Globular clusters and massive stars: a challenging connection

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Dorottya Szécsi

Assistant Prof. &

OPUS group leader

Masters in Gamma-ray bursts

PhD in Stellar Evolution

PD at Institute for Gravitational Wave Astronomy *University of Birmingham*

Humboldt Fellow

Faculty position at NCU

Winning OPUS grant & building my junior research group on Gravitational Wave Progenitors

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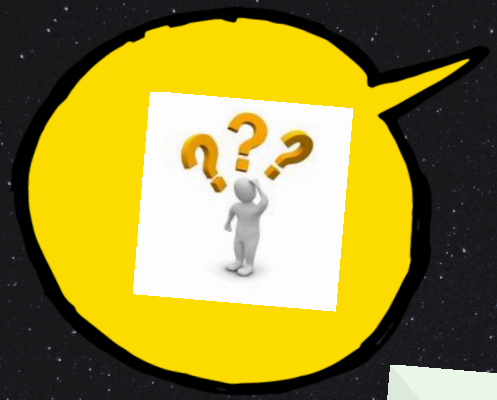

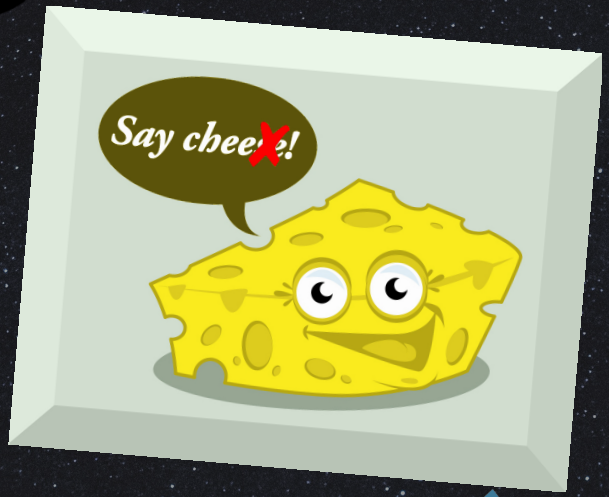

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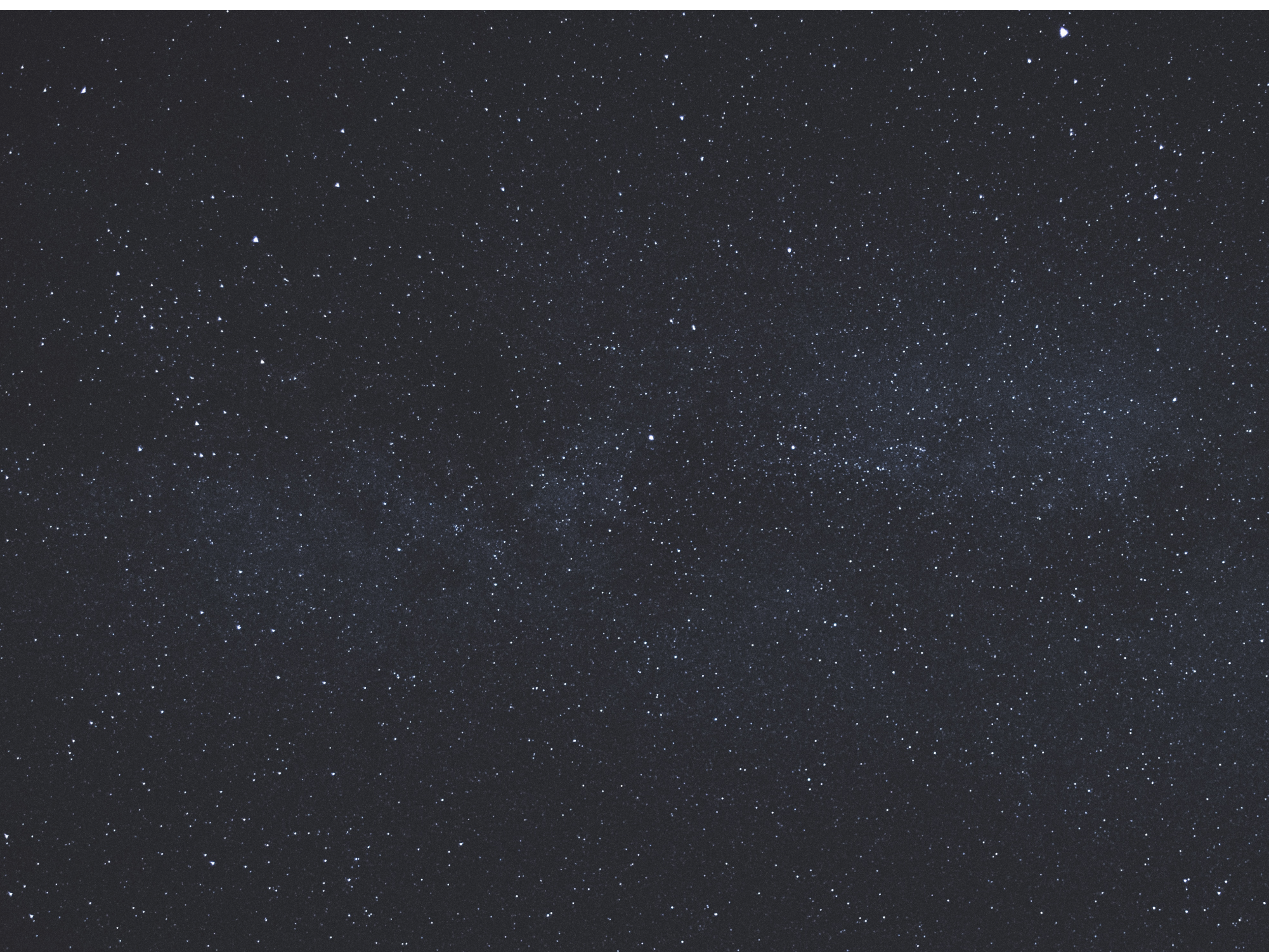
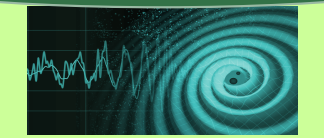


Dwarf galaxies

Gravitational waves



High-redshift Univ.

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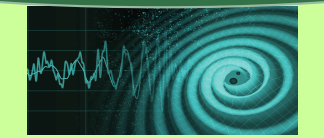

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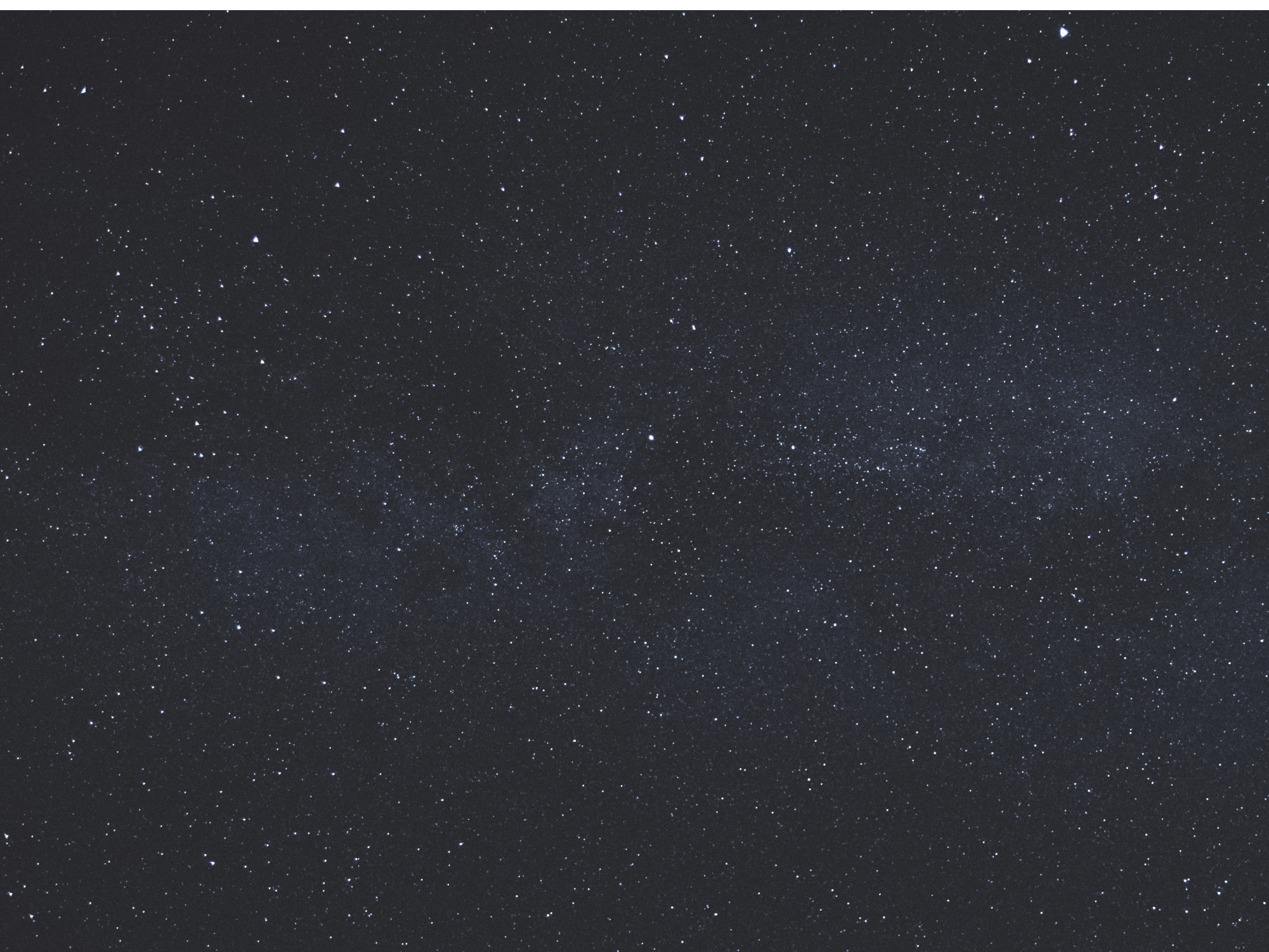
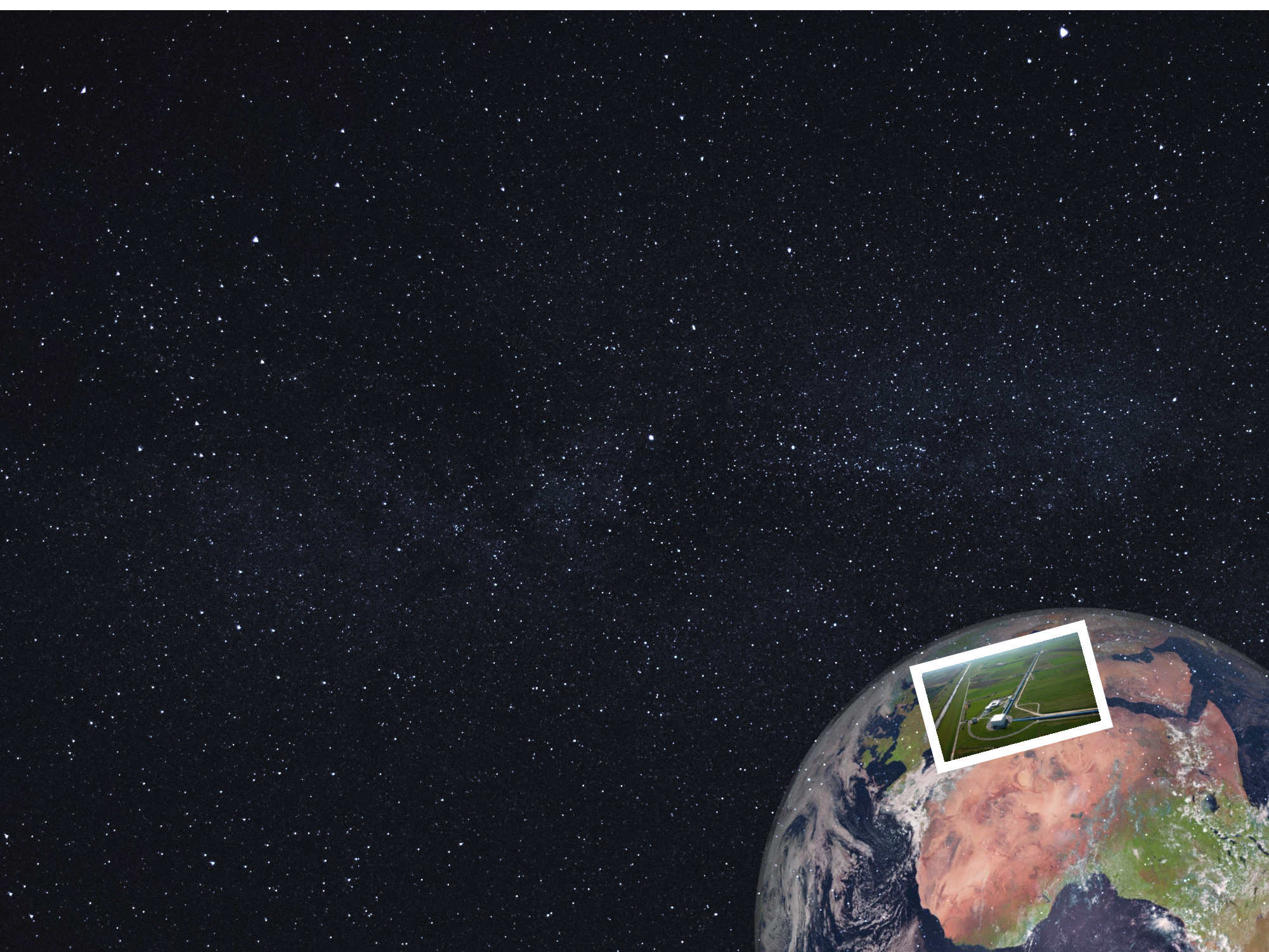
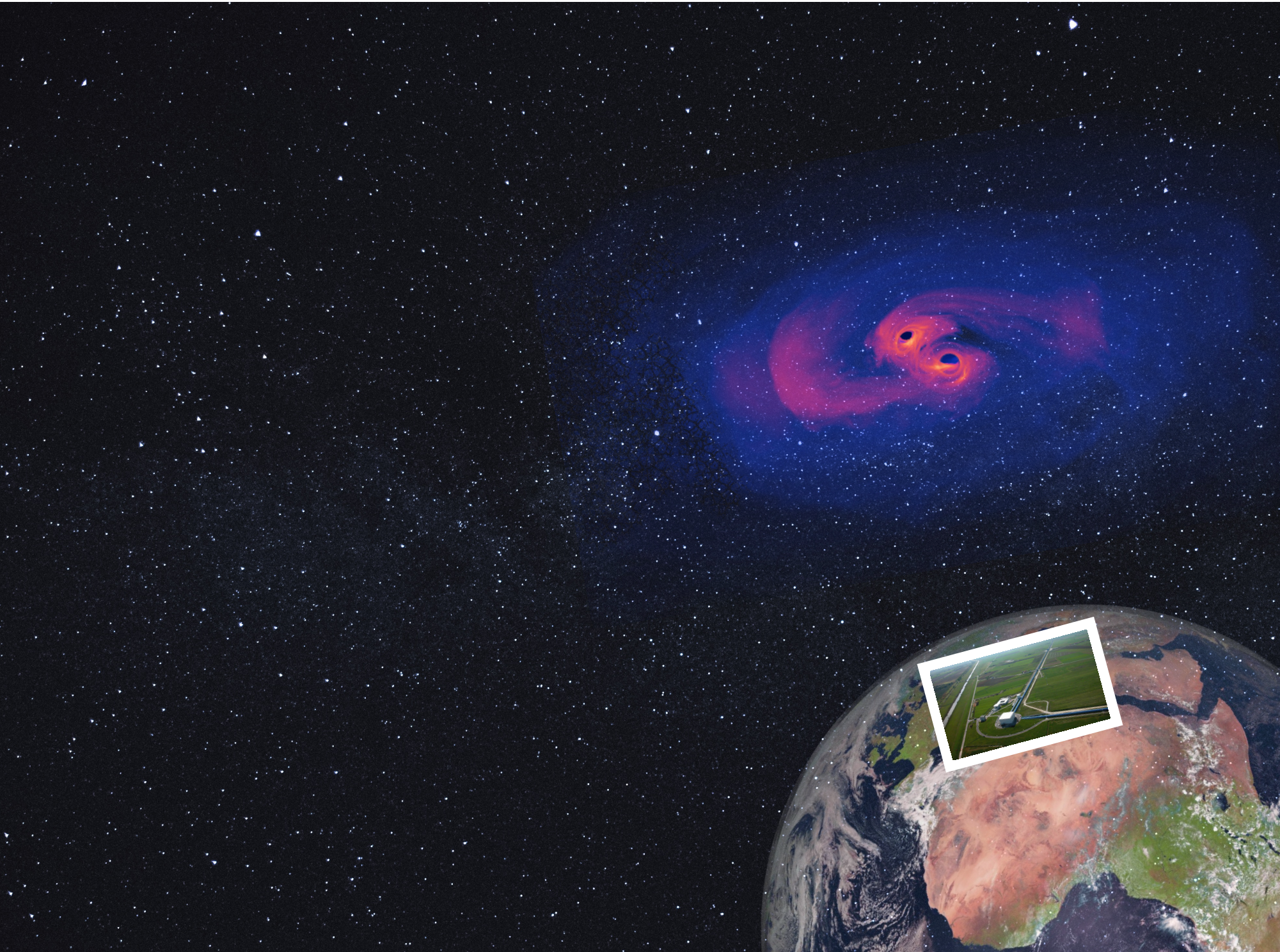
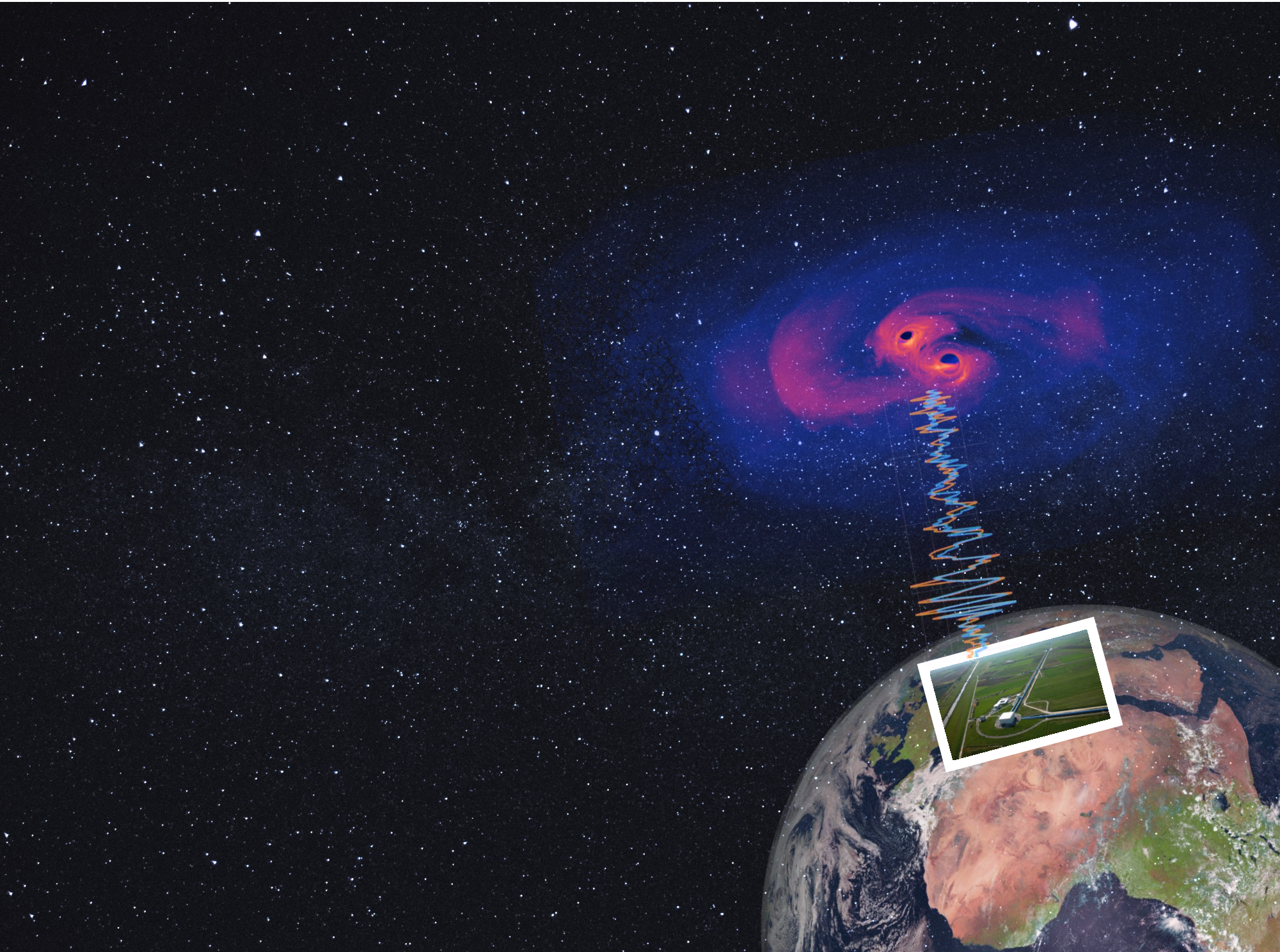


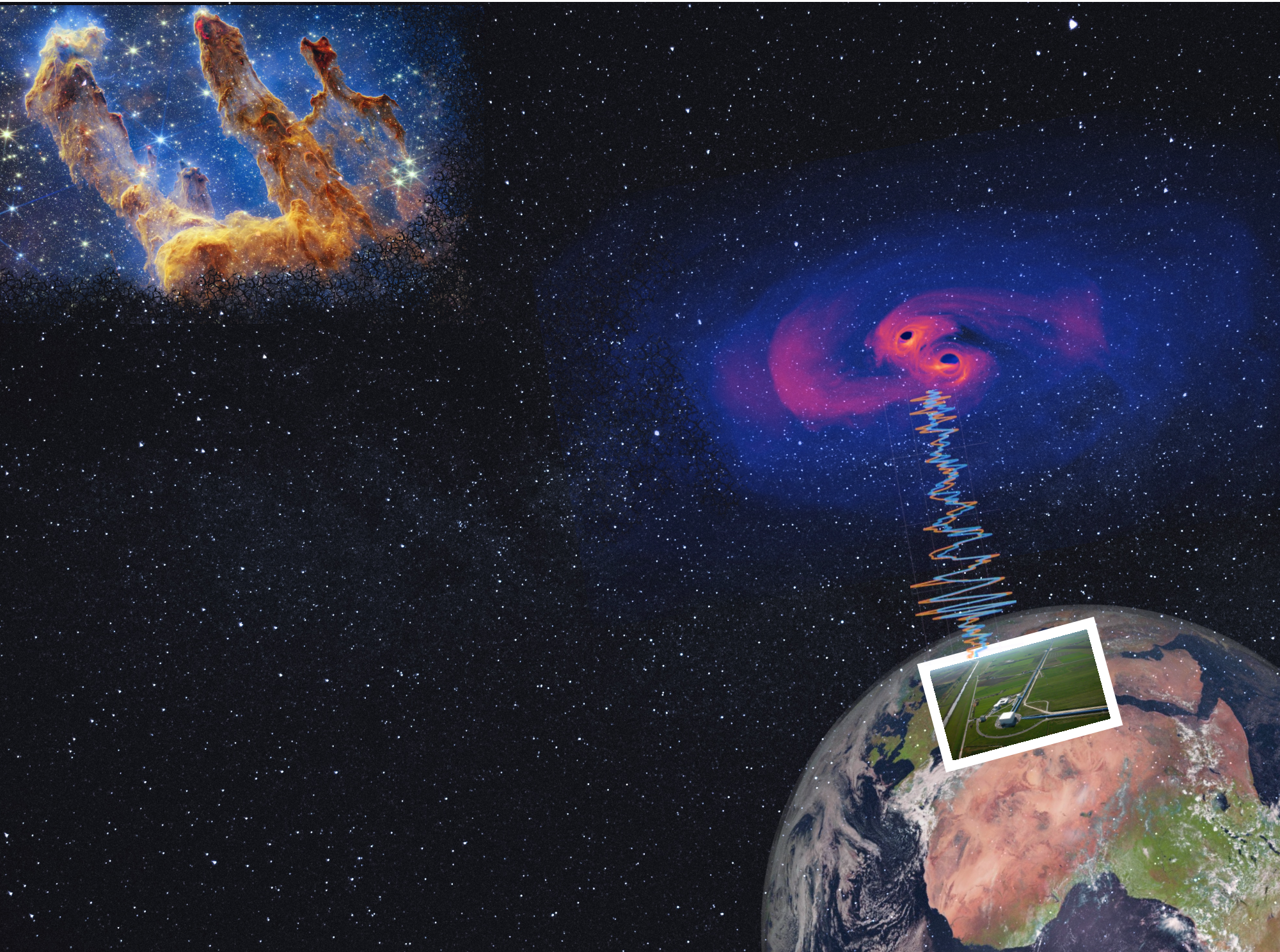
Why?

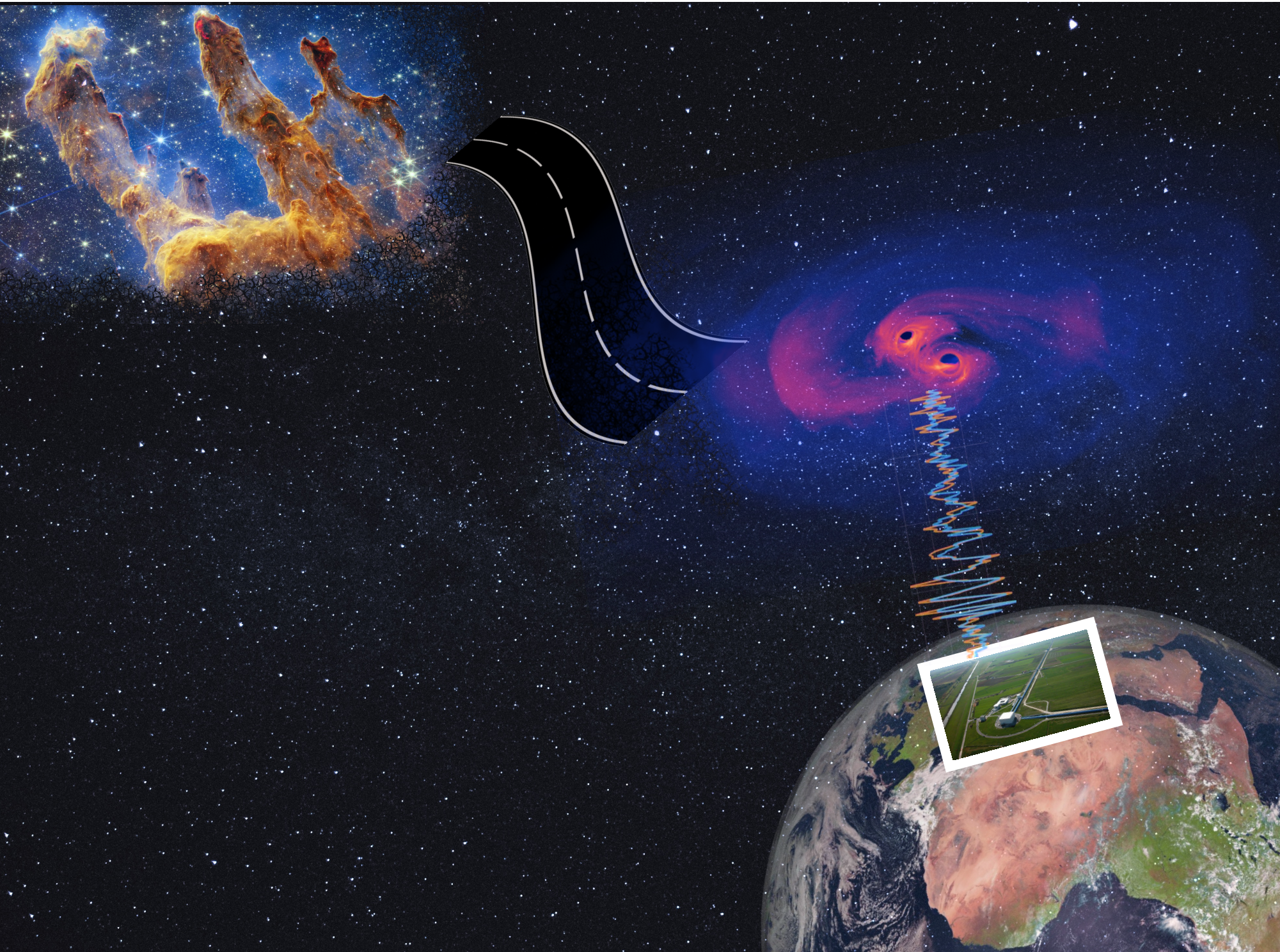
Where do Gravitational Waves come from?

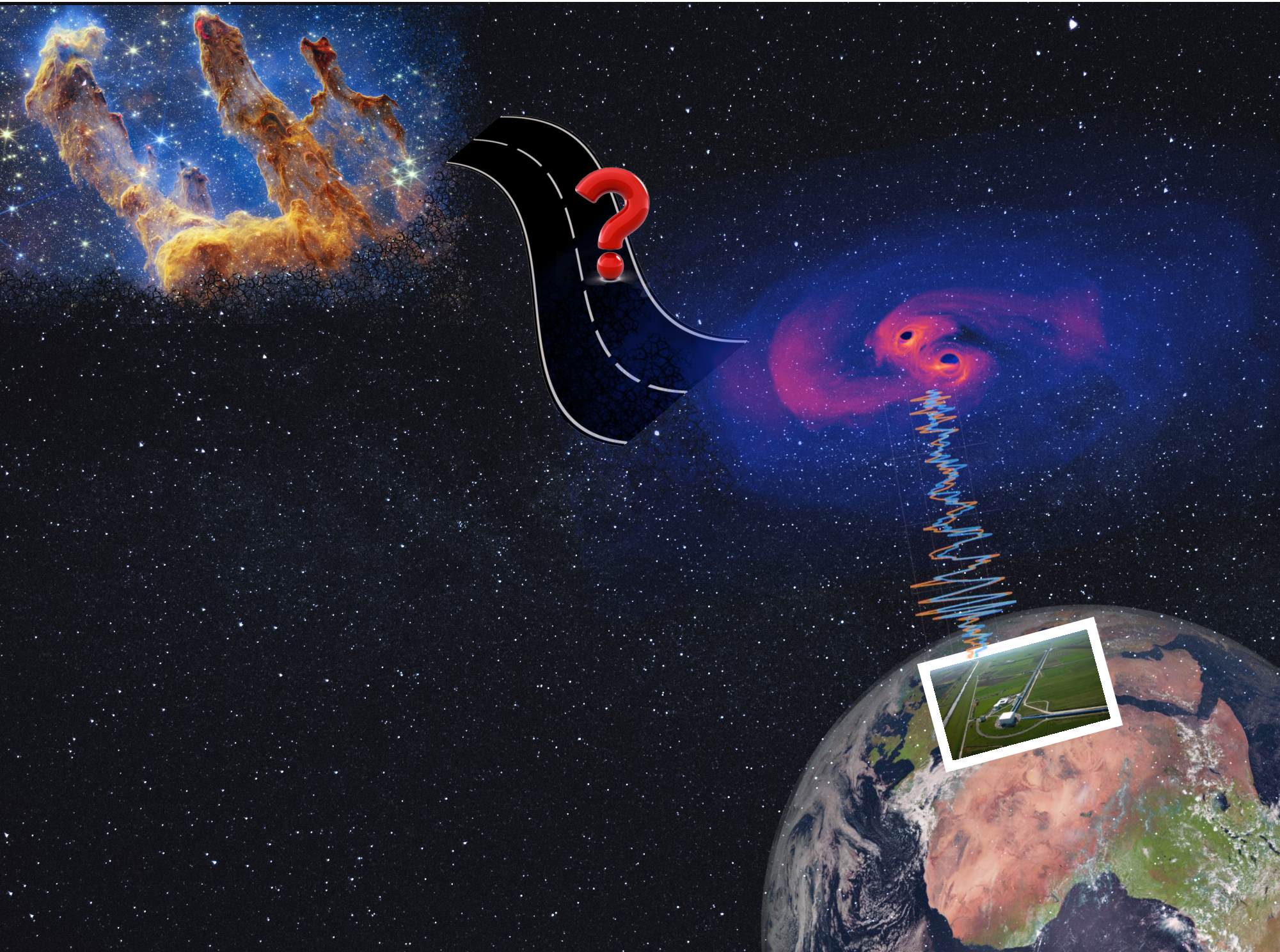












Metal-poor massive stars

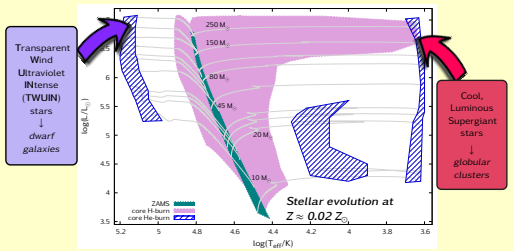
Metal-poor because...

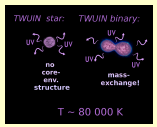
- early epochs of the Universe
- average metallicity: between $0–Z_{\odot}$

Massive stars because...

- 'massive' by def.: $> 8\ M_{\odot}$
- BHs of aLIGO/Virgo: $20–80\ M_{\odot}$

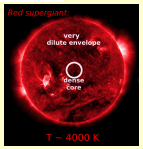
Szécsi et al. 2015:



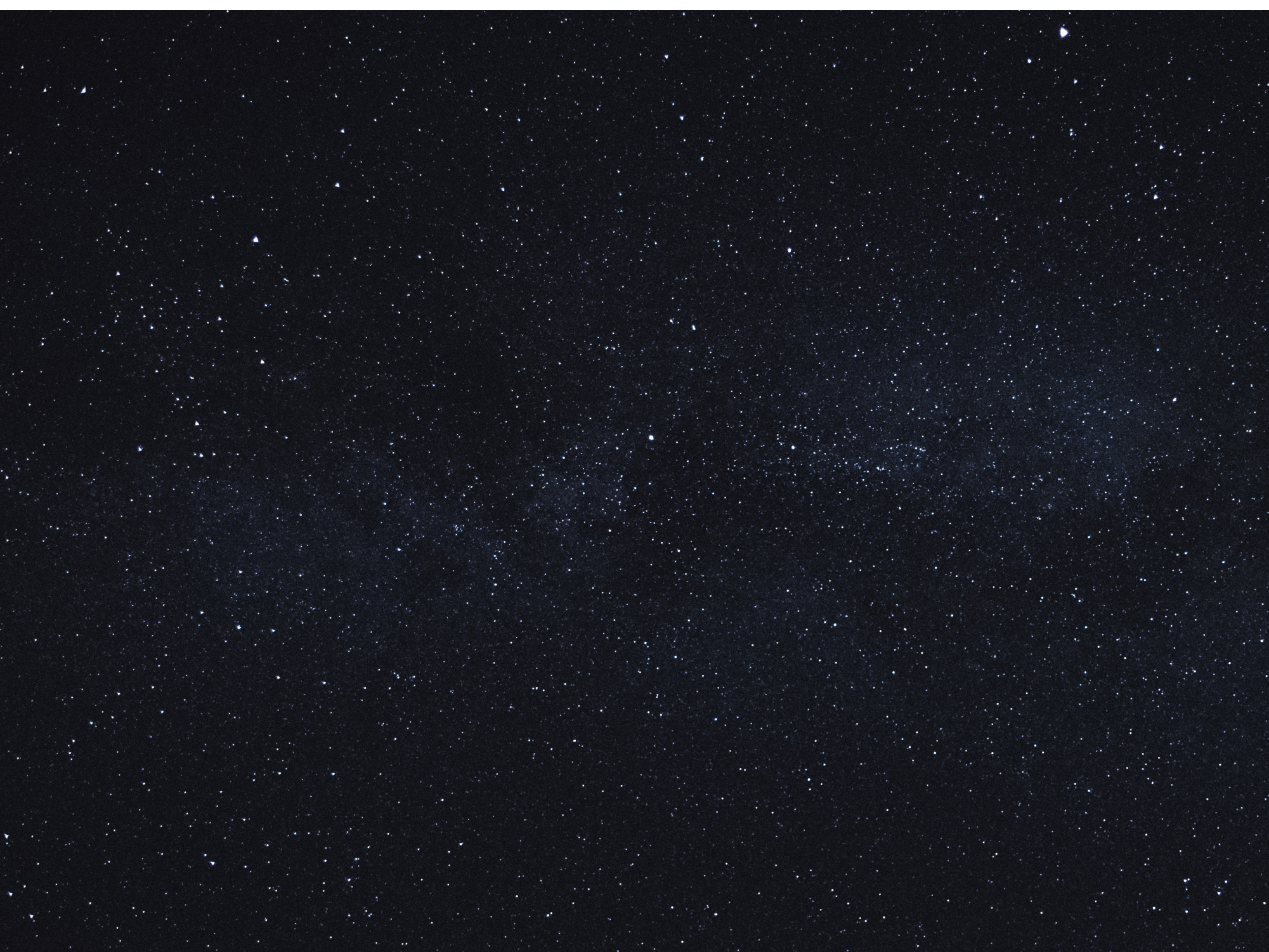


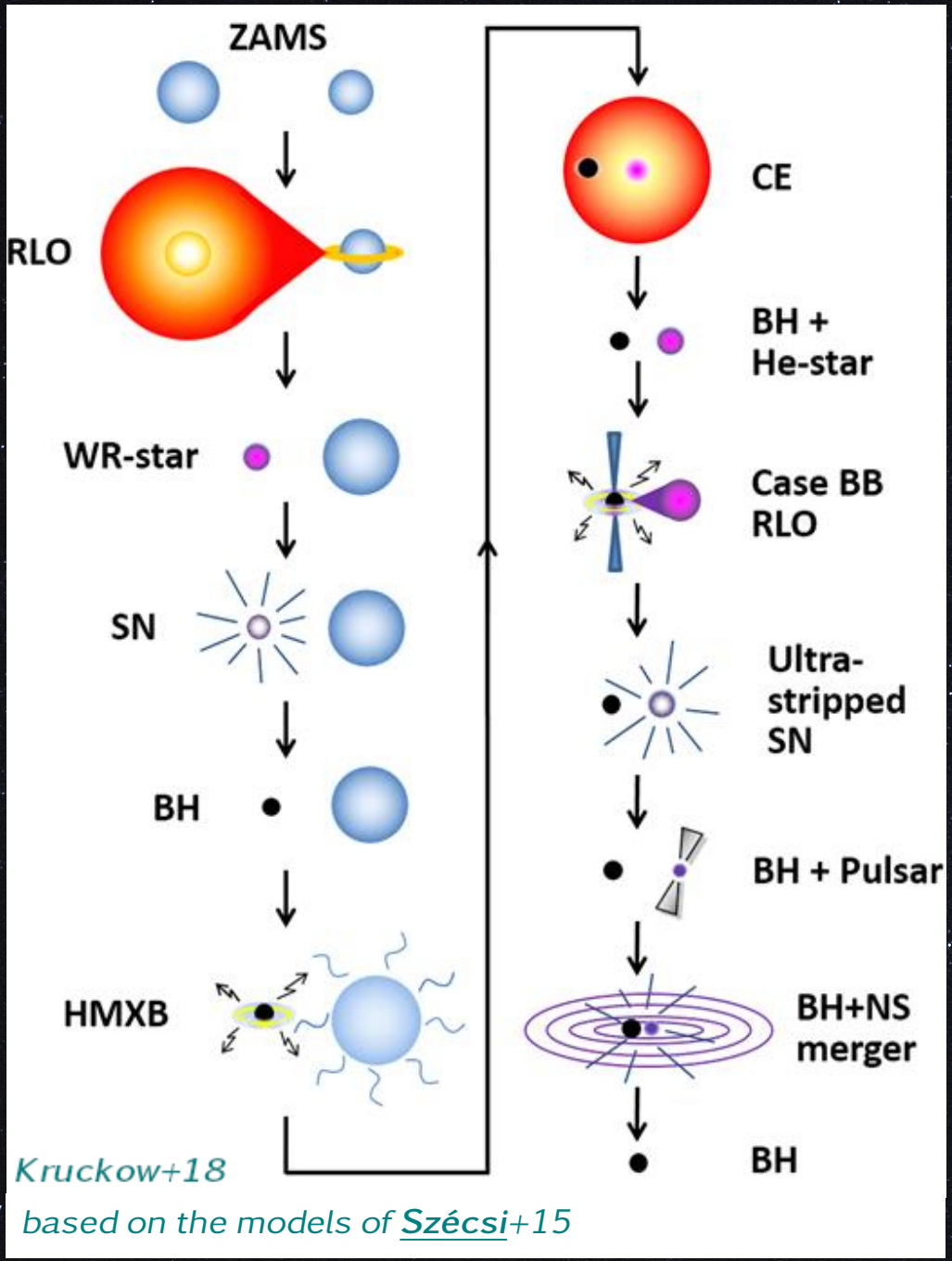
Kubátová & Szécsi+19, Szécsi'17a,'17b

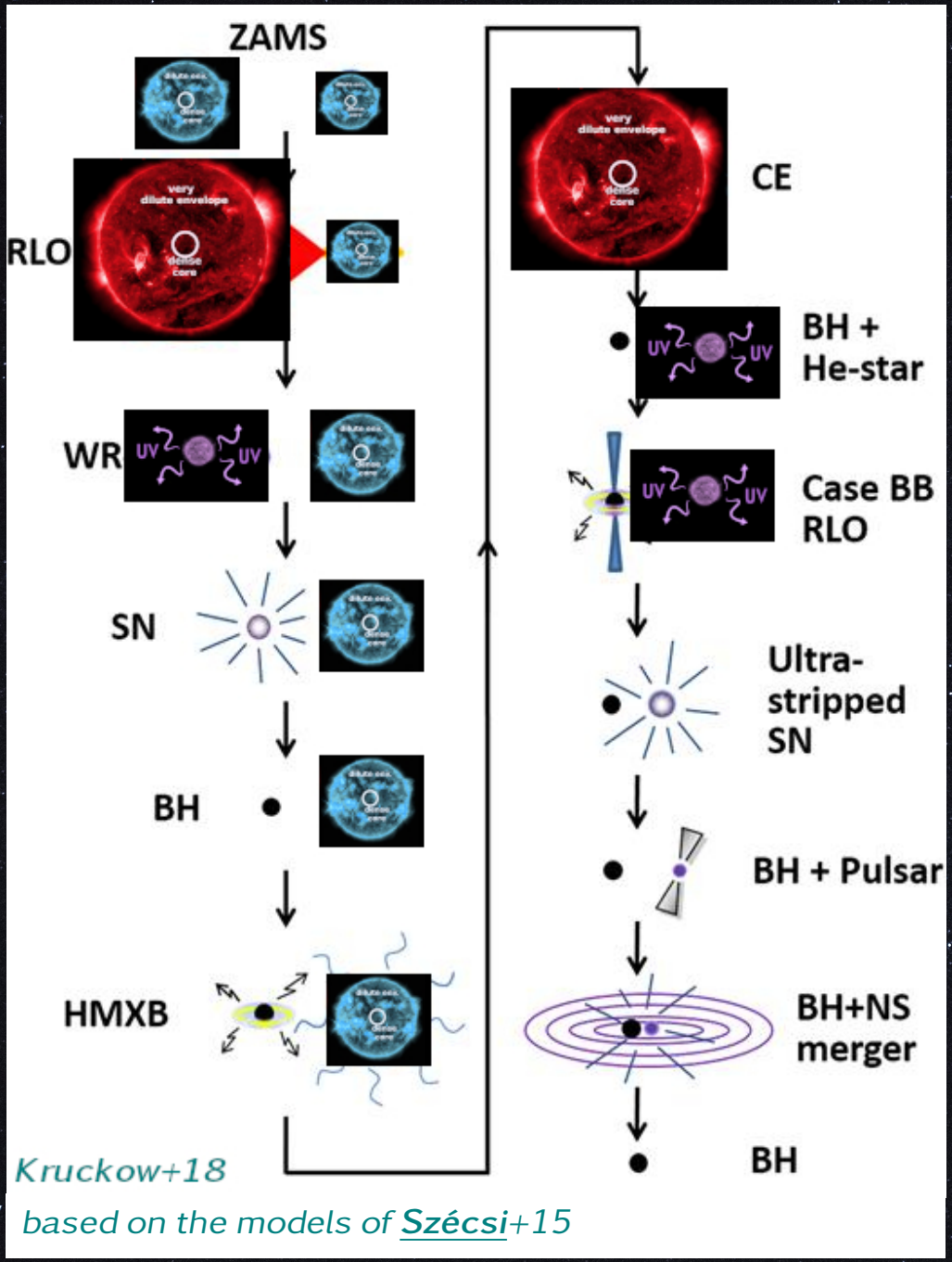
Szécsi+22, Garcia, . . . , Szécsi+21



Szécsi & Wünsch'19, Szécsi+18




ZAMS
RLO
WR-star
SN
BH
HMXB
CE
BH +
He-star
Case BB
RLO
Ultra-
stripped
SN
BH + Pulsar
BH+NS
merger
BH
Kruckow+18
based on the models of Szécsi+15



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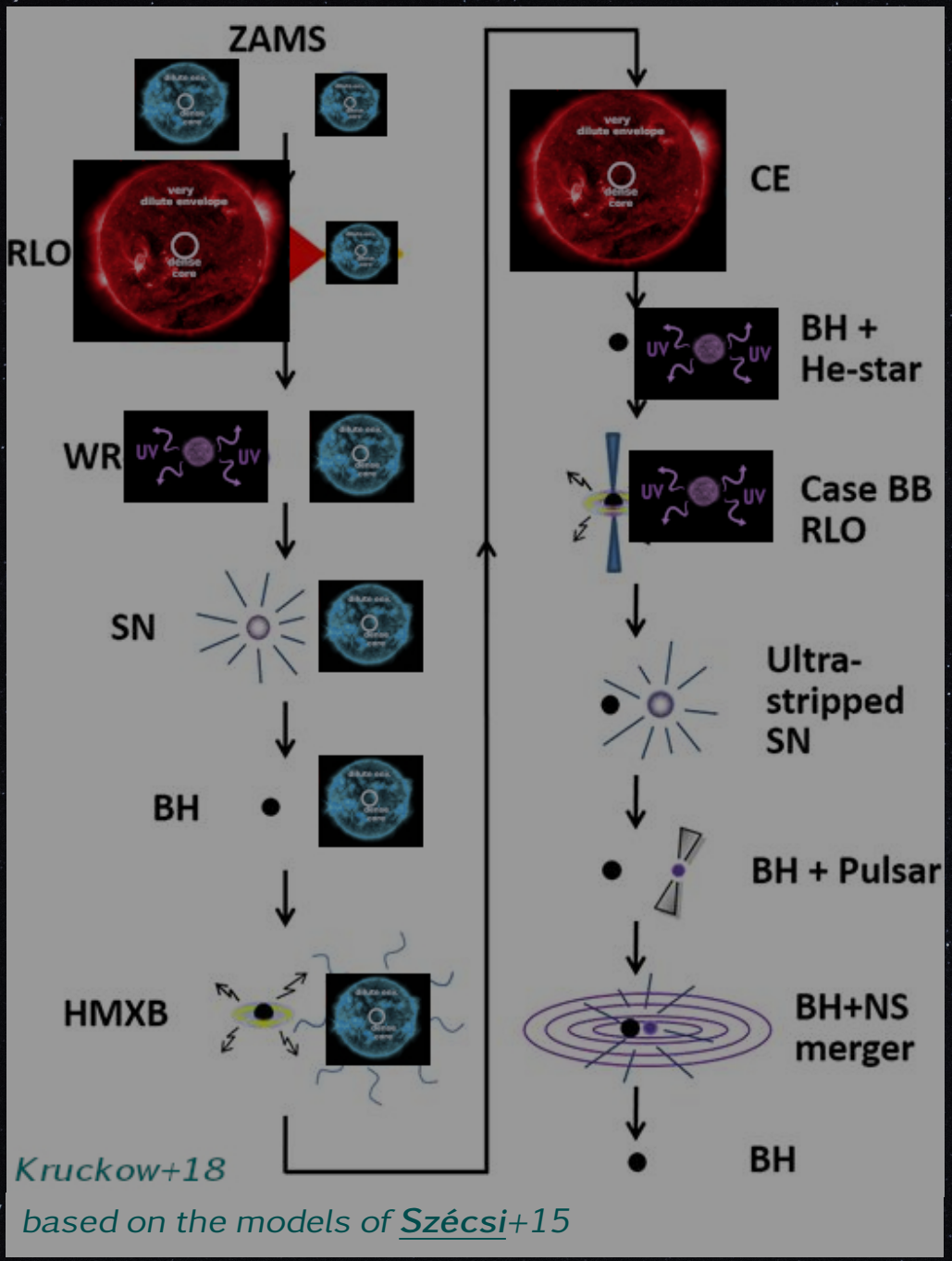
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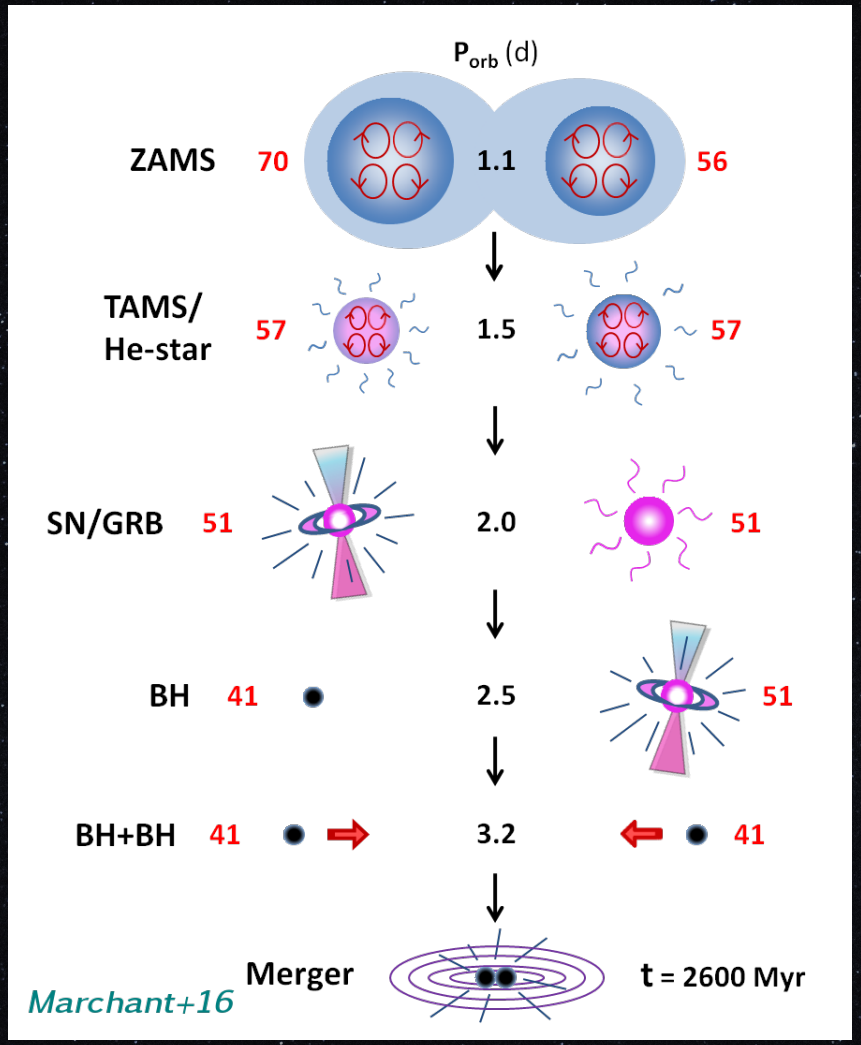
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SN/GRB
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51
BH
41
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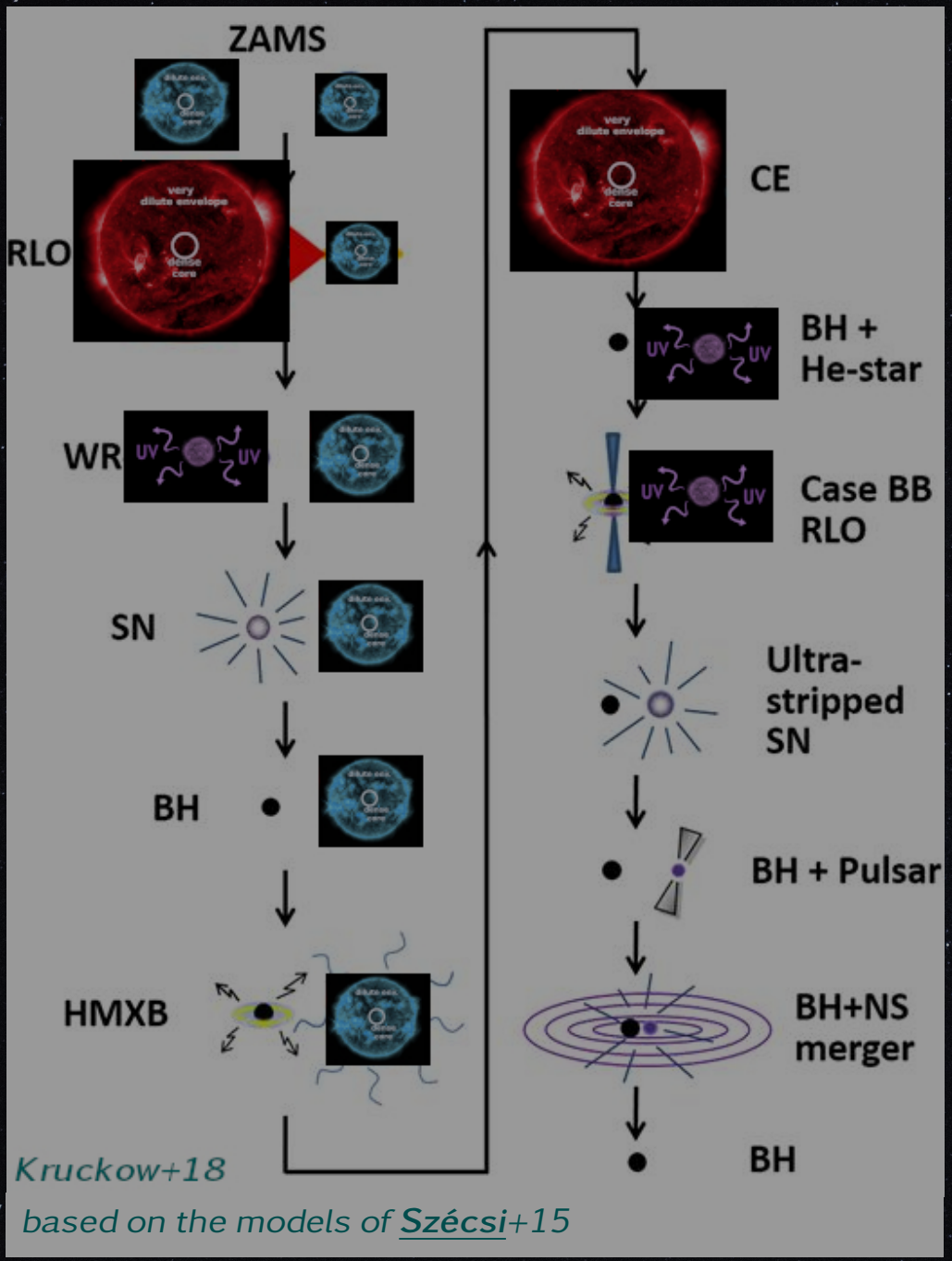
41
3.2
41
Merger
t = 2600 Myr
Marchant+16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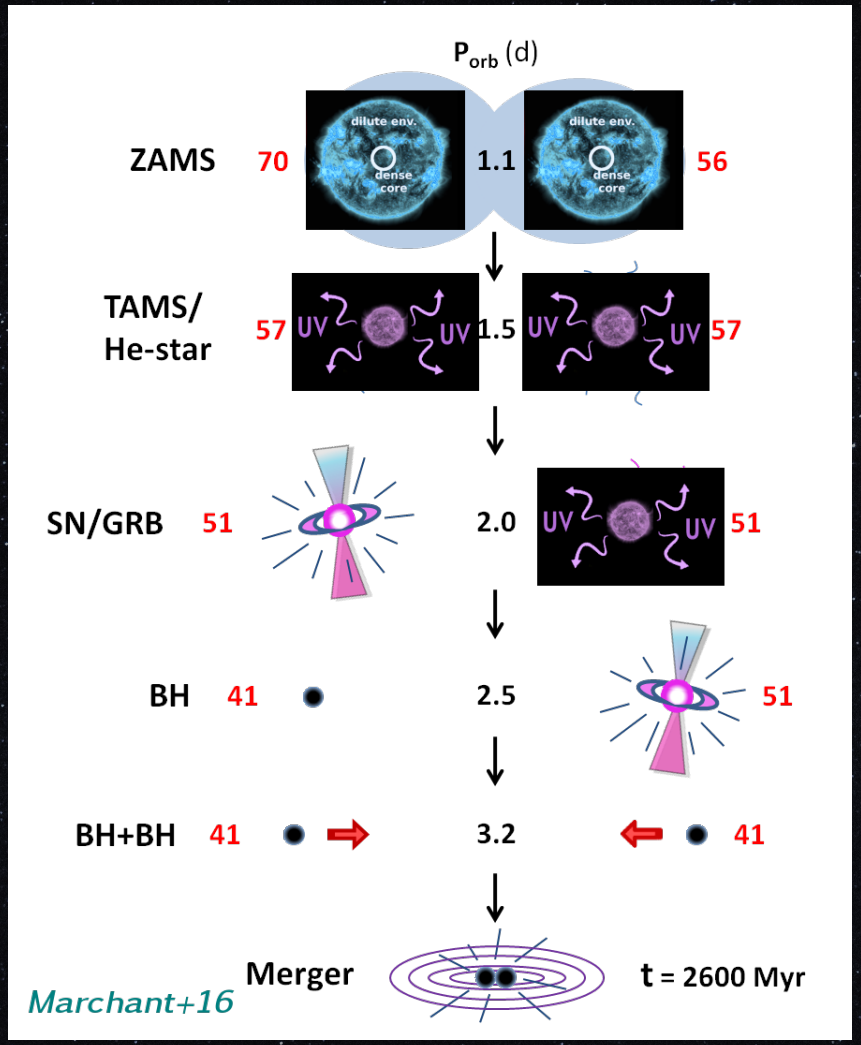
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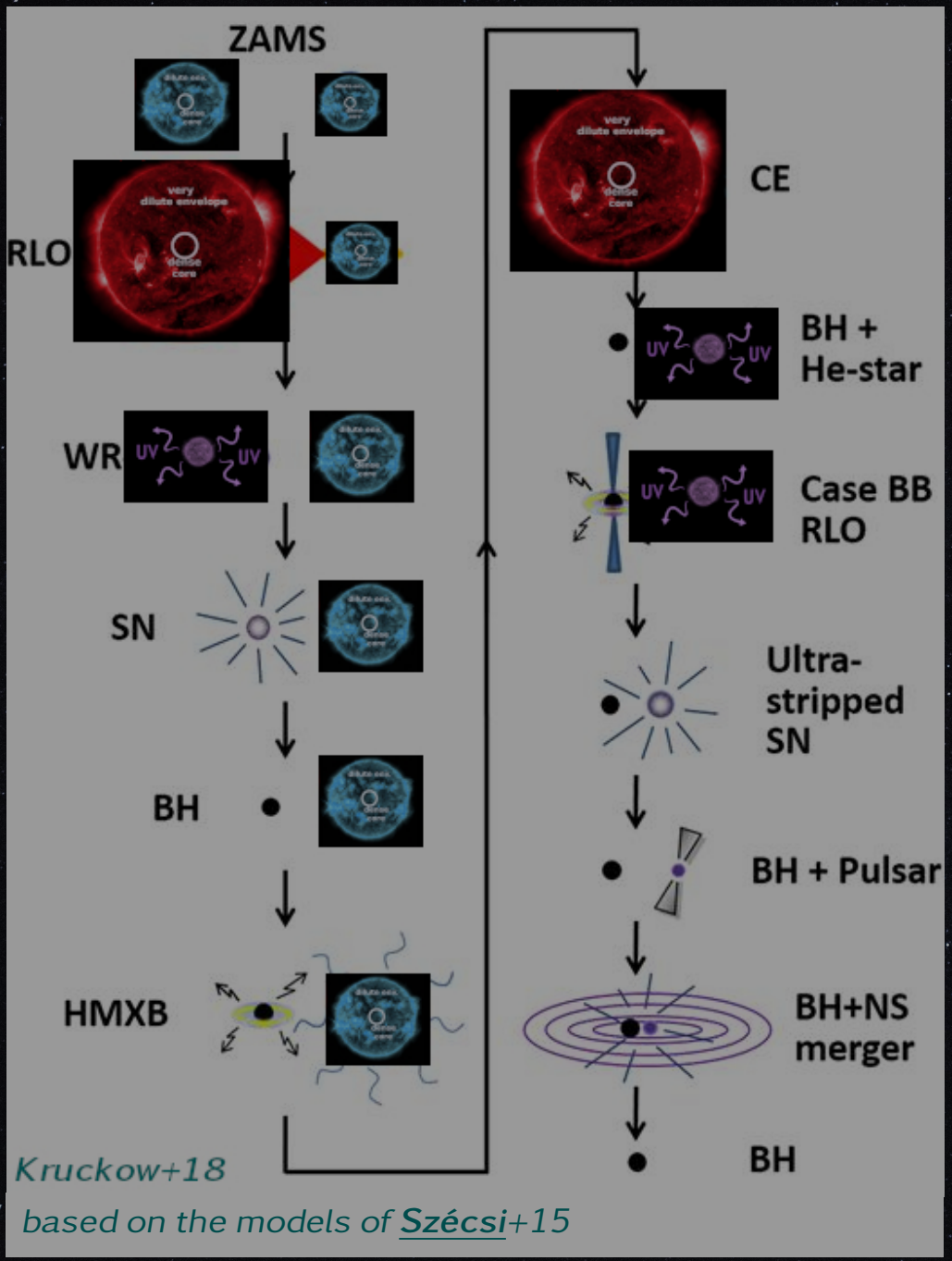
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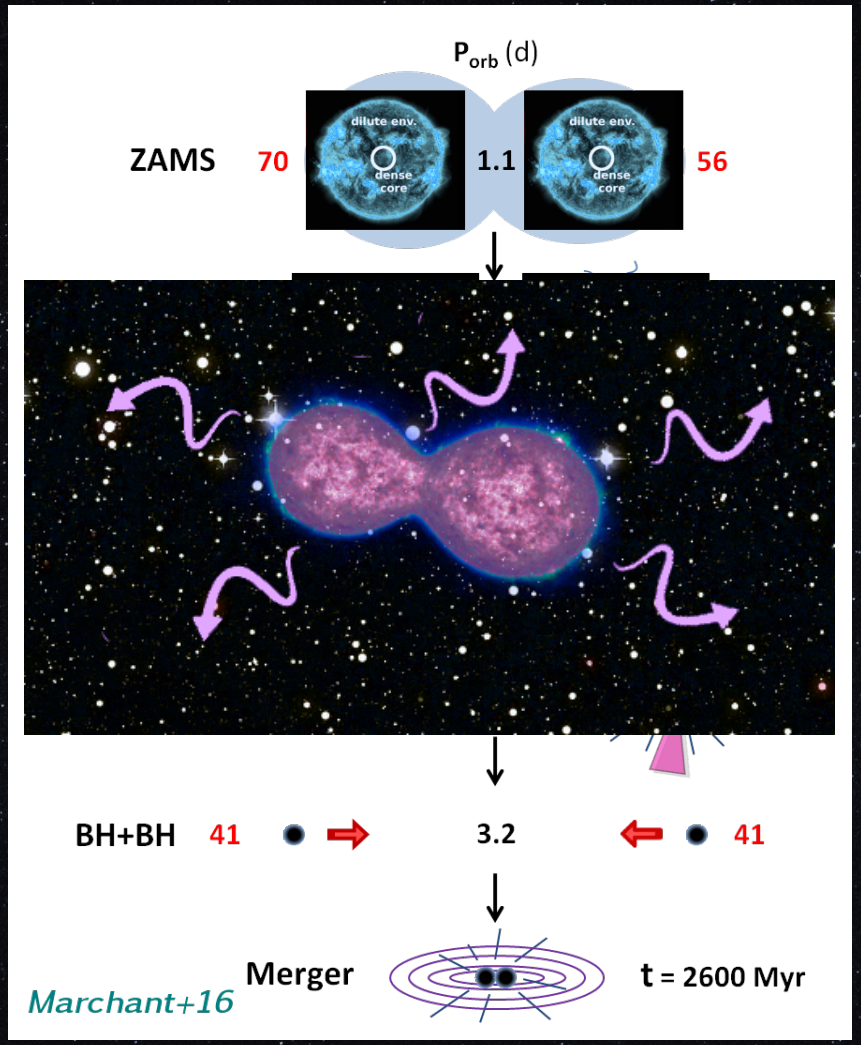
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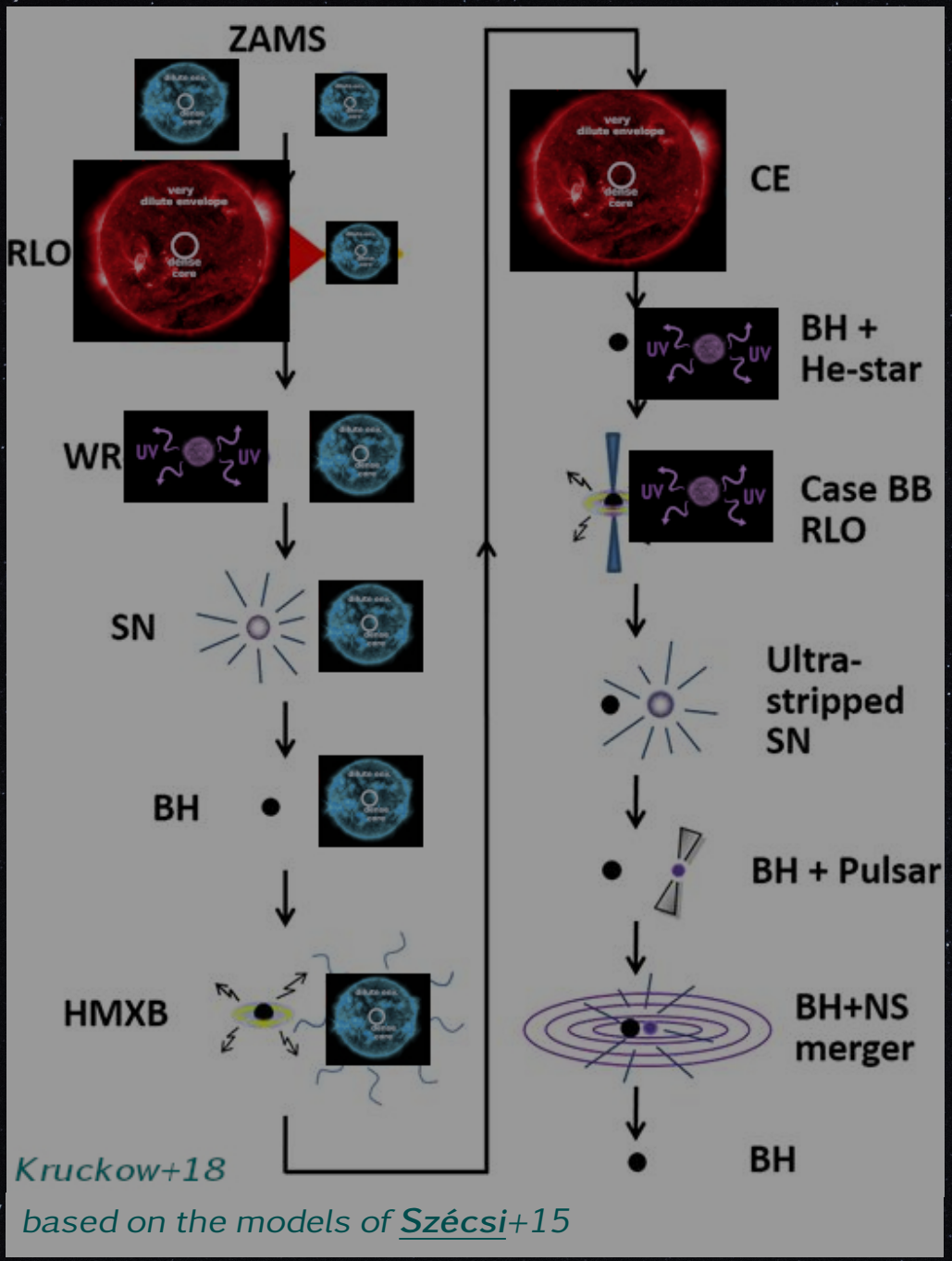
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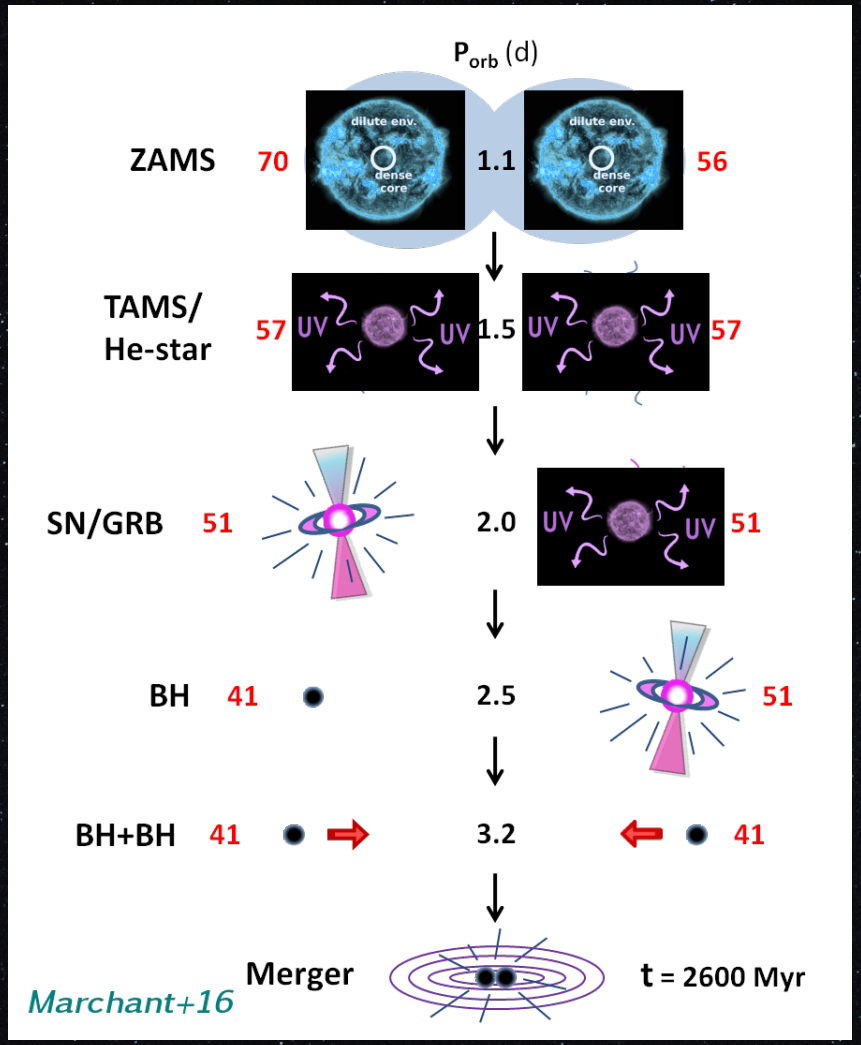
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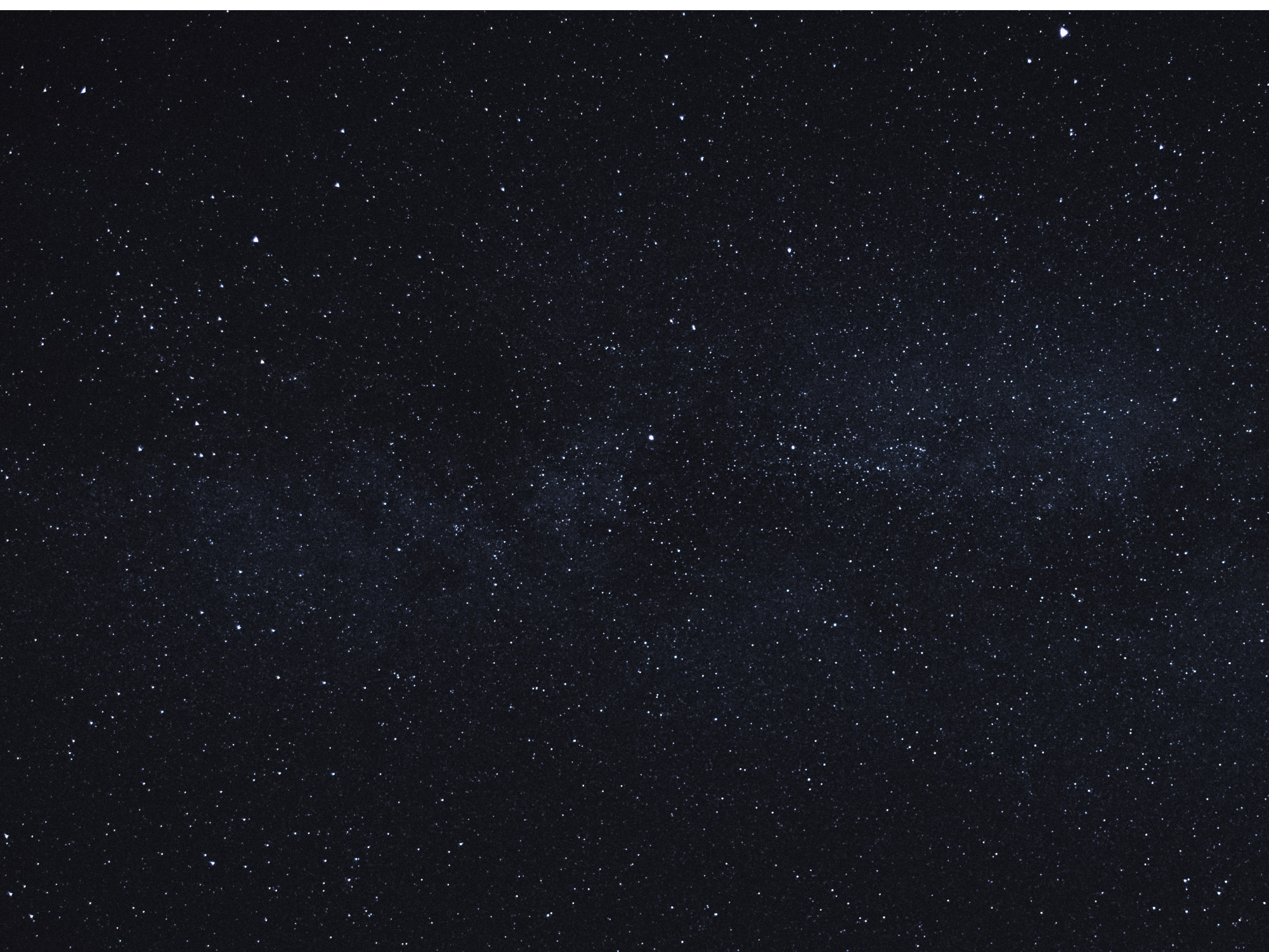
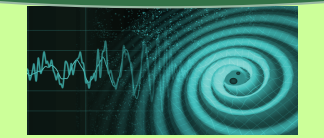


Dwarf galaxies

Gravitational waves



High-redshift Univ.

Metal-poor massive stars

Gamma-ray bursts

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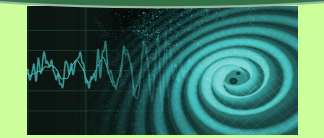

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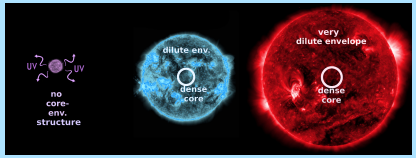

Gamma-ray bursts

Globular clusters

Szécsi+15a | Kubátová & Szécsi+19 | Szécsi+22

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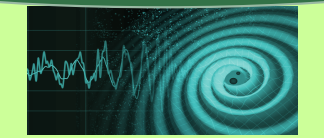
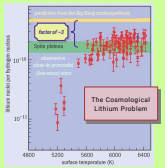
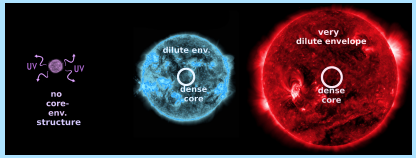


Vigna-Gomez..Szécsi+18 | Stevenson..Szécsi+19

Agrawal..Szécsi+20 | Romagnolo..Szécsi+23

High-redshift Univ.





Gamma-ray bursts

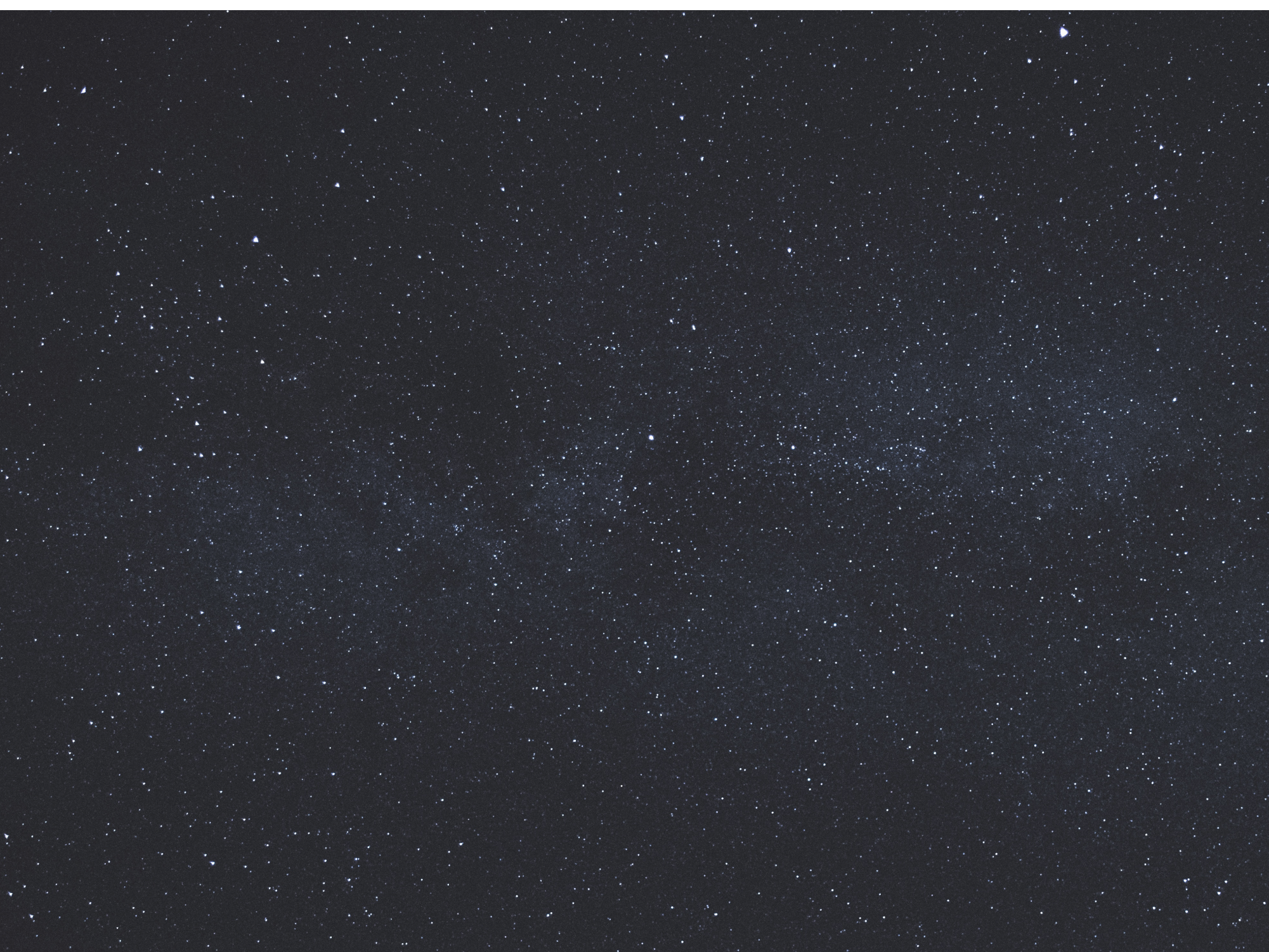
Szécsi+13 | Szécsi+15b | Szécsi'17a,b

ongoing PhD project (R. Sarwar)

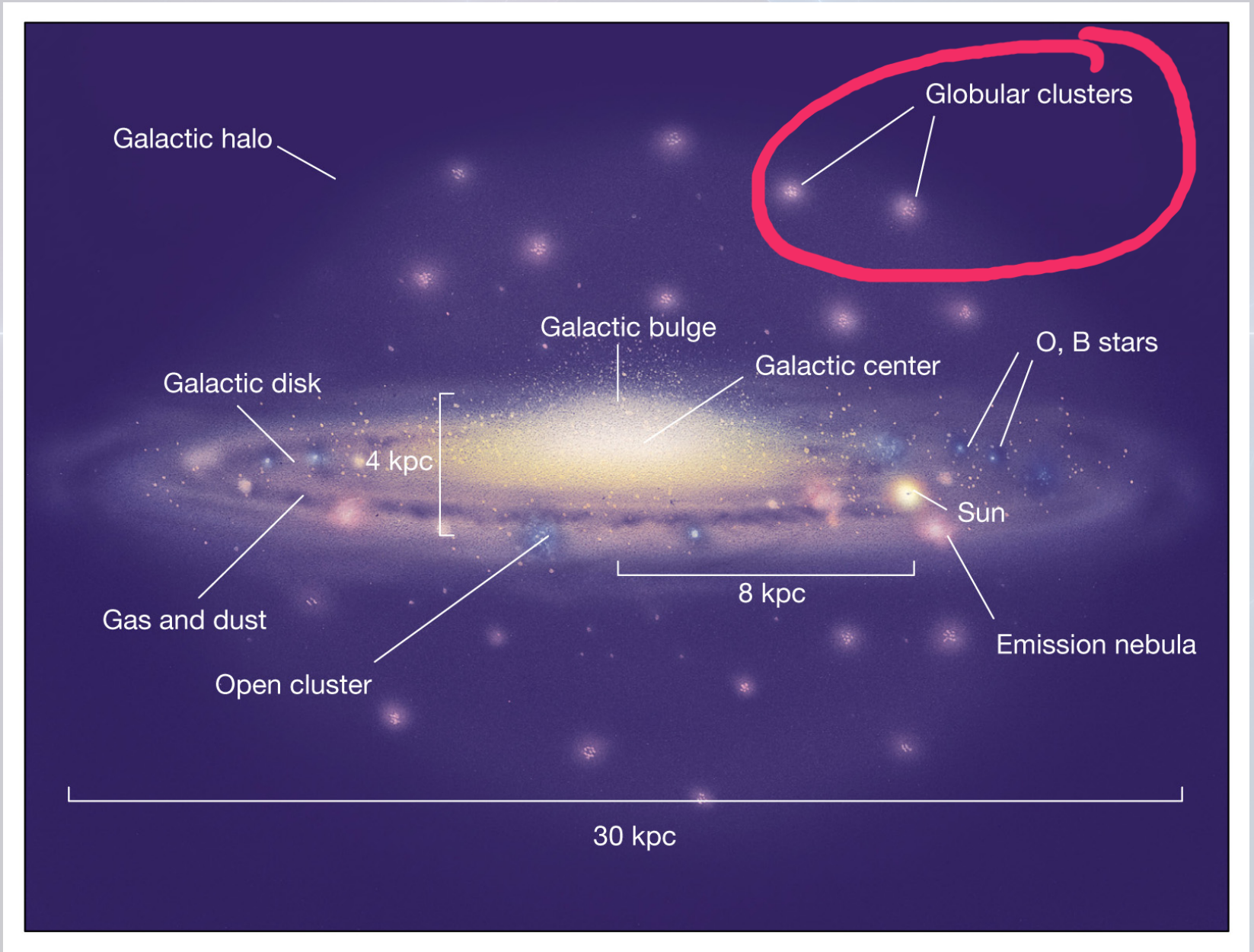
Globular clusters

Szécsi+18 | Szécsi & Wünsch'19

ongoing PhD project (H. Stinshoff)



The problem with globular clusters



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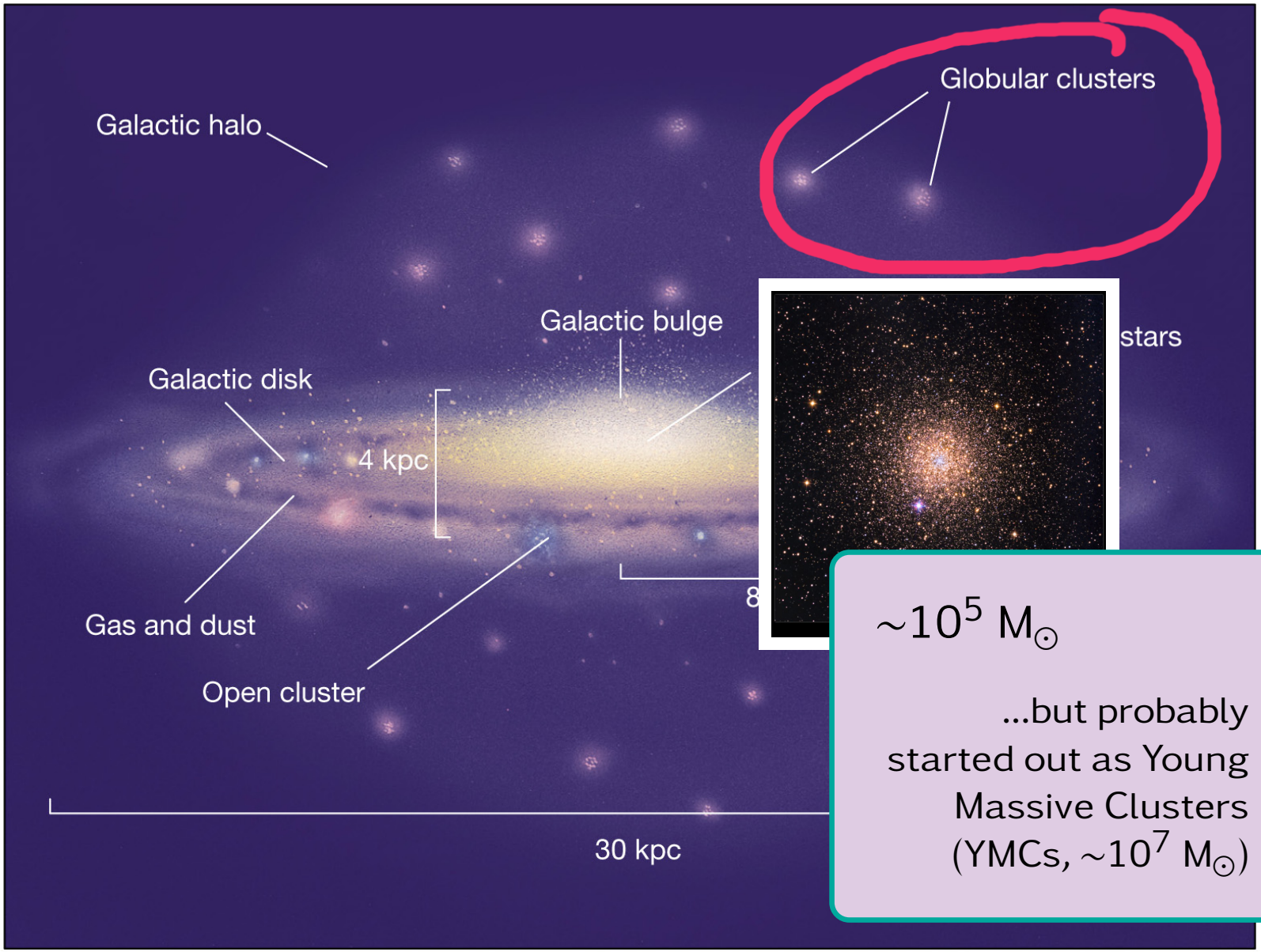
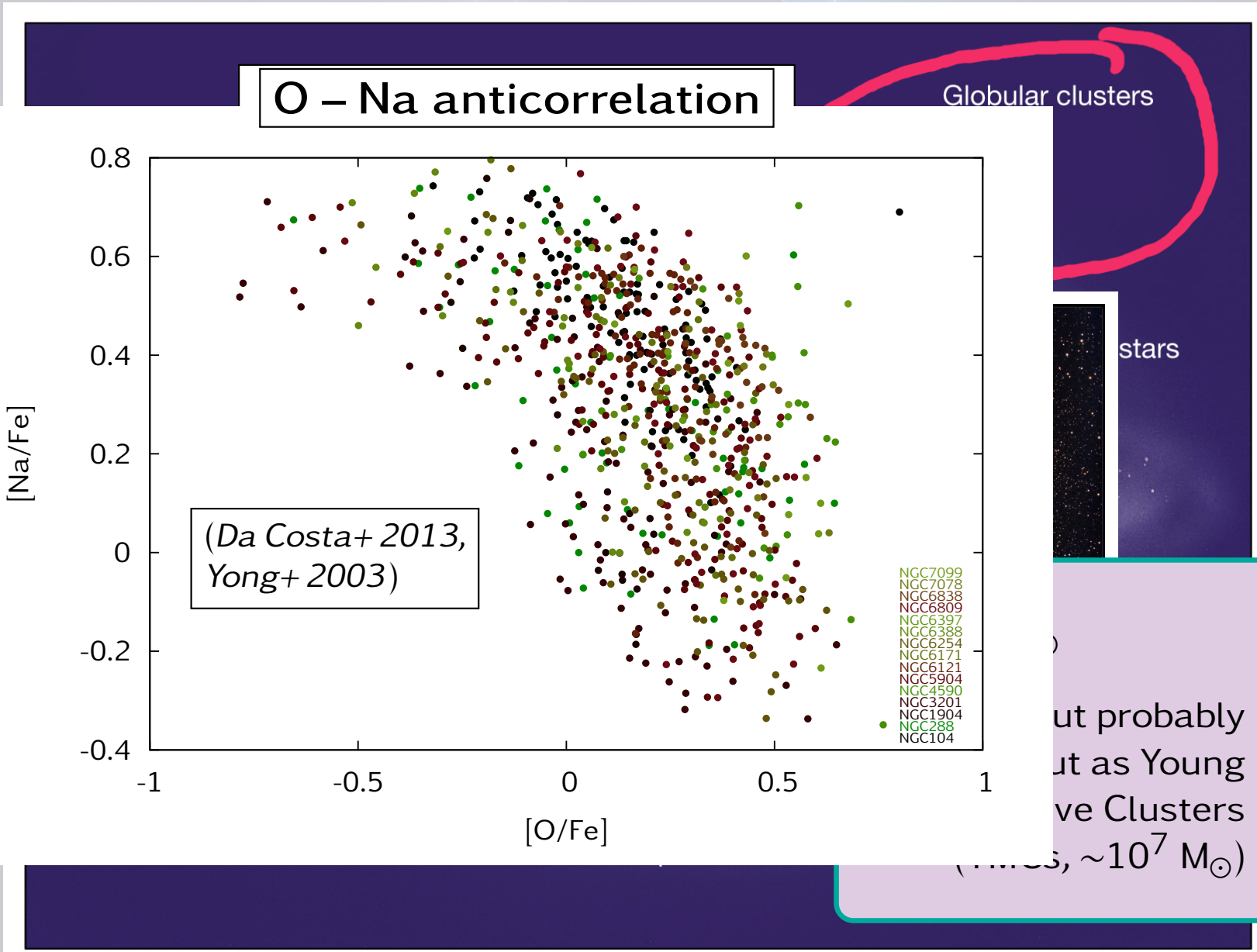


$\sim 10^5\ M_\odot$

...but probably started out as Young Massive Clusters (YMCs, $\sim 10^7\ M_\odot$)

The problem with globular clusters



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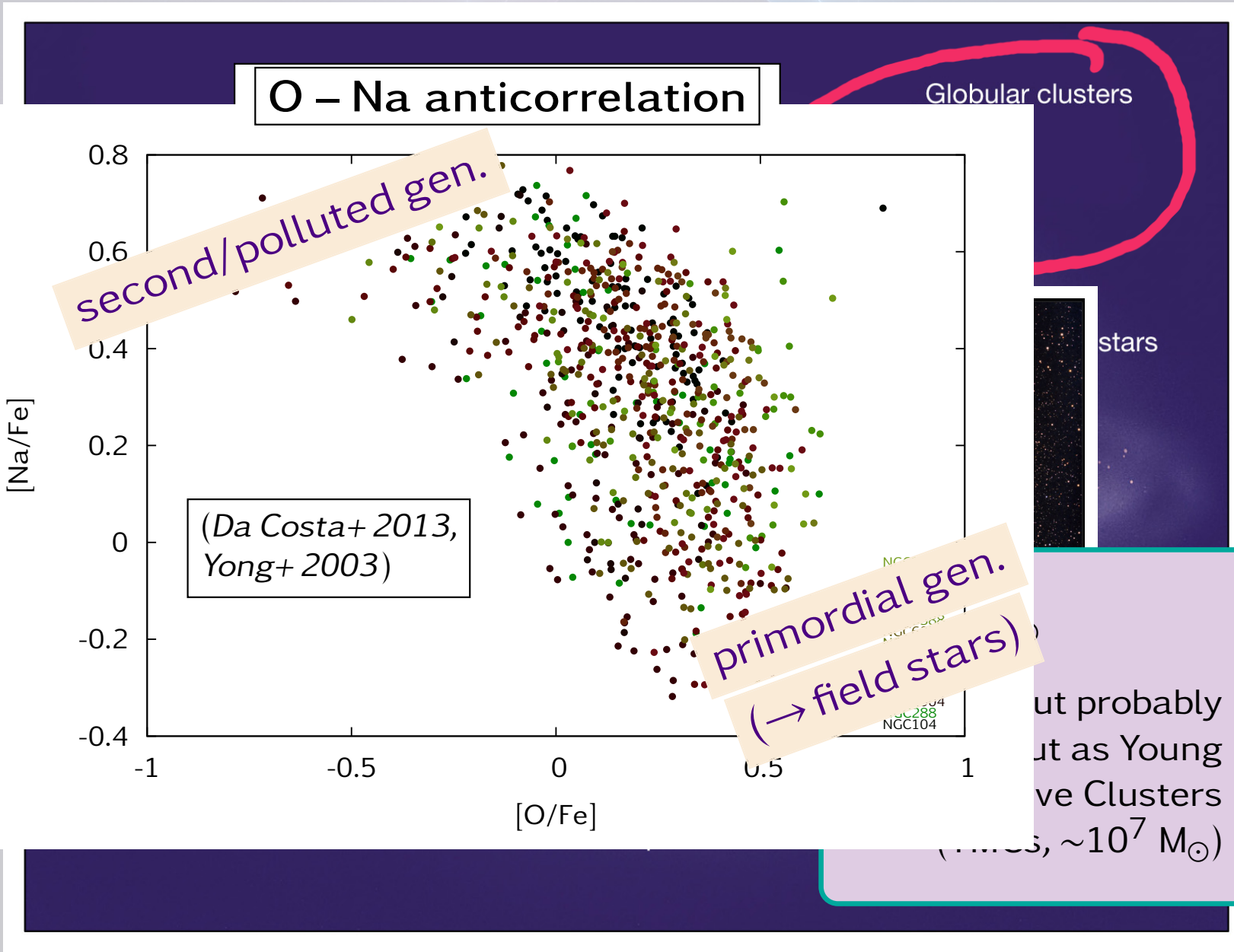

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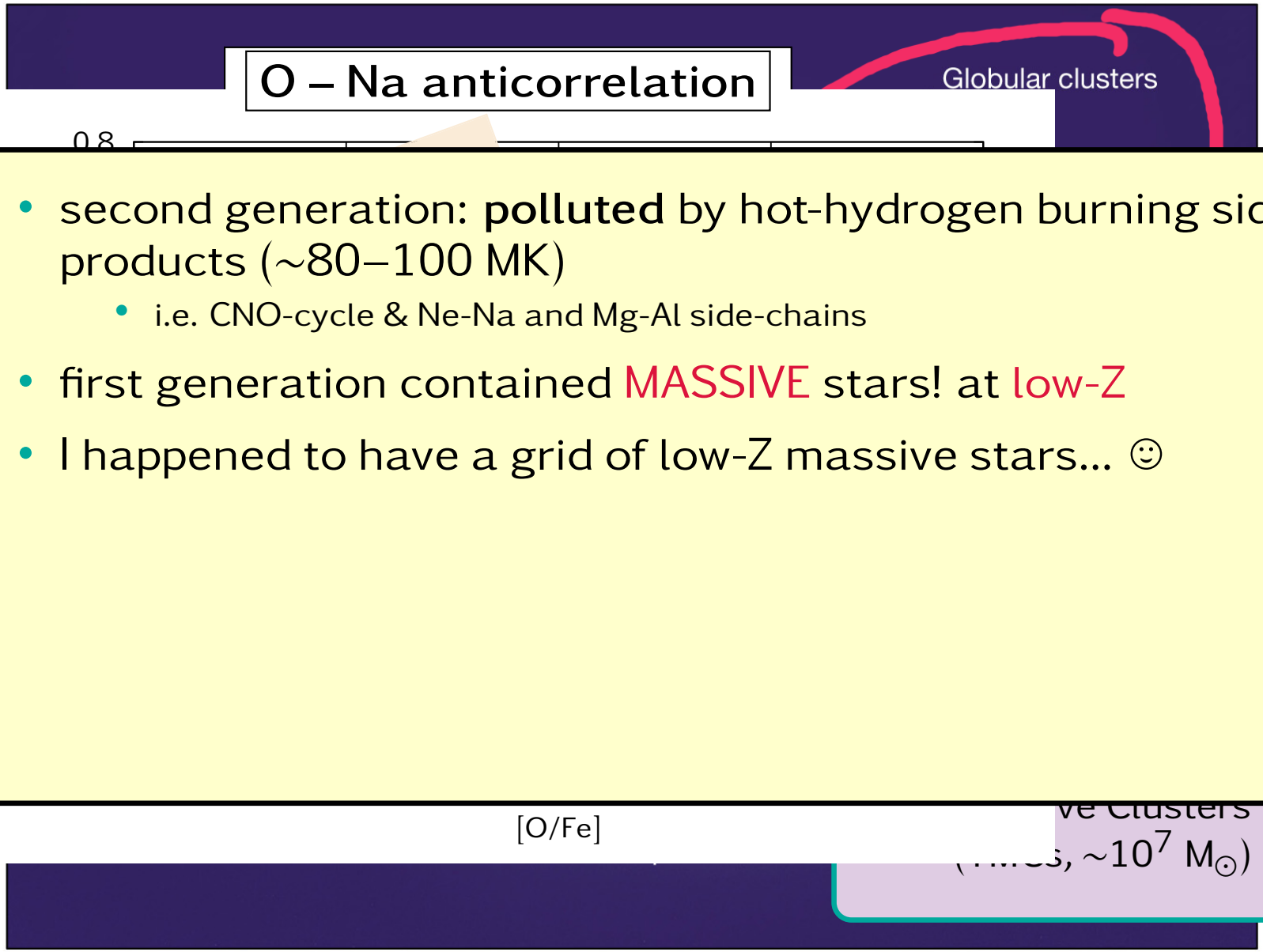
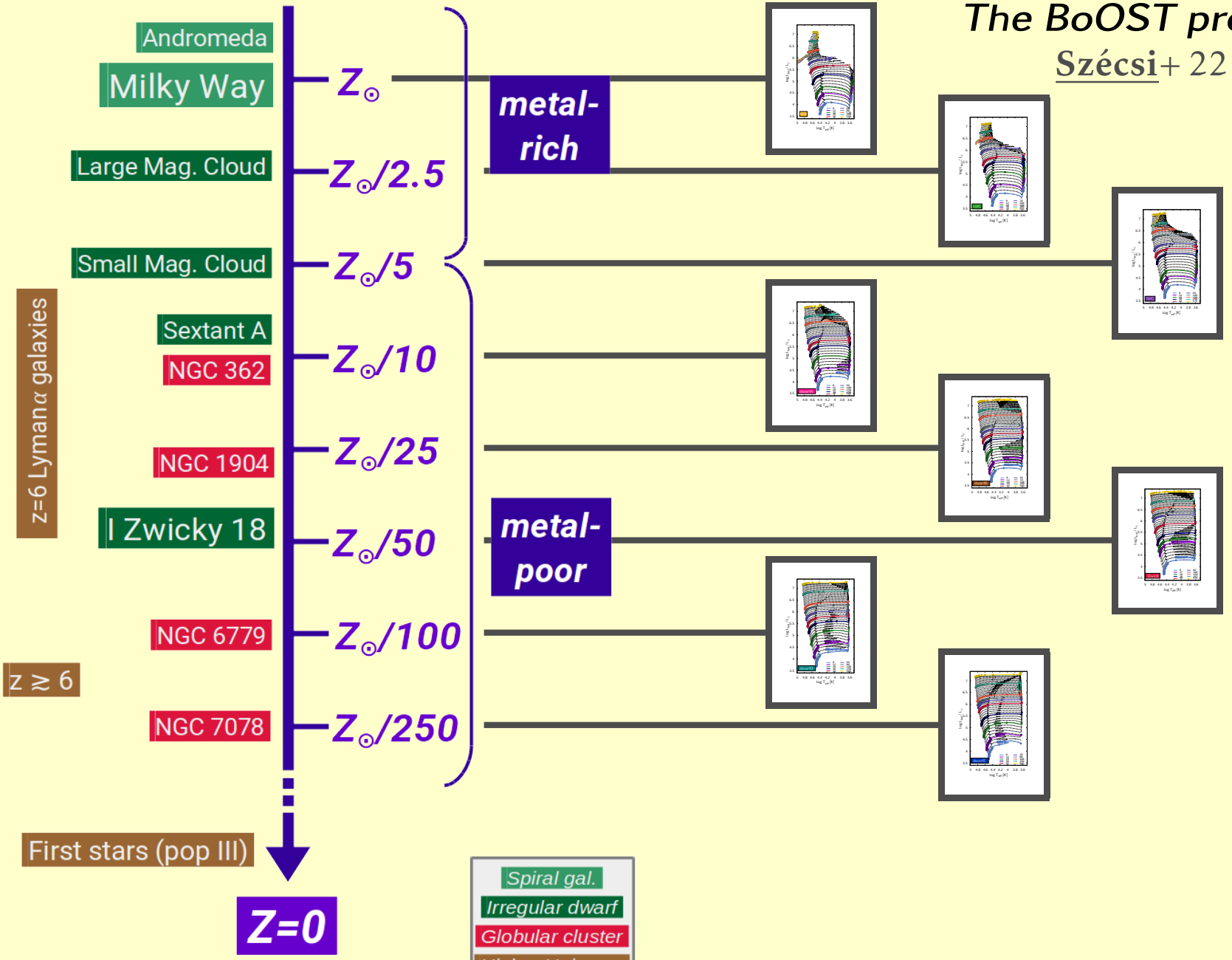


- second generation: **polluted** by hot-hydrogen burning side products (~80–100 MK)
  - i.e. CNO-cycle & Ne-Na and Mg-Al side-chains
- first generation contained MASSIVE stars! at low-Z
- I happened to have a grid of low-Z massive stars… ☺

The BoOST project

Szécsi+ 22



OST project

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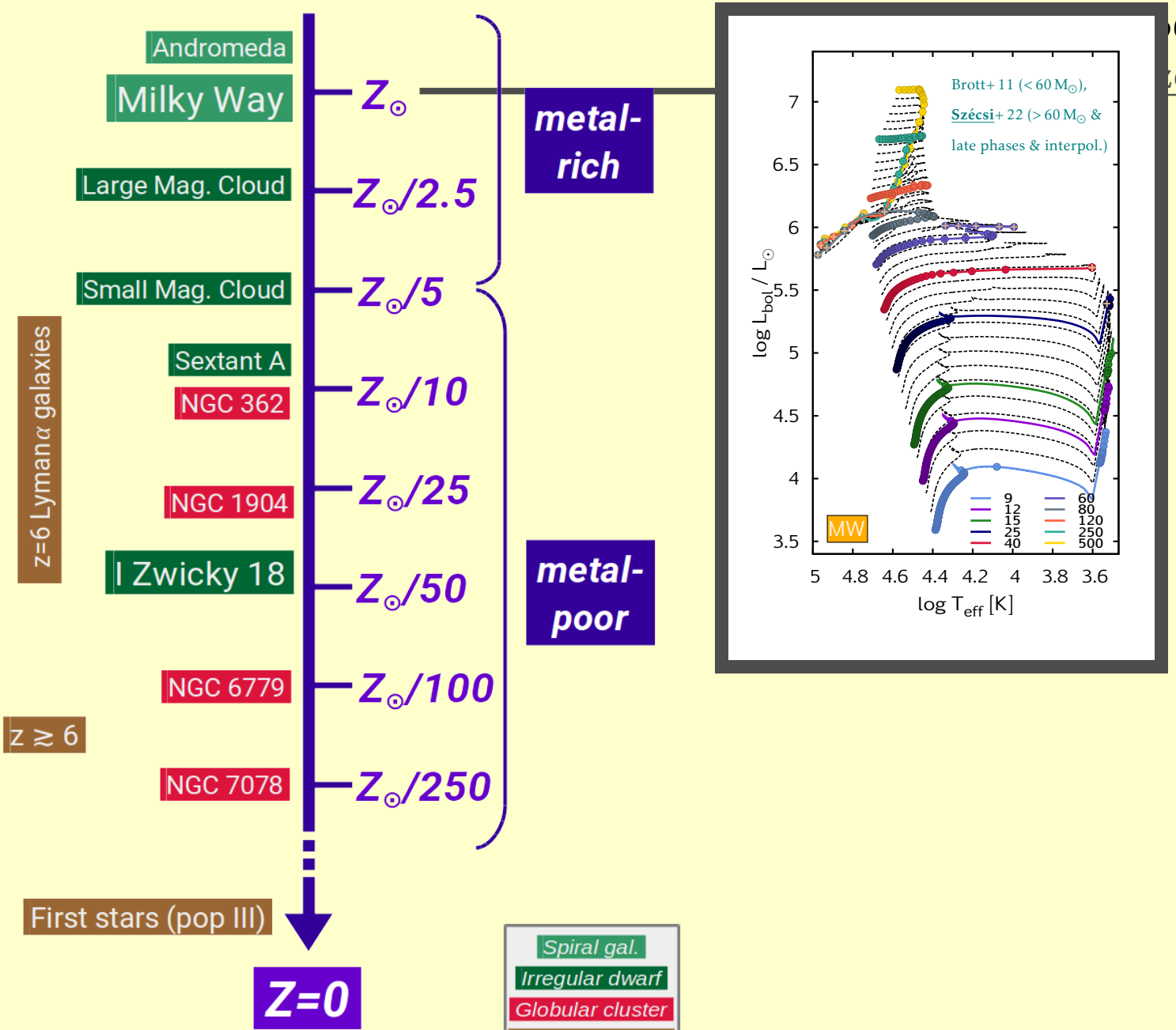
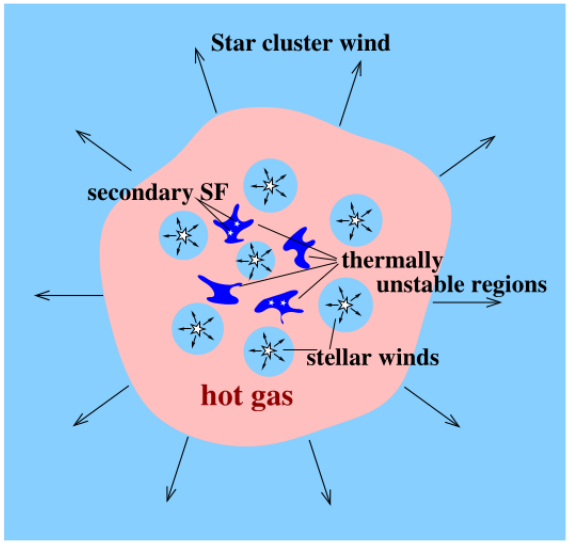


Simulating YMCs

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:

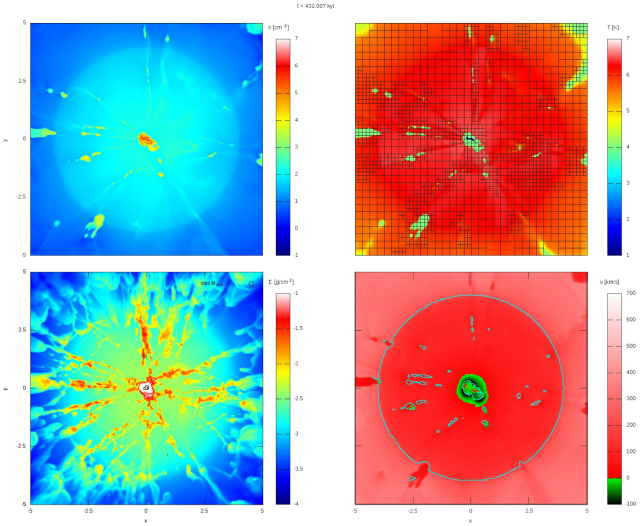
- L_{SC}, $\dot{M}_{SC} \leftarrow M_{1G}$, stellar evolution tracks
- R_{SC} + eventually radial profile (R_c, β)

From 3D hydro to semi-analytic (quick)

RHD simulations:

(Wünsch+17):

- AMR code Flash, 512^3 (finest) (Fryxell+00)
- opt. thin cooling (Schure+09)
- fixed stellar gravity, self-gravity
  → tree code (Wünsch+18)
- ionising radiation
  → TreeRay (Wünsch +2021)



Semianalytic model:

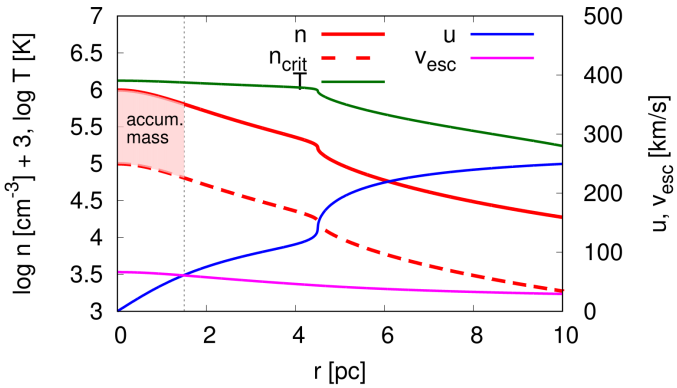
(Chevalier&Clegg+85, Silich+04, Wünsch+17)

$$\frac{1}{r^2}\frac{d}{dr}(\rho u r^2) = q_m$$

$$\rho u \frac{du}{dr} = -\frac{dP}{dr} - q_m u - \nabla\Phi$$

$$\frac{1}{r^2}\frac{d}{dr}\left[\rho u r^2 \left(\frac{u^2}{2} + \frac{\gamma}{\gamma-1}\frac{P}{\rho}\right)\right] = q_e - Q$$

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



Mass accumulation:

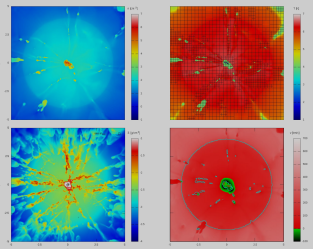
$$M_{\rm acc}(t) = \int_{t_{bs}}^{t}\int_0^{R_{\rm esc}} [q_m(r,t') - q_{m,crit}(r,t')]\,dr dt'$$

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

only clumps formed with $v < v_{\rm esc}$ accumulate

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

RHD simulations:
(Wünsch+17):
- AMR code Flash, 512^3 (finest)
  (Fryxell+00)
- opt. thin cooling (Schure+09)
- fixed stellar gravity, self-gravity
  → tree code (Wünsch+18)
- ionising radiation
  → TreeRay (Wünsch +2021)



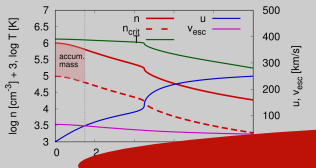
Semianalytic model:
(Chevalier&Clegg+85, Silich+04, Wünsch+17)

$$\frac{1}{r^2}\frac{d}{dr}(\rho u r^2) = q_m$$

$$\rho u \frac{du}{dr} = -\frac{dP}{dr} - q_m u - \nabla\Phi$$

$$\frac{1}{r^2}\frac{d}{dr}\left[\rho u r^2 \left(\frac{u^2}{2} + \frac{\gamma}{\gamma-1}\frac{P}{\rho}\right)\right] = q_e - Q$$

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



Mass accumulation:
$M_{acc}(t) = \int_{t_{bs}}^{t}\int_0^{R_{esc}}[q_m(r,t') - q_{m,crit}(r,t')]d$
rate of the clump formation is given by $q_m - q_{m,crit}$
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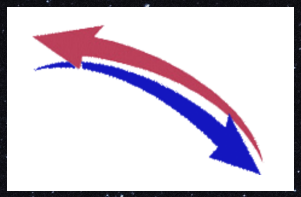
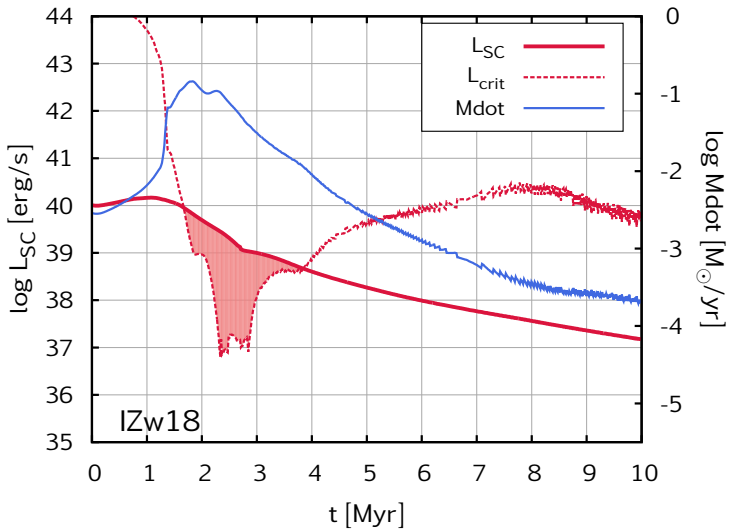


YMC under the influence of Early Stars from BoOST



...and adding BoOST stellar models (Bo

RHD simulations:
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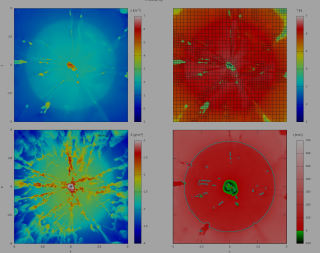

Semianalytic model:
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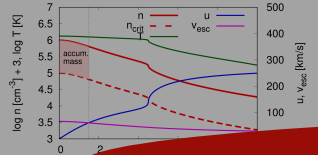

Mass accumulation:
$M_{acc}(t) = \int_{t_{bs}}^{t}\int_0^{R_{esc}}[q_m(r,t') - q_{m,crit}(r,t')]d$
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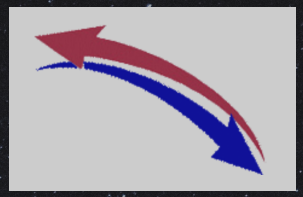
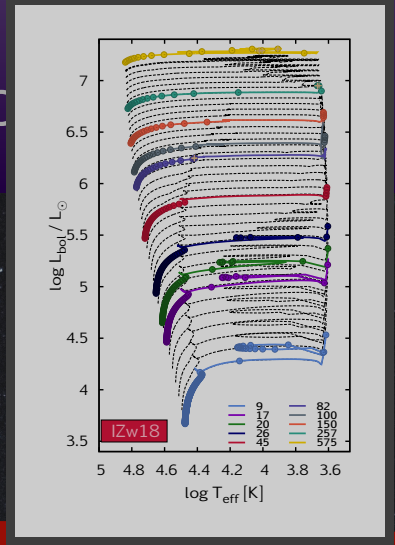
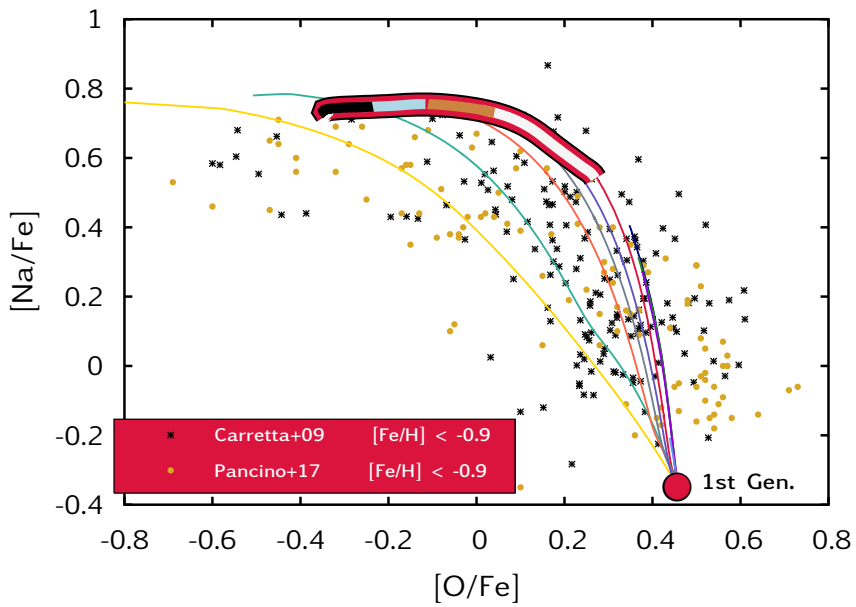
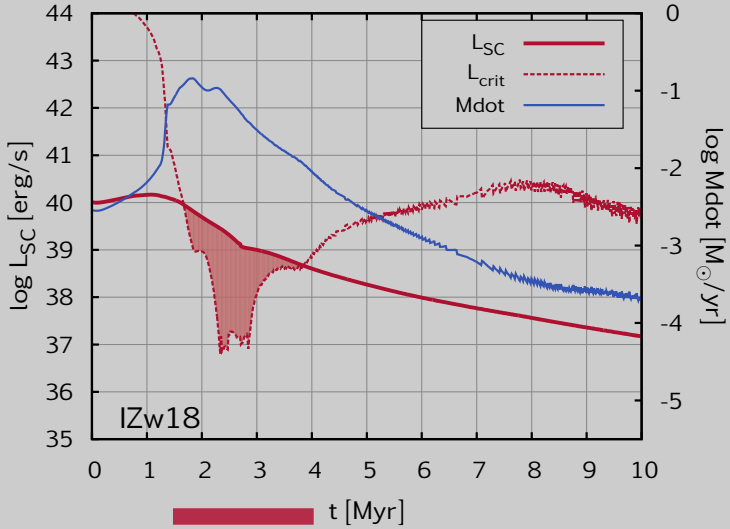


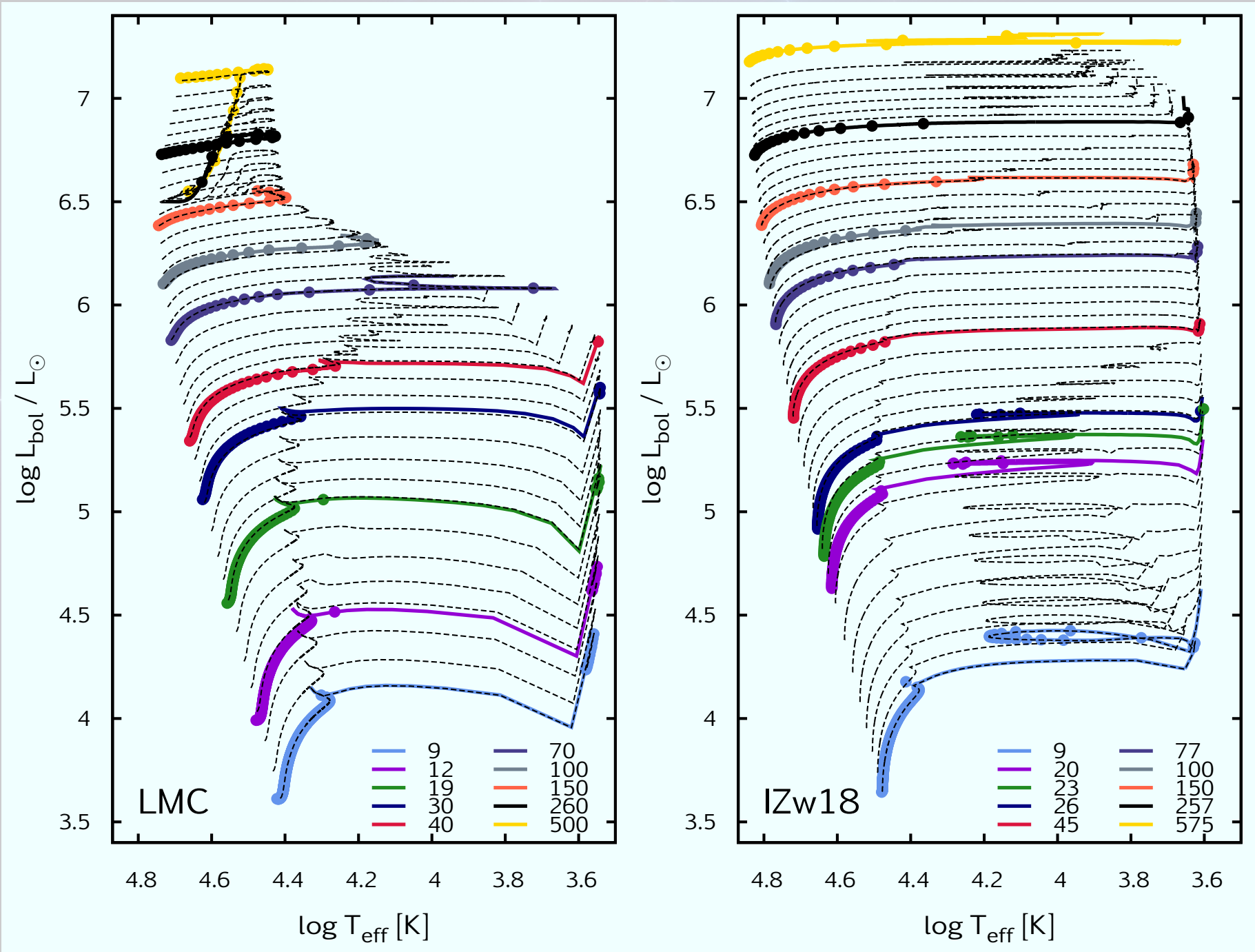


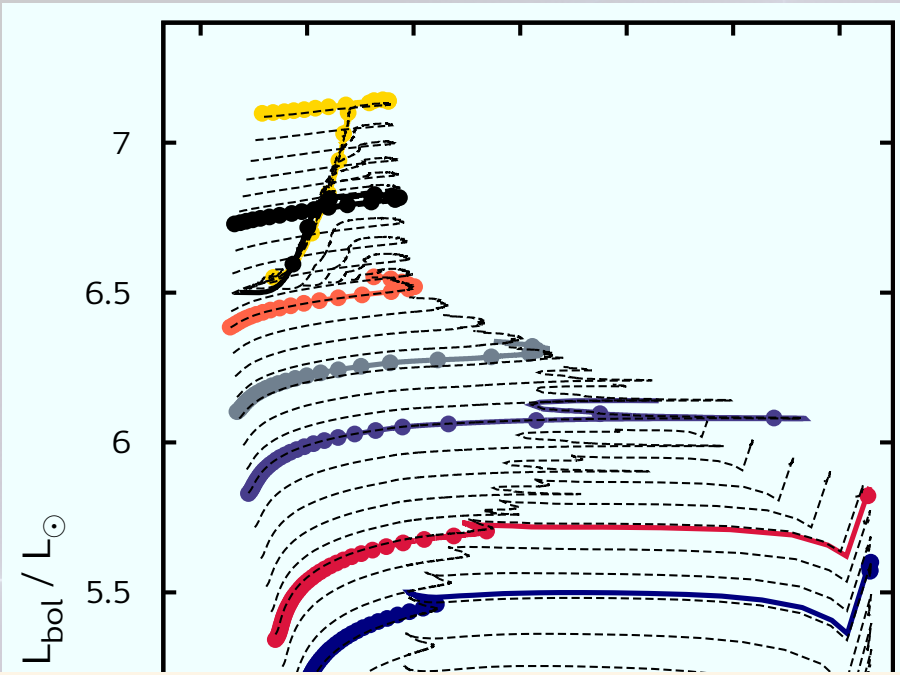
YMC under the influence of Early Stars from BoOST

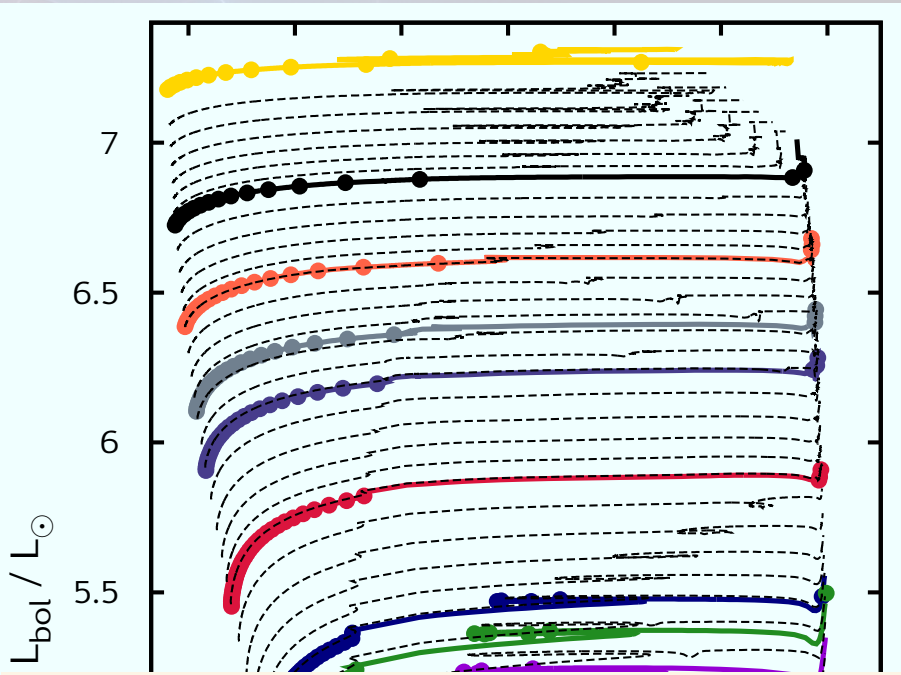


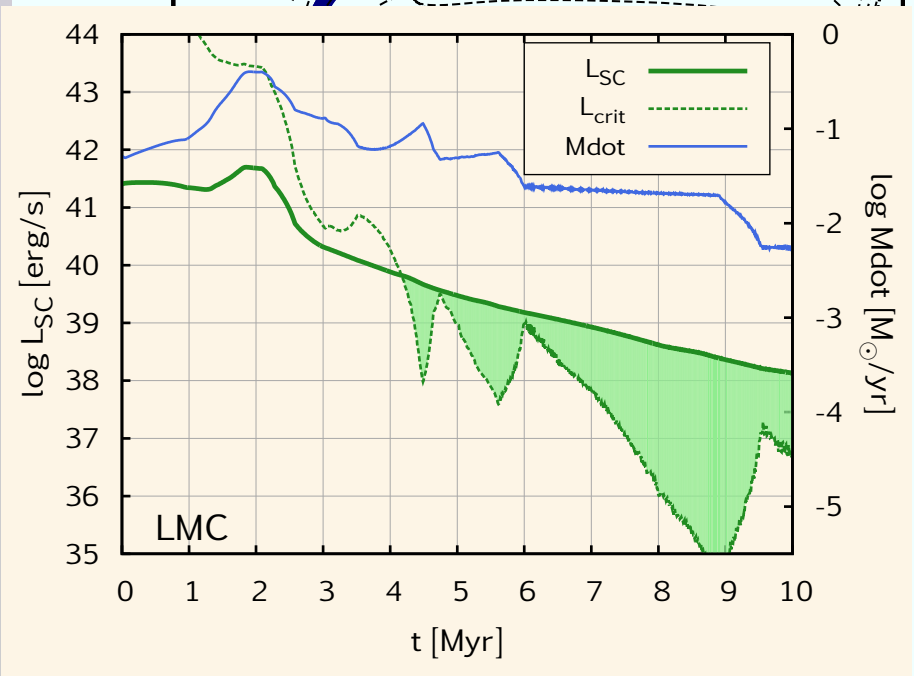


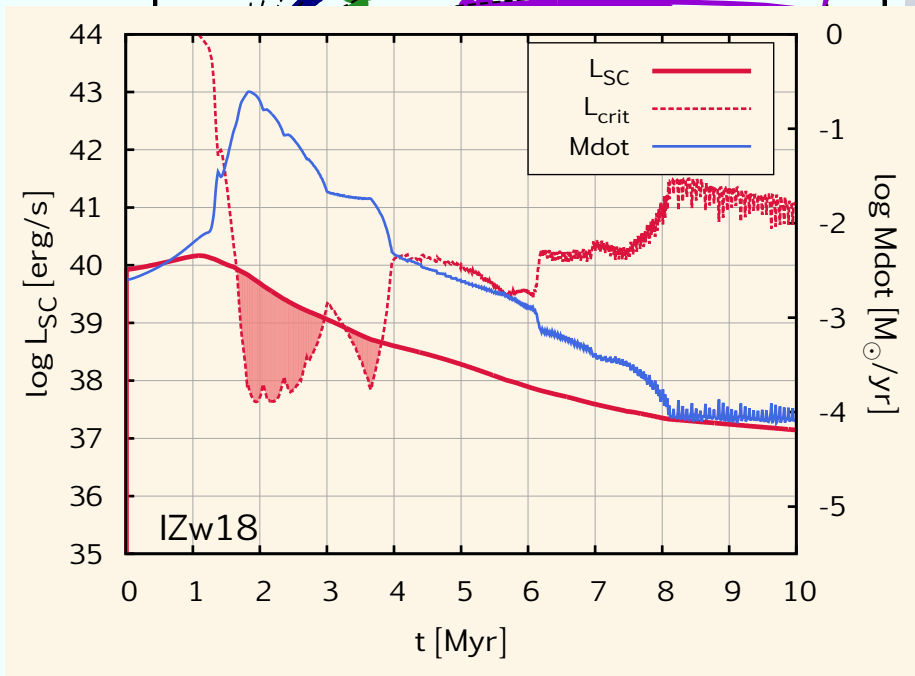
2G stars forming!

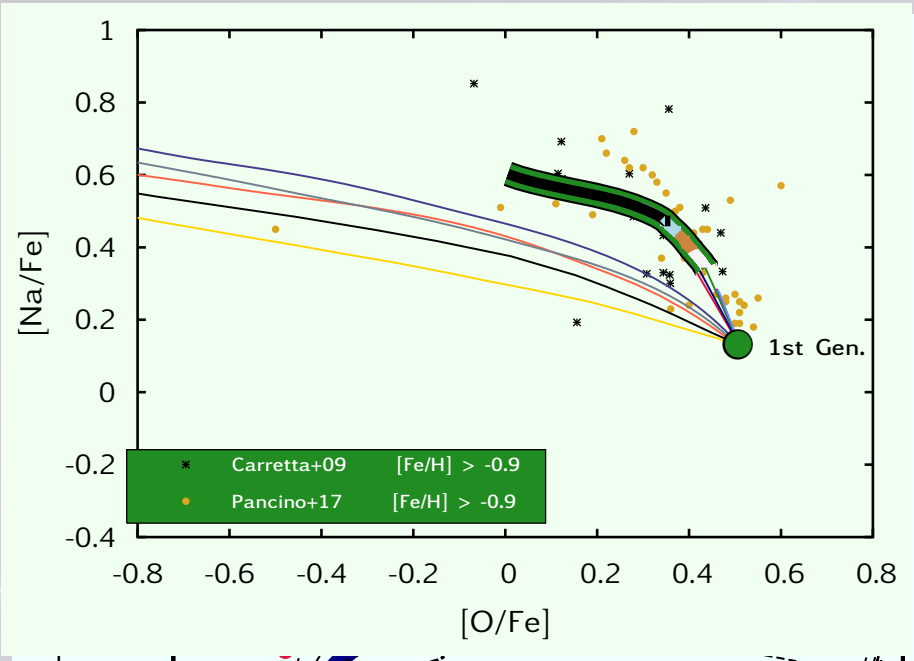

LMC
IZw18
log L_bol / L_⊙
log T_eff [K]
7
6.5
6
5.5
5
4.5
4
3.5
4.8
4.6
4.4
4.2
4
3.8
3.6
9
12
19
30
40
70
100
150
260
500
9
20
23
26
45
77
100
150
257
575

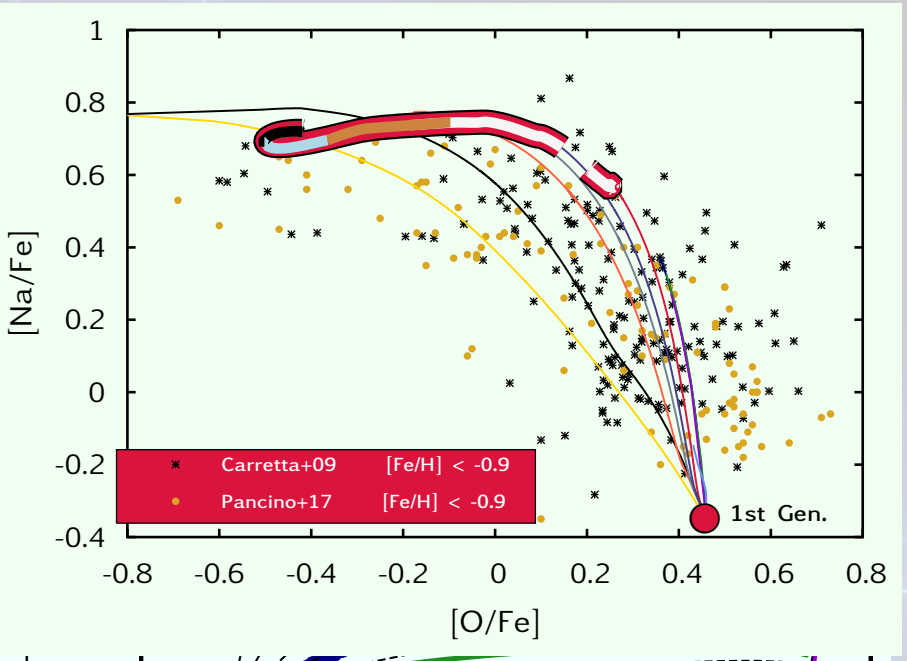

7
6.5
6
5.5
L_{bol} / $L_\odot$

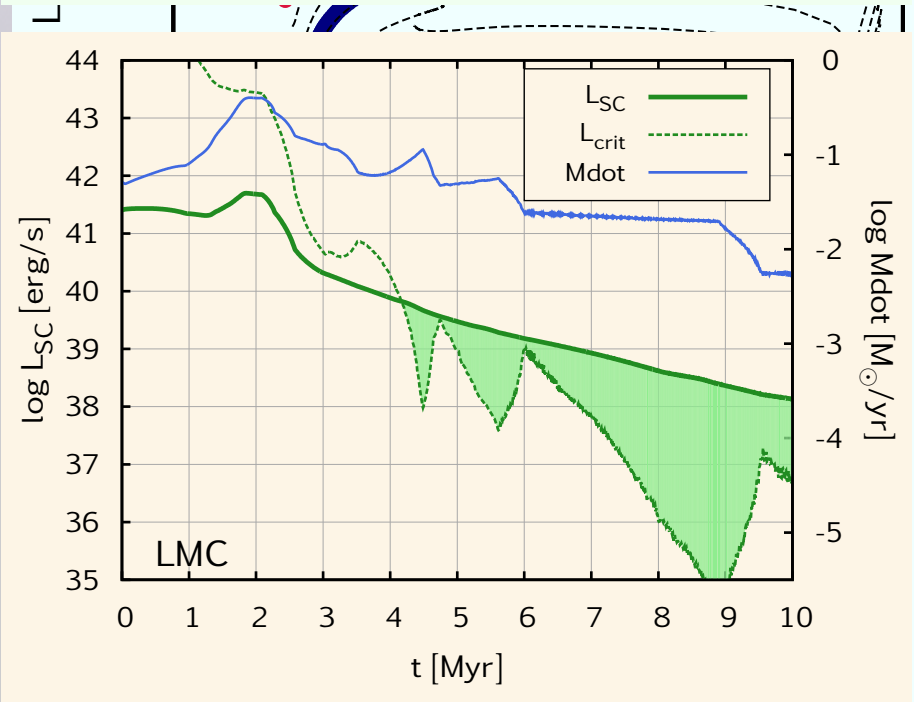

7
6.5
6
5.5
L_{bol} / $L_\odot$

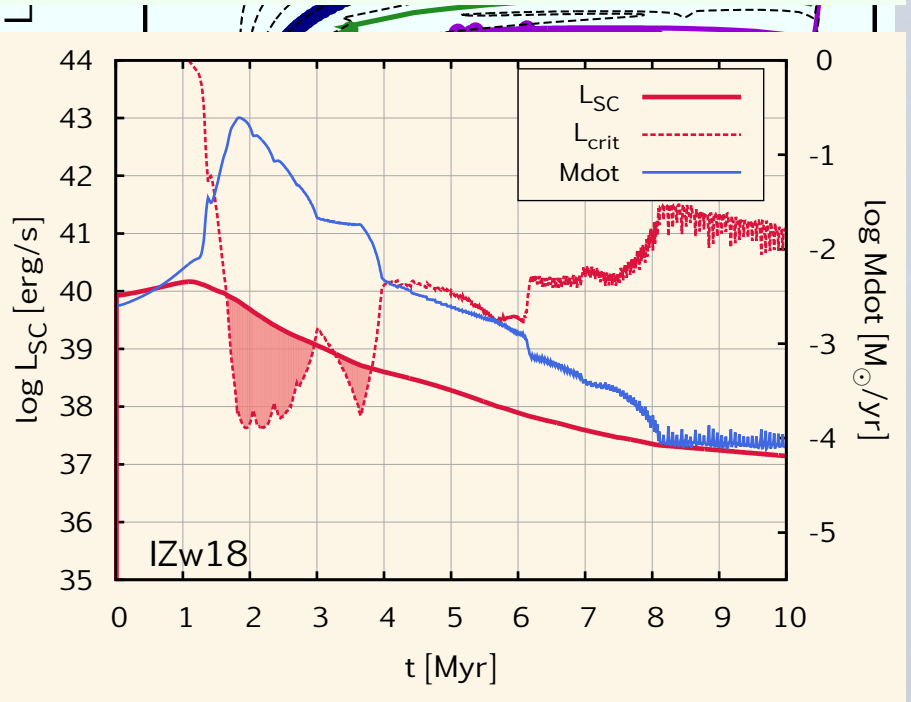

L_{SC}
L_{crit}
Mdot
LMC
log L_{SC} [erg/s]
log Mdot [$M_\odot$/yr]
t [Myr]


L_{SC}
L_{crit}
Mdot
IZw18
log L_{SC} [erg/s]
log Mdot [$M_\odot$/yr]
t [Myr]

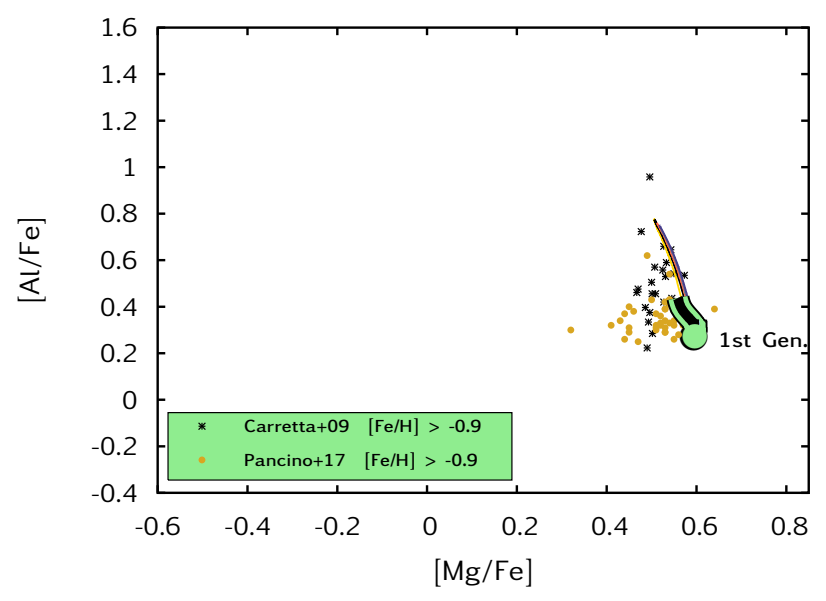

[Na/Fe]
[O/Fe]
1st Gen.
Carretta+09 [Fe/H] > -0.9
Pancino+17 [Fe/H] > -0.9

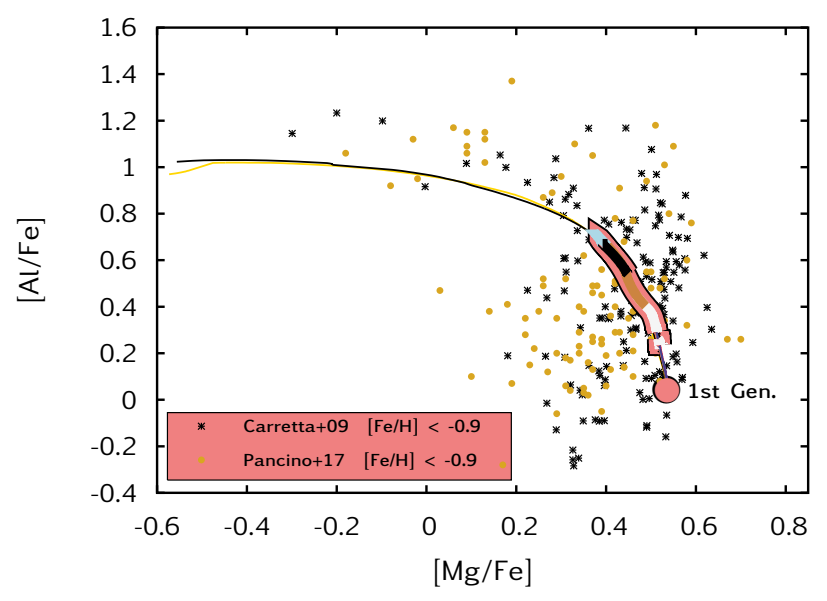

[Na/Fe]
[O/Fe]
1st Gen.
Carretta+09 [Fe/H] < -0.9
Pancino+17 [Fe/H] < -0.9


log L_SC [erg/s]
log Mdot [M⊙/yr]
t [Myr]
L_SC
L_crit
Mdot
LMC

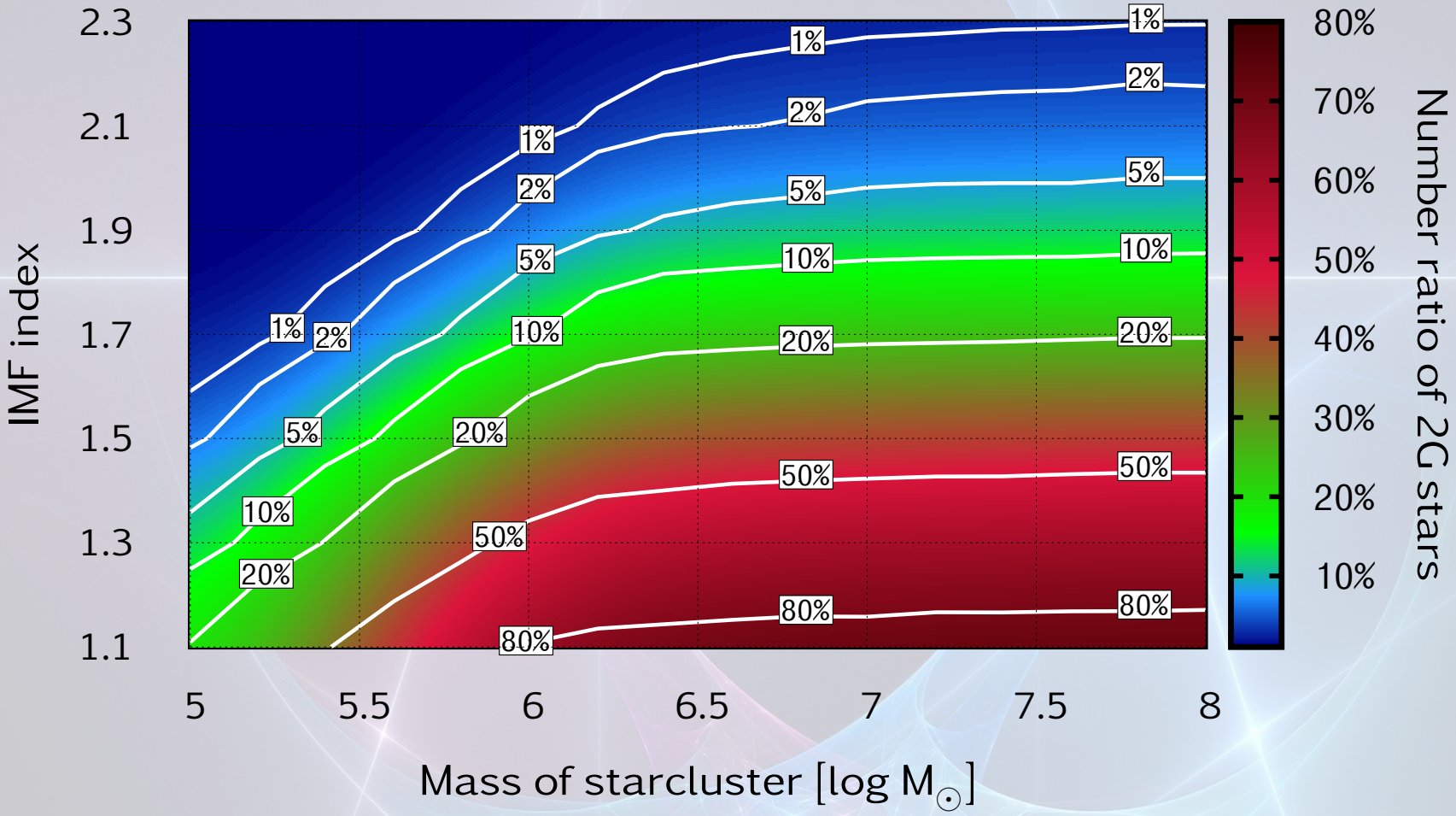

log L_SC [erg/s]
log Mdot [M⊙/yr]
t [Myr]
L_SC
L_crit
Mdot
IZw18

Magnesium & Aluminium

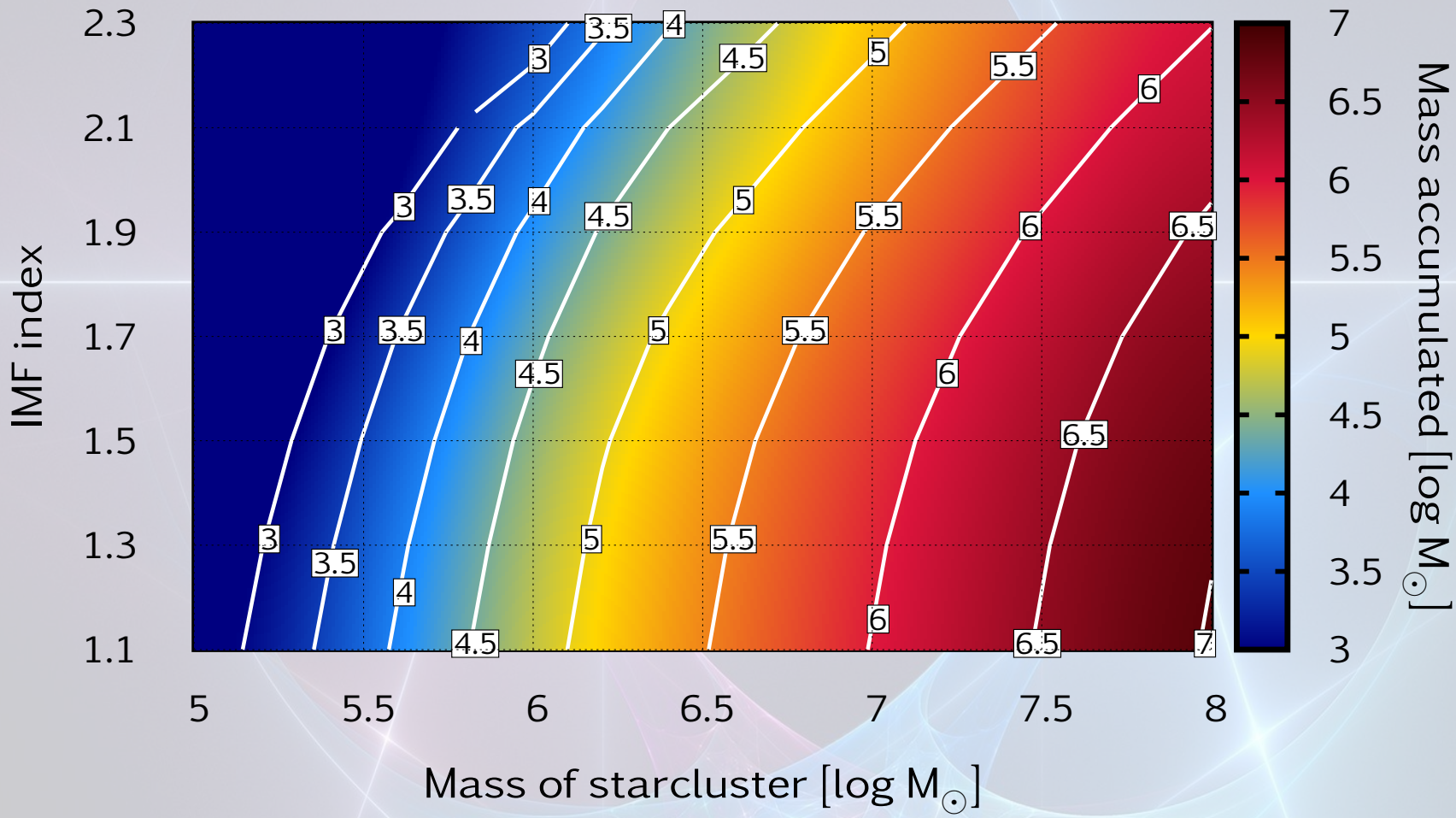




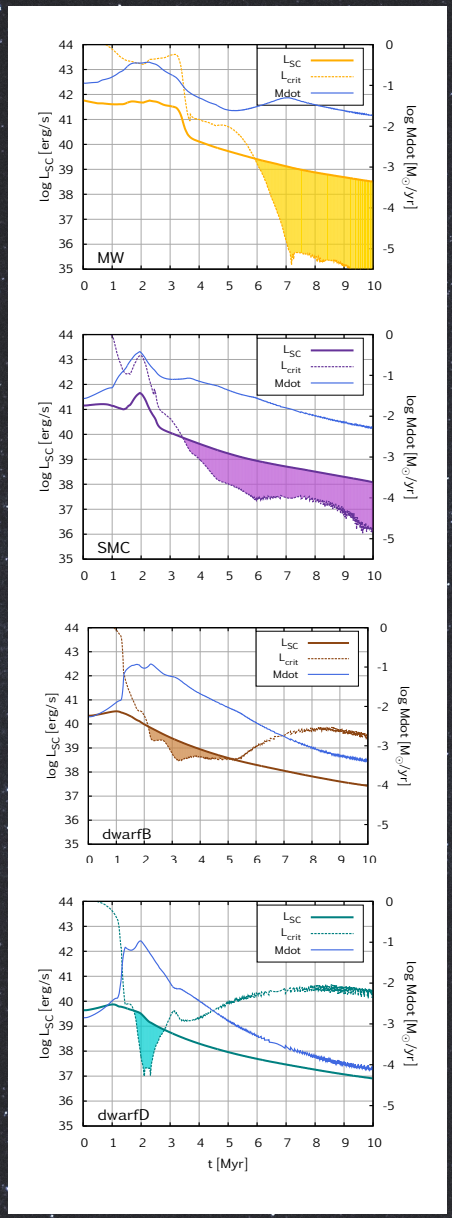
Mass budget

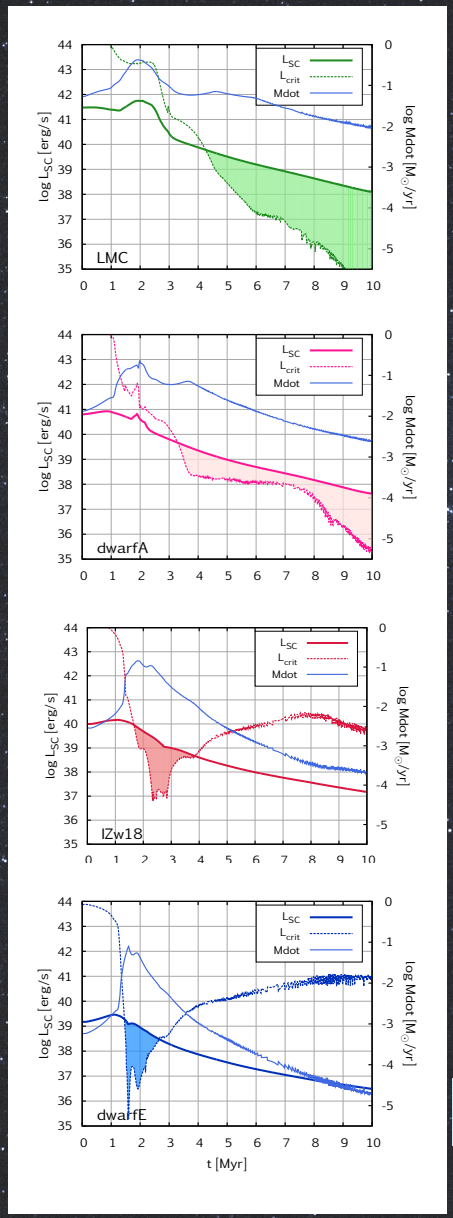

IMF index
2.3
2.1
1.9
1.7
1.5
1.3
1.1
5
5.5
6
6.5
7
7.5
8
Mass of starcluster [log M⊙]
Number ratio of 2G stars
80%
70%
60%
50%
40%
30%
20%
10%
1%
2%
5%
10%
20%
50%
80%

Correlation btw. GC mass & size of 2nd gen.



New results from my OPUS research group





Hanno Stinshoff

PhD student