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

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The following report covers the period from July 2002 through September 2003.

1 INTRODUCTION

The Laboratory for Astronomy & Solar Physics (LASP) is a Division of the Space Sciences Directorate at NASA 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, the interstellar and intergalactic medium, active galactic nuclei, galaxy formation and evolution, and studies of the cosmic microwave background radiation.

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 2002/2003 year was an extremely exciting one in the LASP. In February 2003, the Wilkinson Microwave Anisotropy Probe (WMAP) team announced results from the first year of operations that were truly stunning. The WMAP measurements constrain models of structure formation, the geometry of the universe, and inflation. The results indicate that the universe has a flat (i.e. Euclidean) geometry. Initial observations of polarization were reported, the first detection of reionization, and accurate values for many cosmological parameters. Thirteen papers on the results were published in a special issue of the Astrophysical Journal. At the same time the results were announced, all the data from the first year were made public in the new Legacy Archive for Microwave Background Data Analsyis (LAMBDA). Gary Hinshaw, Ed Wollack, Al Kogut, and Principal Investigator Chuck Bennett are members of the WMAP team at GSFC. WMAP is still operating well, and we look forward to new results in the coming year.

The Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), also provided dramatic new observations of the Sun during the past year. RHESSI was launched on February 5, 2002, and has been operating successfully ever since. Through August 2003, RHESSI has detected over 10,000 flares at energies above 12 keV, and has provided ground-breaking observations, some of which include: (1) the first hard x-ray imaging spectroscopy of flares over a broad energy range, (2) the first high resolution gamma-ray line spectrum of flares, and (3) the first imaging of flare gamma-ray lines. Other discoveries, and a detailed discussion of science results from RHESSI are given later in this report. The first scientific results from RHESSI were published in a special issue of Solar Physics. LASP team members include Brian Dennis (Lead co-invesigator), Carol Crannell, and Gordon Holman. R. Lin at SSL, UC Berkeley is the PI.

The Space Infrared Telescope Facility (SIRTF) was finally launched on August 25, 2003, and the Infrared Array Camera (IRAC) provided the first engineering picture of the sky at 3.6μm. Although the telescope had not cooled down completely, nor had it been focused, the IRAC image was beautiful to those who had spent many years building the camera (G. Fazio at SAO/CfA is the PI, and Harvey Moseley is the instrument scientist). We look forward to the first results from SIRTF later this year.

Excellent progress is being made on the development of the James Webb Space Telescope (JWST). The prime contract was signed with Northrup Grumman Space Technologies to build the telescope, the primary mirror was chosen (Beryllium), the instrument teams are in place, and the detector vendor was chosen. Harvey Moseley, Alex Kutyrev and Bob Silverberg are making good progress on development of a microshutter array as a multi-object selector for the Near-Infrared Spectrograph (NIRSpec) on JWST.

ARCADE (Absolute Radiometer for Cosmology, Astrophysics, and Diffuse Emission) enjoyed its second successful balloon flight in June 2003. The Principal Investigator is Al Kogut, and other members of the team from LASP include Ed Wollack, P. Mirel, D. Fixsen, and M. Limon.

2 PERSONNEL

William Oegerle was chosen by the Space Sciences Directorate at GSFC as the new Lab Chief. He assumed his new position in March 2003. Mr. Michael Horn, an electrical engineer, was chosen as Assistant Lab Chief in April 2003. John Wolfgang is also an Assistant Chief for engineering, and is the Acting Head of the Instrument and Computer Systems Branch. Doug Rabin is Head of the Solar Physics Branch, William Danchi is Head of the Infrared Astrophysics Branch, and Oegerle is 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, Mark Clampin, Carol Crannell, 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, Larry Orwig, Bernard Rauscher, 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.

Dr. Mark Clampin joined the Lab in February 2003 as the Observatory Project Scientist for the James Webb Space Telescope (JWST). Mark comes to the Lab from the Space Telescope Science Institute (STScI), where he was detector scientist for the Advanced Camera for Surveys (ACS) on HST. Also joining the LASP from STScI in the past year was Dr. Bernard Rauscher. Bernie is Deputy Project Scientist for the Instrument Science Module on JWST, and will concentrate on the development of IR detectors. Chris St. Cyr joined the Lab as the new Project Scientist for the "Living with a Star" (LWS) program, replacing Art Poland. Finally, Dr. David Leisawitz transferred into our Lab from the Space Science Data Office at GSFC. Dave's interests are far-IR astronomy and interferometry.

William Behring, Upendra Desai, and Arthur Poland retired and entered the Emeritus program. Art still visits and is now on the staff at George Mason University.

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

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, Stephen Rinehart, Jason Rhodes, and Debra Wallace. Jason Rhodes departed during the year for a position at Caltech.

J. Rajagopal began his tenure as a Michelson Fellow, working with W. Danchi on interferometry.

In March 2003, Duilia F. de Mello arrived to work with J. Gardner. She is a Research Associate of the Catholic University of America.

Krister Nielsen (Catholic University of America) finished his dissertation at University of Lund, Sweden and joined LASP to work with the HST Treasury team to study the star Eta Carina (Gull, local co-investigator).

As the Space Telescope Imaging Spectrograph (STIS) Guaranteed Time Observer Program winds down, a number of research associates have moved on to other positions: Keith Grogan and Harry Teplitz moved to sunny California to work on the SIRTF Project, Povilas Palunas took a position at the University of Texas at Austin working on the Hobby Eberly Telescope, Alain Smette returned to France, and Gerry Williger moved to Johns Hopkins University to work on the Far Ultraviolet Spectroscopic Explorer (FUSE) Project.

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), Sophia Khan (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

J. Davila, L. Ofman, M. Swartz, and R. Thomas joined with colleagues from the University of Maryland to conduct a unique biological experiment involving extremeophile micro-organisms, which can continue to live under extraordinary conditions. Two different types of these creatures were attached to the front of a SERTS sounding rocket and blasted into space, directly exposed to normally lethal doses of solar EUV radiation. As recently reported in the journal FEMS Microbiology Letters, a surprizing number of them survived the trip, giving valuable information on the DNA repair mechanisms that they have evolved.

T. Duvall, with L. Gizon and J. Schou of Stanford University have detected wave properties of the solar supergranulation, long thought to be a purely convective phenomenon. The discovery was made from an analysis of two months of Dopplergrams from the MDI instrument on the SOHO satellite using the technique of time-distance helioseismology. The waves have periods of 5-10 days and only live for a little more than a period. However, the spectrum clearly peaks away from zero frequency, in clear conflict with simple convective models. Strange properties of these waves include an excess of power propagating in the prograde (with respect to rotation) direction and an excess of power propagating towards the equator for waves in both north and south hemispheres. Earlier measurements of the rotation rate of the supergranulation pattern using cross correlation techniques indicated a rotation rate that was too large due to the excess prograde power. The revised rotation rate is similar to that of small magnetic features.

T. Duvall, with J. Beck and L. Gizon of Stanford University have detected a new component of solar dynamics – a north-south flow diverging from the latitude of peak magnetic activity. This flow is presumably related to the torsional oscillation, a pattern of slow and fast rotation which migrates towards the equator during the solar activity cycle. The discovery was made from an analysis of six years of Dopplergrams from the MDI instrument on the SOHO satellite using the technique of time-distance helioseismology. The basic quandary about this flow is whether it is a cause or effect of solar activity: does an upflow at the dominant latitude of magnetic activity cause the resultant diverging north-south flow and the emergence of magnetic activity or does the emergence of magnetic activity cause the flow?

G. Holman has studied how low- and high-energy cutoffs in the distribution of suprathermal electrons accelerated in solar flares can be identified in the gyrosynchrotron radio spectra and the bremsstrahlung x-ray/gamma-ray spectra from flares. The determination of the high-energy cutoff from these spectra establishes the highest electron energies produced by the acceleration mechanism, while determination of the low-energy cutoff is crucial to establishing the total energy in accelerated electrons. In particular, he has studied how flare microwave and hard x-ray spectra can be analyzed together to determine these electron cutoff energies.

L. Sui (CUA), G. Holman, B. Dennis, S. Krucker (UCB), H. Schwartz (SSAI), and K. Tolbert (SSAI) have analyzed and modeled the hard x-ray emission from a small solar flare observed by RHESSI. Their results have been published in a special issue of Solar Physics dedicated to first scientific results from RHESSI.

Holman, Sui (CUA), Schwartz (SSAI), and Emslie (UAH) are studying RHESSI hard x-ray spectra from the 2002 July 23 solar flare. This is the largest flare observed by RHESSI, showing gamma-ray line emission. Their results will be published in a special issue of The Astrophysical Journal Letters dedicated to this flare.

H. Jones, in collaboration with summer research assistant M. Popescu, P. Jones (Univ. of Arizona), and D. Branston (National Solar Observatory) completed a comparison of NASA/NSO Spectromagnetograph (SPM) data with composite total solar irradiance which suggests that two component sunspot-facular models of TSI variation are incomplete or that there are unresolved measurement issues in either the spacecraft or ground-based observations (Jones *et al.*, 2003). Jones (2003) published a study of flat-fielding and analysis procedures for imaging spectroscopy in the difficult He I 1083 nm line. In collaboration with E. Malanushenko, Jones found from such studies that the correlation properties between He I 1083 nm central intensity and half-width provides a potential simple and objective diagnostic for coronal holes. Jones has completed initial comparative analysis of SPM magnetograms with the first results from the SOLIS Vector Spectromagnetograph (VSM) which indicate that VSM data, without detailed polarization calibration, are virtually identical to SPM data.

T. Kucera studied 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.

C. St. Cyr and Professor K. Forbes (CUA) have completed an econometric study of the impact of space weather conditions on the wholesale price of electricity. This is the first quantitative study of the climatological effect of geomagnetic conditions on the wholesale market for power. Their study is based on 18 months of data in the mid-Atlantic region, and the results demonstrate that severe space weather conditions cause an increase in the wholesale price of electricity.

St. Cyr continues to study interesting solar events observed by SOHO, Ulysses, Wind, and other spacecraft. He also remains active in the study of the Kreutz sungrazing comet group.

R. Thomas has carried out end-to-end radiometric calibrations of the SERTS rocket experiment after its flights in 1997, 1999, and 2000. These were done at England's Rutherford-Appleton Laboratory, in the same facility used to provide pre-launch calibration of the CDS experiment now flying onboard the SOHO spacecraft. Through coordinated observations during each of the SERTS flights, he has used these measurements to update the CDS radiometric calibrations to an absolute accuracy on the order of 25%.

R. Thomas has measured polarization in coronal EUV emission above the solar limb using the SOHO/CDS normal-incidence spectrometer. This instrument has a polarization sensitivity greater than 50%, causing variations in intensity response as a function of the spacecraft's roll angle for linearly polarized light. Such observations were made during two special roll-maneuvers of the SOHO spacecraft in 1997 and in 2001. The detected polarization is consistent with radiation above certain heights being dominated by resonance scattering, although the measured modulations are actually much larger than expected from standard models.

3.2 Atomic Physics

A. Bhatia, J. Brosius, J. Davila, and R. Thomas, along with other co-authors, published several papers that compared new atomic physics calculations for Ne III, Si IX, and Na-like ions with solar EUV observations made by the SERTS sounding rocket experiment, finding excellent agreement in most cases.

R. J. Drachman has continued his research into the fundamental interactions of positrons and positronium atoms with hydrogen and helium atoms. Collisions of these exotic antimatter particles give rise to annihilation radiation, gamma rays, whose energy distribution depends on the properties of the local medium. This type of radiation has been observed coming from the Galactic center and plane and also from energetic solar flares, so it serves as another useful diagnostic tool.

A. Temkin continues to work on the intrepretation of phenomena observed from space plasmas (eg. stellar atmospheres). He is accurately calculating electron-atom scattering without making a partial wave expansion (with Janine Shertzer, Holy Cross College). The method, including exchange, is difficult because the scattering orbital is not orthogonal to the bound electron orbital, thus extending the range which was necessary to be included for satisfactory accuracy. A solution has been obtained and is in press (Phys. Rev A). Considerable effort by Temkin has also been spent on the theory of including correlation between scattered and orbital electrons in a non-partial wave way. Such a generalization has not, to his knowledge, been done previously. Temkin and Shertzer have now succeded in devising a correct formulation; a calculation by Shertzer will soon be undertaken.

Temkin and Bhatia have also derived the electron-atom impact ionization threshold law, in an idealization known as the Temkin-Poet model. The idea is to calculate inelastic scattering to ever higher excited (N) states of the target, so that the amplitude can confidently be analytically continued into the continuum ($N \rightarrow i/k$, where k is the momentum of ionized electron). When that dependence is known, the deduction of the threshold law is straightforward. Presently, numerical difficulties have arisen when N becomes large ($N \sim 50$). Temkin believes that these difficulties will be overcome, so that successful completion of this research can be anticipated in the the coming year.

Temkin and colleagues have also worked on the derivation of the threshold law of double-photoionization of neutral atoms (i.e 2-electron ejection of neutral atoms by photon impact). This threshold law is different from electron-atom impact ionization, because in this case the residual ion has two units of charge, so that each electron sees at least one unit of charge. The approach taken, nevertheless, contains certain elements of the e-atom problem (the Coulomb-dipole theory), as a first order correction. That theory gave a new undulating type of threshold law. Now new experimental results for double photoionization of Lithium have been published, which also show such undulations. However, Temkin's approach to the double photoionization problem is rigorously different, and leads to integrals are extemely difficult to evaluate. Temkin and colleagues are now working with Prof. Don Madison of the Univ. of Missouri (Rolla), who is one of the foremost experts in the distorted wave approach to these types of problems, and it is hoped that this collaboration will yield much progress on this problem in the coming year.

3.3 Solar System

S.I. Ipatov (George Mason Univ) and J.C. Mather integrated the orbital evolution of Jupiter-crossing objects and asteroidal, kuiperoidal, and cometary dust particles and calculated the probabilities of their collisions with planets. They found that a small portion of former Jupiter-family comets can obtain typical near-Earth object (NEO) and asteroidal orbits and move in such orbits for millions of years. Results of the simulations favor of at least one of the following conclusions: 1) the portion of 1-km former trans-Neptunian objects (TNOs) among NEOs can exceed several tens of percent, 2) the number of TNOs migrating inside the solar system could be smaller by a factor of several than was earlier considered, 3) most of 1-km former TNOs in NEO orbits disintegrated into mini-comets and dust during a smaller part of their dynamical lifetimes if these lifetimes are not small. The fraction of silicate asteroidal particles that collided with the Earth during their lifetime varied from 1% for 100 micron particles to 0.008% for 1 micron particles. The peaks in the migrating asteroidal dust particles' semi-major axis distribution at the $n:(n+1)$ resonances with Earth and Venus and the gaps associated with the 1:1 resonances with these planets are more pronounced for larger particles. The probability of collisions of cometary particles with the Earth is smaller than for asteroidal particles, and this difference is greater for larger particles.

M. Niedner continues to work with J. Brandt (UNM) and other colleagues on interpreting cometary plasma-tail disconnections and using them as probes of the heliosphere in three dimensions.

R. Oliversen and J. Morgenthaler continue work on a synoptic Io and Io plasma torus program. A collection of over 3100 high resolution [O I] 6300 Å spectra, covering 13 years with over 400 observations added in 2003, were reprocessed with improved reduction algorithms to create a homogeneously processed database with increased signal-to-noise. Model spectral fits are currently underway to study Io's atmosphere and its interaction with the plasma torus.

3.4 Stellar Astrophysics

C. Bowers is carrying out an observational program to study the nebular envelopes of planetary nebulae with H. Dinerstein, (University of Texas, P.I.). They are using absorption line spectroscopy from both STIS and FUSE to probe the nebular envelope looking particularly for the ultraviolet spectrum of molecular hydrogen. The primary goals are to produce a highly sensitive search for the presence or absence of H_2 and determine under what conditions such a neutral species exists, and to use the spectra obtained to investigate the conditions within the photodissociation regions which are subjected to the intense ultraviolet flux from the nearby star. A detailed analysis of the first H_2 source has been completed and a paper is in preparation. An unexpected result of this project was the discovery of enhanced Ge abundance in an ultraviolet line one of our targets (BD+30 3639), an element synthesized in the initial steps of the *s*-process and which can be self-enriched in planetary nebulae.

K. Carpenter collaborated with N. Evans (CfA) and R. Robinson (CUA) in HST studies designed to obtain improved mass estimates of Cepheid stars in binary systems. The velocity measured for the hot companion of the classical Cepheid Y Car from the HST data is very divergent from reasonable predictions for binary motion, implying that the companion is itself a short period binary. The measured velocity changed by 7 km/sec during the 4 days between two segments of the observation, confirming this interpretation. Follow-up study indicates that approximately 50% of "binary" Cepheids are in fact members of triple systems, although this fraction may be overestimated since binary companions increase the orbital motion of the Cepheids and make them more likely to be detected and studied.

K. Carpenter continued his collaborative studies, with E. Bohm-Vitense (U. of Washington) and R. Robinson (CUA), of the mechanisms heating the chromospheres, transition regions, and coronae of cool stars. Most recently, they have investigated whether, in the layers with temperatures around 250,000 K in which the OVI lines are emitted, the temperatures are determined by heat conduction from the coronae or by the same processes which heat the lower temperature regions. They used spectra of Hyades F stars taken by the FUSE satellite to study the OVI lines at 1032 and 1038Å and the CIII lines at 977Å as well as other lower transition layer lines, observed with HST and IUE, and comparisons with existing x-ray data. Preliminary results suggest that, for temperatures below 250,000 K, the transition layers for Hyades F stars are not heated by heat conduction from their coronae.

M. Clampin's research during the past year has focused on observations made with HST's Advanced Camera for Surveys. Clampin worked with ACS science team colleagues, J. Krist, D. Ardila and D. Golimowski on a program to observe circumstellar disks. Observations of the Herbig Ae/Be star HD141569 were the first sequence of coronagraphic science observations made with the ACS Coronagraph. The B, V, and I images show that the disk's previously described multiple-ring structure appears to be a continuous distribution of dust with a tightly wound spiral structure. In addition, extending from the disk are two open spiral arms, one of which appears to reach the nearby binary star HD 141569BC. The results are reported by Clampin et al. (2003). More recently, ACS Coronagraphic observations have made of GG Tau, HD 163296 and HD 100546 and are currently being analyzed.

J. F. Dolan, P. T. Boyd (Laboratory for High Energy Astrophysics/Univ. of Maryland Baltimore County) and J. Holland (San Diego State University) continued the search for dying pulse trains (DPTs) from Cygnus XR-1 using RXTE X-ray data. The detection of DPTs is another test of general relativity, and will provide a positive signature for the existence of a black hole. Although several hours of X-ray data have been searched, no DPT's have been detected. Two DPT candidates were detected in three hours of UV data obtained with the HST; investigations are continuing to restrict the possible causes of the different occurrence rate.

Dolan and L. L. Clark (SDSU) analyzed HST High Speed Photometer data of four AGNs for periodic microvariability on short timescales. No photometric variability was detected > 0.003 mag in any AGN on timescales shorter than 1500 sec. These results restrict the masses of black holes acting as the central engine of an AGN to $> 10^6$ $M_\odot$. They also restrict the parameter space available to any diskoseisology oscillations in any accretion disk around such a black hole.

D. Gezari has been collaborating with W. Danchi on mid-infrared imaging observations of star formation regions and mass-losing stars using the Keck 10-meter telescope. Dramatic images of Orion BN/KL are being analyzed and are the basis for three papers in preparation; one on the luminous sources imbedded near IRC2, one on unusual new time-variable structure observed in the BN Object, and one on the global structure and energetics of the entire complex and the relationship with molecular, maser and radio continuum sources.

S. Heap, T. Lanz, and colleagues are pursuing their extensive spectroscopic analysis of massive stars in the SMC based on FUSE and HST/STIS data. They are extending their work to B supergiants to derive stellar parameters, surface composition, and wind properties. In particular, they found additional evidences that the winds of O stars are clumped, resulting in lower mass loss rates. This analysis is based on the extensive grid of NLTE, line-blanketed model atmsopheres calculated by Lanz & Hubeny. A grid of 690 model atmospheres of O stars is now available at http://tlusty.gsfc.nasa.gov. An extension to B stars is now under way.

R. Iping, T. Gull, D. Massa, G. Sonneborn, and J. Hutchings (HIA) are studying the far-UV spectra of several Luminous Blue Variables. FUSE observations were obtained for Eta Carinae, P Cygni, and AG Carinae. The observed flux from Eta Car at 1160 Å from FUSE (30×30 arcsec aperture) is $20\times$ larger than observed by HST/STIS/E140M at the same wavelength through a 0.2×0.2 arcsec aperture. This difference implies that the observed far-UV spectrum is formed in an extended $\sim 2 - 3$ arcsec diameter UV scattering envelope. The flux level declines toward the Lyman limit where converging molecular and atomic hydrogen features completely blanket the spectrum. The shape of the spectrum shortward of 1110 Å is dominated by strong absorption bands of interstellar molecular hydrogen. In addition to many strong interstellar atomic species, the spectrum contains several prominent broad absorption features (N I, Fe II, P II, C III) that they identify with high-velocity gas. These features are broad (~ 200 km s^{-1}) with unsaturated absorption, whereas Fe II lines in the STIS spectrum are highly saturated, implying that the high-velocity material is patchy and/or only partly covers the UV emitting surface. The far-UV spectra of P Cygni and AG Carinae are very similar and indicate a cooler atmosphere than Eta Car.

R. Iping, Massa, and Sonneborn, in collaboration with L. Kaper and G. Hammerschlag-Hensberge (U. Amsterdam), and J. B. Hutchings (HIA) were awarded FUSE Cycle 4 observing time to study 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 0.0 (X-ray source eclipse) and weakest at phase 0.5. O VI shows the opposite modulation, indicating that O VI is probably a byproduct of the X-ray ionization of the dense stellar wind. SMC X-1 was observed with FUSE for a complete binary orbit (3.89 days) in 2003 July. The data analysis is underway.

D. Massa (SGT) continued his work on the winds of OB stars using far UV spectra from the *FUSE* satellite. This work included a study of the winds of LMC O stars (Massa et a. 2003). This paper had three major conclusions. First, simple models are incapable of describing the ionization structure of O star winds. Second, either the mass loss rates of O stars have been seriously overestimated, or their winds are strongly clumped. Third, the ion fraction of O VI in O star winds is directly related to the terminal velocity of the wind, reinforcing the connection between O VI production and the potential for mechanical heating. Massa also participated in a studies by Lehner et al. (2003) of O VI wind variability in OB stars, and by Zsargó et al. (2003) of the range of temperatures and luminosities of stars which contain O VI wind absorption.

M. Niedner is collaborating with B. McCollum (PI; Caltech) and Co-Is F. Bruhweiler (CUA/GSFC) and A. Schultz (STScI) on an approved HST program to observe and classify young stellar objects in Orion using medium resolution spectroscopy with HST/STIS.

A. Sweigart, T. Lanz, T. Brown (STScI), I. Hubeny, and W. Landsman obtained FUSE spectra of three He-rich sdB stars. Using NLTE line-blanketed model atmospheres, they derived stellar parameters and surface compositions, finding that two of the three stars are carbon and nitrogen-rich. They interpret these observations with new evolutionary calculations which suggest that He-rich sdB stars with C-rich compositions are the progeny of stars which underwent extensive internal mixing during a delayed helium-core flash on the white-dwarf cooling curve. Such flash mixing can be either "deep" or "shallow", depending on whether the hydrogen envelope is mixed deeply into the site of the helium flash or only with the outer layers of the core. Based on both their stellar parameters and surface composition, they suggest that these two stars are examples of deep and shallow mixing. Flash mixing may therefore represent a new evolutionary channel for producing He-rich sdB stars.

A. Sweigart with B. Pritzl (NOAO), H. Smith (MSU), P. Stetson (DAO), M. Catelan (PUC), A. Layden (BGSU) and R. Rich (UCLA) carried out an HST snapshot survey of the variable stars in the inner region of the metal-rich globular cluster NGC 6441. Unlike other metal-rich clusters, the horizontal branch in NGC 6441 extends to high effective temperatures and slopes upward with decreasing B-V. The 24 RR Lyrae variables discovered in this survey have anomalously long pulsation periods, suggesting that NGC 6441 might represent a new Oosterhoff group. One BL Herculis and five W Virginis variable stars were also discovered, making NGC 6441 along with NGC 6388 the most metal-rich globular cluster known to have such variable stars.

B. Woodgate, with Povilas Palunas (U. Texas), Carol Grady (NOAO) and Edward Wassell (CUA), have used the GSFC Fabry-Perot tunable narrow band imager as a coronagraph to provide velocity information with two spatial dimensions for the jets of young Herbig Ae/Be stars and T Tauri stars identified in HST/STIS coronagraphic surveys. They have measured the radial velocity of the DL Tau jet (−140 km/s), and have detected several blobs in the HD163296 receding jet well beyond those found by HST/STIS. They have also begun analysis of the STIS long slit spectroscopy of HD104237 in Lyman α where doppler shifted jets are seen on both sides of the star.

The Eta Carina HST Treasury Program. T. Gull, K. Nielsen (CUA), G. Vieira, N. Collins (SSAI), G. Sonneborn (LASP), E. Verner, R. Iping, F. Bruhweiler (CUA) and A. Danks are participating in a major campaign to follow changes in Eta Carinae and its ejecta across the spectroscopic minimum that occurred as predicted in late June, 2003. Kris Davidson (U Minn) is the Principal Investigator of the Hubble Treasury Program awarded 72 orbits to follow Eta Carinae with STIS, ACS/HRC, and WFPC2. Ted Gull is PI of a FUSE effort to follow the far ultraviolet changes. Mike Corcoran (USRA and LHEA) coordinated a daily monitoring of the x-ray flux with RXTE and x-ray imaging plus spectroscopic observations with Chandra. Kerstin Weis (MPA/Germany) headed monitoring from the ground with the VLA/UVES. Henrik Hartman and Sveneric Johansson (University of Lund) are leading a study of the Strontium Patch, a neutral emission region within a few arcseconds of Eta Carinae. This study, being a major component of Hartman's thesis, is led to the identification of over 600 emission lines in the 1640-10200 Å spectral region arising from this region. Lines of neutral and singly-ionize iron-peak elements (Fe, Cr, Ti, Ni, Ca, Sc, V) and the neutron-capture Sr have been identified in this peculiar structure. With the high spatial and spectral resolution of HST/STIS, an ionized structure in [N II], H II and He I has been identified in structure and velocity that apparently shields this neutral cloud from ionizing radiation, but passed ultraviolet radiation longward of $\sim$ 1500 Å from Eta Carinae. Fe I dominates over Fe II in this neutral region. From the STIS E230H spectra of Eta Carinae, Vieira has identified over 5000 absorption lines originating from approximately twenty ejecta velocity systems in line of sight. Verner and Bruhweiler have modeled the population of the energy levels using CLOUDY with over 800 Fe II lines, plus other elements. They find temperatures and densities in the range of 700 to 7000 K and 10^6 to 10^8 cm^{-3} respectively. Nathan Smith and Jon Morse (U Colorado) have led the ACS/HRS image reduction and analysis from the first Eta Carinae images in October 2002. The Treasury Team obtained ultraviolet images in the 220 nm and 250 nm spectral region, which in conjunction with CCD longslit, moderate dispersion spectra with $0.1''$ spatial resolution and 6000 spectral resolving power demonstrate changes of bright "continuum" emission features to the East and South of Eta Carinae. To the West and North of Eta Carinae are the well-known Weigelt Blobs B, C and D, which are very bright emission features. The six structures appear to form a ring-like structure around the Central Source at a radius of 0.1 to $0.2''$.

John Hillier, also a member of the Eta Car Treasury team at U of Pittsburgh, has been building atmospheric models of Eta Carinae to explain both the STIS spectra from 1175 to 10300Å and the FUSE spectra from 930 to 1180Å. His model now addresses the non-uniform, extended atmosphere, seen in the STIS spectra.

Observations with STIS MAMA echelle modes revealed that the Central Source of Eta Car has structure in the vicinity that, at $0.03''$ spatial resolution and 120,000 resolving power, demonstrates spatial structure local to the Central Source and in the foreground lobe of the Homunculus. Apparently, Eta Carinae is being observed through the non-uniform wall of the expanding ejecta and can resolve in velocity, clumps of ejecta with velocities ranging from −146 km/s to −585 km/s. As the x-ray drop occurred on June 29, observations were executed with STIS seven days before and seven days after. Major changes in ejecta close to the Central Source are detected. Initial interpretation is that iron recombines from Fe III to Fe II (and Fe I) and suddenly equivalent widths increase in known velocity components, while new velocity components between −143 and −385 km/s appear.

Observations of Eta Car are continuing in 2003 and 2004 with three goals: 1) search for evidence of a binary companion, 2) understand the changes of the system over the minimum that lasts for several months of a 5.52 year period and 3) gain insight on the atomic spectroscopy and implied physics of a dense, highly excited, but neutral and singly-ionized gas.

3.5 Interstellar Medium

G. Sonneborn, in collaboration with B. Savage and B. Wakker (Wisconsin), K. Sembach (STScI), and other members of the FUSE Science Team, completed a major study of O VI 1031.93 and 1037.62 Å absorption associated with gas in and near the Milky Way, as detected in the FUSE spectra of 100 extragalactic targets and two distant halo stars. This project was one of the primary scientific objectives of the FUSE mission. Strong O VI absorption over the velocity range ~ -100 to 100 km s^{-1} reveals a widespread but highly irregular distribution of halo (thick disk) O VI, implying the existence of substantial amounts of hot gas with $T \sim 3 \times 10^5$ K in the Milky Way halo. Large irregularities in the distribution of the absorbing gas were found to be similar over angular scales of $< 1^\circ$ to $\sim 180^\circ$, implying a considerable amount of small and large scale structure. The inferred small-scale structures must be quite common in order to provide a large sky covering factor of halo O VI along paths to extragalactic objects. High velocity O VI ($-500 < v_{LSR} < +500$ km s^{-1}, excluding the −100 to 100 km s^{-1} range of the halo and disk gas) traces a variety of phenomena, including tidal interactions with the Magellanic Clouds, accretion of gas, outflowing material from the Galactic disk, and intergalactic gas in the Local Group. Some of the high-velocity O VI features are associated with known H I 21-cm high-velocity structures (the Magellanic Stream, Complexes A and C, etc.). The study concludes that collisions in hot gas are responsible for most of the O VI, and not photoionization, even if the gas is irradiated by extragalactic UV background radiation. Consideration of possible sources of collisional ionization favors production of some O VI at the boundaries between warm/cool clouds of gas and a highly extended ($r > 70$ kpc), hot ($T > 10^6$ K), low density ($n \sim 10^{-4} - 10^{-5}$ cm^{-3}) galactic corona or Local Group medium. Such a medium is consistent with predictions of current galaxy formation scenarios.

3.6 Extragalactic Astronomy

T. Brown (STScI), S. Heap, T. Lanz, and colleagues obtained spatially-resolved UV spectra of the extremely metal-poor galaxy, I Zw 18. They showed that the galaxy's interstellar medium is very patchy, with strongly peaked hydrogen column density towards the fainter (SE) knot of I Zw 18. They could also localize two clusters containing Wolf-Rayet stars of the subtype WC. This detection is surprising because standard evolutionary models do not predict the formation of WC stars at such low metallicities. Models incorporating the effect of rotation predict the formation of WR stars from stars with lower initial masses and might explain the presence of WC stars in I Zw 18.

N. Collins, J. Gardner, E. Malumuth, J.Rhodes, R. Hill, A. Smette, H. Teplitz, G. Williger and B. Woodgate, led by P. Palunas, now of the University of Texas, obtained deep UBVRI+narrow band images of 0.5 square degrees around and including the HDF-South using the Big Throughput Camera on the CTIO 4-m telescope. A paper describing the dataset was submitted to the Astrophysical Journal Supplement.

N. Collins, J. Gardner, R. Hill, S. Heap, D. Lindler, J. Rhodes and B. Woodgate, led by H. Teplitz, now of the SIRTF Science Center, published an analysis of the STIS Parallel Survey, and a description of the data in the Astrophysical Journal and the Astrophysical Journal Supplement.

J. Gardner contributed to a paper describing results from the Hubble Deep Field - South flanking field observations, which appeared in the Astronomical Journal in a paper led by Ray Lucas.

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, Gardner and de Mello contributed to 8 papers which will appear 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 $0 < z < 1$.

J. Gardner, N. 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. 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.

Gardner contributed to HST studies involving FUV imaging of the Hubble Deep Field North (led by Harry Teplitz of the SIRTF Science Center), parallel ACS grism observations (led by Lin Yan of the SSC), and grism spectroscopy of the Ultra-Deep Field (led by Sangeeta Malhotra of the STScI). Data for these programs are being taken.

D. F. de Mello supervised two Master students at Chalmers University of Technology/Onsala Space Observatory in Sweden. Jens Andersson's thesis was entitled the Formation and evolution of field galaxies and Theresa Wiegert's thesis was entitled "Galaxy Evolution – a Deep View of the Universe". The latter has also worked on a High-z Database of Galaxies available at the URL http://www.oso.chalmers.se/∼highz/.

D. de Mello was the main reader of the PhD thesis of Viktor Ziskin at Johns Hopkins University entitled "Simulations of Clusters of Galaxies with Thermal Conduction" supervised by Prof. Colin Norman.

D. de Mello has started a project entitled "High Resolution Spectroscopy of Starbursts at $z \sim 3.4$: Stellar Population, Metallicity and Gas Kinematics" and was granted VLT/UT4 time to observe a sample of high-z galaxies with the FORS2 instrument in collaboration with Heidelberg astronomers, Doerte Mehlert, Imo Appenzeller, Stefan Noll and Prof. Tim Heckman at Johns Hopkins University.

D. de Mello is currently working on a project together with Emanuele Daddi (ESO) et al. using VLT composite spectra of high-z galaxies to search for the epoch of formation of elliptical galaxies at $z \sim 2$.

R. Kimble and A. Sweigart are co-investigators in an HST program led by Tom Brown of STScI, which has used the Advanced Camera for Surveys to take an extraordinarily deep (120 orbits) set of exposures in the halo of the nearby Andromeda Galaxy (M31). The color-magnitude diagram derived from these images showed that the halo of M31 contains a major ($\sim 30\%$ by mass), intermediate-age (6-8 Gyr), metal-rich ([Fe/H] > -0.5) population in addition to a significant globular-cluster age (11-13.5 Gyr), metal-poor population. These findings suggest that galaxy mergers were important in the formation of the M31 halo.

R. Kimble has collaborated with a large team led by Shri Kulkarni (Caltech) to observe the UV/optical afterglows of gamma ray bursts with HST and ground-based telescopes. Several publications have resulted, identifying or constraining the properties of underyling supernovae associated with these energetic events.

R. Iping, S. Neff, and Sonneborn were awarded FUSE Cycle 3 observing time to study two interacting galaxies, NGC 4038/9 (the Antennae galaxies) and NGC 3256. NGC 4038/9 is the nearest ongoing galaxy merger and a prototype of the much more frequent galaxy collisions seen at high redshifts. Recent Chandra observations confirmed the existence of a substantial hot soft X-ray halo around the system, and clearly delineate the locations of very hot gas associated with the moderate starburst ongoing in the system. The FUSE observations probe the kinematics and composition of the hot and warm ISM using a knot of young stars as a background light source. The program is searching for O VI in both emission and absorption, and will use O VI with other shock heated species, to determine the distribution, composition, and dynamics of the hot ($\sim 3 \times 10^5$ K) halo gas and of hot gas in the disk. The observations of NGC 3256 were obtained in 2003 June; NGC 4038/9 awaits scheduling.

H. Moseley, G. Voellmer, D. Dowell (Caltech), D. Benford, J. Staguhn are using the Submillimeter High Resolution Array Camera (SHARC II) described elsewhere in this report for several observing programs at the Caltech Submillimeter Observatory, including a deep imaging survey of the Galactic Center region at 350μm and studies of distant galaxies.

S. Neff continued her research into merging and interacting galaxies, working on the luminosity functions of compact radio sources in an age-ordered sample of large disk-disk mergers. She discovered a "supernova factory" in Arp 299, including a new radio supernova (in prep, with J. Ulvestad (NRAO) and S. Teng (UMd)), and is planning similar observations of several other systems. As part of her work exploring the connections between AGN triggering, nuclear starbursts, and galaxy interaction, Neff (with Ulvestad) initiated a program of VLBA observations which will search for hidden AGN in a large sample of mergers.

Neff is awaiting FUSE observations of shocked gas at the interface between the Cen-A jet and the surrounding ISM, which will be used in collaboration with new GALEX observations of the UV continuum emission along the jet. She will be working with members of the GALEX science team on UV studies of interacting/merging galaxies and of extended haloes around merging and non-merging systems. Neff is providing the radio portion of a joint radio-x-ray study of the hot ISM in merging galaxies, with collaborators at the CfA (Fabbiano, Zezas, Rots), and is working with Iping (CUA) and Sonneborn on a FUSE study of the ISM and superwind in and around the major merger NGC3256.

Neff also expanded her work on the provocative Ultra Luminous X-ray objects (ULXs). After finding that the two ULXs in NGC3256 are both Low-Luminosity AGN (in press), Neff then initiated a program to determine the nature of Ultra-Luminous X-ray Sources (ULXs) in a sample of ~ 50 systems (in collaboration with N. Miller, R. Mushotzsky (GSFC) and K. Johnson (U Wisc)). To date, most ULX's are found to be associated with faint radio emission and with star-forming regions. Further Chandra, XMM, Swift, and VLA observations will be used to constrain the nature of these objects.

G. Sonneborn, R. Iping, with P. Garnavich (Notre Dame) and K. Sembach (STScI), were awarded HST Cycle 12 time to study the halo and ISM of a low-redshift galaxy hosting a bright new supernova ($V \leq 14$). The primary objectives of this Target of Opportunity program are to characterize the ionization state, gas-phase abundances, metallicity, and gas kinematics in the ISM and halo of the host galaxy, and, if the properties of the sightline are favorable, in the intervening intergalactic medium. Core-collapse supernovae occuring in galaxies out to the Virgo cluster are the potential targets for this program. The HST/STIS/E140M spectra will provide a comprehensive set of lines to study the hot, warm, and cool phases of the ISM. The program awaits the discovery of a suitable new supernova.

B. Woodgate continues to pursue evidence for large-scale structure at high redshift using emission line galaxies as tracers of structure. Spectroscopic confirmation has been obtained for 15 Lyman α emission line galaxies in a 40 Mpc long filament at $z = 2.38$ by Paul Francis in collaboration with Woodgate, P. Palunas (U. of Texas), G. Williger (JHU), and H. Teplitz (SIRTF Science Center).

E. Verner has been modeling Fe II spectra in quasars with emphasis on deriving Fe abundances (Verner et al. 2003). An understanding of the Fe abundance would have direct implications on the chemical evolution of our Galaxy and the Universe. This theoretical work has been carried out with collaborators F. Bruhweiler (CUA), D. Verner, S. Johansson (Lund), and T. Gull. This project also includes the analysis of ground-based observational data obtained by international partners from Japan, including Prof. Yoshii, and Prof. Kawara (Institute of Astronomy, University of Tokyo). The first application of the Fe II model for their low-redshift quasar sample is in progress.

3.7 Cosmic Infrared Background

E. Dwek and M. K. Barker (Univ. of Florida) derived a simple analytical formula for the relationship between the cosmic radio and infrared backgrounds for different cosmic star formation histories. D. Fixsen (SSAI) and E. Dwek constructed a model for the zodiacal dust cloud using COBE/FIRAS data, and presented the first far-IR determined mass of the cloud. Both studies were published in Ap.J.

With R. G. Arendt (SSAI), E. Dwek decomposed the COBE/DIRBE determined near-IR emission into Galactic and extragalactic components, deriving a constraint on the 1.25, 2.2, 3.5, and 4.5 micron spectrum of the cosmic infrared background (CIB), and showing the dependence of the 1.25 to 3.5 micron CIB intensity on the model used to represent the foreground emission from the zodiacal cloud.

With V. Zubko, R. G. Arendt (SSAI) and R. K. Smith (CfA), E. Dwek presented an invited paper in the Astrophysics of Dust Conference on probing interstellar dust models by analyzing the X-ray haloes created by small angle X-ray scattering off dust (astro-ph/0307564).

J. Mather worked with A. Kashlinsky (SSAI), S. Odenwald (SSAI), M. Skrutskie (U. Va), and R. Cutri (IPAC) on research on the spatial structure of the cosmic near infrared background (CNIB) radiation. They found evidence for its spatial fluctuations in deep calibration fields observed in the 2MASS survey. Measurements of the CNIB also show that its total brightness exceeds the total produced by known sources by a factor of about 2.

3.8 Cosmology

A. Kogut and N. Phillips develop neural networks as a tool to pull cosmological information from large, stochastic data sets such as galaxy redshift surveys or maps of the cosmic microwave background. Neural networks are particularly well suited for topological or non-Gaussian tests, where information is coded into the phase distribution of the data.

R. Fahey and J. Felten continued their calculations on solutions to the Friedmann-Lemaitre equations for two non-interacting fluids with various cosmological constants and pressures, and the age and size of the universe for various parameters. Fahey continued collaborating with NASA summer faculty fellow, J. DiRienzi (College of Notre Dame, MD) on quantum measurement problems.

4 OPERATING ORBITAL FLIGHT MISSIONS AND INSTRUMENTS

4.1 The Wilkinson Microwave Anisotropy Probe (WMAP)

First cosmological results were announced from the the Wilkinson Microwave Anisotropy Probe (WMAP) mission on 11 February 2003. Thirteen papers submitted to the Astrophysical Journal appeared in a September 2003 special issue of the Supplement Series. These papers present full sky maps based on the first year of flight data at the second Lagrange point, L2. The papers also describe the operation of the radiometers and optics, the data processing techniques, limits on systematic measurement errors, estimates and removal of astrophysical foreground emission, the anisotropy power spectrum, initial polarization results and the first detection of reionization, and a solution for cosmological parameters and the methods used to derive them.

WMAP has measured the physics of the photon-baryon fluid at recombination. From this, WMAP measurements constrain 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 composed of 4.4% baryons, 23% cold dark matter, and 73% dark energy. The equation of state of the dark energy appears much like a cosmological constant. For the first time, specific inflationary models can now be excluded. The era of reionization was found to be about 200 million years after the Big Bang.

The 13 arcmin full-width-half-max (FWHM) resolution full sky maps of the temperature anisotropy of the cosmic microwave background radiation have nearly uncorrelated pixel noise, minimal systematic errors, multi-frequency observations, and accurate calibration. With 45 times the sensitivity and 33 times the angular resolution of the previous COBE mission.

WMAP, a partnership between Princeton University and GSFC, was selected as a MIDEX mission in 1996, confirmed for development in 1997, and launched in 2001. Data from the WMAP mission are archived and disseminated to the community via a cosmic microwave background thematic data center: the Legacy Archive for Microwave Background Data Analysis (LAMBDA; http://lambda.gsfc.nasa.gov). LAMBDA is operated out of the LASP, and serves data and value-added analysis tools to the professional research community.

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), the sixth NASA Small Explorer (SMEX) mission. 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. The single instrument consists of an imager, made up of nine bi-grid rotating modulation collimators (RMCs), in front of a spectrometer with nine cryogenically-cooled germanium detectors (GeDs), one behind each RMC. It 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. The spatial resolution is as fine as 2.3 arcsec with a full-Sun 1-degree field of view, and the spectral resolution is $\sim 1-10$ keV FWHM over the energy range from soft X-rays (3 keV) to gamma-rays (17 MeV).

RHESSI was launched on February 5, 2002, and has been operating successfully since. During the 19 months of observations through August 2003, RHESSI has detected over 10,000 flares at energies above 12 keV, over 200 above 50 keV, and 34 above 800 keV. Two flares show significant gamma-ray line emission. Even more microflares have been detected above 3 keV.

Some of the new 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.
- 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 spectrum, 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, showing that the centroids of the energetic ion and electron sources are separated by ~ 20 arcsec.
- 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.
- 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.
- The detection of 3-15 keV X-ray emission from solar type III radio bursts, sometimes with no obvious relation to flares.
- The discovery of strong polarization in a cosmic gamma-ray burst, implying strong coherent magnetic fields in the source.

A great effort is underway to analyze the observations from these flares, and over 100 papers have already been published on the results obtained to date. 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 flare. 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 value of these RHESSI flare results is greatly enhanced by observations at longer wavelengths and measurements of the escaping energetic particles. These are made with instruments on the fleet of spacecraft already in place – SOHO, WIND, TRACE, ACE, SAMPEX, Ulysses, and GOES – and at many ground-based observatories. These complementary observations provide crucial information on the thermal, magnetic, and morphological context of the flaring region and on the associated solar phenomena that accompany the X-ray and gamma-ray emissions.

The Laboratory was responsible for the nine pairs of flight grids that form the modulation collimators used to achieve the high-resolution imaging. The Center's Cryogenics Branch also provided the flight cooler that continues to successfully maintain the germainium detectors at their operating temperature below 80 K. In addition to the hardware involvement, the Laboratory 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. 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/.

Future prospects for continued operations are excellent since RHESSI has no consumables. In the final report dated 5 August 2003 of the Senior Review of the Sun-Earth Connection Mission Operations and Data Analysis Program, RHESSI was rated the highest of the 14 operating spacecraft. It was recommended for an additional two years of operations with an increased RHESSI specific GI program to fully exploit the data and a funding enhancement "to provide support for training in data usage and data dissemination." According to the Senior Review Panel, the two-year extension "is needed to increase the number of flares and CMEs observed to meet the mission's primary objective..." The panel also stated that, "because of RHESSI's sensitivity in the 3-15 keV range, it will be able to measure micro-flares as the level of solra activity decreses. These measurements will address the very important unsolved problem of coronal heating." With this glowing report from the Senior Review, 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 on June 24, 1999. FUSE provides high resolution spectra in the 905-1187 Å wavelength region. FUSE is a cooperative project of NASA and the space agencies of Canada and France. FUSE 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, Heap, Iping, Landsman, Massa, and Neff were PIs of Cycle 4 observing programs. Massa and D. Lindler (Sigma Scientific) supported the development of the new FUSE science data pipeline and the instrument calibration.

FUSE was given a new lease on life following the successful implementation of new software in three computers that work together to control the precision pointing of the telescope. The design and development of the FUSE "gyroless" control system was completed and the new flight software system loaded and tested in the satellite in the Spring of 2003. This new version of the flight software, developed in response to further evidence of shortened lifetimes of the FUSE laser ring gyros, ensures mission health and safety and performs slews and target acquisitions with any number of operational gyros, including zero. The new system proved itself when one of three gyros currently in use failed on 31 July 2003. The observation in progress at the time continued without interruption.

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 mission was successfully launched April 28, 2003, and began normal science operations in late June. The GALEX science team will use the data to determine the history of star-formation to redshift ~ 2, over 80% of the age of the universe. An Announcement of Opportunity for the Guest Investigator program will be released around January, 2004, which will encourage both new observations and innovative uses of the rich GALEX survey data sets.

4.5 Infrared Array Camera (IRAC)

The Space Infrared Telescope Facility (SIRTF) was launched August 25, 2003 from Cape Canaveral, Florida. One of SIRTF's primary instruments is the Infrared Array Camera (IRAC) (G. Fazio, Principal Investigator, SAO; S. H. Moseley, Instrument Scientist). 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 SIRTF. The first "engineering image" from IRAC was obtained in September 2003, and indicated that IRAC was performing extremely well. The telescope is currently in its 50-day in-orbit checkout, and the temperature is now down to 5.5 K. We all look forward to the SIRTF first-light press release planned for December 2003. Drs. R. Arendt, D. Fixsen, and H. Moseley are working on the development of algorithms for the calibration of IRAC.

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. Much work has gone into supporting studies of the future of HST, with consideration of various numbers of servicing missions and operational approaches to maintaining the longevity of HST. Preparations for Servicing Mission 4 continue, although the precise date for such a mission is not yet known, and depends on the schedule for the return to flight of the Space Shuttle. Niedner supported the Project's response to requests for the development of various HST end-of-mission plans, budget preparations, the HST independent review team, as well as overall scientific planning and servicing mission development. Carpenter's HST Project work also included the defense of the HST Research Funding levels during the annual budget reviews, and the provision of scientific oversight, for the HST Project, of HST Operations in general and of the Space Telescope Science Institute (STScI) in particular. 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. T. Gull is the Deputy Investigator, coordinating the final year (2004) of the STIS Guaranteed Time Observations. Woodgate, C. Grady, and Gull have worked on the HST/STIS imaging and spectroscopic PSF for application to coronagraphic studies of protoplanetary systems. Gull, with A. Danks, G. Vieira and Krister Nielsen (CUA) have been utilizing STIS high dispersion echellograms to identify ejecta lines in the complex spectra of Eta Carinae. D. Lindler has helped Gull to develop a line-by-line extraction procedure for studying STIS spatially-resolved echellograms.

4.8 Solar & Heliospheric Observatory (SOHO)

Despite a problem with its high-gain antenna, SOHO began an eighth 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. Results from the mission so far indicate that the EUV emissions are surprisingly faint, requiring a reassessment of the canonical physical properties of the local interstellar medium. R. Kimble serves as the NASA Project Scientist for CHIPS.

5 FLIGHT MISSIONS AND INSTRUMENTS UNDER DEVELOPMENT

5.1 Living with a Star (LWS)

In January 2003, O. C. St. Cyr undertook the position of Senior Project Scientist for the Living With a Star (LWS) Program. LWS is a program within the Sun-Earth Connection (SEC) theme for NASA's Office of Space Science (OSS). The primary goal of LWS is to perform the basic research necessary to understand the effects of solar variability on the connected Sun-Earth system, particularly those with societal impact. Planned LWS spaceflight missions include: the Solar Dynamics Observatory, an FUV Earth imager, Ionosphere-Thermosphere Storm Probes, Radiation Belt Storm Probes, and Solar Sentinels.

5.2 Solar Dynamics Observatory (SDO)

B. Thompson is the Project Scientist for SDO. In addition, Gurman, Poland, St. Cyr, Kucera, Rabin, and Davila provide active support to the 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)

The solar magnetic field is constantly generated beneath the surface of the Sun by the solar dynamo. To balance this flux generation, there is constant dissipation of magnetic flux at and above the solar surface. The largest phenomenon associated with this dissipation is the Coronal Mass Ejection (CME). SOHO has provided remarkable views of the corona and CMEs, and served to highlight how these large interplanetary disturbances can have terrestrial consequences.

STEREO is the next logical step to study the physics of CME origin, 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.

Each STEREO spacecraft carries a complement of 10 instruments, which include (for the first time) an extensive set of *both* remote sensing and in-situ instruments. The remote sensing suite is capable of imaging CMEs from the solar surface out to beyond Earth's orbit (1 AU), and in-situ instruments are able to measure distribution functions for electrons, protons, and ions over a broad energy range, from the normal thermal solar wind plasma to the most energetic solar particles.

It is anticipated that these studies will ultimately lead to an increased understanding of the CME process and eventually to the ability to predict CME occurrence and thereby forecast the condition of the near-Earth environment.

LASP is involved in the STEREO mission in two ways. As a part of the Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI) we are responsible for the COR1 coronagraph. This coronagraph will provide images of the inner corona from $1.3 - 4.5 R_{\odot}$. In addition, J. Davila is Project Scientist for the STEREO mission. In this capacity he is responsible for the science implementation and requirements for the mission. L. Orwig of the Solar Physics Branch is serving as the Instrument Manager for the COR1 program at GSFC.

5.4 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 (S. H. Moseley, D. J. Benford, R. A. Shafer, and J. G. Staguhn) 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 2006. In the current year, we have developed detector production techniques, developed new detector test facilities, and comissioned the instrument test dewar with the adiabatic demagnetization refrigerator required to cool the detectors. Highlights of the groundbreaking technology being developed for SAFIRE include the demonstration of a cryogenic SQUID multiplexer and the development of near thermodynamically-limited noise performance in TES bolometers. Work in the next year will focus on the development of prototype detector arrays, which will be tested in ground-based facilities.

5.5 Wide Field Camera 3 (WFC3)

Wide Field Camera 3 is an instrument in development for installation on HST in Servicing Mission 4. 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 the past year, efforts have concentrated on testing of the HgCdTe IR detectors for such properties as dark current, quantum efficiency, stability, and noise. These activities have been crucial in guiding the fabrication efforts at Rockwell Science Center. As a result, flightworthy IR arrays have been successfully fabricated and fully characterized, and the best devices have been selected for assembly into the flight and spare detector housings currently in development at Ball Aerospace. LASP personnel also support the general integration and test program for the WFC3 instrument.

5.6 James Webb Space Telescope (JWST)

The James Webb Space Telescope (JWST), is a large aperture follow-on mission to HST and SIRTF under the Origins program (see the JWST website: http://jwst.gsfc.nasa.gov). It is a 6.5-m cooled telescope, sensitive over 0.6 to 27 microns, and optimized to observe the first stars and galaxies. It is planned for launch in 2011, and entered "Phase B" (detailed design) after detailed reviews. The entire US team has been selected, including the prime contractor TRW, now known as Northrop Grumman Space Technologies, with subcontracts to Ball Aerospace, Eastman Kodak, and ATK. The Near Infrared Camera was contracted to the University of Arizona (M. Rieke, P.I.), and the U.S. Mid Infrared Instrument Science Team was selected, with G. Rieke (University of Arizona) as Team Lead. Six Interdisciplinary Scientists and the Telescope Scientist were selected for the Science Working Group. The Space Telescope Science Institute was contracted to be the JWST science and operations center. The European Space Agency agreed to launch JWST on an Ariane 5 launch vehicle, to contribute the Near Infrared Spectrometer (NIRSpec), 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) Project Scientist and is the prime JWST contact for science instrumentation and instrument technology development. The ISIM design progressed rapidly after completion of a project-wide replanning activity. M. Clampin joined the LASP this year as Observatory Project Scientist. A major observatory milestone this year was the selection of Beryllium technology for the primary mirror segments. B. Rauscher joined the LASP this year as Deputy ISIM Project Scientist and Detector Scientist for the NIRSpec. S. H. Moseley's team made rapid progress in building a MEMS-based microshutter array for NIRSpec.

5.7 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 (guest observer) Program to observe a variety of variable stars such as intrinsic variables (including micro-variables), eclipsing variables, interacting binaries (including X-ray binaries), and cataclysmic variables continuously over a five year time span. Some 3,000 objects may be selected each year for the Participating Scientist Program. Kondo will also be responsible for the Kepler Data Analysis Program. J. Mather was appointed to membership in the Standing Review Board for Kepler.

5.8 Wide-field Infrared Survey Explorer (WISE)

J. Mather serves as a co-investigator 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. The WISE was selected for an extended Phase A study, leading to a decision in 2004 on whether to proceed with the development of the mission.

5.9 Mission Concept Studies

M. Clampin is currently developing a Discovery Mission concept called the "Extrasolar Planet Imaging Coronagraph" (EPIC) which is designed to detect extra-solar gas giant planets. The concept is based on the previous Jovian Planet Finder MIDEX mission proposal proposed for installation on the S3 truss of the International Space Station. EPIC is a "freeflying" mission with a 1.5m aperture.

The Single Aperture Far-Infrared (SAFIR) Observatory, recommended by the National Academy of Sciences Decadal Review, has been studied at GSFC as a possible successor mission to JWST. Led by D. J. Benford, a team consisting of J. C. Mather, S.H. Moseley, W. C. Danchi, D. T. Leisawitz and M. Amato (GSFC) has developed a mission concept for this highly capable, 10-m diameter, far-infrared optimized observatory. 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. The mission concept calls for a 10m telescope at L2 cooled to 4 K, with an instrument complement consisting of wide field imagers and high sensitivity spectrometers. Further details are available on GSFC's SAFIR web site at http://safir.gsfc.nasa.gov.

D. Leisawitz, in collaboration with J. T. Armstrong (NRL), D. Benford, W. Danchi, M. Harwit (Cornell), M. Kuchner (Princeton), J. Mather, D. Mozurkewich (NRL), L. Mundy (UMd), H. Moseley, D. Neufeld (JHU), S. Rinehart, R. Silverberg, M. Swain (JPL), and H. Yorke (JPL) continue the development of mission concepts for SPIRIT (Space Infrared Interferometric Telescope) and SPECS (Submillimeter Probe of the Evolution of Cosmic Structure). Recommended in the roadmaps for NASA's Origins and Structure and Evolution of the Universe themes, SPECS, an imaging and spectral interferometer with a 1 km maximum baseline length, would provide HST-class angular resolution and sensitivity at far-IR and submillimeter wavelengths. SPIRIT, recommended in the "Community Plan for Far-IR/Sub-millimeter Space Astronomy" as a scientific pathfinder for SPECS, could make spectral line and far-IR continuum maps of protostars and debris disks at sub-arcsecond resolution to provide definitive observational tests of models for star and planet formation. SPIRIT is envisioned as an interferometer with cryogenic telescopes and next-generation detectors, built on a deployable boom to provide interferometric baselines ranging up to ~ 40 m. Three studies were conducted in collaboration with GSFC engineers in the Instrument Synthesis and Analysis Lab and the Integrated Mission Design Center, yielding a more mature mission concept for SPIRIT. Leisawitz and Mundy (UMd) developed requirements for a study of tethered formation flying for space-based imaging interferometry led by D. Quinn (GSFC). SPECS requires highly reconfigurable formation flying, and tethers may be needed to avoid the need for a prohibitive amount of thruster propellant mass.

D. Leisawitz and S. Rinehart, in collaboration with co-investigators D. Leviton (GSFC), A. Martino (GSFC), L. Mundy (UMd), and an advisory group chaired by J. Mather and comprised of LASP members W. Danchi, D. Gezari, S.H. Moseley, and external members A. Labeyrie (Obs. de Haute Provence), D. Mozurkewich (NRL), P. Nisenson (CfA), S. Ollendorf (GSFC), M. Shao (JPL), and H. Yorke (JPL), have developed the Wide-field Imaging Interferometry Testbed (WIIT) in support of design studies for NASA's future space interferometry missions, in particular the SPIRIT and SPECS far-infrared/submillimeter interferometers. WIIT operates at optical wavelengths and uses Michelson beam combination to achieve both wide-field imaging and high-resolution spectroscopy. It will be used chiefly to test the feasibility of using a detector array located at the image plane of the sky to obtain wide-field interferometry images through spatial multiplexing techniques. In this setup each detector pixel records interferograms corresponding to averaging a particular pointing range on the sky as the optical path length is scanned and as the baseline separation and orientation are varied. The final image is constructed through spatial and spectral Fourier transforms of the recorded interferograms for each pixel, followed by a mosaic/joint-deconvolution procedure covering all the pixels. In this manner the image within the pointing range of each detector pixel is further resolved to an angular resolution corresponding to the maximum baseline separation for fringe measurements. The viability of this technique was recently demonstrated with data from WIIT.

K. Carpenter, R. Lyon, L. Mazzuca, G. Solyar, W. Danchi, and C. Bowers, in collaboration with C. Schrijver (LMMS/ATC), L. Mundy (UMD), D. Mouzurkewich, T. Armstrong, and T. Pauls (NPOI/NRL), R. Allen (STScI), M. Karovska (CfA), and J. Marzouk (Sigma Space) continue the development of a mission concept for a large, space-based UV-optical Fizeau 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. Recent work has included the preparation of a book describing the scientific drivers for the mission, the baseline architectural concepts under study, and the technology roadmap which needs to be followed to enable the mission to become a reality. The first phase (utilizing a 7-element sparse array) of a ground-based experiment, the Fizeau Interferometry Testbed (FIT) has been assembled and is going through initial calibration and alignment procedures. It will be used to explore the principles of and requirements for the 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 in Carpenter et al. (2003).

G. Hinshaw, C. Bennett, A. Kogut, H. Moseley, and E. Wollack, in collaboration with scientists from 10 universities in the United States and Canada, submitted a proposal to NASA Headquarters to study concepts for the Inflation Probe, which is planned by NASA Headquarters as part of the Beyond Einstein program. 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.

J. Mather and G. Sonneborn serve as co-investigators for 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 GEST 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.

Oliversen and Morgenthaler continue work with W. Harris (U. Washington) to develop an EUV/UV mission concept (called Solar Connections Observatory for Planetary Environments, or SCOPE) to study planetary magnetospheres and upper atmospheres and their interactions with the solar wind and radiation.

Oliversen, Harris (U. Washington), Roesler (U. Wisconsin) and collaborators developed 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.

Mission concepts for the next large aperture (10-meter) UV/optical space telescope are under study by a working group consisting of scientists and engineers from GSFC, JPL and the community. The concepts will explore different telescope and optical designs to carry out the science drivers coming out of the Hubble Science Legacy meeting held in Chicago in April 2002. The GSFC team consists of M. Clampin, J. Gardner, B. Woodgate, S. Heap, C. Bowers and R. Kimble.

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. Deming and M. Mumma 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 μm). FKSI is conceived as a scientific and technological precursor to the Terrestrial Planet Finder (TPF) mission. The scientific emphasis of the mission is on 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. 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? In the past year, a detailed design study for FKSI was undertaken at GSFC. 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.

6 SUBORBITAL MISSIONS

6.1 EUNIS

The Solar Physics branch is building an Extreme Ultraviolet Normal Incidence Spectrograph (EUNIS), to be flown in 2004 as a sounding rocket payload. 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.

EUNIS incorporates two independent optical systems, more than doubling the spectral bandwidth of SERTS. The $300 - 370$ Å bandpass includes He II 304 Å and strong lines from Fe XI-XVI, extending the current SERTS range of $300 - 355$ Å to further improve our ongoing series of calibration under-flights for SOHO/CDS and EIT. The second bandpass of $170 - 205$ Å has a sequence of very strong Fe IX-XIII lines and will allow under-flight support for two more channels on SOHO/EIT, two channels on TRACE, one on Solar-B/EIS, and all four channels on the STEREO/EUVI instrument. Continuing the emphasis on flight technology development established by SERTS, EUNIS will employ six Active Pixel Sensors, high-speed and low-power focal plane arrays developed by the Jet Propulsion Laboratory. The optical design (by R. Thomas) of the EUNIS telescopes breaks new ground in terms of compactness and efficiency.

The EUNIS payload will also carry an EUV solar flux monitor provided by U. Southern California; its readings will be used to validate calculations of atmospheric EUV transmission over the rocket's trajectory and to provide an updated calibration for SOHO/CELIAS. As for SERTS, end-to-end radiometric calibrations will be carried out after each flight in the same facility used to characterize the SOHO/CDS experiment at Rutherford Appleton Laboratories.

The past year saw the successful fabrication of all major EUNIS mechanical subsystems, delivery and test of the JPL Active Pixel Sensors, mounting of the flight telescope mirrors, and delivery of the first flight diffraction grating from Zeiss. The results of initial optical and mechanical fit checks on the payload were excellent. EUNIS will be launched from White Sands Missile Range with the support of White Sands and the GSFC Wallops Flight Facility.

In collaboration with the EUNIS team, DiRuggiero (U. Maryland) continued her investigation of the survivability of thermophilic microorganisms under space conditions. The hypothesis under test is that extremely thermophilic, terrestrial microorganisms may include strains with potential for interplanetary microbial transmission, due to their robust physiological properties and their effective DNA repair systems.

6.2 ARCADE

The Infrared Astrophysics Branch (A. Kogut, D. Fixsen, M. Limon, P. Mirel, and E. Wollack, with additional collaborators at JPL and UCSB) celebrated the successful second flight of the Absolute Radiometers for Cosmology, Astrophysics, and Diffuse Emission (ARCADE) in June 2003. ARCADE is a balloon-borne instrument to measure the spectrum of the cosmic microwave background at centimeter wavelengths. 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.

ARCADE uses a novel cryogenic design to compare the spectrum of the cosmic microwave background to a precision on-board blackbody calibration target. 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 demonstrate the feasibility of the windowless design. A larger payload (150 cm aperture) covering the frequency range 3–100 GHz is under development and expected to fly in 2005.

6.3 TopHat

TopHat is a balloon-borne experiment designed to study the anisotropy of the cosmic microwave background and the submillimeter emission from dust. Silverberg, Fixsen, and Cottingham and collaborators from U. Chicago, U. Wisconsin, and U. Massachusetts flew TopHat successfully from McMurdo Station, Antarctica in January, 2001. Since then, analysis of the data has been underway. A paper describing the spectrum of the integrated millimeter flux from the Megallanic Clouds and 30 Doradus was accepted for publication in the Ap. J.

6.4 Explorer of Diffuse Galactic Emission (EDGE)

EDGE is a mission to develop a balloon-borne instrument to study the anisotropy of the Cosmic Infrared Background (CIB) A proposal was submitted by S. Meyer of the University of Chicago with Silverberg, Fixsen, Cottingham as collaborators and other collaborators at U. Mass., U. C. Davis, and U. Wisconsin in 2001. The proposal was highly rated scientifically, but the detector technology proposed was deemed to be immature and demonstration of the required performance was requested. In 2002, the collaboration was awarded a two-year grant to demonstrate that the technical goals set out in the proposal can be achieved. Work on the detectors and design of the mission continue.

7 INSTRUMENTATION AND NON-FLIGHT PROGRAMS

D. Leisawitz and D. Benford, with GSFC engineers C. Baker, C.D. Butler, D. Content, M. DiPirro, S. Ollendorf, J. Pellicciotti, D. Steinfeld (OSC), and T. Swanson began a study of cryogenic optics for future infrared telescopes, such as SAFIR, SIRCE, SPIRIT, and SPECS. This team studied the tradeoffs and design issues associated with the requirement to cool a several meter diameter mirror to 4 K using only passive thermal shielding and cryocoolers. A telescope at this temperature equipped with very low-noise detectors would be natural background limited throughout the far-IR/submillimeter spectral range. Plans for ground testing an integrated cryo-thermal-optical system were developed. This group worked closely with J. Roman (GSFC) and the team developing requirements for the New Millennium ST-9 mission to ensure that requirements were understood, in case the ST-9 mission is selected to serve as a space demonstration platform for cryogenic mirror technology.

A. Kogut, E. Wollack, D. Fixsen, M. Limon, and P. Mirel pursue an active program to develop new devices and techniques at microwave through sub-mm wavelengths. Precision waveguide loads for cryogenic instruments have return loss below -40 dB in a compact design capable of withstanding multiple thermal cycles. Large (50 cm) free-space calibration targets provide an absolute temperature reference. Devices currently under development include a novel reimaging dichroic mirror for off-axis optics.

Near-infrared Cryogenic Fabry-Perot Spectrometer. A. Kutyrev, Moseley and Bennett are developing a high resolution, near-infrared cryogenic temperature tunable spectrometer with solid Fabry-Perot etalons. The high refractive index of the materials used (Si and Ge) have allowed the construction of a very compact fully cryogenic instrument with high throughput. Germanium etalons 20 mm in diameter are quivalent to a gas-spaced Fabry-Perot interferometer of 80 mm in diameter. A temperature tuning technique makes it easy to tune and to control the instrument. New etalons of different thickness have been fabricated, which has permitted the building of a double etalon spectrometer. This improvement, together with upgrades of the order sorting filters, results in a reduced background and a suppression of atmospheric lines. Field tests of the new silicon double etalon has been carried out. Spectral resolution of this instrument is 10^4. At this resolving power in K band, the instrument's sensitivity is limited by the thermal background from the telescope and earth's atmosphere and by the variations in the intensity of atmospheric emission lines.

SPEctral Energy Distribution (SPEED) camera. The SPEED camera is being developed by Silverberg, Fixsen and Cottingham and collaborators from U. Chicago, U. Massachusetts, and U. Wisconsin, to measure the spectral energy distribution of high redshift galaxies. The camera will use Frequency Selective Bolometers to provide a 16 element (4 pixels × 4 spectral bands) array of superconducting transition edge sensor (TES) bolometers to efficiently observe high redshift galaxies using the Heinrich Hertz 10-m telescope. The instrument is being designed so it may also be used on the 50-m Large Millimeter Telescope (LMT) being built in Mexico. Designs are complete and laboratory testing of the detectors is now underway. The development of the electronics, cryostat, multiplexers, and field optics continues.

7.1 Detector Development

H. Moseley, G. Voellmer and D. Dowell (Caltech) led the development of an engineering prototype detector array for the HAWC instrument on SOFIA. Other members of the team included Drs. D. Benford and J. Staguhn. This prototype array has been installed in the Submillimeter High Resolution Array Camera (SHARC) II instrument, which was commissioned at the Caltech Submillimeter Observatory in July 2002. Containing 384 pixels, this is currently the world's largest cryogenic bolometer array camera. This bolometer array allows high sensitivity to be combined with large format, greatly improving submillimeter imaging speed. Various astronomical investigations are already underway, including a deep imaging survey of the Galactic center region in 350μm continuum and studies of distant galaxies.

H. Moseley and G. Voellmer, C. Allen (both in the engineering directorate at GSFC) are leading the development of the detector array for the HAWC instrument on SOFIA. Other members of the team included Drs. D. Benford, D. Chuss, R. Silverberg, and J. Staguhn, all in LASP. The HAWC instrument is being developed by D. A. Harper et al. at the University of Chicago, with GSFC providing cryogenic, optical, and detector 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 2004/2005. The bolometer array will operate at wavelengths between 50μm and 200μm, combining high sensitivity, high angular resolution, and large format, improving submillimeter imaging speed. Delivery of the array is expected early in 2004.

D. Benford is leading a team, with H. Moseley, J. Staguhn, E. Wollack, and J. Chervenak, to develop a detector array and data acquisition subsystem for the Penn Array Receiver, a 3.3 mm wavelength camera for the 100-m Green Bank Telescope (GBT). The detector is an 8×8 array of close-packed superconducting bolometers, and will be the first planar array of Nyquist-sampled far-infrared detectors deployed on a telescope. With the large collecting area of the GBT, this camera will yield an order of magnitude faster mapping, enabling deep surveys of early star formation regions and of the distant universe.

T. Stevenson, H. Moseley, and E. Wollack are investigating the use of doped silicon as a hot electron bolometric sensor element. This new type of direct detector is applicable in the far-infrared, submillimeter, and millimeter spectral ranges. Readout of the device is via a multiplexed superconducting single-electron transistors (SETs) as on-chip readout amplifiers. Noise performance is expected to be near thermodynamic limits, allowing background limited performance for many far infrared and submillimeter photometric and spectroscopic applications, with noise equivalent power (NEP) as low as 10^{-20} W/$\sqrt{Hz}$ possible. This readout concept places a high performance amplifier on-chip with the detector, and adds multiplexing capabilities at the focal plane which will allow larger array sizes than is practical with the JFET readout systems used with existing semiconducting detector arrays.

B. Woodgate, R. Kimble, P. Haas and L. Payne, with T. Norton (SSAI), J. Stock (Swales) and G. Hilton (SSAI) continued development of UV detectors for future flight missions, with the goal of making high QE, large format, zero read noise photon counting arrays. In 2003, the team deposited CsO negative affinity layers on p-doped GaN to increase the QE of NUV detectors, reaching 40% at 185 nm. They worked with JPL in designing and building an event sensing CMOS advanced pixel sensor for readout into a GSFC centroider. The first sample was received at GSFC. The team is also monitoring the development, via a Small Business Innovative Research (SBIR) program, of silicon microchannel plates made by NanoSciences Inc. They plan to deposit the high QE photocathodes on these new chemically cleaner microchannel plate intensifiers.

7.2 Microshutter arrays

Moseley, Silverberg, Kutyrev, and Woodgate, in collaboration with the engineering division at GSFC are developing a programmable multi-object field selector for the JWST Near Infrared Spectrometer (NIRSpec). The device is a large microshutter array of 100μm $\times 200\mu$m shutters fabricated using micro-electro-mechanical systems (MEMS) techniques. This is an all-transmissive design that offers higher contrast, lower diffraction and scattered light and simpler optical design than reflective devices (e. g. micromirrors). The goal for the NIRSpec array is a 350×768 array, which will be assembled from a mosaic consisting of 4 175×384 microshutters. Arrays of size 64×128 have already been constructed and tested at cryogenic temperatures (30K).

7.3 Optical Modeling

C. Bowers has continued his modeling of coronagraphic systems with particular emphasis directed towards the requirements for the Terrestrial Planet Finder (TPF) project. TPF is designed to detect and characterize terrestrial planets in as many as 150 nearby stellar systems. One means of detection is through coronagraphy but at much higher contrast ($\sim 10^{10}$) than traditionally achieved. To achieve such high contrast, the phase and amplitude uniformity of the optical system must correspondingly be much greater than previously achieved, of order 10^{-4} and over a specific range of spatial frequencies. Phase non-uniformities may be corrected by using a very high precision deformable mirror. However the level of amplitude uniformity of large optical systems has not yet been measured to the degree required for TPF. A research program to measure amplitude uniformity for large mirrors with several, typical coatings was initiated by Bowers, a breadboard system tested and first coating measurements will commence this fall. Forseeing that in-flight correction of both phase and amplitude may be necessary to achieve and maintain the required high uniformity levels, Bowers, along with B. Woodgate and Rick Lyon (GSFC) have developed an asymmetric, dual Michelson interferometer system using two deformable mirrors to simultaneously correct an imperfect wavefront in both phase and amplitude to the levels required for TPF. Comparably high accuracy wavefront sensing must also be performed with TPF.

Bowers and Bruce Dean (GSFC) published an analysis of one type of systematic error present in one of the popular wavefront sensing schemes – phase retrieval. Using images taken at multiple defocus positions, phase retrieval permits recovery of wavefront phase from image data, a crucial parameter for wavefront correction. However Bowers and Dean demonstrated the relationship between defocus position and contrast at specific spatial frequencies in the wavefront, providing a potential bias in wavefront retrieval in cases requiring very high accuracy, like TPF. In addition, Bowers has assisted in characterization and analysis of the growing set of coronagraphic observations made with STIS aboard the Hubble Space Telescope.

7.4 Lightweight Mirrors

D. Rabin, J. Davila, and A. Smith collaborated with D. Content, R. Keski-Kuha, S. Antonille, T. Wallace, I. Rodriguez, S. Irish and C. Johnson (GSFC Applied Engineering and Technology Directorate) to develop metrology and imaging performance tests for ultra-precise UV/visible mirrors for solar physics, Earth imaging, and post-HST missions such as the Terrestrial Planet Finder and Stellar Imager.

GSFC took delivery of a 55-cm lightweight (4.6 kg) ULE parabolic mirror from Eastman Kodak. 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, optical imaging performance, and, finally, UV imaging performance. Two precision metrology mounts were designed and fabricated, one for measuring microroughness and mid-frequency performance, the other for figure metrology in conjunction with a computer-generated hologram and phase-shifting interferometer. Close attention has been paid to the end-to-end uncertainty budget and the validation of the finite element model needed to relate the ground-based figure to the zero-g figure.

The near-term goal of this program is to incorporate the Kodak mirror in a suborbital payload for high-resolution imaging of the Sun at ultraviolet wavelengths

(120-280 nm). For this purpose, a flight mirror mount design was developed and subjected to extensive finite element analysis.

7.5 Virtual Solar Observatory

J. Gurman and George Dimitoglou (L-3 GSI) are working with a small group of colleagues at the National Solar Observatory, Stanford University, and Montana State University, and to develop the prototype Virtual Solar Observatory (VSO). Roll-out of the prototype, to be followed by destructive testing by the solar physics community, is expected before the end of 2003. The VSO will consist of an extremely simple, standards-based core (XML and SOAP), and entirely distributed data archives for space- and ground-based solar physics data. In addition to growing interest in the VSO within the solar physics community, the effort is expected to be integrated with a series of virtual observatories in the heliospheric, magnetospheric, and ionospheric disciplines to aid in the Sun-Earth Connections system science endeavor.

7.6 Conferences

D. Benford and D. Leisawitz edited the proceedings of the Second Workshop on New Concepts for Far-Infrared and Submillimeter Space Astronomy, which will be available as NASA publication CP-2003-212233. The proceedings include the “Community Plan for Far-IR/Submillimeter Space Astronomy,” which gives the consensus opinion of the workshop participants. The “Community Plan” builds on recommendations for future far-IR missions made in the Decadal Report and addresses practical considerations, such as the tradeoffs associated with alternative mission designs and the flowdown from scientific objectives to measurement requirements, engineering requirements, and technology needs. It recommends an implementation strategy for technology development and validation, and recommends specific science and technology pathfinder missions (SPIRIT and a far-IR all sky survey mission) that would pave the way for the “roadmap missions” SAFIR and SPECS.

J. Mather chaired a program and edited the proceedings for session 4850, “IR Space Telescopes and Instruments,” at the SPIE meeting in Waikoloa, August 24-28, 2002. This program included 165 papers. Program committee members included : P. Jakobsen, European Space Technology Ctr. (Netherlands); Toshio Matsumoto, Institute of Space and Astronautical Science (Japan); Craig R. McCreight, NASA Ames Research Ctr.; Bernard D. Seery, NASA/GSFC; Eric H. Smith, NASA Headquarters; Michael W. Werner, Jet Propulsion Lab. W. Oegerle served on the Program committee for the session “Future EUV-UV Visible Space Astrophysics Missions and Instrumentation” at the same meeting.

W. Oegerle and C. Blades (STScI) organized the workshop “Innovative Designs for the Next Large Aperture UV/Optical Telescope (NHST)”, held at the STScI in April 2003. The meeting focus on design concepts and technologies for future large aperture optical/UV telescopes. Topics discussed included lightweight, large optics, optical designs, detectors, “in space” construction and deployment techniques. Presentations are posted on-line at STScI. Oegerle, representing the NHST community study team, organized a Topical Meeting on the future of UV/Optical astronomy from space at the 2003 summer AAS meeting in Nashville.

7.7 Education and Public Outreach

D. Leisawitz served as the mentor for SUNBEAMS teacher intern S. Shettel (Temple U.), who developed lesson plans designed to facilitate classroom use of the Multiwavelength Milky Way educational poster and the associated web site http://adc.gsfc.nasa.gov/mw.

SUNBEAMS is now in its sixth year as an educational partnership between NASA GSFC and the District of Columbia Public Schools (DCPS). Dr. Crannell and Ms. Sarah Brown lead the program, which continues to evolve 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. Each spring, fifteen teachers of 6th-grade math and science from the DCPS are invited to GSFC for a five-week paid internship. During the summer, each teacher is paired with a mentor from the scientific and technical staff. The teachers participate in current scientific and technical research and partner with the mentors to develop lessons for middle school students which they subsequently pilot in their own schools and post on the SUNBEAMS web site. 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. students an understanding of the actual methods used by scientists, engineers, and technicians to do space science and technology. Following their week at GSFC, the teacher and students work together to plan a Family Night 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.

A research group at Temple University has obtained a grant from the National Science Foundation and is successfully replicating the SUNBEAMS program emphasizing Earth Science. The University of Minnesota is also currently developing an outreach program inspired by the successful SUNBEAMS model, emphasizing studies in Soils, Water, and Climate. The three groups continue to communicate and share ideas to the benefit of each.

8 ACRONYMS

ACE – Advanced Composition Explorer
ACS – HST/Advanced Camera for Surveys
ARCADE – Absolute Radiometer for Cosmology, Astrophysics, and Diffuse Emission
CDS – Coronal Diagnostic Spectrometer
CELIAS –SOHO/The Charge, Element, and Isotope Analysis System

CHIPS – Coronal Hot Interstellar Plasma Spectrometer
DIRBE – COBE/Diffuse infrared Background Experiment
EDGE – Explorer of Diffuse Galactic Emission
EIT – SOHO/Extreme Ultraviolet Imaging Telescope
EUNIS – EUV Normal Incidence Spectrograph
EUV – Extreme ultraviolet
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 – SIRTF/Infrared Array Camera
ISIM – JWST/Integrated Science Instrument Module
IUE – International Ultraviolet Explorer
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
NHST – Next Hubble Space Telescope
NICMOS – HST/Near Infrared Camera and Multi-Object Spectrometer
NIRCam – JWST/Near Infrared Camera
NIRSpec – JWST/Near Infrared Spectrograph
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
SOAP – Simple Object Access Protocol
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
VLA – Very Large Array
VSO – Virtual Solar Observatory
WIIT – Wide-field Imaging Interferometry Testbed
WMAP – Wilkinson Microwave Anisotropy Probe
WFC3 – HST/Wide Field Camera 3
XML – Extensible Markup Language

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