The Magellanic Clouds Newsletter
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Abstracts of Refereed Papers

Diffuse Gamma-Rays From Local Group Galaxies

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Diffuse $\gamma$-ray radiation in galaxies is produced by cosmic ray interactions with the interstellar medium. With the completion of EGRET observations, the only extragalactic object from which there has been a positive detection of diffuse $\gamma$-ray emission is the Large Magellanic Cloud. We systematically estimate the expected diffuse $\gamma$-ray flux from Local Group galaxies, and determine their detectability by new generation $\gamma$-ray observatories such as GLAST. For each galaxy, the expected $\gamma$-ray flux depends only on its total gas content and its cosmic ray flux. We present a method for calculating cosmic ray flux in these galaxies in terms of the observed rate of supernova explosions, where cosmic ray acceleration is believed to take place. The difficulty in deriving accurate supernova rates from observational data is a dominant uncertainty in our calculations. We estimate the $\gamma$-ray flux for Local Group galaxies and find that our predictions are consistent with the observations for the LMC and with the observational upper limits for the Small Magellanic Cloud and M31. Both the Andromeda galaxy, with a flux of $\sim 1.0 \times 10^{-8}$ photons sec\(^{-1}\) cm\(^{-2}\) above 100 MeV, and the SMC, with a flux of $\sim 1.7 \times 10^{-8}$ photons sec\(^{-1}\) cm\(^{-2}\) above 100 MeV, are expected to be observable by GLAST. M33 is at the limit of detectability with a flux of $\sim 0.11 \times 10^{-8}$ sec\(^{-1}\) cm\(^{-2}\). Other Local Group galaxies are at least two orders of magnitude below GLAST sensitivity.
Detection of an X-ray Pulsar Wind Nebula and Tail in SNR N157B

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We report Chandra X-ray observations of the supernova remnant N157B in the Large Magellanic Cloud, which are presented together with an archival HST optical image and a radio continuum map for comparison. This remnant contains the recently discovered 16 ms X-ray pulsar PSR J0537-6910, the most rapidly rotating young pulsar known. Using phase-resolved Chandra imaging, we pinpoint the location of the pulsar to within an uncertainty of less than 1 arcsec. PSR J0537-6910 is not detected in any other wavelength band. The X-ray observations resolve three distinct features: the pulsar itself, a surrounding compact wind nebula which is strongly elongated and a feature of large-scale diffuse emission trailing from the pulsar. This latter comet tail-shaped feature coexists with enhanced radio emission and is oriented nearly perpendicular to the major axis of the pulsar wind nebula. We propose the following scenario to explain these features. The bright, compact nebula is likely powered by a toroidal pulsar wind of relativistic particles which is partially confined by the ram-pressure from the supersonic motion of the pulsar. The particles, after being forced out from the compact nebula (the head of the “comet”), are eventually dumped into a bubble (the tail), which is primarily responsible for the extended diffuse X-ray and radio emission. The ram-pressure confinement also allows a natural explanation for the observed X-ray luminosity of the compact nebula and for the unusually small X-ray to spin-down luminosity ratio, compared to similarly energetic pulsars. We estimate the pulsar wind Lorentz factor of N157B as about 4 times 10\textsuperscript{6} (with an uncertainty of a factor about 2, consistent with that inferred from the modelling of the Crab Nebula).

ISO/SWS Observations of SN 1987A: II. A Refined Upper Limit on the Mass of \textsuperscript{44}Ti in the Ejecta of SN 1987A.

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ISO/SWS observations of SN 1987A on day 3425 show no emission in [Fe I] 24.05 \textmu m and [Fe II] 25.99 \textmu m down to the limits \~ 0.39 Jy and \~ 0.64 Jy, respectively. Assuming a homogeneous distribution of \textsuperscript{44}Ti inside 2000 km s\textsuperscript{-1} and negligible dust cooling, we have made time dependent
theoretical models to estimate an upper limit on the mass of ejected $^{44}\text{Ti}$. Assessing various uncertainties of the model, and checking the late optical emission it predicts, we obtain an upper limit of \( \simeq 1.1 \times 10^{-4} \text{ M}_\odot \). This is lower than in our previous estimate using other ISO data, and we compare our new result with other models for the late emission, as well as with expected yields from explosion models. We also show that steady-state models for the optical emission are likely to overestimate the mass of ejected $^{44}\text{Ti}$. The low limit we find for the mass of ejected $^{44}\text{Ti}$ could be higher if dust cooling is important. A direct check on this is provided by the gamma-ray emission at 1.157 MeV as a result of the radioactive decay of $^{44}\text{Ti}$.

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A dozen colliding wind X-ray binaries in the star cluster R136 in the 30 Doradus region

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We analyzed archival Chandra X-ray observations of the central portion of the 30 Doradus region in the Large Magellanic Cloud. The image contains 20 X-ray point sources with luminosities between \( 5 \times 10^{32} \) and \( 2 \times 10^{33} \text{ erg s}^{-1} \) (0.2 — 3.5 keV). A dozen sources have bright WN Wolf-Rayet or spectral type O stars as optical counterparts. None of these are within \( \sim 3.4 \) pc of R136, the central star cluster of NGC 2070.

We derive an empirical relation between the X-ray luminosity and the parameters for the stellar wind of the optical counterpart. The relation gives good agreement for known colliding wind binaries in the Milky Way Galaxy and for the identified X-ray sources in NGC 2070. We conclude that probably all identified X-ray sources in NGC 2070 are colliding wind binaries and that they are not associated with compact objects. This conclusion contradicts Wang (1995) who argued, using ROSAT data, that two earlier discovered X-ray sources are accreting black-hole binaries.

Five early type stars in R136 are not bright in X-rays, possibly indicating that they are either: single stars or have a low mass companion or a wide orbit. The resulting binary fraction among early type stars is unusually high; possibly all early type stars in the 30 Doradus region are binaries.

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Spectroscopic Classification of 42 LMC OB Stars: Selection of Probes for the Hot Gaseous Halo of the LMC

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Interstellar C\textsuperscript{iv} absorption line studies of the hot gaseous halo of the Large Magellanic Cloud (LMC) have been hindered by non-ideal selection of early-type probe stars in regions where C\textsuperscript{+3} can be produced locally via photoionization, fast stellar winds, or supernovae. To observe stars outside such regions, precise spectral classifications of OB stars in the field are needed. Therefore, we have obtained medium-dispersion spectra of 42 early-type stars in the LMC that are distributed outside superbubbles or supergiant shells. The spectral classification of these stars is presented in this paper. Nineteen of these program stars have spectral types between B1 and O7, and are thus suitable probes for interstellar C\textsuperscript{iv} absorption line studies of the hot gaseous halo of the LMC.

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Photometric Solutions for Detached Eclipsing Binaries: Selection of Ideal Distance Indicators in the SMC

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Detached eclipsing binary stars provide a robust one-step distance determination to nearby galaxies. As a by-product of Galactic microlensing searches, catalogs of thousands of variable stars including eclipsing binaries have been produced by the OGLE, MACHO and EROS collaborations. We present photometric solutions for detached eclipsing binaries in the Small Magellanic Cloud (SMC) discovered by the OGLE collaboration. The solutions were obtained with an automated version of the Wilson-Devinney program. By fitting mock catalogs of eclipsing binaries we find that the normalized stellar radii (particularly their sum) and the surface brightness ratio are accurately described by the fitted parameters and estimated standard errors, despite various systematic uncertainties. In many cases these parameters are well constrained. In addition we find that systems exhibiting complete eclipses can be reliably identified where the fractional standard errors in the radii are small. We present two quantitatively selected sub-samples of eclipsing binaries that will be excellent distance indicators. These can be used both for computation of the distance to the SMC and to probe its structure. One particularly interesting binary has a very well determined solution, exhibits complete eclipses, and is
comprised of well detached G-type, class II giants.

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New Photometry for the Intermediate-age LMC Globular Cluster
NGC 2121 and the Nature of the LMC Age Gap

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We report new photometry for the cluster NGC 2121 in the Large Magellanic Cloud, which shows a prominent hydrogen core exhaustion gap at the turnoff, and a descending subgiant branch reminiscent of Galactic open clusters. We achieve an excellent fit using the Girardi isochrones, finding an age of $3.2 \pm 0.5$ Gyr, with $[\text{Fe}/\text{H}] = -0.6 \pm 0.2$. The isochrones fit the color and shape of the turnoff and subgiant branch so precisely that we can constrain the metallicity as well as the age. The same isochrones also fit SL 663 and NGC 2155, although our photometry for these clusters has much larger errors. We find these clusters to be 0.8 Gyr younger, and 0.4 dex more metal rich, than recently reported in the literature. Consequently, we argue that NGC 2121, NGC 2155, and SL 663 are not properly assigned to the age gap in the LMC, but instead are among the first clusters to have formed in the relatively metal rich, younger group of LMC clusters. We propose a new definition of the LMC Age Gap as extending from 3.2 to 13 Gyr, with ESO121-SC03 still the only remaining candidate for membership in the age gap.

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Magellanic Cloud Structure from Near-IR Surveys I:
The Viewing Angles of the LMC

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We present a detailed study of the viewing angles of the LMC disk plane. We find that our viewing direction differs considerably from the commonly accepted values, which has important implications for the structure of the LMC.

The discussion is based on an analysis of spatial variations in the apparent magnitude of features in the near-IR color-magnitude diagrams extracted from the DENIS and 2MASS surveys. Sinusoidal
brightness variations with a peak-to-peak amplitude of \( \sim 0.25 \) mag are detected as function of position angle. The same variations are detected for AGB stars (using the mode of their luminosity function) and for RGB stars (using the tip of their luminosity function), and these variations are seen consistently in all of the near-IR photometric bands in both DENIS and 2MASS data. The observed spatial brightness variations are naturally interpreted as the result of distance variations, due to one side of the LMC plane being closer to us than the opposite side. There is no evidence that any complicating effects, such as possible spatial variations in dust absorption or the age/metallicity of the stellar population, cause large-scale brightness variations in the near-IR at a level that exceeds the formal errors (\( \sim 0.03 \) mag). The best fitting geometric model of an inclined plane yields an inclination angle \( i = 34.7^\circ \pm 6.2^\circ \) and line-of-nodes position angle \( \Theta = 122.5^\circ \pm 8.3^\circ \). The quoted errors are conservative estimates that take into account the possible influence of systematic errors; the formal errors are much smaller, 0.7\(^\circ\) and 1.6\(^\circ\), respectively. There is tentative evidence for variations of \( \sim 10^\circ \) in the viewing angles with distance from the LMC center, suggesting that the LMC disk plane may be warped.

Traditional methods to estimate the position angle of the line of nodes have used either the major axis position angle \( \Theta_{\text{maj}} \) of the spatial distribution of tracers on the sky, or the position angle \( \Theta_{\text{max}} \) of the line of maximum gradient in the velocity field, given that for a circular disk \( \Theta_{\text{maj}} = \Theta_{\text{max}} = \Theta \). The present study does not rely on the assumption of circular symmetry, and is considerably more accurate than previous studies of its kind. We find that the actual position angle of the line of nodes differs considerably from both \( \Theta_{\text{maj}} \) and \( \Theta_{\text{max}} \), for which measurements have fallen in the range 140\(^\circ\)–190\(^\circ\). This indicates that the intrinsic shape of the LMC disk is not circular, but elliptical. Paper II of this series explores the implications of this result through a detailed study of the shape and structure of the LMC. The inclination angle inferred here is consistent with previous estimates, but this is to some extent a coincidence, given that also for the inclination angle most previous estimates were based on the incorrect assumption of circular symmetry.

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Also available from the URL http://www.stsci.edu/~marel/abstracts/abs_R31.html
Comment: Check out http://www.stsci.edu/~marel/lmc.html for a large scale (23x21 degree) stellar number-density image of the LMC constructed from RGB and AGB stars in the 2MASS and DENIS surveys.

Magellanic Cloud Structure from Near-IR Surveys II: Star Count Maps and the Intrinsic Elongation of the LMC

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I construct a near-IR star count map of the LMC and demonstrate, using the viewing angles derived in Paper I, that the LMC is intrinsically elongated. I argue that this is due to the tidal force from the Milky Way.

The near-IR data from the 2MASS and DENIS surveys are ideally suited for studies of LMC structure, because of the large statistics and insensitivity to dust absorption. The survey data are used to create a star count map of RGB and AGB stars. The resulting LMC image shows the well-known bar, but is otherwise quite smooth. Ellipse fitting is used for quantitative analysis. The radial number
density profile is approximately exponential with a scale-length $r_d \approx 1.3-1.5$ kpc. However, there is
an excess density at large radii that may be due to the tidal effect of the Milky Way. The position
angle and ellipticity profile both show large radial variations, but converge to $PA_{maj} = 189.3^\circ \pm 1.4^\circ$
and $\epsilon = 0.199 \pm 0.008$ for $r > 5^\circ$. At large radii the image is influenced by viewing perspective (i.e.,
one side of the inclined LMC plane being closer to us than the other). This causes a drift of the center
of the star count contours towards the near side of the plane. The observed drift is consistent with
the position angle $\Theta = 122.5^\circ \pm 8.3^\circ$ of the line of nodes inferred in Paper I.

The fact that $\Theta$ differs from $PA_{maj}$ indicates that the LMC disk is not circular. Deprojection
shows that the LMC has an intrinsic ellipticity $e^{\prime} = 0.31$ in its outer parts, considerably larger than
typical for disk galaxies. The outer contours have a more-or-less common center, which lies $\sim 0.4$
kpc from the center of the bar. Neither agrees with the kinematic center of the HI gas disk. The
LMC is elongated in the general direction of the Galactic center, and is elongated perpendicular to
the Magellanic Stream and the velocity vector of the LMC center of mass. This suggests that the
elongation of the LMC has been induced by the tidal force of the Milky Way.

The position angle of the line of nodes differs from the position angle $\Theta_{max}$ of the line of maximum
line of sight velocity gradient. Results from HI gas and discrete tracers indicate that $\Theta_{max} - \Theta = 20^\circ-60^\circ$.
This could be due to one or more of the following: (a) streaming along non-circular orbits in
the elongated disk; (b) uncertainties in the transverse motion of the LMC center of mass, which can
translate into a spurious solid-body rotation component in the observed velocity field; (c) an additional
solid body rotation component in the observed velocity field due to precession and nutation of the
LMC disk as it orbits the Milky Way, which is expected on theoretical grounds.

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Comment: Check out http://www.stsci.edu/~marel/lmc.html for a large scale (23x21 degree)
stellar number-density image of the LMC constructed from RGB and AGB stars in the 2MASS and
DENIS surveys.
Abstracts of Non-Refereed Papers

The Star Cluster Systems of the Magellanic Clouds

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The characteristics of the cluster systems of the Magellanic Clouds, as inferred from integrated properties, are compared with those from individual cluster studies and from the field population. The agreement is generally satisfactory though in the case of the LMC, the lack of clusters older than \(~3\) Gyr is not reflected in the field population. The possible origin(s) for this cluster “age-gap” are discussed. The SMC cluster age-metallicity relation is also presented and discussed.


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