OPTICAL EXTINCTION AND POLARIZATION STUDIES

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LOCAL INTERSTELLAR EXTINCTION
WITH AN EMPHASIS ON uvbyβ
RESULTS

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Introduction

Despite only a few percentages of the interstellar mass are contained in solid dust grains knowledge of its distribution is of importance per se,for dereddening purposes and because it probably correlates with the interstellar gas.General information on the bulk of the interstellar mass is thus obtainable from continuum absorption studies. Compared to diffuse emission data interstellar reddenings have the additional advantage by including an upper distance to the material observed.

Three dimensional mapping of the local dust has been attempted since the calibration of the uvbyβ system,Strömgren(1966),for B,A and F stars was completed by Crawford (1975,1978,1979). Being the primary calibrating sources makes local field F stars particularly useful as background sources in the search for interstellar reddening matter. Computed distances and color excesses for A and F stars are thought to be more accurate than 15% and 0.01 mag respectively.

Two interpretations of the color excess observations have been suggested. Either is the solar vicinity virtually free from dust within 75 - 100 pc or 4.4 10**-4 clouds/pc**3 filling about 2 % of the volume are distributed randomly in a low density medium.

Average reddenings and the distribution of local dust

Several comprehensive surveys for local dust by means of uvbyβ photometry have been published recently.

Perry and Johnston (1982) obtained data for 3458 northern A and early F stars. Spectral types and limiting magnitudes were selected in order to sound a volume with inner and outer radius 100 and 300 pc respectively. This sample has later been supplemented with data for 305 late F stars within 100 pc, Perry,Johnston and Crawford (1982).

If the scale height of the dust density distribution is about 200 pc the distribution of the dust concentrations in the galactic pole directions, where they are studied most conviniently,may be typical for the solar vicinity. The existence and abundance of matter perpendicular to the galactic have important consequences in galactic as well as in extra galactic studies. Hill,Barnes and Hilditch (1982) have presented uvbyβ data for about 1000 stars

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within 15 deg of the NGP. Program stars were taken from the literature and may lack spectral completeness and a systematic limiting magnitude. This may complicate the interpretation of their results. An identical invesigation comprising 572 HD stars with b< -70 deg has been conducted by McFadzean,Hilditch and Hill (1983).

Knude (1977,1981,1982) has taken a different observational approach by observing magnitude limited,"complete", samples of B,A and F stars in small areas. The three published lists contain data for about 1200 stars.

The distribution of color excesses calculated from published photometric and spectroscopic data,Lucke (1978) leaves the impression that the sun might be located in a dust free region enclosed by more or less coherent large scale structures. But it must be noticed that the lowest reddening contour presented within 500 pc is E(B-V)=0.1 mag ,a rather large excess in the present context. Local excesses are thought to be much smaller. An important parameter in the search for local extinction is the angular spacing of the lines of sight and it is essential for the detection of small dust features how the spacing compares to the projected sizes of the dust structures. Unless the dust distribution is continuous the applied angular separation determines the linear sizes which may be detected. Cloud dimensions were expected smaller than about 10 pc. Within a few hundred pc this requires an angular resolution better than one degree. To be manageable such inverstigations are restricted to smaller areas. The survey of the complete northern hemisphere by Perry and Johnston op.cit. has one star per six square degree,whereas the Hill et.al. and the McFadzean et.al. mappings have 1.4 and 0.5 line of sight per square degree on the average. Knude´s observations have an average ranging from 1 to about 10.

Concerning the existence of local dust,average reddenings may not be representative if the matter happens to have a clumped distribution. A significant amount of material may be concentrated in a small part of space but only covering a minor fraction of the local sky. With an irregular dust distribution within a certain distance the fraction of the sky covered by diffuse dust clouds must be estimated before any average reddening value can be accepted as valid for the volume sounded. Closer than 150 pc less than 50 % of the sky is expected to be covered by diffuse clouds and for galactic latitudes above 70 deg less than 20 % of the area is thought to be reddened, Knude (1983). But dust <u>is</u> present.

The selection of the stellar samples used for probing the dust in a certain volume is most important. If some upper distance limit is chosen a priori the amount of absorption expected must be added to the magnitude of the unreddened sampel stars at this distance. If this is not done the lines of sight observed have a tendency to avoid the reddened directions present,Perry and Johnston op.cit. This point is also illustrated by the observation that in magnitude limited samples the most distant stars are always among the less reddened ones.

The problems of the local dust distribution are closely connected to the questions of the spatial distribution of the varius

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gas phases of the ISM as typified by e.g. McKee and Ostriker(1977) and Fried et al.(1980). Three principal conclusions drawn from Perry et al. op.cit. favor the local void: (a) the sun is located in a reddening free region extending at least 75 pc in all directions.(b) the galactic pole zones have negigibel reddening.(c) the local dust,distances larger than 75 pc, is concentrated in coherent large scale structures,displaying density variations.

Detailed observations in many small areas, Knude (1979) do not corroborate the conclusion (a). A substantial amount of clouds do show up in the reddening data even within 75 pc in an area totaling 5 % of the sky. These clouds have color excesses E(b-y) in the range from 0.014 to 0.1 mag. From statistical considerations,Knude (1981a),a maximum of 750 clouds is estimated to be present within 75 pc, but they will only be seen to cover about 20 % of the complete sky. Tinbergen (1982) finds indications of a very local,D<20 pc, dust patch in the direction (l,b)~(0,-20). In this part of the sky color excess data, Knude (1978), also show that some stars closer than 50 pc have color excesses larger than 0.020 mag. In the distance range from 50 to 75 pc some even have E(b-y): 0.03 - 0.04 mag. This is in the general direction of the proposed large Sco - Cen bubble, Weaver (1977). So in some directions very local, significant amounts of reddening seem present.

Of the published photometric data samples none are well suited to locate any small dust concentrations within 50 pc. The spatial density of the F stars is too small,so the clouds may slip through the network. Background sources more frequent by an order of magnitude is required,but as the column densities of such structures are unknown photometry may prove too inaccurate for a search.

Neither is there any perfect agreement on the existence of local dust in the pole directions. McFadzean et al.(1982) confirm the conclusion that the average reddening at the SGP is about zero, whreas Hilditch et al. (1983) find significant reddening in part of the zone b>75 deg. Knude (1977b,1978) also finds substantial amounts of dust in some regions at both polar caps. On Figure 1 is shown a histogram of color excesses resulting from uvbyβ observations of all stars earlier than G1 and brighter than V~12 mag in SA 141,b~-85.8 deg. The distribution displays a positive tail and the average excess is not zero but 0.02. Figure 2 is a compilation of such data for 50 square degrees with b<-45 deg, and comprises data for about 450 lines of sight. Figure 3 is a similar diagram based on data drawn from Perry and Johnston (1982), Table 1. There is a noticeable difference particularly in the low excess parts of these diagrams. Such a difference is not easy to explain but it is strange tc note that the distribution of the β index observed by Perry and Johnston has a narrow maximum at 2.735 just where other investigations of field stars and galactic cluster find a gap in the distribution and just where the calibrations by Crawford may not be the most accurate.

Perry,Johnston and Crawford op.cit. do not find any variation of color excess with distance (projected) from the galactic plane. The reason for this may be that the observed distance range,200 pc, is too small to pick up any significant changes. Averages excesses in 50 pc bins for the stars in SA 141 within 650 pc are shown on Figure 4. These excesses do show an increasing trend with distance. Assuming an exponential density variation a linear regression of the averages on exp(-z/h) results in a scale height h=160 pc and in an equivalent average gas density in the galactic plane of 0.37 atoms cm** -3. With the patchy dust distribution observed cloud and inter cloud dust need not have identical scale heights. Figure 5 shows a color excess distance diagram for a small area at latitude +25 deg. There may be several explanations of the origin a the lover envelope seen,one that it is a specimen of the effect of intercloud dust exclusively.

Figure 1 of Hilditch,Hill and Barnes (1983) shows that about half the area above b=75 deg has an average reddening 0.001 mag, the remaining half 0.008 mag but also the existence of a patch with E(b-y) = 0.024 mag.

Another investigation of the distribution of the dust at the NGP presently being conducted. T.Oja (1981) has performed a spectral survey at the NGP, b>70 deg, to a limiting magnitude V~11mag finding ~5500 candidates in the spectral range from A2 to G0. Knude,Winther and Strömgren have prepared positions for these stars for subsequent uvbyβ observations. The observations are complete for about 50 % of the sample and some preliminary results for the north pole are presented. As the survey has four stars per square degree these new data are expected to result in a more detailed understanding of the dust distribution at the NGP. Table 1 contains the variation of average excesses in 25 pc bins with distance (not z) as based on color excess and distance for about 2000 stars. The average starts out with a value E(b-y) = 0.011 mag within the first 50 pc and rises to 0.014 mag in the next 25 pc and then remains constant out to 300 pc. This behaviour very much resembles the variation encountered within the first few hundred pc in SA 144 at the SGP,Figure 4. In Table 2 a coarse representation of the reddening variation across the north pole region and within 100 pc is given. The average reddening is doubled from 0.009 to 0.018 mag when the pole is crossed from the center to the anticenter direction. Note that the observations so far is not complete to the same magnitude in the three sections, the final values may therefor change a little. At the north pole a most interesting result is the very small distance within which significant reddening is found. Figure 6a and 6b show the distribution of E(b-y) for the few stars closer than 50 pc and how the excesses vary with distance respectively. For the 18 stars with D< 50 pc E(b-y) = 0.011±0.013 mag and the distribution does show a positive tail. Only two of the stars have photometric distances smaller than 35 pc and have no reddening but between 35 and 50 pc reddenings as large as 0.030 show up. If the matter along these lines of sight is representative one may tentatively conclude that within 35 pc no reddening material is present but in the range from 35 to 50 pc reddening free as well as rather heavily regions do exist. Similar data pertaining to the distances 75 < D < 100 pc ,b>70 deg are shown in Figure 7a,c.

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In order to indicate the preference of positive reddenings for stars at these latitudes Figure 7 b demonstrates the E(b-y) distribution with the entire symmetric counterpart of the E(b-y)<0 part of Figure 7a removed. Figure 7b may be a crude first approximation to the dust column distribution to be expected in the high latitude dust features. Figure 7c displays the considerable scatter of color excesses for a sample of stars with almost the same distance. As Table 1 shows the scatter is nearly constant when moving out to large distances contrary to what is the case in the galactic plane, where the excess distribution is seen to flatten at the larger distances. This is probably an effect of scale height, only in rare cases a high latitude line of sight will penetrate more than one cloud. As a final example of a reddening histogram, the distribution reddenings within 100 pc and with b>70 deg, δ< 20 deg is shown in Figure 8. This area covers the northern part of the Virgo cluster parts of which apparently have absorptions as large as A_v=0.2 mag.

As to whether the local diffuse dust clouds exclusively are located in larger coherent features Figure 9 shows the resulting spatial distribution of clouds for which upper and lower distance limits could be determined from a survey of 63 small areas with |b|<30 deg. The cloud distances are not projected in the galactic plane in order not to overstate their nearness. No clouds are indicated in the immediate solar vicinity ; this does not necessarily imply that no clouds are present but may be caused by the scarcity of very local background sources, most of which are more distant than 50 pc. Apparently diffuse clouds are omnipresent localy with a constant spatial density. There may be a weak tendency that there are fewer clouds for the longtudes l: 340-0-30 deg and those present are concentrated in a smaller volume. This is however not born out by the results on Figure 10, where the clouds with only upper distance limits are pictured. They show much the same distribution as in Figure 9, but some clouds are present even within 50 pc. On basis of Figure 9 and 10 one would rather suggest a homogeneous distribution of the local diffuse dust clouds than that they only exist in large scale features. There is thus only little support from the discrete cloud data to conclude that sun is located in a cavity more or less void of dust, not even a cavity as small as 100 pc across. Within 35 pc 75 clouds are expected, but they are estimated to cover only a mere 10 % of the whole sky.

Some properties of local diffuse dust clouds

From observations of suitable stars in fine but irregular networks and subsequent statistical correction for the sensitivity of the observations to detect various dimensions at different distances the distributions of dust column densities, linear dimensions, spatial density and volume filling factor have been possible, Knude (1981 a,b). It is found that for the distance range from 50 to 150 pc the diffuse clouds in the dimension range from

1.5 to 10 pc occupy 1.8% of space, have a spatial density 4.4 10**-4 pc**-3. Their linear dimensions obey a power law (2R)**-2.62. Their one-dimesional frequncy is 4.3 clouds/kpc . By using the method of moments an average inter cloud density 0.001 mag/100 pc or 0.02 H atoms cm**-3 is estimated, Knude (1979 b). Note how well the local average density derived from cloud statistics n(H) = 0.5 cm**-3 compares to the estimate from the scale height considerations 0.37 cm**-3. The average cloud density is about 20 H atoms cm**-3. The distribution functions of the cloud parameters must of course reflect the physical conditions of the diffuse medium of which the constitute the most massive part. As an example the variation of linear dimension with distance from the galactic plane is shown in Figure 11. For $|z| < 20$ pc there is a remarkable absence of clouds with $(2R) > 5$ pc, whereas clouds in the range $20 < |z| < 40$ pc shown a tendency of being larger on the average. Figure 12 displays the variation of the clouds equivalent density with z-distance. Apparently the high $|z|$ clouds have a lower density than those in the plane. No temperature information is presently available for these specific clouds, but the variation could indicate that the clouds expand in low pressure regions away from the plane?

Little is presently known on shapes and density gradients in the clouds. The clouds used for statistical studies were identified from spatialy confined identical color excesses delineated by lines of sight with negligibel excesses. The clouds were assumed spherical,though only 20 % show equal radial and lateral dimensions. The constancy of the excesses used to identify a cloud may indicate either that the clouds are part of stratified structures or that only the dominating cores have been detected. So far clouds with dimensions as small as 1.5 pc have been identified. An extremely interesting problem is whether the distribution of smaller dimensions follows an extrapolation of the power law or it shows an extremum somewhere below 2 pc. If the distribution shows a maximum its location may be used as an indicator of the ISM pressure. A search for local subparsec structures has been initiated by observing a few areas with approximately 10 stars/ square deg and one area with almost 100 stars/ square deg. Figure 13 is an example of a dust feature within 100 pc and with linear size less than 0.8 pc. At the SGP the elongated feature shown on Figure 14 was found. It has a western extension only 0.2 pc across. The higher resolution data may also be used addressing the unsolved problems on the shapes of the diffuse dust clouds,on there internal structure and whether they generaly posses low density outer envelopes.

As an indication of what may be obtained from the high resolution data a diffuse cloud in SA 141 is discussed. Reddenings along 13 lines of sight within 0.5 square degrees are shown on Figure 15a as they appear on the sky and with stellar distances indicated. A certain systematics is noticed. There are two iso-excess curves: $E(b-y) = 0.0085 \pm 0.0015$ mag and $E(b-y)=0.0335 \pm 0.0013$ mag, two close, nearly identical reddening directions with $E(b-y)=0.049$ and 0.054 respectively and an apparently deviating reddening not fitting any pattern.

Two interpretations are possible:
a. The 0.0085 mag contour represents intercloud lines of sight and consequently delineates a cloud with E(b-y) ≳ 0.017 mag. The excesses 0.049 and 0.054 are the result of a superposition of two clouds with E(b-y)=0.017 and 0.0335 respectively. Figure 15b visualizes this suggestion. The probability of having two clouds within a distance of 300 pc is 0.2 .
b. The angular distribution of these 13 color excesses offers another interesting interpretation in terms of only one cloud displaying a change of column density nearly one order of magnitude from its center to its outer portions. Figure 15 c shows what the column density contours could be like. The cloud appears a little elongated, but for computational convinience it is anyhow assumed spherical. The clouds center is taken between the two largest excesses. The radial dependence of the dust column density is seen on figure 15d, where also is shown a power law fitted to the data: E(b-y) $\propto \varrho$**-0.785 ,r=-0.68. The low correlation coefficient and the largely deviating point are caused by assuming sphericity. Outer low density parts of diffuse clouds may not survive for long if the clouds are overtaken by supernovae blast waves too frequently, Heathcote and Brand (1983). The occurence of clouds with density gradients would accordingly be interesting to evaluate. Unfortunately no unreddened stars have been observed in front of this feature wherefor only an upper distance limit are available, D<300 pc. The clouds equivalent density scales with 1/D. Figure 15e is finally a display of the clouds radial density dependence, assuming a spherical structure. A maximum radius is assumed. The density E(ϱ)/21(ϱ) translates to n(H) = 7958 (E/21)/D(pc) atoms cm**-3. At 100 pc the density will vary from 40 cm**-3 at the center to 10 at the outskirts. At 300 pc the envelope density approximates the WNM density suggested by McKee and Ostriker(1977).

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Table 1

Average color excesses E(b-y) for A and F stars at the NGP, b>70 deg. Only 40 % of the final sample is presented

Distance range pc		N los	E(b-y) mmag	σ(E(b-y)) mmag
20	50	18	11.15	12.75
51	75	102	13.58	14.07
76	100	206	13.52	16.80
101	125	222	13.19	20.61
126	150	286	12.93	19.13
151	175	305	12.94	18.79
176	200	264	13.11	19.43
201	225	210	12.62	19.88
226	250	191	13.57	19.97
251	275	144	15.64	19.38
276	300	108	14.28	17.68

Table 2

Color excess variation across the NGP, b>70 deg, only stars within 100 pc. The three cross sections are defined by the range of BD numbers observed.

BD range	N los	E(b-y) mmag	σ(E(b-y)) mmag
+ 7 2586 +20 2779	112	9.39	17.48
+20 2786 +27 2034	112	13.99	16.59
+27 2037 +44 2289	108	18.41	15.56

Figure Captions

Figure 1. E(b-y) histogram for ~ 150 stars in 15 square deg at the South Galactic Pole.

Figure 2. E(b-y) histogram for ~450 stars in 50 sq.deg below -45 deg.

Figure 3. E(b-y) histogram for 158 stars with b < -45 deg from Perry & Johnston (1982).

Figure 4. Average E(b-y) in 50 pc bins versus distance for the stars in SA 141.

Figure 5. An example of a lower envelope thought due to inter cloud dust.

Figure 6a. Histogram for E(b-y) of stars with b>70 deg and closer than 50 pc.

Figure 6b. Variation of E(b-y) with distance for the stars described in Fig. 6a.

Figure 7a. Caption as for Fig.6a, but for stars with 75 < D < 100 pc .

Figure 7b. As Fig.7a but with the symmetric counterpart to E(b-y) < 0 removed.

Figure 7c. Caption as for Fig 6b, but for stars with 75 < D < 100 pc.

Figure 8. Distribution of dust columns for stars with D 100 pc and b>70 deg, δ<20 deg. This region covers part of the Virgo cluster.

Figure 9. Location of diffuse dust clouds with known distance.

Figure 10. As Fig. 9, but only upper distance limits are available.

Figure 11. Variation of clouds linear dimensions 2R (pc) with their distance from the galactic plane.

Figure 12. Cloud density n(H) cm-3 versus z(pc).

Figure 13. Example of a $\lesssim$ 0.8 pc structure in SA 162.

Figure 14. Example of small elongated feature in SA 141.

Figure 15a. Reddening and distance of 13 stars within 0.5 sq.deg in SA 141, projected on the sky.

Figure 15b. Reddening distribution explained in terms of a superposition of two clouds.

Figure 15c. Reddening angular distribution interpreted as a density gradient in only one feature.

Figure 15d. Column density versus radial distance. A power is adopted to the data assuming a spherical cloud: $E \propto \rho^{-0.785}$.

Figure 15e. Radial variation of equivalent gas density n(H).
n(H) = 7958 E(b-y) (ρ)/21 / D(pc) atoms cm-3. A maximim cloud radius of 50 arc min is assumed. E/21 is measured in mmag/arc min .

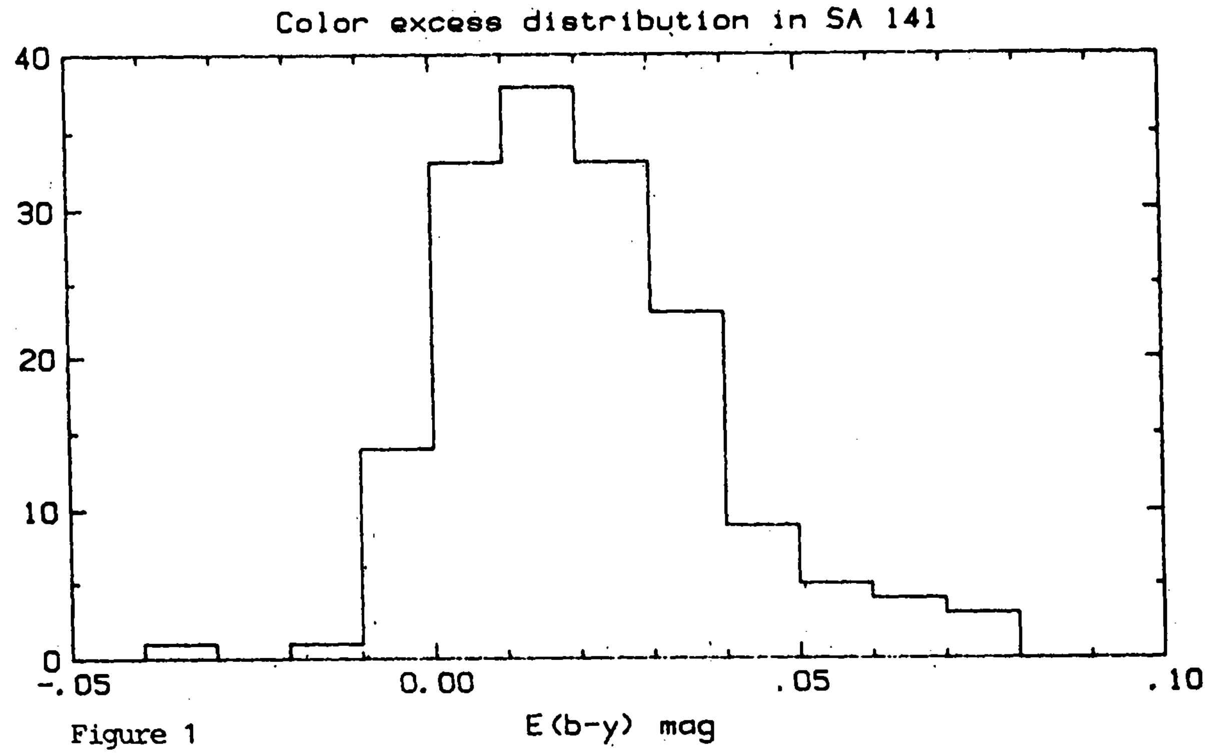

Figure 1

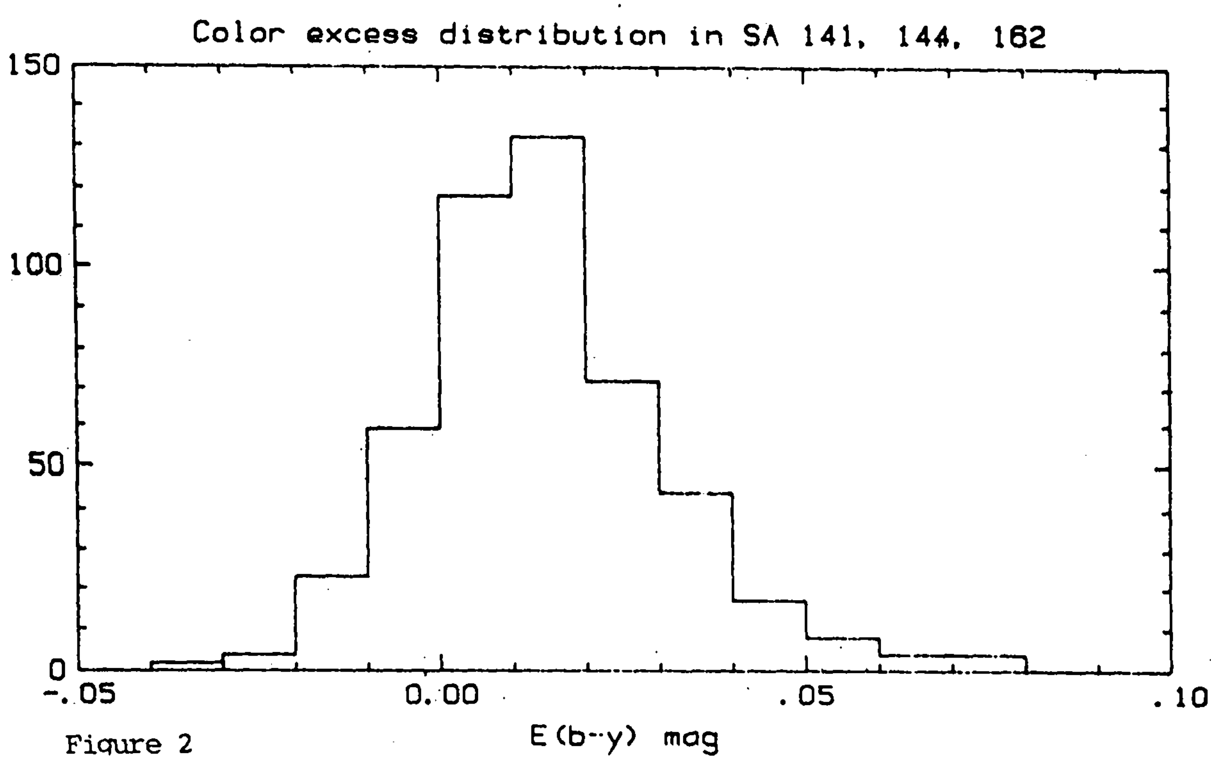

Figure 2

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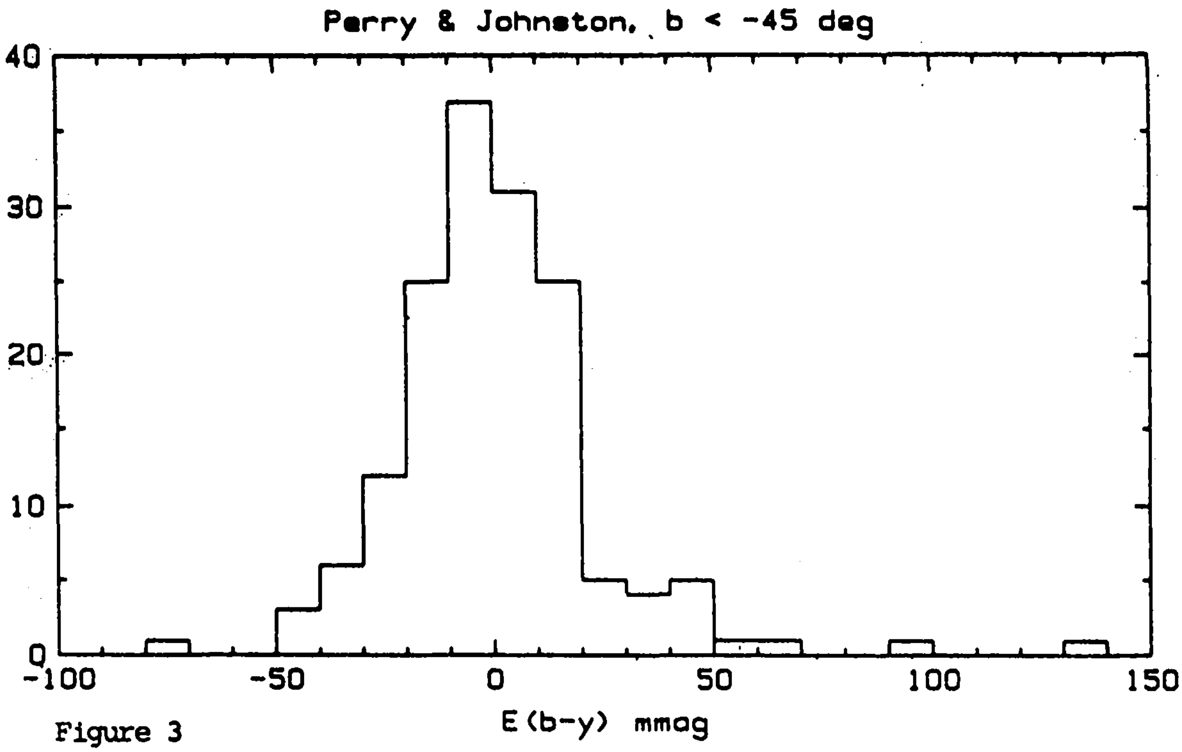

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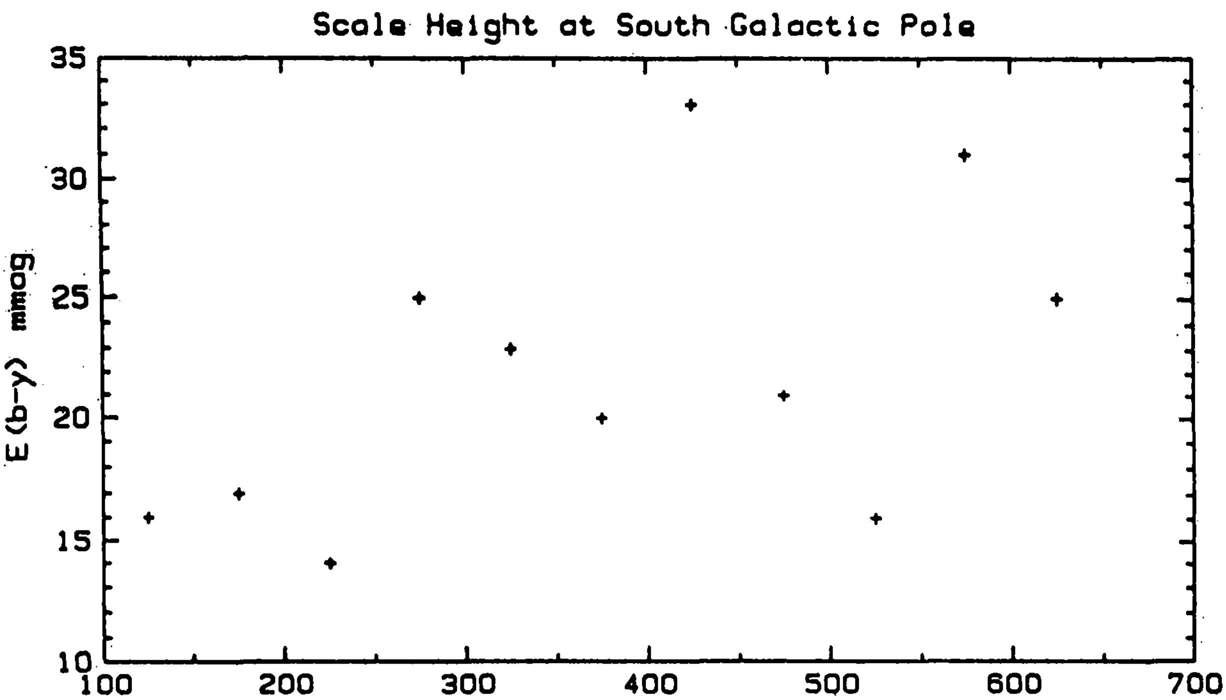

Figure 4

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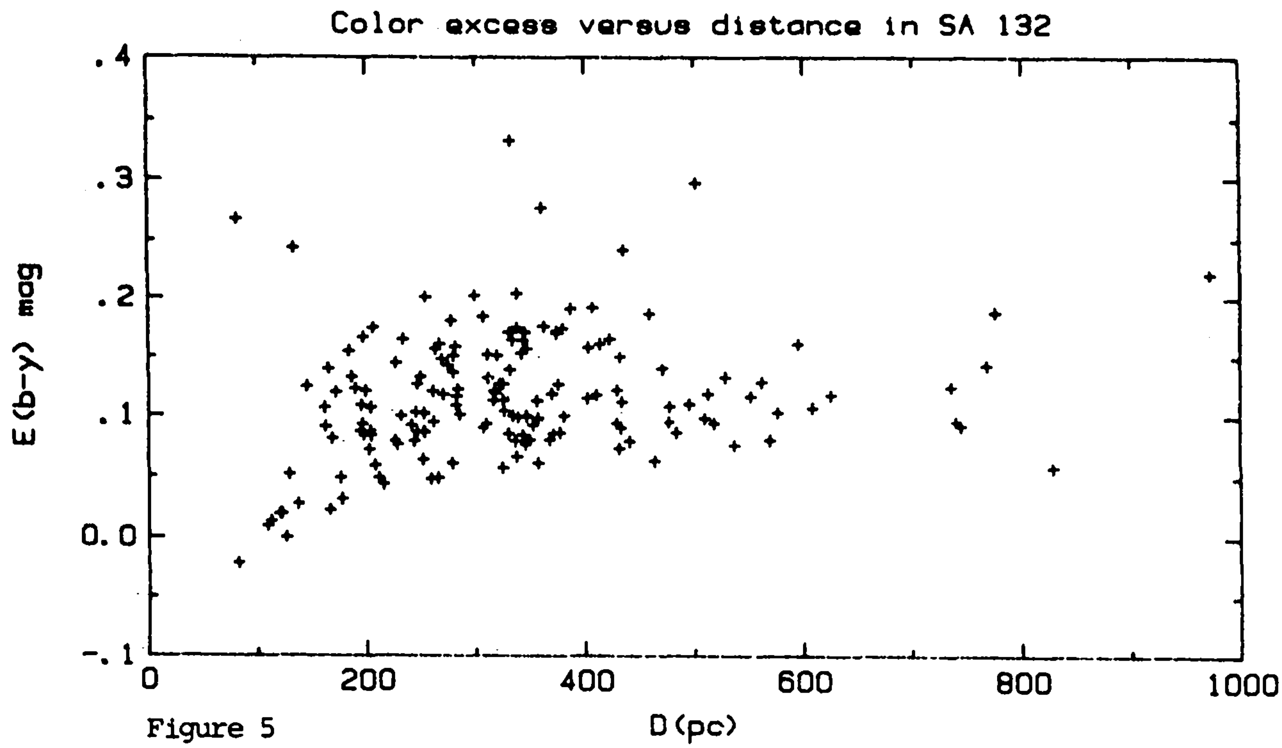

Figure 5

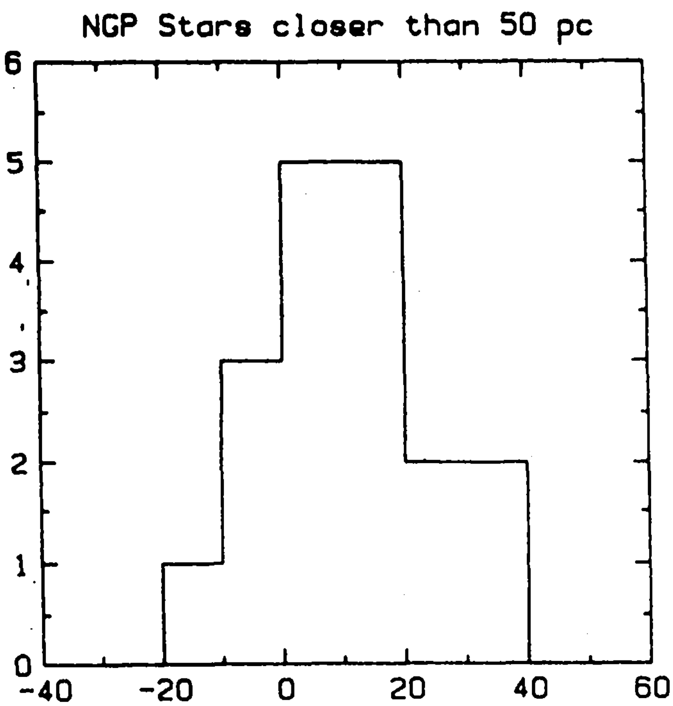

Figure 6a

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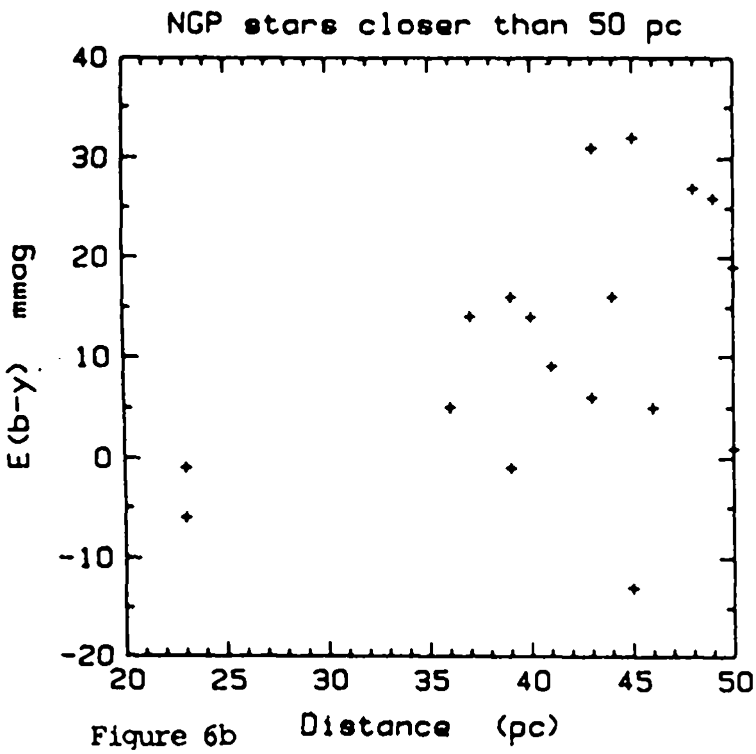

Figure 6b

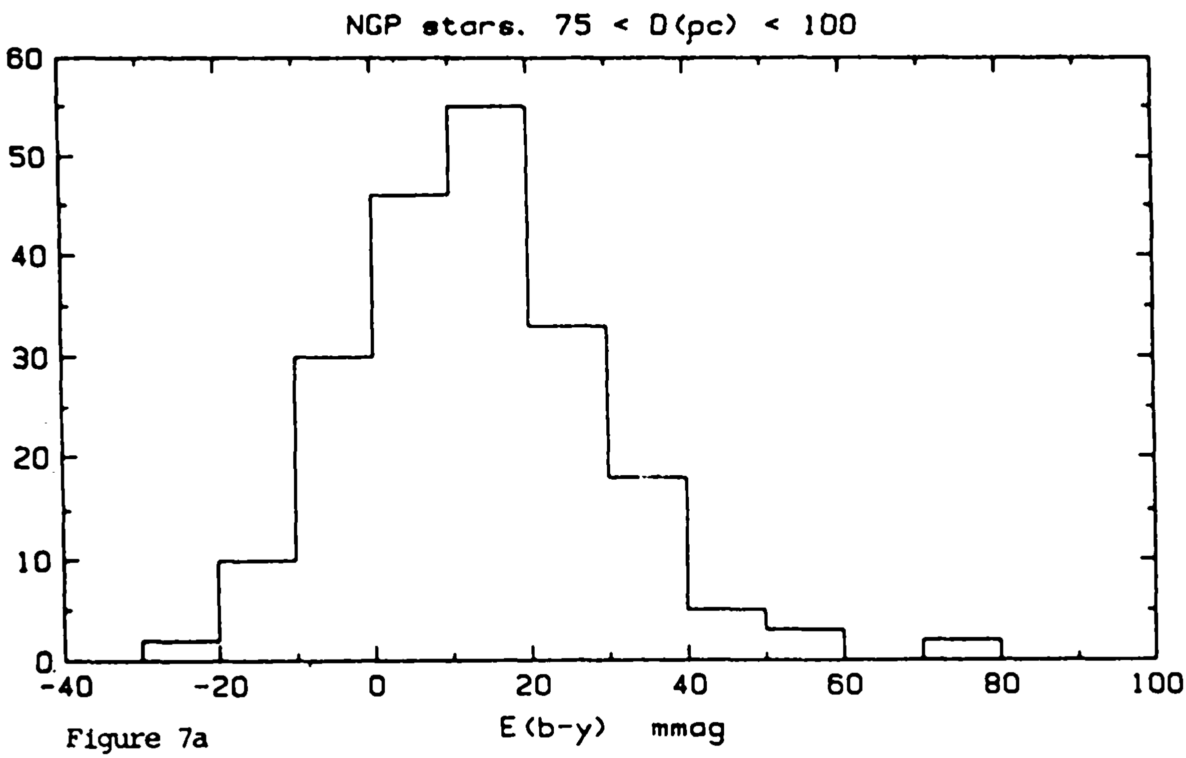

Figure 7a

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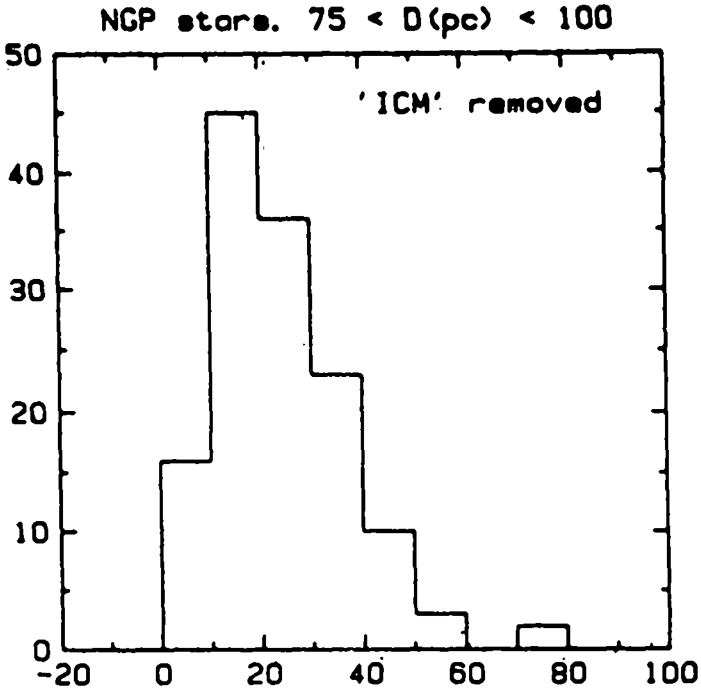

Figure 7b E(b-y) mmag

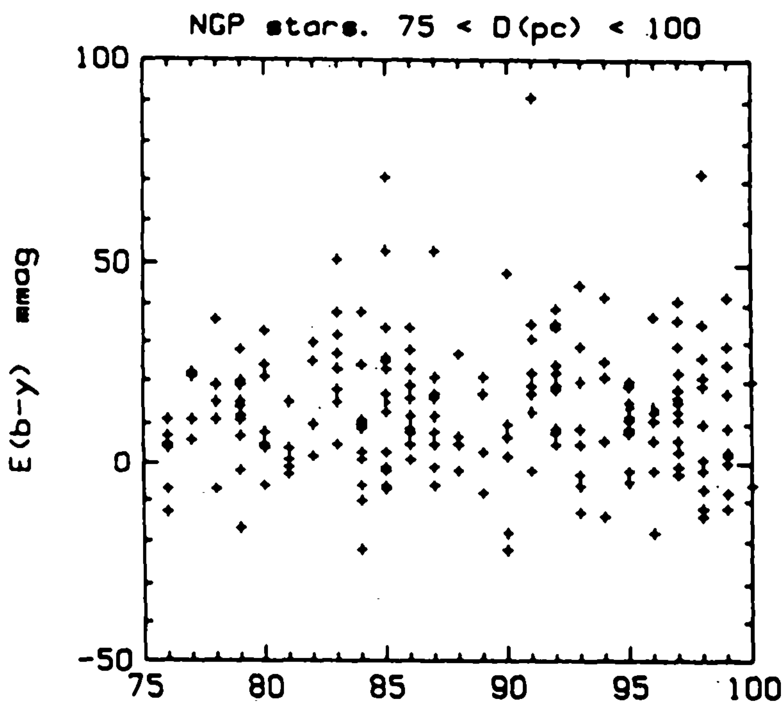

Figure 7c Distance (pc)

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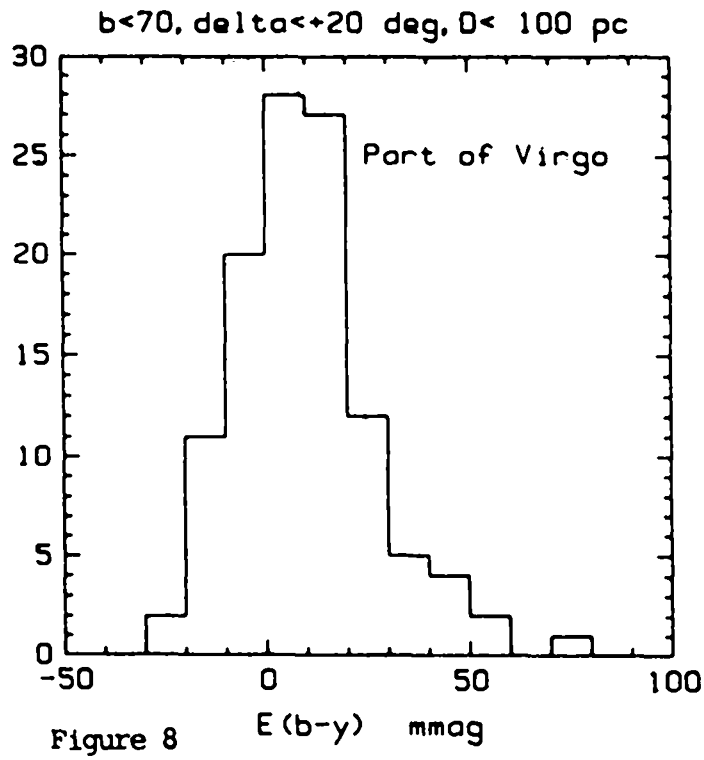

Figure 8

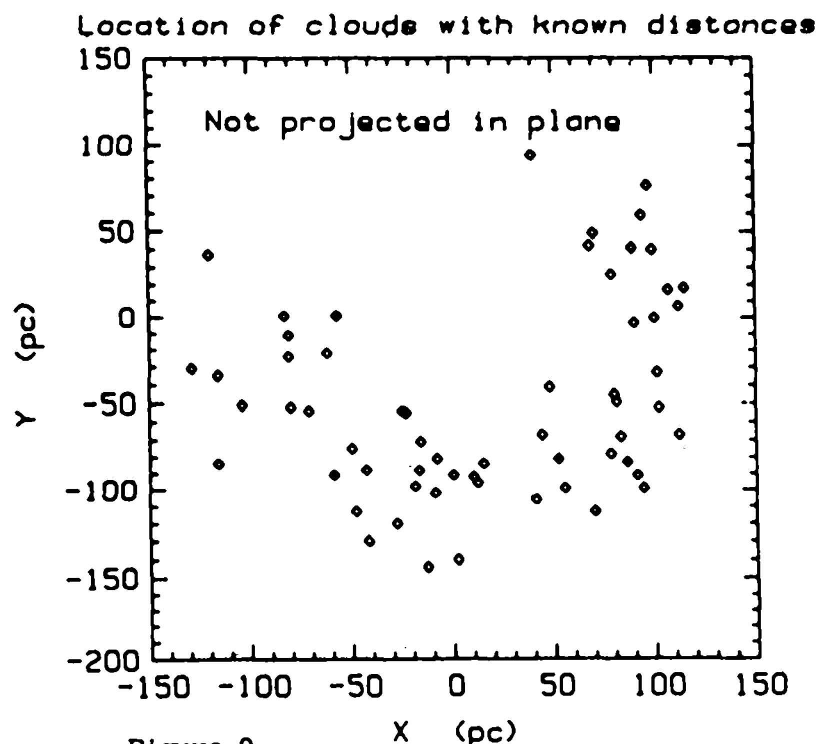

Figure 9

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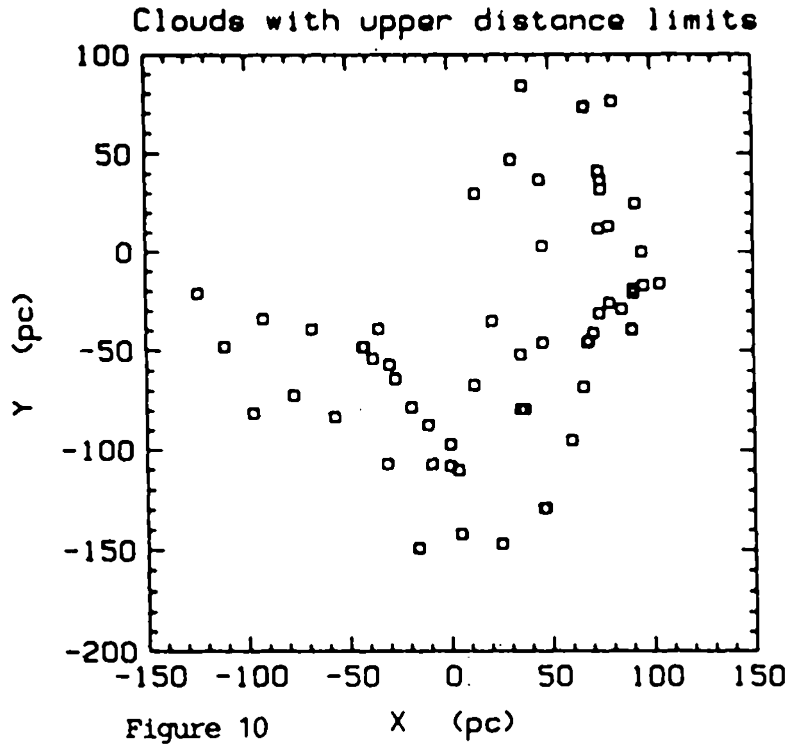

Figure 10

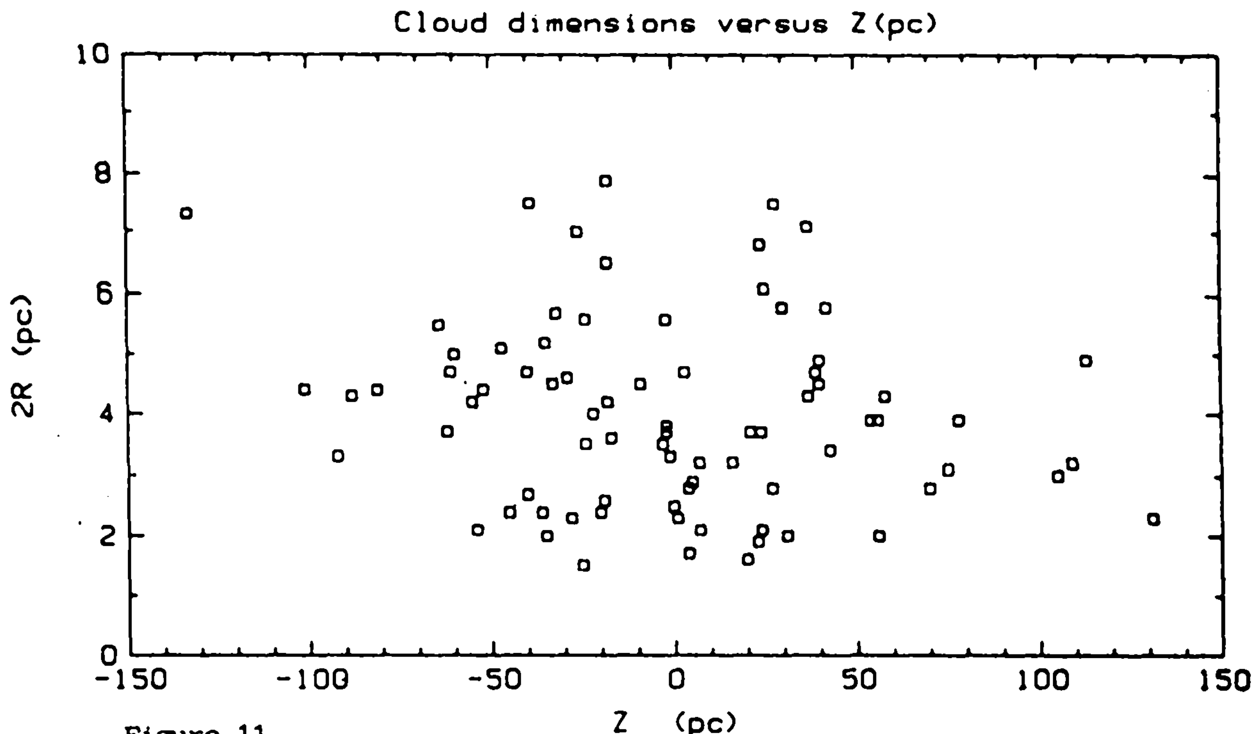

Figure 11

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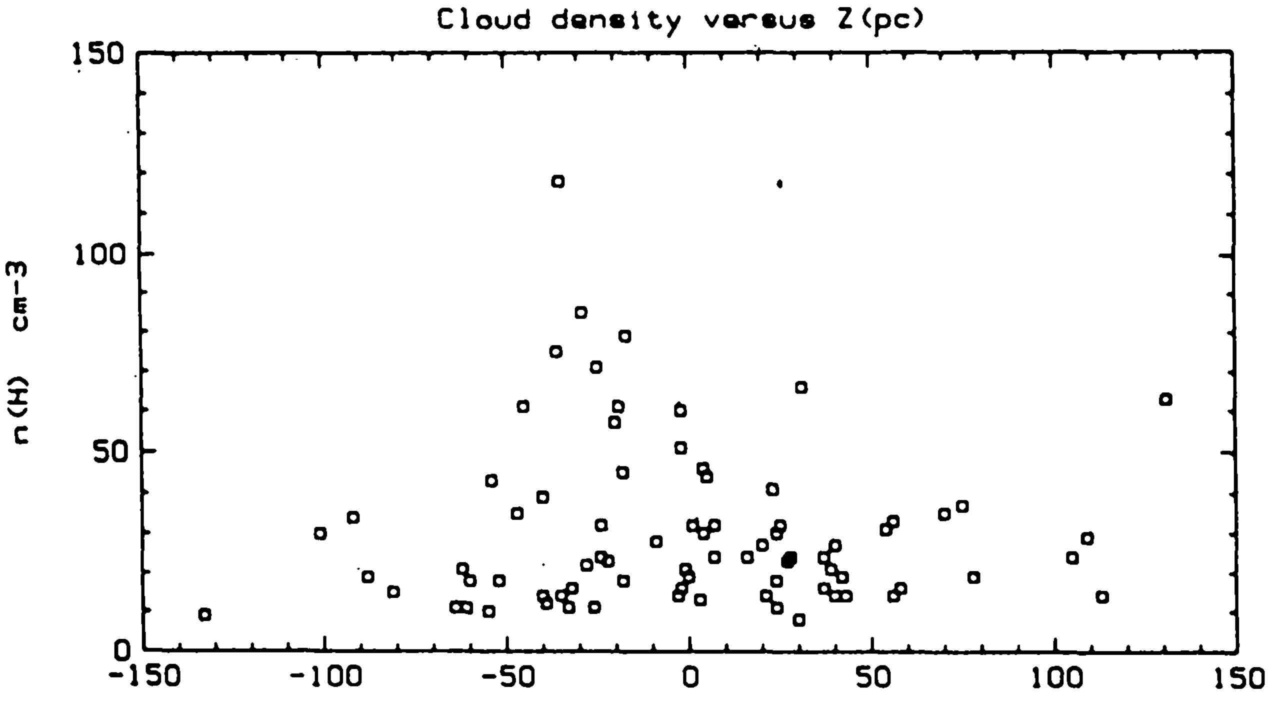

Figure 12

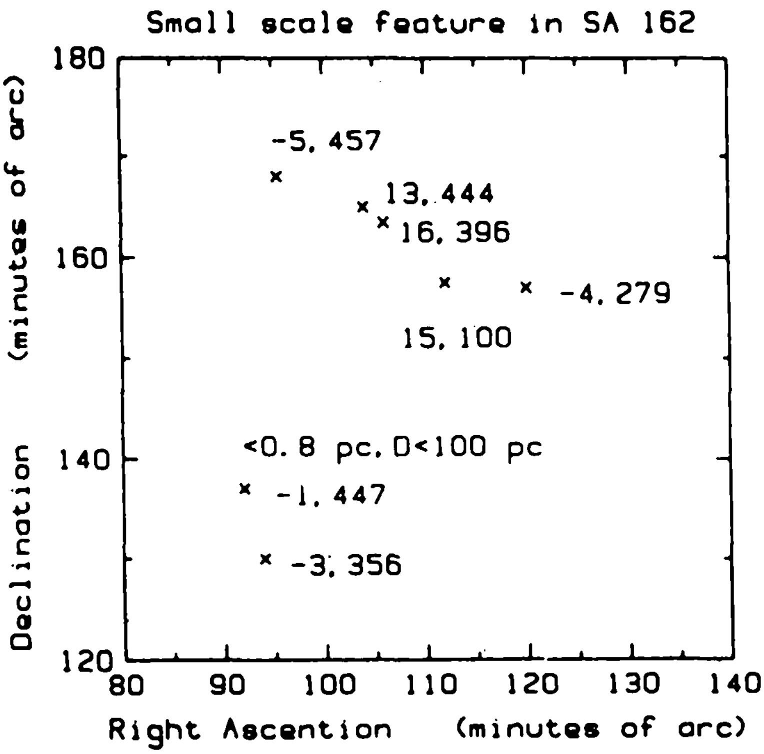

Figure 13

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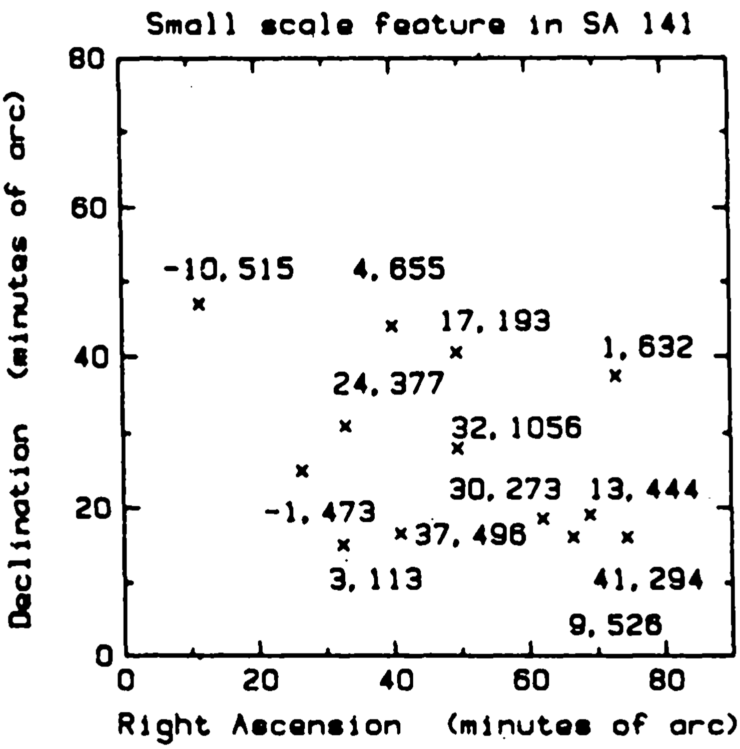

Figure 14

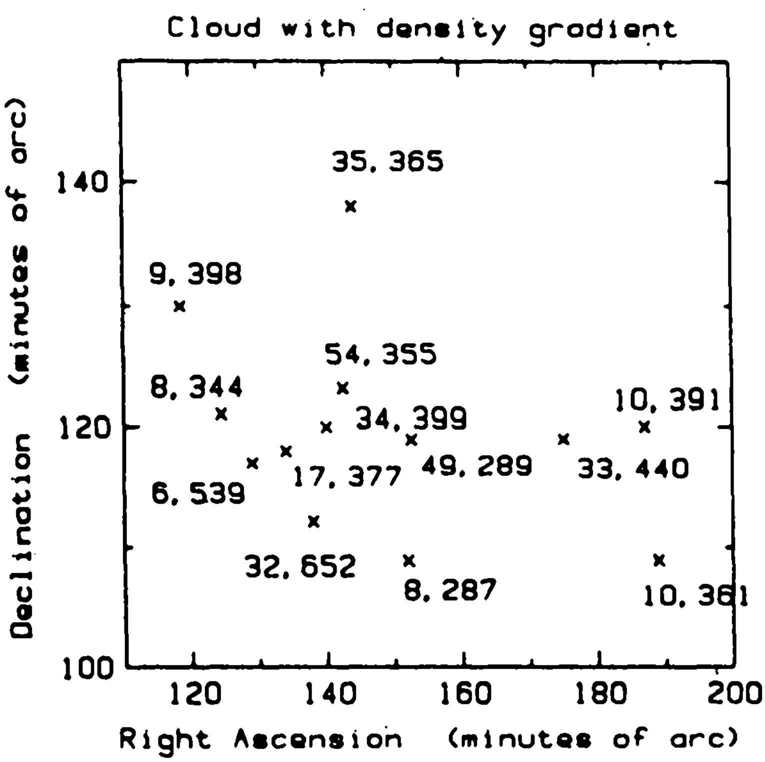

Figure 15a

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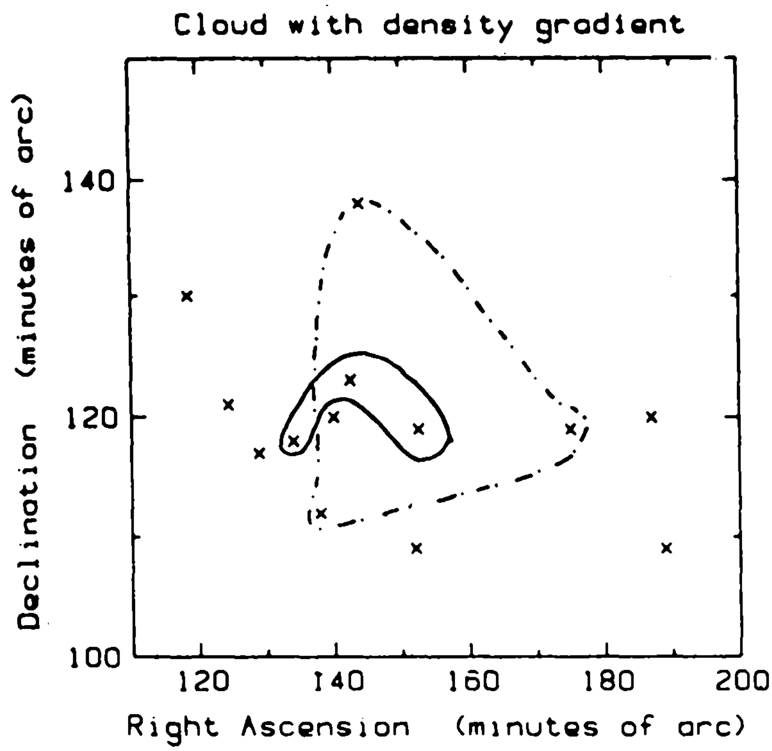

Figure 15b

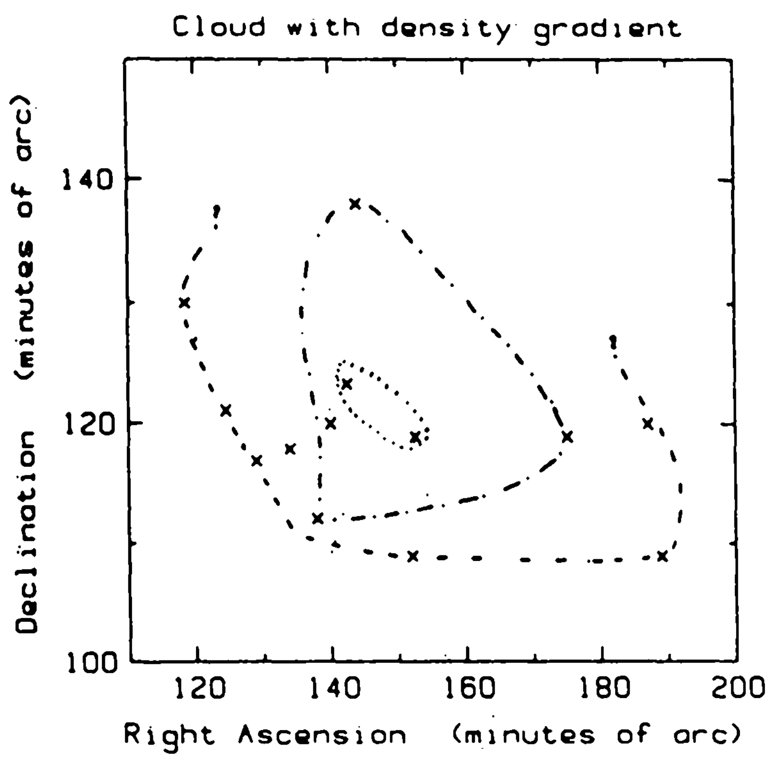

Figure 15c

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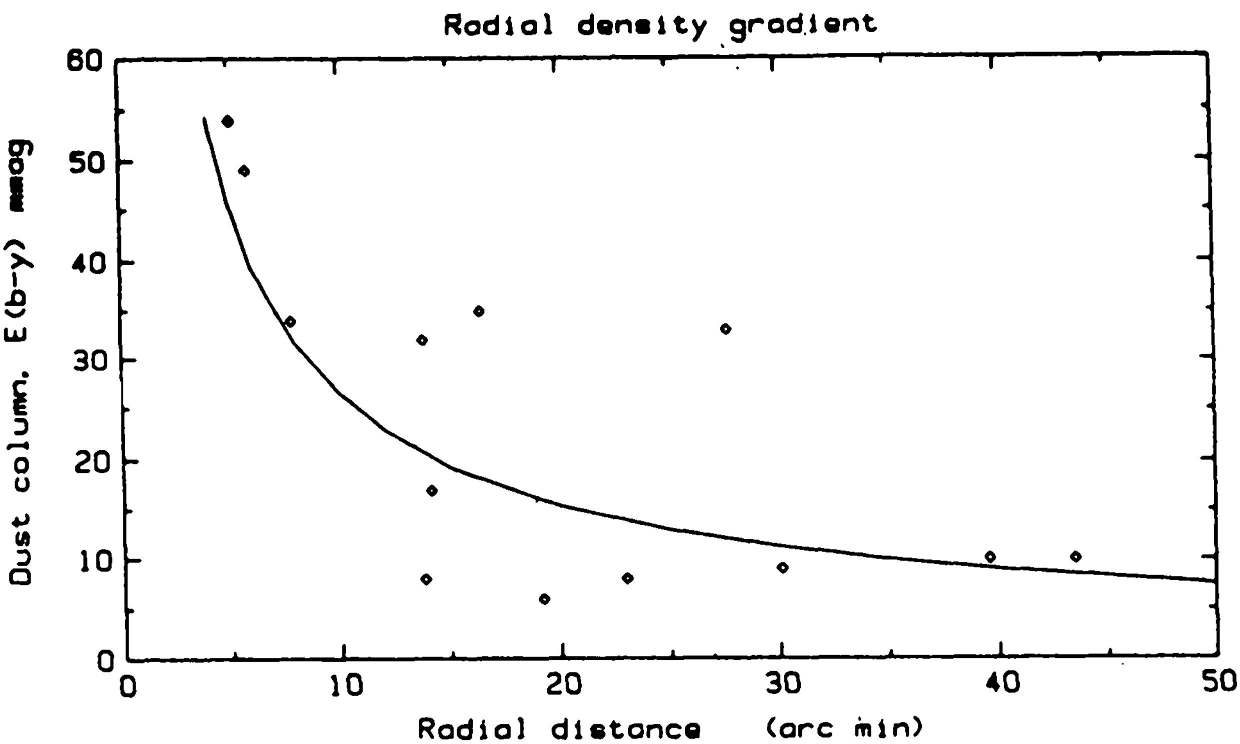

Figure 15 d

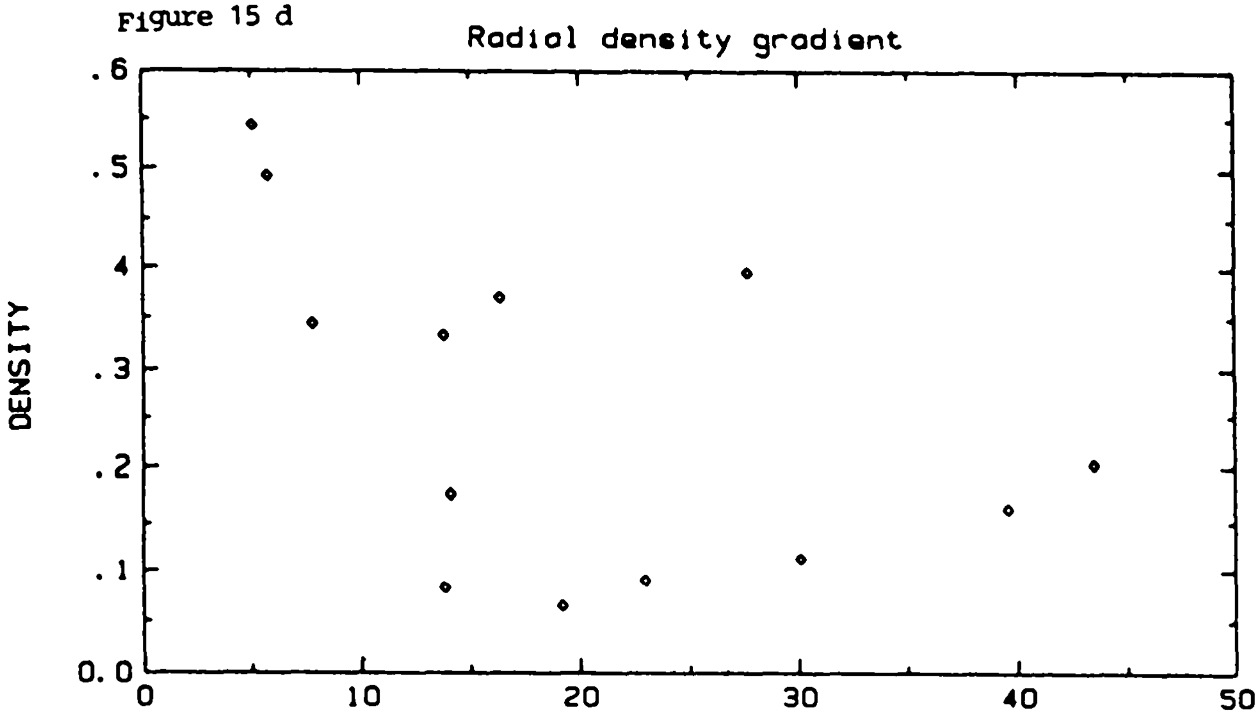

Figure 15e

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