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COMPARISON BETWEEN RADIO AND OPTICAL SURFACE BRIGHTNESS DISTRIBUTIONS IN THE MAGELLANIC CLOUDS

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I

The distribution of radio surface brightness in the Large Cloud has been measured at 3·5 metres by Mills [1], and in the 21-cm. line by Kerr, Hindman and Robinson [2], in Sydney. A comparison with the distribution of the optical surface brightness in red light ($\lambda\lambda$ 5600–6600) [7] and with the surface density of stars brighter than $m_{pg} = 14{\cdot}0 (M_{pg} = -4{\cdot}7)$ [3], determined by the author at Mount Stromlo, is made in this paper.

Fig. 1 shows the observed distributions of red light (i.e. faint stars), bright stars, neutral hydrogen and 3·5 metres radiation.* At 21 cm. the velocity separation makes it easy, at least in principle, to separate-out genuine Cloud features from the foreground galactic radiation. The distinction is still fairly definite in the photometry in red light where the unresolved background radiation, measured on small-scale photographs between the brighter stars ($m < 11$) and corrected for a smooth galactic gradient across the field, must refer mostly to the Cloud. For the bright-star counts confusion by the galactic field stars becomes serious and it is often difficult to decide whether an excess of star density in the outer parts of the field indicates a significant Cloud structure or merely a fluctuation in the foreground. At 3·5 metres the large irregularities of the background and calibration difficulties make most uncertain the separation of the radiation associated with the Cloud. In all cases a rather conservative attitude has therefore been adopted in determining the extent of the excess brightness (or density) associated with the Cloud. The accuracy and reliability of the data is probably best for light and poorest for 3·5 metres, with hydrogen and bright stars intermediate; but all the present data should be considered as preliminary and subject to revision.

* The 21-cm. map differs slightly from that originally published as it includes some subsequent minor revisions of the data.

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For comparison with the radio contours the optical distributions were in each case smoothed with the appropriate reception diagram of the radio-telescopes whose beam-widths between half-power points are $0^\circ\!.8 \times 1^\circ\!.0$ (at 3·5 metres) and $1^\circ\!.5 \times 1^\circ\!.5$ (at 21 cm.). Fig. 2 shows by comparison with Fig. 1 the effect of smoothing with the 21-cm. beam. A key map [3] of the major structural features of the Cloud as shown by direct photography is added for reference in Fig. 4. The complexity or amount of structure shown by the various elements, after smoothing, is greatest for the bright stars, least for 3·5 metres and light, with 21 cm. intermediate. The different methods of reduction used tend, however, to exaggerate the details of the 21-cm. picture and to smooth out any 3·5 metres fine structure.

Bearing this in mind, Figs. 1 and 2 indicate the main characters of the *absolute* distributions as follows:

(1) The faint stars are very strongly concentrated in the axial 'bar' and only moderately so in the spiral arms, especially in the inner, asymmetrical arm near $5^h\,30^m$, -67°. There is also some concentration in the bright region near 30 Doradus ($5^h\,40^m$, -69°).

(2) The bright stars are very strongly concentrated in the spiral arms, especially the inner, asymmetrical arm, and in the bright region around and preceding 30 Doradus. Their near absence in the axial bar is a conspicuous and probably very significant phenomenon [4].

(3) Neutral hydrogen shows a pronounced concentration in the bar and in the 30 Doradus area; there are also indications of relatively high density in the inner, asymmetrical arm.

(4) The 3·5 metres radiation has a sharp maximum around 30 Doradus, superimposed on a smooth distribution which bears little or no resemblance to other structural details of the Cloud. There is definitely no concentration in the bar.

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In order to study more closely the *relative* distributions, contour maps showing the variations of the ratio of each element (with the appropriate smoothing) to each of the three others were established and compared with the main types of structure found in the various parts of the Cloud. By analogy with the usual colour index this ratio was expressed in magnitudes with an arbitrary zero point. Only the variations of the ratio are of interest here. Contours of constant ratio index at half-magnitude intervals have been drawn for a number of combinations. The accuracy of the data does not warrant closer intervals. The most interesting example is reproduced in Fig. 3.

The main points which emerge from the comparisons are as follows:

(1) *Ratio of 21 cm. to light* (Fig. 3). There is a large excess of red light compared to neutral hydrogen in the core. As reference to Figs. 1 and 2 indicates, this is due to the fact that although both elements are markedly

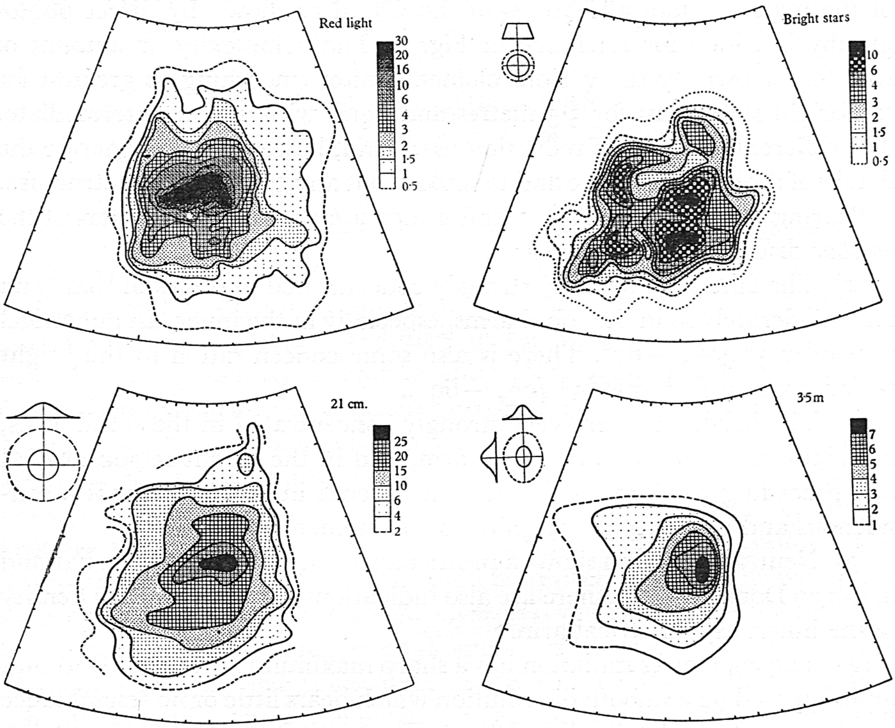

Fig. 1. Observed distributions of red light, bright stars ($m \leqslant 14$), neutral hydrogen (21 cm.) and 3·5 metres radiation in the Large Cloud. Intensities are on arbitrary scales. The beam profiles and diffraction disks are shown on the same scale.

concentrated in the axial bar, the degree of concentration is much higher for red light, i.e. faint stars, than for neutral hydrogen. Another area of excess light relative to hydrogen is in the following section of the Cloud, along R.A. $6^h\ 20^m$, where it is due mostly to the sharp decrease of hydrogen density in this direction—a check on the original data seems to confirm the reality of this hydrogen deficiency in the weak outer spiral arm or loop.

On the contrary there is an excess of hydrogen compared to light in the preceding section of the Cloud, especially near $4^h\ 40^m$, $-67°$, but this

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may be apparent only as there are signs of local (foreground) obscuration in this area. Hydrogen is also in excess relative to light in the regions occupied by the inner spiral arms, in particular near $5^h\ 30^m$, $-67°$; that is, in these spiral arms there is a greater degree of concentration for the gas than for the dwarf stars. Further, hydrogen seems to be also in relative

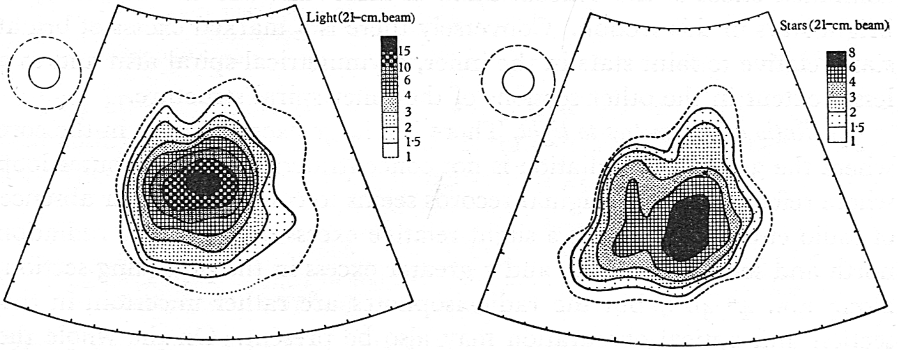

Fig. 2. Contours of the distribution of red light and of bright stars smoothed with an aerial beam of 1°5 diameter in order to make them comparable to the observed radio isophotes shown in Fig. 1.

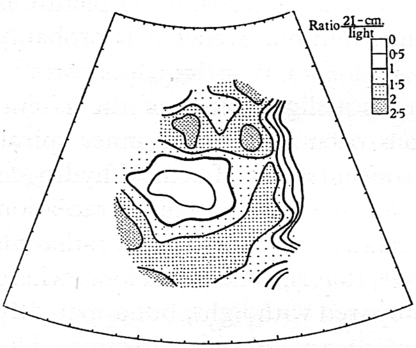

Fig. 3. Sample contour map of ratio index. This map shows the ratio of neutral hydrogen (21 cm.) to faint stars (red light).

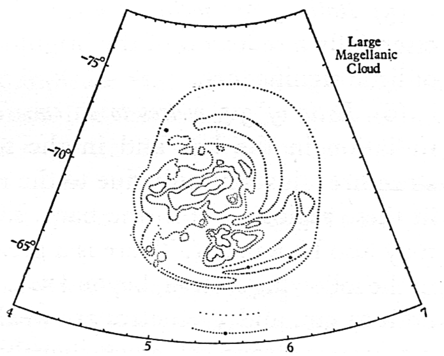

Fig. 4. Key map showing the main structure of the Large Magellanic Cloud appearing on photographs.

excess in the dark inter-arm spaces, for example near $5^h\ 15^m$, $-67°$ and $5^h\ 30^m$, $-73°$, where there is some evidence for the presence of dark matter in the Cloud [5].

(2) *Ratio of* 21 *cm. to bright stars.* There is a pronounced excess of hydrogen relative to bright stars in the axial bar and to the south of it which, as shown by Figs. 1 and 2, is due to both a real concentration of hydrogen and a marked deficiency of bright stars in this section. Conversely the bright stars are in excess in the inner spiral arms which they

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delineate; that is, the concentration of hydrogen in these spiral arms is much less marked than that of supergiant stars. In the outer spiral arm both hydrogen and bright stars seem to be rare or absent.

(3) *Ratio of bright stars to light.* There is a very large excess of light, that is faint stars, relative to bright stars in the axial bar; this results from the combined effect of the concentration of faint stars and the deficiency of bright stars in this section. Conversely there is a marked excess of bright stars relative to faint stars in the inner, asymmetrical spiral arm and to a lesser extent in the other sections of the inner spiral structure.

(4) *Ratio of* 3·5 *metres to light.* There is a large excess of light in the core where the 3·5 metres radiation is not concentrated, and in the outer loop where reference to the original records seems to confirm the near absence of radio emission. There is a slight relative excess of 3·5 metres radiation north and south of the core and a greater excess in the preceding section, along R.A. $4^h\ 40^m$, but the radio isophotes are rather uncertain in this section and optical obscuration may also be present. On the whole the relative distribution is to a large extent a reflexion of the optical distribution with which the radio distribution shows little correlation.

(5) *Ratio of* 3·5 *metres to bright stars.* The relative distribution picture is essentially a reflexion of the bright-star distribution. Hence it is probably of little significance.

(6) *Ratio of* 3·5 *metres to* 21 *cm.* There is a slight excess of the 21-cm. radiation in the bar and in the sections occupied by the inner spiral structure; this is mainly due to the real concentration of neutral hydrogen in these regions, but in the bar a slight deficiency of 3·5 metres radiation may also be a factor. There is a greater relative excess of 21-cm. radiation in the following section, beyond R.A. $6^h\ 00^m$, that is, in the outer loop, where both 21 cm. and 3·5 metres are weak compared with light, but apparently 3·5 metres drops off more sharply than 21 cm. in this direction. The 3·5 metres radiation is in excess in the 30 Doradus area as could be expected from the higher degree of ionization in the giant H II region.

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The main results of the comparisons in sections (2) and (3) may be summarized by the following table.

Scale: ** very strong concentration; * strong concentration; o some concentration; † element present, but not conspicuously concentrated; †† element very weak or absent.

The degree of relative variability, as measured by the range of the ratio

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index, is lowest between 21 cm. and 3·5 metres (range 1 mag.) and highest between bright stars and light (range 3 mag.) with bright stars/3·5 metres, bright stars/21 cm., light/21 cm. and light/3·5 metres intermediate.

Region in L.M.C.	Light	Bright stars	21 cm.	3·5 metres
Bright core (axial bar)	**	††	*	†
Bright region around 30 Dor.	*	**	*	**
Bright inner spiral arms	*	**	*	o
Dark inter-arm spaces	†	††	*	o
Faint outer arms	*	†	†	††

The effective radii defined by $A = \pi r_e^2$, where A is the area of the (smoothed) isophote enclosing half the total energy (or numbers of stars), are listed below for both the 3·5 metres and 21-cm. beams:

	Beam	Light	Bright stars	21 cm.	3·5 metres
Effective	(3·5 metres)	$2^\circ.6$	$2^\circ.7$	—	$3^\circ.0$
Radii r_e	(21 cm.)	$2^\circ.8$	$2^\circ.9$	$3^\circ.1$	—

Hence the gas and the source of the 3·5 metres radiation are somewhat less concentrated than either light (faint stars) or bright stars.

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These results taken as a whole tend to indicate that the space distribution of the source of the 3·5 metres radiation has, except in the H II regions, little in common with the distribution of stellar or interstellar matter. Hence the hypothesis of its originating in a tenuous electronic corona surrounding the main body of the stellar system [2, 6] is not inconsistent with the present evidence.

The existence of a definite concentration of neutral hydrogen in the bar where bright supergiant stars are rare or absent should be regarded as significant. It may be noted that, while ordinary giants (shown by star counts beyond $m = 14$) and dwarfs (as indicated by the red light distribution) are highly concentrated in the bar, dust clouds are rare and well localized in it.

In the inner spiral arms where supergiants are most abundant, there is a definite concentration of both faint stars and neutral hydrogen, but it is more pronounced for the latter which also seems concentrated in some dark (obscured) inter-arm sections.

In the faint outer arms both the brighter supergiants and the gas seem to be rare or absent. The same appears to be true for the outermost extensions, in particular for the 'anti-galactic' arm [3]. This may have evolutionary significance.

In the Small Cloud the data do not warrant as yet detailed comparisons, but if one allows for the smaller size, lower intensity, distortion and tilt of the system, it appears that the same elements bear the same general relations to each other as in the Large Cloud [1].

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