THE MAGELLANIC CLOUDS NEWSLETTER

An electronic publication dedicated to the Magellanic Clouds, and astrophysical phenomena therein

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Editor: Jacco van Loon

Editorial

Dear Colleagues,

It is my pleasure to present you the 178th issue of the Magellanic Clouds Newsletter. It highlights plenty of interesting new results, but do also pay attention to the conference proceedings as these are where sometimes opportunities are taken to share thoughts that may be speculative or perspectual – where one can allow to be philosophical, as opposed to the often mechanistic research industry.

Because of the way IT infrastructure is changing at my institution it is unclear whether I will be able to continue to host the Magellanic Clouds Newsletter.

The next issue is still hoped to be distributed on the 1st of October.

Editorially Yours,
Jacco van Loon

Refereed Journal Papers

Properties of the Be-type stars in 30 Doradus

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The evolutionary status of Be-type stars remains unclear, with both single-star and binary pathways having been proposed. Here, VFTS spectroscopy of 73 Be-type stars, in the spectral-type range, B0–B3, is analysed to estimate projected rotational velocities, radial velocities and stellar parameters. They are found to be rotating faster than the corresponding VFTS B-type sample but simulations imply that their projected rotational velocities are inconsistent with them all rotating at near critical velocities. The de-convolution of the projected rotational velocities estimates leads to a mean rotational velocity estimate of 320–350 km s^{-1}, approximately 100 km s^{-1} larger than that for the corresponding B-type sample. There is a dearth of targets with rotational velocities less than 0.4 of the critical velocity, with a broad distribution reaching up to critical rotation. Our best estimate for the mean or median of the rotational velocity is 0.68 of the critical velocity. Rapidly-rotating B-type stars are more numerous than their Be-type counterparts, whilst the observed frequency of Be-type stars identified as binary systems is significantly lower than that for normal B-type stars, consistent with their respective radial-velocity dispersions. The semi-amplitudes for the Be-type binaries are also smaller. Similar results are found for a SMC Be-type sample centred on NGC 346 with no significant differences being found between the two samples. These results are compared with the predictions of single and binary stellar evolutionary models for Be-type stars. Assuming that a single mechanism dominated the production of classical Be-type stars, our comparison would favour a binary evolutionary history.

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Constraining the Milky Way halo kinematics via its linear response to the Large Magellanic Cloud

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We model the response of spherical, non-rotating Milky Way (MW) dark matter and stellar halos to the Large Magellanic Cloud (LMC) using the matrix method of linear response theory. Our computations reproduce the main features of the dark halo response from simulations. We show that these features can be well separated by a harmonic decomposition: the large scale over/underdensity in the halo (associated with its reflex motion) corresponds to the $\ell = 1$ terms, and the local overdensity to the $\ell \geq 2$ multipoles. Moreover, the dark halo response is largely dominated by the first order "forcing" term, with little influence from self-gravity. This makes it difficult to constrain the underlying velocity distribution of the dark halo using the observed response of the stellar halo, but it allows us to investigate the response of stellar halo models with various velocity anisotropies: a tangential (respectively radial) halo produces a shallower (respectively stronger) response. We also show that only the local wake is responsible for these variations, the reflex motion being solely dependent on the MW potential. Therefore, we identify the structure (orientation and winding) of the in-plane quadrupolar ($m = 2$) response as a potentially good probe of the stellar halo anisotropy. Finally, our method allows us to tentatively relate the wake strength and shape to resonant effects: the strong radial

response could be associated with the inner Lindblad resonance, and the weak tangential one with corotation.

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A transparent window into early-type stellar variability

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Subsurface convection zones are ubiquitous in early-type stars. Driven by narrow opacity peaks, these thin convective regions transport little heat but play an important role in setting the magnetic properties and surface variability of stars. Here we demonstrate that these convection zones are not present in as wide a range of stars as previously believed. In particular, there are regions which 1D stellar evolution models report to be convectively unstable but which fall below the critical Rayleigh number for onset of convection. For sub-solar metallicity this opens up a stability window in which there are no subsurface convection zones. For Large Magellanic Cloud metallicity this surface stability region extends roughly between 8 and 16 $M_\odot$, increasing to 8–35 $M_\odot$ for Small Magellanic Cloud metallicity. Such windows are then an excellent target for probing the relative influence of subsurface convection and other sources of photometric variability in massive stars.

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The VISCACHA survey – IV. The SMC West Halo in 8D

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The structure of the Small Magellanic Cloud (SMC) is very complex, in particular in the periphery that suffers more from the interactions with the Large Magellanic Cloud (LMC). A wealth of observational evidence has been accumulated revealing tidal tails and bridges made up of gas, stars, and star clusters. Nevertheless, a full picture of the SMC outskirts is only recently starting to emerge with a 6D phase-space map plus age and metallicity using star clusters as tracers. In this work, we continue our analysis of another outer region of the SMC, the so-called West Halo, and combined it with the previously analysed Northern Bridge. We use both structures to define the Bridge and Counter-bridge trailing and leading tidal tails. These two structures are moving away from each other, roughly in the SMC–LMC direction. The West Halo form a ring around the SMC inner regions that goes up to the background of the Northern Bridge shaping an extended layer of the Counter-bridge. Four old Bridge clusters were identified at distances larger than 8 kpc from the SMC centre moving towards the LMC, which is consistent with the SMC–LMC closest distance of 7.5 kpc when the Magellanic Bridge was formed about 150 Myr ago; this shows that the Magellanic Bridge was not formed only by pulled gas, but it also removed older stars from the SMC during its formation. We also found age and metallicity radial gradients using projected distances on sky, which are vanished when we use the real 3D distances.

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and from https://ui.adsabs.harvard.edu/abs/2022MNRAS.512.4334D/abstract

The OGLE Collection of Variable Stars. One thousand heartbeat stars in the Galactic bulge and Magellanic Clouds

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We present a collection of 991 heartbeat star (HBS) candidates found in the Optical Gravitational Lensing Experiment (OGLE) project data archive. We discuss the selection process of the HBS candidates and the structure of the catalog itself. It consists of 512 stars located toward the Galactic bulge, 439 stars located in the Large Magellanic Cloud, and 40 in the Small Magellanic Cloud. The collection contains two large groups of HBSs with different physical properties. The main distinction between the two groups is the evolutionary status of the primary star. The first group of about 100 systems contains a hot main-sequence or a Hertzsprung-gap primary star, while the second group of about 900 systems includes a red giant. For each star, we provide two-decade-long time-series photometry, in the Cousins I- and Johnson V-band filters, obtained by the OGLE project. We also present basic observational information as well as orbital parameters derived from the light-curve modeling.

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Photometric analysis of the OGLE heartbeat stars

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We present an analysis of 991 heartbeat stars (HBSs) from the OGLE Collection of Variable Stars. The sample consists of 512 objects located toward the Galactic bulge, 439 in the Large Magellanic Cloud, and 40 in the Small

Magellanic Cloud. We model the I-band OGLE light curves using an analytical model of flux variations reflecting tidal deformations between stars. We present distributions of the model parameters that include the eccentricity, orbital inclination, and argument of the periastron but also the period–amplitude diagrams. On the Hertzsprung–Russell diagram, our HBS sample forms two separate groups of different evolutionary status. The first group, including about 90 systems with short orbital periods ($P \lesssim 50$ days), consists of an early-type primary star lying on (or close to) the main sequence. The second group, including about 900 systems with long orbital periods ($P \gtrsim 100$ days), contains a red giant (RG). The position of the RG HBSs on the period–luminosity (PL) diagram strongly indicates their binary nature. They appear to be a natural extension of confirmed binary systems that include the OGLE ellipsoidal and long secondary period variables. We also present a time-series analysis leading to detection of tidally excited oscillations (TEOs). We identify such pulsations in about 5% of stars in the sample with a total of 78 different modes. This first relatively large homogeneous sample of TEOs allowed us to construct a diagram revealing the correlation between the TEO's orbital harmonic number and the eccentricity of the host binary system.

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First evidence of a stripped star cluster from the Small Magellanic Cloud

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We present results on the recently discovered stellar system YMCA-1, for which physical nature and belonging to any of the Magellanic System galaxies have been irresolutely analyzed. We used SMASH and Gaia EDR3 data sets to conclude that we are dealing with a small star cluster. Its reddening free, field star decontaminated colour–magnitude diagram was explored in order to obtain the cluster parameters. We found that YMCA-1 is a small (435 $M_\odot$), moderately old (age = 9.6 Gyr), moderately metal-poor ([Fe/H] = -1.16 dex) star cluster, located at a nearly Small Magellanic Cloud (SMC) distance (60.9 kpc) from the Sun, at $\sim$ 17.1 kpc to the East from the Large Magellanic Cloud (LMC) centre. The derived cluster brightness and size would seem to suggest some resemblance to the recently discovered faint star clusters in the Milky Way (MW) outer halo, although it does not match their age–metallicty relationship, nor those of MW globular clusters formed *in situ* or *ex situ*, nor that of LMC clusters either, but is in agreement with that of SMC old star clusters. We performed numerical Monte Carlo simulations integrating its orbital motion backward in the MW–LMC–SMC system with radially extended dark matter haloes that experience dynamical friction, and by exploring different radial velocity (RV) regimes for YMCA-1. For RVs $\gtrsim 300$ km s^{-1}, the cluster remains bound to the LMC during the last 500 Myrs. The detailed tracked kinematic of YMCA-1 suggests that its could have been stripped by the LMC from the SMC during any of the close interactions between both galaxies, a scenario previously predicted by numerical simulations.

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Radiative turbulent mixing layers and the survival of Magellanic debris

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The Magellanic Stream is sculpted by its infall through the Milky Way's circumgalactic medium, but the rates and directions of mass, momentum, and energy exchange through the Stream–halo interface are relative unknowns critical for determining the origin and fate of the Stream. Complementary to large-scale simulations of LMC–SMC interactions, we apply new insights derived from idealized, high-resolution "cloud-crushing" and radiative turbulent mixing layer simulations to the Leading Arm and Trailing Stream. Contrary to classical expectations of fast cloud breakup, we predict that the Leading Arm and much of the Trailing Stream should be surviving infall and even gaining mass due to strong radiative cooling. Provided a sufficiently supersonic tidal swing-out from the Clouds, the present-day Leading Arm could be a series of high-density clumps in the cooling tail behind the progenitor cloud. We back up our analytic framework with a suite of converged wind-tunnel simulations, finding that previous results on cloud survival and mass growth can be extended to high Mach number ($\mathcal{M}$) flows with a modified drag time $t_{\rm drag} \propto 1 + \mathcal{M}$ and longer growth time. We also simulate the Trailing Stream; we find that the growth time is long ($\sim$ Gyrs) compared to the infall time, and approximate Hα emission is low on average ($\sim$few mR) but can be up to tens of mR in bright spots. Our findings also have broader extragalactic implications for, e.g., galactic winds, which we discuss.

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The first detection of a protostellar outflow in the SMC

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Protostellar outflows are one of the most outstanding features of star formation. The observational studies over several decades successfully demonstrated that outflows are ubiquitously associated with low- and high-mass protostars in the solar-metallicity Galactic condition. However, the environmental dependence of protostellar outflow properties is still poorly understood, particularly in the low-metallicity regime. Here we report the first detection of a molecular outflow in the Small Magellanic Cloud with 0.2 $Z_\odot$, using ALMA observations at a spatial resolution of 0.1 pc toward the massive protostar Y 191. The bipolar outflow is nicely illustrated by high-velocity wings of CO(3–2) emission with $\gtrsim 15$ km s^{-1}. The evaluated properties of the outflow (momentum, mechanical force, etc.) are consistent with those of the Galactic counterparts. Our results suggest that the molecular outflows, i.e. the guidepost of the disk accretion at the small scale, might be universally associated with protostars across the metallicity range of ~ 0.2–1 $Z_\odot$.

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X-ray properties of early-type stars in the Tarantula Nebula from T-ReX

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We reassess the historical L_X/L_{Bol} relation for early-type stars from a comparison between T-ReX, the *Chandra* ACIS X-ray survey of the Tarantula Nebula in the LMC, and contemporary spectroscopic analysis of massive stars obtained primarily from VLT/FLAMES, VLT/MUSE and HST/STIS surveys. For 107 sources in common (some host to multiple stars), the majority of which are bolometrically luminous (40% exceed 10^6 $L_\odot$), we find an average $\log L_X/L_{Bol} = -6.90 \pm 0.65$. Excluding extreme systems Mk 34 (WN5h+WN5h), R 140 a (WC4+WN6+) and VFTS 399 (O9 IIIn+?), plus four WR sources with anomalously hard X-ray components (R 130, R 134, R 135, Mk 53) and 10 multiple sources within the spatially crowded core of R 136 a, $\log L_X/L_{Bol} = -7.00 \pm 0.49$, in good agreement with Galactic OB stars. No difference is found between single and binary systems, nor between O, Of/WN and WR stars, although there does appear to be a trend towards harder X-ray emission from O dwarfs, through O (super)giants, Of/WN stars and WR stars. The majority of known OB stars in the Tarantula are not detected in the T-ReX point source catalogue, so we have derived upper limits for all undetected OB stars for which $\log L_{Bol}/L_\odot \geq 5.0$. A survival analysis using detected and upper-limit $\log L_X/L_{Bol}$ values indicates no significant difference between luminous O stars in the LMC and the Carina Nebula. This analysis suggests that metallicity does not strongly influence L_X/L_{Bol}. Plasma temperatures for single, luminous O stars in the Tarantula ($\overline{kT_m} = 1.0$ keV) are higher than counterparts in Carina ($\overline{kT_m} = 0.5$ keV).

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Resolving the core of R 136 in the optical

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The sharpest optical images of the R 136 cluster in the Large Magellanic Cloud are presented, allowing for the first time to resolve members of the central core, including R 136 a1, the most massive star known. These data were taken using the Gemini speckle imager Zorro in medium-band filters with effective wavelengths similar to $BVRI$ achieving angular resolutions between 30–40 mas. All stars previously known in the literature, having $V < 16$ mag within the central $2'' \times 2''$ were recovered. Visual companions ($\geq$ 40 mas; 2000 au) were detected for the WN5h stars R 136 a1, and a3. Photometry of the visual companion of a1 suggests it is of mid O spectral type. Based on new photometric luminosities using the resolved Zorro imaging, the masses of the individual WN5h stars are estimated to be between 150–200 $M_\odot$, lowering significantly the present-day masses of some of the most massive stars known. These mass estimates are critical anchor points for establishing the stellar upper-mass function.

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Conference Papers

Distance of optically obscured evolved stars

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As intermediate-mass stars, precursors of planetary nebulae, head towards their final fate, they pass through the red-giant stage where they experience an increase of mass loss. This induces the creation of a circumstellar envelope of dust and gas. By the very end of this evolutionary stage, for those objects exhibiting the highest mass-loss rate, the amount of dust in the circumstellar envelope is such that it blocks optical radiation, turning them into so-called OH/IR stars. These stars are commonly observed throughout the Galaxy and are also observed in the Magellanic Clouds. Since optically obscured, the measurement of their distances using optical parallaxes as, e.g., delivered by Gaia, is not possible. This issue can be circumvented thanks to maser emission. As their name gives it away, the physical conditions turn out to be ideal for a strong (1612-MHz) OH maser emission to be produced in the outer layers of the radially-expanding spherical circumstellar envelope. Combining single-dish monitoring and interferometric mapping of this OH maser emission, the "phase-lag" method provides a way to measure their distance. We have been revisiting this method through a project called "NRT phase-lag distance". Here we present the method itself and the modus operandi of our project. We also present an analysis of the faint emission in the outer OH maser shell of OH 83.4−0.9 and use this analysis to discuss the limitations of the "phase-lag" method. Finally we compare the distances obtained from this method with those obtained from optical and radio astrometry.

Oral contribution, published in European VLBI Network Mini-Symposium and Users' Meeting 2021. Based on the EVN online seminar https://www.youtube.com/watch?v=KMZxi_qapOY
Available from https://pos.sissa.it/399/012/

ULLYSES and complementary surveys of massive stars in the Magellanic Clouds

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An overview is provided of the scientific goals of the Magellanic Cloud component of the STScI Directors Discretionary UV initiative ULLYSES, together with the complementary spectroscopic survey XShootU (VLT/Xshooter) and other ancillary datasets. Together, ULLYSES and XShootU permit the first comprehensive, homogeneous study of wind densities and velocities in metal-poor massive stars, plus UV/optical spectroscopic libraries for population synthesis models and a large number of interstellar sight-lines towards the Magellanic Clouds.

Oral contribution, published in IAU Symposium 361 "Massive Stars Near and Far"
Available from https://arxiv.org/abs/2207.08690