ECOLOGY OF OPEN STAR CLUSTERS

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Computation supplied by the Minnesota Supercomputer Institute

A. Ecology

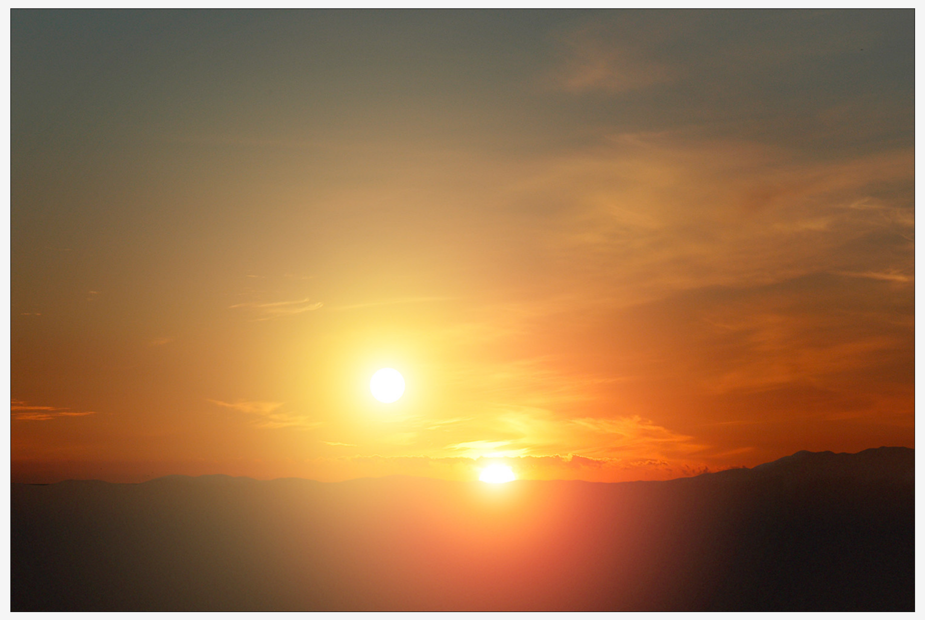
"Ecology of star clusters" examines the interactions of stars, and what can be gleaned from those interactions about the evolution and ultimate fate of star clusters large and small. Questions like,

1. What is the force that causes small star clusters to expand?
2. Why do the ancient globular clusters have many binary stars?
3. Why are close triple stars so rare?

B. Natural law

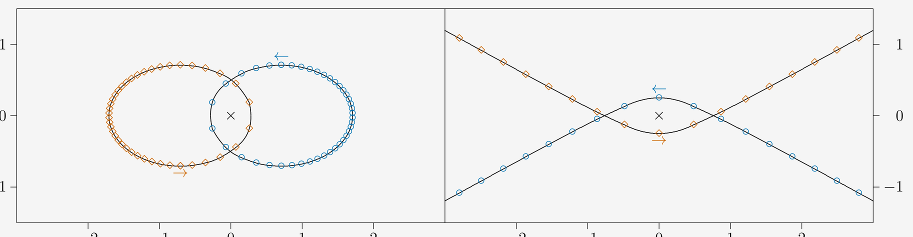
1. Newton's gravitational law holds the planets in their endless orbits, and it also governs stars.
2. But this same law of attraction accomplishes strange things in the ecology of star clusters.
3. The same gravitational force affects large clusters like globulars differently, because of their larger escape velocity.
4. It makes detailed star orbits unpredictable and close triple stars unstable.
5. Incredibly, gravitational attraction leads not to a collapse of the cluster, but forces small star clusters starting at rest to expand endlessly and dissipate into empty space, for long times at average accelerating rates.

Credits and Acknowledgements. *Lower left image: A Rose of Galaxies, by NASA, ESA, and the Hubble Heritage Team. A group of interacting galaxies called Arp 273, about 300 million light years from our sun. Shot from Earth orbit (http://hubblesite.org/newscenter/archive/releases/2011/11/image/a/). Upper image, second column: Imagined sunset on a planet circling a double star, by NASA, JPL–Caltech, R. Hurt. Artist's conception (http://www.spitzer.caltech.edu/images/1762-ssc2007-05c-Alien-Sunset). Upper image, third column: NGC1976, M42 in Orion. A star-forming cloud of interstellar gas. Photo by F. Lehman. Shot from Big Cypress National Preserve in southern Florida through Earth's atmosphere (http://www.starfred.com). Simulation images, fourth column: Screen shots by OmniGlyph with stellar animations. OmniGlyph software by F. Lehman, stellar simulation software by C. Lehman, supercomputer time by UMN MSI. Thanks to R. McGehee, S. Aarseth, and L. Williams for discussions, A. Keen and T. Lehman for comments, and S. Xenos for design. April 12, 2012.*



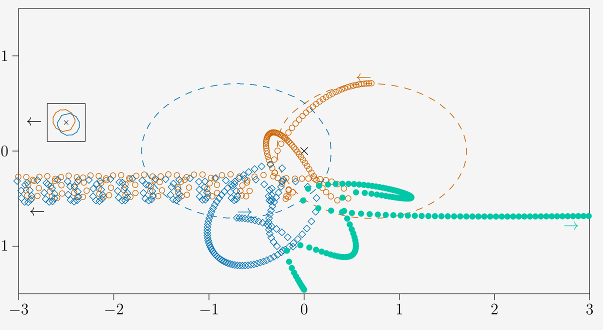
C. Two stars can be bound or not

Two isolated stars can be gravitationally bound, depicted above, forever orbiting the center of mass (below left), or they can pass each other at high speed and depart forever, gravitationally unbound (below right). Newton proved this in the 17th century. As they continue to recede, their hyperbolic paths approach straight lines.



D. Three appear to defy gravity

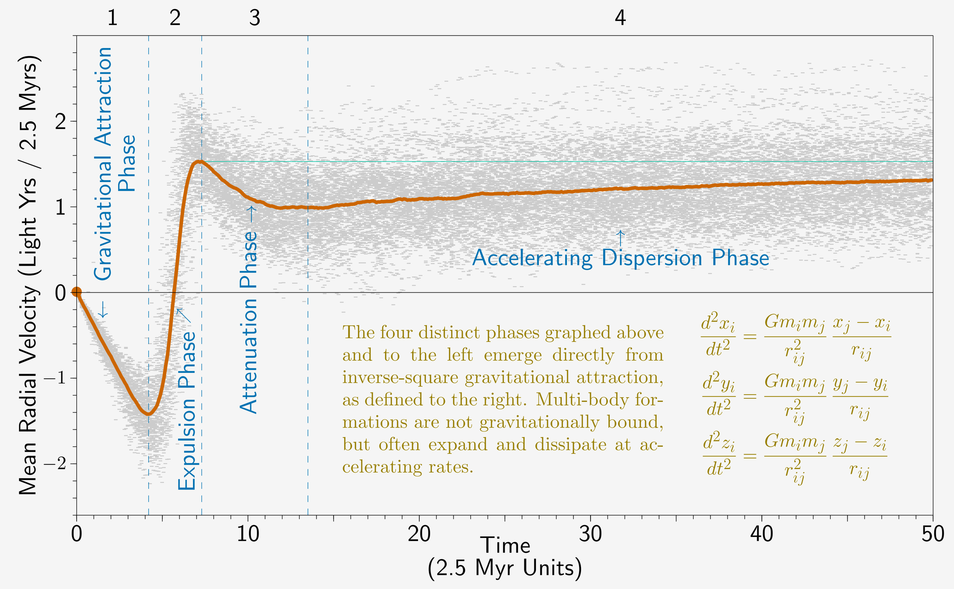
Three-body interactions can trade potential energy for kinetic and blast toward infinity in opposite directions, exceeding their mutual escape velocity. McGehee proved this in the 20th century and Aarseth established its relevance to expanding star clusters. Below, a third stationary body is added to the bound pair, above-left. They now initiate a graceful three-body dance, then a two-body pair forms heading rapidly left and the other shoots to the right at even greater speed. They never return.



E. Evolution in four phases

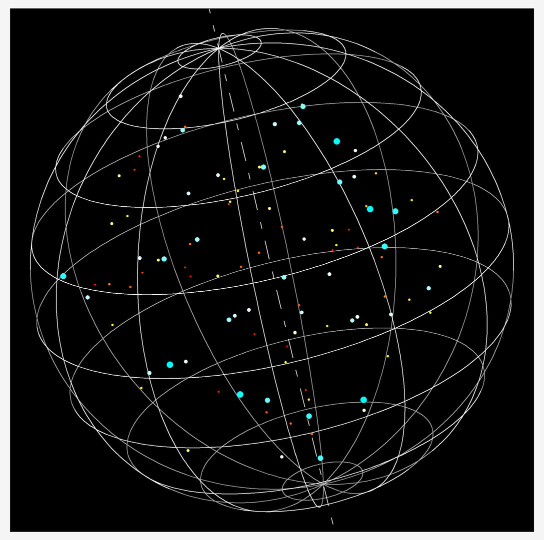
1. Simulated stars born in place from a cloud, as suggested above, initially enter a *gravitational attraction phase* and fall toward one another in the expected way, called "cold collapse."
2. But they do not collapse to a point. Instead they swing about one another through an *expulsion phase*, forming smaller associations and feeling increasing bursts of kinetic energy. The cluster inflates with rapid acceleration.
3. Following that, the acceleration abates. The cluster expands but with decreasing velocity in a short *attenuation phase.*
4. Expansion continues forever in these small clusters, with mean velocity increasing through the final *accelerating dispersion phase.*

The red curve below averages many separate simulations, a fraction of which are shown as background gray. Even though every star expelled from the core of the cluster decelerates, the mean diameter of the cluster does the opposite, accelerating due to ever greater velocities of expulsion.

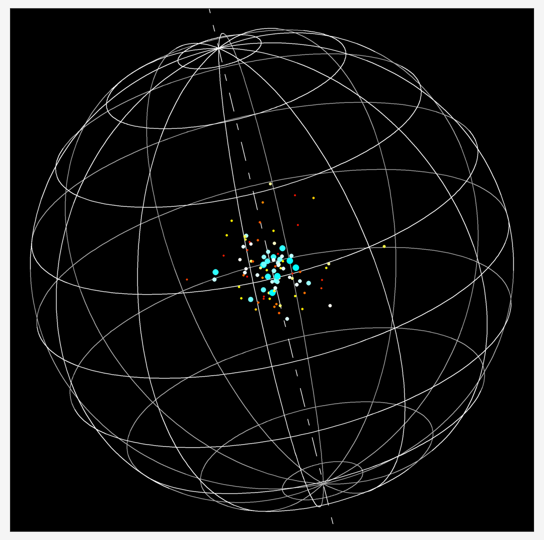


F. Stars in their megayear dance

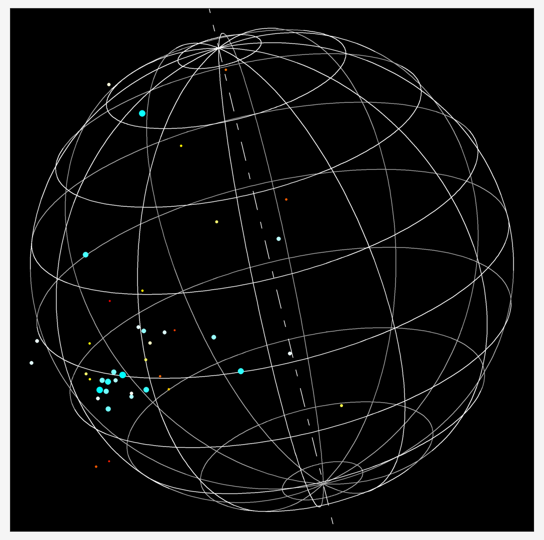
1. A simulated cluster is just borne of a cloud of gas, with stars poised for rapid gravitational approach.



2. In ten million years the cluster has fallen to its smallest size—a jewelbox cluster—with the rapid acceleration of an expulsion phase about to begin.



3. Nearly sixty million years later, most of the stars have dispersed into space, with some large hot stars and smaller companions lingering on.



G. Next research step

Understand the acceleration!

Ordinary Newtonian gravitational attraction in N-body systems paradoxically seems to produce an average expansion that accelerates with passing time.