A review of black hole super absorption and Gamma-ray burst research

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Abstract: The black hole super absorption model is one of the strong candidates for the central engine of gamma-ray bursts. A series of theoretical results of this model will be briefly summarized, taking into account the complex eruptions of Gamma-ray bursts, gravitational waves and their electromagnetic counterparts. At the same time, the history of Gamma-ray bursts and related important theories will be presented.

1. Introduction

Gamma-ray bursts (hereafter, gamma bursts) can be divided into short and long bursts according to the duration timescale T_{90} (defined as the cumulative photon count from 5% to 95%) bounded by 2 s [1], or into Type I and Type II bursts according to their observational characteristics, statistical properties, and possible origins [2]. It is thought that they originate from dense stars (binary neutron stars or black holes and neutron stars) merging [3-4] or massive collapsing stars [5], respectively. Blackhole self-absorption system [6-9] or a millisecond magnetar [10-12] eventually forms at its center, releasing massive energy through relativistic jets and triggering gamma bursts [13-16].

2. Blackhole super-absorption

2.1 Accumulation and suction cups

The concept of spherical accretion was first proposed by Bondi [17], but falling matter often has a certain angular momentum, which leads to the formation of disk-like structures around the central object, which becomes familiar to us. However, falling matter tends to have a definite angular momentum, which results in the formation of a disk-like structure around the central object, which is familiarly known as the accretion disk. The accretion process converts gravitational energy into internal energy and radiation by viscous dissipation of the collapsing matter towards the central object. Various complex physical processes may accompany the accretion, which may lead to innumerable radiations, the formation of secondary structures, or the synthesis of different elements.

High-energy astronomical phenomena often accompany adsorption systems with a black hole as the principal object. At the present stage, the classical black hole accretion, with photon radiation as the main cooling mode, has established a more mature theoretical system. Well-known classical black hole accretion models include the SSD [18] (Shakura-Sunyaev disk, or Standard Thin Disk), the SLE [19] (Shapiro-Lightman-Eardley) disk, the ADAF [20-21] (advection-dominated accretion flow) and slim disks [22] (also known as optical-thickness ADAF), as detailed in [23-24]. In addition, there are several other black hole accretion disk models of interest, such as ADIOS [25] (advection-dominated inflow outflow solution), CDAF [26] (configuration-dominated accretion flow) and LHAF [27] (luminous hot accretion flow) and so on.

Accretion triggers radiation, and when excreted matter accumulates to a certain point, radiation pressure prevents further fall of the matter. When the gravitational force of a focal object on a single particle is in equilibrium with the radiation pressure to which the particle is subjected, the corresponding luminosity is called the Eddington luminosity [23-24], i.e.,

$$L_{\mathrm{Edd}} = \frac{4\pi\, cGMm_H}{\sigma \mathrm{T}} \tag{1}$$

Where M, mH, and σT denote the central object mass (and, unless otherwise stated, the black hole mass in all of the following), the hydrogen atomic mass, and the Thomson scattering cross-section of electrons, respectively. The corresponding absorption rate is called the Eddington absorption rate.

$$M_{\mathrm{Edd}} = \frac{L_{\mathrm{Edd}}}{c^2} \tag{2}$$

In some definitions, the right-hand side of the equation is split by the efficiency η. Some literature refers to the absorption rate defined in the above equation as the critical (analytical) absorption rate of Mcrit [24].

2.2 Blackhole super absorption

The study of the energy mechanisms of gamma burst centers and their related observations has been a hot and difficult topic in the field of gamma bursts. As one of the strong candidates for the central Gamma-ray engine, the black hole super absorption process is defined as an extremely high absorption rate (above about 1012 M_{Edd}, where M_{Edd} is 7.0×10^{-17}m $M_{\odot} \cdot s^{-1}$, where m = $M/M_{\odot}$ refers to the mass of the massless central object, as follows, both denote massless black holes' masses), the density and temperature of the absorption disk is so high that photons are almost always imprisoned in the disk and difficult to escape. Thus, they are unable to extract the blackhole gravitational or rotational energy of the neutrino radiation or the Blandford-Znajek (BZ) mechanism [28-32] (which may be accompanied by magnetic coupling (MC) process [33-35] and the Blandford-Payne (BP) mechanism [36]) as the main energy extraction mode of the absorption process [6]. Among them, the absorption model with neutrino radiation as the main cooling method is called the neutrino-dominated accretion flow (NDAF) model [6,9], and the absorption rate is generally required to be above 0.001 $M_{\odot} \cdot s^{-1}$ (ignition absorption rate [6,37]).

Aframomum et al. first obtained a unified image of the classical black hole absorption disk under the description of α viscosity in the logarithmic space of M-Σ (where M and Σ represent the absorption rate and disk density, respectively) [21]. Figure 1, on the other hand, shows the schematic after incorporating the black hole self-absorption model [6]. It is useful to note that the optical depth of the accretion disk model represented by the left and right curves is optically thin and thick, respectively. The slim disk can show super-Eddington accretion (one of the possible way for producing ultraluminous X-ray), while black hole super-absorption (including NDAF) is a natural extension of the slim disk, and LHAF connects the two curves [27]. In addition, from the point of view of the material component of the absorption disk, the classical absorption disk material is in the plasma state, photons through the electron scattering and absorption process and finally escape from the disk surface, in which the optically thin SLE disk and ADAF belong to the dual-temperature disk, that is, the ion and electron thermal coupling is weak, there is a temperature difference. The black hole self-absorption disk, especially the NDAF, has an extremely high temperature and density, resulting in the possible emergence of free nucleons in its inner region, and most neutrinos are the product of the Urca process involving free neutrons and protons in the region.

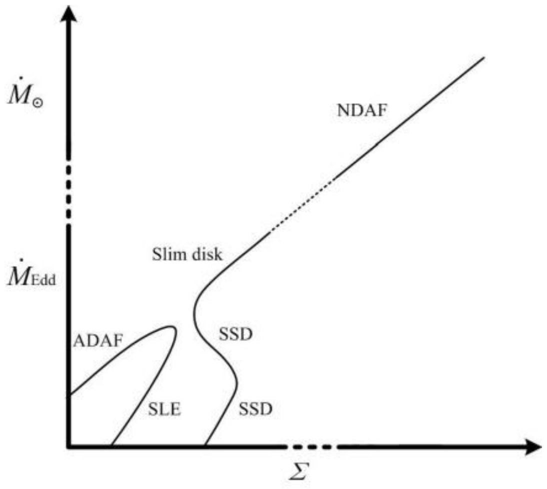

Fig 1. A statistical-description of various types of suction cup models in M-Σ log space [6]

Outflows are one of the notable features of black hole super-Eddington accretion systems. From a theoretical point of view, many numerical calculations, 2-dimensional and 3-dimensional general relativistic magnetohydrodynamic simulation (GRMHD) work [6,38-45], have all contributed to the causes of outflows under classical black hole accretion, intensity, structure, and other influencing factors are examined and discussed in detail. From an observational point of view, the outflow from black hole accretion systems has been directly observed in the case of supermassive black hole accretion systems at galactic centers [46], extragalactic quiet galactic centers [47], and active galactic nuclei [48]. In summary, these suggest that outflows from black hole accretion systems must be carefully considered. If the central engine of gamma bursts is a black hole super-absorption system, the existence of outflows is almost inevitable, and the possible phenomena analogous to the outflows from gamma burst centers have become an issue that needs to be discussed in detail. This kind of black hole hypersecretion model, which fully considers the outflow factor, is called the black hole hypersecretion inflow-outflow model.

Here, I want to clarify the concept of outflow. After the formation of a stable suction disk, there may be a stream of material overflowing from the outer boundary due to the redistribution of angular momentum in its radial direction, which is also called outflow (or radial outflow), and this part of the material will not escape; jet belongs to the general definition of outflow. By outflow, it often means a stream of material made public from the surface of the suction disk (plumb) and can escape completely to infinity. This, in turn, leads to two common terms, disk wind (first suggested as the origin of jets from accretion disks around black holes in the seminal paper by Blandford and Payne [91]) and outflow. In the conventional literature, no distinction is made between these two concepts. I believe that the concept of "wind" in astrophysics comes from the solar (stellar) wind, which by its nature is a tinny, hot plasma gas. Accordingly, the disk wind is more like an ADAF that carries a lot of energy but has a cracked gas density; the outflow in the usual sense corresponds to a much broader flow of matter than the wind.

3. Gamma storm research

3.1 Vela

The discovery of GRB began with a chance observation of the United States Vela satellite in the 1960s. As a military satellite. Vela primarily monitors global nuclear reaction experiments by detecting X-ray and guard-ray scintillation in space. However, at 14:19 UTC on 2 July 1967, Vela's satellites 3 and 4 detected a Gamma-ray beam that was unlikely to have originated from a known atomic experiment on earth. Also ruled out were gamma photon events caused by solar flares and supernova outbursts, as these were not detected by other instruments that day. Although GRBs were first identified immediately, they were not published at the time, and it was not until seven years later [49], in the 0.2-1.5MeV energy band, when 16 similarly identified GRB events were discovered, that the commonality of such astrophysical phenomena was statistically published in astrophysics, in an article entitled Gamma-ray bursts of cosmological origin. "Gamma-ray bursts," an astrophysical phenomenon, is well known to the world for the first time; from then on, the global research of gamma-ray bursts began to boom.

The Vela satellite ushered in a new era of Gamma-ray burst research. Decades later, a large number of instruments and space telescopes have been provided to work on gamma storms. As data samples have increased and the resolution of space-time has improved, various of hypothetical models have been designed to reveal the physical nature of this mysterious phenomenon. While no model is perfect and absolutely self-consistent, several key physical processes are becoming more evident.

3.2 BATSEICGRO

With the launch of the Compton Sky Laboratory (CGRO), there have been many breakthroughs in the study of gamma bursts. Thanks to the high Spatio-temporal resolution (angular resolution of the theoretical 4πstr wide field-of-view, ~4°, which may be obscured by the Earth by 30%) instruments installed on CGRO, such as the Gamma and Transient Source Explorer (BATSE, observing energy band 15keV to 2MeV), CGRO has detected 2704 gamma bursts in the decade 1991-2000. Although the light curves of the gamma bursts are different (e.g., the decays are moderate, fast, and near-power-rate spectral, with durations ranging from milliseconds to minutes), the important properties of gamma bursts can be summarized from a large number of BATSE data [50].

The spatial distribution of gamma bursts prior to BATSE and related issues has been a major academic challenge. The theoretical predictions extend from the Hanoi proximity source all the way to the known cosmic boundary. In the pre-BATSE era, although the spatial distribution of gamma bursts was observed to be homogeneous, it cannot be excluded that this homogeneity is most likely due to a number of instrumental uncertainties. This confusion was resolved after the launch of BATSE, along with further hypotheses of local origin (e.g., Milky Way, Barley Cloud, M31, globular clusters, etc.), whose spatial resolution clarifies the homogeneity of gamma bursts on the celestial sphere. The cosmological origin of gamma bursts has also been debated in the scientific community, as some regional models, such as the extended halo, also produce a uniform distribution [51]. The cosmological origin of gamma bursts was not finally confirmed until 1997 when the gamma burst afterglow was discovered, and the red shift was deduced. After that, the theory of using the gamma burst luminosity to determine the Hubble constant was established.

The band spectrum is an empirical non-thermal radiation spectral formula used primarily to describe the hard to soft change of gamma photon inclusion. The time-averaged formula for the band spectrum is given below [52-58]:

$$\frac{dn_\gamma}{dE_\lambda} \propto \begin{cases} E_\gamma^\alpha \exp(-E_\gamma/E_0), & E_\gamma \langle (\alpha-\beta)E_0 \\ \left[(\alpha-\beta)E_\gamma\right]^{(\alpha-\beta)} E_\gamma^\beta \exp(\beta-\alpha), & E_\gamma \rangle (\alpha-\beta)E_0 \end{cases} \tag{3}$$

Where the statistically averaged spectral indices α, β, and inflection energy E_0 are -1, -2.2 and ~100-500 keV, respectively. $E_p = (\alpha + 2)E_0$ is the peak energy of spectral $vF_v \propto v^2 n_{\gamma,v}$ (when α>-2 or β<-2, the peak energy is already out of the measurable range). Although the majority of gamma bursts can be fitted with non-thermal energy spectra during transient radiation, by using Band spectra, thermal components [59, 60] and additional components have also been found in a significant fraction of bursts; a detailed analysis of time-containing spectra is required to understand the radiative processes involved.

Overall, transient radiation spectra with spectral band features originate from synchrotron radiation processes that accelerate the power-law distribution of electrons in internal excitations. However, this interpretation is subject to a number of crises, such as the "deadline" problem and the "absorption line" problem.

The duration of gamma bursts is described by the T_{90} (or T_{50}) parameter, which refers to the duration of radiation between 5% and 95% (or between 25% and 75%) of the total number of detections. Based on the larger sample of BATSE observations, the gamma burst T_{90} (or T_{50}) distribution spans a long range and shows a double-peak structure with peaks at 30 and 4.3 seconds, respectively. A preliminary classification of gamma bursts based on 2-sec duration was thus established (T_{90} < 2 sec is a "short burst" and accounts for ~30% of all bursts; while "long bursts" with T_{90} > 2 sec have the same structure as "short bursts"). ", with different spectral properties) [61]. In the BATSE era, these two bursts reveal that there are two different predecessor star and central engine mechanisms ("massive stellar collapse" is used to explain the long bursts and "dense star summation" corresponds to the short bursts), and have contributed to the subsequent more detailed physical origin-based Classification [62-64]. In addition, BATSE defines the "stiffness ratio" as the ratio of the number of photons detected in the 100-300 keV band to the number of photons detected in the 50-100 bands, as a method of measuring peak energy flows and spectral indices, by measuring the radiative energy flow at different energy bands of a given storm. In general, short bursts found by BATSE have greater hardness ratios than the long bursts [61, 65].

3.3Beppo-SAX&H ETE-2

Constrained by the limits of field-of-view (FoV) angular fractional localization, even instruments with a resolution such as BATSE are crude in optical and X-ray band measurements. Although some models have previously predicted that gamma bursts should have some late, decaying low-energy band radiation caused by an external excitation wave sweeping through the surrounding medium [66, 67], the identification of the burst source, the surrounding medium, and the precise distance-accurate method by BATSE is also a major problem, so the need for advanced spectrometers is particularly urgent. After the launch of the satellite Beppo-SAX (1996-2002) and the satellite High Energy Transient Event Explorer (HETE-2, 2000-2007), the Dutch/Italian high-precision satellite, a new phase in the study of gamma bursts was reached.

The cosmological origin was not confirmed until the initial detection of the decaying gamma burst, GRB970228, the X-ray afterglow and its location by the Beppo-SAX satellite. The storm was located in a distant host galaxy (z = 0.69), which was confirmed in the following optical, radio and other wavelength images, the earliest evidence for the cosmological origin of the long storm. After the discovery of more and more host galaxies under the Beppo-SAX satellite observations, a redshift confirmation method for gamma storm host galaxies was established, and the dispute over the distance scale of the long storms was resolved [68]. Subsequently, HETE-2 observations revealed that long storms are spatially coordinated with Type Ic supernovae, closely linking gamma storms to the cosmological origins and predecessors of additional high-energy dense object outbursts. The anisotropic energy released during the type's transient radiation period can be estimated from the time-integrated gamma photon flux f~10-7-10-4erg cm-2 and the optical distance dL~1028cm [50].

$$E_{\gamma,iso} = 4\pi\, d_L^2 f (1+z)^{-1} \sim (1+z)^{-1} 10^{50-53} erg \tag{4}$$

If the radiation is directed, the aggregate effect will be minimal. Thus, gamma bursts are the most violent electromagnetic cosmic eruptions ever detected.

X-ray scintillation (XRF) is an X-ray burst phenomenon that was first detected by the Beppo-SAX satellites [69, 70] and subsequently identified as a new class of sources for the high-resolution afterglow observations of HETE-2 [71-73]. X-ray scintillation (XRF) has a very similar spectrum and light curve to typical gamma bursts, although the energy spectrum of XRF is much softer, with peaks occurring at a few KeV or lower energy. Like gamma bursts, XRF afterglow and redshift can be measured [74]. There are numerous models of XRF; however, whether the distinction between XRF and gamma bursts is mainly internal (physical parameters, radiative processes, etc.) or external (distance, observational orientation, etc.) requires further discussion.

3.4 Other theories

Among all the extant theories, one that has been certified by the international mainstream is the continuous injection of energy to supplement the positive excitation following the transient radiation, which eventually leads to the generation of a slow decay [75-79]. To supplement the forward excitation, Zhang [76, 80] proposed three possibilities.

(1) A long time scale exists for the activity of a central engine with gradual decay [81]. In this case, two components are required: a hot fireball leading to transient radiation and a cold bovine flux producing a flat energy injection (on a millisecond rotating pulsar [82] or from a central black hole with falling matter). However, under this hypothesis, the central engine would need to be active for long periods definitely, at least for several hours (104 seconds) during the gamma burst transient radiation. This is the only way to avoid very spooky and large energy input during the transient radiation phase. In this way, the gamma-ray radiation evanescent phase of the "energy effective conversion rate crisis" is bound to aggravate further, because here the gamma-ray radiation will be converted into a large part of the initial kinetic energy [77].

(2) A series of Lorentz factors are injected at once into the shell with a steep power-law distribution. In this case, there is no need for long time scale activity of the central engine and, in fact, continuous energy can be obtained from a rapid injection of the velocity-stratified jet, i.e., the late shell layer gradually builds up on the decelerating shock wave. The inflection at about 10^4s means that the Lorentz factor has a truncation at about dozens [76], which corresponds to the sudden injection termination. Grand also notes that the end of the "slow decay" marks the beginning of the evolution of the outer shock wave with a Blandford-Mckee self-similar solution. At the same time, based on the assumption that the overall Lorentz factor in the local series of the storm is time-inclusive, he also predicted a slow decay of the optical band similar to that of the X-ray band at about the same time [69] [78]. Together, they indicate that most of the energy for relativistic outflows is most likely present in the matter with a Lorentz of 30-50. However, due to the "stacking deceleration", the back excitations of both models are typically non-relativistic [83], which in a way may introduce the densitometry problem mentioned earlier.

(3) Delayed energy transfers to the forward excitation. This case has at least two possibilities as following. One of them is struck by numerical calculations, i.e., a time of 10^4s before the excitation wave enters the self-similar decelerating phase [84], and this process of transferring the kinetic energy of the fireball to the external medium is slow. Another possibility is the assumption that a significant part of the outflow is obtained from the moving flow [76, 85-87]. From the model developed in [88], it can be derived that the transfer of energy from the moving flow to the surrounding medium does not occur during the passage of the reverse surge, but after the end of the reverse surge. However, the key to this model is how long this delay is, and whether there is an existing mechanism that is capable of explaining the observed gradual decay. Although there is no exhaustive numerical simulation [80] to determine this, the possibility of slow decay due to a slow transfer of energy from the ejected material to the surrounding medium cannot be ruled out. Later, in the framework of millisecond pulsars [82], Yu et al [89, 90] investigated the dynamics and radiation characteristics of relativistic stellar wind bubbles as the ejected material sweeps through them, and divided them into forward- and inverse-excitation-dominated bubbles, corresponding to the two cases of no slow decay and apparent flattening, respectively. Based on the different ratios of magnetic energy in the excited material, the radiation of ~102-105s in these two cases corresponds to the excited medium-dominated and stellar wind-dominated cases, respectively. By fitting the gamma bursts with or without slow decaying properties, respectively, they provide a space of feasible parameters responsible for this phenomenon, thus providing some support for the gamma burst origins of the magnetar model.

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