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Core-Collapse Simulations of Very Massive Star: Gravitational Collapse, Black-hole Formation, and Beyond

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We investigate the final collapse of rotating and non-rotating pulsational pair-instability supernova progenitors with zero-age-main-sequence masses of 60, 80, and 115Msun and iron cores between 2.37Msun and 2.72Msun by 2D hydrodynamics simulations. Using the general relativistic NADA-FLD code with energy-dependent three-flavor neutrino transport by flux-limited diffusion allows us to follow the evolution beyond the moment when the transiently forming neutron star (NS) collapses to a black hole (BH), which happens within 350-580 ms after bounce in all cases. Because of high neutrino luminosities and mean energies, neutrino heating leads to shock revival within ~250 ms post bounce in all cases except the rapidly rotating 60Msun model. In the latter case, centrifugal effects support a 10% higher NS mass but reduce the radiated neutrino luminosities and mean energies by ~20% and ~10%, respectively, and the neutrino-heating rate by roughly a factor of two compared to the non-rotating counterpart. After BH formation, the neutrino luminosities drop steeply but continue on a 1-2 orders of magnitude lower level for several 100 ms because of aspherical accretion of neutrino and shock-heated matter, before the ultimately spherical collapse of the outer progenitor shells suppresses the neutrino emission to negligible values. In all shock-reviving models BH accretion swallows the entire neutrino-heated matter and the explosion energies decrease from maxima around 1.5e51 erg to zero within a few seconds latest. Nevertheless, the shock or a sonic pulse moves outward and may trigger mass loss, which we estimate by long-time simulations with the PROMETHEUS code. We also provide gravitational-wave signals.

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