STARS ON THE RUN IN THE MILKY WAY GALAXY

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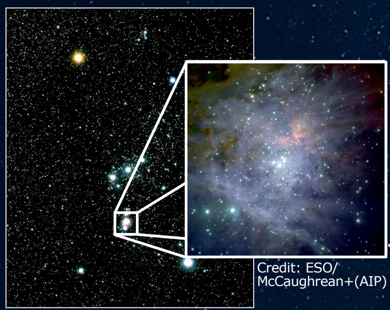
The Dynamical Evolution of Young Star Clusters

Most stars are born in clusters, forming alongside hundreds or even thousands of other young stars within the same gas cloud. As these clusters evolve, the stars interact gravitationally, shaping the cluster's structure and sometimes ejecting stars entirely. By modelling this early evolution, we can work out what the cluster's initial density and spatial structure must have been.

What is a Young Star Cluster?

Young star clusters are compact regions where stars are forming together from the same dense cloud of gas. The Orion Nebula Cluster (ONC) is a nearby example, about 400 pc (1300 light years) away and only 2–3 million years old, making it an ideal laboratory for studying early stellar evolution [3].



Credit: ESO/ McCaughrean+(AIP)

Credit: A. Fujii

Using simulations

We run N-body simulations [4] that track the stellar motions and interactions under different starting conditions. By comparing the predicted number and speed of ejected stars with observations, we can identify which initial cluster configurations are most realistic.

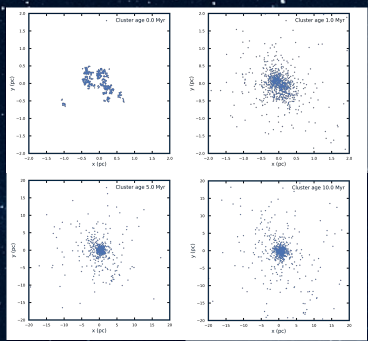


Fig. 2: Positions of cluster stars at four different times for the same cluster, showing the spatial evolution of this cluster.

What are Runaway Stars?

Runaway and walkaway stars are expelled from their birth cluster either through close gravitational encounters or when a companion in a binary system explodes as a supernova. Because they move quickly and travel far, their trajectories help trace the history of the cluster they came from.

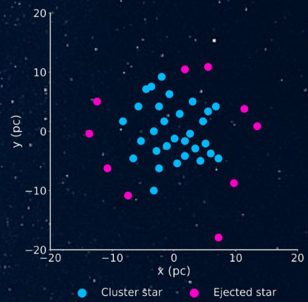


Fig. 3: Positions of cluster and ejected stars at a cluster age of 10 Myr, showing that some stars can travel quite far during this time.

Comparing simulation to observations using Gaia

Gaia is a space-based telescope launched in 2013 by the European Space Agency with the aim of mapping the Milky Way. It provides three-dimensional spatial and velocity information for over a billion stars [6]. Its high-resolution information makes it possible to find many runaways from young star clusters.

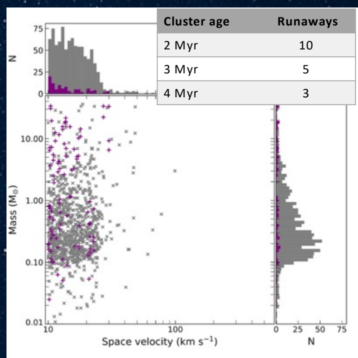
Gaia satellite - credit: ESA

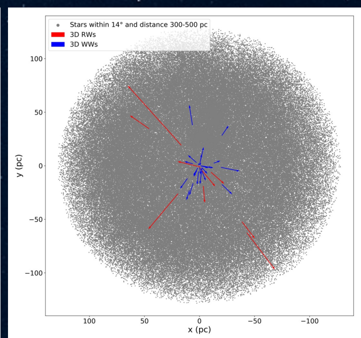
→ Using observations of motions and locations of stars still close to the ONC, we trace these back to find runaways and walkaways. We compare these to our simulations, drawing conclusions about the starting conditions that were present when the stars formed.

Runaways from the ONC

The simulation results on the left suggest 10 runaway stars reducing to 5 for cluster ages up to 2-3 Myr, which is the average age of this cluster. Observations find 8 runaway stars, confirming the assumed initial conditions [2].

Cluster age	Runaways
2 Myr	10
3 Myr	5
4 Myr	3





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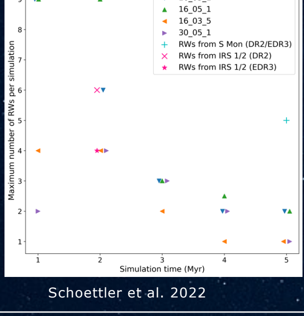
Runaways from the young cluster NGC 2264

We apply this method to another young cluster (see image). We test several different simulations initial set-ups to further explore this approach. We compare the observation numbers with different simulation results [1]. Several initial condition set-ups can be excluded, leaving 2-3 possible options, which were confirmed using alternative methods [5].

Credit: NGC 2264 ESO



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Conclusions

- Combining simulations and observations provides a useful method to constrain starting conditions for young star clusters
- Both tested young clusters appear to have formed from similar initial conditions.
- Our method provides an alternative, complementary approach in untangling the initial state of these clusters using stars that are no longer part of these regions and might therefore be easier to observe

Outlook: Using WEAVE to measure radial velocities

We are continuing this work using Gaia to establish the likely initial conditions of tens of young clusters within 2 kpc of Earth. Gaia does not provide radial velocities for a large number of stars, so we use a different instrument called **WEAVE** on the William Herschel Telescope located in La Palma.

Credit: Gavin Dalton/Oxford University/STFC

References
[1] Schoettler C., Parker R.J., de Bruijne J., 2022, MNRAS, 510, 3178
[2] Schoettler C. et al., 2020. *MNRAS* 495, 3104
[3] Da Rio et al., 2010, *ApJ* 722, 1092
[4] Hut Symposium-International Astronomical Union 208, Cambridge University Press (2003)
[5] Parker & Schoettler, 2022, *MNRAS*, 510, 1136
[6] Gaia Collaboration et al. Astronomy & Astrophysics 616 (2018): A1

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