Massive black hole binaries in the cosmos

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Black Holes in the Universe

Stellar mass black holes

Massive black holes

Something in between?

Figure credit: M. Colpi
The characteristic strain is given by:

\[ f \sim \frac{c}{2\pi R_s} \sim 10^4 \text{Hz} \frac{M_\odot}{M} \]
What can GWs do for MBHs?

What can we infer about the black hole population from the full set of events/background observed by LISA or PTAs?

Use observed distribution of source parameters to compare with models. Which model provides the better explanation of the data?

Arun+2008, Sesana, Gair, Berti, MV 2011; Sesana 2008, 13; Ravi+2012, 15; Kulier+14; McWilliams+14
Massive black holes and gravitational waves

How many galaxies host MBHs
  ➜ when, where, how they form

How MBHs grow in mass over time
  ➜ accretion vs MBH-MBH mergers

How long it takes for MBHs to merge in halo/galaxy merger
  ➜ dynamics of MBHs in mergers
The formation of massive black holes

1. **Dark matter**
   - Gas

2. **Gas**
   - Globally unstable gas inflows towards the galaxy center and a supermassive star forms
   - Locally unstable gas flows towards the galaxy center
   - Star cluster + stellar BHs
   - Gas inflow: increase of the escape velocity

3. **First stars**
   - Maybe one star per galaxy, up to hundred times larger than the sun
   - Stellar mass BHs merge, into a BH ~500-1000 solar masses

4. **Gas**
   - Fragments into stars, and a dense star cluster forms
   - Stellar BHs merge, into a BH ~500-1000 solar masses
   - Gas-driven collapse
   - The black hole swallows the envelope growing up to a million solar masses
   - Remnants of the first stars

5. **Stellar mergers in nuclear star clusters**
   - The stellar core collapses into a small black hole, embedded in what is left of the star
   - Stars merge into a very massive star, that collapses into black hole ~1000 times more massive than the Sun

Adapted from MV 2012
Massive black hole “seeds”

- Primordial black holes
- Cosmic string loops
- Remnants of the first stars
- BH mergers in nuclear clusters
- Stellar mergers in nuclear star clusters
- Gas-driven collapse

![Graph showing the distribution of massive black hole seeds](image-url)
The mass and frequency in galaxies of MBH seeds is a key ingredient for understanding the shape of the redshift and mass distributions of the merger rate.
The evolution of black holes in galaxies
Massive black holes and gravitational waves

MBHs grow along with galaxies through accretion and MBH-MBH mergers

LISA can see black holes at very very early cosmic times: when they form
The journey of two black holes

Gravity

Dynamical Friction

~100 Mpc (cosmology)

~100 kpc - 1 kpc (galaxy mergers)

~1 kpc (binary formation)

~1 millipc (BH merger)

Gas torques? Stellar scattering? Last pc problem

~1 kpc - 1 pc (binary formation)

Courtesy of Hugo Pfister
Summary

A combination of electromagnetic probes and gravitational waves are a unique way of probing massive black hole formation, evolution and dynamics.

Full “merger rate” predictions still have large uncertainties – be careful when you pick a merger rate!