The origin of HI and optical sizes in the dwarf regime

CASPEN Exit Report

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1 Purpose of visit

In massive galaxies like the Milky Way, the radial extent of neutral atomic hydrogen (HI) – the fuel for star formation in galaxies – is frequently thought to be triple that of the stellar distribution observed in the optical. It is, however, unclear if this phenomenon should also be the case for lower mass, dwarf galaxies [13]. The purpose of this visit was to investigate if the cause for this phenomenon can be related to the environmental conditions under which the galaxies are found. We proposed to explore the stellar and gas properties of dwarf galaxies with stellar masses $M_\star < 10^9\,M_\odot$ using publicly available images and catalogues from Fornax Cluster surveys [15, 9].

The proposed approach to address this problem was a comparison between well-established galaxy size–stellar mass scaling relations in HI [19] and optical wavelengths [16, 3] for Fornax galaxies and those of similar stellar mass in lower density environments. Active participation in group meetings and seminars was also anticipated.

2 Research activities & outcomes

The main scientific outcomes of the visit were two fold: 1) a comparison of HI and optical size-mass scaling relations in a wide stellar mass regime $10^6 M_\odot < M_\star < 10^{12} M_\odot$ and 2) the measurement of HI-radii for five dwarf galaxies in the Fornax cluster using publicly available deep MeerKAT data [9]. We visualise these scaling relations and measurements in Fig. 1 and describe each of them as follows. As a reference, we show available estimates for the Milky Way [1, 11] (yellow stars).

HI–stellar mass: The HI diameter is defined at a fixed surface density of $\Sigma_{\mathrm{HI}} = 1\,M_\odot/\mathrm{pc}^2$ and taken from [19] (blue diamonds). This sample consists of 418 galaxies compiled using 15 different HI surveys, predominantly comprising of gas-rich spiral and dwarf irregular galaxies collectively with HI masses between $10^7\,M_\odot < M_{\mathrm{HI}} < 10^{11}\,M_\odot$ from nearly isolated or cluster environments. We mark out cluster member galaxies from the Ursa Major [17] and Virgo [4] surveys in the sample using red bordered blue diamonds.

While HI diameters from [19] are plotted as a function of HI masses M_{HI} where $D_{\mathrm{HI}} \sim M_{\mathrm{HI}}^{1/2}$ with a dispersion of $\sim 0.06\,\mathrm{dex}$, here we plot the same measurements as a function of $M_\star$ for a comparison with the optical sizes of galaxies with similar stellar mass. The stellar masses of the [19] sample were compiled using a combination of several public catalogues, namely the Updated

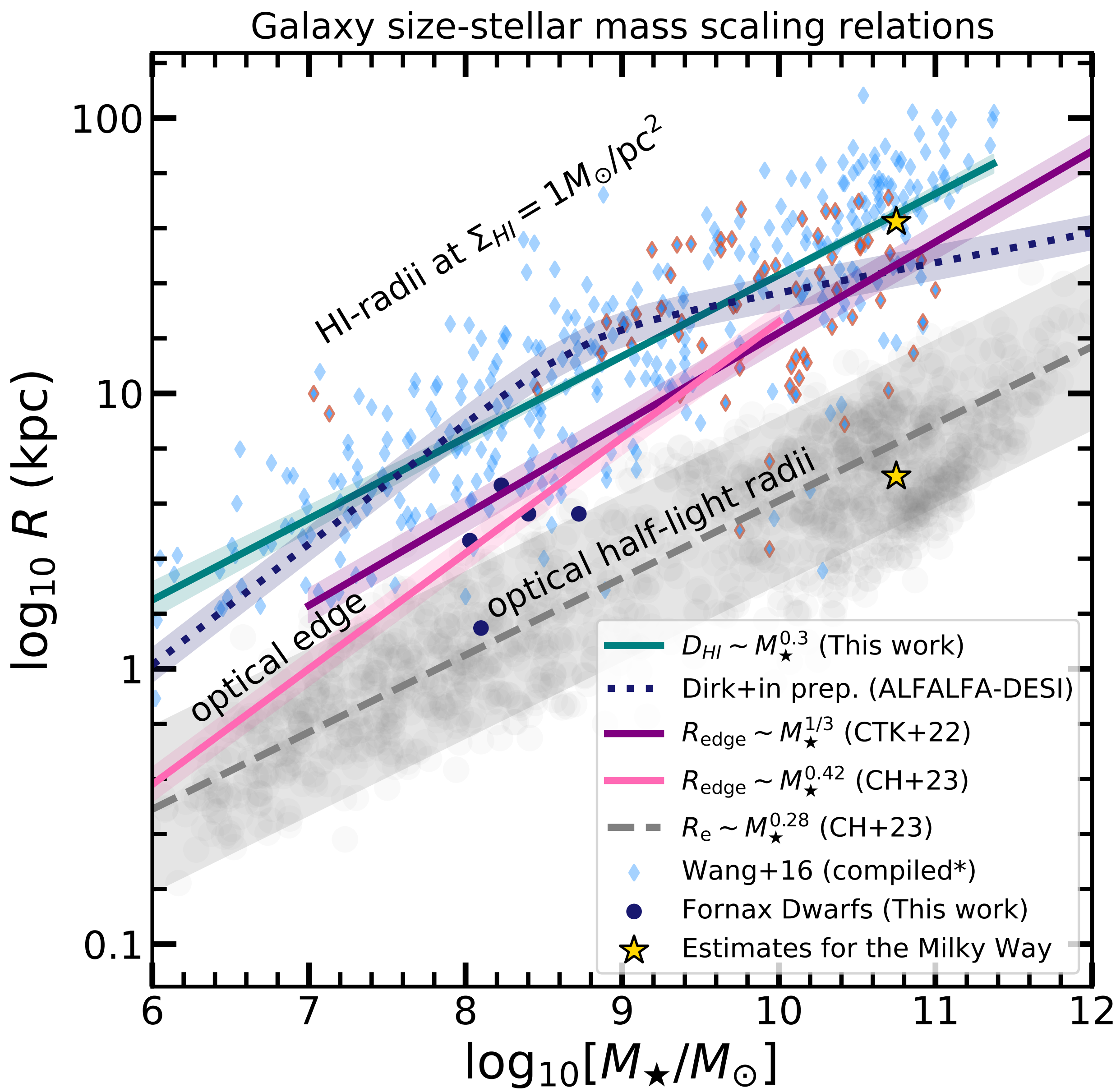

Figure 1: Galaxy HI, optical half-light and edge radii shown as a function of stellar mass. The HI data points are taken from [19] (blue diamonds) and their stellar masses are compiled using several public catalogues [8, 14, 10, 7, 12]. Cluster member galaxies from [19] are red bordered. Best fit relations are taken from Dirk et al. (in prep), [3] and Chamba & Hayes (to be submitted). HI-radii for five dwarf galaxies in the Fornax cluster (solid circles, preliminary) were measured using publicly available MeerKAT data [9]. See text for details.

Nearby Galaxy Catalogue (58 galaxies) [8], GALEX-SDSS-WISE Legacy Catalogue (58) [A2[1]; 14], the $z = 0$ Multi-wavelength Galaxy Synthesis (237) [10, also based on NASA's WISE and GALEX] and the ALFALFA-SDSS (21) [7]. Galaxies which were not in these catalogues were then matched to the Westerbork observations of HI in Irregular and SPiral galaxies (WHISP)-WISE catalogue (2)

[1]See https://salims.pages.iu.edu/gswlc/

[12], LITTLE THINGS (7) [20] and the Local Volume HI Survey (14) [18]. From this compilation, we were able to recover 407 out of the 418 unique galaxies in [19].

In the same panel, we show two best-fit lines for the HI–stellar mass plane (blue lines) that were derived in two ways. The first is a linear regression for galaxies compiled using the [19] sample as described above (this work, solid teal line). The shaded region corresponds to the uncertainty in the slope and intercept. The scatter of the data points themselves are fairly large ~ 0.2 dex and we do not shade this scatter for visualisation purposes. The second fit is a broken power law of the form:

$$\log_{10} f_{\rm HI} = \alpha + \gamma_0 \log_{10}\left[\frac{M'_\star}{10^7}\right] + \frac{\gamma_1 - \gamma_0}{\beta}\log_{10}\left[1 + \frac{M'_\star}{M_0}\right] \quad (1)$$

where $f_{\rm HI} = M_{\rm HI}/M_\star$, $M'_\star = M_\star/h^2$ and all other variables are constants: α is the atomic gas fraction when $M_\star = 10^7\,M_\odot$, γ_0 and γ_1 is the slope of the relation at the low and high mass regime respectively, transitioning at M_0 with a width of β. The fit we use is from ongoing work by UCL PhD student Dirk Scholte et al. (in prep.) who uses a low redshift $z < 0.06$, magnitude limited sample of $\sim 71,000$ galaxies from Year 1 Dark Energy Spectroscopic Instrument (DESI) Survey Validation data within the ALFALFA footprint [6]. This sample is complete at least for galaxies with $M_\star > 10^9\,M_\odot$. Compared to the [19] sample, the DESI-ALFALFA sub-sample also includes several gas poor galaxies, essential for an unbiased comparison of HI and optical radial extents. The fitted $\log_{10} f_{\rm HI}$ values from Dirk et al. (in prep.) was then used to derive $D_{\rm HI}$ using the Wang et al. [19] relation as shown (dotted dark blue line). The shaded region corresponds to the scatter in the HI diameter–mass plane from [19].

Edge radii–stellar mass: The optical best-fit scaling relations are taken from [3, hereafter CTK+22] for group and isolated field galaxies (purple) and on going work (Chamba & Hayes, to be submitted, hereafter CH+23) for Fornax cluster, group satellites and nearly isolated galaxies (pink). The optical 'edge' [3] is defined as the outermost truncation of in situ star formation in a galaxy which can be used as a more physically motivated measure of galaxy size [see also 16]. The shaded regions are the estimated intrinsic scatter of the relation ~ 0.06 dex.

Half-light radii–stellar mass: The half-light radii is defined as the radius which encloses half the total light of a galaxy [5], commonly used as a measure for galaxy size. The half-light radii are shown for the same sample of galaxies as in CTK+22 and CH+23. The shaded region corresponds to the intrinsic scatter of the relations ~ 0.2 dex.

A key difference between the edge and half-light radii is that the latter is biased against the faint outskirts of galaxies because it depends on how light is concentrated [see 2]. As the outskirts are the region which harbours key signatures of gas accretion or removal, processes that can directly impact the total HI radial extent, the CTK+22 (purple) and CH+23 (pink) relations in Fig. 1 are more representative of the stellar boundaries of galaxies. This fact makes those relations better suited for our comparison between HI and optically visible stellar extents compared to half-light radii measurements.

HI radii of Fornax galaxies: The HI-radii for five dwarf galaxies in the Fornax cluster were measured using publicly available MeerKAT data[2] [9] and plotted in Fig. 1 (solid circles). These very preliminary measurements suggest that the HI radii for all but one of the Fornax galaxies are similar to the mean optical edge radii expected for galaxies of similar stellar mass. As a future

[2] https://sites.google.com/inaf.it/meerkatfornaxsurvey/data

step, we hope to extend these results using the rest of the MeerKAT Fornax Cluster Survey and compare our findings with the predictions of cosmological simulations [13].

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