Dear Colleagues,

It is my pleasure to present you the 138th issue of the Magellanic Clouds Newsletter. It contains plenty of stuff to inform and inspire you, from massive stars, their formation, evolution and mass loss, supernova remnants and \( \gamma \)-ray emission, to the Magellanic Stream and other possible tidal debris and "halo" gas (be it Milky Way or Magellanic).

A reminder that pictures for the frontpage of the newsletter are very welcome – just e-mail astro.mcnews@keele.ac.uk.

The next issue is planned to be distributed on the 1st of February 2016. With the Season’s Greetings and wishes for a Happy and Peaceful 2016,

Editorially Yours,

Jacco van Loon
PARSEC evolutionary tracks of massive stars up to 350 $M_\odot$ at metallicities $0.0001 < Z < 0.04$

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We complement the PARSEC data base of stellar evolutionary tracks with new models of massive stars, from the pre-main-sequence phase to the central carbon ignition. We consider a broad range of metallicities, $0.0001 < Z < 0.04$ and initial masses up to $M_{\text{ini}} = 350 M_\odot$. The main difference with respect to our previous models of massive stars is the adoption of a recent formalism accounting for the mass-loss enhancement when the ratio of the stellar to the Eddington luminosity, $\Gamma_e$, approaches unity. With this new formalism, the models are able to reproduce the Humphreys–Davidson limit observed in the Galactic and Large Magellanic Cloud colour–magnitude diagrams, without an ad hoc mass-loss enhancement. We also follow the predictions of recent wind models indicating that the metallicity dependence of the mass-loss rates becomes shallower when $\Gamma_e$ approaches unity. We thus find that the more massive stars may suffer from substantial mass-loss even at low metallicity. We also predict that the Humphreys–Davidson limit should become brighter at decreasing metallicity. We supplement the evolutionary tracks with new tables of theoretical bolometric corrections, useful to compare tracks and isochrones with the observations. For this purpose, we homogenize existing stellar atmosphere libraries of hot and cool stars (Potsdam Wolf–Rayet, ATLAS9 and PHOENIX) and we add, where needed, new atmosphere models computed with WM-BASIC. The mass, age and metallicity grids are fully adequate to perform detailed investigations of the properties of very young stellar systems, both in local and distant galaxies. The new tracks supersede the previous old PADOVA models of massive stars.

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A view of Large Magellanic Cloud H II regions N 159, N 132, and N 166 through the 345 GHz window

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We present results obtained towards the H II regions N 159, N 166, and N 132 from the emission of several molecular lines in the 345 GHz window. Using ASTE we mapped a 2’4 × 2’4 region towards the molecular cloud N 159-W in the $^{13}$CO $J = 3$–2 line and observed several molecular lines at an IR peak very close to a massive young stellar object. $^{12}$CO and $^{13}$CO $J = 3$–2 were observed towards two positions in N 166 and one position in N 132. The $^{13}$CO $J = 3$–2 map of the N 159-W cloud shows that the molecular peak is shifted southwest compared to the peak of the IR emission. Towards the IR peak we detected emission from HCN, HNC, HCO$^+$, $^{12}$CH $J = 4$–3, CS $J = 7$–6, and tentatively C$^{18}$O $J = 3$–2. This is the first reported detection of these molecular lines in N 159-W. The analysis of the C$^{18}$H line yields more evidence supporting that the chemistry involving this molecular species in compact and/or UCH II regions in the LMC should be similar to that in Galactic ones. A non-LTE study of the CO emission suggests the presence of
both cool and warm gas in the analysed region. The same analysis for the CS, HCO$^+$, HCN, and HNC shows that it is very likely that their emissions arise mainly from warm gas with a density between $5 \times 10^5$ to some $10^6$ cm$^{-3}$. The obtained $\frac{\text{HCN}}{\text{HNC}}$ abundance ratio greater than 1 is compatible with warm gas and with a star-forming scenario. From the analysis of the molecular lines observed towards N 132 and N 166 we propose that both regions should have similar physical conditions, with densities of about $10^3$ cm$^{-3}$.

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The Magellanic Stream System: I. Ram-pressure tails and the relics of the collision between the Magellanic Clouds

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We have analyzed the Magellanic Stream (MS) using the deepest and the most resolved H$\text{I}$ survey of the Southern Hemisphere (GASS). The overall Stream is structured into two filaments suggesting two ram-pressure tails lagging behind the Magellanic Clouds (MCs), and resembling two close, transonic, von Karman vortex streets. The past motions of the Clouds appear imprinted in them, implying almost parallel initial orbits, and then a radical change after their passage near the $N(\text{H}\text{I})$ peak of the MS. This is consistent with a recent collision between the MCs, 200–300 Myr ago, which has stripped further their gas into small clouds, spreading them out along a gigantic bow-shock, perpendicular to the MS. The Stream is formed by the interplay between stellar feedback and the ram-pressure exerted by Milky Way (MW) halo hot gas with $n_h = 10^{-4}$ cm$^{-3}$ at 50–70 kpc, a value necessary for explaining the MS multiphase high-velocity clouds. The corresponding hydrodynamical modeling provides the currently most accurate reproduction of the whole H$\text{I}$ Stream morphology, of its velocity, and column density profiles along LMS. The ‘ram-pressure plus collision’ scenario requires tidal dwarf galaxies (TDGs), which are assumed to be the Cloud and dSph progenitors having let imprints into the MS and the Leading Arm, respectively. The simulated LMC and SMC have baryonic mass, kinematics and proper motions consistent with observations. This supports a novel paradigm for the Magellanic Stream System, which could take its origin from material expelled towards the MW by the ancient gas-rich merger that formed M 31.

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Super strong magnetic fields of neutron stars in Be X-ray binaries estimated with new torque and magnetosphere models

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We re-estimate the surface magnetic fields of neutron stars (NSs) in Be X-ray binaries (BeXBs) with different models of torque, improved beyond Klus et al. (2014). In particular, a new torque model (Dai & Li 2006) is applied to three models of magnetosphere radius. Unlike the previous models, the new torque model does not lead to divergent results for any fastness parameter. The inferred surface magnetic fields of these NSs for the two compressed magnetosphere
models are much higher than that for the uncompressed magnetosphere model. The new torque model using the compressed-magnetosphere radius (Shi, Zhang & Li 2014) leads to unique solutions near spin equilibrium in all cases, unlike other models that usually give two branches of solutions. Although our conclusions are still affected by the simplistic assumptions about the magnetosphere radius calculations, we show several groups of possible surface magnetic field values with our new models when the interaction between the magnetosphere and the infalling accretion plasma is considered. The estimated surface magnetic fields for NSs BeXBs in the Large Magellanic Cloud, the Small Magellanic Cloud and the Milky Way are between the quantum critical field and the maximum "virial" value by the spin equilibrium condition.

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Blue supergiants as descendants of magnetic main sequence stars

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About 10% of the massive main sequence stars have recently been found to host a strong, large scale magnetic field. Both, the origin and the evolutionary consequences of these fields are largely unknown. We argue that these fields may be sufficiently strong in the deep interior of the stars to suppress convection near the outer edge of their convective core. We performed parametrised stellar evolution calculations and assumed a reduced size of the convective core for stars in the mass range 16 M_⊙ to 28 M_⊙ from the zero age main sequence until core carbon depletion. We find that such models avoid the coolest part of the main sequence band, which is usually filled by evolutionary models that include convective core overshooting. Furthermore, our "magnetic" models populate the blue supergiant region during core helium burning, i.e. the post-main sequence gap left by ordinary single star models, and some of them end their life in a position near that of the progenitor of Supernova 1987A in the HR diagram. Further effects include a strongly reduced luminosity during the red supergiant stage, and downward shift of the limiting initial mass for white dwarf and neutron star formation.

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High-velocity gas towards the LMC resides in the Milky Way halo

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To explore the origin of high-velocity gas in the direction of the Large Magellanic Cloud (LMC) we analyze absorption lines in the ultraviolet spectrum of a Galactic halo star that is located in front of the LMC at d = 9.2 kpc distance. We study the velocity-component structure of low and intermediate metal ions in the spectrum of RX J0439.8−6809, as obtained with the Cosmic Origins Spectrograph (COS) onboard HST, and measure equivalent widths and column densities for these ions. We supplement our COS data with a Far-Ultraviolet Spectroscopic Explorer spectrum of the nearby LMC star Sk−69°59 and with H I 21cm data from the Leiden–Argentina–Bonn (LAB) survey. Metal absorption towards RX J0439.8−6809 is unambiguously detected in three different velocity components near v_LSR = 0,+60, and +150 km s^{-1}. The presence of absorption proves that all three gas components are situated in front of the star, thus being located in the disk and inner halo of the Milky Way. For the high-velocity cloud (HVC) at v_LSR = +150 km s^{-1} we derive an oxygen abundance of [O/H] = −0.63 (~ 0.2 solar) from the neighbouring Sk−69°59 sightline, in accordance with previous abundance measurements for this HVC. From the observed kinematics we infer that the HVC hardly participates in the Galactic rotation. Our study shows that the HVC towards the LMC represents a
Milky Way halo cloud that traces low-column density gas with relatively low metallicity. It rules out scenarios in which the HVC represents material close to the LMC that stems from a LMC outflow.

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The Ca\textsc{ii} triplet in red giant spectra: \([\text{Fe}/\text{H}]\) determinations and the role of \([\text{Ca}/\text{Fe}]\)

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Measurements are presented and analyzed of the strength of the Ca\textsc{ii} triplet lines in red giants in Galactic globular and open clusters, and in a sample of red giants in the LMC disk that have significantly different \([\text{Ca}/\text{Fe}]\) abundance ratios to the Galactic objects. The Galactic objects are used to generate a calibration between Ca\textsc{ii} triplet line strength and \([\text{Fe}/\text{H}]\), which is then used to estimate \([\text{Fe}/\text{H}]_{\text{CaT}}\) for the LMC stars. The values are then compared with the \([\text{Fe}/\text{H}]_{\text{spec}}\) determinations from high dispersion spectroscopy. After allowance for a small systematic offset the two abundance determinations are in excellent agreement. Further, as found in earlier studies (e.g., Battaglia et al. 2008), the difference is only a very weak function of the \([\text{Ca}/\text{Fe}]\) ratio. For example, changing \([\text{Ca}/\text{Fe}]\) from +0.3 to −0.2 causes the Ca\textsc{ii} based abundance to underestimate \([\text{Fe}/\text{H}]_{\text{spec}}\) by only \(\sim 0.15\) dex, assuming a Galactic calibration. Consequently, the Ca\textsc{ii} triplet approach to metallicity determinations can be used without significant bias to study stellar systems that have substantially different chemical evolution histories.

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AGB stars in the SMC: evolution and dust properties based on \textit{Spitzer} observations

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We study the population of asymptotic giant branch (AGB) stars in the Small Magellanic Cloud (SMC) by means of full evolutionary models of stars of mass \(1\ M_{\odot} \leq M \leq 8\ M_{\odot}\), evolved through the thermally pulsing phase. The models also account for dust production in the circumstellar envelope. We compare \textit{Spitzer} infrared colours with results from theoretical modelling. We show that \(\sim 75\%\) of the AGB population of the SMC is composed by scarcely obscured objects, mainly stars of mass \(M \leq 2\ M_{\odot}\) at various metallicity, formed between 700 Myr and 5 Gyr ago; \(\sim 70\%\) of these sources are oxygen-rich stars, while \(\sim 30\%\) are C-stars. The sample of the most obscured AGB stars, accounting for \(\sim 25\%\) of the total sample, is composed almost entirely by carbon stars. The distribution in the colour–colour ([3.6]–[4.5], [5.8]–[8.0]) and colour–magnitude ([3.6]–[8.0], [8.0]) diagrams of these C-rich objects, with a large infrared emission, traces an obscuration sequence, according to the amount of carbonaceous dust in their surroundings. The overall population of C-rich AGB stars descends from \(1.5-2\ M_{\odot}\) stars of metallicity \(Z = 4 \times 10^{-3}\), formed between 700 Myr and 2 Gyr ago, and from lower metallicity objects, of mass below \(1.5\ M_{\odot}\), 2–5 Gyr old. We also identify obscured oxygen-rich stars \((M \sim 4-6\ M_{\odot})\) experiencing hot bottom burning. The differences between the AGB populations of the SMC and LMC are also commented.

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Multi-frequency study of the newly confirmed supernova remnant MCSNR J0512–6707 in the Large Magellanic Cloud

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We present a study of the supernova remnant MCSNR J0512–6707 in the Large Magellanic Cloud. We used new data from XMM–Newton to characterise the X-ray emission and data from the Australian Telescope Compact Array, the Magellanic Cloud Emission Line Survey, and Spitzer to gain a picture of the environment into which the remnant is expanding. We performed a morphological study, determined radio polarisation and magnetic field orientation, and performed an X-ray spectral analysis. We estimated the its size to be 24.9(±1.5) × 21.9(±1.5) pc², with the major axis rotated ∼29° east of north. Radio polarisation at 3 cm and 6 cm indicate a higher degree of polarisation in the NW and SE tangentially oriented to the SNR shock front, indicative of an SNR compressing the magnetic field threading the interstellar medium. The X-ray spectrum is unusual as it requires a soft (∼0.2 keV) CIE thermal plasma of interstellar medium abundance, in addition to a harder component. Using our results and the Sedov dynamical model, we showed that this emission is not consistent with a Sedov remnant. We suggested that the thermal X-rays can be explained by MCSNR J0512–6707 having initially evolved into a wind-blown cavity and is now interacting with the surrounding dense shell. The origin of the hard component remains unclear. We could not determine the supernova type from the X-ray spectrum. Indirect evidence was found in the study of the local stellar population and star formation history in the literature, which suggests a core-collapse origin. MCSNR J0512–6707 likely resulted from the core-collapse of high mass progenitor which carved a low density cavity into its surrounding medium, with the soft X-rays resulting from the impact of the blast wave with the surrounding shell. The unusual hard X-ray component requires deeper and higher spatial resolution radio and X-ray observations to confirm its origin.

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Mass fluxes for O-type supergiants with metallicity $Z = Z_\odot/5$

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A code used previously to predict O-star mass fluxes as a function of metallicity is used to compute a grid of models with the metallicity of the Small Magellanic Cloud (SMC). These models allow mass-loss rates to be derived by interpolation for all O-type supergiants in the SMC, with the possible exception of extremely massive stars close to the Eddington limit.

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Integral field spectroscopy of massive young stellar objects in the N113 HII region in the Large Magellanic Cloud

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The Spitzer SAGE survey has allowed the identification and analysis of significant samples of Young Stellar Object (YSO) candidates in the Large Magellanic Cloud (LMC). However the angular resolution of Spitzer is relatively poor meaning that at the distance of the LMC, it is likely that many of the Spitzer YSO candidates in fact contain multiple components. We present high resolution K-band integral field spectroscopic observations of the three most prominent massive YSO candidates in the N113 HII region using VLT/SINFONI. We have identified six K-band continuum sources within the three Spitzer sources and we have mapped the morphology and velocity fields of extended line emission around these sources. Brγ, HeI and H2 emission is found at the position of all six K-band sources; we discuss whether the emission is associated with the continuum sources or whether it is ambient emission. H2 emission appears to be mostly ambient emission and no evidence of CO emission arising in the discs of YSOs has been found. We have mapped the centroid velocities of extended Brγ emission and HeI emission and found evidence of two expanding compact HII regions. One source shows compact and strong H2 emission suggestive of a molecular outflow. The diversity of spectroscopic properties observed is interpreted in the context of a range of evolutionary stages associated with massive star formation.

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Large Magellanic Cloud near-infrared synoptic survey. II. The Wesenheit relations and their application to the distance scale

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We present new near-infrared Cepheid Period–Wesenheit relations in the LMC using time-series observations from the Large Magellanic Cloud Near-Infrared Synoptic Survey. We also derive optical+near-infrared P–W relations using V and I magnitudes from OGLE-III. We employ our new JHKs data to determine an independent distance to the LMC of \( \mu_{\text{LMC}} = 18.47 \pm 0.07 \) (statistical) mag, using an absolute calibration of the Galactic relations based on several distance determination methods and accounting for the intrinsic scatter of each technique. We also derive new near-infrared Period–Luminosity and Wesenheit relations for Cepheids in M31 using observations from the PHAT survey. We use the absolute calibrations of the Galactic and LMC \( W_{J,H} \) relations to determine the distance modulus of M31, \( \mu_{\text{M31}} = 24.46 \pm 0.20 \) mag. We apply a simultaneous fit to Cepheids in several Local Group galaxies covering a range of metallicities \( (7.7 < 12 + \log[\text{O/H}] < 8.6 \) dex) to determine a global slope of \( \sim 3.244 \pm 0.016 \) mag dex\(^{-1} \) for the \( W_{J,Ks} \) relation and obtain robust distance estimates. Our distances are in good agreement with recent TRGB based distance estimates and we do not find any evidence for a metallicity dependence in the near-infrared P–W relations.

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Population I Cepheids and understanding star formation history of the Small Magellanic Cloud

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In this paper, we study the age and spatial distributions of Cepheids in the Small Magellanic Cloud (SMC) as a function of their ages using the data from the OGLE III photometric catalogue. A period–age (PA) relation derived for the Classical Cepheids in the Large Magellanic Cloud (LMC) has been used to find the ages of Cepheids. The age distribution of the SMC Classical Cepheids is found to have a peak at log(Age) = 8.40 ± 0.10 which suggests that a major star formation event might have occurred in the SMC at about 250 ± 50 Myrs ago. It is believed that this star forming burst had been triggered by close interactions of the SMC with the LMC and/or the Milky Way (MW). A comparison of the observed spatial distributions of the Cepheids and open star clusters has also been carried out to study the star formation scenario in the SMC.

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The population of X-ray supernova remnants in the Large Magellanic Cloud


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Aims: We present a comprehensive X-ray study of the population of supernova remnants (SNRs) in the Large Magellanic Cloud (LMC). Using primarily XMM–Newton observations, we conduct a systematic spectral analysis of LMC SNRs to gain new insight into their evolution and the interplay with their host galaxy.

Methods: We combined all the archival XMM–Newton observations of the LMC with those of our Very Large Programme LMC survey. We produced X-ray images and spectra of 51 SNRs, out of a list of 59 objects compiled from the literature and augmented with newly found objects. Using a careful modelling of the background, we consistently analysed all the X-ray spectra and measure temperatures, luminosities, and chemical compositions. The locations of SNRs are compared to the distributions of stars, cold gas, and warm gas in the LMC, and we investigated the connection between the SNRs and their local environment, characterised by various star formation histories. We tentatively typed all LMC SNRs, in order to constrain the ratio of core-collapse to type Ia SN rates in the LMC. We also compared the column densities derived from X-ray spectra to H I maps, thus probing the three-dimensional structure of the LMC.

Results: This work provides the first homogeneous catalogue of the X-ray spectral properties of SNRs in the LMC. It offers a complete census of LMC remnants whose X-ray emission exhibits Fe K lines (13% of the sample), or reveals the contribution from hot supernova ejecta (39%), which both give clues to the progenitor types. The abundances of O, Ne, Mg, Si, and Fe in the hot phase of the LMC interstellar medium are found to be between 0.2 and 0.5 times the solar values with a lower abundance ratio [α/Fe] than in the Milky Way. The current ratio of core-collapse to type Ia SN rates in the LMC is constrained to $N_{CC}/N_{Ia} = 1.35^{+0.11}_{-0.24}$, which is lower than in local SN surveys and galaxy clusters. Our comparison of the X-ray luminosity functions of SNRs in Local Group galaxies (LMC, SMC, M 31, and...
M33) reveals an intriguing excess of bright objects in the LMC. Finally, we confirm that 30Doradus and the LMC Bar are offset from the main disc of the LMC to the far and near sides, respectively.

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The VMC survey – XVII. The proper motion of the Small Magellanic Cloud and of the Milky Way globular cluster 47 Tucanae

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In this study we use multi-epoch near-infrared observations from the VISTA survey of the Magellanic Cloud system (VMC) to measure the proper motion of different stellar populations in a tile of 1.5 deg2 in size in the direction of the Galactic globular cluster 47 Tuc. We obtain the proper motion of the cluster itself, of the Small Magellanic Cloud (SMC), and of the field Milky Way stars. Stars of the three main stellar components are selected from their spatial distribution and their distribution in colour–magnitude diagrams. Their average coordinate displacement is computed from the difference between multiple Ks-band observations for stars as faint as Ks = 19 mag. Proper motions are derived from the slope of the best-fitting line among 10 VMC epochs over a time baseline of ~1 yr. Background galaxies are used to calibrate the absolute astrometric reference frame. The resulting absolute proper motion of 47 Tuc is ($\mu_\alpha \cos(\delta), \mu_\delta$) = (+7.26±0.03, −1.25±0.03) mas yr$^{-1}$. This measurement refers to about 35,000 sources distributed between 10 and 60 arcmin from the cluster centre. For the SMC we obtain ($\mu_\alpha \cos(\delta), \mu_\delta$) = (+1.16±0.07, −0.81±0.07) mas yr$^{-1}$, from about 5,250 red clump and red giant branch stars. The absolute proper motion of the Milky Way population in the line-of-sight ($l = 305^\circ.9, b = −44^\circ.9$) of this VISTA tile is ($\mu_\alpha \cos(\delta), \mu_\delta$) = (+10.22±0.14, −1.27±0.12) mas yr$^{-1}$ and results from about 4,000 sources. Systematic uncertainties associated to the astrometric reference system are 0.18 mas yr$^{-1}$. Thanks to the proper motion we detect 47 Tuc stars beyond its tidal radius.

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Dynamical friction and scratches of orbiting satellite galaxies on host systems

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We study the dynamical response of extended systems, hosts, to smaller systems, satellites, orbiting around the hosts
using extremely high-resolution N-body simulations with up to one billion particles. This situation corresponds to minor mergers which are ubiquitous in the scenario of hierarchical structure formation in the universe. According to Chandrasekhar (1943), satellites create density wakes along the orbit and the wakes cause a deceleration force on satellites, i.e. dynamical friction. This study proposes an analytical model to predict the dynamical response of hosts in the density distribution and finds not only traditional wakes but also mirror images of over- and underdensities centered on the host. Controlled N-body simulations with high resolutions verify the predictions of the analytical model directly. We apply our analytical model to the expected dynamical response of nearby interacting galaxy pairs, the Milky Way – Large Magellanic Cloud system and the M31 – M33 system.

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Two evolved supernova remnants with newly identified Fe-rich cores in the Large Magellanic Cloud

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Aims: We present a multi-wavelength analysis of the evolved supernova remnants MCSNR J0506−7025 and MC-SNR J0527−7104 in the Large Magellanic Cloud.

Methods: We used data from XMM–Newton, the Australian Telescope Compact Array, and the Magellanic Cloud Emission Line Survey to study their broadband emission and used Spitzer and H_i data to gain a picture of their environments. We performed a multi-wavelength morphological study and detailed radio and X-ray spectral analyses to determine their physical characteristics.

Results: Both remnants were found to have bright X-ray cores, dominated by Fe L-shell emission, consistent with reverse shock heated ejecta with determined Fe masses in agreement with Type Ia explosion yields. A soft X-ray shell, consistent with swept-up interstellar medium, was observed in MCSNR J0506−7025, suggestive of a remnant in the Sedov phase. Using the spectral fit results and the Sedov self-similar solution, we estimated the age of MC-SNR J0506−7025 to be ~16–28 kyr, with an initial explosion energy of (0.07–0.84)×1051 erg. A soft shell was absent in MCSNR J0527−7104, with only ejecta emission visible in an extremely elongated morphology extending beyond the optical shell. We suggest that the blast wave has broken out into a low density cavity, allowing the shock heated ejecta to escape. We found that the radio spectral index of MCSNR J0506−7025 is consistent with the standard ~0.5 for SNRs. Radio polarisation at 6 cm indicates a higher degree of polarisation along the western front and at the eastern knot, with a mean fractional polarisation across the remnant of P~ (20 ± 6)%.

Conclusions: The detection of Fe-rich ejecta in the remnants suggests that both resulted from Type Ia explosions. The newly identified Fe-rich cores in MCSNR J0506−7025 and MCSNR J0527−7104 makes them members of the expanding class of evolved Fe-rich remnants in the Magellanic Clouds.

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A Hubble Space Telescope study of the enigmatic Milky Way Halo globular cluster Crater

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We analyze the resolved stellar populations of the faint stellar system, Crater, based on deep optical imaging taken with the Advanced Camera for Surveys aboard the Hubble Space Telescope. The HST-based color–magnitude diagram (CMD) of Crater extends $\sim 4$ magnitudes below the oldest main sequence turnoff, providing excellent leverage on Crater’s physical properties. Structurally, we find that Crater has a half-light radius of $\sim 20$ pc and shows no evidence for tidal distortions. We model the CMD of Crater under the assumption of it being a simple stellar population and alternatively by solving for its full star formation history. In both cases, Crater is well-described by a simple stellar population with an age of $\sim 7.5$ Gyr, a metallicity of $[\text{M}/\text{H}] \sim -1.65$, a total stellar mass of $M_\star \sim 1 \times 10^4 M_\odot$, a luminosity of $M_V \sim -5.3$, located at a distance of $d \sim 145$ kpc, with modest uncertainties in these properties due to differences in the underlying stellar evolution models. We argue that the sparse sampling of stars above the turnoff and sub-giant branch are likely to be 1.0–1.4 $M_\odot$ binary star systems (blue stragglers) and their evolved descendants, as opposed to intermediate age main sequence stars. Confusion of these populations highlights a substantial challenge in accurately characterizing sparsely populated stellar systems. Our analysis shows that Crater is not a dwarf galaxy, but instead is an unusually young cluster given its location in the Milky Way’s very outer stellar halo. Crater is similar to SMC cluster Lindsay 38, and its position and velocity are in good agreement with observations and models of the Magellanic stream debris, suggesting it may have accreted from the Magellanic Clouds. However, its age and metallicity are also in agreement with the age–metallicity relationships of lower mass dwarf galaxies such as Leo I or Carina. Despite uncertainty over its progenitor system, Crater appears to have been incorporated into the Galaxy more recently than $z \sim 1$ (8 Gyr ago), providing an important new constraint on the accretion history of the Milky Way.

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Molecular development in the Large Magellanic Cloud

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Using a new network and a new model, we have studied chemical complexity in cold portions of dense clouds of the Large Magellanic Cloud (LMC). We varied the hydrogen number density between $1 \times 10^5$ and $5 \times 10^5$ cm$^{-3}$ and, for each density, we ran models for $A_V = 3, 5, \text{and} 10$. Then, for each density and visual extinction we varied the grain temperature between 10 and 50 K in small intervals, while keeping the gas temperature constant at 20 K. We used a gas-to-dust mass ratio based on a variety of observations and analyses, and scaled the elemental abundances of the LMC so that they are representative of so-called “low” metallic abundances. We found that although the LMC is metal-poor, it still shows a rich chemistry; almost all the major observed species in the gas phase of our Galaxy should be detectable using present-day observational facilities. We compared our model results with observed gas-phase abundances in some cold and dense sources, and found reasonably good agreement for most species. We
also found that some observed results, especially for methanol, are better matched if these regions currently possess lower temperatures, or possessed them in the past. Finally, we discussed our simulated abundances for H$_2$O ice with respect to total hydrogen, and CO$_2$, CO, CH$_3$OH, and NH$_3$ ices with respect to water ice, and compared our values with those for two observed ices – CO$_2$ and CO – detected in front of young stellar objects in the LMC.

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Major mergers with small galaxies – the discovery of a Magellanic-type galaxy at $z=0.12$

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We report on the serendipitous discovery of a star-forming galaxy at redshift $z=0.116$ with morphological features that indicate an ongoing merger. This object exhibits two clearly separated components with significantly different colors, plus a possible tidal stream. Follow-up spectroscopy of the bluer component revealed a low star-forming activity of $0.09$ M$_\odot$ yr$^{-1}$ and a high metallicity of $12 + \log(O/H) = 8.6$. Based on comparison with mass–star-formation-rate and mass–metallicity relations, and on fitting of spectral energy distributions, we obtain a stellar mass of $3 \times 10^9$ M$_\odot$, which renders this object comparable to the Large Magellanic Cloud (LMC). Thus our finding provides a further piece of evidence of a major merger already acting on small, dwarf galaxy-like scales.

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Large and small-scale structure of the Intermediate and High Velocity Clouds towards the LMC and SMC

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We employ Ca$^{+}$K and Na$\lambda$D interstellar absorption-line spectroscopy of early-type stars in the Large and Small Magellanic Clouds to investigate the large- and small-scale structure in foreground Intermediate and High Velocity Clouds (I/HVCs). These data include FLAMES-GIRAFFE Ca$^{+}$K observations of 403 stars in four open clusters, plus FEROS or UVES spectra of 156 stars in the LMC and SMC. The FLAMES observations are amongst the most extensive probes to date of Ca$^{+}$K structures on 20 arcsec scales. From the FLAMES data within a 0.5 degree field-of-view, the Ca$^{+}$K equivalent width in the I/HVC components towards three clusters varies by factors of $>10$. There are no detections of molecular gas in absorption at intermediate or high velocities, although molecular absorption is present at LMC and Galactic velocities towards some sightlines. The sightlines show variations in EW exceeding a factor 7 in CH$^+$ towards NGC 1761 over scales of less than 10 arcminutes. The FEROS/UVES data show Ca$^{+}$K I/HVC absorption in $\sim60$ per cent of sightlines. No Na$\lambda$D is found at non-Magellanic HVC velocities aside from a tentative detection towards the star LHA 120-S93. The range in the Ca$^{+}$/Na$\lambda$I ratio in I/HVCs is from $\sim0.45$ to $+1.5$ dex, similar to previous measurements for I/HVCs. In ten sightlines we find Ca$^{+}$/O$\lambda$I ratios in I/HVC gas ranging from 0.2 to 1.5 dex below the solar value, indicating either dust or ionisation effects. In nine sightlines I/HVC gas is detected in both H$\lambda$I and Ca$^{+}$, and shows similar Ca$^{+}$/H$\lambda$I ratios to typical I/HVCs, and similar velocities, implying that in these sightlines the two elements form part of the same structure.


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The large- and small-scale Ca\textsuperscript{II}K structure of the Milky Way from observations of Galactic and Magellanic sightlines

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Aims: The large and small-scale (pc) structure of the Galactic interstellar medium can be investigated by utilising spectra of early-type stellar probes of known distances in the same region of the sky. This paper determines the variation in line strength of Ca\textsuperscript{II} at 3933.661 \text{	extmu}A as a function of probe separation for a large sample of stars, including a number of sightlines in the Magellanic Clouds.

Methods: FLAMES-GIRAFFE data taken with the Very Large Telescope towards early-type stars in 3 Galactic and 4 Magellanic open clusters in Ca\textsuperscript{II} are used to obtain the velocity, equivalent width, column density, and line width of interstellar Galactic calcium for a total of 657 stars, of which 443 are Magellanic Cloud sightlines. In each cluster there are between 43 and 111 stars observed. Additionally, FEROS and UVES Ca\textsuperscript{II}K and Na\textsuperscript{I}D spectra of 21 Galactic and 154 Magellanic early-type stars are presented and combined with data from the literature to study the calcium column density–parallax relationship.

Results: For the four Magellanic clusters studied with FLAMES, the strength of the Galactic interstellar Ca\textsuperscript{II} equivalent width on transverse scales from \(\sim 0.05–9\) pc is found to vary by factors of \(\sim 1.8–3.0\), corresponding to column density variations of \(\sim 0.3–0.5\) dex in the optically-thin approximation. Using FLAMES, FEROS, and UVES archive spectra, the minimum and maximum reduced equivalent widths for Milky Way gas are found to lie in the range \(\sim 35–125\) mA and \(\sim 30–160\) mA for Ca\textsuperscript{II}K and Na\textsuperscript{I}D, respectively. The range is consistent with a simple model of the ISM published by van Loon et al. (2009) consisting of spherical cloudlets of filling factor \(\sim 0.3\), although other geometries are not ruled out. Finally, the derived functional form for parallax \((\pi)\) and Ca\textsuperscript{II} column density \((N_{\text{CaII}})\) is found to be \(\pi(\text{mas}) = 1/(2.39 \times 10^{13} \times N_{\text{CaII}} (\text{cm}^{-2})) + 0.11\). Our derived parallax is \(\sim 25\) per cent lower than predicted by Megier et al. (2009) at a distance of \(\sim 100\) pc and \(\sim 15\) percent lower at a distance of \(\sim 200\) pc, reflecting inhomogeneity in the Ca\textsuperscript{II} distribution in the different sightlines studied.

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On the brightness of surviving companions in Type Ia supernova remnants

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The progenitor systems for type Ia supernovae are still controversial. One of the methods to test the proposed scenario for the progenitor systems is to identify companions that are supposed to survive according to the so-called single degenerate scenario. These companions might be affected by supernova ejecta. We present several numerical simulations of surviving red-giant companions whose envelopes were stripped and heated. We find that red-giants with less-massive helium cores (\(<0.30\) M\(_{\odot}\)) can be so faint after the supernova that we cannot detect them. In addition, we apply the results to the case of SNR 0509–67.5, and put constraints on the helium core mass, envelope stripping, and energy injection under the single degenerate scenario for type Ia supernovae.

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High-Mass X-ray binaries in the Small Magellanic Cloud

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The last comprehensive catalogue of high-mass X-ray binaries in the Small Magellanic Cloud (SMC) was published about 10 years ago. Since then new such systems were discovered, mainly by X-ray observations with \textit{Chandra} and \textit{XMM–Newton}. For the majority of the proposed HMXBs in the SMC no X-ray pulsations were discovered yet and unless other properties of the X-ray source and/or the optical counterpart confirm their HMXB nature, they remain only candidate HMXBs. From a literature search we collect a catalogue of 148 confirmed and candidate HMXBs in the SMC and investigate their properties to shed light on their real nature. Based on the sample of well established HMXBs (the pulsars), we investigate which observed properties are most appropriate for a reliable classification. Using spectral and temporal characteristics of the X-ray sources and colour–magnitude diagrams from the optical to the infrared of their likely counterparts and taking into account the uncertainty in the X-ray position we define different levels of confidence for being a genuine HMXB. From the lack of an infrared excess of the proposed counterpart, mainly for X-ray sources with large positional uncertainty, and using additional information obtained from more recent observations, we identify 27 objects as likely mis-identifications. This results in a catalogue of 121 relatively high-confidence HMXBs (the vast majority with Be companion stars) with about half of the objects showing X-ray pulsations while for the rest no pulsations are known yet. A comparison of the two subsamples suggests that long pulse periods in excess of a few 100 s are expected for the “non-pulsars”, which are likely undetected because of aperiodic variability on similar time scales and insufficiently long X-ray observations. Highest X-ray variability together with the lowest observed minimum fluxes for short-period pulsars indicate that apart from the eccentricity of the orbit also its inclination against the plane of the Be stars circumstellar disk plays a major role for the outburst behaviour. The large population of HMXBs, in particular Be X-ray binaries, in the SMC provides the largest homogeneous sample of such systems for statistical population studies.

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and from http://www.mpe.mpg.de/heg/SMC

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Rapidly rising transients in the supernova–superluminous supernova gap

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We present observations of four rapidly rising ($t_{\text{rise}} \sim 10$ d) transients with peak luminosities between those of supernovæ (SNe) and superluminous SNe ($M_{\text{peak}} \sim -20$) – one discovered and followed by the Palomar Transient Factory (PTF) and three by the Supernova Legacy Survey (SNLS). The light curves resemble those of SN 2011kl, recently shown to be associated with an ultra-long-duration $\gamma$-ray burst (GRB), though no GRB was seen to accompany our SNe. The rapid rise to a luminous peak places these events in a unique part of SN phase space, challenging standard SN emission mechanisms. Spectra of the PTF event formally classify it as a Type II SN due to broad H$\alpha$ emission, but an unusual absorption feature, which can be interpreted as either high velocity H$\alpha$ (though deeper than in previously known cases) or Si II (as seen in Type Ia SNe), is also observed. We find that existing models of white dwarf detonations, CSM interaction, shock breakout in a wind (or steeper CSM) and magnetar spindown can not readily explain the observations. We look into the intriguing possibility of a ”Type 1.5 SN” scenario for our events, but can not confirm nor reject this interpretation. More detailed models for these kinds of transients and more constraining observations of future such events should help better determine their nature.

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We report on the study of interstellar extinction across the Tarantula nebula (30 Doradus), in the Large Magellanic Cloud, using observations from the Hubble Tarantula Treasury Project in the 0.3–1.6 µm range. The considerable and patchy extinction inside the nebula causes about 3500 red clump stars to be scattered along the reddening vector in the colour–magnitude diagrams, thereby allowing an accurate determination of the reddening slope in all bands. The measured slope of the reddening vector is remarkably steeper in all bands than in the Galactic diffuse interstellar medium. At optical wavelengths, the larger ratio of total-to-selective extinction, namely $R_V = 4.5 \pm 0.2$, implies the presence of a grey component in the extinction law, due to a larger fraction of large grains. The extra large grains are most likely ices from supernova ejecta and will significantly alter the extinction properties of the region until they sublimate in 50–100 Myr. We discuss the implications of this extinction law for the Tarantula nebula and in general for regions of massive star formation in galaxies. Our results suggest that fluxes of strongly star forming regions are likely to be underestimated by a factor of about 2 in the optical.

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methods yield, within the 1σ to 3σ uncertainties, near-zero slopes in the diagnostic plane, largely irrespective of the maximum age or minimum mass imposed on our sample selection, or of the radial bin size adopted. We conclude that, at least in our four well-studied sample galaxies, star cluster formation does not necessarily require an environment-dependent cluster formation scenario, which thus supports the notion of stochastic star cluster formation as the dominant star cluster-formation process within a given galaxy.

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An extremely bright γ-ray pulsar in the Large Magellanic Cloud

The Fermi-LAT collaboration

Pulsars are rapidly spinning, highly magnetized neutron stars, created in the gravitational collapse of massive stars. We report the detection of pulsed giga-electron volt γ rays from the young pulsar PSR J0540−6919 in the Large Magellanic Cloud, a satellite galaxy of the Milky Way. This is the first gamma-ray pulsar detected in another galaxy. It has the most luminous pulsed γ-ray emission yet observed, exceeding the Crab pulsar’s by a factor of 20. PSR J0540−6919 presents an extreme test case for understanding the structure and evolution of neutron star magnetospheres.

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Deep view of the Large Magellanic Cloud with 6 years of Fermi-LAT observations

The Fermi-LAT collaboration

The nearby Large Magellanic Cloud (LMC) provides a rare opportunity of a spatially resolved view of an external star-forming galaxy in γ rays. The LMC was detected at 0.1–100 GeV as an extended source with CGRO/EGRET and using early observations with the Fermi-LAT. The emission was found to correlate with massive star-forming regions and to be particularly bright towards 30 Doradus. Studies of the origin and transport of cosmic rays (CRs) in the Milky Way are frequently hampered by line-of-sight confusion and poor distance determination. The LMC offers a complementary way to address these questions by revealing whether and how the γ-ray emission is connected to specific objects, populations of objects, and structures in the galaxy. We revisited the γ-ray emission from the LMC using about 73 months of Fermi-LAT P7REP data in the 0.2–100 GeV range. We developed a complete spatial and spectral model of the LMC emission, for which we tested several approaches: a simple geometrical description, template-fitting, and a physically driven model for CR-induced interstellar emission. In addition to identifying PSR J0540−6919 through its pulsations, we find two hard sources positionally coincident with plerion N157B and supernova remnant N132D, which were also detected at TeV energies with H.E.S.S. We detect an additional soft source that is currently unidentified. Extended emission dominates the total flux from the LMC. It consists of an extended component of about the size of the galaxy and additional emission from three to four regions with degree-scale sizes. If it is interpreted as CRs interacting with interstellar gas, the large-scale emission implies a large-scale population of ∼1–100 GeV CRs with a density of ∼30% of the local Galactic value. On top of that, the three to four small-scale emission regions would correspond to enhancements of the CR density by factors 2 to 6 or higher, possibly more energetic and younger populations of CRs compared to the large-scale population. An alternative explanation is that this is emission from an unresolved population of at least two dozen objects, such as pulsars and their nebulae or supernova remnants. This small-scale extended emission has a spatial distribution that does not clearly correlate with known components of the LMC, except for a possible relation to cavities and supergiant shells. The Fermi-LAT GeV observations allowed us
to detect individual sources in the LMC. Three of the newly discovered sources are associated with rare and extreme objects. The 30 Doradus region is prominent in GeV γ rays because PSR J0540−6919 and N 157B are strong emitters. The extended emission from the galaxy has an unexpected spatial distribution, and observations at higher energies and in radio may help to clarify its origin.

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Conference Papers

NGC 346: Looking in the cradle of a massive star cluster
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How does a star cluster of more than few 10,000 solar masses form? We present the case of the cluster NGC 346 in the Small Magellanic Cloud, still embedded in its natal star-forming region N 66, and we propose a scenario for its formation, based on observations of the rich stellar populations in the region. Young massive clusters host a high fraction of early-type stars, indicating an extremely high star formation efficiency. The Milky Way galaxy hosts several young massive clusters that fill the gap between young low-mass open clusters and old massive globular clusters. Only a handful, though, are young enough to study their formation. Moreover, the investigation of their gaseous natal environments suffers from contamination by the Galactic disk. Young massive clusters are very abundant in distant starburst and interacting galaxies, but the distance of their hosting galaxies do not also allow a detailed analysis of their formation. The Magellanic Clouds, on the other hand, host young massive clusters in a wide range of ages with the youngest being still embedded in their giant H II regions. Hubble Space Telescope imaging of such star-forming complexes provide a stellar sampling with a high dynamic range in stellar masses, allowing the detailed study of star formation at scales typical for molecular clouds. Our cluster analysis on the distribution of newly-born stars in N 66 shows that star formation in the region proceeds in a clumpy hierarchical fashion, leading to the formation of both a dominant young massive cluster, hosting about half of the observed pre-main-sequence population, and a self-similar dispersed distribution of the remaining stars. We investigate the correlation between stellar surface density (and star formation rate derived from star-counts) and molecular gas surface density (derived from dust column density) in order to unravel the physical conditions that gave birth to NGC 346. A power law fit to the data yields a steep correlation between these two parameters with a considerable scatter. The fraction of stellar over the total (gas plus young stars) mass is found to be systematically higher within the central 15 pc (where the young massive cluster is located) than outside, which suggests variations in the star formation efficiency within the same star-forming complex. This trend possibly reflects a change of star formation efficiency in N 66 between clustered and non-clustered star formation. Our findings suggest that the formation of NGC 346 is the combined result of star formation regulated by turbulence and of early dynamical evolution induced by the gravitational potential of the dense interstellar medium.

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The dynamical importance of binary systems in young massive star clusters

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Characterization of the binary fractions in star clusters is of fundamental importance for many fields in astrophysics. Observations indicate that the majority of stars are found in binary systems, while most stars with masses greater than 0.5 M⊙ are formed in star clusters. In addition, since binaries are on average more massive than single stars, in resolved star clusters these systems are thought to be good tracers of (dynamical) mass segregation. Over time, dynamical evolution through two-body relaxation will cause the most massive objects to migrate to the cluster center, while the relatively lower-mass objects remain in or migrate to orbits at greater radii. This process will globally dominate a cluster’s stellar distribution. However, close encounters involving binary systems may disrupt ‘soft’ binaries. This process will occur more frequently in a cluster’s central, dense region than in its periphery, which may mask the effects of mass segregation. Using high resolution Hubble Space Telescope observations, combined with sophisticated N-body simulations, we investigate the radial distributions of the main-sequence binary fractions in massive young Large Magellanic Cloud star clusters. We show that binary disruption may play an important role on very short timescales, depending on the environmental conditions in the cluster cores. This may lead to radial binary fractions that initially decline in the cluster centers, which is contrary to the effects expected from dynamical mass segregation.

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The HST survey of Magellanic-Cloud clusters and of their stellar populations

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A large number of intermediate-age (~ 1–2-Gyr old) globular clusters (GCs) in the Large and the Small Magellanic Cloud (MC) exhibit either bimodal or extended main-sequence (MS) turn off and dual red clump. Moreover, recent papers have shown that the MS of the young clusters NGC 1844 and NGC 1856 is either broadened or split. These features of the color–magnitude diagram (CMD) are not consistent with a single isochrone and suggest that star clusters in MCs have experienced a prolonged star formation, in close analogy with Milky-Way GCs with multiple stellar populations. As an alternative, stellar rotation or interacting binaries can be responsible of the CMD morphology. In the following I will summarize the observational scenario and provide constraints on the nature of the complex CMD of young and intermediate-age MC clusters from our ongoing photometric survey with the Hubble Space Telescope.

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The Magellanic Clouds are surrounded by an extended network of gaseous structures. Chief among these is the Magellanic Stream, an interwoven tail of filaments trailing the Clouds in their orbit around the Milky Way. When considered in tandem with its Leading Arm, the Stream stretches over 200 degrees on the sky. Thought to represent the result of tidal interactions between the Clouds and ram-pressure forces exerted by the Galactic corona, its kinematic properties reflect the dynamical history of the closest pair of dwarf galaxies to the Milky Way. The Stream is a benchmark for hydrodynamical simulations of accreting gas and cloud/corona interactions. If the Stream survives these interactions and arrives safely in the Galactic disk, its cargo of over a billion solar masses of gas has the potential to maintain or elevate the Galactic star formation rate. In this article, we review the current state of knowledge of the Stream, including its chemical composition, physical conditions, origin, and fate. We also review the dynamics of the Magellanic System, including the proper motions and orbital history of the Large and Small Magellanic Clouds, the first-passage and second-passage scenarios, and the evidence for a Magellanic Group of galaxies.

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