The HI gas content of galaxies around Abell 370, a galaxy cluster at $z = 0.37$

Philip Lah

International SKA Forum 2010
A New Golden Age for Radio Astronomy
Collaborators:

Frank Briggs (ANU)
Michael Pracy (Swinburne)
Jayaram Chengalur (NCRA)
Matthew Colless (AAO)
Roberto De Propris (CTIO)
Method:
Coadding the HI signals from distant galaxies using the galaxies’ known optical positions and redshifts
Giant Metrewave Radio Telescope

Anglo-Australian Telescope

India

Australia
Nearby Galaxy Clusters Are Deficient in HI Gas

The Coma Cluster
So why target moderate redshift clusters for HI gas?
The Butcher-Oemler Effect

Blue Fraction, $f_B$

Redshift, $z$
The Butcher-Oemler Effect

Blue Fraction, $f_B$

Redshift, $z$

- Butcher & Oemler (1984)
- Smail et al. (1998)
- Pimbblet et al. (2002)

Abell 370
Abell 370

a galaxy cluster at $z = 0.37$
Abell 370, a galaxy cluster at $z = 0.37$

large galaxy cluster of order same size as Coma
⇒ similar cluster velocity dispersion and X-ray gas temperature

GMRT $\sim$34 hours on cluster

optical imaging
ANU 40 inch telescope

spectroscopic follow-up with the AAT
324 useful redshifts from AAT observations
324 useful redshifts from AAT observations

GMRT sideband frequency limits
Abell 370 galaxy cluster

324 galaxies
105 blue
(B-V ≤ 0.57)
219 red
(B-V > 0.57)
Abell 370 galaxy cluster

- 3σ extent of X-ray gas
- $R_{200}$ radius at which cluster 200 times denser than the general field
Coadded HI Mass Measurements
The galaxies around Abell 370 are a mixture of *early* and *late* types in a *variety of environments.*
11 blue galaxies within intra-cluster hot x-ray gas appear HI deficient.
HI mass:
- 324 galaxies
- 219 galaxies
- 105 galaxies
- 94 galaxies
- 168 galaxies
- 156 galaxies
- 110 galaxies
- 214 galaxies
HI mass

324 galaxies

219 galaxies

105 galaxies

94 galaxies

156 galaxies

168 galaxies

110 galaxies

214 galaxies
HI Density Comparisons
Distribution of galaxies around Abell 370

- Complete GMRT redshift range
- Cluster redshift

**Graph:**
- Y-axis: Redshift
- X-axis: Distance From Cluster Centre (Mpc)
- Data points represent galaxies within the cluster and non-cluster regions.
- Cluster galaxies are indicated by red dots, while non-cluster galaxies are shown as blue triangles.
Abell 370 All
Abell 370 Blue
Abell 370 All (Ex)
Abell 370 Blue (Ex)
Cosmic $z \sim 0$
Cosmic $z = 0.24$
Cosmic $z \sim 0.6$

Whole Redshift Region
$z = 0.35$ to $0.39$
Distribution of galaxies around Abell 370
Distribution of galaxies around Abell 370

8 Mpc radius region

(cluster redshift)
Abell 370 All
Abell 370 Blue
Abell 370 All (Ex)
Abell 370 Blue (Ex)
Cosmic $z \sim 0$
Cosmic $z = 0.24$
Cosmic $z \sim 0.6$
Abell 370 All 8 Mpc
Abell 370 Blue 8 Mpc
Coma Cluster 8 Mpc

HI Density ($\log M_\odot \text{ Mpc}^{-3}$)

Whole Redshift Region $z = 0.35$ to 0.39
Outer Cluster Region
Distribution of galaxies around Abell 370
Distribution of galaxies around Abell 370 within $R_{200}$ region

- Cluster redshift
- Non-cluster 8 Mpc
HI Density \( (\log M_\odot \text{ Mpc}^{-3}) \)

- Abell 370 All
- Abell 370 Blue
- Abell 370 All (Ex)
- Abell 370 Blue (Ex)
- Cosmic \( z \sim 0 \)
- Cosmic \( z = 0.24 \)
- Cosmic \( z \sim 0.6 \)
- Abell 370 All 8 Mpc
- Abell 370 Blue 8 Mpc
- Coma Cluster 8 Mpc
- Abell 370 Inner
- Coma Cluster Inner
- Abell 1367 Inner
- Virgo Cluster Inner

Whole Redshift Region: \( z = 0.35 \) to \( 0.39 \)

Outer Cluster Region

Inner Cluster Region
HI Mass to Light Ratios
HI mass to optical $B$ band luminosity for Abell 370 galaxies
HI mass to optical $B$ band luminosity for Abell 370 galaxies

Uppsala General Catalog

Local Super Cluster

(Roberts & Haynes 1994)
Galaxy HI mass

vs

Star Formation Rate
Galaxy HI Mass vs Star Formation Rate

HIPASS & IRAS data $z \sim 0$

Doyle & Drinkwater 2006
HI Mass vs Star Formation Rate in Abell 370

all 168 [OII] emission galaxies

Average

Average HI Mass ($M_{\odot}$)

Average [OII] Star Formation Rate ($M_{\odot}$ yr$^{-1}$)

line from Doyle & Drinkwater 2006
HI Mass vs Star Formation Rate in Abell 370

81 blue [OII] emission galaxies

87 red [OII] emission galaxies

Average

line from Doyle & Drinkwater 2006
Star Formation Rate from $[\text{OII}]$ Emission and Radio Continuum Emission
Radio Continuum vs. [OII] Star Formation Rate

Average [OII] emission galaxies

all 168

line from
Bell 2003
Radio Continuum vs. [OII] Star Formation Rate

87 red [OII] emission galaxies

81 blue [OII] emission galaxies

line from Bell 2003
Conclusion
Conclusion

• Abell 370, a galaxy cluster at redshift $z = 0.37$ (~4 billion years ago) contains significantly more HI gas than observed in similar nearby clusters
Conclusion

• Abell 370, a galaxy cluster at redshift $z = 0.37$ (~4 billion years ago) contains significantly more HI gas than observed in similar nearby clusters

• however the galaxies in regions of higher density within Abell 370 have less gas than galaxies located in regions of lower density, the same trend seen in nearby galaxy clusters
Conclusion

• Abell 370, a galaxy cluster at redshift $z = 0.37$ (~4 billion years ago) contains significantly more HI gas than observed in similar nearby clusters.

• However, the galaxies in regions of higher density within Abell 370 have less gas than galaxies located in regions of lower density, the same trend seen in nearby galaxy clusters.

• Despite their high HI mass, the galaxies around Abell 370 appear normal; they have HI Mass to Light Ratio and a Star Formation Rate to HI Gas correlation similar to that seen in nearby galaxies.

Paper: Lah et al. 2009 MNRAS.399.1447L
Additional Slides
For the Future

The SKA pathfinders **ASKAP** and **MeerKAT** can measure the HI 21-cm emission from galaxies out to redshift $z = 1.0$ using the coadding technique with existing optical redshift surveys.
Colour – Mag Diagrams -all

All Galaxies
- [OIII] Emission
- Non [OIII] Emission
Colour – Mag Diagrams -inner

Within X-ray Gas

- [OII] Emission
- Non [OII] Emission
WFI selection
Abell 370 – R band images

10” sq

324 galaxies with useful redshifts (z~0.37)

Ordered by observed R band magnitudes
all Abell 370 galaxies neutral hydrogen gas measurement using 324 redshifts – large smoothing

\[ M_{\text{HI}} = (6.6 \pm 3.5) \times 10^9 \, M_\odot \]
HI Flux – All Galaxies
Blue galaxies outside of x-ray gas measurement of neutral hydrogen gas content

Using 94 redshifts – large smoothing

\[ M_{\text{HI}} = (23.0 \pm 7.7) \times 10^9 \, M_\odot \]
HI Flux – Blue Galaxies Outside X-ray Gas
## HI 21cm emission at $z > 0.1$

<table>
<thead>
<tr>
<th>Telescope</th>
<th>Redshift</th>
<th>Obs Time</th>
<th>Number and HI Mass of galaxies</th>
<th>Who and When</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSRT</td>
<td>$z = 0.18$ Abell 2218</td>
<td>200 hours</td>
<td>1 galaxy $4.8 \times 10^9 \text{M}_\odot$</td>
<td>Zwaan et al. 2001</td>
</tr>
<tr>
<td>VLA</td>
<td>$z = 0.19$ Abell 2192</td>
<td>~80 hours</td>
<td>1 galaxy $7.0 \times 10^9 \text{M}_\odot$</td>
<td>Verheijen et al. 2004</td>
</tr>
<tr>
<td>WSRT</td>
<td>two clusters at $z = 0.19$ &amp; $z = 0.21$</td>
<td>420 hours</td>
<td>42 galaxies $5 \times 10^9$ to $4 \times 10^{10} \text{M}_\odot$</td>
<td>Verheijen et al. 2007</td>
</tr>
<tr>
<td>Arecibo</td>
<td>$z = 0.17$ to 0.25</td>
<td>2 to 6 hours per galaxy</td>
<td>26 galaxies $(2$ to $6) \times 10^{10} \text{M}_\odot$</td>
<td>Catinella et al. 2007</td>
</tr>
</tbody>
</table>
Average HI Mass
Comparisons with Coma
Abell 370 and Coma Comparison

Average HI Mass (log $M_\odot$)

Abell 370 Inner

Coma Cluster Inner

110 galaxies
Abell 370 and Coma Comparison

Average HI Mass (log M$_\odot$)

Abell 370 Inner
Coma Cluster Inner
Abell 370 All
Coma Cluster All

110 galaxies
324 galaxies
Abell 370 and Coma Comparison

Average HI Mass (log M$_{\odot}$)

- Abell 370 Inner
- Coma Cluster Inner
- Abell 370 All
- Coma Cluster All
- Abell 370 Outer
- Coma Cluster Outer

110 galaxies
324 galaxies
214 galaxies
Why target moderate redshift clusters?

• the cluster core to the cluster outskirts are within the field of view of a radio telescope at moderate redshifts
Why target moderate redshift clusters?

- the cluster core to the cluster outskirts are within the field of view of a radio telescope at moderate redshifts

- the number density of galaxies around a cluster is significantly higher than a typical field pointing
Why target moderate redshift clusters?

• the cluster core to the cluster outskirts are within the field of view of a radio telescope at moderate redshifts

• the number density of galaxies around a cluster is significantly higher than a typical field pointing

• the Butcher-Oemler effect