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Quantified Morphology of HI Disks in the Universe

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The upcoming new perspective of the high redshift Universe in the 21 cm line of atomic hydrogen opens possibilities to explore topics of spiral disk evolution, hitherto reserved for the optical regime. The growth of spiral gas disks over Cosmic time can be explored with the new generation of radio telescopes, notably the SKA, and its precursors, as accurately as with the Hubble Space Telescope for stellar disks. Since the atomic hydrogen gas is the building block of these disks, it should trace their formation accurately.

Morphology of HI disks can now equally be quantified over Cosmic time. In studies of HST deep fields, the optical or UV morphology of high-redshift galaxy disks have been characterised using a few quantities: concentration (C), asymmetry (A), smoothness (S), second-order-moment (M_{20}), the GINI coefficient (G), and Ellipticity (E). We have applied these parameters across wavelengths and compared them to the HI morphology over the THINGS sample. NGC 3184, an unperturbed disk, and NGC 5194, the canonical 3:1 interaction, serve as examples for quantified morphology.

We find that morphology parameters determined in HI are as good or better a tracer of interaction compared to those in any other wavelength, notably in Asymmetry, Gini and M_{20} . This opens the possibility of using them in the parameterization pipeline for SKA precursor catalogues to select interacting or harassed galaxies from their HI morphology. Asymmetry, Gini and M_{20} may be redefined for use on data-cubes rather than HI column density image.

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1. Introduction

In the coming years, the SKA precursors, MeerKAT, ASKAP, WSRT/APERTIF and EVLA will take 21 cm line emission data of a large number of nearby and distant galaxies. The resulting data-cubes and zero-order maps will need automated schemes for source detection and characterisation. The morphology of HI disks is greatly informed by recent interaction (Hibbard et al., 2001) and harassment by passing dark matter haloes (Kazantzidis et al., 2008). Therefore an automated morphology classification of HI data is desirable, to comb the future catalogues of HI surveys for interacting or perturbed galaxies. We propose to adapt morphological parameters currently in use to characterise UV/optical data of nearby and distant galaxies for use on HI data in order identify different types of galaxy disks.

2. Quantified Morphology

The morphology of spiral galaxies has been quantified in Hubble Space Telescope images of distant galaxies and reference nearby galaxy samples in the restframe UV and optical using two parameter schemes or a combination thereof. After the initial work by Abraham et al. (1994, 1996), the Concentration-Asymmetry-Smoothness (CAS) space was established by Conselice (2003) and the Gini and Asymmetry parameters by Lotz et al. (2004). Scarlata et al. (2007) added ellipticity for Hubble type classification. The benefits of quantified morphology parameters are that there is no need for an observer, they can be applied to rest-frame UV images, which trace the triggered star-formation in interacting galaxies and the galaxies have an intrinsically high surface brightness, aiding their detection.

The parameters used are:

Concentration: $C = 5 \log\left(\frac{r_{80}}{r_{20}}\right)$,

where r_f is the radius of the circular aperture containing f percent of the light.

Asymmetry: $A = \frac{(I - I_{180})}{I}$,

where I is the image, I_{180} is the image rotated by 180° around the galaxy's center

Smoothness: $S = \frac{(I - I_S)}{I}$,

where I is the image, I_S is the image smoothed with a certain kernel. The 0.2 Petrosian radius boxcar is in use, but we used a 6" Gaussian. This is effectively a parameterized version of unsharp masking (Takamiya, 1999; Malin & Hadley, 1997).

Gini: $G = \frac{1}{\ln(n-1)} \sum_i (2i - n - 1) I_i$,

where I_i is the value of pixel i in an ordered list, n is the number of pixels in the galaxy image, and \bar{I} is the mean pixel value in the image. The Gini parameter is an index of equality in economics, with $G=1$ is perfectly unequal (all the flux in one pixel) and $G=0$ is perfectly equal (all pixel values the same).

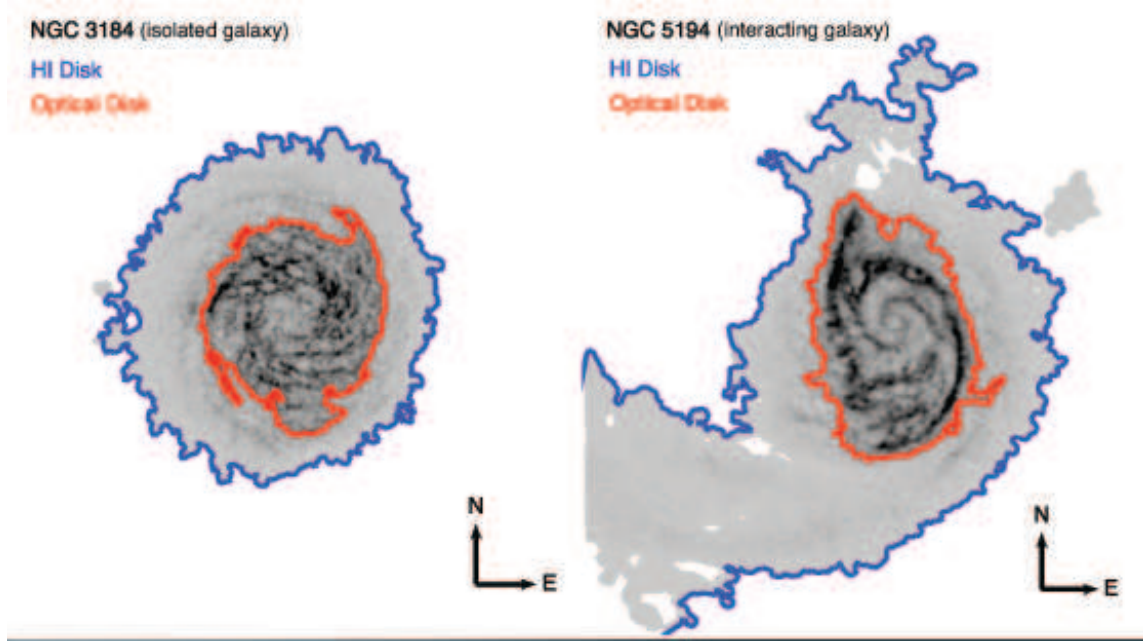


Figure 1: THINGS HI maps (NA) for NGC 3184 and NGC 5194. The edge of the optical or stellar disk is at 3×10^{21} atoms cm^{-2} , indicated by the red contour, and the extent of the HI disk (10^{19} atoms cm^{-2} , the THINGS detection limit) is marked with the blue contour.

M_{20} : the relative contribution of the 20% brightest pixels to the second order moment of the light in the image. The second order moment of pixel i is defined as: $M_i = I_i[(x_i - x_c)^2 + (y_i - y_c)^2]$, where I_i is the value of pixel i in the image, and x_i and y_i are the x and y coordinates of that pixel and x_c and y_c are the position of the galaxy's centre. The total second order is: $M_{tot} = \sum I_i[(x_i - x_c)^2 + (y_i - y_c)^2]$, and M_{20} is defined as: $M_{20} = \log \left(\frac{\sum_i^m M_i}{M_{tot}} \right)$, where m is the 20% brightest pixels.

Ellipticity: $E = 1 - B/A$ where A and B are the major and minor axes of the image.

We note that many of these parameters need a predefined central position of the galaxy and all need a definition of which pixels in an image belong to the object (a segmentation map). We use the areas on the sky defined by HI contours to determine which pixels belong to our target galaxy and the dynamical centres reported in Walter et al. (2008).

3. A case of two galaxies: NGC 3184 and NGC 5194

The above parameters were computed within two contours, one corresponding to approximately the extent of the stellar disk (3×10^{21} atoms/ cm^2) and one to the extent of the HI disk that could be observed with THINGS (Walter et al., 2008), (Figure 1). We applied these contours on images of two galaxies, NGC 3184 and NGC 5194, spanning UV, optical, near and far-infrared from GALEX, SDSS and Spitzer (see also Holwerda et al., 2010a, in preparation). The resulting morphology parameter values are plotted in Figure 2, as computed in the stellar disk (red) and over the extent of the HI disk (blue).

We note that the area over which these parameters are computed does not matter much for many of the parameters but there is extra information at each wavelength. The exception is the Gini parameter, which increases significantly from the stellar disk to the HI disk at all wavelengths. The parameters dependence on wavelength is more significant; Asymmetry, Smoothness and Gini are high in star-formation and 21 cm line emission and Concentration peaks in the optical.

4. HI morphology as a interaction tracer

In Figure 2 we can also compare the isolated, unperturbed galaxy NGC 3184 to the interacting NGC 5194 (M51). In the morphological parameters we can see that Concentration increases in the optical and near-infrared from isolated to interacting. Asymmetry decreases a little from isolated to interaction in UV and 24 μm emission (the star-formation tracers) but increases for HI 21 cm emission. Both Gini and M_{20} increase, notably in HI. From Figure 2 we can conclude that there is as much signal of interaction in HI as in the star-formation tracers (24 μm and UV) but any HI classification scheme will have to be fine-tuned for this signal. Fortunately, we can use existing uniform HI surveys such WHISP (van der Hulst et al., 2001) and THINGS (Walter et al., 2008) to test these morphology parameters (see Holwerda et al., 2010b,c,d, all in preparation)

5. Use in Future Surveys

The coming HI surveys with the SKA precursors will produce a great number of resolved HI datacubes, using a data-pipeline, producing data-cubes, moment order maps and a catalogue with dynamical (W_{20} , W_{50} , V_{sys} , V_{rot} etc.) and flux information. Morphological parameters such as the above, CAS, Gini and M_{20} , of the zero-order moment map (the HI surface density map) could be added to the catalogue, with the intention to expand the catalogue’s parameter space such that first cuts can easily be made for isolated, harassed, and interacting galaxies.

6. Applicability to data-cubes

The application of morphological parameters to HI is thusfar limited to the zero-order map, predominantly for comparison to other wavelengths but one strength of HI data is its third dimension, frequency. Like the spatial dimensions of the data, this it has a finite sampling and range. In the discussions at the Panoramic Radio Astronomy conference, P. Serra mentioned the possibility of redefining these parameters for use on data-cubes. Following his suggestion, three of the above parameters could, in principle, easily be redefined to 3D morphology parameters: Asymmetry, Gini and M_{20} . In the case of asymmetry, the datacube would be mirrored around the central position (x_c , y_c , f_c) in space and frequency, the Gini parameter would simply have more input-pixels ranked by value (unfortunately most of those would be essentially noise), and the second order moment of a pixel i in the datacube would be redefined as: $M_i = I_i[(x_i - x_c)^2 + (y_i - y_c)^2 + (f_i - f_c)^2]$ with M_{20} to follow (see Holwerda et al., 2010d). These three 3D morphology parameters, probably combined with zero-order map morphological parameters and dynamical indicators, could span a parameter space in which it could be possible to determine which datacube has unique HI phenomena like warps, “beards” (anomalous velocity gas on one side of the disk) and of course interaction and harassment.

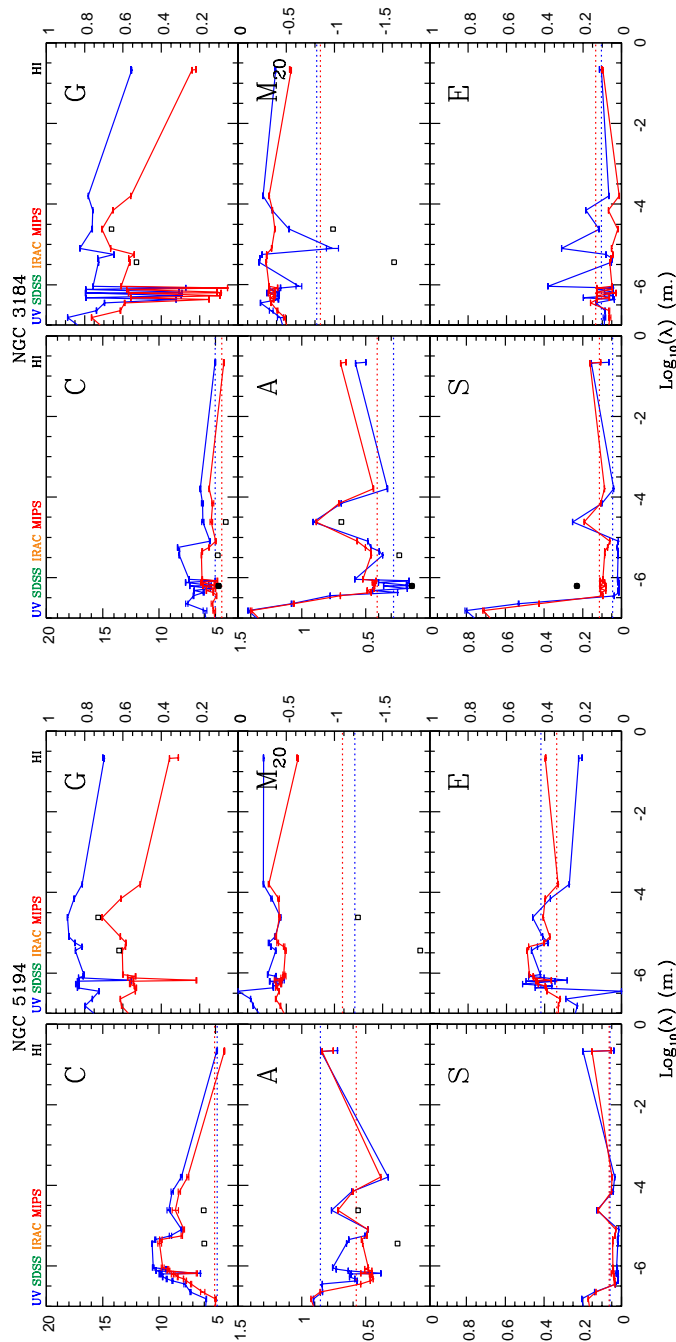


Figure 2: The six structural parameters for the isolated NGC 3184 and interacting NGC 5194 as a function of wavelength. The values for the optical disk (red) and those for the H I disk (blue). The dashed lines are for the contours with equal pixel weights (set to 1) to serve as a reference (for Gini this value is 0, perfect equality). The optical values from Conselice (2003) for NGC 3184 are indicated as black dots and the values for the 3.6 and 24 μm . from Bendo et al. (2007) are indicated with open squares.

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