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The polar ring starburst galaxy NGC 660

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NGC 660 is a gas-rich, peculiar polar ring RSBa-type starburst galaxy with two distinct morphological and kinematic components: an inner disc, seen almost edge-on, with a major axis position angle of 45° and a diameter of ~11 kpc [D=13 Mpc, H_0=75 km s^{-1} Mpc^{-1}], and an outer polar ring (p.a. 170°) with a diameter of 31 kpc, inclined on average about 55° with respect to the major axis of the inner disc.

We obtained deep, 30 min. exposure CCD images of NGC 660 with the 105 cm Schmidt telescope of Kiso Observatory in the B, V, R, and I bands. A preliminary reduction shows that the inner disc is clearly redder than the polar ring and the nucleus.

Optical spectra indicate that the galaxy has a LINER-type spectrum, suggesting intense massive star formation in the nucleus. We obtained a long-slit Hα spectrum along the major axis of the inner disc at ESO, which shows a very steep gradient near the nucleus. Assuming an inclination of 80°, it implies a rotational velocity of about 150 km s^{-1} for the inner disc.

A 2.2 μm near-infrared image we obtained at Hawaii shows a very strong concentration of light in the starburst nucleus. The IRAS data show that NGC 660 has a rather high far-infrared luminosity of $\log(L_{FIR}/L_\odot)$=10.30, as well as a high L_{FIR}/L_B ratio of 4.7; however, its overall star formation efficiency is not very high (see below).

We mapped the galaxy in the 21 cm H I line with the Westerbork Synthesis Radio Telescope with a resolution of 13″×60″ ($\alpha \times \delta$) and 20 km s^{-1}. The total H I mass of NGC 660 is 3.2 10^9 $M_\odot$, indicating an M_{HI}/L_B ratio of 0.75 $M_\odot/L_\odot$, an order of magnitude higher than the gas content of normal Sa galaxies. H I emission was detected in both morphological components, the inner disc and the polar ring.

The H I column density map is shown below, together with an optical image. The H I data also clearly show line absorption against the nucleus. Using our geometrical model (see below) to interpret the H I velocity field, we derive a rather flat rotation curve, with a rotational velocity for the polar ring of about 130 km s^{-1}.

The entire inner disc and parts of the polar ring were mapped in the CO(1–0) and CO(2–1) lines at IRAM and/or Nobeyama with resolutions of 12″–22″. The total estimated H_2 mass of the disc is 3.7 10^9 $M_\odot$, showing that the galaxy is also very rich in H_2 gas for an Sa-type galaxy, and implying a global star formation efficiency of L_{FIR}/M_{H_2} = 5.4 $L_\odot/M_\odot$, considerably lower than the global ratio of classical starburst galaxies, despite the evidence for a nuclear starburst.

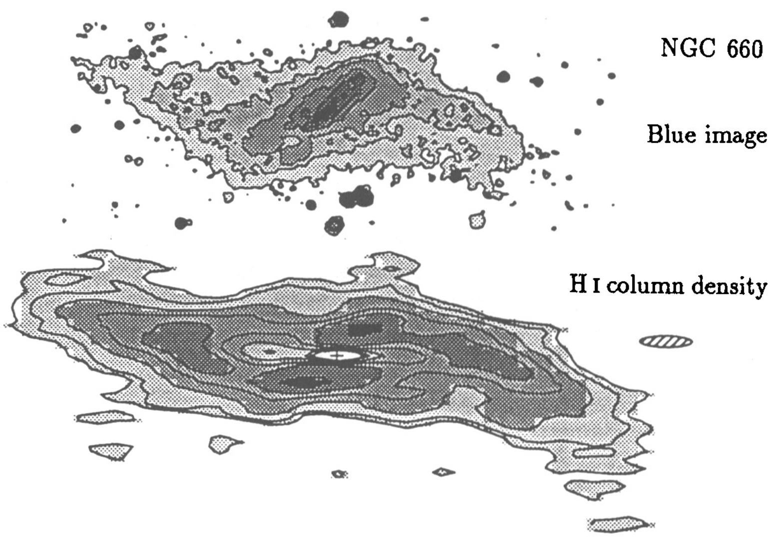
The column density distribution of the inner disc shows a very strong concentration of CO line emission towards the centre. The presence of such a large molecular gas mass in a small volume can explain the presence of a starburst region in the centre. The rotation curve of the inner disc derived from the CO line data is comparable to the Hα and H I results.

We constructed a 3-dimensional model of the polar ring, fitting the optical and H I morphology and kinematics (see Combes et al. 1992, A&A 259, L65). The 7 model rings are all inclined 82° on the sky, with position angles varying linearly with radius. We populated them with an equal number of particles and gave them all a rotational velocity of 135 km s^{-1}. We also added a rotating inner H I disc. The model fit shows that the polar ring is highly warped and twisted, and one of the most inclined 'polar' rings known.

The stability of the NGC 660 system remains a puzzle. Due to the flattened potential, the polar ring is forced to precess around the pole, but the precession depends on radius, making the structure rather short-lived, $\lesssim 10^9$ year. The polar ring could be stabilized by a tumbling bar, radiative cooling, or self-gravity, which could make it rotate as a solid body. However, none of these possible solutions seem obvious candidates in this case, and we will investigate this matter further.

These results will be discussed in detail in a paper to be submitted to Astron. Astrophys. by W. van Driel, F. Combes, F. Casoli, M. Gerin, P. Goudfrooij, M. Hamabe, M. Miyaji, N. Nakai, Y. Sofue, K. Wakamatsu, and S. Yoshida.

Figure: (Top) Blue image, from a digitized POSS plate. (Bottom) H I column density distribution (contours 0.4, 0.8, 1.7(1.2)6.5 10^{21} cm^{-2}); the hatched ellipse indicates the beam size. Note, that North is left and East is down.



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