ハイペロンが星の重力崩壊によるブラックホール形成に与える影響

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In compact astrophysical objects where the density and/or temperature are high enough, some exotic phenomena are expected to occur. In particular, meson condensation, hyperon appearance and quark deconfinement are expected, affecting the equation of state (EOS) markedly. The hyperon interactions with nucleons are relatively well known comparing with other exotic constituents (kaons, pions and quarks). From the recently observed quasi-free Σ production spectra, it is considered that Σ hyperons would feel a repulsive potential in nuclear matter, $U_{\Sigma}^{(N)}(\rho_0) \sim +30$ MeV [1]. Nevertheless, Σ-N interaction, which affects the components of dense matter and the stiffness of EOS, has a large uncertainity even at present.

Massive stars with $\gtrsim$25 solar masses ($M_{\odot}$) will form a black hole at the end of their evolution [2] and provide a site for the exotic phenomena mentioned above. In this study, we investigate numerically the stellar core collapse and black hole formation taking into account the EOS's involving hyperons and/or pions. In particular, we examine both of attractive and repulsive cases for the undetermined Σ-N interaction. Further details of this study can be found in our recent papers [3, 4]. In addition, impacts of quarks are reported in separate papers [5].

Setups— In order to compute the stellar core collapse and black hole formation, we use the numerical code of general relativistic ν-radiation hydrodynamics which solves the Boltzmann equation for neutrinos together with Lagrangian hydrodynamics under spherical symmetry. As an initial condition, the stellar model with $40M_{\odot}$ and solar metallicity from the evolutionary calculation [6] is adopted. We utilize the EOS tables including the hyperons and the thermal pions in finite temperature, where both of attractive and repulsive cases for the undetermined Σ-N interaction are provided [7]. These sets of EOS are based on an $SU_f(3)$ extended relativistic mean field model and constructed as an extension of EOS by Shen et al. (1998) [8]. We perform the numerical simulation adopting the EOS sets with the potential depths $(U_{\Lambda}, U_{\Sigma}, U_{\Xi}) = (-30$ MeV, $+30$ MeV, -15 MeV) for the repulsive case and (-30 MeV, -30 MeV, -15 MeV) for the attractive case, and also EOS sets for the corresponding cases with pions. In the following, we refer to the repulsive EOS with pions, repulsive EOS without pions, attractive EOS with pions and attractive EOS without pions as RP, R, AP and A, respectively. For comparison, we also show the results for the EOS with pions and without hyperons and Shen EOS (purely nucleonic model), which are referred as NP and N, respectively. Note that, for hyperonic models, the maximum masse of neutron stars is smaller than $1.97 \pm 0.04 M_{\odot}$, the mass of the binary millisecond pulsar J1614-2230 [9].

Results— In Figure 1(a), we show the time profiles of the central baryon mass density. These models have a bounce due to nuclear force at the saturation density ($\sim 3 \times 10^{14}$ g cm^{-3}) and then recollapse to a black hole. We can recognize that the time interval

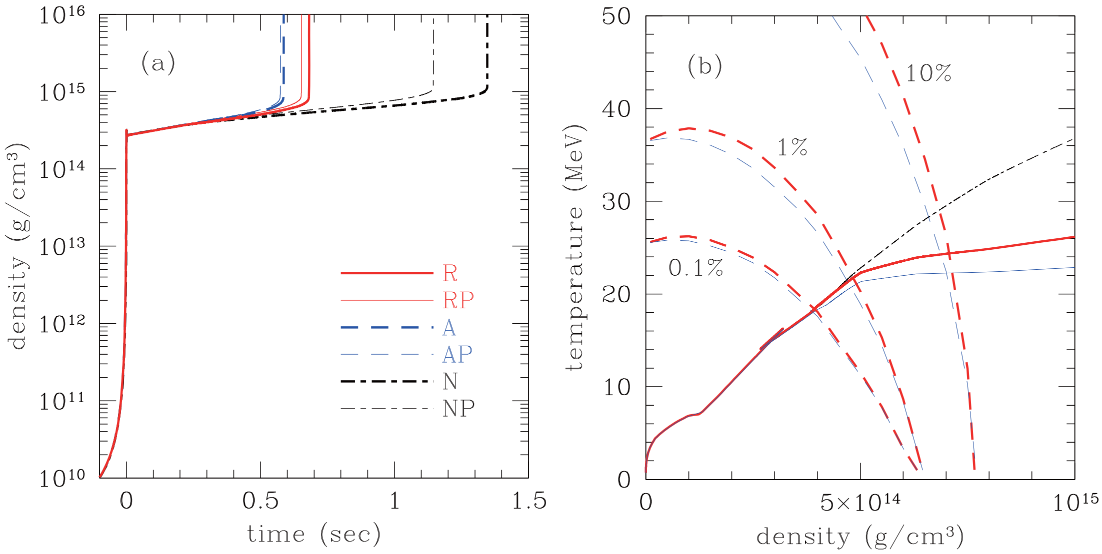

図 1: *(a)* Time evolutions of the central baryon mass density for the collapse. In this panel, thick solid, thin solid, thick dashed, thin dashed, thick dot-dashed and thin dot-dashed lines correspond to the results for EOS's R, RP, A, AP, N and NP, respectively. *(b)* Evolutions of the central density and temperature (solid lines) with hyperon fraction contours for the electron fraction $Y_e = 0.3$ (dashed lines). Thick and thin lines correspond to EOS's R and A, respectively. The dot-dashed line shows the trajectory of the model with EOS N.

between the bounce and black hole formation gets shorter as we put additional degrees of freedom, hyperons and pions. This is because the EOS becomes softer and the maximum mass for the stable configurations of proto–neutron stars gets lower. Note that the mass accretion rate, $\dot{M}$, does not differ among the EOS models because there are not hyperons and pions in low-density outer layer. Moreover, the time interval of the model with EOS R is $\sim$15% longer than that of the model with EOS A. Since the maximum masses of EOS's R and A do not differ very much, the duration time is more sensitive to the hyperonic matter EOS than the neutron star maximum mass is. The reason for the difference in the time interval is because the appearance of Σ^- hyperons is suppressed due to the repulsive potential for the model with EOS R.

We show the evolutions of the central densities and temperatures with hyperon fraction contours for the electron fraction $Y_e = 0.3$ in Figure 1(b). We can see that the central temperature of EOS A is lower than that of EOS R. Since the core collapse process is almost adiabatic except the shock heating, evolutionary tracks are roughly isentropic lines. Therefore EOS R has higher temperature than EOS A for the same value of the entropy. This is equivalent to the fact that EOS A has higher entropy than EOS R for the same value of the temperature. In the attractive case, since Σ hyperons appear more easily and the number of particle species increases, the entropy gets higher for the fixed temperature.

Finally, we would like to emphasize that the stellar core collapse accompanies enormous emission of neutrinos and its duration is almost the same as the interval time from the bounce to the black hole formation. Therefore, using the difference of the time interval, we may be able to probe observationally the hyperon potential in future.

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