HI Absorption and OH megamasers in IC694

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We present high resolution MERLIN observations of the HI absorption, the OH megamaser emission and the 6cm continuum of IC 694 a member of the merger system Arp 299. The radio continuum of IC 694 is consistent with a disk of synchrotron emission powered by supernovae remnants. The atomic and molecular gas is located in a similarly orientated 250 pc large disk. The HI extends up to 250 pc occupying the same space as the CO disk (Aalto et al 1997), whereas the OH masers occupy the inner 100 pc of the disk.

1. Introduction

The merging system Arp 299 (Mrk 171) consists of two interacting galaxies, IC 694 and NGC 3690, at a distance of 42 Mpc (z=0.0103, H_0=75 km s^{-1} Mpc^{-1}). Its far-infrared luminosity of $5.2\times10^{11}L_\odot$ (Soifer et al, 1997) places it in the gap between the nearby starburst galaxies (eg M82) and the more distant and still enigmatic Ultra Luminous far-InfraRed (ULIR) galaxies (eg Arp 220).

The system is rich in molecular gas, with bright CO condensations in the two galactic nuclei, particularly in IC 694, where the molecular gas mass in the inner 280 parsec is $\sim 5\times10^9$ $M_\odot$ (Aalto et al 1999). Furthermore, in the nucleus of IC 694, the mm molecular line rations reveal a highly disrupted molecular ISM with a bulk temperature in excess of 100 K. The detection of OH megamasers and HI absorption in Arp 299 (Baan & Haschick 1990, BH90), further emphasises the notion of extreme conditions in the ISM.

In order to investigate the conditions of the atomic and molecular gas in detail we made sub-arcsecond resolution observations with the MERLIN array of the HI absorption, the OH megamaser emission and at the frequency of the J=1 (1_{10}-1_{11}) K–doublet Formaldehyde (H_2CO) line (λ6cm). MERLIN's linear resolution of 10-40 pc approaches the single cloud detection limit and is an order of magnitude higher than that of BH90. These can then be compared with the 200 pc resolution CO interferometric images (Aalto et al 1999) to study the properties and the kinematics of the gas.

The observations were made in the spring of 1998. At 21cm and 18cm we observed a total bandwidth of 8 MHz with a velocity resolution of $\sim$12 km s^{-1}, and at 6cm, a bandwidth of 16 MHz with a resolution of $\sim$15 km s^{-1}. The observations of the source were interspersed with the nearby calibrator 1125+596. Initial editing and calibration were carried out using standard MERLIN software; further analysis was performed in AIPS. Bandpass calibration and corrections of the antenna gains were derived from imaging the phase calibrator and were applied to the data of Arp 299.

After continuum subtraction in the uv-plane, a cube containing the line data, was formed and imaged. The spectral channels containing the line-free emission were added to form continuum datasets (with bandwidths of 14.5 MHz at λ6cm, 2.0 MHz at 18 cm and 3.7 MHz at 21cm), which were imaged independently.

Naturally weighted and tapered images of Arp 299 that cover $\sim$40$\times$40 arcsec detect λ21 cm continuum emission at both galaxies in the system, IC 694 and NGC3690, as well as the region of interaction between the galaxies. In contrast, at λ6 cm, emission from only the centres of IC 694 and NGC3690 is detected.

The HI absorption line and the OH megamaser line were clearly detected in spectral plots of the continuum-subtracted datasets. On the contrary, no formaldehyde absorption

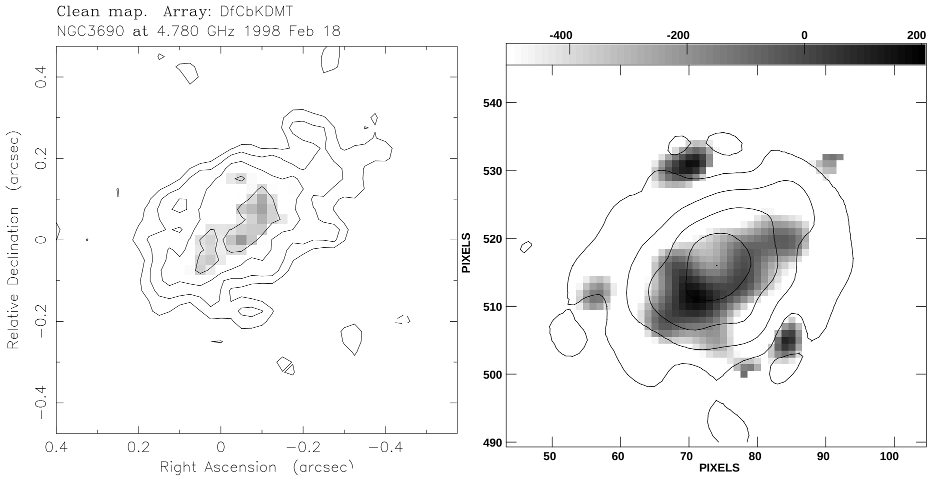

FIGURE 1. Left: The full resolution $\lambda 6$ cm continuum image of IC 694 convolved with a round restoring beam of 55 mas. The contours are 1,2,4,8,16,32,64 $\times$ 0.36 mJy/bm. Right: The spectral index image of IC 694 (grey scale) overlaid on the 150 mas resolution contour image of the $\lambda 21$ cm continuum. Grey scales are from spectral index -0.005 to 0.186 and contours are from 0.32 mJy/bm $\times 1$, 2, 4, 8, 16, 32, 64

or emission lines were detected in the 6cm dataset. In this paper we discuss preliminary results for one of the two interacting galaxies, IC 694.

2. The radio continuum of IC 694

The radio continuum images show a 200 by 250 pc large, elongated structure, orientated at position angle (PA) $\sim 135°$. The overall spectral index of the source is flat between $\lambda 6$ and $\lambda 21$ cm. The highest resolution $\lambda 6$cm image (Figure 1) reveals a 150 parsec long, brighter elongated ridge, surrounded by fainter, diffuse emission (>200pc). This bright ridge is seen to 'break up' in components, with brightness temperatures of the order of 10^5 K, the southwesternmost of which has the most inverted spectral index at $\alpha = -0.169$.

The structure of the source is not that of a typical bright AGN seen at similar resolution; there is no single, bright unresolved core component and the elongated ridge does not have the appearance of a core-jet structure. Instead, the morphology of IC 694 appears consistent with emission from a disk, similar to those found in several other ULIR galaxies (e.g. Mrk 231, Carilli et al 1998, Mrk 273, Carilli & Taylor 2000), which is thought to be synchrotron emission from electrons accelerated by radio supernovae remnants or hypernovae. Then, at higher resolutions the bright subcomponents may be found to be supernovae remnants.

3. HI Absorption in IC 694

HI absorption is detected against all emission regions of the Arp 299 system, similar to BH90's lower resolution VLA observations. The most pronounced absorption is against the nucleus of IC 694.

The velocity-integrated HI absorption intensity image (Figure 2, left) shows that the

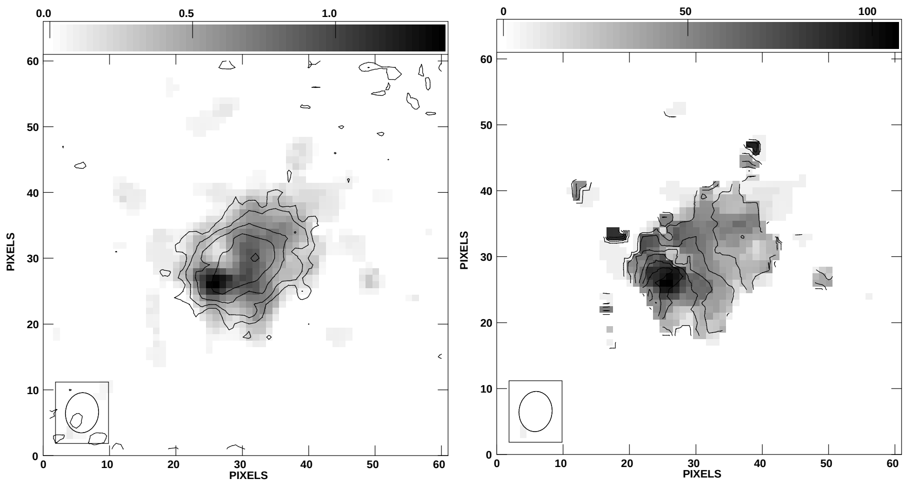

FIGURE 2. The velocity integrated intensity image of the HI absorption system in IC 694 (grey scale) overlaid on the contour image of the 6cm continuum image. Uniform weighting has been used.The contour levels are 0.36mJy/bm × 1,2,4,8,16,32,64. *Right:* The mean velocity field of the HI absorption system in IC 694 (contours) overlaid on the grey scale image of the velocity dispersion (grey scale)

absorption peaks at the southeast end of the bright ridge, while the intensity-weighted mean velocity field (Figure 2, right) reveals a fairly regular looking spider diagram in the inner 240 pc, implying that the HI is located in a rotating disk-like structure with inclination $\sim 60°$, elongated at 135°, along the major axis of the radio continuum. The centre of the rotation coincides with the position of the brightest component at the northwestern part of the continuum. The rotation is close to solid body and has a velocity gradient of 2094.4 km/s kpc^{-1}.

The Position-Velocity diagramme (Figure 3, middle panel) shows several absorption components along the major axis of the continuum, indicating the clumpy nature of the rotating structure. The optical depth ranges between 0.1 to 0.5 for each clump. The total HI column density is $N_{HI} \sim 1.26 \times 10^{20} T_S$, implying a mass for the HI of $M_{HI} = 3.6 \times 10^6 M_\odot$ (for T_S=100 K), roughly 1% of the dynamical mass.

The turbulence of the HI gas is generally high — it often exceeds 100 km/s. The velocity dispersion image (grey scales in Figure 2, right) shows that the highest turbulence does not coincide with the kinematical centre. Instead it occurs towards the southeastern part of the source, at the position of the most inverted spectrum continuum component.

4. OH megamaser emission in IC 694

OH megamaser emission is only observed in IC 694 in agreement with the VLA observations of BH90. The integrated OH maser spectrum shows both the 1667 MHz and the 1665 MHz transitions. However, the 1665 MHz OH line is almost resolved out, implying that it arises in a more extended region. The 1667 MHz line emission arises in a 100 pc large rotating structure with a velocity gradient of 2750 km/s kpc^{-1}, orientated at PA=135°. The Position-Velocity diagramme shows a clumpy nature for the rotating structure similar to that observed in the HI disk.

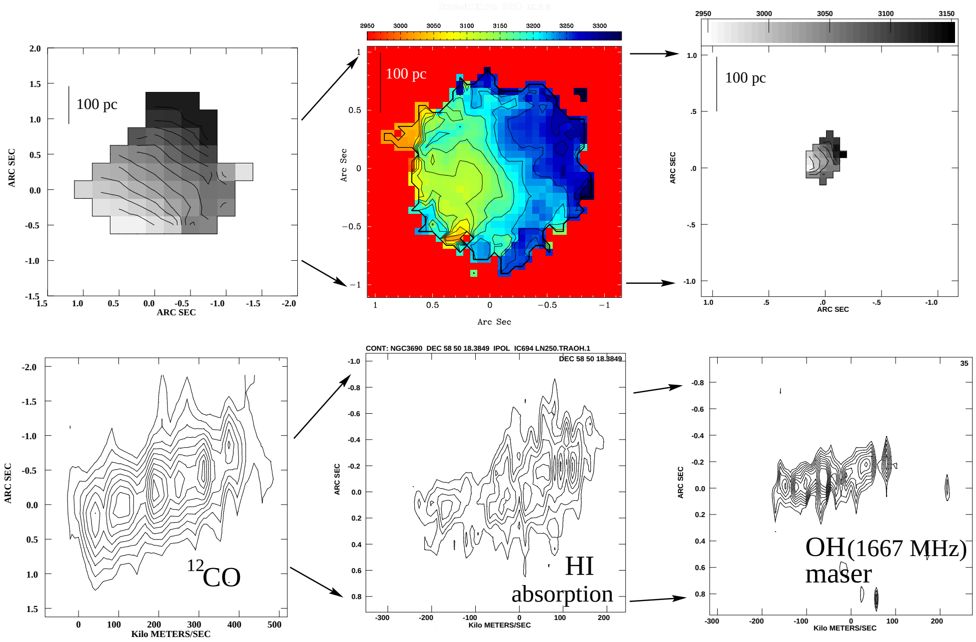

FIGURE 3. A comparative look of the velocity distribution and the position velocity diagrammes of the CO emission (left), the HI absorption (middle) and the OH megamaser (right) lines of IC 694

5. Discussion

Figure 3 presents the velocity fields and the position-velocity diagrammes of the 200 parsec resolution CO observations of Aalto et al. (1999) and our HI and OH observations. The atomic and molecular gas in the nucleus of IC 694, is located in flattened rotating structures that have the same axis and similar velocity ranges. The CO emission and HI absorption seem to occupy the same space suggesting that the HI and molecular gas phases are mixed. It is possible that the HI is a photodissociation product of the molecular gas. The OH seems to be located further in, in the same rotating disk.

The turbulence of the gas is generally high. This is consistent with the notion of extremely high gas pressures in the centres of ULIR galaxies with steep potentials.

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