WESTERBORK 21-cm OBSERVATIONS OF THE LOW AND HIGH VELOCITY H I IN STEPHAN'S QUINTET

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Des cartes à haute résolution d'hydrogène neutre à basse et haute vitesses dans le quintet de Stephan sont présentées. L'émission à basse vitesse a lieu comme attendue, dans la galaxie NGC 7320, et n'apparait pas inhabituelle dans ses caractéristiques. De nombreuses évidences conduisent à une distance de 15 Mpc pour cette galaxie. L'hydrogène neutre à haute vitesse, s'il est situé à 120 Mpc, a une masse de 1.6×10^{10} $M_{\odot}$ et provient d'un grand nuage d'une taille de $\sim$ 150 kpc décalé de $\sim$ 100 kpc (3'E) par rapport à la position du quintet. Les galaxies spirales à haute vitesse du quintet étant extrêmement pauvres en hydrogène, nous suggérons que le nuage H I est le résultat d'une collision de type Spitzer-Baade de deux galaxies auparavant riches en gaz.

Introduction

The group of galaxies known as Stephan's Quintet has been central in the redshift controversy. Within a region of 4 arcmin one finds three galaxies of redshift $\sim$ +6600 km s^{-1} (NGC 7317, 7318a, and 7319), one at +5600 km s^{-1} (NGC 7318b), and one at +800 km s^{-1} (NGC 7320). We now report observations of high angular resolution of the H I at +6600 km s^{-1} and

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that centered at +800 km s^{-1}. The results reveal yet another fascinating and unusual aspect of the Quintet, but they do not unambiguously resolve the critical question of the distances to each member galaxy.

Low Velocity H I

Westerbork 80-channel synthesis maps of 25 x 45 arcsec resolution have been made through 16 filters extending from a heliocentric velocity of +600 to +900 km s^{-1}. The detected H I, out to a contour corresponding to a H I column density of 4×10^{20} cm^{-2}, covers a region roughly the size of the easily visible optical emission from NGC 7320 ($\sim$2 x 1 arcmin). The peak emission in the integrated H I map occurs at a position $\sim$ 0.2 arcmin from the optical center of NGC 7320; also, the distribution of H I is somewhat askew. The global profile of the H I agrees quite well with that obtained with single-dish measurements (e.g., Shostak 1974). The velocity field of the galaxy appears quite normal and can be followed to $\pm$ 80 km s^{-1} from the systemic velocity of +780 km s^{-1}. The positions on the sky of the peak emission in the individual channels define a major axis which lies within 5° of the optical geometrical major axis.

The lack of a noticeably disturbed velocity field allows one to place a rough lower limit on the separation of NGC 7320 from the other members of the Quintet. Making several assumptions concerning masses, geometry, etc., we find that the lack of any disturbances of magnitude $\gtrsim$ 20 km s^{-1} implies that the four high velocity galaxies must be at least 5 times the radius of NGC 7320 distant from NGC 7320. Their projected separations are $\sim$ 2-3 times the radius of NGC 7320, however, and thus the lack of a detectable dynamic interaction is not conclusive evidence as to whether or not all five galaxies are associated. The fact that the H I distribution is slightly offset from the optical center of NGC 7320 also is not unusual; for example, a similar dwarf spiral, M 33 (see below), mapped with similar relative resolution (H I diameter/HPBW $\sim$ 5), shows such an offset (Gordon 1971).

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A detailed comparison of Gordon's study of M 33 and ours of NGC 7320 shows the two galaxies to be very similar in many properties (such as inclination, linear Holmberg diameter, M_{HI}, maximum velocity in rotation curve, M_T, luminosity, diameters of largest H II regions, etc.) if NGC 7320 is placed at its "Hubble distance" of $\sim$ 15 Mpc. Application of the Tully-Fisher method (Tully and Fisher 1976) also yields a distance of $\sim$ 15-20 Mpc. It thus appears quite definite that NGC 7320 is a dwarf spiral, most probably a companion of the nearby ($\sim$ 30 arcmin distant) giant spiral NGC 7331 which lies at a similar distance.

High Velocity H I

Synthesis maps have also been made at Westerbork covering the redshift range +6530 to +6830 km s^{-1}. In order to increase the signal-to-noise ratio for the weak detected H I, all high velocity maps were smoothed to a resolution of 50 x 90 arcsec. Even at this resolution, however, H I is only reliably detected in four channels, from +6570 to +6630 km s^{-1}; after subtraction of a mean continuum level, the rms noise on these maps is 3 mJy per synthesized beam. The peak signal in any channel is 3 rms, and the peak position on the map obtained by averaging over four channels is 4 rms. We thus are reluctant to believe anything but the most salient properties of the H I distribution. For instance, we are not able to construct a reliable velocity field. Nevertheless several strong statements concerning the data can be made.

The high-velocity H I is centered at a position $\sim$ 2 arcmin to the NE of NGC 7320 and $\sim$ 3 arcmin E of the interacting pair NGC 7318a/b. At a resolution of 0.8 x 1.5 arcmin, the reliably detected H I extends over a region of $\sim$ 3 x 4 arcmin in size (to a contour of 4 x 10^{19} cm^{-2}), much larger than the $\lesssim$ 1 arcmin sizes of the optical emission from each of the high-velocity galaxies. Our global profile of the H I, constructed by summing all of the signals within a 5 x 6 arcmin box, agrees quite well with single-dish profiles obtained at Green Bank and Nançay (Shostak 1974; Balkowski *et al.* 1973).

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But the startling new result is of course that this high velocity H I does not coincide in position with NGC 7319 (as assumed in both the above papers) or any other visible galaxy. This means that distances cannot be obtained, at any rate in the usual manner, using properties of the H I. If we place this gas at its Hubble distance of $\sim$ 120 Mpc, the cloud contains 1.6×10^{10} $M_{\odot}$ of H I spread over a region $\sim 100 \times 150$ kpc in projection. If this region is roughly spherical in form, the density of the H I is $\sim 10^{-3}$ cm^{-3} in the central part and $\sim 10^{-4}$ cm^{-3} in the outer parts.

The interpretation of this state of affairs is necessarily speculative until more definitive observations can be made. On the assumption that the high velocity H I and galaxies are at a distance of $\sim$ 120 Mpc, we have discovered an "intergalactic cloud" of H I fully 20 times more massive than any other discovered to date. Its mass in fact is not unlike that contained within a late-type giant spiral, e.g., M 101 has $M_{HI} \sim 2 \times 10^{10}$ $M_{\odot}$. At the same time the peculiar spirals NGC 7318a, 7318b and 7319 appear to be quite hydrogen-poor, possessing a combined value of M_{HI}/L of ~ 0.01, i.e., 20-30 times less than expected for late-type galaxies. We propose that it is then natural to solve both "problems" simultaneously by postulating that the observed H I was indeed once contained within the spiral galaxies. Since these galaxies presently show signs of extreme interaction, it may well have been through a Spitzer-Baade type collision that the H I became displaced from its original parents. If the transverse velocity of the H I cloud with respect to its parents was $\sim$ 100 km s^{-1} following the collision, then the collision took place $\sim 10^9$ years ago. Another feature of the observed gas distribution is also naturally explained--the great size of the cloud is a result of an expansion begun when the originally cool gas was greatly heated to a temperature of $\sim 10^6$ K (if the colliding galaxies had relative velocities of $\sim$ 100 km s^{-1}). In the past billion years there has been ample time for the gas to recombine and cool while it has expanded to its present state.

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We are presently exploring this and other possibilities in more detail in an attempt to explain both the H I distribution and the non-thermal 21-cm continuum extended source first found by Allen and Hartsuiker (1972) and confirmed in our maps. It too appears to be the result of colliding galaxies, but the extreme youth of the synchrotron electrons causing the radio emission argues that probably in this case we are seeing the effects of presently occurring collision. The overall picture then is one of a highly interacting, dense cluster of galaxies, a cluster which seems more enigmatic the closer it is studied. It may well turn out that the high velocity members of Stephan's Quintet are ultimately more useful in terms of understanding interacting galaxies than of resolving the red-shift controversy.

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DISCUSSION

S. SHOSTAK: Relative to your sweeping hypothesis, can you comment on how HI taken from several galaxies could end up with but an 80 km s^{-1} velocity spread?

W.T. SULLIVAN III: In my suggested model, the two colliding galaxies which are swept free of HI have relative velocities of only ~ 100 km s^{-1}. The original gas shortly after the collision is very hot and has a velocity spread of a few 100 km s^{-1}. This gas, however, cools and recombines over a long period (perhaps a billion years) and the presently observed line is thus not so wide. Other cases of large amounts of H I apparently torn from nearby spirals also often show rather narrow velocity spreads.

H. ARP: May I see again your slide showing the neutral hydrogen distribution around NGC 7320? - Thank you. I am disturbed because when I first saw those contours I thought they were good evidence for perturbation of and interaction with NGC 7320. Now Sullivan tells us that this demonstrates there is no perturbation of NGC 7320. I would like to ask some of the other radio observers in the room what their judgement of these contours is.

M.S. ROBERTS: If the lowest contour shown in Sullivan's slide is (1) of high signal-to-noise and (2) corresponds to relatively high HI surface density then this beam-smeared HI distribution appears rather contorted and different from that found for "normal" galaxies.

G. DE VAUCOULEURS: Your evidence for a displacement between HI and star systems in the Stephan Quintet may be a second case of this phenomenon. The LMC is also abnormally poor in HI relative to its optical luminosity, maybe because it was lost to the Magellanic Stream.

W.T. SULLIVAN III: Yes, that is quite possible, but the deficiency seems to be far more severe in the case of the high-redshift spirals in Stephan's Quintet.

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