Why do Star Clusters dissipate?
Collisions

Virial Theorem: $$2E_{kin} = -\Omega$$

Kinetic Energy: $$2E_{kin} = n \cdot m_i \cdot \overline{v}^2 = M \cdot \overline{v}^2$$

$\overline{v}$ … mean velocity of the members relative to the cluster centre

Potential Energy: $$\Omega = -\frac{1}{2} \cdot \frac{G \cdot M^2}{\overline{R}^2}$$

yielding: $$\overline{v}^2 = \frac{G \cdot M}{2\overline{R}^2}$$

Escape Velocity: $\overline{v}_{\infty}^{2} = 4 \cdot \overline{v}^{2}$

Collisions: $t_{coll} \approx \dfrac{1}{\rho \cdot \sigma \cdot \Delta\overline{v}}$

Density ρ and cross section σ:

$$\rho = \frac{N}{\overline{R}^{3}} \quad \sigma = 4\pi \cdot R_{*}^{2} \quad \Rightarrow t_{coll} = \frac{\overline{R}^{3}}{4\pi \cdot N \cdot R_{*}^{2} \cdot \Delta\overline{v}}$$

Example of a typical Open Cluster:

$$N = 1000, \Delta\overline{v} = 10\ \mathrm{km/s},\ R_{*} = 2.5\mathrm{R}_{\odot}, \overline{R} = 5\ \mathrm{pc}$$

$t_{coll} = 10^{25}$ s => Collisions play no role

Even in the most inner core parts, collisions are highly improper, but could occur

Conclusions:

1. Binary and Multiple systems are not results of collisions in later stages but form already at the very beginning
2. Members do, in general, not escape due to collisions (swing-by effect), but their peculiar velocity component is part of the cluster formation or due to SNs

Why do Star Clusters dissipate? Crossing time - escaping

Crossing Time: $t_{cross} = \frac{\bar{R}}{\Delta v}$

$\Delta\overline{v} = 10\ \mathrm{km/s},\ \overline{R} = 5\ \mathrm{pc} \ \Rightarrow\ t_{cross} = 4.9 \cdot 10^8$ yr

Members can escape from a Star Cluster on a relatively short time scale

Reason: Velocity dispersion caused by the cluster formation and SN events

Why do Star Clusters dissipate? Differential Galactic Rotation

Total Mass of the Milky Way: $M_{MW} = 2 \cdot 10^{11} \mathrm{M}_{\odot}$

Gravitational acceleration of the complete star cluster g_{OCL} and the individual member g_* :

$$g_{OCL} = \frac{G \cdot M_{MW}}{R_{GC}^2} \quad g_* = \frac{G \cdot M_{OCL}}{(R_{GC} - r)^2}$$

R_{GC} … Distance of the star cluster's centre to the Galactic centre

r … Distance from star to the star cluster's centre

The difference of these two values, is the force, of which "the Milky Way" tries to pull away a star from the cluster

$$g_{MW,*} = \frac{2 \cdot G \cdot M_{MW} \cdot r}{R_{GC}^3} \quad \text{for} \quad r \ll R_{GC}$$

On the other side we have the gravitational force of the star cluster. The stability radius r_s is defined as:

$$\frac{2 \cdot G \cdot M_{MW} \cdot r}{R_{GC}^3} = \frac{G \cdot M_{OCL}}{r_s^2} \quad \Rightarrow \quad r_s = R_{GC} \cdot \left(\frac{M_{OCL}}{2M_{MW}}\right)^{1/3}$$

$$r_s = 10.9 \cdot \left(\frac{M_{OCL}}{1000}\right)^{1/3} \quad \text{for} \quad R_{GC} = 8\ \mathrm{kpc\ in\ units\ of}\ [\mathrm{M}_\odot, \mathrm{pc}]$$

For 1000 $\mathrm{M}_\odot$ => Diameter 20 pc

Summary

- Star Cluster dissipate because of
  1. Differential Galactic Rotation
  2. Internal Velocity Dispersion
  3. Collisions in the first few Myrs
  4. SN Explosions and corresponding Shock Waves
  5. (Collisions with “Field Stars”)
- Explanations of the existence of Globular Clusters?
- Valid for all Spiral Galaxies

Tidal Forces due to Differential Galactic Rotation

- Star Clusters lose members on their way following the Galactic rotation due to differential rotation and internal velocity distribution as well as “SN kicks”
- These stars become “Galactic field stars”
- For some Star Clusters, also tidal tails were found. These are former members still very weakly bound to the Star Cluster following its path

Why do Star Clusters dissipate? Tidal tails

- Stars leaving in the path around the Galactic centre

The 800pc long tidal tails of the Hyades star cluster

Possible discovery of candidate epicyclic overdensities from an open star cluster

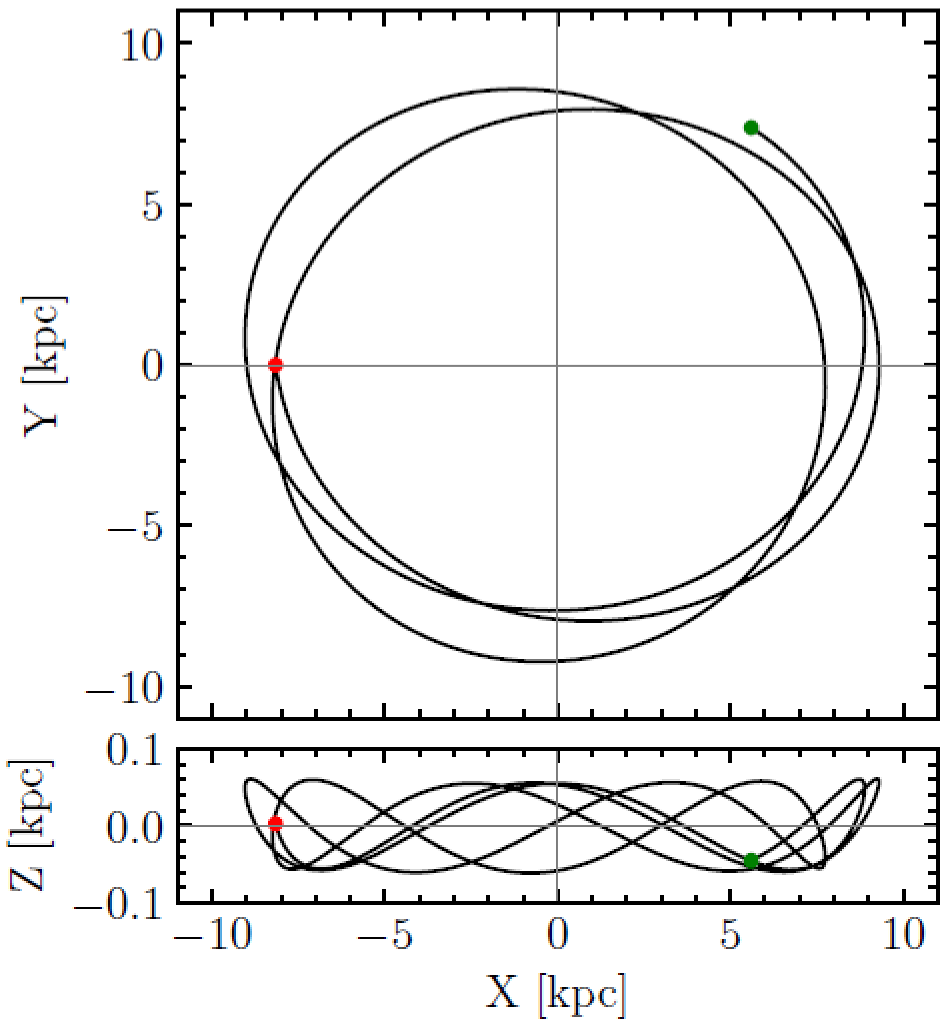
Tereza Jerabkova[1], Henri M.J. Boffin[2], Giacomo Beccari[2], Guido de Marchi[1], Jos H. J. de Bruijne[1], and Timo Prusti[1]

2021, A&A, 647, A137

parameter	value
age	$\approx$ 600-700 Myr
number of stars (r < 30 pc)	724
stellar mass (r < 30 pc)	469 $M_\odot$
3D velocity dispersion (r < 9 pc)	$\approx 0.3 - 0.8$ km/s **

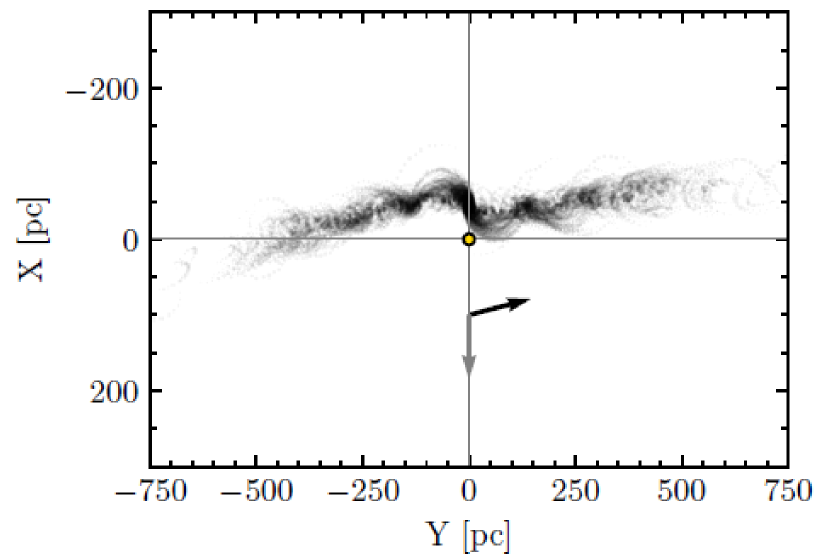
Distance about 45 pc from the Sun

Why do Star Clusters dissipate?
Tidal tails

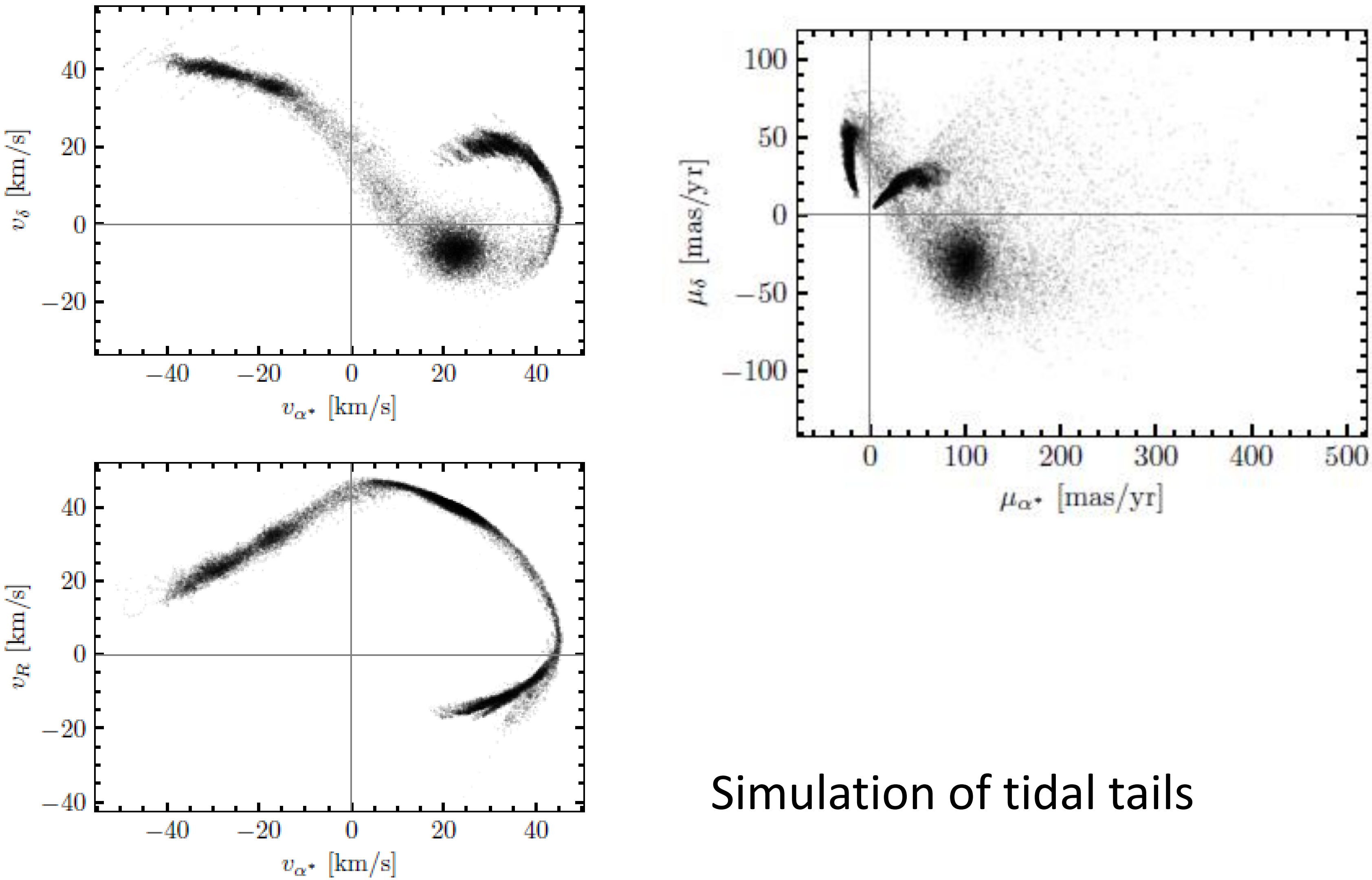


True orbit

Simulation of tidal tails

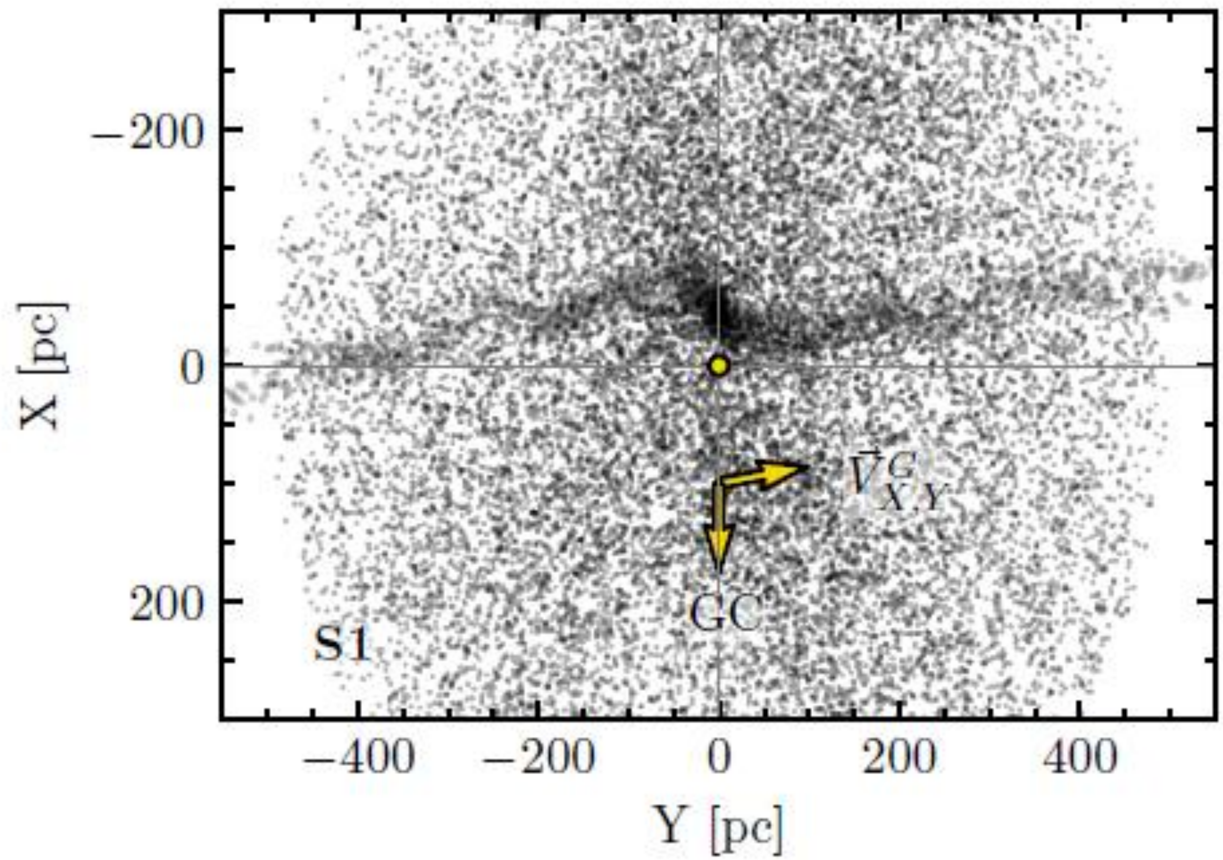


Why do Star Clusters dissipate?
Tidal tails



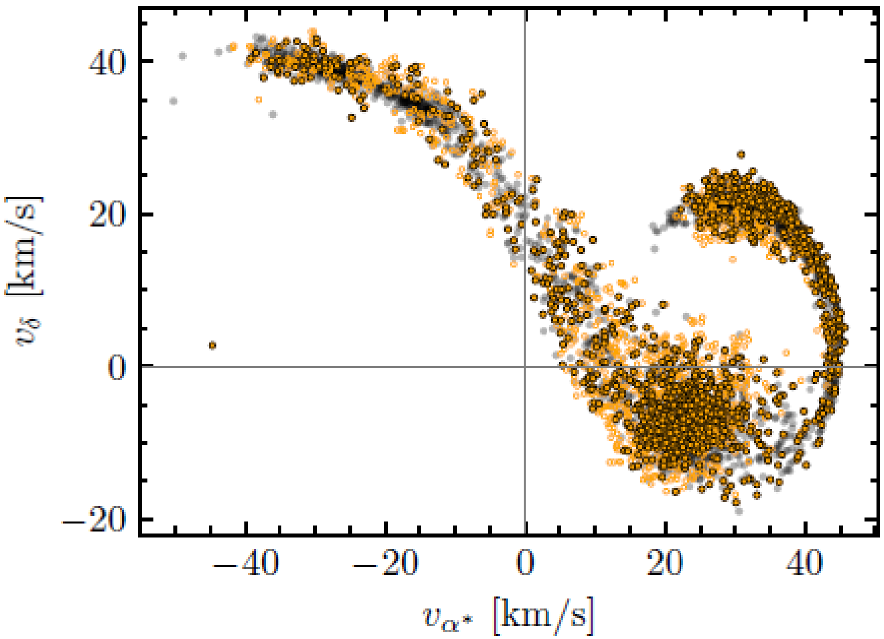
Simulation of tidal tails

Why do Star Clusters dissipate? Tidal tails

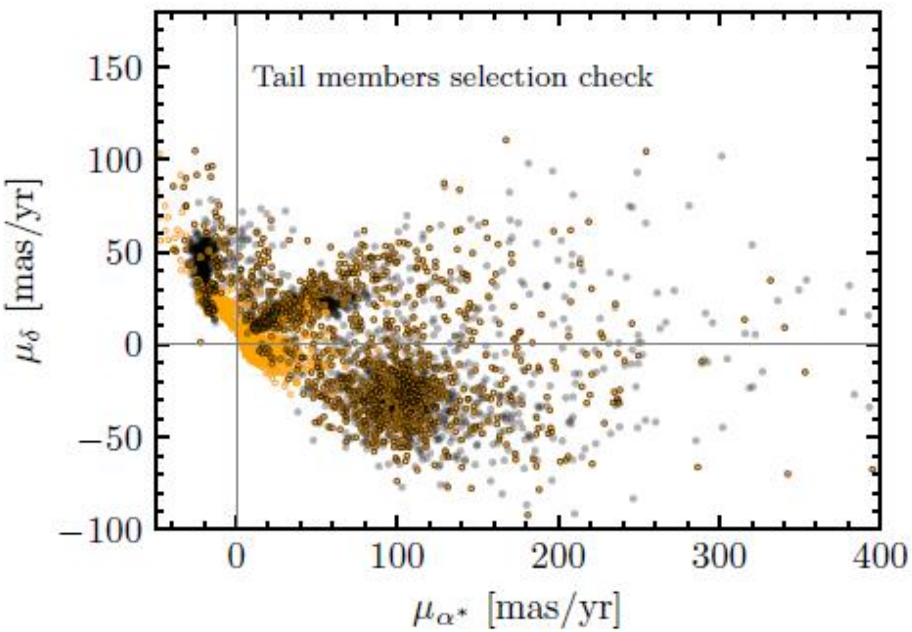


11 000 field stars in the Hyades's field

Why do Star Clusters dissipate?
Tidal tails

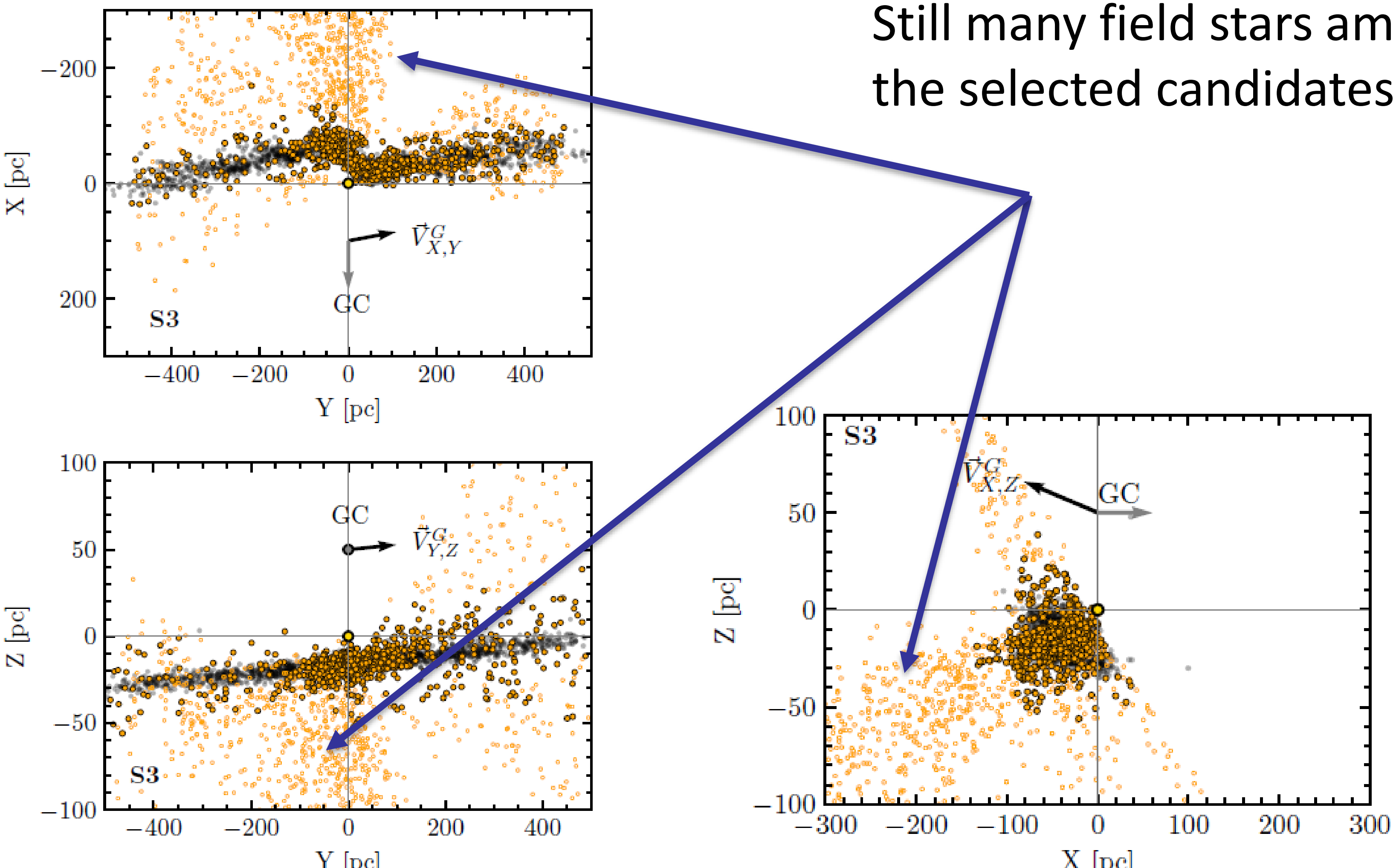


Selected candidates

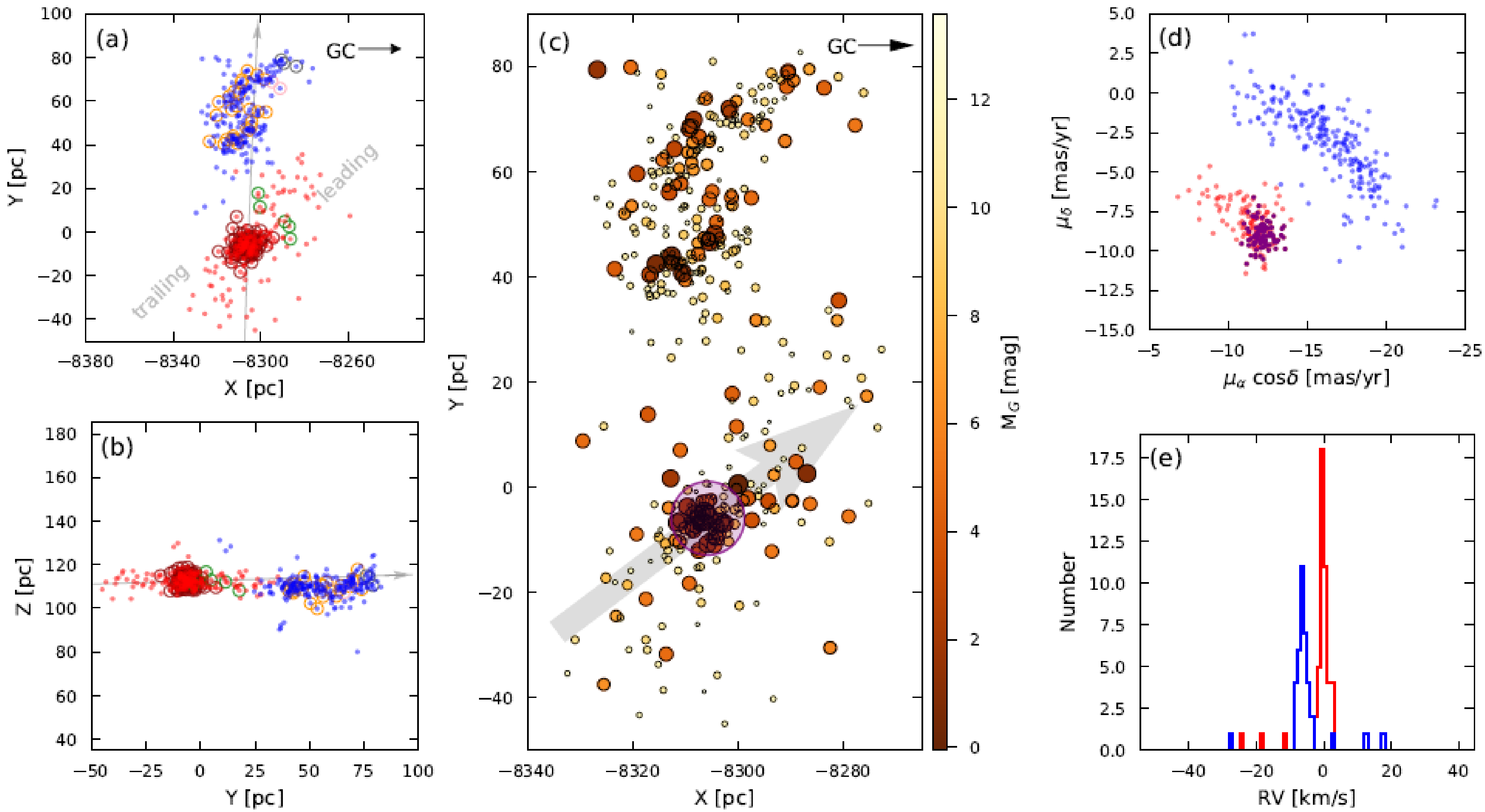


Why do Star Clusters dissipate?
Tidal tails

Still many field stars among the selected candidates



Tidal Trails - Coma Berenices

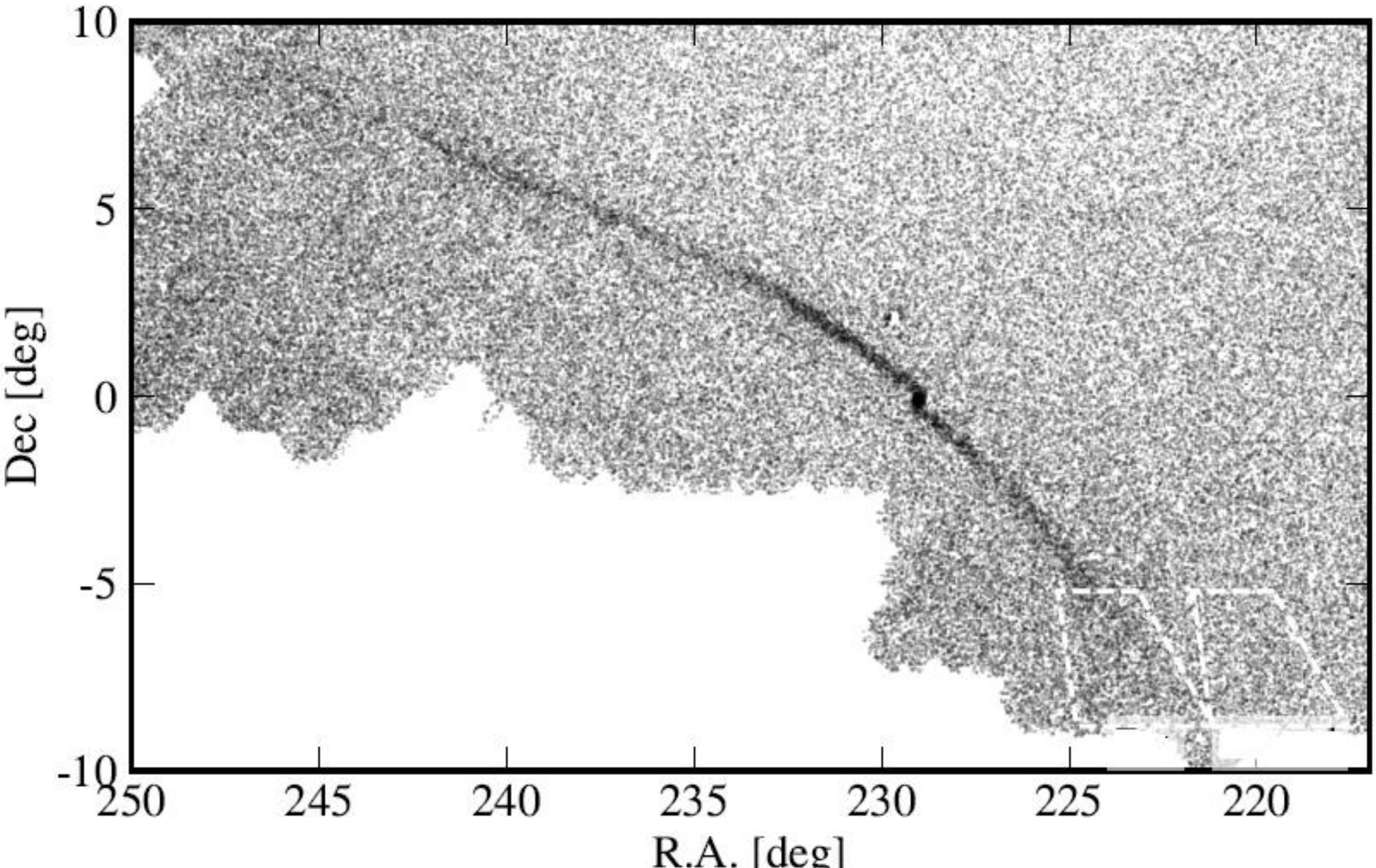


Open Cluster, age about 400 Myr

Tang et al., 2019, ApJ, 877, 12

Tidal Trails – Palomar 5

Bonaca et al., 2020, ApJ, 889, 70



Globular Cluster, age about 11 Gyr

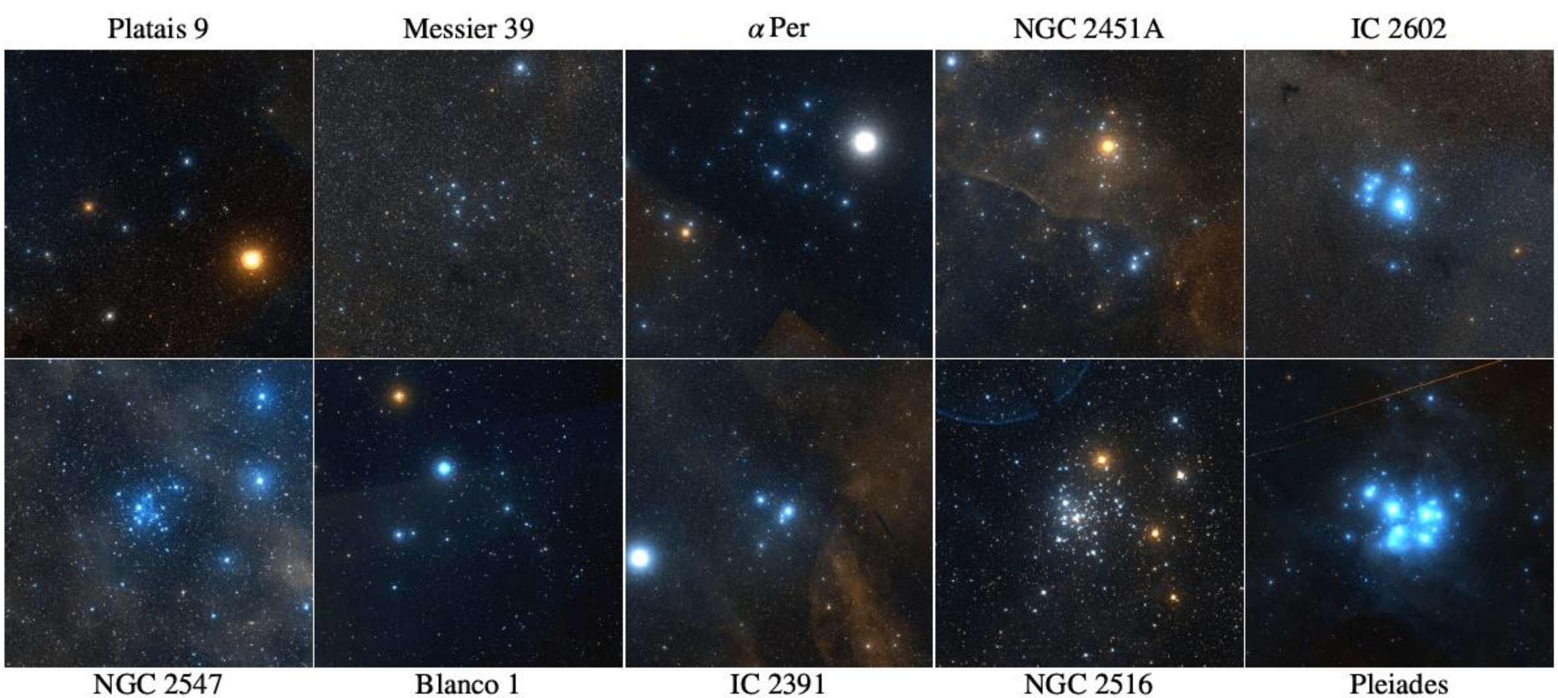
Why do Star Clusters dissipate? "Coronae"

Extended stellar systems in the solar neighborhood

V. Discovery of coronae of nearby star clusters*

Stefan Meingast[1], João Alves[1,2], and Alena Rottensteiner[1]

2021, A&A, 645, A84



Why do Star Clusters dissipate? "Coronae"

Name	Age (Myr)	v_R (km s^{-1})	v_ϕ (km s^{-1})	v_Z (km s^{-1})
Platais 9	100 (78-347)	5.97	229.21	1.66
Messier 39	310 (279-1023)	-31.00	242.08	-5.19
α Per	87 (35-110)	3.11	221.29	1.17
NGC 2451A	44 (32-148)	9.03	232.3	-4.97
IC 2602	35 (30-100)	-8.39	224.84	7.08
NGC 2547	27 (27-78)	-8.07	235.11	-3.78
Blanco 1	94 (63-209)	6.11	239.1	-2.41
IC 2391	36 (26-81)	6.82	231.27	2.09
NGC 2516	251 (63-299)	-1.34	221.13	3.06
Pleiades	86 (86-176)	-5.30	217.13	-6.52

Why do Star Clusters dissipate? "Coronae"

Table 2. Computed cluster parameters and statistics. The columns list a variety of calculated parameters, where d_c is the redetermined distance to the population density maxima, N is the number of selected sources, N_c is the estimated total number of contaminants, M_{tot} is the cumulative total mass of the observed sources, M^*_{tot} is the total system mass based on an extrapolation with mass functions, $f_{M,t}$ is the mass fraction inside the tidal radius of a system, r_t and r_h are the tidal and half-mass radii, respectively, $\sigma_{v_{3D}}$ is the deconvolved 3D velocity dispersion in galactocentric cylindrical coordinates, and k_{xu}, k_{yv}, and k_{zw} are expansion rates and their statistical errors in the corresponding position-velocity planes.

Cluster	d_c (pc)	N (N_c)	M_{tot} ($M_\odot$)	M^*_{tot} ($M_\odot$)	$f_{M,t}$	r_t (pc)	r_h (pc)	$\sigma_{v_{3D}}$ (km s^{-1})	k_{xu} (m/s/pc)	k_{yv} (m/s/pc)	k_{zw} (m/s/pc)
Platais 9	185.4	328 (22)	187.2	285.0	0.07	3.6	29.5	3.6	31.7 ± 8.3	13.8 ± 21.1	25.3 ± 21.0
Messier 39	297.6	351 (7)	235.2	325.0	0.40	6.7	9.9	0.5	32.5 ± 9.8	6.0 ± 18.6	-61.5 ± 33.5
α Per	175.0	1223 (91)	735.0	1030.0	0.41	10.0	16.4	3.8	39.1 ± 18.4	14.5 ± 11.5	19.3 ± 5.9
NGC 2451A	193.8	648 (21)	327.1	425.0	0.39	7.2	11.3	3.3	37.6 ± 3.9	44.3 ± 14.4	23.3 ± 10.9
IC 2602	152.2	648 (12)	339.7	400.0	0.47	7.5	8.3	1.1	42.1 ± 5.8	-26.3 ± 22.9	-44.3 ± 14.3
NGC 2547	392.0	514 (20)	382.8	590.0	0.52	8.9	8.1	1.3	11.6 ± 9.7	6.7 ± 35.3	-12.8 ± 24.1
Blanco 1	237.5	494 (2)	259.9	365.0	0.76	8.5	3.9	0.7	47.7 ± 22.2	4.7 ± 3.1	103.5 ± 72.8
IC 2391	152.1	682 (55)	338.4	445.0	0.37	7.2	23.8	2.9	17.1 ± 8.0	-3.8 ± 12.3	17.6 ± 17.3
NGC 2516	413.8	1860 (51)	1436.7	2550.0	0.71	16.0	8.9	1.4	44.5 ± 5.1	22.8 ± 6.3	27.2 ± 13.9
Pleiades	136.4	1177 (9)	617.8	850.0	0.82	11.8	4.4	1.4	0.9 ± 21.5	7.9 ± 7.4	-9.2 ± 19.6

Never list such values without errors

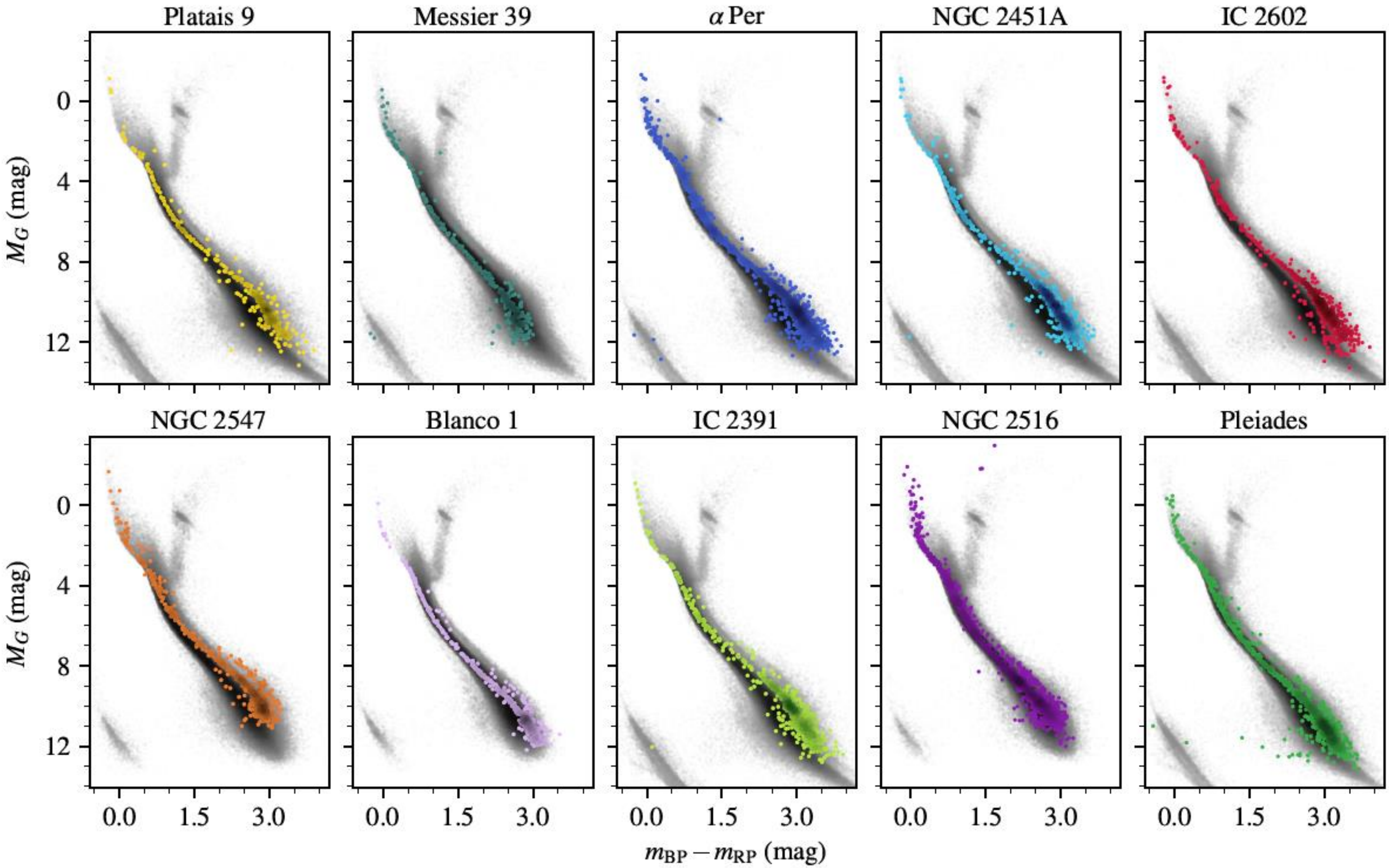


Fig. 7. Observational HRDs for the ten target clusters. Members of each cluster are displayed as colored points. The gray distribution in the background comprises all *Gaia* sources in the initial search box of each population. Our selection results in remarkably clean and narrow main sequences that frequently also show well-visible binary sequences. This clear separation from the broad background distribution acts as validation of the successful application of our member-selection procedure.

Reddening? Objects below the zero age main sequence?

Why do Star Clusters dissipate?
"Coronae"