California Institute of Technology
Infrared Processing and Analysis Center
Pasadena, California 91125

[S0002-7537(93)23941-5]

This report covers the period from August 2000 to October 2001.

1. ORGANIZATION AND STAFF

1.1 Organization

The Infrared Processing and Analysis Center (IPAC) is part of the California Institute of Technology and is associated with the Jet Propulsion Laboratory. Our primary aim is to support selected NASA missions and initiatives, providing planning, design, management, data analysis, science operations, astronomical community support, and archival services. George Helou is the Executive Director of IPAC, Roc Cutri was recently named the Deputy Director, and William Green is the IPAC manager. Approximately 175 staff work at IPAC.

IPAC includes two autonomously managed Centers established by NASA. The Space Infrared Telescope Facility Science Center (SIRTF Science Center, or SSC) is home of the science operations for the SIRTF mission, as described below. The SSC now occupies the Keith Spalding building. Its director is B. Thomas Soifer, a Caltech Physics Professor; the SSC Deputy Director is George Helou; and the implementation manager is Bill Green. The Interferometry Science Center (ISC) is a science analysis and operations support organization that serves NASA's Navigator Program's interferometric projects and the scientists and engineers that use them. The ISC Director is Anneila Sargent, a Caltech Astronomy Professor, the ISC Deputy Director is Andrew Boden, and the ISC manager is Navid Dehghani. The rest of the IPAC staff, involved with 2MASS, *Herschel*, *Planck*, NED, IRSA, and Public Outreach, are located in the Morrisroe Building at Caltech.

1.2 Scientific staff

There are currently 52 Ph.D. astronomers working at IPAC, engaging in nearly all fields of astronomical research. Carol J. Lonsdale is the Head of Science Staff, and William T. Reach was recently named the Deputy Head of Science Staff. In the list below, recent additions to the scientific staff are listed in *italics*. The project to which each scientist is assigned is indicated in parentheses; the acronyms are defined in the following sections of this Report.

Research and Staff Scientists: Rachel Akeson (ISC), Babar Ali (Herschel), *Phil Appleton* (SSC), Lee Armus (SSC), Thomas Barlow (GALEX), Bruce Berriman (IRSA), Andrew Boden (ISC), Roc Cutri (2MASS), *Sergio Fajardo-Acosta* (SSC), Fan Fang (SSC), *David Frayer* (SSC), Ken Ganga (Planck), John Gizis (2MASS, departed to U. Delaware), *William Glaccum* (SSC), *Eric Hivon* (Planck), Robert Hurt (2MASS), *Myungshin Im* (SSC), *Jim Ingalls* (SSC), Thomas Jarrett (2MASS), J. Davy Kirkpatrick (2MASS), Christopher Koresko (ISC), William Latter (SSC), Deborah Levine (SSC), Carol Lonsdale (IPAC), Steve Lord (Herschel), Nanyao Lu (SSC), Vikki Meadows (SSC/JPL), Barry Madore (NED), William Mahoney (SSC), *Vincent Mannings* (SSC), Kenneth Marsh (ISC), *Anthony Marston* (SSC), Frank Masci (SSC), Joseph Mazzarella (NED), Patrick Morris (SSC), Brant Nelson (2MASS), Alberto Noriega-Crespo (SSC), *Joann O'Linger* (SSC), Deborah Padgett (SSC), William Reach (SSC), Jeonghee Rho (SSC), David Shupe (SSC), Nancy Silbermann (SSC), *John Stauffer* (SSC), Lisa Storrie-Lombardi (SSC), *Susan Stolovy* (SSC), Jason Surace (SSC), Michelle Thaller (SSC), Schuyler Van Dyk (2MASS), Ann Wehrle (ISC), William Wheaton (2MASS), Cong Xu (2MASS), and *Lin Yan* (SSC).

Postdoctoral Fellows: Laurent Cambrésy, *Scott Chapman*, Maria del Carmen Polletta, Alessandra Contursi (departed to Max Planck), Daniel Dale (departed to U. Wyoming), Yu Gao, Armando Gil de Paz, *Patrick Lowrance*, Glenn Morrison, *Cristina Popescu*, and *Helene Roussel*.

2. MISSIONS AND PROJECTS

In this section we give a brief progress report on IPAC involvement in missions, emphasizing our role in performing and enabling large research projects. More detail and updates can be found on the IPAC web pages, http://www.ipac.caltech.edu.

2.1 Space Infrared Telescope Facility (SIRTF)

The SIRTF Science Center (SSC) is now located primarily in the Keith Spalding Building of the Caltech campus. Half of the IPAC scientists are part of the SSC. The major organizational groups are Uplink Development, Downlink Development, Instrument Support Teams for the three SIRTF science instruments (MIPS, IRS, and IRAC), Operations planning, Observer Support, and Education and Public Outreach. The SSC is responsible for all scientific activities of the observatory, from soliciting, selecting and funding SIRTF research projects, to implementing and scheduling observations as sequences of instrument and spacecraft commands, to formatting, analyzing, and archiving the observations.

The most significant SSC event for the astronomical community in the past year was the selection of the SIRTF Legacy Science Projects. Each of the six projects involve large (350 to 851 hr) blocks of SIRTF observing time to be executed primarily during the first year of the mission. The selected programs are led by Drs. Ed Churchwell of the University of Wisconsin ('GLIMPSE: Galactic Legacy Infrared Mid-Plane Survey Extraordinaire'), Mark Dickinson of the Space Telescope Science Institute ('GOODS: Great Observatories Origins Deep Survey'), Neal Evans II of the University of Texas ('From Molecular Clouds to Planets'), Robert Kennicutt of the University of Arizona ('SINGS: The SIRTF Nearby Galaxies Survey'), Carol Lonsdale of the Infrared Processing and Analysis Center ('SWIRE: The SIRTF Wide-

area Infrared Extragalactic Survey'), and Michael Meyer of the University of Arizona ('The Formation and Evolution of Planetary Systems'). An SSC liaison scientist has been assigned to each of these projects.

The SSC is responsible for conducting the First Look Survey, which will comprise 100 hours of Director's Discretionary Time near the beginning of the mission (starting just after the In-Orbit Checkout and Science Verification are completed). The First Look Survey is an attempt to provide the essential characterization of the mid-infrared sky at depths comparable to what WIRE (lost in March 1999) would have probed. All data will become available to the public as soon as they are validated, to aid astronomers in planning SIRTF observations. The First Look Survey is divided into three parts to characterize the extragalactic, galactic, and solar system components of the sky. Target fields have now been selected, including a 4 deg^2 field in the northern constant viewing zone (ecliptic latitude greater than 80°), scans perpendicular to the galactic plane and through a molecular cloud, and two, repeated, fields near the ecliptic for asteroids.

The SSC is preparing for the Cycle 1 Call for Proposals, which will be issued 2 months before launch. Proposals will be accepted from all observers (US and international) and will be due two months after the end of the science verification phase of the mission (nominally, 3 months after launch).

2.2 Two Micron All Sky Survey (2MASS)

2MASS is a joint project of the University of Massachusetts and IPAC, funded primarily by the National Aeronautics and Space Administration and the National Science Foundation. The objective of 2MASS is to carry out a highly uniform digital imaging survey of the entire sky in three near infrared bands, and to produce for the astronomical community highly reliable and accurate source catalogs and image products from the survey data. The University of Massachusetts constructed and operated the northern and southern survey observatories and IPAC carries out all science data processing, distribution and archiving of the 2MASS data. Roc Cutri is the 2MASS task leader at IPAC. Significant milestones for 2MASS in the August 2000-2001 period included the completion of the observational phase of the Survey and preliminary data processing and the commencement of the final processing operations.

2MASS survey operations began at Mt. Hopkins in June of 1997 and at CTIO in March of 1998. Northern and southern operations were completed in December 2000 and March 2001, respectively, with 100% of the sky successfully observed. Over 24.5 TB of raw imaging data were collected during this period. IPAC developed the 2MASS Production Processing System to convert the raw image data to calibrated, registered images in the three survey bands and extracted point and extended source catalogs. Preliminary processing of the full set of survey data was completed in April 2001. The March 2000 2MASS Second Incremental Data Release, which included Catalogs and Images covering 47% of the sky, was drawn from the preliminary processing of the survey data.

Final processing of the entire 24.5 TB 2MASS data set was started in the Fall of 2001. This effort makes use of information and experience gathered over the entire survey, including highly consistent internal calibrations, detector and sky behavior, and anomaly characterization. The final 2MASS Catalogs and Image Atlas will be produced from this processing and distributed to the community in the Fall of 2002.

2MASS continues to enable innovative and exciting research in a broad range of fields. There have been over 200 scientific publications that make use of 2MASS data, with nearly 75 of these appearing in the last year alone. A sampling of the research with 2MASS was offered in ''The Big Picture: Latest Science Results from 2MASS'' topical session at the 198th Meeting of the AAS held in June 2001. Thirty-two talks and posters were presented, describing 2MASS research applications in fields ranging from solar system science, stellar and galactic structure astronomy, extragalactic studies of normal and active galaxies, and cosmology.

2.3 NASA Extragalactic Database (NED)

The NASA/IPAC Extragalactic Database (NED) has been in continuous operation at Caltech since its inception here in 1988. NED presently consists of a Team of 12 scientists, programmers and archivists whose task it is to provide seamless electronic access to panchromatic published data on all known extragalactic objects, firmly connected to the literature and cross-linked to other major data centers and wavelength-specific mission archives. Barry Madore is the NED team leader, George Helou the program scientist, and Joe Mazzarella the deputy team leader. At the time of writing, NED contains over 4 million galaxies, quasars and extragalactic radio sources. These are referenced to over 50,000 published papers from which over 210,000 redshifts, 50,000 notes and nearly 4 million photometric measurements have been derived and consolidated.

New features in NED include the on-line availability of over 750,000 science quality FITS images covering the entire electromagnetic spectrum from X-ray images, UV, optical, infrared and radio. In cooperation with CDS/Simbad, NED now offers an interactive display tool, called ALADIN, for the viewing of NED images complete with overlay capabilities showing NED sources as well as USNO objects in the field of view.

LEVEL5: A Knowledgebase for Extragalactic Astronomy and Cosmology is a recent addition to the NED suite of tools and functionality. Among other things LEVEL5 provides on-line versions of review articles as well as seminal and influential papers on cosmology and extragalactic astronomy. An extensive glossary and lexicon of terms is provided, as well as fundamental data, graphical relations, catalogs and atlases. Special arrangements with Cambridge University Press and Annual Reviews Inc. allow LEVEL5 to also provide on-line versions of their review articles and selected chapters of their monograph series.

Presently NED responds to over 1 million Web hits per month; LEVEL5 alone is receiving over 400,000 Web hits per month. Catalogs currently being added to NED include the APM galaxy catalog of 4.1 million objects, and the first releases of 2MASS as well as the Sloan SDSS northern sky

survey. In addition, the radio surveys from the VLA, NVSS and FIRST are well along in being entered and cross-identified with previously observed and cataloged objects. Cross-links to external sites and sister archives are automatically provided on an object-by-object basis. Our next major addition in functionality will be the ability to query the NED holdings based on multiwavelength photometric constraints, in addition to names, object types, redshifts, and positions currently supported.

2.4 Infrared Science Archive (IRSA)

The NASA/IPAC Infrared Science Archive (IRSA) is the designated archive for datasets produced by NASA's infrared and sub-millimeter wave missions. The project is in partnership with the Digital Sky project of the National Partnership for Advanced Computing Infrastructure (NPACI), and the Science Applications of Information Technology (SAIT) program at JPL. Altogether, a total of seven persons have contributed to IRSA in the past year, under the direction of Bruce Berriman (team leader and acting project scientist). IRSA serves publicly released catalogs and images from the IRAS, MSX and 2MASS projects, with a total data volume of nearly 15 TB, and will soon serve sub-millimeter spectra from the SWAS mission. Each month, the archive processes over 100,000 data requests (corresponding to over 250,000 hits) and serves over 40 GB of data. Usage has more than doubled this calendar year.

IRSA has deployed four new services this past year. (1) IRSA's search engine Catscan was replaced with Gator, which includes a simpler interface, and a job monitor. (2) IRSA has also deployed a service that delivers 2MASS Atlas and Quick Look Images in bulk, based on Storage Resource Broker technology at San Diego Supercomputer Center. It was the subject of an article in the NPACI Quarterly Journal, Envision (Vol 17, no. 3, p 14). (3) The MSX image server now provides functionality for building MSX image mosaics on the fly. (4) The On-Line Archive Science Information Services (OASIS), a Java applet that is interoperable between IRSA and NED, CDS (VizieR), MAST, NVSS and FIRST. It is a data fusion and exploration system, and includes features such as the ability to display images of any size, on-the-fly contouring, and automatic reprojection when an image is refreshed. In the next year, IRSA will concentrate on the development of an Infrared Sky Server, which will permit integration and analysis of all infrared data available in any specified region of the sky.

2.5 Interferometry Science Center (ISC)

The ISC's primary mission is operations and science support for NASA Navigator Program missions. These missions include the Palomar Testbed Interferometer (PTI), Keck Interferometer (KI), Large Binocular Telescope Interferometer (LBTI), Space Interferometry Mission (SIM), and Terrestrial Planet Finder (TPF). In order to best exploit the technical and scientific commonality among these different missions, the ISC is developing a core multi-mission science operations system (SOS). This core SOS is then adapted to the specific requirements of each mission, augmented with mission-specific developments necessary to meet each mission's needs. At present the major activities within the ISC are core development, KI development and support, and SIM development.

Operation of the Palomar Testbed Interferometer (PTI) now falls within the auspices of the ISC. PTI is completing its fifth year of operations, and continues its successful program of near-infrared visibility amplitude science. PTI made interferometric observations on approximately 260 nights over the last year, and is highly automated, making on average approximately 90 discrete visibility measurements per night. PTI operates as a collaboration among ISC, JPL, and Caltech personnel, and operates in a queue-scheduled service observing mode staffed by a professional observer. Notable scientific accomplishments during the reporting period are the first direct measurements of angular size changes for a Cepheid variable, and the first direct measurement of the oblateness of a rapidly rotating star. Continuing programs in binary stars, young stellar objects, and Mira variable stars are also PTI scientific priorities.

The Keck Interferometer (KI) obtained first fringes during the reporting period; first with test siderostats on 22 February, and then with the two AO-corrected 10-m aperture Keck telescopes on 12 March. KI development is sponsored by NASA, and is a joint development activity among the Jet Propulsion Lab (JPL), W. M. Keck Observatory (WMKO), and the ISC. The ISC will be responsible for developing the KI Science Operations System, and in the near term is specifically charged with data infrastructure, analysis components, and operational support for KI. During the reporting period NASA conducted a peer-reviewed call for scientists to participate in KI commissioning science. Four teams have been selected to collaborate with scientists and engineers on the KI development team in this capacity.

The Space Interferometry Mission (SIM) is a space-based interferometric astrometric mission that will conduct a broad range of astrophysical investigations, including a high-precision astrometric survey of stars in the solar neighborhood searching for planetary-mass companions. SIM is currently scheduled to launch in 2009. The ISC will be responsible for developing the SIM Science Operations System, and is supporting the SIM project at JPL in that role. During the reporting period, NASA selected ten key science projects for SIM. The principal investigators of these projects comprise the SIM science team, augmented by five mission scientists with relevant scientific or technical expertise. ISC scientists are involved in four of the ten key projects. Anne Wehrle is the principal investigator for a key project investigating possible multiplicity of active galactic nuclei.

2.6 Planck and Herschel

Planck, the third medium sized mission in ESA's Horizon 2000 Scientific Program is scheduled for launch in 2007 along with the Herschel Space Observatory on the same rocket. Planck will look for answers to some of the most fundamental cosmological questions by mapping the anisotropies in the cosmic microwave background radiation (the CMB) with an unprecedented combination of accuracy,

resolution, and sky and spectral coverage. While Planck is an ESA mission, there is significant U.S. involvement in many aspects of Planck, with Caltech and JPL leading teams of scientists at a number of U.S. institutions. IPAC will play a key role as part of the US Planck Data Center. Ken Ganga is the Planck task lead at IPAC.

The NASA Herschel Science Center (NHSC) was established at IPAC during the past year, with a start-up group of scientists and engineers planning for U.S. astronomical community support center for the Herschel Mission. Herschel, the fourth 'Cornerstone Mission' of the European Space Agency's Horizon 2000 program, is a 3.5-m, far-infrared and sub-millimeter space observatory. Herschel launches together with Planck (in 2007) for its three to five year cryogenic mission. The NHSC at IPAC will provide the U.S. community with science and analysis support throughout all phases of the mission: from proposal preparation to data reduction and archival access. George Helou is Director of the NHSC, and Ken Ganga is the task leader and JPL project element manager

This IPAC group, now consisting of four part-time staff members, will grow in size to about thirty by the time of Herschel's launch. Activities in the past year included planning for mission operations, calibration, and analysis tools, working closely with the ESA Herschel Science Center and the three European Instrument Teams: HIFI, SPIRE, and PACS. The Herschel instrumentation includes three spectrometers, an array camera, and a photometric imaging receiver. The NHSC staff have also begun working together with the JPL and Caltech components of the HIFI and SPIRE teams, in their efforts to prepare optimized mixers and bolometer arrays. We have taken the first steps toward establishing a data processing and archiving environment at IPAC tailored to the requirements of Herschel mission. In September of 2001, the NHSC passed its Critical Design Review and was judged ready to proceed in implementing staged growth and preparations that will enable U.S.-based astronomers to take full advantage of the science opportunities of Herschel.

2.7 GALEX

GALEX is a NASA Small Explorer Mission to be launched in May 2002. The PI is Chris Martin of Caltech; Madore is a Science Co-Investigator. The GALEX instrument is a 50-cm telescope operating in the far and near-ultraviolet (135-300 nm) with both imaging and spectroscopic capabilities. The primary goals of the GALEX mission are to study the UV properties of local galaxies, the star formation and metal production history of galaxies over the redshift range $0<z<2$, and global (galaxy-wide) factors that drive star formation and its evolution in galaxies. At IPAC, the NED Team will undertake the assimilation and cross-identification of several million extragalactic GALEX sources into the NED database for multiwavelength studies and general public access.

3. EDUCATION AND PUBLIC OUTREACH

The main goal of education and public outreach (EPO) at IPAC/SSC is to make the public aware of the remarkable and unique view of the universe shown to us through infrared light. As a member of the Astronomical Search for Origins group of missions at NASA, we are also concerned with educating the public about the nature and evolution of the universe, and where life on Earth and elsewhere fits into that picture. To accomplish these goals, the EPO team has created a multiple award-winning web-site filled with educational materials and classroom activities. Many of our web-sites have companion brochures, posters, and videos, which we have taken great care to disseminate into the nations schools, libraries, and science resource centers. Highlights for 2001 include the completion of a Spanish-language version of the main SIRTF web site, a large web tutorial on multi-wavelength astronomy, and a web-site that focuses on the many applications of infrared technology.

In the coming year, the EPO team will step up its involvement with teachers dramatically, offering an on-line course which will be part of a fully accredited master's degree program for teachers, offered through the University of Arizona. We also participate in regular teacher in-service courses and workshops, as well as dozens of classroom visits and public lectures which reach well in excess of 50,000 people a year. In 2001, SIRTF was selected as the topic for the prestigious Von Karman lecture series and web-cast at JPL. Educators have also taken part in the Window on the Universe Week, held in conjunction with the Challenger Center, an intensive week-long event held at several locations across the country. IPAC/SSC scientists also made appearances on the Young Astronauts television program.

As SIRTF's launch date nears, we will dedicate much of our efforts to producing media products, as well as finishing our international naming contest, in which people from all over the world submit names and supporting essays for SIRTF. The person who submits the winning entry will not only get to re-name a NASA space observatory, but will attend the launch in Florida.

4. RESEARCH AT IPAC

4.1 Extragalactic research

The Infrared Space Observatory US key project, the 'Interstellar Medium of Normal Galaxies: Properties and Evolution' is led by Principal Investigator and IPAC Director G. Helou, and IPAC co-investigators IPAC S. Lord, N. Lu, & N. Silbermann to characterize the interstellar medium in 69 normal star-forming galaxies using atomic and ionic fine structure lines and the infrared continuum. Key results, already published in a dozen papers, include new physical insights into the properties and emission characteristics of far-infrared cooling lines and small dust grains in different interstellar environments within elliptical, spiral, and irregular galaxies; characterization of the mid-infrared (2-12 μm) spectrum in normal galaxies; and development of a semi-empirical model for the infrared (2-1100 μm) spectral energy distributions for a wide-range of star-forming galaxies. Of special interest to S. Lord is understanding the action of

spiral density waves as they disturb molecular cloud populations and trigger star formation. In collaboration with A. Boogert and M. Yang (Caltech), he has used the CSO to map the CO ($J=3\rightarrow2$, $2\rightarrow1$) emission along the highly resolved spiral pattern in the galaxy M 83.

B. Nelson and R. Cutri search the 2MASS database for red, dust-obscured AGN, employing a (J-K)>2 color selection. Spectroscopic follow-up of several hundred red QSO candidates has revealed that most of these objects are previously unknown AGN and starburst galaxies that were missed in UV-excess, radio, and X-ray surveys.

The relationship between gravitational tidal interactions, mergers, nuclear starbursts, luminous infrared galaxies, and Active Galactic Nuclei (AGNs), is a major area of research at IPAC, with emphasis on the dominant infrared emission. Luminous Infrared Galaxies (LIRGs), and especially the so-called Ultraluminous Infrared Galaxies (ULIRGs), have been implicated in the formation of quasars, radio galaxies, elliptical galaxies, and massive blue globular star cluster associations. SIRTF will provide a wealth of new information on luminous infrared galaxies over a large range in redshift. Y. Gao studies the properties of molecular (CO, HCN) and atomic gas (H I) and infrared emission traced by ISO in LIRGs and ULIRGs, with IPAC scientist C. Xu. P. Appleton and T. Marston study ring galaxies and the evolution of extended starbursts. These objects involve density-wave inducement of cloud-cloud interactions and/or compressions to produce stars. Appleton and Marston participate in the COLA project (Compact Objects in Low-power AGN), a multi- wavelength approach to understanding under what conditions radio cores are formed in galaxies. The project is an all-sky multi-wavelength survey of 217 IRAS-selected galaxies. Results include the discovery of a galaxy in which the kinematics of one side are traced only in HI and on the other side traced only in CO.

L. Armus is involved in a number of projects focused upon the relationship between starburst and active galaxies at low and high redshift. With B.T. Soifer, he is analyzing near-infrared images and spectra of high-redshift radio galaxies in an effort to disentangle line and continuum emission and place age constraints on the host galaxies. With G. Neugebauer, he is studying the host galaxies of radio-loud and radio-quiet quasars at $z=2-4$. Together with N.Scoville and D. Frayer, he is also obtaining deep images and spectra of dusty, sub-mm selected galaxies. All three of these projects rely heavily on the near-infrared cameras and spectrographs constructed by the infrared group at Caltech and available on the Keck 10m and Palomar 200 inch telescopes. Two ongoing studies of the stellar populations and buried AGN in nearby Ultraluminous Infrared Galaxies with N. Scoville and B.T. Soifer will have a direct impact on future observations of these systems with SIRTF. Finally, a WFPC2 snapshot program is underway to image the host galaxies of red AGN discovered with 2MASS. This project is part of a larger, multi-wavelength study of the host galaxies of these systems undertaken in collaboration with R. Cutri, B. Nelson, and J. Surace.

J. Surace led an imaging study of UV emission from Ultraluminous Infrared Galaxies, showing that in most cases the UV is dominated by a spatially extended starburst that is physically disparate from the source of the systemic extremely high bolometric luminosity. He also led a high resolution infrared and optical imaging study of nearby IR-excess quasars, showing that most reside in spiral galaxies and that a fraction of these show evidence for tidal interactions.

High-resolution, CO ($1\rightarrow0$) interferometry of IRAS 14348-144 by J. Surace, & J. Mazzarella has shown that this merging system has a total molecular gas mass of $\sim3\times10^{10}\ M_{\odot}$ associated with nuclei of the progenitors, with gas densities comparable to the cores of elliptical galaxies.

SIRTF Science Center Director B. T. Soifer and L. Armus used near-infrared data from the Palomar Integral Field Spectrograph to show spatially-unresolved [Si VI] and broad Paschen alpha emission lines indicative of an optically-obscured AGN.

J. Mazzarella leads a program to search for molecular gas in powerful radio galaxies detected by IRAS, resulting in evidence that a large fraction of radio galaxies are not gas-poor. Rather, they contain ample supplies of carbon monoxide (CO), indicating that some powerful radio galaxies may represent the by-product of mergers between gas-rich disk galaxies.

To understand the mid-infrared emissions from galaxies, N. Lu led an effort to provide a uniformly reduced ISO spectroscopic database over the wavelength range 2.5 to 11.6 μm for a sample of about 170 galaxies including normal galaxies from elliptical galaxies to dwarf irregulars and AGN's covering Seyfert types 1 to 2.

David Frayer has been studying high-redshift submillimeter galaxies with CO and near-infrared observations taken at OVRO and Keck.

C. Lonsdale is PI of the largest SIRTF Legacy Project, the SIRTF Wide-area InfraRed Extragalactic Survey, SWIRE. SWIRE, which has a co-I team that includes 8 IPAC scientists, will detect over 2 million galaxies in ~70 deg^2 imaged in seven high latitude fields and seven bands from 3.6 to 160 μm, with the goal of mapping galaxy evolution of spheroids, starbursts and AGN as a function of environment and clustering since $z\sim2.5$.

C. Xu and C. Lonsdale have developed a multi-wavelength model of galaxy evolution to tie together the history of star formation and galaxy evolution from the UV to the radio, and in particular in preparation for interpretation of the SWIRE data. They show that the prominent peak in the deep ISO 15 micron number counts does not imply the emergence of a new infrared galaxy population but is due to the very strong UIB features in the mid-infrared spectrum of almost all star-forming galaxies. F. Fang and F. Masci have developed a hierarchical merger model for infrared galaxy evolution to contrast the results of SWIRE against the simpler luminosity function evolution approach of Xu.

Reach and the French FIRBACK team used observations with ISO to detect abundant far-infrared sources that may be the dominant population that makes the far-infrared background. Combining the *COBE*/DIRBE data with the star catalog from 2MASS, L. Cambrésy, W. Reach, and T. Jarrett have found strong evidence for a cosmic background from

1.25 to 2.2 micron that is far in excess of that due to galaxies that could be detected with the Hubble Space Telescope, suggesting the existence of another energy production mechanism such as early star formation (Population III) or relic particle decay. Reach is planning *SIRTF*/IRAC Guaranteed Time observations to measure the cosmic background at 3.6 μm and constrain it at 4.5–8 μm. Reach is also working on cosmic background as part of the Great Observatories Origins Deep Survey (GOODS) project on SIRTF.

L. Storrie-Lombardi studies the formation and evolution of galaxies using damped Lyman-alpha absorption lines detected in distant quasar spectra. Storrie-Lombardi's work focuses on finding damped absorbers at redshifts $z>3$ and studying the evolution with redshift of their column density distribution and comoving mass density. She is also studying galaxies detected by their MgII absorption lines at redshifts $1<z<2.5$ to find garden variety L^* galaxies at $z\sim2$ when the Universe is 20-25% of its present age.

Schuyler Van Dyk, in collaboration with Michael Egan (AFRL), has used 2MASS in conjunction with data from the Midcourse Space Experiment (MSX) to discover and characterize AGB stars and other infrared-bright objects in the Magellanic Clouds. Van Dyk is also characterizing Galactic Wolf-Rayet stars in the near-infrared and using 2MASS colors to search for new candidates.

Tom Jarrett published papers describing how 2MASS detects and characterizes galaxies and extended sources and, along with Harold Corwin, the morphology of galaxies as seen by 2MASS.

In his recent work, Myungshin Im constructed the luminosity function of field, early-type galaxies at $z\sim1$, finding that early-type galaxies at $z\sim1$ are almost as abundant as today, and that their luminosity evolved passively. The result has a profound implication on the importance of merging in the formation of early-types at $z<1$. Im is currently trying to improve the measurement by expanding the sample size by a factor of 10. He is also leading an HST UV snapshot survey, whose aim is to understand dust extinction properties of nearby star-forming galaxies.

4.2 Research: Star Formation and Interstellar Medium

Rachel Akeson studied the physical properties of T Tauri circumstellar disks using infrared and millimeter interferometry. Vincent Mannings is studying the environments of intermediate-mass pre-main-sequence stars using interferometric mm-wave continuum and spectral line mapping. His work is supported in part by a grant from the NASA Origins of Solar Systems Program. He is also modeling thermal infrared and mm emission from recently proposed outer disks around weak-line T Tauri stars. Babar Ali studied the initial mass function of young embedded clusters.

Some of the best-known deep-sky astronomical objects were subjects of study by IPAC scientists this year. Laurent Cambrésy studied the extinction in the North America nebula using 2MASS star counts and color excess analysis. Jeonghee Rho studied the X-ray emission and 2MASS star populations in the Trifid nebula.

Deborah Levine is studying the structure of the inner few degrees of the galaxy using the results of a survey of H2O masers performed with the VLA. Susan Stolovy studied the extinction in the ionized gas as well as evidence for shocked molecular hydrogen emission in the central few pc of the Milky Way. She is also working on setting constraints on the near-infrared emission from Galactic Center black hole candidate Sgr A* using NICMOS data. In addition, she continues to explore methods of point source extraction and deconvolution in crowded fields.

Alberto Noriega-Crespo, and collaborators, completed a multi-wavelength study of the young stellar outflow Cep E, a study on the far-infrared properties of the HH 1/2 system (based on ISO data) and the optical proper motions of the HH 7-11 jet, as well as its near-infrared properties using NICMOS. Dr. Noriega-Crespo and was awarded a 3-year ADP grant to work on ISO data of star forming regions. Jim Ingalls studied far-infrared C II emission from high-latitude clouds using *ISO* data and the very-small-scale distribution of molecular gas using OVRO observations.

Supernova remnants interacting with molecular clouds have been targets of an ongoing project by Jeonghee Rho. Her most recent paper combines Rosat and ASCA observations of the supernova remnant W28; this study will continue when her *Chandra* observations are performed next year. Reach and Rho observed shocked molecular hydrogen emission from the supernova remnants 3C 391, W 28, and W 44 using the Palomar 200″ telescope. Reach and Rho are comparing the near-infrared observations to millimeter-wave data obtained previously with the 30-m IRAM telescope. Dr. Rho was awarded a 5-year Long Term Space Astrophysics grant to create an atlas of radio, infrared, and X-ray images and spectral data on mixed-morphology supernova remnants that are interacting with molecular clouds.

4.3 Research: Stars

Babar Ali works on young stars and brown dwarfs in clusters, including the following projects: ISOCAM imaging to detect brown dwarf candidates in nearby clusters like the Hyades; near and mid-infrared spectral type diagnostics: to make sense of recent imaging and spectroscopic surveys; an interactive archive of the reference properties of normal properties of Normal Stars and Brown Dwarfs (NSBD).

Analyzing 2MASS photometry, Sergio Fajardo-Acosta recently discovered more than 20 stars with possible orbiting dust grains at temperatures similar to those of the Earth and the asteroid belt. He observed Vega-type systems with ISOPHOT, and and reanalyzed images of a disk structure around the star Fomalhaut.

Davy Kirkpatrick has led a group that includes Patrick Lowrance, Adam Burgasser and John Gizis (now at U. Delaware) that is discovering, classifying and characterizing the population of low mass stars and brown dwarfs in the Solar neighborhood. Patrick Lowrance is currently involved in searching for substellar companions to nearby stars and for the nearest brown dwarf to the Sun.

John Stauffer works on the rotational velocity evolution of low mass stars and searches for brown dwarfs in open clusters. With his collaborators Lee Hartmann and David Barrado, he has recently completed papers which estimate the age of two of the most prominent ''β Pic'' stars. Another

recent paper used the Keck observatory LRIS spectrograph to determine lithium abundances for brown dwarf candidates in the Pleiades, and from the location of the ''lithium depletion edge'' derive an accurate age for that cluster. Many of the brown dwarf candidates observed for that program were selected from deep imaging surveys of the Pleiades.

4.4 Research: Solar System

Vikki Meadows published a paper on infrared observations of the impacts of Comet SL-9 with Jupiter, which appeared on the front cover of *Icarus*. She also became a Principal Investigator for the NASA Astrobiology Institute, with a 5-year project to create a Virtual Planetary Laboratory. This project will model the plausible range of terrestrial extrasolar planet atmospheres, and the interaction of life and planetary processes. Meadows was a recipient of the JPL Lew Allen Award for Excellence for 2001, which is awarded for accomplishments or leadership in scientific research in the early years of a professional career. Vikki Meadows and Carl Grillmair planned the Solar System component of the SIRTF First Look Survey, which will be designed to sample the zodiacal emission and detect asteroids by observing fields on the ecliptic and just about the ecliptic with repeat visits.

William Reach published a paper (also gracing a front cover of *Icarus*) on *ISO* mid-infrared observations of comet Encke, detailing the origin of the dust trail and meteoroid stream from that comet and suggesting that comet could only survive another 10,000 years at its present mass loss rate. Reach and Bidushi Bhattacharya are upgrading the *COBE*/DIRBE model for the zodiacal light to allow predictions of the brightness of interplanetary dust as seen from spacecraft (including, but not limited to SIRTF). Bidushi Bhattacharya has collaborated with Richard Thorne (UCLA) to study auroral particle precipitation in the Jovian magnetosphere using data from NASA's Galileo spacecraft.

Roc Cutri and John Fowler collaborated with Mark Sykes (U. Arizona), David Tholen (U. Hawaii), Michael Skrutskie (U.Virgina) and Stephan Price (AFRL) to publish the first installment of the 2MASS Asteroid and Comet Survey.

William T. Reach
G. Bruce Berriman
Andrew Boden
Roc Cutri
Ken Ganga
George Helou
Carol Lonsdale
Steve Lord
Barry Madore
Michelle Thaller