Motivation
Galaxies don’t evolve in isolation.

- Galaxies usually occur in group/cluster environments of varying density.
- Impact on evolution in the form of tidal interaction, mergers/accretion, and ram pressure.
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H I is a sensitive tracer of environmental effects.
Galaxies don’t evolve in isolation.

- Galaxies usually occur in group/cluster environments of varying density.
- Impact on evolution in the form of tidal interaction, mergers/accretion, and ram pressure.

H$\text{I}$ is a sensitive tracer of environmental effects.

- Hydrogen is the most common chemical element in the universe and a significant constituent of galaxies.
- H$\text{I}$ discs are more extended than stellar discs and hence more susceptible to disturbances.
- Unlike stars, gas is affected by ram pressure.

M$\text{81}$ group (VLA H$\text{I}$ image; Yun et al. 1994)
The H I Mass Function
Environmental dependence of the H\textsc{i} MF:

- Springob et al. (2005): H\textsc{i} MF of high-density regions is flatter.

\[\begin{align*}
\text{Springob et al. (2005)}: & \quad \text{H\textsc{i} MF of high-density regions is flatter.} \\
1.5 < n < 3.0: & \quad \alpha = -1.13 \\
n < 1.5: & \quad \alpha = -1.38 \\
n > 3.0: & \quad \alpha = -1.24
\end{align*}\]
★ Environmental dependence of the H\textsubscript{I} MF:

- Springob et al. (2005): H\textsubscript{I} MF of high-density regions is flatter.
- Zwaan et al. (2005): H\textsubscript{I} MF of high-density regions is steeper.

Springob et al. (2005)

\[ n > 3.0: \quad \alpha = -1.24 \]
\[ 1.5 < n < 3.0: \quad \alpha = -1.13 \]
\[ n < 1.5: \quad \alpha = -1.38 \]

Zwaan et al. (2005)

\[ \alpha \approx -1.5 \]
\[ \alpha \approx -1.2 \]
★ Environmental dependence of the H1MF:

- Springob et al. (2005): H1MF of high-density regions is flatter.
- Zwaan et al. (2005): H1MF of high-density regions is steeper.

\[ \alpha_{\text{Springob et al. (2005)}} \approx \begin{cases} -1.38 & n < 1.5 \ 
-1.13 & 1.5 < n < 3.0 \ 
-1.24 & n > 3.0 \end{cases} \]

\[ \alpha_{\text{Zwaan et al. (2005)}} \approx -1.5 \]
Simulations by Martin Zwaan:

- 10 realisations of 10 contiguous ASKAP fields.

2D SWML = Two-dimensional, stepwise maximum-likelihood method.
Simulations by Martin Zwaan:

- 10 realisations of 10 widely separated ASKAP fields.

2D SWML = Two-dimensional, stepwise maximum-likelihood method.
Simulated H I Mass Function (HI MF) recovery – 10 low-density and 10 high-density ASKAP fields:

10 high-density fields: $\alpha = -1.27$, $\Phi = 2\Phi^*$

10 low-density fields: $\alpha = -1.47$, $\Phi = 0.5\Phi^*$

L. Staveley-Smith
The HI Mass Function

★ HI MF environment precision: how many ASKAP 30 deg² fields?

- ASKAP-12 2D SWML† simulation, excluding spatial resolution effects.
- Each simulation divided into high- and low-density regions.

<table>
<thead>
<tr>
<th>Total ASKAP fields</th>
<th>Galaxies</th>
<th>Measurable slope difference (1σ)</th>
<th>Measurable density difference (1σ)</th>
<th>Observing time (h)</th>
</tr>
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<tbody>
<tr>
<td>5</td>
<td>3,200</td>
<td>±0.07</td>
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<td>25,900</td>
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</table>

Slope difference of 0.1 measurable with > 3σ precision.

† Two-dimensional, stepwise maximum-likelihood method.

L. Staveley-Smith
The HI Mass Function

★ Definition of environment:
  ◁ Springob et al. (2005): IRAS Point Source Catalogue Redshift Survey
  ◁ Zwaan et al. (2005): HIPASS

★ Biases:
  ◁ HI deficient galaxies (e.g. early-types)
Definition of environment:
- Springob et al. (2005): IRAS Point Source Catalogue Redshift Survey
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Biases:
- H1 deficient galaxies (e.g. early-types)
- Deficiency of galaxies with low H1 mass in high-density environments
Definition of environment:
- Springob et al. (2005): IRAS Point Source Catalogue Redshift Survey
- Zwaan et al. (2005): HIPASS

Biases:
- **H I deficient** galaxies (e.g. early-types)
- Deficiency of galaxies with **low H I mass** in high-density environments
- **Confusion** (e.g. pairs, compact groups)

Optical redshift data for definition of environment beneficial.
Ram Pressure
Ram Pressure

- Stellar component not affected, so H I is the most promising tracer.
- Ram-pressure effects in dense clusters:
  - Interaction with hot, dense intra-cluster gas.
  - Strong effect on H I disc and gaseous halo.

Crowl et al. (2005)

NGC 4402

Kenney et al. (2004)
★ Stellar component not affected, so H I is the most promising tracer.

★ Ram-pressure effects in dense clusters:
  ▶ Interaction with hot, dense intra-cluster gas.
  ▶ Strong effect on H I disc and gaseous halo.

★ Ram-pressure effects in low-density groups:
  ▶ Subtle effects on outer H I disc:
    \[ N_{\text{H I}} < 10^{20} \text{ cm}^{-2} \]

★ What is the effect on star formation?

Westmeier et al. (2011, 2013)
★ Results from simulations:

► Gas disc:
  ● High ram pressure can strip entire gas disc; low ram pressure will only disturb and truncate outer disc. (*Kapferer et al. 2009*)

► Star formation:
  ● Compression induces star formation in disc/wake in the short term. (*Kapferer et al. 2009*)
  ● Removal of halo gas starves galaxy of SF fuel in the long term. (*Rödiger 2009*)
Results from simulations:

- **Gas disc:**
  - High ram pressure can strip entire gas disc; low ram pressure will only disturb.

- **Star formation:**
  - Compression induces star formation in disc/wake in the short term. (Kapferer et al. 2009)
  - Removal of halo starves galaxy of fuel in the long term. (Rödiger 2009)

"Several studies (observational and theoretical) suggest that ram pressure causes an enhancement in star formation activity in the remaining gas disk. [...] However, contradicting observations exist, and theoretical work needs confirmation due to the complex nature of star formation physics.” (Rödiger 2009)
How to detect ram pressure?

- Morphology
- 88% > 30"
- 5% > 90"

(Duffy et al. 2012)
Asymmetry Measure of Galaxies
Asymmetry Measure of Galaxies

★ New method developed by WALLABY galaxy kinematics group:

- Asymmetry in H I in the outer region: tail-like features, truncation or warps.
- These morphological and kinematical disturbances are related to the ram pressure and tidal interaction, and are important for understanding galaxy evolution in different environments.
- Problem: Galaxies tend to appear more symmetric when less well resolved (e.g., Christopher et al. 2000).
- ≈ 33 galaxies per ASKAP-12 field are expected to be marginally resolved by more than three 30” beams (based on simulations by Duffy et al. 2012).
- An efficient and reliable algorithm for asymmetry measure is required for (marginally) resolved galaxies from ASKAP-12.
Asymmetry Measure of Galaxies

★ Method:

- Model-based rotation curve fit (e.g., Burkert, NFW or isothermal rotation curves).
- Detailed kinematics in the inner region is not necessary for asymmetry measure in the outer region → applicable to less-resolved data.
Asymmetry Measure of Galaxies

Gaussian Velocity profile decomposition

- Bulk
- Weak non-circular
- Strong non-circular
Asymmetry Measure of Galaxies

Model cube 1 ($v_{\text{max}} \approx 60 \text{ km/s}$) at $4 \text{ Mpc}$ distance:
Model cube 1 ($v_{\text{max}} \approx 60 \text{ km/s}$) at 58.4 Mpc distance:

- **mom1**
- **mom2**
- **BULK**

**strong nonc.**

**weak nonc.**

S. Oh
Optimal Observing Strategy
Optimal Observing Strategy

★ Sensitivity of ASKAP-12

- Assumptions:
  - Configuration proposed in “Early Science with ASKAP” memo.
  - System temp.: $T_{\text{sys}} = 50$ K
  - Efficiency: $\eta = 0.8$.
  - Channel width: $\Delta \nu = 18.5$ kHz.
  - Frequency: $\nu = 1420$ MHz.
  - Declination: $\delta = -30^\circ$.
  - HA coverage: $t = \pm 4$ h.

<table>
<thead>
<tr>
<th>Weighting</th>
<th>Taper</th>
<th>Beam size ($''$)</th>
<th>Max. S.L. (mJy)</th>
<th>rms (mJy)</th>
<th>rms (K)</th>
<th>$M_{\text{HI}}$ ($M_\odot$)</th>
<th>$N_{\text{HI}}$ ($\text{cm}^{-2}$)</th>
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<tbody>
<tr>
<td>uniform</td>
<td>-</td>
<td>$20.4 \times 14.8$</td>
<td>12.4%</td>
<td>4.4</td>
<td>8.8</td>
<td>$6.6 \times 10^6$</td>
<td>$10.5 \times 10^{20}$</td>
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<tr>
<td>robust 0</td>
<td>-</td>
<td>$20.7 \times 14.9$</td>
<td>12.7%</td>
<td>4.4</td>
<td>8.6</td>
<td>$6.6 \times 10^6$</td>
<td>$9.6 \times 10^{20}$</td>
</tr>
<tr>
<td>natural</td>
<td>-</td>
<td>26.9 x 17.7</td>
<td>17.3%</td>
<td>4.1</td>
<td>5.3</td>
<td>$6.1 \times 10^6$</td>
<td>$6.0 \times 10^{20}$</td>
</tr>
<tr>
<td>uniform</td>
<td>1280</td>
<td>35.7 x 26.1</td>
<td>21.0%</td>
<td>5.7</td>
<td>3.7</td>
<td>$8.5 \times 10^6$</td>
<td>$4.2 \times 10^{20}$</td>
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★ ASKAP-12 early H I science: deep or shallow?

▶ Example: 560 h integration

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Summary
Summary

★ H\textsc{I} observing strategy:
- Optimum ASKAP-12 area for H\textsc{I} emission is 300–750 deg\textsuperscript{2} (10–25 ASKAP fields), depending on time available, with \approx 50 h per field. Full ASKAP FoV required.
- Complementary data (optical, UV, etc.) would be greatly beneficial.

★ H\textsc{I} mass function:
- 10 fields needed for $3 \times 10^6 M_\odot$ limit, with an accuracy of \pm 0.15 in the slope.
- 20 fields needed, each of \approx 56 h, to explore environmental effects on slope.

★ Ram pressure:
- ASKAP-12 resolution enables systematic study of ram-pressure stripping and effect on H\textsc{I} mass-to-light ratio and star formation to confirm or discard simulations.

★ Asymmetry measure:
- Powerful new method to measure asym. in large sample of marginally resolved galaxies.