Run–away formation of massive black holes in dense star clusters?

Marc Freitag, Atakan Gürkan, Frederic Rasio

Astronomisches Rechen-Institut, Heidelberg, Germany
Department of Physics and Astronomy, Northwestern University, USA

Summary

We investigate the conditions under which a dense stellar cluster may undergo a phase of collisional run-away leading to the formation of a very massive star (VMS, with $M > 100 M_\odot$), a possible progenitor for an intermediate-mass black hole. In particular, we have established that systems with a realistically broad stellar mass function ($0.2 - 120 M_\odot$) undergo core-collapse driven by mass-segregation in just ~15% of the central core collapse. When we allow for collisions between stars, we find that growth of a VMS star occurs in all cases for which core collapse (driven by relaxation or collisions) takes place before $\sim 100 M_\odot$ stars evolve off the main sequence, i.e. within 3 Myrs, even in proto-galactic nucleus models with a velocity dispersion in excess of 100 km s$^{-1}$.

1 Numerical method

We simulate the evolution of dense stellar clusters using Monte Carlo (MC) codes. Based on the ideas of Hénon, they are ideal compromises, in terms of physical realism and computational efficiency, between direct N body simulations, which, being extremely computer-intensive, are still limited to a few $10^5$ stars, and methods that treat the stellar cluster as a continuum (Fokker-Planck integrations and gaseous models) which do not allow realistic account of many processes (stellar collisions, role of an arbitrary mass or velocity distribution...). The MC code methods are based on the assumptions of spherical symmetry, dynamical equilibrium and diffusive 2-body relaxation. They allow simulations with a few millions particles to be carried out on a single-processor PC. Various prescriptions can be used for the outcome of stellar collisions (mass and energy losses), including inter/extrapolation form the results of some 15 000 SPH simulations.

2 Fast core collapse

Our Monte Carlo simulations have shown that for a broad mass function (Salpeter or Kroupa, typically), core collapse, driven by mass-segregation, occurs very quickly, in order 15% of the initial central relaxation time. Results of a representative simulation are shown in the figure.

3 Formation of a very massive stars

In recent MC simulations, we have introduced collisions between single MS stars. We observe that, provided core collapse occurs within less than ~3 Myrs, the cluster always enters a run-away phase in which a star more massive than 1000 M$_\odot$ grows through repeated mergers.

4 Open questions

- Stellar dynamics
  - Role of binaries: stop collapse and/or foster collisions? (John Fregeau, NU)
  - "Loss-cone" effects for collision with the VMS.
- Minimum number of stars in the core for run-away (suggested by recent N-body work).
- Growth of IMBH to larger masses (through tidal disruptions, collisions, stellar winds; see poster by Pau Amaro-Seeane).
- Hydrodynamics
  - Collisions featuring VMS. Object is kept out of thermal equilibrium by frequent collisions. Is there a "transparency problem"?
- Stellar evolution
  - Role of pre-MS phase and gas in young clusters.
  - Stability and evolution of bombarded VMS.
  - End product of VMS evolution: an IMBH, really?
Acknowledgements.
The work of MF is funded by the Sonderforschungsbereich (SFB) 439 ‘Galaxies in the Young Universe’ (subproject A5) of the German Science Foundation (DFG) at the University of Heidelberg. The work of AG and FR is supported by NASA ATP Grant NAG5-12044 and NSF Grant AST-0206276 to Northwestern University.

References