Fingerprints of intermediate-mass black holes in dense stellar systems

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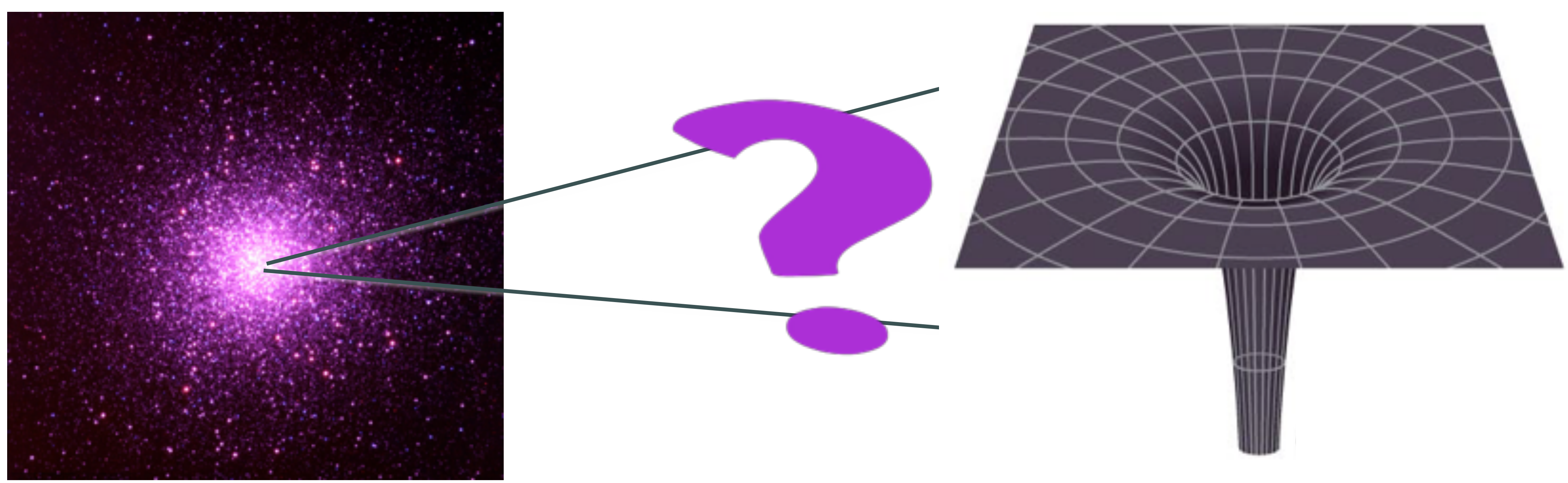
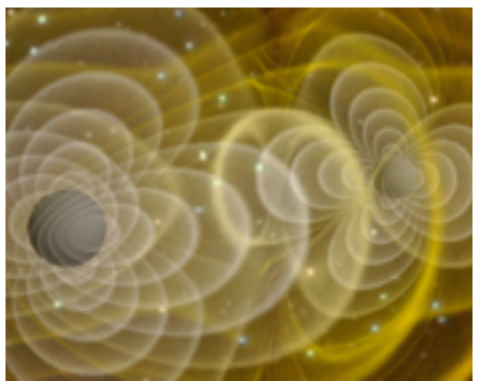
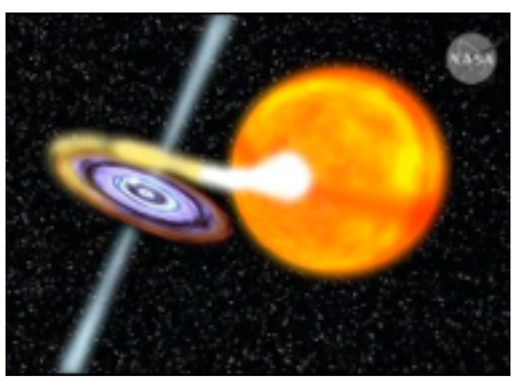


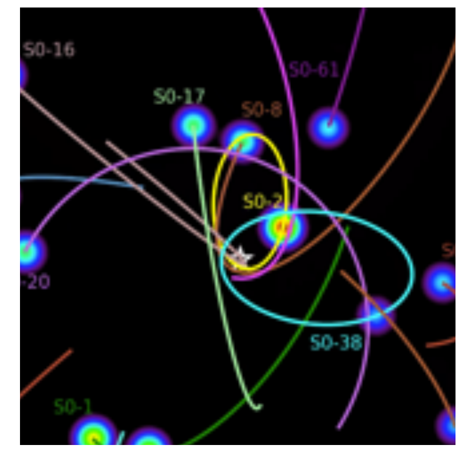
Shining from the heart of darkness: BH accretion and Jets — Kathmandu, October 21 2016

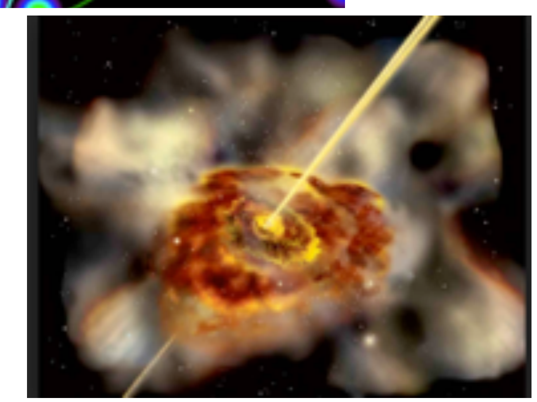
Intermediate Mass Black Holes

- Link between stellar mass and supermassive BHs
  - $M_{IMBH} \sim 10^2 - 10^4\ M_{Sun}$









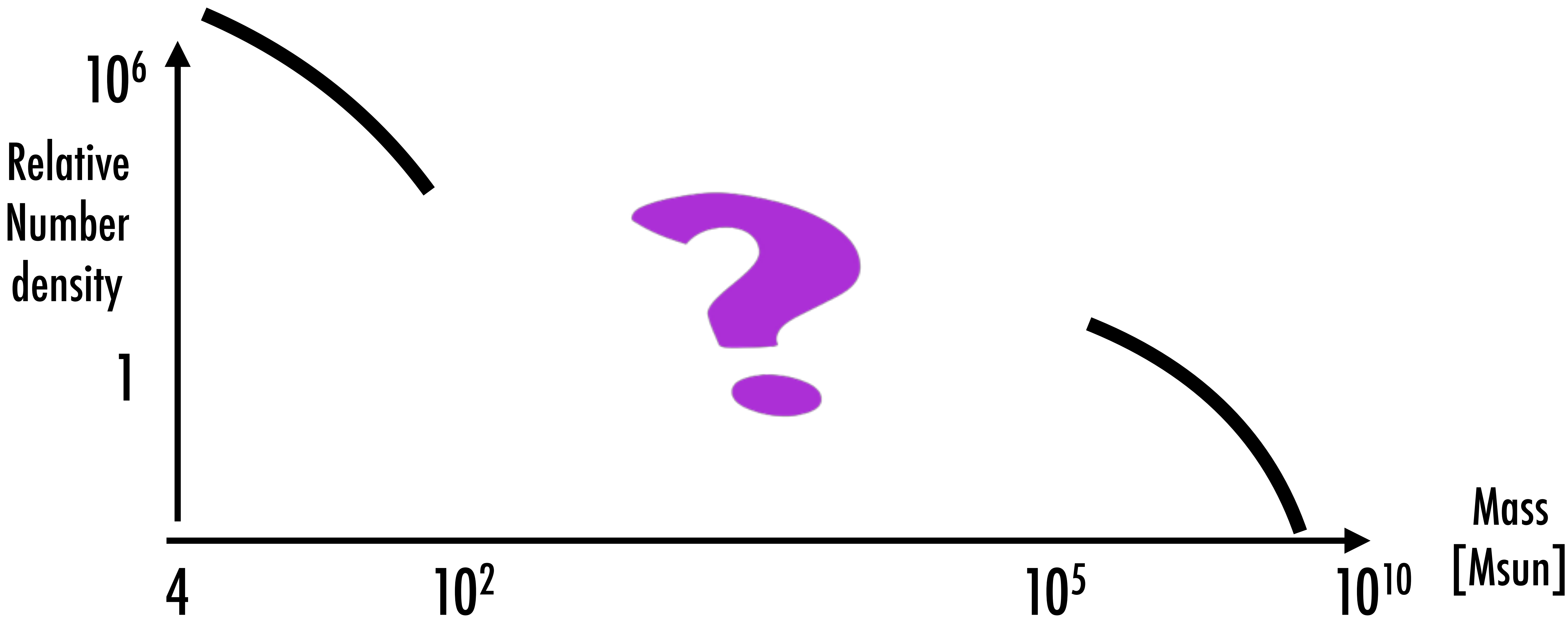
Mass [Msun]

4 — 10^2 — 10^5 — 10^{10}

Do IMBHs exist?

The importance of IMBH

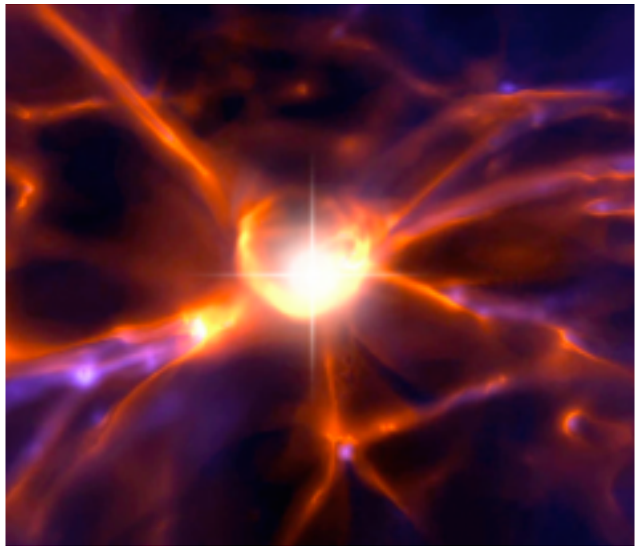
- Millions of stellar mass BHs per galaxy
  - **How do supermassive BHs grow?**



Two distinct BH populations or continuum?

Formation of IMBHs

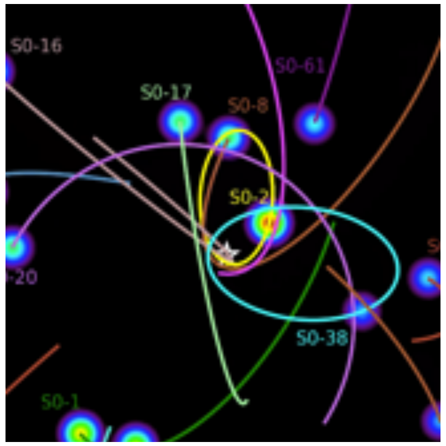
- IMBHs predicted in various astrophysical contexts



- **Special star formation**
  - Metal-free stars at early times (Heger et al. 2004)
- **Dense stellar environments**
  - Run-away stellar collisions & collapse (Portegies-Zwart et al. 2004)
  - Efficient gas accretion on seed BHs (Vesperini et al. 2010)

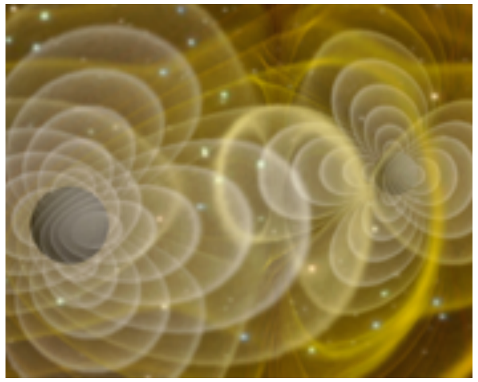
How can we detect black holes?

- **Dynamics**



- **Accretion**

- **Gravitational waves (from binaries)**

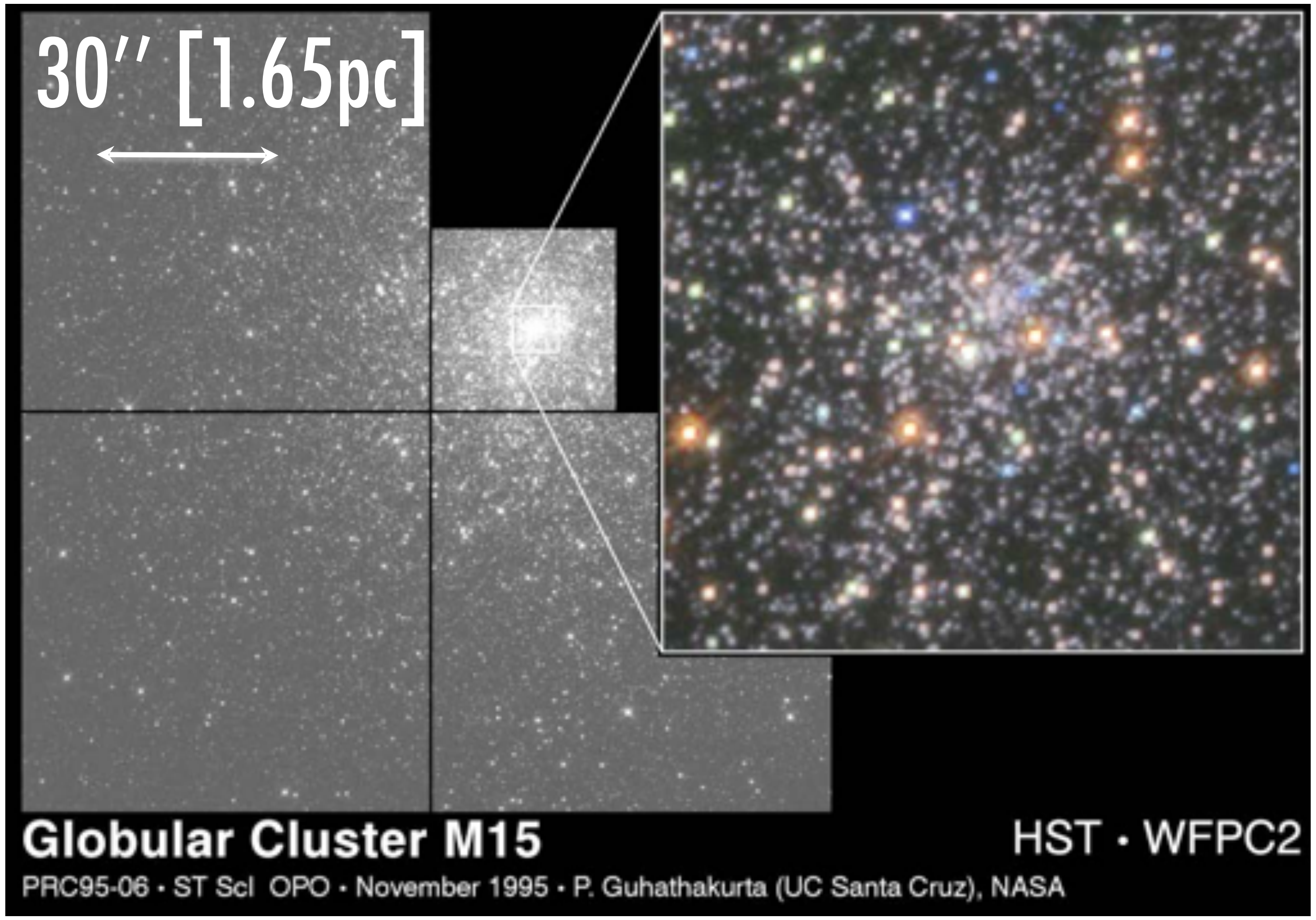


All methods point to search for IMBHs in star clusters

Dense star clusters (globular clusters)

- **Live in/around galaxies (~160 in the MW)**
- **Compact & Old: ~$10^{5.5}$ stars in ~10 pc^3**
  - No (or little) dark matter and gas
  - "Exotic" stellar objects in cores (e.g., BHs, binary pulsars, blue stragglers)

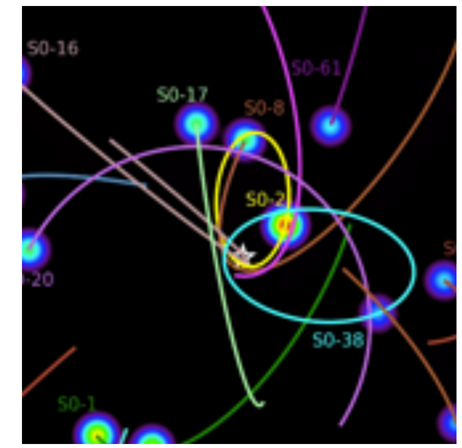
Are there central IMBHs as well?

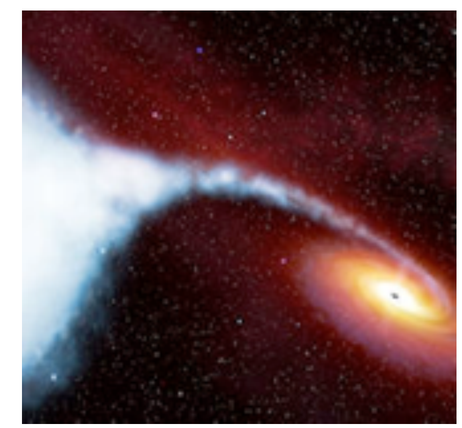


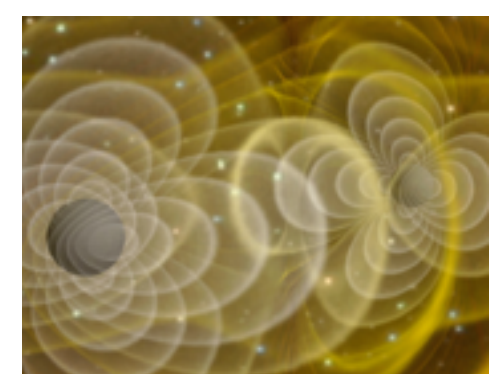
IMBH fingerprints in Globular Clusters

A challenging search

- **Dynamics**
  - Intermediate mass: Low orbital velocity and limited sphere of influence
- **Accretion**
  - Lack of gas: Very faint x-ray/radio (but tidal disruptions)
- **Gravitational waves**
  - Rarity of IMBH binaries?



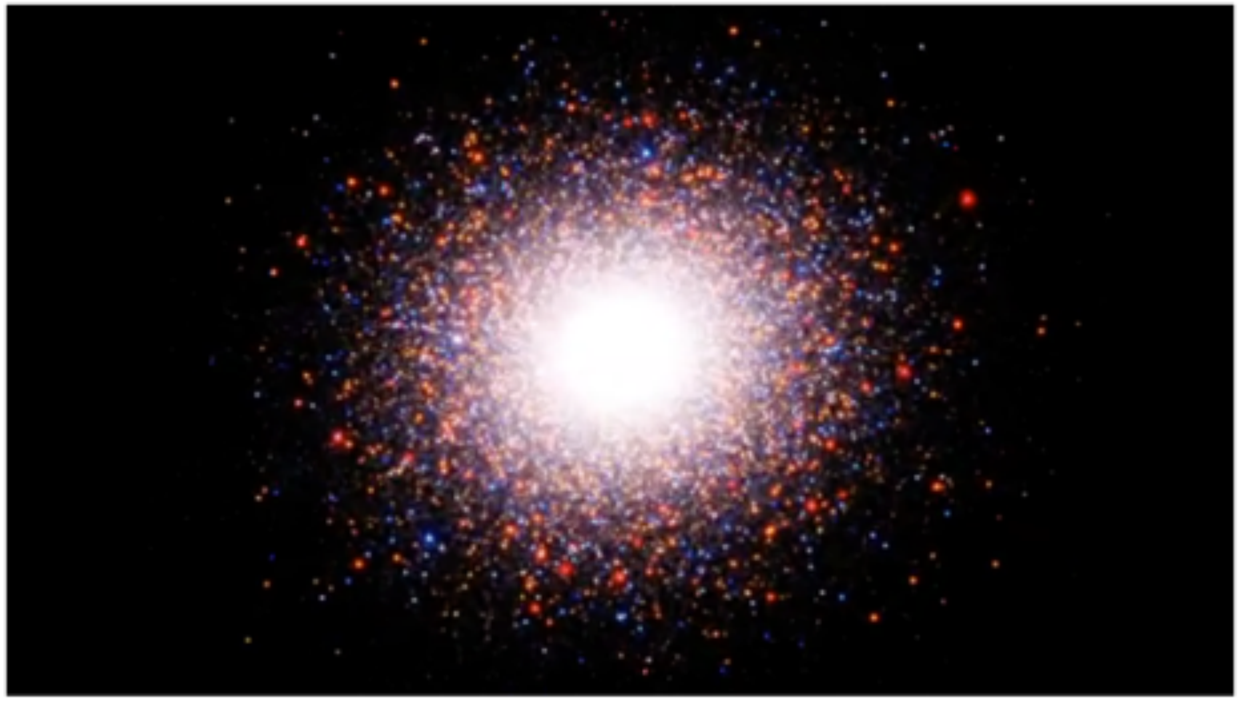




Status of the field: IMBH observations

A VERY challenging search

- **Several claims of detections, but all debated**
  - **Case study: Omega Centauri**



- Controversial velocity dispersion measurements (Noyola et al. 2010; Anderson & van der Marel 2010)

- No accretion signature from 300ks Chandra: IMBH excluded (Haggard et al. 2013)… but modeling caveats

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Modeling IMBH fingerprints

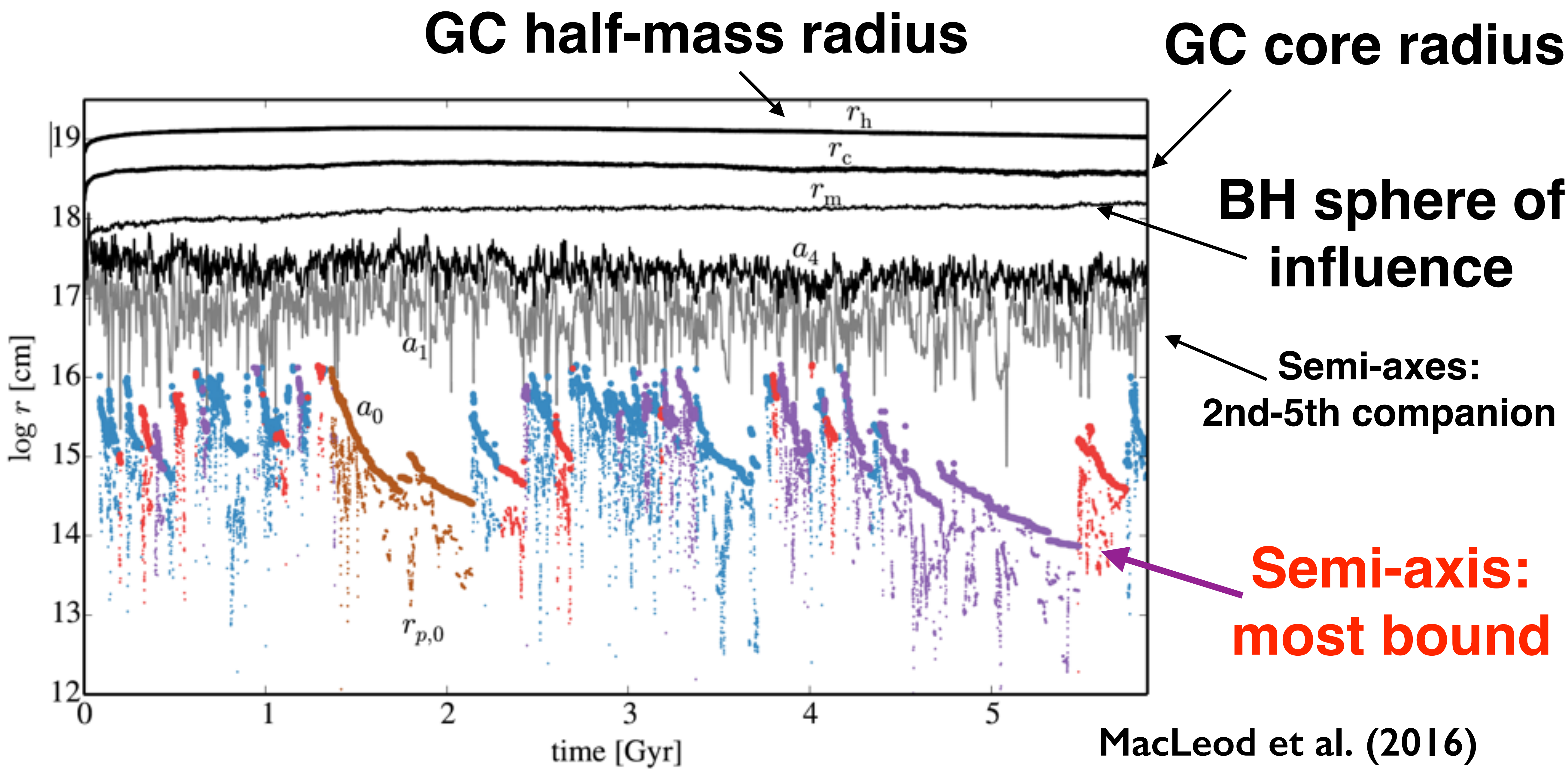
Dynamical simulations of GCs with central IMBH needed to assess (and find) fingerprints

Active research area (e.g., Baumgardt et al. 2004; Trenti et al. 2010; Lützgendorf et al. 2013; Umbreit et al. 2013; MacLeod et al. 2016; …)

- **Our approach**
  - Direct N-body: Exact dynamics but N~256k
- **150 M_{Sun} IMBH added to ~50% of simulations**
  - Characterize dynamical evolution
  - "Observe" simulations and assess IMBH recovery

Global evolution of a GC with an IMBH

IMBH quickly gets strongly bound companion and forms central density cusp

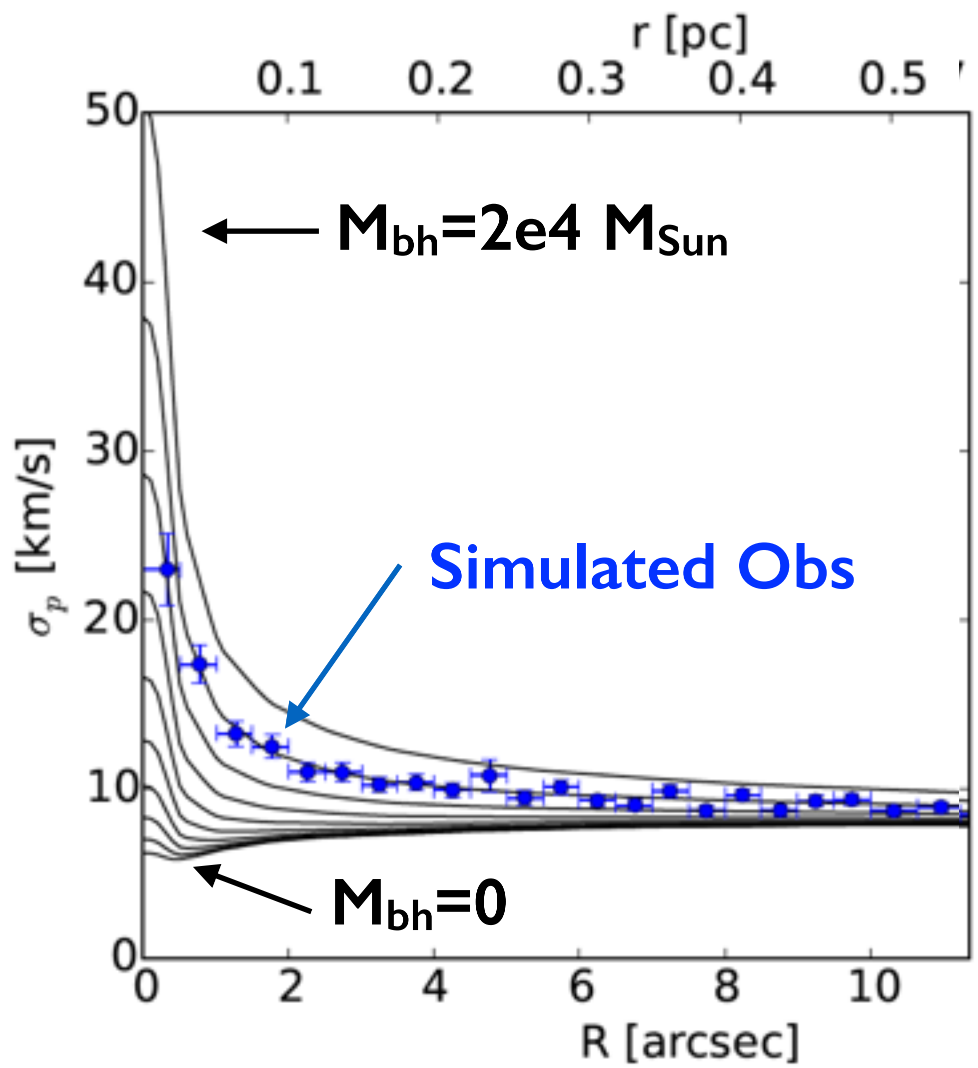


MacLeod et al. (2016)

Modeling Inference: Dynamics

- Central velocity dispersion cusp best direct IMBH diagnostic
    - But noisy, especially from ground (DeVita et al., submitted)
- IMBH displaced from center (~5% r_c)
- Indirect fingerprints:
    - Large r_c/r_h (Baumgardt et al. 2005)
    - Mass segregation/ equipartition quenching (Gill et al. 2008; Trenti & van der Marel 2013)

Simulated velocity dispersion with IMBH 1e4 M_{Sun}

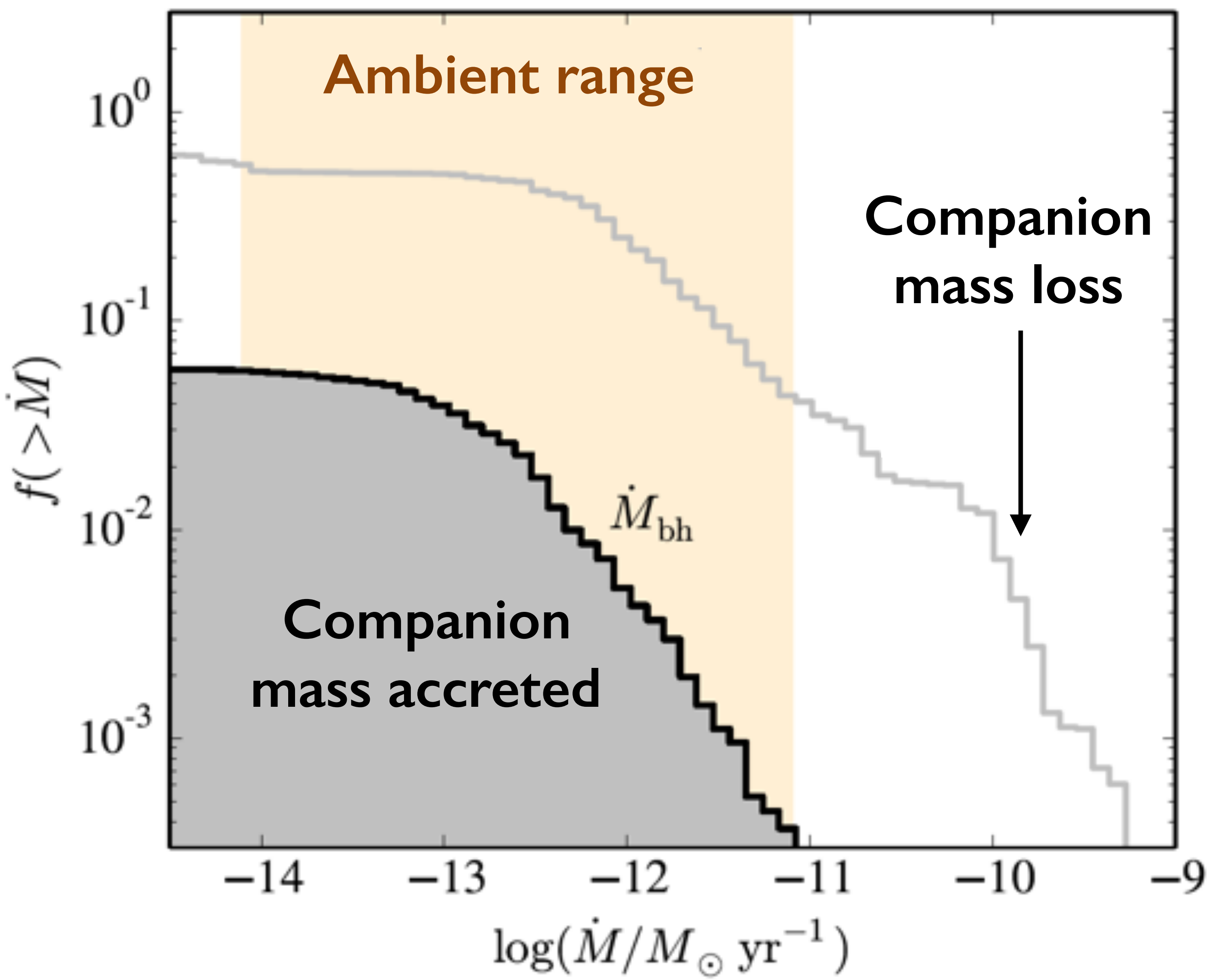


Problem: Are fingerprints unique?

Modeling Inference: Gas accretion

- **Gas in GCs originates from stellar winds**
  - Closest BH companion *rarely* dominant over ambient gas
  - Accretion rates are REALLY low
  - Challenging for radio/x-ray detection

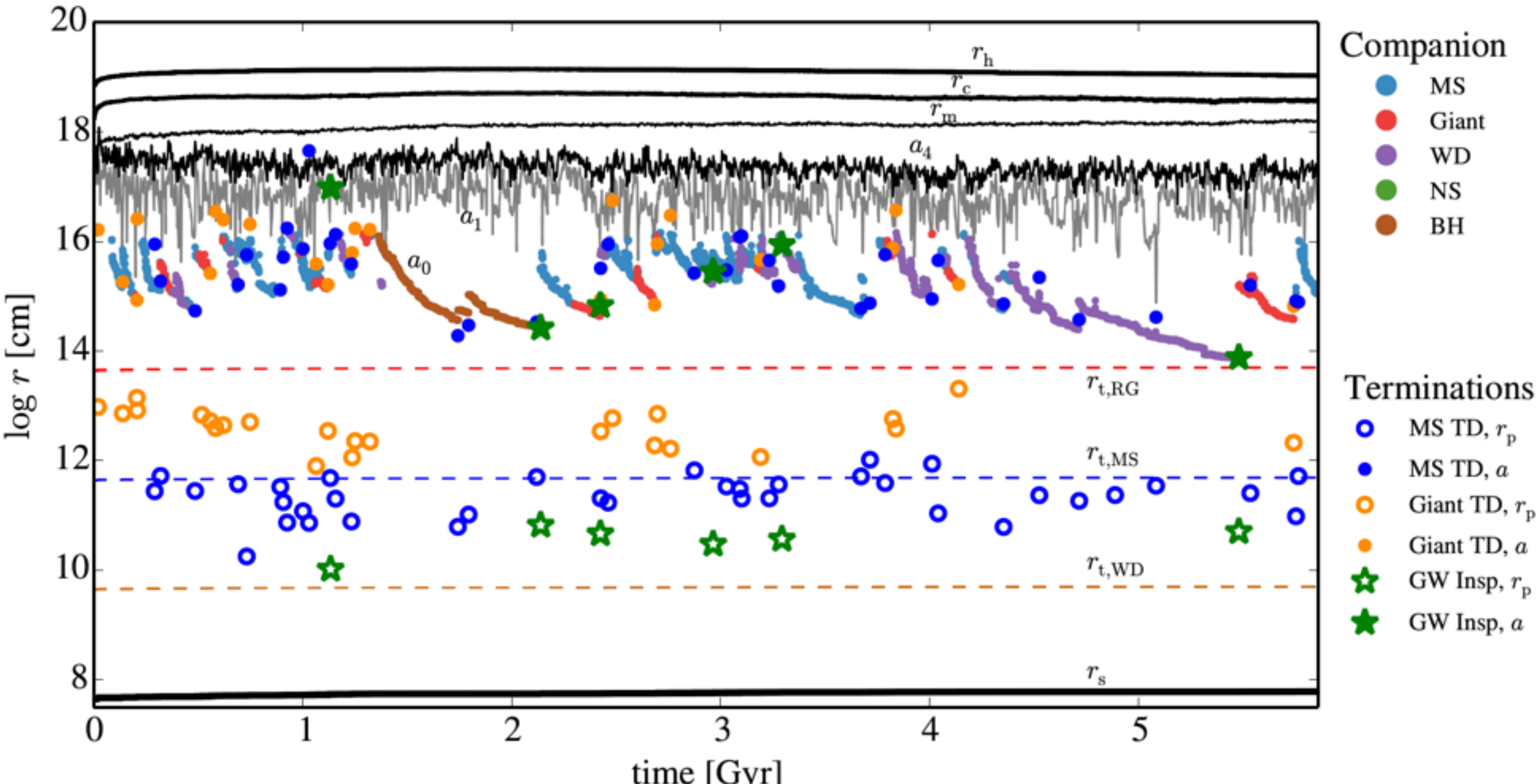
Accretion rate probability distribution (closest companion)



MacLeod et al. (2016)

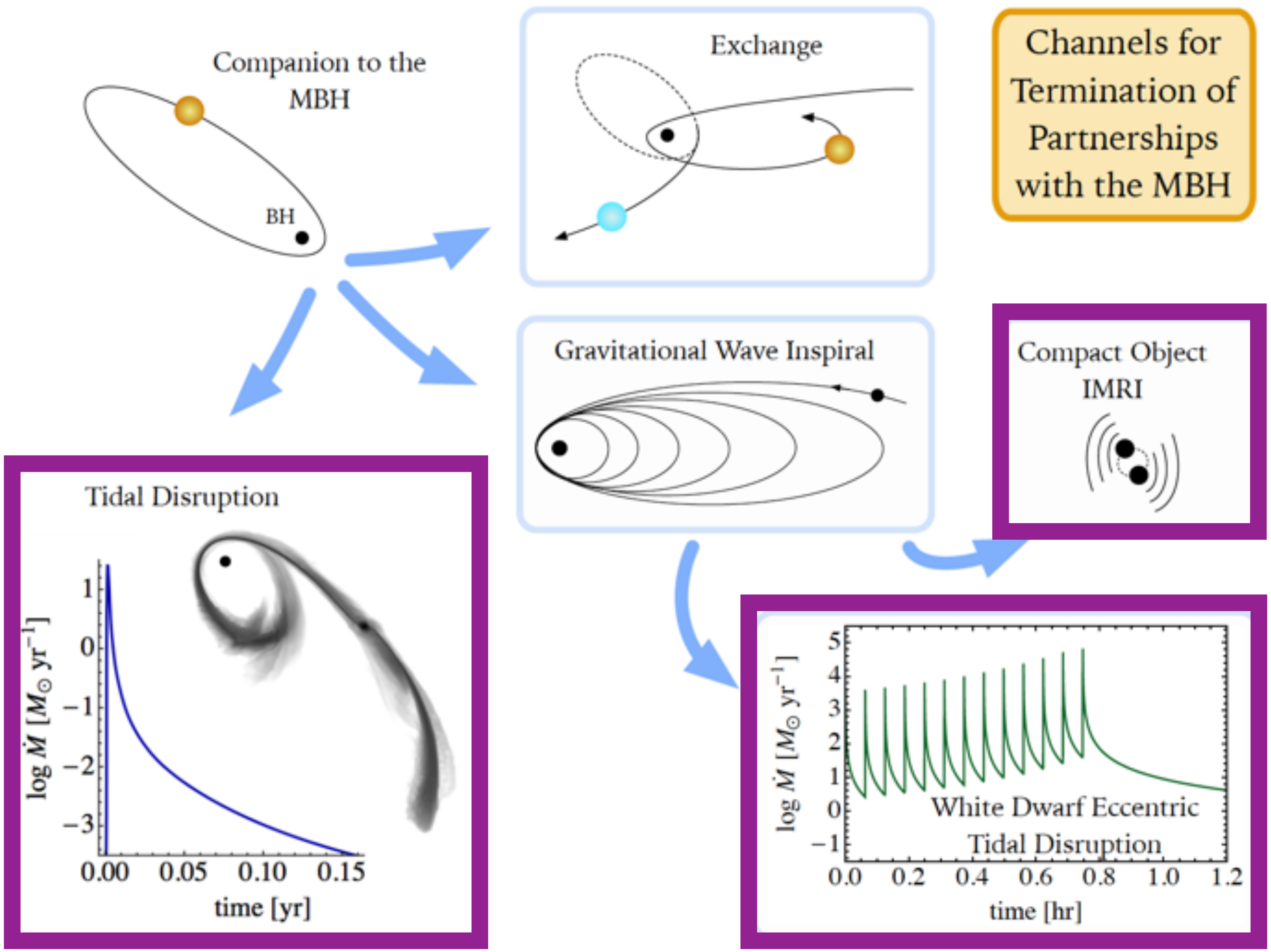
Modeling Inference: Stellar Accretion

Partnership with IMBH becomes tighter over time… before breaking up



Modeling Inference: Stellar Accretion

Break-ups can be detection opportunities!



MacLeod et al. (2016)

Tidal disruptions

- Flare is extremely luminous: $\sim 10^{41} (M_{BH}/10^3\ M_{Sun})$ erg s^{-1}

- Rare: $\sim 10^{-8}$ yr^{-1} in our simulations, but scales with $M_{BH}^{4/3} n_c$
- $\sim 10^{5\text{-}6}$ galaxies for 1 flare/yr (w/unity occupation fraction)
- Challenging today but promising for LSST (all-sky optical)

MacLeod et al. (2016)

Repeated tidal disruption flares

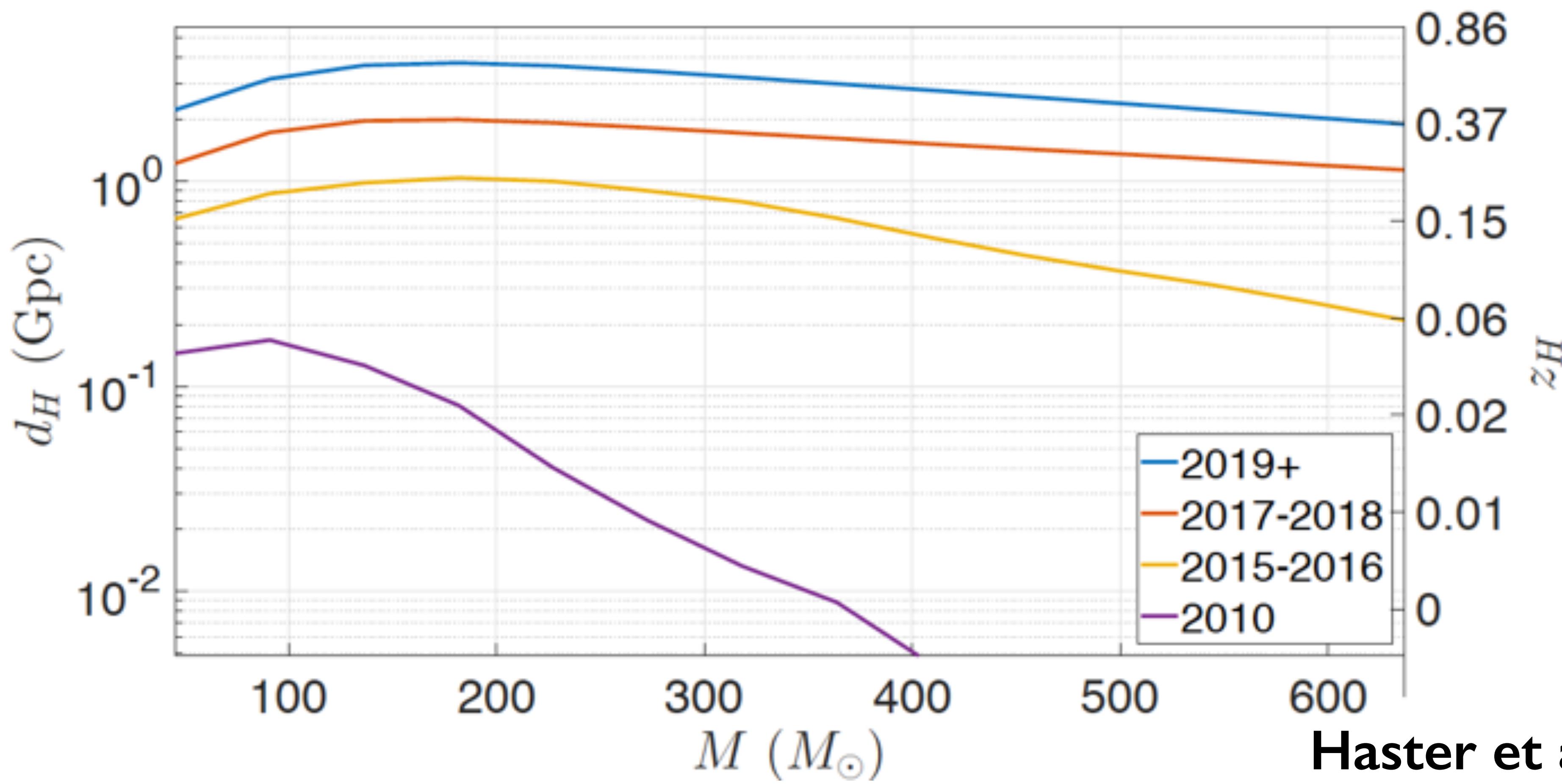
HLX-1: A candidate 10^4 M_{Sun} IMBH with periodic flaring

- **Secular evolution for most bound orbits in our simulations**
- **"Grazing orbits" possible and qualitatively explain HLX-1**
  - **Caveat: Simulated IMBH only 150 M_{Sun}**

MacLeod et al. (2016)

Gravitational Waves

- **Event rate: ~1 Gyr^{-1} /cluster ~ 1 yr^{-1} Gpc^{-3} [with 10^9 GCs / Gpc^3] (MacLeod et al. 2016)**
  - **LIGO can detect IMRI for IMBHs out to z~0.3**



Haster et al. (2016)

Interesting opportunity to explore!

Summary: IMBHs (10^2-10^4 M_{Sun})

Still missing link of stellar to supermassive BHs

- Dense stellar environments good places to look
- Elusive so far… but
  - Interesting physics to explore through modelling
  - Prospects for detections/stringent limits from
    - Stellar dynamics
    - Tidal disruption flares
    - Gravitational waves