Astrophysics with EMRIS, IMRIS, and XMRIS

Formation, evolution, and the information encoded in the gravitational wave signatures

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Apr. 3, 2025

Ten Years to LISA @Jet Propulsion Laboratory

Inspiraling systems: EMRIs, IMRIs, XMRIs

Extreme mass-ratio inspirals (EMRIs): $q = M/m \sim 10^5 - 10^7$

Super Massive Black Hole (SMBH) + Stellar mass black holes (BH) / Neutron stars (NS)/ White dwarfs (WD)

e.g. Rubbo+2006; Amaro-Seoane+2007; Berry+2019

Intermediate mass-ratio inspirals (IMRIs): $q \sim 10^1 - 10^5$

Intermediate mass black hole (IMBH) + SMBH

or

IMBH + BH

e.g. Coleman+2002,Gair+2011; Konstantinidis+ 2013; Haster+2016; Amaro-Seoane+2018

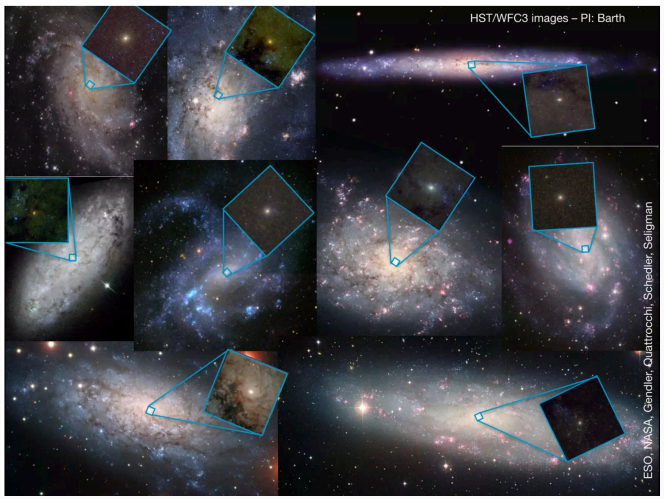
Extremely large mass-ratio inspirals (XMRIs): $q \sim 10^8$

SMBH + Brown dwarf (BD)

Amaro-Seoane,2019

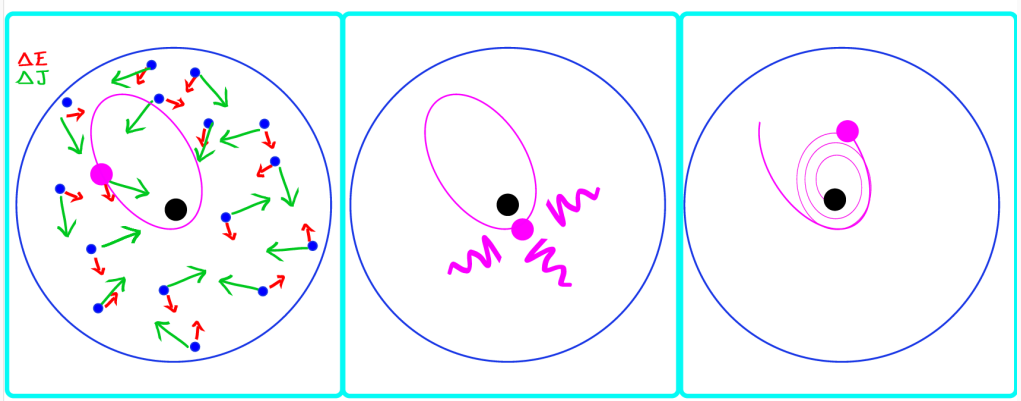
Formation environment and mechanisms

Where are inspirals formed?



Galactic Nuclei and Globular Clusters where density can exceed $10^6\ M_\odot pc^{-3}$

Main formation process: 2-body relaxation



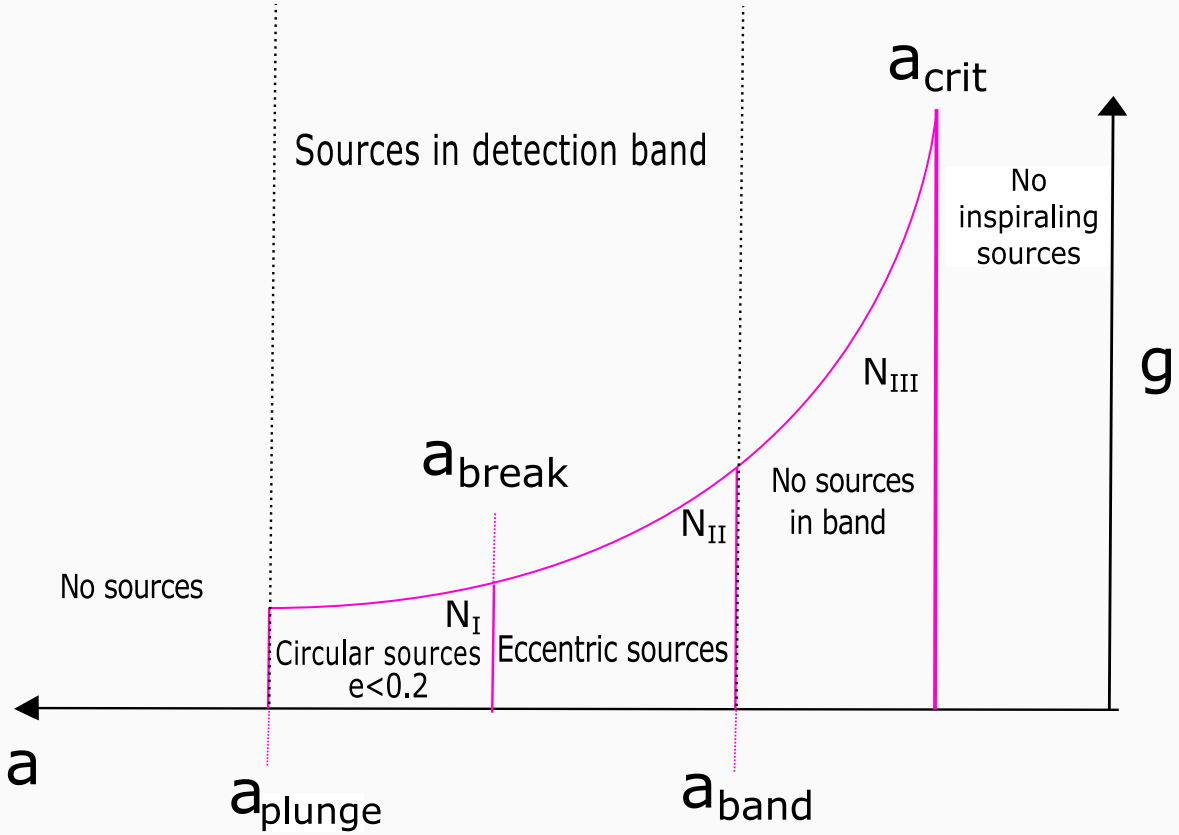
The orbit reaches a critical semimajor axis $a_{\rm crit}$ such that

$$T_{\rm GW} \lesssim T_{\rm rlx}(a_0) \times (1 - e_0^2). \qquad (1)$$

Hopman & Alexander 2005, Amaro-Seoane+2007

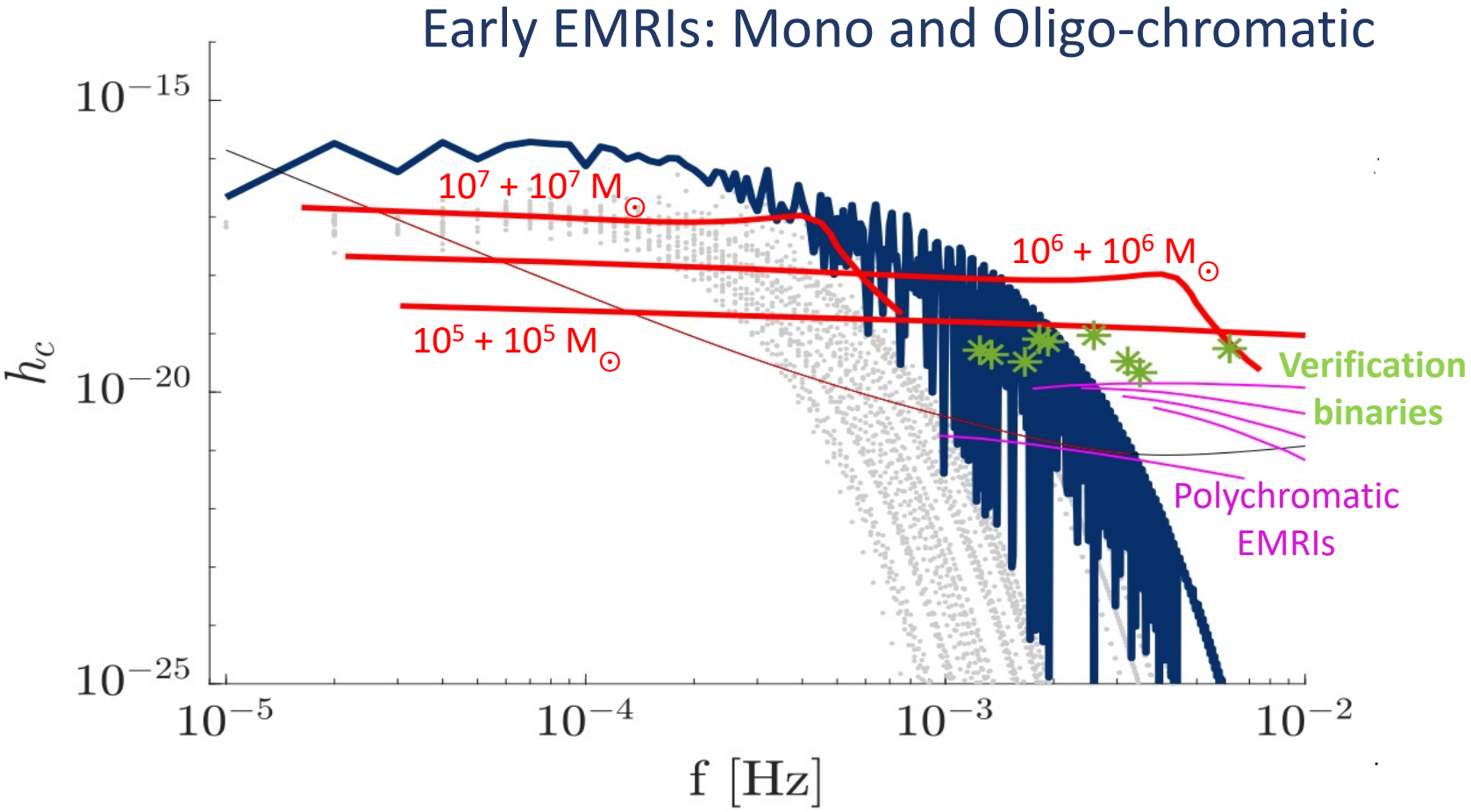
Other channels: Few body interactions

Number of detectable sources



Amaro-Seoane+2019

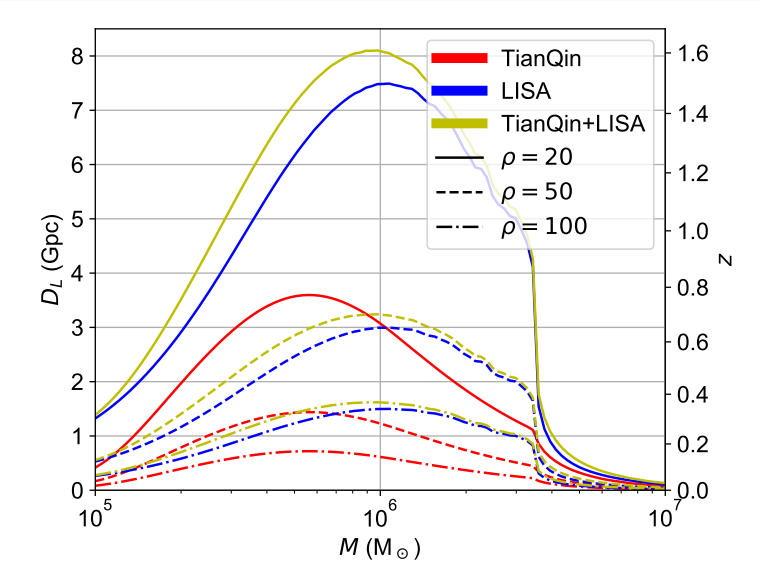
Detectable sources: EMRIs

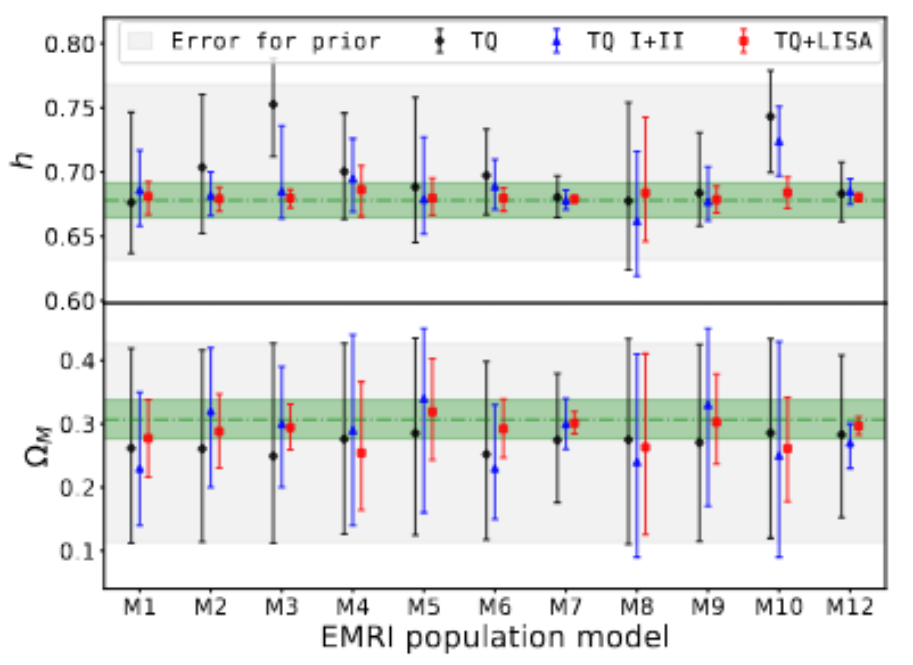


Amaro-Seoane+2025

The Information Encoded in the Gravitational Wave Signatures

Cosmology with EMRIs

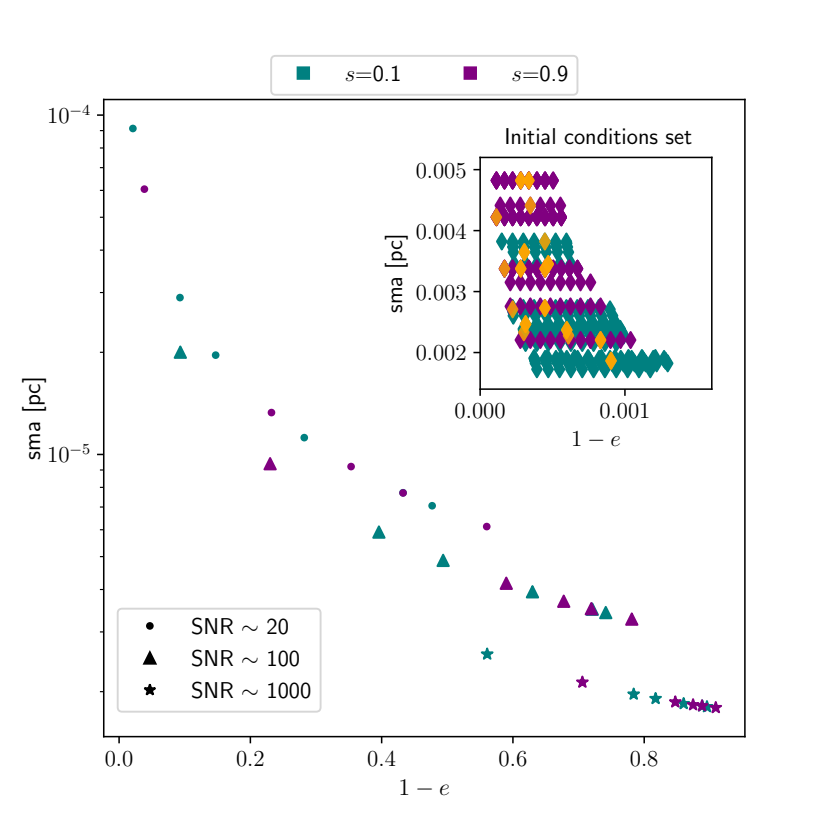


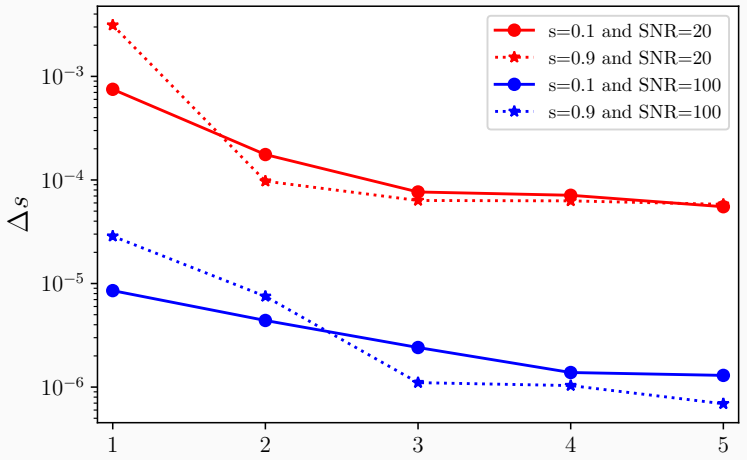


- EMRIs detectable to cosmological redshifts of $\lesssim 1.6$
- use as dark standard sirens to constrain Hubble constant $\delta h \sim 1\,\%$ and matter density $\delta\Omega_M \sim 10\,\%$

ATO+2024, Zhu+2024

Measuring SgrA* with XMRIs

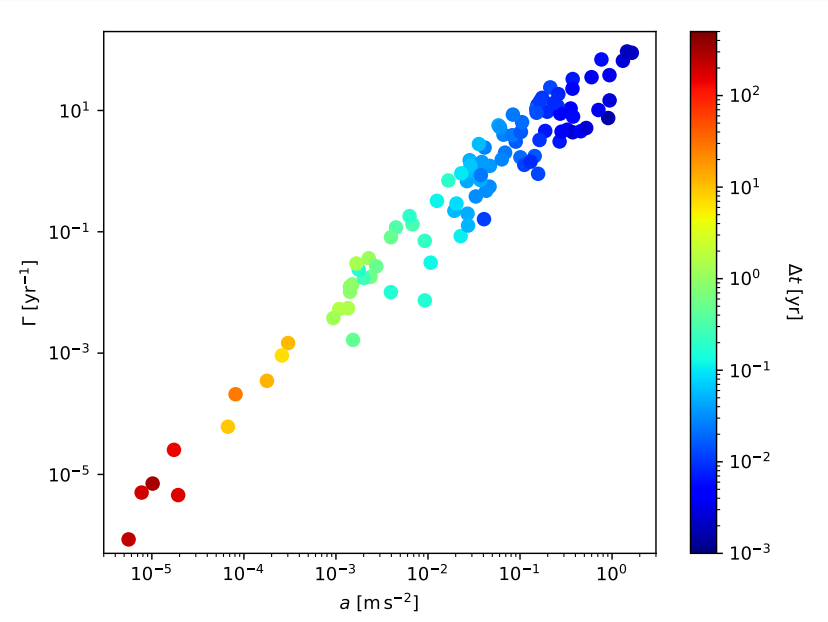


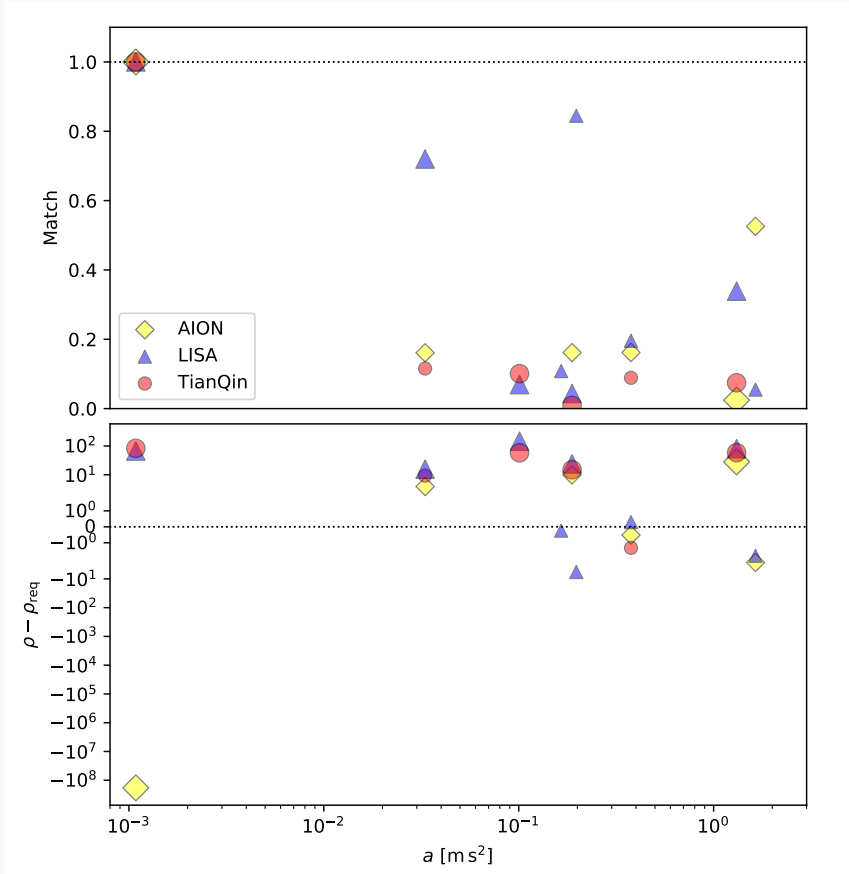


- multiple detectable XMRIs around SgrA*
- measure mass and spin of SgrA*: $\Delta M \sim 10^{-2}\,\mathrm{M}_\odot$ and $\Delta s \sim 10^{-5}$

VVA+2023, VVA+2024

Studying Globular Clusters with IMRIs





- IMRIs undergo frequent weak encounters
- acceleration induces phase shift leading to significant mismatch

ATO+2025