The Eye of the Tornado

An isolated high mass protostellar object near the Galactic centre?

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The Tornado Nebula and its “Eye”

The Tornado Nebula (G357.7-0.1) is an annual nearthermal radio source located close, in projection, to the Galactic centre. It has been classified as a supernova remnant on the basis of its filamentary structure, step radio spectrum and linear polarization. A compact radio source, called the “Eye” (G357.7-0.1), is located about 30° west of its head. The apparent proximity to the Tornado, and location along its axis of symmetry, suggest a connection between the two.

An understanding of both the Tornado and the Eye has been hampered by the debate regarding whether the two objects are related. In this poster we present infrared recombination and molecular line data for the Eye that allows a kinematic distance to be determined. It places the Eye at the same distance as the Galactic Centre, and foreground of the Tornado Nebula. The Eye and the Tornado are therefore separate sources. We then proceed to interpret infrared and radio data for the Eye in terms of a massive protostellar source in the core of a compact, dense molecular cloud - an isolated high mass protostellar object (IMPO).

Observations

The 5.3 m Anglo-Australian Telescope (AAT) was used with the IRS near-infrared camera to obtain J, H, K broad-band continuum images, and line images through narrow-band (1% bandwidth) filters centred at the wavelengths of the hydrogen Brγ (2.166μm) recombination line, and the H2 2.12μm line. Also from the small region of nebulosity associated with the Eye, all of the infrared images show the extended star field at a distance of ~30° from the source directed towards the central regions of the Galaxy. Morphologically, the images of the Eye at 3.5μm and 2.19μm are very similar, with features in the 2.12μm image can be attributed to and may be used to subtract this component from the 2.12μm data, to yield a pure Brγ line image.

Radio continuum observations of the Eye were carried out at 8 and 20 cm with the Very Large Array (VLA). Figure 1a superimposes the radio and infrared images obtained.

The 3.5 m UK Infrared Telescope (UKIRT) was used with the CDS spectrometer to measure the line profile of the Brγ and Hα-12.05μm continuum lines. The echelle mode of the spectrometer was configured to obtain a high-resolution (6Å) and high signal-to-noise (300) profile of the emission on a very short time-scale (2"). The profiles of the two lines are shown in Figure 2 with the velocity scale set to the local standard of rest.

The 15m Swedish European Submillimetre Telescope (SEST) was used to obtain a profile of the CO 1-0 line emission at 2.6 mm from the Eye, as seen in Figure 3. The feature at -205 km/s is associated with the Eye. The CO 1-0 line profile of the Brγ shows a feature at the same velocity in the 12CO J=1-0 line profile. The kinematic velocity is -205 km/s, respectively) and have a line centre at -205 km/s. This corresponds to a feature at the same velocity in the “CO J=1-0 line profile. The kinematic velocity derived from Galactic rotation then places the Eye at the distance of the Galactic Centre (i.e. ~3000 pc) and separated (probably distinct) from the Tornado Nebula. Four knots of emission are seen in the Brγ line, and at 6 and 20 cm. Together with the high-resolution spectral index, we confirm that the Eye is an HH region, but that it is also embedded within a dense molecular core. The knots are UCHII regions, and the core contains a luminous (2 x 104 L☉) embedded, massive protostellar object.

Results

The Eye is resolved by the near-infrared and radio measurements as a compact HH region, and therefore might be undergoing massive star formation. It consists of four knots of emission, each about 3°, or 150 pc, in size and of similar brightness, symmetrically placed about the periphery of a circle of 30° diameter. There are faint continuum extensions -2° to the south and west of the Eye, but no emission from the core.

The emission velocity of the Brγ and CO lines is ~300 km/s. This velocity allows a kinematic distance to be determined, despite the proximity of the sight line to the Galactic centre. The near-infrared Brγ and CO lines are ionized cavities within the molecular core. The knots are UCHII regions, and their emission is also sufficient to account for the source’s IR luminosity. The CO lines do not trace the molecular gas in any detail, with a molecular cloud density of less than 0.1 cm-3, the CO emission is dominated by the HH region, whose emission is also sufficient to account for the source’s IR luminosity. The CO lines do not trace the molecular gas in any detail, with a molecular cloud density of less than 0.1 cm-3, the CO emission is dominated by the HH region, whose emission is also sufficient to account for the source’s IR luminosity.

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The Eye is a dense molecular core within which a massive star is forming. The IRAS far-IR colours place it in the region typical of UCHII regions. It harbours a compact HH region, whose emission is also sufficient to account for the source’s IR luminosity. The CO lines do not trace the molecular gas in any detail, with a molecular cloud density of less than 0.1 cm-3, the CO emission is dominated by the HH region, whose emission is also sufficient to account for the source’s IR luminosity.

Discussion

The Eye may be an isolated (HH) region. Apart from the infrared core, there is no other evidence for star formation associated with the source. For instance, neither H2O nor CH3OH maser emission has been reported. All the activity appears to be concentrated within a 0.2 pc diameter core, harboring a single 0.5 M☉ star, whose mass comprises only a few percent of the core. Of course, there may be lower mass stars which would still be too faint to be detected, so if it were combined with a dense stellar cluster, and each outpost of an extended star forming region. The Eye appears to represent an example of an isolated HHMipo, which will lead to either a single massive star, or a tight stellar cluster whose luminosity is dominated by a single massive star.

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A paper describing these results in more detail will shortly be submitted to Monthly Notices of the Royal Astronomical Society.

Figure 1. Infrared and radio images of the Eye. From bottom left, moving clockwise: (a) 2.19μm continuum image of the field centre on the Eye overlaid with contours of the Brγ line intensity; (b) Continuum subtracted Brγ line image of the Eye, overlaid with contours of the line intensity; (c) 20 cm radio continuum image overlaid with the same contours of Brγ line emission and (d) 6 cm radio image overlaid with contours of 20 cm radio fluxes.

Figure 2. Profiles of the Brγ line emission from the Eye, with the wavelength scale set to the velocity, in km/s, measured with respect to the LSR.

Figure 3. Profile of the CO J=1-0 115 GHz line towards the Eye, with velocity measured with respect to the local standard of rest. The feature at -205 km/s is associated with the Eye.

Figure 4. (a) Profile of the CO J=1-0 115 GHz line towards the Eye, with velocity measured with respect to the local standard of rest. The feature at -205 km/s is associated with the Eye.

Figure 5. Spectral energy distribution for the Eye. IR fluxes have been obtained from the MSX and IRAS survey databases. The best fit two-temperature greybody model to the data is shown in Figure 5, and its parameters listed.