# Special Spatial Orientation of the Orbital Planes of Eclipsing Binaries in NGC 2264: Implications for Cluster Formation

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## 1. Introduction

Time-series photometry of the CoRoT field SRa01 was carried out with the Berlin Exoplanet Search Telescope II (BEST II) in 2008/2009. A total of 1,163 variable stars were detected, 241 of them were previously known and 922 are newly found.

We demonstrate that the observable frequency of the 114 detected Algol-type eclipsing binaries (EAs) is extremely high inside the cluster area compared to the one in the field. A possible explanation of this phenomenon is a well-determined, special spatial orientation of the orbital planes of the binaries in the cluster, giving an additional, new constraint for the star formation theories.

## 2. The excess of Algol-type binaries in the cluster

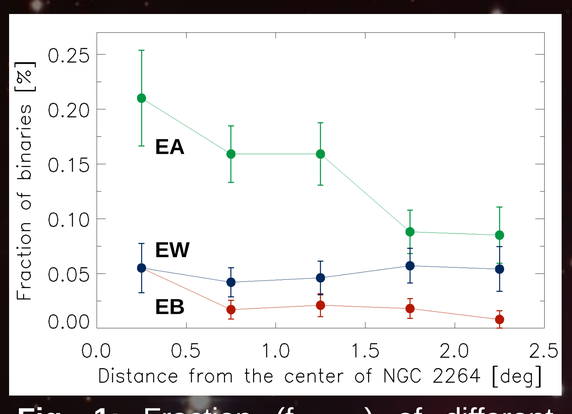


**Fig. 1:** Fraction ($f_{binaries}$) of different types of eclipsing binaries among all stars in the distance intervals from the cluster center in %.

$f_{binaries} = N_{binaries} / N_{all\ stars}$

**$f_{EAs\ in\ the\ field}$ = 0.087±0.016%**
This is the ratio of EAs beyond 1.5 degrees from the center of the cluster.

Since the number of cluster members is ~2000 [1] and the number of all stars in the field is ~90,000, the relative frequency of EAs in the cluster is **25x** higher than in the field.

**$f_{EAs\ in\ the\ cluster}$ = 2.19±0.33%**

$$N_{EAs} = f_{EAs\ in\ the\ cluster} \times N_{stars\ in\ the\ cluster} + f_{EAs\ in\ the\ field} \times N_{stars\ in\ the\ field}$$

## 3. Possible explanation

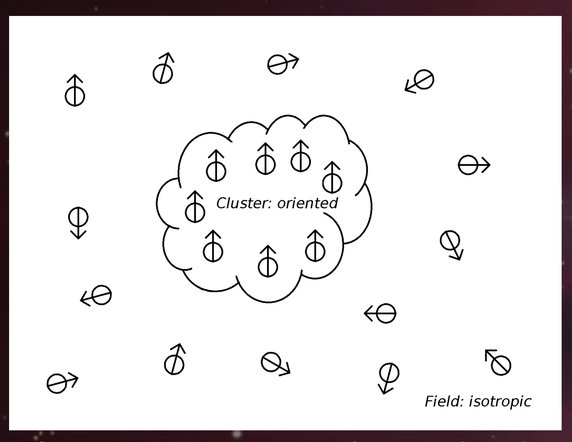


**Fig. 2:** Demonstration of the orientations of the orbital angular momentum vectors.

A possible explanation is that during the stellar and binary formation the systems preserve the original angular momentum vector of their parental cloud resulting in a more or less parallel orientation of the orbital planes of the binaries.

## 4. The model

In order to check this possibility we modeled the fraction of observed EAs:

(1) Period, total mass and mass ratio distributions of binaries are from [2].
(2) Mass-radius relation is: $R_{1,2} = M_{1,2}^{0.8}$ [3].
(3) The eclipse condition is: $i > i_{cr}$, where $i_{cr} = arccos\left(\frac{R_1+R_2}{a}\right)$.

The phase coverage of the orbital periods are also taken into account based on our epochs of observations as well as the limiting amplitude (0.04 mag) we are able to detect.

Assuming 50% of the stars are in binary systems and isotropic orbital angular momentum vector distribution, this model yields an 0.104±0.004% fraction of detectable EAs in the field in our observational data. This agrees well with the observed frequency of 0.087±0.016%.

We assume an inital inclination ($i_0$) and a scatter ($\sigma_i$) with a normal distribution inside the cluster. Using the model we run a Monte Carlo simulation with an initial $i_0$ and a standard deviation $\sigma$ in order to find out what kind of $i_0$ and $\sigma_i$ can produce such a high fraction of Algol-type binaries.

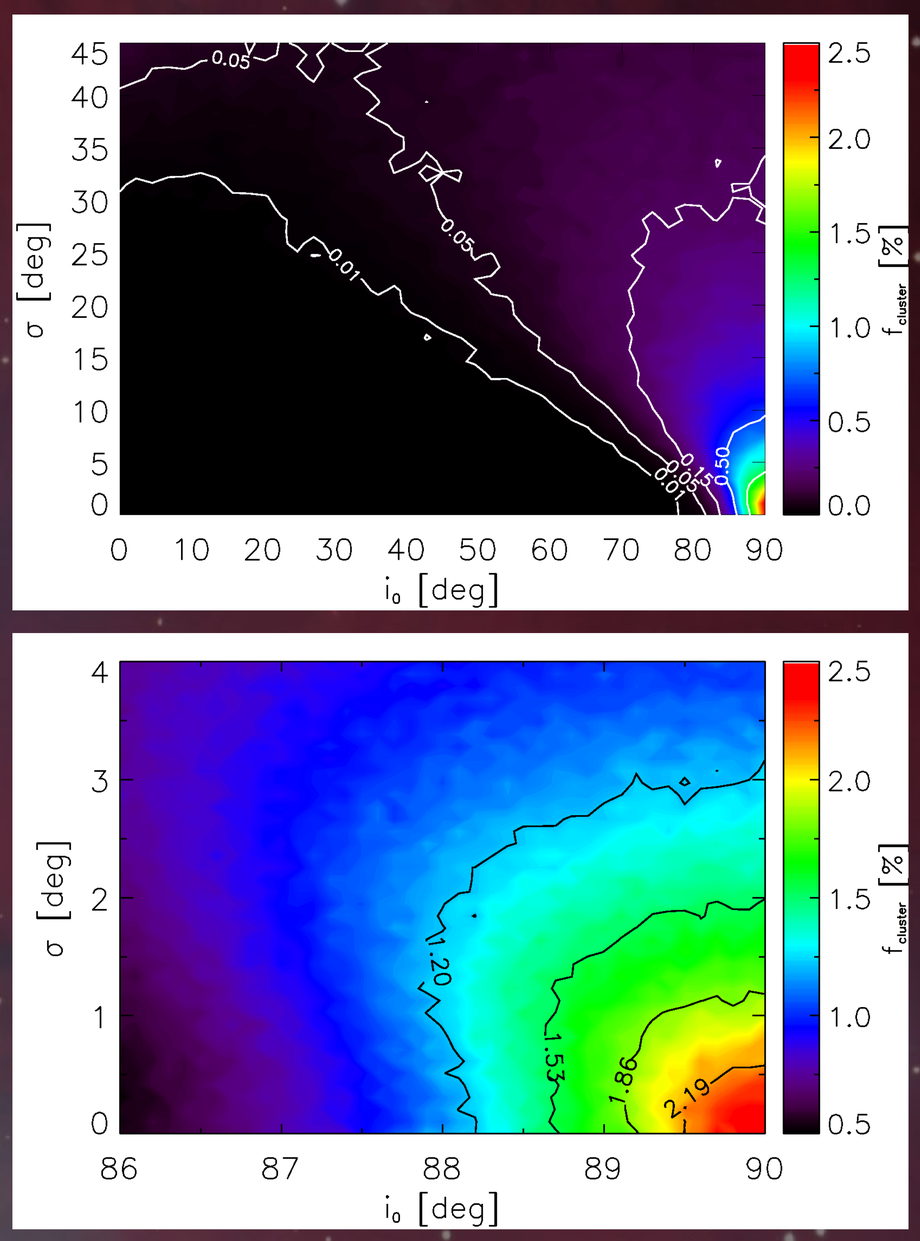


**Fig. 3:** The modeled value of the fraction of observable Algol-type eclipsing binaries in the cluster with an initial inclination $i_0$ and a standard deviation $\sigma_i$. Our observed value of $f_{cluster}$=2.19±0.33% is marked by a black line, as well as the 1σ, 2σ and 3σ uncertainty regions.

## 5. Results

Investigating the spatial distribution of the Algol-type eclipsing binaries within and outside the young open cluster NGC 2264 we found that the fraction of these binaries is extremely high in the cluster. The incidence of these systems is 25 times more frequent than among the field stars. This feature can be explained if we assume that the angular momentum vectors of the orbital motions are directed anisotropically. This direction originates most likely from the original angular vector of the parental cloud. In the case of NGC 2264**, the average inclination of the orbital planes should be more than 88˚ with a standard deviation less than 3˚**. Such idea can explain also the lack of eclipsing binaries in the Pleiades.

## References

[1] Cody et al. 2013, AN, 334, 63
[2] Eggleton 2006, Evolutionary Proc. in Bin. and Multiple Systems, Cambridge Univ. Press
[3] Tingley & Sackett 2005, ApJ, 627, 1011