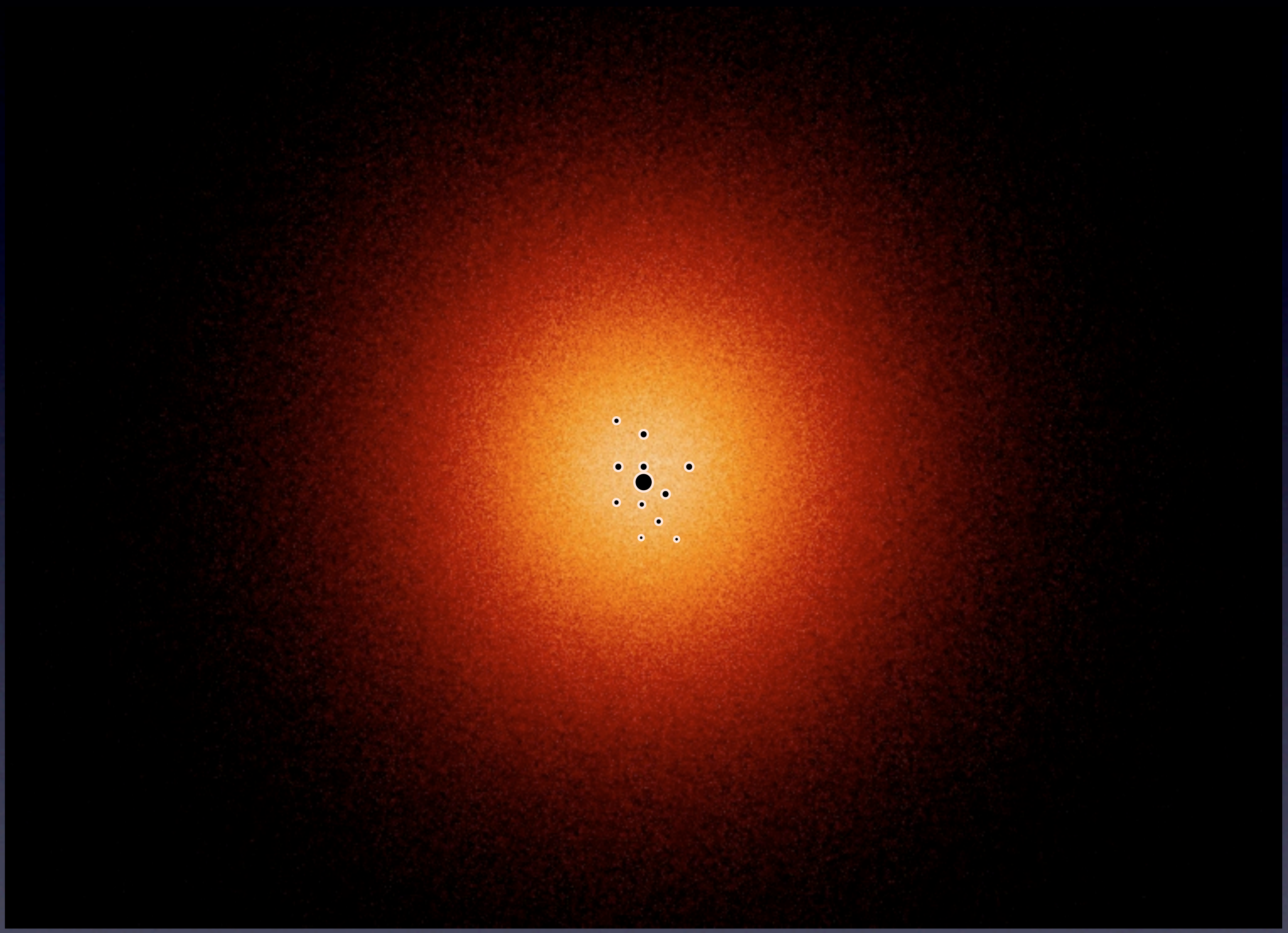
Gravitational Wave Recoil and the Retention of Intermediate Mass Black Holes



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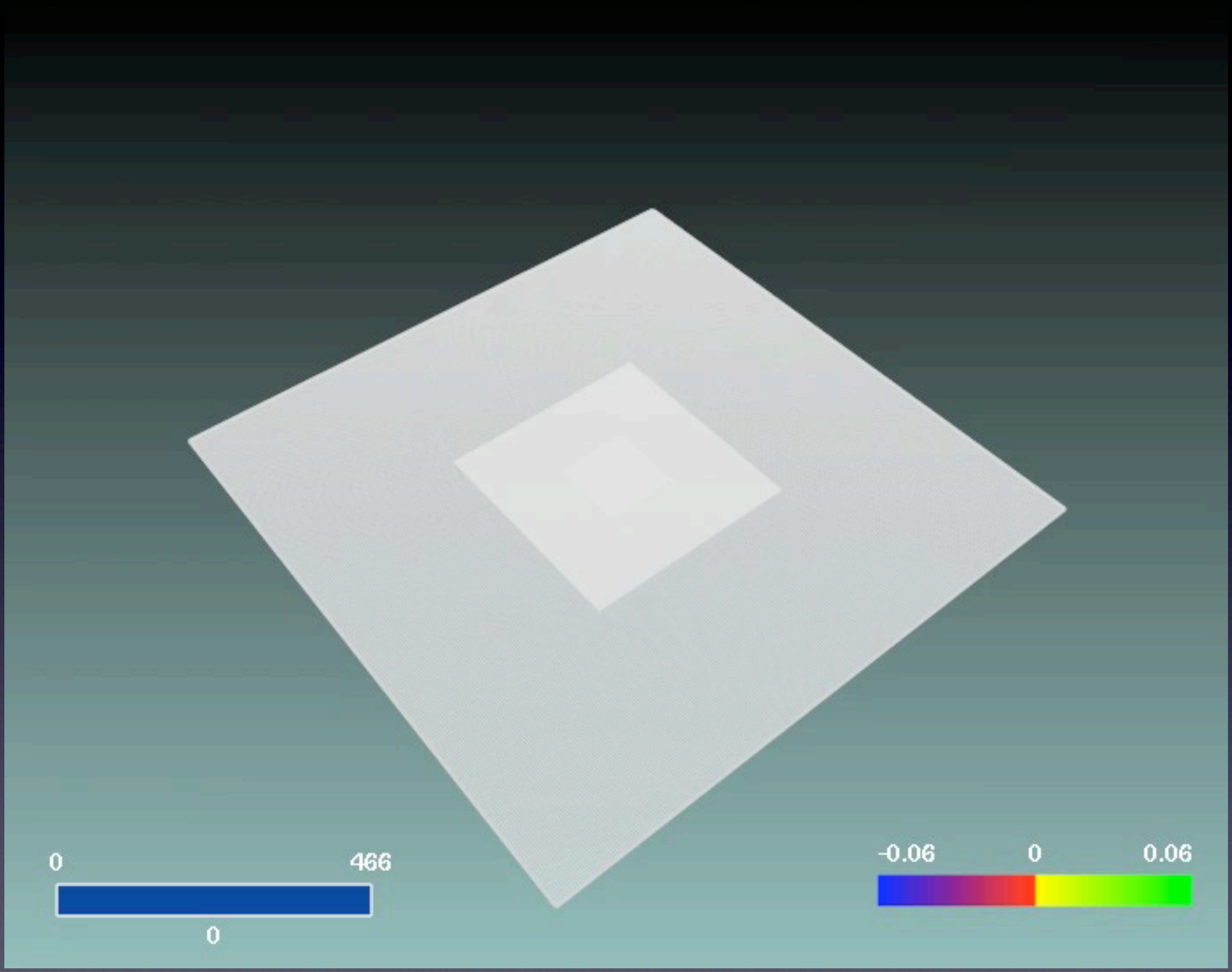
Generically, any asymmetric black hole merger will emit gravitational waves anisotropically. This will cause the new black hole to recoil.

gravitational wave recoil has been predicted for a long time...

Thorne 1980; Kidder 1995; Fitchett 1983; Favata et al. 2004; Damour & Gopakumar 2006; Blanchet et al. 2005; Sopuerta et al. 2006; Herrmann et al. 2007; Baker et al. 2006; Gonzalez et al. 2006; Herrmann et al. 2007; Koppitz et al. 2007; Gonzalez et al. 2007a; Campanelli et al. 2007a,c; Tichy & Marronetti 2007; Sopuerta et al. 2007

Numerical relativists have finally gotten black holes to merge

Pretorius 2005; Campanelli et al. 2005; Baker et al. 2006



Ralf Kaehler (AEI/ZIB), Luciano Rezzola (AEI)

...and the simulations can finally produce these kicks

Campanelli et al. 2007; Sopuerta et al. 2007

$$v_{\rm kick} = (1+e)\left[\hat{x}\ \left(v_m + v_\perp \cos\xi\right) + \hat{y}\ v_\perp \sin\xi + \hat{z}\ v_\parallel\right]$$

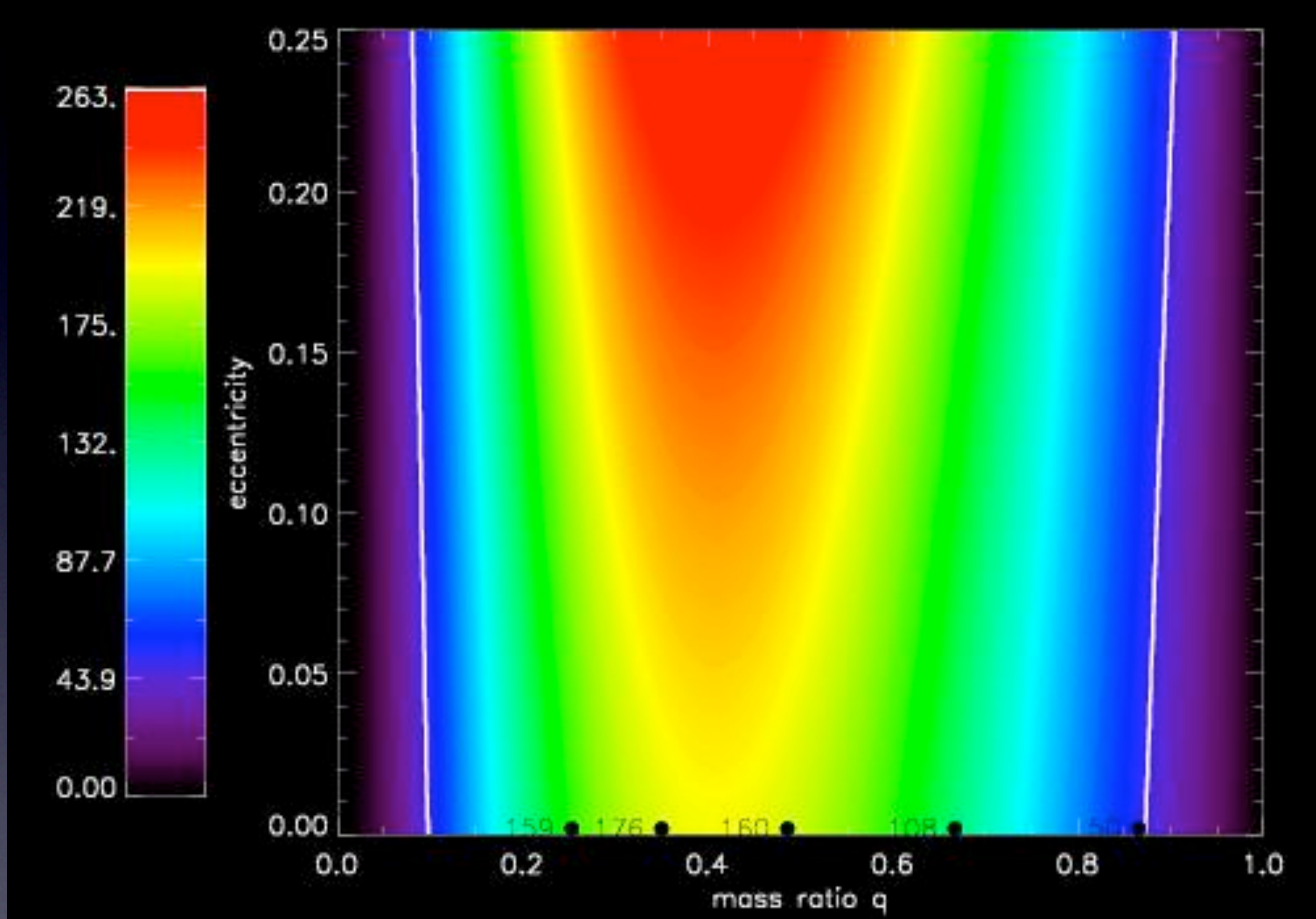
$$v_m = A\frac{q^2\,(1-q)}{(1+q)^5}\left[1 + B\frac{q}{(1+q)^2}\right]$$

$$v_\perp = H\frac{q^2}{(1+q)^5}\left(\alpha_2^\parallel - q\alpha_1^\parallel\right)$$

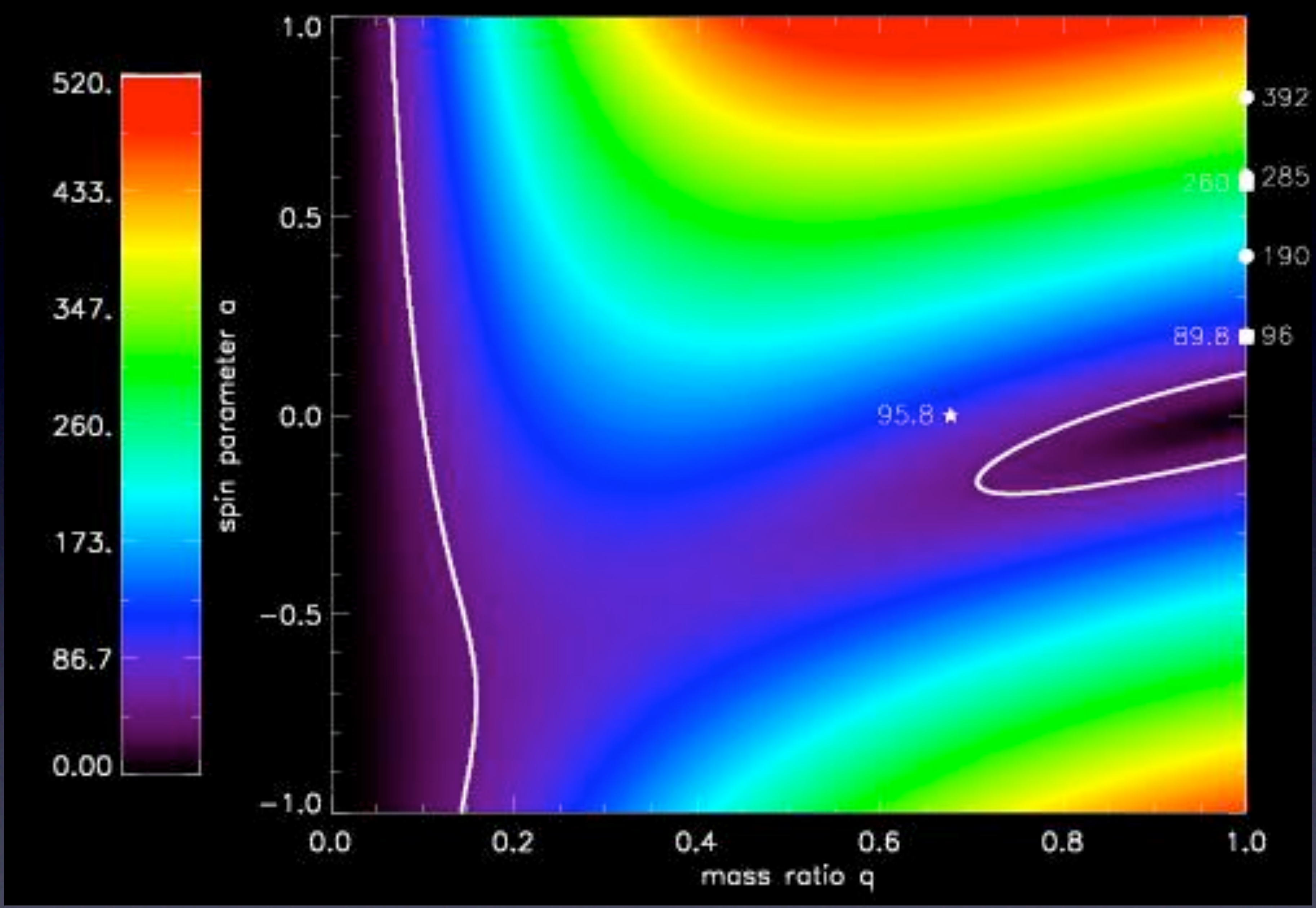
$$v_\parallel = K\cos\left(\Theta - \Theta_0\right)\frac{q^2}{(1+q)^5}\left(\alpha_2^\perp - q\alpha_1^\perp\right)$$

$$A = 1.2\times 10^4$$
$$B = -0.93$$
$$H = (7.3 \pm 0.3)\times 10^3$$
$$K = (6.0 \pm 0.1)\times 10^4$$

Unspinning black holes have kicks in the ~100 km/sec range

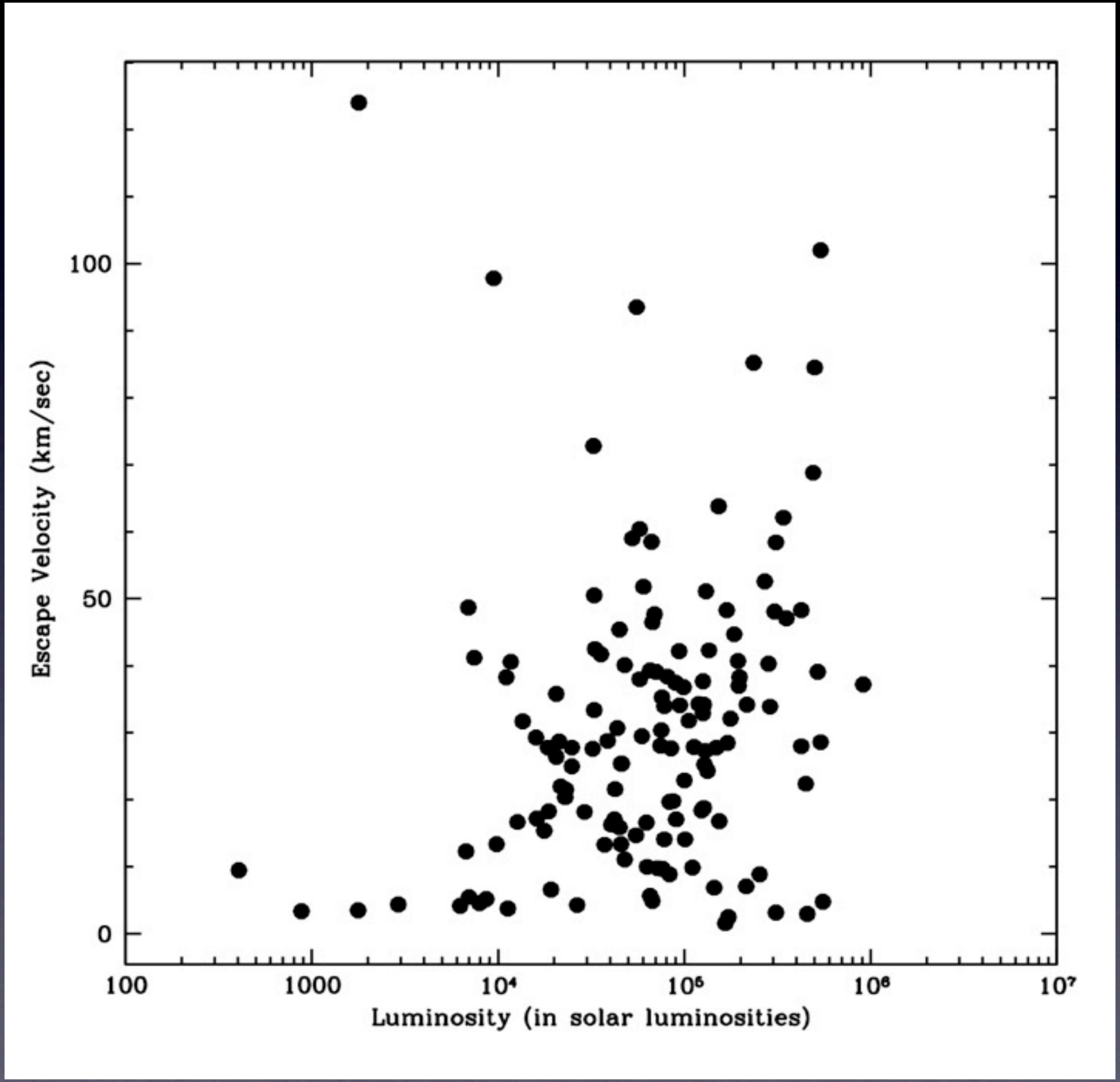


Spinning black holes have much higher kicks



...up to 4000 km/sec for certain configurations!

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.

Spitzer 1969; Portegies Zwart & McMillan 2002; Fregeau et al. 2002; Gurkan et al. 2004; Merritt et al 2004; Freitag et al. 2005

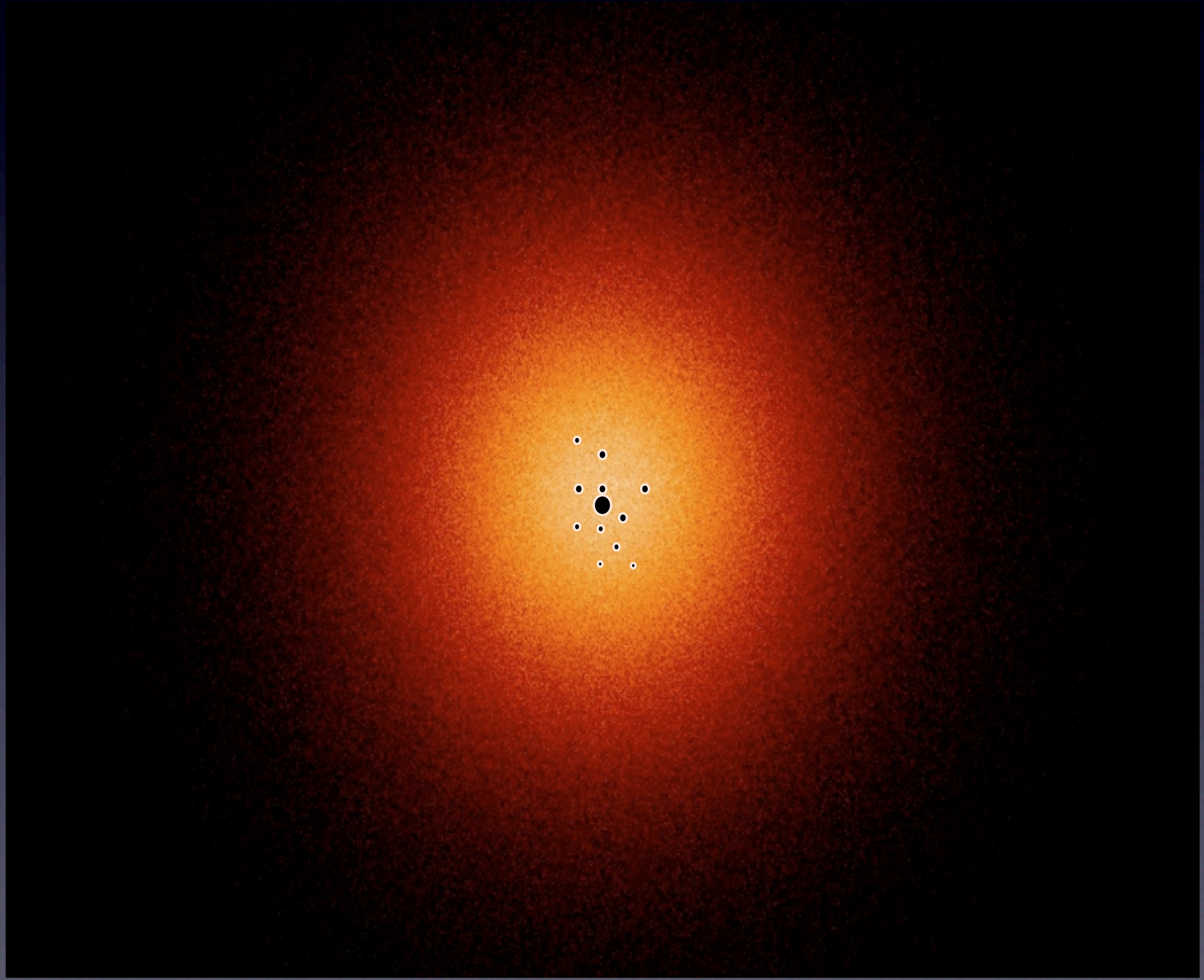
Many are themselves ejected by Newtonian dynamics

Kulkarni 1993; Sigurdsson & Phinney 1993; Baumgardt et al. 2004; O'Leary et al. 2006; Mackey et al. 2007, Moody & Sigurdsson 2008

but the rest would interact with the IMBH...if it's there.

Gill et al. 2008; Trenti et al. 2007

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.

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 are the spins and spin orientations distributed?

How many mergers with black holes do IMBHs undergo?

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

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let's explore a wide range

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this is critical. let's talk

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uniformly

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~25

Gultekin et al. 2006

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

YES

(but see Baker et. al 2008 and AAS 09 scuttlebutt)

The Black Hole Mass Function Matters

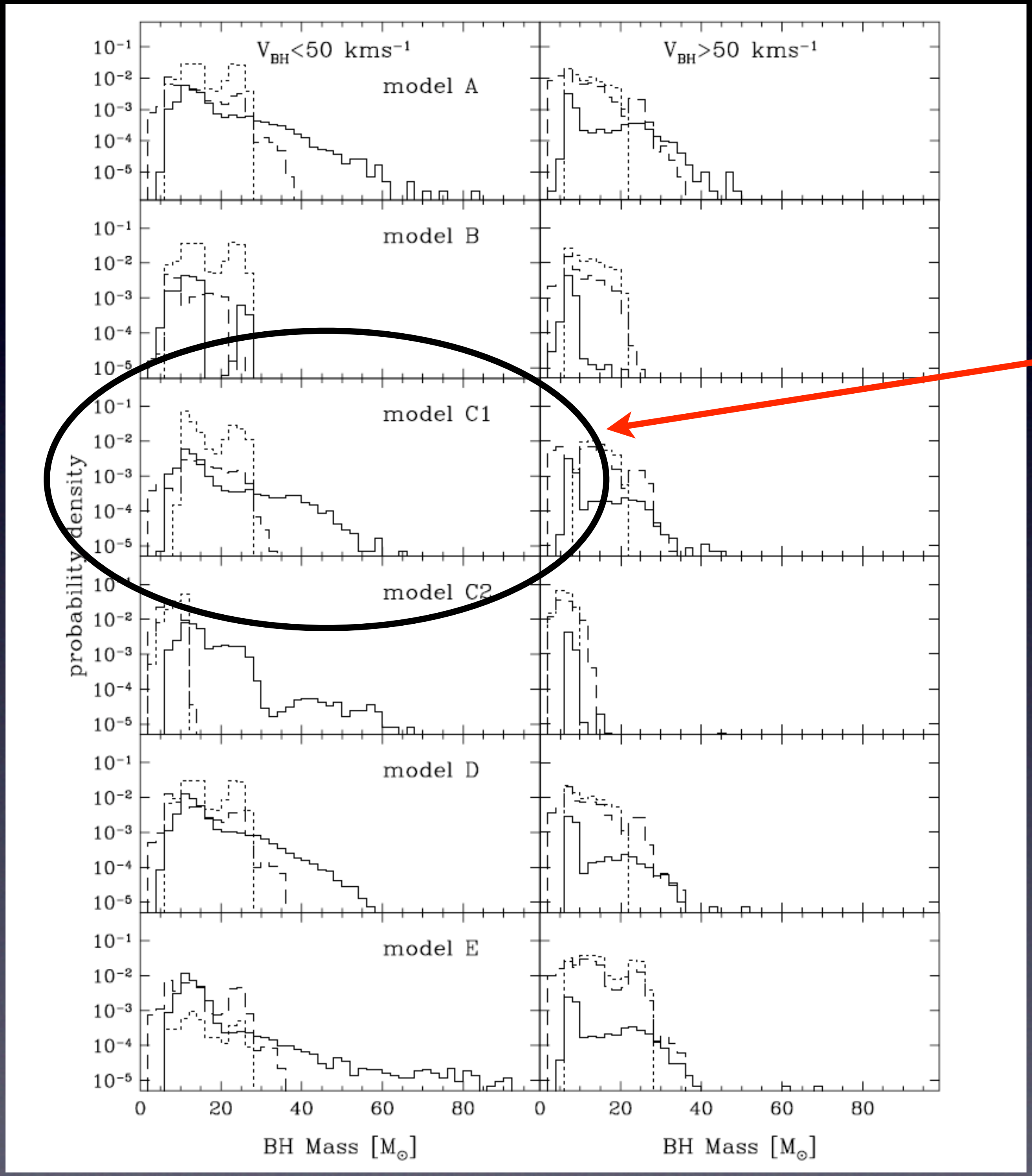
The *field* black hole mass distribution is flat and sharply truncates at ~20 $M_\odot$

Fryer & Kalogera 2001

...but globular clusters are metal poor and collisional, so the GC initial black hole mass function probably doesn't

we varied the black hole mass function to bracket predicted models.

Primordial Black Hole Mass Function via Population Synthesis



Using Startrack with a Kroupa IMF, Z=0.0001, natal kicks

Belczynski et al. 2006

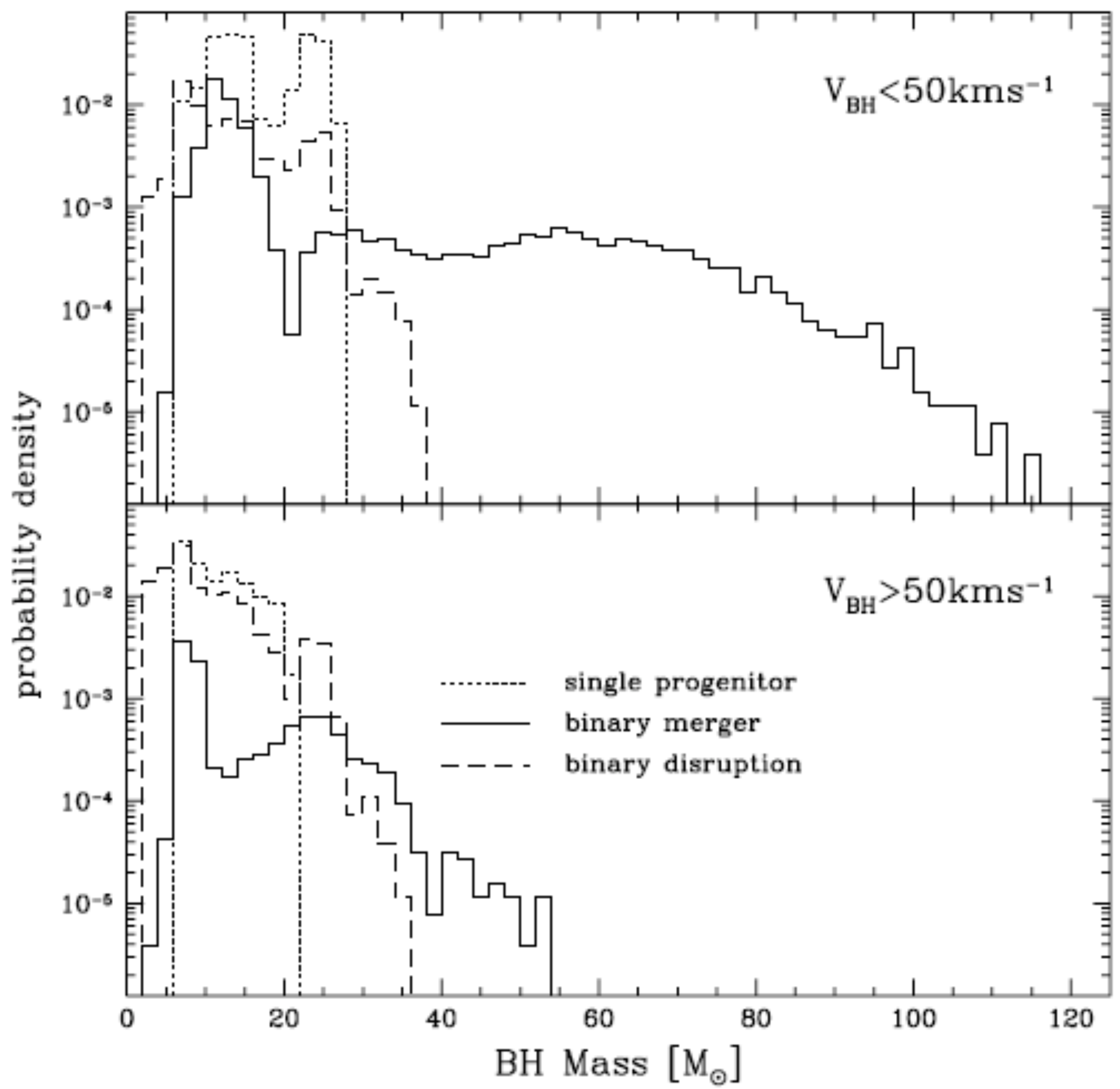


FIG. 8.—Same as Fig. 7, but for a model in which the merger mass is calculated from the total mass of the two merging binary components. See § 3.1.3 for details.

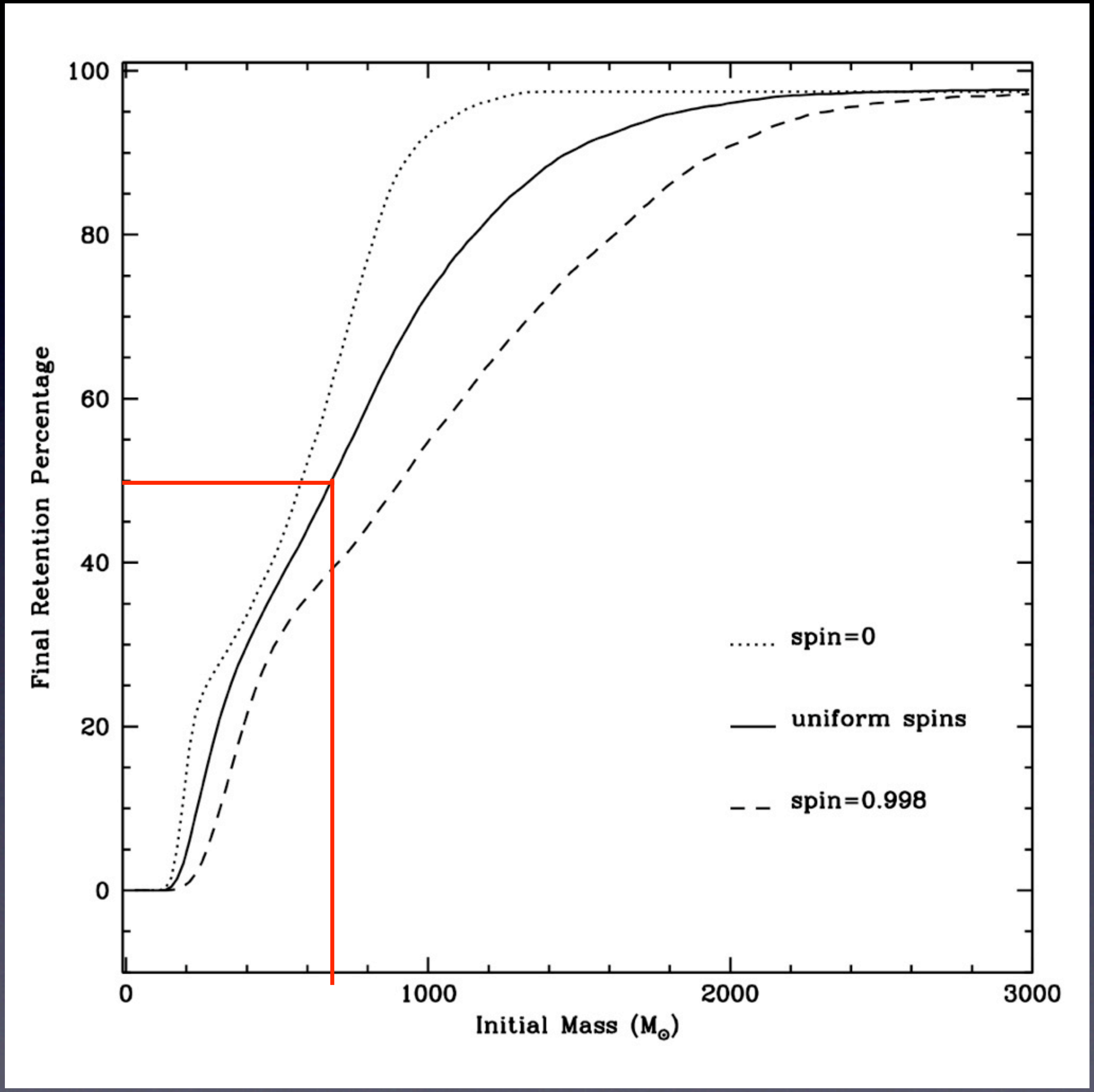
If single stars merge, black hole masses can be even larger.

(see also Suzuki et al. 2007)

Belczynski et al. 2006

With the Belczynski Black Hole Mass Function

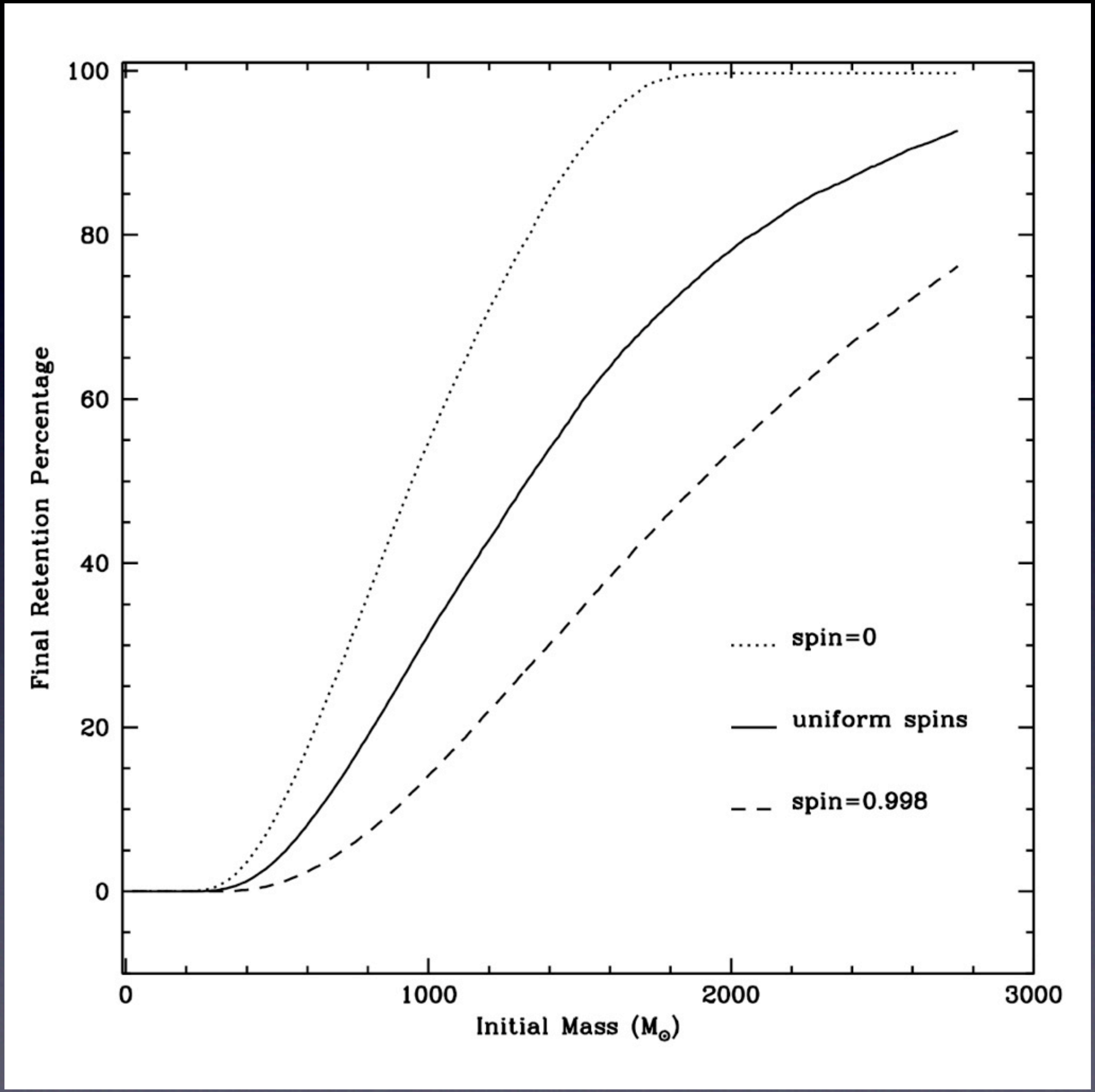
A 700 $M_\odot$ IMBH is retained 50% of the time in a globular cluster with v_{esc}=50 km/sec



Mergers still make good gravitational wave sources…but the predicted mass function will shift to smaller average total mass…

With our 'Kroupa' Black Hole Mass Function

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



few-body versus gravitational wave recoil

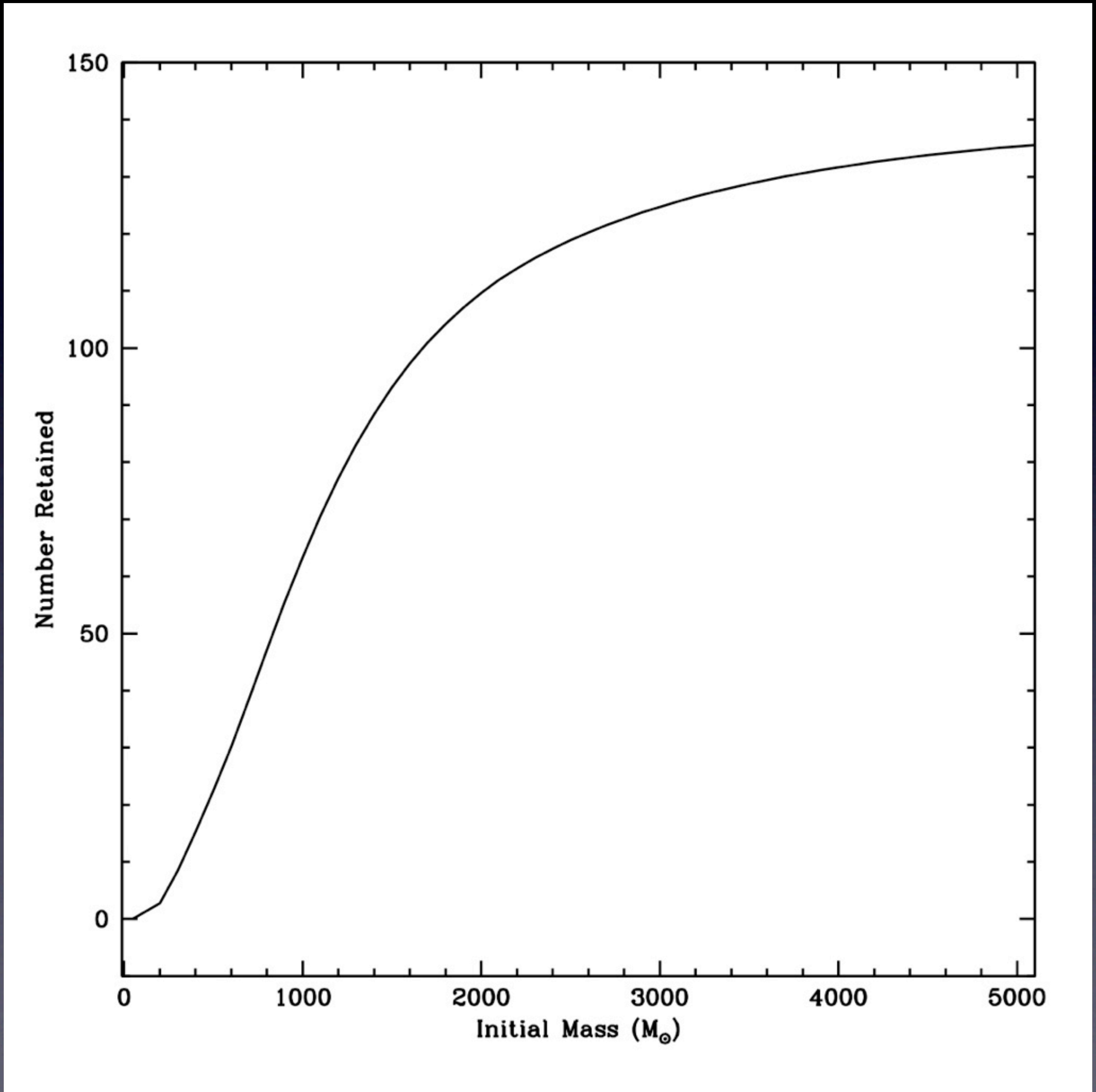
The three-body recoil of a binary with a dominant IMBH scales as:

$$v_b^2 \sim \frac{m_{\rm comp} m_{\rm int}^2}{m_b} \frac{m_{\rm comp} + m_b}{(m_{\rm int} + m_b)^2} \sim \frac{m_{\rm comp} m_{\rm int}^2}{m_b^2}$$

Scaling from Gultekin et al. 2006, for M_{imbh}=500$M_\odot$, M_{comp}=80$M_\odot$, and M_{int}=11$M_\odot$:

Gravitational wave recoil is twice as efficient as dynamical ejections.
See, however, Moody & Sigurdsson; Mackie et al. 2008.

Averaging over the Milky Way Globular Clusters



If every IMBH begins as a seed of 200 $M_\odot$, we should observe only 3 globular clusters with IMBHs, each less than 600 $M_\odot$ and each occurring in the most massive clusters (with the highest escape velocities).

If seed IMBHs form instead with an initial mass of 2000 $M_\odot$, roughly 2/3 of the Milky Way globulars could retain them, and the typical current IMBH mass would be 2400 $M_\odot$

Intermediate Mass Black Holes are tough to retain!

Even if every one of the 150 globular clusters formed 500 $M_\odot$ IMBHs, only 15 would retain them against the onslaught of gravitational wave kicks.

Retained black holes may have large offsets from center, and may oscillate about the globular cluster center -- a nice heating source, ωCen!

To retain an IMBH, globular clusters must have formed high mass seed black holes quite early -- M54!

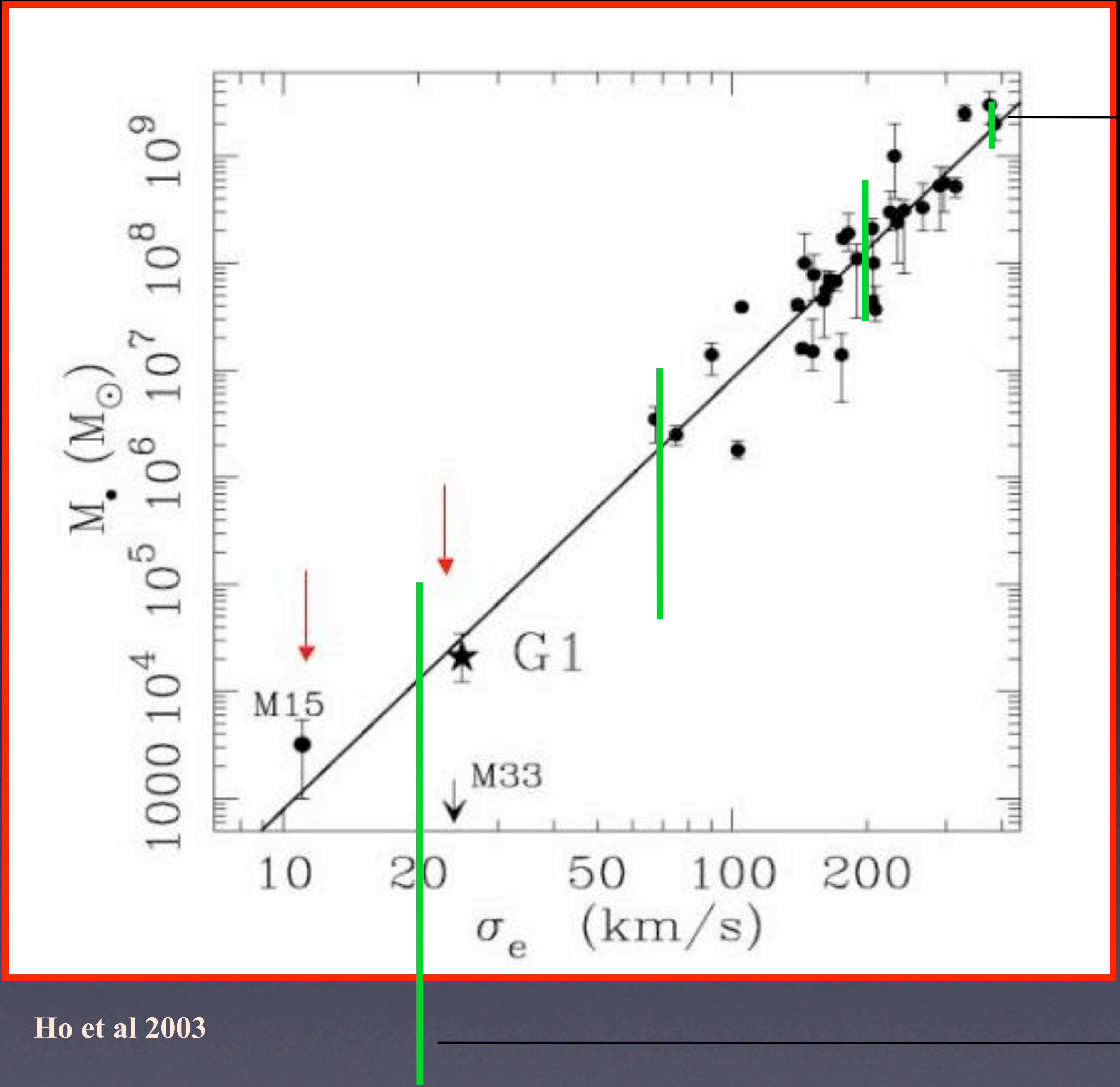
This means that about 100 low mass 'rogue' black holes in the halo. Unless they're accreting gas, they're invisible.

The real black hole mass function will depend on how few-body scattering and mass segregation act in tandem within a globular cluster.

More Kicks Consequences

- Supermassive black holes can have large offsets from the galaxy center
- Recoil may squelch or delay supermassive black hole growth
- Stellar mass black holes can be ejected from a cluster by recoil, too
- How do you retain seed black holes in protogalaxies?

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



Ho et al 2003

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

IMBHs have many formation/growth channels+ kicks efficient