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The Galactic center region (~500 pc) is luminous in the far-infrared (FIR), however dominant heating sources of its luminosity are still controversial. There are many pieces of evidence for active star-formation in some areas in the Galactic center region such as the Sgr B2 HII region. On the other hand, it is proposed that dominant heating sources for the dust in the general Galactic center region may not be young OB stars but the population of cool stars, K and M giants (Cox & Laureijs 1989). This is supported by the large infrared excess (IRE), which is defined as infrared luminosity over Lyman alpha luminosity and is an indicator of the star-formation activity. The IRE is ~30 in the Galactic center region, while it is ~10 in typical HII region in the Galactic disk. This suggests that the star-formation in the Galactic center region is currently inactive as a whole.

Previous Galactic [CII] line observations revealed that the [CII] emission did not show a dominant peak in the Galactic center (e.g. Bennett et al. 1994; Nakagawa et al. 1995, 1998). Especially, observations using the *Balloon-borne Infrared Carbon Explore* (*BICE*) showed that the ratio of the [CII] line to the FIR continuum emission was systematically low toward the Galactic center. Nakagawa et al. (1995, 1998) suggested that the low [CII]/FIR ratio was caused by softer UV radiation in the Galactic center region than in the Galactic disk, supporting that the luminosity of the Galactic center region may be attributed to late-type stars. However, because the observations were made in the [CII] line alone, they could not rule out other possibilities to explain the low [CII]/FIR ratio in the Galactic center and multi-line spectroscopy was required to resolve their problem conclusively.

In this thesis, in order to reveal the dominant heating source of the FIR luminosity, the physical condition of the ISM in both general and local regions of the Galactic center has been investigated in detail by multi-line spectroscopy in the FIR. The FIR spectral region is rich with many spectral lines that are important for the study of interstellar physics and chemistry. The spectroscopic data are obtained for large-scale areas along the Galactic plane with the LWS on *ISO* as well as small-scale mapping observations of Galactic center clouds by the FIS/FTS on *AKARI* and the LWS; the *ISO* data were taken from the archives, while the *AKARI* data were derived from observations for calibration of the FIS/FTS.

The observations consist of two types: one is large-scale observations and the other is small-scale observations. For the large-scale observations, the data were selected for the area covering $|l| < 10$ ° and $|b| < 0.1$ ° and least contaminated by strong HII regions, i.e., on-plane general diffuse regions. The results show that the ratio of the [CII] to the FIR continuum emission is systematically low toward the Galactic center, whereas that of the [OI] to the FIR is almost constant; the former result is consistent with that of the previous *BICE* [CII]-line mapping (Nakagawa et al. 1995, 1998). The physical parameters of the ISM in the Galactic center region have been obtained by using the PDR model (Spaans et al. 1994) that takes account of variation of an effective temperature of interstellar radiation field. The results show that the radiation effective temperatures are significantly low in the Galactic center region; the radiation effective temperature of 6600 ± 300 K in the Galactic center region and 8600 ± 500 K in the Galactic disk region, while similar hydrogen densities of

$n_H \sim 10^{2.8-3.0}$ cm^{-3} are obtained for both regions. It is therefore concluded that the suppression of the [CII]/FIR ratio toward the Galactic center is most probably due to soft radiation field in the Galactic center region. The present study has unambiguously identified the cause of the low [CII]/FIR ratio by the multiple-line spectroscopy.

To discuss the physical implications of the soft radiation field in the Galactic center region, two star-formation models are introduced, where the numbers of H- and C-ionizing photons produced by stars are calculated and effective color temperatures of the radiation field from ratios of these photons are derived. As a result, the observed effective temperature supports the model in which star-formation activities in the Galactic center region started a long time ago (1×10^9 yr) and turned off in the past. Hence it is concluded that dominant sources of the FIR luminosity are not likely to be young OB stars but rather cool stars, K and M giants, which implies that current star-formation activity is rather low in the Galactic center region.

As for the small-scale observations, the *ISO* data were selected from the mapping observations of the area including the Sgr B1 region, the giant molecular clouds in the Ridge region, and the Pistol region. The *AKARI* mapping data cover the Pistol region and the Arches cluster region; on the basis of the Pistol region overlapped with *ISO*, the absolute line fluxes of FIS/FTS data have been calibrated. The Sgr B1, the Pistol, and the Arches cluster regions are representative of star-forming regions, while the giant molecular clouds in the Ridge are representative of quiescent regions. Throughout these small-scale observations, the [CII] line intensity shows good linear correlation with the [OI] line intensity, suggesting that the [CII] line originates mostly from PDRs not from HII regions. It is also found that local variations in both [CII]/FIR and [OI]/FIR ratios are very small as compared to the [OIII]/FIR ratio, which ensures that [CII] and [OI] lines are not concentrated in HII region and the results of the large-scale observations are not affected by local variations. From the Ridge region, the results show lower G_0 but even smaller [CII]/FIR ratios than those in the large-scale Galactic center region, while the [OI]/FIR ratios in the Ridge region are similar to those in the large-scale region. Hence it is suggested that the radiation field in the Ridge region is consistent with, or even softer than that obtained from the large-scale observations.

Finally, from the *AKARI* mapping data of the Arches cluster regions, the detailed structures of the ISM are discussed. The marked differences in the spatial distribution among the [OIII], [NII], and [CII] emission lines are found in the area near the Arches cluster; the [OIII] distribution has a peak near the cluster and spatially corresponds well to one of the radio filaments seen in this region. The [NII] distribution has a peak at the position different from that of the [OIII] distribution, located farther away from the Arches cluster, and the [CII] distribution is extended farthest among them. This result shows that the emission of the ionic line with higher ionization potential is distributed closer to the Arches cluster, which is the first direct evidence that UV photons from Arches cluster are ionizing the surface of the nearby molecular cloud forming the radio filament and penetrating deeper to dissociate the cloud.

論文の審査結果の要旨

遠赤外線による天体の観測は大気が不透明なため宇宙空間から行うことが不可欠であり、他の波長に比べてまだ観測例が少ない。本学位論文は、2つの赤外線天文衛星（Infrared Space Observatory: ISO および「あかり」）によって取得された遠赤外線観測データを用いることにより、1）銀河中心領域にある星間ガスの加熱源を特定し、2）銀河中心領域での星形成史に関する新たな知見を得るとともに、3）大質量星クラスター周りの電離ガスの分布・物理状態を明らかにした。

銀河中心は星間塵による減光のため可視光では観測することができない。これまで、X線、赤外線および電波の観測により高温プラズマ、非熱放射、大量のガスとダストの放射が観測されており、活発な星形成および大質量星クラスターなどが確認されている。遠赤外線領域では銀河中心を中心として銀河面に広がったダストからの熱放射が観測され、活発な星形成がエネルギー源と考えられている。一方で、これまでの遠赤外線観測では電離炭素放射強度が比較的弱いことが報告されており、銀河中心領域に広がったガスの加熱源が比較的有効温度の低い星間放射場である可能性が指摘されていた。

本論文では、遠赤外線領域で観測される電離炭素（CII）、酸素原子（OI）、電離窒素（NII）、電離酸素（OIII）、それぞれの放射を銀河面に広く分布する複数の観測点のデータを詳細に解析することにより、銀河中心領域の広がった光解離領域（PDR）の加熱源を明らかにし、銀河中心領域の星形成史について議論を行ったものである。論文の前半部では、赤外線天文衛星 ISO のアーカイブデータから、銀河面の広域放射成分を代表するデータ点を選び CII および OI の放射の解析から星間ガスを加熱する星間放射場の有効温度を決定した。さらに、銀河中心領域での星形成史との関連で解析を進め、銀河中心領域で過去に大規模な星形成が起こっていたという結論を導いた。また、論文後半では、ISO および「あかり」による空間分解能を生かした個別領域の解析により、前半部の結論を再確認すると共に、大質量星クラスター領域の周りで3つのイオンからの線放射の分布の違いを明らかにし、大質量星クラスター周りの電離ガス分布を始めて明らかにした。

本論文は、銀河中心を含む広い領域での電離ガスの物理状態、および大質量星クラスター領域などのコンパクトな領域を遠赤外線の原子・イオンからの線放射を複数観測することで、光解離・電離領域を総合的に研究した非常に価値の高い論文である。以前の電離炭素（CII）ラインの観測では銀河中心領域でのダスト放射強度に対する CII 線強度の相対的な減少について原因が特定できていなかったが、本論文では複数のイオン・原子線放射を観測することで、ガスの加熱源となる星間放射場の有効温度が低いためであると結論した。この結果を用いて銀河の星形成史についての考察を行い、過去の爆発的星形成を示唆する結果を導いたのは大変興味深いことである。大質量星クラスター周りでの電離ガスの分布を明らかにしたことは、「あかり」の特長を生かした成果であり、広領域の解析結果をさらに補強する成果となっている。このように本論文は2つのスペースからの観測装置を有効に活用して得られた成果として高く評価できる。

また、本論文の後半部分は、赤外線天文衛星「あかり」による遠赤外線分光観測として最初のものであり、出願者は観測計画の立案、解析プログラム開発で大きな貢献を行った。特に、「あかり」遠赤外分光データの較正は、今後の「あかり」遠赤外分光データ解析に対する大きな貢献である。これらの結果として本論文の科学的成果が得られたことは高く評価できる。

以上により、本研究は、我々の銀河系中心領域の星間ガスの物理状態および星形成史の解明において極めて重要な貢献をしたものと判断され、申請論文は博士学位論文としてふさわしい水準にあると判定した。