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1. INTRODUCTION

The astronomy and astrophysics program at the University of Colorado 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.

2. SCIENTIFIC DEVELOPMENTS

2.1 Instrumentation

Colorado's hardware role in the Far Ultraviolet Spectroscopic Explorer [FUSE] concluded with delivery of the spectrograph to Johns Hopkins in 1998. The mission was successfully launched in summer 1999. At this writing, the instrument checkout phase is in progress. Dr. James Green, PI of the Colorado hardware effort, is a member of the FUSE Science Working Group, together with CASA astronomers Drs. Cash, Linsky, Shull, and Snow. Post-launch efforts are focussing on development of software tools to analyze the far-UV spectra anticipated from the early GTO observation phase, and subsequent Guest Observer programs.

The CASA hardware team continues work on the Cosmic Origins Spectrograph (COS), to be installed in NASA's Hubble Space Telescope circa 2004. The powerful ultraviolet instrument will be built jointly with Ball Aerospace and Technologies Corp. in Boulder. 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 FUSE, giving HST the greatest possible grasp of faint UV targets, ensuring that Hubble maintains a powerful UV spectroscopic capability through the end of its mission.

2.2 Space Astronomy

CASA astronomers have made intensive use of NASA spacecraft. In 1999, there were awards from the Hubble Space Telescope (HST), Extreme Ultraviolet Explorer(EUVE), and ASCA; as well as future observing with recently launched Chandra X-ray Observatory and FUSE. Grants were received from other NASA opportunities including Astrophysics Theory, Data Analysis and Long-Term Programs. Observing proposals for ESA's XMM and the Japanese Astro-E X-ray spectroscopy missions are pending.

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 continue to secure a partnership in a new optical telescope, in order to enhance teaching and research efforts within the APS Department, as well as the affiliated organizations.

3. SELECTED INDIVIDUAL RESEARCH

Tom Ayres has been involved in a wide range of observational projects including: the solar McMath-Pierce Infrared Imaging Spectrometer (IRIS), the PHOENIX nighttime cryogenic IR spectrometer, HST/STIS ultraviolet spectroscopy, EUVE, and the solar satellites SOHO and TRACE. Ayres is PI of a large project in HST cycle 8, involving collaborators from a number of institutions world-wide, to record the UV emission spectra of a diverse sample of late-type stars using STIS. One of the recent observations–of RS CVn system HR1099–was done contemporaneously with a Chandra transmission grating pointing, in support of CXO's ''Emission Line Project.'' Ayres also has been working with other STIS data sets including a carry-over observation of the red giant Arcturus obtained last year, more recent pointings on Beta Ceti (K0 III) and Alpha TrA (K2 II) from Jeff Linsky's GTO program, and long-slit low-res observations of R CrB stars (with Geoff Clayton of LSU) and the enigmatic Hyades F0 star 71 Tauri (with Ted Simon of Hawaii's IfA). Programs completed and published included: an EUV flare on the yellow giant Mu Velorum, recorded by EUVE; HST/GHRS observations of solar-type stars in young clusters; and a ROSAT/HRI pointing on a ''noncoronal'' red giant. Ayres also is analyzing extensive solar data sets from the SOHO/Sumer UV spectrometer obtained in May 1999 in conjunction with time-resolved UV mapping from TRACE and imaging spectroscopy (of CO 5 micron lines) from the IRIS experiment.

Ayres continues to chair the National Solar Observatory Users Committee, and continues to serve as Assoc. Director of CASA. He is supervising (together with Alex Brown) 4th-year graduate student Rachel Osten. Ayres heads up the sci-

entific organizing committee of the 12th Cambridge Workshop on Cool Stars, Stellar Systems and the Sun, to be held in Boulder in early August 2001.

Jeff Bennett continued his work on developing innovative approaches to mathematics and science education. He authored articles on general approaches to teaching both in mathematics and astronomy, and maintained an active speaking schedule on these topics. He also continued work on his textbook project. One new book was completed: The Cosmic Perspective Brief Edition (with Megan Donahue, Nicholas Schneider, and Mark Voit; from Addison Wesley), which is a condensed and updated version of the textbook he published last year. He also worked on a new textbook in Statistics to be published next year. In addition, Bennett continued his work as Co-PI on the Voyage project to build a scale model solar system on the National Mall; the project is jointly sponsored by NASA, the Smithsonian Institution, and the Challenger Center for Space Science Education. He also continued to teach for the U. of Colorado's Honors Program.

Phil Bennett's past summer marked the successful completion of the extensive set of observations obtained by HST GO program 7269: ''The 1997/98 Eclipse of VV Cephei.'' This program monitored the evolution of the ultraviolet spectrum during the eclipse and egress phases of this long-period (20.3 yrs) binary system (M2 Iab + B). Monitoring of the UV spectrum continues at a reduced frequency by HST GO program 8257, which will run through the end of Cycle 10 in 2002. We have also obtained UV spectra of the VV Cephei stars KQ Puppis and HR 8164, both systems of which contain an M2 supergiant primary star. In addition, we obtained a low-resolution UV spectrum of the (single) M2 Ia supergiant mu Cephei. The objective of these observing programs is to determine the structure of the chromosphere and wind of an M2 supergiant. Preliminary results for VV Cephei were presented at the Cool Stars, Stellar Systems, and the Sun: 11th Cambridge Workshop held at Tenerife, Spain in October, 1999.

E. Ellingson and collaborators have continued work on intermediate redshift X-ray selected clusters at both optical and X-ray wavelengths. Previous cluster mass estimates based on galaxy dynamics (Carlberg, Yee and Ellingson 1997) were confirmed using ROSAT and ASCA measurements, with estimated systematic uncertainties at the $\sim$ 20% level (Lewis *et al.*, 1999). Discrepancies with gravitational lensing masses remain significant, however, which will be addressed using planned observations with Chandra. Studies of galaxy populations in intermediate redshift clusters via spectroscopic principal component analysis suggest that infall from the field may be responsible for the increasing blue fraction in clusters with redshift (Ellingson *et al.* 1999). Decomposition of the cluster populations into an old ''cluster'' population and galaxies with younger ''field galaxy'' stellar populations suggest that the former are in a relatively unevolving, virilized state, while the latter form a broader spatial distribution which is declining over time. This link between galaxy populations and cosmology is broadly consistent with a low matter density universe.

Brad Gibson maintained his active presence in the HST Key Project on the Extragalactic Distance Scale. His research was primarily related to the use of Type Ia supernovae as standard candles in measuring the expansion rate of the universe - i.e., the Hubble Constant. His work led to the first supernova-based Hubble Constant which was in agreement with that derived independently via other secondary distance indicators, such as the Tully-Fisher relationship, reconciling a long-standing discrepancy in the field. Gibson was an invited speaker at the Chicago AAS Topical Session on the Distance Scale. Gibson and Maloney investigated claims that the Cepheid-based extragalactic distance scale has been compromised by an unappreciated systematic effect due to blending of overlapping stellar images in HST data; their results have show these claims to be unsubstantiated. Gibson and his student Mary Putman (Australian National University) continue to map the High-Velocity Cloud (HVC) distribution in the southern sky. In tandem, Gibson (with Shull, Stocke, Penton, and Giroux) continues to investigate the metallicity and ionization structure of HVCs as observed as part of their HST program. Further FUSE investigations are planned for 2000. Gibson undertook a large survey of over 1000 astronomy graduates, in an attempt to ascertain the importance of one's PhD institute in pursuing a long-term research career in astronomy. These results were presented at a Special Session of the Chicago AAS. Gibson was invited to participate in the AAS Council Meeting in June, as an under-40 representative member of the community. Gibson organized two international meetings on the Galactic halo and HVCs, the proceedings for which he edited and published in the ASP Conference Series.

Nick Gnedin continued his research on numerical simulations in cosmology. He has completed the major project on modeling reionization of the universe, fully accounting for the time-dependent and spatially inhomogeneous radiative transfer.

Ricotti, Gnedin, and Shull have developed a technique for measuring the effective equation of state of the intergalactic medium from the observational data on the Lyman-alpha forest. The method was utilized to analyse the large set of observational data, and the effective equation of state of the IGM was measured at cosmological redshifts from 0 to 4. They discovered an epoch of secondary reheating of the IGM, which they tentatively identified with the reionization of helium.

Jon Morse continued research on processes in the interstellar medium, including HST studies of protostellar jets, oxygen-rich supernova remnants, and Eta Carinae.

Morse is the Project Scientist for the Cosmic Origins Spectograph (COS) for the Hubble Space Telescope. He is responsible for coordinating and executing the COS GTO science program, and interfacing with both hardware and software engineers to ensure that the science goals can be met by the instrument design.

Morse was the principal editor of two conference proceedings: ''Ultraviolet-Optical Space Astronomy Beyond HST,'' ASP Conf. Ser., Vol. 164 (eds. J.A. Morse, J.M. Shull, and A.L. Kinney), and ''Eta Carinae at the Millennium,'' ASP Conf. Ser., Vol. 179 (eds. J.A. Morse, R.M. Humphreys, and A. Damineli).

Bo Reipurth has continued his analysis of Herbig-Haro

jets from young stars, especially based om HST NICMOS data. Studies of nine embedded jet sources have revealed that [FeII] is an important contributor to the emission from the jets, and have also demonstrated the importance of stellar multiplicity for the evolution of the jets. Groundbased observations obtained together with John Bally have demonstrated that parsec-scale outflows are common, and a number of such jets have been found emanating from the L1641-N embedded cluster. Analysis of the proper motion vectors of the well known objects HH 28 and 29 have revealed that they are probably not driven by the L1551-IRS5 source, as generally assumed, but rather by the nearby L1551-NE source, underlining the importance of confusion in star forming regions. Finally, a string of protostars in OMC 2/3, many of which are driving powerful outflows, have been detected for the first time with the VLA.

Michael Shull's interests lie in studies of interstellar and intergalactic matter, supernova remnants, and active galaxies. His research group carries out theoretical studies, as well as space observations with the Hubble Space Telescope (HST) and the Far Ultraviolet Spectroscopic Explorer (FUSE). Data from FUSE are now arriving on interstellar H2 and O VI, and on intergalactic matter in the low-redshift Ly-alpha forest. The HST data are also plentiful during cycles 7 and 8. Over the past year, Shull led a NASA-sponsored study on future UV/Optical Space Astronomy beyond HST. Their committee recommended a new ''Space Ultraviolet Observatory,'' referred to as SUVO or ST-2010. The committee's report on the science goals of the ST-2010 Mission appeared as a White Paper, available on astro-ph/9907101. A book giving the proceedings of the Boulder Conference on UV/Optical Space Astronomy appeared in the ASP Conf. Series, Vol. 164 (ed. Morse, Shull, and Kinney 1999).

Recent scientific publications of the group include theoretical models of the intergalactic ionizing radiation field and the He II Gunn-Peterson Effect (Fardal, Giroux, and Shull 1998; Shull, Roberts, Giroux *et al.* 1999; Tumlinson *et al.* 1999), and an an observational review of our HST results on the low-z Lyman alpha forest (Shull, Penton, and Stocke 1999). Our group also published HST studies of a cluster of strong, possibly primordial, low-redshift Ly-alpha absorbers toward PKS 2155-304 (Shull, Penton, Stocke *et al.* 1998), with $[Si/C] < 0.003$ solar metallicity. These studies probe the chemical evolution of the IGM. We are following up these studies with both HST/STIS and FUSE.

Current work is underway in similar areas. Penton, Stocke, and Shull just submitted 3 major papers to ApJ on the low-z Ly-alpha forest observations and analysis with HST. Their work shows that the low-z Ly-alpha absorbers may contain 20baryons believed to be present from nucleosynthetic estimates. Shull, James Dove, and student Massimo Ricotti are now modeling the escape of ionizing photons from superbubbles and from primordial spheroidal galaxies, to understand their role in the warm ionizewd medium of galaxies and the IGM. Riccoti, Gnedin, and Shull are studying the effective equation of state of the IGM, using both data (Ly-alpha line widths) and numerical hydrodynamical models.

Ted Snow continued his interstellar medium research, concentrating on problems related to the interaction of gas and dust in interstellar clouds, the connnection between interstellar and interplanetary dust, and the longstanding question of the unidentified diffuse interstellar bands (DIBs). These research programs involve both observational and laboratory studies. During the past year, Snow's observational programs were largely ground-based, with several observing runs at Kitt Peak (Coudé Feed Telescope) and Mauna Kea (the IRTF and the Keck I telescopes) - but space-based observations, particularly with the Far Ultraviolet Spectroscopic Explorer (FUSE), are becoming Snow's primary focus as we near the end of this reporting period. Snow's ground-based observations, done in collaboration with graduate student Ralph Shuping, included infrared spectroscopy of heavily-reddened hot stars within or behind dense interstellar clouds, with the aim of determining the degree of depletion of CO from the gas onto icy grain mantles. Three papers have come from this work in the past year, all led by Shuping: Shuping, R. Y., Snow, T. P., Chiar, J. E., and Kerr, T. ''Solid-State CO toward r Oph Elias 25: Ice Thresholds Revisited,'' Astrophs. J., in press; Shuping, R. Y., Snow, T. P., and Chiar, J. E. ''A Direct Measure of the CO Depletion in the Taurus Dark Cloud: The Elias 18 Line of Sight,'' Nature, submitted; and R. Y. Shuping, T. P. Snow, B. L. Lutz, and R. Crutcher 1999, CO and C2 Absorption Toward W40 IRS 1a, Astrophys. J., 520, 149. Snow's Keck I observations, done in collaboration with G. Blake (Cal Tech) and Shuping, were aimed at measuring optical atomic and molecular lines toward OB stars behind dense molecular clouds, a regime that has previously been unexplored. The observations were successful, but analysis is not complete at this writing. The Coude Feed observations at Kitt Peak were aimed at two distinct programs: (1) amassing high-resolution optical spectra to support the analysis of molecular hydrogen (H2) bands to be observed with FUSE (for which Snow has primary responsibility for dense-cloud H2 observations); and (2) new studies of the DIBs. The FUSE support data will help in the analysis of strong H2 bands to be observed with FUSE, whose spectral resolution is insufficient to allow the direct derivation of multi-component velocity structure. The DIBs data are being used to determine whether the diffuse bands form in lines of sight toward cool stars, as a means of testing certain DIBs models in which high UV fluxes are required. At this writing the analysis is not complete. Regarding the connection between interstellar and interplanetary grains, Snow continued his collaboration with J. P. Bradley (MVA, Inc.) on spectroscopic studies of grains from both environments, and this led to the discovery that the 10-micron infrared spectrum of silicate inclusions in interplanetary particles called GEMS (Glasses with Embedded Metals and Sulfides) match the interstellar 10-micron feature better than any terrestrial silicates yet measured, lending strong support to the hypothesis that the GEMS are primordial interstellar silicate grains right here in our hands. This work has been published: Bradley, J. P., Keller, L., Snow, T. P., Flynn, G. J., Gezo, J. C., Clemett, S. J., Brownlee, D. E., Hanner, M. S., and Bowey, J. E. 1999, ''An Infrared Spectral Match between GEMS and Interstellar

Grains,'' Science, 285, 1716-1718. Finally, Snow's ongoing laboratory study of candidate carriers of the DIBs led to new results on ionized polycyclic aromatic hydrocargons (PAHs): Le Page, V., Y. Keheyan, Y., T.P. Snow, and V. M. Bierbaum 1999, ''Gas Phase Chemistry of Pyrene and Related Cations with Molecules and Atoms of Interstellar Interest,'' International Journal of Mass Spectrometry, 185/186/187, 949-959; and LePage, V., Y. Keheyan, T. P. Snow, and V. M. Bierbaum 1999, ''Reactions of Cations Derived from Napthalene with Molecules and Atoms of Interstellar Interest,,'' J. Am. Chem. Soc., 121, 9435-9446. Continuing studies in this program are focused on carbon chain ions, which have recently been suggested as the carriers of some of the DIBS; preliminary results indicate serious difficulties with this hypothesis. Snow's current activities, at the close of the reporting period, are centered on FUSE, which was launched in June, 1999, and is now producing data on molecular hydrogen in regions never previously observed for this dominant species. The laboratory chemistry program will continue to focus on carbon chain ions reaction with neutral atoms such as H, and will then move on to studies of reactions of atomic cations such as C+ with neutral PAH and carbon chain molecules.

4. PERSONNEL CHANGES DURING 1999

New Research Associates: Dr. Steven Penton (University of Colorado); Dr. Brian Rachford (University of Wyoming);

Research Associate Departures: Dr. Jim Dove (Metro State, Colorado) Dr. Beverly Smith (University of Tennessee)

CASA Visiting Scientists: Dr. Steven Heathcote (Cerro Tollolo Observatory, Chile)

New Graduate Students: Matthew Beasley, Glenn Laurent

New Staff: Stephane Beland, Kendra Michaud, David Ratchford, Erin Wood, Brian Zumbach

5. PUBLICATIONS DURING 1998/99

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