

氏 名 姜 碧 湧

学位（専攻分野） 博士(理学)

学位記番号 総研大甲第266号

学位授与の日付 平成9年3月24日

学位授与の要件 数物科学研究科 天文科学専攻

学位規則第4条第1項該当

学位論文題目 Observational Study of AGB stars in the outer
Galactic disk

論文審査委員 主 査 教 授 稲谷 順司
教 授 笹尾 哲夫
助 教 授 出口 修至
教 授 辻 隆（東京大学）
助 教 授 野口 邦男（国立天文台）

論文内容の要旨

Asymptotic Giant Branch (AGB) stars are low- and intermediate-mass stars that have developed an electron-degenerate C-O core after the exhaustion of central helium. They are detected in large amount by IRAS due to the strong middle- and far-infrared radiation from their cold circumstellar envelopes which are resulted from the mass loss at a rate of about 10^{-7} to $10^{-5} M_{\odot} \text{ yr}^{-1}$. The third dredge-up process in AGB phase digs out the newly produced C (and/or N) in the burning shells and transforms some stars into C-rich. Because these stars play an important role to recruit the interstellar medium as well as the evolution to the end of a stellar life, observations in multi-wavelength and by versatile methods have been made. This thesis puts emphasis on these AGB stars in the outer disk of the Galactic plane.

The survey in SiO maser lines was performed to the IRAS PSC sources in the outer disk of the Galaxy, which are candidates for AGB stars according to their IRAS colors. In May of 1994, 1995 and 1996, 244 AGB stars in the second and third quadrants of the Galactic plane were searched for the ^{28}SiO $J=1-0$, $v=1$ and $v=2$ transitions and the isotopic ^{29}SiO $J=1-0$, $v=0$ transition simultaneously by taking the wide-band advantage of the 45m telescope system. The SiO maser emission stronger than 1Jy was detectable at 5 sigma level and at a velocity resolution of 0.3 km s^{-1} . 76 stars were detected the ^{28}SiO maser emissions with 64 new detections. It's found that the $v=1$ and $v=2$ lines appear simultaneously in most cases as also shown in the bulge SiO maser emitters. The ^{29}SiO maser emission was detected in 12 stars, adding 10 new members to the previously known 20 such rare stars partly due to that the ^{29}SiO is only about 1-20th abundant as ^{28}SiO in the circumstellar envelopes of AGB stars. The isotopic maser lines are found to be detectable only in strong SiO maser sources, located at the same velocity and about 1-10th to 1-100th strong in terms of integrated intensity as the normal SiO maser lines.

The SiO maser sources are mostly associated with long-period large-amplitude variables. Except several of them, the others are all optically identified in the observations made at V and I bands by using the Kiso Schmidt telescope. By taking the CCD images about once a month for more than one year that started from 1994 August, these stars are found to be as red as $V - I > 2 \text{ mag}$ and their amplitudes of variability are $> 2 \text{ mag}$ at I band. The low resolution spectra taken by using the 216cm telescope in 1995 October at Beijing Astronomical Observatory (BAO) showed that all the 10 observed SiO maser sources are late-M5-type stars. They could be Mira-type or semi-regular variables as the bulge SiO maser stars are. In spite that there is no clear difference in the properties of SiO maser spectra or SiO maser stars when compared with that in the bulge, the survey in the outer disk was out of expected high detection rate. Previously a survey in the SiO maser lines towards the bulge direction yielded the historically highest detection rate (66%) and it's attributed to the good sensitivity of the 45m telescope system at Nobeyama Radio Observatory and appropriate selection of sources in IRAS colors. The sample of the outer disk survey was selected under similar criteria and the same sensitivity was reached as in

the bulge survey. However the detection rate, 31%, is less than half that of the bulge survey.

The outer disk sample was suspected to be consisted of more C-rich AGB stars responsible for the much lower detection rate. As is known that the non-detection of SiO maser emission in AGB stars can be caused by the weakness of SiO maser line beyond the detection limit or no emission intrinsically as in case of a C-rich AGB star. While the former reason could not bring about big difference since the same detection limit was achieved in both the bulge and the outer disk surveys and the outer disk sample stars are even averagely closer. In order to investigate how much proportion of C-rich AGB stars is in the AGB stars in the outer disk, optical spectroscopy and near-infrared photometry were carried out to 19 and 95 sources respectively, a subsample of the SiO maser-searched. The optical spectroscopy to 9 SiO non-detections revealed 4 C-rich stars. Because many of the stars are optically invisible, near-infrared identification and photometry were supplemented by using the 126cm infrared telescope at BAO and the 188cm telescope at Okayama Astrophysical Observatory in the fall of 1995. Combining the data of molecular lines, IRAS LRS spectra and optical spectroscopy, we found that the separation of C-rich from O-rich AGBs is feasible based on their near-infrared colors J-K and H-K. About half of the stars are then of typical near-infrared colors of C-rich AGB stars. Though this proportion of C-rich stars is quite high compared with the value of 10% among the neighbourhood late-type stars, it is consistent with the low metallicity in the outer disk since the proportion of C-rich stars is high in metal poor environment as seen in external galaxies. The content of 50% C stars can explain the major difference in SiO maser detection rate between the outer disk sample and the bulge sample. It is also in agreement with the results of Arecibo OH maser survey towards a similar sample of AGB stars in the outer disk.

論文の審査結果の要旨

本論文は、多数の A G B (Asymptotic Giant Branch) 星について、一酸化珪素 (SiO) メーザーの観測を行い、その検出頻度が銀河系の中心領域 (バルジ領域) と外部円盤領域とで大きく異なっていることを発見し、それがそれぞれの領域における A G B 星の大気組成の違いに起因することを示したものである。

論文は 6 章から構成されている。第 1 章では、A G B 星の理論と従来の観測結果が紹介され、とくに、A G B 星が C 型 (Carbon-rich) と O 型 (Oxygen-rich) とに大別され、両者の間で、赤外線及び電波観測の結果が系統的に異なっていることが述べられる。第 2 章、第 3 章では、赤外線天文衛星 I R A S のカタログに基づき、A G B 星候補天体 2 9 7 個について、SiO メーザーの観測を行った結果が示される。観測には国立天文台野辺山宇宙電波観測所の 4 5 m 電波望遠鏡が使用された。第 4 章では、I R A S カタログに基づく A G B 星候補天体 1 0 2 個について、光学観測 (V、I バンド) を行った結果、約 5 0 % が光学天体に同定され、それらはミラ型の変光星と判明したことが述べられる。第 5 章では、同じく I R A S カタログに基づく A G B 候補天体 9 5 個について近赤外線観測 (J、H、K バンド) を行った結果、近赤外線の 2 色図上で C 型と O 型がきれいに分離され、銀河中心から遠くなるほど、両者の個数比 (C 型 / O 型) が増加の傾向を示すことを見出している。第 6 章では、以上の観測に基づいて、銀河系の外部円盤領域における SiO メーザー検出頻度 (31%) が、銀河系中心領域におけるそれ (66%) に比べて著しく低いこと、その原因は、外部円盤領域における A G B 星の中では、SiO メーザーを出さない C 型星の割合が約半数をしめることによると考えられること、が結論されている。

本論文は、銀河系の全体構造をさぐり得るプローブとして有望な SiO メーザー現象について、その検出頻度が銀河系の大域構造と関連し、しかも、それが A G B 星の大気の化学組成と密接な関係をもっていることを明らかにした点に独創性があり、高く評価される。著者は、この仕事を、電波、光、近赤外線にわたる膨大な観測を丹念に積み重ねることによって達成しており、このような波長横断的な視野の広い研究スタイルも本論文のすぐれた特徴である。さらに、今後、変光観測の継続により変光周期が明らかになれば A G B 星の距離推定が可能となり、銀河系における化学組成の空間分布が一層明瞭に浮かび上がることが想定され、本論文は発展性の高い研究成果となっていることも特筆される。

なお、本論文第 2 章、第 4 章はすでに査読学術雑誌に発表されており、完成度の高い成果となっている。

以上を考慮し、審査委員会は、本論文は博士 (理学) の学位を受けるに相応しいものと判断した。