Extraplanar Gas Extent of Edge-on Galaxies
A Comparison of the Galaxies NGC4244 and NGC891

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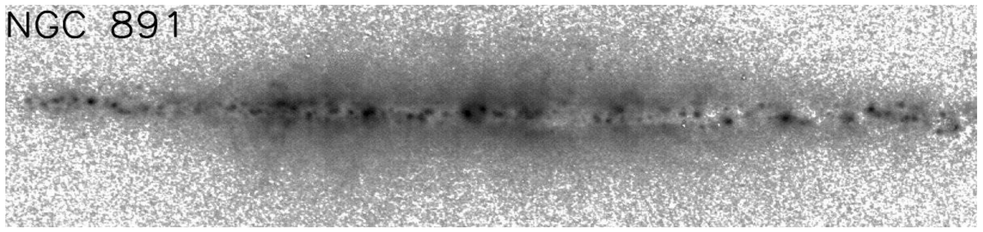
Introduction

Galaxies viewed edge-on provide a unique opportunity to image the gaseous material above and below the galactic disk. Studying this extraplanar gas is important for galactic research and for understanding the relationship between star formation in the disk and the gas in the halo surrounding it. The extraplanar gas may be infalling onto the disk or may be outflowing, having originated from star forming regions in the disk.

Pulsar dispersion measurements and Reynolds' Hα imaging of the Milky Way ISM provided evidence for a thick ionized gas disk with an exponential scale height of 600 to 1000 pc, larger than what typically was found for the HI scale height. Such thick Hα disks were also seen in several edge-on spirals. More recent HI data for edge-on systems (also for the Milky Way, see e.g. Lockman et. al. 2002), however, show vertically extended HI disks that rival or exceed the extent of the DIG. If the theory that most of the diffuse ionized gas is ionized by stars in the disk is correct, then we would expect neutral gas at high vertical distance for the stars to ionize. Here, we investigate in more detail whether the HI is as or even more extended than the diffuse ionized gas seen in edge-on galaxies. We explore the vertical gas extent of ionized gas in the galaxies NGC4244 and NGC891 and compare it to the vertical extent of neutral hydrogen. The galaxies NGC4244 and NGC891 represent two extremes of both high and low star formation; NGC4244 is a quiescent late-type spiral, while NGC891 is a prominent Sb with a high star formation rate per unit area.



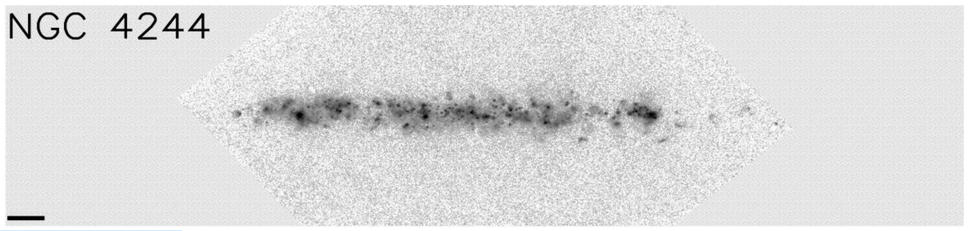
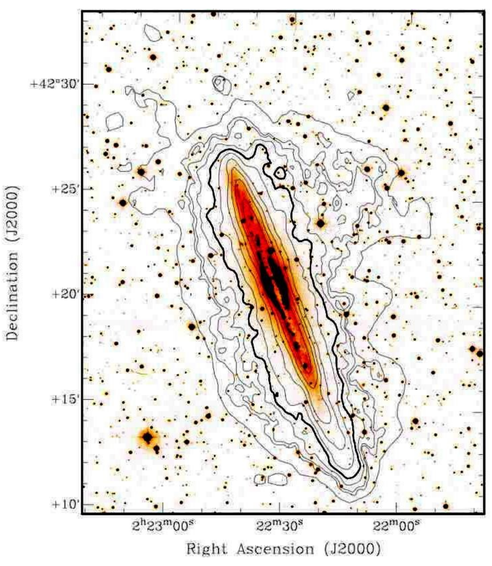


Fig. 1

Images in Hα of the two edge-on galaxies NGC891 and NGC4244, on the same linear scale. These images demonstrate the difference in the brightness and spatial extent of the ionized gas halos in these two systems. The bar shown in the lower left of the image is 1 kpc in length. (Figure taken from Hoopes et. al., 1999)



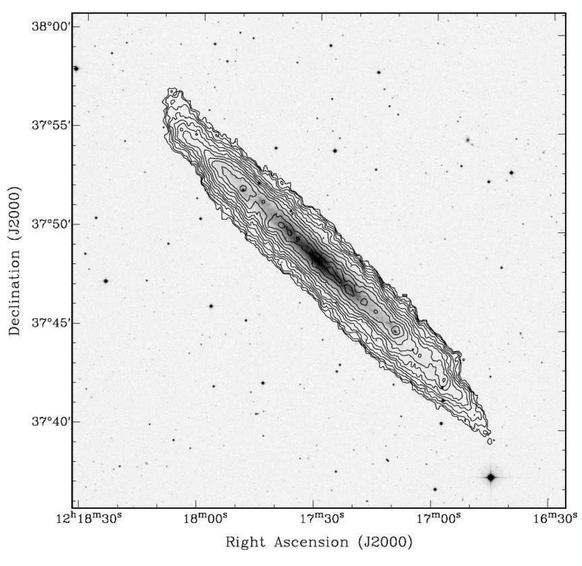


Fig. 2

Top Left: Image in HI of NGC891 at 30" resolution from Osterloo et. al., 2007 with contour levels 0.01, 0.02, 0.05, 0.1 (thick line), 0.2, 0.5, 1.0, 2.0 and 5.0 × 10^{21} cm^{-2}. The HI halo extends vertically on average as far out as 14 kpc from the disk and 22 kpc in the northwest region.

Top Right: Image in HI of NGC4244 at 4" resolution from Dahlem et. al. 2005 with contour levels 0.03 (=1.7 × 10^{20} cm^{-2}), 0.042, 0.06, ..., 1.344 Jy km s^{-1}. The image is 28.1 kpc on each side.

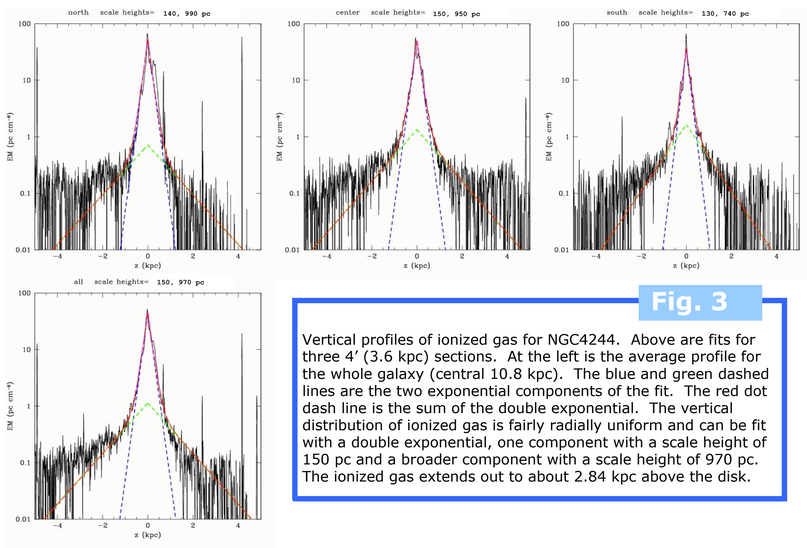


Fig. 3

Vertical profiles of ionized gas for NGC4244. Above are fits for three 4' (3.6 kpc) sections. At the left is the average profile for the whole galaxy (central 10.8 kpc). The blue and green dashed lines are the two exponential components of the fit. The red dot dash line is the sum of the double exponential. The vertical distribution of ionized gas is fairly radially uniform and can be fit with a double exponential, one component with a scale height of 150 pc and a broader component with a scale height of 970 pc. The ionized gas extends out to about 2.84 kpc above the disk.

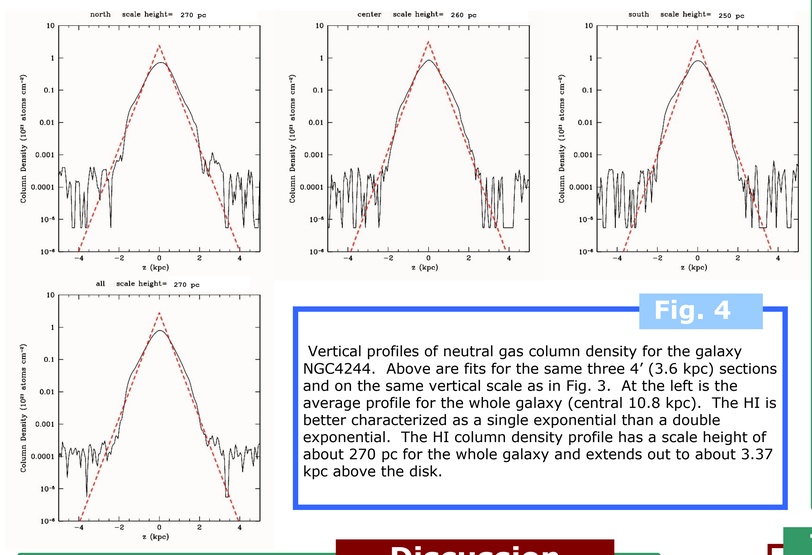


Fig. 4

Vertical profiles of neutral gas column density for the galaxy NGC4244. Above are fits for the same three 4' (3.6 kpc) sections and on the same vertical scale as in Fig. 3. At the left is the average profile for the whole galaxy (central 10.8 kpc). The HI is better characterized as a single exponential than a double exponential. The HI column density profile has a scale height of about 270 pc for the whole galaxy and extends out to about 3.37 kpc above the disk.

Analysis

NGC4244 and NGC891 were observed in March 1992 and January 1996 respectively on the 0.9 meter telescope at KPNO, as published by Hoopes et. al. 1999. The HI column density image of NGC4244 was obtained with WSRT in March 2003 and published by Dahlem et. al. 2005.

We created vertical profiles from the reduced .fits format continuum subtracted images by outputting the values of EM/column density in columns parallel to the minor axis of the objects using IRAF, after subtracting the sky background zero level determined by the rms of the median value of several sections of each image far from the plane of the galaxy. Then we fit double exponentials to the average vertical profiles for three sections of both galaxies. The fitting routine uses a chi-square minimization that varies four parameters, the amplitudes and scale heights of both exponentials, to find the best fit. Figures 3 and 5 show the vertical profiles of emission measure for both galaxies overlaid with the best fit double exponential. For the HI image of NGC4244, the profile was better characterized by a single exponential than a double exponential. Figure 4 shows the vertical profile of neutral gas overlaid with the best fit single exponential.

Table 1. below gives the best fit scale heights for both galaxies for HI (the NGC891 values taken from Oosterloo et. al. 2007), the central narrow layer and extended components of Hα, and the inferred electron scale heights for the extended component, assuming the emission were uniformly distributed. The inferred electron scale height is taken as twice the Hα scale height, since emission measure is proportional to n_e^2. We do not expect to see the same scale heights for Hα and HI, since the HI profile is best described by a Gaussian shape and gives column density whereas the Hα is described by a double exponential and gives emission measure rather than column density. In addition, Hα is only found in regions where ionizing photons can reach the gas, and these regions are not expected to be uniformly distributed.

Also listed is the total vertical extent out to which the ionized and neutral gas can be detected in the images. In both galaxies, the HI extends farther from the disk compared to Hα. The values for NGC891 are from Oosterloo et. al. WSRT observations. The northwest quadrant of the HI halo extends out to about 22 kpc, while the other quadrants extend out to about 14 kpc.

Discussion

Hoopes et. al. 1999 similarly uses a double exponential function to fit to the vertical emission measure profile for several edge-on galaxies including NGC891 and NGC4244. The authors looked specifically at the central 10 kpc of both galaxies, while we break up both galaxies into several smaller sections and compare each section to HI data on the same regions.

Collins et. al. (2000) compare the DIG of the edge-ons NGC5775 and NGC3044 to the HI halo. They find that both NGC5775 and NGC3044, galaxies with high SFR per unit area, have extended features in the DIG and extraplanar HI filaments in the same regions that extend farther. Here, we compare two galaxies with high and low star formation and conclude that the neutral hydrogen indeed has an extended vertical profile comparable or greater to the DIG.

Warps and flaring are important features to take into account while studying extraplanar gas in edge-ons. In the study by Oosterloo et. al., the authors rule out the idea that extraplanar HI in NGC891 is due to a line-of-sight warp. NGC4244 according to Olling (1996) has an HI warp at about 8.5 kpc, but the orientation may be such that it does not create line-of-sight false extraplanar gas.

Our analysis of the extraplanar gas in both galaxies is consistent with ionization of the DIG from stars inside the disk. The DIG appears to be a result of inside-out ionized HI.

Table 1.

Region	Scale Heights				Total Extent	
	Hα (central)	Hα (extended)	e^- (extended)	HI	Hα	HI
NGC4244 (whole)	150 pc	970 pc	1.94 kpc	270 pc	2.84 kpc	3.37 kpc
NGC4244 (north)	140 pc	990 pc	1.98 kpc	270 pc	2.67 kpc	3.37 kpc
NGC4244 (center)	150 pc	950 pc	1.90 kpc	260 pc	3.43 kpc	3.37 kpc
NGC4244 (south)	130 pc	740 pc	1.48 kpc	250 pc	2.69 kpc	3.01 kpc
NGC891 (whole)	450 pc	1.68 kpc	3.36 kpc	2.2 kpc*	4.26 kpc	14 kpc*
NGC891 (north)	420 pc	1.70 kpc	3.40 kpc	2.2 kpc*	4.32 kpc	22 kpc*
NGC891 (center)	500 pc	1.64 kpc	3.28 kpc	2.2 kpc*	4.42 kpc	14 kpc*
NGC891 (south)	590 pc	1.15 kpc	2.30 kpc	2.2 kpc*	2.35 kpc	14 kpc*

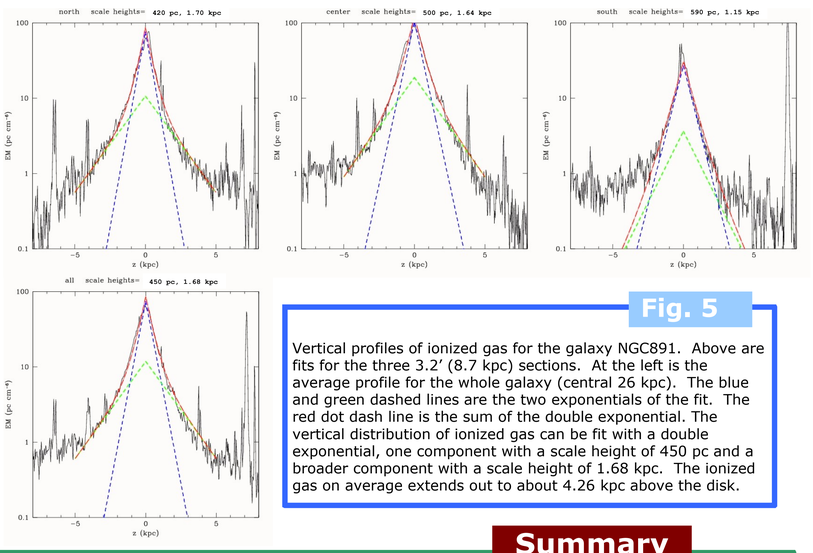


Fig. 5

Vertical profiles of ionized gas for the galaxy NGC891. Above are fits for the three 3.2' (8.7 kpc) sections. At the left is the average profile for the whole galaxy (central 26 kpc). The blue and green dashed lines are the two exponentials of the fit. The red dot dash line is the sum of the double exponential. The vertical distribution of ionized gas can be fit with a double exponential, one component with a scale height of 450 pc and a broader component with a scale height of 1.68 kpc. The ionized gas on average extends out to about 4.26 kpc above the disk.

Summary

Edge-on galaxies provide an excellent opportunity to study the gas above and below the disk. Here we compare the extraplanar gas in two uniquely different galaxies, NGC4244 and NGC891. Motivated by recent evidence for extended halos of HI gas around galaxies, we compare the diffuse ionized gas vertical extent to the HI halo for a galaxy with high star formation and a galaxy with low star formation. For both galaxies, the Hα profiles are best fit with a double exponential, one exponential for a narrow central layer of gas with a lower scale height and one exponential for a broader extended layer of gas with a larger scale height. For NGC4244, the HI profile is Gaussian, and we determine a scale height from a single exponential fit. For both galaxies, the total vertical extent of the HI is larger than the ionized gas. This suggests that in all cases, there may be HI that extends at least as far as the DIG, which may predict that one does not expect significant leakage of ionizing photons from normal star forming galaxies.

References

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