A Study of Circumstellar Silicon Monoxide Masers

A Thesis
submitted for the Degree of
Doctor *of Philosophy*
in the Faculty of Science

By

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To my parents

Kalavati and Amritlal

“ℒ⟩∫⊔⌉\ ⊔≀ ⊒⟨⊣⊔ 𝓘 ⇕⌉⊣\, \≀⊔ ⊔≀ ⊒⟨⊣⊔ 𝓘 ∫⊣†.”

—𝓡. 𝓟. 𝓕⌉†\⇕⊣\

Declaration

I hereby declare that the work presented in this thesis is entirely original, and has been carried out be me at the *Raman* Research Institute under the auspices of the Department of *Physics*, Indian Institute of Science. I further declare that this has not formed the basis *for* the award of **any** degree, diploma, membership, associateship or similar title of any *Universit*v or Institu*tion*.

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Abstract

Maser emission from circumstellar matter around Mira variables is a well known phenomenon but not yet completely understood. This thesis presents an observational study of about 170 Mira variables, which are pulsating red-giants. Observations were carried out at the frequency of 86.2 GHz which corresponds to the v=1, J=2—1 transition in SiO. The aim was to study the dependence of the maser phenomenon on the intrinsic properties of the Mira variables like — spectral-type, luminosity, evolutionary stage, amplitude of pulsation and infra-red spectrum.

The outline of the thesis is as follows.

- Beginning with a historical introduction to the subject of observations of molecules at millimeter wavelengths, Chapter 1 lists some physical parameters of the SiO molecule. The properties of Mira variables are then summarized. Finally, we review the characteristics of SiO maser emission as obtained from the available observations.

- Since the observations reported in this thesis are the first ones made using the Raman Research Institute 10.4 m millimeter-wave telescope, its instrumental characteristics and pointing and gain calibration, some aspects of which are peculiar to this telescope, are presented in detail, in Chapter **2.** In the following Chapter, the performance of the telescope is evaluated by observing some standard sources, and the errors in the measurement of absolute fluxes are estimated.

- Chapter 4 presents the observations of the Mira variables. The method of observations is described. Tables of results and spectral-lines are given. Among the seven new detections, a surprising result is that of T Cnc, which is a unique carbon star, in showing the SiO maser emission.

- To know the relation between the maser phenomenon and any intrinsic property of the Mira variable, one must convert the observed maser flux from a source into luminosity, for which one needs to know the distance to the source. In chapter 5, we review first the known methods for determining distances to the Mira variables. Distances are calculated from a comparison of the apparent infra-red magnitude at 2.2 microns, and the absolute magnitude obtained from a period-luminosity relation. The ohserved fluxes are then converted to luminosities, after correcting for all telescope losses.

- Chapter 6 presents the results which can be summarized as follows.

  1. Not all Mira variables show the SiO maser emission. The masing M-giant Mira variables are restricted in the range of mean spectral-types M6—M10.

  2. The maser luminosity is also found to be correlated with the bolometric magnitude.

  3. In the H-R diagram, it is found that the masing Mira variables are restricted in a region described by the limits: $M_{bol} \leq -4.8$ and $\log T_{eff} \leq 3.48$. This can be interpreted as implying a lower limit of $\sim 300 R_{\odot}$ to the radius of a masing star.

  4. There is an indication of an anti-correlation between the SiO photon-

luminosity and the amplitude of pulsation in the visual magnitude.

- In Chapter 7 we discuss these results and suggest some interpretations. The cut-off in the maser luminosity below M6 may be due to a lack of SiO abundance in these stars. The decrease in maser luminosity for stars having large pulsational amplitudes may be due to a shorter coherence length as suggested by a correlation between the expansion velocity of circumstellar matter with the amplitude of pulsation. The correlation of maser luminosity with bolometric magnitude suggests a radiative pump mechanism. We show that the radiative pump mechanism is consistent with several other observations, as well as with a theoretical model atmosphere of a typical Mira variable. Some strong masers for which the radiative pump had failed to produce the observed maser-power, we suggest an additional source of pump photons to be the circumstellar dust shell. This is suggested by the observations of optically thick dust shells around these stars.