X-RAYS FROM THE COSMIC WEB

THE (CURIOUS) CASE OF ABELL 133

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FILAMENTS IN THE COSMIC WEB
“We do not find any filament emission”
RETROSPECTIVE

10 YEARS AGO: EXPLOITING FORTUITOUS SIGHTLINES

Merger between Abell 222 / 223

Merging boosts temperature and density – enhanced visibility, but biased measure of “typical” conditions

Werner et al. 2008
Dietrich et al. 2012
<10 YEARS AGO: EXPLOITING FORTUITOUS SIGHTLINES

Alvarez et al. 2018
Tittley et al. 2001

Bulbul et al. 2016
The amount of substructure around A2744 is a challenge for $\Lambda$CDM

Schwinn et al. 2017
We can see the diffuse gas in filaments, but we need lucky sightlines. This means we have a biased, incomplete view of the cosmic web.
LOOKING AHEAD

0–5 YEARS FROM NOW: EROSITA


Letter to the Editor

Search for X-ray filaments between galaxy clusters

Ulrich G. Briel¹ and J. Patrick Henry¹² The eROSITA team

POOR ANGULAR RESOLUTION BUT CAN STACK THEIR WAY TO DETECTING FILAMENTS

“We do not find any filament emission”
LOOKING AHEAD

10 YEARS FROM NOW: AXIS (PROBE-CLASS MISSION)

Aim to capture twice a cluster’s virial radius

May be able to ride out along over densities of filaments

Mushotzky 2018
LOOKING AHEAD

10+ YEARS FROM NOW: ATHENA

100 ks X-IFU observation – 4 filaments in emission

About 1,000 serendipitous detections over 5 year mission

AthenaX Supporting Paper 4
Kaastra et al. 2013
LOOKING AHEAD

15+ YEARS FROM NOW: LYNX

Planned legacy survey:
10 Ms over 10 sq. deg
(depth of 100ks at all points)

Revolutionize our understanding of filaments

If this is visible at 100 ks depth, targeted cluster observations could provide further detections.
TODAY
2.4 Ms combined observation covering ~1 square degree.

Depth of at least 100 ks at all points

Abell 133 (z~0.055)
Connor et al. 2018, 2019c
Abell 133 (z~0.055)
Connor et al. 2018, 2019c
Abell 133 (z~0.055)
Connor et al. 2018, 2019c
Temperature: $2.0 \pm 0.3$ keV
Width: $S_x \sim (1 + r^2/r_c^2)^{-3 \times 0.67 - 0.5}$
with $r_c \approx 0.5 \text{Mpc}$
Density: $\rho_{g,0} \approx 1500 \, \Omega_b \, h^2 \, \rho_c$
Gas content: $M_g / M_{\text{tot}} \approx 0.2$

Vikhlinin et al. in prep
To see filaments, we need to be able to resolve clumps (background clusters?) and individual point sources.
But the X-ray sky is **full of virialized structures**

An independent check is needed to confirm that these are cosmic web filaments

- $0.0 < z < 0.5$
- $0.5 < z < 1.0$
- $1.0 < z < 1.4$
Over 3000 new and archival redshifts

Connor et al. 2018
Over 300 identified cluster members

Connor et al. 2018
LARGER SCALES

Connor et al. 2018
LARGER SCALES

Connor et al. 2018
LARGER SCALES
Over 3000 new and archival redshifts

Connor et al. 2018
Over 10000 new and archival redshifts

Connor et al. in prep
Complete survey of all r<20 mag galaxies in virial radius

Connor et al. in prep
CONDITIONS OF THE FILAMENT

Connor et al. 2019c
UNDER REVIEW
CONDITIONS OF THE FILAMENT

Connor et al. 2019c
UNDER REVIEW
No HI absorption detected at this position
All cold gas heated this close to cluster?
Is the cold gas just clumpy?

Table I. Constraints on Absorption Properties

<table>
<thead>
<tr>
<th>Species</th>
<th>Transition</th>
<th>(W_r^a) (mÅ)</th>
<th>(\log(N/cm^{-2})^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H I</td>
<td>1215</td>
<td>&lt;160</td>
<td>&lt;13.7</td>
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<tr>
<td>C II</td>
<td>1334</td>
<td>&lt;238</td>
<td>&lt;14.4</td>
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<tr>
<td>Ca II</td>
<td>3934</td>
<td>&lt;127</td>
<td>&lt;12.2</td>
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<tr>
<td>Si II</td>
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<td>&lt;13.4</td>
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<td>Si III</td>
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<td>&lt;153</td>
<td>&lt;13.1</td>
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<tr>
<td>Si IV</td>
<td>1393</td>
<td>&lt;231</td>
<td>&lt;13.7</td>
</tr>
</tbody>
</table>

\(^a\) All reported values are 2\(\sigma\) upper limits
\(^b\) Converted from the upper limit on \(W_r\) assuming \(b = 20 \text{ km s}^{-1}\).
SUMMARY

We are entering the era of observing filaments of the Cosmic Web in X-ray emission.

Abell 133 is the practice for this future.

Redshift surveys needed to match the gaseous and galaxy components of the filaments.

Abell 133

Filaments: 2 keV

Galaxies match X-rays

Large-scale structure mapping underway

Limits on cooler gas from COS absorption lines