Dear Colleagues,

It is my pleasure to present you the 100th issue of the Magellanic Clouds Newsletter. Although the number 100 is in no fundamental way different from 99 or 101, it is as good an excuse as any for a little party. Hence, this issue features some diagrams and unpublished work. Hopefully it inspires you, along with the other exciting pieces of research presented in the following pages.

The photograph on the frontpage, taken by Eduardo Balbinot, shows the Large Magellanic Cloud. We are now all too familiar with the spectacular technicolor pictures showing great detail, and features our eyes were never designed to ever capture. The photograph is much closer to the experience of watching the Magellanic Clouds on a dark night with the unaided eye. 30 Doradus is a bright “star”, and the milky white of the LMC Bar is what also gave our Galaxy its name. It is humbling to realise that this image, recorded by people over many millenia, has only recently changed so dramatically, that we can resolve 30 Doradus into thousands of stars, and measure their individual masses, rotation rates, chemical composition, supersonic winds... And that we can see these galaxies painted in the colours of photons that would harm our tissues, of the glow that could warm our skin, and of waves that could carry our voices.

The next issue will be distributed on the 3rd of October 2009; the deadline for contributions is the 2nd of October.

Editorially Yours,
Jacco van Loon

The puzzling dredge-up pattern in NGC 1978

Michael T. Lederer¹, Thomas Lebzelter¹, Sergio Cristallo², Oscar Straniero², Kenneth H. Hinkle³ and Bernhard Aringer¹,⁴,⁵

¹University of Vienna, Department of Astronomy, Türkenschanzstraße 17, A-1180 Vienna, Austria
²INAF, Osservatorio Astronomico di Collurania, 64100 Teramo, Italy
³National Optical Astronomy Observatories, P.O. Box 26732, Tucson, AZ 85726, USA
⁴Osservatorio Astronomico di Padova - INAF, Vicolo dell’Osservatorio 5, I-35122 Padova, Italy
⁵Dipartimento di Astronomia, Università di Padova, Vicolo dell’Osservatorio 2, I-35122 Padova, Italy

Low-mass stars are element factories that efficiently release their products in the final stages of their evolution by means of stellar winds. Since they are large in number, they contribute significantly to the cosmic matter cycle. To assess this contribution quantitatively, it is crucial to obtain a detailed picture of the stellar interior, particularly with regard to nucleosynthesis and mixing mechanisms. We seek to benchmark stellar evolutionary models of low-mass stars. In particular, we measure the surface abundance of $^{12}$C in thermally pulsing AGB stars with well-known mass and metallicity, which can be used to infer information about the onset and efficiency of the third dredge-up. We recorded high-resolution near-infrared spectra of AGB stars in the LMC cluster NGC 1978. The sample comprised both oxygen-rich and carbon-rich stars, and is well-constrained in terms of the stellar mass, metallicity, and age. We derived the C/O and $^{12}$C/$^{13}$C ratio from the target spectra by a comparison to synthetic spectra. Then, we compared the outcomes of stellar evolutionary models with our measurements. The M stars in NGC 1978 show values of C/O and $^{12}$C/$^{13}$C that can best be explained with moderate extra-mixing on the RGB coupled to a moderate oxygen enhancement in the chemical composition. These oxygen-rich stars do not seem to have undergone third dredge-up episodes (yet). The C stars show carbon-to-oxygen and carbon isotopic ratios consistent with the occurrence of the third dredge-up. We did not find S stars in this cluster. None of the theoretical schemes that we considered was able to reproduce the observations appropriately. Instead, we discuss some non-standard scenarios to explain the puzzling abundance pattern in NGC 1978.

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Revisiting the role of M 31 in the dynamical history of the Magellanic Clouds

Nitya Kallivayalil\textsuperscript{1}, Gurtina Besla\textsuperscript{2}, Robyn Sanderson\textsuperscript{1} and Charles Alcock\textsuperscript{2}

\textsuperscript{1}MIT, USA
\textsuperscript{2}CfA, USA

We study the dynamics of the Magellanic Clouds in a model for the Local Group whose mass is constrained using the timing argument/two-body limit of the action principle. The goal is to evaluate the role of M 31 in generating the high angular momentum orbit of the Clouds, a puzzle that has only been exacerbated by the latest HST proper motion measurements. We study the effects of varying the total Local Group mass, the relative mass of the Milky Way and M 31, the proper motion of M 31, and the proper motion of the LMC on this problem. Over a large part of this parameter-space we find that tides from M 31 are insignificant. For a range of LMC proper motions approximately $3\sigma$ higher than the mean and total Local Group mass $> 3.5 \times 10^{12} \text{M}_\odot$, M 31 can provide a significant torque to the LMC orbit. However, if the LMC is bound to the MW, then M 31 is found to have negligible effect on its motion and the origin of the high angular momentum of the system remains a puzzle. Finally, we use the timing argument to calculate the total mass of the MW–LMC system based on the assumption that they are encountering each other for the first time, their previous perigalacticon being a Hubble time ago, obtaining $M_{\text{MW}} + M_{\text{LMC}} = (8.7 \pm 0.8) \times 10^{11} \text{M}_\odot$.

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The Structure of the LMC Stellar Halo Derived Using OGLE-III RR Lyr stars

O. Pejcha\textsuperscript{1} and K. Z. Stanek\textsuperscript{1}

\textsuperscript{1}Department of Astronomy, The Ohio State University, USA

We use the recently released OGLE-III catalog of 17692 fundamental mode RR Lyr stars in the Large Magellanic Cloud to investigate the structure of its stellar halo. We apply conservative cuts in period, amplitude and magnitude to remove blends and other contamination. We use period–luminosity and period–color relations to determine distance and extinction of every star in our final sample of 9393 stars. In order to determine the scatter of our method, we compare the distributions of distances in two regions at the edges of the covered area with a central region. We determine the intrinsic line-of-sight dispersion in the center to be 0.135 mag or 3.21 kpc (FWHM of 0.318 mag or 7.56 kpc), assuming zero depth in one of the edge regions. The conservative cuts we apply reduce the derived depth significantly. Furthermore, we find that the distribution of RR Lyr stars is deformed in the sense that stars on the Eastern side are closer than on the Western side. We model the RR Lyr distribution as a triaxial ellipsoid and determine its axes ratios to be 1:2.00:3.50 with the longest axis inclined by 6° from the line of sight. Another result of our analysis is an extinction map of the LMC and a map of internal reddening, which we make publicly available.

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and from http://www.astronomy.ohio-state.edu/~pejch/lmc_extmap/
Using the data obtained with the Spitzer Space Telescope as part of the Surveying the Agents of a Galaxy’s Evolution (SAGE) legacy survey, we have studied the variations of the dust composition and abundance across the Large Magellanic Cloud (LMC). Such variations are expected, as the explosive events which have lead to the formation of the many H\textsubscript{i} shells observed should have affected the dust properties. Using a model and comparing with a reference spectral energy distribution from our Galaxy, we deduce the relative abundance variations of small dust grains across the LMC. We examined the infrared color ratios as well as the relative abundances of very small grains (VSGs) and polycyclic aromatic hydrocarbons (PAHs) relative to the big grain (BG) abundance. Results show that each dust component could have different origins or evolution in the interstellar medium (ISM). The VSG abundance traces the star formation activity and could result from shattering of larger grains, whereas the PAH abundance increases around molecular clouds as well as in the stellar bar, where they could have been injected into the ISM during mass loss from old stars.

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Properties of RR Lyrae stars in the inner regions of the Large Magellanic Cloud. III. Near-infrared study.

J. Borissova\textsuperscript{1}, M. Rejkuba\textsuperscript{2}, D. Minniti\textsuperscript{3}, M. Catelan\textsuperscript{3,4} and V.D. Ivanov\textsuperscript{5}

\textsuperscript{1}Departamento de Física y Astronomía, Facultad de Ciencias, Universidad de Valparaíso, Ave. Gran Bretaña 1111, Playa Ancha, Casilla 53, Valparaíso, Chile
\textsuperscript{2}European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748,Garching b. München, D-85748, Germany
\textsuperscript{3}Department of Astronomy, Pontificia Universidad Católica de Chile,Az. Vicuña Mackenna 4860, 782-0436 Macul, Santiago, Chile and Vatican Observatory, V00120 Vatican City State, Italy
\textsuperscript{4}John Simon Guggenheim Memorial Foundation Fellow. On sabbatical leave at Catholic University of America, Department of Physics, 200 Hanham Hall, Washington, DC 20064, USA
\textsuperscript{5}European Southern Observatory, Av. Alonso de Córdoba 3107, Casilla 19,Santiago 19001, Chile

RR Lyrae variable stars are the primary Population II distance indicator. Likewise, the LMC constitutes a key step in the extragalactic distance scale. By combining near-IR photometry and spectroscopically measured metallicities for a homogeneous sample of 50 RR Lyr stars in the Large Magellanic Cloud (LMC), we investigate the metallicity dependence of the period–luminosity relation in the near-infrared (IR), use the newly derived relations to re-derive the distance to the LMC, and compare the distance moduli obtained from RR Lyr and red clump stars. This paper presents new (single-epoch) J-band and (multi-epoch) K\textsubscript{s}-band photometry of RR Lyr stars in 7 different LMC fields, observed with the near-IR camera SOFI at ESO’s New Technology Telescope. Additional K\textsubscript{s}-band data for another
two LMC fields were taken with the ISPI infrared array at CTIO’s Blanco 4m telescope. The near-IR photometry was cross-correlated with the MACHO and OGLE databases, resulting in a catalog of 62 RR Lyr stars with $BVRiJK_s$ photometry. A subsample of 50 stars also has spectroscopically measured metallicities. In the deep $JK$ color–magnitude diagrams of 7 fields, red giant branch, red clump and RR Lyr stars are detected. The majority of RR Lyr stars are located within the instability strip with near-IR colors between $0.14 \leq (J-K_s) \leq 0.32$ mag. The period–luminosity relation only has a very mild dependence on metallicity in the $K$ band, consistent with no dependence:

$$M_{Ks} = 2.11(\pm 0.17) \log P + 0.05(\pm 0.07) [\text{Fe/H}] - 1.05.$$ 

In the $J$ band the currently available data do not allow firm conclusions regarding the metallicity dependence of the period–luminosity relation. The distance modulus of the LMC, derived using our near-IR period–luminosity-metallicity relation for RR Lyr stars, is $(m-M)_0 = 18.53\pm0.13$ mag, in very good agreement with the distance modulus from the red clump stars, $18.46 \pm 0.07$ mag. However, LMC modulus derived from the RR Lyrae stars depends on the parallax of the star RR Lyrae.

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New Magellanic Cloud R Coronae Borealis and DY Per type stars from the EROS-2 database: the connection between RCBs, DYPers and ordinary carbon stars

P. Tisserand$^{1,2}$, P.R. Wood$^1$, J.B. Marquette$^3$ and the EROS-2 Collaboration

$^1$Research School of Astronomy and Astrophysics, ANU, Australia
$^2$CEA, DSM, DAPNIA, Centre d’études de Saclay, France
$^3$Institut d’Astrophysique de Paris, UMR7095 CNRS, France

R Coronae Borealis stars (RCB) are a rare type of evolved carbon-rich supergiant stars that are increasingly thought to result from the merger of two white dwarfs, called the Double degenerate scenario. This scenario is also studied as a source, at higher mass, of type Ia Supernovae (SnIa) explosions. Therefore a better understanding of RCBs composition would help to constrain simulations of such events. We searched for and studied RCB stars in the EROS Magellanic Clouds database. We also extended our research to DY Per type stars (DYPers) that are expected to be cooler RCBs ($T \sim 3500$ K) and much more numerous than their hotter counterparts. With the aim of studying possible evolutionary connections between RCBs and DYPers, and also ordinary carbon stars, we compared their publically available broad band photometry in the optical, near, and mid-infrared. The light curves of $\sim 70$ million stars, monitored for 6.7 years (from July 1996 to February 2003), have been analysed to search for the main signature of RCBs and DYPers: a large (up to 9 mags) drop in luminosity. Carbon stars with fading episodes were also found by inspecting numerous light curves of objects that presented an infrared excess in the 2MASS and Spitzer SAGE and S$^3$MC databases. Follow-up optical spectroscopy was used to confirm each photometric candidate found. We have discovered and confirmed 6 new Magellanic Cloud RCB stars and 7 new DYPers, but also listed new candidates: 3 RCBs and 14 DYPers. Optical and infrared colour magnitude diagrams that give new insights into these two sets of stars are discussed. We estimated a range of Magellanic RCB shell temperatures between 360 and 600 K. We confirm the wide range of absolute luminosity known for RCB stars, $M_V \sim -5.2$ to $-2.6$ mag. Our study further shows that mid-infrared surveys are ideal to search for RCB stars, since they have thinner and cooler circumstellar shells than classical post-AGB stars. In addition, by increasing the number of known DYPers by $\sim 400\%$, we have been able to shed light on the similarities in the spectral energy distribution between DYPers and ordinary carbon stars. We also observed that DYPer circumstellar shells are fainter and hotter than those of RCBs. This suggests that DYPers may simply be ordinary carbon stars with ejection events, but more abundance analysis is necessary to give a status on a possible evolutionary connection between RCBs and DYPers.

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and from http://eros.in2p3.fr/Variables/RCB/
The low-mass stellar mass functions of rich, compact clusters in the Large Magellanic Cloud

Q. Liu\textsuperscript{1,2}, R. de Grijs\textsuperscript{3,1}, L.C. Deng\textsuperscript{1}, Y. Hu\textsuperscript{1,2} and S.F. Beaulieu\textsuperscript{4}

\textsuperscript{1}National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, P.R. China
\textsuperscript{2}Graduate University of the Chinese Academy of Sciences, Beijing 100049, P.R. China
\textsuperscript{3}Department of Physics & Astronomy, The University of Sheffield, Sheffield S3 7RH, UK
\textsuperscript{4}Département de Physique, de Génie Physique et d’Optique and Centre de Recherche en Astrophysique du Québec, Université Laval, Québec, QC G1V 0A6, Canada

We use Hubble Space Telescope photometry of six rich, compact star clusters in the Large Magellanic Cloud (LMC), with ages ranging from 0.01 to 1.0 Gyr, to derive the clusters’ stellar mass functions (MFs) at their half-mass radii. The LMC is an ideal environment to study stellar MFs, because it contains a large population of compact clusters at different evolutionary stages. We aim to obtain constraints on the initial MFs (IMFs) of our sample clusters on the basis of their present-day MFs, combined with our understanding of their dynamical and photometric evolution. We derive the clusters’ present-day MFs below 1.0 M\textsubscript{☉} using deep observations with the Space Telescope Imaging Spectrograph and updated stellar population synthesis models. Since the relaxation timescales of low-mass stars are very long, dynamical evolution will not have affected the MFs below 1.0 M\textsubscript{☉} significantly, so that — within the uncertainties — the derived MFs are consistent with the solar-neighbourhood IMF, at least for the younger clusters. The IMF in the low-density, low-metallicity environment of the LMC disk is not significantly different from that in the solar neighbourhood.

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The Effect of Stellar Rotation on Colour–Magnitude Diagrams: On the apparent presence of multiple populations in intermediate age stellar clusters

Nate Bastian\textsuperscript{1} and Selma de Mink\textsuperscript{2}

\textsuperscript{1}Institute of Astronomy, Cambridge University, UK
\textsuperscript{2}Astronomical Institute, Utrecht University, The Netherlands

A significant number of intermediate age clusters (1–2 Gyr) in the Magellanic Clouds appear to have multiple stellar populations within them, derived from bi-modal or extended main sequence turn offs. If this is interpreted as an age spread, the multiple populations are separated by a few hundred Myr, which would call into question the long held notion that clusters are simple stellar populations. Here we show that stellar rotation in stars with masses between 1.2–1.7 M\textsubscript{☉} can mimic the effect of a double or multiple population, whereas in actuality only a single population exists. The two main causes of the spread near the turn-off are the effects of stellar rotation on the structure of the star and the inclination angle of the star relative to the observer. Both effects change the observed effective temperature, hence colour, and flux of the star. In order to match observations, the required rotation rates are 20–50% of the critical rotation, which are consistent with observed rotation rates of similar mass stars in the Galaxy. We provide scaling relations which can be applied to non-rotating isochrones in order to mimic the effects of rotation. Finally, we note that rotation is unlikely to be the cause of the multiple stellar populations observed in old globular clusters, as low mass stars (< 1 M\textsubscript{☉}) are not expected to be rapid rotators.

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The Cepheid Period–Luminosity (PL, also known as the Leavitt Law) relation at 3.6 and 4.5 μm, derived by matching the LMC Cepheids in the OGLE-III catalog to the archival SAGE database. More details can be found in Ngeow et al. 2009, ApJ, 693, 691.
Chemical signature of a major merger in the early formation of the Small Magellanic Cloud

Takuji Tsujimoto¹ and Kenji Bekki²

¹National Astronomical Observatory of Japan, Japan
²University of New South Wales, Australia

The formation history of the Small Magellanic Cloud (SMC) is unraveled based on the results of our new chemical evolution models constructed for the SMC, highlighting the observed anomaly in the age–metallicity relation for star clusters in the SMC. We first propose that evidence of a major merger is imprinted in the age–metallicity relation as a dip in [Fe/H]. Our models predict that the major merger with a mass ratio of 1:1 to 1:4 occurred at \( \sim 7.5 \) Gyr ago, with a good reproduction of the abundance distribution function of field stars in the SMC. Furthermore, our models predict a relatively large scatter in [Mg/Fe] for \(-1.4 < [\text{Fe}/H] < -1.1\) as a reflection of a looping feature resulting from the temporally inverse progress of chemical enrichment, which can be tested against future observational results. Given that the observed velocity dispersion (\( \sim 30 \) km s\(^{-1}\)) of the SMC is much smaller than that (\( \sim 160 \) km s\(^{-1}\)) of the Galactic halo, our finding strongly implies that the predicted merger event happened in a small group environment that was far from the Galaxy and contained a number of small gas-rich dwarfs comparable to the SMC. This theoretical view is extensively discussed in the framework that considers a connection with the formation history of the Large Magellanic Cloud.

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Radio Planetary Nebulae in the Magellanic Clouds

M.D. Filipović¹, M. Cohen², W.A. Reid³, J.L. Payne¹, Q.A. Parker⁴, E.J. Crawford¹, I.S. Bojić³, A.Y. De Horta¹, A. Hughes⁴,5, J. Dickel⁶ and F. Stootman¹

¹University of Western Sydney, Locked Bag 1797, Penrith South DC, NSW 1797, Australia
²Radio Astronomy Laboratory, University of California, Berkeley, CA 94720, USA
³Department of Physics, Macquarie University, Sydney, NSW 2109, Australia
⁴Swinburne University of Technology, Hawthorn, VIC 3122, Australia
⁵CSIRO Australia Telescope National Facility, P.O. Box 76, Epping, NSW 1710, Australia
⁶Department of Physics and Astronomy, University of New Mexico, 800 Yale Blvd NE, Albuquerque, NM 87131, USA

We report the extragalactic radio-continuum detection of 15 planetary nebulae (PNe) in the Magellanic Clouds (MCs) from recent Australia Telescope Compact Array+Parkes mosaic surveys. These detections were supplemented by new and high resolution radio, optical and IR observations which helped to resolve the true nature of the objects. Four of the PNe are located in the Small Magellanic Cloud (SMC) and 11 are located in the Large Magellanic Cloud (LMC). Based on Galactic PNe the expected radio flux densities at the distance of the LMC/SMC are up to \( \sim 2.5 \) mJy and \( \sim 2.0 \) mJy at 1.4 GHz, respectively. We find that one of our new radio PNe in the SMC has a flux density of 5.1 mJy at 1.4 GHz, several times higher than expected. We suggest that the most luminous radio PN in the SMC (NS 68) may represent the upper limit to radio peak luminosity because it is \( \sim 3 \) times more luminous than NGC 7027, the most luminous known Galactic PN. We note that the optical diameters of these 15 MCs PNe vary from very small (\( \sim 0.08 \) pc or 0′′; SMP L47) to very large (\( \sim 1 \) pc or 4′′; SMP L83). Their flux densities peak at different frequencies, suggesting that they may be in different stages of evolution. We briefly discuss mechanisms that may explain their unusually high radio-continuum flux densities. We argue that these detections may help solve the ”missing mass problem” in PNe whose central stars were originally 1–8 M\(_{\odot}\). We explore the possible link between ionised halos ejected by the central stars in their late evolution and extended radio emission. Because of their higher than expected flux densities we tentatively call this PNe (sub)sample “Super PNe”.

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Carbon abundance in Small Magellanic Cloud planetary nebulae through Advanced Camera for Surveys prism spectroscopy: constraining stellar evolution at low metallicity.

L. Stanghellini\(^1\), T.-H. Lee\(^2\), R. A. Shaw\(^1\), B. Balick\(^3\) and E. Villaver\(^4\)

\(^1\)NOAO, Tucson, USA
\(^2\)Western Kentucky University, USA
\(^3\)University of Washington, USA
\(^4\)Universidad Autónoma de Madrid, Spain

We perform near ultraviolet ACS prism spectroscopy of 11 Small Magellanic Cloud (SMC) planetary nebulae (PNe) with the main aim of deriving the abundance of carbon. The analysis of the ACS spectra provide reliable atomic carbon abundances for all but a couple of our targets; ionic C\(^{2+}\) abundances are calculated for all target PNe. With the present paper we more than double the number of SMC PNe with known carbon abundances, providing a good database to study the elemental evolution in low- and intermediate-mass stars at low metallicity. We study carbon abundances of Magellanic Cloud PNe in the framework of stellar evolution models and the elemental yields. Constraining SMC and LMC stellar evolutionary models is now possible with the present data, through the comparison of the final yields calculated and the CNO abundances observed. We found that SMC PNe are almost exclusively carbon rich, and that for the most part they have not undergone the hot-bottom burning phase, contrary to \(~\)half of the studied LMC PNe. The yields from stellar evolutionary models with LMC and SMC metallicities broadly agree with the observations. In particular, evolutionary yields for M\(_{\odot}\) < 3.5 M\(_{\odot}\) well encompass the abundances of round and elliptical PNe in the SMC. We found that the carbon emission lines are major coolants for SMC PNe, more so than in their LMC counterparts, indicating that metallicity has an effect on the physics of PNe, as predicted by Stanghellini et al. (2003).

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RAVE spectroscopy of luminous blue variables in the Large Magellanic Cloud


\(^1\)INAF Astronomical Observatory of Padova, 36012 Asiago, Italy

The RAVE spectroscopic survey for galactic structure and evolution obtains 8400–8800 Å spectra at 7500 resolving power at the UK Schmidt Telescope using the 6dF multi-fiber positioner. More than 300 000 \(9^\circ < I < 12^\circ\) and \(|b| > 25^\circ\) southern stars have been observed to date. This paper presents the first intrinsic examination of stellar spectra from the RAVE survey, aimed at evaluating their diagnostic potential for peculiar stars and at contributing to the general understanding of Luminous Blue Variables (LBVs). We used the multi-epoch spectra for all seven LBVs observed, between 2005 and 2008, in the Large Magellanic Cloud (LMC) by the RAVE survey. We demonstrate that RAVE spectra possess significant diagnostic potential when applied to peculiar stars and, in particular, LBVs. The behaviour of the radial velocities for both emission and absorption lines, and the spectral changes between outburst and quiescence states are described and found to agree with evidence gathered at more conventional wavelengths. The wind outflow signatures and their variability are investigated, with multi-components detected in S Doradus. Photoionisation modelling of the rich emission line spectrum of R 127 shows evidence of a massive detached ionised shell that was ejected during the 1982–2000 outburst. Surface inhomogeneities in the nuclear-processed material, brought to the surface by heavy mass loss, could have been observed in S Doradus, even if alternative explanations are possible. We also detect the transition from quiescence to outburst state in R 71. Finally, our spectrum of R 84 offers one of the clearest views of its cool companion.

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Spitzer observations of the N 157B supernova remnant and its surroundings

E.R. Micelotta¹, B.R. Brandl¹ and F.P. Israel²

¹Sterrewacht Leiden, Leiden University, P.O. Box 9513, 2300 RA Leiden, The Netherlands

Aims. We study the LMC interstellar medium in the field of the nebula N 157B, which contains a supernova remnant, an OB association, ionized gas, and high-density dusty filaments in close proximity. We investigate the relative importance of shock excitation by the SNR and photo-ionization by the OB stars, as well as possible interactions between the supernova remnant and its environment. Methods: We apply multiwavelength mapping and photometry, along with spatially resolved infrared spectroscopy, to identifying the nature of the ISM using new infrared data from the Spitzer space observatory and X-ray, optical, and radio data from the literature. Results: The N 157B SNR has no infrared counterpart. Infrared emission from the region is dominated by the compact blister-type H II region associated with 2MASS J05375027−6911071 and excited by an O8–O9 star. This object is part of an extended infrared emission region that is associated with a molecular cloud. We find only weak emission from the shock-indicator [Fe II], and both the excitation and the heating of the extended cloud are dominated by photo-ionization by the early O stars of LH 99. Conclusions: Any possible impact by the expanding SNR does not now affect the extended cloud of molecules and dust, despite the apparent overlap of SNR X-ray emission with infrared and Hα emission from the cloud. This implies that the supernova progenitor cannot have been more massive than about 25 M☉.

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Suzaku observations of SN 1987A

Richard Sturm¹, Frank Haberl¹, Günther Hasinger¹,², Kyoko Kenzaki³ and Masayuki Itoh³

¹Max-Planck-Institut für extraterrestrische Physik, Gießenbachstraße, 85748 Garching, Germany
²Max-Planck-Institut für Plasmaphysik, Boltzmannstraße 2, 85748 Garching, Germany
³Kobe University, 3-11 Tsurukabuto, Nada-ku, Kobe 657-8501, Japan

We report on Suzaku observations of SN 1987A in the Large Magellanic Cloud, performed in November 2005 and June 2006. The observations provide medium resolution X-ray spectra during the phase of the interaction between the supernova blast wave and the inner circumstellar ring. The Suzaku observations complement XMM-Newton and Chandra observations and were used to investigate the spectral evolution of SN 1987A. The spectra were analyzed with two-temperature emission model from shocked gas. For the flux in the soft band (0.5–2.0 keV) we obtained 25.7⁺¹.⁴⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⟵

Discovery of a dense molecular cloud towards a young massive embedded star in 30 Doradus

M. Rubio¹, S. Paron² and G. Dubner²

¹Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile
²Instituto de Astronomía y Física del Espacio (IAFE), CC 67, Suc. 28, 1428 Buenos Aires, Argentina

The 30 Doradus region in the Large Magellanic Cloud is one of the most outstanding star forming regions of the Local Group and a primary target to study star formation in an environment of low metallicity. In order to obtain a more
complete picture of the not yet consumed or dispersed cool gas, we searched for line emission from molecular clouds that could be associated with molecular hydrogen emission detected in the region. We obtained a high sensitivity $^{12}$CO J=2–1 map with the 15-m SEST telescope, complemented by pointed observations of $^{13}$CO J=2–1 and CS J=2–1. We report the discovery of a dense molecular cloud towards an embedded young massive star at $\sim 20''$ ($\sim 5$ pc, at the distance of 50 kpc) northwest of R 136, the compact massive central stellar cluster powering 30 Doradus in the LMC, that could be triggering star formation in the surrounding molecular clouds. We derived a molecular mass of $\lesssim 10^4 M_\odot$, a linear radius of 3 pc, as an upper limit, and a mean density of $\gtrsim 10^3$ cm$^{-3}$ for the cloud. The detection of CS J=2–1 emission line indicates larger densities, $\sim 10^6$ cm$^{-3}$. The dense molecular cloud is associated with molecular $2.12 \mu$m H$_2$ emission. We suggest that the observed molecular gas could be the remains of dense molecular material surviving the action of strong UV fields and winds in which the young massive star has formed.

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Spitzer SAGE Infrared Photometry of Massive Stars in the Large Magellanic Cloud

A.Z. Bonanos$^1$, D.L. Massa$^1$, M. Sewilo$^1$, D.J. Lennon$^1$, N. Panagia$^1$, L.J. Smith$^1$, M. Meixner$^1$, B.L. Babler$^2$, S. Bracker$^2$, M.R. Meade$^2$, K.D. Gordon$^1$, J.L. Hora$^3$, R. Indebetouw$^4$ and B.A. Whitney$^5$

1Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD, 21218, USA
2Department of Astronomy, 475 North Charter St., University of Wisconsin, Madison, WI 53706, USA
3Harvard-Smithsonian Center for Astrophysics, 60 Garden St., MS 67, Cambridge, MA 02138, USA
4Department of Astronomy, University of Virginia, P.O. Box 3818, Charlottesville, VA 22903, USA
5Space Science Institute, 4750 Walnut St., Suite 205, Boulder, CO 80301, USA

We present a catalog of 1750 massive stars in the Large Magellanic Cloud, with accurate spectral types compiled from the literature, and a photometric catalog for a subset of 1268 of these stars, with the goal of exploring their infrared properties. The photometric catalog consists of stars with infrared counterparts in the Spitzer SAGE survey database, for which we present uniform photometry from 0.3–24 $\mu$m in the UBVIJHK$_s$+IRAC+MIPS24 bands. The resulting infrared color–magnitude diagrams illustrate that the supergiant B[e], red supergiant and luminous blue variable (LBV) stars are among the brightest infrared point sources in the Large Magellanic Cloud, due to their intrinsic brightness, and at longer wavelengths, due to dust. We detect infrared excesses due to free-free emission among $\sim 900$ OB stars, which correlate with luminosity class. We confirm the presence of dust around 10 supergiant B[e] stars, finding the shape of their spectral energy distributions (SEDs) to be very similar, in contrast to the variety of SED shapes among the spectrally variable LBVs. The similar luminosities of B[e] supergiants ($\log L/L_\odot \geq 4$) and the rare, dusty progenitors of the new class of optical transients (e.g. SN 2008S and NGC 300 OT), plus the fact that dust is present in both types of objects, suggests a common origin for them. We find the infrared colors for Wolf-Rayet stars to be independent of spectral type and their SEDs to be flatter than what models predict. The results of this study provide the first comprehensive roadmap for interpreting luminous, massive, resolved stellar populations in nearby galaxies at infrared wavelengths.

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A general catalogue of extended objects in the Magellanic System

E. Bica$^1$, C. Bonatto$^1$, C.M. Dutra$^2$ and J.F.C. Santos Jr.$^3$

1Departamento de Astronomia, Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves 9500, Porto Alegre 91501-970, RS, Brazil
2Universidade Federal do Pampa — UNIPAMPA, Centro de Ciências da Saúde, Rua Domingos de Almeida, 3525, Bairro São Miguel, Uruguaiana 97500-009, RS, Brazil
3Departamento de Física, ICEX, Universidade Federal de Minas Gerais, Av. Antônio Carlos 6627, Belo Horizonte 30123-970, MG, Brazil
Figure 1: Angular distribution of the 9305 extended objects in the Magellanic System. Clusters older than 4 Gyr are shown as large gray circles. The derived LMC and SMC centroids are indicated by white triangles. The position of 30 Dor is shown by the plus sign.
Figure 2: Angular distribution of the 794 H I shells and super shells (top left panel), 3326 stellar associations (top right), 1445 emission nebulae (bottom right), and 3763 star clusters (bottom right).
Figure 3: Left panels: apparent diameter distribution function, $\phi(D_{\text{app}}) = dN/dD_{\text{app}}$, of the star clusters and associations. LMC, SMC, and Bridge distributions are shown separately, as well as these three spatial structures together (top-most panel). Fits of $\phi(D_{\text{app}}) \sim D_{\text{app}}^{-\eta}$ to the large-size tail are shown for the associations (solid line) and clusters (dashed). Right panels: same as the left ones for the ellipticity ($e = 1 - b/a$) distribution function, $\phi(e) = dN/d_e$. Fits in the right panels correspond to the exponential-decay function $\phi(e) \sim e^{-e/e_0^2}$. 

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Figure 4: Top panels: apparent diameter distribution function of the LMC, SMC, and Bridge built with star clusters (top) and associations (middle). SMC and Bridge apparent diameters have been multiplied by 1.2 to correct for the different distances with respect to the LMC. These functions have been normalised to the LMC number of objects. Bottom panel: tidal radius distribution function of the Milky Way GCs, in absolute scale. For a consistent comparison with the MCs apparent diameters, the dynamical range of the abscissa is equal in all panels.
RR Lyrae stars in the inner LMC: Where did they form?

Annapurni Subramaniam and Smitha Subramanian

Indian Institute of Astrophysics, Bangalore, India

RR Lyrae stars (RRLS) belong to population II and are generally used as a tracer of the host galaxy halo. The surface as well as vertical distribution of RRLS in the inner Large Magellanic Cloud (LMC) are studied to understand whether these stars are actually formed in the halo. RRLS identified by the OGLE III survey are used to estimate their number density distribution. The scale-height of their distribution is estimated using extinction corrected average magnitudes of ab type stars. The density distribution mimics the bar, confirming results in the literature. The distribution of their scale height indicates that there may be two populations, one with smaller scale-height, very similar to the red clump stars and the other, much larger. The distribution of the reddening-corrected magnitude along the minor axis shows variation, suggesting an inclination. The inclination is estimated to be \( i = 31.3 \pm 3.5 \) degrees, very similar to the inclination of the disk. Thus, the RRLS in the inner LMC mimic the bar and inclination of the disk, suggesting that a major fraction of RRLS is formed in the disk of the LMC. The results indicate that the RRLS in the inner LMC trace the disk and probably the inner halo. They do not trace the extended metal-poor halo of the LMC. We suggest that a major star formation event happened in the LMC at 10–12 Gyrs ago, resulting in the formation of most of the inner RRLS, as well as probably the globular clusters, inner halo and the disk of the LMC.

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Properties and origin of the high-velocity gas toward the Large Magellanic Cloud

Nicolas Lehner, Lister Staveley-Smith and J. Chris Howk

University of Notre Dame, USA
University of Western Australia, Australia

In the spectra of 139 early-type Large Magellanic Cloud (LMC) stars observed with FUSE and with deep radio Parkes HI 21-cm observations along those stars, we search for and analyze the absorption and emission from high-velocity gas at \( +90 < v < +175 \) km s\(^{-1}\). The HI column density of the high-velocity clouds (HVCs) along these sightlines ranges from \( < 10^{18.4} \) to \( 10^{19.2} \) cm\(^{-2}\). The incidence of the HVC metal absorption is 70%, significantly higher than the HI emission occurrence of 32%. We find that the mean metallicity of the HVC is \([\text{O} \text{I}]/\text{H} \text{I}] = -0.51^{-0.12}_{+0.16}\). There is no strong evidence for a large variation in the HVC metallicity, implying that these HVCs have a similar origin and are part of the same complex. The mean and scatter of the HVC metallicities are more consistent with the present-day LMC oxygen abundance than that of the Small Magellanic Cloud or the Milky Way. We find that on average \([\text{Si} \text{II}]/\text{O} \text{I}] = +0.48^{+0.15}_{-0.25}\) and \([\text{Fe} \text{II}]/\text{O} \text{I}] = +0.33^{+0.14}_{-0.21}\), implying that the HVC complex is dominantly ionized. The HVC complex has a multiphase structure with a neutral (O I, Fe II), weakly ionized (Fe II, N II), and highly ionized (O VI) components, and has evidence of dust but no molecules. All the observed properties of the HVC can be explained by an energetic outflow from the LMC. This is the first example of a large (> \( 10^6 \) M\(_\odot\)) HVC complex that is linked to stellar feedback occurring in a dwarf spiral galaxy.

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The Structure of a Low Metallicity Giant Molecular Cloud Complex

A.K. Leroy¹, A. Bolatto², C. Bot³, C.W. Engelbracht⁴, K. Gordon⁵, F.P. Israel⁶, M. Rubio⁷, K. Sandstrom⁸ and S. Stanimirović⁹

¹MPIA Heidelberg, Germany
²University of Maryland, USA
³Observatoire Astronomique de Strasbourg, France
⁴Steward Observatory, University of Arizona, USA
⁵STScI, USA
⁶Sterrewacht Leiden, The Netherlands
⁷Universidad de Chile, Chile
⁸U.C. Berkeley, USA
⁹University of Wisconsin, Madison, USA

To understand the impact of low metallicities on giant molecular cloud (GMC) structure, we compare far infrared dust emission, CO emission, and dynamics in the star-forming complex N 83 in the Wing of the Small Magellanic Cloud. Dust emission (measured by Spitzer as part of the S³MC and SAGE-SMC surveys) probes the total gas column independent of molecular line emission and traces shielding from photodissociating radiation. We calibrate a method to estimate the dust column using only the high-resolution Spitzer data and verify that dust traces the ISM in the H i-dominated region around N 83. This allows us to resolve the relative structures of H₂, dust, and CO within a giant molecular cloud complex, one of the first times such a measurement has been made in a low-metallicity galaxy. Our results support the hypothesis that CO is photodissociated while H₂ self-shields in the outer parts of low-metallicity GMCs, so that dust/self shielding is the primary factor determining the distribution of CO emission. Four pieces of evidence support this view. First, the CO-to-H₂ conversion factor averaged over the whole cloud is very high $4 - 11 \times 10^{21}$ cm$^{-2}$/(K km s$^{-1}$), or 20–55 times the Galactic value. Second, the CO-to-H₂ conversion factor varies across the complex, with its lowest (most nearly Galactic) values near the CO peaks. Third, bright CO emission is largely confined to regions of relatively high line-of-sight extinction, $A_V \sim 2$ mag, in agreement with PDR models and Galactic observations. Fourth, a simple model in which CO emerges from a smaller sphere nested inside a larger cloud can roughly relate the H₂ masses measured from CO kinematics and dust.

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Spectroscopic study of the N 159/N 160 complex in the Large Magellanic Cloud

Cecilia Farína¹, Guillermo L. Bosch¹-², Nidia I. Morrell³, Rodolfo H. Barbá⁴,⁵ and Nolan R. Walborn⁶

¹Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, 1900 La Plata, Argentina
²IALP-CONICET, Argentina
³Las Campanas Observatory, Observatories of the Carnegie Institution of Washington, La Serena, Chile
⁴Complejo Astronómico El Leoncito, Avda. España 1412 Sur, San Juan, Argentina
⁵Departamento de Física, Universidad de La Serena, Benavente 980, La Serena, Chile
⁶Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA

We present a spectroscopic study of the N 159/N 160 massive star-forming region South of 30 Doradus in the Large Magellanic Cloud, classifying a total of 189 stars in the field of the complex. Most of them belong to O and early B spectral classes; we have also found some uncommon and very interesting spectra, including members of the Onfp class, a Be P Cygni star, and some possible multiple systems. Using spectral types as broad indicators of evolutionary stages, we considered the evolutionary status of the region as a whole. We infer that massive stars at different evolutionary stages are present throughout the region, favoring the idea of a common time for the origin of recent star formation in the N 159/N 160 complex as a whole, while sequential star formation at different rates is probably present in several subregions.

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Joint analysis of near-infrared properties and surface brightness fluctuations of LMC star clusters

Gabriella Raimondo

1INAF-Osservatorio Astronomico di Teramo, Italy

Surface brightness fluctuations have been proved to be a very powerful technique to determine the distance and characterize the stellar content in extragalactic systems. Nevertheless, before facing the problem of stellar content in distant galaxies, we need to calibrate the method onto nearby well-known systems. In this paper we analyze the properties at $J$ and $K_s$ bands of a sample of 19 star clusters in the Large Magellanic Cloud (LMC), for which accurate near-infrared (NIR) resolved star photometry, and integrated photometry are available. For the same sample, we derive the SBF measurements in $J$ and $K_s$-bands. We use the multi-purpose stellar population code SPoT (Stellar POpulations Tools) to simulate the color–magnitude diagram, stellar counts, integrated magnitudes, colors, and surface brightness fluctuations of each cluster. The present procedure allows us to estimate the age and metallicity of the clusters in a consistent way, and provides a new calibration of the empirical $s$-parameter. We take advantage of the high sensitivity of NIR surface brightness fluctuations to thermally pulsing asymptotic (TP-AGB) stars to test different mass-loss rates affecting the evolution of such stars. We argue that NIR-SBFs can contribute to the disentangling of the observable properties of TP-AGB stars, especially in galaxies, where a large number of these stars are present.

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Long secondary periods in variable red giants

C.P. Nicholls1, P.R. Wood1, M.-R.L. Cioni2 and I. Soszyński3

1Research School of Astronomy and Astrophysics, Australian National University, Cotter Road, Weston Creek ACT 2611, Australia
2Centre for Astrophysics Research, University of Hertfordshire, College Lane, Hatfield, AL10 9AB, UK
3Warsaw University Observatory, Aleje Ujazdowskie 4, 00-478, Warsaw, Poland

We present a study of a sample of LMC red giants exhibiting Long Secondary Periods (LSPs). We use radial velocities obtained from VLT spectral observations and MACHO and OGLE light curves to examine properties of the stars and to evaluate models for the cause of LSPs. This sample is much larger than the combined previous studies of Hinkle et al. (2002) and Wood, Olivier & Kawaler (2004).

Binary and pulsation models have enjoyed much support in recent years. Assuming stellar pulsation, we calculate from the velocity curves that the typical fractional radius change over an LSP cycle is greater than 30 per cent. This should lead to large changes in $T_{\text{eff}}$ that are not observed. Also, the small light amplitude of these stars seems inconsistent with the radius amplitude. We conclude that pulsation is not a likely explanation for the LSPs. The main alternative, physical movement of the star — binary motion — also has severe problems. If the velocity variations are due to binary motion, the distribution of the angle of periastron in our large sample of stars has a probability of $1.4 \times 10^{-3}$ that it comes from randomly aligned binary orbits. In addition, we calculate a typical companion mass of 0.09 $M_\odot$. Less than 1 per cent of low mass main sequence stars have companions near this mass (0.06 to 0.12 $M_\odot$) whereas $\sim 25$ to 50 per cent of low mass red giants end up with LSPs. We are unable to find a suitable model for the LSPs and conclude by listing their known properties.

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The age–metallicity relation for LMC/SMC star clusters for the age range up to 1 Gyr

M. Kontizas\textsuperscript{1}, E. Kontizas\textsuperscript{2}, A. Dapergolas\textsuperscript{2}, E. Livanou\textsuperscript{1}, I. Bellas-Velidis, \textsuperscript{2} B. Nordström\textsuperscript{3}, J. Andersen\textsuperscript{3}, B. Dirsch\textsuperscript{4}, D. Petsori \textsuperscript{1} and A. Karampelas\textsuperscript{1}

\textsuperscript{1}Department of Astrophysics Astronomy & Mechanics, Faculty of Physics, University of Athens, Greece
\textsuperscript{2}IAA, National Observatory of Athens, Greece
\textsuperscript{3}The Niels Bohr Institute, Astronomy Group, Copenhagen
\textsuperscript{4}Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Argentina

The age–metallicity relation (AMR) for LMC (Triangles) and SMC (Squares) star clusters for the age range up to 1 Gyr. The selected clusters are mainly small clusters covering distances from the center to the outer regions of both galaxies. Strömgren photometry CMDs have been used in order to find the age of their stellar content.

1) It shows a possible jump of metallicity and a considerable increase at the age of about $6 \times 10^8$ yr. Is this connected to the latest LMC-SMC interaction?

2) The AMR for the LMC is also displaying a gradient of metallicity, since all clusters with metallicity $-1.0$ to $-1.5$ dex are all located at the outermost regions of the galaxies.
The mysterious bar of the Large Magellanic Cloud: What is it?

Annapurni Subramaniam\textsuperscript{1} and Smitha Subramanian\textsuperscript{1}

\textsuperscript{1}Indian Institute of Astrophysics, Bangalore, India

The bar of the Large Magellanic Cloud (LMC) is one of the prominent, but controversial feature regarding its location with respect to the disk of the LMC. In order to study the relative location of the bar with respect to the disk, we present the high resolution map of the structure across the LMC. We used the reddening corrected mean magnitudes ($I_0$) of red clump (RC) stars from the OGLE III catalogue to map the relative variation in distance (vertical structure) or variation in RC population across the LMC. The bar does not appear as an identifiable vertical feature in the map, as there is no difference in $I_0$ values between the bar and the disk regions. We conclude that the LMC bar is very much part of the disk, located in the plane of the disk and it is not a separate component within 0.02 mag. We identify warps or variation in RC population with increase in radial distance.

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Modulations in multi-periodic blue variables in the LMC

\textit{J. Robert Buchler\textsuperscript{1}, Peter R. Wood\textsuperscript{2} and Robert E. Wilson\textsuperscript{3}}

\textsuperscript{1}Physics Dept., University of Florida, Gainesville, FL, USA
\textsuperscript{2}RSSA, Mt. Stromlo, ANU, Canberra, Australia
\textsuperscript{3}Astronomy Dept., University of Florida, Gainesville, FL, USA

As shown by Mennickent et al., a subset of the blue variable stars in the Large Magellanic Cloud exhibit brightness variability of small amplitude in the period range 2.4 to 16 days as well as larger amplitude variability with periods of 140 to 600 days, with a remarkably tight relation between the long and the short periods. Our re-examination of these objects has led to the discovery of additional variability. The Fourier spectra of 11 of their 30 objects have 3 or 4 peaks above the noise level and a linear relation of the form $f_a = 2(f_b - f_L)$ among three of the frequencies. An explanation of this relation requires an interplay between the binary motion and that of a third object. The two frequency relations together with the Fourier amplitude ratios pose a challenging modeling problem.

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Tracing the Magellanic Clouds back in time

\textit{P. James E. Peebles\textsuperscript{1}}

\textsuperscript{1}Princeton University, USA

A solution is presented for the past motions of the Magellanic Clouds, the Milky Way galaxy, and M31, fitted to the measured velocities of the Clouds and M31, under some simplifying assumptions. The galaxies are modeled as isolated bodies back to redshift about 10, when their velocities relative to the general expansion of the universe were small, consistent with the gravitational instability picture for the growth of structure. Mass outside the Local Group is modeled as a third massive dynamical actor that is responsible for the angular momentum of the Clouds. A plausible solution under these assumptions requires that the circular velocity of the Milky Way is in the range $200 < v_c < 230$ km s$^{-1}$. The solution seems to be unique up to the modest variations allowed by the choices of $v_c$ and the position of the exterior mass. In this solution the proto-Magellanic Clouds at high redshift were near the South pole of the Milky Way (in its present orientation), at physical distance about 200 kpc from the Milky Way and moving away at about 200 km s$^{-1}$.

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The second survey of the molecular clouds in the Large Magellanic Cloud by NANTEN. II. Star formation

Akiko Kawamura¹, Yoji Mizuno¹, Tetsuhiro Minamidani¹², Miroslav D. Fillipović³, Lister Staveley-Smith⁴, Sungeun Kim⁵, Norikazu Mizuno¹, Toshikazu Onishi⁶, Akira Mizuno⁷ and Yasuo Fukui¹

¹Department of Astrophysics, Nagoya University, Furocho, Chikusaku, Nagoya 464-8602, Japan
²Department of Physics, Faculty of Science, Hokkaido University, N10W8, Kita-ku, Sapporo 060-0810, Japan
³University of Western Sidney, Penrith South DC, NSW 1797, Australia
⁴School of Physics, M013, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia
⁵Astronomy & Space Science Department, Sejong University, 98 Kwangjung-dong, Seongbuk-gu, Seoul, 143-747, Korea
⁶Department of Physical Science, Osaka Prefecture University, Sakai 599-8531, Japan
⁷Solar-terrestrial Environment Laboratory, Nagoya University, Furocho, Chikusaku, Nagoya 464-8601, Japan

We studied star formation activities in the molecular clouds in the Large Magellanic Cloud. We have utilized the second catalog of 272 molecular clouds obtained by NANTEN to compare the cloud distribution with signatures of massive star formation including stellar clusters, and optical and radio H II regions. We find that the molecular clouds are classified into three types according to the activities of massive star formation; Type I shows no signature of massive star formation, Type II is associated with relatively small HII region(s) and Type III with both HII region(s) and young stellar cluster(s). The radio continuum sources were used to confirm that Type I GMCs do not host optically hidden HII regions. These signatures of massive star formation show a good spatial correlation with the molecular clouds in a sense they are located within ~100 pc of the molecular clouds. Among possible ideas to explain the GMC Types, we favor that the Types indicate an evolutionary sequence; i.e., the youngest phase is Type I, followed by Type II and the last phase is Type III, where the most active star formation takes place leading to cloud dispersal. The number of the three types of GMCs should be proportional to the time scale of each evolutionary stage if a steady state of massive star and cluster formation is a good approximation. By adopting the time scale of the youngest stellar clusters, 10 Myrs, we roughly estimate the timescales of Types I, II and III to be 6 Myrs, 13 Myrs and 7 Myrs, respectively, corresponding to a lifetime of 20–30 Myrs for the GMCs with a mass above the completeness limit, 5 × 10⁴ M⊙.

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Conference Papers

IR imaging surveys of AGB stars in the Magellanic Clouds

Maria-Rosa L. Cioni³

³University of Hertfordshire, UK

AGB stars are ideal IR targets because they are cool and bright. Most of them escaped detection in optical or shallow IR surveys in the eighties contributing to the puzzling missing number of AGB stars with respect to theoretical predictions and former stages of evolution. Observations and AGB models have advanced steadily in the following decades providing us with an almost complete view of the AGB stars in the Magellanic Clouds. Their properties are tracers of structure and chemistry across galaxies. New surveys will be able to fill-in the gaps, in terms of sensitivity and monitoring, providing new constraints for the formation and evolution of the Magellanic Clouds.

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Fermi LAT Measurements of the Gamma-Ray Emission from the Large Magellanic Cloud

T. A. Porter\textsuperscript{1}, J. Knödlseder\textsuperscript{2} and Fermi LAT collaboration

\textsuperscript{1}Santa Cruz Institute for Particle Physics, USA
\textsuperscript{2}CESR, France

Apart from the Milky Way, the Large Magellanic Cloud (LMC) is the only other normal star-forming galaxy that was conclusively detected in high energy ($>100$ MeV) $\gamma$ rays by the Energetic Gamma Ray Telescope (EGRET) on the Compton Gamma-Ray Observatory. However, the sensitivity of EGRET was sufficient only to marginally resolve the LMC. We report on measurements of the $\gamma$-ray emission from the LMC by the Large Area Telescope (LAT) on the Fermi Gamma-ray Space Telescope. For the first time an externally viewed star-forming galaxy is well resolved in $\gamma$ rays. We discuss the distribution of the LMC diffuse emission as seen by the LAT and implications for cosmic-ray physics.

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Galactic C and S stars as guidelines for Magellanic Cloud AGB stars

R. Guandalini\textsuperscript{1} and M. Busso\textsuperscript{1}

\textsuperscript{1}Department of Physics, University of Perugia and INFN, Section of Perugia, Italy

The study of the evolutionary properties of Asymptotic Giant Branch stars still presents unresolved topics. Progress in the theoretical understanding of their evolution is hampered by the difficulty to empirically explain key physical parameters like their luminosity, mass loss rate and chemical abundances. We are performing an analysis of Galactic AGB stars trying to find constraints for these parameters. Our aim is of extending this analysis to the AGB stars of the Magellanic Clouds and of the Dwarf Spheroidal Galaxies using also mid-infrared observations from the Antarctic telescope IRAIT. AGB sources from the Magellanic Clouds will be fundamental in our understanding of the AGB evolution because they are all at a well defined distance (differently from the Galactic AGBs). Moreover, these sources present different values of metallicity: this fact should permit us of examining in a better way their evolutionary properties comparing their behaviour with the one from Galactic sources.

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Period–Luminosity relation for type II Cepheids

Noriyuki Matsunaga\textsuperscript{1}, Michael W. Feast\textsuperscript{2,3} and John W. Menzies\textsuperscript{3}

\textsuperscript{1}University of Tokyo, Japan
\textsuperscript{2}University of Cape Town, South Africa
\textsuperscript{3}South African Astronomical Observatory, South Africa

We have estimated JHK\textsubscript{s} magnitudes corrected to mean intensity for LMC type II Cepheids found in the OGLE-III survey. Period–luminosity relations (PLRs) are derived in JHK\textsubscript{s} as well as in a reddening-free VI parameter. The BL Her stars ($P < 4$ d) and the W Vir stars ($P = 4$ to 20 d) are co-linear in these PLRs. The slopes of the infrared relations agree with those found previously for type II Cepheids in globular clusters within the uncertainties. Using the pulsation parallaxes of V553 Cen and SW Tau, the data lead to an LMC modulus of $18.46 \pm 0.10$ mag, uncorrected for any metallicity effects. We have now established the PLR of type II Cepheids as a distance indicator by confirming
that (almost) the same PLR satisfies the distributions in the PL diagram of type II Cepheids in (at least) two different systems, i.e. the LMC and Galactic globular clusters, and by calibrating the zero point of the PLR. RV Tau stars in the LMC, as a group, are not co-linear with the shorter-period type II Cepheids in the infrared PLRs in marked contrast to such stars in globular clusters. We note differences in period distribution and infrared colors for RV Tau stars in the LMC, globular clusters and Galactic field. We also compare the PLR of type II Cepheids with that of classical Cepheids.

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The dependency of the Cepheid Period–Luminosity relation on chemical composition

M. Romaniello¹, F. Primas³, M. Mottini¹, S. Pedicelli¹², B. Lemasle³, G. Bono²⁴, P. François⁵, M.A.T. Groenewegen⁶ and C.D. Laney⁷

¹European Southern Observatory, Germany
²Università di Roma Tor Vergata, Italy
³Université de Picardie, France
⁴INAF - Osservatorio Astronomico di Roma, Italy
⁵Observatoire de Paris-Meudon, France
⁶Royal Observatory of Belgium, Belgium
⁷West Mountain Observatory, Utah, USA

The dependency of the Cepheid Period–Luminosity relation on chemical composition at different wavelengths is assessed via direct detailed abundance analysis of Galactic and Magellanic Cepheids, as derived from high resolution, high signal-to-noise spectra. Our measurements span one order of magnitude in iron content and allow to rule out at the $\sim 9\sigma$ level the universality of the Period–Luminosity Relation in the V band, with metal rich stars being fainter than metal poor ones by $\sim 0.3$ mag. The dependency is less pronounced in the K band. Its magnitude and statistical significance decisively depend on detailed distance measurements to individual stars, as inferred via the Infrared Surface Brightness Method.

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