Disruption of open clusters In the Galactic disk with Gaia EDR3

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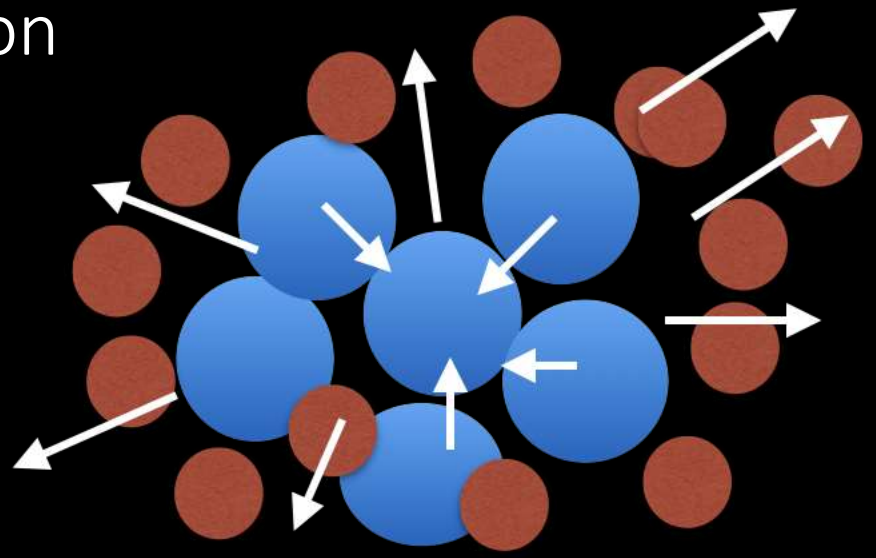
Thijs Kouwenhoven (XJTLU), Qi Shu (PKU, XJTLU)

01

Dynamical Disruption

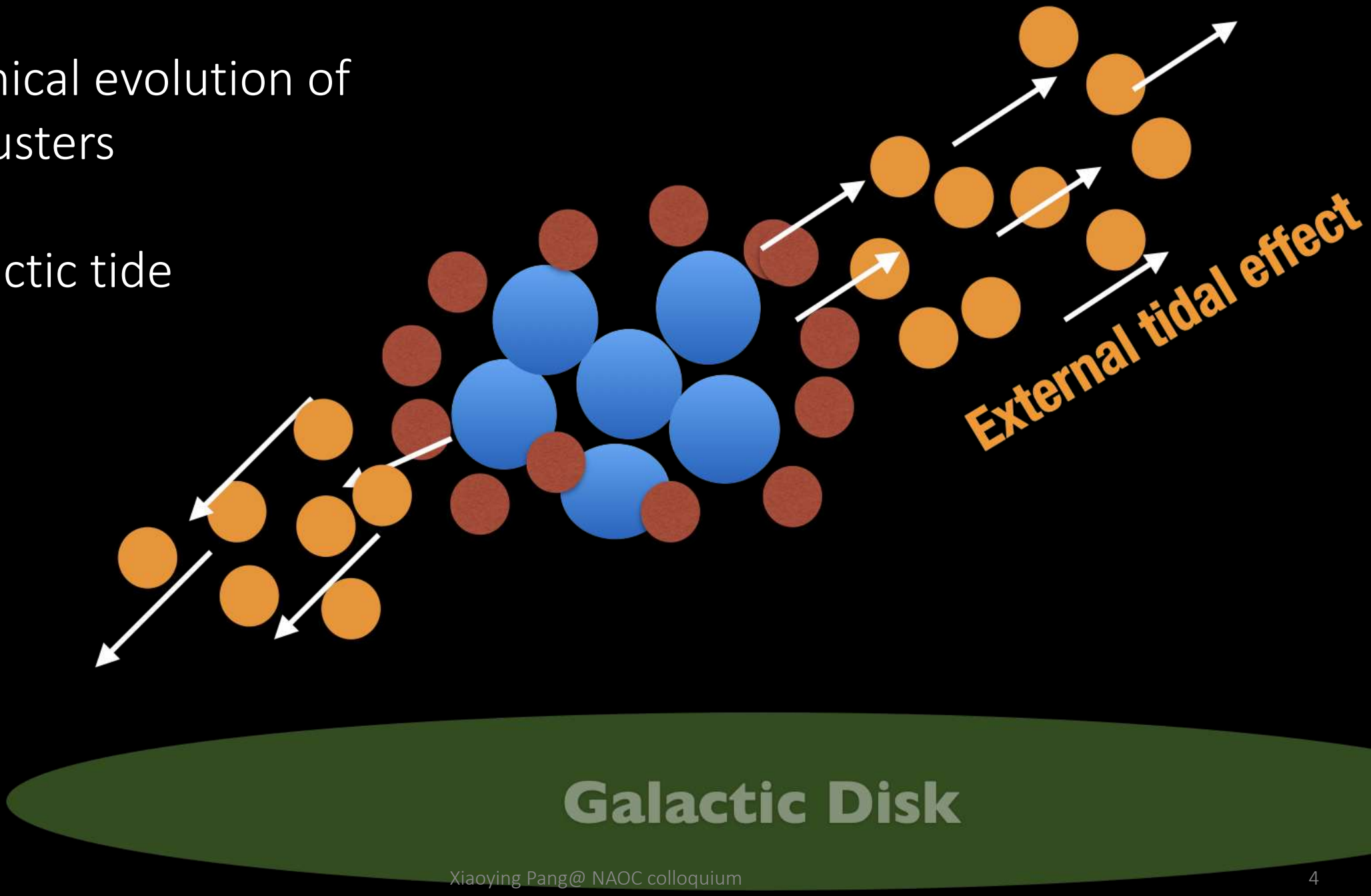
Dynamical evolution of star clusters

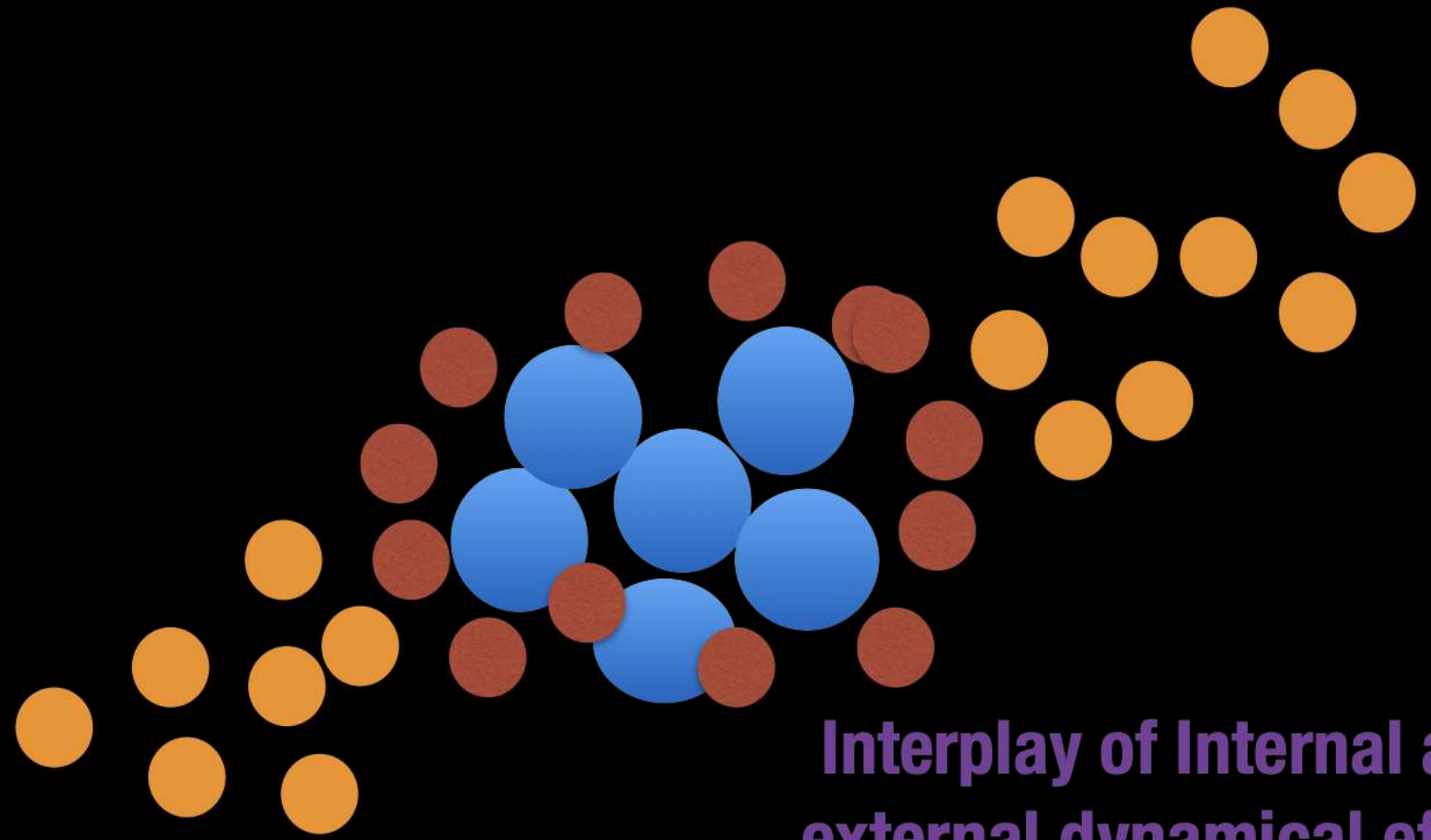
- Two-body relaxation



Dynamical evolution of star clusters

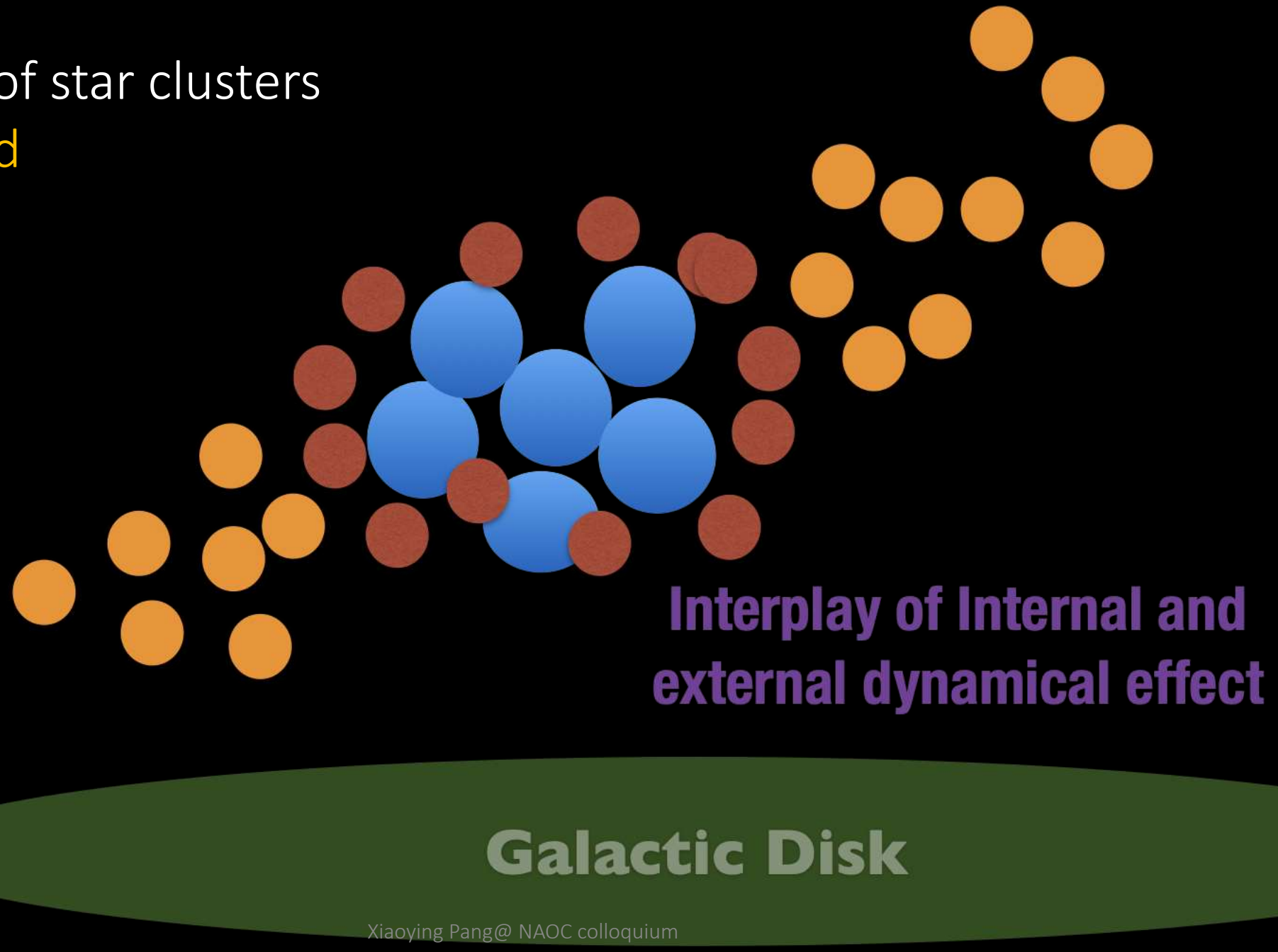
- Galactic tide




Interplay of Internal and
external dynamical effect
Galactic Disk

Disruption of star clusters

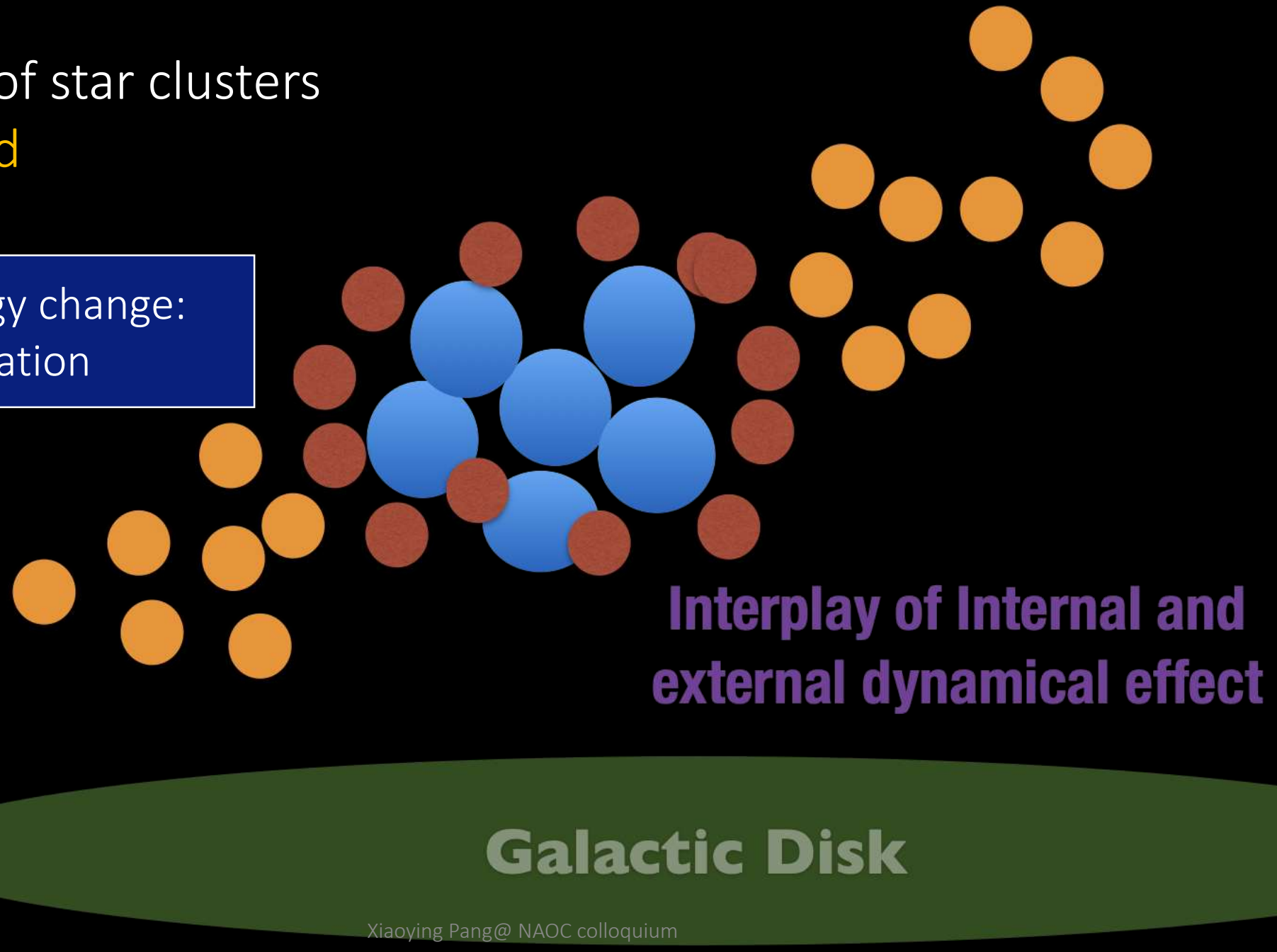
→ Unbound



Disruption of star clusters

→ Unbound

Morphology change: elongation



02

Motivation

Star cluster

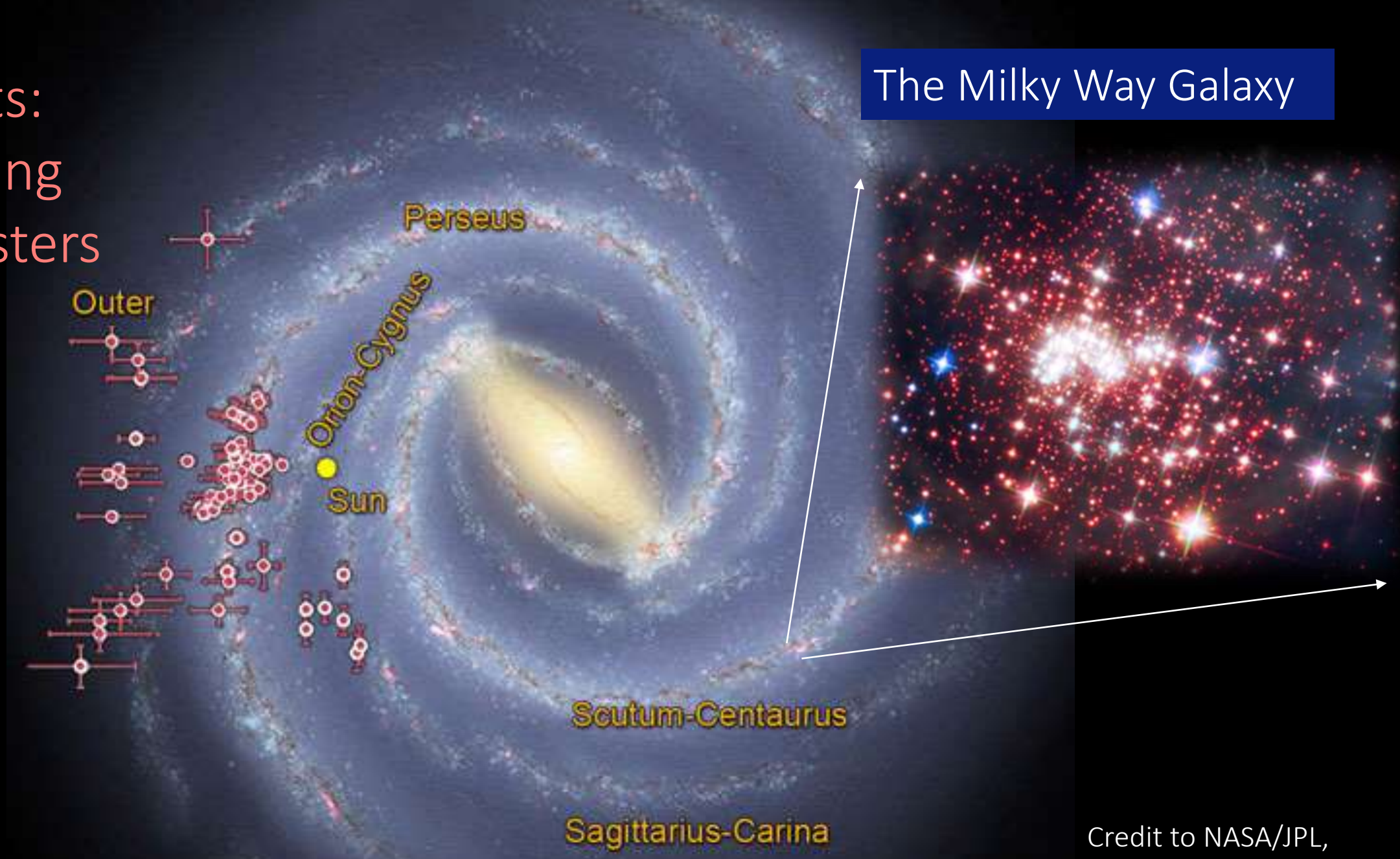
Westerlund 2 (credit to NASA/HST)

Galaxy

Planetary system

Dots: Young clusters

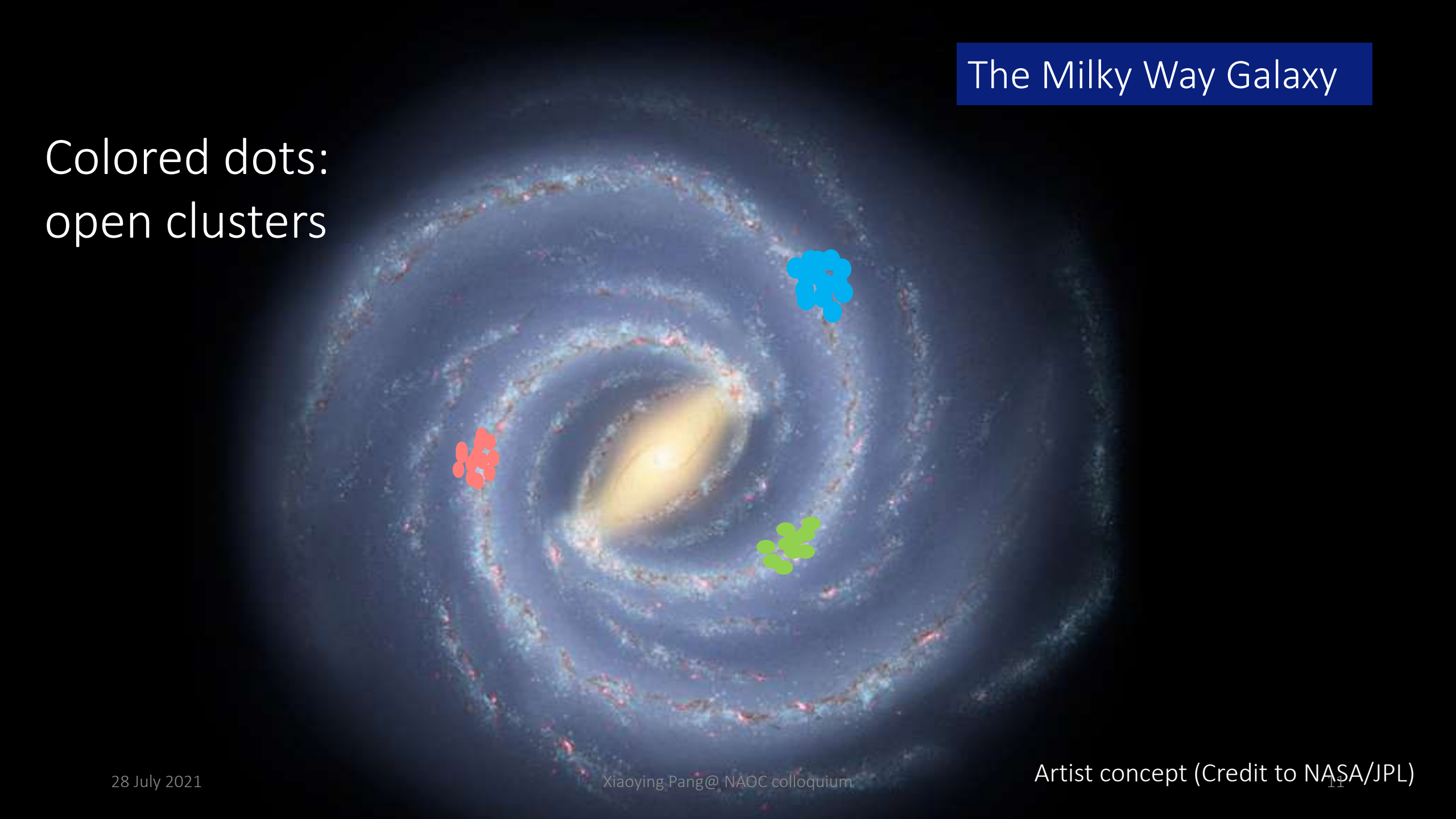
The Milky Way Galaxy



Credit to NASA/JPL, Camargo et al. (2015)

The Milky Way Galaxy

Colored dots:
open clusters

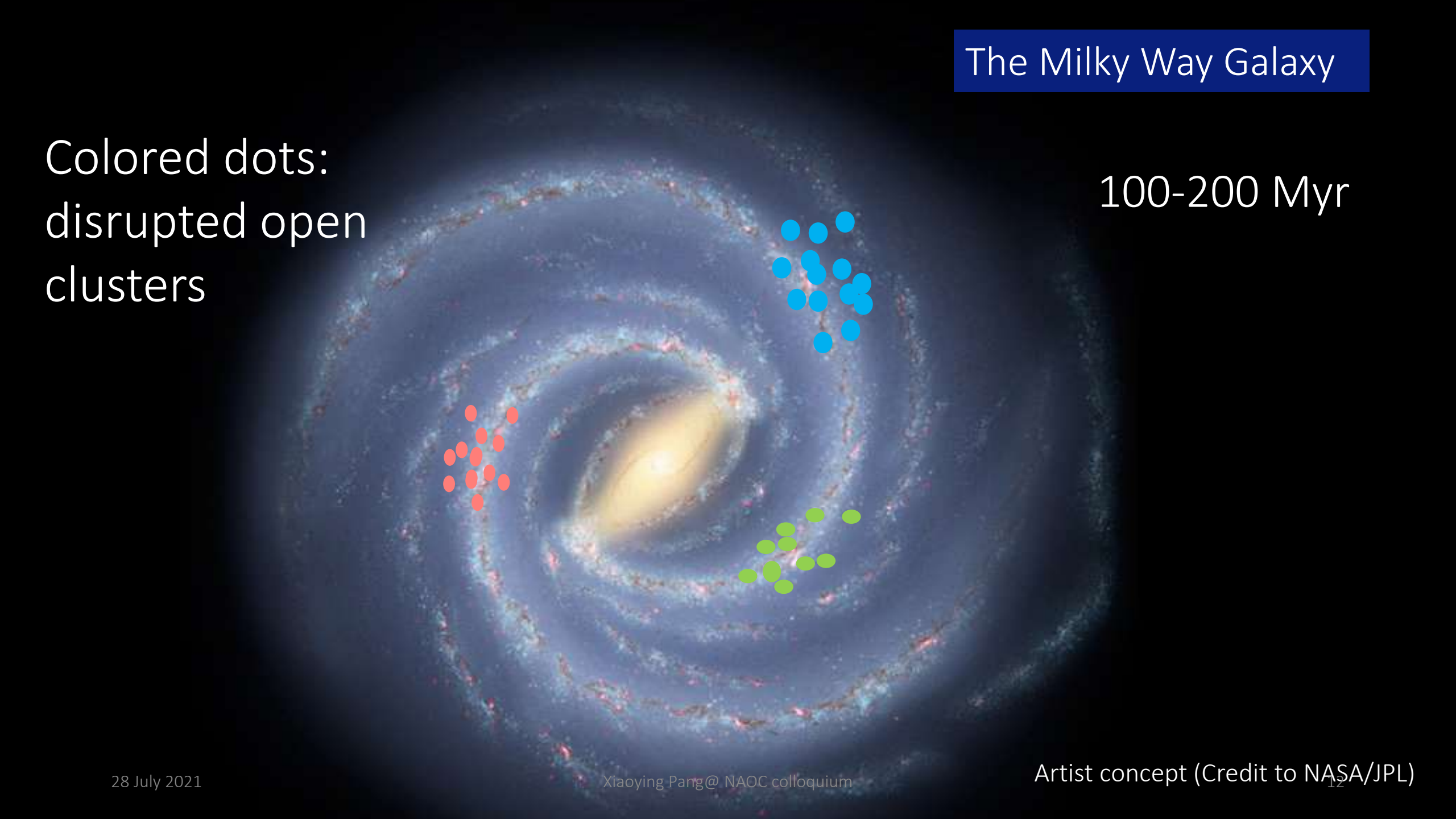


Artist concept (Credit to NASA/JPL)

The Milky Way Galaxy

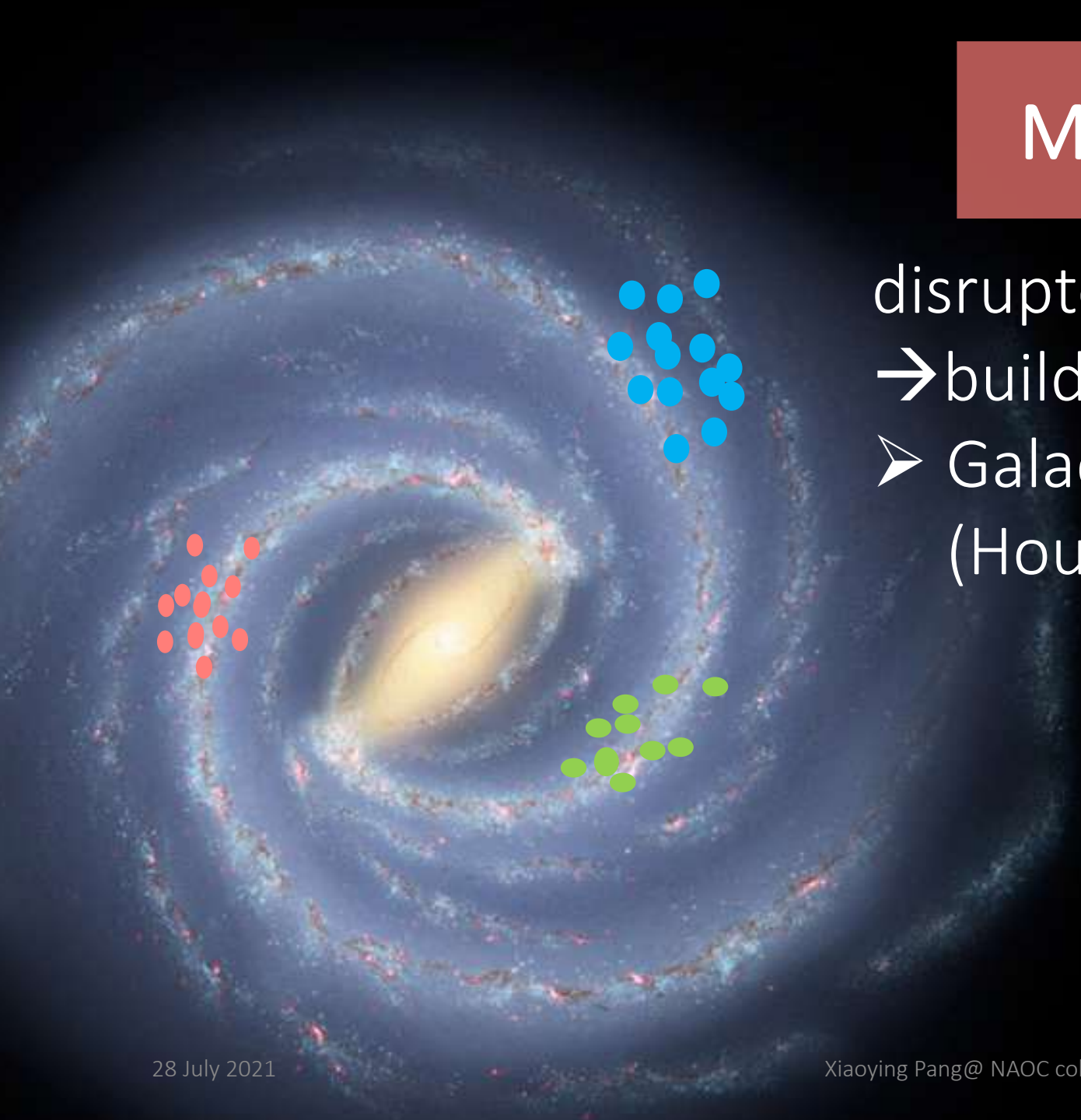
Colored dots: disrupted open clusters

100-200 Myr



Artist concept (Credit to NASA/JPL)

Motivation



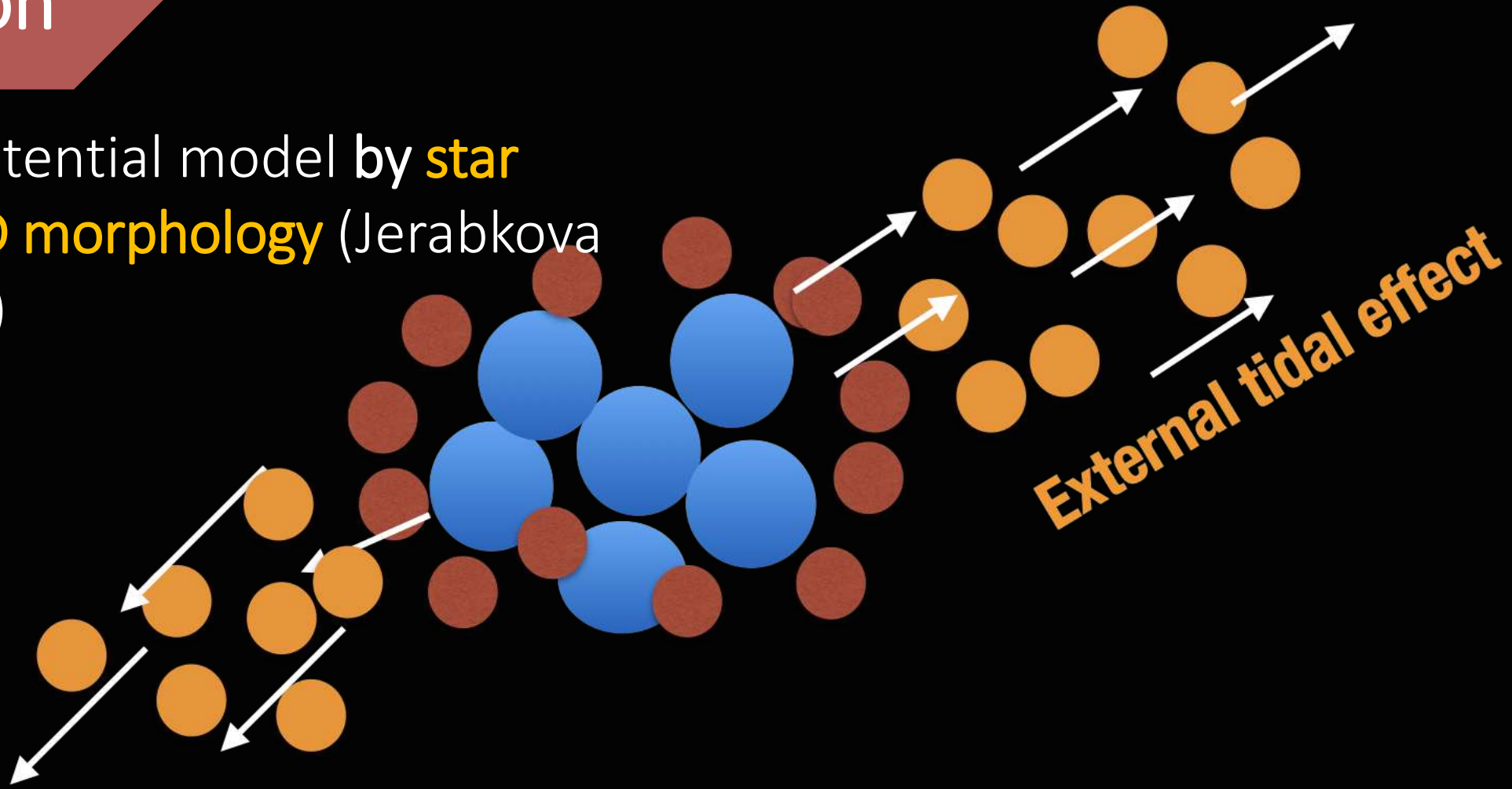
disrupted open clusters

→build up the Galactic disk

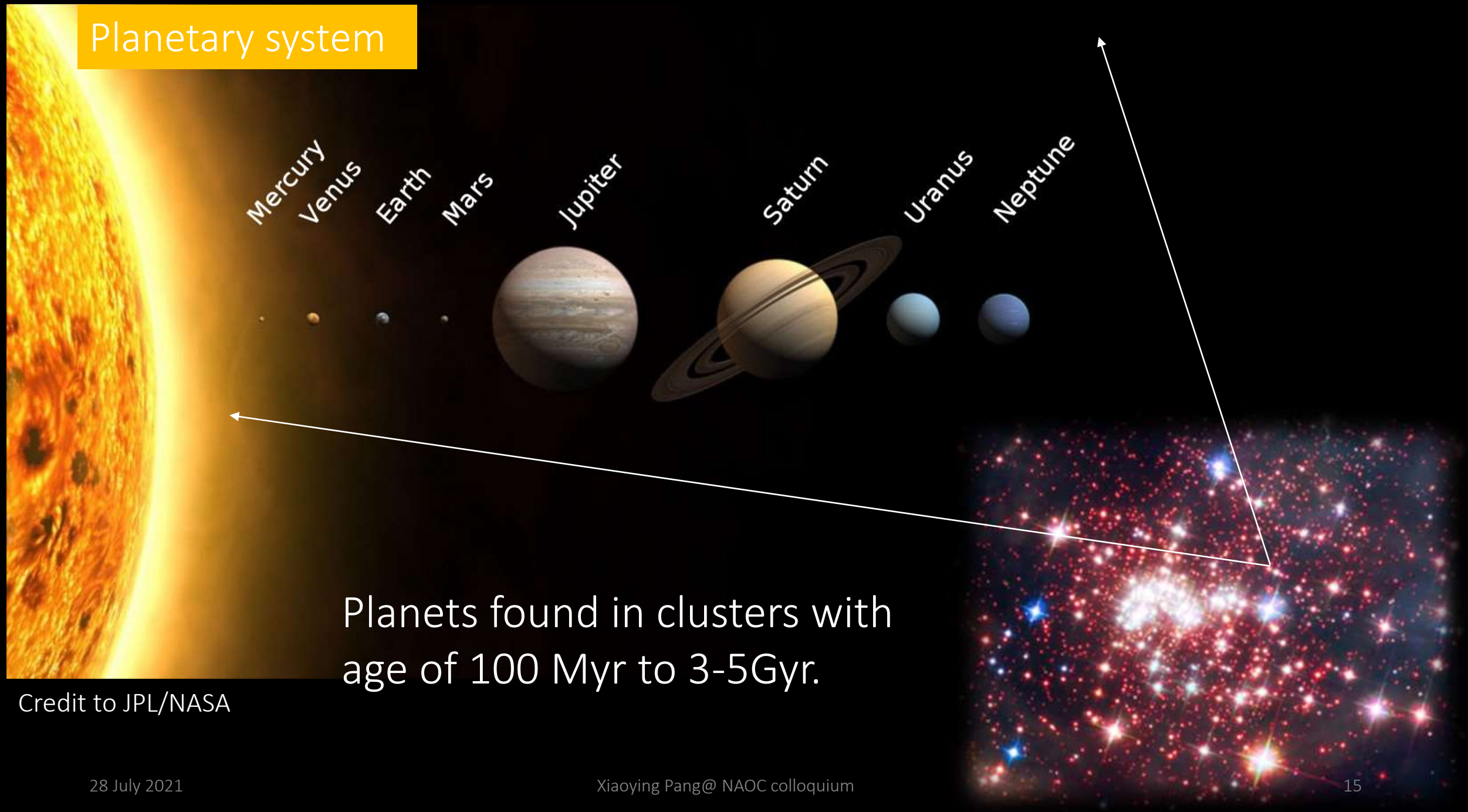
➢ Galactic star formation history (Hou et al. 2000; Fu et al. 2009).

Motivation

- Galactic potential model **by** star clusters' 3D morphology (Jerabkova et al. 2021)



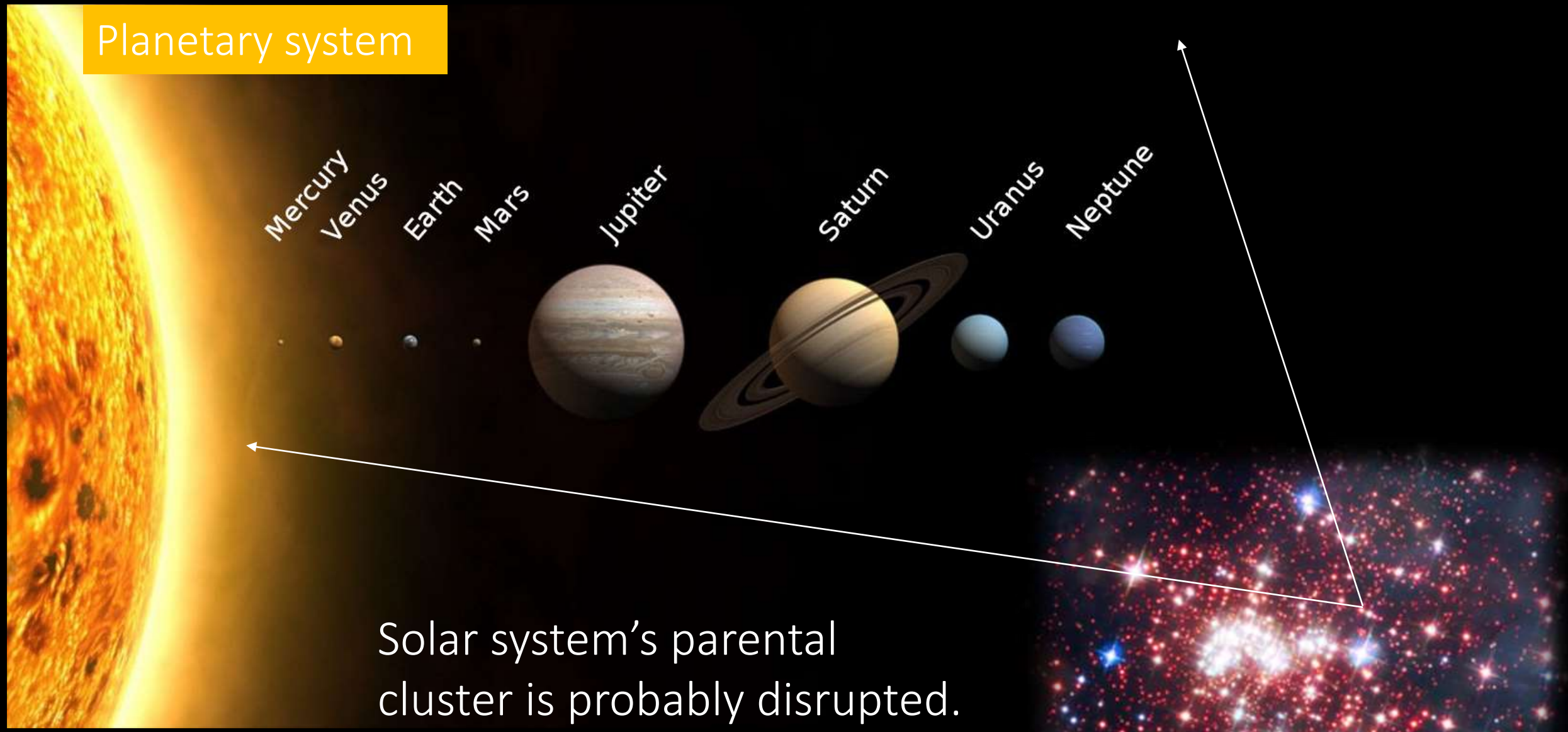
Planetary system



Planets found in clusters with age of 100 Myr to 3-5Gyr.

Credit to JPL/NASA

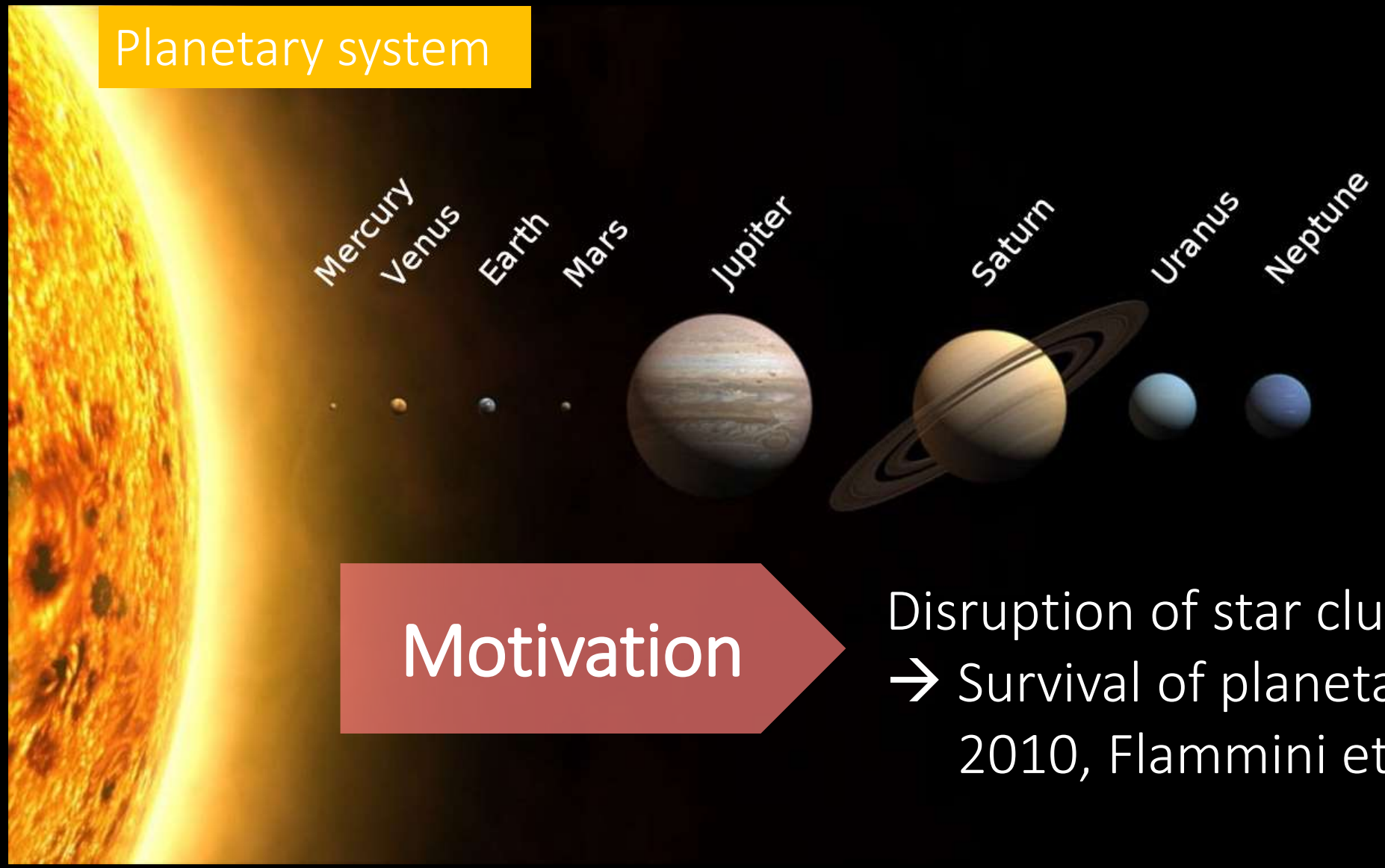
Planetary system



Solar system's parental cluster is probably disrupted.

Credit to JPL/NASA

Planetary system



Credit to JPL/NASA

Motivation

Disruption of star clusters
→ Survival of planetary system (Adams 2010, Flammini et al. 2020)

Indispensable
Star cluster disruption

Westerlund 2 (credit to NASA/HST)

Galactic structure formation

Planetary system evolution

03

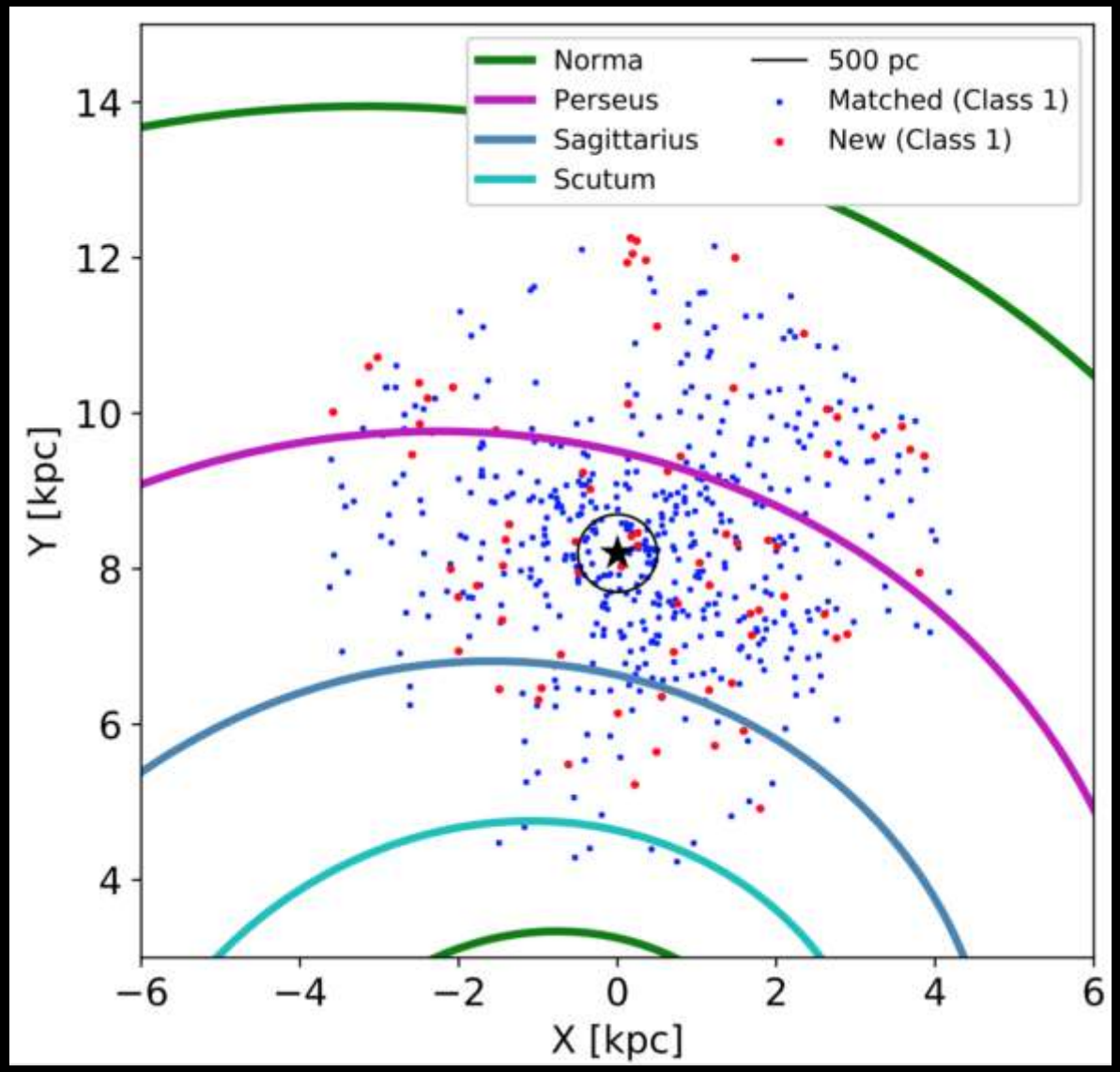
DATA & METHOD

Data

Gaia

DR2
EDR3

Open clusters within 500 pc



62 open clusters (Liu & Pang 2019)
32 from other catalogs (Kharchenko et al. 2013, Cantat Gaudin et al. 2020)

87 pc – 482 pc
25 Myr – 2.65 Gyr

3D Morphology

Liu & Pang (ApJS, 2019, 245, 32)

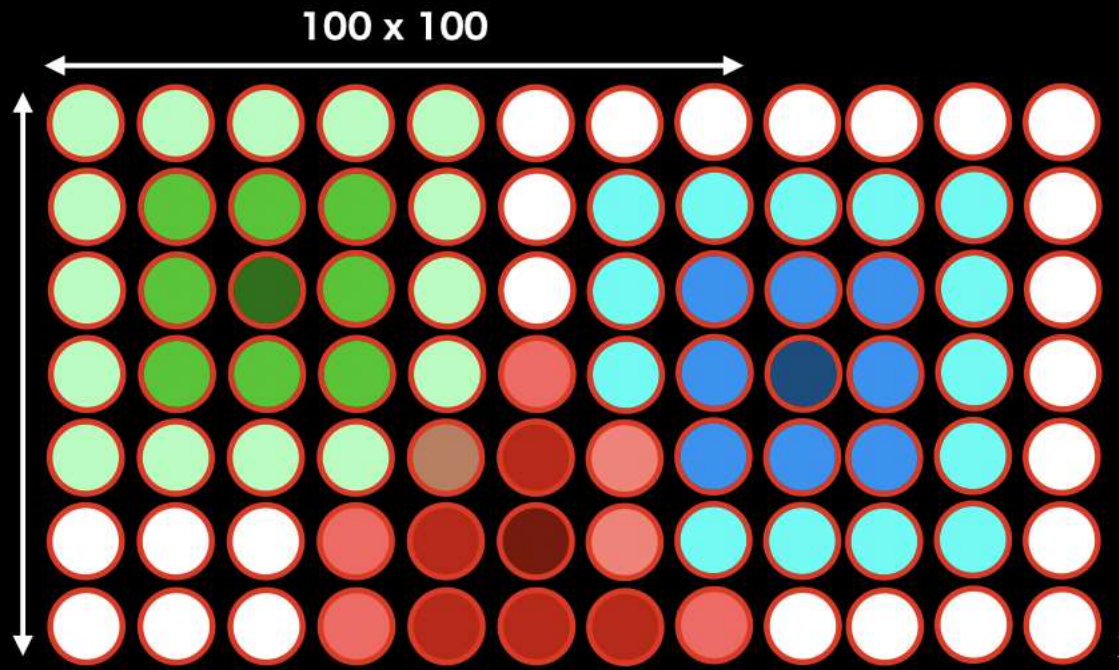
Method

Self-organizing map (SOM): well-established unsupervised learning algorithms based on artificial neural network with controlled contamination rate (5%).

StarGO
(Yuan et al. 2018)

5D space:
X, Y, Z, proper motions
(normalized)

Topology conservation



SOM carton credit to Shih-Yun Tang

Method

Self-organizing map (SOM): well-established unsupervised learning algorithms based on artificial neural network with controlled contamination rate (5%).

StarGO
(Yuan et al. 2018)

5D space:
X, Y, Z,
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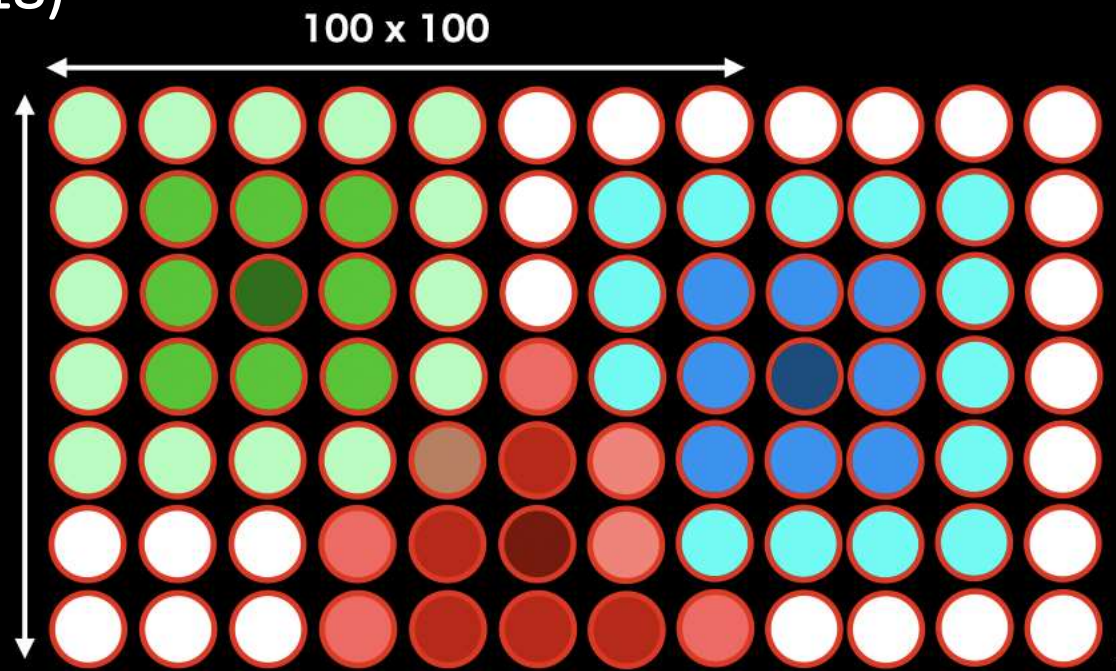
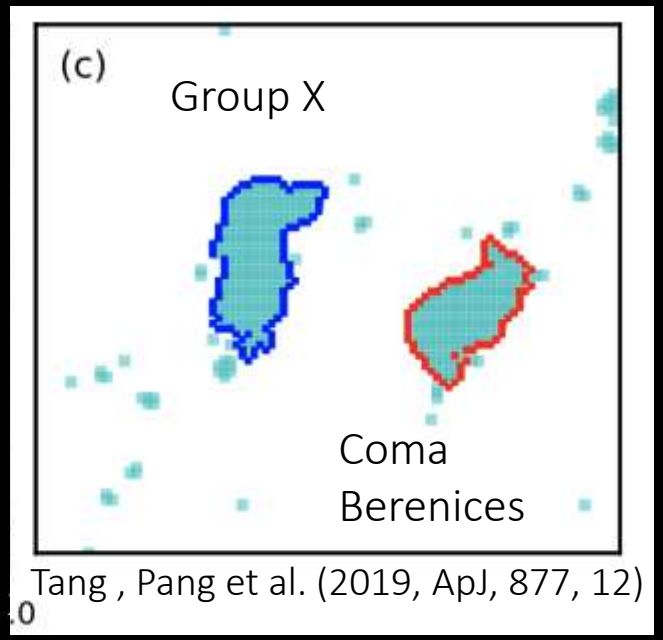




Tang , Pang et al. (2019, ApJ, 877, 12)

04

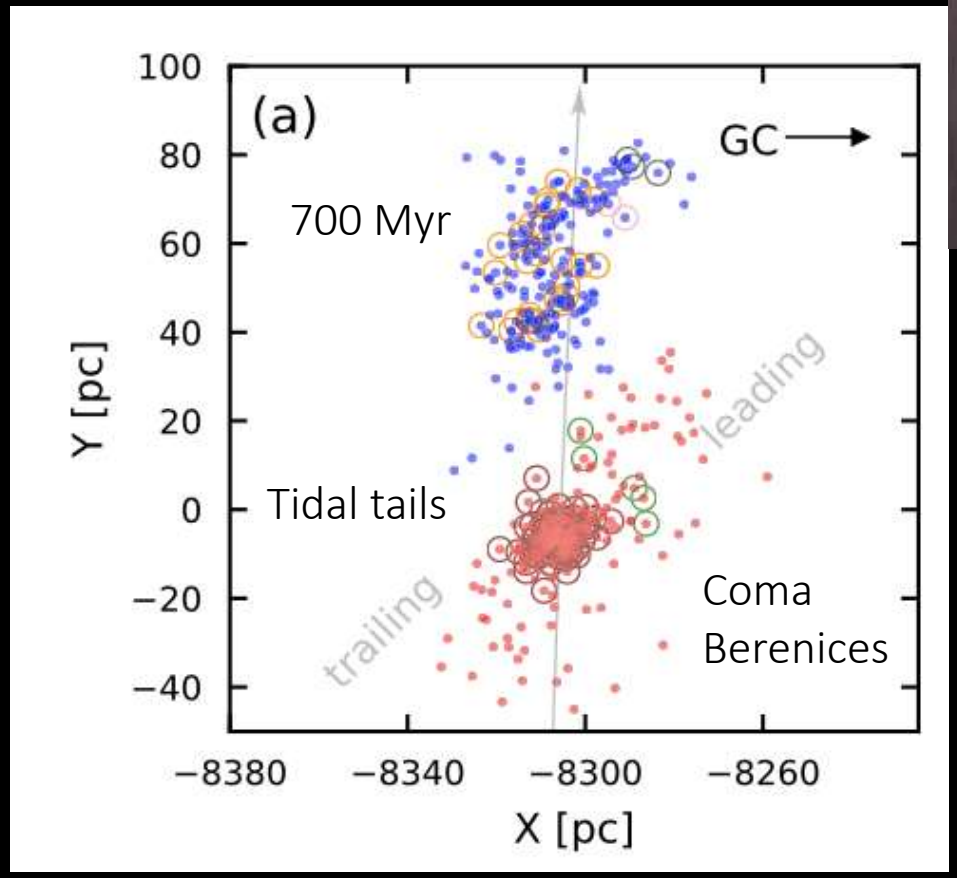
3D

Morphology star clusters

3D

Morphology

Gaia DR2



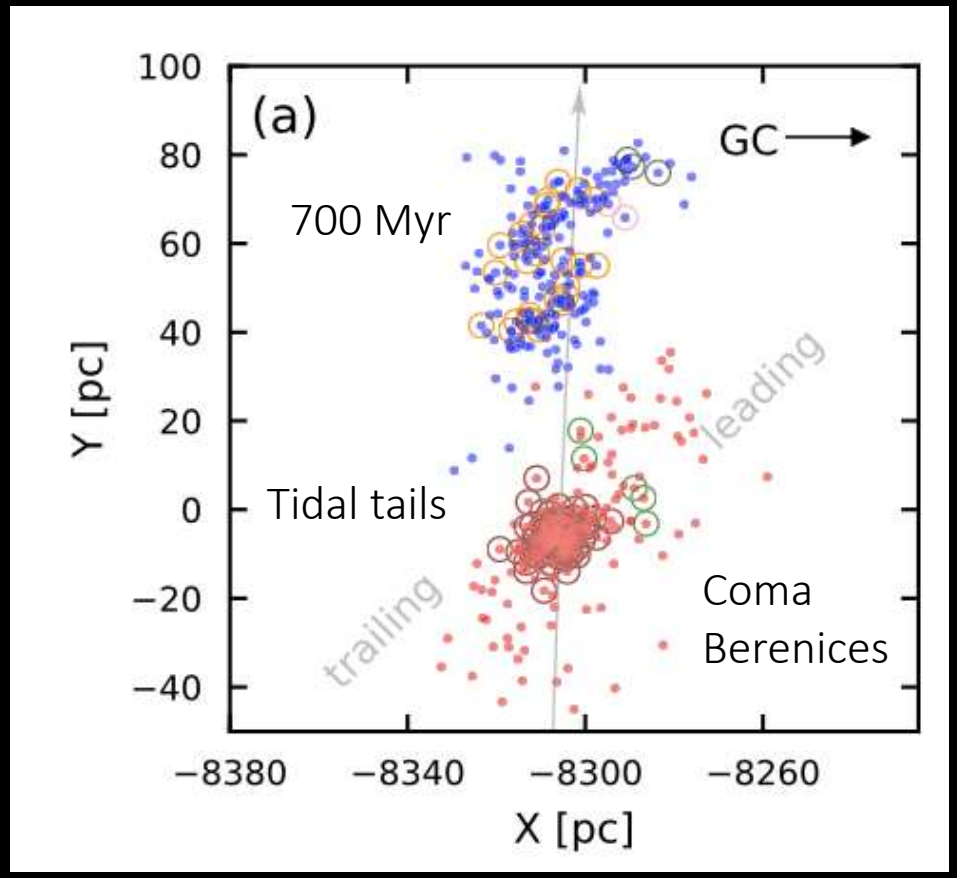
Tang , Pang et al. (2019, ApJ, 877, 12)

Shih-Yun Tang

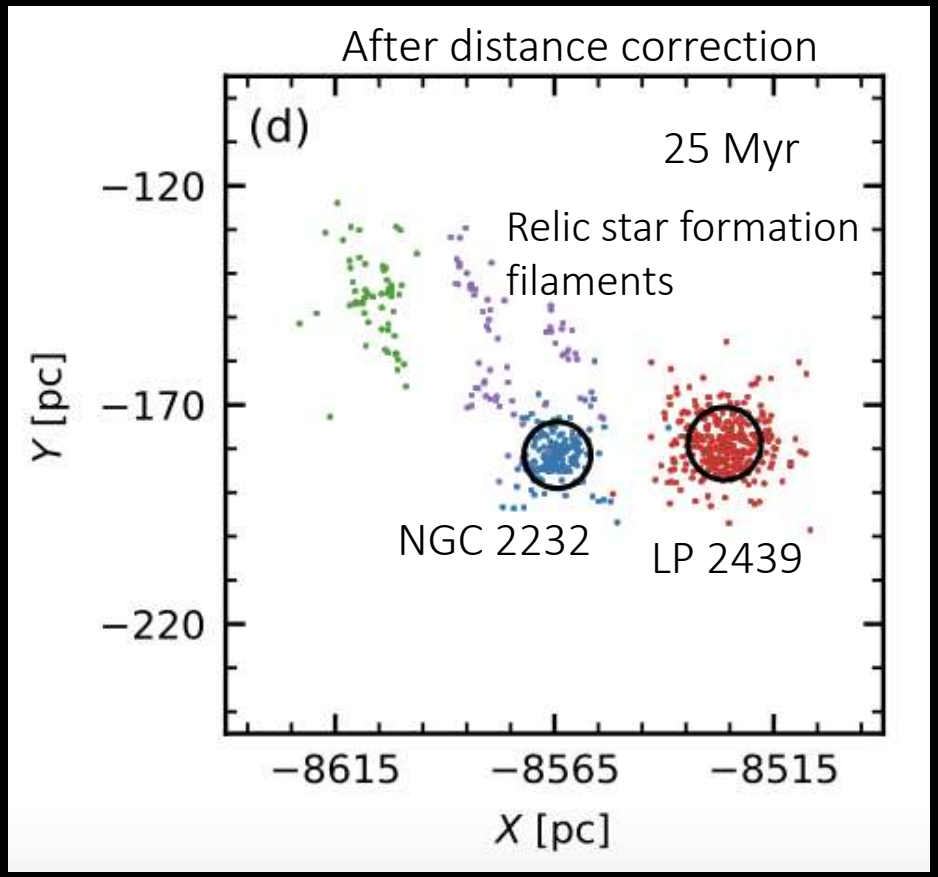
3D

Morphology

Gaia DR2



Tang , Pang et al. (2019, ApJ, 877, 12)



Pang et al. (2020, ApJL, 900, 4)

3D

Morphology

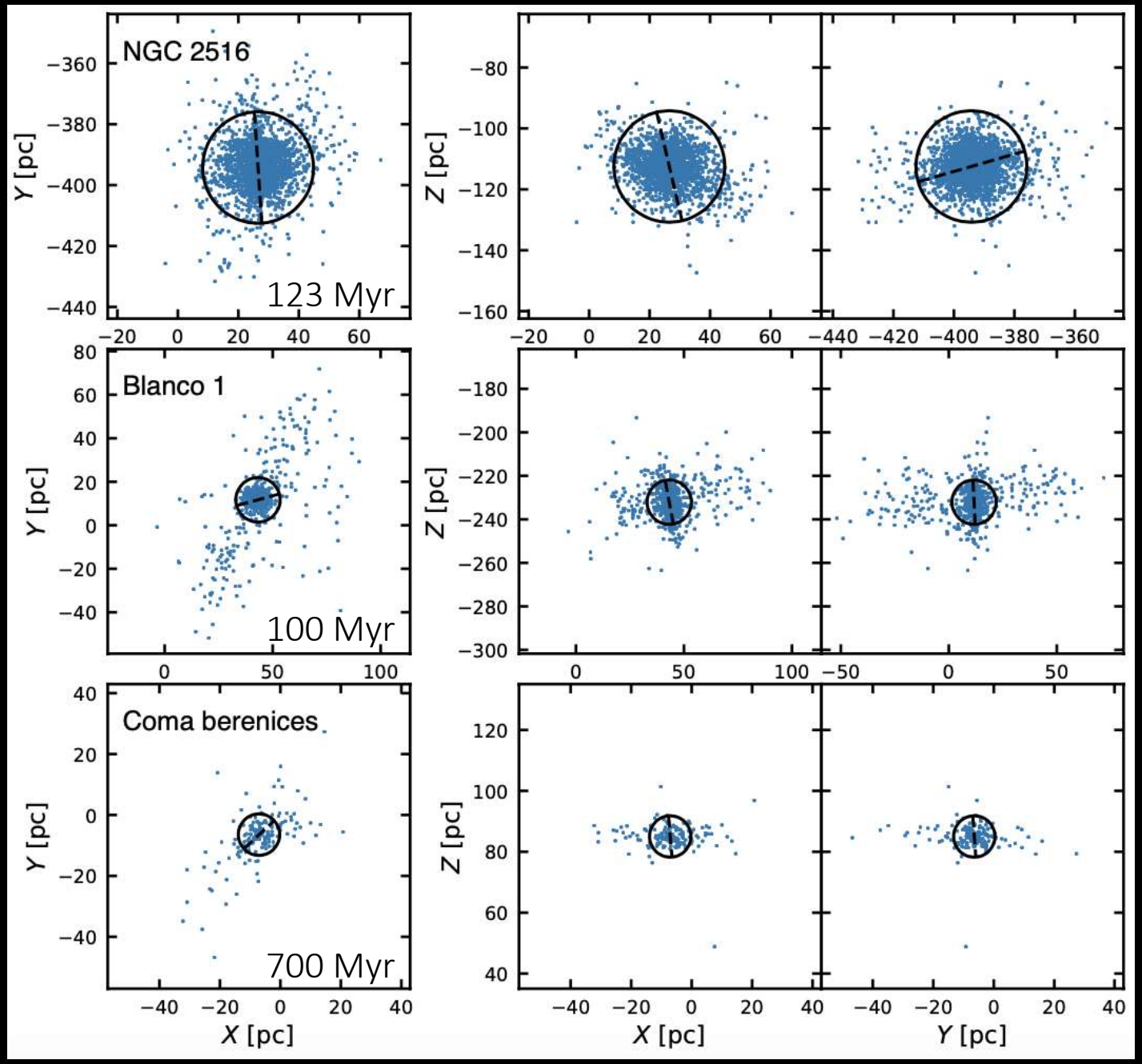
Zeqiu Yu

Yuqian Li

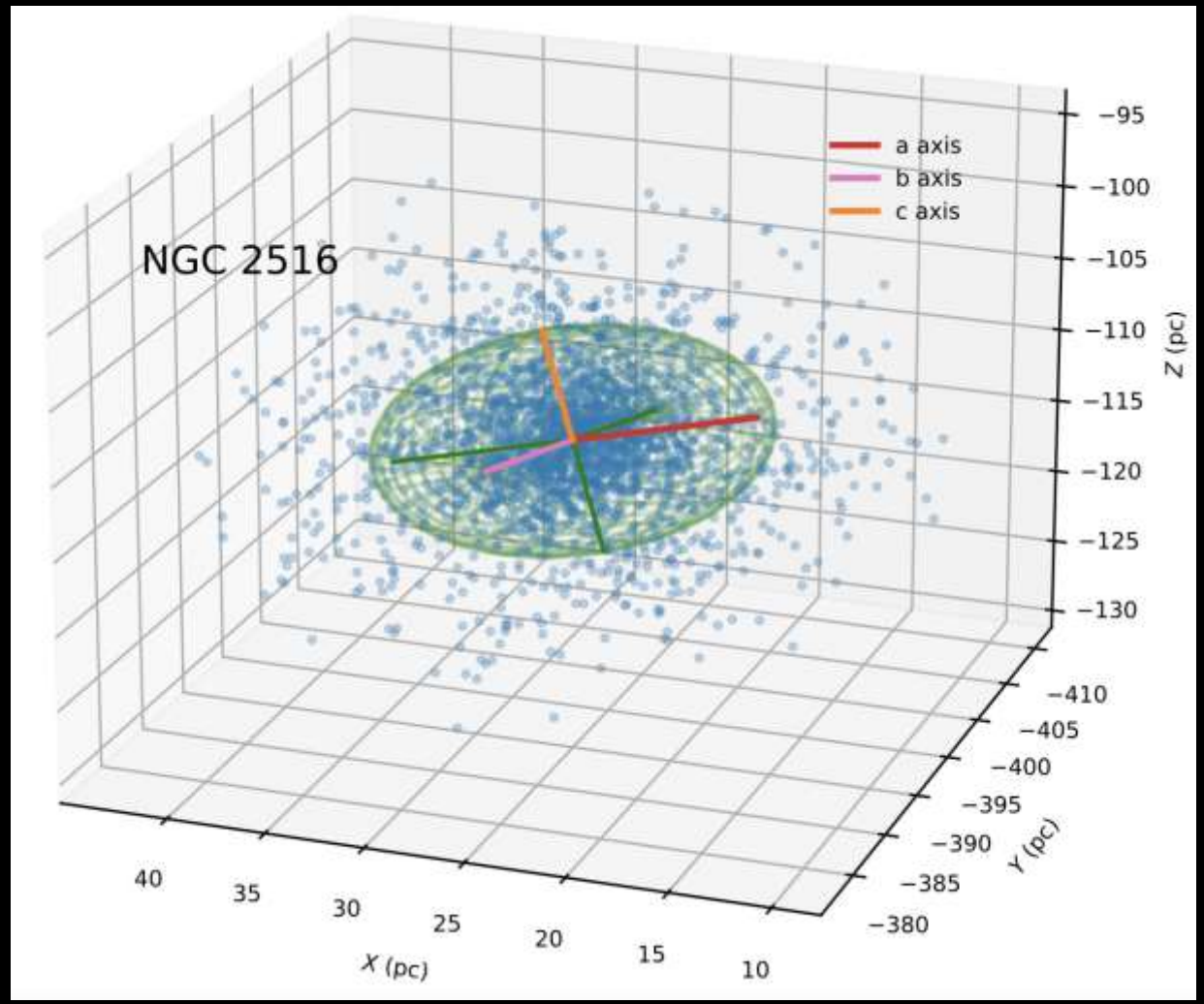
Black circle: tidal radius

After distance correction

Pang, Li, Yu et al. (2021a, ApJ, 912, 162)



Morphology quantification



Ellipsoid fitting to the 3D spatial distribution of stars within tidal radius.

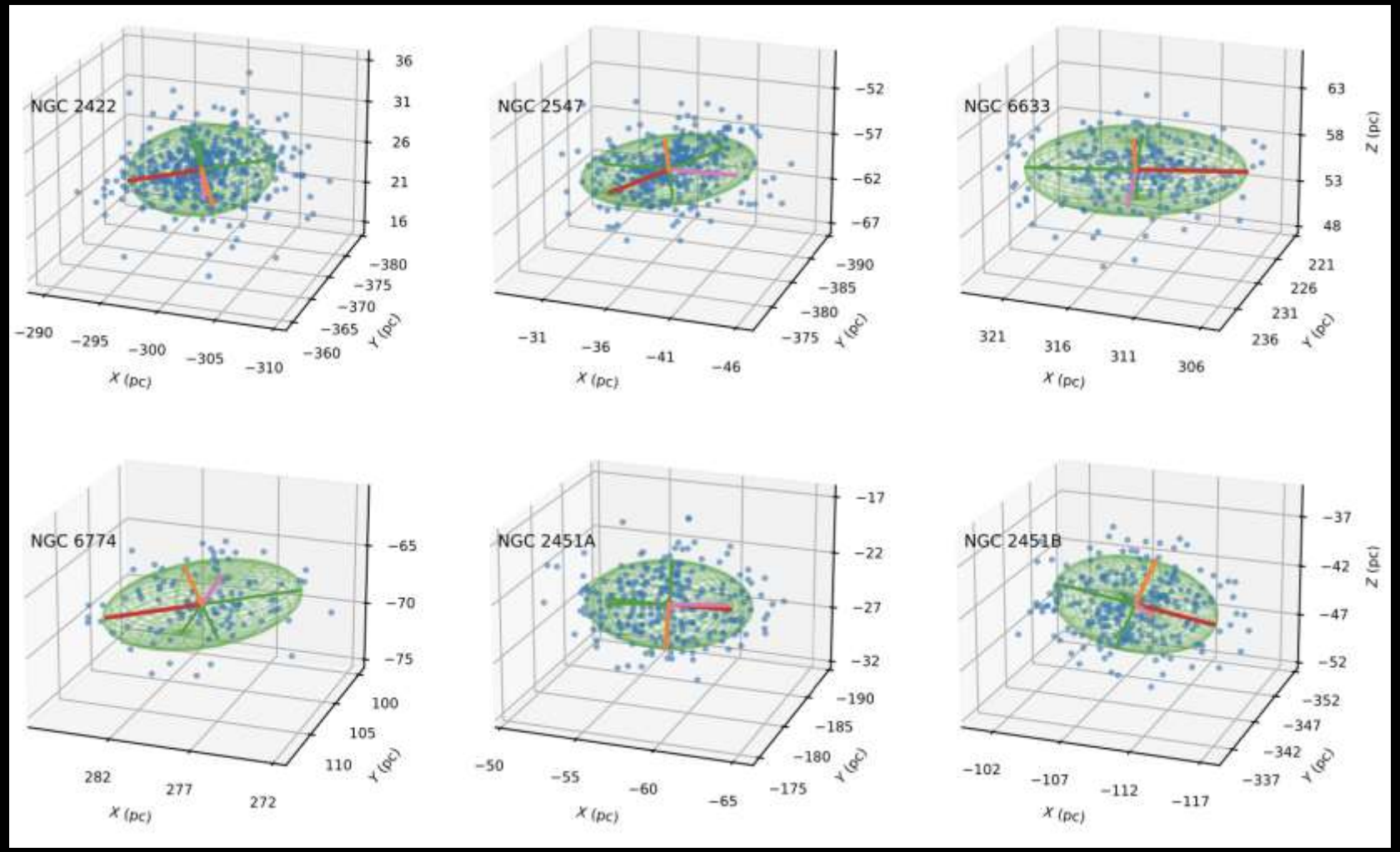
a: semi-major axis (elongation direction)

b: semi-intermediate axis;

c: semi-minor axis;

Pang et al. (2021a, ApJ, 912, 162)

Morphology quantification



Elongation direction of open cluster (a: semi-major axis)

→ Mostly parallel to the plane

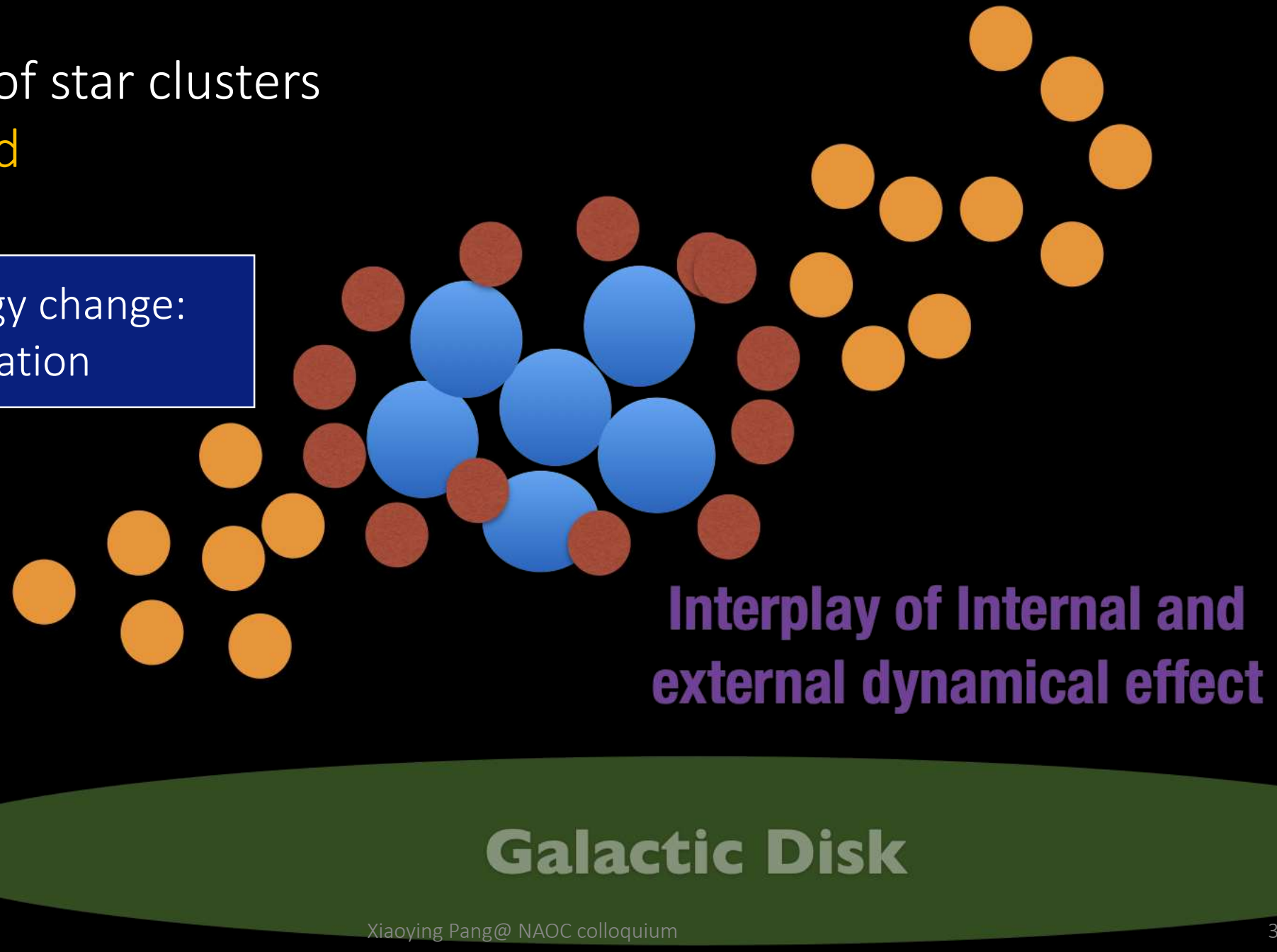
Tidal effect

Pang et al. (2021a, ApJ, 912, 162)

Disruption of star clusters

→ Unbound

Morphology change: elongation



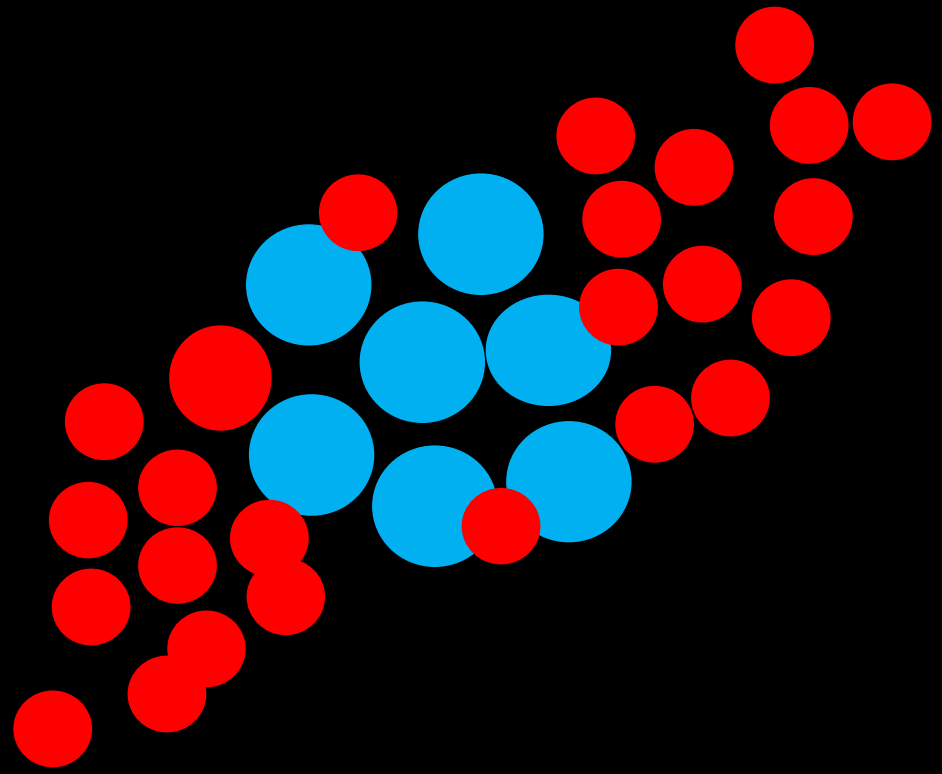
05

Dynamical state & Disruption

Disruption of star clusters

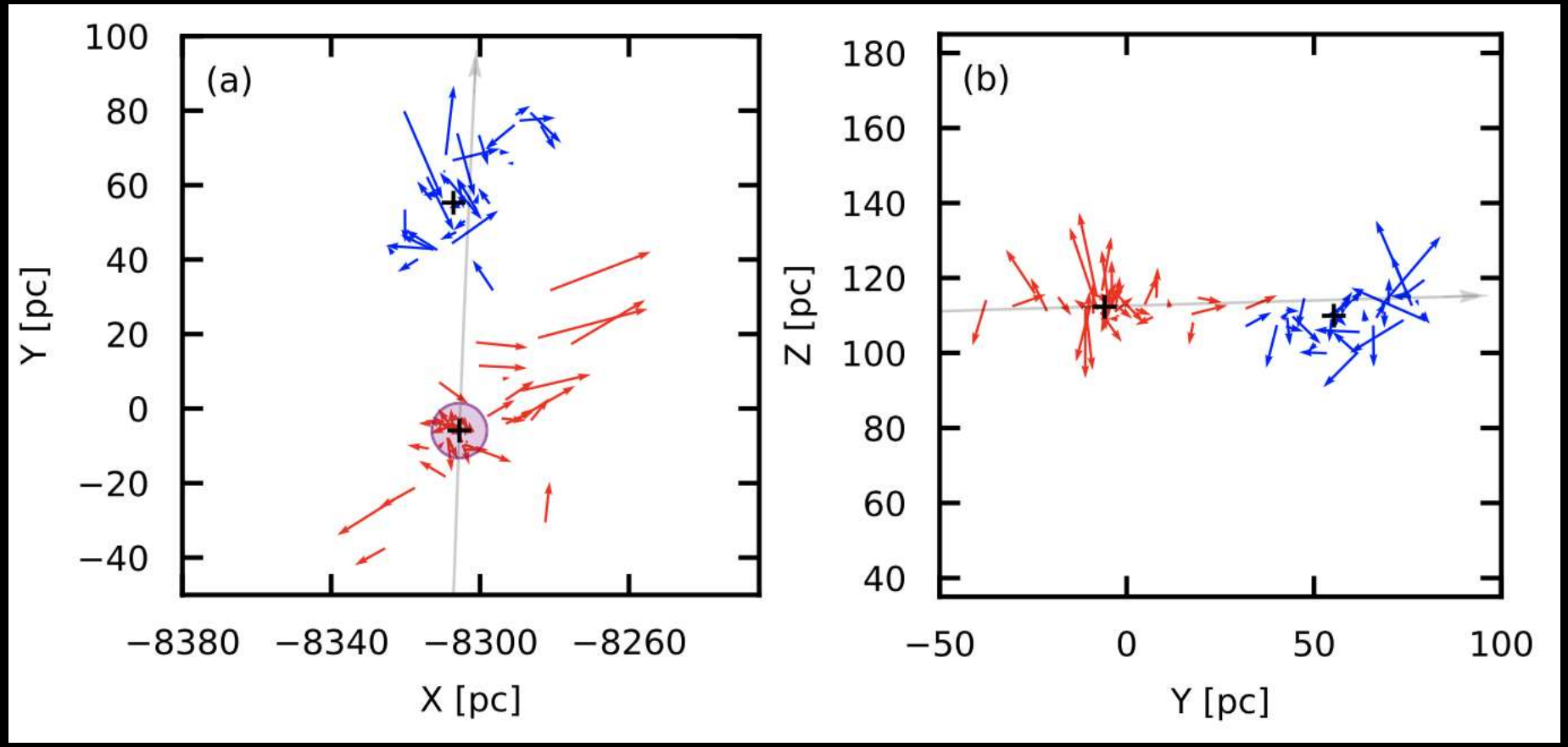
→ Unbound

→ expand



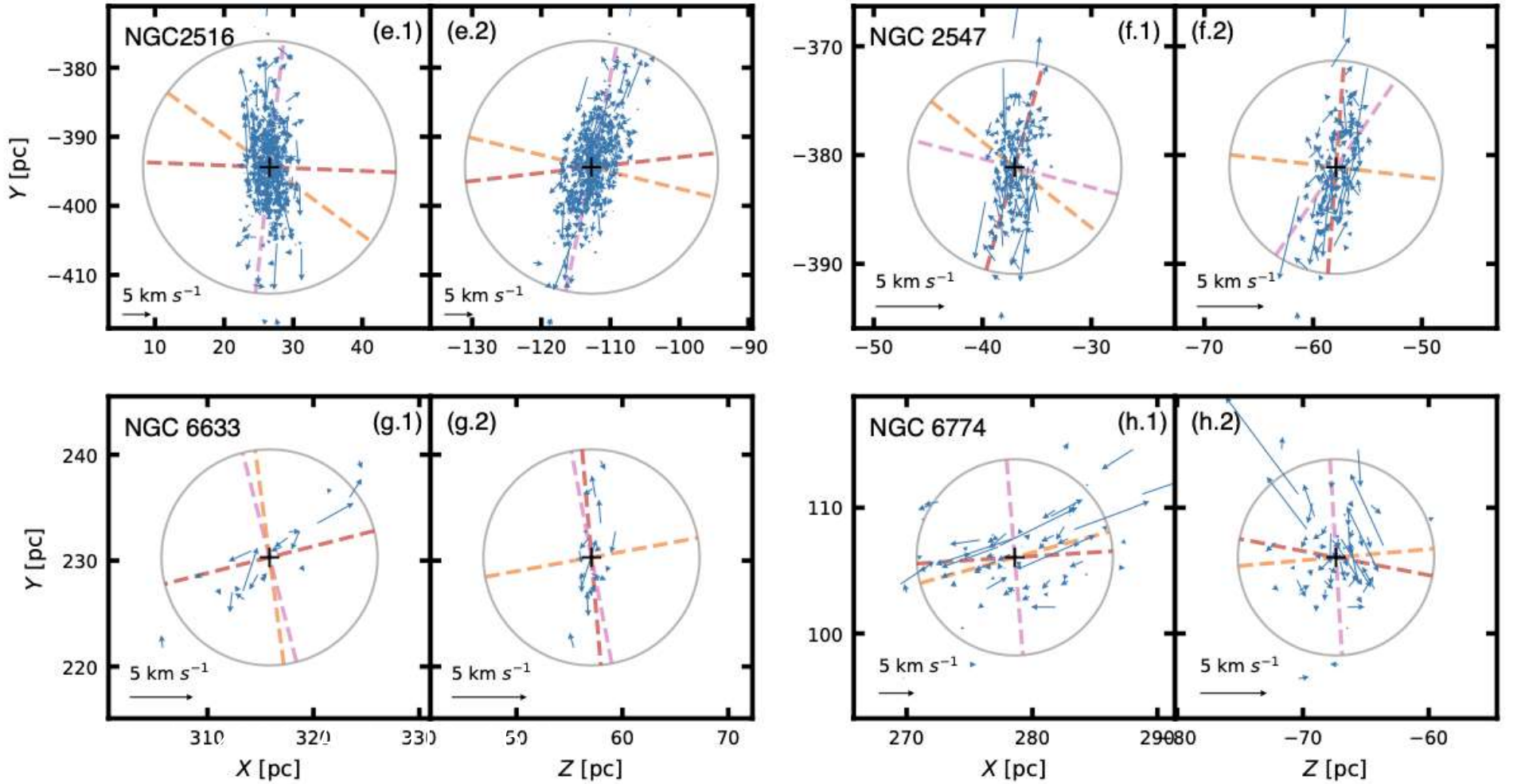
Expansion

Coma Berenice (700 Myr)



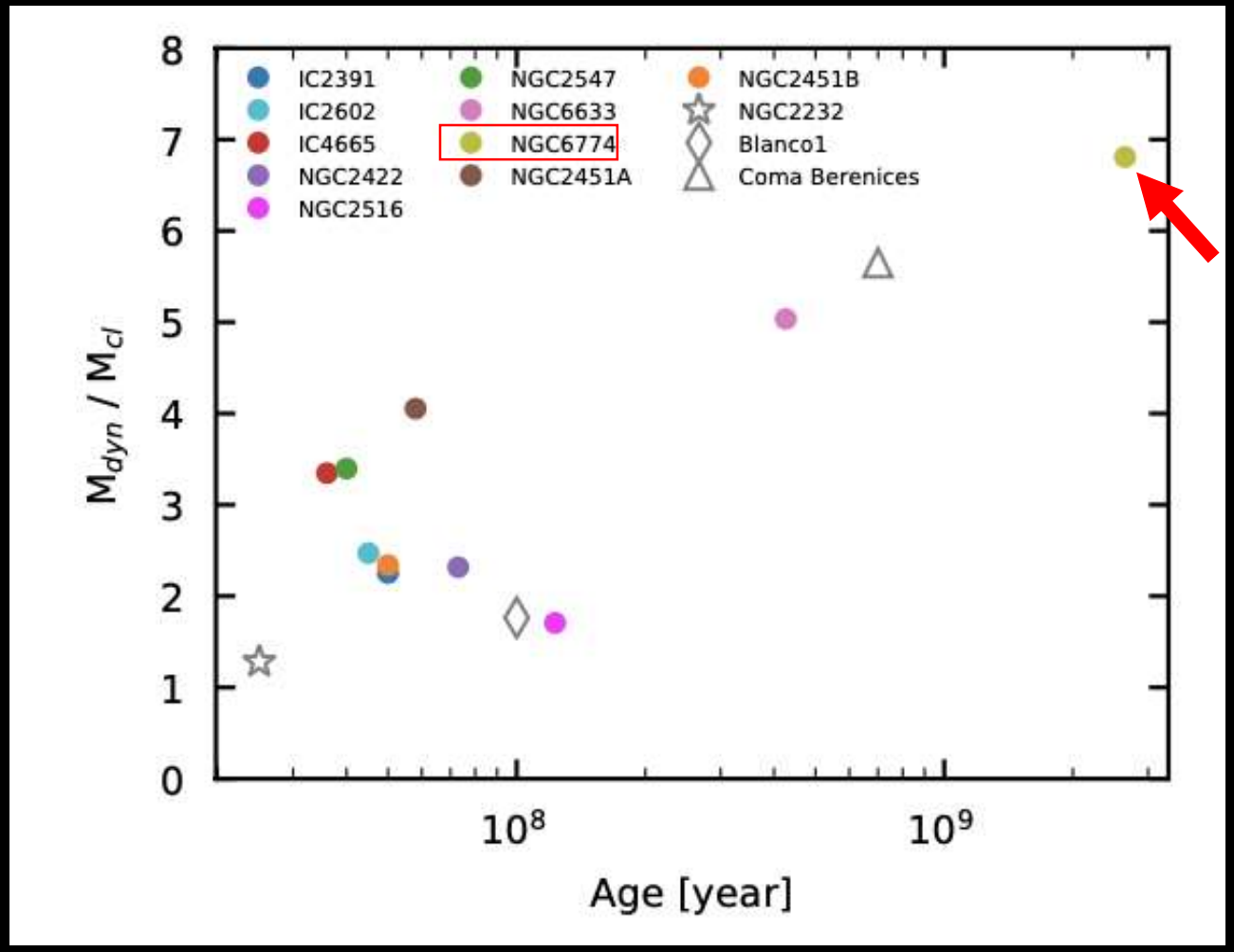
Tang , Pang et al. (2019, ApJ, 877, 12)

Expansion



Pang et al. (2021a, ApJ, 912, 162)

Dynamical state

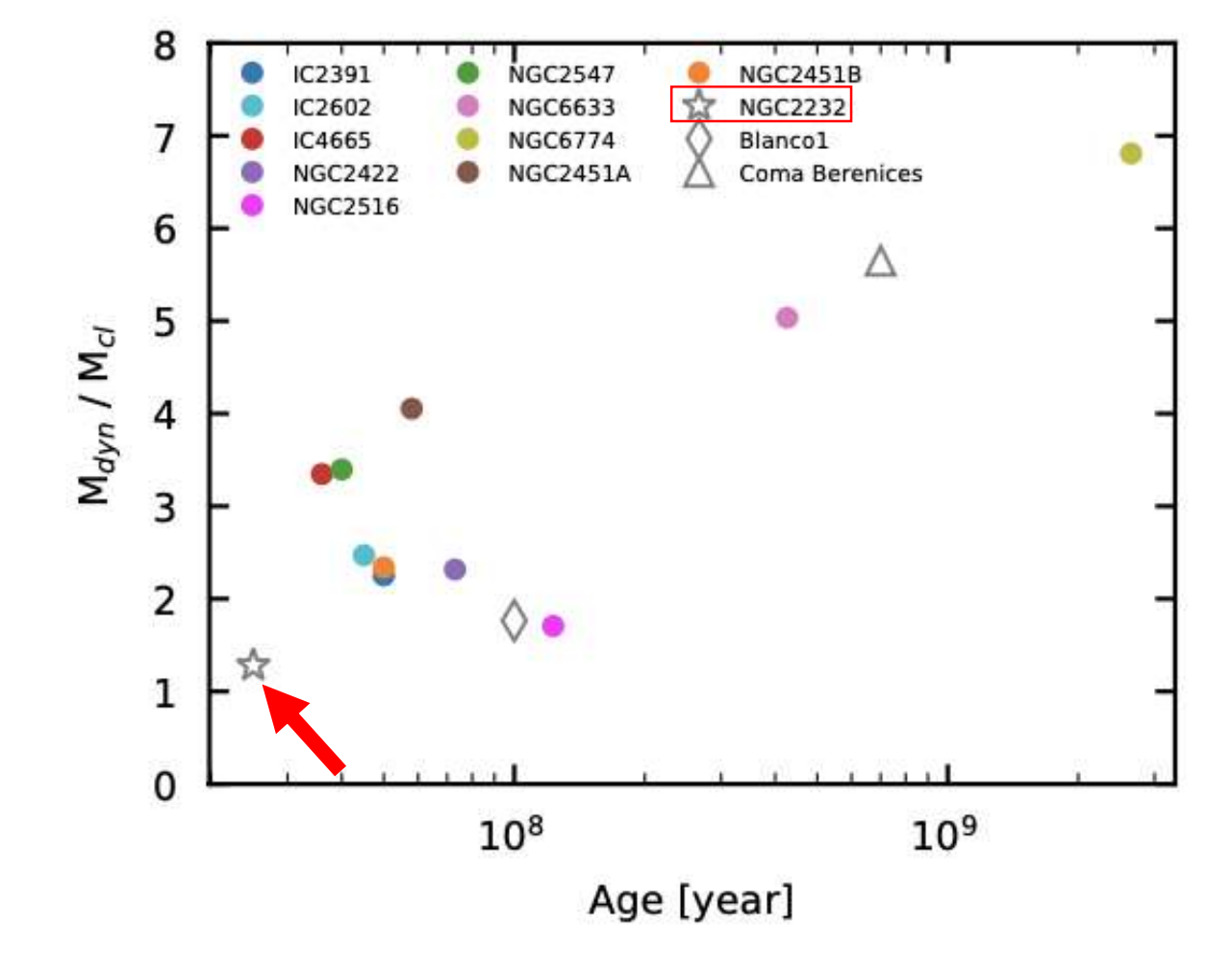


Velocity dispersion
→ dynamical mass

The large values of the ratio suggests that most of the clusters may be super-virial.

Pang et al. (2021a, ApJ, 912, 162)

Dynamical state



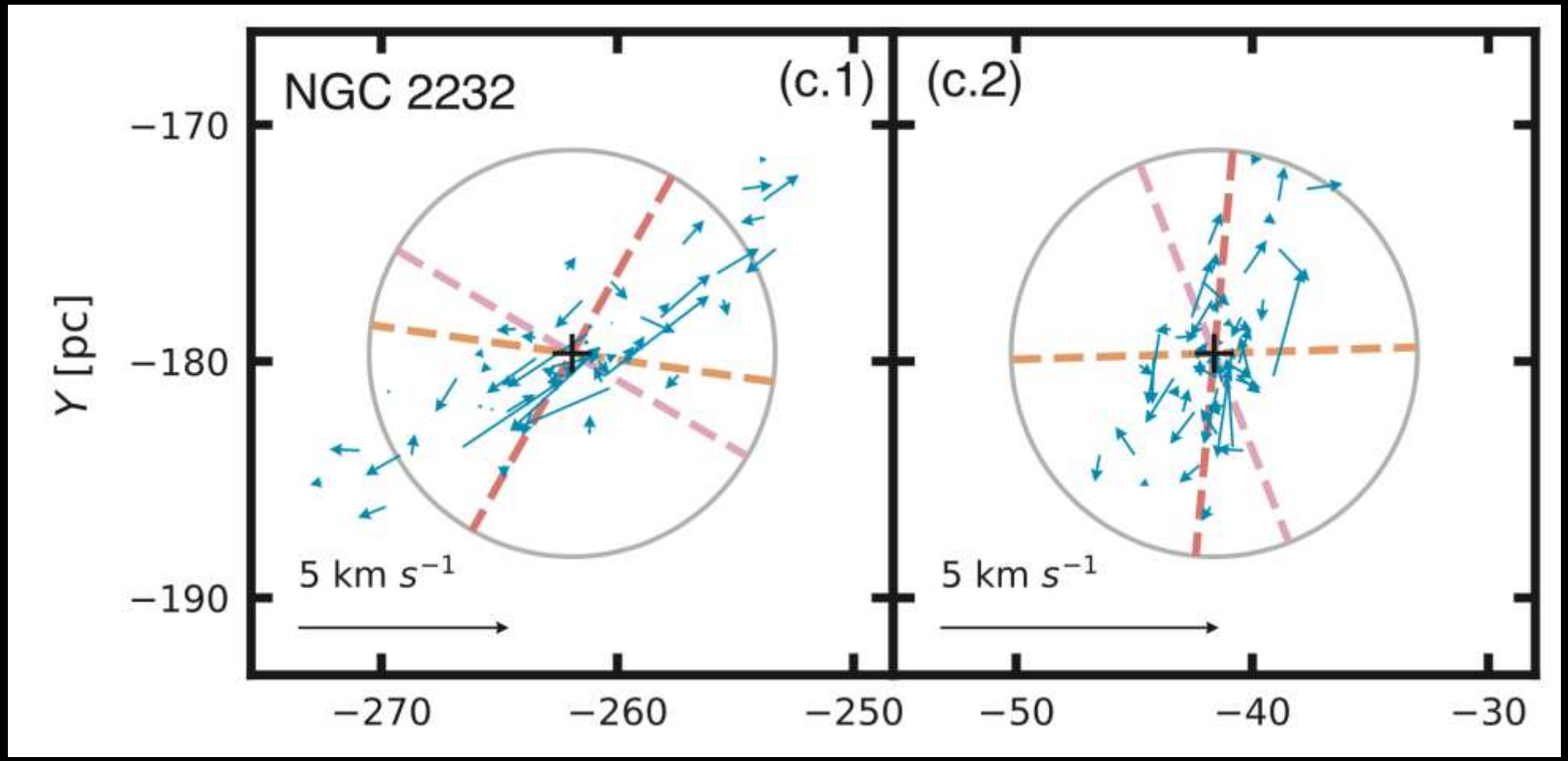
NGC 2232

Ratio close to 1

Pang et al. (2021a, ApJ, 912, 162)

Expansion

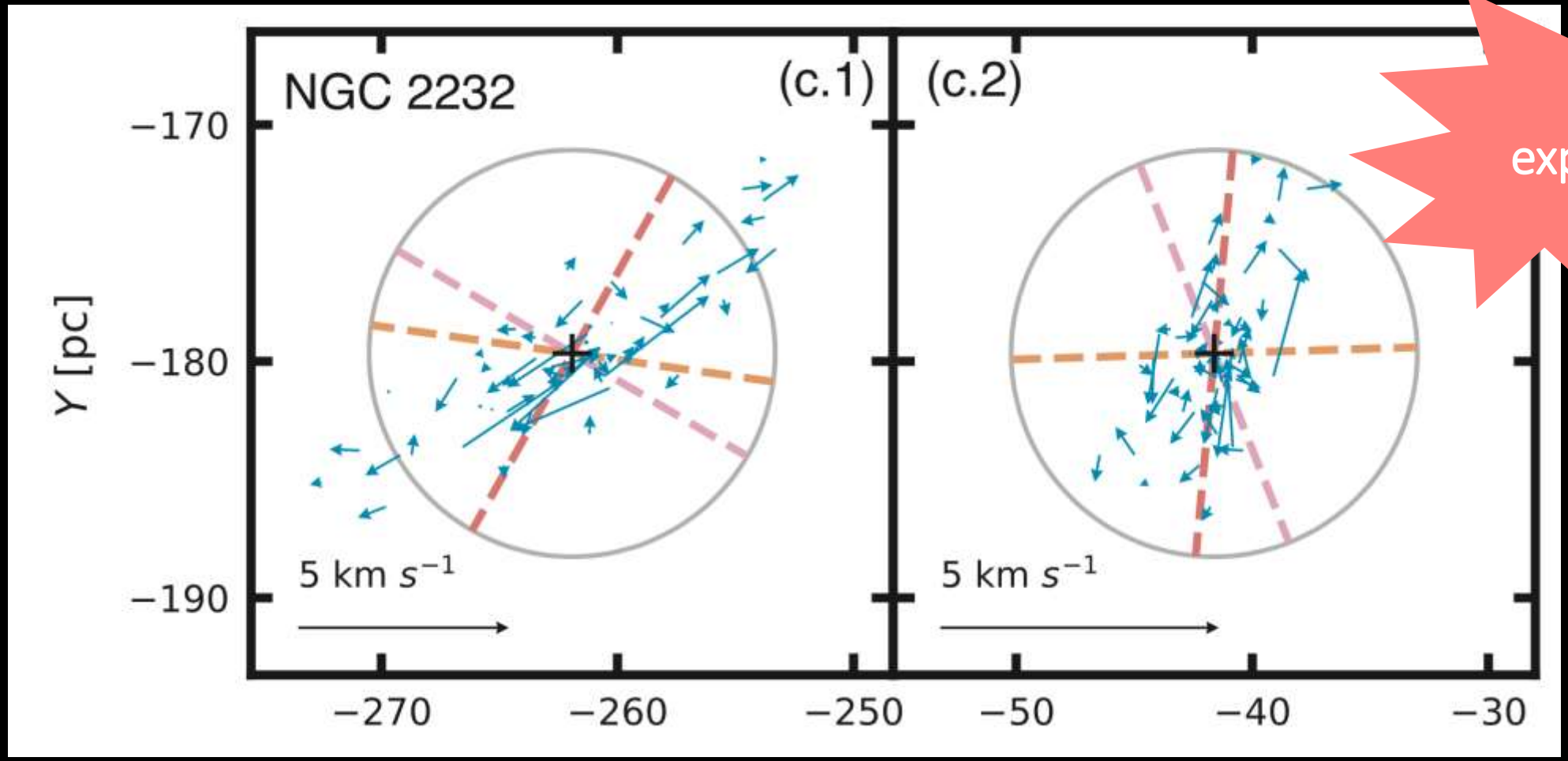
NGC 2232 (25 Myr)



Pang et al. (2021a, ApJ, 912, 162)

Expansion

NGC 2232 (25 Myr)



Gas expulsion

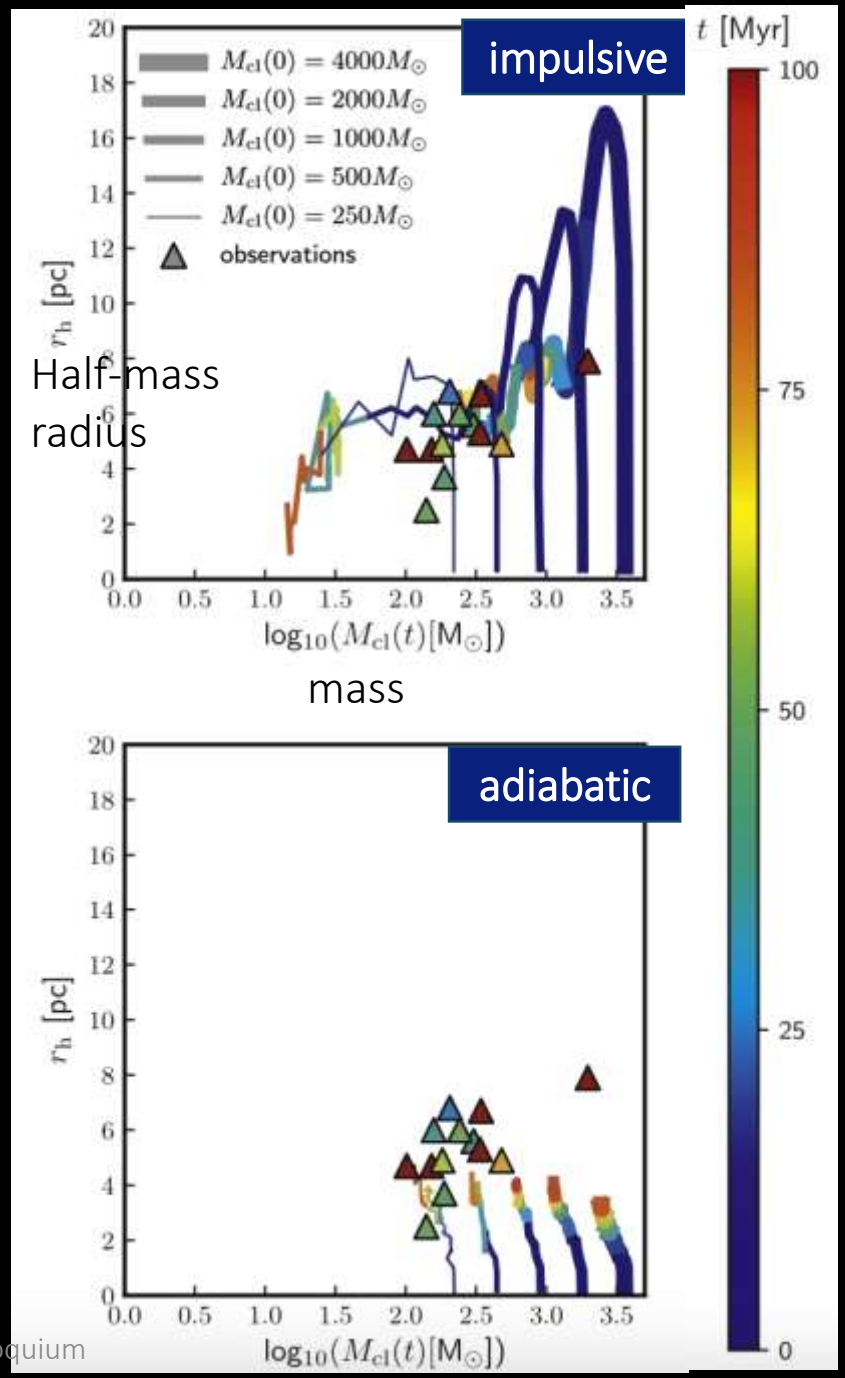
Pang et al. (2021a, ApJ, 912, 162)

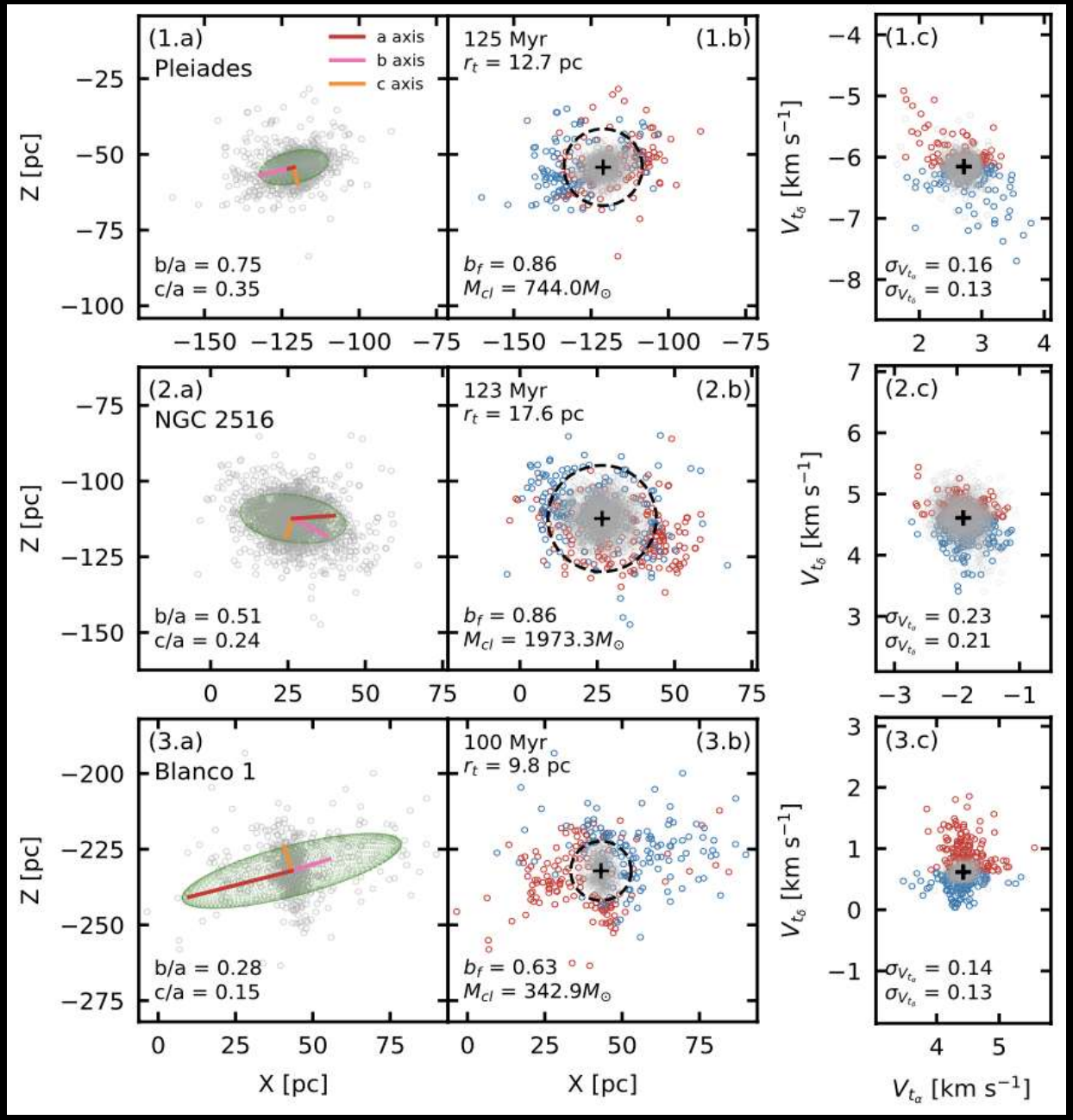
Gas expulsion

N-body models with star formation efficiency of ≈ 1/3

- Impulsive gas expulsion
  → clusters more massive than 250 $M_\odot$
- Adiabatic gas expulsion
  → clusters less massive than 250 $M_\odot$

Pang et al. (2021a, ApJ, 912, 162)





Morphology vs. Kinematics

Yezhang Li

- Blanco 1: advanced disruption with 50 pc long tidal tails.
- A correlation between the tidal tails of Blanco 1 and its kinematic tails:
- → Pleiades and NGC 2516 (early stage of disruption).

Li, Pang, & Tang (2021, RNAAS, 5, 173)

A Summary

- ✓ We find that most clusters in our samples **are expanding and supervirial**, regardless of their ages.
- ✓ **Gas expulsion** accelerate the disruption process that generate expansion in young clusters.
- ✓ **Established a quantitative method** to measure the 3D morphology and dynamical state of star clusters.

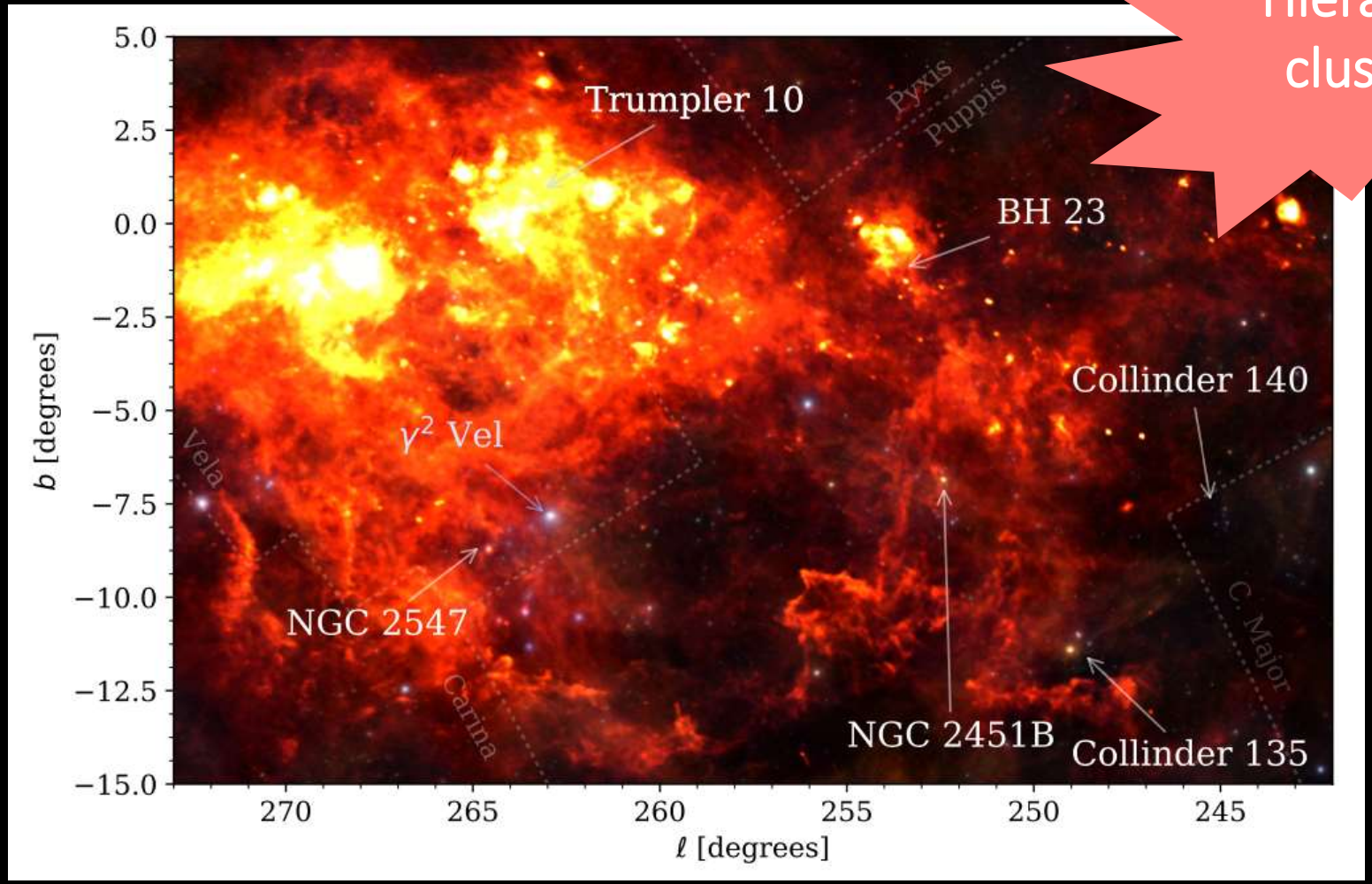
More cluster samples are being reduced for statistical analysis.

06

Hierarchical clustering in stellar complex

arXiv:2106.07658

Vela OB2 complex



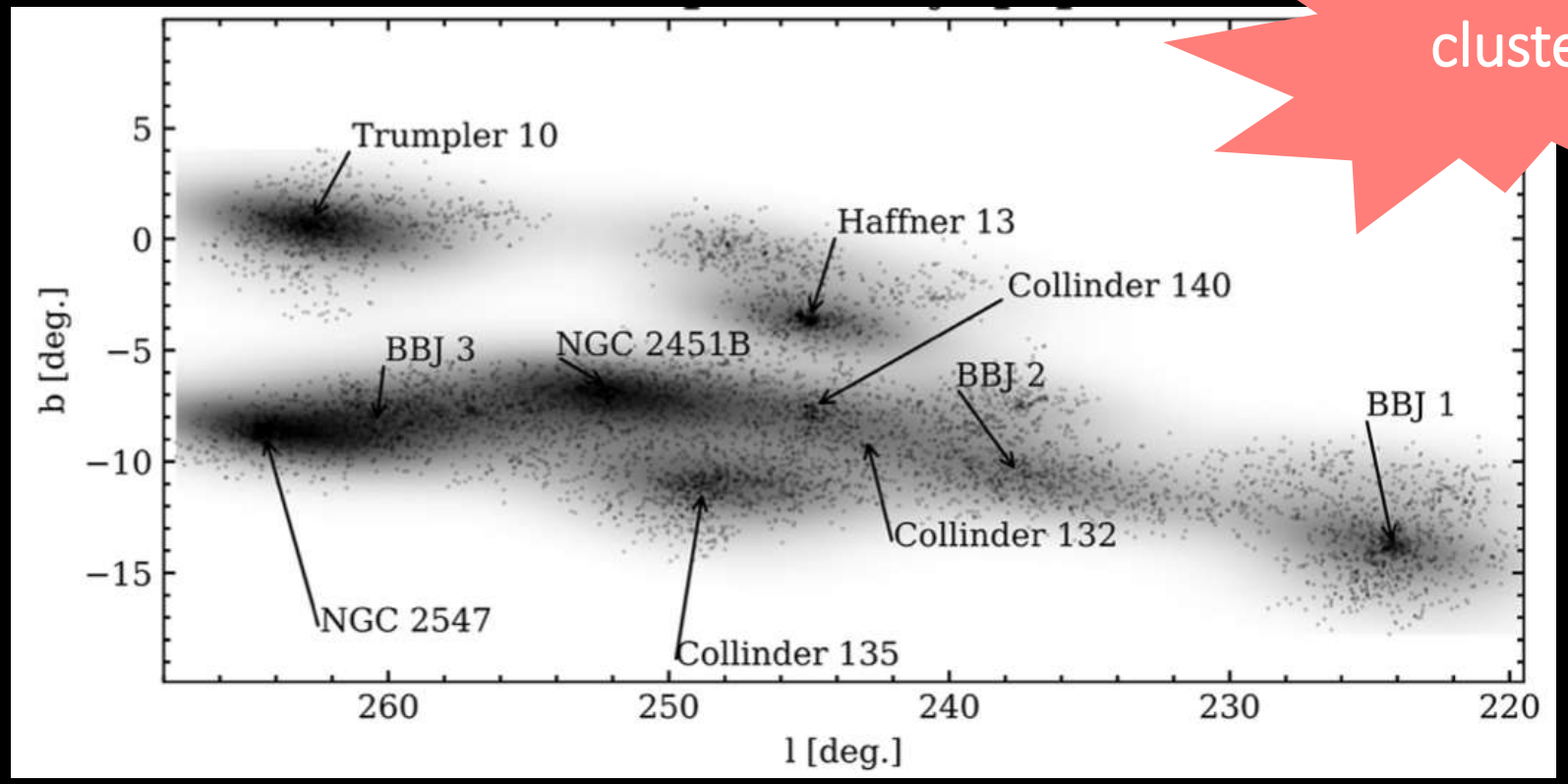
Hierarchical clustering

- several OB associations and a few young clusters
- star formation process
  - a few to a dozen million years

IRIS 60 μm image (Miville-Deschênes & Lagache 20

Stellar complex

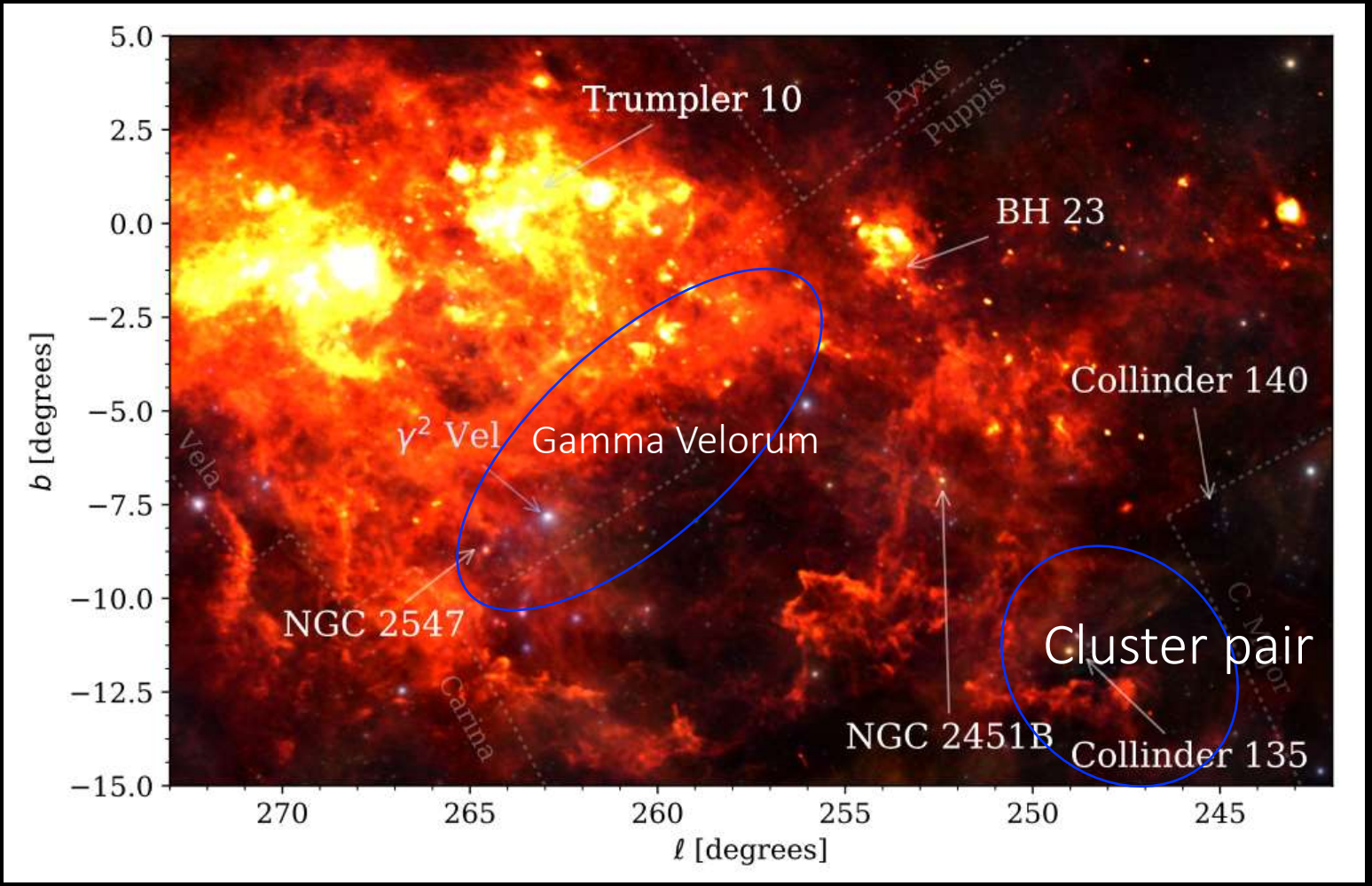
Hierarchical clustering



Beccari et al. (2019)

- several OB associations and a few young clusters
- star formation process
  - a few to a dozen million years

Vela OB2 complex

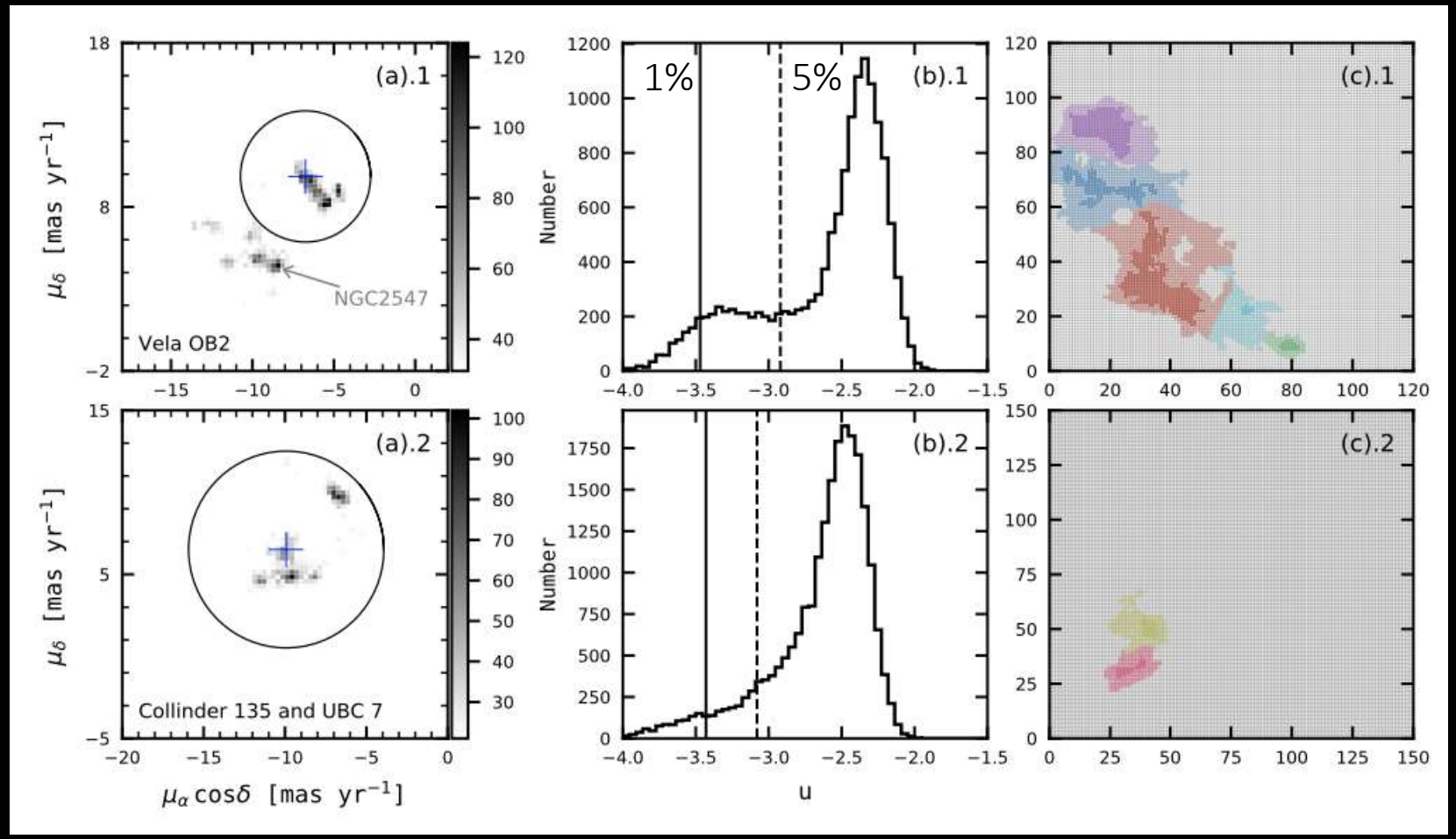


IRIS 60 μm image (Miville-Deschênes & Lagache 20

- Targets:
  - Gamma Velorum cluster in Vela OB2
  - Cluster pair
- Motivation:
  - Identify spatially and kinematically coherent cluster groups

Disentanglement

arXiv:2106.07658

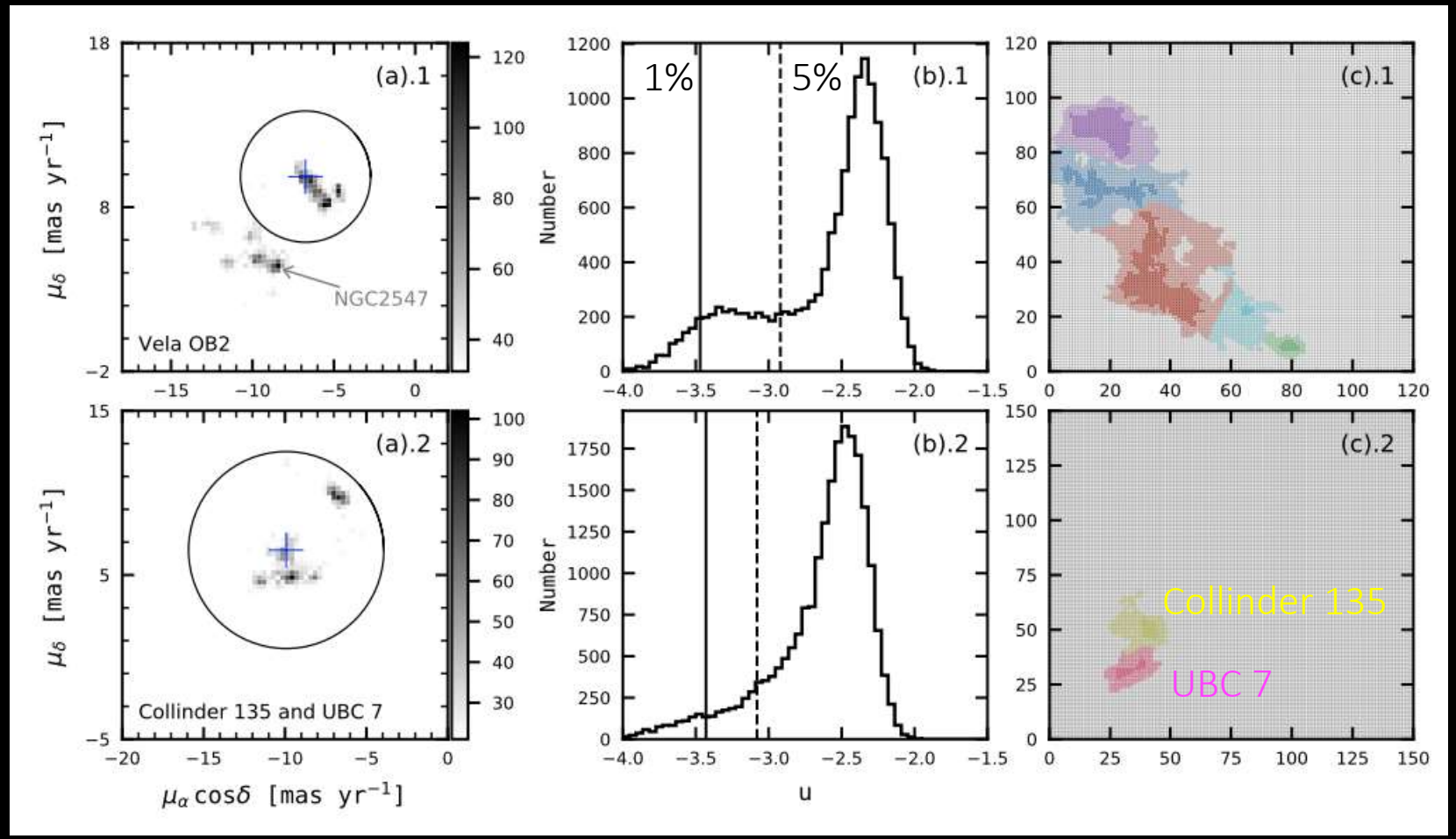


- Top-down method
- Transparent color patch as a whole → top-level structure (5% contamination rate).
- Vela OB2
- Cluster pair: Collinder 135 and UBC 7

Pang et al. (2021b, arXiv:2106.07658)

Stellar complex

arXiv:2106.07658



- Vela OB2: 5 second-level subtructures
- Cluster pair: Collinder 135 and UBC 7

Pang et al. (2021b, arXiv:2106.07658)

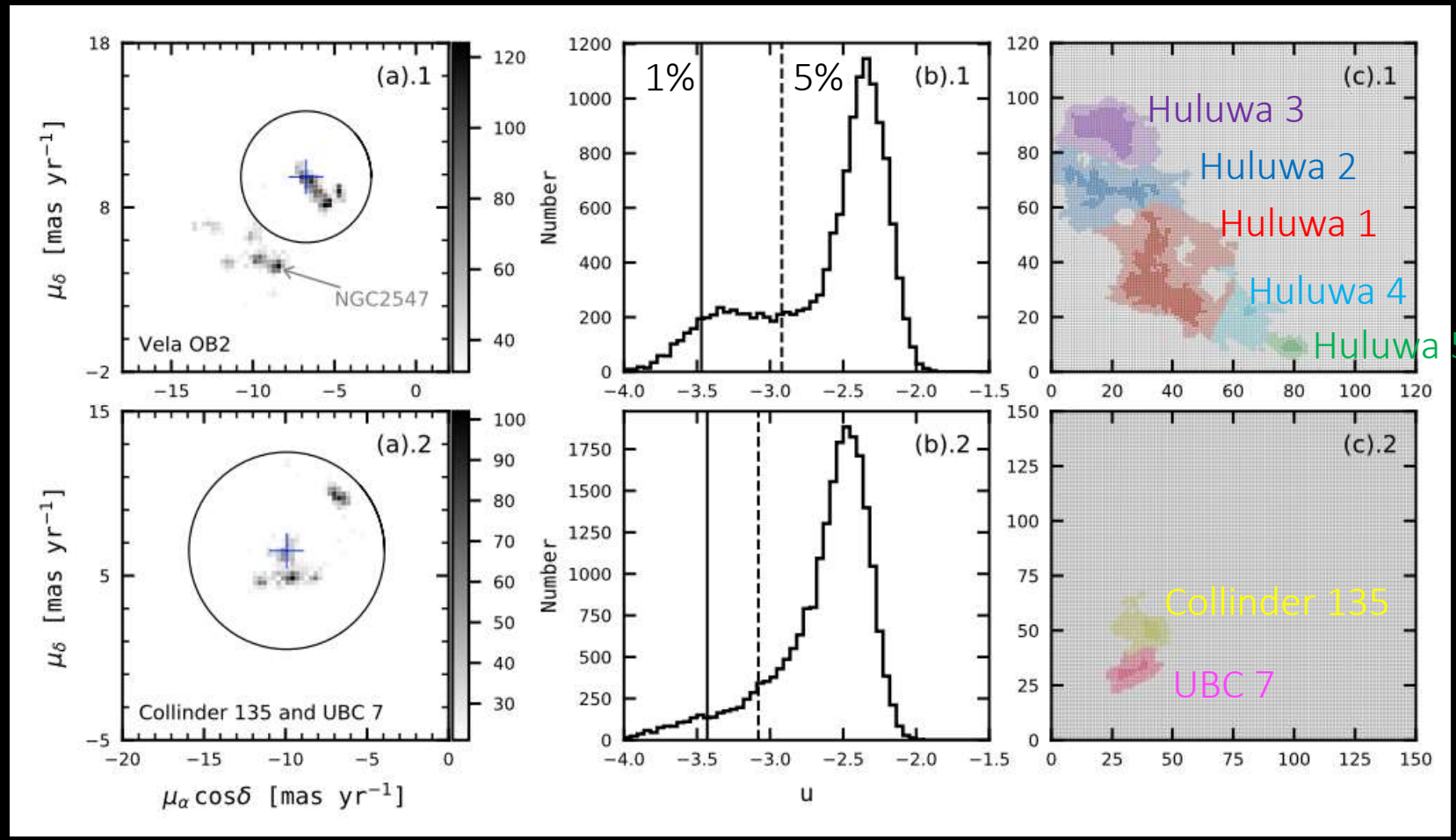
Huluwa (Calabash brothers)
葫芦娃

A famous Chinese animation in 1980s.

The Calabashes sequentially fall off from the same stem, and transform into seven boys.

Stellar complex

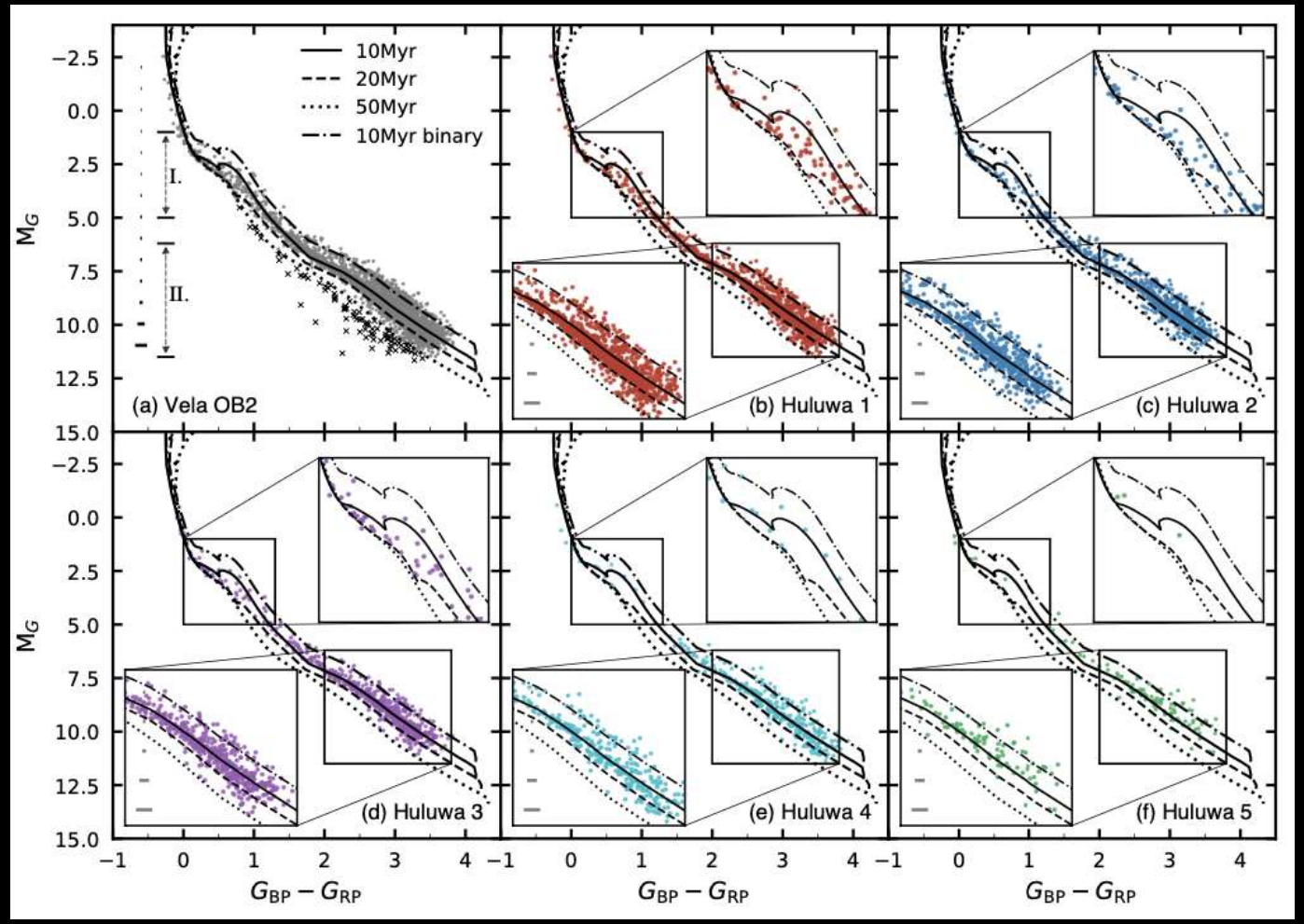
arXiv:2106.07658



- Vela OB2: 5 second-level subtructures
- Cluster pair: Collinder 135 and UBC 7 (members identified within two clusters at the first time)

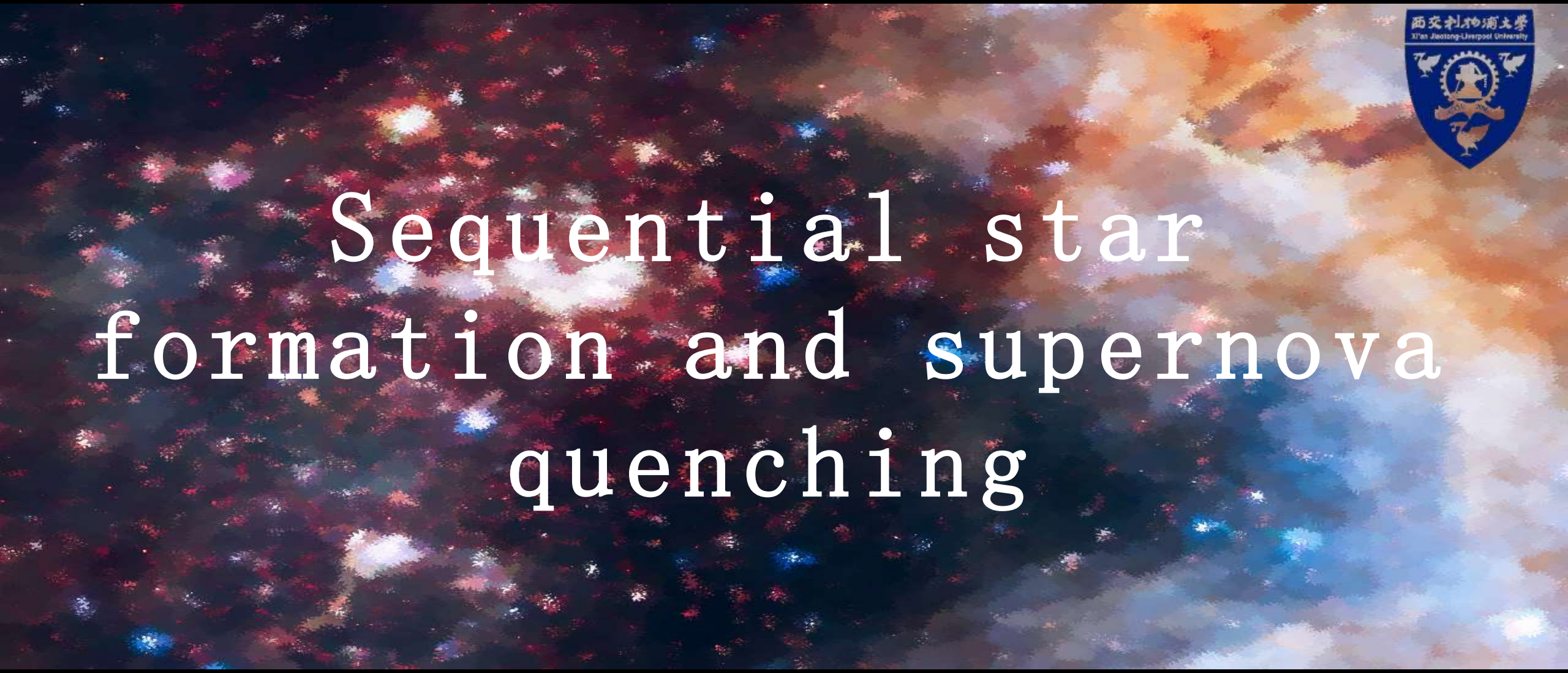
Pang et al. (2021b, arXiv:2106.07658)

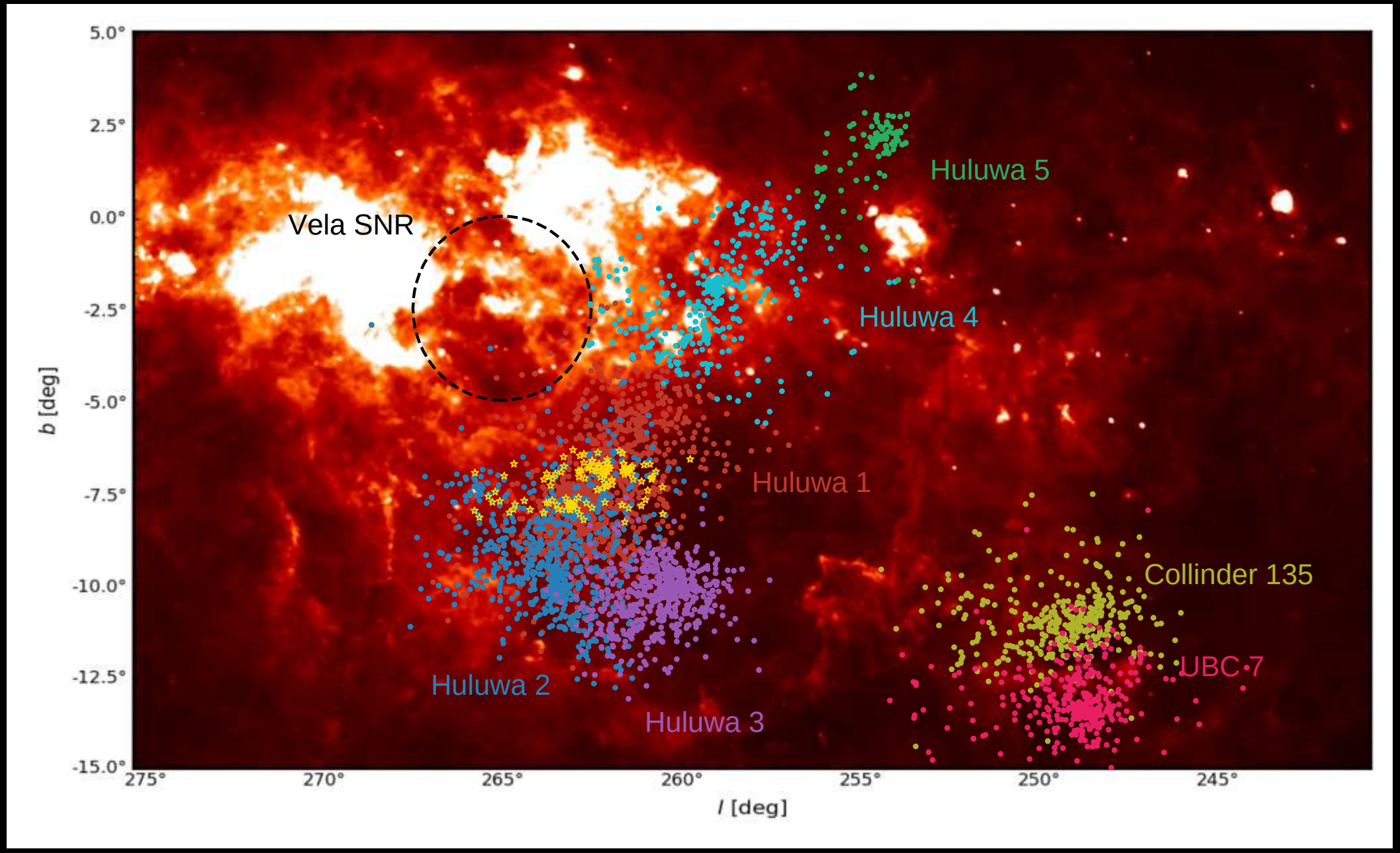
Color magnitude diagram



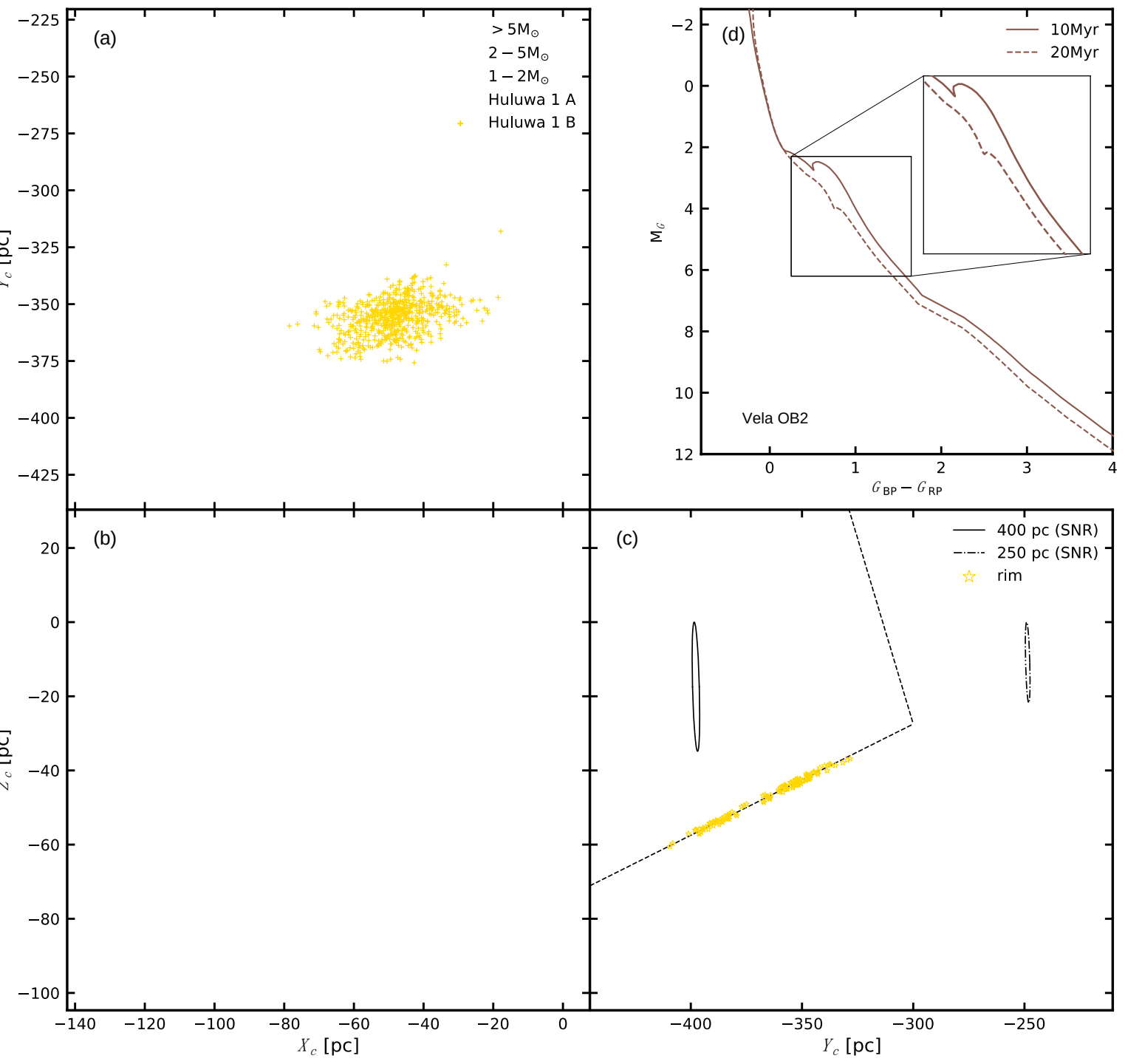
- Huluwa 1-3: 10-20 Myr (older generation)
- Huluwa 4-5: 10 Myr (younger generation)

Pang et al. (2021b, arXiv:2106.07658)

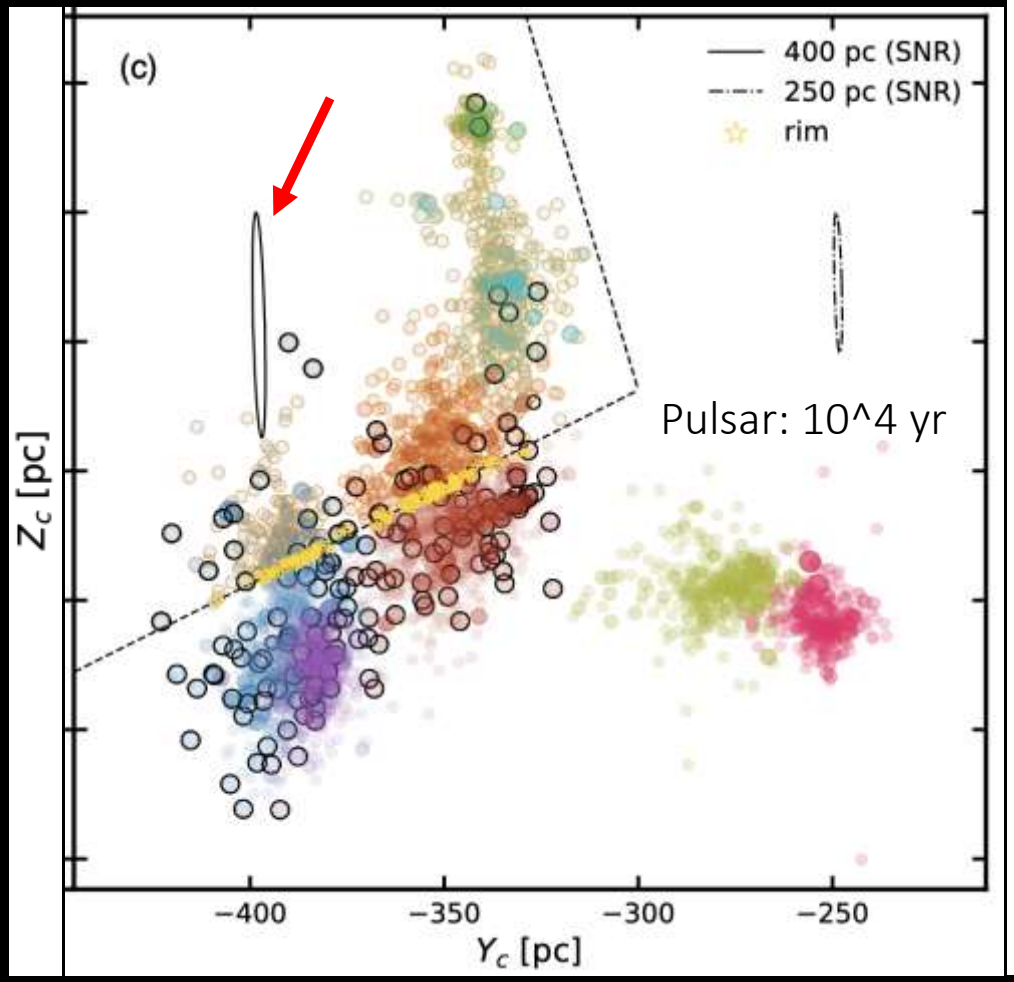

Sequential star formation and supernova quenching

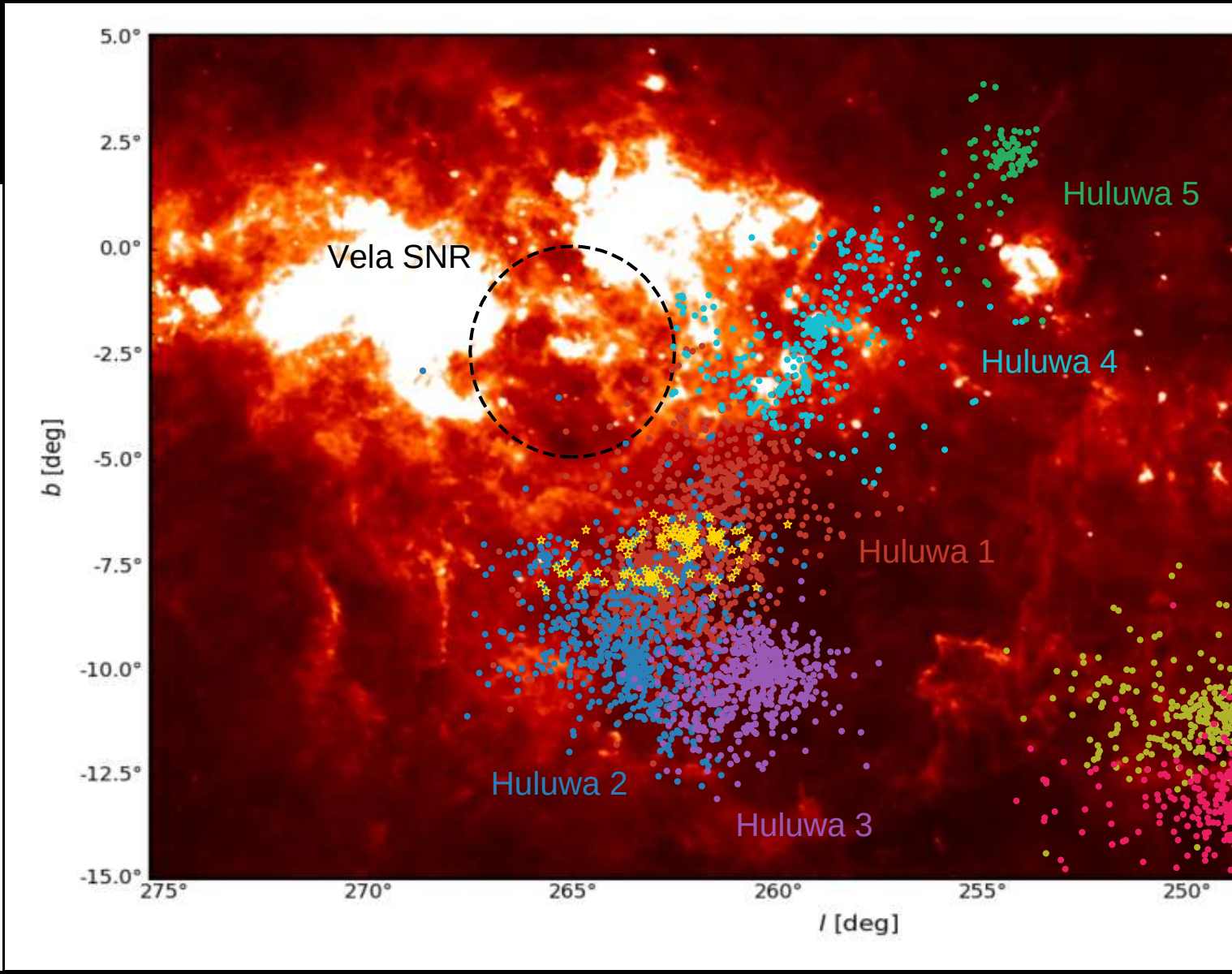


Pang et al. (2021b, arXiv:2106.07658)

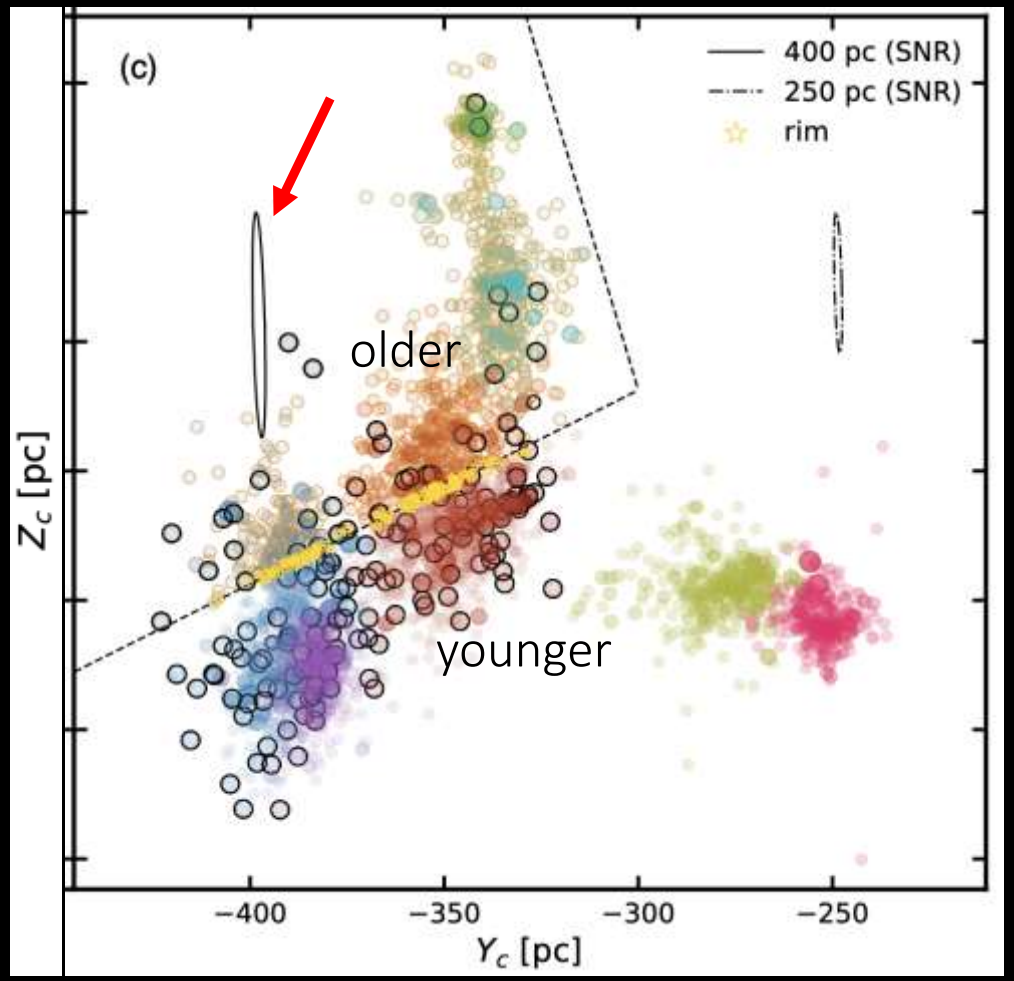


Pang et al. (2021b, arXiv:2106.07658)



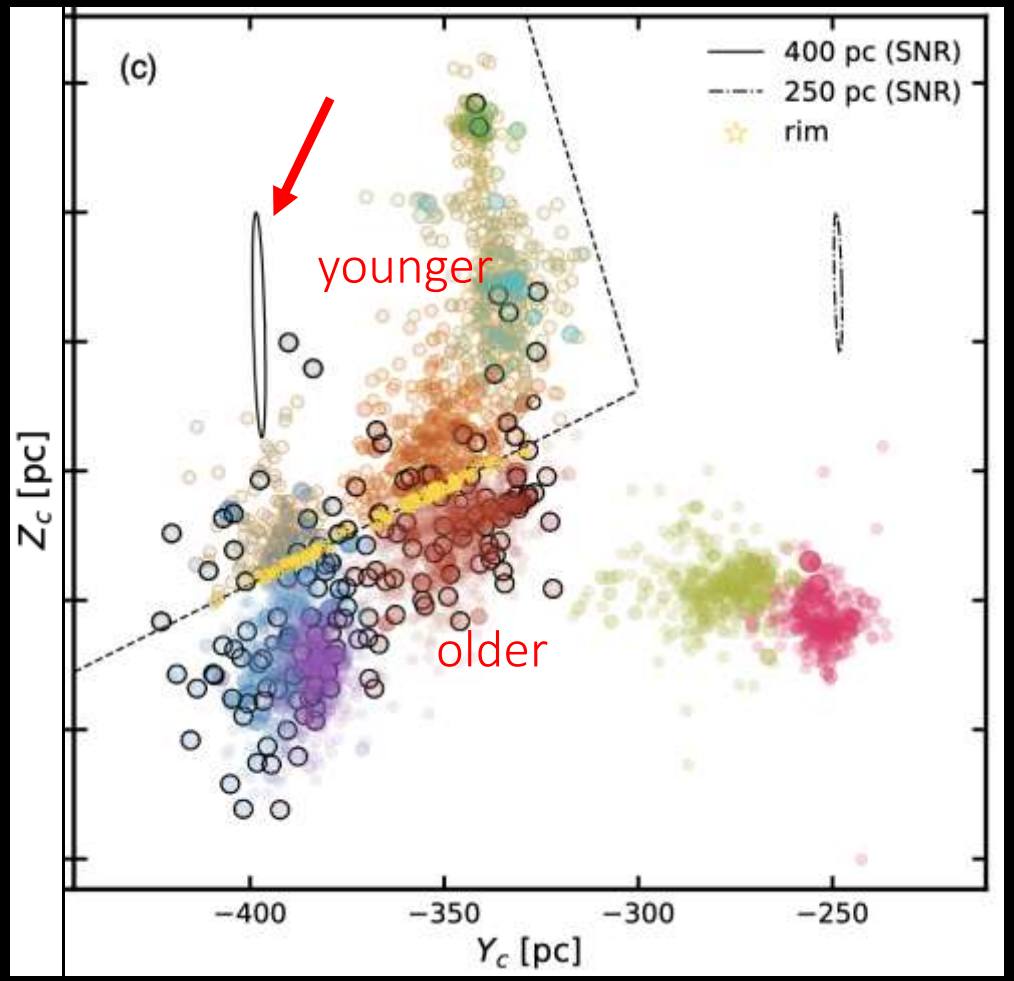


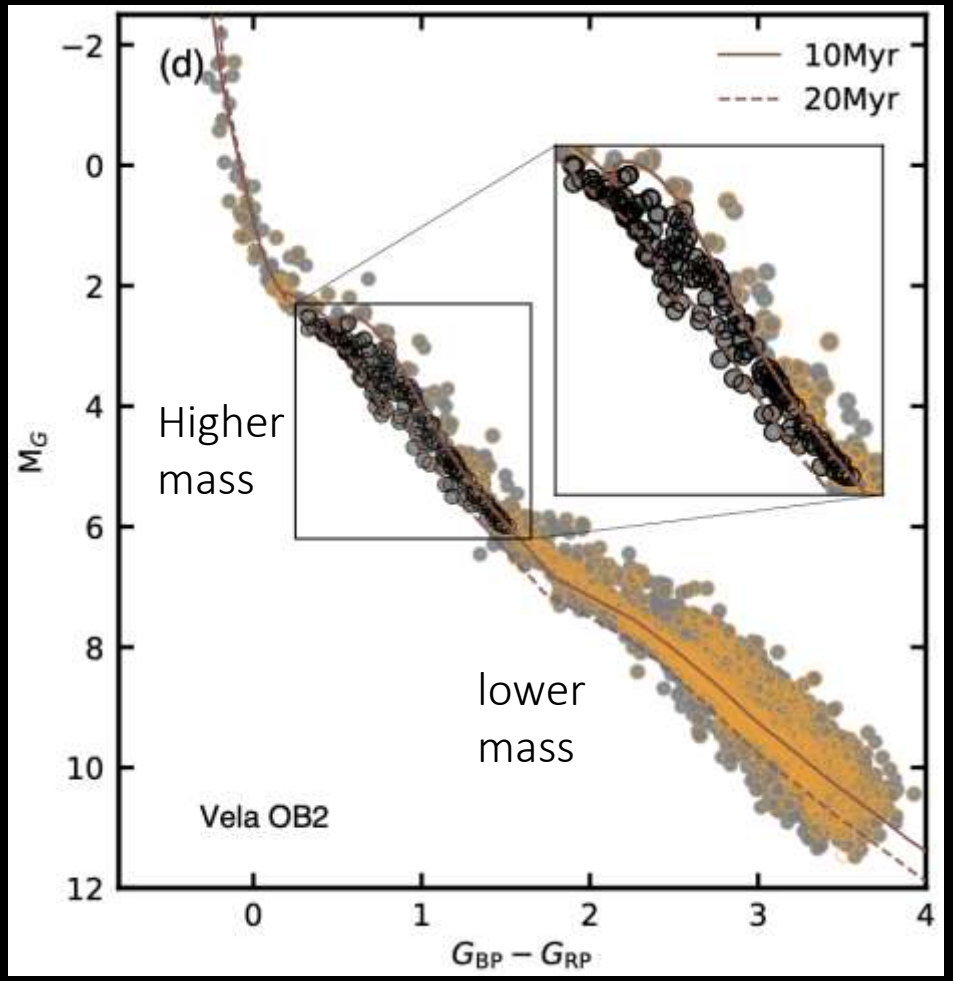
Pang et al. (2021b, arXiv:2106.07658)



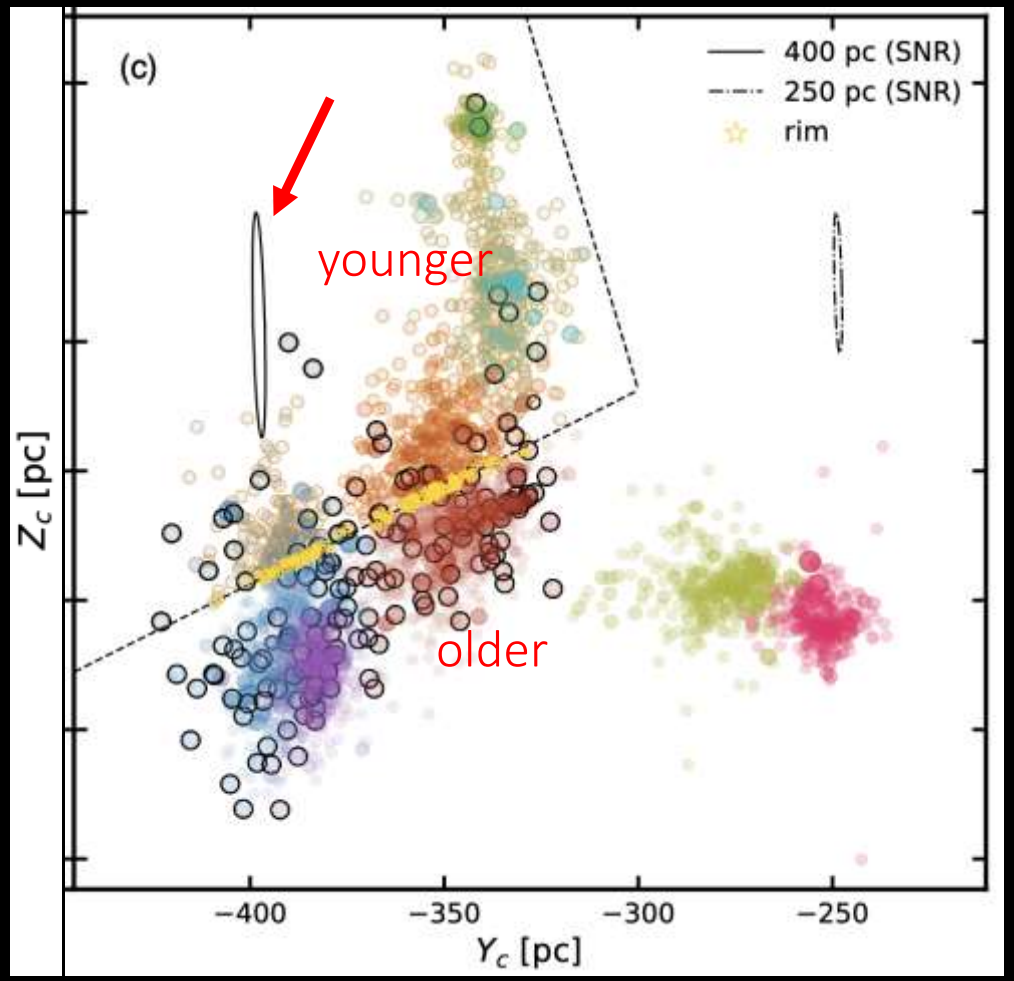
- Supernova triggered star formation (Cantat Gaudin et al. 2019)
- Younger generation in the outer shell and older generation in the inner shell.

Pang et al. (2021b, arXiv:2106.07658)



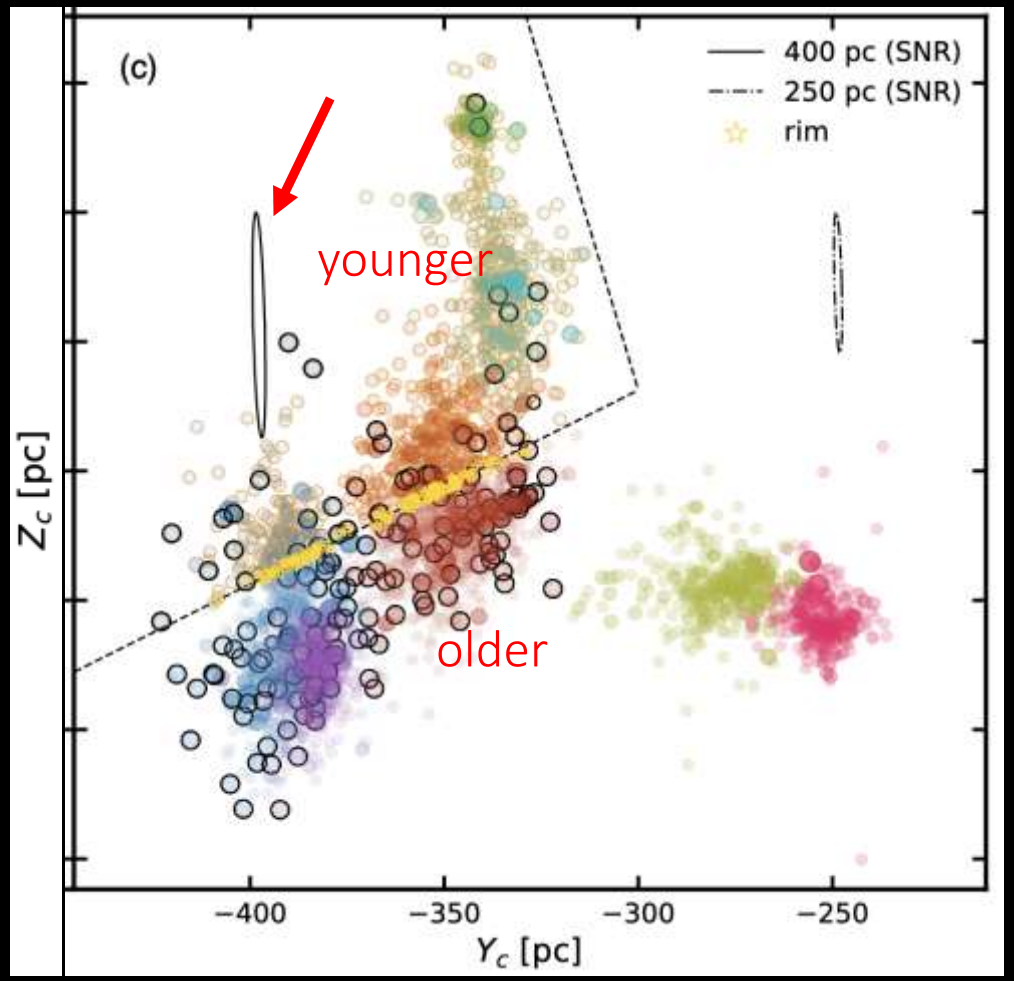


Pang et al. (2021b, arXiv:2106.07658)



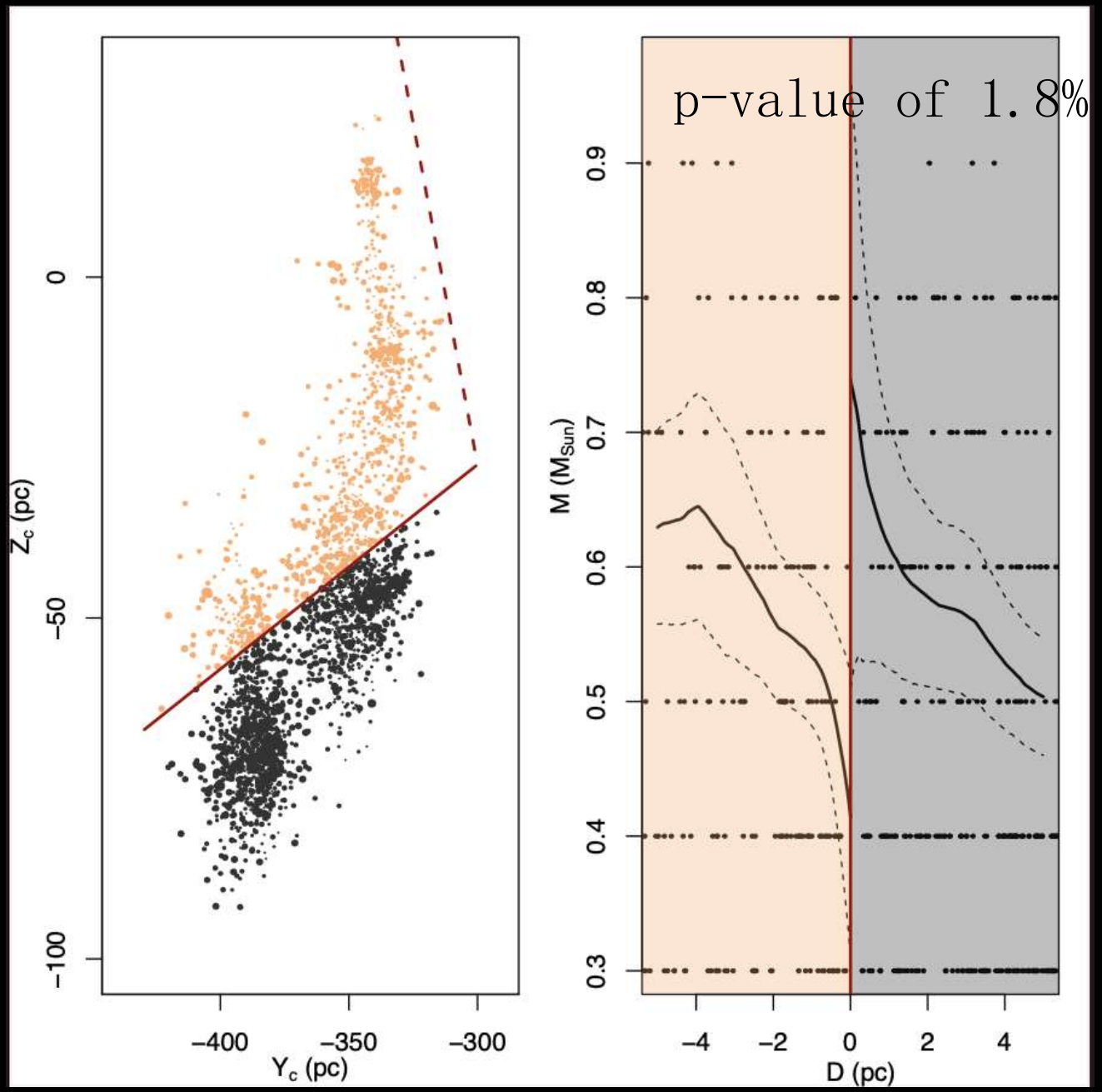
- Inconsistent with the scenario of Supernova triggered star formation (Cantat Gaudin et al. 2019)

Pang et al. (2021b, arXiv:2106.07658)

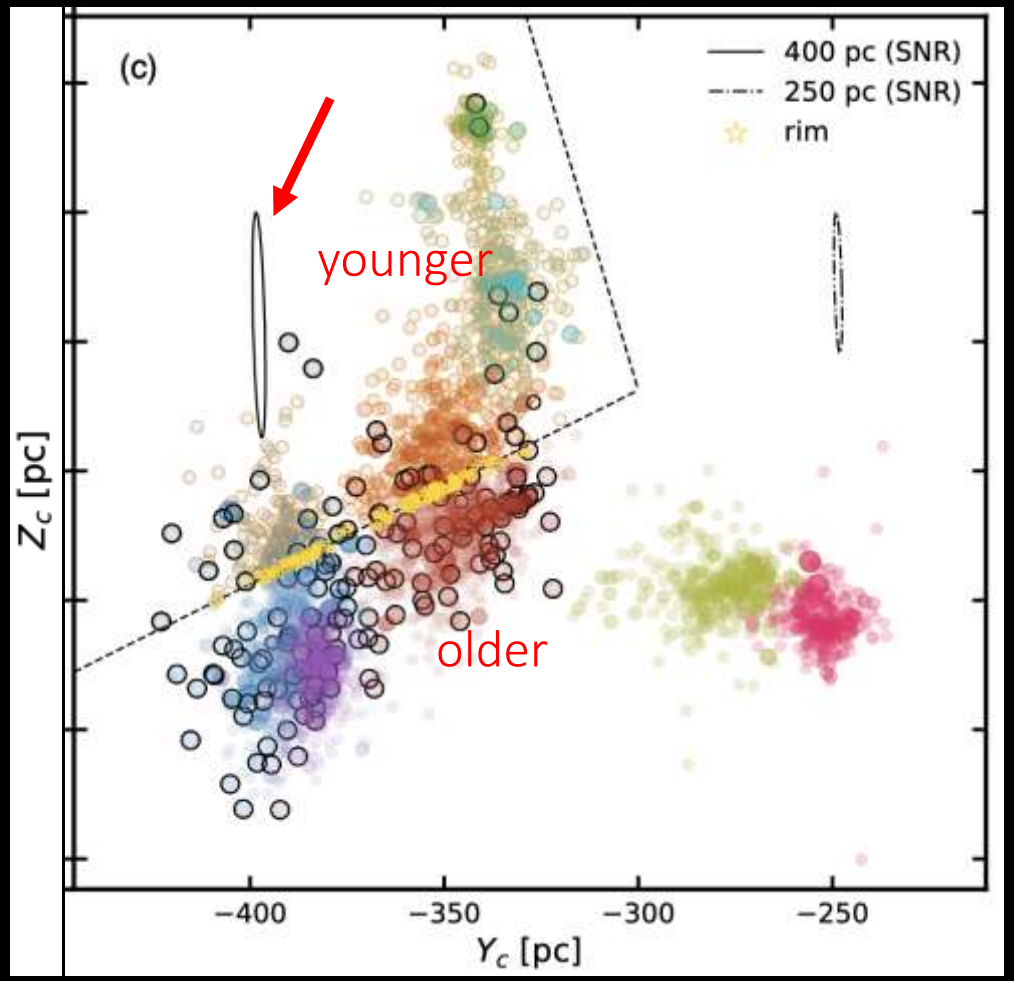


- Mass stratification
  - Lower-mass stars in the front shell region facing the supernova.
  - Higher-mass stars in the back shell.

Pang et al. (2021b, arXiv:2106.07658)

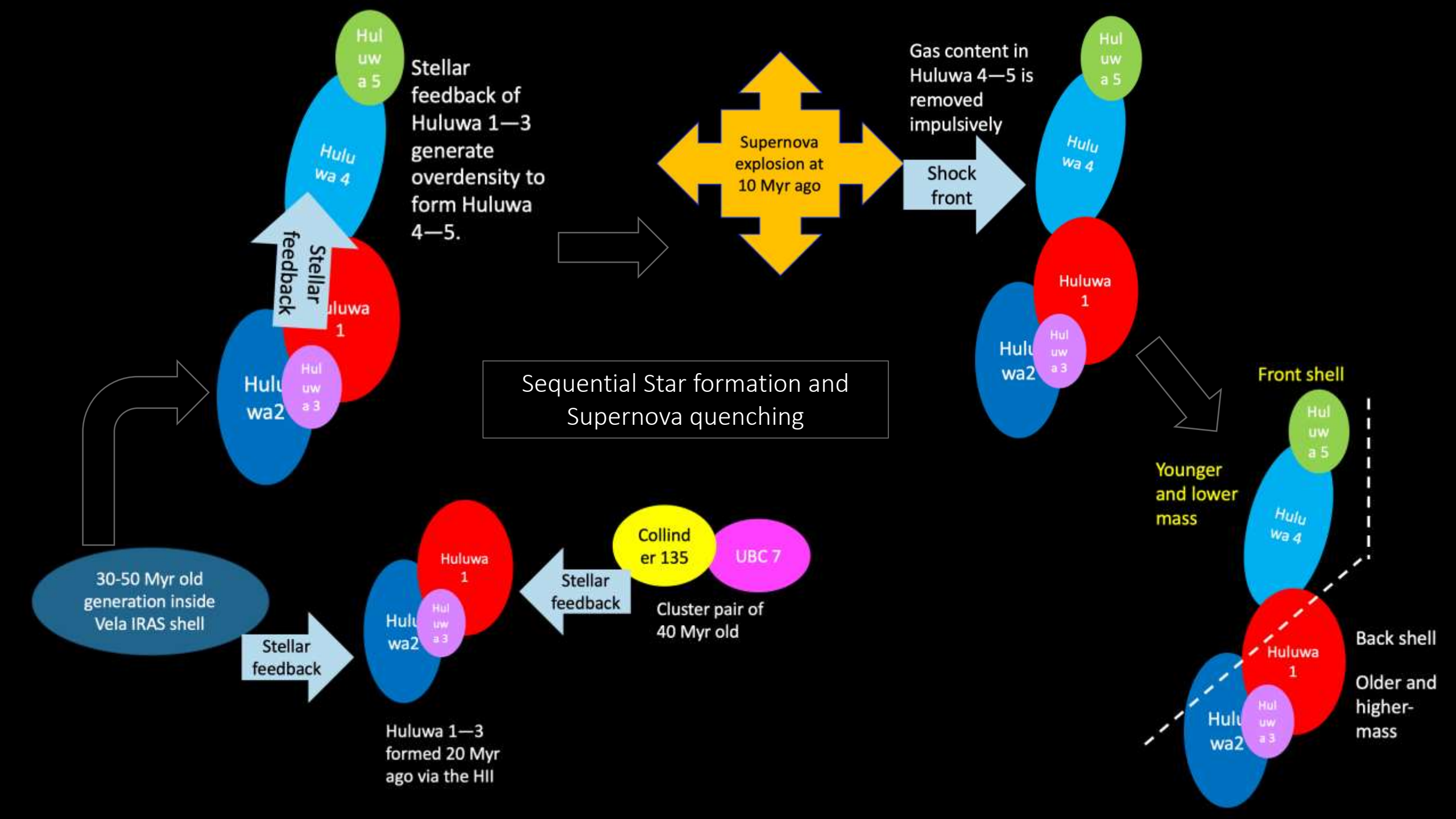


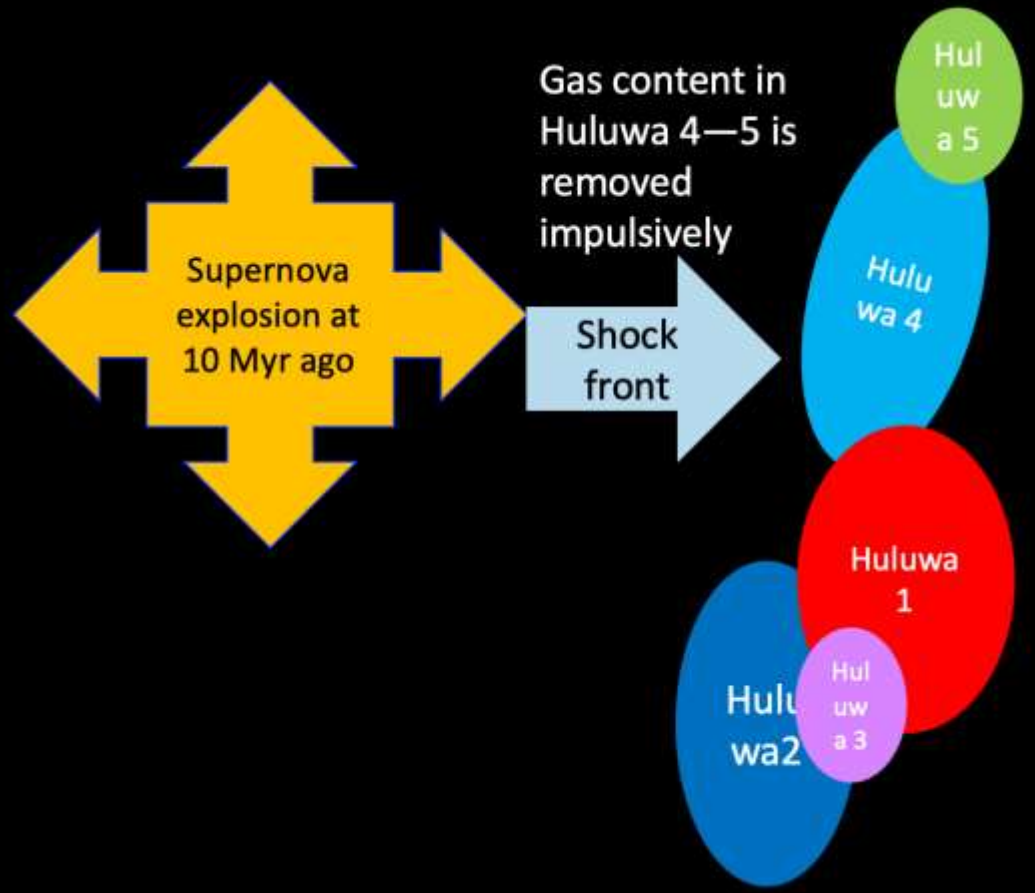
- Mass stratification
  - **Regression discontinuity estimation**
  - Estimate the probability of the proposed cause effect: the masses of stars on either side of the shell should differ only due to the influence of the supernova explosion.



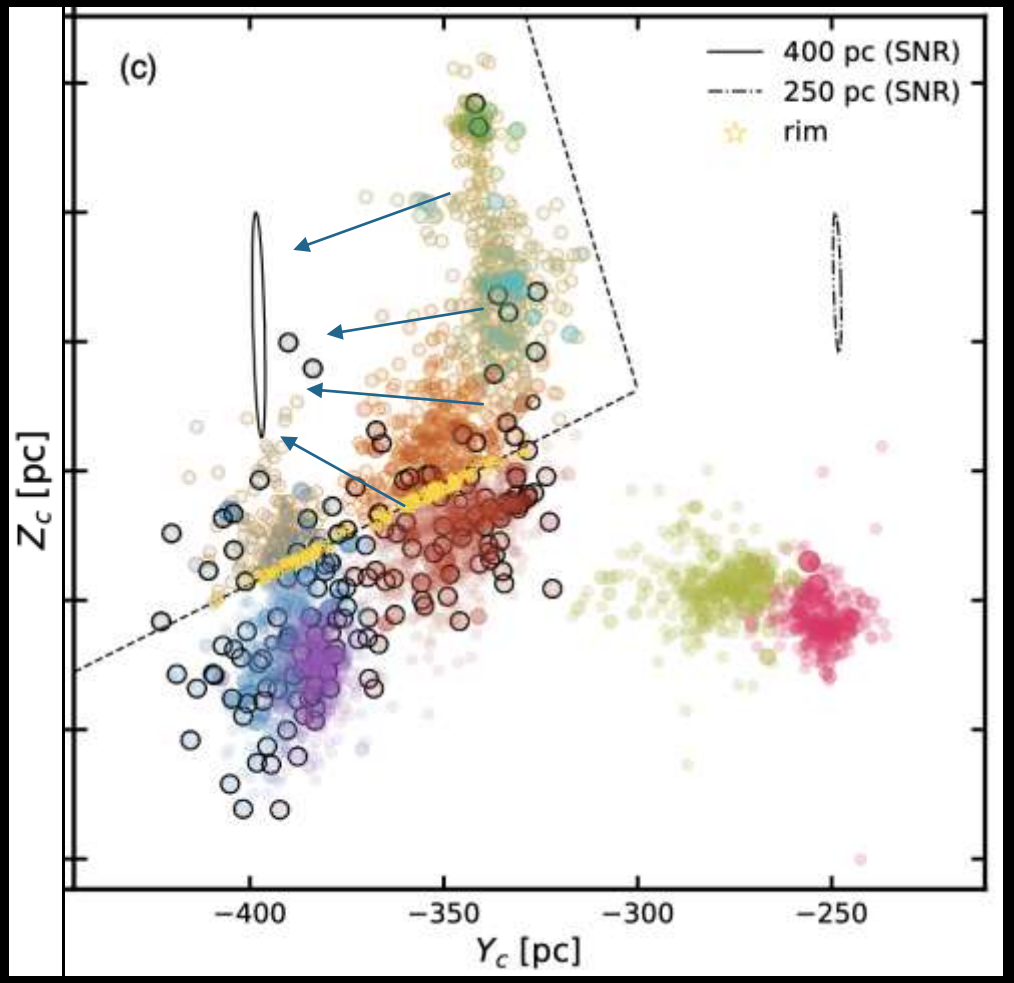
- Mass and age stratification cross the shell
  - Younger and lower-mass stars in the front shell region facing the supernova.
  - Older and higher-mass stars in the back shell.

Pang et al. (2021b, arXiv:2106.07658)

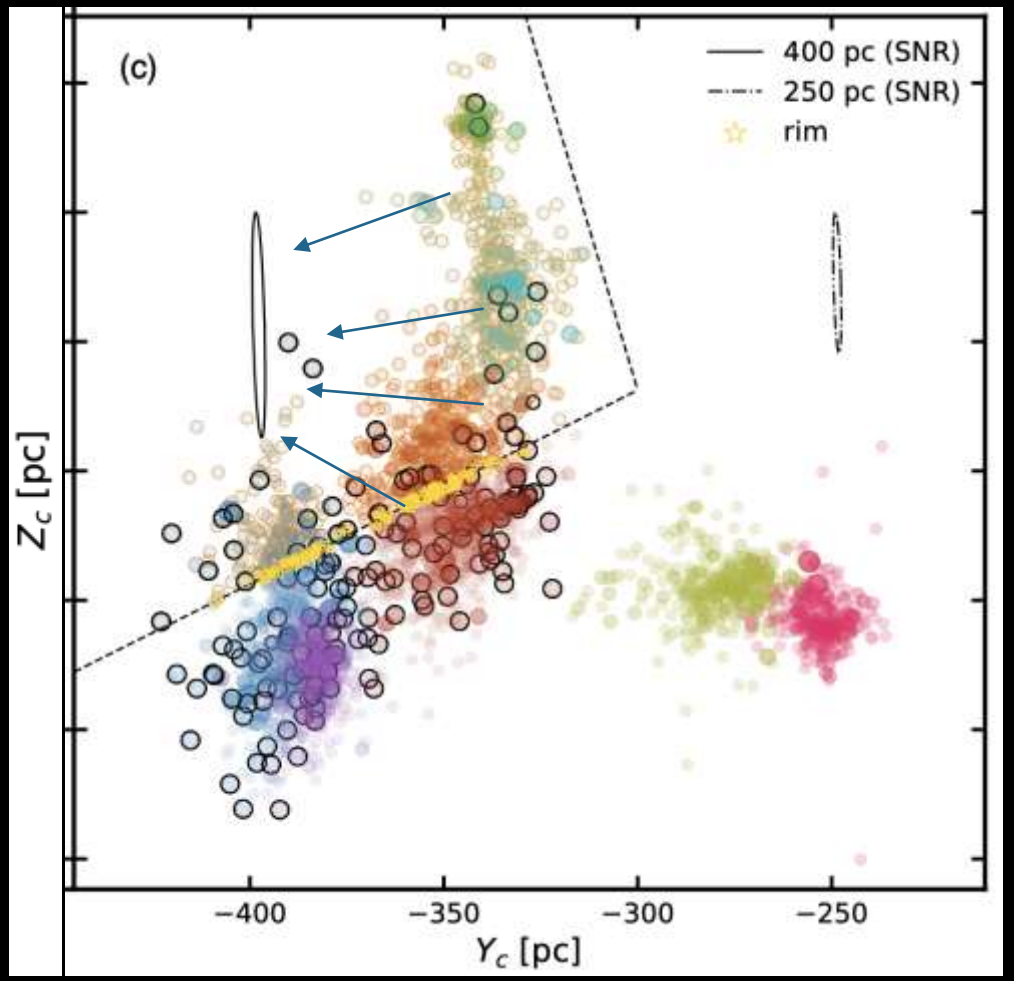

Hul uw a 5
Hulu wa 4
Huluwa 1
Hul uw a 3
Hulu wa2
Stellar feedback of Huluwa 1—3 generate overdensity to form Huluwa 4—5.
Stellar feedback
Supernova explosion at 10 Myr ago
Gas content in Huluwa 4—5 is removed impulsively
Shock front
Sequential Star formation and Supernova quenching
Front shell
Younger and lower mass
Back shell
Older and higher-mass
30-50 Myr old generation inside Vela IRAS shell
Stellar feedback
Collinder 135
UBC 7
Cluster pair of 40 Myr old
Stellar feedback
Huluwa 1—3 formed 20 Myr ago via the HII



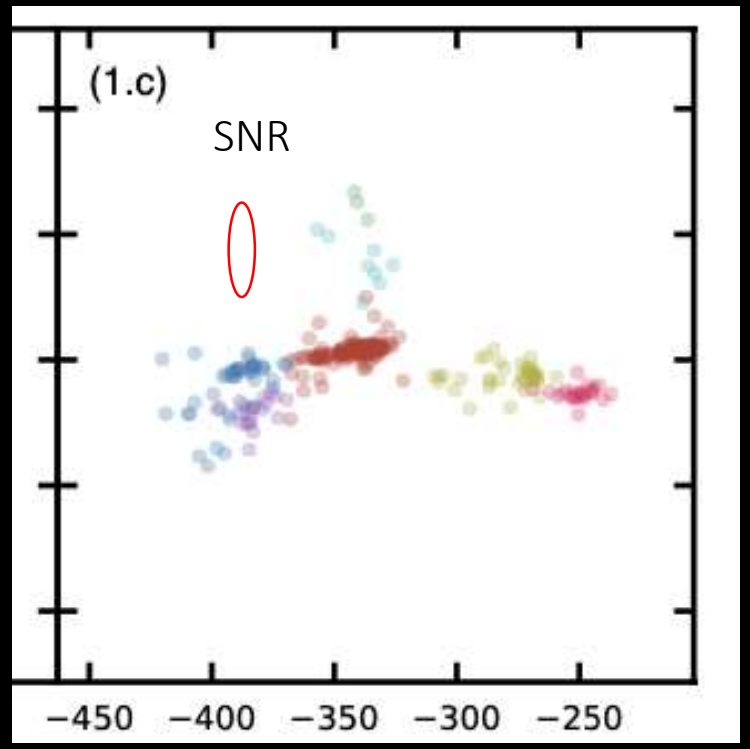
- Trace back star to past 10 Myr
- The motions of stars follow the motion of gas in which they are formed.
  - 3D velocity within 1 sigma
  - Assume linear motions



- Trace back star to past 10 Myr
  - 3D velocity within 1 sigma
  - Assume linear motions



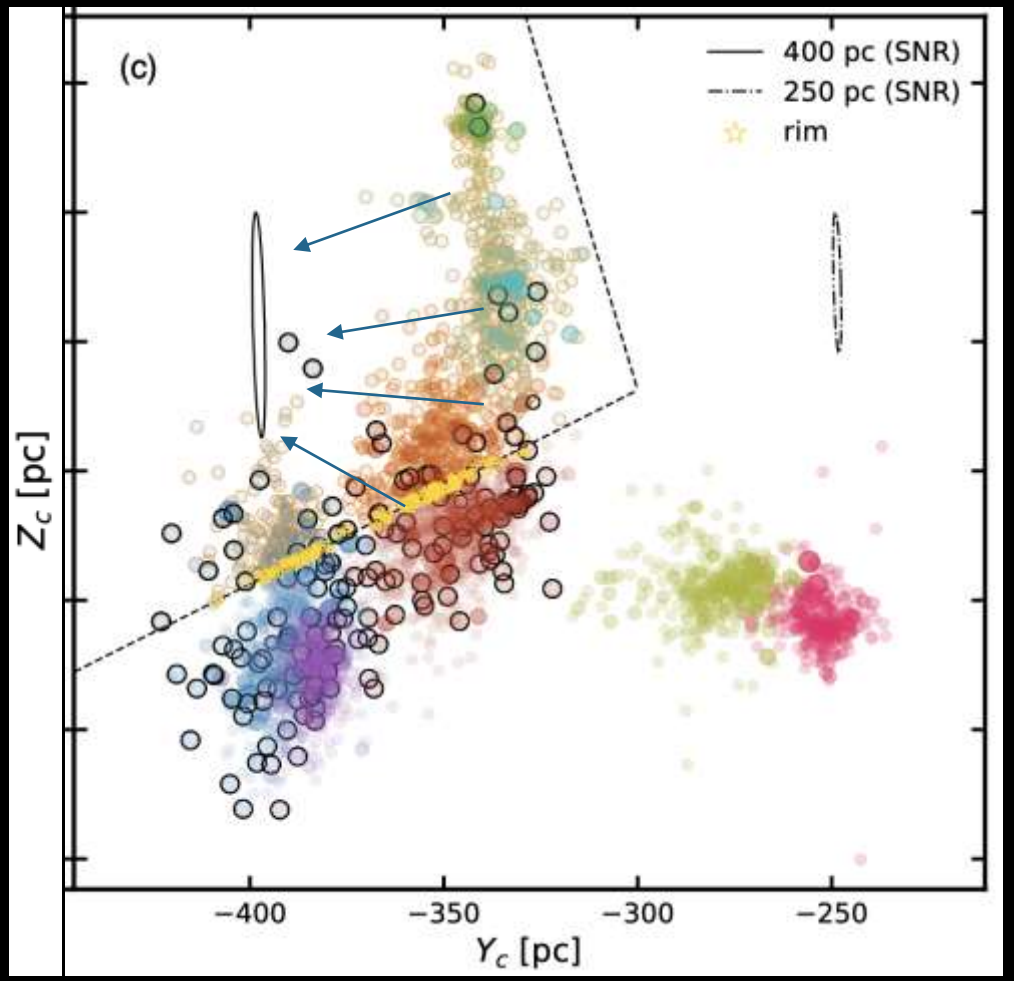
- Trace back star to past 10 Myr
  - 3D velocity within 1 sigma
  - Assume linear motions



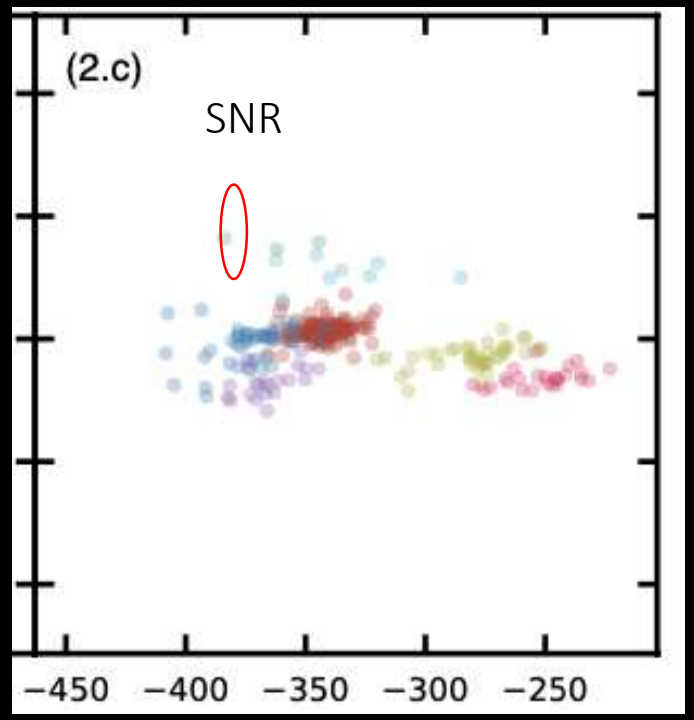
Zc (pc)

Yc (pc)

Present



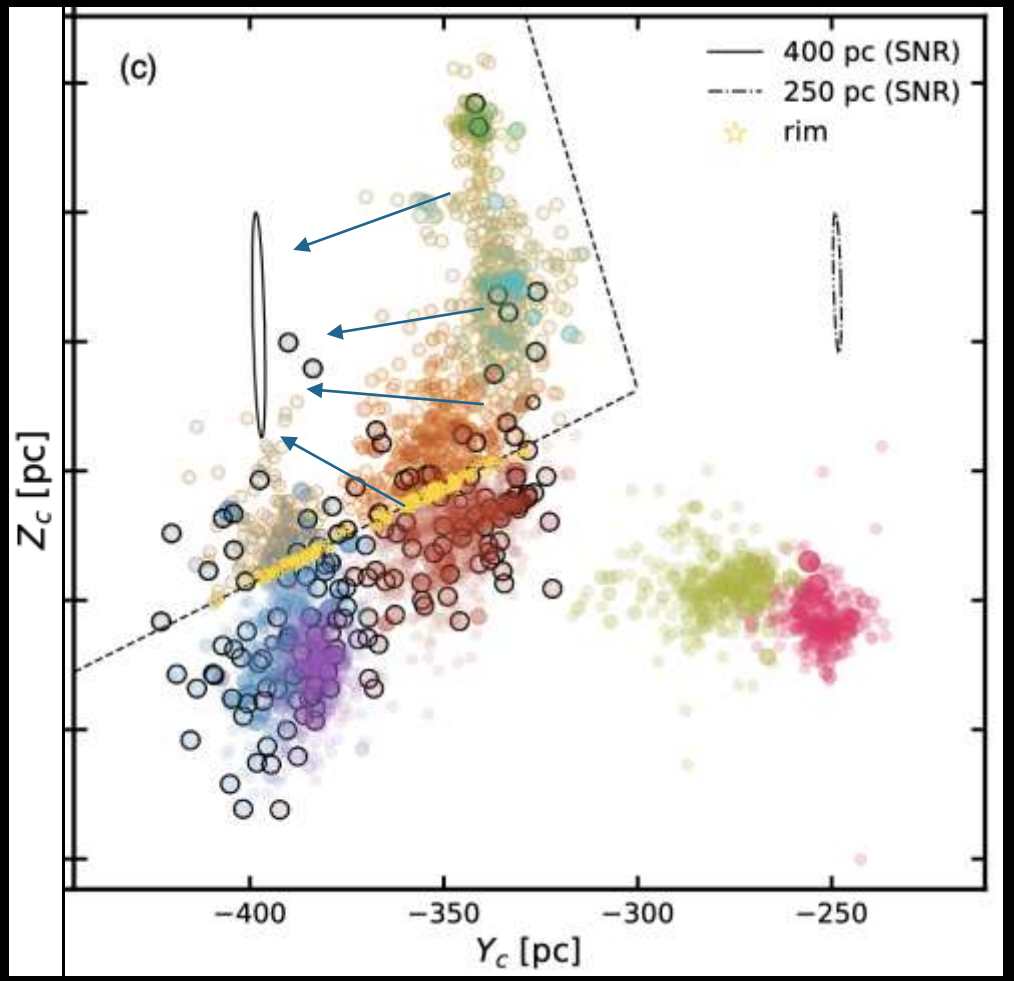
- Trace back star to past 10 Myr
  - 3D velocity within 1 sigma
  - Assume linear motions



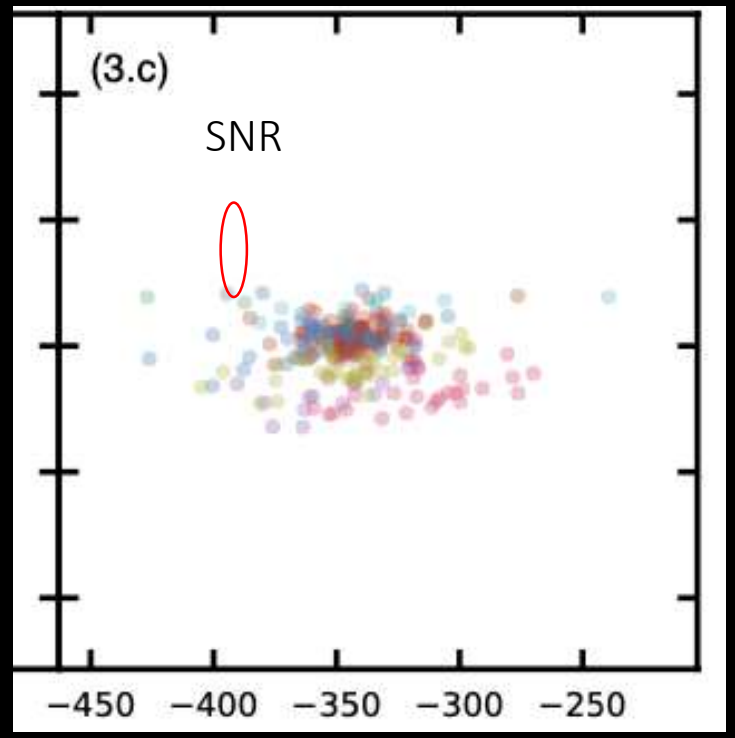
Zc (pc)

Yc (pc)

-5 Myr



- Trace back star to past 10 Myr
  - 3D velocity within 1 sigma
  - Assume linear motions



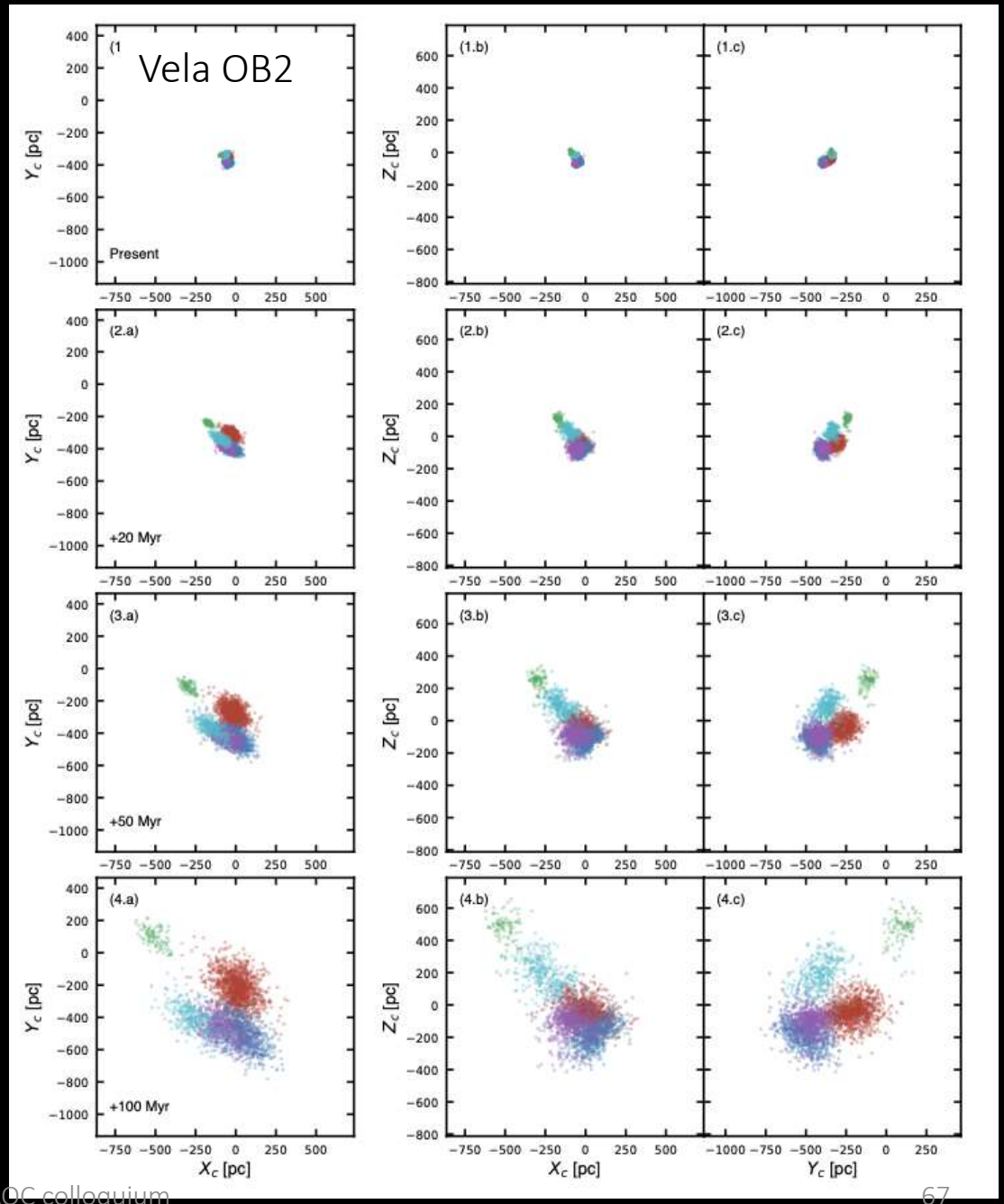
Zc (pc)

Yc (pc)

-10 Myr

Disruption

- NBODY simulations
  - Current observed XYZ positions
  - 3D velocity
    - Proper motions (PM)
    - Assumed gaussian distribution for radial velocity and adopt the dispersion （1，1/2， 2） of PM.



Disruption

- NBODY simulations
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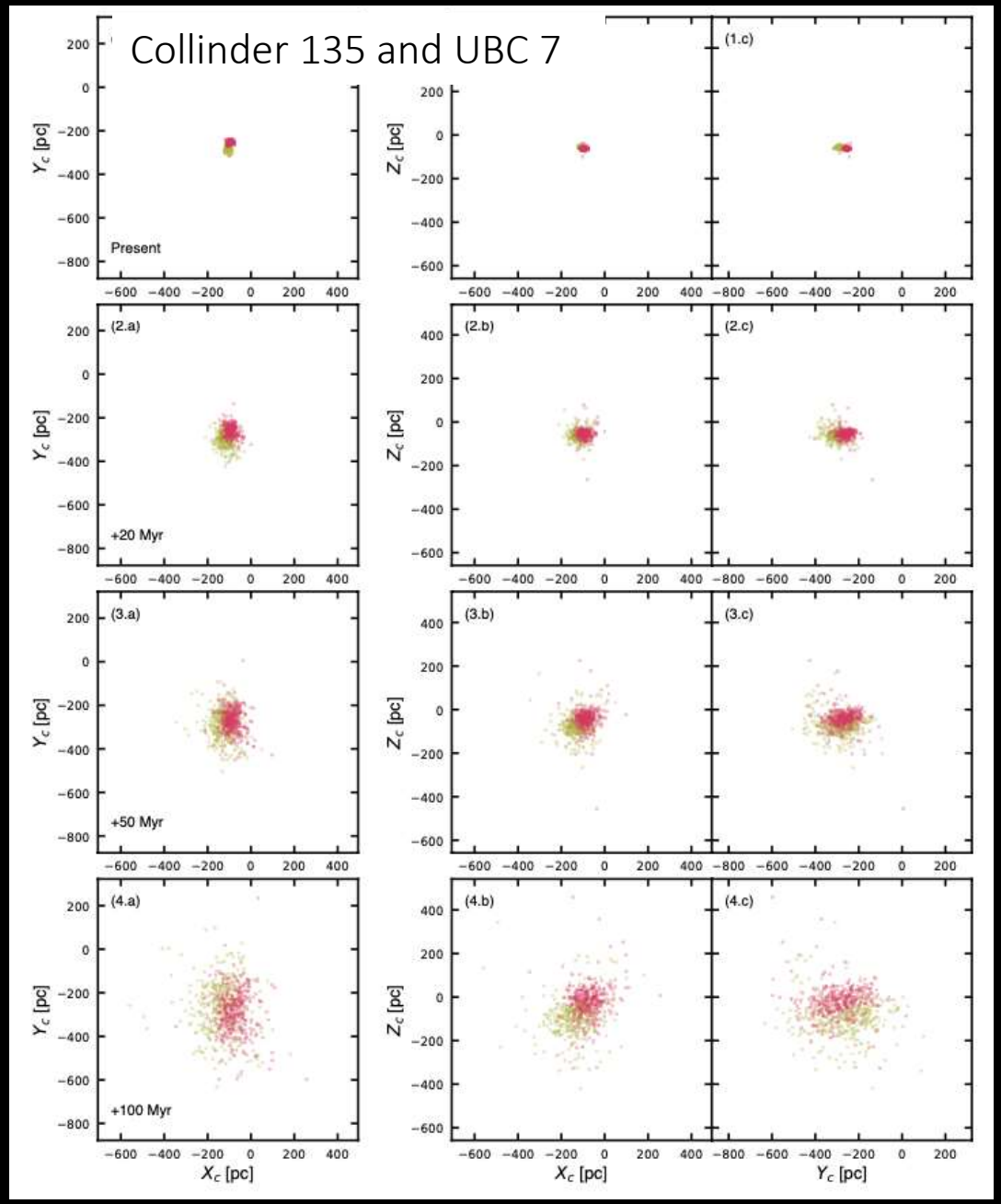

B

Summary

- ✓ Five hierarchical second level clusters are identified in the stellar complex Vela OB2 and two for the cluster pair Collinder 135 and UBC7.
- ✓ Both regions are disrupting and no mutual interaction or mergers in the future 100 Myr.
- ✓ We propose a sequential star formation for the five clusters Huluwa 1-5 in Vela OB2. And the SN plays a destructive role in removing all the gas.


Thank you for
you attention!