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How Low Can You Go: Exploring the Extreme Mass Ratio of Massive Binary Stars

Erin ABRAHAM[1,*], Saida M. CABALLERO-NIEVES[1] and Maddalena REGGIANI[2]

[1] Embry–Riddle Aeronautical University, Daytona Beach FL
[2] KU Leuven, Belgium
[*] Corresponding author: abrahae1@my.erau.edu

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Abstract

Massive stars burn bright and die young, and yet play a vital role in the evolution of our Universe. Massive stars are primarily found with companions in binary or multiple systems, but observational bias has obstructed the detection of extreme mass ratio binaries. With the advancement of high spatial resolution instrumentation, we are now poised to explore the lower end of the binary mass ratio, consisting of sub-solar, pre-main sequence stars. Here I present an analysis of seven massive stars in the young, active star-forming region M17 using data from the Spectro-Polarimetric High contrast Exoplanet REsearch (SPHERE) instrument on the Very Large Telescope. A radial velocity study of M17 by Ramirez–Tannus et al. (2017, DOI:10.1051/0004-6361/201629503) found fewer binary systems than expected. Our study is complementary to the previous work in the region to search for wide companions to massive stars in order to fill in our picture of massive star formation and the effect of multiple systems on the dynamical history of the region. SPHERE is uniquely capable of probing the lower end of the binary mass ratio due to its ground-breaking extreme adaptive optics and coronagraphic capabilities which allow us to achieve greater contrast ratios than traditional adaptive optics. We utilized the high spatial resolution imaging techniques of SPHERE in order to resolve binary systems with contrast ratios of up to 10 mag in the infrared and detect stellar companions to massive stars in the subsolar mass ranges. We present simultaneous dual-band imaging and integral-field spectroscopy of massive stars ranging from O4V–O9V. From a preliminary inspection, we found potential companions for all seven target stars. We measured flux contrast, position angles, and angular separation of our systems. Utilizing the Vortex Image Processing pipeline, we applied the negative fake companion technique in order to characterize the companions with differential magnitudes. Using this analysis, we will determine if the detected companions are foreground or field objects and estimate their mass ratio.

Keywords: massive stars, extreme mass-ratio, binary stars

1. M17 Observations with SPHERE

We present initial results from SPHERE's Infra-Red Dual-band Imager (IRDIS) which probes angular separations of less than $6''$ [1]. The IR observational capabilities of SPHERE probe the Rayleigh–Jeans tail of the spectral energy distribution, allowing for larger contrast sensitivity between primary stars and companions.

We observed seven young, bright O-type stars in M17 ($d = 1.98^{+0.14}_{-0.12}$ kpc; [2]) with SPHERE, as depicted in Fig. 1 and Table 1. These stars range in spectral type from O4V to O9V [9, 10]. We processed the images using Principle Component Analysis and Angular Differential Imaging to reduce quasistatic noise and detect sources near the central object. One of the target systems, CEN 1, has been previously determined to be a hierarchical quintuplet (see Fig. 2). Sources 0 and 19, as seen in Fig. 3, are already known as part of this system. We analyzed the science images to measure angular separation, position angle, and flux contrast for each companion in each wavelength channel. The potential companions had contrast ratios ranging from 5 to 13 mag in the infrared, as seen in Figure 4. The frequency, separation, and spectral types of the companions we measure will provide clues to the role multiplicity plays in the formation and evolution of massive stars.

2. Wide Binaries in M17

We were able to detect potential companions to all seven of our target stars including potential companions to two stars that have no previously known companions (CEN 16 and CEN 25). We found a total of 113 potential companions to the seven massive stars, indicating that the multiplicity could be as high as 100% for our sample. We detected candidate companions within

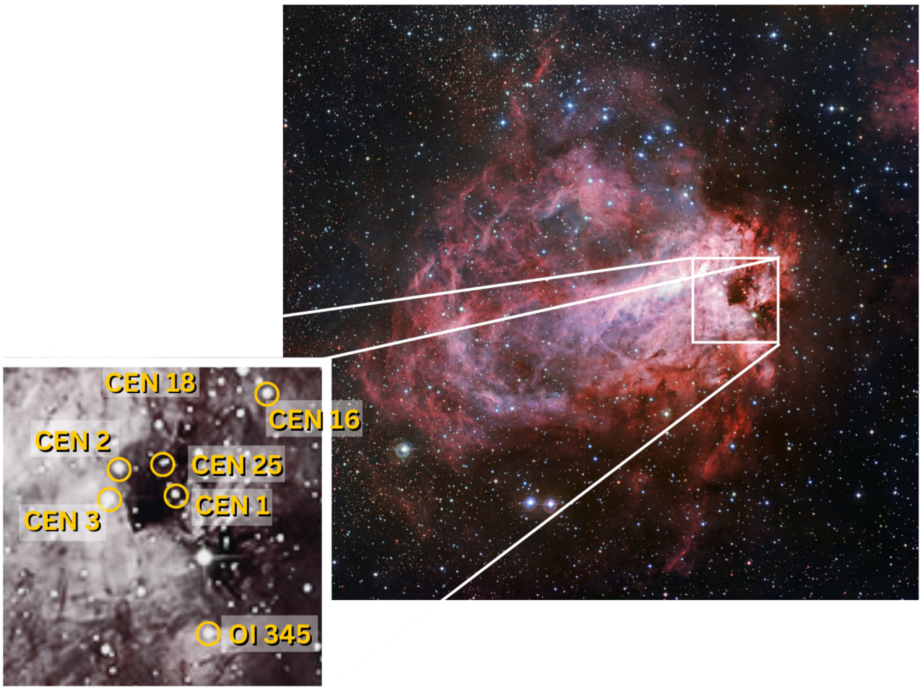

Figure 1: The M17 nebula with the region of study highlighted and the target stars circled and labeled in yellow. Image via ESO.

Table 1: Table of the targets in M17 that are studied in this proposal. The first column is the identifier used in this proposal to refer to the target star according to the nomenclature of Chini, Elsaesser, and Neckel [3], and Ogura and Ishida [4]. The second and third columns display the right ascension (α) and declination (δ) (J2000), respectively. The spectral types are listed in the fourth column with the magnitude in the fifth column.

Targets	α (J2000)	δ (J2000)	Spectral Type	V Mag.	Potential Companions	Known Companions
CEN 1	$18^h20^m29\overset{s}{.}8$	$-16°10'44''$	O4V [5]	11.5	28	4 [6]
CEN 2	$18^h20^m34\overset{s}{.}5$	$-16°10'12''$	O4.5V [7]	9.81	19	1 [6]
CEN 3	$18^h20^m35\overset{s}{.}4$	$-16°10'49''$	O9V [7]	8.95	16	1 [6]
CEN 16	$18^h20^m22\overset{s}{.}7$	$-16°08'34''$	O8.5V [8]	12.05	18	0 [7]
CEN 18	$18^h20^m25\overset{s}{.}9$	$-16°06'32''$	O6V [7]	12.07	16	2 [6]
CEN 25	$18^h20^m30\overset{s}{.}9$	$-16°10'08''$	O6V [8]	13.74	11	0 [7]
OI345	$18^h20^m27\overset{s}{.}4$	$-16°13'32''$	O6V [7]	10.58	5	2 [6]

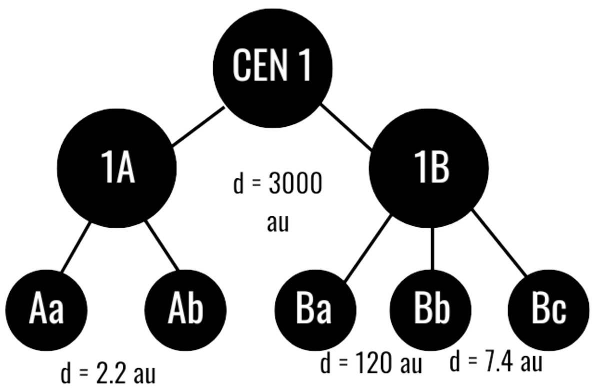

Figure 2: Schematic of the CEN 1 system.

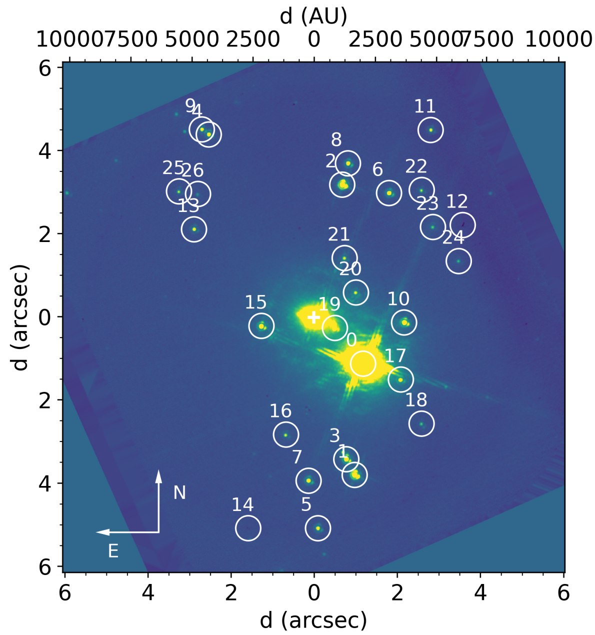

Figure 3: Reduced and combined image of CEN 1 in K_1 filter with detected companions with a signal-to-noise ratio above the threshold of 5 sigma.

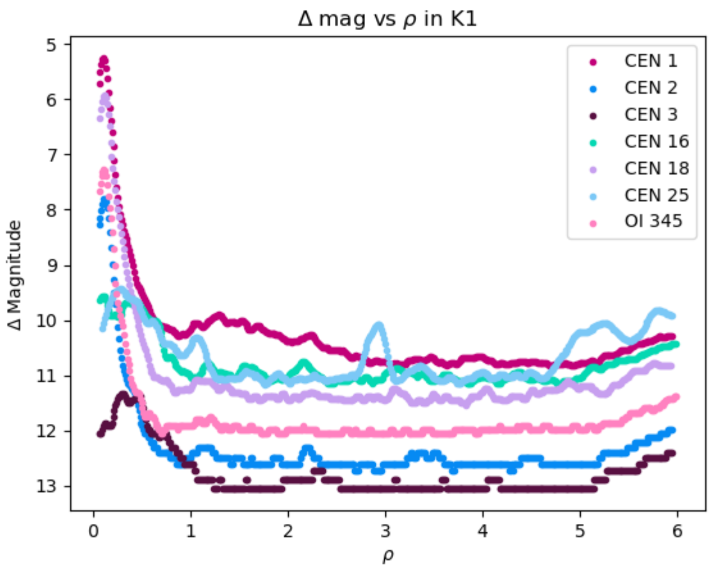

Figure 4: Plot of the differential magnitude by projected separation of all seven targets showing the detection limits of SPHERE. The ability to go down to a differential magnitude of 10 to 13 is just under 1 arcsecond.

an angular separation of 0.5″–6″ from the primary star, which corresponds to a projected separation range of about 600–10000 AU.

3. Future Work

All seven of our targets have been observed previously with the Near-Infrared Integral Field Spectrometer (NIFS) on Gemini North, using its Adaptive Optics and Natural Guide Source capabilities. Our stars were observed between April and July 2009 with Gemini and in August 2015 with SPHERE, so we will be able to use this archival data to study the companions at two epochs. The NIFS data was taken over the full range of its capabilities: 0.95–2.5 microns.

Our next steps will be to analyze data taken with SPHERE IFS to characterize all 113 potential companions and determine which ones are likely to be gravitationally bound. For IFS, we will be doing the same process as IRDIS with a signal to noise ratio calculation and spectral differential imaging rather than angular. The IFS low-resolution spectroscopic data along with the IR color information will allow us to distinguish pre-main sequence objects from foreground field stars. For example, the Brγ emission is associated with young stellar objects and extremely early O supergiants [11], but will be absent in field stars. We expect to see this emission in the NIFS data.

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Further Information

Authors' ORCID identifiers

0009-0003-9242-2541 (Erin Abraham)
0000-0002-8348-5191 (Saida M. Caballero-Nieves)
0000-0003-2911-0898 (Maddalena Reggiani)

Author contributions

E. A. contributed to writing and investigating. S. C. contributed to conceptualization and supervision, and M. R. contributed to methodology.

Conflicts of interest

The authors declare that there is no conflict of interest.

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