The Magellanic Clouds Newsletter
An electronic exchange of Magellanic Clouds information
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No. 13  September 23, 1997

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News and Views

IAU Symposium No. 190:
New Views of the Magellanic Clouds

At its 70th meeting in Kyoto, the Executive Committee of the International Astronomical Union reviewed the proposals for IAU-sponsored meetings to be held in 1998. We are pleased to announce that the EC approved the proposed Symposium on “New Views of the Magellanic Clouds”, to be held in Victoria, Canada, on July 13-19, 1998.

Outline of Scientific Program:
1. Recent observations of stars and the ISM of the Magellanic Clouds.
2. The physical properties and structure of the multiple-phase ISM.
3. Interactions between stars/OB association/clusters and the ISM.
4. Stellar evolution - observations vs theoretical models.
5. Stellar systems - IMFs, abundances, ages, dynamics, populations.
7. The global structure of the Magellanic Clouds - populations, distributions of matter, and dynamics.
8. The Distance to the Magellanic Clouds.
9. Connections to other Magellanic irregulars and the distant universe.
Scientific Organizing Committee:
E. Brocato (Italy), Y.-H. Chu (co-chair, USA), A. Cowley (USA), K. Freeman (Australia), P. Hodge (USA), M. Rubio (Chile), M. Spite (France), L. Staveley-Smith (Australia), N. Suntzeff (co-chair, Chile), N. Walborn (USA), D. Welch (Canada), and H. Zinnecker (Germany).

Local Organizing Committee:
D. Bohlender (Victoria), D. Crampton (Victoria), J. Gallagher (Wisconsin, USA), D. Hartwick (Victoria), J. Hesser (chair, Victoria), S. Morris (Victoria), B. Parrish (Victoria), D. VandenBerg (Victoria).

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A comprehensive First Announcement will be issued in October.

The Formation and Evolution of Rich Star Clusters in the LMC

HST GO program 7307 has been allocated 95 orbits using all of WFPC2, STIS and NICMOS to study rich clusters and the IMF in the LMC. Given the scale of the project, and the wide interest in its results, we provide the abstract here.

The Large Magellanic Cloud (LMC) is unique in containing massive star clusters at all stages of evolution. We will obtain deep images of optimally selected clusters, to probe their stellar content down to 0.2 $M_\odot$. In conjunction with state-of-the-art N-body models, these observations will help us understand the origin and evolution of rich star clusters in our own Galaxy, in the LMC, and beyond. In the youngest clusters the fraction of primordial binaries, the stellar initial mass function (IMF), and the degree of primordial mass segregation will quantify the process of star formation in a protocluster. Age spreads and a search for pre-main-sequence stars will reveal both the timescale for star formation, which has important implications for its trigger, and whether the low or high mass stars form first. In the intermediate and old clusters we will trace the development of mass segregation and the binary fraction in the core and at the half-mass radius; binaries play a crucial role in the structural evolution of a cluster, and in particular, affect the onset of core collapse. Finally, a comparison of the IMFs in our clusters will help answer the far-reaching question of whether there is such a thing as a universal IMF: the assumption of a universal IMF is fundamental to all attempts to use integrated light to infer the characteristics of stellar populations in galaxies too distant to resolve.

Reported by: Gerry Gilmore$^1$, Becky Elson$^1$, Basilio Santiago$^2$, Sverre Aarseth$^1$, Melvyn Davies$^1$, & Steinn Sigurdsson$^1$ ($^1$ Institute of Astronomy, Cambridge, UK; $^2$ Universidade Federal do Rio Grande do Sul, Porto Alegre, Brasil)
Abstracts of Refereed Papers

On the Distribution of Dust in the Large Magellanic Cloud

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We present a detailed map of the reddening in a 1.9° × 1.5° section of the Large Magellanic Cloud (LMC), constructed from \textit{UBVI} photometry of 2069 O and B main sequence stars. We use two reddening-free photometric parameters to determine the line-of-sight reddening to these stars. We find a mean reddening, \( \langle E(B - V) \rangle_{\text{LMC}} = 0.20 \) mag, with a non-Gaussian tail to high values. When the reddening is corrected for foreground Galactic extinction (Östreicher et al. 1995), we find \( \langle E(B - V) \rangle_{\text{LMC}} = 0.13 \) mag. The line-of-sight values are then interpolated onto a uniform grid with a local least-squares plane fitting routine to construct a reddening map of the region. We use the distribution of reddening values to constrain the line-of-sight geometry of stars and dust in the LMC, and to test and normalize a standard extinction correction for galaxy photometry. We attempt to distinguish between line-of-sight depth effects and structure in the dust distribution as possible causes for the observed differential reddening through this region.

We conclude: (1) that our data are consistent with a vertical exponential distribution of stars and dust in the LMC, for which the dust scale height is twice that of the OB stars; (2) that the dust distribution must be non-uniform (clumpy) to account for the full distribution of measured reddening values (i.e., line-of-sight effects alone are insufficient to explain the observed structure); and (3) that the \( B \)-band optical depth, \( \tau_B \), through the observed region of the LMC is \( 0.69 < \tau_B < 0.82 \).

Accepted by: The Astronomical Journal
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Also available from the URL http://www.ucolick.org/~jharris/
or by anonymous ftp at ftp.ucolick.org/pub/outgoing/jharris

Comparison of H II region luminosities with observed stellar ionizing sources in the Large Magellanic Cloud

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We estimate the total predicted Lyman continuum emission rates of OB associations for which the complete census of O star spectral types exists. The results are compared to the observed H\( \alpha \) luminosities of the host HII regions. We find evidence for substantial leakage of ionizing photons from some HII regions, while others appear to be radiation bounded. We estimate that overall for the LMC, 0–51\% of the ionizing radiation escapes the local nebulae, and would be available to ionize the diffuse, warm, ionized medium (WIM) in that galaxy. This range of values is consistent with the observed 35\% fraction of H\( \alpha \) luminosity emitted by the WIM in the LMC, as well as the corresponding
fractions observed in other nearby galaxies. It is therefore possible that photoionization by O stars is indeed the dominant ionization mechanism for the WIM.

Accepted by: Monthly Notices of the Royal Astronomical Society
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Also available from the URL http://www.ast.cam.ac.uk/~oey/oeypubs.html

The Hourglass Nebulae of Sher 25 and SN1987 A: Two of a Kind?

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We have performed a detailed study of the morphology and kinematics of the hourglass-shaped nebula around the blue supergiant Sher 25 in the galactic giant H\textsc{ii} region NGC 3603. Near-infrared high resolution adaptive optics images in the Br\textgamma line and HST/NICMOS images in the Hei 1.08\mu m line were compared with iso-velocity maps in the H\alpha and [N\textsc{ii}] lines.

The adaptive optics observations clearly resolved the width of the ring (0\textdegree.9, i.e., 0.027 pc), yielding $\delta R/R=1:8$. We show that the H\alpha and [N\textsc{ii}] lines trace the entire silhouette of the hourglass. The bipolar lobes of the hourglass expand at 70 km s\textsuperscript{-1}, whereas the ring around the waist of the hourglass expands at 30 km s\textsuperscript{-1}. Both the ring and the bipolar lobes have about the same dynamical age, indicating a common origin and a major outburst and mass-loss event 6630 yr ago. The ionized mass within the hourglass is between 0.3 M\odot and 0.6 M\odot - quite comparable to the total mass suggested for the expanding (pre-supernova) shell around SN 1987 A.

The hourglass structure around Sher 25 is similar to that of SN 1987 A in spatial extent, mass, and velocities. The major differences between these two nebulae might arise from environmental effects. Both internal and external ionization sources are available for Sher 25’s nebula. Furthermore, Sher 25 and its hourglass-shaped nebula appear to be moving to the south-west with respect to the ambient interstellar medium, and ram pressure has apparently deformed the hourglass. We conclude that the circumstellar nebulae around SN 1987 A and Sher 25 are very similar and define a new class of nebulae around blue supergiants in their final evolutionary stage.

Accepted by: Astrophysical Journal Letters
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Star Formation in R136: A Cluster of O3 Stars Revealed by Hubble Space Telescope Spectroscopy

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The R136 cluster in 30 Doradus is the prototype “super star cluster”, and the only example sufficiently close that its massive star content can be studied directly. We have used *Hubble Space Telescope* to obtain spectra of 65 of the bluest, most luminous stars in R136, and find that the majority of these stars are of type O3, the hottest, most luminous and massive stars known. The total number of O3 stars in this one cluster exceed the total number known elsewhere in the Milky Way or Magellanic Clouds. The highest luminosity stars found are O3 If\(^*\), O4 If+\(^+\), O3 If/WN6-A, and H-rich WN stars, with masses in excess of 120 \(M_\odot\), the highest masses for which appropriate evolutionary tracks are currently available. In accord with de Koter, Heap, & Hubeny, we conclude that these WN stars must be core-H burning stars whose spectra are WR-like due to high luminosity, and we find that their individual luminosities are a factor of 10 higher than normal WN stars of similar type, but like those found in the Galactic cluster NGC 3603, which they also resemble spectroscopically. Our spectroscopy does include stars as late as B0 V, and samples most stars in the core of the R136 cluster with masses \(> 50M_\odot\). The spectroscopy has been combined with *HST* photometry to study the star formation history and initial mass function of the R136 cluster. The young age (\(< 1 - 2\) Myr) for the highest mass stars, combined with what was previously known for the intermediate-mass populations, suggests that the lower mass stars began forming 4–5 Myr ago, and continued until the high mass stars formed, consistent with the paradigm in which the formation of massive stars shuts down further star formation in the molecular cloud. Despite the unique preponderance of the highest mass and luminosity stars ever seen, the IMF is found to be completely normal, with a slope \(\Gamma = -1.3\) to \(-1.4\). The number of high mass stars is in good accord with that predicted by the IMF of the intermediate-mass stars, suggesting that a Salpeter-like IMF holds over the mass range 2.8 \(M_\odot\) to 120 \(M_\odot\) within the R136 cluster. The fact that the IMF slope in R136 is indistinguishable from those of Galactic and Magellanic Cloud OB associations suggests that star formation produces the same distribution of masses over a range of \(\sim 200\) \(\times\) in stellar density, from that of sparse OB associations to that typical of globular clusters. The large number of O3 stars in R136 is then simply a consequence of its youth (\(< 1 - 2\) Myr) and its richness, suggesting that the upper mass “cutoff” to the IMF seen in OB associations may simply be the result of their sparcity.

*Accepted by: The Astrophysical Journal*

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UV Spectral Classification of O and B Stars in the Small Magellanic Cloud

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We present an ultraviolet classification system for O and B stars of the Small Magellanic Cloud (SMC). This system is defined by a set of standard, low resolution, International Ultraviolet Explorer (IUE) spectra. This UV classification system results from the development of spectral sequences demonstrating systematic patterns of UV spectral features. These spectral sequences yield UV classifications for 133 O and B stars of the SMC, which we also present. Although independent of the MK System, our UV classifications show general agreement with those deduced from visual data. This UV classification system is designed to be applicable to O and B stars in other nearby galaxies of metallicity comparable to the SMC. The classification technique itself is applicable to any UV dataset of sufficient size and quality, and can be used to extend our UV classification system to other galactic metal abundances. These UV classification systems will be essential for analysis of datasets from new spaceborne instrumentation such as the Space Telescope Imaging Spectrograph (STIS), which will be capable of observing stars in external galaxies for which no optical classifications exist.

Accepted by: The Astronomical Journal

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No stellar age gradient inside supergiant shell LMC4

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The youngest stellar populations of a 'J'-shaped region inside the supergiant shell (SGS) LMC4 have been analysed with CCD photometry in the \(B, V\) passbands. This region consists of 2 coherent strips, one from the east to the west reaching about 400 pc across the OB superassociation LH77 and another extending about 850 pc from south to north.

The standard photometric methods yield 25 colour-magnitude diagrams (CMDs), which were used for age determination of the youngest star population by isochrone fitting. The resultant ages lie in the range from 9 Myr to 16 Myr without correlation with the distance to the LMC4 centre. We therefore conclude that there must have been one triggering event for star formation inside this great LMC SGS with a diameter of 1.4 kpc.

We construct the luminosity function and the mass function of five regions consisting of 5 fields to ensure that projection effects don’t mask the results. The slopes lie in the expected range (\(\gamma \in [0.22; 0.41]\) and \(\Gamma \in [-1.3; -2.4]\) respectively). The greatest values of the slope occur in the north, which is caused by the absence of a young, number-dominating star population.

We have calculated the rate with which supernovae (SNe) have exploded in LMC4, based on the finding that all stars are essentially coeval. A total of \(5 \times 10^3\) supernovae has dumped the energy of \(10^{54.5}\) erg over the past 10 Myr into LMC4, in fact enough to tear the original star-forming cloud apart in the time span between 5 and 8 Myr after the star formation burst. We conclude that LMC4
can have been formed without a contribution from stochastic self-propagating star formation (SSPSF), although the ring of young associations and H\textsc{ii} regions around the edge have been triggered by the events inside LMC 4.

Accepted by: Astronomy & Astrophysics (Main Journal)
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Far-Ultraviolet Imaging of the Large Magellanic Cloud Populous Cluster NGC 1978 with WFPC2

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We have imaged the \(\approx 2.2\) billion-year-old Large Magellanic Cloud populous cluster NGC 1978 in the far-ultraviolet and visible with the second Wide Field/Planetary Camera (WFPC2) on the Hubble Space Telescope. The far-ultraviolet images show a sparse stellar field with little apparent density enhancement in the cluster core. The visible images are dominated by the cluster’s first-ascent and second-ascent red giants, which are completely invisible to the far-ultraviolet filter. No evidence for a hot horizontal branch population of core-helium-burning stars is seen; nor is there any apparent indication of a significant blue straggler population. These results suggest that the presence of a rich, young population of field stars in the NGC 1978 region is responsible for the unusual location of the cluster in the integrated light color-color plots produced by IUE.

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Also available from the URL http://www.astro.wisc.edu/prints/cole/ngc1978.ps
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A Search for Old Star Clusters in the Large Magellanic Cloud

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There are only a handful of known star clusters in the LMC that are genuinely old, i.e. of similar age to the globular star clusters in the Milky Way. We report the first results of a color-magnitude diagram survey of 25 candidate old LMC clusters, which were uncovered by means of integrated UBV photometry and Ca\textsc{ii} triplet spectroscopy during previous investigations. The photometry was carried out with the Washington system \(C, T_1\) filters on the Cerro Tololo 0.9m telescope. For almost all of the sample, it was possible to reach the turnoff region, and in many clusters we have several magnitudes of the main sequence. The efficiency and efficacy of the technique are demonstrated by
 Accepted by: The Astronomical Journal
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Also available from the URL http://xxx.lanl.gov/abs/astro-ph/9709191

Obscured Asymptotic Giant Branch stars in the Magellanic Clouds IV. Carbon stars and OH/IR stars

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We present N-band photometry for a sample of 21 dust-enshrouded AGB stars in the Large Magellanic Cloud, and three additional sources in the Small Magellanic Cloud. Together with near-infrared photometry, this is used to give a tentative classification into carbon and oxygen-rich atmospheres. Bolometric luminosities are also estimated for these stars. In addition, we present the results of a survey for OH masers in the LMC, which resulted in the discovery of OH maser emission from
IRAS04407–7000. Spectra between 600 and 1000 nm have been obtained for two heavily obscured AGB stars in the LMC, confirming them to be highly reddened very late M-type giants. Because the dust-enshrouded stars are clearly undergoing heavy mass loss they are assumed to be very near the termination of their respective Asymptotic Giant Branch phases. The fraction of mass-losing carbon stars decreases with increasing luminosity, as expected from Hot Bottom Burning. The best candidate carbon star, with $M_{\text{bol}} \sim -6.8$ mag, is the most luminous mass-losing carbon star in the Magellanic Clouds, and amongst the most luminous AGB stars. At lower luminosities ($M_{\text{bol}} \sim -5$ mag) both oxygen and carbon stars are found. This may be explained by a range in metallicity of the individual mass-losing AGB stars.

Accepted by: Astronomy and Astrophysics, Main Journal
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Also available from the URL http://xxx.lanl.gov/abs/astro-ph/9709119

The MACHO Project SMC Variable Star Inventory:
I. The Second-overtone Mode of Cepheid Pulsation From First/Second Overtone (1H/2H) Beat Cepheids

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We report the discovery of 20 1H/2H and 7 F/1H beat Cepheids in the SMC by the MACHO Project. We utilize the 20 1H/2H stars to determine lightcurve shape for the SMC second-overtone (2H) mode of Cepheid pulsation. We predict, similar to the findings of Alcock et al. (1997, ApJ, submitted), that 2H Cepheids will have nearly or purely sinusoidal light variations; that the P-L relation for 2H Cepheids will not be distinguishable from the P-L relation for 1H Cepheids within photometric accuracy; and that 2H stars may be discernible from F and 1H stars using the amplitude-period diagram and Fourier parameter progressions for periods P < 0.7 days, our current sample 2H period limit.

Submitted to: The Astronomical Journal
First detection of a gravitational microlensing candidate towards the Small Magellanic Cloud

The MACHO Collaboration: C. Alcock\textsuperscript{1,2}, R.A. Allsman\textsuperscript{3}, D. Alves\textsuperscript{1,4}, T.S. Axelrod\textsuperscript{3,1}, A.C. Becker\textsuperscript{5,2}, D.P. Bennett\textsuperscript{6,1}, K.H. Cook\textsuperscript{1,2}, K.C. Freeman\textsuperscript{3}, K. Griest\textsuperscript{7,2}, M.J. Keane\textsuperscript{8}, M.J. Lehner\textsuperscript{7,2}, S.L. Marshall\textsuperscript{1}, D. Minniti\textsuperscript{1}, B.A. Peterson\textsuperscript{3}, M.R. Pratt\textsuperscript{5}, P.J. Quinn\textsuperscript{9}, A.W. Rodgers\textsuperscript{3}, C.W. Stubbs\textsuperscript{5,2}, W. Sutherland\textsuperscript{10}, A. B. Tomane\textsuperscript{5}, T. Vandehei\textsuperscript{7,2}, D. Welch\textsuperscript{11}

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We report the first discovery of a gravitational microlensing candidate towards a new population of source stars, the Small Magellanic Cloud (SMC). The candidate event’s light curve shows no variation for 3 years before an upward excursion lasting $\sim 217$ days that peaks around January 11, 1997 at a magnification of $\sim 2.1$. Microlensing events towards the Large Magellanic Cloud and the Galactic bulge have allowed important conclusions to be reached on the stellar and dark matter content of the Milky Way. The SMC gives a new line-of-sight through the Milky Way, and is expected to prove useful in determining the flattening of the Galactic halo.

Submitted to: Astrophysical Journal Letters
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Evidence for an Intervening Stellar Population Toward the Large Magellanic Cloud

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We identify a vertical extension of the red clump stars in the color magnitude diagram (CMD) of a section of the Large Magellanic Cloud (LMC). After subtracting the principal red clump component, we find a peak in the residual stellar distribution that is $\approx 0.9$ mag brighter than the peak of the principal red clump distribution. We consider and reject the following possible explanations for this population: inhomogeneous reddening, Galactic disk stars, random blends of red clump stars, correlated blends of red clump stars (binaries), evolution of the red clump stars, and red clump stars from a younger LMC stellar population.
Combinations of these effects cannot be ruled out as the origin of this stellar population. A natural interpretation of this new population is that it consists of red clump stars that are closer to us than those in the LMC. We find corroborating evidence for this interpretation in Holtzman et al.’s (1997) Hubble Space Telescope CMD of the LMC field stars. The derived distance and projected angular surface density of these stars relative to the LMC stars (< 5 to 7%) are consistent with (1) models that attribute the observed microlensing lensing optical depth (Alcock et al. 1997) to a distinct foreground stellar population (Zhao 1997) and (2) tidal models of the interaction between the LMC and the Milky Way (Lin, Jones, & Klemola 1995). We conclude that the standard assumption of a smoothly distributed halo population out to the LMC cannot be substantiated without at least a detailed understanding of red clump stellar evolution, binary fractions, binary mass ratios, the spatial correlation of stars within the LMC, possible variations in the stellar populations of satellite galaxies, and differential reddening—all of which are highly complex.

Accepted by: The Astronomical Journal
For preprints, contact dennis@ucolick.org
Also available from the URL http://xxx.lanl.gov/abs/astro-ph/9709055

The dynamics of the Large Magellanic Cloud periphery: mass limit and polar ring

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Radial velocities of 759 carbon stars on the periphery of the LMC are used to determine the rotation curve from 3 to 12 kpc. After a peak of 42 km s⁻¹ at 4 kpc the velocities decline to 35 km s⁻¹ at 6.5 kpc, suggesting that 90 percent of the LMC’s matter lies inside this radius. The rising velocities seen at larger radii are explained by PP N-body simulations as arising from tidal interactions between LMC and both the SMC and the Galaxy. For an inclination of 33° the mass contained within a 5 kpc radius is 6.2 ± 0.9 × 10⁹ M☉. An upper limit on the LMC halo mass is determined.

Accepted by: Astrophysical Journal Letters
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Abstracts of Non-Refereed Papers

The Nature of the Circumstellar Rings around SN 1987A

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An analysis of several HST-FOS spectra of portions of the inner ring and the northern outer ring, complemented with HST-WFPC2 narrow band imaging and ground-based spectroscopy, reveals that these circumstellar features consist of highly N enriched material that was ejected by the supernova progenitor in two distinct episodes, the inner ring corresponding to the last, more N-rich ejection.

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Perspectives of Core-Collapse Supernovae beyond SN 1987A

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The observation of neutrinos from Supernova 1987A has confirmed the theoretical conjecture that these particles play a crucial role during the collapse of the core of a massive star. Only one percent of the energy they carry away from the newly formed neutron star may account for all the kinetic and electromagnetic energy responsible for the spectacular display of the supernova explosion. However, the neutrinos emitted from the collapsed stellar core at the center of the explosion couple so weakly to the surrounding matter that convective processes behind the supernova shock and/or inside the nascent neutron star might be required to increase the efficiency of the energy transfer to the stellar mantle and envelope. The conditions for a successful explosion by the neutrino-heating mechanism and the possible importance of convection in and around the neutron star are shortly discussed. Neutrino-driven explosions turn out to be very sensitive to the parameters describing the neutrino emission of the proto-neutron star and to the details of the dynamical processes in the collapsed stellar core. Therefore uniform explosions with a well defined energy seem unlikely and type-II supernova explosions do not offer promising perspectives for being useful as standard candles.

To be published in: Supernovae and Cosmology, Proc. of the Colloquium in Honor of Prof. G. Tammann, Landgut Castelen, Augst, Switzerland, June 13, 1997
For preprints, contact thj@mpa-garching.mpg.de
Also available from the URL http://www.mpa-garching.mpg.de/~petra/reports97.html
HST Study of the Stellar Population within 30 pc of SN 1987A

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We present the preliminary results of a study of the stellar population around SN 1987A based on an analysis of multi-band \textit{HST-WFPC2} images.

The effective temperature, radius and reddening of each star were determined by fitting the measured broad band magnitudes to the ones calculated with model atmospheres. In addition, all stars with H\alpha equivalent widths in excess of 8\AA{} were identified.

An inspection of the H-R diagram reveals the presence of several generations of stars, with ages between 1 and 150\textit{Myrs}, superposed on a much older field population. The youngest stars in the field appear to be \textit{T Tau} stars, characterized by strong H\alpha excesses. We conclude that SN 1987A is associated with a region in which star formation has been active over a long stretch of time and is still very active at present.


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A \sim{} 14 Days Star With Two Phase-Locked Modes of Pulsation in the EROS Database

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Using CCD photometry obtained by the EROS collaboration in 1991–1993, we have discovered an LMC variable star with a light curve that is oscillating with a mean period of \sim{} 14 days and an amplitude of \sim{} 0.3 mag. The oscillations appear with irregular amplitude variations.

The Fourier spectrum shows that the pulsation of this star is phase locked between two modes of frequencies \( f_0 \) and 1.5\times f_0. Moreover, this object has strong H\alpha and H\beta emission lines and neutral lines of Helium that suggest a spectral type between late O and early B. In a preliminary analysis, we derive a luminosity of \( L = 3.4–3.8L_\odot \) and an effective temperature in the range \( \log(T_{\text{eff}}) = 3.85–4.2 \).


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\textit{Also available from the URL} http://xxx.lanl.gov/abs/astro-ph/9708074

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Meeting Announcements

Hot Stars in Open Clusters of the Galaxy and Magellanic Clouds
Workshop to celebrate the 100th Anniversary of La Plata University, La Plata, Argentina
December 1 – 5, 1997

Preliminary Program
(Invited speakers are in parenthesis)

Session 1:
• Introductory address (A.F.J. Moffat)
• Intrinsic properties of hot stars in environments of different metallicities
• Observations in different spectral domains
  (D. Lennon, M. Corcoran, N. Morrell, W. Seggewiss, J. Parker)

Session 2:
• Demography of hot stars in clusters and associations
  (K.A. van der Hucht, B. Westerlund, A. Feinstein, R. Vazquez)

Session 3:
• Hot star atmospheres, Evolution of hot stars
  (A. Maeder, R. Sagar, W. Schmutz)

Session 4:
• IMF (PDMF), multiplicity, sequential star formation
  (P. Massey, G. Koenigsberger, H. Dottori)

Session 5:
• 30 Dor. and the starburst connection
  (D. Hunter, E. Grebel, J. Melnick, R. & E. Terlevich)

Scientific Organizing Committee:
A. Feinstein (Argentina, chair); D. Lennon (Germany); H. Levato (Argentina);
A. Maeder (Switzerland); A.F.J. Moffat (Canada); N. Morrell (Argentina);
V. Niemela (Argentina); R. Sagar (India); W. Seggewiss (Germany); N. Walborn (USA)

Abstract and registration deadline: October 1, 1997.
For more information, see http://www.fcaglp.unlp.edu.ar/~hoc97/.

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