A unified & metallicity-dependent theory of Globular Clusters and Gravitational Waves

Dorottya Szécsi

Assistant Prof. & OPUS group leader
NCU

KU Leuven, 3rd May 2023

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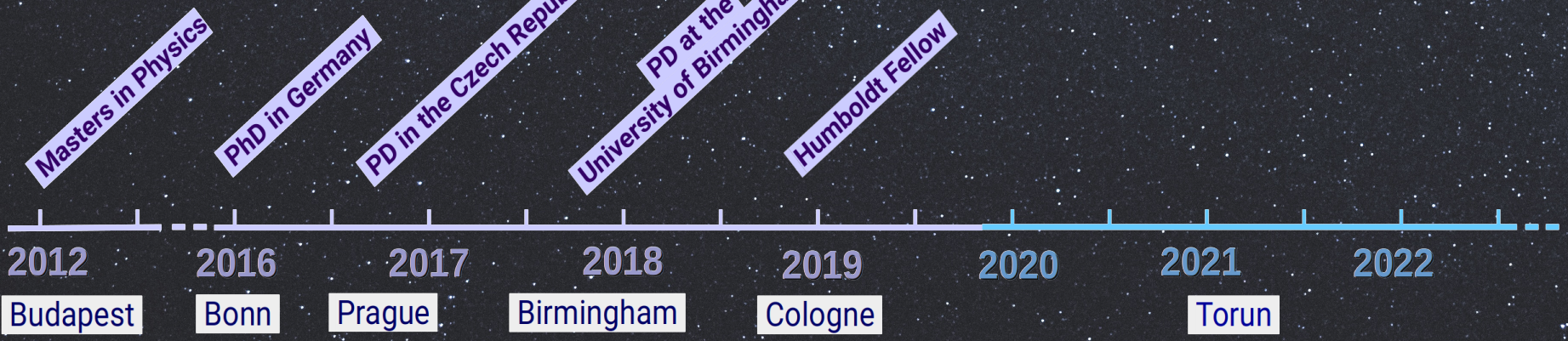

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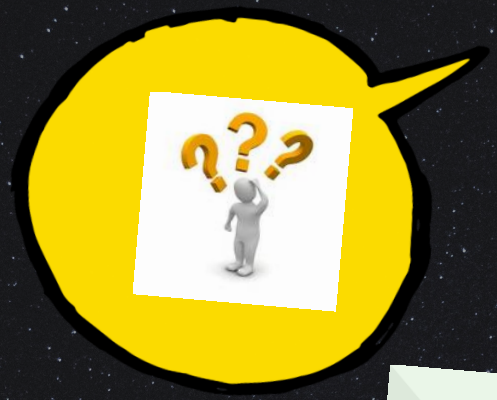

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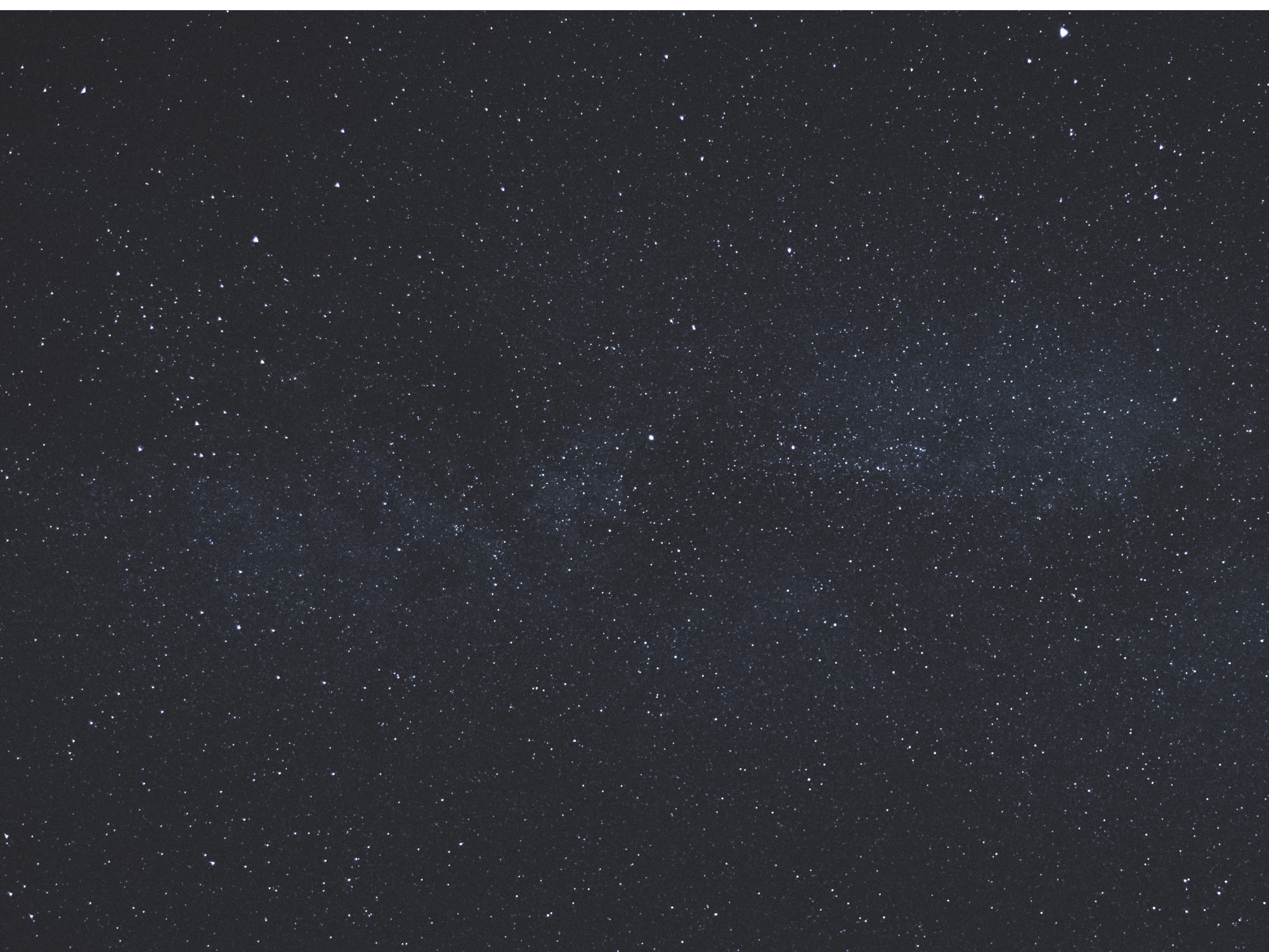
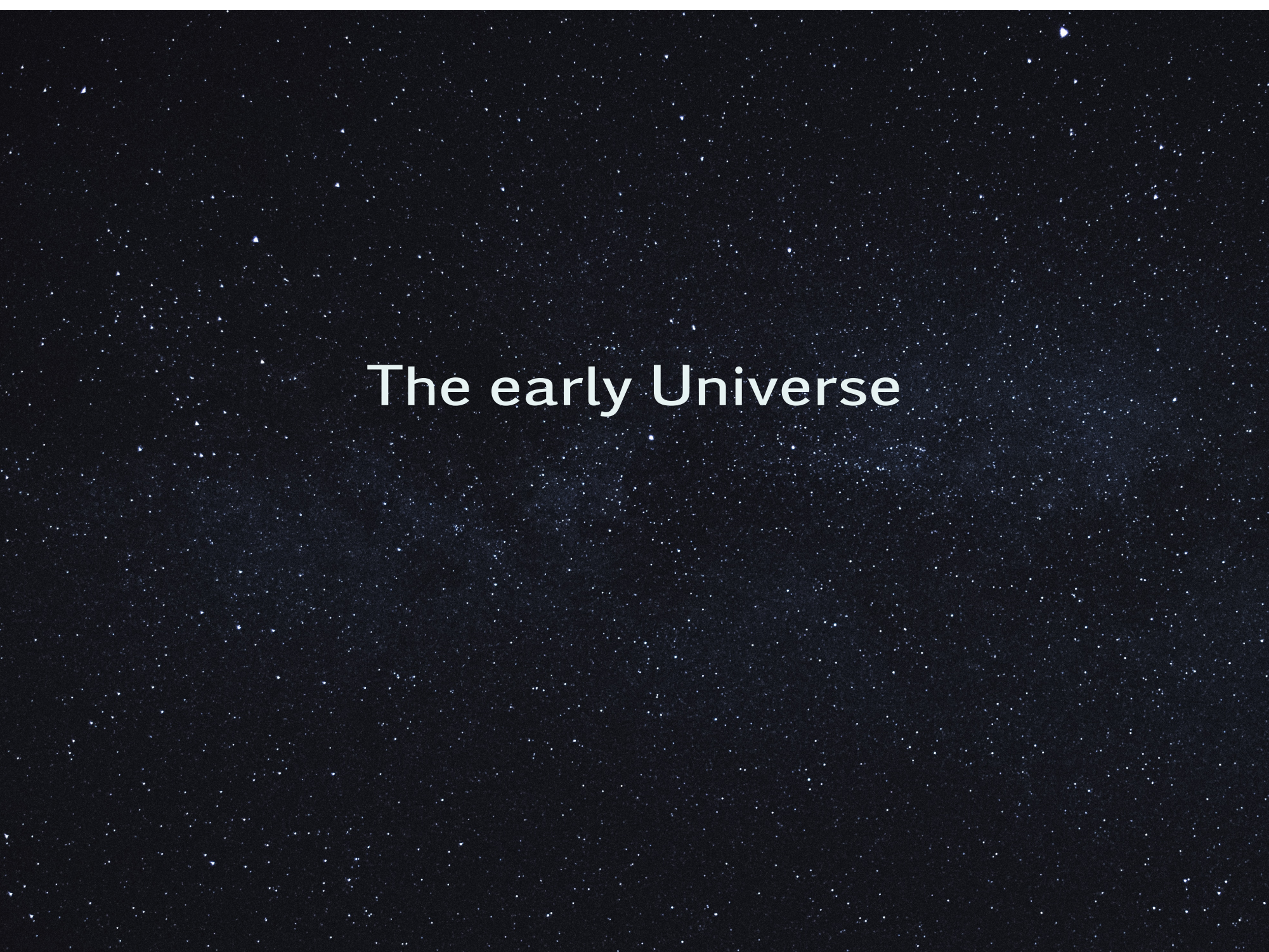
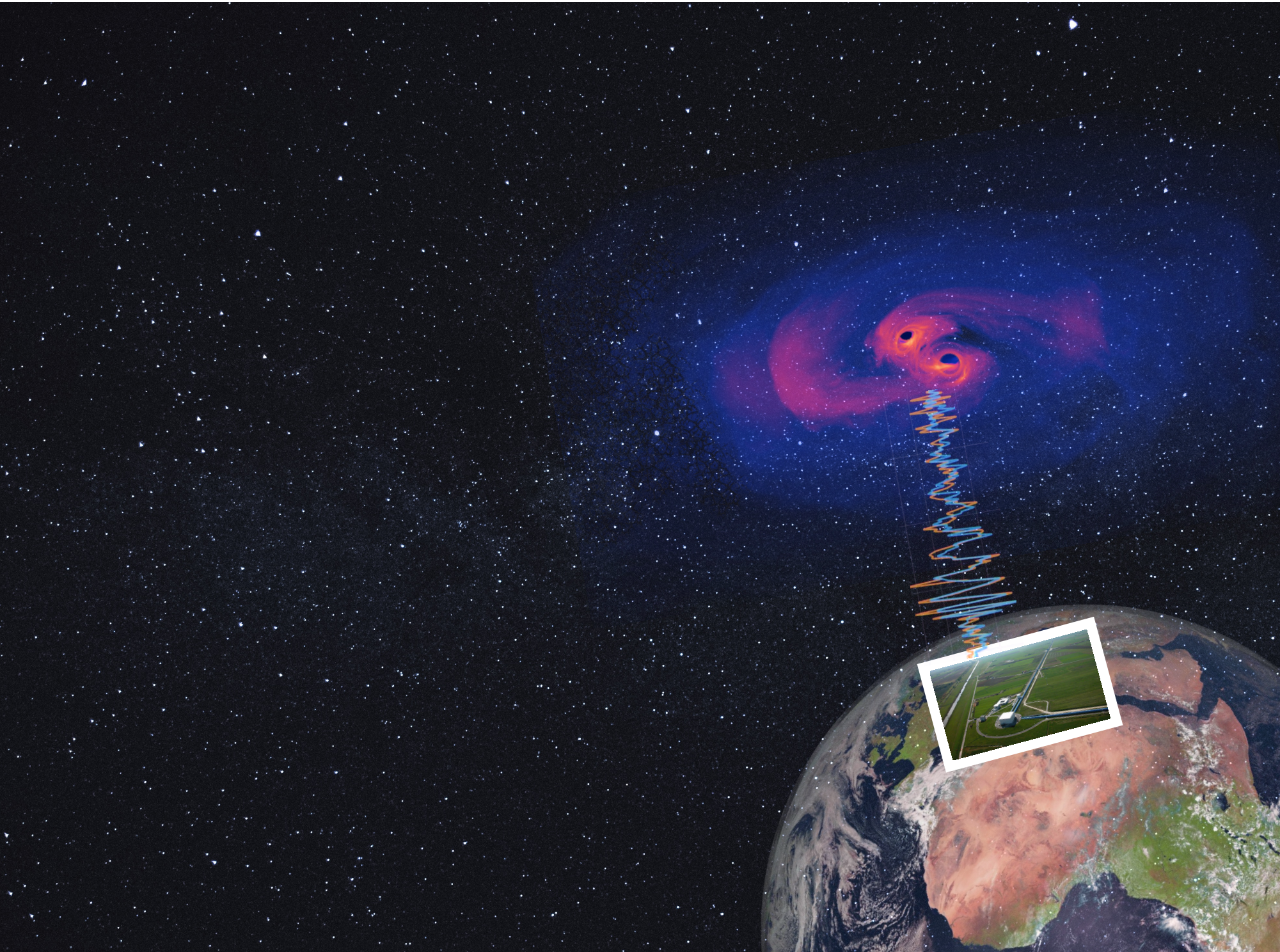
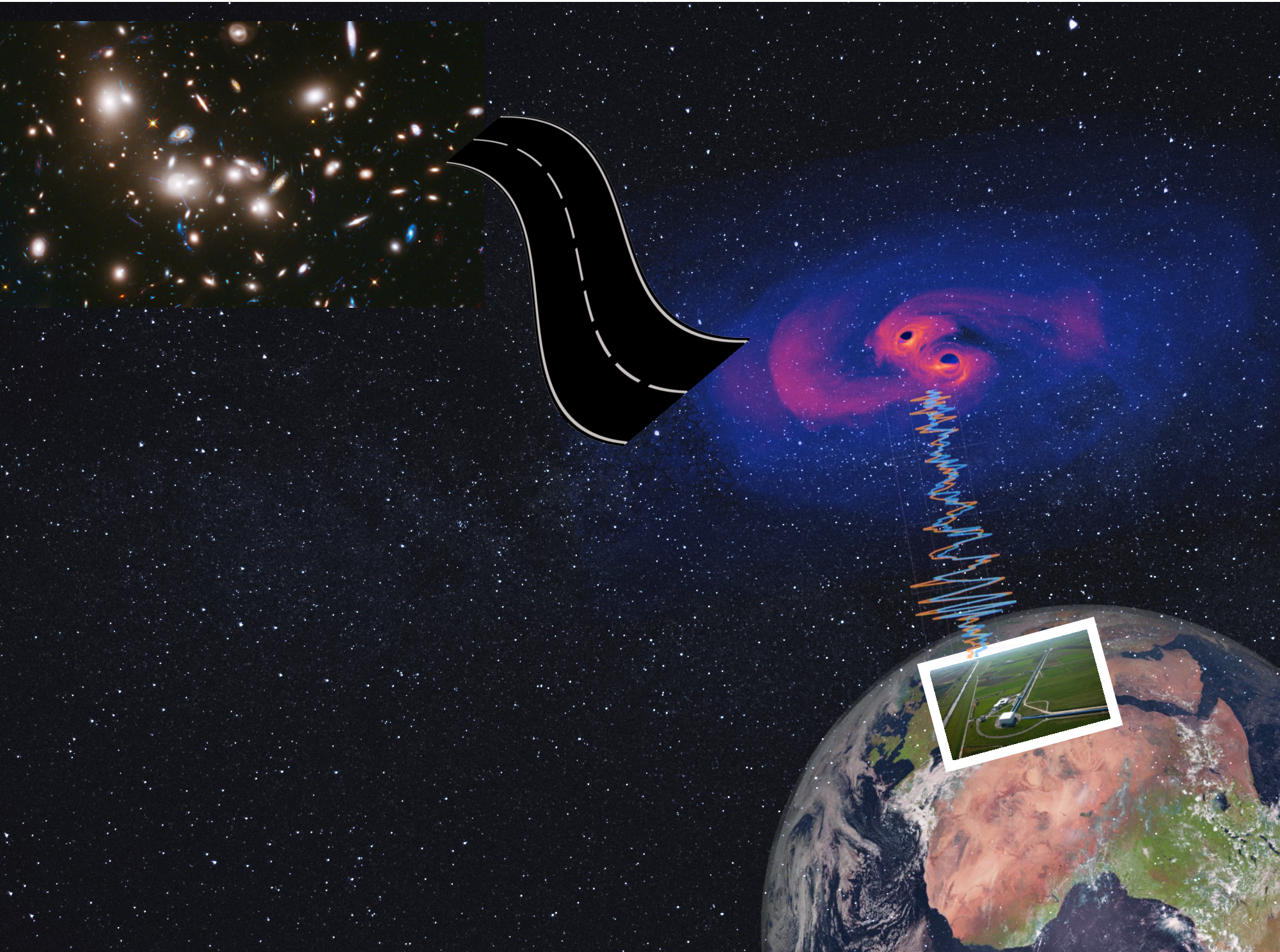
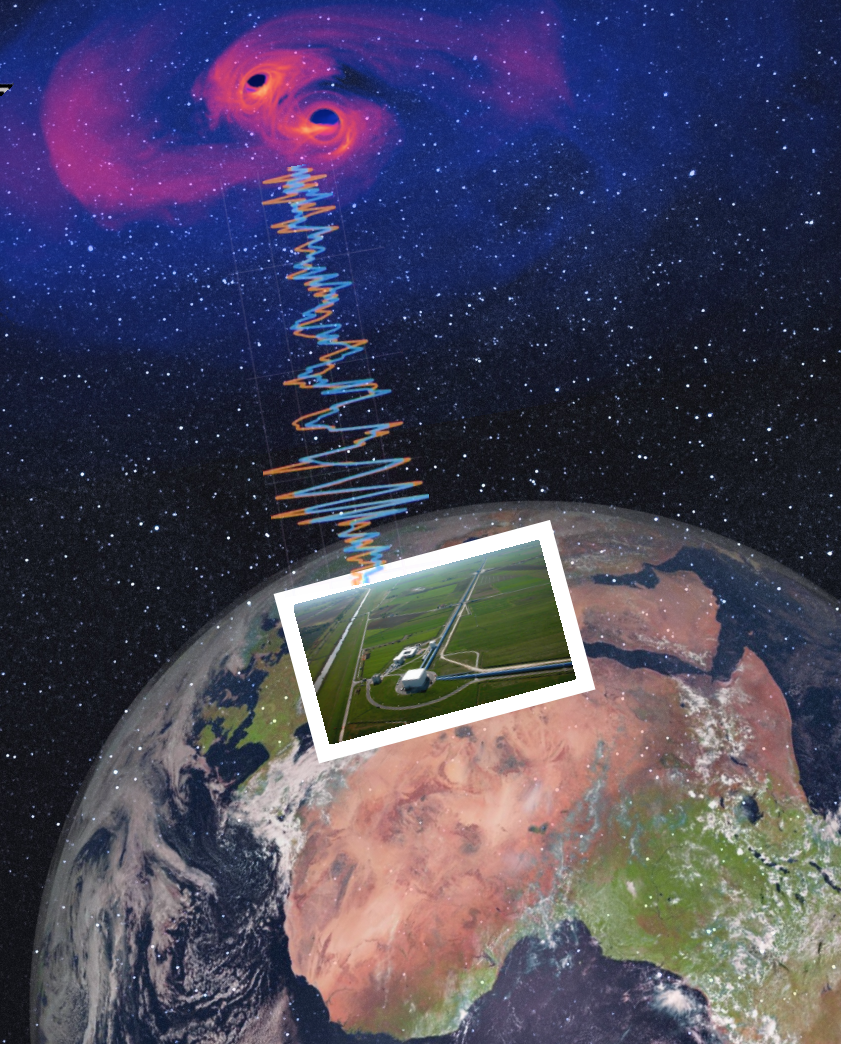



The early Universe







Metal-poor because...

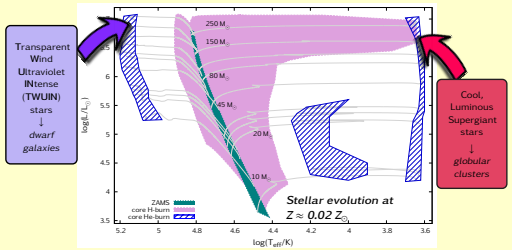
Big Bang nucleosynthesis...

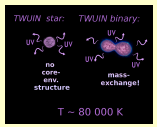
- H & He
- first (and second, and third...) stars created metals (Z)

First (and second, and third...) stars were massive...

- Pop-III ($Z = 0$) and (massive) Pop-II ($Z \lesssim Z_{SMC}$)
- 'massive' by def.: $> 8\ M_\odot$
- BHs of aLIGO/Virgo: up to 70/80 $M_\odot$

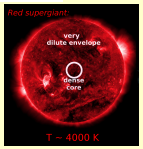
Szécsi et al. 2015:



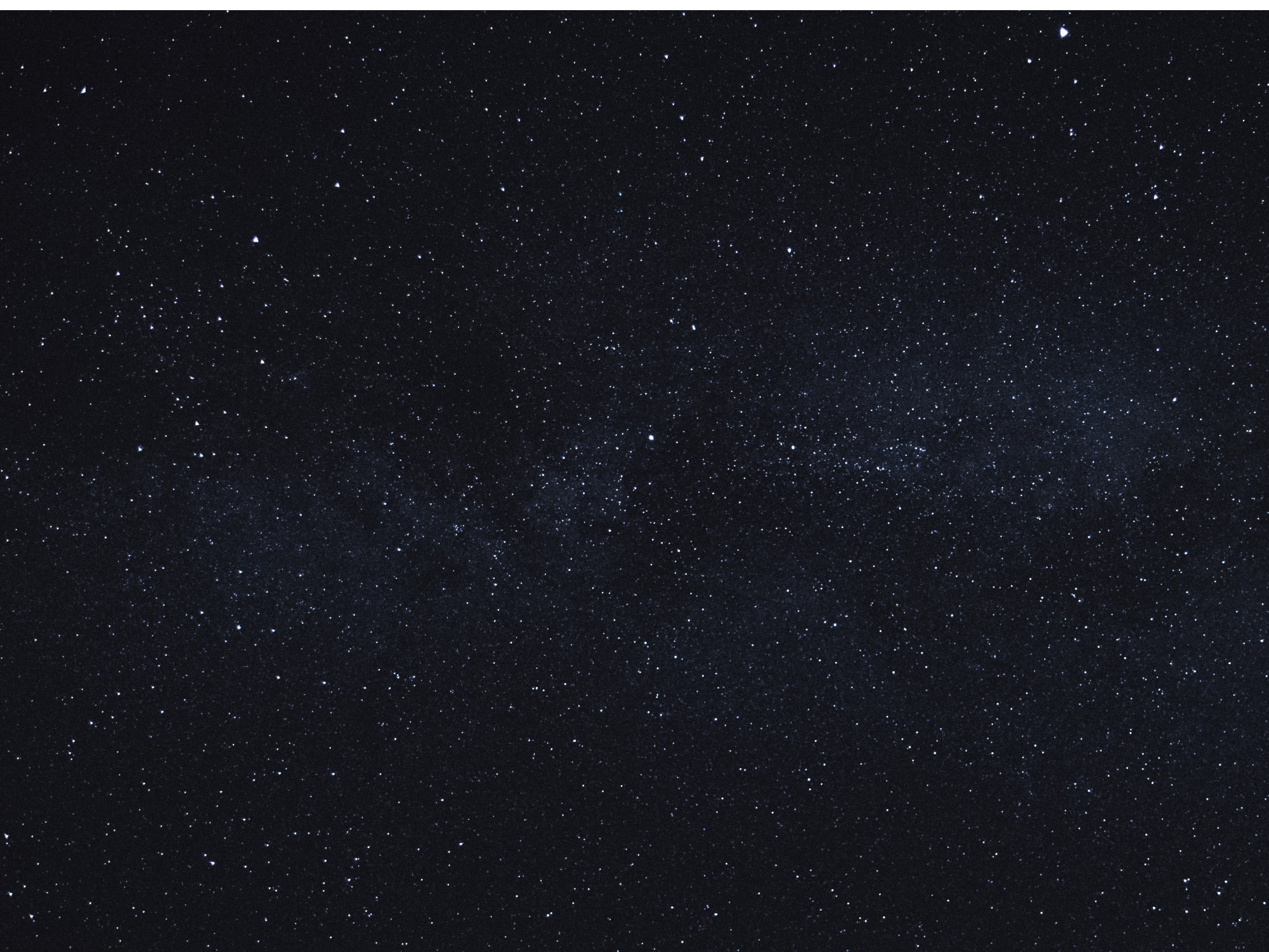


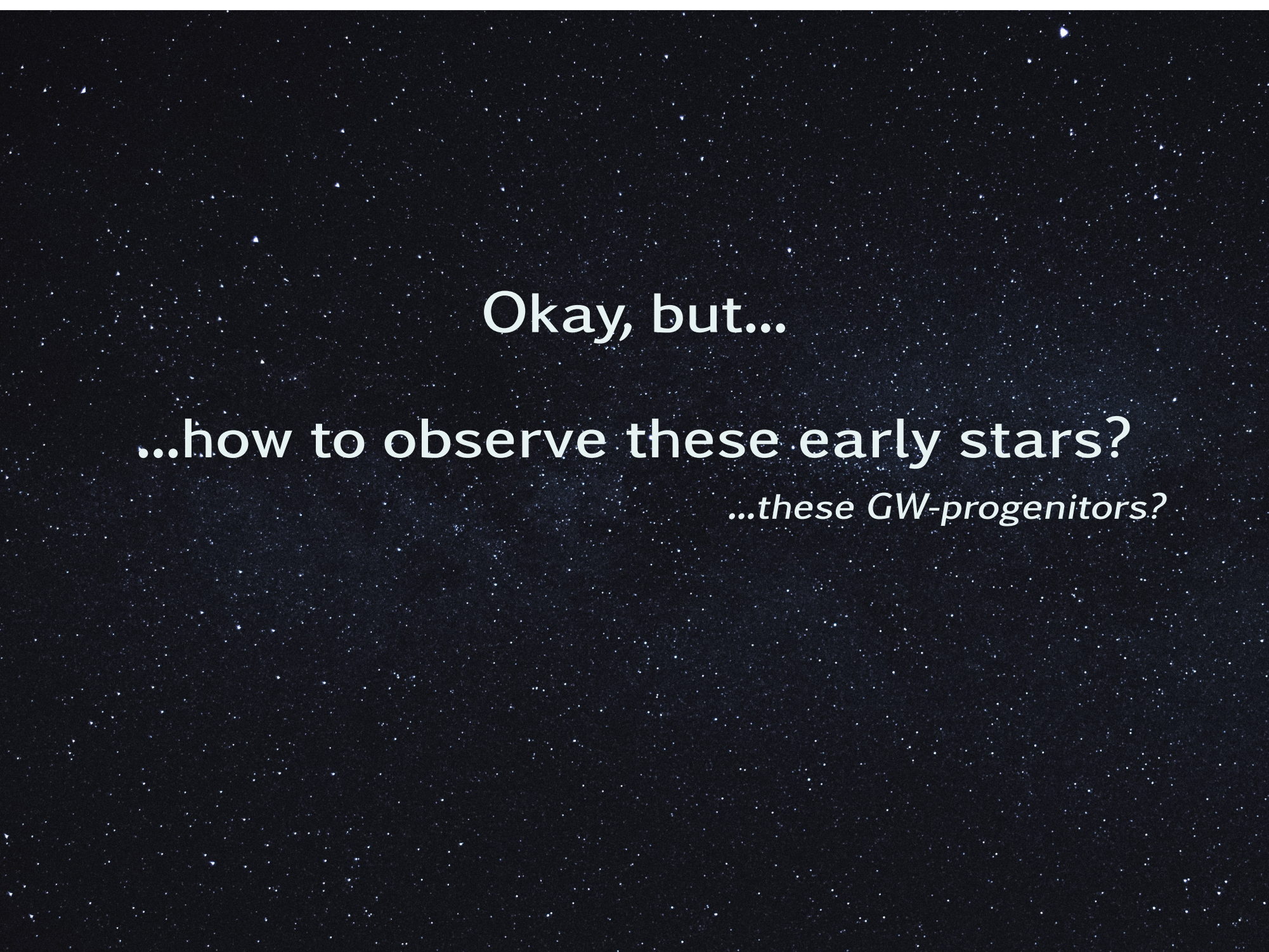
Kubátová & Szécsi+19, Szécsi'17a,'17b

Szécsi+22, Garcia, . . . , Szécsi+21



Szécsi & Wünsch'19, Szécsi+18




Okay, but...
...how to observe these early stars?
...these GW-progenitors?

We see their low-mass siblings still today!

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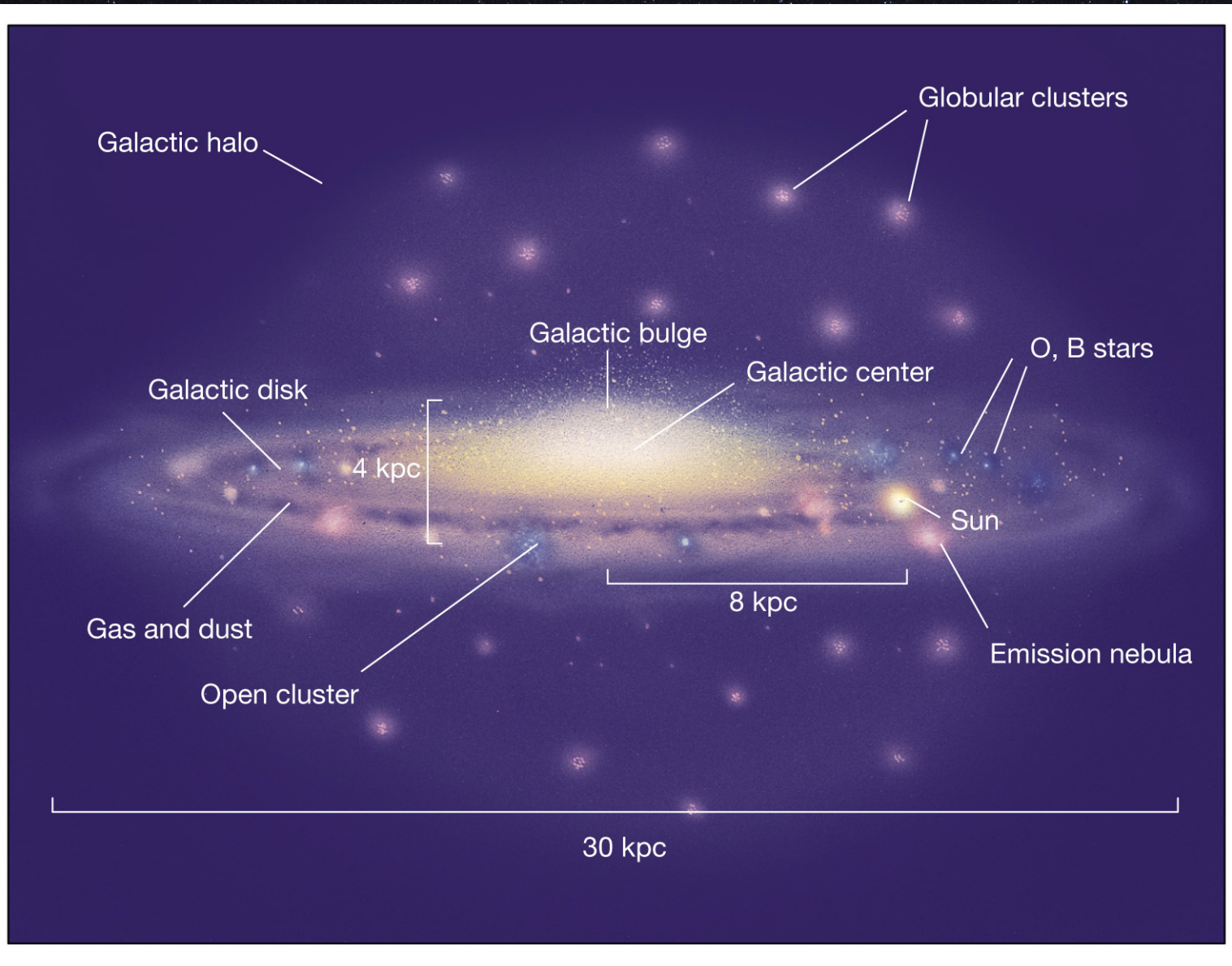

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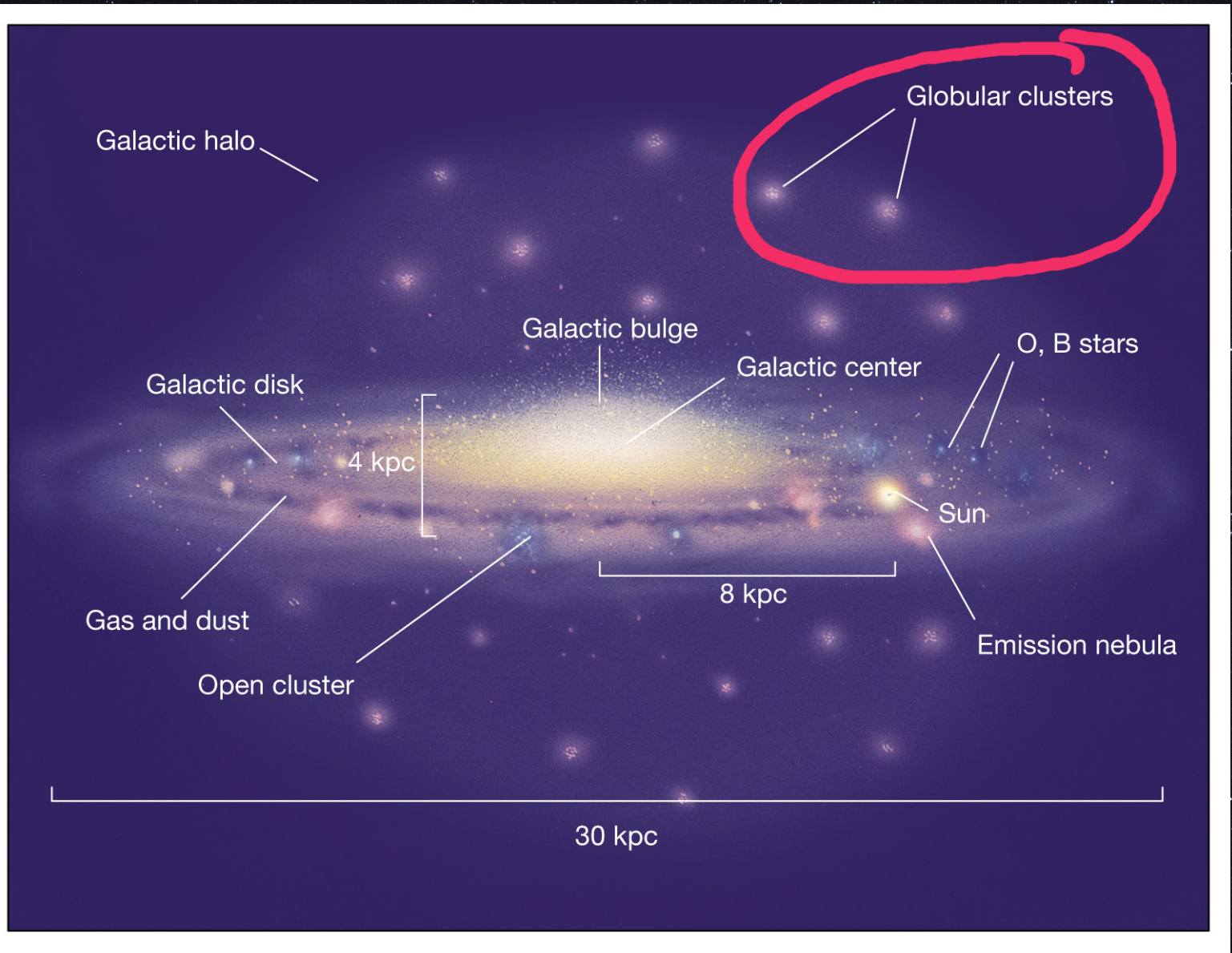

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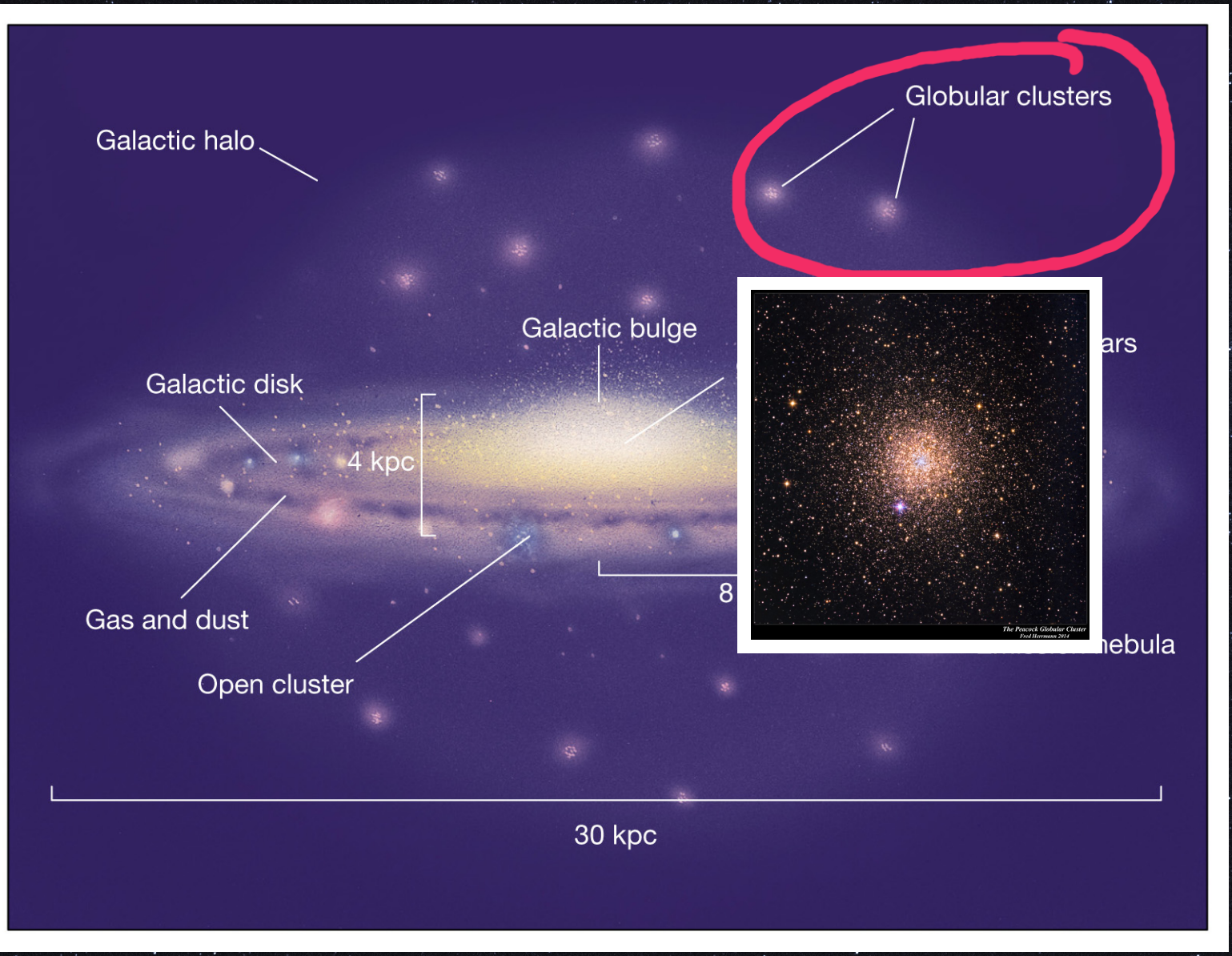

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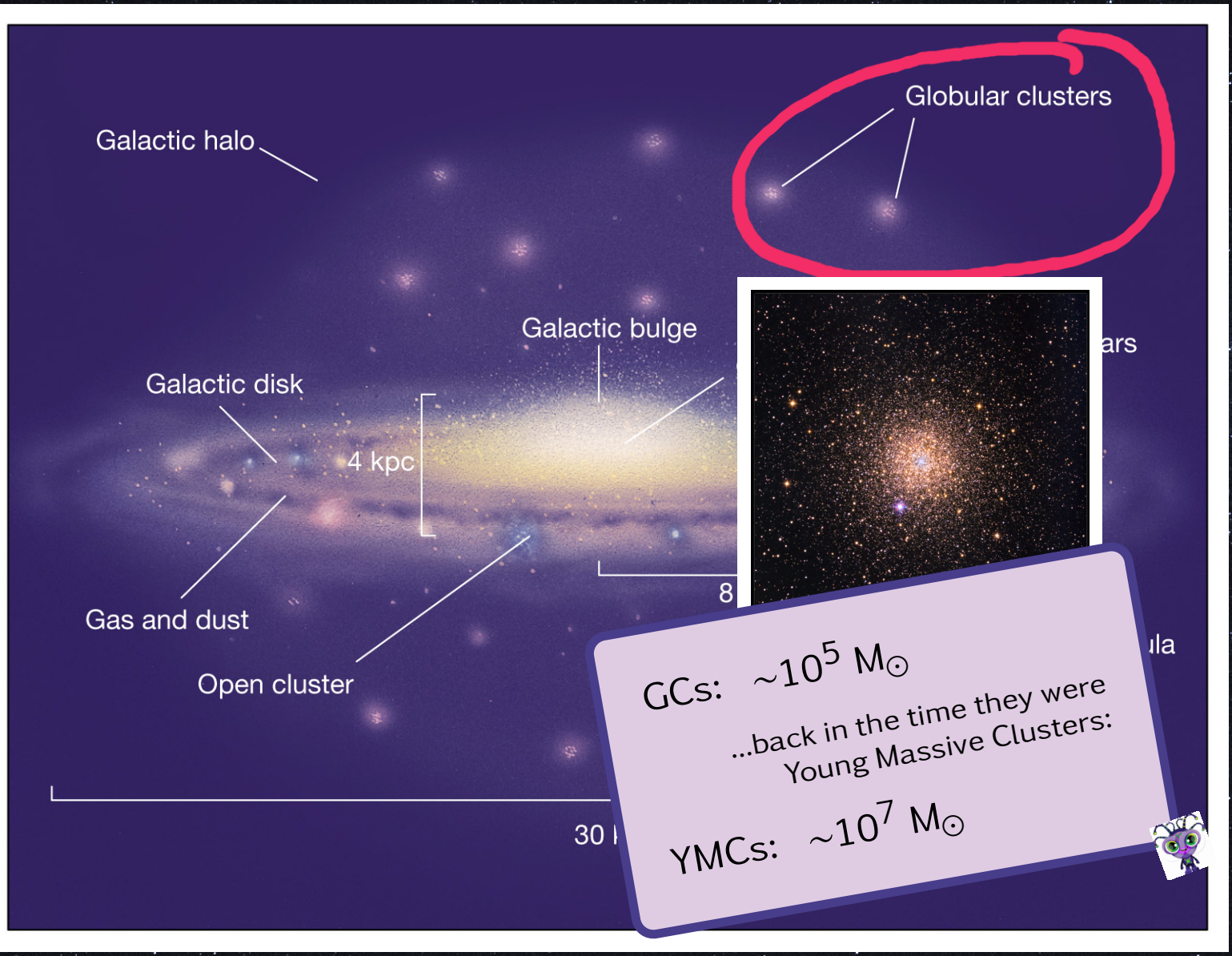

Simulating YMCs

under the influence of the First
(and Second etc.) Stars

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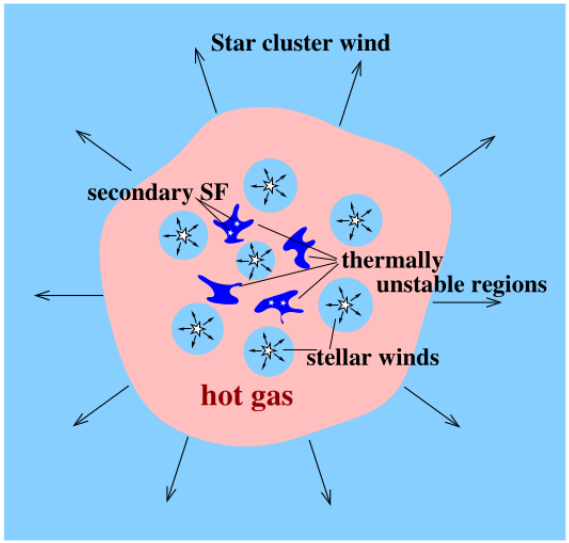
under the influence of the First (and Second etc.) Stars

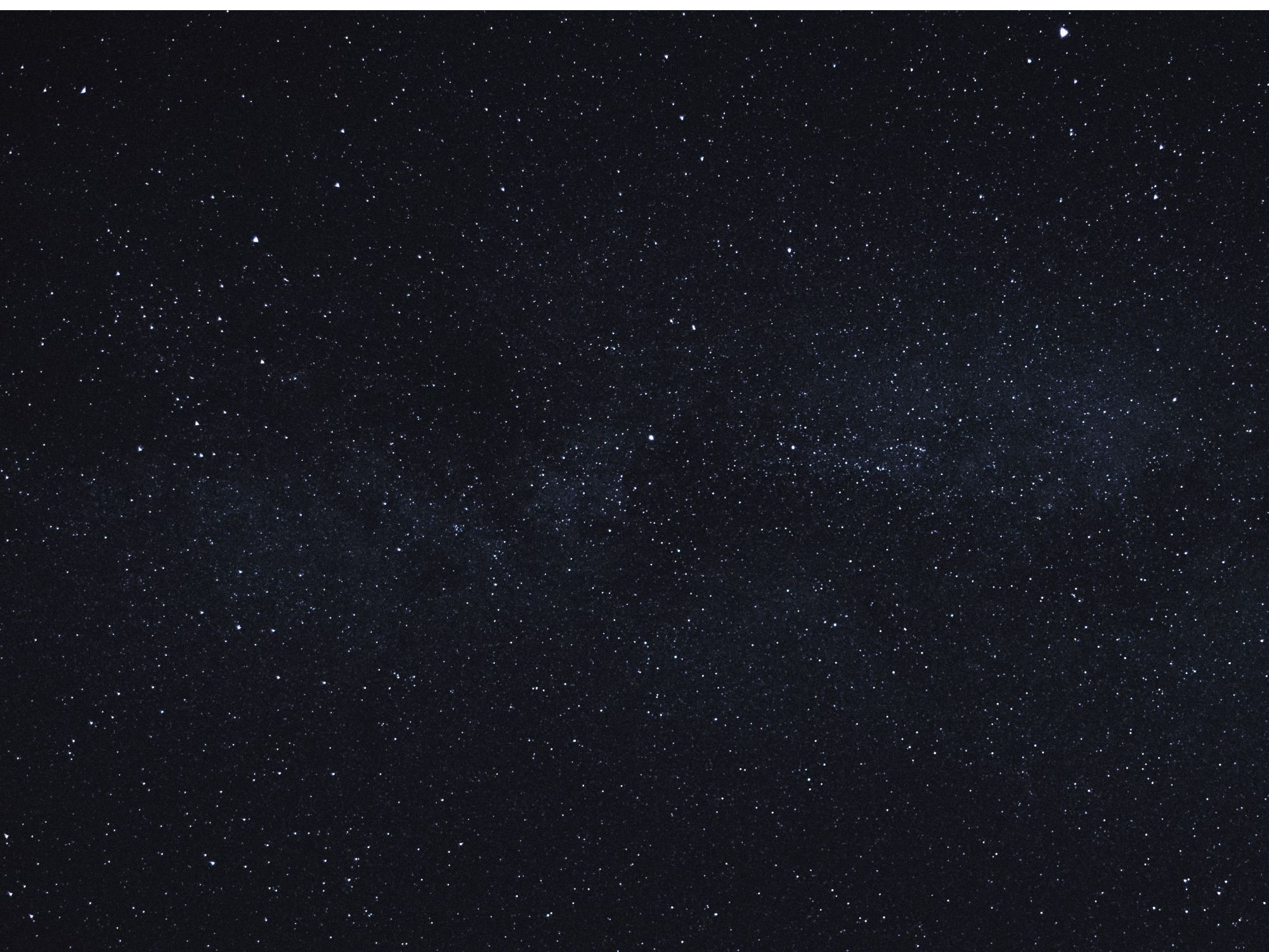
- young massive clusters have winds
  stellar winds → collisions → shocked wind → outflow
- thermal instability, rapid cooling
  if the cluster is massive and compact enough
- dense warm/cold clumps are formed
  cluster gravity ⇒ clumps fall to the centre;
  accumulation ⇒ self-shielding against EUV radiation
- 2nd generation (2G) stars formed
  enriched by products of massive stars chem. evolution



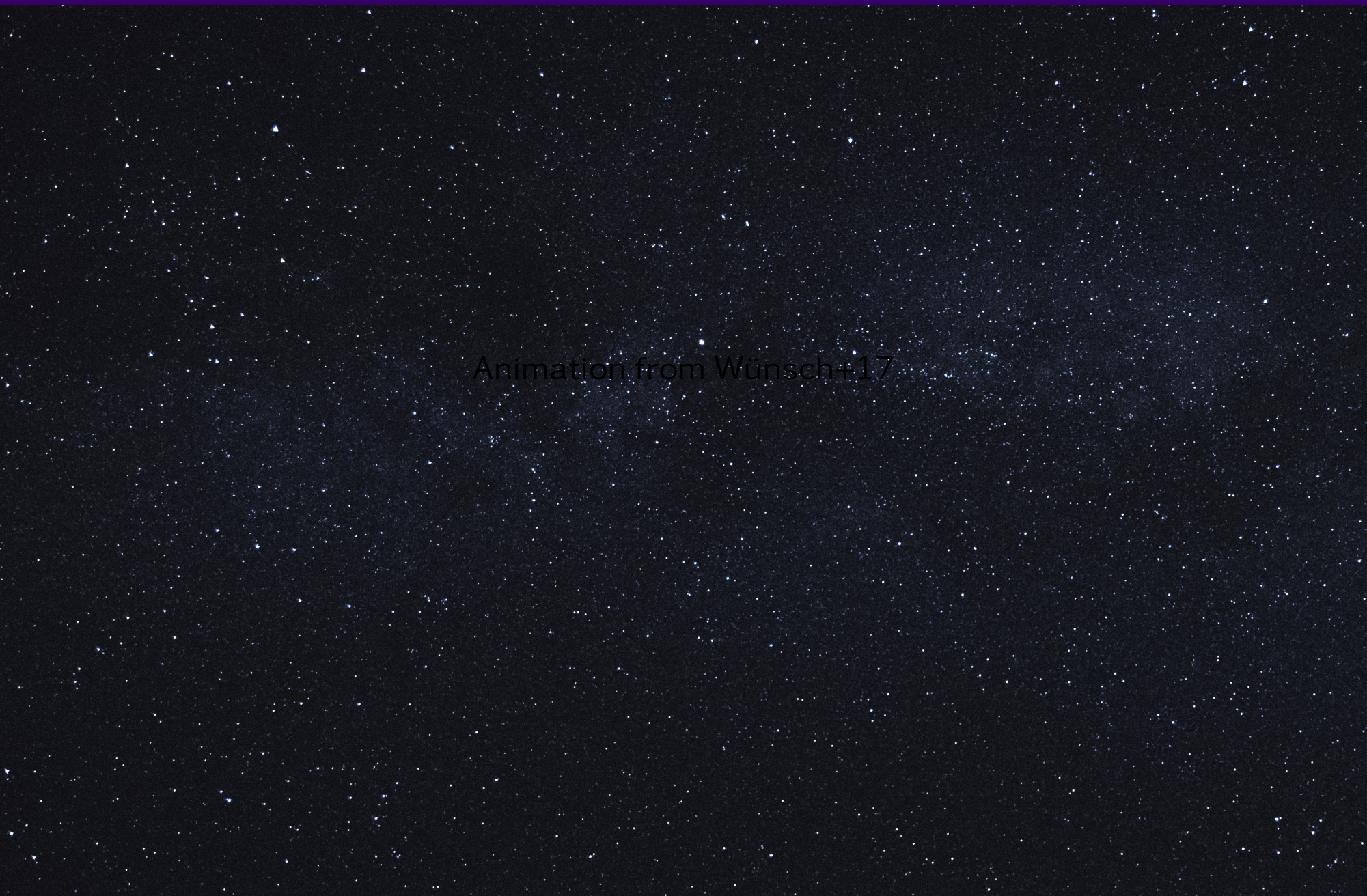
Credit: R. Wünsch (ASU)

Basic parameters:

- L_{SC}, $\dot{M}_{SC} \leftarrow M_{1G}$, stellar evolution tracks
- R_{SC} + eventually radial profile (R_c, β)



From 3D hydro to semi-analytic (quick)



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RHD simulations:
(Wünsch+17):

- AMR code Flash, 512^3 (finest) (Fryxell+00)
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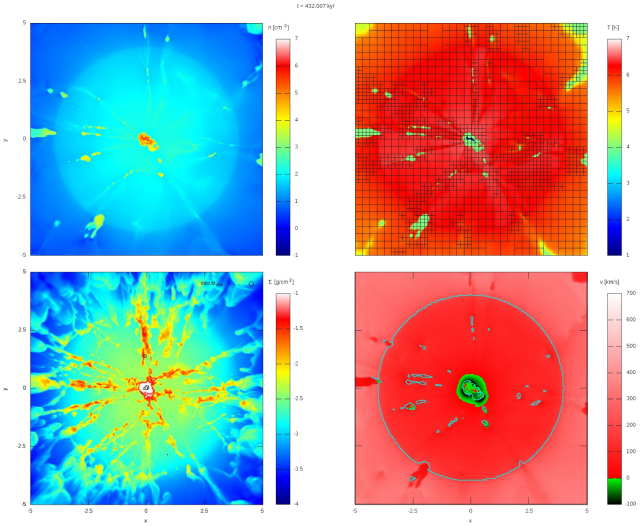

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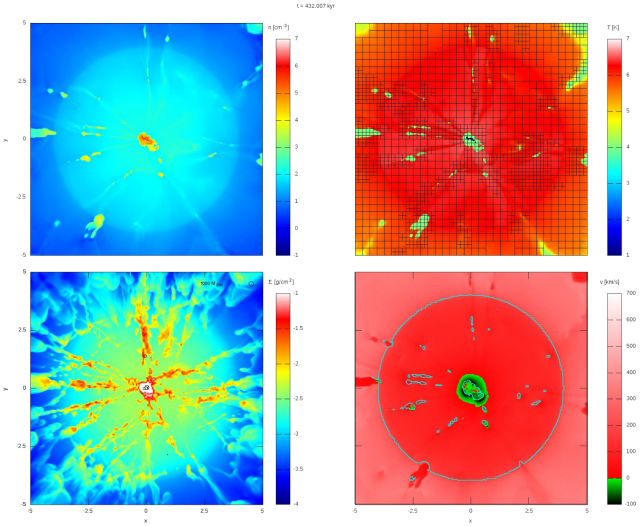

Semianalytic model:

(Chevalier&Clegg+85, Silich+04, Wünsch+17)

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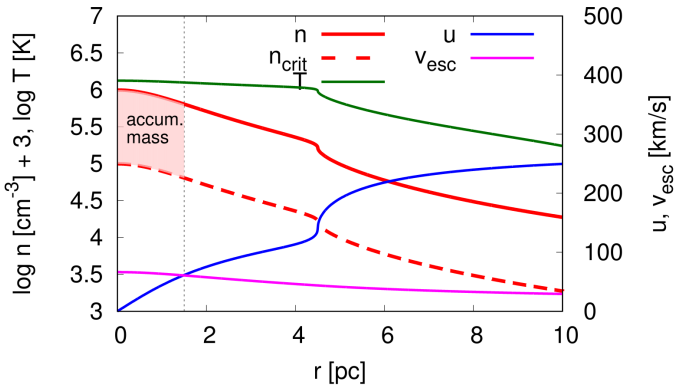
$$q_m, q_e \propto (1 + (r/R_c)^2)^{-\beta} \text{ for } r < R_{SC}$$



Mass accumulation:

$$M_{\rm acc}(t) = \int_{t_{bs}}^{t}\int_0^{R_{\rm esc}} [q_m(r,t') - q_{m,crit}(r,t')]\,dr dt'$$

rate of the clump formation is given by $q_m - q_{m,crit}$

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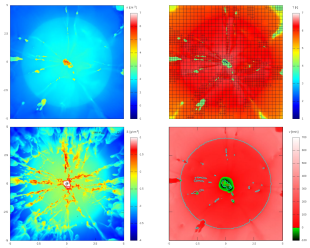

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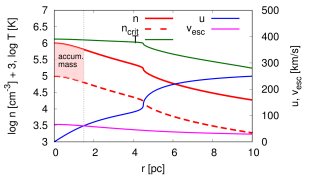

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...and adding BoOST stellar models (Bonn code)

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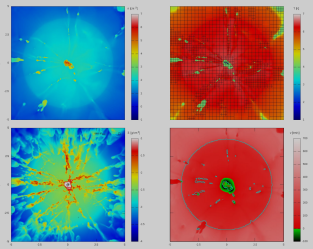

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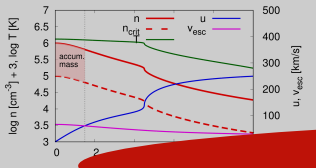

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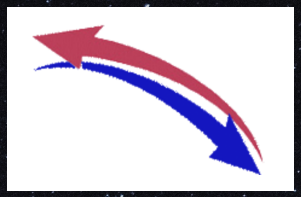
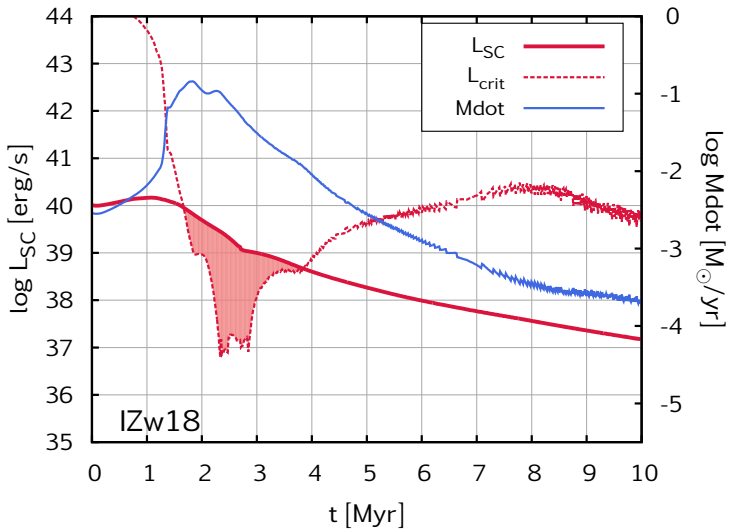


YMC under the influence of Early Stars from BoOST




The BoOST project
Szécsi+ 22

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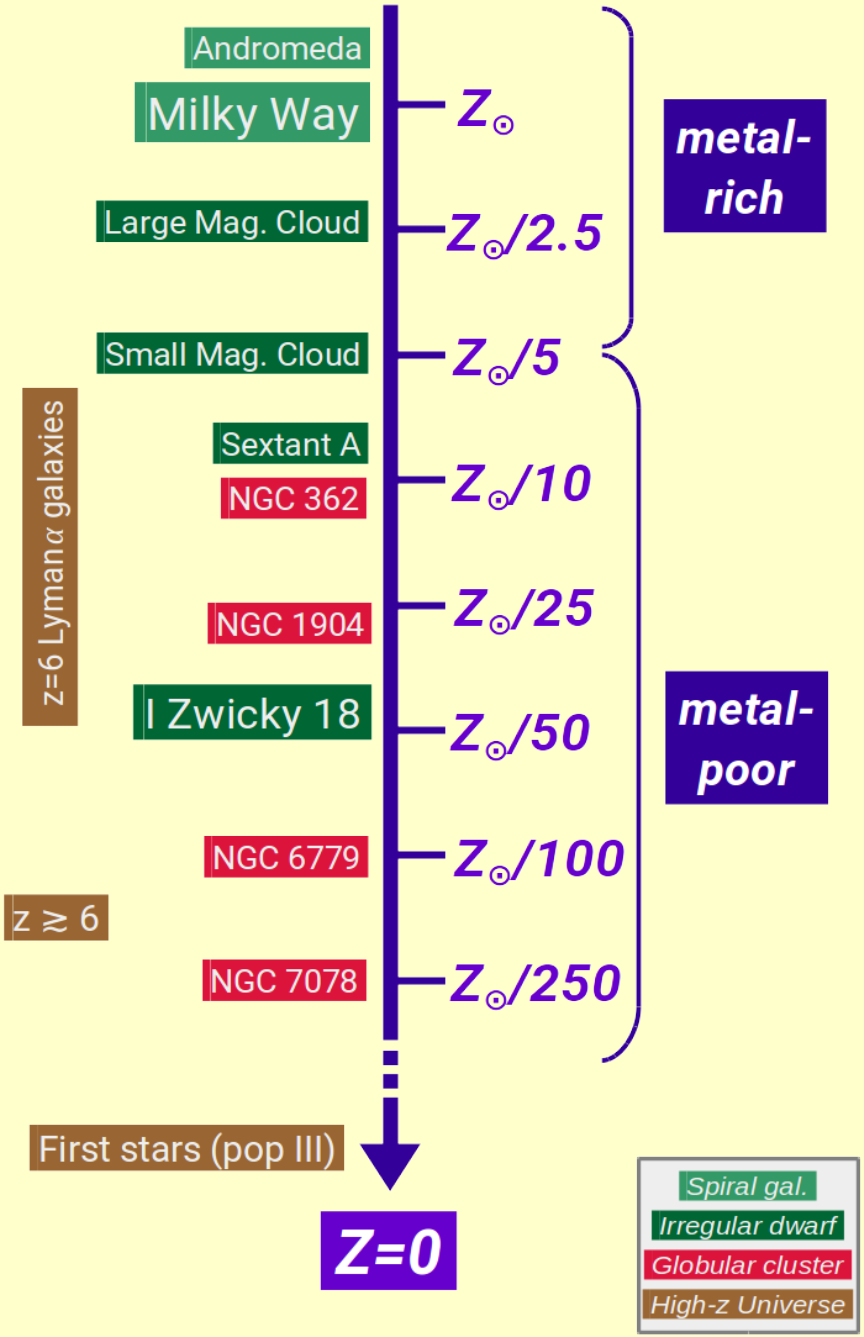

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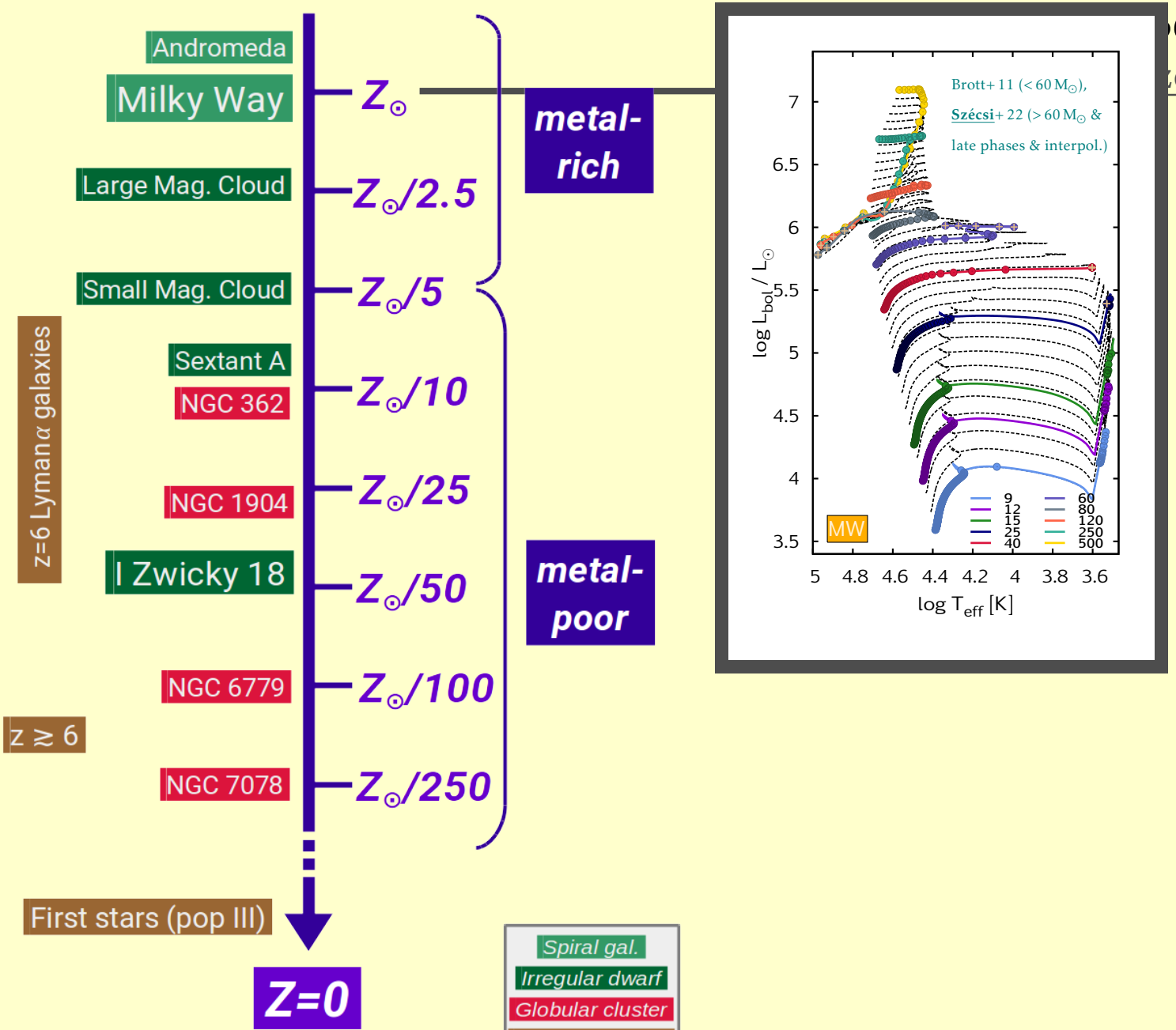

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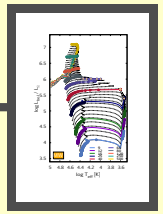


Andromeda

Milky Way — $Z_\odot$

Large Mag. Cloud — $Z_\odot/2.5$

Small Mag. Cloud — $Z_\odot/5$

Sextant A

NGC 362 — $Z_\odot/10$

NGC 1904 — $Z_\odot/25$

I Zwicky 18 — $Z_\odot/50$

NGC 6779 — $Z_\odot/100$

NGC 7078 — $Z_\odot/250$

metal-rich

metal-poor

z=6 Lyman α galaxies

$z \gtrsim 6$

First stars (pop III)

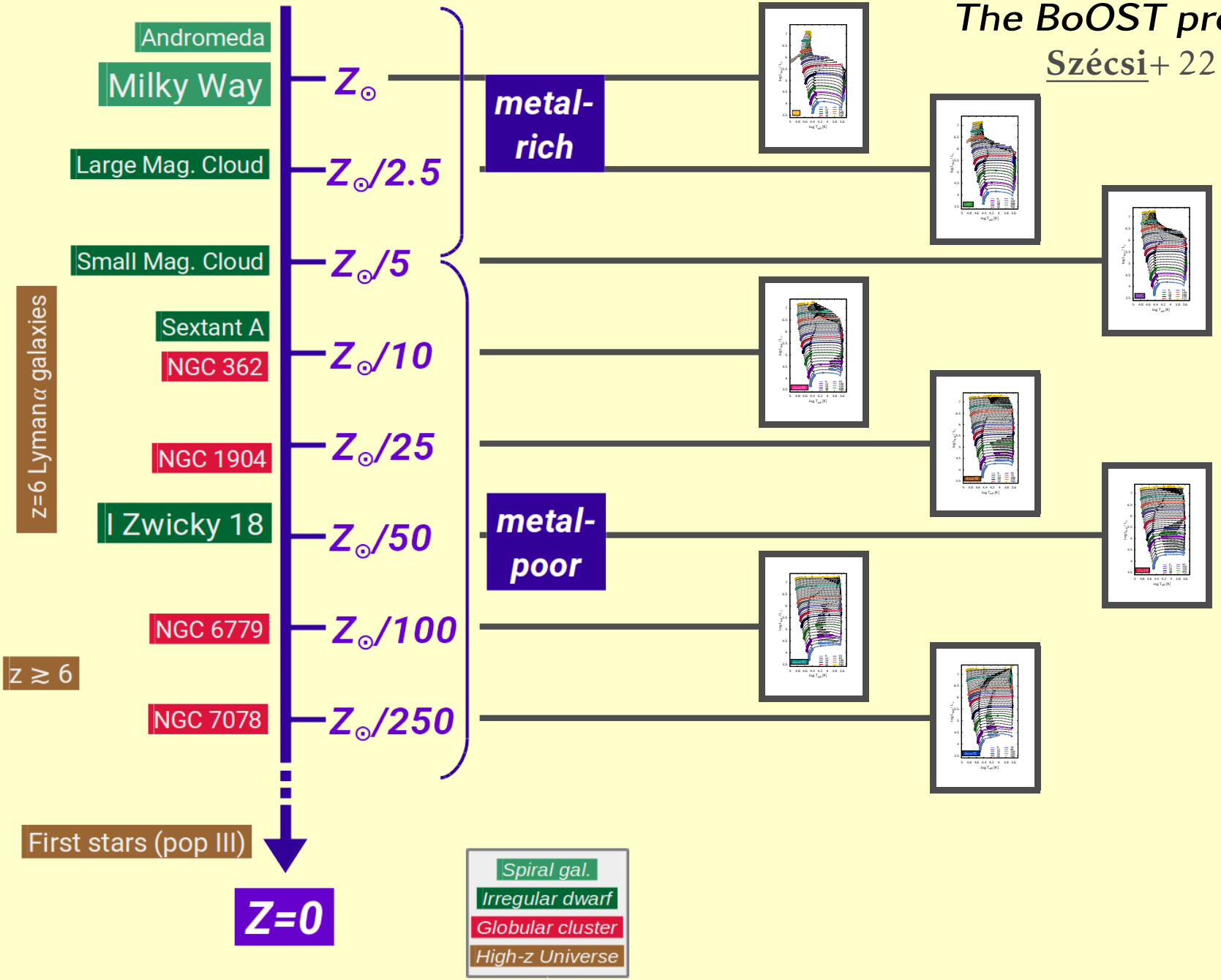
Z=0

Spiral gal.

Irregular dwarf

Globular cluster

High-z Universe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Z=0
Z⊙
Z⊙/2.5
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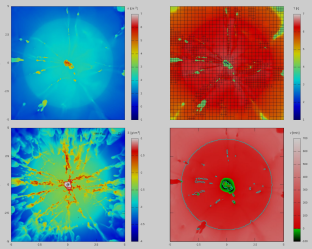

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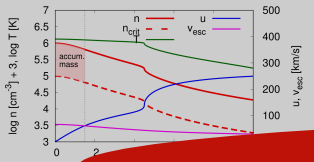

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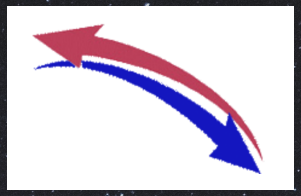

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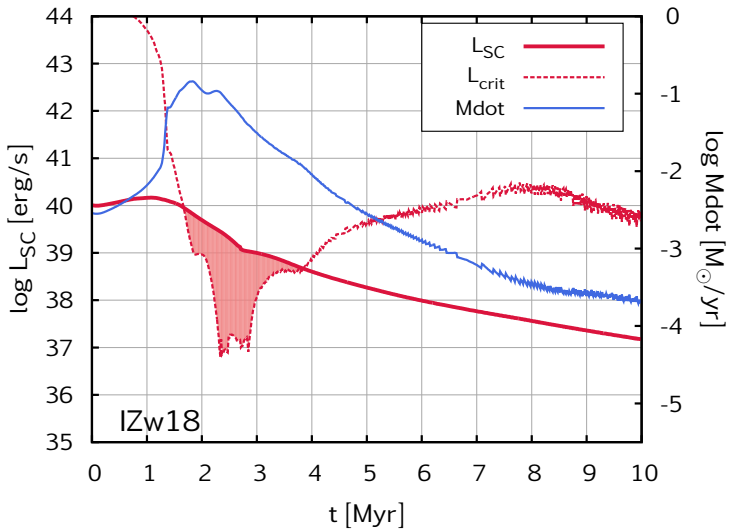

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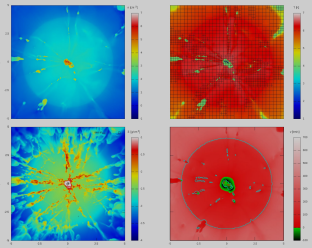

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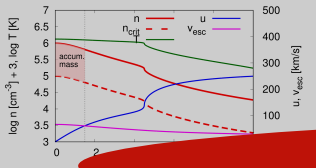

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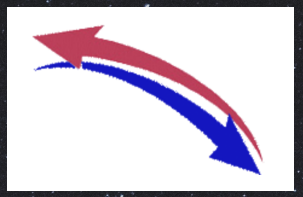

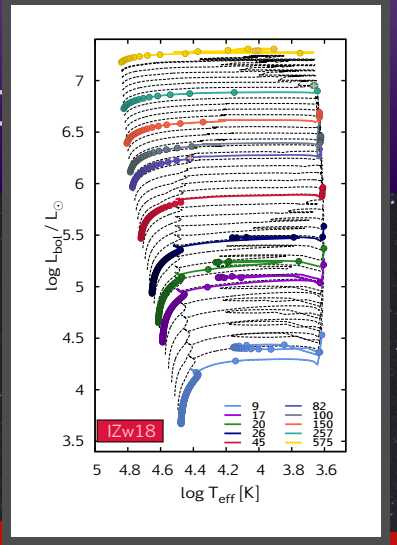

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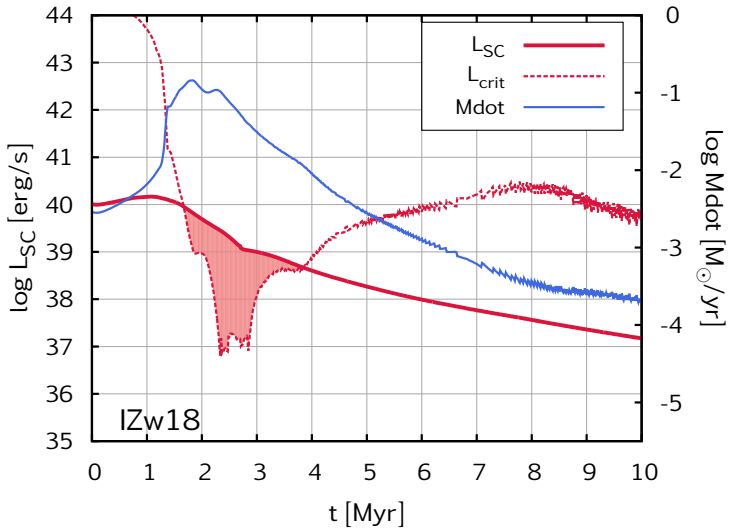

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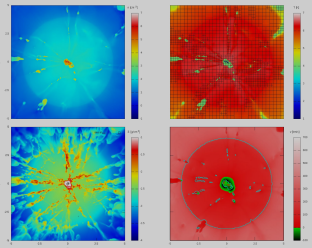

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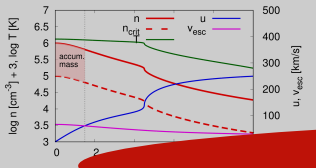

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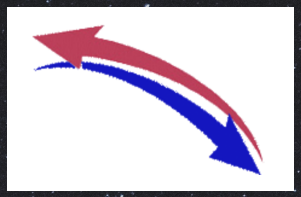

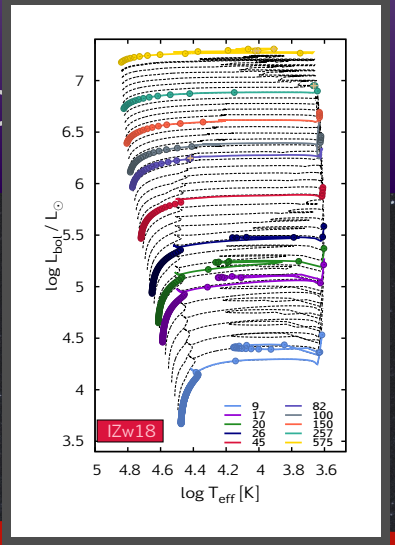

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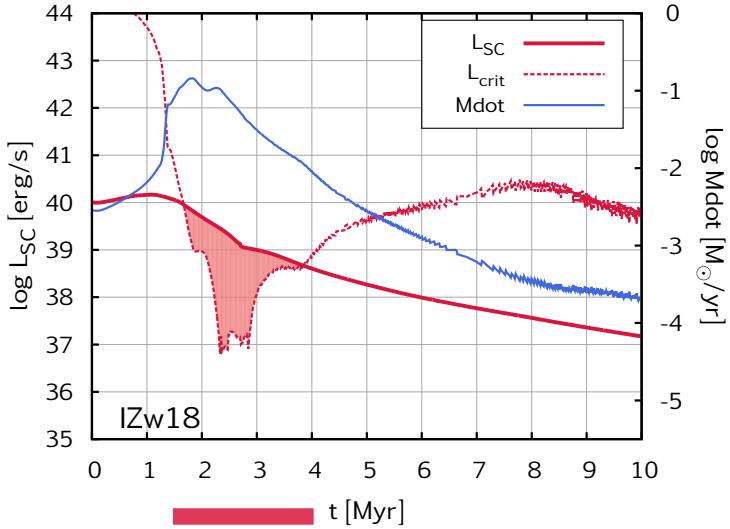

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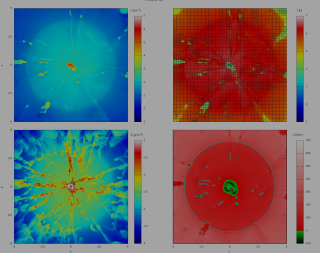

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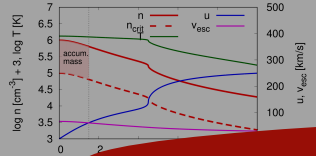

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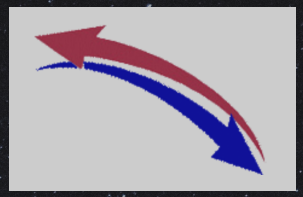

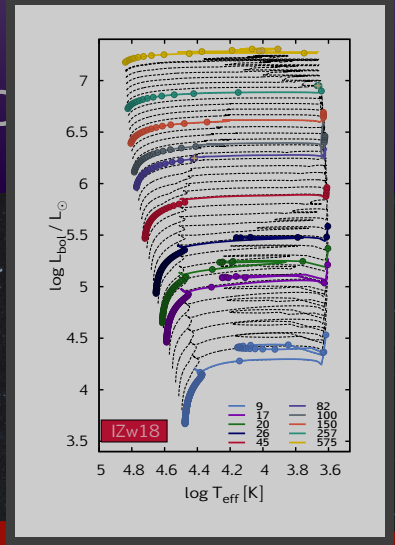

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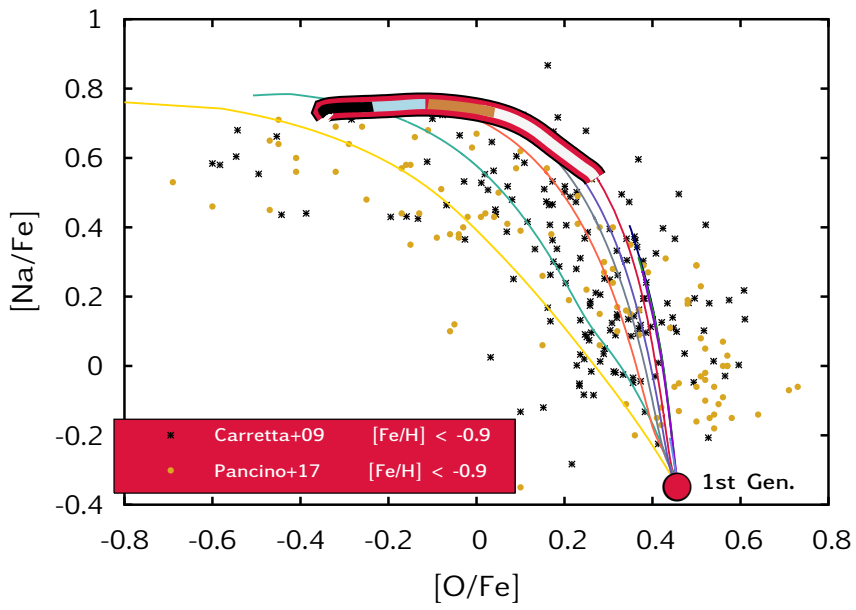

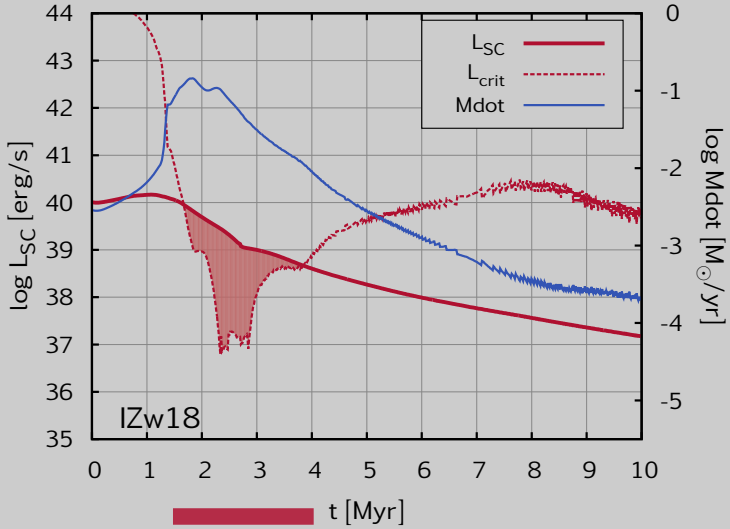

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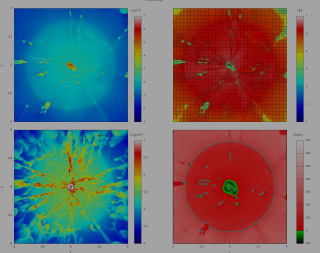

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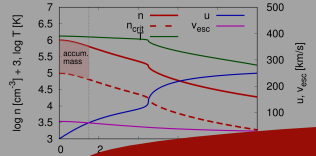

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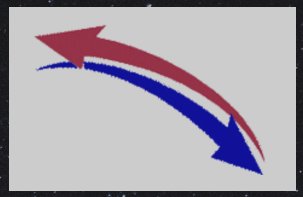

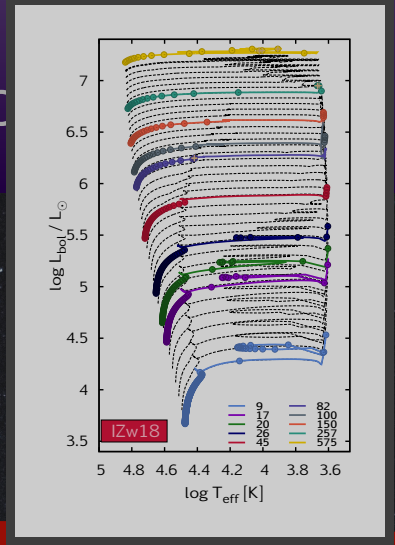

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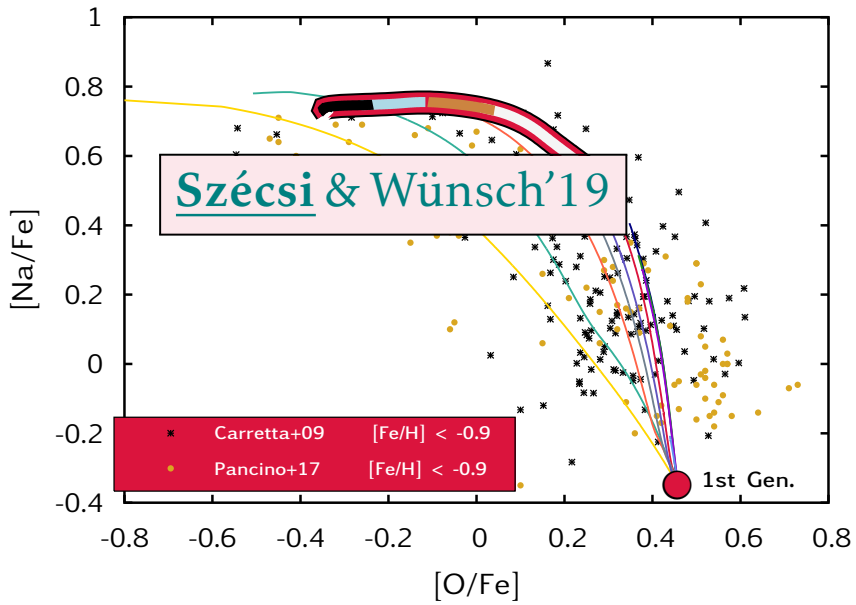

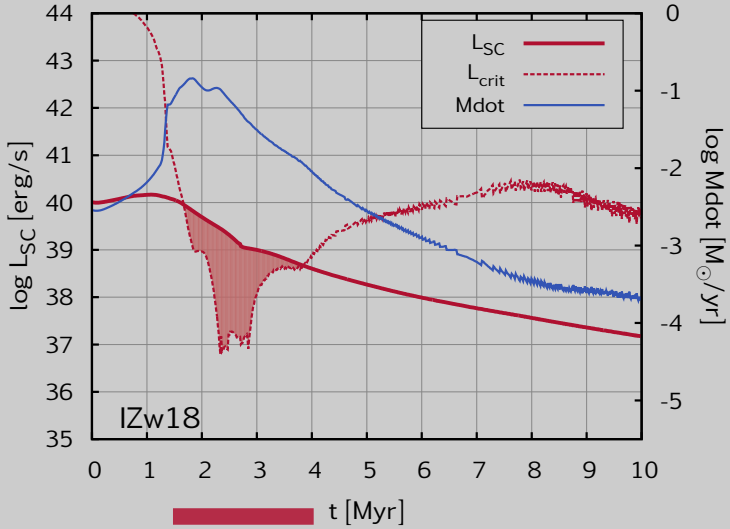

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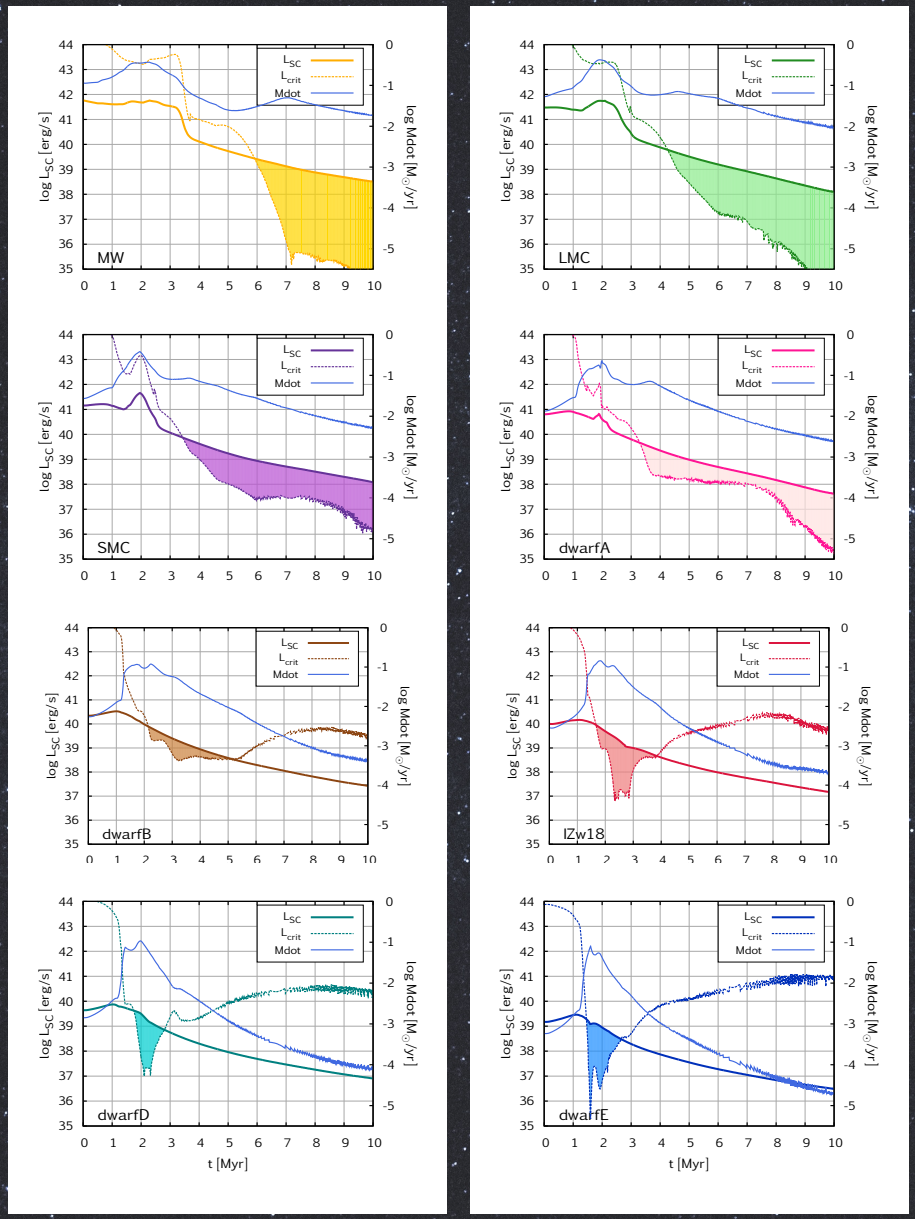

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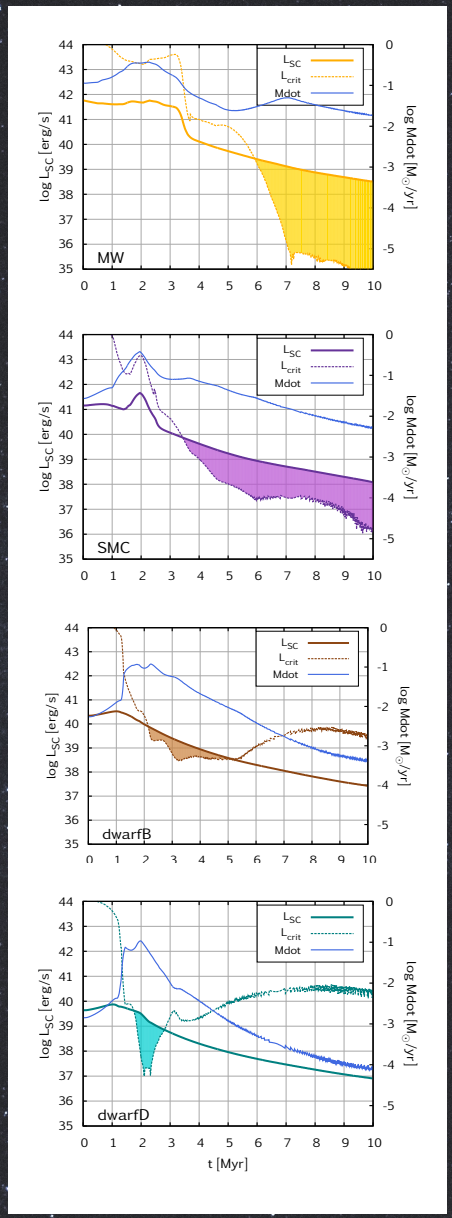

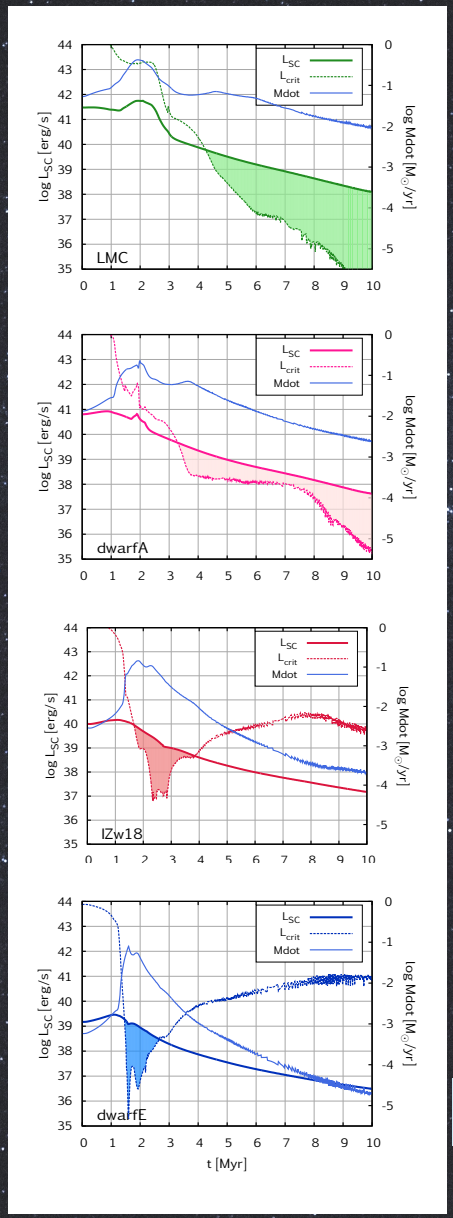

Hanno Stinshoff

PhD student

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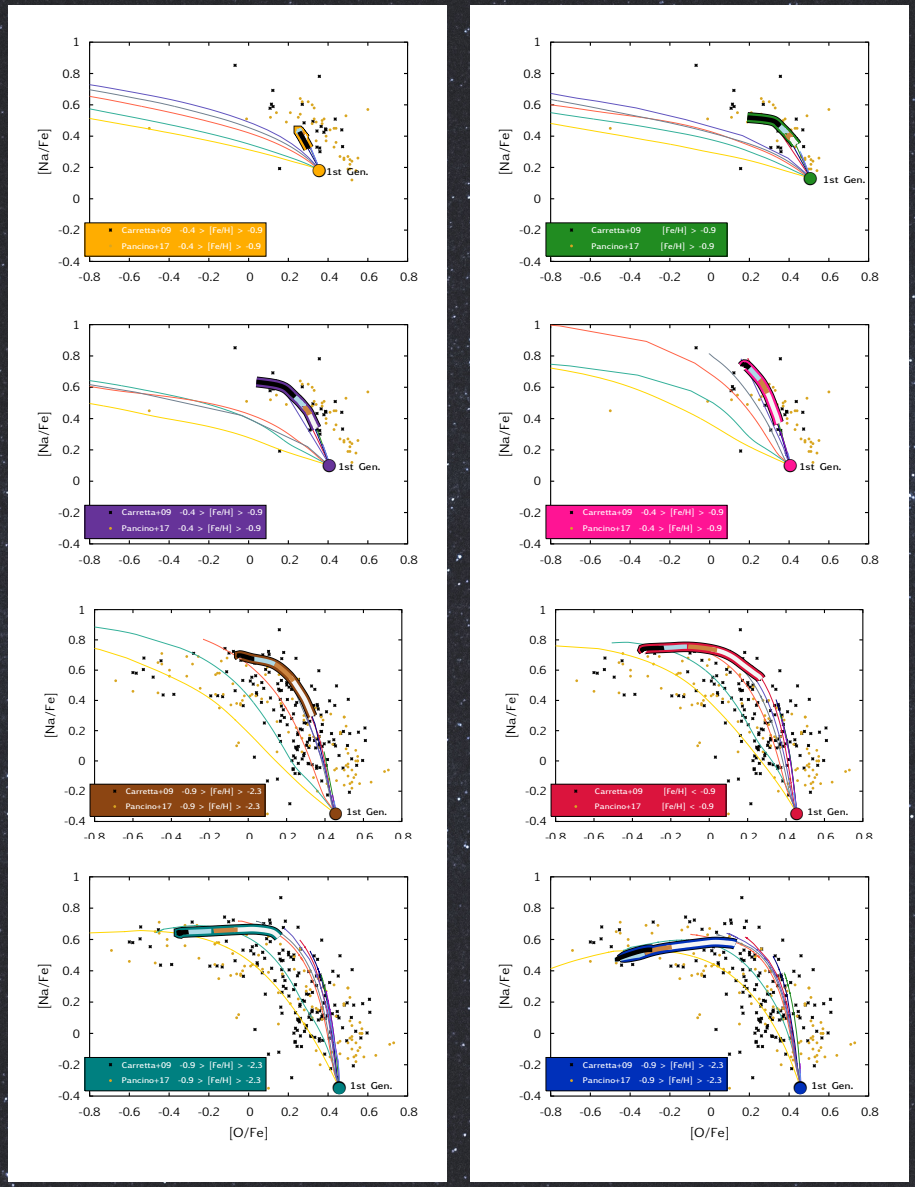

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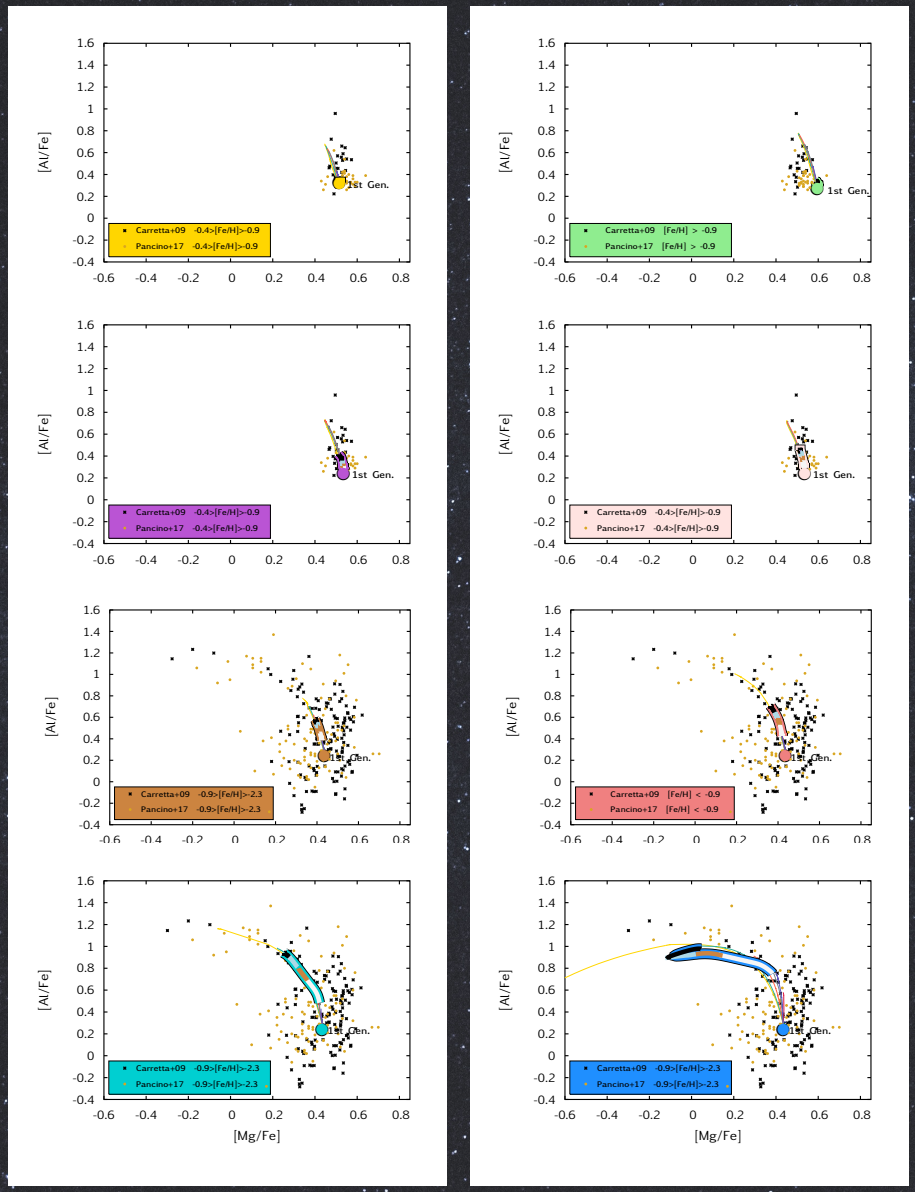

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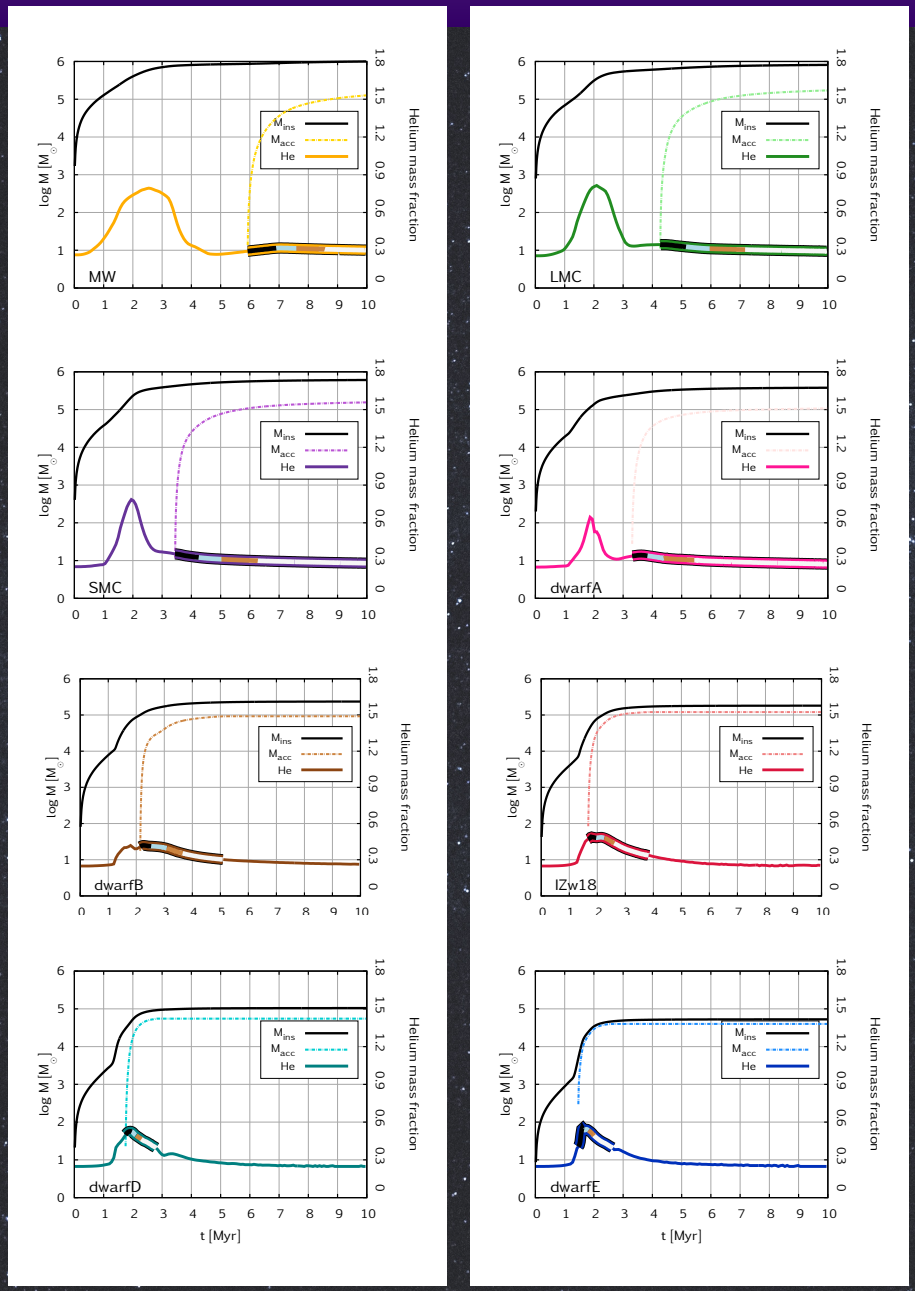
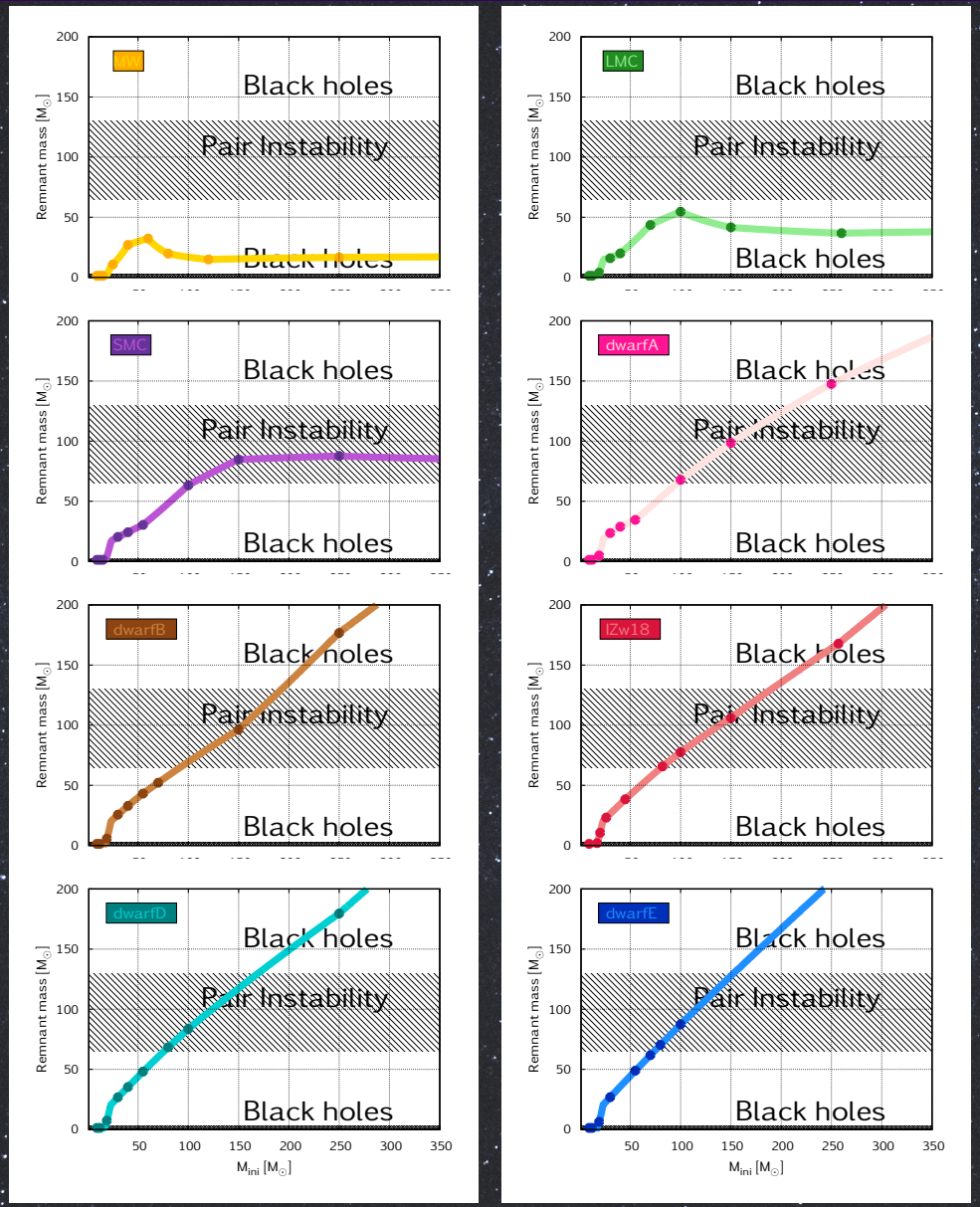



But most importantly...

Connecting G.Clusters & Gravitational Waves



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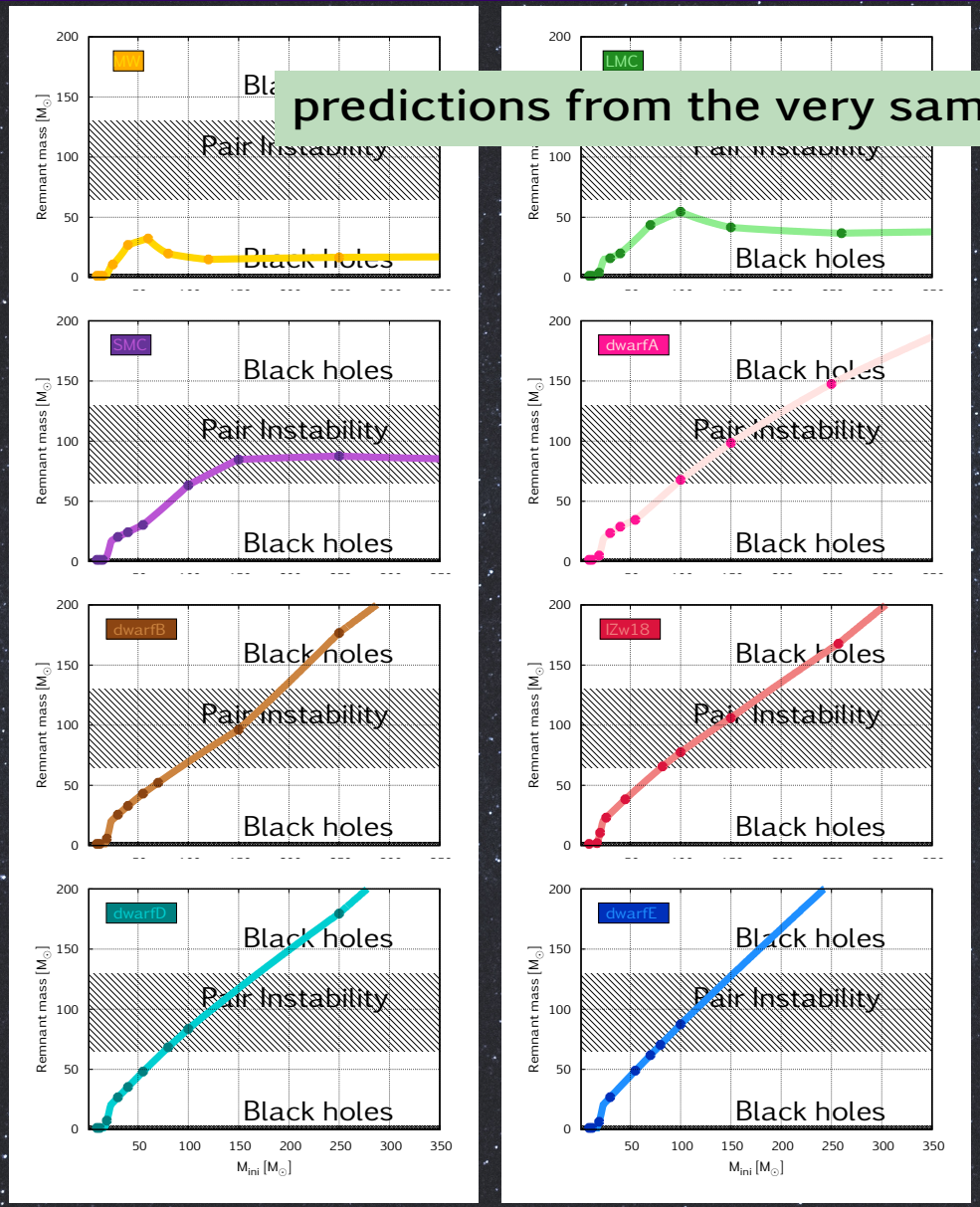

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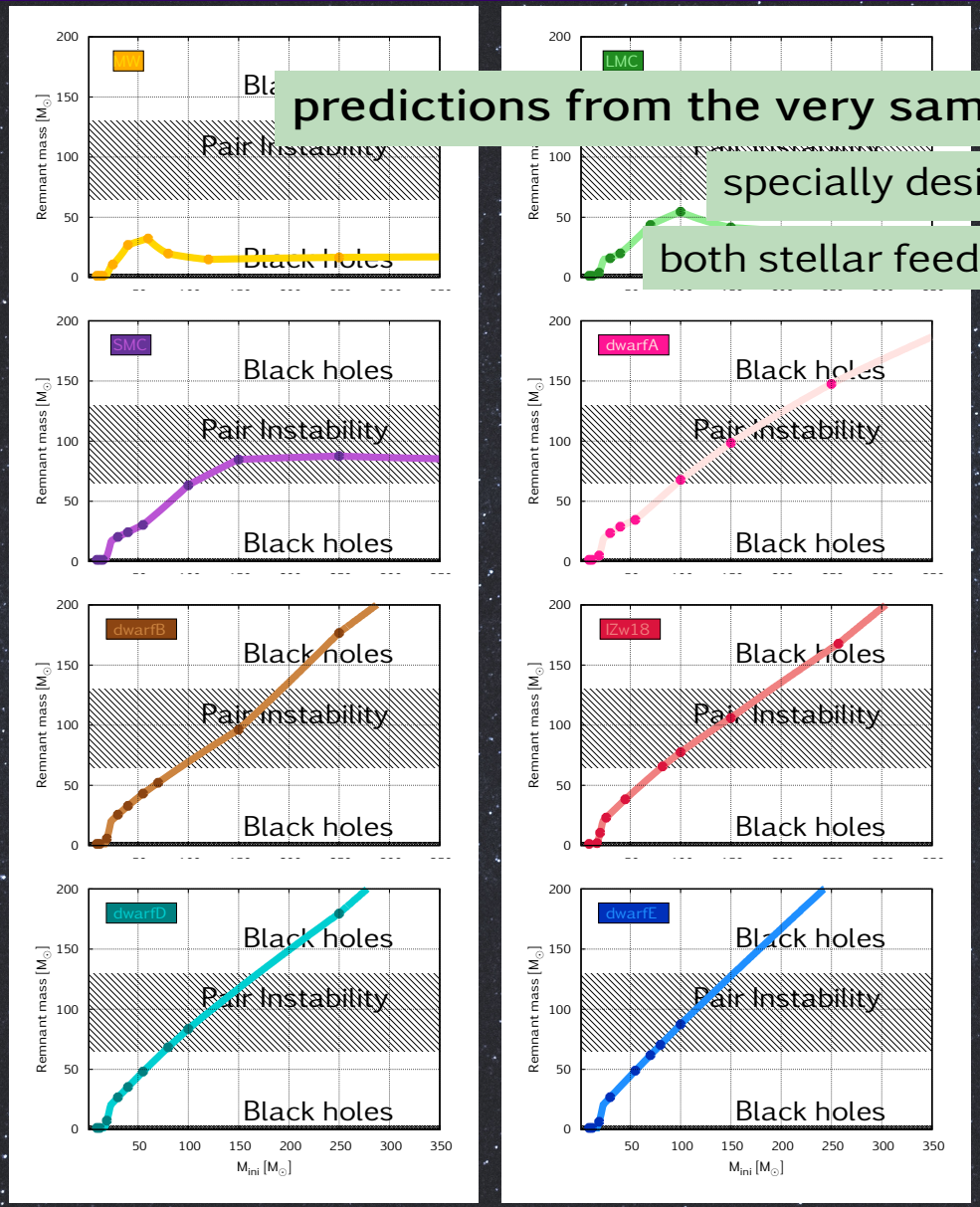

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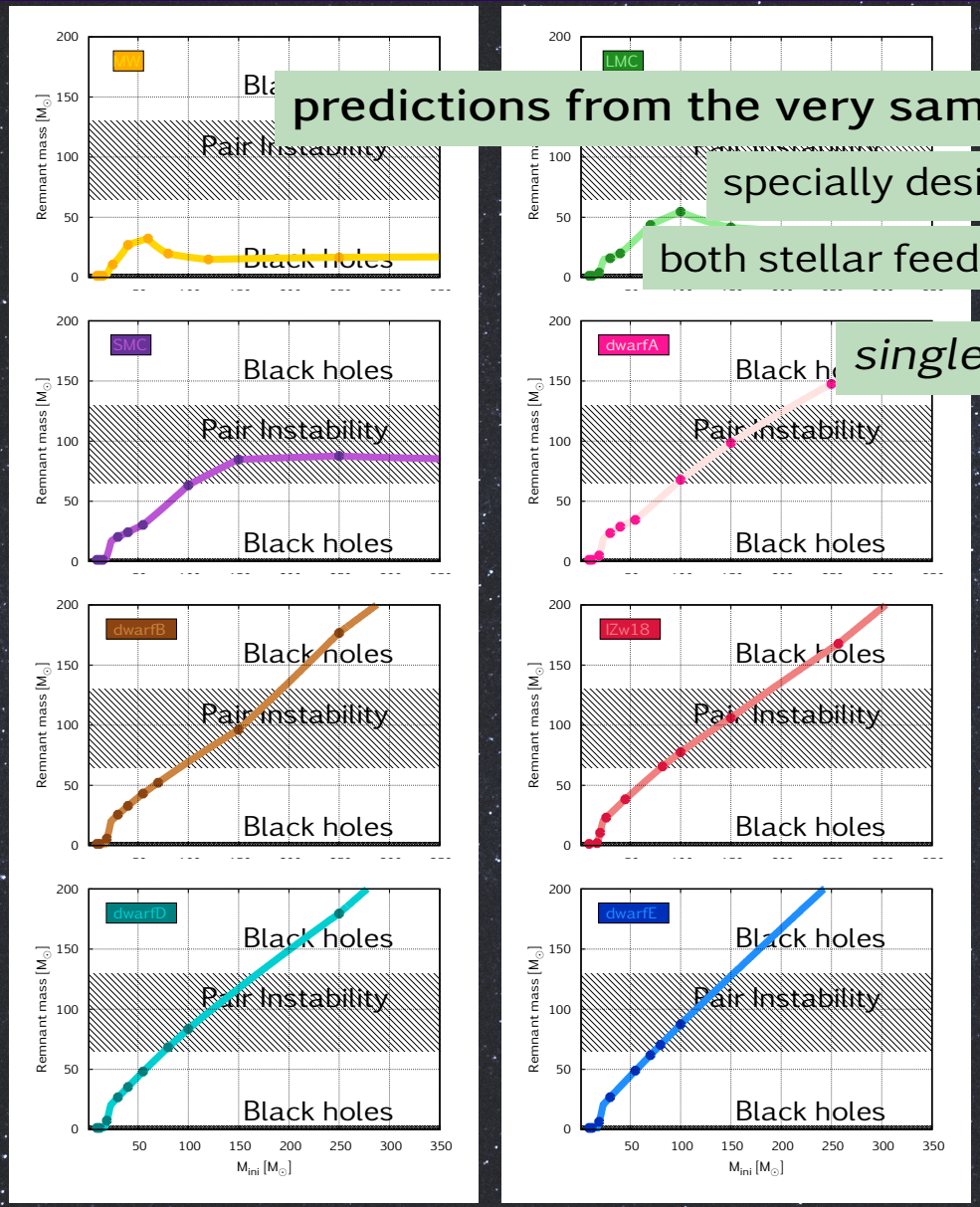

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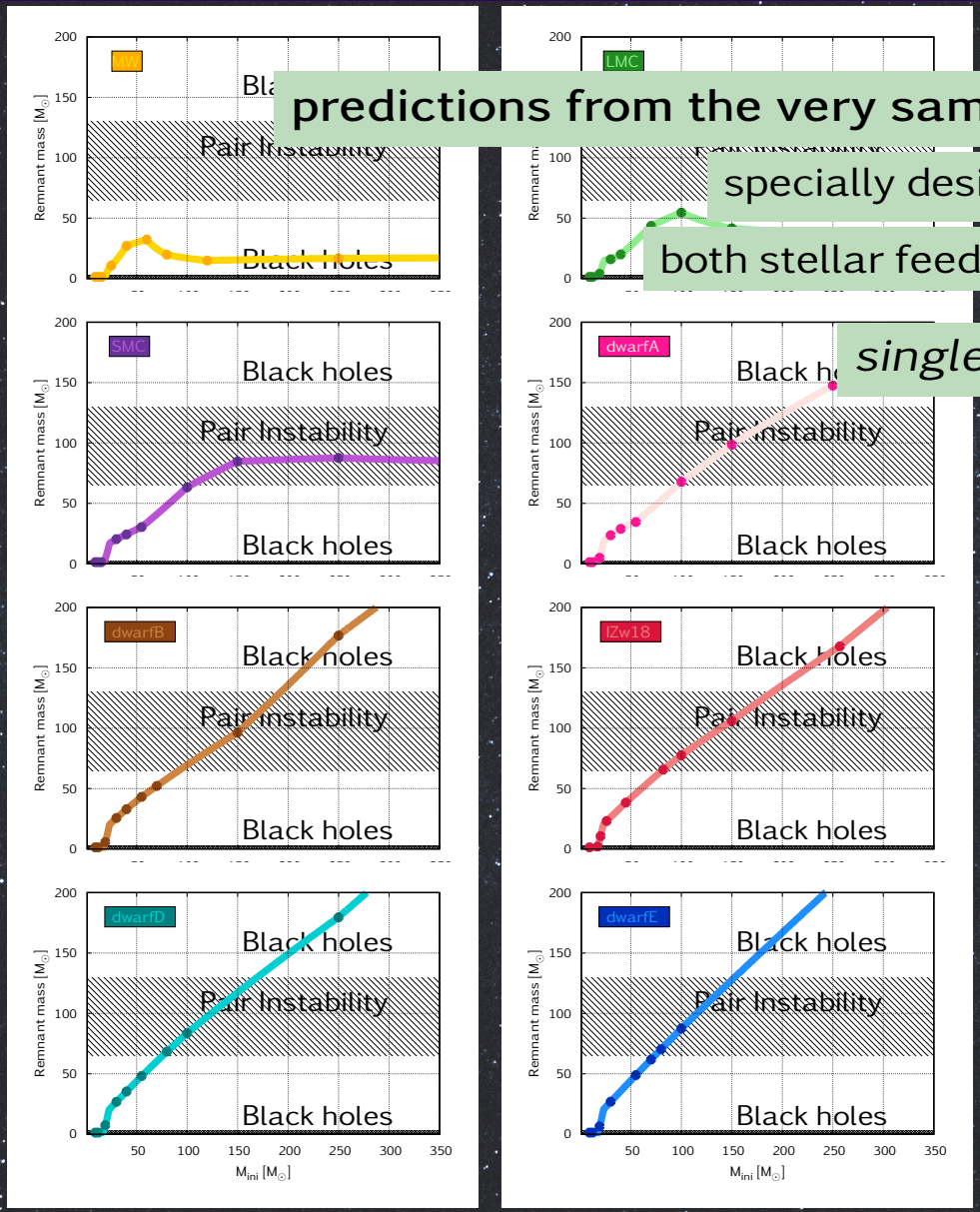

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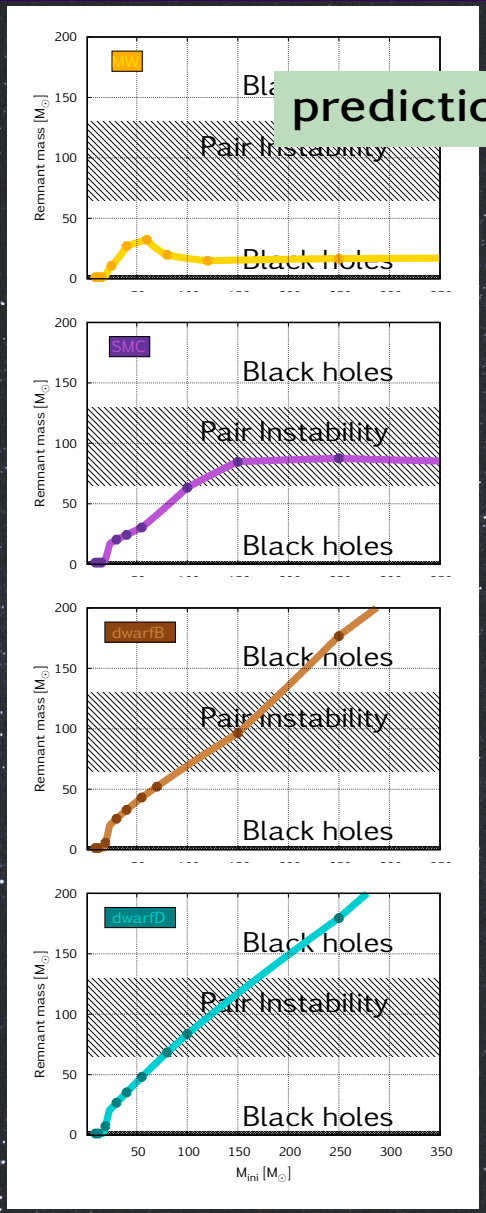

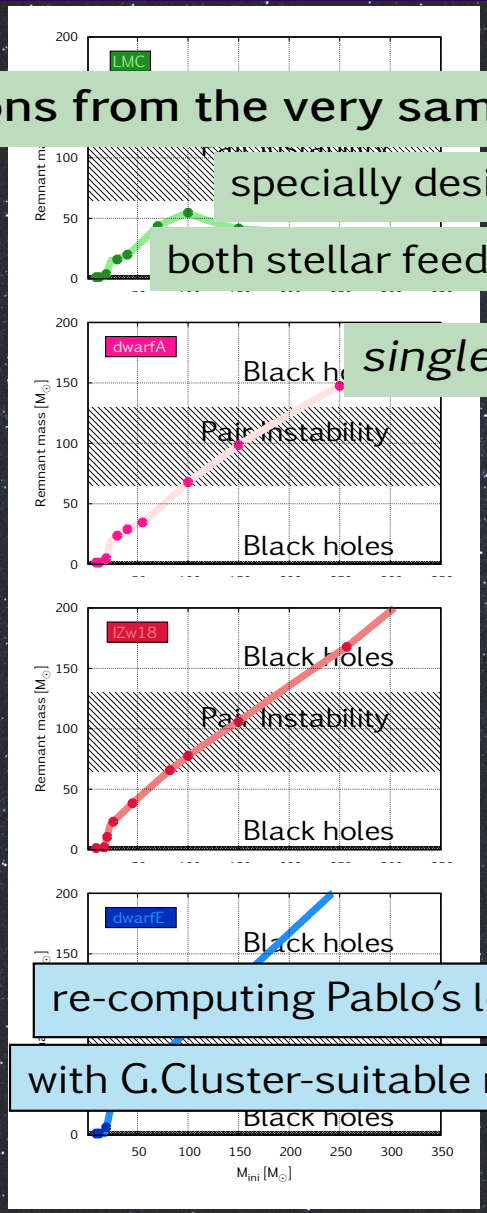

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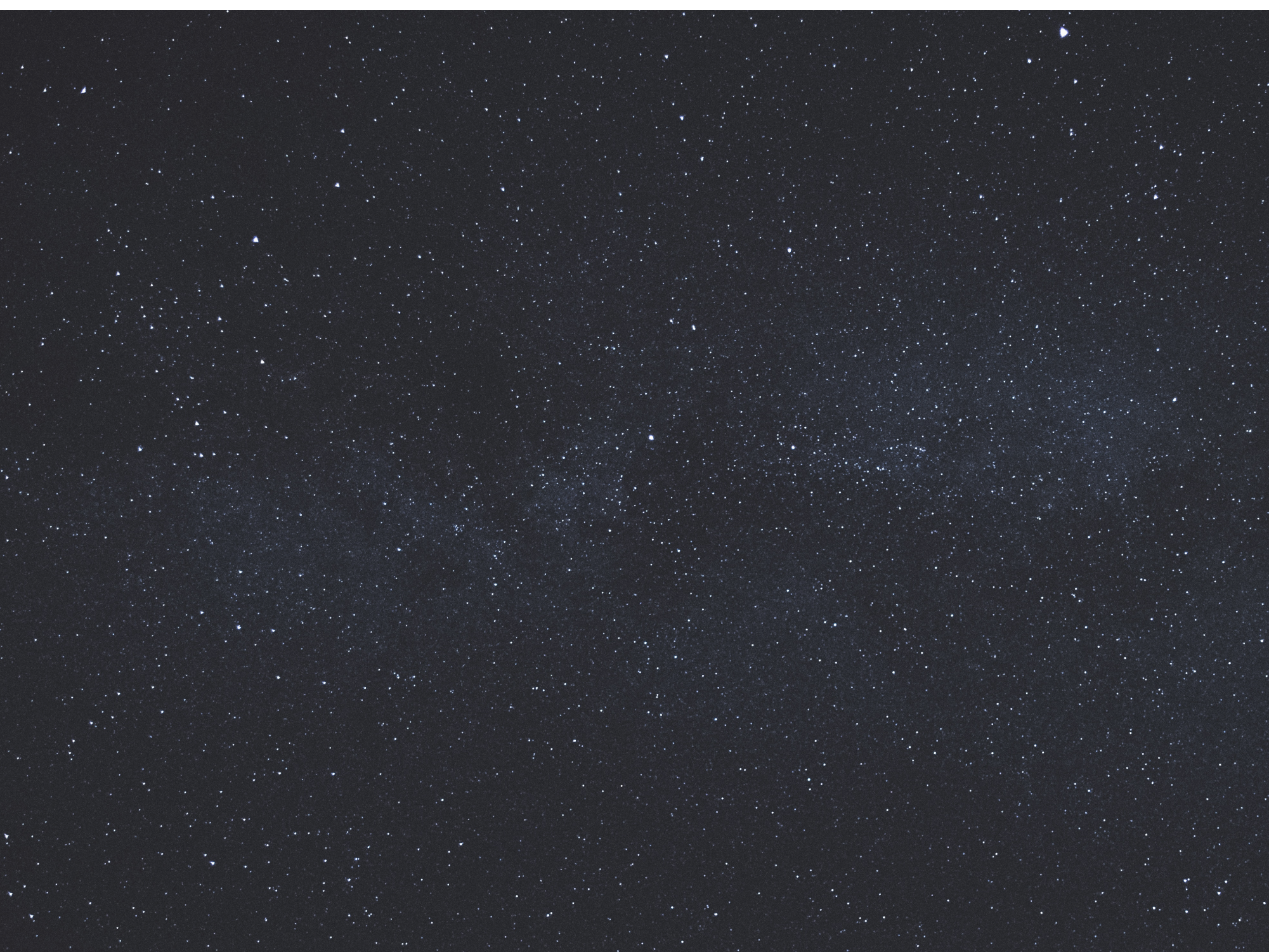

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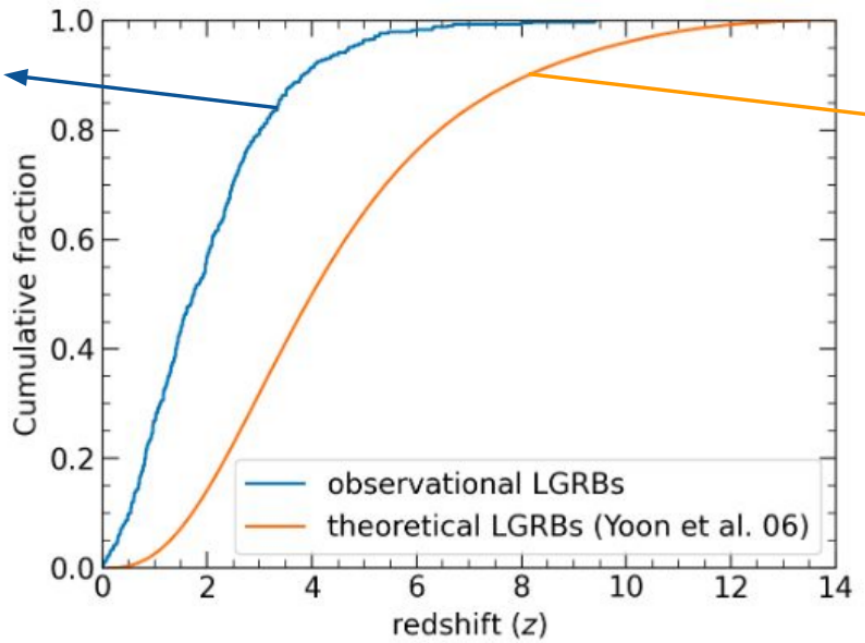
Testing stellar models *simultaneously* not only in **Globular Cluster** and **Gravitational Wave** but **ALSO** in **Gamma-ray burst** research:

Observational LGRBs Data:

475 GRBs
447 LGRBs
28 SGRBs



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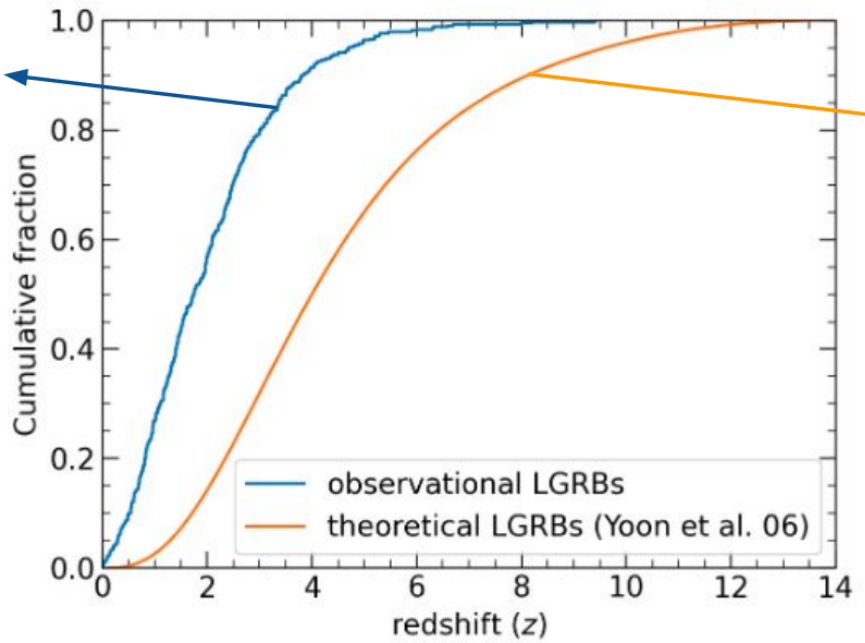

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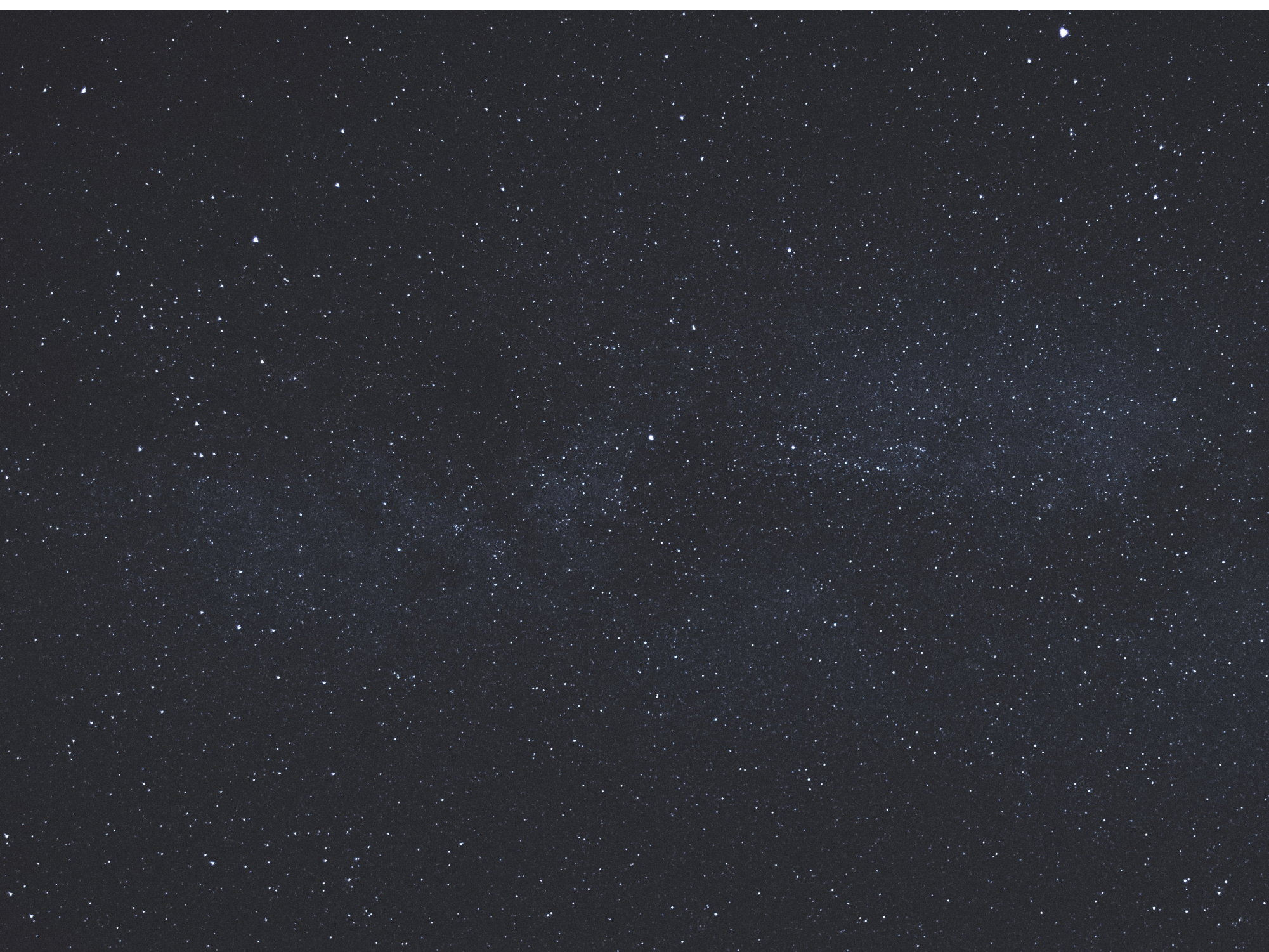
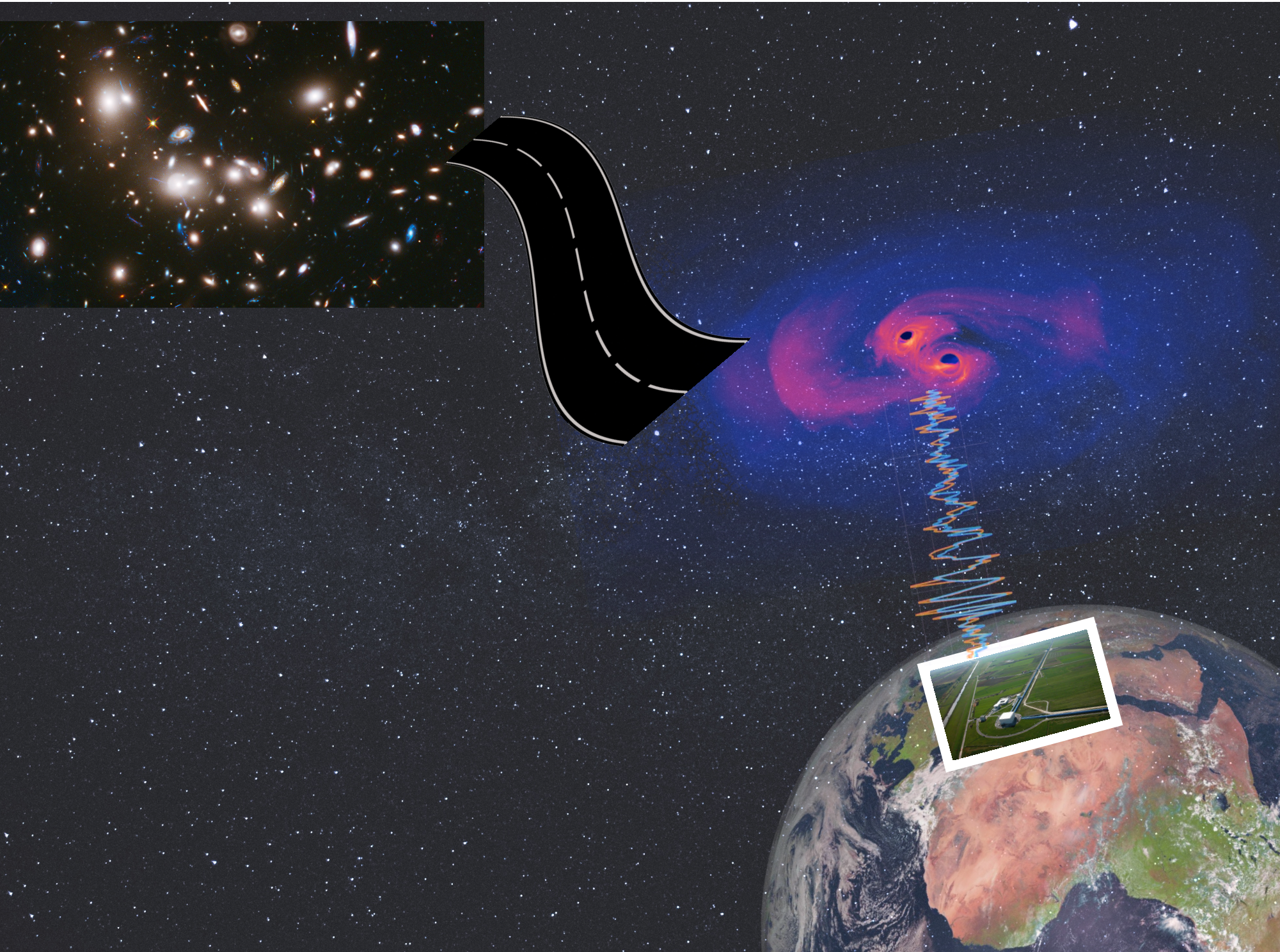


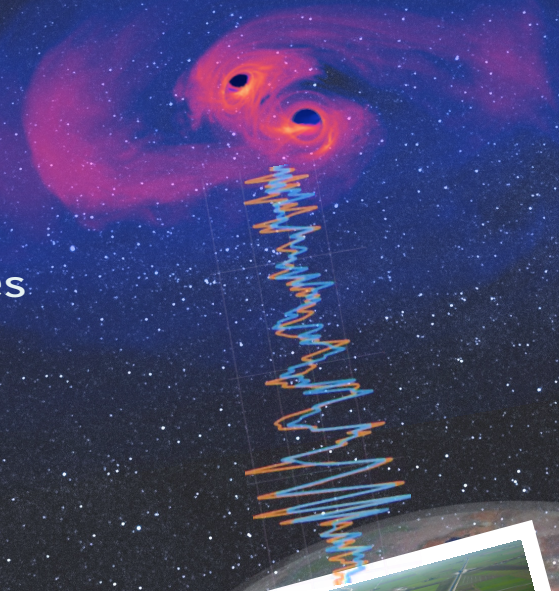


The early Universe

Gravitational Waves

Globular clusters

Gamma-ray bursts



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Low-metallicity stellar evolution (single and binary)

Financed for 4 years (OPUS)

My people

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(now post-doc at Carnegie, USA)

At the NCU:

Dr. Koushik Sen
(post-doc)

Hanno Stinshoff
(PhD student)

Rafia Sarwar
(PhD student)

Dr. Áron Szabó
(PD fellow)

National Science Centre
Opus

Nicolaus Copernicus University