PROCEEDINGS OF SCIENCE

# Concluding remarks I.

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1. Peculiar Milestone: SN and GRB.
2. GW: BH+BH, NS+NS.
3. BH Shadow.
4. “Cyclotron” lines and polarisation.
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**Peculiar milestone: SN and GRB.** SN – GRB connection is based on the peculiar (very weak) GRB, if this connection is real. This burst is the only one, far outside from the Amati relation (Fig.1), and was interpreted initially as a distant ordinary long GRB, contaminated with SN 1998bw. Later it was accepted as the first evidence that gamma-ray bursts and supernovae are related (several talks on the session "Jet sources & gamma-ray bursts").

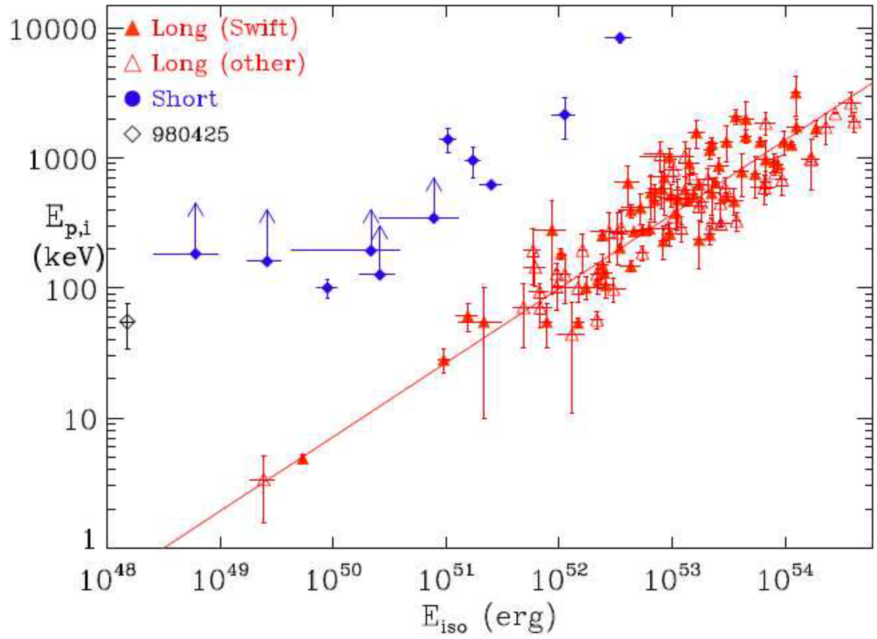



**Figure 1:** The $E_{p,i}$ and $E_{iso}$ values of all long GRBs, with the already mentioned exception of the peculiar GRB980425, are strongly correlated (Spearman's = 0.86 for 108 events. GRBs in the Ep,i – Eiso plane as of end of 2009. The continuous line is the best fit power–law of the 108 long GRBs.) From [1]

**GW: BH+BH, NS+NS**. The talks of D. Rosinska, R Padovani, W.Kundt considered different aspects of GW detection by LIGO/VIRGO instruments. On 2017 August 17 a binary neutron star coalescence candidate (later designated as GW170817) with merger time 12:41:04 UTC was observed through gravitational waves (GW) by the Advanced LIGO and Advanced Virgo detectors. It was observed in EM on about 100 instruments in all possible wavelengths The GW from merging of 2 NS should be seen as short GRB, according to present views. The GRB 171205A, observed in this event occurs to have an extremely low energy $< 10^{48}$ erg in comparison with average short GRB. May be 2 NS merging model is not capable to explain short GRBs?

Most GW from LIGO/VIRGO are identified with 2 BH merging of massive BH binary, never observed before. The EM silence of 2 BH binary system could be connected with absence of surrounding matter. GW from 2 NS have been predicted basing on close binary PSR observations. Note, that 2 NS events are very much rarer than 2 BH ones. It would be interesting to do simulation of population synthesis, and to compare theoretical predictions for relative frequencies of these events with observations.

**BH Shadow.** Observation of BH shadow in M87 nuclei gives a possibility to direct view of the horizon, and is the first experiment with strong gravity. The problems related to BH shadow have been considered in several talks, including the review of M. de Laurentis. The dark ring diameter $42 \pm 3$ $\mu$as, observed at millimeter wavelengths 230 GHz, corresponds to BH mass $6.5 \pm 0.7 \times 10^9 M_\odot$, which is close to one of the previous, the larger one, mass estimations. The BH shadow with accretion disk visible from the edge, was computed in [9], see Fig. 2.

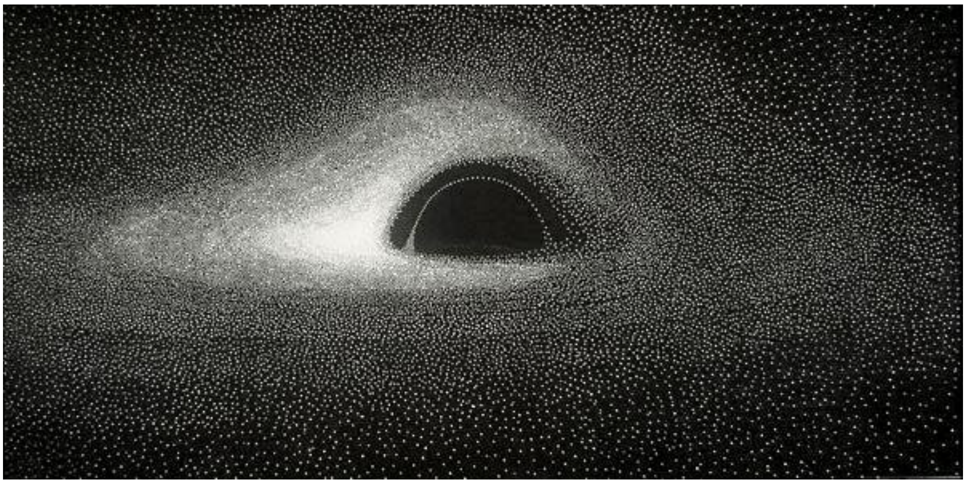


**Figure 2:** Simulations of a shadow of BH, surrounded by accretion disk, from [9]. Luminet calculated in 1979 using the IBM 7040 mainframe, an early transistor computer with punch card inputs. Using numerical data from the computer, he drew directly on negative image paper with black India ink, placing dots more densely where the simulation showed more light.

The measured shadow is represented by a round dark spot, with asymmetric light circle (Fig 3). The preferred model is an almost front situated accretion disk, rather than a light sphere, which should be extremely faint. Optical VLBI could give an angular resolution up to $10^{-6}$ arcsec, what would permit to see BH shadow at large redshift ($z \leq 10$), when the angular size is growing with $z$ due to cosmological expansion (Fig.4). It could permit to measure a BH mass in very distant galaxies and quasars.

**"Cyclotron" lines in X-ray sources** The first line in the hard X-ray spectrum of X-ray pulsar Her X-1 was observed in 1978 [13], and was interpreted a cyclotron line with $\omega = \omega_B = \frac{eB}{m_e c}$. That permitted to define the magnetic field strength on the NS surface as $B \sim 6 \cdot 10^{12}$ Gs, if it belongs to emission line, and slightly lower $B$ in the case of absorption. Some questions about this line, and similar lines in other X-ray sources are still open: time variability of line energy; emission or absorption nature of this line; correlation of the line energy with luminosity; etc.

By classification Her X-1, reviewed in the talk of N.S. Shakura, belongs to the class of a young recycling pulsars, with decreasing period, which are characterized by relatively low B values [4, 8]. While the cyclotron interpretation of the observed line indicates to much larger value of the magnetic field, the detailed observations of the light curve of the Her X-1 from the satellites ASTRON, RXTE and Ginga [11, 5, 12] could be understood only with much smaller field $\sim 5 \cdot 10^{10}$ Gs. The light curve of 35 day cycle, and evolution of the pulsar profile, may be explained by the reflected light at low-on state, what is possible only when the inner edge of accretion disk radius $R_{inner} \sim 20 R_*$, see Fig.5.

The consistency of the energy of the line with the observed light curve takes place if the

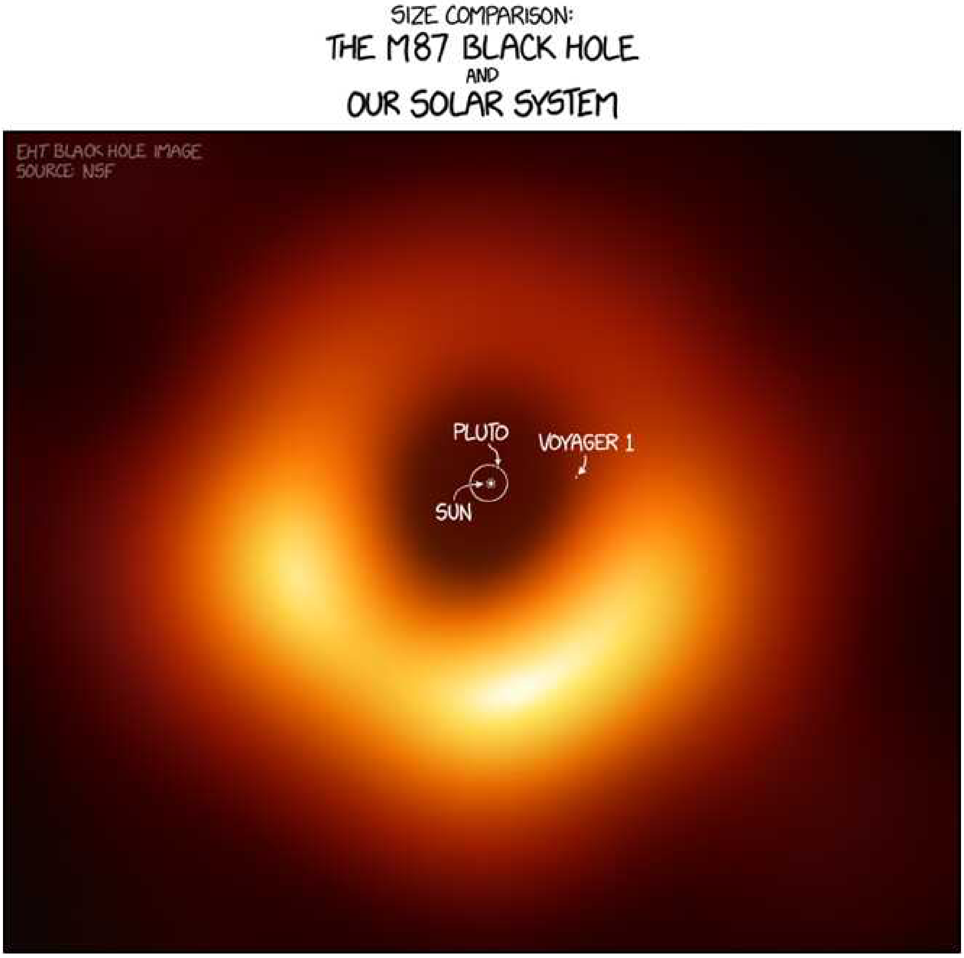



**Figure 3:** First M87 Event Horizon Telescope Results. The Shadow of the Supermassive Black Hole: how big the M87 black hole is compared to the Solar system. Image by Randall Munroe, from [7].

relativistic magneto-dipole radiation mechanism with highly anisotropic electron distribution, with large relativistic factor along the field, and a small one in perpendicular direction.

$$\gamma_{||} = \frac{1}{\sqrt{1-(v_{||}^2/c^2)}} \gg 1, \quad \frac{v_\perp}{c} \ll 1.$$

The visible line energy is $E_{line} = 2\gamma_{||}E_{cycl} = 2\gamma_{||}\frac{eB}{m_e c}\hbar$. At $v_{||} = 40$, the observed emission line at $E \approx 50$ keV is formed at $B \sim 6 \cdot 10^{10}$ Gs [11]. The observations of the time variability of energy of X-ray lines in X-ray sources show [10] decrease of $E_{line}$ with increasing luminosity $L$. It is consistent with the model of formation of a strong non-collisional shock wave near NS surface, where larger $L$ increase a radiation drag, resulting at smaller $\gamma_{||}$, and visible energy of the line [2], see Fig.6.

The difference between the cyclotron and magneto-dipole origin of the X-ray lines is imprinted in the polarization properties of the pulsar beam, studied in [3] The cyclotron radiation has a circural polarization in the beam, of almost 100%. The polarisation properties of a relativistic dipole

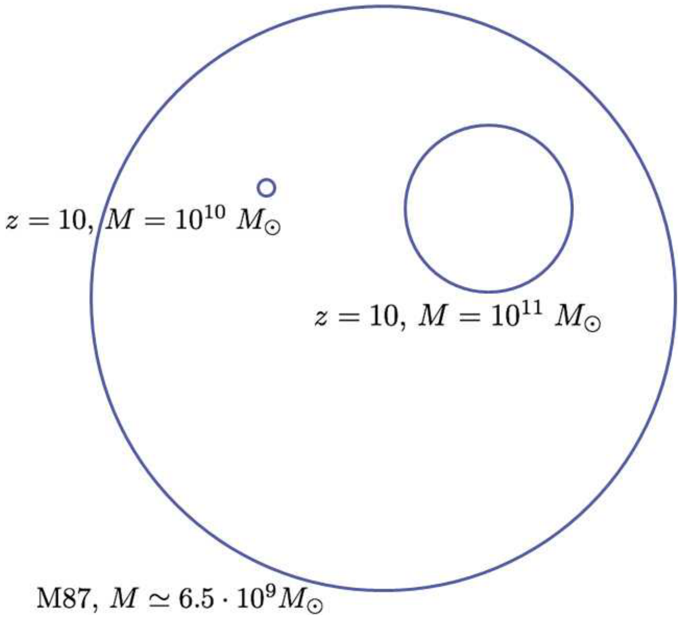



**Figure 4:** Relative shadow size of BH shadow for different masses. at different redshifts. Image by O. Tsupko.

radiation are more complicated. The level of linear polarization in the beam is $\approx 0.36\%$. Denoting $x = \frac{\omega}{\gamma_{||}\omega_B}$, we have the circular polarisation level $P_{circ} \approx 0.42$ at $0 < x < 1$; and $P_{circ} \approx 0.71$ at $1 < x < 2$, with opposite sign. Most lines from the X-ray sources lye in the NuSTAR energy band. Perspectives of hard X-ray polarization observations are reviewed in [6].

**Flight to other planets.** D. Fargion suggested to protect cosmonavts/astronavts against cosmic radiation putting their capsule in the middle of fuel tank. The fuel would absorb the high energy CR, and cosmonavts/astronavts could fly more safely.

I would like to express my deep gratitude to the organizers, and first of all, to Franco Giovannelli.

## References

[1] Amati L. ArXiv:1002.2232v1 [astro-ph.HE], 10 Feb 2010.

[2] Baushev A.N., & Bisnovatyi-Kogan G.S. Astron. Rep. **43**, 241 (1999).

[3] Bisnovatyi-Kogan G.S. and Lyakhova Ya.S. MNRAS **456**, 3186 (2016).

[4] Bisnovatyi-Kogan G.S. and Komberg B.V. Soviet Astron. **18**, 217 (1974).

[5] Deeter G., Scott D.M., Boynton P., et al. ApJ **502**, 802 (1998).

[6] Fabiani S. Galaxies **6**, number 2, article number 54 (2018); arXiv:1805.04454.

[7] https://xkcd.com/2135/

[8] Lorimer D., Living Reviews in Relativity, **11**, no. 8 (2008).

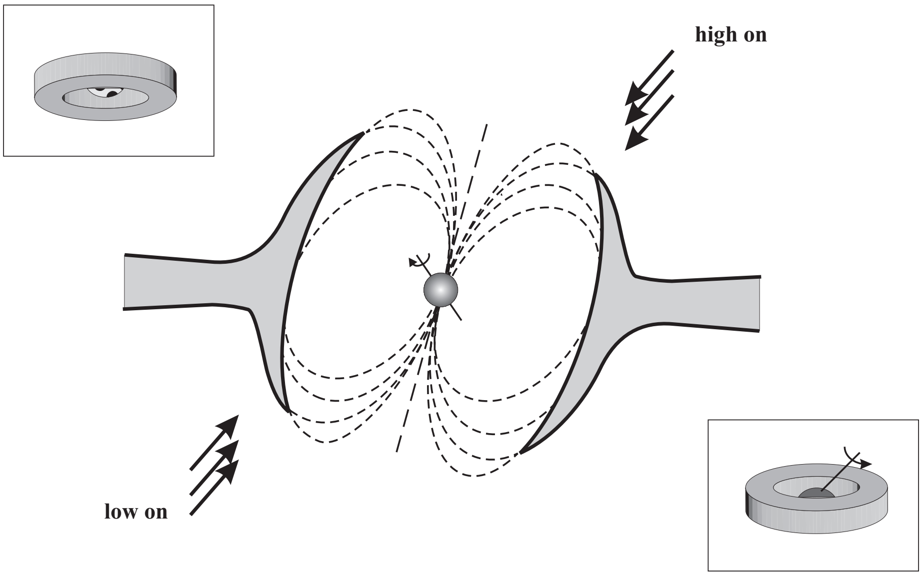



**Figure 5:** Configuration of the inner edge of the disk and the neutron star; neutron star and the disk in the "high-on" state (left top box), and in the "low-on" state (right bottom box), from [11].

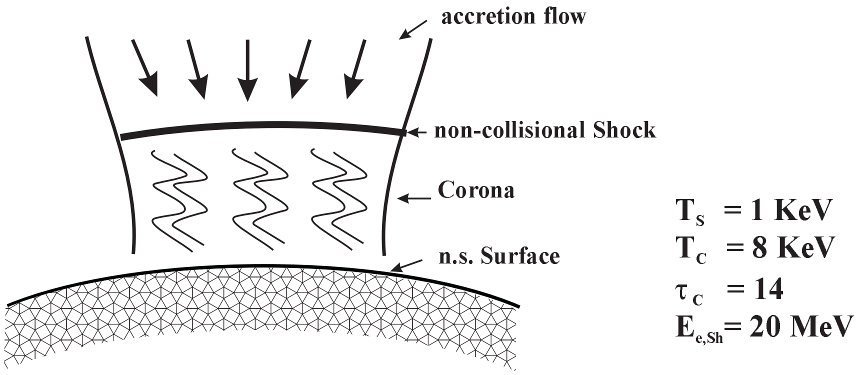

[9] Luminet J.-P. Astron. Astrophys **75**, 228 (1979).

[10] Mihara, T., Makishima, K., Nagase, F. , Proc. Workshop *"All-sky X-ray Observations in the next decade"*, p. 135 (1997).

[11] Sheffer, E., et al. Soviet Astron. **36**, 41 (1992).

[12] Scott D.M., et al. ApJ **539**, 392 (2000).

[13] Truemper et al. ApJ **219**, L105 (1978)



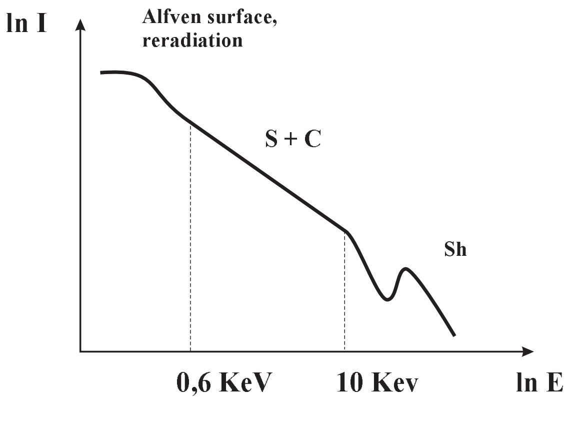




**Figure 6:** Schematic structure of the accretion column near the magnetic pole of the neutron star (top), and its radiation spectrum (bottom), from [2].