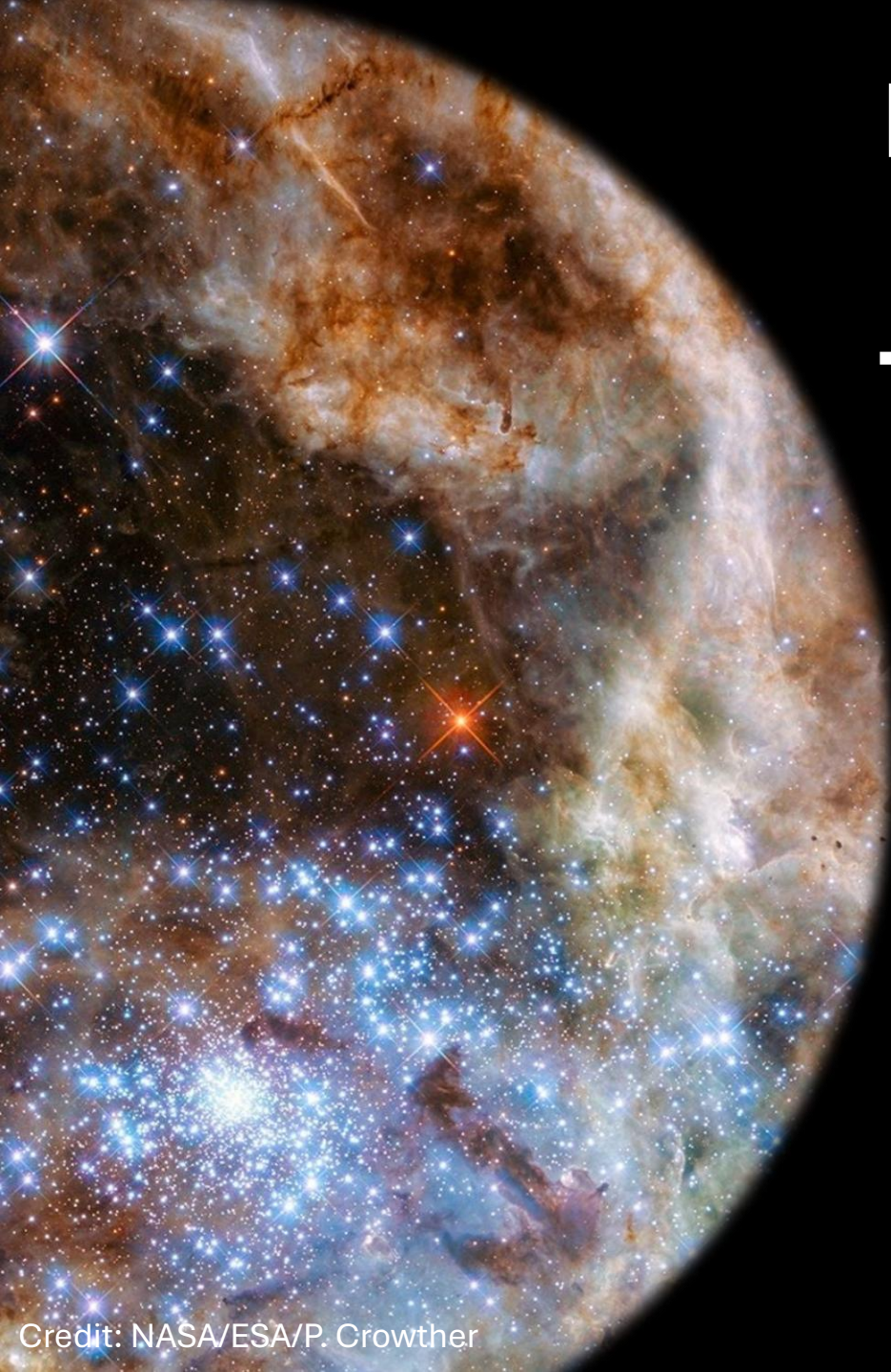




# Building up an intermediate mass black hole: The role of stellar collisions

Filippo Simonato

PhD Student

Supervisors:

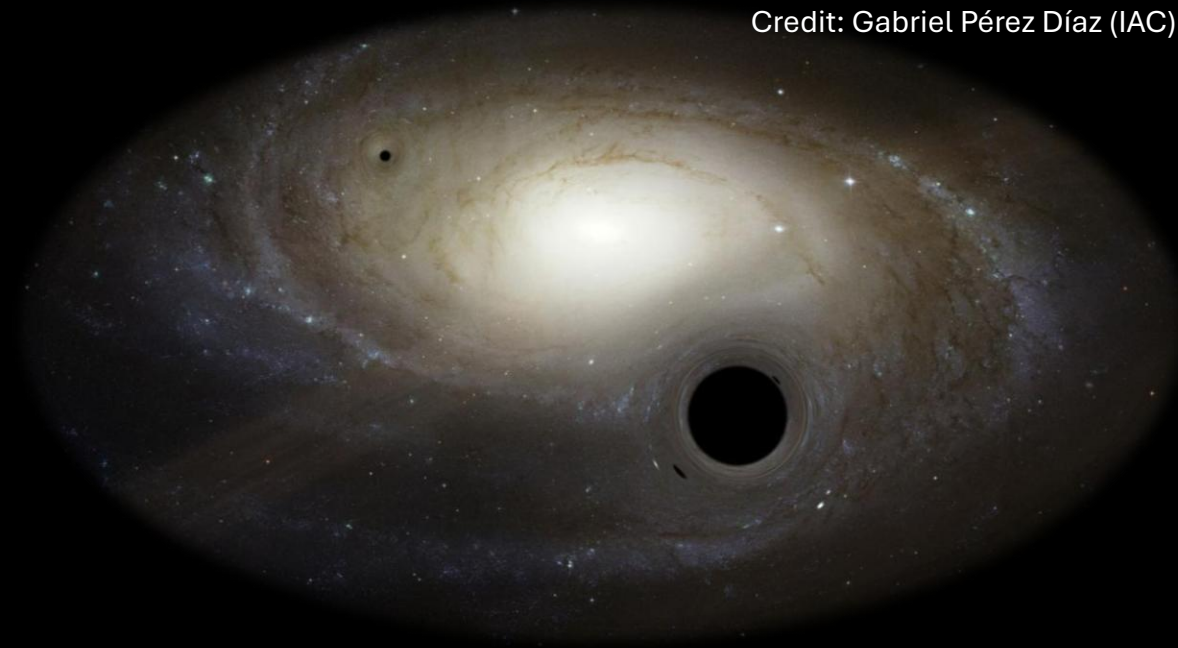
Manuel Arca Sedda,  
Marica Branchesi,  
Gor Oganessian

Collaborators:

Cristiano Ugolini, Lavinia  
Paiella, Benedetta Mestichelli,  
Taeho Ryu, Jakub Klencki,  
Giuliano Iorio, Sara Rastello



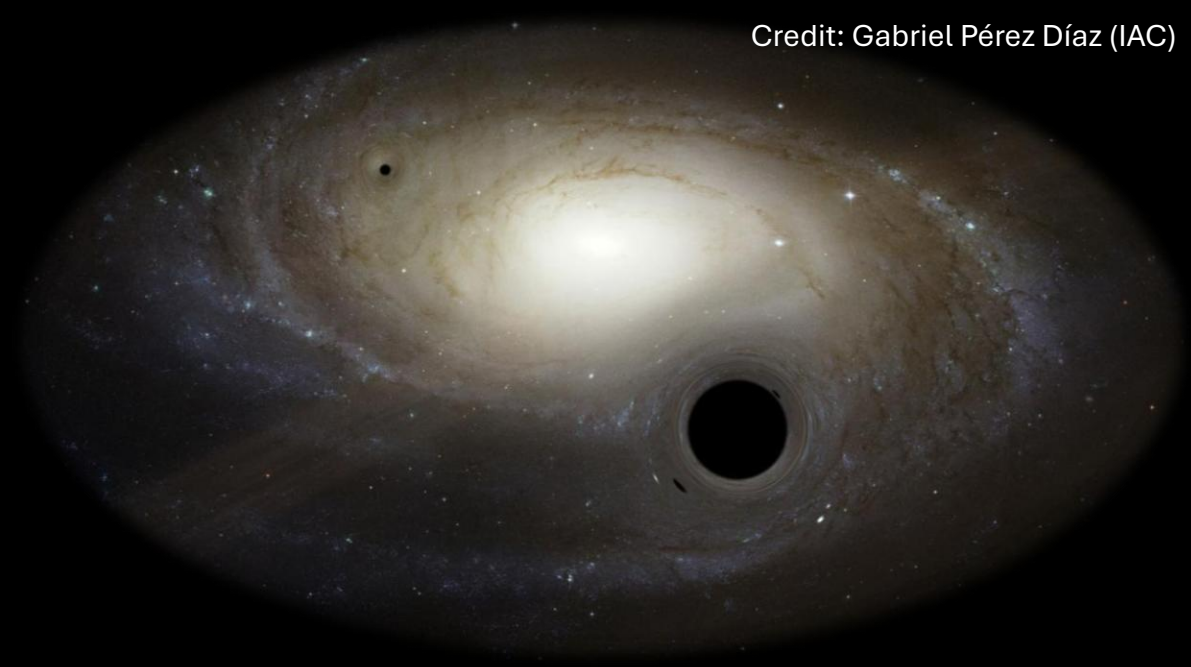
By definition...



By definition...

Intermediate-mass black holes:

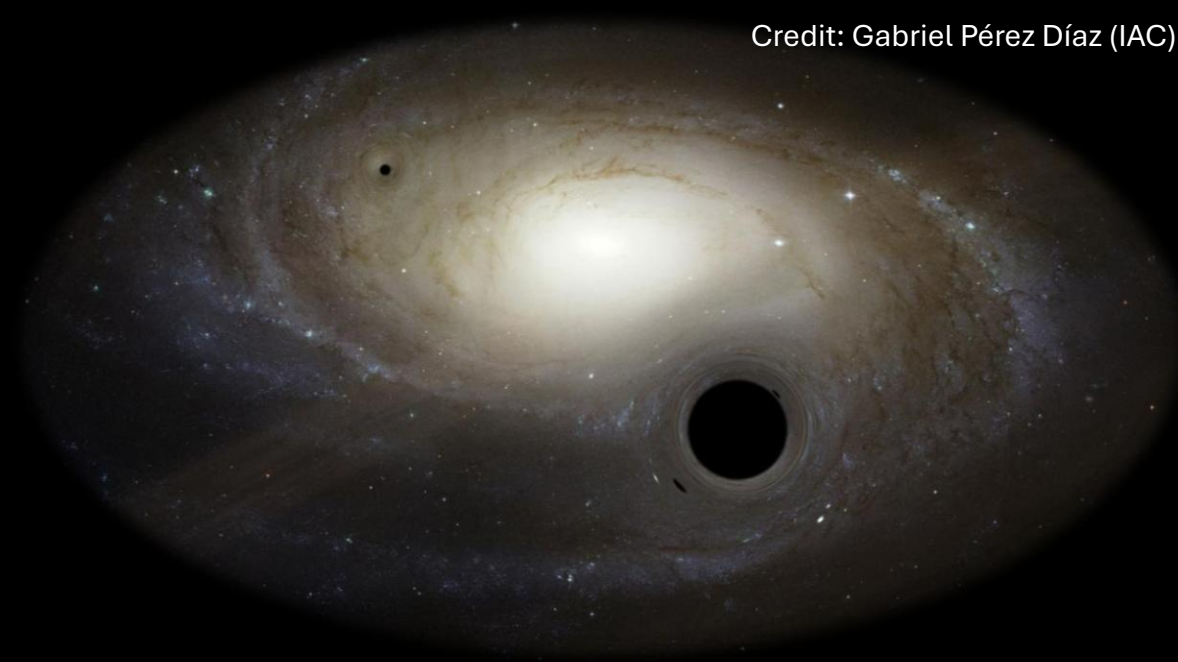
$$10^2 M_{\odot} \leq M_{\text{BH}} \leq 10^5 M_{\odot}$$



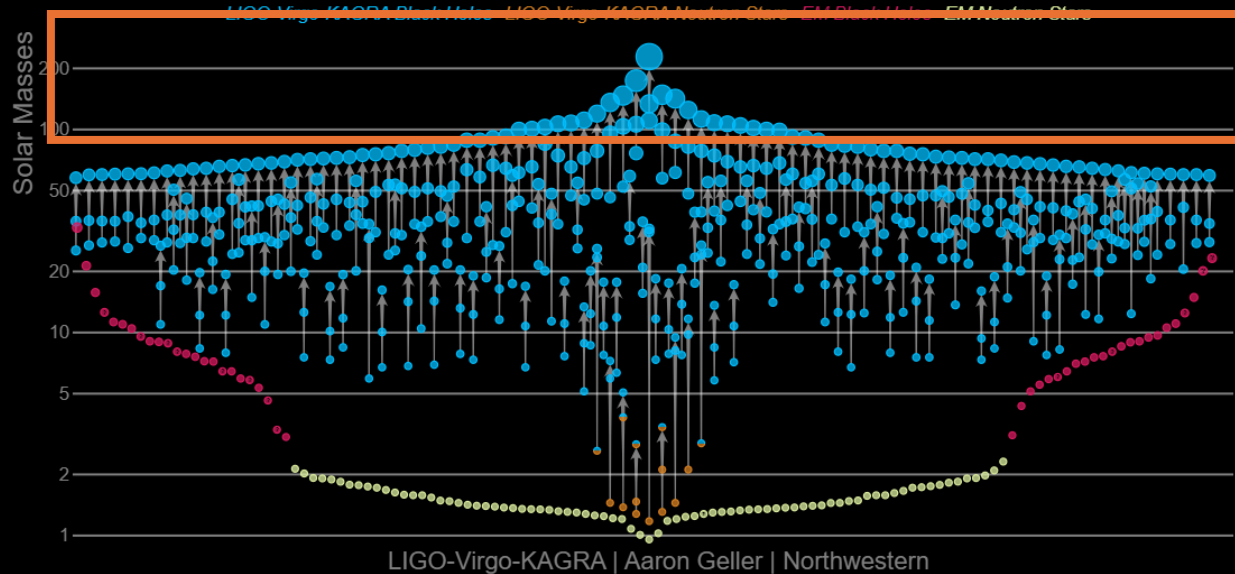
By definition...

Intermediate-mass black holes:

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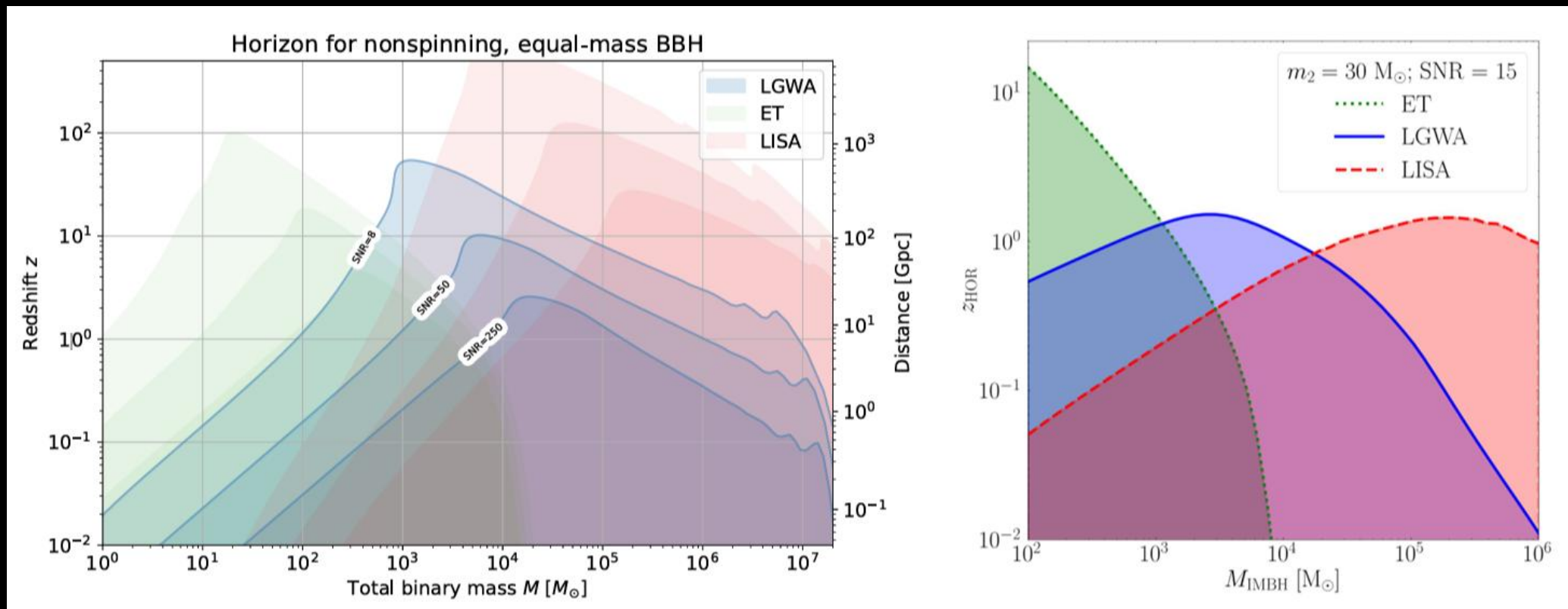
### Masses in the Stellar Graveyard



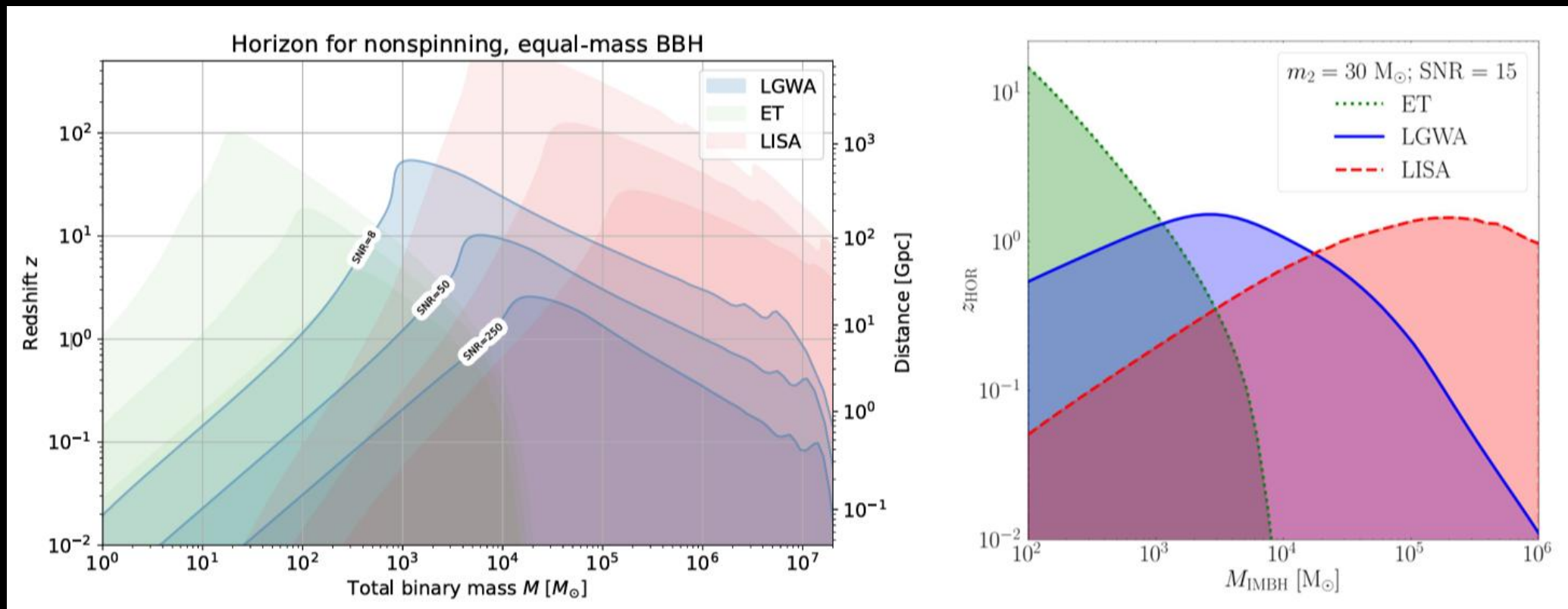
We have seen a few...

But with next generation interferometers...

But with next generation interferometers...



But with next generation interferometers...



Aijith et al 2024

We will see more of them!

However...

Very Massive Stars  
(VMSs,  $m_* \geq 150 M_{\odot}$ )

However...

Very Massive Stars  
(VMSs,  $m_* \geq 150 M_\odot$ )

$32 M_\odot \leq M_{\text{He}} \leq 135 M_\odot$   
PI regime

new PISN rate:  
Simonato et al 2025

PISN = Pair-Instability SuperNova

However...

Very Massive Stars  
(VMSs,  $m_* \geq 150 M_\odot$ )

$32 M_\odot \leq M_{\text{He}} \leq 135 M_\odot$   
PI regime

$M_{\text{He}} > 135 M_\odot$   
Direct collapse onto IMBH

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Simonato et al 2025

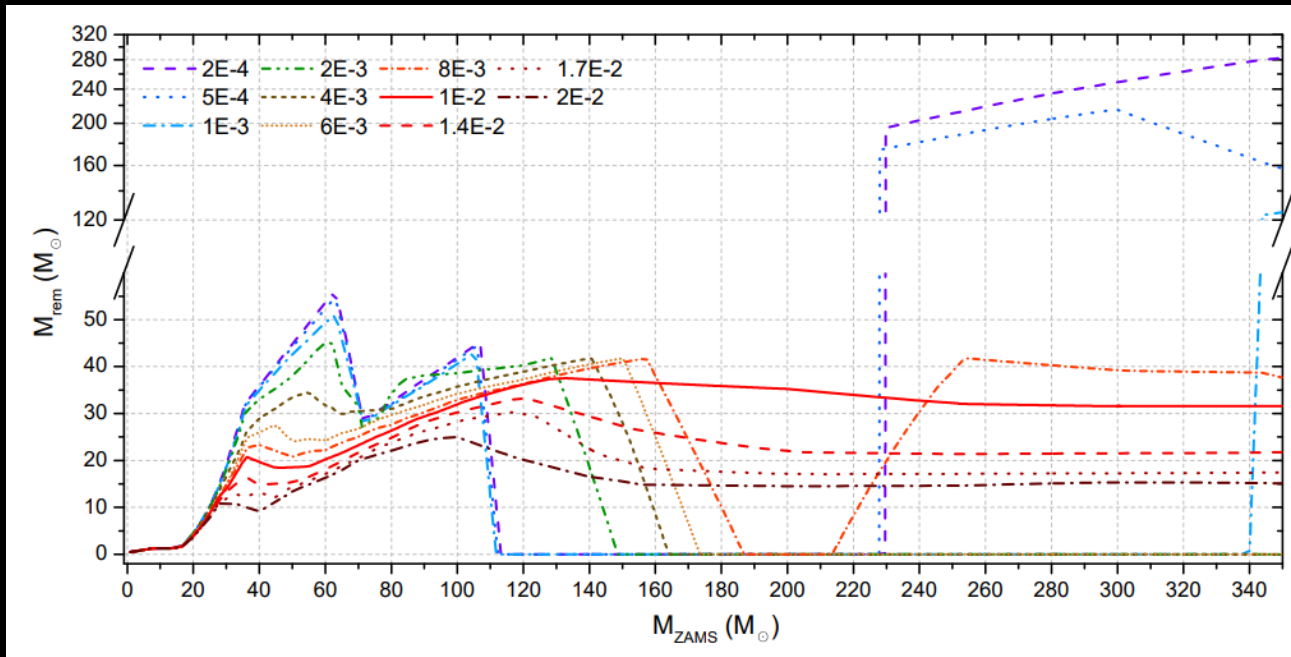
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Direct collapse onto IMBH



Spera & Mapelli 2017

PISN = Pair-Instability SuperNova

So...

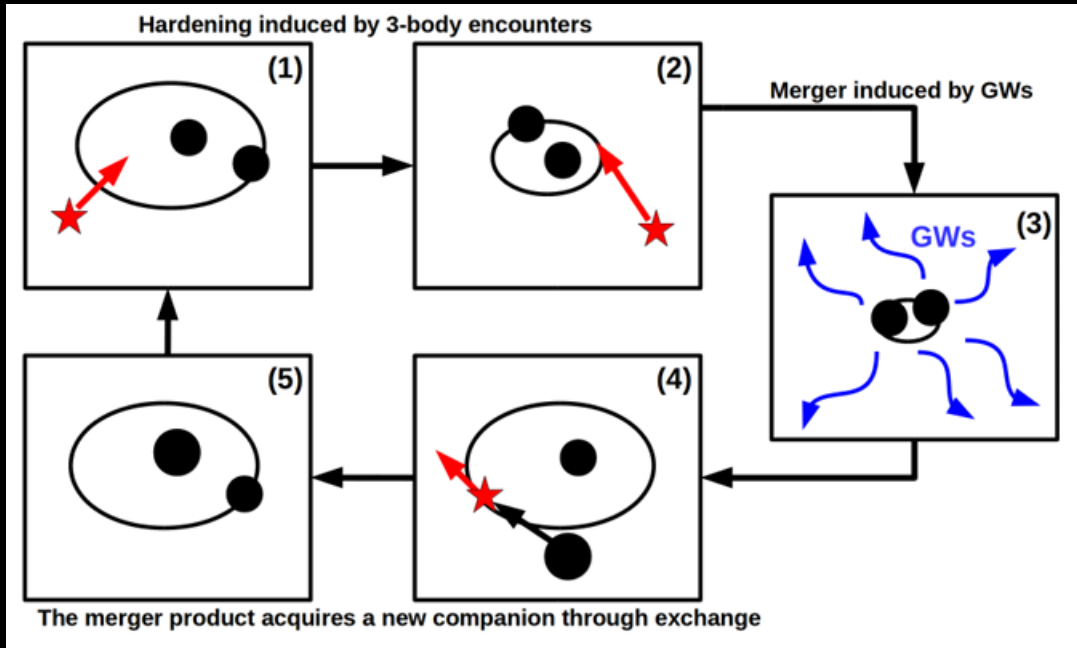
Dynamics matter!

Two main complementary channels:

# Dynamics matter!

## Two main complementary channels:

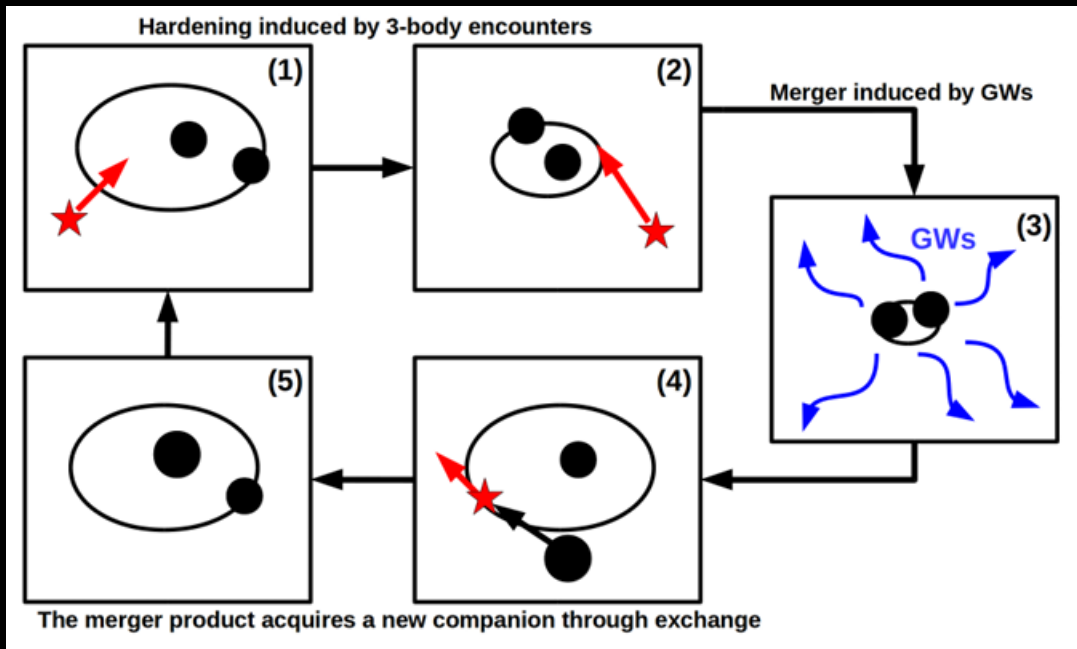
Hierarchical BH-BH mergers



# Dynamics matter!

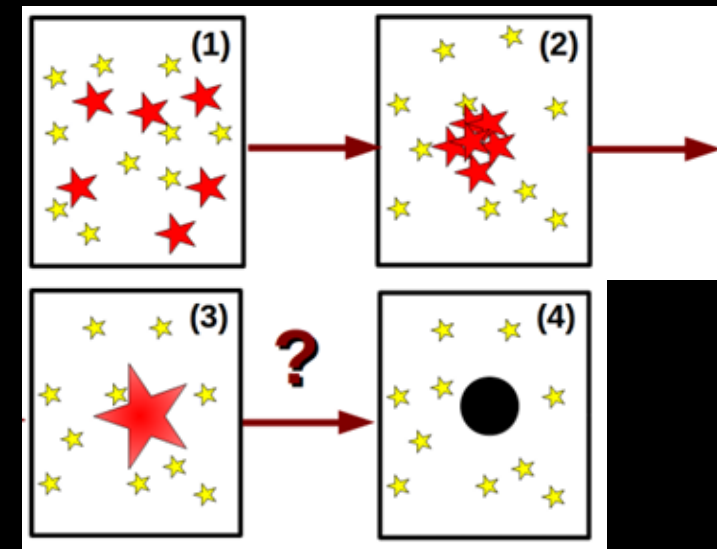
Two main complementary channels:

Hierarchical BH-BH mergers



Mapelli 2021

Runaway collisions



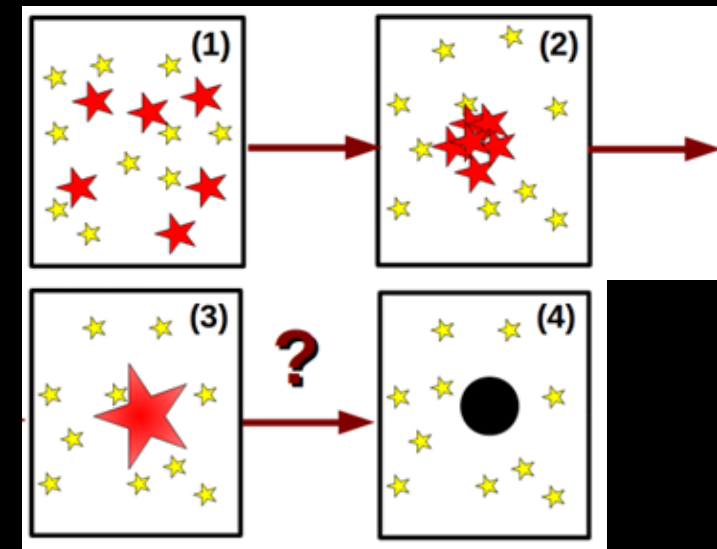
VMS = Very Massive Star ( $m_* > 150 M_\odot$ )

Mapelli 2021

# Dynamics matter!

## Two main complementary channels:

Runaway collisions



I will focus on  
this channel!

Following results from Simonato et al (in prep)

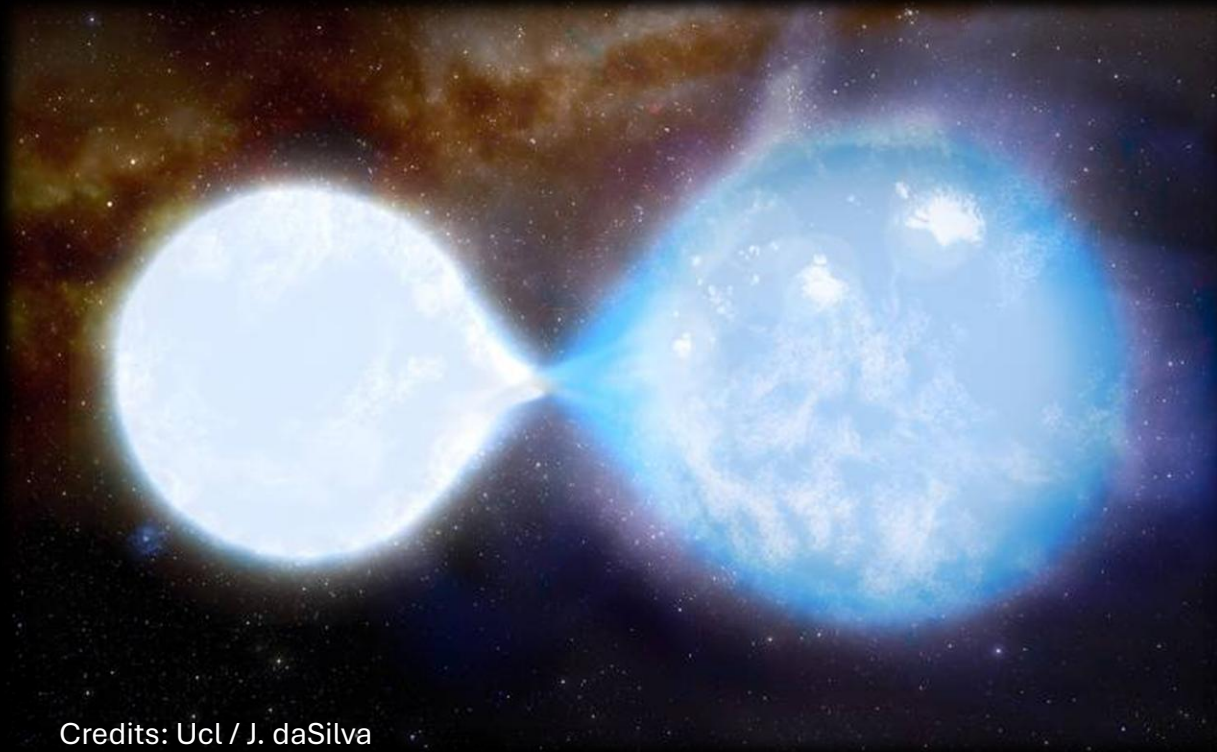
VMS = Very Massive Star ( $m_* > 150 M_\odot$ )

Mapelli 2021

# STARfall: a semi-analytic approach

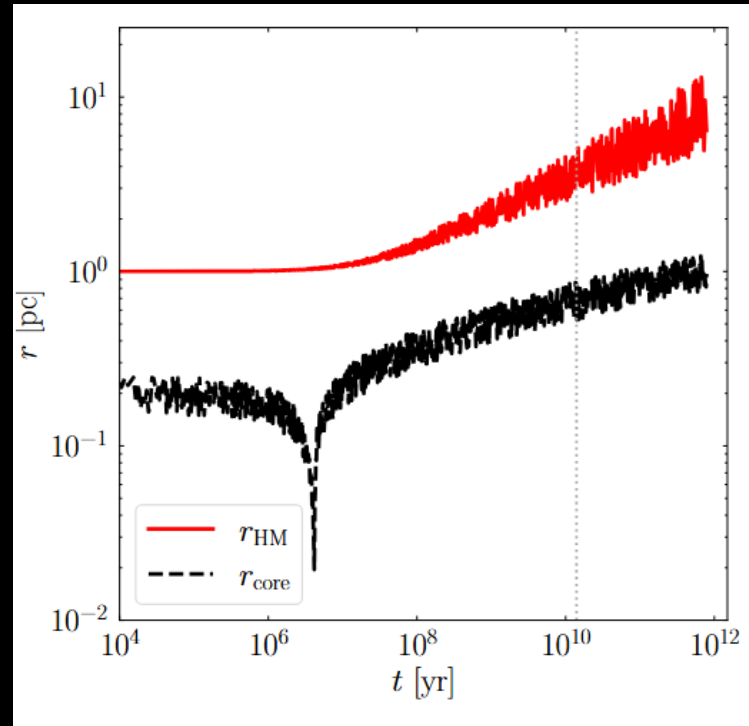
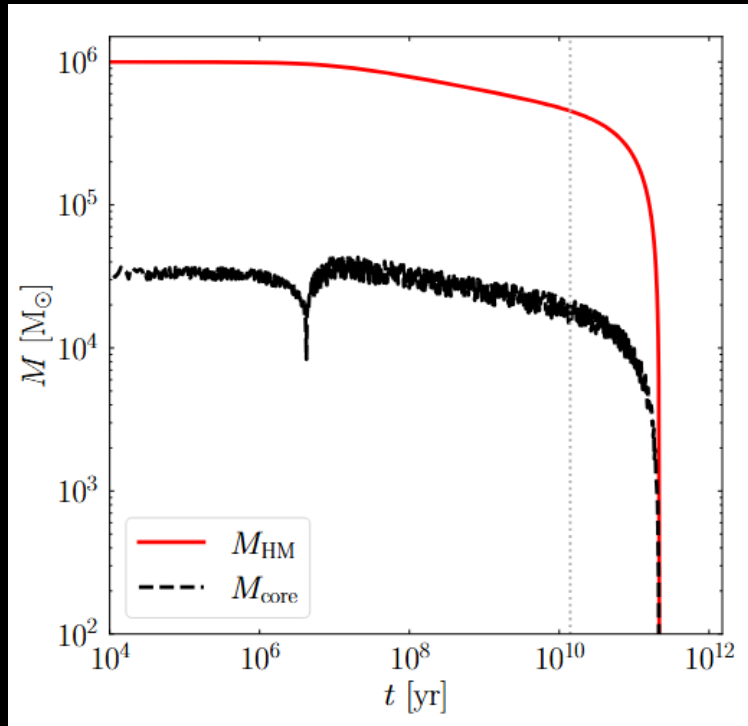
- Massive stellar binary evolution

Moe & Di Stefano 2017



Credits: Ucl / J. daSilva

# STARfall: a semi-analytic approach



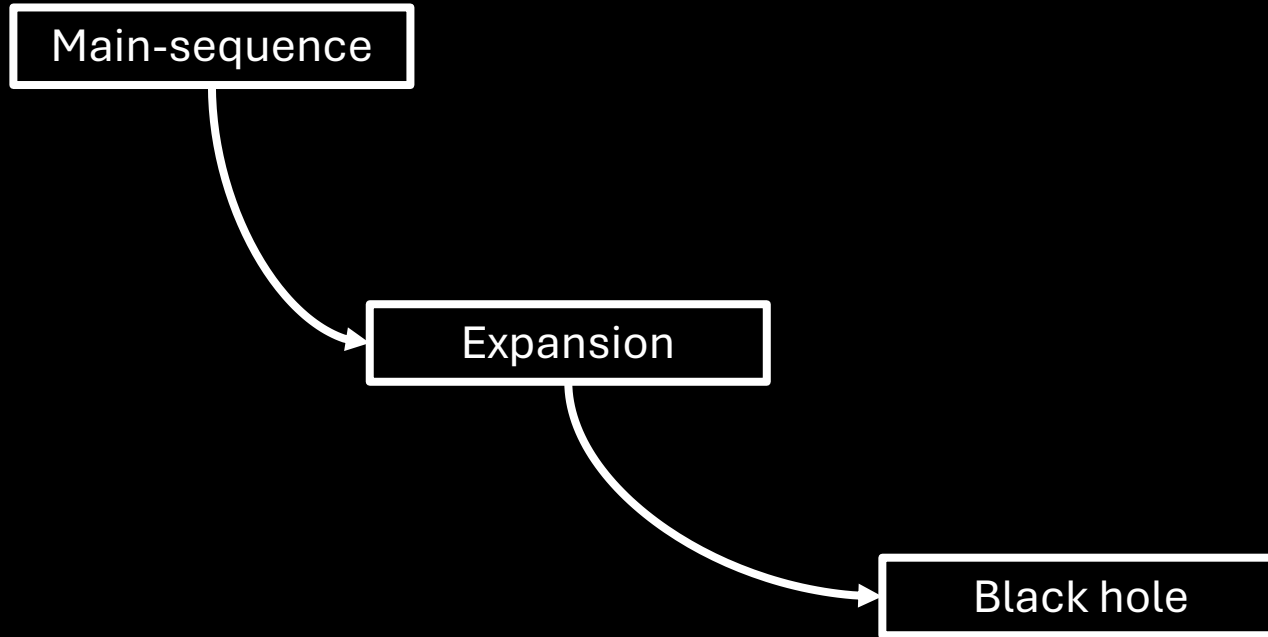
- Massive stellar binary evolution
- Host cluster evolution

Moe & Di Stefano 2017

Arca Sedda et al 2026

Arca Sedda et al 2026

# STARfall: a semi-analytic approach



- Massive stellar binary evolution

Moe & Di Stefano 2017

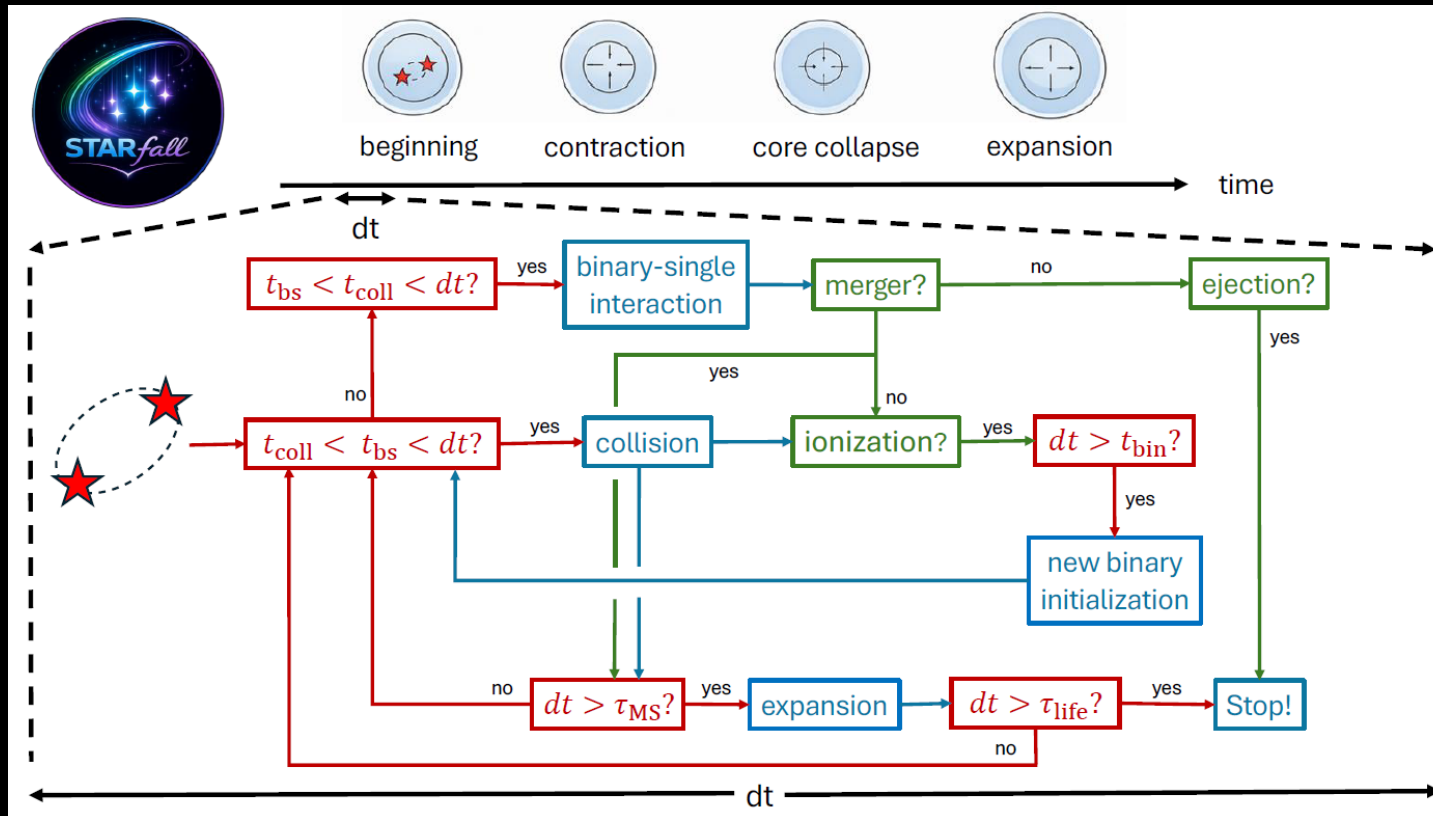
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- Simplified stellar evolution

Iorio et al 2023

# STARfall: a semi-analytic approach



- Massive stellar binary evolution

Moe & Di Stefano 2017

- Host cluster evolution

Arca Sedda et al 2026

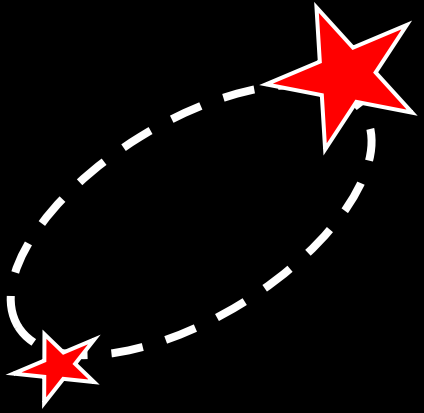
- Simplified stellar evolution

Iorio et al 2023

- Stellar mergers & collisions

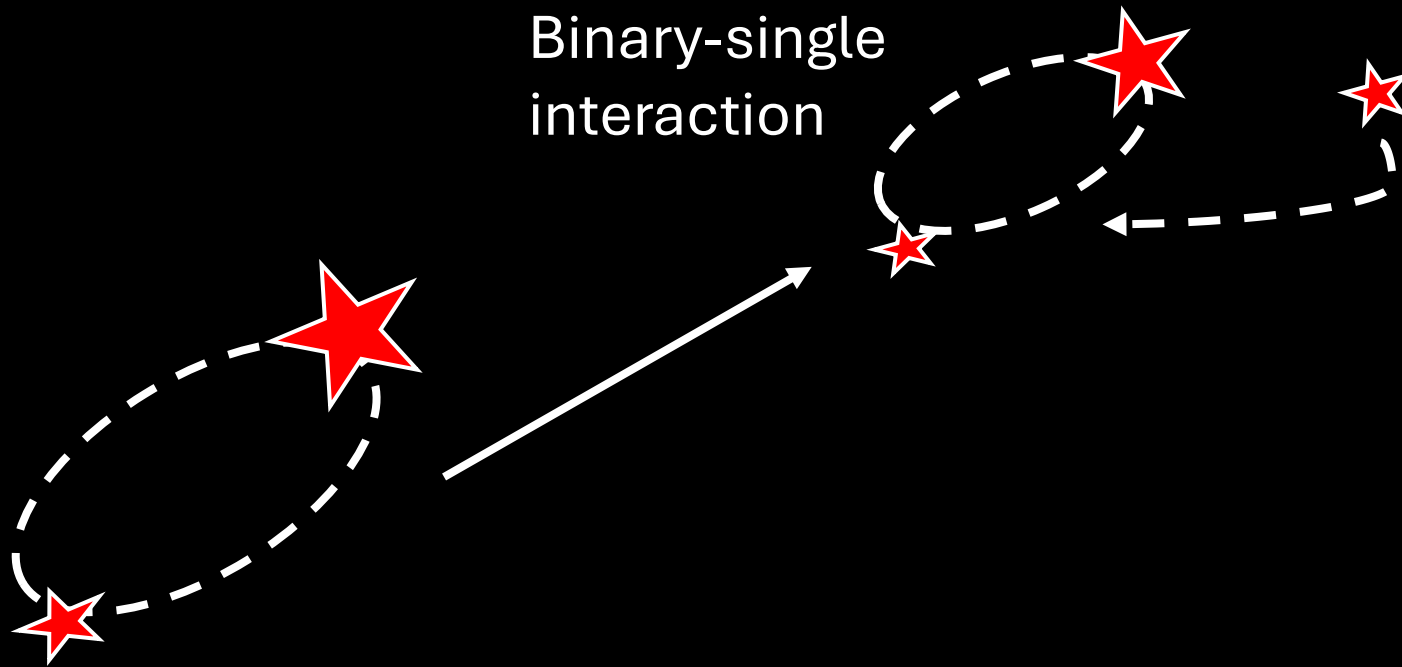
Sigurdsson & Phinney 1993

# STARfall: a semi-analytic approach

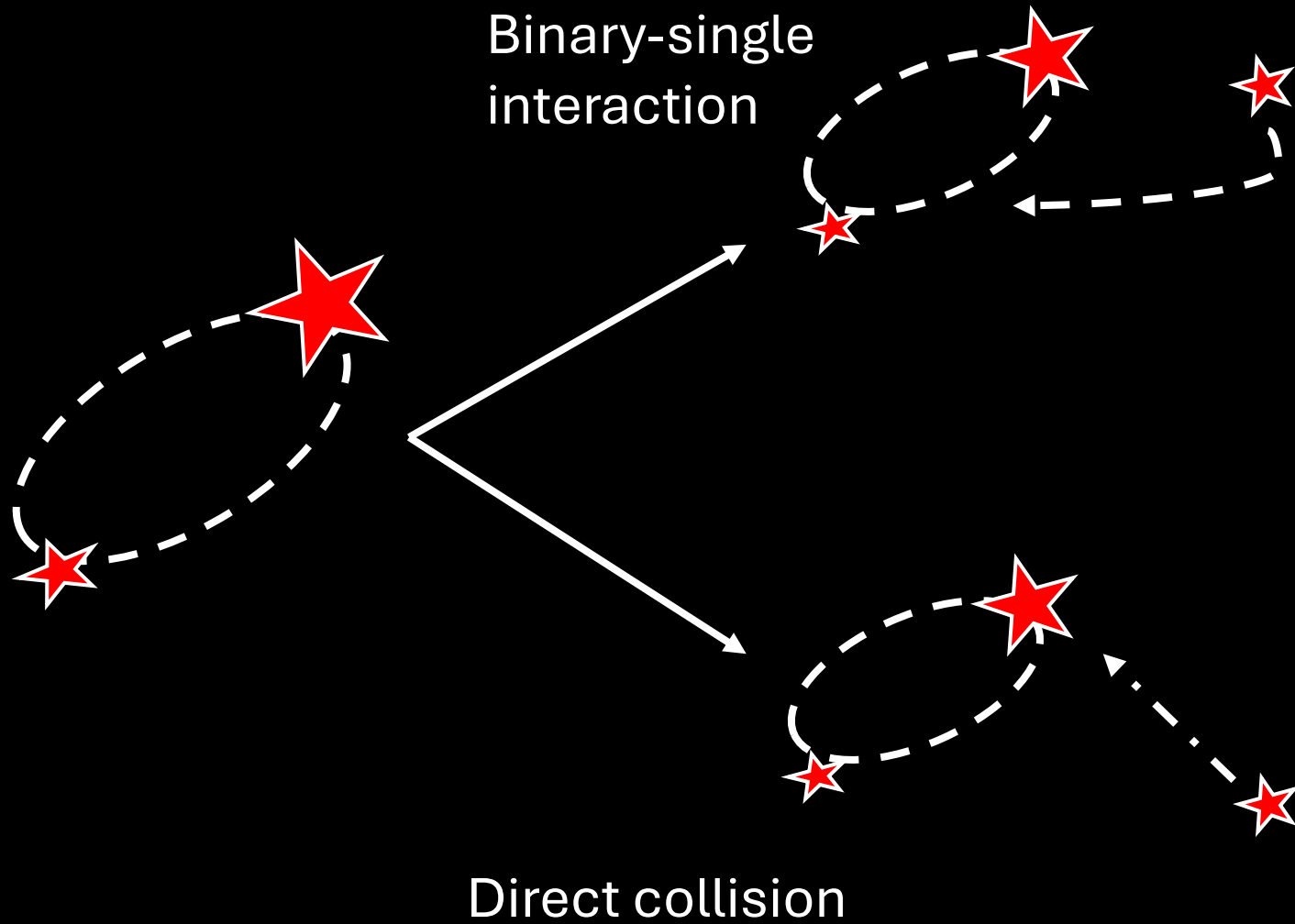


We can discuss further details later, or just contact me: [filippo.simonato@gssi.it](mailto:filippo.simonato@gssi.it)

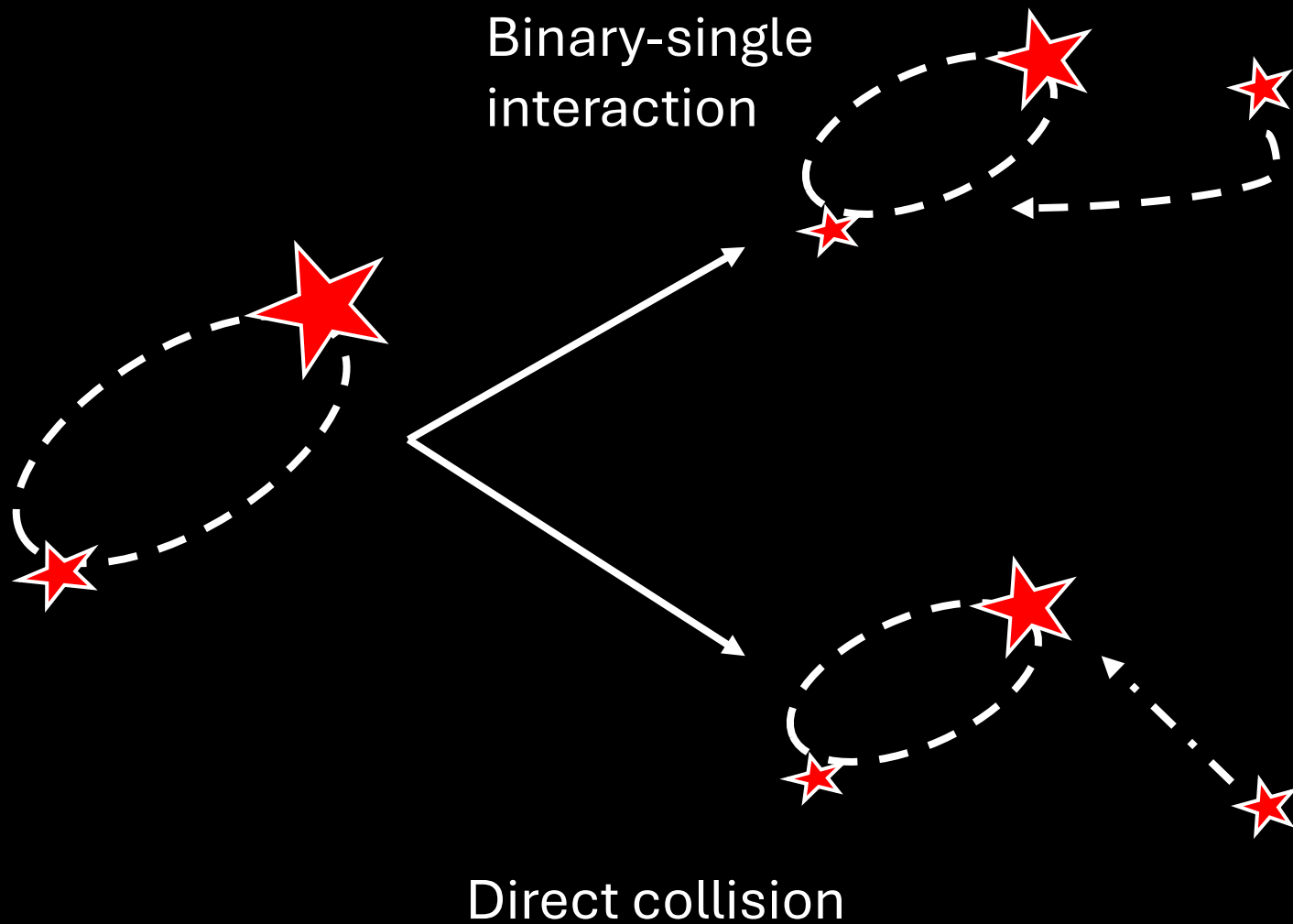
# STARfall: a semi-analytic approach



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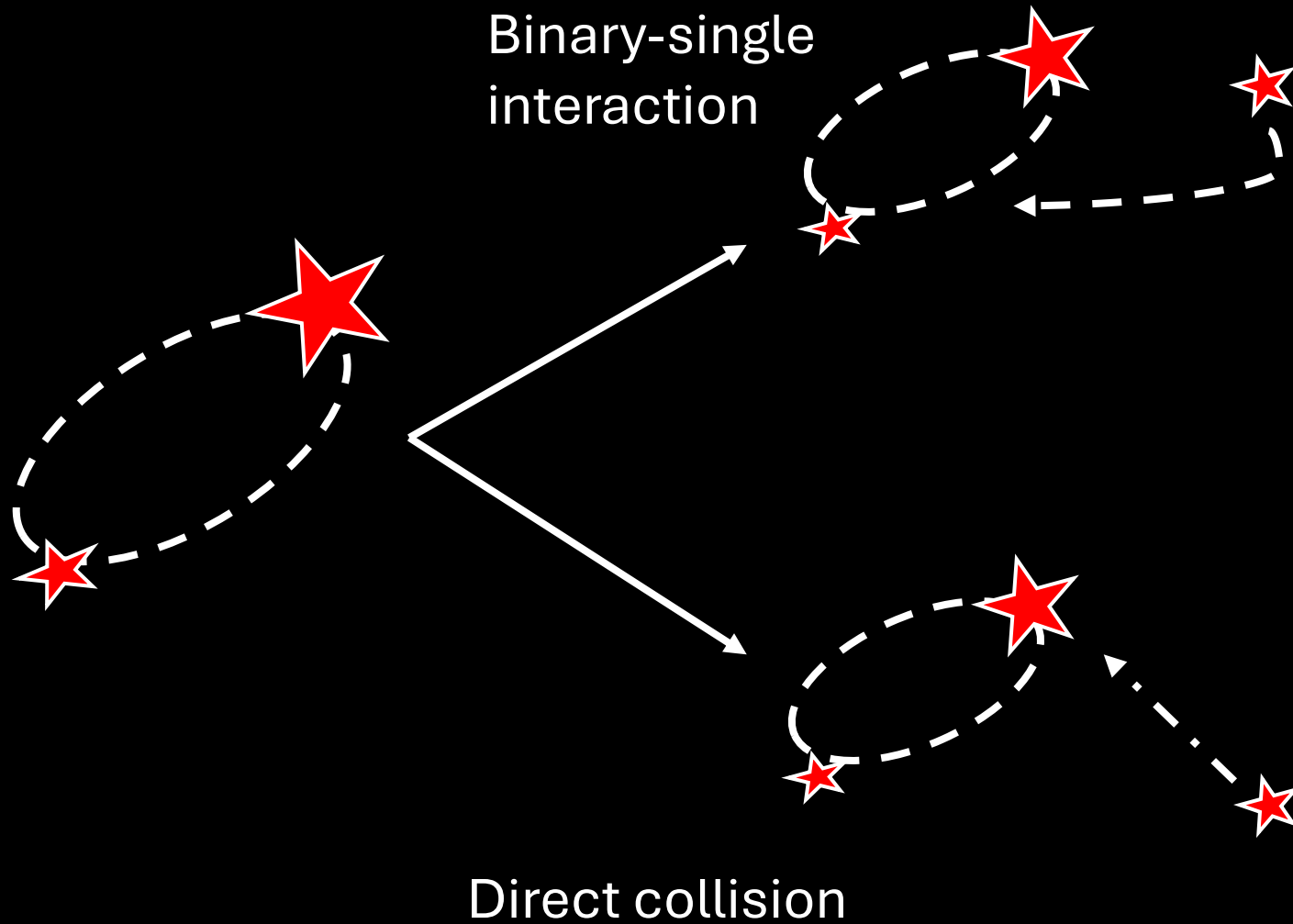


## STARfall: a semi-analytic approach



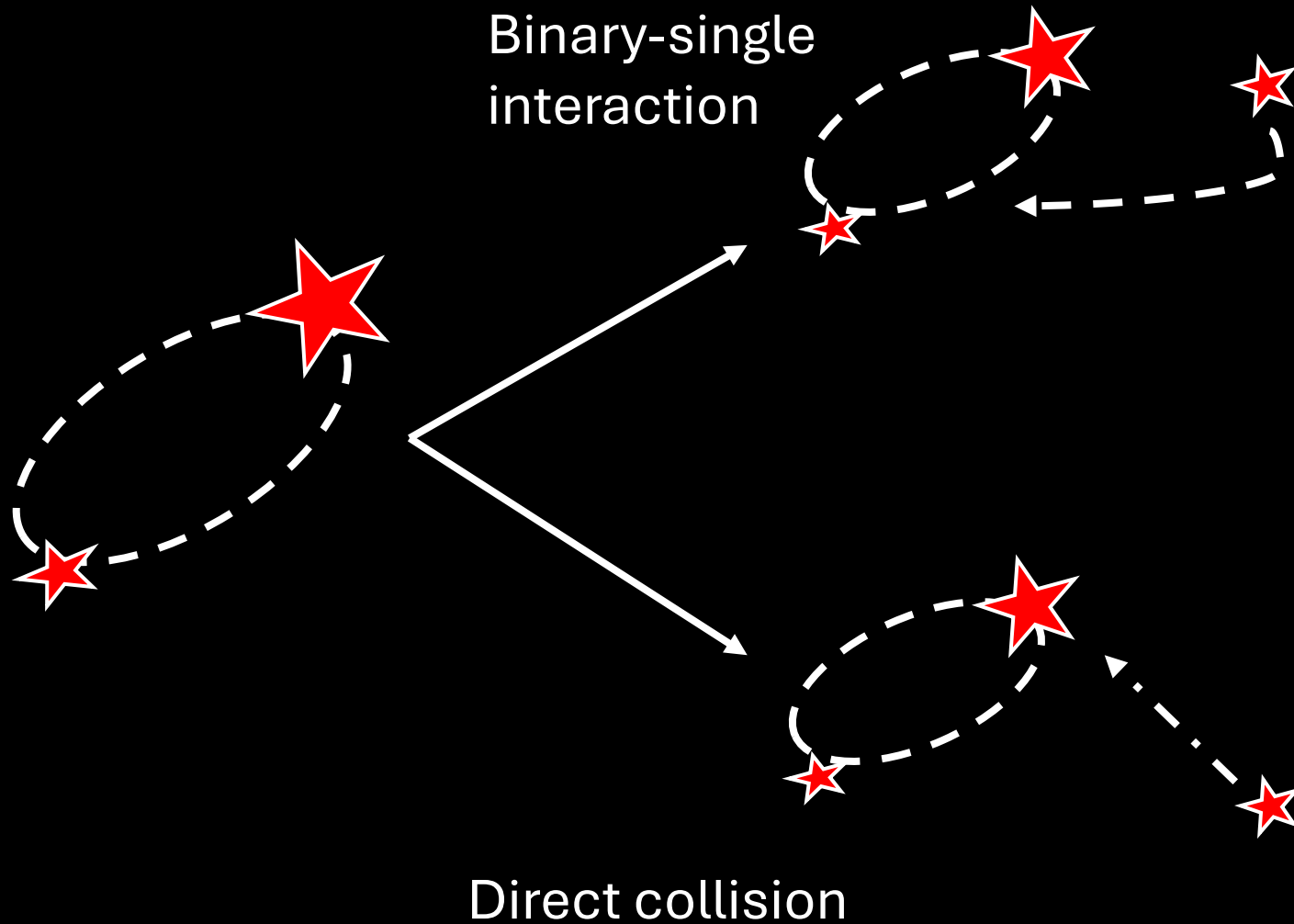
- Mergers or collisions?

## STARfall: a semi-analytic approach



- Mergers or collisions?
- Probability to form a VMS?

## STARfall: a semi-analytic approach



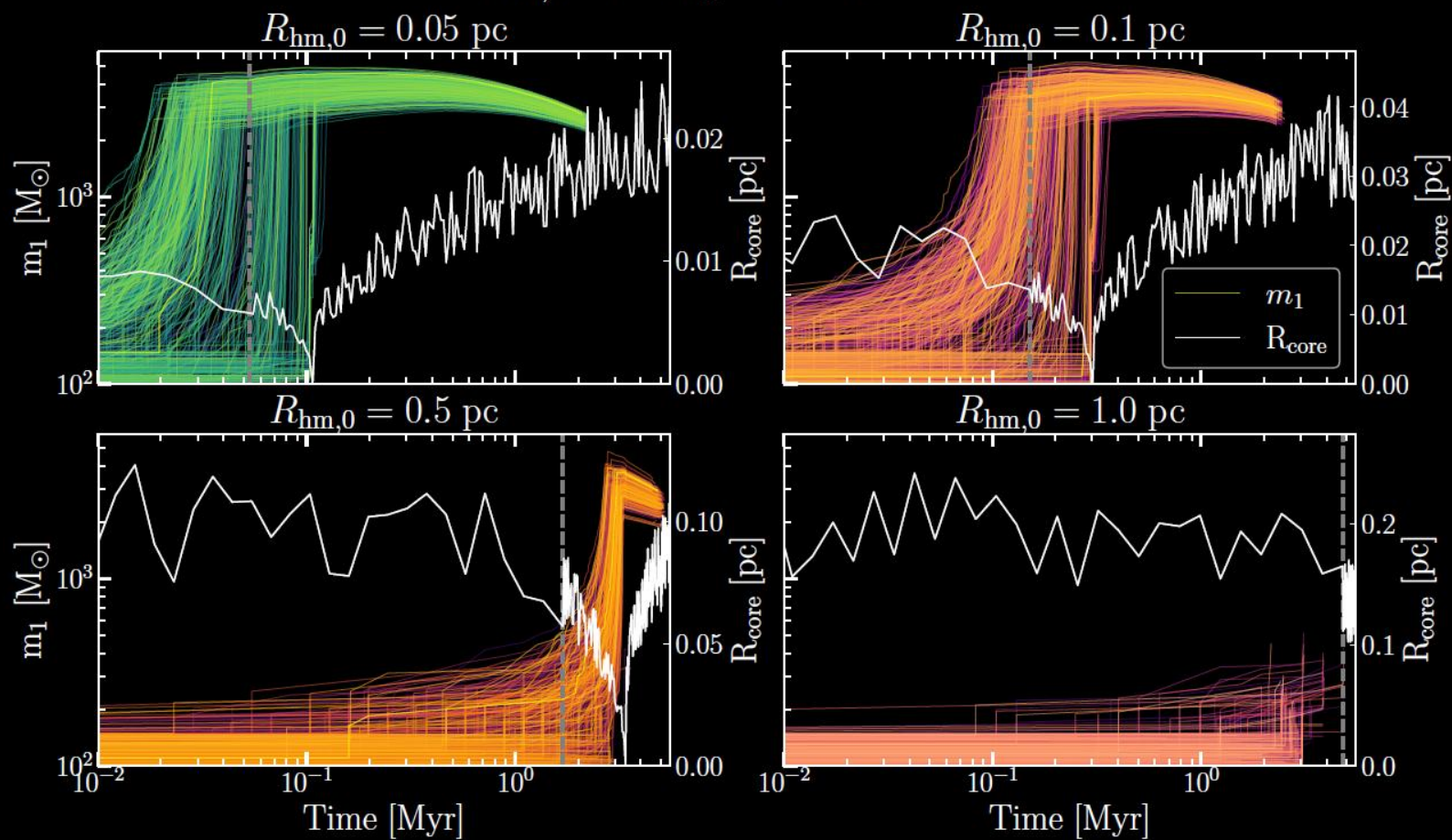
- Mergers or collisions?
- Probability to form a VMS?
- How much mass can be accreted?

First of all...mass growth

# First of all...mass growth

Simonato et al (in prep)

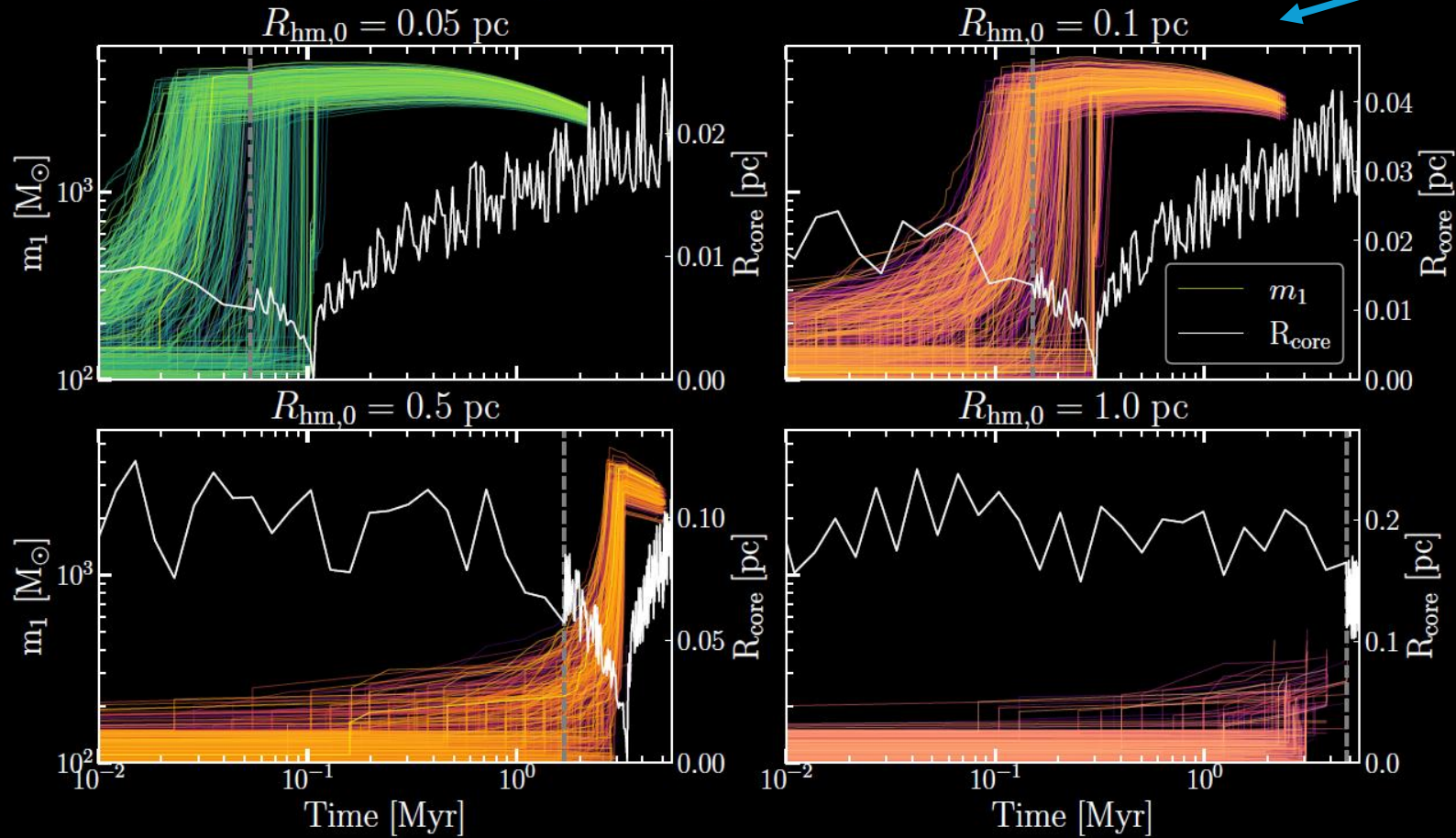
$$M_{\text{cl},0} = 10^6 M_{\odot} - Z = 0.0002$$



First of all...mass growth

Simonato et al (in prep)

$$M_{\text{cl},0} = 10^6 M_{\odot} - Z = 0.0002$$

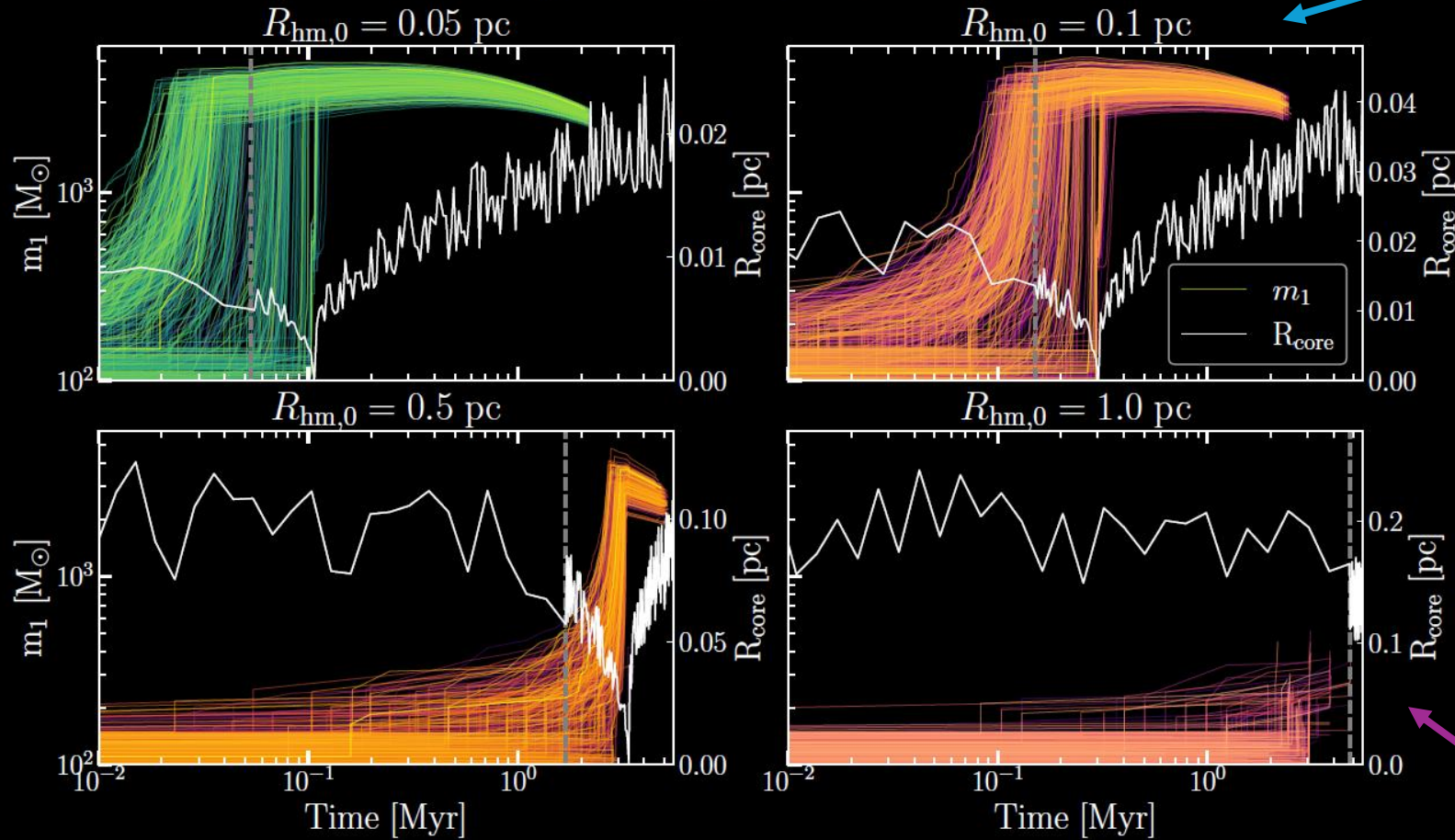


Core-collapse  
timescale relevant in  
denser environments

First of all...mass growth

Simonato et al (in prep)

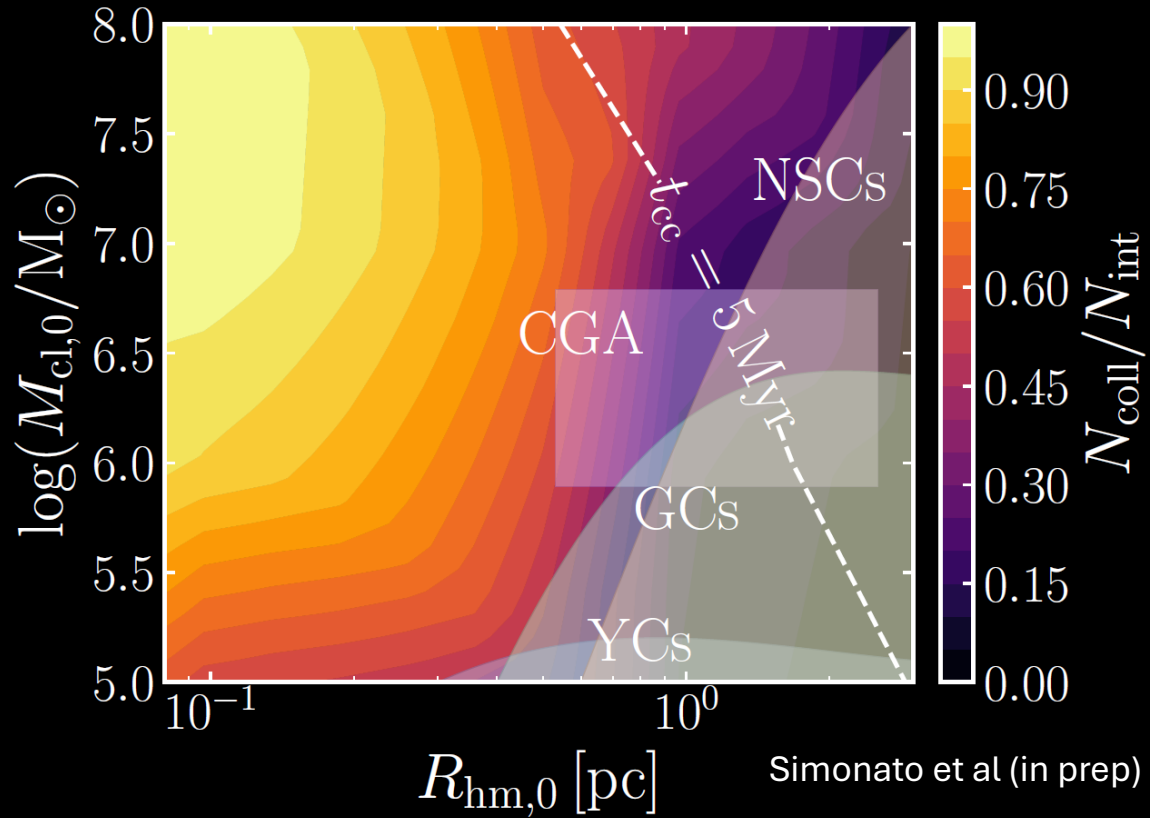
$$M_{\text{cl},0} = 10^6 M_{\odot} - Z = 0.0002$$



Core-collapse  
timescale relevant in  
denser environments

Stellar evolution  
relevant in less  
dense environments

## Mergers or Collisions?



$M_{cl,0}$  = initial mass

$R_{hm,0}$  = initial half-mass radius

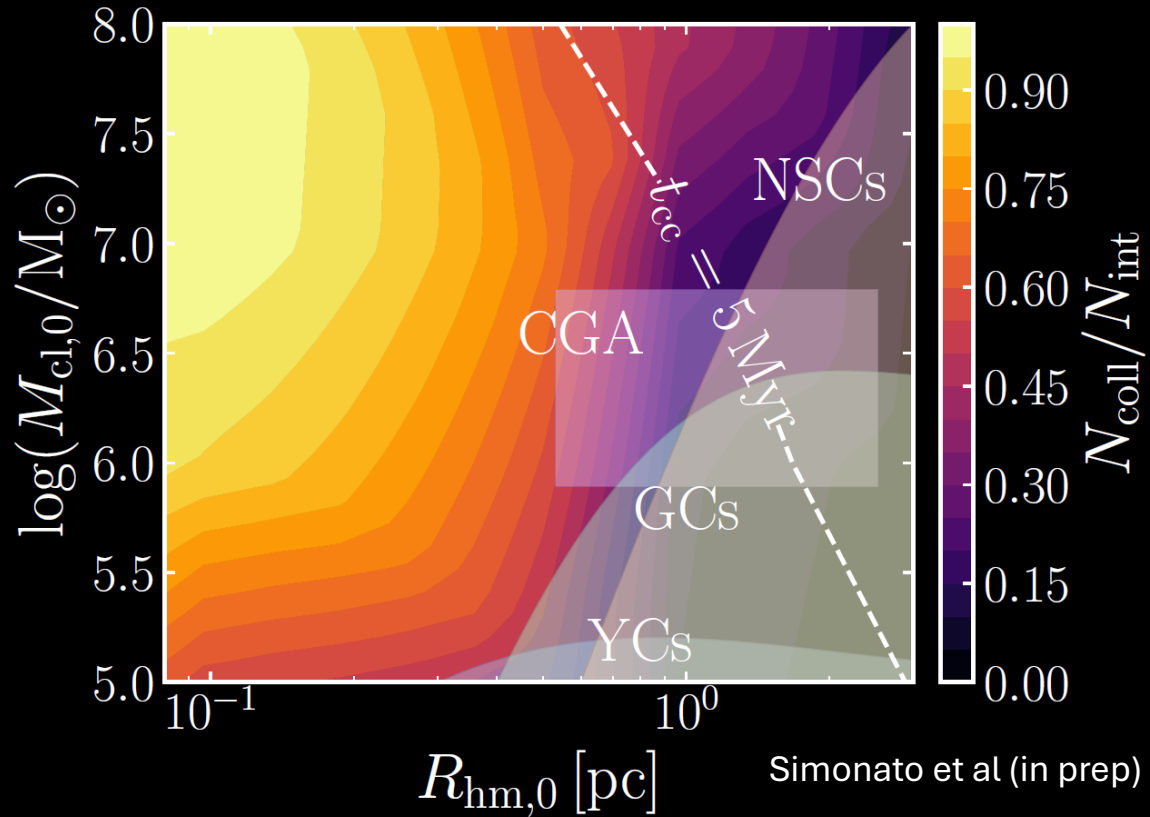
NSCs = Nuclear Star Clusters

GCs = Globular Clusters

YCs = Young star Clusters

CGA = Cosmic Gems Arc

## Mergers or Collisions?



$M_{\text{cl},0}$  = initial mass

$R_{\text{hm},0}$  = initial half-mass radius

→ It depends on the initial density

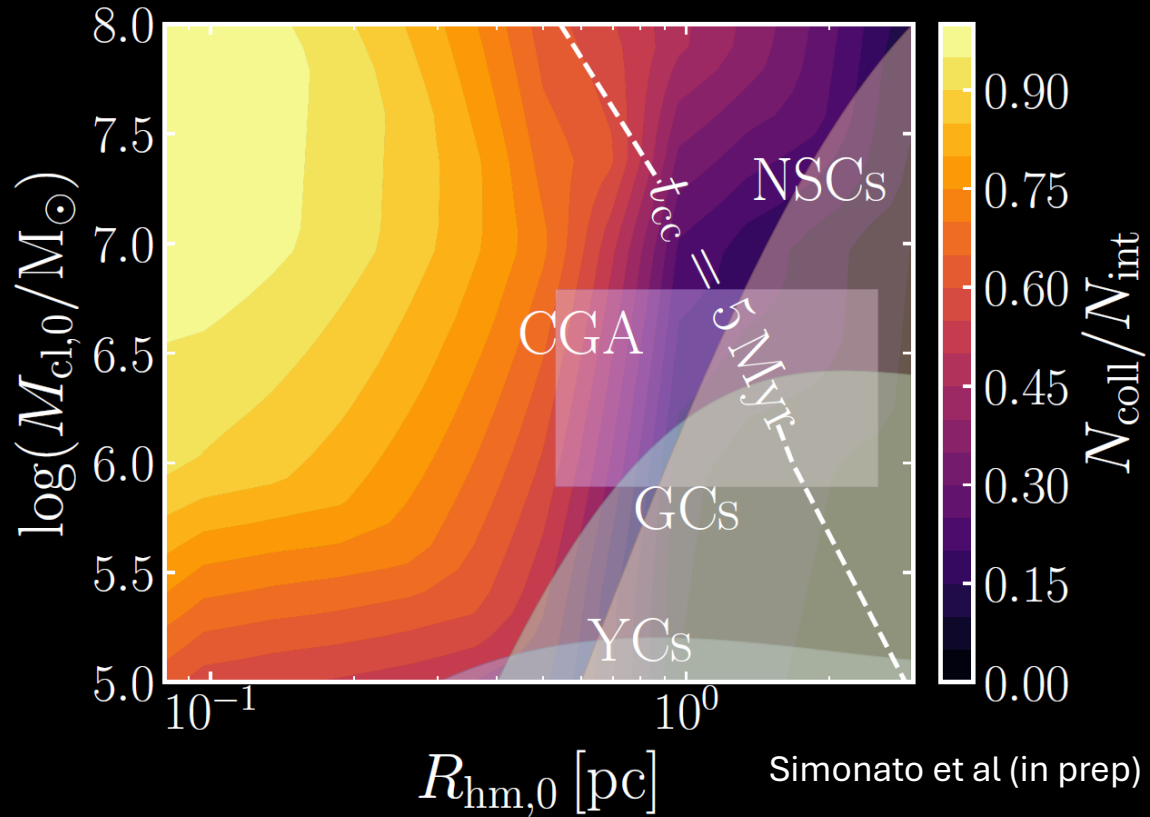
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## Mergers or Collisions?



$M_{cl,0}$  = initial mass

$R_{hm,0}$  = initial half-mass radius

→ It depends on the initial density

→ Closely related to the probability of VMS formation

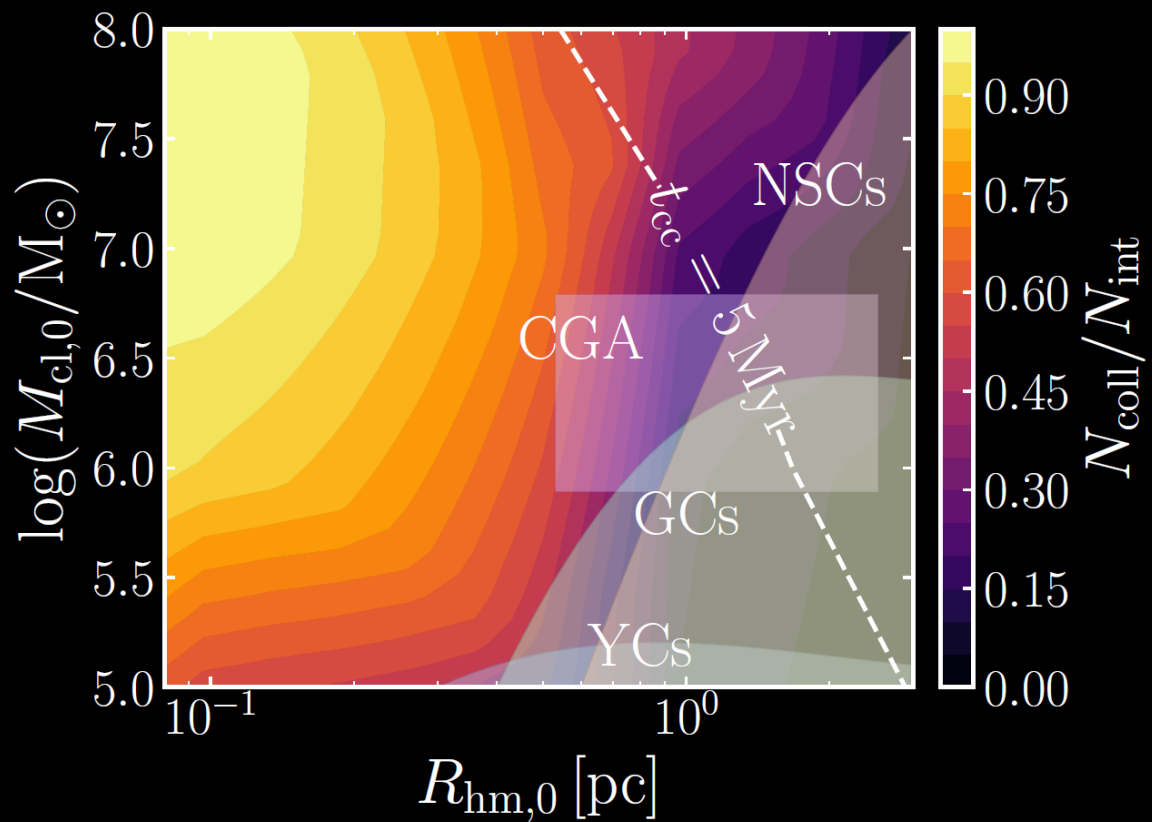
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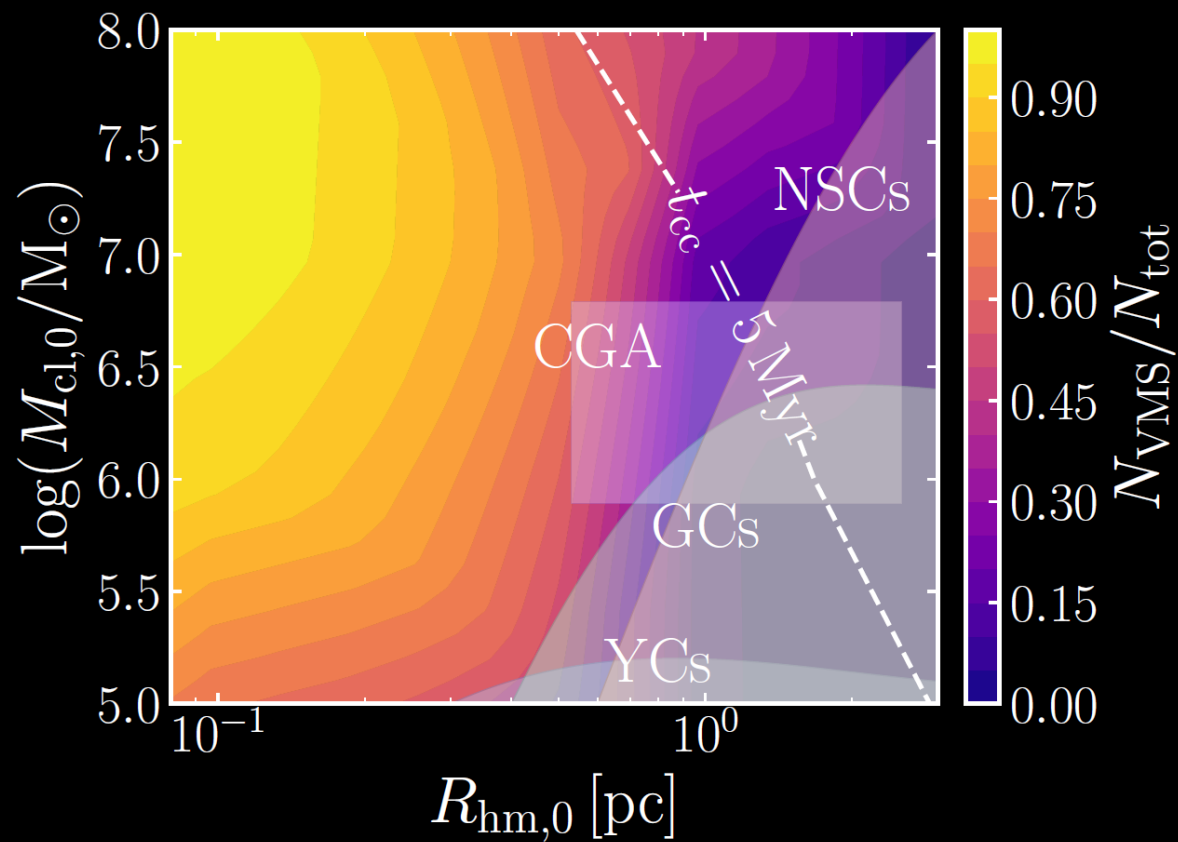
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## Megers or Collisions?

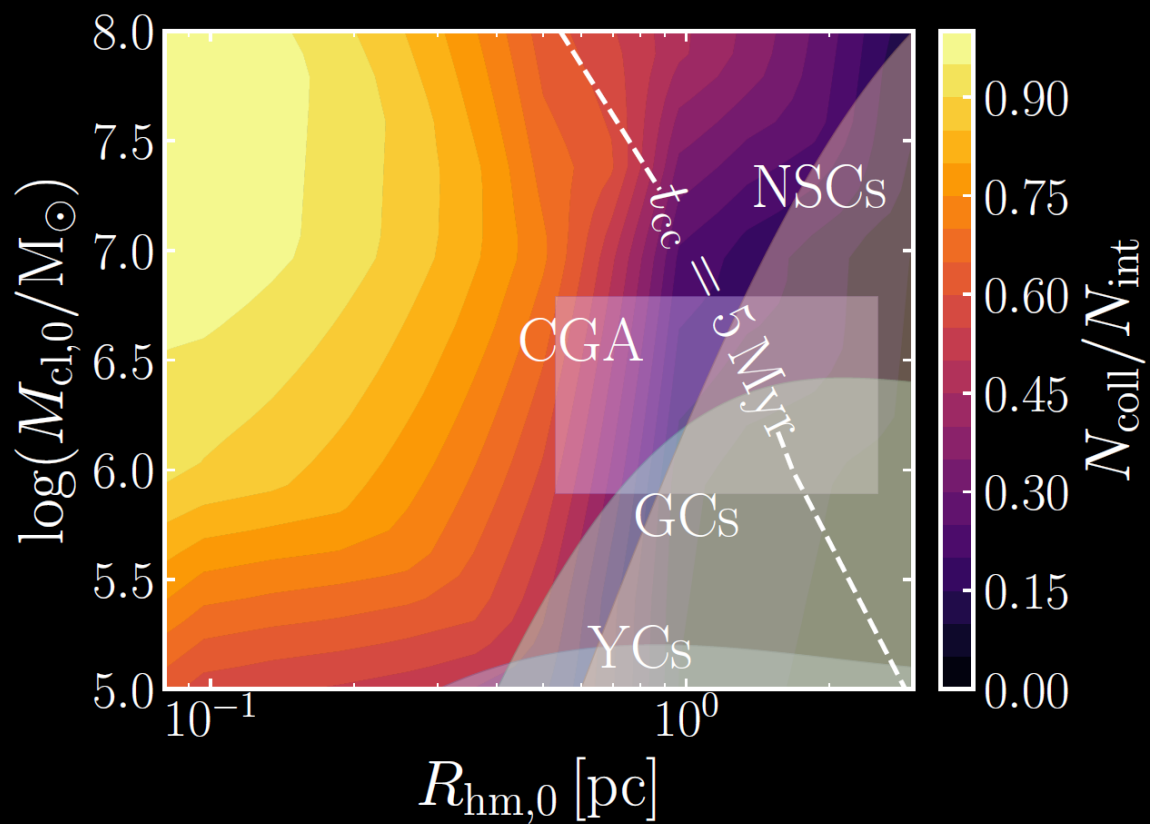


## Probability to form a VMS?

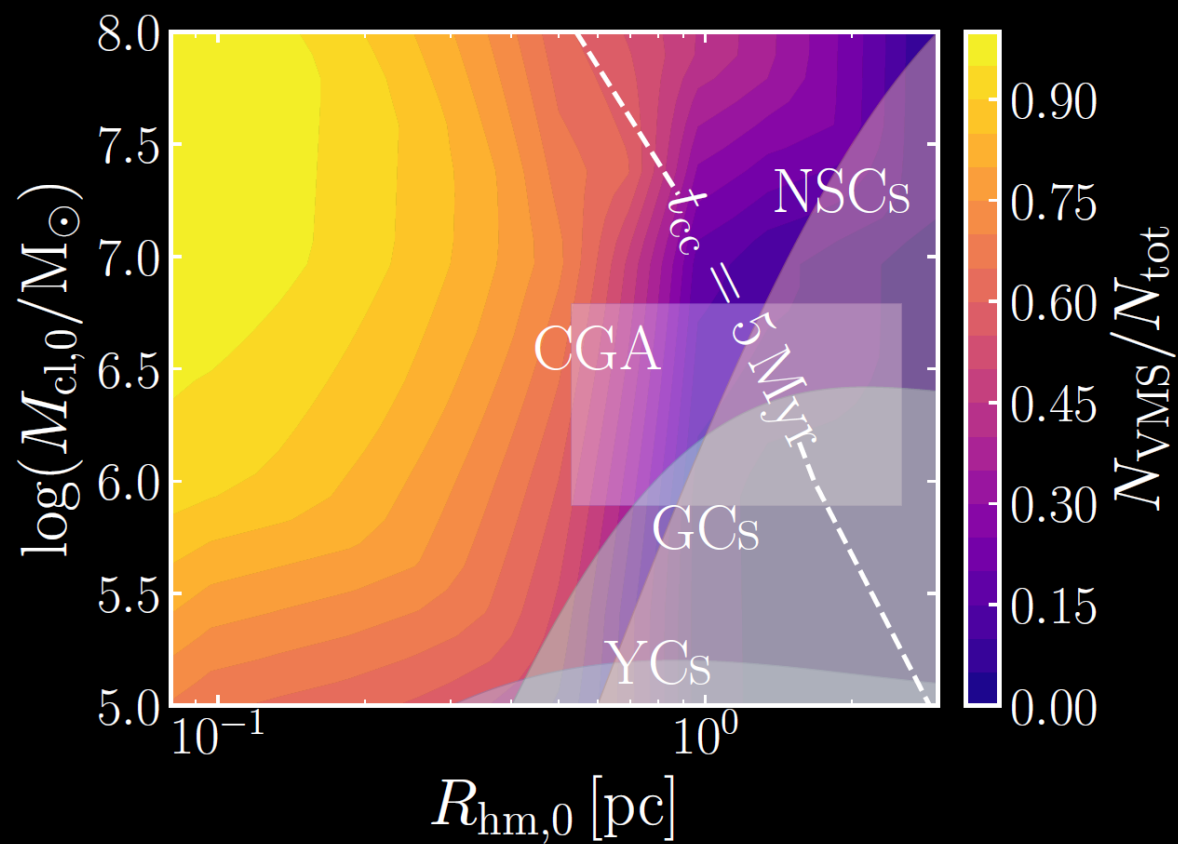


VMS = Very Massive Star ( $m_* > 300 M_{\odot}$ )

## Megers or Collisions?



## Probability to form a VMS?

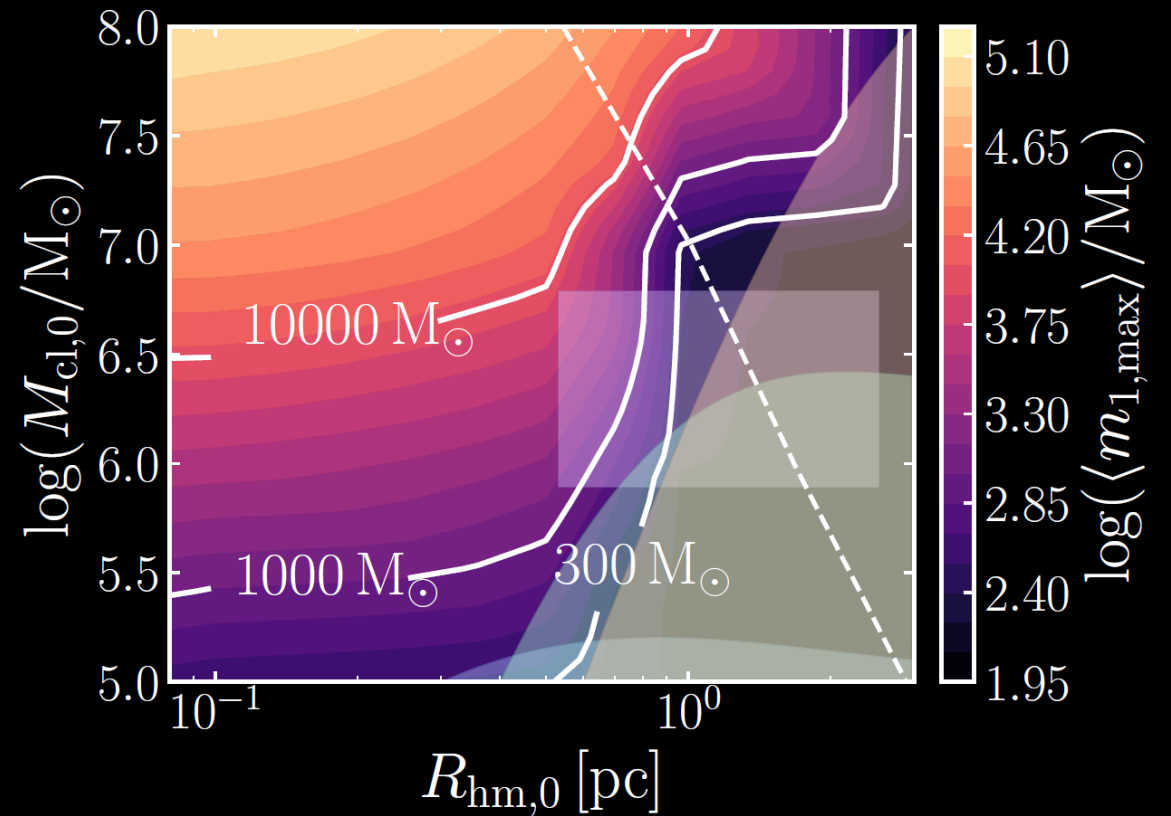


Same features!!!

VMS = Very Massive Star ( $m_* > 300 M_{\odot}$ )

Simionato et al (in prep)

How much mass can be accreted?



NSCs = Nuclear Star Clusters

GCs = Globular Clusters

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CGA = Cosmic Gems Arc

Simionato et al (in prep)

→ Up to  $\sim 10^4 M_\odot$  in compact systems

→ GCs can host VMSs up to  $\sim 10^3 M_\odot$

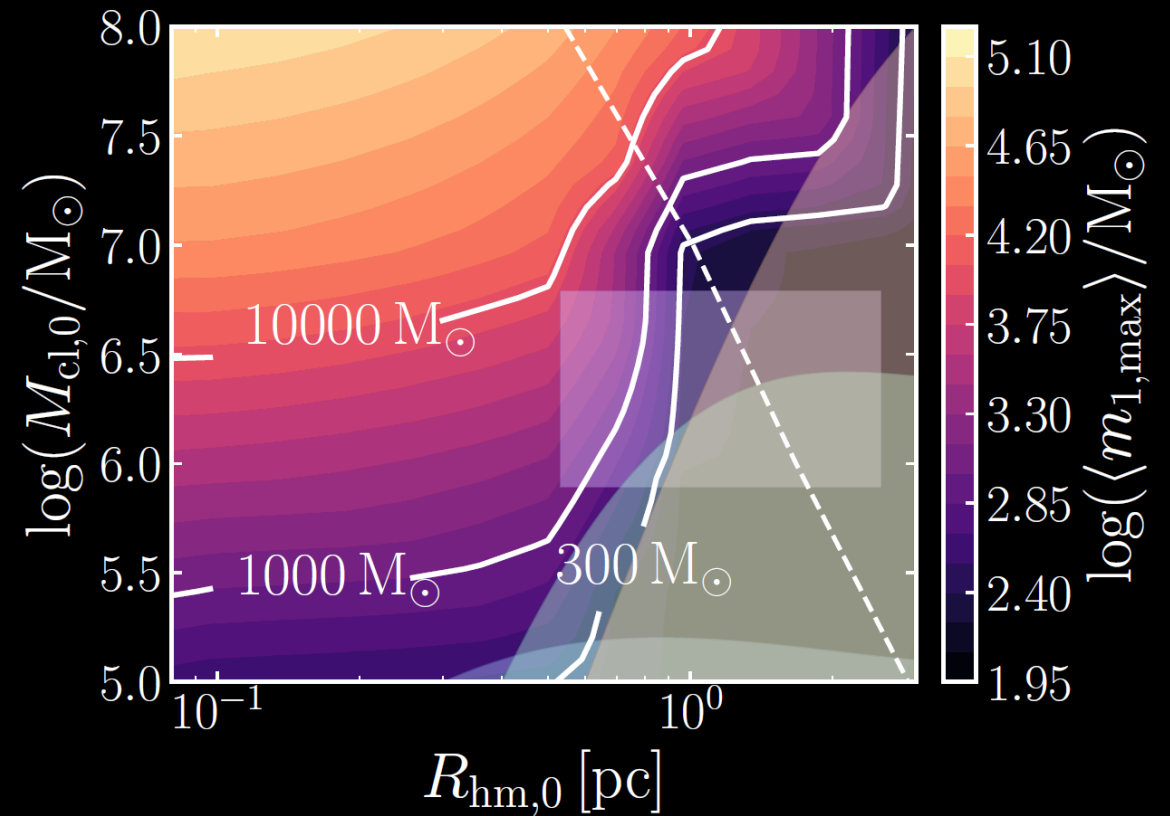
NSCs = Nuclear Star Clusters

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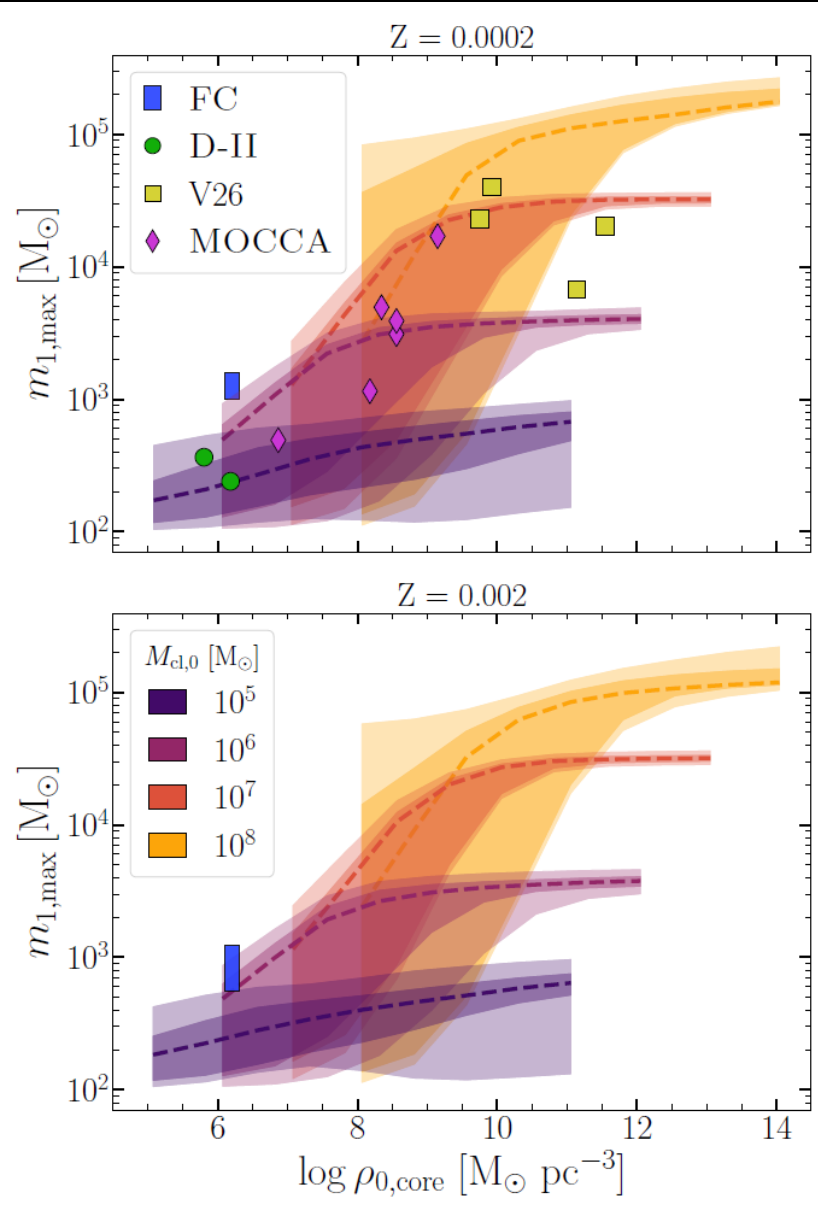
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How much mass can be accreted?



Simionato et al (in prep)

# VMS & IMBH mass distribution



$M_{cl,0}$  = initial mass

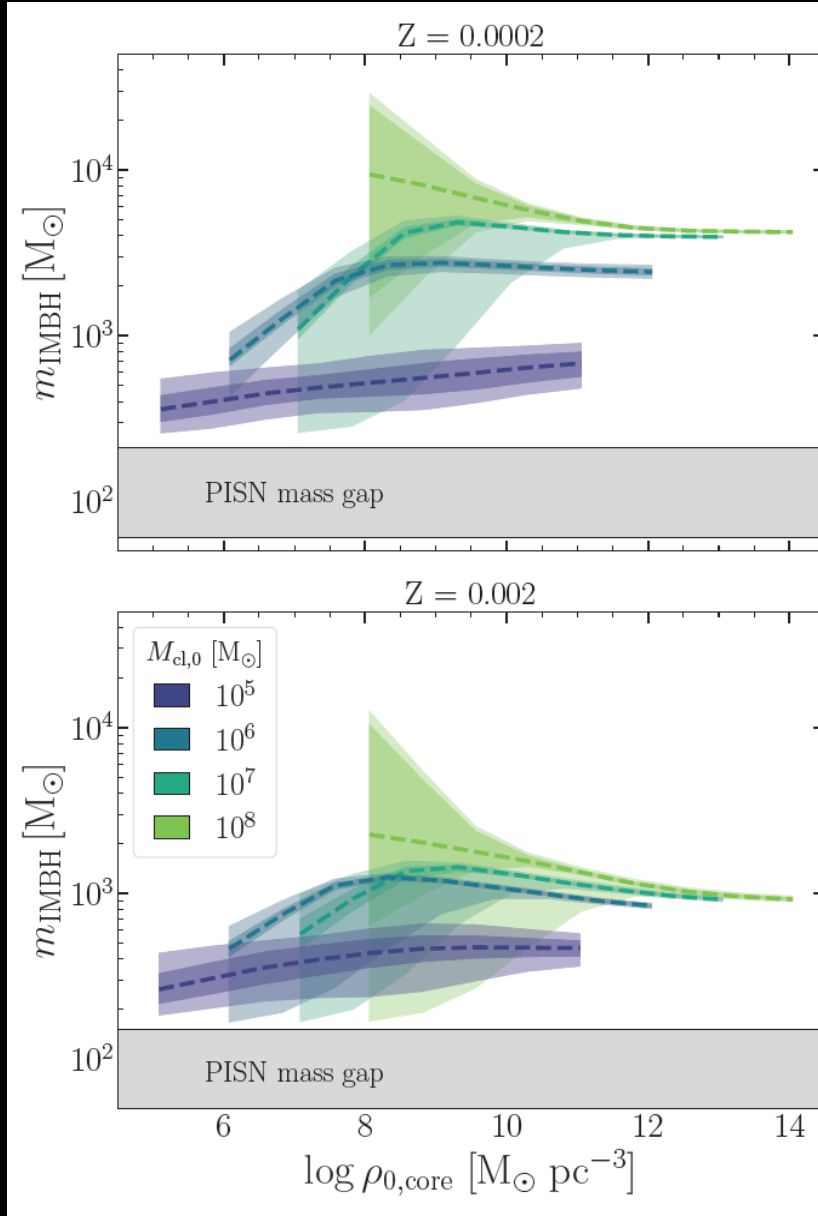
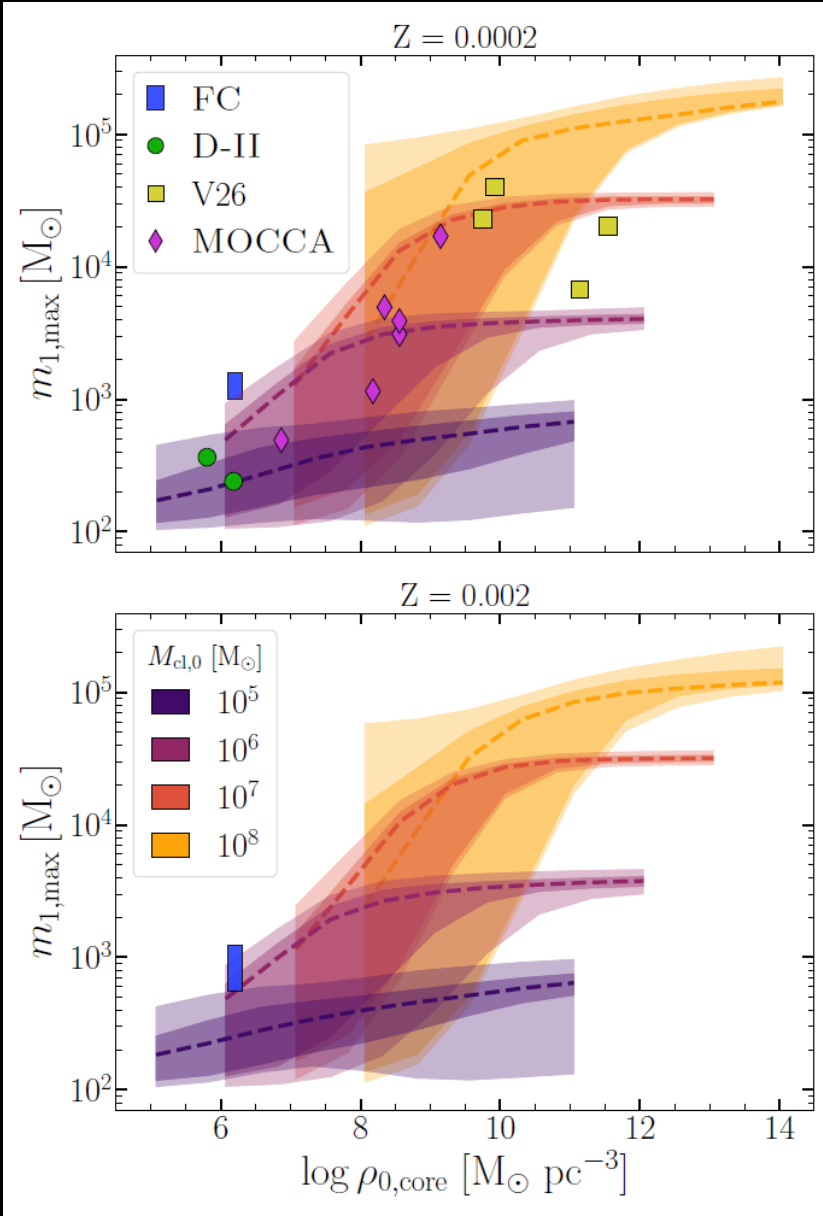
FC = Frost-Clusters (Rantala et al 2026)

D-II = Dragon-II (Arca Sedda et al 2023)

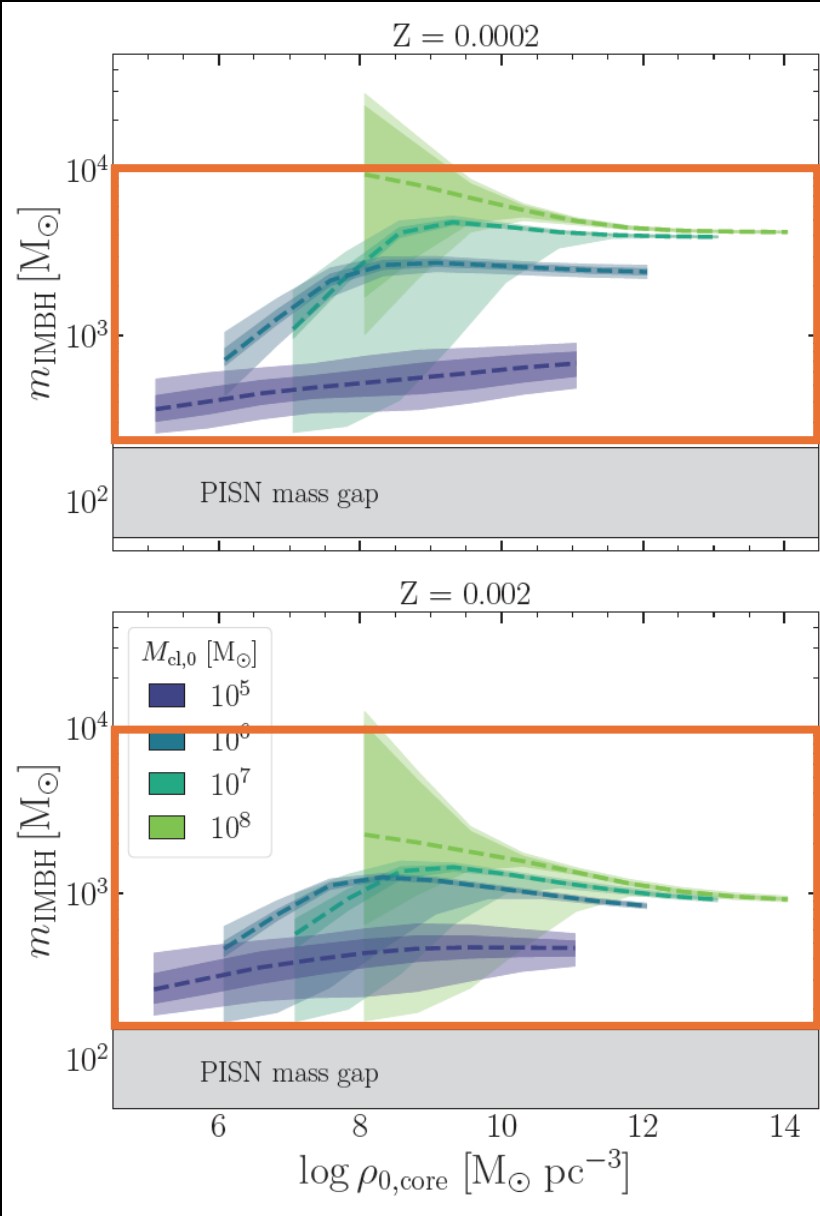
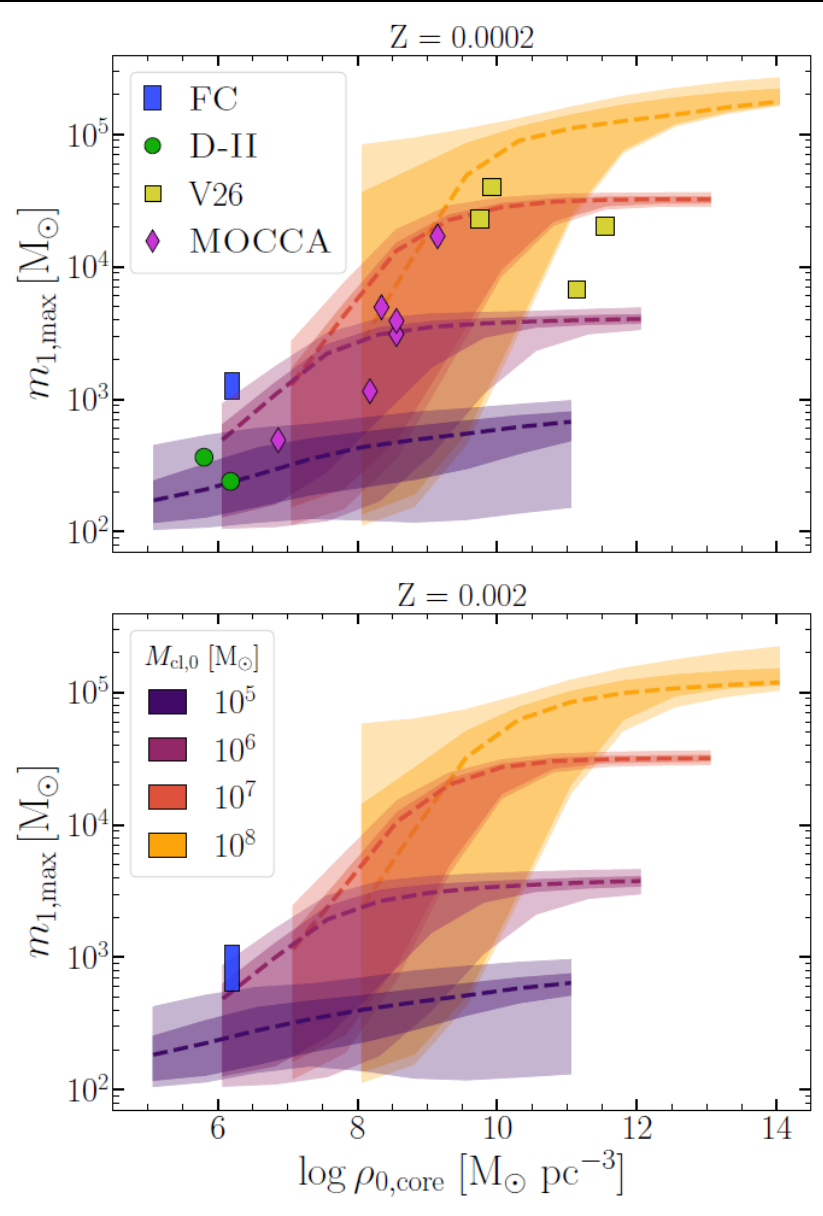
NB6 = Nbody6++GPU (Vergara et al 2025)

MOCCA (Askar et al, in prep; Giersz et al in prep)

## VMS &amp; IMBH mass distribution

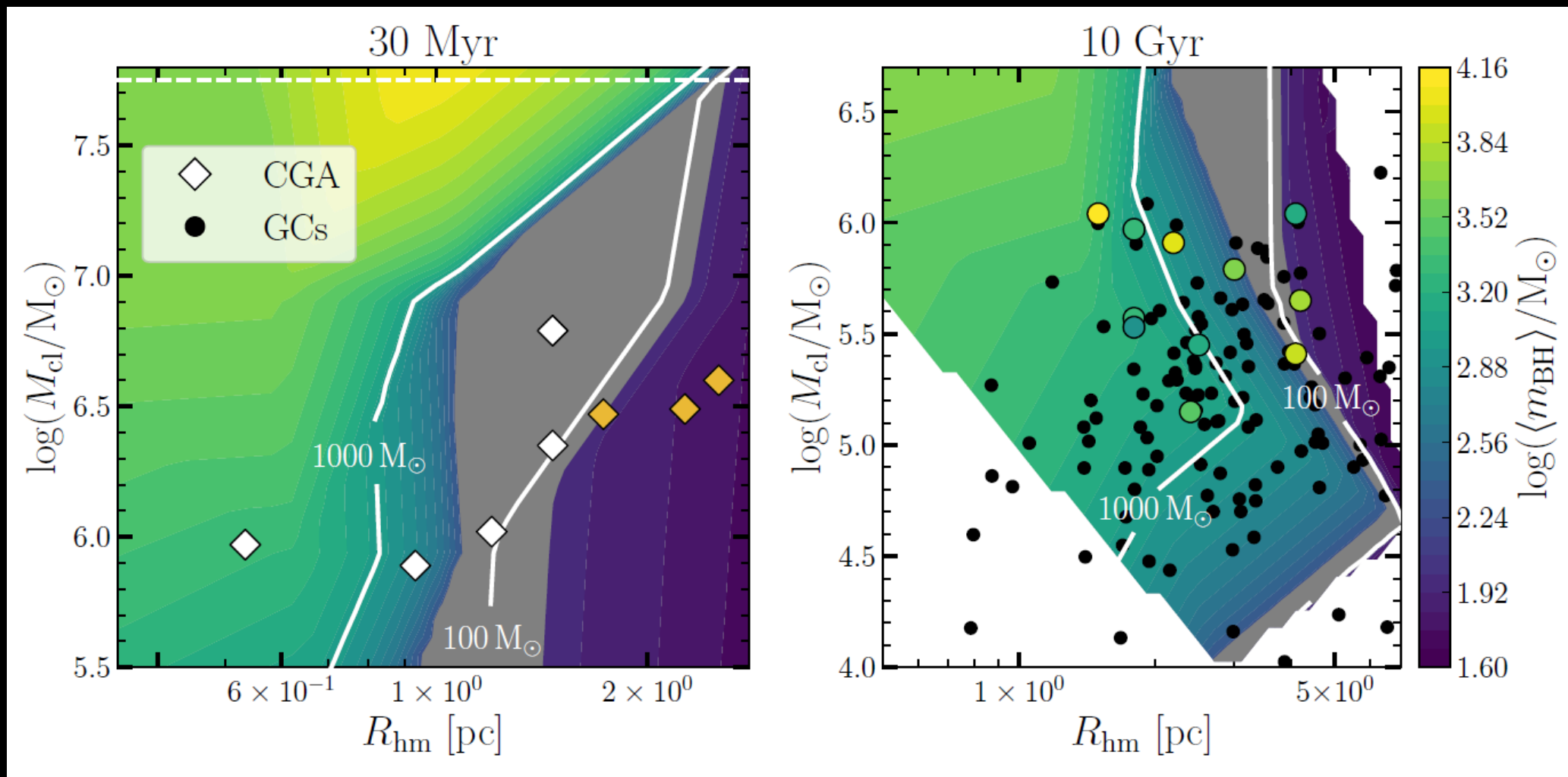


# VMS & IMBH mass distribution



LGWA  
SNR  $\geq 8$   
up to  $z \sim 10$

# Implications for Cosmic Gems Arc & Globular Clusters



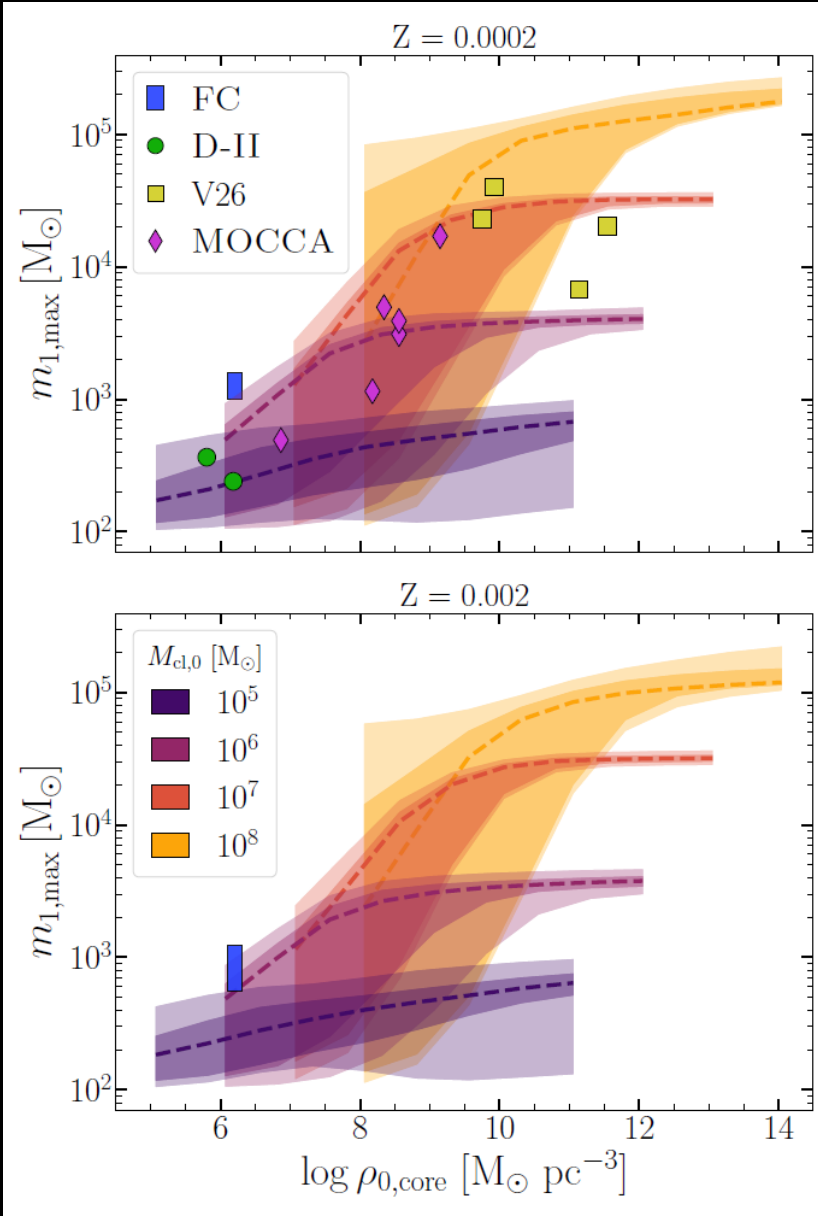
Gray area = PISN mass gap

Orange squares = counter-images

Simonato et al (in prep)

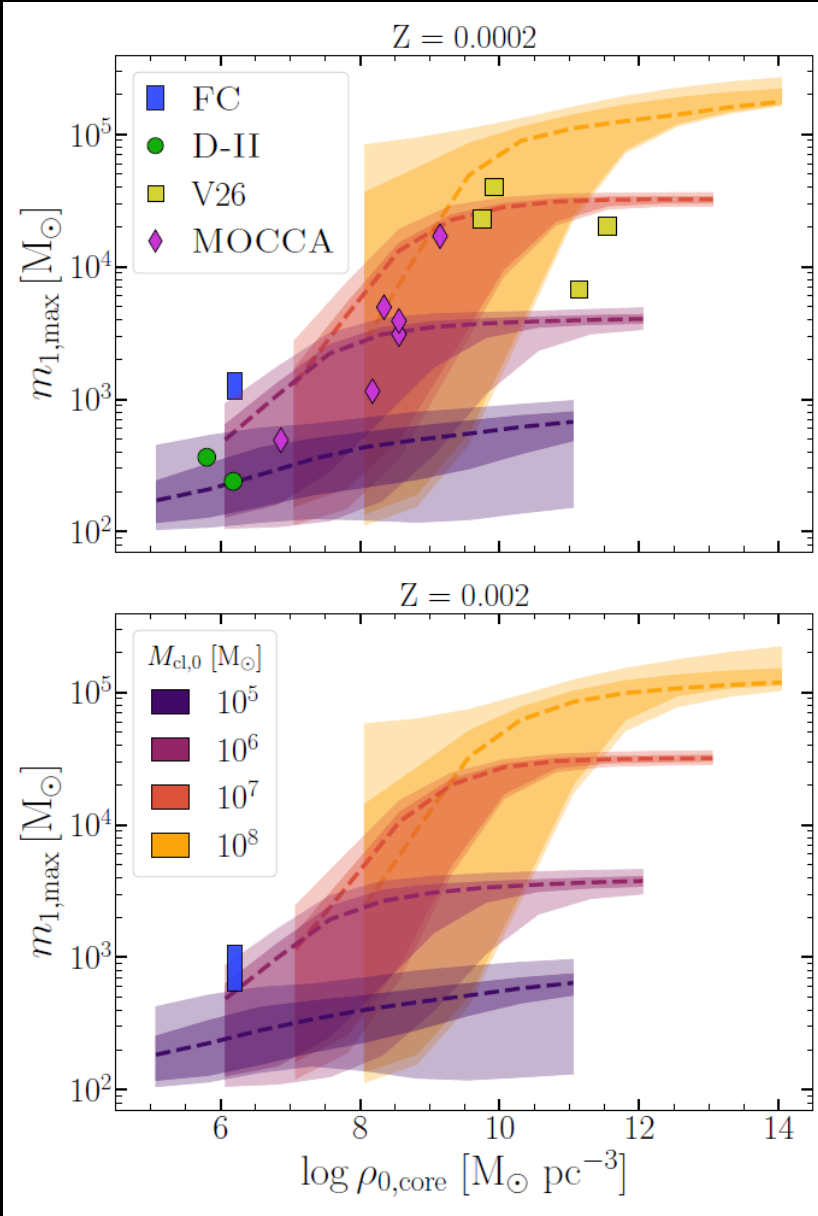
# Conclusions

- Collisions main driver for mass growth in dense systems



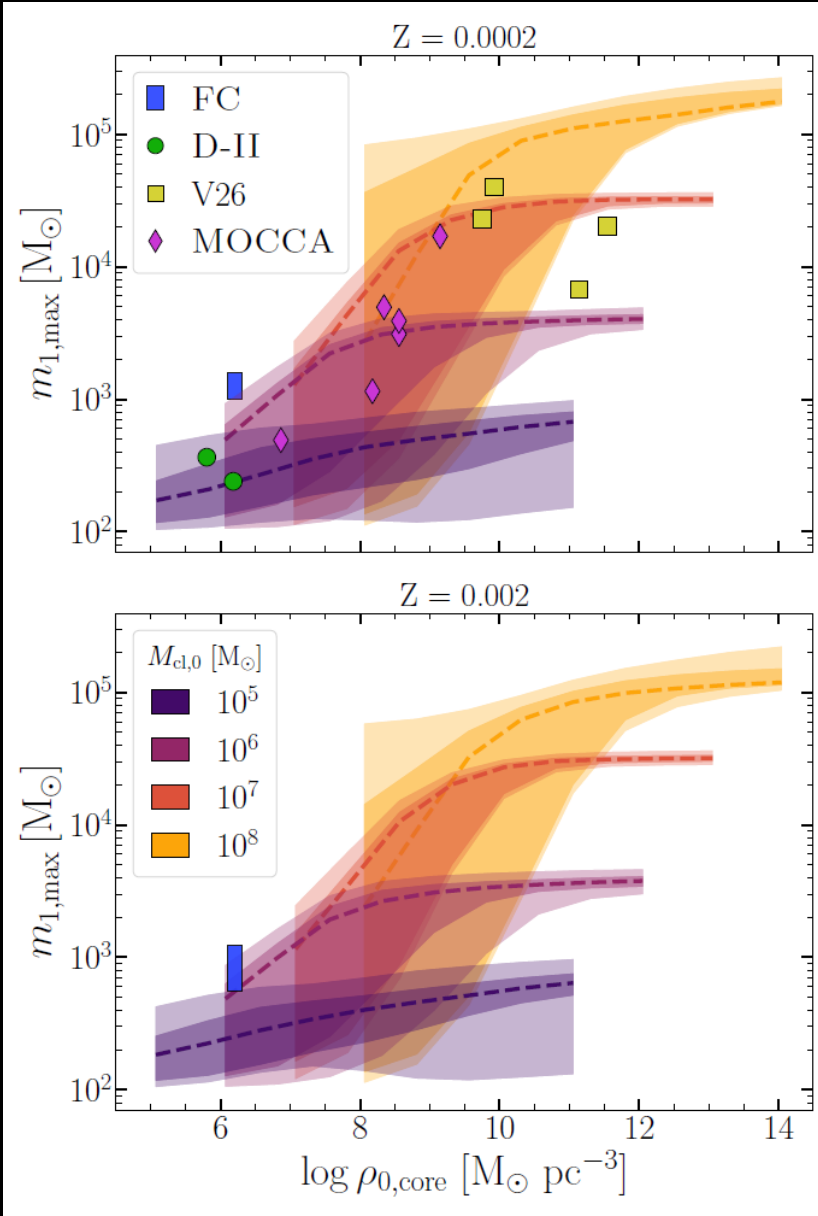
# Conclusions

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- Stars with masses up to  $\leq 10^4 M_{\odot}$  can form in dense young systems



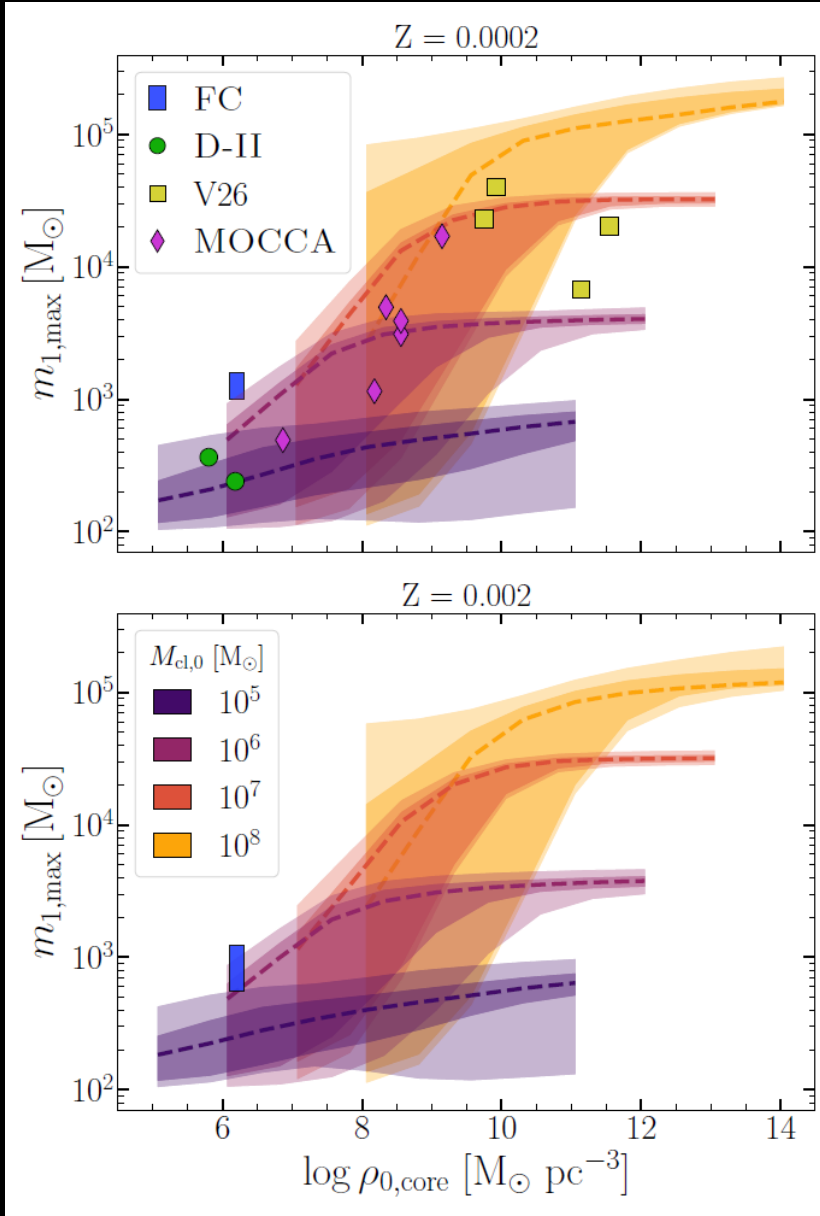
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