NASA's Goddard Space Flight Center
Laboratory for Astronomy & Solar Physics

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The following report covers the period from September 2003 through September 2004.

1 INTRODUCTION

The Laboratory for Astronomy & Solar Physics (LASP) is a Division of the Space Sciences Directorate at NASA's Goddard Space Flight Center (GSFC). Members of LASP conduct a broad program of observational and theoretical scientific research. Observations are carried out from space-based observatories, balloons, and ground-based telescopes at wavelengths extending from the EUV to the sub-millimeter. Research projects cover the fields of solar and stellar astrophysics, extrasolar planets, the interstellar and intergalactic medium, active galactic nuclei, and the evolution of structure in the universe.

Studies of the sun are carried out in the gamma-ray, x-ray, EUV/UV and visible portions of the spectrum from space and the ground. Solar physics research includes studies of solar active regions, the solar corona, solar eruptions and the science of space weather, helioseismology and photospheric magnetic fields.

In order to carry out these observational programs, the Lab has a number of development efforts to produce ultraviolet and infrared detectors, lightweight mirrors, Fabry-Perot spectrographs, coronagraphs, MEMS-based microshutter arrays, and interferometry testbeds. New and innovative instruments and telescopes have also been developed for suborbital missions using both rockets and balloons.

A fairly large number of post-doctoral and graduate students work in the Lab on research projects. LASP is committed to NASA's Education and Public Outreach effort. A vigorous summer internship program provides both High School and graduate students an opportunity to enrich their educational experience through hands-on scientific research.

LASP is organized into four Branches: (1) the Solar Physics Branch, (2) the UV/Optical Astronomy Branch, the (3) Infrared Astrophysics Branch, and (4) the Instrument and Computer Systems Branch. These branches work together to carry out NASA's strategic plan as embodied in the Origins, Structure and Evolution of the Universe, and Sun-Earth Connection themes. The Lab website is: http://lasp.gsfc.nasa.gov.

A list of acronyms is provided at the end of this report.

1.1 Year in Review

The past year has been been a tumultous one for NASA, in wake of the tragic loss of the Columbia orbiter the previous year. In January 2004, the NASA Administrator announced the cancellation of the next servicing mission (SM4) to the Hubble Space Telescope (HST), citing safety concerns about sending the Shuttle into an orbit that did not have a "safe haven" (namely, the International Space Station). Subsequently, the Administrator authorized GSFC to begin study of a robotic repair of HST, which would add new batteries, gyroscopes, and install both of the new instruments intended for installation on SM4 – the Cosmic Origins Spectrograph (COS) and the Wide Field Camera 3 (WFC3). An intensive engineering effort in the HST Project at Goddard is currently underway to determine if this robotic repair is technically possible within the allowed time-fame (before the HST batteries die). WFC3 has completed a successful initial thermal vacuum test at Goddard under the leadership of Instrument Scientist Randy Kimble. However, on a decidedly sad note for LASP, the Space Telescope Imaging Spectrograph (STIS; Woodgate, PI), installed in HST in 1997, suffered a power supply failure and ceased to operate. STIS is the only spectrograph on HST (outside of the grisms in the imaging cameras), and so until COS is installed, there will be no spectroscopic capability onboard HST. A possible robotic repair of STIS is also being studied.

Both of the currently operating Explorer missions in LASP, the Wilkinson Microwave Anisotropy Probe (WMAP) and the Reuven Ramaty High Energy Spectroscopic Explorer (RHESSI) continue to return excellent science data. Scientific results based on the first 2 years of WMAP data will be announced soon, and the data will be made available to the community on the LAMBDA archive website. A WMAP proposal to the 2003 Senior Review has resulted in approval for an eight year mission duration, pending continued spacecraft health and scientific progress. RHESSI also received an excellent grade (the top grade of all 14 SEC missions) and its mission was extended for another two years.

Two important instrument deliveries were made this year. First, the detector array for the High Angular Resolution Wideband Camera (HAWC) was delivered to instrument Principal Investigator Dr. Al Harper at the University of Chicago. The detector is a bolometer array for operation at 50-200 μm, and is a first-light instrument for the Stratospheric Observatory for Infrared Astronomy (SOFIA). The detector development in LASP is led by Drs. S. H. Moseley and G. Voellmer along with D. Benford, D. Chuss, R. Silverberg and J. Staguhn. Second, the COR1 coronagraph was delivered to the Naval Research Laboratory for integration into the Sun Earth Connection Cornonal and Heliospheric Investigation (SECCHI) instrument for flight on the Solar Terrestrial Relations Observatory (STEREO) in 2007. J.

Davila is the instrument scientist for COR1.

The James Webb Space Telescope (JWST) is making notable progress towards a 2011 launch. All industrial and university partners are now in place, and the mission is in Phase B (detailed design). Specific technologies under development in LASP for JWST include design and development of the MEMs microshutter array (H. Moseley, Principal Investigator) and development and testing of the near-IR detector arrays (B. Rauscher) for the Near Infrared Spectrograph.

Work on the Terrestrial Planet Finder (TPF) has accelerated, after a decision in January 2004 to build and launch a visible coronagraph as the first TPF mission. This mission is dubbed TPF-C, while the infrared interferometeric version of TPF is called TPF-I. Goddard is partnering with the Jet Propulsion Lab on both missions (JPL is the Project lead). For TPF-C, Goddard has responsibility for delivering the telescope.

During the year, the Normal incidence Extreme Ultraviolet Spectrograph (NEXUS) Small Explorer proposal (J. Davila, Principal Investigator) was selected for a 6-month Phase A study. This study was completed in August 2004, and we are currently waiting to hear if this mission will be chosen for flight. Instruments on NEXUS will obtain time resolved, spatially resolved EUV spectra of the Sun in order to study coronal dynamics.

Several members of LASP were presented with notable awards in the past year. John Mather received a 2003 Presidential Rank Award for Distinguished Senior Professionals. This is the first time that a scientist has won this award. Brian Dennis received the 2004 John C. Lindsay Memorial Award, for his role in the successful development and scientific operation of RHESSI. This is Goddard's highest scientific award. Charles Bennett was inducted as a Fellow into the American Academy of Arts and Sciences in a ceremony in Cambridge, Massachusetts. Bernard Rauscher was presented with a Space Act Award for his role in developing large-format sensitive infrared arrays for space astronomy.

1.2 Organizational Change

In the past year, NASA Headquarters has merged the Space and Earth Science Directorates, and GSFC intends to mirror this organization. Thus, in the Fall of 2004, the Space Sciences Directorate began a reorganization process. The Solar Physics Branch will move to the new Sun-Earth Exploration Division, and the UV/Optical Astronomy Branch and the Infrared Astrophysics Branch will move to the Exploration of the Universe Division. Consequently, this is the last BAAS report from an organization at Goddard named LASP.

LASP was formed in 1978, from the merger of the Laboratory for Optical Astronomy and the Laboratory for Solar Physics and Astrophysics. Dr. John Brandt was the first Chief of LASP. The scientific achievements produced by members of LASP over the past 25 years has been astounding. We fully expect to continue this tradition in our new organizational entities.

2 PERSONNEL

William Oegerle served as the Chief of the Lab, and Michael Horn and John Wolfgang continued as Assistant Lab chiefs. Doug Rabin is Head of the Solar Physics Branch. William Danchi served as Head of the Infrared Astrophysics Branch for most of the year, and then stepped down in August 2004 to devote more time to research and to developing mission concepts for space-based interferometry. Oegerle continued as the Acting Head of the UV/Optical Astronomy Branch.

The civil service scientific staff also includes: Dominic Benford, Charles Bennett, Anand Bhatia, Charles Bowers, Kenneth Carpenter, David Chuss, Mark Clampin, Joseph Davila, Brian Dennis, Joseph Dolan, Richard Drachman, Tom Duvall, Eli Dwek, Richard Fahey, Jon Gardner, Daniel Gezari, Matthew Greenhouse, Theodore Gull, Joseph Gurman, Sara Heap, Gary Hinshaw, Gordon Holman, Harrison Jones, Stuart Jordan, Randy Kimble, Alan Kogut, Yoji Kondo, Terry Kucera, Dave Leisawitz, John Mather, Harvey Moseley, Susan Neff, Malcolm Niedner, Ron Oliversen, Bernard Rauscher, Stephen Rinehart, Richard Shafer, Robert Silverberg, Andrew Smith, Chris St. Cyr, George Sonneborn, Marvin Swartz, Allen Sweigart, Aaron Temkin, Roger Thomas, Barbara Thompson, Ed Wollack, and Bruce Woodgate.

New civil servants added to the staff this year include David Chuss and Stephen Rinehart. Larry Orwig and Carol Crannell retired from the civil service. Carol entered the Emeritus program and still devotes her time to education and outreach efforts.

The civil service engineering and computing staff includes Patrick Haas, Peter Kenney, David Linard, Les Payne and Joseph Novello.

R. Fahey continues his detail at the U. S. Naval Acadmy holding the Naval Space Command Research Chair for 50% of his time. He has taught such courses as "Physics of the Space Environment," "Spacecraft Design," and "Cosmology for the Engineer." He has also continued to implement a cooperative agreement for research and education between GSFC and USNA.

J. Gardner spent 6 months on a detail to NASA Headquarters, where he split his time between being the Spitzer Space Telescope program scientist and being deputy to NASA's chief scientist, John Grunsfeld.

The following scientists held National Research Council Resident Research Associateships during this period: David Chuss, Lars Koesterke, Neal Miller, Jeff Morgenthaler, Satoshi Morita, Ken Phillips, Jeremy Richardson, Stephen Rinehart, and Debra Wallace. J. Rajagopal continued as a Michelson Fellow, working with W. Danchi on interferometry. Lars Koesterke departed during the year for a postdoctoral position at the University of Texas, and Jeff Morgenthaler moved on to a position at the University of Washington. Neal Miller accepted a Janksy Fellowship, and will carry it out at the Johns Hopkins University.

Fred Bruhweiler is a long-term visitor from Catholic

University of America (CUA).

Graduate students carrying out their thesis research in LASP are: Lisa Mazzuca (U of Md) and Linhui Sui (CUA).

There are many more research associates working in the Lab than can be listed here. Please see our website for a full listing.

3 RESEARCH PROGRAMS

3.1 Solar Physics

Duvall, with J. Zhao and A. Kosovichev of Stanford University, have measured the rotation of magnetic elements using the technique of time-distance helioseismology with data from the MDI instrument onboard the SOHO satellite. They find that the non-sunspot magnetic elements rotate faster than the quiet Sun and that the rotation rate is approximately a linear function of the magnetic field strength. The dependence of rotation rate on field strength had not been studied before and should lead to new understanding of the near-surface dynamics.

Duvall, with A. Birch and A. Kosovichev of Stanford University, calculated the sensitivity of time-distance helioseismic measurements to sound-speed perturbations in the solar interior. They find that the technique is sensitive to the details of the measurement procedure, in particular the phase-speed filter commonly used to enhance the signal to noise ratio. The measurement procedure needs to be incorporated into the analysis. Improved understanding of the time-distance technique will enhance our ability to measure properties of the solar interior.

Holman, Sui (CUA/GSFC), Schwartz, and Emslie (UAH) studied the energetics of nonthermal electrons and thermal plasma in the 2002 July 23 gamma-ray flare observed by RHESSI. The total energy in nonthermal electrons is sensitive to the low-energy cutoff of the evolving electron distribution. They found that they could deduce the maximum value of the low-energy cutoff from spectral fits and, therefore, the minimum energy in nonthermal electrons. They found this minimum energy to be comparable to the energy in thermal flare plasma deduced from RHESSI spectral fits and GOES flare data. A comprehensive study of the energetics of this flare and the 2002 April 21 flare has been prepared by Emslie, Dennis, Holman, Schwartz, and coauthors for publication in the Journal of Geophysical Research.

Lin (UCB), Krucker (UCB), Holman, Sui (CUA), Hurford (UCB), and Schwartz studied the pre-impulsive phase of the 2002 July 23 gamma-ray flare. The RHESSI images show an extended, apparently coronal X-ray source. The spectra, however, show a nonthermal, double-power-law component. The best spectral fits for the evolution of the flare X-ray emission gave a thermal component at low energies, with the double-power-law component at energies above this thermal component. Lin et al. concluded that the flare contained a coronal, thick-target, nonthermal bremsstrahlung X-ray source in its pre-impulsive phase.

Sui (CUA/GSFC) and Holman studied the evolution of a solar flare observed by RHESSI on 2002 April 15. They discovered a compact, coronal X-ray source that separated from the flare loop and propagated outward at a speed equal to that of a subsequent coronal mass ejection. The top of the flare loop moved upward at a slower speed when the coronal source propagated outward, after first shrinking downward. The outer layer of the coronal looptop was hotter than the inner layers, but the lower part of the compact coronal source was cooler than the upper part. They concluded that these observations provide strong evidence for the presence of a current sheet between the looptop and the coronal source, where magnetic reconnection was occurring. Sui, Holman, and Dennis have prepared a comparison of this flare with two homologous flares on April 14 and 16 for publication in The Astrophysical Journal.

Holman gave an invited talk at the Denver Meeting of the American Physical Society titled "Solar Flares Observed with the Ramaty High Energy Solar Spectroscopic Imager (RHESSI)." He also gave an invited talk titled "Energetic Electrons in Solar Flares as Viewed in X-Rays" at the 35th COSPAR Scientific Assembly in Paris. Holman was a group leader at the Fourth RHESSI Workshop in Meudon, France.

H. Jones has completed comparison of magnetograms obtained with the new Solar Optical Long-term Investigations of the Sun (SOLIS) Vector Spectromagnetograph (VSM), the NASA/National Solar Observatory (NSO) Spectromagnetograph (SPM), which has been replaced by the VSM, the high resolution Global Oscillations Network Group (GONG) interferometers, and SOHO/MDI. VSM, SPM, and GONG magnetograms without correction agree very well with each other, while MDI data are about 1.4 times more sensitive. Jones has also recently published results showing that polarity inversion on the Sun ("neutral lines") is a multiscale phenomenon showing fractal characteristics over several orders of magnitude of scale. Jones with NSO collaborator Olena Malanushenko published results concerning the analysis of SPM He I 1083 nm imaging spectroscopy and the use of correlative properties between central intensity and line half-width for automatic, objective recognition of important solar features such as coronal holes. Malanushenko and Jones have recently demonstrated the viability of VSM observations for He I 1083 nm imaging spectroscopy in spite of strong fringing in the detectors.

T. Kucera continues to study the temperature distributions of motions in solar prominences using ultraviolet data from SOHO spectrographs, SUMER and CDS, and the TRACE spacecraft. These studies shed light on the mechanisms which energize material seen flowing in these solar structures.

T. Moran and J. Davila obtained the first three-dimensional reconstructions of coronal mass ejections (CMEs) through polarization analysis of SOHO/LASCO images. Analysis shows that CMEs expand radially from their source region and that halo mass ejections appear to be expanding loop arcades. In addition, the instrumental polarization of the LASCO C2 and C3 coronagraphs was characterized using in-situ measurements of K-corona polarization angles and corrections for both instruments were formulated This work was carried out with J. Morrill and R. Howard and will be submitted to Solar Physics.

C. St. Cyr collaborated with C. de Koning (LANL) and others investigating the fastest coronal mass ejection (CME) detected by the ESA/NASA Ulysses spacecraft. This interesting event arose from the October-November 2003 high levels of solar activity.

C. St. Cyr and student M.L. Malayeri (UMd) collaborated with E. Quemerais (CNRS) on a CME observing campaign using several instruments on SOHO (SWAN, LASCO, EIT). Although some positive detections were found, the preliminary results indicate that CMEs are difficult to detect in Lyman-alpha emission, at least with the sensitivity of the SOHO telescopes.

C. St. Cyr continued his collaboration with K. Forbes (CUA) in quantifying the economic impact of space weather disturbances on the electricity industry. Summer intern S. Lou (MIT) worked with them discovering impacts in international power grids.

C. St.Cyr worked with V. Bothmer and H. Cremades (MPI) on a study of the morphological signatures of flux rope CMEs observed by SOHO. They have found that the direction of the magnetic neutral line at the Sun frequently determines the appearance of the CME in a coronagraph. This was not previously known, and it is important because a statistical survey of CMEs then gives the average three-dimensional properties of these events, which are the primary causes of severe geomagnetic storms.

3.2 Atomic Physics

R. J, Drachman and J. DiRienzi (College of Notre Dame of Maryland) have continued their program of theoretical research on systems containing antimatter. These are interesting for application to the observed gamma radiation from the sun and from the galactic center. They have completed work on the interaction of low-energy positronium colliding with helium atoms, and their report has been accepted for publication in Physical Review A. They are now beginning work on the formation of the interesting positron-helium triplet-spin bound state.

A. Temkin worked on a method of accurately calculating electron-atom scattering without making a partial wave expansion continues. The paper on the implementation of the method with inclusion of exchange-but no other correlation (the exchange approximation) has been accepted for publication in Physical Review A. The extension of the method to include correlation, is now starting to be programmed by Prof. Janine Shertzer.

Temkin continues work on the derivation of the threshold law for electron-atom (specifically hydrogen) impact ionization in the Temkin-Poet model. The derivation depends critically on solving for excitation of hydrogen to very highly excited states and then analytically continuing the result into the continuum. The calculation has proved to be a very demanding computer problem. A new approach is now in process involving a change of the integration variable.

Temkin's work on the derivation of the threshold law for 2-electron photoionization of neutral atoms (or positively charged ions) has entered a new phase. Together with A. K. Bhatia, they have determined a way of connecting the asymptotic wave function with an inner wave function, so that the whole transition matrix element can be evaluated, from which the cross section is evaluated for direct comparison with experiment. The experimental result (for threshold photo-double ionization) shows modulations which the previous (Wannier) theory cannot explain.

The Handbook on Atomic, Molecular, and Optical Physics (AIP Press, 1996) is now being revised, to be published by Springer Verlag. Chapter 25 on Autoionization, originally authored by Temkin, has been revised and augmented, and will be published with A. K. Bhatia as coauthor.

3.3 Solar System

S. I. Ipatov (CUA) and J. C. Mather integrated the orbital evolution of 30,000 Jupiter-family comets (JFCs), 1300 resonant asteroids, and 7000 asteroidal, kuiperoidal, and cometary dust particles during their lifetimes. Some former JFCs reached Earth-crossing orbits with aphelion distance $Q < 4.2$ AU and even inner-Earth orbits (with $Q < 0.983$ AU), Aten orbits, or typical asteroidal orbits for Myrs. The probability of such events is $\sim 10^{-4}$, but the probability of collision of such an object with the Earth can be greater than the total probability for thousands of other JFCs. The trans-Neptunian belt might provide a significant fraction of 1-km near-Earth objects if the former trans-Neptunian objects do not disintegrate during their dynamical lifetimes. The probability of collision of an asteroidal or cometary dust particle with the Earth during its lifetime was maximum at diameter $d \sim 100$ μm. At $d < 10$ μm the fraction of trans-Neptunian particles near the Earth can be considerable. Based on the computer simulation results of migration of different dust particles, S.I. Ipatov (CUA), A.S. Kutyrev, J.C. Mather, S.H. Moseley (GSFC), G.J. Madsen, and R.J. Reynolds (U. of Wisconsin-Madison) investigated how the scattered solar spectrum is Doppler-shifted by the zodiacal cloud grains and compared it with the results of observations of the zodiacal spectra. The model results are relatively insensitive to the scattering function. With more precise observations it will be possible to distinguish the sources of the dust and estimate the particle size.

M. Niedner continues to assess, with J. Brandt (UNM) and other colleagues, the relative importance of correlated structures in the solar wind and IMF that are close to the times and locations of plasma-tail disconnection events (DEs) in comets. The two-fold objective is to pinpoint the physical trigger of DEs, then to use the information to probe the heliosphere out of the ecliptic using comets as natural probes.

Oliversen, Harris (U. Washington), Roesler (U. Wisconsin) and collaborators made Fabry-Perot [O I] observations of comet Neat (Q4) using the McMath-Pierce Telescope to determine water production rates. In addition, they conducted engineering tests of two spatial heterodyne spectrometer designs, one for OH at 3085 Å and one for [O I] 6300 Å, using the McMath-Pierce West Auxiliary. Oliversen and J. Morgenthaler continue work on Io [O I] synoptic program to study Io's interaction with the plasma torus

3.4 Stellar Astrophysics

In the past year, D. R. Alves (National Research Council) continued his work on the structure and stellar populations of the Large Magellanic Cloud (LMC), methods to reduce and analyze data from wide-field and time-domain surveys, and infrared observations of mass loss from Population II red giants.

D. Alves in collaboration with A. Muzzin, C. Clement (McMaster), and the MACHO team published new analyses of LMC RR Lyrae variable stars pulsating in first-overtone and fundamental modes. In collaboration with D. Minniti, J. Borissova, M. Rejkuba (U Catolica), K. Cook (LLNL), and K. Freeman (RSAA/MSO), Alves reported the first detection of a kinematically hot stellar halo in the LMC based on spectra of RR Lyrae variable stars. Elsewhere, Alves modeled the surface density of LMC RR Lyrae stars from microlensing survey databases, and estimated the mass, luminosity, and microlensing properties of the LMC stellar halo. In addition, Alves analyzed the surface density of red giants on the LMC's periphery using 2MASS photometry data, and showed that these stars, some of which are the same population as RR Lyrae stars, are distributed in an inclined disk. Alves also found evidence for an outward radial gradient of decreasing metallicity. Remarkably, Alves also found evidence that the line-of-sight depth of metal-poor red giants is greater than that of metal-rich red giants near the LMC's periphery based on their respective projected centroids, which is a clue to the formation history of Magellanic-type disk galaxies. Alves also published a review of the distance to the LMC, made the case that all distance indicators have converged to a standard modulus of 18.50, and showed with models that apparent warps in the LMC's disk inferred from single-color photometry of red clump giants were subject to large systematic error due to known age/reddening degeneracies and the possibility of a non-uniform red clump population.

M. Clampin continued his study of disks around young stars. He is the lead for the HST/Advanced Camera for Surveys (ACS) team in this area. During the past year, the team obtained the first HST/ACS observations of the edge-on debris disk AU Mic and obtained follow-up mid-IR observations at the Gemini Observatory. A new reflected-light circumstellar disk was discovered around HD 107146, and has been accepted for publication in ApJ Letters. Clampin also is conducting coronagraphic imaging of Herbig Ae/Be stars and searching for planets around Altair.

K. Carpenter and R. Robinson (CUA) have assessed important parameters of the stellar winds of two very similar M giant stars, γ Cru (M3.5III) and μ Gem (M3III), using high resolution HST/GHRS spectra and found surprising differences in the characteristics of their winds and in their total mass-loss rates. The wind parameters, including flow and turbulent velocities, the optical depth of the wind above the region of photon creation, and the mass-loss rate, have been estimated by fitting line profiles computed using the "Sobolev with Exact Integration" (SEI) radiative transfer code (Lamars et al. 1987), along with simple models of the outer atmospheric structure and wind. These computed profiles are fit to chromospheric emission lines which show self-absorptions produced by the photon-scattering winds of these stars. The SEI code has the advantage of being computationally fast and allows a great number of possible wind models to be examined. The analysis is iterative in nature. Estimates of the wind parameters are specified, line profiles are calculated for the Mg II (UV1) lines and a range of unblended Fe II lines (which have a wide range of wind opacities and therefore probe different heights in the atmosphere), and then the computed profiles are compared with the observations. The assumed wind properties are modified and the process repeated until the predicted profiles match the observations over as many lines as possible. Surprisingly, they find that the γ Cru wind exhibits a significantly higher terminal velocity, wind turbulence, and mass-loss rate than its fellow M-giant μ Gem.

K. Carpenter continued his collaborative studies, with E. Bohm-Vitense (U. of Washington) and R. Robinson (CUA), of the mechanisms heating the outer layers of cool dwarf stars. In their most recent study they specifically sought to determine whether in the layers with temperatures around 250,000-300,000 K, in which the O VI lines are emitted, the temperatures are determined by heat conduction from the coronae or by the same processes that heat the lower temperature regions. To study this 22 spectra of Hyades F stars were taken by the Far Ultraviolet Spectroscopic Explorer (FUSE) satellite to study the O VI lines at 1032 Å and the C III lines at 977 Å, to enable comparison of them with other lower transition layer lines, observed with HST and IUE, and with existing X-ray data. For the targets with B-V$>$ 0.4, the X-ray fluxes of single F stars were found to increase, on average, slowly with increasing B-V, while the O VI line fluxes show the same steep decrease around B-V= 0.43 as previously found for the lower temperature transition layer lines. For single stars the X-ray fluxes decrease with increasing vsini, except for the stars with B-V between 0.418 and 0.455, while for the O VI lines, as for the other transition layer lines, fluxes increase with increasing vsini, if vsini is larger than 30 km s^{-1}. For smaller vsini, line fluxes are independent of vsini. The B-V and vsini dependences of the O VI line fluxes are thus very different from those of the X-ray fluxes. The main conclusion of the study is that, for electron temperature T_e below 300,000 K, the transition layers for Hyades F stars are not mainly heated by heat conduction from their coronae.

W. Danchi, in collaboration with his post-graduate researchers (Drs. J. Rajagopal, J. Richardson, and D. Wallace) and graduate student (Mr. R. Barry) are using a number of stellar interferometers, including the Center for High Angular Resolution Astronomy (CHARA) array, the Infrared and Optical Telescope Array (IOTA), the Keck Interferometer (KI), the Very Large Telescope Interferometer (VLTI), and the Infrared Spatial Interferometer (ISI), to investigate the formation and evolution of dust around a variety of stars. Some of the classes of objects under investigation include young stellar objects such as Herbig Ae/Be stars, late-type mass losing Mira stars, and hot stars such as LBV stars and Wolf-Rayet stars. These projects are ongoing and publications from the observing programs are expected within the next year.

J. F. Dolan, P. B. Etzel (San Diego State Univ.) and P. T. Boyd (Univ. Md. Baltimore County) proposed a new method of measuring the mass of neutron star 4U0900-40 dynamically that does not require explicit knowledge of the rotational velocity of the primary or the illumination pattern of the X-ray pulses on the secondary. 4U0900-40 is the most massive neutron star known; determining its mass to $\sim 0.1\ M_{\odot}$ will significantly constrain the equation of state of NS matter and identify the evolutionary track of their progenitor stars.

J. F. Dolan and J. N. Holland (Univ. Cal. Irvine) continued searching for dyning pulse trains (DPT's) in RXTE observations of black hole candidate Cyg XR-1. No DPT's were found in 10 hours of data, indicating that the two candidate DPT's found previously in HST UV observations may be statistical anomalies. The upper limits on DPT event rate as a function of BH luminosity state are of value in constraining theories of the environs of BH event horizons.

C. Grady, B. Woodgate, Sahu, Williger (JHU), Bouret (OAMP), Roberge (DTM/CIW), have been carrying out a survey of Herbig Ae stars under the auspices of the FUSE Legacy program. Preliminary results of the survey indicate that activity in the form of FUV excess light, enhanced emission in O VI, C III, C II, and Fe II is common among Herbig Ae stars through 10 Myr. The objects studied by FUSE, all of which are nearby and with minimal foreground reddening, have O VI surface fluxes in a narrow band which lies a factor of 50-100 above O VI detections or upper limits for more centrally cleared, but similar age A stars with debris disks. Few objects have been detected with surface fluxes intermediate between the two groups indicating that activity drops rapidly after the end of accretion onto the star. Some activity persists to at least 12 Myr, with a further drop to levels typical of UMa stream A stars ($t = 200 - 400$ Myr) between 20 and 50 Myr. The accreting Herbig Ae stars have distinctive C III 1176 Å emission profiles, with the blue emission component at the jet footprint velocity in HD 163296 and HD 104237. Using interferometrically derived system inclinations for the Herbig Ae stars, we find that the wind terminal velocity in Ly alpha is highest for the stars viewed close to pole-on and drops systematically as the viewing inclination approaches the disk mid-plane. This result suggests that many other Herbig Ae stars are driving jets. We have begun a search for semi-forbidden emission features in the integrated-light spectra of other Herbig Ae stars with similar C III profiles. To date, we report the discovery of O III] emission in MWC 480 and Si III] and C III] emission in AB Aur.

B. Woodgate, Grady, Palunas (UT Austin), Wassell (Thomas Aquinas College) have been carrying out an ultra-narrow band coronagraphic imaging survey of jets and HH knots associated with nearby Herbig Ae stars using the Goddard Fabry-Perot (GFP) at the Apache Point Observatory 3.5m telescope. To date, this program has yielded detection of large-scale, bipolar outflows associated with HD 163296, which is seen by HST in the optical and UV, and by Chandra in soft x-rays. An observing run in May 2004 yielded the discovery of a new HH knot associated with HD 150193. The GFP data are being supplemented with wider-field narrow band imagery in collaboration with Stecklum (TLS).

Woodgate co-authored papers with C. Grady et al. on the performance of the STIS coronagraph, and on the environment of the Herbig Ae star HD 104237, combining data from STIS coronagraphy and UV long slit imaging spectroscopy with IR ground based imaging. This star is the second example of an Ae star several million years old with a jet and counter-jet. Their observations of the first Ae star with a jet were extended using the Goddard Fabry-Perot at Apache Point Observatory, with ten knots in the jet and counter-jet.

Grady, Woodgate, Kimble, Gull, Bowers, and Sahu with Stapelfeldt (JPL), Padgett (SSC), Henning (MPIA-HD), Grinin (CRAO), Quirrenbach (Leiden), Eiroa (UA Madrid), Sitko and Carpenter (U. Cincinnati), Lynch and Russell (Aerospace Corporation), Williger (JHU), Bouret (OAMP), and Perry (NASA's LRC) have been combining white-light coronagraphic data obtained with HST/STIS with mid-IR spectroscopy and archival UV and FUV spectra. For the Herbig Ae stars we find that the disk surface brightness does not correlate with bulk measures of the disk, including mass, but instead correlates with features which are formed in a PDR in the outer regions of the disk. The Herbig Ae disk surface brightess for stars with known, large protoplanetary disks are correlated with the mid-IR PAH emission features. For the Classical T Tauri stars, we find a similar correlation but with the spatially resolved fluorescent molecular hydrogen emission. Both samples suggest that the optically brightest disks are those which are a) large and b) have large flare angles. After 5 Myr, some large disks are a factor of at least 50-100 times fainter than the detected systems. Models for Herbig Ae disks have suggested that flat disks can be produced either by shadowing by material in the inner disk,or due to grain growth and settling. Since the shadowing mechanism is expected to be less effective in T Tauri disks, and disks which have begun to centrally clear, the similarity between the Herbig Ae and T Tauri samples favors grain growth and settling for disks associated with stars between 0.7 and 2.5 solar masses.

Grady, Woodgate, and Nuth have begun a study in collaboration with Sitko (U. Cincinati), Henning (MPIA-HD), Stecklum (TLS) and Quirrenbach (Leiden) to identify low-mass companions to nearby Herbig Ae stars with the goal of improving the dating of the Herbig Ae stars. The first round of observing proposals for this effort have been submitted.

R. Fahey completed work for publication concerning a new technique for extracting signals, such as pulsar emission, in very low signal to noise situations. The paper entitled "Rapid Binary Gage Function to Extract a Pulsed Signal Buried in Noise" is now in press.

D. Gezari continued his work on direct detection of extrasolar planets as a co-investigator on the EPIC Team, which proposed a next-generation imaging coronagraphic space telescope as a Discovery class mission. Gezari also led the on-going data reduction and analysis effort for two mid-infrared imaging programs using the Keck telescope – one studying the luminosity sources and energetics of the Galactic Center, and the other modeling warm dust emission in the star formation region Orion BN/KL. He is pursuing complementary projects to both studies as co-investigator on two successful Spitzer/IRAC proposals. One is a photometric imaging survey of the central degree of the Galactic Center, and the other is a study of the relationship between the bright sources BN/KL and the Trapezium cluster, the faint extended emission connecting those sources, and their role in the M42 HII region.

T. Gull focused upon studies of Eta Carinae. He coordinated the extensive planning for the HST Eta Carinae Treasury program extending from early 2002 through to March 2004. This program focused upon STIS spectroscopy as Eta Carinae went through the predicted 2003.5 spectroscopic minimum. Long slit CCD medium dispersion spectra were taken of Eta Carinae, the Homunculus and the Weigelt Blobs at times estimated to be critical for measuring changes. Echelle observations (E230H 2400-3160 Å, E230M 1600-2380 Å, E140M 1150 - 1700 Å) were recorded through several apertures in an effort to record not only changes in the star but also in the very nearby nebulosities. The X-Ray minimum occurred on schedule on June 29, 2003 and very crucial observations with STIS were recorded seven days before and after the drop. Initial results indicate that indeed the Weigelt Blobs and the Little Homunculus respond very rapidly to the drop in photo-ionizing flux from the companion star, thought to be an O-star. The multiple narrow line absorptions due to multiple ejecta clumps in the line of sight also responded in varying degrees. Gull et al. (submitted ApJ) measured the kinetic temperature of Fe II in the Little Homunculus to be 6400K with a density of 10^8 cm^{-3} at a distance of 1300 AU from Eta Carinae, and of Ti II in the Homunculus to be 760K with a density larger than 10^7 cm^{-3} at an estimated distance of 10,000 AU. K. Nielsen, Gull and G. Vieira have completed a catalog of identified absorption lines from $1300-2380$ Å of these ejecta. They are also preparing a series of papers cataloging lines in the 2400-3160 Å spectral region. Relative abundances of many iron-peak singly-ionized and neutral species are being measured from this data.

M. Niedner, with B. McCollum (PI; Caltech), M. Castelaz (PARI), F. Bruhweiler (CUA/GSFC), and A. Schultz (STScI) obtained the first spectra of proplyd central stars, in Orion, using the HST/STIS. Initial work is concentrating on the spectral typing of three of the young stars, and the comparison of the results with theoretical pre-MS evolutionary models.

Nate Smith, J. Morse (ASU), Nick Collins and Gull published an ApJ Letter describing the shadowing effect of the binary system across the spectroscopic minimum. As the hot secondary passes through the primary massive wind, the ultraviolet radiation becomes increasingly trapped. Many iron-peak ions in singly- and doubly-ionized state relax in ionization resulting in effective shadows in the region several thousand AU from the star.

E. Verner, F. Bruhweiler and Gull have studied the ionization flux required to support the various emission line structures betweeen and including the very bright, but partially ionized Weigelt Blobs, located about 500AU from the star. They find strong evidence for an O-star of temperature 35,000 K is needed. This is consistent with the result by J. Pittard and M. Corcoran that the x-ray spectrum of Eta Carinae requires a hot massive companion with a 3000 km s^{-1}, 10^{-5} $M_\odot$/year wind.

Gull, G. Sonneborn, and R. Iping used the FUSE to monitor changes of Eta Carinae across the minimum. However spacecraft safety issues prevented observations during the actual minimum and the observations were changed to HIRS aperture. A very different spectrum with deep Fe II resonance absorptions was found in early April 2004. Followup observations of two field stars are being scheduled to check for contamination in the previous LWRS spectra.

Gull continues to work with Sveneric Johansson and his Atomic Physics Group at University of Lund. Identification and measures of the thousands of absorption lines have required further laboratory work and literature research to improve reference wavelengths, energy level lifetimes and gf-values. Henrik Hartman recently completed his doctoral thesis at University of Lund. Included in his work is a paper in Astronomy and Astrophysics with Johansson, Gull and N. Smith as coauthors. Over 500 emission lines were identified in the Eta Carina Strontium Filament, an extended region in the disk between the lobes of the Homunculus that is a neutral emission region. 150 of these lines come from Ti II. Other iron-peak elements include Fe I, V II, Co II, Ni II. The Strontium Filament name originates from the initial discovery of strong [Sr II] lines in the near red and Sr II lines in the blue, seen for the first time in nebular emission.

In collaboration with G. McCluskey (Lehigh D.), E. Guinan (Villanova D.) and J. Sahade (La Plata Observatory), Y. Kondo is analyzing the synoptic observations of the interacting binary systems D Cephei and Algol. The ultraviolet spectra show mass flow within and out of these binary systems. In addition, the data show evidence of hot regions on – or in the vicinity of – the B components due probably to the accretion of the gas flowing out of the late type companions in those binaries. It is expected that papers based on the analysis will be written within a year or so.

D. Massa (SGT) continued his work on the winds of OB stars using far UV spectra from the FUSE satellite. Massa, Fullerton (JHU), and Prinja (UCL), obtained FUSE cycle 5 time to observe the P V wind lines in a sample of Milky Way O stars which have empirical mass loss rates determined from either their radio fluxes or Hα profiles. The P V lines are extremely important since they are not saturated (due to the low abundance of phosphorus) and nearly all of the P is expected to be P V in the winds of mid-O stars, making it a reliable mass loss indicator. In addition to the new observations, the project incorporated all existing P V observations obtained by either FUSE, *Copernicus* or ORFEUS. Initial results for 25 stars were presented at the conference "Astrophysics in the Far Ultraviolet, Five Years of Discovery with FUSE", and demonstrated that O star winds are strongly clumped. Massa, Prinja and Fullerton were also awarded *Chandra* time to examin the wind conditions in the mid-O star ξ Per. Initial analysis of the X-ray spectra suggest that the X-ray profiles are too symmetric to be formed in a homogenious, uniformly expanding wind, suggesting that the wind of this star is highly structured. Time series analysis of these data is currently ongoing. Massa also collaboration with other members of the UCL group and the FUSE team in the publication of a FUSE Spectral Atlas of WR stars (Willis et al. 2004). Massa, Prinja (UCL) and Searle (UCL) have also submitted a letter to A&A describing the ionization structure of the winds of Galactic B supergiants. Massa also continued his collaboration with Fitzpatrick (Villanova) in the study of B stars. Their most recent work (AJ, in press) presents a novel calibration of synthetic photometry, which incorporates distances determined by the *Hipparcos* satellite.

R. Iping (CUA), Massa, and G. Sonneborn, in collaboration with L. Kaper and G. Hammerschlag-Hensberge (U. Amsterdam), and J. B. Hutchings (HIA) obtained FUSE observations of two eclipsing high-mass X-ray binaries, 4U1700-37 and SMC X-1. 4U1700-37 was observed at the quadrature points of the 3.41-day orbit in 2003 April and August. The spectra show an orbital modulation in the P V, S IV, and O VI resonance lines (the Hatchett-McCray effect) in this system for the first time. P V and S IV are strongest at phase 0.75 and weakest at phase 0.5 (X-ray source conjunction). O VI is strongest at phase 0.5 and weakest at phase 0.0, indicating that O VI is a byproduct of the X-ray ionization of the stellar wind. SMC X-1 was observed with FUSE for a complete binary orbit (3.89 days) in 2003 July and October, and 2004 August. This comprehensive coverage provides a detailed map of the ionization structure of the stellar wind that is severely modified by the strong X-ray source. Analysis and modelling of these data are underway.

Iping, Gull, Massa, Sonneborn, and J. Hutchings (HIA) are studying the far-UV spectrua of the Luminous Blue Variable η Carinae. About half of the observed FUV flux of η Car through the FUSE 30×30 arcsec aperture appears to be due to two 10^{th} magnitude B-type stars near the edge of the aperture, $14''$from η Car. The HIRS (1.25×20 arcsec) aperture spectrum of η car reveals the intrinsic FUV spectrum of η Car without this stellar contamination. The HIRS spectrum contains strong interstellar H_2 having high rotational excitation (up to $J = 8$). Most of the atomic species with prominent ISM features (C II, Fe II, Ar I, P II, etc) also have strong blue-shifted absorption to $v \sim -580$ km/s that is associated with expanding debris from the 1840 eruption.

A. Sweigart participated in an HST program led by Tom Brown of STScI to study a halo field in the Andromeda Galaxy (M31). The deep exposures obtained in this program have yielded a complete census of the RR Lyrae stars in this halo field. A total of 55 RR Lyrae stars were discovered, consisting of 29 RRab, 25 RRc and one RRd stars. Interestingly this RR Lyrae population cannot be placed into either of the Oosterhoff classifications. The ratio of RRc/RRabc is typical of Oosterhoff II globular clusters, while the mean RRc period is typical of Oosterhoff I clusters. The mean RRab period falls between the two Oosterhoff groups.

Sweigart collaborated in a study of the globular cluster SKHB-312 as part of the HST program led by Tom Brown on the Andromeda galaxy. These observations have provided the first color-magnitude diagram to reach below the main sequence turnoff in an old M31 globular cluster. The luminosity difference between the turnoff and the horizontal branch in this cluster is smaller than in the Milky Way clusters 47 Tuc and NGC 5927, indicating that SKHB-312 is 2-3 Gyr younger. This supports the possibility that M31 might have more young globular clusters than the Milky Way, perhaps due to a different halo formation history.

3.5 Interstellar Medium

Dr. Sonneborn, in collaboration with K. Sembach (STScI) and B. Wakker (Wisconsin), and other members of the FUSE Science Team, completed a major study of the first D/H measurement at zero redshift outside the confines of the neighborhood of the Sun and interstellar medium of the Galactic disk. The FUSE determination of D/H is in a high velocity cloud, Complex C, on the line of sight toward the QSO PG1259+593. The metallicity of the gas as inferred from the oxygen abundance is $[O/H] = -0.78 \pm 0.15$. $D/H = 22 \pm 7$ ppm in Complex C, consistent with weak astration of primordial material.

3.6 Extragalactic Astronomy

The Great Observatories Origins Deep Survey HST Treasury team, led by Mauro Giavalisco of the STScI, used 400 orbits to image wide areas around the Hubble Deep Field North and Chandra Deep Field South regions. As members of the GOODS team, J. Gardner and Duilia de Mello contributed to 8 papers which appeared in a special issue of the Astrophysical Journal Letters. De Mello led an analysis of parallel F300W images taken with WFPC2 during the redder ACS observations. The preliminary results from these near-UV selected objects shows a mixed population of starbursts with ages < 1 Gyr over the redshift range $0 < z < 1$.

Gardner, Collins and R. S. Hill contributed to a study led by Jason Rhodes, now of Caltech, of the cosmic shear using STIS parallel images. They detected the shear at the 0.51 arcminute scale at a 5.1σ significance level, and published the results in the Astrophysical Journal. While consistent with previous measurements, these results favor a high value of the cosmic biasing factor σ_8. A follow-on study, awarded 260 orbits of parallel ACS images, should detect the mass power spectrum amplitude, $\sigma_8\Omega_m^{0.5}$, at the 20σ level. Analysis of these data is proceeding.

The Grism ACS program for Extragalactic Science (GRAPES), led by Sangeeta Malhotra of the STScI, used 40 HST orbits to obtain slitless grism spectroscopy of the Hubble Ultra Deep Field. This unbiased study achieved continuum detections as faint as $z_{AB} = 27.2$, and detected fainter emission line sources. As a member of the GRAPES team, Gardner contributed to a paper presenting the catalog of sources in the GRAPES data, and to a paper describing a $z = 5.4$ Lyman α emitting galaxy with a linear morphology.

Gardner contributed to a study of the Groth Strip region using a 200 ksec Chandra observation led by Kirpal Nandra of Imperial College London. The region includes 158 X-ray sources; an analysis of these sources was submitted for publication in MNRAS. The sample as a whole has a spectral index comparable to the X-ray background, but the fraction of sources with significant obscuration is only about 25 percent; significantly less than that predicted by AGN population synthesis models. After accounting for absorption, the mean spectrum is similar to those of local Seyfert galaxies. The region has been observed by many facilities including HST and Spitzer, and multi-wavelength analysis is proceeding.

Gardner contributed to HST studies involving FUV imaging of the Hubble Deep Field North (led by H. Teplitz of the Spitzer Science Center), parallel ACS grism observations (led by Lin Yan of the SSC). Data for these programs are being analyzed.

D. de Mello is currently working with Jonathan P. Gardner, Yogesh Wadadekar(STScI), Swara Ravindranath (STScI), and Stefano Casertano (STScI) on the analysis of the deepest U-band images ever taken with the Hubble Space Telescope during the Ultra Deep Field campaign in January 2004. More than 400 galaxies are seen in the WFPC2 U band and are also detected in the multiwavelength ACS/GOODS images. Analysis of their morphology, sizes, and redshift distribution are in progress.

D. de Mello worked with Emanuele Daddi (ESO) and the K20 team on the analysis of the VLT composite spectrum of near-infrared luminous galaxies to search for the epoch of formation of massive galaxies. They found evidence of high metallicity, together with high masses, high star formation rates, and possibly strong clustering, which well qualify these galaxies as progenitors of local massive elliptical galaxies.

D. de Mello worked with Theresa Wiegert and Cathy Horellou (Onsala Space Observatory, Sweden) on a paper summarizing the main results of the Master's thesis of Mrs. Wiegert which has been accepted for publication by the Astronomy and Astrophysics journal. They have used the Hubble Deep Field South images to assess the galaxy population out to $z = 2$. They used two methods of templates fitting of the spectral energy distributions to obtain photometric redshifts and classify the objects. Analysis of the rest-frame color distribution shows a bimodality out to $z = 1.4$. Although in low numbers, a population of early-type galaxies (or heavily obscured low redshift galaxies) is seen out to $z = 2$.

D. de Mello, Jonathan P. Gardner and collaborators began examining archival data from GALEX and HST to study the UV properties of moderate redshift galaxies as a function of HST morphology.

A. Kashlinsky (SSAI), R. Arendt (SSAI), J. Gardner (NASA), J. Mather (NASA) and S. Moseley (SSAI) have proposed a novel way to probe the existence of the Population III era objects, the (so far) hypothetical first stars formed when the Universe was only ~ 200 million years old. They pointed out that, if these stars were massive as currently expected, they would leave a measurable signature in the angular spectrum of the near-IR anisotropies in the cosmic infrared background (CIB). This signal may already have been seen in earlier CIB anistropies results obtained by them from DIRBE and 2MASS data analysis. These datasets, however, contain significant contributions from ordinary galaxies, and better angular resolution and sensitivity will be needed to unambiguously isolate the signal from the Population III era. They also proposed an experiment that would be able to detect this signal between 1 and 5 micron.

B. Woodgate joined P. Palunas (U. of Texas), G. Williger (JHU) and H. Teplitz (Spitzer Science Center) in a press conference at the January 2004 AAS meeting to publicize their ApJ paper (with P. Francis, ANU) describing detection of an filament of Lyman Alpha galaxies at redshift 2.38, overdense a linear morphology. compared to CDM models. Stories appeared on CNN, in the New York Times, Washington Post, etc. Several of these galaxies have now been detected at 24 microns with Spitzer/MIPS by J. Colbert (Spitzer Science Center) and the team above.

4 OPERATING ORBITAL FLIGHT MISSIONS AND INSTRUMENTS

4.1 The Wilkinson Microwave Anisotropy Probe (WMAP)

In Feb 2003, the Wilkinson Microwave Anisotropy Probe (WMAP) team announced their first results. The WMAP measurements constrained models of structure formation, the geometry of the universe, and inflation. The results indicate that the universe has a flat (i.e. Euclidean) geometry, is dominated by dark energy (73%) and cold dark matter (23%). Accurate values were reported for many cosmological parameters, with thirteen papers on the results published in a special September 2003 issue of the Astrophysical Journal. The WMAP results were highlighted by Science magazine as the 2003 "breakthrough of the year." The data were made public in the Legacy Archive for Microwave Background Data Analysis (LAMBDA). Gary Hinshaw, Ed Wollack, Al Kogut, and Principal Investigator Chuck Bennett are members of the WMAP team at GSFC. Hinshaw leads the LAMBDA data center. WMAP continues to operate well, and additional releases will occur, with data made available via LAMBDA. A WMAP proposal to the 2003 Senior Review has resulted in approval for an eight year mission duration, pending continued spacecraft health and cosmological progress. Team members have spoken on the WMAP results around the world, and WMAP was covered on Alan Alda's "Scientific American Frontiers" and NOVA's "Origins" TV programs.

4.2 Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI)

The LASP team led by B. Dennis is collaborating with Principal Investigator, Robert Lin (Space Sciences Laboratory, University of California, Berkeley) on the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI). RHESSI is designed to investigate particle acceleration and energy release in solar flares through imaging and spectroscopy of hard X-ray/gamma-ray continua emitted by energetic electrons, and of gamma-ray lines produced by energetic ions. See last year's LASP BAAS contribution for a summary of the instrument. RHESSI provides the first high resolution hard X-ray imaging spectroscopy, the first high-resolution gamma-ray line spectroscopy, and the first imaging above 100 keV including the first imaging of gamma-ray lines.

RHESSI was launched on February 5, 2002, and has been operating successfully since. During the 32 months of observations through September 2004, RHESSI has detected over 13,000 flares at energies above 12 keV, over 350 above 50 keV, and 9 above 800 keV. Five flares show significant gamma-ray line emission. Even more microflares have been detected above 3 keV. Some of the results include:

- The first hard X-ray imaging spectroscopy of flares from thermal to non-thermal energies.
- The first flare high resolution X-ray spectroscopy that resolves the thermal-nonthermal energy transition, showing that the non-thermal power law extends down to $\lesssim 10$ keV in some cases, implying an energy content in the accelerated electrons at least several times higher than previous > 20 keV estimates.
- Strong evidence for a current sheet above the flaring magnetic loops that is the likely location for magnetic reconnection releasing energy to power the flare. Two separate thermal sources were imaged with RHESSI. They had oppositely directed temperature gradients such that the higher temperatures in the two sources were adjacent to one another suggesting that the energy release must have taken place between them.
- The discovery that flare non-thermal X-ray spectra often have a relatively sharp downward break, usually in the range 30-50 keV for small flares but as high as > 100 keV in larger flares.
- The first high resolution flare gamma-ray line spectra, measuring redshifts of a fraction of a percent, implying directivity of the energetic ions as well as non-radial magnetic fields.
- The first imaging of flare gamma-ray lines. The images for the event on 23 July 2002 showed that the centroids of the energetic ion and electron sources are separated by ~ 20 arcsec. This suggests that the ions may be accelerated preferentially on longer magnetic loops that are the electrons as suggested by one model. The stronger event on 28 October 2003, however, could be resolved into two sources with similar separations for both the ions and the electrons. Clearly, more gamma-ray line flares must be imaged to determine what the difference is between ion and electron acceleration.
- The detection of a non-thermal coronal source with a double-power law spectrum during the onset of a large flare. This source requires a significant energy release into the corona prior to the impulsive phase.

RHESSI makes observations down to 3 keV with high sensitivity, fine energy resolution (~ 1 keV FWHM), and wide dynamic range. Apart from the spatial information obtained from the images at these low energies, these observations provide the following unique spectral information about solar flares:

- The thermal free-free and free-bound continuum emission in this energy range gives the temperature and emission measure of the thermal plasma at temperatures above ~ 8 MK with very high sensitivity.
- The intensity ratio of the Fe-line complex at ~ 6.7 keV and Fe/Ni line complex at ~ 8 keV seen in RHESSI spectra gives the temperature and emission measure independent of the continuum measurements.

- The iron abundance relative to hydrogen (thought to vary from flare to flare) can be determined from the equivalent width of the Fe-line complex at 6.7 keV (essentially the ratio of the Fe-line flux to the continuum flux at the Fe-line energy). This can generally not be measured with crystal spectrometers because of fluorescence emission dominating over the solar continuum, whereas RHESSI measures the continuum unambiguously.

- Deviations from single temperature line and continuum spectra provide information about the multi-temperature nature of the thermal plasma.

- Comparison with the hard X-ray spectrum provides information about the ratio of thermal to nonthermal emission during flares in the critical energy range where they overlap, usually between $\sim$ 10 and 30 keV.

- The detection of 3-15 keV X-ray emission from solar type III radio bursts, sometimes with no obvious relation to flares.

- The first detection of continuous glow from the Sun at 3-15 keV energies, with frequent microflaring. The microflares have non-thermal power-law spectra indicating substantial energy in accelerated electrons. With RHESSIs high sensitivity to such soft X-ray emission some 300 times more sensitive than previous instrument, it will be important to monitor this continuous emission and microflaring as we progress through the solar cycle.

A great effort is underway to analyze the observations from these flares; a quick survey of the publications using RHESSI as a keyword in the NASA Astrophysics Data System (ADS) revealed 269 abstracts in 2002 - 2004 with 78 in refereed journals. A special issue of Solar Physics (Vol. 210, Nos. 1-2, 2002) was devoted to papers on early results along with detailed instrument descriptions. The October 1, 2003, issue of The Astrophysical Journal Letters contains 14 papers on the RHESSI observations of the July 23, 2002, gamma-ray line are. A Goddard press release on September 3, 2003, presented a popular description of these first-ever gamma-ray images of a flare and the spectroscopic evidence for an "antimatter factory" on the Sun.

The LASP RHESSI team has developed software to display, analyze, interpret, and archive all calibration and flight data. The software is being used to carry out basic data manipulation functions to produce catalogs, light curves, images, spectra, etc. All of the RHESSI data are made immediately available on line to interested members of the scientific community, and the IDL analysis software is widely distributed as part of the Solar Software (SSW) tree.

In the last Senior Review (2003) conducted by NASA HQ, RHESSI received the highest grade of all active SEC missions and was extended for an additional two years. Future prospects for continued operations are excellent since RHESSI has no consumables. Hence, we look forward to operating RHESSI for many years to come.

4.3 Far Ultraviolet Spectroscopic Explorer (FUSE)

The Far Ultraviolet Spectroscopic Explorer (FUSE) was launched in 1999 and provides high resolution spectra in the 905-1187 Å wavelength region. FUSE, a cooperative project of NASA and the space agencies of Canada and France, is operated for NASA by Johns Hopkins University in Baltimore, MD. The FUSE Principal Investigator is W. Moos (JHU). Sonneborn and Woodgate are Co-Is. Sonneborn is the Project Scientist. Grady, Gull, Iping, Lanz, Massa, and Neff are PIs of current observing programs. Massa and D. Lindler supported the continuing development of the FUSE science data pipeline and instrument calibration.

The primary mission goal, to study key species in Milky Way interstellar and halo gas through spectroscopy of Galactic and extragalactic sources, has expanded dramatically to address a wide range of astronomical problems proposed by Guest Investigators (GIs). With the demonstrated ability to obtain high resolution, high signal-to-noise spectra in the far-ultraviolet, GIs are making detailed measurements of the physical conditions and abundances of celestial objects and their environments, from the solar system to the distant universe.

FUSE provides unique access to two essential markers for astrophysics: the ground state transitions of H_2 and the resonance doublet of O VI. For the study of molecular material, abundant in galaxies and dominant in star forming regions, access to H_2 is as fundamental as access to the Lyman and Balmer series lines for atomic hydrogen. O VI is the only unambiguous tracer of gas in the crucial 10^5 <T<10^6 K regime in which much, if not most, of the missing baryons lie. These species have been central to many FUSE advances, including abundances and physical conditions in protoplanetary disks, high-velocity clouds, star-forming regions, and the hot intergalactic medium.

NASA's Senior Science Review in June 2004 ranked FUSE highly for its scientific results to date and the expectation of continued scientific achievement. Based on this assessment, FUSE was authorized to continue operations through 2006, and through 2008 pending confirmation in the next Senior Review in 2006.

FUSE operations remains very efficient, especially in view of the reaction wheel and gyro failures a couple years ago. The new control system is robust against gyro failures, having been demonstrated capable of conducting scientific operations with two, one, or even zero gyros. The FUSE annual sky coverage is now as high as it was early in the mission.

4.4 Galaxy Evolution Explorer (GALEX)

The Galaxy Evolution Explorer (GALEX) is a Small Explorer (SMEX) that is conducting an all-sky survey at ultraviolet wavelengths. The PI is Chris Martin (Caltech); Susan Neff is the NASA Project Scientist. The

GALEX science team will use the primary mission data to determine the history of star-formation to redshift ~ 2, over 80% of the age of the universe. An early release dataset was made available during the past year, and an Announcement of Opportunity for the Guest Investigator program was released in January, 2004.

4.5 Infrared Array Camera (IRAC)

The Spitzer Space Telescope (aka Space Infrared Telescope Facility (SIRTF)) has been operational for the past year, and delivering spectacular infrared images and spectra of celestial objects. One of Spitzer's primary instruments is the Infrared Array Camera (IRAC) (G. Fazio/SAO, Principal Investigator) which was built at GSFC under the leadership of S. H. Moseley. IRAC is a four-band $3-9\mu$m camera. One of its primary science goals is the study of galaxy evolution, where it will obtain galaxy luminosity functions out to $z \sim 3$. This high performance camera will offer revolutionary capabilities for a wide variety of astronomical investigations during the five year lifetime of Spitzer. Drs. R. Arendt, D. Fixsen, and H. Moseley are working on the development of algorithms for the calibration of IRAC. D. Gezari is analyzing images of the Galactic center. An issue of the Astrophysical Journal was dedicated to initial results from Spitzer in September 2004.

4.6 Hubble Space Telescope (HST)

A number of scientists from LASP work on the development and continuing operations of HST: M. Niedner as the HST Deputy Senior Project Scientist, Ken Carpenter as Project Scientist for HST Operations, and Randy Kimble as Project Scientist for Development and Instrument Scientist for WFC3. Following the January 2004 cancellation of Servicing Mission 4 (SM4), much work has gone into consideration of options for the future of HST, including the development of robotic servicing techniques to accomplish the most important EVA tasks – such as COS and WFC3 installation, and battery and gyro replacement – that had been planned for SM4. If NASA decides to execute a full-up robotic servicing mission to HST, the launch date will be in approximately December of 2007. Niedner supported requests that the HST Project and the STScI develop measures that would optimize the total Hubble science return until 2007 in the presence of declining battery capacity and diminished gyro assets. He further assisted NASA HQ in a preliminary evaluation of mission options. Kimble oversees development of WFC3 at GSFC and Ball Aerospace (see WFC3 section below) and reviews development of the Cosmic Origins Spectrograph (COS; J. Green is PI at Univ of Colorado).

4.7 Space Telescope Imaging Spectrograph (STIS)

B. Woodgate continues as the Principal Investigator (PI) of the STIS instrument on board the HST. This year marks the completion of the STIS GTO activities. Along with the acceptance of the LASP proposal in 1984 to design, build and deliver the STIS for use in HST, came an award of 553 orbits. These were used by the STIS IDT to demonstrate the capabilities of STIS and to try new observations that were possibly too high risk to be accepted by the STScI TAC but promised good science results. Important papers on galactic nuclear black holes, on protoplanetary disks, on the ISM, and the evolved star Eta Carinae, have come out of these observations. Few of these results would have been possible without the near-diffraction-limited performance of HST and the ability of STIS to fully utilize that spatial resolution along with a selection of appropriate spectral dispersions throughout the ultraviolet and visible wavelengths. The unfortunate news is that STIS ceased to operate due to a power supply failure in early August 2004, 7.5 years after installation. Invesigations are underway to determine if the failure could be repaired during the robotic repair mission.

4.8 Solar & Heliospheric Observatory (SOHO)

Despite a problem with its high-gain antenna, SOHO began an ninth year of nearly continuous, remote-sensing observations of the Sun and in-situ measurements of the solar wind, with six of the twelve Principal Investigator teams continuing to staff the Experimenters' Operations Facility for daily planning meetings and command generation. LASP scientists J. B. Gurman (US project scientist) and T. Kucera (Deputy US project scientist), S. Jordan, R. Thomas, and B. Thompson remain directly involved in science operations, instrument calibration, and analysis, along with more than twenty-five colleagues from ESA and the PI teams also located at GSFC.

4.9 Cosmic Hot Interstellar Plasma Spectrometer (CHIPS)

CHIPS is a University-class Explorer (UnEx) mission that was launched in January 2003 to carry out a spectroscopic survey of diffuse EUV emission from the hot gas in the putative local bubble (extending ~ 100 pc) surrounding the solar system. The PI team, led by Mark Hurwitz of the University of California, Berkeley, is searching for emission in the 100–250 Å range to constrain the distribution, temperature, composition, and emission measure of the local hot gas. A paper presenting initial results from CHIPS has been submitted to the Astrophysical Journal. Emission from Fe IX 171 Å has been observed at an intensity level about a factor of 10 less than expected, based on the soft x-ray observations. No detection of EUV lines from Fe X - Fe XII were observed, which is quite puzzling. These observations may require a re-evaluation of the standard model of the local bubble. R. Kimble serves as the NASA Project Scientist for CHIPS.

5 FLIGHT MISSIONS AND INSTRUMENTS UNDER DEVELOPMENT

5.1 Living with a Star (LWS)

St. Cyr continued his position as Senior Project Scientist for the Living With a Star (LWS) Program. The primary goal of LWS is to gain the scientific understanding of the effects of solar variability, particularly those with societal impact. The Program, along with Solar Dynamics Observatory (SDO), the first mission in the line, were confirmed to proceed with implementation in Spring 2004. Other LWS activities included the formation of Science Definition Teams to study a Solar Probe mission and the Solar Sentinels component of the Program.

5.2 Solar Dynamics Observatory (SDO)

During the past year, B. Thompson stepped down as Project Scientist to devote more time to research. Thompson, Gurman, Poland, St. Cyr, Kucera, Rabin, and Davila continue to provide active support to the SDO science team. These roles include the support of missions, committees, and meetings which involve the broader LWS community.

SDO is scheduled to launch in 2008 and consists of a set of investigations designed to understand the origins of the flow of energy from the solar interior, through various regions of the Sun out to the solar corona. With SDO, astronomers will be able to investigate the Sun's transient and steady-state behavior and understand the solar drivers of variability at Earth.

5.3 Solar Terrestrial Relations Observatory (STEREO)

STEREO is the next logical step to study the physics of the origin of coronal mass ejections (CMEs), their propagation, and terrestrial effects. Two spacecraft with identical instrument complements will be launched on a single launch vehicle in November 2007. One spacecraft will drift ahead and the second behind the Earth at a separation rate of 22 degrees per year. Observation from these two vantage points will for the first time allow the observation of the three-dimensional structure of CMEs and the coronal structures where they originate.

As a part of the Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI) instrument, LASP is responsible for the COR1 coronagraph. This coronagraph will provide images of the inner corona from $1.3 - 4.5 R_{\odot}$. Construction of this instrument was completed in 2004 and delivered to NRL for integration into SECCHI. J. Davila is the instrument scientist for COR1.

5.4 Normal incidence EXtreme Ultraviolet Spectrograph (NEXUS)

LASP/GSFC, in partnership with the Naval Research Lab and Rutherford Appleton Lab, has proposed to build NEXUS as a Small Explorer. J. Davila (LASP) is the Principal Investigator. J. Gurman, T. Kucera, A. Poland (emeritus), D. Rabin, C. St. Cyr, R. Thomas and B. Thompson (all of LASP) are co-investigators. In 2004, NEXUS was chosen by NASA for a Phase A concept study. This study was completed in June 2004.

NEXUS observes the fundamental physical properties responsible for regulating the transfer of energy through the solar chromosphere and corona, and then outward into the interplanetary medium. Understanding the energy flow in these regions is essential for predicting solar influences throughout the heliosphere. NEXUS is proposed to be launched into a Sun-synchronous polar orbit in order to provide long periods of uninterrupted solar viewing.

5.5 Submillimeter and Far Infrared Experiment (SAFIRE)

The Submillimeter and Far Infrared Experiment (SAFIRE) is a far infrared imaging spectrometer for the Stratospheric Observatory for Infrared Astronomy (SOFIA). It is being built at GSFC (P.I. is S. H. Moseley, with D. J. Benford, R. A. Shafer, and J. G. Staguhn in LASP, J.A. Chervenak also at GSFC) in collaboration with F. Pajot (Institut d'Astrophysique Spatiale), K. D. Irwin (NIST), and G. J. Stacey (Cornell University). The instrument provides background limited sensitivity with a resolving power of ~ 1500 over the 100μm to 650μm spectral range. The instrument will employ a 16×32 element array of superconducting transition edge sensor (TES) bolometers operating at 0.1 K. This detector will employ a novel multiplexing scheme using superconducting SQUID amplifiers developed at NIST. The instrument is scheduled for first light in 2007. In the current year, the prototype instrument for SAFIRE, the Fabry-Perot Bolometer Research Experiment (FIBRE) was successfully operated at the Caltech Submillimeter Observatory. Furthermore, the data acquisition electronic system was completed and tested by J. Forgione (GSFC).

5.6 Wide Field Camera 3 (WFC3)

Wide Field Camera 3 is an instrument in development for installation on HST at its next servicing. It will provide a panchromatic imaging capability from the near UV to the near infrared, enabling a broad science program including the observation of high-z galaxies in formation, star formation processes in nearby galaxies, and resolved stellar populations. R. Kimble serves as Instrument Scientist for this HST facility instrument. The principal technical contribution of LASP personnel to the WFC3 effort has been the performance testing of candidate Charged Coupled Device (CCD) and IR detectors in the Detector Characterization Laboratory. In August 2004, WFC3 successfully completed an initial thermal vacuum test at GSFC. Further testing of WFC3 will be impacted by possible changes to the instrument to accomodate the robotic repair of HST – specifically the mounting of gyroscopes to the outer portion of WFC3.

5.7 James Webb Space Telescope (JWST)

The James Webb Space Telescope (JWST) is a large aperture follow-on mission to HST and Spitzer Space Telescope under the Origins program (see the JWST website: http://www.jwst.nasa.gov). It is a 6.5-m cooled telescope, sensitive from 0.6 to 27 microns, and optimized to observe the first stars and galaxies. It is planned for launch in 2011, and is in "Phase B" (detailed design). The entire international team is in place, including the prime contractor Northrop Grumman Space Technologies, with subcontracts to Ball Aerospace, Eastman Kodak (now known as ITT), and ATK. The Near Infrared Camera is provided by the University of Arizona (M. Rieke, P.I.), and the Mid Infrared Instrument is provided by an international team with G. Rieke (University of Arizona) as Science Team Lead with G. Wright of the UKATC. Six Interdisciplinary Scientists and the Telescope Scientist are also members the Science Working Group. The Space Telescope Science Institute is the JWST science and operations center. The European Space Agency plans to launch JWST on an Ariane 5 launch vehicle, to contribute the Near Infrared Spectrometer (NIRSpec) by contract to Astrium, and to be responsible for the European consortium providing the optical and mechanical system for the Mid Infrared Instrument. J. Mather serves as the JWST Senior Project Scientist. J. Gardner is the Deputy Senior Project Scientist and Project Scientist for Operations. M. Greenhouse is the Integrated Science Instrument Module (ISIM) Scientist and is the prime JWST contact for science instrumentation and instrument technology development. M. Clampin is Observatory Scientist. B. Rauscher is Deputy ISIM Scientist and Detector Scientist for the NIRSpec. S. H. Moseley's team made rapid progress in building a MEMs-based microshutter array for NIRSpec.

5.8 Terrestrial Planet Finder (TPF)

In January, 2004, a decision was made by NASA HQ and the TPF Project at JPL to build and launch two versions of TPF – a visible coronagraph (TPF-C) and an infrared interferometer (TPF-I). TPF-C will be built first with a goal of launching in 2014. TPF-I, with collaboration from the European Space Agency, will launch later in the decade ($\sim$ 2020). Goddard is now partnering with JPL, who leads the overall Project. Goddard has responsibility for delivering the telescope, which has a 3.5×8m aperture. This will be a monumental effort, given the extremely tight tolerances required on the optics and mechanical structure. S. Heap is the TPF-C Telescope Scientist, and C. Bowers is the Deputy Scientist.

W. Danchi has been working on the TPF mission during the past two years as a member of the TPF Science Working Group (TPF-SWG) and as a member of the European Space Agency (ESA) Darwin Terrestrial Exoplanet Science Advisory Team (TE-SAT). During the past year, the TPF mission has gained considerable momentum, with completion of a preliminary design for a Structurally Connected Interferometer (SCI) on a 36-m boom that could detect up to approximately 50 earth-like planets in the habitable zone of nearby solar-type stars. Preliminary designs for the free-flyer version of TPF-I are capable of completing the full mission of at least 150 nearby stars. Additional personnel from GSFC, particularly in the engineering groups have also become involved in the TPF project, notably on the design of the telescopes for the mission.

5.9 Kepler

Y. Kondo serves as co-investigator for the Kepler Mission to to detect Earth-like planets in our galaxy, which has been approved by NASA Headquarters for launch in 2007 for a 4–5 year mission. He is responsible for the Participating Scientist and Guest Observer Program to observe all manner of variable stars such as intrinsic variables (including micro-variables), eclipsing variables, interacting binaries (including X-ray binaries), and cataclysmic variables within the 100 square-degree Kepler field in the Cygnus region, continuously from one to 4–5 years. Some 3,000 objects may be selected each year for the Guest Observer and Participating Scientist Programs. He will also be reponsible for the Kepler Data Analysis Program. J. Mather serves on the Standing Review Board for Kepler.

5.10 Wide-field Infrared Survey Explorer (WISE)

J. Mather serves as a co-investigator and D. Leisawitz serves as Mission Scientist for the Wide-field Infrared Survey Explorer (WISE, formerly the Next Generation Sky Survey), with P. I. Edward L. Wright of UCLA. WISE will provide an all-sky survey from 3.5 to 23 microns with up to 1000 times more sensitivity than the IRAS survey to find the most luminous galaxies in the universe and the closest stars to the Sun. In August 2004, the WISE was approved to proceed into Phase B. The mission is scheduled to launch in 2008.

5.11 Mission Concept Studies

M. Clampin is the Principal Investigator for a Discovery Mission concept called the "Extrasolar Planet Imaging Coronagraph" (EPIC) which is designed to directly image and characterize extra-solar gas giant planets at typical distances of 2 to 20 AU from the parent star, and will therefore find solar-system analogs – those most likely to harbor earth-like planets. Such systems will be the primary targets for NASA's subsequent planet searches with the Terrestrial Planet Finder (TPF). EPIC's direct planet discovery capabilities are complemented by its unique ability to image the dust disks and very low-mass companions close in to stars. The EPIC concept employs a visible coronagraph and a $\sim$ 1.5m aperture telescope. The key technical feature of EPIC is that it employs an approach to planet detection that avoids extremely challenging optical stability requirements from the telescope, thus mitigating most of the risk associated with more conventional coronagraphic approaches. Co-investigators include a broadly based team of scientists from Harvard/CfA, Johns Hopkins University, JPL, ST ScI, and OCIW/DTM.

J. Mather led a team of local co-investigators Ed Cheng (Conceptual Analytics), Matt Greenhouse, Randy Kimble, Mal Niedner, and Bernie Rauscher for the Microlensing Planet Finder (MPF) (formerly known as the Galactic Exoplanet Survey Telescope (GEST)), a proposed mission headed by P.I. David Bennett (Notre Dame) to discover planets by their microlensing effects. The MPF would observe 100 million stars in the Galactic bulge and could detect a planet roughly every day, with an Earth-like planet every few weeks. The mission was submitted as a Discovery proposal this year.

W. Danchi is leading the development of the Fourier Kelvin Stellar Interferometer (FKSI), with Drs. D. Benford, D. Leisawitz, D. Gezari, S. Rinehart, J. Rajagopal, D. Wallace, and D. Deming at GSFC, together with numerous members of the community. FKSI is a mission concept for a nulling interferometer for the near to mid infrared spectral region ($3 - 8\mu$m). FKSI is conceived as a scientific and technological precursor to the Terrestrial Planet Finder interferometry (TPF-I) mission. FKSI will address key questions about exosolar planets: (1) what are the characteristics of exosolar giant planets? (2) what are the characteristics of exosolar zodiacal clouds around nearby stars? and (3) are there giant planets around classes of stars other than those already studied? Additional studies with FKSI will emphasize the evolution of protostellar systems, from just after the collapse of the precursor molecular cloud core, through the formation of the disk surrounding the protostar, the formation of planets in the disk, and eventual dispersal of the disk material. A detailed design study for FKSI was undertaken at GSFC two years ago and new studies are anticipated this coming year in the light of the current replanning process for the Terrestrial Planet Finder mission. Using a nulling interferometer configuration, the optical system consists of two 0.5m telescopes on a 12.5m boom feeding a Mach-Zender beam combiner with a fiber wavefront error reducer to produce a 0.01% null of the central starlight. With this system, planets around nearby stars can be detected and characterized using a combination of spectral and spatial resolution. A number of conference papers and an Astrophysical Journal Letter concerning the FKSI mission have been published within the last year.

The Single Aperture Far-Infrared (SAFIR) Observatory, recommended by the National Academy of Sciences Decadal Review, was selected by NASA as one of the Vision Missions for detailed mission concept study. Led by D. Lester (U.T. Austin), a team consisting of D.J. Benford, M. Greenhouse, D. T. Leisawitz, J. C. Mather, S.H. Moseley, (all LASP) and K. Walyus, K. Parrish, and M. Amato (also at GSFC) and others from JPL and universities are in the process of developing the mission concept for this highly capable, 10-m diameter, far-infrared optimized observatory. The LASP team members lead the SAFIR Vision Mission studies of mission architecture, cryogenic systems, and instrument systems, and are also members of the SAFIR Science Development Team and the SAFIR Observatory Concept Development Team. If approved for funding, SAFIR could launch as early as 2017. The scientific objective of SAFIR is to conduct investigations into the earliest stages of star and planet formation and the formation of the first galaxies and stars in the universe. A comprehensive review of the GSFC mission concept work to date has been published in the journal Astrophysics & Space Science (2004, in press). Further details are available on GSFC's SAFIR web site http://safir.gsfc.nasa.gov.

K. Carpenter, R. Lyon, J. Leitner, R. Moe, L. Mazzuca, W. Danchi, and C. Bowers, in collaboration with C. Schrijver and D. Chenette (LMMS/ATC), D. Mouzurkewich (Seabrook Engineering), S. Kilston (BATC), T. Armstrong (NPOI/NRL), R. Allen (STScI), M. Karovska and J. Phillips (SAO), and J. Marzouk (Sigma Sp.) continue the development of a mission concept for a large-baseline ($>$ 500m), space-based UV-optical imaging interferometer, named Stellar Imager (SI). SI is designed to image the surfaces of nearby stars, probe their subsurface layers through asteroseismology, and improve our understanding of the solar and stellar dynamos. The ultimate goal of this mission is to achieve the best-possible forecasting of solar activity as a driver of climate and space weather on time scales ranging from months up to decades, and an understanding of the impact of stellar magnetic activity on life on earth and elsewhere in the Universe. The SI team was awarded a "Vision Mission" grant in the spring of 2004 to further develop the mission concept and technology roadmap needed to enable the implementation of the mission. The first phase (utilizing a 7-element sparse array) of a ground-based experiment, the Fizeau Interferometry Testbed (FIT) is now in operation at GSFC. It is being used to explore the principles of and requirements for the SI concept and other Fizeau Interferometers and Sparse Aperture Telescope missions. In particular it will be used to demonstrate closed-loop control of a large number of articulated mirrors and the overall system to keep the optical beams in phase and to optimize imaging. Further information on this mission and the FIT can be found at URL: http://hires.gsfc.nasa.gov/∼si and references therein.

The Submillimeter Probe of the Evolution of Cosmic Structure (SPECS) was selected for study under the ROSS/Vision Mission Study program, with PI M. Harwit (Cornell), D. Leisawitz as GSFC Institutional PI, J. Pearson as JPL Institutional PI, and Co-Is D. Benford, W. Danchi, W. Langer (JPL), C. Lawrence (JPL), R. Lyon (GSFC), J. Mather, H. Moseley, L. Mundy (UMd), E. Serabyn (JPL), M. Shao (JPL), R. Silverberg, and H. Yorke (JPL). An external Advisory Panel chaired by C. Townes (UCBerkeley), with members N. Evans (UTAustin), J. Fischer (NRL), G. Melnick (SAO), W. Traub (SAO), and A. Weinberger (Carnegie) provides independent advice. Ball Aerospace, Boeing SVS, Lockheed Martin, and Northrop Grumman participate in the study as industry partners. The Goddard Engineering Directorate provides support for the study. During the past year the science team developed a Design Reference Mission, and the engineering team refined the SPECS architecture and mission concept. SPECS is a kilometer maximum baseline imaging and spectral ("double Fourier") interferometer which provides angular resolution comparable to that of the Hubble Space Telescope at far-IR and submillimeter wavelengths. An Advisory Review Panel meeting was held on 24 August 2004 at Goddard, and a 1-week concurrent engineering study was conducted in the Goddard Instrument Synthesis and Analysis Lab. SPECS was recommended as a successor to SAFIR in the "Community Plan for Far-IR/Sub-millimeter Space Astronomy," and it is included in the NASA space science roadmaps for the Astronomical Search for Origins and for the Structure and Evolution of the Universe.

The Space Infrared Interferometric Telescope (SPIRIT) was selected for study under the ROSS/Origins Science Mission Concept study program, with PI D. Leisawitz and Co-Is A. Barger (UWisc), D. Benford, A. Blain (Caltech), J. Carpenter (Caltech), M. DiPirro (GSFC), J. Fischer (NRL), J. Gardner, M. Harwit (Cornell), L. Hillenbrand (Caltech), T. Hyde (GSFC), A. Kogut, M. Kuchner (Princeton), A. Mainzer (JPL), A. Martino (GSFC), J. Mather, L. Mundy (UMd), S. Ollendorf (GSFC), J. Pellicciotti (GSFC), S. Rinehart, R. Silverberg, G. Stacey (Cornell), J. Staguhn (GSFC/SSAI), and P. Stahl (MSFC). An external Advisory Panel chaired by G. Melnick (SAO), with members D. Miller (MIT), H. Moseley, E. Serabyn (JPL), M. Shao (JPL), W. Traub (SAO), S. Unwin (JPL), and E. Wright (UCLA) provides independent advice. Ball Aerospace, Boeing SVS, Lockheed-Martin, and Northrop Grumman participate in the study as industry partners. The Goddard Engineering Directorate provides additional support for the study. SPIRIT, a candidate "Origins Probe," was recommended in the "Community Plan for Far-IR/Submillimeter Space Astronomy" as a science pathfinder for SPECS. SPIRIT is a double Fourier far-IR/submillimeter interferometer with sub-arcsecond imaging and moderate resolution ($R \sim 1000$) spectroscopic capability. SPIRIT could be launched in about a decade to provide angular resolution one hundred times better than that of the Spitzer Space Telescope, and sensitivity $100-1000\times$ better than that of Spitzer, the Herschel Space Observatory, or the Stratospheric Observatory for Infrared Astrophysics (SOFIA), complementing the measurement capabilities of JWST and the Atacama Large Millimeter Array (ALMA). SPIRIT will measure the resonant structures in exozodiacal debris disks to find and characterize extrasolar planets; characterize the atmospheres of selected extrasolar gas giant planets; elucidate the evolution of young stellar systems and their planet-forming potential; and track the luminosity evolution and chemical and dust enrichment history of galaxies on a cosmological timescale.

Work continues on two concept studies for Einstein Probes. Gardner is leading a concept study of the NASA-DOE Joint Dark Energy Mission. Working with the Supernova/Acceleration Probe team, Gardner, Fixsen, Greenhouse, R J Hill, Hinshaw, Kimble, Mather, Moseley, Oegerle, Rauscher and Woodgate are studying the infrared detectors, the spectrograph, and the calibration requirements of the mission. In a separate study, G. Hinshaw, Bennett, A. Kogut, H. Moseley, and E. Wollack, in collaboration with scientists from 10 universities continued their study of the Inflation Probe. This probe is intended to measure the polarization of the cosmic microwave background anisotropy to search for the signature of gravity waves left over from a period of inflationary expansion in the very early universe.

Oliversen, Harris (U. Washington), Roesler (U. Wisconsin) and collaborators continued the development of a spatial heterodyne spectrometer concept for the Jupiter Icy Moons Orbiter (JIMO) mission to study the Jovian magnetosphere and especially the local environment near the Galilean satellites.

6 SUBORBITAL MISSIONS

6.1 EUNIS

LASP is preparing the Extreme Ultraviolet Normal Incidence Spectrograph (EUNIS) for a Black Brant sounding rocket launch in 2005. This new instrument builds on technical innovations achieved by the Solar Extreme ultraviolet Research Telescope and Spectrograph (SERTS) experiment over ten successful flights. The new design features nearly two orders of magnitude greater sensitivity as well as improved spatial and spectral resolutions. The high sensitivity will enable new studies of transient coronal phenomena, such as the rapid loop dynamics seen by TRACE, and searches for non-thermal motions indicative of magnetic reconnection or wave heating. It will also be possible to obtain EUV spectra 2-3 solar radii above the limb, where the transition between the static corona and the solar wind is expected to occur.

The past year saw the completion of all fabrication and the initiation of the integration, alignment and test phase. The two microchannel plate intensifiers were damaged during vibration testing of the main bulkhead assembly. Fortunately, collaborator O. Siegmund (U. California Berkeley) was able to repair the intensifiers, and their support structure has been strengthened. EUNIS will be launched from White Sands Missile Range with the support of White Sands and the GSFC Wallops Flight Facility. The EUNIS team includes A. Bhatia, J. Davila, P. Haas, S. Jordan, P. Kenny, D. Linard, J. Novello, L. Payne, D. Rabin, M. Swartz and Thomas (LASP), C. Engler, S. Irish, J. Miko, M. Nowak, T. Plummer, I. Rodriguez, R. Scott, J. Stewart, and L. White (GSFC Applied Engineering and Technology Directorate), J. Brosius (Catholic U.), R. Harrison (Rutherford Appleton Laboratory), F. Keenan (Queens U. Belfast), E. Landi (NRL) and S. McIntosh (HAO/NCAR). Summer students included B.

Gates (UMBC) and T. Guha-Gilford (Roosevelt High).

6.2 ARCADE

The ARCADE team (A. Kogut [PI], D. Fixsen, M. Limon, P. Mirel, and E. Wollack, with additional collaborators at JPL and UCSB) published new measurements of the blackbody spectrum of the cosmic microwave background based on the successful June 2003 flight. ARCADE (Absolute Radiometer for Cosmology, Astrophysics, and Diffuse Emission) is a balloon-borne instrument to compare the spectrum of the cosmic microwave background to a precision on-board blackbody at centimeter wavelengths, a decade below the measurements made by the COBE/FIRAS instrument. Deviations from a blackbody spectrum at these long wavelengths result from free-free emission at the end of the "cosmic dark ages". ARCADE probes the poorly-understood redshift range 10–20 when the first collapsed structures reionized the intergalactic medium. Results from the 2003 flight show the CMB temperature to be 2.720 ± 0.010 K at 10 GHz, consistent with a blackbody. Two papers describing the instrument and the CMB spectrum measurement were published in The Astrophysical Journal, with a third paper describing the on-board calibrator accepted for publication in Review of Scientific Instruments.

ARCADE uses a novel cryogenic design to reduce systematic uncertainty. To eliminate corrections from warm objects in the beam, it uses open-aperture cryogenic optics at the mouth of a large bucket dewar, with no windows between the 2 K optics and the atmosphere. Instead, boiloff helium gas from the superfluid LHe reservoir serves as a barrier to prevent condensation of solid nitrogen on the optics. Two flights using a "small" (60 cm aperture) dewar demonstrated the feasibility of the windowless design. A larger payload (150 cm aperture) covering the frequency range 3–100 GHz is now being built and is expected to fly in 2005. Graduate student Jack Singal of the University of California at Santa Barbara has joined the team to build and fly the "Big Dewar."

ARCADE makes use of several innovations in radiometry and cryogenic design. We have developed precision waveguide loads with return loss below -40 dB in a compact, isothermal design capable of withstanding multiple thermal cycles. Large (50 cm) free-space calibration targets provide an absolute temperature reference within a compact footprint. A project with a high school student intern successfully developed superfluid helium "fountain effect" pumps housed in common plumbing fixtures.

6.3 PAPPA

The Primordial Anisotropy Polarization Pathfinder Array (PAPPA) was selected for development in October 2003. PAPPA is a balloon-borne instrument to measure the polarization of the cosmic microwave background and search for the signature of gravity waves excited during an inflationary epoch shortly after the Big Bang. PAPPA combines sensitive transition-edge superconducting detector technology with phase-sensitive correlation techniques from radio astronomy to build a "polarimeter-on-a-chip" scalable to the large (kilopixel) arrays anticipated for future space missions. The PAPPA team within the LASP includes Al Kogut (PI), D. Chuss, D. Fixsen, G. Hinshaw, M. Limon, S.H. Moseley, N. Phillips, and E. Wollack, with additional co-investigators M. Devlin at the University of Pennsylvania and K. Irwin at NIST.

6.4 High Angular resolution Wideband Camera (HAWC)

S. H. Moseley, along with G. Voellmer and C. Allen (GSFC engineering directorate) led the development of the detector array for the HAWC instrument on SOFIA. Other LASP members of the team included Drs. D. Benford, D. Chuss, R. Silveberg, and J. Staguhn. The HAWC instrument is being developed by D.A. Harper et al. at the University of Chicago, with GSFC providing detector, cryogenic, optical, and software subsystems. The detector array contains 384 pixels, and will be the premier bolometer array camera for far-infrared wavelengths when it achieves first light in 2005. The bolometer array will operate at wavelengths between 50 μm and 200 μm, combining high sensitivity, high angular resolution, and large format, improving submillimeter imaging speed. The array was completed in February 2004 and delivered to Yerkes Observatory in March 2004, where integration with the rest of the instrument is ongoing. Software for this important instrument is being provided by T. Ames (GSFC engineering directorate).

6.5 Explorer of Diffuse Galactic Emission (EDGE)

Development of the high frequency (1-1.5 THz) frequency selective bolometers (FSBs) needed for the EDGE experiment is nearly complete. The EDGE mission would study the anisotropy of the Cosmic Infrared Background in a long duration balloon flight from Antarctica to determine the details of the structure and evolution of early galaxies. The collaboration between S. Meyer (U. Chicago), G. Wilson (U. Massachusetts) and R. Silverberg (GSFC) was awarded a two-year grant in 2002 to demonstrate high frequency FSBs in the laboratory.

7 INSTRUMENTATION AND NON-FLIGHT PROGRAMS

D. Leisawitz and Co-Is T. Armstrong (NRL), D. Leviton (GSFC AETD), R. Lyon (GSFC Code 930), A. Martino (GSFC AETD), J. Mather, L. Mundy (UMd), T. Pauls (NRL), and S. Rinehart continued their effort to develop a wide-field double Fourier imaging interferometry technique for the SPIRIT, SPECS, and TPF-I missions. The Wide-field Imaging Interferometry Testbed (WIIT) at Goddard is delivering the data needed to test and evaluate alternative spatial-spectral "image" synthesis algorithms. WIIT was designed to demonstrate that a Michelson stellar interferometer equipped with a multi-pixel detector array can image a complex, extended scene over a wide field of view (i.e., $\theta_{FOV} >> \lambda/d$, where d is the diameter of the aperture of an individual interferometer array element). The team's NASA ROSS/APRA proposal was approved in 2003, providing the support needed to develop this technique to Technology Readiness Level 5 over a three-year period.

A. Kutyrev, H. Moseley, C. Bennett and D. Rapchun are developing a high resolution, near-infrared cryogenic temperature tunable spectrometer with solid Fabry-Perot etalons. With small 1 inch diameter silicon Fabry-Perot etalons this instrument is capable of achieving large etendue, equivalent to up to 80 mm diameter conventional Fabry-Perot spectrometers. All components of the instrument are inside cryostat, which reduces the thermal background noise and improve the detection limit. To study a large scale structure of the diffuse ionized hydrogen in the Galactic plane observing is carried out in Brackett-γ line of hydrogen. The instrument has resolving power of 12.5^3 and instantaneous velocity coverage of 300 km s^{-1} and the field of view is 0.50° with the current 12.5" telescope. The instrument operates in a non-imaging mode, acquiring an integral spectrum of all the objects in the field of view. A successful observing run of the inner Galactic disk has been carried out last summer. We have observed a number of fields at $b = 0°$, $l = 355°$ to $l = 34°$ with 1° step.

The SPEctral Energy Distribution (SPEED) camera is being developed by R. Silverberg (GSFC), D. Cottingham (GST) and D. Fixsen (SSAI) with collaborators G. Wilson (U. Massachusetts) and S. Meyer (U. Chicago). It is designed to measure the spectral energy distribution of high redshift galaxies in four bands accessible from the ground. The prototype camera will use Frequency Selective Bolometers (FSBs) to provide a 16 element (4 pixels $\times 4$ spectral bands) array of superconducting transition edge sensor (TES) bolometers to efficiently map galaxies. SPEED will be deployed initially on the Heinrich Hertz 10m telescope in Arizona. It is being designed so it may also be used with higher angular resolution on the 50m Large Millimeter Telescope (LMT) currently being built in Mexico.

B. Woodgate has continued to work on Integral Field Spectrograph concepts for the TPF Coronagraph and for the Joint Dark Energy Mission (JDEM) and as a mode in the ground-based Fabry-Perot imager, and to develop focal plane masks for microlens arrays to remove scattered light.

7.1 Detector Development

A team of far-infrared astrophysicists in LASP (including S.H. Moseley, D.J. Benford and J.G. Staguhn) have pushed the boundaries of superconducting transition edge sensor (TES) bolometer arrays. Destined for use in the SOFIA/SAFIRE imaging Fabry-Perot spectrometer, the ASTRO/SPIFI imaging Fabry-Perot spectrometer, the JCMT/ZEUS grating spectrometer, and the GBT/Penn Array Receiver broadband millimeter camera, these arrays are pushing limits of sensitivity, speed, and pixel count. In the past year, recent developments in these detectors have resulted in some of the lowest-noise and some of the fastest infrared TES bolometers ever built.

The Atacama Cosmology Telescope (ACT) is a multi-institution collaboration headed by Principal Investigator L. Page (Princeton Univ) aiming to produce arcminute-resolution and micro-Kelvin sensitivity maps of the microwave background temperature over 200 square degrees of the sky in three frequency bands. A GSFC team led by S.H. Moseley and consisting of J.A. Chervenak (engineering directorate), E. Wollack, D. Benford, and J. Staguhn (LASP) are contributing the three thousand-element bolometer arrays for ACT. The first components of the ACT arrays have been built and are in testing at LASP.

B. Woodgate, R. Kimble, T. Norton (SSAI), J. Stock (Swales) and G. Hilton (SSAI) continued their development of photocathodes for zero read noise photon counting arrays, obtaining a quantum efficiency of 65% at 185 nm using cesiated p-doped GaN. They also demonstrated a field emission assistance effect due to sharp surface structure in GaN nanowires supplied by K. Bertness (NIST, Boulder). They plan to extend this work into the visible with InP and GaAs, and to incorporate the photocathodes into Electron Bombarded CCD detectors in partnership with C. Joseph (Rutgers U.).

Development of Polarization-sensitive Frequency Selective Bolometers (pFSBs) was initiated in collaboration with J. Ruhl (CWRU). pFSBs may be an important component of instruments for multi-frequency polarization sensitive observations at millimeter and submillimeter wavelengths. The detector components are being constructed and assembled at GSFC while testing of sub-assemblies has been taking place at CWRU.

7.2 Optics

C. Bowers, B. Woodgate, and R. Lyon are investigating a novel means for correction of optical wavefront in both phase and amplitude for coronagraphy. While previous work has focused on phase (ϕ) correction only, wavefront amplitude uniformity is equally important. For example, requirements for TPF-C are $\delta\phi \sim 10^{-4}\lambda$ to reduce speckle and permit imagery of faint exosolar planets. Bowers et al are proposing a means of simultaneously correcting both wavefront errors to high accuracy. The approach incorporates a modified, 3-mirror Michelson interferometer (two deformable mirrors (DMs) in one arm and a fixed mirror in the other) with an asymmetric beam splitter. Point-to-point adjustment of the shape of the two DMs can remove both phase and amplitude errors of the final recombined beam. A laboratory testbed is under construction to characterize performance.

C. Bowers is also investigating the uniformity of mirror coatings such as Al/MgF_2 and protected silver. High contrast imaging applications place stringent requirements on wavefront amplitude errors induced by non-uniform coatings.

Rabin and Smith collaborated with D. Content, R. Keski-Kuha, S. Antonille, T. Wallace, S. Irish and C.

Stevens (GSFC Applied Engineering and Technology Directorate) to carry out metrology of a 55-cm lightweight (4.6 kg) ULE mirror that has a construction architecture very similar to the larger mirror specified for the Terrestrial Planet Finder Coronagraph. This fast ($f/1.2$) mirror is specified to be parabolic in zero-g, with rms figure accuracy of 7 nm rms and microroughness less than 1 nm rms. GSFC is verifying this performance through a complete determination of the surface power spectral density and optical imaging performance. During the last year, the microroughness of the mirror was thoroughly characterized. A mid-frequency and figure metrology mount which incorporates a holographic null lens, phase-shifting interferometer, and hexapod positioning robot, was 80% designed and 50% fabricated. Detailed design of a flight-capable mirror mount was iniated in conjunction with an end-to-end uncertainty budget and a test program to validate the finite element model used to relate the ground-based figure to the zero-g figure. The near-term goal of the program is to incorporate the mirror in a Solar High Angular Resolution Photometric Imager (SHARPI), a suborbital experiment to image the Sun at ultraviolet wavelengths ($120-280$ nm). Summer intern J. Landes (U. Kansas) worked on the design and structural analysis of a telescope metering structure.

In a separate effort, P. Chen continued collaboration with R. Oliversen and K. Carpenter on the development of new techniques to fabricate large lightweight mirrrors with ultra-smooth surfaces made from composite materials. Oliversen is working with a company through the government's Small Business Innovative Research (SBIR) program to develop actuators for deformable mirrors.

8 CONFERENCES

J. Mather chaired a program and edited the proceedings for session 5487, "Optical, Infrared, and Millimeter Space Telescopes," at the SPIE meeting in Glasgow, June 21-25, 2004. M. Clampin was a co-chair of the conference. This program included over 200 papers. The Program Committee was: James B. Breckinridge, JPL; Lee D. Feinberg, GSFC; Silvano Fineschi, Osservatorio Astronomico di Torino; Jonathan P. Gardner, LASP/GSFC; Matthew A. Greenhouse, LASP/GSFC; Matthew J. Griffin, Univ. of Wales Cardiff; Hashima Hasan, NASA HQ; Martin F. Kessler, ESA; Oliver LeFevre, Lab. d'Astrophysique de Marseille; Knox S. Long, STScI; Howard A. MacEwen, SRS Technologies; Toshio Matsumoto, ISAS (Japan); H. Philip Stahl, MSFC; Saku Tsuneta, NAOJ (Japan); Paul Wesselius, SRON (Netherlands).

J. Davila, B. Thompson, and N. Gopalswamy (GSFC, Lab for Extraterrestrial Physics) organized a workshop in April 2004 to begin planning U.S. participation in the International Heliospherical Year (IHY). The IHY will commence on the fiftieth anniversary of the International Geophysical Year (IGY, 1957-58) that produced an unprecedented level of understanding of geospace and saw the start of the Space Age. Like the IGY, the objective of the IHY is to discover the physical mechanisms that link Earth and the heliosphere to solar activities.

K. Carpenter was the organizer of a Topical session at the 204th meeting of the AAS in June 2004 entitled "UV/Optical Universe at Ultra-High Angular Resolution".

A joint workshop with scientists associated with the Advanced Composition Explorer (ACE) and the Wind spacecraft was held in Taos, NM, in October 2003, and attended by G. Holman and B. Dennis from RHESSI. The joint analysis of data for the same solar events is motivated by the need to understand the relation between the near-Sun particles seen indirectly with RHESSI through their X-ray and gamma-ray emissions and the near-Earth particles measured in situ with instruments on ACE and Wind. Several joint studies were initiated as a result of this workshop and at least one has resulted in a paper accepted for publication (Emslie et al. 2004).

At the Denver AAS Solar Physics Division meeting in Denver, CO, in June 2004, a special session called "When the Sun Went Wild" was organized by B. Dennis on the solar events from the period of intense solar activity from 19 October through 5 November 2003. During that period, 12 GOES X-class flares occurred including probably the most intense flare ever recorded that has been estimated to have been an X28. many of these flares were recorded with RHESSI including at least two that showed gamma-ray line emission. A total of 12 talks (4 invited) were presented during the session with innumerable posters.

Dennis attended a meeting of the Community of European Solar Radio Astronomers (CESRA) held in the Isle of Skye, Scotland, in June 2004, and gave an invited talk on RHESSI results.

Dennis served on the science organizing committee for a special 2-day RHESSI-related session at the Paris COSPAR meeting in July 2004 on Energy Release and Particle Acceleration at the Sun and in the Inner Heliosphere. Holman gave an invited talk on Energetic Electrons in Solar Flares as viewed in X-rays. Dennis gave a talk on thermal and nonthermal contributions to the solar flare X-ray flux.

Dennis, Holman, Schwartz, and Schmahl attended the fourth RHESSI workshop held in Meudon, France, immediately after the COSPAR meeting. This 4-day session was attended by about 50 scientists from around the world, all actively pursuing the analysis of RHESSI data.

9 EDUCATION AND OUTREACH

The SUNBEAMS program completed its seventh year as an educational partnership between GSFC and the District of Columbia Public Schools (DCPS). Oliversen and S. Brown lead the program. Oliversen, a mentor since the beginning of the program, took over from Crannell who retired this past year. The program serves as a model urban intervention technique for sixth grade teachers and students by empowering the teachers and inspiring the students through participation in the process and excitement of science and technology. The program is comprised of three parts. Each summer, 10 – 15 DCPS 6th-grade math and science teachers come to GSFC for a five-week paid internship. Each teacher, paired with a mentor from the scientific or technical staff, develop lessons, aligned with national standards, using NASA activities for middle school students, which they subsequently pilot in their own schools. During the school year, each teacher brings a class of up to thirty students to GSFC for a week of total immersion in math and science activities. Lastly, the teacher and students work together to plan a Family Night or star party at their school to provide the school community and their GSFC partners an opportunity to share in the students' impressions and reactions to their experiences.

During the past year, Carpenter gave several educational talks: (1) "Stars and Planets: The View from HST", at the Opening of the "Smithsonian Institution Traveling Exhibition" (SITES) in it new permanent location at the GSFC Visitor's Center, Oct. 2003, and (2) "Hubble Space Telescope: Witness to a Universe of Wonders", at the "Space 2004" AIAA Conference, held in San Diego, CA, September 2004.

J. Gardner gave several public lectures on "Finding our Origins with the Hubble and James Webb Space Telescopes."

The LASP RHESSI team is involved in an extensive education and public outreach activity. Many students and teachers work at GSFC on RHESSI activities ranging from hands-on help with analyzing flight data, testing the data analysis software, and upgrading the RHESSI website at http://hesperia.gsfc.nasa.gov/rhessi/.

10 ACRONYMS

ACE – Advanced Composition Explorer
ACS – HST/Advanced Camera for Surveys
ARCADE – Absolute Radiometer for Cosmology, Astrophysics, and Diffuse Emission
CDS – Coronal Diagnostic Spectrometer
CIB – Cosmic Infrared Background
CHIPS – Coronal Hot Interstellar Plasma Spectrometer
DIRBE – COBE/Diffuse infrared Background Experiment
EDGE – Explorer of Diffuse Galactic Emission
EIT – SOHO/Extreme Ultraviolet Imaging Telescope
EPIC – Extrasolar Planet Imaging Coronagraph
EUNIS – EUV Normal Incidence Spectrograph
EUV – Extreme ultraviolet
FIBRE – Fabry-Perot Bolometer Research Experiment
FKSI –Fourier-Kelvin Stellar Interferometer
FUSE – Far Ultraviolet Spectroscopic Explorer
GALEX – Galaxy Evolution Explorer
GBT – Green Bank Telescope
GOES – Geostationary Operational Environmental Satellite
GSFC – Goddard Space Flight Center
HDF – Hubble Deep Field
HST – Hubble Space Telescope
IR – Infrared
IRAC – Spitzer/Infrared Array Camera
ISIM – JWST/Integrated Science Instrument Module
IUE – International Ultraviolet Explorer
JCMT – James Clerk Maxwell Telescope
JFET – Junction Field Effect Transistor
JWST – James Webb Space Telescope
LASP – Laboratory for Astronomy & Solar Physics
LAMBDA – Legacy Archive for Microwave Background Data Analysis
LWS – Living with a Star
MEMS – micro-electro-mechanical systems
MPF – Microlensing Planet Finder
NIRCam – JWST/Near Infrared Camera
NIRSpec – JWST/Near Infrared Spectrograph
PAPPA – Primordial Anisotropy Polarization Pathfinder Array
RHESSI – Reuven Ramaty High Energy Solar Spectroscopic Imager
SAFIR – Single Aperture Far-Infrared Observatory
SAFIRE – SOFIA/Submillimeter and Far Infrared Experiment
SAMPEX – Solar Anomalous and Magnetospheric Particle Explorer
SDO – Solar Dynamics Observatory
SERTS – Solar EUV Research Telescope and Spectrograph
SHARC – Submillimeter High Resolution Array Camera
SI – Stellar Imager
SIRTF – Space Infrared Telescope Facility
SOFIA – Stratospheric Observatory for Infrared Astronomy
SOHO – Solar and Heliospheric Observatory
SPECS – Submillimeter Probe of the Evolution of Cosmic Structure
SPEED – SPEctral Energy Distribution Camera
SPIRIT – Space Infrared Interferometer Telescope
SQUID – superconducting quantum interference device
STEREO – Solar Terrestrial Relations Observatory
STIS – HST/Space Telescope Imaging Spectrograph
SUMER – SOHO/Solar Ultraviolet Measurements of Emitted Radiation
SUNBEAMS – Students United with NASA Becoming Enthusiastic About Math and Science
TES – Transition Edge Sensor
TPF – Terrestrial Planet Finder
TRACE –Transition Region and Coronal Explorer
UV – ultraviolet
VLT – Very Large Telescope
WIIT – Wide-field Imaging Interferometry Testbed
WMAP – Wilkinson Microwave Anisotropy Probe
WFC3 – HST/Wide Field Camera 3

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