11th Iberian Gravitational Waves Meeting

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THE MASSIVE BINARY BLACK HOLE POPULATION ACROSS COSMIC TIME SEEN UNDER A SEMI-ANALYTICAL PERSPECTIVE

UNIVERSITA' DEGLI STUDI DI MILANO BICOCCA

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OUTLINE

* Introduction : Massive black holes and massive binary black holes

* The model used to study the massive (binary) black holes in a cosmological context

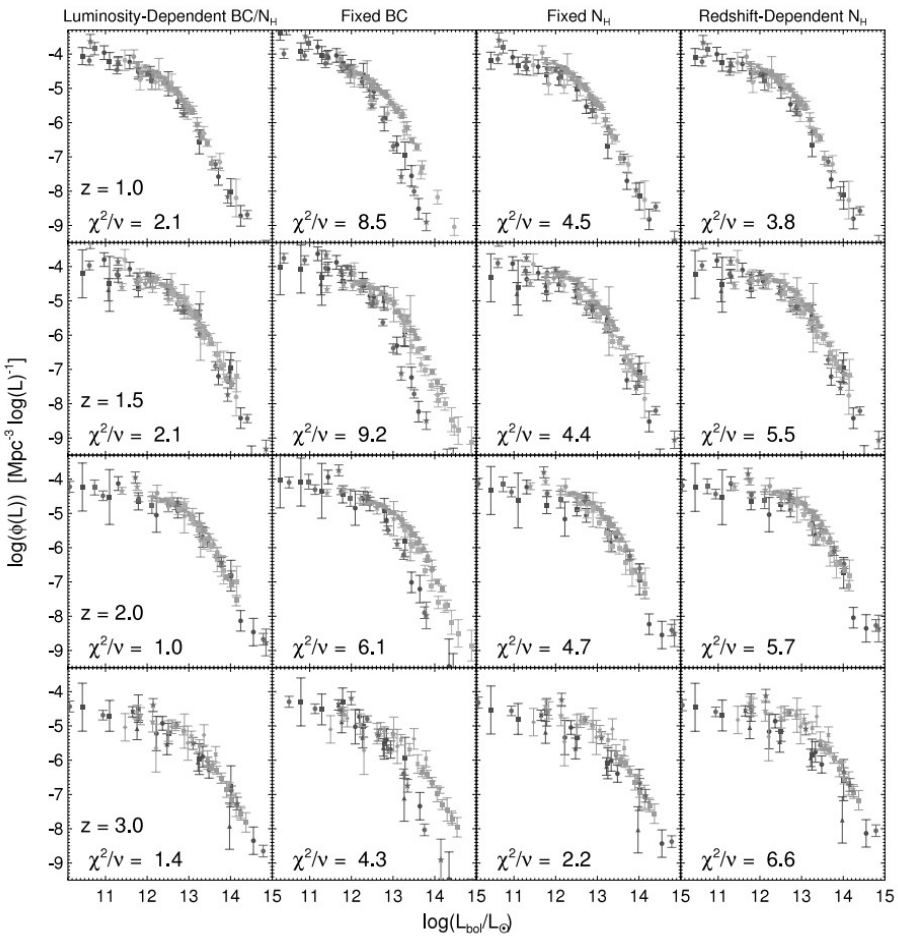
* Results

* Conclusions

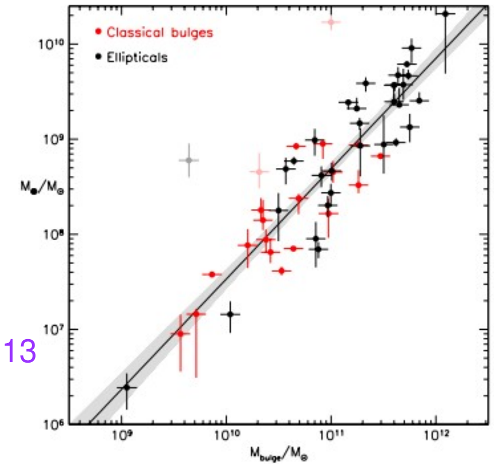
INTRODUCTION

* Our relationship with massive black holes started in 1963 when Schmidt M. found the first quasar

* More and more people studied the population of quasars: Luminosity functions, scaling relations …

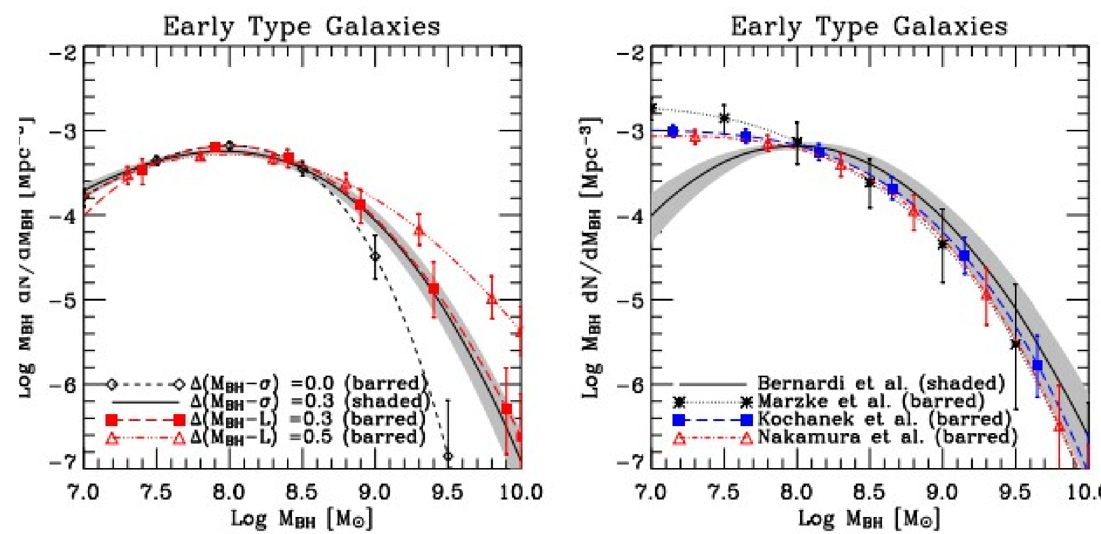


Hopkins et al. 2009



Kormendy & Ho et al. 2013

Marconi et al. 2004



* We reached the <u>CONCLUSION</u> that

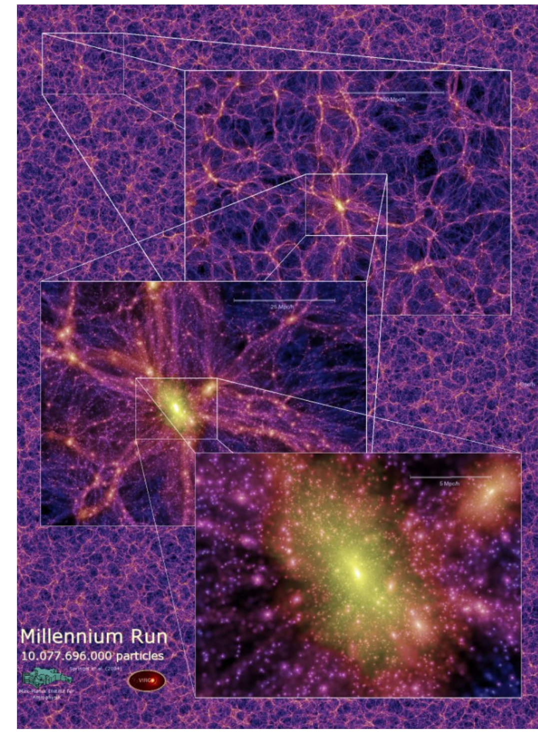
MASSIVE BLACK HOLES (>10^6 M_{sun}) ARE UBIQUITOUS IN ALL GALAXIES

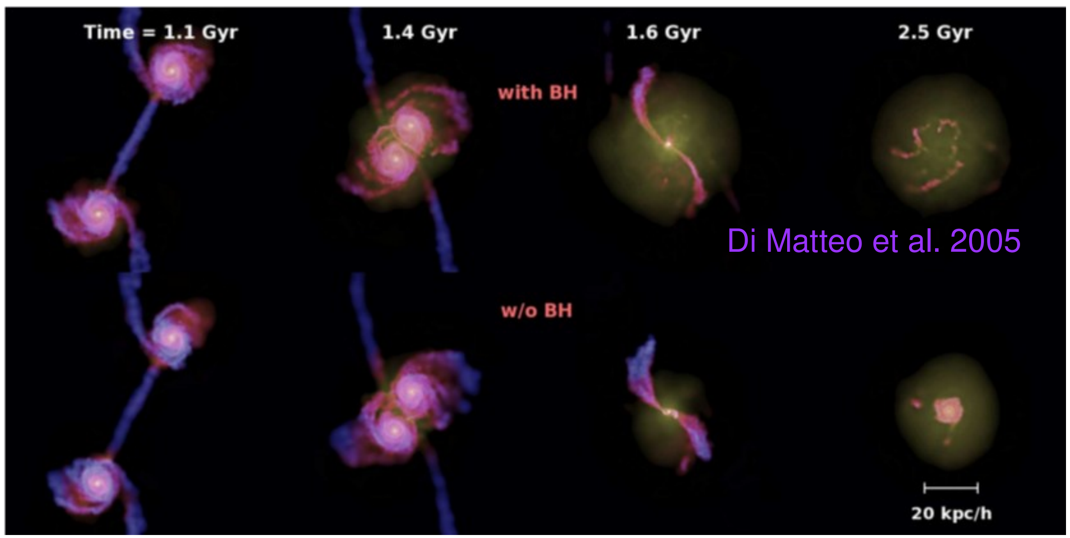
INTRODUCTION

* MASSIVE BLACK HOLES (>10^6 M_{sun}) ARE UBIQUITOUS IN ALL GALAXIES

HIERARCHICAL GROWTH OF THE STRUCTURES:

Mergers are one of the main drivers of galaxy evolution





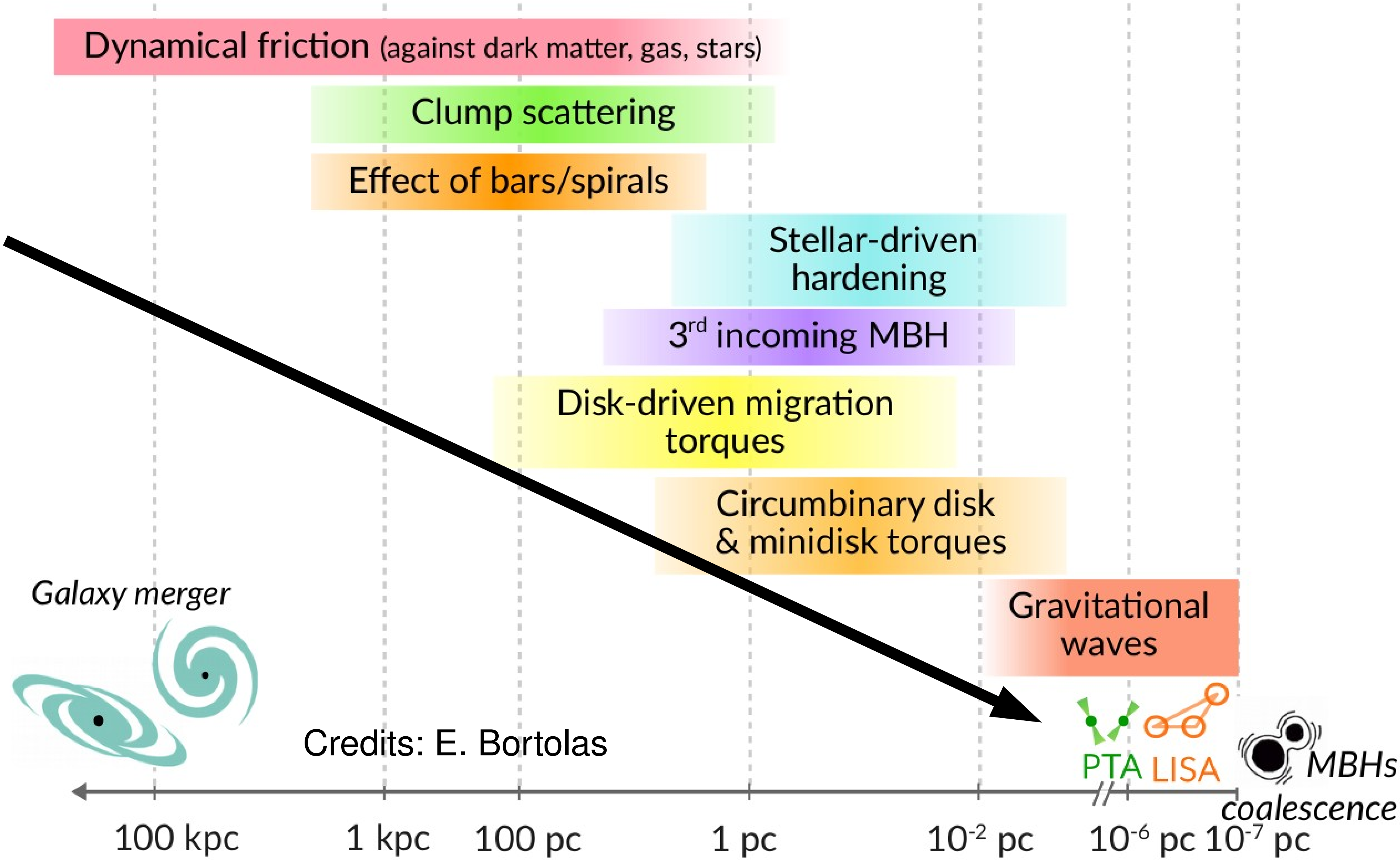
GALAXIES MIGHT HOST **MORE** THAN ONE MASSIVE BLACK HOLE

BLACK HOLES ARE DEPOSITED FAR AWAY (> kpc)

IS POSSIBLE BRING THE TWO BLACK HOLES TOGETHER (~pc) ?

INTRODUCTION

Many works have tackled this problem...



Credits: E. Bortolas

INTRODUCTION

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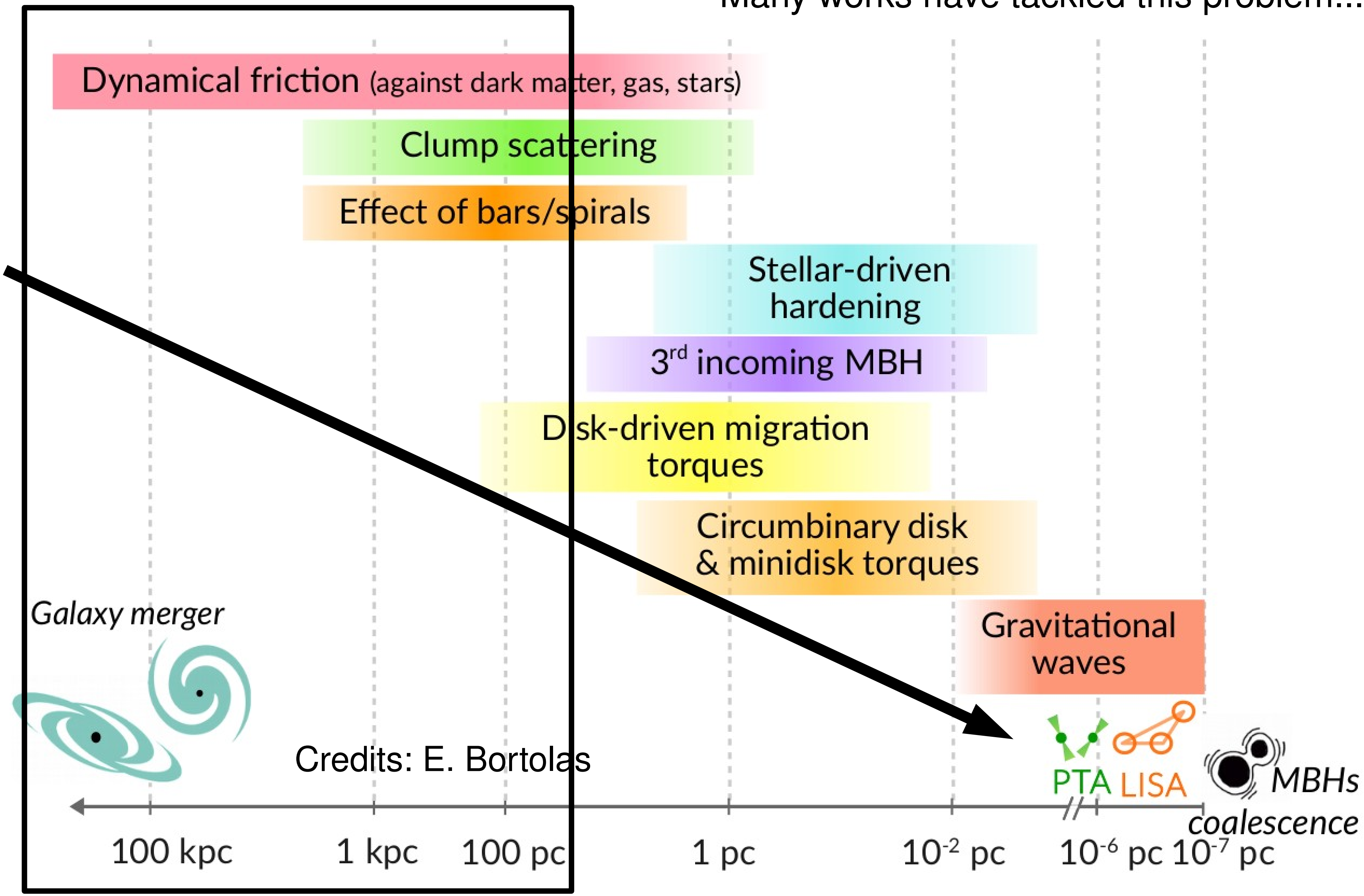
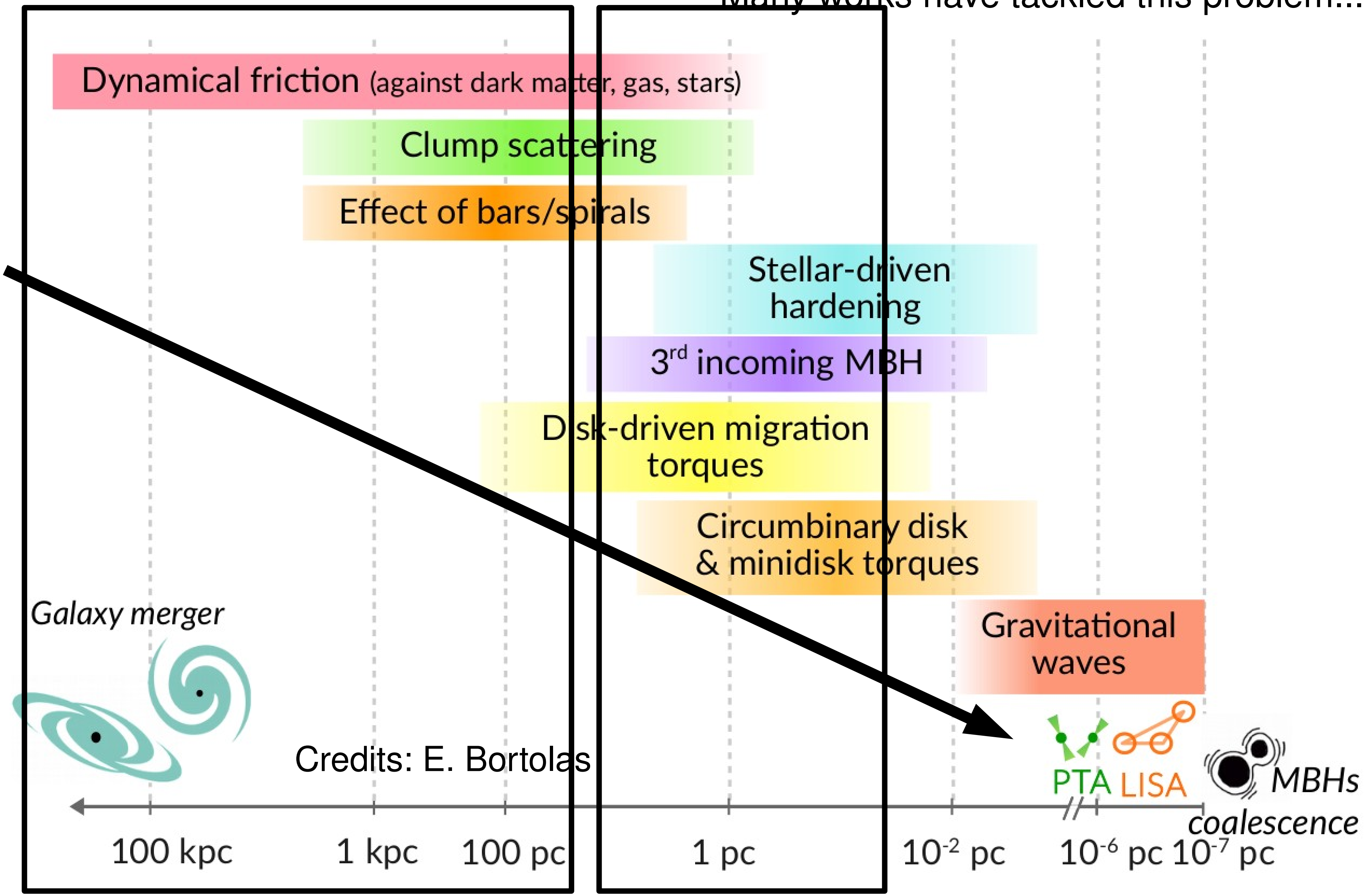


Dynamical friction or pairing phase

INTRODUCTION

Many works have tackled this problem...



Dynamical friction or pairing phase

Hardening phase

INTRODUCTION

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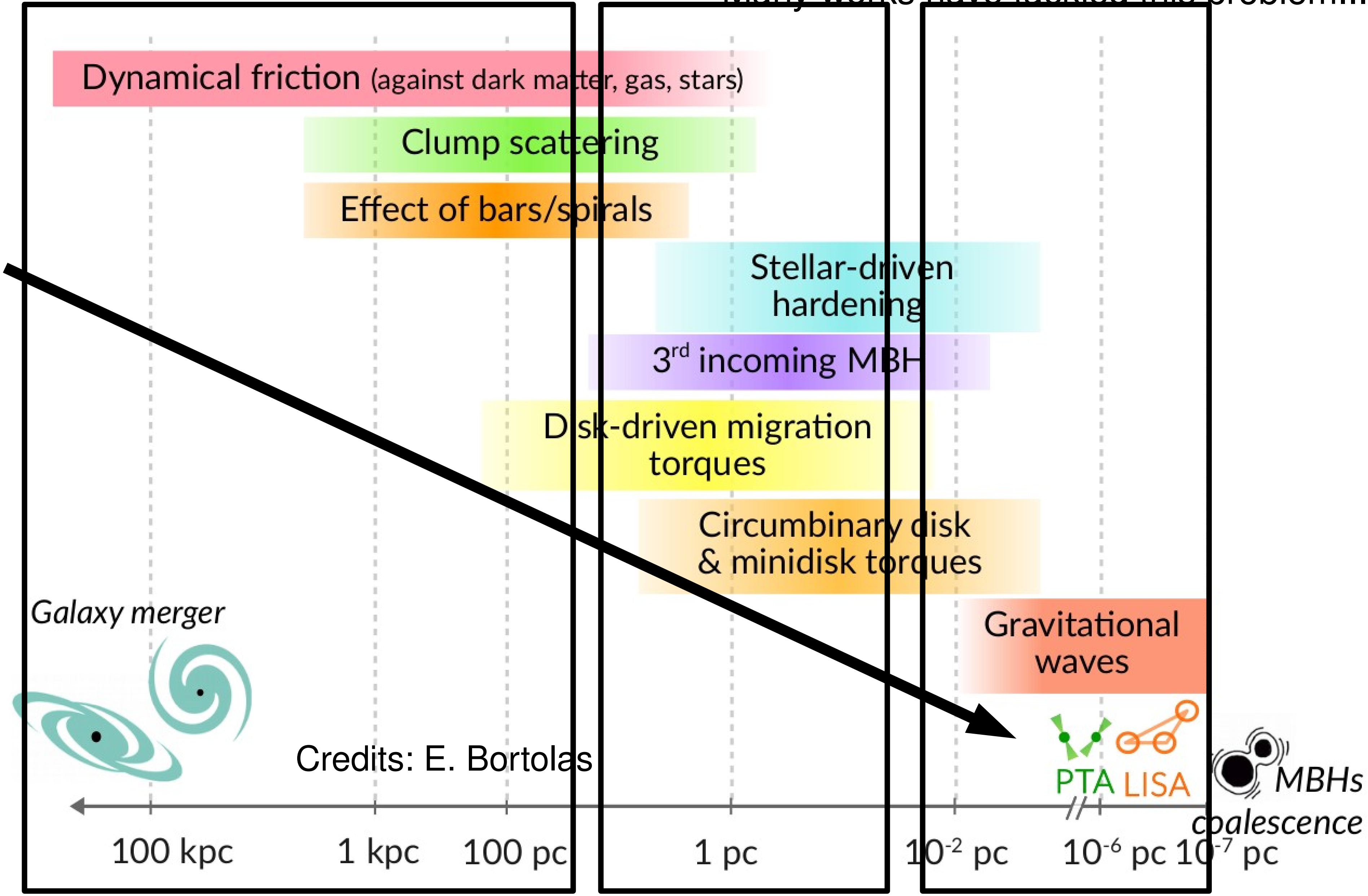

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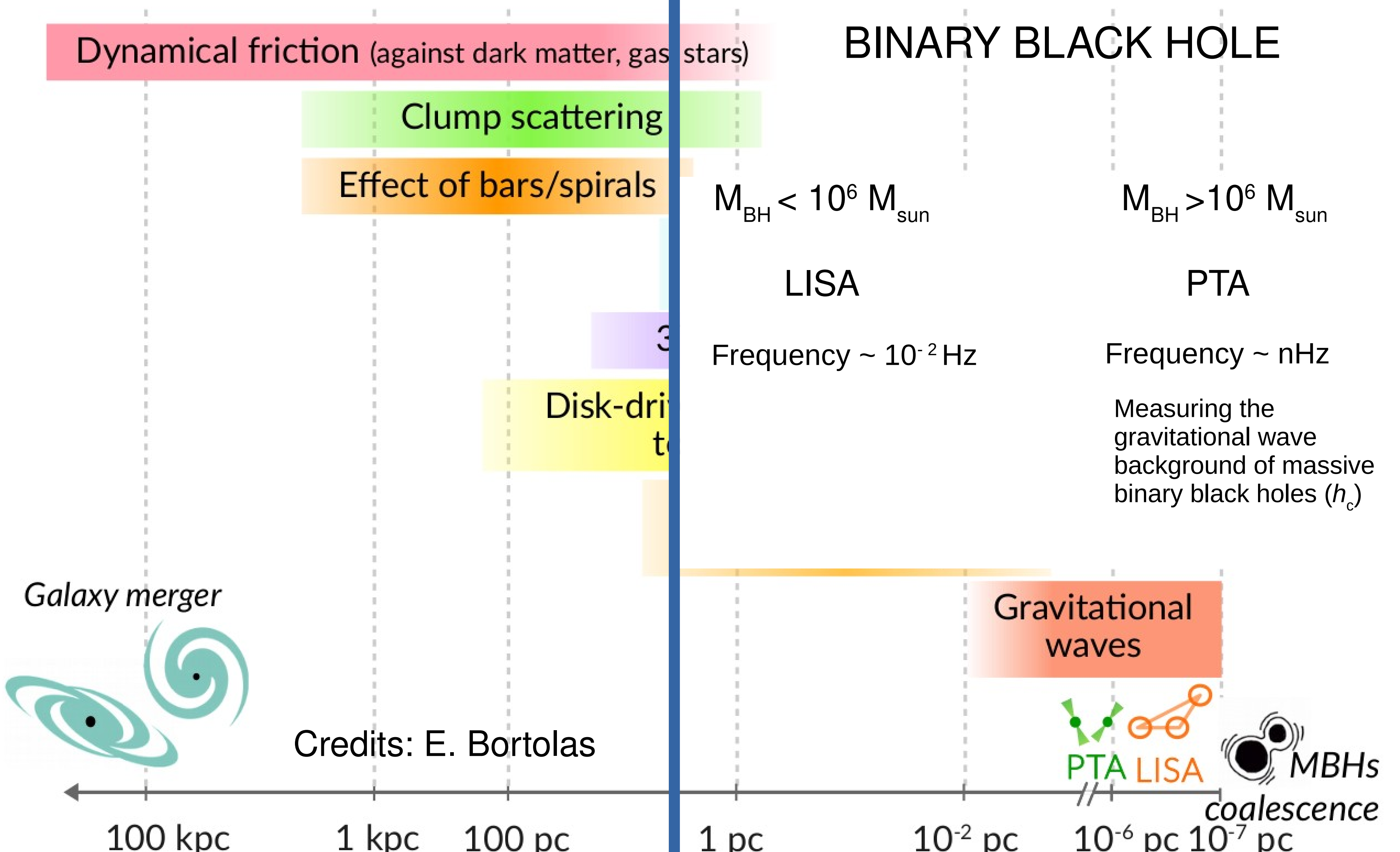
Dynamical friction or pairing phase

Hardening phase

GW phase

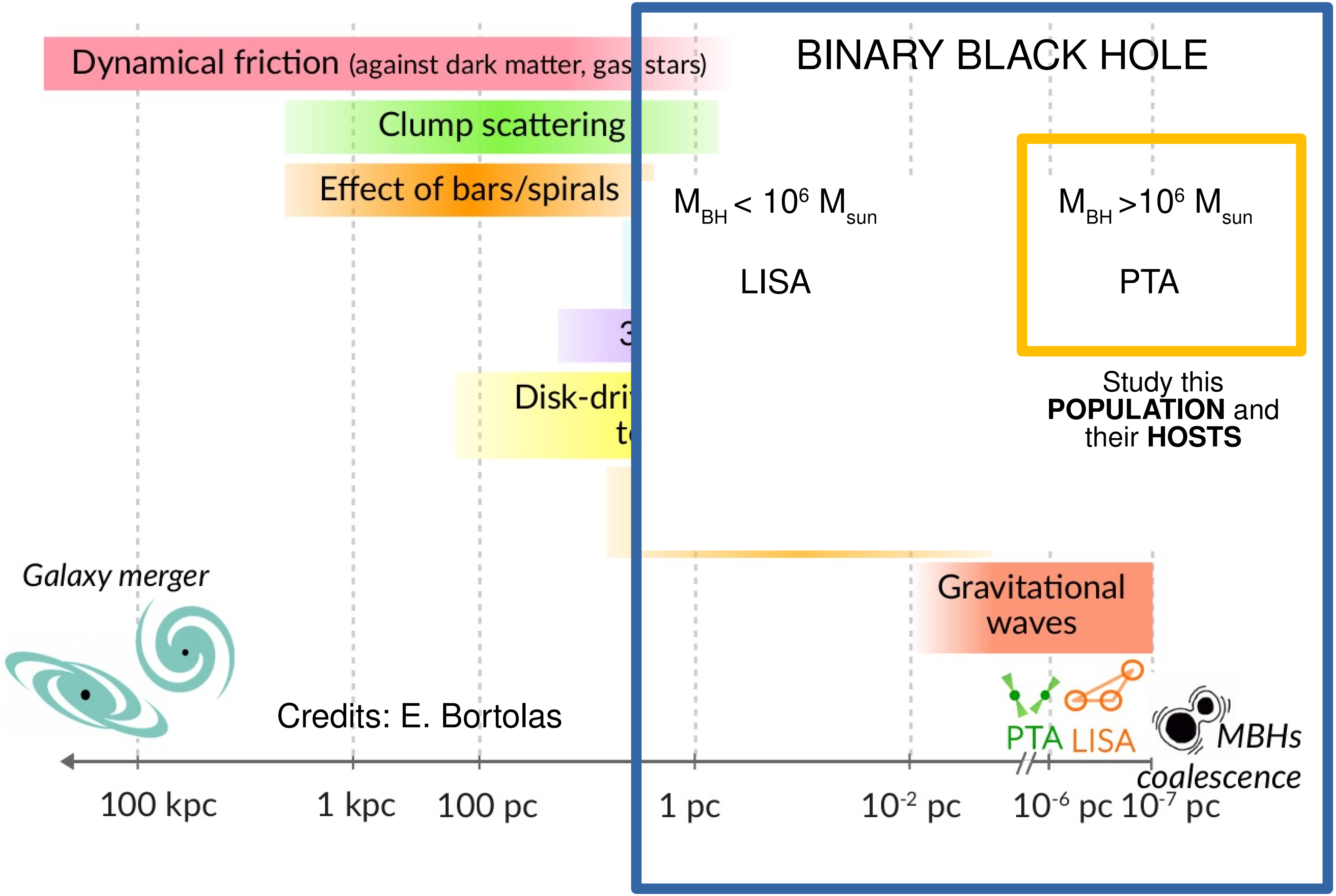
INTRODUCTION



BINARY BLACK HOLE

$M_{BH} < 10^6\ M_{sun}$	$M_{BH} > 10^6\ M_{sun}$
LISA	PTA
Frequency ~ 10^{-2} Hz	Frequency ~ nHz
	Measuring the gravitational wave background of massive binary black holes (h_c)

INTRODUCTION



THE MODEL

In order to study the population and hosts of massive binary black holes ($>10^6$ M_{sun}) we need several ingredients

RELIABLE GALAXY POPULATION

RELIABLE BLACK HOLE POPULATION

MODEL FOR THE BINARY POPULATION

THE MODEL

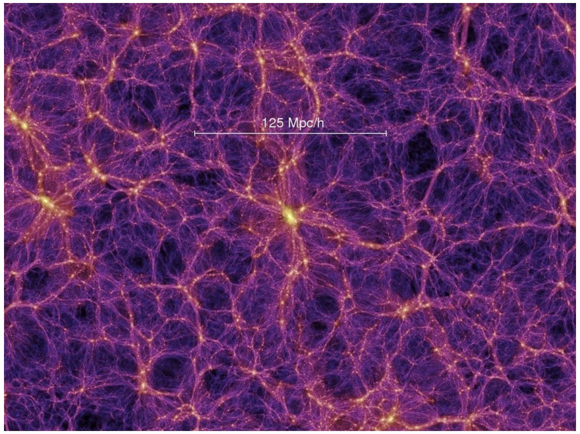
In order to study the population and hosts of massive binary black holes (>10^6 M_{sun}) we need several ingredients

RELIABLE GALAXY POPULATION | RELIABLE BLACK HOLE POPULATION | MODEL FOR THE BINARY POPULATION

1) MILLENNIUM SIMULATION Springel et al. 2005

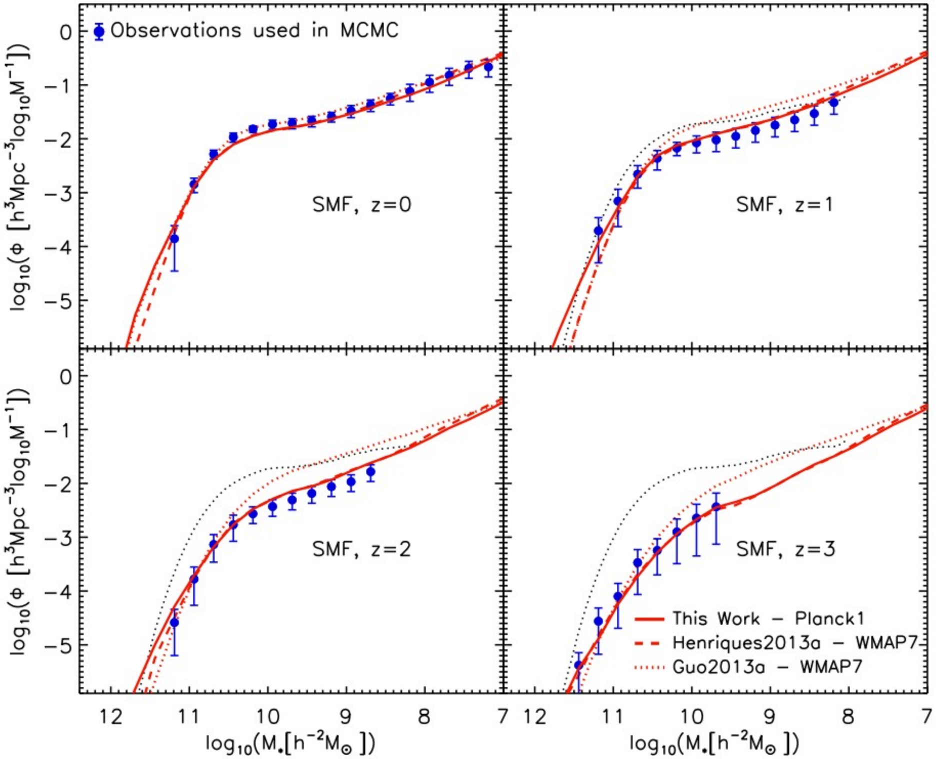
L_{box} = 500 Mpc / *h*

M_{halo} ~ 1.7×10^{10} M_{sun}



Proof of concept

Evolution of the *STELLAR MASS FUNCTION*



Henriques et al. 2015

2) SEMI-ANALYTICAL MODEL

L-Galaxies, Munich Galaxy Formation Model

Guo et al. 2011, Henriques et al. 2015

THE MODEL

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RELIABLE GALAXY POPULATION

RELIABLE BLACK HOLE POPULATION

MODEL FOR THE BINARY POPULATION

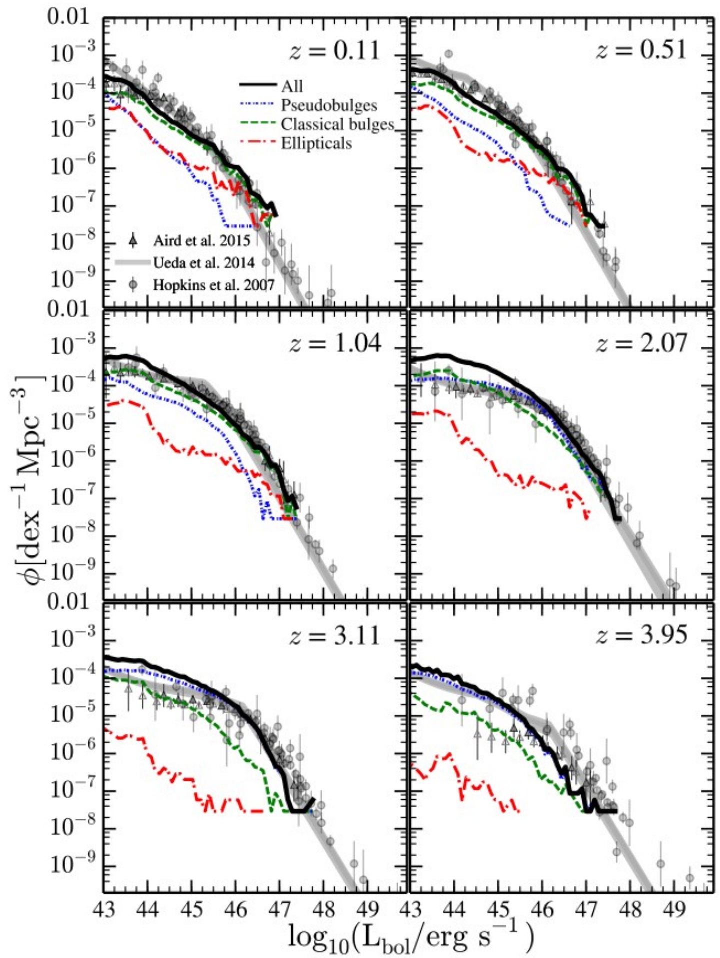
1) MILLENNIUM SIMULATION

2) SEMI-ANALYTICAL MODEL

- Growth → Mergers & Disk instabilities
- Spin evolution → Link with the bulge formation and evolution
- Recoil velocities
- Wandering black holes

Izquierdo-Villalba et al. 2020

Evolution of the *QUASAR BOLOMETRIC LUMINOSITY FUNCTION*



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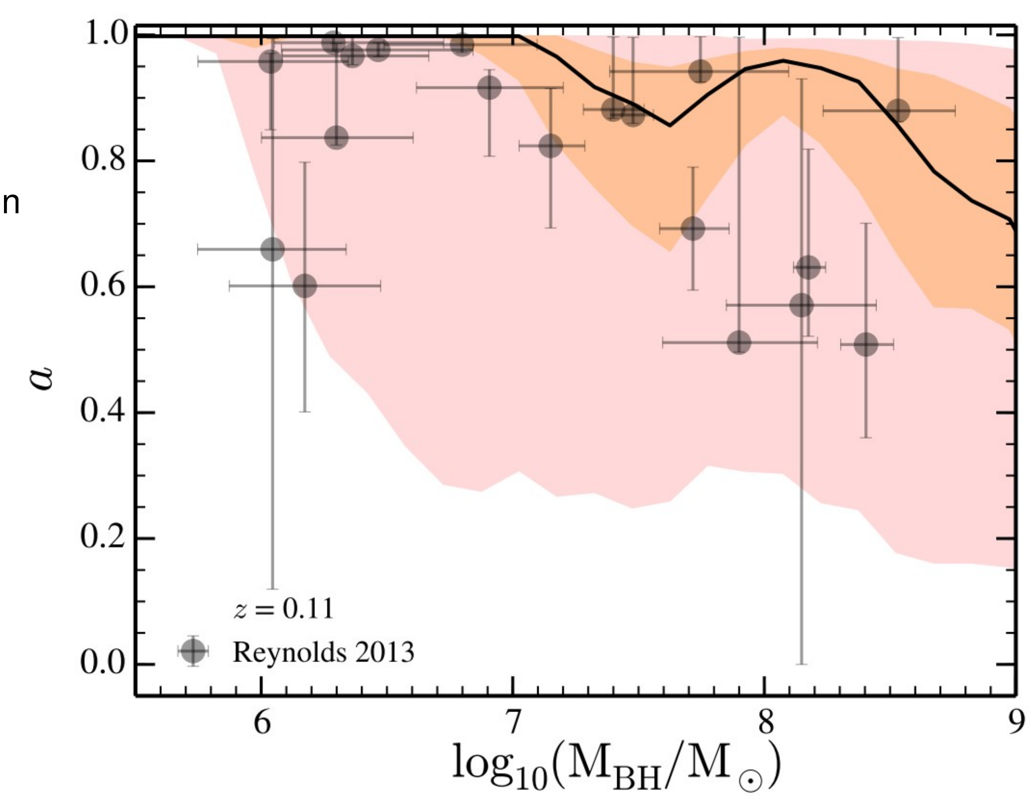
Izquierdo-Villalba et al. 2020

SPIN PARAMETER AT z = 0



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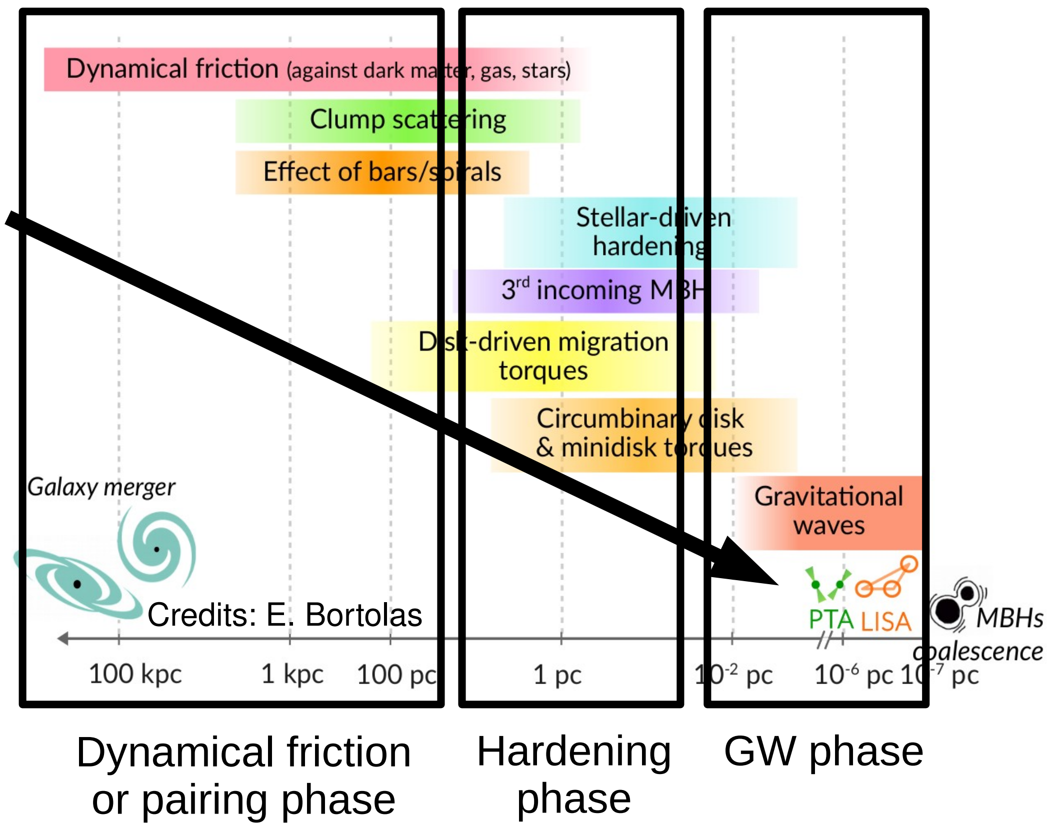
MODEL FOR THE BINARY POPULATION

Here in Milan ...

- Dynamical friction phase
- Hardening/GW phase



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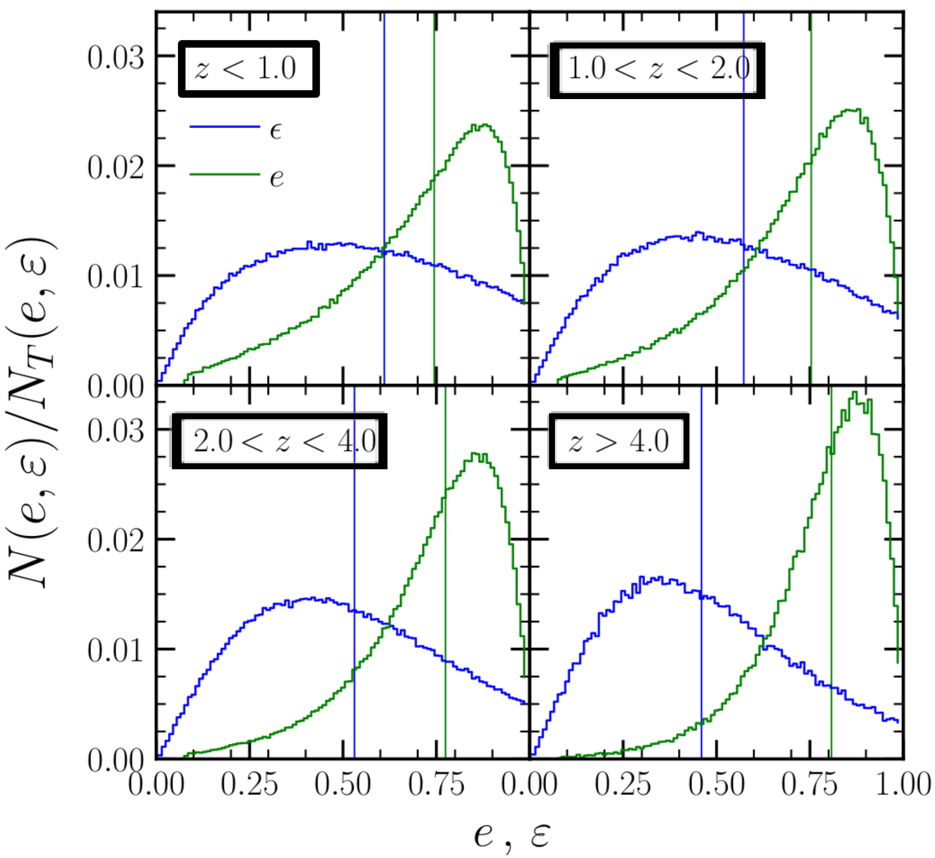
MODEL FOR THE BINARY POPULATION

- Dynamical friction phase

$$t_{\rm dyn}^{\rm BH} = 19\, f(\varepsilon) \left(\frac{r_0}{4\,{\rm kpc}}\right)^2 \left(\frac{\sigma}{200{\rm km/s}}\right) \left(\frac{10^8\,{\rm M}_\odot}{{\rm M}_{\rm BH}}\right) \frac{1}{\Lambda}\,[{\rm Gyr}]$$

CIRCULARITY of the black hole orbit → Computed form the circularity of the **GALAXY ORBIT**



- Hardening/GW phase

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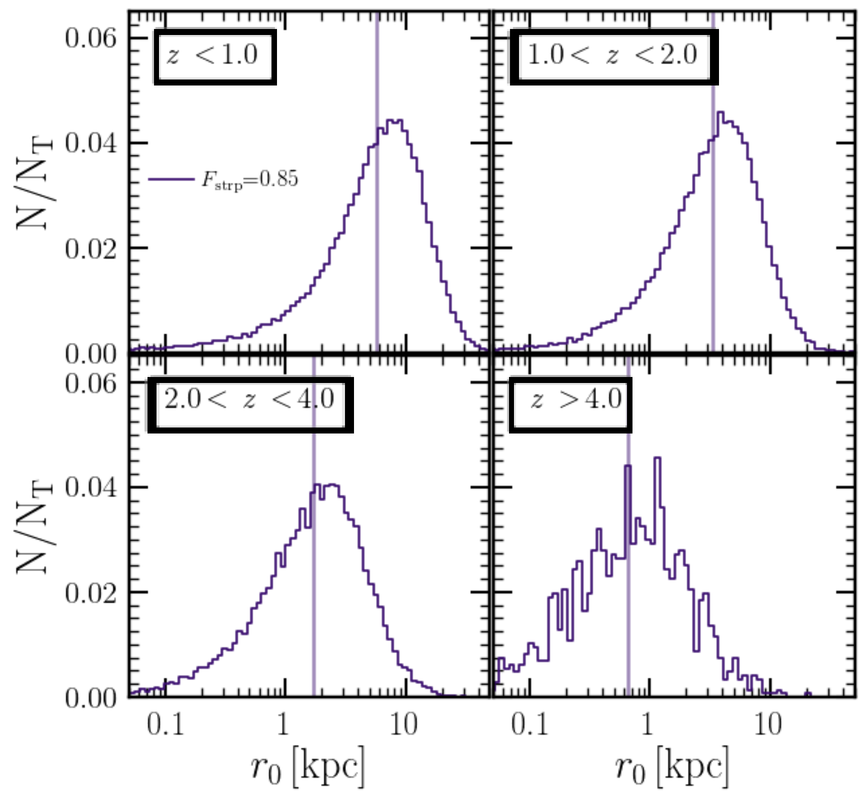
INITIAL POSITION of the black hole → Computed according to the galaxy **TIDAL RADIUS**

$$\frac{d^2\Phi(r)}{dr^2} = \omega^2 - \frac{G\,M_{\rm sat}(<R)}{R^3}$$

- Hardening/GW phase



THE MODEL

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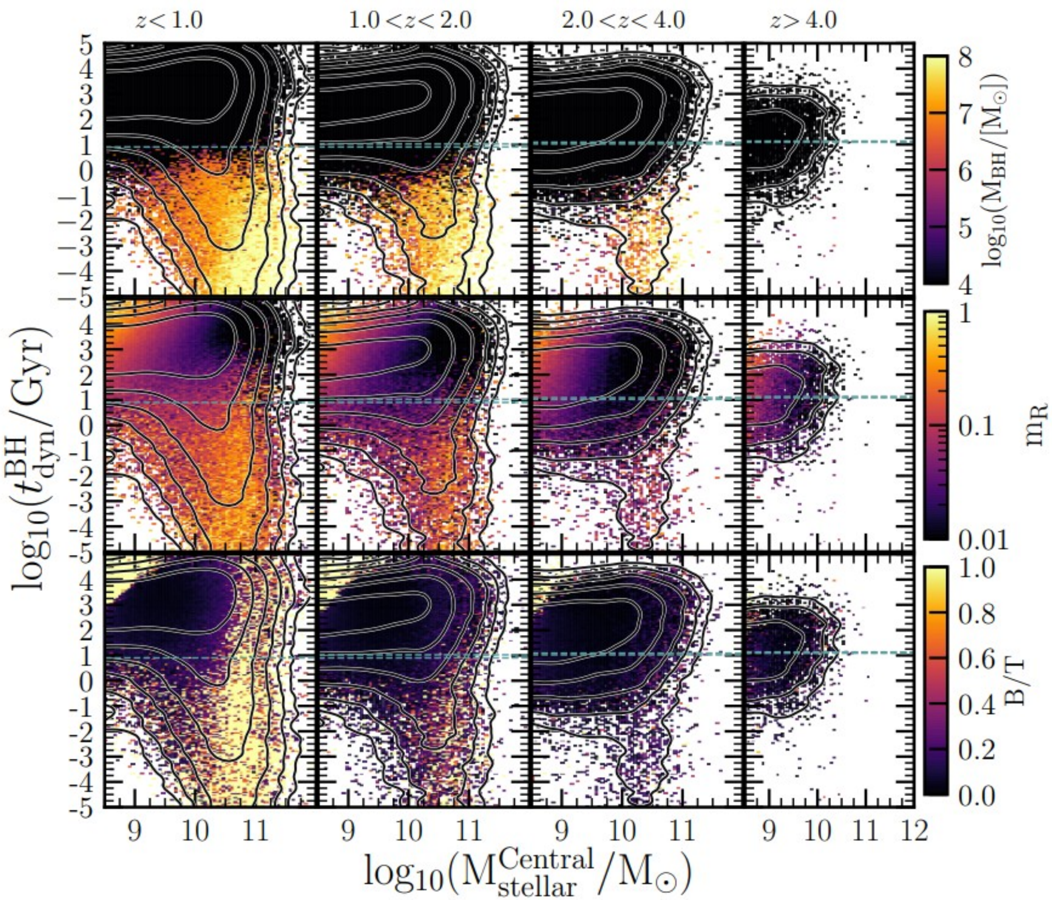
RELIABLE GALAXY POPULATION

RELIABLE BLACK HOLE POPULATION

MODEL FOR THE BINARY POPULATION

REDSHIFT

- Dynamical friction phase



Black hole mass

Baryonic merger ratio

Galaxy morphology

$t_{dyn}^{BH} < t_H$ when:

- Massive black holes (>10^6 M_{sun})
- Large merger rations
- Typically in elliptical galaxies

THE MODEL

In order to study the population and hosts of massive binary black holes (>10^6 M_{sun}) we need several ingredients

RELIABLE GALAXY POPULATION | RELIABLE BLACK HOLE POPULATION | MODEL FOR THE BINARY POPULATION

- Dynamical friction phase

- Hardening/GW phase: We have assumed a **Sércic model profile** $\rho_B(r) = \rho_0 \left(\frac{r}{R_e}\right)^{-p} e^{-b\left(\frac{r}{R_e}\right)^{1/n}}$

Biava et al. 2019

1) Gas rich mergers : Disk torques driven the binary merge

$$\frac{da_{BH}}{dt} = -\frac{2\dot{M}}{\mu}\sqrt{\frac{\delta}{1-e^2}}\, a_{BH}$$

Bonetti et al. 2018

2) Gas poor mergers : The stellar background drives the binary merge Sesana & Khan 2015

$$\frac{da_{BH}}{dt} = \left(\frac{da_{BH}}{dt}\right)_{Hard} + \left(\frac{da_{BH}}{dt}\right)_{GW} = -\frac{GH\rho_{inf}}{\sigma_{inf}} a_{BH}^2 - \frac{64G^3(M_{BH_1}+M_{BH_2})^3 F(e)}{5c^5(1+q)^2 a_{BH}^3}$$

$$\frac{de}{dt} = a_{BH}\frac{G\rho_{inf}HK}{\sigma_{inf}} - \frac{304}{15}\frac{G^3 q(M_{BH_1}+M_{BH_2})^3}{c^5(1+q)^2 a_{BH}^4(1-e^2)^{5/2}}\left(e + \frac{121}{304}e^3\right)$$

a) The initial eccentricity is assumed to be random between [0,1]

b) The initial separation is computed as $M_{Bulge}(<a_0) = 2M_{BH,2}$

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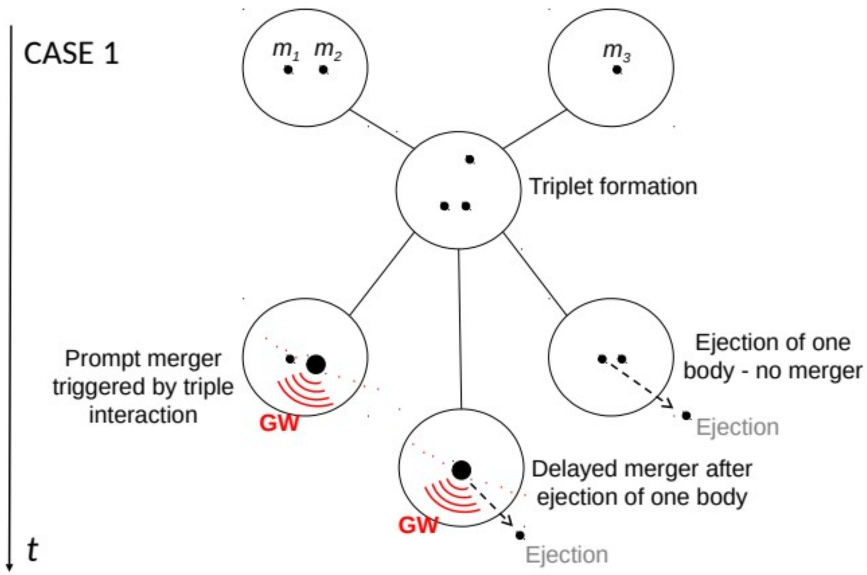
RELIABLE BLACK HOLE POPULATION

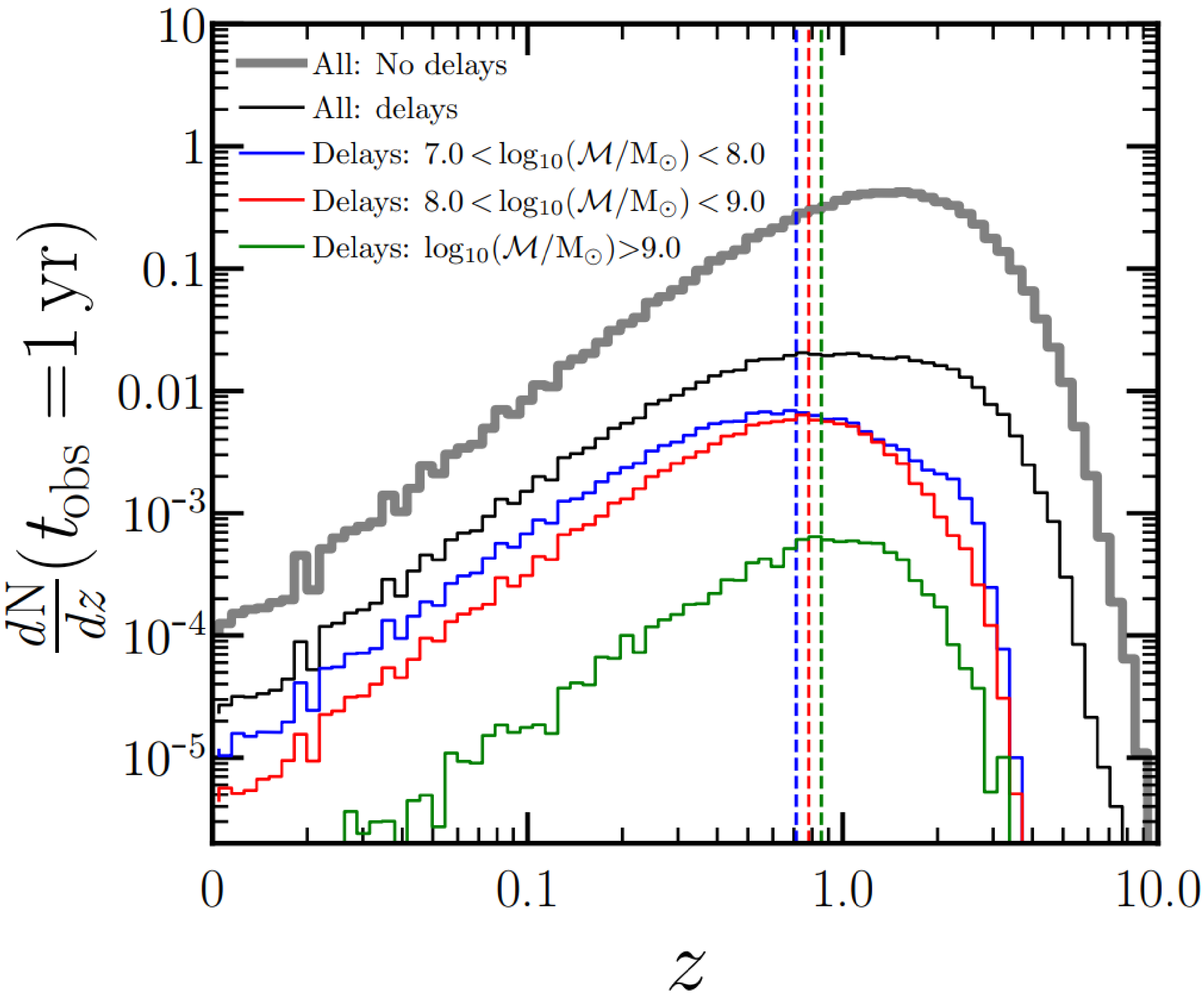
MODEL FOR THE BINARY POPULATION

- Dynamical friction phase
- Hardening/GW phase
- Merger caused by intruder massive black hole (Bonetti et al. 2018)



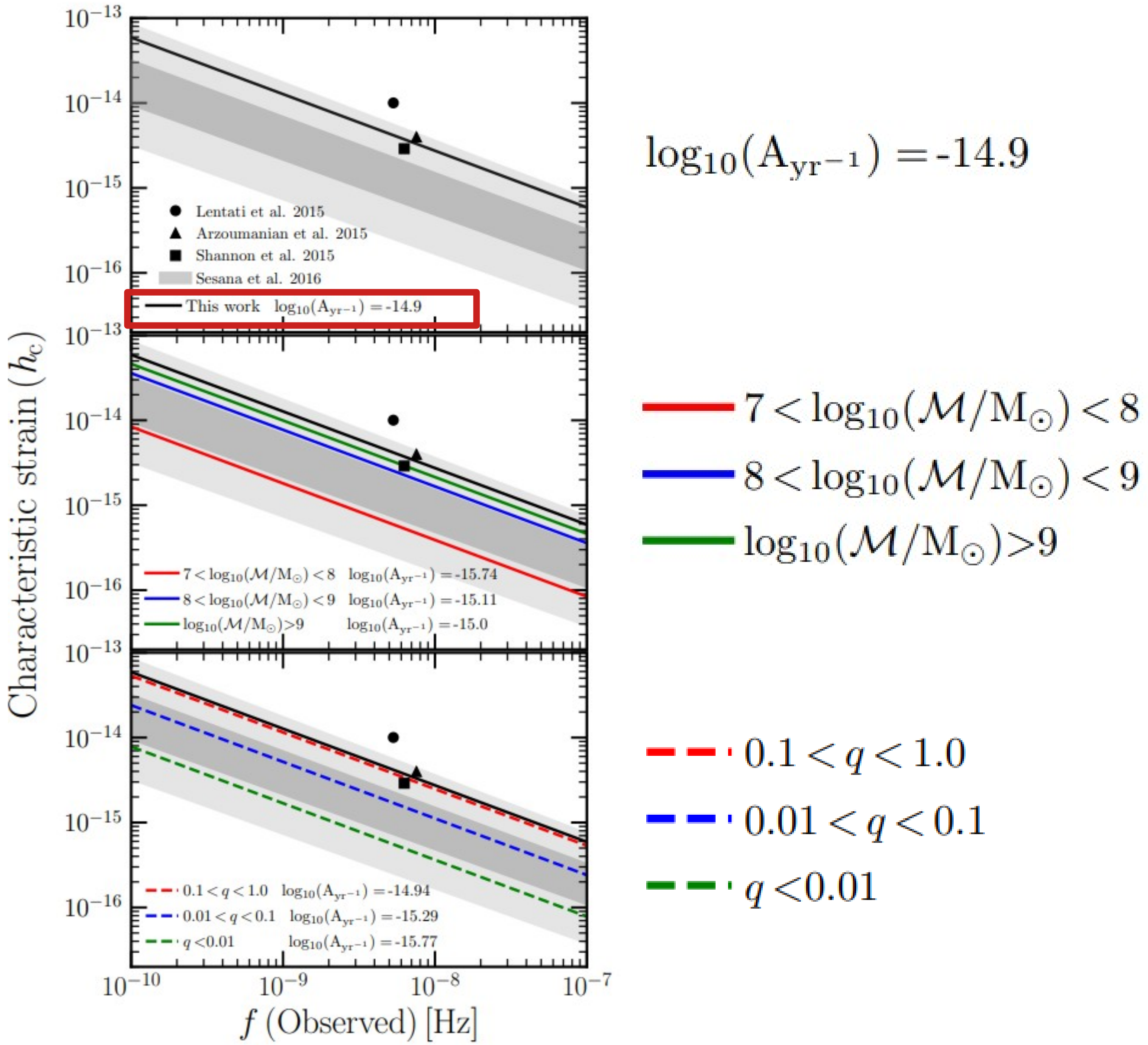
RESULTS

MERGER RATE



RESULTS

AMPLITUDE OF THE GRAVITATIONAL WAVE BACKGROUND IN THE PTA BAND



CONCLUSIONS

* We have tackled the formation and evolution of massive black hole binaries (>10^6 M_{sun}) in the PTA band

  - Dark matter merger trees from N-body simulations
  - Semi-analytical model
  - Proper treatment of the growth and spin evolution

* For galaxies $M_{stellar}$ > 10^9 M_{sun} only black holes >10^6 M_{sun} can reach the nucleus of its central galaxy
  - After baryonic merger with merger ratios > 0.1
  - Seems to have a correlation between the wandering time and the galaxy morphology

* The merger rate of binary black holes of >10^6 M_{sun} is quite low < 0.01 event per year

* The amplitude of the gravitational wave background at nHz is consistent with the expectations AND most of the signal comes form binary black holes merging in elliptical galaxies

* The amplitude of the gravitational wave background at nHz is produced by:
  - Very massive binaries: M_{chirp} > 10^8 M_{sun}
  - Binary merger ratios q > 0.1

THANKS