

## The Vertical Dust Structure in Spiral Disks

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**Abstract.** The halo of NGC 891 has been the subject of studies for more than a decade. One of its most striking features is the large asymmetry in H $\alpha$  emission. We have taken a quantitative look at this asymmetry at different wavelengths for the first time. We propose that NGC 891 is intrinsically almost symmetric, as seen in *Spitzer* observations, and the large asymmetry in H $\alpha$  emission is mostly due to dust attenuation. We quantify the additional optical depth needed to cause the observed H $\alpha$  asymmetry. A comparison of large strips on the North East side of the galaxy with strips covering the same area in the South West we can quantify and analyze the asymmetry in the different wavelengths. From the 24  $\mu$ m emission we find that the intrinsic asymmetry in star-formation in NGC 891 is small i.e., approximately 30%. The additional asymmetry in H $\alpha$  is modeled as additional symmetric dust attenuation which extends up to  $\sim 40''$  (1.9 kpc) above the plane of the galaxy with a mid-plane value of  $\tau=0.8$  and a scale height of 0.5 kpc. This observational technique offers the possibility to quantify the effects of vertical ISM disk stability as an explanation for dust lanes in massive galaxies (Dalcanton et al. 2004).

### 1. Dust in and out of the disk

Extinction by dust manifests itself most conspicuously in the dark dust lanes seen in optical images of edge-on galaxies. Occasionally dark structures can be observed extending out of the plane (Howk and Savage 1997; Howk 1999; Howk and Savage 1999; Thompson et al. 2004; Howk 2005). The study of these dust-rich structures is hampered by the need to have enough stellar light back-lighting the dark structures. Previous observations of the scale-height in nearby, mostly edge-on, galaxies appeared to find small scale-heights for dust (e.g, Xilouris et al. 1999; Holwerda et al. 2005; Bianchi 2007) but recent observations indicate a much higher scale-height for the dust (e.g., Seth et al. 2005), one that is similar to the stellar scale-height.

In many edge-on galaxies an H $\alpha$  halo can be observed. Heald et al. (2006) and Kamphuis et al. (2007b) reported on the kinematics of this H $\alpha$  halo for NGC 891. Its H $\alpha$  distribution is extremely asymmetric: the NE side halo is much more extended and brighter (Figure 1). Is this due to an intrinsic asymmetry in the H $\alpha$  emission or an extinction effect?

In Kamphuis et al. (2007a), we compared two star-formation driven emissions (H $\alpha$  and *Spitzer* 24  $\mu$ m). The 24  $\mu$ m is much more symmetric (Figure

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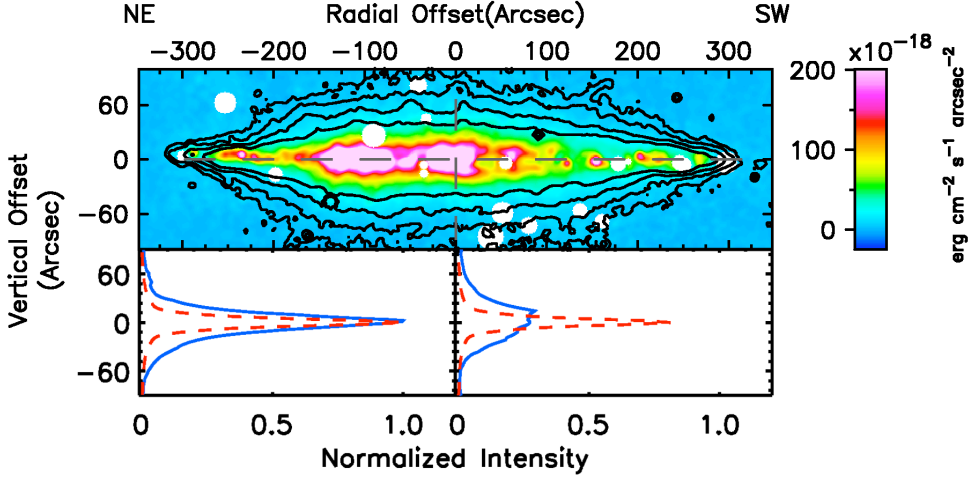


Figure 1. The  $H\alpha$  emission (false color from Rand 1994) with  $24\ \mu\text{m}$  contours overlaid, below are the integrated vertical profiles in  $H\alpha$  (blue) and  $24\ \mu\text{m}$  (red dashed line), normalized to the top in the NE side. Both types of emission are powered by ongoing star-formation. The  $24\ \mu\text{m}$  is very symmetrical while the  $H\alpha$  is not. Figure from Kamphuis et al. (2007a).

1). Assuming both types of emission originate from star-formation regions in the spiral arms of NGC 891 and that the NE arm is closest to us (Figure 2), the difference in symmetry between the two types of emission can be attributed to extinction in the inner disk extending out of the plane of the disk ( $\tau_{add}$ ). The inferred scale-height of the out-of-the plane dust (Figure 3) is similar to the heights to which Howk and Savage (1997) report dark structures in NGC 891. Still this height is much less than the height of dust emission in the halo as reported by M. Burgdorf & M. Ashby, (*this volume*).

Dalcanton et al. (2004) link the appearance of dust lanes to the vertical stability of spiral disks. In more massive disks, gravitation wins over the star-formation driven turbulence and the dust-rich ISM collapses into the characteristic dust lane, notably in the inner scale-length of the disk. In contrast, low-mass galaxies display a more flocculant appearance of dust structures. The additional extinction out-of-the plane of NGC 891, a massive galaxy seems to be in contradiction to this. However, NGC 891 is undergoing significant star-formation ( $\log(L(FIR)) = 10.42 L_{\odot}$ ) and much of its ISM is in the dustlane.

## 2. Future work

$H\alpha$  haloes are relatively common (Rossa and Dettmar 2003) around edge-on spiral galaxies. *Spitzer*/MIPS observations are available for 28 edge-ons. Many of these show signs of asymmetric  $H\alpha$  emission in and out of the plane of the disk. This offers the opportunity to analyze a sample of edge-ons in the same way as explored in Kamphuis et al. (2007a).

The symmetry analysis can be extended to include lower-mass disks and disks with different levels of star-formation. Both are an input into the vertical

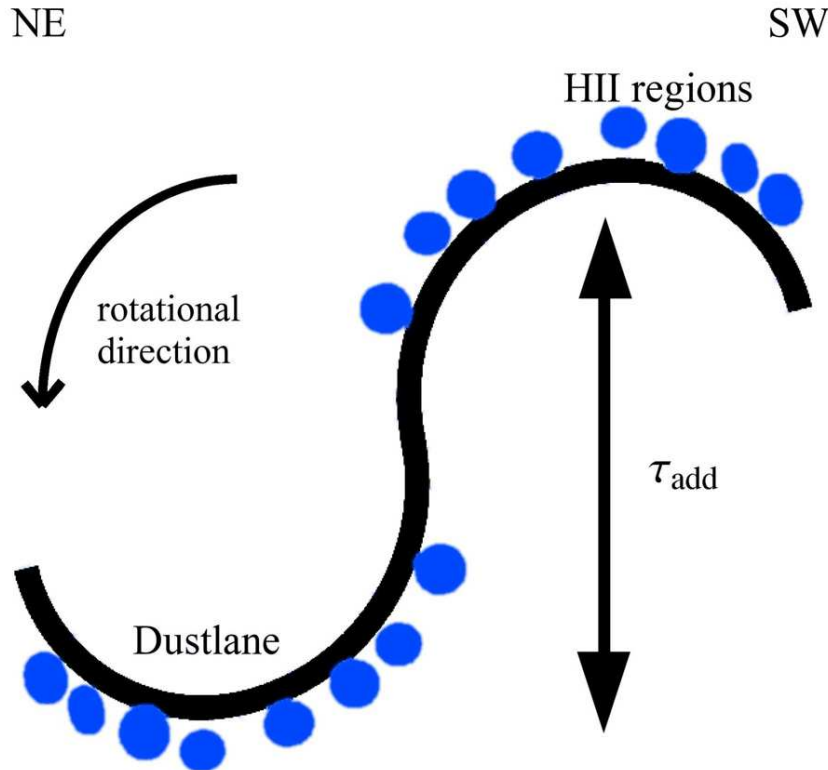


Figure 2. A sketch of our model of NGC891. The emission originates predominantly from HII regions (blue) and much of the dust is in the spiral arms (thick black S-shape). The  $H\alpha$  emission is more absorbed in the SW case ( $\tau_{add}$ ). Figure from Kamphuis et al. (2007a).

disk stability model of Dalcanton et al. (2004). The advantages of the method are (1) a measure of the ISM's vertical extent right around the inner part of the spiral disks and (2) the measurement is independent of the stellar distribution, often needed to backlight or heat the dust in other measurements of dust thickness. An additional benefit is that the method can be applied to a data-set with a widely inhomogeneous data-quality because we compare the left and right symmetries of the images. *Spitzer*  $24\ \mu\text{m}$  observations resolve the vertical structure of some galaxies but the resolution is not critical for the method because the *Spitzer* observations are used to verify the symmetry argument for the  $H\alpha$  data.

The drawbacks of the method are: (1) the assumption of a direct spatial relation between the  $H\alpha$  and  $24\ \mu\text{m}$  emission. This may well not hold true in low-level starformation regions or well outside the disk. And (2), the need for a specific spiral arm geometry. The position of the spiral arms in NGC 891, is undoubtedly the most favorable. The method may not work as well if the spiral arms are positioned different than in Figure 2 or if the spiral pattern is flocculant instead of grand-design.

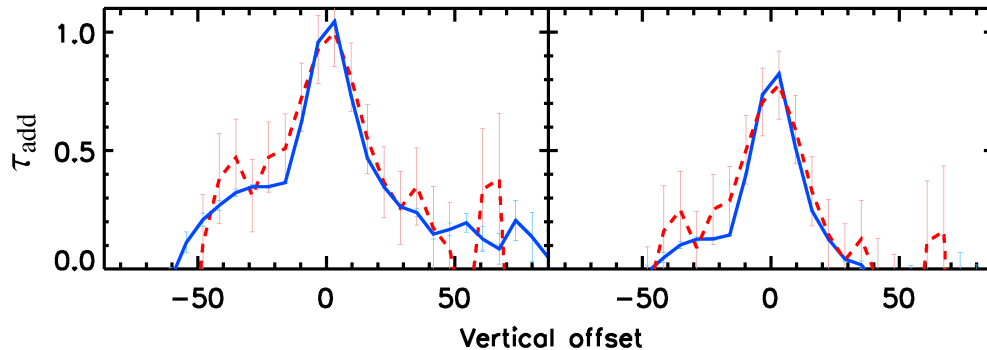


Figure 3. The vertical extent in arcseconds of the additional absorption ( $\tau_{add}$ ), assuming perfect NE/SW symmetry (left) and taking the  $24\ \mu\text{m}$  symmetry as the intrinsic one (right). The blue solid line is from the Rand (1994)  $\text{H}\alpha$  data and the dashed red line based on the Kamphuis et al. (2007b)  $\text{H}\alpha$  data. Figure from Kamphuis et al. (2007a).

The physical conditions in spiral disks determine the ISM morphology: the turbulence and energy input by star-formation versus the local gravitational pull by the disk’s mass in gas and stars. What are the global conditions in a disk for a dustlane to form? Symmetry measurements of edge-on spiral disks in wavelengths that are strongly affected by extinction – $\text{H}\alpha$ – and those that are not – $24\ \mu\text{m}$ – can shed light on the global conditions that prevail in disks when dust lanes form.

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