

## PUBLICATIONS

**The Weibel instability in relativistic plasmas. I. Linear theory,** [Achterberg, A.](#); [Wiersma, J.](#), Astronomy and Astrophysics, Volume 475, Issue 1, November III 2007, pp.1-18

We discuss the linear theory of the Weibel instability in a relativistic plasma driven by ultra-relativistic beams, describing the physics of the generation of magnetic fields in the ultra-relativistic shocks associated with Gamma Ray Bursts (GRBs). We perform a detailed analysis of the linear dispersion relation for the benefit of non-linear calculations that we discuss in the companion paper. Methods: We use a covariant approach, where the linear response of the beam-plasma system is determined from the polarization tensor. This tensor relates the four-current density to the four-potential of the electromagnetic field. Showing that two approaches, one based on a fluid model and one on a kinetic description that uses a waterbag distribution for the phase-space density of the beam particles, yield essentially the same result, we compare our results to those obtained by other approaches. We mainly consider the symmetric case of two counterstreaming (but otherwise identical) beams. Results: We show that the effect of an asymmetry in the beam densities is small for typical parameters, and briefly discuss the effect of an ambient magnetic field. The dispersion relation of the Weibel instability driven by ultra-relativistic beams is rather insensitive to the model used to describe the plasma. The properties of the instability, such as the growth rate and the range of unstable wavelengths, are governed by only two parameters: the ratio of the plasma frequency squared of the beam and hot background plasma, and a “Mach number”, which is essentially the ratio of the beam momentum and the momentum associated with thermal velocity ( $\sim$ sound speed) in the beam plasma. We also show that, at least for the parameters associated with the ultra-relativistic shocks in GRBs, the influence of the magnetic field is small, and the results for an unmagnetized plasma can be used.

**The Weibel instability in relativistic plasmas. II. Nonlinear theory and stabilization mechanism,** [Achterberg, A.](#); [Wiersma, J.](#); [Norman, C. A.](#), Astronomy and Astrophysics, Volume 475, Issue 1, November III 2007, pp.19-36

We discuss the onset of the nonlinear stage of the electromagnetic Weibel instability in a relativistic plasma, and the process of current coalescence that follows this instability. The Weibel instability has been proposed as a possible source of the magnetic fields needed to explain the non-thermal synchrotron emission from gamma ray bursts. Methods: We present two different calculations of the nonlinear saturation of the Weibel instability: one based on a fluid model, and one using kinetic plasma theory. These approaches yield a similar result for the amplitude of the magnetic field at saturation. We then consider the further growth of the magnetic field due to the coalescence of current filaments, a process that has been observed in numerical simulations. Results: These calculations show that the exponential linear stage of the instability is terminated by trapping of the beam particles in the wave. The trapping leaves a magnetic field that acts as the seed field for further amplification through coalescence. Further field amplification

is limited to magnetic fields on scales less than the effective plasma skin depth of a background plasma. We show that coalescence of current filaments thicker than a few times the skin depth proceeds at an exponentially slow rate. Conclusions: The amplitude of saturation is determined mostly by the plasma frequency of the hot (shocked) background plasma, which is usually dominated by the electrons. The typical field amplitude at this stage is almost independent of the mass of the beam particles. Further field amplification through current coalescence, a process that follows the exponential Weibel instability, “stalls” once the current filaments reach a size that is comparable to the skin depth of the background plasma. This process concentrates the currents, but the resulting field amplification is small. This implies that the resulting magnetic field energy density never reaches equipartition with the kinetic energy density of the heavy particle species (ions) in the incoming beams.

### **Models for the Circumstellar Medium of Long Gamma-Ray Burst Progenitor Candidates**

[van Marle, A. J.](#); [Langer, N.](#); [Achterberg, A.](#); [García-Segura, G.](#)

Circumstellar Media and Late Stages of Massive Stellar Evolution (Eds. G. García-Segura & E. Ramirez-Ruiz) *Revista Mexicana de Astronomía y Astrofísica (Serie de Conferencias)* Vol. 30, pp. 1-5 (2007) (<http://www.astroscu.unam.mx/~rmaa/>)

We present hydrodynamical models of circumstellar medium (CSM) of long gamma-ray burst (GRB) progenitor candidates. These are massive stars that have lost a large amount of mass in the form of stellar wind during their evolution. There are two possible ways to probe the CSM of long GRB progenitors. Firstly, the GRB afterglow consists of synchrotron radiation, emitted when the GRB jet sweeps up the surrounding medium. Therefore, the lightcurve is directly related to the density profile of the CSM. The density can either decrease with the radius squared (as is the case for a freely expanding stellar wind) or be constant (as we would expect for shocked wind or the interstellar medium). Secondly, material between the GRB and the observer will absorb part of the afterglow radiation, causing absorption lines in the afterglow spectrum. In some cases, such absorption lines are blue-shifted relative to the source indicating that the material is moving away from the progenitor star. This can be explained in terms of wind interactions in the CSM. We can use the CSM of these stars to investigate their prior evolutionary stage.

### **Multiyear search for a diffuse flux of muon neutrinos with AMANDA-II**

Achterberg, A., Duvoort, M., Heise, J., multi-co-authors  
*Physical Review D*, vol. 76, Issue 4, id. 042008

A search for TeV-PeV muon neutrinos from unresolved sources was performed on AMANDA-II data collected between 2000 and 2003 with an equivalent live time of 807 days. This diffuse analysis sought to find an extraterrestrial neutrino flux from sources with nonthermal components. The signal is expected to have a harder spectrum than the atmospheric muon and neutrino backgrounds. Since no excess of events was seen in the data over the expected background, an upper limit of  $E^2\Phi_{90\%C.L.} < 7.4 \times 10^{-8} \text{GeVcm}^{-2}\text{s}^{-1}\text{sr}^{-1}$  is placed on the diffuse flux of muon neutrinos with a  $\Phi \propto E^{-2}$  spectrum in the energy

range 16 TeV to 2.5 PeV. This is currently the most sensitive  $\Phi \square E^{-2}$  diffuse astrophysical neutrino limit. We also set upper limits for astrophysical and prompt neutrino models, all of which have spectra different from  $\Phi \square E^{-2}$ .

### **Detection of atmospheric muon neutrinos with the IceCube 9-string detector**

Achterberg, A., Duvoort, M., Heise, J., multi-co-authors

Physical Review D, vol. 76, Issue 2, id. 027101

The IceCube neutrino detector is a cubic kilometer TeV to PeV neutrino detector under construction at the geographic South Pole. The dominant population of neutrinos detected in IceCube is due to meson decay in cosmic-ray air showers. These atmospheric neutrinos are relatively well understood and serve as a calibration and verification tool for the new detector. In 2006, the detector was approximately 10% completed, and we report on data acquired from the detector in this configuration. We observe an atmospheric neutrino signal consistent with expectations, demonstrating that the IceCube detector is capable of identifying neutrino events. In the first 137.4 days of live time, 234 neutrino candidates were selected with an expectation of  $211 \pm 76.1(\text{syst}) \pm 14.5(\text{stat})$  events from atmospheric neutrinos.

### **Search for Neutrino-induced Cascades from Gamma-Ray Bursts with AMANDA**

Achterberg, A., Duvoort, M., Heise, J., multi-co-authors

The Astrophysical Journal, Volume 664, Issue 1, pp. 397-410.

Using the neutrino telescope AMANDA-II, we have conducted two analyses searching for neutrino-induced cascades from gamma-ray bursts. No evidence of astrophysical neutrinos was found, and limits are presented for several models. We also present neutrino effective areas which allow the calculation of limits for any neutrino production model. The first analysis looked for a statistical excess of events within a sliding window of 1 or 100 s (for short and long burst classes, respectively) during the years 2001-2003. The resulting upper limit on the diffuse flux normalization times  $E^2$  for the Waxman-Bahcall model at 1 PeV is  $1.6 \times 10^{-6} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$  (a factor of 120 above the theoretical prediction). For this search 90% of the neutrinos would fall in the energy range 50 TeV to 7 PeV. The second analysis looked for neutrino-induced cascades in coincidence with 73 bursts detected by BATSE in the year 2000. The resulting upper limit on the diffuse flux normalization times  $E^2$ , also at 1 PeV, is  $1.5 \times 10^{-6} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$  (a factor of 110 above the theoretical prediction) for the same energy range. The neutrino-induced cascade channel is complementary to the up-going muon channel. We comment on its advantages for searches of neutrinos from GRBs and its future use with IceCube.

### **Five years of searches for point sources of astrophysical neutrinos with the AMANDA-II neutrino telescope**

Achterberg, A., Duvoort, M., Heise, J., multi-co-authors

Physical Review D, vol. 75, Issue 10, id. 102001

We report the results of a five-year survey of the northern sky to search for point sources of high energy neutrinos. The search was performed on the data collected with the AMANDA-II neutrino telescope in the years 2000 to 2004, with a live time of 1001 days. The sample of selected events consists of 4282 upward going muon tracks with high reconstruction quality and an energy larger than about 100 GeV. We found no indication of point sources of neutrinos and set 90% confidence level flux upper limits for an all-sky search and also for a catalog of 32 selected sources. For the all-sky search, our average (over declination and right ascension) experimentally observed upper limit  $\Phi^0 = (E/(1\text{TeV}))^\gamma \cdot (d\Phi)/(dE)$  to a point source flux of muon and tau neutrino (detected as muons arising from taus) is  $\Phi_{\nu_{\mu+\nu^-}_{\mu}} + \Phi_{\nu_{\tau+\nu^-}_{\tau}} = 11.1 \times 10^{-11} \text{TeV}^{-1} \text{cm}^{-2} \text{s}^{-1}$ , in the energy range between 1.6 TeV and 2.5 PeV for a flavor ratio  $\Phi_{\nu_{\mu+\nu^-}_{\mu}} / \Phi_{\nu_{\tau+\nu^-}_{\tau}} = 1$  and assuming a spectral index  $\gamma=2$ . It should be noticed that this is the first time we set upper limits to the flux of muon and tau neutrinos. In previous papers we provided muon neutrino upper limits only neglecting the sensitivity to a signal from tau neutrinos, which improves the limits by 10% to 16%. The value of the average upper limit presented in this work corresponds to twice the limit on the muon neutrino flux  $\Phi_{\nu_{\mu+\nu^-}_{\mu}} = 5.5 \times 10^{-11} \text{TeV}^{-1} \text{cm}^{-2} \text{s}^{-1}$ . A stacking analysis for preselected active galactic nuclei and a search based on the angular separation of the events were also performed. We report the most stringent flux upper limits to date, including the results of a detailed assessment of systematic uncertainties.

### **What Does The Jet Of Cas A Tell Us About Its Progenitor Star? Hydrodynamics Inc.**

[Schure, Klara](#); [Vink, J.](#); [García-Segura, G.](#); [Achterberg, A.](#)

American Astronomical Society Meeting 210, #15.03

The shape of a supernova remnant (SNR) is largely determined by its circumstellar medium, which is formed by the supernova's progenitor star. In the Cassiopeia A SNR, a jet is apparent in the North-East and, less prominently, in the South-West. The progenitor of Cas A is thought to have had a red supergiant phase followed by a Wolf-Rayet (WR) phase. With 2D-hydrodynamical simulations of an axisymmetric explosion and the progenitor wind, using the ZEUS-3D code, we try to reproduce the morphology of Cas A and put restrictions on its progenitor history and the energy budget of the jet.

In our simulations, the main variables are the duration of the WR phase and the jet energies. The other variables, such as density and explosion energy, are constrained by demanding that the main shock radius and velocity match those observed for Cas A. We find that the presence of a jet severely constrains the duration of the WR phase. For a long duration the contrast in density between the WR wind and the surrounding shell, and the mass and thickness of the shell, become so large that the jet is destroyed as soon as it hits the shell. Our main conclusion is therefore that the WR phase must have been short ( $< 5000$  yrs), if present at all. Since the actual jet length is unknown, we can only derive a lower limit for the jet energy, which is  $10^{50}$  erg. We report on an analytical formula for the jet length as a function of jet energy that fits the results from simulations quite well.

### **AGN neutrino source candidates (Achterberg+, 2006)**

Achterberg, A., Duvoort, M., Heise, J., multi-co-authors

VizieR On-line Data Catalog: J/other/APh/26.282. Originally published in:  
2006APh....26..282A

The sensitivity of a search for sources of TeV neutrinos can be improved by grouping potential sources together into generic classes in a procedure that is known as source stacking. In this paper, we define catalogs of Active Galactic Nuclei (AGN) and use them to perform a source stacking analysis. The grouping of AGN into classes is done in two steps: first, AGN classes are defined, then, sources to be stacked are selected assuming that a potential neutrino flux is linearly correlated with the photon luminosity in a certain energy band (radio, IR, optical, keV, GeV, TeV). Lacking any secure detailed knowledge on neutrino production in AGN, this correlation is motivated by hadronic AGN models, as briefly reviewed in this paper.

The source stacking search for neutrinos from generic AGN classes is illustrated using the data collected by the AMANDA-II high-energy neutrino detector during the year 2000. No significant excess for any of the suggested groups was found.

### **Design Options for the Extreme Polarimeter (ExPo)**

[Rodenhuis, M.](#); [Keller, C. U.](#)

Proceedings of the conference In the Spirit of Bernard Lyot: The Direct Detection of Planets and Circumstellar Disks in the 21st Century. June 04 - 08, 2007. University of California, Berkeley, CA, USA. Edited by Paul Kalas.

The Extreme Polarimeter, ExPo, is being developed for the detailed study of circumstellar disks and exoplanet characterization at the 4.2-m William Herschel Telescope at La Palma. This imaging polarimeter is designed to measure linear polarization at the 10<sup>-5</sup> level around bright stars at distances outward of about 0.5 arcsec. We will discuss the design options for this instrument as well as the advantages and disadvantages of specific components such as the Atmospheric Dispersion Compensator, the polarising beamsplitting element, the coronagraph mask, and the polarisation modulator based on either ferroelectric or nematic liquid crystals. The merits and disadvantages of each of these will be discussed along with the impact of a certain choice on the overall instrument performance. Finally, an analysis of several off-the-shelf scientific cameras for the actual image recording will be presented.

### **Science Goals of the Extreme Polarimeter (ExPo)**

[Jeffers, S. V.](#); [Keller, C. U.](#); [Rodenhuis, M.](#); [Miesen, N.](#)

Proceedings of the conference In the Spirit of Bernard Lyot: The Direct Detection of Planets and Circumstellar Disks in the 21st Century. June 04 - 08, 2007. University of California, Berkeley, CA, USA. Edited by Paul Kalas.

To advance our understanding of the formation, evolution and structure of extra-solar planetary systems we are building a high-precision imaging polarimeter (ExPo). ExPo will initially be located at the 4.2m William Herschel Telescope on La Palma. We will

use polarimetric techniques similar to those developed for high-precision solar polarimetry to reach a sensitivity of  $10^{-5}$ , to polarimetrically image and characterize planets and protoplanetary debris discs. I will present a review of the proposed data analysis techniques and science goals that will be achievable using the significant improvement in polarimetric imaging capabilities.

### **Seething Horizontal Magnetic Fields in the Quiet Solar Photosphere**

[Harvey, J. W.](#); [Branston, D.](#); [Henney, C. J.](#); [Keller, C. U.](#); [SOLIS Team](#); [GONG Team](#)  
The Astrophysical Journal, Volume 659, Issue 2, pp. L177-L180.

The photospheric magnetic field outside of active regions and the network has a ubiquitous and dynamic line-of-sight component that strengthens from disk center to limb as expected for a nearly horizontal orientation. This component shows a striking time variation with an average temporal rms near the limb of 1.7 G at  $\sim 3''$  resolution. In our moderate-resolution observations the nearly horizontal component has a frequency variation power-law exponent of -1.4 below 1.5 mHz and is spatially patchy on scales up to  $\sim 15''$ . The field may be a manifestation of changing magnetic connections between eruptions and evolution of small magnetic flux elements in response to convective motions. It shows no detectable latitude or longitude variations.

### **Magnetic fields and accretion flows on the classical T Tauri star V2129 Oph**

[Donati, J.-F.](#); [Jardine, M. M.](#); [Gregory, S. G.](#); [Petit, P.](#); [Bouvier, J.](#); [Dougados, C.](#); [Ménard, F.](#); [Cameron, A. C.](#); [Harries, T. J.](#); [Jeffers, S. V.](#); [Paletou, F.](#)  
Monthly Notices of the Royal Astronomical Society, Volume 380, Issue 4, pp. 1297-1312.

From observations collected with the ESPaDOnS spectropolarimeter, we report the discovery of magnetic fields at the surface of the mildly accreting classical T Tauri star (cTTS) V2129 Oph. Zeeman signatures are detected, both in photospheric lines and in the emission lines formed at the base of the accretion funnels linking the disc to the protostar, and monitored over the whole rotation cycle of V2129 Oph. We observe that rotational modulation dominates the temporal variations of both unpolarized and circularly polarized line profiles.

We reconstruct the large-scale magnetic topology at the surface of V2129 Oph from both sets of Zeeman signatures simultaneously. We find it to be rather complex, with a dominant octupolar component and a weak dipole of strengths 1.2 and 0.35 kG, respectively, both slightly tilted with respect to the rotation axis. The large-scale field is anchored in a pair of 2-kG unipolar radial field spots located at high latitudes and coinciding with cool dark polar spots at photospheric level. This large-scale field geometry is unusually complex compared to those of non-accreting cool active subgiants with moderate rotation rates.

As an illustration, we provide a first attempt at modelling the magnetospheric topology and accretion funnels of V2129 Oph using field extrapolation. We find that the magnetosphere of V2129 Oph must extend to about  $7R_*$  to ensure that the footpoints of

accretion funnels coincide with the high-latitude accretion spots on the stellar surface. It suggests that the stellar magnetic field succeeds in coupling to the accretion disc as far out as the corotation radius, and could possibly explain the slow rotation of V2129 Oph. The magnetospheric geometry we derive qualitatively reproduces the modulation of Balmer lines and produces X-ray coronal fluxes typical of those observed in cTTs.

Based on observations obtained at the Canada-France-Hawaii Telescope (CFHT) which is operated by the National Research Council of Canada, the Institut National des Sciences de l'Univers of the Centre National de la Recherche Scientifique of France, and the University of Hawaii. Email: s.v.jeffers@uu.nl

### **Radiative magnetohydrodynamic simulations of solar pores**

[Cameron, R.](#); [Schüssler, M.](#); [Vögler, A.](#); [Zakharov, V.](#)

Astronomy and Astrophysics, Volume 474, Issue 1, October IV 2007, pp.261-272

Solar pores represent a class of magnetic structures intermediate between small-scale magnetic flux concentrations in intergranular lanes and fully developed sunspots with penumbrae. Aims: We study the structure, energetics, and internal dynamics of pore-like magnetic structures by means of exploratory numerical simulations. Methods: The MURaM code has been used to carry out several 3D radiative MHD simulations for pores of various sizes and with different boundary conditions. Results: The general properties of the simulated pores (morphology, continuum intensity, magnetic field geometry, surrounding flow pattern, mean height profiles of temperature, pressure, and density) are consistent with observational results. No indications for the formation of penumbral structure are found. The simulated pores decay by gradually shedding magnetic flux into the surrounding pattern of intergranular downflows (“turbulent erosion”). When viewed under an angle (corresponding to observations outside solar disc center), granules behind the pore appear brightened. Conclusions: Radiative MHD simulations capture many observed properties of solar pores.

### **Aperture Increase Options for the Dutch Open Telescope**

[Hammerschlag, R. H.](#); [Bettonvil, F. C. M.](#); [Jägers, A. P. L.](#); [Rutten, R. J.](#)

The Physics of Chromospheric Plasmas ASP Conference Series, Vol. 368, Proceedings of the conference held 9-13 October, 2006 at the University of Coimbra in Coimbra, Portugal. Edited by P. Heinzel, I. Dorotovič, and R. J. Rutten. San Francisco: Astronomical Society of the Pacific, 2007., p.573

This paper is an invitation to the international community to participate in the usage and a substantial upgrade of the Dutch Open Telescope on La Palma (DOT, <http://dot.astro.uu.nl>).

We first give a brief overview of the approach, design, and current science capabilities of the DOT. It became a successful 0.2-arcsec-resolution solar movie producer through its combination of (i) an excellent site, (ii) effective wind flushing through the fully open design and construction of both the 45-cm telescope and the 15-m support tower, (iii) special designs which produce extraordinary pointing stability of the tower, equatorial

mount, and telescope, (iv) simple and excellent optics with minimum wavefront distortion, and (v) large-volume speckle reconstruction including narrow-band processing. The DOT's multi-camera multi-wavelength speckle imaging system samples the solar photosphere and chromosphere simultaneously in various optical continua, the G band, Ca II H (tunable throughout the blue wing), and H $\alpha$  (tunable throughout the line). The resulting DOT data sets are all public. The DOT database (<http://dotdb.phys.uu.nl/DOT>) now contains many tomographic image sequences with 0.2-0.3 arcsec resolution and up to multi-hour duration. You are welcome to pull them over for analysis.

The main part of this contribution outlines DOT upgrade designs implementing larger aperture. The motivation for aperture increase is the recognition that optical solar physics needs the substantially larger telescope apertures that became useful with the advent of adaptive optics and viable through the DOT's open principle, both for photospheric polarimetry at high resolution and high sensitivity and for chromospheric fine-structure diagnosis at high cadence and full spectral sampling.

Our upgrade designs for the DOT are presented in an incremental sequence of five options of which the simplest (Option I) achieves 1.4 m aperture using the present tower, mount, fold-away canopy, and multi-wavelength speckle imaging and processing systems. The most advanced (Option V) offers unblocked 2.5 m aperture in an off-axis design with a large canopy, a wide 30-m high support tower, and image transfer to a groundbased optics lab for advanced instrumentation. All five designs employ adaptive optics. The important advantages of fully open, wind-transparent and wind-flushed structure, polarimetric constancy, and absence of primary-image rotation remain. All designs are relatively cheap through re-using as much of the existing DOT hardware as possible.

Realization of an upgrade requires external partnership(s). This report about DOT upgrade options therefore serves also as initial documentation for potential partners.

### **Towers for Antarctic Telescopes**

[Hammerschlag, R. H.](#); [Bettonvil, F. C. M.](#); [Jägers, A. P. L.](#); [Nielsen, G.](#)

EAS Publications Series, Volume 25, 2007, pp.265-272

To take advantage of the exceptional seeing above the boundary layer on Antarctic sites, a high-resolution telescope must be mounted on a support tower. An open transparent tower of framework minimizes the upward temperature-disturbed airflow. A typical minimum height is 30m. The tower platform has to be extremely stable against wind-induced rotational motions, which have to be less than fractions of an arc second, unusually small from a mechanical engineering viewpoint. In a traditional structure, structural deflections result in angular deflections of the telescope platform, which introduce tip and tilt motions in the telescope. However, a structure that is designed to deflect with parallel motion relative to the horizontal plane will undergo solely translation deflections in the telescope platform and thus will not degrade the image. The use of a

parallel motion structure has been effectively demonstrated in the design of the 15-m tower for the Dutch Open Telescope (DOT) on La Palma. Special framework geometries are developed, which make it possible to construct high towers in stories having platforms with extreme stability against wind-induced tilt. These geometric solutions lead to constructions, being no more massive than a normal steel framework carrying the same load. Consequently, these lightweight towers are well suited to difficult sites as on Antarctica. A geometry with 4 stories has been worked out.

### **Determination of the Velocity of Meteors Based on Sinodial Modulation and Frequency Analysis,**

Bettonvil, Felix

Earth, Moon and Planet, Online First, DOI 10.1007/s11038-007-9166-2

### **Completely Open Foldable Tent Constructions still Colasble in Strong Wind**

Hammerschlag, R.H., Bettonvil, F.C.M., Jägers, A.P.L., Sliepen, G.

IASS Symposium Beijing 16-19 October 2006, paper 108 in : New Shell and Spatial Structures, Proceedings IASS, paper MB08

### **Temporal Variations in Fibril Orientation**

[Koza, J.](#); [Sütterlin, P.](#); [Kučera, A.](#); [Rybák, J.](#)

The Physics of Chromospheric Plasmas ASP Conference Series, Vol. 368, Proceedings of the conference held 9-13 October, 2006 at the University of Coimbra in Coimbra, Portugal. Edited by P. Heinzel, I. Dorotovič, and R. J. Rutten. San Francisco: Astronomical Society of the Pacific, 2007., p.115

We measure variations in orientation of fourteen dynamic fibrils as a function of time in a small isolated plage and nearby network using a 10-min time sequence of H $\alpha$  filtergrams obtained by the Dutch Open Telescope. We found motions with average angular velocities of the order of 1 deg min<sup>-1</sup> suggesting systematic turning from one limit position to another, particularly apparent in the case of fibrils with lifetimes of a few minutes. Shorter fibrils tend to turn faster than longer ones, which we interpret as due to vortex flows in the underlying granulation that twist magnetic fields.

### **The height dependence of temperature velocity correlation in the solar photosphere**

[Koza, J.](#); [Kučera, A.](#); [Rybák, J.](#); [Wöhl, H.](#)

Modern solar facilities - advanced solar science, Proceedings of a Workshop held at Göttingen September 27-29, 2006 ISBN 978-3-938616-84-0 382 pages, many illustrations, soft-bound, Price: 23.- Euros Published by Universitätsverlag Göttingen (<http://univerlag.uni-goettingen.de> The online edition (PDF, 12 MB) is available free of charge at: [http://webdoc.sub.gwdg.de/univerlag/2007/solar\\_science\\_book.pdf](http://webdoc.sub.gwdg.de/univerlag/2007/solar_science_book.pdf), p.139

We derive correlation coefficients between temperature and line-of-sight velocity as a function of optical depth throughout the solar photosphere for the non-magnetic photosphere and a small area of enhanced magnetic activity. The maximum anticorrelation of about -0.6 between temperature and line-of-sight velocity in the non-

magnetic photosphere occurs at  $\log [\tau]_5 = -0.4$ . The magnetic field is another decorrelating factor along with 5-min oscillations and seeing.

### **The height dependence of quiet-sun photospheric temperature fluctuations in observations and simulations**

Koza, J., Kucera, A., Rybák, J., Wöhl, H.

Meeting of ASP held at the National Solar Observatory. Solar MHD Theory and Observations: a High Spatial Resolution Perspective. – San Francisco: Astronomical Society of the Pacific, 2006. ISBN 978-1-583812-22-8. Vol. 354, p. 43-48

### **Magnetic Patches in internetwork areas**

de Wijn, A.G., R.J. Rutten, E.M.W.P. Haverkamp, P. Sütterlin,

in: Solar MHD: Theory and Observations, Procs. 23<sup>rd</sup> NSO workshop, eds. H.

Uitenbroek, J. Lebacher, R.F. Stein, ASP Conf. Ser. 354, p.20, 2007

### **The Ba II 4554 H $\beta$ imaging polarimeter for the Dutch Open Telescope**

Snik, F., F.C.M. Bettonvil, A.P.L. Jägers, R.H. Hammerschlag, R.J. Rutten, C.U. Keller, in: Procs. 4th Solar Polarization Workshop, ASP Conf. Ser. 358, R. Casini and B.W. Lites, p. 205

### **On the nature of the solar chromosphere,**

Rutten, R.J.

in : Solar MHD: Theory and Observations, Procs. 23<sup>rd</sup> NSO Workshop, eds. H.

uitenbroek, J. Lebacher, R.F. Stein, ASP Conf Ser. 354, p. 282

### **Search for photospheric footpoints of quiet Sun transition region loops**

[Sánchez Almeida, J.](#); [Teriaca, L.](#); [Sütterlin, P.](#); [Spadaro, D.](#); [Schühle, U.](#); [Rutten, R. J.](#)

Astronomy and Astrophysics, Volume 475, Issue 3, December I 2007, pp.1101-1109

The footpoints of quiet Sun Transition Region (TR) loops do not seem to coincide with the photospheric magnetic structures appearing in traditional low-sensitivity magnetograms. Aims: We look for the so-far unidentified photospheric footpoints of TR loops using G-band bright points (BPs) as proxies for photospheric magnetic field concentrations.

Methods: We compare TR measurements with SoHO/SUMER and photospheric magnetic field observations obtained with the Dutch Open Telescope. Results:

Photospheric BPs are associated with bright TR structures, but they seem to avoid the brightest parts of the structure. BPs appear in regions that are globally redshifted, but they avoid extreme velocities. TR explosive events are not clearly associated with BPs.

Conclusions: The observations are not inconsistent with the BPs being footpoints of TR loops, although we have not succeeded to uniquely identify particular BPs with specific TR loops.

### **Non-equilibrium hydrogen ionization in 2D simulations of the solar atmosphere**

[Leenaarts, J.](#); [Carlsson, M.](#); [Hansteen, V.](#); [Rutten, R. J.](#)

Astronomy and Astrophysics, Volume 473, Issue 2, October II 2007, pp.625-632

The ionization of hydrogen in the solar chromosphere and transition region does not obey LTE or instantaneous statistical equilibrium because the timescale is long compared with important hydrodynamical timescales, especially of magneto-acoustic shocks. Since the pressure, temperature, and electron density depend sensitively on hydrogen ionization, numerical simulation of the solar atmosphere requires non-equilibrium treatment of all pertinent hydrogen transitions. The same holds for any diagnostic application employing hydrogen lines. Aims: To demonstrate the importance and to quantify the effects of non-equilibrium hydrogen ionization, both on the dynamical structure of the solar atmosphere and on hydrogen line formation, in particular H $\alpha$ . Methods: We implement an algorithm to compute non-equilibrium hydrogen ionization and its coupling into the MHD equations within an existing radiation MHD code, and perform a two-dimensional simulation of the solar atmosphere from the convection zone to the corona. Results: Analysis of the simulation results and comparison to a companion simulation assuming LTE shows that: a) non-equilibrium computation delivers much smaller variations of the chromospheric hydrogen ionization than for LTE. The ionization is smaller within shocks but subsequently remains high in the cool intershock phases. As a result, the chromospheric temperature variations are much larger than for LTE because in non-equilibrium, hydrogen ionization is a less effective internal energy buffer. The actual shock temperatures are therefore higher and the intershock temperatures lower. b) The chromospheric populations of the hydrogen  $n = 2$  level, which governs the opacity of H $\alpha$ , are coupled to the ion populations. They are set by the high temperature in shocks and subsequently remain high in the cool intershock phases. c) The temperature structure and the hydrogen level populations differ much between the chromosphere above photospheric magnetic elements and above quiet internetwork. d) The hydrogen  $n = 2$  population and column density are persistently high in dynamic fibrils, suggesting that these obtain their visibility from being optically thick in H $\alpha$  also at low temperature.

Movie and Appendix A are only available in electronic form at <http://www.aanda.org>

### **Inter-network regions of the Sun at millimetre wavelengths**

[Wedemeyer-Böhm, S.](#); [Ludwig, H. G.](#); [Steffen, M.](#); [Leenaarts, J.](#); [Freytag, B.](#)

Astronomy and Astrophysics, Volume 471, Issue 3, September I 2007, pp.977-991

The continuum intensity at wavelengths around 1 mm provides an excellent way to probe the solar chromosphere and thus valuable input for the ongoing controversy on the thermal structure and the dynamics of this layer. The synthetic continuum intensity maps for near-millimetre wavelengths presented here demonstrate the potential of future observations of the small-scale structure and dynamics of internetwork regions on the Sun. Methods: The synthetic intensity/brightness temperature maps are calculated on basis of three-dimensional radiation (magneto-)hydrodynamic (MHD) simulations. The assumption of local thermodynamic equilibrium (LTE) is valid for the source function.

The electron densities are also treated in LTE for most maps but also in non-LTE for a representative model snapshot. Quantities like intensity contrast, intensity contribution functions, spatial and temporal scales are analysed in dependence on wavelength and heliocentric angle. Results: While the millimetre continuum at 0.3 mm originates mainly from the upper photosphere, the longer wavelengths considered here map the low and middle chromosphere. The effective formation height increases generally with wavelength and also from disk-centre towards the solar limb. The average intensity contribution functions are usually rather broad and in some cases they are even double-peaked as there are contributions from hot shock waves and cool post-shock regions in the model chromosphere. The resulting shock-induced thermal structure translates to filamentary brightenings and fainter regions in between. Taking into account the deviations from ionisation equilibrium for hydrogen gives a less strong variation of the electron density and with it of the optical depth. The result is a narrower formation height range although the intensity maps still are characterised by a highly complex pattern. The average brightness temperature increases with wavelength and towards the limb although the wavelength-dependence is reversed for the MHD model and the NLTE brightness temperature maps. The relative contrast depends on wavelength in the same way as the average intensity but decreases towards the limb. The dependence of the brightness temperature distribution on wavelength and disk-position can be explained with the differences in formation height and the variation of temperature fluctuations with height in the model atmospheres. The related spatial and temporal scales of the chromospheric pattern should be accessible by future instruments. Conclusions: Future high-resolution millimetre arrays, such as the Atacama Large Millimeter Array (ALMA), will be capable of directly mapping the thermal structure of the solar chromosphere. Simultaneous observations at different wavelengths could be exploited for a tomography of the chromosphere, mapping its three-dimensional structure, and also for tracking shock waves. The new generation of millimetre arrays will be thus of great value for understanding the dynamics and structure of the solar atmosphere.

### **Non-equilibrium Hydrogen Ionization in the Solar Atmosphere**

[Leenaarts, J.](#); [Wedemeyer-Böhm, S.](#); [Carlsson, M.](#); [Hansteen, V. H.](#)

The Physics of Chromospheric Plasmas ASP Conference Series, Vol. 368, Proceedings of the conference held 9-13 October, 2006 at the University of Coimbra in Coimbra, Portugal. Edited by P. Heinzel, I. Dorotovič, and R. J. Rutten. San Francisco: Astronomical Society of the Pacific, 2007., p.103

The assumption of statistical equilibrium for atomic level populations of hydrogen does not hold under the conditions of the chromosphere due to the low density and the short dynamic timescale. In order to calculate the hydrogen ionization balance and the electron density one has to solve the time-dependent rate equations. We present results from 2D and 3D radiation-magneto-hydrodynamics simulations of the solar atmosphere incorporating the time-dependent rate equations for hydrogen. Both the hydrogen ionization degree and the electron density in our models are much more constant than LTE and statistical equilibrium theory predict. These simulations provide multi-dimensional model atmospheres with realistic electron densities and hydrogen level

populations that can be used in detailed radiative transfer modeling.

### **Chromospheric and Transition-Region Dynamics in Plage**

[de Wijn, A. G.](#); [de Pontieu, B.](#); [Rutten, R. J.](#)

The Physics of Chromospheric Plasmas ASP Conference Series, Vol. 368, Proceedings of the conference held 9-13 October, 2006 at the University of Coimbra in Coimbra, Portugal. Edited by P. Heinzel, I. Dorotovič, and R. J. Rutten. San Francisco: Astronomical Society of the Pacific, 2007., p.137

The Astrophysical Journal, Volume 654, Issue 2, pp. 1128-1134.

We study the dynamical interaction of the solar chromosphere with the transition region in mossy and non-mossy active-region plage. We carefully align image sequences taken with the Transition Region And Coronal Explorer (TRACE) in the ultraviolet passbands around 1550, 1600, and 1700 Å and the extreme ultraviolet passbands at 171 and 195 Å. We compute Fourier phase-difference spectra that are spatially averaged separately over mossy and non-mossy plage to study temporal modulations as a function of temporal frequency. The 1550 versus 171 Å comparison shows zero phase difference in non-mossy plage. In mossy plage, the phase differences between all UV and EUV passbands show pronounced upward trends with increasing frequency, which abruptly changes into zero phase difference beyond 4 -- 6 mHz. The phase difference between the 171 and 195 Å sequences exhibits a shallow dip below 3 mHz and then also turns to zero phase difference beyond this value. We attribute the various similarities between the UV and EUV diagnostics that are evident in the phase-difference diagrams to the contribution of the C IV resonance lines in the 1550 and 1600 Å passbands. The strong upward trend at the lower frequencies indicates the presence of upward-traveling disturbances. It points to correspondence between the lower chromosphere and the upper transition region, perhaps by slow-mode magnetosonic disturbances, or by a connection between chromospheric and coronal heating mechanisms. The transition from this upward trend to zero phase difference at higher frequencies is due to the intermittent obscuration by fibrils that occult the foot points of hot loops, which are bright in the EUV and C IV lines, in oscillatory manner.

### **Observing the Solar Chromosphere**

[Rutten, R. J.](#)

The Physics of Chromospheric Plasmas ASP Conference Series, Vol. 368, Proceedings of the conference held 9-13 October, 2006 at the University of Coimbra in Coimbra, Portugal. Edited by P. Heinzel, I. Dorotovič, and R. J. Rutten. San Francisco: Astronomical Society of the Pacific, 2007., p.27

This review is split into two parts: one on chromospheric line formation in answer to the frequent question "where is my line formed", and one presenting state-of-the-art imagery of the chromosphere. In the first part I specifically treat the formation of the Na D lines, Ca II H&K, and H $\alpha$ . In the second I show DOT, IBIS, VAULT, and TRACE images as

evidence that the chromosphere consists of fibrils of intrinsically different types. The straight-up ones are hottest. The slanted ones are filled by shocks and likely possess thin transition sheaths to coronal plasma. The ones hovering horizontally over "clapotispheric" cell interiors outline magnetic canopies and are buffeted by shocks, most violently in the quietest regions.

In the absence of integral-field ultraviolet spectrometry, H $\alpha$  remains the principal chromosphere diagnostic. The required fast-cadence profile-sampling imaging is an important quest for new telescope technology.

### **ESMN in Memoriam (1998 -- 2006)**

[Rutten, R. J.](#)

The Physics of Chromospheric Plasmas ASP Conference Series, Vol. 368, Proceedings of the conference held 9-13 October, 2006 at the University of Coimbra in Coimbra, Portugal. Edited by P. Heinzel, I. Dorotovič, and R. J. Rutten. San Francisco: Astronomical Society of the Pacific, 2007., p.21

The EC-FP5 European Solar Magnetism Network (ESMN) was terminated during this conference. Together with its FP4 predecessor, the European Solar Magnetometry Network (ESMN), it funded 22 postdoc and 9 graduate-student appointments at nine solar physics groups in Western Europe, it enhanced Europe-wide collaboration in solar physics, and it contributed to the integration of East-European groups in West-European enterprises. Its unfortunate demise results from lack of further fortune in the FP6 lottery. The FP6-funded Utrecht-Stockholm-Oslo graduate school in solar physics represents offspring, the FP6 Solaire network is a partial replacement, and the EAST undertaking and pledge to build an EST is a most worthy FP7 stake. The EC's policy shifts from postdoc to predoc funding and from requiring (too) small to requiring (too) large consortia are criticized.

### **The young star cluster system in the Antennae: evidence for a turnover in the luminosity function**

[Anders, P.](#); [Bissantz, N.](#); [Boysen, L.](#); [de Grijs, R.](#); [Fritze-v. Alvensleben, U.](#)

Monthly Notices of the Royal Astronomical Society, Volume 377, Issue 1, pp. 91-106.

The luminosity functions (LFs) of star cluster (SC) systems (i.e. the number of clusters per luminosity interval) are vital diagnostics to probe the conditions of SC formation. Early studies have revealed a clear dichotomy between old globular clusters and young clusters, with the former characterized by Gaussian-shaped LFs, and the latter following a power law. Recently, this view was challenged by studies of galaxy merger remnants and post-starburst galaxies. In this paper, we re-evaluate the young (<~few hundreds of Myrs, with the majority <~few tens of Myrs) SC system in the ongoing spiral-spiral major merger system NGC 4038/39, the 'Antennae' galaxies. The Antennae galaxies represent a very active and complex star-forming environment, which hampers cluster selection and photometry as well as the determination of observational completeness fractions. A main issue of concern is the large number of bright young stars contained in most earlier

studies, which we carefully exclude from our cluster sample by accurately determining the source sizes. The resulting LFs are fitted both with Gaussian and with power-law distributions, taking into account both the observational completeness fractions and the photometric errors, and compared using a likelihood-ratio test. The likelihood-ratio results are rigidly evaluated using Monte Carlo simulations. We perform a number of additional tests, for example, with subsets of the total sample, all confirming our main result: that a Gaussian distribution fits the observed LFs of clusters in this preferentially very young cluster system significantly better than a power-law distribution, at a (statistical) error probability of less than 0.5 per cent.

### **N-body simulations of star clusters,**

P. Anders

contr. Talk, 2 pages, IAU Symp. 246, "Dynamical Evolution of Dense Stellar Systems" eds. E. Vesperini, M. Giersz, A. Sills, Capri (I)

### **Measurements on fast open foldable tent domes; developments to extremely large sizes**

Bettonvil, F., R.H. Hammersschlag, A. Jägers, G. Sliepen,  
Procs IASS, paper 204

### **The B Supergiant Discontinuous Drop in X-ray Luminosity at Spectra Type B1**

[Waldron, Wayne L.](#); [Cassinelli, J.](#); [Oskinova, L.](#); [Lamers, H.](#)

American Astronomical Society, AAS Meeting #211, #80.05

At spectral type B1, the stellar winds of B supergiants (SGs) display a discontinuous drop in their observed terminal velocities which is referred to as the "bi-stability jump". Similarly, Einstein satellite observations of B SG also revealed evidence for a discontinuous drop in their observed X-ray luminosities at B1. Since the X-ray emission is believed to arise from stellar wind shock structures, B SGs provide an excellent laboratory for testing the still uncertain relationships between the radiation forces, wind properties, and the resultant X-ray emission. This interesting coincidence at spectral type B1 has not been explored in depth mostly due to the insufficient number of B SGs with high S/N X-ray observations. To explore the significance and interconnection of the X-ray and wind discontinuous drops, we obtained high S/N XMM-Newton EPIC observations of a sample of B SGs in the vicinity of spectral type B1. The good sensitivity of EPIC allows us to carry out a thorough X-ray spectral analysis of these stars and extract well constrained X-ray parameters. Our observations confirmed the B1 discontinuous drop in X-ray luminosity by a factor of 4, and this X-ray drop is found to coincide with the same effective temperature of the wind bi-stability jump. Although current shock X-ray emission models are found to be roughly consistent with predicting the observed drop in the X-ray luminosity, our detailed X-ray analyses have revealed several discrepancies with these models. For example, since shock produced X-ray

temperatures scale with the flow velocity squared, we expected to see a dramatic drop in the spectral hardness across the discontinuity due to the drop in wind speed, but this is not observed. We discuss the significance of our X-ray results with regards to understanding the wind-dynamics of B SGs and suggest alternative X-ray source models.

### **The Age Distributions of Clusters and Field Stars in the SMC**

[Kruijssen, J. M. Diederik](#); [Lamers, Henny J. G. L. M.](#)

Differences between the inferred star formation histories (SFHs) of star clusters and field stars seem to suggest distinct star formation processes for the two. The Small Magellanic Cloud (SMC) is an example of a galaxy where such a discrepancy is observed. We model the observed age distributions of the SMC clusters and field stars using a new population synthesis code, SPACE, that includes stellar evolution, infant mortality and cluster dissolution. We find that the two observed age distributions can be explained by a single SFH, thus eliminating the need to assume two separate mechanisms for star formation.

### **Neon Abundances from a Spitzer/IRS Survey of Wolf-Rayet Stars**

[Ignace, R.](#); [Cassinelli, J. P.](#); [Tracy, G.](#); [Churchwell, E.](#); [Lamers, H. J. G. L. M.](#)

The Astrophysical Journal, Volume 669, Issue 1, pp. 600-605.

We report on neon abundances derived from Spitzer high resolution spectral data of eight Wolf-Rayet (WR) stars using the forbidden line of [Ne III] 15.56  $\mu\text{m}$ . Our targets include four WN stars of subtypes 4-7, and four WC stars of subtypes 4-7. We derive ion fraction abundances  $\gamma$  of  $\text{Ne}^{2+}$  for the winds of each star. The ion fraction abundance is a product of the ionization fraction  $Q_i$  in stage  $i$  and the abundance by number  $A_E$  of element  $E$  relative to all nuclei. Values generally consistent with solar are obtained for the WN stars, and values in excess of solar are obtained for the WC stars.

### **On the Interpretation of the Age Distribution of Star Clusters in the Small Magellanic Cloud**

[Gieles, Mark](#); [Lamers, Henny J. G. L. M.](#); [Portegies Zwart, Simon F.](#)

The Astrophysical Journal, Volume 668, Issue 1, pp. 268

We reanalyze the age distribution ( $dN/dt$ ) of star clusters in the Small Magellanic Cloud (SMC) using age determinations based on the Magellanic Cloud Photometric Survey. For ages younger than  $3 \times 10^9$  yr the  $dN/dt$  distribution can be approximated by a power-law distribution,  $dN/dt \sim t^{-\beta}$ , with  $-\beta = -0.70 \pm 0.05$  or  $-\beta = -0.84 \pm 0.04$ , depending on the model used to derive the ages. Predictions for a cluster population without dissolution limited by a V-band detection result in a power-law  $dN/dt$  distribution with an index of  $\sim -0.7$ . This is because the limiting cluster mass increases with age, due to evolutionary fading of clusters, reducing the number of observed clusters at old ages. When a mass cut well above the limiting cluster mass is applied, the  $dN/dt$  distribution is flat up to 1 Gyr. We conclude that cluster dissolution is of small importance in shaping the  $dN/dt$  distribution, and incompleteness causes  $dN/dt$  to decline. The reason that no (mass independent) infant mortality of star clusters around  $\sim 10$ -20 Myr is found is explained by a detection bias

toward clusters without nebular emission, i.e., clusters that have survived the infant mortality phase. The reason we find no evidence for tidal (mass dependent) cluster dissolution in the first gigayear is explained by the weak tidal field of the SMC. Our results are in sharp contrast to the interpretation of Chandar et al., who interpret the declining  $dN/dt$  distribution as rapid cluster dissolution. This is due to their erroneous assumption that the sample is limited by cluster mass, rather than luminosity.

### **ACS imaging of star clusters in M 51. I. Identification and radius distribution**

[Scheepmaker, R. A.](#); [Haas, M. R.](#); [Gieles, M.](#); [Bastian, N.](#); [Larsen, S. S.](#);  
[Lamers, H. J. G. L. M.](#)

Astronomy and Astrophysics, Volume 469, Issue 3, July III 2007, pp.925-940

Size measurements of young star clusters are valuable tools to put constraints on the formation and early dynamical evolution of star clusters. Aims: We use HST/ACS observations of the spiral galaxy M 51 in F435W, F555W and F814W to select a large sample of star clusters with accurate effective radius measurements in an area covering the complete disc of M 51. We present the dataset and study the radius distribution and relations between radius, colour, arm/interarm region, galactocentric distance, mass and age. Methods: We select a sample of 7698 (F435W), 6846 (F555W) and 5024 (F814W) slightly resolved clusters and derive their effective radii ( $R_{\text{eff}}$ ) by fitting the spatial profiles with analytical models convolved with the point spread function. The radii of 1284 clusters are studied in detail. Results: We find cluster radii between 0.5 and  $\sim 10$  pc, and one exceptionally large cluster candidate with  $R_{\text{eff}} = 21.6$  pc. The median  $R_{\text{eff}}$  is 2.1 pc. We find 70 clusters in our sample which have colours consistent with being old GC candidates and we find 6 new “faint fuzzy” clusters in, or projected onto, the disc of M 51. The radius distribution can not be fitted with a power law similar to the one for star-forming clouds. We find an increase in  $R_{\text{eff}}$  with colour as well as a higher fraction of clusters with  $B-V \geq 0.05$  in the interarm regions. We find a correlation between  $R_{\text{eff}}$  and galactocentric distance ( $R_G$ ) of the form  $R_{\text{eff}} \propto R_G^{0.12 \pm 0.02}$ , which is considerably weaker than the observed correlation for old Milky Way GCs. We find weak relations between cluster luminosity and radius:  $R_{\text{eff}} \propto L^{0.15 \pm 0.02}$  for the interarm regions and  $R_{\text{eff}} \propto L^{-0.11 \pm 0.01}$  for the spiral arm regions, but we do not observe a correlation between cluster mass and radius. Conclusions: The observed radius distribution indicates that shortly after the formation of the clusters from a fractal gas, the radii of the clusters have changed in a non-uniform way. We find tentative evidence suggesting that clusters in spiral arms are more compact.

Based on observations made with the NASA/ESA Hubble Space Telescope, obtained from the data archive at the Space Telescope Institute. STScI is operated by the association of Universities for Research in Astronomy, Inc., under the NASA contract NAS 5-26555.

### **The Young Cluster Population of M82 Region B**

[Smith, L. J.](#); [Bastian, N.](#); [Konstantopoulos, I. S.](#); [Gallagher, J. S., III](#); [Gieles, M.](#); [de Grijs, R.](#); [Larsen, S. S.](#); [O'Connell, R. W.](#); [Westmoquette, M. S.](#)  
The Astrophysical Journal, Volume 667, Issue 2, pp. L145-L149.

We present observations obtained with the Advanced Camera for Surveys on board the Hubble Space Telescope of the "fossil" starburst region B in the nearby starburst galaxy M82. By comparing UBV photometry with models, we derive ages and extinctions for 35 U-band-selected star clusters. We find that the peak epoch of cluster formation occurred  $\sim 150$  Myr ago, in contrast to earlier work that found a peak formation age of 1.1 Gyr. The difference is most likely due to our inclusion of U-band data, which are essential for accurate age determinations of young cluster populations. We further show that the previously reported turnover in the cluster luminosity function is probably due to the neglect of the effect of extended sources on the detection limit. The much younger cluster ages we derive clarifies the evolution of the M82 starburst. The M82-B age distribution now overlaps with the ages of the nuclear starburst, the clusters formed on the opposite side of the disk, and the last encounter with M81, some 220 Myr ago.

Based on observations with the NASA/ESA Hubble Space Telescope, obtained at the Space Telescope Science Institute, which is operated by AURA, Inc., under NASA contract NAS5-26555. These observations are associated with program 10853.

### **Hierarchical star formation in M33: fundamental properties of the star-forming regions**

[Bastian, N.](#); [Ercolano, B.](#); [Gieles, M.](#); [Rosolowsky, E.](#); [Scheepmaker, R. A.](#); [Gutermuth, R.](#); [Efremov, Yu.](#)

Monthly Notices of the Royal Astronomical Society, Volume 379, Issue 4, pp. 1302-1312.

Star formation within galaxies appears on multiple scales, from spiral structure, to OB associations, to individual star clusters, and often substructure within these clusters. This multitude of scales calls for objective methods to find and classify star-forming regions, regardless of spatial size. To this end, we present an analysis of star-forming groups in the local group spiral galaxy M33, based on a new implementation of the minimum spanning tree method. Unlike previous studies which limited themselves to a single spatial scale, we study star-forming structures from the effective resolution limit ( $\sim 20$  pc) to kpc scales. Once the groups are identified, we study their properties, for example, size and luminosity distributions, and compare them with studies of young star clusters and giant molecular clouds (GMCs). We find evidence for a continuum of star-forming group sizes, which extends into the star cluster spatial scale regime. We do not find a characteristic scale for OB associations, unlike that found in previous studies, and we suggest that the appearance of such a scale was caused by spatial resolution and selection effects. The luminosity function of the groups is found to be well represented by a power law with an index, -2, the same as has been found for the luminosity and mass functions (MFs) of young star clusters, as well as the MF of GMCs. Additionally, the groups follow a similar mass-radius relation as GMCs. The size distribution of the groups is best described by a lognormal distribution, the peak of which is controlled by the spatial scale

probed and the minimum number of sources used to define a group. We show that within a hierarchical distribution, if a scale is selected to find structure, the resulting size distribution will have a lognormal distribution. We find an abrupt drop of the number of groups outside a galactic radius of  $\sim 4$  kpc (although individual high-mass stars are found beyond this limit), suggesting a change in the structure of the star-forming interstellar medium, possibly reflected in the lack of GMCs beyond this radius. Finally, we find that the spatial distribution of HII regions, GMCs, and star-forming groups are all highly correlated.

### **The effect of spiral arm passages on the evolution of stellar clusters**

[Gieles, M.](#); [Athanassoula, E.](#); [Portegies Zwart, S. F.](#)

Monthly Notices of the Royal Astronomical Society, Volume 376, Issue 2, pp. 809-819

We study the effect of spiral arm passages on the evolution of star clusters on planar and circular orbits around the centres of galaxies. Individual passages with different relative velocity ( $V_{\text{drift}}$ ) and arm width are studied using N-body simulations. When the ratio of the time it takes the cluster to cross the density wave to the crossing time of stars in the cluster is much smaller than one, the energy gain of stars can be predicted accurately in the impulsive approximation. When this ratio is much larger than one, the cluster is heated adiabatically and the net effect of heating is largely damped. For a given duration of the perturbation, this ratio is smaller for stars in the outer parts of the cluster compared to stars in the inner part. The cluster energy gain due to perturbations of various duration as obtained from our N-body simulations is in good agreement with theoretical predictions taking into account the effect of adiabatic damping. Perturbations by the broad stellar component of the spiral arms on a cluster are in the adiabatic regime and, therefore, hardly contribute to the energy gain and mass loss of the cluster. We consider the effect of crossings through the high-density shocked gas in the spiral arms, which result in a more impulsive compression of the cluster. The energy injected during each spiral arm passage can exceed the total binding energy of a cluster, but, since most of the energy goes in high velocity escapers from the cluster halo, only relatively little mass is lost. A single perturbation that injects the same amount of energy as the initial (negative) cluster energy causes at most  $\sim 40$  per cent of the stars to escape. We find that a perturbation that delivers  $\sim 10$  times the initial cluster energy is needed to completely unbind a cluster in a single passage. The net effect of spiral arm perturbations on the evolution of low mass ( $< \sim 100 M_{\text{solar}}$ ) star clusters is more profound than on more massive clusters ( $> \sim 1000 M_{\text{solar}}$ ). This is due to the fact that the crossing time of stars in the latter is shorter, causing a larger fraction of stars to be in the adiabatic regime. The time-scale of disruption by subsequent spiral arm perturbations depends strongly on position with respect to the radius of corotation ( $R_{\text{CR}}$ ), where  $V_{\text{drift}} = 0$ . The time between successive encounters scales with  $V_{\text{drift}}$  as  $t_{\text{drift}} \sim V_{\text{drift}}^{-1}$  and the energy gain per passage scales as  $\Delta E \sim V_{\text{drift}}^2$ . Exactly at  $R_{\text{CR}}$  passages do not occur, so the time-scale of disruption is infinite. The time-scale of disruption is shortest at  $\sim 0.8-0.9 R_{\text{CR}}$ , since there  $V_{\text{drift}}$  is low. This location can be applicable to the solar neighbourhood. In addition, the four-armed spiral pattern of the Milky Way makes spiral arms contribute more to the disruption of clusters than in a similar but two-armed galaxy. Still, the disruption time due to spiral arm

perturbations there is about an order of magnitude higher than what is observed for the solar neighbourhood, making spiral arm perturbations a moderate contributor to the dissolution of open clusters.

### **Ionized and neutral gas in the peculiar star/cluster complex in NGC 6946**

[Efremov, Yu. N.](#); [Afanasyev, V. L.](#); [Alfaro, E. J.](#); [Boomsma, R.](#); [Bastian, N.](#); [Larsen, S.](#); [Sánchez-Gil, M. C.](#); [Silchenko, O. K.](#); [García-Lorenzo, B.](#); [Muñoz-Tuñón, C.](#); [Hodge, P. W.](#)

Monthly Notices of the Royal Astronomical Society, Volume 382, Issue 2, pp. 481-497.

The characteristics of ionized and H I gas in the peculiar star/cluster complex in NGC 6946, obtained with the 6-m telescope (BTA) Special Astrophysical Observatory Russian Academy of Sciences (RAS), the Gemini North telescope, and the Westerbork Synthesis Radio Telescope, are presented. The complex is unusual as hosting a super star cluster, the most massive known in an apparently non-interacting giant galaxy. It contains a number of smaller clusters and is bordered by a sharp C-shaped rim. We found that the complex is additionally unusual in having peculiar gas kinematics. The velocity field of the ionized gas reveals a deep oval minimum,  $\sim 300$  pc in size, centred 7 arcsec east of the supercluster. The  $V_r$  of the ionized gas in the dip centre is  $100 \text{ km s}^{-1}$  lower than in its surroundings, and emission lines within the dip appear to be shock-excited. This dip is near the centre of an H I hole and a semi-ring of H II regions. The H I (and less certainly, H II) velocity fields reveal expansion, with the velocity reaching  $\sim 30 \text{ km s}^{-1}$  at a distance about 300 pc from the centre of expansion, which is near the deep minimum position. The superstar cluster is at the western rim of the minimum. The sharp western rim of the whole complex is plausibly a manifestation of a regular dust arc along the complex edge. Different hypotheses about the complex and the  $V_r$  depression's origins are discussed, including a high-velocity HI cloud/dark minihalo impact, a blue compact dwarf galaxy merging, and a gas outflow due to release of energy from the supercluster stars.

### **UBVI photometry of NGC 45 star clusters (Mora+, 2007)**

[Mora, M. D.](#); [Larsen, S. S.](#); [Kissler-Patig, M.](#)

VizieR On-line Data Catalog: J/A+A/464/495. Originally published in: 2007A&A...464..495M

Star clusters are present in almost all types of galaxies. Here we investigate the star cluster population in the low-luminosity, unperturbed spiral galaxy NGC 45, which is located in the nearby Sculptor group. Both the old (globular) and young star-cluster populations are studied. Previous ground-based observations have suggested that NGC 45 has few if any "massive" young star clusters. We aim to study the population of lower-mass "open" star clusters and also identify old globular clusters that could not be distinguished from foreground stars in the ground-based data. Star clusters were identified using UBVI imaging from the Advanced Camera for Surveys (ACS) and the Wide Field Planetary Camera 2 (WFPC2) on board the Hubble Space Telescope. From broad band colors and comparison with simple stellar population (SSP) models assuming

a fixed metallicity, we derived the age, mass, and extinction. We also measured the radius for each star cluster candidate.

### **Planetary Nebulae in Extragalactic Young Star Clusters**

[Larsen, S. S.](#); [Richtler, T.](#)

Stellar Populations as Building Blocks of Galaxies, Proceedings of IAU Symposium #241. Edited by A. Vazdekis and R. F. Peletier. Cambridge: Cambridge University Press, 2007, pp.453-454

### **Formation History of Stars and Star Clusters in Nearby Galaxies**

[Larsen, S. S.](#); [Mora, M. D.](#); [Brodie, J. P.](#); [Richtler, T.](#)

Stellar Populations as Building Blocks of Galaxies, Proceedings of IAU Symposium #241. Edited by A. Vazdekis and R. F. Peletier. Cambridge: Cambridge University Press, 2007, pp.435-439

We present first results from an HST/ACS imaging survey of stars and star clusters in five nearby spiral galaxies. This contribution concentrates on NGC 1313, a highly distorted late-type barred spiral. We compare the field star and cluster formation histories in our three ACS pointings for this galaxy. In one pointing, both the cluster and field star age distributions show clear evidence for a ramp-up in the star formation rate about 100 Myrs ago.

### **Resolving Extragalactic Star Clusters with HST/ACS**

[Larsen, S. S.](#)

eprint arXiv:0707.0205

With HST, colour-magnitude diagrams (CMDs) can be obtained for young star clusters well beyond the Local Group. Such data can help constrain cluster ages and metallicities, and also provide a reference against which intermediate- and high mass stellar models can be compared. Here, CMDs are presented for two massive ( $>10^5$  Msun) clusters and compared with Padua and Geneva isochrones. The problem of the ratio of blue to red supergiants is also addressed.

### **The spatially resolved stellar populations of isolated early-type galaxies**

[Reda, Fatma M.](#); [Proctor, Robert N.](#); [Forbes, Duncan A.](#); [Hau, George K. T.](#);

[Larsen, Søren S.](#)

Monthly Notices of the Royal Astronomical Society, Volume 377, Issue 4, pp. 1772-1784.

We present radial stellar population parameters for a subsample of 12 galaxies from the 36 isolated early-type galaxies of Reda et al. Using new long-slit spectra, central values and radial gradients for the stellar age, metallicity  $[Z/H]$  and  $\alpha$ -element abundance  $[E/Fe]$  are measured. Similarly, the central stellar population parameters are derived for a further five isolated early-type galaxies using their Lick indices from the literature. On average,

the 17 isolated galaxies have mean central  $[Z/H]_0$  and  $[E/Fe]_0$  of  $0.29 \pm 0.03$  and  $0.17 \pm 0.03$ , respectively, and span a wide range of ages from 1.7 to 15 Gyr. We find that isolated galaxies follow similar scaling relations between central stellar population parameters and galaxy velocity dispersion to their counterparts in high-density environments. However, we note a tendency for isolated galaxies to have slightly younger ages, higher metallicities and lower abundance ratios. Such properties are qualitatively consistent with the expectation of an extended star formation history for galaxies in lower density environments. Generally, we measure constant age and  $[E/Fe]$  radial gradients. However, three galaxies show remarkable positive age gradients and two galaxies have negative age gradients. We find that the age gradients anticorrelate with the central galaxy age. Thus as a young starburst evolves, the age gradient flattens from positive to almost zero. Metallicity gradients range from near zero to strongly negative. For our high-mass galaxies ( $\sigma > 160 \text{ km s}^{-1}$ ) metallicity gradients are shallower with increasing mass. Such behaviour is not predicted in dissipational collapse models but might be expected in multiple mergers. The metallicity gradients are also found to be correlated with the central age and metallicity, as well as to the age gradients. In conclusion, our stellar population data for a sample of isolated early-type galaxies are more compatible with an extended merger/accretion history than early dissipative collapse.

### **Imaging of star clusters in unperturbed spiral galaxies with the Advanced Camera for Surveys. I. The low luminosity galaxy NGC 45**

[Mora, M. D.](#); [Larsen, S. S.](#); [Kissler-Patig, M.](#)

Astronomy and Astrophysics, Volume 464, Issue 2, March III 2007, pp.495-505

Context: Star clusters are present in almost all types of galaxies. Here we investigate the star cluster population in the low-luminosity, unperturbed spiral galaxy NGC 45, which is located in the nearby Sculptor group. Both the old (globular) and young star-cluster populations are studied. Aims: Previous ground-based observations have suggested that NGC 45 has few if any "massive" young star clusters. We aim to study the population of lower-mass "open" star clusters and also identify old globular clusters that could not be distinguished from foreground stars in the ground-based data. Methods: Star clusters were identified using UBVI imaging from the Advanced Camera for Surveys (ACS) and the Wide Field Planetary Camera 2 (WFPC2) on board the Hubble Space Telescope. From broad band colors and comparison with simple stellar population (SSP) models assuming a fixed metallicity, we derived the age, mass, and extinction. We also measured the radius for each star cluster candidate.

Results: We identified 28 young star cluster candidates. While the exact values of age, mass, and extinction depend somewhat on the choice of SSP models, we find no young clusters with masses higher than a few  $1000 M_\odot$  for any model choice. We derive the luminosity function of young star clusters and find a slope of  $\alpha = -1.94 \pm 0.28$ . We also identified 19 old globular clusters, which appear to have a mass distribution that is roughly consistent with what is observed in other globular cluster systems. Applying corrections for spatial incompleteness, we estimate a specific frequency of globular clusters of  $S_N = 1.4-1.9$ , which is significantly higher than observed for other late-type

galaxies (e.g. SMC, LMC, M 33). Most of these globular clusters appear to belong to a metal-poor population, although they coincide spatially with the location of the bulge of NGC 45.

Based on observations made with the NASA/ESA Hubble Space Telescope, obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555.

### **Continuous Star Cluster Formation in the Spiral NGC45**

[Mora, Marcelo](#); [Larsen, Søren S.](#); [Kissler-Patig, Markus](#)

ISLAND UNIVERSES, Astrophysics and Space Science Proceedings. ISBN 978-1-4020-5572-0. Springer, 2007, p. 445

We determined ages for 52 candidate star clusters with masses  $\leq 106 M_{\odot}$  in the low surface brightness spiral galaxy NGC45. Four of these candidates are old globular clusters located in the bulge. The remaining ones span a large age range. The cluster ages suggest a continuous star/cluster formation history without evidence for bursts, consistent with the galaxy being located in a relatively unperturbed environment in the outskirts of the Sculptor group.

### **The Globular Cluster Systems Around NGC 3311 and NGC 3309**

[Wehner, Elizabeth H.](#); [Harris, W. E.](#); [Whitmore, B.](#); [Rothberg, B.](#); [Woodley, K. A.](#)

American Astronomical Society, AAS Meeting #211, #73.04

We present extensive new photometry in (g',i') of the large globular cluster (GC) system around NGC 3311, the central cD galaxy in the Hydra cluster. We find that NGC 3311 has an exceptionally large population of 16,000 GCs, similar to the prototypical high specific frequency Virgo giant M87. The color-magnitude distribution shows that the metal-poor blue GC sequence and the metal-richer red sequence are both present, with nearly equal numbers of clusters. Bimodal fits to the color distributions confirm that the blue sequence shows the same trend of progressively increasing metallicity with GC mass that has previously been found in many other large galaxies. By contrast, the red sequence shows no change of mean metallicity with mass, but it shows an upward extension to much higher than normal luminosity into the UCD-like range, strengthening the potential connections between massive GCs and UCDs. Within the Hydra field, another giant elliptical, NGC 3309, is sitting just 100" from the cD NGC 3311. We use our data to solve simultaneously for the spatial structure and total GC populations of both galaxies at once. Their specific frequencies are  $SN(N3311) = 12.5 \pm 1.5$  and  $SN(N3309) = 0.6 \pm 0.4$ . NGC 3311 is completely dominant and entirely comparable with other cD-type systems such as M87 in Virgo.

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### **Supernovae Precursor Stars in the Interval of 23 to 33 Solar Masses and their Circumstellar Media**

[Pérez-Rendón, B.](#); [García-Segura, G.](#); [Langer, N.](#)

From Stars to Galaxies: Building the Pieces to Build Up the Universe. ASP Conference Series, Vol. 374, proceedings of the conference held 16-20 October 2006 at Istituto Veneto di Scienze, Lettere ed Arti, Venice, Italy. Edited by Antonella Vallenari, Rosaria Tantalò, Laura Portinari, and Alessia Moretti., p.75

In this work we build a grid of evolutionary tracks of massive stars of 23, 28, 30 and 33 solar masses with solar metallicity and mass loss, from ZAMS to presupernova. Our stars finish their life like RSG, BSG or WR stars, depending of their mass loss history. The stellar mass loss also modifies the circumstellar medium (CSM) during the star life and we model the complete CSM evolution with a hydrodinamical code (ZEUS-3D) during each evolutionary stage. We observe the formation of shells and bubbles surrounding the star depending of the evolutionary track of the star and the time that spends in each stage. The supernova (SN) shock wave interacts with this modified CSM. We also realized numerical simulations of their interaction.

### **Massive Stars as Progenitors of Supernovae and GRBs**

[Langer, N.](#); [van Marle, A. J.](#); [Poelarends, A. J. T.](#); [Yoon, S. C.](#)

From Stars to Galaxies: Building the Pieces to Build Up the Universe. ASP Conference Series, Vol. 374, proceedings of the conference held 16-20 October 2006 at Istituto Veneto di Scienze, Lettere ed Arti, Venice, Italy. Edited by Antonella Vallenari, Rosaria Tantalò, Laura Portinari, and Alessia Moretti., p.61

The evolutionary fate of massive stars in our Milky Way is thought to be reasonably well understood: stars above  $\sim 8 M_{\odot}$  produce neutron stars and supernovae, while those above  $\sim 20\text{--}30 M_{\odot}$  are presumed to form black holes. At metallicities below that of the SMC, however, our knowledge becomes poor. We show that, possibly, a type of supernova dominates in the low-Z universe which hardly occurs at solar metallicity, and that stars of only  $10 M_{\odot}$  initially may form black holes rather than neutron stars.

### **Long GRBs from Binary Stars: Runaway, Wolf-Rayet Progenitors**

[Cantiello, M.](#); [Yoon, S.-C.](#); [Langer, N.](#); [Livio, M.](#)

UNSOLVED PROBLEMS IN STELLAR PHYSICS: A Conference in Honor of Douglas Gough. AIP Conference Proceedings, Volume 948, pp. 413-418 (2007)

The collapsar model for long gamma-ray bursts requires a rapidly rotating Wolf-Rayet star as progenitor. We test the idea of producing rapidly rotating Wolf-Rayet stars in massive close binaries through mass accretion and consecutive quasi-chemically homogeneous evolution - the latter had previously been shown to provide collapsars below a certain metallicity threshold for single stars. The binary channel presented here may provide a means for massive stars to obtain the high rotation rates required to evolve quasi-chemically homogeneous and fulfill the collapsar scenario. Moreover, it suggests that a possibly large fraction of long gamma-ray bursts occurs in runaway stars.

### **Thermohaline Mixing in Low-mass Giants: RGB and Beyond**

[Cantiello, M.](#); [Hoekstra, H.](#); [Langer, N.](#); [Poelarends, A. J. T.](#)

UNSOLVED PROBLEMS IN STELLAR PHYSICS: A Conference in Honor of Douglas Gough. AIP Conference Proceedings, Volume 948, pp. 73-77 (2007).

Thermohaline mixing has recently been proposed to occur in low mass red giants, with large consequence for the chemical yields of low mass stars. We investigate the role of thermohaline mixing during the evolution of stars between  $1 M_{\text{solar}}$  and  $3 M_{\text{solar}}$ , in comparison to other mixing processes acting in these stars. We use a stellar evolution code which includes rotational mixing and internal magnetic fields. We confirm that thermohaline mixing has the potential to destroy most of the  ${}^3\text{He}$  which is produced earlier on the main sequence during the red giant stage, in stars below  $1.5 M_{\text{solar}}$ . We find this process to continue during core helium burning and beyond. We find rotational and magnetic mixing to be negligible compared to the thermohaline mixing in the relevant layers, even if the interaction of thermohaline motions with the differential rotation may be essential to establish the timescale of thermohaline mixing in red giants.

### **Pair creation supernovae at low and high redshift**

[Langer, N.](#); [Norman, C. A.](#); [de Koter, A.](#); [Vink, J. S.](#); [Cantiello, M.](#); [Yoon, S.-C.](#)

Astronomy and Astrophysics, Volume 475, Issue 2, 2007, pp.L19-L23

Pair creation supernovae (PCSN) are thought to be produced from very massive low metallicity stars. The spectacularly bright SN 2006gy does show several signatures expected from PCSNe. Here, we investigate the metallicity threshold below which PCSN can form and estimate their occurrence rate. Methods: We perform stellar evolution calculations for stars of  $150 M_{\odot}$  and  $250 M_{\odot}$  of low metallicity ( $Z_{\odot}/5$  and  $Z_{\odot}/20$ ), and analyze their mass loss rates. Results: We find that the bifurcation between quasi-chemically homogeneous evolution for fast rotation and conventional evolution for slower rotation, which has been found earlier for massive low metallicity stars, persists in the mass range considered here. Consequently, there are two separate PCSN progenitor types: (I) fast rotators produce PCSNe from very massive Wolf-Rayet stars, and (II) slower rotators that generate PCSNe in hydrogen-rich massive yellow hypergiants. Conclusions: We find that hydrogen-rich PCSNe could occur at metallicities as high as  $Z_{\odot}/3$ , which - assuming standard IMFs are still valid to estimate their birth rates - results in a rate of about one PCSN per 1000 supernovae in the local universe, and one PCSN per 100 supernovae at a redshift of  $z = 5$ . PCSNe from WC-type Wolf-Rayet stars are restricted to much lower metallicity.

### **The empirical metallicity dependence of the mass-loss rate of O- and early B-type stars**

[Mokiem, M. R.](#); [de Koter, A.](#); [Vink, J. S.](#); [Puls, J.](#); [Evans, C. J.](#); [Smartt, S. J.](#);

[Crowther, P. A.](#); [Herrero, A.](#); [Langer, N.](#); [Lennon, D. J.](#); [Najarro, F.](#); [Villamariz, M. R.](#)

Astronomy and Astrophysics, Volume 473, Issue 2, October II 2007, pp.603-614

We present a comprehensive study of the observational dependence of the mass-loss rate in stationary stellar winds of hot massive stars on the metal content of their atmospheres. The metal content of stars in the Magellanic Clouds is discussed, and a critical assessment is given of state-of-the-art mass-loss determinations of OB stars in these two satellite systems and the Milky-Way. Assuming a power-law dependence of mass loss on metal content,  $\dot{M} \propto Z^m$ , and adopting a theoretical relation between the terminal flow velocity and metal content,  $v_\infty \propto Z^{0.13}$  (Leitherer et al. 1992, ApJ, 401, 596), we find  $m = 0.83 \pm 0.16$  for non-clumped outflows from an analysis of the wind momentum luminosity relation (WLR) for stars more luminous than  $10^{5.2} \{L_\odot\}$ . Within the errors, this result is in agreement with the prediction  $m = 0.69 \pm 0.10$  by Vink et al. (2001, A&A, 369, 574). Absolute empirical values for the mass loss, based on H $\alpha$  and ultraviolet (UV) wind lines, are found to be a factor of two higher than predictions in this high luminosity regime. If this difference is attributed to inhomogeneities in the wind, and this clumping does not impact the predictions, this would imply that luminous O and early-B stars have clumping factors in their H $\alpha$  and UV line forming regions of about a factor of four. For lower luminosity stars, the winds are so weak that their strengths can generally no longer be derived from optical spectral lines (essentially H $\alpha$ ) and one must currently rely on the analysis of UV lines. We confirm that in this low-luminosity domain the observed Galactic WLR is found to be much steeper than expected from theory (although the specific sample is rather small), leading to a discrepancy between UV mass-loss rates and the predictions by a factor 100 at luminosities of  $L 10^{4.75} \{L_\odot\}$ , the origin of which is unknown. We emphasize that even if the current mass-loss rates of hot luminous stars would turn out to be overestimated as a result of wind clumping, but the degree of clumping would be rather independent of metallicity, the scalings derived in this study are expected to remain correct.

Appendix A is only available in electronic form at <http://www.aanda.org>

### **Rotation in White Dwarfs: Stellar Evolution Models**

[Langer, N.](#)

15<sup>th</sup> European Workshop on White Dwarfs ASP Conference Series, Vol. 372, proceedings of the conference held 7-11 August, 2006 in Leicester, United Kingdom. Edited by Ralf Napiwotzki and Matthew R. Burleigh. San Francisco: Astronomical Society of the Pacific, 2007., p.3

We perform stellar evolution calculations for stars in the mass range  $1 \text{ to } 3 M_\odot$ , including the physics of rotation, from the zero age main sequence into the TP-AGB stage. We calculate two sets of model sequences, with and without inclusion of magnetic fields. From the final computed models, we can accurately predict the angular momenta and rotational velocities of the emerging white dwarf for each sequence. While sequences including magnetic fields predict white dwarf rotational velocities between 2 and 10 km s<sup>-1</sup>, those from the non-magnetic sequences are found to be one to two orders of magnitude larger, well above the spectroscopic upper limit derived by Berger et al. (2005). We find the situation analogous to that in the neutron star progenitor mass range,

and conclude that internal magnetic fields appear capable to reproduce the observed slow rotation of compact stellar remnants.

### **The Evolution of Circumstellar Medium around Rotating Massive Stars**

[Chita, S. M.](#); [van Marle, A. J.](#); [Langer, N.](#); [García-Segura, G.](#)

Circumstellar Media and Late Stages of Massive Stellar Evolution (Eds. G. García-Segura & E. Ramirez-Ruiz) Revista Mexicana de Astronomía y Astrofísica (Serie de Conferencias) Vol. 30, pp. 80-83 (2007) (<http://www.astroscu.unam.mx/~rmaa/>)

A rotating  $12M_{\odot}$  star, after its main-sequence evolution, becomes a redsupergiant when it starts core He burning. During core helium burning, as consequence of a variation of the hydrogen shell burning efficiency, the star undergoes a so called "blue loop", i.e. it evolves into a blue supergiant stage, where it finishes core helium burning and becomes a redsupergiant again, before exploding as a supernova. We try to explain the structures in Sher5 and in SN987A through wind asymmetry caused by rotation. We use a stellar evolution model to provide us with the time dependent stellar wind parameters such as wind velocity and mass-loss rate. These parameters serve as an input for hydrodynamical simulation of the circumstellar medium. The blue loop causes a very aspherical structure due to rotation, while the main sequence and redsupergiant phases are basically spherical. We can conclude that the asymmetry of Sher 25 can be explained through stellar rotation.

### **Models for the Circumstellar Medium of Long Gamma-Ray Burst Progenitor Candidates**

[van Marle, A. J.](#); [Langer, N.](#); [Achterberg, A.](#); [García-Segura, G.](#)

Circumstellar Media and Late Stages of Massive Stellar Evolution (Eds. G. García-Segura & E. Ramirez-Ruiz) Revista Mexicana de Astronomía y Astrofísica (Serie de Conferencias) Vol. 30, pp. 1-5 (2007) (<http://www.astroscu.unam.mx/~rmaa/>)

We present hydrodynamical models of circumstellar medium (CSM) of long gamma-ray burst (GRB) progenitor candidates. These are massive stars that have lost a large amount of mass in the form of stellar wind during their evolution. There are two possible ways to probe the CSM of long GRB progenitors. Firstly, the GRB afterglow consists of synchrotron radiation, emitted when the GRB jet sweeps up the surrounding medium. Therefore, the lightcurve is directly related to the density profile of the CSM. The density can either decrease with the radius squared (as is the case for a freely expanding stellar wind) or be constant (as we would expect for shocked wind or the interstellar medium). Secondly, material between the GRB and the observer will absorb part of the afterglow radiation, causing absorption lines in the afterglow spectrum. In some cases, such absorption lines are blue-shifted relative to the source indicating that the material is moving away from the progenitor star. This can be explained in terms of wind interactions in the CSM. We can use the CSM of these stars to investigate their prior evolutionary stage.

### **Constraints on gamma-ray burst and supernova progenitors through circumstellar absorption lines. II. Post-LBV Wolf-Rayet stars**

[van Marle, A. J.](#); [Langer, N.](#); [García-Segura, G.](#)

Wolf-Rayet stars are thought to be the progenitors of type Ib/c supernovae and of long gamma-ray bursts. Aims: As shown by van Marle et al. (2005, A&A, 444, 837, Paper I), circumstellar absorption lines in early type Ib/c supernova and gamma-ray burst afterglow spectra may reveal the progenitor evolution of the exploding Wolf-Rayet star. While the quoted paper deals with Wolf-Rayet stars which evolved through a red supergiant stage, we investigate here the initially more massive Wolf-Rayet stars which are thought to evolve through a Luminous Blue Variable (LBV) stage. Methods: We perform hydrodynamic simulations of the evolution of the circumstellar medium around a  $60 M_{\odot}$  star, from the main sequence through the LBV and Wolf-Rayet stages, up to core collapse. We then compute the column density of the circumstellar matter along rays from the central light source to an observer at infinity, as a function of radial velocity, time and angle. This allows a comparison with the number and velocities, or blue-shifts, of absorption components in the spectra of LBVs, Wolf-Rayet stars, type Ib/c supernovae and gamma-ray burst afterglows. Results: Our simulation for the post-LBV stage shows the formation of various absorption components. In particular, shells with velocities in the range of  $100 \text{ km s}^{-1}$  to  $1200 \text{ km s}^{-1}$  are formed at the beginning of the Wolf-Rayet stage, which are, however, rather short lived; they dissipate on time scales shorter than 50 000 yr. As the LBV stage is thought to occur at the beginning of core helium burning, the remaining Wolf-Rayet life time is expected to be one order of magnitude larger. Conclusions: When interpreting the absorption components in the afterglow spectrum of GRB 021004 as circumstellar, it can be concluded that the progenitor of this source did most likely not evolve through an LBV stage, as no intermediate velocity absorption components are predicted to prevail until core collapse. However, a close binary with a late common-envelope phase (Case C) may produce a circumstellar medium that closely resembles the LBV to Wolf-Rayet evolution, but with a much shorter Wolf-Rayet period. This scenario can not be ruled out.

### **Are the Models for Type Ia Supernova Progenitors Consistent with the Properties of Supernova Remnants?**

[Badenes, Carles](#); [Hughes, John P.](#); [Bravo, Eduardo](#); [Langer, Norbert](#)

The Astrophysical Journal, Volume 662, Issue 1, pp. 472-486.

We explore the relationship between the models for progenitor systems of Type Ia supernovae and the properties of the supernova remnants that evolve after the explosion. Most models for Type Ia progenitors in the single-degenerate scenario predict substantial outflows during the presupernova evolution. Expanding on previous work, we estimate the imprint of these outflows on the structure of the circumstellar medium at the time of the supernova explosion, and the effect that this modified circumstellar medium has on the evolution of the ensuing supernova remnant. We compare our simulations with the observational properties of known Type Ia supernova remnants in the Galaxy (Kepler, Tycho, SN 1006), the Large Magellanic Cloud (0509-67.5, 0519-69.0, N103B), and M31 (SN 1885). We find that optically thick outflows from the white dwarf surface (sometimes known as "accretion winds") with velocities above  $200 \text{ km s}^{-1}$  excavate large low-density cavities around the progenitors. Such large cavities are incompatible with the

dynamics of the forward shock and the X-ray emission from the shocked ejecta in all the Type Ia remnants that we have examined.

### **The VLT-FLAMES survey of massive stars: Wind properties and evolution of hot massive stars in the LMC**

[Mokiem, M. R.](#); [de Koter, A.](#); [Evans, C. J.](#); [Puls, J.](#); [Smartt, S. J.](#); [Crowther, P. A.](#); [Herrero, A.](#); [Langer, N.](#); [Lennon, D. J.](#); [Najarro, F.](#); [Villamariz, M. R.](#); [Vink, J. S.](#)

[Abridged] We have studied the optical spectra of 28 O- and early B-type stars in the Large Magellanic Cloud, 22 of which are associated with the young star-forming region N11. Stellar parameters are determined using an automated fitting method, combining the stellar atmosphere code FASTWIND with the genetic-algorithm optimisation routine PIKAIA. Results for stars in the LH9 and LH10 associations of N11 are consistent with a sequential star formation scenario, in which activity in LH9 triggered the formation of LH10. Our sample contains four stars of spectral type O2, of which the hottest is found to be  $\sim 49\text{-}54$  kK (cf.  $\sim 45\text{-}46$  kK for O3 stars). The masses of helium-enriched dwarfs and giants are systematically lower than those implied by non-rotating evolutionary tracks. We interpret this as evidence for efficient rotationally-enhanced mixing, leading to the surfacing of primary helium and to an increase of the stellar luminosity. This result is consistent with findings for SMC stars by Mokiem et al. For bright giants and supergiants no such mass-discrepancy is found, implying that these stars follow tracks of modestly (or non-)rotating objects. Stellar mass-loss properties were found to be intermediate to those found in massive stars in the Galaxy and the SMC, and comparisons with theoretical predictions at LMC metallicity yielded good agreement over the luminosity range of our targets, i.e.  $5.0 < \log L/L(\text{sun}) < 6.1$ .

### **Binary star progenitors of long gamma-ray bursts**

[Cantiello, M.](#); [Yoon, S.-C.](#); [Langer, N.](#); [Livio, M.](#)

*Astronomy and Astrophysics*, Volume 465, Issue 2, April II 2007, pp.L29-L33

The collapsar model for long gamma-ray bursts requires a rapidly rotating Wolf-Rayet star as progenitor. Aims: We test the idea of producing rapidly rotating Wolf-Rayet stars in massive close binaries through mass accretion and consecutive quasi-chemically homogeneous evolution - the latter had previously been shown to provide collapsars below a certain metallicity threshold. Methods: We use a 1D hydrodynamic binary evolution code to simulate the evolution of a  $16+15 M_{\odot}$  binary model with an initial orbital period of 5 days and SMC metallicity ( $Z=0.004$ ). Internal differential rotation, rotationally induced mixing and magnetic fields are included in both components, as well as non-conservative mass and angular momentum transfer, and tidal spin-orbit coupling. Results: The considered binary system undergoes early Case B mass transfer. The mass donor becomes a helium star and dies as a type Ib/c supernova. The mass gainer is spun-up, and internal magnetic fields efficiently transport accreted angular momentum into the stellar core. The orbital widening prevents subsequent tidal synchronization, and the mass gainer rejuvenates and evolves quasi-chemically homogeneously thereafter. The mass donor explodes 7 Myr before the collapse of the mass gainer. Assuming the binary to be broken-up by the supernova kick, the potential gamma-ray burst progenitor would

become a runaway star with a space velocity of  $27 \text{ km s}^{-1}$ , traveling about 200 pc during its remaining lifetime.

Conclusions: The binary channel presented here does not, as such, provide a new physical model for collapsar production, as the resulting stellar models are almost identical to quasi-chemically homogeneously evolving rapidly rotating single stars. However, it may provide a means for massive stars to obtain the required high rotation rates. Moreover, it suggests that a possibly large fraction of long gamma-ray bursts occurs in runaway stars.

### **The VLT-FLAMES survey of massive stars: wind properties and evolution of hot massive stars in the Large Magellanic Cloud**

[Mokiem, M. R.](#); [de Koter, A.](#); [Evans, C. J.](#); [Puls, J.](#); [Smartt, S. J.](#); [Crowther, P. A.](#); [Herrero, A.](#); [Langer, N.](#); [Lennon, D. J.](#); [Najarro, F.](#); [Villamariz, M. R.](#); [Vink, J. S.](#)  
Astronomy and Astrophysics, Volume 465, Issue 3, April III 2007, pp.1003-1019

We have studied the optical spectra of a sample of 28 O- and early B-type stars in the Large Magellanic Cloud, 22 of which are associated with the young star forming region N11. Our observations sample the central associations of LH9 and LH10, and the surrounding regions. Stellar parameters are determined using an automated fitting method (Mokiem et al. 2005), which combines the stellar atmosphere code fastwind (Puls et al. 2005) with the genetic algorithm based optimisation routine pikaia (Charbonneau 1995). We derive an age of  $7.0 \pm 1.0$  and  $3.0 \pm 1.0$  Myr for LH9 and LH10, respectively. The age difference and relative distance of the associations are consistent with a sequential star formation scenario in which stellar activity in LH9 triggered the formation of LH10. Our sample contains four stars of spectral type O2. From helium and hydrogen line fitting we find the hottest three of these stars to be  $49\text{-}54$  kK (compared to  $45\text{-}46$  kK for O3 stars). Detailed determination of the helium mass fraction reveals that the masses of helium enriched dwarfs and giants derived in our spectroscopic analysis are systematically lower than those implied by non-rotating evolutionary tracks. We interpret this as evidence for efficient rotationally enhanced mixing leading to the surfacing of primary helium and to an increase of the stellar luminosity. This result is consistent with findings for SMC stars by Mokiem et al. (2006). For bright giants and supergiants no such mass discrepancy is found; these stars therefore appear to follow tracks of modestly or non-rotating objects. The set of programme stars was sufficiently large to establish the mass loss rates of OB stars in this  $Z \sim 1/2 Z_{\odot}$  environment sufficiently accurate to allow for a quantitative comparison with similar objects in the Galaxy and the SMC. The mass loss properties are found to be intermediate to massive stars in the Galaxy and SMC. Comparing the derived modified wind momenta  $D_{\text{mom}}$  as a function of luminosity with predictions for LMC metallicities by Vink et al. (2001) yields good agreement in the entire luminosity range that was investigated, i.e.  $5.0 < \log L/L_{\odot} < 6.1$ .

Appendix A is only available in electronic form at <http://www.aanda.org>

### **Tides in asynchronous binary systems**

[Toledano, O.](#); [Moreno, E.](#); [Koenigsberger, G.](#); [Detmers, R.](#); [Langer, N.](#)  
Astronomy and Astrophysics, Volume 461, Issue 3, January III 2007, pp.1057-1063

Stellar oscillations are excited in non-synchronously rotating stars in binary systems due to the tidal forces. Tangential components of the tides can drive a shear flow which behaves as a differentially forced rotating structure in a stratified outer medium. Aims: The aims of this paper are to show that our single-layer approximation for the calculation of the forced oscillations yields results that are consistent with the predictions for the synchronization timescales in circular orbits,  $\tau_{\text{sync}} \propto a^6$ , thus providing a simplified means of computing the energy dissipation rates,  $\dot{E}$ . Furthermore, by calibrating our model results to fit the relationship between synchronization timescales and orbital separation, we are able to constrain the value of the kinematical viscosity parameter,  $\nu$ . Methods: We compute the values of  $\dot{E}$  for a set of  $5 M_{\odot} + 4 M_{\odot}$  model binary systems with different orbital separations,  $a$ , and use these to estimate the synchronization timescales. Results: The resulting  $\tau_{\text{sync}}$  vs.  $a$  relation is comparable to that of Zahn (1977, A&A, 57, 383) for convective envelopes, providing a calibration method for the values of  $\nu$ . For the  $4+5 M_{\odot}$  binary modeled in this paper,  $\nu$  is in the range  $0.0015\text{--}0.0043 R_{\odot}^2/\text{day}$  for orbital periods in the range 2.5–25 d. In addition,  $\dot{E}$  is found to decrease by 2 orders of magnitude as synchronization is approached, implying that binary systems may approach synchronization relatively quickly but that it takes a much longer timescale to actually attain this condition. Conclusions: The relevance of these results is threefold: 1) our model allows an estimate for the numerical value of  $\nu$  under arbitrary conditions in the binary system; 2) it can be used to calculate the energy dissipation rates throughout the orbital cycle for any value of eccentricity and stellar rotational velocity; and 3) it provides values of the tangential component of the velocity perturbation at any time throughout the orbit and predicts the location on the stellar surface where the largest shear instabilities may be occurring. We suggest that one of the possible implications of the asymmetric distribution of  $\dot{E}$  over the stellar surface is the generation of localized regions of enhanced surface activity.

### **Progenitor Models of Wolf-Rayet+O Binary Systems**

[Petrovic, J.](#); [Langer, N.](#)

Massive Stars in Interactive Binaries, ASP Conference Series 367. Edited by Nicole St.-Louis and Anthony F.J. Moffat. San Francisco: Astronomical Society of the Pacific, 2007., p.371

Since close WR+O binaries are the result of a strong interaction of both stars in massive close binary systems, they can be used to constrain the highly uncertain mass and angular momentum budget during the major mass-transfer phase. We explore the progenitor evolution of the three best suited WR+O binaries HD186943, HD90657 and HD211853, which are characterized by a WR/O mass ratio of  $\sim 0.5$  and periods of 6–10 days. We are doing this through simple mass loss and angular momentum loss estimates and through binary-evolution models including rotation of both components and a physical model which allows one to compute mass and angular momentum loss from the binary system as a function of time during the mass-transfer process. Our results show that the mass transfer in all three systems must have been highly non-conservative, with on average only  $\sim 10\%$  of the transferred mass being retained by the mass-receiving star. This result gives support to our system mass and angular-momentum loss model, which predicts that,

in the considered systems, about 90% of the overflowing matter is expelled by the rapid rotation of the mass receiver close to the  $\Omega$ -limit, which is reached through the accretion of the remaining 10%.

### **Advanced Binary Evolution**

[Langer, N.](#); [Petrovic, J.](#)

Massive Stars in Interactive Binaries, ASP Conference Series 367. Edited by Nicole St.-Louis and Anthony F.J. Moffat. San Francisco: Astronomical Society of the Pacific, 2007., p.359

We discuss recent progress in the modeling and understanding of the mass-transfer process in massive close binary systems and its consequences for their advanced evolution. We then highlight the spin evolution of both binary components and its dependence on accretion, mass loss and internal angular-momentum transport processes. In particular, we consider the influence of an internal magnetic field, which appears to be required on observational and theoretical grounds. We find that while magnetic fields lead to an agreement of predicted with observed rotation frequencies of white dwarfs and neutron stars, accretion does not always lead to rapidly spinning cores - as they are required within the collapsar model for gamma-ray bursts.

### **Commission 35: Stellar Constitution**

[Dziembowski, Wojciech A.](#); [D'Antona, Francesca](#); [Charbonnel, C.](#); [Christensen-Dalsgaard, J.](#); [Guzik, J.](#); [Langer, N.](#); [Larson, R.](#); [Liebert, J.](#); [Meynet, G.](#); [Müller, E.](#); [Saio, H.](#); [Vandenberg, D.](#)

IAU Transactions, Vol. 26A, Reports on Astronomy 2002-2005. Edited by O. Engvold. Cambridge: Cambridge University Press, 2007., pp.205-213

The triennial report from Commission 35 covers its organizational activities and highlights accomplishments in various topics of stellar interior physics.

### **Critically-rotating Stars in Binaries-An Unsolved Problem**

[de Mink, S. E.](#); [Pols, O. R.](#); [Glebbeek, E.](#)

UNSOLVED PROBLEMS IN STELLAR PHYSICS: A Conference in Honor of Douglas Gough. AIP Conference Proceedings, Volume 948, pp. 321-325 (2007).

In close binaries mass and angular momentum can be transferred from one star to the other during Roche-lobe overflow. The efficiency of this process is not well understood and constitutes one of the largest uncertainties in binary evolution.

One of the problems lies in the transfer of angular momentum, which will spin up the accreting star. In very tight systems tidal friction can prevent reaching critical rotation, by locking the spin period to the orbital period. Accreting stars in systems with orbital periods larger than a few days reach critical rotation after accreting only a fraction of their mass, unless there is an effective mechanism to get rid of angular momentum. In low-mass stars magnetic field might help. In more-massive stars angular-momentum loss

will be accompanied by strong mass loss. This would imply that most interacting binaries with initial orbital periods larger than a few days evolve very non-conservatively.

In this contribution we wish to draw attention to the unsolved problems related to mass and angular-momentum transfer in binary systems. We do this by presenting the first results of an implementation of spin up by accretion into the TWIN version of the Eggleton stellar-evolution code.

### **Carbon-enhanced Metal-poor Stars and Thermohaline Mixing**

[Stancliffe, Richard J.](#); [Glebbeek, Evert](#); [Izzard, Robert G.](#); [Pols, Onno R.](#)

UNSOLVED PROBLEMS IN STELLAR PHYSICS: A Conference in Honor of Douglas Gough. AIP Conference Proceedings, Volume 948, pp. 79-83 (2007).

One possible scenario for the formation of carbon-enhanced metal-poor stars is the accretion of carbon-rich material from a binary companion which may no longer be visible. It is generally assumed that the accreted material remains on the surface of the star and does not mix with the interior until first dredge-up. However, thermohaline mixing should mix the accreted material with the original stellar material as it has a higher mean molecular weight. We investigate the effect that this has on the surface abundances by modelling a binary system of metallicity  $Z = 10^{-4}$  with a  $2 M_{\text{solar}}$  primary star and a  $0.74 M_{\text{solar}}$  secondary star in an initial orbit of 4000 days. The accretion of material from the wind of the primary leads to the formation of a carbon-rich secondary. We find that the accreted material mixes fairly rapidly throughout 90% of the star, with important consequences for the surface composition. Models with thermohaline mixing predict very different surface abundances after first dredge-up compared to canonical models of stellar evolution.

### **When Stars Collide**

[Glebbeek, E.](#); [Pols, O. R.](#)

UNSOLVED PROBLEMS IN STELLAR PHYSICS: A Conference in Honor of Douglas Gough. AIP Conference Proceedings, Volume 948, pp. 57-64 (2007).

When two stars collide and merge they form a new star that can stand out against the background population in a star cluster as a blue straggler. In so called collision runaways many stars can merge and may form a very massive star that eventually forms an intermediate mass blackhole. We have performed detailed evolution calculations of merger remnants from collisions between main sequence stars, both for lower mass stars and higher mass stars. These stars can be significantly brighter than ordinary stars of the same mass due to their increased helium abundance. Simplified treatments ignoring this effect give incorrect predictions for the collision product lifetime and evolution in the Hertzsprung-Russell diagram.

### **Testing Models Of Interacting Binaries Against Observations**

[de Mink, S. E.](#); [Pols, O. R.](#)

Binary Stars as Critical Tools and Tests in Contemporary Astrophysics, International Astronomical Union. Symposium no. 240, held 22-25 August, 2006 in Prague, Czech Republic, S240, p. 384

One of the big uncertainties in evolution of binary stars is the efficiency of mass transfer. Can it be described as a conservative process or is a significant amount of mass and angular momentum lost? As the uncertainties in hydrodynamical simulations are still very large, currently the best way to address the problem is to compare observations with stellar evolution models. Recently Hilditch et al (2005) presented the fundamental parameters of 50 double lined eclipsing binaries in the Small Magellanic Cloud (SMC) with orbital periods between 1 and 5 days. 28 systems are currently transferring mass. This sample is the largest and the most unbiased sample of OB binaries available in any galaxy and therefore suitable to test stellar evolution models of interacting binaries. No applicable models are currently available for the metallicity of the SMC. Therefore we present a large grid of conservative and non-conservative binary evolution tracks computed with using the fast detailed stellar evolution code STARS (based on Eggleton, 1971). We compare observations and models by fitting evolution tracks to each individual system and by comparing the whole sample at once to a synthetic population. In the near future we plan to present detailed binary evolution models for a larger range of metallicities and orbital periods.

#### **Inflation of luminous metal-rich WR stars a clue to mass loss?**

[Pols, Onno R.](#)

Highlights of Astronomy, Volume 14, p. 200-200

We investigate the influence of metallicity and wind mass loss on the radii of luminous Wolf-Rayet stars.

#### **The Ps - e relation of double neutron stars**

[Dewi, J. D. M.](#); [Podsiadlowski, Ph.](#); [Pols, O. R.](#)

THE MULTICOLORED LANDSCAPE OF COMPACT OBJECTS AND THEIR EXPLOSIVE ORIGINS. AIP Conference Proceedings, Volume 924, pp. 656-660 (2007).

The seven Galactic double neutron stars (DNS)s exhibit a relation between the pulsar spin period and the orbital eccentricity. We show that this relation can only be produced if the second neutron star received a kick that is substantially smaller (with a velocity dispersion of less than 50 km s<sup>-1</sup>) than the standard kick received by a single radio pulsar. This demonstrates that the kick mechanism depends on the evolutionary history of the NS progenitor and that the orbital parameters of DNSs are completely determined by the evolution in the preceding helium star - neutron star phase.

#### **The s-process in stellar population synthesis: a new approach to understanding AGB stars**

[Bonačić Marinović, A.](#); [Izzard, R. G.](#); [Lugaro, M.](#); [Pols, O. R.](#)

Astronomy and Astrophysics, Volume 469, Issue 3, July III 2007, pp.1013-1025

Thermally pulsating asymptotic giant branch (AGB) stars are the main producers of slow neutron capture (s-) process elements, but there are still large uncertainties associated with the formation of the main neutron source,  $^{13}\text{C}$ , and with the physics of these stars in general. Observations of s-process element enhancements in stars can be used as constraints on theoretical models. Aims: For the first time we have applied stellar population synthesis to the problem of s-process nucleosynthesis in AGB stars, in order to derive constraints on free parameters describing the physics behind the third dredge-up and the properties of the neutron source. Methods: We utilize a rapid evolution and nucleosynthesis code to synthesize different populations of s-enhanced stars, and compare them to their observational counterparts to find out which values of the free parameters in the code produce synthetic populations that fit the observed populations best. These free parameters are the amount of third dredge-up, the minimum core mass for third dredge-up, the effectiveness of  $^{13}\text{C}$  as a source of neutrons, and the size in mass of the  $^{13}\text{C}$  pocket. Results: We find that galactic disk objects are reproduced by a spread of a factor of two in the effectiveness of the  $^{13}\text{C}$  neutron source. Lower metallicity objects can be reproduced only by lowering the average value of the effectiveness of the  $^{13}\text{C}$  neutron source needed for the galactic disk objects by at least a factor of 3. Using observations of s-process elements in post-AGB stars as constraints we find that dredge-up has to start at a lower core mass than predicted by current theoretical models, that it has to be substantial ( $\lambda \approx 0.2$ ) in stars with mass  $M \approx 1.5 M_{\odot}$ , and that the mass of the  $^{13}\text{C}$  pocket must be about 1/40 that of the intershell region.

### **Efficiency of mass transfer in massive close binaries. Tests from double-lined eclipsing binaries in the SMC**

[de Mink, S. E.](#); [Pols, O. R.](#); [Hilditch, R. W.](#)

*Astronomy and Astrophysics*, Volume 467, Issue 3, June I 2007, pp.1181-1196

Aims. One of the major uncertainties in close binary evolution is the efficiency of mass transfer  $\beta$ : the fraction of transferred mass that is accreted by a secondary star. We attempt to constrain the mass-transfer efficiency for short-period massive binaries undergoing case A mass transfer. Methods: We present a grid of about 20 000 detailed binary evolution tracks with primary masses  $3.5\text{--}35 M_{\odot}$ , orbital periods 1-5 days at a metallicity  $Z = 0.004$ , assuming both conservative and non-conservative mass transfer. We perform a systematic comparison, using least-squares fitting, of the computed models with a sample of 50 double-lined eclipsing binaries in the Small Magellanic Cloud, for which fundamental stellar parameters have been determined. About 60% of the systems are currently undergoing slow mass transfer. Results: In general we find good agreement between our models and the observed detached systems. However, for many of the semi-detached systems the observed temperature ratio is more extreme than our models predict. For the 17 semi-detached systems that we are able to match, we find a large spread in the best fitting mass-transfer efficiency; no single value of  $\beta$  can explain all systems. We find a hint that initially wider systems tend to fit better to less conservative models. We show the need for more accurate temperature determinations and we find that

determinations of surface abundances of nitrogen and carbon can potentially constrain the mass-transfer efficiency further.

Figure 10 is only available in electronic form at <http://www.aanda.org>

### **Carbon-enhanced metal-poor stars and thermohaline mixing**

[Stancliffe, R. J.](#); [Glebbeek, E.](#); [Izzard, R. G.](#); [Pols, O. R.](#)

*Astronomy and Astrophysics*, Volume 464, Issue 3, March IV 2007, pp.L57-L60

One possible scenario for the formation of carbon-enhanced metal-poor stars is the accretion of carbon-rich material from a binary companion which may no longer be visible. It is generally assumed that the accreted material remains on the surface of the star and does not mix with the interior until first dredge-up. However, thermohaline mixing should mix the accreted material with the original stellar material as it has a higher mean molecular weight. We investigate the effect that this has on the surface abundances by modelling a binary system of metallicity  $Z=10^{-4}$  with a  $2 M_{\odot}$  primary star and a  $0.74 M_{\odot}$  secondary star in an initial orbit of 4000 days. The accretion of material from the wind of the primary leads to the formation of a carbon-rich secondary. We find that the accreted material mixes fairly rapidly throughout 90% of the star, with important consequences for the surface composition. Models with thermohaline mixing predict very different surface abundances after first dredge-up compared to canonical models of stellar evolution.

### **Mass and Angular Momentum Loss in Massive Binary Evolution**

[Pols, O. R.](#)

*Massive Stars in Interactive Binaries*, ASP Conference Series 367. Edited by Nicole St.-Louis and Anthony F.J. Moffat. San Francisco: Astronomical Society of the Pacific, 2007., p.387

I discuss uncertainties in the amount of mass loss and angular momentum loss during mass transfer in massive close binaries, concentrating on the first phase of mass transfer. On the basis of the reaction of the accreting star, one expects the fraction of mass lost from the binary to be a function of the orbital parameters, i.e. mass ratio and orbital period. Although spin-up of the accretor is expected to play a crucial role in limiting the amount of accretion, some binaries (e.g.  $\phi$  Per) manage to have evolved in an almost conservative manner. On the other hand, common-envelope evolution is usually expected to lead to substantial mass loss, and very substantial angular momentum loss from a binary. Nevertheless there are systems that have apparently evolved through such a phase without losing much angular momentum, resulting in fairly wide current orbits.

### **Galactic Sodium from AGB Stars**

[Izzard, R. G.](#); [Gibson, B. K.](#); [Stancliffe, R. J.](#)

*Why Galaxies Care About AGB Stars: Their Importance as Actors and Probes*. ASP Conference Series, Vol. 378, proceedings of the conference held 7-11 August 2006 at

University Campus, Vienna, Austria. Edited by F. Kerschbaum, C. Charbonnel, and R. F. Wing. San Francisco: Astronomical Society of the Pacific, 2007., p.121

Galactic chemical evolution (GCE) models which include sodium from type II supernovae (SNe) alone underestimate the abundance of sodium in the interstellar medium by a factor of 2 to 3 over about 3 dex in metallicity and predict a flat behavior in the evolution of  $\text{r(Na/Fe)}$  at super-solar metallicities. Conversely, recent observations of stars with  $\text{r(Na/Fe)} \sim +0.4$  suggest that  $\text{r(Na/Fe)}$  increases at high metallicity. We have combined stellar evolution models of asymptotic giant branch (AGB) and Wolf-Rayet (WR) stars with the latest SN yields in an attempt to resolve these problems and have created many more.

### **The Century-old R-Star Mystery**

[Izzard, Robert G.](#); [Jeffery, C. Simon](#); [Lattanzio, John](#)

UNSOLVED PROBLEMS IN STELLAR PHYSICS: A Conference in Honor of Douglas Gough. AIP Conference Proceedings, Volume 948, pp. 51-55 (2007).

The R stars are carbon-rich K-type giants. For more than a century their origin has remained a mystery. The warmest of them, the early-R stars, have luminosities similar to core helium burning stars yet canonical stellar evolution theory suggests they should not be carbon rich. The early-R stars are chemically peculiar, being enhanced in  $^{12}\text{C}$ ,  $^{13}\text{C}$  and  $^{14}\text{N}$  but not in s-process elements, and are all single stars. Binary mergers have been suggested as the evolutionary channel which leads to the early-R stars: we test this scenario with a state-of-the-art binary population synthesis.

### **Window To The Stars**

Izzard, R.G; [Glebbeek, E.](#)

Binary Stars as Critical Tools and Tests in Contemporary Astrophysics, International Astronomical Union. Symposium no. 240, held 22-25 August, 2006 in Prague, Czech Republic, S240, p. 213

We present a graphical user interface to the popular TWIN stellar evolution code. It removes the drudgery associated with the traditional approach to running the code, while maintaining the power, output quality and flexibility a modern stellar evolutionist requires.

### **Origin of the early-type R stars: a binary-merger solution to a century-old problem?**

[Izzard, R. G.](#); [Jeffery, C. S.](#); [Lattanzio, J.](#)

Astronomy and Astrophysics, Volume 470, Issue 2, August I 2007, pp.661-673

The early-R stars are carbon-rich K-type giants. They are enhanced in  $^{12}\text{C}$ ,  $^{13}\text{C}$  and  $^{14}\text{N}$ , have approximately solar oxygen, magnesium isotopes, s-process and iron abundances, have the luminosity of core-helium burning stars, are not rapid rotators, are members of the Galactic thick disk and, most peculiarly of all, are all single stars. Conventional single-star evolutionary models cannot explain such stars, but mergers in binary systems have been proposed to explain their origin. We have synthesized binary star populations

to calculate the number of merged stars with helium cores which could be early-R stars. We find many possible evolutionary channels. The most common of which is the merger of a helium white dwarf with a hydrogen-burning red giant branch star during a common envelope phase followed by a helium flash in a rotating core which mixes carbon to the surface. All the channels together give ten times more early-R stars than we require to match recent Hipparcos observations - we discuss which channels are likely to be the true early-R stars and which are not. For the first time we have constructed a viable model of the early-R stars with which we can test some of our ideas regarding common envelope evolution in giants, stellar mergers, rotation, the helium flash and the origin of the early-R stars.

### **Reaction rate uncertainties and the operation of the NeNa and MgAl chains during HBB in intermediate-mass AGB stars**

[Izzard, R. G.](#); [Lugaro, M.](#); [Karakas, A. I.](#); [Iliadis, C.](#); [van Raai, M.](#)

Astronomy and Astrophysics, Volume 466, Issue 2, May I 2007, pp.641-648

Context: We test the effect of proton-capture reaction rate uncertainties on the abundances of the Ne, Na, Mg and Al isotopes processed by the NeNa and MgAl chains during hot bottom burning (HBB) in asymptotic giant branch (AGB) stars of intermediate mass between 4 and 6  $M_{\odot}$  and metallicities between  $Z = 0.0001$  and 0.02. Aims: We provide uncertainty ranges for the AGB stellar yields, for inclusion in galactic chemical evolution models, and indicate which reaction rates are most important and should be better determined. Methods: We use a fast synthetic algorithm based on detailed AGB models. We run a large number of stellar models, varying one reaction per time for a very fine grid of values, as well as all reactions simultaneously. Results: We show that there are uncertainties in the yields of all the Ne, Na, Mg and Al isotopes due to uncertain proton-capture reaction rates. The most uncertain yields are those of  $^{26}\text{Al}$  and  $^{23}\text{Na}$  (variations of two orders of magnitude),  $^{24}\text{Mg}$  and  $^{27}\text{Al}$  (variations of more than one order of magnitude),  $^{20}\text{Ne}$  and  $^{22}\text{Ne}$  (variations between factors 2 and 7). In order to obtain more reliable Ne, Na, Mg and Al yields from IM-AGB stars the rates that require more accurate determination are:  $^{22}\text{Ne}(p,\gamma)^{23}\text{Na}$ ,  $^{23}\text{Na}(p,\gamma)^{24}\text{Mg}$ ,  $^{25}\text{Mg}(p,\gamma)^{26}\text{Al}$ ,  $^{26}\text{Mg}(p,\gamma)^{27}\text{Al}$  and  $^{26}\text{Al}(p,\gamma)^{27}\text{Si}$ . Conclusions: Detailed galactic chemical evolution models should be constructed to address the impact of our uncertainty ranges on the observational constraints related to HBB nucleosynthesis, such as globular cluster chemical anomalies.

Table 13 is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via <http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/466/641>

### **Reaction rates of NeNa-MgAl chains in AGB stage (Izzard+, 2007)**

[Izzard, R. G.](#); [Lugaro, M.](#); [Karakas, A. I.](#); [Iliadis, C.](#); [van Raai, M.](#)

VizieR On-line Data Catalog: J/A+A/466/641. Originally published in: 2007A&A...466..641I

We use a fast synthetic algorithm based on detailed AGB models. We run a large number of stellar models, varying one reaction per time for a very fine grid of values, as well as all reactions simultaneously.

### **Light s-Process Element Production in Solar Metallicity AGB Stars**

[Karakas, A. I.](#); [Lugaro, M.](#); [Gallino, R.](#)

Why Galaxies Care About AGB Stars: Their Importance as Actors and Probes. ASP Conference Series, Vol. 378, proceedings of the conference held 7-11 August 2006 at University Campus, Vienna, Austria. Edited by F. Kerschbaum, C. Charbonnel, and R. F. Wing. San Francisco: Astronomical Society of the Pacific, 2007., p.37

Spectral lines of highly ionized neutron-capture elements have recently been detected in planetary nebulae (PNe), with derived abundances ranging from solar to factors of 3 to ~ 30 above solar. These observations indicate that the slow neutron-capture process (s process) operated in the parent star during the thermally-pulsing asymptotic giant branch (TP-AGB) phase. We compute a number of solar metallicity AGB models to compare with these observations. Within the uncertainties allowed by the observations, the models produce a reasonable match to the composition of most PNe. Model uncertainties (e.g. convection, mass loss) affect the results and could account for the composition of the most s-process-enriched objects. The occurrence of third dredge-up episodes at the tip of the AGB, when the envelope mass is small, or a late thermal pulse on the post-AGB track, could provide further enrichment. Further study is required to better assess how the model uncertainties affect the predictions and, consequently, whether a late TP should be invoked.

### **NanoSIMS isotopic analysis of small presolar grains: Search for Si<sub>3</sub>N<sub>4</sub> grains from AGB stars and Al and Ti isotopic compositions of rare presolar SiC grains**

[Zinner, Ernst](#); [Amari, Sachiko](#); [Guinness, Robert](#); [Jennings, Cristine](#); [Mertz, Aaron F.](#); [Nguyen, Ann N.](#); [Gallino, Roberto](#); [Hoppe, Peter](#); [Lugaro, Maria](#); [Nittler, Larry R.](#); [Lewis, Roy S.](#)

Geochimica et Cosmochimica Acta, Volume 71, Issue 19, p. 4786-4813. ([GeCoA Homepage](#))

### **Stellar population synthesis of post-AGB stars: the s-process in MACHO 47.2496.8**

[Bonačić Marinović, A.](#); [Lugaro, M.](#); [Reyniers, M.](#); [van Winckel, H.](#)

Astronomy and Astrophysics, Volume 472, Issue 1, September II 2007, pp.L1-L4

Context: The low-metallicity RV Tauri star MACHO 47.2496.8, recently discovered in the Large Magellanic Cloud, is highly enriched in carbon and heavy elements produced by the slow neutron capture process (s-process), and is most probably a genuine post-C(N-type) asymptotic giant branch (AGB) star. The intrinsic interpretation of the enrichment is further strengthened by detection of a significant infrared excess. The circumstellar dust is the relic of a recent episode of heavy mass loss. We use the analysis of the abundances of MACHO 47.2496.8 to constrain free parameters in AGB models. Aims: We test which values of the free parameters describing uncertain physical

mechanisms in AGB stars, namely the third dredge-up and the features of the  $^{13}\text{C}$  neutron source, produce models that better match the abundances observed in MACHO 47.2496.8. Methods: We carry out stellar population synthesis coupled with s-process nucleosynthesis using a synthetic stellar evolution code. Results: The s-process ratios observed in MACHO 47.2496.8 can be matched by the same models that explain the s-process ratios of Galactic AGB and post-AGB stars of metallicity  $>Z_{\odot}/10$ , except for the choice of the effectiveness of  $^{13}\text{C}$  as a neutron source, which has to be lower by roughly a factor of 3 to 6. The less effective neutron source for lower metallicities is also required when comparing population synthesis results to observations of Galactic halo s-enhanced stars, such as Pb stars. The  $^{12}\text{C}/^{13}\text{C}$  ratio in MACHO 47.2496.8 cannot be matched simultaneously and requires the occurrence of extra-mixing processes. Conclusions: The confirmed trend of the decreased efficiency of the  $^{13}\text{C}$  neutron source with metallicity requires an explanation from AGB s-process models. The present work is to date the first comparison between theoretical models and the detailed abundances of an extragalactic post-AGB star.

### **What can pre-solar grains tell us about AGB stars?**

[Lugaro, Maria A.](#); [Höfner, Susanne](#)

Highlights of Astronomy, Volume 14, p. 345-348

The vast majority of pre-solar grains recovered to date show the signature of an origin in asymptotic giant branch (AGB) stars. In AGB stars, the abundances of elements lighter than silicon and heavier than iron are largely affected by proton- and neutron-capture processes, respectively, while the compositions of the elements in between also carry the signature of the initial composition of the star. Dust is produced and observed around AGB stars and the strong mass loss experienced by these stars is believed to be driven by radiation pressure on dust grains. We briefly review the main developments that have occurred in the past few years in the study of AGB stars in relation to dust and pre-solar grains. From the nucleosynthesis point of view these include: more stringent constraints on the main neutron source nucleus,  $^{13}\text{C}$ , for the slow neutron capture process (the s process); the possibility of pre-solar grains coming from massive AGB stars; and the unique opportunity to infer the ‘isotopic’ evolution of the Galaxy by combining pre-solar grain data and AGB model predictions. Concerning the formation of grains in AGB stars, considerable progress has been achieved in modelling. In particular, self-consistent models for atmospheres and winds of C-stars have reached a level of sophistication which allows direct quantitative comparison with observations. In the case of stars with  $\text{C}/\text{O} < 1$ , however, recent work points to serious problems with the dust-driven wind scenario. A current trend in atmosphere and wind modelling is to investigate the possible effects of inhomogeneities (e.g., due to giant convection cells) with 2D/3D models.

### **Germanium Production in Asymptotic Giant Branch Stars: Implications for Observations of Planetary Nebulae**

[Karakas, Amanda I.](#); [Lugaro, Maria](#); [Gallino, Roberto](#)

The Astrophysical Journal, Volume 656, Issue 2, pp. L73-L76.

Observations of planetary nebulae (PNe) in the work of Sterling, Dinerstein, & Bowers have revealed abundances in the neutron-capture element germanium (Ge) from solar to factors of 3-10 above solar. The enhanced Ge is an indication that the slow neutron-capture process (the s-process) operated in the parent star during the thermally pulsing asymptotic giant branch (TP-AGB) phase. We compute the detailed nucleosynthesis of a series of AGB models to estimate the surface enrichment of Ge near the end of the AGB. A partial mixing zone of constant mass is included at the deepest extent of each dredge-up episode, resulting in the formation of a  $^{13}\text{C}$  pocket in the top approximately one-tenth of the He-rich intershell. All of the models show surface increases of  $[\text{Ge}/\text{Fe}] < \sim 0.5$ , except the  $2.5 M_{\text{solar}}$ ,  $Z=0.004$  case, which produced a factor of 6 enhancement of Ge. Near the tip of the TP-AGB, a couple of extra thermal pulses (TPs) could occur to account for the composition of the most Ge-enriched PNe. Uncertainties in the theoretical modeling of AGB stellar evolution might account for larger Ge enhancements than we predict here. Alternatively, a possible solution could be provided by the occurrence of a late TP during the post-AGB phase. Difficulties related to spectroscopic abundance estimates also need to be taken into consideration. Further study is required to better assess how the model uncertainties affect the predictions and, consequently, if a late TP should be invoked.

### **On the asymptotic giant branch star origin of peculiar spinel grain OC2**

[Lugaro, M.](#); [Karakas, A. I.](#); [Nittler, L. R.](#); [Alexander, C. M. O'd.](#); [Hoppe, P.](#); [Iliadis, C.](#); [Lattanzio, J. C.](#)

Astronomy and Astrophysics, Volume 461, Issue 2, January II 2007, pp.657-664

Context: Microscopic presolar grains extracted from primitive meteorites have extremely anomalous isotopic compositions revealing the stellar origin of these grains. Multiple elements in single presolar grains can be analysed with sensitive mass spectrometers, providing precise sets of isotopic compositions to be matched by theoretical models of stellar evolution and nucleosynthesis. Aims: The composition of presolar spinel grain OC2 is different from that of all other presolar spinel grains. In particular, large excesses of the heavy Mg isotopes are present and thus an origin from an intermediate-mass (IM) asymptotic giant branch (AGB) star was previously proposed for this grain. We discuss the O, Mg, Al, Cr and Fe isotopic compositions of presolar spinel grain OC2 and compare them to theoretical predictions. Methods: We use detailed models of the evolution and nucleosynthesis of AGB stars of different masses and metallicities to compare to the composition of grain OC2. We analyse the uncertainties related to nuclear reaction rates and also discuss stellar model uncertainties. Results: We show that the isotopic composition of O, Mg and Al in OC2 could be the signature of an AGB star of IM and metallicity close to solar experiencing hot bottom burning, or of an AGB star of low mass (LM) and low metallicity ( $\approx 0.004$ ) suffering very efficient cool bottom processing. Large measurement uncertainty in the Fe isotopic composition prevents us from discriminating which model better represents the parent star of OC2. However, the Cr isotopic composition of the grain favors an origin in an IM-AGB star of metallicity close to solar. Conclusions: Our IM-AGB models produce a self-consistent solution to match the composition of OC2 within the uncertainties related to reaction rates. Within this solution we predict that the  $^{16}\text{O}(p,\gamma)^{17}\text{F}$  and the  $^{17}\text{O}(p,\alpha)^{14}\text{N}$  reaction rates should be

close to their lower and upper limits, respectively. By finding more grains like OC2 and by precisely measuring their Fe and Cr isotopic compositions, it may be possible in the future to derive constraints on massive AGB models from the study of presolar grains.

### **Observational evidence for origin of stellar exotica in globular clusters**

[Verbunt, Franciscus W. M.](#)

Highlights of Astronomy, Volume 14, p. 440-441

The formation of special binaries in a globular cluster is regulated by the total encounter rate  $\gamma$  in the cluster, but their life expectancy by the number of encounters  $\gamma$  that one system experiences. The orbital periods indicate whether a neutron star or white dwarf entered a binary via direct collision, via tidal capture, or via exchange encounter. The numbers of X-ray binaries with a neutron star scales with  $\gamma$ . Magnetically active binaries (including blue stragglers) are formed via evolution of primordial binaries, and their numbers scale with the cluster mass. Cataclysmic variables are formed by stellar encounters or via evolution of a primordial binary in clusters with high and low central density, respectively.

### **A longer XMM-Newton look at I Zwicky1: physical conditions and variability of the ionized absorbers**

[Costantini, E.](#); [Gallo, L. C.](#); [Brandt, W. N.](#); [Fabian, A. C.](#); [Boller, Th.](#)

Monthly Notices of the Royal Astronomical Society, Volume 378, Issue 3, pp. 873-880.

We present a spectral analysis of the narrow-line Seyfert 1 galaxy I Zwicky1, focusing on the characteristics of the ionized absorbers as observed with XMM-Newton in 2005. The soft X-ray spectrum shows absorption by two components of ionized gas with a similar column density ( $N_{\text{H}} \sim 10^{21} \text{ cm}^{-2}$ ) and ionization parameters  $\log \xi \sim 0$  and 2.5. Comparing this observation with a 2002 XMM-Newton data set, we see a clear anticorrelation between the X-ray ionization parameter  $\xi_{\text{X}}$  and the 0.1-10keV luminosity. Viable explanations for this effect include transient clouds or filaments crossing the line of sight in a complex geometry or a gas observed in non-equilibrium. The outflow velocity of the X-ray low-ionization absorber is consistent with the outflow of the ultraviolet (UV) absorber detected in a past Hubble Space Telescope observation. In addition, the ionic column densities of CIV and NV derived from the X-ray model are consistent with the UV values. This suggests that the low-ionization outflowing gas may survive for many years, despite large changes in flux, and that there is a tight connection between the X-ray and UV absorbers that can only be confirmed with a simultaneous UV and X-ray observation.

### **A longer XMM-Newton look at I Zwicky - 1. Distinct modes of X-ray spectral variability**

[Gallo, L. C.](#); [Brandt, W. N.](#); [Costantini, E.](#); [Fabian, A. C.](#)

Monthly Notices of the Royal Astronomical Society, Volume 377, Issue 3, pp. 1375-1382.

The short-term spectral variability of the narrow-line Seyfert 1 galaxy I Zwicky 1 (I Zw 1) as observed in an 85ks XMM-Newton observation is discussed in detail. I Zw 1 shows distinct modes of variability prior to and after a flux dip in the broad-band light curve. Before the dip the variability can be described as arising from changes in shape and normalization of the spectral components. Only changes in normalization are manifested after the dip. The change in the mode of behaviour occurs on dynamically short time-scales in I Zw 1. The data suggest that the accretion-disc corona in I Zw 1 could have two components that are co-existing. The first, a uniform, physically diffuse plasma responsible for the 'typical' long-term (e.g. years) behaviour; and a second compact, centrally located component causing the rapid flux and spectral changes. This compact component could be the base of a short or aborted jet as sometimes proposed for radio-quiet active galaxies. Modelling of the average and time-resolved rms spectra demonstrate that a blurred Compton-reflection model can describe the spectral variability if we allow for pivoting of the continuum component prior to the dip.

**X-ray/ultraviolet observing campaign of the Markarian 279 active galactic nucleus outflow: a close look at the absorbing/emitting gas with Chandra-LETGS**

[Costantini, E.](#); [Kaastra, J. S.](#); [Arav, N.](#); [Kriss, G. A.](#); [Steenbrugge, K. C.](#); [Gabel, J. R.](#); [Verbunt, F.](#); [Behar, E.](#); [Gaskell, C. M.](#); [Korista, K. T.](#); [Proga, D.](#); [Quijano, J. Kim](#); [Scott, J. E.](#); [Klimek, E. S.](#); [Hedrick, C. H.](#)

*Astronomy and Astrophysics*, Volume 461, Issue 1, January I 2007, pp.121-134

We present a Chandra-LETGS observation of the Seyfert 1 galaxy Mrk 279. This observation was simultaneous with HST-STIS and FUSE observations, in the context of a multiwavelength study of this source. The Chandra pointings were spread over ten days for a total exposure time of ~360 ks. The maximal continuum flux variation is of the order of 30%. The spectrum of Mrk 279 shows evidence of broad emission features, especially at the wavelength of the O vii triplet. We quantitatively explore the possibility that this emission is produced in the broad line region (BLR). We modeled the broad UV emission lines seen in the FUSE and HST-STIS spectra following the "locally optimally emitting cloud" approach. This method considers the emission from BLR as arising from "clouds" with a wide range of densities and distances from the source. We find that the X-ray lines luminosity derived from the best fit BLR model match the observed X-ray features, suggesting that the gas producing the UV lines is sufficient to account for the X-ray emission. The spectrum is absorbed by ionized gas whose total column density is  $\sim 5 \times 10^{20} \text{ cm}^{-2}$ . The absorption spectrum can be modeled by two distinct gas components ( $\log \xi \sim 0.47$  and  $2.49$ , respectively) both showing a significant outflow velocity. However, the data also allow for the presence of intermediate ionization components. The distribution of the column densities of such extra components as a function of the ionization parameter is not consistent with a continuous, power-law like, absorber, suggesting a complex structure for the gas outflow for Mrk 279.

**Hubble Space Telescope Ultraviolet Spectroscopy of 14 Low-Redshift Quasars**

[Ganguly, Rajib](#); [Brotherton, Michael S.](#); [Arav, Nahum](#); [Heap, Sara R.](#); [Galliano, Emmanuel](#); [Green, Richard F.](#); [Hall, Patrick B.](#); [Hines, Dean C.](#); [Junkkarinen, Vesa T.](#); [Kaastra, Jelle S.](#);

The Astronomical Journal, Volume 133, Issue 2, pp. 479-486.

We present low-resolution ultraviolet spectra of 14 low-redshift ( $z_{em} < 0.8$ ) quasars observed with the Hubble Space Telescope STIS as part of a Snapshot project to understand the relationship between quasar outflows and luminosity. By design, all observations cover the C IV emission line. Ten of the quasars are from the Hamburg-ESO catalog, three are from the Palomar-Green catalog, and one is from the Parkes catalog. The sample contains a few interesting quasars, including two broad absorption line (BAL) quasars (HE 0143-3535 and HE 0436-2614), one quasar with a mini-BAL (HE 1105-0746), and one quasar with associated narrow absorption (HE 0409-5004). These BAL quasars are among the brightest known (although not the most luminous) since they lie at  $z_{em} < 0.8$ . We compare the properties of these BAL quasars to the  $z_{em} < 0.5$  Palomar-Green and  $z_{em} > 1.4$  Large Bright Quasar Survey samples. By design, our objects sample luminosities in between these two surveys, and our four absorbed objects are consistent with the  $v \sim L^{0.62}$  relation derived by Laor & Brandt (2002). Another quasar, HE 0441-2826, contains extremely weak emission lines, and our spectrum is consistent with a simple power-law continuum. The quasar is radio-loud but has a steep spectral index and a lobe-dominated morphology, which argues against it being a blazar. The unusual spectrum of this quasar resembles the spectra of the quasars PG 1407+265, SDSS J1136+0242, and PKS 1004+13, for which several possible explanations have been entertained.

### **Complex X-ray morphology of Abell 3128: a distant cluster behind a disturbed cluster**

[Werner, N.](#); [Churazov, E.](#); [Finoguenov, A.](#); [Markevitch, M.](#); [Burenin, R.](#); [Kaastra, J. S.](#); [Böhringer, H.](#)

Astronomy and Astrophysics, Volume 474, Issue 3, November II 2007, pp.707-716

We present here the results of a detailed study of the X-ray properties of the cluster of galaxies Abell 3128 ( $z = 0.06$ ), based on the analysis of deep (100 ks) XMM-Newton data. The most obvious feature of the X-ray morphology of A3128 is the presence of two X-ray peaks separated by  $\sim 12'$ . By detecting the redshifted Fe K line, we find that the Northeast (NE) X-ray peak observed toward A3128 is a distant luminous cluster of galaxies at redshift  $z = 0.44$ . Our subsequent optical spectroscopic observation of a distant radio bright galaxy in the centre of the NE X-ray peak with the Magellan telescope also revealed a redshift of  $z = 0.44$ , confirming the association of the galaxy with the cluster seen in X-rays. We detect a gravitational arc around the galaxy. The properties of this galaxy indicate that it is the cD galaxy of the cluster in the background. The properties of the Southwest X-ray peak suggest that it is the core of a group merging with A3128 along our line of sight. Based on 2D maps of thermodynamic properties of the intra-cluster medium determined after subtracting a model for the background cluster, we conclude that an enhanced surface brightness region at a distance of  $\sim 2.8'$  from the centre of the galaxy distribution is the centre of the gravitational potential of the cluster

A3128. The unrelaxed nature of A3128 can be attributed to its location in the high density environment of the Horologium-Reticulum supercluster.

**Possible non-thermal nature of the soft-excess emission in the cluster of galaxies Sérsic 159-03**

[Werner, N.](#); [Kaastra, J. S.](#); [Takei, Y.](#); [Lieu, R.](#); [Vink, J.](#); [Tamura, T.](#)

Astronomy and Astrophysics, Volume 468, Issue 3, June IV 2007, pp.849-858

We present an analysis of new Suzaku data and archival data from XMM-Newton of the cluster of galaxies Sérsic 159-03, which has a strong soft X-ray excess emission component. The Suzaku observation confirms the presence of the soft excess emission, but it does not confirm the presence of redshifted O VII lines in the cluster. Radial profiles and 2D maps derived from XMM-Newton observations show that the soft excess emission has a strong peak at the position of the central cD galaxy and the maps do not show any significant azimuthal variations. Although the soft excess emission can be fitted equally well with both thermal and non-thermal models, its spatial distribution is neither consistent with the models of intercluster warm-hot filaments, nor with models of clumpy warm intracluster gas associated with infalling groups. Using the data obtained by the XMM-Newton Reflection Grating Spectrometers we do not confirm the presence of the warm gas in the cluster centre with the expected properties assuming the soft excess is of thermal origin. The observed properties of the soft excess emission are consistent with the non-thermal interpretation. While the high density of relativistic electrons associated with the peak of the soft emission in the cluster centre might have been provided by an active galactic nucleus in the central cD galaxy, the underlying population might have been accelerated in diffuse shocks.

**Constraining supernova models using the hot gas in clusters of galaxies**

[de Plaa, J.](#); [Werner, N.](#); [Bleeker, J. A. M.](#); [Vink, J.](#); [Kaastra, J. S.](#); [Méndez, M.](#)

Astronomy and Astrophysics, Volume 465, Issue 2, April II 2007, pp.345-355

Context: The hot X-ray emitting gas in clusters of galaxies is a very large repository of metals produced by supernovae. During the evolution of clusters, billions of supernovae eject their material into this Intra-Cluster Medium (ICM). Aims: We aim to accurately measure the abundances in the ICM of many clusters and compare these data with metal yields produced by supernovae. With accurate abundances determined using this cluster sample we will be able to constrain supernova explosion mechanisms. Methods: Using the data archive of the XMM-Newton X-ray observatory, we compile a sample of 22 clusters. We fit spectra extracted from the core regions and determine the abundances of silicon, sulfur, argon, calcium, iron, and nickel. The abundances from the spectral fits are subsequently fitted to supernova yields determined from several supernova type Ia and core-collapse supernova models. Results: We find that the argon and calcium abundances cannot be fitted with currently favoured supernova type Ia models. We obtain a major improvement of the fit, when we use an empirically modified delayed-detonation model that is calibrated on the Tycho supernova remnant. The two modified parameters are the density where the sound wave in the supernova turns into a shock and the ratio of the

specific internal energies of ions and electrons at the shock. Our fits also suggest that the core-collapse supernovae that contributed to the enrichment of the ICM had progenitors which were already enriched. Conclusions: The Ar/Ca ratio in clusters is a good touchstone for determining the quality of type Ia models. The core-collapse contribution, which is about 50% and not strongly dependent on the IMF or progenitor metallicity, does not have a significant impact on the Ar/Ca ratio. The number ratio between supernova type Ia and core-collapse supernovae suggests that binary systems in the appropriate mass range are very efficient (~5-16%) in eventually forming supernova type Ia explosions.

### **The mass-energy budget of the ionised outflow in NGC 7469**

[Blustin, A. J.](#); [Kriss, G. A.](#); [Holczer, T.](#); [Behar, E.](#); [Kaastra, J. S.](#); [Page, M. J.](#); [Kaspi, S.](#); [Branduardi-Raymont, G.](#); [Steenbrugge, K. C.](#)

Astronomy and Astrophysics, Volume 466, Issue 1, April IV 2007, pp.107-118

Although AGN feedback through ionised winds is of great importance in models of AGN/galaxy coevolution, the mass and energy output via these winds, even in the nearby universe, is poorly understood. The issue is complicated by the wide range of ionisation in the winds, which means that multiwavelength observational campaigns are required to obtain the complete picture. In this paper, we use a ~160 ks XMM-Newton RGS spectrum to get the most accurate view yet of the ionised outflow (warm absorber) in NGC 7469 as seen in X-rays, finding that there is a wide range of ionisation, with  $\log \xi$  in the range ~0.5-3.5  $\text{erg cm s}^{-1}$ , and two main velocity regimes, at 580-720 and 2300  $\text{km s}^{-1}$ , with the highest velocity gas being the least ionised. The total absorbing column density in the X-rays is of order  $3 \times 10^{21} \text{ cm}^{-2}$ . We find that the lowest ionisation phase of the absorber is probably identical with one of the phases of the UV absorber discovered in previous studies. We show that both X-ray and UV absorbers are consistent with an origin near the base of a torus wind, where matter is being launched and accelerated. Calculating the mass outflow rate and kinetic luminosity of all the absorber phases, we demonstrate that the X-ray absorbing gas carries respectively ~90% and 95% of the mass and kinetic energy output of the ionised outflow.

### **On the Putative Detection of $z > 0$ X-Ray Absorption Features in the Spectrum of Mrk 421**

[Rasmussen, Andrew P.](#); [Kahn, Steven M.](#); [Paerels, Frits](#); [Herder, Jan Willem den](#); [Kaastra, Jelle](#); [de Vries, Cor](#)

The Astrophysical Journal, Volume 656, Issue 1, pp. 129-138. ([ApJ Homepage](#))

In a series of papers, Nicastro et al. have reported the detection of  $z > 0$  O VII absorption features in the spectrum of Mrk 421 obtained with the Chandra Low Energy Transmission Grating Spectrometer (LETGS). We evaluate this result in the context of a high-quality spectrum of the same source obtained with the Reflection Grating Spectrometer (RGS) on XMM-Newton. The data comprise over 955 ks of usable exposure time and more than  $2.6 \times 10^4$  counts per 50 mÅ at 21.6 Å. We concentrate on the

spectrally clean region ( $21.3 < \lambda < 22.5$ ), where sharp features due to the astrophysically abundant O VII may reveal an intervening, warm-hot intergalactic medium (WHIM). We do not confirm detection of any of the intervening systems claimed to date. Rather, we detect only three unsurprising, astrophysically expected features down to the  $\log(N_i) \sim 14.6$  ( $3 \sigma$ ) sensitivity level. Each of the two purported WHIM features is rejected with a statistical confidence that exceeds that reported for its initial detection. While we cannot rule out the existence of fainter, WHIM related features in these spectra, we suggest that previous discovery claims were premature. A more recent paper by Williams et al. claims to have demonstrated that the RGS data we analyze here do not have the resolution or statistical quality required to confirm or deny the LETGS detections. We show that our analysis resolves the issues encountered by Williams et al. and recovers the full resolution and statistical quality of the RGS data. We highlight the differences between our analysis and those published by Williams et al. as this may explain our disparate conclusions.

### **X-ray variability of Capella**

[Raassen, A. J. J.](#); [Kaastra, J. S.](#)

*Astronomy and Astrophysics*, Volume 461, Issue 2, January II 2007, pp.679-683

We discuss 12 individual observations of stable calibration source Capella over the last five years. The light curves and spectra, derived from LETGS on board CHANDRA are investigated. The spectra cover the wavelength range 1-175 Å. Nine of the twelve observations show comparable count rates, while the three most recent observations between March 2005 and April 2006 show a 40-50% higher count rate. No individual flares were recognised. Line flux ratios between different observations show that the variations are related to the hotter plasma. Variations in line fluxes of highly ionised iron lines show a strong resemblance with earlier line flux variations in the years 1992-1995. A time interval of 10.7(.2) year is determined between two maxima in line fluxes. Emission measure modellings to the total spectra have been made by means of spex in combination with mekal. Observations with higher count rates have a higher emission measure at higher temperature.

### **Revisiting the Soft X-Ray Excess Emission in Clusters of Galaxies Observed with XMM-Newton**

[Nevalainen, J.](#); [Bonamente, M.](#); [Kaastra, J.](#)

*The Astrophysical Journal*, Volume 656, Issue 2, pp. 733-738.

We analyze XMM-Newton galaxy clusters Abell 1795, Abell S1101, Abell 1835, and MKW 3s in order to test whether their soft X-ray excess emission in the 0.2-0.5 keV band as reported by Kaastra et al. maintains after application of current knowledge of the XMM-Newton background and calibration. In this context, we examine the claim (Bregman & Lloyd-Davies) that the XMM-Newton sub-Galactic H I column density, and the accompanying soft excess continuum emission in the 0.2-0.5 keV band, is an artifact of an incorrect background subtraction. We show that since the cluster regions under scrutiny are within 500 kpc of the bright cluster center, the X-ray background level is negligible compared to the cluster emission level. Thus, at least in the central 500 kpc regions of the studied clusters, the reported soft excess is not a background artifact. We

also study the possibility that the incomplete calibration information in the early phase of the XMM-Newton mission resulted in sub-Galactic H I column density, which was interpreted with the presence of a soft excess emitter. Our reanalysis of the four XMM-Newton observations with the MOS instruments yields evidence for the soft excess in all clusters. However, using the PN instrument, the best-fit H I column densities in Abell 1795, Abell 1835, and MKW 3s are at odds with the 2003 analysis of Kaastra et al. and in general agreement with those measured from 21 cm data in the direction of the clusters (Dickey & Lockman). Abell S1101 continues to feature a sub-Galactic NH also with the PN instrument, indicative of soft excess emission in both EPIC detectors. These differences are compatible with the current level of uncertainty in the calibration of both instruments.

### **Chemical Abundances in an AGN Environment: X-Ray/UV Campaign on the Markarian 279 Outflow**

[Arav, Nahum](#); [Gabel, Jack R.](#); [Korista, Kirk T.](#); [Kaastra, Jelle S.](#); [Kriss, Gerard A.](#); [Behar, Ehud](#); [Costantini, Elisa](#); [Gaskell, C. Martin](#); [Laor, Ari](#); [Kodituwakku, C. Nalaka](#); [Proga, Daniel](#); [Sako, Masao](#); [Scott, Jennifer E.](#); [Steenbrugge, Katrien C.](#) The Astrophysical Journal, Volume 658, Issue 2, pp. 829-839.

We present the first reliable determination of chemical abundances in an active galactic nucleus (AGN) outflow. The abundances are extracted from the deep and simultaneous Far Ultraviolet Spectroscopic Explorer (FUSE) and Hubble Space Telescope (HST) STIS observations of Mrk 279. This data set is exceptional for its high signal-to-noise ratio, unblended doublet troughs, and little Galactic absorption contamination. These attributes allow us to solve for the velocity-dependent covering fraction and therefore obtain reliable column densities for many ionic species. For the first time, we have enough such column densities to simultaneously determine the ionization equilibrium and abundances in the flow. Our analysis uses the full spectral information embedded in these high-resolution data. Slicing a given trough into many independent outflow elements yields the extra constraints needed for a physically meaningful abundance determination. We find that relative to solar, the abundances in the Mrk 279 outflow are (linear scaling) carbon  $2.2 \pm 0.7$ , nitrogen  $3.5 \pm 1.1$ , and oxygen  $1.6 \pm 0.8$ . Our UV-based photoionization and abundance results are in good agreement with the independent analysis of the simultaneous Mrk 279 X-ray spectra. This is the best agreement between the UV and X-ray analyses of the same outflow to date.

Based on observations made with the NASA/ESA Hubble Space Telescope and the NASA-CNES-CSA Far Ultraviolet Spectroscopic Explorer, and obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555.

### **Carbon and Nitrogen in the X-ray Emitting Hot Gas of M 87**

[Werner, N.](#); [Böhringer, H.](#); [Kaastra, J. S.](#); [Plaa, J. De](#); [Simionescu, A.](#); [Vink, J.](#)

Heating versus Cooling in Galaxies and Clusters of Galaxies, *Eso Astrophysics Symposia*, Volume . ISBN 978-3-540-73483-3. Springer-Verlag Berlin Heidelberg, 2007, p. 309

We compare the abundance ratios of carbon, nitrogen, oxygen, and iron in the interstellar medium (ISM) of M 87 with those in the stellar population of our Galaxy. The relative contribution of core-collapse supernovae to the enrichment of the ISM in M 87 is significantly lower than in the Milky Way. The abundance ratios indicate that the enrichment of the ISM by iron through Type Ia supernovae and by carbon and nitrogen is occurring in parallel. This suggests that the main sources of carbon and nitrogen in M 87 are the low- and intermediate-mass asymptotic giant branch stars.

### **Exploration of SN Ia remnants in LMC**

[Kosenko, D.](#); [Vink, J.](#); [Blinnikov, S.](#); [Rasmussen, A.](#)

SUPERNOVA 1987A: 20 YEARS AFTER: Supernovae and Gamma-Ray Bursters. AIP Conference Proceedings, Volume 937, pp. 316-318 (2007).

We report on X-ray observations of the supernova remnant 0509-67.5 in the Large Magellanic Cloud with XMM-Newton. The Reflective Grating Spectrometer (RGS) data show that the remnant has a very high expansion velocity of 6000 km/s. The imaging spectroscopy data (EPIC) show that the remnant has an asymmetric ejecta structure: the bright southwest region of the remnant shows an overabundance of Si, S, Fe. This could be a sign of an asymmetric explosion or it could be the result of a density enhancement of the ISM in the Southwest. In addition to the data analysis we also present an hydrodynamical modeling of the remnant. The simulations allow us to put some constraints on its basic parameters.

### **The Suzaku Observation of RCW 86 Northeastern Shell**

[Yamaguchi, Hiroya](#); [Koyama, Katsuji](#); [Nakajima, Hiroshi](#); [Bamba, Aya](#); [Yamazaki, Ryo](#); [Vink, Jacco](#); [Kawachi, Akiko](#)

eprint arXiv:0709.3151

This paper reports the Suzaku results on the northeast shell of RCW 86. With the spatial and spectral analysis, we separated the X-rays into three distinct components; low ( $kT_e \sim 0.3\text{keV}$ ) and high ( $kT_e \sim 1.8\text{keV}$ ) temperature plasmas and a non-thermal component, and discovered their spatial distributions are different from each other. The low temperature plasma is dominated at the east rim, whereas the non-thermal emission is the brightest at the northeast rim which is spatially connected from the east rim. The high temperature plasma, found to contain the  $\sim 6.42\text{keV}$  line (K alpha of low-ionized iron), is enhanced at the inward region with respect to the east rim and has no spatial correlation with the non-thermal X-ray (the northeast). The Fe-Kalpha line, therefore, is not related to the non-thermal emission but originates from Fe-rich ejecta heated to the high temperatures by the reverse shock. Since the metal abundances of the low temperature plasma are sub-solar, the most possible origin of this component is interstellar medium heated by a blast wave. The non-thermal X-ray, which has a power-law index of  $\sim 2.8$ , is likely to be synchrotron emission. A possible scenario to explain these morphologies and

spectra is: A fast moving blast wave in a thin cavity of OB association collided with a dense interstellar medium or cloud at the east region very recently. As the result, the reverse shock in this interior decelerated, and arrived at the Fe-rich region of the ejecta and heated it. In the northeast rim, on the other hand, the blast wave is still moving fast, and accelerated high energy electrons to emit synchrotron X-rays.

### **Examination Of The X-ray Spectrum From The SNR 0509-67.5**

[Kosenko, Daria](#); [Vink, J.](#); [Blinnikov, S.](#); [Rasmussen, A.](#)

American Astronomical Society Meeting 210, #123.09

We report on X-ray observations of the supernova remnant 0509-67.5 in Large Magellanic Clouds with XMM-Newton. The Reflective Grating Spectrometer data show that the remnant has a very high expansion velocity of 6000 km/s. The imaging spectroscopy data (EPIC) show that the remnant has an asymmetric ejecta structure: the bright southwest region of the remnant shows an overabundance of Si, S, Fe. This could be a sign of an asymmetric explosion or it could be the result of a density enhancement of the ISM in the Southwest. In addition to the data analysis we also present a hydrodynamical modeling of the remnant. The simulations allow us to put some additional constraints on the SNR properties and density of the environment.

### **Are The X-ray Synchrotron Filaments In Cas A Associated Only With The Shock Front?**

[Helder, Eveline](#); [Vink, J.](#)

American Astronomical Society Meeting 210, #15.04

We present preliminary results of our research on the non-thermal continuum emission of Cassiopeia A. Chandra discovered in 2001 thin non-thermal rims at a distance of 150" to the center of Cas A. These rims can be associated with the forward shock and contain a surprisingly high magnetic field 0.1 - 0.5 mG. This feeds the thought that forward shocks of young shell-type supernova remnants are able to accelerate cosmic rays at least up to the knee, at  $10^{15}$  keV. The Chandra image shows that not all non-thermal filaments are associated with the forward shock.

A natural question is whether these filaments are due to forward shock filaments projected to the interior of the remnant, or whether the filaments have another origin. We investigated this issue by employing a deprojection technique. Assuming spherical symmetry, we deproject the surface brightness into the intrinsic emissivity as a function of the radius. A surprising result of this deprojection is that we see the reverse shock coming up in the (deprojected) emissivity. This might indicate cosmic ray acceleration in the reverse shock.

### **XMM-Newton observations of HESS J1813-178 reveal a composite Supernova remnant**

[Funk, S.](#); [Hinton, J. A.](#); [Moriguchi, Y.](#); [Aharonian, F. A.](#); [Fukui, Y.](#); [Hofmann, W.](#); [Horns, D.](#); [Pühlhofer, G.](#); [Reimer, O.](#); [Rowell, G.](#); [Terrier, R.](#); [Vink, J.](#); [Wagner, S. J.](#) Astronomy and Astrophysics, Volume 470, Issue 1, July IV 2007, pp.249-257 ([A&A Homepage](#))

Aims. We present X-ray and  $^{12}\text{CO}(J=1-0)$  observations of the very-high-energy (VHE)  $\gamma$ -ray source HESS J1813-178 with the aim of understanding the origin of the  $\gamma$ -ray emission. Methods: High-angular resolution X-ray studies of the VHE  $\gamma$ -ray emission region are performed using 18.6 ks of XMM-Newton data, taken on HESS J1813-178 in October 2005. Using this data set we are able to undertake spectral and morphological studies of the X-ray emission from this object with greater precision than previous studies. NANTEN  $^{12}\text{CO}(J=1-0)$  data are used to search for correlations of the  $\gamma$ -ray emission with molecular clouds which could act as target material for  $\gamma$ -ray production in a hadronic scenario. Results: The NANTEN  $^{12}\text{CO}(J=1-0)$  observations show a giant molecular cloud of mass  $2.5 \times 10^5 M_{\odot}$  at a distance of 4 kpc in the vicinity of HESS J1813-178. Even though there is no direct positional coincidence, this giant cloud may have influenced the evolution of the  $\gamma$ -ray source and its surroundings. The X-ray data show a highly absorbed ( $n_{\text{H}} \sim 1. \times 10^{23} \text{ cm}^{-2}$ ) non-thermal X-ray emitting object coincident with the previously known ASCA source AX J1813-178 exhibiting a compact core and an extended tail towards the north-east, located in the centre of the radio shell-type Supernova remnant (SNR) G12.82-0.02. This central object shows morphological and spectral resemblance to a Pulsar Wind Nebula (PWN) and we therefore consider that this object is very likely to be a composite SNR. We discuss the scenario in which the  $\gamma$ -rays originate in the shell of the SNR, and that in which they originate in the central object, in terms of a time-dependent one-zone leptonic model. We demonstrate, that in order to connect the core X-ray emission to the VHE  $\gamma$ -ray emission electrons have to be accelerated to energies of at least 1 PeV.

### **The highly ionized disk wind of GRO J1655-40**

[Sala, G.](#); [Greiner, J.](#); [Vink, J.](#); [Haberl, F.](#); [Kendziorra, E.](#); [Zhang, X. L.](#)

Astronomy and Astrophysics, Volume 461, Issue 3, January III 2007, pp.1049-1056

Aims. The galactic superluminal microquasar GRO J1655-40 started a new outburst in February 2005, after seven years in quiescence, rising to a high/soft state in March 2005. In this paper we study the X-ray spectra during this rise. Methods: We observed GRO J1655-40 with XMM-Newton on 27 February 2005 in the low/hard state, and on three consecutive days in March 2005 during the rise of the source to its high/soft state. The EPIC-pn camera was used in the fast-read burst mode to avoid photon pile-up. Results: First, we contributed to the improvement of the calibration of the EPIC-pn, since the high flux received from the source required some refinements in the correction of the charge transfer efficiency of the camera. Second, we find that the X-ray spectrum of GRO J1655-40 is dominated in the high/soft state by the thermal emission from the accretion disk, with an inner radius of 13-14[D/3.2 kpc] km and a maximum temperature of 1.3 keV. We detected two absorption lines in the EPIC-pn spectra at 6.7-6.8 and 7.8-8.0 keV, which can be identified as the  $K\alpha$  and  $K\beta$  lines of either blended Fe XXV and Fe XXVI

or blueshifted Fe XXV. We find no orbital dependence on the X-ray properties, which provides an upper limit for the inclination of the system of  $73^\circ$ . The RGS spectrometers reveal interstellar absorption features at  $17.2 \text{ \AA}$ ,  $17.5 \text{ \AA}$  (Fe L edges), and  $23.54 \text{ \AA}$  (OI  $K\alpha$ ). Finally, while checking the interstellar origin of the OI line, we found a general correlation of the OI  $K\alpha$  line equivalent width with the hydrogen column density using several sources available in the literature.

### **The quasi-persistent neutron star soft X-ray transient 1M 1716-315 in quiescence**

[Jonker, P. G.](#); [Bassa, C. G.](#); [Wachter, S.](#)

Monthly Notices of the Royal Astronomical Society, Volume 377, Issue 3, pp. 1295-1300.

We report on our analysis of a 20 ks Chandra X-ray observation of the quasi-persistent neutron star soft X-ray transient (SXT) 1M 1716-315 in quiescence. Only one source was detected in the HEAO-1 error region. Its luminosity is  $1.6 \times 10^{32}$ - $1.3 \times 10^{33} \text{ erg s}^{-1}$ . In this, the range is dominated by the uncertainty in the source distance. The source spectrum is well described by an absorbed soft spectrum, e.g. a neutron star atmosphere or blackbody model. No optical or near-infrared counterpart is present at the location of the X-ray source, down to a magnitude limit of  $I > \sim 23.5$  and  $K_s > \sim 19.5$ . The positional evidence, the soft X-ray spectrum together with the optical and near-infrared non-detections provide strong evidence that this source is the quiescent neutron star SXT. The source is 10-100 times too bright in X-rays in order to be explained by stellar coronal X-ray emission. Together with the interstellar extinction measured in outburst and estimates for the source distance, the reported optical and near-infrared limit give an upper limit on the absolute magnitude of the counterpart of  $I > 8.6$  and  $K_s > 5.1$ . This implies that the system is either an ultra-compact X-ray binary having  $P_{\text{orb}} < 1\text{h}$  or the companion star is an M-dwarf. We reconstructed the long-term X-ray light curve of the source. 1M 1716-315 has been active for more than 12 yr before returning to quiescence, the reported Chandra observation started  $16.9 \pm 4.1$  yr after the outburst ended.

### **Detection of the radial velocity curve of the B5-A0 supergiant companion star of Cir X-1?**

[Jonker, P. G.](#); [Nelemans, G.](#); [Bassa, C. G.](#)

Monthly Notices of the Royal Astronomical Society, Volume 374, Issue 3, pp. 999-1005.

In this paper, we report on phase-resolved I-band optical spectroscopic and photometric observations of Cir X-1 obtained with the Very Large Telescope. The spectra are dominated by Paschen absorption lines at nearly all orbital phases except near phase zero (coinciding with the X-ray dip) when the absorption lines are filled in by broad Paschen emission lines. The radial velocity curve of the absorption lines corresponds to an eccentric orbit ( $e = 0.45$ ) whose period and time of periastron passage are consistent with the period and phase predicted by the most recent X-ray dip ephemeris. We found that the I-band magnitude decreases from 17.6 to  $\sim 16.8$  near phase 0.9-1.0 this brightening coincides in phase with the X-ray dip. Even though it is likely that the absorption-line

spectrum is associated with the companion star of Cir X-1, we cannot exclude the possibility that the spectrum originates in the accretion disc. However, if the spectrum belongs to the companion star, it must be a supergiant of spectral type B5-A0. If we assume that the compact object does not move through the companion star at periastron, the companion star mass is constrained to  $< \sim 10 M_{\text{solar}}$  for a  $1.4 M_{\text{solar}}$  neutron star, whereas the inclination has to be . Alternatively, the measured absorption lines and their radial velocity curve can be associated with the accretion disc surrounding a  $1.4 M_{\text{solar}}$  neutron star and its motion around the centre of mass. An absorption-line spectrum from an accretion disc is typically found when our line of sight passes through the accretion disc rim implying a high inclination. In this scenario, the companion star mass is found to be  $\sim 0.4 M_{\text{solar}}$ . However, from radio observations it was found that the angle between the line of sight and the jet axis is smaller than  $5^\circ$ . This would mean that the jet ploughs through the accretion disc in this scenario, making this solution less probable.