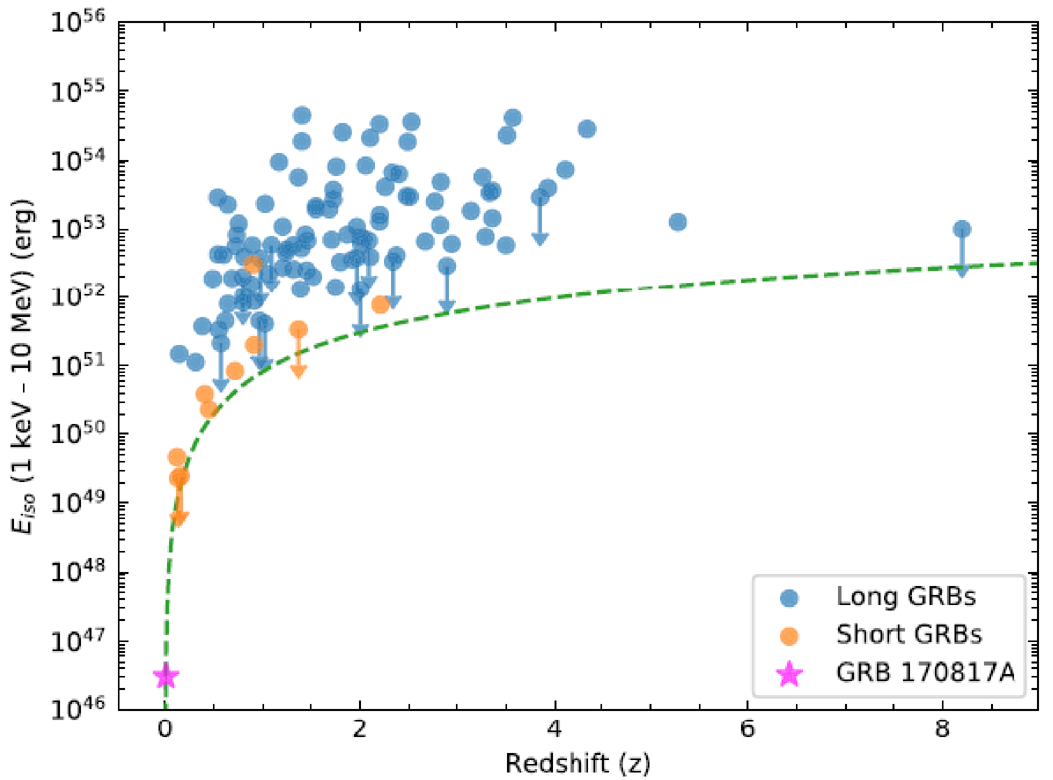
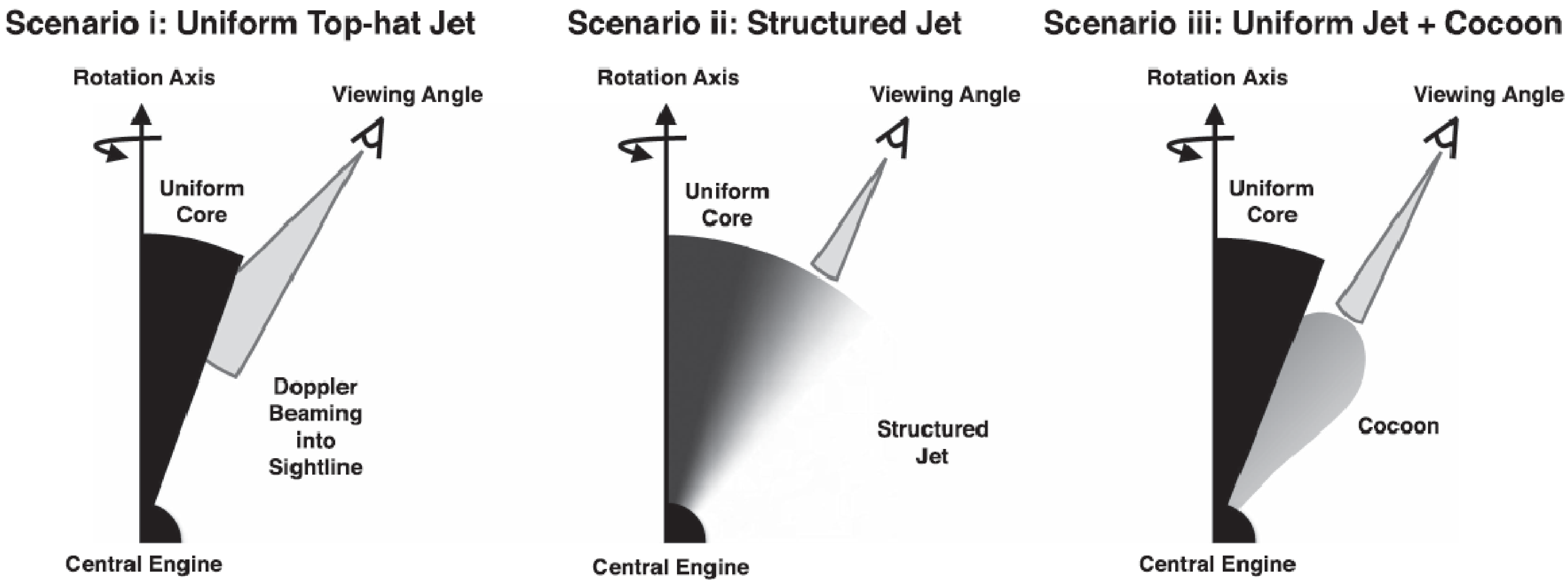


Figure 1. Dynamical ejecta masses and velocities from various binary neutron star merger simulations encompassing different numerical techniques, various equations of state, binary binary mass ratios 0.65 – 1.0, effects of neutrinos and magnetic fields [77,78,64,73,65], together with the corresponding ejecta parameters inferred from the 'blue' and 'red' kilonova of GW170817 (see the text for details).

Y_e >0.2
Y_e <0.2


E_{iso} (1 keV - 10 MeV) (erg)
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

Альтернатива:

модель обдирания (stripping)

THE ASTROPHYSICAL JOURNAL, 215: 311–322, 1977 July 1

EVOLUTION OF CLOSE NEUTRON STAR BINARIES

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Observatory and Department of Physics, Yale University
Received 1976 November 11; revised 1976 December 17

ABSTRACT

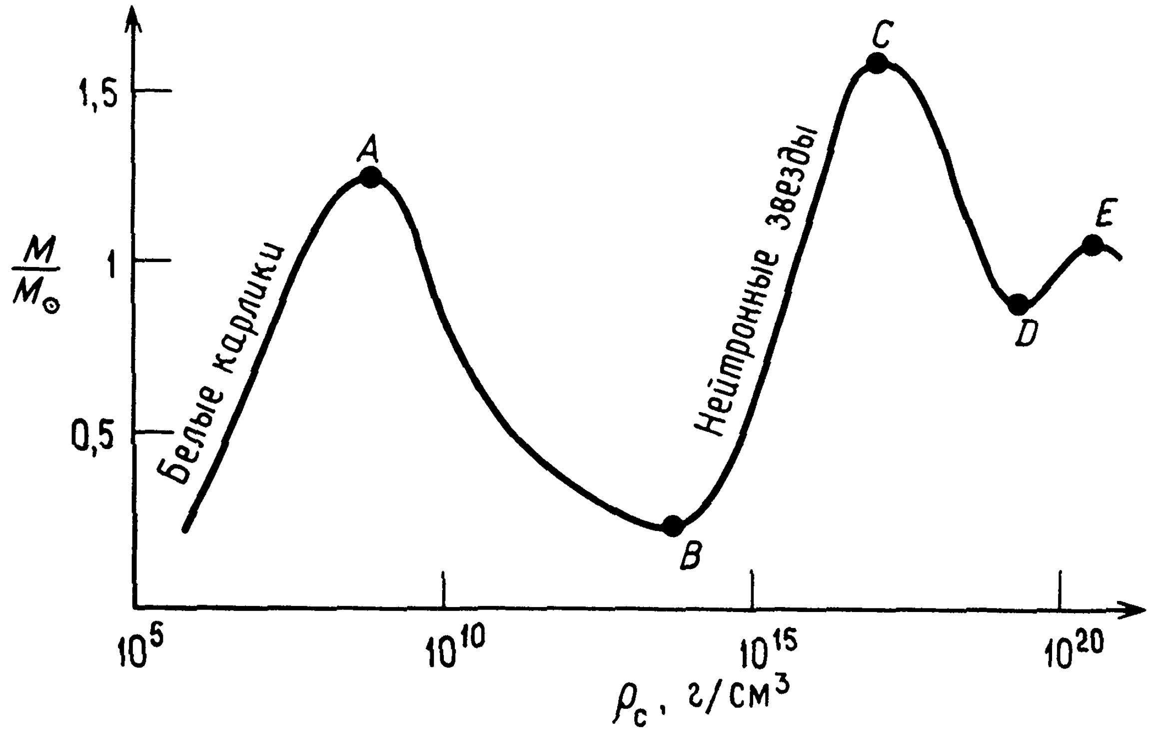
In binary systems consisting of two neutron stars, the orbit decays by gravitational radiation. A crude model shows that the less massive star may suffer either immediate tidal disruption or slow mass stripping when it reaches its Roche radius, depending on the initial masses and on the details of mass exchange or mass loss. Typical energy releases are 4×10^{52} ergs in gravitational waves before the onset of stripping, 2×10^{52} ergs in gravitational waves after the onset of stripping, 2×10^{53} ergs in neutrinos after the onset of stripping. The stripping process always ends in tidal disruption of the less massive star after a few seconds or a few hundred revolutions.

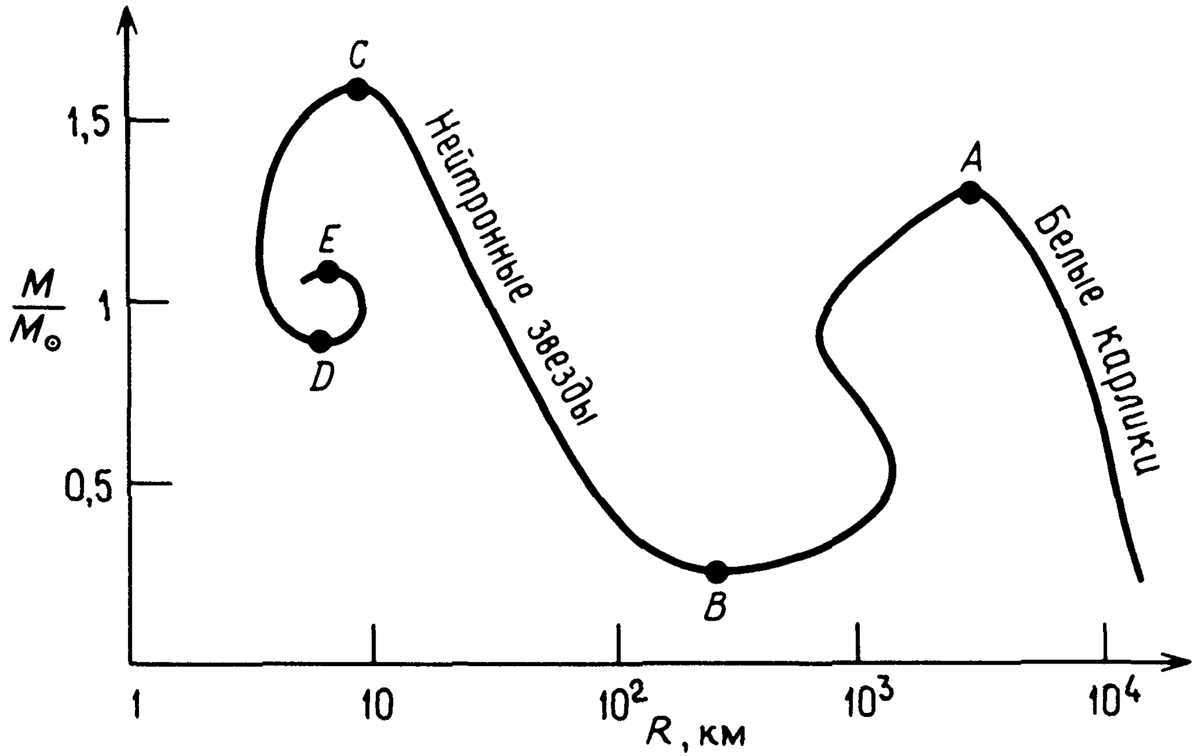
As the endpoint of binary stellar evolution, such events are estimated to occur only every ~ 100 yr out to a radius of 15 Mpc, and are thus less important than supernovae as sources of gravitational waves; the observed wave amplitude would be $h \sim 10^{-21}$. Such events may occur in Type II supernovae, if the collapsing stellar core rotates rapidly enough to fission into two neutron stars.

Subject headings: gravitation — stars: binaries — stars: evolution — stars: neutron

Stuart L. Shapiro
Saul A. Teukolsky

Black Holes, White Dwarfs, and Neutron Stars





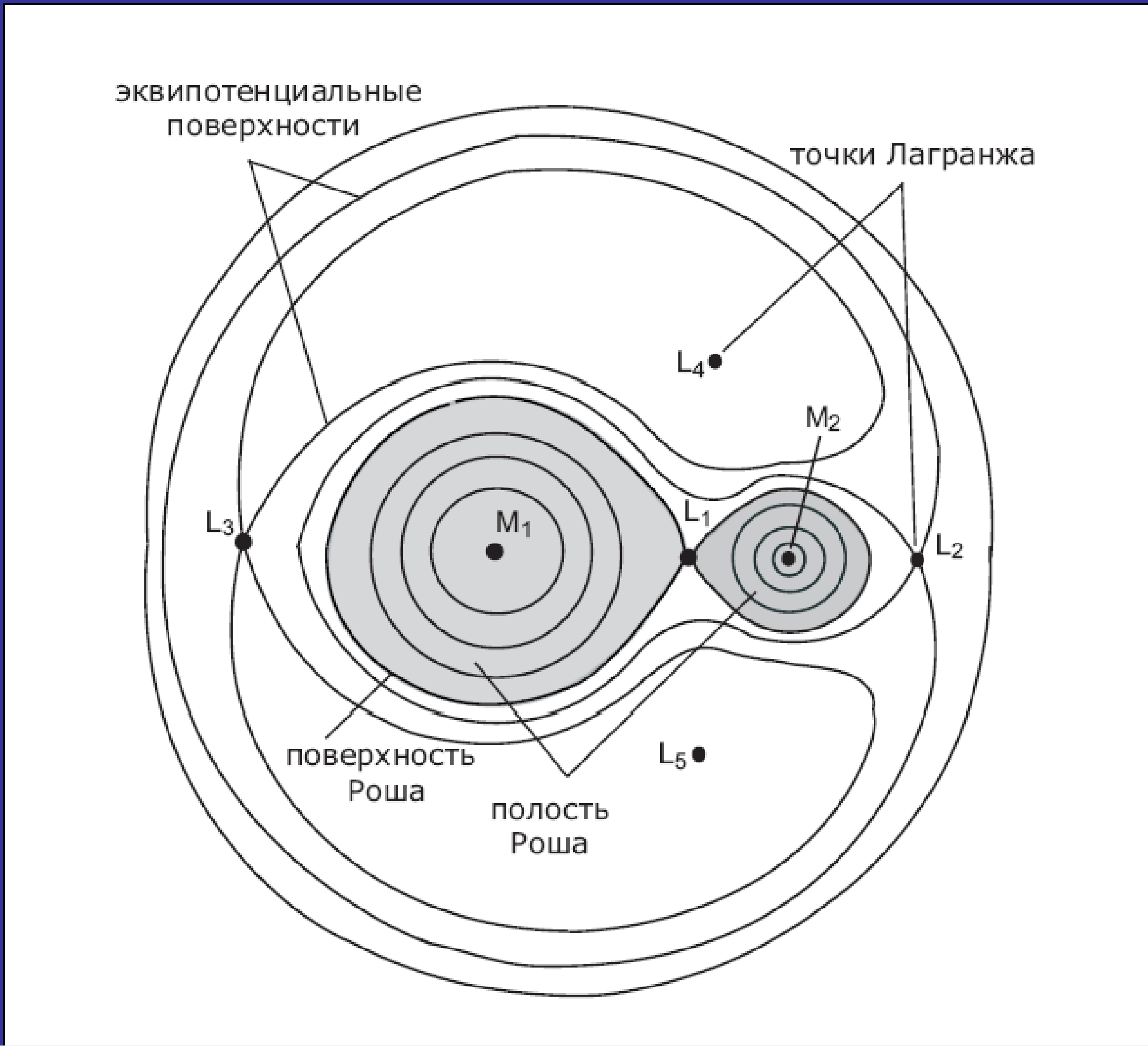
$$t_{\rm grav} \approx (10^{10}\ {\rm yr}) \left(\frac{m_1}{10^{33}\,{\rm g}}\right)^{-1} \left(\frac{m_2}{10^{33}\,{\rm g}}\right)^{-1} \left(\frac{m_1}{10^{33}\,{\rm g}} + \frac{m_2}{10^{33}\,{\rm g}}\right)^{-1} \left(\frac{a}{R_\odot}\right)^4$$

$$\Phi = -\frac{GM_1}{r_1} - \frac{GM_2}{r_2} - \frac{1}{2}\omega^2\left[(x-\mu a)^2 + y^2\right]$$

$$\omega = \sqrt{\frac{G(M_1+M_2)}{a^3}}$$

$$L = \sqrt{G\frac{M_1^2 M_2^2}{M_1+M_2}a}$$

$$\frac{d\ln R_2}{d\ln M_2} > 2\frac{M_2}{M_1} - \frac{5}{3}$$



$$\omega = \sqrt{\frac{G(M_1 + M_2)}{a^3}}$$

$$L = \sqrt{G\frac{M_1^2 M_2^2}{M_1 + M_2} a}$$

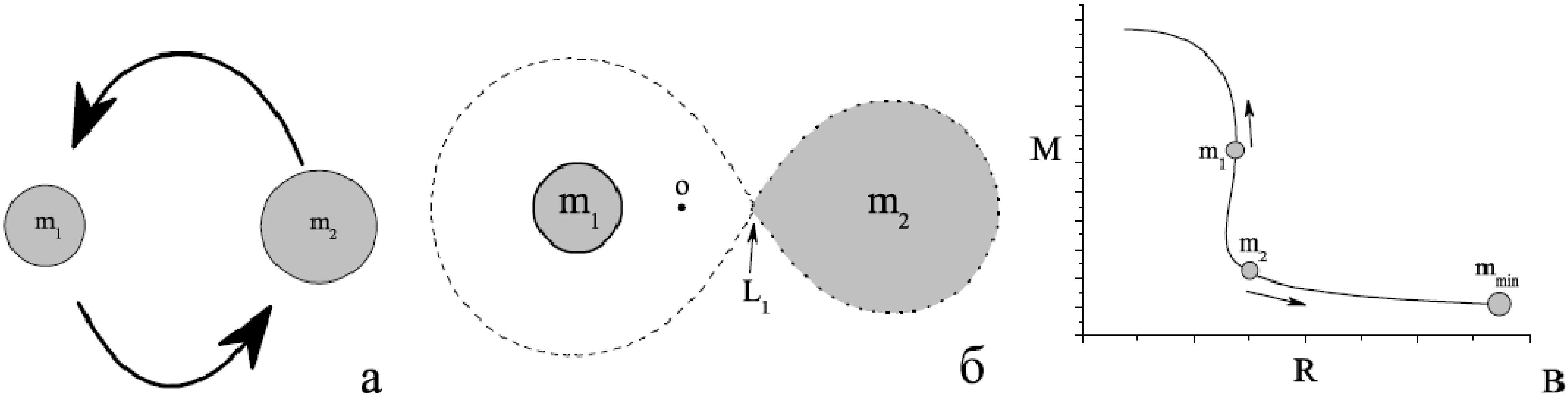


Рис. 1. Сценарий обдирания (схематично): а) две НЗ сближаются из-за гравитационного излучения; б) МНЗ переполняет свою полость Роша и начинается перетекание; в) в результате этого на диаграмме масса-радиус компоненты двойной системы m_1 и m_2 движутся в направлении стрелок.

$$\frac{dJ}{dt} = -\frac{32}{5}\frac{m_1^2 m_2^2}{M^2}\frac{G}{c^5}a^4\omega^5$$

$$J = m_1 m_2 \sqrt{\frac{Ga}{M}}$$

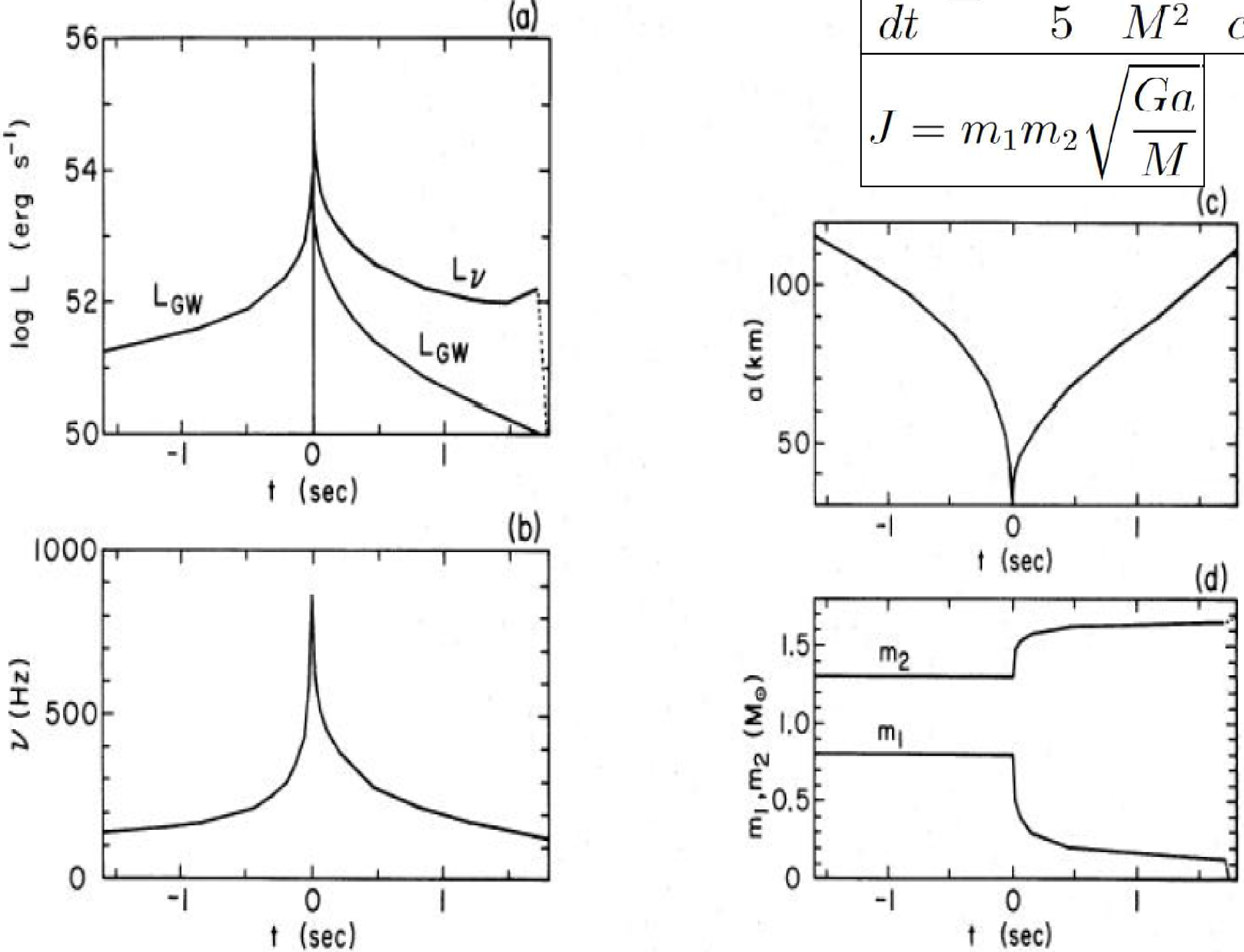


FIG. 7—Time evolution of a system with initial masses 0.8 and 1.3 $M_\odot$. (*a*) Neutrino and gravitational wave luminosities. (*b*) Frequency of gravitational wave. (*c*) Separation of components. (*d*) Masses of stars.

Exploding neutron stars in close binaries

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

Institute of Theoretical and Experimental Physics, Moscow
and Institute for Space Research, USSR Academy of Sciences, Moscow

(Submitted January 27, 1984)

Pis'ma Astron. Zh. **10**, 422–428 (June 1984)

A close binary system comprising a neutron star and another neutron star (or a black hole) will evolve so that the less massive component sheds mass, passing through a series of quasiequilibrium states, until it achieves its minimum possible mass $m_{\min} \approx 0.09\ M_\odot$ and explodes. In a compact globular cluster or the nucleus of a galaxy, such evolution can terminate in an explosion in less than the Hubble time.

Explosion of a low-mass neutron star

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

Institute of Theoretical and Experimental Physics, Space Research Institute, USSR Academy of Sciences

(Submitted April 4, 1990)

Astron. Zh. **67**, 1181–1194 (November–December 1990)

The process of hydrodynamic destruction of a neutron star that occurs when its mass becomes somewhat less than the minimum mass $M_{\min} \approx 0.1\ M_\odot$ is calculated. It is shown that this process occurs explosively and results in the complete dispersal of the neutron star with a kinetic energy ~ 4.8 MeV per nucleon. The calculated results hardly depend on the means by which the mass of the neutron star is reduced to less than $M_{\min}$ (transfer to a companion in a binary system, decay of nucleons, an equivalent mass decrease due to a decrease in the gravitational constant). Destruction of the neutron star should be accompanied by a short (hundredths of a second) burst of hard thermal x rays and soft gamma rays ($kT \approx 10$–100 keV), which should be followed by the considerably longer "tail" of x rays and gamma rays associated with a decay of long-lived radioactive nucleons. Some fraction of the explosive energy is carried off in the form of neutrinos.

Exploding neutron stars in close binaries

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

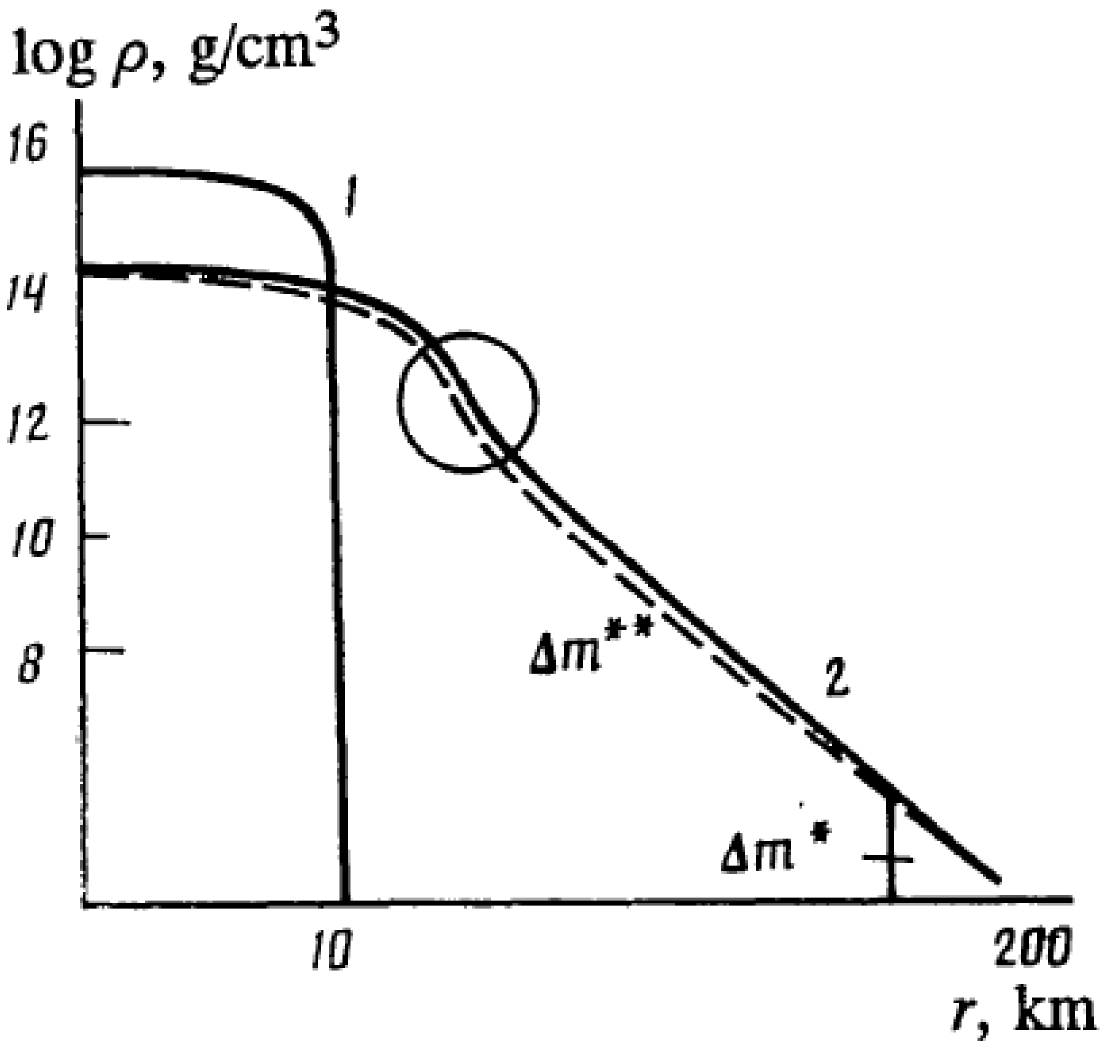
Once having achieved $m_2 = m_{min}$, star 2 will lose its hydrostatic stability and will begin to expand at a rate determined by t_{hyd} and the amended equation of state. Clark and Eardley[6] estimate that perhaps one neutron star may undergo tidal disruption every 100 yr within a 15-Mpc radius; thus 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).

Постановка задачи о взрыве

Explosion of a low-mass neutron star

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

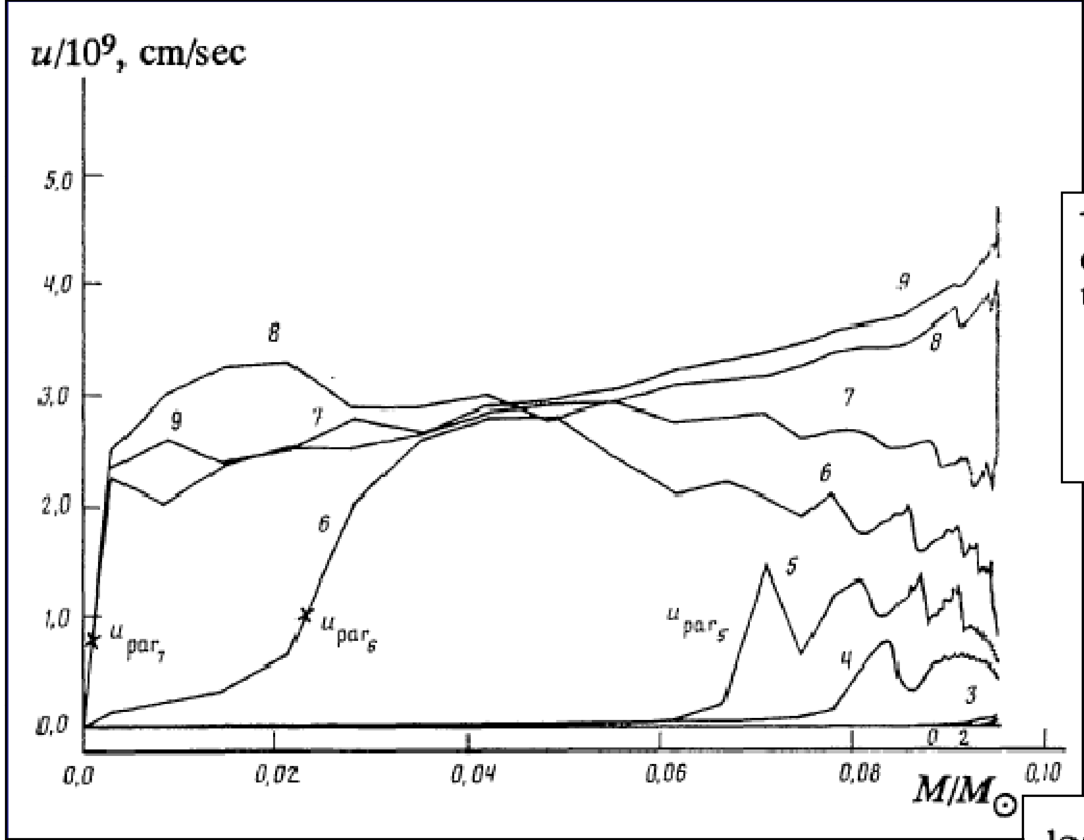


$$P = P_0(\rho) + \rho \tilde{R} T + \frac{1}{3} a T^4,$$

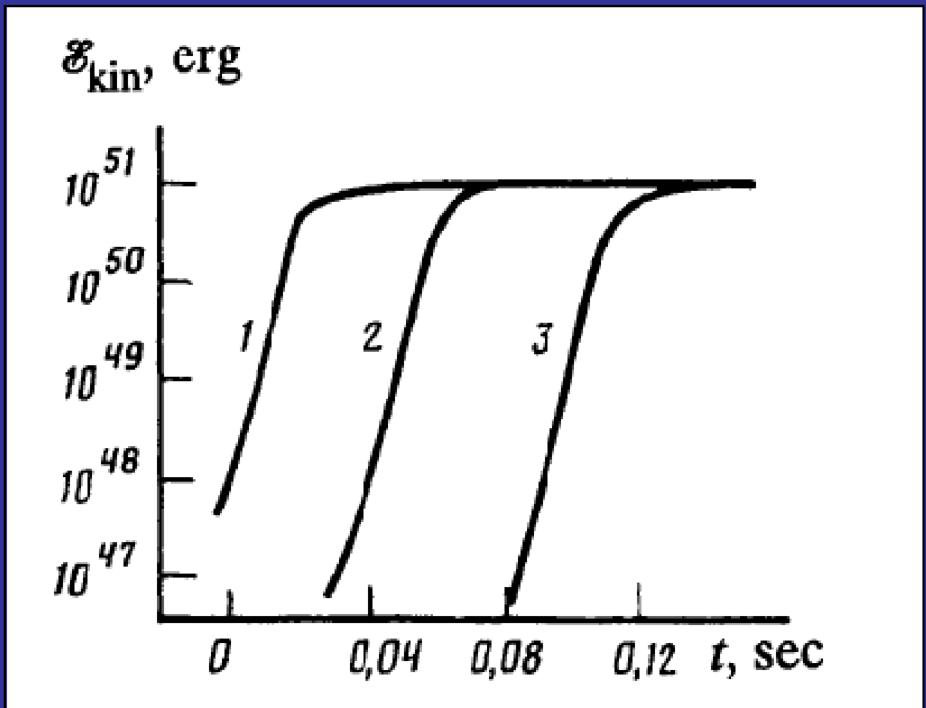
$$E = E_0(\rho) + \frac{3}{2} \tilde{R} T + \frac{a T^4}{\rho}.$$

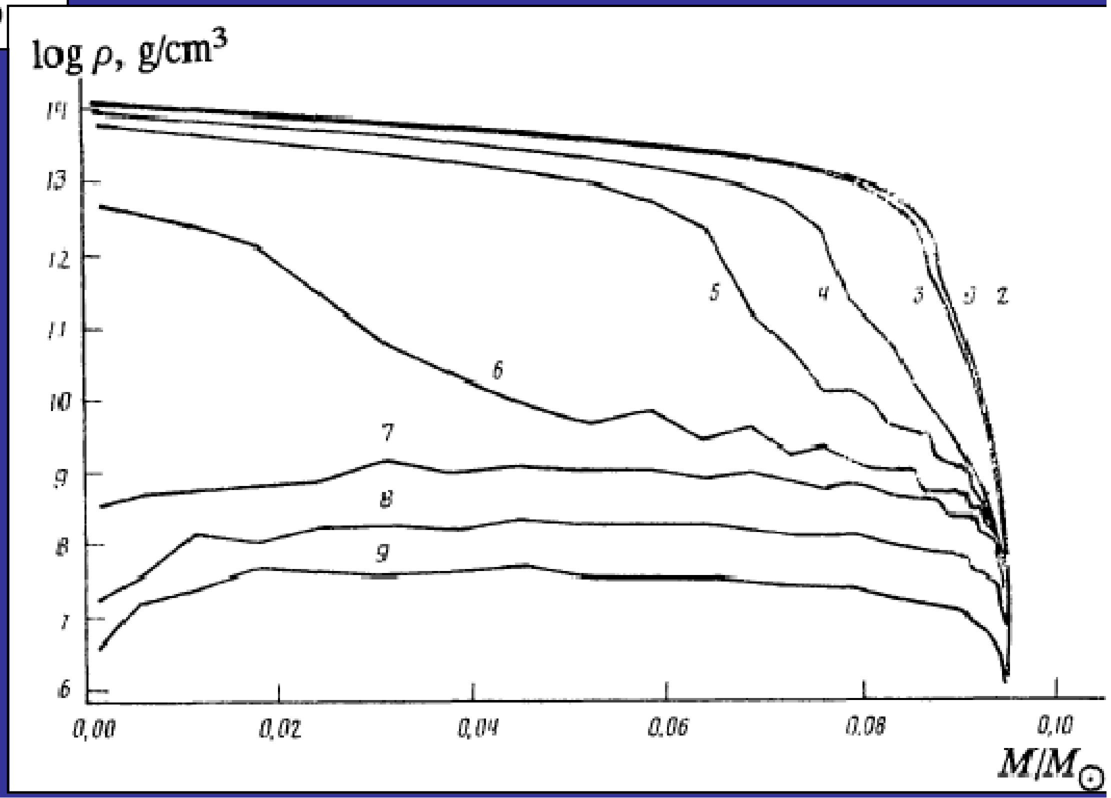
$$t_{\mathrm{hyd}} \approx \frac{1}{\sqrt{6\pi G \bar{\rho}}} \approx 0.3 \text{ msec}$$

$$\begin{cases} \dfrac{\partial r}{\partial t} = u, \\ \dfrac{\partial u}{\partial t} = -4\pi r^2 \dfrac{\partial P}{\partial m} - \dfrac{Gm}{r^2}, \\ \dfrac{1}{\rho} = \dfrac{4\pi}{3} \dfrac{\partial r^3}{\partial m}, \\ \dfrac{\partial E}{\partial t} + P \dfrac{\partial 1/\rho}{\partial t} = 0. \end{cases}$$



Curve No. in the figures	Curve No. in the figures	Curve No. in the figures	Time, sec	Curve No. in the figures	Time, sec
0	0	4	$9{,}70\cdot10^{-2}$	7	$1{,}20\cdot10^{-1}$
1	$5{,}60\cdot10^{-3}$	5	$1{,}03\cdot10^{-1}$	8	$1{,}31\cdot10^{-1}$
2	$2{,}63\cdot10^{-2}$	6	$1{,}11\cdot10^{-1}$	9	$1{,}44\cdot10^{-1}$
3	$5{,}52\cdot10^{-2}$				





surface layers can be maintained at 10^8-10^9 K. This should lead to a burst of hard thermal x rays and soft gamma rays with a total energy of 10^{43}-10^{47} erg.

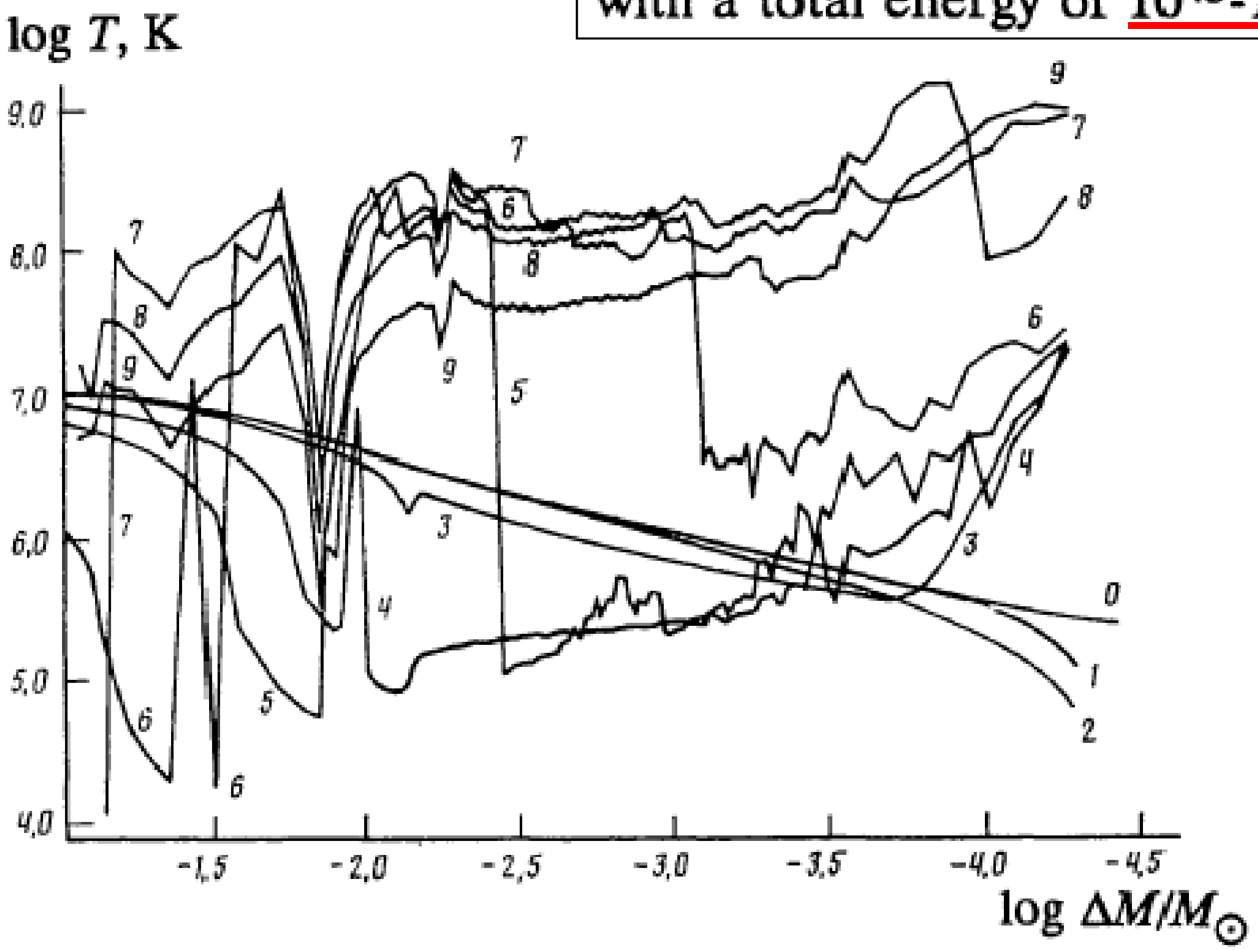
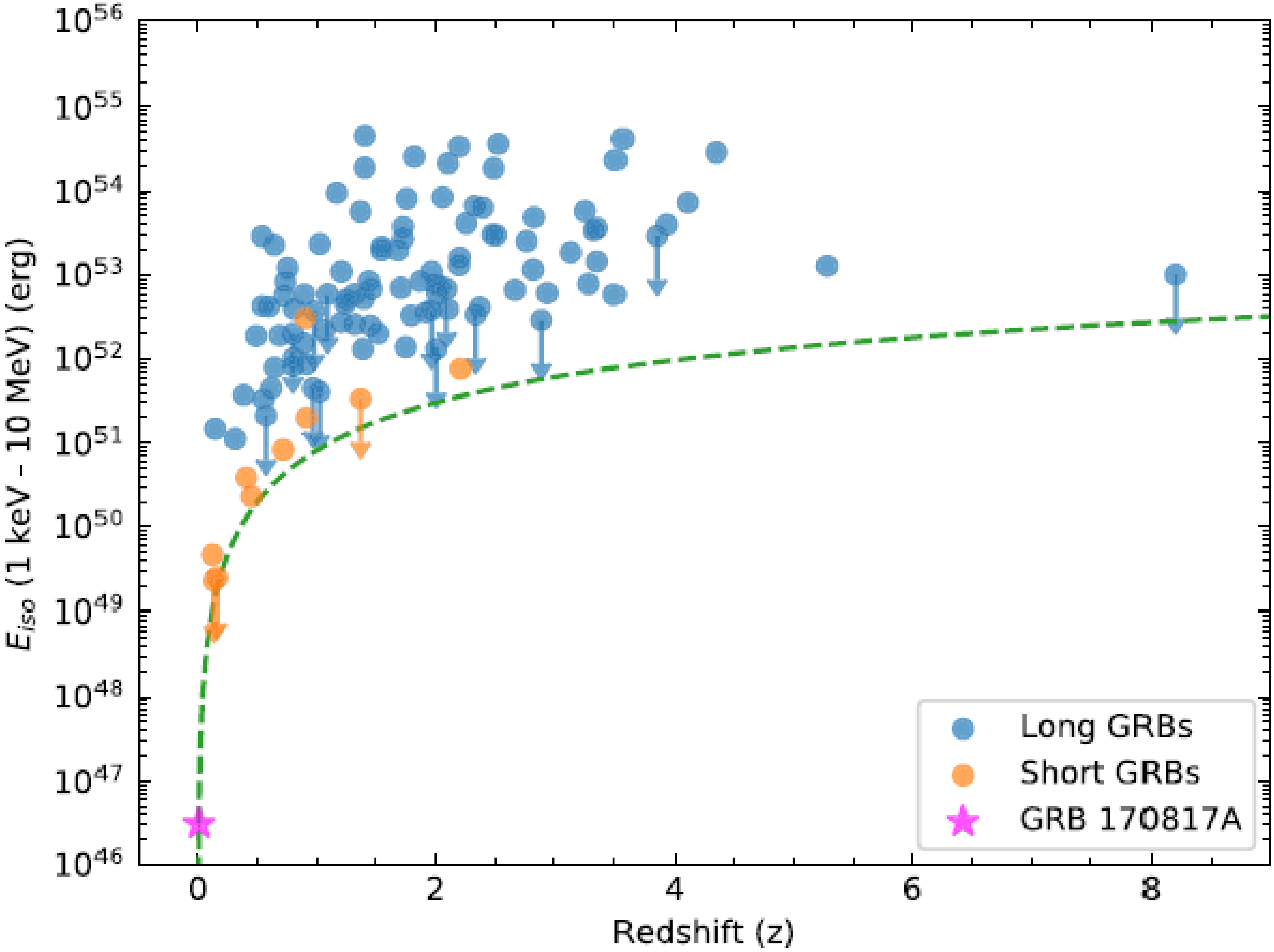


FIG. 12. Temperature distributions along the Lagrangian coordinate (ΔM is the mass reckoned from the surface) in the course of the explosion of a neutron star of mass $M = 0.09499\ M_{\odot}$ at different times (Table I). The temperature increase to 10^8-10^9 K at the surface indicates the possibility of thermal x-ray and gamma-ray bursts accompanying the explosions of neutron stars.



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

GW170817–the first observed neutron star merger and its kilonova: implications for the astrophysical site of the r-process

Daniel M. Siegel[1,2]

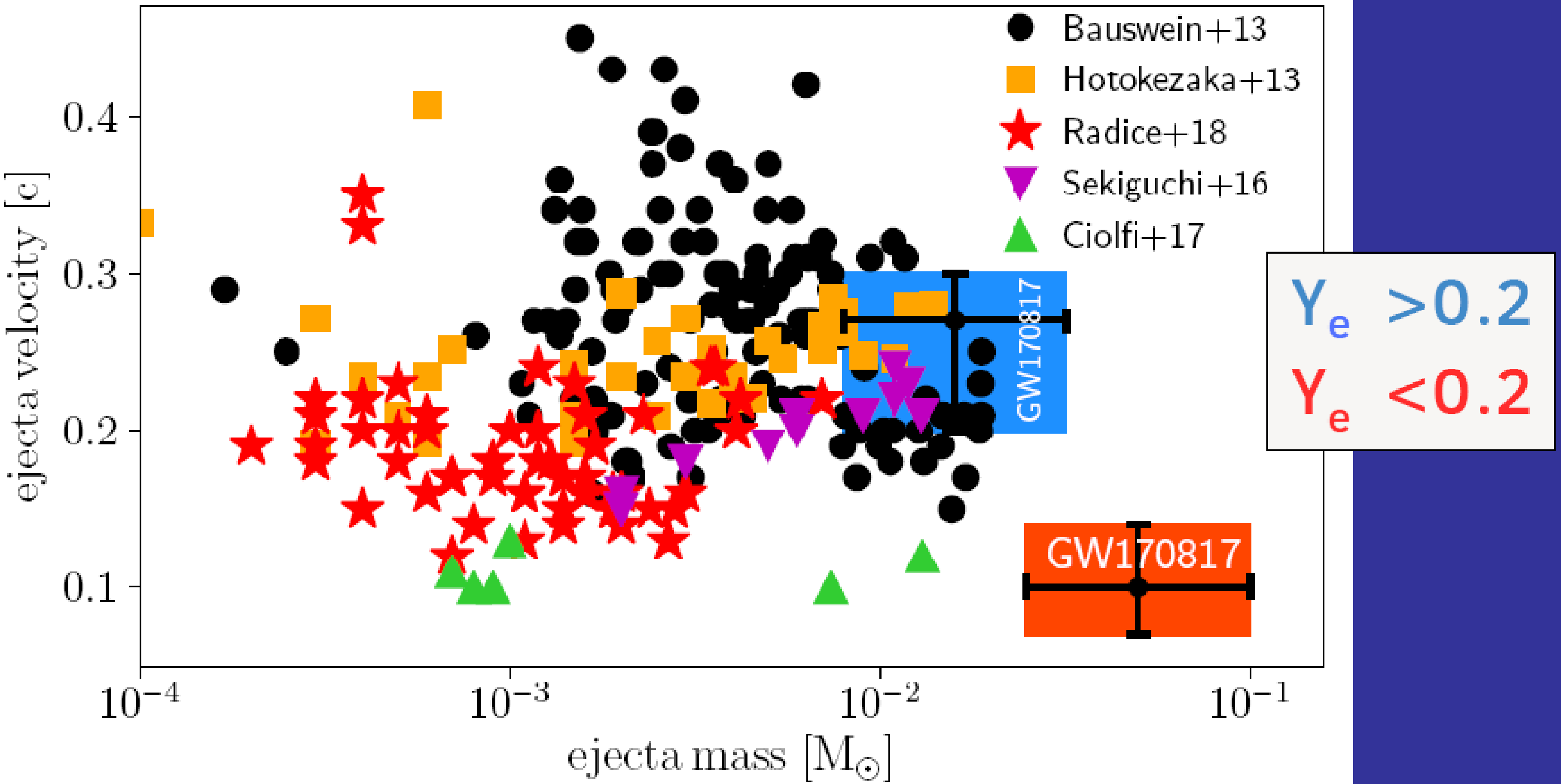
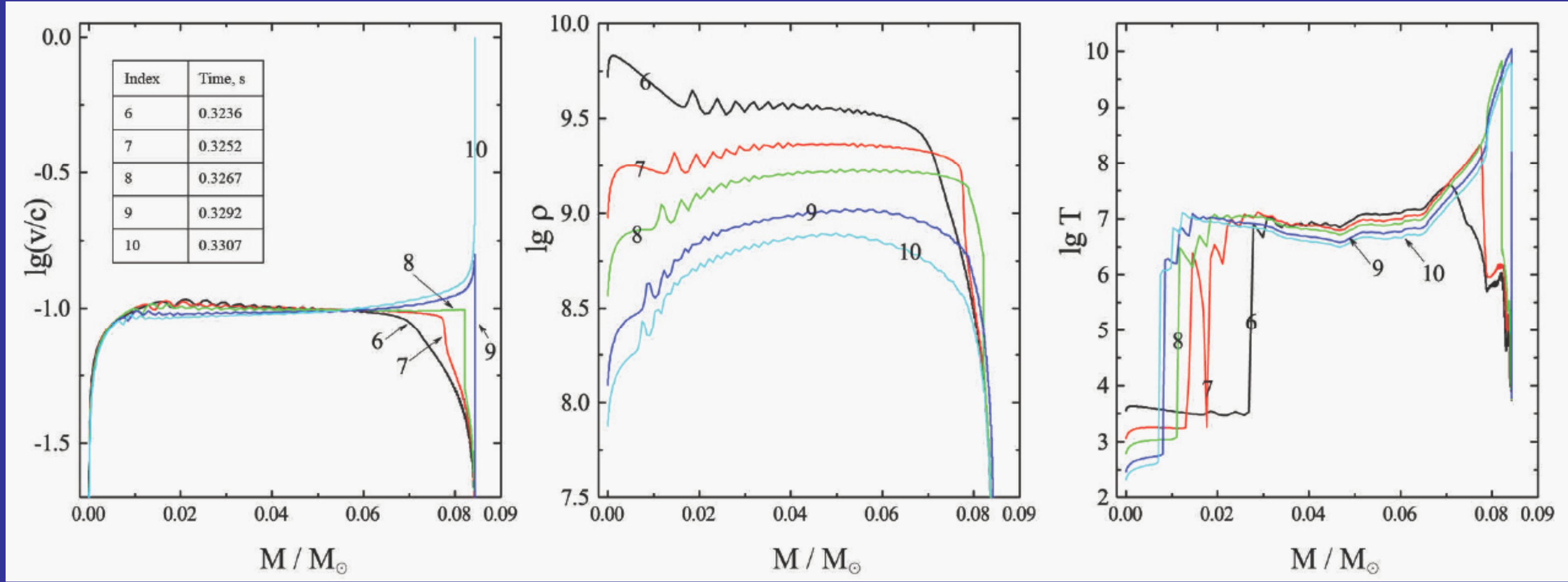
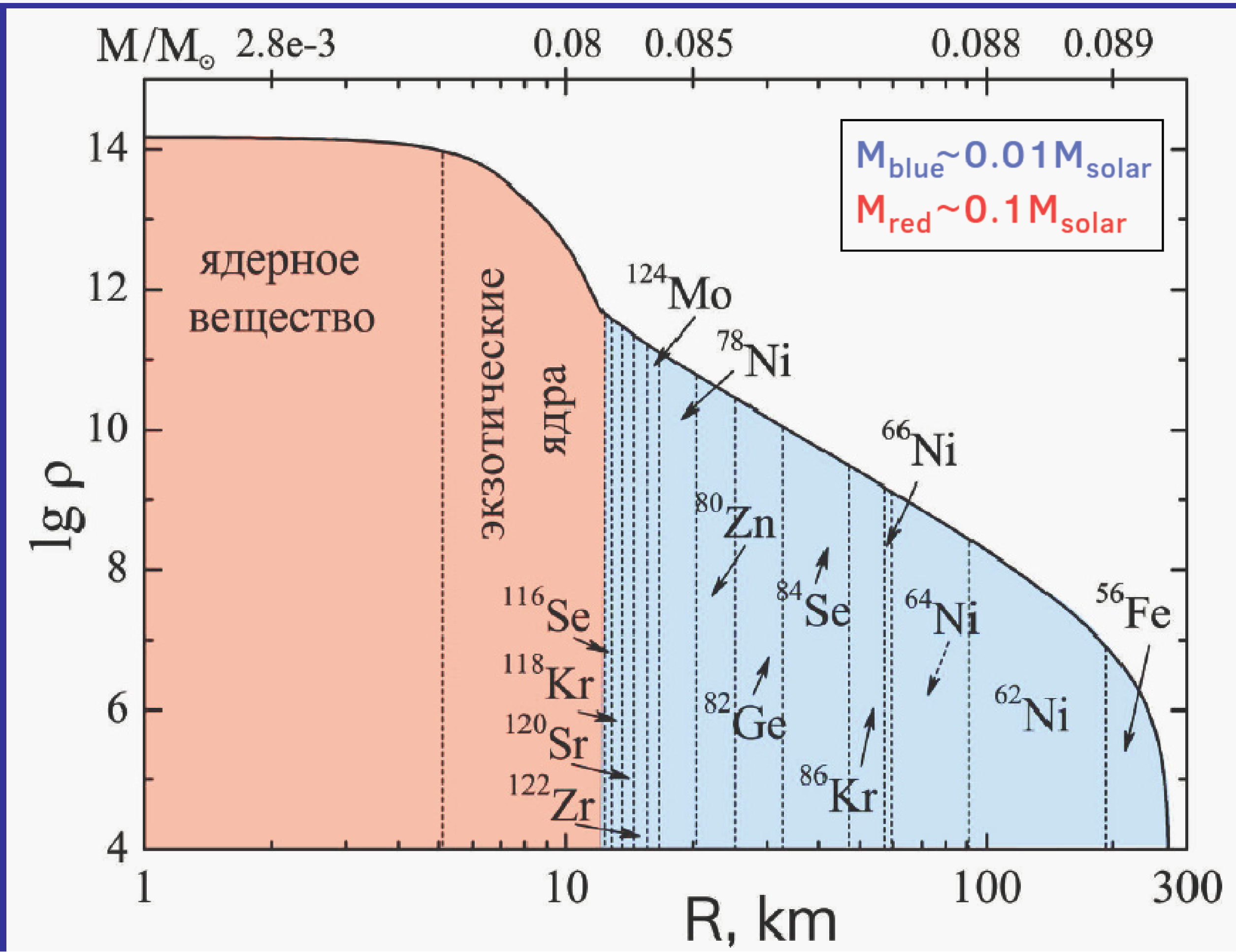


Figure 1. Dynamical ejecta masses and velocities from various binary neutron star merger simulations encompassing different numerical techniques, various equations of state, binary binary mass ratios 0.65 – 1.0, effects of neutrinos and magnetic fields [77,78,64,73,65], together with the corresponding ejecta parameters inferred from the 'blue' and 'red' kilonova of GW170817 (see the text for details).



Index
Time, s
6
0.3236
7
0.3252
8
0.3267
9
0.3292
10
0.3307
lg(v/c)
lg ρ
lg T
M / M⊙
M / M⊙
M / M⊙

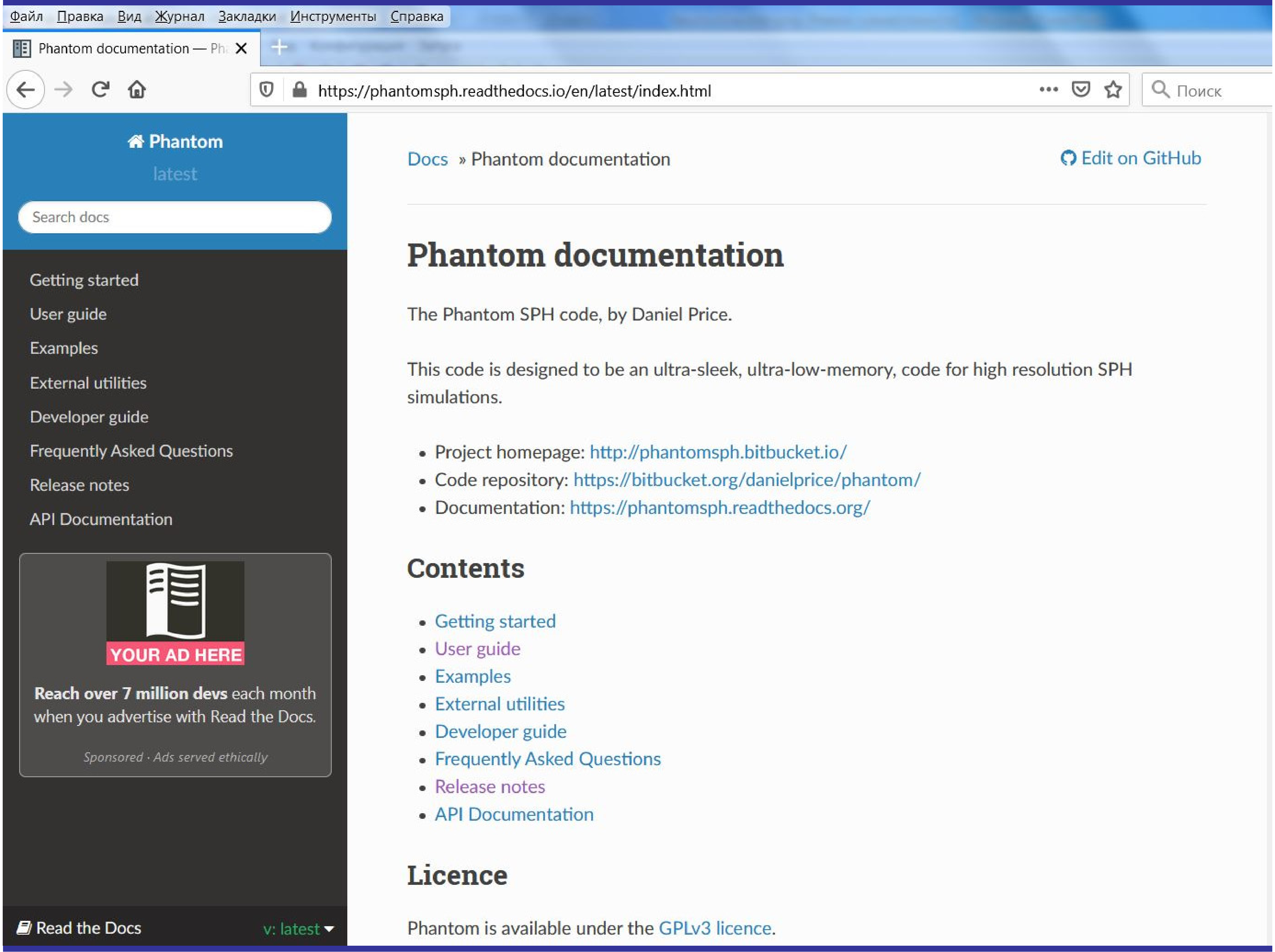


M/M⊙
2.8e-3
0.08
0.085
0.088
0.089
M_blue~0.01M_solar
M_red~0.1M_solar
ядерное вещество
экзотические ядра
124Mo
78Ni
66Ni
80Zn
84Se
64Ni
62Ni
56Fe
116Se
118Kr
120Sr
122Zr
82Ge
86Kr
lg ρ
R, km

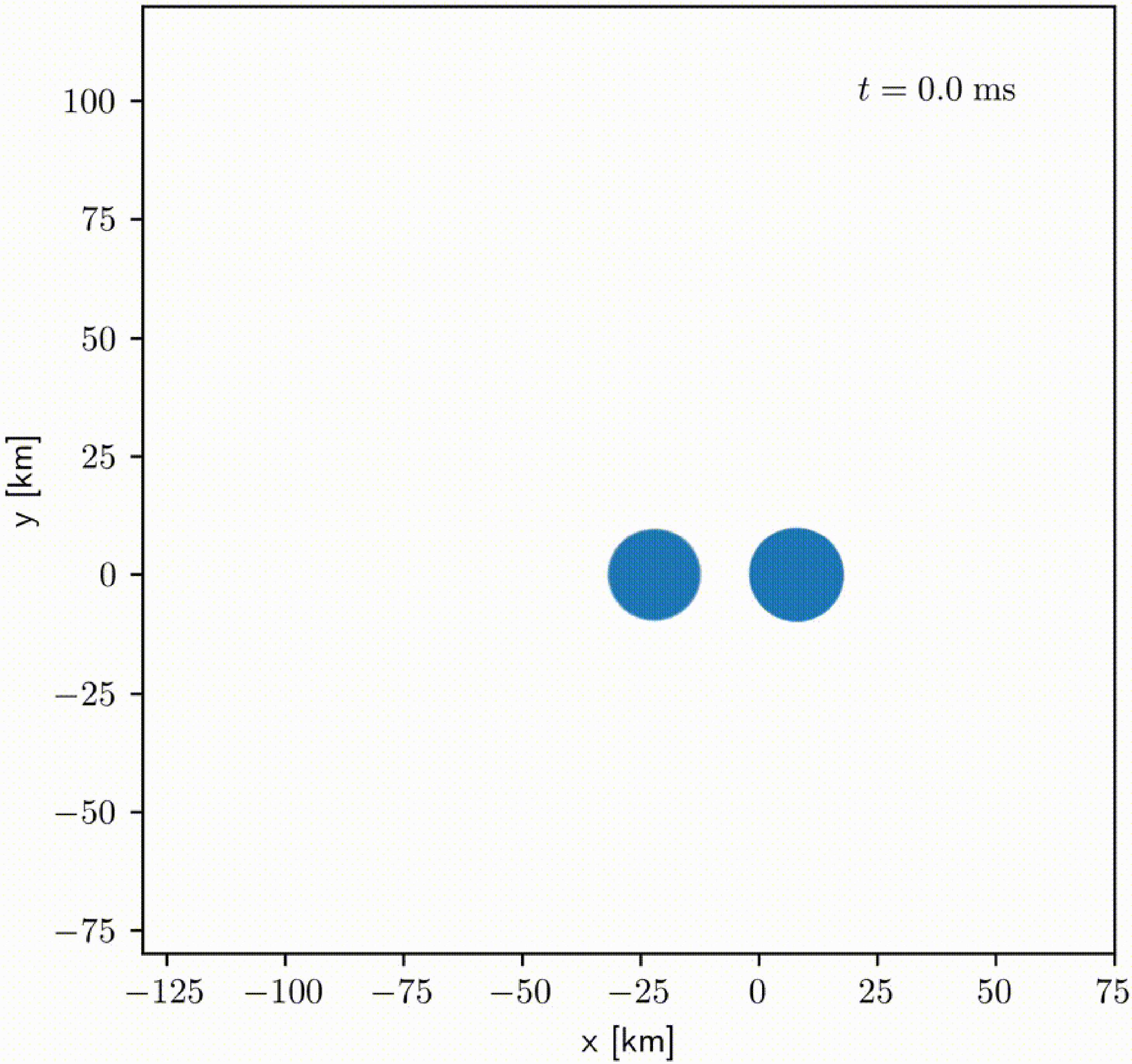
Y_e >0.2

Y_e <0.2

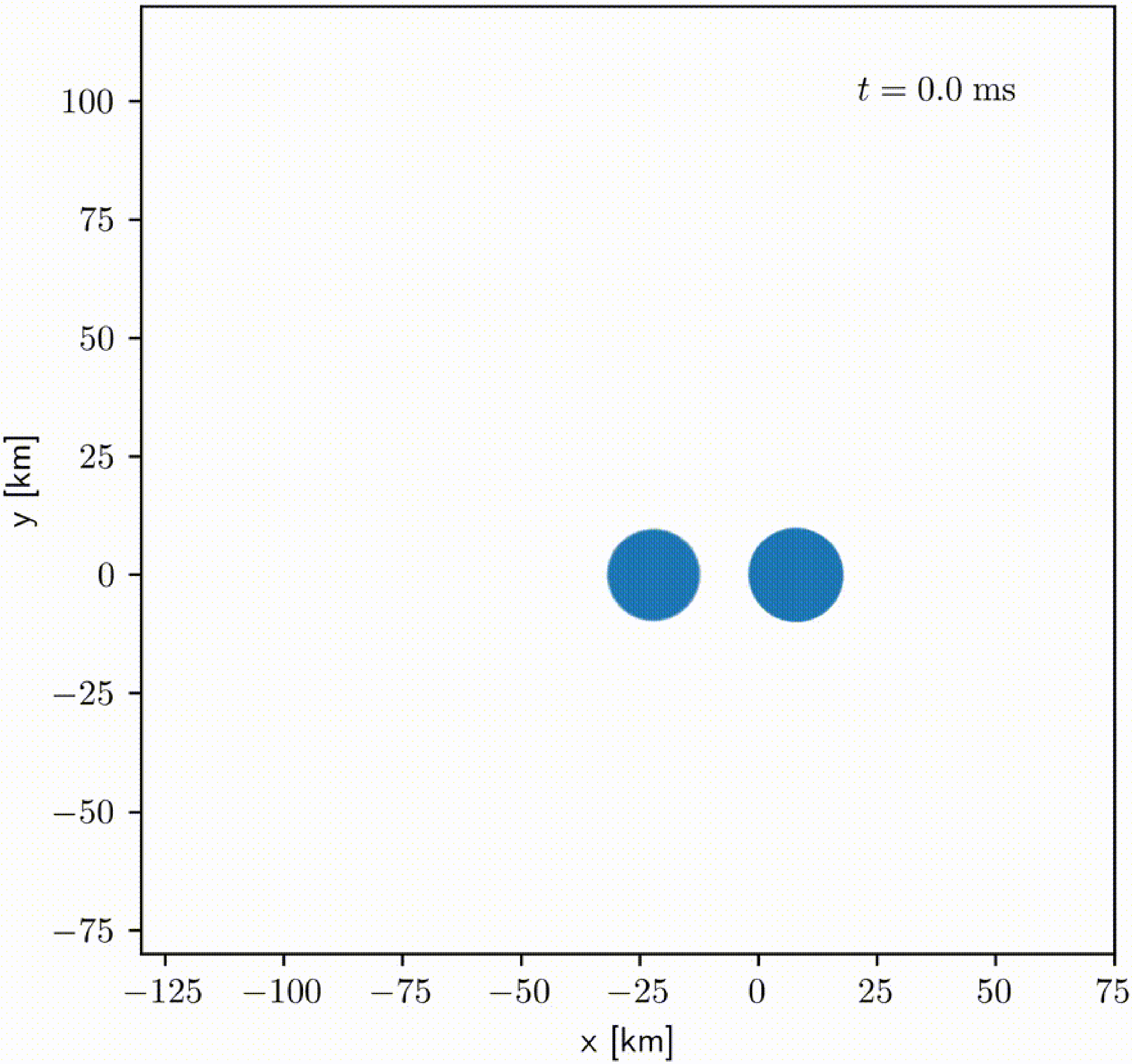
Открытые вопросы, проблемы, дальнейшее развитие…


Файл Правка Вид Журнал Закладки Инструменты Справка
Phantom documentation — Ph
https://phantomsph.readthedocs.io/en/latest/index.html
Поиск
Phantom
latest
Search docs
Getting started
User guide
Examples
External utilities
Developer guide
Frequently Asked Questions
Release notes
API Documentation
YOUR AD HERE
Reach over 7 million devs each month when you advertise with Read the Docs.
Sponsored · Ads served ethically
Read the Docs
v: latest
Docs » Phantom documentation
Edit on GitHub
Phantom documentation
The Phantom SPH code, by Daniel Price.
This code is designed to be an ultra-sleek, ultra-low-memory, code for high resolution SPH simulations.
• Project homepage: http://phantomsph.bitbucket.io/
• Code repository: https://bitbucket.org/danielprice/phantom/
• Documentation: https://phantomsph.readthedocs.org/
Contents
• Getting started
• User guide
• Examples
• External utilities
• Developer guide
• Frequently Asked Questions
• Release notes
• API Documentation
Licence
Phantom is available under the GPLv3 licence.

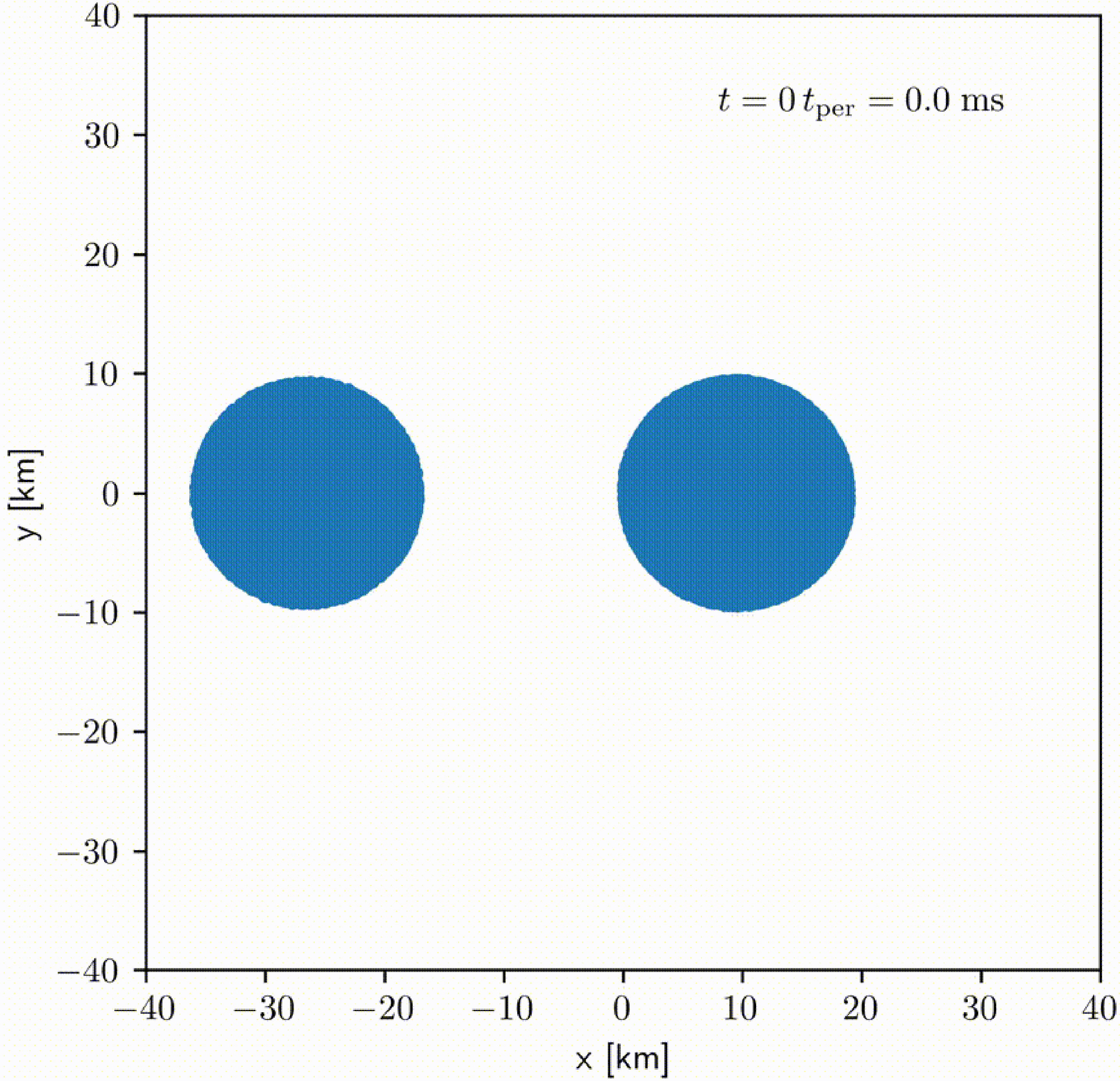
Two NS at distance 30 km



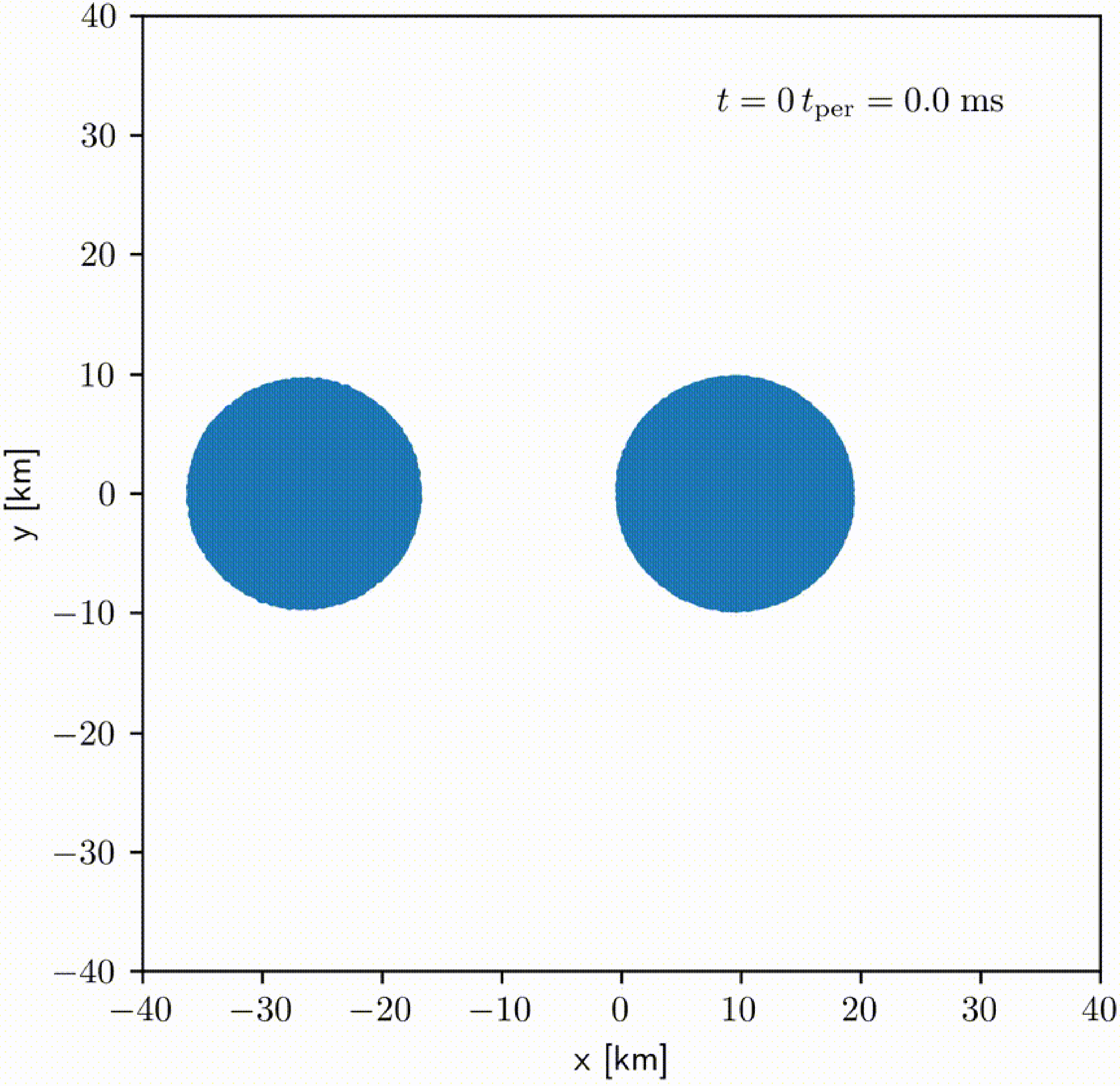
Two NS at distance 30 km



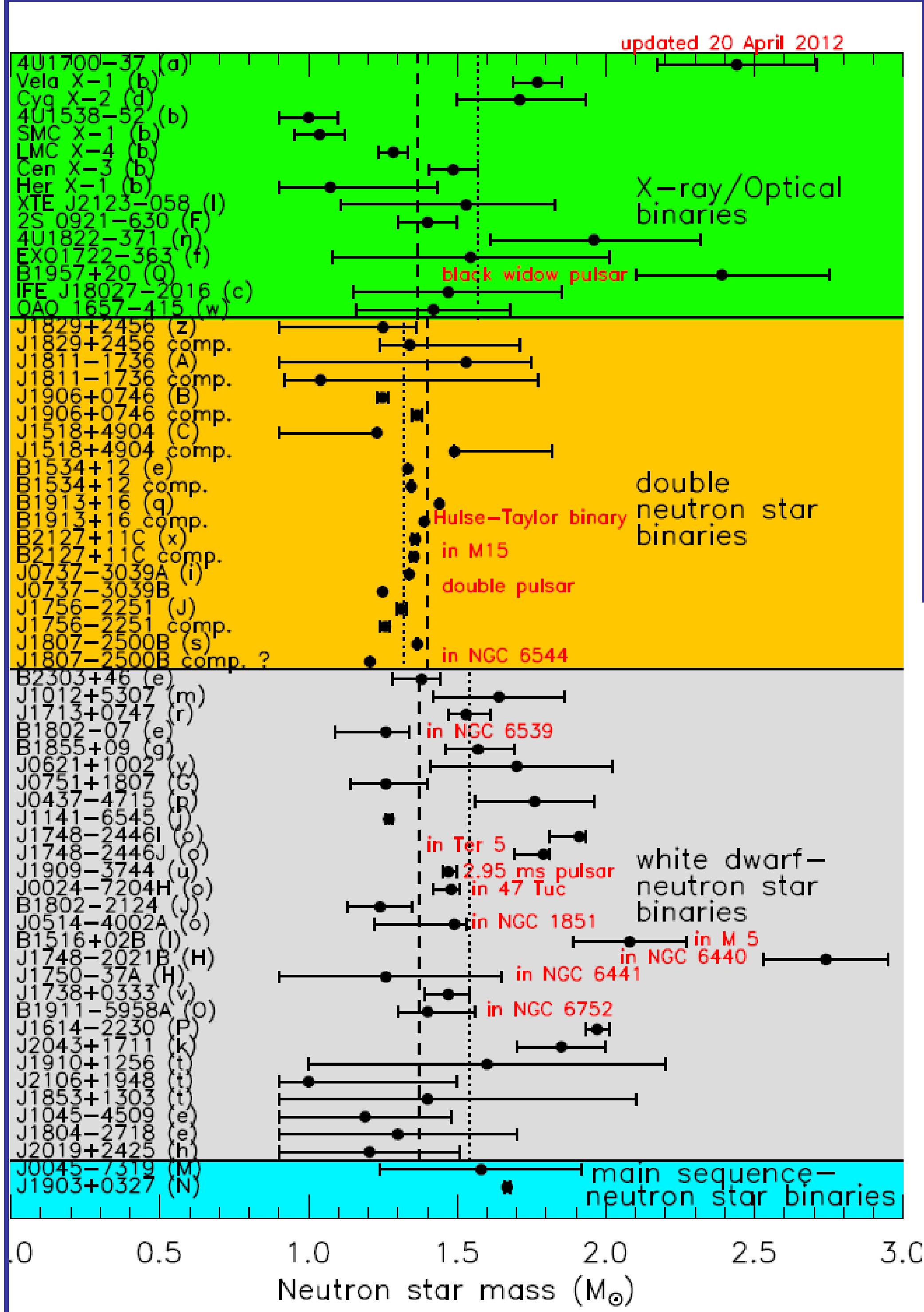
Two NS at distance 36 km



Two NS at distance 36 km

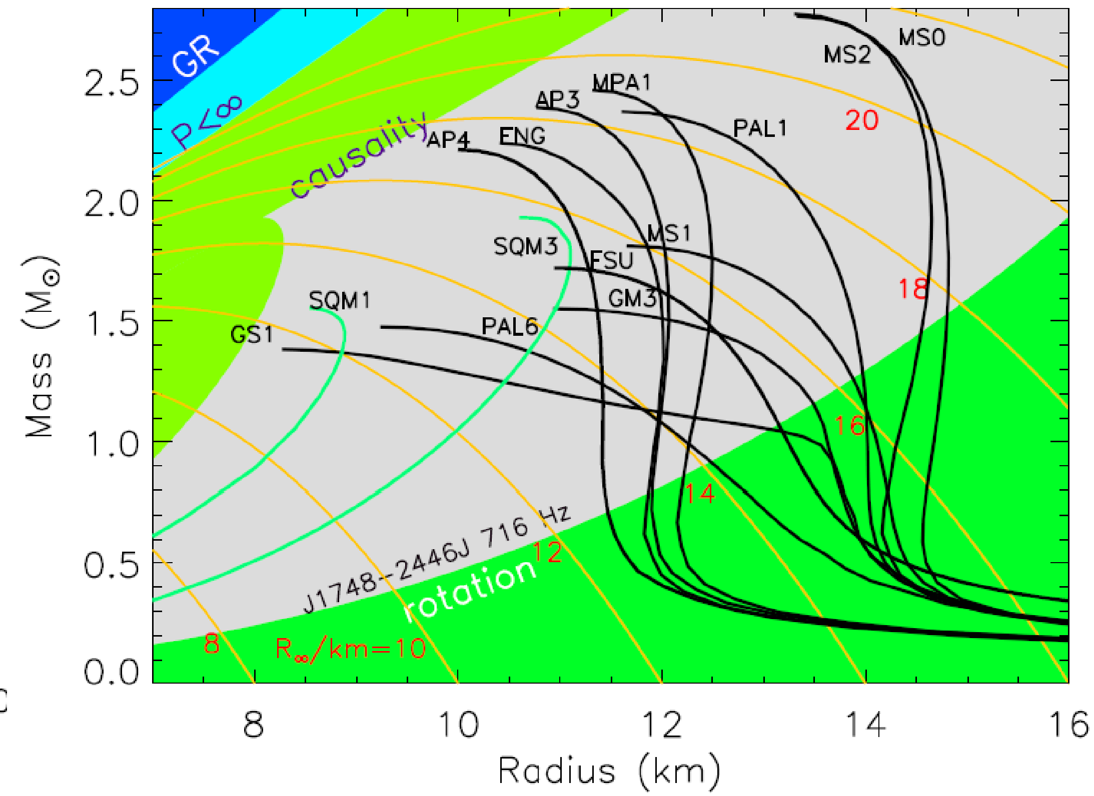


Maximum neutron star mass



J.M. Lattimer

Annual Review of Nuclear and Particle Science, vol. 62, issue 1, pp. 485-515 (2012)



Article https://doi.org/10.1038/s41550-022-01800-1

A strangely light neutron star within a supernova remnant

Received: 31 March 2022

Accepted: 1 September 2022

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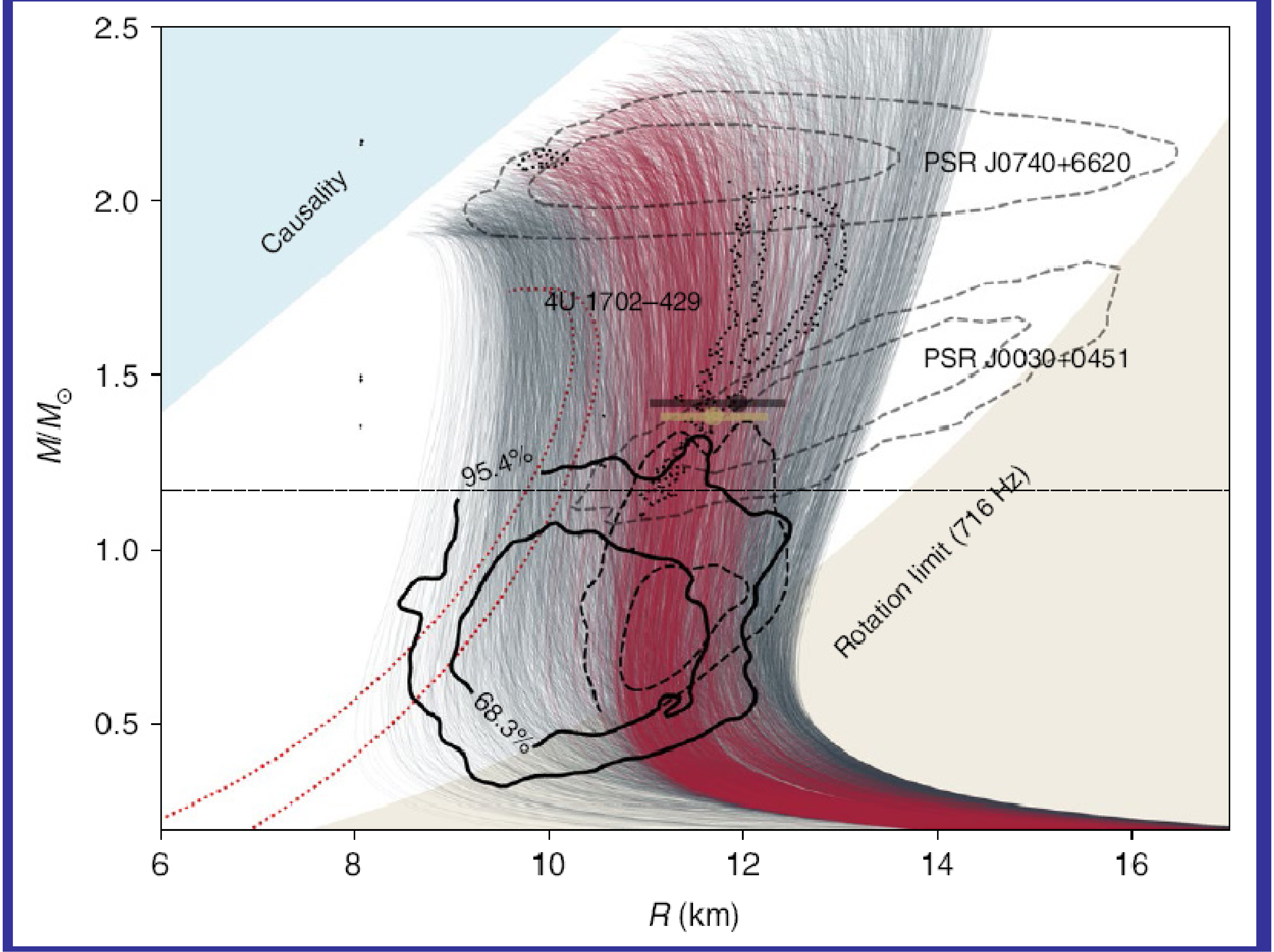
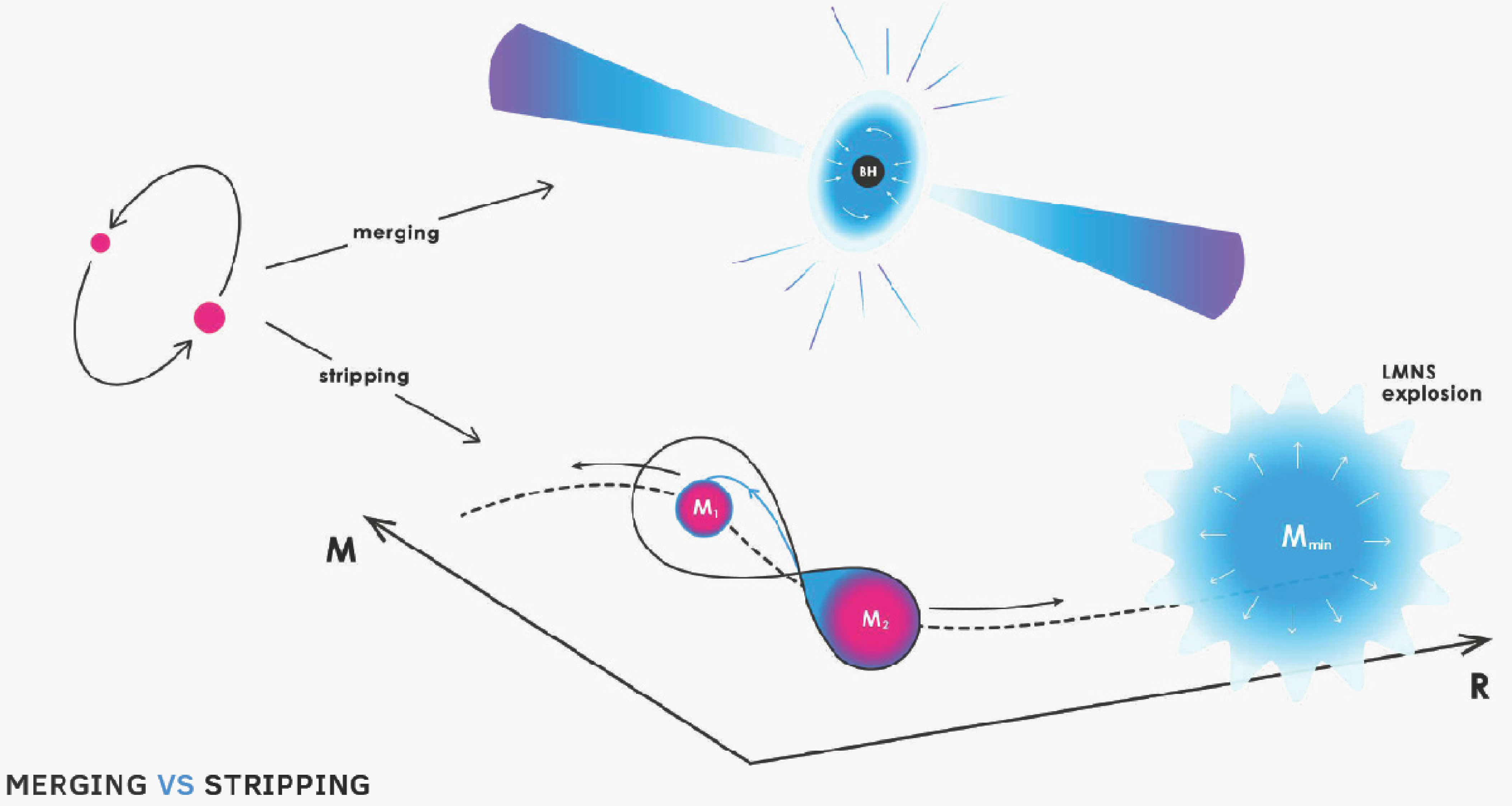
To constrain the equation of state of cold dense matter, astrophysical measurements are essential. These are mostly based on observations of neutron stars in the X-ray band, and, more recently, also on gravitational wave observations. Of particular interest are observations of unusually heavy or light neutron stars which extend the range of central densities probed by observations and thus permit the testing of nuclear-physics predictions over a wider parameter space. Here we report on the analysis of such a star, a central compact object within the supernova remnant HESS J1731-347. We estimate the mass and radius of the neutron star to be $M = 0.77^{+0.20}_{-0.17}\,M_{\odot}$ and $R = 10.4^{+0.86}_{-0.78}$ km, respectively, based on modelling of the X-ray spectrum and a robust distance estimate from Gaia observations. Our estimate implies that this object is either the lightest neutron star known, or a 'strange star' with a more exotic equation of state. Adopting a standard neutron star matter hypothesis allows the corresponding equations of state to be constrained.



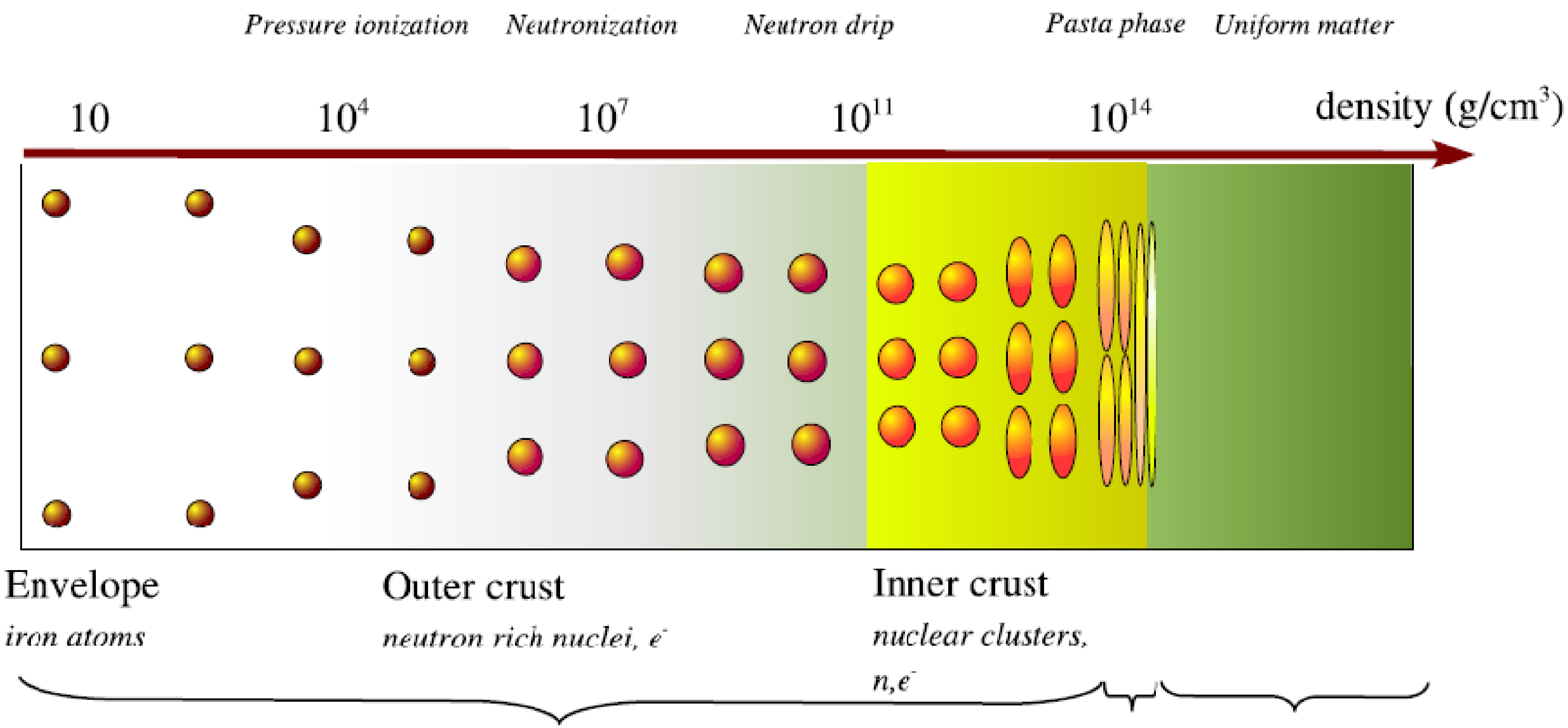
2.5
2.0
1.5
1.0
0.5
M/M⊙
6
8
10
12
14
16
R (km)
Causality
PSR J0740+6620
4U 1702−429
PSR J0030+0451
95.4%
68.3%
Rotation limit (716 Hz)

merging и stripping: не или/или, а и то и другое

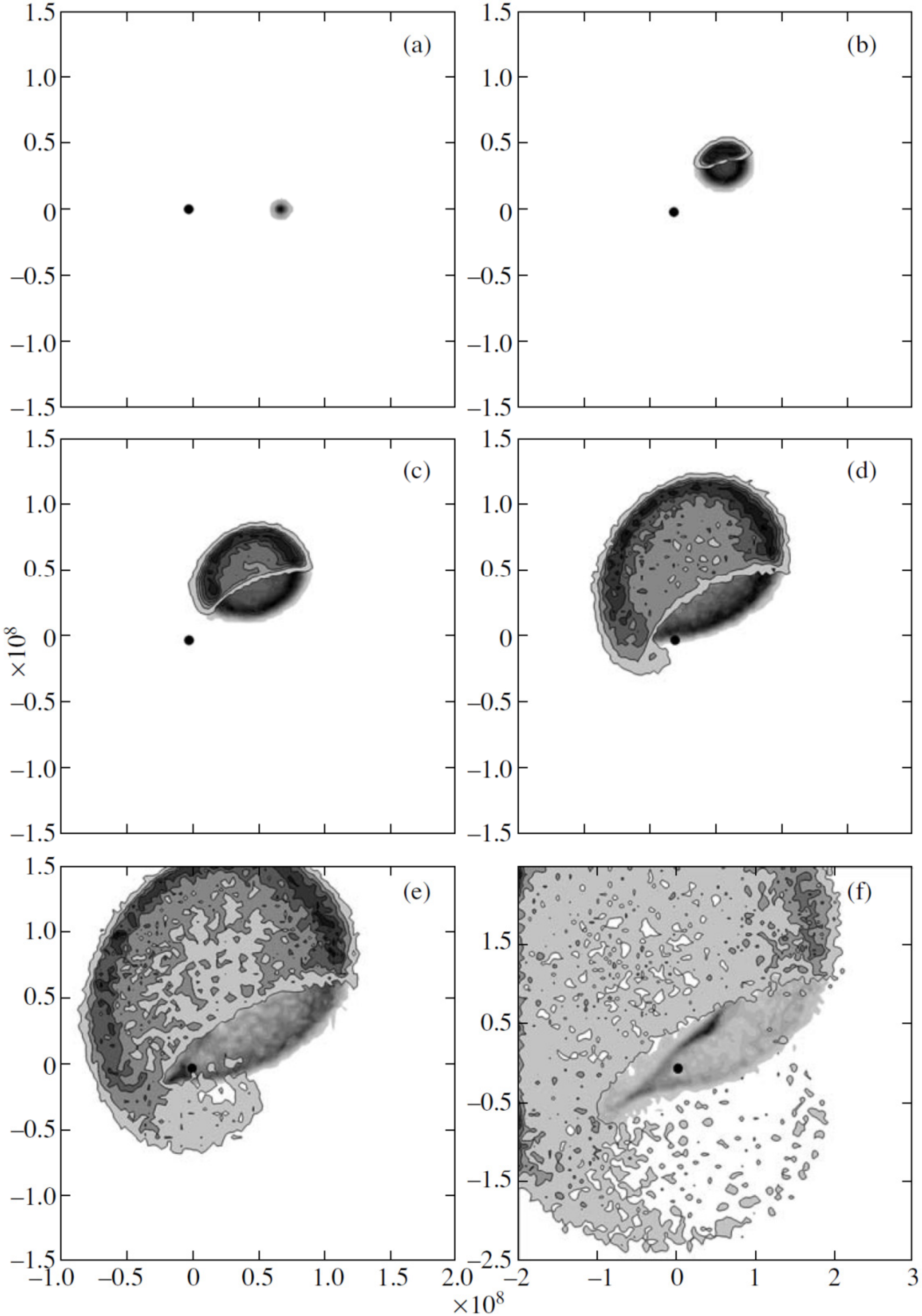


Спасибо за внимание!

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



$\rho_{\max}$ [g/cm^3]	Element	Z	N	$R_{\rm cell}$ [fm]
8.02×10^6	^{56}Fe	26	30	1404.05
2.71×10^8	^{62}Ni	28	34	449.48
1.33×10^9	^{64}Ni	28	36	266.97
1.50×10^9	^{66}Ni	28	38	259.26
3.09×10^9	^{86}Kr	36	50	222.66
1.06×10^{10}	^{84}Se	34	50	146.56
2.79×10^{10}	^{82}Ge	32	50	105.23
6.07×10^{10}	^{80}Zn	30	50	80.58
8.46×10^{10}	^{82}Zn	30	52	72.77
9.67×10^{10}	^{128}Pd	46	82	80.77
1.47×10^{11}	^{126}Ru	44	82	69.81
2.11×10^{11}	^{124}Mo	42	82	61.71
2.89×10^{11}	^{122}Zr	40	82	55.22
3.97×10^{11}	^{120}Sr	38	82	49.37
4.27×10^{11}	^{118}Kr	36	82	47.92



3D-расчёт взрыва

Model for the Explosion of a Critical-Mass Neutron Star in a Binary System

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Model	M1	M2	M3	M4	M5	M6	M7	M8	M9
E_{exp}, 10^{51} erg	0.63	0.66	0.65	0.67	0.72	0.77	0.76	0.45	0.66
V_p, 10^3 km s^{-1}	0.71	0.66	0.59	0.56	0.72	0.85	0.48	0.39	0.60
η	0.23	0.25	0.20	0.23	0.16	0.09	0.03	0.36	0.20

Note. E_{exp} is the total explosion energy, V_p is the final pulsar velocity, and η is the mass fraction of the ejecta's material gravitationally bound to the pulsar.

Versions of jet mechanism

The impressive success of multimessenger astronomy in 2017 was slightly overshadowed by the fact that this gamma-ray burst turned out to be rather peculiar. In particular, it was 10,000 times fainter than other known short gamma-ray bursts and initially showed indistinct signs of a structured jet. More recent VLBI observations explained it within an off-axis structured jet model (Mooley+ 2018). Another model, that of the choked jet, was advanced by (Nakar+ 2018) where the latter write that **"choked jet seems to be incompatible with GW170817"**. Nevertheless, X-ray observations do not exclude that afterglow emission arises from a quasi-spherical mildly relativistic outflow (Nynka2018, Hajela2022). Moreover, recent data confirm "a growing tension between the observations and the jet model" (Troja2022).

Troja et al. X-ray lightcurve of GW170817

X-ray emission from the gravitational wave transient GW170817 is well described as non-thermal afterglow radiation produced by a structured relativistic jet viewed off-axis. We show that the X-ray counterpart continues to be detected at 3.3 years after the merger. Such long-lasting signal is not a prediction of the earlier jet models characterized by a narrow jet core and a viewing angle $\approx$20 deg, and is spurring a renewed interest in the origin of the X-ray emission.

We present a comprehensive analysis of the X-ray dataset aimed at clarifying existing discrepancies in the literature, and in particular the presence of an X-ray rebrightening at late times. Our analysis does not find evidence for an increase in the X-ray flux, but **confirms a growing tension between the observations and the jet model**. Further observations at radio and X-ray wavelengths would be critical to break the degeneracy between models. 2022MNRAS.510.1902T