HI ASSOCIATED WITH CAS A

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Abstract: A small HI absorption feature has been detected in front of Cas A at a velocity of -66 km/s. This HI feature can probably be associated with a recombined high density QSF.

Introduction: Using the 100 m telescope with a resolution of 9 arc min, Mebold and Hills (1975) observed a weak absorption line at -65 km/s in the direction of Cas A. These authors suggested that the low opacity line (tau=0.004) might result from a small cloud covering only a part of Cas A and which could be physically associated with Cas A. If this were the case, then the distance estimates of ~ 3 kpc based on the HI absorption velocities need not be revised.

In November 1979, Cas A was mapped with the WSRT in a 2 x 12^h period. The number of interferometers was 18 and the synthesized beam was 27 x 32 arc sec (RA x Dec.) with grating rings at radii of 10 x 12 arc min. Since the size of Cas A is ~5 arc min, the grating rings fall outside the source. The shortest spacing is 36 m and this corresponds to a fringe spacing of 20 arc min. The velocity range from -105 to 23 km/s was covered with a velocity resolution of 0.62 km/s. The rms noise in the line channels is 150 mJy/beam and is limited by the precision of the video calibration. In Fig. 1 the continuum map is shown; the total flux density is 2114 Jy.

Opacity maps in HI were calculated using a continuum cut-off of 3.5 Jy/beam (5 % of the peak) in the clean map. In the Perseus arm feature at -48 km/s, the optical depths are saturated over a great

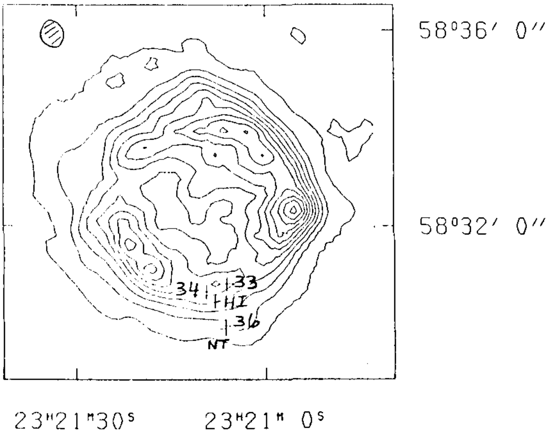

Figure 1: WSRT 1420 MHz continuum map of Cas A with a resolution of 27 x 32 arc sec. The contour units are 0.75 , 7.75 , 14.75 , 21.75 .... 70.75 Jy/beam. The peak in the map is 74.4 Jy/beam. The four crosses represent various objects near the HI feature ("HI"). The three QSF R33,34 and 36 are indicated as well as the prominent radio non-thermal knot near R36 ("NT"). The HPBW is indicated in the upper left hand corner. One Jy/beam is a brightness temperature of 714 K.

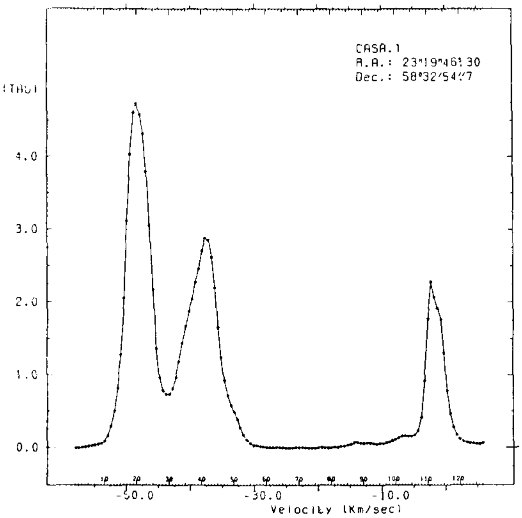

Figure 2: The average optical depth profile over Cas A including the local feature (-1Km/s) and the two prominent Perseus arm features at -37 and -48 Km/s. The cut-off in the continuum was 3.5 Jy/beam and in the -48 Km/s feature an optical depth cut-off of 5 was applied. 127 of the 255 channels are shown. Velocity is with respect to the lsr.

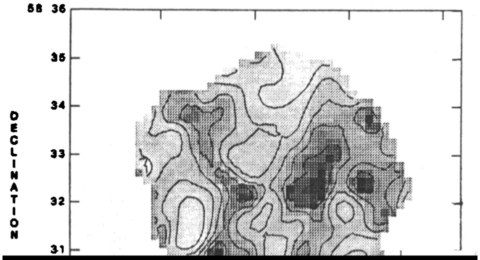

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Figure 3 : A channel map in opacity at a velocity of -36.9 Km/s in the higher velocity Perseus arm feature. The max and min tau's are 4.8 and 1.4. The grey scale range is 1 to 5.

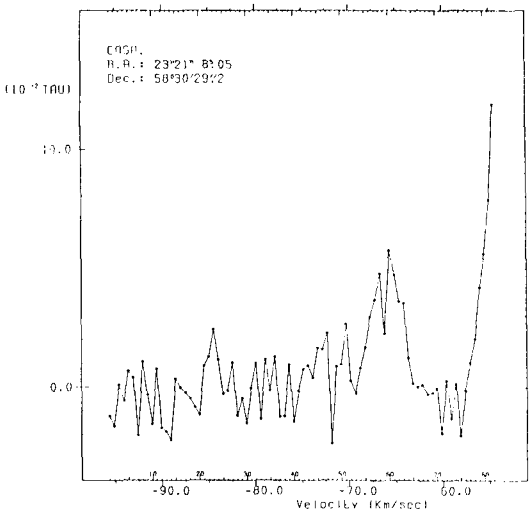

Figure 4 : A profile at the position of the peak of the HI feature at -66 Km/s. The beginning of the -48 Km/s Perseus arm feature is seen at the extreme right hand edge. The continuum intensity at this position is 22.8 Jy/beam.

deal of the source and an opacity cut-off at tau=5 was used. In Fig. 2 the average opacity profile over the source is shown. The two prominent Perseus arm features are at velocities of -37 and -48 km/s and the local absorption is at -1 km/s. In Fig. 3 a sample opacity channel map at a velocity of -36.9 km/s is shown. These results will be discussed in a later paper.

The -66 km/s feature: In the integrated opacity profile, the -66 km/s line was not detected with a 2 sigma upper limit of 0.006 (the line detected by Mebold and Hills was 0.004). However at this velocity a point source of HI absorption was detected at RA (1950)= $23^h\ 21^m\ 08.1^s$ Dec. (1950) = 58° 30′ 29" (2 sigma error in position is 10 arc sec). The position is indicated in Fig. 1. In Fig. 4 the profile at this position is shown. The upper limit for the angular size is 25 arc sec. The fitted parameters are: tau = 0.05 ± 0.01, integral over velocity = 0.19 ± 0.03 tau km/s, velocity = -66.0 ± 0.2 km/s and full-width at half maximum = 3.6 ± 0.7 km/s. The velocity is in good agreement with the previous 100 m observations and the optical depth is an order of magnitude larger due to beam dilution.

The lower limit to the column density (since the source is unresolved) is 2×10^{19} $(T_0/50)$ cm^{-2}, where T_0 is the spin temperature. There is, of course, no independent information on the value of T_0. Since the HI is probably combined shocked gas (see discussion), the T_0 could be much warmer and values in the range 100-1000 K are posssible. The derived density is >20 $(T_0/50)$ cm^{-3} and the HI mass is < 0.01 $(T_0/50)$ solar masses.

The location of the HI feature is within 30 arc sec of three prominent quasi-stationary flocculi (QSF) discussed by van den Bergh and Kamper (vdBK, 1985). These QSF are R33, R34 and R36 and are indicated in Fig. 1 (the position of R34 is taken from their plate 4 and not from their Table 2). R36 = A is one of the five QSF discussed by van den Bergh and Kamper (1983) which lies outside the main supernova shell. It is noteworthy in two respects: 1) this QSF turned on in the mid to late 1960's and 2) it may be associated with a knot in the non-thermal radio emission (eg Bell, 1977). The radio emission position from Bell is also shown slightly south of the QSF R36 in Fig. 1. As vdBK suggest: "Thus, we have been able to observe the appearance of a new QSF, presumably as the expanding shock reaches the pre-existing circumstellar or interstellar material." Given the small fraction of the surface of Cas A that is covered by QSF's (a total of about 40, with a typical size of 2-3 arc sec), the proximity of the HI feature to the three QSF does seem significant.

The HI feature is unlikely to be a standard interstellar HI feature due to its small angular size and unusual velocity. As Mebold and Hills (1975) remark, there are no obvious emission counterparts near Cas A at this velocity. If the feature had shown more or less continuous coverage over Cas A, then the kinematic distance to Cas A would have to be revised.

The most likely interpretation for this feature is that it represents some HI which is physically associated with Cas A and is observed in projection. It is detectable due to the unusually bright continuum background of Cas A.

Discussion: If we make the assumption that the HI feature can be identified with a recombined high density QSF, then the true velocity may be estimated. Following McKee and Cowie (MC, 1975), we have assumed that the HI feature is moving radially outward with respect to the center of the SNR and that it lies in the region of the shocked interstellar (or circumstellar medium) between the blast wave and the inner surface of diffuse ejecta (Braun, 1987). These clouds will likely be rapidly ablated after they have collided with the ejecta itself (MC). The radial velocity of the HI feature (at a projected distance of 119 arc sec or 1.67 pc) is uncertain since the systemic velocity of Cas A is unknown. A reasonable estimate is -52 (±4) km/s (see Fig. 2) and thus an approximate value for the radial velocity is abs [-66 + 52] = 14 (±4) km/s. The total velocity is, of course, much higher since the HI feature is projected against the outer boundary of Cas A. The location of the HI feature near R 33-34 corresponds with the position 2 described by Braun (1987), where the radius of the outer blast wave is 1.76 pc (or 125 arc sec) and the surface of shocked diffuse ejecta is at 1.62 pc. If we assume that the young HI feature is physically located close to the blast wave itself, then a lower limit to the angle between the velocity vector and the line of sight can be estimated. This angle is about 70 degrees and thus the lower limit to the velocity is $\sim 14/\cos(70) = 44$ km/s. Naturally if the true location of the HI is closer to the inner shock the true velocity will be much higher.

The density of the HI feature must be higher than an average QSF in order that the object can cool faster (MC) and thus can have recombined to HI. If the density is higher than the average QSF, then the velocity of the shocked cloud will be lower since $v_c \propto n_c{}^{-0.5}$ (MC), where v_c and n_c are the velocity and density in the shocked cloud. The approximate lifetime of a QSF is the time it takes for the shocked diffuse ejecta to reach the material first shocked by the blast wave. Using the current velocity of the reverse shock wave at position 2 of 1700 km/s (Braun, 1987) and the distance between the two shocks of 0.14 pc, the lifetime, t, is about 80 years. This age is comparable with the estimate suggested by MC. This HI may be related to the shocked HI observed in a number of older SNR (Braun and Strom, 1986).

We can attempt to estimate the expected column density of HI and compare this with the limits derived in section 2. The density in the shocked QSF can be expressed using equation 6 of MC which can be written as: $n_c v_c{}^2 = 3\, n_0\, v_b{}^2$, where n_0 is the pre-shock density and v_b is the blast velocity. The factor 3 is the over-pressure in the shocked cloud for the maximum contrast case. At position 2 Braun finds n_0=1.8 cm^{-3} and v_b=2800 km/s. The lower limit from the observations for v_c is 44 km/s. If the velocity were as high as 150 km/s (MC) the object would still be a conventional QSF and would not have recombined. Thus, we will assume that an estimate for v_c is ~100km/s. In this case the value of n_c is $4x10^3$ cm^{-3}. The implied column density, N_{HI}, would be n_cL, where L is the extent of the recombined QSF along the line of sight. An estimate for L is v_ct. Thus L would be about $2.5x10^{16}$ cm or 0.6 arc sec. This is comparable with the size of the smallest QSF's. The predicted N_{HI} is thus $10x10^{19}$ cm^{-2} which is consistent with the observed value of N_{HI} $>2x10^{19}$ $(T_0 /50)$ cm^{-2}.

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