Preliminary results from ISO: US guaranteed time projects

G. Helou

IPAC, JPL/Caltech, Pasadena, CA 91125, U.S.A.

E. E. Becklin

Dept. of Physics & Astronomy, UCLA, Los Angeles, CA 90095, U.S.A.

R. E. Stencel

Dept. of Physics & Astronomy, U. Denver, Denver, CO 80208, U.S.A.

B. J. Wilkes

SAO, Cambridge, MA 02138, U.S.A.

Abstract.

First results are reported from the four “Key Projects” carried out under the US Guaranteed Time on ISO. The Dust Debris Around Solar Mass Stars project (Becklin et al.) studies the dust disks discovered by IRAS around stars, and searches for additional examples in 150 nearby stars. It addresses the evolution of dust disks around stars with masses comparable to the Sun. The Birth and Death of Planetary Systems project (Stencel et al.) pursues the determination of the statistics of occurrence of Vega-like disk phenomena by surveying carefully selected samples. It also maps twelve bright cases of dust disk extensions, and surveys material possibly located in the Kuiper belt selected from the COBE survey. The Interstellar Medium of Normal Galaxies projects (Helou et al.) observes about 60 galaxies with infrared spectroscopy and infrared imaging, in order to derive the physical parameters of their interstellar dust, gas and radiation fields, and establish a better understanding of the galaxy-wide star formation process, its drivers and inhibitors. The Far-Infrared to X-Ray Continua of Quasars project (Wilkes et al.) surveys a representative sample of 95 quasars and active galactic nuclei at wavelengths between 5 and 200μm. The data are used to address the properties and nature of the infrared emission, compare the infrared spectrum to detailed models of quasars, in particular testing the “unified model” of quasars.

1. Introduction

The National Aeronautics and Space Administration (NASA) contributes to the Infrared Space Observatory (ISO) by providing ground tracking from the
Deep Space Network complex in Goldstone, CA. The ISO Guaranteed Time provided by the European Space Agency (ESA) in consideration of the NASA participation has been allocated by NASA peer review to four independent "Key Projects". This paper reports results to date from each of the Key Projects, which cover the areas of dust disks around stars, far infrared emission from quasars, and the interstellar medium of star forming galaxies.

2. Dust Debris around Solar Mass Stars

E. Becklin et al. are using the ISO instruments to study dusty disks discovered by IRAS around stars of F and G types. They are also searching for additional examples of such disks by surveying 150 nearby stars, and a number of nearby star clusters. The purpose of these studies is to characterize the evolution of dust debris disks around solar-type stars. The primary approach was to look for far infrared excess in the emission of the target stars, but they shifted their emphasis to mid-infrared excess searches after analyzing the first few weeks' worth of data.

3. The Birth and Death of Planetary Systems

R. Stencel et al. concentrate on a detailed study of well-known infrared-excess stars, emphasizing spatial mapping. In a recent paper (Fajardo-Acosta et al. 1996), they report imaging 60μm emission in five Vega-type systems, using the PHT-C100 3 x 3-pixel camera in the P32 over-sampled mapping mode. The maps were centered on the stars, and spanned 6' x 5'45" (RA x DEC), at a spatial sampling of 15". The maps of four of these sources (α CrB, σ Her, α CenB, and γ Oph) did not show any evidence of extended emission when compared to a model point-spread function obtained from a similar map of α Boo. However, the map of α PsA shows diffuse emission extending ~30 - 45" out from the star. The peak brightness of the extended feature above the background is ~13 MJy sr⁻¹, about a 4σ significance level.

From the map of α PsA, some physical parameters can be derived for the 60μm emitting dust. The innermost ~30" ~210 AU from the star are relatively dust-depleted. The emitting dust appears mostly between ~210 and ~560 AU from the star, with the 60μm peak located at about 320 AU. With the latter as a typical location, and a characteristic temperature of 72 K derived from IRAS colors (Backman & Paresce 1993), the observed dust grains are ~1.5μm in size. To account for the 11.9 Jy spread out across ~3.4 x 10⁻³ arcsec² in total emission, these grains would have to add up to a total mass of about 3 x 10⁻³ M☉.

4. The Far-Infrared to X-Ray Continua of Quasars

B. Wilkes et al. are surveying a representative sample of 95 quasars and active galactic nuclei (AGN) at wavelengths between 5 and 200μm. This survey addresses the properties and nature of the infrared emission, compared the infrared spectrum to detailed models of quasars, and tests the grand unified theory of AGN and quasars. In early results from this survey, Wilkes et al. measure...
a clear infrared excess in the near-IR emission of PG1543+489, a radio-quiet quasar at a redshift of 0.400, suggesting a warm dust component of emission. The spectrum turns over near $\lambda \sim 100\mu m$. In the far-infrared, the measured excess is comparable to the emission from a L* galaxy in the infrared luminosity function, suggesting a relatively normal host galaxy with the dust in a torus configuration. However, a non-thermal origin for the IR excess cannot be ruled out.

Similarly, Wilkes et al. measure a clear near-IR excess in PG1244+026 ($z=0.048$), with the turnover occurring between 25 and 60$\mu m$. In this, lower luminosity AGN, the far-infrared excess is comparable to the infrared emission from a typical spiral galaxy.

In their initial results for high redshift objects, they find one source at $z=3.03$ (Q1946+7658) whose rest-frame near-IR energy distribution is very similar to that of low-redshift ($z<0.4$) quasars and a second at $z=4.69$ (1202-0727) whose near-IR emission is $\sim 2$ orders of magnitude higher than its low-redshift counterparts.

5. The Interstellar Medium of Normal Galaxies

Helou et al. are studying the interstellar medium in star-forming galaxies, deriving the physical properties of the interstellar gas, dust and radiation field in a broad sample of "normal" disk galaxies. The purpose is to gain a better understanding of the star formation process on the scale of galaxies, identifying in particular drivers and inhibitors. The data collected include ionic and atomic fine-structure line and continuum fluxes from ISO-LWS, continuum maps at 7 and 15$\mu m$ from ISO-CAM, and spectro-photometry from 3 to 12$\mu m$ from ISO-PHT-S. The project targets about 60 distant, unresolved (at the arcminute level; LWS beam) disk galaxies spanning the full range of morphology, luminosity, IR-to-blue ratio and IRAS colors. This sample is complemented with observations of selected regions within about eight nearby galaxies such as NGC 6946, M 101 and IC 10.

Early results from this project appeared in the special ISO issue of the A&A. Malhotra et al. (1996) reported ISO-CAM observations of the nearby spiral galaxy NGC 6946, at 7" resolution and sub-MJy sr$^{-1}$ sensitivity. Images taken with CAM filters LW2 (7$\mu m$) and LW3 (15$\mu m$) reveal an exponential disk with a scale length of 75". This is 60% of the scale length in the optical R-band and about half the scale length of the radio continuum. The nuclear starburst region has a surface brightness exceeding 12–15 times that of the inner disk, itself 10–20 times brighter than the outer diffuse disk. The arms and interarm regions are clearly outlined, with each of these components contributing about equally to the disk emission. The arm-interarm contrast is a factor 2–4 in the mid-IR, close to that measured in the visible R band light and lower than the contrast in H$\alpha$, suggesting that non-ionizing radiation contributes significantly to dust heating.

Helou et al. (1996) analyzed the ISO-CAM maps of NGC 6946 for variations in the color ratio of the 7-to-15$\mu m$ emission. They find this color remarkably constant between arms and inter-arm regions, and as a function of radius in the disk, excluding the nuclear region. As surface brightness ranges by more than
an order of magnitude and the radius runs from 0.5 to 3 kpc, the color ratio remains constant to about \( \pm 20\% \). They conclude regions, that (1) hard UV radiation from OB stars does not dominate the heating of the grains radiating in the mid-infrared; and (2) surface brightness increases are primarily driven by surface-filling fraction in the disk, and then by radiation intensity increases in starburst environments such as the nucleus of NGC 6946.

Malhotra et al. (1997) report ISO-LWS measurements of the [C II] fine structure line at 157.74 \( \mu \text{m} \) in 30 normal star-forming galaxies (see also Lord et al. 1996). The ratio of the line to total far-infrared luminosity, \( L_{\text{[CII]}}/L_{\text{FIR}} \), measures the ratio of the cooling of warm gas and dust and the efficiency of the grain photoelectric heating process. This ratio varies by more than a factor of 40 in the current sample. About two-thirds of the galaxies have \( L_{\text{[CII]}}/L_{\text{FIR}} \) ratios in the narrow range of \( 2 - 7 \times 10^{-3} \). The other one-third show trends of decreasing \( L_{\text{[CII]}}/L_{\text{FIR}} \) with increasing dust temperature (measured by the 60-to-100 \( \mu\text{m} \) IRAS color ratio) and with increasing star-formation activity (measured by the ratio of far-infrared and blue band luminosity \( L_{\text{FIR}}/L_{\text{B}} \)). We also find three FIR bright galaxies which are deficient in the cooling lines from photodissociated regions (PDR): [C II] and [O I] are undetected with 3\( \sigma \) upper limits of \( L_{\text{[CII]}}/L_{\text{FIR}} < 0.5 - 2 \times 10^{-4} \).

The trend in the \( L_{\text{[CII]}}/L_{\text{FIR}} \) ratio with the temperature of dust and with star-formation activity may be due to decreased efficiency of photoelectric heating of gas at high UV radiation intensity. Dust grains in UV intense environments become positively charged, decreasing the number and mean energy of ejected photoelectrons. The three galaxies with no observed PDR lines have the highest \( L_{\text{FIR}}/L_{\text{B}} \) and \( F_{\nu}(60\mu\text{m})/F_{\nu}(100\mu\text{m}) \) ratios. Their mid-infrared and radio images place most of the emission in an unresolved nucleus. Their lack of PDR lines may be due to a continuing trend of decreasing \( L_{\text{[CII]}}/L_{\text{FIR}} \) with increasing star-formation activity and dust temperature; in that case the upper limits on \( L_{\text{[CII]}}/L_{\text{FIR}} \) imply a ratio of UV flux to gas density \( G_0/n10\text{cm}^{-3} \) (where \( G_0 \) is in the units of local average interstellar field). The low \( L_{\text{[CII]}}/L_{\text{FIR}} \) could also be due to self-absorption of the lines in the cooler outer layers of a starburst. Another possibility is that the bulk of FIR originates from warm dust in completely ionized regions such as dense HII regions or in plasma ionised by hard radiation of AGNs.

Lu et al. (1996) reported on mid-infrared spectra of star-forming galaxies from 2.5 to 5 \( \mu\text{m} \) and from 6 to 12 \( \mu\text{m} \), obtained using the PHT-S spectrometer on ISO. These spectra are dominated by the aromatic features at 6.2, 7.7, 8.6 and 11.3 \( \mu\text{m} \), with a low-level continuum contributing less than 15 to 30\% of the luminosity between 5 and 12 \( \mu\text{m} \). In spite of their diverse IR and optical properties, most of the observed galaxies show quite similar mid-IR spectra, with relatively constant ratios among the various emission features. The only exception appears to be the 11.3 \( \mu\text{m} \) feature, whose strength relative to other features decreases by a factor \( \sim 2 \) from IR-cool quiescent galaxies to IR-warm starburst-like objects. The spectra also reveal a continuum component between 3 and 5 \( \mu\text{m} \), with \( f_\nu \) constant, comparable in flux density to the continuum at 9–10 \( \mu\text{m} \), and carrying 15–30\% of the luminosity between 3 and 12 \( \mu\text{m} \). More data are needed to establish its origin, but it is most likely due to small dust particles near HII regions, heated stochastically to high temperatures by absorp-
tion of individual ultraviolet photons, as first reported by Sellgren et al. (1983). The aromatic feature at 3.3 μm, well known in Galactic sources and some external galaxies, is generally not detected in our galaxies. This is consistent with the prevailing ratio of the 3.3 μm to the longer wavelength features observed in Galactic sources (Geballe 1996; Tokunaga in this Symposium).

The dominance of these aromatic features in both the ISM of our Galaxy as well as in all extragalactic objects suggests a strategy for distinguishing the extragalactic IR background from the Milky Way foreground. The extragalactic background component results form the superposition of galaxies at many redshifts, so one would expect its spectrum to be a “smeared” version of the Milky Way cirrus spectrum, with less prominent features. A simultaneous spectral and spatial decomposition of the sky brightness would then distinguish effectively between these two diffuse components. The limiting term to the sensitivity of such an experiment in the mid-IR would be the Zodiacal light foreground, which suggests that it is best done from a spacecraft launched towards the outer Solar System (Beichman in this Symposium).

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References

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Discussion

A. Franceschini: Are the QSOs for which you showed spectra typical of the entire sample, or are they IR-excess objects?

G. Helou: These objects were pre-selected to have IRAS detections, so they are best described as IR-excess objects.

T. Hasegawa: On the three compact galaxies with unusually small [C II] line-to-continuum ratio, is it possible to think of an additional continuum-emitting component that also alters the colors of these galaxies?

G. Helou: That is a possibility. However, this component must be dust, since the continuum has the spectral signature of warm dust. Given the lack of PDR lines, this dust cannot be in PDR or in diffuse neutral media, so one is pretty much restricted to dust in an ionized medium, implying a “PDR-poor” galaxy.

T. Nakagawa: Do you see any systematic change of PAH features as a function of FIR color?

G. Helou: The only such effect we see is that the 11.3\mu m feature is relatively stronger in cooler galaxies.

T. Nakagawa: The ratio of [C II] to FIR is extremely low towards Sgr B2, similar to what you observe in the C II-deficient galaxies.

G. Helou: Yes, but in that case the [O I] line picks up the cooling of the gas, and is many times stronger than [C II], whereas in these galaxies neither of these PDR lines is detected.

T. Roellig: Is there a shift in the 7-to-15\mu m color ratio in the outer regions of N6946? Why does the image look greener there?

G. Helou: The green color is an artifact of the display. The data, though noisy in the outer parts, are consistent with a constant 7-to-15\mu m ratio out to a 3' radius.