Multimessenger Signatures of Intermediate Mass Black Holes

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How do you build a SMBH?

Problem: SMBHs have erased their seed history
IMBHs in dwarf galaxies

• How do they get there? And when?

• Are they the seeds to SMBHs in massive galaxies?
Two places to look:

Dwarf Galaxy AGN

RGG 118, Baldassare+ 17

Off-nuclear / halo sources

HLX-1, Mapelli+ 13
Tool: Cosmological Simulations

- **code**: ChaNGa
- **Four zoom-in dwarf volumes**
  
  “Marvel-ous Dwarfs”

- **Four zoom-in MW-like simulations, including copious dwarf satellites**
  
  “DC Justice League”
Seed BH Formation History

Peak of seed formation is $z \sim 10 - 20$

Bellovary+19
BHs form in halos with total mass of $10^{8-9} \, M_\odot$.

These are small!
Occupation Fraction at $z = 0$

Total (halo) Mass

Stellar Mass

Bellovary+ 19
Dwarf BHs do not accrete much

- Fraction of accreted gas mass / total mass
- Dwarf galaxies hosting MBHs give clues to original seed BH masses

Bellovary+19
IMBHs merge! Gravitational Waves!

LISA! The Laser Interferometer Space Antenna
What will LISA find?

Intermediate Mass Black Hole mergers at $10 < z < 20$
BH mergers in dwarf galaxies

$0 > z > 12$

(mostly)

$0.2 > q > 1$

Bellovary+19
Merging BHs including massive galaxies

Very few mass ratios are 1:1!

Most are \( \sim 1:50 \)
AND NOW FOR SOMETHING COMPLETELY DIFFERENT
Diversion: Let’s talk about planets

- Protoplanets migrate in the disk, depending on how they are torqued
- There are “sweet spots” where the torques balance

MIGRATION TRAPS
Back to black holes, and migration traps

- Protoplanets → stellar mass black holes
- Protoplanetary disk → SMBH accretion disk
- Black holes can migrate too!

→ MIGRATION TRAPS

Result → lots of black hole mergers, making bigger and bigger black holes?!

McKernan+ 12, 18, Bellovary+ 16
Gravitational Wave Implications

• **LIGO**: Provides explanation for large masses

• **LISA**: Runaway growth in disk creates an IMBH ($10^2-10^3 \, M_\odot$), if merge with SMBH we get an EMRI/IMRI (McKernan+ 12)

• **EM Counterparts**… the AGN wins 😞 but target searches on AGN instead of galaxies for improved efficiency! 😊

See Saavik Ford’s talk on Wednesday in the MMA-SAG session
Conclusions

• Dwarf and wandering SMBHs can give us clues to the original seed mass

• Few SMBH mergers in low mass galaxies environments are 1:1

• AGN disks can also be places to seek IMBHs
Extra slides
BHs in Simulations

• Form at mass of 50,000 $M_\odot$ from dense, collapsing, low-metallicity, low-$H_2$ gas

• Dynamical friction (Tremmel+ 15)

• Accretion: modified Bondi-Hoyle

• Feedback: thermal (Tremmel+ 17)
Low Luminosities

Simulated Galaxies
- Maximum Luminosity reached
- z=0 luminosities

Observed Galaxies
- Local Dwarf AGN
- High z IMBH candidates (Mezcua +18)

Graph showing the relationship between redshift and luminosity over time. The graph includes data points for simulated and observed galaxies.

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Intermediate BH merger signatures