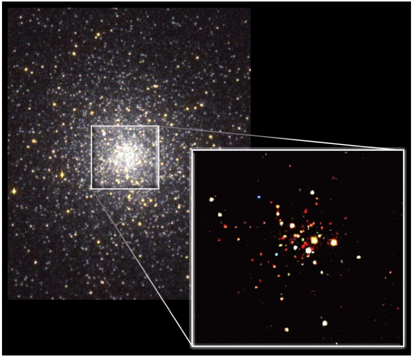
Monte-Carlo Methods for Globular Clusters

John M. Fregeau

Northwestern University

Aug 12, 2004

Physics of Globular Clusters


47 Tuc in optical and X-ray

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

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

Assumptions Underlying Monte-Carlo Method

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

Hénon Method

- 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

NORTHWESTERN UNIVERSITY

Anatomy of a Timestep

- start with particle positions and velocities
- calculate potential under assumption of spherical symmetry
- choose timestep to be a fraction of relaxation time
- [include additional physics]
- perform representative encounters (relaxation)
- new E, J for each star
- choose r for each new orbit by time-weighted average

NORTHWESTERN UNIVERSITY

Summaries

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

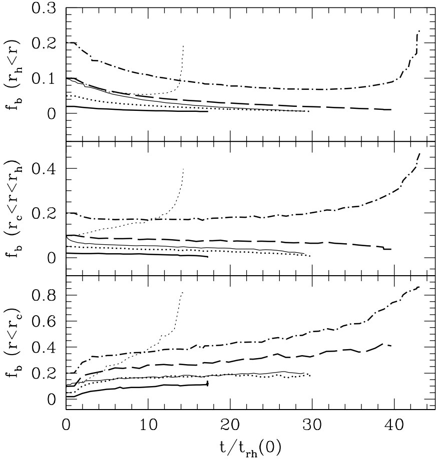
Comparison Chart

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		
binary interactions	x	x	x		x	x
three-body binaries	x	x			x	x
violent relaxation	x					
rotation	x					
central BH	x	x		x		
external effects	x	x	x	x	x	x
large-angle scattering	x	x		x		
realistic N_{star}, N_{bin}		x	x	x	x	x

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

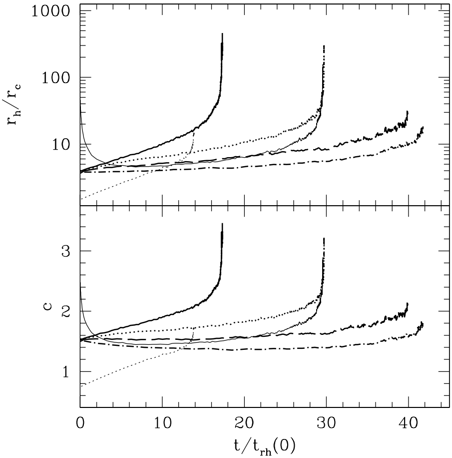
NORTHWESTERN UNIVERSITY

Comparison with Observations



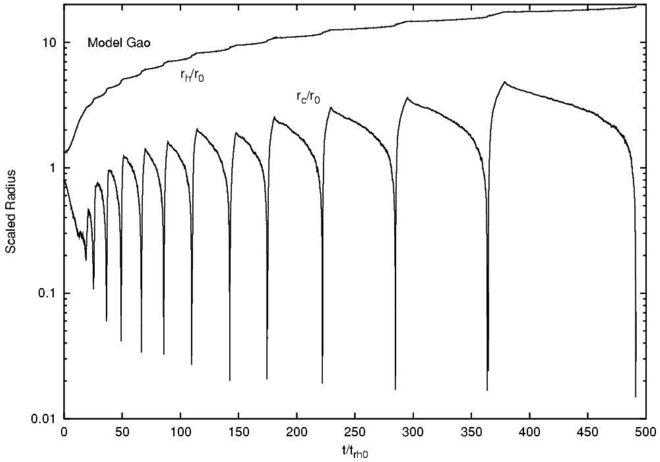
Fregeau, Gürkan, Joshi, & Rasio (2003)

Comparison with Observations



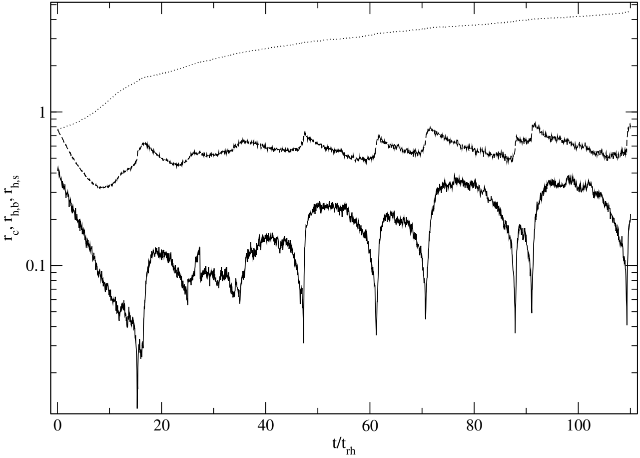
Fregeau, Gürkan, Joshi, & Rasio (2003)

Binary Interactions



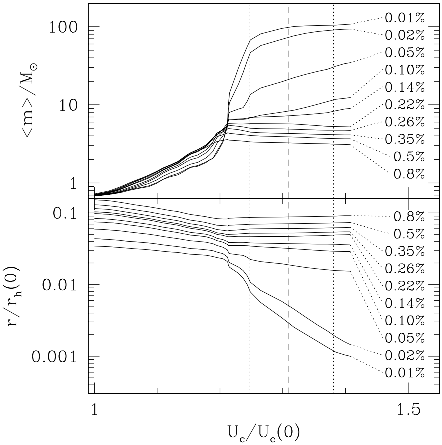
Giersz & Spurzem (2003)

Binary Interactions



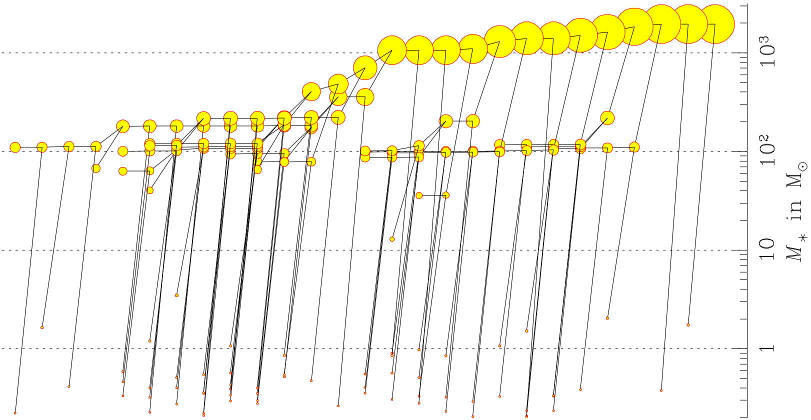
Fregeau (Ph.D. Thesis)

BH Formation



Gürkan, Freitag, & Rasio (2004)

BH Formation



Freitag, Gürkan, & Rasio (in preparation)

Future Directions

- binary interactions + stellar collisions
- binary stellar evolution
- 3-D