Neutrino-heated gamma-ray bursts

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Gamma-ray bursts (GRBs) have long attracted the attention of astrophysicists since their accidental discovery in 1970s. Regarding the long-duration GRBs, there have been accumulating observations identifying a massive stellar collapse as their origin. For their central engines, the so-called collapsar has received quite some interest for more than decade.

In the collapsar scenario, the central cores with significant angular momentum collapse into a black hole. Neutrinos emitted from the accretion disk heat matter in the polar funnel region to launch the GRB outflows. Paczynski (1990) pioneerlingly proposed that the energy deposition proceeds predominantly via neutrino and antineutrino annihilation into electron and positron (e.g., $\nu+\bar{\nu} \rightarrow e^- + e^+$, hereafter "neutrino pair annihilation"). There have been only a few studies pursuing the possibility of generating jets by the energy deposition via neutrino pair annihilation. This is mainly because the neutrino emission from the accretion disk generally becomes highly aspherical, thus demanding us to solve a multidimensional neutrino transfer problem.

We have presented a numerical code and scheme for calculating the deposition of energy and momentum via neutrino pair annihilation in a Kerr spacetime, in which we solve the general relativistic radiative equation along the null geodesics[1]. The charged-current β-processes are taken into account, which are dominant in the vicinity of the accretion tori. With these improvements, the newly developed code would provide a more realistic estimation of the annihilation rates than before.

As for the hydrodynamic data (such as density, electron fraction, and entropy), we take the ones at 9.1 s after the onset of gravitational collapse for model J0.8 (Figure 1, left panel), which show a clear accretion-disk and BH system with the polar funnel regions along the spin axis of the disk. The position of the inner boundary of the computational domain is set to be $4\,M_\odot$, which mimics the event horizon of the BH. We set the Kerr parameter $a^* = 0.999$ to mimick the extreme Kerr geometry.

To trigger the neutrino-heating explosion, the neutrino-heating timescale should be smaller than the advection timescale, which is characterised by the freefall timescale in the polar funnel regions (e.g., [2]). This condition is akin to the condition of the successful neutrino-driven explosion in the case of core-collapse supernovae.

The right panel of Figure 1 depicts the ratio of the dynamical τ_{dyn} to the heating timescales τ_{heat} for an extreme Kerr geometry, showing that the ratio becomes greater than unity in the polar funnel regions. This indicates the possible formation of the neutrino-driven outflows there, if coupled to the collapsar's hydrodynamics. Our obtained results here suggest the neutrino pair annihilation has a potential importance equal to the conventional magnetohydrodynamic mechanism for igniting the GRB fireballs.

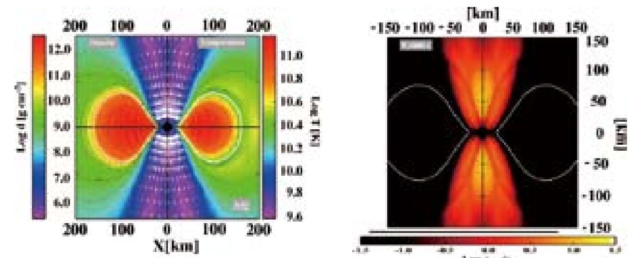

Figure 1: Left panel shows hydrodynamic configuration employed in the ray-tracing calculation. This is the snapshot at 9.1 s after the onset of gravitational collapse for model J0.8 when the accretion disk is in a stationary state (see [3] for more detail). The logarithmic density (in $g\,cm^{-3}$, left-half) and temperature (in K, right-half) are shown. The white solid line denotes the area where the density is equal to $10^{11}\,g\,cm^{-3}$, representing the surface of the accretion disk. The central black circle ($\approx 4\,M_\odot$) represents the inner boundary of our computations Right panel is τ_{dyn}/τ_{heat} (:the dynamical timescale τ_{dyn} versus the heating timescale τ_{heat}) in an extreme Kerr geometry (left).

References

[1] Harikae, S., Kotake, K., Takiwaki, T., Sekiguchi, Y.-i.: 2010, *ApJ*, **720**, 614.
[2] Kotake, K., Sato, K., Takahashi, K.: 2006, *Reports of Progress in Physics*, **69**, 971.
[3] Harikae, S., Kotake, K., Takiwaki, T.: 2010, *ApJ*, **713**, 304.