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THE GALACTIC CENTER SPUR—A JET FROM THE NUCLEUS?

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ABSTRACT

We report the possible detection of a 4 kpc long jetlike feature emanating from the Galactic center region. The feature is some 200 pc in diameter and extends almost perpendicular to the Galactic plane and may be related to some activity in the Galactic center. The structure may possibly be a radio jet from the nucleus, or it might be a magnetic tornado produced by a twisted poloidal magnetic field between the disk and halo.

Subject headings: galaxies: jets — galaxies: nuclei — galaxies: The Galaxy — radio sources: galaxies

I. INTRODUCTION

Nuclei of spiral galaxies are sometimes associated with large-scale jet phenomena of a few kiloparsecs in extent (Duric *et al.* 1983; Hummel, Kotanyi, and van Gorkom 1983). Our Galactic center also shows various ejection features. However, the cylinder-shaped Galactic center lobe (GCL) of a few hundred parsecs scale has been supposed to be the largest object among the ejection features (Sofue and Handa 1984; Sofue 1985). The existence of larger scale jets has remained an open question, except for the suggested "H I Chimney" of a few kpc length (Kundt 1987).

In expectation that our Galaxy may have experienced a kpc-scale ejection, we have searched for a radio jet feature around the Galactic center. Such an object, if exists, may give an important clue to investigate the activity and, in particular, the acceleration mechanism of a kpc-scale jet. In this *Letter* we call attention to a prominent radio spur near the Galactic center, which originally appeared on the 408 MHz all-sky survey and has been considered to be a local object representing internal ridging within the North Polar Spur (Haslam *et al.* 1981, 1982). Adding new observations at 1408 MHz, we show that the spur is likely to be a structure connected to the Galactic center.

II. A PROMINENT SPUR IN THE GALACTIC CENTER

A survey for jetlike features extending from the Galactic disk has been made (Sofue 1988) by using the all-sky radio data at 408 MHz (Haslam *et al.* 1982). However, a problem which arises when we look for a faint, extended object near the Galactic plane, in particular in such a bright region as the Galactic center, is the confusion with the background disk emission and the difficulty of visualizing the faint object. In order to avoid this we need to eliminate the diffuse background components from the data. For this purpose we have applied the background filtering (BGF) method (Sofue and Reich 1979).

The BGF method is composed of the following procedures: The original 408 MHz map, T, with HPBW of 0°.85 is convolved with a Gaussian beam of HPBW 5° (the filtering beam) to yield T_0^1. Then T_0^1 is subtracted from T to yield $\delta T^1 = T - T_0^1$. We then make $T_0'^1 = T - \delta T^1$ for $\delta T^1 > 0$, while $T_0'^1 = T$ for $\delta T^1 < 0$. $T_0'^1$ is further convolved with the filtering beam to create T_0^2, $\delta T^2 = T - T_0^2$, and $T_0'^2$. This procedure is repeated for i times until T_0^i-converges to a unique background, or until $|T_0^i - T_0^{i-1}|$ becomes smaller than the rms noise everywhere on the map. Usually this is attained in several times of iteration. In the present case we took $i = 10$. We finally obtain $\delta T^i = T - T_0^i$, which we define the small-scale (BGF) map. Obviously the sum of this small-scale map and the background map gives the original, and the result is unique depending only on one parameter, the filtering beam size. Unlike the filtering by Fourier transformation, the BGF method, which uses Gaussian convolution, is useful even for such a region as the Galactic center where an extremely high dynamic range is required. Also note that the method is free from accumulation of numerical errors during the iteration.

Figure 1 shows the BGF map of the central region of the Galaxy, where we can see a prominent spur running from the Galactic center. Inserted is the subtracted background map. (See also the original in Haslam *et al.* 1982). A BGF map obtained for a filter size of 2° showed almost the same structure, except that more patchy structures are enhanced. This spur is visible from $(l, b) \sim (1°, 5°)$ and runs toward the north west. It bends at $l \sim 1°.5$, $b \sim 9°.5$, then extends almost straight toward the west along constant declination, $\delta \sim -21°$, and reaches $l \sim 350°$, $b \sim 24°$. Note that the larger gradient of the brightness on the northern side at $l = 350° \sim 358°$ to $b = 24° \sim 15°$ seen in the original map is due to the superposition of the background emission with steep gradient. The BGF map after subtraction of the background effect does not show this any more. The connection of the spur to the Galactic center, or its extension below $b \sim 5°$ is not clearly seen from the 408 MHz map because of the still remaining contamination of the bright Galactic disk. However, we emphasize that the Galactic nucleus lies apparently on the extension of the lower latitude extension of the spur. No clear southern counterpart to the spur is visible. We also mention that the spur runs almost independently of the H I chimney (Kundt 1987).

In order to get a higher resolution map of this object and to clarify the connection to the Galactic center, we performed 1408 MHz continuum observations using the 100 m Effelsberg telescope at a resolution of 9'.4. In Figure 2 we show the result in a gray-scale representation. In the present limited mapping observations it was difficult to measure the accurate zero level of the map, so we subtracted the smooth component of extent more than 5° from the obtained map. (Detailed contour diagrams of the object will be published elsewhere.) The spur seen

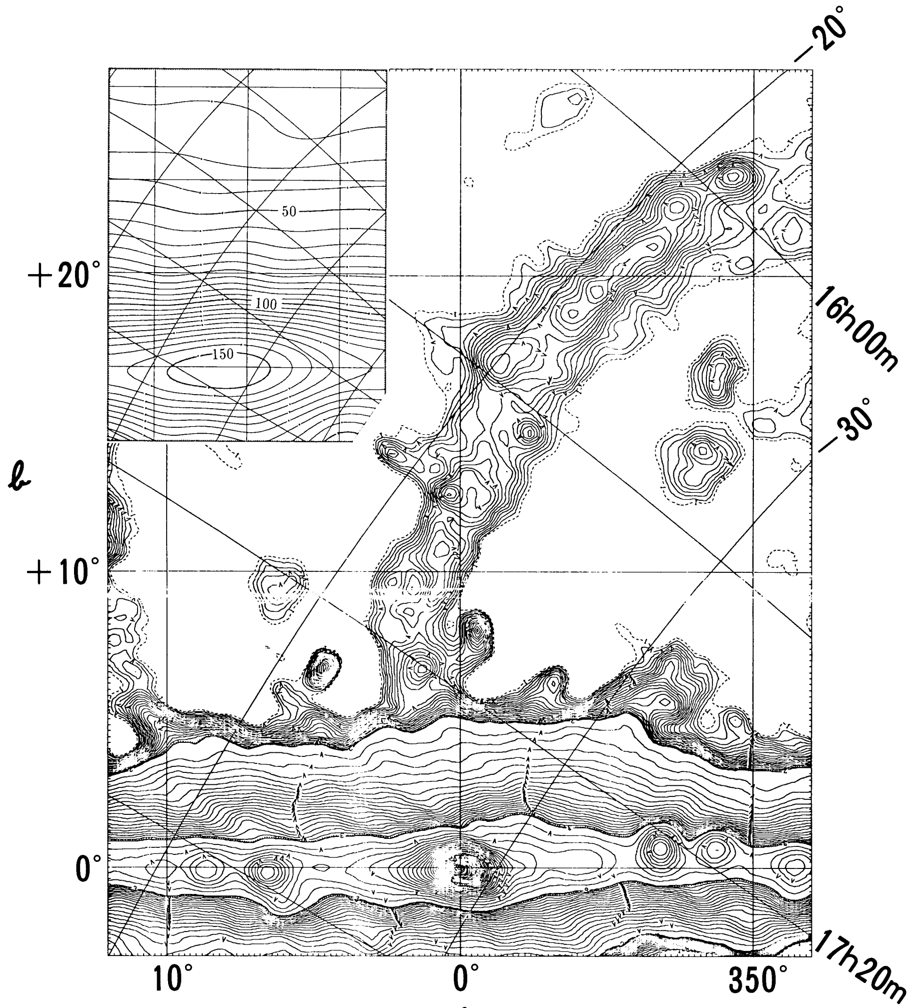

FIG. 1.—The Galactic center spur at 408 MHz map. Structures with scale sizes greater than 5° have been subtracted by the use of the background filtering method. The lowest contour is at 2 K T_b, and the contour interval is 1 K up to 20 K T_b. Then the interval is 10 K up to 200 K T_b, above which the interval is 40 K. Each interval between the labeled contours is divided into 10 equal steps. Inserted in the upper left-hand corner is the subtracted background emission, and the labeled contour numbers are in K T_b (see Haslam *et al.* 1982 for original).

at 408 MHz is clearly visible at 1408 MHz. In addition a large number of clumps and unresolved sources have been detected. The region at $b < 5°$ is now resolved into two narrow ridges extending toward the Galactic center: The spur at 1408 MHz narrows at $b < 5°$ and its major part runs toward $b = 2°$, $l = -0.°8$. This feature is also recognized on a 2.3 GHz map (Jonas, de Jager, and Baart 1985), although much less pronounced. Besides this ridge, there runs another ridge from $(l, b) \sim (3°, 4°)$ toward (1°, 1°), which seems also to connect the spur with the Galactic center region.

III. DISCUSSION

From the appearance of the spur emanating from the Galactic disk we may consider it to be a Galactic object. However, its location in the Galaxy is not directly known. About the location and possible interpretation, we may envision the following two cases: case (a) A local shell-like object such as an old supernova remnant; or case (b) an ejection feature associated with the Galactic center activity.

Case (a) encounters some difficulties: First of all, we could trace neither optical filaments along the feature on the Palomar Sky Survey prints, nor any associated H I feature (Heiles 1980). Even if the spur is a part of a loop, whose diameter must be some tens of degrees, the spur composes only a small fraction of the loop and the remaining part is totally missing (Sofue 1988), so that it is difficult to argue for its loop structure. Although it is bending at some points, the spur is too straight for a loop object and some parts are even convex with respect to the assumed center. Moreover, we find no sharpening of the ridge toward the outer (convex) edge of the spur, which is expected if it is a shocked shell as in a supernova remnant. Note that the larger gradient of the northern edge seen in the original map (Haslam *et al.* 1982), which was due to steep gradient of the disk emission, does not show up any more in the BGF map. The one-sidedness, or the fact that the spur does not extend across the Galactic plane, is also difficult to explain as a supernova remnant. Furthermore, the object is an extremely bright spur: there is no comparable object on the whole sky except for the North Polar Spur, while the close proximity to the Galactic center is very peculiar.

From these we may conclude that case (b) is more probable, and we may attempt to discuss this prominent spur on the assumption that it is associated with the galactic center, so that

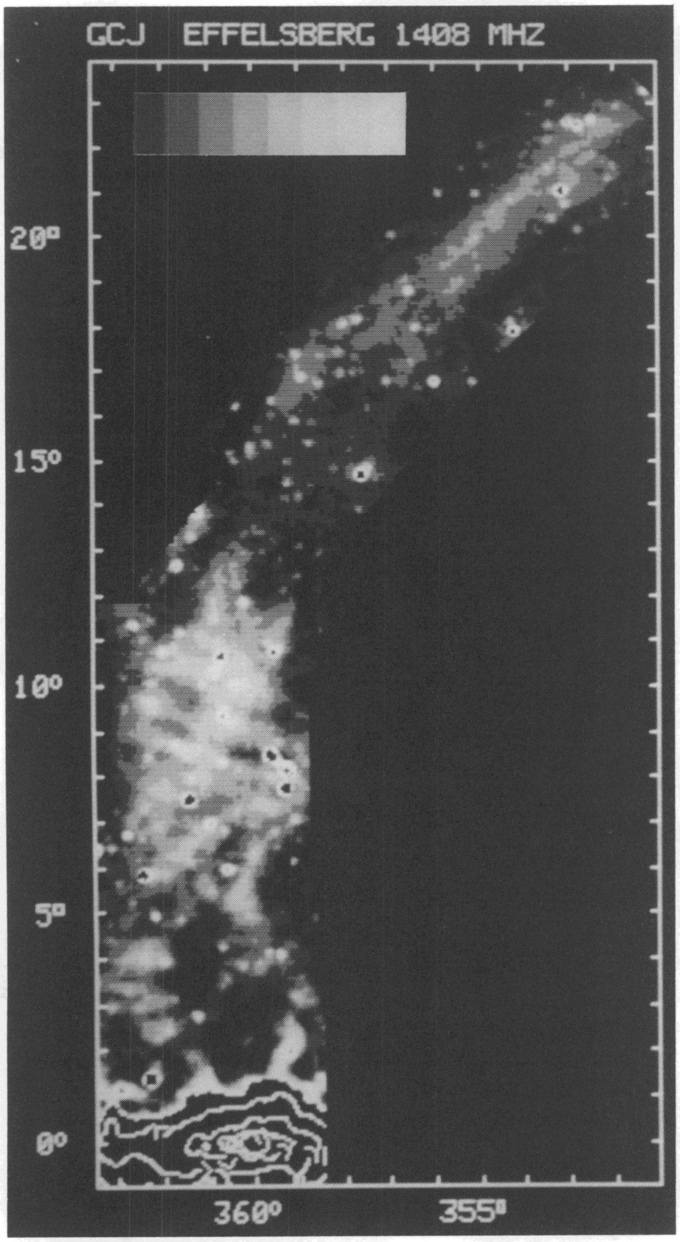

FIG. 2.—1408 MHz map of the GCS in a gray-scale representation as observed with the 100 m Effelsberg telescope at a resolution of 9'.4. The gray scales are given above 50 mK T_b in steps of 150 mK. The contours represent in 5, 20, 50, and 100 K T_b. The GCS has been almost resolved. The rms noise on the map is typically 30 mK. Note the connection toward the Galactic center.

we assume the distance to be 8 kpc. We call hereafter this object the Galactic center spur (GCS) after its appearance.

At the distance of 8 kpc the height of the spur ($b \sim 25°$) above the Galactic plane is about 3.5 kpc and the projected length is approximately 4 kpc. The width is as narrow as 1°.5, or only 200 pc. The spur shows a double-ridge morphology at $b \sim 5$ to 15° on the 1408 MHz map. This may be understood if the spur is a cylinder of diameter of about 2° (300 pc).

The average brightness temperature along the ridge at $b \sim 6°$–20° is about 12 K at 408 MHz and is about 0.4 K at 1408 MHz. Adding data at 2.3 MHz (Baart, de Jager, and Mountfort 1980), we obtain a spectral index along the spur of $\alpha \simeq -0.6$ (with surface brightness $\propto \nu^{\alpha}$). This indicates that the spur is definitely a nonthermal object. The flux density of the GCS at 408 MHz is approximately 10^3 Jy. The radio power at 408 MHz is $P \sim 5 \times 10^{18}$ W Hz^{-1}, and the total luminosity integrated from 0.1 to 100 GHz for a spectral index of $\alpha = -0.6$ is of the order of 10^{36} ergs s^{-1}. Since the emission is most probably synchrotron, we may roughly estimate the minimum magnetic field strength on the assumption of equipartition between the magnetic and cosmic-ray pressures, and we obtain $B > 1.3 \times 10^{-6}$ G. The total energy of magnetic and cosmic-ray energies involved is hence of the order of or greater than 10^{51} ergs. However, the radio luminosity is 10^{-2} to about 10^{-3} times those observed for extragalactic radio lobes in spiral galaxies (Duric *et al.* 1983; Hummel, Kotanyi, and van Gorkom 1983), while the linear scale is of the same order.

Although the origin of this highly collimated jetlike object is open to discussion, we suggest some possible mechanisms: The GCS may be a high-energy plasma beam (jet) ejected from Sgr A, possibly as a counterjet to the "low-energy jet" found by Yusef-Zadeh *et al.* (1986). Alternatively, it may be a mild magnetohydrodynamical jet accelerated by the rotating disk and vertical magnetic field (Uchida, Shibata, and Sofue 1985), or it might be a "magnetic tornado" of kiloparsec scale produced by the differential rotation between the disk and halo.

We finally emphasize that the acceleration mechanism of cosmic jets can be understood only when the site of acceleration is resolved. Namely, for the research of jets it is essential to look observationally into how the jet and the involved magnetic field are interacting with the rotating disk. In this context, the GCS, if it is really a jet from the Galactic nuclear disk, may provide an opportunity to study the jet formation mechanism in the greatest detail because of its proximity to us and its almost resolved structure.

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