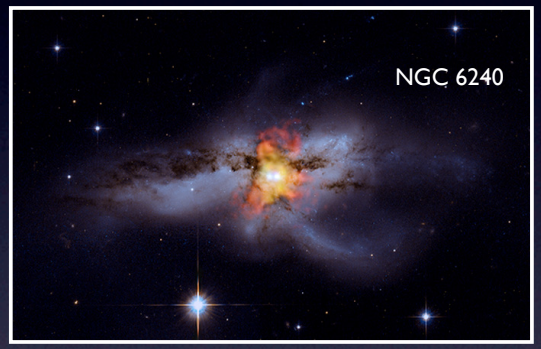
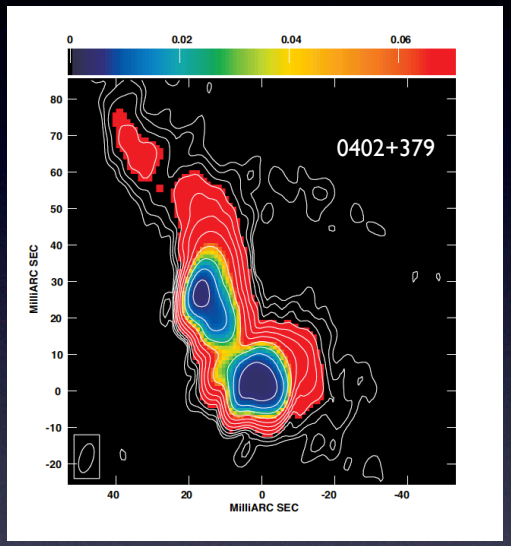
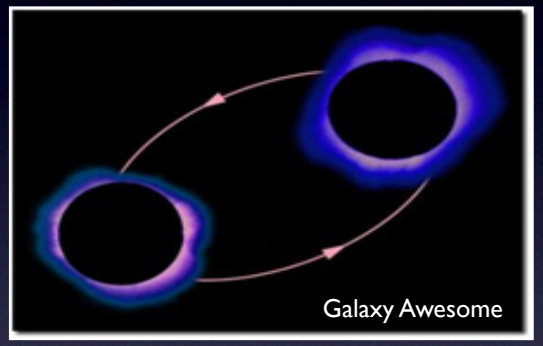
New Modes of Growing the Lightest Supermassive Black Holes







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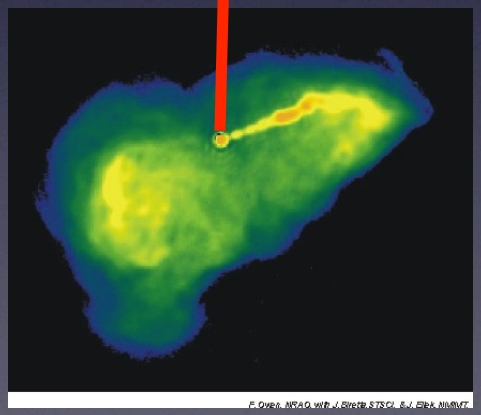
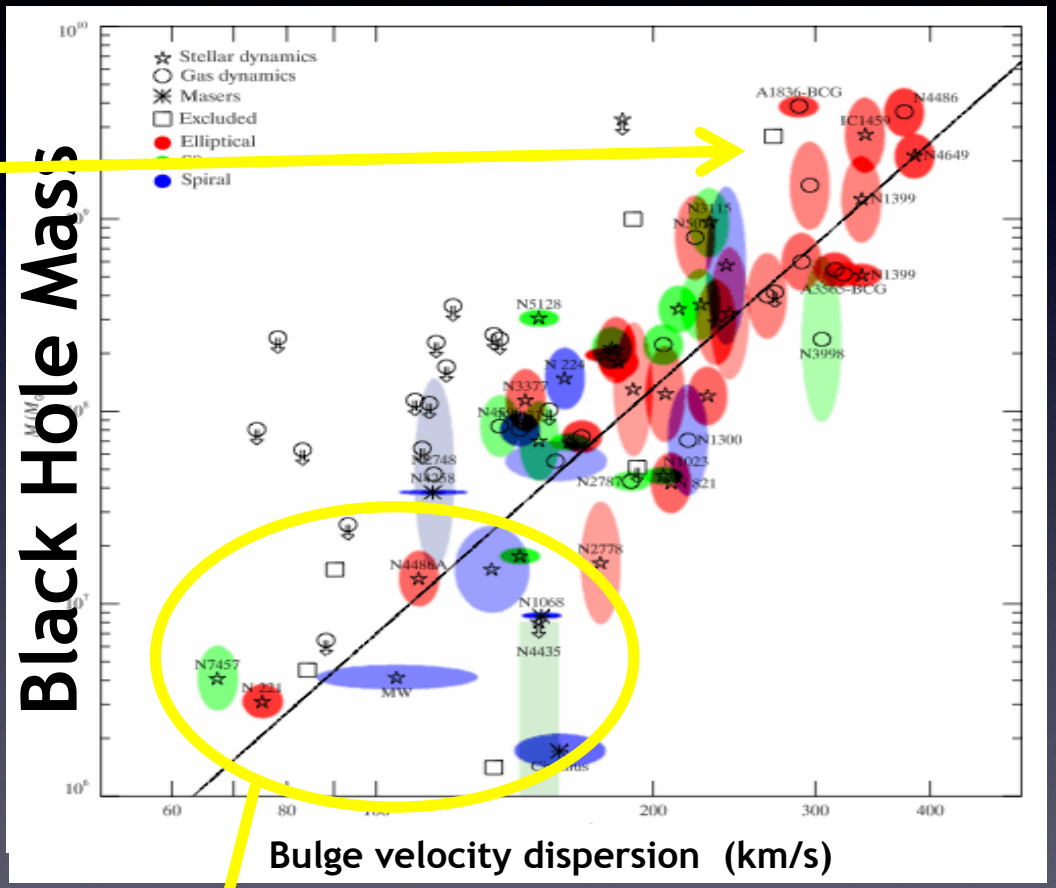
The Biggest Supermassive Black Holes



Rare!



Gultekin+ 09

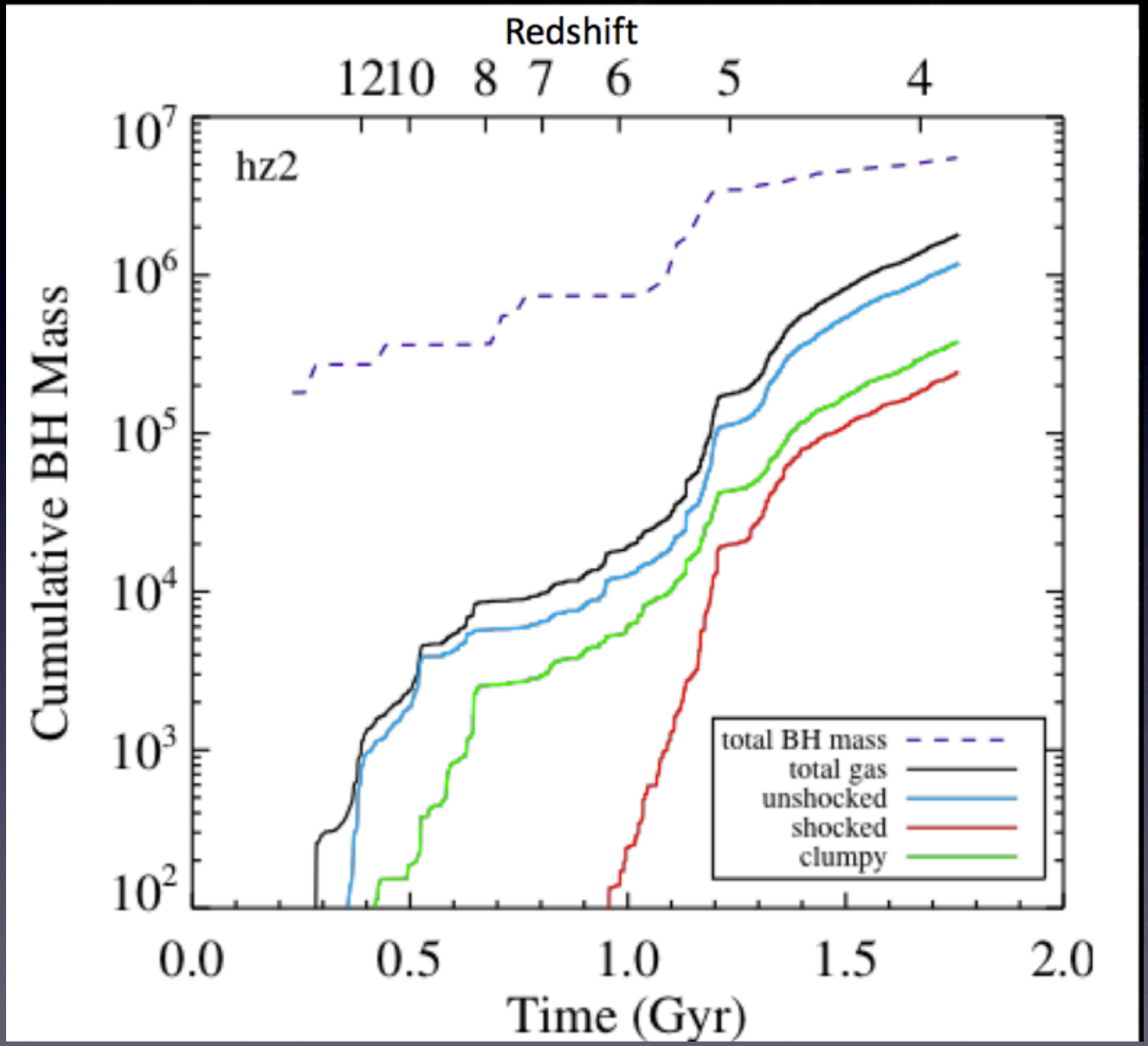
Common!

Hook #1 -- What type of gas fuels a light SMBH?

Bellovary et al. 2013

(MOVIE HERE)

Light SMBHs prefer a cold breakfast



This zoom-in hydro+nbody high resolution cosmo sim tells us:

Most of the early SMBH growth is not from gas...

...and the gas that does fuel the SMBH is not from mergers!

Hook #2: What if we cook up a MW SMBH only with mergers?

Micic, KHB + Sigurdsson 2011; KHB, Micic, Sigurdsson + Rubbo 2010; Micic, KHB + Sigurdsson 2008; Micic, KHB, Sigurdsson + Abel 2007

(movie here)

The broad approach: zoom-in collisionless n-body simulations to generate merger trees, and incorporate the gas physics semi-analytically

Recipe for growing the lightest supermassive black holes

Micic, KHB, Sigurdsson 2009

KHB, Micic, Sigurdsson+ Rubbo 2010

see Hirschmann et al; Tanaka et al

We use PopIII stellar remnants as our black hole seeds.

After halos merge, we merge the BHs after a dynamical friction timescale -- assume the final parsec is solved.

Our black holes grow by a combination of direct mergers and galaxy merger-driven gas accretion: e.g. Johansson et al 2009

$$M_{\rm acc} = M_{\rm BH,0}(e^{\frac{\alpha t_{\rm acc}}{t_{\rm sal}}} - 1),$$

$$\alpha = \left(\frac{M_{\rm s}}{M_{\rm p}} - \alpha_0\right),$$

We add gravitational wave recoil, too -- 10^6 realizations of possible spins and orientations

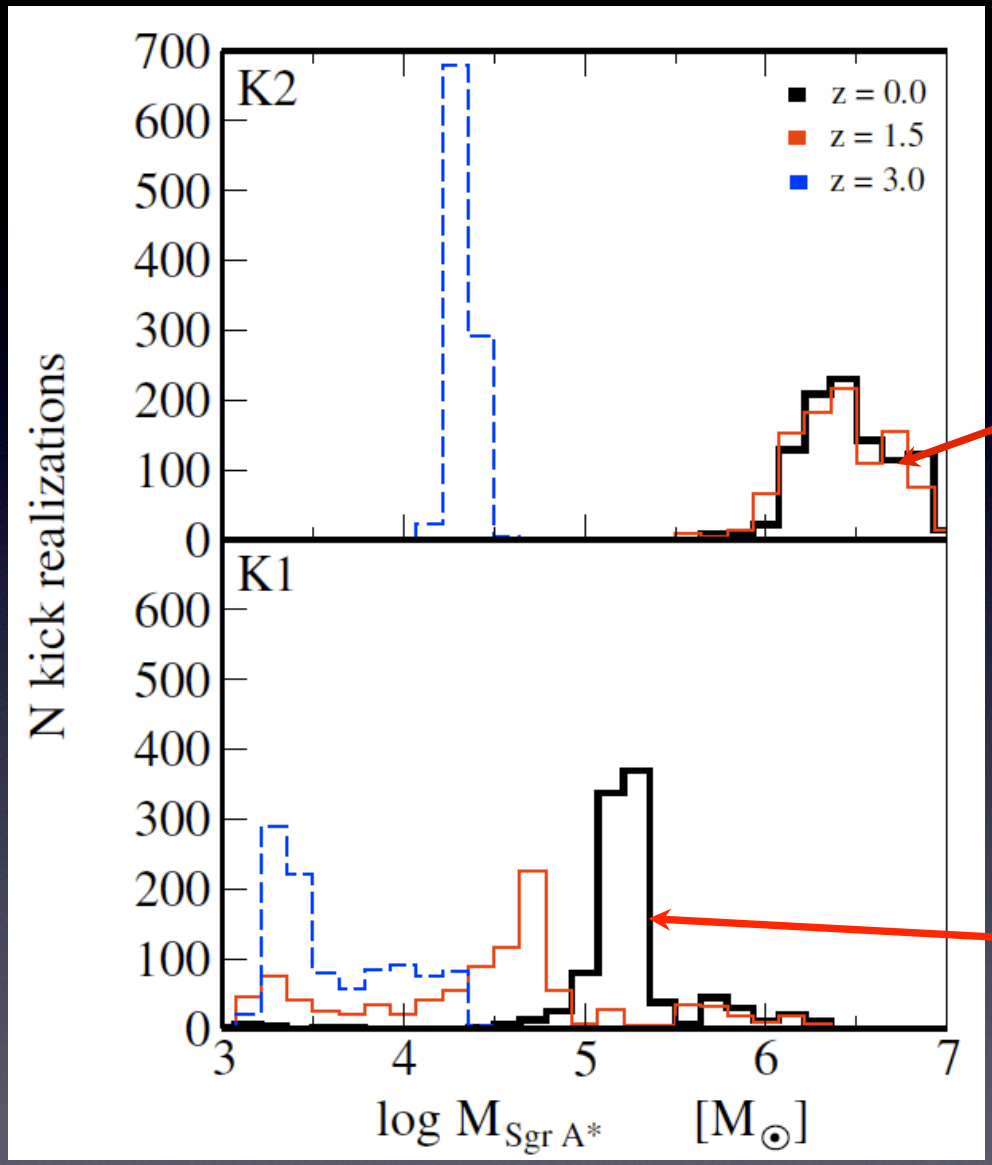
We found 3 classes of black holes:

Massive central

Slowly sinking

Ejected

Is SgrA* an oddball?



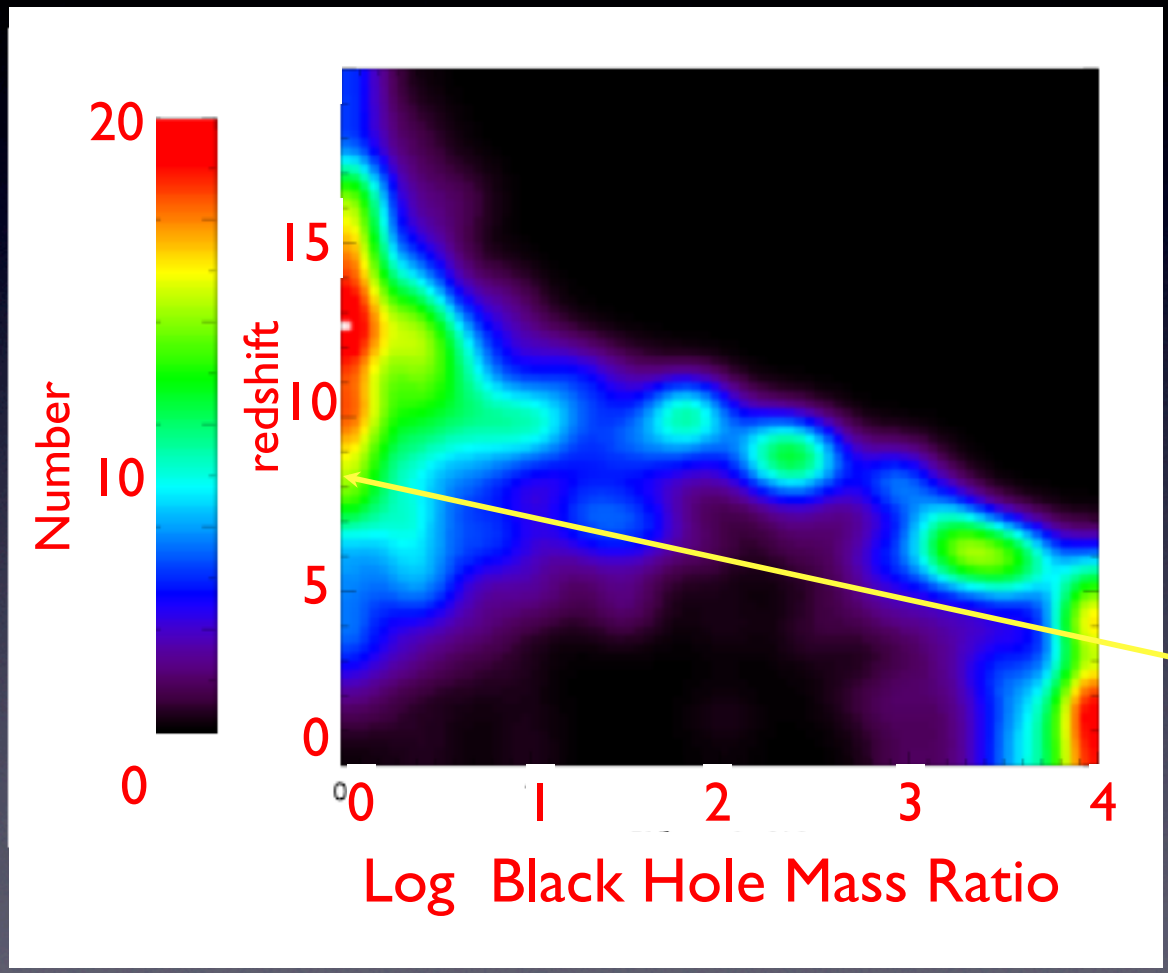
small kicks:
SgrA* is common

If kicks are large:
20% of halos form
proper SMBH

Massive central

Light SMBHs don't assemble from equal mass (or even nearly equal mass) mergers

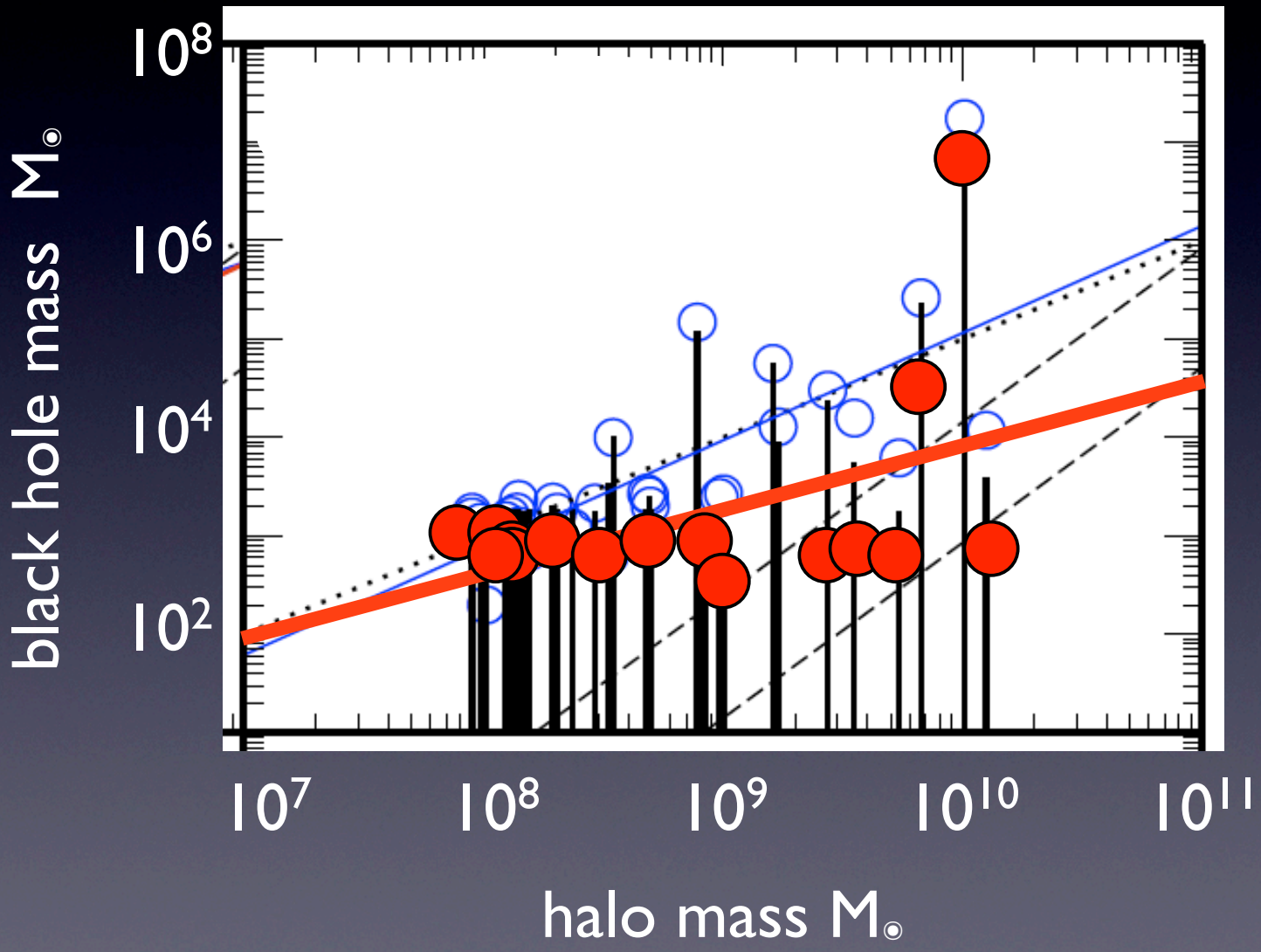
KHB et al. 2010



after the dark ages, there are few major mergers

Dwarf galaxies may also have central black holes

see also Micic, KHB 2007, Volonteri + Priya 2009, Peng 2010



Proof in the Pudding? Henize 2-10

Reines et al. 2011

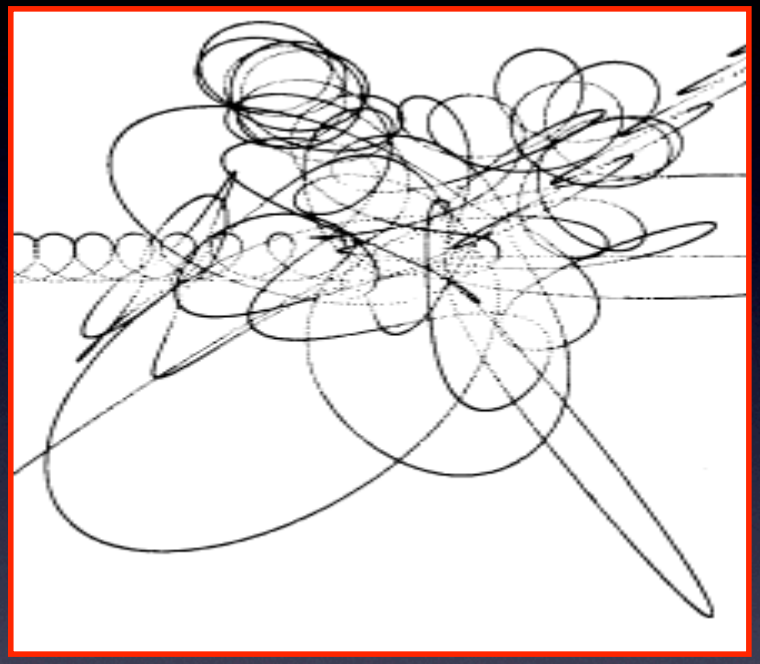
with a prescription built on the merger paradigm....

MW-like SMBHs in MW-like galaxies grow more from minor mergers than from major mergers.

Hook#3 for Dual AGN folks: The Final Parsec Problem is not a problem...

Binary black holes sink closer via 3-body scattering.

Quinlan 1997; Sesana et al 2006, 2007, 2008



$$a_h := \frac{G\mu_r}{4\sigma^2} \sim \frac{1}{4}\frac{q}{(1+q)^2} r_h,$$

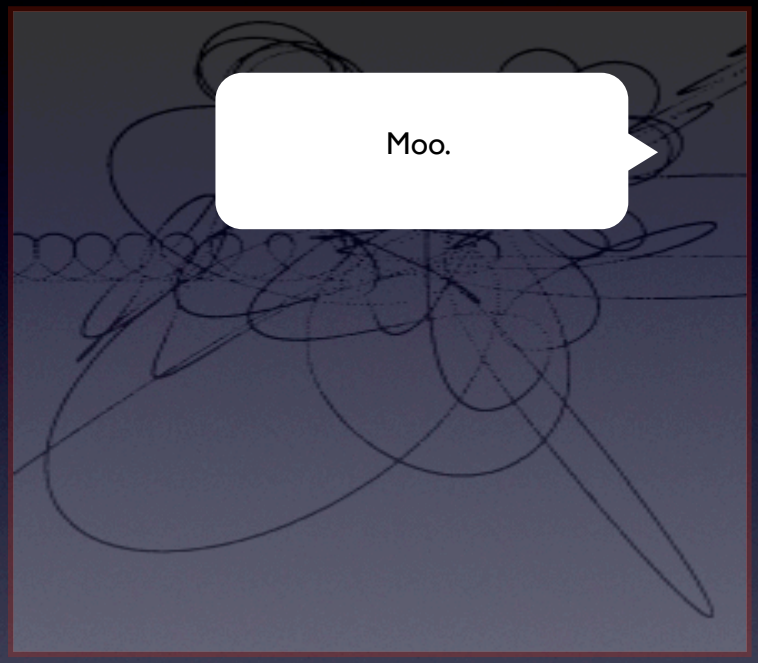
O(10) pc

> $O(10^{10})$ yr!**

**in a static, gas-free, spherical galaxy with permanent ejections and no resonances

The final parsec problem -- refilling a spherical loss cone takes > t_{Hub}

Quinlan 1997; Sesana et al 2006, 2007, 2008



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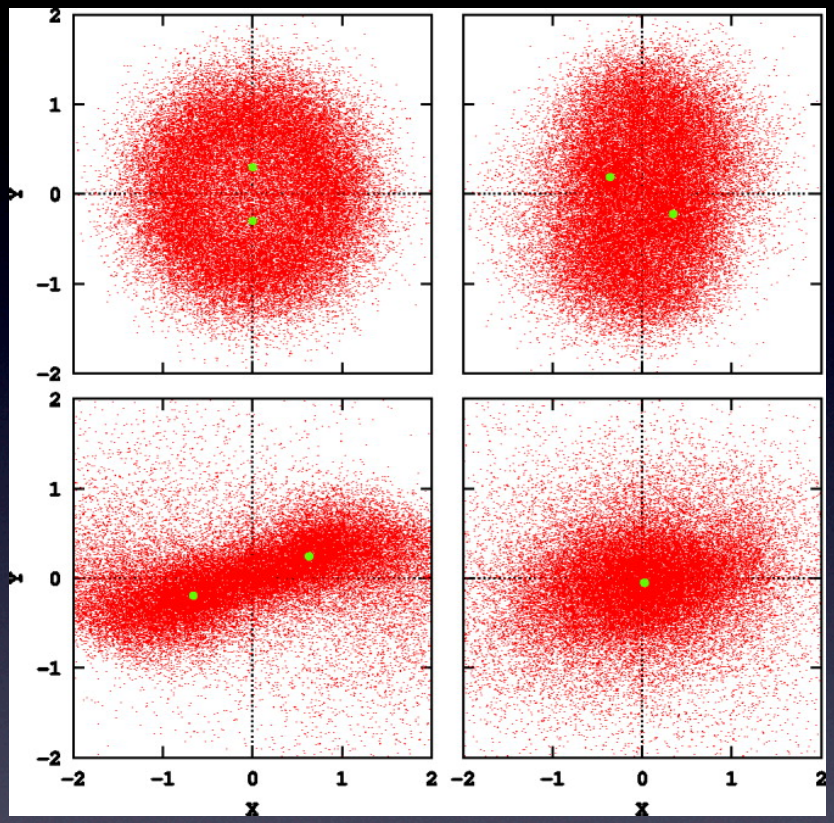
O(10) pc

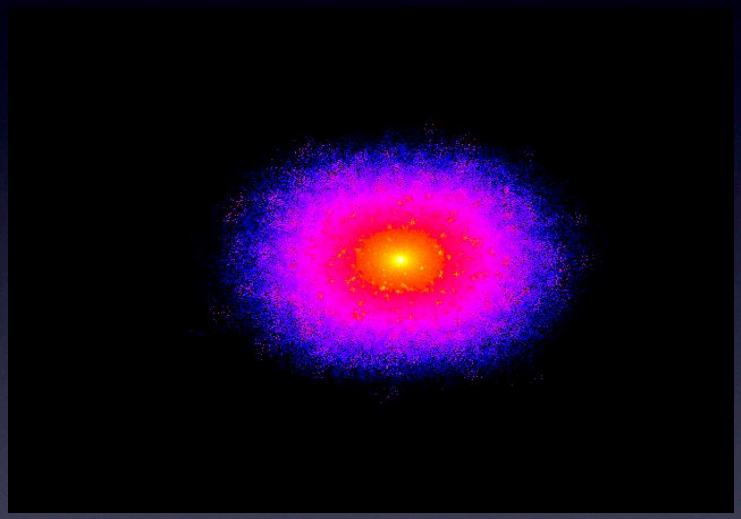
> $O(10^{10})$ yr!**

**in a static spherical galaxy with permanent ejections and no resonances

Final Parsec Problem? Not a problem for a non-spherical galaxy!



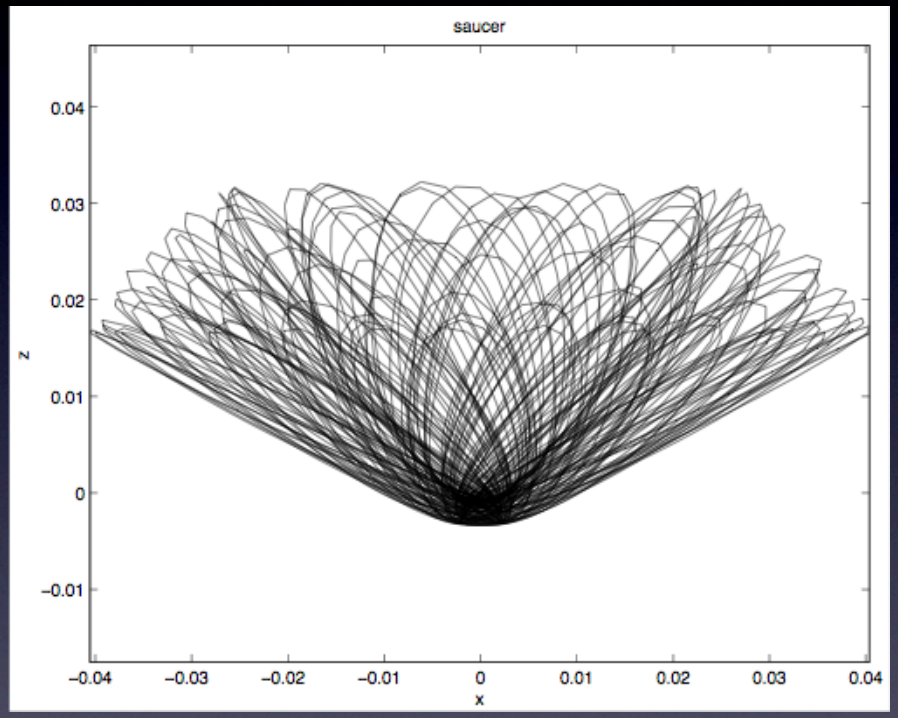
Berczik et al. 2006

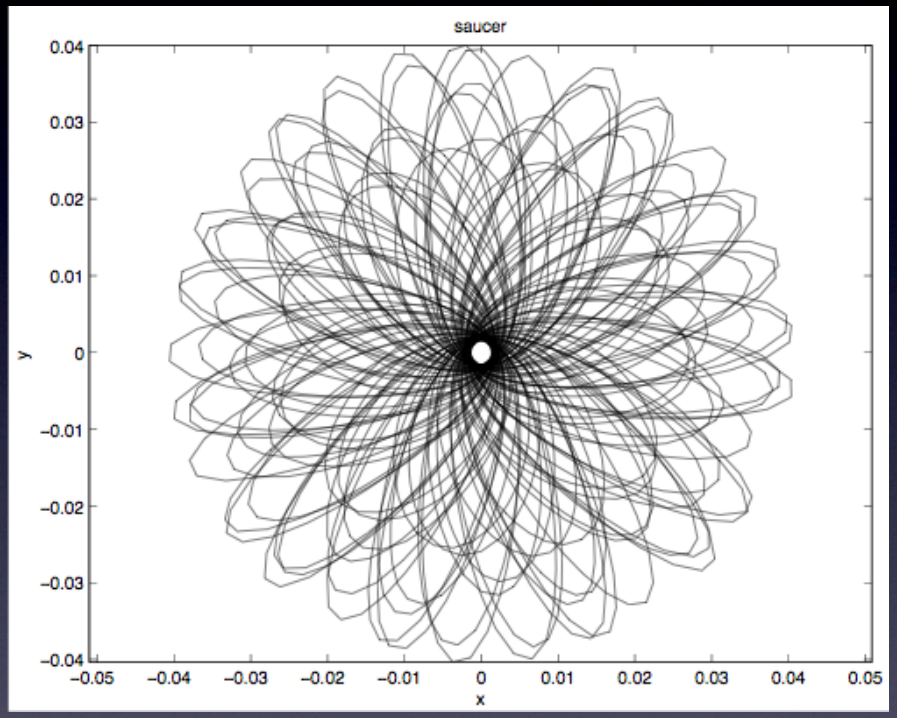


KHB+Sigurdsson 2006
Khan+KHB 2013

Expect 10^8 $M_\odot$ Binary BHs to take less than 3 Gyr to coalesce in an equilibrium axisymmetric galaxy

Axisymmetric galaxies have low angular momentum orbits that overfill the loss cone





Li, KHB+Khan in prep

~60% of the stars within the inner 100 pc are saucers

There are lots of ways to plunge through the final parsec:

Gas

Non-equilibrium models: rotation, bar unstable, post merger

Extra precession: Post-newtonian and resonant relaxation

Triaxiality

axisymmetry

Kozai -- high eccentricity

3rd black hole

Recap: it's time to consider deviations from the major merger paradigm

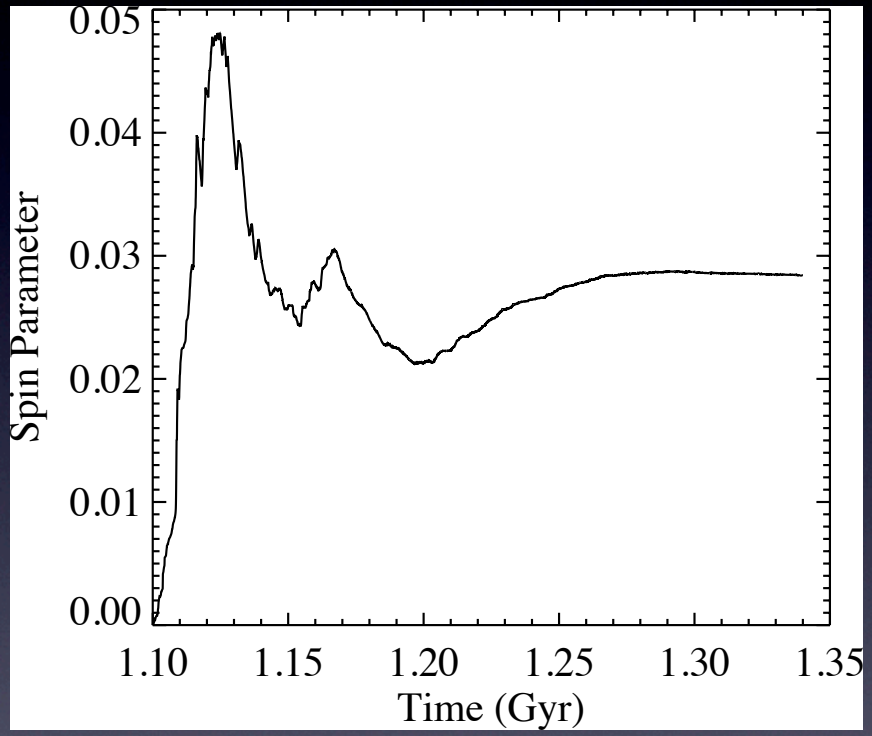
- Most gas fueling may be cold (at least at high redshift/low halo mass).

- The lightest supermassive black holes assemble more from minor mergers than major ones.

Jillian's next step: spin in cosmo simulations

- On-the-fly 3D spin tracking
- Aid in GW predictions

WORK IN PROGRESS



Come chat with me about:

BH Accretion and spin!

(Jillian)

The M-σ relation!

The final parsec problem!

(Kelly HB) Hypervelocity stars!

Galaxy Flybys as AGN Triggers!

2LPT vs ZA and seed BHs!

and much, much more!

For more information:

P.S. Please cite generously!

Khan, KHB, et al 2013

Bellovary et al. 2013, 2014

Sinha + HB 2012

HB, Wise + Sinha 2012

Palladino, Schlesinger, HB, Allende Prieto, Beers, Lee, Schneider 2013

Lang, HB, Bogdanovic, Sesana, Amaro-Seoane, Sinha, 2013

Micic, HB + Sigurdsson 2011

HB, Micic, Sigurdsson + Rubbo 2010

Micic, HB + Sigurdsson 2008

Micic, HB, Sigurdsson + Abel 2007