Stellar- and intermediate-mass black holes in star clusters and galactic nuclei: dynamics and implications for GW astronomy

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ELTE Seminar

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Research project: **The evolution of black holes from stellar to galactic scales**

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Research project: ~~**The evolution of black holes from stellar to galactic scales**~~

Chasing B(H)ATS: Black Holes At all The Scales

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Research project: **~~The evolution of black holes from stellar to galactic scales~~**

Chasing B(H)ATS: Black Holes At all The Scales

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Q&A

How, when, where do black holes form in star clusters?

How do they pair and merge?

What about intermediate mass black holes in globulars?

How do they get into galactic nuclei?

Can we distinguish BHs merging in different environments?

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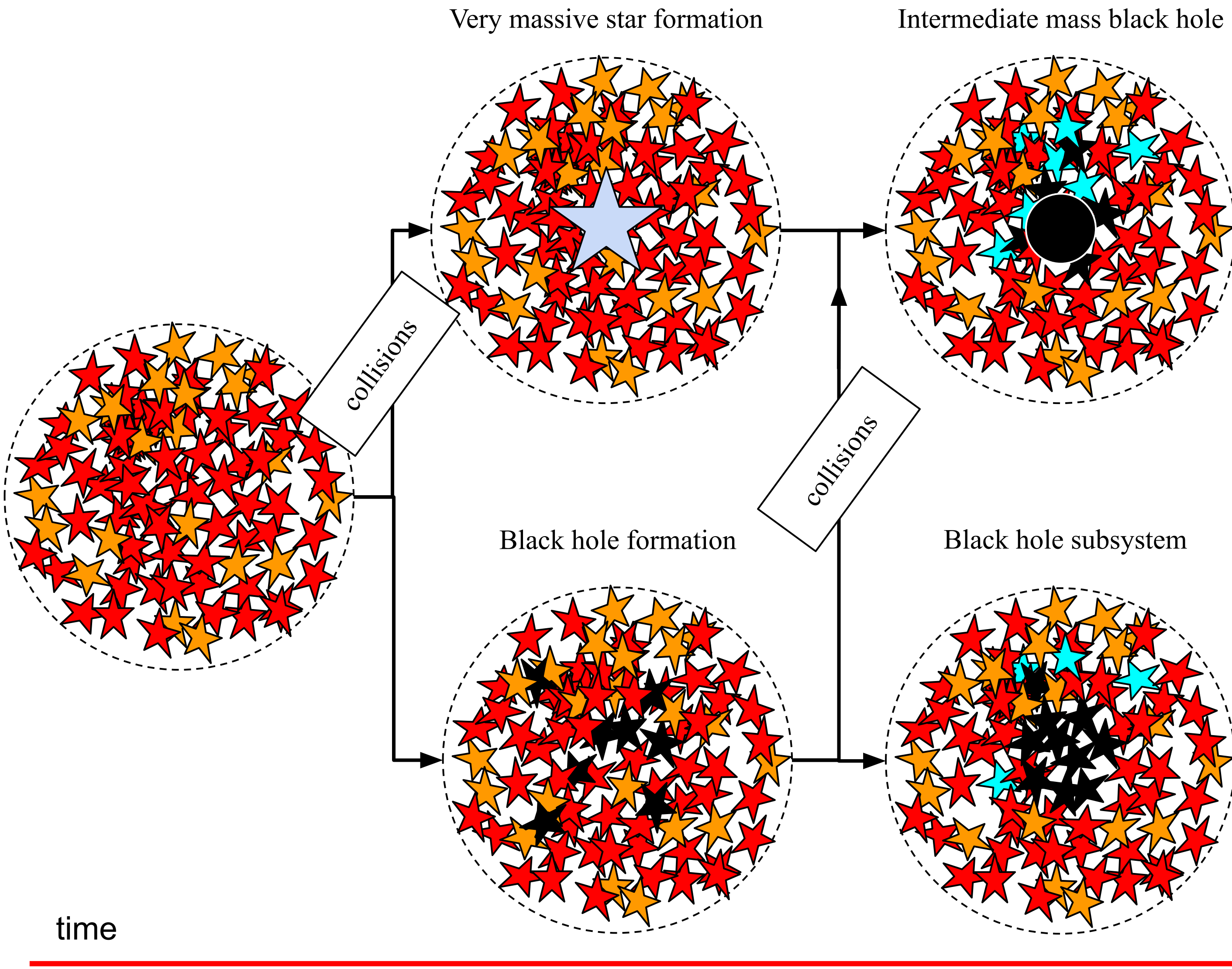


Different observational signatures

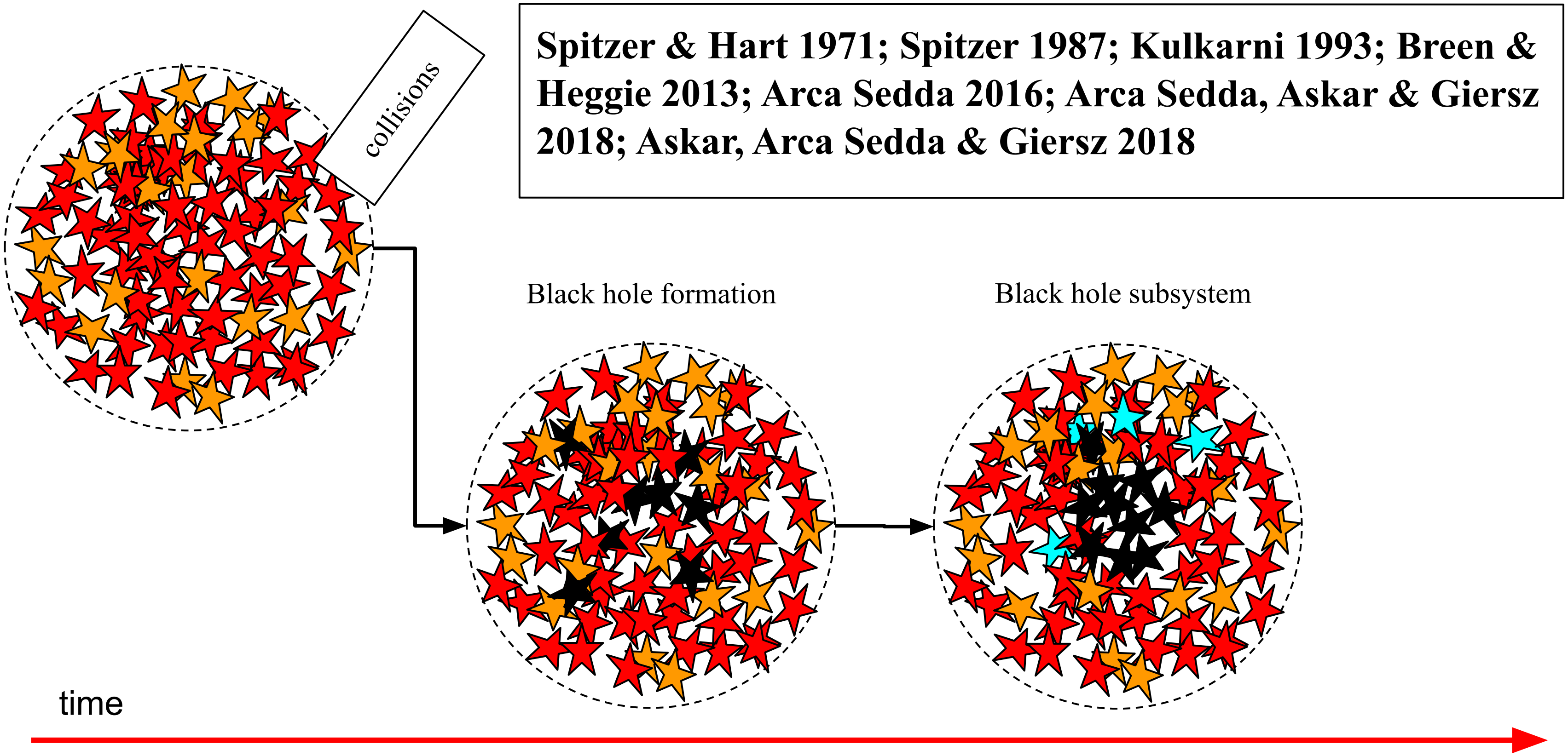
Baumgardt+(2013)
Lutzgendorf + (2013)
Arca Sedda (2016)
Zocchi+(2017)
Arca Sedda, Askar & Giersz (2018)
Askar, Arca Sedda & Giersz (2018)

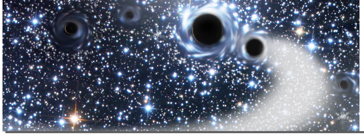
Different GW signals

Amaro-Seoane 2018
Fragione + 2018
Arca Sedda, Li & Kocsis (2019)
Arca Sedda & Benacquista (2019)
Askar + (2017)
Belczynski + (incl. AS, 2018)
Samsing & D'orazio (2018)
Banerjee (2017,2018)

What is a Black Hole Subsystem?

Spitzer & Hart 1971; Spitzer 1987; Kulkarni 1993; Breen & Heggie 2013; Arca Sedda 2016; Arca Sedda, Askar & Giersz 2018; Askar, Arca Sedda & Giersz 2018





What is a Black Hole Subsystem (BHS)?

Arca Sedda, Askar & Giersz, 2018, MNRAS
Askar, Arca Sedda & Giersz, 2018, MNRAS

What did we use?
The MOCCA SURVEY DATABASE: over 2000 Monte Carlo models of Globular clusters with different properties

What did we select?
Our subsample consists of GC models retaining N>10 BHs at 12 Gyr

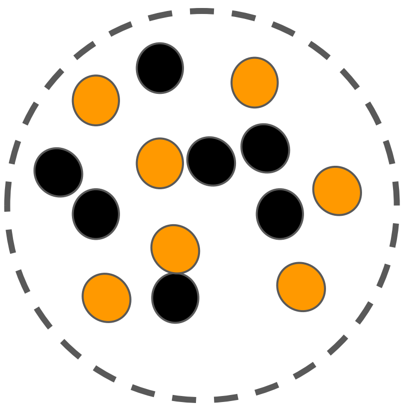
How did we define a Black Hole Subsystem (BHS)?
We define the typical BHS radius as that enclosing half mass in BHs and the remaining in stars:

BHS mass:

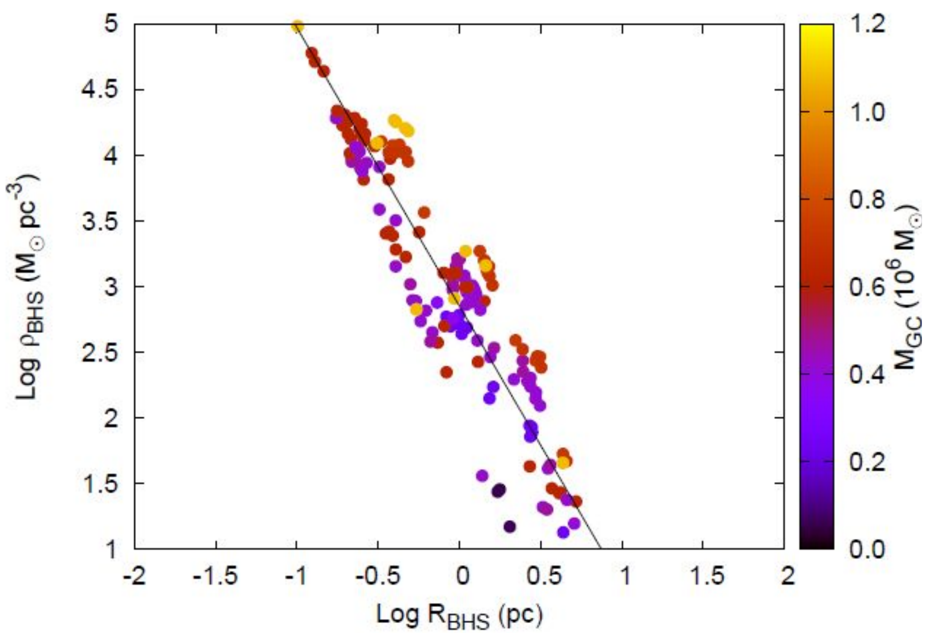
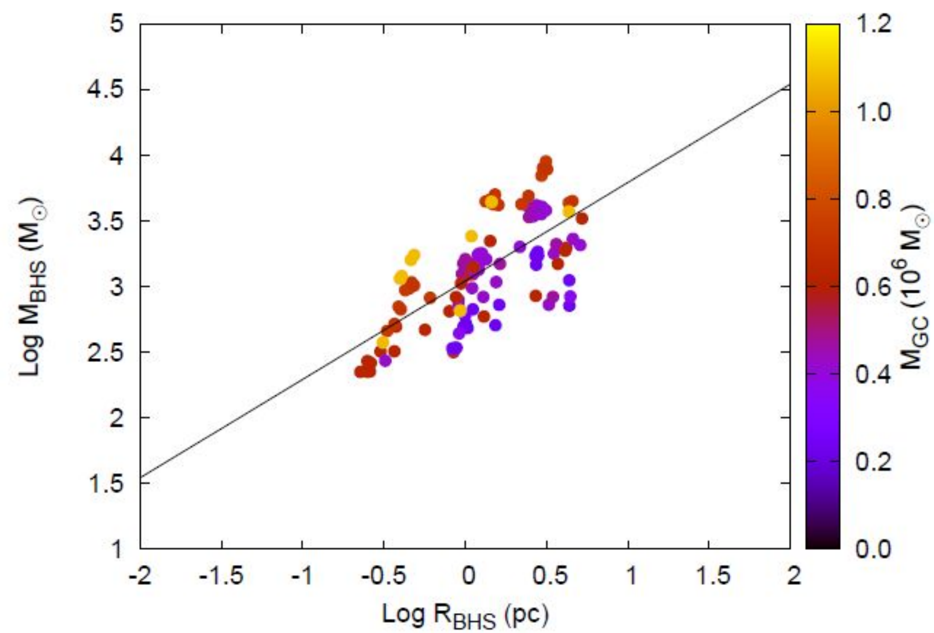
$$M_{\rm BHS}(r_{\rm BHS}) = 0.5 M_{\rm GC}(r_{\rm BHS})$$

BHS density:

$$\rho_{\rm BHS} = M_{\rm BHS}/r^3_{\rm BHS}$$



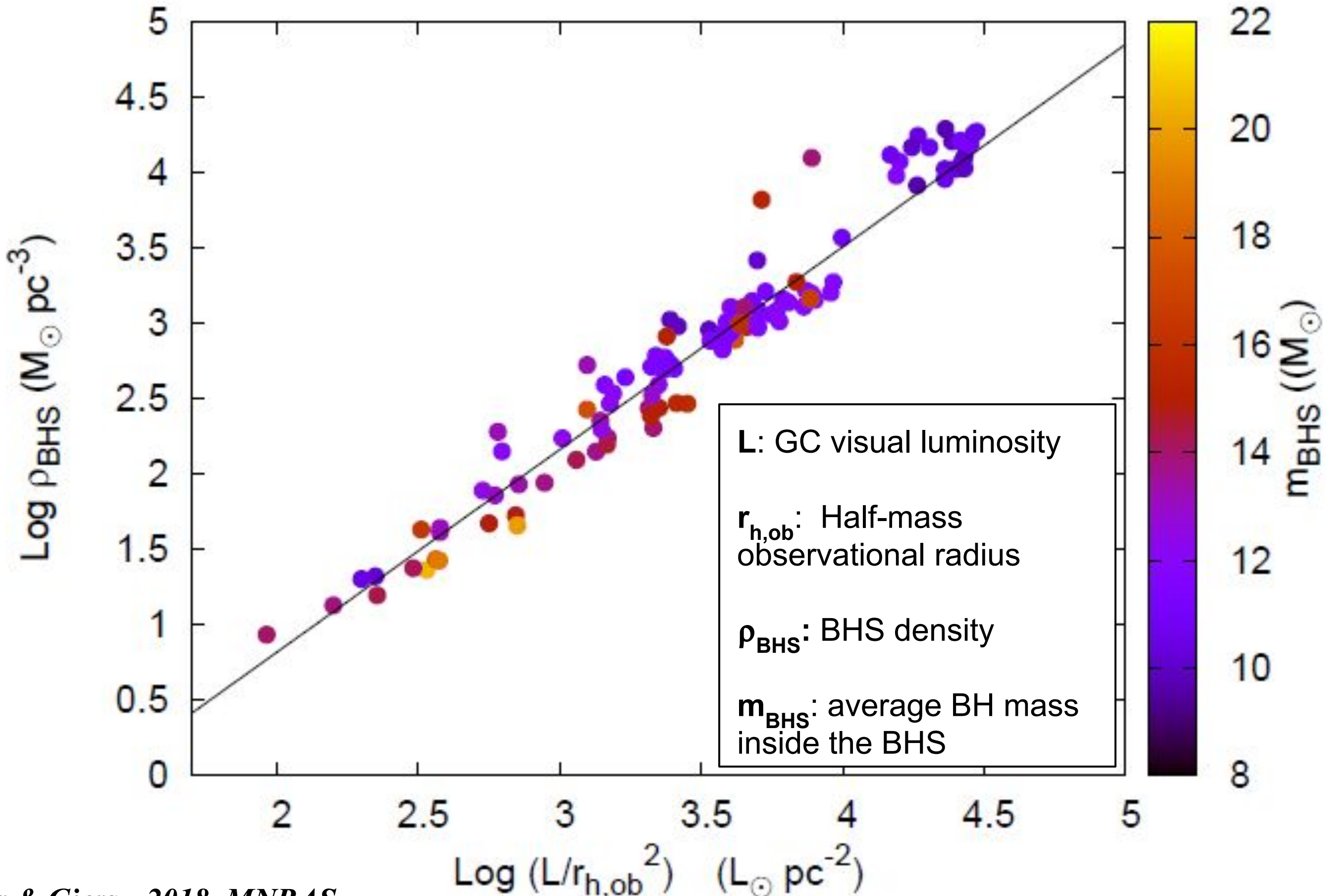
What is a Black Hole Subsystem (BHS)?

BHS Radius	BHS Mass
	
$$\mathrm{Log}\left(\frac{\rho_{\rm BHS}}{\mathrm{M}_\odot\ \mathrm{pc}^{-3}}\right) = \alpha \mathrm{Log}\left(\frac{R_{\rm BHS}}{\rm pc}\right) + \beta,$$ with $\alpha = -2.11 \pm 0.07$ and $\beta = 2.86 \pm 0.03$.	$$\mathrm{Log}\left(\frac{M_{\rm BHS}}{\mathrm{M}_\odot}\right) = \alpha \mathrm{Log}\left(\frac{R_{\rm BHS}}{\rm pc}\right) + \beta,$$ with $\alpha = 0.77 \pm 0.07$ and $\beta = 3.05 \pm 0.03$
Propagated error: ~ 25-31%	Propagated error: ~ 22-28%

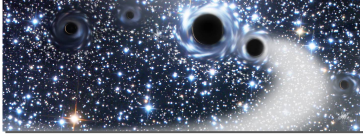
Arca Sedda, Askar & Giersz, 2018, MNRAS
Askar, Arca Sedda & Giersz, 2018, MNRAS

What is a Black Hole Subsystem (BHS)?

A fundamental plane for BHSs

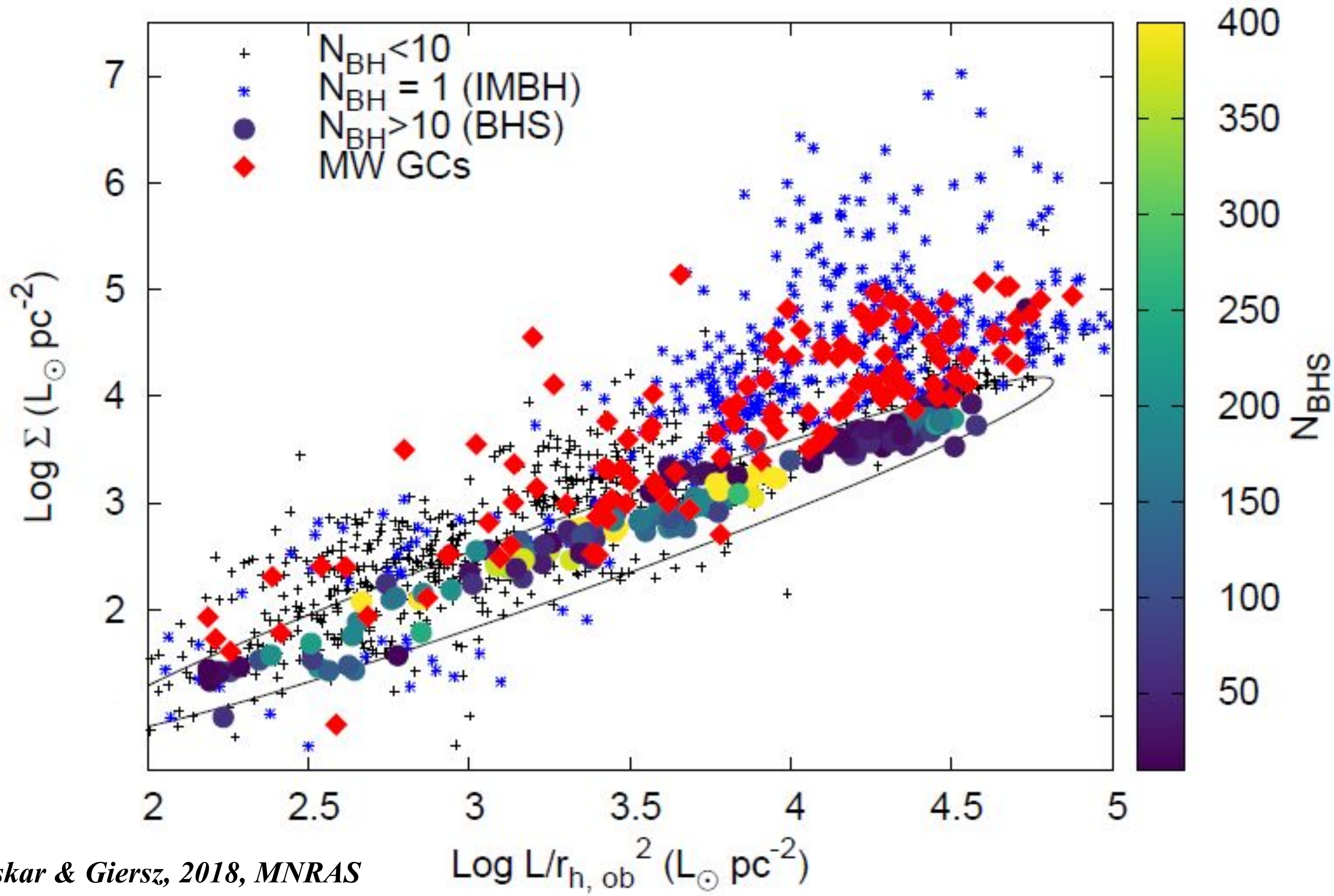


Arca Sedda, Askar & Giersz, 2018, MNRAS
Askar, Arca Sedda & Giersz, 2018, MNRAS



What is a Black Hole Subsystem (BHS)?

How do models and observations look like together?



Arca Sedda, Askar & Giersz, 2018, MNRAS
Askar, Arca Sedda & Giersz, 2018, MNRAS

What is a Black Hole Subsystem (BHS)?

A fundamental plane for BHSs: 29 Galactic GCs harbouring BHSs

How is the selection made? →

- Half-mass radius
- Central velocity dispersion
- Total luminosity
- Visual magnitude

GC name	R_{BHS} (pc)	M_{BHS} ($M_\odot$)	N_{BH}	N_{BH} in binaries
NGC 4372	$0.89^{+0.28}_{-0.20}$	1027^{+342}_{-217}	85^{+37}_{-23}	8^{+17}_{-5}
NGC6101	$0.96^{+0.30}_{-0.21}$	1085^{+370}_{-234}	89^{+40}_{-24}	8^{+18}_{-5}
NGC3201	$0.64^{+0.19}_{-0.14}$	796^{+237}_{-152}	68^{+27}_{-17}	7^{+15}_{-5}

Arca Sedda, Askar & Giersz, 2018, MNRAS
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Q&A

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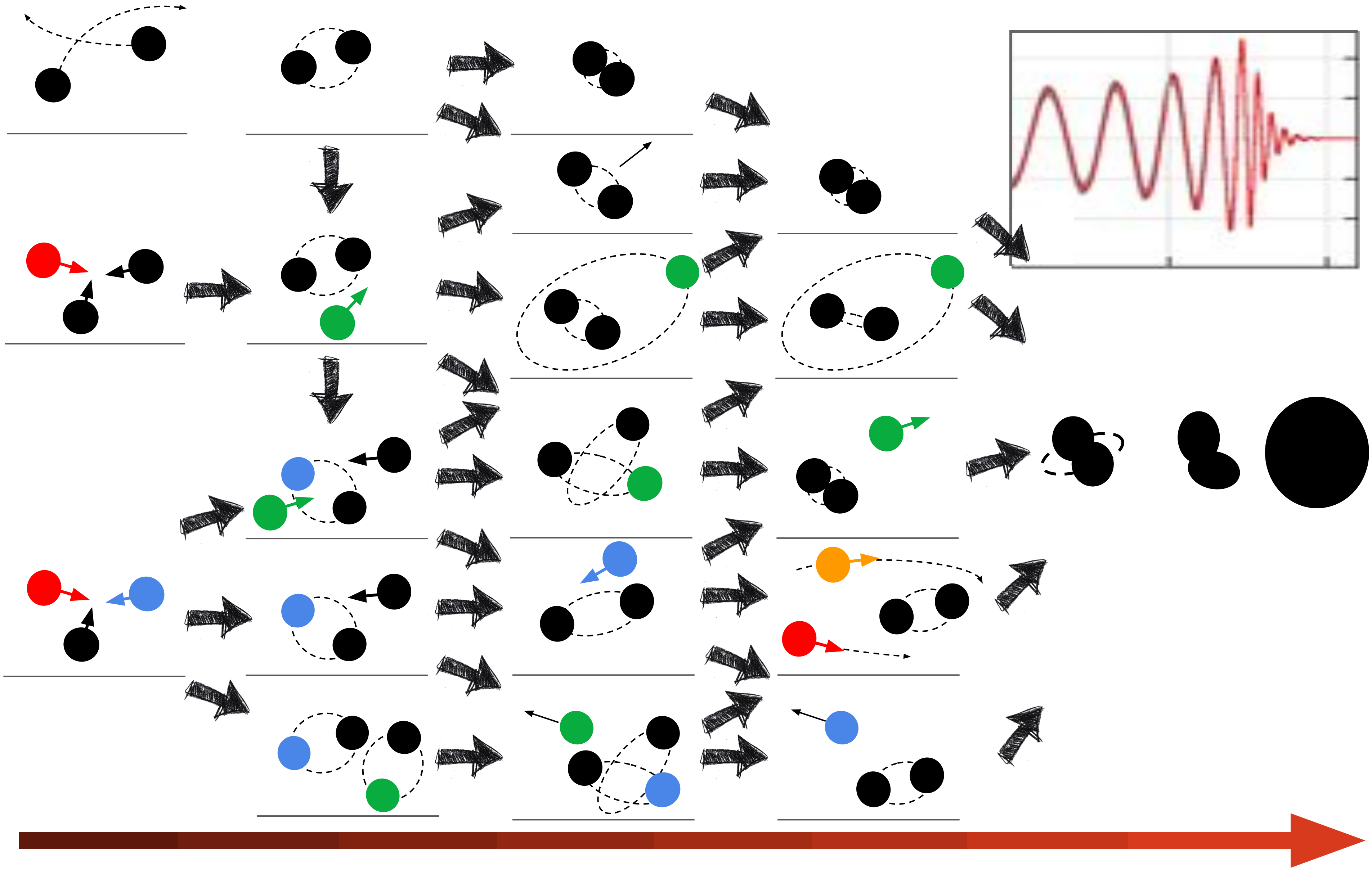
Stellar BH pairing and coalescence



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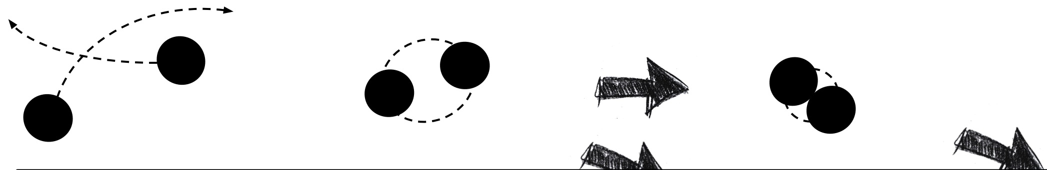
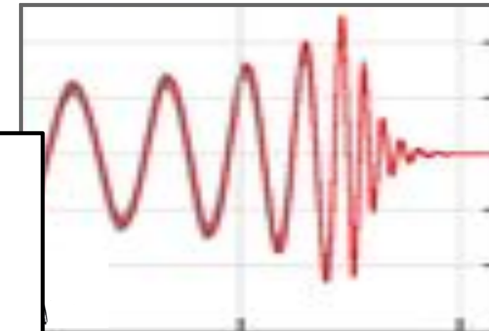


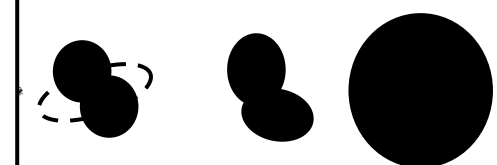


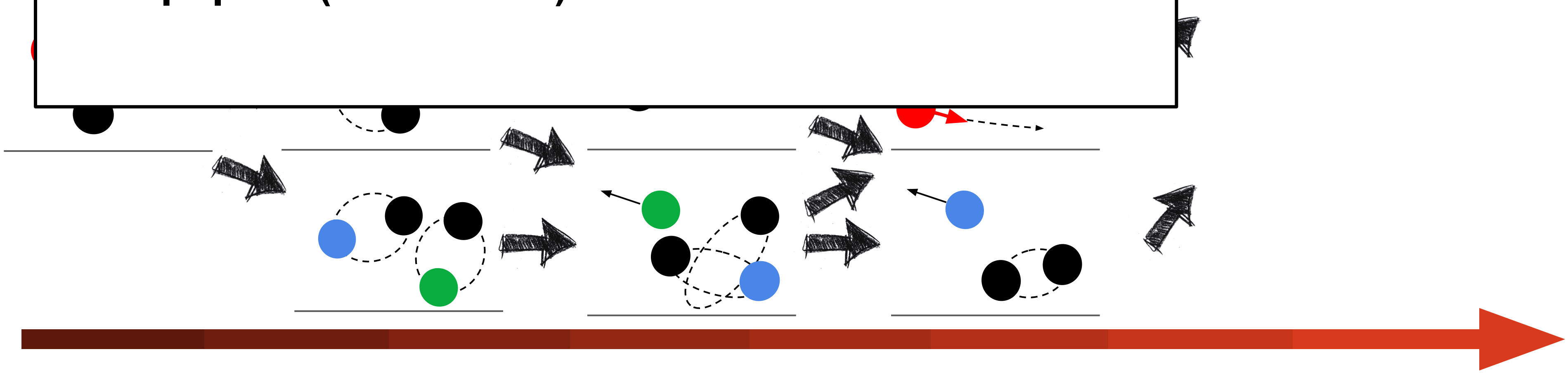
SEARCH ON NEW ADS:

full:"black hole" full:"merger" full:"star cluster"

RESULTS:

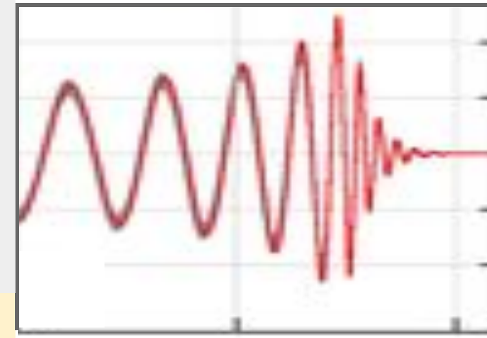
6130 papers (since 1973) **308749 citations**

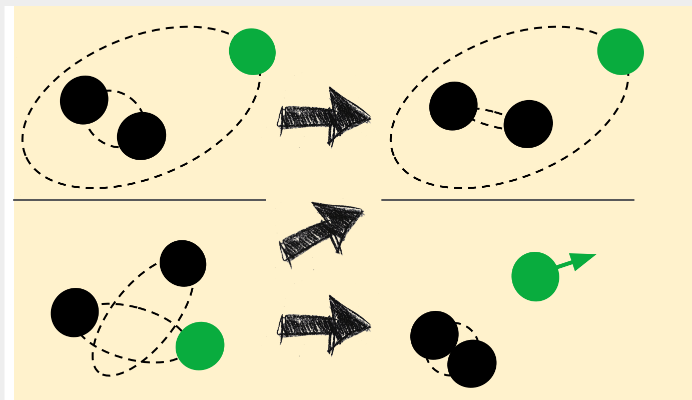


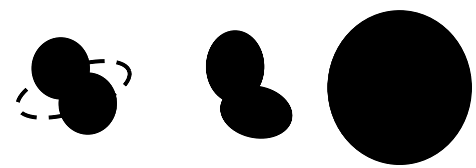


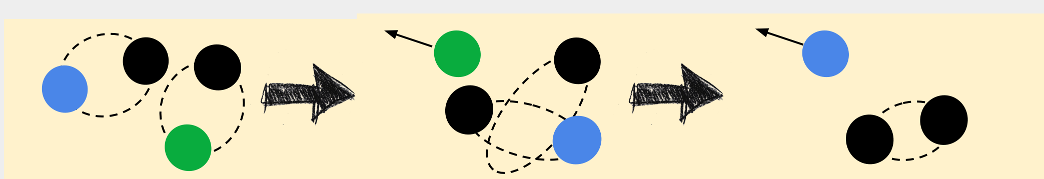
Stellar BH pairing and coalescence: evolution of non-hierarchical triples

Arca Sedda, Li & Kocsis, arxiv:1805.06458
Arca Sedda et al, in prep

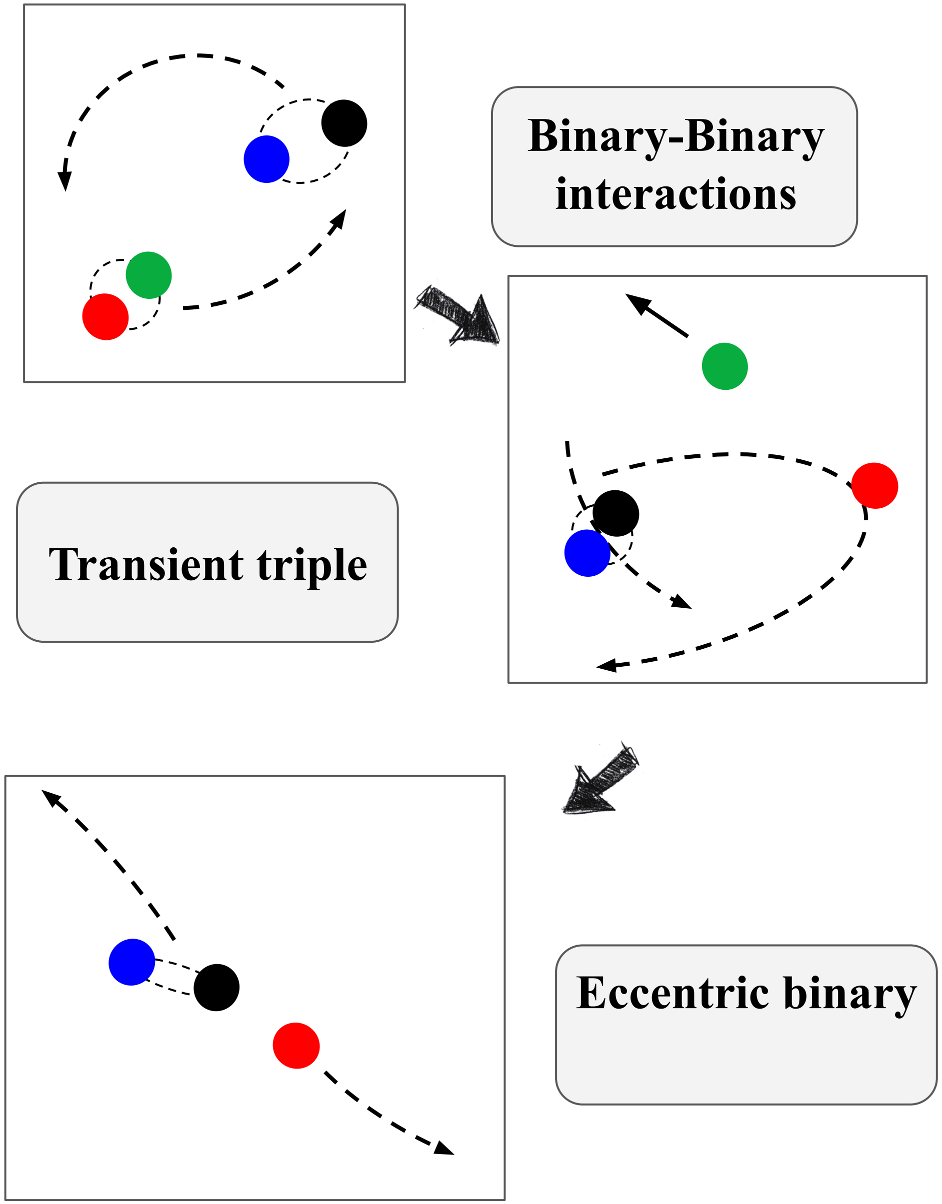








Stellar BH pairing and coalescence: evolution of non-hierarchical triples



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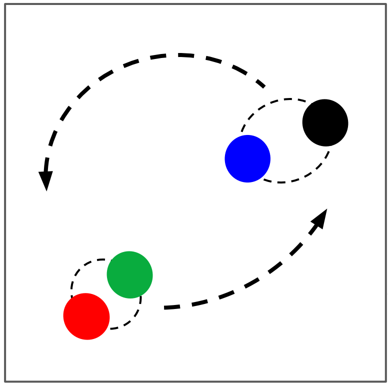
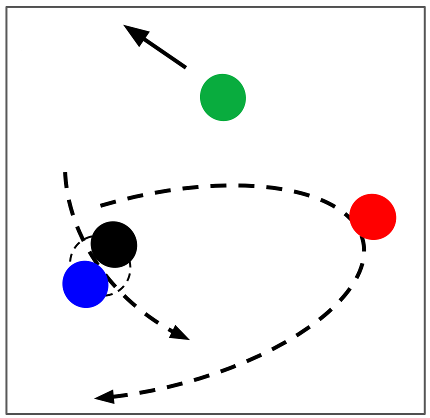
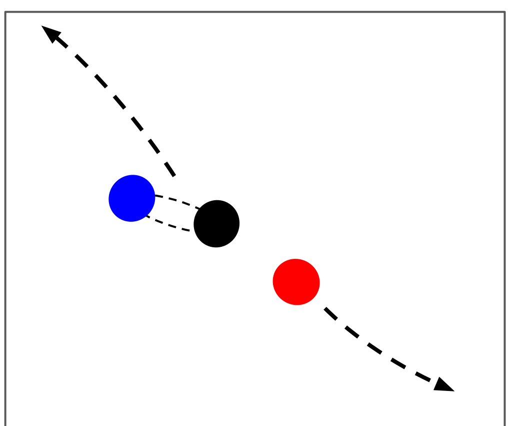


Binary-Binary interactions



Transient triple



Eccentric binary

Arca Sedda, Li and Kocsis, Arxiv: 1805.06458

Are BHB-BHB frequent?

MOCCA models: Monte Carlo models of GCs with realistic initial conditions.

Subsample: 172 models retaining >10 BHs after 12 Gyr
(Arca Sedda, Askar & Giersz 2018; Askar, Arca Sedda & Giersz 2018)

$$\boldsymbol{N_{4b} = 0.4(M_{GC})^{0.6}}$$

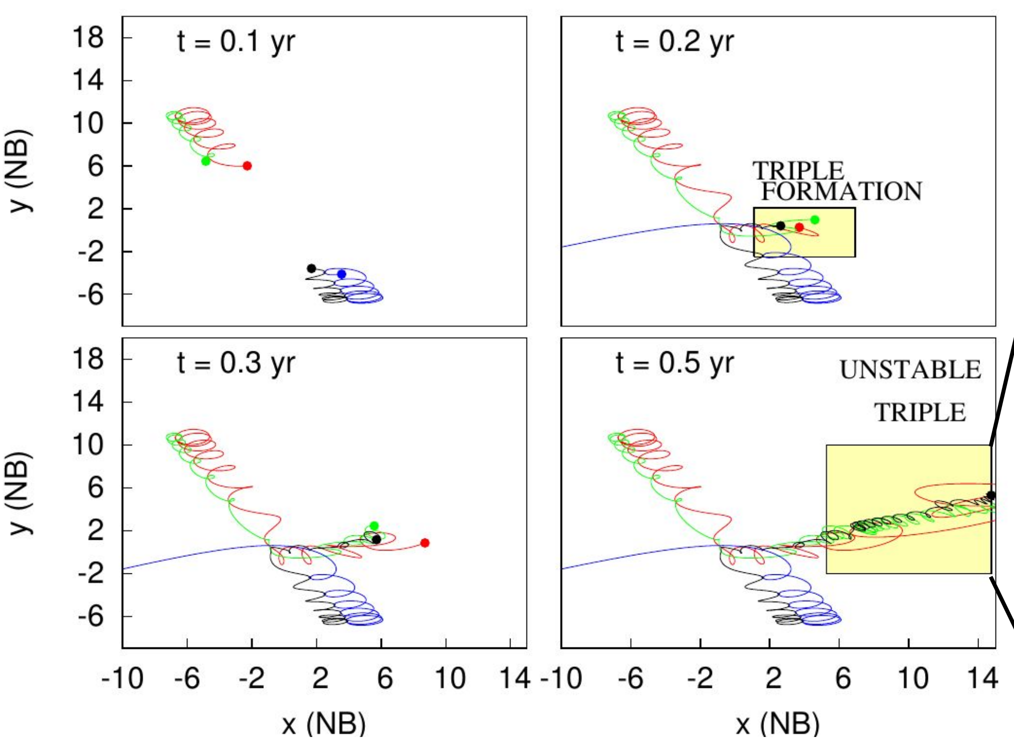
(i.e. 30-150 Gyr^{-1} for $M_{GC}=10^5$-$10^6 M_\odot$)

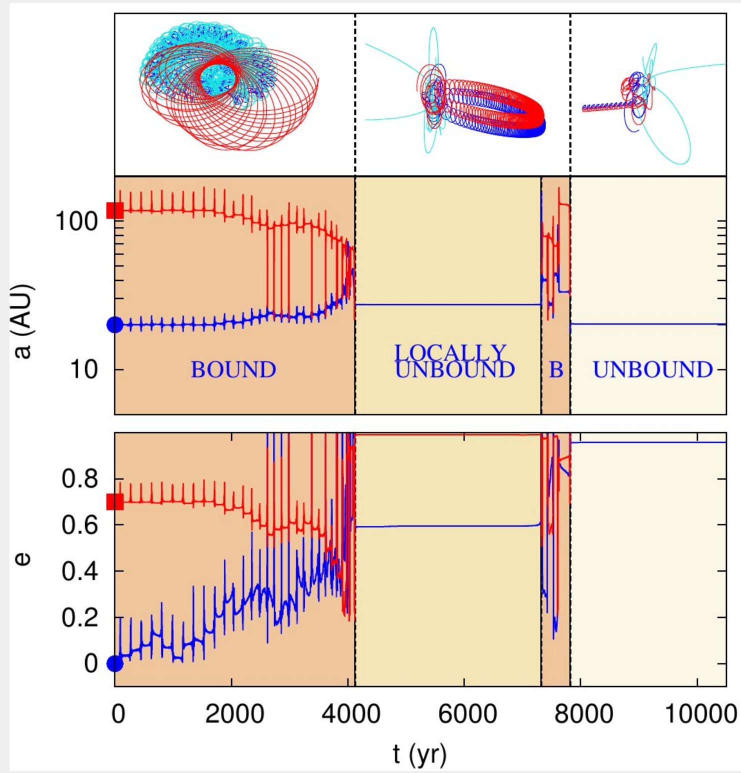
On average:

900 BHB-BHB interactions / 12 Gyr / GC

Stellar BH pairing and coalescence: evolution of non-hierarchical triples

Arca Sedda, Li and Kocsis, 2018, Arxiv: 1805.06458



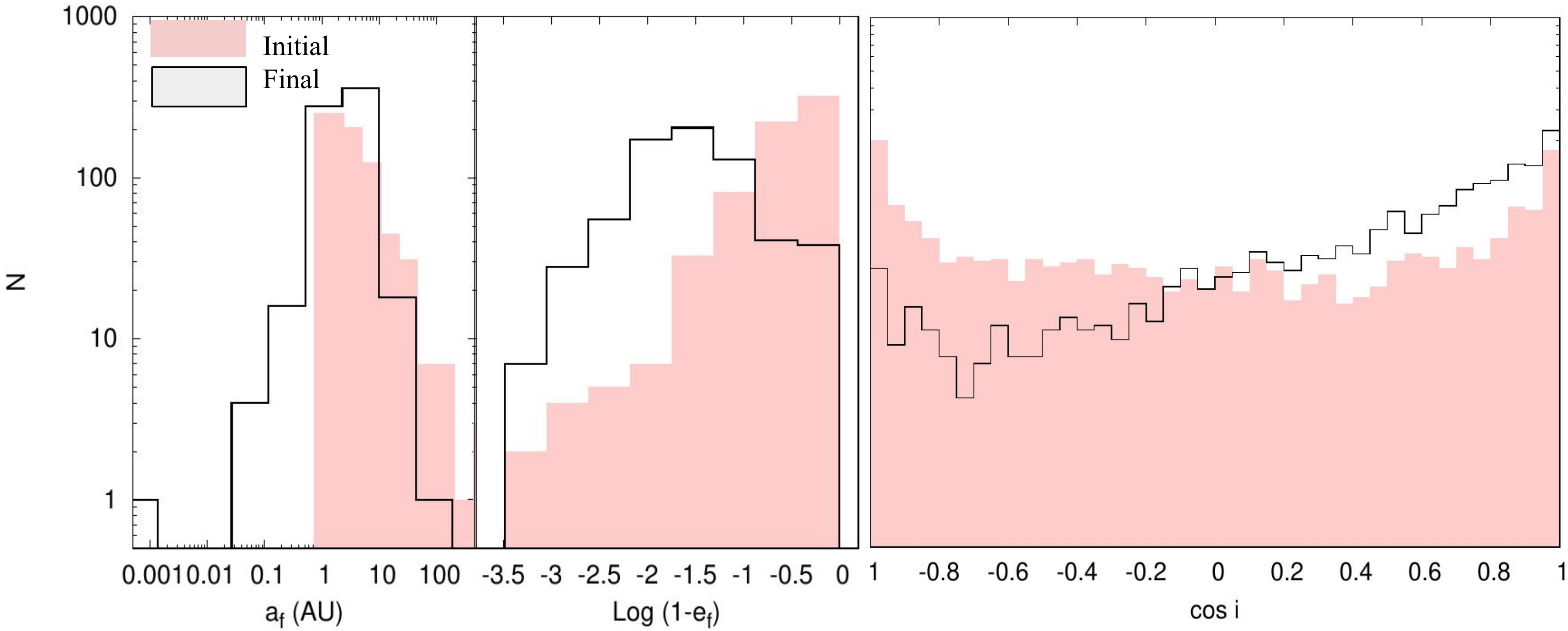


*Integration done with ARGdf (**Arca Sedda and Capuzzo-Dolcetta 2019**) and ARCHAIN (Mikkola and Tanikawa 1999, Mikkola and Merritt 2008)*

Stellar BH pairing and coalescence: evolution of non-hierarchical triples

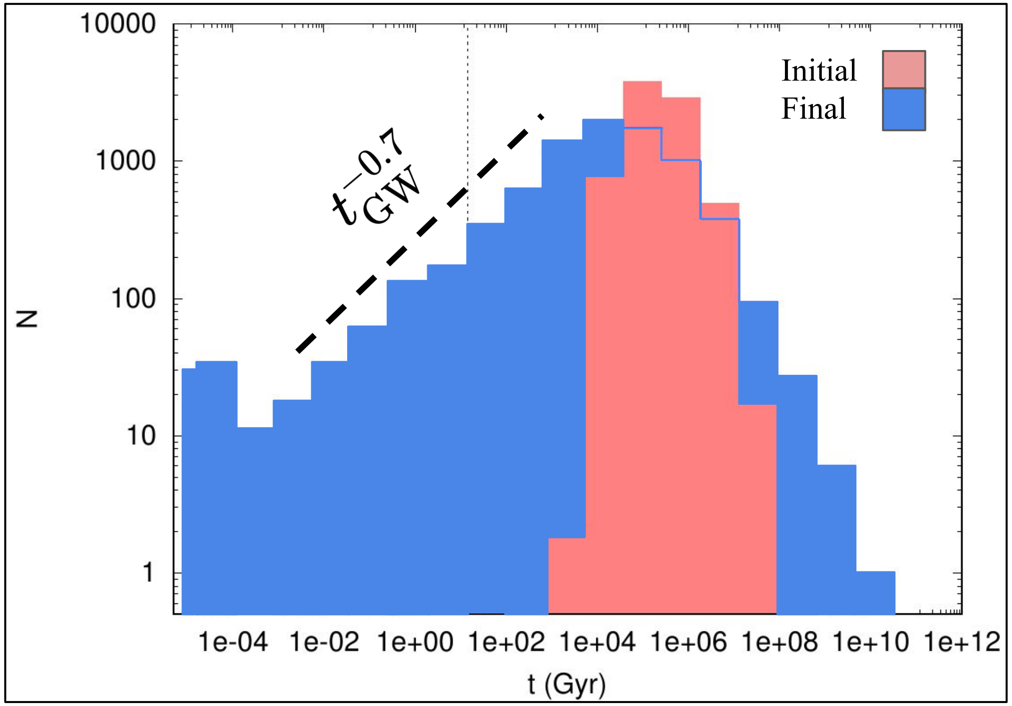
Triples:

get harder - more eccentric - prograde



Arca Sedda, Li & Kocsis, Arxiv: 1805.06458
Arca Sedda et al, in prep.

Stellar BH pairing and coalescence: evolution of non-hierarchical triples



- Semi-major axis ~10AU
  $P_{\rm merge} = 0.25\%$
- Semi-major axis ~ 1AU
  $P_{\rm merge} = 8.5\%$
- Triples tend to evolve toward co-rotation
- Triples flipping from co to counter rotation shrink more efficiently
- The distribution of GW timescales follows a powerlaw

$$\frac{{\rm d}N}{{\rm d}t_{\rm GW}} \propto t_{\rm GW}^{-0.7}$$

Arca Sedda, Li & Kocsis, Arxiv: 1805.06458
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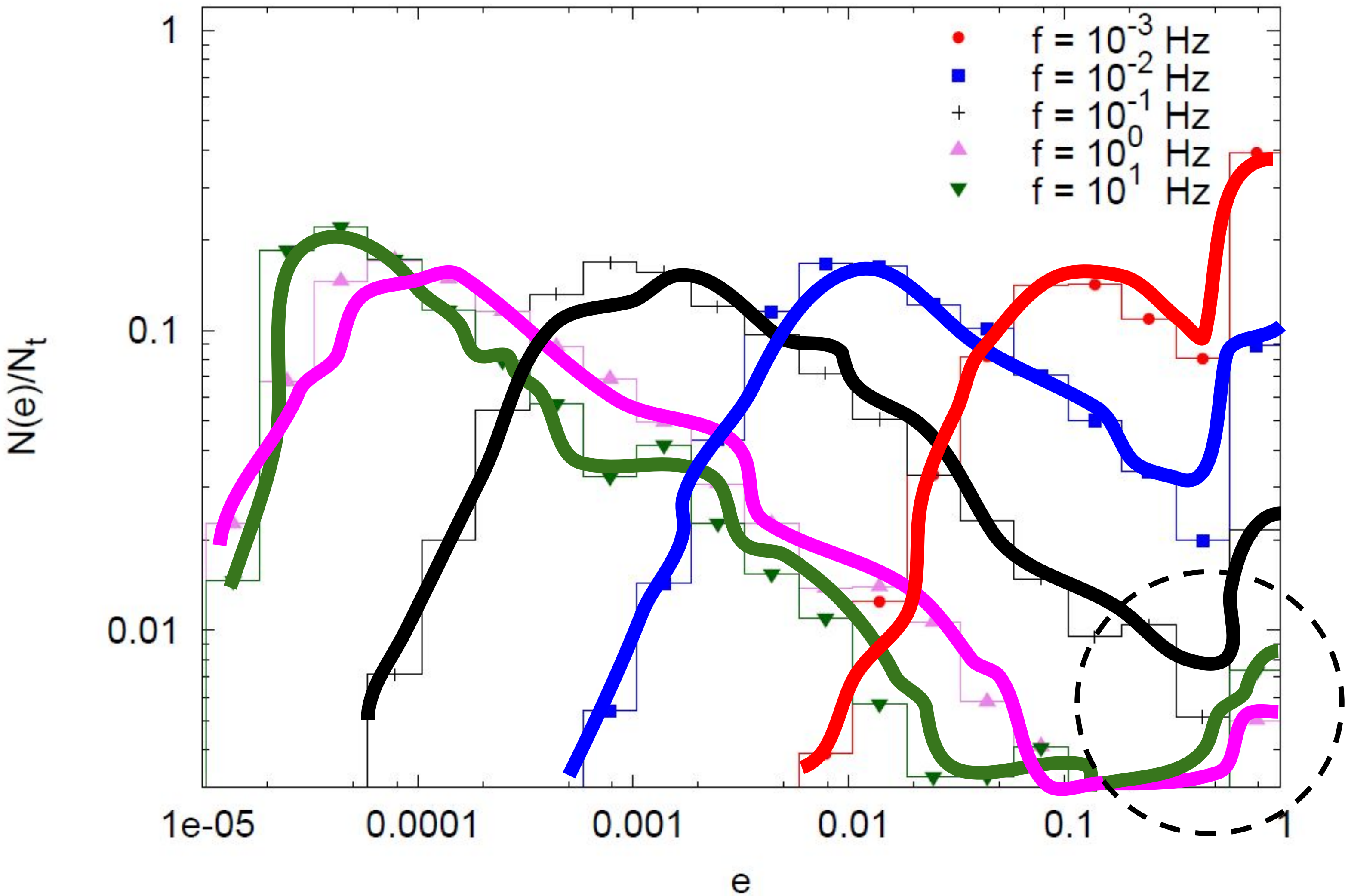
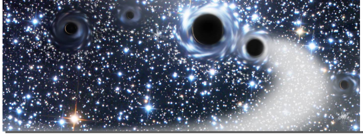
Stellar BH pairing and coalescence: evolution of non-hierarchical triples



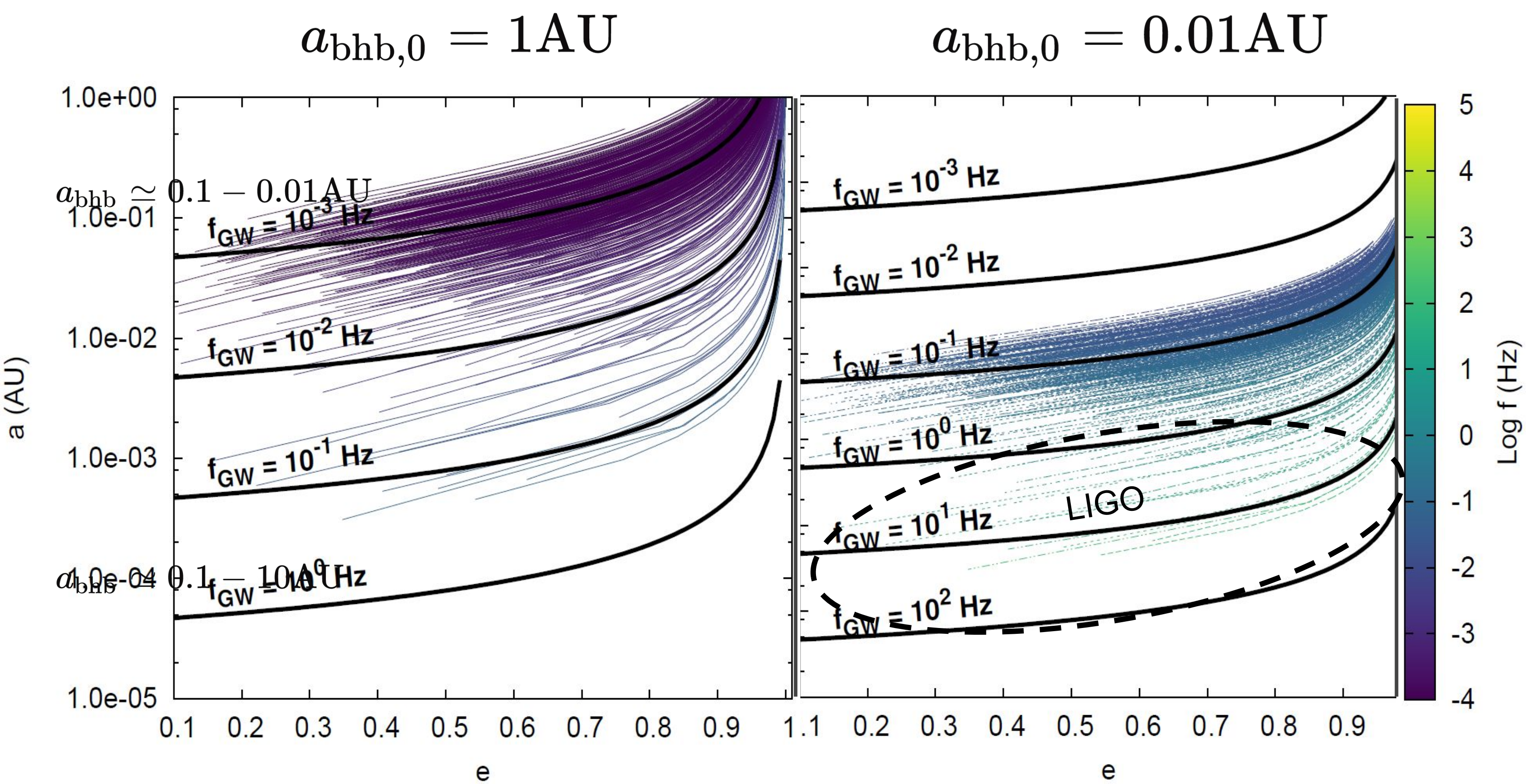
~ O(1%) sources in the Hz band with e = 0.1 - 1

Eccentric sources possibly audible by LIGO (tiny prob.)

Arca Sedda, Li & Kocsis, Arxiv: 1805.06458
Arca Sedda et al, in prep.



Stellar BH pairing and coalescence: evolution of non-hierarchical triples



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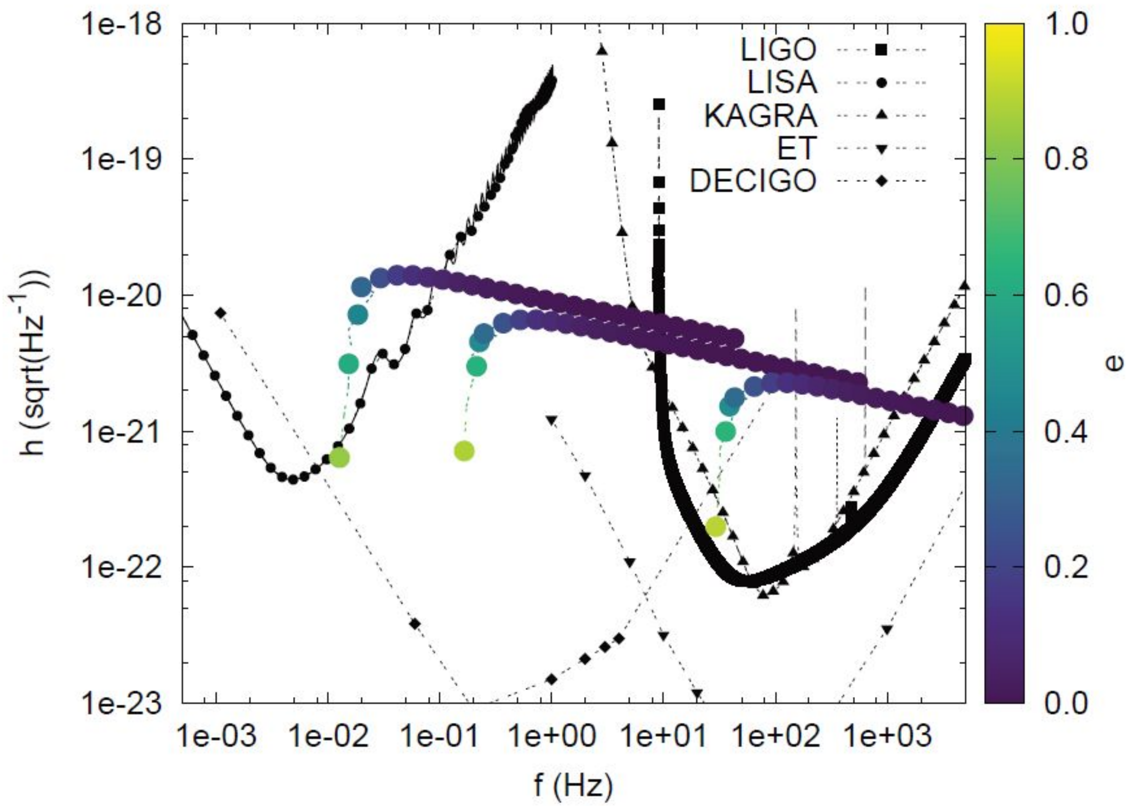
Stellar BH pairing and coalescence: evolution of non-hierarchical triples

Nuclear and dense Globular clusters

- Hard BHB can shrink down to $a_{\rm bhb} \simeq 0.1 - 0.01{\rm AU}$
- Most likely to be ejected
- Is LIGO observing BHB originating from GCs and NCs?

Young and Open clusters

- Shrinking efficiency smaller $a_{\rm bhb} \simeq 0.1 - 10{\rm AU}$
- Is LISA observing BHB originating in sparse star clusters?



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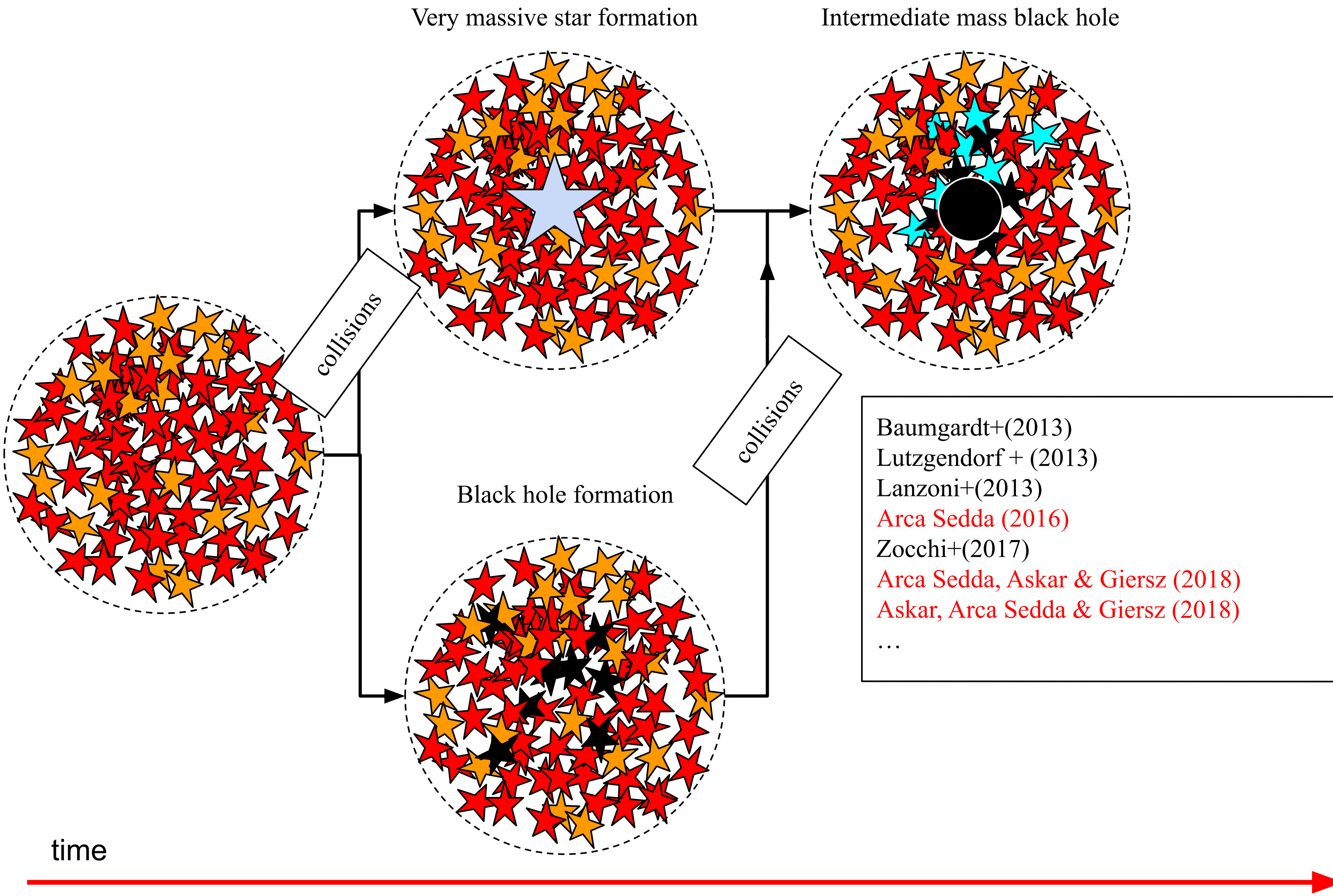

Baumgardt+(2013)
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Askar, Arca Sedda & Giersz (2018)
…

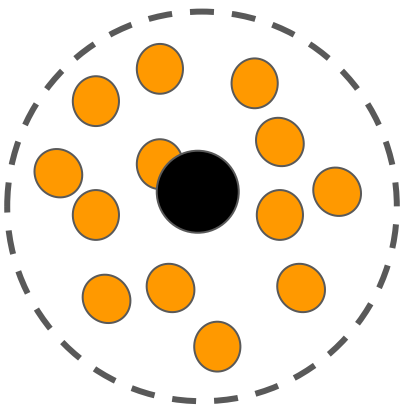
Intermediate mass black holes in globulars

Arca Sedda, Askar & Giersz, 2018, MNRAS
Arca Sedda, Askar & Giersz, in prep.

What did we use?
The MOCCA SURVEY DATABASE: over 2000 Monte Carlo models of Globular clusters with different properties

What did we select?
Our subsample consists of GC models having one BH with mass > 100 M_{SUN} at 12 Gyr

How did we characterize the IMBH?



Mass $$M_{\rm IBH}(12\ {\rm Gyr}) > 100{\rm M}_\odot$$

Influence radius $$M_*(R_{\rm IBH}) = 2M_{\rm IBH}$$

Sphere of influence density $$\rho_{\rm IBH} = 2M_{\rm IBH}/(4\pi R_{\rm IBH}^3)$$

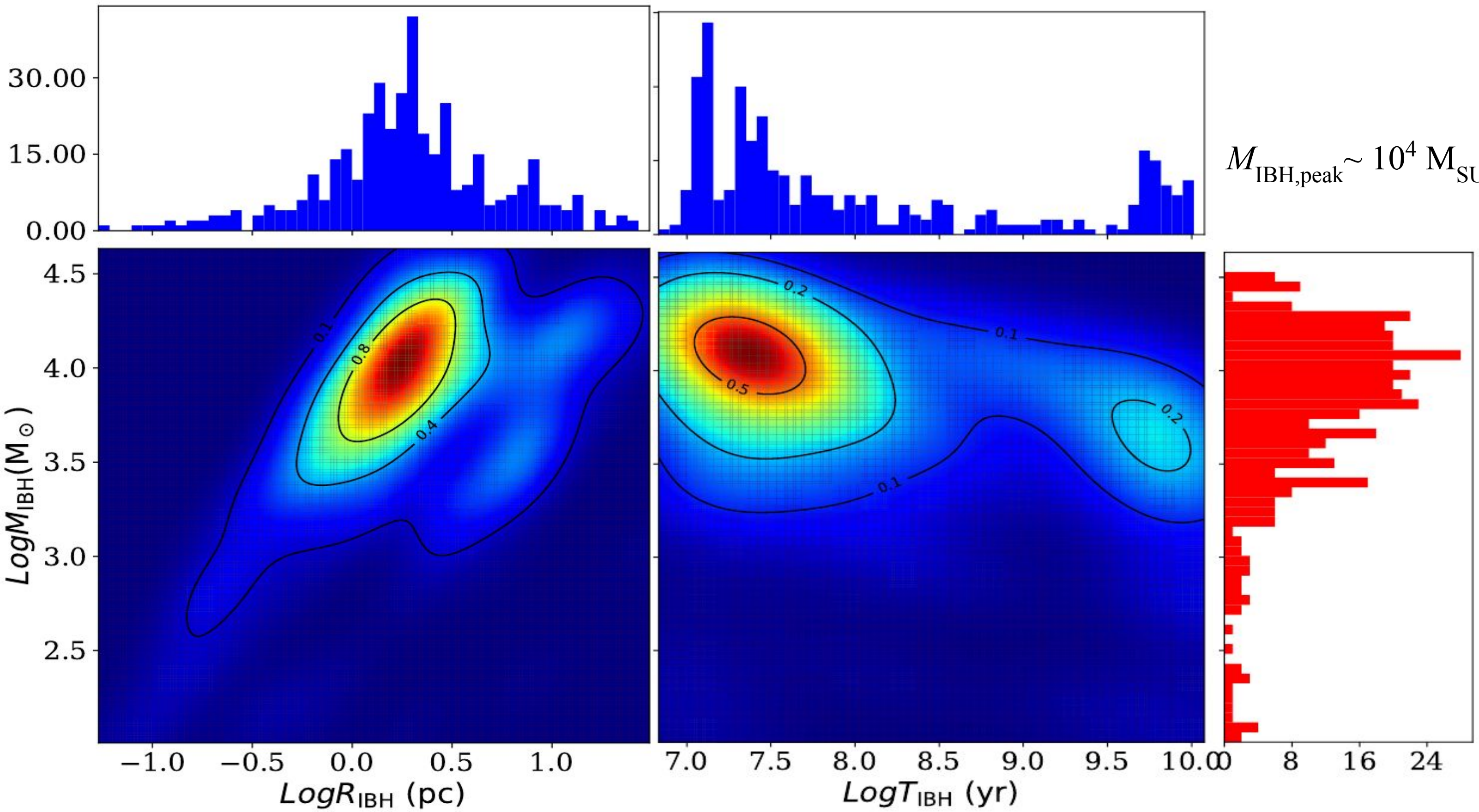
Formation time $$M_{\rm IBH}(T_{\rm IBH}) > 100{\rm M}_\odot$$

Intermediate mass black holes in globulars

$R_{\mathrm{IBH,peak}} \sim 3$ pc

FAST **SLOW**

$M_{\mathrm{IBH,peak}} \sim 10^4\ \mathrm{M_{SUN}}$



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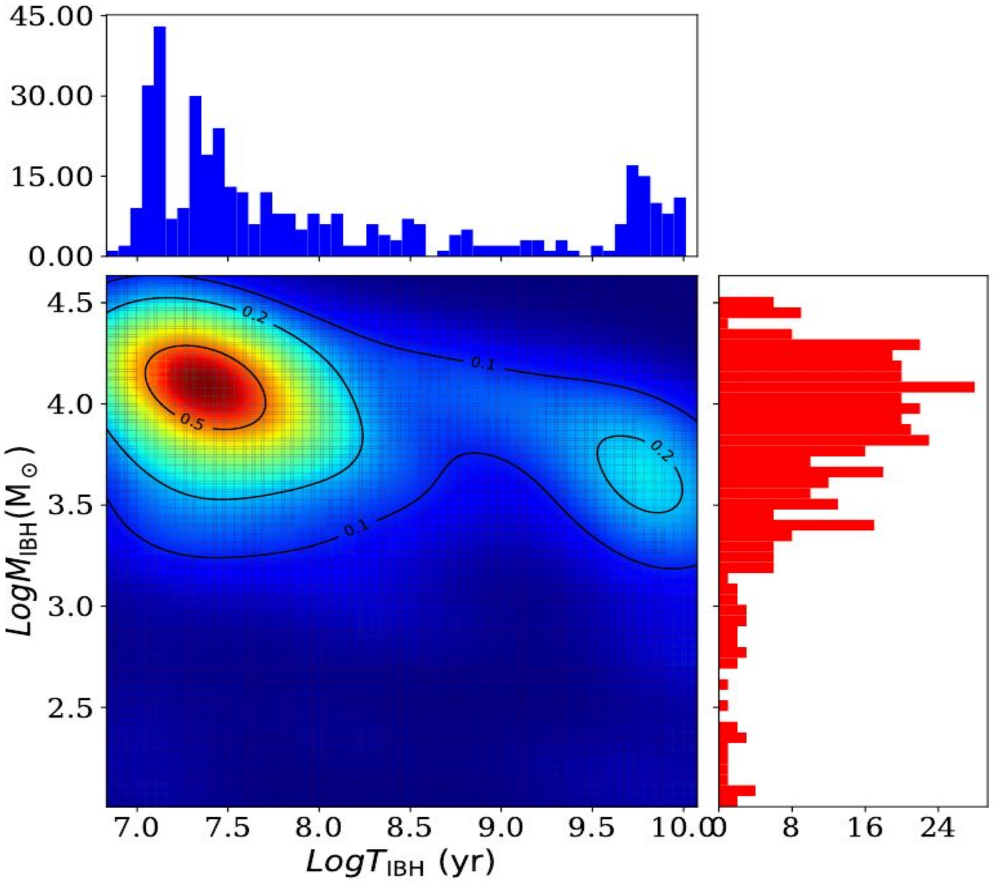
Intermediate mass black holes in globulars



FAST

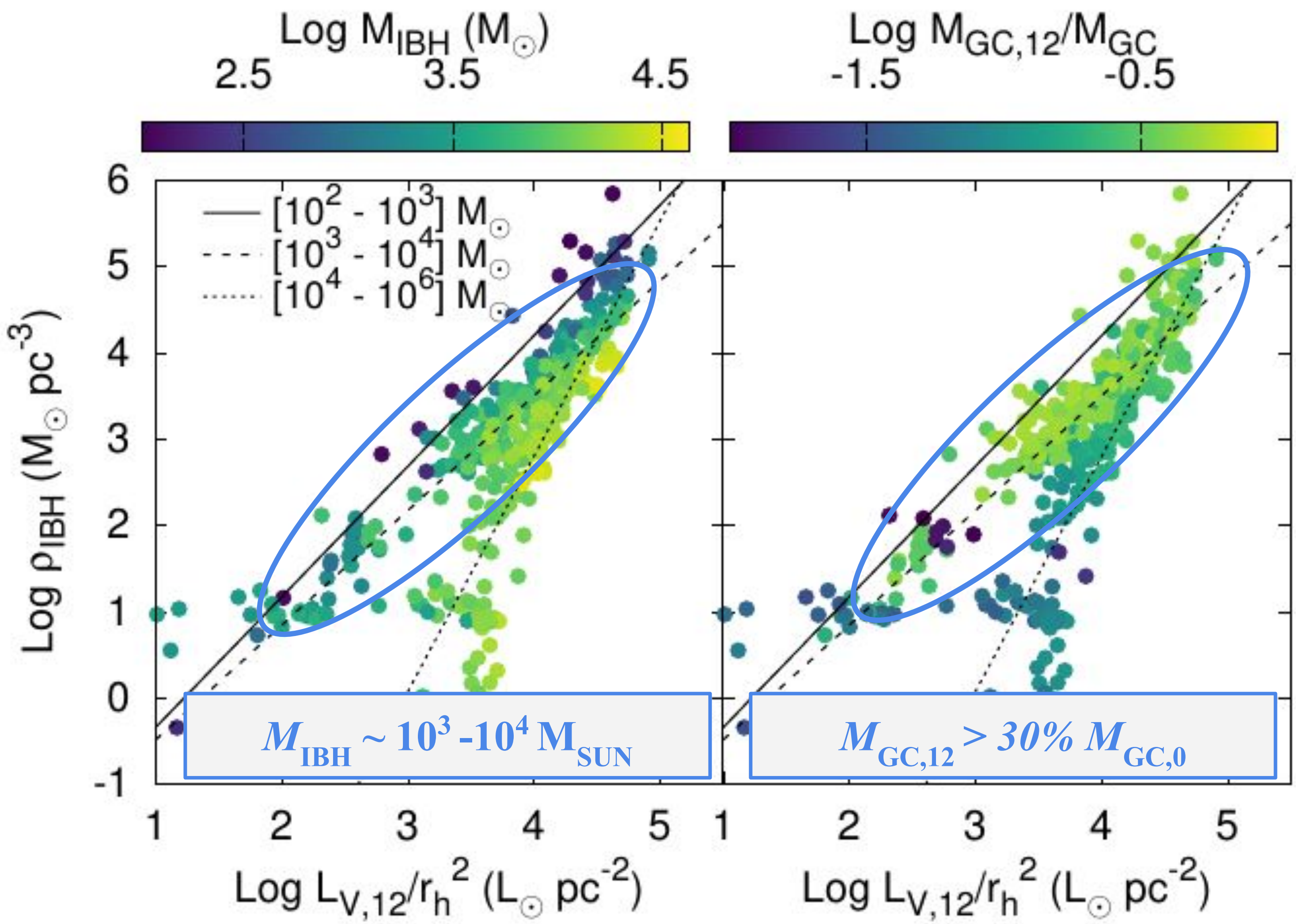
- Formation time < 1 Gyr
- Very massive star formation via stellar collisions and BH accretion
- Extreme density

SLOW

- Formation time > 1 Gyr
- Dynamical interactions eject all BHs but one or two
- Retained BH slowly grows via accretion

Arca Sedda, Askar & Giersz, 2018, MNRAS
Arca Sedda, Askar & Giersz, in prep.

Intermediate mass black holes in globulars



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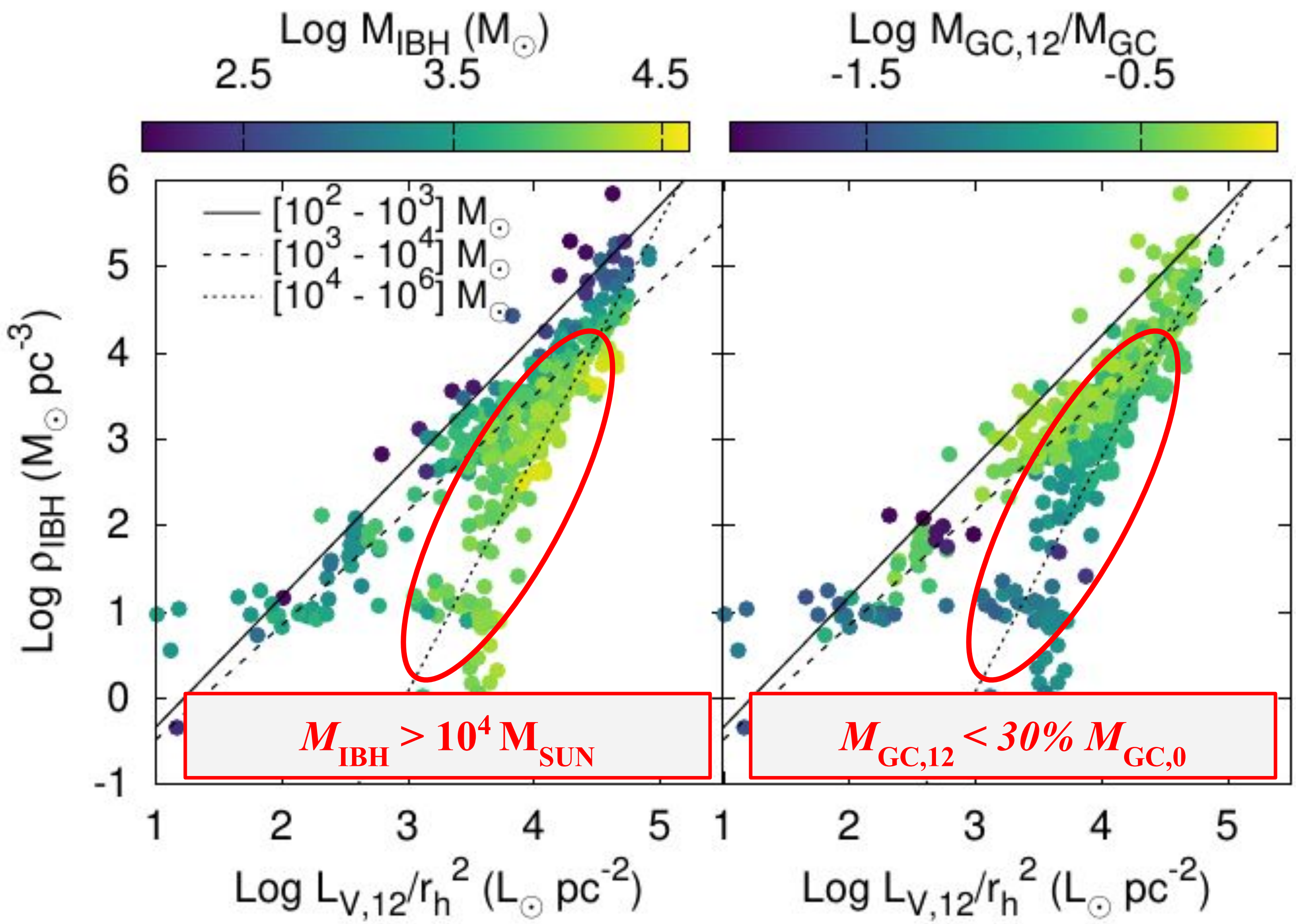

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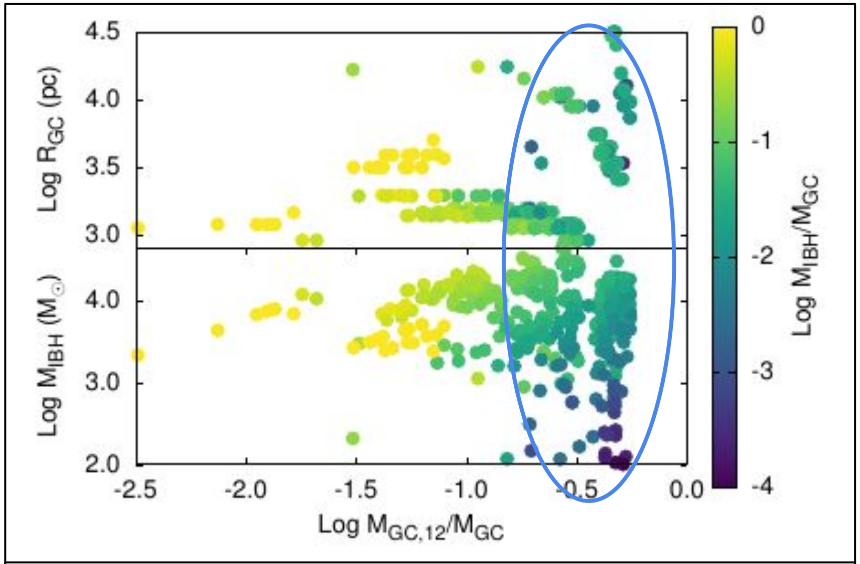
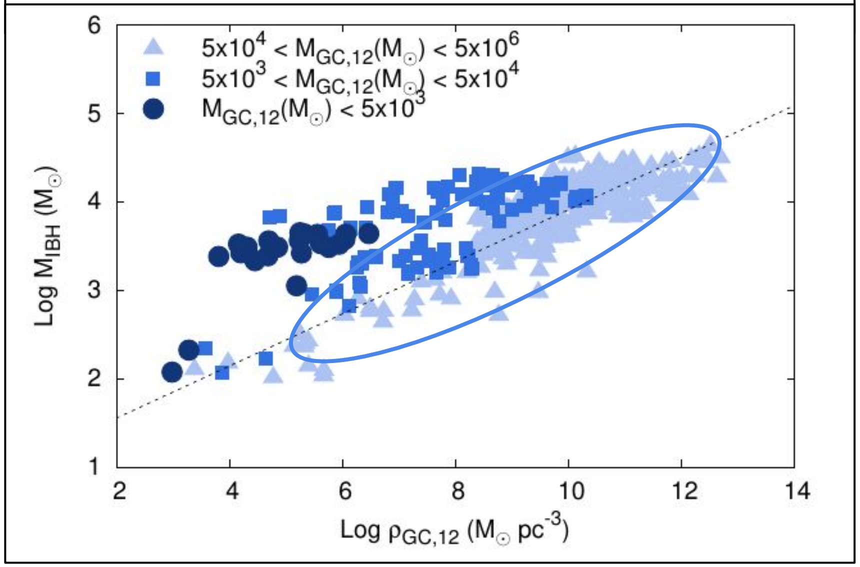
Intermediate mass black holes in globulars





"Surviving" clusters

- Orbits outside 5 kpc from Galaxy centre

- IMBH-GC mass at 12 Gyr

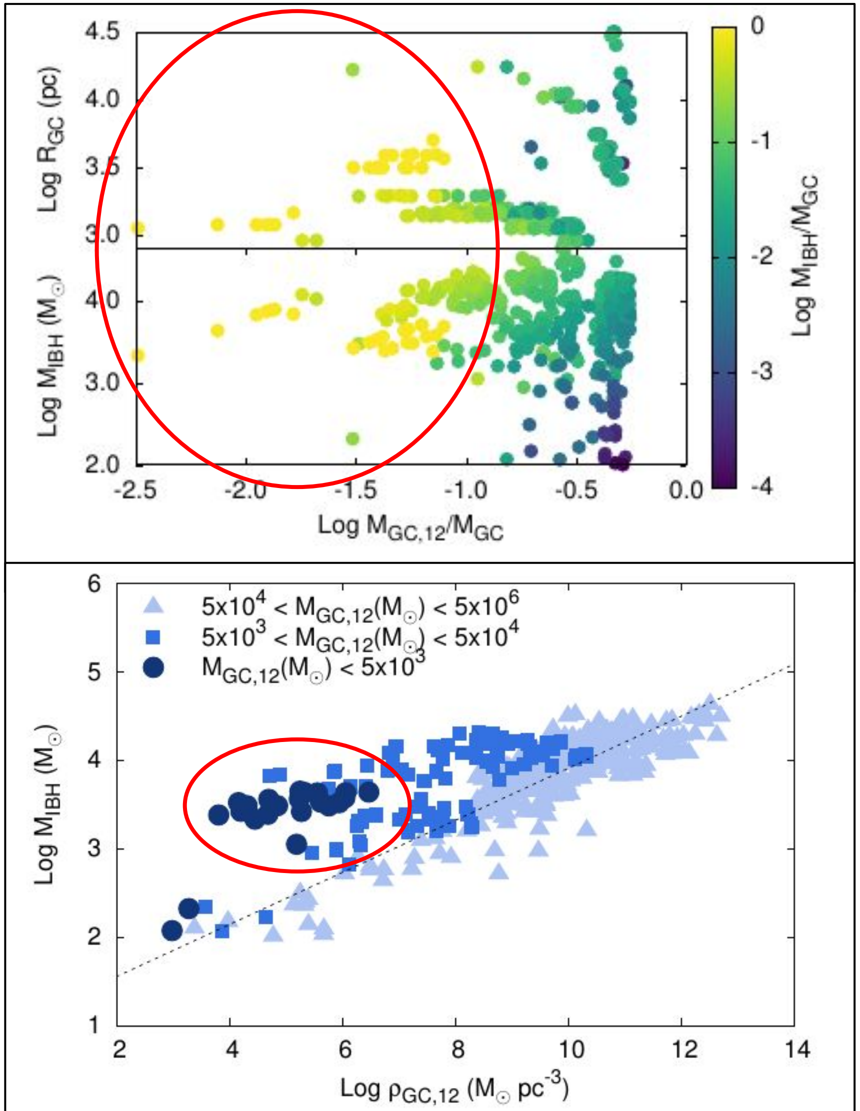
$$M_{\rm IBH} \simeq (10^{-4} - 10^{-2}) M_{\rm GC,12}$$

- Show clear correlation with IMBH mass

$$\frac{M_{\rm IBH}}{\rm M_\odot} = \left(\frac{\rho_{\rm GC,12}}{\rm M_\odot\ pc^3}\right)^{0.3}$$

Arca Sedda, Askar & Giersz, 2018, MNRAS
Arca Sedda, Askar & Giersz, in prep.

Intermediate mass black holes in globulars



"Dark" clusters

- Orbits inside 5 kpc from Galaxy centre
- IMBH-GC mass at 12 Gyr

$$M_{\rm IBH} > 0.1 M_{\rm GC,12}$$

- Have masses below $10^3 M_{SUN}$

Arca Sedda, Askar & Giersz, 2018, MNRAS
Arca Sedda, Askar & Giersz, in prep.

Intermediate mass black holes in globulars

Does Milky Way GCs harbour an IMBH at present time?

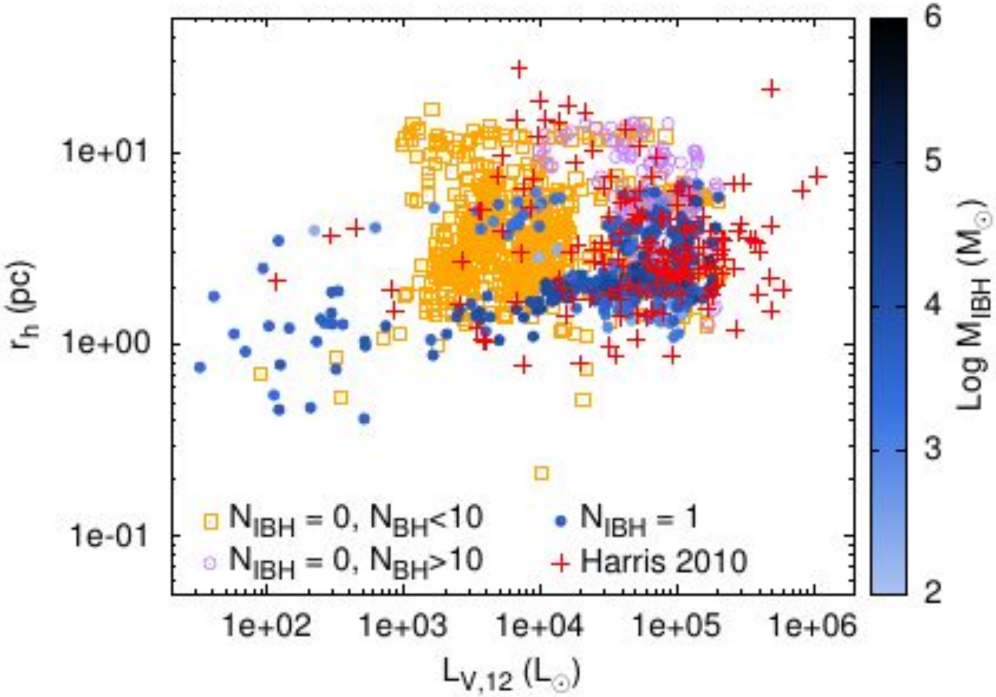
Define a norm as the distance between observed and simulated parameters

$$||\mathcal{N}||^2 = \Sigma_i(\Delta\mathcal{V}_i)^2 = (L_{\rm V,obs} - L_{\rm V,mod})^2 + (r_{\rm h,obs} - r_{\rm h,mod})^2 + \ldots$$

Ranking the 10 closest models:

$N_{IBH} > 5$ IMBH host candidate

$N_{BHS} > 5$ BHS host candidate



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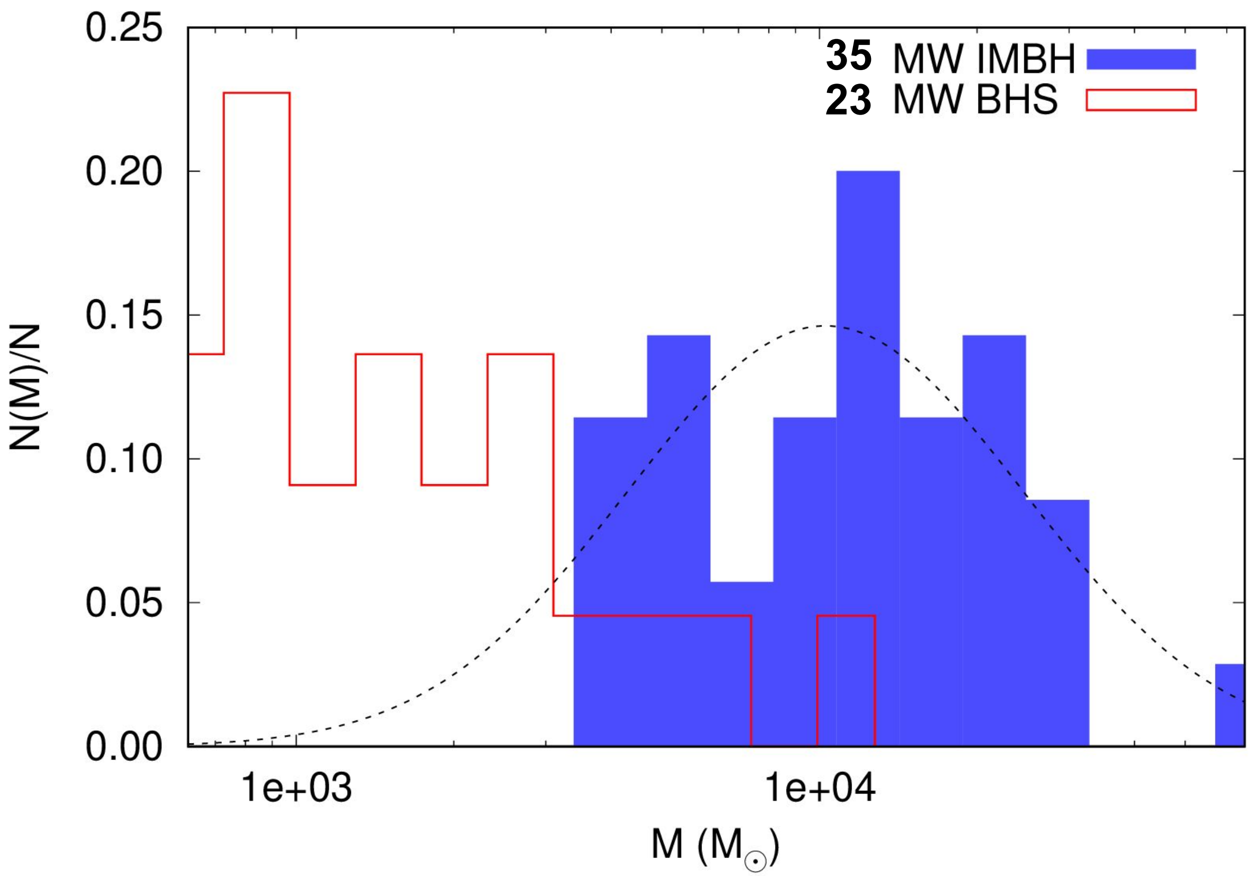
Intermediate mass black holes in globulars

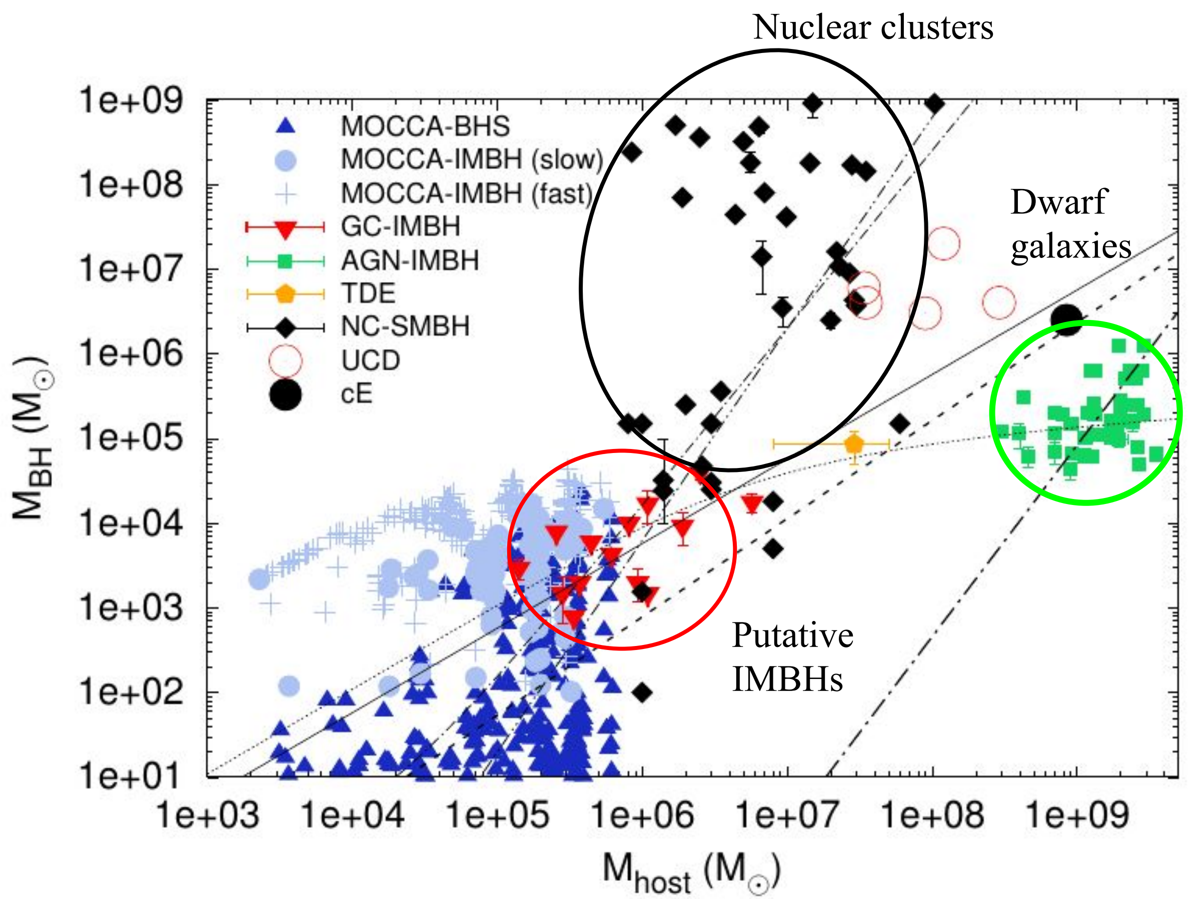
Does Milky Way GCs harbour an IMBH at present time?



Arca Sedda, Askar & Giersz, 2018, MNRAS
Arca Sedda, Askar & Giersz, in prep.

Intermediate mass black holes in globulars

What is the link between IMBHs and SMBHs?



Arca Sedda, Askar & Giersz, 2018, MNRAS
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Intermediate mass black holes in globulars

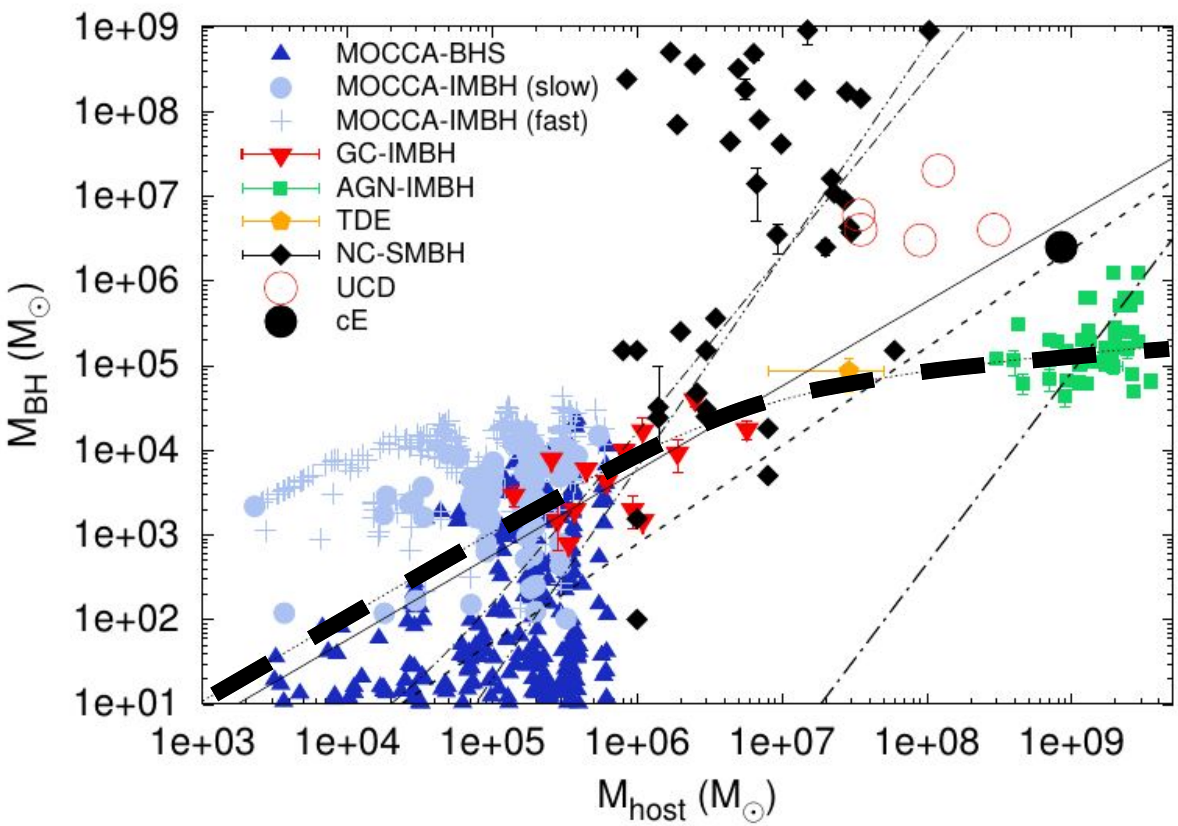
What is the link between IMBHs and SMBHs?

Logarithmic fit on MOCCA IMBHs

$$\mathrm{Log} M_{\mathrm{IBH}} = \alpha (M_{\mathrm{host}}/\beta + 1)^{\gamma}$$

Matches AGN in Dwarf galaxies

Matches TDE in massive cluster



Arca Sedda, Askar & Giersz, 2018, MNRAS
Arca Sedda, Askar & Giersz, in prep.

Intermediate mass black holes in globulars

What is the link between IMBHs and SMBHs?

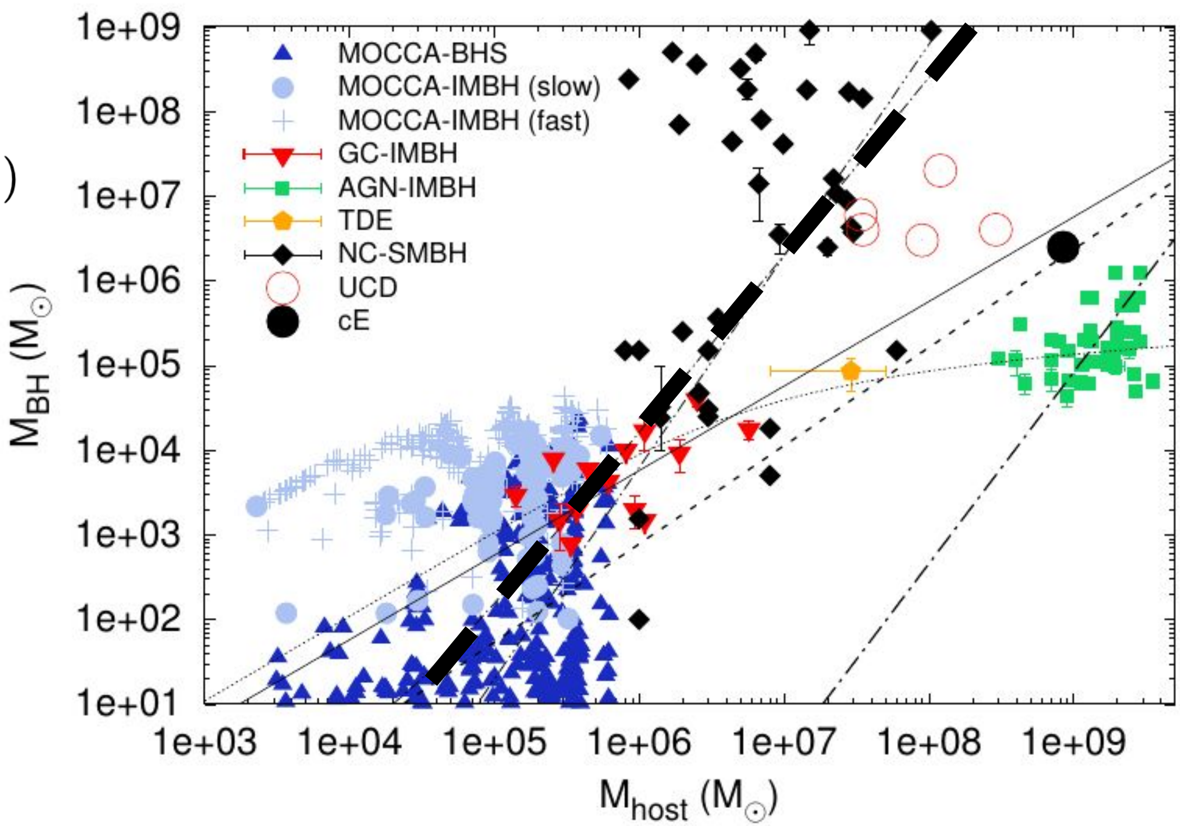
Powerlaw fit on MOCCA IMBHs

$$\mathrm{Log} M_{\mathrm{IBH}} = \alpha \mathrm{Log}\left(M_{\mathrm{host}}/\beta + 1\right)$$

Matches NCs in MW-like galaxies

Matches low-mass UCDs

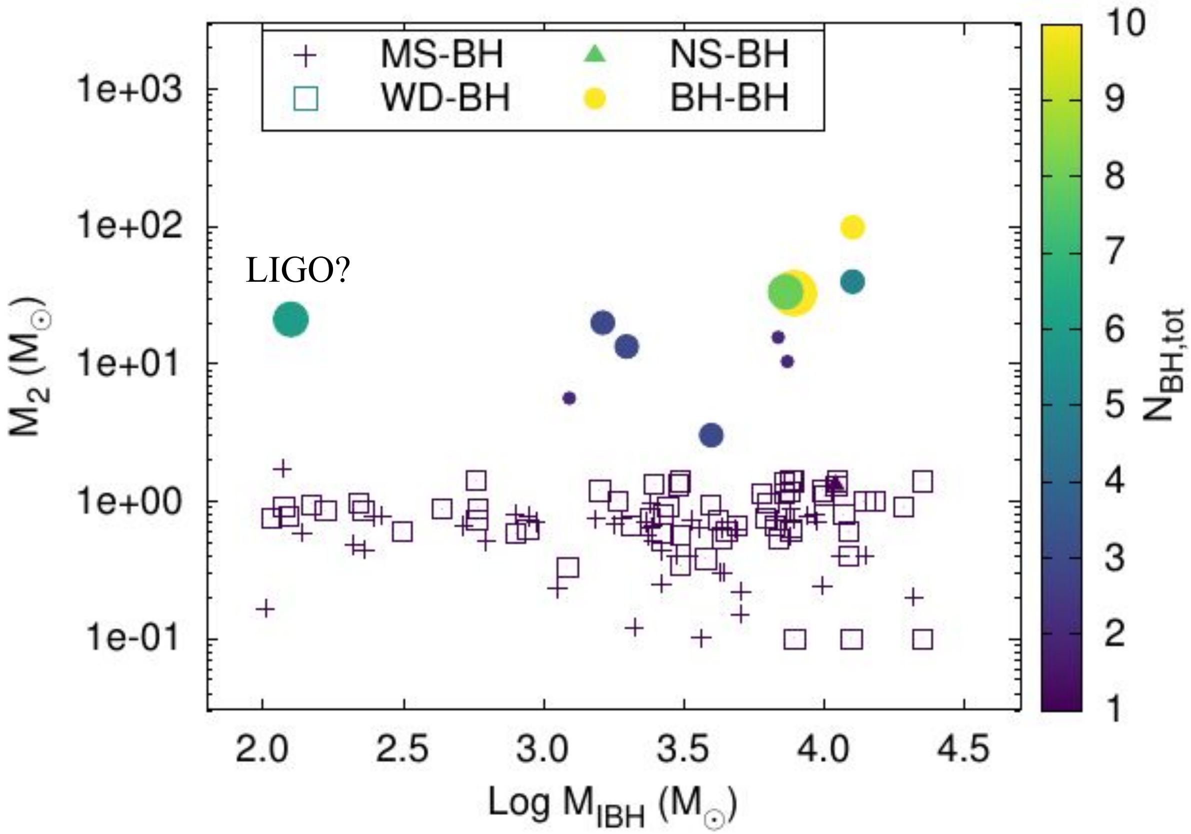
NB Probably NC formed after SMBH buildup!



Arca Sedda, Askar & Giersz, 2018, MNRAS
Arca Sedda, Askar & Giersz, in prep.

Intermediate mass black holes in globulars: binarity

Out of 407 MOCCA models we find a few cases in which the IMBH is in a binary



Potential TDEs progenitors:

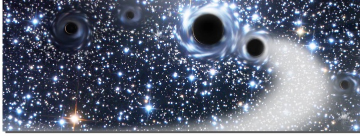
- 56 MS-IMBH

Potential GW+EM emitters:

- 66 WD-IMBH
- 1 NS-IMBH

Intermediate mass ratio inspirals:

- 11 BH-IMBH
  (1 potential LIGO source)



Q&A

How, when, where do black holes form in star clusters?

How do they pair and merge?

What about intermediate mass black holes in globulars?

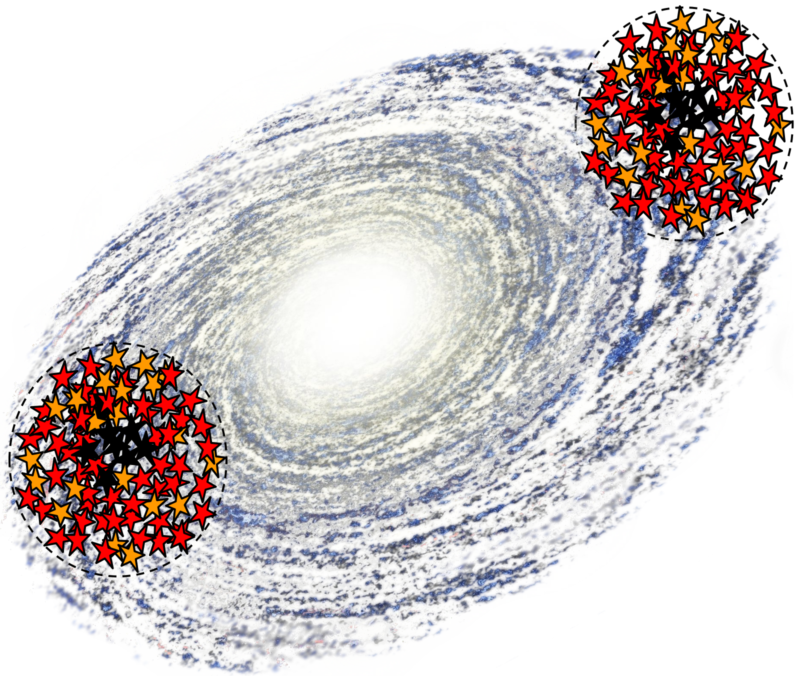
How do they get into galactic nuclei?

Can we distinguish BHs merging in different environments?

How do they get into galactic nuclei?
The formation of nuclear clusters

Phase I:
GCs form within the galaxy, some of them in the inner region (r < 500 pc)

Stellar evolution of massive stars and core collapse drive the formation of either stellar BHs or an IMBH



Arca Sedda & Capuzzo-Dolcetta, 2014, MNRAS
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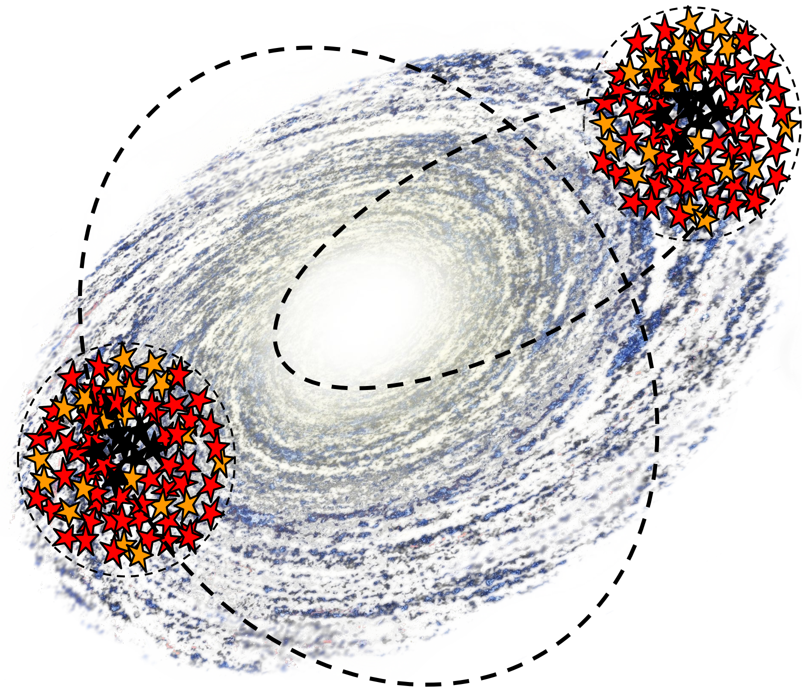
How do they get into galactic nuclei?
The formation of nuclear clusters



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GCs form within the galaxy, some of them in the inner region (r < 500 pc)

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Phase II:
Dynamical friction erases part of the GCs orbital energy, forcing them to spiral toward the galaxy centre

Tidal forces tend to strip GCs stars away, driving the cluster disruption

Arca Sedda & Capuzzo-Dolcetta, 2014, MNRAS
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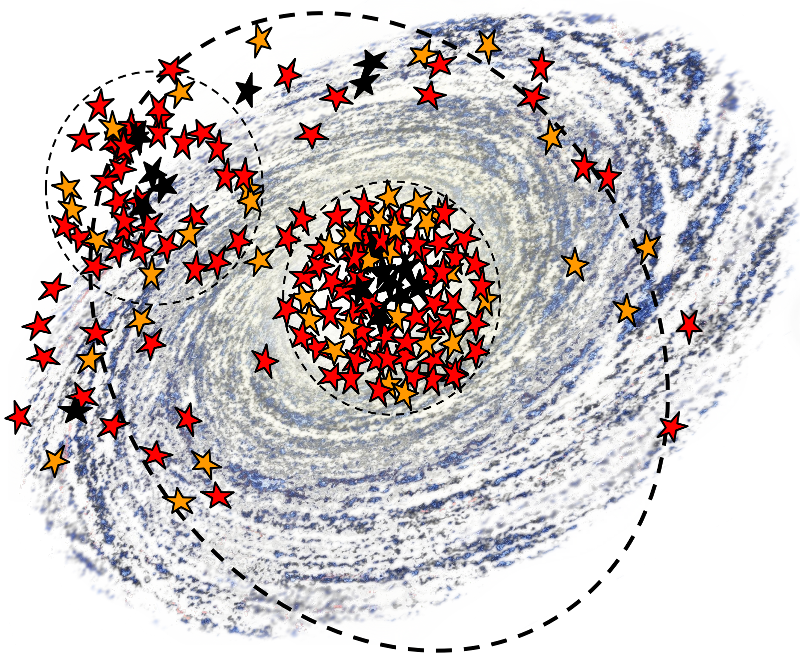
Arca Sedda et al., in prep.

How do they get into galactic nuclei?
The formation of nuclear clusters



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Phase III:
A bright nuclear cluster form

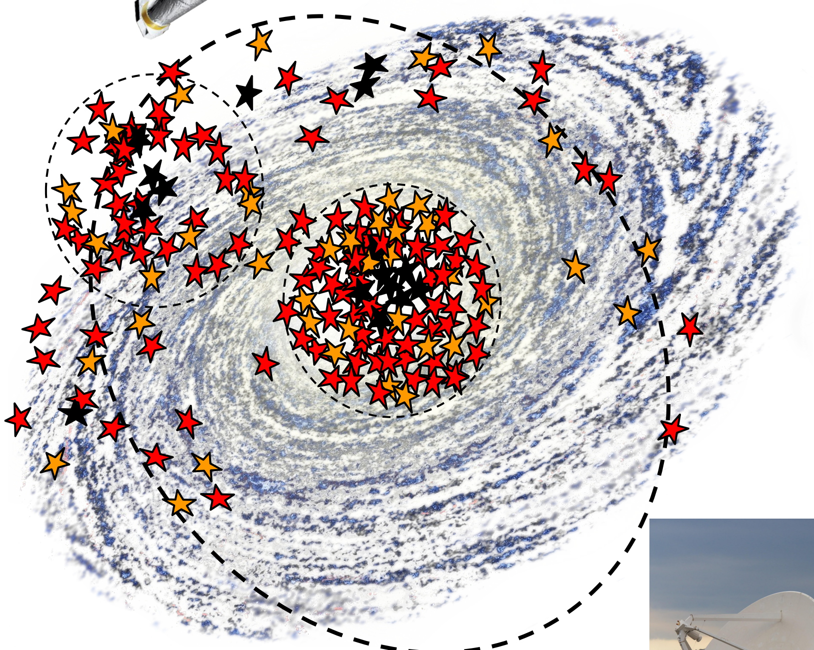
GCs compact remnants (BHs, NSs, WDs) are delivered into the galaxy centre

GC debris are left in the surrounding nucleus

Arca Sedda & Capuzzo-Dolcetta, 2014, MNRAS
Arca Sedda, Kocsis & Brandt, 2018, MNRAS
Arca Sedda et al., in prep.

Tremaine 1975, Capuzzo Dolcetta 1993, Antonini+2012, Perets & Mastrobuono-Battisti 2014, Gnedin et al 2014, Arca Sedda and Capuzzo Dolcetta 2014, 2016a,b, 2017, 2019, Arca Sedda et al 2015, Tsatsi 2017, Abbate 2018, Arca Sedda and Gualandris 2018)

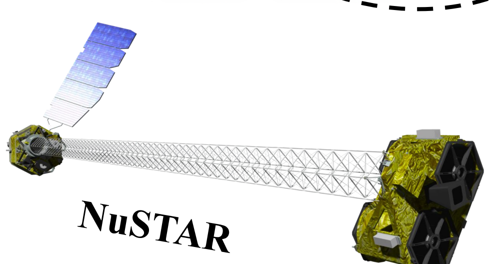
How do they get into galactic nuclei?
The formation of nuclear clusters



Phase IV:

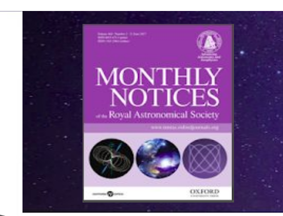
Observations collected from the galactic centre tell us the story of our nuclear cluster.

(Hooper & Goodenough 2011, Perez + 2011, Brandt & Kocsis 2015, Bartels + 2016, Tsatsi + 2017, Arca Sedda, Kocsis & Brandt 2018, Abbate + 2018, Fragione + 2018, Hailey + 2018, Eckart + 2018, Bartels + 2018)



A bright spot in the dark: Gamma and X-rays tell us the story of the Galactic Centre

BY MANUEL ARCA SEDDA   SEPTEMBER 14TH 2018



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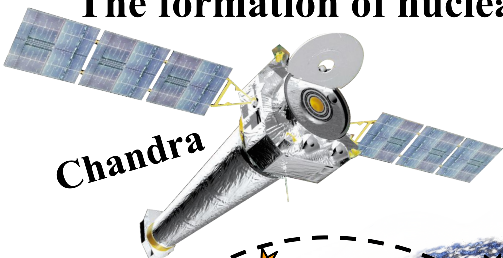
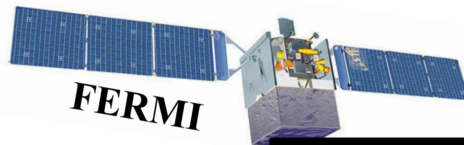
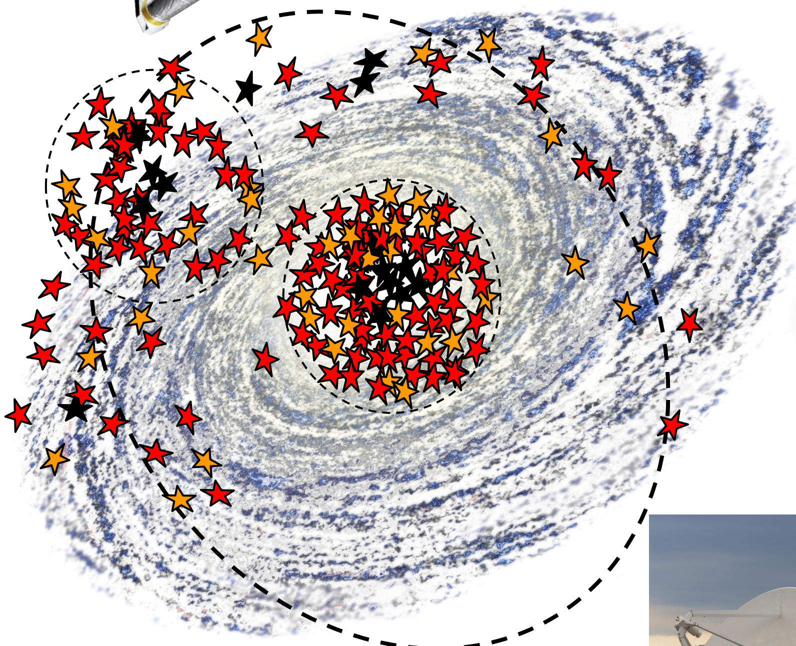
The formation of nuclear clusters

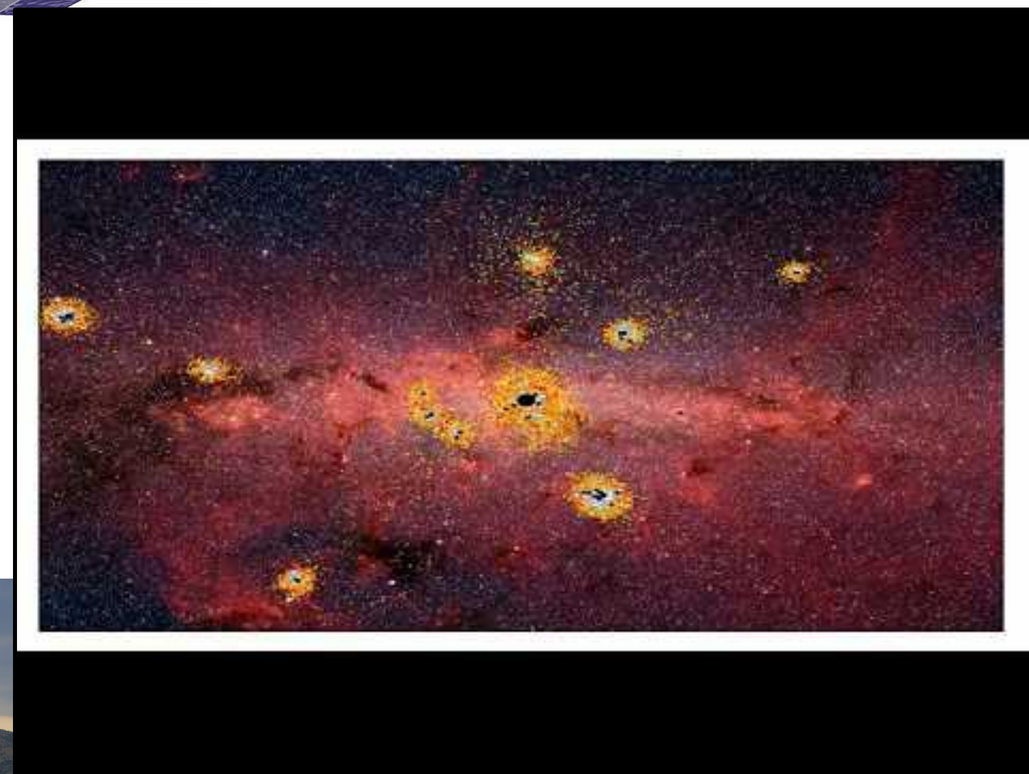


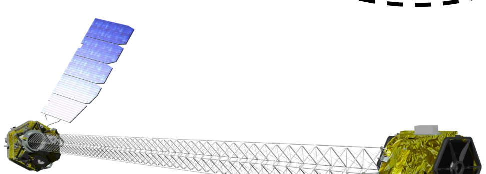
Chandra



FERMI

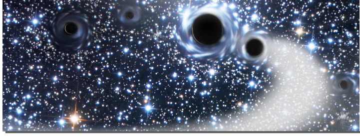






NuSTAR

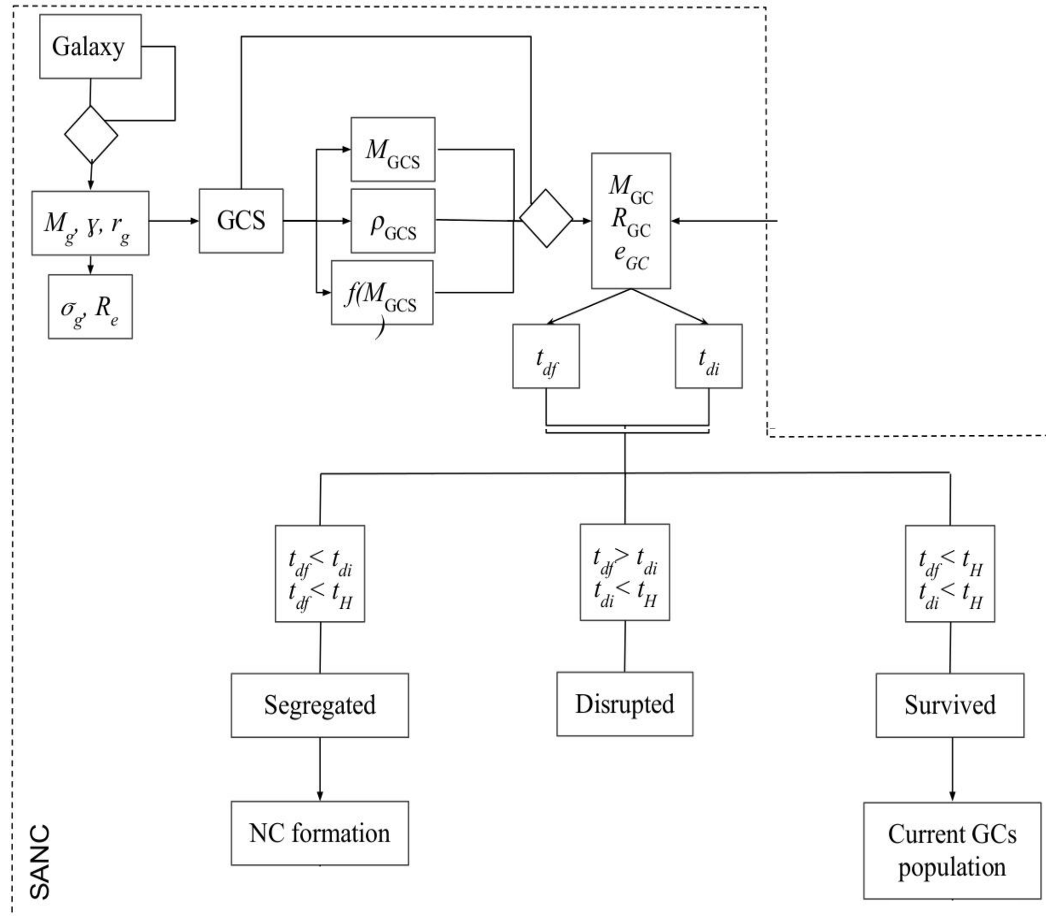
MEERKAT



The formation of nuclear clusters: semi-analytic approach

Semi-Analytical model for Nuclear Clusters (SANC)

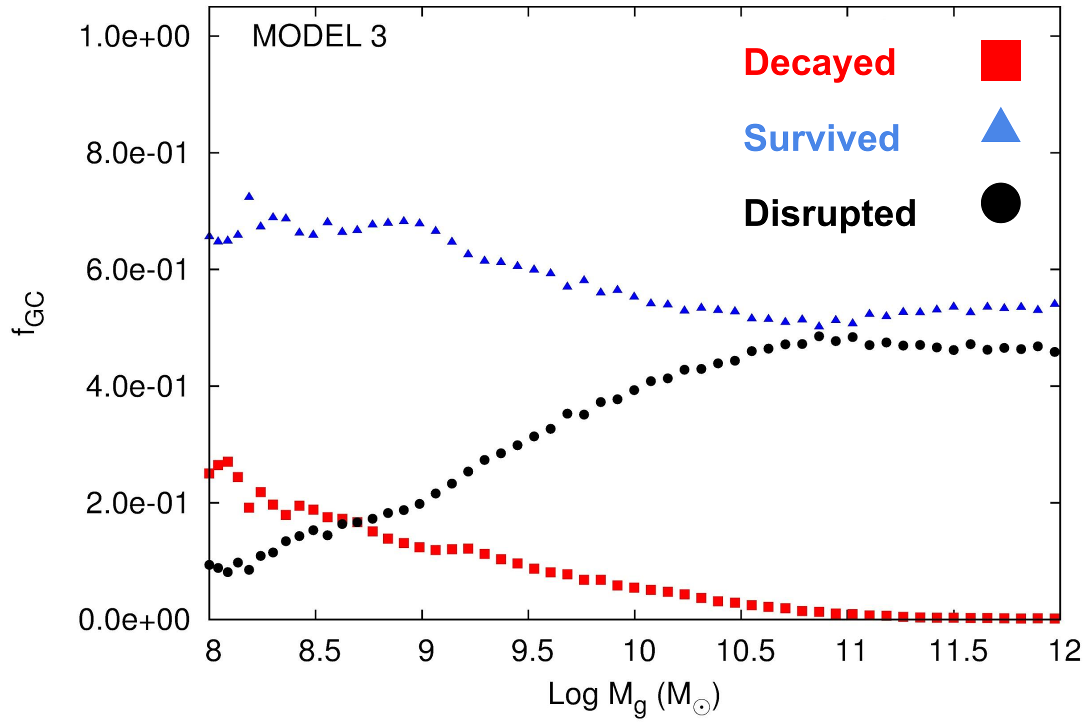
- Select the galaxy mass
- Populate the galaxy with a star clusters
  - ✓ Mass distribution
  - ✓ Radial distribution
  - ✓ Orbital distribution
- For each cluster must calculate
  - ✓ Dynamical friction time-scale
  - ✓ Tidal disruption time-scales (disk/bulge shock, 2body dissolution, collisions with giant molecular clouds)
- Calculate
  - ✓ Number of surviving clusters and current mass distribution
  - ✓ NC mass → observational scaling relations

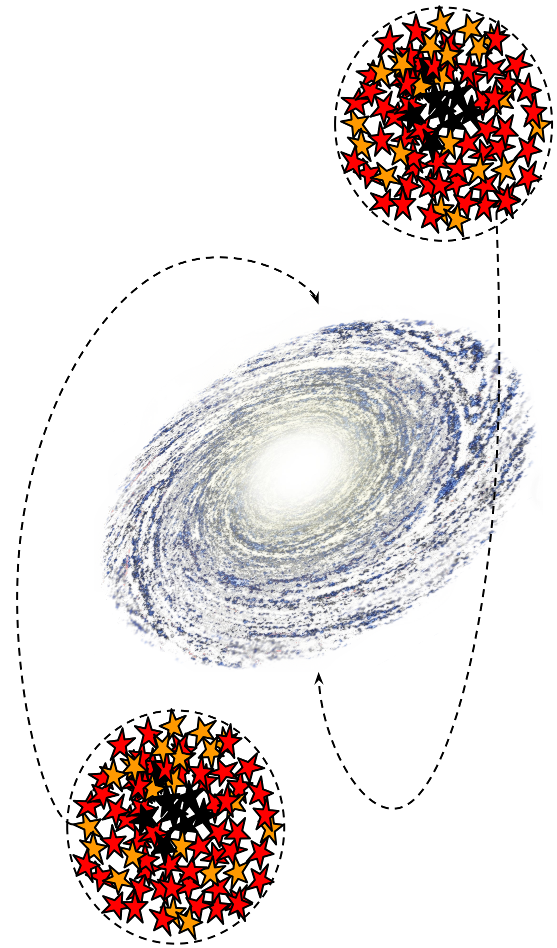


Arca Sedda & Capuzzo-Dolcetta, 2014, MNRAS
Arca Sedda et al., in prep.

The formation of nuclear clusters: semi-analytic approach

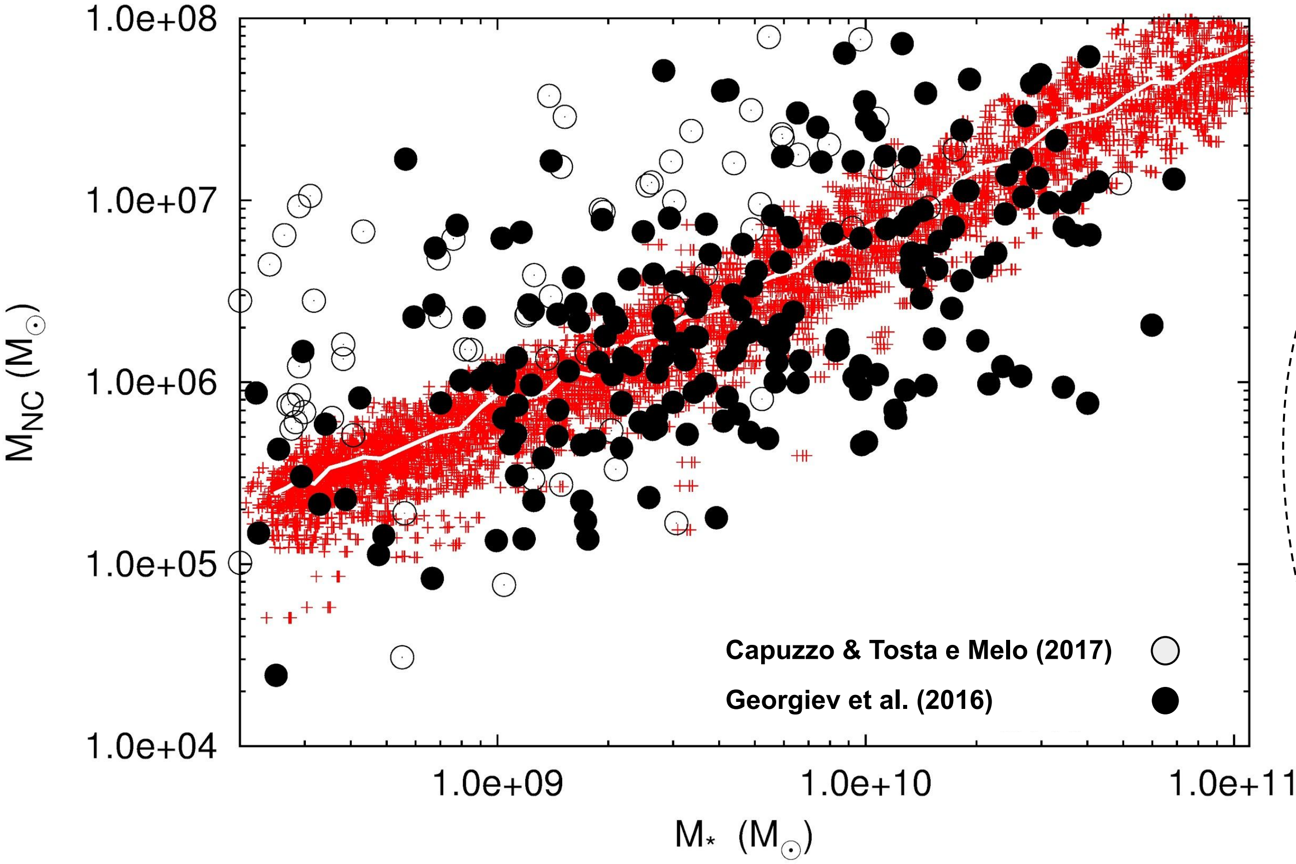
Fraction of GCs as a function of the galaxy mass

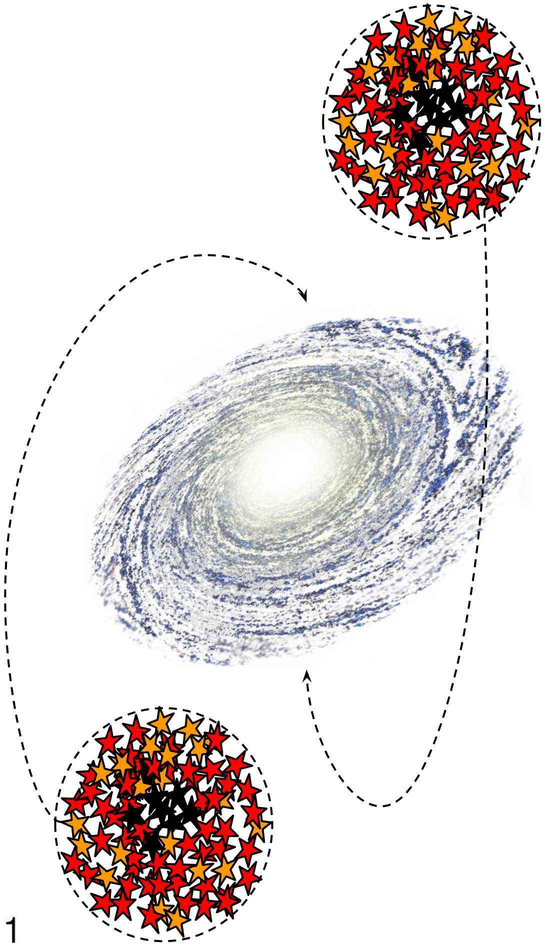




The formation of nuclear clusters: semi-analytic approach

$$M_{\rm NC} \propto M_*^{\alpha}, \;\; M_* < 3 \times 10^{10}\,{\rm M}_{\odot};$$
$$\alpha = 0.971 \pm 0.008$$





Delivery of compact remnants in galactic nuclei

Taxonomy of GW sources in dense clusters:

- In GCs or NCs w/o an SMBH

BH+BH: Black hole binary (BHB)

BH+BH+BH: Black hole triples

BH+IMBH: intermediate mass ratio inspirals (IMRIs)

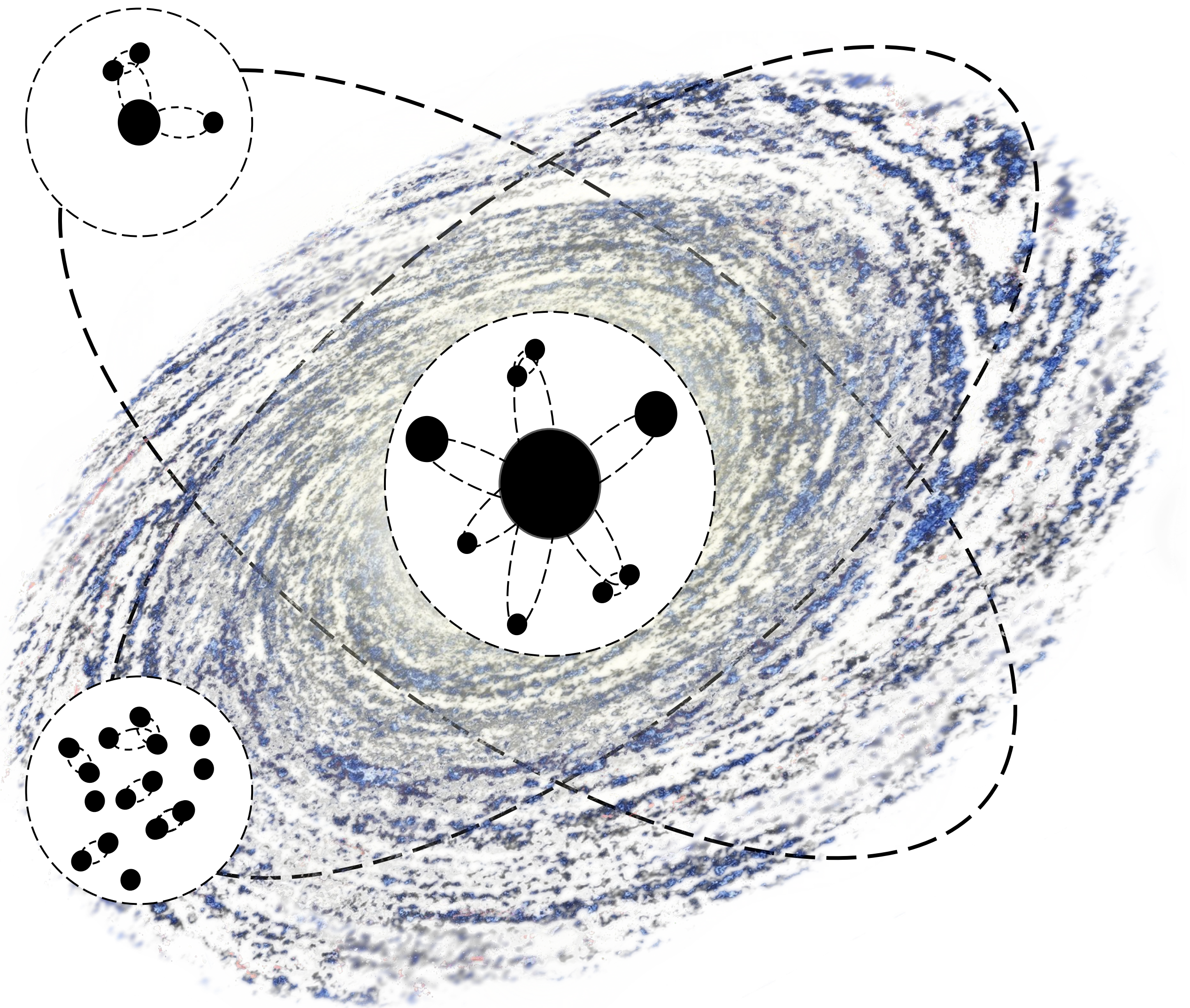
BHB+IMBH: hierarchical triple

- In Galactic nuclei w an SMBH

BH+SMBH: extreme mass ratio inspiral (EMRI)

BHB+SMBH: hierarchical triple

n(IMBH)+SMBH



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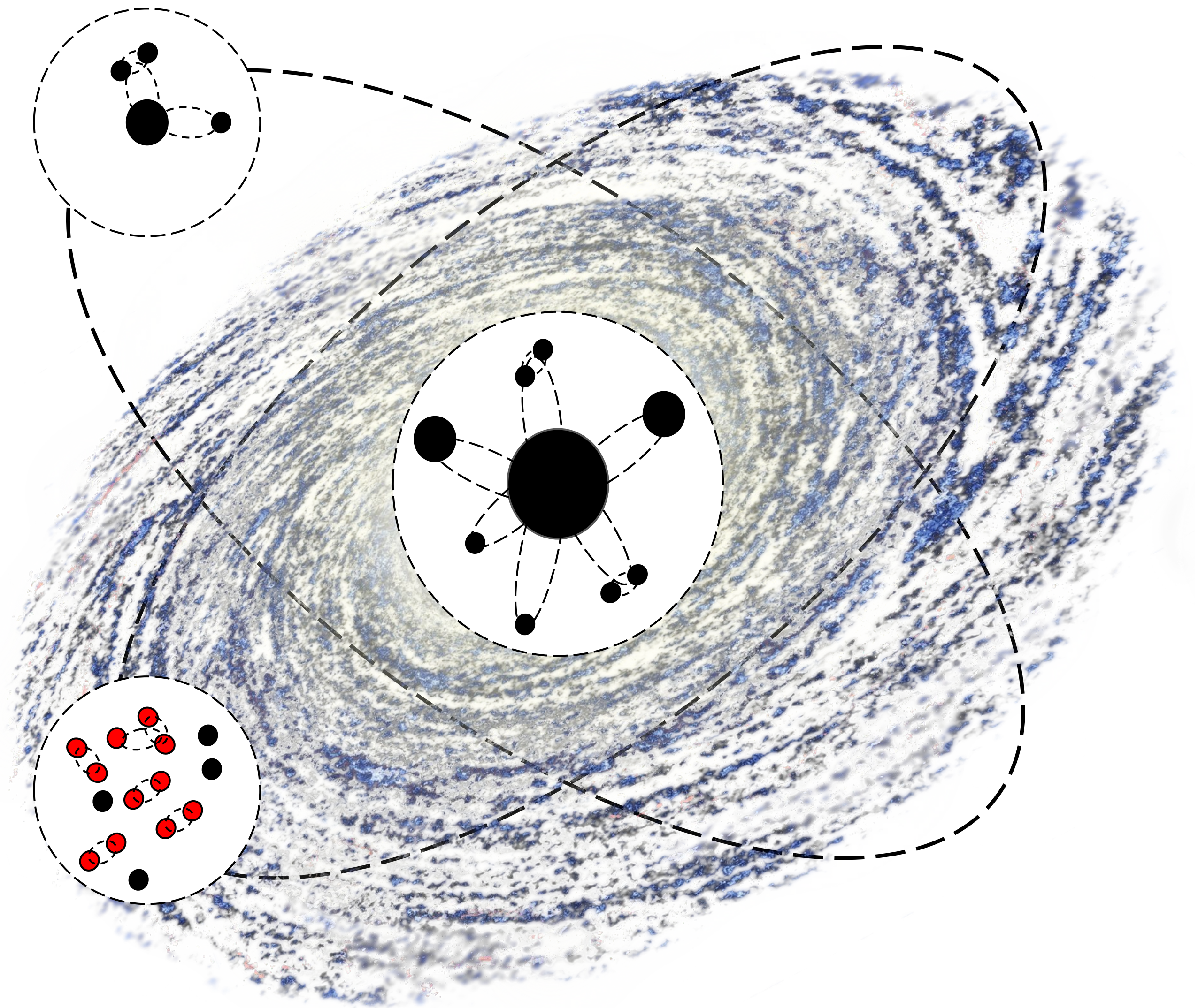

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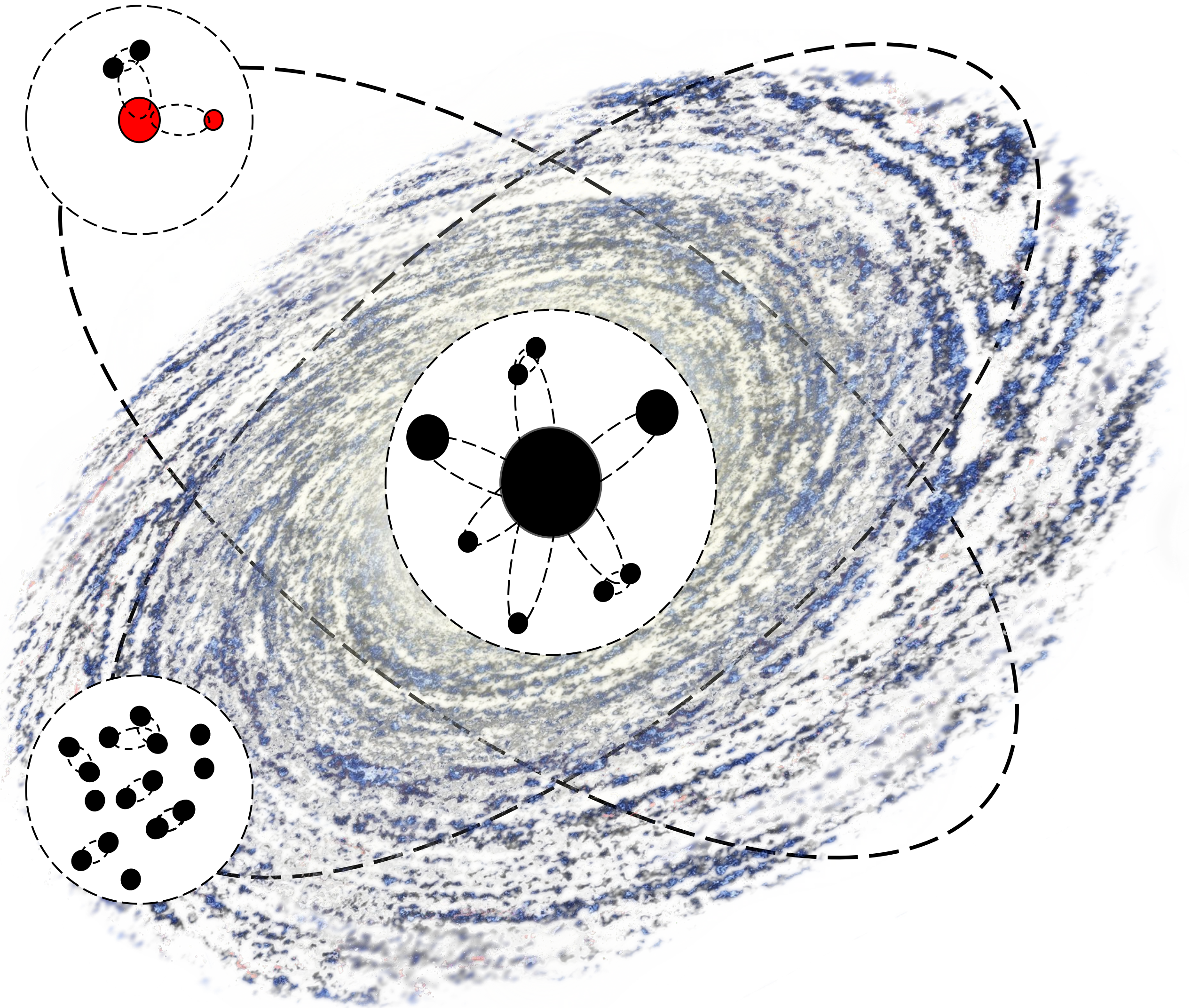

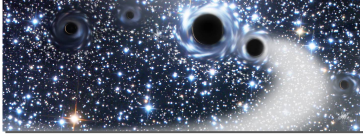

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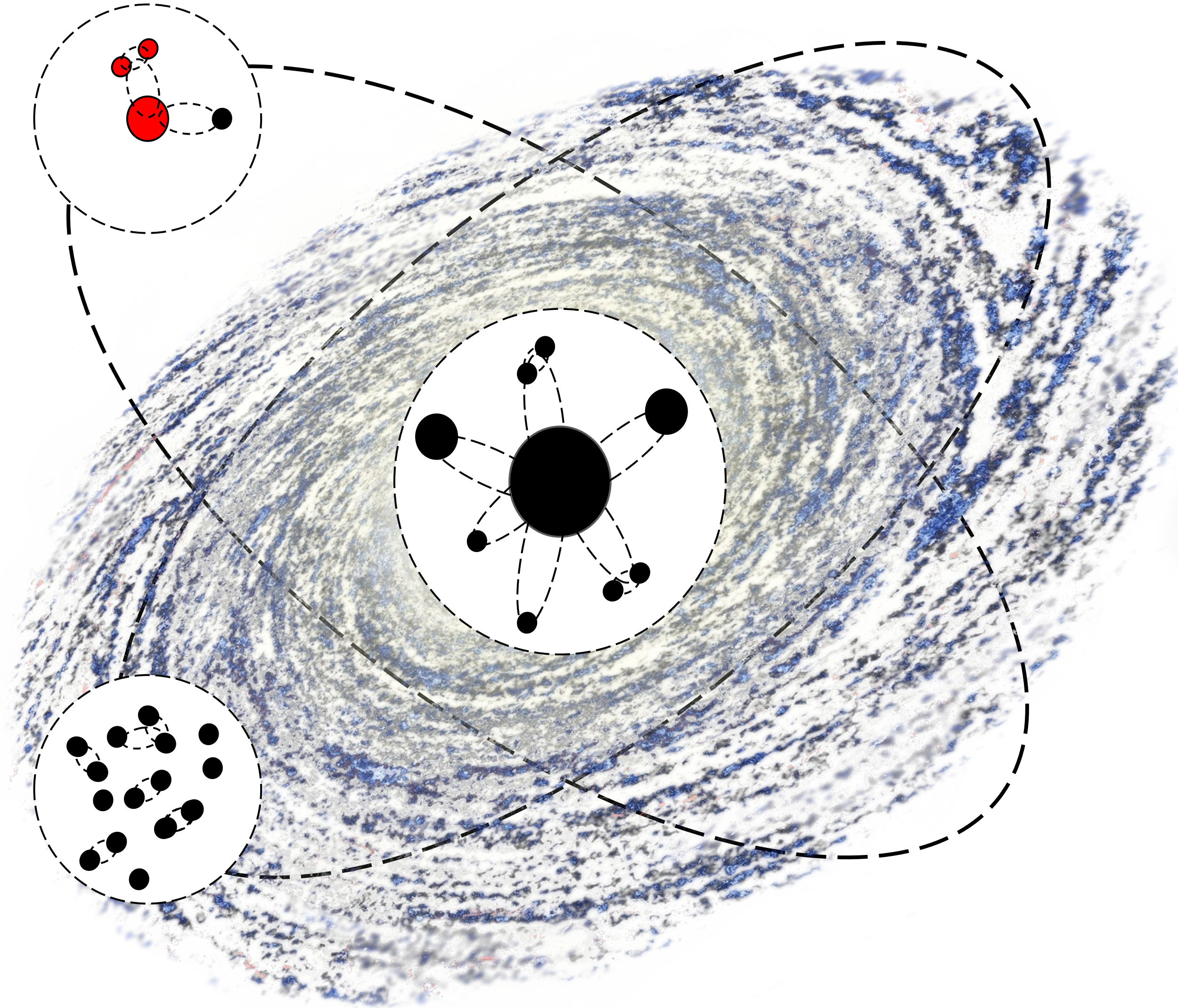

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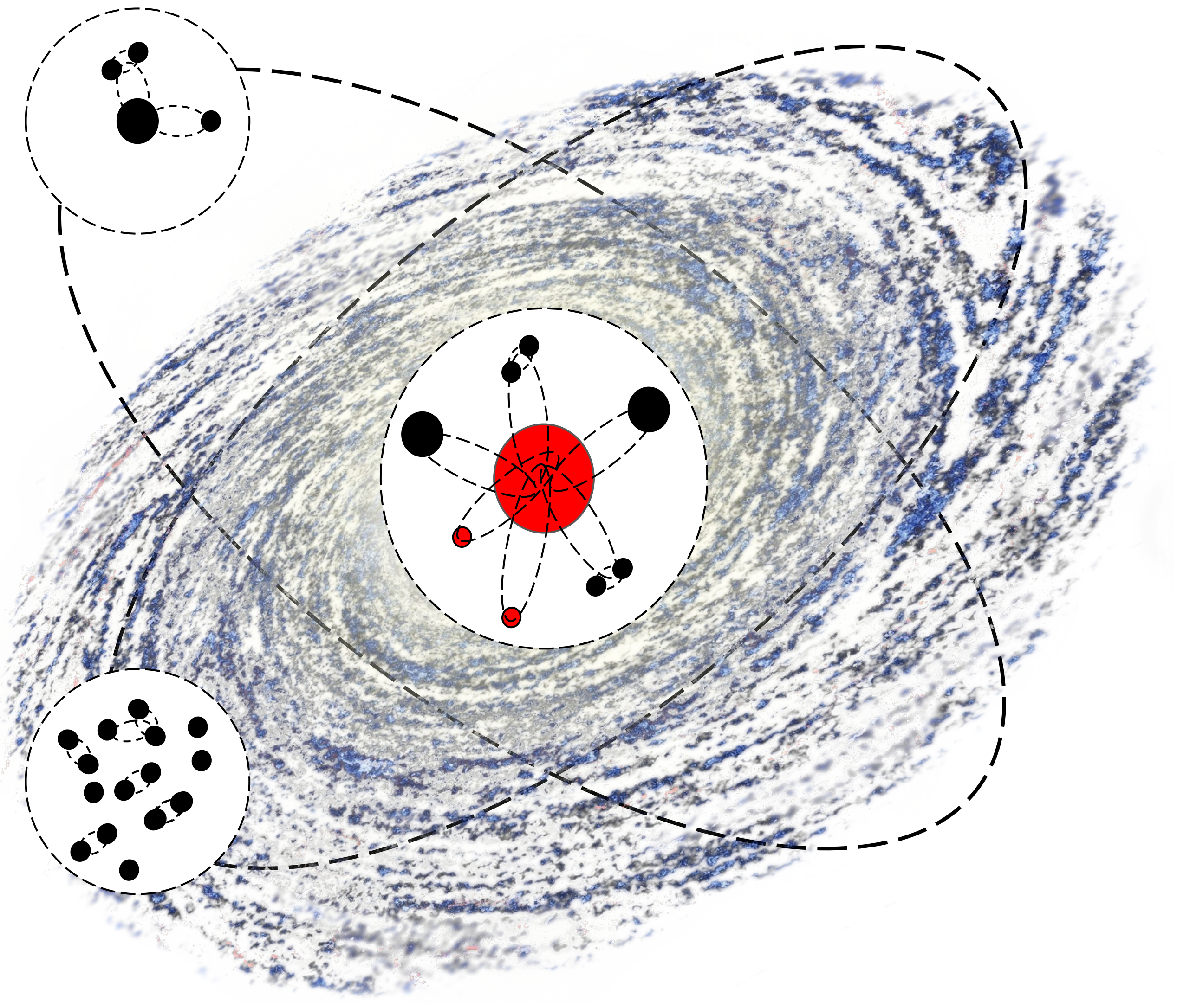

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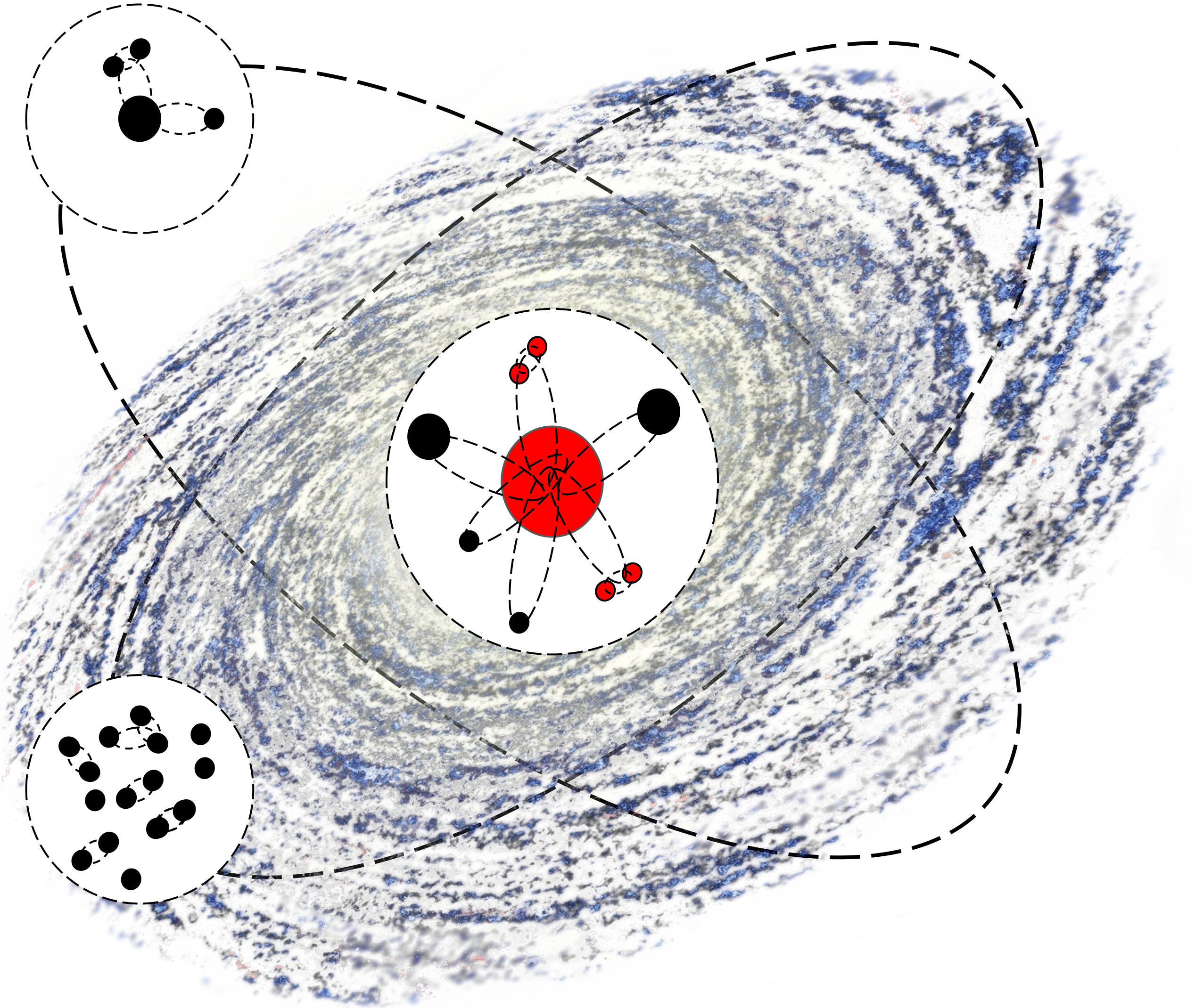

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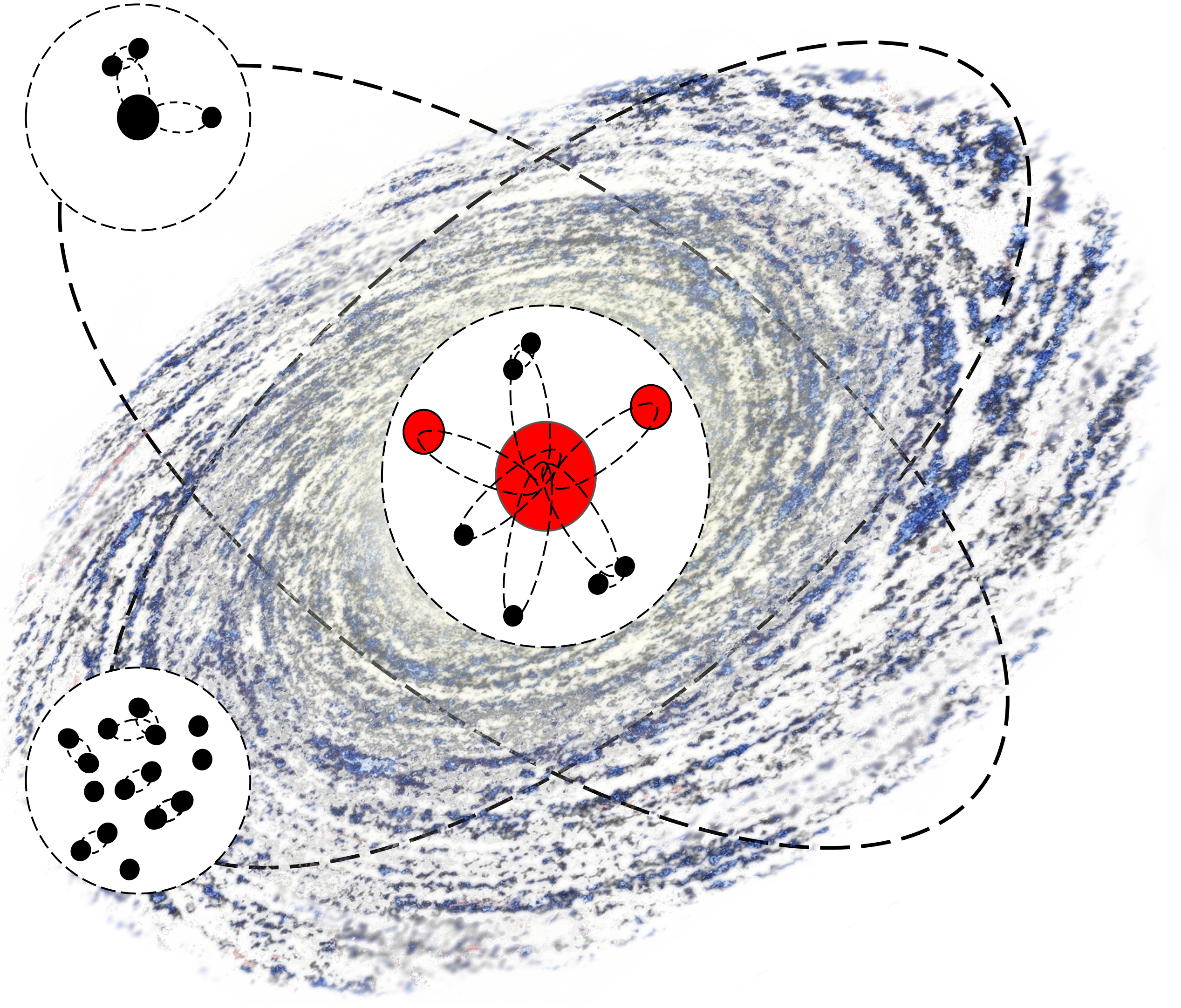
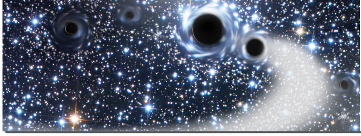




TAKEHOME MESSAGES

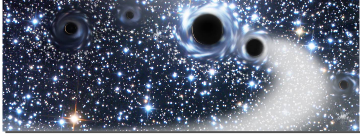
1. **BH subsystem** might long-live **in star clusters** up to present time
2. Their properties can be **connected to observational clusters' quantities**
3. In our **MW** can be as much as **20 GCs** containing **tens to hundreds BHs** at present

4. **Star clusters** are unique places to follow **BHs pairing** and merging processes
5. One of the channel -- formation of **unstable triples** from BH binary binary interactions -- can **contribute** significantly **to** the overall population of BH **mergers**
6. These mergers can **differ from** those occurring in the **field**, possibly helping us in **disentangling** different mergers **formation pathways**

7. **Star clusters** containing an IMBH have peculiar **properties**, depending on the **IMBH formation history**
8. Using these properties, we targeted up to **35 Galactic GCs** that might be **harbouring** an **IMBH** at present
9. The **link between IMBH** and their nurseries can tell us something about potential connections with **SMBHs in Galactic Nuclei**

10. If **Galactic Nuclei** form **from** mergers of **spiralling** star **clusters**, they will be polluted with star clusters compact remnants
11. This can explain some observed features of our **Milky Way** centre -- **Gamma** and **X-ray emission**
12. Such mechanism can **replenish** the **population** of stellar mass **BHs** and **IMBHs** in Galactic Nuclei, possibly giving rise to a **zoology of GW sources**.


Köszönöm a figyelmet!
VideoShow



IMBH around an SMBH: Milky Way - like galaxy

Models Set A
(Arca Sedda & Gualandris 2018)

ZENTRUM FÜR ASTRONOMIE

- Zentrum für Astronomie
- Personnel at ZAH
- Astronomisches Rechen-Institut
- Institut für theoretische Astrophysik
- Landessternwarte
- Gliese Fellowship Program
- SFB 881 "The Milky Way System"
  - Management
  - Participating Institutions
  - PIs and Members
  - Research (2015-2018)
  - Research (2011-2014)
  - News
  - Conferences & Schools

Gravitational waves emitted from black holes in the Galactic Centre

Gravitational waves emitted from black holes in the Galactic Centre

May 17, 2018

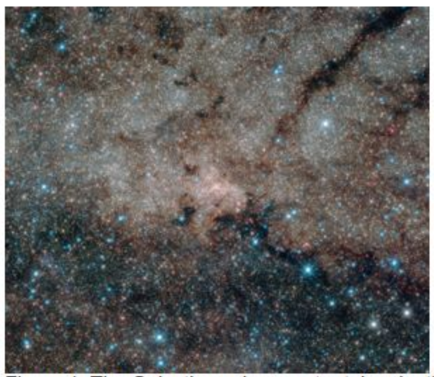


Figure 1: The Galactic nuclear centre taken by the NASA/ESA Hubble Space Telescope in the infrared, 27 000 light-years away from Earth. At the centre of this nuclear star cluster — and also in the centre of this image — the Milky Way's supermassive black hole is located. Credit by: NASA, ESA, T. Do and A. Ghez (UCLA), and V. Bajaj (STScI)

The centre of our Milky Way seems to be a very crowded region. A massive stellar system, called a nuclear star cluster, dominates the innermost 30 light years, harbouring in its centre a supermassive black hole (SMBH) weighing more than 4 million solar masses, called Sgr A*.

Nuclear clusters are thought to form, at least in part, through repeated collisions among massive star clusters born in the inner galactic regions. During the past 12 billion years, also the Galactic Centre itself may have been the site of such cataclysmic events, giving rise to one of the densest stellar systems of the Universe known to us, comprised of more than 20 million stars.

SFB 881

LATEST NEWS

SFB 881 public lecture series "Astronomie am Sonntagmorgen"

SEMINARS

SFB Seminar
Cluster Meeting
Scientific results from the Gaia mission

CONFERENCES/WORKSHOPS

- Survival of Dense Star Clusters in the Milky Way System
- Chemical evolution and nucleosynthesis across the Galaxy
- 13th Heidelberg Summer School: Gaia Data & Science
- Star Clusters around the Milky Way and in the Local Group (Observations, Dynamics, Modelling

IMBH around an SMBH: Milky Way - like galaxy

Model 1: A spiralling GC containing an IMBH

1. Galaxy models: steep or shallow cusp
   a. Steep: a NC is already present
   b. Shallow: the Galaxy does not host a NC
2. $N_{sim.} = 9$ simulations
3. $M_{IMBH} = 10^3 - 10^4\ M_\odot$
4. Orbital eccentricity e = 0,0.7,1.0
5. $M_* = 33\text{-}45\ M_\odot$
6. $N_* = 1048576$
7. Study:
   a. Effects due to the IMBH mass
   b. Effects due to the galaxy structure
   c. Formation of IMBH-SMBH binaries

Model 2: A spiralling GC containing many BHs

1. Galaxy models: shallow cusp
   a. GCs arrive at the Galactic Centre on short time-scales
2. $N_{sim.} = 3$ simulations
3. $M_{BH} = 20 - 40\ M_\odot$
4. Orbital eccentricity e = 0,0.7,1.0
5. $M_* = 10\ M_\odot$
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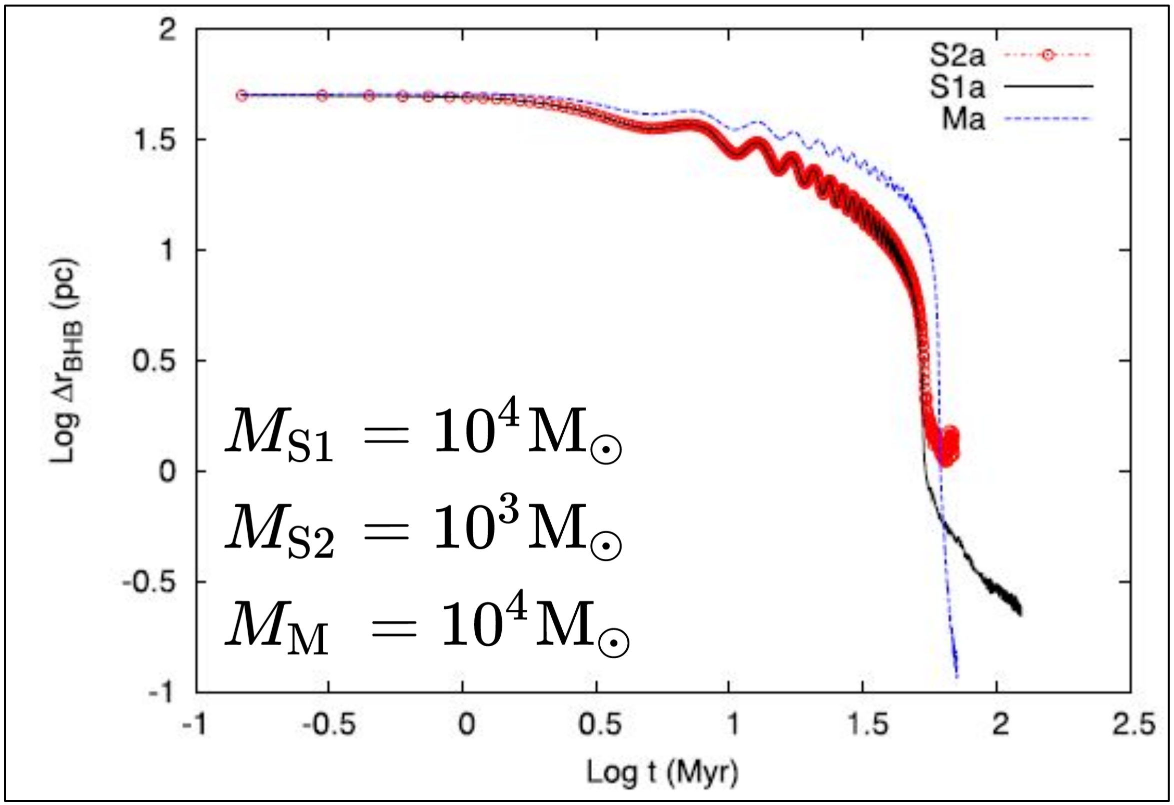


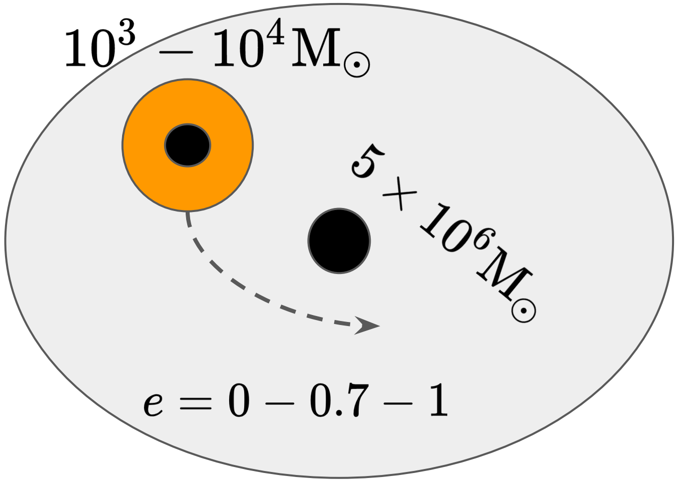
MODEL		t_{GW} (Gyr)
S1a	Shallow models	26
S1b		2.2
S1c		1.3
S2a		679
S2b		77
S2c		6.6
Ma	Steep models	3.3
Mb		2.0
Mc		0.3

Fun facts: The Milky Way might have witnessed an IMBH-SMBH in the last few Gyr

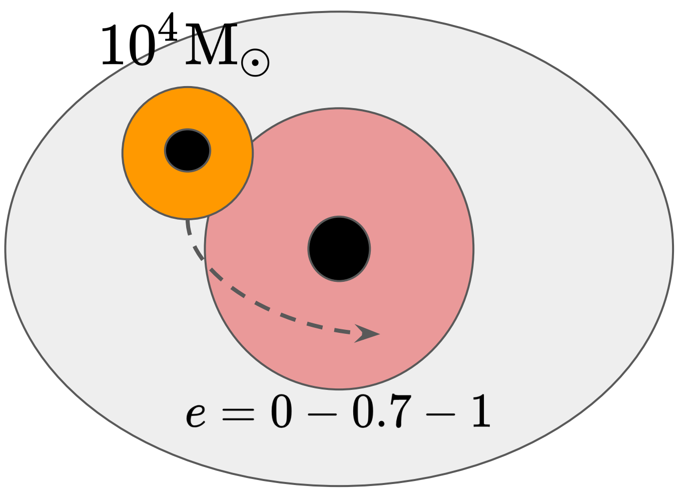
IMBH around an SMBH: Milky Way - like galaxy

Models Set A
(Arca Sedda & Gualandris 2018)

NC not formed yet



NC formed yet



What did we assume?

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currently inhabiting the galactic centre of MW-like galaxies

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Typical mergers in MW-like galaxies

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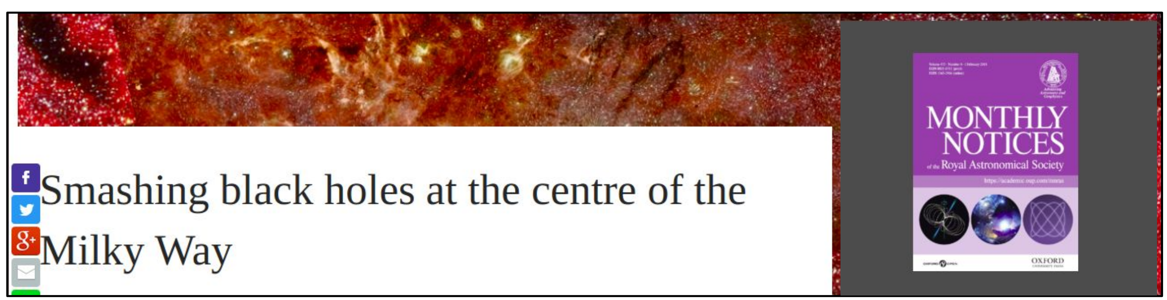

IMBH around an SMBH: Milky Way - like galaxy

Models Set A
(Arca Sedda & Gualandris 2018)

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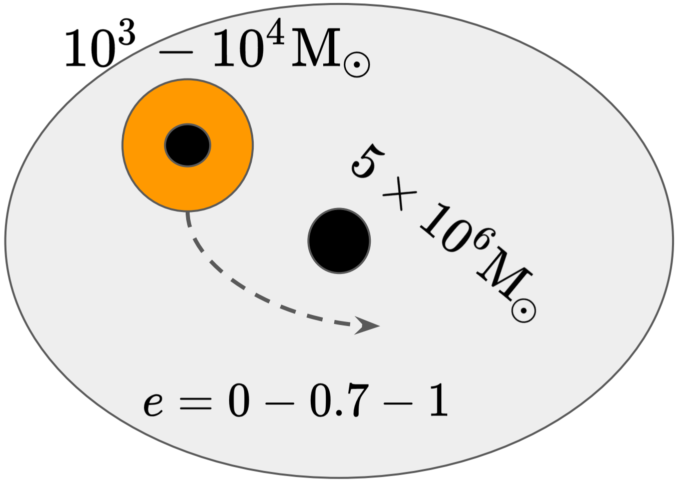

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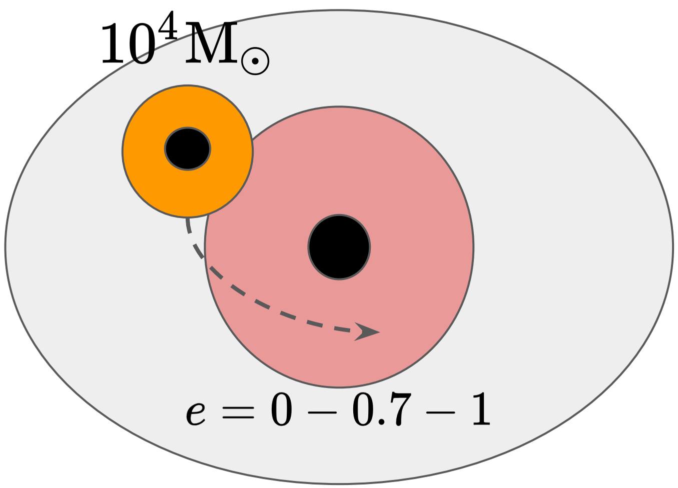
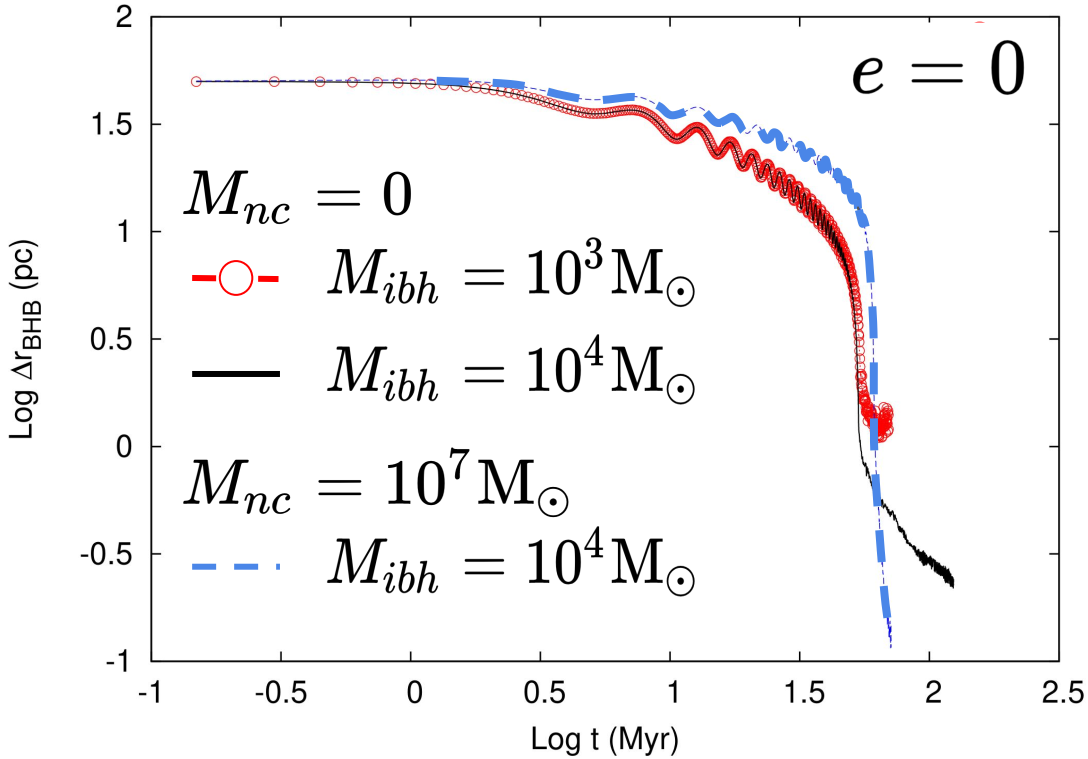


$N = 10^6$ - only 1 GC - direct Nbody



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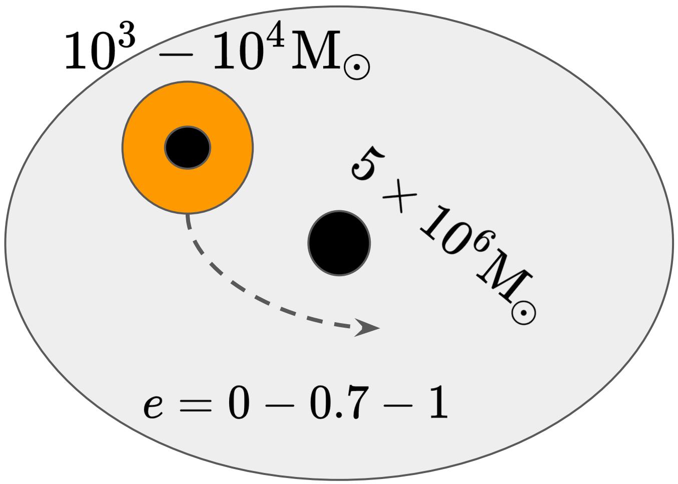

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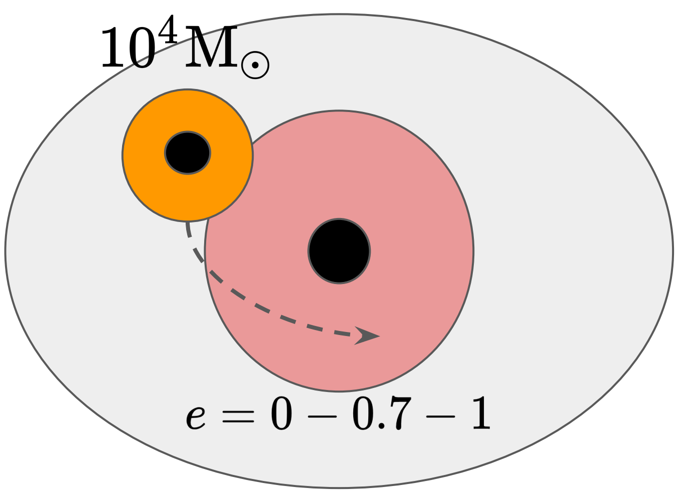

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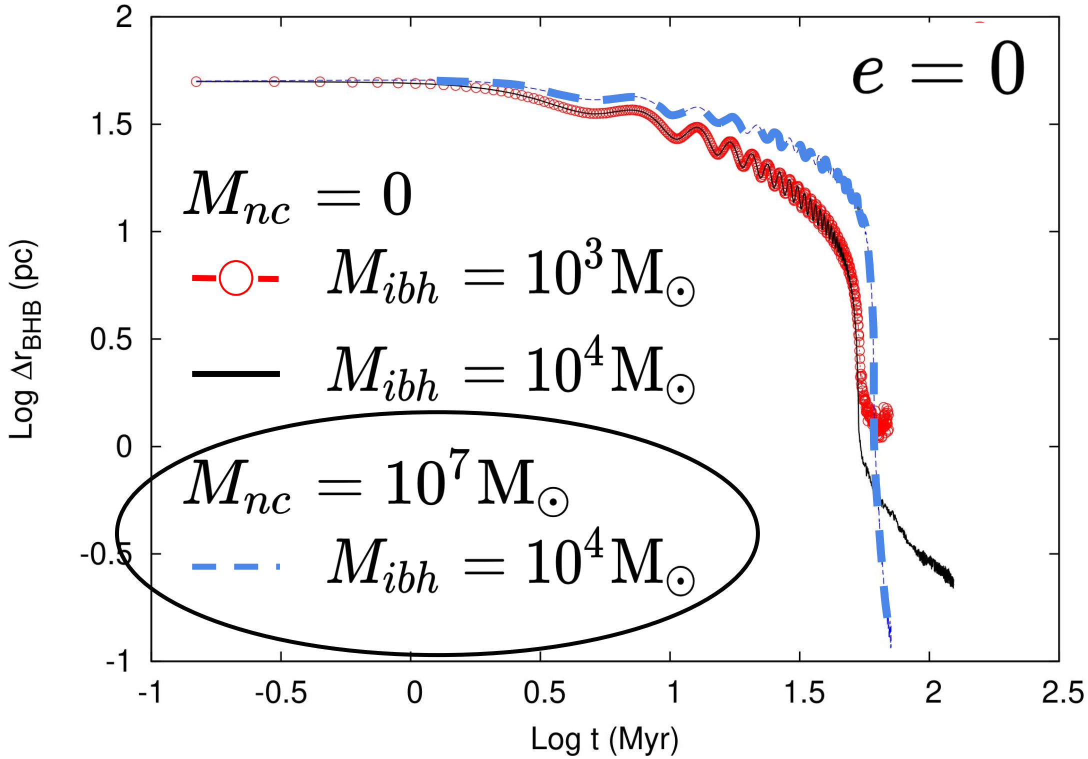

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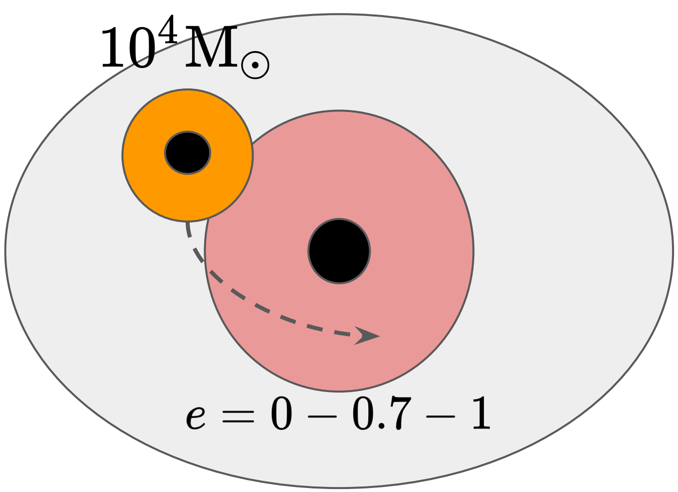

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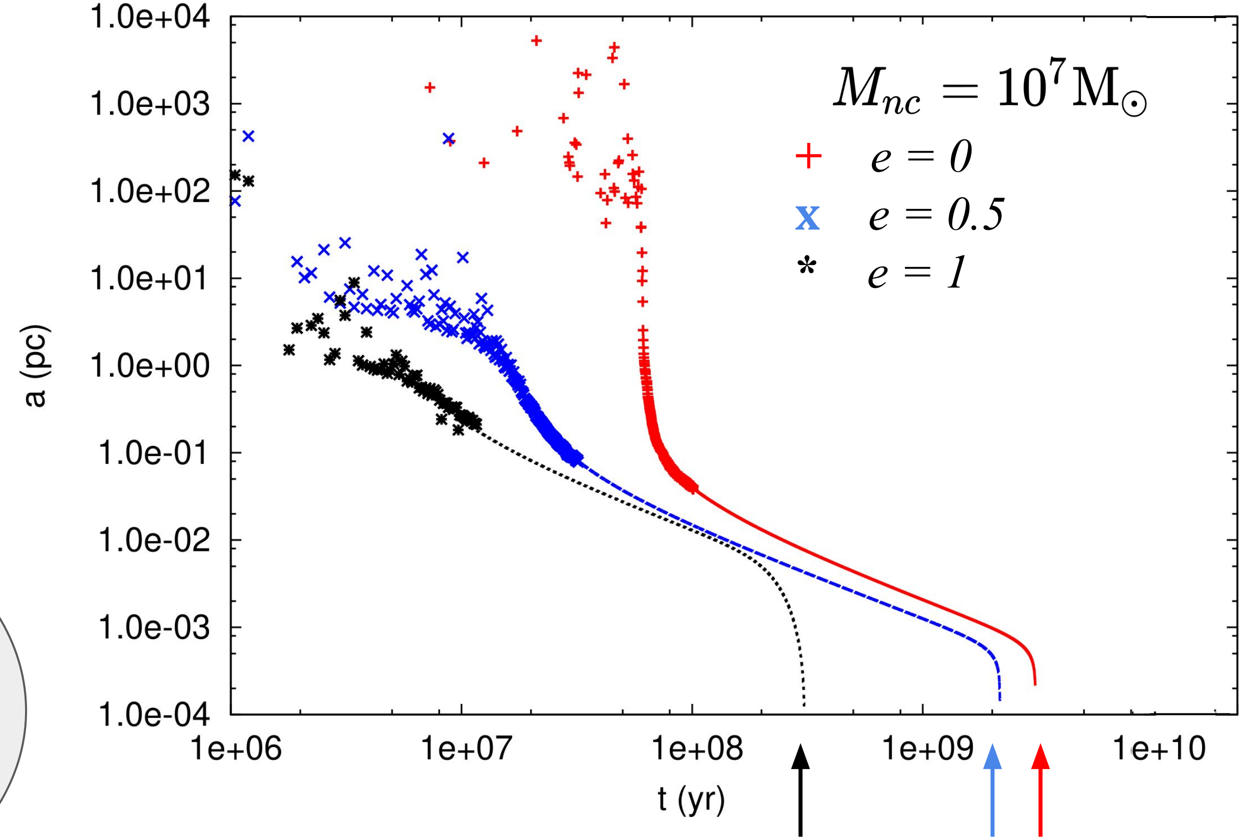


Merger time ~ here

IMBH around an SMBH: Milky Way - like galaxy

MW-like galaxies with IMBHs

Infalling clusters pollute the Galactic Centre with their stars and compact remnants: implications for
→ Gamma ray emission *(Arca Sedda, Kocsis & Brandt, 2018, MNRAS)*
→ stellar and intermediate mass BHs interacting with SMBH *(Arca Sedda and Gualandris, 2018, MNRAS)*

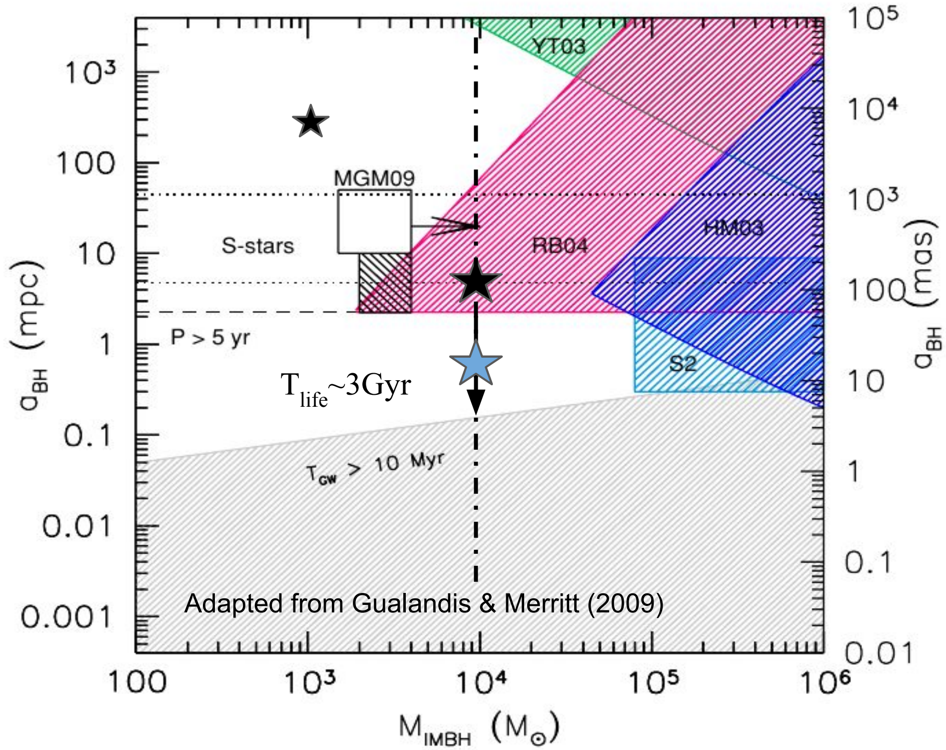
$$M_{NC} = 0\ \mathrm{M}_\odot$$

★ $a_{\rm BH} = 498 - 85$ mpc

★ $a_{\rm BH} = 28 - 3$ mpc

$$M_{NC} = 10^7\ \mathrm{M}_\odot$$

☆ $a_{\rm BH} = 2 - 0.5$ mpc



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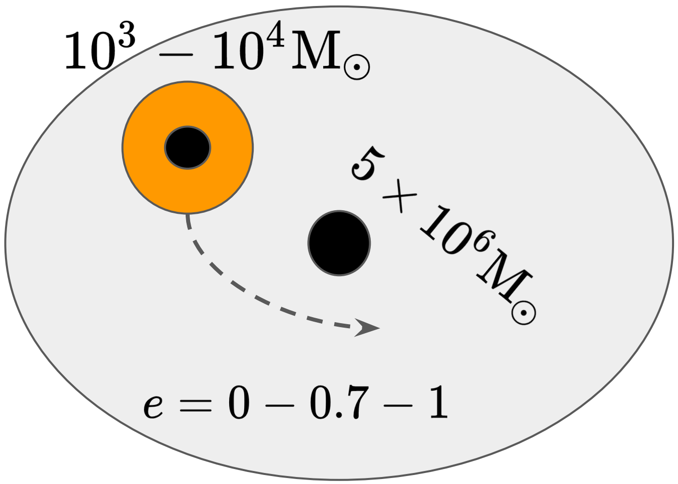

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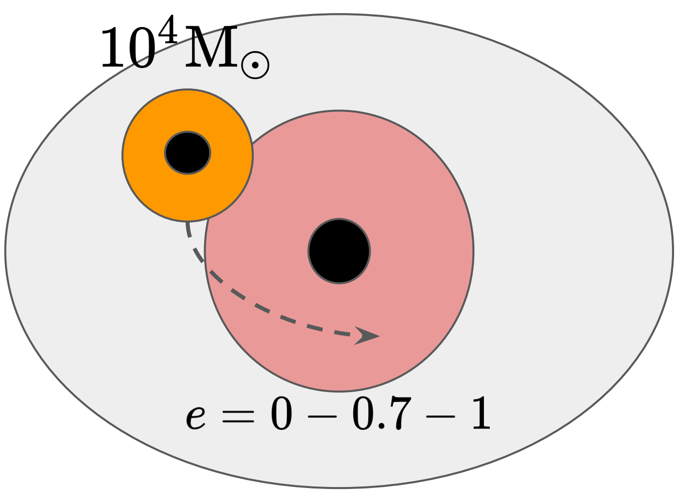

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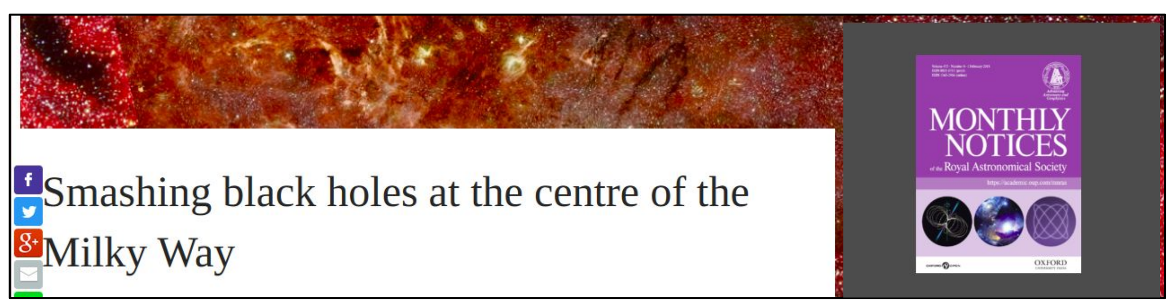
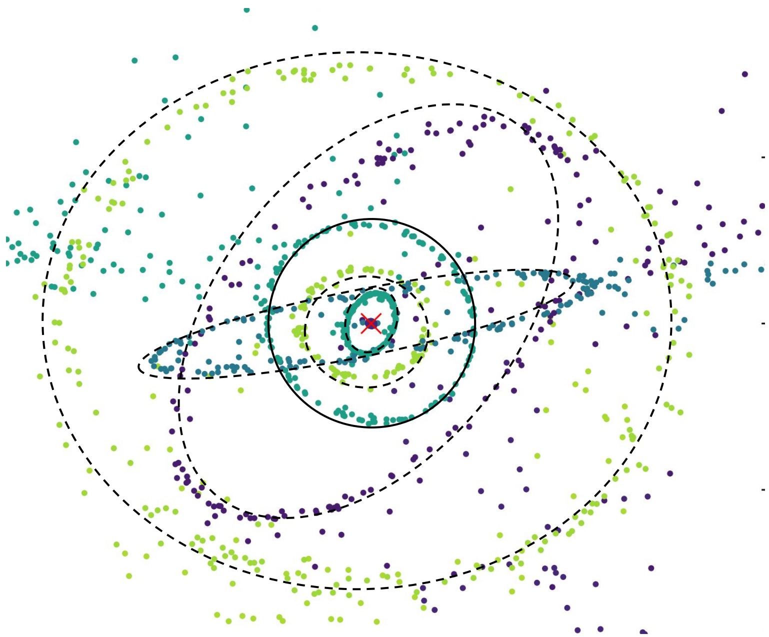


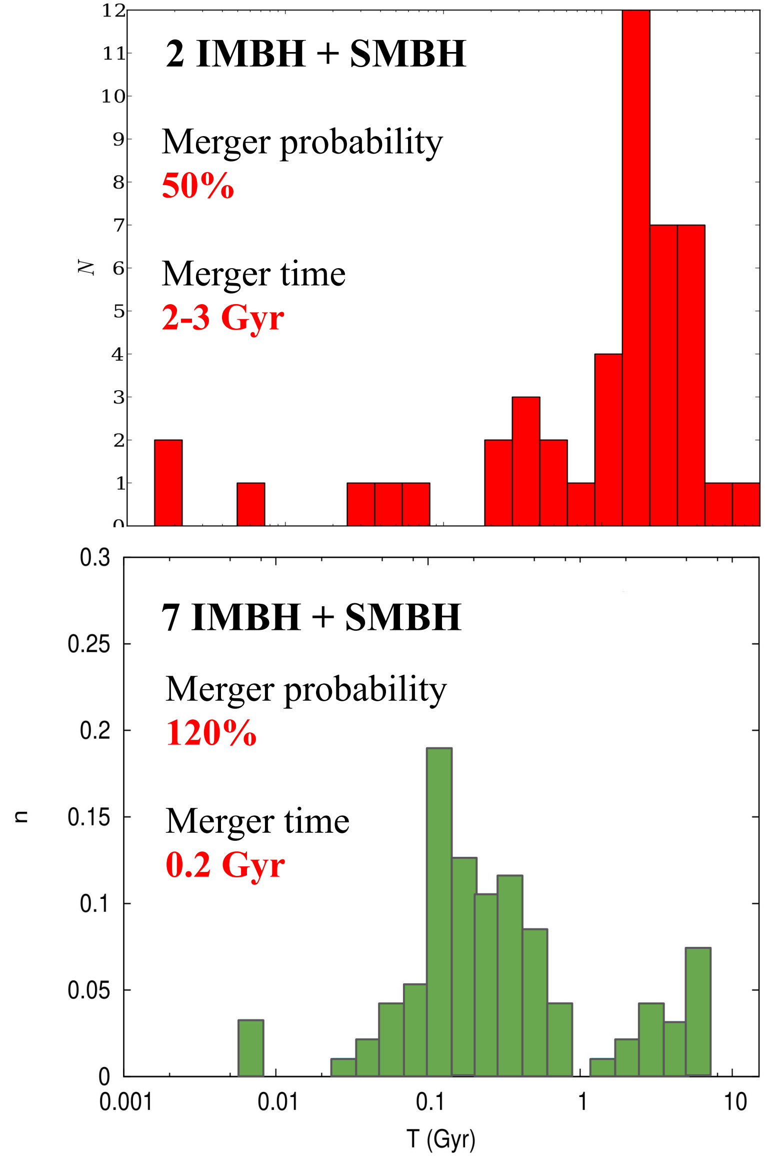
IMBH around an SMBH: Milky Way - like galaxy

Simulations
Direct N-body models with N>10^6
(largest number ever used for galaxy nuclei)

Massive ellipticals with IMBHs

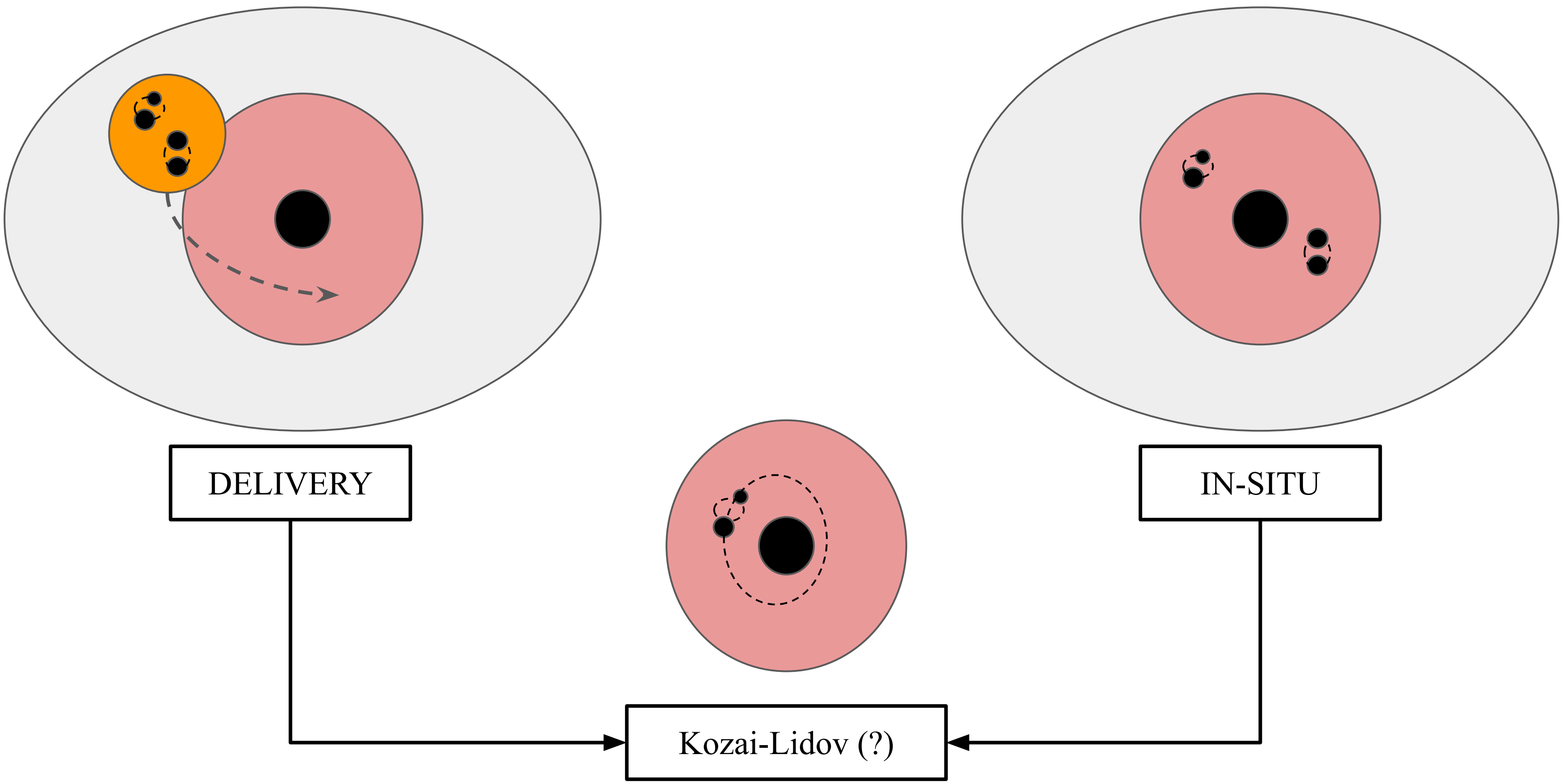
Large number of massive clusters falling onto the galaxy centre
→ IMBHs and BHs accumulation around the SMBH





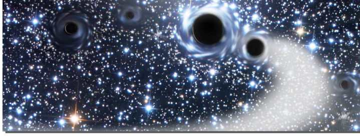
(Arca Sedda & Capuzzo-Dolcetta, 2019, MNRAS)

GW sources in Nuclear Clusters: stellar BH binaries



Arca Sedda & Gualandris, MNRAS, 2018
Arca Sedda, ApJ subm.

Arca Sedda & Capuzzo-Dolcetta, MNRAS, 2019



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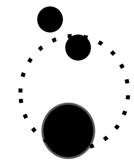
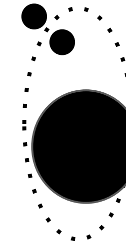




We perform 1000 simulations of this kind, modelling the IMBH, the BHB and the SMBH

Binary BHs around IMBH ...

We find **3%** of probability for BHBs to merge $\Gamma \simeq 2\ \mathrm{yr}^{-1}\ \mathrm{Gpc}^{-3}$

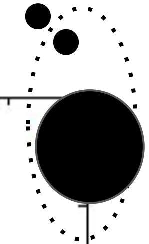
- Occurrence of IMBH formation
- IMBH-stellar BH interplay
- BH binary formation and evolution in star clusters
- Number density of galaxies in the local Universe

... or SMBH

We find **5.2%** of probability for BHBs to merge $\Gamma \simeq 1\ \mathrm{yr}^{-1}\ \mathrm{Gpc}^{-3}$

- BH binary formation and evolution in galactic nuclei (Arca Sedda, almost ready)
- Role of SMBH mass on the merger probability (Arca Sedda, almost ready)
- SMBH occupation fraction
- Number density of galaxies in the local Universe

Arca Sedda & Capuzzo-Dolcetta 2018

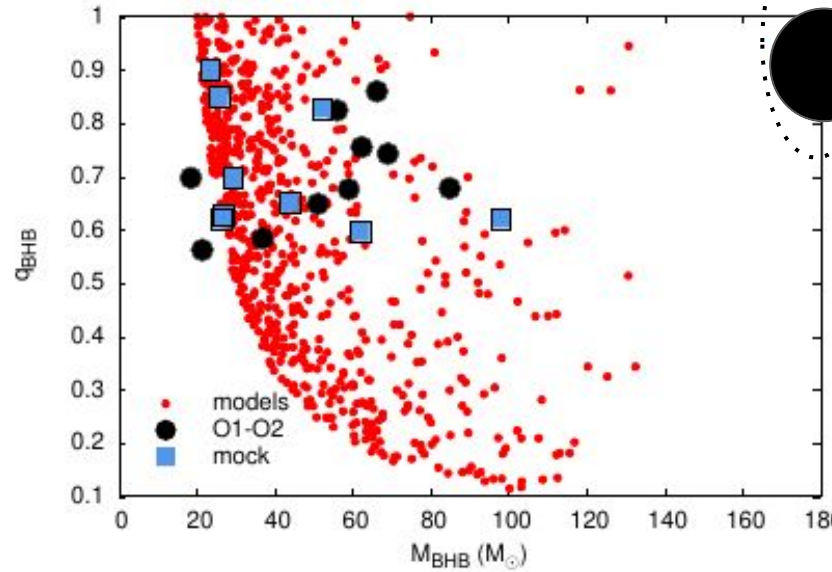


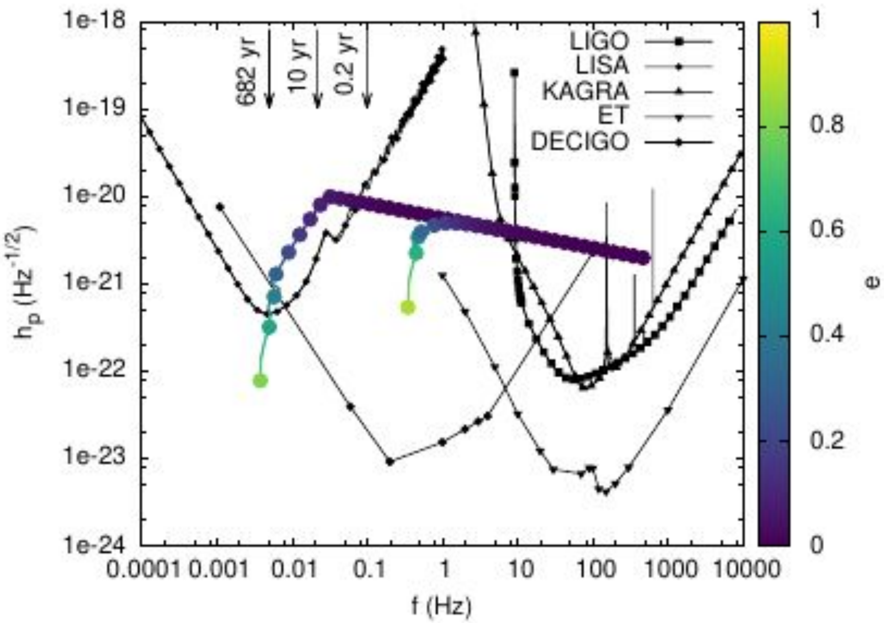
... or SMBH (preliminary)

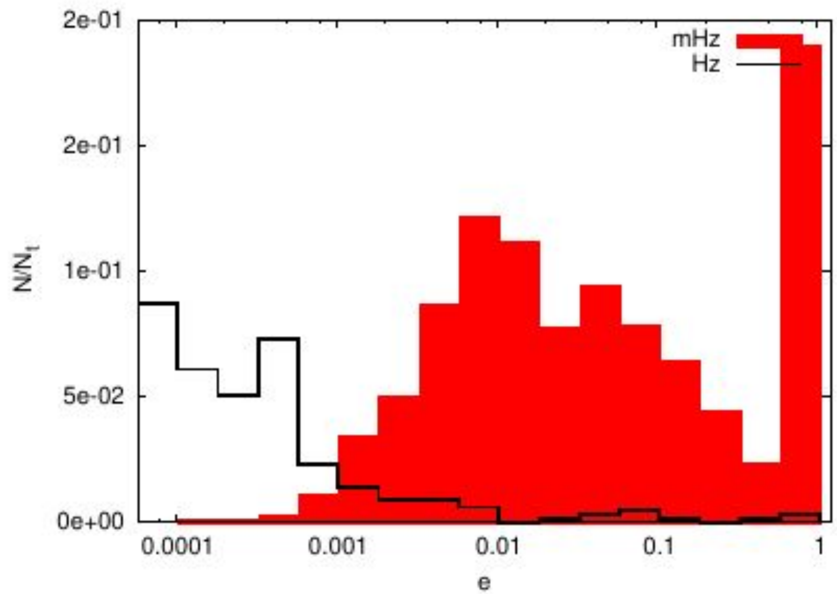
-- The probability for BHB mergers is maximized in MW like galaxies --

-- They can appear eccentric in the LISA band, and merge in the LIGO band --

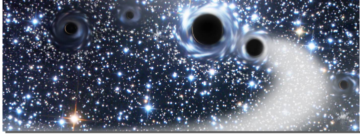
-- Some of the observed LIGO sources might be originated around an SMBH --







Arca Sedda, ApJ subm.



Q&A

How, when, where do black holes form in star clusters?

How do they pair and merge?

What about intermediate mass black holes in globulars?

How do they get into galactic nuclei?

Can we distinguish BHs merging in different environments?

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What LIGO and VIRGO are going to observe during O3?

- Isolated binary (50%)
  - Spins mildly aligned
- Dynamical binaries from
  - Open clusters
    - Low recycling
  - Globular clusters
    - Recycling possible
  - Nuclear clusters
    - Recycling
- Metallicity distribution of local Universe (+ merger dependency!)

Arca Sedda & Benacquista, 2019, MNRAS
Arca Sedda et al, in prep

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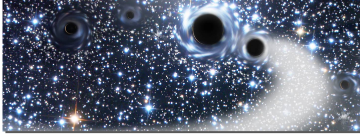

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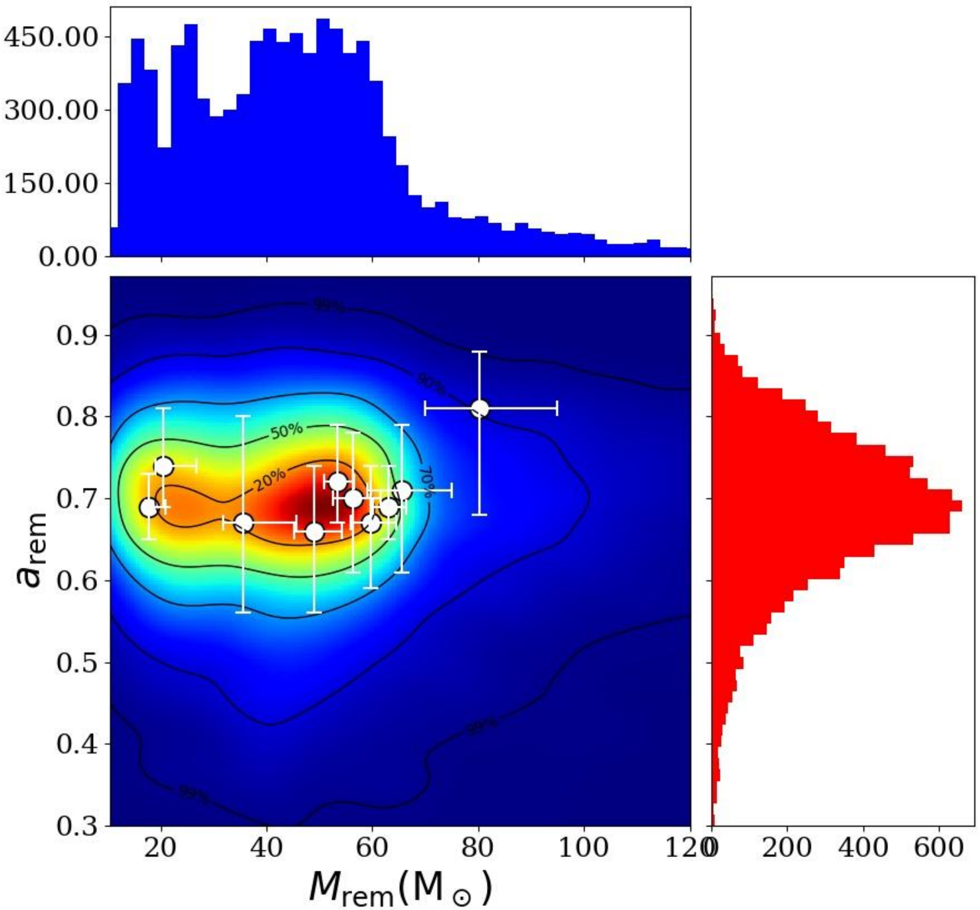

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