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## The Structure and Kinematics of Halos in Disk Galaxies

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# Chapter 6

## Extra-planar gas at peculiar velocities in NGC 7814

Adapted from Kamphuis et al. (2007b)\*

### Abstract

THE origin of H I at anomalous velocities and at large distances above the disk, detected in a few spiral galaxies, is still a puzzle. Here we will present deep HI observations of the edge-on Sa galaxy NGC 7814. Even though NGC 7814 shows no evidence for a halo, we have detected extra-planar gas, at velocities higher than the maximal rotational velocity, above and below the plane. This gas is located near the center of the galaxies and is symmetric around it in its spatial distribution as well as its velocity distribution. The origin of this gas is unclear but might be related to the edges of the suspected bar in NGC 7814.

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\* A Study of Extra-Planar HI Gas

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## 6.1 Introduction

The picture of the vertical HI gas distribution in spiral galaxies emerging from recent deep HI observations of a number of galaxies (Schaap et al. 2000; Lee et al. 2001; Barbieri et al. 2005; Westmeier et al. 2005; Boomsma et al. 2005; Rand & Benjamin 2008) is that of a cold thin disk surrounded by a thick layer of more slowly rotating gas (halo gas). In NGC 891 this halo extends up to 15 kpc ( $\sim 40\times$  optical scale height) from the plane of the disk. 3D-modeling shows that this gas rotates more slowly than the gas in the disk (see Fig. 4 in Swaters et al. (1997)). In a different galaxy, UGC 7321, gas has been found in the halo up to 2.4 kpc ( $h_{z,H} \sim 140$  pc) and this gas also is rotating slower than the gas in the disk. This high latitude HI material might be analogous to the Galactic High Velocity Clouds (HVCs) (Fraternali et al. 2002), and might provide an answer to the question of the origin of the HVCs.

Gas in halos is not the only extra-planar gas found in galaxies. Many galaxies show a warped distribution in their outer edges (Sancisi 1976; García-Ruiz et al. 2002). In merging galaxies gas can be found almost anywhere around the merging pair and in the most fantastic distributions. Also in cluster disk galaxies the gas is often disturbed and seemingly stripped.

Here we present deep HI observations of the edge-on Sa galaxy NGC 7814 (UGC 0008). The analysis of the 'normal' disk is presented in Chapter 5 and we will focus solely on the extra-planar gas at peculiar velocities. The observations presented here were done with the Westerbork Synthesis Radio Telescope (WSRT) in september 2004.

NGC 7814 is a relatively nearby edge-on Sa galaxy ( $D=16.4$  Mpc\*) with a systemic velocity of  $1050 \text{ km s}^{-1}$ . The galaxy has an angular diameter on the sky of  $5.5'$  ( $D_{25}$ ) (de Vaucouleurs et al. 1992) which translates to 26 kpc at said distance. It contains a large bulge, a small disk (van der Kruit & Searle 1982) and a clear dust lane (See Figure 1.2). It is one of the more massive spirals (max. rot. vel. 240 km/s) and quiescent with respect to its star forming activity.

This Chapter is structured as follows. In § 6.2 we will describe the observations and the data reduction, respectively. § 6.3 will contain the presentation of gas at peculiar velocities in this galaxy which we will discuss in § 6.4.

## 6.2 Observation and Data Reduction

The 21 cm line emission, or HI observations, were obtained with the WRST during four nights in september 2004. In total 4 complete 12 hr observations were performed using the Maxi-Short configuration. The observations and data reduction were in general done in exactly the same way as the HI observations for UGC 1281 and for a more extended discussion we refer to Chapter 4. Here we shall only discuss an additional step of the data reduction which was not done for UGC 1281.

For NGC 7814 we reduced the data in two ways. One with a uniform weighting function as is common and another with a natural weighting function. This was done because in the original data cube, which was reduced with a uniform weighting function, no extra planar gas could be found. When the data is reduced with a natural weighting function instead of a uniform weighting function large faint structures are brought to the

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\* Taken from the NASA Extragalactic Database

Parameter	Full Resolution	Natural weight.	Circular beam
Spatial resolution (arcsec)	$54.46 \times 12.8$	$68.29 \times 24.27$	$70.0 \times 70.0$
Beam size (kpc)	$4.33 \times 1.02$	$5.43 \times 1.93$	$5.56 \times 5.56$
rms noise (mJy beam <sup>-1</sup> )	0.5	0.37	1.6
Min. det. col. density ( $3\sigma$ ; cm <sup>-2</sup> )	$3.9 \times 10^{19}$	$1.2 \times 10^{19}$	$1.7 \times 10^{19}$

**Table 6.1:** Parameters of the HI Data Cubes

foreground and more easily detected ().

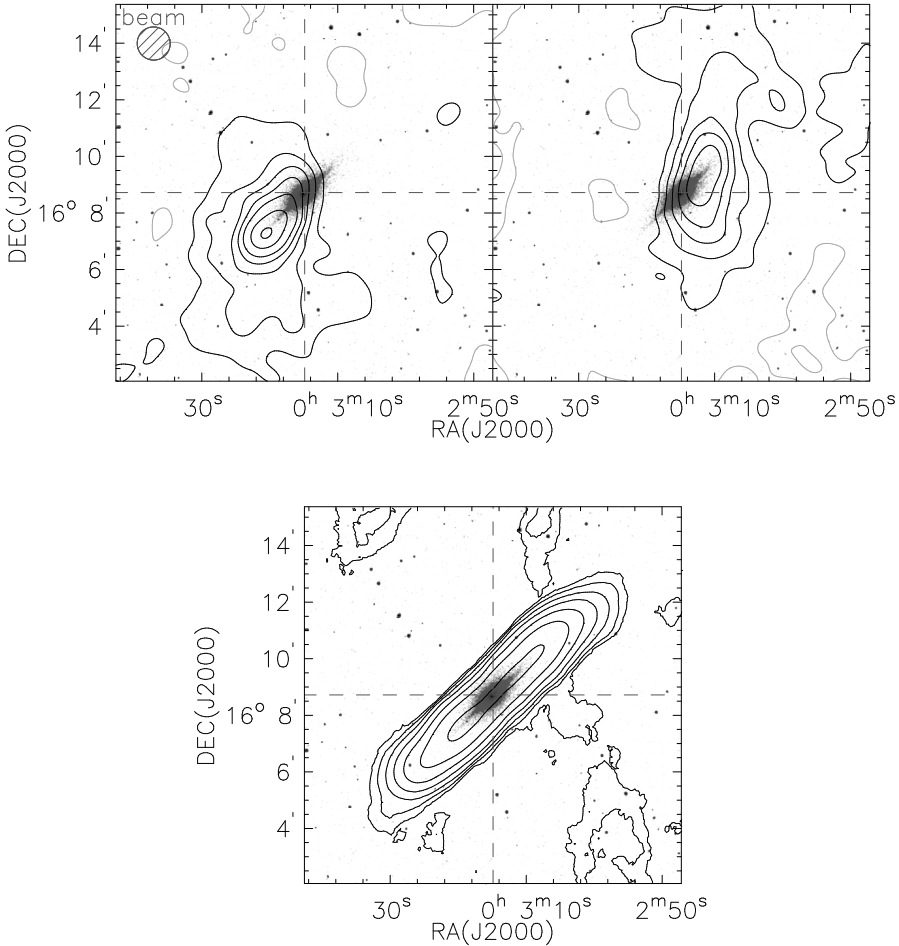
After the reduction and calibration additional analysis was performed with the GIPSY package (van der Hulst et al. 1992). The final cubes had 160 velocity channels with a velocity spacing of  $4.12 \text{ km s}^{-1}$ , which results in a velocity resolution after Hanning smoothing of  $8.24 \text{ km s}^{-1}$ . The original uniform (natural) weighted cube has a spatial resolution of  $54.46'' \times 12.8''$  ( $68.29'' \times 24.27''$ ) (See Table 6.1). The observations of the natural weighted cube were smoothed to a circular beam ( $70'' \times 70''$ ) to avoid orientation effects of the beam. The position of the center of the galaxy, as determined by Cotton et al. (1999), was set to zero in the three cubes and they were rotated by  $-45^\circ$  (PA =  $135^\circ$ , de Vaucouleurs et al. (1992)) to orient the major axis of the galaxy parallel to the x-axis of the image. This last step was done to easily visualize the Position Velocity diagrams along the minor and major axis.

## 6.3 Results

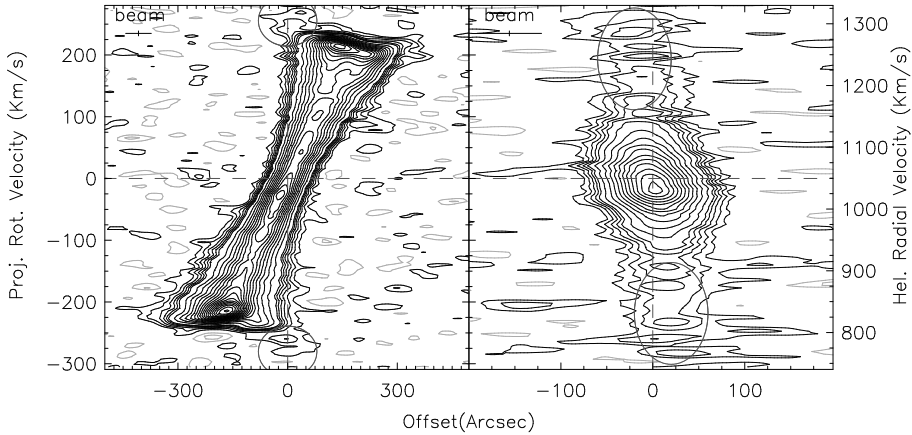
As already mentioned in the previous section we could find no extra-planar gas in the uniform weighted cube (See also Figs. 7.35 and 7.36). However, a close inspection of the Position-Velocity diagram (PV-diagram) along the major axis showed a hint of gas at extreme velocities in the center of the galaxy. Therefore we decided to reduce the data with a natural weighting function as well.

Already during a first inspection of this natural weighted data cube, two features extending out from the plane (see Fig 6.1) were clearly visible at rotational values higher than the maximum rotational velocities at the edge of the disk. These structures have a small velocity dispersion ( $\pm 15 \text{ km/s}$ ) and both are detectable in 3-4 channel maps of the data. They appear to be symmetrically situated around the center of the galaxy.

Figure 6.2 shows a PV-diagram along the major axis (Left panel) and the minor axis (Right panel) of the natural weighted data cube. In this figure the emission associated with the features is circled. In the PV-diagram along the major axis of NGC 7814 it is easily seen that the rotational velocities of the features are much higher than those in the rest of the galaxies' disk. When we look at the PV diagram along the minor axis (Fig. 6.2, Left panel) it becomes clear that this high velocity gas extends much further from the plane of the galaxy than the rest of the disk. This can also be seen in Figure 6.1 if one positions the beam on the center of the optical image. Since there is no extra-planar gas in the disk, except for the features presented here, this beam gives the maximum vertical extent of the rest of HI disk.



**Figure 6.1:** Contour plots showing the extra-planar H I features (3 channels stacked) (Top panels) and the total integrated velocity map (Bottom panel) overlaid on an optical image. For the Top panels the contours are from  $-3\sigma$  (grey) to  $+6\sigma$  (black) in steps of  $1.5\sigma$  ( $\sigma = 1.6$  mJy/beam), the 0 contour is omitted. After  $+6\sigma$  the contours run from 12.5 mJy/beam increasing with steps of 5 mJy/beam. The left (right) panel shows the feature at  $1285 \pm 8$  km/s ( $804 \pm 8$  km/s). These are the highest (lowest) velocity channels. The systemic velocity is  $1050 \pm 8$  km/s. For the bottom panel the contours are  $1.5\sigma, 3\sigma, 6\sigma, 12\sigma$  etc. with  $\sigma = 8.25$  mJy/beam



**Figure 6.2:** Position - Velocity diagrams of the HI along the major axis (left panel) and along the minor axis (right panel) in NGC 7814. The circles and ellipses indicate the anomalous gas. Contours are from  $-3\sigma$  (grey) to  $+6\sigma$  (black) in steps of  $1.5\sigma$  ( $\sigma = 0.5$  mJy/beam); the 0 contour is omitted. After  $+6\sigma$  the contours are from 4.2 mJy/beam, increasing with steps of 2.5 mJy/beam.

## 6.4 Discussion

The origin and dynamics of this gas is a puzzle. The fact that the features appear symmetrically around the center of the galaxy gives the impression that they are part of the same rotating structure. This in turn indicates that they are related to some structure in the galaxy. One would simply not expect this symmetry in the spatial as well as the velocity distribution when the features were created by some process related to infalling material. If the structures are related to a process in the plane of the galaxy it is natural to think that the gas is blown out of the plane of NGC 7814. One of the most obvious explanations for gas to be blown out of the plane is the galactic fountain (Shapiro & Field 1976) or chimney model (Norman & Ikeuchi 1989). For these processes to work in such a way would mean that the star formation in NGC 7814 has to be located in two massive star forming clumps around the center of the galaxy that rotate at speeds higher than the rotational velocities in the disk.

The outer edges of a bar could give a natural explanation for two star forming regions distributed symmetrically around the center. It can even potentially explain the high velocities of the gas observed here. However, as yet there is no evidence that NGC 7814 contains a bar and this has to be investigated. Even if there was a bar a careful comparison between the location of the bar and the extra-planar gas presented here is necessary.

To summarize, we presented here deep HI observations in NGC 7814. If we reduce the data with a natural weighting function we can clearly detect two features which show an extended vertical distribution which appear to rotate at velocities higher than the maximal rotation velocity in the disk. These features are distributed symmetrically around the center in the spatial direction as well as their rotational velocities. This gives the impression that they are part of or caused by a rotating structure in the plane of

the galaxy. These features adds to the wide variety of of extra-planar gas distributions detected in spiral galaxies. As for so many of these extra-planar structures the origin and dynamics of these features remain a puzzle.