Why do Star Clusters dissipate? Collisions

Virial Theorem: $2Ek_{in} = -\Omega$

Kinetic Energy: $2Ek_{in} = n \cdot mi \cdot \overline{v}^2 = M \cdot \overline{v}^2$

$\overline{v}$ … 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_* :

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

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

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

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

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

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

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