

From Spitzer to Herschel and Beyond

The Future of Far-Infrared Space Astrophysics

Conference Program and Abstracts

June 7-10, 2004 Pasadena Convention Center, Pasadena, California, USA

From Spitzer to Herschel and Beyond:
The Future of Far-Infrared Astrophysics

**Conference
Program and Abstracts**

Edited by

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Jet Propulsion Laboratory
Pasadena, California

June 2004

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Preface

The mid-IR through millimeter wavelength regime is becoming increasingly important for understanding the universe's fundamental processes. The combination of new detector technologies in increasing arrays and larger, colder apertures is bringing the far-IR / submillimeter regime of age, revealing otherwise undetected activity on all scales: from protostellar collapse and planet-bearing debris disks in our Galaxy, to the global history of dust-obscured energy release through cosmic time. This revolution is just beginning – the far-IR / submillimeter capabilities are still developing and maturing, and unlike the shorter wavelengths, there are still orders of magnitude of improvement possible before fundamental measurement limits are reached. The technologies required for far-IR astrophysics are unique. Unlike at shorter wavelengths, where astrophysics has been the beneficiary of technologies developed by the military and elsewhere, far-IR detectors and instruments must be custom-built by the researchers themselves. Ongoing dialog between astrophysicists and technology experts is thus critical to plan for the future and insure the best technology investments to achieve our long-term scientific goals.

This conference, *From Spitzer to Herschel and Beyond, the Future of Far-Infrared Space Astrophysics* provides a forum for this discussion. The far-IR community is gathered to articulate the current scientific questions, examine the technical hurdles of the next two decades, and to plan as a group for the future. The conference is being hosted jointly by the Infrared Processing and Analysis Center (IPAC) at Caltech, and by the Center for Long-Wavelength Astrophysics (CLWA) at JPL. The agenda is framed around a series of scientific and technical oral sessions, interspersed with one another to encourage overlap. Each session includes 3 to 5 talks, all invited in an attempt to gather experts in important fields. To complement the talks, a week-long poster session accommodates a variety of contributed posters with more detailed information. The conference topics include:

- Recent scientific results and technical successes of the Spitzer Space Telescope
- Current astrophysical questions running the gamut from our solar system to the era of reionization
- Progress in critical far-IR technologies, especially detectors and sub-K coolers
- Upcoming missions: Herschel and Astro-F
- The community's plans for future missions: larger, colder telescopes and interferometers

Conference Agenda

Monday, June 7

12:30 Welcome Chas Beichman,
John Hong

Session A: Spitzer Early Results and New Questions

12:45 *The Spitzer Space Telescope Mission* Michael Werner

13:10 *Infrared Spectroscopy with the Spitzer IRS* Lee Armus

13:35 *Early Results with the Spitzer MIPS* George Rieke

14:00 Break

Session B: Cooling Systems for Large Space Telescopes

14:30 *Cryogenic Thermal Design Challenges and Status of NASA's James Webb Space Telescope* Keith Parrish

14:55 *Herschel Cryo System and Status of European Cooler Development* Lionel Duband

15:15 *Thermal Design of SPICA* Takao Nakagawa

15:35 *NASA Cryocooler Development Program Overview* Ron Ross

15:55 *ADR Cooling for IR Telescope and Detectors* Peter Shirron

Session C: First Stars, First Galaxies

16:45	<i>Beyond WMAP</i>	Lloyd Knox
17:10	<i>Infrared Radiation from the First Stars</i>	Volker Bromm
17:35	<i>H₂ and HD Line Emission from Pop. III Star Formation</i>	Ryoichi Nishi
18:00	<i>The Formation of Massive Galaxies</i>	Scott Chapman
18:25	Adjourn	

Tuesday, June 8

Session D: Structure and Evolution of Galaxies

- 08:30 *Prospects for IR/Submm Studies of Galaxies at $z < 2$* George Helou
- 09:00 *The Dusty Universe at $2 < z < 4$* Ranga-Ram Chary
- 09:30 *Predictions from Galaxy Modeling* Joel Primack
- 10:00 Break

Session E: Suborbital Observatories

- 10:30 *SOFIA: Opportunities in the Far-IR* Jackie Davidson
- 10:50 *Large Single Aperture Ground Based Submm Telescopes* Gordon Stacey
- 11:10 *Upcoming Technology, Facilities, and Science at mm-Wavelengths* Grant Wilson
- 11:30 *Interferometric Arrays During Spitzer and Beyond* Lee Mundy
- 11:50 Poster summaries (1 Minute Poster Introductions)
- 12:10 Lunch

Wednesday, June 9

Session H: Debris Disks / Planetary Systems / Planets

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|-------|---|-------------------|
| 08:30 | <i>Signatures of Planets in Debris Disks</i> | Amaya Moro-Martin |
| 08:55 | <i>Optical and Infrared Imaging Studies of Debris Disks</i> | Karl Stapelfeldt |
| 09:20 | <i>Dust, Disks, and Planets</i> | David Wilner |
| 09:45 | <i>Connecting the Solar System and Extra-Solar Systems with SAFIR</i> | John Stansberry |
| 10:10 | Break | |

Session I: Future Space Missions – Filled Apertures

- | | | |
|-------|--|------------------|
| 10:30 | <i>WISE: The Wide-field Infrared Survey Explorer</i> | Peter Eisenhardt |
| 10:50 | <i>Large Area Infrared Survey with ASTRO-F</i> | Hideo Matsuhara |
| 11:10 | <i>SPICA: 3.5 m Space Infrared Telescope for Mid- and Far-infrared Astronomy</i> | Takao Nakagawa |
| 11:35 | <i>The Single Aperture Far Infrared Telescope (SAFIR): Making Dreams Come True</i> | Dan Lester |
| 12:00 | Poster summaries (1 Minute Poster Introductions) | |
| 12:15 | Lunch | |

Session J: Future Space Missions – Interferometers

- 14:00 *ESPRIT: Exploratory submm Space Radio-Interferometric Telescope* Thijs de Graauw
- 14:25 *SPIRIT and SPECS: Science Capabilities and Mission Concepts* Dave Leisawitz
- 14:50 *Technology Challenges for Future Far IR and Submm Systems* Jim Breckinridge
- 15:15 Panel Discussion
- Dispersive or Heterodyne vs. Interferometric Spectroscopy* John Mather

Session K: Technology for Large Apertures in Space

- 16:15 *The Vision for Space Exploration and the Future for Space Astronomy Missions* Harley Thronson
- 16:35 *Mirror Requirements for SAFIR* Scott Smith
- 16:55 *Structural Technology for Future Large Cryogenic Apertures* Lee Peterson
- 17:15 *Wavefront Sensing and Control* Dave van Buren
- 17:35 *Recent Advancements in Multidisciplinary Analysis* Greg Moore
- 17:55 Adjourn

Thursday, June 10

Session L: Detectors / Instruments

08:30	<i>Technology Needs for Space-based Cameras and Spectrometers</i>	Dominic Benford
09:00	<i>Far-infrared Spectroscopy at the Background Limit with a Cryogenic Space Telescope</i>	Matt Bradford
09:20	<i>The Next Generation of Coherent Detector Systems for Far Infrared Astronomy</i>	John Pearson
09:40	<i>Photoconductors: Spitzer and Beyond</i>	Erick Young
10:00	Break	
10:25	<i>Bolometer Array Technology Development at NIST</i>	Kent Irwin
10:45	<i>Superconducting Devices for Millimeter Through Far-Infrared Detection</i>	Jonas Zmuidzinas

Session M: Summary and Future Direction

11:15	<i>Does the Vision for Space Exploration See Beyond 28 μm</i>	Eric Smith
11:35	<i>From Spitzer to Herschel and Beyond: Conference Summary</i>	Martin Harwit
11:55	<i>From Spitzer to Herschel and Beyond: Conference Summary</i>	Tom Phillips
12:15	<i>Infrared Astronomy Beyond Spitzer: What is Next?</i>	Chas Beichman

Jet Propulsion Laboratory Tour

14:00

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Oral Presentation Abstracts

Monday Sessions

- Session A: Spitzer Early Results and New Questions
- Session B: Cooling Systems for Large Space Telescopes
- Session C: First Stars, First Galaxies

The Spitzer Space Telescope Mission

Michael Werner

(Email: Michael.W.Werner@jpl.nasa.gov)

Jet Propulsion Laboratory / California Institute of Technology, Pasadena, California

The Spitzer Space Telescope (formerly known as SIRTf) was successfully launched on August 25, 2003, and has completed its initial in-orbit checkout and science validation and calibration period. The measured performance of the observatory has met or exceeded all of its high-level requirements, it entered normal operations in January 2004, and is returning high-quality science data. A superfluid-helium cooled 85-cm diameter telescope provides extremely low infrared backgrounds and feeds three science instruments covering wavelengths ranging from 3.6 to 160 microns. The telescope optical quality is excellent, providing diffraction-limited performance down to wavelengths below 6.5 microns. Based on the first helium mass and boil-off rate measurements, a cryogenic lifetime in excess of 5 years is expected. Even after only a few months on orbit, it is clear that Spitzer will be a very important scientific and technical pacesetter for Herschel and all future infrared missions. This presentation will include scientific highlights but is intended mainly to provide a summary of the overall performance of the observatory, with an emphasis on those performance parameters that have the greatest impact on its ultimate science return.

Infrared Spectroscopy with the Spitzer IRS

Lee Armus

(Email: lee@ipac.caltech.edu)

Spitzer Science Center, California Institute of Technology, Pasadena, California

The Infrared Spectrograph (IRS) on Spitzer consists of four separate modules that cover the 5–40 micron wavelength range. Two of these operate at low resolution ($R\sim 80$) and cover the full 5–40 micron range, and two operate at high resolution ($R\sim 600$) in the 10–40 micron range. An on-board peak-up camera allows for accurate placement of targets on the narrow slits. The wavelength coverage and sensitivity of the IRS represent a significant leap in the capabilities for spectroscopic study of Solar System, Galactic, and extragalactic targets in the mid-infrared. We briefly describe the capabilities of the IRS, and focus on some early extragalactic science results covering both low and high-redshift galaxies.

Early Results with the Spitzer MIPS

George Rieke

(Email: grieke@as.arizona.edu)

University of Arizona, Tucson, Arizona

Early results from the MIPS instrument on Spitzer include the following. We find that the planetary zones in circumstellar disks may start to clear in only a few million years in some cases and generally clear in 100 MYr or less. The forward shock in the supernova remnant Cas A is colliding with a massive interstellar cloud, and the interaction region is lit up in emission from interstellar dust, as well as by synchrotron emission. Active Galactic Nuclei at high redshift do not appear to follow the correlation of X-Ray hardness with bright infrared emission predicted by simple unified models. I will discuss each of these results briefly and indicate how SAFIR could make further advances in these same areas.

Cryogenic Thermal Design Challenges and Status of NASA's James Webb Space Telescope

Keith Parrish¹, John Pohner², Stuart Glazer¹,
Shaun Thomson¹, and Robert Mackey³

(Email: Keith.A.Parrish@nasa.gov)

¹NASA Goddard Space Flight Center, Greenbelt, Maryland

²Northrop Grumman Space and Technology

³Lockheed Martin Missiles and Space

NASA's James Webb Space Telescope (JWST), scheduled to launch in 2011, will include a multi-module science instrument package with near-infrared detectors passively cooled to below 40 Kelvin. Instrumentation will also include a mid-infrared camera with detectors cooled to less than 7 Kelvin via a solid Hydrogen dewar. These complex cooling configurations, combined with a large deployed and actively controlled six meter telescope passively cooled to below 50 Kelvin, serve to make JWST one of the most unique and thermally challenging missions flown to date. This presentation describes JWST's current status and baselined thermal/cryogenic systems design. The extreme thermal challenges facing JWST are described and accompanied by a discussion of the JWST thermal modeling approach, development activities, and verification plans.

Herschel Cryo System and Status of European Cooler Development

Lionel Duband

(Email: lionel.duband@cea.fr)

Service des Basses Températures, Commissariat à l'Énergie Atomique (CEA), France

The Herschel/Planck mission of the ESA Horizon 2000 Science Program accommodates two spacecrafts for a joined launch on Ariane 5 in 2007. The Herschel payload consists in three instruments built by international scientific consortia, HIFI (Heterodyne Instrument for FIRST), PACS (Photoconductor Array Camera and Spectrometer) and SPIRE (Spectral and Photometric Imaging Receiver). The spacecraft provides the environment for astronomical observations in the infrared and sub-millimeter wavelength range requiring cryogenic temperatures for the cold focal plane units. A key requirement for the bolometric detectors, used in PACS and SPIRE, is that they will have to be cooled down to 290 mK. This will be achieved by two ^3He adsorption coolers for which CEA-SBT is responsible. These sub-Kelvin sorption coolers provide a wide range of heat lift capability at temperature below 400 mK. Helium adsorption coolers rely on the capability of porous materials to adsorb or release a gas when cyclically cooled or heated. Using this physical process one can design a compressor/pump which, by managing the gas pressure in a closed system, can condense liquid at some appropriate location, and then perform an evaporative pumping on the liquid bath to reduce its temperature. Various coolers and components have been designed and flown using this technology. This presentation will focus on these cryogenic systems. Additionally a brief overview of the on going Sub 4 K developments in Europe will be given.

Thermal Design of SPICA

Takao Nakagawa¹ and the SPICA Working Group

(Email: nakagawa@ir.isas.jaxa.jp)

¹Department of Infrared Astrophysics, Institute of Space and Astronautical Science (ISAS),
Japan Aerospace Exploration Agency (JAXA), Yoshinodai, Sagami-hara, Kanagawa, Japan

Abstract not available.

NASA Cryocooler Development Program Overview

Ron Ross

(Email: Ronald.G.Ross-Jr@jpl.nasa.gov)

Jet Propulsion Laboratory, Pasadena, California

Mechanical cryocoolers, building on a history of successful development over the years, represent a significant enabling technology for NASA's future observatory missions. Since 1991, long-life cryocoolers have been reliably providing a wide variety of multi-year infrared and gamma-ray space missions with continuous cooling in the 55-80 K range. Two more NASA cryocooler missions are scheduled to launch in 2004. The largest technology push within NASA right now is in the temperature range of 4 to 10 K. Missions such as the James Web Space Telescope (JWST) and Terrestrial Planet Finder (TPF) have baselined infrared detectors operating between 6-8 K, typically arsenic-doped silicon arrays, with IR telescopes from 3 to 6 meters in diameter. Similarly, bolometer-based missions such as Planck, and X-ray microcalorimeter missions such as Constellation-X, require 4-6 K cooling to precool the refrigerators required to achieve their sub-Kelvin detector temperatures. Future missions such as SAFIR plan to cool even the telescope itself to on the order of 4 K. To address cryocooler development for the next-generation missions, NASA is funding the Advanced Cryocooler Technology Development Program (ACTDP) as part of the TPF project. This paper summarizes NASA's cryocooler successes to date and presents an overview of the ACTDP program including programmatic objectives and timelines, and conceptual details of the cooler concepts under development.

ADR Cooling for IR Telescope and Detectors

Peter Shirron, Michael DiPirro, Edgar Canavan, and James Tuttle

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NASA Goddard Space Flight Center, Greenbelt, Maryland

Over the last decade, adiabatic demagnetization refrigerators (ADR) have evolved from single-stage systems requiring relatively low heat sink temperatures to multi-stage systems capable of rejecting heat to as high as 5 K. There is now current work focusing on extending this range to as high as 30 K with cooling power at 4 K of 10s to 100s of mW. In this temperature range and cooling capacity ADRs will become suitable for replacing low efficiency sub-10 K mechanical cooler stages, as well as sub-Kelvin instruments. When combined with a 30 K cryocooler or a passive radiative cooler, the high temperature ADR gives a low mass, high efficiency, high reliability, low vibration option for cooling future large space telescopes and instruments. This paper will discuss the relative merits of various ADR and cryocooler configurations, and identify potential trade-offs between the two in an effort to develop guidelines for optimizing total system performance. The paper will also discuss the present status of ADR technology and future development needed to produce an optimal system.

Beyond WMAP

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Future missions beyond WMAP will have improved angular resolution, sensitivity and frequency coverage. With these improvements, we can greatly improve our understanding of inflation (or whatever created the primordial inhomogeneities), probe the reionization history of the inter-galactic medium, and possibly detect the influence of non-zero neutrino mass on the energy density of relic neutrinos. Cosmological parameters will be determined well enough that analyses of low-redshift probes (e.g., cosmic shear and SNe-Ia) can consider them fixed, allowing for tight constraints on dark energy parameters.

Infrared Radiation from the First Stars

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I review the nature of star formation at very high redshifts, and the resulting signature at infrared wavelengths to be observed with next-generation missions. In particular, I discuss the imprint of the first stars on the near-infrared background, as well as the molecular hydrogen line radiation emitted during the formation of the first stars.

H₂ and HD Line Emission from Pop. III Star Formation

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We investigate the H₂ and HD line radiation emitted in the formation process of metal-free stars. We show that the maximum luminosity is attained in the accretion phase for strong emission lines. In the accretion phase, rovibrational line emission becomes prominent, contrary to the runaway collapse phase, where the pure-rotational lines are always dominant. We also estimate the detectability of these lines by future far infrared telescopes, such as SPICA.

The Formation of Massive Galaxies

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Massive elliptical galaxies mark the highest density regions of the Universe, and their environment must be an important factor in their evolution. How were these luminous galaxies formed? Submm and infrared observations have opened a new window on the process of dusty galaxy formation at high redshifts. We now understand that massive galaxies assembled near $z = 2.5$, on a timescale comparable to their star-formation, with luminous, dusty star-bursts emitting in the rest-frame far-IR wavelengths. However, our current facilities - Spitzer Space Telescope, and modern submm arrays - are just probing the tip of the ice-berg. I will discuss observational signatures of high-redshift forming galaxies possible with a post-Spitzer instrument operating at wavelengths longer than $20 \mu\text{m}$, both in the continuum and lines.

Tuesday Sessions

- Session D: Structure and Evolution of Galaxies
- Session E: Suborbital Observatories
- Session F: Milky Way ISM and Star Formation
- Session G: Herschel Space Observatory

Prospects for IR/Submm Studies of Galaxies at $z < 2$

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Detailed studies of nearby galaxies at high spatial resolution are crucial to understanding the mechanics of star formation on large scales and in galactic nuclear environments. The ISM diagnostics unique to the IR/Submm will continue to further this topic as the missions improve in spatial resolution. Similarly, tracing the energy production history of the universe back to $z \sim 2$ will require the extinction-free probes and the large collecting areas that future IR/Submm missions are designed to deliver. Examples of specific questions that will benefit from the succession of Spitzer, Herschel and future missions will be presented.

The Dusty Universe at $2 < z < 4$

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Lyman-break galaxies selected at visible wavelengths at $z \sim 3$ are thought to be the progenitors of present day galaxies. Measuring the amount of dust obscuration in these objects is important to understand how the star-formation rate and mass of galaxies evolves with cosmic time. Thus far, this has been estimated from the rest-frame ultraviolet emission in a demonstrably inaccurate way. At long wavelengths, the SCUBA/850 micron observations are capable of detecting dust emission at these redshifts but these can detect only the brightest infrared luminous galaxies which contribute a miniscule fraction of the cosmic far-infrared background. The GOODS/MIPS observations are sensitive to detecting “typical” dusty galaxies at $z \sim 3$ and a comparison between their 24 micron fluxes with their UV properties will place better constraints on the nature of dust extinction at these redshifts. This will provide a more robust measure of the dust-enshrouded star-formation at $z \sim 3$ and enhance/reject the observed dichotomy between Lyman-break galaxies and SCUBA galaxies. Finally, I will discuss the uncertainties associated with measuring infrared luminosities and thereby, the dust emission properties of galaxies and evaluate the possibilities for minimizing these with future long-wavelength studies.

Predictions from Galaxy Modeling

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Physics Department, University of California, Santa Cruz, California

I plan to present new results in collaboration with Rachel Somerville extending our semi-analytic modeling of galaxies (*Somerville and Primack*, 1999; *Somerville et al.*, 2001) into the mid and far IR, as well as some exciting new dissertation research that two of my UCSC grad students are doing on hydro simulations of galaxy interactions including radiative transfer and dust modeling (*Cox et al.*, 2004; and additional papers in preparation). The images of interacting galaxies resulting from these simulations are being compared with galaxy images in various spectral bands using new galaxy morphology measures (*Lotz et al.*, 2004).

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- [a] Somerville, Rachel S., and Primack, Joel R., Semi-Analytic Modeling of Galaxy Formation: The Local Universe, *MNRAS*, **310**, 1087–1110, 1999.
 - [b] Somerville, Rachel S., Primack, Joel R., and Faber, S.M., The Nature of High-Redshift Galaxies, *MNRAS*, **320**, 504–528, 2001.
 - [c] Cox, T.J., Primack, Joel R., Jonsson, Patrik, and Somerville, Rachel, Generating Hot Gas in Simulations of Disk Galaxy Major Mergers, *ApJ*, **607**, L87–L90, 2004.
 - [d] Lotz, Jennifer M., Primack, Joel, and Madau, Piero, A New Nonparametric Approach to Galaxy Morphological Classification, *AJ*, **128**, 163–182, 2004.

SOFIA: Opportunities in the Far-IR

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SOFIA-USRA

The Stratospheric Observatory for Infrared Astronomy - SOFIA - is an observatory with a 2.5 meter telescope in a Boeing 747SP aircraft, being developed by NASA and DLR (the German Aerospace Center). SOFIA will operate over a 20 year lifetime, flying into the stratosphere, allowing astronomical measurements covering the wavelength range from 0.3 μm to 1.6 mm, with an emphasis on the spectral regions inaccessible from the ground, such as the 6-8 μm and 30-300 μm spectral regions. SOFIA will support a diverse and changing complement of state-of-the-art science instruments with spectral resolutions ranging from 0.5 to 108. It will have a General Investigator Program with an annual proposal/observing cycle. This paper will overview the capabilities of SOFIA with its first-light instrument complement and give a projection of its capabilities over the observatory's life-time, 2005-2025.

Large Single Aperture Ground Based Submm Telescopes

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I plan to discuss future ground based submillimeter telescope projects, their direct detection instrumentation, and primary science goals. I will focus on the astrophysical applications of the Cornell/Caltech 25 m telescope envisioned for a high site near the ALMA array, the 12 m APEX telescope also near the ALMA array, and the 10 m South Pole Telescope (SPT). The discussion will include site selection, instrumentation, and important astrophysical goals.

Upcoming Technology, Facilities, and Science at mm-Wavelengths

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University of Massachusetts

The recent advent of hundred, and soon thousand, pixel focal plane detector arrays combined with a new investment in large field-of-view ground-based telescopes has revitalized millimeter and sub-millimeter astronomy. Far from being put to rest by the WMAP satellite, the intriguing cosmology still hidden in the anisotropy of the CMB at the scales of clusters and smaller is technologically within our reach and is the target of at least two major telescope construction initiatives. Yet other new telescopes are now planning to study these clusters not as cosmological probes, but in detail as laboratories for the physics of gravitational collapse. At even smaller scales the study of dust-enshrouded high-redshift galaxies (and at larger scales their clustering) will soon enter a new era with planned instruments being capable of detecting several hundreds of sources an hour. Each of these areas of exploration require the high sensitivity of large arrays of detectors along with the large spatial dynamic range afforded by a large single dish telescope. In this talk I review this class of experiments, focusing on the new telescopes, detector arrays, and science soon to be available at mm wavelengths.

Interferometric Arrays During Spitzer and Beyond

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Ground-based arrays at centimeter, millimeter, and submillimeter wavelengths will be developing major new capabilities during the next decade. The higher sensitivity and resolution afforded by the next generation arrays will enable new science in areas ranging from debris disk structure to the formation of the first galaxies. The largest new addition is the Atacama Large Millimeter Array (ALMA) which is funded and under construction with early operation at the end of 2007, and full operation by 2012. With its unprecedented sensitivity and resolution, and its high altitude site, ALMA pushes the boundary between traditional ground-based and space-based science. These arrays will be essential complements to space-based instruments.

Evolution of Circumstellar Disks

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Most young solar type stars are surrounded by circumstellar accretion disks. These disks provide the raw materials for the formation of planetary systems, and indeed, the increasing number of Jupiter-mass objects found orbiting older stars suggests that planet formation is a common outcome of the star formation process. One key to understanding planet formation is establishing the lifetime of the dust and gas in circumstellar accretion disks. In this talk, I review the current observational constraints on disk lifetimes, and discuss how Spitzer, Herschel, and future far-infrared interferometric missions will dramatically improve our understanding on how disks evolve around solar-type stars.

The Interstellar Medium: Expected Advances from Spitzer, Herschel, and Beyond

Edwin A. Bergin

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University of Michigan

In this talk I will focus on the expected advances in our understanding of the Galactic Interstellar Medium from both Spitzer and Herschel. Particular emphasis will be placed on heterodyne observations and how detections of molecular emission and absorption lines, previously hidden by the atmosphere, will lead to important gains in our understanding in areas including the chemistry and thermal balance of molecular clouds, the physics of interstellar shock waves, the life cycle of water during star formation, and the existence of “astrobiological” molecules. Future heterodyne space missions, beyond Spitzer and Herschel, can be expected to offer significant improvements in angular resolution at long wavelengths and I will discuss how this will benefit ISM studies.

Star Formation Highlights from Spitzer

Erick Young

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Steward Observatory, University of Arizona, Tucson, Arizona

We present a sampler of recent star formation results from Spitzer. With its unprecedented combination of sensitivity and angular resolution, Spitzer has produced some remarkable observations of young stars and their environs. We feature observations from the Young Disks program, where clusters ranging in age from < 1 Myr to > 100 Myr are surveyed in the four IRAC bands and the three MIPS bands. We present observations from a number of these clusters including NGC 2068, NGC 2071, IC 1396, and NGC 2547. In the youngest clusters we find the expected population of Class 0 and Class I sources, and we show detailed spectral energy distributions for representative objects. For the 25–30 Myr cluster NGC 2547, we present a study of the disk frequency in probable members. We find that in the IRAC bands, there is little evidence for residual disks except possibly at the lowest masses. We find a modest number of members with significant excess emission at $24 \mu\text{m}$.

The Herschel Mission: Overview and Observing Opportunities

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Herschel Project Scientist, European Space Agency

The Herschel Space Observatory (formerly known as FIRST) is the fourth cornerstone mission in the European Space Agency (ESA) science program. It will perform imaging photometry and spectroscopy in the far infrared and submillimeter part of the spectrum, covering approximately the 55–650 micron range. The key science objectives emphasize current questions connected to the formation of galaxies and stars, however, having unique observing capabilities, Herschel will be a facility available to the entire astronomical community. Herschel will carry a 3.5 meter diameter passively cooled telescope. The science payload complement - two cameras/medium resolution spectrometers (PACS and SPIRE) and a very high resolution heterodyne spectrometer (HIFI) - will be housed in a superfluid helium cryostat. The ground segment will be jointly developed by ESA, the three instrument teams, and NASA/IPAC. Herschel will be launched in 2007. Once operational, Herschel will offer a minimum of 3 years of routine observations; roughly 2/3 of the available observing time is open to the general astronomical community through a standard competitive proposal procedure. I intend to report on the current implementation status of the various elements that together make up the Herschel mission, and to introduce the mission from the perspective of the prospective user of this major facility.

The SPIRE Instrument for the ESA Herschel Observatory

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Rutherford Appleton Lab, United Kingdom

SPIRE, the Spectral and Photometric Imaging Receiver, is one of three scientific instruments which will fly on the European Space Agency's Herschel Space Observatory. SPIRE contains two sub-instruments: a three-band imaging photometer operating at 250, 360, and 520 μm , and an imaging Fourier Transform Spectrometer (FTS) covering 200-670 μm . The detectors are arrays of feedhorn-coupled NTD spider-web bolometers cooled to 300 mK. The photometer field of view is 4×8 arcminutes, observed simultaneously in the three spectral bands. An internal beam steering mirror allows spatial modulation of the telescope beam and will be used to jiggle the field of view in order to produce full sampled images. Observations can also be made by scanning the telescope without chopping. The FTS has an approximately circular field of view with a diameter of 2.6 arcminutes, and employs a dual-beam configuration with broad-band intensity beam dividers to provide high efficiency and separated output and input ports. The spectral resolution can be adjusted between 0.04 and 2 cm^{-1} ($\lambda/\Delta\lambda = 20\text{--}1000$ at 250 μm). The instrument design, operating modes, and estimated sensitivity are described, and the current status of the project is reported.

The Herschel-Heterodyne Instrument for the Far-Infrared (HIFI)

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⁴KOSMA, Germany

The Heterodyne Instrument for the Far-Infrared is a single-pixel, high-resolution (>300.000), spectrometer for ESA's Herschel Space Observatory. The instrument comprises 5 frequency bands covering 480–150 GHz with SIS mixers and a sixth dual band for the 1410–1910 GHz range with Hot Electron Bolometer Mixers. The LO subsystem consists of a X-band synthesizer followed by 14 chains of frequency multipliers, 2 for each frequency band. A pair of Auto-Correlators and a pair of Acousto-optic spectrometers provide instantaneous frequency coverage of 4 GHz with a set of resolutions (140 kHz to 1 MHz) better than < 0.1 km/s. Each frequency band has two mixers operating at orthogonal polarizations. All mixers are designed to have noise performance close to the quantum noise limit. One frequency band is operated at a time. Because of its high spectral resolution and wide frequency coverage, HIFI is expected to make a deep impact on a wide variety of astrophysical investigations, ranging from comets, planetary-satellite atmospheres, star formation, and AGB stars to galactic nuclei. The main science drivers are emission and absorption lines of Water, N[II] and C[II] emission in the ISM, and a molecular inventory of regions as shocked molecular clouds, dense Photon-Dominated Regions (PDRs), diffuse atomic clouds, Hot Cores and proto-planetary disks around newly formed stars, winds from dying stars and toroids interacting with AGN engines.

The Photodetector Array Camera and Spectrometer (PACS) for the Herschel Space Observatory

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⁹Istituto di Fisica dello Spazio Interplanetario, Rome, Italy

The Photodetector Array Camera and Spectrometer (PACS) is one of the three science instruments for ESA's far infrared and submillimeter observatory Herschel. It employs two Ge:Ga photoconductor arrays (stressed and unstressed) with 16×25 pixels, each, and two filled Si bolometer arrays with 16×32 and 32×64 pixels, respectively, to perform imaging line spectroscopy and imaging photometry in the 60–210 μm wavelength band. In photometry mode, it will simultaneously image two bands, 60–85 or 85–130 μm and 130–210 μm , over a field of view of $\sim 1.75' \times 3.5'$, with full beam sampling in each band. In spectroscopy mode, it will image a field of $\sim 50'' \times 50''$, resolved into 5×5 pixels, with an instantaneous spectral coverage of ~ 1500 km/s and a spectral resolution of ~ 175 km/s. In both modes, background-noise limited performance is expected, with sensitivities (5σ in 1 h) of ~ 3 mJy or $3\text{--}10 \times 10^{-18}$ W/m², respectively. We describe the design of the instrument and its observing modes, report first results from instrument level tests of the Qualification Model, and give examples of the observing capabilities of PACS onboard Herschel for several key questions of modern astronomy, illustrated by examples from the emerging Guaranteed Time Programme of the PACS consortium.

Acknowledgment. This work is supported by the following funding agencies: ASI (Italy), BMVIT (Austria), CEA/CNES (France), DLR (Germany), ESA-PRODEX (Belgium), and CDTI (Spain).

U.S. Community Support for Herschel from the NASA/Herschel Science Center

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The NASA/Herschel Science Center (NHSC) at IPAC has been funded by NASA to support the U.S.-based community in using Herschel. It is working closely with the ESA HSC to support observers at all stages, from observation planning to data analysis, by providing information, expertise, software tools and liaison to HSC. The near-term plans are to support Key Project process and to keep the U.S. community informed on progress of mission and upcoming opportunities.

Wednesday Sessions

- Session H: Debris Disks / Planetary Systems / Planets
- Session I: Future Space Missions – Filled Apertures
- Session J: Future Space Missions – Interferometers
- Session K: Technology for Large Apertures in Space

Signatures of Planets in Debris Disks

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Main sequence stars are commonly surrounded by debris disks, composed of cold far-IR emitting dust generated by a reservoir of undetected dust-producing planetesimals. In debris disks harboring massive planets, the trapping of dust in gravitational resonances with the planet creates a density enhancement in a ring-like structure outside the orbit of the planet, while gravitational scattering with the planet creates a clearing of dust inside the planet's orbit. Massive planets, therefore, can create structure in the dust disk, and the study of this structure can help us survey a range of planetary parameters that are not detected by other methods. Spitzer will obtain spatially unresolved spectrophotometric observations of many of these systems. We discuss how the structure carved by massive planets affects the shape of the disk's spectral energy distribution (SED), and consequently how the SED may be used to infer the presence of planets. We show, however, that the SED modeling presents some degeneracies that can only be broken if spatially resolved images of the dust disks are obtained, justifying the need of SAFIR for the interpretation of debris disk structure in terms of planetary architectures. In addition, the very high sensitivity of SAFIR will allow us to understand whether debris disks originate from a steady production of dust, or from stochastic collisional events. SAFIR will provide unique capabilities to study stars at a stage when terrestrial planet formation might be taking place, results that will allow us to learn whether terrestrial planets are common or rare.

Optical and Infrared Imaging Studies of Debris Disks

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The presence of debris disks around nearby main sequence stars requires ongoing dust production from asteroidal collisions and cometary passages, and therefore suggests the presence of a planetary system. The internal structure of these disks includes central holes, azimuthal asymmetries, radial gaps, and warps that can betray the presence of unseen planetary perturbers. In this talk, I'll review what is known about the internal structure of debris disks from optical, near-IR, and thermal-IR measurements, including very recent results from the Spitzer Space Telescope, and speculate on the contributions that Herschel and SAFIR might make to this field.

Dust, Disks, and Planets

David Wilner

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Harvard Center for Astrophysics

The unique capabilities of SAFIR can provide insight into many issues in the formation and evolution of planetary systems. I briefly discuss two examples that rely on far-infrared observations of dust emission, one from each end of the evolutionary spectrum: (1) Dust coagulation and settling in the disks around young stars is a key early step in making planets. The far-infrared can provide important diagnostics because depletion of dusty material in the upper layers of a disk reduces opacity and results in a flatter surface, lower temperatures in the interior, and marked changes in emission. (2) Resonant dust features in debris disks around main-sequence stars are rapidly becoming a way to study remnant planetesimal populations and to infer the presence of planets. The basic idea is that the radial decay of particle orbits by drag forces can be resisted by the periodic perturbations of a planet, which creates long lasting dust features. A large far-infrared aperture should produce a dramatic increase in the sample of resolved disks. And since particle size is important in both dynamics and emission, resolved images over a wide wavelength range can provide new constraints on planetary perturbers.

Connecting the Solar System and Extra-Solar Systems with SAFIR

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We explore the uses of a 10 m-class, cold, space-based telescope for exploring objects in the solar system, and objects in extra-solar planetary systems. We present Spitzer solar system observations, using those as a starting point for discussing what types of things could be learned using SAFIR. We also explore whether SAFIR would provide unique capabilities for discovering and perhaps characterizing extra-solar planets.

WISE: The Wide-field Infrared Survey Explorer

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The Wide-field Infrared Survey Explorer (WISE, formerly known as NGSS) is a Medium Explorer currently in extended Phase A study, with launch planned for 2008. WISE will map the entire sky with a sensitivity hundreds of thousands of times better than COBE at 3.5 and 4.7 microns, and up to a thousand times better than IRAS at 12 and 23 microns. WISE will discover objects ranging from the nearest stars to the most luminous galaxies, define the framework for the James Webb Space Telescope (JWST), and provide a scientific legacy that endures for decades.

Large Area Infrared Survey with ASTRO-F

Hideo Matsuhara

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Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency

ASTRO-F is the first Japanese infrared satellite dedicated for large area IR surveys. I will show the overview, uniqueness and operational plan of the ASTRO-F mission. I will especially describe how ASTRO-F is complementary to the Spitzer Space Telescope.

SPICA: 3.5 m Space Infrared Telescope for Mid- and Far-infrared Astronomy

Takao Nakagawa¹ and the SPICA Working Group

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We present the current status of the SPICA (Space Infrared Telescope for Cosmology and Astrophysics) project. SPICA is a unique mission with a large, cooled telescope; we propose to cool a 3.5 m class telescope down to 4.5 K by moderate mechanical cryogenic coolers with the help of effective radiative cooling (i.e. SPICA will not carry any liquid Helium). The cooled, large telescope makes SPICA optimum for high-resolution mid- to far-infrared observations with unprecedented sensitivity. We present some of the preliminary results of the technical development programs for SPICA. The target launch year of SPICA is early 2010s.

The Single Aperture Far Infrared Telescope (SAFIR): Making Dreams Come True

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The astronomical community looks forward to SAFIR, a 10-m class cold space telescope, as a visionary successor to Spitzer and Herschel. This facility observatory would fully bridge the decade of spectrum between JWST and ALMA, and build on the scientific legacies of currently funded projects. SAFIR represents a convergence of fundamental science need with emerging technological feasibility. I review how SAFIR responds to our high priority scientific challenges, both well defined and rapidly evolving, and strategies for bringing the observatory to fruition. I report on the NASA OSS SAFIR Vision Mission study, now in progress.

ESPRIT: Exploratory submm Space Radio-Interferometric Telescope

Thijs de Graauw, J. Cernicharo, A. Bos, J. Bregman, L. Darcio,
J.-W. den Herder, A. Gunst, F. Helmich, P. Maat, J. Noordam,
A. Quirrenbach, P. Roelfsema, L. Venema, P. Wesselius,
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¹SRON National Institute for Space Research of The Netherlands

²ASTRON Netherlands Foundation for Research in Astronomy

³CSIC Instituto de Estructura de la Materia, Madrid, Spain

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We will present a mission concept for a free-flying FIR imaging interferometer using radio techniques. The ultimate goal is to reach a Hubble ST-equivalent spatial resolution for the FIR wavelength range. The main scientific objectives are imaging in the emission lines of water and molecular ions, imaging in important atomic fine-structure lines: CII, NII, OI, and imaging in high excitation lines of CO, HCN, HCO+, etc., of star forming regions and proto-planetary systems with emphasis on studies of the evolution of disks. The facility will be the FIR complement of the ground-based ALMA without any atmospheric attenuation and disturbance in phase and transmission. It will be a follow-up mission of ISO-LWS, SWAS, ODIN, SIRTf, ASTRO-F; Herschel-PACS and -HIFI and of MIRI on JWST.

The aimed characteristics are:

Telescope sizes:	~ >3.5 meter ; off-axis
Number of elements:	$N > 6$; free-flying
Proj. Baselines:	~ 7–500 meter
Frequency coverage:	in the 1.5–6 THz range (200 m 50 m)
Spectral Resolution:	1 km/s at 100 m. (0.1 goal)
Spatial Resolution:	0.02 at 100 m
F.O.V.:	~ 6
Pointing Requirements:	- accuracy: 0.2; - knowledge: 0.1
Image Dynamic range:	100
Spectral Dynamic range:	1000
Tsys:	1000 K (N receiver bands; HEB mixers @5 K; dual polarisation; QCL as LOs)
IF:	4 GHz wide; InP pre-amps
Correlator:	4 sections of 1 GHz, each 128 channels

From the inherent narrow band capability of heterodyne techniques, the substantial advantages for path length difference compensation and tracking will be elaborated as well as the expected detection and imaging sensitivity. We will present a study program covering the scientific objectives, instrumentation, interferometer configuration, delay lines and correlation techniques.

SPIRIT and SPECS: Science Capabilities and Mission Concepts

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Space-based far IR/submillimeter interferometry is needed to learn how stars and planetary systems form and to answer fundamental questions concerning the development of structure in the universe. I will describe concepts for the Space Infrared Interferometric Telescope (SPIRIT) and the Submillimeter Probe of the Evolution of Cosmic Structure (SPECS). Both are imaging and spectral Michelson interferometers operating in the wavelength range $\sim 40\text{--}800\ \mu\text{m}$. SPIRIT, which could be launched in a decade, is built on a deployable boom and has a maximum baseline of $\sim 30\text{--}50\ \text{m}$, providing sub-arcsecond resolution in the far-IR. This NASA Origins Probe candidate will image extrasolar debris disks and protostars in the far-IR, where their brightness peaks, and it will beat extragalactic source confusion and provide the continuum and line spectra of galaxies out to high redshifts. SPECS, a NASA Vision Mission, uses formation flying to attain baseline lengths up to 1 km, and thus angular resolution comparable to that of the Hubble Space Telescope (HST), the James Webb Space Telescope (JWST), and the Atacama Large Millimeter Array (ALMA). SPIRIT and SPECS will provide access to many important cooling and diagnostic spectral lines and to the bulk of the thermal emission from dust, and make observations complementary to those obtainable with ALMA, SAFIR, and JWST.

Technology Challenges for Future Far IR and Submm Systems

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Requirements, technology hurdles, inventions, schedules, metrics and need for clear system visions will be discussed in a conversation with members of the audience. The strong interdependence between structures, mirrors, thermal control, focal planes and science establishes a frame work for planning the next 10 years.

Dispersive or Heterodyne vs. Interferometric Spectroscopy

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Abstract not available.

The Vision for Space Exploration and the Future for Space Astronomy Missions

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NASA's Vision for Space Exploration is only six months old, with a vast number of elements to be understood and agreed upon, but some aspects of its effect on space astronomy may be discerned. The Office of Space Science contributed to the preparation of the Vision over the past autumn, which explains the relative prominence of space astronomy in a document that has attracted attention mainly to human missions to the Moon and Mars. The search for life is the dominant science theme within the Vision. Thus, such science programs as planet detection and study, the birth of stars and planetary systems, and the composition and structure of protostellar and protoplanetary systems are most consistent with the Vision. In the near term, a priority goal of the Office of Space Science, among other things, will be to invest in key technologies likely to be necessary to enable plausible future missions in these areas, including large, lightweight optics and precision structures, thermal control systems, sensors, and deployment schemes. Careful consideration will be given to the role of astronauts and coordination with the new Office of Exploration systems.

Mirror Requirements for SAFIR

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Large-aperture lightweight low-cost cryogenic mirrors are an enabling technology for planned NASA far-infrared and sub-millimeter missions such as CMB-Pol, SAFIR and SPECS. This paper examines the mirror requirements necessary to design, build and characterize mirror segments for large space telescopes operating at temperatures of less than 10 K. Such mirrors should be diffraction limited in the far-IR with an areal density of less than 10 kg/m², aperture of 1 to 2 meters and cost of less than \$500,000 per square meter.

Structural Technology for Future Large Cryogenic Apertures

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This paper will discuss technological requirements and capabilities for future large aperture cryogenic telescope instruments. Recently developed design rules for large space structures allow complex system trades to be distilled into simple design scaling laws. These scaling laws directly compare the benefits of various structural technologies. For example, the benefit of deployable structure technologies can be directly compared with the benefit of advanced materials and active control methods. Specific examples will be included for a 10-meter class IR telescope suitable for the SAFIR mission. One trade that will be illustrated is between the passive stability of the deployed instrument and active adjustment of the optical elements and/or wavefront control. An additional trade is between the extremely low damping of cryogenic structures and the overall stiffness of the deployed structure. This leads to a quantitative measure of the benefit between deployable depth, passive damping treatments, and possibly active vibration control.

Wavefront Sensing and Control

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The drive toward lightweight large apertures combined with the properties of engineering materials and packaging constraints leads toward active control of optical surfaces to initiate and maintain image quality. A number of diverse technology challenges must be met to reach this goal, and progress to date has been sustained. We anticipate an upcoming era where large spaceborne telescopes routinely image beyond the diffraction limit (wavefront errors $\ll 1/14$ wave), opening new frontiers in astrophysics, extrasolar planetary systems, and planetary reconnaissance.

Recent Advancements in Multidisciplinary Analysis

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Accurately predicting optical system performance for any of the large aperture scenarios that are currently envisioned is a uniquely challenging task, and one that has served to highlight a number of areas of necessary advancement in the field of computer-aided engineering analysis. The strongly coupled nature of these classes of problems, combined with unprecedented levels of required optical precision, demand a solution approach that is itself fundamentally integrated if accurate efficient analyses, capable of pointing the way toward improved designs, are to be achieved. Recent advancements in this area have picked up on the spirit of the original JPL-developed IMOS code (Integrated Modeling of Optical Systems), and have served to lay the groundwork for an entirely new analytical capability; one that is open, highly extensible, is hosted from within Matlab, yet is based on core high-performance computational modules written in C, and natively understands Nastran analysis model descriptions. Capabilities currently under development, a few of which will be highlighted here, will soon capture behavioral aspects of coupled nonlinear radiative heat transfer, structures, and optics problems to a level of accuracy and performance not yet achieved for these classes of problems, in an environment that will greatly facilitate future research, development, and technical oversight efforts.

Thursday Sessions

- Session L: Detectors / Instruments
- Session M: Summary and Future Direction

Technology Needs for Space-based Cameras and Spectrometers

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The next generation of far-infrared through millimeter space missions will feature cryogenically cooled, large aperture, low background telescopes. To make the most of these observatories, instruments that can image large areas or accept broad spectral coverage will be needed, and these instruments will be designed to achieve the best sensitivity possible, technology permitting. The first capability - large area imaging - will require large format arrays of direct detectors, which is self-evident. In addition, they will require careful optical design to enable the best use of the focal plane real estate, and spectral coverage and/or polarimetry to deliver the science product desired by the community. The second capability - direct detection spectrometers - promises to yield advances in far-infrared spectroscopy limited only by the extremely low natural backgrounds in space. However, the detectors for such an instrument are orders of magnitude more sensitive than any yet produced in this wavelength range, and represent a substantial technological challenge. Survey missions such as proposed Explorer- and Probe-class experiments will begin to tap into these technologies, while future Observatory-class missions such as SAFIR and SPECS would need to use them fully to bring the ultimate promise of this spectral regime.

Far-infrared Spectroscopy at the Background Limit with a Cryogenic Space Telescope

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The combination of a 3+ meter cryogenic space telescope with sensitive direct detectors can provide 3–5 orders of magnitude improvement over existing platforms for moderate resolution spectroscopy from 40 to 400 microns. The capability will enable new astrophysics – namely the first routine spectroscopic observations of large and diverse samples of high-redshift galaxies. The broadband far-IR spectra will provide a critical complement to optical and far-IR continuum studies by measuring the conditions in the bulk of the material, measuring redshifts, and overcoming spatial confusion. While the 3+ meter cryogenic observatories and SAFIR are under development, the sensitive, broadband spectroscopy capability presents technical challenges, in particular the detector sensitivity and the spectrometer architecture. Bolometer and photoconductor arrays at the current state of the art are a good match to an imaging Fourier-transform type instrument. The ultimate sensitivity is possible only with a dispersive system and will require some advances in detector sensitivity. I outline these potential approaches and their scientific capability.

The Next Generation of Coherent Detector Systems for Far Infrared Astronomy

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Very high-resolution spectroscopy is necessary for study of a number of fundamental topics in astrophysics. Coherent technology has been developed and deployed throughout the far infrared, and has had an enormous impact on many areas of astrophysics. In spite of the impact of this technology, the systems developed to date are rather limited in capability and autonomy and require significant advancements to address the next generation of high-resolution questions. A number of architecture advances including spatial arraying for mapping, phase arraying for spatial resolution and reduced complexity of subsystems are required for future telescopes. Additionally, a number of basic component technologies require invention, improvement or simplification. Lastly operational test beds to perform science are necessary for verification of technologies and system architectures. A brief view of the future potential of coherent high-resolution astronomy will be presented.

Photoconductors: Spitzer and Beyond

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Photoconductor detectors have been the primary far-infrared sensors for space astronomy for over two decades. The MIPS instrument on the Spitzer Space Telescope features large arrays at 24, 70, and 160 μm . We present details of these detector arrays with an emphasis on in-orbit performance. The 24 μm band uses a 128×128 Si:As Blocked Impurity Band, and it has met all the expected performance goals. The 32×32 Ge:Ga array at 70 μm suffers from excess noise in half the array due to faulty cryostat cable, but it is still producing excellent astronomical data. The 2×20 Stressed Ge:Ga array is operating within a factor of two pre-launch predictions. We describe adjustments to the observing strategy to account for on-orbit conditions. Examples of representative observations will be presented. The progress in developing the next generation of arrays for Herschel and SOFIA will be discussed, and the needs for more distant facilities like SAFIR will be covered.

Bolometer Array Technology Development at NIST

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We report on the development of detector, readout and on-chip micro-refrigerator technologies at NIST for large-format bolometer arrays with performance appropriate for missions including SAFIR. We manufacture both superconducting transition-edge sensor (TES) bolometers and normal-insulator-superconductor (NIS) bolometers. TES bolometer arrays include SCUBA-2, which will have more than 10,000 pixels. We are also developing NIS bolometers for low noise-equivalent power (NEP) applications. Large arrays of low-temperature detectors can be read out with cryogenically multiplexed SQUID amplifiers. At low frequencies, we use time-division multiplexers in which SQUIDS are turned on one at a time to sequentially read out large arrays of detectors. This mature technology is being used in arrays as large as 10,000 pixels (the SCUBA-2 instrument). We are also developing multiplexers based on ultra-low-power SQUID amplifiers frequency-division multiplexed at microwave frequencies. Microwave SQUID multiplexers may make it possible to read out many thousands of bolometers in a single HEMT amplifier channel. Finally, we present recent results using on-chip NIS micro-refrigerators. These integrated micro-refrigerators make it possible to operate detectors at temperatures well below 240 mK from He-3 cooling stages. It may also be possible to operate detectors at temperatures well below 40 mK from adiabatic demagnetization refrigerators. These temperatures were previously not available from an orbital platform. Operation at these temperatures may be useful in ultra-low-NEP applications (such as SAFIR spectrometers).

Superconducting Devices for Millimeter Through Far-Infrared Detection

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Superconductivity offers solutions for many difficult technical problems that arise when developing sensitive detection systems for long-wavelength astrophysics. A variety of superconducting devices are being developed at JPL and Caltech, with the goal of enabling future missions such as CMBPol and SAFIR. Examples include narrow-beam planar antenna arrays, dual-polarization antennas, antenna-coupled TES bolometers, on-chip filters and switches, and kinetic inductance detectors. Much of this work builds on our previous experience with semiconducting bolometers and superconducting mixers.

Does the Vision for Space Exploration See Beyond 28 μm

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Abstract not available.

From Spitzer to Herschel and Beyond: Conference Summary

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Abstract not available.

From Spitzer to Herschel and Beyond: Conference Summary

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Infrared Astronomy Beyond Spitzer: What is Next?

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This Conference has highlighted some of the very first results from Spitzer, an event that veteran infrared astronomers have been awaiting for many years. What will be the next steps in the coming “century” of the infrared? I will discuss some of the scientific breakthroughs we might expect to achieve with planned new facilities such as Herschel, Planck, and JWST and then with more far-future facilities such as the TPF-Interferometer, SAFIR, and CMBPOL. I will also point out some of the pitfalls that we as a community must avoid if we are to move briskly into this very promising future.

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Poster Abstracts

Viewing the Milky Way Through Space and Time: A Proposed Herschel Far-IR/Submm Survey of the Galactic Plane

Babar Ali¹, S. Molinari², B. Swinyard³, L. Testi⁴, A. Abergel⁵,
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A 60–600 micron 5 band, 4–40" diffraction limited beam FWHM, photometric imaging survey with Herschel of ~ 1500 square degrees along the galactic plane, will be a very ambitious Herschel Key-Project with a promise of breakthroughs in many fields of galactic astronomy. It will also provide the community with a publicly available, homogeneous and calibrated dataset of extraordinary legacy value for decades to come. From diffuse interstellar cirrus to dense atomic and molecular clouds, from protostellar to post-AGB envelopes, from supershells to supernovae remnants, the equatorial plane of our galaxy provides the ideal laboratory to carry out investigations of the global and integrated properties of the different phases of the galactic ISM, its evolution and interactions. Further, results from the last generation of infrared observatories demonstrate that the warm and cold dust component is not only the main contributor to the overall energy budget of galaxies, but a most important and effective tracer of the structural, physical and evolutionary conditions of the material throughout the whole life-cycle of a galaxy. The Herschel satellite offers the optimum and unique combination of spectral coverage, spatial resolution, and sensitivity to efficiently survey the entire galactic plane in the far-infrared and submillimeter. Such a survey, when combined with complimentary atomic and molecular gas surveys, will provide the definitive and statistically significant measurements of the properties of both the gas and the dust component of the ISM. This dataset is uniquely capable of addressing important and fundamental issues such as: what are the timescales for cloud formation and their evolution (e.g., transition from atomic to molecular clouds)? What is the history of star formation in the Milky Way? What is the star-formation efficiency and its variation with galactocentric radius and environment? What is the life-cycle of dust, and how or why do dust properties evolve? What, if any, are the conditions for triggering star formation and what is the relative importance of sequential vs. induced star formation? What is the timeline for the formation of massive stars? What are the variations in the gas and dust ratio, and what factors govern these variations?

Structural Technology for Future Large Apertures

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The SPIRE ICC (Instrument Control Centre) is concerned with all aspects of running the SPIRE instrument on Herschel, from observational operations to cryogenic testing. We are responsible for defining the AOTs (Astronomical Observing Templates) which will be the observers' interface to the instrument, with generating the calibration files, and with writing data reduction and testing software. This poster reviews various elements of the SPIRE ICC's work, including AOT definition, the use of our QLA (Quick Look Analysis) software in testing, and the development of the data reduction pipeline and IA (Interactive Analysis) software. The SPIRE ICC is a multi-centric organization with sites at Imperial College London, Rutherford Appleton Lab (RAL) in Oxfordshire, and the Centre pour Energie Atomique (CEA) in Saclay, France.

Concept for an Origins Probe of Interstellar Magnetic Fields and Dynamics

C. Darren Dowell¹, William Langer¹, David Chuss², Richard Crutcher³,
Peter Day¹, Mark Dragovan¹, Margaret Frerking¹, Mark Heyer⁴,
Roger Hildebrand⁵, Warren Holmes¹, Martin Houde⁶,
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We describe a mission concept, recently proposed to NASA for further study, that probes the formation of stars and the life cycle of the Galaxy and nearby galaxies. The Galactic Life Cycle Observatory (GLCO) is a survey mission of two key components of galactic structure and dynamics: (1) molecular hydrogen “hidden” in clouds partially shielded from interstellar radiation, and absent in traditional surveys such as CO and HI, and (2) the magnetic field structure of neutral interstellar clouds. We cannot understand the formation of stars in galaxies, near and far, without a clear picture of the role of magnetic fields and the un-surveyed molecular hydrogen. GLCO addresses this issue with surveys of dust polarization at 50 to 200 μm , and spectrally-resolved C+ 158 μm emission, with a 1 m telescope at L2. No mission in operation or development carries out surveys in these important tracers.

The Dual Anamorphic Reflector Telescope (DART) Concepts: Recent Developments and Future Prospects

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The DART concept uses two crossed cylindrical mirrors, each formed from a stretched membrane. The concept provides the potential for ultra-light telescopes, with an areal density 10–100 times lower than that of conventional architectures which rely on massive backing structures. The DART testbed is a development project at JPL with the objective of modeling the membrane and experimentally verifying the predictions. A prototype DART telescope has been build with diffraction limited performance at 40 microns.

The Effect of Thermal Fluctuations on the Measured Detector Signal of Planck HFI

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A summary is presented of work done to model the thermal fluctuations of the Planck High Frequency Instrument (HFI) and the effect of these fluctuations on the measured detector signal of the instrument. HFI bolometric detectors must operate at 0.1 K, with their performance highly dependent on both absolute temperature and temperature stability. To achieve this, a cryogenic cooling chain is implemented incorporating active and passive elements, with each stage dependent on the previous one. The spacecraft provides passive cooling to 60 K using a series of radiators, which thermally decouple the payload from the warm service module. A sorption refrigerator cools the HFI precooling stage and the Low Frequency Instrument to 20 K and a Joule-Thomson cooler then cools the HFI to 4 K. Cooling to 0.1 K is achieved using a dilution refrigerator, with an intermediate 1.6 K stage providing radiative and conductive decoupling from the 4 K stage. The complex interactions between instruments, coolers and spacecraft mean end-to-end modeling is critical. Geometrical models of the instruments have been constructed by instrument groups and integrated with a spacecraft model to calculate radiative couplings. These have been incorporated into a detailed thermal mathematical model of the spacecraft, instruments and coolers to produce a Global Thermal Model (GTM). To provide a link between the GTM and the production of Time Ordered Data of the measured signal, a Radiative Thermal Transfer Model (RTTM) has been created to model the effect of thermal fluctuations on detector output. Using simulated sky data, outputs from the GTM have been linked to the RTTM to produce prototype data streams. These will be passed on to Planck Data Processing teams who are developing algorithms to remove the effects of the thermal fluctuations from the measured sky signal. A summary of the Global Thermal Model is shown, and an overview of the Radiative Thermal Transfer Modeling.

Optical Design and Analysis Techniques for FIR/submm Imaging and Spectrometry

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The need for wide-field imaging at diffraction-limited spatial resolution can force the design of astronomical FIR/submm instruments to grow in size beyond the requirements of a space instrument. The use of shaped elements, based on extended aspheric surfaces, can allow more degrees of freedom in compact systems with a reduced number of optical elements. The ray-tracing-based design is then complemented by targeted diffraction methods chosen on the basis of the performances to assess (in-field spatial response or out-of-field stray light rejection). Associated experimental verification of the performances during ground-testing can make use of standard intensity and beam pattern measurements for modal reconstruction and optical system-level characterization. These approaches are illustrated by examples of applications for different FIR/submm systems. Instruments are also often required to merge the imaging and spectroscopic functionalities. Review of current imaging spectrometer types show that instrument needs are in general well-addressed by imaging FTS. For medium and/or high spectral resolution, a FP-FTS cascade imaging spectrometer is presented and compared to more compact dispersed FTS design with no moving parts. Finally long-wavelength effect limiting fringe visibility and effective spectral resolution in such compact interferometric systems is briefly discussed.

SPIRE Thermal/Systems Analysis

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The SPIRE instrument will be flying onboard Herschel in 2007 along with the PACS and the HIFI instruments. SPIRE consists of five bolometer arrays, which will be cooled and controlled at 310 mK for nominal observation periods of 46 hours. To achieve such a low temperature, SPIRE will interface with four temperature stages of the Herschel cryostat nominally operating at 15, 12, 4, and 1.7 K. The final 300 mK temperature stage is provided by a He³ sorption cooler onboard SPIRE itself. This poster presents the technical aspects of the instrument thermal design and implementation. The SPIRE Focal Plane Unit (FPU) is mounted off the Herschel Optical Bench (HOB) at 12 K on isolating supports to limit the parasitic loads into the instrument. Two JFET electronic boxes also mounted off the HOB are thermally linked to the 15 K stage of the cryostat to heat sink most of their internal power dissipation during operation. The JFET electronic boxes connect to SPIRE FPU through low conductance harnesses to reduce their heat leak into the instrument. The SPIRE FPU is then thermally linked to the 4 K stage of the cryostat to heat sink most of the parasitic loads from the 12 K stage as well as additional heat dissipated by the various mechanisms mounted inside SPIRE FPU. The 300 mK detectors are fitted within internal enclosures, mounted off the SPIRE FPU on isolation supports and thermally linked to the 1.7 K stage of the cryostat. The last 300 mK temperature stage is provided by a He³ Sorption cooler mounted off the SPIRE FPU, with its cold tip connected to each detector through an arrangement of thermal straps. This cooler operates 48 hr cycle which consists of 2 hr of recycling during which the cooler He3 is being regenerated, followed by a nominal 46 hr operation period during which the detectors runs at an absolute temperature of 310 mK. A thermal control has also been implemented on the 300 mK strap to maintain the detector temperature as stable as possible. The poster also presents the thermal model of SPIRE developed to analyze and optimize the instrument thermal design. The Herschel cryostat performances are highly dependent on the loads from SPIRE. Therefore the instrument thermal model has then been integrated with the Herschel cryostat thermal model to allow the analysis of the cryostat temperature stages dynamics in conjunction with the instrument performances.

Infrared Imaging of the LMC Star Forming Region Henize 206

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Henize 206 is a region of star formation in the Large Magellanic Cloud (LMC) of the approximate scale of the Orion belt and sword. Our Spitzer Space Telescope infrared images and Cerro Tololo Inter-American Observatory (CTIO) optical images show that the region is experiencing very energetic star formation. The radiation from young stars has excited strong PAH emission throughout Henize 206, except on the side of the nebula with the prominent young supernova remnant. As is also seen in early Spitzer observations of M81, star formation rates calculated from H Alpha for Henize 206 may be biased low by extinction, compared with star formation rates calculated from far infrared emission. For one of the highest surface brightness regions of Henize 206, we obtained snapshot exposures with T-ReCS on Gemini South to explore the complex structure. A few percent of the total energy from these brightest regions in Henize 206 emanates from infrared peaks of subparsec scale. Their luminosities are equivalent to those of B stars, similar to the excitation agents in Orion. In the future, the Herschel Space Observatory should be able to detect star forming regions like He 206 out to a few Mpc and confirm the conclusions from Spitzer for a larger sample extragalactic star forming regions.

The Gradient-T SZE: A Direct Measurement of Heat Conductivity in Galaxy Clusters

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The inverse Compton scattering of the cosmic microwave background (CMB) radiation with electrons in the intracluster medium which has a temperature gradient, was examined by the third-order perturbation theory of the Compton scattering. A new type of the spectrum distortion of the CMB was found and named as gradient T Sunyaev-Zel'dovich effect (gradT SZE). The spectrum has a universal shape. There is a zero distortion point at 326 GHz. When the hotter region locates closer to an observer, the intensity becomes brighter than the CMB in the frequency region lower than 326 GHz and fainter than the CMB in the frequency region higher than 326 GHz. The amplitude of the spectrum distortion is proportional to the heat conductivity and the total temperature variation along a line of sight. Therefore, the observations of the gradT SZE by future mm and submm observations provide an opportunity of direct measurement of the heat conductivity and the thermally inequilibrium electron momentum distribution function in the ICM.

**“GISMO”: A New Flavor for SAFIR?
A Conceptual Design for a Giant (30 m) Very Cold (~ 13 K)
FIR and Submm Fresnel Space Telescope**

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We propose a 32-zone, 30 m diameter Fresnel lens 2.2 mm thick, made of Ultra-High Molecular-Weight Polyethylene (UHMW-PE), with a 3000 m focal length, for use in the (F)IR and submm bands. In an Earth-Sun L2 halo orbit, behind a 5-layer sunshade, the lens will cool to ~ 13 K in a year. At its focus a 6 m \times 3 m off-axis Ritchey-Chretien field optics system re-images the lens on a Fresnel corrector to produce an achromatic output beam. The lens performs well from ~ 700 μm down to 50, possibly 20, μm . The design is error-tolerant, so that simple deployment strategies should be possible. The Field Optical System requires only 3 mirror segments. Equipped with comparable instruments, GISMO would outperform a 10 m 4 K (segmented-mirror) telescope by $3\times$ in angular resolution and by $2\times$ to $6\times$ in sensitivity for observations at all wavelengths, except for spectroscopy at ~ 300 μm where GISMO might be up to $3\times$ less sensitive. We believe that this conceptual design (launch mass ~ 5 tons, volume ~ 4.3 m \times 3 m \times ~ 13 m) is scientifically attractive, probably cheaper and possibly less risky than the multiple-segmented, cryogenic, 10 m aperture designs being examined for SAFIR at present.

SCUBA-2: An Innovative Wide-field Submillimeter Camera for the JCMT

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SCUBA-2 is a wide-field submillimeter camera for the James Clerk Maxwell telescope. Unlike many previous instruments (such as SCUBA) which have used discrete detectors, SCUBA-2 has two monolithic arrays with a total of $\sim 10,000$ pixels. It will offer simultaneous imaging of a 50 sq-arcmin field-of-view at wavelengths of 450 and 850 microns. The absorber-coupled pixels use superconducting transition edge sensors operating at 100 mK for sky background limited performance and a SQUID time-domain multiplexer for readout. The monolithic silicon detector arrays are fabricated using silicon micromachining techniques. Once operational in 2006, SCUBA-2 will have a huge impact on the study of galaxy formation and evolution in the early Universe as well as star and planet formation in our own Galaxy. Mapping the sky 1000 times faster than SCUBA, it will can out large-area “legacy-type” surveys and act as a pathfinder for the new submillimeter interferometers such as ALMA. This paper will present an update on the current status of the project and will describe some of the technological innovations that make this unique instrument possible. The prospects for applying this technology to future missions and scaling up the array sizes still further are also discussed.

Submillimeter Imaging of Debris Dust Disks

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Studying the debris disks of cold dust around nearby stars can give vital clues about the planetary formation process. The imaging of such disks gives an effective “time series” showing how planetary systems form and evolve from their primordial disks. This paper describes submillimeter observations of debris disks using the SCUBA camera on the JCMT. Surprisingly, the observations have revealed the existence of clumps and cavities within the disks and modeling has shown that these structures are evidence of perturbations from unseen planets. Furthermore, these planets have been pin-pointed and their masses and evolutionary histories determined. The disks studied so far are comparable in size to the Solar System and hence this research provides a unique way of exploring the outer regions of extrasolar planetary systems. In addition, the paper will describe some of the modeling that our group has undertaken to aid the interpretation of the disk structure. Some very recent disk images around several nearby stars will also be presented.

SCUBA Observations of the Environments of High- z Quasars

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Over the last few years we have been engaged in a study of star-formation in the host galaxies of optically-selected quasars in the high-redshift universe. In this poster, I will present the results of a submillimeter-wave study of the environments of three quasars at $z > 5$. Using SCUBA, we obtained deep maps at 850 and 450 μm , which have revealed a number of submillimeter sources in the quasar fields. I will discuss and interpret our findings, and place them into the context of SAFIR.

Far-IR Detection Limits: Sky Confusion Due to Galactic Cirrus

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Fluctuations in the observed brightness of the background radiation can lead to confusion with real point sources. Such background emission confusion will be important for infrared observations with relatively large beam sizes since the degree of fluctuation tends to decrease with angular scale. In order to quantitatively assess the effect of this background emission on the detection of point sources for current and future far infrared observations by space-borne missions such as Spitzer, ASTRO-F, Herschel and SPICA, we have extended the Galactic emission map below the currently accessible scale to higher resolution. Using this high resolution map, we estimate the sky confusion noise due to the emission from interstellar dust clouds or cirrus, based on fluctuation analysis as well as carrying out photometry over realistically simulated images. We find that when the separation parameter is chosen to be the same value as the parameter related to the background estimation in the photometry, the confusion noise estimated by this fluctuation analysis generally agrees well with that based on realistic simulations. Though the confusion noise becomes dominant in longer wavelength bands for each space mission, the confusion due to cirrus structure is expected to be much less significant for the next generation of the space missions with larger aperture sizes (e.g. Herschel and SPICA) than that estimated from the observational data.

SIS Receiver for THz Radioastronomy

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The SIS receiver technology is a relatively new approach to the problems of the molecular spectroscopy in a far-infrared part of the electromagnetic spectrum. Until the development of the NbTiN-based SIS devices, other technologies (e.g., such as Hot Electron Bolometer or Schottky mixers) were considered as a sole competitive approach to heterodyne spectroscopy in the 1–2 THz band. We developed a 1.1–1.25 THz SIS mixer for the Herschel Space Observatory HIFI instrument. The minimum DSB SIS receiver noise is 6 hv/k, apparently for the first time in the far-infrared band. The local oscillator (LO) power used for frequency mixing is only 100 nW. The combination of a low noise and a low LO power requirement makes the SIS receiver a potential component for a space radio observatory. The developed SIS mixer has a quasi-optical design, with a double slot planar antenna and a Si hyper-hemispherical lens. The SIS junctions are Nb/AlN/NbTiN with a critical current density of about 40 KA/cm² and with a junction area of about a quarter of a micron square. For ease of the Josephson current suppression, the SIS junctions are diamond-shaped. The simultaneous suppression of the Josephson currents in the two SIS junctions is a particular advantage of the shape used. In the mixer circuit a low loss Nb/Au micro-strip transmission line is used. The achieved mixer IF band is 4–8 GHz, and it may be extended. The minimum uncorrected Double Sideband receiver noise is 550 K. The minimum receiver noise, corrected for the local oscillator beam splitter and for the cryostat window, is 330 K. This type of receiver may be useful for observations with single aperture instruments and for radio interferometers in space. We will discuss the prospect of SIS receiver use at the 1–2 THz frequencies.

The Influence of Turbulent Mixing on the Chemistry of Protoplanetary Disks

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Protoplanetary disks are known to be turbulent. The mixing caused by the motions in the disk may have an effect on the chemistry by bringing material from the cold central regions to warmer surface layers and vice versa. Here we present preliminary results from a model of the outer disk ($R > 100$ AU) which incorporates turbulent diffusive mixing in the vertical direction. We present abundance profiles of important species and discuss how mixing affects the chemical composition of the disk.

Acknowledgment. This research was performed at the Jet Propulsion Laboratory under support from NASA's Origins program.

First Results From Herschel/SPIRE Performance Tests

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The Spectral and Photometric Imaging Receiver (SPIRE) is one of three scientific instruments of the European Space Agency's Herschel mission. In February 2004 the cryogenic qualification model was pre-vibration tested and the full set of the performance tests available was exercised. The model consists of the SPIRE photometer with one of the three detector arrays fitted. This paper will present the first results from these ground tests.

Far-Infrared Emission Line Diagnostics of Galaxies

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We present ISO-LWS measurements of the three strong emission lines [OI]63 μm , [OIII]88 μm , and [CII]158 μm in a large sample of galaxies of various types. We show that simple combinations of the ratios of these lines provide an excellent diagnostic of the source of the excited and ionized gas. Even fairly rough measurements can separate quiescent disk galaxies from those harboring starbursts or Seyfert nuclei. These strong lines will thus be prime spectroscopic diagnostics for the dusty high-redshift galaxies which will be uncovered by Herschel.

Direct Imaging Detectors and Interferometers: Development Status

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Performance evaluation of superconducting direct detectors and demonstration of aperture synthesis imaging using a double input Fourier spectrometer is presented. Superconducting direct detectors using niobium tunnel junctions show superior sensitivity and high dynamic range. The detectors consist of 12-element distributed niobium junctions of about 2 micron in diameter and log-periodic antennas. Input coupling is optimized at 650 GHz and have 10% bandwidth that is tuned by the distributed junctions. Measurement of quantum efficiency and current noise gives NEPs of 1×10^{-16} W Hz² at operating temperature of less than 0.8 K and dynamic range larger than 106. The aperture synthesis interferometer consists of Martin-Puplett type interferometer with double input aperture. Spectral information as well as polarization and imaging information were successfully retrieved using a bolometric detector in submillimeter-wave. The interferometer demonstrated advantages over conventional heterodyne interferometer, such as wide frequency coverage, large dynamic range and use of high sensitivity direct detectors.

Comments. The development is made in Advanced Technology Center of NAOJ for future application to Terahertz Space Projects, such as SPECS. The presentation will be focused on the first laboratory demonstration of new detector and interferometer technology that we are applying to ground based observations in coming years, one on ASTE (Atacama Submillimeter Telescope Experiment) and another in Nobeyama Radio Observatory for SZ observations of nearby cluster of galaxies.

WaFIRS - Enabling Ultra-Sensitive, Broad-Band Spectroscopy from Space

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Recent long-wavelength observations have revealed a large population of high-redshift galaxies. The Spitzer and Herschel missions will produce catalogs of thousands of objects that are very difficult to observe optically. Yet spectroscopic capabilities in the far-infrared/submillimeter/millimeter lag behind imagers primarily because of the large optical volume or complexity required for spectrographs. The WaFIRS concept combines a curved, optimized Rowland grating and parallel-plate wave-guide confinement to significantly reduce both size and complexity versus existing spectrometer designs. An individual WaFIRS module can instantaneously cover nearly 50% bandwidth while minimizing the background noise seen by each detector. Since each module is essentially two-dimensional, many modules can be stacked to give continuous coverage in the far-infrared and submillimeter. We will present results from a millimeter-wave prototype that we are preparing for astronomical observations in the fall.

Development of Large Cooled Telescope System for the SPICA Mission

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The SPICA mission requires a large aperture mirror (3.5 m) for cryogenic use. C/SiC composite and SiC have been selected as the prime candidate materials for the SPICA telescope mirror. Several improvements in the C/SiC fabrication technology have been made and a 700 cm C/SiC mirror blank has been successfully produced. The cryogenic performance of C/SiC mirrors is being tested. The supporting structure for cryogenic use will become one of the key issues in the design.

SAFIR Mission Architecture Study Report: Passive Thermal Radiator Performance

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We are developing a parametric model of a SAFIR-class architecture which utilizes passive cooling of radiation shields, plus active heat lift from the telescope at 4 K and from the support structure at higher temperatures. Results of the study will include an understanding of the lowest temperature attainable at passive radiation shields, optimization of active heat intercept within the shield support and deployment structure, and the impact upon telescope reflector thermal performance and heat lift requirements as a function of the conductive and radiative environment which is dominated by the thermal shields performance. We will report on early results of an advanced passive thermal shield structure which is consistent with launch and deployment for a SAFIR-class instrument.

The Properties of Far-IR Sources in Deep Spitzer Fields

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We present source counts from deep Spitzer imaging, which include 50,000 sources at 24 μm to an 80% flux-density completeness limit of 60 μJy . The peak in the differential 24 μm number counts correspond to a population of fainter sources that are not expected from predictions based on 15 μm counts from ISO. We present evidence that this corresponds to a significant population of infrared-luminous galaxies at $z \sim 1-3$. Integrating the counts, we derive a lower limit on the 24 μm background intensity. Combining the observed counts with updated phenomenological models, we estimate the flux confusion limits for Spitzer at 24–160 μm , and discuss implications for future far-IR observatories.

Star and Planet Evolutionary Conditions Interferometric Exploration Spectrometer (SPECIES)

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The Star and Planet Evolutionary Conditions Interferometric Exploration Spectrometer (SPECIES) is a mission concept proposal submitted in response to NASA's Origins Theme call for mission concepts. The SPECIES mission is a free-flying interferometric array, operating in the submillimeter/far-infrared bands, using heterodyne receivers capable of very high-resolution imaging and spectroscopy. SPECIES is optimized to observe the early phases of star-formation with sufficient spatial resolution to characterize the internal structure of star- and planet-forming disks in the nearest molecular clouds.

The Wide-Field Imaging Interferometry Testbed: Developing a Powerful Technique for Future Space Based Interferometers

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We present recent results from the Wide-Field Imaging Interferometry Testbed (WIIT). Using a multi-pixel detector for spatial multiplexing, WIIT has demonstrated the ability to acquire wide-field imaging interferometry data. Specifically, these are “double Fourier” data that cover a field of view much larger than the subaperture diffraction spot size. This ability is of great import for a number of proposed missions, including the Space Infrared Interferometric Telescope (SPIRIT), the Submillimeter Probe of the Evolution of Cosmic Structure (SPECS), and the Terrestrial Planet Finder (TPF-I)/DARWIN. The recent results are discussed and analyzed, the characteristics and behavior of the testbed is discussed, and future study directions are described.

Science Drivers for the SPICA Mission: Extrasolar Planets and their Formation

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It is needless to say that the detection and characterization of extrasolar planets is one of the most important topics of any future optical-IR observatories. The SPICA is the space mission to launch a 3.5-m diameter, cooled, single-mirror telescope working at mid- and far-infrared wavelengths. Although the spatial resolutions are not high enough to resolve the planets discovered by the radial velocity measurements, the high sensitivity of the SPICA is a powerful tool to conduct imaging and spectroscopy of possible planets and companion brown dwarfs relatively away from the central star. This potential will be enhanced if a coronagraphic instrument is equipped for SPICA, which takes advantages of its non-segmented large primary mirror. Direct observations of the formation site of such planets, protoplanetary disks, also merit from such a capability. In this contribution, we will describe the SPICA coronagraph instrument and its various scientific applications for studies on extrasolar planet, brown dwarf studies, and planet formation.

Detection of D_2H^+ in the Dense Interstellar Medium

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The 692 GHz para ground-state line of D_2H^+ has been detected at the Caltech Submillimeter Observatory towards the pre-stellar core 16293E. The derived D_2H^+ abundance is comparable to that of H_2D^+ , as determined by observations of the 372 GHz line of ortho- H_2D^+ . This is an observational verification of recent theoretical predictions (*Roberts, Herbst & Millar, 2003*), developed to explain the large deuteration ratios observed in cold, high-density regions of the interstellar medium associated with low mass pre-stellar cores and protostars. This detection confirms expectations that the multiply deuterated forms of H_3^+ were missing factors of earlier models. The inclusion of D_2H^+ and D_3^+ in the models leads to predictions of higher values of the D/H ratio in the gas phase.

[a] Roberts, Helen, Herbst, Eric, and Millar, T.J., Enhanced Deuterium Fractionation in Dense Interstellar Cores Resulting from Multiply Deuterated H_3^+ , *ApJ Lett.*, **591**, L41–L44, 2003.

Space TeraHertz Observatory (STO): A Terahertz Observatory for Origins Research

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The 10-meter-class Space Terahertz Observatory (STO) has been proposed as a NASA Origins concept study and is designed to 1) conduct origin studies of planets, stars, and molecular clouds; 2) trace the life cycle of the Interstellar Medium (ISM) and star formation rate throughout the Galaxy; 3) measure the gas content of formative pre-planetary disks; and 4) observe the distribution of atomic and molecular gas in both nearby and distant galaxies. STO will achieve these goals through high spectral and angular resolution observations of C⁺, O, N⁺, HD, and H₂O lines in the far-infrared. The science goals of STO can be achieved either through a dedicated mission with an uncooled 8–10 meter primary or by implementing heterodyne instrumentation on SAFIR and extending its operational lifetime. As part of the NASA concept study, we will investigate the relative merits of these two approaches. The STO instrument concept can be used to define technological roadmaps for THz astronomy and instrument development in the coming decades. The instrument utilizes four 8 × 8 and two 4 × 4 heterodyne receiver arrays to produce a total of 288 diffraction-limited beams in the focal plane, yielding angular resolution from 1.7'' at 60 microns to 16'' at 540 microns. Each beam will produce a 2048-element spectrum with ~0.3 km/s resolution. STO science objectives are closely aligned with NASA's Origins Roadmap and drive the creation of a new generation of heterodyne array instrumentation that benefits directly from technologies developed for the Herschel HIFI instrument.

Chemical Abundance Profiles in a 2-D Planet-forming Disk

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Deuterium chemistry is a useful tool for tracing the influence of interstellar material on the composition of protoplanetary disks and for tracing the formation history of planetary bodies. Several deuterium bearing molecules have been measured in solar system materials and their deuterium enhancements derived. In addition a couple of deuterium molecules have been observed in disks (c.f. *Kessler et al.*, 2002). Here we present the results of a chemical model of a protoplanetary disk that includes deuterium chemistry. We show the calculated radial and vertical profiles and compare them to the available observations.

[a] Kessler, J.E., Qi, C., and Blake, G.A., Observations of HDO and DCN in circumstellar disks around the protostars LkCa 15, MWC 480 and HD 163296, AAS 200th Meeting, Albuquerque, NM, Session 850, #85.02, 2002.

Near Quantum-Noise Limited HEB Heterodyne Detectors and Arrays for Up to 12 THz

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The most promising heterodyne detector for future space instruments in the terahertz range beyond Herschel is the HEB mixer. We have recently demonstrated a prototype 1.6 THz three element HEB array with integrated MMIC IF amplifiers, and will present plans for extending such arrays to the higher terahertz frequencies. Such development requires a new approach for fabrication and array architecture. We will also discuss new technological solutions for the problems of antenna coupling, LO injection and MMIC integration which must be solved for the next generation of detectors/arrays. We have presented the first theoretical analysis of quantum noise in HEB mixers, and will show results which indicate that these detectors should yield system noise temperatures up to 12 THz of ten times hf/k and most likely better than this. Measurements are in progress to verify this.

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