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This report covers the period of September 1995 to August 1996 and summarizes the research in astronomy and astrophysics carried out at the Department of Physics & Astronomy, University of California – Irvine.

1. PERSONNEL

Our personnel includes the following

Faculty: Drs. Steve Barwick, Gregory Benford, Gary Chanan, Rognvald Garden, Steve Ruden, Tammy Smecker-Hane, Virginia Trimble, Gerard Van Hoven, Gaurang Yodh

Research Scientists: Drs. Anthony Shoup, Patrick Mock, Yung Mok, Alan V. Schiano (UCI, Dept. of Academic Computing)

Post Doctoral Researchers: Dr. Douglas Hendrix

Research Staff: Mitchell Troy, John Gandolfo

Graduate Students: John Breault, Romana Crnkovic, Frank Dekens, Chris Frank, Douglas Hendrix, Neil Hillis, Scott Hugenberger, Isabel Leonor, Rodin Porrata, Eric Schneider, Wagner Truppel

Undergraduate Students: Jim Kreuziger, Catherine O'Hara, Goro Takei

Summer Students: Christine Chen, Giles Goodwin, M. Masequesmay (REU program)

This year Dr. Tammy Smecker-Hane joined the faculty as an assistant professor. Graduate students Douglas Hendrix and Neil Hillis successfully completed their Ph. D. theses, and graduate student Romana Crnkovic advanced to candidacy.

2. RESEARCH SUMMARY

The following is a brief summary of the research activities of our department. Interested readers are encouraged to browse our department web page (http://www.ps.uci.edu/physics) or contact us directly for more details.

2.1 Infrared Astronomy

The Infrared Astronomy Group at UC Irvine, headed by Dr. R. Garden, is currently involved in three instrument development programs: (1) The construction of a mid-infrared (8–13 micron) imaging Fabry-Perot interferometer (MIRFI) for the Keck/Lick Telescopes; (2) the design of a mid-infrared (8-28 micron) imager for the Gemini Telescopes, and (3) the design of a two-channel (8–28 and 18–40 micron) imager/spectrometer for the NASA SOFIA mission. First light with the unique MIRFI instrument is scheduled for January 1997.

We are also pursuing an active observational program with the Keck Telescopes. The two major areas of investigation at this time are (1) a study of the morphology and kinematics of the shock-excited gas associated with young stellar jets at near-infrared wavelengths, and (2) a search for thermal emission from debris disks around nearby solar-type stars at 10/20 microns.

2.2 Galaxy Evolution

The evolution of galaxies both nearby and at large distances is the focus of Dr. Smecker-Hane's research. She has recently completed work with R. Abraham (Cambridge), J. Hutchings (DAO), and collaborators on the star formation histories of galaxies in the cluster Abell 2390. Abell 2390 is a rich cluster of galaxies at a redshift of $z = 0.23$, analogous to the local Coma cluster, that was observed in the CNOC cluster redshift survey (see Yee, Ellingson & Carlberg 1996, ApJS, 102, 269). They found a surprisingly strong radial gradient in the properties of galaxies in Abell 2390. Gradients in the colors and strengths of spectral features show that the galaxy population changes gradually from a very evolved, early-type population in the inner 0.4 h^{-1} Mpc to a progressively later-type population in the outer envelope that extends to 3 h^{-1} Mpc. By comparing their data to spectral synthesis models, they conclude that cluster has been gradually built up by the infall of field galaxies over ~ 8 Gyr, and that star formation in infalling spirals was truncated upon accretion. Because few of the cluster galaxies show signs of undergoing a strong starburst, they conclude that galaxy evolution in the cluster at that redshift is dominated by spirals gradually being transformed into S0 galaxies rather than spirals undergoing mergers to form ellipticals.

Smecker-Hane and colleagues A. McWilliam (OCIW) and D. Geisler (NOAO) are measuring the abundances of numerous chemical elements in stars in Baade's Window to determine chemical history of the bulge of our Galaxy and constrain the timescale on which it formed. They recently finished obtaining high dispersion, high signal-to-noise spectra of 75 red giants using the CTIO 4m telescope and Argus multi-fiber spectrograph, and they are now reducing the data.

Smecker-Hane is also leading a studying the evolution of nearby dwarf galaxies. Dwarfs are in theory the simplest galaxies, and thus the best sites in which to study the processes that regulate star formation. There are many outstanding questions about how dwarf galaxy evolution. For example, what are their star-formation rates? Are supernovae-driven galactic winds and massive dark matter halos important in shaping their evolution?

To answer these questions, Smecker-Hane, P. Stetson (DAO) and J. Hesser (DAO) have undertaken a major investigation to determine the star-formation and chemical-evolution histories of the Carina and Fornax dwarf spheroidal galaxies (dSphs). In order to combat the degeneracy of age and metallicity in color-magnitude diagrams, they are combining photometry that spans the tip of the giant branch to well below the main-sequence turnoff with metallicity distributions measured from spectra of a few hundred stars in each galaxy. The dSphs are low mass galaxies (10^7 to $10^9 M_\odot$) that were generally believed to have formed in brief bursts early in the history of the Universe. Supernovae were thought to drive large-scale galactic winds that stripped the

gas out of the galaxies and constrained them evolve passively from then until now. However, the photometry obtained by Smecker-Hane, Stetson & Hesser clearly shows that the evolution of the Carina and Fornax dSphs has been surprisingly complex. The Carina dSph had four distinct episodes of star formation ~2, 4, 5 to 7, and 11 to 14 Gyr ago, yet little chemical enrichment occurred between successive generations of stars. The lack of chemical enrichment proves that metal enriched gas was expelled in galactic winds and *not* reaccreted. However, the long duration of activity shows that galactic winds did not couple readily to the dense interstellar medium (ISM), and the loss of the entire ISM occurred gradually over many Gyr. In contrast, the more massive Fornax dSph has had a more constant star-formation rate and exhibits a wide range in chemical abundances. Although the star-formation rate of Fornax rapidly declined approximately 3 Gyr ago, stars as young as 500 Myr are seen. These results show that a complicated balance exists between ongoing star formation and disruptive feedback from massive stars via photoionization and supernovae explosions, which leads to self-regulated star formation even in these very low mass galaxies.

To constrain the evolution of the gas in dSphs, Smecker-Hane along with A. McWilliam (OCIW), R. Ibata (UBC) and R. Wyse (JHU) are using the Keck Telescope to obtain high-dispersion spectra of stars in the Sagittarius dSph. For the first time, the compositions of numerous chemical elements will be determined for stars outside of our own Galaxy. The abundance patterns will tell us the slope of the massive end of the stellar initial mass function, the rate of enrichment from Type Ia and Type II supernovae, and, thus, how the star-formation rate and gas content evolved. The chemical compositions will be compared to those of Galactic halo stars to test the idea that many dwarf galaxy-sized fragments merged to form the Galactic halo.

2.3 High Energy Astrophysics

The High Energy Astrophysics Group lead by Drs. S. Barwick and G. Yodh is leading the design and construction of the AMANDA neutrino telescope, an ambitious program funded by the National Science Foundation. Their objective is to construct an array of light sensors that will be deployed 2 kilometers below the surface of the ice at the South Pole. This instrument would be capable of observing very high energy neutrinos from some of the most violent and energetic sources in the Universe. By early 1997, they plan to complete construction of the 10 string prototype and soon after that they will begin to develop novel and more capable technologies that are required to build a detector with dimensions of 1 kilometer. The science reach of this telescope encompasses particle physics, astrophysics, and glaciology.

Under the direction of Dr. S. Barwick, the group also participates in the High Energy Antimatter Telescope (HEAT) program, which is funded by NASA. HEAT is a balloon-borne magnetic spectrometer which has measured the energy spectrum of positrons in the cosmic radiation between 1 and 50 GeV. The group was responsible for the design, construction, calibration, and integration of the electromagnetic calorimeter into the HEAT payload. The results from their investigation show no evidence for a dramatic rise in the positron fraction in the cosmic rays, as previously reported. They are now developing new detector components with the capability to measure the antiproton content of cosmic rays. Antiprotons are unique tracers of the origin of cosmic rays. They hope to launch the antiproton version of the HEAT spectrometer in late 1997 or 1998.

Another major effort of the High Energy Astrophysics Group is the construction of a new high energy gamma ray air shower telescope called Milagro. The UCI effort is led by Drs. G. Yodh, A. Shoup, and S. Barwick with graduate students, Scott Hugenberger and Isabel Leonor. Milagro will be the first water-Cherenkov detector specifically built to study extensive air showers. It is being built in an existing man-made pond 60m × 80m × 8m, located in the Jemez mountains near Los Alamos, New Mexico. Unlike conventional air shower detectors, which sample less than 1% of the particles that reach detector level, MILAGRO will be totally sensitive to the electrons, photons, hadrons, and muons in the air shower. The threshold of the MILAGRO detector is comparable to atmospheric Cherenkov detectors, however it has several advantages over these optical detectors. MILAGRO is operational 24 hours a day in all weather conditions, and it has an open aperture which allows it to view the entire northern sky every day. These capabilities allow for a systematic all-sky survey to be done for the first time at very high energies (VHEs). MILAGRO will measure the Crab spectrum with high significance. In addition, it will detect and measure the spectra from AGN's such as MRK 421. MILAGRO will be the first VHE detector capable of recording gamma ray bursts at energies above 250 GeV. MILAGRO will search for point sources of VHE gamma radiation, both steady and episodic.

2.4 History of Astronomy and Astrophysics

Trimble has completed an investigation of the papers and citations to those papers resulting from data collected at large optical telescopes throughout the world. There are 39 such telescopes (of 2-meters or larger diameter) located in 10 countries. On average, 20 papers per year report results from each, and each paper is cited an average of 3.5 times per year a few years later, but the range in both quantities is more than an order of magnitude. Some correlations are no surprise; you don't learn much from a telescope at a rainy site or one that you cannot afford to maintain. Thus the Russian 6-meter is much less productive than the 2.1-meter at Kitt Peak. There were also some surprises. The most productive telescope in both papers and citations is the Anglo-Australian Telescope. Tied for second place (depending on whether you count papers or citations) are the Canada-France-Hawaii Telescope and the CTIO 4-meter Telescopes. All are four meters or smaller in diameter. All draw observers from more than one country (but they have quite different total potential numbers of users), and all are rather difficult to get to for their main users, perhaps providing some self-selection of people who are used to working hard and know and love their favorite facilities.

Trimble is currently investigating the history of our understanding of the processes of star formation. Star formation

(and solar system formation) were regarded as a legitimate, if somewhat speculative, part of astronomy through the 19th and early 20th centuries. Curiously, there was a period from about 1930 until shortly after World War II when most astronomers seem to have been persuaded that all stars (including the Sun, and Earth) were about 2 Gyr old, the same as the expansion time scale of the Universe (as understood when Hubble's constant was 5000 km/sec/Mpc) and, therefore, that stars had formed as part of the same processes in the early Universe that produced galaxies. During this period, suggesting that there might be very young stars or stars currently in the process of formation was not respectable.

2.5 Jets at the Galactic Center

The oddest and longest filament discovered at our galactic center is a uniquely kinked structure about 150 light years long and two to three light years wide–the Snake. G. Benford modeled this structure in terms of the electrodynamic view of the center, in which currents set up coherent magnetic structures (Benford, G., 1988, ApJ, 333, 735). The kinks arise from a kinking instability in progress, producing the Snake's brightest regions. The Snake's display of kinks without a sausage instability constrains the pinch field to be strong, comparable to the ambient field. Nonlinear large kink excursions should drive shocks, producing particle acceleration and the observed peaked synchrotron emission at the kink maxima. Filamentary instabilities can rapidly evolve in current-driving acceleration zones (perhaps the observed H II regions), feeding further filamentary structures as the system evolves. A circuit picture seems capable of qualitative agreement with Snake properties.

Recent theoretical work on the intra-day variability of quasars proposes that coherent emission explains their high brightness. Instabilities between jets emerging from active galactic nuclei and the surrounding plasma can lead to highly ordered, compact, zones of strong electric field. These scatter jet electrons collectively, leading to greatly enhanced power per electron, in a power-law spectrum. Absorption by surrounding plasma is insufficient to block this emission. Crucial tests of this idea can come from the predicted observation of high brightness in quasars which have two-sided jets, and thus are probably not pointing directly at us.

2.6 Theoretical Astrophysics

N. Hillis completed his Ph. D. thesis under the supervision of S. Ruden. Dr. Hillis's thesis was entitled ''Numerical Investigations of Planet–Induced Wave Propagation in Thin Disks.'' He developed a two–dimensional hydrodynamics code to evolve gas dynamics in thin disks. The code was based on the method of lines and incorporated monotonicity constraints to perform accurate transport. Using the code, Hillis and Ruden investigated spiral density waves generated by a low mass planet in a protoplanetary disk. They followed the nonlinear evolution of the gas in the disk as waves generated by the planet caused an annular gap to form at the position of the planet.

2.7 Theoretical Plasma Astrophysics

The Astrophysical Plasma Theory Group is lead by Dr. G. Van Hoven and it includes Drs. Y. Mok, D.L. Hendrix and their collaborators J.A. Linker, Z. Mikić and D.D. Schnack (Science Applications International Corp.) and J.F. Drake (Univ. of Maryland). Their research focuses on evolutionary and instability studies of the energetics and dynamics of solar magnetic activity, with emphasis on nonlinear computer simulation and their connection with space and terrestrial observations.

In the group's continuing program to understand *coronal heating*, they investigated the dynamic evolution of the (E.N.) Parker mechanism wherein the convective photospheric shuffling of the feet of coronal magnetic loop fields leads to the formation of narrow current sheets and enhanced dissipation. They completed a series of MHD simulations examining the contribution of localized 3-D coalescence and reconnection and the resulting magnetic turbulence, and evaluated the detailed energy balance and parameter scaling. This work is reported in the Ph. D. thesis, ''A Study of the Formation and Dissipation of Current Filaments as a Coronal Heating Mechanism'' (UCI, 1996) of D.L. Hendrix.

Thermal instability forced by optically thin radiation is believed to drive the formation of filaments and prominences in the solar corona. An important aspect of the condensation process involves the parallel (to **B**) nonuniform energetics of hot and diffuse coronal loops or arcades which are thermally anchored in the cool and dense chromosphere, and the *magnetic support of prominences* against gravity. It has been found that either a drop in the apex heating rate or a finite-amplitude perturbation can lead to the siphon-effect formation of cool, dark, apex prominences, which are often observed to be suspended in the corona. The group at UCI has added the constraints imposed by the self-consistent effects of dynamic anti-buoyant modifications of the ambient coronal fields in 2D. The heavy condensation thereby forms its own magnetic ''hammock'' in which it is stably supported in the solar atmosphere. They are now working on a self-consistent *initiation mechanism*, arising from the convectively driven reconfiguration (reconnection) of the coronal magnetic field.

The Astrophysical Plasma Theory group has also continued the development of a simulation program devoted to the *evolution of coronal fields* (determined from vector magnetograms) in response to shear flows or flux emergence arising from the convective solar surface. Their aim is to comprehend the growth of magnetic stress and energy, and the subsequent transition to instability or eruption of the coronal field. Their first successful effort demonstrated the *formation of a coronal loop* as the result of the effects of localized vortical convection on the footpoints of a pre-existing current-free/potential-field bipole. The loop field becomes progressively twisted and the stored magnetic energy increases. If the twisting is stopped before the instability/eruption threshold is crossed, then the field settles into a force-free form whose *S* shape agrees with observations.

The group has begun an investigation of the dynamics of *emerging flux*. Their model for this mysterious process includes evolving boundary conditions, presented to the corona

by the photosphere, which cause the emergence of line-of-sight magnetic flux and current density, as would be measured by a series of vector magnetographs. They have successfully emerged a current-free bipole (which could, for instance, provide the initial state for coronal-loop formation, as described in the previous paragraph). They are continuing to study the emergence of a twisted (non-current-free) magnetic loop.

Finally, during the past year, Drs. G. Van Hoven, S. Ruden, and A. V. Schiano have greatly expanded their time-dependent hydrodynamic *solar wind models* by simultaneously solving for a three-fluid wind (electrons, protons, and alpha particles) including nonlinear thermal conduction, localized electron and ion heating, and nonspherical geometries (expanding/diverging flux tubes). They have continued their calculations into three-fluid steady-state solar outflows and have begun to investigate the influence that transient phenomena such as solar flares or coronal mass ejections have on the solar wind. Their results indicate that coronal heating mechanisms that primarily provide energy to the electrons are highly inefficient with most of the energy being conducted back into the chromosphere rather than providing kinetic energy to the wind. Models of ion heating are currently under investigation.

2.8 Wavefront Sensing at the Keck Telescopes

During the past year, the Wavefront Sensing Group, lead by Dr. G. Chanan, continued its efforts to improve the alignment and phasing of the first Keck Telescope and also installed a phasing camera in the second Keck Telescope. Keck II was successfully phased on the first attempt, and both telescopes are now routinely phased to a level of about 50 nm. This phasing is essential if the telescopes are to meet their specifications of diffraction-limited imaging in the mid-infrared.

Work also continued on the characterization of atmospheric turbulence at Keck. An important conclusion of this program is that the so-called outer scale of turbulence, which is usually assumed to be of infinite size, appears to be no more than 100 meters in length. This surprising result has important implications for image motion and for the design of adaptive optics at the Keck Observatory.

3. THE UCI TELESCOPE

Smecker-Hane led work on the recently acquired 24 inch telescope that is located on the outskirts of the campus. Giles Goodwin, a summer student, painstakingly realigned the telescope and characterized the telescope and CCD camera. Even before careful refinement of the optical alignment, the image quality is quite reasonable (PSF FWHM $= 2.5''$). We are now updating the observatory computer and creating a software interface for the camera to make using it more efficient to use. The telescope promises to be valuable tool for teaching our undergraduate students about the practical aspects of astronomical research as well as educating non-science majors and the general public about physics and astronomy.

4. SPECIAL DISTINCTIONS

Virginia Trimble was elected to the board of directors of Sigma Xi, the Scientific Research Society, and served as Mills Lecturer at Kalamazoo College, White Lecturer at Otterbein College, Dean Lecturer at the California Academy of Sciences, and IBM Lecturer at Wittenberg University during 1995–1996.

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Tammy Smecker-Hane