

LETTERS

A magnetic torsional wave near the Galactic Centre traced by a 'double helix' nebula

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The magnetic field in the central few hundred parsecs of the Milky Way has a dipolar geometry and is substantially stronger than elsewhere in the Galaxy, with estimates ranging up to a milligauss (refs 1–6). Characterization of the magnetic field at the Galactic Centre is important because it can affect the orbits of molecular clouds by exerting a drag on them, inhibit star formation, and could guide a wind of hot gas or cosmic rays away from the central region. Here we report observations of an infrared nebula having the morphology of an intertwined double helix about 100 parsecs from the Galaxy's dynamical centre, with its axis oriented perpendicular to the Galactic plane. The observed segment is about 25 parsecs in length, and contains about 1.25 full turns of each of the two continuous, helically wound strands. We interpret this feature as a torsional Alfvén wave propagating vertically away from the Galactic disk, driven by rotation of the magnetized circumnuclear gas disk. The direct connection between the circumnuclear disk and the double helix is ambiguous, but the images show a possible meandering channel that warrants further investigation.

The new image was obtained using the Multiband Imaging Photometer (MIPS) camera⁷ on the Spitzer Space Telescope at a wavelength of 24 μm . It reveals the elongated, double helix nebula (DHN) shown in Fig. 1. This nebula clearly extends beyond the edge of the observed field. The full extent of the DHN is evident in mid-infrared images previously obtained with the Midcourse Space Experiment (MSX) satellite (Fig. 10 of ref. 8; see also ref. 26). In the MSX data (Fig. 2), it is possible with hindsight to recognize the double helix, although the sensitivity and spatial resolution are not sufficient to have revealed this structure before the Spitzer observation. The MSX images show that the structure extends towards smaller Galactic latitude (b) from the region observed with Spitzer; it is at least 20 arcmin (50 pc) in length, extending between Galactic longitude $l = 0.08$, $b = 0.5$ and $l = 0.02$, $b = 0.80$, and it is possibly part of a larger structure (see below). However, there is no evidence in the MSX data that the helical strands persist outside the region observed with MIPS. It is also noteworthy that there is no sign in MSX images of a negative-latitude counterpart to the DHN.

The four wavelengths observed with the MSX satellite (8.3, 12.1, 14.7 and 21.3 μm) provide a sampling of the spectral energy distribution of the mid-infrared emission. The surface brightnesses at a few sample locations, measured relative to the local background, uniformly indicate that the emission is substantially strongest at the shorter wavelengths (detailed in Supplementary Information). The best-fit colour temperature is 630 ± 40 K. If the emission corresponds to thermal emission from dust for which the mid-infrared emissivity is proportional to ν^p , where ν is the frequency, then the implied best-fit dust temperature is 410 ± 16 K ($p = 1$) or 310 ± 10 K ($p = 2$). If the two shortest-wavelength channels of MSX are affected by strong emission from bands of polycyclic aromatic hydrocarbon molecules (PAHs), as is frequently the case,

then these temperatures might be strongly overestimated, and detailed spectroscopy will be needed to infer the physical dust temperature.

If the high dust temperatures are upheld, two possible dust heating mechanisms that might be considered are: (1) heating by streaming of gas particles with respect to the dust (for example, as in a Galactic wind⁹) and (2) impulsive heating of small grains by ambient Galactic starlight. For reasonable densities of the streaming gas, the former mechanism provides inadequate heating, even for a relative gas–dust drift velocity as large as the Alfvén velocity in this region ($\sim 10^3$ km s⁻¹, see below). The second mechanism warrants further investigation. Ignoring dust extinction, the equilibrium temperature of dust in the Galactic bulge, 100 pc from the Galactic Centre, is only 30–40 K, but small grains can undergo large temperature excursions as they absorb ultraviolet photons¹⁰, and the total mass required in small grains to account for the DHN emission, although sensitive to the assumed impinging ultraviolet intensity and grain size distribution, is much less than a solar mass.

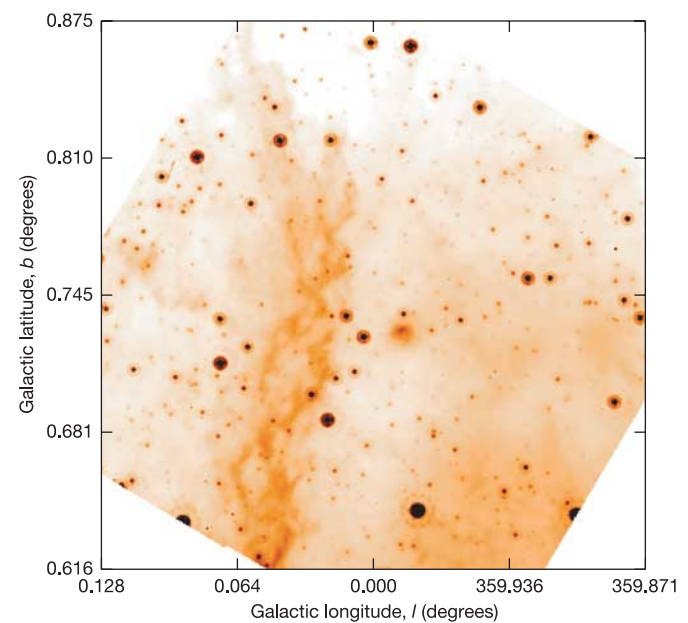


Figure 1 | The double helix nebula (DHN), observed at the infrared wavelength of 24 μm with the MIPS camera on the Spitzer Space Telescope. The spatial resolution is 6 arcsec. At the 8 kpc distance of the Galactic Centre, 1 arcmin corresponds to 2.5 pc. The full region observed extends well to the lower right of the region shown, and consists of a long strip centred on the bright infrared source AFGL5376²⁵, upon which we will report separately.

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Two potential alternatives to thermal dust emission—thermal bremsstrahlung emission by hot electrons and non-thermal emission from a population of relativistic electrons—are both rendered unlikely by the observed spectral slope, as detailed in Supplementary Information. In any case, the average variance of the data from the best-fitting non-thermal power-law models is twice as large as that of the best-fitting thermal model—that with $p = 2$. Consequently, we conclude that the emission observed from the double helix most probably arises from thermal dust emission. Shorter-wavelength observations in the four bands of the Infrared Array Camera (IRAC) on Spitzer will help clarify this point.

The sky location and orientation of the DHN are very suggestive of an association with the centre of the Galaxy. Not only does the long axis of this structure point roughly to the Galactic Centre, less than a degree away, but it is also oriented along the Galaxy's axis of rotation. Furthermore, as we argue below, an association with the Galactic Centre provides a natural explanation for this structure. At an assumed Galactic Centre distance of 8 kpc, the wavelength of the individual strands of the double helix—about 7.5 arcmin—corresponds to a length of 19 pc, and the maximum strand separation (that is, the overall width of the structure) is 1.4 arcmin, or ~ 3.5 pc. The individual strands are just barely resolved, with a width of about 7 or 8 arcsec at their narrowest locations, compared to the full-width at half-maximum of the MIPS point spread function at 24 μm , which is 6 arcsec.

The observed helical structure is far too large to be attributed to stellar activity. Rather, it probably results from a dynamically ordered, large-scale, interstellar phenomenon involving interstellar gas, dust and magnetic fields. We propose that the DHN is a magnetohydrodynamic torsional Alfvén wave propagating more or less vertically out of the Galactic plane, along magnetic field lines, from the near vicinity of the Galactic Centre. This hypothesis conforms to the apparent, global dipolar geometry of the Galactic Centre magnetic field¹. It is natural to ascribe the driving of the torsional wave to rotation about the Galactic Centre, and an obvious candidate to do this is the circumnuclear disk (CND)^{1,11–14}. The characteristics of the CND match those needed to produce the characteristics of the

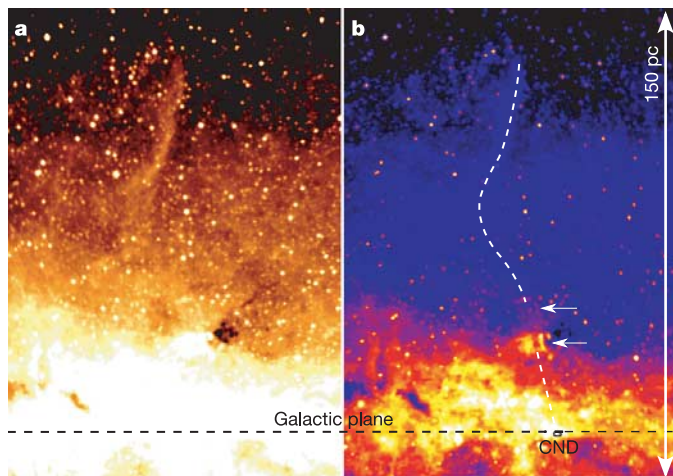


Figure 2 | Images of a 1° field (from -0.1° to $+0.9^\circ$ in Galactic latitude) that include the Galactic plane, the Galactic Centre, and the DHN. These data were taken with the MSX satellite. The spatial resolution of these images is 20 arcsec. **a**, A-band image ($8.3 \mu\text{m}$) with a colour scale chosen to emphasize the DHN. **b**, Same image with a different colour scale. The relative locations and sizes of the DHN, the circumnuclear disk (CND), and the proposed channel linking them, are all shown, along with the two bright channel segments marked with arrows and described in the text. These channel segments are located at Galactic coordinates (l, b) $(-0.01^\circ, 0.15^\circ)$ and $(0.0^\circ, 0.23^\circ)$. Additional MSX images of the channel segments are available in Supplementary Information.

proposed torsional wave: it has an inner radius of ~ 1 pc, and extends out to several parsecs, being somewhat asymmetric in its outer regions, possibly because of an interaction with the SgrA East supernova remnant^{1,15–17}. The lateral extent of the proposed torsional wave, ~ 3.5 pc, is consistent with the planar extent of the CND, 2–7 pc, and thus with the hypothesis that the rotation of the CND is responsible for a torsional wave propagating through a uniform field. Little lateral growth of the helical structure is expected as long as the Alfvén speed is much greater than the rotation speed of the driving disk, or as long as the longitudinal wavelength is much greater than the lateral extent of the feature, which is clearly the case. Furthermore, the CND is strongly magnetized, and its predominant shear-induced azimuthal field is believed to merge smoothly with the ambient vertical Galactic Centre field^{18–20}.

The rotation velocity of the CND is approximately constant at 100 km s^{-1} , giving a period of $10^4 R$ years at radius R (where R is in units of pc). Drawing a correspondence between the period of the CND and the wavelength of the double helix, we can derive the Alfvén velocity: $V_A = 10^3 \text{ km s}^{-1}$. This, in turn, can be used to estimate the magnetic field strength, B , in this region, with $V_A^2 = B^2 / (4\pi m_p n_p)$, where n_p is the proton density in the medium through which the wave propagates, and m_p is the proton mass. This gives $B = 0.5 n_p^{1/2} \text{ mG}$. The density in this region is not known; if the medium through which the wave propagates is the hot (10^8 K) medium evidenced in diffuse X-rays²¹, then $n_p \approx 0.1 \text{ cm}^{-3}$, and consequently, $B = 0.1 \text{ mG}$. The DHN is located on the outskirts of the region to which the 10^8 K gas may extend²², but given previous estimates for B ranging from 0.01 to 1 mG (refs 1, 4, 5), this is a plausible field strength. If, on the other hand, the field strength is that estimated from the rigidity of the non-thermal radio filaments, $B \approx 1 \text{ mG}$ (ref. 1), we infer a local density of $n_p \approx 5 \text{ cm}^{-3}$, which does not violate any observational constraints.

A possible weakness of this hypothesis is that the torsional wave cannot yet be followed all the way down to its hypothetical source, the CND, presumably because of the enhanced confusion by intervening material and superimposed emission structures closer to the Galactic plane. The MSX data do, however, show a potential meandering channel along which the wave might propagate (Fig. 2). Such a meander can be ascribed to the kink instability, arising naturally in a twisted magnetic field. Although the contrast of this potential channel with the local background emission is evidently weak, there are two locations at which evidence for a channel exists in the form of parallel, linear emission features having a separation (~ 5 pc) comparable to the width of the helical structure (marked with arrows in Fig. 2). These features (shown in greater detail in Supplementary Information) can be interpreted as limb-brightened cylinders having relatively thin, emitting walls. Patchy absorption abutting the brighter, lower-latitude one of these indicates the presence of a nearby concentration of dust and gas, so the emission from this apparent part of the channel might be attributable to an interaction between the magnetic energy in the torsional wave channel and the surrounding, relatively dense, interstellar material. (The recently released images from IRAC, however, indicate that this patchy absorption is likely to be in the relatively near foreground (S. Stolovy, personal communication).) One might also speculate that the meander of the apparent channel is partially caused by this interaction, deflecting the wave energy towards positive Galactic longitude. The absence of a negative-latitude counterpart is another potential weakness of the torsional wave hypothesis, inasmuch as such waves should propagate equally in both directions away from the driving disk, if that disk is symmetric about its midplane. However, the MSX images show a brighter, more complex background at negative latitudes, so some combination of background confusion and dissipative shock interactions—both common in the Galactic Centre—could account for the absence of a counterpart.

One question that our hypothesis leaves unanswered is why the helical structure has two strands. A uniform, axisymmetric, rotating

disk driving a torsional wave in a field perpendicular to the disk would produce a cylindrically symmetric structure. The presence of two strands indicates that the driver has an $m = 2$ symmetry (surface density has a term of the form $\exp(im\phi)$, where ϕ is the azimuthal angle). This could take the form of a bar, or, in the extreme case, one could attribute the strands of the double helix to two diametrically opposed blobs into which the vertical magnetic flux threading the disk had been concentrated. As the timescale for propagation of an Alfvén wave from the CND to the observed double helix, ~ 100 pc away, is 10^5 yr, or $10/R$ rotation periods of the disk, there has been sufficient time for the strong shear in the CND to have eliminated any $m = 2$ deviation from axisymmetry that may have been present when the double helix was launched. Nonetheless, the CND is somewhat non-axisymmetric at present, and its inner portions have two prominent concentrations of material on opposite sides of the centre along the major axis of the projected disk^{11,13,14,23,24}. Consequently, it is possible that the $m = 2$ deviation from axisymmetry is still in place, or that it has re-formed since the double helix was launched.

Finally, if the favoured mechanism for the mid-infrared emission from the DHN remains thermal dust emission, then we must face the question of why dust is present at all in the torsional wave. If the emission is from small dust grains, then such grains are likely to carry a net charge, in which case they can then be carried aloft by the torsional wave.

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Supplementary Information is linked to the online version of the paper at www.nature.com/nature.

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