Adler Planetarium & Astronomy Museum
Astronomy Department

Chicago, Illinois 60605

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The following report covers Astronomy Department activities from October 2001 through October 2002.

1. FOREWORD

The primary missions of the Astronomy Department are: (1) to conduct forefront research in astronomy, astrophysics, and cosmology, while effectively integrating research programs with public outreach; (2) to be a leading resource in conveying the methodology, concepts and discoveries of astronomy to the public; (3) to provide content for Adler projects that convey the process of science; and (4) to be a leading center of highly skilled science interpreters, who can effectively bridge the gap between the research and educational communities, and help train other scientists to become more effective in their outreach efforts.

2. PERSONNEL

Current department personnel and research interests:

K. Coble, NSF Astron. & Astrop. Postdoctoral Fellow, Univ. of Chicago/Adler (Ph.D. Univ. of Chicago 1999) − *Cosmology, Cosmic Microwave Background*

L. Fortson, Director, Adler Astronomy Department; Senior Research Associate, Univ. of Chicago; Associate Member, Univ. of Chicago Center for Cosmological Physics (Ph.D. Univ. of California, Los Angeles 1991) − *Cosmic Rays, High Energy Astrophysics*

E. Gates, Adler Vice President for Science & Education; Senior Research Associate, Univ. of Chicago (Ph.D. Case Western Reserve Univ. 1990) − *Cosmology, White Dwarfs, Cosmic Baryon Budget & Metal Production*

G. Gyuk, Adler Astronomer; Research Scientist, Univ. of Chicago; Associate Member, Univ. of Chicago Center for Cosmological Physics (Ph.D. Univ. of Chicago 1996) − *Cosmology, Microlensing, White Dwarfs, Cosmic Baryon Budget & Metal Production*

M. Hammergren, Adler Astronomer; Adjunct Professor of Astronomy, Benedictine Univ.; Participating Guest, Lawrence Livermore National Laboratory; External Collaborator, Sloan Digital Sky Survey (Ph.D. Univ. of Washington 1998) − *Solar System, Asteroids*

D. Roberts, Adler Astronomer; Visualization Support Specialist, Northwestern Univ.; Adjunct Researcher, Physics & Astronomy Department, Northwestern Univ.; (Ph.D. Univ. of Oklahoma 1992) − *Galactic Center, Masers, Radio Astronomy*

J.F. Salgado, Adler Astronomer; Adjunct Professor of Astronomy, Benedictine Univ. (Ph.D. Univ. of Michigan 2000) − *Interstellar Medium, Radio Astronomy, Visualization of Astronomical Data*

G. Wolf-Chase, Adler Astronomer; Research Scientist, Univ. of Chicago (Ph.D. Univ. of Arizona 1992) − *Star Formation, Molecular Clouds, Infrared & Microwave Astronomy, Protostars, Jets & Outflows*

3. FACILITIES

The Adler Astronomy Department has the unique distinction of being located on the premises of the newly-renovated Adler Planetarium & Astronomy Museum. Through joint appointments at the University of Chicago, the Adler Astronomy Department has access to the Apache Point Observatory 3.5-m telescope, which is owned and operated by the Astrophysical Research Consortium.

The Doane Observatory is located on the site of the Adler Planetarium, on the shore of Lake Michigan in downtown Chicago, and houses a research-grade 0.5-m Cassegrain telescope by DFM Engineering. Instrumentation has recently been upgraded, and includes a 1Kx1K Finger Lakes Instrumentation CCD camera, a SBIG STV high-speed CCD camera, and several video cameras, with a standard complement of astronomical filters. The observatory is routinely used for public observing events, evening classes, and live sky shows. A research program involving the photometric monitoring of active galactic nuclei is planned following the completion of the instrumentation upgrade.

March 2002 saw the completion of CyberSpace − an interactive multimedia environment containing Vision Stations for virtual reality experiences, a distance learning classroom with state-of-the-art videoconferencing equipment, and a computer classroom for interactive learning activities. The fast time scale with which new content can be disseminated in CyberSpace opens new doors for effectively integrating research programs with educational outreach. Also in March, new interactive components were installed in Adler's largest exhibit gallery − the Milky Way Galaxy.

4. SCIENTIFIC ACCOMPLISHMENTS

4.1 Composition of Cosmic Rays

It is extremely important to understand the composition in the knee region of the all particle spectrum, primarily because the knee is the only distinguishing feature of an otherwise impressively continuous power law extending over ∼10 decades in energy. This break in the spectrum provides reason to believe that cosmic rays below and above the knee are produced by different astrophysical mechanisms. Current theories using supernova shock acceleration and galactic diffusion models predict that the composition should become increasingly iron-like just above the knee. Composition measurements at the knee are then one of the few directly measurable predictions that can be used to confirm this model.

As the PI of the BLANCA experiment, Fortson has recently led an effort to measure the composition of cosmic rays between 10^{14} eV and 10^{16} eV by studying the Cherenkov radiation associated with the air showers produced at these energies. The Broad Lateral Non-imaging Cherenkov Array operated in conjunction with the Chicago Air-Shower Array in Dugway, Utah through May, 1998. Results from this experiment generally agree with the model where a lighter composition is seen at energies below the knee changing to more iron-like composition above the knee. However, there is an intriguing feature in this composition trend which was not predicted and which has also been detected by competing experiments such as Kascade. A workshop was hosted by Fortson and collaborators at the Adler Planetarium in 2000 to study this feature and review the recent results from many new experiments studying composition of cosmic rays at the knee. Fortson was a principle author on the paper resulting from this workshop which was published in 2002. This paper has been cited in the Particle Physics Data Book on the section on Cosmic Rays as the reference paper for cosmic rays at the knee.

With collaborators at the Univ. of Chicago, Fortson is participating in an effort that would detect the emission of Cherenkov light directly from the primary particle as it enters and interacts with the atmosphere. By studying BLANCA data, we can place a limit on very high mass ($Z \geqslant 26$) nuclei fractions in the composition of cosmic rays. Fortson presented her work on composition of cosmic rays at the Aspen Winter School, January 2002.

4.2 Cosmology

4.2.1 Cosmic Microwave Background

Coble focuses on Cosmic Microwave Background (CMB) observations and analysis. She has been working with the DASI and SZE groups at the Univ. of Chicago. CMB measurements critically test the standard theory of structure formation as well as constrain cosmological parameters. The Sunyaev-Zel'dovich (S-Z) effect is a signature in the CMB from the interaction of CMB photons and the hot x-ray gas associated with galaxy clusters. Combining S-Z and x-ray observations of galaxy clusters can yield measurements of the Hubble constant, the matter density and constrain galaxy cluster physics. Coble has been using SZ and VLA data to determine the effects of point sources on CMB and SZ experiments.

4.2.2 Microlensing in the Andromeda Galaxy (M31)

Although there is compelling evidence that spiral galaxies are embedded in extended non-luminous halos there is little direct information concerning halo composition. X-ray observations rule out a hot, gaseous halo, and the Hubble Space Telescope has placed tight limits on the contribution of faint stars. The most promising candidates for the halo dark matter are cold dark matter (CDM) particles and baryons in the form of MACHOs (Massive Astrophysical Compact Halo Objects). Observation of microlensing events towards the Large Magellanic Cloud (LMC) over the last few years has posed very intriguing questions about the baryonic content of the Milky Way's halo. Recent microlensing experiments suggest that perhaps 20% of the Galactic halo may be composed of compact objects (MACHOs) with masses roughly in the range $0.1 - 1$ solar masses. Astrophysical candidates for MACHOs − white dwarfs, neutron stars, and black holes − each present serious challenges for stellar formation and evolution theories.

Unfortunately, the paucity of lines of sight and the low event rate make studying the structure of our galactic halo through LMC microlensing very difficult. Furthermore, there is the question whether the Milky Way is a typical galaxy. Microlensing towards M31 (Andromeda) address all three of these concerns. By looking at the variation of the optical depth across the face of M31, MEGA probes a wide variety of lines of sight through its halo. Because of the high inclination of M31 (77°), the optical depths to the disk are considerably higher than for the LMC. Finally, microlensing observations will directly address the question of the uniqueness of the LMC measurements: finding a MACHO halo around the Andromeda galaxy would demonstrate that baryonic halos are a generic consequence of galaxy formation and evolution (at least for spirals).

Geza Gyuk continues as an active member of the MEGA (Microlensing Exploration of the Galaxy and Andromeda) collaboration, a long-term project to search for microlensing events in Andromeda. MEGA uses an innovative image subtraction technique that radically increases the experimental sensitivity to changes in the flux due to microlensing. With a multi-year baseline already obtained, the MEGA collaboration is starting its last season of observing M31. On the theoretical front, along with Arlin Crotts, (Columbia) Gyuk has shown that with observation of M31 over a period of a few years we should expect hundreds of events and a clear halo signal for halo fractions greater than 0.1. MEGA expects to focus on construction of a data pipeline and analysis of its data over the next year. The result should be strong limits not only on the total M31 mass in MACHOs but also on some of the halo's structural parameters such as the core radius, flattening and radial distribution. As a sideline, MEGA expects to collect a vast database on Andromeda including variable stars, bulge and disk profiles, luminosity functions etc.

4.2.3 White Dwarf Search in the Sloan Survey

Gates and Gyuk have been studying an ancient, very cool, white dwarf population on both the theoretical and observational fronts. They have proposed a new component of the Galaxy, a very thick disk-like "shroud" which reduces the required mass while at the same time maintaining the observed LMC microlensing. While many newly observed ancient white dwarfs appear to have kinematics halfway between halo objects and disk objects, unfortunately the number of such ancient white dwarfs known is still very small.

Gyuk and Gates are searching for more white dwarf candidates in the Sloan Digital Sky Survey (SDSS). Theoretical models indicate that these objects should be far bluer than previously expected. Since the Sloan Survey images in five colors, they select out only those objects that meet the criteria for white dwarfs. Removing all objects that are astrometrically fixed (quasars, blue galaxies, etc.) yields a sample that can be confirmed spectroscopically. By the time the SDSS is finished they expect to have discovered somewhere between 10 and 100 very cool white dwarfs.

4.2.4 Cosmic Baryon Budget and Metal Production

Light element abundances and the CMB fix the baryon density at about 5% of critical density, far above that observed directly in galaxies. Various candidates for the remaining baryons, such as MACHOs or intermediate temperature intergalactic gas, have been proposed. Gates and Gyuk have recently begun collaborating with Brian Fields (Univ. of Illinois, Urbana/Champaign) to explore the metallicity history and baryon budget of the Universe. They are synthesizing data from many observational techniques as well as computer simulations to obtain a global picture of where the metals are produced and where they end up.

4.3 Galactic Center

Roberts, working with Yusef-Zadeh (Northwestern Univ.), has continued radio observations of the ionized gas at the center of the Galaxy. Roberts made new radial velocity measurements of the HII region at the center of the Galaxy, Sgr A West. These observations are being combined with two earlier epochs to determine the change in radial velocity due to acceleration of the gas. These radial velocity changes are being compared with proper motion velocities of Sgr A West made in the radio continuum.

4.4 Masers

Along with colleagues Yusef-Zadeh (Northwestern Univ.) and Wardle, Roberts has carried out radio observations of OH (1720 MHz) masers to determine the amount of absorption at the OH main lines (1665 and 1667 MHz). Main line absorption, lack of main line maser emission and 1720 MHz maser emission appear to be tracers of supernova−molecular cloud interactions.

4.5 Solar System

4.5.1 Asteroids

Hammergren has continued his studies of solar system objects as an external collaborator with the Sloan Digital Sky Survey (SDSS). With his colleagues on the SDSS, he has examined the properties of approximately 10,000 asteroids in the Early Data Release of the survey. They determined the size distribution of main-belt asteroids down to diameters of approximately 400 meters, and found that there are around one-fourth as many small asteroids as had previously been believed. They also demonstrated that the SDSS can detect the color segregation among asteroids across the main belt, which is believed to be due to an intrinsic compositional gradient in the solar nebula.

Hammergren is examining the SDSS for pre-discovery images of near-Earth asteroids and comets. Unlike other pre-discovery archives currently being searched, the SDSS reaches a considerably fainter magnitude than the discovery surveys themselves, and provides multicolor photometry that can help determine the taxonomic type (and thus rough surface composition) of such objects.

Along with colleagues B. Macintosh (LLNL), S. Gibbard (LLNL), C. Max (LLNL), and D. Gavel (LLNL), Hammergren is investigating the size and shape of asteroid (216) Kleopatra through speckle interferometric imaging obtained with the Keck I telescope. They find that this unusual dog-bone-shaped asteroid is significantly longer than a radar-derived shape model (Ostro *et al.*, Science 288, 836), which has implications for formation scenarios.

Hammergren is conducting a program of astrometric follow-up of near-Earth asteroids that are in urgent need of observations, using the ARC 3.5-m telescope at the Apache Point Observatory. This program is one component of a weekly transient observing effort organized in conjunction with colleagues at the Adler and Univ. of Chicago.

4.6 Star Formation

4.6.1 Protostars, Jets & Outflows

One of the outstanding questions in star formation is whether high-mass stars form − and drive outflows − in a similar manner to low-mass stars, but the answer to this question is poorly constrained observationally. Although the tendency for stars to form in clusters in regions of intermediate- and high-mass star formation has been firmly established, the main database for infrared data on these stellar nurseries remains that of *IRAS*, which typically probes large cloud structures identified with the formation of clusters or groups of stars (clumps), rather than the smaller condensations ($\sim$0.1 pc − cores) out of which single stars or multiple stellar systems form. In confused regions, determining the luminosities and spectral energy distributions (SEDs) of individual star-forming cores is a shaky business at best. It is not at all clear what an SED means in cases where it describes not a single star-forming core, but rather a group of objects, which may or may not be coeval, yet the *IRAS* database has been used extensively to help determine the luminosities of young stellar objects (YSOs) and to establish correlations between YSO and outflow properties. In principle, such correlations can be used to investigate the relationship between outflow and accretion rates, and thus distinguish between different theories of the outflow mechanism.

Wolf-Chase, with colleagues Moriarty-Schieven (JAC, Hilo), Fich (Univ. of Waterloo), and Barsony (Space Science Institute), has been using observations acquired with the Submillimetre Common-User Bolometer Array (SCUBA) at the James Clerk Maxwell Telescope (JCMT)[1] on Mauna Kea to help model resolution enhanced (HIRES-processed) *IRAS* data in order to determine the contributions of individual star-forming cores (and more evolved objects) to *IRAS* fluxes in protostellar clumps. She has found that most of the 60 & 100 μm flux comes from very young objects that have sub-millimeter counterparts, but most of the 12 & 25 μm flux comes from more evolved objects in the field. Many of the clumps containing these objects have been previously associated with one molecular outflow, but with the aid of large-scale millimeter-wave maps of outflows in these regions, acquired at the Arizona Radio Observatory 12-m telescope, and previously published observations of jets and outflows, Wolf-Chase is finding that regions formerly associated with single

[1]The JCMT is operated by the Joint Astronomy Centre on behalf of the Particle Physics and Astronomy Research Council of the United Kingdom, the Netherlands Organization for Scientific Research, and the National Research Council of Canada.

outflows show far more complicated outflow morphology than previous lower-resolution maps indicate. Just as the *IRAS* flux is distributed among different sources, multiple sources contribute to outflows in clustered or grouped regions.

These results suggest that many of the previously noted source−outflow correlations reflect the sum total of source and outflow properties from protoclusters rather than the properties of individual sources within the cluster. Hence, the relationship between outflow momentum and source bolometric luminosity at high source luminosities is particularly called into question. These results have implications for the method of using outflow momentum deposition rates and source bolometric luminosities in order to infer the fraction of the accretion flow that is ejected into the wind of protostars, and thus for using this method to distinguish between different proposed launching mechanisms. It is clear that in many cases outflow momentum deposition rates cannot be unequivocally correlated with source luminosities in many of the clustered regions for which luminosities were derived using *IRAS* fluxes.

Wolf-Chase and collaborators O'Linger (SIRTF Science Center), Cole (JPL), and Ressler (JPL) have been conducting surveys of both low- and high-mass protostellar regions using the high-sensitivity mid-infrared camera, MIRLIN, at the NASA Infrared Telescope Facility (IRTF). Due to MIRLIN's high-spatial resolution ($\sim 1''$) and wide field of view at the IRTF ($\sim 1'$), it is possible to study both the properties and the immediate environs of the target sources and resolve protostellar binaries at $< 2''$separation. These observations are being be used to establish a more accurate consensus of objects in star-forming clumps and their physical properties.

By studying jets and Herbig-Haro Objects associated with outflows from young stars, we can probe conditions in the underlying wind more directly, and we gain dramatically in resolution over single-dish millimeter-wave observations. Since protostars are deeply embedded objects suffering from high extinction, many jets from these objects are better observed at near-infrared, rather than optical, wavelengths. H_2 2.122 and [Fe II] 1.644 μm lines are particularly useful tracers of the shocked gas in protostellar jets. In particular, shock-excited H_2 emission can trace sites of momentum transfer between stellar jets and their associated CO outflows. Although jets from low-mass YSOs have been studied in great detail, this is not the case for high-mass YSOs, especially those few that have been associated with the main accretion phase of protostellar evolution.

With colleagues Al Harper (Univ. of Chicago) and Rhodri Evans (Univ. of Wales), Wolf-Chase is conducting a survey for near-infrared jets in massive protostellar regions, using the GRIM II near-infrared camera and low resolution spectrograph on the Astrophysical Research Consortium (ARC) 3.5-meter telescope at Apache Point Observatory (APO). These observations will be compared with MIRLIN mid-infrared images, as well as MSX and 2MASS survey data, in order to investigate whether the objects(s) producing the bulk of the luminosity are also driving jets, or whether the jets are driven by lower-mass objects in the field. The near-infrared survey data will be compared to millimeter-wave outflow survey data to investigate the similarities and differences between jets from young low-mass and high-mass stars.

Determining the nature of protostellar objects in massive and intermediate-mass star-forming regions will greatly help to clarify the connection between outflow and accretion rates for high-luminosity objects, and thus for establishing the similarity to lower-mass protostars. Additionally, this work is a first-step in observationally addressing whether high-mass stars form in a similar manner to low-mass stars, or via coalescence of lower-mass star-forming cores.

4.7 Very High Energy Gamma Rays

Towards the end of the last century the Compton Gamma Ray Observatory detected hundreds of gamma ray sources up to 40 GeV. Today, only a handful of sources are known to emit at TeV energies. The detection of gamma rays above 300 GeV was first accomplished by the Whipple Telescope Atmospheric Cherenkov Technique telescopes. As the follow-on to Whipple, the VERITAS collaboration is set to build four ACTs to continue the discovery and study of very high energy gamma ray emitting objects in the universe. Fortson is an active member of this collaboration through the University of Chicago group. Apart from her work in the construction efforts for the first telescope (first light predicted Spring 2003), Fortson is the Coordinator for Optical Campaigns for VERITAS. In this role, she is involved in monitoring the optical and gamma-ray bands of TeV selected Active Galactic Nuclei to study the correlations in hopes of understanding the gamma-ray emission mechanisms. Fortson has time on the APO 3.5 meter and the WIYN 0.9 meter to pursue her monitoring campaigns. She, along with colleagues Gyuk, Hammergren, and Königl (Univ. of Chicago), is currently seeking funding to build a 16'' robotic telescope at the Apache Point Observatory for a dedicated monitoring program.

4.8 Visualization of Astronomical Data

Salgado has been working on techniques for the visualization of astronomical data for professional science journals as well as for disseminating science research to the public via different kinds of media (e.g., sky shows, gallery exhibits, web publishing).

Roberts has worked on 3D visualization of astronomy data in the 3D visual workstations in CyberSpace. Roberts, working with Frisch (Univ. of Chicago) and Hanson (Univ. of Indiana Computer Science), has helped to present data on the heliopause and the Sun's motion through the Galaxy. Roberts has also worked with SubbaRao (Univ. of Chicago) to deploy a visualization of an initial component of the Sloan Digital Sky Survey on the visual workstations in CyberSpace.

5. OUTREACH & EDUCATION

General Astronomy Department educational & outreach activities include:

Providing the content presented in exhibits, shows, and programs; including delineating the scope of the content and working with other departments to develop the content in the relevant media

Presenting lectures to staff and to the public

Developing and providing astronomy on the web, including in-depth content, inquiries, and news

Establishing mutually beneficial connections with other research and academic institutions

Interfacing with colleagues to identify opportunities for collaboration, including, for e.g., grant proposals, course instructors, and lecturers

Interacting with the media, including responding to requests for radio, print, and television interviews, as well as helping to identify and develop topics of potential interest to the media

Keeping staff apprised of news and discoveries in Astronomy

Leading a dynamic program of public observing events and opportunities

5.1 Highlights

Coble has focused on bringing cosmology and Antarctic science to the public, through courses, lectures, articles and electronic media. In September 2002, she organized and moderated the Cosmo-02 Cosmology Education Forum. Coble, Fortson, and Roberts organized Antarctica Day in May 2002, a day-long event held at Adler, which highlighted research at the South Pole.

Fortson became Director of the Astronomy Department in December 2001. In this capacity, she oversees the outreach efforts of the department in specific relation to their duties at Adler such as development of theater shows and exhibitions as well as other educational programming. Apart from this managerial role, she represents the astronomy department on the CyberSpace Steering Committee which sets the direction for content and educational programming in the CyberSpace Gallery. Fortson is an Adler liaison to the Jet Propulsion Laboratory's Mars Visualization Alliance and advisor to their Museum Liaison. She is also a member of the Education and Outreach Committee for the Center for Cosmological Physics, involved in determining their EPO programs. Fortson has given numerous presentations at conferences and meetings over the past year including University of Chicago's Images and Ideas: Exhibiting Science in Museums and NASA's Office of Space Science Education and Public Outreach Conference, where she was a member of the final overview panel.

Gyuk is P.I. for Astro-Science Workshop, a NSF funded summer outreach program for high-school students interested in Astronomy. The ASW program is in its 39th year and includes such distinguished alumnae as Astronaut John Grunsfeld.

Hammergren continued as Associate Academic Director of the Summer Science Program (SSP), in Ojai, California, a residential summer program in astronomy and physics for high school sophomores and juniors that has been held annually since 1959. Hammergren has been asked to serve as Academic Director at a new Socorro, New Mexico branch of SSP in 2003, the first expansion of the Program in 44 years. He is also on the teaching faculty of Benedictine University.

Roberts worked as a science advisor on Discovery Channel's hour-long ''Unfolding Universe,'' which aired in June, 2002. NCSA visualization specialists worked with Roberts to create animations of the environment surrounding the black hole at the center of the Galaxy. Roberts also programmed the interactive segments of the 3D StarRider show on the Sun−Earth Connection entitled ''Solar Storms,'' which opened in the fall of 2001.

Salgado, the designer of Adler's web site, continues to develop astronomy content (text and graphics) for the public that includes news, celestial events and skywatching information. He is a member of the El Universo a Sus Pies (Spanish version of the Astronomical Society of the Pacific's The Universe at Your Fingertips) Board of Advisors and, along with Wolf-Chase, a member of the NASA JPL Navigator program Peer Review Panel. Salgado is also on the teaching faculty of Benedictine University.

Wolf-Chase directed a second phase of exhibit development in Adler's largest exhibit gallery, the Milky Way Galaxy. The new components were installed in March 2002. Wolf-Chase was responsible for providing content and working closely with exhibit designers to ensure the integrity of the content, and effectiveness of the presentation, at all stages of development. Three of the new components resulted from collaborations with academic colleagues Adam Frank (Univ. of Rochester), Andrea Ghez (Univ. of California, Los Angeles), and Curt Struck (Iowa State Univ.). The collaboration with Adam Frank assisted in his establishment of a new software company for astronomical visualizations. Wolf-Chase coordinates public lectures for the department and maintains an ongoing presence on Adler committees that develop sky shows, educational programs, publications, and special events. Wolf-Chase served on the committee to name SIRTF, which met at the SIRTF Science Center in May 2002.

PUBLICATIONS

The publication list includes papers published or submitted by the staff between October 2001 and October 2002.

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Coble, K., 2002, ''Astronomy Education: A Museum − University Partnership'' BAAS, 34, #48.04

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Wolf-Chase, G., Moriarty-Schieven, G., Fich, M., & Barsony, M., 2002, ''Star Formation in Massive Protoclusters in the Monoceros OB1 Dark Cloud,'' MNRAS (to be published)

Yusef-Zadeh, F., Wardle, M., **Roberts, D.A.**, Rho, J. 2002, ''Supernova Remnant (SNR) Masers and their Relationship to Mixed Morphology SNRs'' BAAS, 34, #78.04

G. Wolf-Chase