VLA OBSERVATIONS OF FAR-IR SOURCES TOWARD THE GALACTIC CENTER

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ABSTRACT. Preliminary results are presented from a 4.8-GHz VLA study of 5 far-IR sources within 1^{o} of the Galactic center. Sgr-D and FIR-27 appear to be nearly featureless radio sources similar to young blister type HII regions, and FIR-21 has a filamentary structure similar to bright rimmed HII regions or Crab-like supernova remnants. Also presented are additional observations of Sgr-C.

1. INTRODUCTION

The flux-limited, far-IR survey described by Odenwald (1982) and Odenwald and Fazio (1984:OF) identified 47 discrete sources similar to HII regions containing O-type stars. In order to confirm that these discrete far-IR sources are star forming regions, 21 were selected that were located in uncluttered regions, and were mapped with the VLA in order to identify internal structures indicative of recent massive star formation, such as ionization fronts or compact HII regions (Ho and Haschick, 1981; Haschick and Ho, 1983; Schwartz, 1985).

2. OBSERVATIONS

The observations were made on 1984 April 9-10 using the Very Large Array in the C configuration at 4.8 GHz, with a beam size of ~4" x 8" and with each source observed for 10 minutes. Since the far-IR positions were not known to better than ±1′, an 8′ x 8′ area centered on each far-IR position was mapped to a typical noise level of ~2 mJy/beam. The maps have been CLEANED using the algorithm of Clark (1980), and corrected for the primary beam response.

3. RESULTS

Many of the fields (FIR-22,24,39,40,41 and 43) contained no recognizable radio sources in excess of the background noise level. Several

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fields (FIR 1-5, 11, 25, 28 and 36), however, contained patchy radio emission possibly an artifact of the CLEAN algorithm itself. In what follows, I describe the radio sources for which a distinction between background clutter and source emission could be made with reasonable confidence, namely, Sgr-C, Sgr-D, FIR-14, FIR-21, and FIR-27.

Table 1 : Summary of Far-IR and Radio Continuum Observations

(1) Source	(2) FIR Size (′)	(3) FIR Flux (Jy)	(4) VLA Size (")	(5) VLA Flux (Jy)	(6) Tot. Flux (Jy)	(7) L	(8) N_L	(9) IRE	(10) EM	(11) N_e	(12) Sp.
Sgr-C	1.6	5200	71x42	3.655	9.9	5.9	49.8	3	5	460	O4
Sgr-D	1.1	4000	17x11	1.660	9.4	5.8	49.8	2	35	2500	O5.5
FIR-27	1.5	1300	32x22	0.795	1.9	4.0	47.8	3	4.5	1400	B0
FIR-21	2.3	6400	96x42	0.731	2.2	4.7	47.9	14	0.7	350	O8.5
FIR-14	3.8	8400	121	0.470	...	6.1	48.5	81	0.3	160	O4
DGSW-47			60x30	1.643	...		49.0	23	3.7	450	O4

The far-IR sizes and flux densities (Table 1) are based on the 40-250 μm survey by OF, and have uncertainties of $\pm$0.5′ and $\pm$30%. The total far-IR luminosities given as $\log(L/L_\odot)$ in col. 7 are based on a distance of 8.7 kpc (Graham, 1979) for Sgr-C, D, and FIR-14, and 2 kpc for FIR-21 and 27 as recommended by OF. The Lyman continuum flux, N_L, given as $\log(\sec^{-1})$ in col. 8 utilizes large-beam measurements by DWBW at 4.87 GHz appearing in col. 6. The ratio of L to N_L is given by the Infra Red Excess (IRE) in col. 9, computed according to the method of OF. The emission measures and electron densities in cols. 10 and 11 presented in units of 10^5 pc cm^{-6} and cm^{-3} respectively are based on the VLA data in cols. 4 and 5. The estimated stellar types in col.12 were determined by matching both the L and N_L with the OB star tabulations of Panagia (1973).

3.1 Sgr-C (G359.438-0.082)

With a far-IR luminosity, Lyman continuum flux and IRE for Sgr-C consistent with those of a single O4 ZAMS star, this source is probably an HII region, a possibility also indicated by radio studies of this object (Downes et al. 1978: DGSW; Pankonin and Downes, 1976). An earlier 1.6-GHz VLA study by Liszt (1985) with a resolution of 13" x 24", revealed a ring-like structure (r ~9 pc) with a sharp western edge. The current survey appears to resolve the bright core into about 10 discrete clumps. However, the entire region has a mottled appearance due to CLEAN algorithm artifacts so that this apparent clumpy structure may be spurious. The modest, 3-fold, electron density contrast between the clumps and the extended background, together with the ring-like morphology, suggests a clumpy ionization rim similar to

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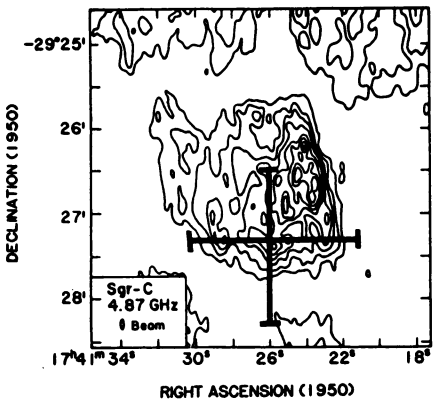
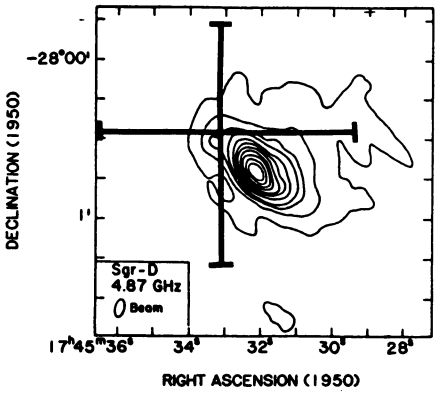


(a)



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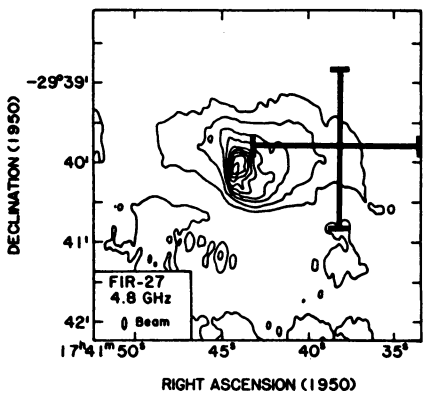
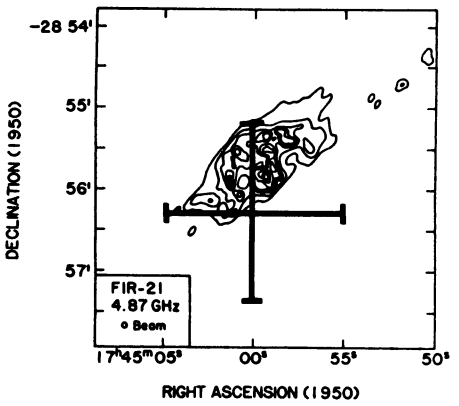
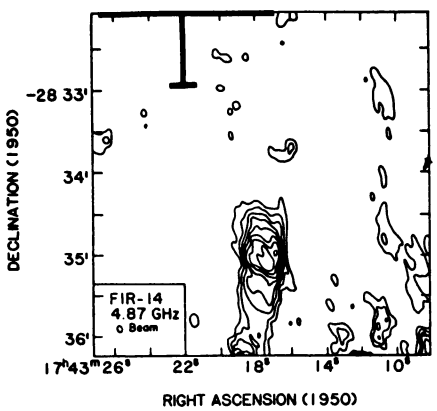


(c)



(d)



(e)

Figure 1

VLA maps of selected far-IR sources at 4.8 GHz. Crosses indicate far-IR source positions and uncertainties. Contours at:
a) (2,3,4,5,6,7,8,9,10) x 2.6 mJy/beam
b) (0.5,1,1.5,2,3,4,5,6,7,8,9,10) x 16.4 mJy/beam
c) (1,2,3,4,5,6,7,8,9,10)x 2.5 mJy/beam
d) (1,1.2,1.4,1.6,1.8,2.5,5,7.5,10) x 4.6 mJy/beam
e) (2,3,4,5,6,7,8,9,10) x 3.6 mJy/beam

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those often observed around early-type stars elsewhere in the Galaxy.

Notably missing from the current 4.8 GHz data is the bright filament near RA= $17^h\ 41^m\ 19^s$ and Dec= $-29^o\ 24'$ observed by Liszt with a peak surface brightness of 90 mJy/beam. Its absence in Fig 1(a), allowing for the difference in beam sizes, implies a steep spectral index with $\alpha > 0.4$. The filament appears to be a non-thermal feature similar to those observed by Morris and Yusef-Zadeh (1985).

3.2 Sgr-D (G1.130-0.106)

Sgr-D has also been identified as an HII region by DGSW, Wink, Altenhoff, and Mezger (1982:WAM) and Downes et al. (1980:DWBW). The presence of H_2CO absorption lines at 84 and 123 km/s, whose velocities are typical of Galactic center molecular clouds, leads to a probable association of Sgr-D with the Galactic center. Sgr-D is also situated ~5′ (15 pc) north of the SNR G1.05-0.1 which has an estimated age of ~20,000 yrs (Odenwald,1982).

In spite of its high luminosity, Sgr-D has a surprisingly smooth appearance, in contrast with Sgr-C, which has comparable far-IR and radio luminosities. This morphology is also similar to that of DR-15 and DR-22 described by Odenwald et al. (1986). Both are core-halo HII regions with >50% of their radio emission in the halo component, situated near the edges of molecular clouds, implying a blister-type structure. The small physical size (0.5 pc) for the core component of Sgr-D, along with its large electron density, are consistent with it being a relatively young source. An assumed expansion velocity of 10 km/s implies an age of 5×10^4 yrs, similar to that of DR-15 and DR-22.

3.3 FIR-27 (G359.28-0.26)

FIR-27 is probably a nearby HII region as evidenced by the H90α recombination line observations by WAM indicating T_e ~6100 K. The H_2CO absorption lines detected by DWBW at -2 km/s imply kinematical distances of 2.4 and 17.6 kpc. The near distance was favored by OF since FIR-27 is adjacent to the optical nebula RCW-137.

The VLA map in Figure 1(c) shows that G359.28-0.26, like Sgr-D, has a nearly circular appearance with a sharp gradient in brightness to the east and south, though to the north and west the gradient is considerably flatter. It is also associated with a molecular cloud detected by DWBW, so that its identification as a 'blister' HII region is at least consistent with the available information.

3.4 FIR-21 (G0.3-0.5)

FIR-21 is located sufficiently far from the galactic plane that it was originally classified by OF as a foreground object unrelated to the galactic center population. Optical emission nebulae associated with RCW-138, 141, and 142 are prominent in this region, with Hα velocities (Georgelin and Georgelin, 1970) similar to the H110α and H_2CO line velocities in the direction of G0.3-0.5 (DWBW). Based on the radio

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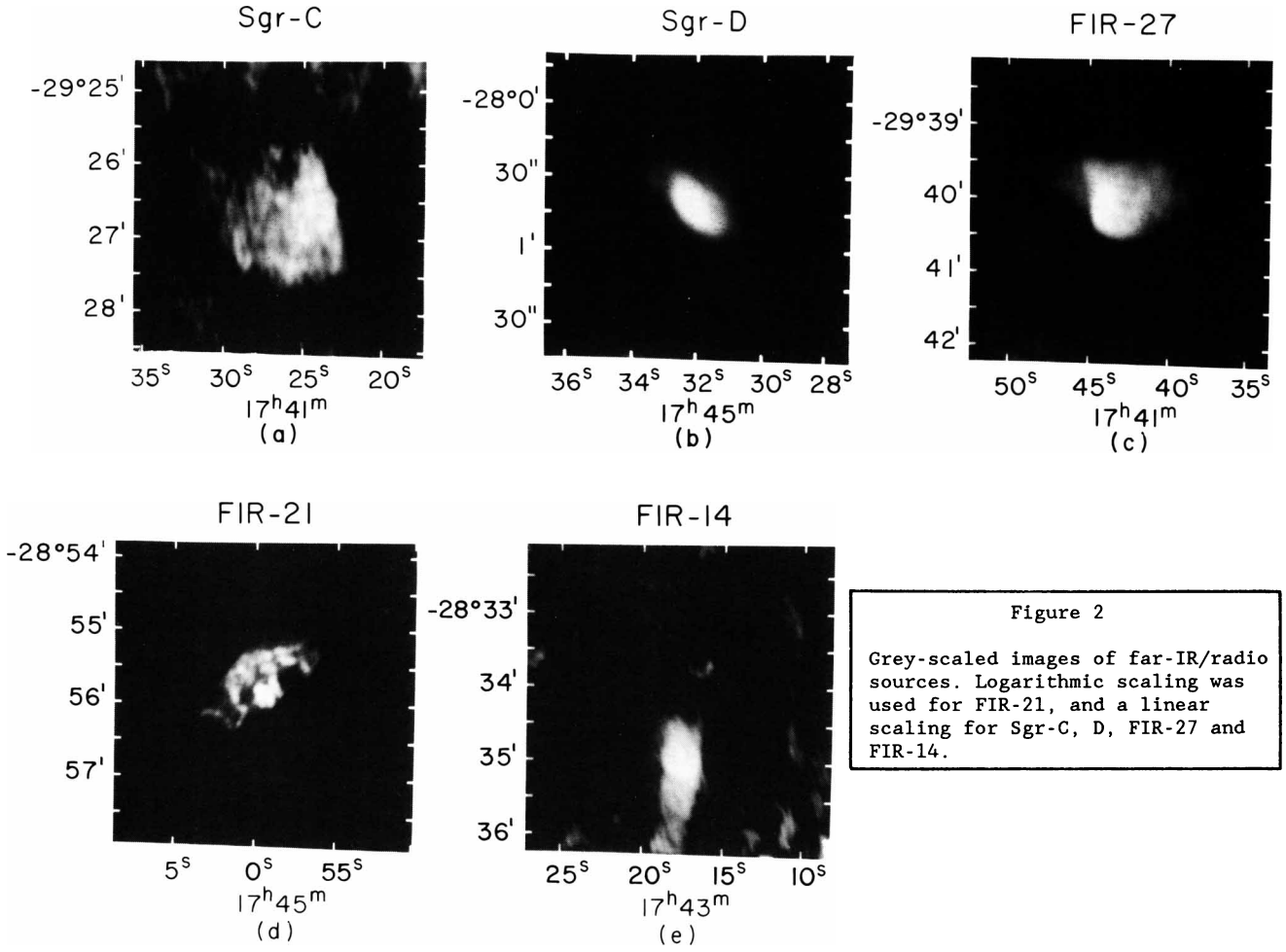

Figure 2

Grey-scaled images of far-IR/radio sources. Logarithmic scaling was used for FIR-21, and a linear scaling for Sgr-C, D, FIR-27 and FIR-14.

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continuum observations by Altenhoff et al.(1978) and Reich et al. (1984), G0.3-0.5 has an estimated total flux density of 2.2 Jy at 4.8 GHz, and 2.41 Jy at 2.7 GHz, implying a spectral index of $\alpha = 0.12$, indicating thermal emission.

Figure 1(d) and the radiograph in Figure 2 show that G0.3-0.5 has a bright, unresolved core partially surrounded by what appear to be weak, discrete clumps or filaments ~30" (0.3 pc) in diameter subtending ~180^{o} with respect to the core source. If this filamentary component is material ejected by the core source with V ~10 km/s, its expansion age would be ~30,000 yrs.

The overall properties of FIR-21 compare favorably with those of a bright rimmed HII region associated with a young O8.5 ZAMS star, however, the similarity between the VLA map of FIR-21 and the SNR G351.2+0.1 observed by Becker and Helfand (1988) is actually quite striking. Although FIR-21 has a spectral index dominated by thermal emission, SNR such as G24.7+0.6 also has detectable far-IR emission (Becker and Helfand, 1987).

3.5 FIR-14 (G0.43+0.3)

This source is 1.1′ east of an extended radio continuum source observed by DGSW at 10.7 GHz located at RA= $17^{h}\ 43^{m}\ 17^{s}$ and Dec= $-28^{o}\ 32'$. Based on this radio identification, although it has a luminosity equivalent to an O4 star, FIR-14 has an IRE = 81, more appropriate to late B-type stars, making it a unique object in our far-IR survey. This position also coincides with a prominent non-thermal source identified by LaRosa and Kassim (1985).

Figure 1(e) shows that G0.43+0.3 was not detected by the VLA, suggesting that its structure was completely resolved in the C configuration. However, a bright, unresolved source is apparent 3.0′ SW of the far-IR position and is identified by DGSW as No. 47 (hereafter DGSW-47) in their catalog. It is unlikely that the far-IR position is this poorly known; furthermore, the identification of FIR-14 with DGSW-47 does little to reduce the IRE of this source to values more typical of O4 stars and normal HII regions ($3 < IRE < 10$). A second possibility may be that FIR-14 does, indeed, correspond to G0.43+0.3 and that they are simply an inhomogeneity within the diffuse radio/far-IR background. Lacking an embedded stellar population, the computed IRE and spectral type are not meaningful parameters.

4. CONCLUSIONS

The radio appearance of Sgr-C is consistent with a clumpy ionized rim associated with a single O4 ZAMS star. Due to CLEANing artifacts, a more definitive interpretation must await data with improved UV coverage.

The radio morphologies of Sgr-D and FIR-27 suggest that they are probably young O5.5 and B0 ZAMS 'blister' HII regions near the surfaces of molecular clouds, similar to the Cygnus-X sources DR-15 and DR-22.

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FIR-21 has an unusual radio appearance. Although similar in morphology to the Crab-like SNR G24.7+0.6, the radio spectrum and luminosity are, nevertheless, consistent with those of an HII region powered by an O8.5 ZAMS star.

The far-IR and radio properties of FIR-14 may be a local density enhancement in the diffuse background emission without an embedded stellar source.

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