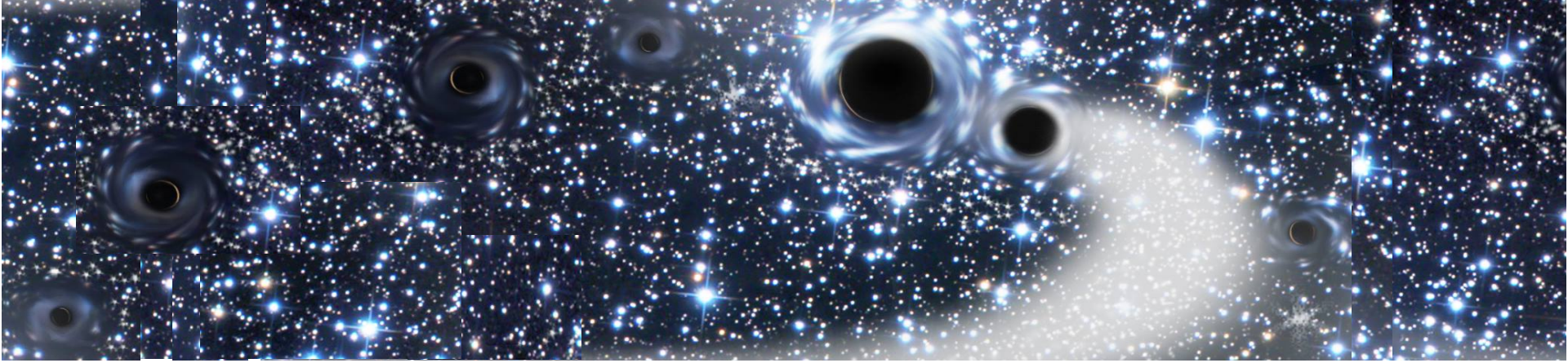

Black hole binary mergers in galactic nuclei

Manuel Arca Sedda

Project: The evolution of Black Holes from stellar to galactic scales

LISA WG meeting
IAP, Paris

12/14 - 12 - 2018

Unterstützt von / Supported by
Alexander von Humboldt
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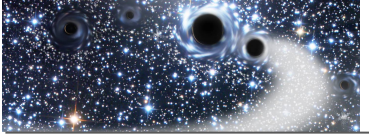


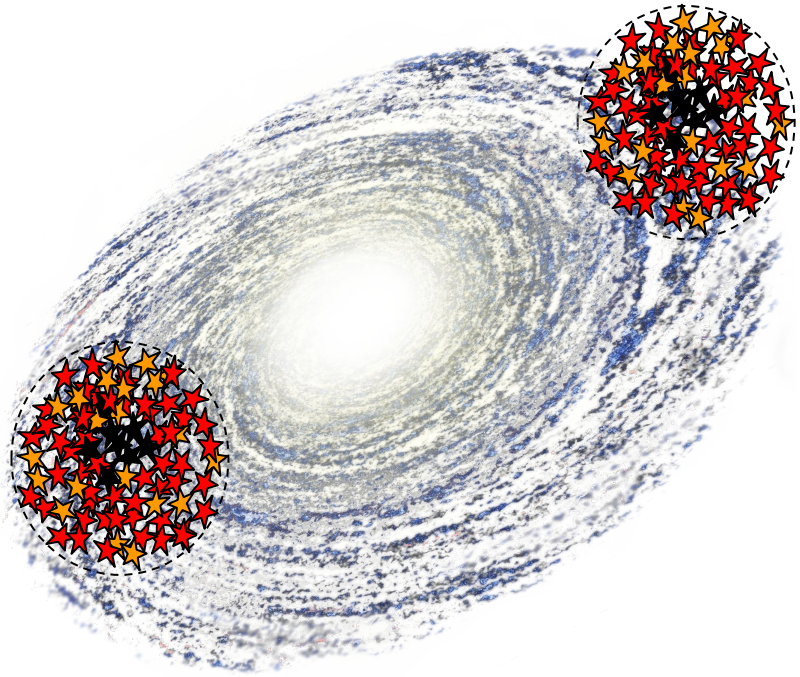
References

Arca Sedda & Gualandris, 2018, MNRAS, 477(4), 4423-4442
Arca Sedda & Capuzzo-Dolcetta, 2018, MNRAS, 10.1093/mnras/sty3096
Arca Sedda, in prep.

Outline

- Delivery of compact remnants in galactic nuclei
- Milky Way like environments
- Massive elliptical galaxies
- Take home

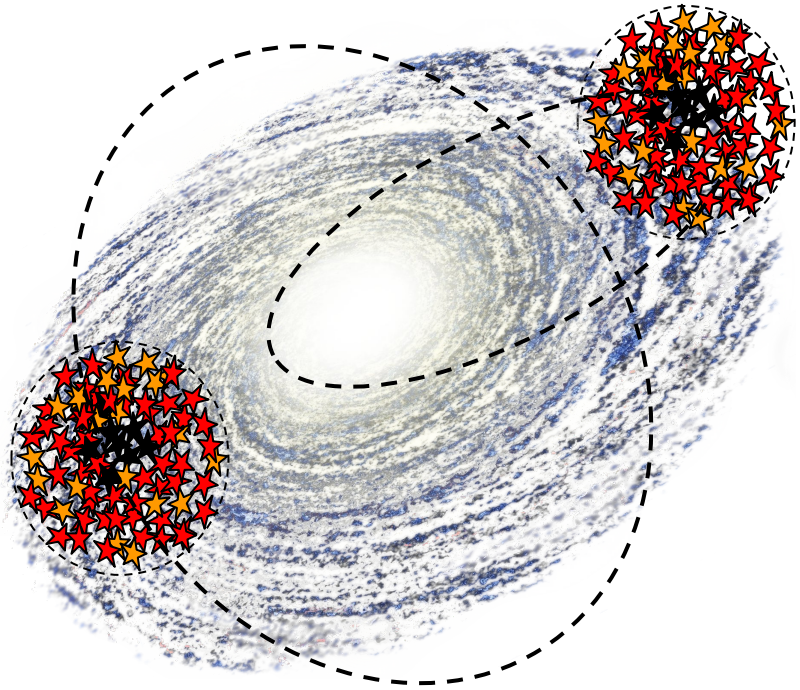
Delivery of compact remnants in galactic nuclei



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

Delivery of compact remnants in galactic nuclei



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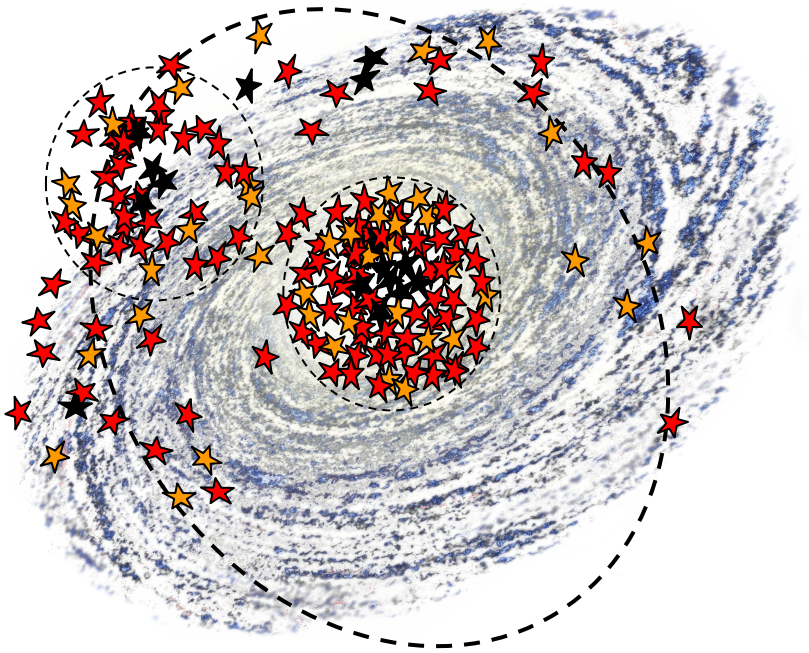
Dynamical friction erases part of the GCs orbital energy, forcing them to spiral toward the galaxy centre

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

Delivery of compact remnants in galactic nuclei



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

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

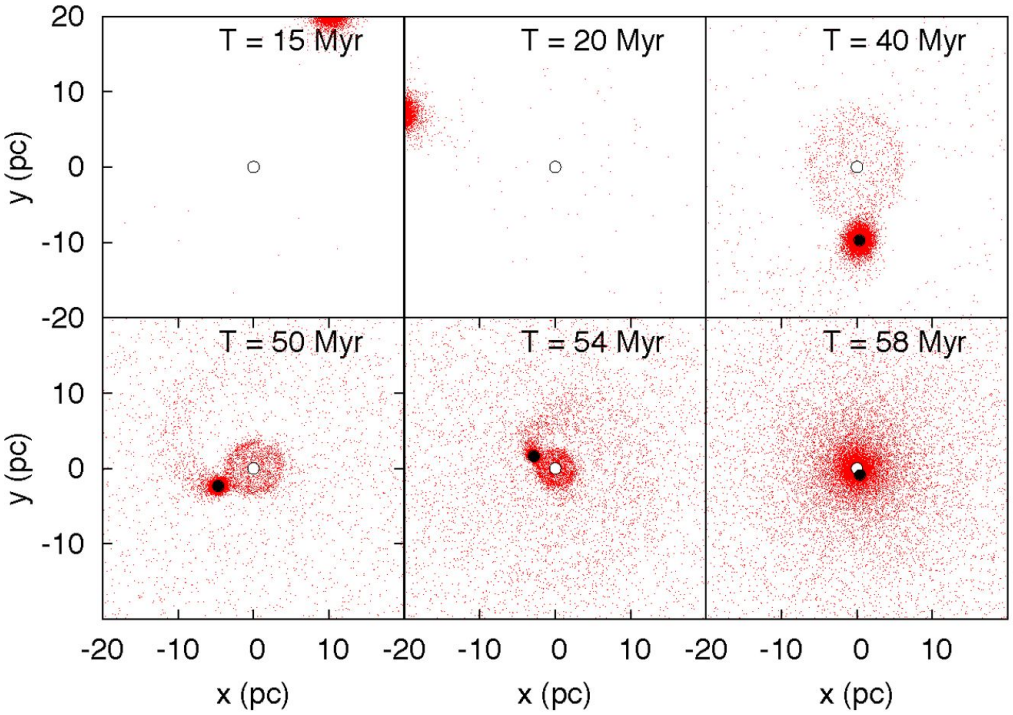
Milky Way like environments

Number of particles to model the GCs and the galaxy with the SMBH: > 500k - 1M particles

We use HiGPUs* to develop the MEGaN galaxy models (direct N-body models with N>1 million bodies)

Models Set A (Arca Sedda & Gualandris 2018)

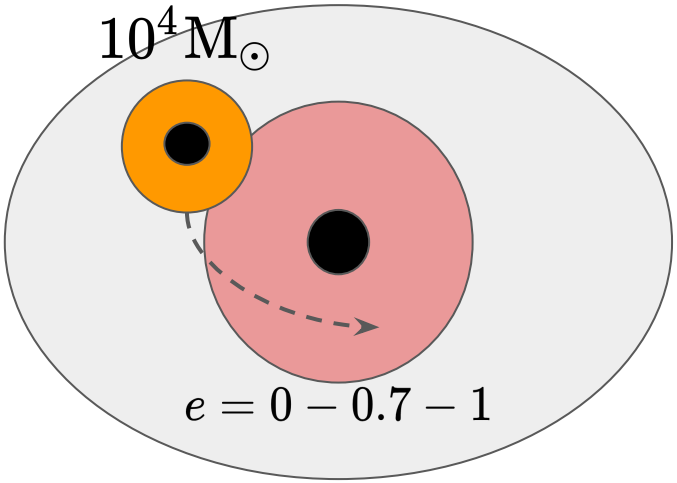
12 DIRECT N-BODY SIMULATIONS	
SMBH mass	$5 \times 10^6 M_\odot$
Density slope (galaxy)	0.5 - 2.0
NC mass	$0 - 10^7 M_\odot$
N. infalling clusters	1
eccentricity	0 - 0.7 - 1
N. IMBH	0 - 1
IMBH mass	$10^{3\text{-}4} M_\odot$
N. BHs (if No. IMBH = 0)	114

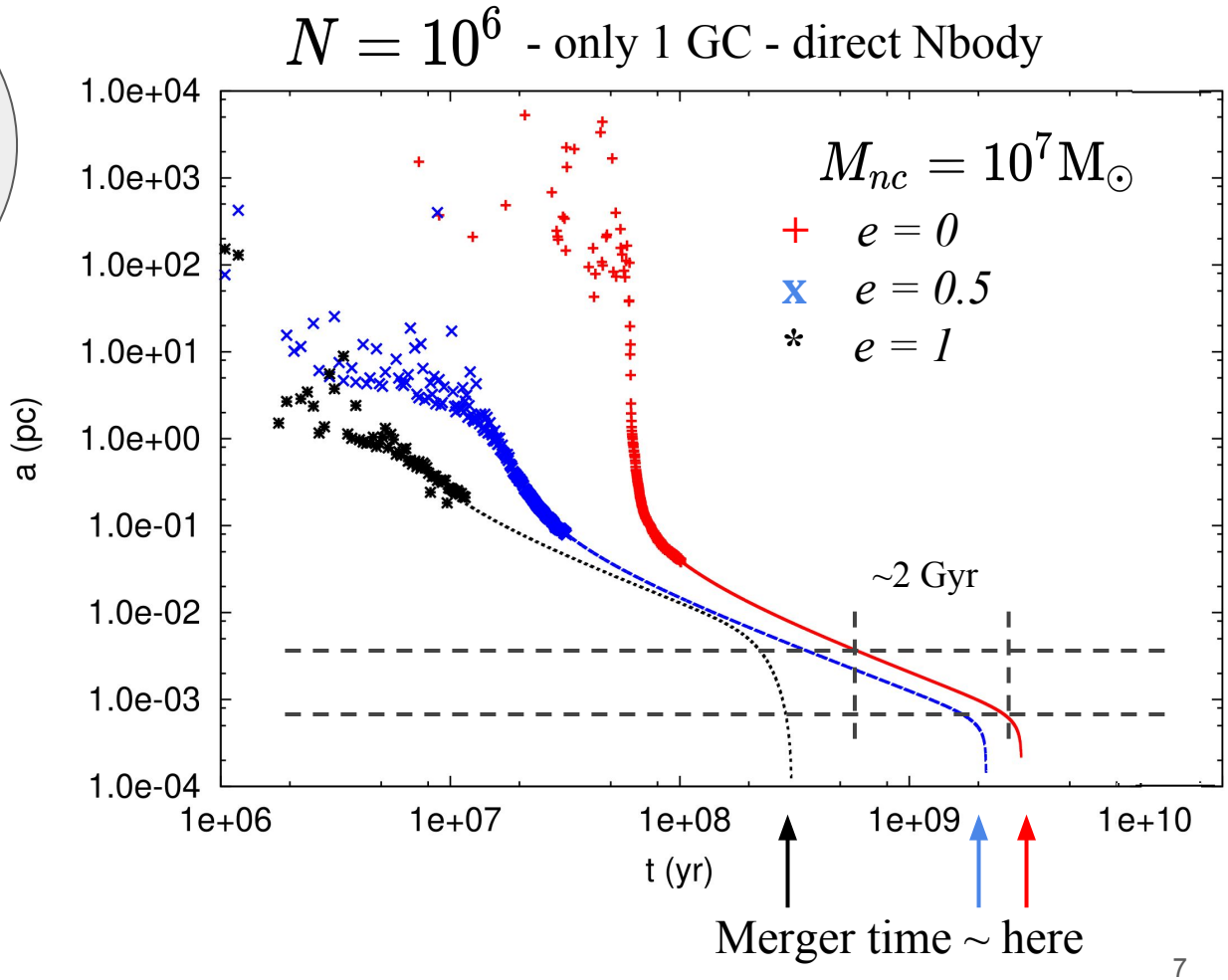


* **Capuzzo-Dolcetta, Spera & Punzo (2013)**

Milky Way like environments

NC formed yet

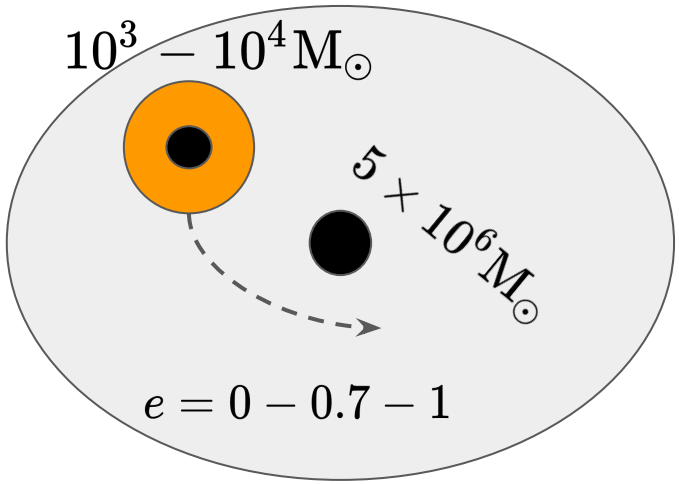


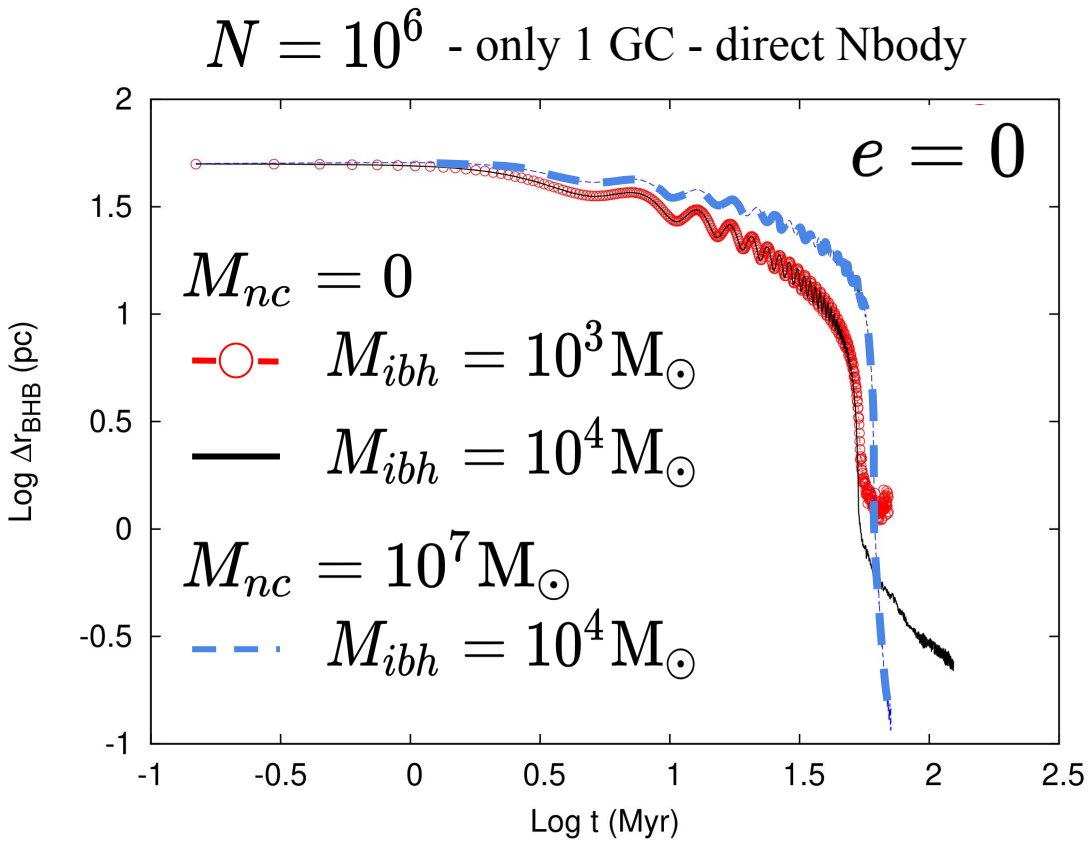


Arca Sedda & Gualandris 2018

Milky Way like environments

NC not formed yet





Arca Sedda & Gualandris 2018

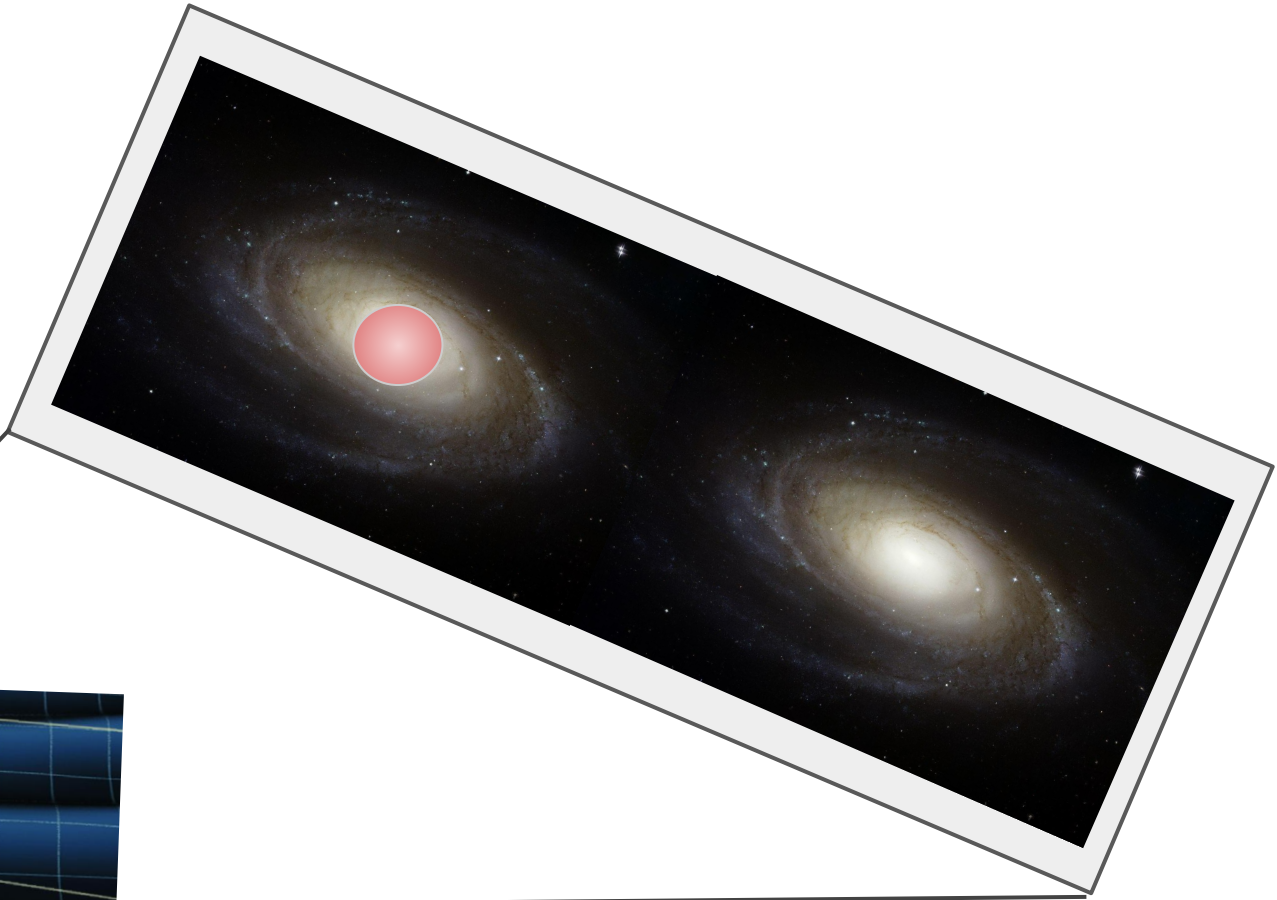
Milky Way like environments

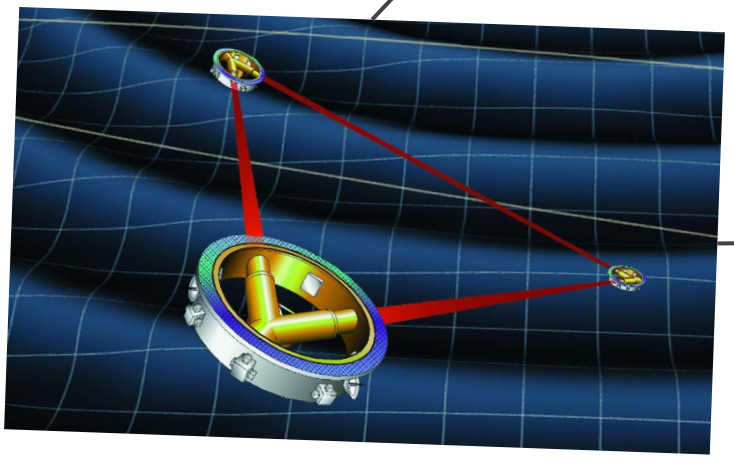
What about LISA?

-- Galaxies lacking NCs are unlikely to witness SMBH-IMBH mergers --

-- Galaxies with an NC can have short-living SMBH-IMBH binaries (age < 5 Gyr) --

-- Can we use this info to shortlist possible host ? --

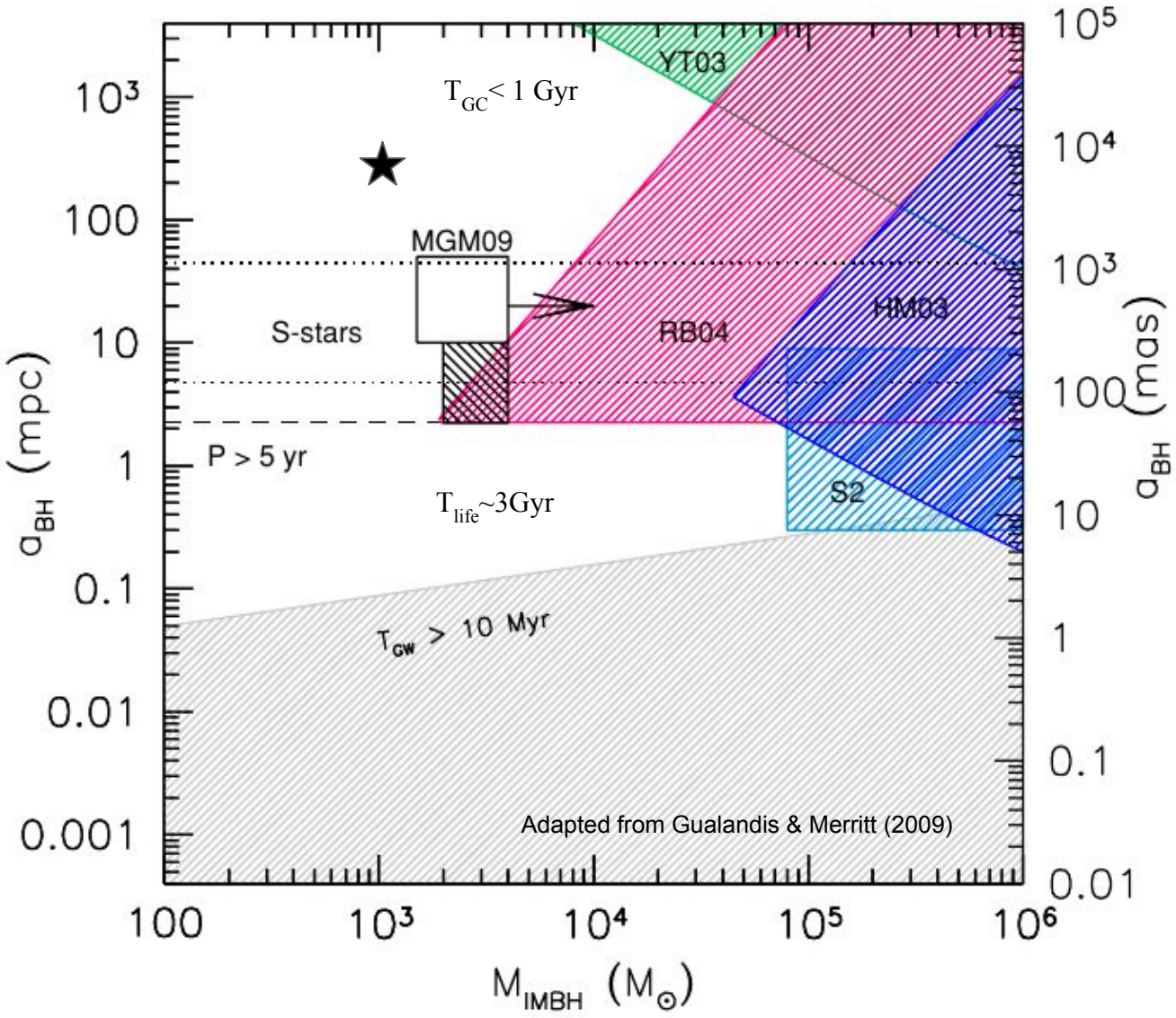




Milky Way like environments

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

★ $a_{\mathrm{BH}} = 498 - 85$ mpc



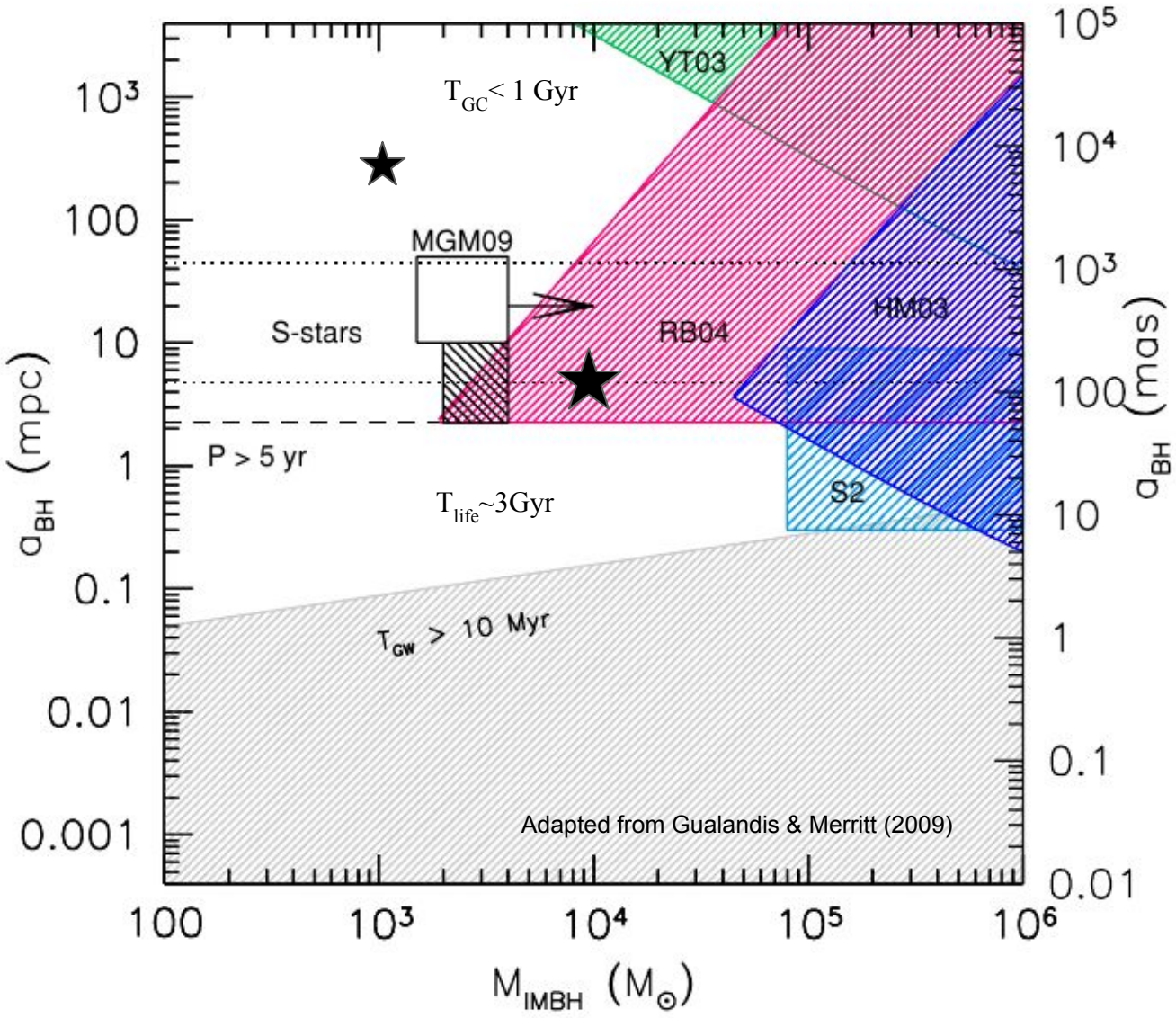
Arca Sedda & Gualandris 2018

Milky Way like environments

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

★ $a_{\mathrm{BH}} = 498 - 85$ mpc

★ $a_{\mathrm{BH}} = 28 - 3$ mpc



Arca Sedda & Gualandris 2018

Milky Way like environments

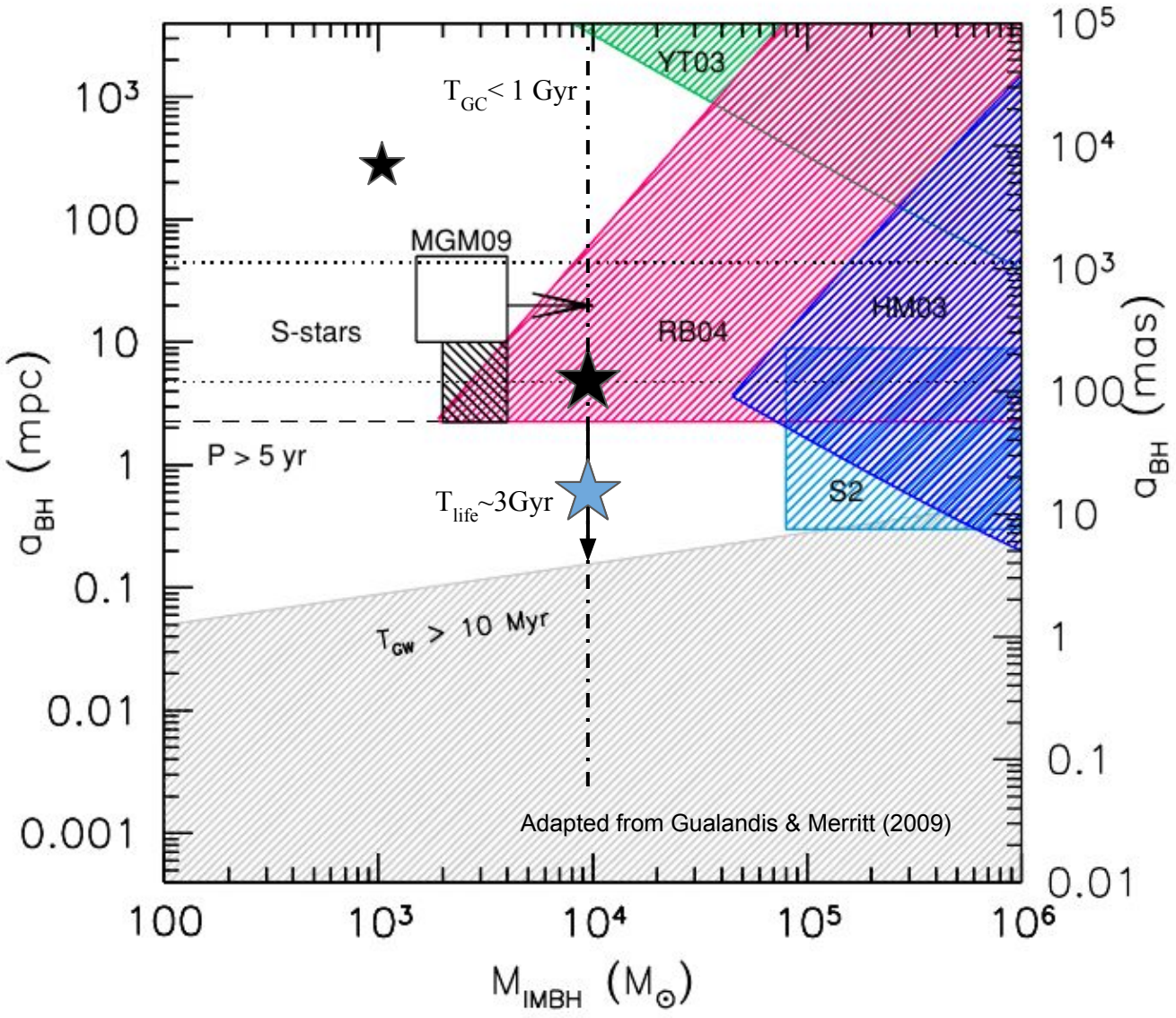
$M_{NC} = 0\ \mathrm{M}_{\odot}$

★ $a_{\mathrm{BH}} = 498 - 85$ mpc

★ $a_{\mathrm{BH}} = 28 - 3$ mpc

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

★ $a_{\mathrm{BH}} = 2 - 0.5$ mpc

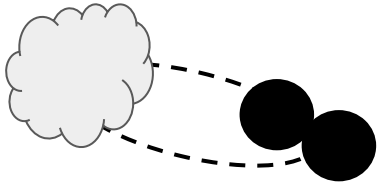


Arca Sedda & Gualandris 2018

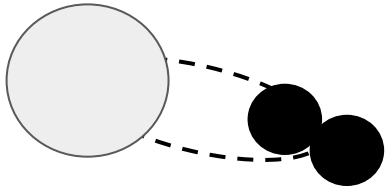
Milky Way like environments

What can help in absence of a NC?

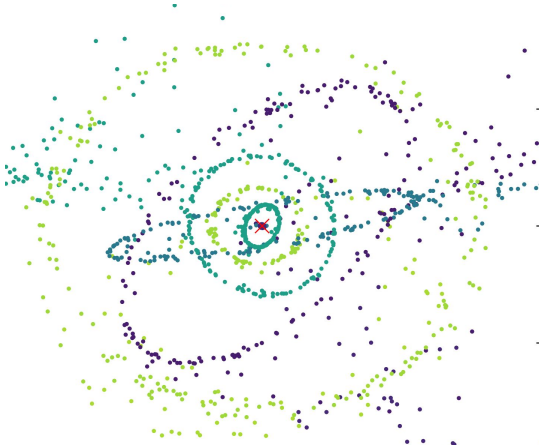
Gaseous perturbers
(Goicovic et al. 2016, 2018
Maureira-Freides et al. 2018)



Star clusters
(Perets & Alexander 2012,
Arca Sedda et al. 2018)

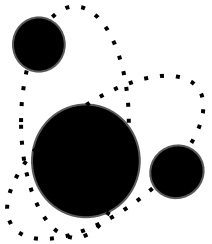


More IMBHs
(Arca Sedda & Capuzzo-Dolcetta 2018)



Massive elliptical galaxies

WARNING: $M_{\rm SMBH} = 10^8 {\rm M}_\odot$



2 IMBH-SMBH ...

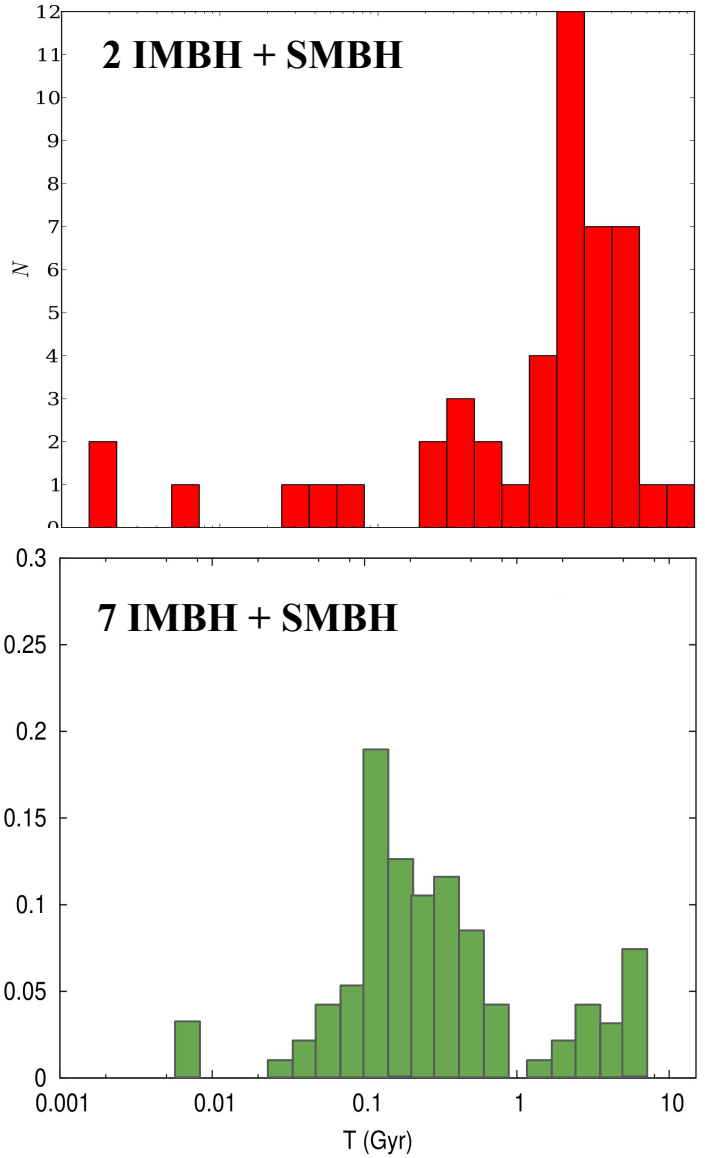
Merger probability **50%**

Merger time **2-3 Gyr**

... 8 IMBH-SMBH

Merger probability **120%**

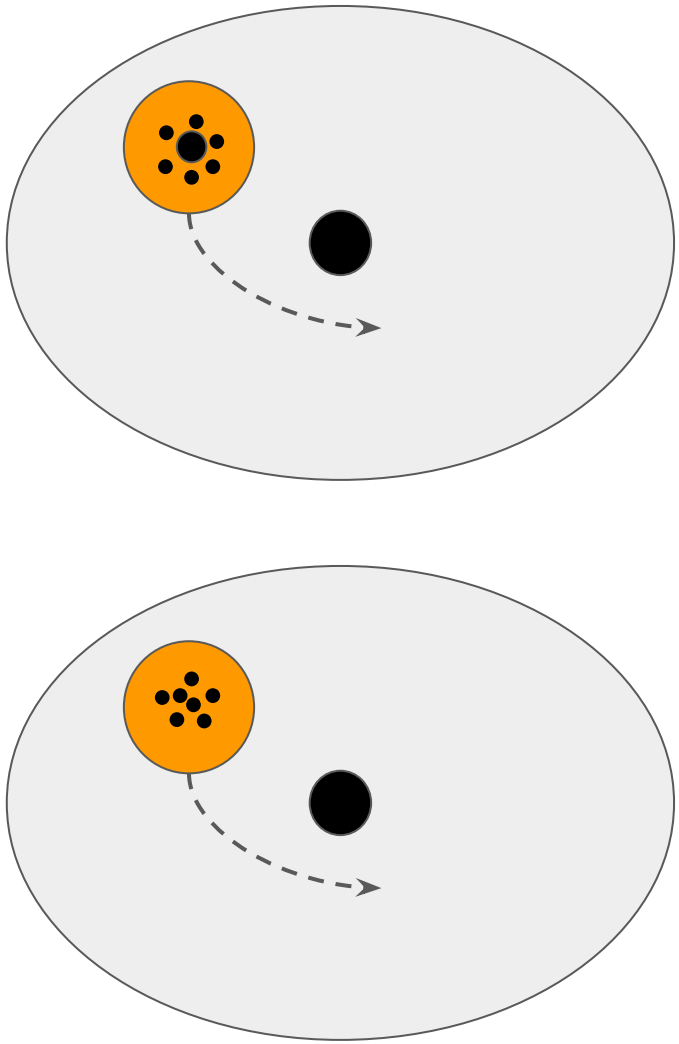
Merger time **0.2 Gyr**

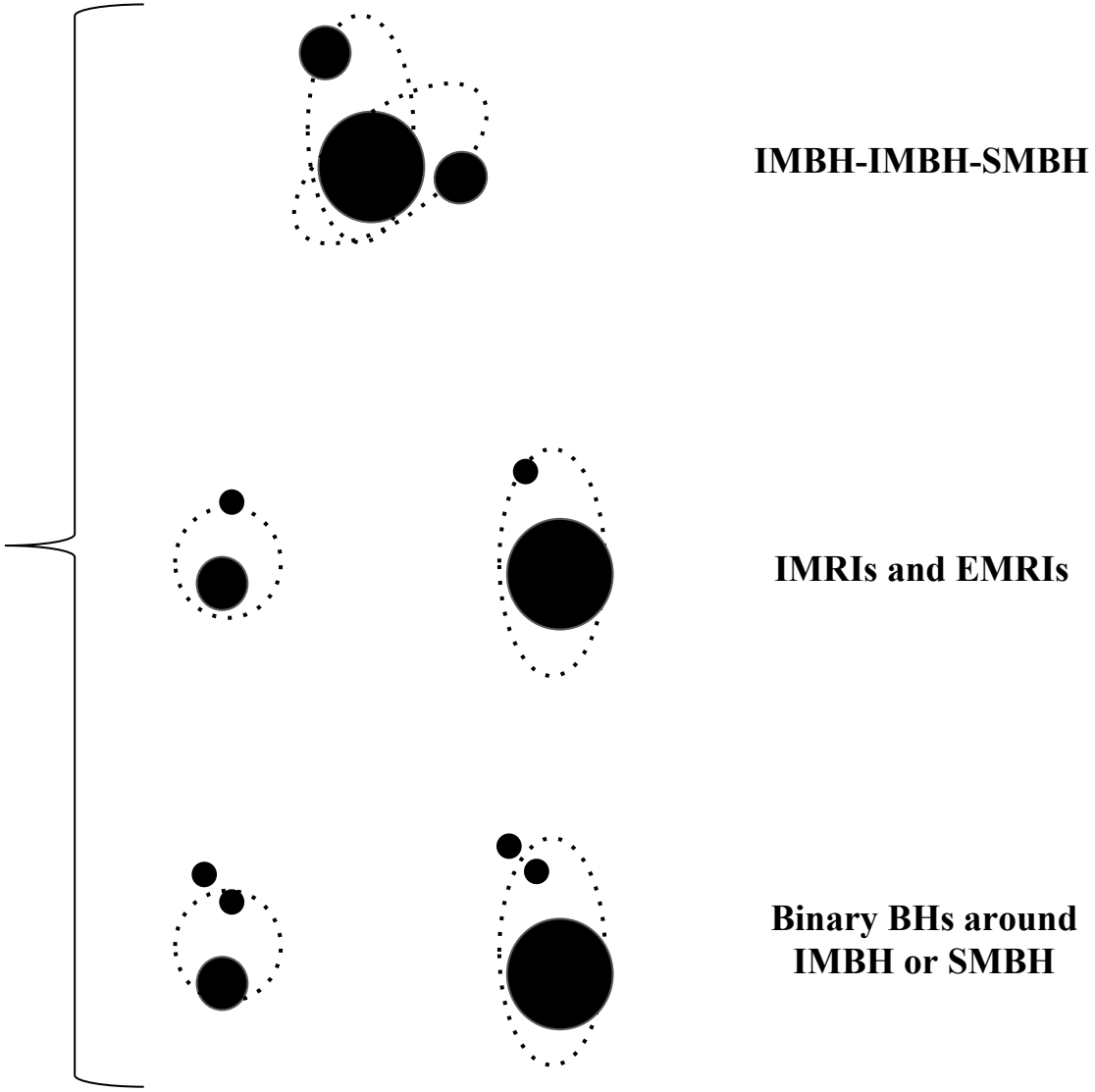


Arca Sedda & Capuzzo-Dolcetta 2018

Massive elliptical galaxies

$$M_{\rm SMBH} = 10^8 {\rm M}_\odot \qquad M_{\rm NC} = 0$$



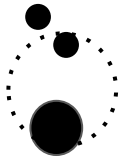


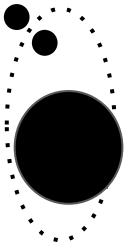
IMBH-IMBH-SMBH

IMRIs and EMRIs

Binary BHs around IMBH or SMBH

Massive elliptical galaxies





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

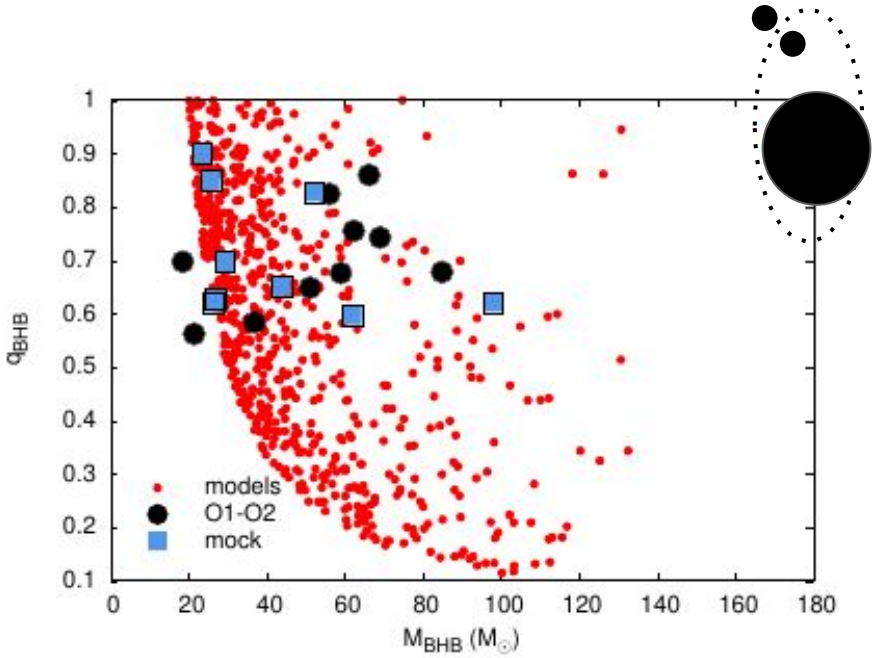
Massive elliptical galaxies

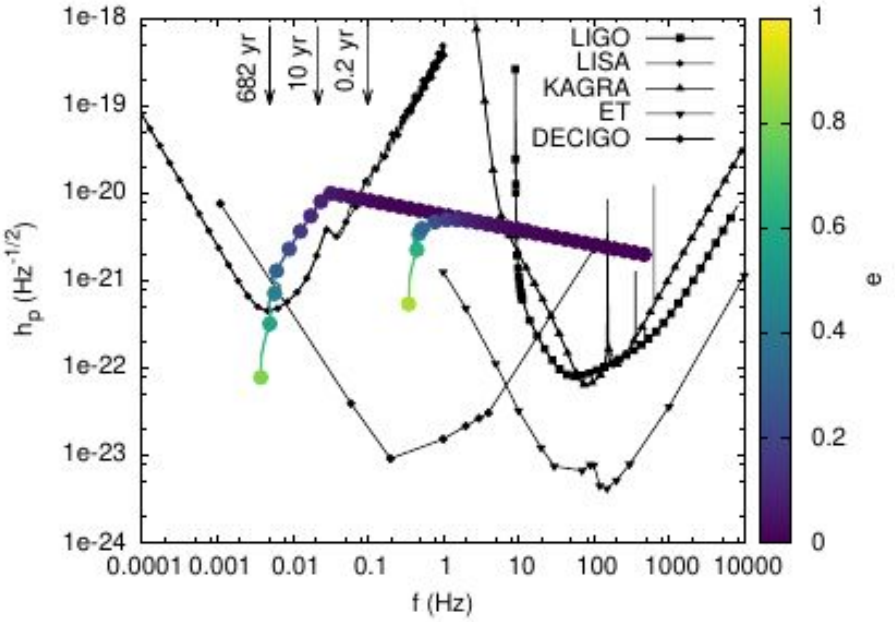
... or SMBH (preliminary)

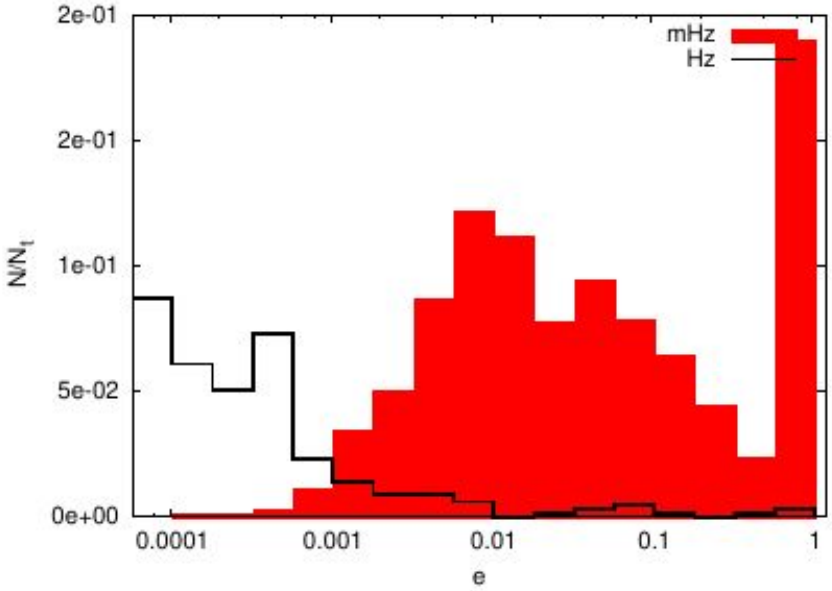
-- The probability for BHB mergers is maximized in MW like galaxies --

-- 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, in prep.

Massive elliptical galaxies

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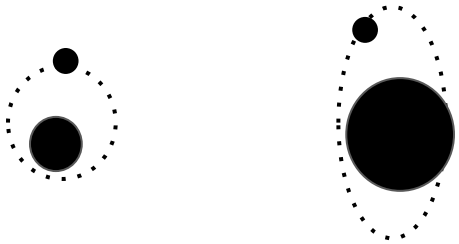


IMRIs ...

We find **15%** of probability for BH-IMBH to merge $\Gamma \simeq 9.5\ \mathrm{yr}^{-1}\ \mathrm{Gpc}^{-3}$

- Occurrence of IMBH formation
- IMBH-stellar BH interplay (Arca Sedda and Amaro-Seoane, almost ready?)
- Number density of galaxies in the local Universe

and EMRIs

We find **~1000-5000** candidates $\Gamma \simeq 0.02 - 0.25\ \mathrm{yr}^{-1}\ \mathrm{Gpc}^{-3}$

- BH formation and evolution in galactic nuclei
- SMBH occupation fraction
- Number density of galaxies in the local Universe

Arca Sedda & Capuzzo-Dolcetta 2018

Take home

-- Sgr A might have undergo a merger with an IMBH in the past 3-4 Gyr --*

-- If a relatively small IMBH was deposited into the Galactic Centre before the NC assembly, it might still be wandering @ ~1 pc from Sgr A --*

-- Galaxies with an NC represent preferential locations for hosting IMBH-SMBH merging events --

-- In massive galaxies, there is a wide variety of GW sources that might form: hierarchical triples, EMRIs, IMRIs.. Which might have quite large merger rate. These channels deserve detailed investigations and modelling, as they rely on many approximations --

-- Stellar mass BHBs forming in galactic nuclei can appear as eccentric sources in LISA for a long time, or they can shift toward DECIGO and LIGO bands possibly allowing to follow BHBs pre-merger phases in detail --

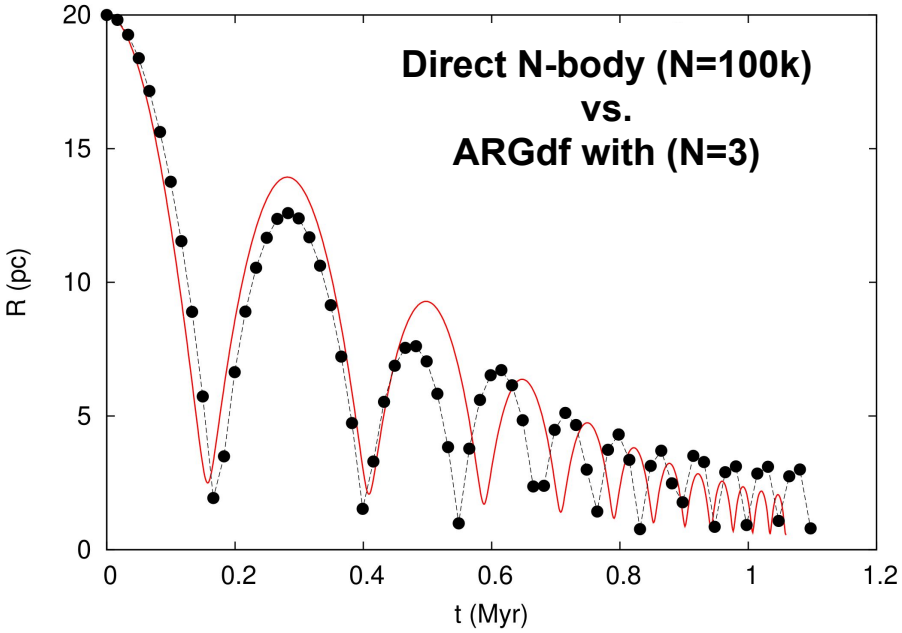
-- If a number of IMBHs are delivered around the SMBH, three-body encounters will inevitably drive at least one IMBH-SMBH merger, with a time-scale that decreases at increasing the IMBH number --

Massive elliptical galaxies

--We need a code that maintain high-accuracy over long simulated times--

We use ARGdf*
(Arca Sedda and Capuzzo-Dolcetta, 2018)

- direct N-body
- algorithmic regularization for close encounters
- includes post-Newtonian terms
- galaxy field and dynamical friction



*** based on ARCHAIN, a regularized code developed by Mikkola and Tanikawa (1999)**

Gravitational wave sources in galactic nuclei: a zoology

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)

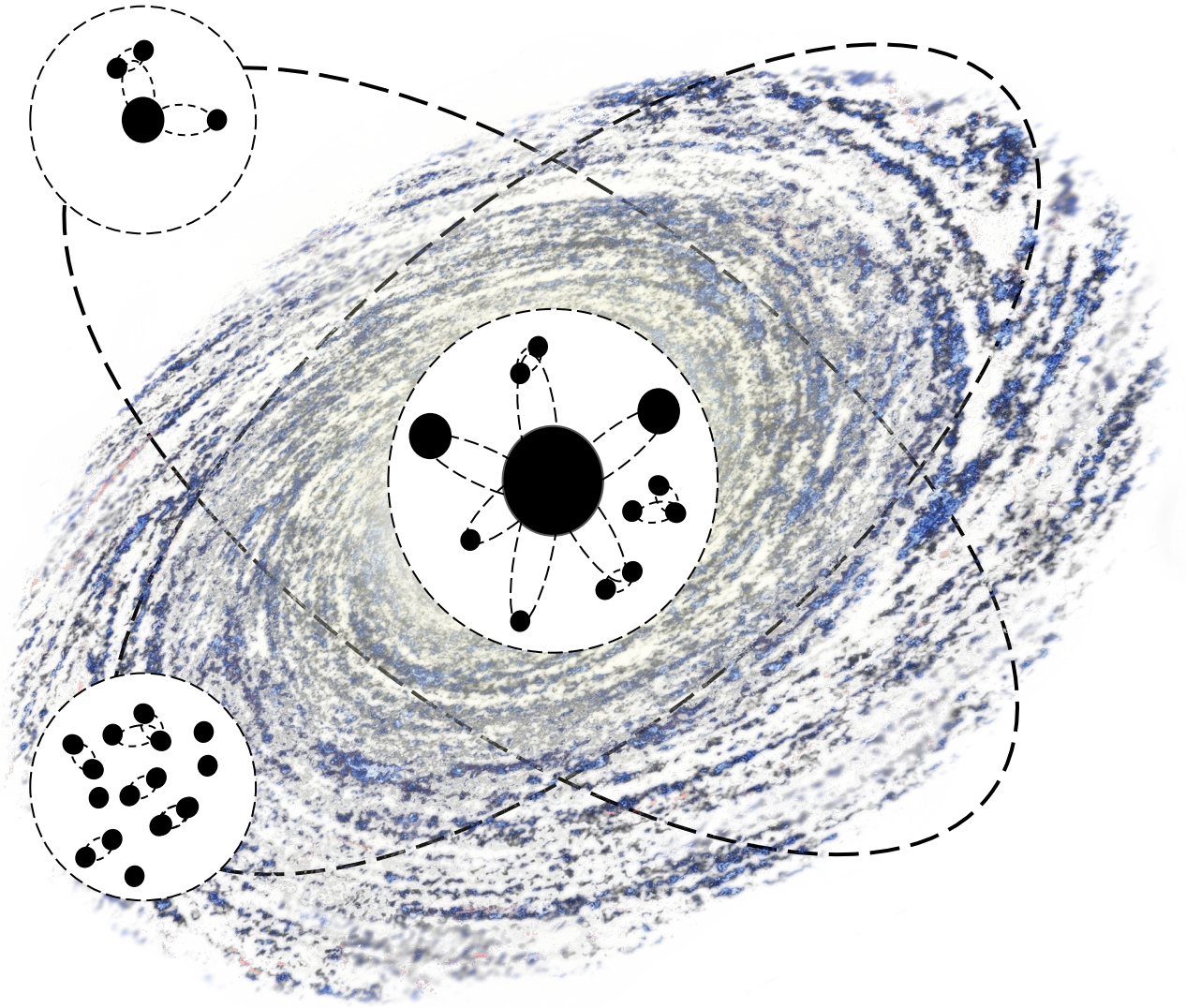
BHB+IMBH: hierarchical triple

- In Galactic nuclei w an SMBH

BH+SMBH: extreme mass ratio inspiral (EMRI)

BHB+SMBH: hierarchical triple

n(IMBH)+SMBH



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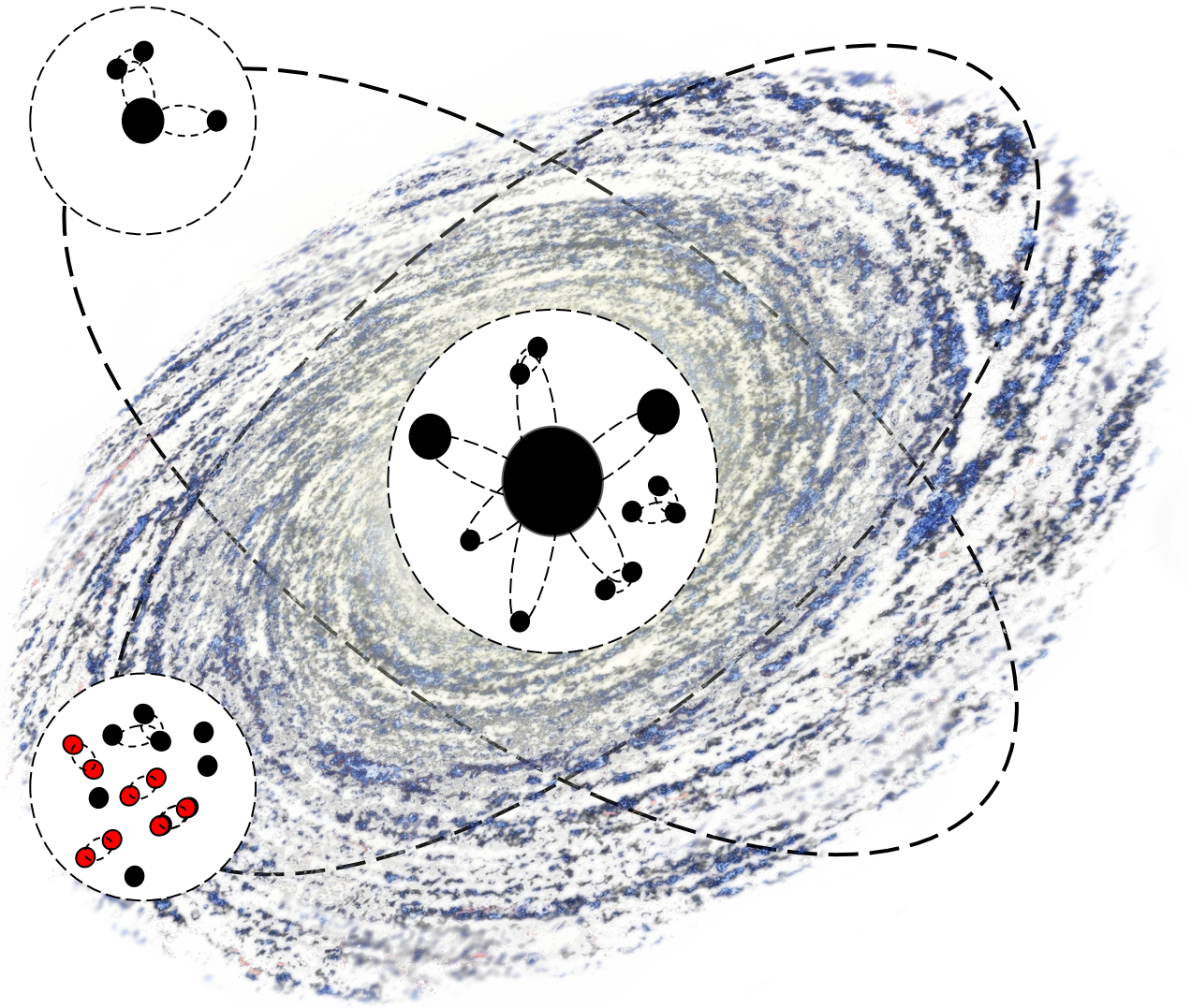

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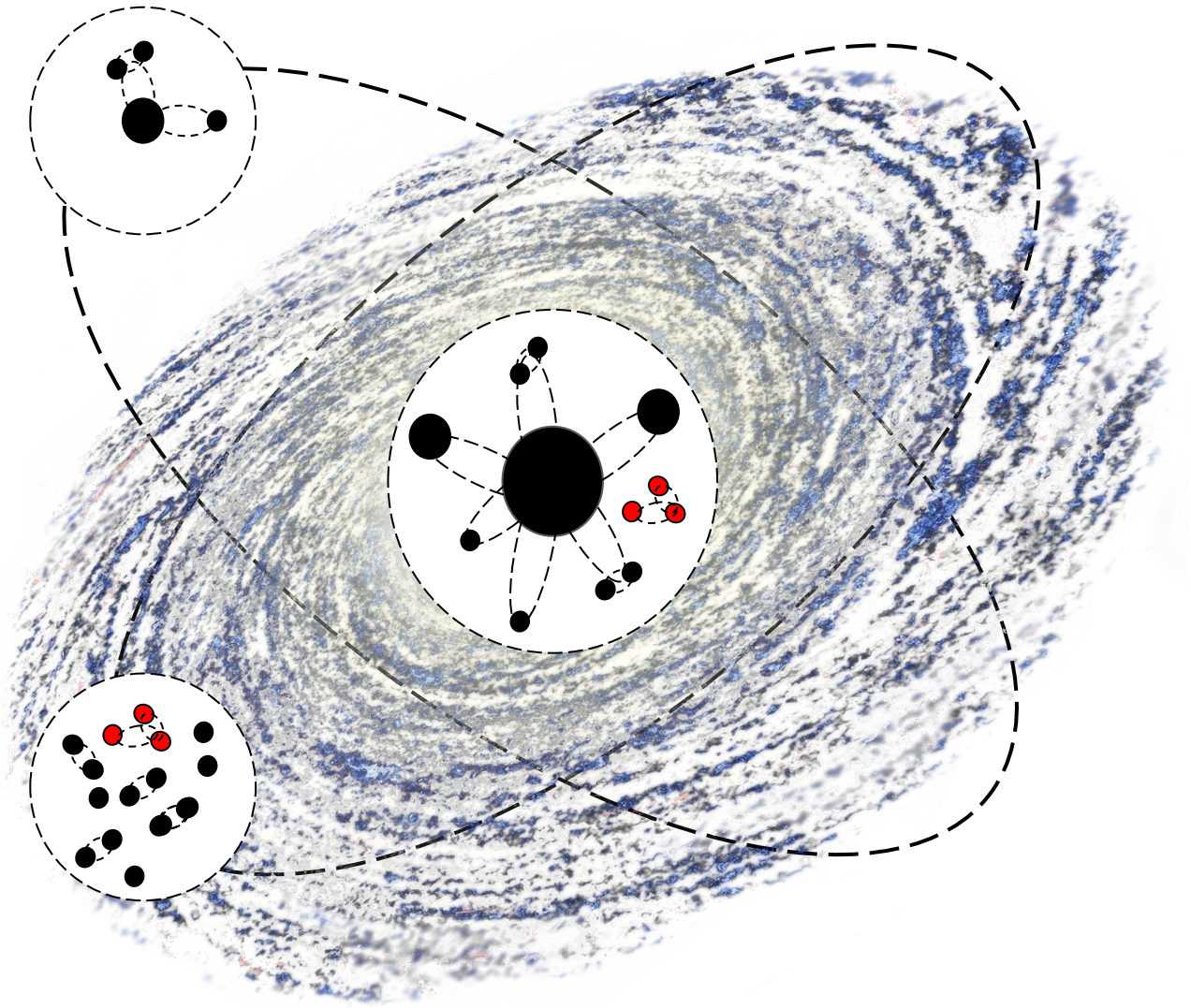

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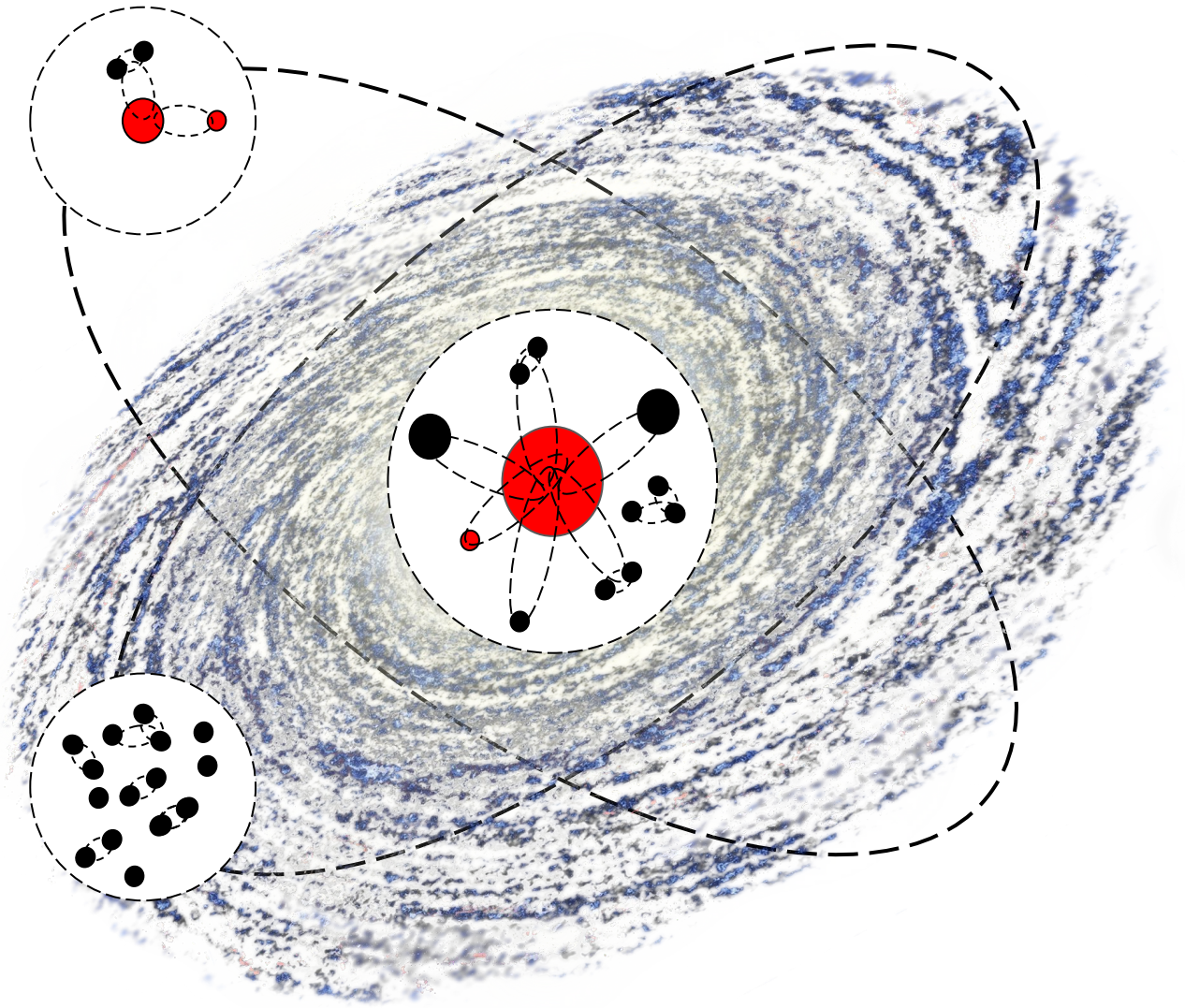

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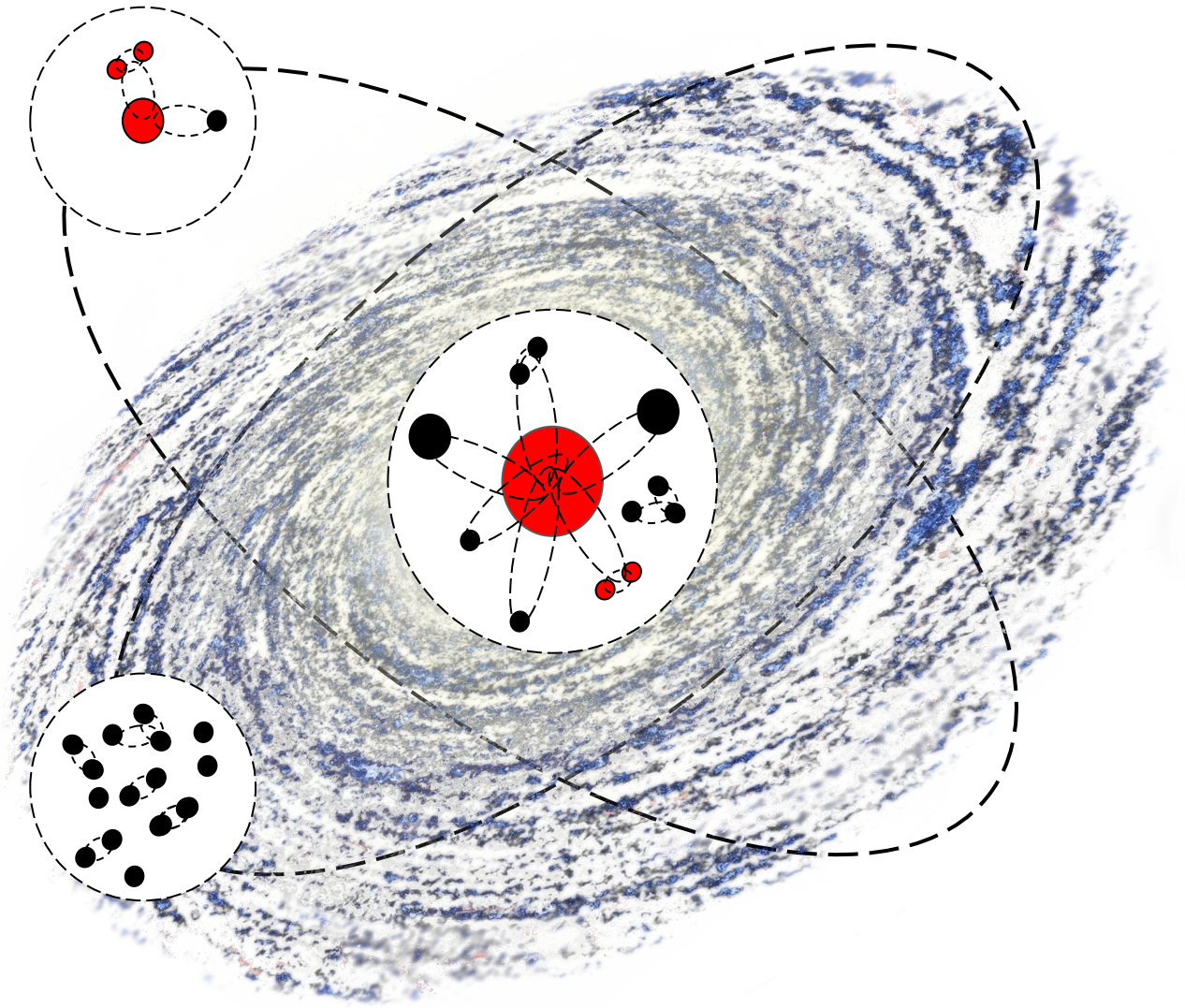

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