The Future Utilisation of Schmidt Telescopes
ASP Conference Series, Vol. 84, 1995
J. M. Chapman, R. D. Cannon, S. J. Harrison and B. Hidayat (eds)

A Search for Late M Supergiant Stars in the Direction of Galactic Latitude $-2° < b < 2°$ and Galactic Longitude $351° < l < 1°$

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Abstract. Optical late M stars (spectral type later than M4) with IRAS colours of $0.7 < m_{12} - m_{25} < 1.6$ belong to two possible luminosity classes; giants or supergiants (Raharto 1994). We have searched for supergiant candidates among the late M stars at low galactic latitude, between galactic longitude $351° < l < 1°$ and galactic latitude $-2° < b < +2°$, using data from the M star Catalogue (Raharto et al. 1984) and the IRAS Point Source Catalogue (Beichman et al. 1987). The search area is located in the direction of the galactic centre. M supergiants found in this survey will be necessarily a mixture of M supergiants in star forming regions in the interarm and galactic centre regions and M supergiants in the inner galactic arms.

We found 154 of 1146 late M stars with unique IRAS point source counterparts within 15 arcsec. 122 of the 154 stars have good flux qualities in the 12 and 25 μm bands. 112 of these, or 73 per cent of the late M stars (later than M4), have IRAS infrared colours in the range $0.7 < m_{12} - m_{25} < 1.6$. Only two stars out of 122 have infrared colours redder than 1.7.

https://doi.org/10.1017/S0252921100022077 Published online by Cambridge University Press

1. Introduction

Late M supergiants are important objects for studying the evolution of massive stars at late stages of stellar evolution. However, the number of late M supergiants known in the Galaxy is very small. The scarcity of the late M supergiants in the Galaxy is partly due to observation. The radio luminous OH/IR stars are interpreted as being M supergiants with Mira-like characteristics where the central stars are obscured by thick circumstellar dust shells and are at a later evolutionary stage than the optically visible late M supergiant stars (Jones et al. 1988).

Observations of late M supergiants in the near-infrared and infrared allow one to reveal the structure of the distant arms. M supergiants within 40 kpc can be detected within the limiting magnitude reached by the IRAS survey. We introduced a method to discover late M supergiant candidates using the M star data obtained from the near-infrared survey of M stars and from the IRAS Point Source Catalogue.

2. Search for Late M Supergiant Stars among Late M Stars

The surface number density of M stars at low galactic latitude down to a limiting magnitude of $I = 12$ is about 20–40 stars per square degree (Mavridis 1971). The large number of M stars is composed of giants, bright giants and supergiants. The number of M supergiants is statistically small, being only a few percent of the M stars at low galactic latitude (Neckel 1966).

Two observational steps are needed to discover M supergiants; first to discover candidates and second to assign the luminosity class of the candidates. A well known method for selecting M supergiant candidates is to use the taper shape found in shorter wavelength region of near-infrared M star spectra (Nassau, Blanco & Morgan 1954). These stars are thought to be located far from the sun and so suffer large amounts of interstellar extinction. The stars must therefore be luminous so that they can be detected at large distances. However, this method may cause a selection effect on the number of M supergiants discovered in the Galaxy. Most of the candidates are early M stars. The follow-up observations of the candidates to confirm the luminosity classes are usually done using 8-colour photometric methods in the near-infrared (Wing 1989); near-infrared spectroscopy (Slof 1978; MacConnell 1987); or an infrared colour discriminator for the luminosity class of optical early M stars identified with IRAS point sources (Raharto 1994). The latter method may be used not only to discover early M supergiant stars with the taper shape in near-infrared spectra, but also to discover M supergiants with untapered spectra (Raharto 1991a; 1991b).

In the infrared colour - spectral type diagram of optical M giants, Miras and M supergiants (Raharto, 1994), late M stars with colours of $0.7 < m_{12} - m_{25} < 1.6$ mostly have luminosity classifications as giant or supergiant stars. This is used to identify late M supergiant candidates towards the galactic center. For this purpose we used the M star catalogue compiled by Raharto et al. (1984). This catalogue includes 2116 M stars obtained in a near-infrared survey for M stars using the Schmidt telescope (51/71/127 cm) at the Bosscha Observatory. The catalogue consists of M stars detected in the region of galactic longitude

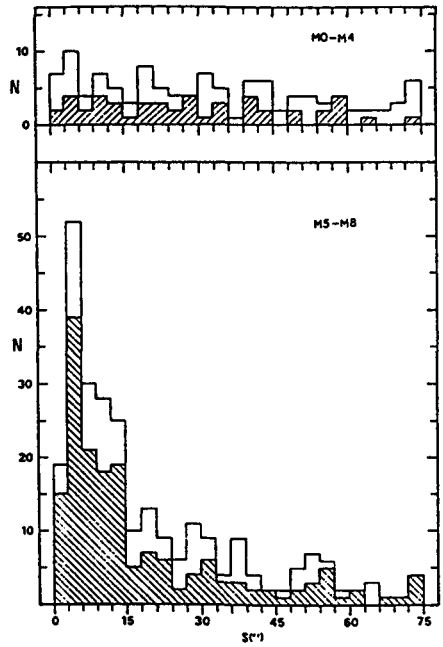

Figure 1. Frequency distribution of positional differences between M stars and their IRAS point source counterparts, in arcsec. The striped regions show the IRAS counterparts for M stars with a colour range of $0.7 < m_{12} - m_{25} < 1.6$.

$351° < l < 1°$ and galactic latitude of $-2° < b < 2°$ with a positional accuracy of 1.5 arcsec and a limiting magnitude of $I = 12$. The high positional accuracy of M stars is similar to the positional accuracy of SAO stars. It is therefore appropriate to search for the IRAS point source counterparts of the M stars.

According to the results of an experiment on the positional accuracy of IRAS Point Sources (cross scan) compared with SAO stars, the positions of about 95 per cent of IRAS Point Sources coincided within 15 arcsec with the positions of SAO stars (Beichman et al. 1987). This value is therefore adopted as the radius of the circle of coincidence to search for IRAS far-infrared counterparts of the late M stars (in the M star catalogue). All IRAS point sources within 15 arcsec of the late M stars are considered to be associated with the late M stars. Fig. 1 shows a frequency distribution for the positional separation between the M stars and the IRAS point sources for search radii up to 75 arcsec. It is noted that the larger search radii do not give unique IRAS counterparts and therefore have dubious associations.

The frequency distribution for the positional differences between M stars and their IRAS counterparts is similar to the results of Beichman et al. (1987). It was found that 187 out of 2116 M stars in the M star catalogue have an IRAS counterpart within 15 arcsec. 154 of the 187 sources are identified as late M stars. 79 per cent (122 out of 154) of the late M stars with IRAS counterparts

https://doi.org/10.1017/S0252921100022077 Published online by Cambridge University Press

within 15 arcsec have good flux qualities in the 12 and 25 μm bands, so their infrared colours can be calculated. It is found that more than 73 per cent of the counterparts are IRAS point sources with good flux qualities at 12 and 25 μm and colours within $0.7 < m_{12} - m_{25} < 1.6$. Only 10 of 122 stars have colours outside this range.

3. Data – Late M Supergiant Candidates

The data of late M supergiant candidates will be published elsewhere. Statistics for the late M supergiants candidates is given in Table 1.

Table 1: Statistics for late M Supergiant Candidates

Sp.Type \ Group	I	II	III	IV	V	VI
early M star	970	33	15	5	2	11
late M star	1146	154	112	8	2	32

Column 1: The total number of M stars from the M star Catalogue of Raharto et al. (1984). **Column 2:** The total number of M stars with IRAS counterparts within 15arcsec. **Column 3:** The total number of the IRAS counterparts with good flux qualities at 12 and 25 micron and colour range of $0.7 < m_{12} - m_{25} < 1.6$. **Column 4:** The IRAS counterparts with good flux qualities at 12 and 25 μm and colour range of $0.7 < m_{12} - m_{25} < 1.6$. **Column 5:** The IRAS counterparts with good flux qualities at 12 and 25 μm and colour range of $m_{12} - m_{25} > 1.7$. **Column 6:** The IRAS counterparts with good flux qualities at 12 or 25 μ only.

The limiting I magnitude of late M stars with IRAS counterparts within 15 arcsec is about 12 mag, about 0.5 mag brighter than the limiting magnitude reached by the M stars survey. The limiting magnitude in m_{12} of those late M stars is about 2 mag brighter than the limiting magnitude reached by the IRAS survey.

It is noticed that the number of early M stars with IRAS counterparts is about four times fewer than that of late M stars. This probably indicates that late M stars are more luminous infrared sources than early M stars. The completeness of detectability of the late M stars was about 10 per cent better than for the early stars in the near-infrared survey. At low galactic latitudes, the IRAS survey had considerable confusion. This confusion will clearly reduce the degree of detection completeness for supergiants at low galactic latitutes.

The completeness of M supergiants in the IRAS survey is deduced from an experiment to find IRAS counterparts for 91 K and M supergiants (Raharto & Ishida 1994). They found 87 IRAS counterparts for 91 K and M supergiants in the list of Elias et al. (1985). The completeness of the optical-infrared survey for

late supergiants would be over 90 per cent. The maximum interstellar extinction of those M supergiants is about 6 mag in the visual band (A(lk) is about 3 mag) and the distances are within 5 kpc. It can be predicted that we will find M supergiants with a maximum interstellar extinction of 6 mag in the I band to the limiting IRAS magnitude of $m_{12} = 4$. Since the completeness of the M star survey is over 90 per cent, we argue that the completeness of searching optical-infrared late M supergiants candidates would be over 80 per cent.

It is clear that the majority of late M supergiants candidates are optical M stars which are luminous in the infrared. Optical M stars with infrared colour of $0.7 < m_{12} - m_{25} < 1.6$ are known to be luminous IR sources compared to optical M stars with colour bluer than 0.7 which are usually identified with optical Miras or M giants. Optical M stars with colour redder than 1.6 are rarely found (2 out of 122). This is probably a colour cut off between optical Miras or M supergiants and infrared giants (Miras) or infrared supergiants stars or some rare cool massive stars in the Galaxy.

Acknowledgements

MR would like to thank ITB (Bandung Institute of Technology), JSPS and VGHE for providing supports and to RONPAKU scholarship. Part of this work was done using facilities of the Kiso Observatory, the Institute of Astronomy, University of Tokyo, and the National Astronomical Observatory in 1992 and 1993. MR would like to express his thanks to these institutions.

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