MAD Science Demonstration Proposal

Title: massive star clusters in the Carina nebula region:
a critical diagnostic for massive star multiplicity

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Abstract:
While the number and the nature of the companions of a massive star provide a direct signature of the formation and early evolution of these objects, accurate figures are still lacking. Targetting the massive star clusters in the Carina nebula region, we propose to use the unique capabilities of MAD to provide a deep insight into some of the fundamental nowadays questions in the massive star field : What are the multiplicity of the massive stars ? How does the properties of the massive star companions compare to the properties of the population considered as a whole ? Are the companion randomly drawn from a Salpeter IMF ?

Scientific Case:

Massive stars play a fundamental role for many fields of astronomical research. They are the main source of ionizing radiation. By their powerful winds and by their death as SNe, they are shaping the surrounding ISM. The chemical enrichment of the universe with metals is dominated by the feedback from the very massive stars as well as the UV and optical spectral energy distribution in unresolved populations like starburst galaxies is dominated by massive hot stars. Even on the cosmological side, massive stars play a critical role. First massive stars are believed to have been responsible for the re-ionization of the Universe while, since recently, massive stars are considered as probable progenitors for the GRB phenomenon.

While massive stars are often so bright that they can be studied with small telescopes up to distance of a few kilo-parsecs, our understanding of these objects is still fragmentary and simple (but fundamental) physical properties remain ill-constrained. Among the latter, their multiplicity, although generally admitted to be high, is a source of major uncertainty. It is however a key parameter that critically affects our understanding of the formation and evolution of these objects.

The lack of accurate figures reflects the actual difficulty to provide the observational data required to tackle this problem. Because massive stars are rare, hence on average far away, resolving nearby pairs is challenging. Because massive stars are also bright and because the masses (thus the luminosity) involved can be very different, disentangling those nearby pairs is even more challenging :

- Spectroscopic studies looking for the Doppler signature of a Keplerian motion have proved to be a useful tool for very close binaries, but are limited to relatively short periods and to systems with objects having masses of the same order of magnitude. As a consequence, spectroscopic studies only provide one piece of the puzzle.

- Photometric observations on the other hand allow in principle to study much wider system and to reach mass ratios close to 100, though depending of the relative properties of the objects studied.

Therefore, only by combining long-term spectroscopic monitoring with high-resolution high-dynamics astro-photometric data of a significant sample of relatively nearby objects will we be able to address the problem. While several clusters [1, 4, 5] of massive stars have been the target of such a long-term spectroscopic monitoring, the photometric data are still lacking. Only the very few massive stars in the Orion nebula have been investigated in details yielding, interestingly, a fraction of companions per massive stars as high as 1.4 [3].

Extending these investigations to a statistically significant sample of objects is however required to probe the properties of the population as a whole. However, so far, the required spatial resolution was only available from space or from AO ground-based systems. The narrow field of view (fov) of the latter, however, was requiring to observe each object individually, rendering the required amount of telescope time rather prohibitive.

In this context, the AO capabilities of MAD on a large fov combined with the sensitivity provided by an 8-m class telescope offer a unique opportunity to collect the missing photometric observations of a statistically significant set of massive stars to tackle this question.

Current project:

The Carina nebula region ($d \sim 2.3$ kpc) definitely offers one of the closest and best sample of massive stars spanning the whole mass spectrum up to about $80 M_\odot$ (Tr 16 includes η Car while Tr 14 hosts one of the very rare O2 star with an estimated zero-age mass about $80 M_\odot$). The massive stars population in the Carina nebula is spread into 6 different clusters: Tr 14, Tr 15 and Tr 16 are located in the core of the H II region and displays a compact core while Cr 228, Bo 10 and Bo 11 are slightly loser aggregates, somewhat offsets from the nebula core.

We propose to acquire high-dynamics image of the core of 5 of the 6 clusters in the Carina region. All together, these clusters shelter no less than 60 O-type stars, and over a hundred early B objects [6]. Their multiplicity has already been addressed using spectroscopic data and only appropriate photometric data are missing. While the K-band is the best suited for the purpose of finding the companions (better AO correction, better contrast between early-type stars and late-type companions), completing these observations with J and H filters will further allow us to better characterize the nature of the companions.

The obtained data will allow us to probe the mass-function distribution of the massive star companions. Comparing the latter with the (possibly revised) mass function in the core of these clusters, one will be able to address the following questions : are the companion of massive stars drawn randomly from the same initial mass function than the cluster population ? If not, what are the properties of such mass function ? Answering the latter questions will bring strong constraints on the formation and early evolution of the massive stars. [2, 8]

Summary:

All in all, this project will provide us with **a unique characterization of the massive star environment and companionship** the clusters in the Carina region, **increasing the number of objects studied with such an accuracy by over one order of magnitude**. By bringing to firmer ground the estimation of the number of companion per massive stars and by investigating the global properties of the companion population, **the obtained data set will provide key observational guidelines to one of the nowadays most critical astrophysical questions : how do massive stars form ?**

1. Garcìa & Mermilliod 2001, A&A 368, 122
2. Malkov & Zinnecker 2001, MNRAS 321, 149
3. Preibisch et al. 2001, IAU Symp., 200, 69
4. Sana 2005, PhD thesis, Liège University
5. Sana et al. 2007, MNRAS, in press
6. Smith 2006, MNRAS 367, 763
7. Tapia et al. 2003, MNRAS 339, 44
8. Weidner & Kroupa 2007, MNRAS, submitted

Targets and integration time

Target	**RA**	**DEC**	**Filter**	**Magnitudes**	**Total integration time** (sec)	**Field** (arcmin)
Tr 14	10 43 57	-59 32 53	J	J=6.2-19	150	2
Tr 14	10 43 57	-59 32 53	H	H=6.1-19	150	2
Tr 14	10 43 57	-59 32 53	Ks	K=6.0-17	300	2
Tr 16	10 45 03	-59 41 03	J	J=7.7-19	150	2
Tr 16	10 45 03	-59 41 03	H	H=7.7-19	150	2
Tr 16	10 45 03	-59 41 03	Ks	K=7.6-17	300	2
Tr 15	10 44 42	-59 51 59	J	J=9.0-19	150	2
Tr 15	10 44 42	-59 51 59	H	H=9.0-19	150	2
Tr 15	10 44 42	-59 51 59	Ks	K=9.0-17	300	2
Cr 228	10 43 52	-60 06 06	J	J=9.1-19	150	2
Cr 228	10 43 52	-60 06 06	H	H=8.7-19	150	2
Cr 228	10 43 52	-60 06 06	Ks	K=8.6-17	300	2
Bo 11	10 47 15	-60 05 41	J	J=7.2-19	150	2
Bo 11	10 47 15	-60 05 41	H	H=7.1-19	150	2
Bo 11	10 47 15	-60 05 41	Ks	Ks=6.8-17	300	2

Guide stars list and positions

Target: Tr 14			
	RA$''_{rel}$	**DEC**$''_{rel}$	**V Mag**
GS1	10:43:48.82	-59:33:24.8	10.7
GS2	10:43:59.92	-59:32:25.4	9.3
GS3	10:43:57.69	-59:33:39.2	11.2
Target: Tr 15			
GS1	10:44:40.60	-59:22:28.4	10.6
GS2	10:44:40.99	-59:21:11.9	11.0
GS3	10:44:46.86	-59:21:52.6	11.6
Target: Tr 16			
GS1	10:45:05.85	-59:40:06.4	8.2
GS2	10:45:11.21	-59:41:11.3	10.8
GS3	10:44:57.96	-59:41:03.5	11.8
Target: Cr 228			
GS1	10:43:52.26	-60:07:04.0	6.5
GS2	10:43:46.98	-60:05:49.3	9.7
GS3	10:44:00.43	-60:06:00.0	8.8
Target: Bo 11			
GS1	10:47:12.49	-60:05:49.9	8.4
GS2	10:47:22.08	-60:05:57.7	10.7
GS3	10:47:15.84	-60:05:39.9	10.3

Time Justification:

To be able to probe the low-mass end of the companion mass-function down to 0.5 $M_\odot$, one needs to reach magnitude K$\sim$17. To have an unambiguous detection, one further requires to reach SNR>10. Given the specification of CAMCAO, this corresponds to total integration time of 300s in the K-band. Corresponding magnitude are reached in the J and H band using 150 sec (also accounting for the lower emissivity of the low mass stars in this range).

Ideal case: 10.5h Accounting for the 5 point dither pattern to cover the 2'x2' fov, plus one minute overhead per point in the dither pattern and 20 min overhead to acquire the object, one obtains a total on sky time of 5x(300+60)+1200s=3000s in the K band and 5x(150+60)+1200=2250s in the J and H bands, yielding 2.1h per cluster. Summing over the 5 clusters yields 10.5h.

Reduced case: While studying the all 6 clusters in the Carina region would definitely maximize the scientific output, one could also aim for a less extended study according to the following scheme:

- **6.3h:** Tr 14, Tr 15, Tr 16 display the densest cores and the largest massive star population. They are thus our prime targets.
- **8.4h:** Cr 228 is considered by some authors as being part of Tr16 [6] and one would definitely benefit to include it in the analysis as it also display a rich massive star population.
- **10.5h:** Bo 11 is a secondary target. Displaying a handful O-type stars only, the main interest reside in the lack of detailed study so far. Being looser and offset from the nebula core, the analysis will definitely be easier. As a consequence, though secondary, it is a very straightforward target.
- NOTE: Bo 10 is the 6th cluster in the Carina region. Being far less compact, its core does not even fill-in the 2'x2' fov. As it contains only 2 massive stars (1 late O-type star + 1WC6 star), we do not include it in the list of proposed target as the scientific gain is not worth the additional telescope time needed.