
DEPARTMENT OF ASTROPHYSICS,
UNIVERSITY OF OXFORD

Director: Professor D.E.Blackwell
Report for the period 1987 August 1 to 1988 July 31
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1 SOLAR PHYSICS

Miss Adam has continued her work on magnetic and velocity fields in sunspots.

Blackwell, Booth, Menon and Petford have made an analysis of the Ti I and Cr I lines in the solar photospheric spectrum using Oxford oscillator strengths and damping constants in conjunction with the Holweger–Müller solar model atmosphere and a theoretical model. The Ti I abundances change regularly with multiplet number, whilst Cr I abundances show a large almost random spread at low excitation. It is suggested that these effects are due to non-LTE.

Blackwell and Petford with Grevesse (Liège) have placed the Oxford oscillator strengths for Ti I on an improved absolute scale. As a consequence, it is proposed that all Oxford oscillator strengths for Ti I should be increased by 0.056 dex and the corresponding titanium solar abundances should be decreased by this amount.

Pearce, Harrison and Skumanich have made a comparison of the flaring rates, flare powers and quiescent X-ray luminosities of dMe (red dwarf) stars with those of solar active regions. In dMe stars, these properties are found to be closely related, and this may have significant influence on our understanding of the flare process and coronal heating. For example, a correlation between flare-rate and quiescent X-ray luminosity suggests that both may be driven by processes on a differing scale. It is a natural extension of this work to investigate similar relationships for the Sun. The relationships between the various parameters are not as clear for the Sun as for dMe stars; some solar properties appear to vary in a manner similar to the dMe analysis, and some contradict the dMe case. A study of flare statistics has also been undertaken using data from the Solar Maximum Mission (SMM) satellite. The duration, maximum intensities and intensity profiles of the flares are examined. The distributions of the measured parameters with respect to one another reveal some interesting results. In common with the past studies, it is concluded that there is no evidence to suggest that more than one type of event is being viewed, despite a desire in the literature to place events into distinct groups.

Pearce, Harrison and Sime have studied spectacular surge events in 1980. In this study they find remarkable similarities between two surge events seen by the High Altitude Observatory's Prominence Monitor on Mauna Loa, Hawaii, and instrumentation on the SMM satellite. In both events, a soft X-
ray burst occurs adjacent to a large quiescent prominence structure. It is concluded in the light of the data, that the surge is not a blast originating from the burst site, and it is not siphon flow into coronal loops due to the enhanced temperatures of the burst plasma. The results have been submitted for publication.

2 STELLAR PHYSICS

Smith and Drake have continued their programme of low-noise, high-resolution spectroscopy of calcium line regions in bright stars. Analysis of spectra of ε Eri (K2 V) and β Gem (Ko III), obtained at McDonald Observatory in 1986 December is nearing completion. To assist interpretation of the spectra, Drake is developing a computer code to calculate the statistical equilibrium of calcium in late-type stellar atmospheres.

The programme of narrow band (1–4 μm) infrared photometry of 176 stars by Blackwell, Booth, Haddock, Selby and Hepburn (Imperial College), Arribas (La Laguna), Leggett (Edinburgh) and Mountain (ROE) has now been completed and the results submitted for publication. These data will be used in conjunction with measurements of the stellar integrated flux in the wavelength range 380–900 nm, made using a reticon spectrometer by Petford, Blackwell, Booth, Haddock, Leggett (Edinburgh), Mountain (ROE), Selby (Imperial College) and Arribas (La Laguna), for a determination of the effective temperatures and angular diameters of these stars using the infrared flux method.

Lynas-Gray with Fernley (University College London), Skillen (Leicester), Jameson (Leicester), Kilkenny (SAAO), Marang (SAAO) and Longmore (ROE) have applied the Blackwell and Shallis infrared flux method to X Arietis (a metal-deficient RR Lyrae). Extensive photometry (from 0.2 to 2.5 μm) obtained around the pulsation cycle is used, together with published photometry. A comparison with other determinations for metal-deficient RR Lyrae stars (and X Arietis in particular) suggests that the infrared flux method yields precise effective temperature variations.

Lynas-Gray, with Jeffery (St Andrews) has shown the extreme helium star HD 124448 to be non-variable. The non-variability of HD 124448 supports the theoretical model of Saio & Jeffery.

A grid of LTE model atmospheres for metal-deficient OB stars has been computed by Lynas-Gray, in collaboration with Howarth (UCL), using the program ATLAS6 developed by Kurucz and implemented by the Collaborative Computational Project No. 7 on the University of London CRAY-1S computer. Particular attention has been paid to obtaining convergence as close as possible to the Eddington limit. The grid to be published will serve as a useful extension of the Kurucz (1979) grid.

3 HIGH ENERGY ASTROPHYSICS

The ultraviolet observations of the dwarf nova, YZ Cancri, carried out by Drew and Verbunt that were described in last year’s report have been prepared and accepted for publication in Monthly Notices. The very marked variation of the resonance line profiles with orbital phase can be more easily
explained by departures from axial symmetry in the mass outflow than by accretion disk asymmetry.

Woods and Drew have obtained the best of the IUE high spectral resolution observations of dwarf novae and nova-like variables with a view to fitting the observed C iv $\lambda 1549$ line profiles to profiles synthesized on the basis of a simple disk wind model (e.g. that discussed by Drew 1987, Mon. Not. R. astr. Soc., 224, 595). Owing to the sensitivity limits of IUE, this involves only four objects. So far it has emerged that the blue-shifted absorption can be fitted to synthetic profiles quite readily. However, it has been found in one case, that of the dwarf nova SS Cygni, there is clearly considerable excess emission that cannot be explained by a simple wind model. For the nova-like variable CPD $-48^\circ$ 1577, there exists a time sequence of high-resolution spectra indicating some line profile variability. A special study of this, which will also take into account existing low-resolution spectra, is now under way.

Dr Bath examined a model for the quasi-periodicities and periodicities observed in low-mass X-ray binaries and dwarf novae. Assuming a simple orbiting inhomogeneity model of the periodicities it has been shown that the observed frequency–intensity relationship can be accounted for if the field geometry is more complex than dipolar. The implied surface fields have been derived. Masses of white dwarfs have been derived assuming that their observed periodicities are formed in the boundary layer.

Honey, Bath, Charles and Whitehurst have searched for evidence of superhumps in the wide outbursts of SS Cygni. No such modulations were found. This is in accord with the expectations of Whitehurst’s tidal model for the superhumps.

McHardy, together with Stewart, Edge and Cooke from Leicester, has observed the rich cluster of galaxies, Abell 2218, with the Japanese/UK X-ray astronomy satellite GINGA. Abell 2218 is the cluster in which there is most confidence that a real detection of the Sunyaev–Zeldovich effect (i.e. the upscattering of microwave background photons by the hot gas in clusters of galaxies) has been found. Previous workers have shown that the SZ microwave decrement measurement, when combined with an X-ray measurement of the surface brightness and gas temperature, can in principle provide a direct measurement of the Hubble constant, $H_0$, independently of the usual classical stepping-stone arguments. Abell 2218 is too faint for previous satellites (e.g. EXOSAT) to have measured its temperature, so this measurement was performed with GINGA. The measured temperature ($6.7 \pm 1.2$ keV) is much lower than predictions based on an assumed isothermal gas distribution, on the measured microwave decrement, and assuming $H_0 = 50$ km sec$^{-1}$ Mpc$^{-1}$. Given its luminosity, $L_x$, the temperature is, however, entirely consistent with the well-established $L_x/T$ correlation and we have no reason to doubt its accuracy. If the microwave decrement is taken at face value, it is concluded that either a very low value of $H_0$ ($\sim 25$ km sec$^{-1}$ Mpc$^{-1}$) is accepted, or one must invoke a more complex gas distribution.

In conjunction with Marscher from Boston University, multifrequency VLBI observations of the OVV Quasar 1156$+295$ have been carried out. These observations, with a resolution of $\sim 0.2$ milliarcsec, show a faint
component emanating from the core at position angle $19^\circ$. This extension is visible at $1.3, 2.8$ and $6$ cm and we note, with interest, that its position angle on milliarcsec scales is in a different direction to the very impressive 2 arcsec jet in pa $-22^\circ$ seen by MERLIN (work carried out in conjunction with Muxlow, Jodrell Bank). We therefore conclude that a bending jet comes out of the core of this quasar.

A bending shocked-jet provides a good explanation of the multifrequency variability seen in this source. Close to the core, in the region where most X-rays are produced (in shocked-jet models), the jet points more or less directly towards us. Relativistic beaming hence allows rapid X-ray variability, as is observed. Further down the jet, the expanding shock will radiate predominantly at radio wavelengths. At this point it will be pointing further from the line of sight and so radio variability will be slower, again as observed.

This model also explains the spectral evolution of the radio outbursts. The observed flux density, in any band, is boosted by $\delta^3$ over the non-beamed case, where $\delta$ is the relativistic doppler factor, and the frequency at which the self-absorbed spectrum peaks, $\nu_{\text{m}}$, is changed by one factor of $\delta$ in moving to the observer's frame. Thus the observer expects to see the peak flux, $\delta^3 \nu_{\text{m}}$, vary as $\nu^{-3}$ in the decay phase of the outburst, more or less exactly as is observed.

Hassall, together with other members of the group [Harlaftis, Machin (Oxford), Naylor (Madrid), Charles (La Palma), Sonneborn (GSFC)] has continued to study eclipsing SU UMa dwarf novae. Successful observational campaigns have been carried out on both a superoutburst and a normal outburst of Z Cha. Work primarily by Harlaftis on the IUE observations during the superoutburst of Z Cha shows that the UV continuum and line flux are modulated on the orbital period in much the same way as for the related system OY Car. The results imply the presence of a 'cool' spot on the edge of the accretion disk, which periodically occults the brighter inner regions. In contrast, preliminary analyses of comparable normal outburst data reveal a much bluer continuum and little or no variability with orbital phase. Thus it appears that the accretion disk only takes on extended vertical and asymmetric azimuthal structure during the prolonged superoutburst.

In conjunction with collaborators [Wade, Berriman (Steward), Williger (Cambridge)], Hassall has completed a study of the long period dwarf nova BV Cen, which reveals a quiescent UV flux distribution rising toward the red. A careful analysis of the contributions from the white dwarf and red secondary, suggest that the UV flux originates in the disk, which is more likely to be optically thick than thin. If the outbursts are due to a disc instability, triggering would occur in the optically thick central regions leading to a rather symmetric outburst lightcurve, for which there is some observational support.

The search for the orbital periods of low-mass X-ray binaries is continuing. CCD photometry of GX339-4 from three observatories round the globe were used by Honey, Charles, Hassall, Thorstensen (Dartmouth) and Tuohy (ANU) while it was in an unusually faint state ($M(v) = 21$) to detect a modulation semi-amplitude of $0.2$ mag with a period of 5618 days. Reanalysis of previous data sets at normal brightness confirms the presence of this
orbital period, which, combined with existing spectroscopic measurements by the group, leads to the tentative conclusion that GX339-4 does not contain a black hole. A similar set of photometric observations of Ser X-1 is being investigated for a period of about 13 hours suspected from the X-ray lightcurve.

Other work in progress includes the study of the results of the long-term IUE monitoring of the dwarf nova CN Ori [Hassall with collaborators La Dous, Pringle (Cambridge)]. Hassall and other members of the IUE Target of Opportunity team for Novae, chaired by Snijders (RGO) have been working on the IUE and optical data of Nova Muscae 1983. Line ratios have been used to follow the development of the electron temperature and density and to derive the elemental abundances. The latter demonstrate that Nova Muscae has enrichment relative to solar abundances, of N and O in its ejecta but not of Ne.

A large collaboration including Callanan, Machin, Hassall and groups from MSSL, RGO and Madrid, has been looking for optical counterparts of high energy systems. The optical counterpart of the eclipsing binary radio pulsar PSR1957+20 was observed to undergo a 3 magnitude minimum coinciding with the radio eclipse. A null result from the search for the optical counterpart of the binary millisecond pulsar PSR1855+09 has been used to place lower limits on the age of the neutron star in the system. Spectroscopic studies of the globular cluster CV candidate V101 in M5 put a lower limit of 3.5 hr on the orbital period. Assuming it is a member of the cluster, its absolute magnitude at its brightest is about $M(v) \sim 30$, compatible with the brighter long-period CVs in our own neighbourhood.

The LMC transient source A0538-66 went into outburst early this year, and Callanan has been coordinating a worldwide campaign to monitor it at optical, UV and X-ray energies. This source is capable of exceeding five Eddington luminosities at X-ray energies in its most active state. The combined results of the campaign indicate that this was not a major outburst – the campaign did however manage to secure the first simultaneous X-ray and optical coverage of a flare. Any model of the system must explain why the optical output of the system was reduced by only 0.5 mag from that observed during its most violent outburst, yet the X-ray luminosity is only one per cent of that observed during the corresponding period.

An optical campaign to determine the orbital period of LMC X-2, the brightest LMXRB known in the X-ray energy, was carried out early in the year in collaboration with van Paradijs (Amsterdam). Preliminary analysis does not indicate a statistically significant period, but the data must yet be combined with more acquired during a two-week MSSSO run $\sim$ four months later. In collaboration with Thorstensen, the same summer campaign yielded evidence for a $\sim$ 7 hr binary period for the LMXRB Serpens X-1.

Observations with Charles and Machin during the three-week June FOS run on the WHT were carried out on most of the northern hemisphere LMXRB’s and many CV’s (especially magnetic), in collaboration with Durham and MSSL. The data included spectra of several CV candidates in globular clusters.

CCD imaging was also obtained using a 0.1 arcsec/pixel scale, enabling the group to perform CCD photometry of the binary millisecond pulsar.
PSR1957+20 (the evaporating white dwarf system), perform deep CCD exposures of the field of PSR1855+09 (another binary millisecond pulsar system) and make sensitive searches for contaminating stars near optical counterparts of LMXRBs. Data for PSR1957+20 have been used to constrain the model for this remarkable system. Those for PSR1855+09 have shown that the proposed optical counterpart of this system is incorrect, and have enabled an upper limit of 26:5 (V) to be placed on the magnitude of any counterpart. Because the system is comparatively close, this in turn implied that it is very old, due to the time-scale required for the white dwarf companion to cool to such a low luminosity.

Data taken during a subsequent WHT run enabled the group to perform the first simultaneous photometry and spectroscopy of M15/AC211 system, as well as to confirm that the optical lightcurve of PSR1957+20 is asymmetric. This later discovery has major implications for any excited wind model for this system.

Several suites of software necessary for the proper reduction of the optical and X-ray data on the microVAX have been accumulated. With Lynas-Gray, the Leicester GINGA data reduction package has been installed on the departmental microVAX making the department self-sufficient in its data reduction requirements.

A collaboration between astronomers at the University of Oxford (Pearce, Charles), the University of Durham (Allington-Smith, Parry), Rutherford Appleton Laboratory (Patchett), the Royal Greenwich Observatory (Murdo), the I.A.C. (Sanchez), and astronomers at the Observatorio del Roque de los Muchachos, has resulted in a wealth of data being produced and analysed for the supernova SN1987A. Other aspects of the supernova research currently in progress include theoretical modelling. This involves modelling of the heating of the interstellar medium by SN1987A and predicting the infra-red emission from interstellar grains heated by this supernova. The infrared emission resulting from grains condensing from the ejecta of SN1987A is also being investigated.

Pearce has also used IRAS data to investigate dust grain composition and distribution in the ecliptic plane.

4 GALACTIC SPIRAL ARM STUDIES

Following the detection of an intermittent 15 Myr cycle in the terrestrial record, and the suggestion due to Clube and Napier that it is due to the unseen matter in local spiral arms proposed by Woolley thirty years ago to explain the vertical force law derived from young stars, Clube has developed arguments suggesting most of the warm dust in the disc may be a pre-stellar phase lasting \( \leq 10^8 \) yr associated with a hot, differentiating medium in spiral arms. This favours an ejection theory for the ultimate origin of spiral structure. Also, in collaboration with Waddington, Clube has reinterpreted new spectroscopic measurements of several bright infra-red sources seen towards the Galactic Centre (Geballe, Baas & Wade, in press) as indicating that the local standard of rest has an outward motion of around 40 km sec\(^{-1}\) relative to the circumnuclear ring, in agreement with direct kinematic evidence from hot molecular hydrogen in the ring and earlier kinematic
studies in the solar neighbourhood. This result also favours an ejection theory for spiral structure and highlights the importance of re-examining similar behaviour by the globular cluster system. Following recent improvements to basic globular cluster data, Clube and Waddington have also found strong evidence for large-scale expansion in the Galactic halo as well which is difficult to explain other than by a violent gravitational mechanism. This process is currently being explored.

5 EXTRAGALACTIC PHYSICS AND COSMOLOGY

Peach has completed the reductions of Dixon’s photometry of the double cluster of galaxies A2197/99. The photometry includes magnitudes, \( (b-r) \) colours, position angles and ellipticities for 6925 galaxies in a 5 square degree field enclosing the clusters. He has compared the observed colour–magnitude diagrams with model diagrams based on a field galaxy luminosity function and suitable K-corrections with the cluster superimposed and shows that they are consistent. The diagrams also provide a way of excluding part of the distant field from the sample and separating cluster spirals and early type galaxies. The mass-to-light ratios of the clusters in the \( b \)-band are 408 for A2199 and 267 for A2197. There are enough velocities in A2199 to analyse the character of the orbits using the run with radius of the velocity dispersion and the surface density. Although there are considerable uncertainties in the problem, strongly radial orbits appear unlikely.

There has been a natural scepticism about reports of galaxy major-axis position angle (p.a.) alignments in clusters, not only because further investigations often fail to confirm the effect but also because obvious systematic errors can simulate an alignment. But the theoretical importance of any such effects in clusters would be great, as present alignments would be remnants of protocluster properties, either angular momentum in the case of disc galaxies or velocity anisotropies in the case of ellipticals. Elongated linear clusters have been chosen as the most promising sites for observing the effects, but the only confirmed claim for systematic alignments of galaxy p.a.s in the direction of the cluster major-axis has been in A2197.

Peach and Dixon have measured p.a.s using image moments for 1560 galaxies brighter than \( b = 21.7 \) in a 1° square field around A2197, using PDS scans of Palomar 48-inch Schmidt plates; Peach and Bunn have then repeated the measurements visually for the brightest 1117 of the sample to \( b = 21.2 \). The latter measures were made by the two observers independently, each measuring the cluster in two orthogonal orientations on the measuring table of the Bessy film measuring machine. The measured p.a.s agree well with the few previous measurements by Adams, Strom and Strom.

Both sets of measurements show a p.a. alignment at the 10 per cent significance level of the cluster galaxies and the alignment is within 20° of the position angle of the cluster major-axis. The significance of the alignment is highest for the brighter galaxies and for those galaxies chosen from areas of highest galaxy density. This probably reflects not the physical correlation of the effect with brightness or environment, but the enhancement of the galaxy alignment signal relative to the random superimposed field galaxy component; the signal-to-noise ratio is increased by choosing the brightest
galaxies, which for \( b \sim 18 \) are nearly all cluster members, or by excluding that part of the field which dominates the region outside the main cluster concentration. The removal of background galaxies on the basis of their very red colours also enhances the effect.

If the alignment signal in A2197 is typical of linear rich clusters it could have been missed for the more distant clusters that have been previously examined due to the increase with redshift of the field galaxy component in the samples measured. Examination of these clusters with this component partially removed by spectroscopic or colour measurements might show the alignment effect to be more common than has been supposed.

Miller has been based at the International School for Advanced Studies (SISSA) in Trieste, but has continued to spend some time working in the Department. This work has been mainly in two areas; study of the cosmological quark-hadron transition, with Pantano (Trieste), and general relativistic gravitational collapse calculations, with Motta (Catania).

The cosmological quark-hadron transition may have had important consequences for dark matter creation, formation of pre-galactic structure and cosmic nucleosynthesis. Miller and Pantano have been carrying out a detailed study of the hydrodynamics of the transition and have constructed a computer code to follow the growth of hadron bubbles. This code is fully general relativistic and uses an interface-tracking technique to follow motion of bubble surfaces with iterative solution of junction conditions derived using the Gauss–Codazzi formalism. Runs have been made for various assumptions about the input physics, allowing an analysis to be made of the relative importance of uncertainties in different parameters. The study has shown that some assumptions commonly made in the literature are ill-founded and that the problem is subtle and complicated from the point of view of the hydrodynamics as well as from that of the particle physics.

The use of null slicing relativity has several advantages. Miller and Motta have extended earlier work on applying this to spherical collapse, giving an improved treatment of initial conditions. The results then obtained give a very satisfactory picture of spherical black hole formation.

6 LABORATORY WORK

Smith has extended his measurements of oscillator strengths in Ca I, using the carbon tube furnace, to lines of 2.9 eV excitation. The new measurements have been linked to earlier measurements, made using the same equipment, for lines of 2.5 and 2.7 eV excitation. The complete set of measurements, when combined with recent lifetime measurements, establishes an absolute scale of oscillator strengths for Ca I with an uncertainty of only ±5%.

Blackwell and Petford have measured the oscillator strengths of a further 67 Fe I lines with excitation potential up to 3.38 eV. These and other lines are being used as a basis for extension of the measurements to higher excitation potentials.

7 PERSONAL

Dr A. Booth resigned his post as Departmental Research Assistant to take up a Lectureship in the Chatterton Astronomy Department, the University
of Sydney, Australia. He has been succeeded by Dr A.E.Lynas-Gray, who joined the Department on 1988 February 1.

The Halley Lecture for 1988 was given by Mr C.A.Murray (RGO) on 3 May.

8 PUBLICATIONS


