THE WANDERING PHASE OF THE FIRST MBH SEEDS: IMPLICATIONS FOR JWSTAND LISA EXPERIMENTS

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UNIVERSITA' DEGLI STUDI DI MILANO BICOCCA

LISA AstroWorking Group
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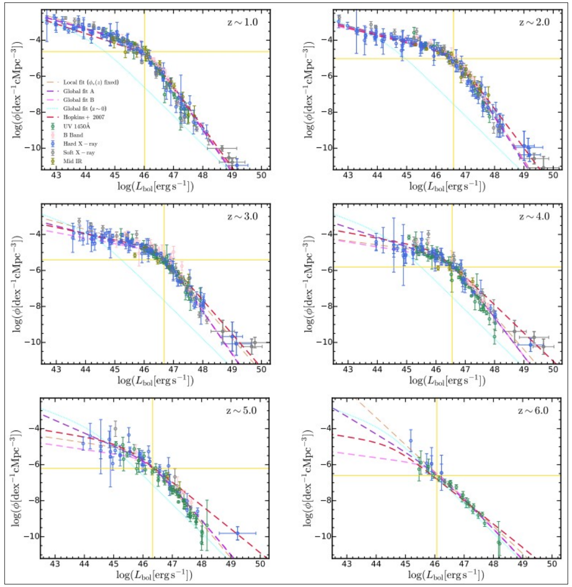
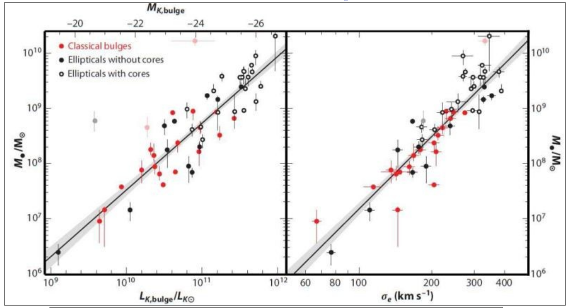
INTRODUCTION

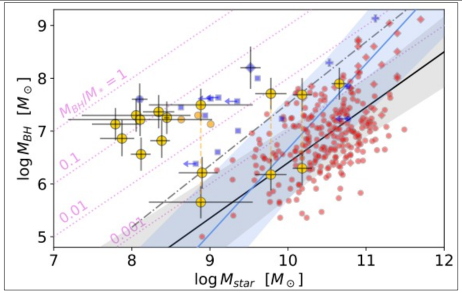
Many different observations of massive black holes → Most of the galaxies host a massive black hole >10^6 [M_o] at their centers



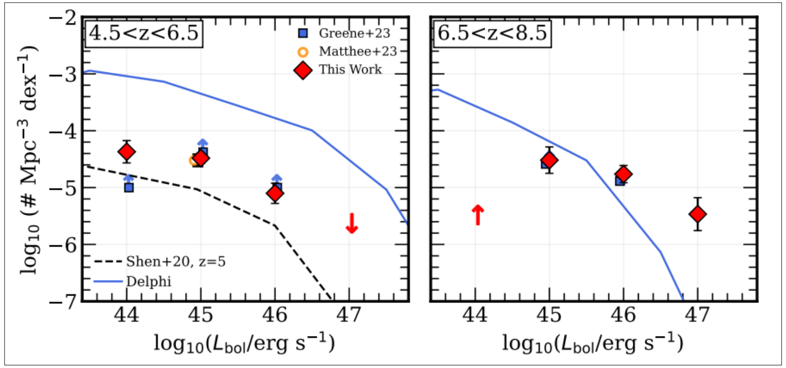
Shen et al. 2020

Kormendy et al. 2013





Maiolino et al. 2023



Kokorev et al. 2023

INTRODUCTION

Many different
hydrodinamical simulations
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semi-analytical models → Place MBH seeds at the center of the galaxies → Letting them to evolve (grow / merger etc)

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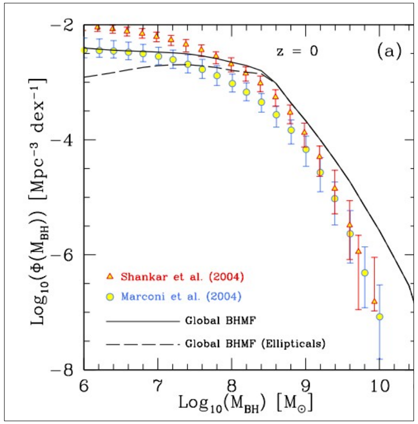
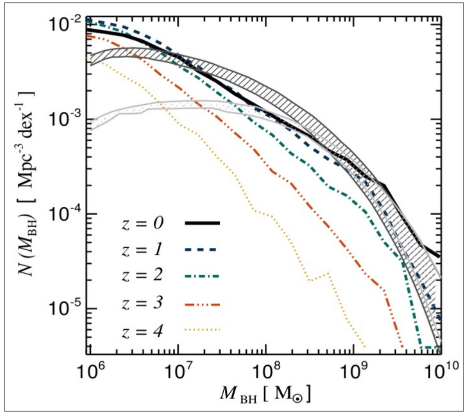
<u>Black hole mass functions</u> (two out of many...)

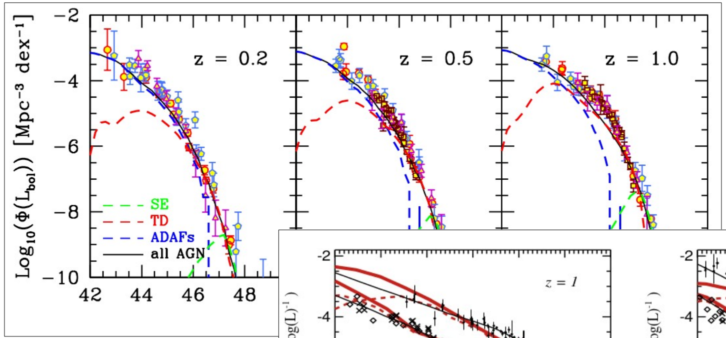


Fanidakis et al. 2010
(GALFROM SAM)



Sijaki et al. 2015
(Illustris hydro)

<u>Black hole luminosity functions</u> (two out of many...)



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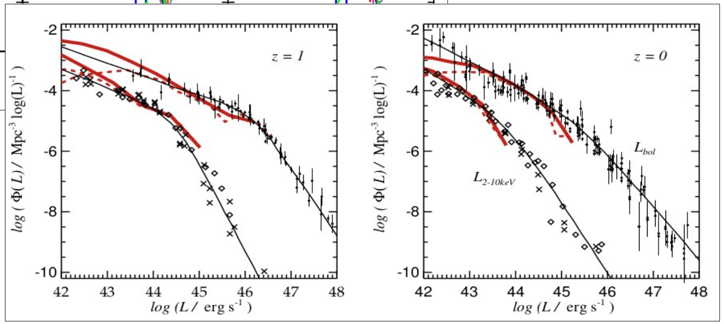

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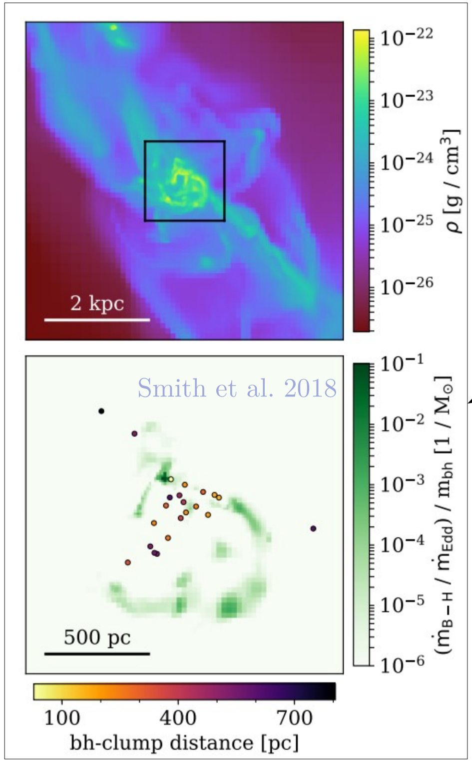
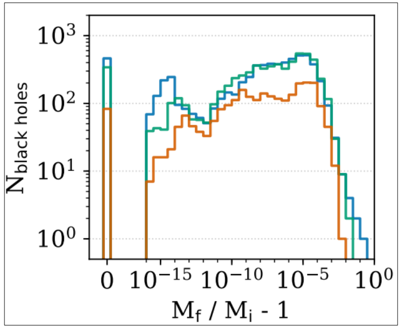


Renaissance simulations: Study the population of Population III remnants at z>9 (light seed population)

1) **Number** of that seeds inside the galaxy is **high** (~8-10)

2) Light population stays **far from the "center"**

3) The off-center position prevents the encounter with massive gas clouds **hindering the growth** of MHB seeds



Smith et al. 2018

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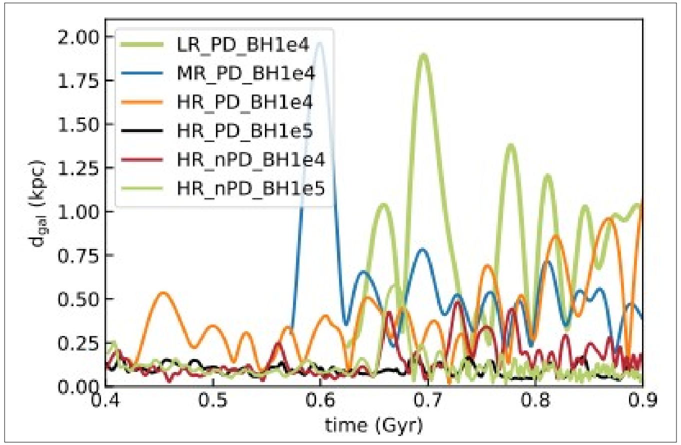
Hydro sims about the dynamical life of black hole seeds in high-z galaxies: Pfister et al. 2019



Pfister et al. 2019

1) The lack of a deep potential well in these galaxies and their irregular morphologies make MBH seeds undergo a random walk out of the galactic centre

2) The random walk force the MBH seed to stay far from the dense gas regions, inhibiting important accretion events

3) ~10^5 [M_o] seems to be the minimum requirement to imagine that a BH is well stabilized in the center of its host

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Many open questions...

Does this wandering phase of MBH seeds affect the population of MBHs?

Does it rule out all the predictions made about MBHs in the EM and GW spectrum?

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L - GALAXIES

Springel et al. 2005; Guo et al. 2011, Henriques et al. 2015, Henriques et al. 2020, Yates et al. 2021

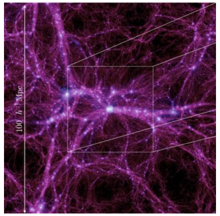
METHODOLOGY

L - GALAXIES

Dark matter merger trees

MILLENNIUM SUIT OF SIMULATION

$L_{box} = 100$ Mpc / h
$M_{halo} \sim 10^{8}$ M_{sun}



$L_{box} = 500$ Mpc / h
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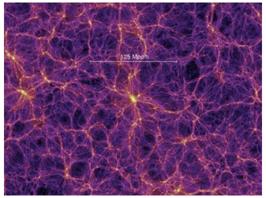

$L_{box} = 3$ Gpc / h
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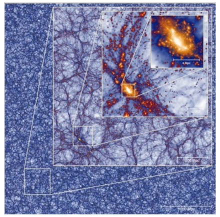
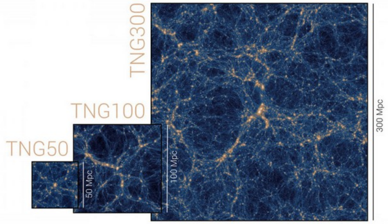


TNG SUITE OF SIMULATION



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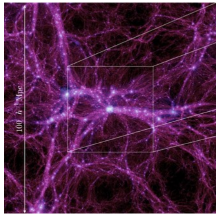

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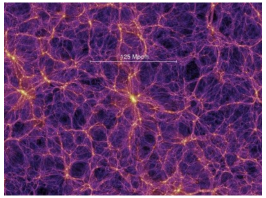

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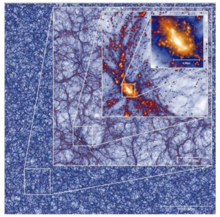

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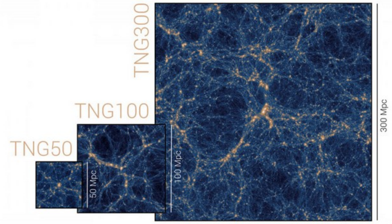

Galaxy physics

Henriques et al. 2015

In-situ processes:
- Star formation
- Supernovae feedback

Environmental processes:
- AGN feedback
- Galaxy tidal disruption
- Gas stripping
- ...

METHODOLOGY

L - GALAXIES

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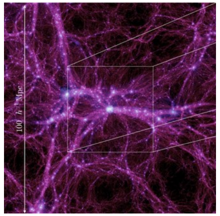

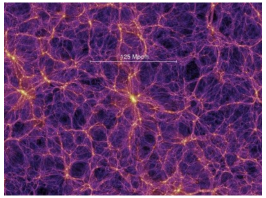

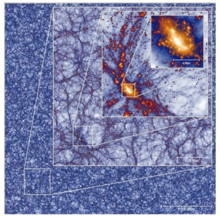

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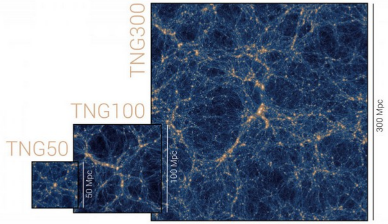

Galaxy physics

Henriques et al. 2015

Massive black hole physics

- **Seeding**: PopIII, RSM, DCBH
- **Growth**: Eddington, Sub-Eddington & Super-Eddington
- **Spin** evolution
- **AGN feedback**
- **Massive binary evolution**

Izquierdo-Villalba et al. 2020, 2022, Spinoso et al 2023, Spinoso et al. (in prep)

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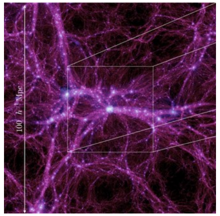

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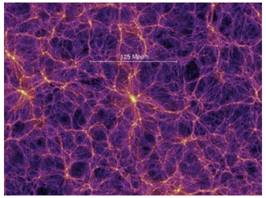

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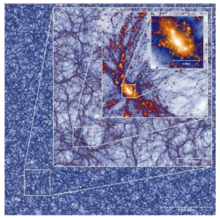

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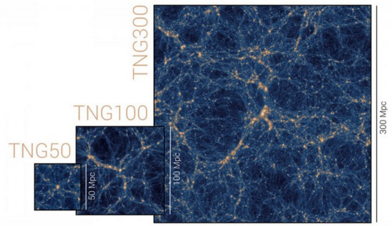
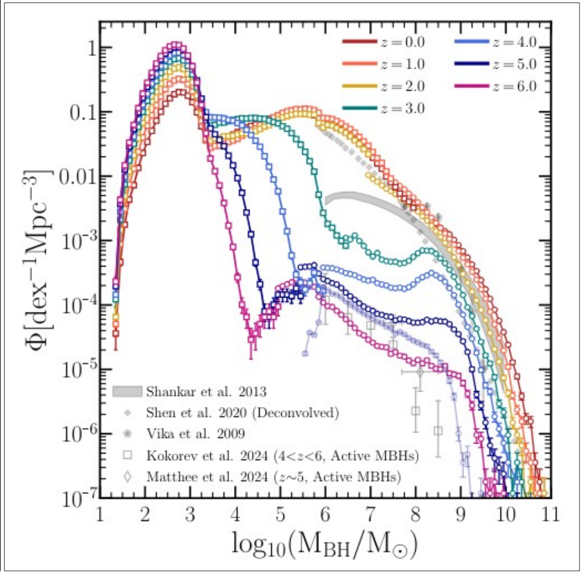
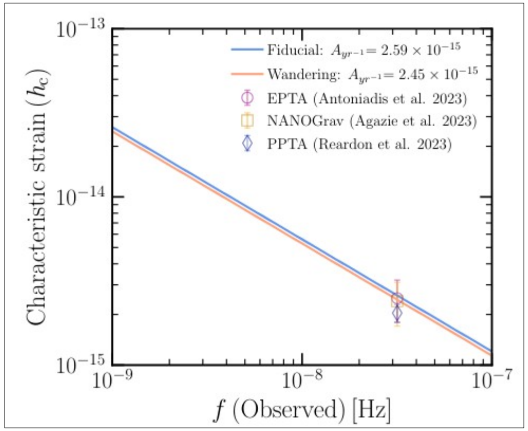


Black hole mass function

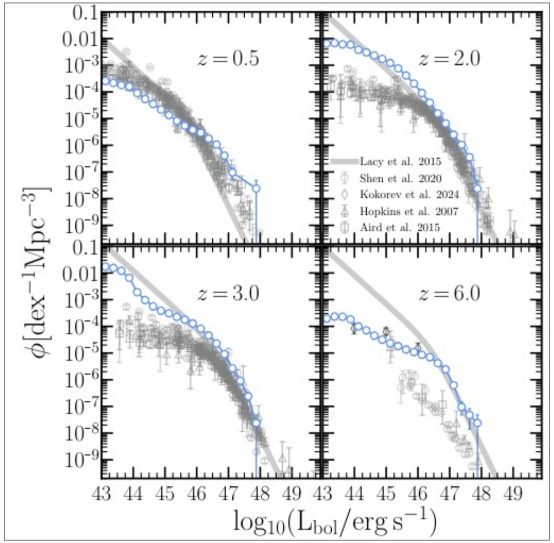


sGWB at nHz frequencies



Izqueirdo-Villalba et al. (in prep)

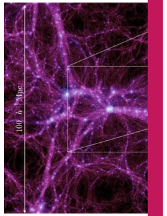
Black hole luminosity function



METHODOLOGY

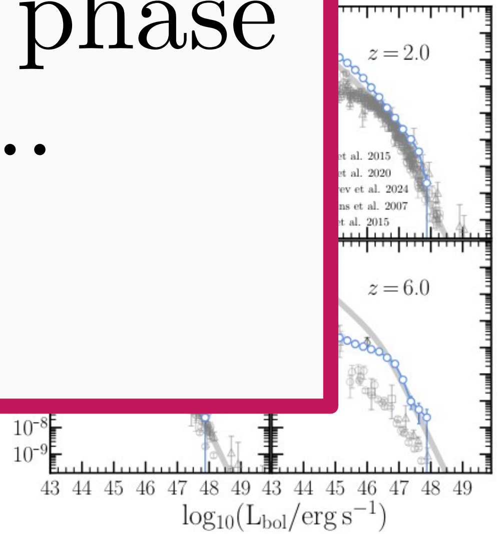
Dark matt

L_{box} = 100 M
$M_{halo} \sim 10^8$ M



prep)

function



Let's include the wandering phase of the first MBH seeds...

MILLENNIUM-II SIMULATION

Izqueirdo-Villalba et al. (in prep)

METHODOLOGY

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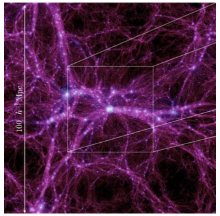
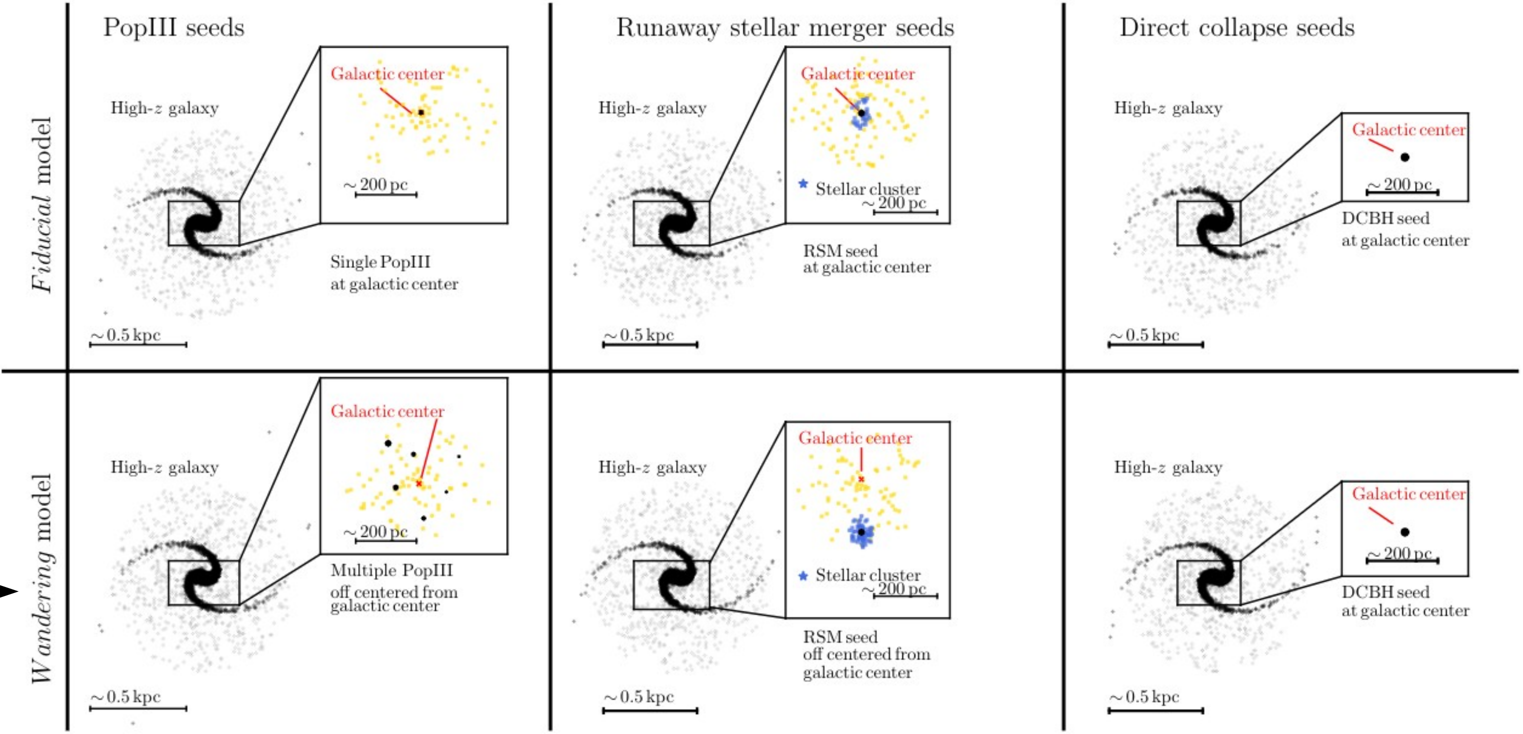


→ L - GALAXIES



Parameteres

1) **Initial position** of the seed at formation time

2) **Number of PopIII formed** inside a galaxy (Spinoso et al. in prep)

3) **Time needed** to reach the center

4) **Growth** in the wandering phase

Izquierdo-Villalba et al. (in prep)

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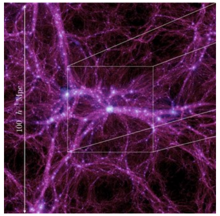

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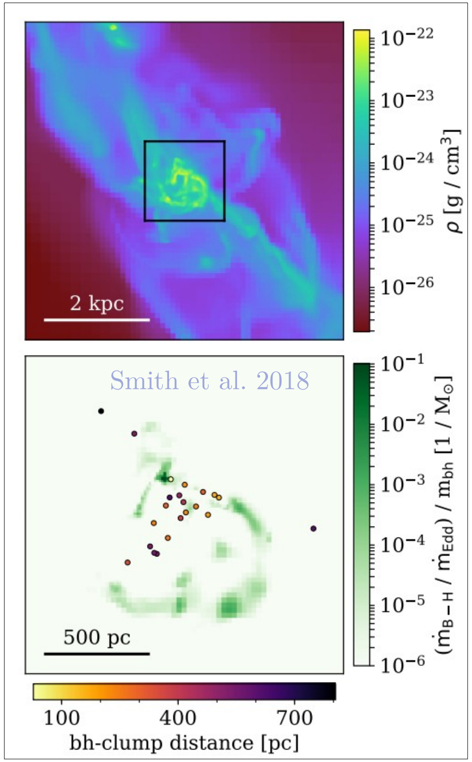

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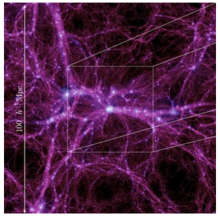

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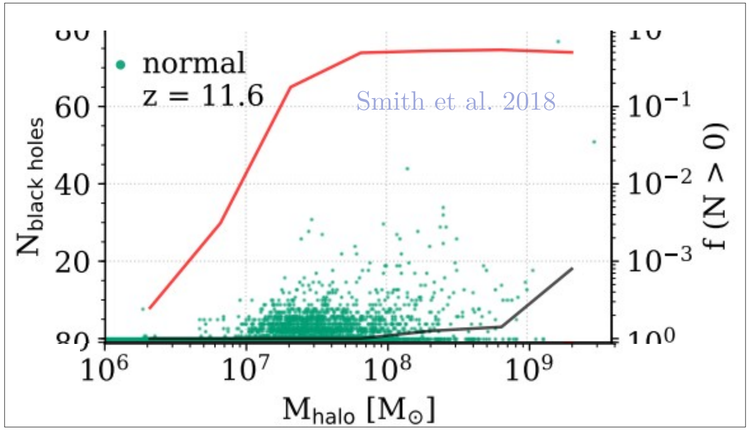
Sampled from the Larson IMF



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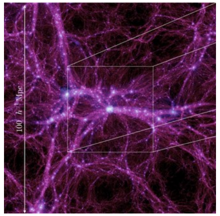

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3) **Time needed** to reach the center Bionney& Tremanine 2008

$$t_{\mathrm{w}}^{\mathrm{BH}} = 19\, f_s\, f(\varepsilon) \left(\frac{r_0}{5\,\mathrm{kpc}}\right)^2 \left(\frac{\sigma}{200\,\mathrm{km/s}}\right) \left(\frac{10^8\,\mathrm{M}_\odot}{\mathrm{M_{BH}}}\right) \frac{1}{\Lambda}\ [\mathrm{Gyr}]$$

Parameteres

4) **Growth** in the wandering phase

Izqueirdo-Villalba et al. (in prep)

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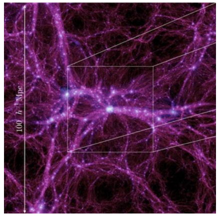

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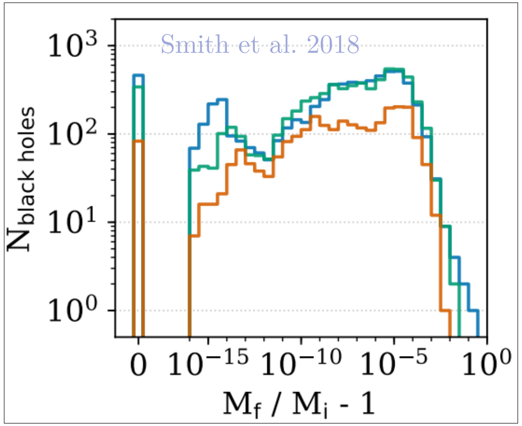
$$M_{BH}(z_R) = M_{BH}(z_f)\exp\left[f_{Edd}\frac{1-\eta(t)}{\epsilon(t)}\frac{\delta t}{t_{Edd}}\right]$$

Sub-Eddington → $f_{Edd} = 0.001$



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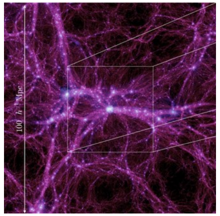

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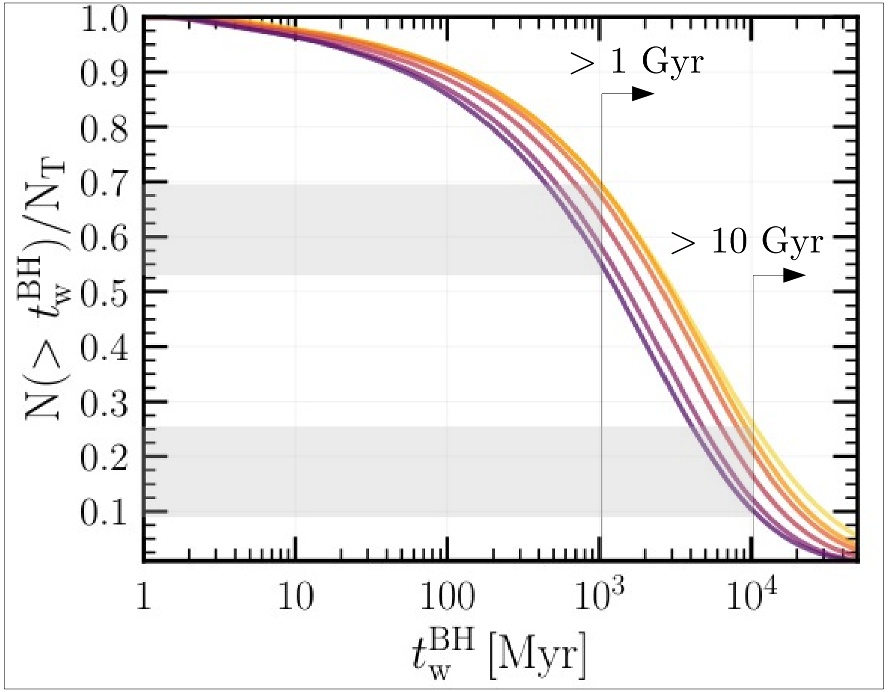
Time needed to stabilize in the galactic center



Results

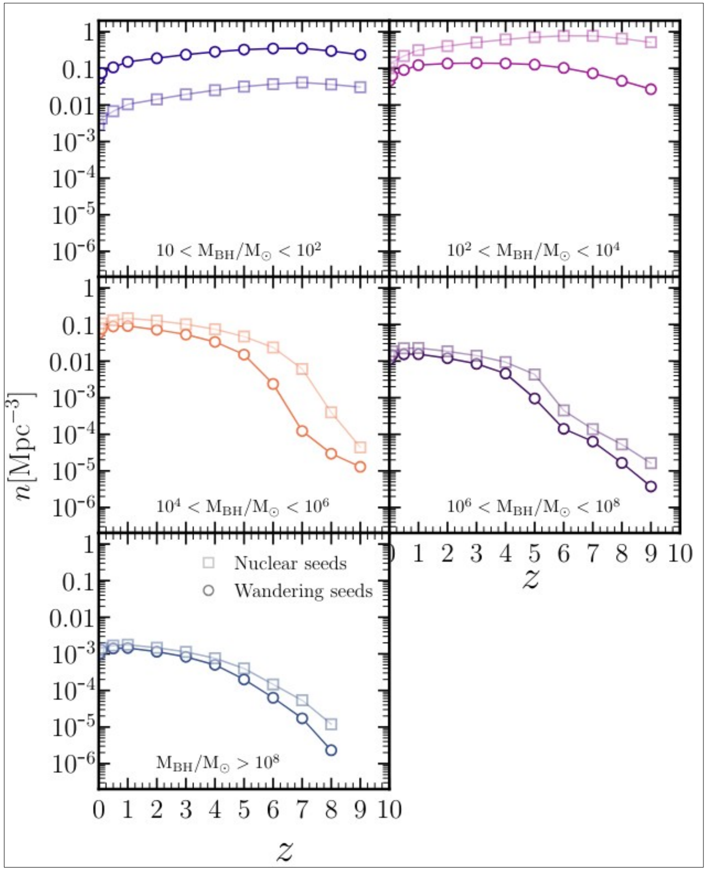
Global population of MBHs

Global population of MBHBs

Results

Global population of MBHs

Comoving number density of nuclear MBHs



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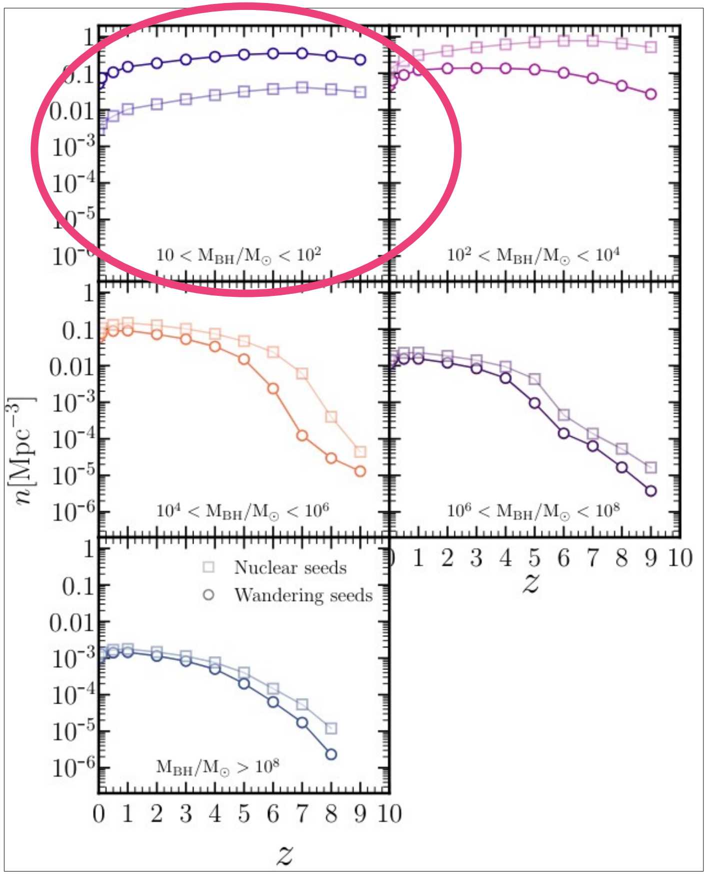

1) Effect in low-mass objects

Global population of MBHBs

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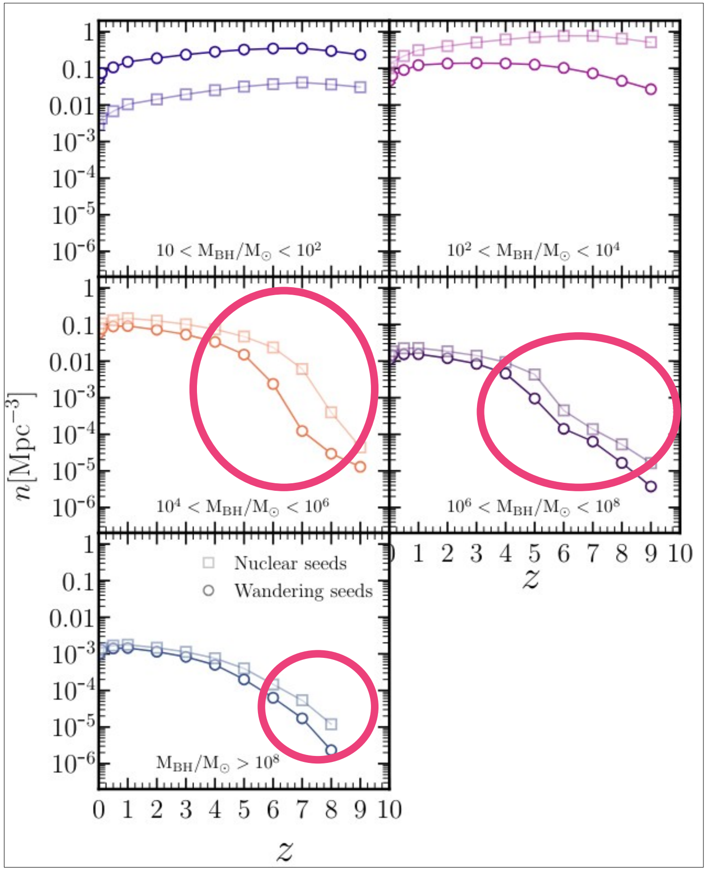


1) Effect in low-mass objects

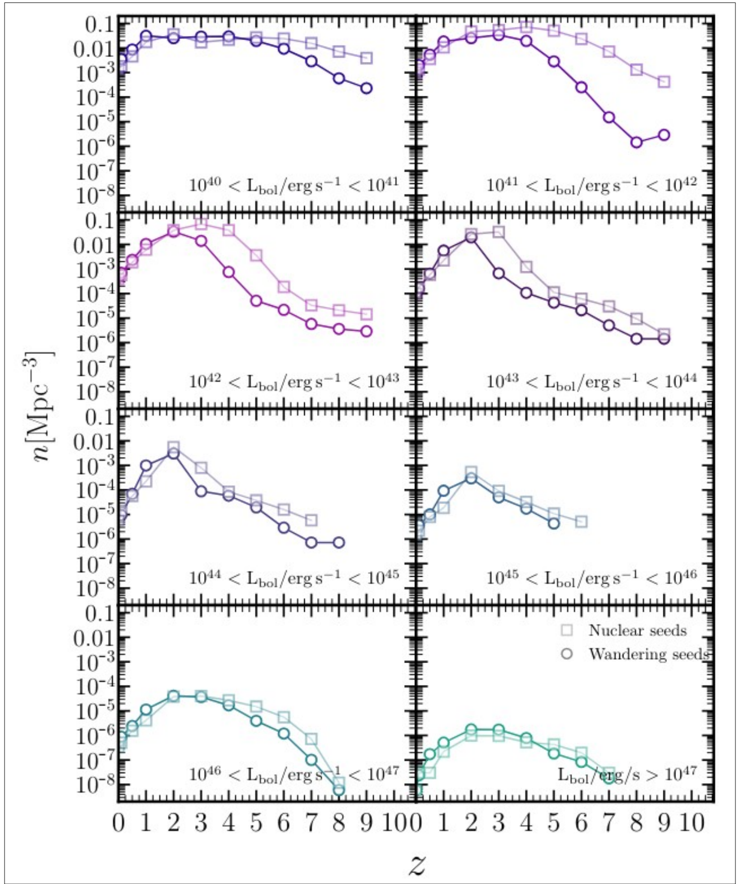
2) Delay the assembly of MBHs $>10^4$ M_o

Global population of MBHBs

Results

Global population of MBHs

Comoving number density of active MBHs



Global population of MBHBs

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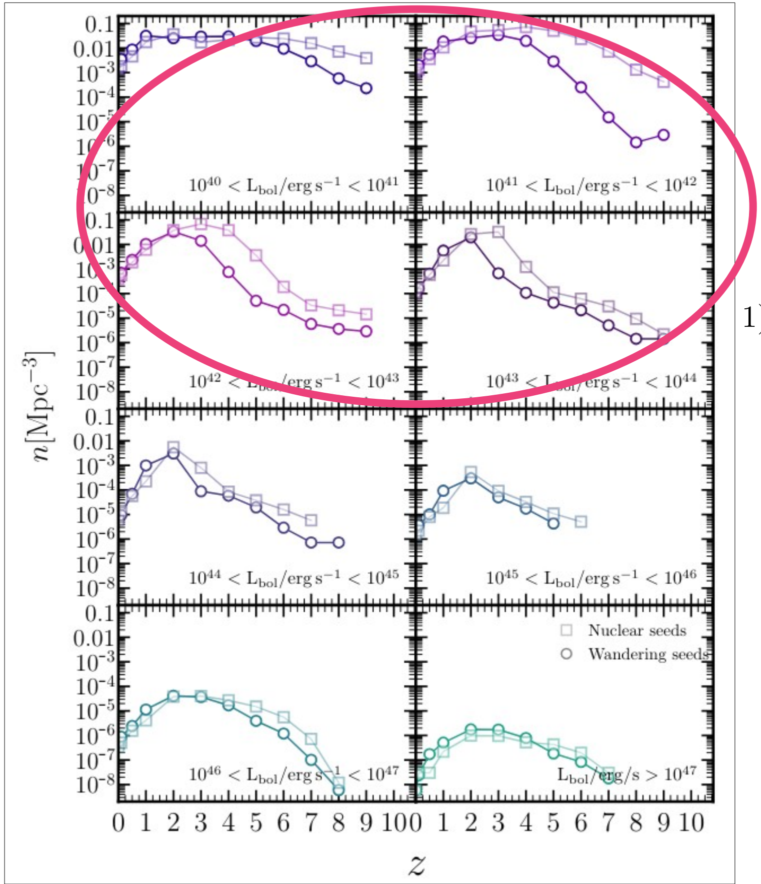
Global population of MBHs

Comoving number density of active MBHs



1) Effect on the population with $L_{bol} < 10^{44}$ erg/s

Global population of MBHBs

Results

Global population of MBHs

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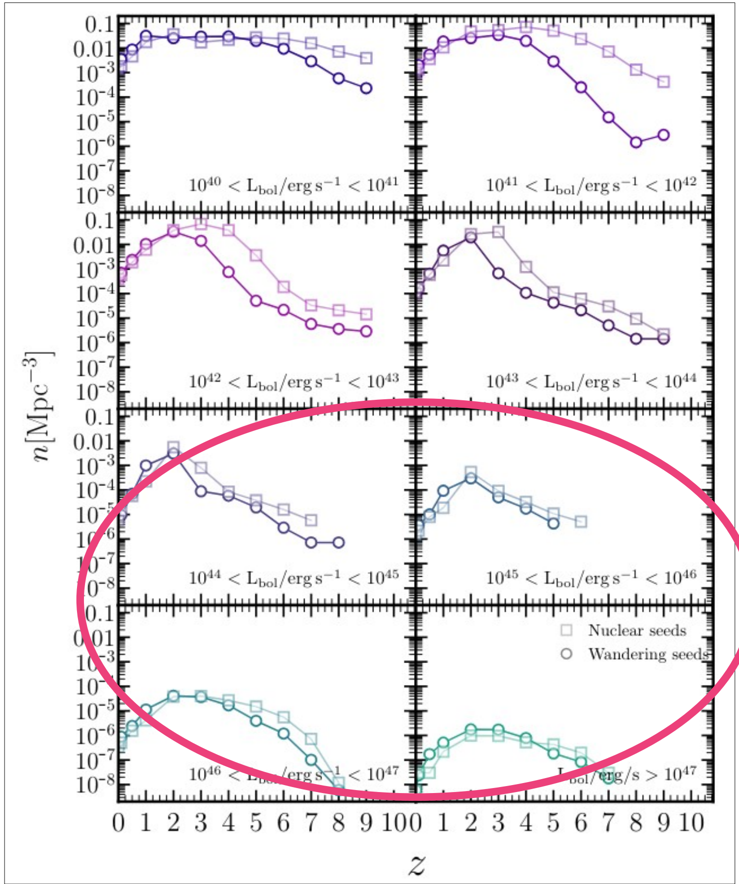

1) Effect on the population with $L_{bol} < 10^{44}$ erg/s
2) Almost **negliglible** effect on the population with $L_{bol} > 10^{44}$ erg/s (JWST targets!)

Global population of MBHBs

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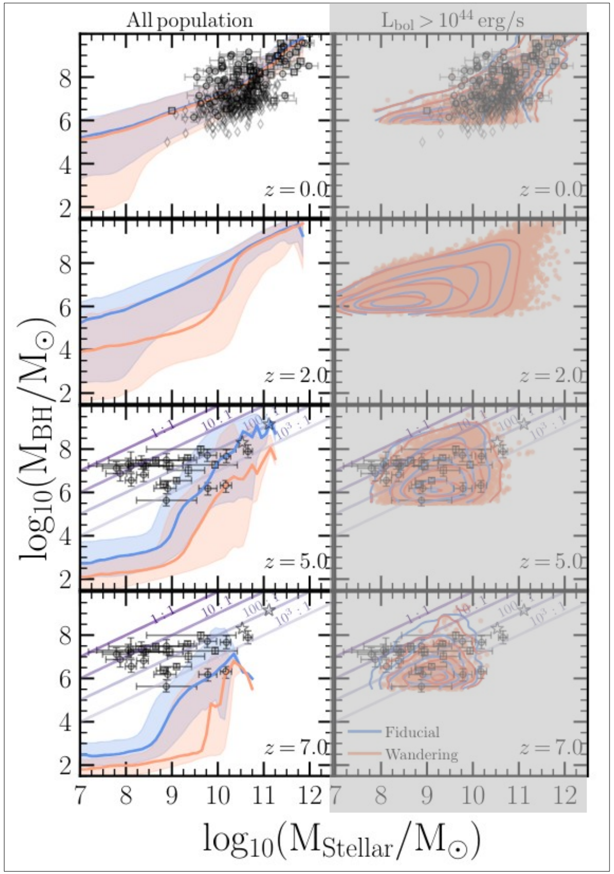
Global population of MBHs

Scaling relations



Global population of MBHBs

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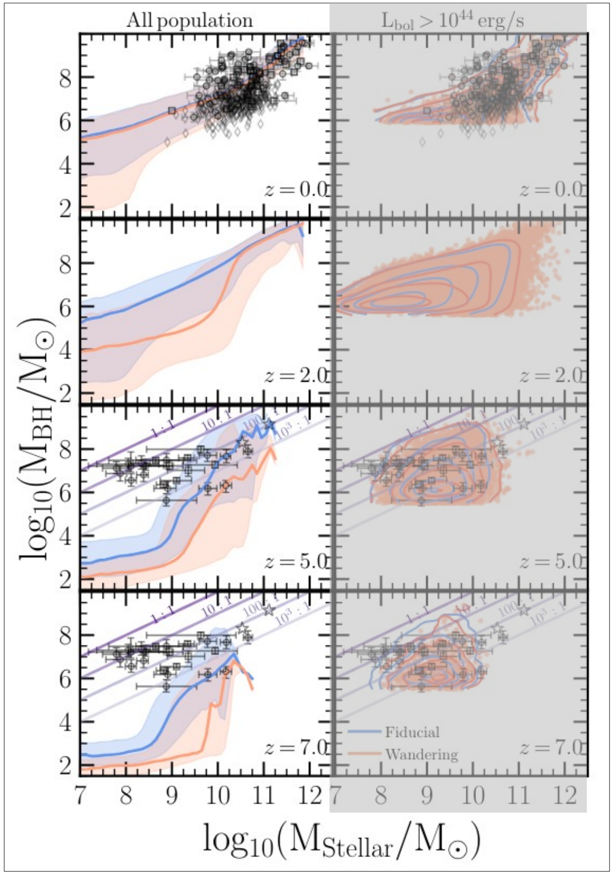

1) The main effect is at high-z and low mass
2) But... at z = 0 no differences

Global population of MBHBs

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Global population of MBHs

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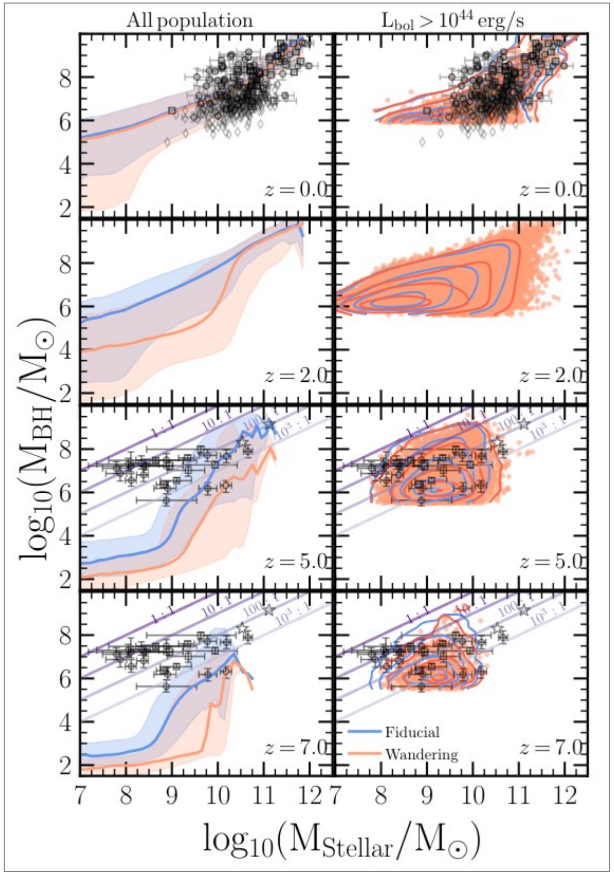

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3) The overmassive balck holes are present in both Fiducial and Wandering model

JWST data cannot detect the features of the wandering phase

Global population of MBHBs

Results

Global population of MBHs

Comoving number density of nuclear MBHs

1) Effect on low-mass objects
2) Delay the assembly of MBHs $>10^4$ M_o

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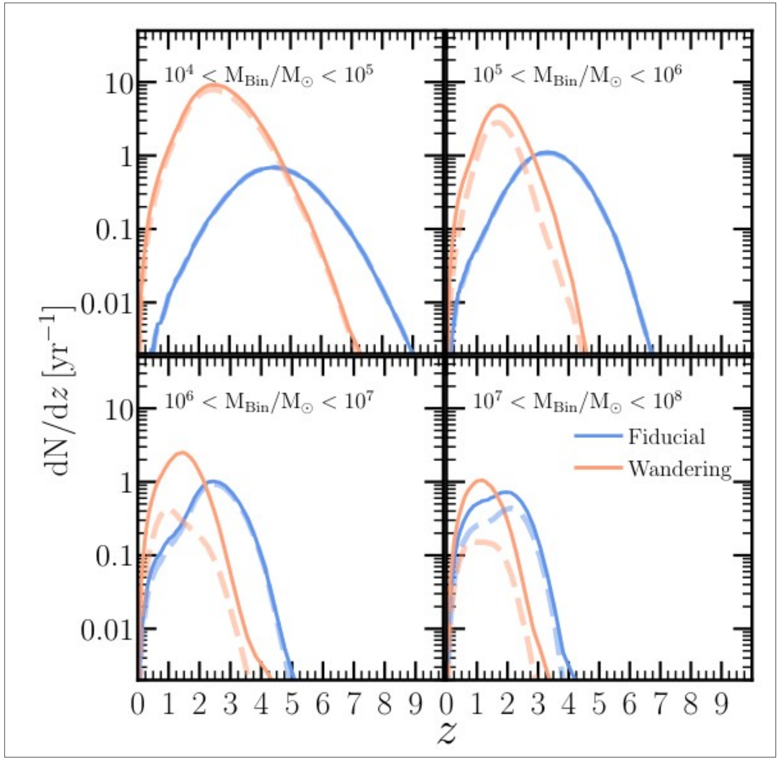

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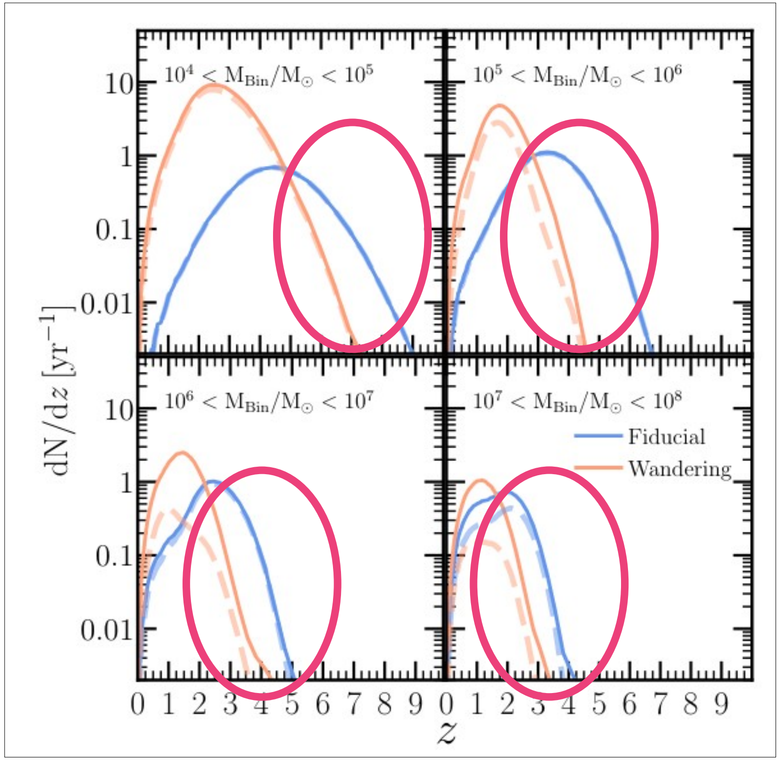

1) Suppression of high-z events

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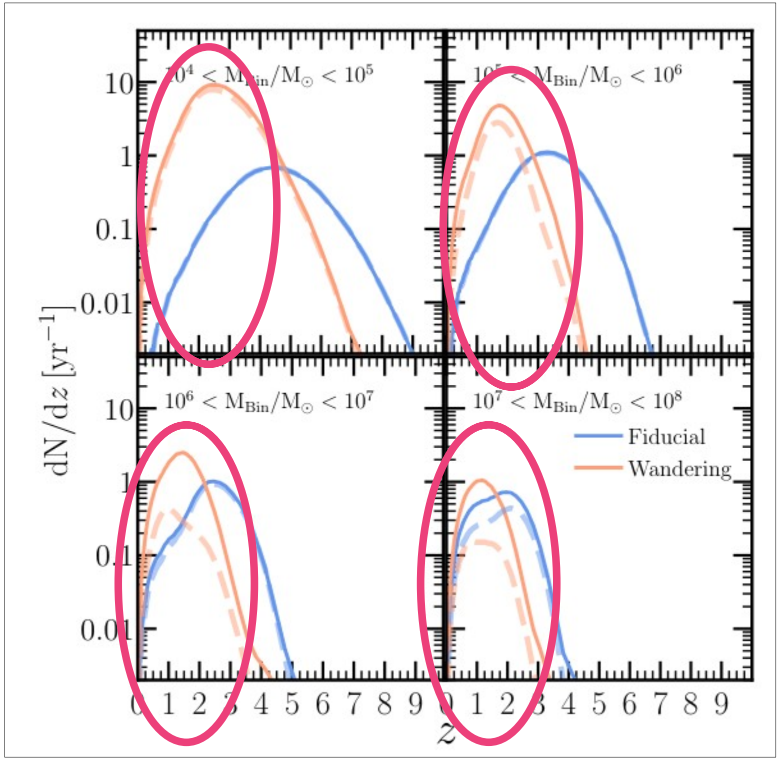

1) Suppression of high-z events
2) Enhancement of low-z events

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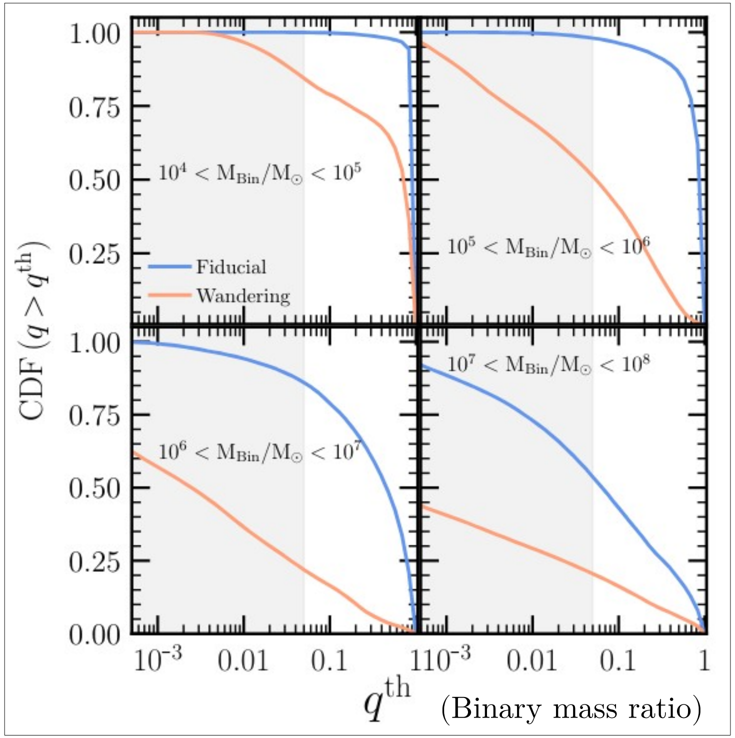

1) Suppression of high-z events
2) Enhancement of low-z events
3) Most of the events have q<0.05

CONCLUSIONS

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Global population of MBHBs

1) Suppression of high-z events
2) Enhancement of low-z events
3) Most of the events have $q<0.05$

The MBHBs detected by LISA will have smaller mass ratios than expected!

THANKS!