Tracing massive star cluster formation: insights from the LISCA project

Alessandro Della Croce
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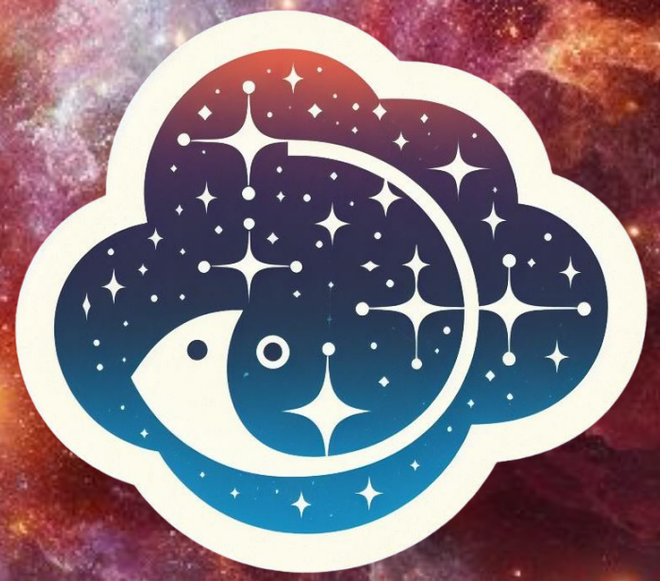


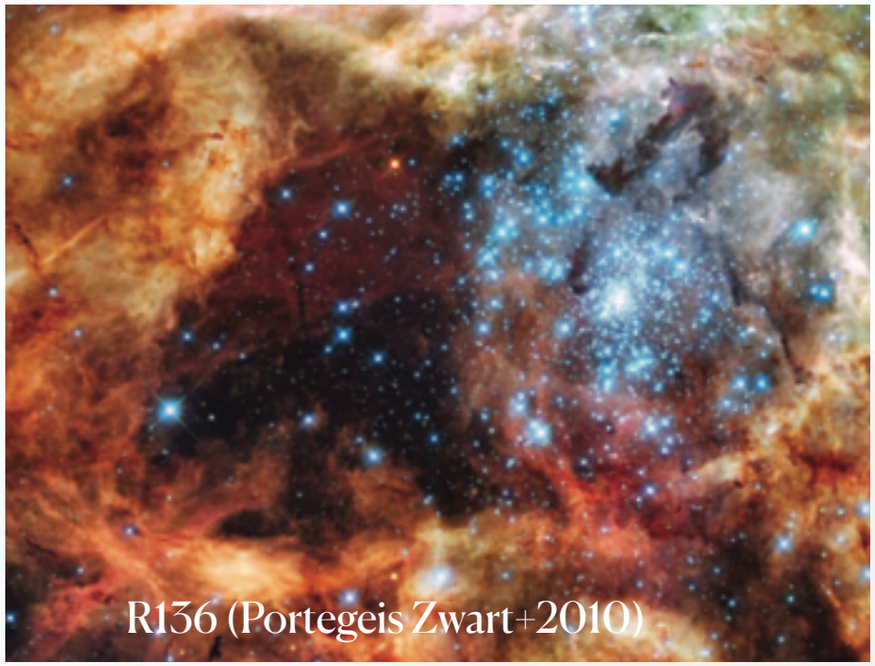
Main collaborators: **E. Dalessandro** (INAF-OAS), E. Vesperini (IU), A. R. Livernois (IU), L. Origlia (INAF-OAS), M. Bellazzini (INAF-OAS), C. Fanelli (INAF-OAS)

INAF ISTITUTO NAZIONALE DI ASTROFISICA — OAS BOLOGNA

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

MODEST 2024 — Warsaw

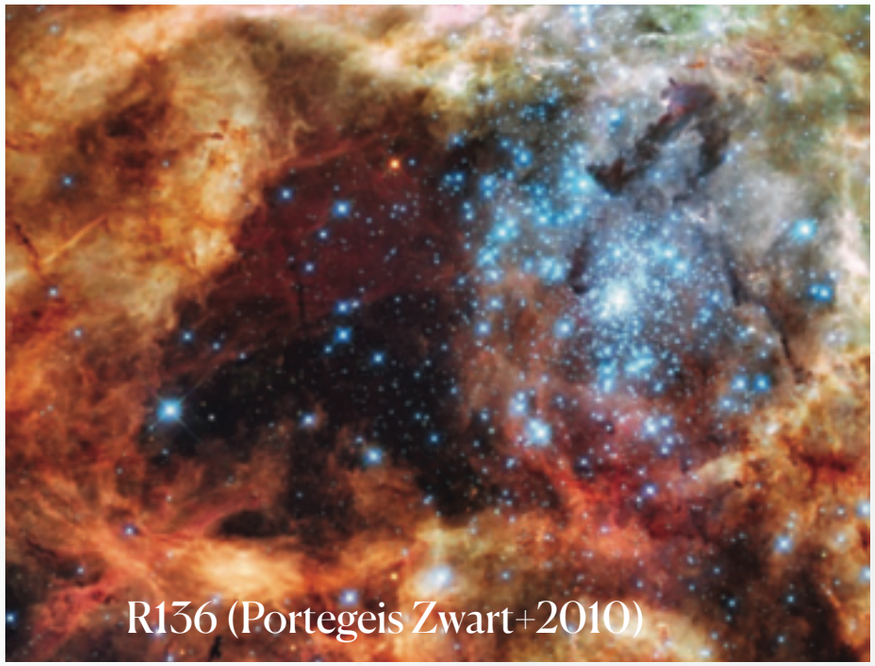
“Clustered” star formation


R136 (Portegeis Zwart+2010)

The majority of stars form in “groups”
(70% - 90%) (e.g. Lada & Lada 2003)

Star formation,
gas and stellar dynamics

“Clustered” star formation



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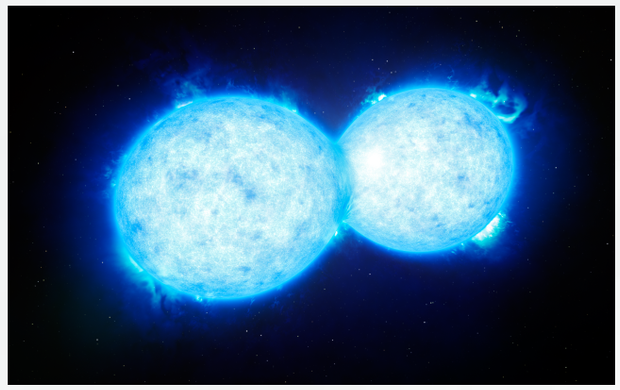
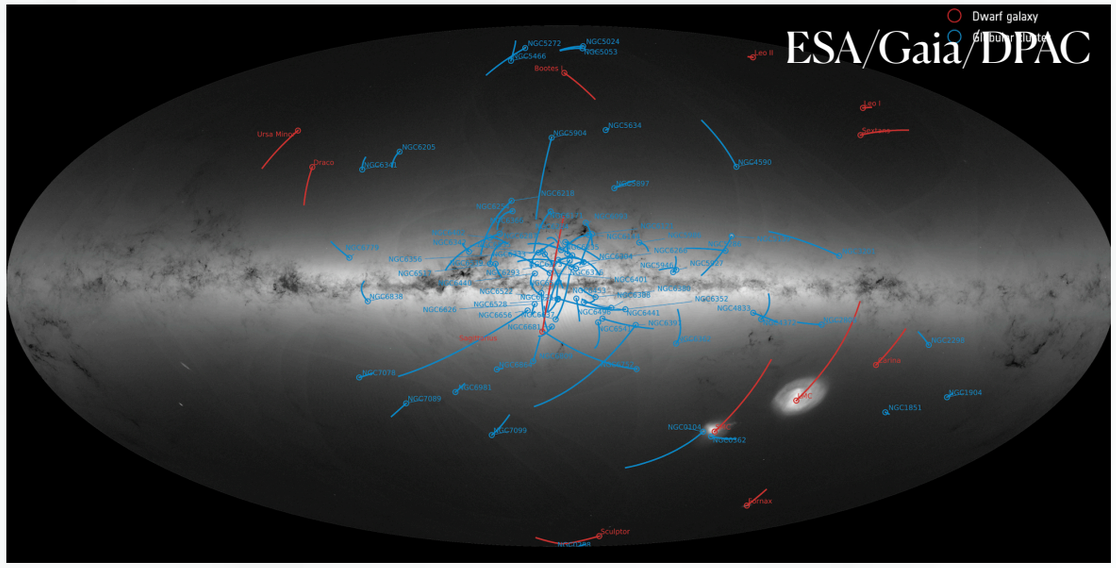


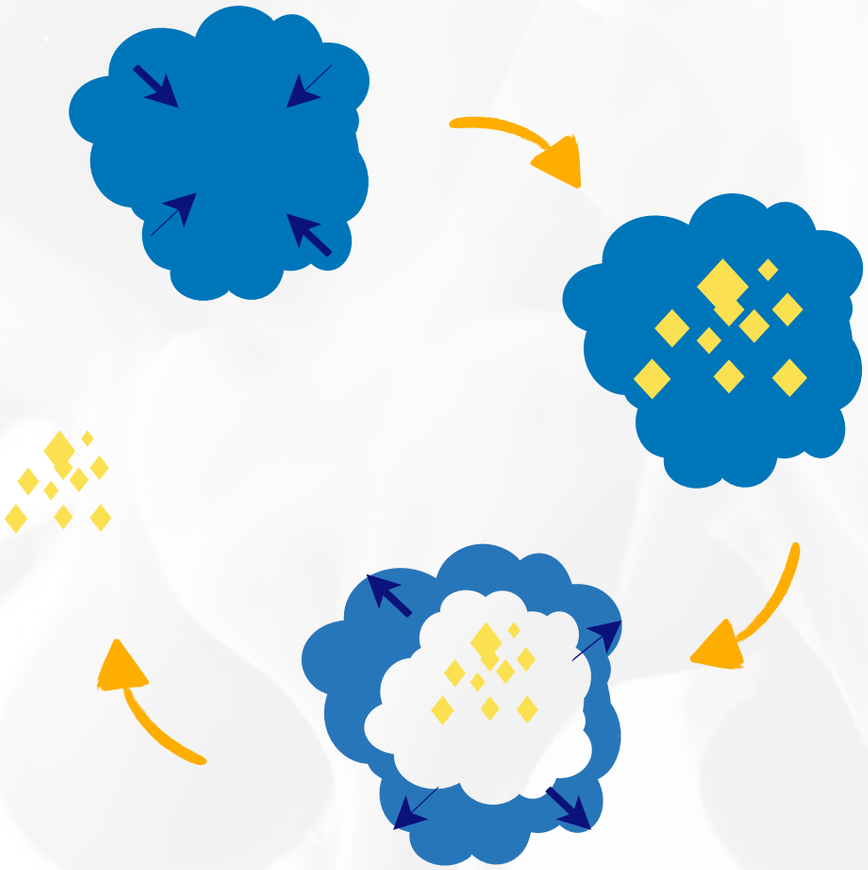
Star clusters:

- Stellar dynamics and evolution
  (binaries, GW sources)
- Galactic properties
  (disc, DM halo, assembly)



Cluster formation scenarios

Monolithic formation



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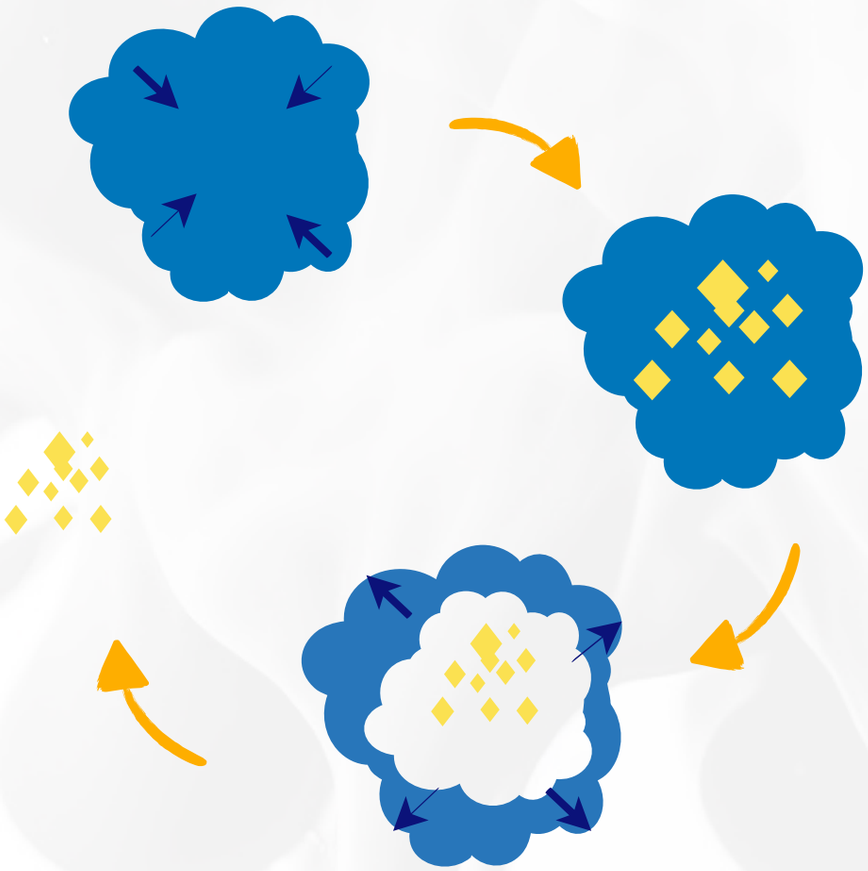
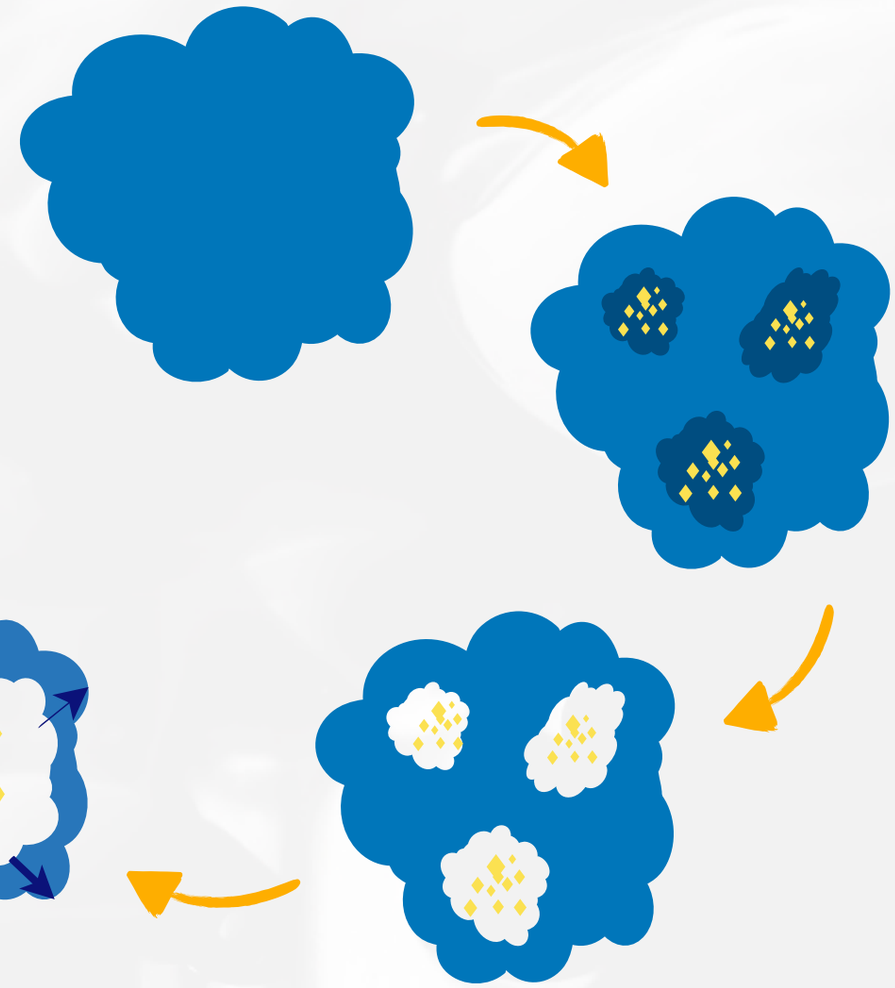


Hierarchical formation



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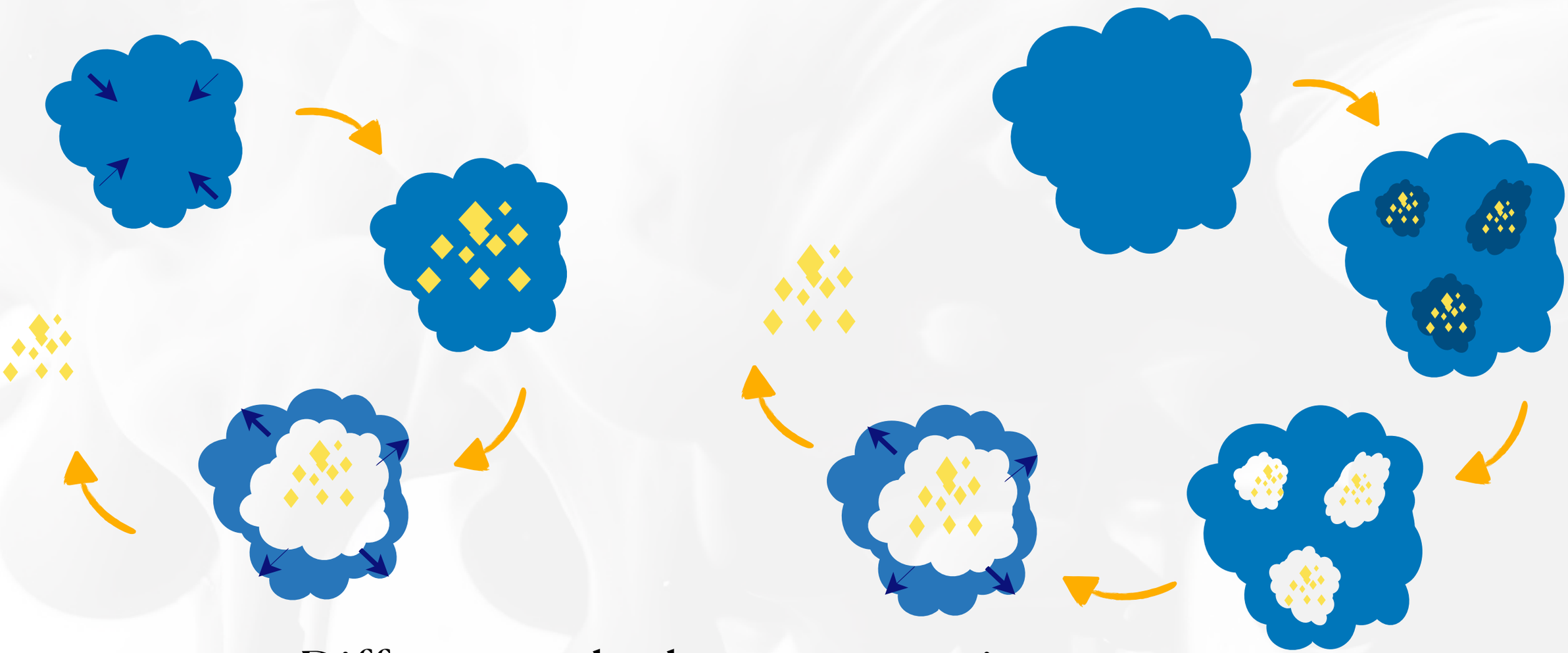


Different early cluster properties

e.g. mass segregation, dynamics, feedback, etc.

(e.g. de Oliveira+98; McMillan, Vesperini & Portegies Zwart 2007;
Moeckel & Bonnell 2009; Allison+09; Gavagnin, Mapelli & Lake 2016; Hong+17
Krumholz+19; Krause+20; Livernois+21; Karam & Sills 2022; Guszejnov+22; Rantala+24)

The LISCA project

Lively Infancy of Star Clusters and Associations

Alessandro Della Croce

Warsaw — August 20

The LISCA project

Lively Infancy of Star Clusters and Associations

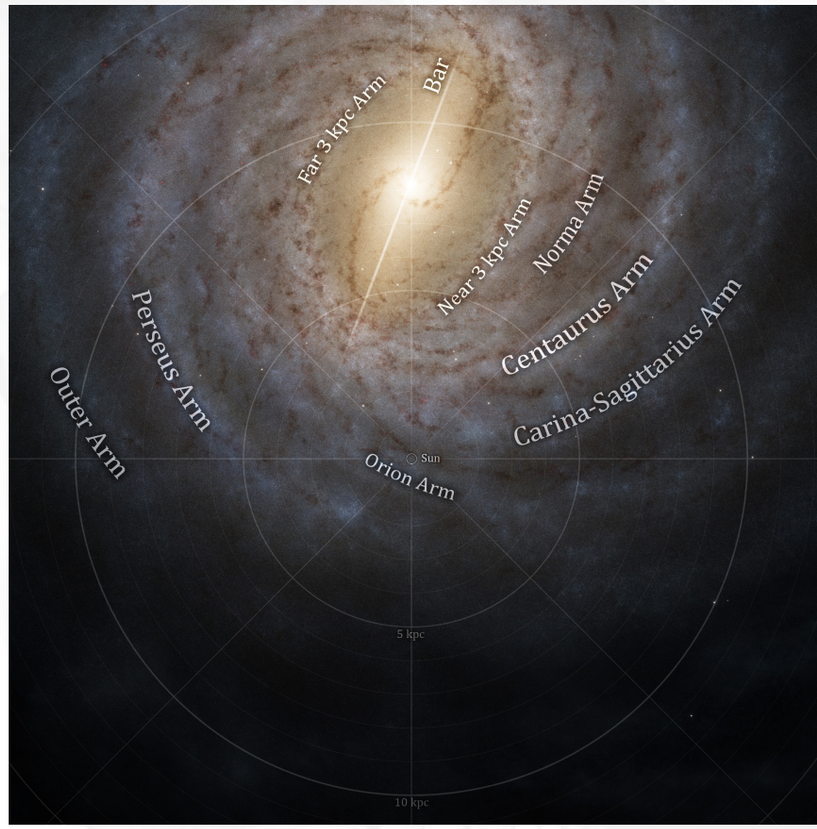
Gaia DR3 data

gaia

Sky position, parallax,
and proper motions

G, G_{BP}, G_{RP}

1.8 billion sources



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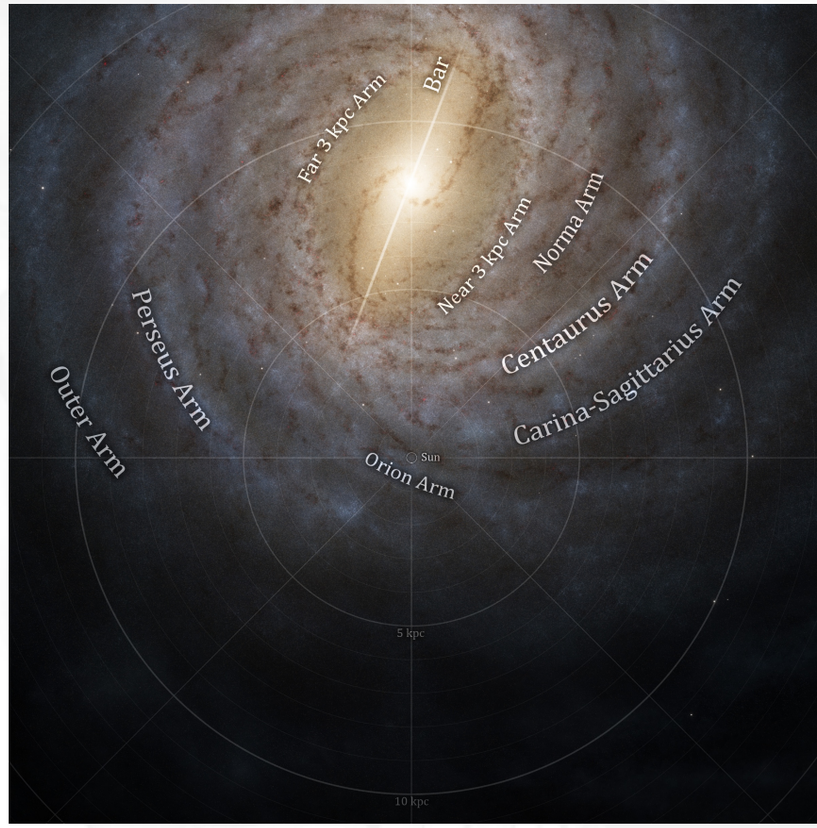

Gaia DR3 data

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→ Sky position, parallax, and proper motions

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High-resolution spectroscopy

SPA @ TNG

Fanelli et al. 2022a, b

→ 70 nights (PI Origlia)

optical (R=115,000)

NIR (R=50,000)

LOS velocity + chemistry

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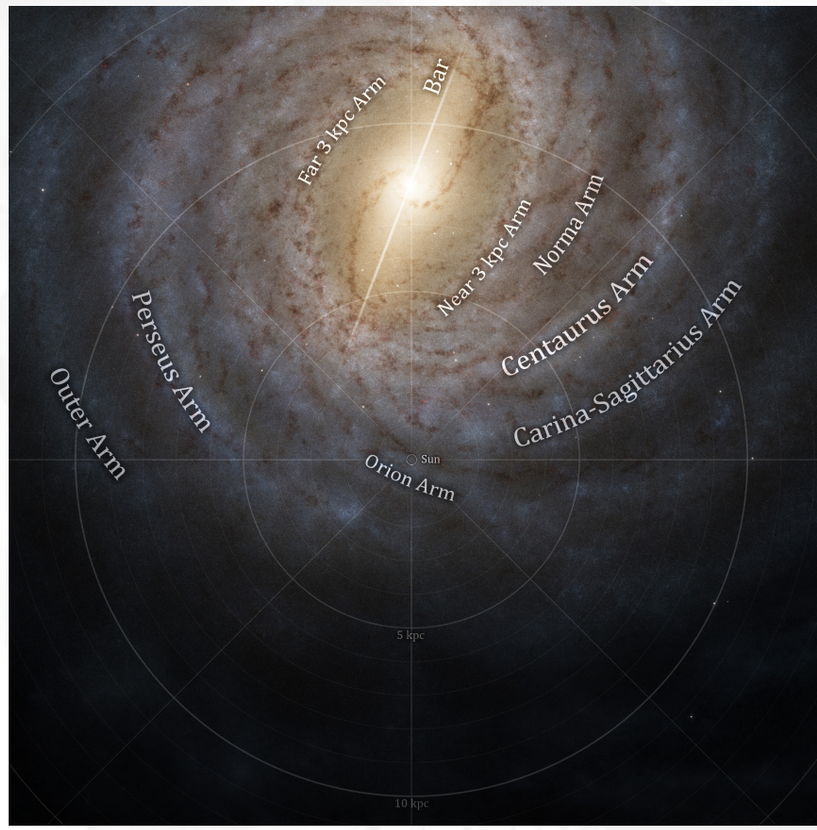

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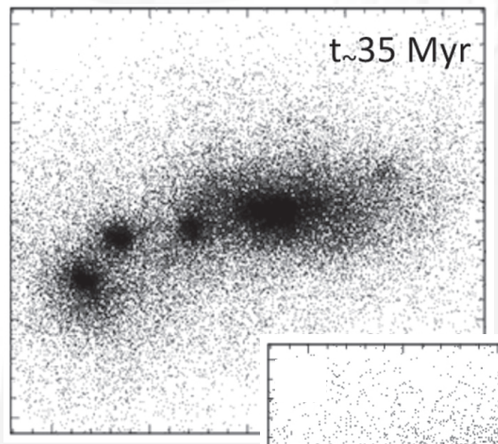
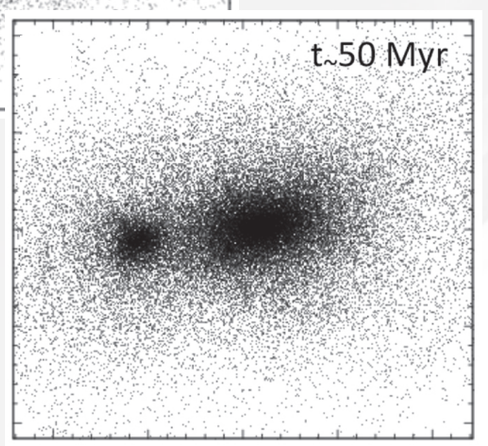




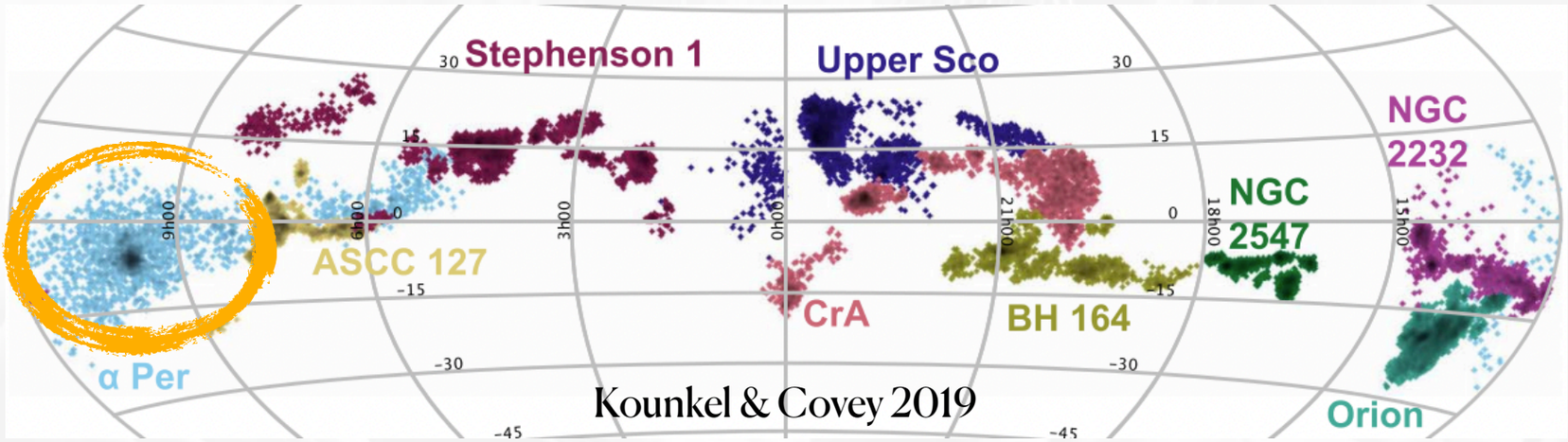
N-body simulations

Livernois et al. 2021

→ 10^5 particles

violent relaxation

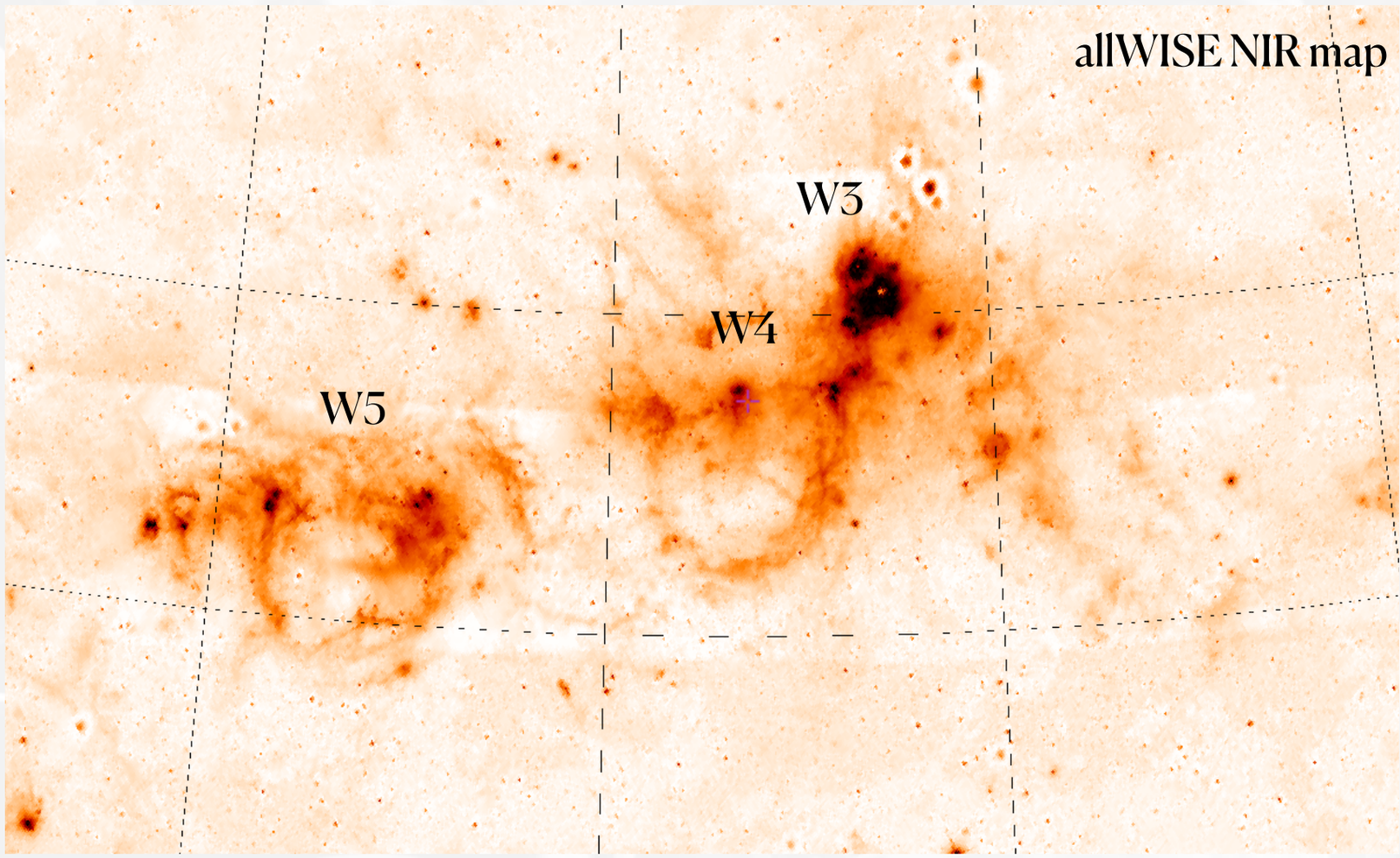
The Perseus complex



Perseus spiral arm
2.5 kpc away
major star-forming site

Several young star clusters

(Goudis & White 1980; Sugitani+1991; Massey+1995; Straizys+2013; Jose+2016; Panwar+2017, 2019; Roman-Zuniga+2019; Roman-Lopes+2019; Lim+2020)



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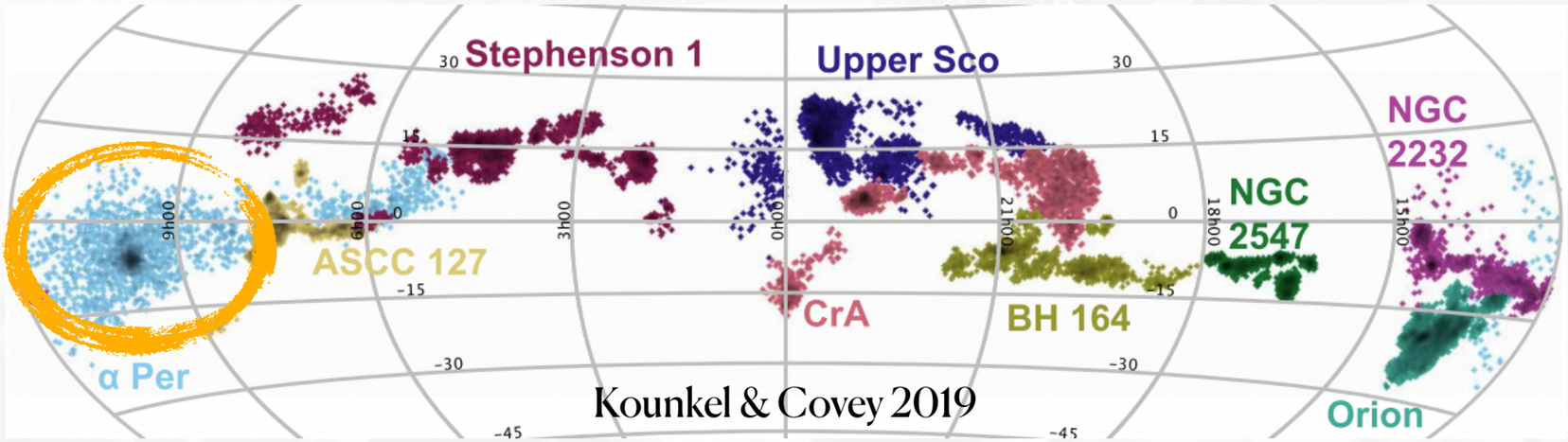

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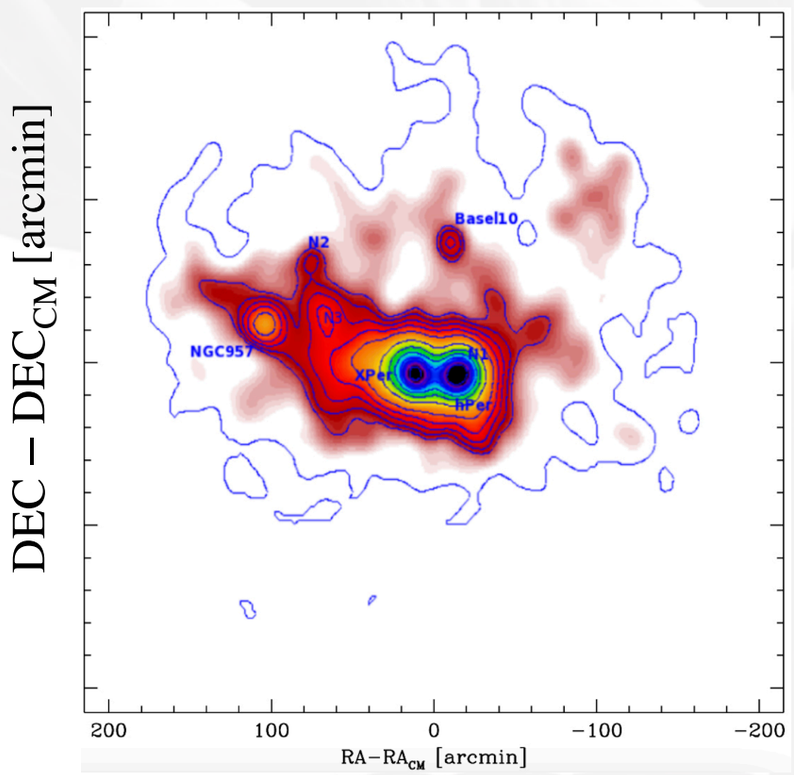
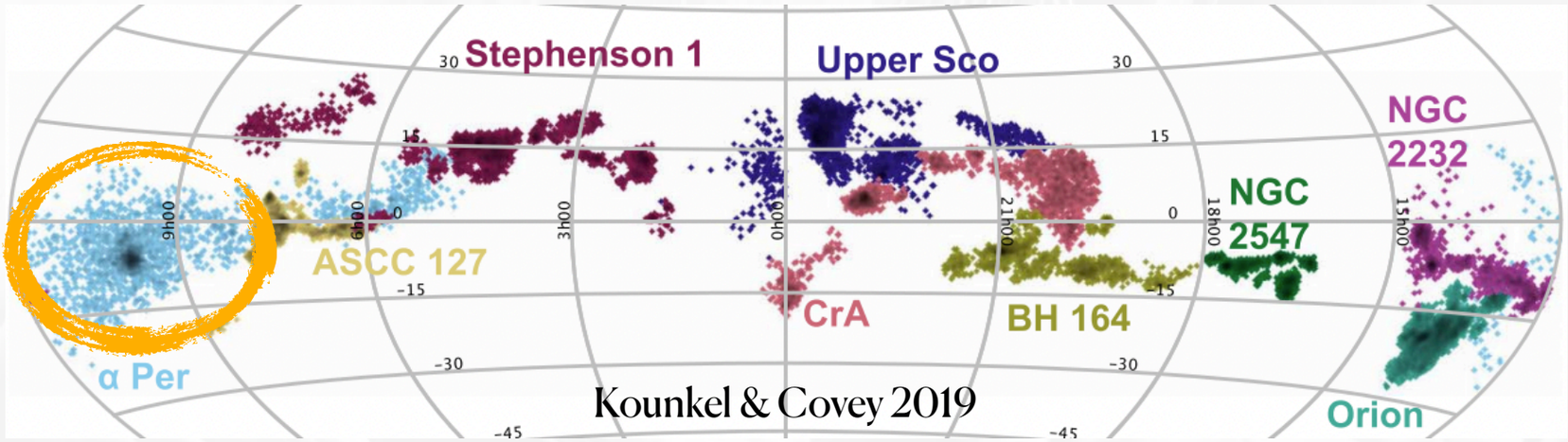


Dalessandro et al. 2021, ApJ, 909, 90

The first hierarchical structure
$h-$Per and $\chi-$Per
about $10^5\,M_\odot$

→ LISCA I

The Perseus complex



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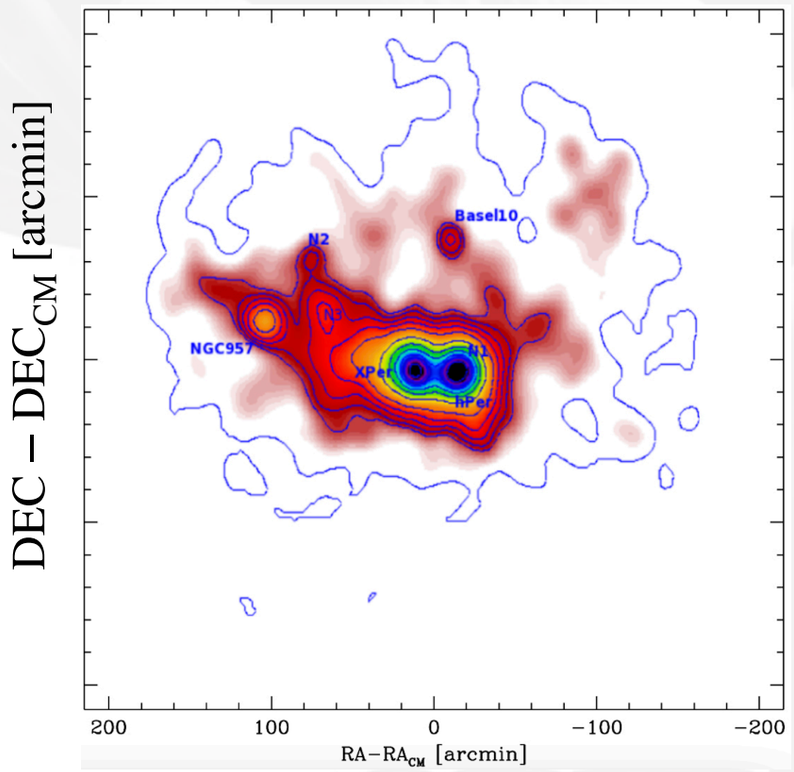

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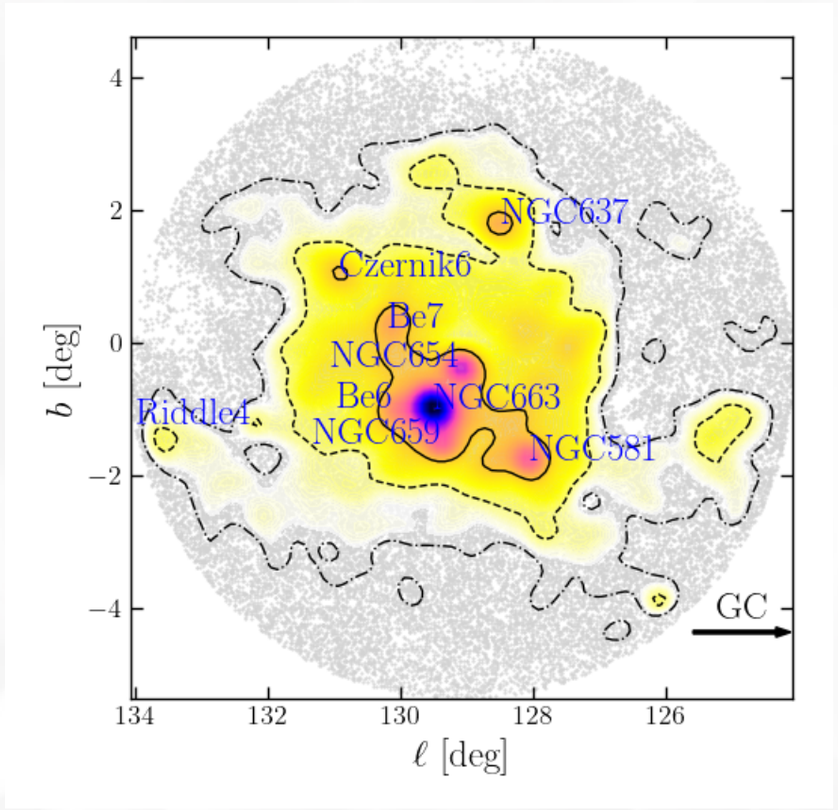
detailed characterization of
hierarchical formation

The LISCA II structure

Della Croce et al. 2023, A&A, 674, A93



Nine stellar clusters } Co-moving (7.5 km/s)

diffuse "*stellar halo*" } Same 3D position ($R_{\rm hm}$ = 150 pc)

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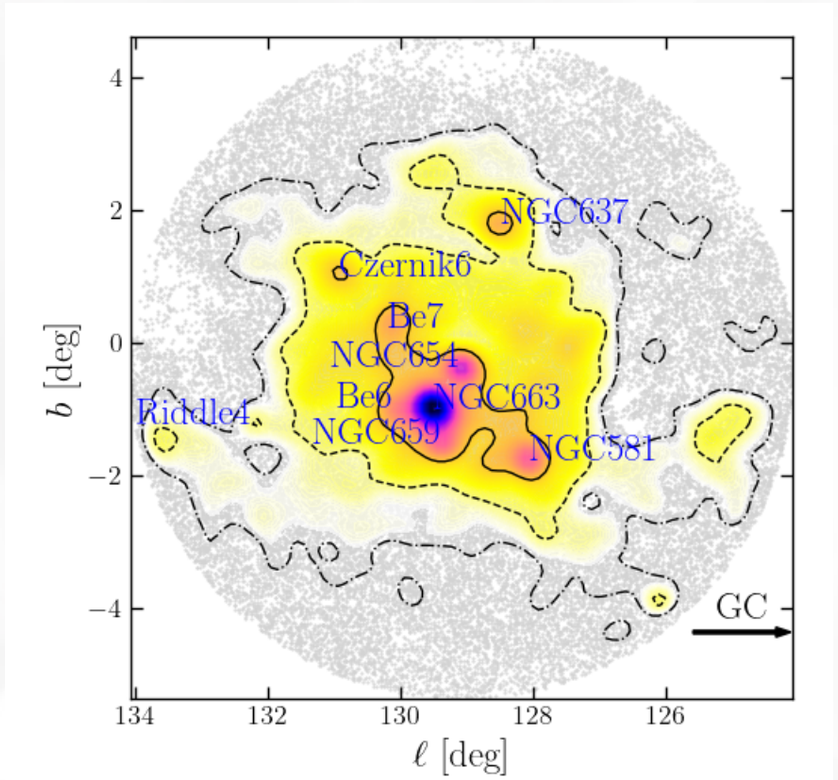

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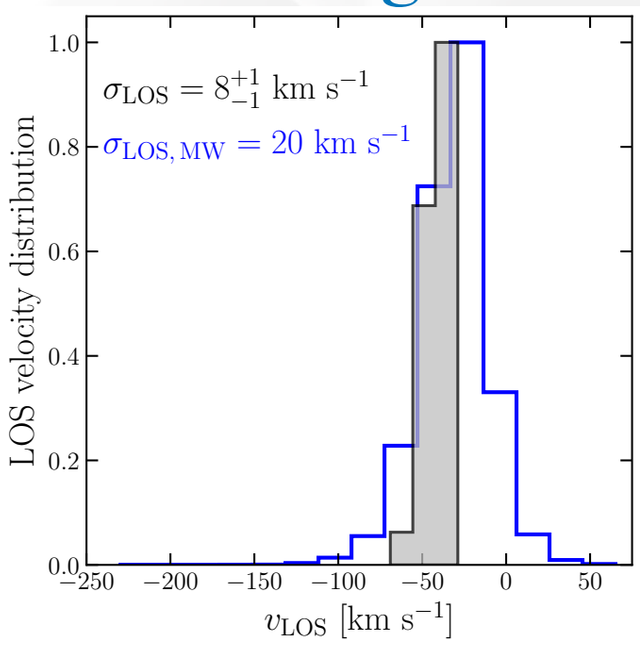
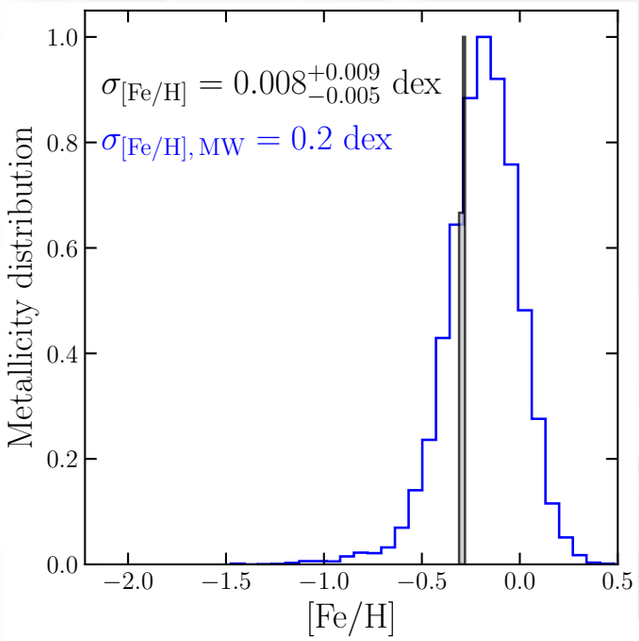


mono-metallic



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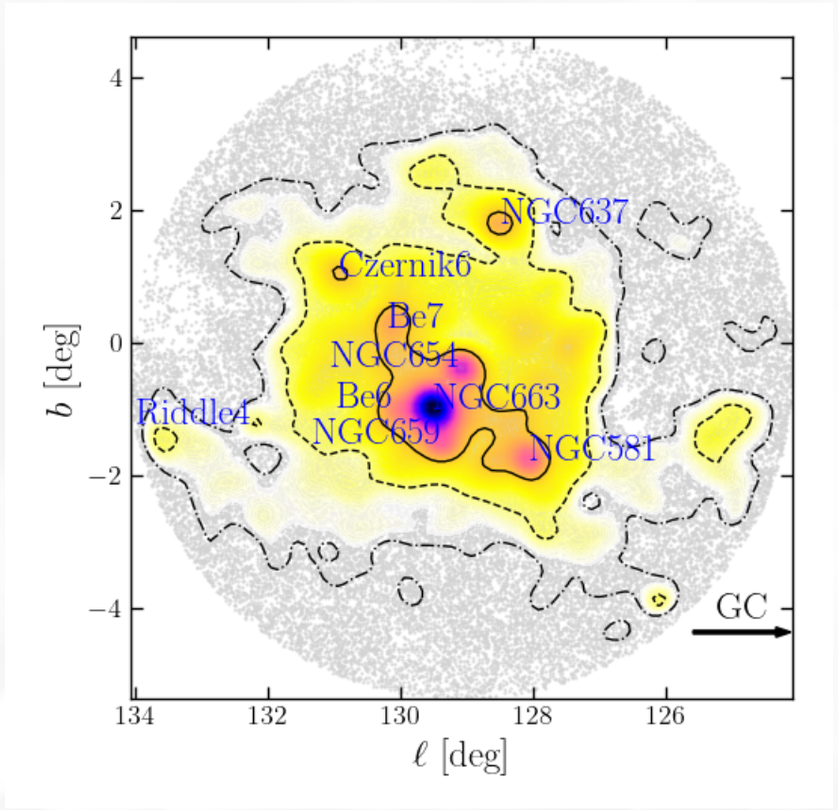

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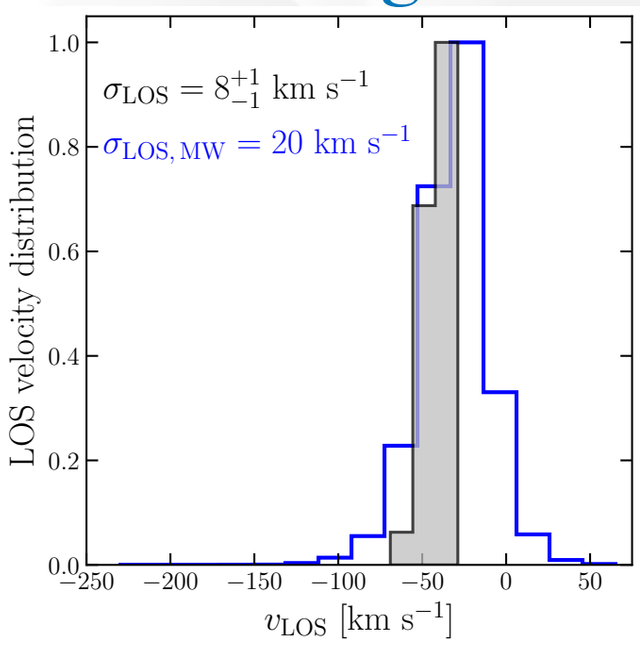

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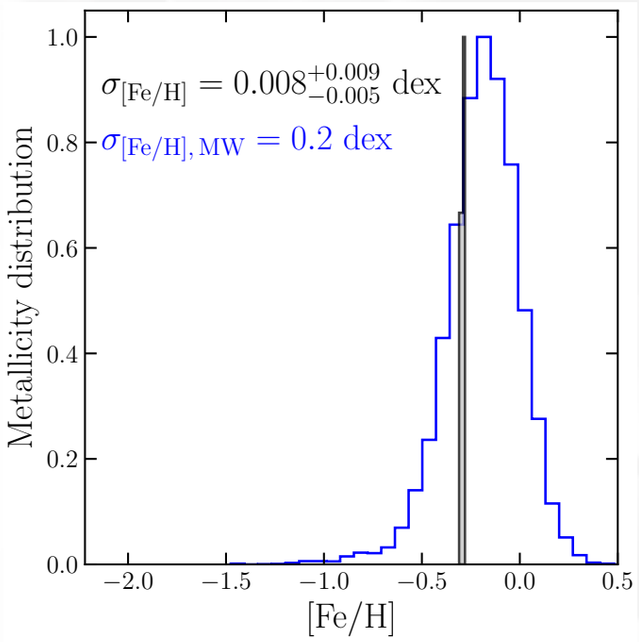
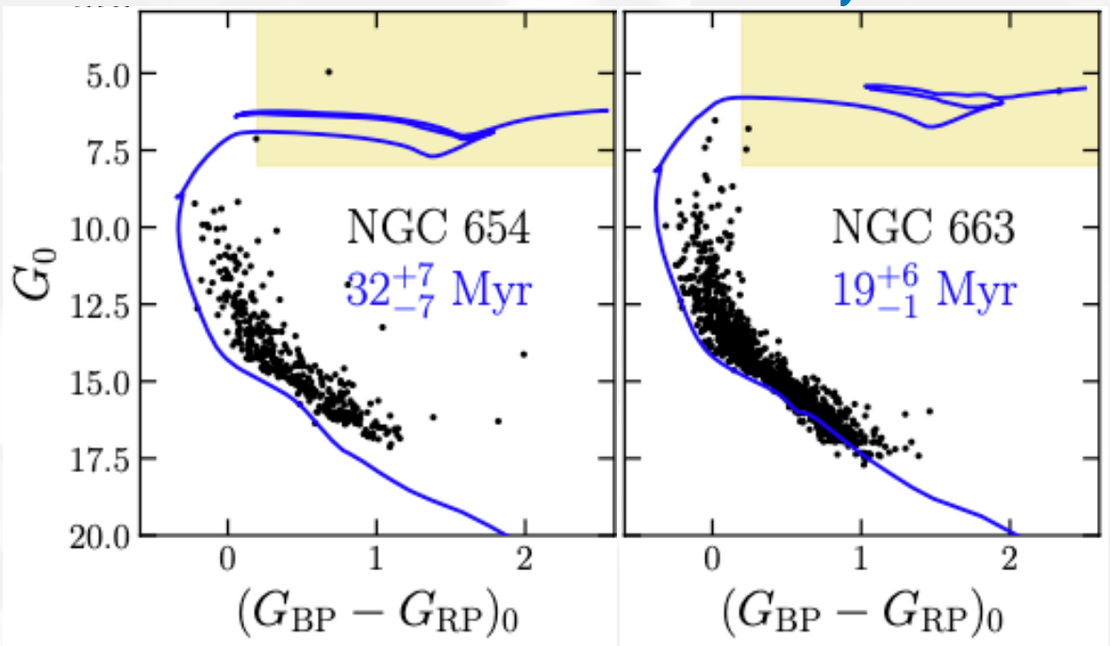


coeval (14-44 Myr)



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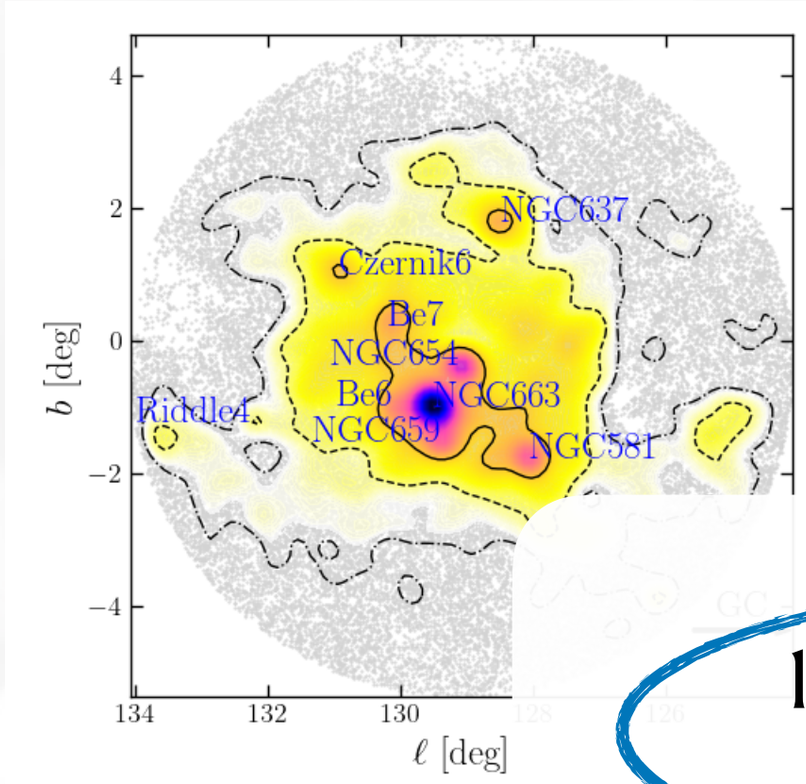


Nine stellar clusters

- Co-moving (7.5 km/s)
- Same 3D position (R_{hm} = 150 pc)

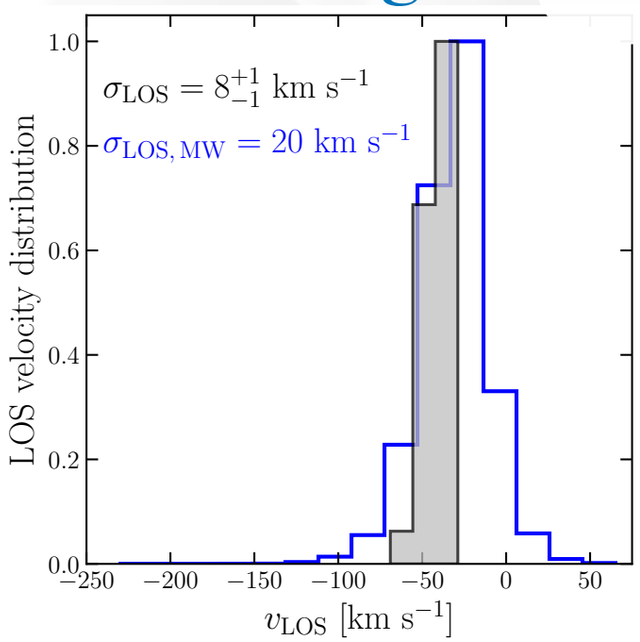
diffuse "*stellar halo*"

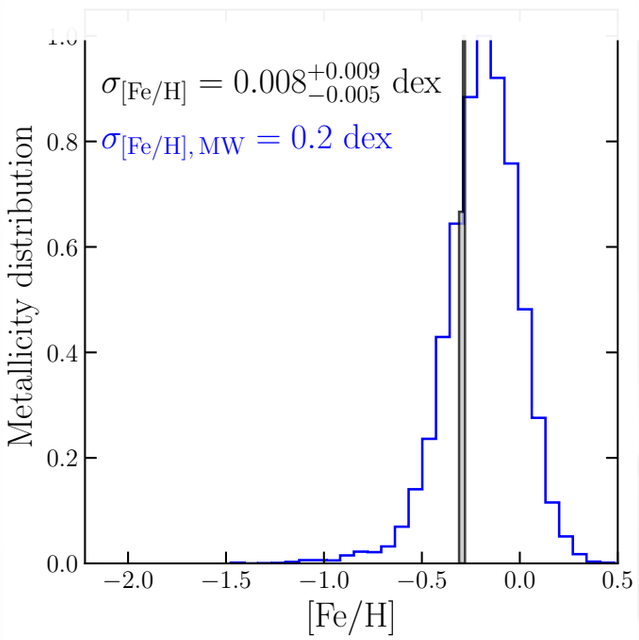
likely formed within the same molecular cloud

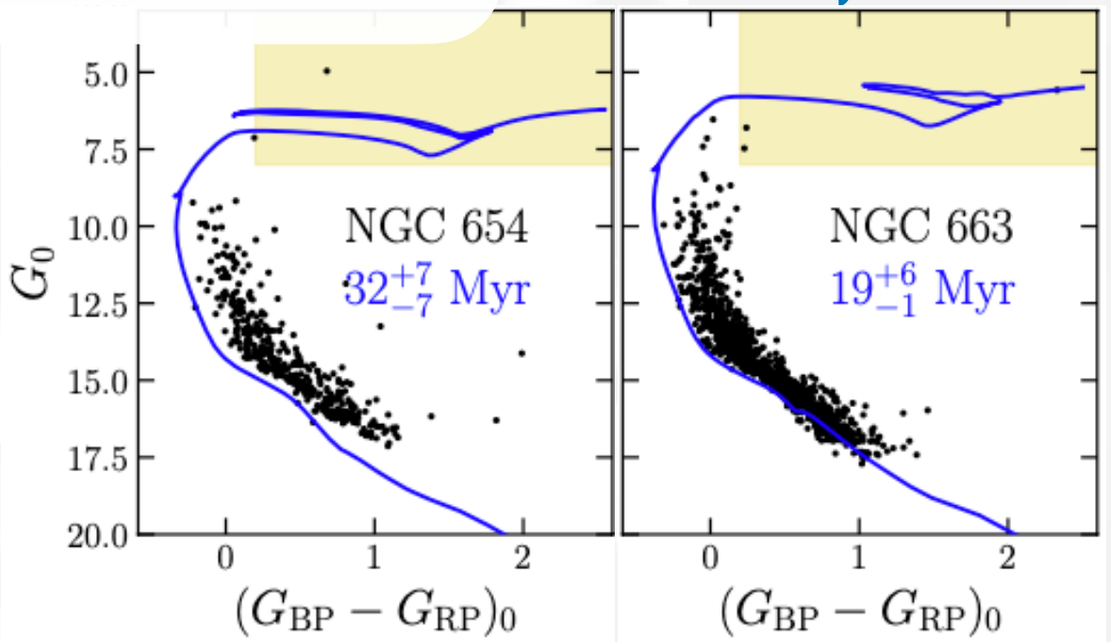
comoving in 3D

mono-metallic

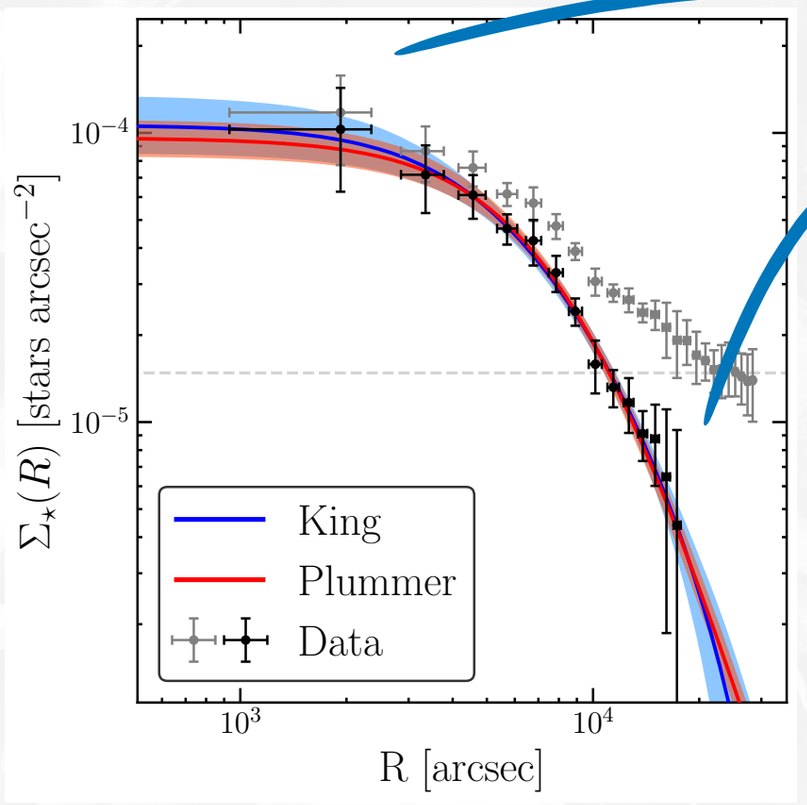
coeval (14-44 Myr)







The structure of LISCA-like systems



denser in the central part

cluster-like density profile

$0.6 - 1.2 \times 10^5\, M_\odot$

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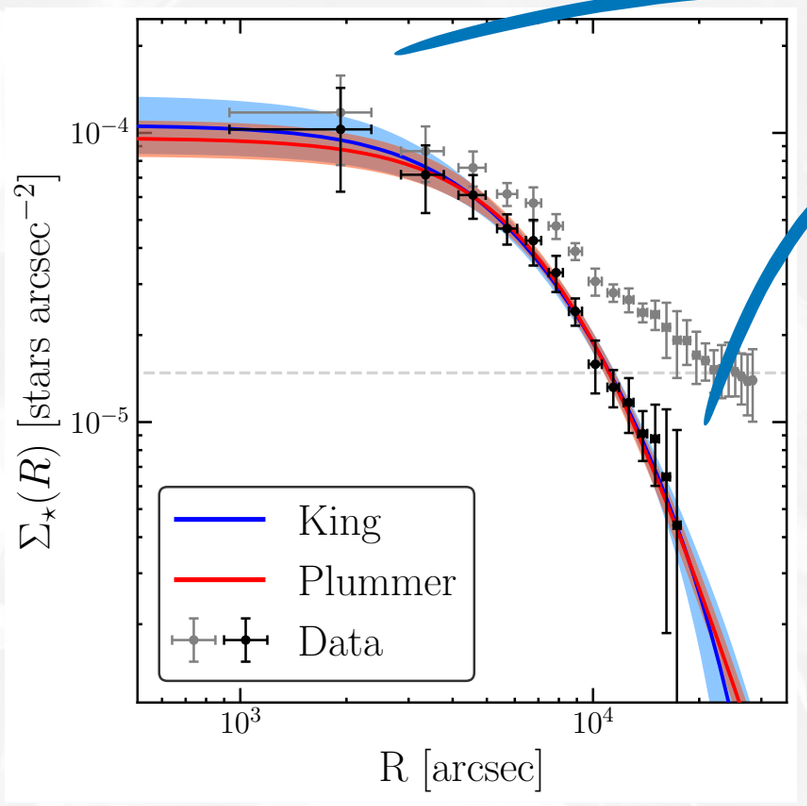

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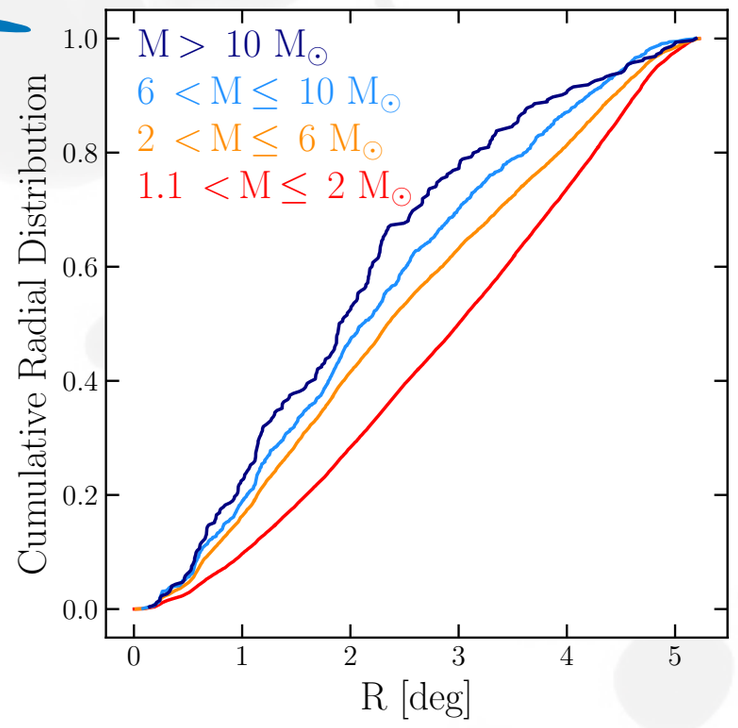
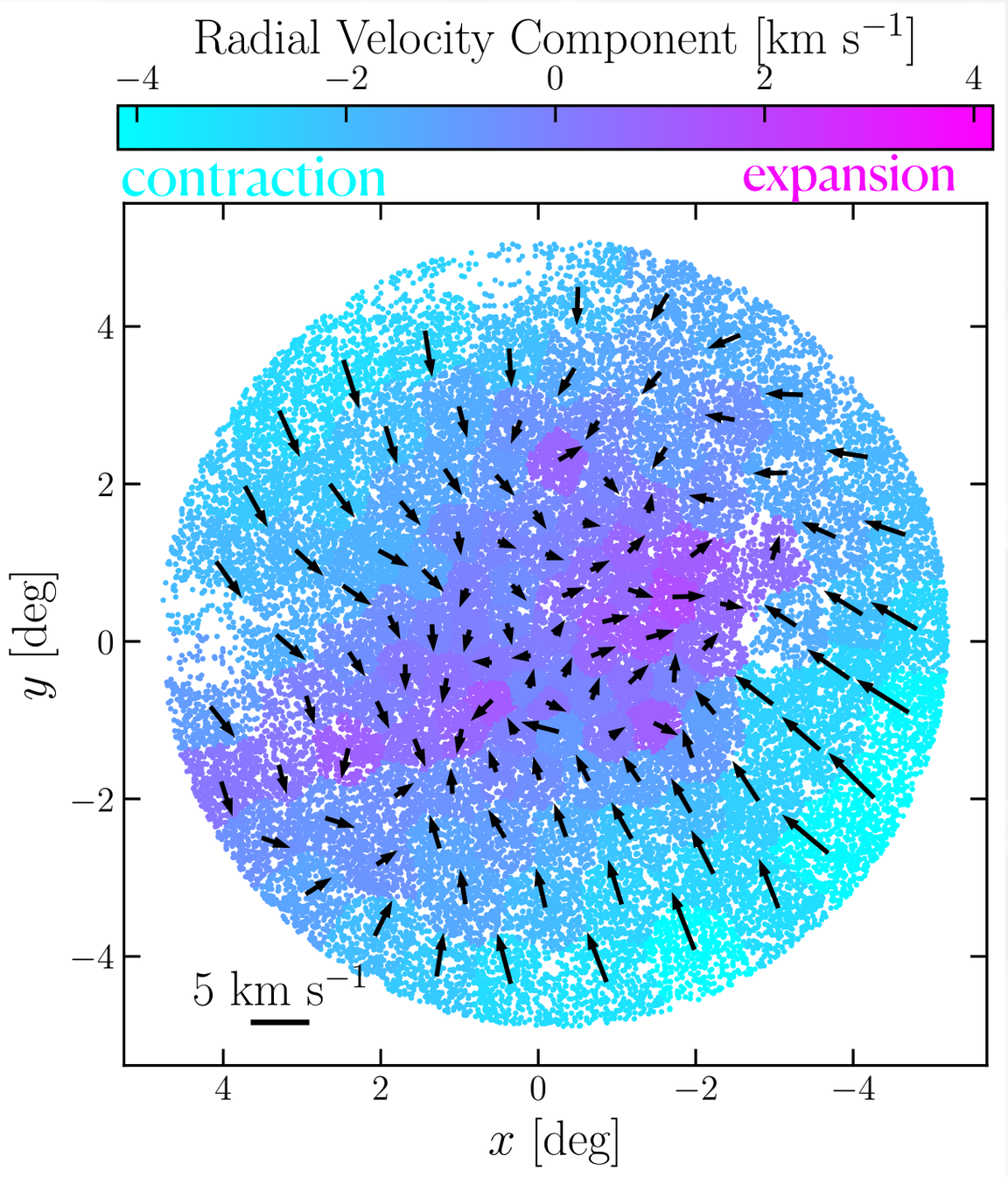
mass segregation
on a “global” scale

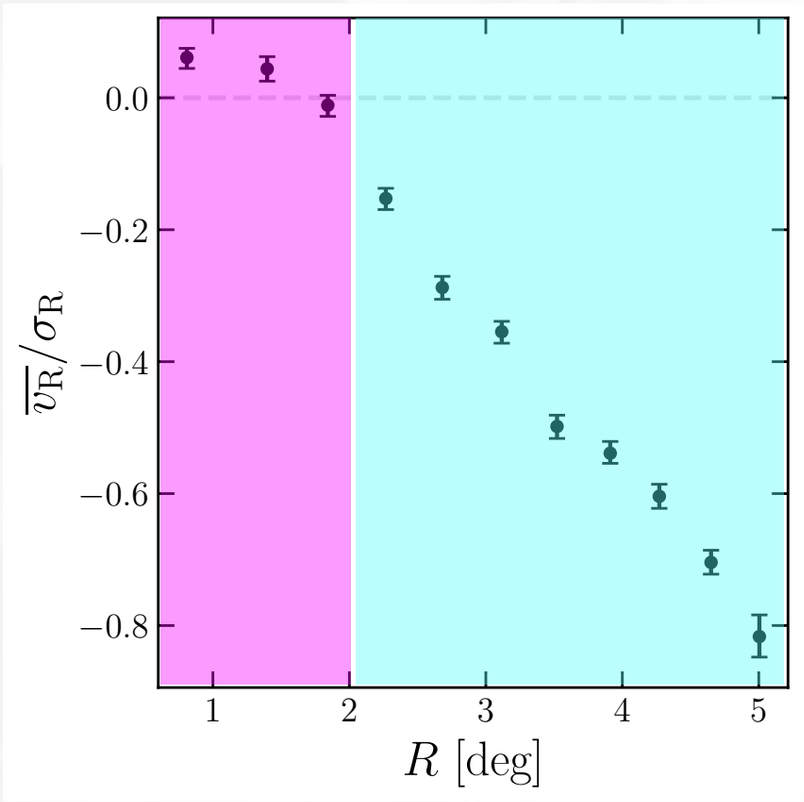


The kinematics of LISCA-like systems

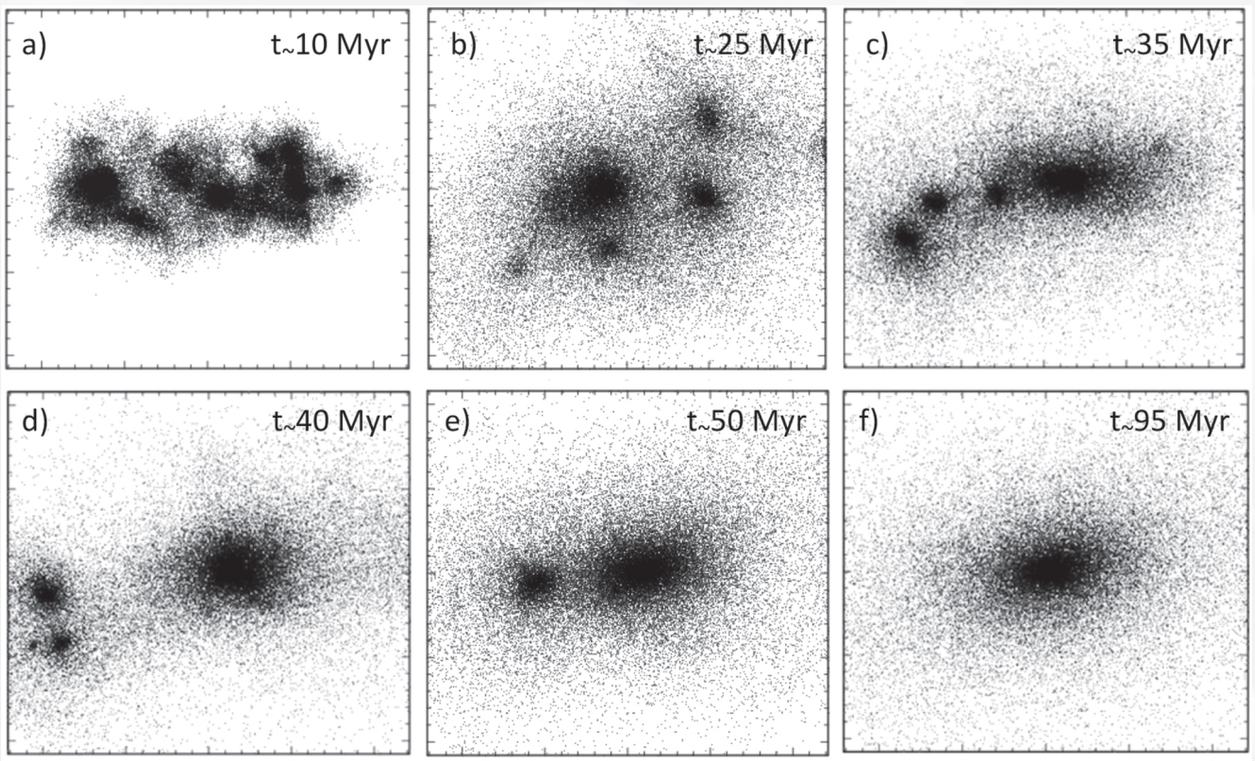


Coherent contraction

Inner regions mildly expanding



Numerical simulations of LISCA systems



N-body following violent relaxation

Homogeneous and fractal, rotating; Galactic tidal field; multi mass

(Livernois et al. 2021, MNRAS, 506, 5781)

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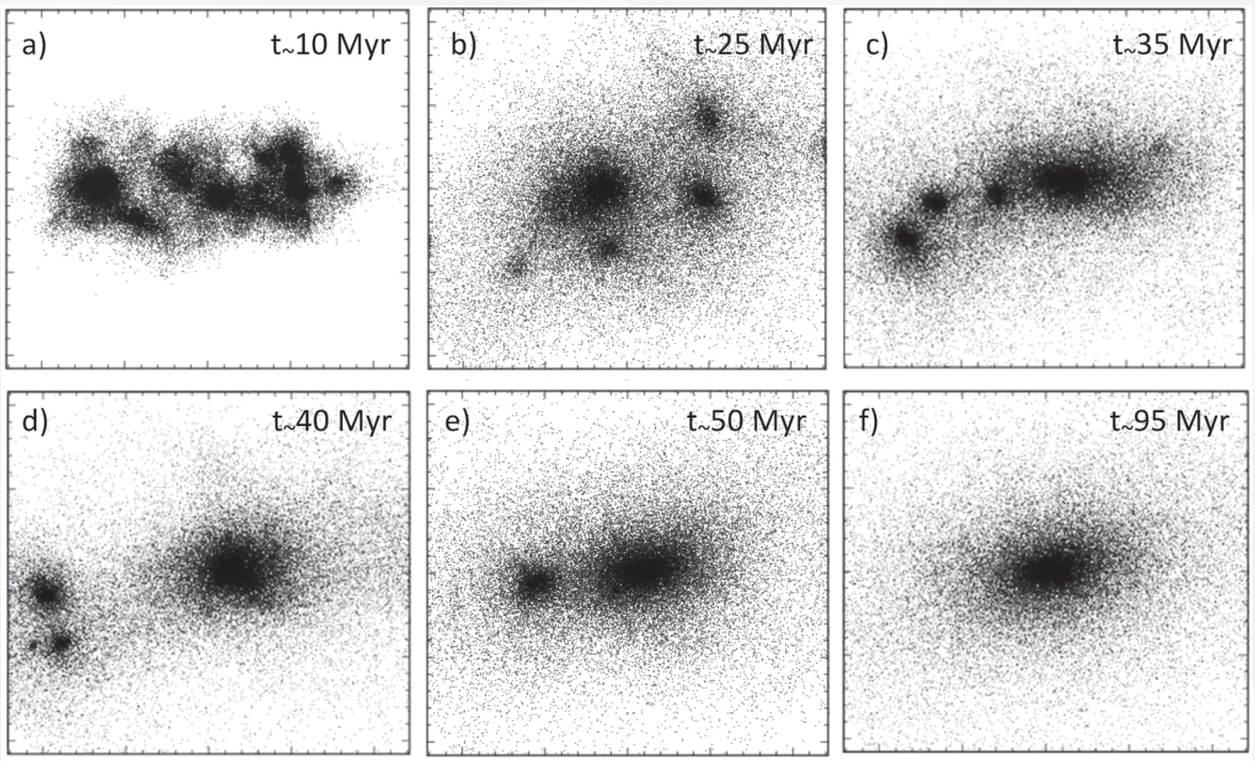

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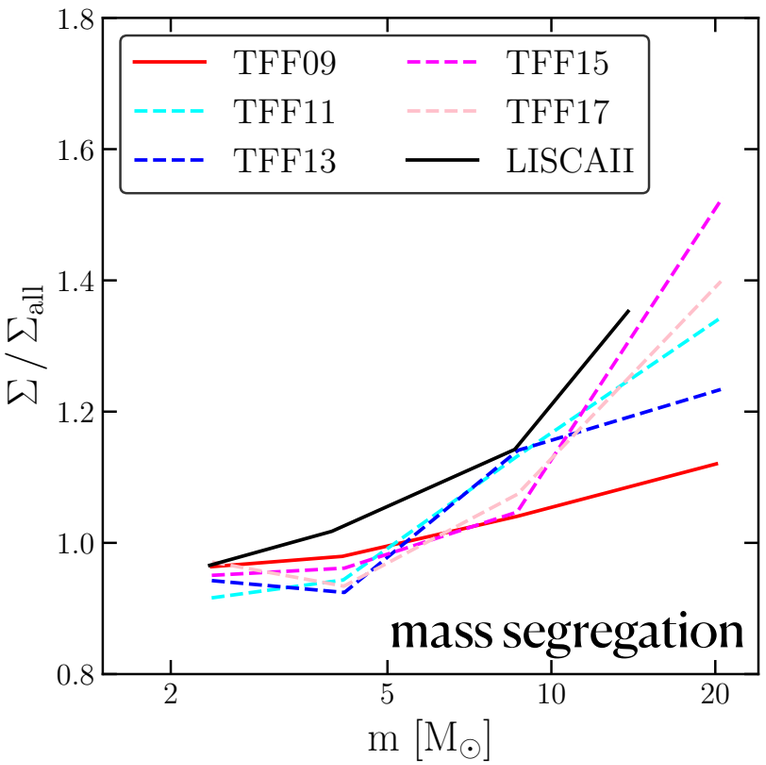

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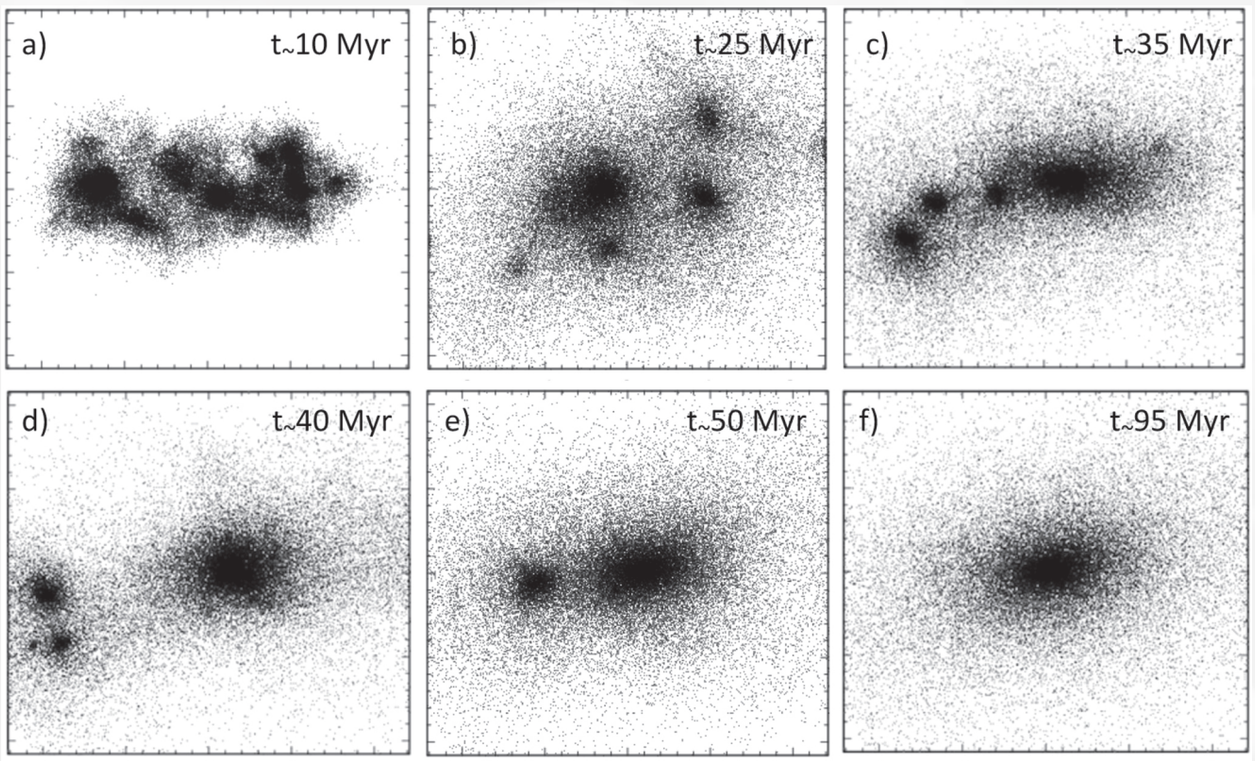

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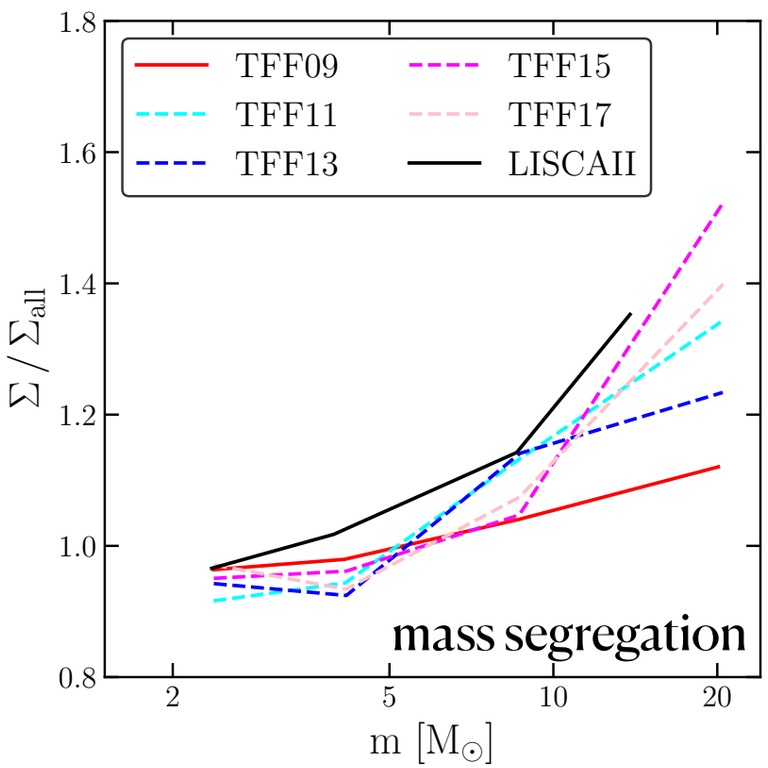

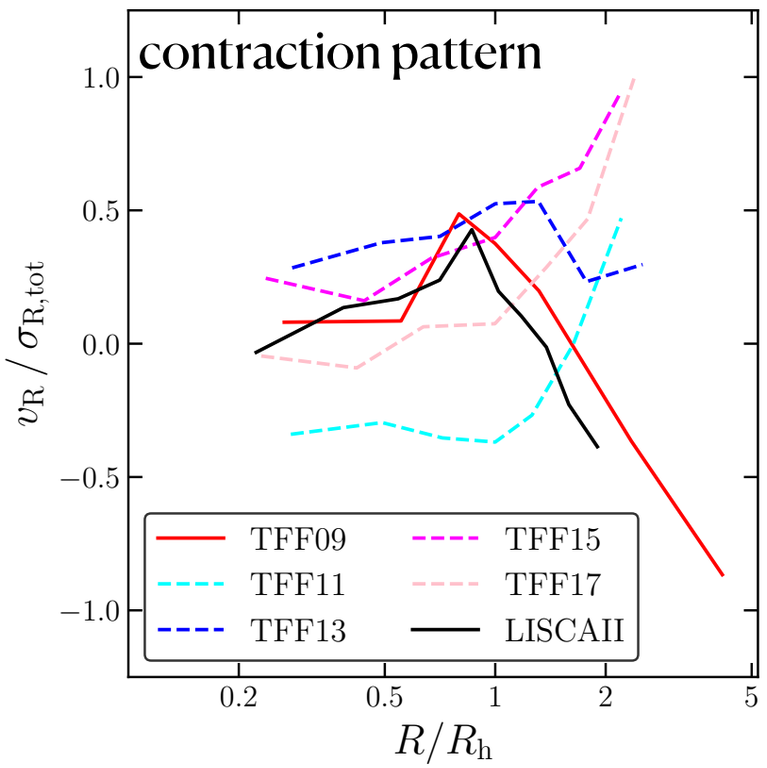

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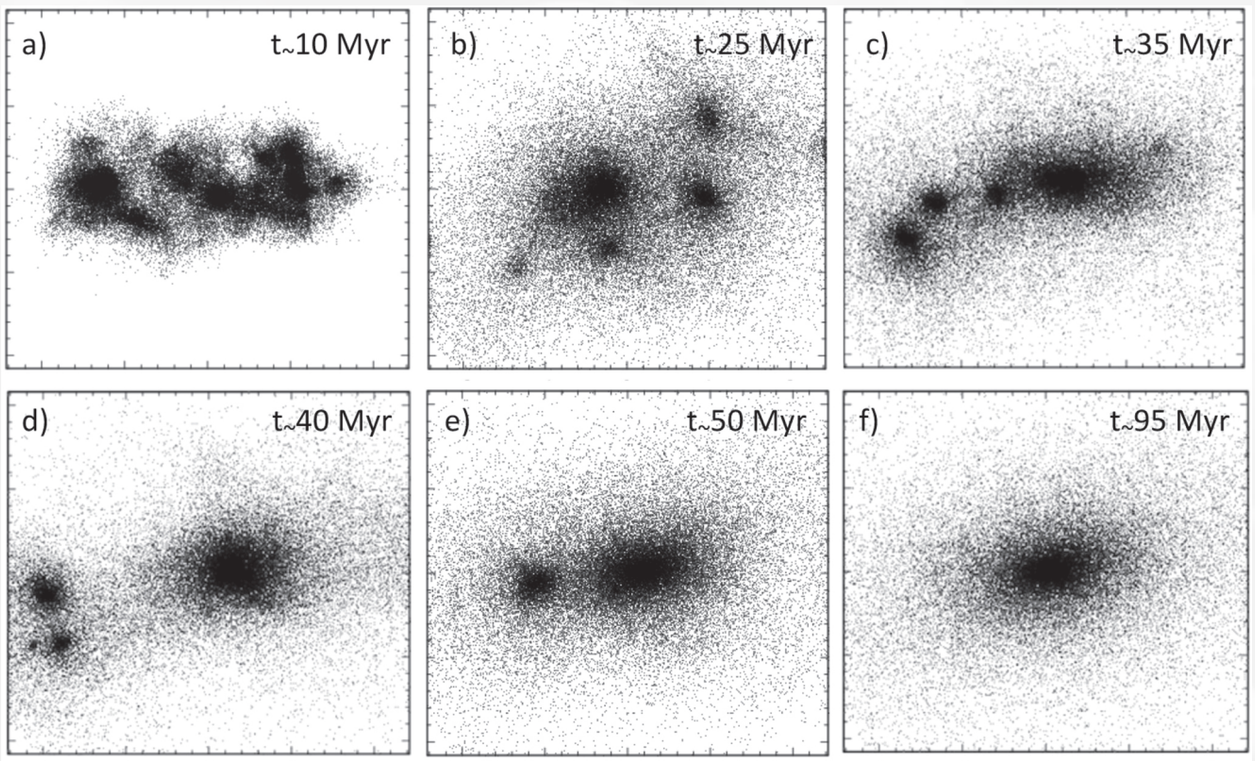

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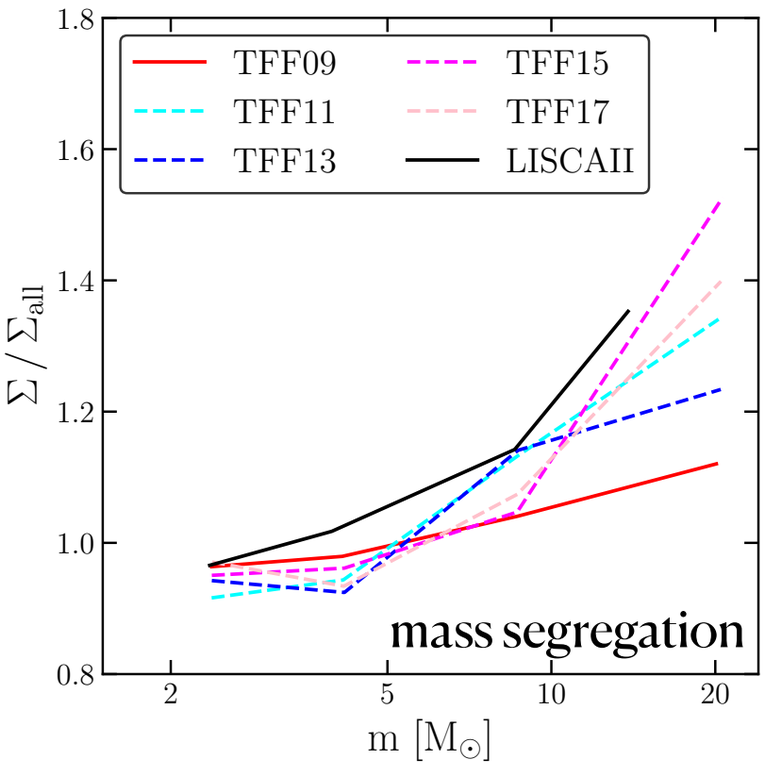
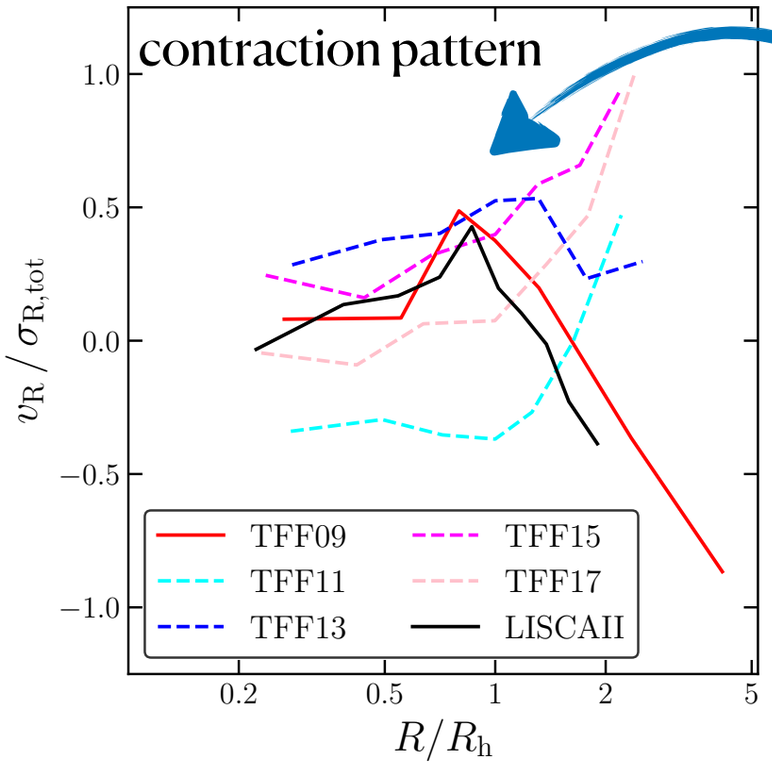




early stages about $t_{\rm ff}$

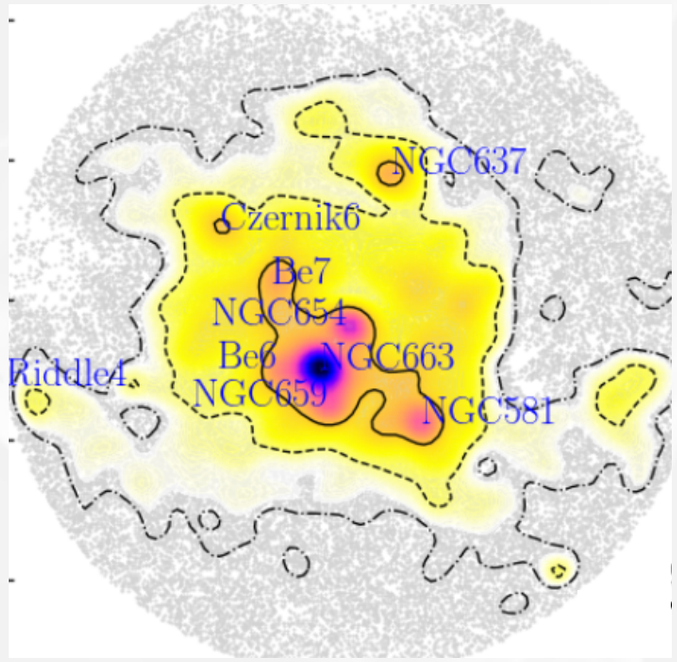
Summary and conclusions

The LISCA project:

nearby star-forming regions

Gaia in synergy ***with spectroscopic surveys***

numerical simulations



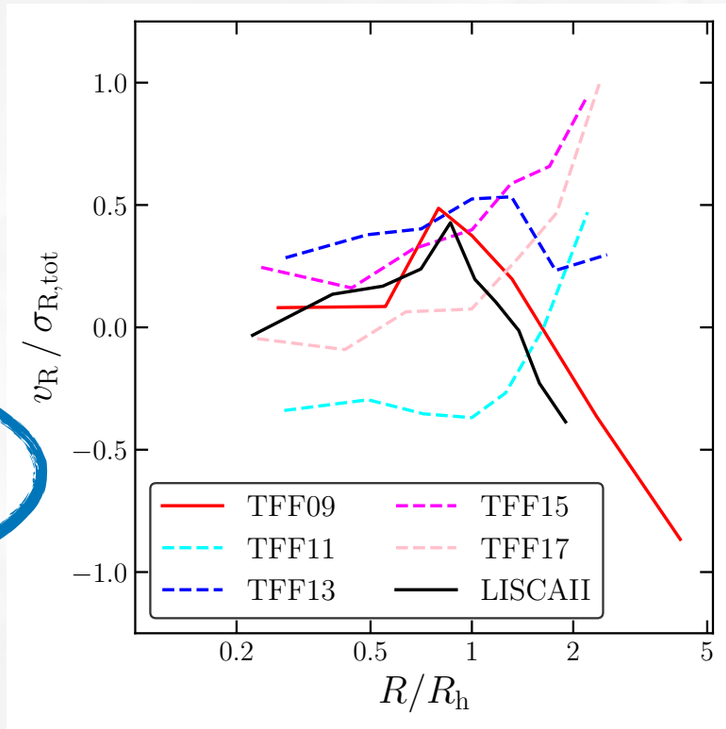
The LISCA II structure:

hierarchical structure

forming a ***massive ($10^5\,M_\odot$) cluster***

mass segregation on local and global scales

early stages of assembly



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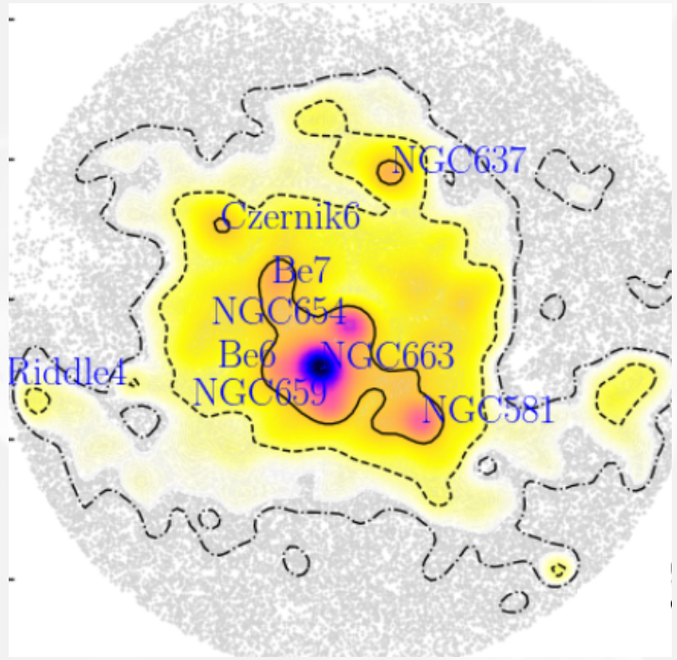
The LISCA II structure:

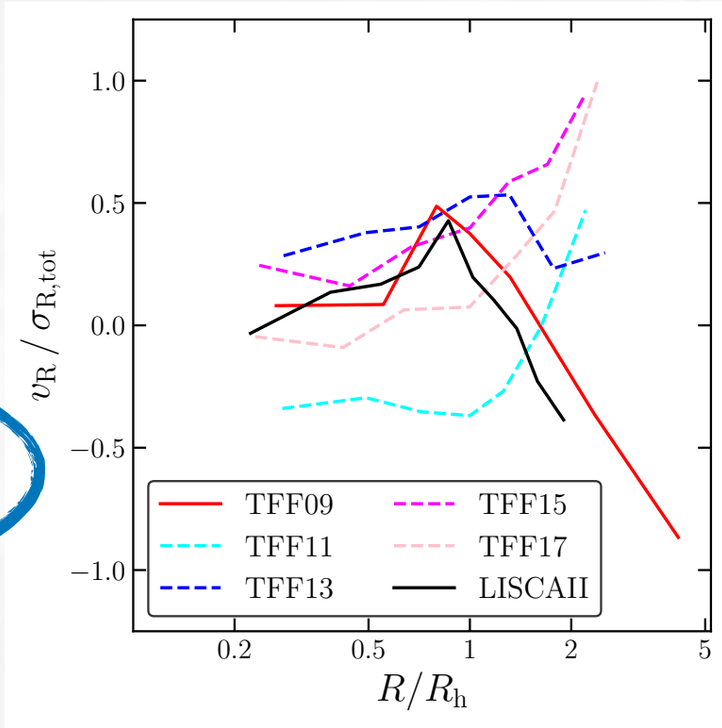
hierarchical structure

forming a ***massive (10^5 $M_\odot$) cluster***

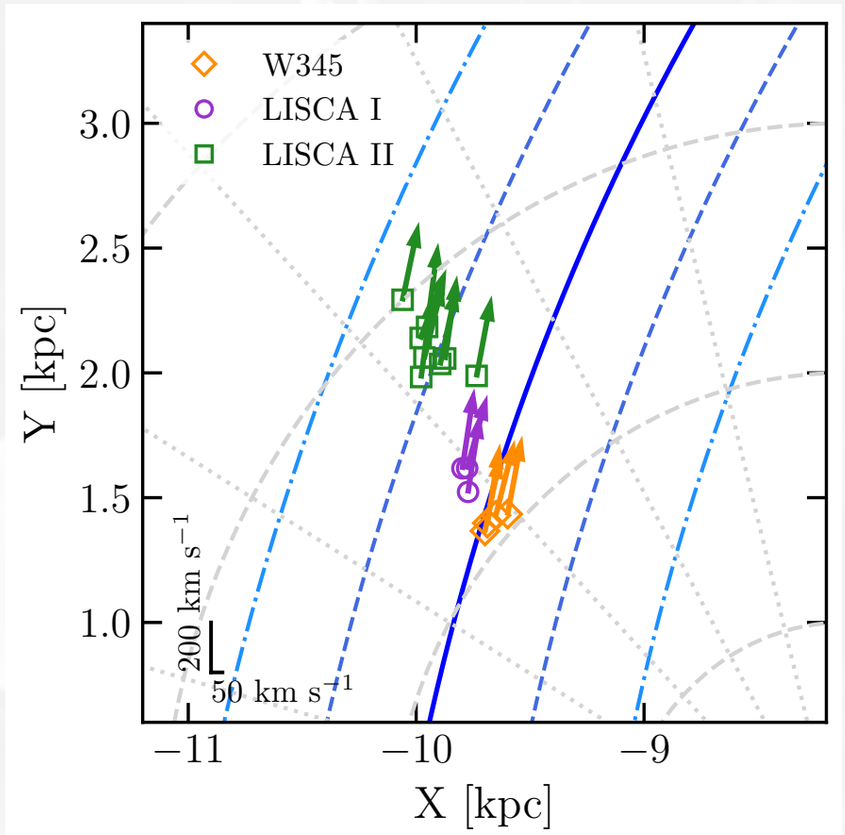
mass segregation on local and global scales

early stages of assembly



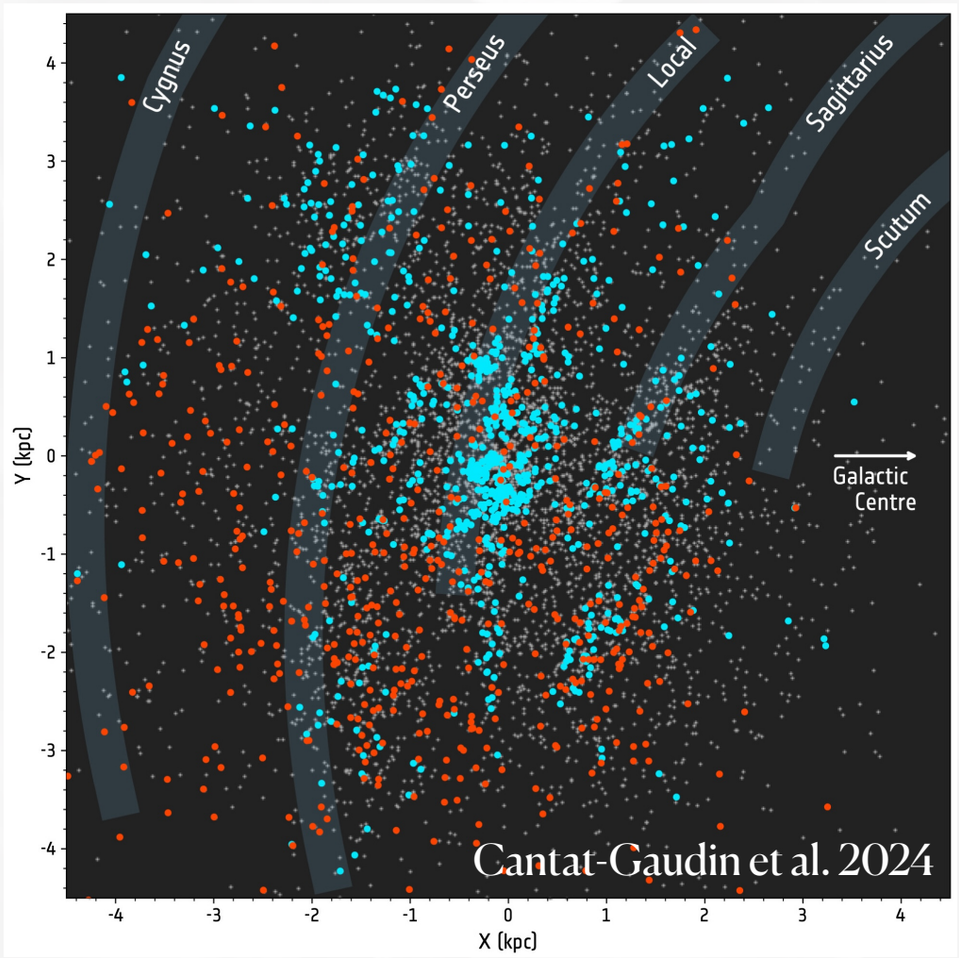


Current state and future perspectives



Della Croce et al. (in prep.)

Hierarchical structures
in a Galactic framework



Extensive search for
hierarchical structures
in the Galaxy

Back-up slides

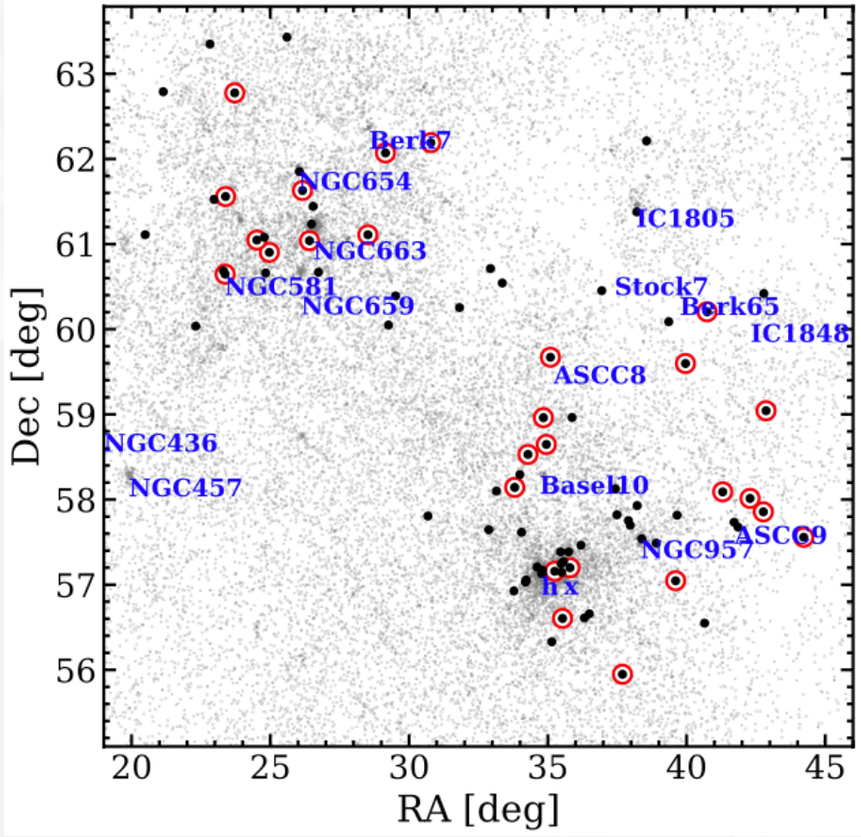
Stellar population astrophysics program

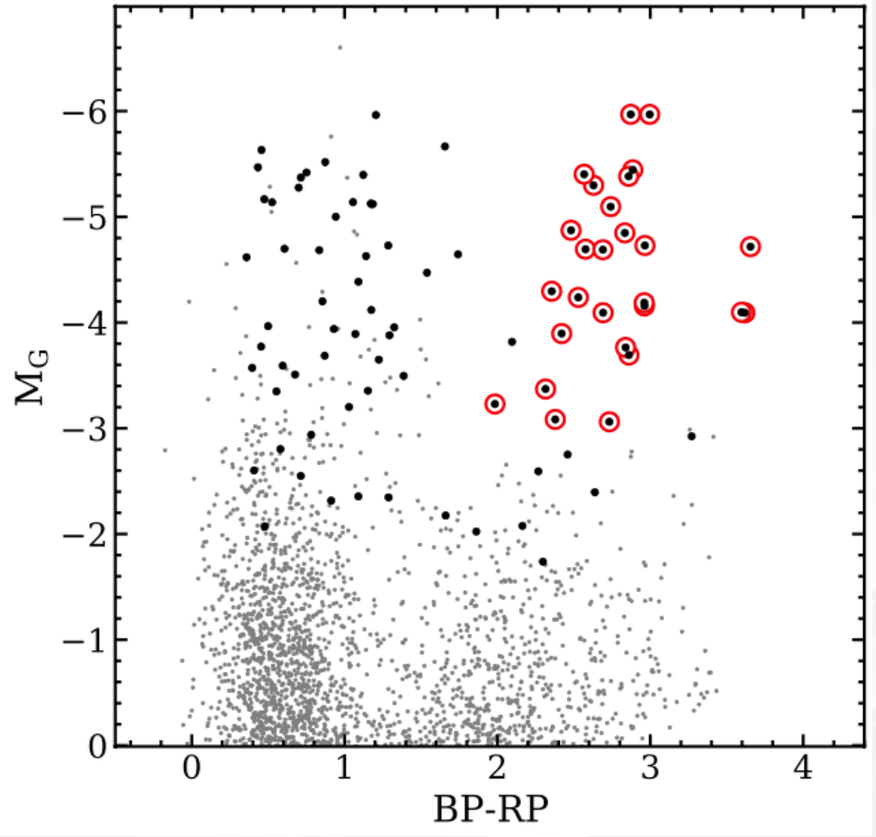
High-resolution spectroscopy SPA @ TNG

→

~ 70 nights (PI Origlia)
Optical (R=115,000)
NIR (R=50,000)

Fanelli et al., 2022, A&A, 660, A7
Fanelli et al., 2022, ApJ, 931, 61



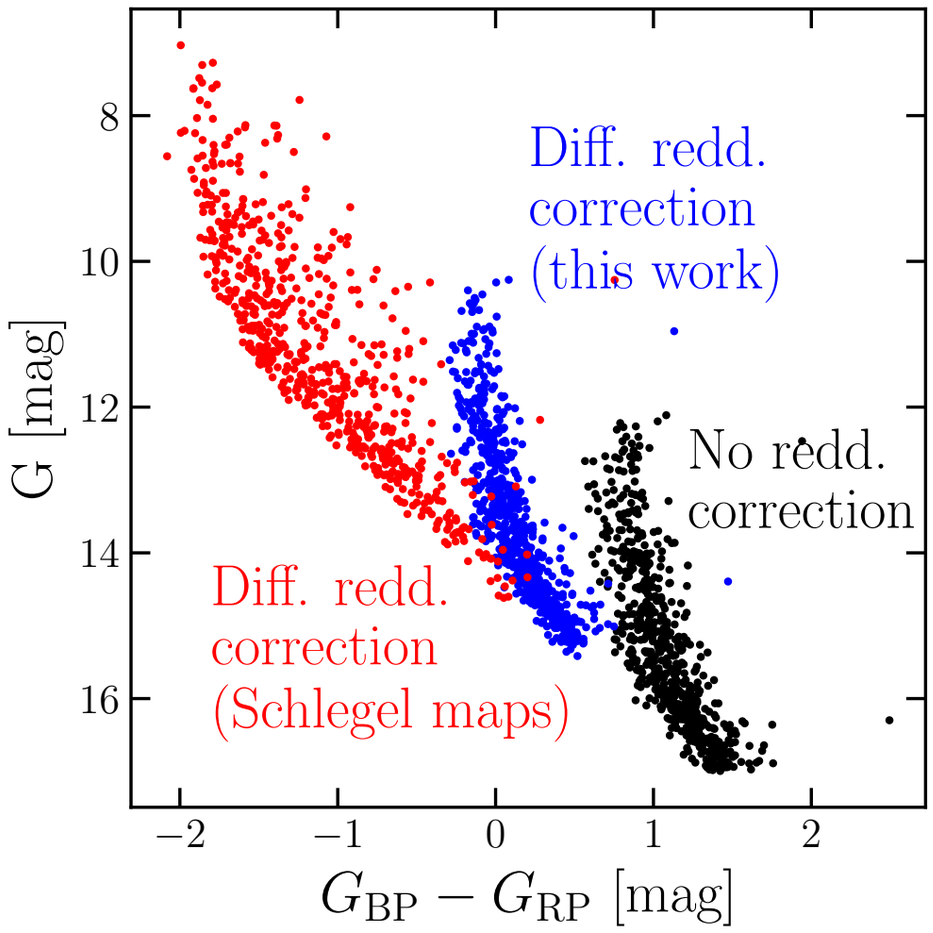


84 stars (27 RSG)

LOS velocity

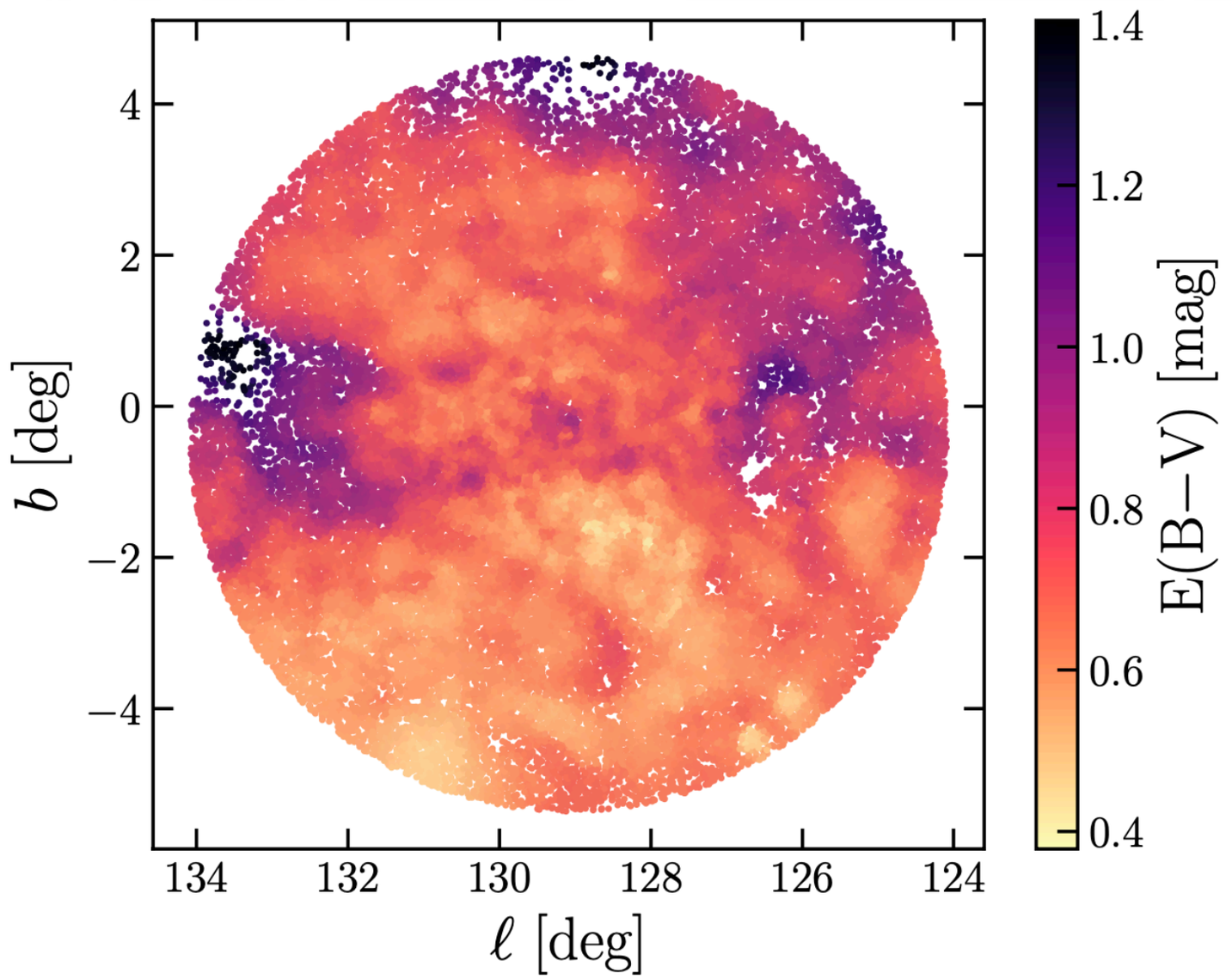
abundances
for 23 species
(including Li)

Differential reddening in LISCA II



color-color diagram

G-r vs i-z



minimizing differences along the reddening vector

Gaia completeness in LISCA II