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Final Technical report for NASA-JPL Grant NAG 5-1186 (A NASA ADP/IRAS Grant) entitled

The Search for Extended Infrared Emission near Interacting and Active Galaxies

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for the attention of Technical Officer for Grants)

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1. Final Technical Report

1.1 Introduction and Aims of Project.

This project was motivated by the remarkable data archives of the Infrared Astronomical Satellite (IRAS). The IRAS satellite made the first (and so far only) all-sky survey of the infrared sky at far infrared (FIR) wavelengths (at wavelengths of 12, 25, 60 & 100 microns). The depth of the survey, combined with the fact that the detectors made multiple passes over much of the sky (hence allowing emission features to be confirmed) led us to consider using survey data to search for faint extended extragalactic emission.

1.2 Search For Extended Far IR Emission in Tidal Filaments

The original aim of the project was to search for extended FIR emission (at 60 and 100 microns) on the scale of 5-30 arcminutes, which might be associated with a large sample of a) interacting galaxies and, b) galaxies with active galactic nuclei (AGN's such as Seyfert 1 or 2 galaxies). In the case of a), there is considerable evidence, from 21cm neutral hydrogen observations and from deep optical CCD observations for the existence of faint filament of stars and gas extending to considerable distances from galaxies. These plumes, filaments, bridges and tails are almost certainly the result of the action of tides between galaxies in the galaxy group environment. It is the low-density of gas present in these filaments, combined with evidence that star formation is occurring in them that motivated the search for FIR emission. In the case of at lease one tidally generated filament (The HI/optical plume in the Leo Triplet of galaxies ; Hughes, Appleton and Schombert 1991) a faint FIR IRAS counterpart was discovered. This motivated us to search for other examples in the hope that the infrared observations would help to unravel the mysteries of low-density star formation. Such measurements would also help to tie down the uv continuum flux from the massive stars which presumably is responsible for the heating of dusty grains leading to FIR emission.

1.3 Active Galactic Nuclei versus Extended Starbursts

A second aim of the original project was to attempt to distinguish between dust grains heated by non-thermal AGN sources (in the nuclei of active galaxies) from the normal star formation processed going on in the disk of those galaxies. This was to have principally been through the use of the Maximum Entropy Method (MEM) developed by Dr. A. Marston at Drake University (Des Moines). Dr Marston was to have been funded under a sub-contract with Iowa State University. Unfortunately, due to the fact that the project was funded at only 50% of the planned level, this aspect of the project was reluctantly removed from the final project Dr. Marston did however make MEM maps of one of our more interesting interacting galaxy fields (NGC4631 see below).

1.4 Development of a Morphological Filter ; Attempts to remove Galactic Cirrus from 100 micron IRAS Maps.

A third, but important component of our original proposal was to develop and explore a variety of relatively new image processing techniques in order to improve our chances of detecting faint emission associated with tidal plumes. This work was to have drawn on the considerable experience of Dr. J. Basart in the areas of both radio astronomy and Non-destructive Evaluation (NDE).

Because of the budget cut-backs we decided to concentrate on the development of Grey-scale Morphology and its application to the problem of foreground Galactic *"cirrus"* emission. This turned out to be one of the main thrusts of the project and the results are, we believe, extremely promising (See Section 1.2.2).

The cuts in the funding level of the project from the expected $72,000 to the $30,000 were sufficiently large that we were forced to significantly cut-back our original plans. The project became a pilot study of the galaxy groups and a limited, (but successful) development of the Morphological Image Processing Technique. A description of our progress in these two areas therefore forms the bulk of this report.

2. Achievements

2.1 The Search for Extended Emission in Galaxy Groups.

Approximately half the effort expended on this project was aimed at searching for possible Far-IR counterparts to optical or HI plumes associated with interacting or colliding galaxies. Originally, a large sample of groups or pairs of galaxies were to have been investigated, but as mentioned, the budget cut-backs forced us to make only a limited "pilot study" of a selection of extragalactic systems which exhibited large (>4 arcminute) extended structures such as tidal bridges and tails. Most of this work was carried out by P.N.Appleton and graduate student Pam M. Marcum during 1989.

2.2 A Brief Review of the Flattening Algorithm.

The technique used to search for faint emission was similar to that used by Hughes, Appleton and Schombert (1991) to explore the FIR emission in the Leo Triplet of galaxies. A significant amount of time was spent by Pam Marcum in developing a software package written in Fortran suitable for our Apollo workstation. When completed, the package was successfully run CRDD 2-d focal plane scans at 60 and 100 microns for all target fields.

The new rigorous fitting routine was applied to 2-d focal plane IRAS CRDD survey data on a scan by scan basis to reveal any extended low surface brightness features in the IRAS data. Three stages of processing are necessary. In stage 1, a 2-d polynomial surface is fitted to a particular scan as a first approximation to the background. Using the rms residual values for this very rough fits, any pixels greater than +/5 sigma were removed from the scan.(Before the scan was processed, significantly bad detector stripping was removed from the image. Typically, 3-4 bad detectors columns were removed from each scan.) In stage 2, the residual scan from stage 1 was used as an input to an iterative procedure in which a 3rd order polynomial was fitted to each scan. A bi-cubic spline routine was used to derive a fit to the residual scan. In order to remove the effects of bright sources in each scan, of the order of 8-10 iterations were usually required until the histogram of the residuals showed no significant skewness and its standard deviation converged. In stage 3, the final background subtracted scans in each of the 60 and 100 micron maps were re-gridded and co-added to form typically a 2.25 x 2.25 degree^2 field covering the region of interest. The pixel sizes of the final maps was 0.5 are 1 arcmins for the 60 and 100 micron data respectively. The typical rms noise level in the final maps (for a typical IRAS coverage of a source = 2 HCON's) was typically 0.05 to 0.07 MJy/Str at 100 microns and a factor of 2 worse at 60 microns.

2.3 The Target groups

Table 1 lists the galaxy pairs or groups that were studied. Since this was a pilot study, the selection of the objects was based on the large angular size of the optical or HI inter-galactic filament or plume. Tidally generated filaments with angular extent greater than 6-10 arcminutes were included, since they would be spatially resolvable with IRAS at 60 and 100 microns. In addition to these galaxies, a search was made for FIR counterparts to 3 extragalactic neutral hydrogen clouds which do not have obvious optical counterparts. All three clouds lie in or near galaxy groups and may be primordial clouds. More likely, the clouds have formed as a result of tidal interactions with nearby galaxies. The one exception to this is the Haynes-Giovannelli cloud (Haynes and Giovannelli 1990) which was discovered in late 1989 with the Arecibo radio telescope. This cloud, although considered a potential Protogalaxy by Haynes and Giovanelli, is almost certainly HI associated with two extremely low surface brightness dwarf galaxies. A small optical counterpart was later discovered associated with the more massive of the HI components.

Table 1

Target Objects in Deep Search For Extended FIR Emission.

Name	RA(1950)	Dec(1950)	Comments
NGC 2444/5 =Arp143	07hr 43.5m	39d 9'	30 arcmin HI plume to north.[1]
NGC4631/4656 =Arp281	12hr 39.8m	32d 49'	large HI Fingers bridge between galaxies.[2,3]
NGC4038/9 =Arp244	11hr 59.3m	-18d 35'	(The Antenna)Long HI/opt tails[4,5]
NGC4725/4747	12hr 48.1m	25d 46'	HI plumes[6]
AM0410-325	04hr 10m	-32d 30'	V.blue optical tails[7].
NGC3561A-C =Arp105	11h 8.52m	28d 59.2'	Long optical plume. Blue Knots.

(1)Appleton et al 1987a,b. (2) Weliachew et al (1978) (3) Appleton and Marcum (VLA Observations, in prep). (4) van der Hulst 1979. (5) Wevers et al 1984, (6) Schombert, Wallin & Struck-Marcell(1989).

Potential Inter-galactic HI Clouds

Name	RA(1950)	Dec(1950)	Comments
NGC4026 Group Cloud	11hr 56.8m	51d 14.4'	HI Intergalactic Cld.[1]
Leo Group Cloud			HI Clouds[2]
Haynes/Giovanelli Cld.			Large HI stucture.[3]

(1) van Driel, Davies & Appleton(1988).(2) Schneider (1986)(3) Haynes &Giovannelli (1990).

3.0 Results

The results of the deep survey of emission were summarized by Marcum et al 1990 and Marcum and Appleton (in Preparation). Figure 1a-l shows contour maps of the target regions at 60 and 100 microns wavelength, with the first contour level representing the 2.5 sigma level. A brief summary of each field is given below. Except for the special case of NGC4631, no obvious emission was detected from the extended optical or HI filaments down to the 2.5 sigma level.

In order to search for very extended components of emission associated with the galaxies, we also smoothed some of the images with a gaussian to improve the sensitivity to extended structure. In some cases this was not possible because of the result of "confusion" resulting from the detection of faint extended emission which we presumed to be Galactic *"cirrus"*.

3.1.1 NGC4725/NGC4747

This pair of galaxies is known to have considerable extended HI emission associated with both a long optical plume to the north of NGC4747 and scattered HI associated with the outer spiral arm of NGC4725 (Wevers et al 1984). The 60 and 100 micron maps of the region show significant emission from the two galaxies (Fig.1a,b) and a background galaxy to the south-west, but no obvious emission from the northern optical/HI plume (see also Figure 2a which shows the 100 micron emission superimposed on an optical image). Of note is the considerable extended structure associated with NGC4725 and its spiral arms. This preliminary study indicates that this galaxy is worthy of further study using techniques such as MEM or MCM to bring out the structure in this galaxy.

3.1.2 NGC2444/5=Arp143

The Arp143 pair of galaxy has been shown to exhibit a huge HI plume which was detected using the VLA by Appleton et al 1987a,b. The HI plume was later found to contain a faint optical counterpart near the base of the plume. Our deep IRAS images (Fig 1c,d) showed emission from the Arp143 system alone, with no hint of any IRAS counterpart to the HI plume. (See also Fig 2b showing the contour map superimposed on the optical image).

3.1.3 NGC4038/9 (The "Antenna").

Fig 2c shows the 100 micron map of the "Antenna" interacting galaxy pair.and Figs. 1e,f show the 60 and 100 micron images of a sub-image of the larger field showing very little obvious emission from the HI and optical plumes. This galaxy, along with NGC4631 does show potentially extended emission associated with the galaxy pair, but this field is heavily contaminated with foreground Galactic *"cirrus"* which makes the interpretation of the emission difficult. The larger field does however show emission associated with two other galaxies (One of them a companion galaxy, Arp 22 which lies 30 arcmins to the sw of the "Antenna".) the latter of which shows a tail of FIR emission extending back towards NGC4038/9. In addition, NGC4038/9 shows a trail of 100 micron emission extending to the north. We believe that the emission extending from Arp22 is probably foreground Galactic *"cirrus"* and that the trail to the north of NGC4038/9 is a combination of a noisy detector (the apparent emission runs along the scan direction) and further galactic *"cirrus"*.

3.1.4 AM0410-325

This large edge-on spiral galaxy show an optical tail extending to an angular distance of 8 arcmins from the galaxy. Our observations show (Fig 1g,h) that no 60 or 100 micron emission is detected from the tail down to a level of 0.16 MJy/Str. The field appears to be relatively free from Galactic *"cirrus"*. The tail is probably part of a spiral arm seen edge-on.

3.1.5 Arp105=NGC3561A-C

Arp 105 is a peculiar galaxy multiple system, one component on which appears to be in the throws of a violent merger. A long tidal stream extends from the merging pair to an angular distance of 5 arcminutes. This plume and a bright knot at the end of the plume, was shown by Schombert, Wallin and Struck-Marcell(1990) to be extremely blue, indicating considerable recent star formation. We are able to just resolve the galaxy with IRAS and again, we did not detect any extended emission in the direction of the blue knots down to the limit of observation. (Fig. 1i,j)

3.1.6 NGC4631 : A Case of an Extended Dust Halo?

One of the most interesting systems that we studied was that of the edge-on galaxy NGC4631 (See enclosed pre-print). The galaxy is known to be interacting tidally with its companion NGC4656 which lies 40 arcminutes to the South-east. NGC4631 itself subtends a large angular size. As indicated in the pre-print, this galaxy show evidence fro extended emission on a large angular scale, especially along the minor axis. If the emission is due to warm dust, our result represents a major discovery, since no galaxy yet observed with IRAS shows evidence for an extended structure of this kind. The galaxy is one of two galaxies known to have a bright extended radio continuum halo also. However, it has been drawn to our attention that NGC4631 is extremely bright at 100 microns (Its 100 micron flux is 200 Jy which is about 20x brighter than the brightest IRAS flux measured in our galaxy sample). Since the galaxy is so bright, it is possible that scattered light in the optics of the IRAS telescope could produce the appearance of a dust halo which would not be real. In order to test this possibility, we are currently (as of May 1991) conducting further tests of the IRAS point spread function using data obtained from the Rutherford-Appleton labs (UK). There is a major shortage of point sources in the IRAS data base brighter than 200 Jy which are truly unresolved at high Galactic latitudes.There are many bright point sources at low galactic latitudes but these lie in the galactic plane and suffer from the effects of "confusion" It is hoped that in the near future we should be able to evaluate the degree to which our data on NGC4631 is effected by low-level scattered light in the optics, and we plan to re-assess our results in the light of this work.

3.1.7 The Search for Emission from Intergalactic HI Clouds.

There have been many attempts over the years to find protogalaxies at both high and low red-shift. Such objects may show up as large HI clouds which have not yet formed stars. We searched for dust emission from three such candidate objects (See Table 1b). In all cases we failed to detect dust emission from the clouds presumably because any dust present is at too low a temperature to radiate significantly at IRAS wavelengths (T< 20K). Upper limits to the total dust mass are derived from our data (Appleton and Marcum , in Prep). Figs. 1k,l show an example of a deep image of the NGC4026 group. We detect most of the nearby group members but fail to detect emission from the HI cloud which is marked as the solid line in the Figure.

3.2 Morphological Image Processing; The Development of a Spatial Filter to remove Galactic *"Cirrus"* emission from IRAS maps made at a Wavelength of 100 microns.

The other main topic performed under the grant was the development of Morphological Image Processing. This work was carried out jointly between Dr. Appleton and Dr. Basart (Electrical Engineering) and EE graduate student Paul. Siqueira. Siqueira played a crucial role in the development of the technique and a large part of his MS thesis was based on his work on this project (Siqueira 1989). The development of Morphological Image Processing for this application is the first major application of the method to astronomy and involved much innovation in its use. *Morphology* has been largely overlooked by astronomers in the past although it has a large number of potentially useful applications. The development of this method has been the subject of a number of short papers (Siqueira et al. 1989; Siqueira, Appleton & Basart 1990) and a major publication, describing our results is almost complete (Appleton, Siqueira & Basart 1991).

3.2.1 The Astronomical Problem and the Method of Morphological Image Processing.

The problem faced by astronomers who wish to study extragalactic emission from warm (T=20-40K) dust in the universe is the existence of diffuse emission from our own galaxy. The discovery of faint highly extended 60 and 100 micron emission from dust associated with diffuse (*"cirrus"*) clouds was a major discovery of IRAS. However, the fact that this material extends to high galactic latitudes and appears to be ubiquitous is a significant hindrance in the study of extended FIR emission from galaxies or intergalactic dust clouds. We have already presented in the earlier section our negative results regarding our attempts to find emission from such sources. A significant problem (See for example the problem of the interpretation of the emission near NGC4038/9) is the existence of extended foreground *"cirrus"* which complicates and confuses our view of the extragalactic sky.

3.2.2 Morphological Image Processing

Siqueira, Appleton and Basart have developed and extended the technique of Morphological Images Processing (hereafter referred to as *Morphology*) in a successful attempt to characterize the emission properties of the foreground Galactic *"cirrus"* emission , especially at 100 microns. The method is outlined in detail in a variety of papers (Siqueira et al 1989; Siqueira ,Appleton and Basart 1990 ; Appleton, Siqueira & Basart, in Preparation) and therefore only a brief overview of the technique will be given here.

Our approach to the problem of *"cirrus"* is based upon the image processing techniques of Grey-scale Morphology , hereafter *Morphology*, (Haralich et al 1987; Giardina & Dougherty, 1988). *Morphology* is a method of analyzing the structural and shape dependence of sources or field objects within an image. The method allows the size and shape of a source to be explored as a function of its flux ("Growth maps"). This characteristic of our *Morphology* analysis (called "sieving" by Serra 1982) is especially useful in the case of discriminating between *"cirrus"* emission from very nearby diffuse dust clouds and very distant sources of extragalactic emission. As discussed earlier, there are reasons to believe that the organization of dust in nearby clouds would be dominated by rather different physical processes (for a given angular scale) than dust in distance galaxies. The IRAS 100 micron detectors would be sensitive to structures on very small scales, most likely dominated by processes such as viscosity and turbulence (extending from 1-100 pc), whereas extended structures which might be seen in nearby galaxies (the M81 group for example) would be sampled on large scales (of 1-100kpc.). Such scales in galaxies are often dominated by large scale density waves, bar-like structures and other large-scale phenomena, and are not likely to have the same structural characteristics as the foreground *"cirrus"*. Our analysis of the M81 group region relies on such structural differences. Our success in the case of the heavily contaminated M81 group region would appear to show that such differences actually do exist..

3.2.3 The Heavily Contaminated M81 Galaxy Group Region

Fig.3 shows a 100 micron image of the M81 group made by co-adding CRDD data for a region approximately 4x4 degree across centered on the M81 group. Considerable extended emission is present in the maps (the majority of which is well documented as galactic *"cirrus"* , since much of it is seen on deep optical plates of the region as Galactic Reflection nebulosity (Sandage 1976). In Fig 4 a-f we show the "Growth" maps of the M81 region obtained as a result of the application of the *Morphology* algorithm referred to in detail in Appleton, Siqueira & Basart (1991). The maps represent the growth of structures in the image on a steadily increasing angular scale.

We arranged a set of such maps into a 3-d cube, and by sampling down through the cube , the growth of structure in well defined *"cirrus"* regions was explored. By exploring many such vertical sections through obvious Galactic *"cirrus"* a pattern emerged which we were able to quantify as "average cirrus". Fig 5 shows the typical growth pattern of galactic cirrus derived from many such vertical sections. Once we were satisfied that we had determined a reasonable "average" growth pattern for *"cirrus"* we then subtracted this pattern from every pixel in the cube. This has the effect of removing any structure from the cube that has the characteristics of "average cirrus".

Using the mathematical properties of the cube (see paper) we were able to compress the cube back to a 2-d image of the M81 group region, with the "average cirrus" pattern removed. This image is shown in Figure 6. It is obvious that the vast majority of the cirrus emission has been removed. Only point sources and a number of interesting extended regions remain. Most of the sources left in the map are either M81 group galaxies or catalogued background galaxies. One source may be an embedded star in the galactic cirrus. We note that extended emission is found associated with M81 (spiral arm) and M82. This extended emission was NOT removed from the map because it did not conform to the pattern of growth found for the *"cirrus"*. The emission from M82 may not be truly extended emission, since the extended structure around the galaxy may be the result of scattered light in the optics of the telescope producing extended flux around the galaxy. However, the fact that the method has left this emission in the map is impressive, since the region was extremely contaminated with extended emission on many scales in the original map. We consider this experiment with *Morphology* extremely encouraging since the majority of the foreground emission has been removed successfully, without removing the extended emission associated with the M81 group galaxies.

3.2.4 Limitations of Grey-Scale Morphology

a) The Morphology filter will remove any astrophysical structure with growth properties similar to "average cirrus".

The method of *Morphology* is limited to removing structure based on its shape and growth characteristics. As such, it is a powerful technique if the structure of the desired object is well defined. In our case, it seems that the growth pattern of *"cirrus"* is on average surprisingly well defined and is therefore easily removed from IRAS images. However, it is also possible that some extragalactic structure could, in principal, contain similar patterns to the nearby *"cirrus"*. For example, a galaxy could contain a dust halo with structure on the scales of 1-10 kpc which might look quite similar to a nearby *"cirrus"* cloud. If extragalactic emission is found with a similar growth pattern to nearby *"cirrus"* it will be removed from the map. (We stress that this is not really a problem with the technique as such, but merely a statement that the two kinds of emission are truly indistinguishable on the grounds of structure alone.). We have not attempted to include spectral (i.e. wavelength) information in our *"cirrus"* filter. The inclusion of growth patterns for different IRAS wavebands (hence including some information about the variation of spectral scale with temperature) would be an obvious extension of the method and may lead to the development of a more powerful filter of galactic *"cirrus"*.

b) Our technique suffers from a problem associated with "saddle points" between two bright, but overlapping sources.

Such points can in principal show concave structure in the image plane. Our *Morphology* filter is built-up assuming that all sources are convex and the gaussian "structuring element" is not sensitive to concave structures. Any such regions in a map are therefore incorrectly left in the final "filtered" map. In Fig.6 we identify two faint such areas which are not "real" sources, but are saddle points between two bright regions of *"cirrus"*. We are experimenting with an application of *Morphology* in which we also remove "saddle points" from the image by "Erosion". Our first attempts at this were partly successful, although they could be significantly improved. This goes beyond the scope of the current report.

4. Conclusions

Both major goals of the project have been successfully met, namely a pilot study of extended Far-IR emission from tidally generated filaments, bridges and tails and the development of a spatial filter to remove Galactic *"cirrus"* from IRAS images. We have searched, through our deep imaging technique, 9 nearby groups of galaxies for extended Far-IR emission associated with regions of low density star formation in tidal plumes or HI structures at wavelengths of 60 and 100 microns. In all cases (with the exception of NGC4631) no emission was found down to very low levels of significance. Our results suggest that either little dust has been created in these regions or that the dust is not warm enough to be detected by IRAS.

(T< 20K). Similarly, no dust emission was detected from three intergalactic clouds which are seen only through there neutral hydrogen radio emission. Our upper limits represent the best that can be done with IRAS data for extended structures. These groups would be ideal targets for the SIRTF telescope in the late 1990's.

We have also made significant advances in the design of a spatial filter to remove Galactic *"cirrus"* emission from IRAS maps of extragalactic fields. This emission significantly hampers the detection of extended Far-IR emission from galaxies. Our technique, which has potentially very wide astrophysical applications, was shown to successfully remove *"cirrus"* from the heavily contaminated M81 Group region. The resultant "filtered" image shows extended emission associated with both M81 and M82 as well as many background point sources associated with galaxies. Further work will be required to refine the technique which is beyond the scope of the current project.

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6. Figure Captions

Fig.1a-l Contour maps of the 60 and 100 micron IRAS emission from various target fields.
Fig.1a-b NGC4725 Field
Fig.1c-d Arp143 Field
Fig.1e-f NGC4038/9 ("The Antenna")
Fig.1g-h AM0410-325
Fig.1i-j Arp105 System
Fig.1k-l NGC4026 Inter-galactic Cloud

Fig.2a 100 micron contours superimposed over the optical image of the NGC4725/4747 region. Note the lack of emission from the northern plume associated with NGC4747.
Fig.2b. 100 micron emission from Arp143. No evidence is seen for a FIR counterpart to the HI plume which extends to large distances to the north.
Fig.2c. 100 micron contours superimposed on the optical image of the antenna system.
Fig. 3 100 micron contour of the M81 group regions including extensive foreground "galactic" cirrus. This image is the input image to the "Morphology" process described in the text.
Fig. 4a-e. Successive output "difference" images from the Morphology process. Each image represents the growth of flux within the input map (Fig. 3) on successively increasing angular scales. Note how the galaxies show different growth characteristics from the "cirrus" regions. Each of these maps are stacked to produce a 3-d cube of the growth in the input map. associated with Galactic "cirrus".
Fig.5 The result of averaging many different "vertical" sections through the Morphology cube. This function is then used to effectively remove cirrus from the cube.
Fig. 6 The final result of having filtered out the "average" cirrus on morphological grounds alone. Note that *EXTENDED EXTRAGALACTIC* emission has *NOT* been removed from the map. (associated with M81 and M82).

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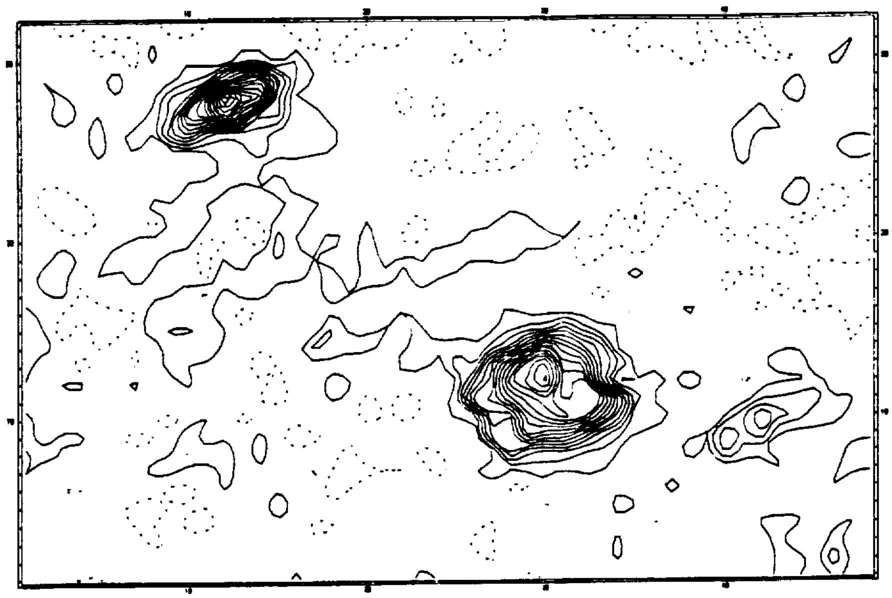

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Fig 1a

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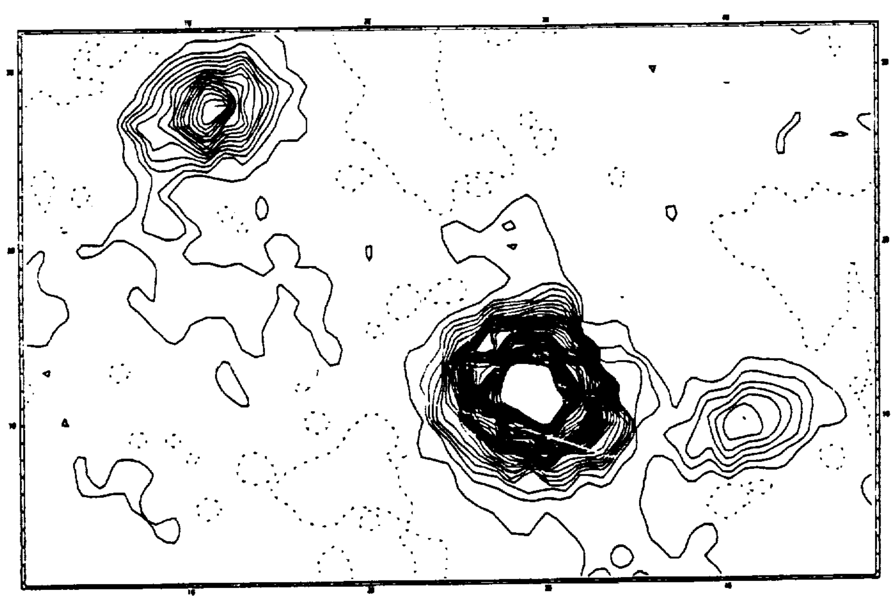

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Fig 1b

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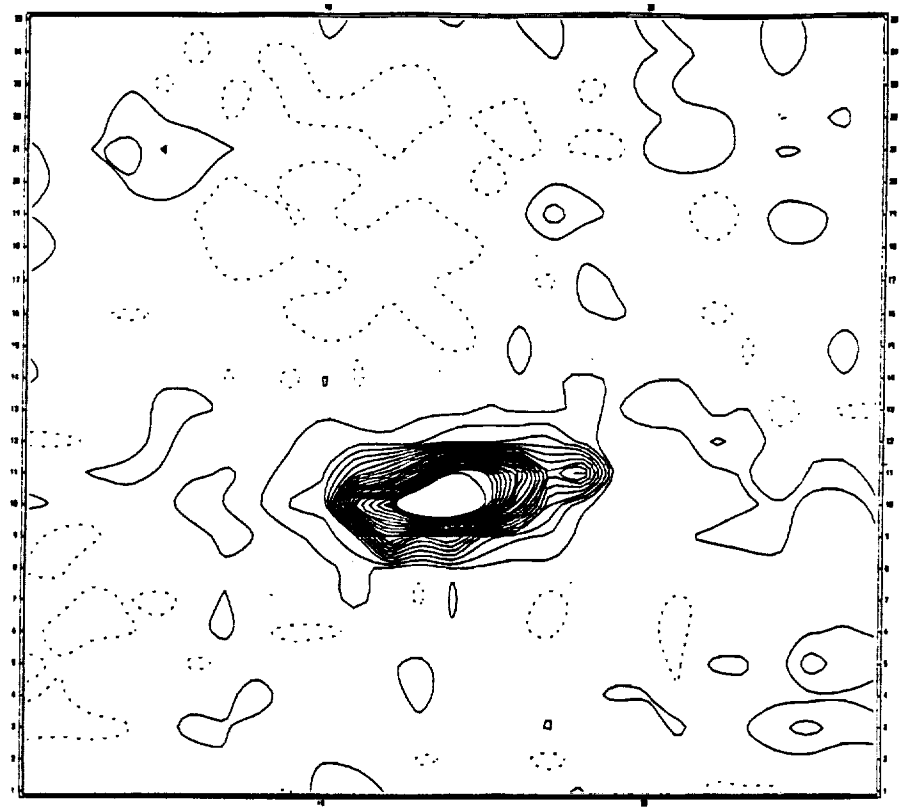

Fig 1c

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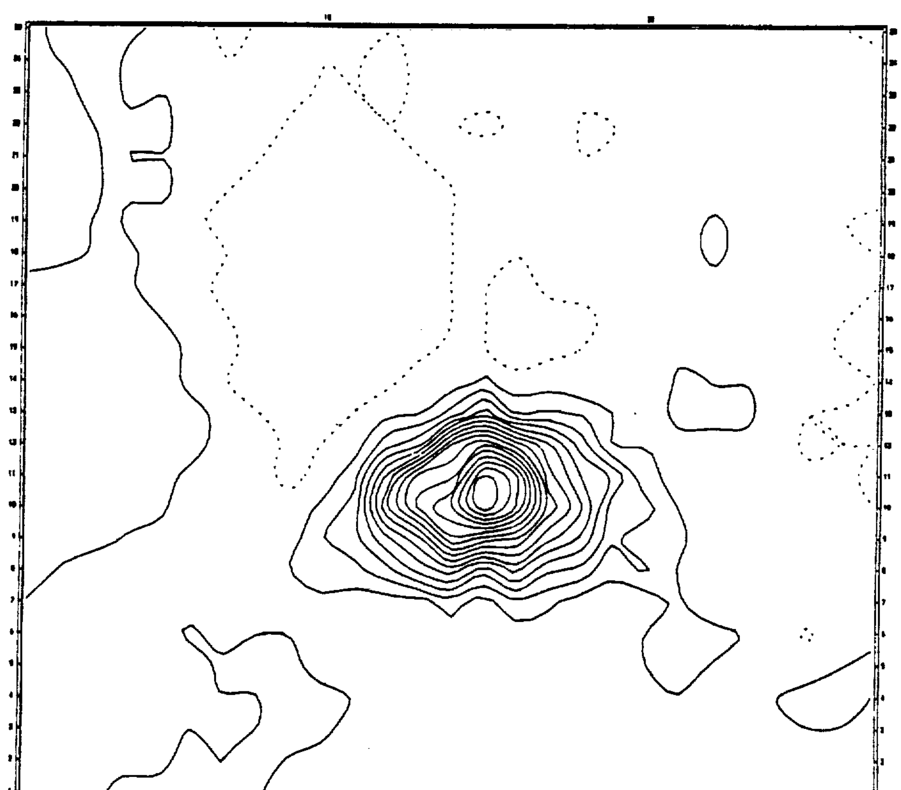

Fig 1d

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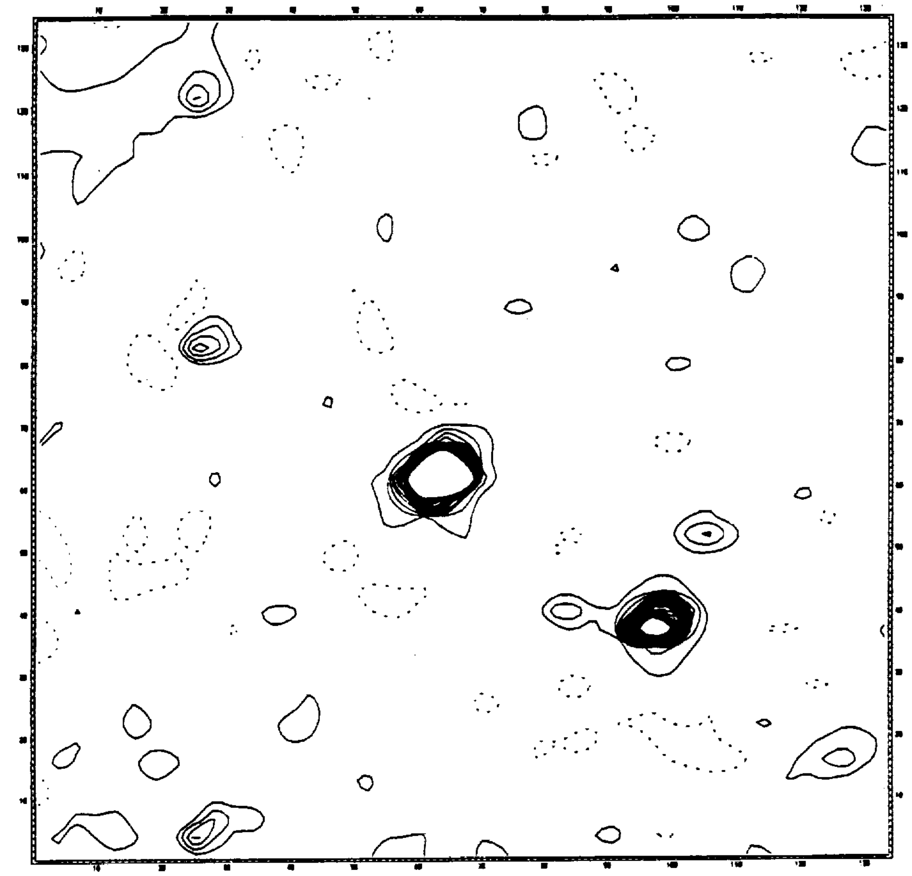

Fig 1e

contoured from -250000. to 9750000., interval = 500000., labels scaled by 1.000000E-4
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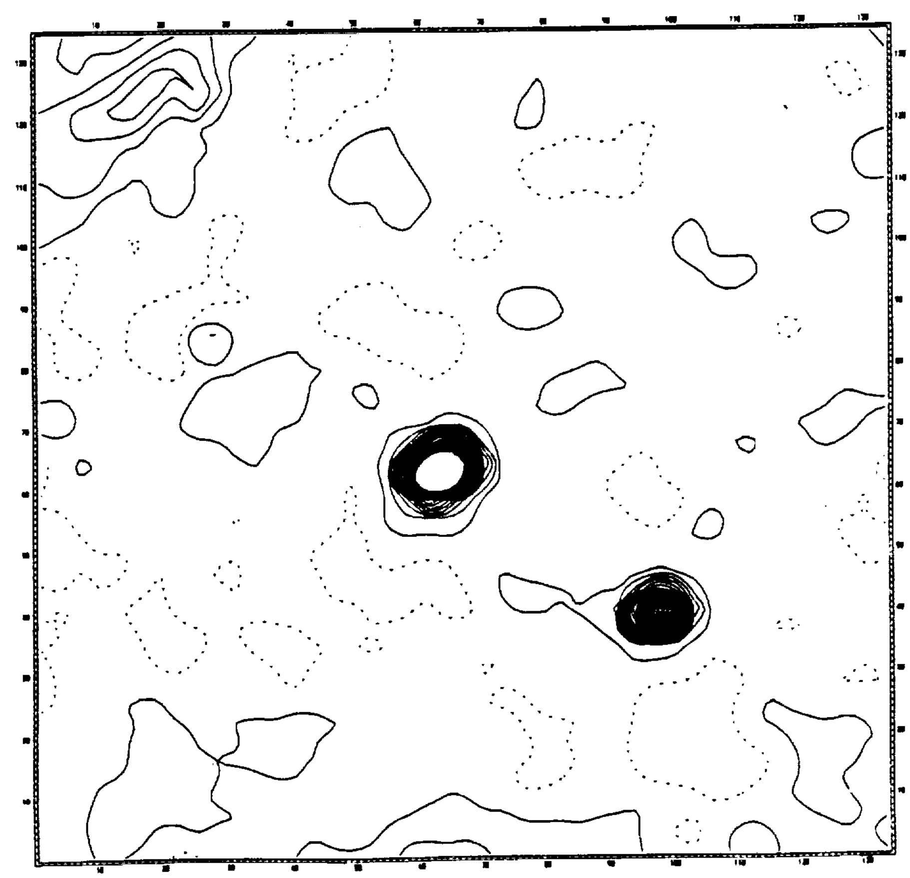

Fig 1f

contoured from -120000. to 9240000., interval = 240000., labels scaled by 1.000000E-4
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a105b3.ı . SS 0

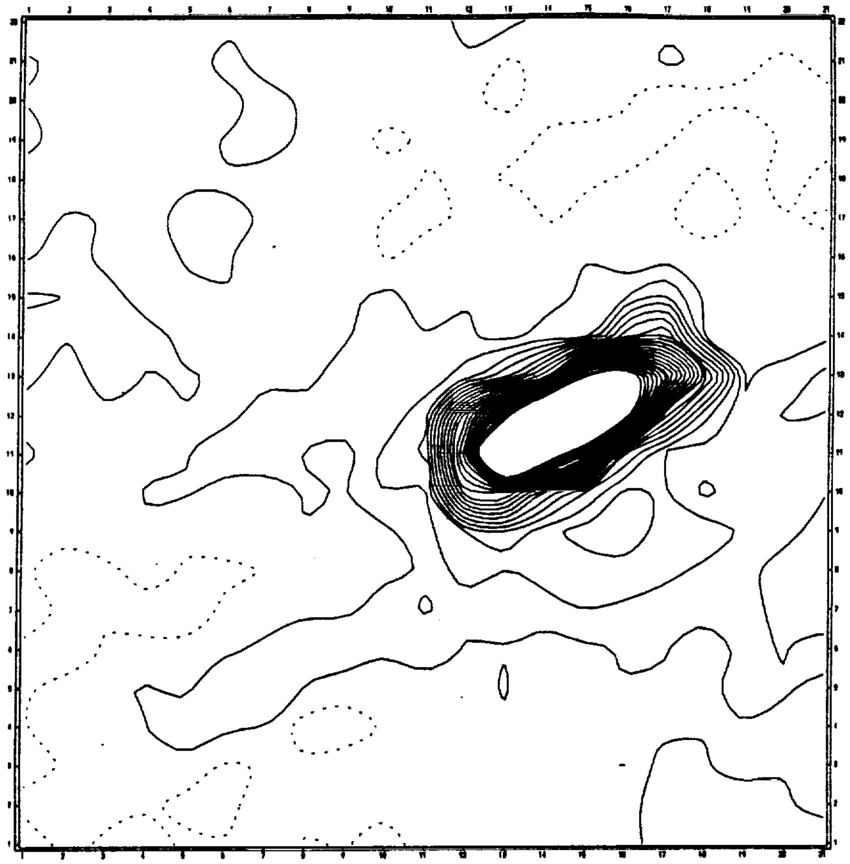

Fig 1g

contoured from -210000. to 9870000., interval = 420000., labels scaled by 1.000000E-4
NOAO/IRAF V2.9EXPORT iraf@astro Sat 17:06:18 27-Apr-91

Fig 1j

a105b4.. ı SS 0

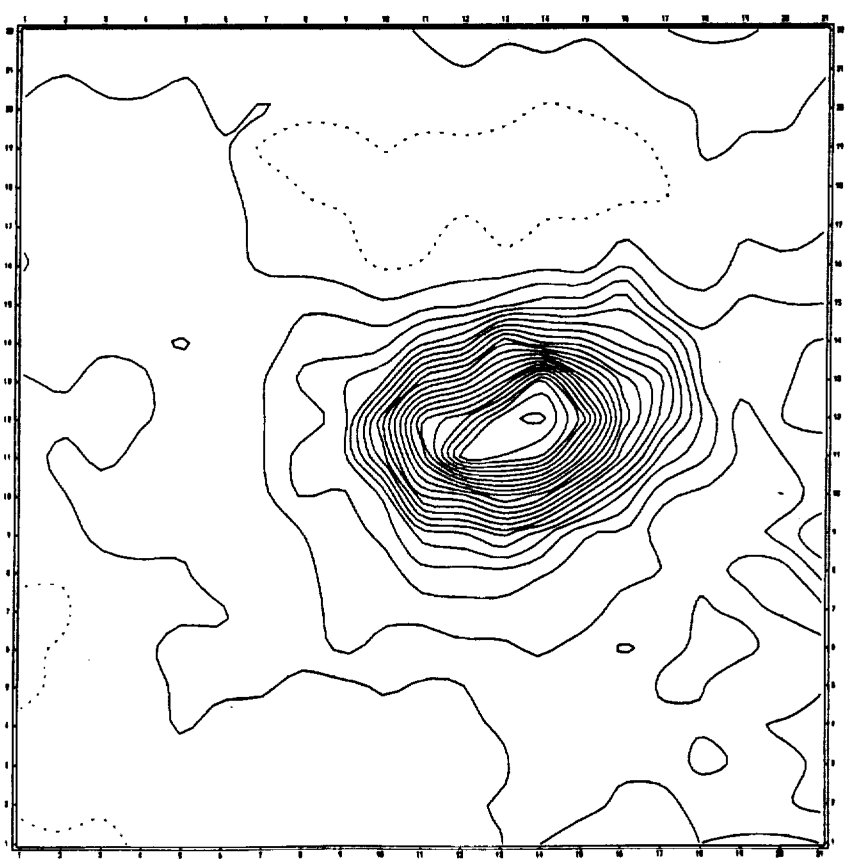

Fig 1h

contoured from -81000. to 6237000., interval = 162000., labels scaled by 1.000000E-4
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a0410b3. : SS 0

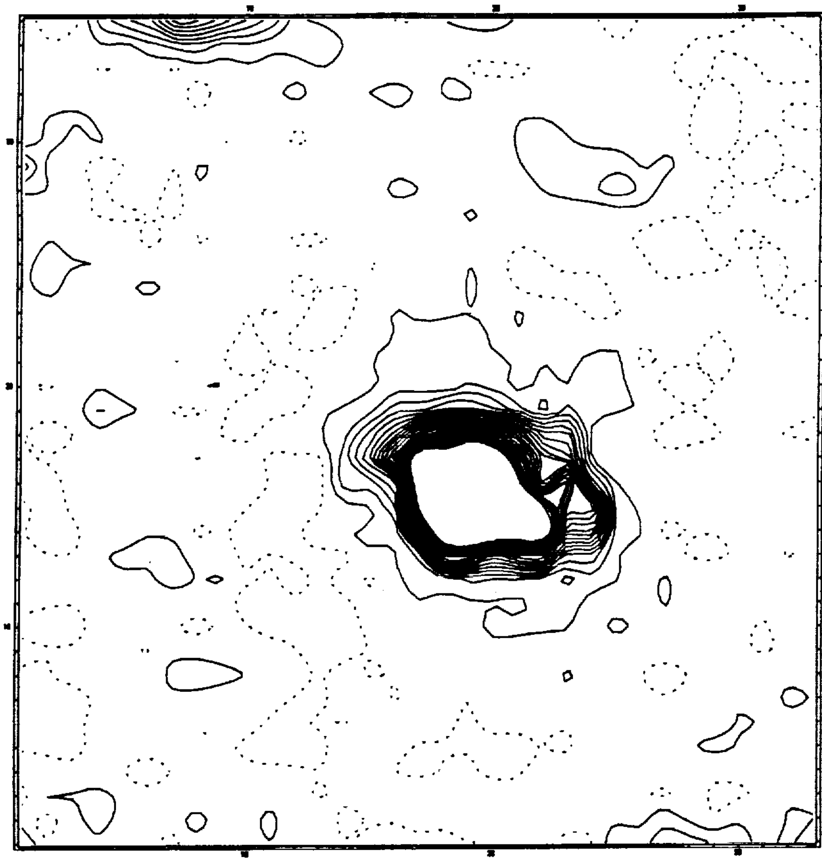

Fig 1j

a0410b4. : SS 0

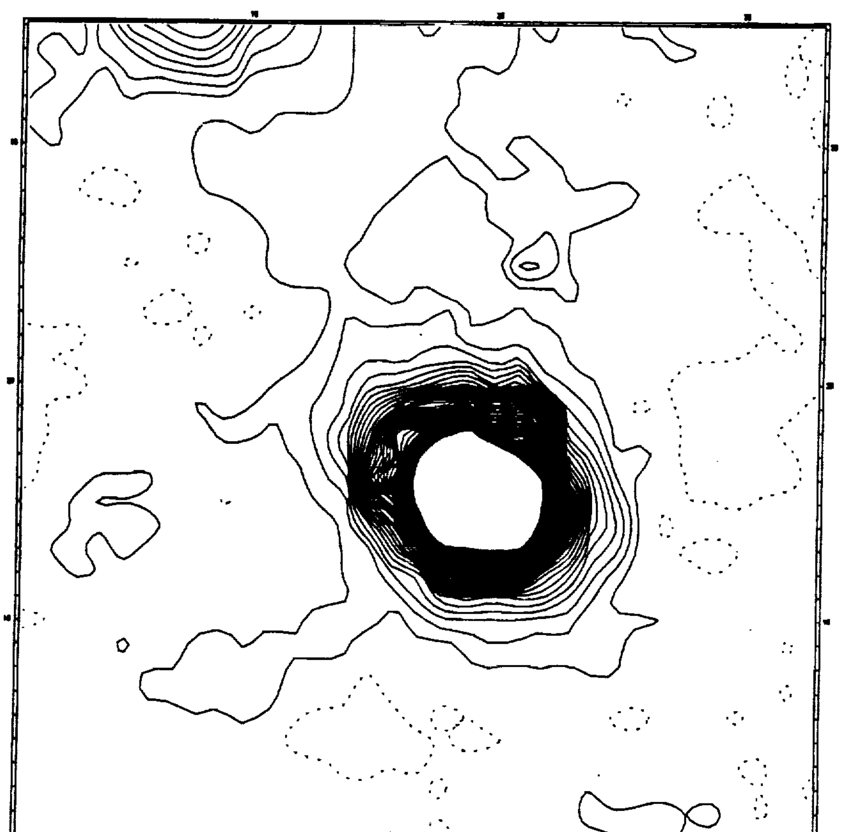

Fig 1k

contoured from -81000. to 6237000., interval = 162000., labels scaled by 1.000000E-4
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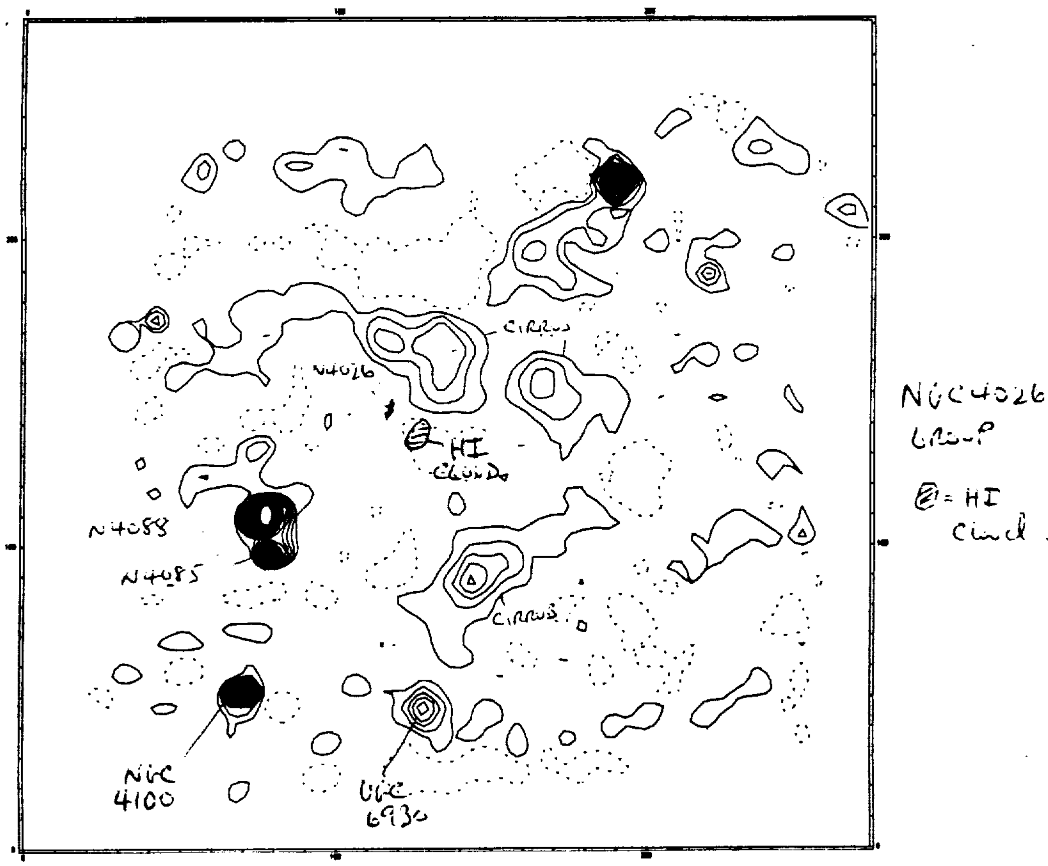
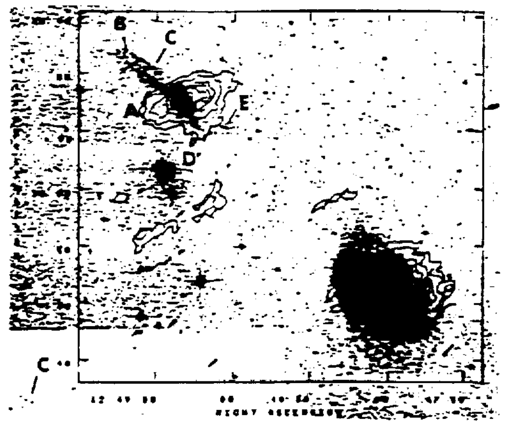
n4026b SS 0

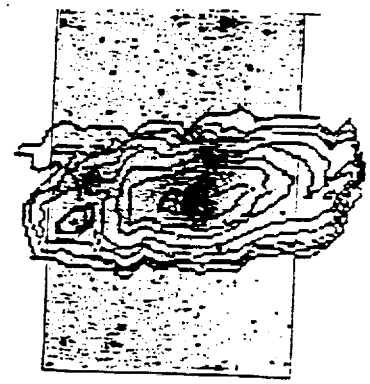


contoured from -110000. to 8470000., interval = 220000., labels scaled by 1.000000E-4
NOAO/IRAF V2.9EXPORT iraf@astro Fri 15:06:26 26-Apr-91

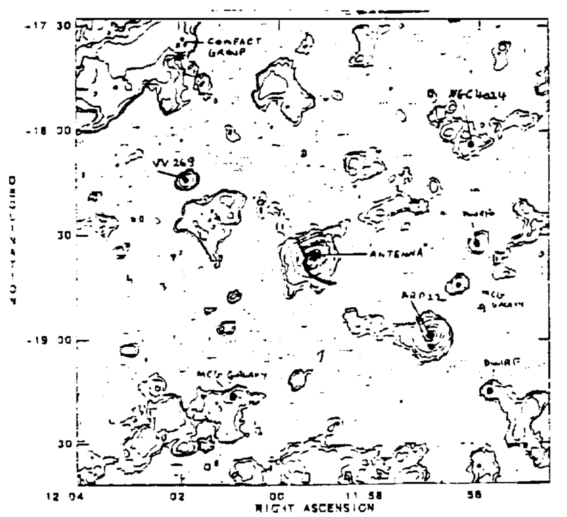
Fig 1b



N 4725 FIG 2a



ARP 143
Fig 2b



Levels x 10⁻¹ MegaJy/Sr
-2, 2, 3, 5, 10, 50, 100, 200, 500

100μm

"ANTENNA"

Fig 2c

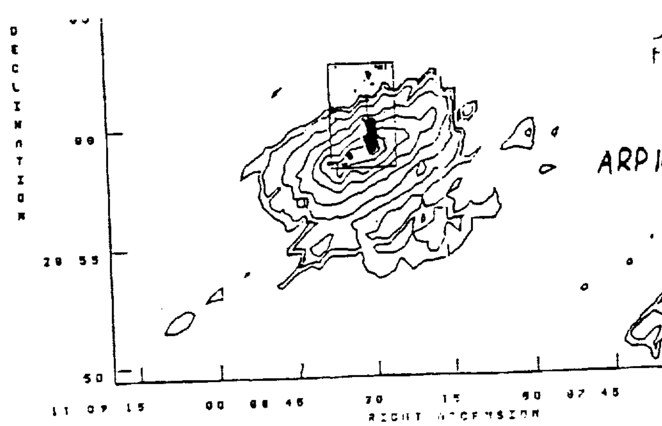
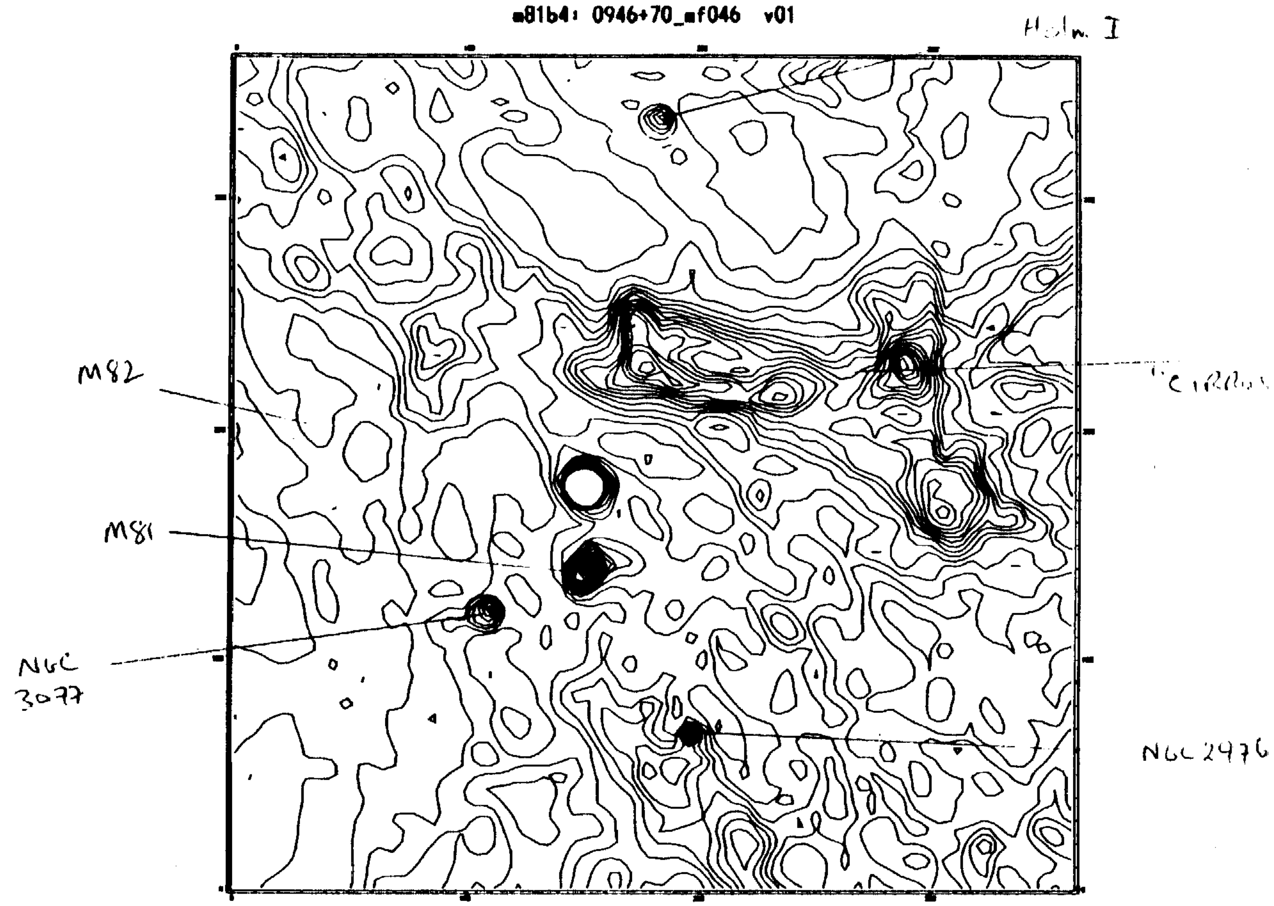


Fig 2d

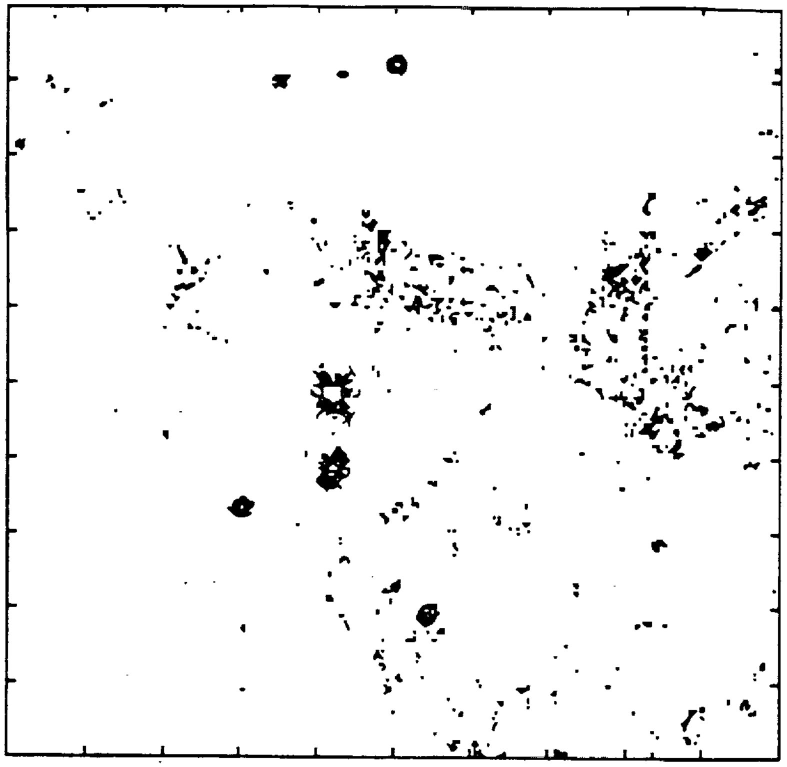
ARP 105

ORIGINAL PAGE IS OF POOR QUALITY

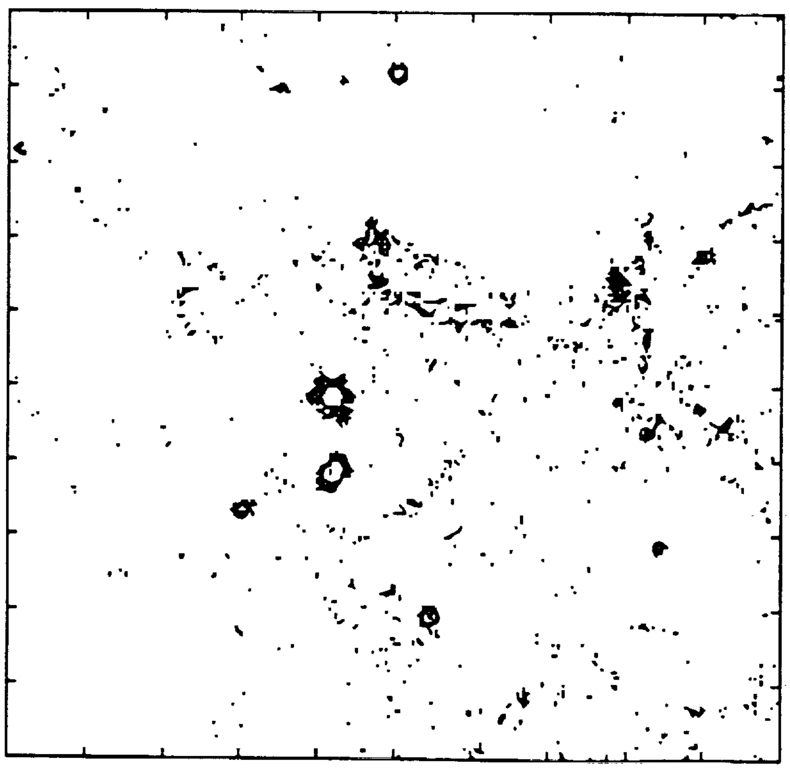


contoured from 0.1 to 19.6, interval = 0.5
NOAO/IRAF V2.9EXPORT iraf@mantra Wed 14:24:59 22-May-91

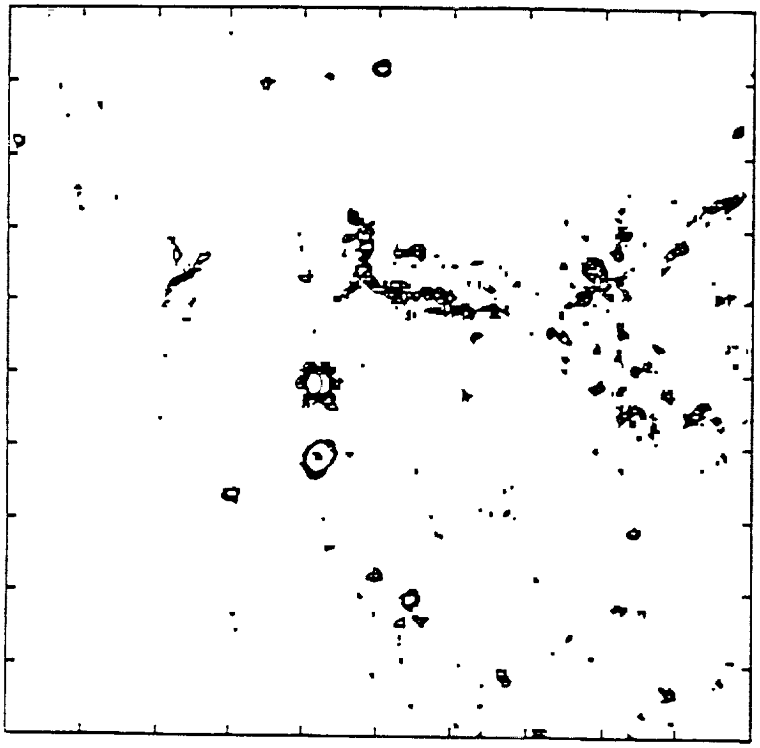
Fig 3 M81 - 100µm (RAW)



m81: 7-5 growth map Fig 4a

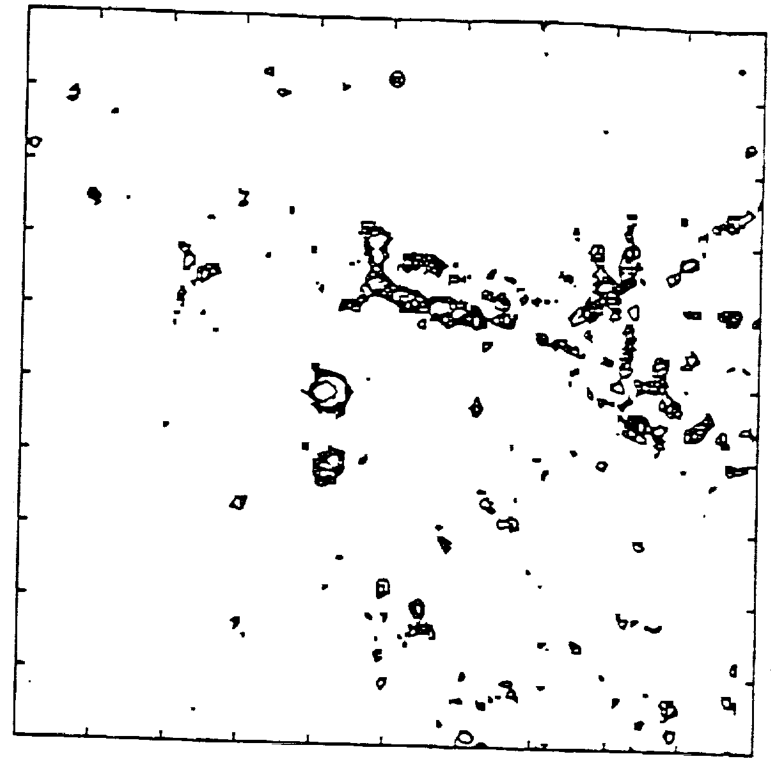


m81: 9-7 growth map Fig 4b



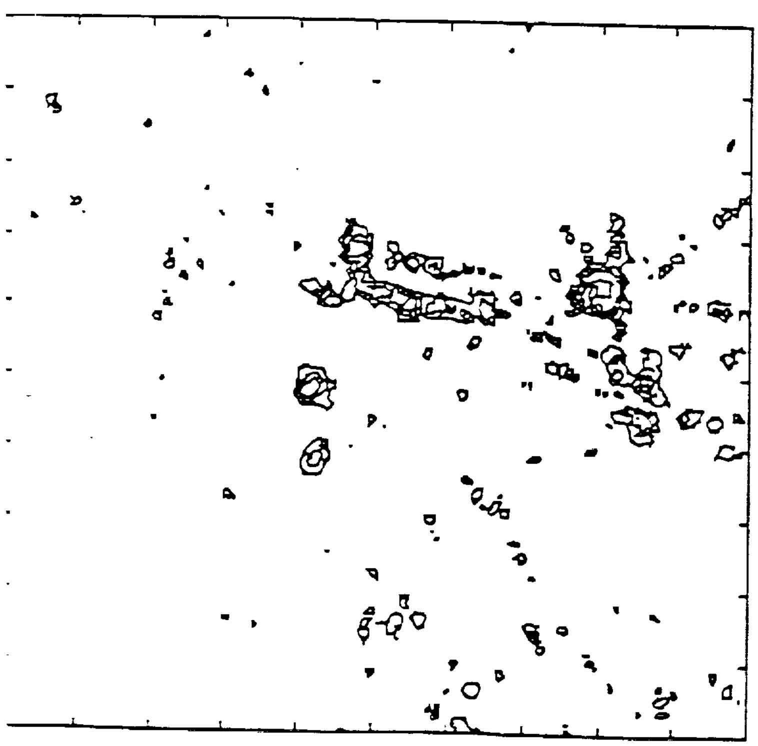
m81: 13-11 growth map

Fig 4c



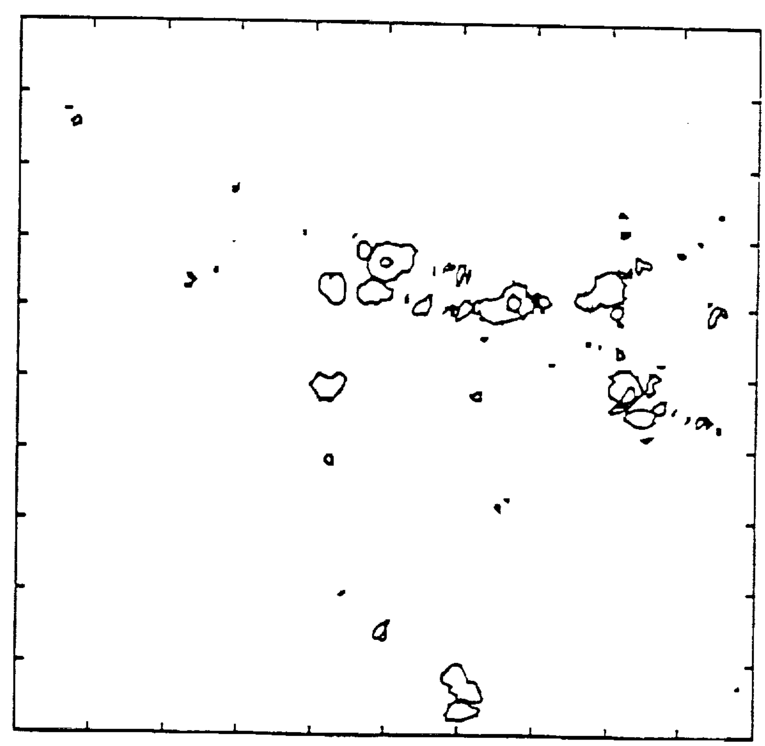
m81: 17-15 growth map

Fig 4d



m81: 23-21 growth map

Fig 4e



m81: 35-33 growth map

Fig 4f

Average Cirrus Growth (44 points)

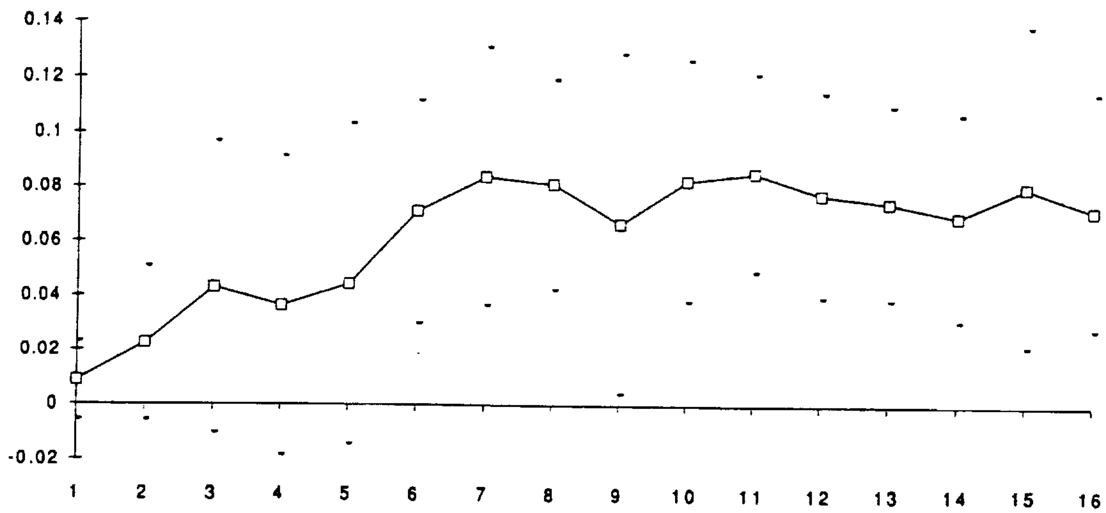
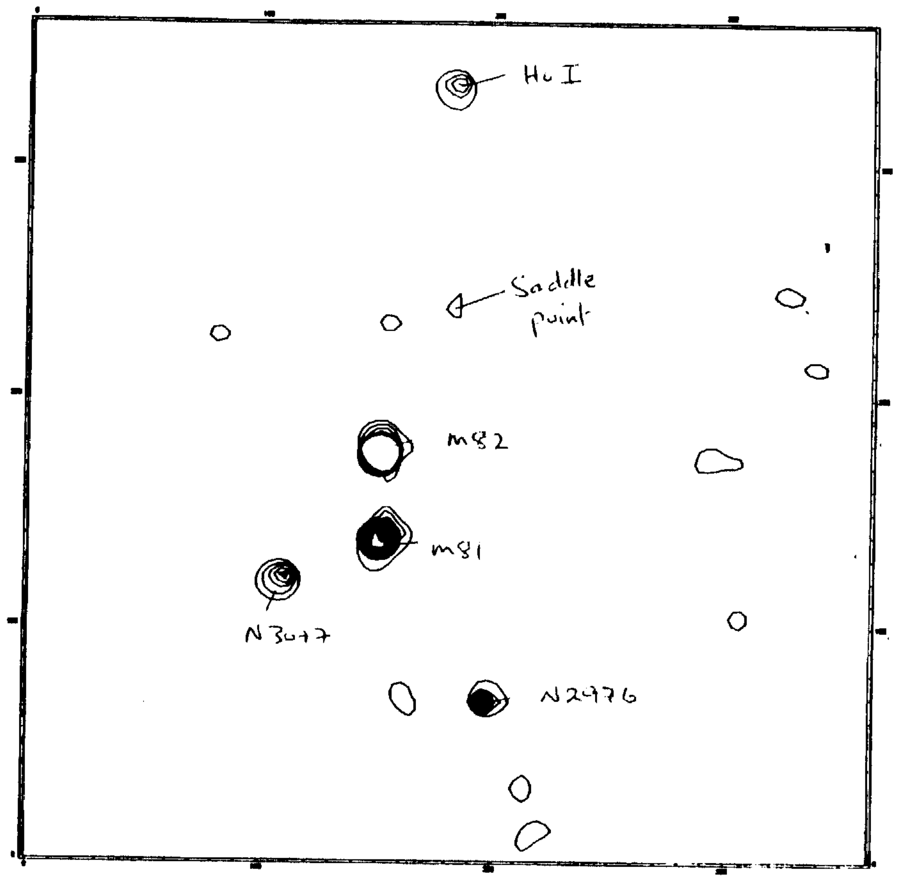


Fig 5.

m81.mor1



contoured from 0.1 to 19.6, interval = 0.5

Fig 6 M81 Group (After Morphology)

7. Personnel

Philip N. Appleton, P.I.,Assist.Professor of Astrophysics, Iowa State University (ISU).

Antony P. Marston, Co-PI, Assist. Professor of Astronomy, Drake University.

John P. Barsart, Co-PI, Professor of Electrical Engineering, ISU.

Pamela Marcum, Grad Student in Physics and Astronomy, ISU.

Paul Siqueira, Grad. Student in Electrical Engineering, ISU.

8. Publications Arising from Research

Appleton, P. N. ,Siqueira, P .R . & Basart ,J .P .,1991, " *An Attempt to Remove Galactic Far Infrared "Cirrus" Emission from Extragalactic IRAS fields using a Morphological Filter"*, A.J.,(In Prep.).

Marcum, P. M. , Appleton, P. N., Marston, A. P. & Wallin, J. W. ,1990. *"The Search for Infrared Counterparts to Extended Optical Emission in Interacting Galaxies", B.A.A.S.*, **22**, 881.

Marcum, P. M., Appleton, P. N., Marston, A. P. & Wallin, J. W. ,1991." *A Dust Halo Around the Galaxy NGC4631: Evidence for a Nuclear Outflow?"*,(Preprint).

Siqueira, P. R. ,1989, MS Thesis *"Signal and Image Processing in Astronomy Using Grey-Scale Morphology, Phase Corrections and the Maximum Entropy Method"*, Iowa State University.

Siqueira, P. R. ,Appleton, P. N. & Basart, J. P.,1990." *A Morphological Filter to remove Galactic Cirrus" , B.A.A.S.*, **22** , 807.

Siqueira, P. R. ,Appleton, P. N. ,Chackal, M. S. & Basart, J. P. ,1989. *" Detection of Extended Far-IR Emission using Morphological Filtering", B.A.A.S.*, **21**, 760.