XXXth IAU General Assembly, August 2018
Claude Carignan & Danail Obreschkow, ed.
DOI: 10.5281/zenodo.1481548

Does Angular Momentum Regulate the Atomic Gas Content in HI-deficient Spirals?

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Abstract. The neutral atomic hydrogen (H I) content of spiral galaxies has been observed to vary with environment, with spirals residing in high-density environments being more H I-deficient. This can been explained by environmental effects such as ram pressure stripping and tidal interactions, which remove H I from the discs of galaxies. However, some spirals in low-density environments have also been observed to have relatively low H I mass fractions. The low densities of the Intra Galactic Medium and lack of nearby galaxies in such environments make ram pressure stripping and tidal interactions unlikely candidates of gas removal. What then could be making these spirals H I deficient? In this work, we show that for a sample of H I-deficient spirals from low-density environments, their specific angular momentum influences their H I gas content through its ability to regulate global star formation in their discs. We find that our sample of H I-deficient galaxies consistently follow the model predicted by Obreschkow et al., where the atomic gas fraction (f_{atm}), in a symmetric equilibrium disc is a function of the global atomic stability parameter (q), which depends on specific angular momentum.

Keywords. galaxies: evolution, galaxies: fundamental parameters , galaxies: ISM, galaxies: kinematics and dynamics

1. Introduction

H I scaling relations of late type galaxies, such as the $M_{\rm H\,I} - \rm M_R$ relation (Dénes et al. 2014) as in Fig. 1 show a large scatter, with some galaxies appearing to be H I-excess, and others appearing to be H I-deficient for the same R-band magnitude. The origin of this scatter could be associated with both the influence of the environment on the galaxies' H I content as well as internal parameters that maybe regulating their H I gas. It is well known that the atomic gas fraction in spiral galaxies residing in denser environments is on average less compared to galaxies of similar type and stellar mass, residing in the field (Davies & Lewis 1973; Giovanelli & Haynes 1985; Solanes et al. 2001). This can be associated with gas removing mechanisms in dense environments, such as ram pressure and tidal stripping, which remove H I gas from galaxies, making them H I-deficient (Gunn & Gott 1972; Fasano et al. 2000; Bekki et al. 2011).

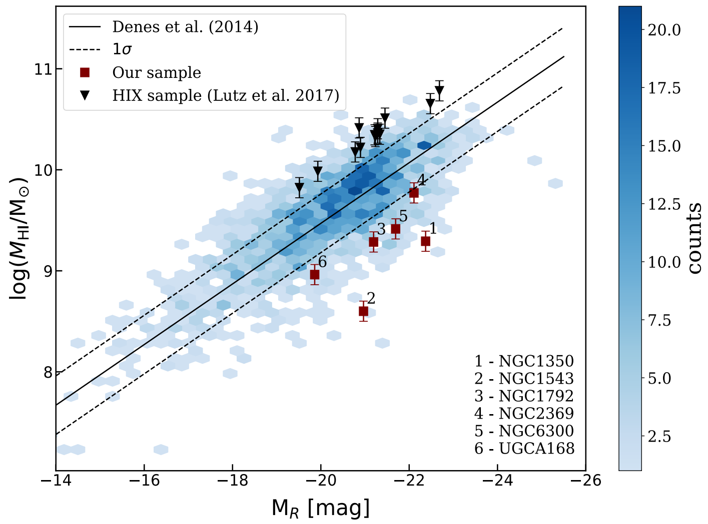

Figure 1: The $M_{\rm H\,I} - {\rm M}_R$ scaling relation from Dénes et al. (2014) for over 1700 HIPASS galaxies from the HOPCAT catalogue. The colourbar shows the number density of galaxies within each hexagon in the plot. The maroon squares represent the current sample of H I-deficient galaxies, which have at least 3 times less H I as is expected for their R-band magnitudes. In contrast, also shown in black (inverted triangles) are the H IX sample of H I-excess galaxies from Lutz et al. (2017).

However, a few studies, notably Kilborn et al. (2005), Sengupta & Balasubramanyam (2006) and Hess & Wilcots (2013) have shown that some galaxies in lower density environments such as loose groups are also HI-deficient. The low densities of the Intra Group and Intra Galactic Medium (IGM) in such environments make ram pressure and tidal stripping unlikely candidates for gas removal. What then could be making these galaxies H I-deficient? This suggests that some other internal physics maybe driving their H I gas content.

Angular momentum is regarded as one of the fundamental properties of galaxies. Many previous works have linked stellar angular momentum to other fundamental properties of a galaxy, such as its stellar mass and bulge-to-total ratio (Fall 1983; Romanowsky & Fall 2012). Recently, a relation between specific angular momentum and atomic gas fraction in late-type galaxies has been established. Obreschkow et al. (2016)[hereafter O16] introduced a parameter-free quantitative model connecting the neutral atomic mass fractions of isolated disc galaxies to their specific angular momentum. A strong test for this model are disc galaxies that are particularly gas-excess or gas-deficient for their stellar content. Lutz et al. (2017) studied a sample of 13 H I-excess galaxies (with a median $\log M_{\rm H\,I}[{\rm M}_\odot] \sim 10.4$) from the H I eXtreme (H IX) survey and find that the H IX galaxies have a low star forming efficiency owing to their large angular momenta.

In this study we examine if this effect is also observed among H I-deficient spirals and test if their deficiency is driven by their specific angular momentum. We select six H I-deficient spirals from the $M_{\rm H\,I} - {\rm M}_R$ relation (Fig. 1), with the condition that they have an isophotal diameter $D_{25} > 210''$, so that we maybe able to perform 3D kinematic fits to the data to derive their rotation curves and other kinematic parameters. They have also been sampled from low-density environments with no close neighbours so as to minimize the effects of the environment on their H I gas. The H I observations have been made using the Australia Telescope Compact Array (ATCA), with a typical synthesized beam resolution of $\sim 30''$.

2. The $f_{atm} - q$ relation

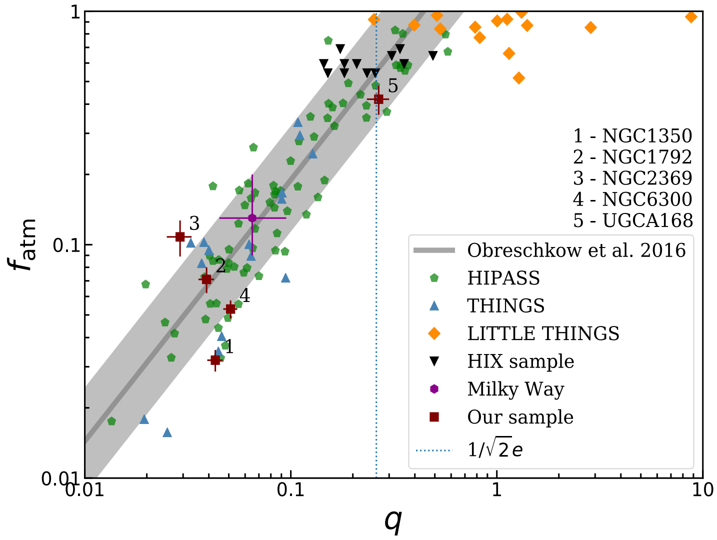

Figure 2: The $f_{atm} - q$ relation. The galaxies in our sample are represented by the maroon squares. The dark gray line is the analytical model for f_{atm} from O16. The shaded gray region shows the 40% scatter about the model. Also shown are galaxies from THINGS, LITTLE THINGS, HIPASS and the H IX surveys. The vertical dotted line represents $q = 1/\sqrt{2}e$, the threshold beyond which axially symmetric exponential disks of constant velocity can remain entirely atomic.

O16 find a tight relation between the atomic mass fraction $f_{atm} = \frac{1.35 M_{\rm H\,I}}{M}$ and the stability parameter $q = \frac{j\sigma}{GM}$, where $M = M_{\star}+1.35(M_{\rm H\,I}+M_{\rm H_2})$ is the total baryonic mass and $M_{\rm H\,I}$, $M_{\star}$ and $M_{\rm H_2}$ are the H I, stellar and molecular hydrogen mass respectively. The factor 1.35 accounts for the 26% He in the local universe. σ is the dispersion velocity of the Warm Neutral Medium (WNM), and G is the universal gravitational constant. The authors describe the stability parameter as a global analog to the local Toomre stability parameter of a hypothetical single-component WNM disc. We test this model for our H I-deficient sample. We fit 3D tilted ring models to the data to derive the rotation velocities and the inclination and position angles for the rings. The 3D tilted rings are then projected onto the 2D intensity maps to compute the H I and stellar mass within each ring. To calculate the H I mass we use the moment 0 (integrated flux) maps and to calculate the stellar mass, we use the 2MASS (Skrutskie et al. 2006) background subtracted images. The H I and stellar mass is calculated within each tilted ring and summed up across all rings to get the total mass. Finally we compute the neutral atomic gas mass fractions (f_{atm}), specific angular momentum (j) and the q values for the sample galaxies. We note that we have assumed a constant velocity dispersion (σ) of 10 km s^{-1}for all galaxies in our sample. Fig. 2 shows the scaling relation between f_{atm} and q for a sample of local disc galaxies. We find that the galaxies in our sample follow the relation fairly consistently but with some scatter. This result comes in support of the idea that angular momentum plays an important role in regulating the H I gas content in disc galaxies, particularly those from low-density environments. Galaxies with lower specific angular momentum have lower q values which directly sets instabilities in the disc leading to increased star formation. This tends to deplete their H I gas reservoir. On the contrary, galaxies with higher specific angular momenta will support a more stable disc leading to a reduced star formation efficiency. These systems will appear to have excess H I for their given R-band magnitudes (or stellar mass). Angular momentum by virtue of its cosmic variance, will play an important role in controlling the evolution of galaxies, with galaxies having higher specific baryonic AM retaining a larger fraction of their gas and appearing H I-excess and those with lower specific AM depleting gas more efficiently and appearing gas-depleted. This effect will naturally contribute to the scatter that is observed in the various scaling relations. This result solidifies the role of specific angular momentum in controlling the H I gas fraction in disc galaxies and consequently their evolution.

References

K. Bekki and W. J. Couch. Transformation from spirals into S0s with bulge growth in groups of galaxies. *MNRAS*, 415:1783–1796, August 2011. .

R. D. Davies and B. M. Lewis. Neutral hydrogen in Virgo cluster galaxies. *MNRAS*, 165: 231–244, 1973. .

H. Dénes, V. A. Kilborn, and B. S. Koribalski. New H I scaling relations to probe the H I content of galaxies via global H I-deficiency maps. *MNRAS*, 444:667–681, October 2014. .

S. M. Fall. Galaxy formation - Some comparisons between theory and observation. In E. Athanassoula, editor, *Internal Kinematics and Dynamics of Galaxies*, volume 100 of *IAU Symposium*, pages 391–398, 1983.

G. Fasano, B. M. Poggianti, W. J. Couch, D. Bettoni, P. Kjærgaard, and M. Moles. The Evolution of the Galactic Morphological Types in Clusters. *ApJ*, 542:673–683, October 2000. .

R. Giovanelli and M. P. Haynes. Gas deficiency in cluster galaxies - A comparison of nine clusters. *ApJ*, 292:404–425, May 1985. .

J. E. Gunn and J. R. Gott, III. On the Infall of Matter Into Clusters of Galaxies and Some Effects on Their Evolution. *ApJ*, 176:1, August 1972. .

K. M. Hess and E. M. Wilcots. Evolution in the H I Gas Content of Galaxy Groups: Pre-processing and Mass Assembly in the Current Epoch. *AJ*, 146:124, November 2013. .

V. A. Kilborn, B. S. Koribalski, D. A. Forbes, D. G. Barnes, and R. C. Musgrave. A wide-field HI study of the NGC 1566 group. *MNRAS*, 356:77–88, January 2005. .

K. A. Lutz, V. A. Kilborn, B. Catinella, B. S. Koribalski, T. H. Brown, L. Cortese, H. Dénes, G. I. G. Józsa, and O. I. Wong. The HIX galaxy survey I: Study of the most gas rich galaxies from HIPASS. *MNRAS*, 467:1083–1097, May 2017. .

D. Obreschkow, K. Glazebrook, V. Kilborn, and K. Lutz. Angular Momentum Regulates Atomic Gas Fractions of Galactic Disks. *ApJL*, 824:L26, June 2016. .

A. J. Romanowsky and S. M. Fall. Angular Momentum and Galaxy Formation Revisited. *ApJSS*, 203:17, December 2012. .

C. Sengupta and R. Balasubramanyam. HI content in galaxies in loose groups. *MNRAS*, 369: 360–368, June 2006. .

M. F. Skrutskie, R. M. Cutri, R. Stiening, M. D. Weinberg, S. Schneider, J. M. Carpenter, C. Beichman, R. Capps, T. Chester, J. Elias, J. Huchra, J. Liebert, C. Lonsdale, D. G. Monet, S. Price, P. Seitzer, T. Jarrett, J. D. Kirkpatrick, J. E. Gizis, E. Howard, T. Evans, J. Fowler, L. Fullmer, R. Hurt, R. Light, E. L. Kopan, K. A. Marsh, H. L. McCallon, R. Tam, S. Van Dyk, and S. Wheelock. The Two Micron All Sky Survey (2MASS). *AJ*, 131:1163–1183, February 2006. .

J. M. Solanes, A. Manrique, C. Garcia-Gomez, G. González-Casado, R. Giovanelli, and M. P. Haynes. The H I Content of Spirals. II. Gas Deficiency in Cluster Galaxies. *ApJ*, 548: 97–113, February 2001. .