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Australian Theses in Astronomy: Abstracts

PhD Theses

Selected Studies of Southern Molecular Clouds

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This thesis presents the results of distinct but related studies of selected Southern Molecular Clouds. In the first part of the thesis we present the first results of a program to measure the line-of-sight magnetic field strength in southern molecular clouds with the Parkes radiotelescope, through the Zeeman effect in OH. For 18 clouds observed we detected the Zeeman effect in one cloud associated with RCW38, with a field strength of 38 ± 3 μG, and possibly in a cloud associated with RCW57, with a strength of -203 ± 25 μG. A comparison with field strengths estimated from a simple spherical cloud model indicates that our results are consistent with large scale cloud support against gravitational collapse being due to the magnetic field. The results are also consistent with the observed line-widths being due to hydromagnetic wave motions.

In the second part of the thesis we present the results of a detailed study of the proto-stellar molecular outflow originating in the Bok globule BHR71. This outflow is driven by a very young low mass proto-stellar object, and lies almost in the plane of the sky, with bipolar outflow lobes extended up to $0\cdot3$ pc from the protostar. The abundances of a number of molecular species are enhanced within the outflow, compared to the values determined within the globule. The species carbon sulphide, silicon monoxide and methanol all show abundance enhancements, of up to 400 in the case of silicon monoxide. These large enhancements are most likely due to the release from dust grains of ice mantles and silicon bearing species, via shocks produced by the interaction of the outflow and the stationary gas of the globule in the presence of a magnetic field. However, we find that the abundance of the formyl ion is decreased by a factor of 20 in the outflow. All these results are in agreement with predictions from the most advanced C-shock models available.

Finally, in the main appendix we report on a mid-infrared study of the southern HII region RCW38. Our observations are consistent with the region containing IRS1 being due to a ridge or shell of material surrounding a cavity of about $0\cdot1$ pc radius centred on the exciting hot massive young star(s) IRS2. The derived dust temperature in the IRS1 ridge is remarkably uniform, a result which is best explained as due to heating by resonantly trapped Lyman alpha photons, rather than by direct stellar heating. We deduce the effective temperature of IRS2 to be about 45,000 K, consistent with an O5 ZAMS star.

Bars in Edge-on Spiral Galaxies

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The main goal of this thesis is to deepen our understanding of the structure and dynamics of bars in spiral galaxies. We first tackle the issue of the pattern speed of bars. We measure directly the bar pattern speed in the galaxy NGC 2915, the first time this has been achieved in a late-type gas-rich system. NGC 2915 is a unique object, possessing a blue compact dwarf galaxy core and a HI disk with a bar and spiral arms pattern extending far beyond the optical galaxy. The bar pattern speed is slow, putting corotation at more than $1\cdot7$ bar radii, a value incompatible with self-consistent models of barred disks. We demonstrate that the spiral pattern cannot be due to interactions, cannot be sustained by swing amplification, and cannot be driven by the bar. Because the disk of NGC 2915 is dominated by dark matter, we argue that an extensive triaxial dark halo with a slow figure rotation could drive the disk morphology. The existence of such halos is supported by a preliminary analysis of a set of CDM simulations. If our interpretation is right, objects like NGC 2915 offer new opportunities to probe the structure and dynamics of dark halos.

The main part of this thesis is concerned with the vertical structure of bars, and with observational tests of the bar-buckling mechanism for the formation of boxy/peanut-shaped (B/PS) bulges in (edge-on) spiral galaxies. Because bars in edge-on spirals are hard to identify morphologically, we first had to develop bar diagnostics. We use the kinematical signature that a bar imposes on the position–velocity diagram (PVD) of an edge-on disk. We first use periodic orbit families as building blocks to model the

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structure of real galaxies. We show that the global structure of the PVDs is a reliable bar diagnostic in edge-on disks. Gaps between the signatures of the various periodic orbit families arise in the PVDs due to the non-homogeneous distribution of orbits in a barred disk. We show specifically how the signatures of the x_1 and x_2 families of periodic orbits can be used to determine the viewing angle with respect to the bar.

We also develop bar diagnostics for edge-on disks using hydrodynamical simulations, which specifically target the gaseous component of spiral galaxies. We show that, when a nuclear spiral is formed, associated with the existence of x_2 orbits, the presence of a gap in the PVDs, between the signature of the nuclear spiral and that of the outer parts of the disk, reliably indicates the presence of a bar. This gap is caused by shocks and inflows which lead to depletion of the gas in the outer bar region. The shape of the signature of the nuclear spiral also allows us to determine the viewing angle to the bar.

The last part of this thesis constitutes an extensive observational study of the relationship between bars and B/PS bulges. Using emission line spectroscopy, we search for bars in a large sample of edge-on spiral galaxies with B/PS bulges, and in a smaller control sample of spirals with more spheroidal bulges. We show that almost all B/PS bulges are due to a thick bar viewed edge-on, while only a few extreme cases may be due to the accretion of external material. This strongly supports the bar-buckling mechanism for the formation of B/PS bulges, and implies that accretion plays at most a minor role in the formation of these objects. None of the galaxies in the control sample shows evidence for a bar, which suggests conversely that all bars are B/PS. Studies of this type open up for the first time the possibility of studying observationally the vertical structure of bars. We introduce a number of related ongoing projects before concluding this thesis.

Weak Gravitational Lensing with the Ray Bundle Method

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This thesis describes a new technique, the ray bundle method (RBM), for investigating weak gravitational lensing due to realistic cosmological distributions of dark matter, generated with N-body simulations. It is shown that the gravitational lensing calculations are robust to the choices of N-body simulation parameters, and the way the lensing method is implemented and interpreted.

The RBM determines the magnification of gravitationally lensed sources, in addition to providing detailed information on lensing-induced shape distortions. The RBM is a powerful and efficient technique giving high accuracy in the weak lensing limit. The magnification probability distribution (MPD) is used to make a detailed comparison between the RBM magnifications and those obtained through analytic results and with conventional ray shooting methods.

The MPD is then used as the primary tool for comparisons between the weak lensing properties of cosmological models. Sixteen different models are investigated, which are variations on three broad classes of cold dark matter model: the standard model with $(\Omega_0, \lambda_0) = (1, 0)$, the open model with $(\Omega_0, \lambda_0) = (0\cdot3, 0)$ and the lambda model, which is a flat model with a cosmological constant $(\Omega_0, \lambda_0) = (0\cdot3, 0\cdot7)$. The cosmological models were generated with the HYDRO N-body code of Couchman, Thomas & Pearce (1995).

The Kolmogorov–Smirnov test and statistical estimators of the MPDs are used to determine whether it is possible to distinguish between the cosmological models in the weak lensing limit. It is shown that it is possible to distinguish between the magnification distributions of the standard, open and lambda models.

The effects of varying the Hubble parameter H_0, the power spectrum shape parameter Γ, and the cluster mass normalisation σ_8 is studied. It is shown that there is no signature of these parameters in the weak lensing magnification distributions. The MPDs are also shown to be independent of the numerical parameters such as the lens mass and simulation box size in the N-body simulations. A comparison between cosmological and random lens distributions suggests that the weak lensing MPD is independent of the actual lens distribution, and depends only on the optical depth of lenses.

The MPDs are used to place limits on measurements of the deceleration parameter q_0 from a population of high redshift standard candles. The results are interpreted with respect to both empty and full beams, which place upper and lower limits on q_0 respectively. It is shown that weak lensing can produce an error in the inferred value of q_0 as large $\sim$30% by redshift $z = 1$. It is possible to fit more than one cosmological model to the weakly lensed standard candles, so that standard candles should not be used on their own to determine the cosmological parameters.

The RBM provides the opportunity to follow the changes in shape of a light beam as it propagates through a sequence of lens planes, providing a flexibility which is not present in conventional ray shooting techniques. Probability distributions of

shear, convergence and image ellipticity are obtained for the three classes of cosmological model.

It is anticipated that the RBM has many potential applications to future studies of cosmological gravitational lensing.

Couchman, H. M. P., Thomas, P. A., & Pearce, F. R. 1995, ApJ, 452, 797

Barrels, Jets and Smoke-rings: Understanding the Bizarre Shapes of Radio Supernova Remnants

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This thesis considers the various morphologies of radio supernova remnants (SNRs), and attempts to determine whether their appearance results from the properties of the progenitor star and its supernova explosion, or from the structure of the interstellar medium (ISM) and ambient magnetic field into which a SNR consequently expands. High-resolution observations of Supernova 1987A show a young remnant whose appearance and evolution are completely dominated by the structure of its progenitor wind. A statistical study of the Galactic population of bilateral SNRs demonstrates that the symmetry axes of these remnants run parallel to the Galactic Plane. This result can be explained by the interaction of main sequence stellar wind-bubbles with the ambient magnetic field; expansion of SNRs into the resulting elongated cavities results in a bilateral appearance with the observed alignment. Radio observations of SNR G296·8–00·3 show a double-ringed morphology which is best explained by expansion either into an anisotropic main-sequence progenitor wind or into multiple cavities in the ISM. Data on SNRs G309·2–00·6 and G320·4–01·2 (MSH 15–5*2*) make a strong case that the appearance of both remnants is significantly affected by collimated outflows from a central source; for G309·2–00·6 the source itself is not detected, but for G320·4–01·2 there is now compelling evidence that the remnant is associated with and is interacting with the young pulsar PSR B1509–58. I conclude that, while the youngest SNRs are shaped by their progenitor's circumstellar material, the appearance of most SNRs reflects the properties of the local ISM and magnetic field. Remnants which interact with an associated pulsar or binary system appear to be rare, and are easily distinguished by their unusual and distorted morphologies.

Instrumentation Developments in Hard X-ray Astronomy

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The AXEL (Astrophysical X-ray Experimental Laboratory) balloon-borne payload was flown from Alice Springs, Australia, in September 1995, and carried a 32-tube high-pressure xenon-filled proportional counter array and a Phoswich scintillation detector. This thesis describes the multi-disciplinary research I performed as a contribution towards the development of the AXEL payload.

The proportional counter array is a new and innovative approach to astronomical X-ray detection. Preparation of the tube array required significant research into the gaseous physics of the proportional counter, for which investigations were directed specifically to argon- and xenon-based gas mixtures containing small concentrations of quenching gases methane, ethylene or iso-butane. Research involved examination of the counter's performance, with emphasis placed on determination of optimum energy and spatial resolutions, and gas gains for each gas at various pressures up to 30 atm for Ar-based and 10 atm for Xe-based gas mixtures. Two gas mixtures, Ar+2% methane at 30 atm and Xe+2% methane at 7·5 atm, were found to provide optimum performance characteristics and were used in the AXEL payload proportional counter array on its maiden flight.

Two gas handling and purification systems were developed and assembled to provide facilities for the purification of Ar- and Xe-based gas mixtures, and for the filling of the proportional counter tubes. The main gas purification and filling system was designed as a portable unit such that it is deployable in the laboratory or in the field.

The AXEL astronomical pointing system, operated in the azimuthal-zenith reference frame, employed a three axis magnetometer, rotational sun sensor and GPS to provide coordinates for the astronomical pointing system software. A ground based quick-look software utility was developed to allow for in-flight real-time scientific data analysis, monitoring of the payload pointing and monitoring of the payload status.

Relative Stellar Fluxes with a New Fibre-fed Spectrophotometer

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This thesis describes the design and development of instrumentation for measuring the spectral flux

distribution of light from stars (spectrophotometry) and reports the results of observations made with it.

The empirical determination of the emergent flux at the surface of a star and the effective temperature of a star require the combination of the flux received from the star with its angular diameter. The Sydney University Stellar Interferometer (SUSI) is engaged in a programme of measuring the angular diameters of stars (see Davis et al. 1994) and spectrophotometric data are needed for many of the stars in the programme. To meet this need a spectrophotometric system (SUSPECT) has been developed to measure relative stellar flux distributions in the visual region of the spectrum (see Kelz & Booth 1996; Kelz 1996). After flux calibration these distributions can be combined with ultraviolet and infrared flux data to complete the spectral flux distribution received from a star.

The conventional approach to obtain fluxes has been to use a large telescope capable of carrying the significant weight of the necessary instrumentation. This has posed problems of instrumental stability and also of obtaining time on large telescopes. The new system achieves high accuracy using an optical fibre link between a 0·35 m telescope and the spectrometer, which is mounted in a fixed configuration and located in a stable environment away from the telescope. While fibres have been used for high resolution spectroscopy on large telescopes, they have not been used successfully for accurate spectrophotometry on small telescopes.

The design, development, testing and commissioning of the new instrumentation, including the spectrometer, the fibre link and the telescope-fibre coupler is described in the thesis. An observational programme has been carried out and the scientific results are reported. The data have been investigated for internal consistency and the results are compared in detail with both spectrophotometric standards and earlier published work. The analysis of twenty observed programme stars shows for the first time how a fibre-fed instrument can be made to yield relative stellar energy distributions in the optical with an accuracy comparable to the best work using conventional direct-mounted instrumentation.

Further information about the instrument and some results are also available at
www.physics.usyd.edu.au/∼kelz/suspect/

Davis, T. 1996, Aust. J. Astron., 6, 175
Kelz, A. 1996, ASP Conf. Ser. Vol. 90 (San Francisco: ASP), p. 51
Kelz, A., & Booth, A. J. 1996, Aust. J. Astron., 6, 223

The Association of Ultracompact HII Regions and Methanol Maser Emission

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An extensive and comprehensive survey has been undertaken to investigate the relationship between 6·7 GHz methanol maser emission and ultracompact (UC) HII regions, selected from their far-infrared IRAS colours. Out of 534 regions surveyed by the Parkes radiotelescope, 199 exhibit maser emission. Luminosities and single star spectral types are presented for many of these sources. The broader distribution of IRAS sources without maser emission about the Galactic plane, compared with the distribution of those with associated maser emission, suggests contamination of the IRAS selection criteria.

Arcsecond resolution images of most of these sources, taken with the Australia Telescope Compact Array, show 187 maser sites and 177 UC HII regions. The brightness of maser emission is not significantly affected by the presence of an UC HII region, whether it is near or behind the maser site.

Although it was expected that the maser emission is associated with UC HII regions, only 25% of all maser sites have a detectable radio continuum counterpart. Methanol maser sites are associated with hot ammonia clumps, suggested by Cesaroni et al. (1994) as a pre UC HII phase of massive star formation. The projected sizes of UC HII regions which have associated maser emission are generally smaller than the projected sizes of other UC HII regions.

These results have been used to form a picture of the relationship between methanol maser emission and UC HII regions: the maser emission appears *before* the UC HII region is visible and is destroyed as the UC HII region evolves and expands beyond about 200 mpc.

It is possible, in some cases, that the maser emission arises in a circumstellar disk, but it is extremely unlikely for all cases. A shock model can also explain the observed characteristics of the maser emission, without the problems encountered in the circumstellar disk model.

An NIR survey has been conducted towards a selection of IRAS sources. A total of 66 maser sites and UC HII regions has been imaged, and about half of these have a very reddened counterpart at 3·3 microns. The SEDs of eight IRAS sources with one dominant NIR source indicate that they are all associated with Class I protostars.

Cesaroni, R. et al. 1994, A & A, 288, 903

The Application of High Precision Timing in the High Resolution Fly's Eye Cosmic Ray Detector

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This thesis represents work performed by the author on the development of the High Resolution Fly's Eye (HiRes) detector for the study of extremely high energy ($>10^{18}$ eV) cosmic rays. Chapter 1 begins with a review of this field: it details the development of the field, the physics questions we seek to answer, and our current understanding based on experimental and theoretical results. It also provides the basis for understanding why detectors such as HiRes are being constructed.

This review leads into Chapter 2, which discusses the development of cosmic ray induced extensive air showers (EAS) and the techniques used to study them. Particular emphasis is placed upon the air fluorescence technique utilised by HiRes. The two site HiRes prototype detector is then discussed in detail in Chapter 3. This covers the different components that form the detector, together with details of the calibration performed to extract useful information from the data.

Chapter 4 discusses the installation and subsequent testing of GPS based clock systems for the two sites that make up the HiRes prototype detector. The entire timing system was checked, and some previously hidden bugs fixed. This chapter concludes with work performed on the time to digital converter calibration for the second HiRes site.

The high relative timing accuracy provided by the GPS clocks allowed the use of timing information in programs to reconstruct the arrival directions of cosmic rays. Chapter 5 covers the development of a program to use geometrical and timing information to reconstruct EAS viewed by both HiRes sites. This chapter concludes with an evaluation of the likely reconstruction accuracy of the new HiRes (stage 1) detector.

A well reconstructed EAS trajectory is the first step in the determination of more interesting parameters such as primary particle energy. Chapter 6 covers the collation and analysis of EAS viewed by both sites of the prototype detector. This includes an evaluation of effects such as the atmosphere, and an estimation of the performance of the new (stage 1) HiRes detector based on results with the prototype detector.

Finally the conclusions from this thesis are summarised and suggestions made for further follow up work.