Constraining the Features of the Low-mass Stellar Multiple Population in the Orion Nebula Cluster

Christopher Liu[1], Matthew De Furio[1], Michael Meyer[1]

[1] University of Michigan

Introduction

- We aim to describe the multiple population of low mass stars (0.1-0.6Msun) in the Orion Nebula Cluster (ONC)
- Our sample consists of M-type stars for which we are sensitive to companions ≥ 10 AU (0.025") for high signal-to-noise sources, roughly 0.5*λ/D
- Low mass, low density stellar associations like Taurus have been shown to contain a companion frequency roughly twice that of the Galactic field, from 3-5000 AU over all mass ratios (Kraus et al. (2011)). High mass, higher density clusters like the ONC do not exhibit an excess of multiples relative to the field
- By detecting and characterizing more binaries, we will place constraints on the companion frequency, orbital separation distribution and the companion mass ratio distribution of the ONC, and search for environmental impacts on the multiple population.

Previous Work

- We identified all the members within the ONC treasury program data (archival Hubble Space Telescope images) that are unsaturated in all 5 filters of Advanced Camera for Surveys (ACS) (Robberto et al. (2013))
- We applied a double point-spread function (PSF) fitting procedure using empirical PSF models on each image of all targets based on the work of De Furio et al. (2019)
- Our code converges on the binary best-fit to each image within each filter in which the target appears
- We calculated the probability that the best-fit binary model is a false positive based on the work of *De Furio et al. (2022)*
- All targets with a combined false positive probability < 0.1% are classified as binaries
- We have identified 44 candidate companions with projected separations as low as 13 AU

Acknowledgements

Based on observations made with the NASA/ESA Hubble Space Telescope, obtained from the data archive at the Space Telescope Science Institute. STScI is operated by the Association of Universities for Research in Astronomy, Inc. under NASA contract NAS 5-26555.
.

Citations

Da Rio, N., et al., 2016, ApJ, 818, 1.
De Furio, M., Reiter, M., Meyer, M. R., et al. 2019, ApJ, 886, 95
De Furio *et al.* 2022, *ApJ*, **925**, 112
Fontanive, C., Biller, B., Bonavita, M., & Allers, K. 2018, MNRAS, 479, 2702
Kraus, A. L., Ireland, M. J., Martinache, F., & Hillenbrand, L. A. 2011, ApJ, 731, 8
Reggiani, M., & Meyer, M. R. 2013, A&A, 553, A124
Robberto, M., Soderblom, D. R., Bergeron, E., et al. 2013, ApJS, 207, 10

Results

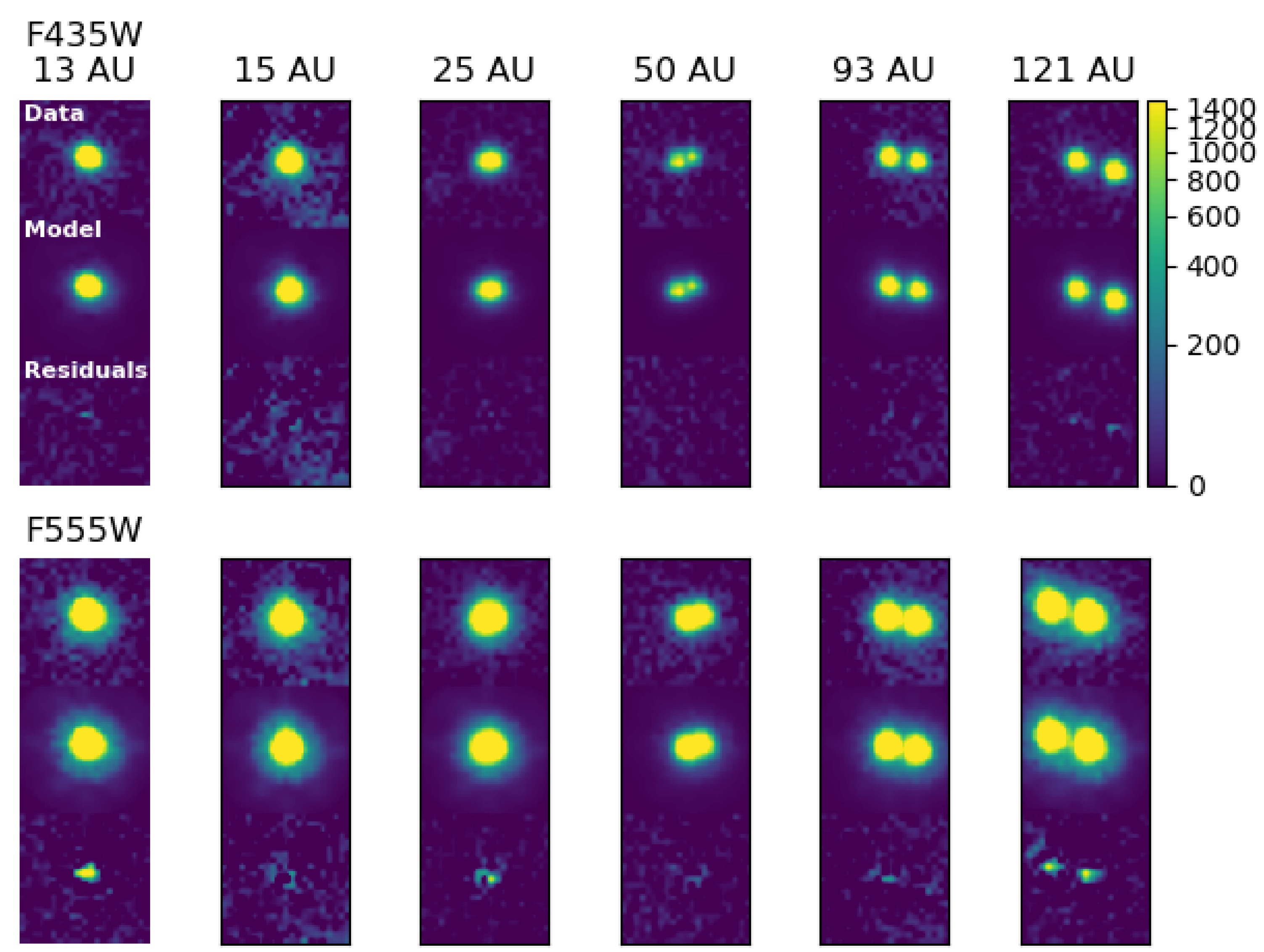

Fig 1. Example candidate binaries: For each block, the top image is the raw HST data, the middle image is the double-PSF fit, and the bottom image is the residual. Each column contains the same binary in the F435W and F555W filters, and we list their approximate projected separation (AU). Images are scaled by arcsinh(x). Note that the binaries are all brighter in the F555W filter.

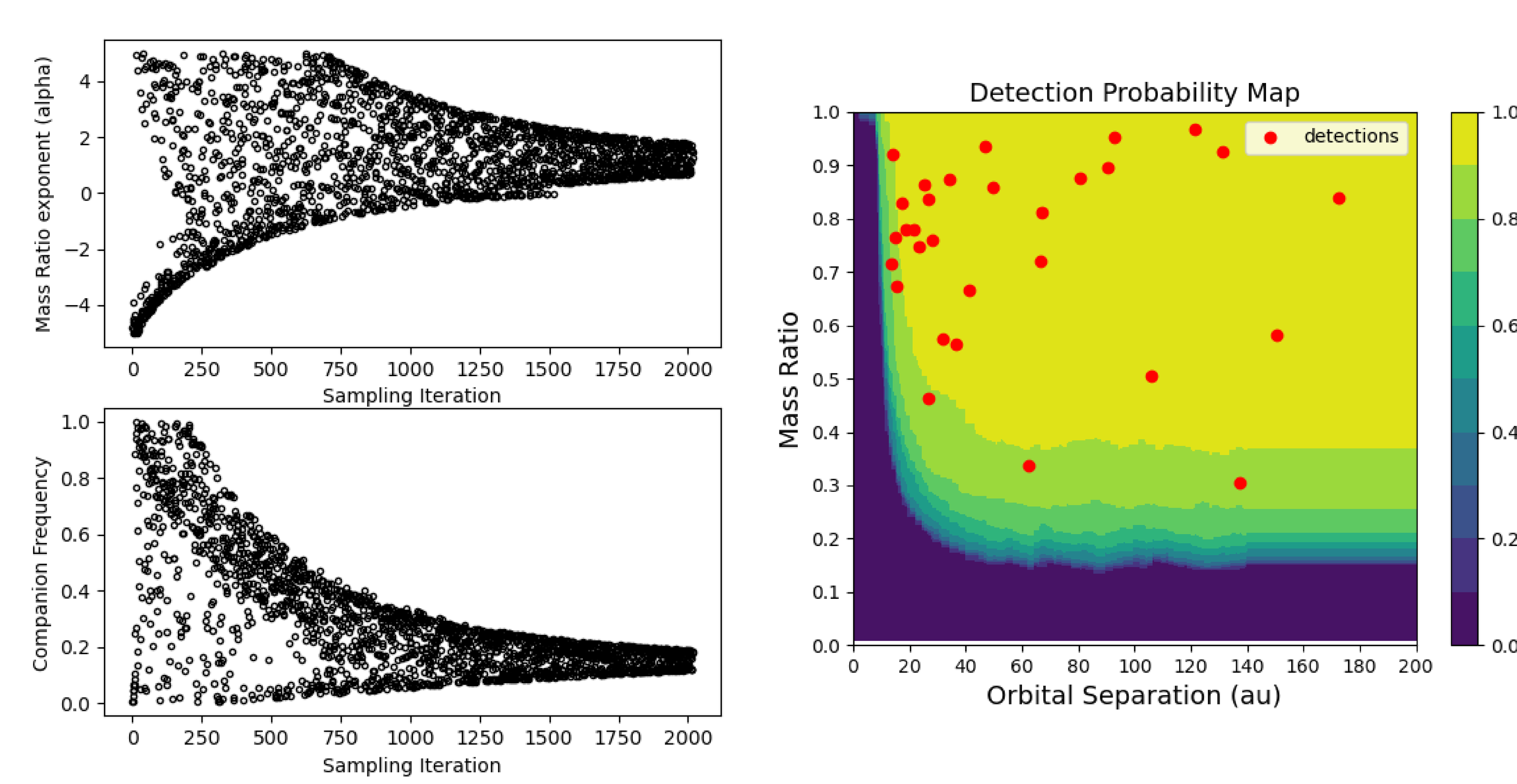

Fig 2. The left hand plots demonstrate walkers in our MC algorithm gradually converging towards a best fit. The right hand plot is our detection probability map with our detections represented by the red points,

$$\mathcal{L}(d \mid k) = \frac{k^d e^{-k}}{d!}$$

Shown above is the likelihood function where k is the expected number of detections after generating a population sampled from each model, weighted by our detection probability map, and d is our number of detections. We also scale this by companion frequency

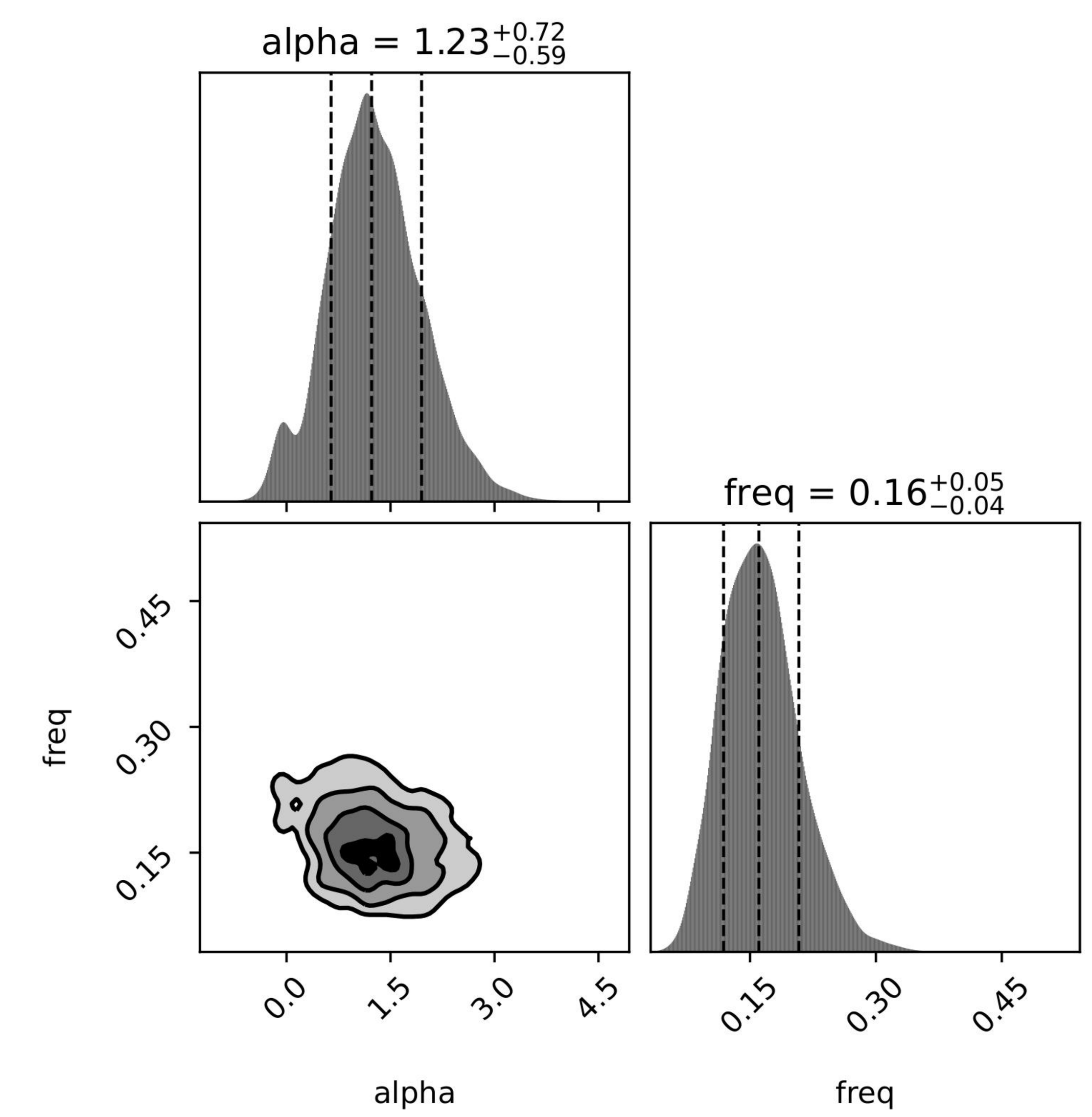

Fig 3. Pictured are two probability distributions from the Bayesian analysis: alpha is the exponent in our power-law fit for our mass ratio distribution model, and freq. refers to the companion frequency. The dotted lines represent the median and +- sigma values. The bottom left plot is the contour of the two distributions, and we notice that both converge (same as in Fig. 2)

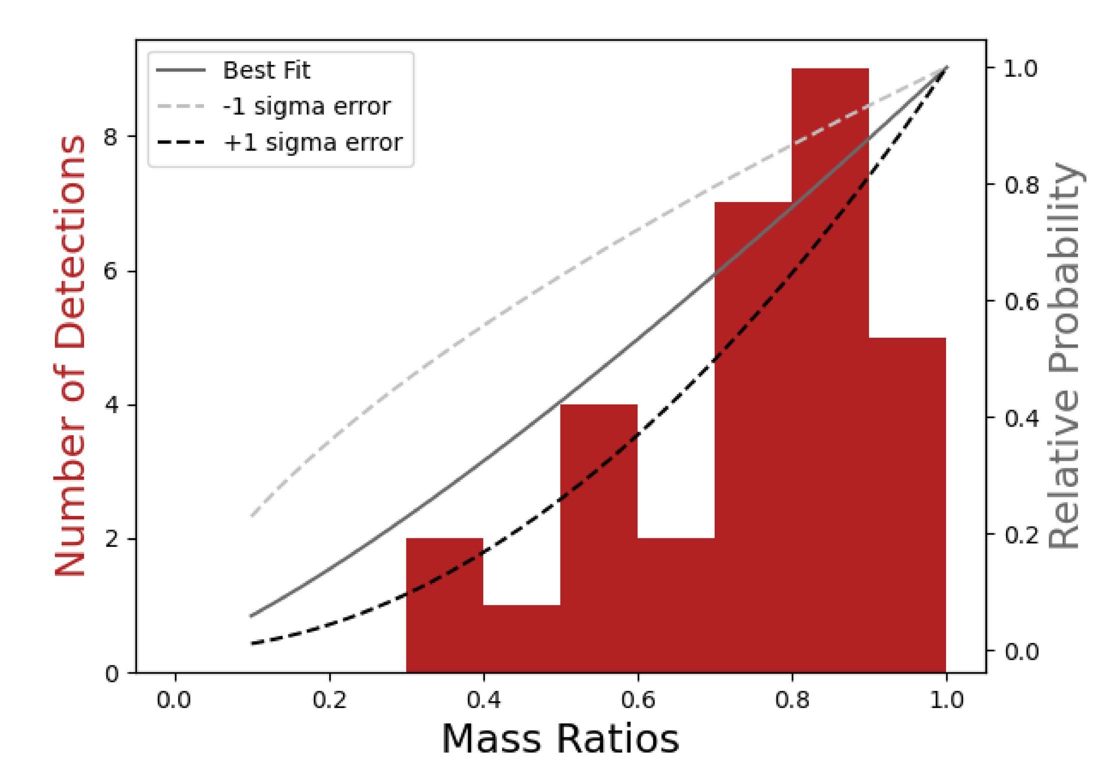

Fig 4. Mass Ratio Distribution fitted with a power law. Our best fit is alpha of 1.23, with -1 sigma 0.64 and +1 sigma 1.95. This fit is valid over q = 0.1-1.0 and a = 10-200 AU. Below is the mass ratio distribution functional form.

$$\frac{dN}{dQ} \sim q^{\alpha}$$

Methodology

- Obtained masses for members found in F435W, F555W, and F775W (F658N is the Halpha filter and thus cannot be used)
  - Used extinctions and effective temperatures from Da Rio et al. (2016) and the BT-Dusty Isochrone for our evolutionary model
  - Used F555W magnitudes to calculate mass if available for a target, otherwise F435W (due to excess accretion luminosity)
- Most multiplicity surveys model mass ratio distributions with a power law, and orbital separation distributions with a log-normal, but we assume a flat distribution for separation due to our small parameter range (10-200AU)
- We performed a statistical analysis with a Bayesian Approach, using a nested sampling Monte Carlo algorithm (Multinest, Buchner et al. 2014), and define a likelihood function based on Fontanive et al. (2018) as a Poisson distribution
- The likelihood of each model is scaled by our detections and maximized by the MC model, giving us our best fit

Conclusion

- We have detected 44 candidate binaries, and calculated mass ratios for 30 of them
- We found a best fit of 1.23+0.72-0.59 for the mass ratio distribution, and companion frequency 16+5-4% (1 sigma error)
- These are consistent with those derived for the galactic field M-star companion population over 2 sigma (Reggiani and Meyer 2013), i.e. flat distribution
- These are likely not consistent with brown dwarfs in the field, which tend to much higher alpha values