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LET US WATCH A COLLAPSING STAR: HOW DOES IT LOOK?

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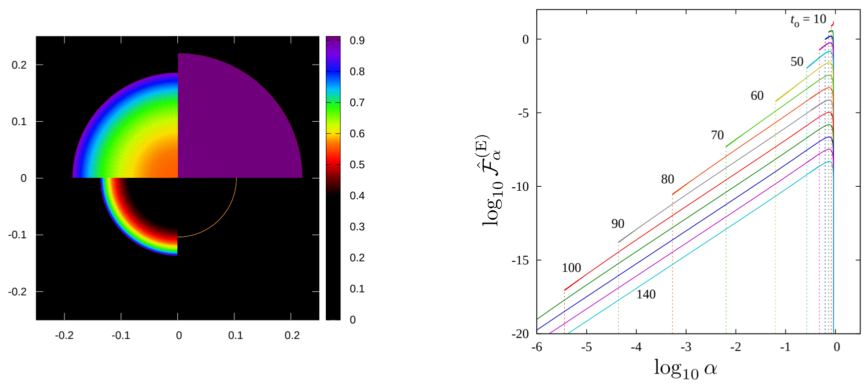
Time evolution of an optical image of a pressureless star under gravitational collapse is studied in the geometric optics approximation. The star surface is assumed to emit radiation obeying Lambert's cosine law but with arbitrary spectral intensity in the comoving frame. This issue is a classical problem that was studied in several literatures [1–4]. However, in our opinion, they are not very satisfactory due to lack of the numerical resources at that time or due to the use of approximate formulas. We develop a formalism for predicting physical quantities related to observations by photon counting and by radiometry, in particular, spectral photon flux and spectral radiant flux. Then, this method is applied to the two cases where emitted radiation is monochromatic radiation and Planck radiation, and the spectral fluxes are calculated numerically.



Left panel of the above figure presents images of the star observed by a telescope for $t_\mathrm{o}/M = 0$, 30, 50, and 69 (counter-clockwise from top right) in the case that the star surface emits near ultraviolet monochromatic radiation of the wavelength $\lambda'_\mathrm{e} \sim 353$ nm. After the collapse starts, a redder region appears at the center, and waves of the central region becomes infrared (i.e., black to our eyes). The wavelength at the limb is unchanged and light rays remain visible in its neighborhood, showing rainbow colors. Right panel of the figure shows the spectral radiant flux $\hat{F}_\alpha^{(\mathrm{E})}$ as a function of $\alpha := \omega_\mathrm{o}/\omega'_\mathrm{e}$ (where ω'_e and ω_o are emitted and observed angular frequencies, respectively) for $t_\mathrm{o}/M = 10$–140 (both axes are shown in the logarithmic scale). Except for very small α, the spectrum keeps its shape and decays exponentially. The observed frequency remains nonzero finite values and the star becomes gradually invisible by decay of the flux. We also develop an approximate method to present analytic formulas that describe the late time behavior.

Our analysis can be approximately applied also to emission of high-energy neutrinos. It was argued in Ref. [5] that intense neutrino flux from the neutronized core and the neutrinosphere might suddenly cease because of the black hole formation. Furthermore, the Super-Kamiokande has the ability to determine the energy of each neutrino with time resolution of the order of $\sim$ ns [6]. Therefore, our study is a good starting point for predicting time dependence of high-energy neutrinos from so-called failed supernovae.

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[1] W. L. Ames and K. Thorne, Astrophys. J. **151**, 659 (1968).
[2] K. Lake and R. C. Roeder, Astrophys. J. **232**, 277 (1979).
[3] V. P. Frolov and H. K. Lee, Phys. Rev. D **71**, 044002 (2005) [gr-qc/0412124].
[4] V. P. Frolov, K. Kim and H. K. Lee, Phys. Rev. D **75**, 087501 (2007) [gr-qc/0701001].
[5] T. Sasaqui, T. Kajino, and A. B. Balantekin, Astrophys. J. **634**, 534 (2005) [astro-ph/0506100].
[6] K. Abe *et al.*, Nucl. Instrum. Meth. A **737**, 253 (2014) [arXiv:1307.0162 [physics.ins-det]].