Recent interests and results: Bright stars in the Disk of the Milky Way

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My latest publications are about (a) the properties of Galactic red supergiants and (b) the content of evolved massive stars in giant molecular clouds.

Bright late-type stars in the Galaxy

Massive stars allow for a morphological and kinematic mapping of the youngest components of the Milky Way, such as spiral arms and the central 200 pc disk. Massive stars are a measure of the youth and thickness of the disk, and they can be used to map variations of chemical abundances in the disk. Among them, red supergiants (RSGs) are cool stars with temperatures from 4500 K to 3000 K and ages from 8 to 30 Myr. Unfortunately, uncertain distances and dust obscuration of the inner regions hamper the detection of most RSGs, which remain hidden in a sea of AGB stars with similar properties. In order to study the morphology and evolution of the Milky Way, it is crucial to distinguish RSGs from AGB stars. The spatial distribution of RSGs in the Galactic disk suffers from small number statistics (less than 1,000 RSGs are known in the whole Galaxy and more than 5,000 expected). Inspired by this science curiosity, we have undertaken a study of Galactic RSGs. We searched for matches in the Gaia DR2 catalog to about 1400 known candidate RSGs, which were collected and listed by Skiff 2016 (Messineo M., Brown, A. G. A., 2019, AJ, 158, 20). We counted 43 stars (5%) brighter than the AGB luminosity limit (Mbol=-7.1 mag) and we estimated that at least 41% of the stars brighter than Mbol=-5.0 mag, of spectral type earlier than M4, are more massive than 7 $M_{\odot}$ making them likely RSGs. We searched for new obscured Galactic RSGs in the GLIMPSE I North area of the inner Galaxy and increased their number by 25%, by discovering about 60 secure RSGs (Messineo et al. 2017, ApJ, 836, 65). We searched for isolated RSGs, using GLIMPSE I North data points and the color criteria developed by Messineo et al. (2012, A&A, 537, A10). Only 2% of the new RSGs are located in the direction of known stellar clusters.

Recently, we analyzed low-resolution spectra (R=2000) of late-type stars covering from 0.7 to 2.4 µm (Messineo et al. 2021, AJ, 162, 187), and identified five lines correlating in strengths with the stellar luminosity (from 1.16 µm to 1.29 µm due to Fe, Ti, Mn, and Ca). These atomic lines help us to distinguish RSGs from AGBs. Usually, the presence of continuum absorption due to water vapor is used, but in about 7% of RSGs water vapor is also seen.

Bright evolved early-type massive stars in giant molecular complexes

Massive stars form continuously, generating new HII regions within their natal giant molecular clouds, and chemically enriching the interstellar medium. We searched for massive evolved stars and young clusters in two giant molecular clouds (e.g. Messineo et al. 2014 A&A, 569, 20; 2015, ApJ, 805, 110). The spatial and temporal distribution of these massive stars yields information on the star formation history of the clouds. W33 is characterized by discrete sources and is a younger active cloud with only 3-5 Myr of star formation history, which is now propagating from west to east. Some bubbles decorate the surroundings of the detected massive stars. The GLIMPSE survey has unveiled several hundred Galactic bubbles, which marvelously decorate the spiral arms of the Milky Way. Despite the detection of an associated HII region, no stellar clusters are detected in about 40% of the bubbles and the identification of sparse ionizing stars is quite challenging (Messineo et al. 2018, ApJ 201, 862, 10; Messineo et al. 2015, ApJ, 805, 110). These bubbles are active regions of star formation as demonstrated by the presence of numerous proto-stars and pre-stellar cores detected at millimetric wavelengths. While massive stars are preferentially located at the center of the bubble, the compact molecular clumps nicely mark a shell surrounding the bubble.

Forthcoming developments

There are many new Galactic investigations to be carried out in this new era of deep photometric data and high-resolution spectroscopic surveys. This is the epoch of Galactic cross-matching science and data mining. The already available infrared-photometric surveys 2MASS, DENIS, UKIDSS, VISTA, VVV, GLIMPSE, WISE, MSX allow us to identify obscured inner Galactic stars and to roughly characterize their stellar energy distribution. The VPHAS+ surveys enable us to identify massive evolved stars with winds and line emissions. GAIA, PANNSTAR, and the forthcoming LSST surveys provide light curves. Parallactic distances, spectral types, and radial velocities will be available for more than a million stars from Gaia DR4. While WFIRST-AFTA surveys will enable us to transfer our Galactic knowledge to the Virgo cluster, to analyze and characterize the detected brightest stars.

In the next decade, millions of Galactic high-resolution stellar spectra at optical wavelengths will be at our disposal from LAMOST, GALAH, and 4MOST surveys. The full exploitation of the infrared APOGEE spectral database will bring further discoveries in the inner Galaxy.

In the future, I would like to continue my current studies of Galactic stars with high and intermediate masses, such as the spectroscopic and photometric characterization of bright-evolved stars in giant molecular complexes, and their distribution in the Galactic disk. A summary of possible future works is provided below. The proposed work may serve as a preparation for future studies of massive stars in extragalactic galaxies with the E-ELT, the Thirty Meter telescopes, and the WFIRST-AFTA satellite mission.

Massive stars, molecular complexes, and supernovae remnants

Massive stars lose mass at high rates and end their lives as core-collapse supernovae. It has been traditionally assumed that young and populous massive clusters host the most massive stars, such as Wolf-Rayet (WR) stars, luminous blue variables (LBVs), and red supergiants (RSGs). Massive stars form continuously, generating new HII regions within their natal giant molecular cloud and supernovae (SN) remnants when they die.

By analyzing the content of bright-evolved massive stars within giant molecular complexes, one can determine the surface density of evolved massive stars and relative isolation and infer clues on the best models of massive star formation of their cloud (for example monolithic collapse versus hierarchical star formation).

Massive stars with initial masses from 8 to 25 $M_{\odot}$ will all explode and likely produce neutron stars and stars more massive than that even black holes. However, very few pulsars and (core-collapse) supernova remnants are known to be associated with young stellar clusters; spatial coincidences are mostly random super-positions along the same line of sight. Why aren't SN remnants associated with young and massive stellar clusters? Clusters with ages from a few to 30 Myr contain massive explosive stars, while the remnants only survive about 500000 yr. It is likely that stellar ejections bring the most massive stars away from the stellar clusters and/or the bulk of explosive stars are sparsely populating molecular complexes/associations.

This has brought me to search for evolved massive stars in extended complexes of the Milky Way rich in SN remnants and I would like to continue with the identification of massive stars/lose associations in the direction of known SNRs. By definition, supernova remnants are rarely associated with giant HII regions. Indeed, they are detected and classified as strong synchrotron emission not associated with mid-IR emission. Indeed, the SN remnants listed in the catalog of Green (2014) are not associated with the giant HII regions listed by Conti & Crowther (2004). This is partially due to an observational bias and partially to the fact that these bright Lyman continuum reservoirs are still too young. For example, the most massive stars seen in W33 have ages from 2-4 Myr. Perhaps, the most massive, and evolved massive stars, the analogous of Eta Carina are hidden in more evolved HII regions, with a good example being the extended HII region G332.809-0.132 (Rahman & Murray 2010). G332.809-0.132 coincides with the Nor OB4 association reported by Alter (1970). It is rich in SNRs and X-ray sources and is located at (l,b)=(332°,-0.132°) (Messineo et al. 2020, AJ, 160, 65). In the core of G332.809-0.132 (80 pc size), more than 100 OB stars were identified and several candidate free-free emitters, including IRAS 16115-5044. Free-free emitters are 4 pc distant from an OB star. This IRAS star is a rare LBV (Figer, D.F. et al. 2020 ApJL, 901, 15), with only ≈20 other LBV stars known in the entire Milky Way.

Gaia DR4 data will release radial velocities, parallaxes, and spectral of 1.5 billion stars. I may study the connections between the optical associations (Alter's catalog) and the extended HII regions seen at radio and mid-infrared wavelengths. There are 14 HII regions listed in the work of Rahman & Murray (2010). I plan to search for rare ionizing massive sources in some extended HII regions. The spatial and temporal distribution of these massive stars yields information on the star formation history of the clouds and reveals some of the most massive stars.

The galactic highway: arms traced by red supergiants

In the next decade, enormous progress is foreseen on our Galactic knowledge of late-type stars. I would like to continue some observational studies, several being already possible with currently available archival data. For example, ***i)*** Gaia DR4 in 2024 will allow us to obtain the first ever-made initial mass function of Galactic red supergiants (RSGs) located within 2 kpc from the Sun, by providing spectral types and parallactic distances. ***ii)*** Since, infrared light is 10 times less affected by dust obscuration than visual light, and enables us to penetrate the Galactic center region and even behind it, we should detect the entire population of luminous late-type stars in the near side of the Galaxy. Their distances are often uncertain and complicated by uncertain luminosities (due to large amplitude photometric variations), while the colors and low-resolution spectra of asymptotic giant branch stars (AGBs) and RSGs are very similar. Time-domain data and spectroscopy will allow us to separate the bulk of Mira AGB stars from RSGs. Mira AGBs have very large amplitudes. **iii)** The enormous amount of upcoming spectroscopic survey data at high-resolution and with large wavelength coverage will enable to establish a secure chemical clock also for cool late stars of high and intermediate masses. ***iv)*** The spatial distribution of RSGs in the Galactic disk suffers from small number statistics (less than 1,000 RSGs are known in the whole Galaxy and more than 5,000 expected), but it should be very different than that of AGBs. While AGBs are excellent tracers of the Galactic Bar, RSGs should be absent there, being mostly concentrated along the spiral arms, as recently seen in M33 and M31. There could be substantial differences in the properties of RSGs associated with the various spiral arms.

In conclusion, the lines of sights to the inner and obscured Galaxy are complicated by the overlap of several spiral arms. Radial velocities determinations are needed to properly map the distribution of RSGs. We shall wait for Gaia DR4, which will provide spectral types and radial velocities. We will improve our existing knowledge of Galactic large-scale morphology and history, and draw the first Galactic highway map of RSGs.

v) The study of cool bright stars is hampered by our poor knowledge of the mechanism of mass-loss, which also determines the presence of extended envelopes, where maser emission from SiO, H_2O, or OH molecules may arise. The availability of multi-wavelength photometric and spectroscopic data will enable a proper study of their stellar energy distribution and its connections with the maser shells.

vi) Surprisingly, Gaia proper motion anomalies suggest that a large fraction of RSGs is made of binaries. A fine work of comparison between observations and revised stellar tracks is needed to refine the suggested relations between colors, luminosities, and mass loss.