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Infrared Astronomy Satellite (IRAS)

Peering Beyond IRAS: The 100 - 350 μm Dust Emission from Galaxies

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I. JUSTIFICATION AND RATIONALIZATION

microns

Several arguments can be made to study the continuum emission from dust in galaxies at wavelengths between the cutoff of the *IRAS* survey (about 100 μm) and the shortest wavelength that is commonly accessible from the ground (about 350 μm). Some theoretical work (see the summary by Cox and Mezger 1989) indicates that there are very cool (~~$T_d \le 25$ K~~) components to the dust emission that emit primarily at wavelengths between 100 μm and 250 μm. In fact, a significant fraction of the total luminosity, representing a large fraction of the dust mass in some types of galaxies, is emitted at long far-infrared wavelengths. In such cases, the cool dust must play a major role in regulation of the energy balance of the ISM and in shielding the cores of neutral clouds.

interstellar radiation (ISRF)

(T cold less than or equal to 25 K)

II. THE OBSERVATIONS

For four years we have been mapping the continuum dust emission from disk galaxies using the Yerkes Observatory 32-element far-infrared photometric array system onboard NASA's Kuiper Airborne Observatory (KAO). This array has a beam size of 45″ and a set of filters that isolates the emission in bands from about 60 to 250 μm.

Our program has concentrated on irregular galaxies, especially Magellanic Irregulars, and lenticulars (S0), galaxies that until very recently had been widely believed to be devoid of a significant cool interstellar medium. We are particularly interested in both types of galaxies as they are often found to be forming stars in an environment devoid of spiral structure. The S0s were also observed because these galaxies are the only abundant morphological class that has shown all major components of the ISM.

Our conclusions discussed in this summary are based on the data summarized in Table 1, as well as the 160 μm/100 μm vs. 100 μm/60 μm color-color plot in Figure 1. We have not included our results for irregular galaxies in the table as H_2 masses derived from millimeter-wave CO observations are unreliable for these metal-poor systems.

III. THE SOURCE OF THE COOL DUST EMISSION

Based on the data available at present, a straightforward explanation for the source of the continuum emission from galaxies in the 100 - 350 μm range is dust mixed within both the diffuse atomic gas ("cirrus"?), as well as within the surface layers of molecular clouds. Dust in both locations will be heated by photons from the same sources: diffuse interstellar

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radiation, augmented by light from massive stars if active star formation is widespread in the galaxy. This dust is distinct from that immediately associated with regions of active star formation or buried deep within molecular clouds. However, because it is part of a widely-distributed component of the cool ISM, these grains will intercept an important fraction of the galaxian radiation field and may interact strongly with X-ray-emitting, high-energy gas in the early-type galaxies in our sample.

Our conclusion on the location of the dust is based primarily on the very good correlation between the total 160 μm "luminosity" ($L_{160} \equiv 4\pi D^2 \nu F_\nu$) and the total derived HI mass for the galaxies presented in Table 1. In particular, we find $M(HI) = 0.34L_{160} + 6.5$, with a correlation coefficient of 0.86 for M(HI) and L_{160} in units of 10^8 $M_\odot$ and 10^8 $L_\odot$, respectively. We also derive an average $M(HI)/M_d = 750$. Our sample showed a much poorer correlation between both L_{160} vs. $M(H_2)$, with the molecular mass derived from CO observations, and between L_{160} and $M(HI) + M(H_2)$.

In contrast, for some of the same galaxies, Maloney (1987) argued that the 160 μm flux was arising from molecular material, based on a good point-to-point correspondence between the H_2 column density derived from $J = 1 \rightarrow 0$ CO observations and the long-wavelength dust emission. If, as we suggest, the cool dust is mixed with both the HI gas *and* the outer part of the molecular clouds, a correlation will be found between the 160 μm emission and whichever cool gaseous component (HI or H_2) dominates. For many disk systems, $M(H_2) \gg M(HI)$ over much of the inner radius of a galaxy, R, and a correlation will be found between the CO emission and the emission from the cool dust in surface layers of molecular clouds. However, since the gas mass increases in proportion to R^2, for the entire galaxy, $M(HI) \sim M(H_2)$ (Table 1). Correlations between *global* parameters, such as that which we report, will then show a strong relation between the sub-millimeter emission and the HI mass.

IV. COMPONENTS OF THE SUB-MILLIMETER DUST EMISSION

We suggest that emission from a minimum of two dust components is necessary to explain Figure 1 and the global spectra of galaxies between about 50 and 350 μm. Most of the emission longward of about 100 μm commonly arises from the cool dust that we describe above, while the emission over the range 50 - 100 μm includes a contribution from hotter grains, perhaps more intimately associated with HII regions. However, our color-color diagram indicates that as the average interstellar radiation field becomes more intense, as in a "starburst" system such as NGC 1569, the *cooler* dust component becomes more luminous and begins to also dominate the emission at shorter (50 - 100 μm) wavelengths. In our view, dust temperatures, T_d, derived at wavelengths longward of $\sim$ 100 μm, including, perhaps, from the 160 μm/100 μm ratio, are plausible estimates of a true dust temperature, as are estimates using wavelengths shorter than about 50 μm (see also Stark *et al.* 1989; Eales, Wynn-Williams, and Duncan 1989). However, T_d derived from emission in the $\sim$ 50 - 100 μm range are specious and are instead sensitive to the relative emission from multiple components of the dusty ISM.

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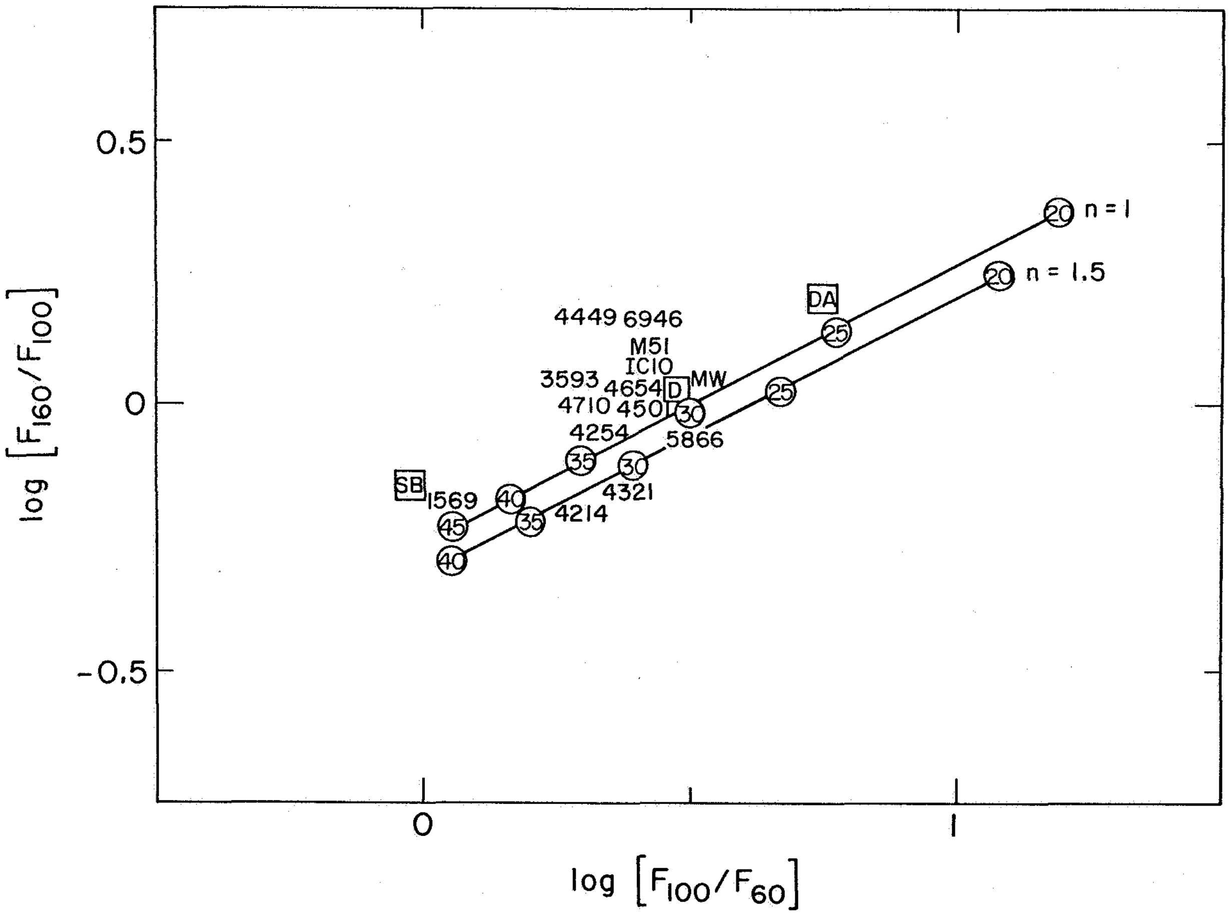
Object	Type	Dist Mpc	M(HI) 10^8 M$_\odot$	M(H_2) 10^8 M$_\odot$	M_d 10^6 M$_\odot$	L_{160} 10^8 L$_\odot$	Refs
M51	Sbc(s)	9.6	50	90	18	200	1, 2, 3
NGC 3593	S0/a	12.4	7	15	2.3	3.5	4, 5, 6
NGC 4254	Sc(s)	20	90	110	6.0	180	7, 8, 9
NGC 4321	Sc(s)	20	65	190	3.2	110	7, 8, 9
NGC 4501	Sbc(s)	20	30	180	6.1	140	7, 8, 9
NGC 4654	SBc(rs)	20	55	50	5.1	90	7, 8, 9
NGC 4710	$S0_3(9)$	20	0.28	8.8	0.5	25	10, 11
NGC 5866	$S0_3(8)$	11	$\leq$2.5	3.0	0.4	11	10, 11
NGC 6946	Sc(s)	10.1	110	120	44	300	12, 13

The 160 μm "luminosity" is defined as $L_{160} = 4\pi D^2 \nu F_\nu$, with 1 $L_\odot = 3.85 \times 10^{33}$ ergs s^{-1}. We remind the casual reader who chances upon this note that there are wide, unexplained variations in the definitions of both "luminosity" and $L_\odot$ in the literature.

References: (1) Weliachew and Gottesman 1973, (2) Young and Scoville 1983, (3) Smith 1982, (4) Hunter, Gallagher, and Rautenkranz 1982, (5) Thronson *et al.* 1989b, (6) Hunter *et al.* 1989, (7) Huchtmeier *et al.* 1983, (8) Stark *et al.* 1986, (9) Stark *et al.* 1989, (10) Kenney and Young 1988, (11) Thronson *et al.* 1990b, (12) Tacconi and Young 1986, (13) Smith, Harper, and Loewenstein 1984.



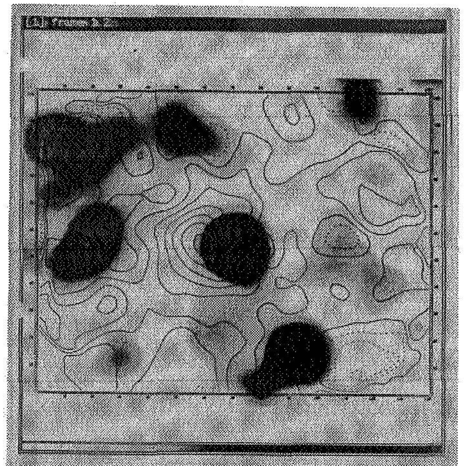


Fig. 2 b

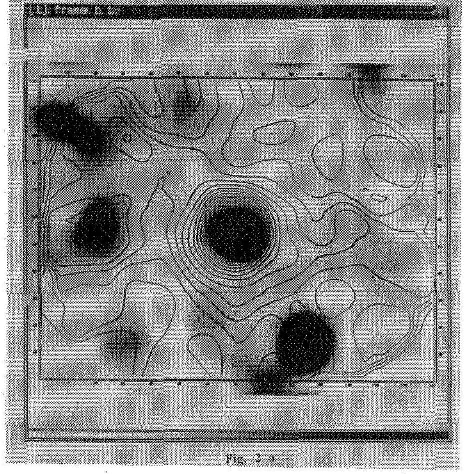


Fig. 2 a

Fig. 3 a

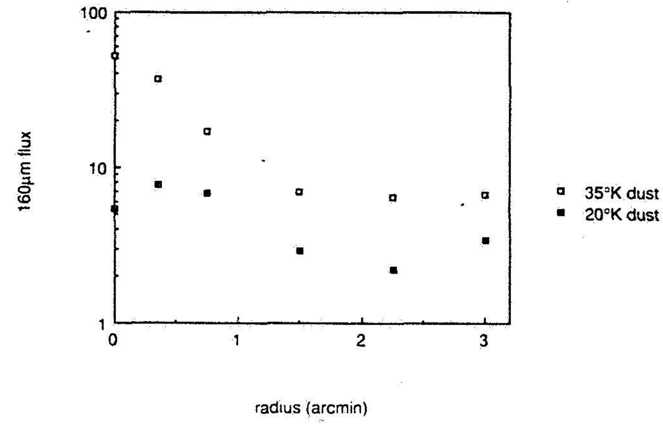
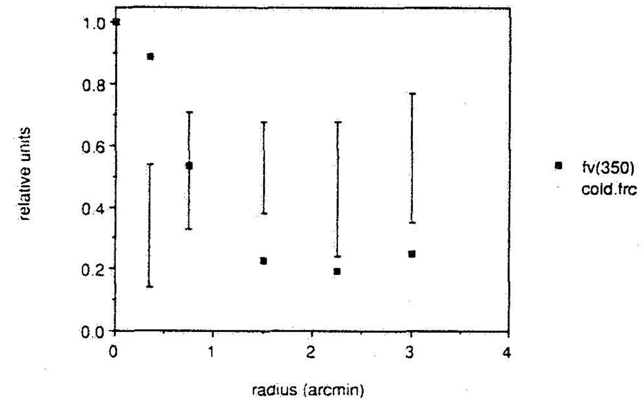


Fig. 3 b



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Yerkes Infrared

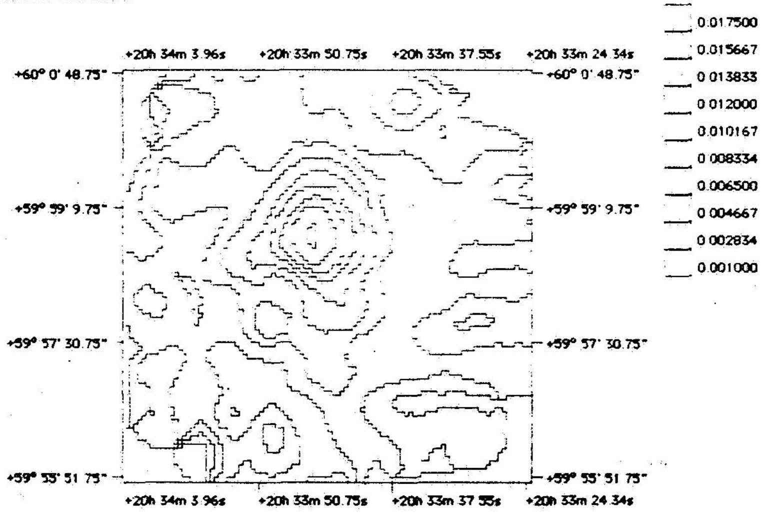

Fig. 4

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