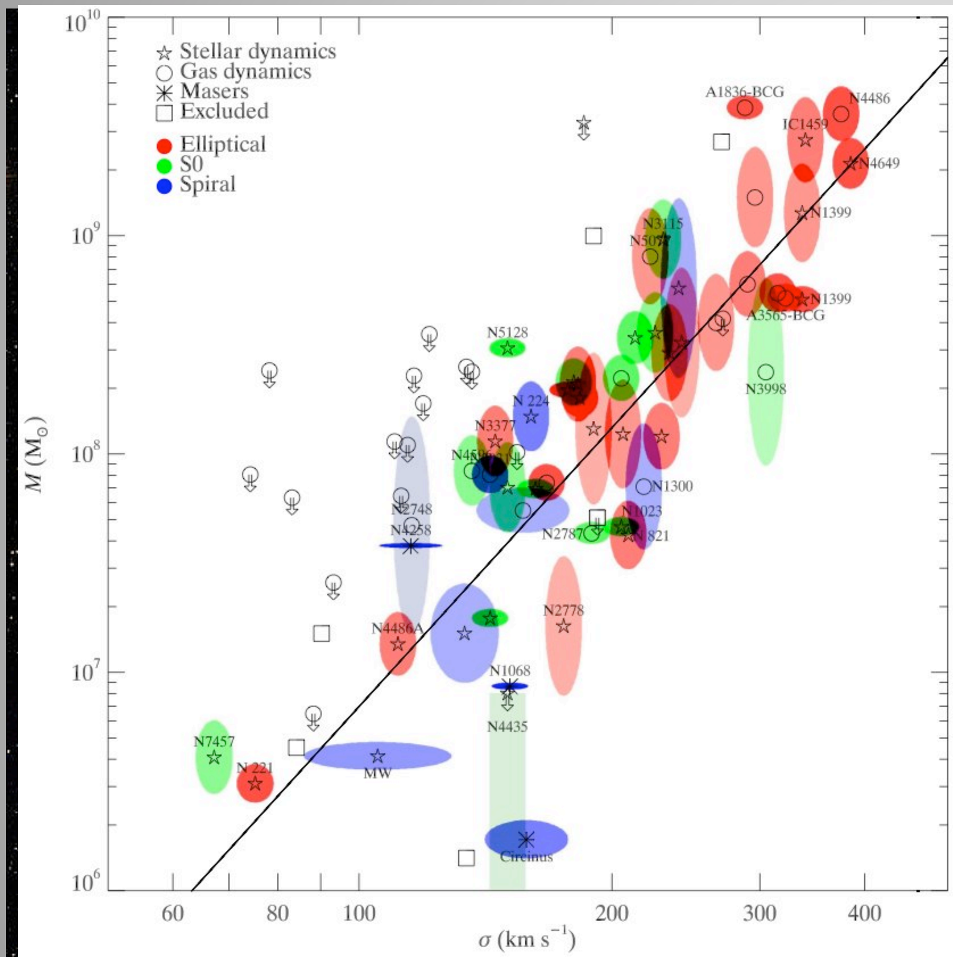
Massive Black Holes Lurking in Milky Way Satellites

Sandor Van Wassenhove
Advisor: Marta Volonteri (UMichigan)
Collaborators:
Matthew Walker, Jon Gair (Cambridge)

Signatures of BH Formation

- Black holes found in the centers of most nearby galaxies
- Original properties of BHs in massive galaxies overwritten by accretion and mergers (Volonteri & Natarajan 2009)
- BH population with little growth required to study original seed population

Dwarf Galaxies



Fornax ESO/Digitized Sky Survey 2
Gültekin et al. 2009

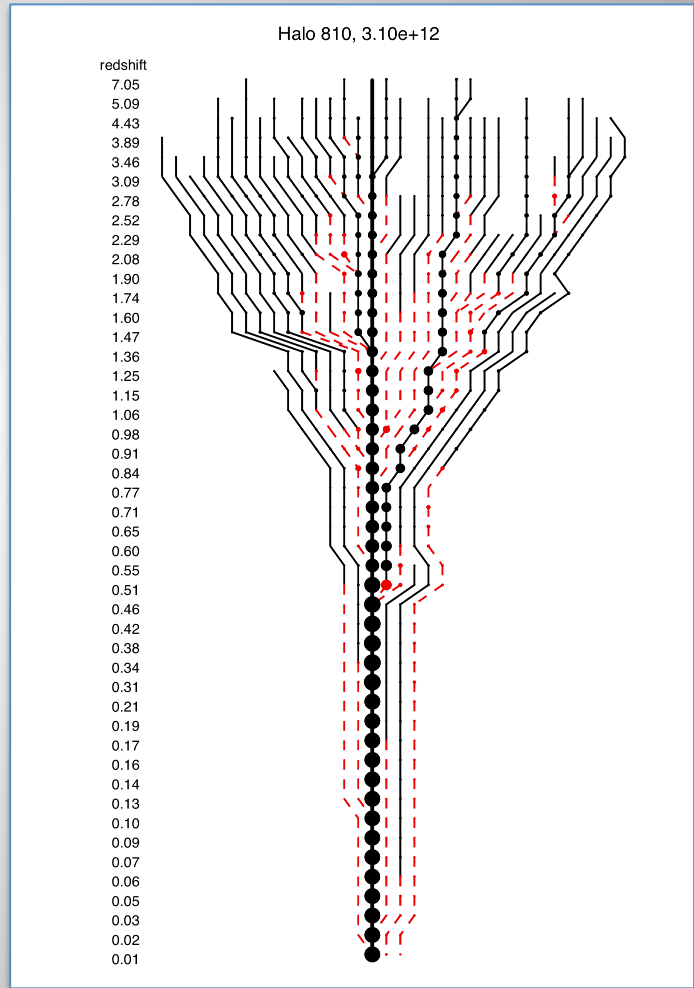
- Quieter merger histories than more massive galaxies – less merger induced BH accretion (Volonteri et al. 2008)
- Strongly affected by reionization – shallow potential wells
- How often do dwarfs host BHs?
- Do dwarfs follow the BH mass scaling relations?

Methods Overview

- Used merger trees to study the build up of a Milky Way type galaxy from z=20

  (Volonteri et al. 2003)

- Haloes seeded with BHs at high redshift using two different seed formation schemes
- Implemented a simple model for MBH growth through halo mergers
- Unmerged haloes at z=0 form analogue dwarf galaxy population



Stewart et al. 2008

High Redshift BH Seeds

(Volonteri et al. 2008)

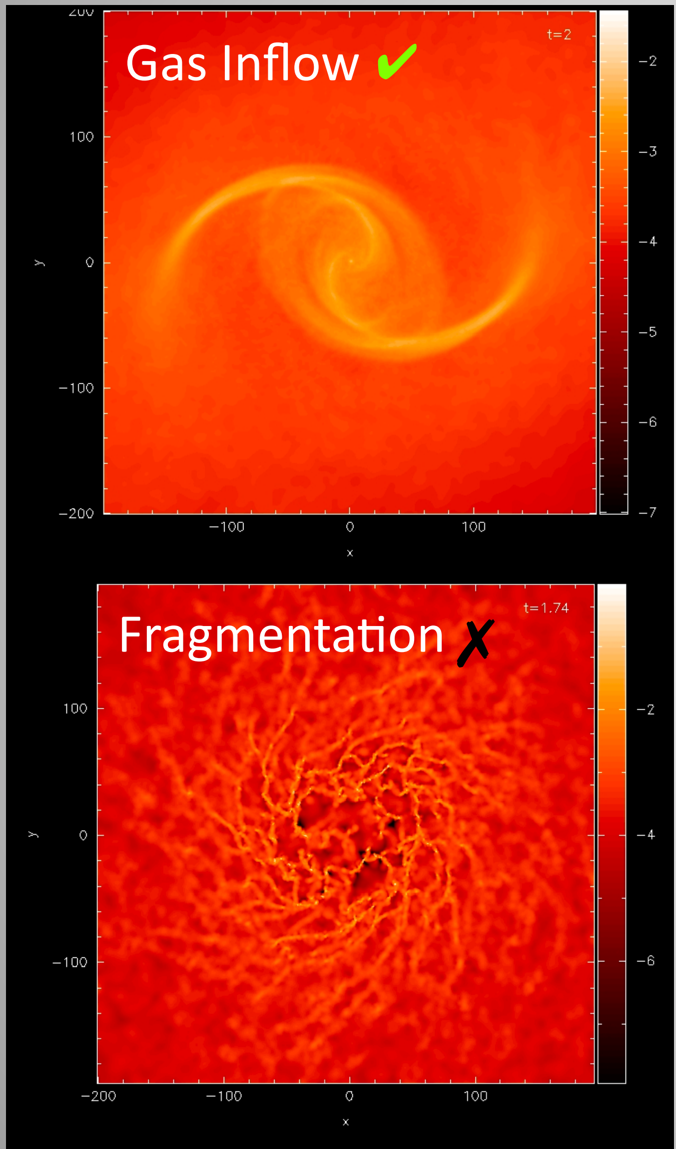
- Models match integrated BH mass density, AGN luminosity function, and z=0 BH mass function
- Constraints on formation:
  - Low metallicity environment ($z > 12$)
  - Haloes must be massive enough to have significant cooling

Population III Stellar Remnants

- Inefficient H_2 cooling may lead to a top heavy IMF (e.g. Carr et al. 1984, Abel et al. 2000)
- Stars may collapse with little mass loss to form BHs with mass 10^2-10^3 M_{sun}
  (Fryer et al. 2001, Madau & Rees 2001)
- Our model:
  - 3σ density peaks ($M > 10^5$ at z=20, $M > 10^8$ at z=12)
  - Require $T_{vir} > 2500$ K for H_2 cooling
    (Tegmark et al. 2007, Yoshida et al. 2006)
  - $M_{seed} = 100\ M_{sun}$

‘Massive Seeds’

(Lodato & Natarajan 2006)

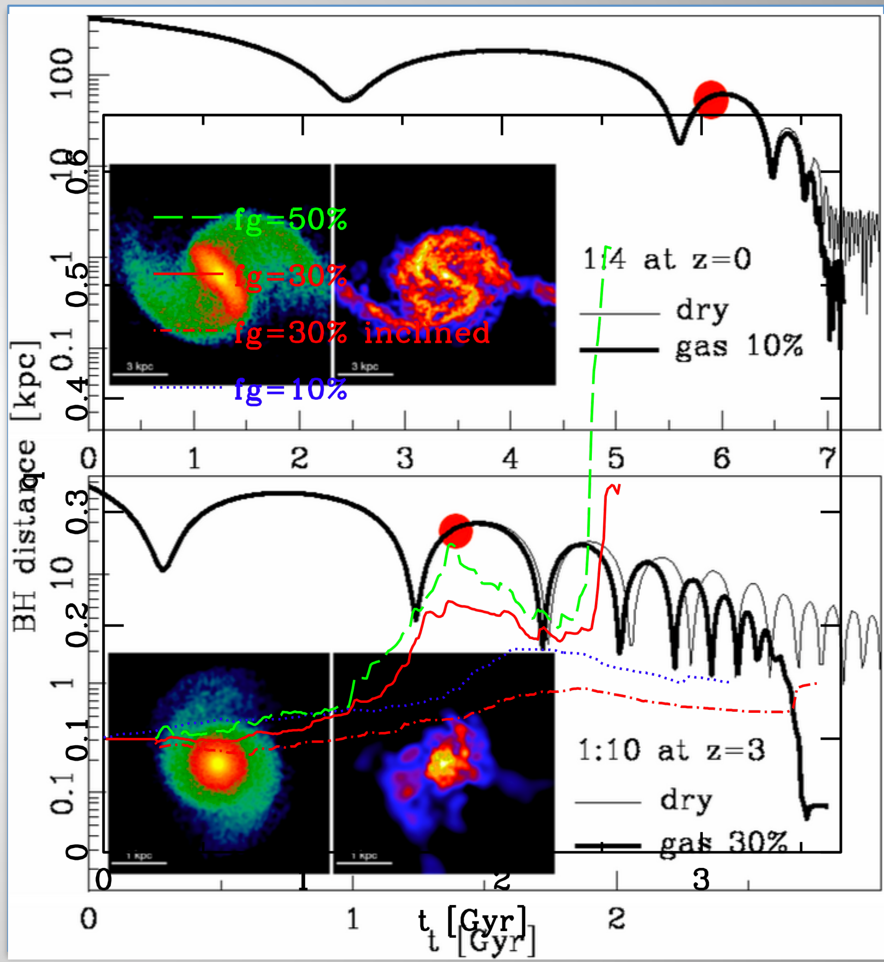


- Gas dynamical instabilities cause gas inflow until the disk stabilizes
- Cooling dominated by H
- Our model:
  - $M > 10^8\ M_{sun}$
  - $T_{vir} < 14000$ K to prevent fragmentation and global star formation
  - $M_{seed} \approx 10^5\ M_{sun}$

courtesy of Devecchi

Effects of Reionization on MBH Growth

- Simulations by Callegari et al. (2009) show that BH growth depends on gas fraction
- Haloes with shallow potentials lose their gas due to ultraviolet heating – reionization
- Follow Okamoto et al. (2008) to track baryon fractions of haloes after reionization
- We set $z_{reionization} = 9$



Callegari et al. 2009, 2010

Black Hole Growth

- Gas rich haloes: $f_b = \frac{M_b}{M_b + M_{DM}} \geq 0.1$ $\quad \frac{\Omega_b}{\Omega_m} \approx 0.18$
- Minor mergers (mass ratio < 1:10): black holes do not pair efficiently; no merger or accretion
- Major mergers (mass ratio > 1:10): black holes merge and accrete in gas rich haloes
- Accreted mass scales with the velocity dispersion of the resulting halo

$$M_{acc} = 10^8 M_{sun} \left(\sigma / 200 km/s \right)^4 \qquad \log(V_c) = 0.74 \log(\sigma) + 0.8$$

$$M_{BH,final} = M_{BH1} + M_{BH2} + M_{acc}$$

Tremaine et al. 2002, Pizzella et al. 2005

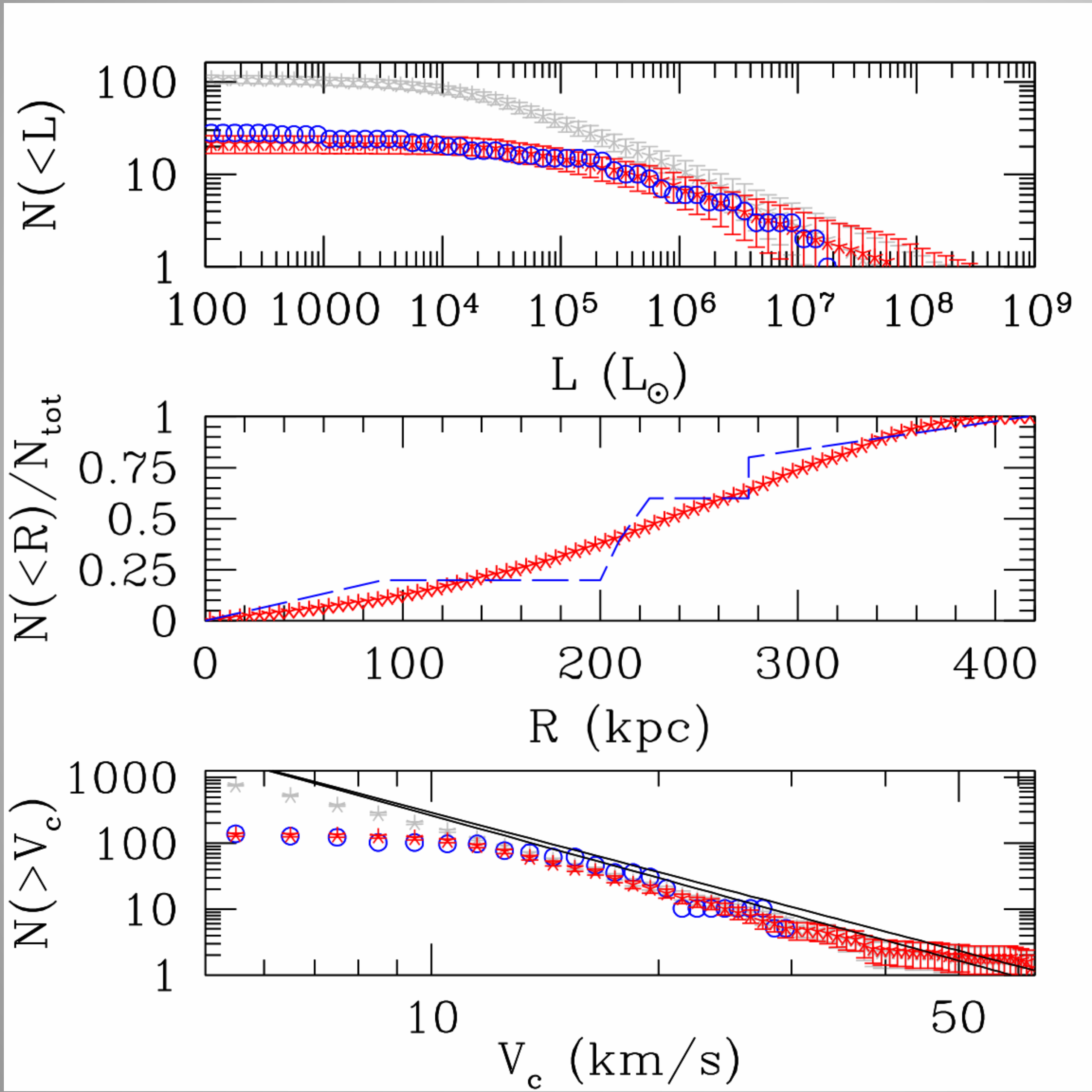
Satellite Population

- Analytically evolve the satellites in the potential well of the host with tidal stripping and dynamical friction
- Halo and BH mergers follow the merger timescale from Boylan-Kolchin et al. (2008)

$$\frac{\tau_{merge}}{\tau_{dynam}} = \frac{0.4\left(M_{host}/M_{sat}\right)^{1.3}}{\ln\left(1+M_{host}/M_{sat}\right)} \qquad \tau_{dynam} = \sqrt{R_{vir}^3/GM_{host}}$$

- Haloes that will not finish merging by z=0 become satellites of the host halo

Statistics of our Satellite Population



Luminosity Function

Observed

Our results

Radial Distribution

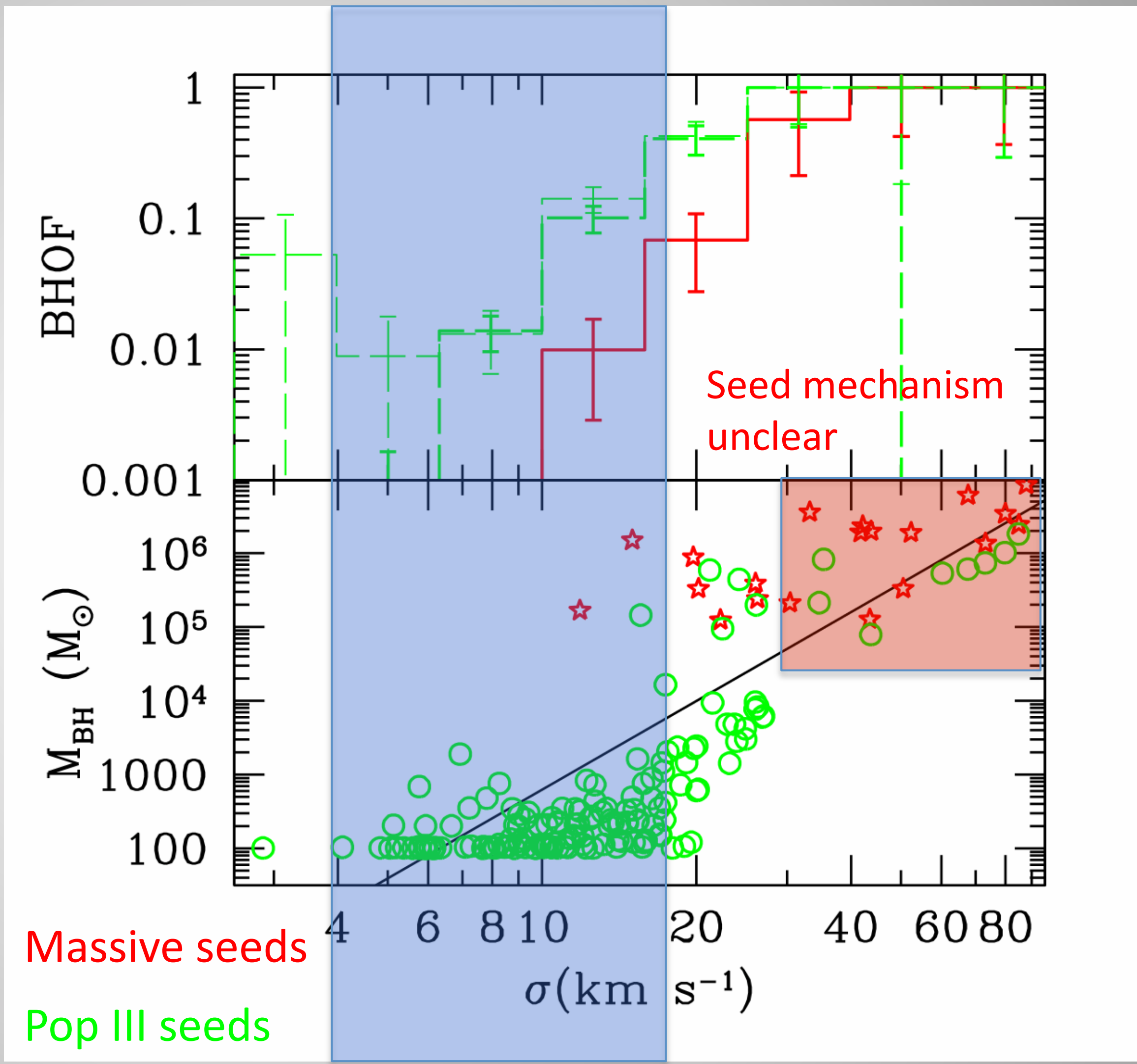
Velocity Distribution

Van Wassenhove et al. 2010

BH Diagnostics

Pop III BHs are far more common than massive seed BHS

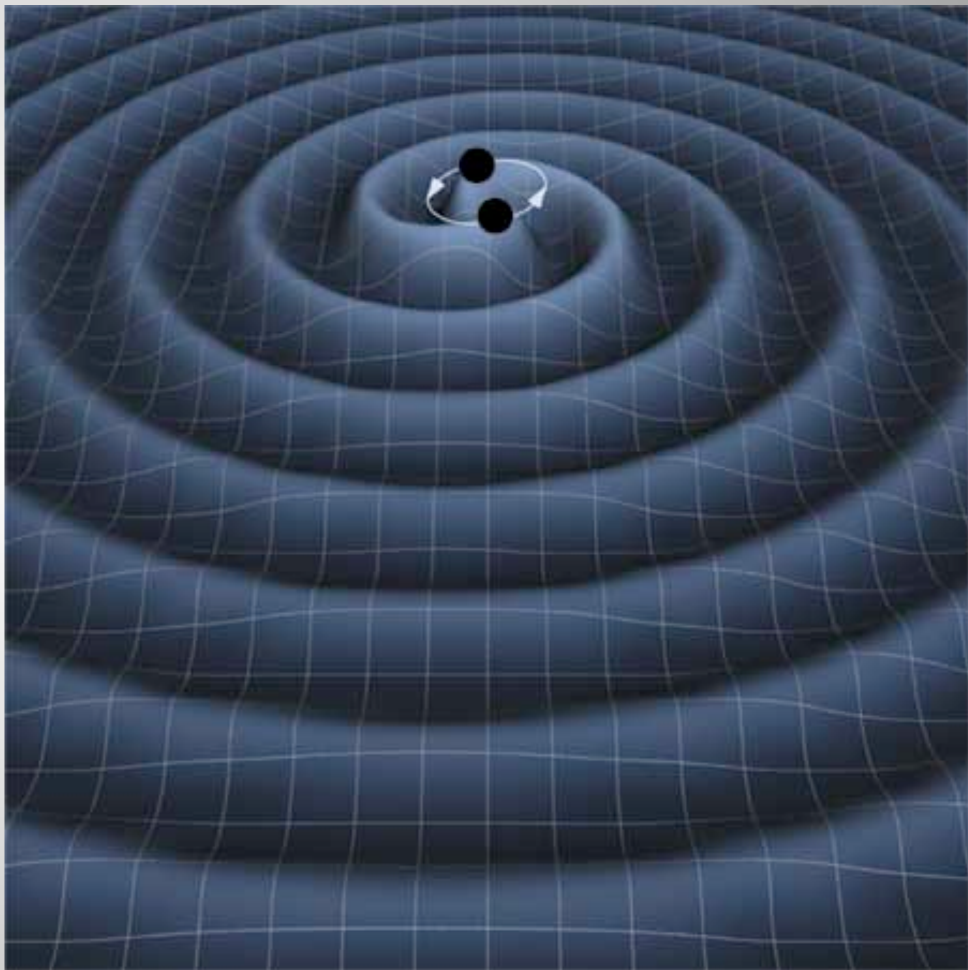
Current BH population is relatively unchanged from the seed population at low velocity dispersions



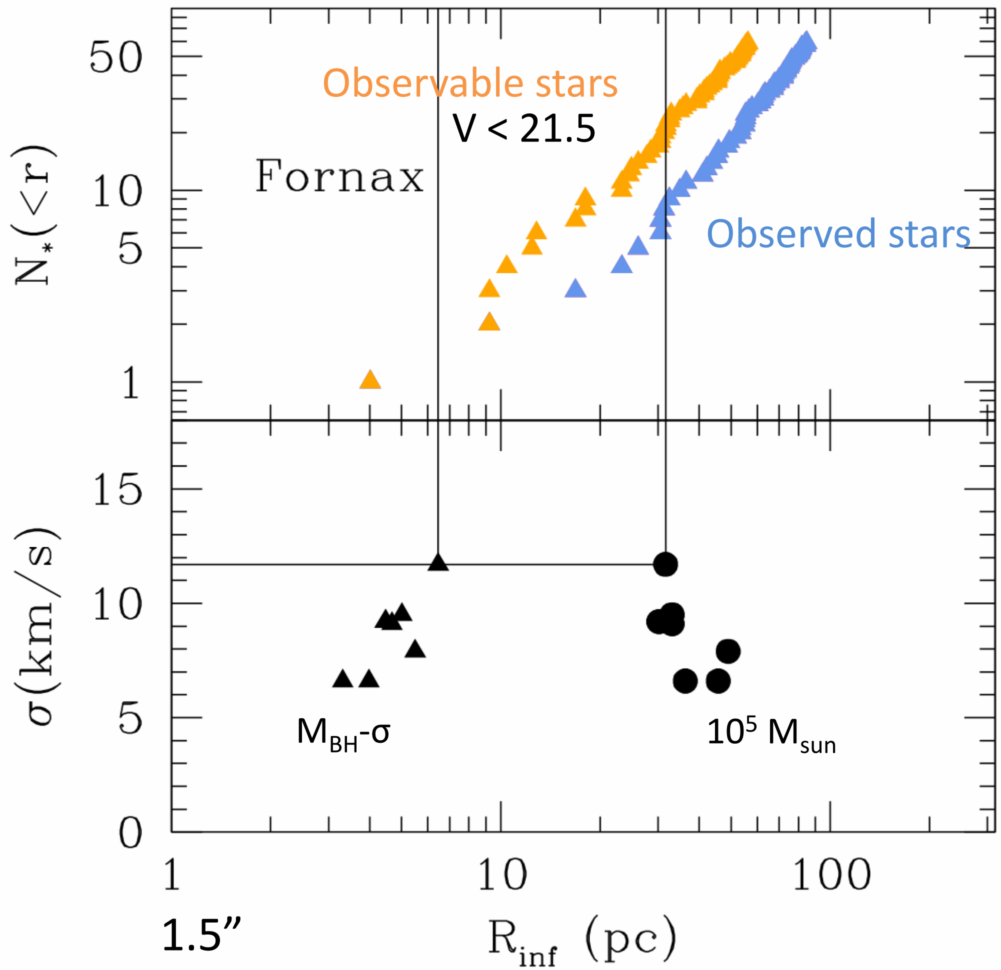
Van Wassenhove et al. 2010

Observables

- Gravitational waves from EMRIs with the Einstein Telescope
  (<< 1/year expected)
- BH accretion from stellar winds
  (likely unobservable, Dotti et al. in prep.)
- Stellar orbital dynamics



Observational Prospects



Van Wassenhove et al. 2010

For 10^5 M_{sun} BHs, a few tens of orbits are available, but the MBHs are rare

Pop III BHs are not observable, but are common

$$M(r < R_{\rm inf}) = 2M_{BH}$$