# Observable Signatures of Ejected Black Holes

Laura Blecha Harvard Center for Astrophysics

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# **How Are SMBHs Ejected?**

- Dynamical kick (3-body SMBH interaction)
  - Requires t<sub>merge,BH</sub> > t<sub>merge,galaxy</sub> ("dry" mergers?)
  - Ejection of lightest BH less common than merger of two BHs (Hoffman & Loeb 2007)
     (Wiseman 1992)
- Gravitational-wave (GW)
  recoil kick
  - Results from asymmetrical GW emission during BH merger
  - Relevant mechanism for wider range of systems

 $\begin{array}{c} \mathbf{v}_{2} \\ \mathbf{v}_{2} \\ \mathbf{w}_{2} \\ \mathbf{w}_{2} \\ \mathbf{w}_{2} \\ \mathbf{w}_{2} \\ \mathbf{w}_{2} \\ \mathbf{w}_{1} \\ \mathbf{w}_{2} \\ \mathbf{w}_{1} \\ \mathbf{w}_{1} \\ \mathbf{w}_{2} \\ \mathbf{w}_{1} \\ \mathbf{w}_{2} \\ \mathbf{w}_{1} \\ \mathbf{w}_{2} \\ \mathbf{w}_{2} \\ \mathbf{w}_{1} \\ \mathbf{w}_{2} \\ \mathbf{w}$ 

## **GW Recoil Kick Speeds**

- Kicks up to ~4000 km/s are possible (Campanelli et al. 2007)
- Kick velocity PDF: (Schnittman & Buonanno 2007)
  - $-a_1 = a_2 = 0.9$
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  - Which types of recoiling systems are most likely to be observed?

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- Need EM counterpart
- Recoiling quasars:
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- Scatter in  $M_{_{BH}}$ - $\sigma$  relation

#### (Ferrarese & Ford 2005)



## **Observational Constraints**

- "Empty" galaxies generally not seen locally
- Search for kinematic offsets in quasar spectra
  null result (Bonning et al. 2007)
- SDSS quasar with 2650 km/s offset between BLR and NLR
   => GW recoil candidate (Komossa et al. 2008)

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# A model for recoiling SMBHs

- Integrate trajectory of recoiling BH
  - Smooth potential (stellar bulge + gas disk)
  - Stellar and gaseous dynamical friction
- Calculate accretion rate using hybrid model (α-disk + Bondi)
- Free parameters: recoil kick speed and inclination
- Fiducial Model:

$$- M_{BH} \sim 10^8 M_{\odot}$$
  
 $- M_{gas} = 0.5 M_{*}$ 

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- Observational challenges + self-regulated growth => cannot exclude significant population of moving BHs