Monte-Carlo Methods for Dense Stellar Systems

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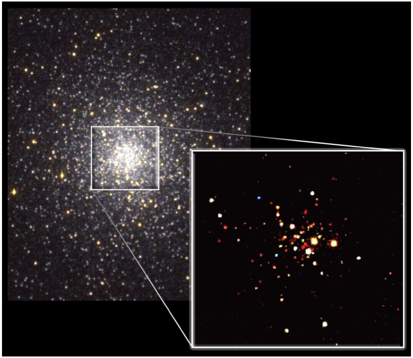
Old Stuff

Old Stuff

Physics of Dense Stellar Systems



47 Tuc in optical and X-ray

- two-body relaxation
- stellar evolution
- stellar collisions
- binary interactions
- external effects
- central BH
- rotation
- violent relaxation
- large-angle scattering
- three-body binary formation

Numerical Solution Methods

- N-Body: direct integration of the equations of motion
- Fokker-Planck: direct integration of the Fokker-Planck equation
- Monte-Carlo: particle-based method which uses Monte-Carlo to apply relaxation in the Fokker-Planck approximation
- Gas model: cluster modeled as conducting gas
- Hybrid methods: gas+MC, FP+N-body, etc.

Assumptions Underlying Monte-Carlo Method

- diffusive two-body relaxation
- spherical symmetry
- dynamical equilibrium
- Fokker-Planck approximation

Hénon's Trick

- cannot realistically sum two-body scatterings over all stars
- instead, perform representative encounter with nearby star
- choose impact parameter so deflection angle is consistent with the effects of relaxation due to whole cluster

The Major Monte-Carlo Codes

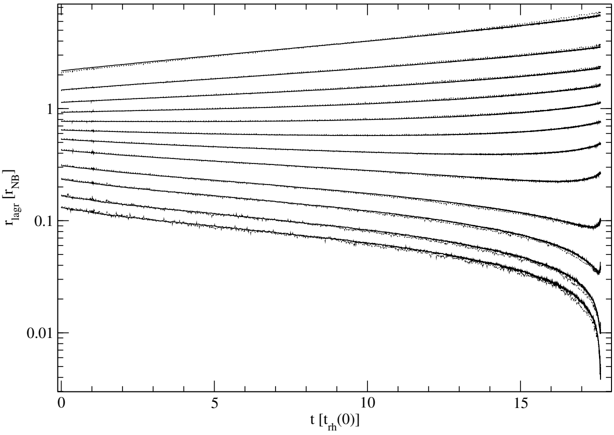
- MIT/NU: Hénon method with common timestep
- Freitag: Hénon method with individual timesteps
- Giersz: Hénon method with zones (based on Stodolkiewicz's code)
- Giersz & Spurzem: hybrid approach (anisotropic gas model for single stars, MC for binaries)

Comparison Chart

Physics	NB	MC	MN	F	G	GS
two-body relaxation	x	x	x	x	x	x
stellar evolution	x	x	x	x	x	
stellar collisions	x	x	x	x		
binary interactions	x	x	x		x	x
external effects	x	x	x	x	x	x
central BH	x	x		x		
rotation	x					
violent relaxation	x					
large-angle scattering	x	x				
three-body binaries	x	x			x	x
large $N_{\rm star}$, $N_{\rm bin}$		x	x	x	x	x

NB=N-body, MC=Monte-Carlo, MN=MIT/Northwestern, F=Freitag, G=Giersz, GS=Giersz & Spurzem

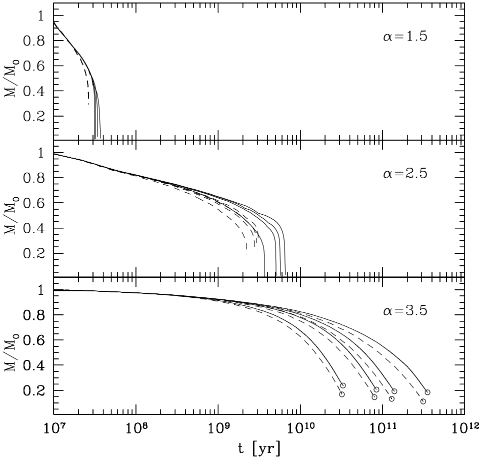
Core Collapse for Single-Component Model



Isolated Plummer model, compared with *N*-body.

Fregeau, Gürkan, & Rasio (in prep)

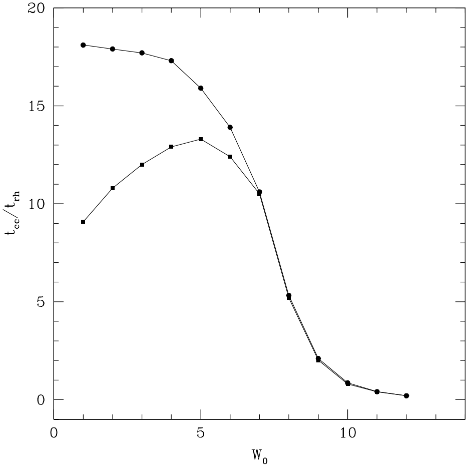
Stellar Evolution



Single star evolution, compared with FP models.

Joshi, Nave, & Rasio (2001)

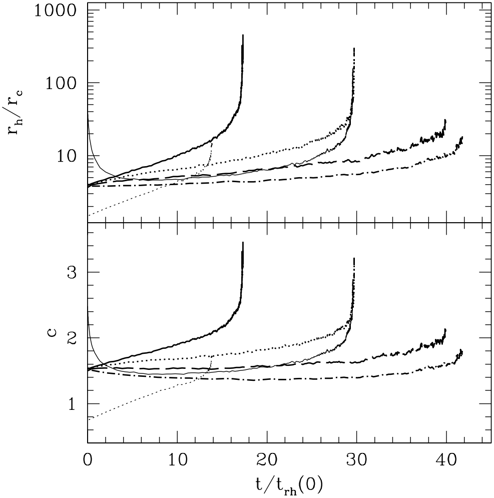
Tidal Effects



Tidal boundary due to Galactic potential.

Joshi, Nave, & Rasio (2001)

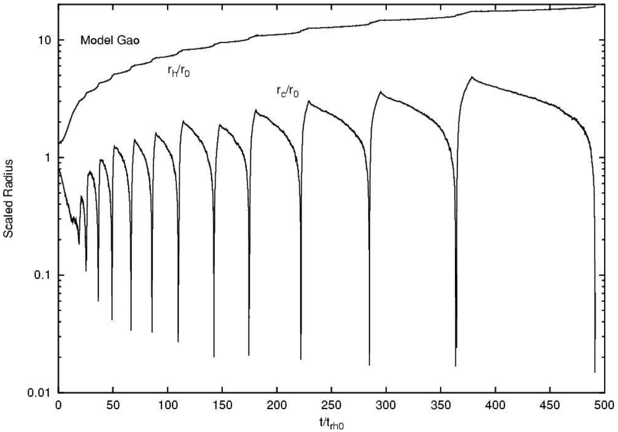
Primordial Binary Interactions



Recipes for binary interactions, comparison with observations.

Fregeau, et al. (2003)

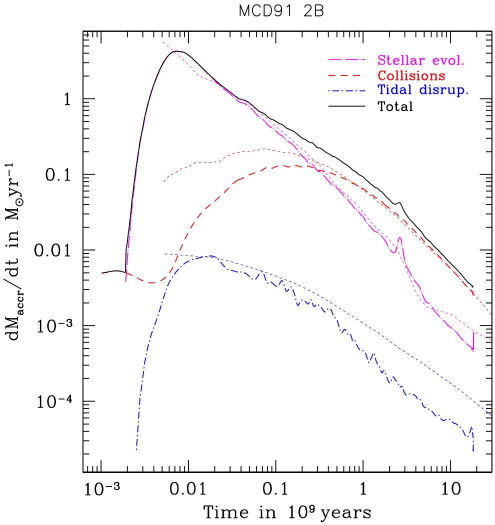
Primordial Binary Interactions



Direct integration of binary interactions.

Giersz & Spurzem (2003)

Central Black Hole



Mass accretion rate onto central BH in galactic nucleus, compared with FP models.

Freitag & Benz (2002)

New Stuff

New Stuff

Newly Added Physics

- direct integration of binary interactions (GS, MN)
- physical collisions (F, MN)
- better treatment of wide mass spectra (F, MN)
- improved energy conservation (F, MN)

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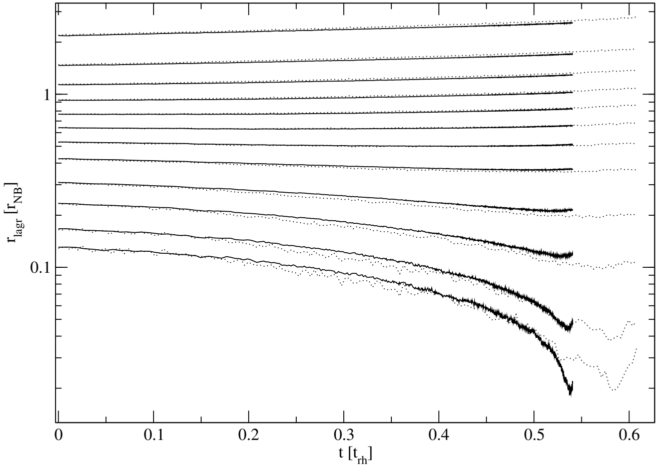
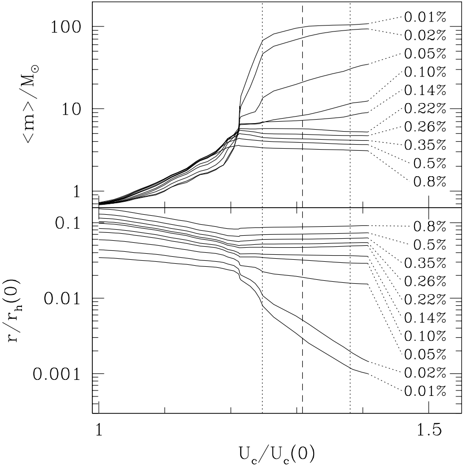
Mass Spectrum: Kroupa from 0.1 to 10$M_\odot$



Evolution of model with Kroupa IMF, compared with N-body.

Fregeau, Gürkan, & Rasio (in prep)

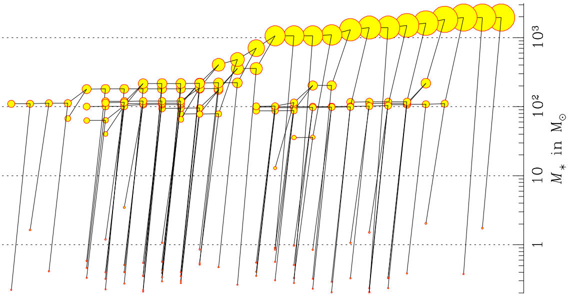
Mass Going Into Core Collapse



Robust results that $t_{cc} \approx 0.15 t_{rc}(0)$ for wide mass spectra, and $\approx 0.2\%$ of cluster mass goes into core collapse.

Gürkan, Freitag, & Rasio (2004)

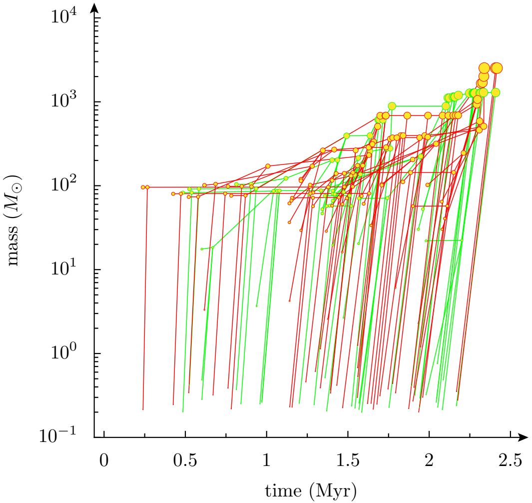
IMBHs: VMS Formation



Runaway collisional growth of a “very massive star” unavoidable for systems with $t_{cc} \lesssim 3\,\mathrm{Myr}$.

Freitag, Gürkan, & Rasio (2005)

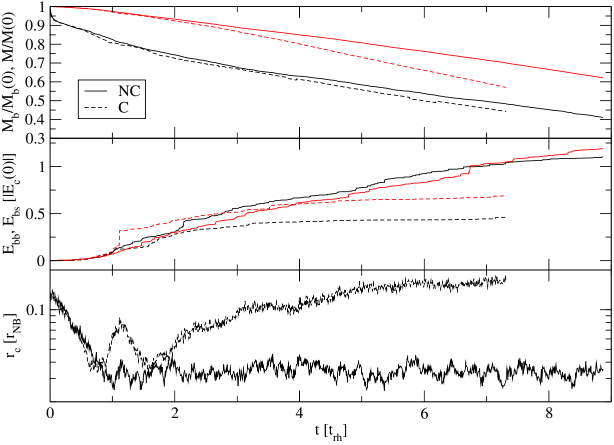
IMBHs: VMS Formation with Primordial Binaries



Multiple, concurrent runaway collisional growth generic in clusters with primordial binaries.

Gürkan, Fregeau, & Rasio (in prep)

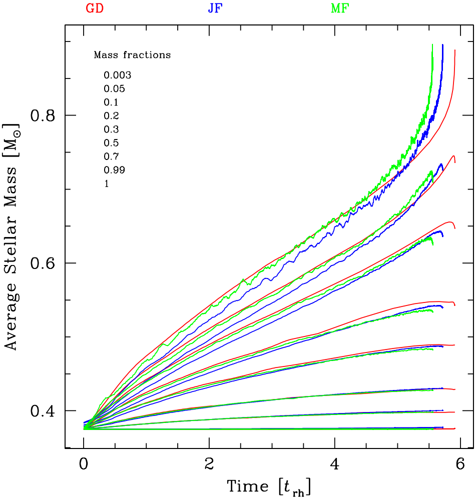
Cluster Evolution with Collisions and Binaries



Long-term cluster evolution with primordial binaries and stellar collisions.

Fregeau, Gürkan, & Rasio (in prep)

Comparison of "Approximate" Techniques



Comparison of active FP and Monte-Carlo codes with *N*-body (during this very meeting!).

The Future

- binary stellar evolution (catching up with N-body...)
- 3-D?
- block timesteps?
- completely new techniques?