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Reflective black holes

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In this paper, a brief analysis of repeated and overlapped gamma-ray bursts, fast radio bursts and gravitational waves is done. These signals may not be emitted by isolated cataclysmic events and we suggest interpreting some of them within the impenetrable black hole model, as the radiation reflected and amplified by the black hole horizons.

Keywords: Black holes; gamma-ray bursts; fast radio bursts; gravitational waves.

1. Introduction

Extremely energetic astrophysical processes, occurring mostly outside our galaxy, are thought to be responsible for creating exotic forms of radiation: ultra-high-energy cosmic rays, Gamma-Ray Bursts (GRB), Fast Radio Bursts (FRB) and Gravitational Waves (GW). There is a plethora of literature about the origin and the emission mechanism of these signals, but their true nature still remains poorly understood.

In our resent papers,[1,2] some mysterious high-energy transients in the universe were suggested to be explained as reflection of radiation from massive Black Holes (BH). In contrast to the standard view that a BH horizon is simply a coordinate singularity, this model offers the view that a BH horizon might represent more singular surface than is usually thought and creates a real physical barrier to the particles/fields trying to cross it. By re-examining boundary conditions for the wave equations close to a BH horizon, the real-valued exponentially time-dependent term (with the complex phases) was found in the wave amplitudes[1,2]

$$A \sim e^{\pm t/2M}, \tag{1}$$

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where t is the time parameter and M is the BH mass. Equation (1) shows that close to the horizon, the amplitude of the wave can be exponentially declined or increased. Therefore, BHs may be able to capture, amplify and emit matter particles and gravitational radiation. Massive BHs usually are surrounded by dust clouds and there are problems with observations of strong lensings (due to spurious radiation and large extinctions of waves by accreting materials), which should be formed close to their horizons. For GWs dust and noise do not present an obstacle, while in the case of electromagnetic radiation it is expected that, due to absorption (larger for smaller wavelength), only the short duration relativistic lensing signals in the form of radio (largest wavelength) and gamma (most energetic) waves could escape the dust clouds surrounding the BH. Ultimately, in our papers,[1,2] it was suggested that some rare high-energetic signals, like ultra-high-energy cosmic rays, GRBs, FRBs and GWs, can be explained by strong gravitational lensing carried by massive BHs.

If the model discussed above is true, one might be able to observe extra-galactic repeated GRB, FRB and GW signals, coming from one and the same direction. If we see some repetition of the signals coming from the same point, and/or if different kinds of the rare signals are arriving from the same place, this might imply that there exists a massive "BH reflector" that makes the lensing and increases the amplitude of some random signals.

In this regard, there are other theories too that treat BH horizons as a physical barrier, like the firewall proposal.[3] Also, BHs were suggested to act as the "information mirrors",[4] that through Hawking radiation return the in-falling information in a time comparable to the time it takes the information to fall into the BH.

In this paper, we try to pick up the events from existing data, that potentially can fit into the mechanism explained above. In Secs. 2–4, we briefly discuss high energetic radiation, GRBs, FRBs and GWs, and their possible repetitive character. In Sec. 5, we search for different types of events, sources of which may overlap on the sky and we argue that, such signals can be products of massive BHs, which catches some incident signals, amplifies and emits them towards us. In Sec. 6, we mention some other astrophysical phenomena that can potentially be related to the "BH reflector"; model. Finally, Sec. 7 presents our conclusions.

2. Gamma-Ray Bursts

GRBs are rapid, high-energy flashes of electromagnetic radiation that can last from milliseconds to hours and are followed by a broadband (X-ray to radio frequency) longer-lived fading afterglow emissions (see Ref. 5 for a review). GRBs were first detected by Vela satellites in 1967,[6] but their origin was not clear until the detection of an afterglow radiation in 1997.[7–9]

GRBs are classified into two classes: "short" with duration < 2 s, and "long" — lasting > 2 s.[10] The majority of the detected events are long GRBs and they are believed to be a consequence of a core-collapse supernovae (see Ref. 11 for a review). The discovery of an afterglow of short GRB,[12] encouraged theories of coalescing compact binaries, double Neutron Star (NS) or NS-BH systems, as their progenitors, but the true nature of short GRB sources is still under debate (see Ref. 13 for a review).

GRBs occur at an average rate of one event per day, randomly distributed across the sky. They arrive from cosmological distances, no GRB within the Milky Way has been detected and no repeated GRB has been recorded so far.[11] However, there exist a different class of GRBs, called Soft-Gamma Repeaters (SGR), that have a different emission mechanism and they do repeat (for a review see Ref. 14). Initially, they were considered as usual GRBs, but having repetitive character destructive events, like supernovae or binary merger, were excluded as their progenitors and today SGR are treated as a different class of signals.

NSs with powerful magnetic field (magnetars) were thought to be responsible for creating SGRs.[15,16] According to the theory, bursts cause the loss of energy and the object should slow down, increasing its period of rotation. For example, measuring the spindown rate 2.610^{-3} s yr^{-1} of SGR1806-20, magnetar with magnetic field strength 8×10^{10} teslas, perfectly fitted the theory.[17] Currently, there are 15 magnetars associated with SGRs, with 11 confirmed and 4 candidate events.[18] Another 14 magnetars (12 confirmed, 2 candidate) are linked to anomalous X-ray pulsars.[18] X-ray pulsar is binary system of a magnetized NS and a stellar object. Gas of the stellar companion is accreted on the NS and its magnetic field generates two or more hotspots that emit X-rays.[19] As the NS rotates pulses of X-rays are observed. However, in rare cases, the presence of companion bright objects was excluded and a separate class of pulsars — anomalous X-ray pulsars was created,[20] which later was suggested to be generated by magnetars.[16] The majority of the pulsars detected so far lie within the Milky Way galaxy.

3. Fast Radio Bursts

FRBs are transient bright radio signals that last from a fraction of a millisecond to the few milliseconds. Their source and origin still remains mysterious. They were first detected in 2007[21] and were thought to emerge from some cataclysmic astrophysical events, like NSs coalescence,[22] or collapse of super-massive rotating NSs.[23] However, with more data in hands, FRBs revealed a repeating character, arriving several times from the same spot of the sky,[24–26] indicating that the source survives the energetic event that creates the bursts, ruling out cataclysmic events as their origin.

The first detected repeated event FRB 121102 had 10 follow-ups,[24] encouraging the idea of extragalactic magnetar as its source.[27,28] Later, six repeated bursts from the event FRB 180814.J0422+73 were reported.[25] Then, eight more repeated FRB sources were announced, with 6 sources detected twice, one three times and another one ten times.[26] Lately, the number of bursts in the event FRB 180916.J0158+65 was increased from 10 to 38 and the periodicity of 16.35 ± 0.15 days was found.[29] In addition, long-term monitoring campaign of the event FRB 121102 declared possible 157 day periodicity.[30] Recently, a 12 h observation of position of the event FRB 180301,[31] revealed 15 new bursts, with a burst rate $1.2^{+0.8}_{-0.7}\mathrm{h}^{-1}$.[32] By the time of writing this article, CHIME/FRB collaboration reported detection of the new signal FRB 20201124A, that has repeated six times.[33] To sum up, as of today, five FRB events have been recorded, which have repeated six or more times.

4. Gravitational Waves

The direct detection of GWs started a new era in multimessenger astronomy. In their first two observing runs, Advanced LIGO/Virgo detectors witnessed 10 events of binary BH merger and one event of binary NS coalescence,[34] accompanied by a gamma-ray counterpart.[35,36] The catalog of the new detections from the first half of the third observing run is already published,[37] and it contains several surprising events: merger of the BHs with highly asymmetric masses;[38] coalescence of the compact objects whose total mass is more than the mass of any binary NS system known so far;[39] merger of a BH with a compact object with the mass lying in a mass gap[40] and the detection of the first ever intermediate mass BH, by coalescence of the BHs with the masses that are forbidden by the pair-instability supernova processes.[41]

Besides the merger of binary compact objects, the source of GWs can also be an asymmetric supernova explosion,[42] or stochastic background of GWs produced by inflation.[43,44] All these processes are cataclysmic events and so, GWs do not repeat. However, there are implications that some of the detected GWs, may be lensed images of one and the same merger. For example, the events GW170809 and GW170814, from the LIGO/Virgo's second observing run, were separated by 5 days and overlap on the sky by 90% credible region. Their waveforms and chirp masses are very similar and, there is a suggestion that these two signals can be the lensed images of the same binary BH merger.[45] The two signals GW190828_063405 and GW190828l_065509 detected by LIGO/VIRGO during the third observing run, were separated only by 21 min and came from the very close area of the sky. Nonetheless, it was argued that spatial separation of these events was too large (~ 100 larger than the strongest lensing observed) and time separation too low and, therefore, they cannot be lensed images.[46]

Some low-frequency LIGO signals may be magnified by an intervening galaxy.[47] However, taking into account the predicted number of expected GW sources and distribution of galaxy lenses in the universe, only one in the thousand observed events is estimated to be lensed.[48,49] So, with only the dozen events in hands, it can be reasonably assumed that none of the GWs detected so far were lensed.[50]

5. Overlapping Energetic Signals

Localization of a GW source on the sky is crucial for searching electromagnetic and neutrino counterparts, but it is not an easy job to do. Observed time delays of the signals at different detectors is a main parameter, which makes it possible to

Table 1. Repeating FRBs: 121102,[24] 180916,[29] 180814.$J0422+73$,[25] 180301,[31] 20201124A,[33] GRBs from the nearby 4 degree arcs and GWs that contain these FRB coordinates within 90% credible sky localization ($\Delta\Omega$).

Name	Ra	Dec	Trigger Time
FRB 121102	**05 32 00**	**+33 05 00**	**Repeating**
GRB 150928359	05 35 07	+34 14 24	2015-09-28 08:37:19
GRB 090802235	05 37 19	+34 05 24	2009-08-02 05:39:03
GRB 140209313	05 25 19	+32 29 17	2014-02-09 07:30:58
GRB 090610648	05 36 48	+35 25 12	2009-06-10 15:33:25
GRB 180219482	05 44 53	+32 18 36	2018-02-19 11:34:12
FRB 180916	**01 58 01**	**+65 43 00**	**Repeating**
SGR 150228213	02 02 31	+65 32 24	2015-02-28 05:06:55
GRB 191009298	01 47 14	+65 43 48	2019-10-09 07:08:56
GRB 140110814	02 07 26	+65 09 36	2014-01-10 19:31:34
GRB 080727964	02 10 24	+64 06 00	2008-07-27 23:07:46
GRB 130106995	01 55 02	+63 22 48	2013-01-06 23:52:25
GW 190408	$\Delta\Omega = 140$ deg^2		2019-04-08 18:18:02
GW 190519	$\Delta\Omega = 770$ deg^2		2019-05-19 15:35:44
GW 190707	$\Delta\Omega = 1300$ deg^2		2019-07-07 09:33:26
GW 190930	$\Delta\Omega = 1800$ deg^2		2019-09-30 13:35:41
FRB 180814	**04 22 22**	**+73 40 00**	**Repeating**
GRB 150919606	04 20 24	+71 42 00	2015-09-19 14:33:18
GRB 160720767	03 52 37	+73 53 35	2016-07-20 18:23:56
GRB 130502327	04 27 03	+71 03 39	2013-05-02 07:51:11
GRB 131028076	03 47 48	+72 11 24	2013-10-28 01:49:02
GW 170608	$\Delta\Omega = 392$ deg^2		2017-06-08 02:01:16
GW 190513	$\Delta\Omega = 490$ deg^2		2019-05-13 20:54:28
GW 190707	$\Delta\Omega = 1300$ deg^2		2019-07-07 09:33:26
FRB 180301	**06 12 55**	**+04 38 44**	**Repeating**
GRB 111124308	06 16 14	+04 37 48	2011-11-24 07:24:10
GRB 190502168	06 16 43	+03 17 24	2019-05-02 04:01:30
GRB 130504978	06 06 31	+03 50 02	2013-05-04 23:28:57
GRB 150923995	06 09 07	+06 31 48	2015-09-23 23:52:52
GRB 120111051	06 21 22	+05 00 00	2012-01-11 01:13:27
GW 190602	$\Delta\Omega = 720$ deg^2		2019-06-02 17:59:27
FRB 20201124A	**05 08 00**	**+26 11 00**	**Repeating**
GRB 100406758	05 11 10	+26 51 36	2010-04-06 18:11:26
GRB 170803172	05 06 00	+23 58 12	2017-08-03 04:07:16
GRB 181119649	04 50 12	+26 25 48	2018-11-19 15:35:09

localize the object on the sky using triangulation.[51] For today, the most accurately localized event is the binary NS merger, having sky localization area 16 $\deg^2$ with 90% credible interval. However, not all of the events are three-detector observations and so, their sky localization accuracy is far more uncertain and can be even order of $\sim 10^4$ $\deg^2$.[34,37] That is why, despite a strong effort, GRB 170817A[35,36] remains the only companion of the GWs detected so far.

The sky localization of FRBs is quite precise and its uncertainty does not exceed order of arcminutes (can be even order of milliarcseconds).[26,52,53] But the uncertainties in sky coordinates of GRB sources are somewhat high and can be a few degrees.[54–59]

In our papers,[1,2] it was suggested that any type of highly energetic signals can be generated by massive BHs. So, whenever such events overlap on the sky, we can argue that they were emitted by one and the same source. To start a search for correlated high energetic radiation, we begin with FRBs, as they do repeat and are the most accurately localized.

We take the coordinates of five repeating FRBs: 121102,[24] 180814.J0422+73,[25] 180916,[29] 180301,[31] 20201124A[33] and search the sky for GRBs, in 4 degrees radius around their sources. Besides, we look at the sky maps of LIGO/VIRGO data and seek for the GWs that contains these FRB coordinates within their 90% credible intervals. As localization of GWs have asymmetric errors, instead of exact coordinates, we use 90% credible interval sky localization $\Delta\Omega$ of the signals measured in $\deg^2$.

In Table 1, we present five separate groups of events that are associated with repeating FRBs (in bold). In our opinion, the events presented in each group of the Table 1 have a probability of being correlated with each other, as all of these events are very highly energetic and their coordinates overlap. According to the theory suggested in the papers,[1,2] different types of such powerful radiation can be related to the same source — massive BH that amplifies and emits incident matter particles and gravitational waves.

6. Other Astrophysical Phenomena

Before the concluding part, in this section, we discuss other astrophysical phenomena that can potentially be related to “BH reflectors”.

Recent discovery[60] of X-ray echoes from behind a supermassive BH may stand as a good support in favor of wall-like models of BH horizon. The photons detected in this new study, reverberate off the far side of the accretion disk, bent around the BH and magnified by the strong gravitational field. This scenario fits well with the analyses of BH horizon given in our previous papers.[1,2]

Controversial observations of redshifts of quasars[61] and superluminal motions in relativistic jets of M87[62] may also be linked with “BH reflectors”. Gravitational corrections for the radiation of quasars and of the M87 are usually ignored, since they are estimated to be about two orders of magnitude smaller than Doppler shifts due to random motions in galaxies. However, we note that it may not be a correct approach. In the framework of our model,[1,2] singular features of a BH horizon can be modeled by introduction of the effective negative cosmological constant, which leads to additional redshift of outgoing radiation from this region. Due to this dark-energy-like features, the spacetime close to a BH horizon looks accelerated for a distant observer. Standard approach misses this additional acceleration and that is the reason of apparent anomalous behaviors of jets.

Other possible consequence of the "BH reflector" can be associated with Ultraluminous X-ray (ULX) sources. ULXs are class of accreting compact objects displaying X-ray luminosities higher than 10^{39} erg s^{-1}.[63] Rare X-ray flaring activity was spotted in the ULX source NGC 4559 $X7$.[64] The accreting object is probably a BH and the X-ray flaring may be caused by the mechanism discussed in our papers.[1,2]

Another candidates that can be related to "BH reflectors" are Extreme-Energy Cosmic Rays (EECR), with the energy exceeding the so-called GZK limit, 5×10^{19} eV. EECRs are extremely rare, only one event per square km per century. Since the first observation in 1991,[65] at least seven EECRs have been recorded.[66] Several origins of the EECR have been proposed, including the relativistic jets of active galactic nuclei, the large-scale shocks associated with galaxy clusters and NSs (see the recent review Ref. 67). The unknown (hypothetical) sources of EECR are called Zevatrons, since they should be capable of accelerating particles to 1 ZeV (10^{21} eV). The exceed of their energies of GZK cutoff shows that, most likely, EECRs are emitted by some relatively close sources and we believe that they are the reflections from supermassive BHs in the centers of nearby galaxies.

We also want to mention the recent discovery of the variable radio source ASKAP J173608.2-321635, located near the galactic center.[68] It is considered as a new class of objects, since non-detection of multi-wavelength counterparts rules out flaring stars, binary systems, NSs, GRBs, or supernovae as its source. These radio signals are highly-polarized that suggests scattering, probably by the BH. ASKAP J173608.2-321635 share some properties with another type of mysterious signals spotted near the galactic center, known as Galactic Center Radio Transients, which are also yet to be explained.

As last example, some sources of gamma-rays are thought to be anti-stars, that annihilate accreting interstellar matter.[69] But the true source of energetic radiation can be a BH, which catches some incident low-energy waves and amplifies it to the high-energy gamma-rays.

7. Conclusions

Extremely energetic astrophysical radiation probably is generated by cataclysmic events like supernova explosion or merger of heavy compact binary system. However, in rare cases, high energetic signals may repeat, that rules out cataclysmic processes as their origin. FRBs definitely display this repetitive nature. A distinct class of

GRBs, called soft gamma repeaters, also repeat. GWs, since the dawn of their direct discovery, have not yet demonstrated any clear repetition, as they are believed to be generated only by cataclysmic events and the probability of lensing is low.

One possible mechanism for generation of highly energetic radiation was suggested to be the horizon of a BH.[1,2] In this scenario, a massive BH can catch incident radiation, amplify its energy and emit it as a high energetic signal.

As a particular BH may do this with any incident radiation, that can then be radiated towards the Earth, this can be observed here as the bursts of electromagnetic radiation, GRB or FRB. If one finds periodicity of these signals, it may imply that some object like a pulsar, may be shining a light onto a BH, that is continuously amplifying its radiation and directing towards us.

The same mechanism can apply to GWs too. GW emitted by a coalescing compact object (or by supernova process) may be caught, amplified and directed towards the Earth by a massive BH. So, its real source may be more distant, or can be less massive. This can potentially explain the LIGO event GW190521,[41] the source of which is a very massive binary system, that lies in the forbidden region of current existing models.

Besides that, "BH reflectors" can reflect both, electromagnetic and gravitational radiation and so, observers on the Earth can see GRBs, FRB and GWs that have the same source. In this paper, we selected the unusual high energetic electromagnetic and gravitational signals, that have the overlapping sky coordinates (Table 1). In our opinion, the events presented in Table 1 are the best candidates for the reflections caused by "BH reflectors". Moreover, we mentioned several astrophysical phenomena, like the recent discovery of X-ray echoes from behind a supermassive BH, superluminal motion, quasars, Extreme-Energy Cosmic Rays, Ultraluminous X-rays and gamma-rays without definite source, that can also be linked with "BH reflector" scenario.

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