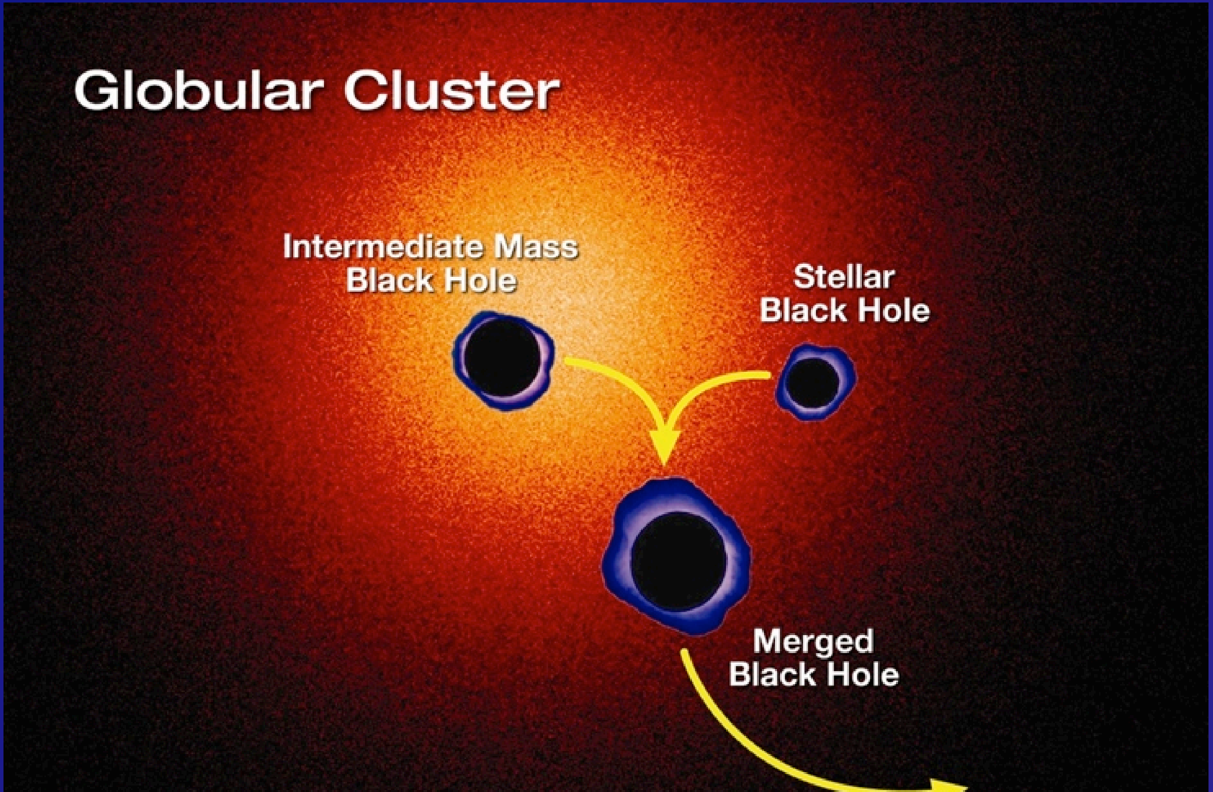
We discovered that there may be hundreds of black holes, each with ~ 100-1000 solar masses, careening through the Milky Way



Michael Smeltzer, Vanderbilt University
http://www.vanderbilt.edu/News/newsImage/GlobularClusterandBlackHole.JPG

Kelly Holley-Bockelmann, Vanderbilt University
Kayhan Gulekin, University of Michigan
Deirdre Shoemaker and Nico Yunes, Penn State University

Gravitational waves can kick a black hole during a merger

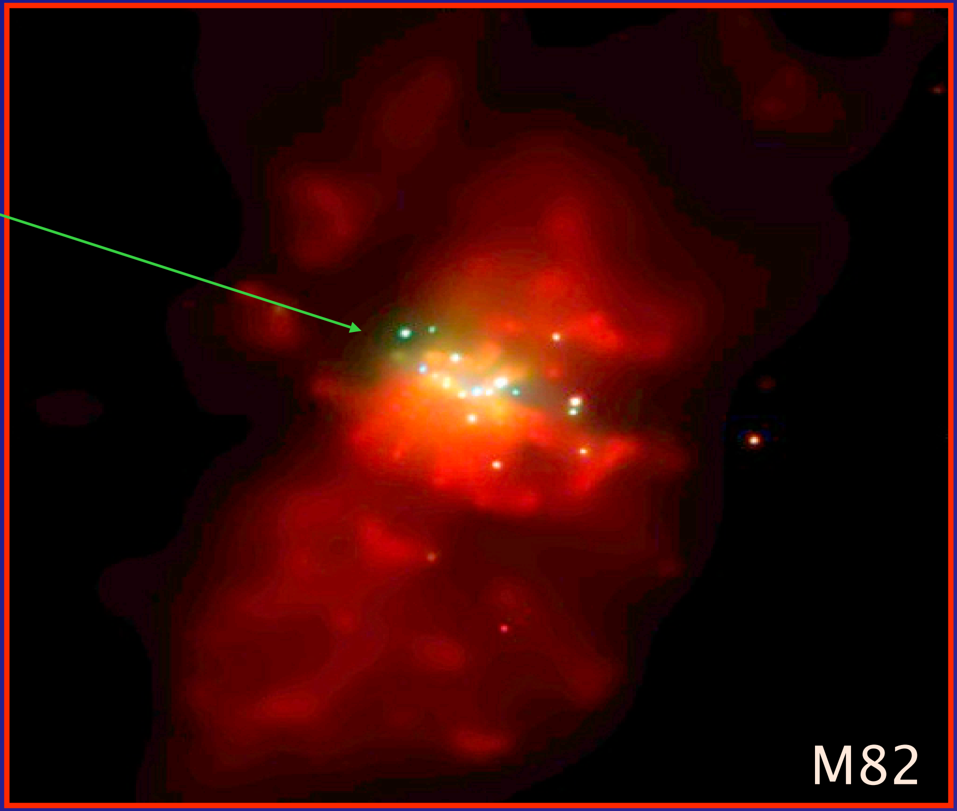
...up to 9 million mph!

Ripples in spacetime from two equal mass, non spinning black holes on an initially circular orbit

These rogue “intermediate mass” black holes are ejected from globular clusters by asymmetric gravitational wave emission during mergers with smaller, stellar mass black holes

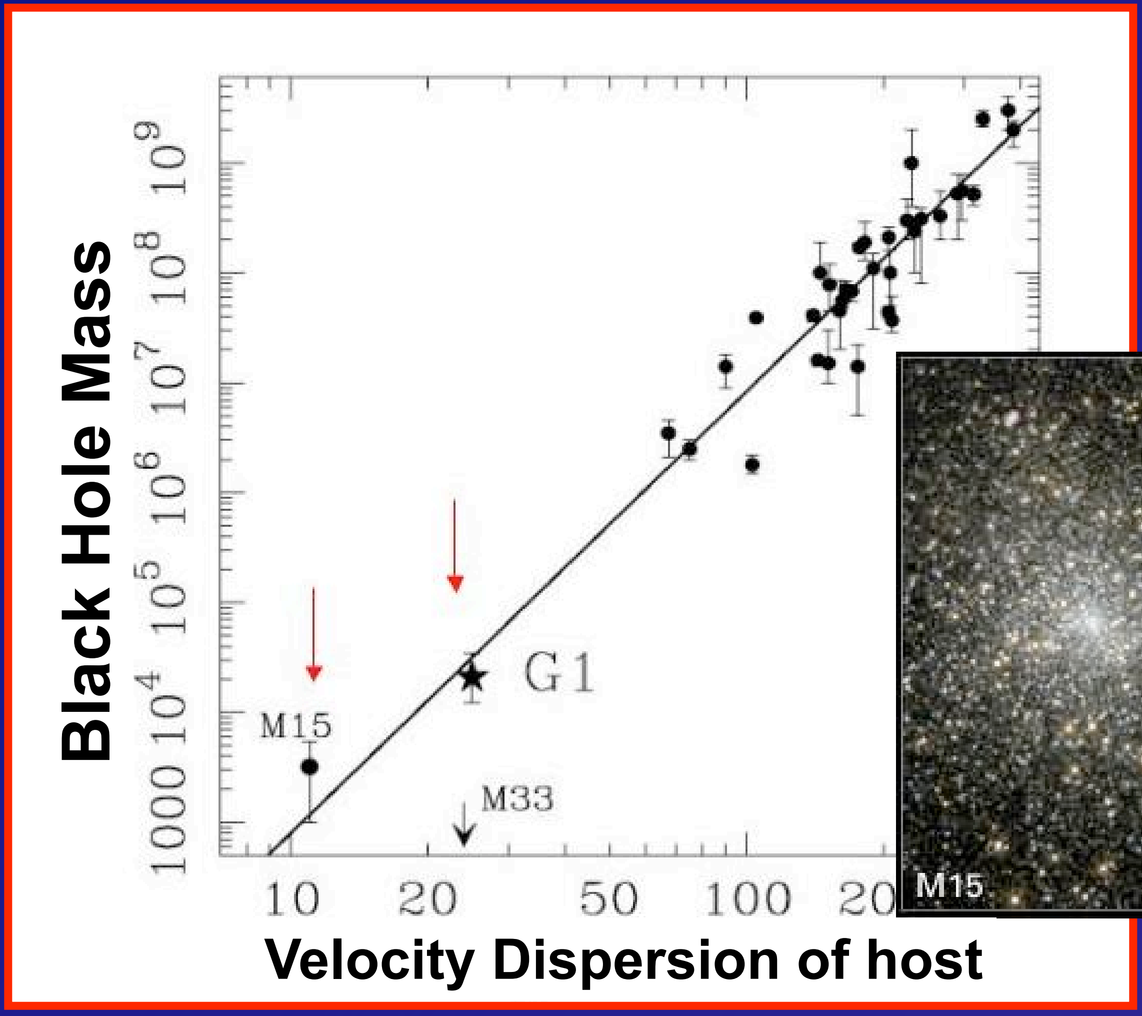
The existence of this third class of middle weight black hole is hotly debated

Chandra revealed Ultra Luminous Xray Sources. Perhaps made by a gas-accreting black hole with 100–1000s of solar masses, an Intermediate Mass Black Hole?



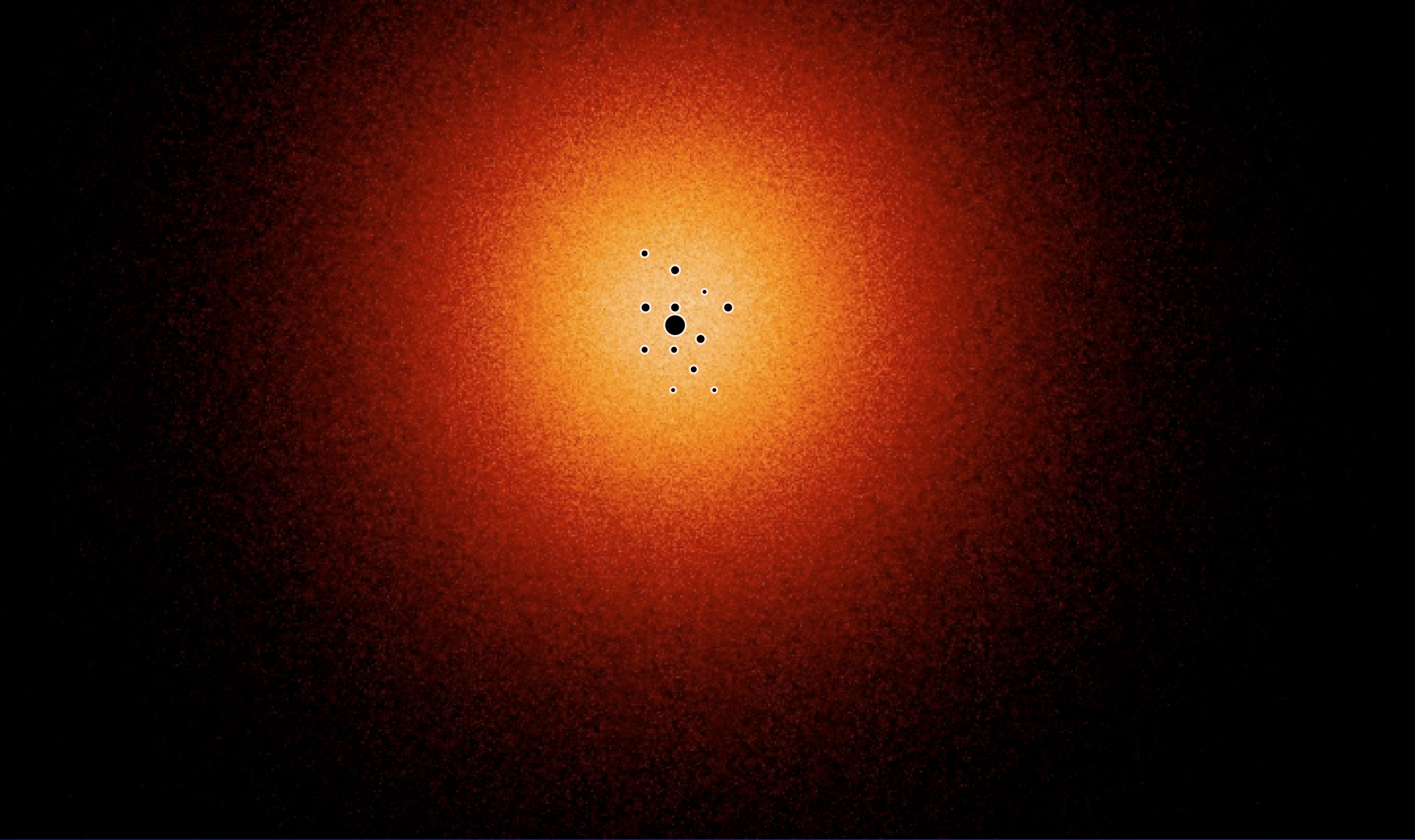
NASA/SAO/G. Fabbiano et al.

However, globular clusters may be natural sites for Intermediate Mass Black Holes

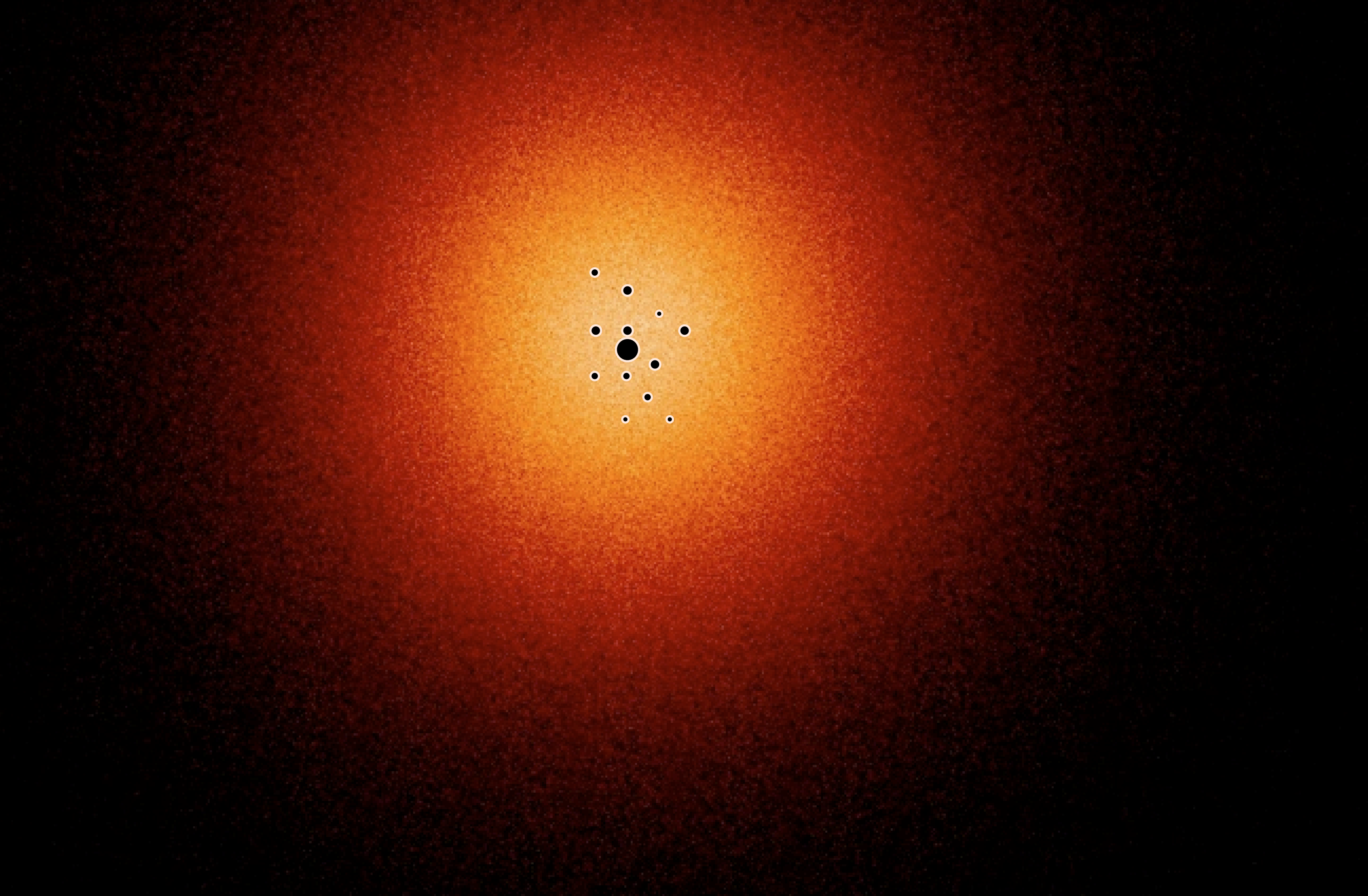


Gebhardt, Rich, and Ho 2003

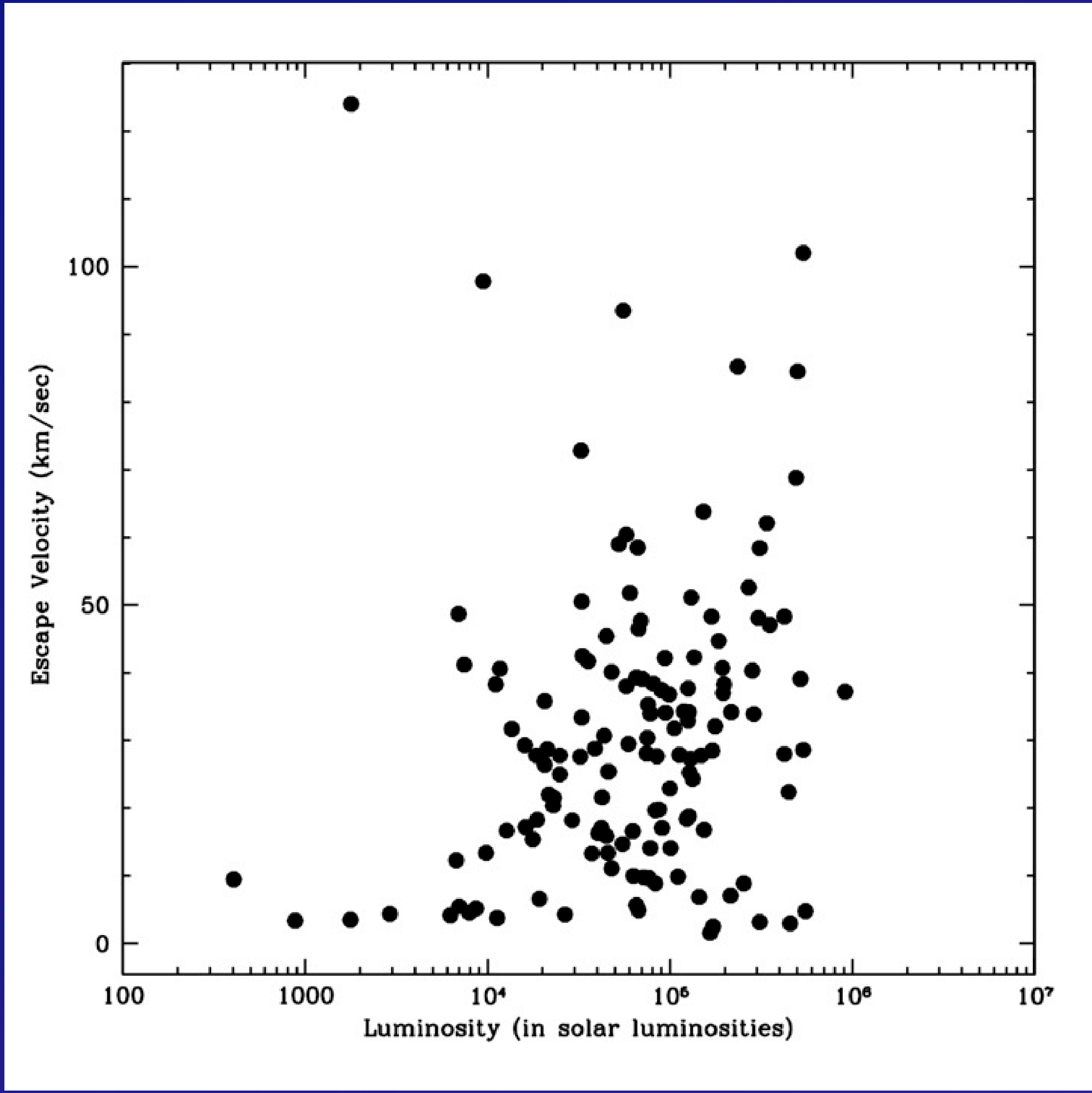
The centers of globular clusters are rife with stellar mass black holes that sink toward the center and may merge with the Intermediate Mass Black Hole



This means that a typical Intermediate Mass Black Hole in a globular cluster merges with ~ 25 stellar mass black holes in its first 3 million years of existence.



Unfortunately, it's easy to get kicked out of a globular cluster



So if globular clusters host intermediate mass black holes today, the IMBH must've survived this onslaught of mergers with other black holes without ever receiving a significant kick.

Assuming a globular cluster forms an IMBH, how likely can it retain it against this gauntlet of stellar mass black hole mergers?

We simulated a million IMBH–BH merger chains, where each merger mass, spin, orientation, and eccentricity is selected from distributions that reflect what we ‘know’ about the primordial globular cluster environment and IMBH formation.

Each merger chain consists of roughly 25 mergers drawn from our primordial globular cluster initial conditions.

ACCRE, Vanderbilt University

Decisions, Caveats, and other ways to pick a fight.

Do IMBHs exist in globular clusters?

How do IMBHs form? (what mass does an IMBH have at birth?)

What is the mass distribution for stellar mass black holes in globular clusters?

How many mergers with black holes do IMBHs undergo?

Are these gravitational wave kick velocities certain for all black hole merger configurations?

Intermediate Mass Black Holes are tough to retain!

Even if every one of the 150 globular clusters formed IMBHs, only 5–30 would retain them against the onslaught of gravitational wave kicks.

This means that about 100 low mass ‘rogue’ IMBHs in the halo. Unless they’re accreting gas, they’re invisible.

Retained black holes may be offset from center, and may briefly oscillate about the globular cluster center.

To retain an IMBH, globular clusters must have formed high mass seed black holes quite early.

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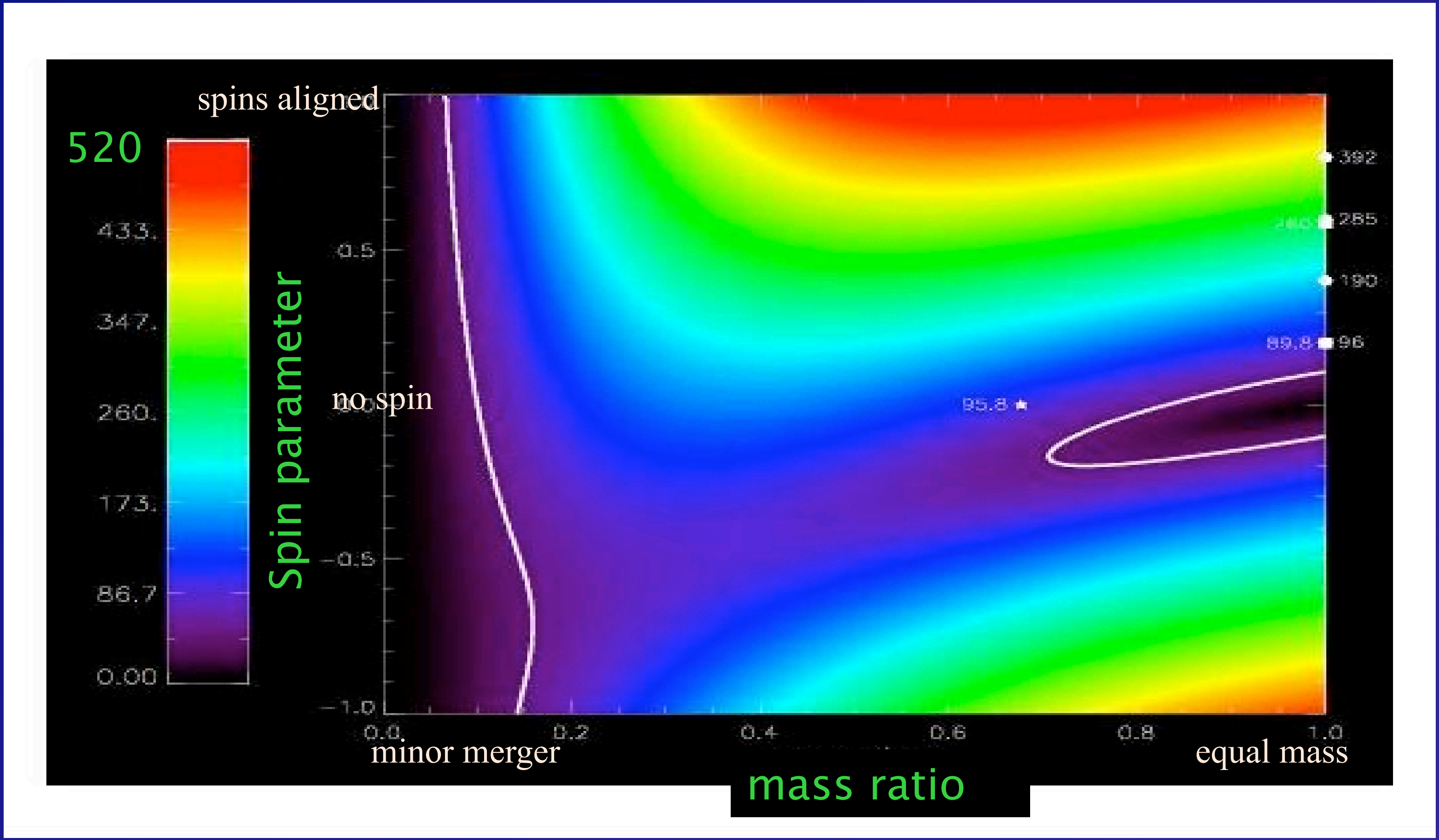
Are we in any danger? No.

Retained black holes may be offset from center, and may briefly oscillate about the globular cluster center.

To retain an IMBH, globular clusters must have formed high mass seed black holes quite early.

Visit poster 49.02 for more information

The problem is that asymmetric black hole mergers can yield fast kicks



These kick velocities correspond to black holes with spins equal in magnitude and parallel to the orbital angular momentum

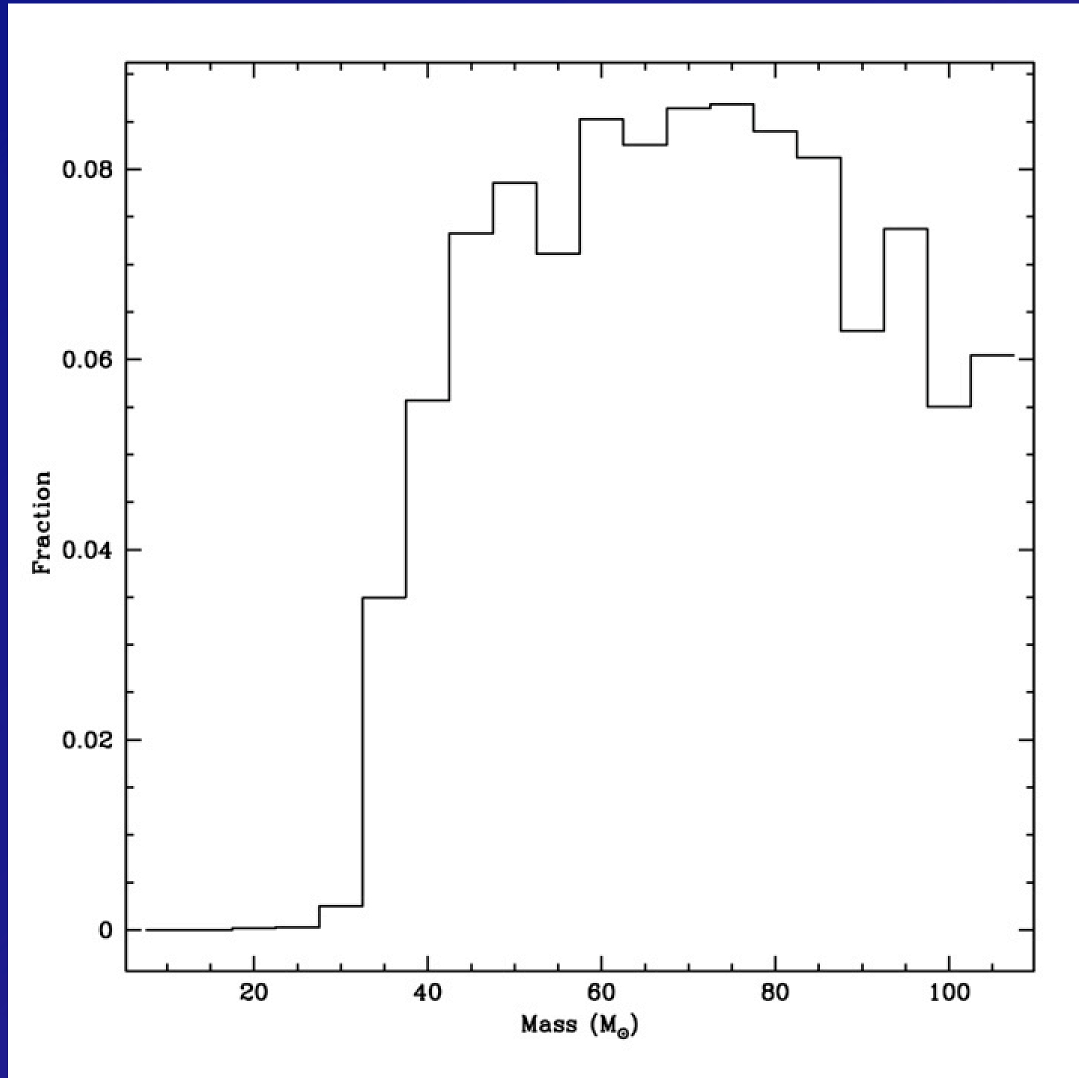
Other configurations can generate 4000 km/sec kicks!

Abstract

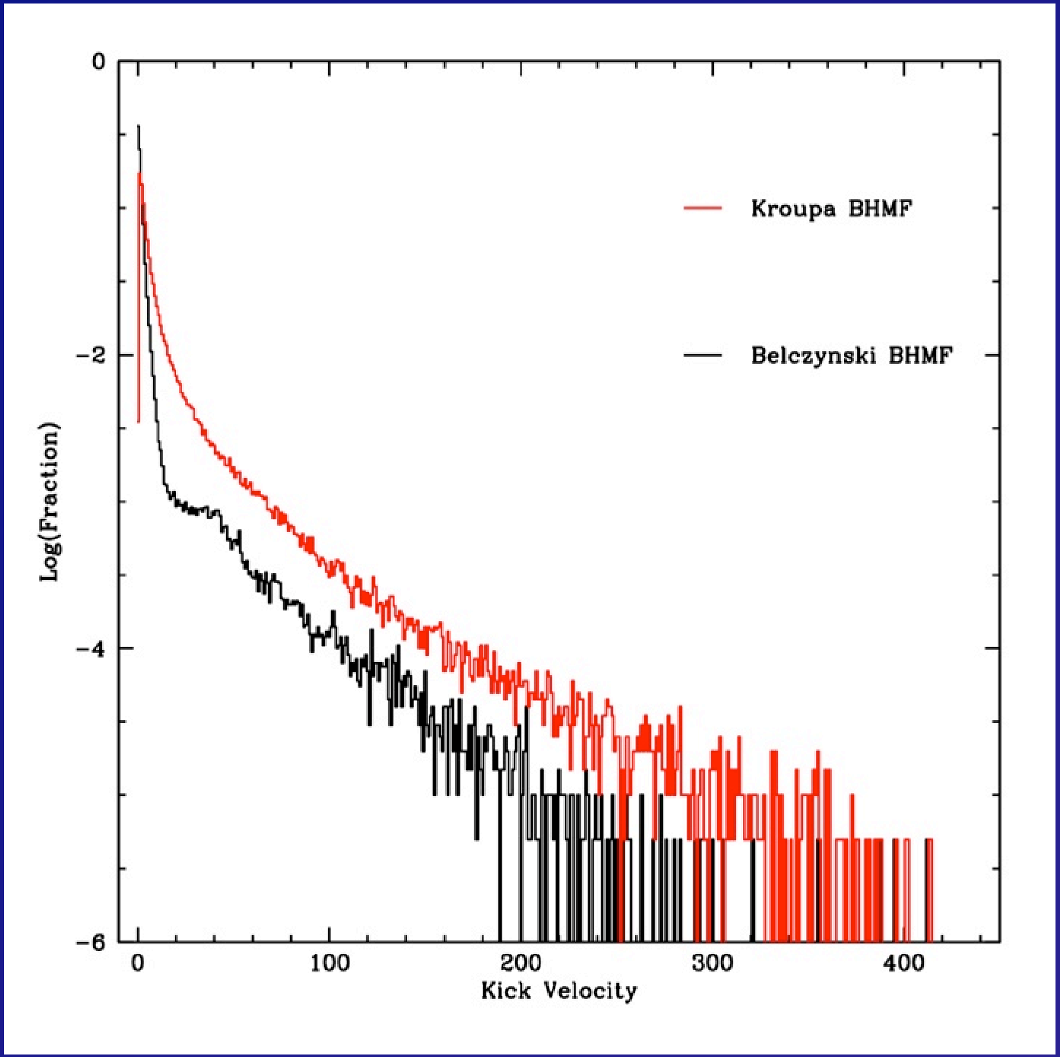
During the inspiral and merger of a binary black hole, gravitational radiation is emitted anisotropically due to any asymmetry in the orbital configuration. This anisotropic radiation leads to a gravitational wave kick, or recoil velocity, as large as 4000 km/sec. We investigate the effect gravitational wave recoil has on the retention of intermediate mass black holes (IMBH) within Galactic globular clusters. Assumung that our current understanding of IMBH-formation is correct and yields an IMBH-seed in every globular cluster, we find a significant problem retaining low mass IMBHs (< 1000 $M_{\odot}$) in the typical merger-rich globular cluster environment. Given a uniform black hole spin distribution and orientation and a Kroupa black hole mass function, we find that at most 3% of the globular clusters can retain an IMBH larger than 1000 $M_{\odot}$ today. For a population of black hole that better approximates mass loss from winds and supernovae, we find that 16% of globulars can retain an IMBH larger than 1000 $M_{\odot}$. Our calculations show that if there are black holes larger than 60 $M_{\odot}$ in a cluster, repeated IMBH-BH encounters will eventually eject a 1000 $M_{\odot}$ IMBH with greater than 30% probability. As a consequence, a large population of rogue black holes may exist in our Milky Way halo. We discuss the dynamical implications of this subpopulation, and its possible connection to ultraluminous X-ray sources (ULXs).

More Kicks Consequences

- Large offsets for supermassive black holes from galaxy center if merger was major and recent
- How does this effect (or constrain) the growth mechanisms for SMBHs?
- Rogue black holes within galaxy halos – ULXs? Dynamical effects on galaxy disk?
- How do you retain seed black holes within small structures in the early universe?

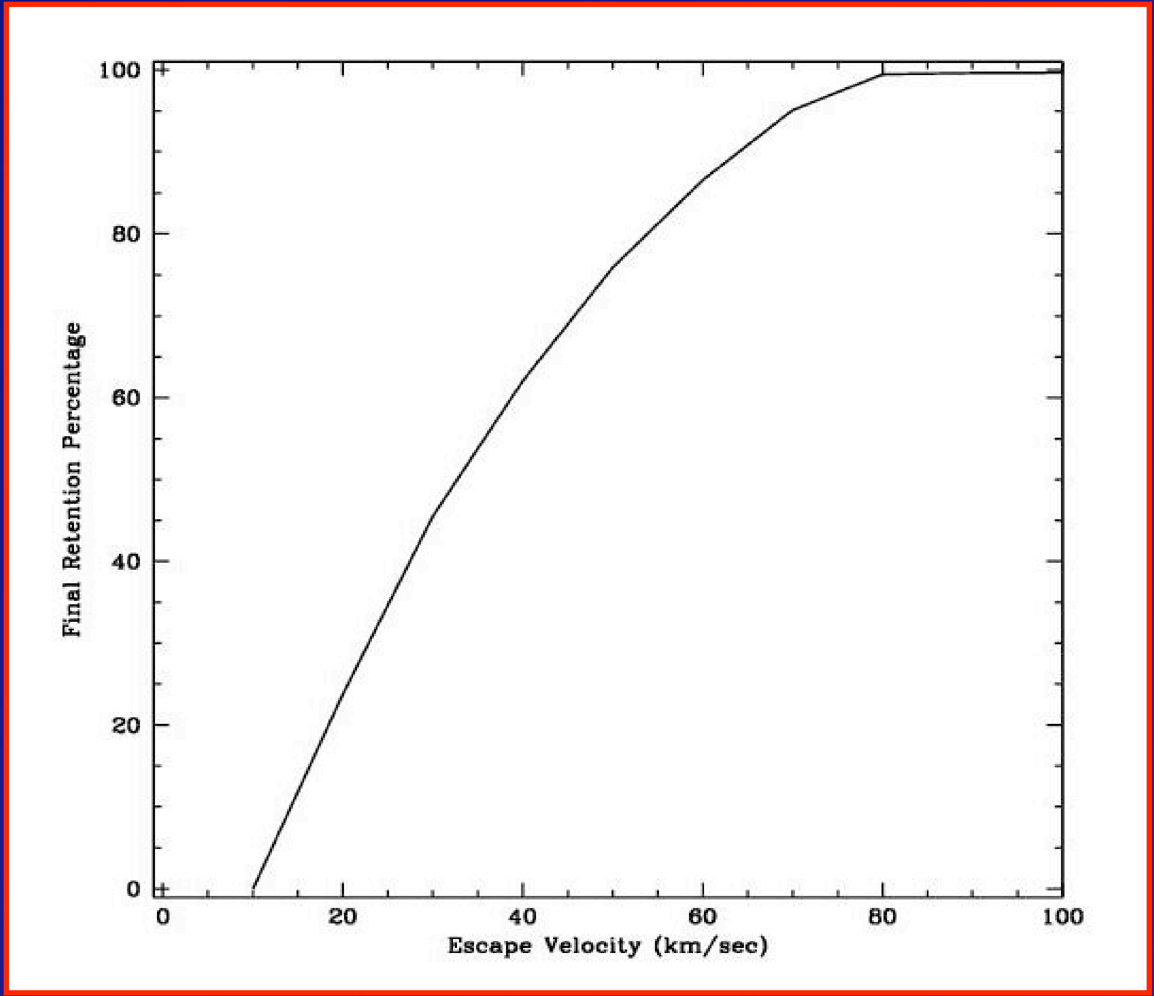


A histogram of the black hole masses that eject a 1000 $M_\odot$ IMBH. In this experiment, we assumed a Kroupa black hole mass function, and that the spin orientations and magnitudes are distributed uniformly. Ejecting a 1000 $M_\odot$ black hole is possible with masses as low as 20 $M_\odot$, but the overwhelming majority of ejections result from black holes with masses > $50_\odot$ M.



The spectrum of possible stellar mass black holes matters in generating large kicks. The black hole mass functions that are seeded with more massive black holes yield rogues more easily.

Fraction of encounters as a function of kick velocity for two black hole mass functions (BHMF). The Kroupa BHMF has the same functional form as a Kroupa IMF (i.e. no mass loss), while the Belczynski BHMF takes into account mass loss within stellar populations as metal poor as globular clusters. We assume the IMBH has a mass of 1000 $M_\odot$, and that the spin magnitudes and orientations are distributed uniformly.



Retention probability as a function of the escape velocity of the host structure. We assume a secondary mass of 20 $M_{\odot}$, and M_{IMBH}= 500 $M_{\odot}$, random spin orientations and magnitudes

Decisions, Caveats, and other ways to pick a fight.

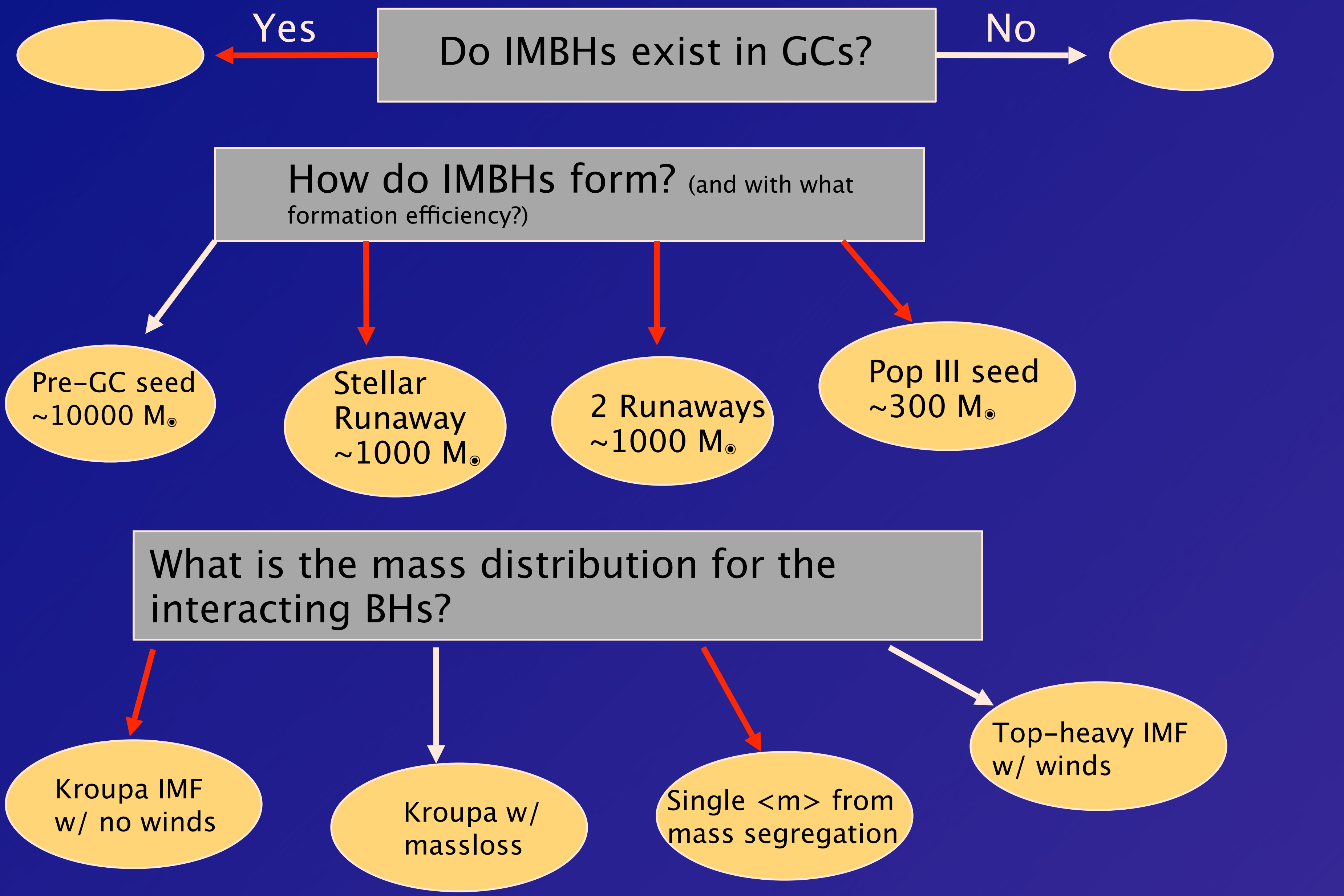
- assume uniform black hole spin distribution

- assume uniform spin orientation distribution (no gas to align the spins)

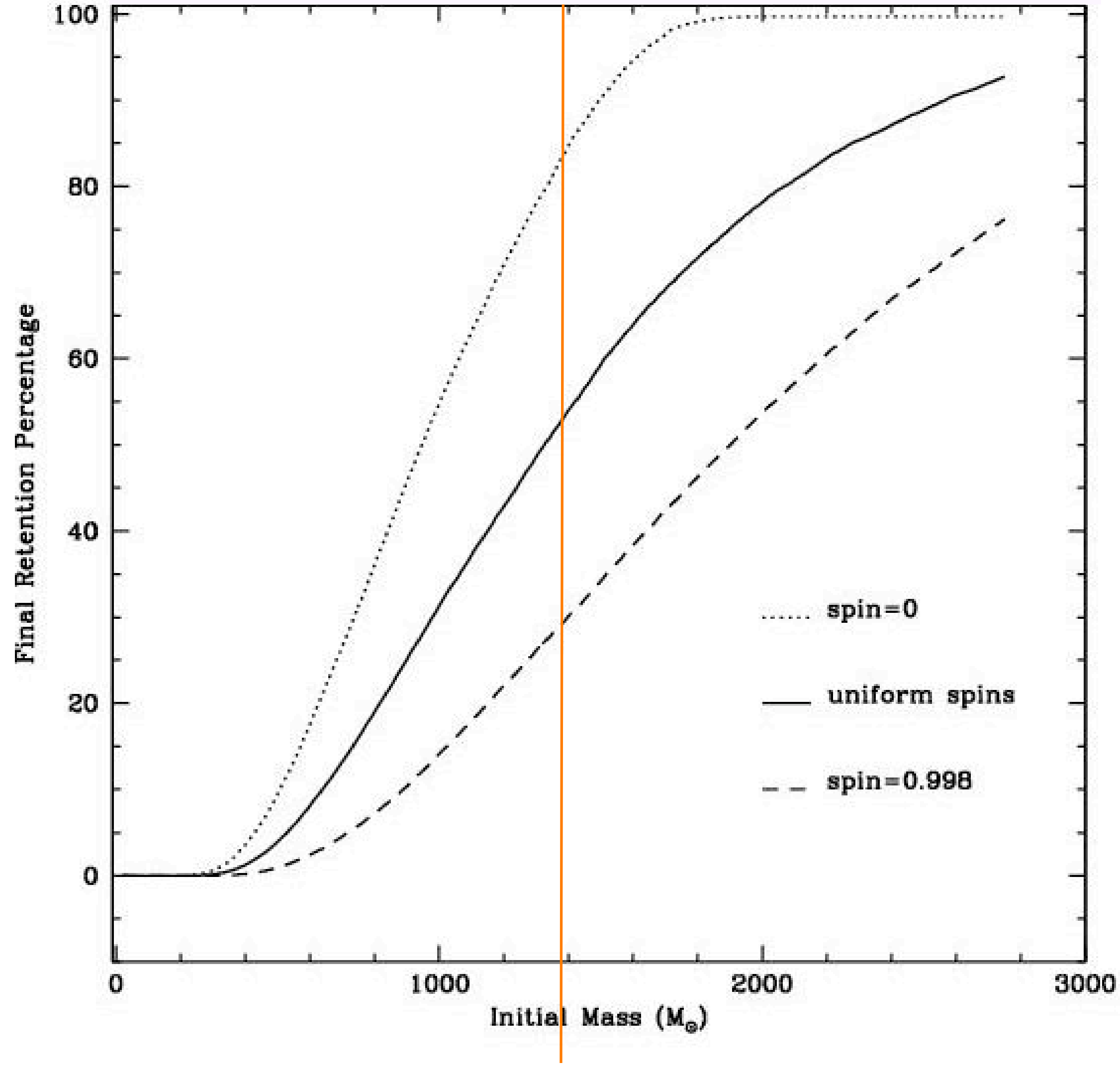
- assume eccentricity distribution given by simulations of few-body encounters in globular clusters can have e~1 IMBH-BH mergers.

- assume early globular clusters rife with mergers -- 1st ~3 Myr, IMBH experiences ~ 25 mergers before few-bod/ IMBH interactions evacuate center of stellar mass BHs.

Decisions, Caveats, and other ways to pick a fight.



Kroupa Black Hole Mass Function

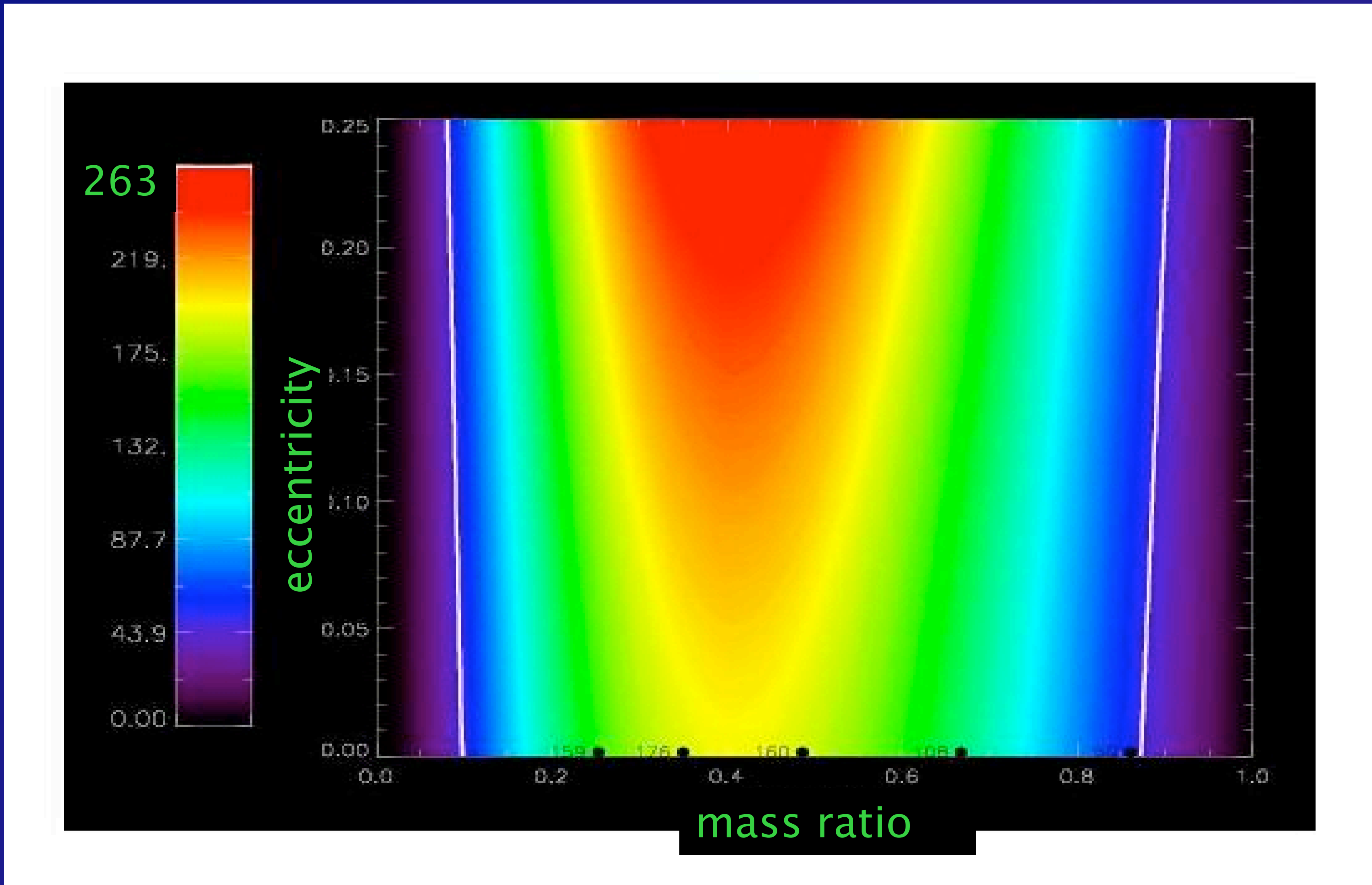


An IMBH has to be above 1500 $M_\odot$ before it has >50% probability of remaining in the globular cluster

Mergers still can be LISA/LIGO sources…but the predicted mass function will shift to smaller average total mass…

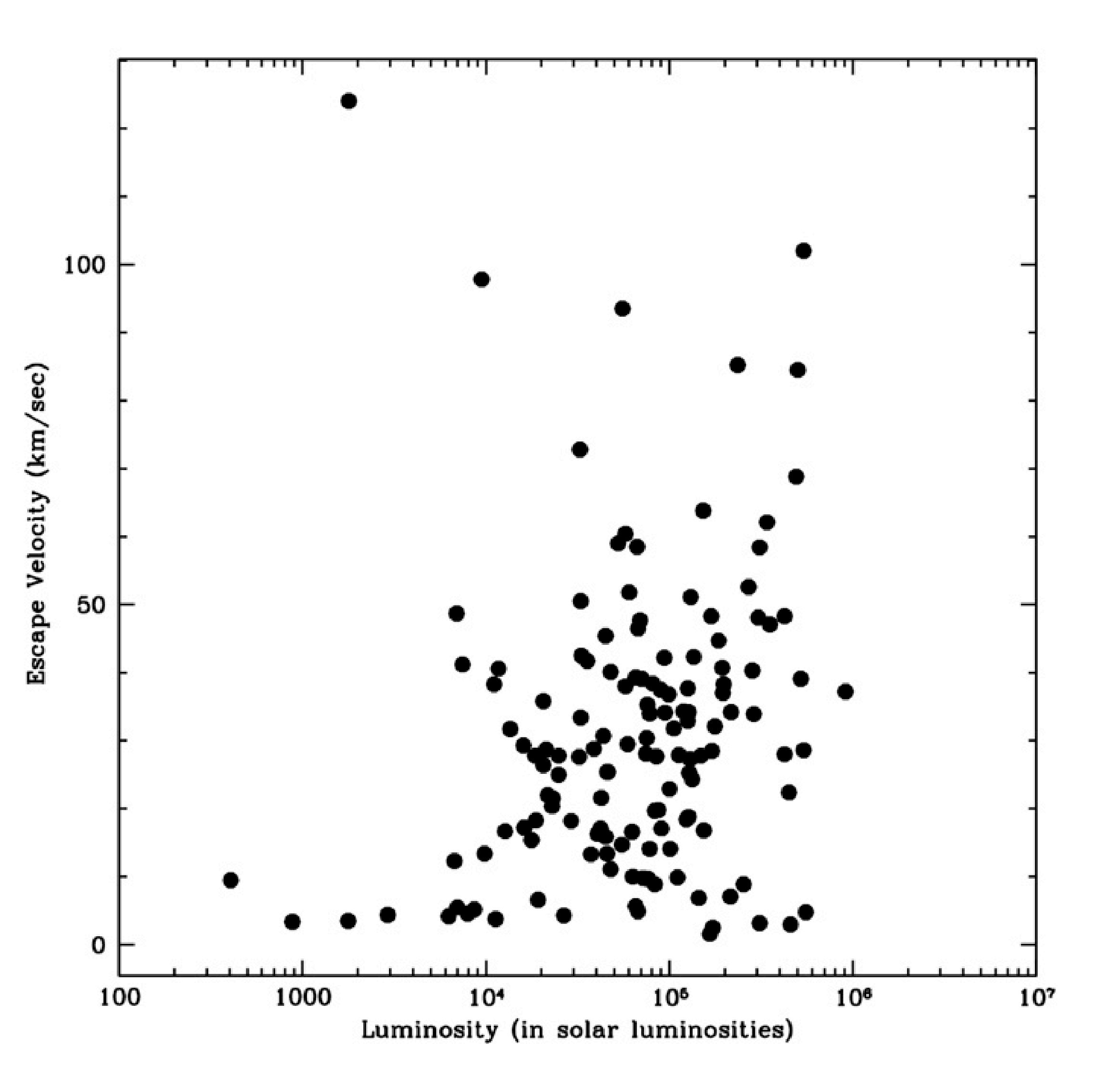
Note: by changing the black hole mass function, it's possible to retain 50% of the 600 solar mass IMBHs

Gravitational wave recoil velocity from non-spinning black holes



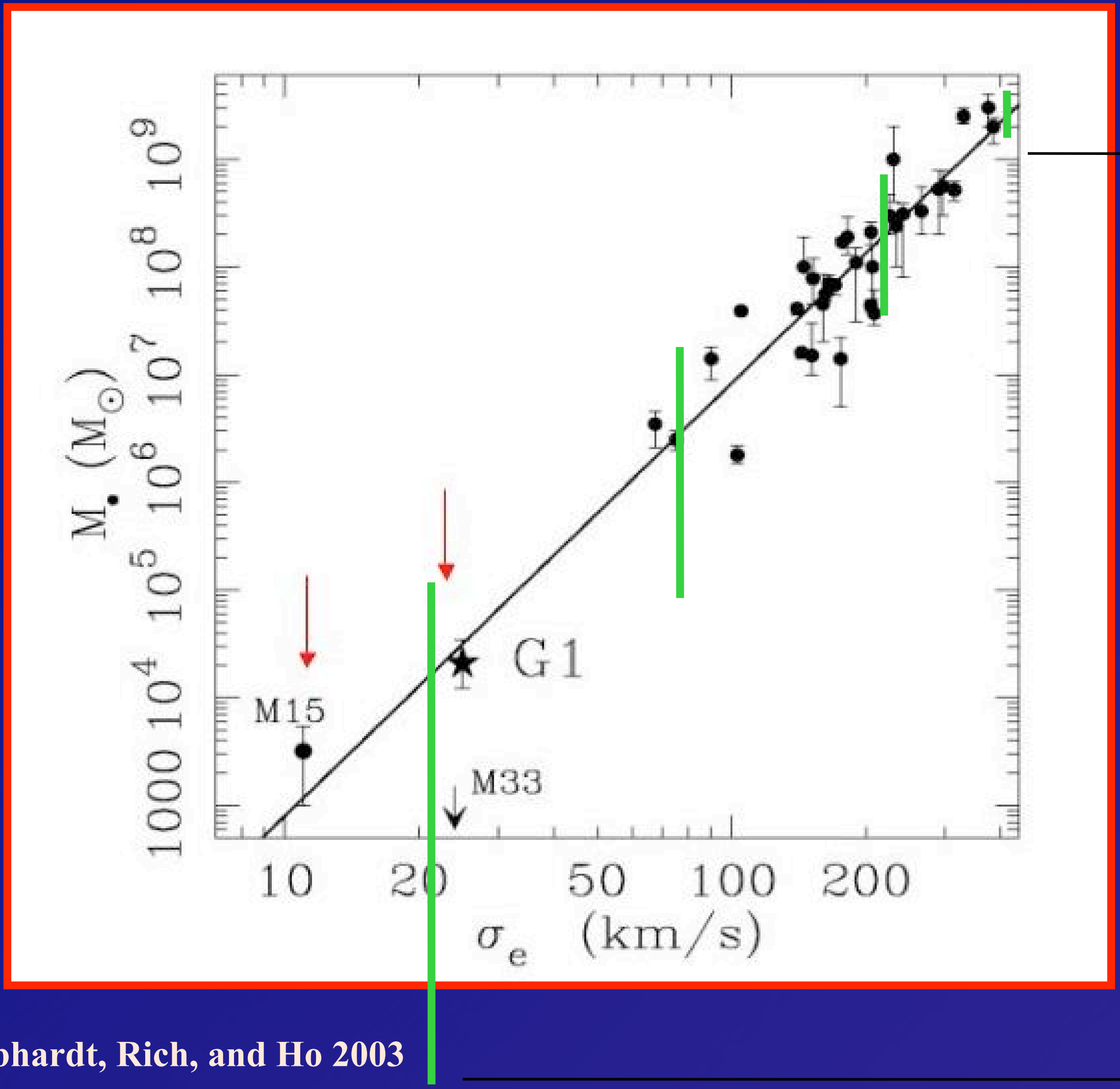
fit from Campanelli et al. 2007 with a post-Newtonian correction for eccentricity from Sopuerta et al. 2007...this correction goes as 1+e

It's easy to kick something out of a globular cluster



Early globular clusters are rife with stellar mass black holes that settle into the center. Many are themselves ejected from three-body interactions, but the rest would interact with the IMBH…if it's there.

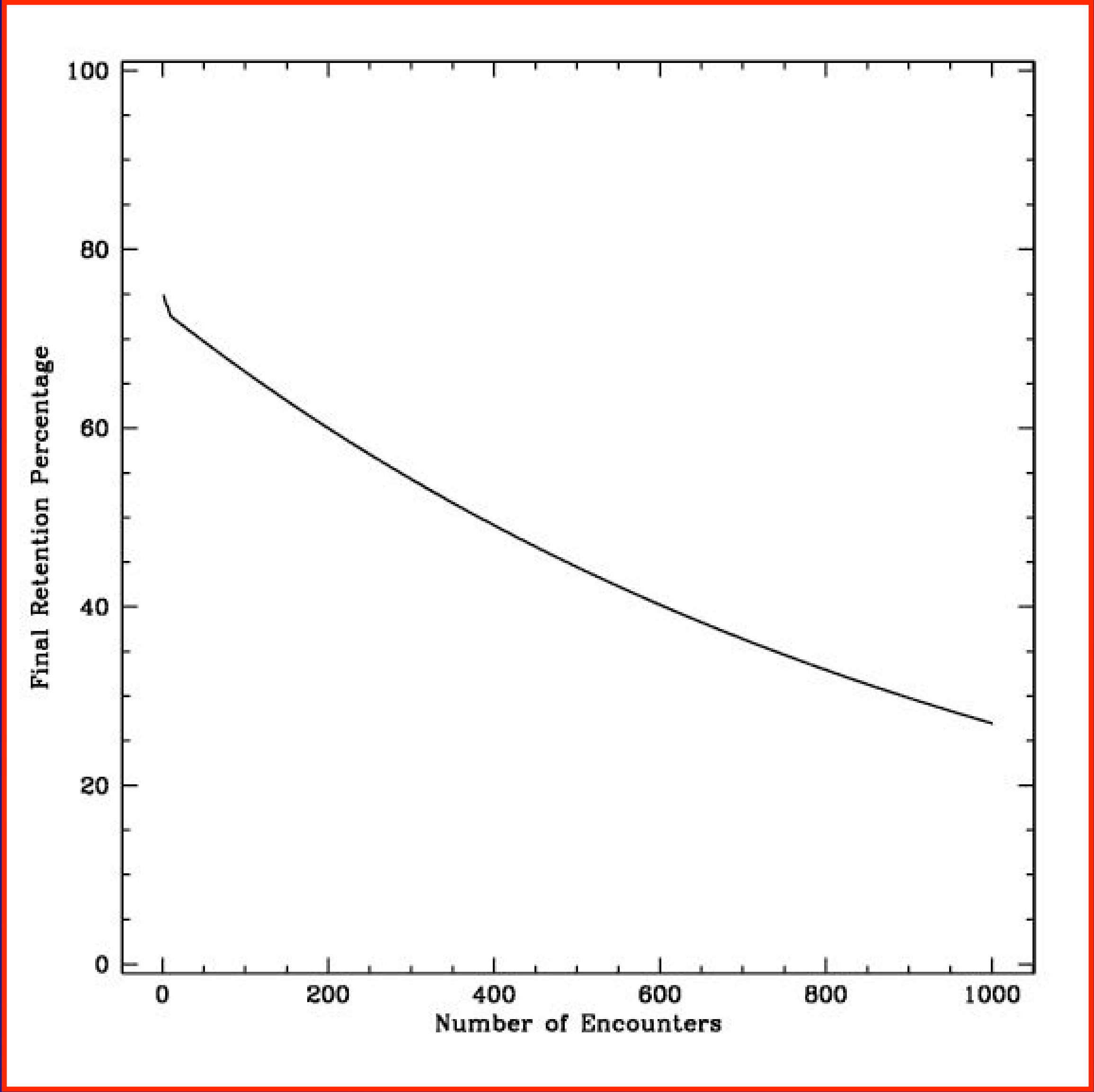
Kick this idea around: Is there a variable spread in M-sigma?



Gebhardt, Rich, and Ho 2003

Largest SMBHs require ‘all’ accretion mechanisms + kicks inefficient (early growth)

IMBHs have many formation/growth channels + kicks efficient



100
80
60
40
20
0
0
200
400
600
800
1000
Number of Encounters
Final Retention Percentage