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Exotic Stars in N-Body Models

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ABSTRACT

We examine a large grid of open cluster N-body simulations to identify exotic stars. We derive the frequency of exotic stars' existence over time for different initial star populations. Moreover, we investigate the predicted distributions of exotic star spin, eccentricity, period, and mass-ratio over time. These N-body predictions provide expectations for how the frequencies and parameters of exotic stars in real open clusters depend on characteristics of those clusters.

Keywords: exotic stars, Blue-Lurkers, Blue-Stragglers, Sub-Subgiants, N-body models

INTRODUCTION

Most stars like our Sun exist within binary systems and interactions between companion stars may be responsible for abnormal, "exotic," stars. Some exotic stars occupy regions of the color-magnitude diagram where no stellar population is predicted, and others have unusual qualities for their region. Sub-Subgiants are dimmer and cooler than typical subgiants; Blue-Stragglers are brighter and hotter than the main sequence turnoff point; Blue-lurkers are rotating more rapidly than counterparts of similar mass and age.

It is suspected that many types of exotic stars are formed from mass transfer within the binary system, where an evolving star donates mass to its companion. The angular momentum bonus may spin up the accretor and the inherited hydrogen may rejuvenate the accretor, making it appear younger.

An investigation of N-body models permits us to study these unusual objects and their histories freely, creating expectations for their frequencies in open clusters, their parameters, and the characteristics of the clusters in which they exist.

SIMULATIONS

We conducted this study with a sophisticated numerical simulation code developed by Sverre Aarseth and Keigo Nitador, called NBODY6++. It vigilantly models the evolution of a star cluster using integration of Newtonian equations of motion while simultaneously managing and collecting parameters about stellar evolution. This allows us to probe the dynamical and evolutionary histories of exotic stars.

We use simulations of open clusters with variable initial body (star) populations. These initial populations are 1,000, 2,000, 3,000, 4,000, 5,000, 10,000, and 20,000 stars. Moreover, each N-type simulation is run for a total of 320,000 stars, totalling about 530 simulations. The number of simulations is split evenly between metallicities of a solar abundance and a subsolar abundance, and all simulated clusters are approximately at the sun's radius from the galactic center. Each simulation terminates when the open cluster disperses.

METHODS

Analysis of the simulation data was accomplished with Python.

We organize and execute the criteria for the "exotic" designation. First, within the binary system, one star must be a white dwarf and the other must be a main sequence or giant star. The white dwarf hopefully gifted its expelled

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mass to the main sequence or giant star and made it into a Blue Lurker, Blue Straggler, or Sub-Subgiant. Second, we avoid wide binaries. A companion star must be in the proximity of the white dwarf to accrete its ejected material, so we restrict our exotic star category to having orbital periods less than 10,000 days. As a minor third criteria, stored only in a separate list, we review the binary stars' mass histories and check whether the main sequence or giant star beared a mass increase of at least 0.1 solar masses. Irregularities with NBODY6++ during a common envelope phase may not accurately track mass transfer. We identify eligible exotic stars that meet the first two criteria.

We next create a Hertzsprung Russel (HR) diagram of the open cluster. The exotic stars are highlighted in different colors to distinguish them as points of interest in the cluster and as preexotic and exotic stars. The function to create the diagram is iterated through every time step to illustrate the tracks of the exotic stars, even while they are pre-exotic (not yet matching the criteria.)

Furthermore, we took averaged parameter information, like period, spin, eccentricity, mass, radius, and stellar type, about single stars, binary stars, and exotic stars at every time step. We took compositional information about the cluster, like the number of single and binary stars, at every time step. We traced and captured the histories of all exotic stars about whether they existed in single or binary star systems. We packaged these data analysis functions into a laterally applicable code for use on all simulations and submitted the job to the supercomputer QUEST.

ONGOING RESULTS AND DISCUSSION

Simulations with identical initial body populations and metallicities (N and Z values,) were combined. Their time steps were averaged and used to reassign bins. Then, the parameter histories of the star-ids captured and labeled as "exotic" were adjusted to these bins and averaged to combine. 530 simulations coalesced into 18 averaged data frames of exotic star and general population star parameter information.

The first goal of this analysis was to uncover the frequency of exotic stars in open clusters. We plotted the average number of exotic stars for each N-type at a single metallicity value. The number of exotic stars increased with N and the total number of exotic stars peaks around the middle of the cluster lifetime.

We standardized the exotic star frequencies by examining the fraction of binary stars that are exotic over time. Exotic star frequency is directly correlated with initial stellar population size. If the same fraction of primordial binaries became exotic stars, the fraction of binary stars that are exotic would be identical for different N. However, we understand that the frequency of exotic star formation must be affected by this cluster parameter, N. Increased frequency of interaction between stars that are not primordial binaries may provoke the formation channels of exotic stars and therefore cause the increase of exotic star frequency with N.

The long-term compositional information about the open cluster's binary fraction suggested that single stars preferentially escape the cluster because the binary fraction increases dramatically at the end of the cluster lifetime. This was the motivation to graph the fraction of binary stars that are exotic rather than total stars that are exotic, and this allowed us to compare exotic stars with their nonexotic binary counterparts more significantly. The fraction of binary stars that are exotic peaks toward the end of the cluster's lifetime. The nonstandard graph of the total number of exotic stars in time reminded us that the total number of exotic stars peaks toward the middle of the cluster's lifetime, so these results allowed us to infer that exotic binary stars are preferentially retained in the open cluster compared to nonexotic binary stars. In the future, we will examine the lifespan distribution of exotic and nonexotic binary stars.

The second goal of this analysis was to investigate the parameters of exotic and nonexotic stars. Exotic stars were identified on the main sequence and we sought to discern whether they were potential Blue Lurker candidates, meaning whether their spins were abnormal compared to other main sequence stars.

We inspected their spins by plotting the spin ratio of the spin of the average exotic star on the main sequence and the spin of the average nonexotic binary star on the main sequence in time. We plotted these ratios for each N type at a single metallicity value. If the spins of exotic and nonexotic binary stars on the main sequence were identical or similar, the spin ratios would be at or around one. However, we discovered that the spin ratios were rarely one and generally an order of magnitude higher. Meaning, that the spins of exotic stars on the main sequence are overall greater than the spins of nonexotic stars on the main sequence. Having qualified as exotic stars, existing on the main sequence, and spinning abnormally fast, these are potential blue lurker candidates.

In the future, we intend to probe other parameter histories like eccentricity, period, and mass-ratio. We will compare, like with spin, exotic stars to population and binary stars.

The simulation data promises exciting results about the origins of exotic stars. The essential goals of the study are to determine the number of exotic stars likely to exist in certain exotic star regions at any given time, decipher how

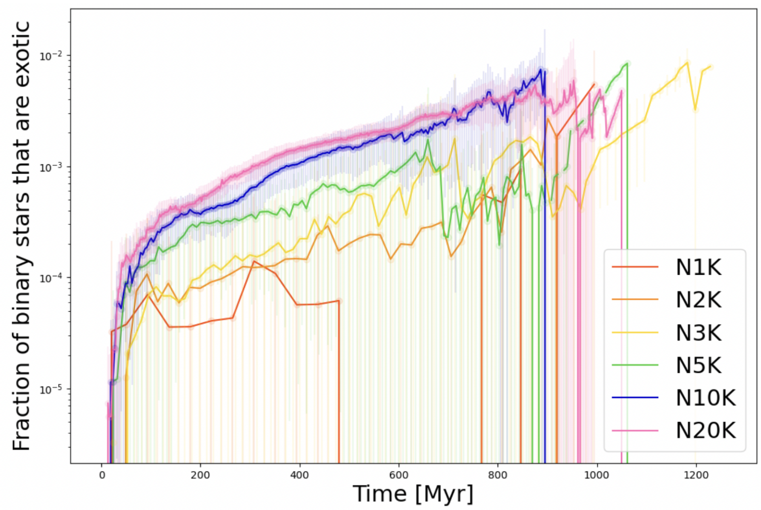

Figure 1. The fraction of binary stars that are exotic for different initial N. Although the total number of exotic objects peaks in the middle of the cluster's lifetime, the fraction of exotic binaries increases with cluster age. The frequency of exotic binaries increases with initial N.

exotic star frequencies depend on cluster parameters, and summarize the abnormal characteristics that exotic stars share. This will set expectations for probing the existence exotic stars in real clusters.

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