# FORMATION CHANNELS OF BINARY BLACK HOLES: CLUSTERS *AND* BINARIES?

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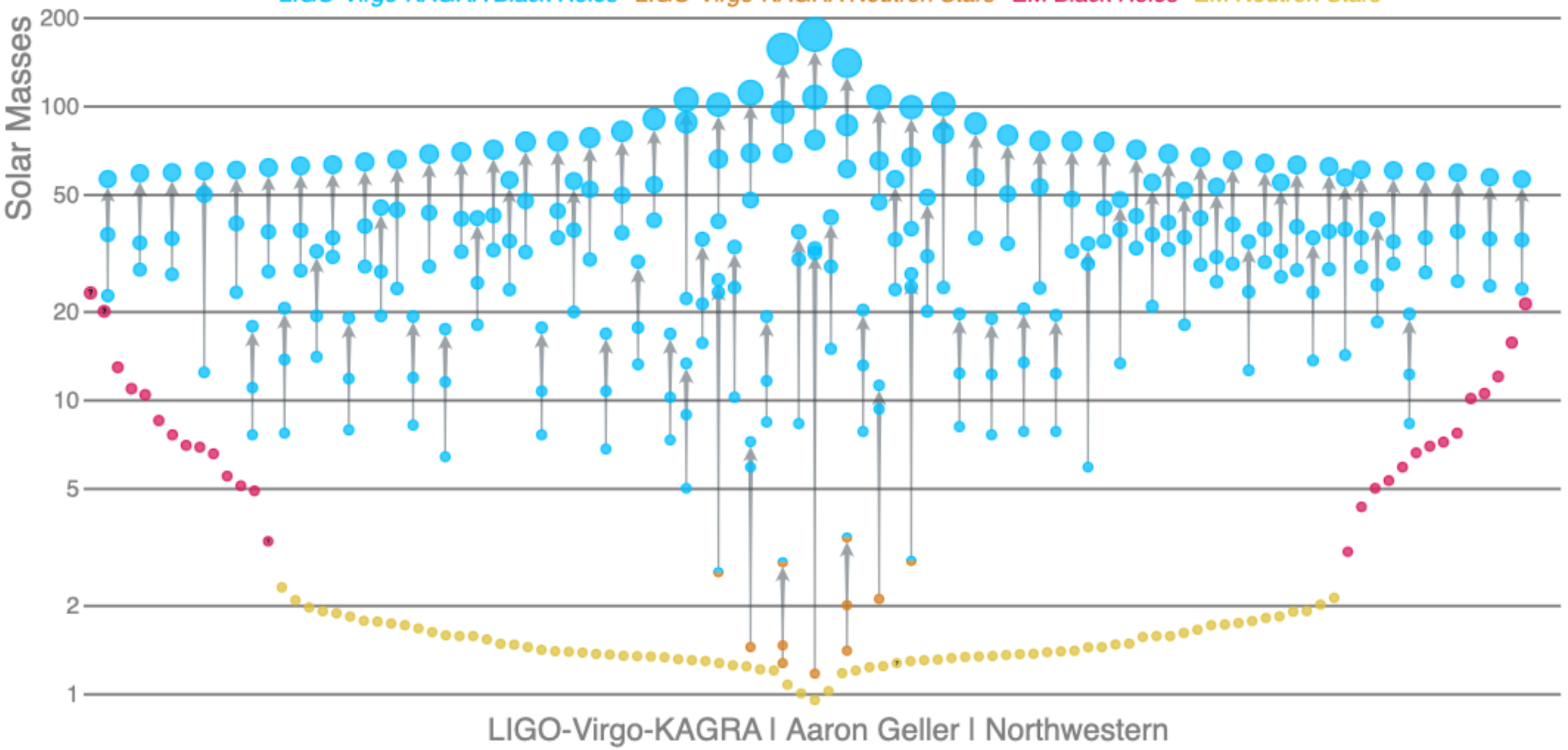
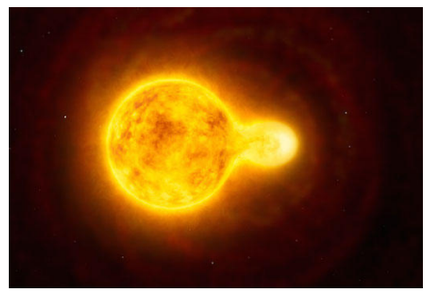
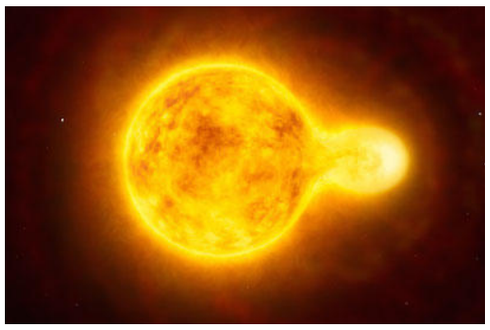
# Masses in the Stellar Graveyard

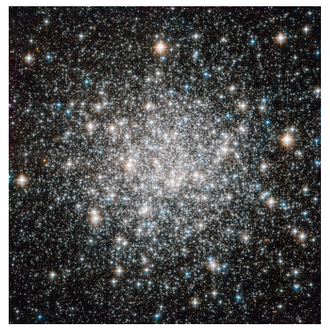



Where do these distributions come from?



# DIFFERENCES (BASED ON MODELS)





higher masses (2nd gen. + low Z)

equal masses preferred  Unequal masses possible

spins aligned

unclear spin amplitude

Isotropic distribution

possibly high spins  (2nd gen)

(often) long time delays

faster mergers possible?

Can explain BBH rate

Explains BNS/NSBH rate

too low BNS/NSBH rate

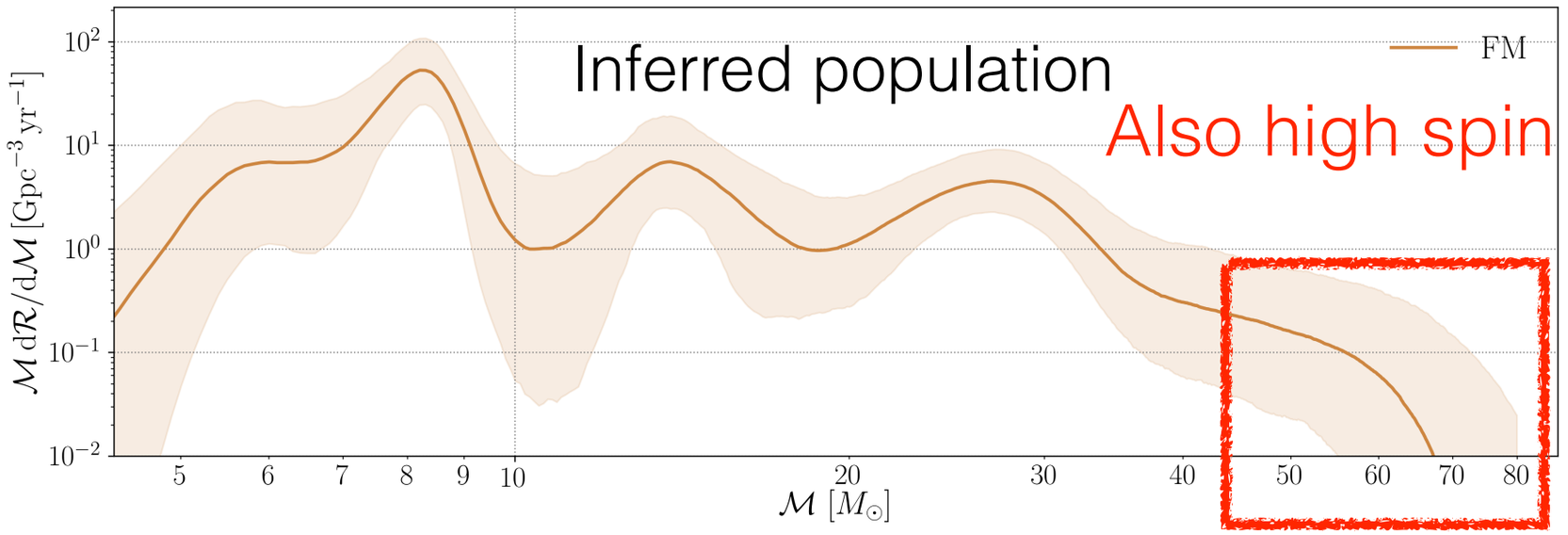
steeper redshift evolution?

Possibly detectable eccentricity?

# DATA PREFERS AT LEAST TWO CHANNELS

High mass BHs challenge binary formation (e.g GW190521)

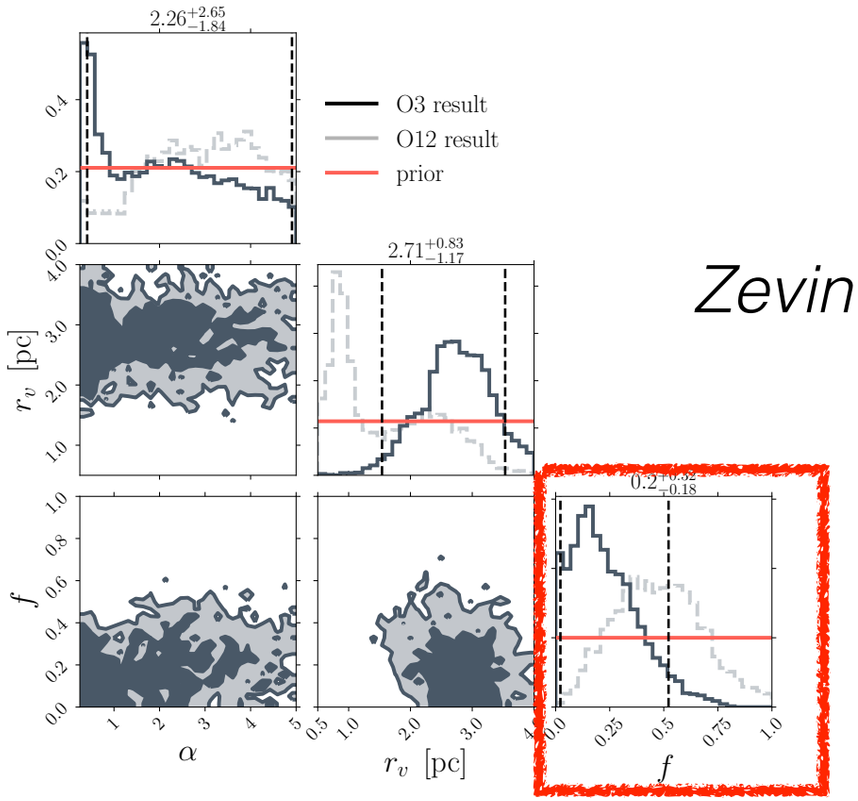
Spins suggest 2 populations




*LVC: GWTC-3 populations paper based on O3a*

« Simple » astro modes:
at least two merger channels
(*Zevin+20, Wong+20, Kimball+20, Bouffanais+21*)

More data -> need for better models

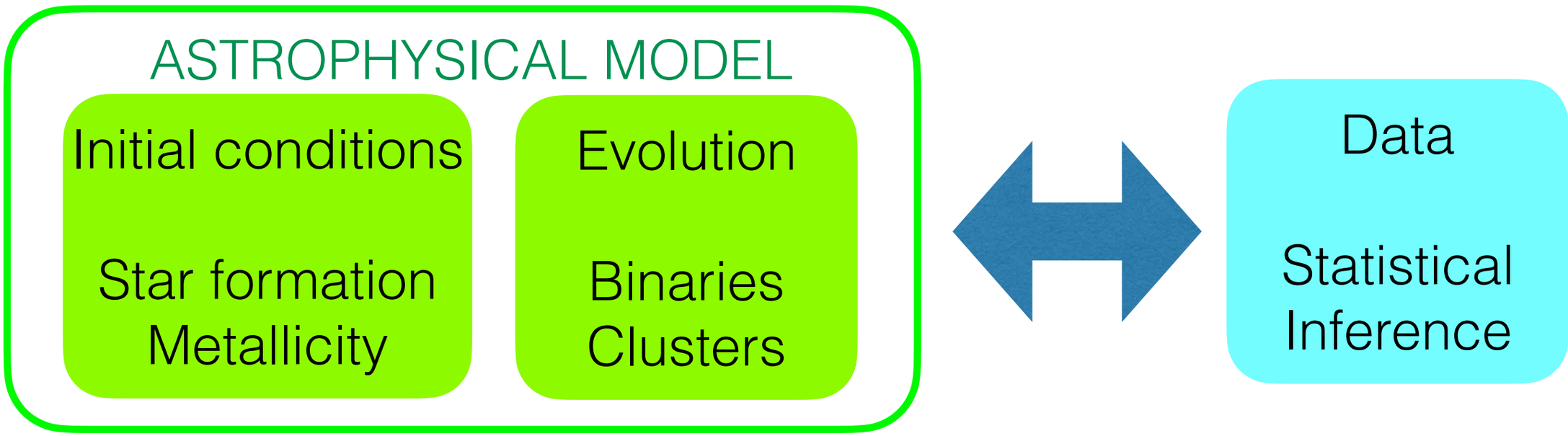



*Zevin+20*

# MODELLING GW POPULATIONS

Models of formation channels should:

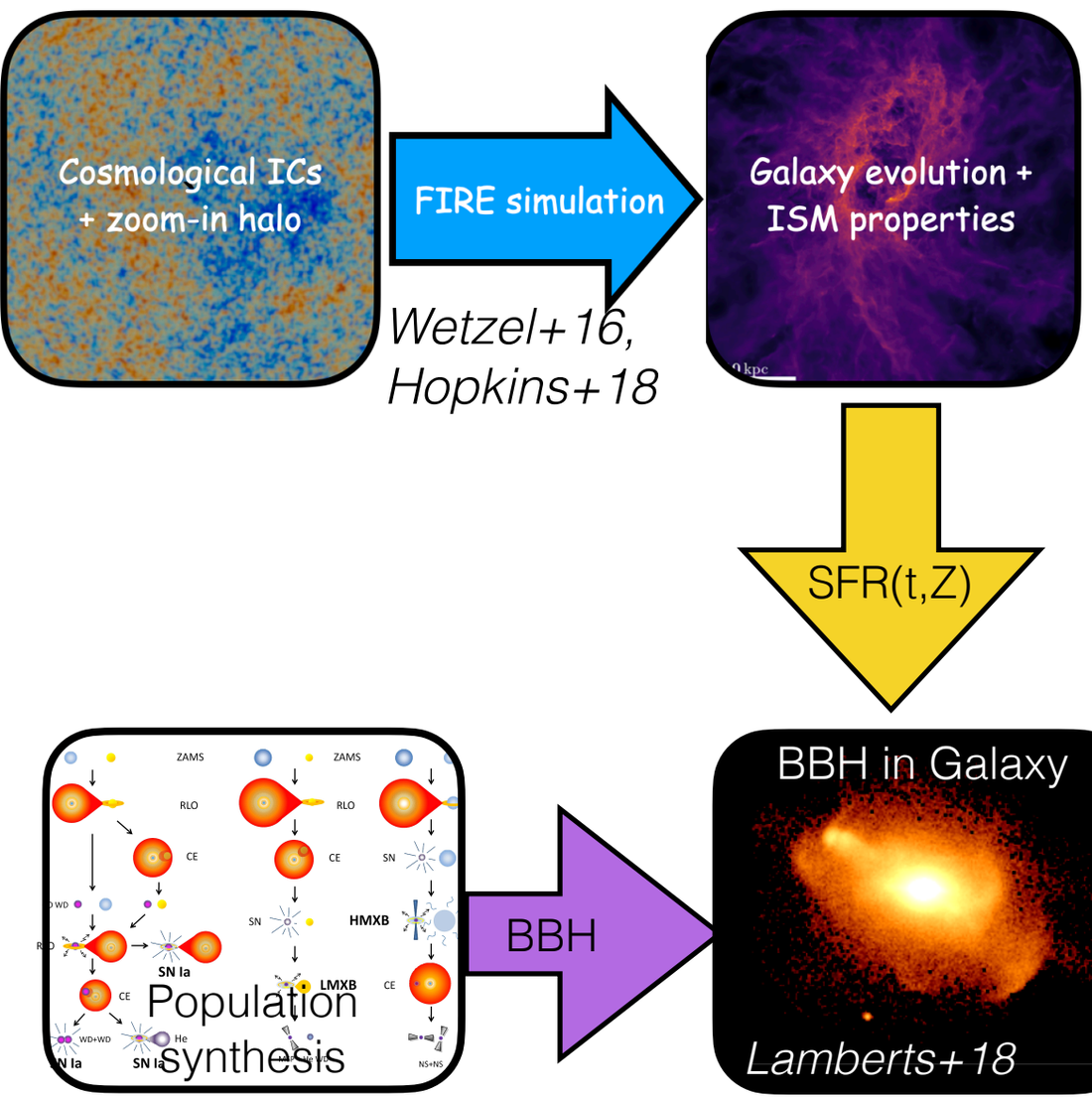
- Be consistent (e.g: supernovae & wind physics)
- Account for complex star formation




Binary models: ok with star formation models
Cluster models: simple models so far (formation times? Mass profiles? Metallicities?)

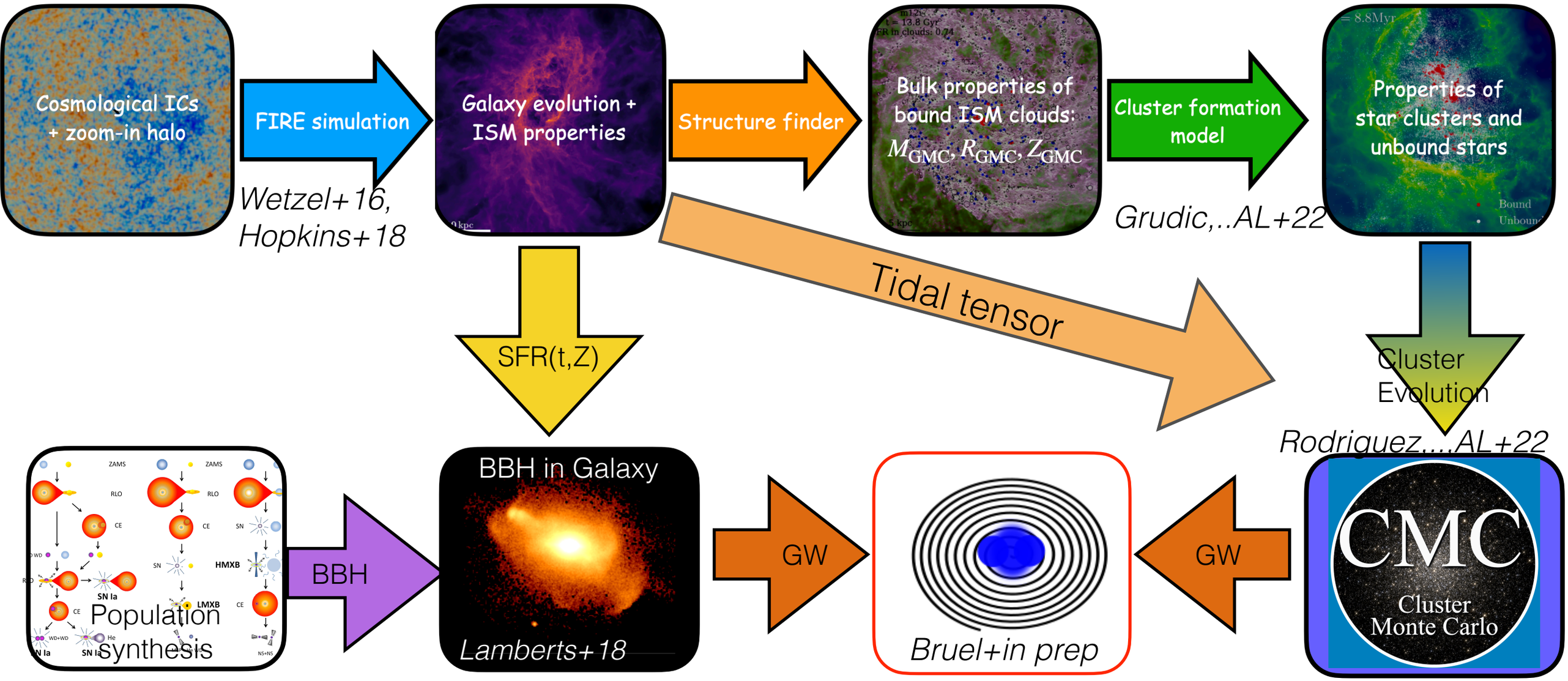
**Project goal: improved models to interpret/predict GWs**

# GROWING COMPACT BINARIES IN GALAXIES



# GROWING COMPACT BINARIES IN GALAXIES

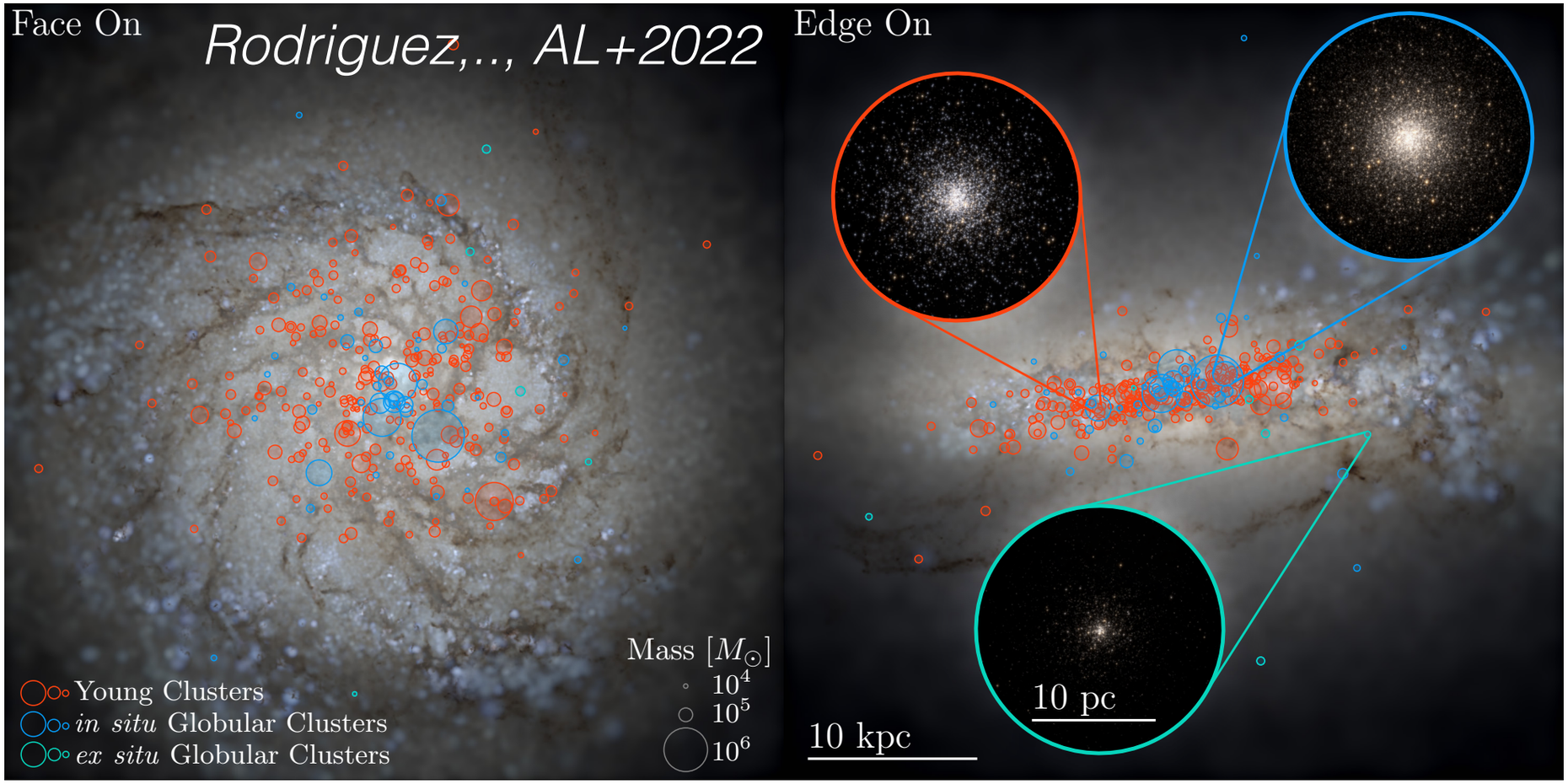
*In clusters*



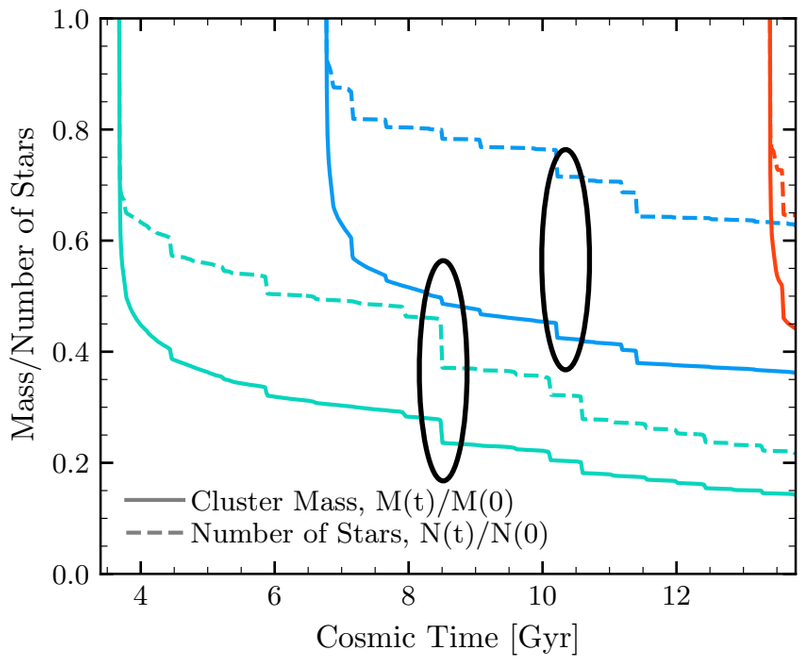

**A first consistent population from binaries and clusters**

PhD project Tristan Bruel, range of galaxy masses

# CLUSTERS IN A REALISTIC ENVIRONMENT

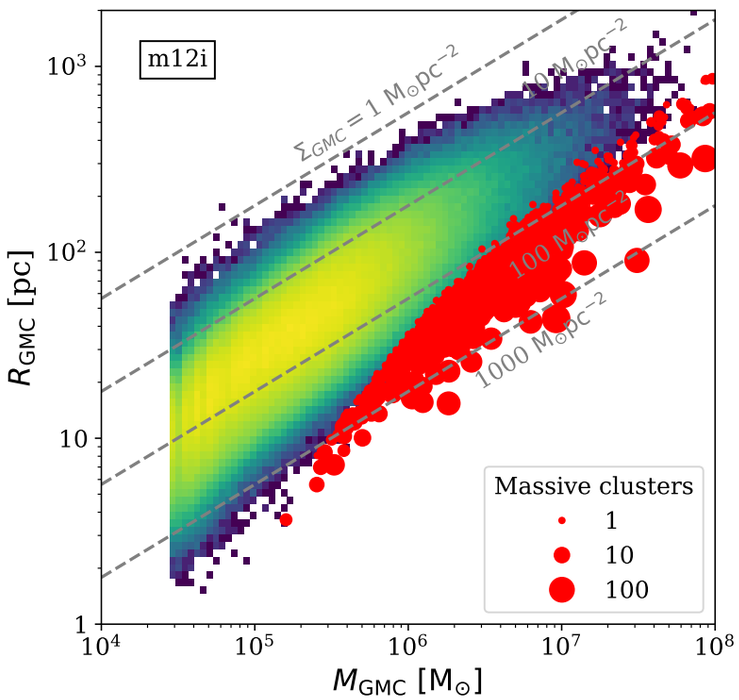



Tidal forces -> disc crossings -> stripping
-> more realistic population

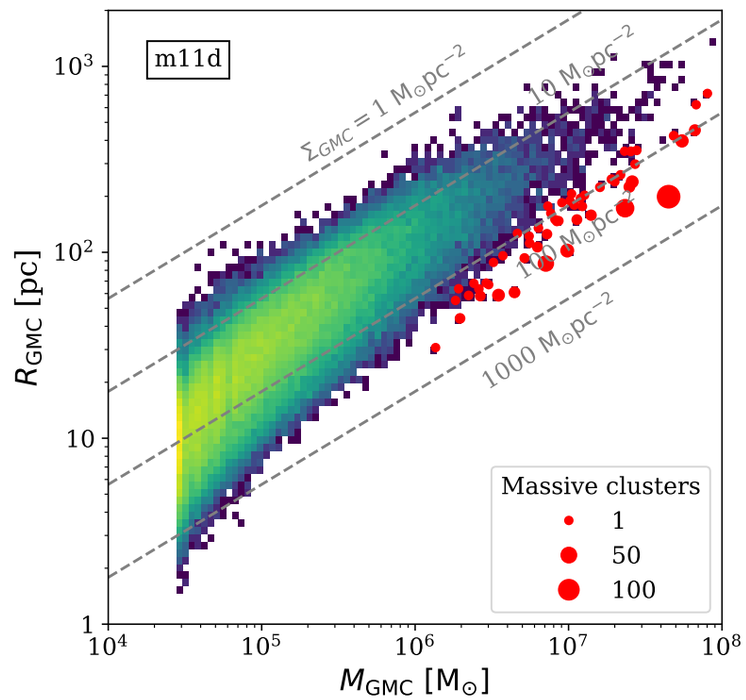


# CLUSTERS FROM THE DENSEST CLOUDS

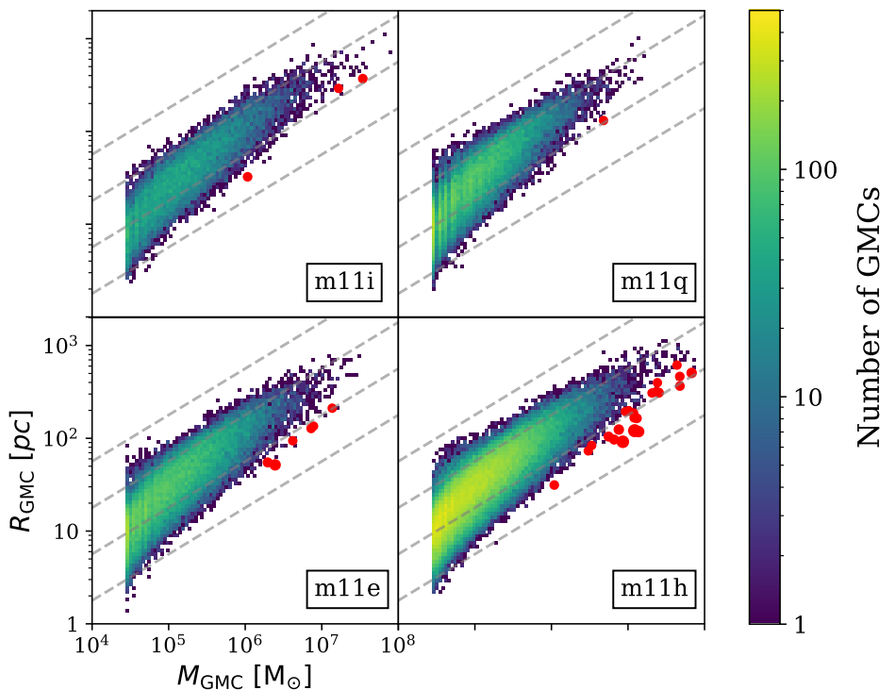
## MW-like galaxy




## ~ LMC



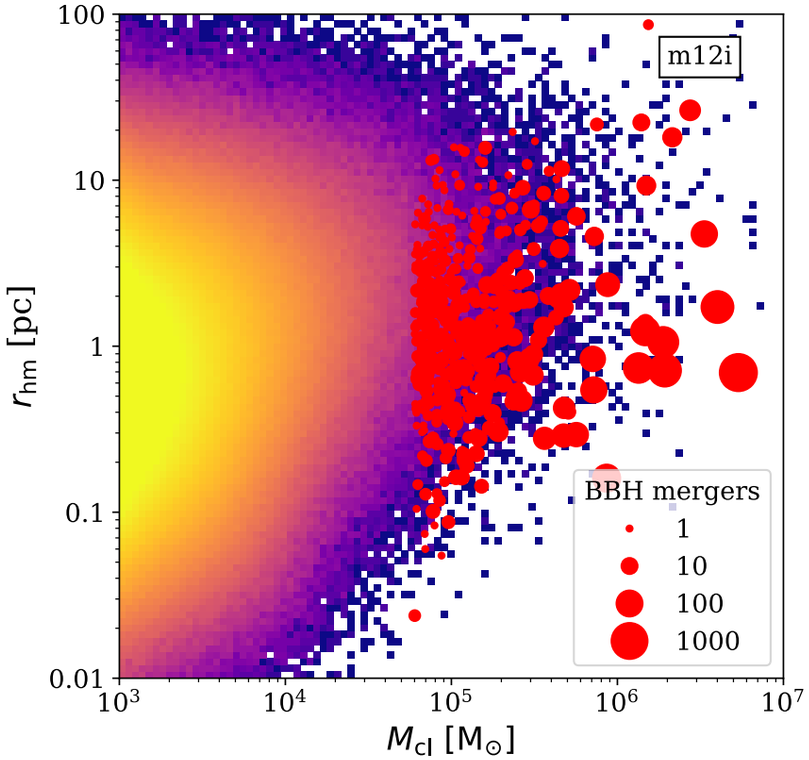

## Smaller dwarfs

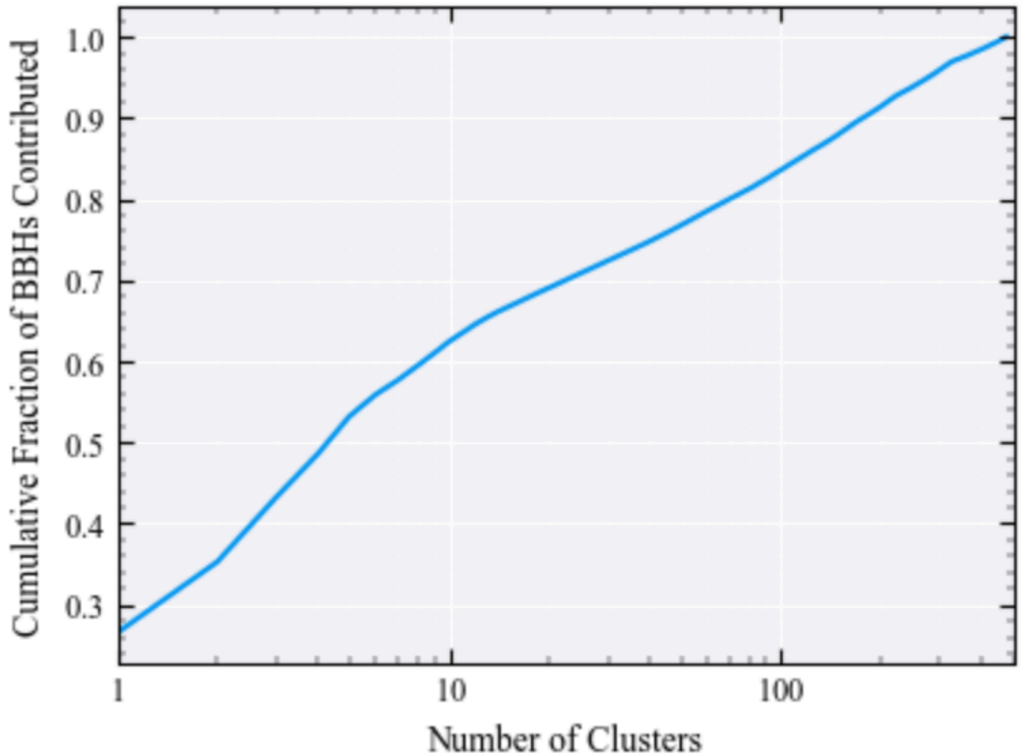



BBH-forming clusters come from the densest (and most massive) clouds

->many clusters in massive galaxies
->important scatter in dwarfs
-> no contribution expected from small dwarfs

# MERGERS DOMINATED BY MOST MASSIVE CLUSTERS

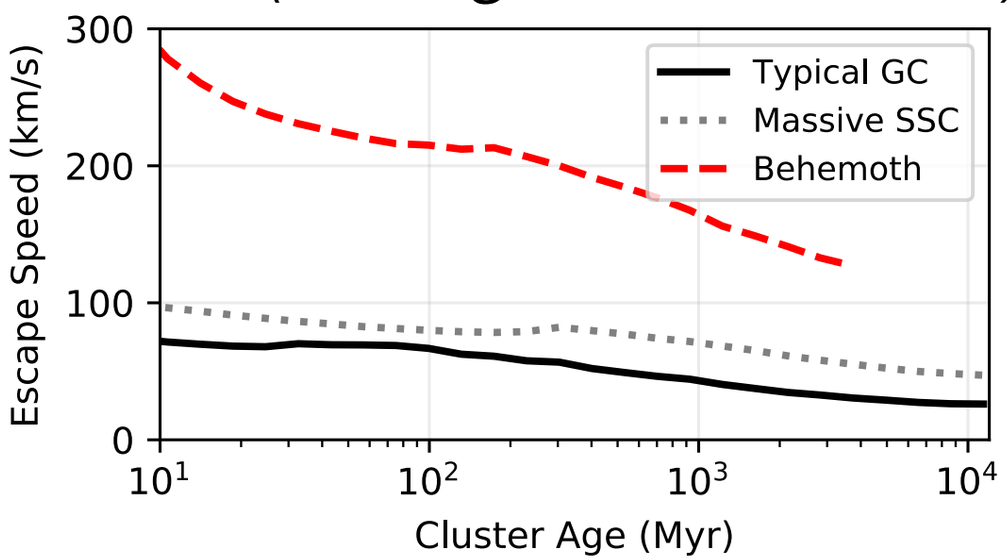


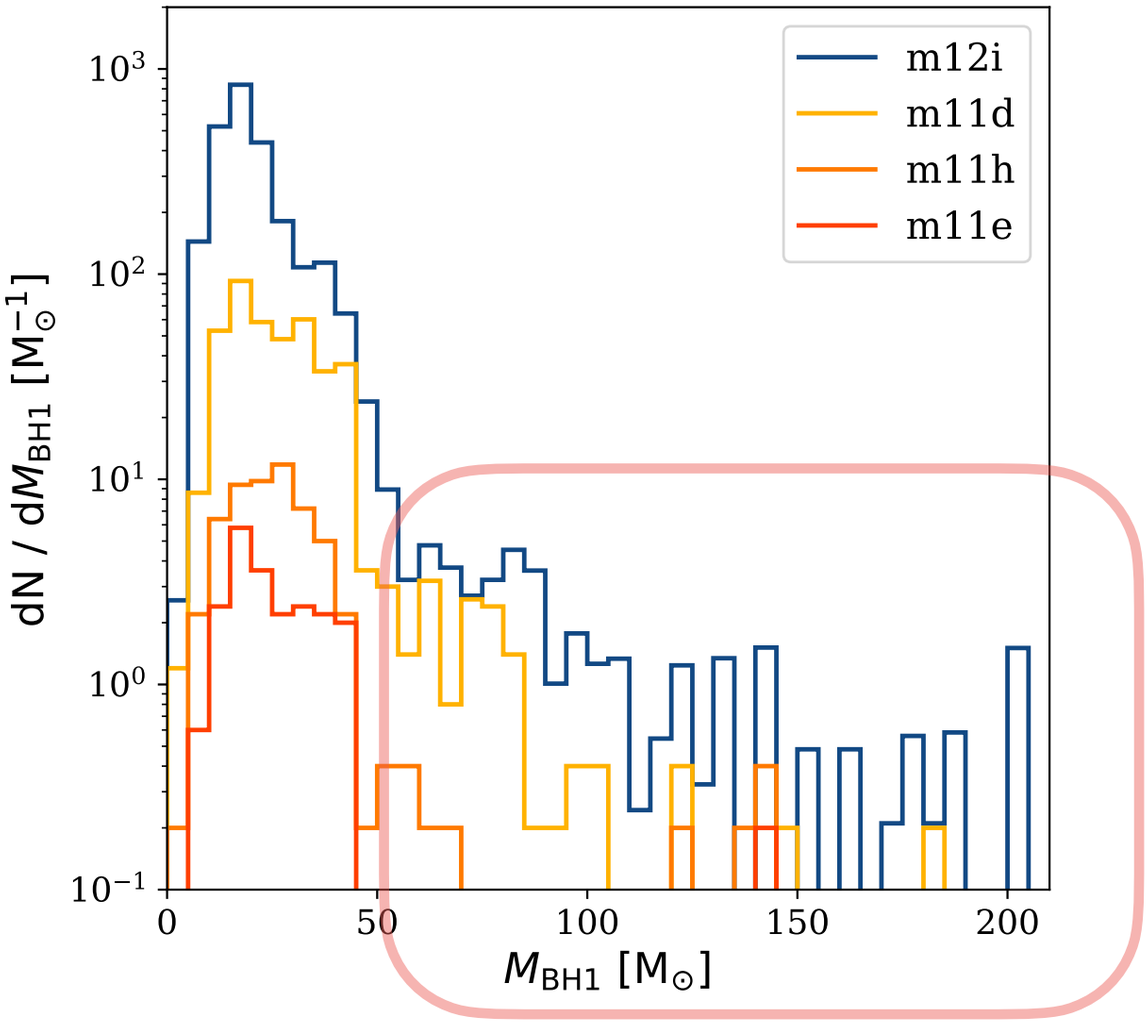

*(Rodriguez,…, AL+20)*

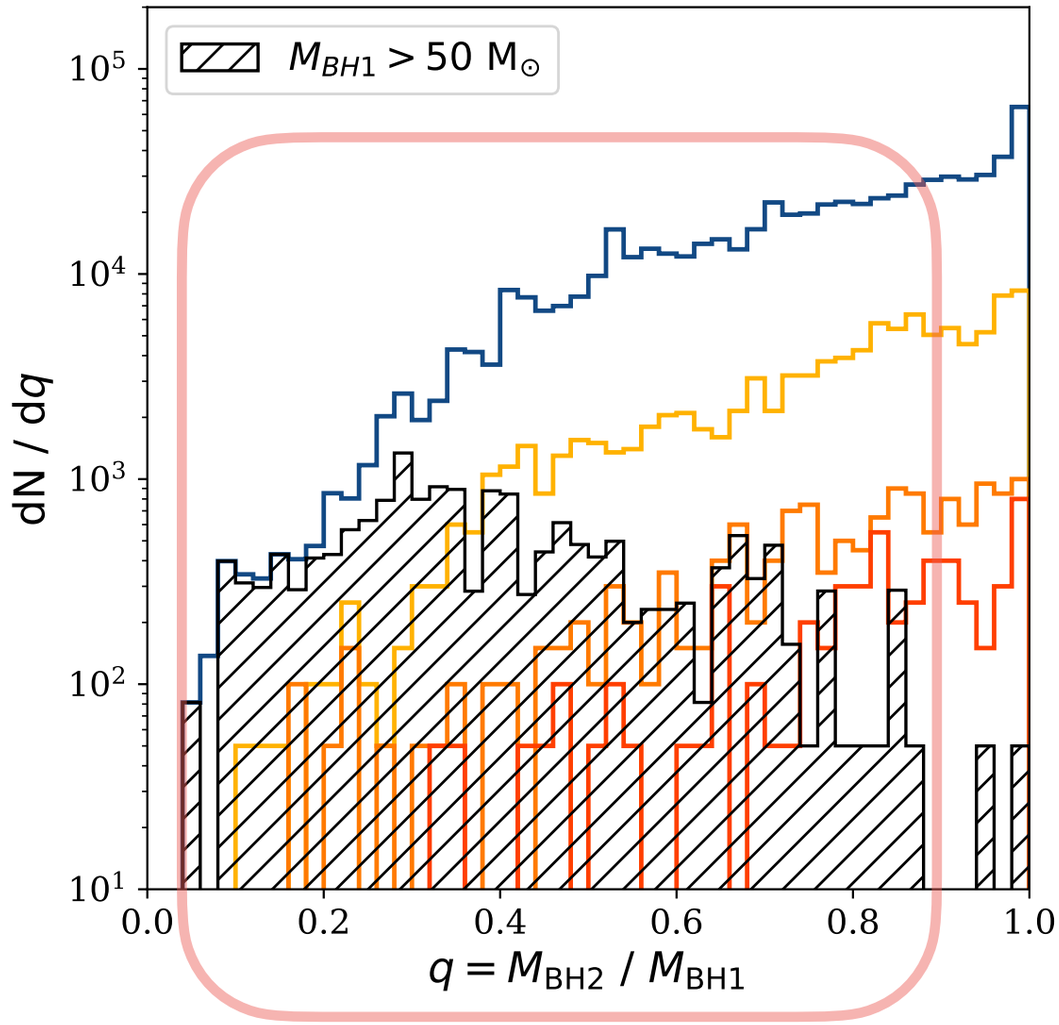
50% of mergers in  4 clusters

- Correlation with most extreme clouds
- Large escape speed -> several generations
- Not found in « simple » models



# MERGING BBHS FROM CLUSTERS




->formation of massive BBH mergers (not expected in binaries)
-> distribution of wide range of mass ratios
-> several generations in most massive clusters
->GW190412 (29.7+8.4 Msun): asymmetric merger -> naturally present

# WHERE DO BLACK HOLE MERGERS COME FROM?

GWTC-3 O(100) events
O4 observations ongoing: O(300) events

Need for consistent astrophysical models

Origin of mergers?

Binaries or clusters?

Environment?

Stellar evolution?

First consistent model of BBH mergers in clusters in different types of galaxies (Bruel et al, to be submitted soon)

Diversity of conditions of star formation matters, even more for clusters than binaries

Next? Cosmological  merger rates
Connection to galaxy mergers
Stochastic background estimates (w. Irina Dvorkin, thanks PNHE!)
Interpretation of O4 events (postdoc Shanika Galaudage)