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Extended Abstract

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Collapsar model for the central engine of gamma ray bursts

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Gamma ray bursts (GRBs) are the most explosive and brightest known photon sources in the universe. The initial bursts of GRBs found so far typically have a spectral peak between ∼100 keV and 1 MeV. Most of their gamma ray prompt emissions last for ∼100 s or less. The jets ejected from 'the central engine' are thought to be responsible for these bursts. According to the currently accepted scenario, a black hole produced by the merger of compact objects (such as black holes and/or neutron stars) is responsible for shorter bursts while collapse of a massive star directly to a black hole produces longer bursts, although clear-cut distinction may not exist. In this paper, we consider the latter case, a collapsar model responsible for longer GRBs. They are more interesting in the sense that they are more energetic and hence their studies can be extended to first Population III GRBs, which may give some constraints on the understanding of the early universe. In this paper, we are interested mainly in the "central engine", the region created by the collapse of a rotating massive star to a spinning black hole and its surrounding area created by the stellar remnant because the conditions of the jet propagation change once they are outside in the interstellar medium. We first follow the process of how a progenitor massive star collapses and forms a central disk-black hole system, how powerful jets are produced and ejected from that system, and how the jets propagate and penetrate the surrounding stellar medium. The continued journey of the jets outside the star and the mechanisms for GRB emissions are outside the scope of this short paper.

Gamma ray bursts (GRBs) are ultra-luminous events occurring throughout the universe, which flood an almost dark gamma-ray sky for a short period of time — a fewseconds to several hundreds of seconds. These bursts, while lasting, far outshine all other gamma ray sources in the sky. They are the most concentrated and brightest explosions in the universe, which involve not just prompt gamma rays, but other lower energy photons in the X-ray, optical and even down to radio bands, as longer lasting afterglows. By now, the gamma ray satellite missions such as Swift and Fermi and other waveband observatories have produced multi-wavelength data for numerous GRBs. The currently accepted interpretation of this phenomenon is that a few solar rest mass worth of energy is released in a very short period in a very small region in a tremendous explosion. The general understanding is that it is caused by either the merger of compact objects such as neutron stars and black holes, or the collapse of a massive star. The former tends to cause shorter bursts while the latter tends to last longer, although a clear-cut distinction may not exist. In both cases, eventually it ends up as a stellar mass black hole.

In this scenario, a small fraction of the enormous amount of gravitational energy released by the accretion of matter onto the central collapsed core and black hole is converted into electromagnetic radiation, which is channeled into a collimated relativistic outflow with Lorentz factor of $\Gamma > 100$. The observed gamma rays and subsequent afterglows are thought to be emitted by the jets much further away from the "central engine" where they originate. (By the central engine, we refer to the central power house consisting of a black hole and the surrounding stellar remnant.) The mechanisms of generating the observed mostly nonthermal photons are thought to be synchrotron emission and\or inverse Compton (IC) scattering by relativistic electrons which have been accelerated to a power law distribution in the shocks in the optically thin regions of the outflow further away from the center.

Soon after a presupernova is formed, the central iron core of a rapidly rotating massive star collapses to a disk-black hole system which is responsible for the ejection of the jets. In some cases, the surrounding layers of the star explode and ejected, becoming a supernova — some GRB are indeed associated with supernovae. However, in some other cases, the explosion fails (failed supernovae) but the collapsed core still produces a disk-black hole system and the jets. Very often, the outermost Hydrogen envelope is already lost prior to the collapse, and then the collapse starts in a Helium star. Without sufficient angular momentum (rotation), the collapse does not results in a GRB. However, with substantial and adequate amount of angular momentum, the collapsed core can form the disk-black hole system which is responsible for the ejection of outflowing matter and photons as powerful jets. There is an upper limit to the angular momentum, however, because if it is too high, the whole system will fall apart and ejected, and the central core may not collapse. Although what really happens in the immediate vicinity closest to the black hole is still uncertain and it has to depend on some speculations and estimates, there has been some progress in this area in recent years which is summarized in this report. The journey of the jets through the surrounding stellar material to the surface is more straightforward and we introduced various important studies already carried out in this area. Finally, we reviewed the work already carried out for the studies and predictions of first Population III GRBs. Although these objects may not have been discovered convincingly yet, potential for such discovery in the near future is high, and if such discovery is made and confirmed, that will be invariable for obtaining some insight and constraints on various problems related to the early universe.

Bottom Note: *This work is partly presented at 3rd International Conference on High Energy Physics, December 11-12, 2017, Rome, Italy*