Westerbork ultra-deep HI observations at z=0.2

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What is the role and fate of cold gas in galaxy evolution?
Why clusters at higher redshift?

Content of galaxy clusters and the surrounding field evolves over cosmic time.

→ Exploratory steps towards understanding the role and fate of cold gas in cosmological evolution.

Why $Z \sim 0.2$ ?

→ Highest redshift for ‘practical’ HI imaging with existing arrays

→ Lowest redshift where cosmological evolutionary effects are seen
Butcher-Oemler effect

The fraction of blue (starforming?) galaxies in clusters increases with redshift and peaks in cluster outskirts.

A963

Butcher & Oemler, 1984

Key question: different accretion rate/efficiency or different field population?
Morphological mix in clusters depends on redshift and compactness

- HEC
- LEC

Fasano et al., 2000
Clusters of different compactness

Concentration of ellipticals:

High $\rightarrow$ S0/E low

Low $\rightarrow$ S0/E high

Fasano et al., 2000
Goals of HI observations at intermediate z

• Characterize nature of blue galaxy population
  ➔ gas content, SFR, stellar populations

• Witness galaxy transformation in various environments
  ➔ which physical mechanisms dominate where?
    gas accretion and depletion

• SFR versus environment and gas content

• Evolving $\Omega_{\text{HI}}$ from *blind* HI 21cm emission surveys

• Evolving HI Mass Function?
  ➔ HIMF in different environments

• HI based Tully-Fisher and rotation curve studies
A tale of two clusters
work in progress

Abell 963  
INT - B,R  
z=0.206

Abell 2192  
1 Mpc  
z=0.188

(thesis Boris Deshev)
A tale of two clusters
work in progress
(thesis Boris Deshev)

Abell 963
z = 0.206

Abell 2192
z = 0.188
SDSS @ Z=0.2 is of insufficient quality to determine morphologies and detect LSB galaxies.
Ultra-deep WSRT observations

- Minimum detectable HI mass:
  \[ 2 \times 10^9 \, M_{\odot} \text{ over } 150 \, \text{km/s profile width} \]
  \( (4\sigma \text{ in each of 3 spectral resolution elements}) \)

- Corresponding limiting column density:
  \[ 3 \times 10^{19} \, (\text{cm}^{-2}) \text{ over } 80 \, \text{km/s profile width at } 7\sigma. \]

This requires:
- \( 78 \times 12^{\text{hr}} \) for A2192 at \( z=0.188 \)
- \( 117 \times 12^{\text{hr}} \) for A963 at \( z=0.206 \)
Survey Volume & Large Scale Structure

combined volume: $7 \times 10^4$ Mpc$^3$

325 Mpc

SDSS redshift slice
WSRT observational setup

- Long-term program over 8 semesters
- 8x10MHz bands, overlapping to cover 1160-1220 MHz, surveyed volume $\approx 70,000$ Mpc$^3$
- 8x256 channels, covering 18,000 km/s velocity range, 20 km/s velocity resolution (after Hanning smoothing)
- Dual polarisation, 2-bit correlation, recirculation
- 117x12 hr on Abell 963, 78x12 hr on Abell 2192
- RMS noise per channel: 14 $\mu$Jy and 17 $\mu$Jy ($\Delta V=80$ km/s)
- ~5-15% lost to RFI, antenna 5 offline (APERTIF prototype)
### WSRT observational setup

- Long-term program over 8 semesters

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<th>semester</th>
<th>A963</th>
<th>A2192</th>
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<td>hours</td>
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- To cover 1160-1220 MHz
- Surveyed volume ≈ 70,000 Mpc³
- 100 km/s velocity range
- 20 km/s velocity resolution (after Hanning smoothing)
- Dual polarisation, recirculation
- 117x12 hr on Abell 963, 78x12 hr on Abell 2192
- rms noise per channel: 14\(\mu\)Jy and 17\(\mu\)Jy (\(\Delta V=80\) km/s)
- 5-15% lost to RFI, antenna 5 offline (APERTIF prototype)

achieved rms noise

Δν = 80 km/s

Flagged: 5-8%  15-17%
achieved rms noise

Δν = 80 km/s

Flagged: 5-8%

before

after

Wallaby science meeting - Dec 2 2010
IF-based selfcal
Abell 2192

σ = 7 μJy/beam (confusion limited)

SFR ≈ 10 M_{sun}/yr

( deep GALEX data more sensitive )

Abell 963

σ = ~12 μJy/beam (DR limited)
Velocity smoothing the data cubes:

\[ \Delta V = (1+Z) \times C \times \Delta f/f_0 = (1+Z) \times 8.24 \text{ km/s} \]

R2 : \( R = 2\Delta V = 20 \text{ km/s} \) \( \rightarrow \) 1544 channels

R4 : \( R = 4\Delta V = 40 \text{ km/s} \) \( \rightarrow \) 768 channels

R6 : \( R = 6\Delta V = 60 \text{ km/s} \) \( \rightarrow \) 510 channels

R8 : \( R = 8\Delta V = 80 \text{ km/s} \) \( \rightarrow \) 383 channels
Detection criteria: 1x8σ or 1.5x6σ or 2x5σ or 3x4σ or 4x3σ in N consecutive spectral resolution elements.

Spectrally smoothed to R=20, 40, 60, 80 km/s
simple source finding results

Positive detections

Negative detections

R2  R4  R6  R8

1x8σ

2x5σ

3x4σ

4x3σ
simple source finding results

positive detections

negative detections
Stellar counterparts

INT optical
- R-band
- B-band

GALEX ultra-violet
- Near-UV
- Far-UV
Cube dimensions : 9.5 x 9.5 x 325 Mpc^3
Synthesized beam size : 65 x 80 kpc^2 x 80 km/s
surroundings of Abell 963

Cube dimensions: 9.5 x 9.5 x 85 Mpc³

0.164 redshift 0.224
Examples of detections (based on pilot data)
Examples of detections (based on pilot data)
detected HI masses

(both clusters combined)

144 HI detections with SDSS counterparts

Determination of HI Mass Function and $\Omega_{HI}$ requires completion corrections: to be done...
Relative H\textsubscript{I} gas mass fractions

- Abell 963 ($z=0.206$)
- Abell 2192 ($z=0.188$)
- UMa ($z=0$)
Stacking HI spectra (based on pilot data)

Average HI mass: $\sim 2 \times 10^9 M_\odot$
Conclusions

- Expected rms achieved with the WSRT
- HI emission from >150 individual galaxies at $Z \approx 0.2$
- Blind HI surveys uncover LSS not seen by SDSS
- Blue ‘BO-galaxies’ gas-poor wrt similar field galaxies
- $\Omega_{\text{HI}}$ and HI-based TF at $Z=0.2$ expected soon

The HI-universe at $Z \approx 0.2$ is under reach!