A radio lobe over the galactic centre

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Extended radio continuum emission from the central region of our Galaxy has been extensively studied in relation to diffuse H II regions near the galactic plane[1] using radio survey data[2–4]. However, since Kerr and Sinclair[5] called attention to a 'jet'-like feature in the central region, no extensive research has been done on off-plane diffuse radio emission, which is characterized by radio spurs at steep angles to the galactic plane. We report here a prominent off-plane radio lobe structure above the galactic nucleus, which has been revealed during a 10-GHz continuum survey of the galactic plane.

The observations were made in April 1983 using the 45-m telescope at the Nobeyama Radio Observatory (NRO)[6]. The half power beam width (HPBW) was 2.6 arc min at the central frequency of 10.5 GHz. The first side lobe level was below −20 D, which provided high dynamic range measurements. We used a cooled parametric amplifier combined with a Dicke switching system. The bandwidth was 500 MHz and the system temperature was 150 K. We mapped a squared area of 4°×4° centred on the galactic centre by scanning in the direction of the latitude at an interval of 1.2 arc min. The integration time per beam area was effectively 1.4 s. The two extreme edges of each scan at $b = \pm 2°$ were taken as the zero levels. The data were reduced using the radio astronomical reduction system at the NRO.

The 10-GHz continuum maps reveal spur structures emerging from the galactic plane towards high latitudes[6]. The most prominent are the two at $l = 0.2°$ and at $l = -0.6°$, both extending towards positive galactic latitudes at steep angles to the galactic plane. They already appear in the previous surveys at lower frequencies[2–4].

We emphasize here that both the spurs bend convex with respect to the galactic centre and are connected to a radio arc at around $b = 1.2°$ to form an Ω shape. Figure 1 shows the whole structure, where the map has been smoothed to a 3.6 arc min HPBW. Figure 2 shows a grey-scale representation of the same region at a 3 arc min resolution, where a background smooth component of scale sizes > 1° has been subtracted using a background filtering (BGF) method[7], which enhances finer-scale structures. Figures 1 and 2 demonstrate that the two spurs form a giant Ω-shaped radio loop—the GCL (galactic centre lobe). The geometrical centre of the lobe is at $(l, b) = (-0.3°, 0.6°)$. Its angular diameter in the longitude direction is about 1.06°, which corresponds to a linear size of 185 pc at a 10 kpc distance. The height of the lobe is about 1.2° from the galactic plane, or about 210 pc, if the lobe is located at the galactic centre region.

We emphasize that the lobe has steeper gradients of radio emission towards the outer edges. This is seen in Fig. 3 which shows a cross-section of the lobe along a line of constant latitude at $b = 0.4°$. Figure 3 also shows a cross-section along the same line at 5 GHz taken from the Bonn survey[3]. The cross-sections show a brightness distribution typical of a compressed shell. This may indicate that the lobe is a result of an explosive or an energetic outflow phenomenon. The cross-sections are well represented by a superposition of two components: a lobe component with two sharp maxima and a smooth background component as indicated by the dashed lines.

The background component has a steep spectral index $\alpha = -0.6$ to -1 (surface brightness $\propto \nu^{\alpha}$), which indicates a nonthermal origin. On the other hand, the lobe component, after subtraction of the background component, has a flat spectrum of $\alpha = -0.1$. Such a flat spectrum is not expected for a shell type supernova remnant (SNR), and we may exclude the possibility that the GCL is a nearby foreground SNR. The total flux density of the lobe component integrated at $b \geq 0.2°$ is calculated to be 132 ± 10 Jy. The flat spectrum suggests a thermal (free–free) radiation from an ionized gas. If the lobe is composed of ionized H II gas, we can estimate its electron density and mass. If we assume a temperature of 5,000 K, which has been derived for extended low-density H II disk[1], the total mass of the ionized gas in the lobe is estimated to be $4 \times 10^5 M_{\odot}$. The mean electron density in the lobe is $n_e \simeq 5 \text{ cm}^{-3}$; the total thermal energy is $\sim 3 \times 10^{50}$ erg. If the gas is ionized by radiation, the number of UV photons required is $\sim 10^{51} \text{ s}^{-1}$, about one-third of that required for ionization of the extended low-density H II disk around the nucleus[1].

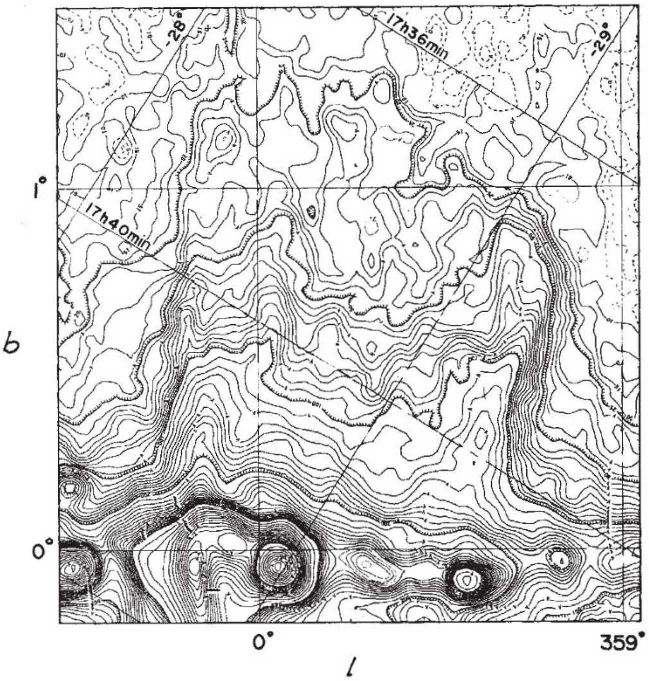

Fig. 1 A 10.5-GHz radio continuum map of the galactic centre region showing the whole structure of the GCL. The map has been convoluted to a 3.6 arc min HPBW gaussian beam. The numbers on contours are in unit of 5.77 mJy per beam of 2.6 arc min HPBW $(= 9.1 \times 10^{-23} \text{ W m}^{-2}\text{Hz}^{-1}\text{sr}^{-1} = 2.7 \text{ mK } T_b)$.

The geometrical appearance of the GCL in wider area maps of the galactic centre region[2–6] strongly supports its association with the nuclear disk. We emphasize that the galactic plane at $10° \geq l \geq -10°$ is a region where strong radio sources are rarely found except for the nuclear region at $2° > l > -2°$. The flat spectrum of the GCL suggests a common origin for the lobe gas and the extended low-density H II gas in the disk. To examine the association of high-velocity gases with the GCL, a survey of the CO line emission has been carried out using a 4-m millimetre-wave telescope at Nagoya University. Preliminary CO line data (I. Suwa, Y. Fukui, Y.S. and T.H., in preparation) show a possible association of a high-velocity ($v_{LSR} \sim 100 \text{ km s}^{-1}$) feature with the western ridge. Such a high velocity cannot be expected from the foreground and background gases. From these arguments we conclude that the GCL is probably associated with the nuclear disk.

The southern extension of the GCL remains uncertain. However, Fig. 1 and a larger area map at 10 GHz (see ref. 6) show a possible connection of the eastern ridge with the 'radio arc' at $l = 0.2°$, $b = 0°$. In the larger area map, we can also find a possible extension of the ridge towards the south reaching to $(l, b) = (0.1°, -0.8°)$, where the ridge is rather broad. We have

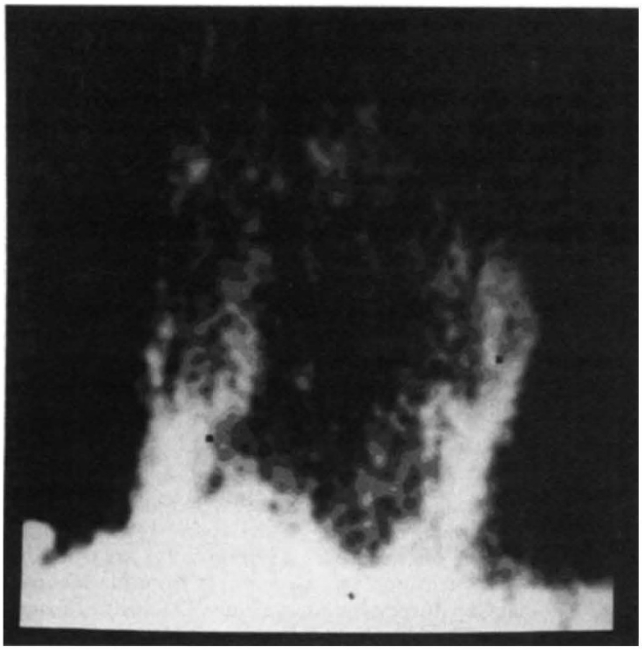

Fig. 2 The same region as in Fig. 1 but on a grey scale. The background smooth structure with scale sizes > 1° has been subtracted from the original, so that the ridge structures are clearer. The map has been convoluted to a 3 arc min beam.

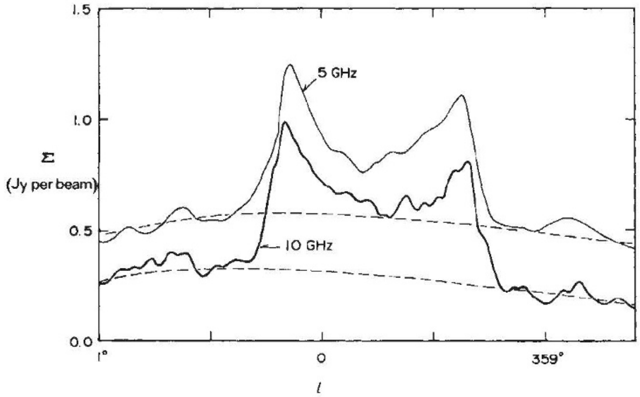

Fig. 3 Brightness distributions across the GCL at 5 and 10 GHz both in Jy per 2.6 arc min beam along a line at $b = 0.4°$, showing that the lobe has a cross-section typical of a shock-compressed shell. The background component, as indicated with the dashed lines, has a steep spectrum of $\alpha \approx -0.6$ to ~ -1, while the lobe component has a flat spectrum of $\alpha \approx -0.1$.

no clear southern extension associated with the western ridge, although we can see a small spur-like feature starting from a strong peak at $(l, b) = (-0.6°, -0.1°)$ and extending to $(-0.5°, -0.3°)$. To see the situation more clearly, however, we need higher resolution observations of the region close to the galactic plane.

We propose the following possible formation mechanisms for the origin of the GCL.

(1) Channelled exhaust from the nuclear disk: a shock wave produced by an explosion or an energetic outflow of matter from the nuclear region will be channelled in the direction perpendicular to the galactic disk[8]. If the distribution of gas in the disk is anisotropic, the flow will be channelled in a one-sided cone and blown off into a less-dense side, resulting in an Ω-shaped lobe. To blow off the gas of mass $4 \times 10^5 M_\odot$ to the height of 100–200 pc of the galactic plane requires the explosion energy to be $\geq 10^{51}$ erg. If the expansion velocity is comparable to that of the high-velocity CO gas, the explosion energy will be of the order of 10^{54} erg, far larger than that of a single supernova. A channelled exhaust can also be produced by a magnetic field running perpendicularly to the disk and to the existence of an accreting gas disk[9]: the accreting gas twists the magnetic lines of force, and the twist propagates along the field, with which the ionized gas is accelerated to produce a cylindrical outflow perpendicular to the disk plane, reproducing the GCL shape (Y. Uchida and K. Shibata, in preparation).

(2) Galactic loop prominence: inflation of a giant loop of magnetic tube filled with ionized gas, similar to a solar loop prominence, may produce an Ω-shaped lobe in the halo. The inflation may be triggered by the Parker-type instability in a magnetized nuclear disk in the presence of cosmic rays. In this case, the magnetic energy should be comparable with, or greater than the thermal and gravitational energy of the gas involved in the lobe. This leads to a field of ~20 μG.

Off-plane radio structures perpendicular to galaxy disks have been observed in the central regions of several edge-on spiral galaxies[10,11]. In particular, the radio lobe found in the central region of NGC3079 suggests inflation of magnetic bubbles from the nuclear disk into the halo[11]. The Ω-shaped lobe in our Galaxy may be a similar phenomenon, although on a different scale: the linear size of the GCL is ~200 pc, while those in the other spiral galaxies are ~1–3 kpc. Such a channelled exhaust perpendicular to the galaxy disk or a 'cosmic jet', of various scales, is likely to be a common phenomenon associated with active nuclei of spiral galaxies including our own Galaxy.

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Search for pulsed optical emission from the millisecond pulsar PSR1937+214

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A search has been made for optical pulses from the 1.6-ms pulsar PSR1937+214, using the 3.9-m Anglo-Australian Telescope (AAT). Despite previously reported indications[1] of pulsed emission at this period from the red star discussed by Djorgovski[2], we now believe the results of the search to be negative with an upper limit on the *R* magnitude of the pulsed emission of ~25. Furthermore, astrometric observations show that the red star is displaced about 2.4 arc s north of the pulsar position and, hence, that it is likely to be a chance association.

Optical pulses have previously been detected from the Crab pulsar[3] and the Vela pulsar,[4] both of which have relatively short periods, 33 and 89 ms respectively. The relative luminosity of the optical emission from these pulsars is approximately in accord with the relation proposed by Pacini[5], $L \propto B_0^4 P^{-10}$, where L is the optical luminosity, B_0 is the surface magnetic flux density (a dipole field structure is assumed) and P is the pulsar period.