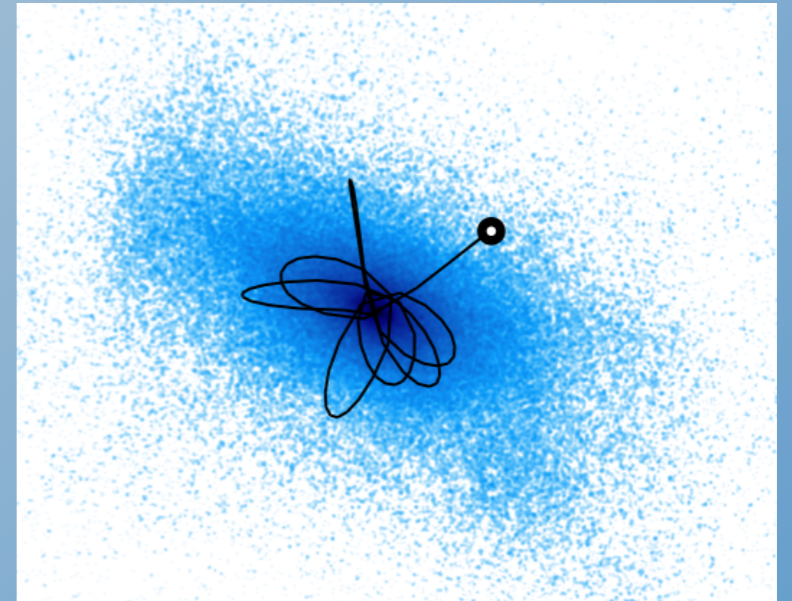# The Observability of
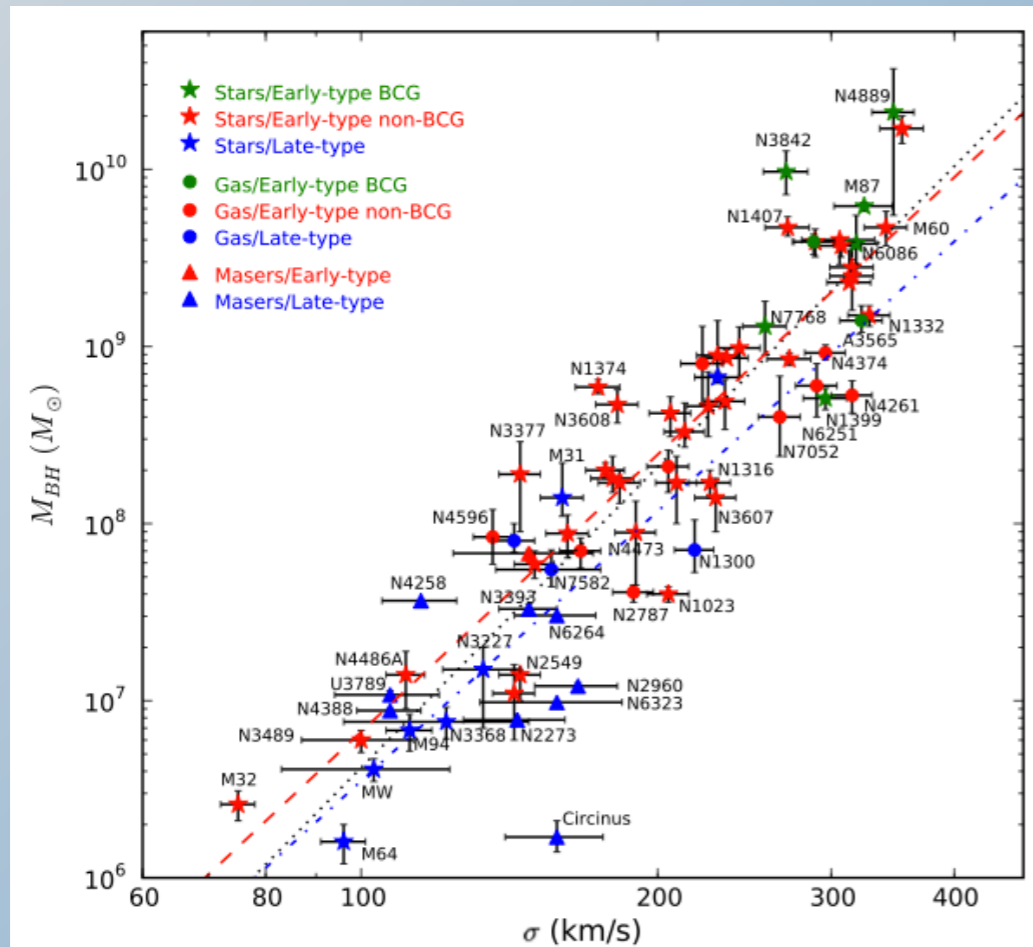# Recoiling Black Holes
as Offset Quasars
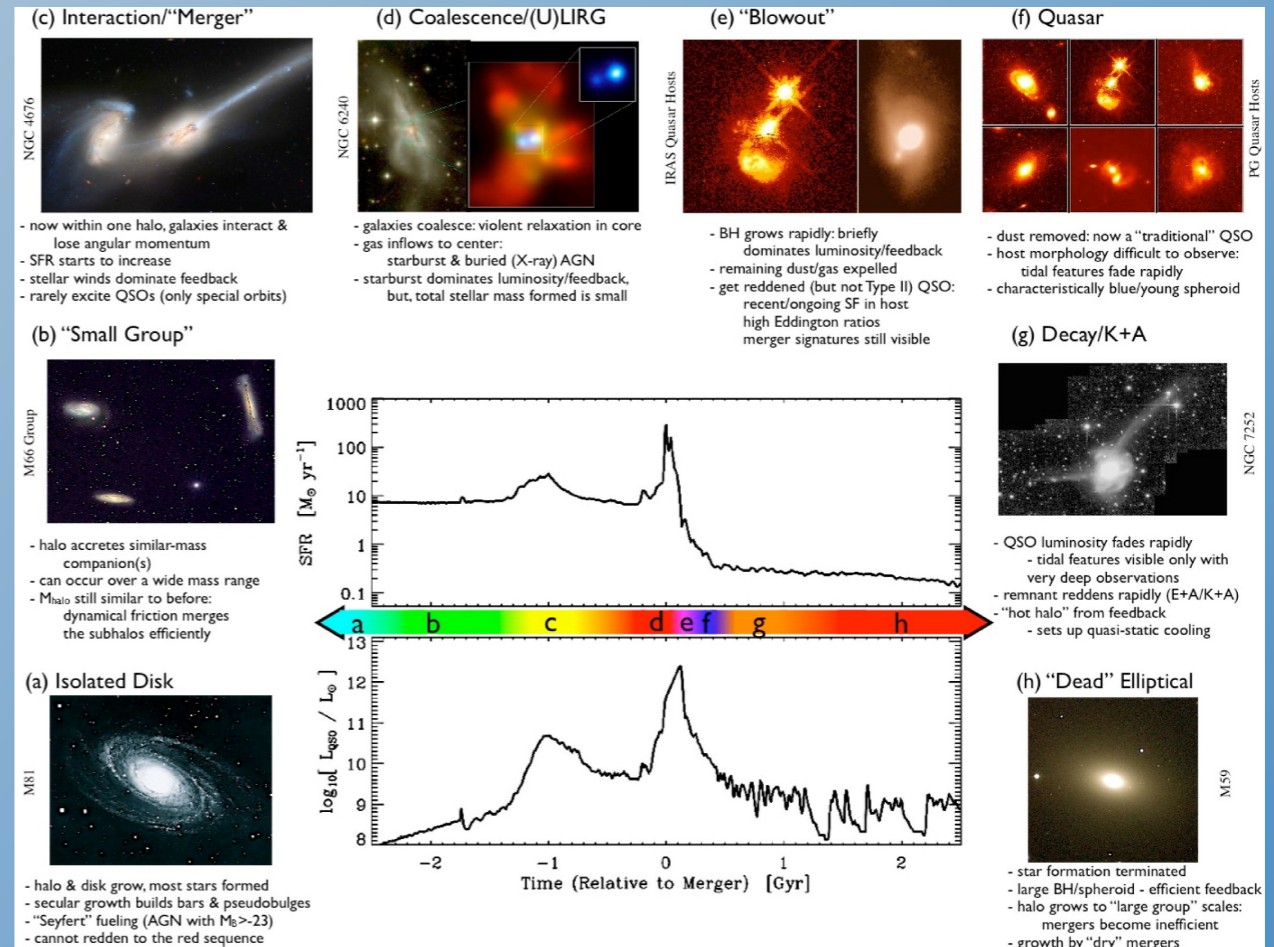

Civano et al. 2010

Laura Blecha
Einstein and JSI Fellow
University of Maryland

Einstein Fellows Symposium
Center for Astrophysics
October 28-29, 2014

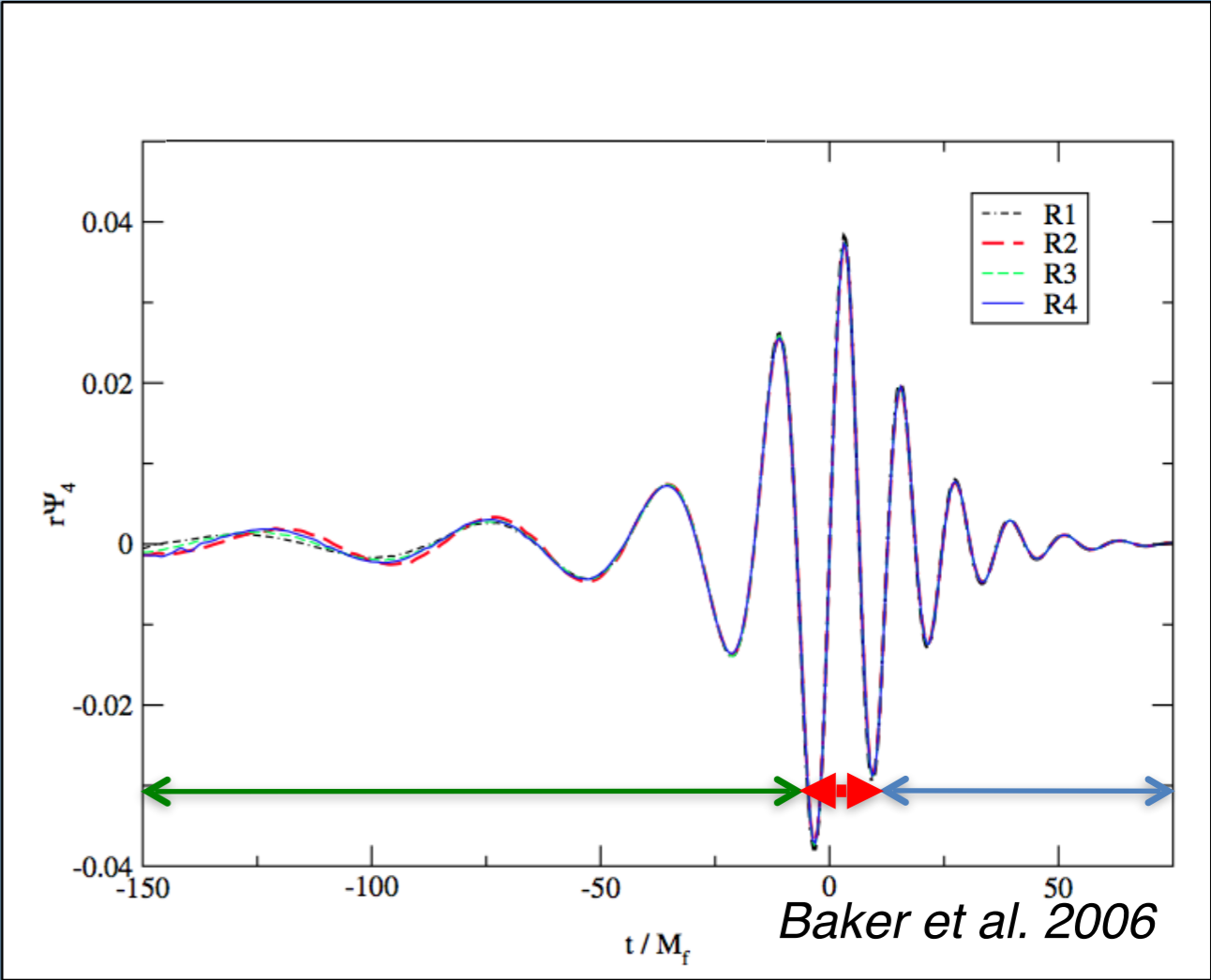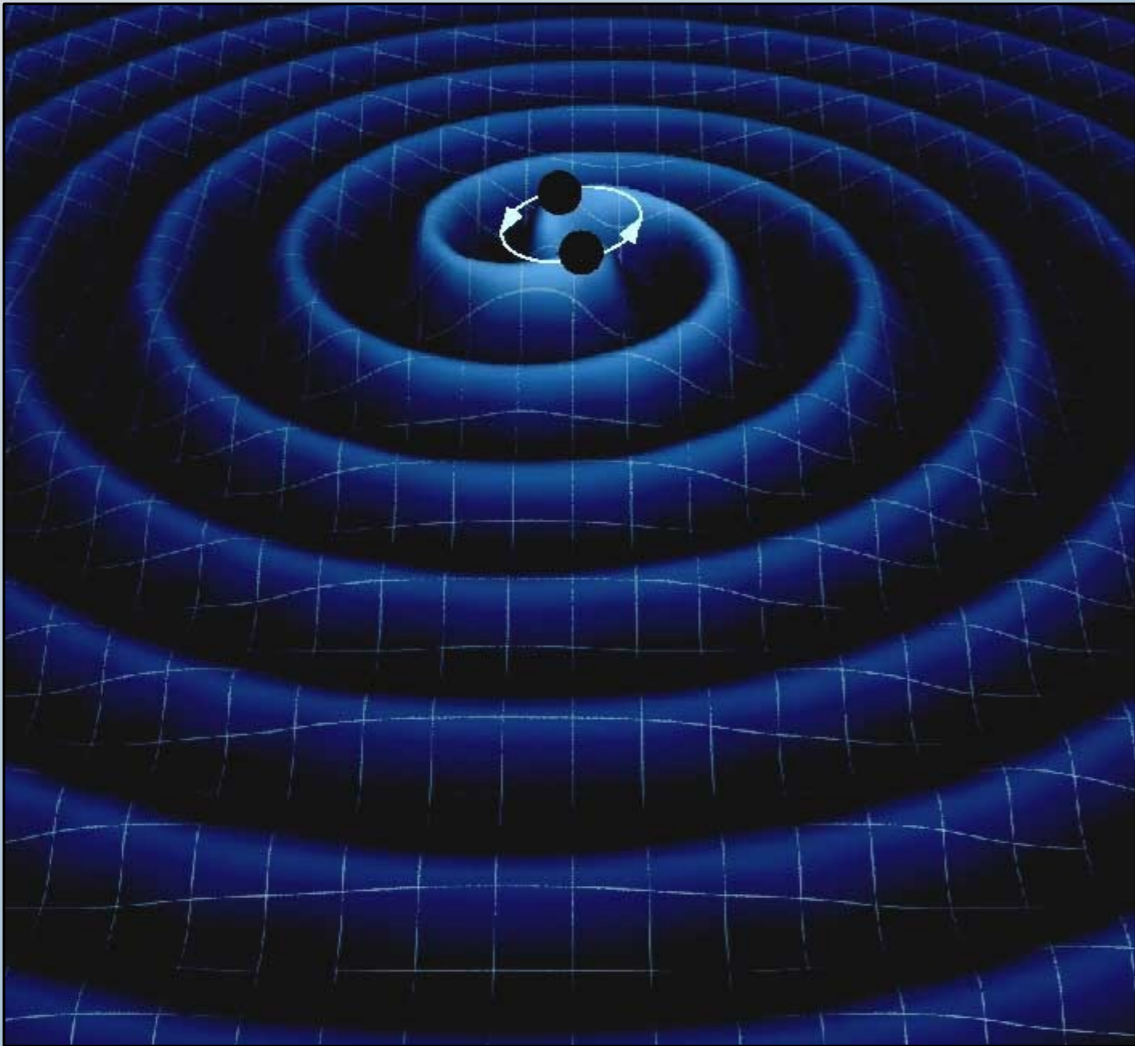# SMBH/galaxy co-evolution:
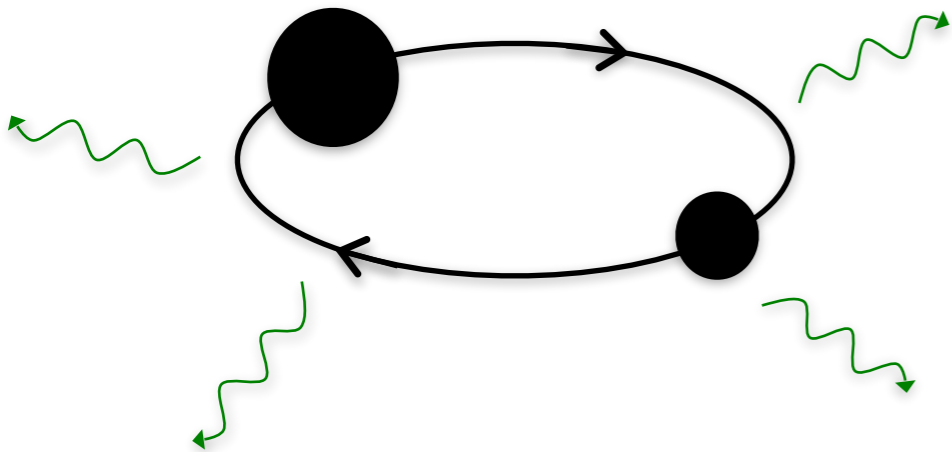## the merger-driven paradigm

McConnell & Ma 2013

Hopkins et al. 2008

- Simultaneous growth of galaxy bulges and SMBHs

- (Self-)regulation of growth via stellar and AGN *feedback*

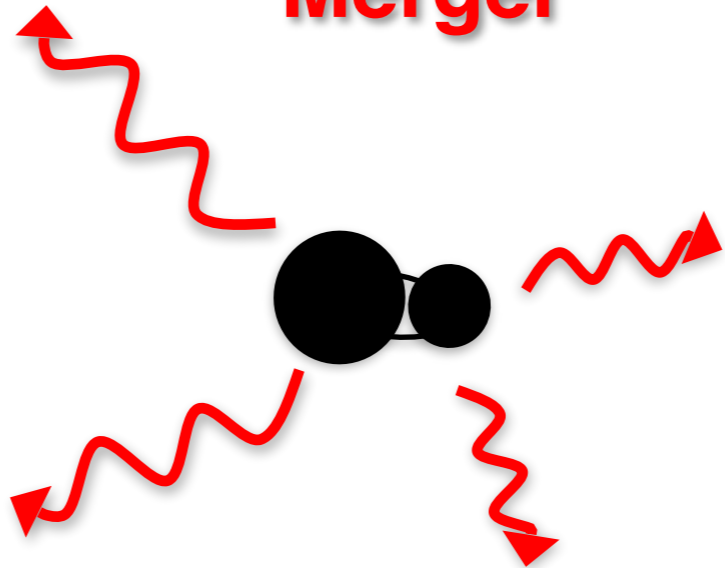- Formation of *SMBH pairs,* and possibly *SMBH mergers and recoils*
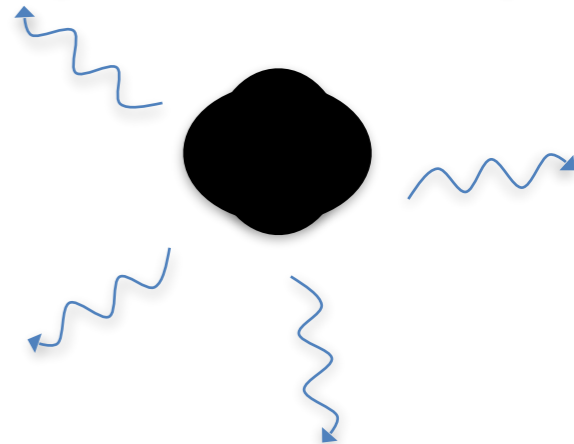
Gravitational Waves from SMBH Mergers

Baker et al. 2006

Inspiral

Merger

Ringdown (and recoil!)

Recoiling BH simulation movie available at:
http://www.astro.umd.edu/~lblecha/UMD/Misc.html

Gravitational-Wave (GW) Recoil

- GW beaming imparts a "kick" to the merged BH

- Max kick is ~ **5000 km/s!** [1,2]

- For randomly-oriented, high spins, **34% of kicks are > 500 km/s** [3]

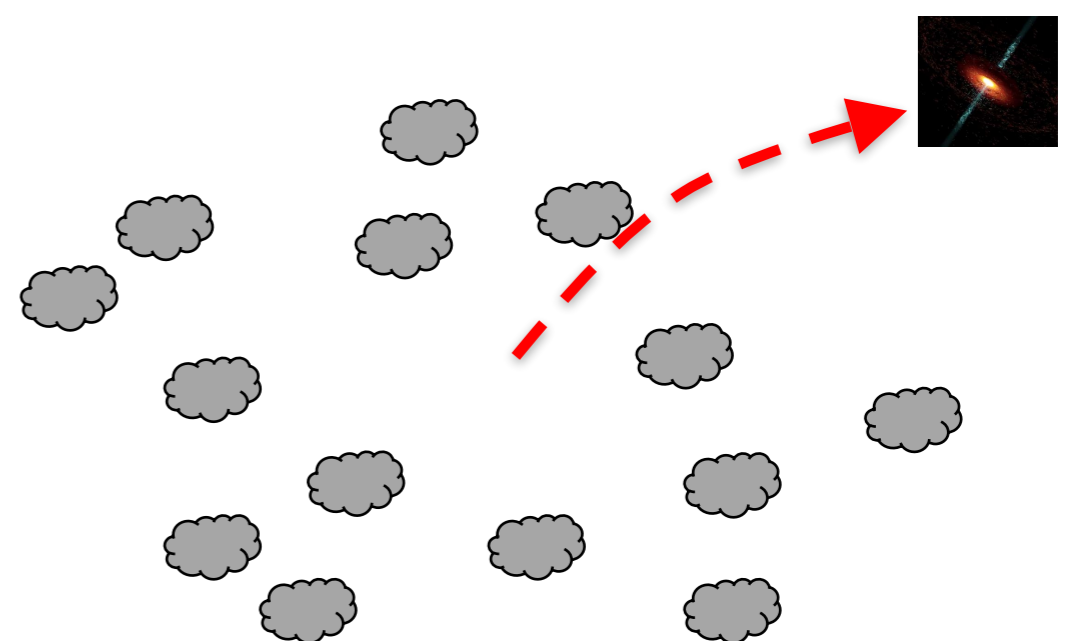- Kicks are lower if **spin alignment** occurs prior to merger (more on this later…) [4-7]

1) Campanelli et al. 2007, 2) Lousto et al 2012, 3) Lousto et al. 2013, 4) Bogdanovic et al 2007, 5) Dotti et al. 2009, 2012, 6) Kesden et al. 2010, 7) Miller & Krolik 2013
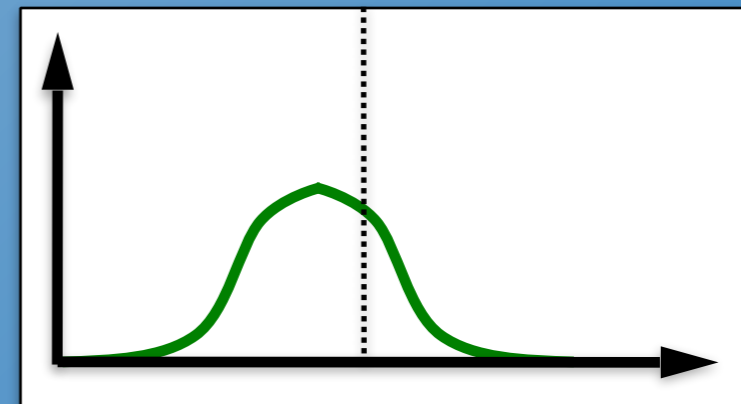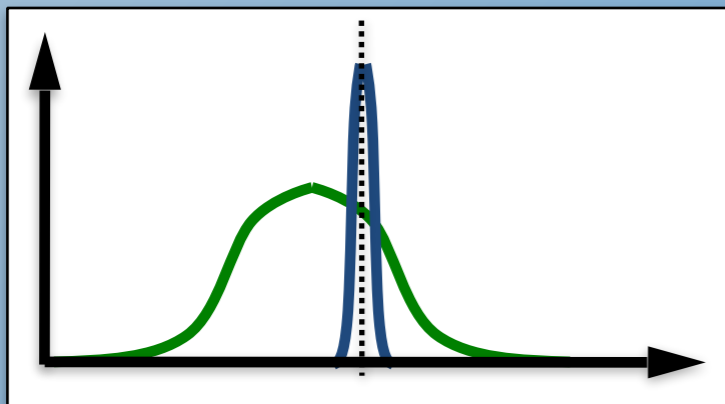

Wiseman 1992

$m_1 > m_2$
$|v_1| < |v_2|$
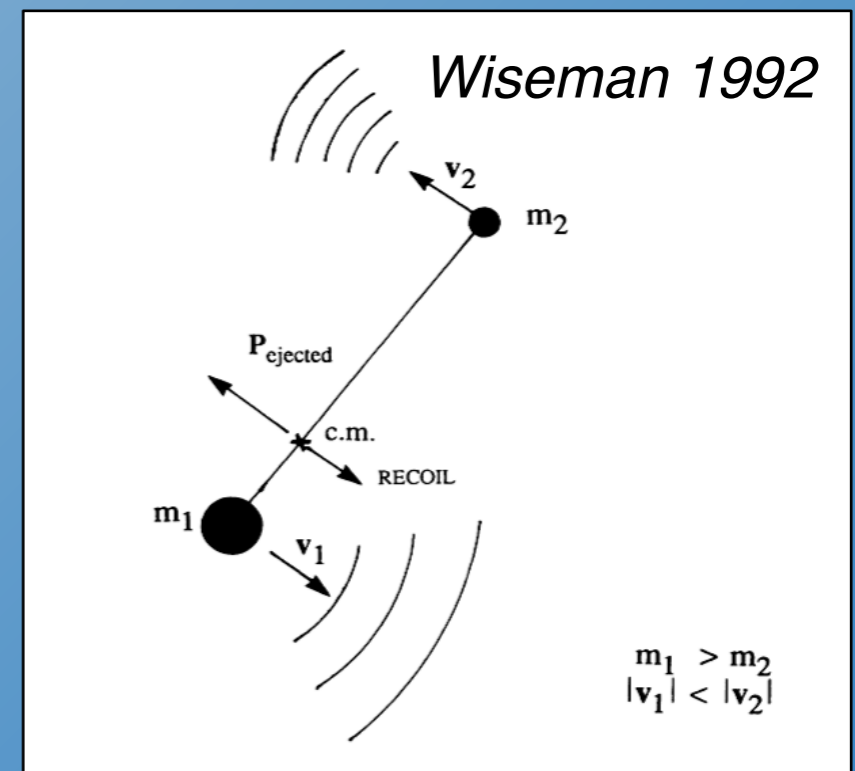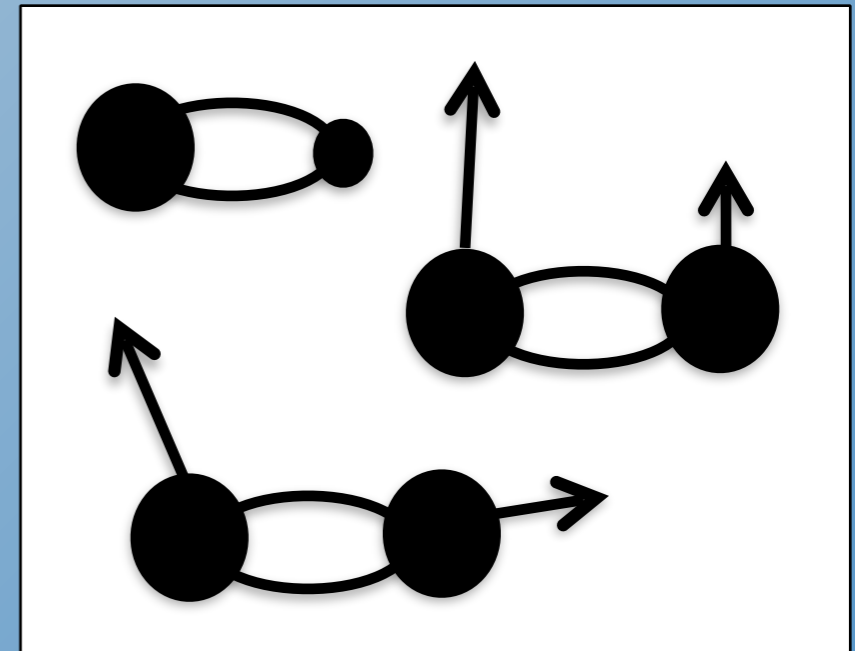
Signatures of recoiling AGN
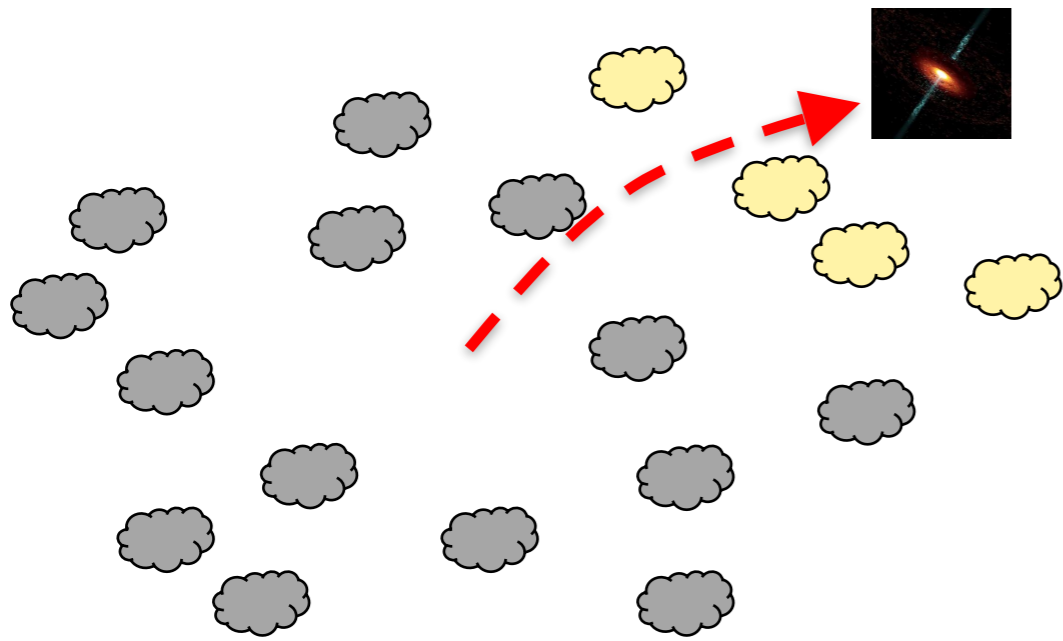
Kinematic offset between BLs and NLs (+ spatial offset)

Kinematically-offset BLs, with no NLR (+ spatial offset)
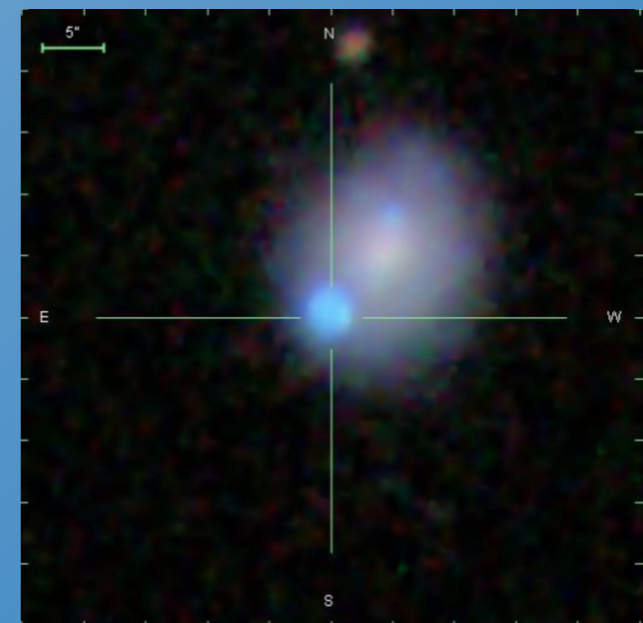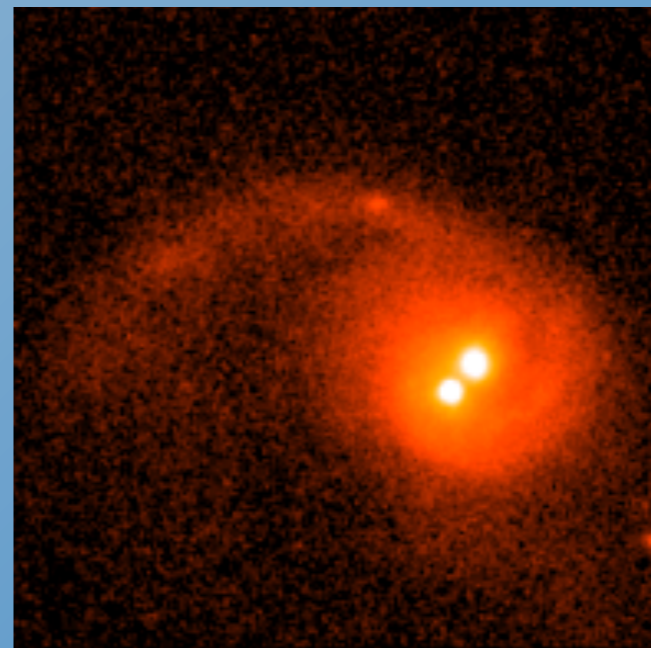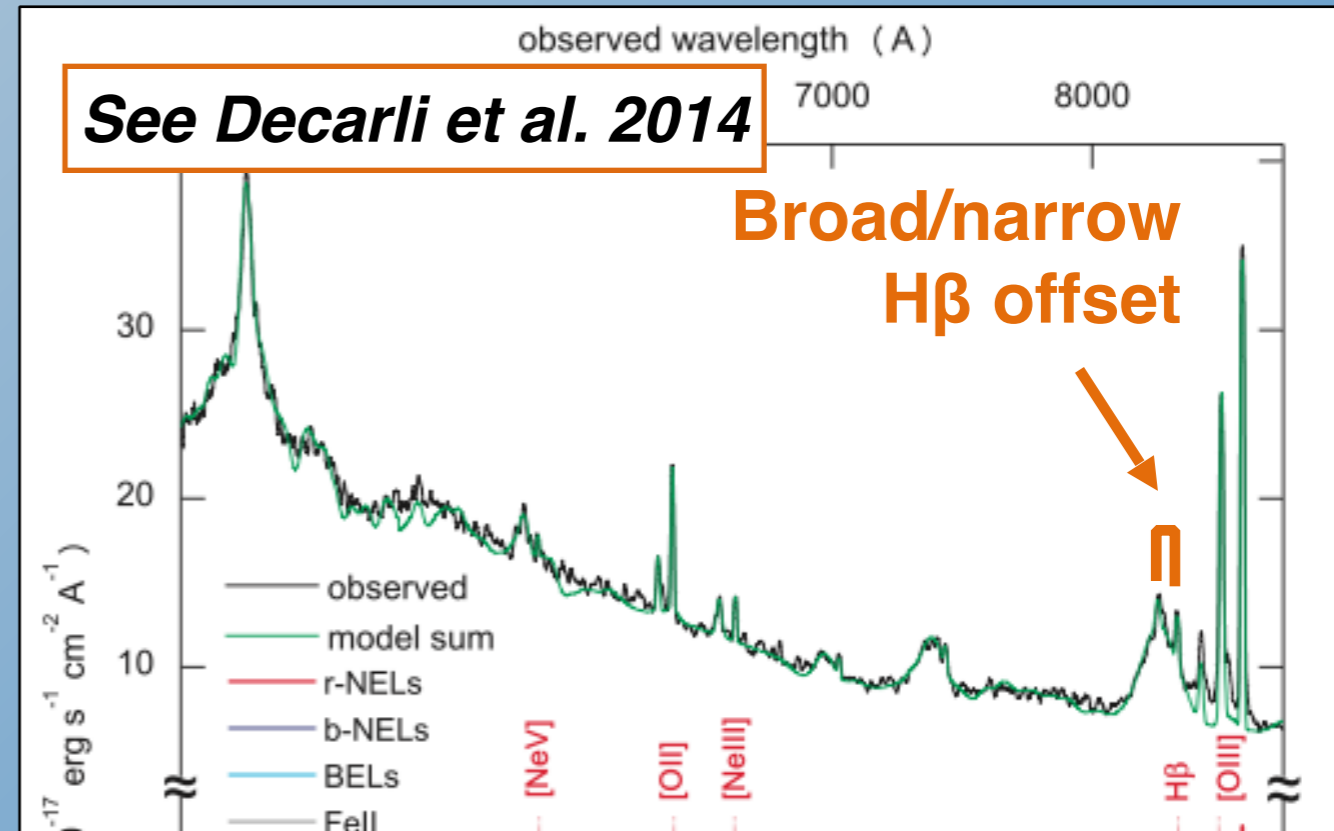
Recoiling AGN candidates

Kinematic offsets

see Komossa et al. 2008; Shields et al. 2009; Robinson et al. 2010

Spatial offsets

*see Batcheldor et al. 2010; Jonker et al. 2010; **Koss, LB et al. 2014***

Kinematic *and* spatial offsets

see Civano et al. 2010, 12, Blecha et al. 2013


See Decarli et al. 2014

Broad/narrow Hβ offset

Recoiling AGN: Open Questions

- *How many recoiling AGN do we expect to be observable (as a function of L, Mbh, z, etc.)?*

- *What are the most likely **host galaxies** of observable, offset AGN?*

- *How can we best design a **systematic** search for offset AGN?*

- *How do the answers depend on the **BH spin distribution**? Can we learn something about BH spins from observations of offset AGN?*
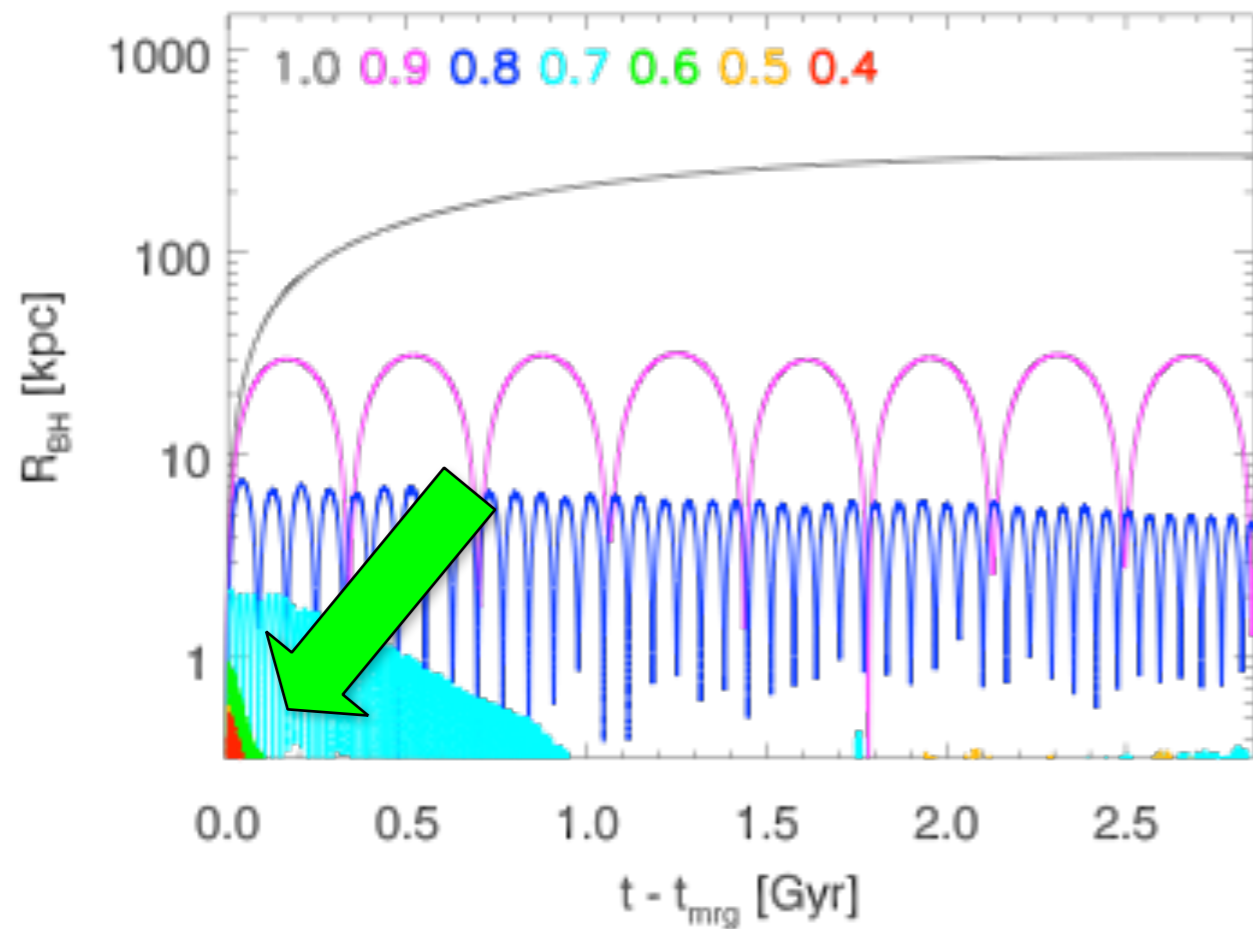
Recoiling AGN source counts
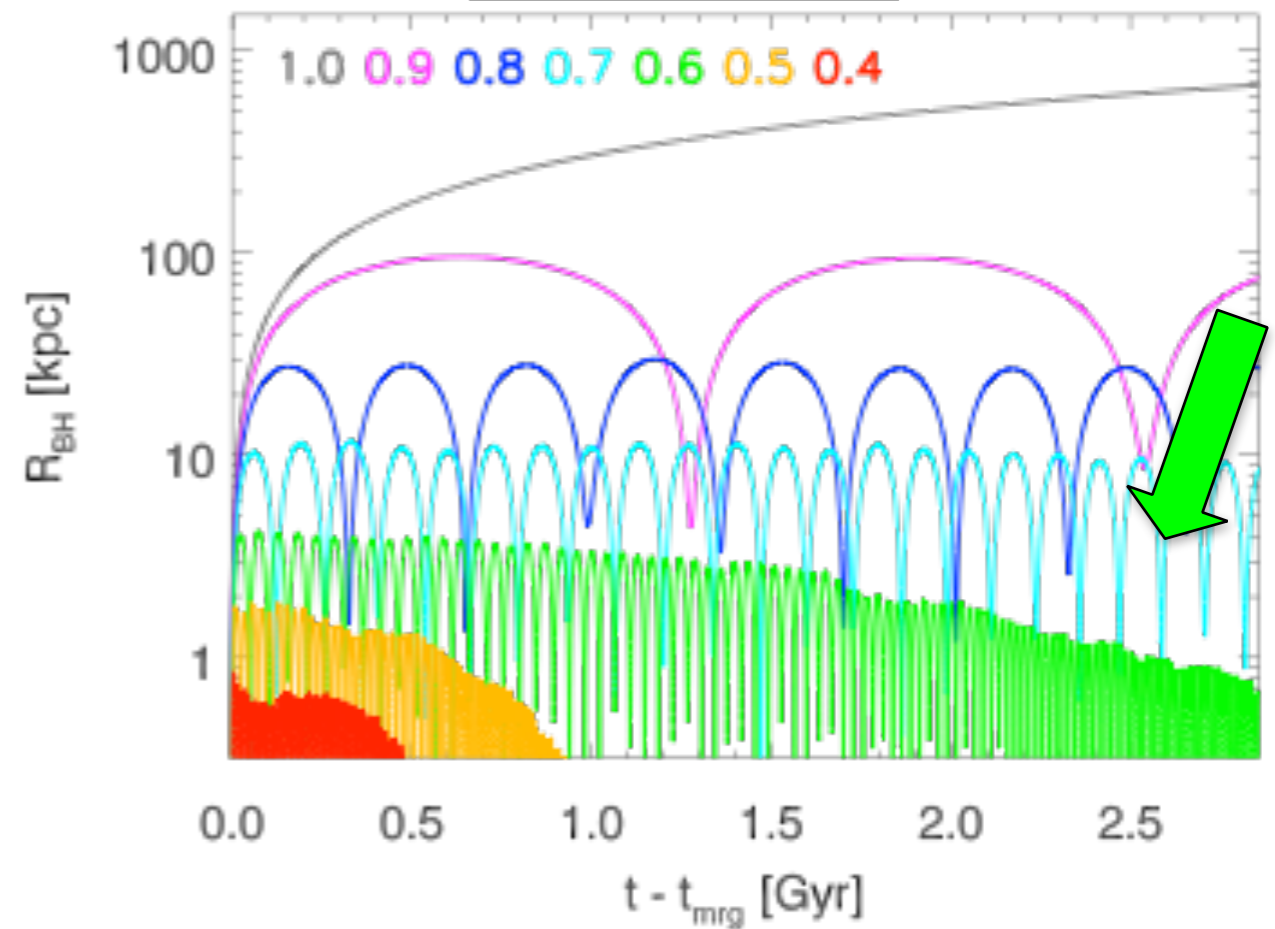## from semi-analytic modeling

Volonteri & Madau 2008
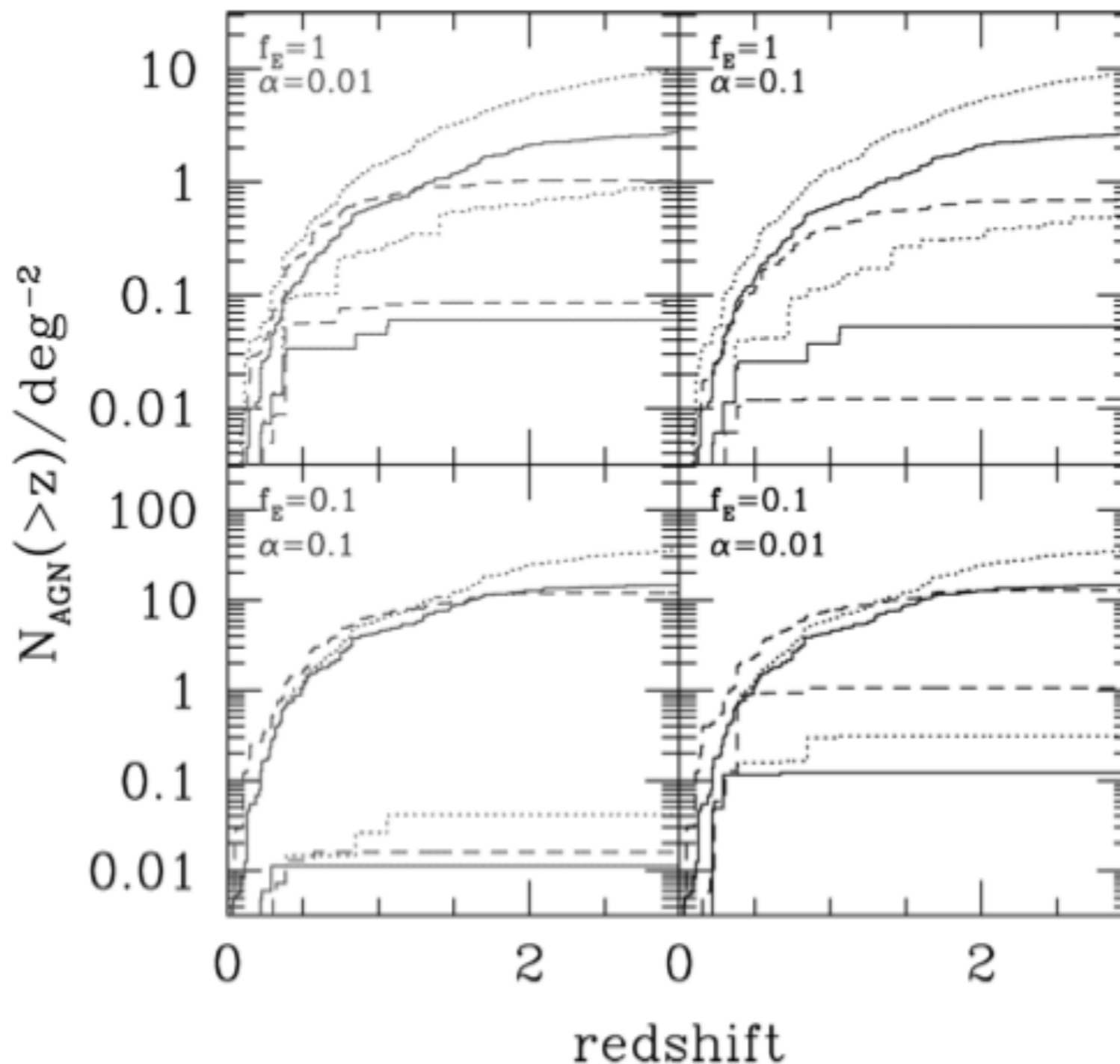
Recoiling BH dynamics:
## *hydro effects matter!*

60% gas

10% gas

Blecha et al. 2011

BH spin alignment

- Recoil kick velocities depend **strongly** on progenitor BH spin vectors

- Spins may be efficiently **aligned** prior to merger via torques from a **circumbinary gas disk** *(Bogdanovic et al. 2008, Dotti et al. 2009, 2012, Miller & Krolik 2013)*

- Maximum possible recoil kick is **~ 5000 km/s**

- Maximum kick with perfectly aligned spins is **< 200 km/s!**

Roedig et al 2012
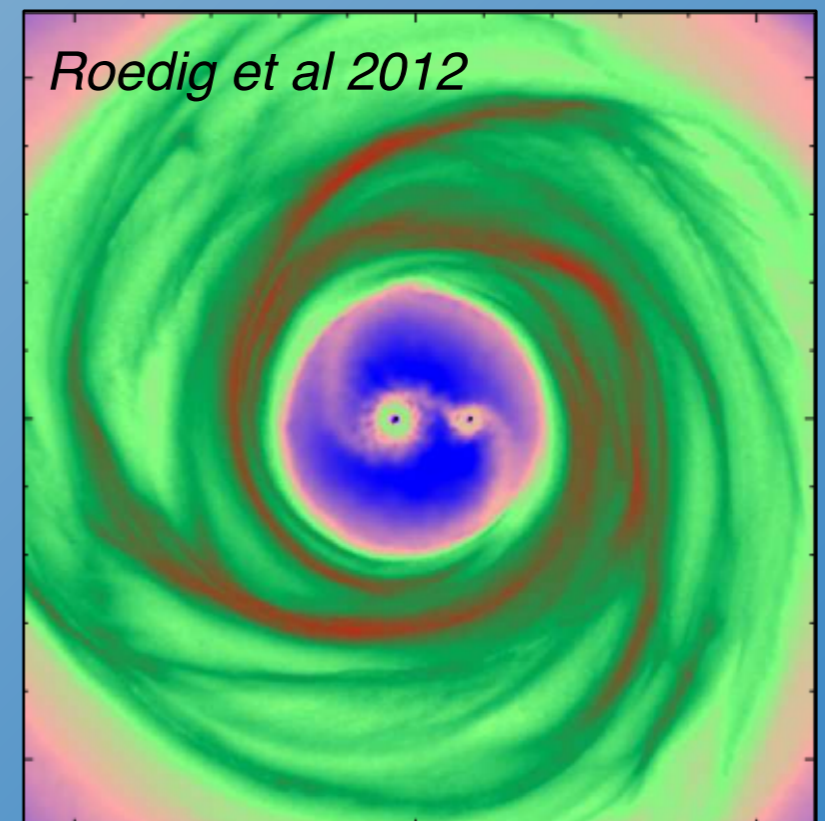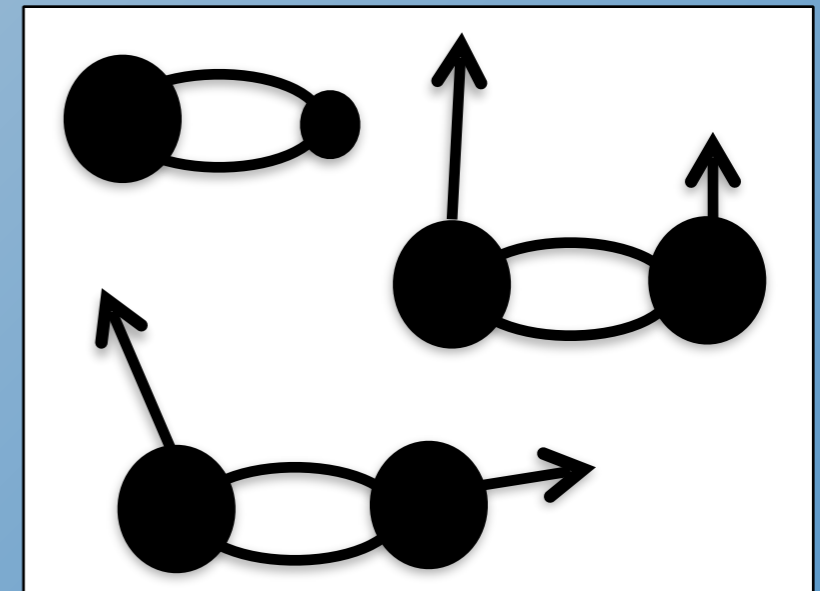
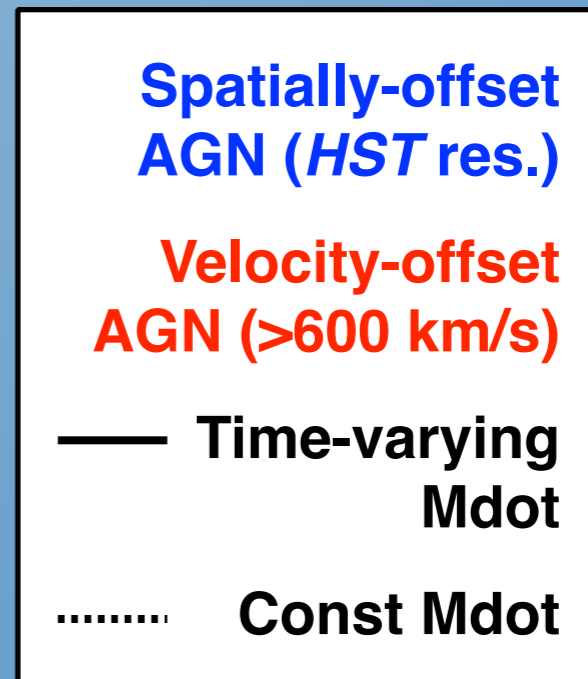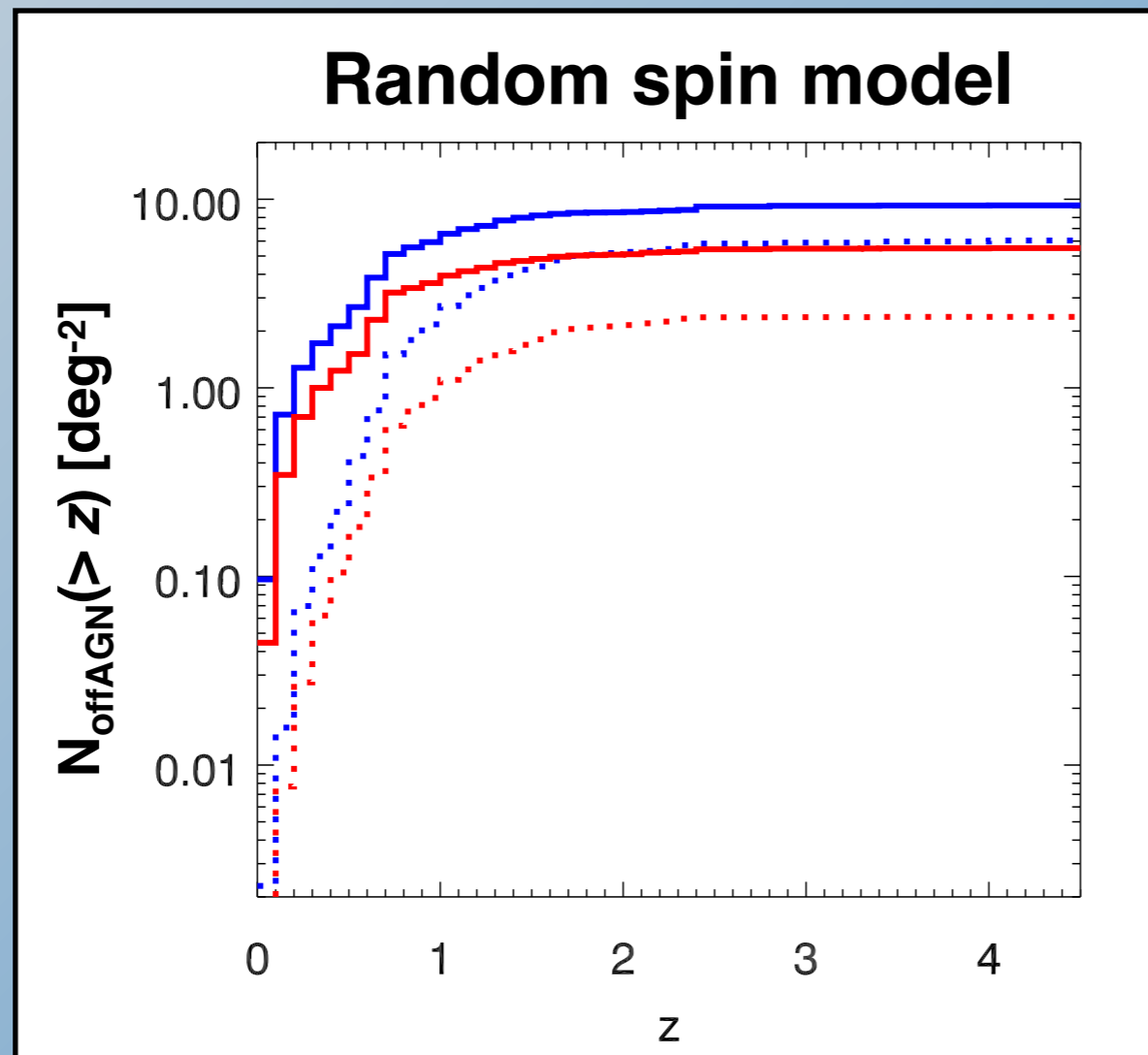# The Illustris Project:
cosmology with moving-mesh hydrodynamics

- ~ 100 Mpc^3 volume

- 2 x 1820^3 resolution elements

- Hydrodynamics are solved on an unstructured, moving mesh

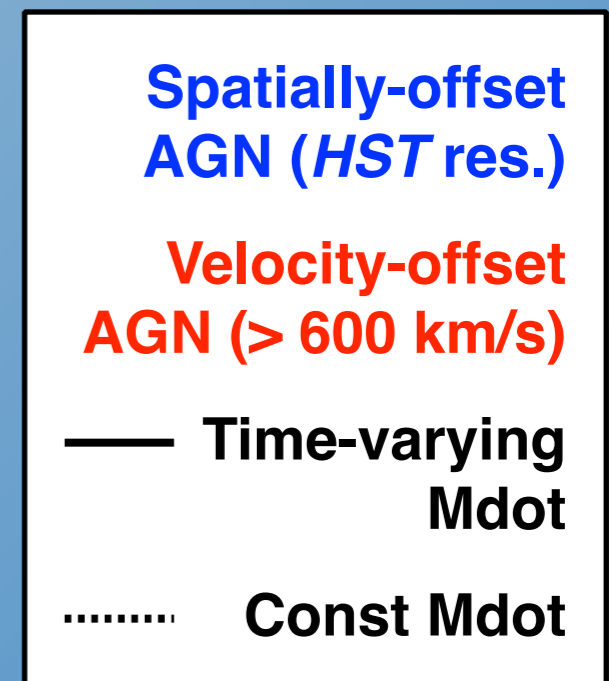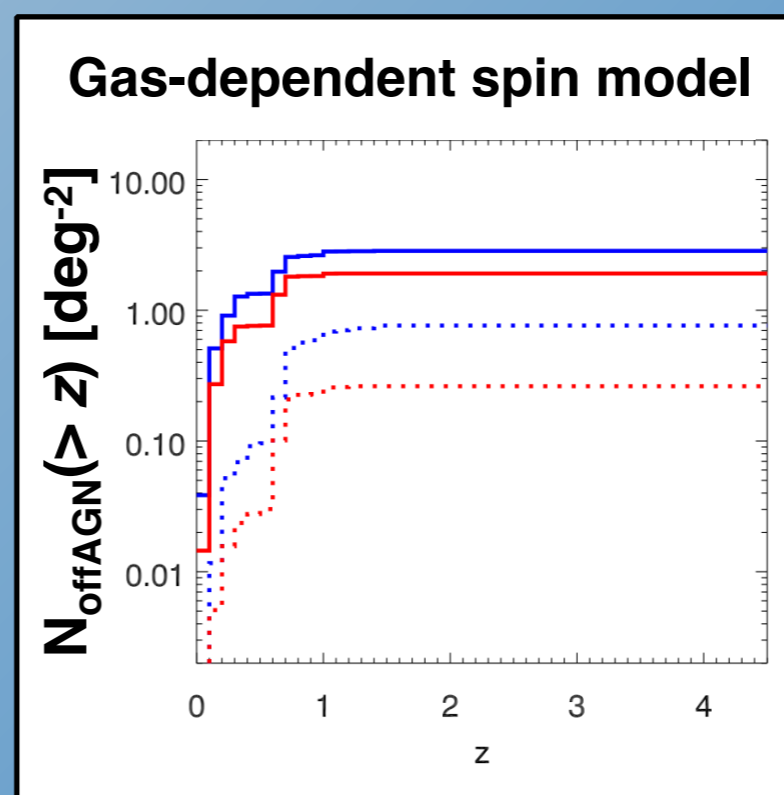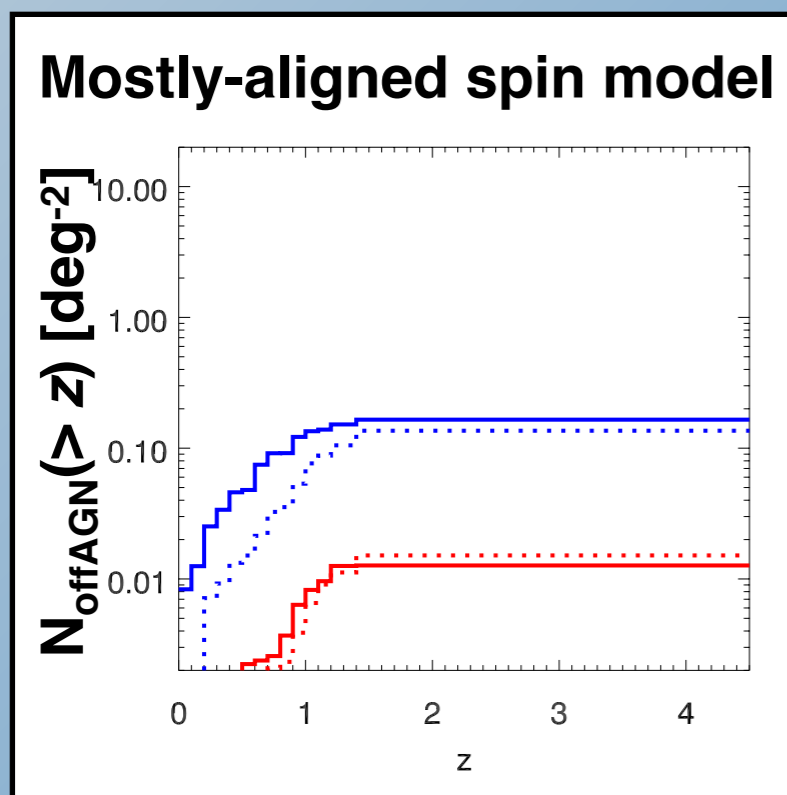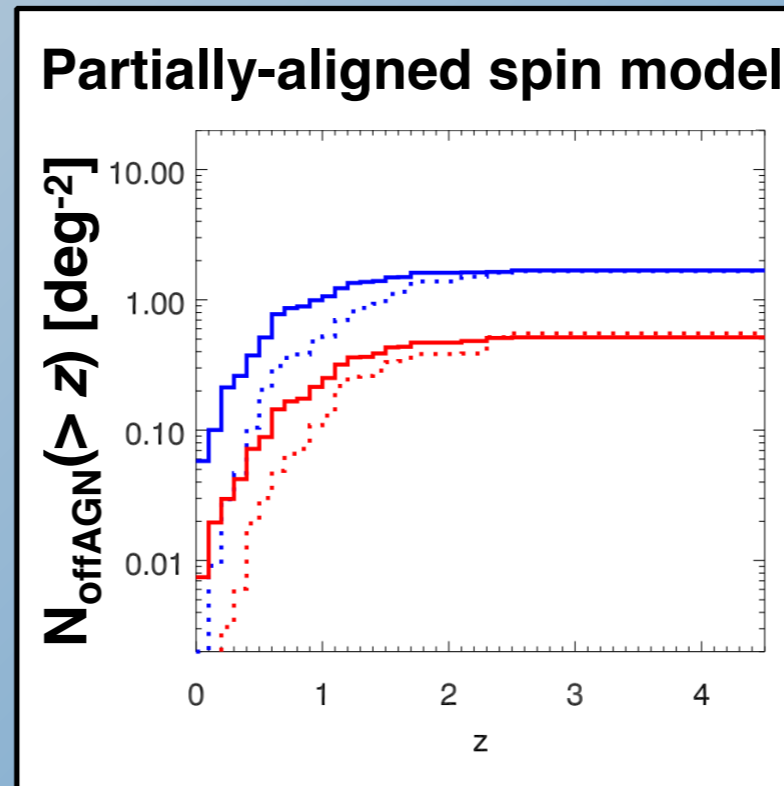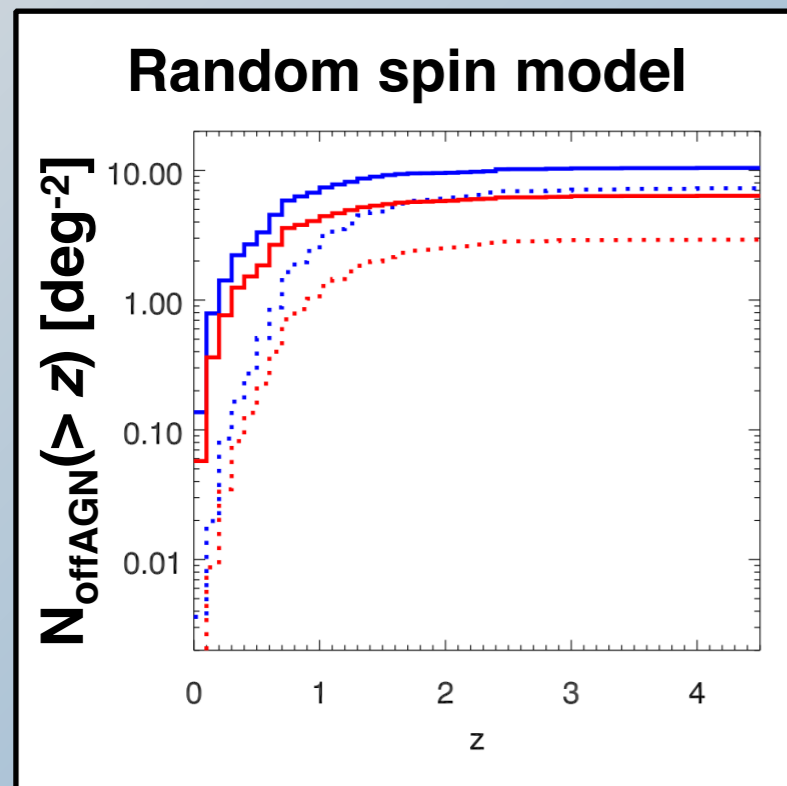- Good match to SFRD, stellar & BH MF

Vogelsberger et al. 2014a
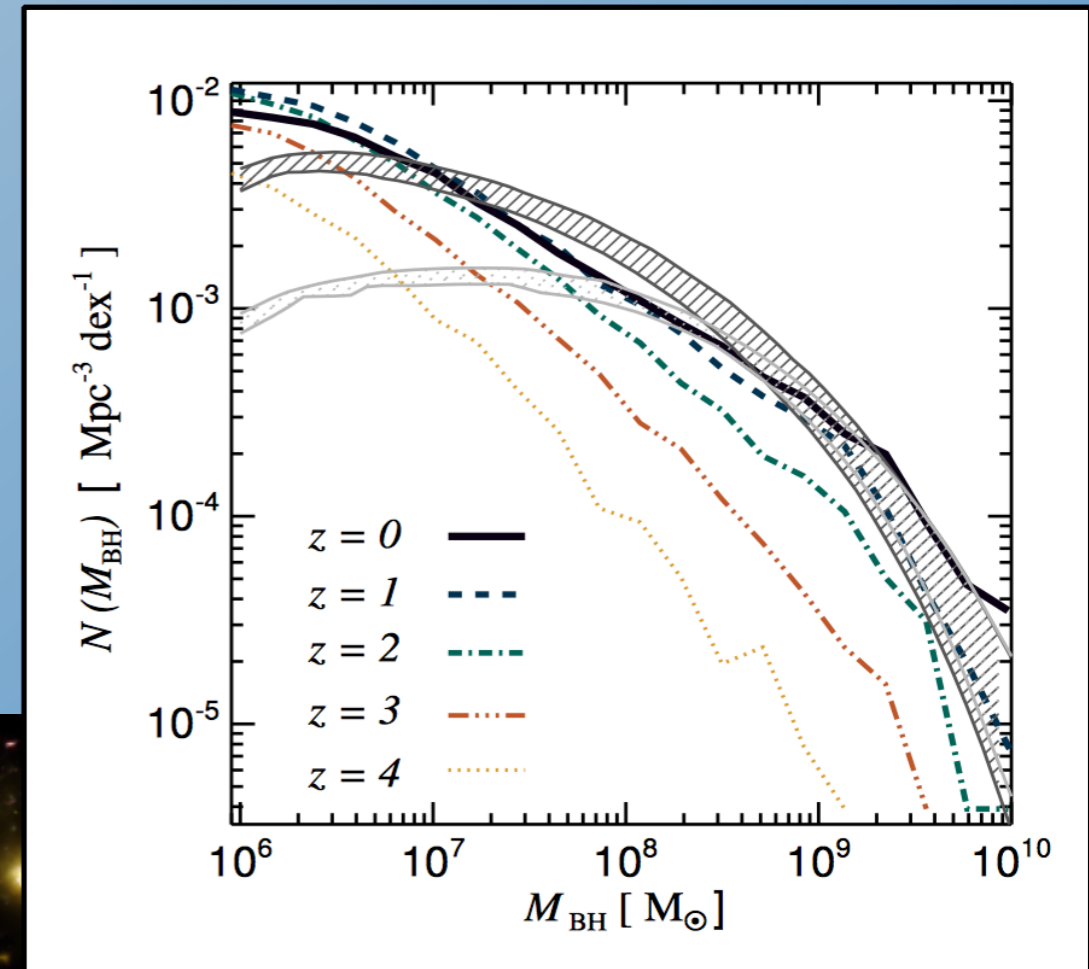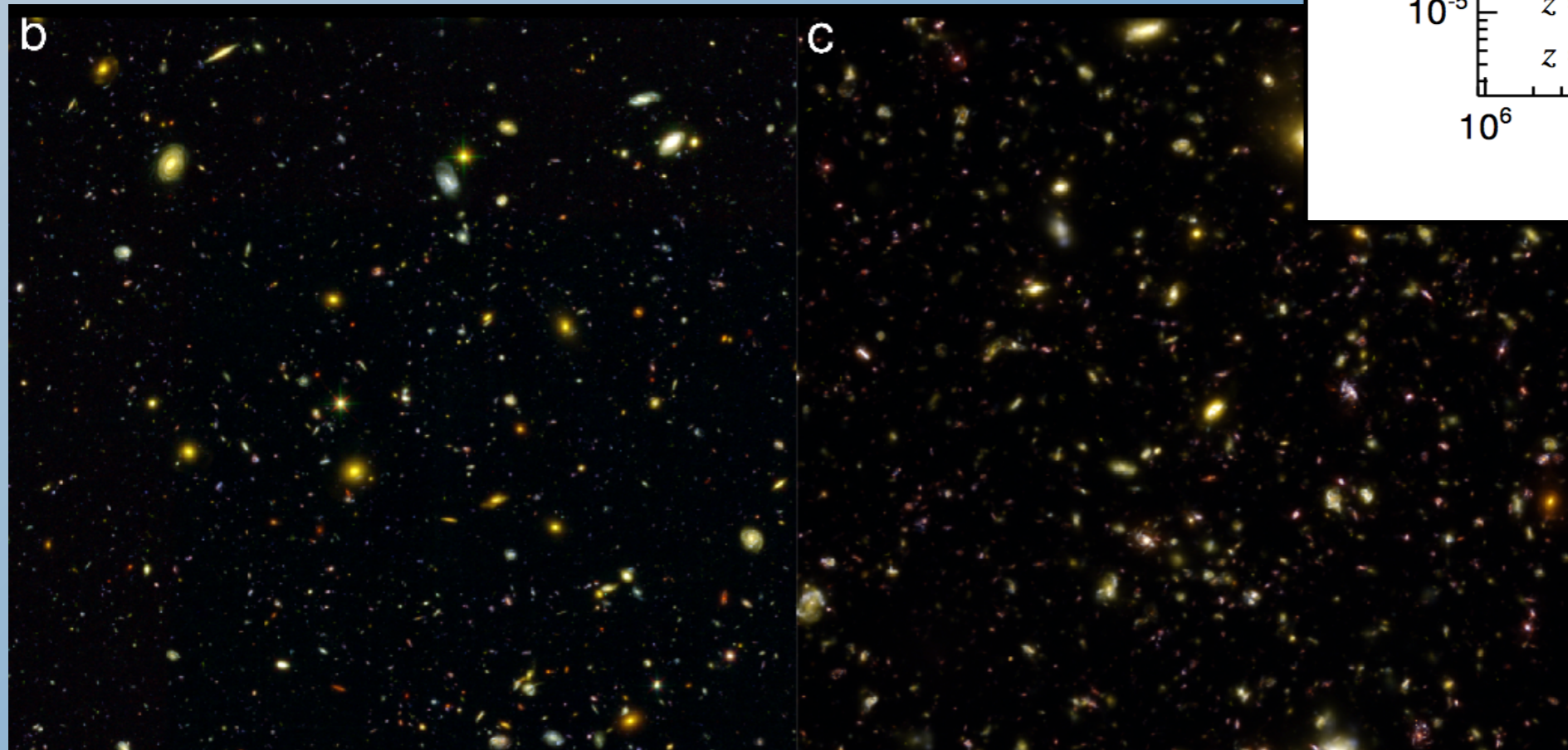
Sijacki et al. 2014

Recoiling AGN source counts
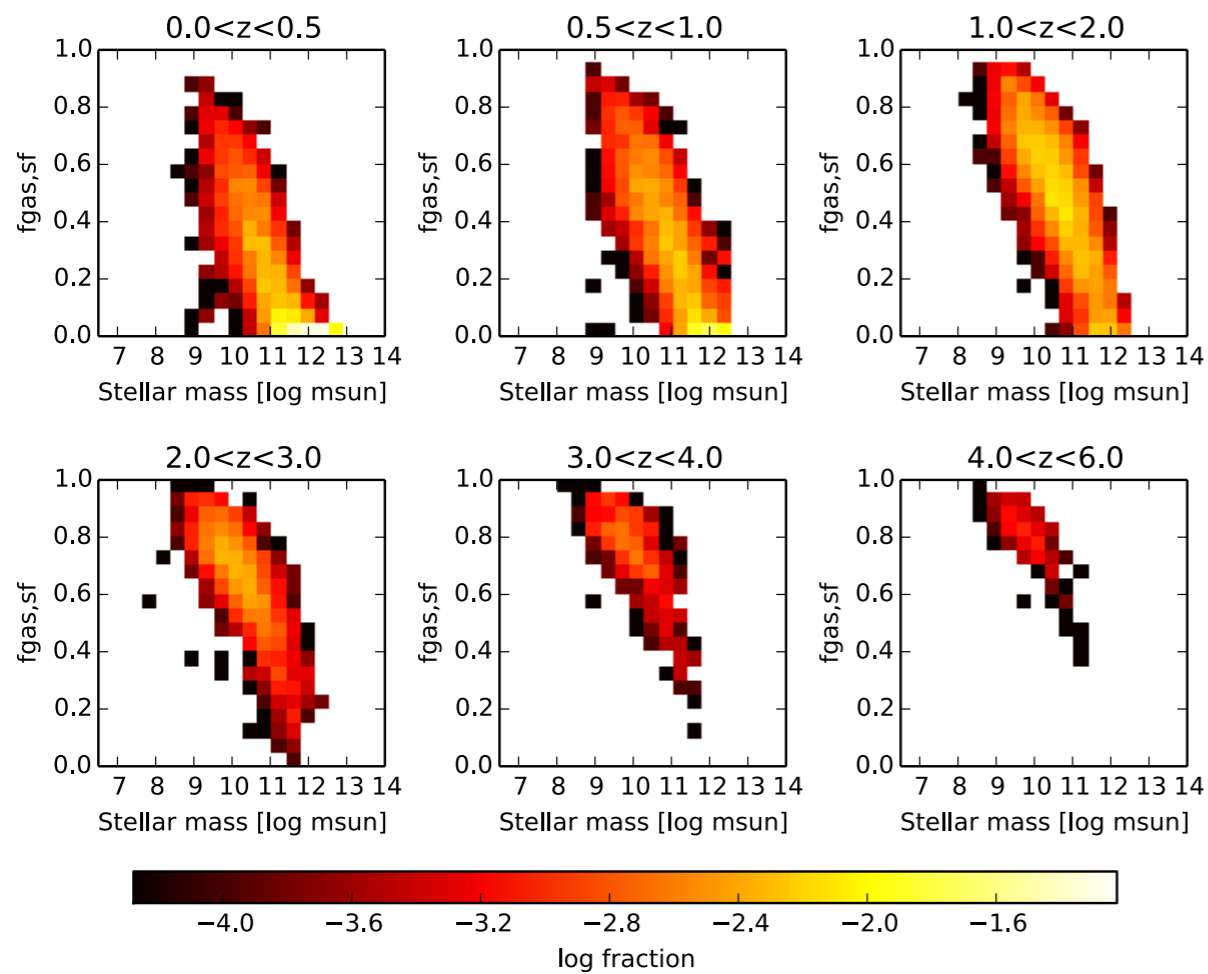## from cosmological sims + semi-analytic models

Recoiling AGN source counts
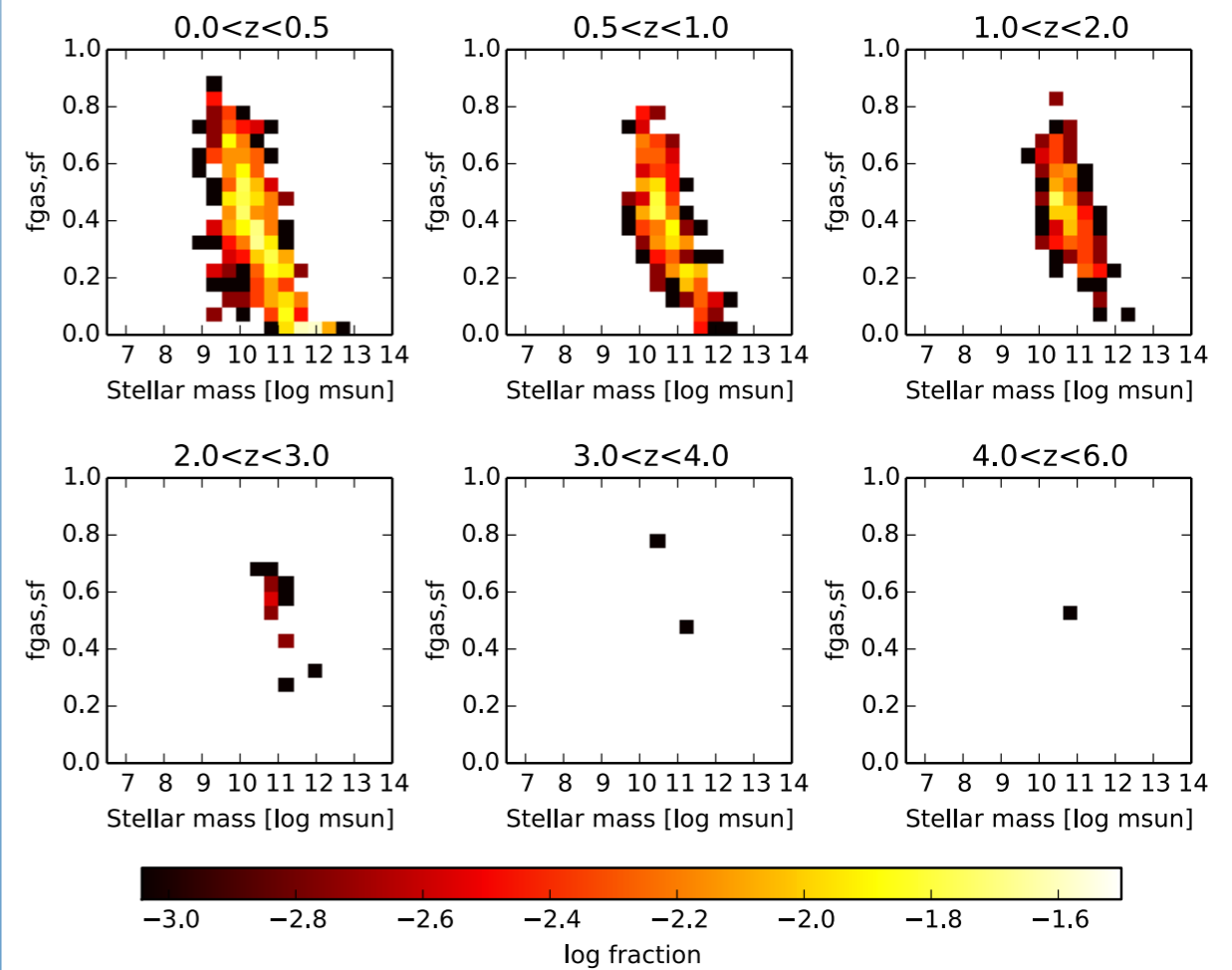## from cosmological sims + semi-analytic models

Host galaxy properties

Cold gas fraction vs. stellar mass

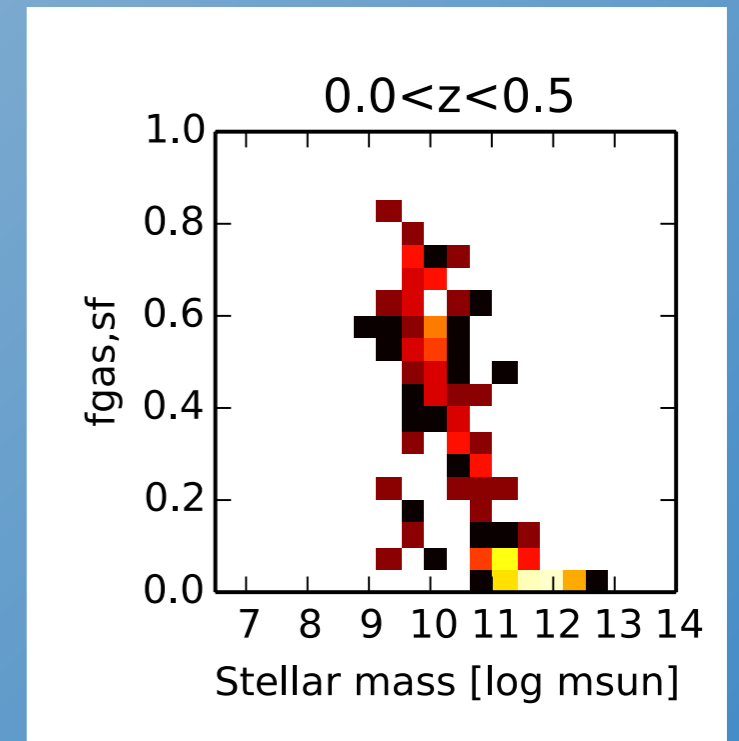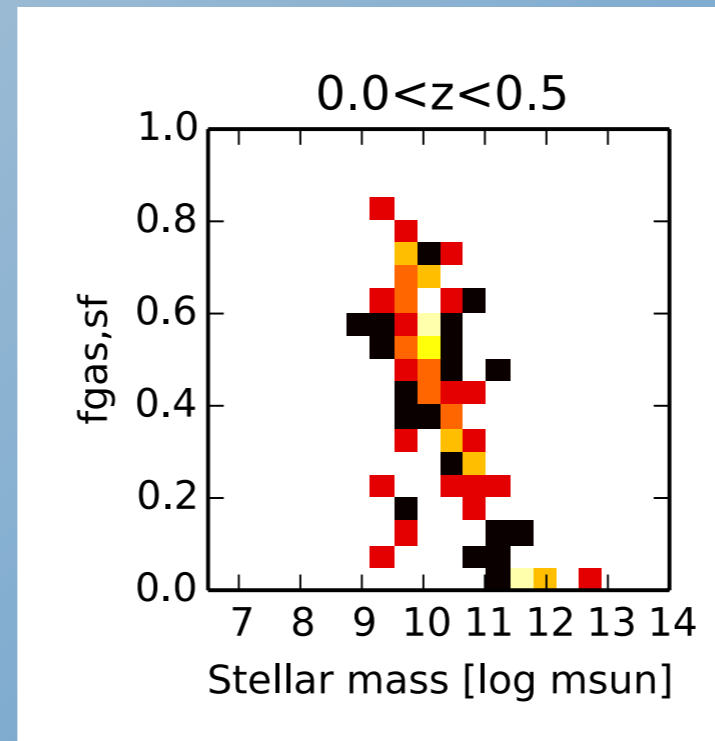**All BH merger hosts**

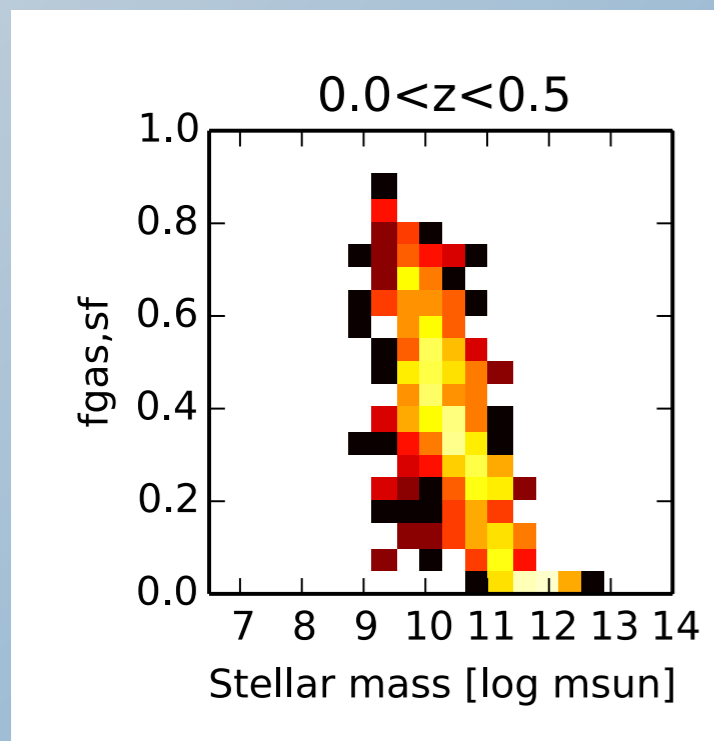**Offset AGN hosts**
(random spin model)

Host galaxy properties

Cold gas fraction vs. stellar mass

Random spin model

Mostly-aligned spin model

Gas-dependent spin model

Summary

- Observations of GW recoil events may offer the best prospects for identifying SMBH mergers in advance of GW detections

- Promising candidate recoiling AGN have been identified, and more systematic searches are ongoing

- Offset AGN appear to inhabit preferred host galaxies, may find several per deg^2 in the most optimistic case

- Detections of recoiling AGN may be able to distinguish between models for BH spin alignment