N87-24366

IRAS OBSERVATIONS OF AGN CANDIDATES AT LOW FLUX LEVELS

Marinus H.K. de Grijp
William C. Keel

Sterrewacht Leiden, Postbus 9513 RA LEIDEN, The Netherlands

George K. Miley

Space Telescope Science Institute, Baltimore MD 21218, U.S.A.
Affiliated to the Astrophysics Divisions, Space Science Department of ESA; on leave from Sterrewacht Leiden.

ABSTRACT. IRAS Additional Observations have been used to obtain a sample of point sources at much fainter flux levels than hitherto available through the IRAS Point Source Catalog (hereafter PSC). This sample is being used to compile an incomplete but representative catalog of faint IRAS candidate AGN's and to study the evolution of the infrared bright galaxies. Ground based follow up observations (optical spectroscopy) are mainly hampered by identification confusion.

1. INTRODUCTION

We have previously shown that IRAS colours are a remarkably efficient predictor of nuclear Seyfert activity (de Grijp et al. 1985). By investigating the properties of sources in the IRAS Point Source Catalog (PSC) which have similar "warm" IR spectra to those of known AGN's, we compiled a catalog of 563 IRAS AGN candidates. Optical spectroscopy has now been carried out on several hundred of these objects, of which 69% have Seyfert spectra, most of them previously unknown.

It is clearly of great cosmological interest to extend this study to lower flux levels. We have begun to do this by examining serendipitous sources in the IRAS Additional Observations (AOs). These AOs reach sensitivities of between ~5 and ~15 deeper than the PSC. The median redshift of 0.03, and highest of 0.9 obtained for the "strong" IR Seyferts from the PSC, extrapolate to redshifts of 0.12 and 2.0 respectively for intrinsically similar objects observed to be a factor 15 fainter. It is hoped that this will bring us into realms where cosmological evolution is important.

2. AO-GRIDS AND DATA REDUCTION

To extend our survey to weaker sources we considered all AO observations carried out in the "DPS" observational mode. Each of these observations was made using a raster scan resulting in a map of a region typically 0.5 by 1.5 degrees around an object for which deep IRAS observations were deemed desirable. In addition to the source under study, each of these fields usually contained as "bonus" a few serendipitous sources. It is these sources in which we are interested here.

Many fields were observed more than once; overlapping grids were added to

PRECEDING PAGE BLANK NOT FILMED

obtain maximum signal/noise. Up to 11 grids of the same field were added; at this level the maps started to become confusion limited. The standard IRAS source extraction program (which was originally derived from the Leiden-Westerbork image processing system) was used on the IBM 3700 computer at Leiden to extract point-source data from the 4 bands and a band merging algorithm developed by D. Gregorich was used to compile a list of sources observed in at least 2 of the 3 longest wavelength IRAS bands (25, 60 and 100 microns).These longer wavelengths are most sensitive to galaxies.

Data covering 1040 fields were considered in this study. These fields were distributed throughout the sky and comprised all available data except for fields at low galactic latitude ($|b|<20°$) where contamination by galactic sources is significant. The outer 2 arcminutes of each field was omitted from consideration because of edge effects. To minimize problems with cirrus, grids containing more than 20 sources at 100 microns were ignored.

All sources that passed the above selection criteria were flux-calibrated as described by Young et al. (1986) and manually checked for confusion and reliability; cases where the source extraction algorithm was confused by nearby sources or cirrus were omitted. Figure 2c shows a colour-colour distribution for the 900 resultant sources detected in all 3 bands.

3. COMPARISON OF PSC AND AO SOURCES

Whereas the PSC encompasses ~95% of the sky above 20° galactic latitude (~27000 square degrees), the AO grids have a total extent of ~800 square degrees. However, because the AO grids are on average ~10 times deeper than the PSC (fig. 1), both datasets include a comparable volume of space.

Fig 1: Noise statistics of AO grids

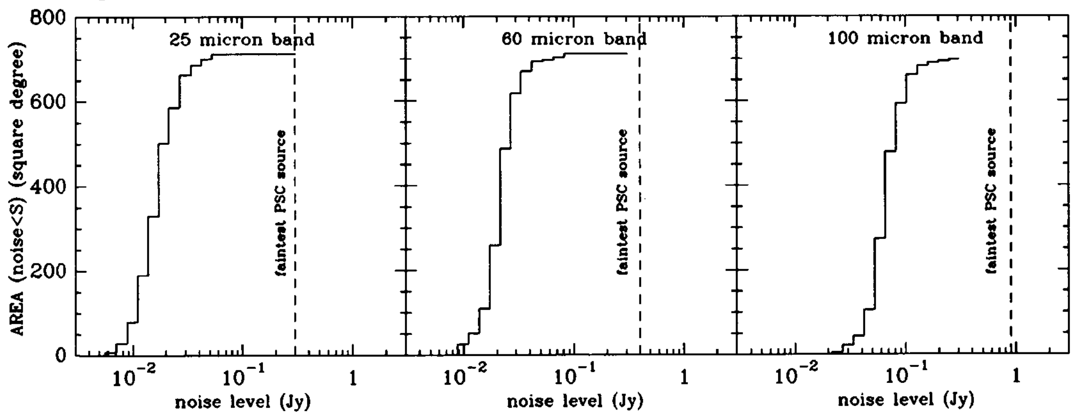

Figure 1: Each AO grid has different noise levels and size. This figure gives an overview of the total area covered at different noise levels. The lowest noise figures are reached for grids that are averages of up to 11 originals grids.

The colour-colour distribution (fig. 2a and 2c) of PSC and AO sources is virtually identical (see also next section); the major difference between them is an excess at $\alpha(25,60)=-4$, α $(60,100)= -3$. These very cold sources are probably due to cirrus.

Fig 2: Colour – colour distribution of sources

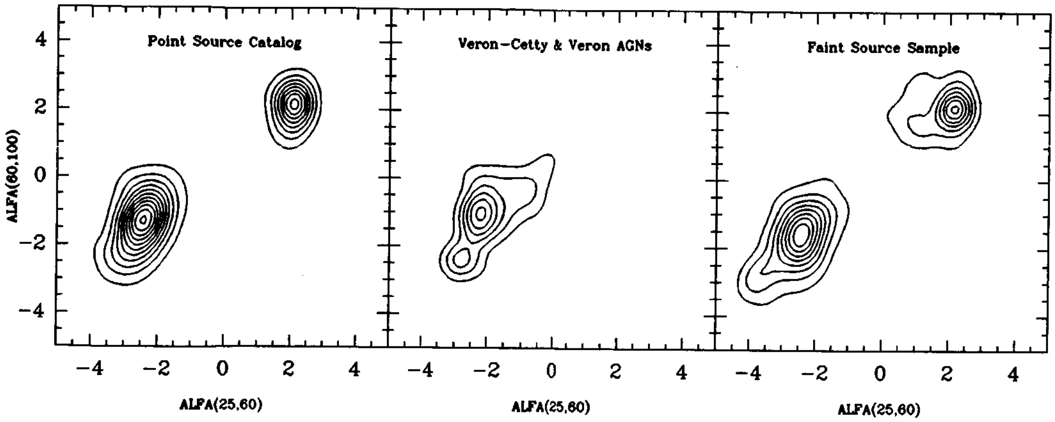

Figure 2: Source density distributions in the 25 - 60 - 100 micron colour-colour diagram. This figure shows that AGN's have flatter spectra than normal galaxies, and that faint source counts are similar to counts for bright sources. A contour representation of binned data was chosen rather than a scatter diagram to assist in a quantitative analysis of source counts. The source density units are sources per square degree per unit colour bin; the spectral index α is defined as $S_\nu \propto \nu^\alpha$. The counts in fig. 2c are weighted with a factor (flux limit P.S.C./Flux limit AO)$^{-1.5}$; so that if the counts are from a non-evolving population, they should be the same. Furthermore, the source counts are corrected to a uniform sensitivity at 60 microns; the other bands do not limit the sensitivity in this diagram.

a - Point Source Catalog sources above $|b|$=20 degrees; stars are concentrated at α(25,60)=2.0, α(60,100)=2.0 (Rayleigh-Jeans limit); galaxies cluster around α(25,60)=-2.5, α(60,100)=-1.5. The contour levels are linear increments of 0.02.

b - Point Source Catalog sources that were identified with AGN's (Veron-Cetty & Veron, 1985). Note that they extend to much flatter spectra than normal galaxies. Contour levels are linear increments of 0.001.

c - AO sources. The similarity with fig. 2a is obvious; differences are a number of stars with IR excess (probably due to mass loss), and an excess of very cold sources, which is probably due to cirrus. Contour levels are as in fig. 2a.

The galaxy counts in fig. 2a and 2c are consistent with a non-evolving population with $N \propto S^{-1.5}$

4. SOURCE COUNTS; EVOLUTION

A detailed examination of fig. 2 can be used to assess the amount of evolution as revealed in the source counts. As shall be discussed in the next section, redshifts for most of the sources under consideration are so low that K-corrections are still unimportant. Therefore it is possible to directly compare figures 2a and 2c: a spot in the colour-colour diagrams refers to sources with the same intrinsic spectral shape, but at different flux levels. Overlaying these figures reveals no significant differences between them other than an excess of very cold AO sources discussed in section 3. This comparison is not meaningful for stars, of course, since at the galactic latitudes concerned distant stars are not as numerous.

As a whole these source counts do not show evidence of evolution. In the next section we will investigate the redshifts probed, and thus the level up to which evolution does not seem to play an important role.

5. OPTICAL FOLLOWUP

Our original AGN detection criterion implemented on the PSC was based on the spectral indices between 25 and 60 microns of $-1.5<\alpha(25,60)<0.0$ (de Grijp and Miley 1986). From the AOs we have compiled a source list of more than 100 sources which have the same colours and we are simultaneously carrying out a program of follow up optical spectroscopy.

Spectra for a number of the discussed sources have been obtained at the European Southern Observatory (3.6 m telescope + EFOSC) and at Roque de los Muchachos Observatory (2.5-m Isaac Newton Telescope + faint-object spectrograph).

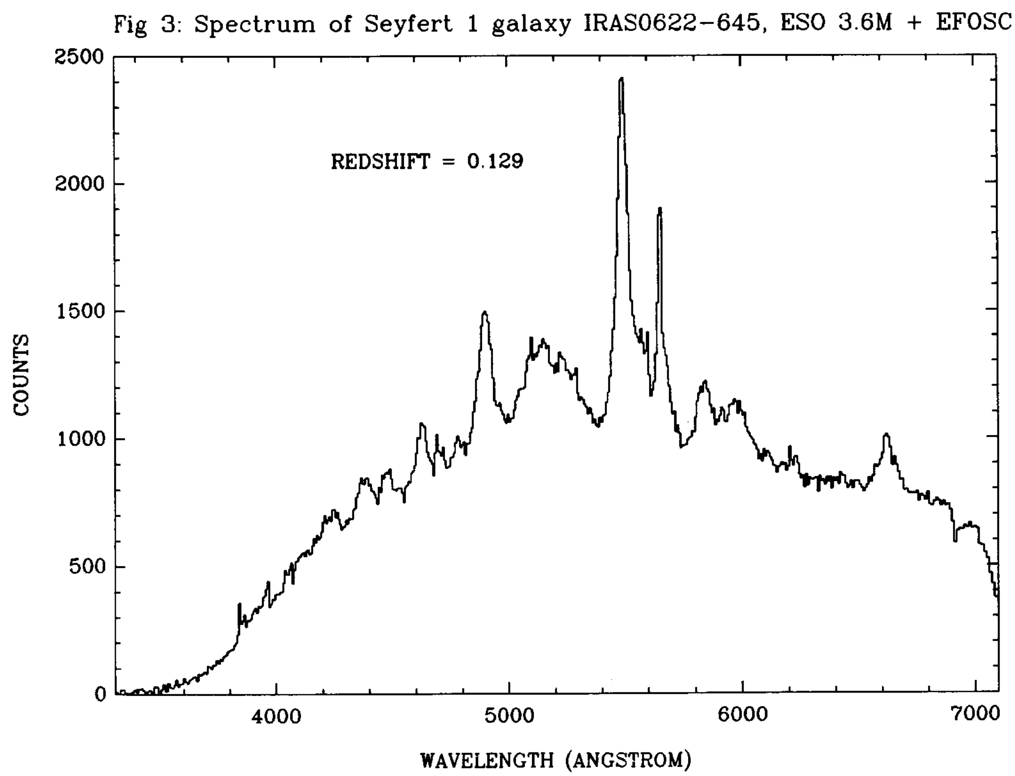

Figure 3: Spectrum of a previously unknown Seyfert 1 galaxy obtained at ESO. This elliptical galaxy was identified by taking a slitless spectrogram for a 2 x 3 arcmin field around the IRAS position. This emission line object was less than 20" from the IRAS position.

Uncertainties in the IRAS positions have so far proved to be the major difficulty in identifying optical counterparts. Since experience with the PSC showed that 90% of all objects with $-1.5<\alpha(25,60)<0.0$ are emission-line objects, this can in principle be used as a secondary identification criterion. Slitless spectroscopy with EFOSC proved to be a boon in this respect.

Although the sample observed is by no means statistically complete, the redshifts found are on average 3 times higher than for objects in the PSC, and AGNs cluster in the same part of the colour-colour diagram. As 20% of them have redshifts above z=0.2, careful selection of the sources in the deepest grids may yield a luminosity function for Seyferts at redshifts of ~0.3. Also a number of sources at redshifts of 1 to 2 can be expected.

We conclude that although uncertainties in the IRAS positions is a major limitation in identifying optical counterparts, high redshift objects obtained from the AO data may prove to be important for investigating cosmological evolution of AGNs.

6. ACKNOWLEDGEMENTS

The optical observations discussed here were carried out at the ESO observatory in Chile and at Roque de los Muchachos observatory on La Palma. We thank their staffs for support at the telescope. We thank H. van der Laan for useful discussions.

7. REFERENCES

de Grijp, M.H.K., Miley, G.K., Lub, J. and de Jong, T. 1985, Nature, 314, 240

IRAS Catalogs and Atlases, Explanatory Supplement, 1985 ed. Beichman, C.A., Neugebauer, G., Habing, H.J., Clegg, P.E. and Chester, T.J. (Washington DC: US Government Printing Office)

IRAS Point Source Catalog, 1985, Joint IRAS Science Working Group. (Washington DC: US Government Printing Office)

de Jong, T., Clegg, P.E., Soifer, B.T., Rowan Robinson, M., Habing, H.J., Houck, J.R., Aumann, H.H. and Raimond, E. 1984, Ap. J. (Letters) 278, L67

Miley, G.K., Neugebauer, G. and Soifer, B.T. 1985, Ap. J. (Letters) 293, L11

Neugebauer, G. et al. 1984, Ap. J. (Letters), 278, L1

Veron-Cetty, M.P. and Veron, P. 1985, A Catalog of Quasars and Active Nuclei (Munich: European Southern Observatory), Scientific Report No.4.

Young, E.T., Neugebauer, G., Kopan, E.L., Benson, R.D., Conrow, T.P., Rice, W.L. and Gregorich, D.T. 1986, A User's Guide to IRAS Pointed Observation Products (Washington DC: US Government Printing Office)

8. DISCUSSION

MALKAN: To find a reasonable number of AGN's you adopt quite restrictive IRAS colour criteria. Our work on an unbiased sample of Seyfert galaxies shows that you exclude about 80% of all AGN's. How, then, is it possible for you to construct a meaningful AGN luminosity function?

DE GRIJP:You are correct that we can only construct a luminosity function for AGNs whose IR spectra are consistent with our colour-criteria. This is about 70% of all Seyfert-like AGNs. Comparison with optical/UV-selected samples of AGN's (Neugebauer et al. 1984, Miley et al. 1985) shows that we miss 25-30%, mainly at the steep spectrum side of the adopted colour range. Presumably these steep spectrum AGN's are dominated by cold disk emission, in other words their nuclei are relatively faint. So we expect that a luminosity function constructed on the basis of our colour criterion might be underestimated at the low luminosity end, but essentially complete at high luminosities.

WINDHORST: You mentioned in your talk that your AO source counts do not support (cosmological) evolution. Hacking yesterday claimed from somewhat deeper 60 micron counts evidence for evolution. Do your and his counts agree in amplitude and slope?

DE GRIJP: I have not yet been able to compare Hacking's figures with mine in detail. From what I understood about his talk, it is not the source counts as such that are high, but the prediction of the number of faint sources that is low. This is because for his model Hacking used a luminosity function of Rowan Robinson that is low by a factor of 2 (Weedman, private communication) as compared to more recent results. (Editor's note: Hacking in fact used the local luminosity function of Soifer et al. (these proceedings)).

WINDHORST: What fraction of your 60 micron galaxies is at cosmological distances (z>>0.1)? Namely, if this fraction is considerable, even a Euclidean slope of -1.5 would be indicative of a non-uniform source distribution in a relativistic universe.

DE GRIJP: Some 20% have redshifts over 0.2, and a (small) number should have redshifts over 1.0 (based on extrapolation from the Point Source Catalog). So although there is a fraction of sources at high redshifts, I don't think that source counts alone will be enough to make a hard claim of evolution because of the low numbers involved.