PROTOPLANETARY MATERIAL AROUND NEARBY STARS

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ABSTRACT. A statistical analysis of IRAS observations indicates that about 20% of the nearby main sequence stars, and probably a similar fraction of main sequence stars not detectable by IRAS, shows evidence of significant infrared excess beyond 12 microns. Spectral type A dwarfs are predominant, but not exclusive in showing large 60 micron excesses. Our solar system, when viewed from sufficient distance, appears to have, in contrast to this, less than 1% of cool infrared excess. These observational facts are consistent with the working hypothesis that cold infrared excess in stable main sequence stars is due to proto-planetary material, observable during the accretion phase in the evolution of a solar system.

1. INTRODUCTION

The recent discovery of proto-planetary material in orbit about alpha Lyrae (Aumann et al. 1984), which was detected by IRAS as cold infrared excess, and the report of similar infrared excesses in three other nearby main sequence stars (Gillett et al. 1984) have raised two very interesting questions: How many other such stars are there nearby and can these observations be interpreted as indirect evidence for the existence of "other" solar systems. In the following we will address these question using two results from IRAS: Observations of stars within 25 parsec of the sun and measurements of dust emission in our solar system.

2. IRAS OBSERVATIONS OF NEARBY STARS.

The IRAS pointsource Working Survey Data Base (WSDB) contains the positions and fluxes of all sources which are fully seconds, hours and months confirmed (Neugebauer et al 1984). (This is the data base which, after final adjustments for calibration and screening for reliability, will be used to produce the IRAS point source catalog.) The WSDB contained (as of Feb. 1984) 53000 objects, which were reliably detected and confirmed at least at 12 and 25 microns. Sources within three degrees from the galactic plane were excluded from this sample to avoid difficulties with the photometry in the region of high source density. Of these stars, 335 associate by position with

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stars within 25 pc of the sun (Woolley 1979), 68 of the 335 stars were detected by IRAS at 12, 25 and 60 microns.

Figure 1. shows a plot of the 12 micron observed magnitude versus the 25 micron minus the 12 micron magnitude, i.e. the [25] - [12] color. The zero point of the IRAS magnitude system is defined as the flux from a 10000 K black body subtending a solid angle of 1.57×10^{-14} sterad. At 10 microns this definition is numerically identical to the most recent absolute calibration of the ground-based photometric system (Rieke et al. 1984). Figure 2 shows the [60] - [12] micron color versus the 12 micron magnitude. Based on detailed observations and photospheric models of standard stars (Aumann et al. 1985) we would expect the [25] -[12] and [60] - [12] micron colors of normal main sequence stars with spectral classification earlier than M to have a mean of less than 0.1 . Inspection of Figure 1. shows that the distribution of the colors of the nearby stars has non-zero mean and is scewed towards stars with cool excess. The median of the [25]-[12] color, shown has the heavy solid line in Figure 1., is -.20 magnitudes. The dispersion of the [25]-[12] micron color, based on the central 50% of the population, is 0.13, in agreement with the expected statistical scatter in the IRAS photometry. (We are using the median and an estimate of the dispersion based on the 50% of the population closest to the median. This decreases the weight of sources with large infrared excess on the estimate of the mean and sigma of the presumed dominant gaussian distributed population.) The shift of the [25]-[12] color by -.20 magnitudes is due to the use of preliminary calibration procedures in the WSDB, which will be corrected in the final survey catalog. Of the 335 sources in Figure 1, 80 show an excess of more than -.25, equivalent to about two sigma above the median. This is 24% of the sample. For a gaussian population we would have expected about 4 sources to be more than two sigma above the mean. Nine sources have more than one magnitude of excess.

In Figure 2. the [60]-[12] micron colors shows a zero shift of about -0.1 magnitudes, for the similar reasons as the [25]-[12] micron color. Of the 68 sources observed, 14 show more than one magnitude of excess above the mean. In Figure 2. the spectral classes of the giants are listed by letters B, A, F, G, K and M, the spectral class of subgiant, dwarfs and unclassified stars are given by the corresponding numbers 0 through 5. The stars with more than one magnitude of excess are, with 3 exceptions, A and F spectral type dwarfs. None are giants. There are four K-giants which have a statistically significant excess, but large excess of up to 5 magnitudes are associated exclusively with main sequence stars.

In Figures 1 and 2 the stars alpha Lyr, alpha PsA, epsilon Eri, and beta Pic which were reported by Gillett et al. (1984) are identified. Note that with the exception of beta Pic, which with a [25]-[12] color of -2.8 is offscale in Figure 1., the excess in alpha Lyr, alpha Psa and epsilon Eri is so cold that the infrared color [25]-[12] is below our 2 sigma statistically significant cutoff.

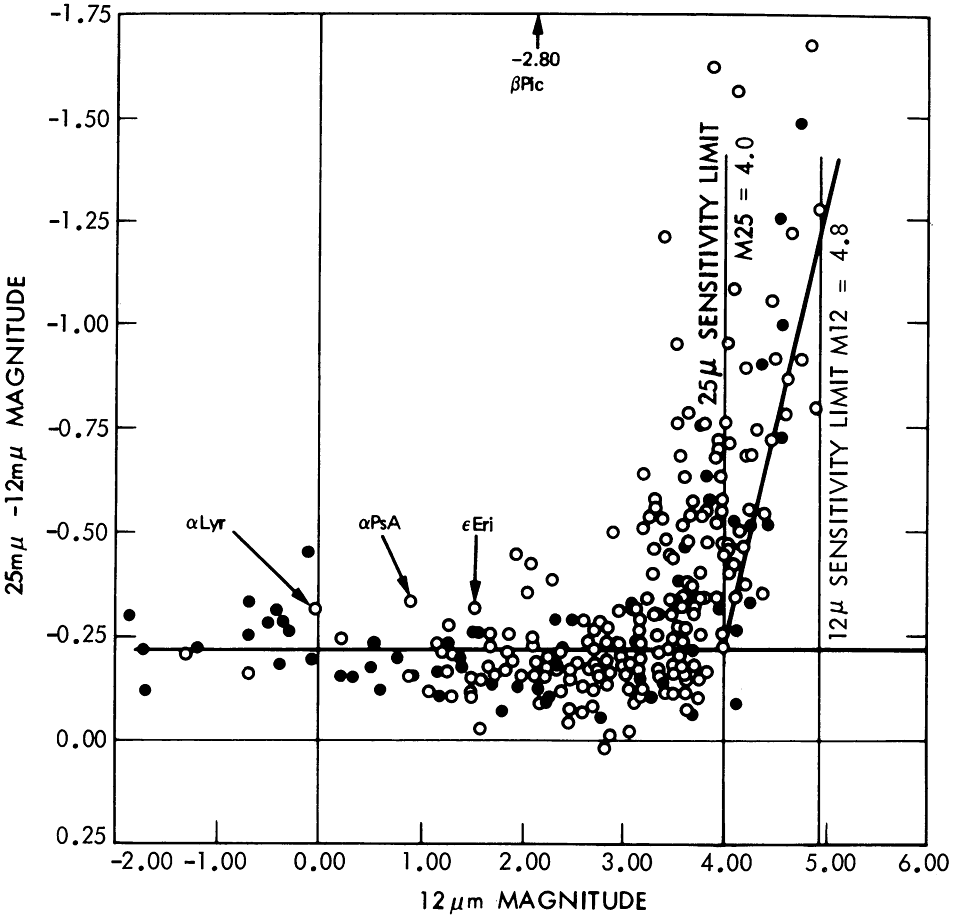

Figure 1. Observed 12 micron magnitude vers. 25 micron minus 12 micron magnitude. The absence of stars to the right of the slanted line is due to the lower IRAS sensitivity at 25 microns compared to 12 microns. Giants are shown as solid circles, subgiants and dwarfs are shown with open circles.

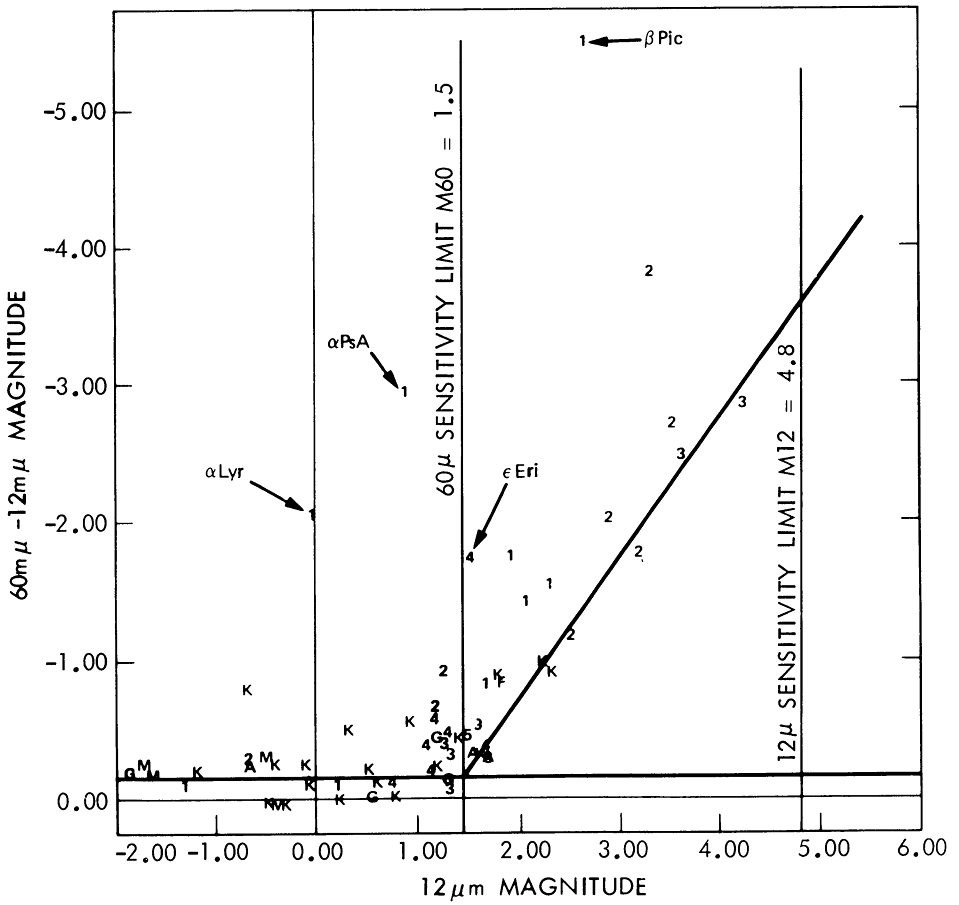

Figure 2. Observed 12 micron magnitude vers. 60 micron minus 12 micron magnitude. The absence of stars to the right of the slanted line is due to the fact that the IRAS sensitivity at 60 microns is lower than at 12 microns. The spectral classes of giants are shown with letters A through M, the spectral classes of subgiants and dwarfs are shown with the corresponding letters 1 through 5.

In order to estimate the fraction of all nearby stars with cold infrared excess, we have estimate the magnitude of an IRAS sensitivity related observational selection effect: The sensitivity of IRAS to stars decreases at the longer wavelengths. This tends to overemphasize the fraction of source with infrared excess.

The IRAS survey sensitivity cutoff for fully confirmed point sources at 12m, 25 and 60 microns is approximately at magnitude 4.8, 4.0 and 1.5, respectively. Thus, a star with magnitude +4.8 magnitudes at 12 micron will be detected at 25 microns, where the sensitivity cutoff occures at +4.0 magnitude, only if the star has more than 0.8 magnitudes of excess. At 60m, where the sensitivity cutoff is at magnitude +1.5, this effect is even more pronounced. In Figures 1. and 2. this cut-off region is to the right of the heavy slanted line. We can bound the fraction of all nearby dwarf stars with cold infrared excess, including those not observed because of the IRAS sensitivity cutoff in the following way: The fraction is less that the number of dwarfs observed with excess (69) divided by the total number of dwarfs detected at 12 and 25 microns (292), i.e. 69/292 = 24%. If we assume that none of the dwarfs which were not detected by IRAS between +4.0 and +4.8 have infrared excess, we obtain a lower limit. Using the photospheric fluxes predicted by Johnson and Wright (1983), we expect to find 550 subgiants and dwarfs to magnitude +4.8. This means that more than 69/550 = 13% show cold infrared excess of more than .25 magnitudes. Similar arguments bound the fraction of subgiants and dwarfs with more than one magnitude of excess in the [60]-[12] micron color to between 9 and 33%, with 15% the most likely number.

We conclude that about 20% of the nearby dwarf stars show a significant cool infrared excess (25 microns) and about 15% have large cold excess (60 microns) and that the large cold excesses at 60 micron are observed predominantly in A and F stars. We estimate that spectral type A dwarfs with large 60 micron excess may constitute 50% of the total nearby A dwarf population brighter than +4.0 at 12 microns. However, a detailed analysis of spectral class and luminosity class selection effects in the IRAS observation of near stars has not been completed.

3. ESTIMATE OF THE INFRARED EXCESS OF THE SOLAR SYSTEM.

The finding that a significant fraction of the nearby main sequence stars observed by IRAS shows cold infrared excess and the potential implication to models of formation of planetary systems raises the questions: Would our solar system, when viewed from sufficient distance, show infrared excess due to planets and/or dust.

We define infrared excess from a star as

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E= (observed radiance / expected photospheric radiance) – 1.

The 60 micron excess due to all the planets of our solar system, given to first order by the ratio of the projected area of all the planets times their mean effective surface temperatures to the area of the sun times its photospheric temperature, is less than 10^{-8}. A "direct" observation of the planets using IRAS is thus ruled out.

The dominant source of 12, 25 and 60 micron radiation for IRAS looking out of the solar system is due to the zodiacal dust, distributed in a thick disk approximately in the ecliptic plane (Hauser et al. 1984). From the condition of radiative equilibrium between the sun and the dust, the far-infrared excess from the dust can be expressed as

$$E < 4\ TAU\ (R_c/R_*)^{3/2} / EPS^{1/4},$$

for dust grains with optical depth TAU (as seen by IRAS looking from the inside out), with emissivity EPS, at a maximum distance of R_c from the sun. The radius of the sun is R_*. Using $TAU=3*10^{-8}$ from Hauser et al.(1984) and assuming EPS=1 and R_c=2 AU we find E<.01. In contrast to this, we find E=6.4 for alpha Lyr (Aumann et al. 1984).

We conclude that, based on our current understanding of the diffuse radiation from dust in the solar system, the solar system, as seen from sufficient distance, would exhibit insignificant excess compared to alpha Lyrae and would not be flagged as abnormal by IRAS. (Even if IRAS could measure an infrared excess of 1%, this excess could not be flagged as abnormal, because of the uncertainty in current photospheric models.)

4. DISCUSSION

From the IRAS observations we have deduced three observational facts:

1. Cold infrared excess in main sequence stars is not restricted to a few isolated spectral type A dwarfs, but is observed in a significant fraction of at least the nearby dwarfs detectable by IRAS.

2. Stars with the large cold infrared excesses at 60 microns are predominantly, but not exclusively spectral type A dwarfs.

3. The sun, a spectral type G dwarf, does not show a significant amount of infrared excess when viewed from sufficient distance to include the whole solar system.

These facts are independent of the interpretation of the nature or the source of the infrared excess. In the case of alpha Lyrae and alpha PsA we have argued that the source of the infrared excess is protoplanetary material, i.e. solid grains, in orbit about the star, which probably accreted from gas and dust residuals from the central star (Aumann et al. 1984). The key arguments for this conclusion were the following: The physical distance of the emitting region from the central star was deduced from the angular diameter of the emitting region measured by IRAS and the known distance of the stars. In addition, both stars were stable on the main sequence and there was no other mechanism to produce the observed radiation, consistent with the constraints imposed by the spatial size measurements.

The situation with the interpretation of the infrared excess in the nearby stars detected in the survey is more complicated. On one hand, spatial extent at 60 micron, similar to the one measured for alpha Lyrae and alpha PsA using special observations, cannot be resolved with survey observations. On the other hand, we have the three additional observational facts outlined above. In combination there is sufficient circumstantial evidence to argue that, at least for the stars which show strong excess at 60 microns, we are also dealing with protoplanetary material, even though a direct measurement of the spatial extent is not available. This circumstantial evidence is as follows:

1. The similarity in terms of spectral class and luminosity class. We are dealing predominantly with A dwarfs like alpha Lyrae and alpha PsA.

2. The fact that not all A dwarfs show the effect, lets us deduce a better estimate of the duration of the effect. Since an estimated 50% of the A star population show the excess, we are dealing with an effect which statistically lasts for 50% of the lifetime of a typical A star. Spectral type A dwarfs have lifetimes of between 1/20 to 1/100 of the lifetime of the sun, i.e. of 1 - 5 X 10^8 years. This means that we are dealing with an effect which lasts between 5 x 10^7 and 2 x 10^8 years. The accretion time for the major planets is of the order of 10^8 years (Safronov 1982), which happens to be consistent with the above estimate of the lifetime of the cold infrared excess.

3. The sun, when viewed from sufficient distance shows no significant infrared excess. In the case of the sun, a G dwarf with an age of 5 x 10^9 years, the bulk, if not all of the protoplanetary dust and debries which at one time may have surrounded the sun, has accreted into the planets. We should therefore not expect a significant amout of infrared excess.

The circumstantial evidence for protoplanetary material is sufficient to suggest the following working hypothesis: Cold infrared excess in stable main sequence stars is due to protoplanetary material, which, given enough time, may accrete into larger objects or may simply disperse. The result in either case would be essentially no infrared excess seen in the central star. The absence of infrared excess detectable by IRAS can therefore not be interpreted as evidence that accretion into planet size objects has taken place. A more detailed analysis correlating infrared excess, main sequence age and lifetime for A through K spectral type dwarfs to firm up this hypothesis is currently in progress.

5. CONCLUSIONS

A statistical analysis of IRAS observations indicates that about 20% of the nearby main sequence stars, and probably a similar fraction of main sequence stars not detectable by IRAS, shows evidence of significant infrared excess beyond 12 microns. Spectral type A dwarfs are predominant, but not exclusive in showing large 60 micron excesses. Our solar system, when viewed from sufficient distance, appears to have, in contrast to this, less than 1% of cool infrared excess. These observational facts are consistent with the working hypothesis that cold infrared excess in stable main sequence stars is due to proto-planetary material, observable during the accretion phase in the evolution of a solar system.

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