Compact Object Binaries in Star Clusters

Using N-body and Monte Carlo Methods with a little PN

J.M.B. Downing & Rainer Spurzem

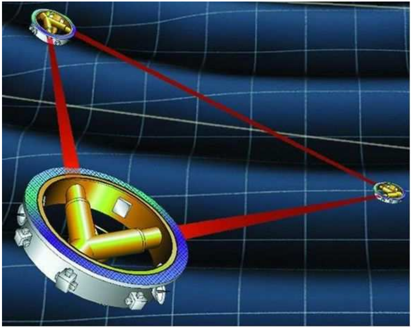
Astronomisches Rechen-Institut
Zentrum für Astronomie der Universität Heidelberg

Clusters09
KITP, Santa Barbara, CA, USA
26 February 2009

Outline

Gravitational Wave Detection - Detectors

Ground-based detectors (VIRGO/LIGO) detect stellar mass mergers



Space-based detectors (LISA) detect mergers of super massive black holes and possibly wide stellar mass binaries.

Gravitational Wave Detection - Sensitivity Curves

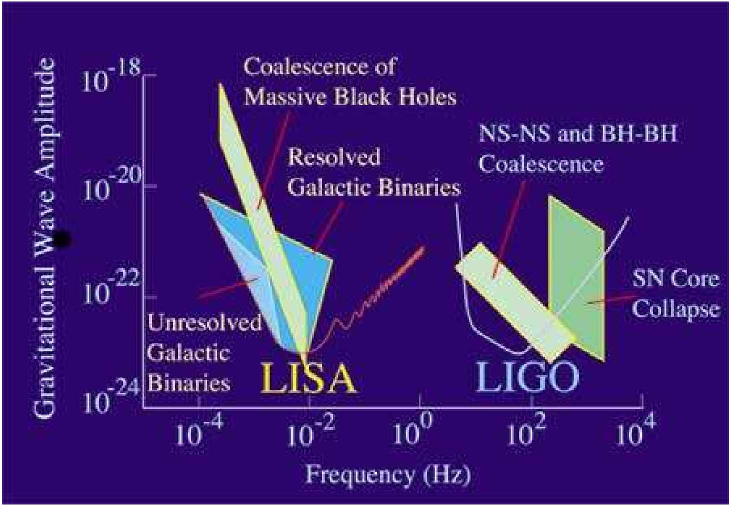


Fig. NASA

Monte Carlo Methods

The Monte Carlo Code

Using the Giersz Monte Carlo code (Giersz 1998, 2001,2006, Giersz, Heggie and Hurley 2008, Giersz and Heggie 2008).

- Stodolkiesicz Monte Carlo scheme (variation on Henon) for dynamics.
- Binary interactions calculated from analytic cross-sections (mainly by Heggie).
- Full stellar and binary evolution according to BSE (Hurley, Tout and Pols 2002).

Complete population of binaries and binary mergers at each Monte Carlo timestep.

- "Isolated" merger details can be calculated from previous timestep using a relativistic two-body code.

Parameters of escaping binaries also recorded.

- Can be evolved in isolation using BSE/relativistic two-body code.

Compact Mergers Within the Cluster

Find relatively few compact mergers within the cluster and all occur early.

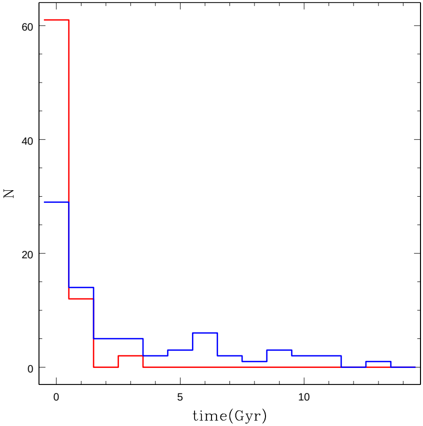
- Example: Plummer model with 250k single stars and 250k binaries
- Three mergers, two BH-NS one BH-BH
- All merge within the first 50 Myr
- Chirp masses, $M_{chirp} = \frac{(M_1 M_2)^{3/5}}{(M_1+M_2)^{1/5}}$, of 3.53 $M_\odot$, 4.18 $M_\odot$ and 7.43 $M_\odot$

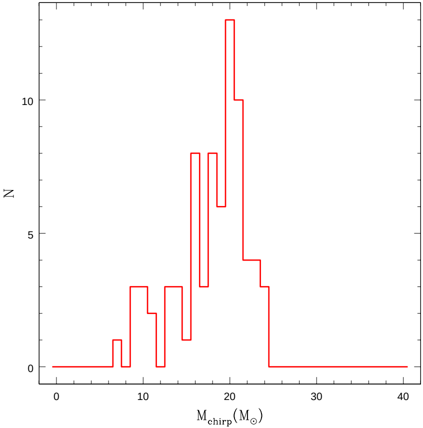
Exploring parameter space of King models.

- Lots of crashes due to bad parameters
- No mergers of compact objects within clusters yet

Mergers of Escapers

Lots of escapers merge within a Hubble time.





All black-hole-black-hole mergers with high chirp masses.

Direct N-Body with Post Newtonian Terms

NBODY6++

We can also explicitly follow relativistic evolution as part of a direct N-Body simulation:

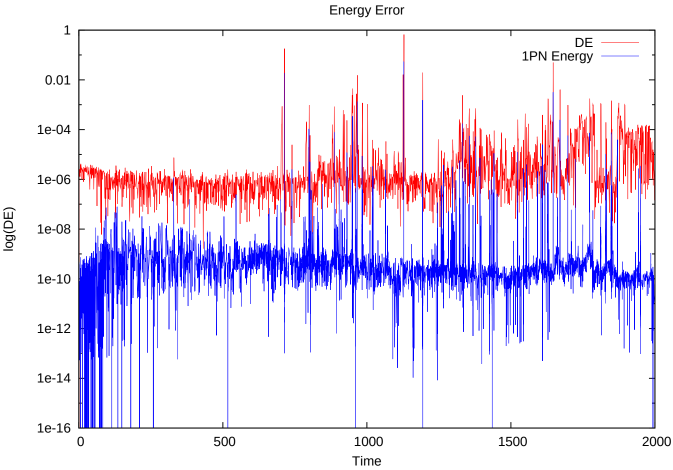
- Modify NBODY6++ code to treat Post-Newtonian binaries.
  - Aarseth (1999), Spurzem (1999), Kupi, Amaro-Seoane & Spurzem (2006)

- NBODY6++ regularises binaries and external forces can be applied as a perturbation.

$$H = \frac{p^2}{2\mu} - \frac{GmM}{r} = E_0 \quad \Rightarrow \quad \Gamma = \frac{P^2}{8\mu} - GmM - E_0 u^2$$

- PN corrections applied as a perturbation to regularised binary.

Problems Abound

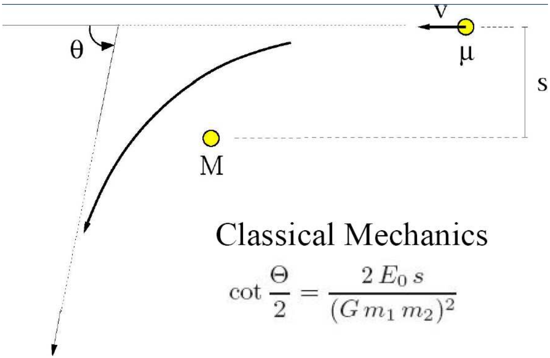


Global energy conservation fails, probably due to incorrect treatment of triples and exchanges.

Post-Newtonian Two-Body Scattering Experiments

Scattering in a Central Potential

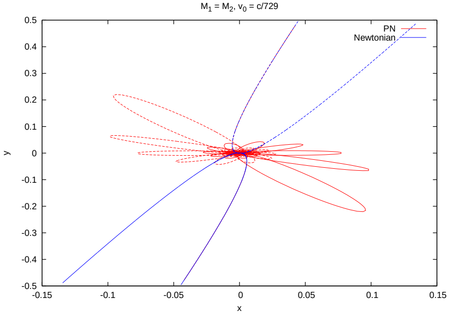
Compute gravitational scattering experiments using a Post-Newtonian two-body code.

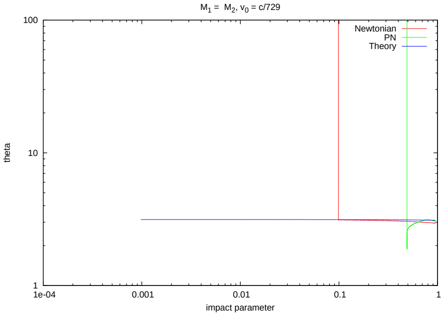


- Code by Berentzen (Berentzen et al. 2009, in press)
- Computes two-body PN orbits with a fourth-order Hermite scheme
- Look for differences between Newtonian and PN scattering

Quite Different Indeed

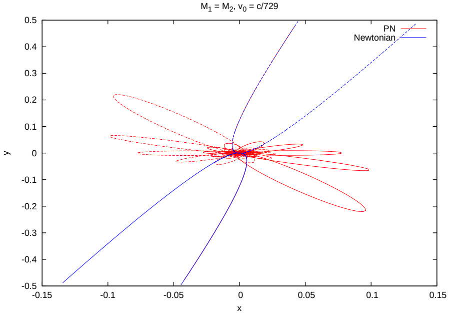
Leads to larger deflection angles and more mergers.

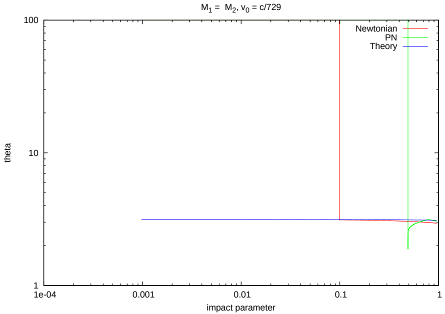




Quite Different Indeed

Leads to larger deflection angles and more mergers.





Question: Is this interesting to anyone?

Summary

Monte Carlo Code:

- Produces information on compact binary population
- Can search parameter space but uses approximation for few-body encounters
- Some teething problems but generally working OK

Direct N-Body with PN:

- Can resolve all few-body encounters with Post-Newtonian relativistic dynamics
- Difficult to include energy checks and generally check relativistic dynamics, slow.

PN Scattering Experiments:

- Some info on the nature of PN dynamics
- Interesting for statistical studies?