Aspects of Geneva photometry : part 6 : clouds of dust

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Aspects of Geneva Photometry[1]

Part 6 – Clouds of Dust

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In this sixth part of the article, we apply the ability of our photometry to determine the distance and reddening of B-type stars. These young and massive stars are still partially associated with the interstellar clouds that formed them, and their high intrinsic luminosity facilitates their observation out to great distances. Various techniques can be applied to the description of the dust distribution in the solar vicinity via the mapping of interstellar reddening. One of the more recent methods uses techniques akin to tomography as practised in the medical sciences and by geophysicists. It is used here to map the local interstellar dust clouds up to a distance of about 2 kiloparsecs.

6. Our immediate neighbourhood in the Galaxy

6.1. Overview

As we have mentioned in the preceding sections, our solar system is presently in a particularly empty region in the galactic plane. The local atomic gas density (essentially hydrogen and helium) is of the order of 0.1 cm^{-3} and that of interstellar dust particles is about 10^{-14} cm^{-3}. At distances greater than some 100 pc, we encounter densities of gas and dust exceeding the local ones by an order of magnitude, or more. In dense star forming clouds, these values may increase by several further orders of magnitude.

[1] Adapted from *Archs Sci. Genève, Vol. 56, Fasc. 1, pp. 11-38, Juillet 2003*. Based on data acquired at the La Silla (ESO, Chile), Jungfraujoch and Gornergrat (HFSJG International Foundation, Switzerland), and Haute-Provence (OHP, France) observatories.

Very little is known regarding the presence, in interstellar space, of larger aggregates with „macroscopic" sizes ranging from a few millimetres to even a few kilometres. There is some direct evidence for particles of „shooting-star" size. Occasional micro-meteorites having „interstellar" velocities (100 km/s or more) have been detected by radar surveys. No larger bodies have yet been observed. They are reasonably expected to be much rarer, but cannot be ruled out altogether. We may reflect on the recent discovery of large, planetary sized objects in the KUIPER belt region by new telescopes equipped with powerful detectors. We are currently facing a selection effect in that regard, whereby the largest objects are discovered first, implying that a far greater number of smaller bodies are also present. The number of the latter will depend on the *mass distribution* of the relevant population – which is unknown. The estimated total mass of the KUIPER belt as well as that of the OORT cloud may have to be revised upward in the coming years.

Comparable dark bodies in interstellar space are all the more difficult to detect due to the greater distances involved and to their remoteness from stellar sources of radiation. However, considering the tenuous gravitational binding of the OORT cloud objects with our Sun, and the reasonable assumption that our star is not overly exceptional in comparison with its kin, we should expect that a large number of „cometary" objects gradually escape from their parent stars and do populate interstellar space. There is no evidence whatsoever supporting the assumption that their presence contributes appreciably to the large scale distribution of interstellar mass density due to gas and dust, nor to any significant degree to the question of the „missing mass" in our galaxy. The subject is, nevertheless, most interesting from an astrophysical point of view; and is truly embarrassing from that of the Science Fiction author who has to send his star-ship crews cruising at light speed through such a perilous and unpredictable medium!...

So, „coming down to Earth again", we may sum up by stating that our ground-based perception of interstellar space is essentially limited to the study of gas via various spectroscopic techniques and to that of dust via photometry. As discussed in the previous sections of this article, interstellar dust is indeed one of the more important factors affecting multicolour photometry.

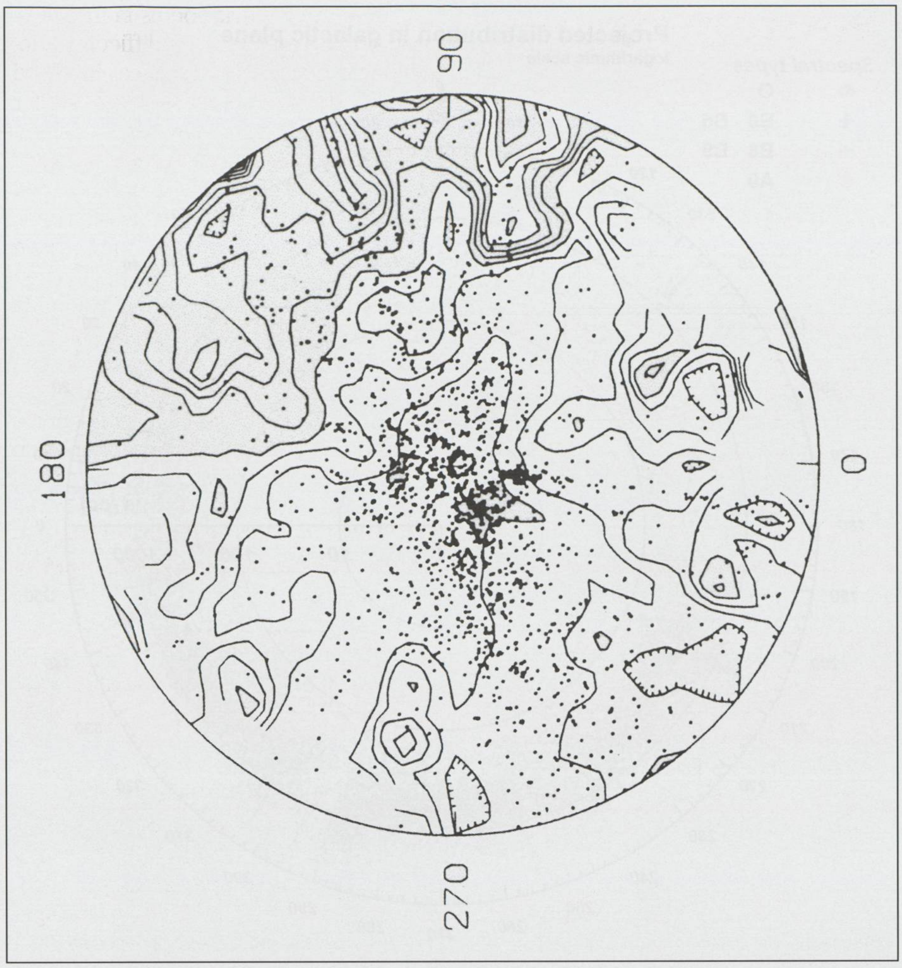
6.2. Detecting and measuring dust clouds

Ever since E. E. BARNARD (1857-1923) charted dark interstellar dust clouds in the early 20th century, and provided the proof that they were not just voids in space but consisted of material that absorbed the light of stars in the background, the estimate of their space distribution and density has been one of the recurring problems of astrophysics.

The most straightforward way of tackling the question is by first estimating the light absorption in the foreground of stars and relating that extinction to the quantity of dust encountered along the respective lines of sight. The remaining quantities to be determined are the distances of each of those stars.

The colour excesses measured by multicolour photometry have been quite generally used to that end during the second half of the 20th century. The pho-

Fig 66. Clouds of water vapour are driven over the Theodul Pass by a strong Föhn wind, as seen by moonlight from the Gornergrat Observatory.



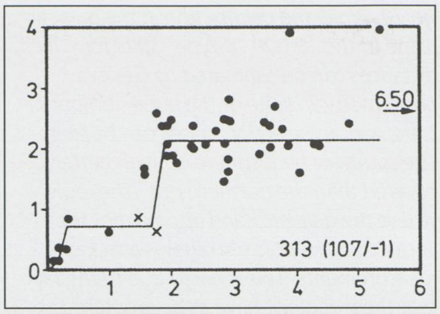


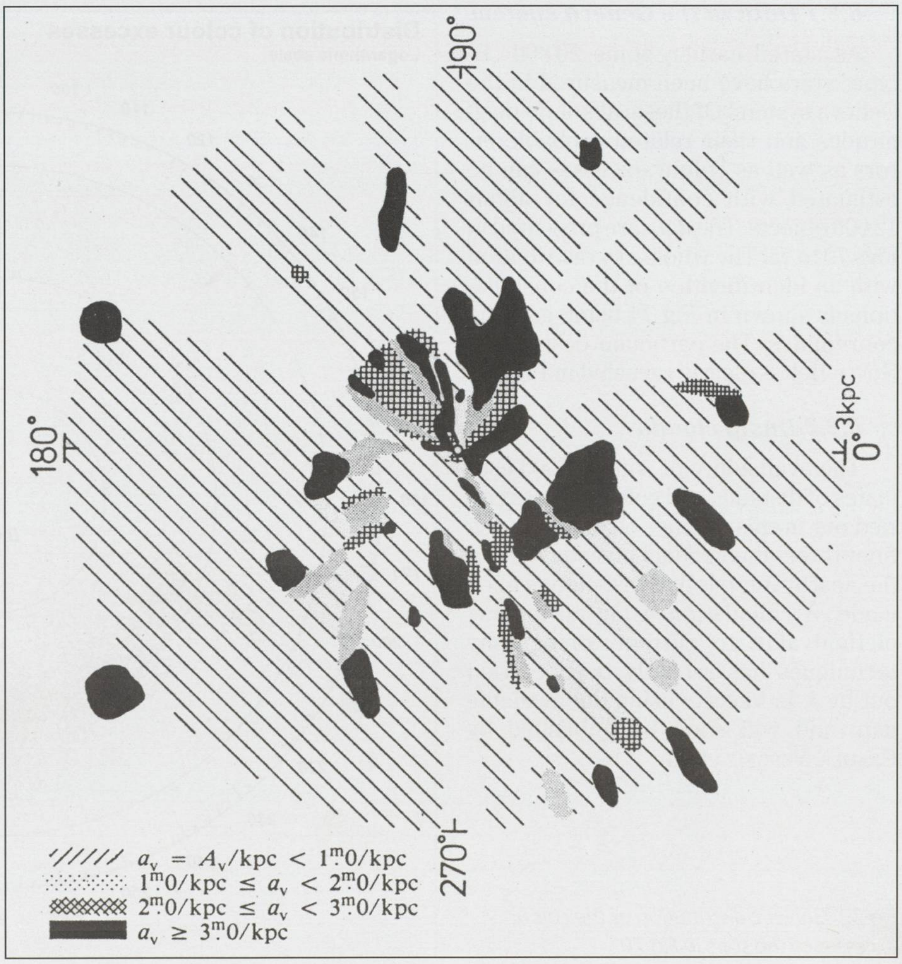
Fig 68. One of the 325 fields in the galactic belt explored by NECKEL and KLARE (1980) to establish the interstellar dust distribution in the solar neighbourhood. The graph shows visual absorption in magnitudes as a function of estimated stellar distance in kpc. One notes absorption starting at about 100 pc and increasing up to about 300 pc due to a cloud that is consequently some 200 pc thick. Absorption then remains constant throughout a clear region until about 1.8 kpc when another similar, but apparently denser cloud is encountered along the same line of sight. The interstellar medium then becomes essentially transparent from 2 kpc onwards and up to at least 5 kpc (adapted from NECKEL and KLARE, 1980).

Fig 69. The distribution of visual absorption by dust in the 3 kpc radius surrounding the Sun in the galactic plane as determined by NECKEL and KLARE (1980).

Fig 67. Distribution of visual colour excess in the galactic plane within 500 parsecs as determined by Lucke (1978).

tometry most extensively used was the UBV system. We can mention the work of PETER B. LUCKE (1978), who estimated the colour excess distribution in the galactic plane and provided their iso-contours out to distances reaching 1000 pc (Fig 67). The intrinsic colours he used for deriving the colour excesses and the absolute magnitudes of the stars were computed using relations between the latter quantities and their MK spectral classification.

Another notable study of the distribution of interstellar extinction in the galactic plane surrounding us was made by TH. NECKEL and G. KLARE (1980). UBV photometry and spectral classification were likewise at the basis of their work, but the authors also used an M_V versus β index calibration to estimate the absolute magnitudes when such photometry was available. Their method consisted in estimating the visual absorption versus distance behaviour in a large number of restricted areas identified by photographic surveys and showing significant extinction in the galactic plane. Their mapping of dark clouds extends up to almost 3 kpc (Figs 68 and 69).



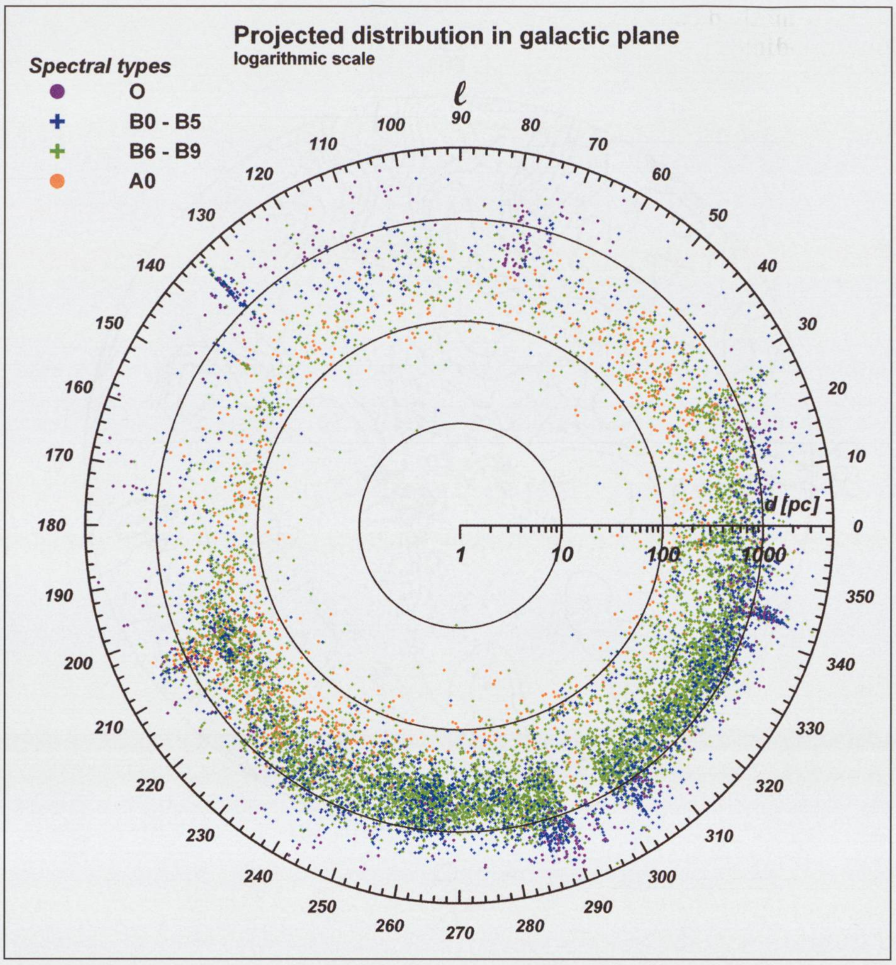


Fig 70. Projected distribution in the galactic plane of the 12 000 "B-type" stars for which distances can be estimated by Geneva photometry. In spite of the large number of stars, various selection biases can be seen. The southern hemisphere is much better covered than the northern one. The region where the galactic band approaches the South celestial pole also shows a lack of measurements. This is partly due to the fact that those regions have to be measured at higher air masses, and were neglected by the observers.

The data collected in the Geneva system are, however, more homogeneous than UBV photometry and MK spectral classification from a metrological point of view, and the calibrations described in this series of articles are more self-consistent regarding the B-type stars than the other available methods. On the other hand, the whole-sky coverage is less complete – particularly in the northern hemisphere – because of the dedication of the P7 photometer to observations in the optimal conditions offered by the ESO La Silla site in Chile. The quantity of data is nevertheless important, and we present here a first result of the mapping of dust clouds up to a distance of about 2 kpc using our calibrations.

6.2.1 Data in the Geneva system

As stated earlier, some 20 000 „B-type" stars have been measured in the Geneva system. Of these, absolute magnitudes and their related probable errors as well as colour excesses can be estimated with confidence for about 12 000 objects. The data are presented in Figs 70 to 75. The whole-sky distribution with an identification of the constellations is shown in Fig 74 using galactic coordinates. The particular case of the GOULD Belt is clearly revealed in Fig 75.

6.2.2 Dusty clouds

The availability of some 12 000 estimates of distance and colour excess carried out in this manner enables a much finer three-dimensional investigation of the nearby interstellar dust clouds to be made. A calculation using an inverse method akin to current tomography techniques has recently been carried out by J.-L. VERGELY using the available data and will soon be published by CRAMER, VERGELY et al.

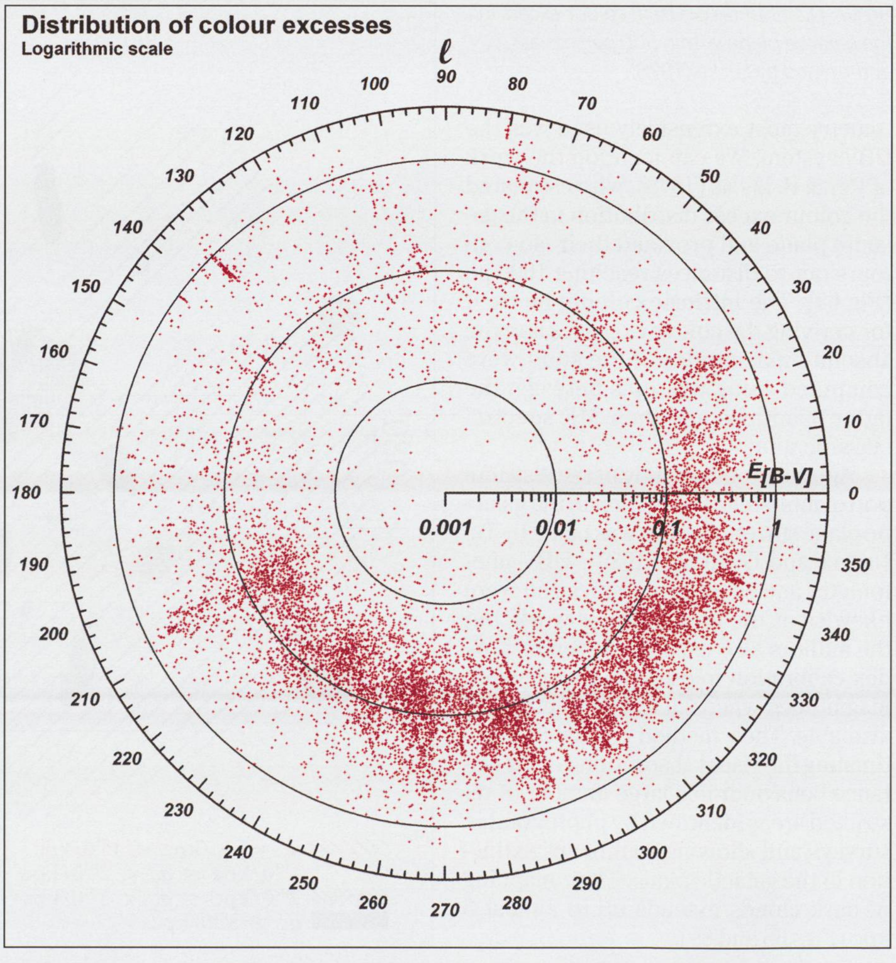


Fig 72. Galactic distribution of the colour excesses of the stars in Fig 70.

The method consists in constructing a 3-dimensional model of interstellar absorption that reproduces the observed data via their intrinsic values estimated by calibrations. It is highly computation–intensive (inverting of 12 000 12 000 x 12 000 matrices in the present case) but has the advantage of largely eliminating the formation of radial heliocentric biasing that inevitably occurs with an indiscriminate use of error-prone distance estimates.

The spatial resolution of the method depends critically on the density of the stellar population. B-type stars are relatively sparsely distributed. But, on the other hand, their colour excesses can be determined with higher accuracy than those of later types. In the current survey, the effective „smoothing length" of the modelling is about 150 pc. We therefore describe the *large-scale* dust structures. Small features, such as the Coal Sack dark cloud, for example, do not stand out.

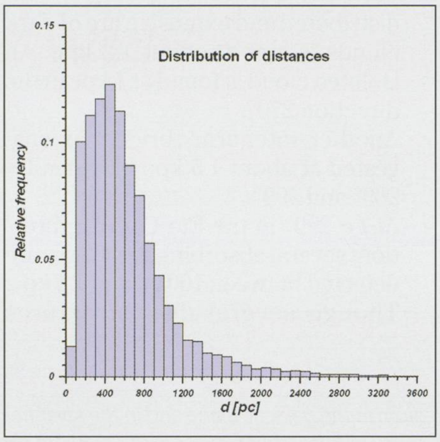


Fig 71. Frequency distribution of the distances of the stars in Fig 70. The sampling becomes less and less complete for distances greater than some 600 pc.

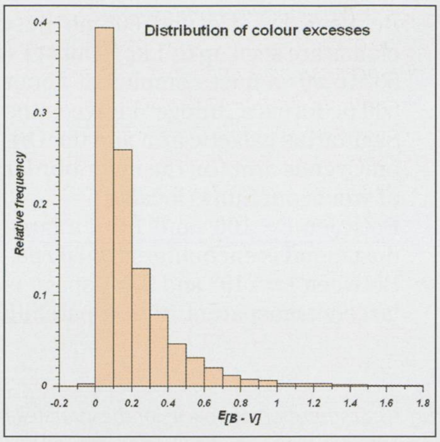
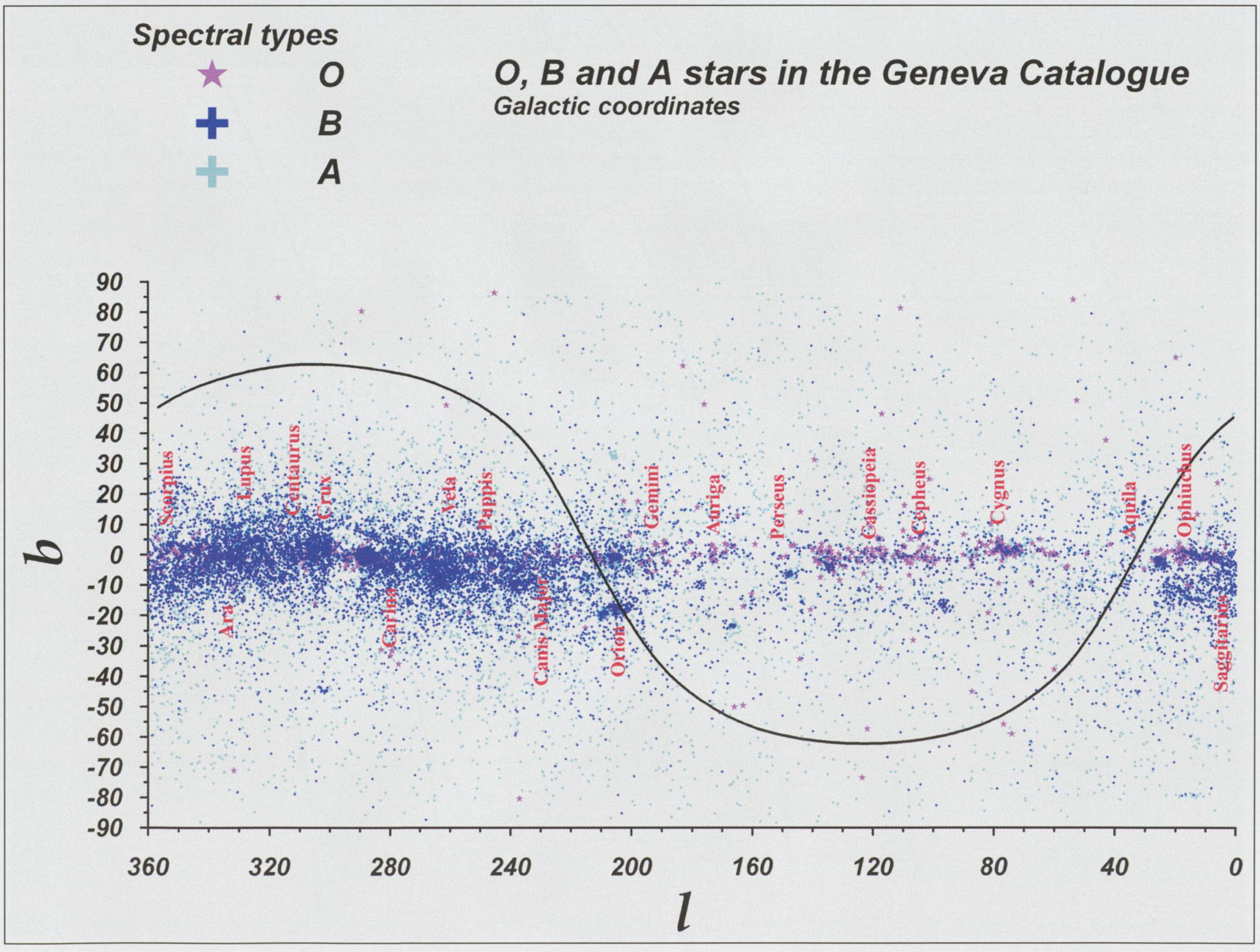


Fig 73. Frequency distribution of the colour excesses of the stars in Fig 70.

Though yet unpublished in its definite form, we discuss here some of the salient features exposed by that study in the galactic plane (Figs 76 and 77).

As expected, dust clouds are detected in relation with the GOULD belt. Notably the Ophiuchus complex in the direction of the galactic centre and above the plane at a distance of some 150 pc; or the Orion complex, below the galactic plane, at l ≈ 210° with d ≈ 500 pc. Otherwise, if we limit our view strictly to the galactic plane as in fig 76, we note:

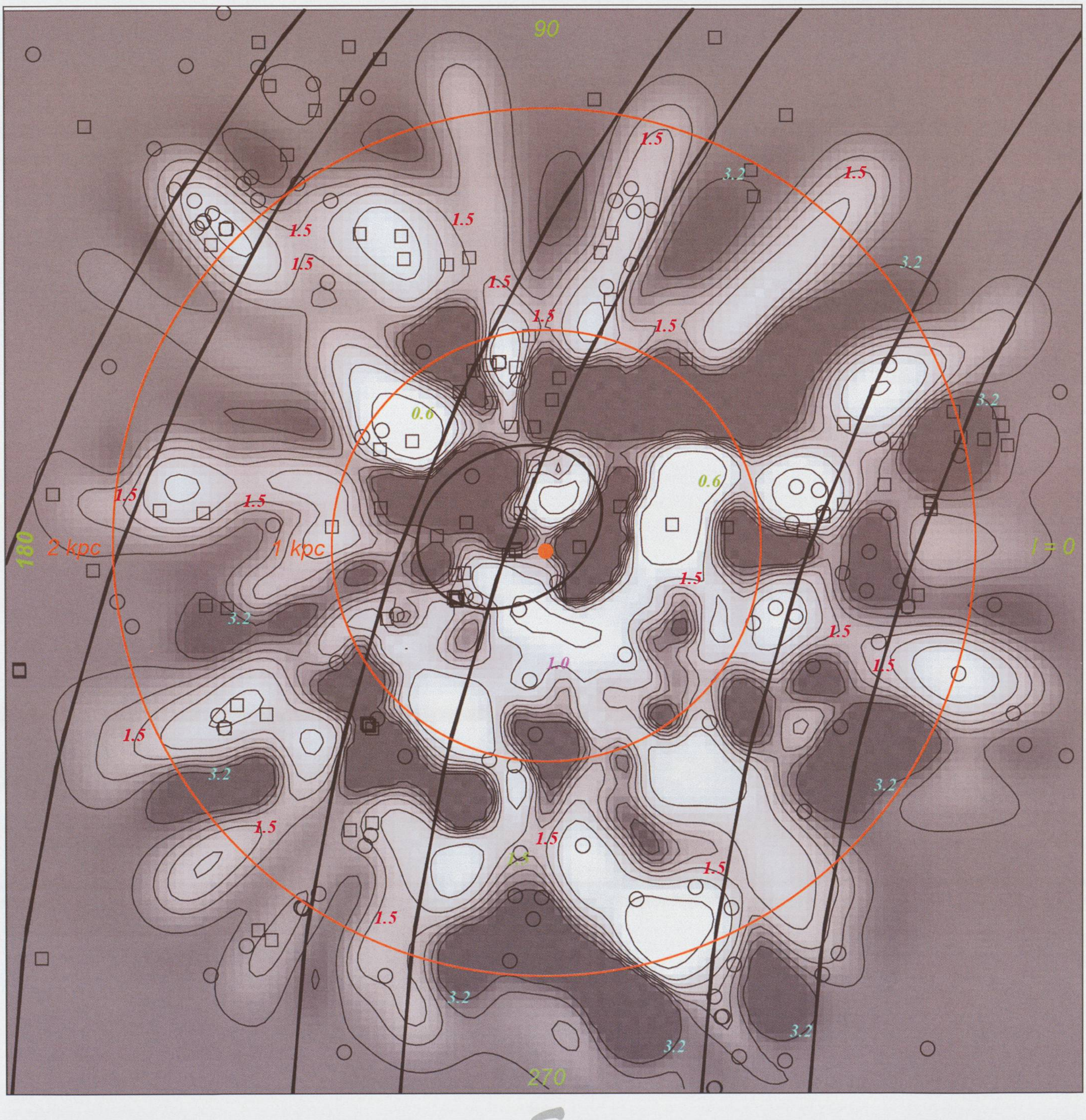
Fig 74. Distribution of the stars in Fig 70 in galactic coordinates. The solid line is the celestial equator. The mean longitudes of the galactic constellations are indicated.



- Between l = 45° and 60° no dust clouds are seen up to 1 kpc, but at l = 60° to 90° a dust complex at about 500 pc forms a „bridge“ between the Sagittarius galactic arm and the Orion-Cygnus arm (on the inner border of which our Sun is located).
- Between l = 100° and 140°, a large dust cloud is encountered at 300 pc.
- Between l = 210° and 270°, space is largely transparent until a patchily distributed and extensive arc of dark clouds is met at about 1.2 kpc. An isolated cloud is found at 1 kpc in the direction 270°.
- Another inter-arm „bridge“ is suggested at about 1.5 kpc between l = 260° and 290°.
- At l ≈ 290° in the Eta Carinae direction, several absorbing structures are detected between 100 pc and 1.5 kpc.

Though several dust structures do appear to be associated with spiral arms, no evident overall correlation seems to exist between extinction by dust and spiral arm indicators such as H II regions and young clusters. In our galactic neighbourhood, dust structures are distributed in the inter-arm regions and tend to “bridge” the arms as may also be observed in other similar disk galaxies (see Fig 78).

Fig 76. Distribution of opacity of the interstellar medium in the galactic plane and in the solar neighbourhood. The figure is a cross-section of the 3-dimensional opacity distribution derived by CRAMER, VERGELY et al. Centred on the Sun, it also shows the position of the GOULD belt (ellipse at centre) as well as (from left to right) the bands corresponding to the Perseus, Orion-Cygnus and Sagittarius arms. Open squares are H II regions, open circles are young open clusters. The galactic centre lies in the direction l = 0, to the right, and this map may be directly compared with Figs 67 and 69. The apparition of radial features beyond 2 kpc is due to the scarcity of our data at those distances. The iso-contours are the estimated dust density in terms of 10^{-13} grains cm^{-3} and are given in steps of 0.425. The dust density is computed in the same manner as discussed in Part 5.



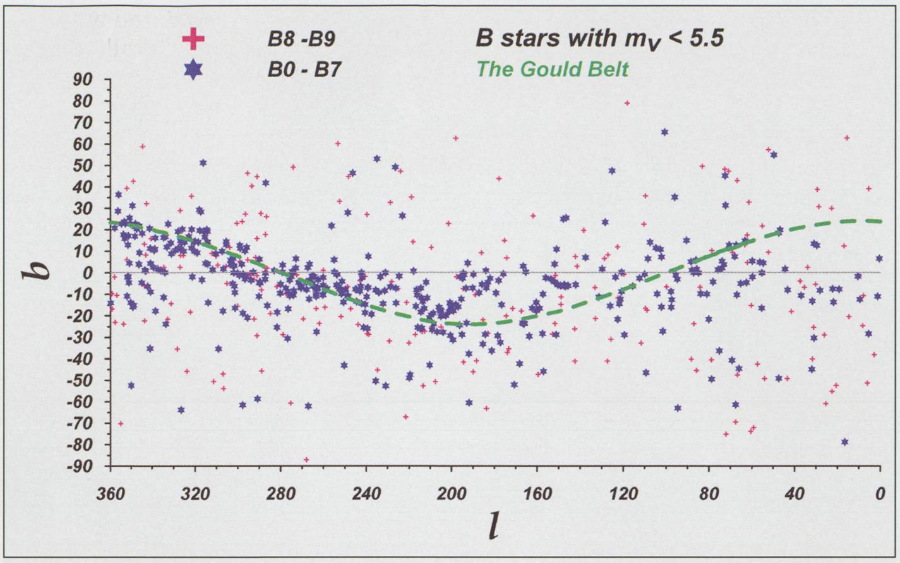


Fig 75. If the data are restricted to the B-type stars brighter than $m_v = 5.5$, the location of that young and nearby population stands out very clearly as a disk inclined relatively to the galactic plane by about 20°. The Scorpio-Centaurus association and the Orion region are prominent features of that roughly ring-shaped star forming region known as the "Gould Belt". Its formation is still actively debated, and its dynamical age (20 to 30 million years) conflicts with the estimated ages of its stellar content (30 to 60 Myr). The youngest OB stars (Upper Scorpius region) were formed 20 to less than 10 million years ago. One of the possible origins of the „Gould Belt" could have been a chain of supernova events occurring near the α Per association some 35 Myr ago.

The more detailed discussion of the method used, including the complete 3-D cartography with density distribution of the mentioned features and a comparison with the literature is to be published in a forthcoming issue of *Archives des Sciences*.

6.3. Concluding remarks

As these three examples have shown, the mapping of the „solid" matter pervading the „empty space" in our galactic neighbourhood in the form of dust is not yet close to being an „exact" science. But the situation is expected to improve greatly if the GAIA satellite mission is carried out successfully in the years following 2012. So, star-ship captains beware! Wait another few years before starting out on your journey.

The next – and last – part of this article will address the subject of chemically peculiar massive stars.

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Fig 77: Distribution of opacity of the interstellar medium perpendicular to the galactic plane for two adjacent sections at 15° in galactic longitude to each-other. The first one points toward the Scorpius-Ophiuchus clouds, inward; and to Gemini-Auriga, outward. The second looks toward Ara-Lupus, inward; and to Auriga-Perseus, outward. A total of 12 such sections give us a 3-Dimensional view of the large scale dust distribution in the local galactic medium. The densest dust clouds are bordered by dust densities of more than $3\ 10^{-13}$ grains cm^{-3}.

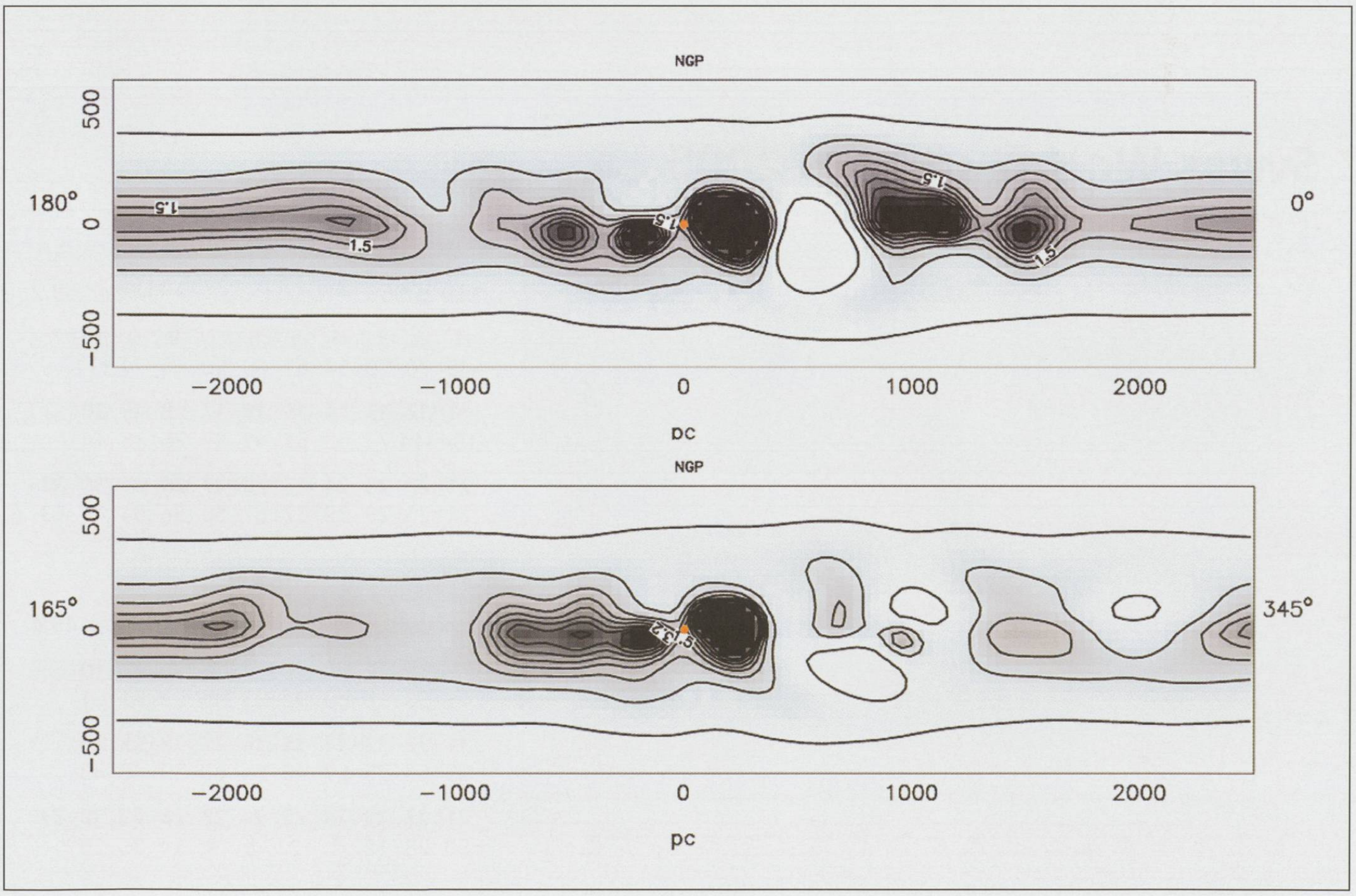

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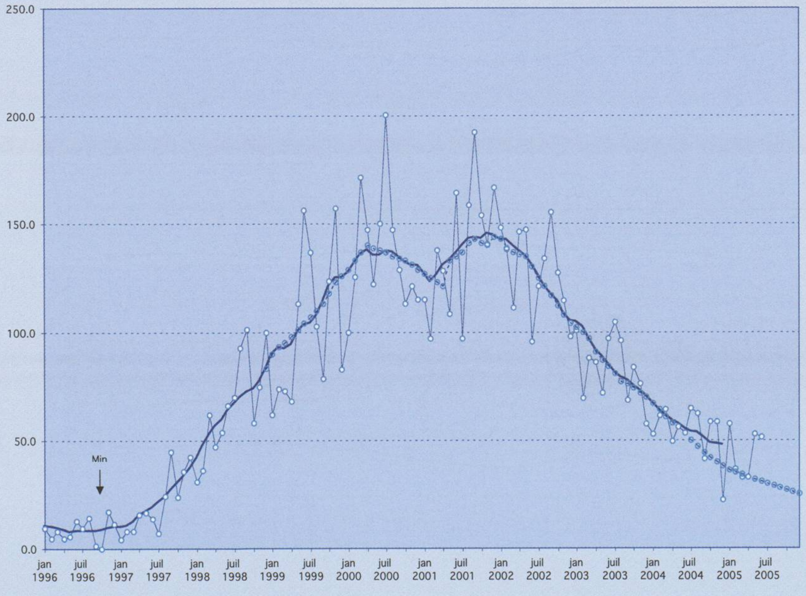
Fig 78. The spiral galaxy M 74 (NGC 628). At a distance of 10.7 Mpc (35 million light years) and slightly smaller in size and stellar population than our own galaxy (about 30 kpc in diameter), M 74 is oriented face-on and gives a good idea of what we would see if we were able to travel a few hundred kpc above our galactic plane. The spiral structure is highlighted by vast amounts of gas and dust that provide the basic materials for star formation. Young star forming regions rich in hot massive stars give the bluish tinge to the less central parts of the spiral arms. The redder central regions of the galaxy are more densely populated by older, less massive and cooler stars as well as occasional evolved red giants. Our galaxy would, however, present more tightly woven spiral arms and portray a larger and slightly elongated ("barred") central bulge. The yellow circle has been scaled so as to put into context the heliocentric region of 2 kpc radius explored in fig 76 relatively to our position in our own galaxy, and illustrates its very local nature. Such a "small" sampling would not be suited to infer the large scale spiral structure of our galaxy (Radio- and infrared wavelengths are applied to that purpose). Our study does, however, show that dust lanes are not uniquely distributed along the spiral arms but also tend to bridge them, as seen at several locations in M 74. (Photo: Gemini North Observatory, GMOS team, Hawaii).

Swiss Wolf Numbers 2005

Marcel Bissegger, Gasse 52, CH-2553 Safnern



Mai 2005 Mittel: **53.2**

1	2	3	4	5	6	7	8	9	10
49	70	59	54	61	60	50	60	74	111

11	12	13	14	15	16	17	18	19	20
104	114	73	63	53	49	37	26	18	14

21	22	23	24	25	26	27	28	29	30	31
21	26	23	29	37	57	56	56	54	47	63

Juni 2005 Mittel: **46.4**

1	2	3	4	5	6	7	8	9	10
73	58	38	69	91	93	107	93	81	81

11	12	13	14	15	16	17	18	19	20
69	66	35	57	49	64	60	39	42	43

21	22	23	24	25	26	27	28	29	30	31
50	28	12	2	2	2	9	14	35	85	