Assessing the Accuracy of Binary Star Detection Methods using Numerical Simulations of Star-Forming Clouds

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Introduction

It has long been established that stars form in groups. During the collapse of giant molecular clouds, hundreds of stars are formed. Some of these stars form together and remain bound to each other, these are **binary stars.** Understanding the number and frequency of binary stars is an important question in all stages of a star's life.

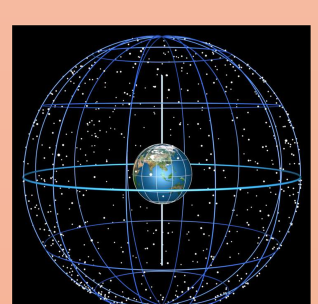
If a binary is observed when stars form, the stars will likely remain together forever.

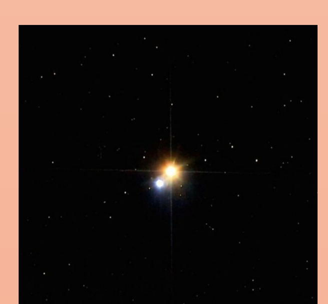
It is debated whether planetary systems can remain stable around binary stars.

The supernova debris creates new star-forming clouds, and the cycle repeats.

Mass exchange can occur when one star reaches the end of its life, sometimes resulting in a supernova.

Motivation





Observational astronomers identify binaries based on their apparent separations in the sky. However from our perspective on Earth, the sky appears like a giant planetarium dome, which lacks a third dimension. This limited perspective can result in misidentification. It is still debated whether the stars shown above on the right, for example, are an actual binary system or simply appear close to one another. This led me to consider the question:

How frequently do astronomers mislabel binary systems in star-forming clouds?

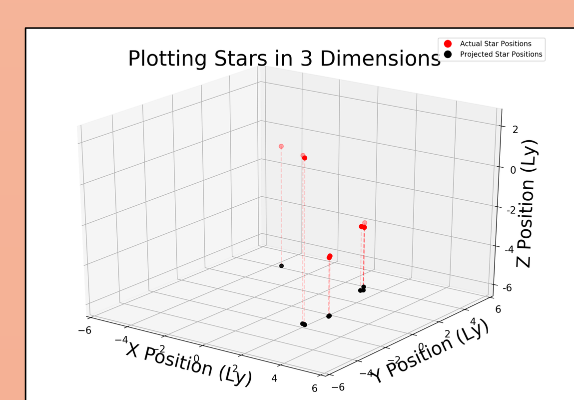
Methods

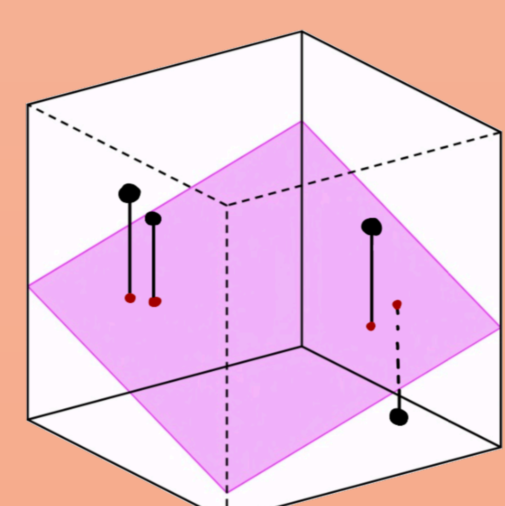
I use data from one simulation of Lee et al. (2019), which simulated a star-forming cloud over nearly a million years. The cloud generated dozens of stars, which I can use as my mock observation sample.

Brief Overview of my method:

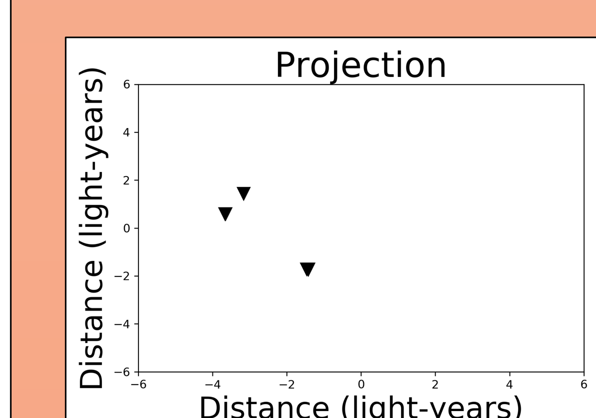
- I observe these three-dimensional systems from some random viewing angle, creating a two-dimensional projection of the data.
- **True binary star systems** are determined based on physics—their mutual gravitational interactions keep them bound to one another. The simulation data provides me enough information to calculate this.
- **Perceived binaries systems** are determined by finding the "smallest" apparent separation between stars in my projections.
- Finally I ask: Do the labels agree?

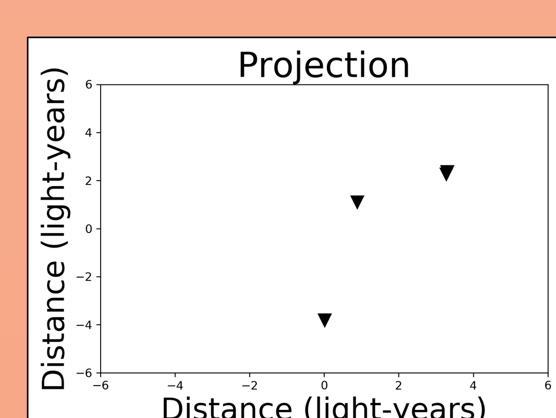
Stars that we see from Earth *actually* live in 3D space (right figure), but we are only able to see stars as two-dimensional projections onto the celestial sphere.





I project 3D simulation data onto a 2D plane, which I will treat as one projection, as shown in the figure on the left. By doing this, I can effectively treat the simulated stars as though I were an observer from Earth.



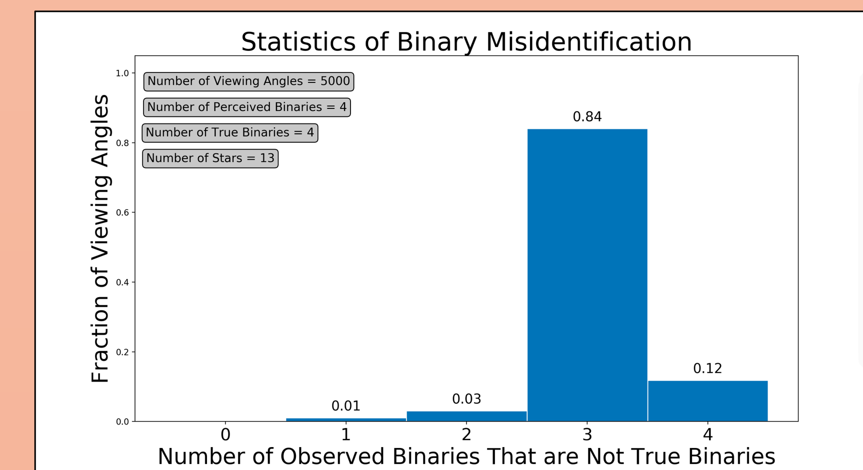


Two examples of the same three stars, viewed at different viewing angles, are shown above.

A **mistake in identification** is when an observer labels two stars as a binary system that are not a true binary pair.

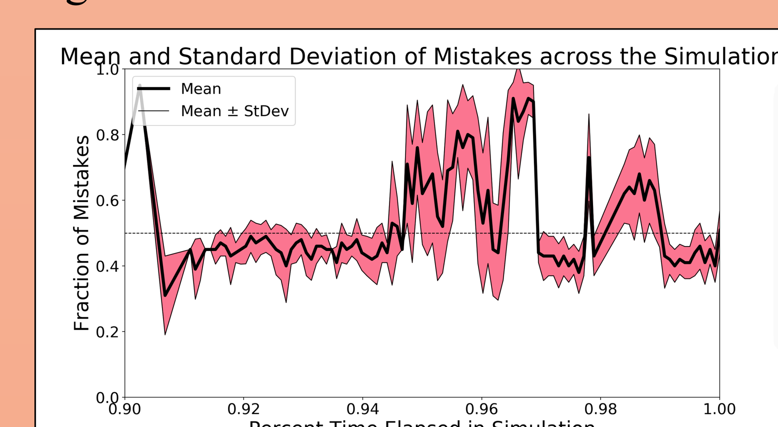
Results

I can identify true and perceived binaries for a variety of viewing angles, creating statistics on mistakes made. Using 5000 projections of a data output late in the simulation (after many stars had formed), this revealed the following interesting distribution:



Here, there are four true binaries and each projection found four perceived binaries. However, the fact the 0-bin is empty says that **there was never a case where the observer correctly identified all four true binaries**! Furthermore, over 90% of the time the observer identified at least three perceived binaries that are not true binaries (implying a fraction of mistakes above 75%).

I repeated this for all data generated in the 10% of the simulation. This meant that I was now looking at how the fraction of mistakes (total mistakes / total true binaries) behaves as a function of time. The following shows the mean fraction of mistakes at each point in time, with the red shading corresponding to one standard deviation.



The fact that the data all lies either close to a 50% fraction of mistakes or higher suggests:

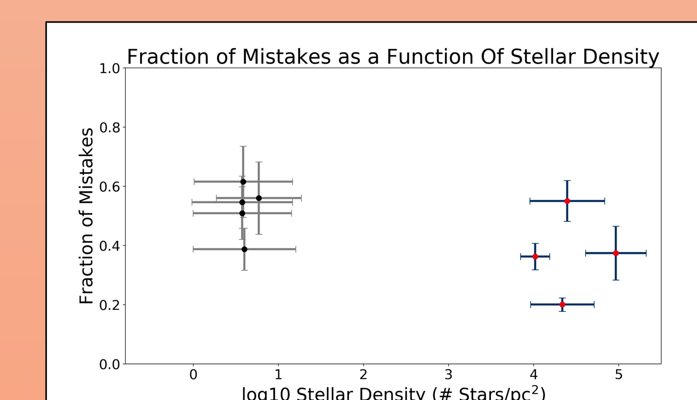
Approximately 50% of all observed binaries may not be binaries at all!

This plot also shows a series of "spikes" in the fraction of mistakes—we hypothesized that this was because the stars were migrating into more crowded environments (i.e., regions of increased stellar density). However, we tested this hypothesis and found that the average stellar density does not change considerably across the times shown in the plot above.

How stellar density plays a role is a new and interesting question.

Results

To explore this stellar density question, I repeated this entire process using another simulation from Lee et al. (2019). This simulation has considerably larger stellar densities compared to what I had previously analyzed. Nonetheless, as shown below, increased stellar density did not correlate with an increased fraction of mistakes--if anything, more crowded environments appear to have the same or fewer misidentifications overall!



Next Steps

- Lee et al. (2019) ran three large simulations of star forming clouds, each a different environment. Considering all three simulations might inform whether stellar density impacts the mistake fraction.
- Looking at the fraction of mistakes as a function of stellar separation will inform how distances between clusters of stars or the stars themselves can affect the misidentification statistics.
- If the results are insensitive to stellar density, does that suggest something about the kind of binaries formed? High stellar densities may make tighter true binaries—which are less likely to be misidentified.
- Allowing for triple-star systems to be identified in my program to see if the member-swapping in triple systems causes the fraction of mistakes to increase.

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References:

Tobin, John J., Leslie W. Looney, Zhi-Yun Li, Claire J. Chandler, Michael M. Dunham, Dominique Segura-Cox, Sarah I. Sadavoy, et al. "The Vla Nascent Disk And Multiplicity Survey Of Perseus Protostars (Vandam). Ii. Multiplicity Of Protostars In The Perseus Molecular Cloud." *The Astrophysical Journal* 818, no. 1 (2016): 73. https://doi. org / 10.3847/0004-637x/818/1/73.