The Fate of the Neutral Gas in Group Environments

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## Busy Function
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## Ram pressure
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## NGC 55 / 300
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Motivation
Motivation

- H I deficiency in groups and clusters
  - Increases towards group centre
  - Increases with group size

Solanes et al. (2001)

Hess & Wilcots (2013)
Motivation

★ Gas stripping in high-density environments
  ▶ Removal of neutral gas through
    ● Tidal interaction
    ● Ram-pressure stripping
  ▶ Effect on HIMF and star formation

Kenney et al. (2004)

Kilborn et al. (2006)
Observations and Data
Observations and Data

★ HIPASS 2

- $\sigma_{\text{rms}} \approx 4.8 \text{ mJy}$ (at 26.4 km/s)
  - $M_{\text{H}1} \approx 5 \times 10^6 \, M_\odot \left[ d / 5 \text{ Mpc} \right]^2$ (10σ at 26.4 km/s)
  - $N_{\text{H}1} \approx 9 \times 10^{17} \text{ cm}^{-2}$ (5σ at 26.4 km/s)

★ Deep Parkes H I survey

- $\sigma_{\text{rms}} \approx 11 \text{ mJy}$ (at 1.6 km/s)
  - $M_{\text{H}1} \approx 4 \times 10^6 \, M_\odot \left[ d / 5 \text{ Mpc} \right]^2$ (10σ at 20 km/s)
  - $N_{\text{H}1} \approx 5 \times 10^{17} \text{ cm}^{-2}$ (5σ at 20 km/s)
Source Finding Application (SoFiA)

- New 3D source finding pipeline
- Graphical user interface
- Novel algorithms created for HI surveys
  - Smooth + clip finder (Serra et al. 2012, PASA, 29, 296)
  - Reliability calculation (Serra et al. 2012, PASA, 29, 296)
  - 2D–1D wavelet finder (Flöer et al. 2012, PASA, 29, 244)
  - CNHI finder (Jurek 2012, PASA, 29, 251)
- Download SoFiA
  - GitHub: https://github.com/SoFiA-Admin/SoFiA
  - Wiki, documentation, bug reports, feature requests
- Paper
  - Serra, Westmeier, et al., submitted to MNRAS
The Busy Function

\[ B(x) = \frac{a}{4} \times \left[ \text{erf}(b_1 (w + x - x_e)) + 1 \right] \times \left[ \text{erf}(b_2 (w - x + x_e)) + 1 \right] \times \left[ c (x - x_p)^n + 1 \right] \]

- **Purpose**
  - Fit **double-horn** profiles of galaxies
  - Measure galaxy parameters: line width, peak flux, integrated flux, radial velocity, etc.

- **More accurate than direct measurements, in particular for peak flux and line width**

- **Paper**
  - Westmeier et al., 2014, *MNRAS*, 438, 1176

- **Fitting software**
  - **BF_dist** ([https://code.google.com/p/busy-function-fitting/](https://code.google.com/p/busy-function-fitting/), written by Russell Jurek)
Observations and Data

★ Galaxies detected

► 31 H I detections
  ● $v = 220 \ldots 1200$ km/s
  ● $d = 2 \ldots 15$ Mpc
  ● $\log(M_{\text{H I}}/M_\odot) = 6.6 \ldots 9.4$

► 14 detections not in HIPASS
  ● 5 due to velocity limit
  ● 8 new H I detections of dwarf galaxies
  ● NGC 59 (Beaulieu et al. 2006)

► All H I detections have (tentative) optical counterpart in DSS / GALEX

► No intergalactic gas / “dark galaxies”
Observations and Data

★ New HI detections

- $M_{\text{HI}} \lesssim 10^8 \, M_\odot$
- compact
- irregular
- not much data available (photometric, spectroscopic)

Images: DSS
Results
Results

★ HI mass vs. distance

► $M_{\text{HI}} \gtrsim 10^7 \, M_\odot$

► Fairly even spread of galaxies across mass range
Comparison with HI mass function

- Schechter function
  \[ \Theta(m) \, dm = \Theta^* \, m^\alpha \exp(-m) \, dm \]
  where \( m \equiv M_{\text{HI}} / M_{\text{HI}}^* \)

- Global HIPASS HI mass function
  \[ \alpha = -1.37 \]
  \[ \log(M_{\text{HI}}^* / M_\odot) = 9.80 \]
  \[ \Theta^* = 0.0060 \]
★ Comparison of simulation and observation

► Too many high-mass galaxies
  • $M_{\text{HI}} \gtrsim 10^9 \, M_\odot$

► Too few intermediate-mass galaxies
  • $M_{\text{HI}} \approx 10^7\ldots8 \, M_\odot$

► Similar result for ALFALFA HIMF (Martin et al. 2010)

► Is this result significant?
Comparison of simulation and observation

- Kolmogorov–Smirnov test
  - Cumulative H I mass distribution

- Results
  - $D \approx 0.17$
  - $p \approx 31\%$

- The chance of a statistical fluctuation creating a discrepancy greater than the one observed is 31% if model and observation were drawn from the same H I mass function.

- Discrepancy not statistically significant due to small sample size.
Discussion
Reason for lack of low-mass galaxies?

- Environmental effects
  - Tidal interaction and accretion
  - Ram-pressure stripping
- Internal effects (SF & AGN)
  - Ionisation of neutral gas
  - Ejection of gas
- Local Group
  - HI deficiency in dwarf galaxies (Grcevich & Putman 2009)
  - Quenching of star formation
- Ram-pressure stripping?

Based on data from Grcevich & Putman (2009)
Reason for lack of low-mass galaxies?

- Environmental effects
  - Tidal interaction and accretion
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- Internal effects (SF & SNe)
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- Ram-pressure stripping?
Ram pressure: NGC 55

- Studies hampered by disc inclination ($\approx 80^\circ$)
- Asymmetric HI disc

Westmeier et al. (2013)
Ram pressure: NGC 300

- Again asymmetric H I disc

Westmeier et al. (2011)
Ram pressure: NGC 300
- Again asymmetric H I disc
- Ram pressure significant at $R \gtrsim 15$ kpc

Westmeier et al. (2011)
**Ram pressure: NGC 300**

- Again asymmetric H I disc
- Ram pressure significant at $R \gtrsim 15$ kpc
- Kinematic signature

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**Discussion**

Ram pressure: NGC 300

- Again asymmetric H I disc
- Ram pressure significant at $R \gtrsim 15$ kpc
- Kinematic signature
★ Outlook: systematic study of ram pressure in Sculptor galaxies

- Use galaxies as probes to
  - determine density of IGM
  - measure 3D motions of galaxies

- Determine role of ram pressure in
  - removal of neutral gas
  - impact on star formation history
Summary
Summary

★ Deep H I survey of Sculptor group region
  ▶ 31 H I detections, 8 entirely new, no “dark galaxies”
  ▶ Comparison with H I mass function
    ● Too many galaxies with $M_{\text{HI}} \gtrsim 10^9 M_\odot$, too few with $M_{\text{HI}} \approx 10^{7-8} M_\odot$
    ● Discrepancies not statistically significant due to small sample size
  ▶ ASKAP / Apertif and SKA 1 Survey needed

★ Ram-pressure effects in groups
  ▶ Evidence for ram pressure in Sculptor group
    ● morphological + model of Haan & Braun (2014)
    ● $n_{\text{IGM}} \approx 10^{-5} \ldots 10^{-4} \text{ cm}^{-3}$
  ▶ Ram pressure important for galaxy evolution in groups

★ “Missing satellites” problem might be an illusion
Motivation

Impact on H I mass function

- Steeper in…
  - …high-density environments (Zwaan et al. 2005)
  - …low-density environments (Springob et al. 2005)
★ Deep HI survey of Sculptor group

- Nearby
- HI mass sensitivity < $10^7 M_\odot$
- High spatial resolution
- But: large area on the sky
Results

★ Simulation of HIPASS H I mass function

- Assumptions
  - Homogeneous distribution of galaxies
  - Random mass of $6 < \log(M_{\text{HI}}/M_\odot) < 10$ following HIPASS Schechter function
  - Random orientation (→ inclination)
  - H I line width from global HIPASS $\Delta v$–$M_{\text{HI}}$ relation
  - Random distance of $2 < d < 15$ Mpc (taking survey geometry into account)

- Calculate SNR and keep detectable galaxies
  - SNR $> 10$

Duffy et al. (2012)
Comparison with Springob et al. (2005)

- Environmental effect on HIMF
  - Low-density HIMF ($n < 1.5$)
    - $\alpha = -1.38$
    - $\log(M_{H\text{I}}^*/M_\odot) = 10.07$
  - High-density HIMF ($n > 3.0$)
    - $\alpha = -1.24$
    - $\log(M_{H\text{I}}^*/M_\odot) = 9.95$

- Results
  - Low density: $p = 43\%$
  - Med. density: $p = 8.5\%$
  - High density: $p = 21\%$

Springob et al. (2005)
★ Peak flux density maps

Observations and Data
Discussion

★ Ram pressure

- Ram pressure: \( P_{\text{ram}} = \varrho v^2 \)
- Gravitational pressure: \( P_{\text{grav}} = \Sigma_{\text{gas}}(r) \left| \frac{\partial \Phi(r)}{\partial z} \right|_{\text{max}} \)
- Face-on situation, but accurate for inclination angles of up to 60° (Rödiger et al. 2005)