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This report covers the Astronomy and Astrophysics group from October 1997 through August 1998.

1. INTRODUCTION

The group included Professors Jeffrey Kuhn, Susan Simkin, Horace Smith, and Robert Stein, Associate Professors Timothy Beers, Suzanne Hawley, and Edwin Loh, Visiting Professor Eugene Capriotti, and Emeritus Professor Albert Linnell. Capriotti was on leave for the period January through August, spending the spring semester at San Diego State University and the summer at the Space Telescope Science Institute.

2. RESEARCH

2.1 The SOAR Project

Michigan State University is participating in the SOAR project to build a four meter telescope in Chile in conjunction with the University of North Carolina, NOAO, and Brazil. Construction at the site on Cerro Pachon is underway. Loh and Kuhn worked on the design of an infrared imager for the SOAR telescope.

2.2 Solar and Stellar Astrophysics

Timothy Beers has completed follow-up spectroscopic observations of some 5000 candidate metal-poor stars from the the HK objective-prism/interference-filter survey, the goal of which is to identify and study large numbers of the most metal-deficient stars in the Galaxy. These observations, obtained in collaboration with groups in Australia, Europe, and the US, are being assembled into a set of four data papers to be submitted within the next year. A paper describing a new calibration of Beers' techniques to estimate metal abundance from medium-resolution spectroscopy has been submitted to the AJ.

Beers and colleagues from the South African Astronomical Observatory (D. O' Donoghue, D. Kilkeny, C. Koen, and R. Stobie) and S. Rossi of the University of São Paulo have applied the new calibration technique to the estimation of metal abundance for some 200 stars identified as likely metal-poor stars from the ongoing Edinburgh-Cape Blue Object Survey. They have demonstrated that the "contaminants" of the EC survey contain a large number of quite metal-poor stars, and plan to continue this effort as the survey progresses.

Along with colleagues C. Flynn of the Tuorla Observatory (Finland), W. Schuster of UNAM (Mexico), P. Nissen of the University of Aarhus, R. Wilhelm of the University of Texas, N. Christlieb of the University of Hamburg, and S. Rossi of the University of São Paulo, Beers has obtained broadband *UBV* photometry for a set of ~ 100 distant field horizontal-branch stars selected from the Hamburg/ESO prism survey. This information will be combined with spec-

troscopy to be obtained in the fall of 1998 in order to make full use of these stars as kinematic probes of the halo of the Galaxy up to 25 kpc from the sun.

Along with colleagues S. Rossi of the University of São Paulo, and Chris Sneden of the University of Texas, Beers has obtained estimates of carbon abundances for ~ 50 metal-poor stars from the HK survey which were shown in previous work to have strong CH G-bands relative to that expected for their abundance and temperature. The upper envelope of $[C/Fe]$ appears to rise with declining $[Fe/H]$, suggesting that mechanisms for the enhancement of carbon in a stellar atmosphere may be related to the overall abundance of the star itself, an idea which is being pursued both with additional observations and with theoretical models.

Beers and graduate student J. Rhee continue to refine their methodology to select new candidate metal-poor stars from the HK survey plates, which are being scanned with the APM facility in Cambridge (in collaboration with M. Irwin). Tests to date indicate that many thousands of additional metal-poor candidates should be identifiable through these efforts.

Beers and graduate student L. Saleh continue their work on theoretical models for element production and mixing in the early Galaxy, in collaboration with G. Mathews (University of Notre Dame).

Capriotti is in the process of establishing criteria for the relative importance of stellar winds and ionizing radiation on the structure and evolution of gaseous nebulae.

Hawley, Neill Reid (Caltech) and graduate student Jon Tourtellot finished their work on two of the open clusters from a large survey. They examined both magnetic activity and dynamical evolution in the clusters.

Hawley and Neill Reid (Caltech) observed a sample of low mass Hyades candidates with Keck, and found that only one was a possible Hyades brown dwarf member. Several others may be background pre-main sequence brown dwarfs.

Hawley, Neill Reid (Caltech) and John Gizis (U. Mass) continued their work on a survey of field and cluster stars aimed at describing magnetic activity in the mid-M dwarf range, and calibrating an age-activity relationship.

Hawley, George Fisher, Chris Johns-Krull (Space Sciences Lab) and several students continued their study of a flare on AD Leo observed with ASCA and several optical telescopes. The time resolution of the high resolution spectroscopic (optical) data is unprecedented and should lead to new results on the dynamics during the impulsive phase.

Graduate student Bill Abbett finished his PhD thesis on solar flare models, incorporating dynamics into the non-LTE radiative transfer code. He is currently a postdoc with Hawley at Space Sciences Lab, where they are refining the solar models and beginning a program to model stellar flares.

Kuhn and Edmunds completed the design and construction of a new 1-5 μm infrared camera using a new line of 256×256 pixel HgCdTe array detectors developed by Rock-

well, Inc. The new instrument was used on an open Hercules C130 airplane during a total eclipse over the South Pacific in February of this year. The experiment detected the brightest and reddest IR coronal emission line yet.

Kuhn and graduate student J. Armstrong have developed a model for computing the high order asphericity of the sun with a level of accuracy comparable to the recent satellite measurements of the sun's shape. Their results imply new constraints on the solar interior rotation.

Linnell has continued development and application of the BINSYN suite of programs for binary stars. A photometric and spectrophotometric study of MR Cygni was published in collaboration with P.B. Etzel, I. Hubeny, and E.C. Olson. A synthetic spectrum fit to the continuum of IUE spectra produced a value for the effective temperature of the primary component. Synthetic spectra achieved very accurate fits to new radial velocity spectra by Etzel and Olson. A synthetic photometry program, using a series of synthetic spectra at fiducial orbital longitudes, generated UB_V photometry that accurately simulated new observations by Linnell. The new analysis demonstrates that MR Cygni does not consist of components near or on the main sequence, as earlier analyses had concluded, but rather that the system belong to the group of hot Algols studied by Popper. The accretion disk capability of BINSYN has been used in a study of beta Lyrae, in collaboration with I. Hubeny and P. Harmanec. Our results demonstrate that the standard accretion disk model, by Hubeny and Plavec, shows significant residuals from observations, both photometric and spectroscopic, and that no changes in adjustable parameters are able to remove the residuals. The basic problem is that the Hubeny and Plavec model requires a small visible segment of the hot star at the center of the accretion disk and this requirement conflicts with the photometric evidence. We find that no model with an accretion disk thick enough to hide the central star can satisfy either the photometry or IUE spectra. To resolve the impasse we suggest the presence of a light-scattering region above the accretion disk faces. The region scatters light from the central star into the line of sight. A paper in press describes these results. The BINSYN suite is being extended to permit simulation of the proposed scattering region.

Graduate student Barton Pritzl, Smith, Marcio Catelan (GSFC), and Allen Sweigart (GSFC) have begun a photometric study of variable stars in the metal-rich globular clusters NGC 6388 and NGC 6441 using data obtained with the 0.9-m telescope at CTIO. Unlike most metal-rich globular clusters, NGC 6388 and NGC 6441 have significant blue horizontal branch components and contain significant numbers of RR Lyrae stars.

Smith and several collaborators continued to use the MSU 0.6-m telescope for photometry of multimode RR Lyrae variables. Smith, Michael Barnett (Indiana U.), Pamela Gay (Texas), and Nancy Silbermann (JPL) completed an analysis of photometry of AR Her, an RR Lyrae star which shows the Blazhko Effect. The data were not in complete accord with oblique rotator-pulsator models of the Blazhko Effect.

Stein, Bercik, Geogobiani (MSU) and Nordlund (Copenhagen) modeled convection by solving the three-dimensional equations of mass, momentum and energy conservation, the

induction equation for the vector potential and the equation for LTE, non-gray, radiative transfer. A third order leapfrog predictor corrector is used to advance the variables in time and spatial derivatives are calculated using compact third and sixth order fits to the functions. The code is stabilized by a hyperviscosity.

Results of simulations of solar granulation appeared in the *Astrophys. J.*, **499**, 914-933, (1998). These simulations have produced a paradigm shift in our perception of convection: Solar convection is inherently non-local. It is driven from the thin surface thermal boundary, on the intermediate scale of granulation, by radiative cooling of the tiny fraction of ascending fluid that reaches the surface. This produces low entropy, overdense fluid that forms the cores of coherent, turbulent downflow plumes. Buoyancy work occurs mostly in these plumes and drives both larger scale cellular, diverging, laminar upflows and smaller scale turbulent motions in the downflows. Mass conservation controls the topology of convection – most ascending fluid must turn over within approximately a scale height and become entrained in a downflow. For further details see: <http://www.pa.msu.edu/~steinr/research.html>.

Stein, Bercik and Geogobiani initiated two series of magneto-convection simulations: one with a unipolarity, initially uniform vertical, magnetic field, and another with a bipolar magnetic field produced by horizontal field advected into the computational domain by fluid entering at the bottom.

The magnetic field is swept into the downflows by the diverging upflows. In the bipolar case, advection and buoyancy stretch the field into loops. Where the magnetic flux tubes are evacuated, strong (> 1.5 kG) surface fields appear as bright points in the intergranular lanes. Where the magnetic flux tubes are not evacuated, they appear darker than the field free intergranular lanes. In the unipolarity case, when the magnetic flux through the surface is large, ($< B > \sim 400$ G) pores form in the intergranular lanes. In both cases, the magnetic field significantly modifies the granulation pattern, producing small more irregular granules.

Stein and Mats Carlsson (Oslo) used their 1D, non-LTE, radiation-hydrodynamic code to investigate dynamic phenomena in the solar atmosphere. The natural state of the solar chromosphere is dynamic, not static, with large amplitude variations. In such dynamic atmospheres one must be cautious in applying traditional analysis methods developed for static atmospheres. Care must be taken in interpreting Doppler velocities as a proxy for fluid velocity and intensity as a proxy for fluid temperature, because of dynamic changes in line formation heights and slow excitation, ionization, and recombination rates, leading to large departures from equilibrium.

Stein, Nordlund, Rosenthal (HAO), Christiansen-Dalsgaard and Trampedach (Aarhus) investigated the effect of convection in altering the resonant cavity of solar p-modes. Differences between observed and theoretical eigenfrequencies of the Sun depend on frequency, ν , but not degree, ℓ (when scaled by the ratio of the mode mass to the mode mass of a radial mode of the same frequency) and the difference is small for the lowest frequencies and grows as

the frequency approaches the cut-off frequency of the solar photosphere (≈ 5 mHz). Hence, the cause of the discrepancy resides in layers to which the low frequency modes hardly penetrate, but where the high frequency modes have a significant amplitude. Low frequency modes have their upper turning point below the highly superadiabatic region near the top of the convection zone. High frequency modes have their upper turning points above this layer. The cavity for high frequency modes is enlarged by turbulent pressure support and 3D radiative transfer effects which increase the average temperature required to produce a given effective temperature in an inhomogeneous compared to a homogeneous atmosphere. The p-mode eigenfrequencies calculated from the mean simulation atmosphere are significantly closer to the observed mode frequencies than those for standard spherically symmetric, mixing length models.

Stein and Nordlund studied the excitation of solar p-modes. Stochastic, non-adiabatic, gas pressure fluctuations, produced by the interaction of the convective motions and radiation near the solar surface, excite the p-modes via PdV work, where P is the total (gas+turbulent) pressure and dV is the mode compression and expansion. The p-mode excitation rate in the simulation is in excellent agreement with observations. The mode driving decreases at low frequencies because the mode compression decreases and the mode mass increases. The mode driving decreases at high frequency because the pressure fluctuations decrease.

2.3 Galactic and Extragalactic Astronomy

Kuhn, Smith, and Hawley have analyzed new extended color magnitude photometry from the Ursa Minor and Draco dwarf spheroidals. Their results prove that these systems are extended at least 2-5 degrees from the core and are characterised by leading-trailing asymmetry in their surface densities along their long axis.

Working with E. M. Sadler (School of Physics, University of Sydney), R. Sault (CSIRO), S. J. Tingay (JPL), Simkin and Jake Callcutt (1996 MSU graduate) have discovered kinematic and morphological evidence for non-disruptive redirection of a radio jet by interstellar gas clouds in the double-lobed radio galaxy Pictor A. Their data include HST continuum and [OIII], emission-line images (at a resolution of 25 – 100 mas) and ground-based imaging and spectroscopy (at a resolution of $\sim 1.5''$), 3 cm Australia Telescope images of the core, at a resolution comparable to that of the optical, ground-based images, and a VLBI image of a jet in the compact core. The data and its interpretation have been submitted to the *Astrophysical Journal* for publication.

As a followup to their discovery of a double nucleus in Markarian 315, Simkin (and J. Mackenty, STScI) have observed this object with the C array of the VLA, and mapped the extended HI gas found in its outer regions. Contrary to expectations, they find that the HI in the region of the galaxy is not associated with the ionized filament which stretches 70 arc seconds to the NW of the nucleus but instead lies on the opposite (SE) side of the galaxy. The disturbed morphology of the HI gas tends to support the merger hypothesis for the origin of this object but the path for the merger is difficult to

identify. This analysis has been submitted to the *Astronomical Journal* for publication.

Working with B. I. Grimberg (MSU) and E. M. Sadler, Simkin has found evidence for significant differences between the extended emission line gas (EELG) in the outer regions of FR II radio galaxies (such as the lobes) and that the gas closer to the nucleus. These differences suggest that the latter may be subject to more powerful disruption. In particular, they find that the values for [NII]:H α are lower than those usually found for active galaxy nuclei with similar values of [OI]:H α . Some of this work is already in press (*ASS*, January, 1999) and the rest is being prepared for publication.

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