Evolved Massive Stars at Low-metallicity
A Source Catalog for the Small Magellanic Cloud

myang@noa.gr

Ming Yang[1], Alceste Bonanos[1], Bi-Wei Jiang[2], Jian Gao[2], Panagiotis Gavras[3], Grigoris Maravelias[1], Yi Ren[2], Shu Wang[4], Meng-Yao Xue[5], Frank Tramper[1], Zoi Spetsieri[1], Ektoras Pouliasis[1] and Stephan A. S. de Wit[1]

[1]IAASARS, National Observatory of Athens, Penteli, Greece, [2]Department of Astronomy, Beijing Normal University, Beijing, China, [3]Rhea Group for ESA/ESAC, Madrid, Spain, [4]National Astronomical Observatories, Chinese Academy of Sciences, Beijing, China, [5]ICRAR, Curtin University, Bentley, Australia

Summary

We present a clean, magnitude-limited (IRAC1 or WISE1 ≤ 15.0 mag) multiwavelength source catalog for the SMC with 45,466 targets in total, with the purpose of building an anchor for future studies, especially for the massive star populations at low-metallicity. The catalog contains data in 50 different bands including 21 optical and 29 infrared bands, ranging from the ultraviolet to the far-infrared. Additionally, radial velocities and spectral classifications were collected from the literature, as well as infrared and optical variability statistics were retrieved from different datasets. The catalog was essentially built upon a 1″ crossmatching and a 3″ deblending between the SEIP source list and *Gaia* DR2 photometric data. Further constraints on the proper motions and parallaxes from *Gaia* DR2 allowed us to remove the foreground contamination. We estimated that about 99.5% of the targets in our catalog were most likely genuine members of the SMC. By using the evolutionary tracks and synthetic photometry from MIST and the theoretical J−Ks color cuts, we identified 1,405 RSG, 217 YSG and 1,369 BSG candidates in the SMC in five different CMDs. We ranked the candidates based on the intersection of different CMDs. A comparison between the models and observational data shows that the lower limit of initial masses for the RSGs population may be as low as 7 or even 6 M⊙, making RSGs a unique population connecting the evolved massive and intermediate stars, since stars with initial mass around 6 to 8 M⊙ are thought to go through a second dredge-up to become AGBs. We encourage the interested reader to further exploit the potential of our catalog.

Sample Selection

The catalog was essentially built upon a 1″ crossmatching and a 3″ deblending between *Spitzer* Enhanced Imaging Products (SEIP) source list and *Gaia* DR2 photometric data, with **limiting magnitude of IRAC1 or WISE1 ≤ 15.0 mag**. We further constrained the proper motions (PMs) and parallaxes from *Gaia* DR2 to remove the foreground contamination. **The membership of the SMC was defined by a Gaussian profile of the parallax with an additional elliptical constraint derived from $PM_{R.A.}$ and $PM_{Decl.}$** (the 5σ limits of Gaussian profile fitting in $PM_{R.A.}$ and $PM_{Decl.}$ were taken as the primary and secondary radii, respectively), which resulted in **45,466 targets** as shown in Figure 1 and 2. We estimated that about **99.5%** of the targets in our catalog were most likely to be genuine members of the SMC. Figure 3 illustrates the *Gaia* color-magnitude diagram (CMD) before (gray) and after (red) applying the astrometric constraints, where the large amount of foreground contamination is swept out.

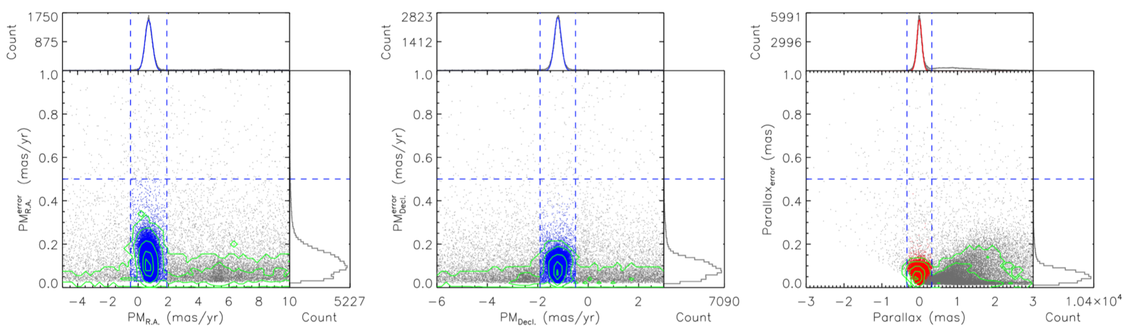

Figure 1. Evaluation of the *Gaia* astrometric solution. Errors are limited to 0.5 as shown by the horizontal dashed lines. Gaussian profiles are fitted to $PM_{R.A.}$, $PM_{Decl.}$, and parallax and the limits of ±5σ are calculated (vertical dashed lines), while an additional elliptical constraint is also applied to the parallax with the 5σ limits of $PM_{R.A.}$ and $PM_{Decl.}$ taken as the primary and secondary radii, respectively.

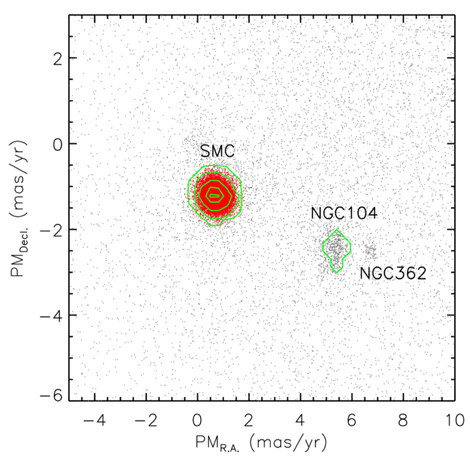

Figure 2. $PM_{R.A.}$ versus $PM_{Decl.}$ diagram, in which the separation of selected SMC members (red), NGC104 and NGC362 is clearly shown.

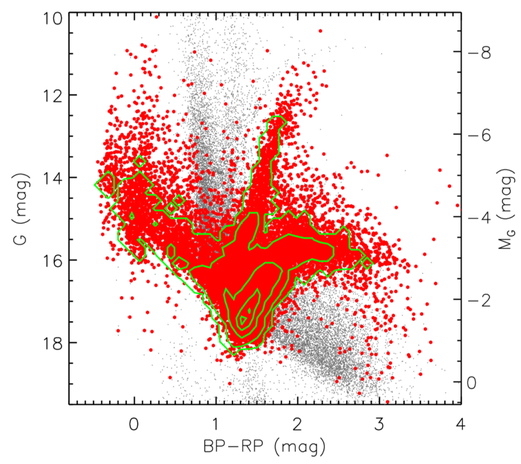

Figure 3. G versus BP-RP diagram for the *Gaia* data before (gray) and after (red) the astrometric constraints, where the large number of foreground contamination is swept out.

References

Bonanos, A. Z., et al., 2010, AJ, 138, 1003
Boyer, M. L., et al., 2011, AJ, 142, 103
Choi, J., et al., 2016, ApJ, 823, 102
Cioni, M.-R. L., et al., 2006, A&A, 448, 77
Cioni, M.-R. L., et al. 2011, A&A, 527, A116
Gaia Collaboration, et al., 2018, A&A, 616, A1
Gonzalez-Fernandez, et al., 2015, A&A, 578, A3
Ita, Y., et al., 2010, PASJ, 62, 273
Kato, D., et al., 2007, PASJ, 59, 615
Nidever, D. L., et al., 2018, AJ, 156, 131
Wolf, C., et al., 2018, PASA, 35, e010
Yang, M., et al., 2018, A&A, 616, A175

Multiwavelength Source Catalog and Time-Series Data

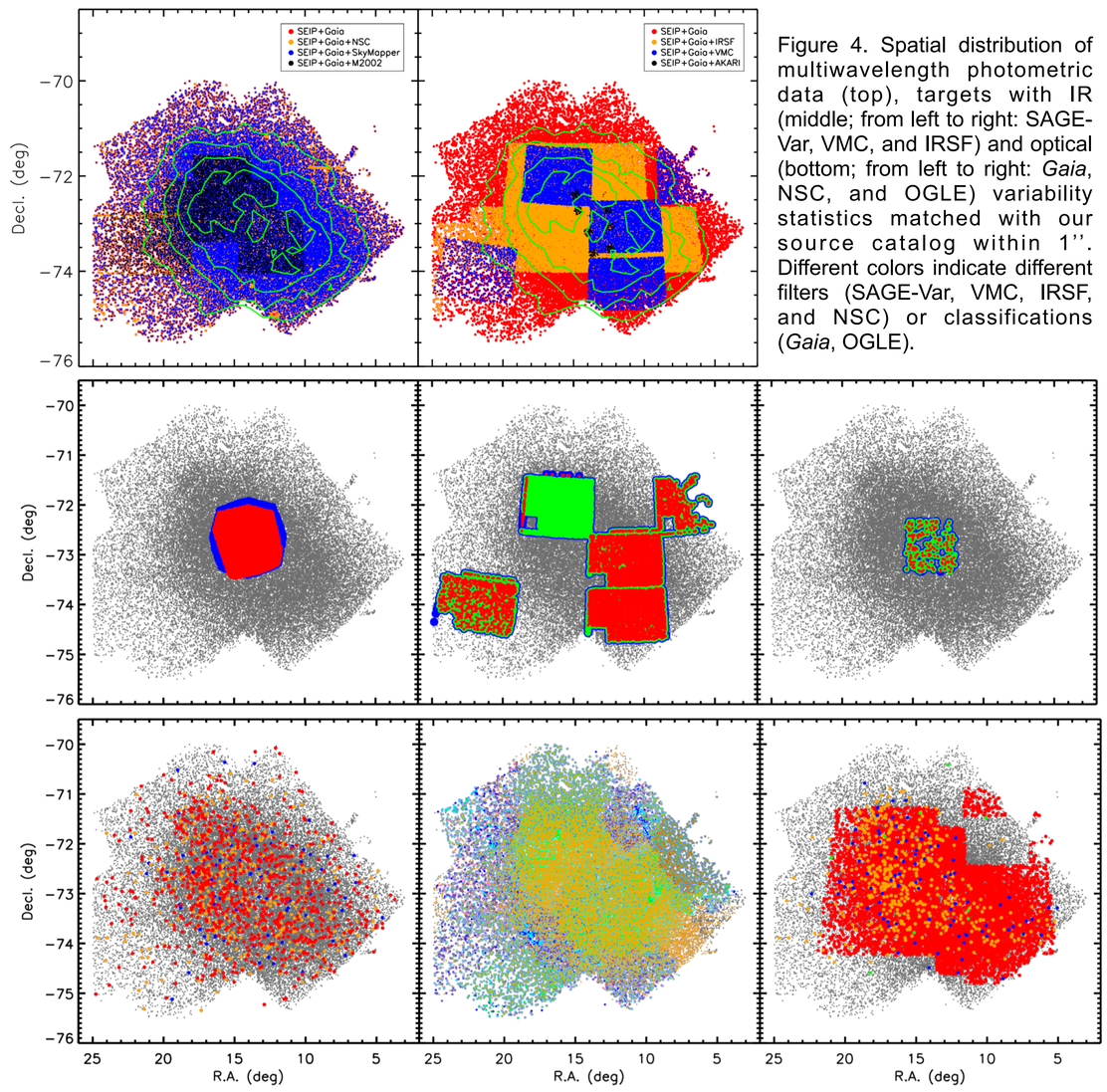

Figure 4. Spatial distribution of multiwavelength photometric data (top), targets with IR (middle; from left to right: SAGE-Var, VMC, and IRSF) and optical (bottom; from left to right: *Gaia*, NSC, and OGLE) variability statistics matched with our source catalog within 1″. Different colors indicate different filters (SAGE-Var, VMC, IRSF, and NSC) or classifications (*Gaia*, OGLE).

We retrieved **multiwavelength photometric data in 50 different bands** from SEIP, VMC, IRSF, AKARI, HERITAGE, *Gaia*, SkyMapper, NSC, Massey et al. (2002), and *GALEX*, as well as **infrared and optical variability statistics (MAD, SD, Amp)** from *WISE*, SAGE-Var, VMC, IRSF, *Gaia*, NSC, and OGLE as shown in Figure 4.

Evolved Massive Stars Candidates

By using the evolutionary tracks and synthetic photometry from MIST and also the theoretical J−Ks color cuts (only for RSGs), we identified three evolved massive star populations in the SMC, namely the BSGs, YSGs and RSGs, in five different CMDs (*Gaia*, SkyMapper, NSC, M2002 and 2MASS). Figure 5 shows one example of 2MASS CMD. **There are 1,405 RSG, 217 YSG and 1,369 BSG candidates, respectively.** We ranked (Rank 0 to 5) the candidates based on the intersection between different CMDs, where Rank 0 indicated that a target was identified as the same type of evolved massive star in all five CMDs by the MIST models and so on, and Rank 5 indicated the additional RSG candidates identified by the J−Ks color cuts but not recovered by the MIST models as shown in Figure 6. Regarding to the spatial distribution of evolved massive star candidates, it is clearly shown that due to the interaction between LMC and SMC, a bunch of candidates are stretched towards the Magellanic Bridge as shown in Figure 7.

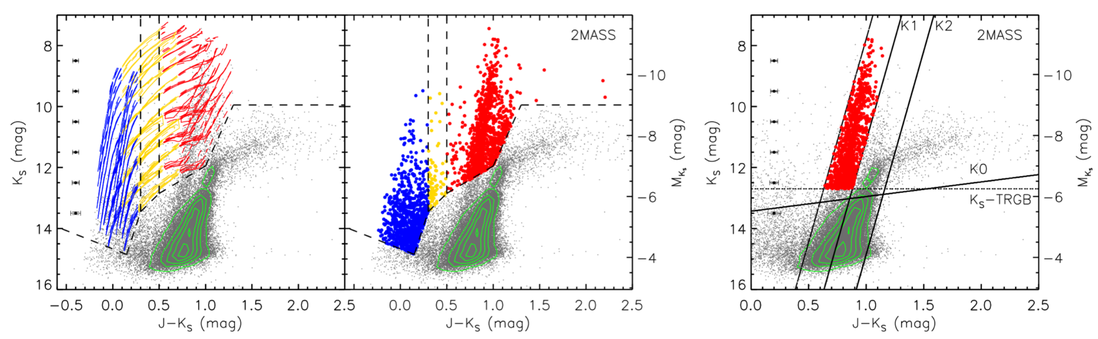

Figure 5. Ks versus J−Ks diagram for the 2MASS dataset. The left panel shows the massive star candidates selected by MIST tracks, which are color coded by the equivalent evolutionary phases of BSGs (blue), YSGs (yellow), and RSGs (red). The right panel shows the selection of RSGs candidates by using the theoretical J−Ks color cuts.

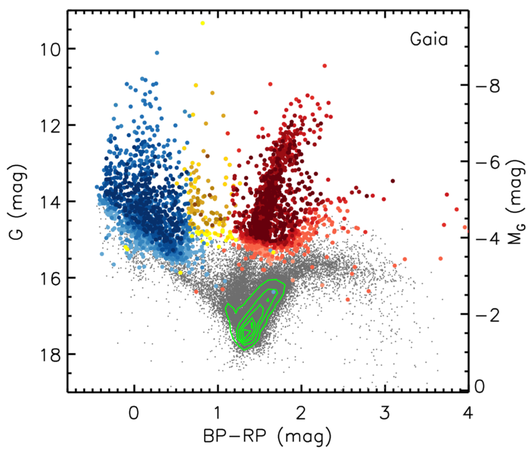

Figure 6. CMD of *Gaia* dataset with RSG (red), YSG (yellow), and BSG (blue) candidates colors coded from dark (Rank 0) to light (Rank 5).

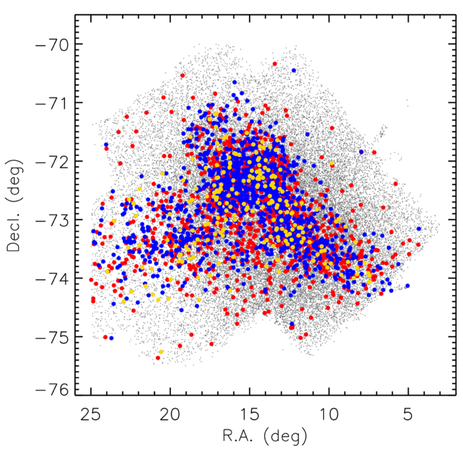

Figure 7. Due to the interaction between LMC and SMC, a bunch of evolved massive star candidates are stretched towards the MB.