Searching for high-redshift galaxy protoclusters using ALMA

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PRINCETON UNIVERSITY ASTROPHYSICS × CARDIFF UNIVERSITY PRIFYSGOL CAERDYĐ — School of Physics and Astronomy — Ysgol Ffiseg a Seryddiaeth
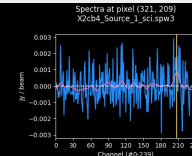
Summer 2023 Internship hosted by
Cardiff University School of Physics and Astronomy
Cardiff, Wales, UK

What is a protocluster?

Galaxy clusters are groups of galaxies that are **gravitationally stable** (the cluster does not expand or collapse). Galaxy **protoclusters** are groups of galaxies that **will** become stable.
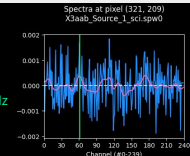
We call it a "cluster" if we have a 10^{14} $M_\odot$ massive collapsed core, and we call it a "protocluster" if there isn't such a massive core yet (Overzier 2016).

Fig. 1

Fig. 2

Why are high-redshift protoclusters so hard to detect?

Fig. 3

There are many methods to detecting protoclusters—Look for Inverse Compton Scattering (SZ effect), Ly-α tomographic maps, look for x-rays or in the infrared, but these **all fail at high-redshift.** Most known protoclusters lie around **z ~ 1.5–2**, as it becomes hard to find protoclusters at **z ~ 2 or 3**, and *incredibly difficult* to make large searches at **redshifts beyond 3**.

The galaxies in high-redshift protoclusters:
 - have the most massive halos at high redshift
 - were the first galaxies at high redshift to go from
 - played a crucial role during the epoch of reionization

Gas Cooling dominated by Cold Streams → Hot Intracluster Gas Regime

What I did / How I did it

Hubble Deep Field   SCUBA: 51 hours

H-ATLAS 16 hours

Fig. 4

My advisor had previously conducted a **wide, low-resolution** survey with over 500,000 candidates at **z ~ 4**, only one of which was suitable to **possibly** be a protocluster. He then asked ALMA to focus in on these six sources in the group to get high-resolution radio data for me to analyze.

Fig. 6

Discovery!

Spectra at pixel (321, 209)
X2cb4_Source_1_sci.spw3

Spectra at pixel (321, 209)
X3aab_Source_1_sci.spw0

Source 1: CO5-4 @ 112.36GHz, CO4-3 @ 89.89GHz
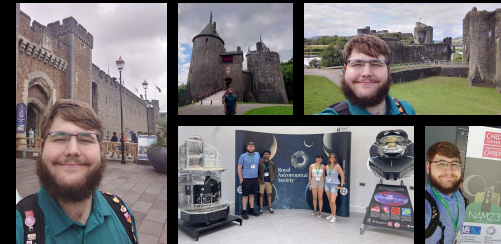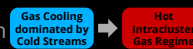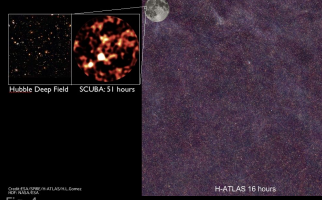z = 4.13

I wrote an algorithm to process, trim, and analyze the radio data (as it can often be **quite messy**). Here we are looking for CO emission lines, which would confirm that a galaxy in this group is part of a protocluster. I started with the brightest CO5-4 lines and looked for another CO4-3 line at the same position in the sky, and if I get a pair of CO lines, I know that a galaxy is confirmed to be in the protocluster, and I know its precise redshift.

Success! I was able to find a protocluster galaxy in 5 / 6 of the sources in the survey! This means that we have found a protocluster with galaxies at **z > 4!**

RADIO   ALMA BANDS
85GHz CO4-3   CO5-4 114GHz

My time in Wales

Cardiff is a wonderful place with the perfect blend of the calm, beautiful landscapes of Wales with the liveliness of a busy city in the UK! I loved every bit of my time here, and getting to meet a whole new astrophysics community and explore a new country I've never been to all while doing my dream job made for the summer of a lifetime. I've fallen in love with the UK, Wales, and the people here at Cardiff!

Me visiting Welsh castles Cardiff, Coch, and Caerphilly, as well as the other interns and me at the UK Royal Astronomical Society's National Astronomy Meeting (NAM), which was hosted here at Cardiff this year.

References and Thanks!

Special thanks to my advisors as well as all of the professors, grad students, and postdocs in the Cardiff Physics and Astronomy department for taking us in over the summer and making us feel like a welcome part of your community! Thanks to everyone on the IIP team, and to Princeton and Cardiff University for making this life-changing experience possible.

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Fig. 1, Fig. 2: https://www.sci.news/astronomy/two-massive-protoclusters-young-galaxies-early-universe-05948.html
Fig. 3: https://www.iac.es/en/outreach/news/astronomers-witness-birth-cluster-galaxies-early-universe
Fig. 4: https://herscheltelescope.org.uk/news/the-herschel-atlas/
Fig. 5: https://www.britannica.com/topic/Atacama-Large-Millimeter-Array
Fig. 6: https://www.eso.org/public/images/eso1342a/

Fig. 5