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1. ASTROPHYSICS AT THE UNIVERSITY OF COLORADO, BOULDER

1.1 Introduction

The astronomy and astrophysics program at the University of Colorado (<http://casa.colorado.edu>) exists within the structure of the Astrophysical and Planetary Sciences Department (APS), with its affiliated units – the Center for Astrophysics and Space Astronomy (CASA), the Joint Institute for Laboratory Astrophysics (JILA), and the Laboratory for Atmospheric and Space Physics (LASP). Previous Observatory Reports provide details on the organizational arrangement.

The APS Department offers an academic program leading to the PhD degree in a variety of areas of astrophysics and planetary sciences. Students obtain basic theoretical knowledge common to these related fields, before specializing. Faculty have active research programs funded by NASA, NSF, and DOE.

In this report, we emphasize new developments and recent publications specifically within CASA and its membership. In astrophysics, particular strengths of CASA lie in hot and cool stars, interstellar and intergalactic matter, high-energy astrophysics, solar physics and UV/Xray/IR/sub-mm instrumentation.

1.2 Scientific Developments

1.2.1 Instrumentation

Colorado's role in the Far Ultraviolet Spectroscopic Explorer [FUSE] is nearing completion in Phase C/D (construction) work. Dr. James Green is a member of the FUSE Hardware Working Group and Science Working Group, and PI of the Colorado effort, along with Dr. Wilkinson, Mr. Andrews, Ms. Shipley, and Mr. Kushner directly supporting the Phase C/D effort at Boulder. Drs. Cash, Linsky, Shull, and Snow also participate in the FUSE Science Working Group.

NASA recently selected the Cosmic Origins Spectrograph (COS), an ultraviolet spectrograph to be built jointly by CU's Center for Astrophysics and Space Astronomy and Ball Aerospace & Technologies Corp. in Boulder, for installation aboard the Hubble Space Telescope in 2002. COS will bring the diagnostic power of UV spectroscopy to bear on such fundamental issues as the ionization and baryon content of the intergalactic medium and the origin of large-scale structure in the Universe; the ages, dynamics, and chemical enrichment of galaxies; and stellar and planetary origins. COS will build on the legacies of Copernicus, IUE, GHRS, FOS, STIS, and in the future, FUSE, giving HST the greatest possible grasp of faint UV targets, a capability perhaps not available from future space-based observatories for decades. COS will thus complement and extend the suite of HST instruments, ensuring that Hubble maintains a powerful UV

spectroscopic capability from 2002 until the end of its mission.

1.2.2 Space Astronomy

CASA astronomers continue intensive use of NASA spacecraft. In 1997, there were awards from the Hubble Space Telescope (HST), Extreme Ultraviolet Explorer (EUVE), ASCA, X-ray Timing Explorer (XTE), and ROSAT. Grants were received from other NASA programs including Astrophysics Theory, Data Analysis and Long-Term Programs.

1.2.3 Groundbased Astronomy

CASA scientists continue to make extensive use of National groundbased optical and radio facilities for solar, stellar, interstellar, and extragalactic research. Efforts are underway to secure a partnership in a new optical telescope development effort, in order to enhance teaching and research efforts within the Department, as well as the affiliated organizations.

1.3 Selected Individual Research

Tom Ayres is involved in a number of ongoing observational projects with the solar IR spectrograph at the McMath-Pierce telescope, as well as the new Phoenix nighttime IR spectrometer (which he and his colleagues also used recently for selected solar measurements). Recent stellar work has focussed on the evolution of hot coronae on moderate mass giants; and the fate of magnetic activity among old low mass red giants. Recent observations include HST/GHRS measurements of hyperactive solar-type stars in young galactic clusters, and ASCA pointings on the unusual Hertzsprung gap giant HR9024. New programs include EUVE spectroscopy of additional gap giants; HST/STIS repeat observations of the archetype red giant Arcturus (a previous GHRS observation failed owing to acquisition problems); and a ROSAT/HRI search for faint X-ray emissions from K-type giants in depths of the coronal "graveyard." Work continues on an RXTE measurement of the bright coronal source Capella. In addition, Ayres and several CASA colleagues participated again as weekly science planners for the SUMER spectrometer on SOHO (May 1997), and are actively engaged in analyzing the substantial amounts of long-slit far-UV solar spectra acquired during that period. Ayres also is continuing to serve as Assoc. Director of CASA, and is supervising (together with Alex Brown) 2nd-year graduate student Rachel Osten.

Jon Morse continued research on processes in the interstellar medium over the past year, including HST studies of protostellar jets, oxygen-rich supernova remnants, the high-velocity debris of Eta Carinae, a new planetary nebula in the globular cluster NGC 6441, and the extended line-emitting

region in the Seyfert galaxy NGC 5252. Recent papers and HST images are posted on the Web site <http://casa.colorado.edu/~morse/>.

Morse has re-calculated a dense grid of synthetic stellar spectra based on Kurucz model atmospheres for use as templates in the CfA Stellar Velocity program. Spectra cover the wavelength range 5145 - 5230Å. The grid spans the following parameters: $T_{\text{eff}} = 3500$ to 10000 K in 250 K steps, $\log g = 0.5$ to 5.0 in steps of 0.5 , $[M/H] = +0.5$ to -4.0 in steps of 0.5 , and 22 $v_{\text{sin}i}$'s ranging from 1 to 140 km/s.

Morse is the Project Scientist for the Cosmic Origins Spectrograph (COS), to be installed aboard HST in 2002. He is responsible for coordinating and executing the COS GTO science program, and interfacing with both hardware and software engineers to ensure the science goals can be met by the instrument design.

Jeff Bennett continued his work in developing new approaches to mathematics and science education, as well as continuing his teaching for the U. of Colorado's Honors Program. He has nearly completed work on two textbooks that will be published in 1998: one a textbook in mathematics for liberal arts students, the other a new textbook for introductory astronomy. Both will be published by Addison-Wesley. Another long-time project of his, the Voyage project to build a scale model solar system on the National Mall, was recently approved by the Smithsonian Institution and will be funded by NASA. Bennett is co-I on this project with Jeff Goldstein of the Challenger Center. Construction is expected to occur in 1999.

Mike Shull's interests lie in studies of interstellar and intergalactic matter, supernova remnants, and active galaxies. M. Giroux, M. Fardal, and Shull made theoretical studies of the reionization of the high-redshift IGM and He II Gunn-Peterson effect, including a refinement of the intergalactic opacity and the ionizing radiation field from quasars and starbursts. Giroux and Shull published a theoretical paper that used the Si IV and C IV absorption lines in the high- z Lyman-alpha forest to diagnose chemical evolution and local effects of photoionization from starburst galaxies. With S. Penton and J. Stocke, Shull used HST/GHRS spectra of low-redshift Lyman-alpha clouds to estimate the spatial distribution, masses, and metallicities of these absorbers; they could contain 20 percent of the cosmological baryon density at low redshift. R. Fesen and Shull published a study of the circumstellar environment of the Crab Nebula, suggesting a disk and bipolar outflow. Shull participated in several IUE-AGN variability campaigns for three active galaxies (Fairall 9, NGC 7469, and PKS 2155-304), and is active in science planning for two new NASA ultraviolet missions: FUSE and HST/COS. The scientific program for these missions includes studies of D/H, O VI, H₂, AGN, and the hot/ionized IGM, with the "Far Ultraviolet Spectroscopic Explorer" (launch Oct. 1998) and the "Cosmic Origins Spectrograph" for the Hubble Space Telescope 2002 refurbishment mission.

Ted Snow focused most of his attention during the past year on problems related to interstellar abundances and depletions (the fraction of each element which adheres to dust grains instead of being in the gas form), and on the unidentified diffuse interstellar bands (a series of some 200

spectral absorption features whose origin is unknown after more than 75 years since they were first noticed). An IUE-based study of abundances and depletions toward stars within and near the Orion nebula (Shuping and Snow, *Astrophys. J.*, 480, 272, 1997) showed that depletions in this region of high ultraviolet flux are little altered as compared with other diffuse clouds. In a more recent, HST-based analysis, Snow *et al.* (*Astrophys. J. Letters*, in press) showed that the depletions of carbon and oxygen, both thought by some to be constant, actually do vary with dust extinction properties, with the carbon depletion in particular growing rapidly in translucent interstellar clouds (i.e. clouds with moderate extinction, greater than in the diffuse clouds on which previous results were based). Snow's work on abundances and depletions culminated with a major review paper (written for the NATO International School of Space Chemistry, held in Erice, Sicily, in March 1997), in which the evidence for systematically smaller abundances of heavy elements in the local galaxy, as compared with the solar system, was summarized, and optimum directions for future research were described. The proceedings of the Erice school are in press. On the diffuse bands question Snow, in collaboration with V. Bierbaum (of the Chemistry Department at Colorado) measured chemical reaction rates in molecular ions (PAH cations) suggested as carriers of the interstellar features. The results (published by Bierbaum *et al.*, *J. American Chem. Soc.*, 119, 8373, 1997) show that small PAH cations will migrate quickly to their hydrogen-rich (protonated) forms, and that therefore ions of the standard parent PAHs are not good diffuse band candidates (the protonated forms are not expected to have optical spectra). A second paper on the astrophysical analysis of these results was in press (in *Nature*) as of late 1997 (Snow *et al.*), and a third (Le page *et al.*) was in preparation, soon to be submitted to *J. American Chem. Soc.* (this paper provides a complete description of the laboratory work and results). Further diffuse bands work by Snow involved a study of the relationships between strong and weak diffuse bands, and the resulting paper is in press (Krelowski *et al.*, *Pub. Astron. Soc. of the Pacific*, October 1997). In addition, a major analysis of the profile of the 4430Å diffuse band, based on high-quality CCD data, is in progress (Snow *et al.*, in preparation).

1.4 Personnel Changes During 1997

New Research Associates: Dr. David Devine (University of Colorado).

Research Associate Departures: Dr. Philip Duggan (Canada).

CASA Visiting Scientists: Dr. Wendy Bauer (Wellesley College) Dr. Tom Ray (Dublin Institute) Dr. Bo Reipurth (ESO/Chile)

New Graduate Students: Massimo Ricotti.

New Staff: Joel Johnson, Jerry Wagner.

2. PUBLICATIONS DURING 1996/97

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