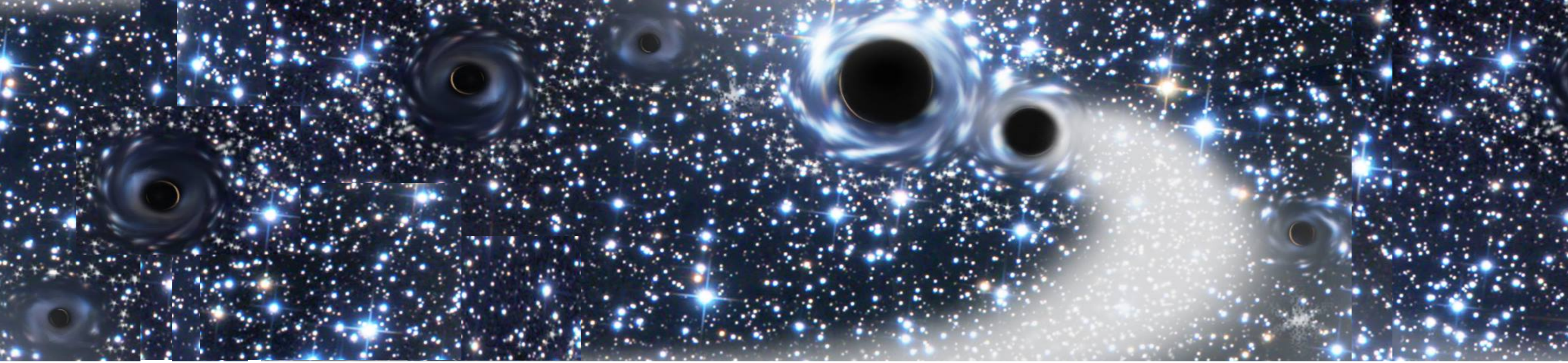


Uncovering the origin of intermediate-mass black holes with LISA and other future GW detectors

Manuel Arca Sedda

grace

GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

LGWA

LISA CONSORTIUM

LSC LIGO Scientific Collaboration

VIRGO

ET EINSTEIN TELESCOPE

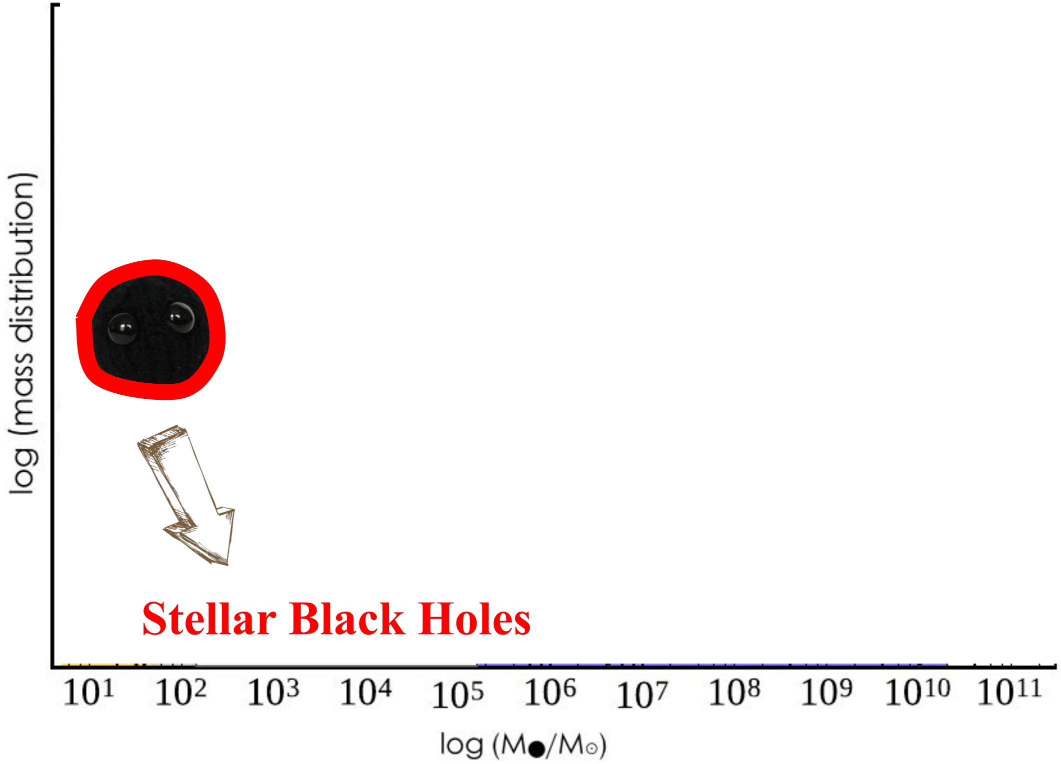
LISA AstroWG
MPA-Garching

05/07 - 11 - 2024

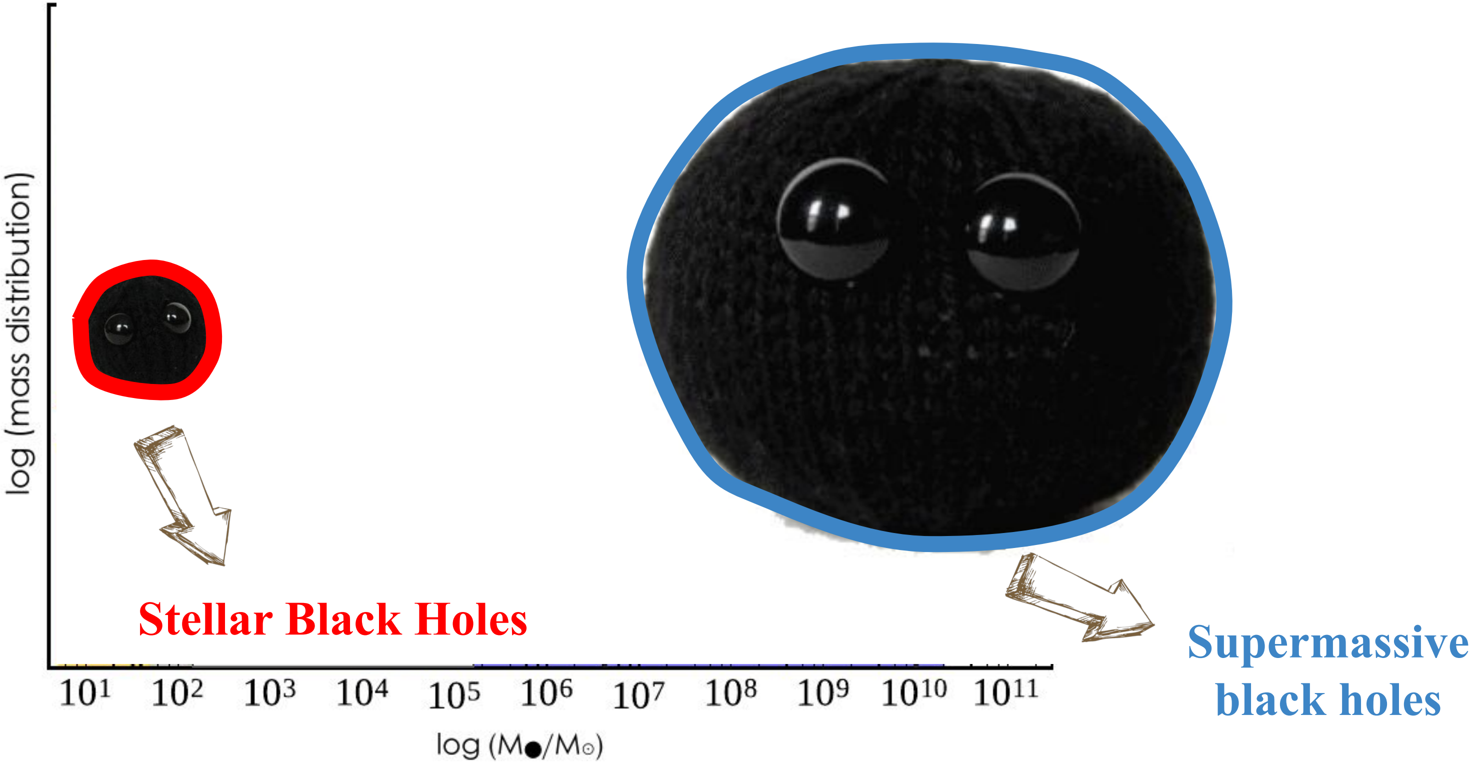
MERAC

MARIE CURIE ACTIONS

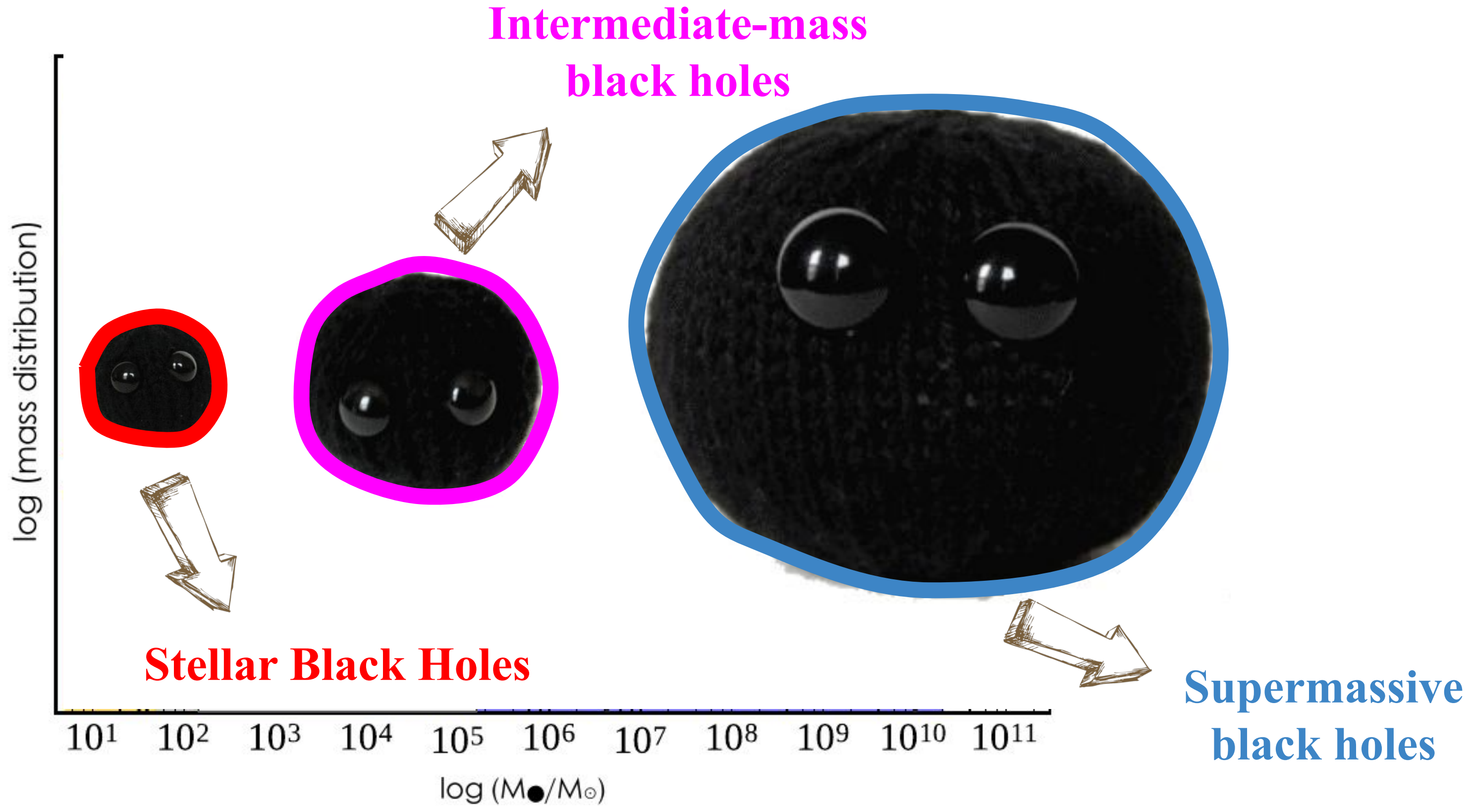
IMBHs: what we do and don't know



IMBHs: what we do and don't know



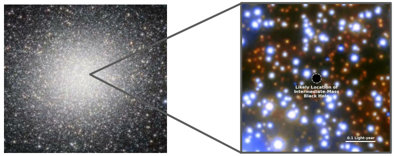
IMBHs: what we do and don't know

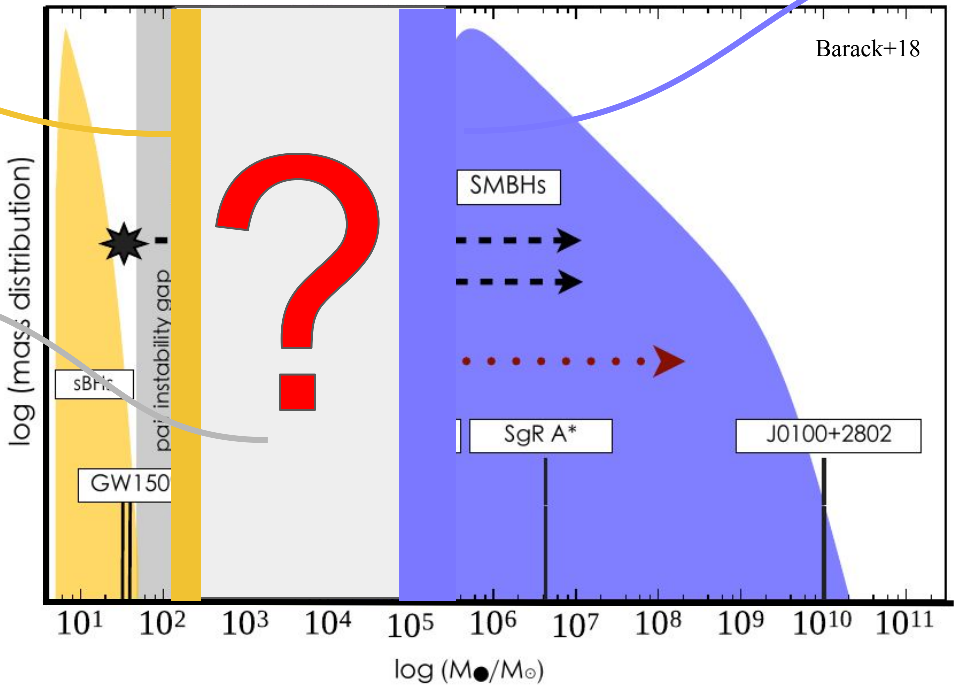


IMBHs: what we do and don't know

GW
(e.g. LVK+21)

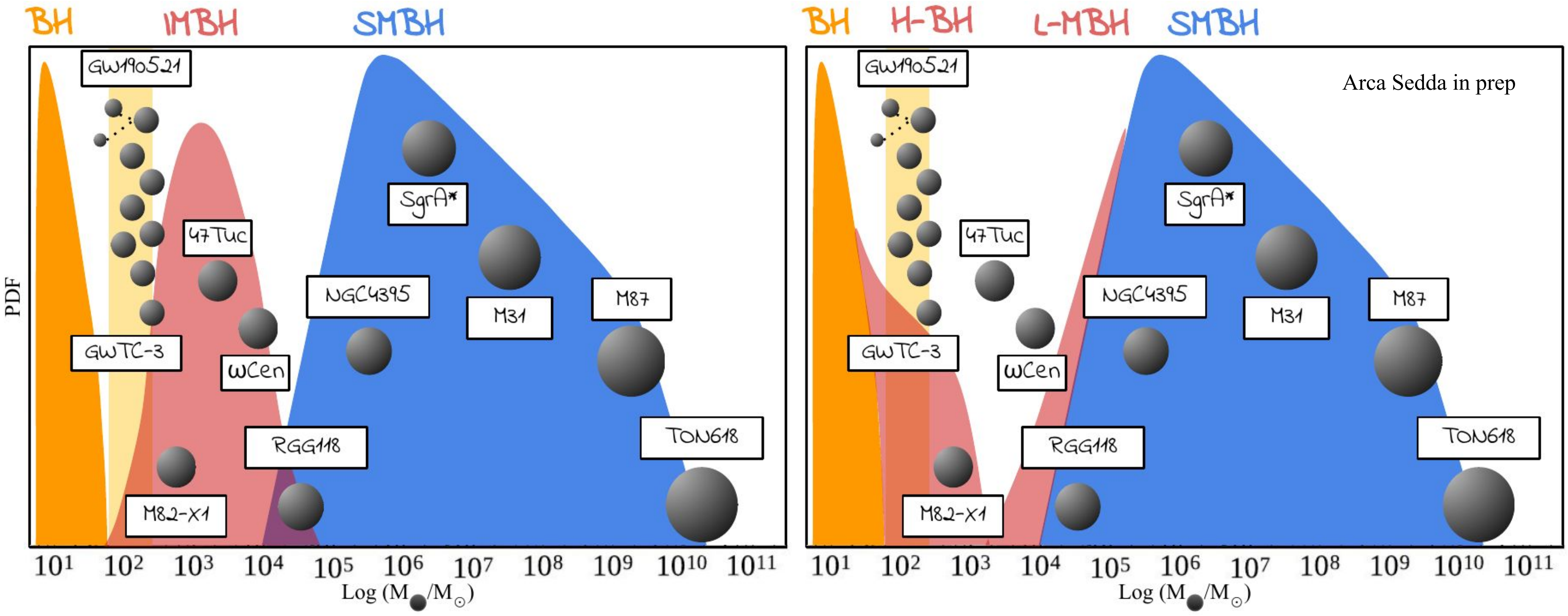
Globular Clusters
(e.g. vanderMarel+10, Noyola+10, Lanzoni+13, Lutzgendorf+13, Kiziltan+17, Perera+17, Lin+18, Abbate+19, Tiengo+21, Haberle24)





Dwarf
(e.g. Reines&Volonteri15
Chilingarian+18)

IMBHs: what we do and don't know

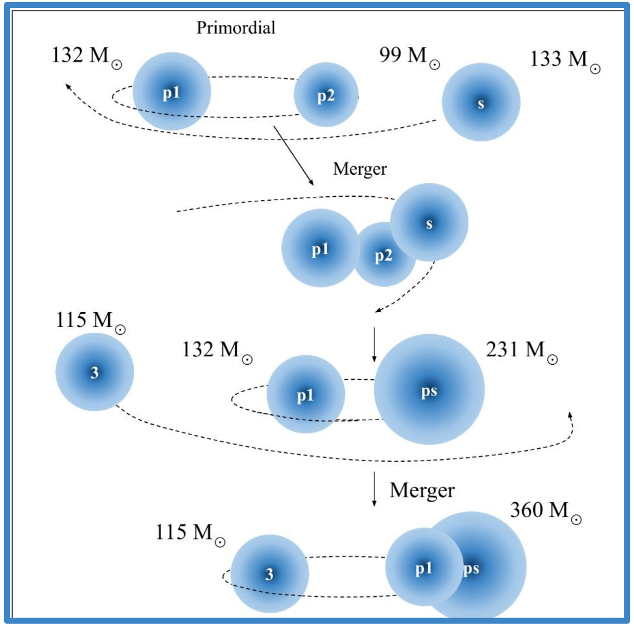


Scenario #1: IMBHs are a BH category

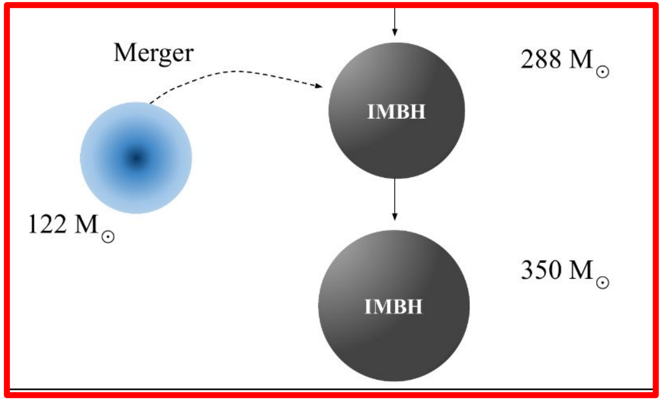
Scenario #2: IMBHs populate the tail of BH and SMBH mass functions

IMBHs: formation in dense star clusters

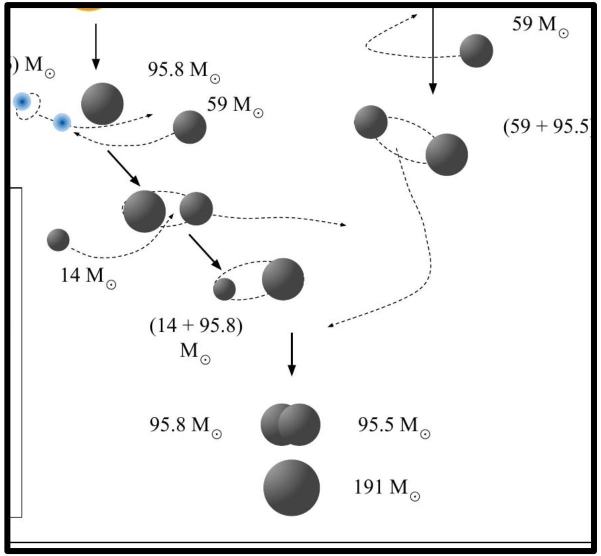
Multiple stellar collisions



Star-BH accretion



Repeated BH mergers



see e.g. "The DRAGON-II simulations" paper series (rewarding, but computationally expensive)

Arca Sedda et al 2023a, 2024a,b

see also e.g. Portegies-Zwart&McMillan02, Giersz+15, Mapelli16, Di Carlo+20, Rizzuto+21, Gonzalez+21, Chattopadhyay+23, Barber+24

DRAGON-II vs B-POP: beast and beauty

Arca Sedda et al 2023a, 2024a,b
Arca Sedda in prep

Nbody simulations PROs:

- *Accurate*
- *Impact of primordial binaries*
- *Impact of cluster evolution and structure*

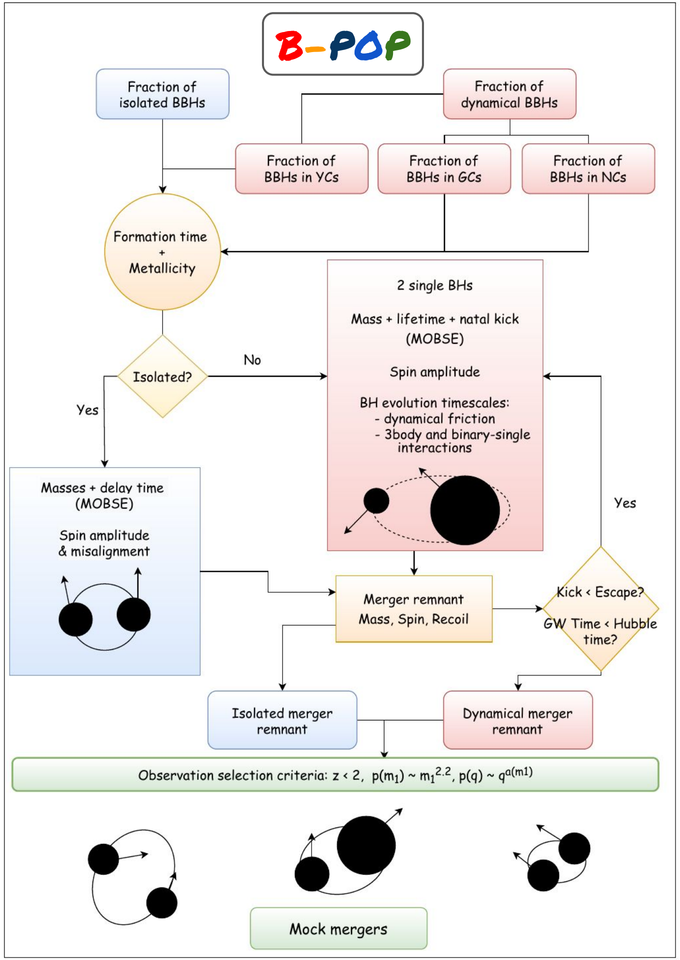
Nbody simulations CONs:

- *High computational cost*
- *No reliable statistics within reasonable times*

(~ 78 BBHs in 5 months, ~ 8 IMBHs in 5 months)

SOLUTION:

- *Population synthesis code encoding dynamics+stellar evolution (~ 10^6 in 0.5 hrs)*
- *Rapid exploration of the parameter space (Metallicity, SFR, environment, BH natal spin, mass, kicks…)*

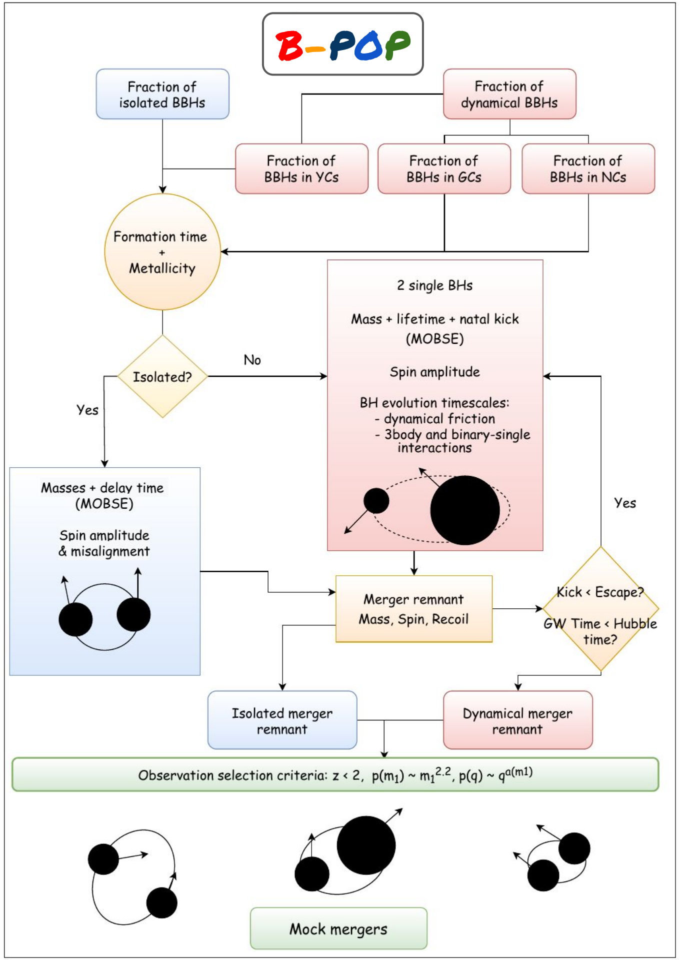


DRAGON-II vs B-POP: beast and beauty

Arca Sedda et al 2023a, 2024a,b
Arca Sedda in prep

B-POP

- *Population synthesis code encoding dynamics+stellar evolution (10^6 BBH/hr)*
    - *Formation of IMBH seeds from stellar collisions*
    - *Fraction of isolated binaries*
    - *SFR normalisation*
    - *SFR for YC, GC, NC*



DRAGON-II vs B-POP: beast and beauty

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B-POP

- *Population synthesis code encoding dynamics+stellar evolution (10^6 BBH/hr)*
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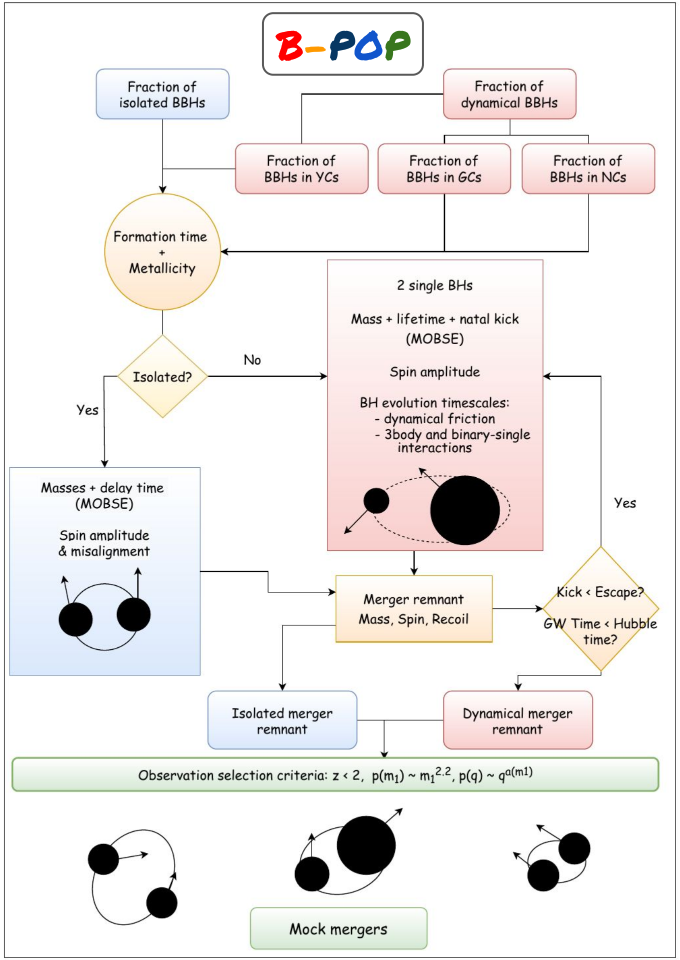
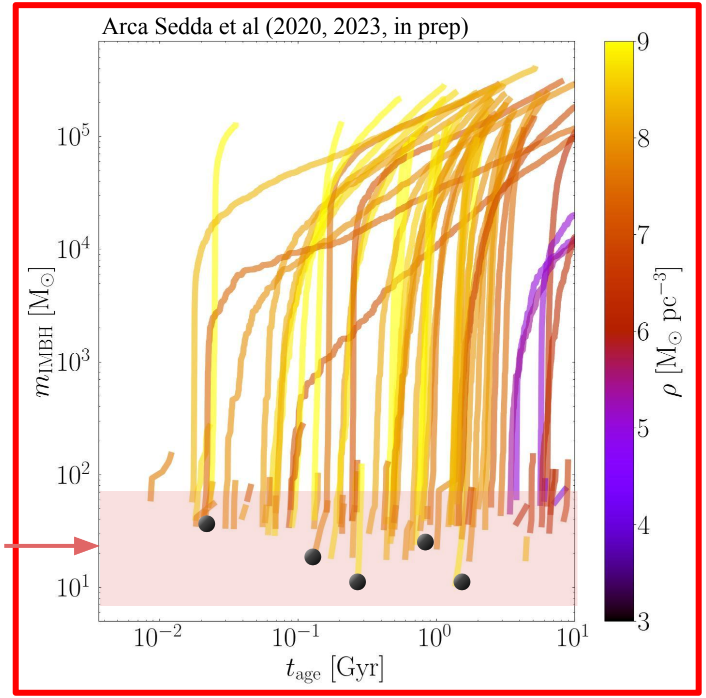


B-POP: making isolated and dynamical BBH mergers has never been that easier

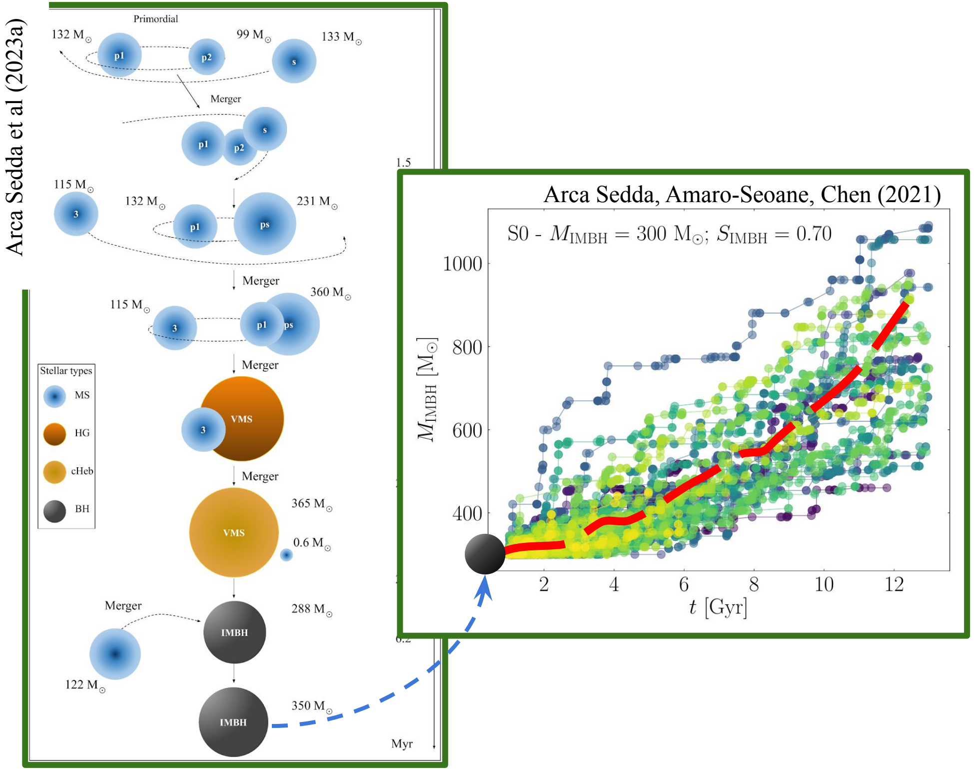
*Arca Sedda and Benacquista 2019, Arca Sedda et al 2020,2023, Arca Sedda in prep, Paiella+in prep***

Case #1: no IMBH seed progenitors



Stellar BHs

Case #2: IMBH seed from stellar collisions



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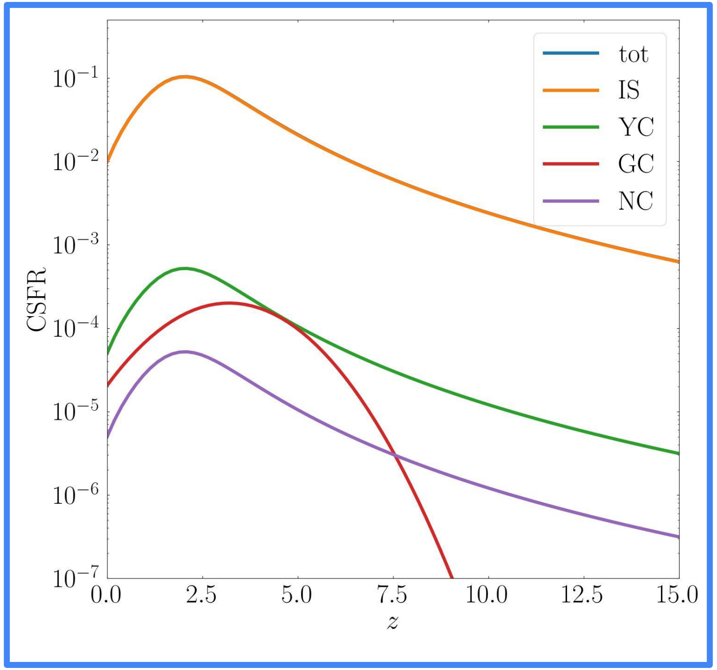
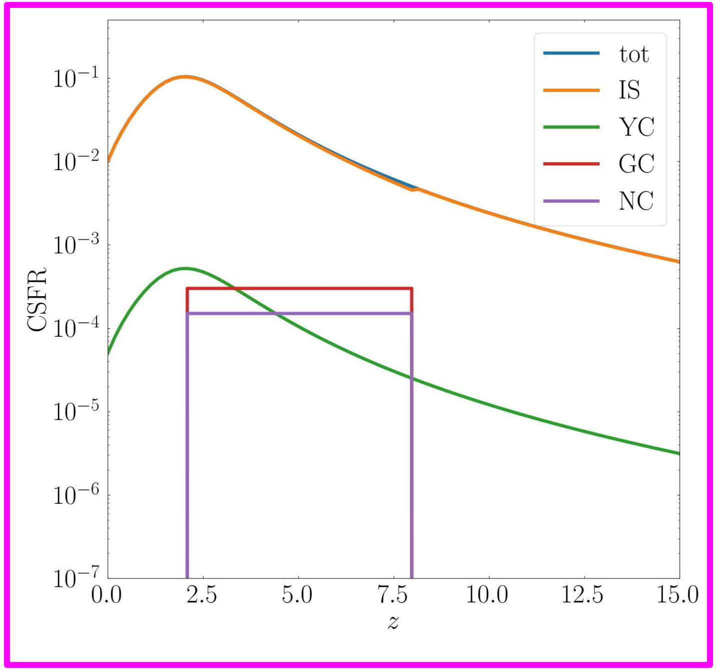
Model S2a

SFR for IBs, YCs, NCs: Madau & Fragos 2017
SFR for GCs: El-badry+2019



Model S5a

SFR for IBs, YCs: Madau & Fragos 2017
SFR for GCs & NCs: Katz & Ricotti 2013



B-POP: making isolated and dynamical BBH mergers has never been that easier

*Arca Sedda and Benacquista 2019, Arca Sedda et al 2020,2023, Arca Sedda in prep, Paiella+in prep***

Model S2a

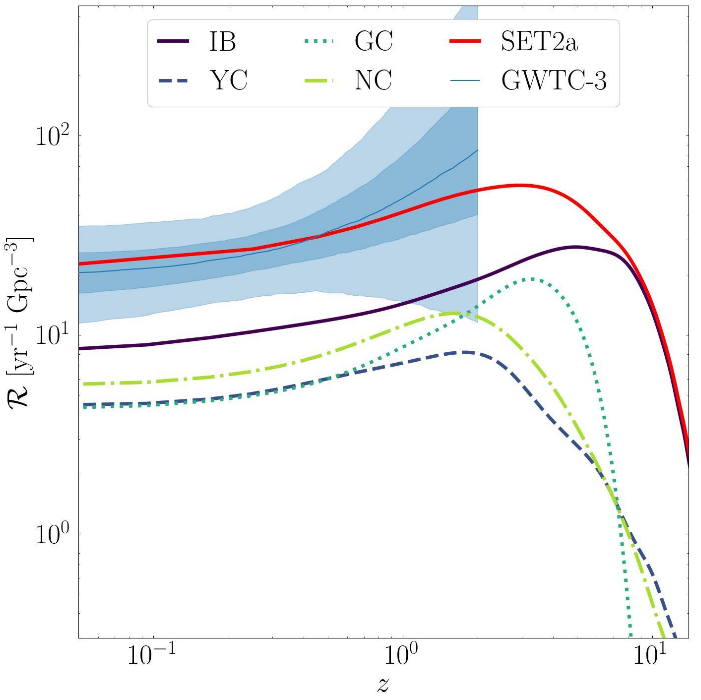
Model S5a

First things first: do these model predict a reasonable BBH merger rate?

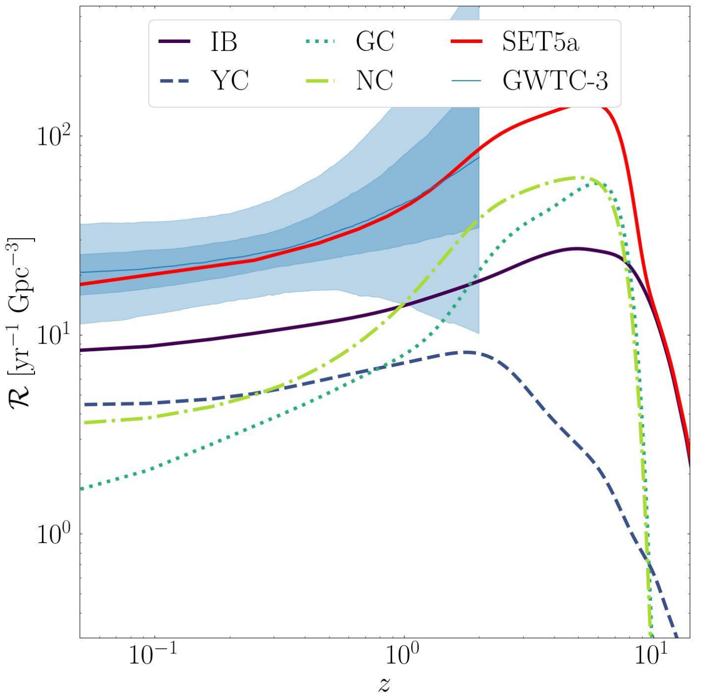
B-POP: making isolated and dynamical BBH mergers has never been that easier

*Arca Sedda and Benacquista 2019, Arca Sedda et al 2020,2023, Arca Sedda in prep, Paiella+in prep***

Model S2a



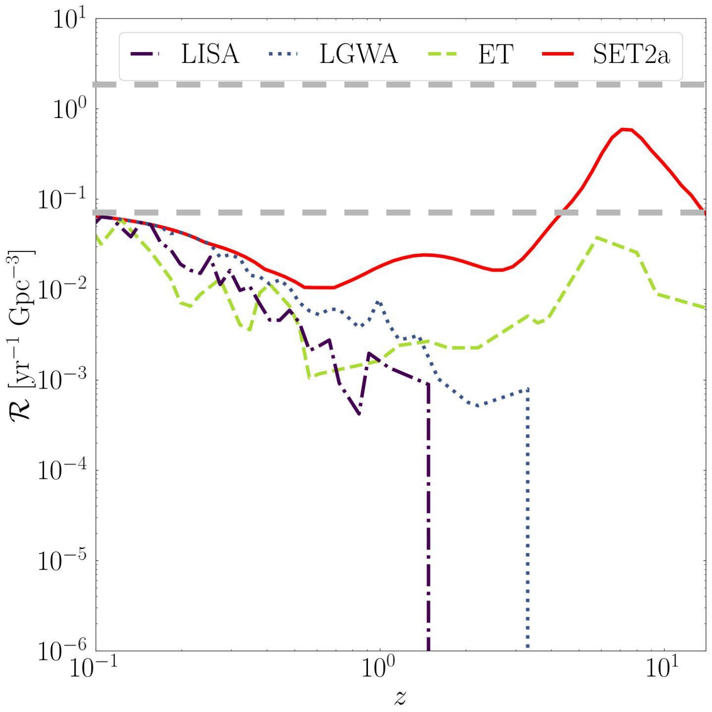
Model S5a



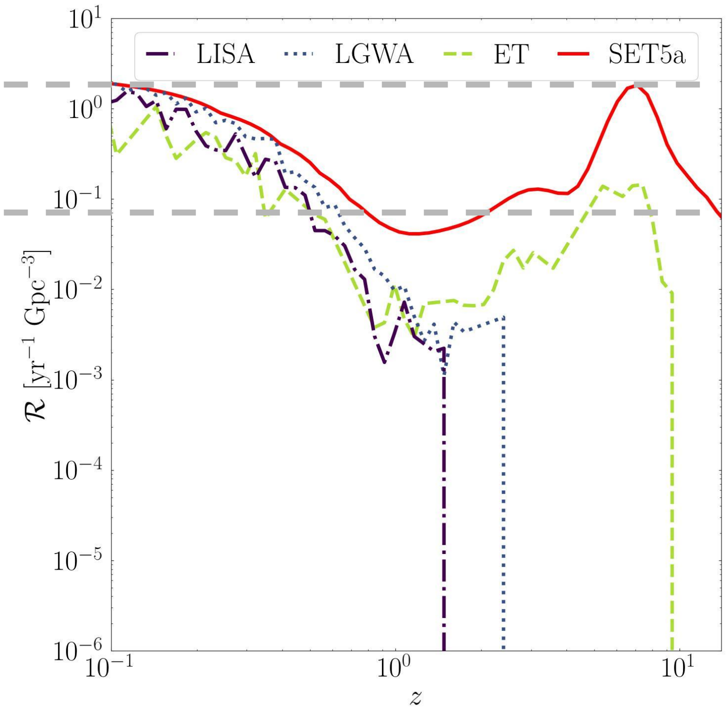
B-POP: The "dynamical" IMBH merger rate and detection prospects

*Arca Sedda+21, Arca Sedda+24b, Arca Sedda in prep, Paiella+in prep***

Model S2a

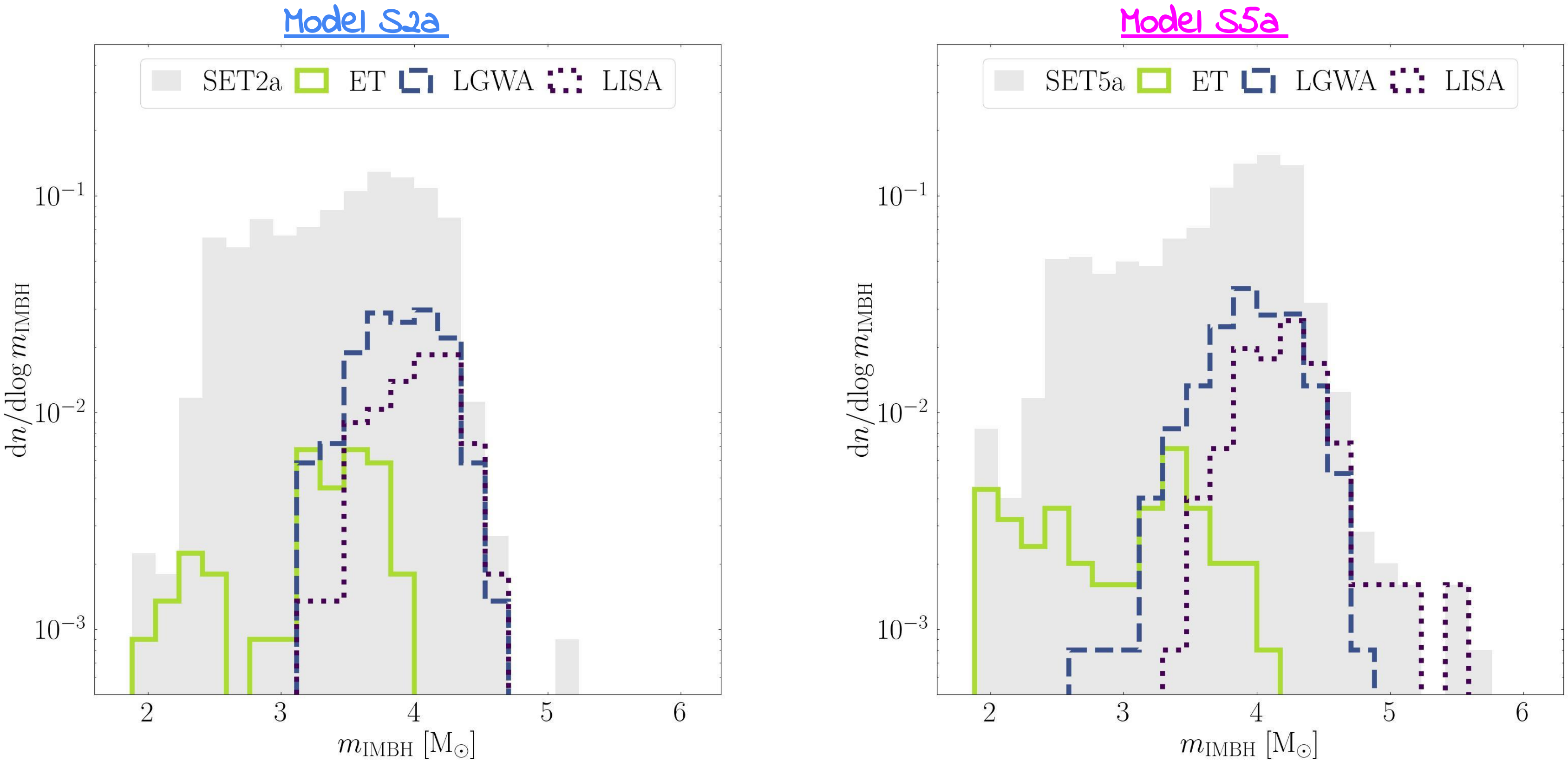


Model S5a



B-POP: The "dynamical" IMBH mass spectrum

*Arca Sedda and Benacquista 2019, Arca Sedda et al 2020,2023, Arca Sedda in prep, Paiella+in prep***



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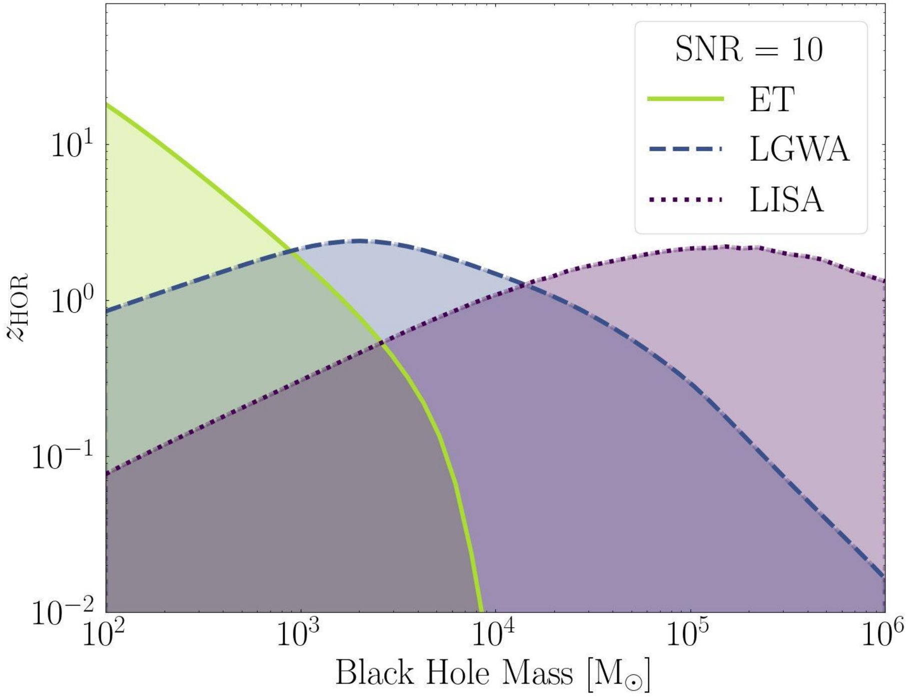


$$\Gamma_{\rm IMRI} = \Omega_s \int_{M_1}^{M_2} \int_0^{z_{\rm hor}} \frac{dn_{\rm IMRI}}{dM_{\rm IMBH} dz} \frac{dV_c}{dz} \frac{dz}{1+z} dM_{\rm IMBH}$$

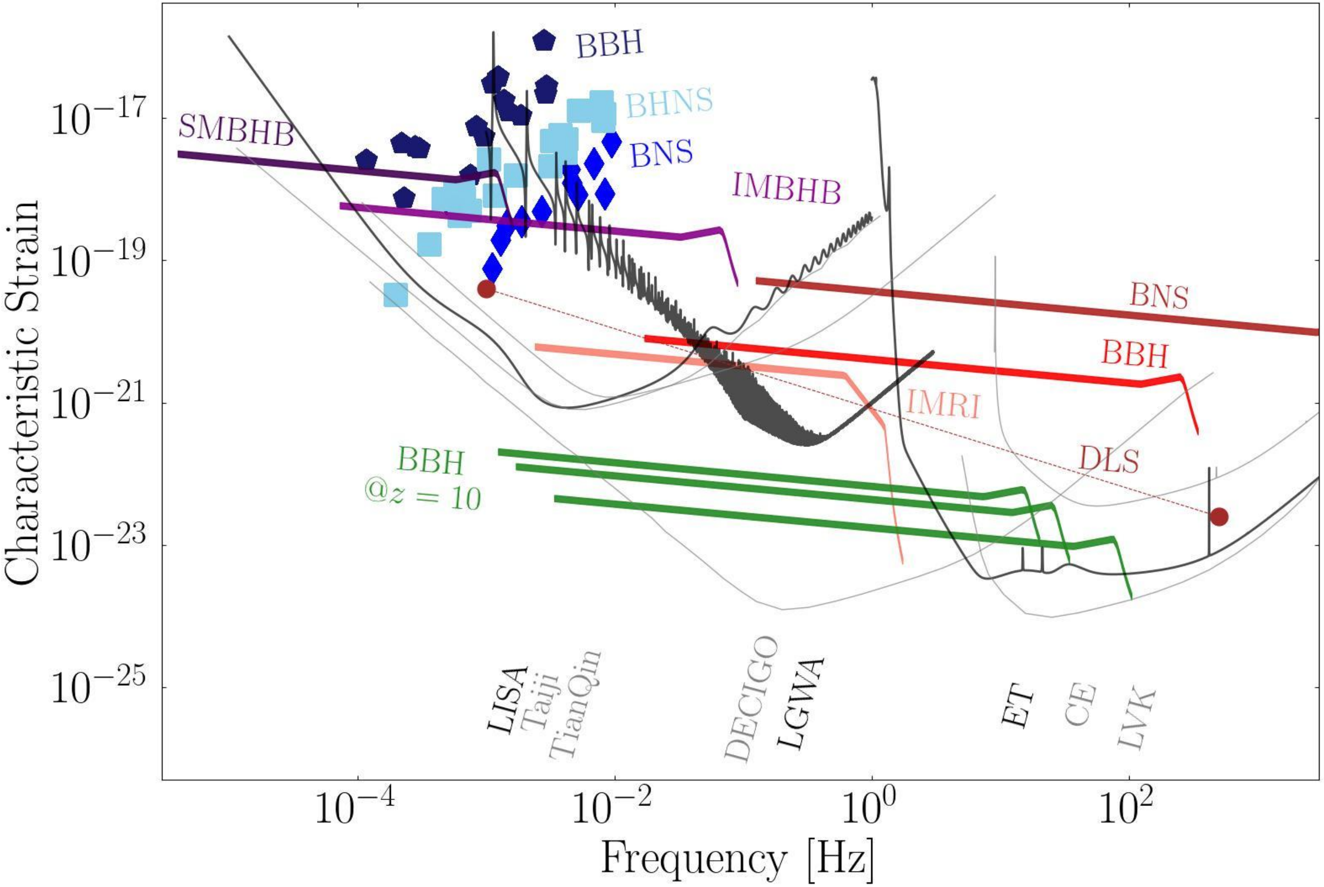
Detector 10 yr mission*	Rate Model S2a	Rate Model S5a
LISA	5	80
ET	90	390
LGWA	14	150

*Around 20-30% of sources are multiband

Summary

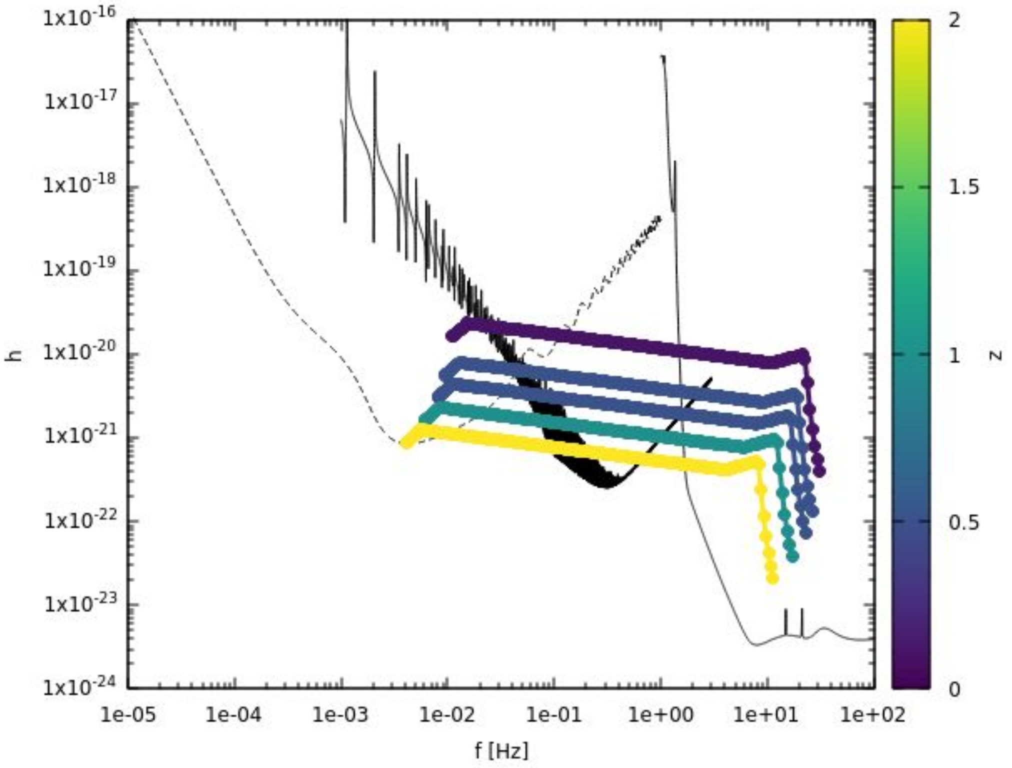
- ***B-POP enables us to model simultaneously isolated and dynamical BBHs altogether with IMBH seeding and growth***
- ***We build synthetic Universe models to derive the BBH merger rate and other observables (e.g. mass spectrum)***
- ***The IMBH mass spectrum depends on the fraction of binaries and the SFR of star clusters***
- ***A significant fraction of IMRIs may appear as multiband source***
- ***Future detection of IMRIs can help placing constraints on the formation of massive star clusters***

IMBHs: what we do and don't know



IMBHs: formation in dense star clusters

t_{coal} = 2 yr; $M_{1,2}$ = (500 + 30) M_{SUN} ; e = 0			
z	**SNR**		
	ET	**LGWA**	**LISA**
0.1	4740	99	23
0.3	1521	32	9
0.5	808	18	6
1.0	389	9	4
2.0	164	5	2



B-POP: making isolated and dynamical BBH mergers has never been that easier

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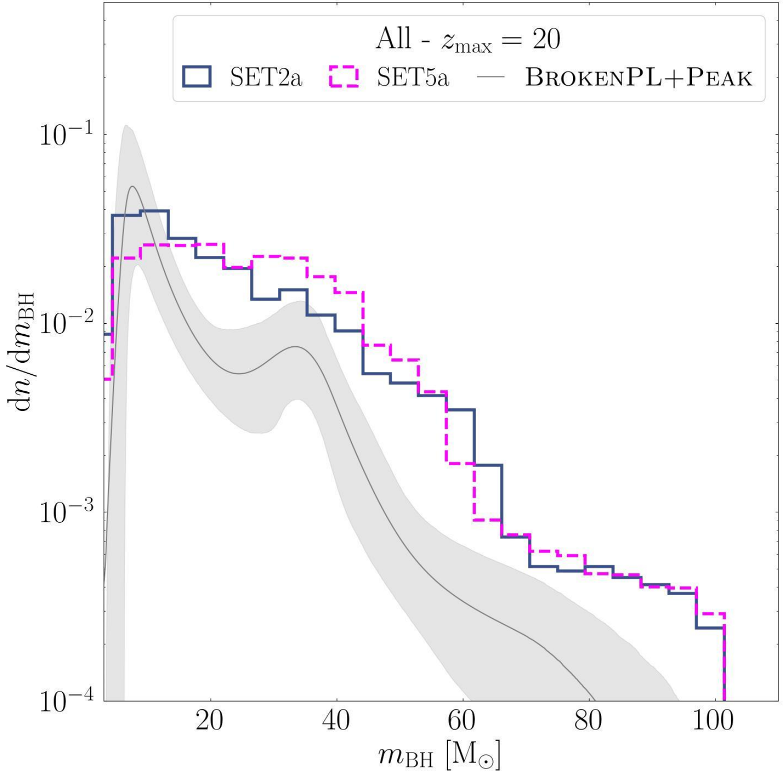

Global mass spectrum of merger primary

All mergers
models show clear differences at m < 30 Msun

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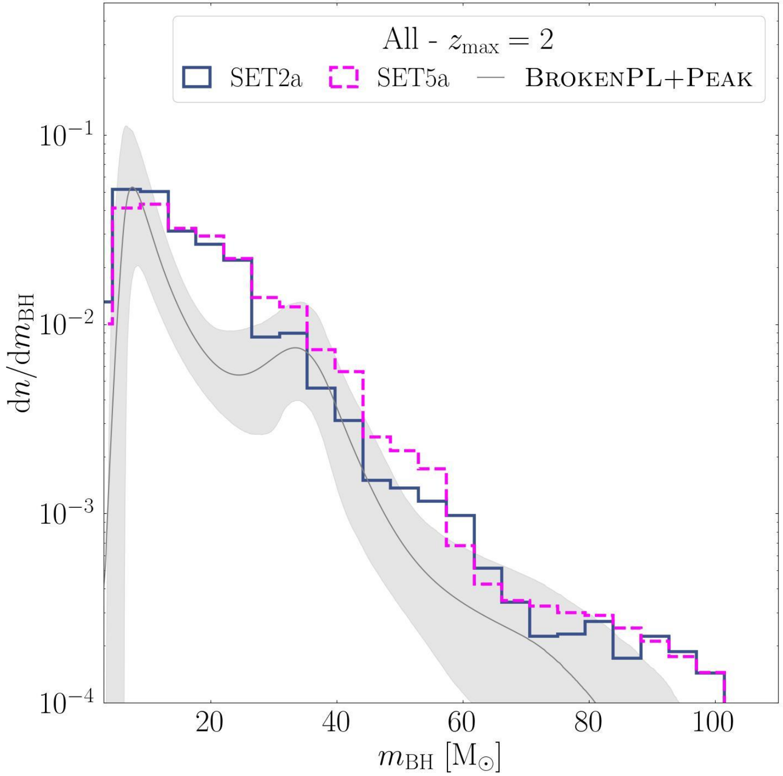
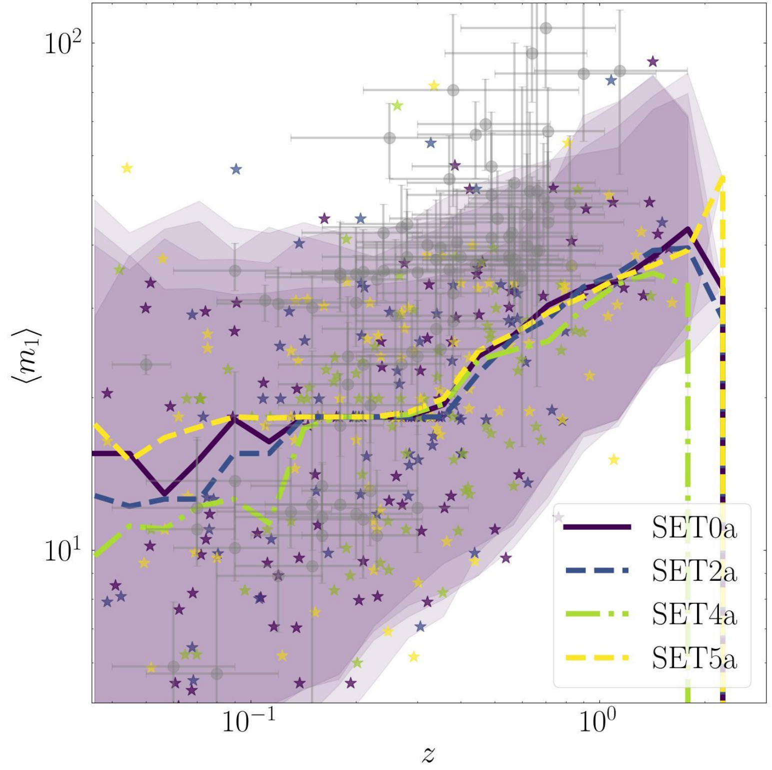


Global mass spectrum of merger primary

All mergers
models show clear differences at m < 30 Msun

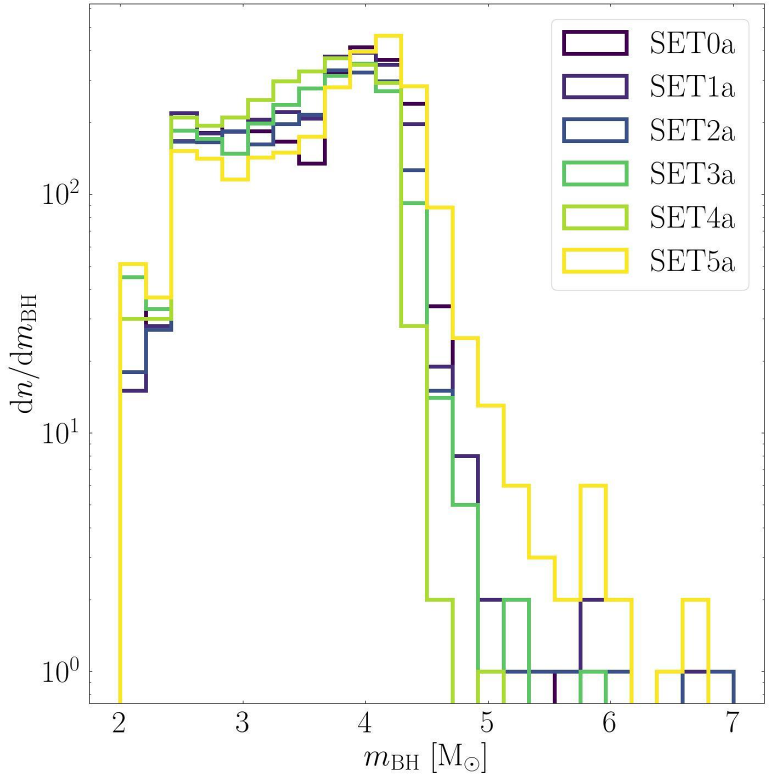
Mergers at **z < 2**
models are barely distinguishable

B-POP: making isolated and dynamical BBH mergers has never been that easier



B-POP: The "dynamical" IMBH mass spectrum

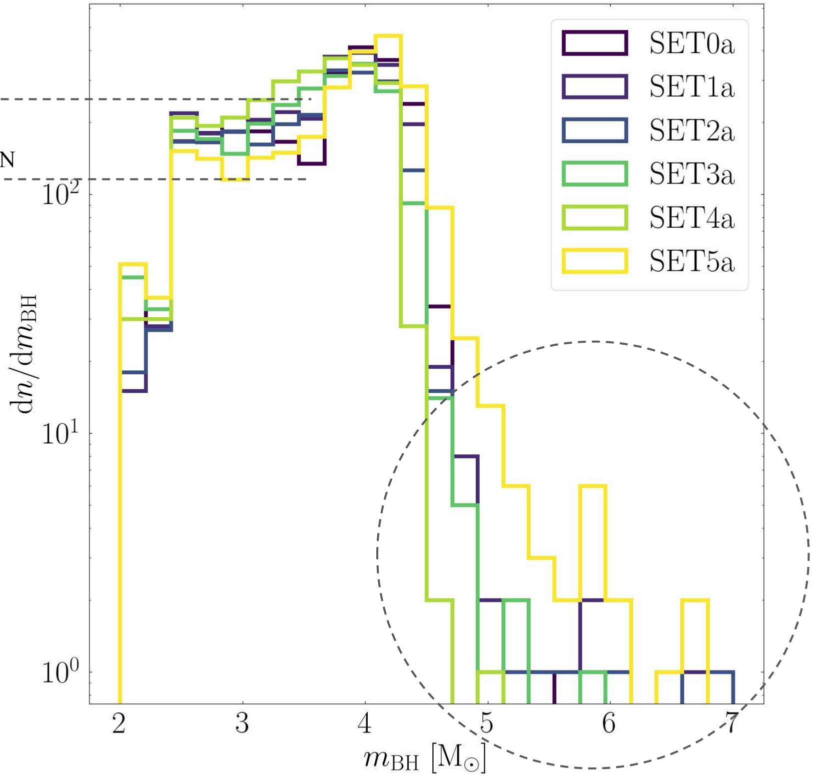
*Arca Sedda and Benacquista 2019, Arca Sedda et al 2020,2023, Arca Sedda in prep, Paiella+in prep***



B-POP: The "dynamical" IMBH mass spectrum

*Arca Sedda and Benacquista 2019, Arca Sedda et al 2020,2023, Arca Sedda in prep, Paiella+in prep***

~ flat in the range 500-5,000 M_{SUN}



massive BH tail depends on
- binary fraction
- SFR