MULTIWAVELENGTH MORPHOLOGY OF THE GALACTIC NUCLEAR BULGE

Shashikiran Ganesh[(1)], **Umesh C. Joshi**[(2)], **Kiran S. Baliyan**[(3)]

and the ISOGAL Collaboration[4,5,6]

[(1)] ***Physical Research Laboratory, Astronomy & Astrophysics Division, Navarangpura, Ahmedabad 380009, India, Email:- shashi@prl.ernet.in***

[(2)] ***As (1) above, but Email:- joshi@prl.ernet.in***

[(3)] ***As (1) above, but Email:- baliyan@prl.ernet.in***

[(4)] ***Principal Investigator: Alain Omont, Institut d'Astrophysique de Paris, 98bis, Blvd Arago, Paris, 75014, France, Email:- omont@iap.fr***

ABSTRACT

The inner region of the Milky Way has been the subject of surveys in the near-infrared (DENIS & 2MASS), mid-infrared(ISOGAL), molecular line CO, and at various radio wavelengths using the Very Large Array (VLA). In the present contribution, we discuss the near-infrared derived extinction maps and their comparison with the large scale CO surveys. Morphological comparisons of regions observed around the Galactic Center in the infrared surveys with archival VLA data (3.6, 20 and 90cm) are also presented. The CO emission at different velocities provide clues regarding the location of the mid-infrared absorbing clouds along the line of sight.

INTRODUCTION

The inner region of the Milky Way Galaxy has been the subject of large-scale surveys such as the Infrared Space Observatory GALactic (ISOGAL) survey, DEep Near Infrared Southern Sky Survey (DENIS) and the 2Micron All Sky Survey (2MASS), molecular line CO surveys, various surveys at radio wavelengths using the Very Large Array (VLA), and smaller scale surveys at other wavelengths such as the submm. Multi-wavelength observations are important in order to have a complete understanding of the Galaxy and its constituents. Archival data are a major source of information at other wavelengths particularly radio molecular line CO, etc, and low frequency continuum emission.

NEAR-INFRARED EXTINCTION MAPS

Near infrared data from DENIS allow to map the extinction along various lines of sight towards the inner Galaxy (Fig. 1). In the topmost panel we show the extinction map derived from the isochrones of the AGB/RGB population using the J and K_S bands of the DENIS survey. For comparison we show the COBE near-IR emission map in panel 2, the IRAS integrated fluxes in panel 3 and the integrated low resolution CO map in panel 4 of figure 1. Comparison with molecular line CO data from [1] showed that towards some directions closer to the centre of the Milky Way, the interstellar extinction was so large ($> 35mag$ in the visual band) that observations at the shortest infrared band of the DENIS and 2MASS surveys didnot detect sources seen at longer near-infrared bands. Part of the problem was due to large pixel sizes of these two surveys. We carried out deep imaging observations using the SIRIUS camera on the IRSF at the South African Astronomical Observatory, Sutherland. The resulting photometry is seen to be atleast 2 magnitudes deeper than the DENIS and 2MASS ones and is expected to throw new light on the highly obscured inner regions of the Milky Way[2].

[5]ISOGAL Co-Investigators include: C. Alard, J.Blommaert, C.Cesarsky, N. Epchtein, M. Felli, P. Fouqu'e, R. Genzel, G. Gilmore, F. Guglielmo, H. Habing, A. Omont(PI), M. P'erault, S. Price, A. Robin and G. Simon

[6]ISOGAL data reduction team includes: C. Alard, T. August, J. Blommaert, E. Copet, S. Ganesh, M. Messineo, D. Ojha, M. P'erault, F. Schuller, M. Schultheis, G. Simon and M. Unavane

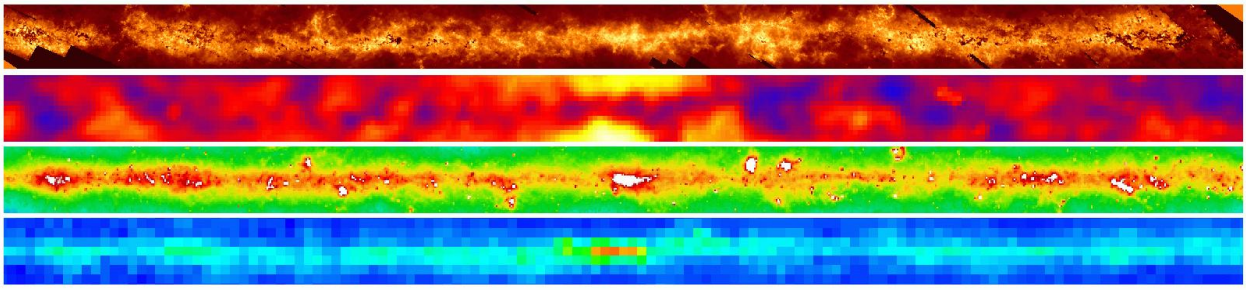

Figure 1: First row from top: Visual extinction (A_V) from the DENIS giant branch stars spanning 30 degrees on either side of the Galactic Center (galactic coordinates), second row: COBE near-infrared emission map, third row: IRAS far infrared emission map, fourth row: ^{12}CO emission map (Dame et al)

MID-INFRARED EXTENDED EMISSION

Using the mid-infrared ISOGAL data [3], a mosaic of the Galactic Nuclear Bulge (about 300 parsec around the Galactic Center with a 3" per pixel resolution) was constructed at 7μm and 15μm. Since this region exhibits very strong sources, this is out of range of the Spitzer infrared observatory and the ISO data constitute the best resolved images of the large scale Galactic Nuclear Bulge in the mid-infrared. We find spectacular extended emission features as well as point sources, many of which have never been seen before. Also present are regions showing strong absorptions (Fig. 2 and 3). In Fig. 2 we show the 7μm mid-infrared map of the well known Sgr B region. This is shown in reverse gray scale with light areas representing strong absorption and point sources appearing as dark dots.

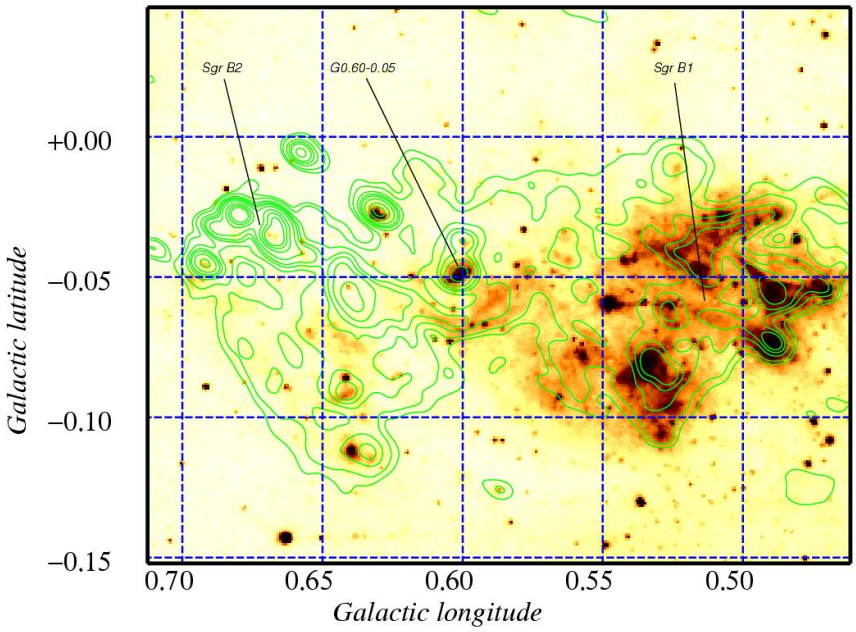

Figure 2: Mid-infrared (7μm) image of the Sgr B region near the Galactic Center. Overlaid on this are contours from the VLA 20cm archival data (Yusef-Zadeh et al).

Comparing with longer wavelength archival data such as the radio survey data from the VLA (contours in Fig. 2 are at levels of 0.03, 0.05, 0.1, 0.15, 0.2, 0.3, 0.5, 0.7 and 0.9 Jy/beam constructed from the fits image) one sees strong emission at low frequencies in regions exhibiting absorption at mid-infrared wavelengths. The regions in absorptions at mid-infrared show up in emission at sub-mm 450μm, 850μm continuum(see for e.g. [4], [5]). Note particularly that the strong radio source Sgr B2 shows no significant emission in the mid-infrared image. Strong emission is seen from this source at longer wavelengths such as at sub-mm onwards. It appears that this source is too young or too highly obscured to show up in mid-infrared emission. On the other hand, mid infrared point sources towards the Sgr B1 giant molecular cloud (GMC) show good correspondence with their radio counterparts. There is very close correspondence between the mid-infrared extended emission and the radio contours towards this GMC.

COMPARISON WITH CO SPECTRAL SURVEYS

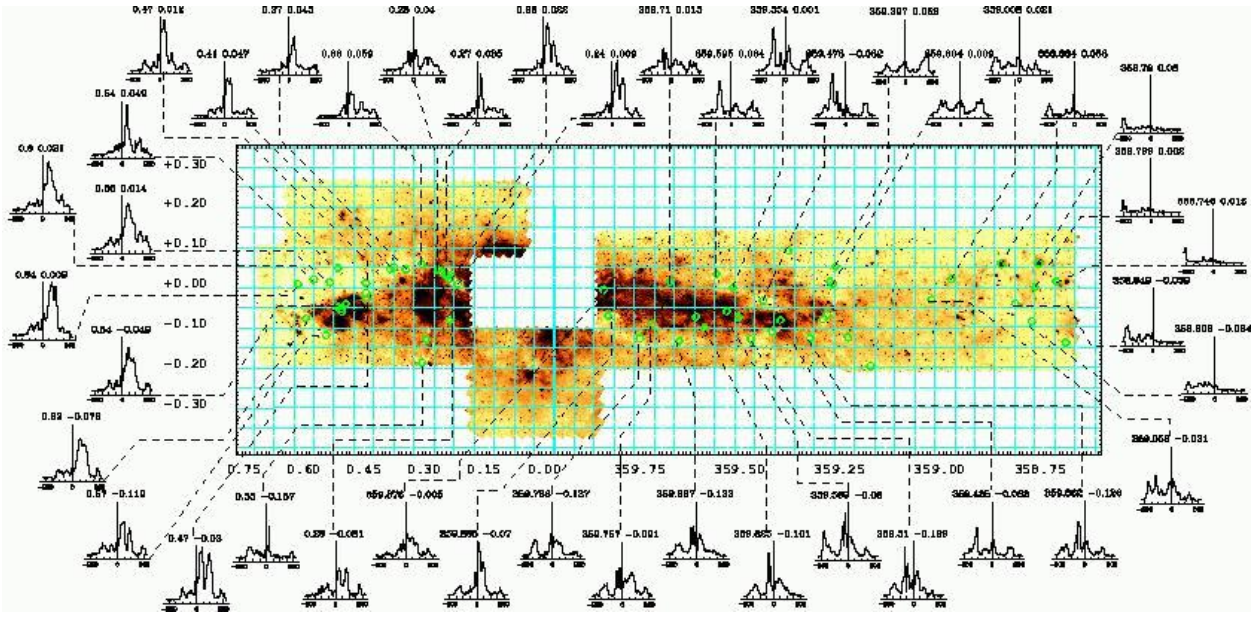

Figure 3: Mid-infrared (7μm) image of the Galactic Nuclear Bulge (galactic coordinates). Observations of the central square around the Galactic Center were not carried out to avoid damaging the detectors due to strong saturation. Image is shown in reverse gray scale with light areas representing strong absorption and point sources appearing as dark dots. CO spectra from Oka et al., are shown at various locations around this map and the bulk of the absorbing material appears to be at velocities close to those expected in the innermost regions of the Galaxy.

We inspected the ^{12}CO spectra at different locations exhibiting absorption in the mid-infrared maps (Fig. 3). These spectra provide interesting clues regarding the location of the mid-infrared absorbing clouds along the line of sight. The spectra are peaked at velocities corresponding to those associated to the Giant Molecular Clouds near the nuclear bulge. Contour plots were also studied and indicate that the material responsible for the strong absorption at mid-infrared wavelengths is at the distance of the Galactic Bulge. Further study is in progress.

SUMMARY

A multiwavelength study of the nuclear bulge is in progress with the comparison of the mid-infrared images with the archival data at other wavelengths. Radio data provides complementary information regarding the absorbing clouds and emission regions close to and within the Nuclear Bulge. We plan further study of these regions at low frequency using the Giant Metre Wave Radio Telescope (GMRT) at Pune, India in the near future.

ACKNOWLEDGEMENTS

We thank T. Oka for providing the CO data in electronic format. Archival VLA data (donated by Yusef-Zadeh et al.,) were obtained from NCSA Astronomical Digital Image Library. We would like to thank the ISOGAL and DENIS teams for providing access to the data. The figures in this paper were made with the SAO DS9 image display software. This study makes use of the NASA ADS. Research at PRL is supported by the Dept of Space, Govt of India.

REFERENCES

[1] T. Oka, T. Hasegawa, F. Sato, M. Tsuboi, A., Miyazaki, "A Large Scale CO Survey of the Galactic Center," *Astrophysical Journal Supp.* vol 118, pp455-515, 1998

[2] K. S. Baliyan, S., Ganesh, U. C. Joshi, I. S. Glass, T. Nagata, "Study of the Nuclear Bulge region of the Galaxy", *Astronomische Nachrichten, Supplementary Issue 1, Proceedings of the Galactic Center Workshop 2002 - The central 300 parsecs of the Milky Way.,* pp47-51 2003

[3] A. Omont, G. Gilmore, C. Alard, B. Aracil, T. August, K. S. Baliyan et al., ISOGAL: A deep survey of the obscured inner Milky Way with ISO at 7 μm and 15 μm and with DENIS in the near-infrared," *Astron. & Astroph.*, vol 403, pp.975-992

[4] D. Pierce-Price, J. S. Richer, J. S. Greaves, W. S. Holland, T. Jenness, A. N. Lasenby et al., "A Deep Submillimeter Survey of the Galactic Center," *The Astrophysical Journal,* vol. 545, pp.L121-L125, 2000

[5] S. Ganesh, U. C. Joshi, K. S. Baliyan, I. S. Glass, A. Omont, D. Pierce-Price, J. Richer, G. Simon, "Mid-infrared and sub-mm morphology of the Galactic Nuclear Bulge," *Proceedings of the International Conference on Submillimetre Science & Technology held at PRL, Ahmedabad, India.* in press