The Interstellar Extinction Toward the Galactic Central Region

著者	Ichikawa Takashi, Hamajima Kiyotoshi, Ishida Keiichi, Hidayat Bambang, Raharto Moedji
journal or publication title	Publications of the Astronomical Society of Japan
volume	34
number	2
page range	231-239
year	1982
URL	http://hdl.handle.net/10097/52574

Publ. Astron. Soc. Japan 34, 231–239 (1982)

The Interstellar Extinction toward the Galactic Central Region

Takashi ICHIKAWA*

Department of Astronomy, University of Kyoto, Sakyo-ku, Kyoto 606

Kiyotoshi HAMAJIMA† and Keiichi ISHIDA

Tokyo Astronomical Observatory, University of Tokyo, Mitaka, Tokyo 181

and

Bambang HIDAYAT and Moedji RAHARTO§

Bosscha Observatory, Institut Teknologi Bandung, Lembang, Java, Indonesia

(Received 1981 November 18)

Abstract

Interstellar extinction within 5 kpc from the sun is investigated in the field of $351° \leq l \leq 10°$ through $l=0°$ and $|b| \leq 2°$. About 2700 late M giants were detected in the field on Schmidt objective-prism plates in near-infrared wavelengths. The effective limiting distance of the survey and the interstellar extinction are estimated from the observed surface number density of the late M giants. The resultant extinction is presented in each area of $0\overset{\circ}{.}5 \times 0\overset{\circ}{.}5$. The averaged visual interstellar extinction per kiloparsec $\bar{a}_V$ and the limiting distance $\bar{r}_{\rm lim}$ in the whole region of $351° \leq l \leq 10°$ are $(\bar{a}_V, \bar{r}_{\rm lim}) = (1.8 \text{ mag kpc}^{-1}, 4.0 \text{ kpc})$ in $1° \leq |b| \leq 2°$ and $(2.1 \text{ mag kpc}^{-1}, 3.6 \text{ kpc})$ in $|b| \leq 1°$. Several transparent regions with low interstellar extinction are reported; these regions are useful for examining the inner region of the Galaxy.

Key words: Galactic structure; Galactic windows; Interstellar extinction; M giants.

1. Introduction

Transparent regions with low interstellar extinction are useful for examining the inner regions of the Galaxy. Baade's (1946) window ($l \sim 0\overset{\circ}{.}9$, $b \sim -3\overset{\circ}{.}9$) has most frequently been used for the study of the central bulge of the Galaxy (cf. van den Bergh 1968). In order to study the structure of the inner galactic disk or the inner spiral arms, new galactic windows should be searched for near the galactic plane.

---

* Visiting astronomer, Bosscha Observatory.

† Present address: Sugiyamajogakuen, Yamazoe 2-chome, Chikusa-ku, Nagoya 464.

§ Present address: Kiso Branch, Tokyo Astronomical Observatory, Mitake-mura, Kiso-gun, Nagano 397-01.

The surface distribution of the absorbing matter can be seen on the atlases of dark clouds (Khavtasi 1960; Lynds 1968). The space distribution of the interstellar extinction has been studied using color excesses of early-type luminous stars (Neckel 1967; FitzGerald 1968; Neckel and Klare 1980). These data are, however, based on observations at visual wavelengths and are restricted to within a few kiloparsecs from the sun.

Near-infrared observations of M giants are an efficient way to investigate interstellar extinction at considerable distances toward the galactic center. At low galactic latitudes the surface density of M-type stars is generally large, and these are in actuality no dwarfs (Blanco 1963). Moreover these stars can be detected and classified into the spectral subclasses easily on objective-prism plates at near-infrared wavelengths. Late M giants are considered to be relatively old and therefore represent the old stellar disk with an age of several times 10^9yr. We expect them to be more or less homogeneously distributed in the disk within a moderate scale height from the plane. Using these late M giants, we can investigate the interstellar extinction in the field of $351° \leq l \leq 10°$ and $|b| \leq 2°$. A detailed investigation in $354° \leq l \leq 358°$ and $|b| \leq 2°$ has been performed by Hamajima et al. (1981, 1982).

The present work uses the plates taken for the general red-giants survey covering $l=330°$ to $30°$ through $l=0°$ between $b=-2°$ and $+2°$, which is in progress at the Bosscha Observatory (Ichikawa et al. 1982).

Table 1. Plate log.

Field center (l, b)	Plate No.*	Date	Emulsion	Filter	Exposure time (min)	Prism vertex
Region 1	P1004	1979 July 26	IN$^+$	RG8	30	South
(353°, 0°)	P1012	August 25	IN$^+$	RG8	30	West
	P1033	August 28	IN$^+$	RG8	7, 3‡	West
Region 2	P 999	July 25	IN$^+$	RG8	35	South
(356°, 0°)	P1013	August 25	IN$^+$	RG8	10	West
	P1021	August 26	IN$^+$	RG8	20	West
	P1038	August 28	IN$^+$	RG8	7, 1.5‡	West
	1707	August 21	IN	RG8	30	—
Region 3	P 990	July 21	IN$^+$	RG8	45	South
(359°, 0°)	P1020	August 26	IN$^+$	RG8	22	West
	P1034	August 28	IN$^+$	RG8	7, 1.5‡	West
Region 4	P1051	1980 May 15	IN$^+$	RG8	30	North
(2°, 0°)	P1058	May 16	IN$^+$	RG8	30	East
	P1067	July 12	IN$^+$	RG8	35	East
Region 5	P1075	July 13	IN$^+$	RG8	30	South
(5°, 0°)	1895	July 7	IN	RG8	20	—
	1901	July 18	IN	RG8	20	—
Region 6	P1081	August 1	IN$^+$	RG8	30	South
(8°, 0°)	P1093	August 4	IN$^+$	RG8	40	East
	1910	August 16	IN	RG8	20	—
	1911	August 16	IN	RG8	20	—

* Capital P attached to the plate number means an objective-prism plate.
+ Hypersensitized plate with silver nitrate solution.
‡ Double-exposed plate.

2. Observations

The observations were carried out with the 51/71/127-cm Schmidt telescope of the Bosscha Observatory in 1979–1980. Unwidened spectral plates were taken with a 5° objective prism. The reciprocal dispersion of the spectra is 1870 Å mm^{-1} at the atmospheric A band. After being hypersensitized with silver nitrate solution, Kodak spectroscopic I-N plates were exposed through Schott RG8 filter. The resultant spectral range, called *I* hereafter since it is close to the Kron *I* band, is between $\lambda\lambda$ 6800 Å and 8800 Å. Pairs of plates were obtained with different vertex directions in order to avoid the effect of image overlaps.

Direct image plates for the *I* magnitude were also taken with the same emulsion-filter combination as for the spectral plates. These give us the limiting magnitude of the spectral plates.

The studied region of $351° \leq l \leq 10°$ and $|b| \leq 2°$ consists of six fields, each of which covers an area as large as $5° \times 5°$, with a separation of 3° to the next field center (figure 1). The spectral and direct plates of each field were obtained within one-month separation in order to avoid the effect of the variability of late M-type stars. A total of 32 spectral and 22 direct plates were obtained in the whole region, and 21 plates with good quality were analyzed for the present study. The plates used are listed in table 1.

3. Detection of Late M-Type Stars and the Limiting Magnitude

Searches for M-type stars were made on each spectral plate by two of the authors (TI and KH), who examined each plate at least twice. The spectral classification is based on the Case system (Nassau and Velghe 1964). Early M-type stars (M0–M4) were excluded from the count because of incomplete detection and possible contamination of the young population in spiral arms (cf. Mavridis 1971; Ichikawa 1981). A total number of 2748 late M-type stars (M5–M10) were recorded with confidence. The average surface number density is 37 stars per square degree. The number of stars in each area of $0°.5 \times 0°.5$ is shown in figure 1. The limiting magnitudes of the spectral plates were determined individually in

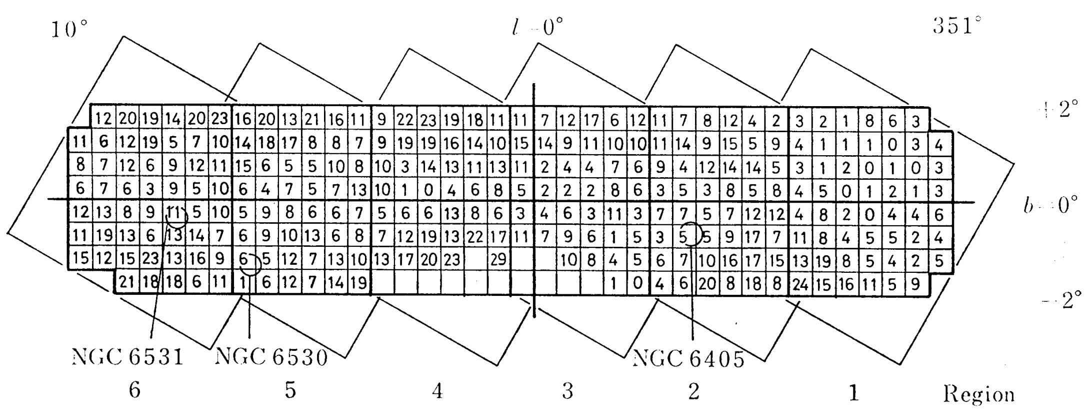

Fig. 1. The number of late M giants detected in each area of $0°.5 \times 0°.5$. The empty places are the field out of the present investigation because of the presence of too many stars on the spectral plates. The plate coverage of the six fields is also shown. Circles denote the positions of the open clusters, which offer the photometric standard sequences.

Table 2. The limiting magnitude m_{lim} of the present survey for each region shown in figure 1.

	Region					
	1	2	3	4	5	6
m_{lim} (mag)	12.0	12.3	12.2	12.4	12.5	12.6

regions 2, 3, 5, and 6 of figure 1, based on the cumulative number of the observed late M-type stars; if the increase of the cumulative number of the stars brighter than a given magnitude ceases or becomes comparatively small, the magnitude is regarded as the limiting magnitude. The limiting magnitude thus determined is expected to have an error of ± 0.2 mag at most.

The photometric standard sequences in the I magnitude were obtained from the conversion of the UBV data for three open clusters, NGC 6405 (Antalová 1972), NGC 6530 (Walker 1957), and NGC 6531 (Hoag et al. 1961), taking into account E_{B-V} to the clusters (Becker and Fenkart 1971). The transformation equation is adopted from Ichikawa (1981) as

$$I = V - 1.00(B-V) - 0.5E_{B-V} + 0^{m}.20 \quad (1)$$

for the stars of $-0^{m}.26 + E_{B-V} \leq B-V \leq 1^{m}.20 + E_{B-V}$. The positions of these clusters are indicated with circles in figure 1. The photometry was carried out with the irisphotometer at the Kiso Observatory of the Tokyo Astronomical Observatory and the microdensitometer at the Bosscha Obseratory.

The limiting magnitudes of regions 1 and 4 were estimated from the observed star numbers in the overlapped areas with the neighboring fields, since there are no photometric standard sequences. The limiting magnitudes thus obtained in regions 1 to 6 are between 12.0 mag and 12.6 mag in the I system, and are listed in table 2.

4. Interstellar Extinction

Adopting a space distribution model of the stars, one can estimate the limiting distance r_{lim} of the survey from the observed surface density. Using this r_{lim} in kiloparsecs, the absolute magnitude M_I on the present I band, and the limiting magnitude m_{lim} in table 2, one can obtain the total interstellar extinction A_I up to r_{lim}.

The stars we have at hand are the late M-type stars detected on the objective prism plates at the I color band. The late M-type stars thus detected can all safely be assumed as giant stars (Ishida and Mikami 1982).

For late M giants, M_I is obtained from the visual absolute magnitudes M_V given by Mikami (1978) with the intrinsic color $(V-I)_0$ of Blanco (1964) as shown in table 3. Since eighty percent of the late M giants detected are M 5–M 6.5 stars and the values of M_V for the later M giants are still uncertain, we adopted the mean absolute magnitude $M_I = -3.6$ mag of M 5–M 6.5 giants for all the late M giants.

Mikami et al. (1982) constructed from the star count in the Scutum region a space distribution model of the stars contributing to the near-infrared radiation in the Galaxy. The model demonstrates that the red giants are one of the major contributors to the 2.4-μm surface brightness (Maihara et al. 1978), as is shown

Table 3. Assumed absolute magnitudes of late M giants.

Quantity	Spectral type				
	M5	M6	M7	M8	M9
M_V	−0.9	0.1	0.5:	0.5:	
$(V-I)_0$	3.02	3.46	4.03	4.7:	5.4:
M_I	−3.9	−3.4	−3.5	−4.2	

Table 4. The predicted surface number density of late M giants from the space distribution model in an area of 0°.5×0°.5 as a function of the distance r from the sun.

(l, b)	r (kpc)						
	1	2	3	4	5	6	7
(0°, 0°)............	0	1	3	9	26	65	148
(10°, 2°)............	0	1	3	9	23	55	117

for the volume emissivity in the solar neighborhood (Mikami and Ishida 1981). The space density n of late M giants is expressed approximately by the following formula in the space volume concerned at the present investigation:

$$n(R, z)=n_0 \exp\left[-(R-R_0)/R_e\right] \exp\left(-z^2/2z_e^2\right), \qquad (2)$$

where R and z are the distances from the galactic center and from the galactic plane, $R_0=10$ kpc the distance of the sun from the galactic center, n_0 the space density in the solar neighborhood, $R_e=2.3$ kpc the scale radius of the galactic disk, and z_e the effective height of the disk. We adopted $n_0=1.5$ stars per 10^6 pc^3 and $z_e=0.39$ kpc for late M giants from the result of an analysis of the IRC catalog (Mikami and Ishida 1981).

The predicted surface number density in an area of 0°.5×0°.5 from the space distribution model is shown in table 4 as a function of the distance r from the sun in two representative directions. Referring to this predicted surface density, we obtain r_{11m} in each direction and show it in figure 2a. After correcting for Malmquist's effect of 0.4 mag, we depict in figure 2b the average visual interstellar extinction a_V (mag kpc^{-1}) converted from A_I and r_{11m} with the relation $a_V=2A_I/r_{11m}$.

The error in r_{11m}, which is the propagated statistical error in the observed star number, is about 15 percent at 3 kpc and 5 percent at 5 kpc from the sun. The error in a_V is due to the error in r_{11m}, the error in the limiting magnitude (about ±0.2 mag), and the dispersion of the absolute magnitude (about ±0.6 mag); the resultant error is ±0.7 mag kpc^{-1} at 3 kpc and ±0.3 mag kpc^{-1} at 5 kpc.

5. Discussion

We find several interstellar windows in figure 2b, for example, in the directions of $(l, b)\sim(355°, -1°.5)$, $(2°, -1°)$, and $(9°, -1°)$. Hamajima et al. (1981, 1982) investigated one of these windows near $l=355°$, $b=-1°$, and concluded that the low interstellar extinction in this direction probably caused the anomalous enhancement of the infrared 2.4-μm diffuse radiation observed by Oda et al. (1979). From the present study this window turns out to extend to $l\simeq352°.5$, $b\simeq-2°$ and

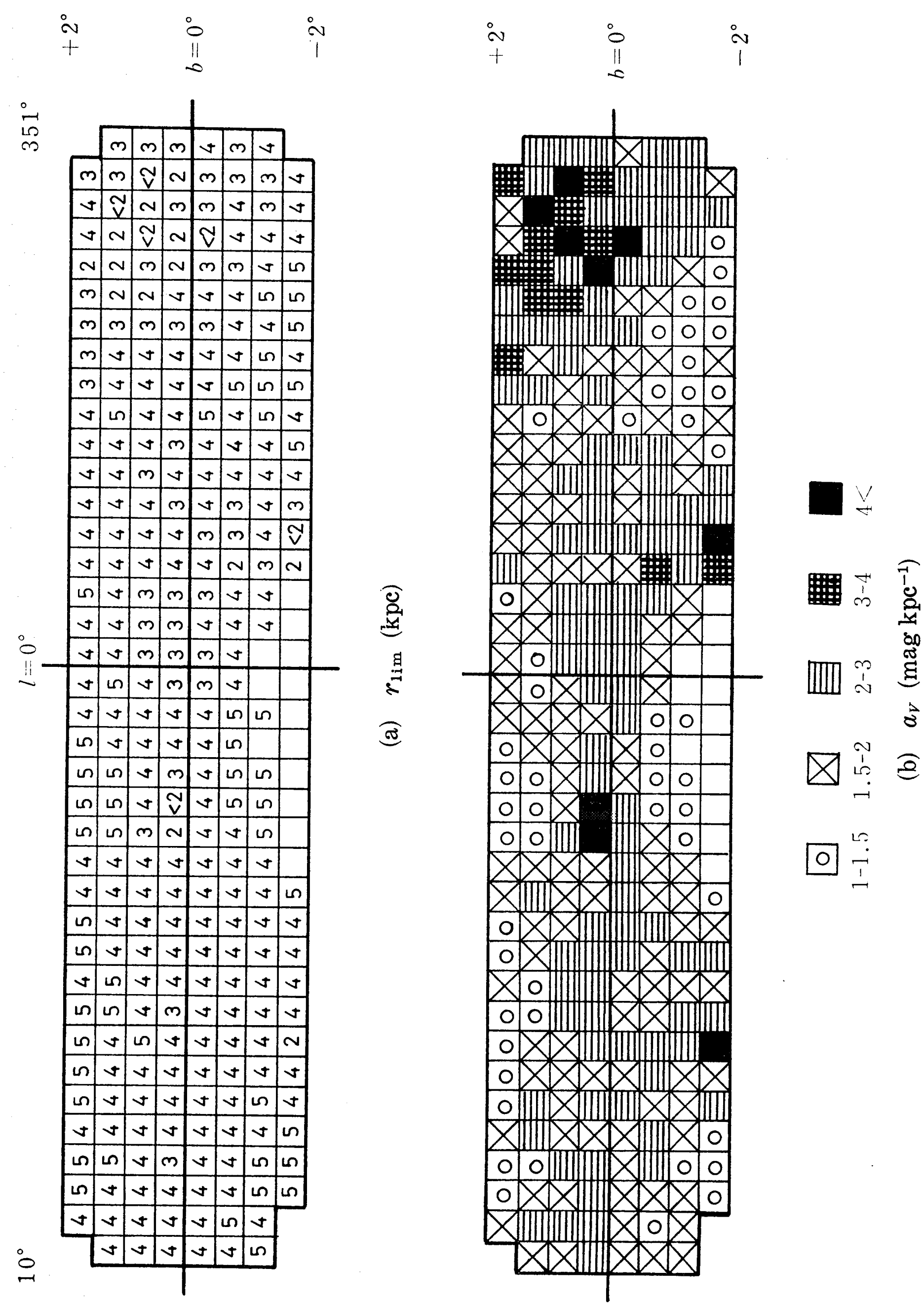

Fig. 2. (a) The limiting distance $r_{\rm lim}$ of the present survey in each area. (b) The average visual interstellar extinction a_V to the distance shown in (a).

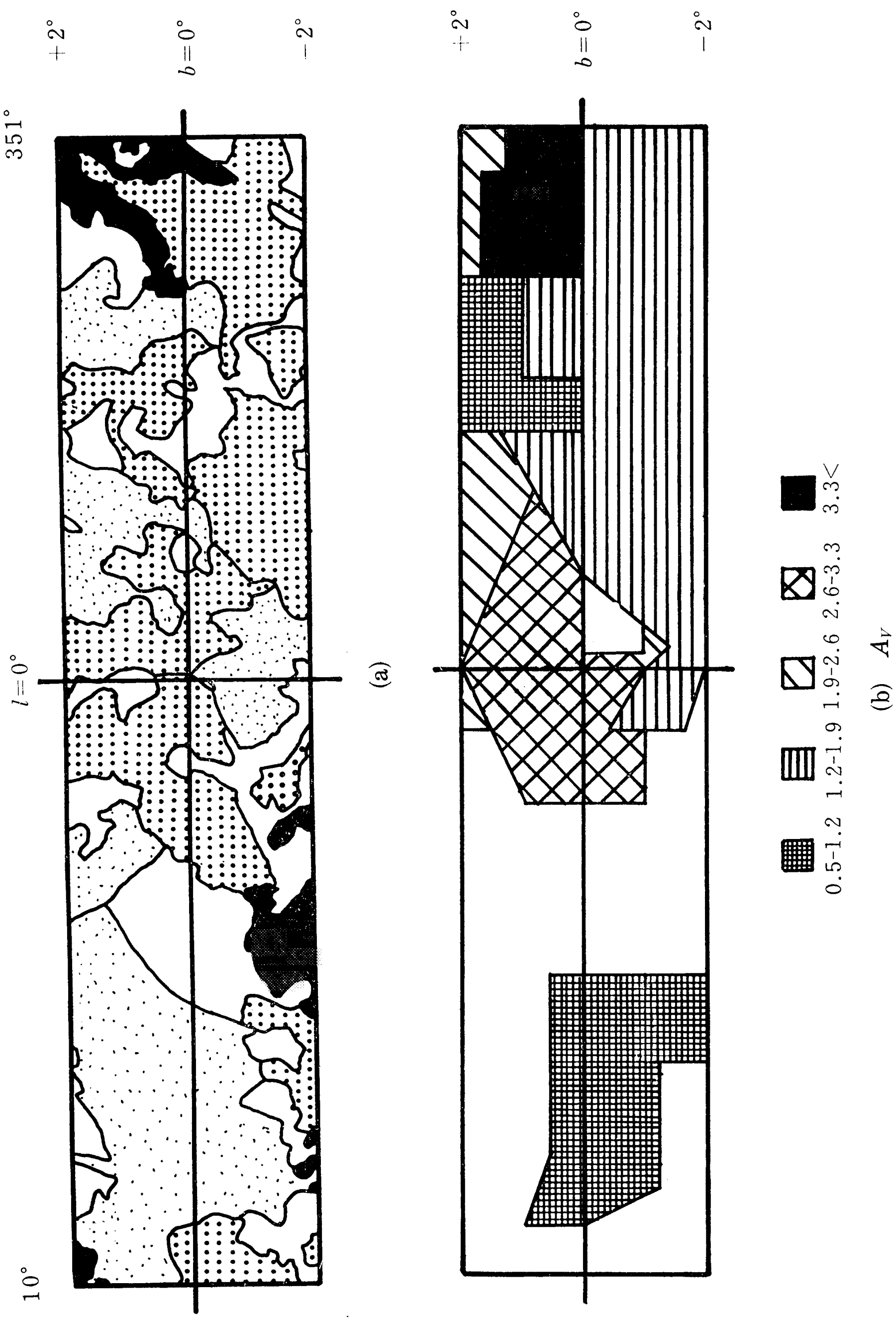

Fig. 3. (a) The atlas of dark clouds of Khavtasi (1960). (b) The surface distribution of the total interstellar extinction A_V up to 1 kpc from the sun given by Neckel and Klare (1980).

to have a size as large as about 3.5 square degrees. The region of $l \sim 358.^\circ5$ to 3.5° and $b \sim -2^\circ$ to -1° may be most transparent, since the background density there on our spectral plates is too high due to the overlapping of stars to find M-type stars. This region is considered to form a part of the Sagittarius star cloud A which contains three well-known galactic windows (van den Bergh 1968).

We reproduce in figure 3a the distribution of dark clouds drawn by Khavtasi (1960) in our investigated region. Neckel and Klare (1980) have given a detailed map of the spatial distribution of the interstellar extinction in the whole galactic plane of $|b| \leq 7.^\circ6$, using the color excesses of luminous stars. Figure 3b shows their result up to 1 kpc from the sun. In comparison with figure 3b, it is noted that figure 2b depicts more detailed features in the distribution of the interstellar extinction, which are helpful in a search for small galactic windows. The most opaque region around $l \simeq 352.^\circ5$, $b \simeq +1^\circ$ seen in figures 3a and 3b is found also in figure 2b. The opaque regions in figure 2b are generally more concentrated on the galactic plane than those of figure 3a; this concentration is to be expected from the fact that the present result represents the distribuion of the interstellar matter at more distant places. The averaged $\bar{a}_V$ and $\bar{r}_{11m}$ in the whole region of $351^\circ \leq l \leq 10^\circ$ are $(\bar{a}_V, \bar{r}_{11m}) = (1.8$ mag kpc^{-1}, 4.0 kpc) in $1^\circ \leq |b| \leq 2^\circ$ and (2.1 mag kpc^{-1}, 3.6 kpc) in $|b| \leq 1^\circ$, while Sharov (1964) has given $a_V = 1.6$ mag kpc^{-1} at $b = 0^\circ$ near the sun.

The present study is based on the space distribution model of late M giants constructd from the data in the Scutum region alone (Mikami et al. 1982). The investigation of the space distribution of late M giants in the galactic windows reported here will improve the model. Although the inhomogeneity of the space distribution might affect our result, its effect would be small in the windows because of the large limiting distances.

The term "galactic window" used in this paper for convenience may not be appropriate, since our windows reported here are not so transparent as other well-known windows such as Baade's (1964). As a matter of fact our investigation is limited to about 5 kpc from the sun, partly because of the presence of too many stars on the spectral plates due to the small scale of our plates (170″ mm^{-1}). A telescope with a larger plate scale will improve the limiting distance and reveal additional transparent regions of smaller size by means of the same procedures that are used here.

Part of this work was financially supported by the Japan Society for the Promotion of Science and Directrate General for Higher Education, Ministry of Education and Culture, Indonesia, allocated to the Institut Teknologi Bandung. The travel expenses of T. Ichikawa between Japan and Indonesia are supported from the Exchange of Astronomers Program of IAU.

References

Antalová, A. 1972, *Bull. Astron. Inst. Czech.*, **23**, 126.
Baade, W, 1946, *Publ. Astron. Soc. Pacific*, **58**, 249.
Becker, W., and Fenkart, R. 1971, *Astron. Astrophys. Suppl.*, 4, 241.
Blanco, V. M. 1963, *Astrophys. J.*, **137**, 513.
Blanco, V. M. 1964, *Astron. J.*, **69**, 730.
FitzGerald, M. P. 1968, *Astron. J.*, **73**, 983.

Hamajima, K., Ichikawa, T., Ishida, K., Hidayat, B., and Raharto, M. 1981, *Publ. Astron. Soc. Japan*, **33**, 591.

Hamajima, K., Ishida, K., Ichikawa, T., Hidayat, B., and Raharto, M. 1982, *Contr. Bosscha Obs.*, No. 74.

Hoag, A. A., Johnson, H. L., Iriarte, B., Mitchell, R. I., Hallam, K. L., and Sharpless, S. 1961, *Publ. U.S. Naval Obs., 2nd Ser.*, **17**, 349.

Ichikawa, T. 1981, *Publ. Astron. Soc. Japan*, **33**, 107.

Ichikawa, T., Hamajima, K., Ishida, K., Hidayat, B., and Raharto, M. 1982, *Contr. Bosscha Obs.*, No. 75.

Ishida, K., and Mikami, T. 1982, *Publ. Astron. Soc. Japan*, **34**, 89.

Khavtasi, Dzh. Sh. 1960, *Atlas Galakticheskikh Temnykh Tumannostej* (Abastumanskaya Astrofizicheskaya Observatoriya, Akademiya Nauk Gruzinskoj SSR).

Lynds, B. T. 1968, in *Nebulae and Interstellar Matter*, ed. B. M. Middlehurst and L. H. Aller (The University of Chicage Press, Chicago), p. 119.

Maihara, T., Oda, N., Sugiyama, T., and Okuda, H. 1978, *Publ. Astron. Soc. Japan*, **30**, 1.

Mavridis, L. N. 1971, in *Structure and Evolution of the Galaxy*, ed. L. N. Mavridis (D. Reidel Publishing Company, Dordrecht, Holland), p. 110.

Mikami, T. 1978, *Publ. Astron. Soc. Japan*, **30**, 191.

Mikami, T., and Ishida, K. 1981, *Publ. Astron. Soc. Japan*, **33**, 135.

Mikami, T., Ishida, K., Hamajima, K., and Kawara, K. 1982, *Publ. Astron. Soc. Japan*, **34**, 223.

Nassau, J. J., and Velghe, A. G. 1964, *Astrophys. J.*, **139**, 190.

Neckel, Th. 1967, *Veröff. Landessternw. Heidelberg-Königstuhl*, **19**, 1.

Neckel, Th., and Klare, G. 1980, *Astron. Astrophys. Suppl.*, **42**, 251.

Oda, N., Maihara, T., Sugiyama, T., and Okuda, H. 1979, *Astron. Astrophys.*, **72**, 309.

Sharov, A. S. 1964, *Soviet Astron.*, **7**, 689.

van den Bergh, S. 1968, *J. Roy. Astron. Soc. Canada*, **62**, 145.

Walker, M. F. 1957, *Astrophys. J.*, **125**, 636.