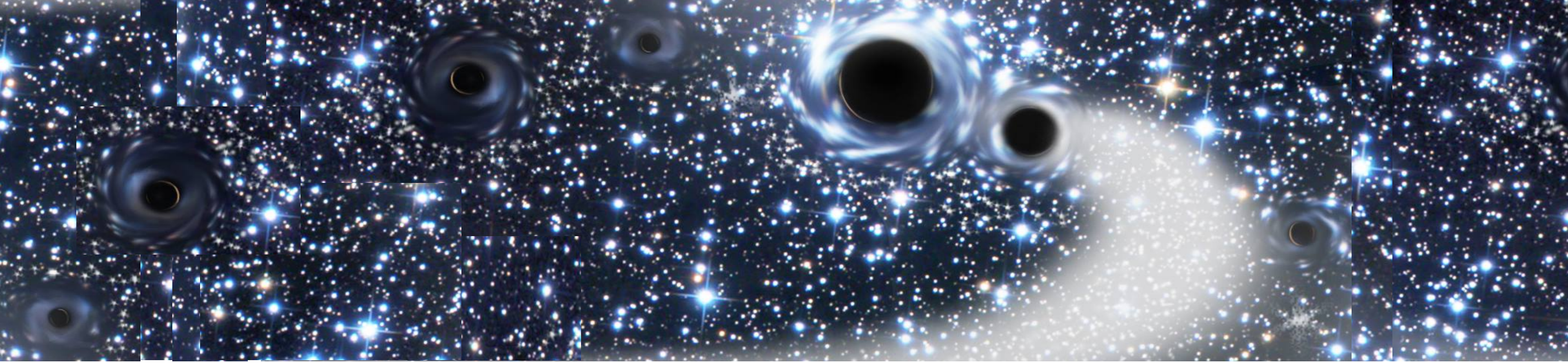


# Unveiling the nature of intermediate-mass black holes with LGWA, ET, and LISA

*Manuel Arca Sedda*

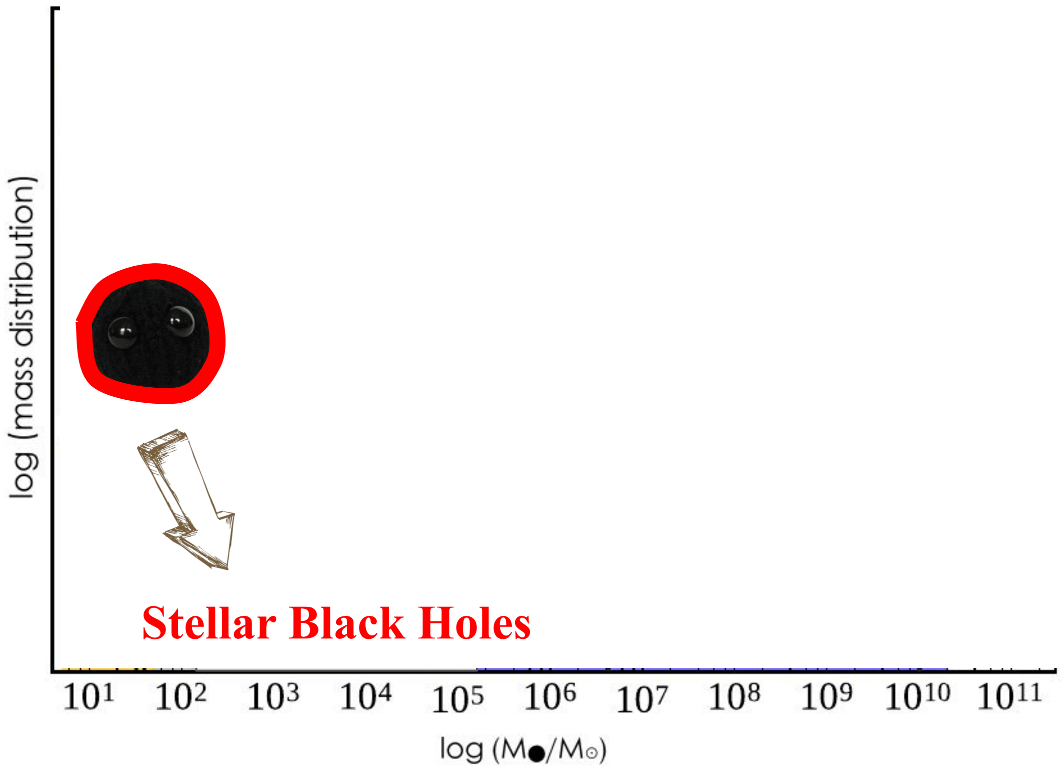
GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

LGWA Workshop
Castel Gandolfo

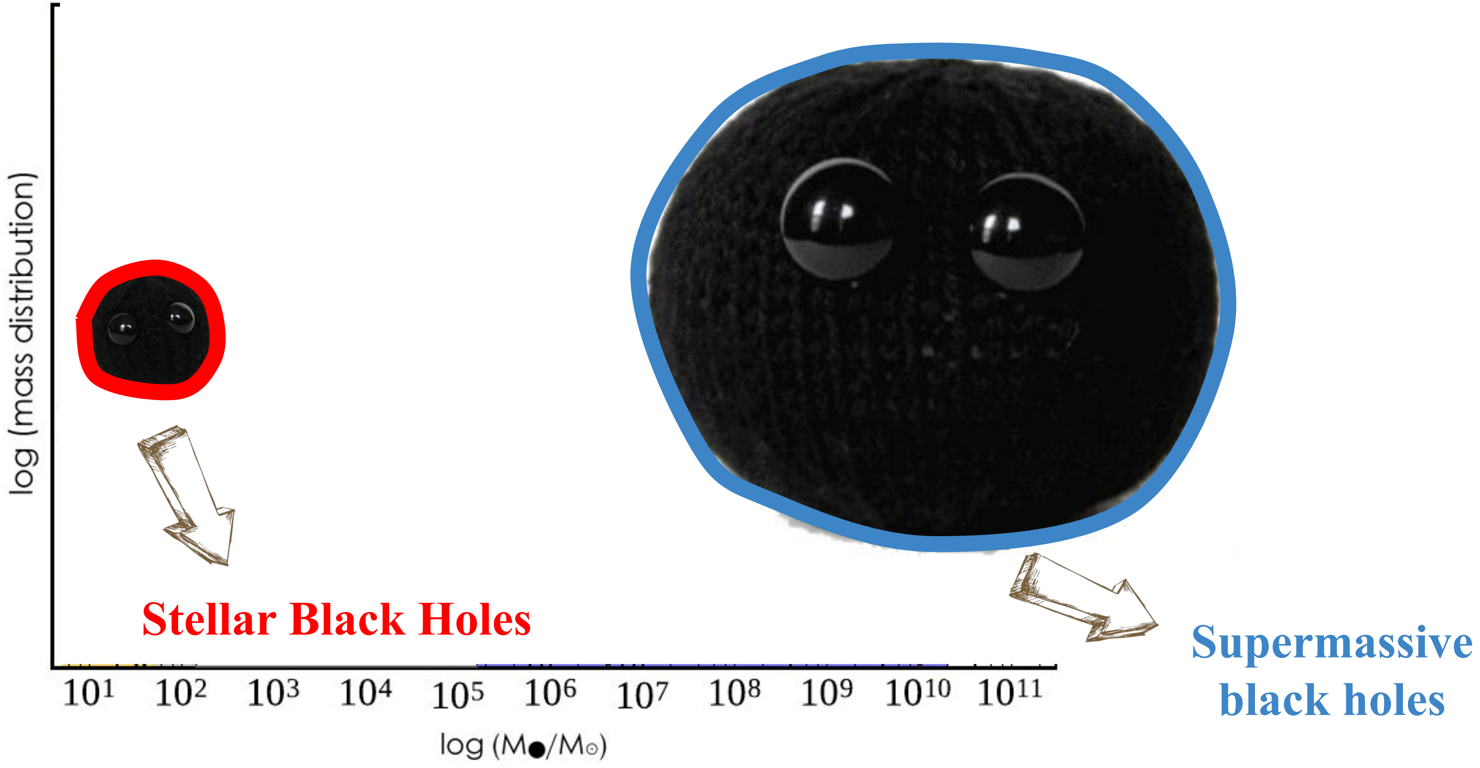
08 - 10 - 2024

LGWA · LISA CONSORTIUM · LIGO Scientific Collaboration · VIRGO · EINSTEIN TELESCOPE · grace · MERAC · MARIE CURIE ACTIONS

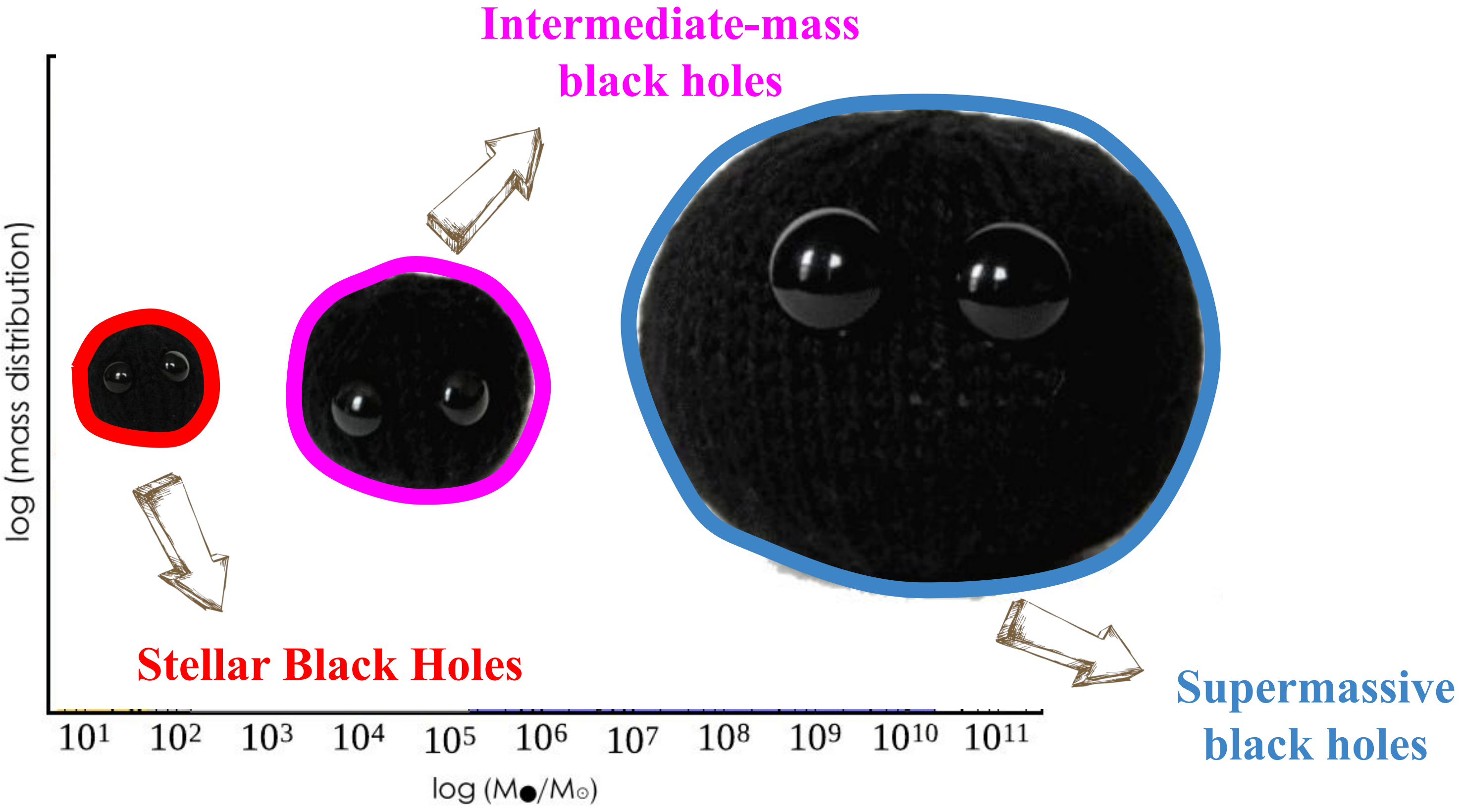
# IMBHs: what we do and don't know



# IMBHs: what we do and don't know

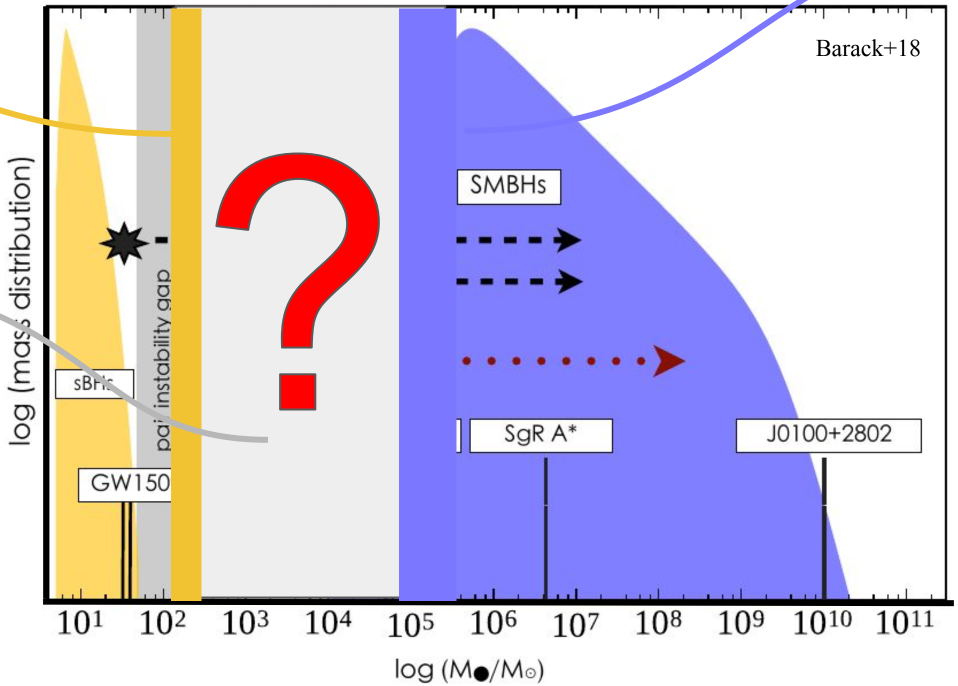


# IMBHs: what we do and don’t know



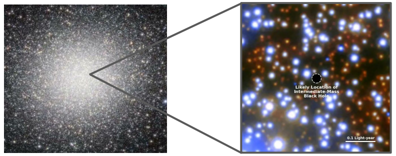
# IMBHs: what we do and don't know

GW
(e.g. LVK+21)

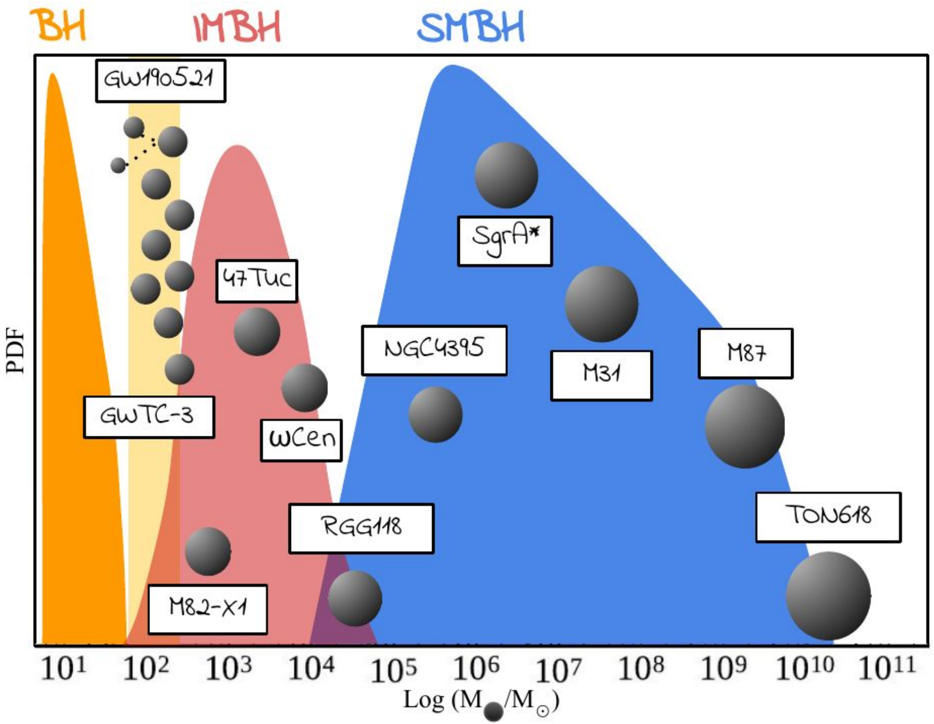



Dwarf
(e.g. Reines&Volonteri15
Chilingarian+18)

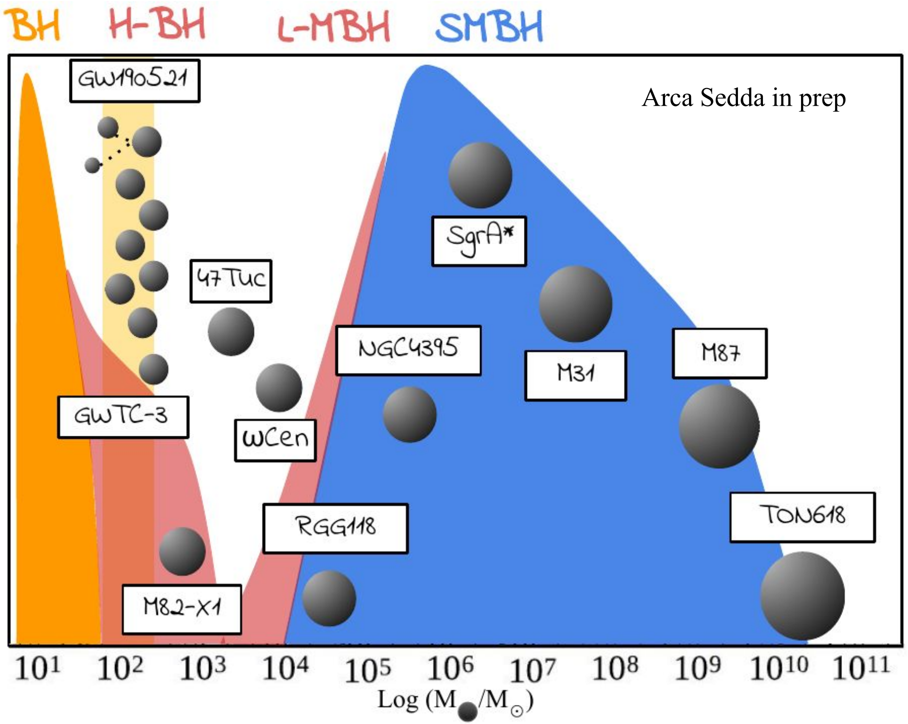
Globular Clusters
(e.g. vanderMarel+10, Noyola+10,
Lanzoni+13, Lutzgendorf+13,
Kiziltan+17, Perera+17, Lin+18,
Abbate+19, Tiengo+21, Haberle24)



# IMBHs: what we do and don't know



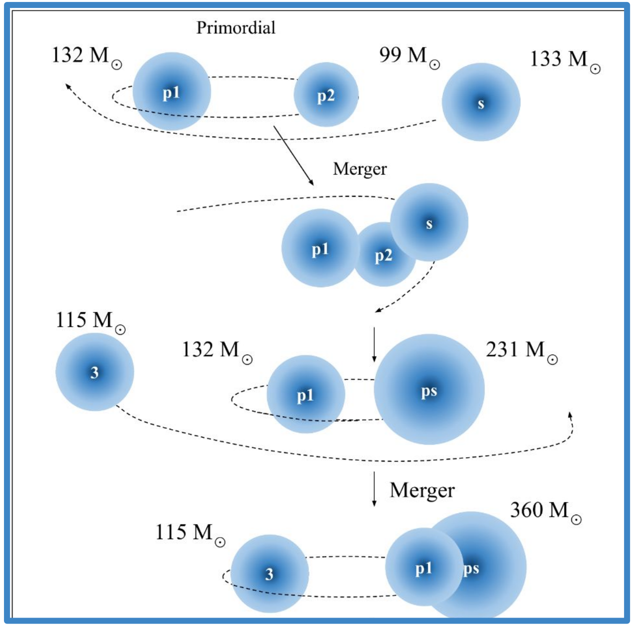

*Scenario #1: IMBHs are a BH category*



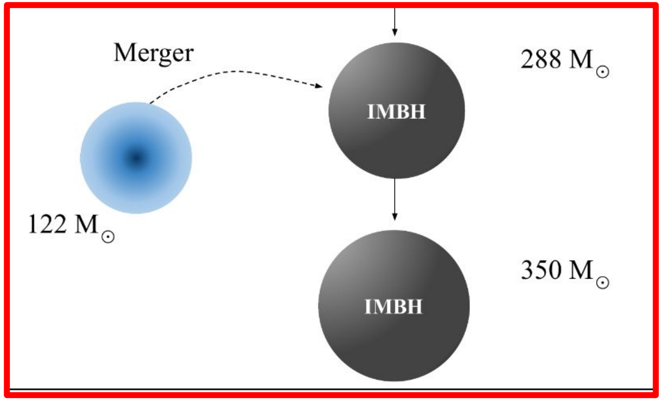

*Scenario #2: IMBHs populate the tail of BH and SMBH mass functions*

# IMBHs: formation in dense star clusters

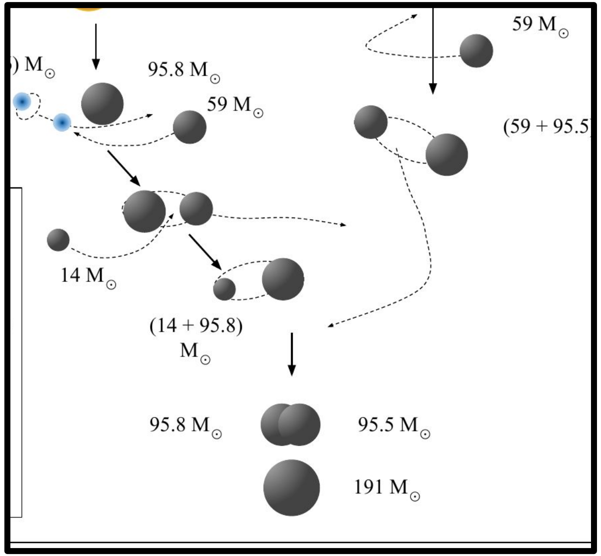
**Multiple stellar collisions**




**Star-BH accretion**




**Repeated BH mergers**

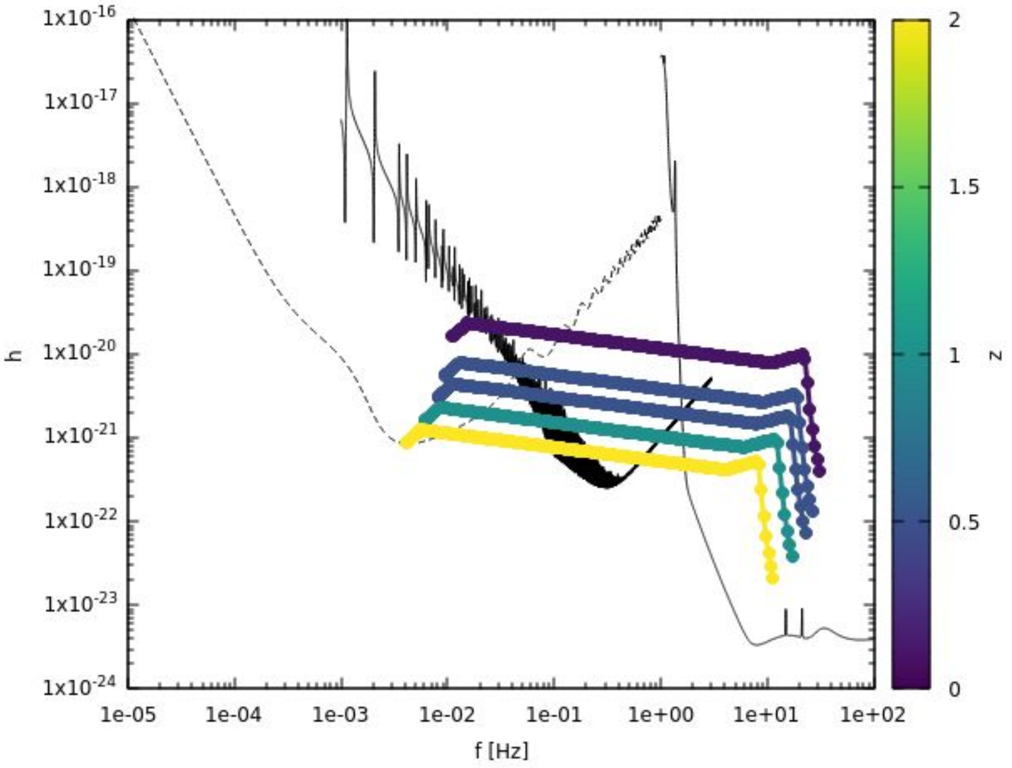



**see e.g. "The DRAGON-II simulations" paper series (rewarding, but computationally expensive)**

*Arca Sedda et al 2023a, 2024a,b*

# 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 |



# DRAGON-II vs B-POP: beast and beauty

*Arca Sedda et al 2023a, 2024a,b*

***Nbody simulations PROs:***

*- Accurate*

*- Impact of primordial binaries*

*- Impact of cluster evolution and structure*

***Nbody simulations CONs:***

*- High computational cost*

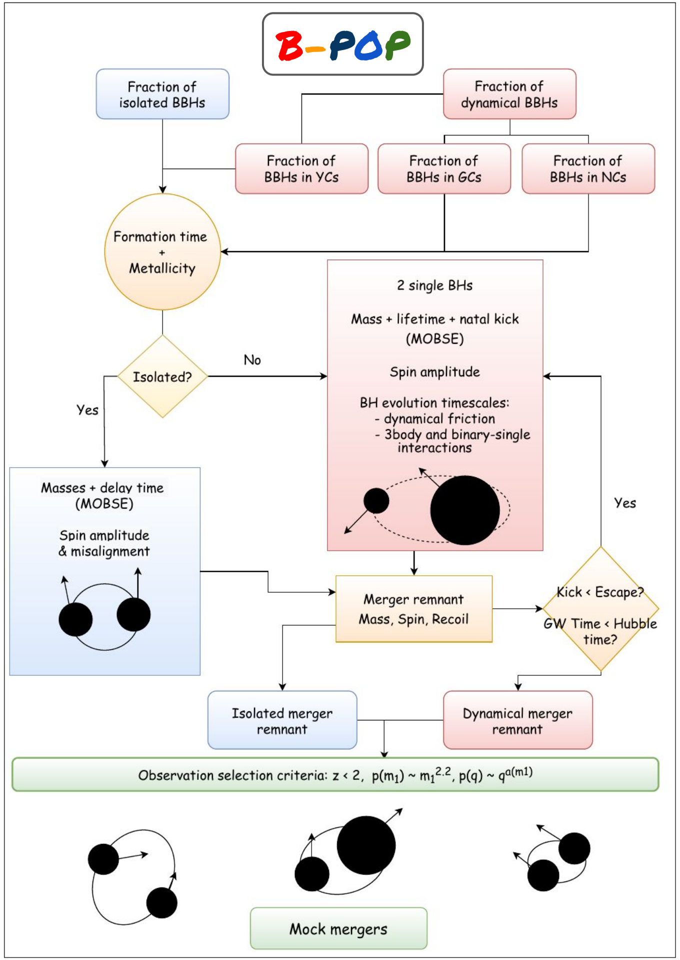
*- No reliable statistics within reasonable times*

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

***SOLUTION:***

*- Population synthesis code encoding dynamics+stellar evolution ( ~ $10^6$ in 0.5 hrs)*

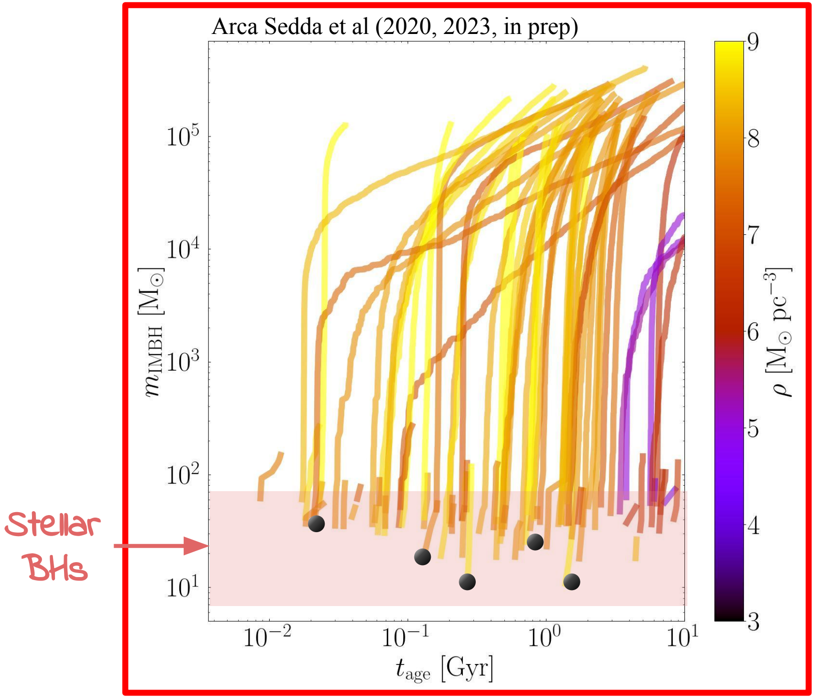
*- Rapid exploration of the parameter space (Metallicity, SFR, environment, BH natal spin, mass, kicks…)*



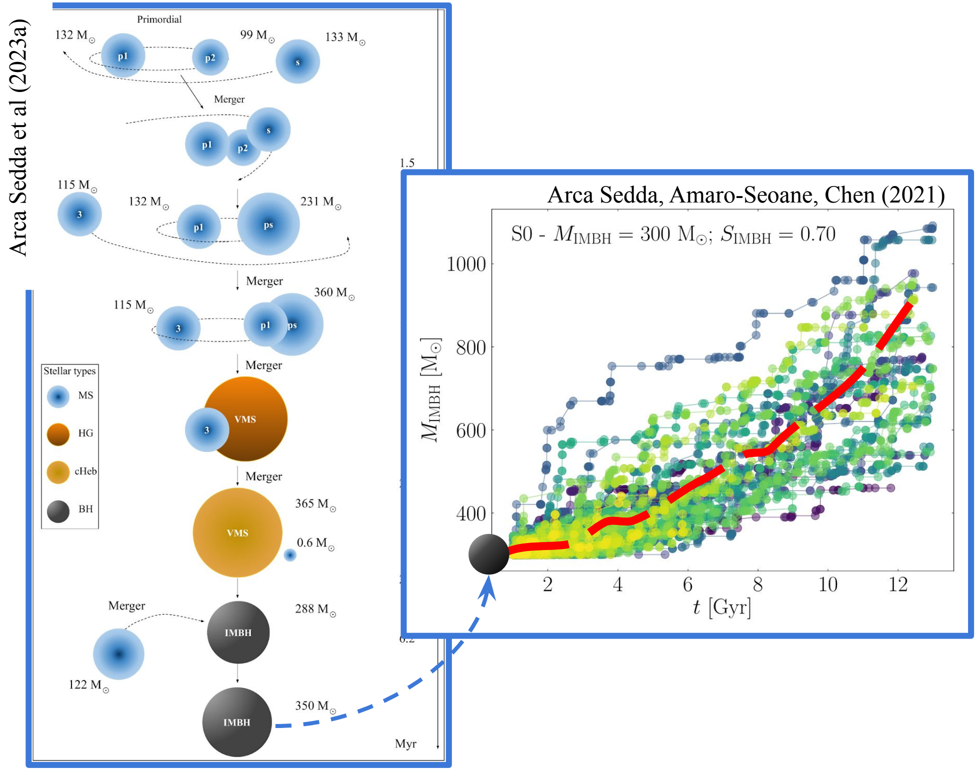
# B-POP: making isolated and dynamical BBH mergers has never been that easier

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

## Case #1: no IMBH seed progenitors




## Case #2: IMBH seed from stellar collisions

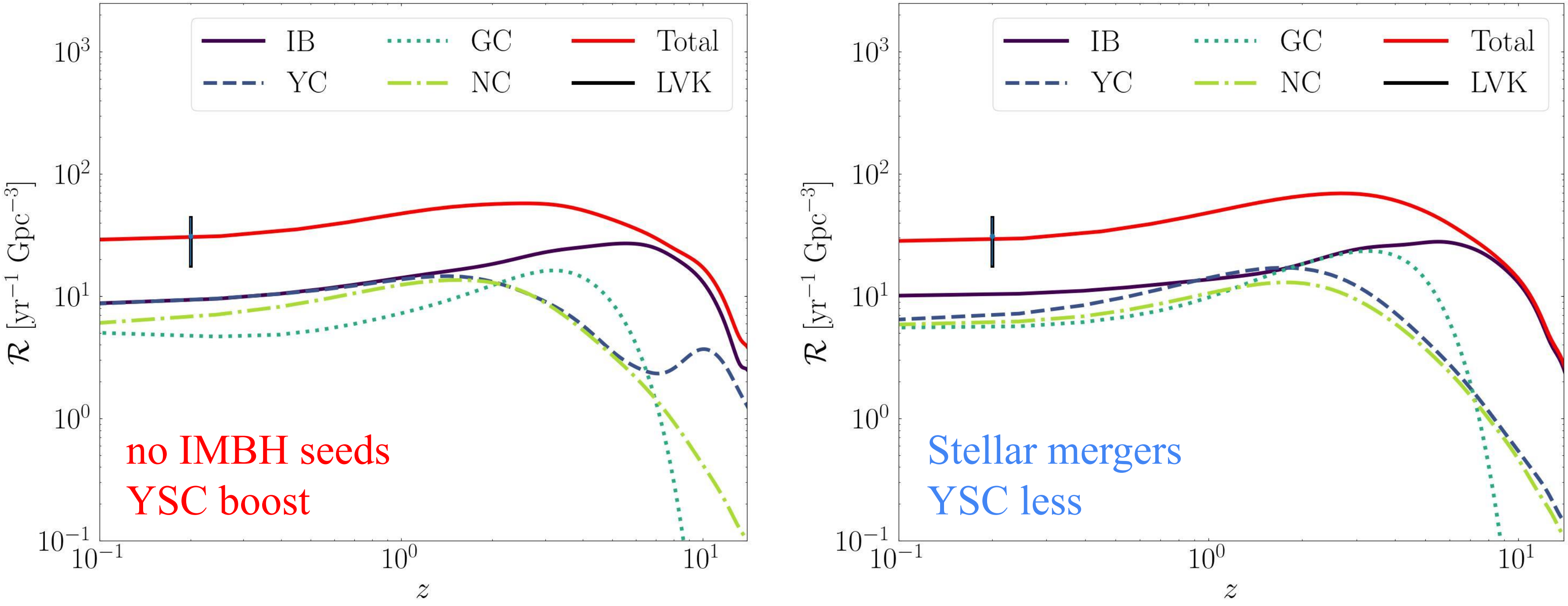


# B-POP: making isolated and dynamical BBH mergers has never been that easier

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

Case #1: no IMBH seed progenitors

Case #2: IMBH seed from stellar collisions



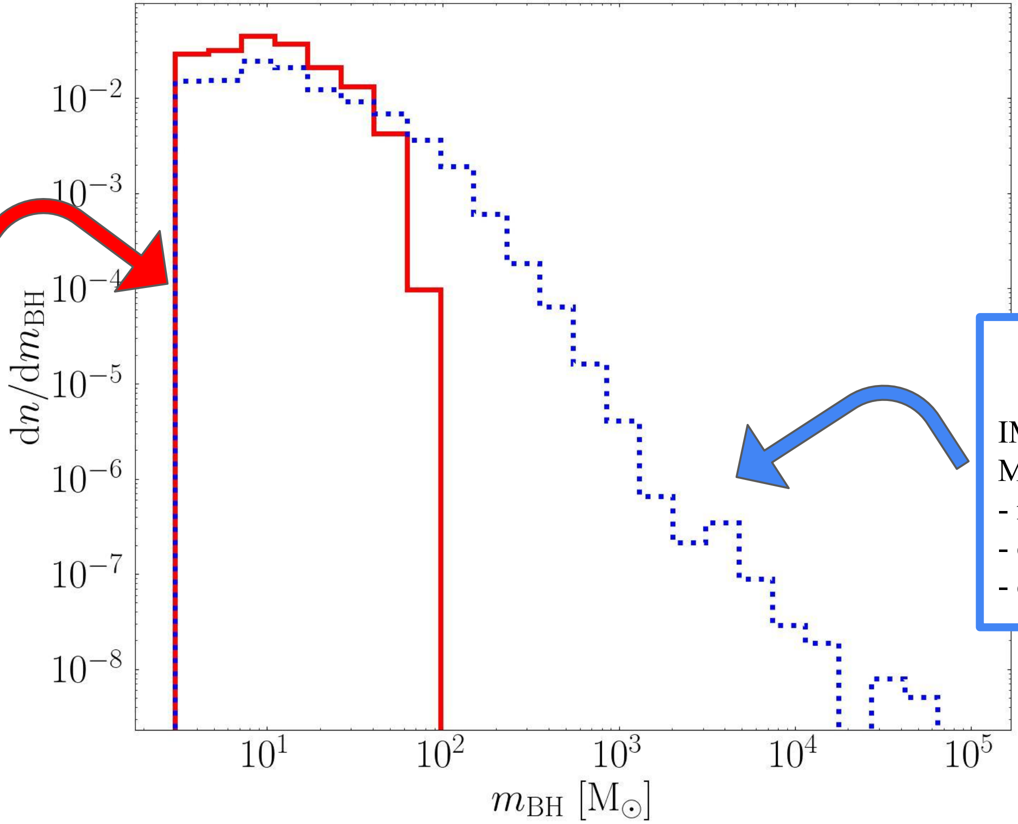
# B-POP: The "dynamical" IMBH mass spectrum

**No IMBH seeds**

Only densest NSCs
- Mass $>10^8$ $M_S$
- Rho $> 5\times10^6$ $M_S$ $pc^{-3}$

form IMBHs, with
Mass IMBH $> 10^4$ $M_S$

<u>Why?</u> Because of star cluster mass-loss and expansion




**Stellar mergers**

IMBHs in all types of clusters
Main drivers:
- mass of the seed,
- cluster formation time
- cluster mass and density

# B-POP + GWFISH = perspectives for future GW detectors

B-POP
*ArcaSedda+23*

inject

GWFISH
*Dupletsa+23*

**NOW LET'S FOCUS ON THE SUB-POP OF IMBHs**

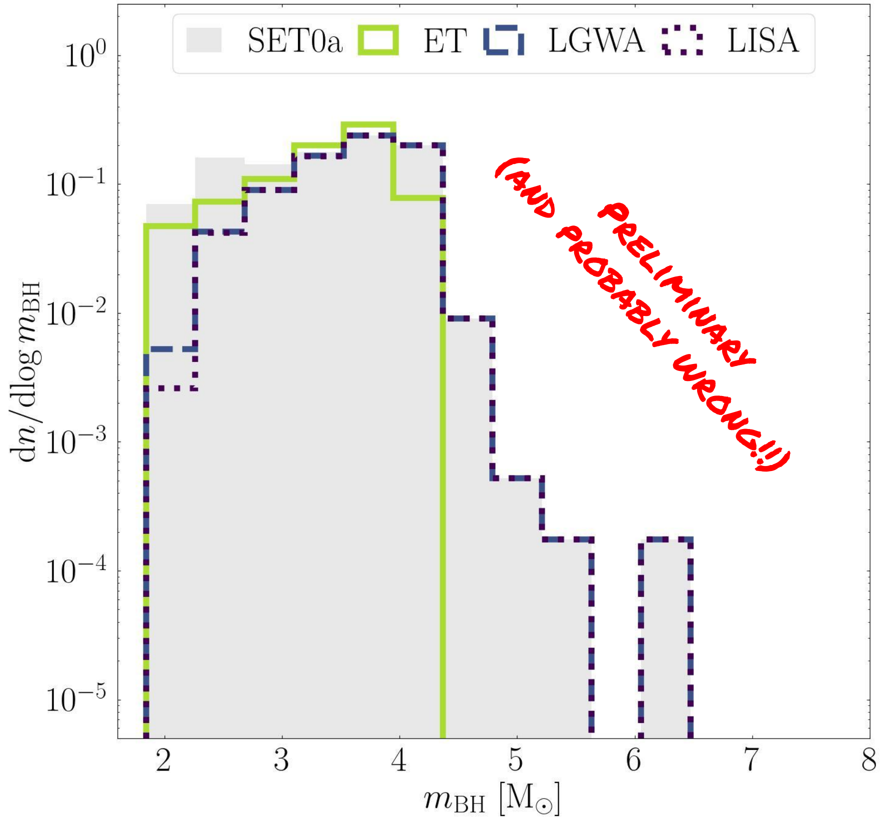
# B-POP + GWFISH = perspectives for future GW detectors

B-POP
*ArcaSedda+23*

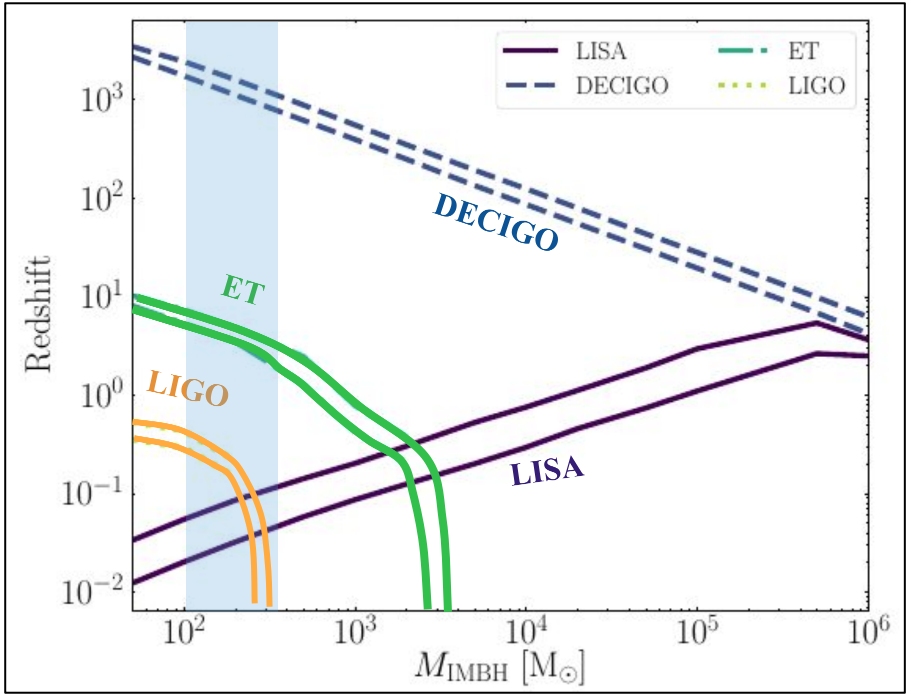
inject

GWFISH
*Dupletsa+23*

Case #2



# B-POP + GWFISH = perspectives for future GW detectors




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

| Detector | $M_{\rm IMBH,max}$ ($M_{\rm SUN}$) | $z_{\rm max}$ | Rate ($yr^{-1}$) |
|---|---|---|---|
| LIGO | 200 | 0.4-0.6 | 1-2 |
| LISA | $>10^5$ | 0.7-1.8 | 5-60 |
| ET | ~ 2,000 | >6 | 2-600 |
| DECIGO | $>10^5$ | >6 | $>10^3$ |

Arca Sedda, Amaro-Seoane, Chen (2021)

# Summary

- *We have presented results from the B-POP code, which models BBH mergers from different channels across cosmic times*
- *We find that the IMBH mass function critically depends on the nursery in which IMBHs form*
- *If hierarchical mergers are the "dynamical" dominant process, IMBHs in the $10^{3\text{-}4} M_{SUN}$ range should be quite rare*
- *If IMBH seeds from stellar collisions play a role, IMBHs could fill the whole mass range (what mass spectrum? power-law?)*
- *Future detectors like Einstein Telescope and LISA could, especially together, reveal the IMBH mass spectrum and bring new insights on their formation channels and true nature*