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ASTROPHYSICS

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CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

School of Physics and Astronomy
Ysgol Ffiseg a Seryddiaeth

Searching for high-redshift protoclusters using ALMA

by Xander Jenkin

advised by Professor Steve Eales

and Professor Matt Smith

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What is a protocluster?

Galaxy clusters are groups of galaxies that are **gravitationally stable** (the cluster does not expand or collapse)

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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)
https://arxiv.org/abs/1610.05201

*Image Credit: ESO/ALMA/Miller et al.
https://www.sci.news/astronomy/two-massive-proto clusters-young-galaxies-early-universe-05948.html

*Image Credit: ESO/M. Kornmesser
https://www.sci.news/astronomy/two-massive-proto clusters-young-galaxies-early-universe-05948.html

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There are many methods to detecting protoclusters:

- Look for Inverse Compton Scattering (SZ effect)
- Ly-α tomographic maps
- Look for x-rays
- Look in the infrared

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*Image Credit: ESA/Hubble & NASA, RELICS
https://www.nasa.gov/image-feature/goddard/2018/hubble-spies-glowing-galaxies-in-massive-cluster

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THESE DO NOT WORK WELL AT HIGH-REDSHIFT!

Why high-redshift protoclusters?

Most known protoclusters lie around z ~ 1.5–2. **High-redshift** protoclusters are **even harder** to detect.

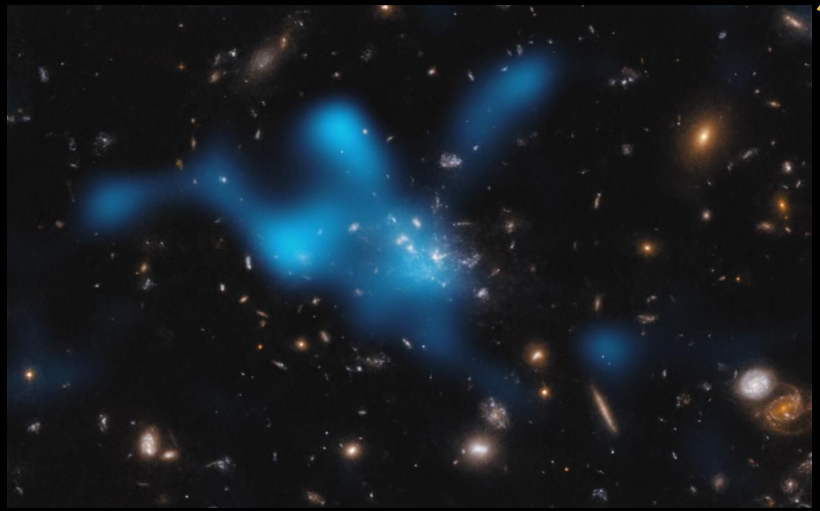

*Image Credit: ESO/ALMA/Di Mascolo et al. https://www.iac.es/en/outreach/news/astronomers-witness-birth-cluster-galaxies-early-universe

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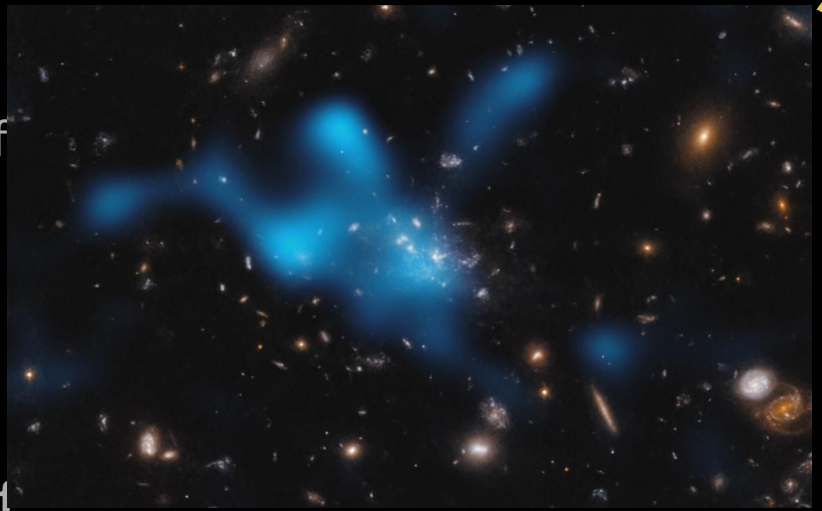
- The **most massive halos** at high redshif
- The **first** galaxies at high redshift to

Gas Cooling dominated by Cold Streams → Hot Intracluster Gas Regime

- Played a crucial role during the **epoch of reionization**



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(Overzier 2016)

What my professors did

Conducted a **wide, low-resolution survey** of data from **Herschel** searching through over **500,000** high-redshift candidates (z ~ 4) for protoclusters looking for hot x-ray emitting gas that were grouped but hadn't clustered.

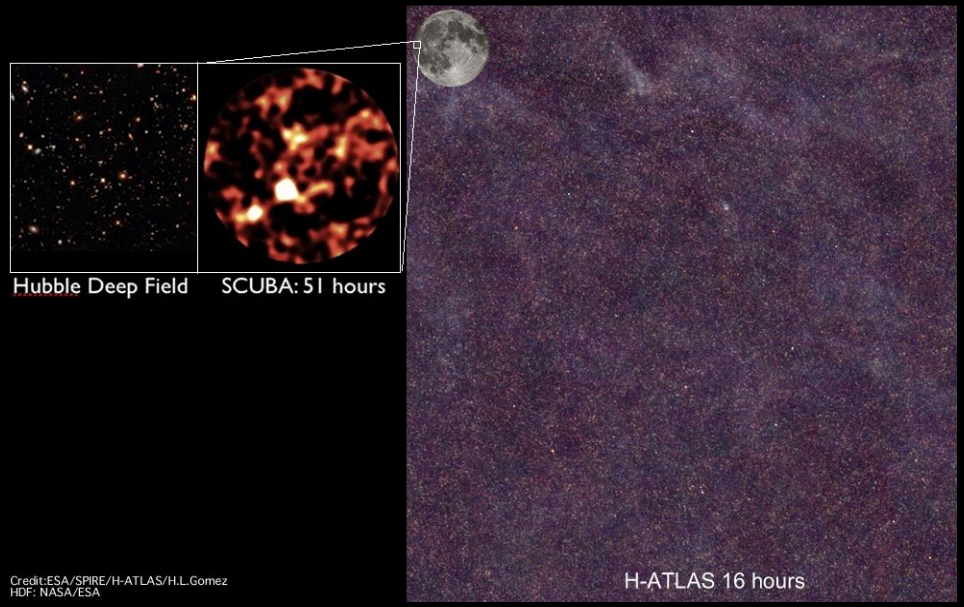

*Image Credit: ESA/SPIRE/H-ATLAS/H.L. Gomez
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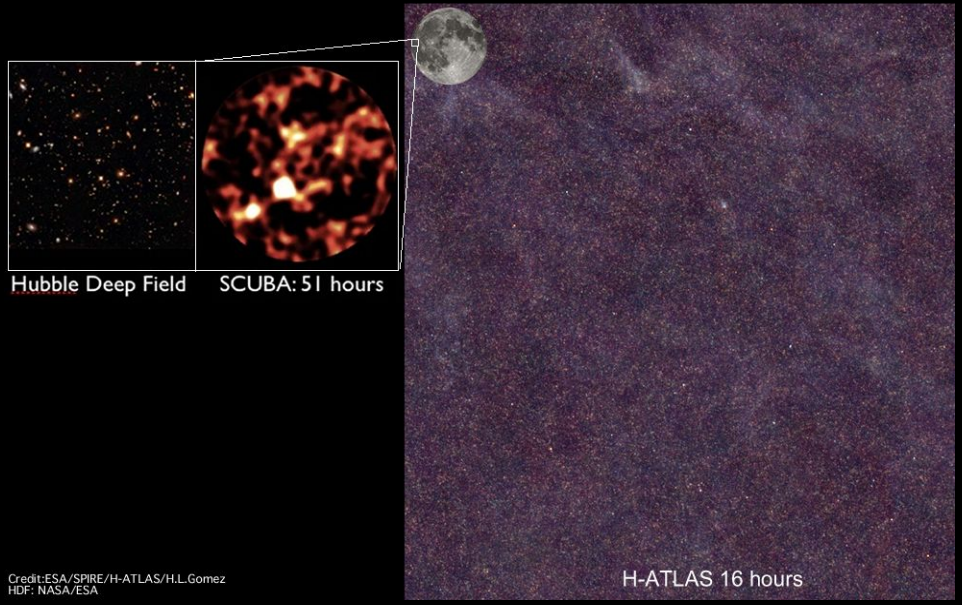
Only **one possible group** of galaxies was identified…



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https://herscheltelescope.org.uk/news/the-herschel-atlas/

What my professors did

Asked **ALMA** to focus on these **six radio galaxies** in the possible protocluster to get **high-resolution** data.

*Image Credit: ESO/ALMA
https://www.britannica.com/topic/Atacama-Large-Millimeter-Array

Where I come in

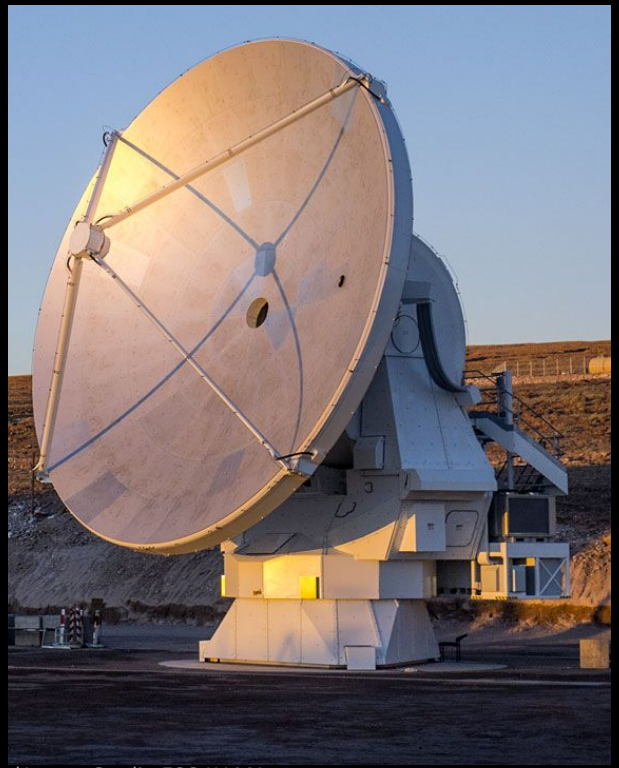

*Image Credit: ESO/ALMA
https://www.eso.org/public/images/eso1342a/

I went through ALMA data for each of these six sources looking for **Carbon Monoxide** lines

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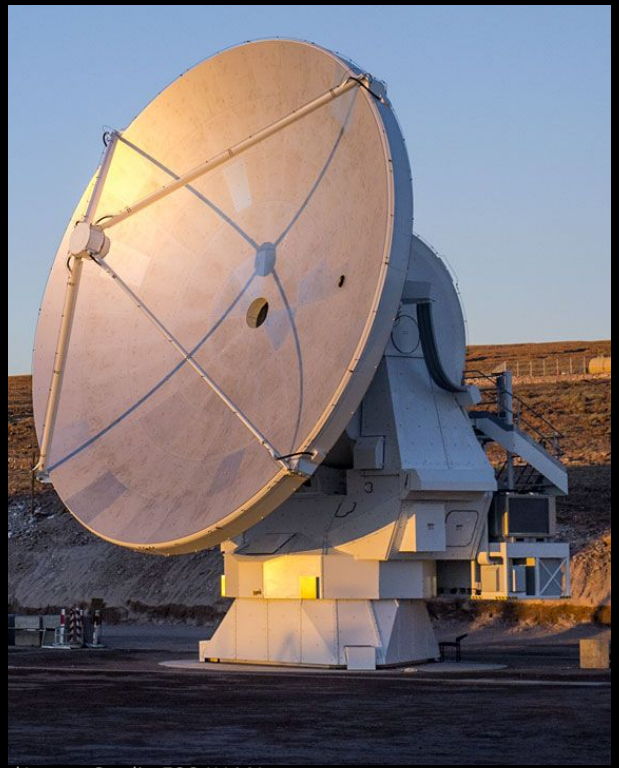

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This is all redshifted, so I need to find a **pair** of lines to **confirm** what they are

Where I come in

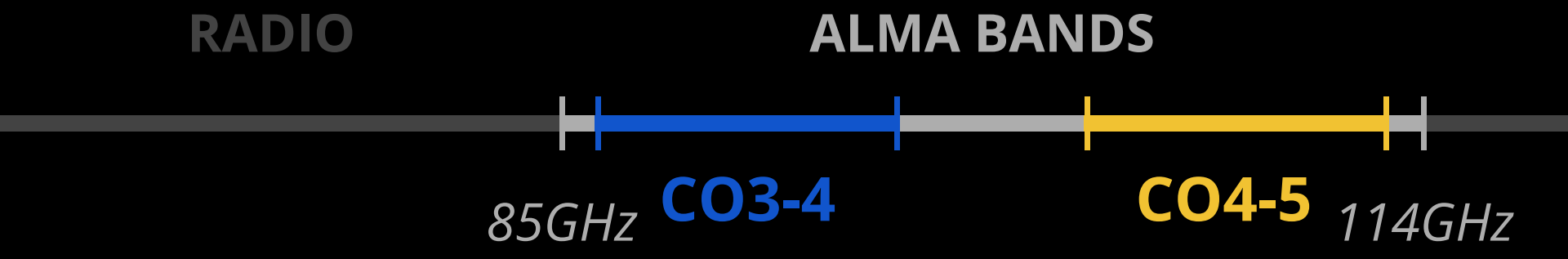
RADIO

ALMA BANDS

85GHz *114GHz*

*Image Credit: NAOJ/ALMA
https://www.nao.ac.jp/en/research/telescope/alma.html

Where I come in



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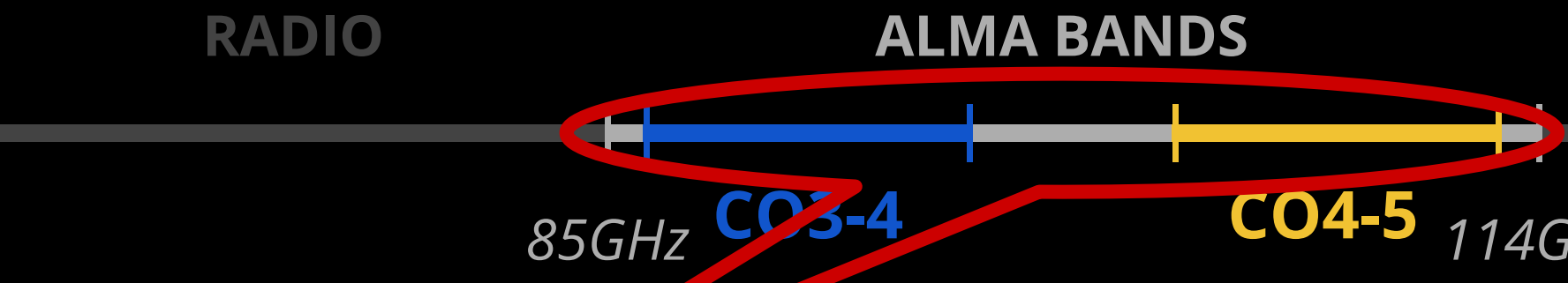

4.055 < z < 4.436

*Image Credit: NAOJ/ALMA
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My Methods

Radio data can be a quite **messy,** so I need to clean it up a bit.

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I then took the **brightest CO4-5** lines and tried to find **dimmer, matching CO3-4** lines at the same RA and Dec (order is arbitrary).

My Results

5/6 Sources Confirmed!

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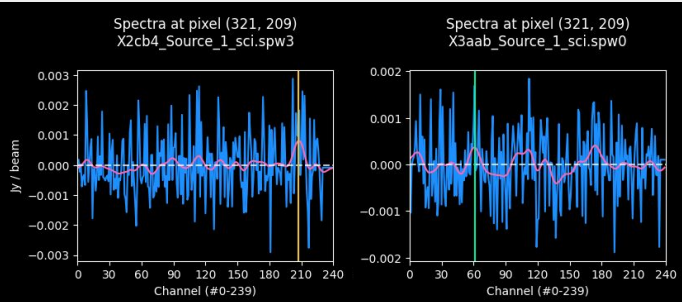

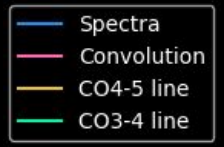

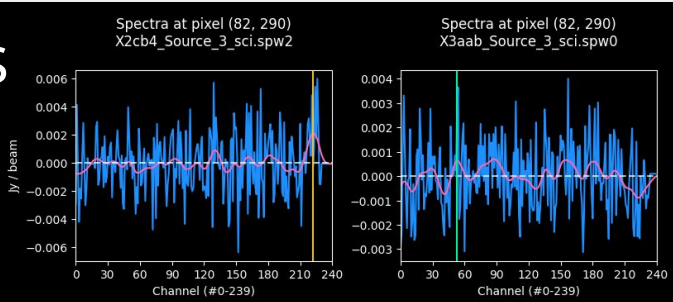

Source 1: CO4-5 @ 112.36GHz, CO3-4 @ 89.89GHz
z = 4.13

Source 3: CO4-5 @ 112.46GHz, CO3-4 @ 89.97GHz
z = 4.12

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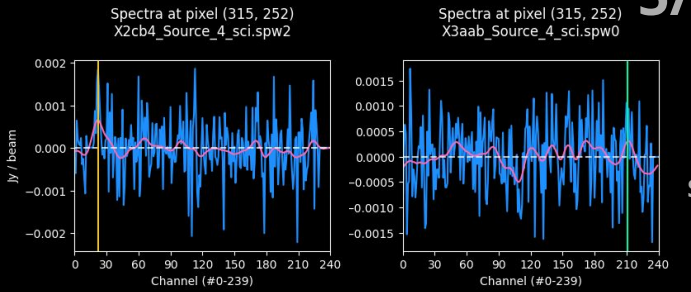
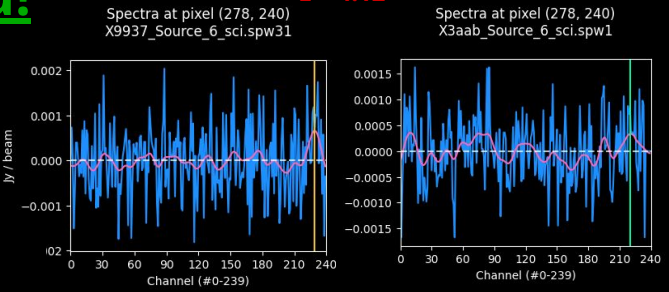
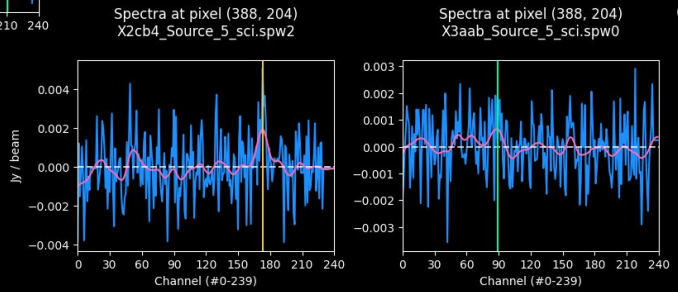




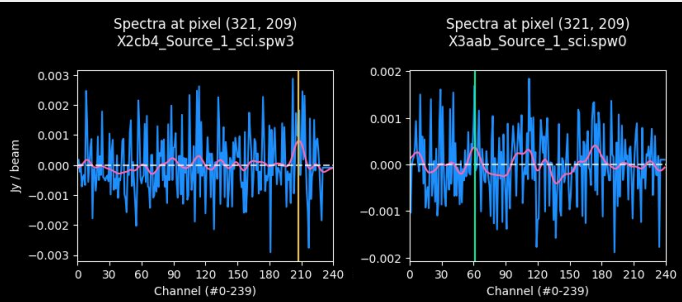
Source 5: CO4-5 @ 112.09GHz, CO3-4 @ 89.68GHz
z = 4.14

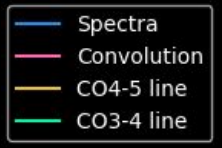


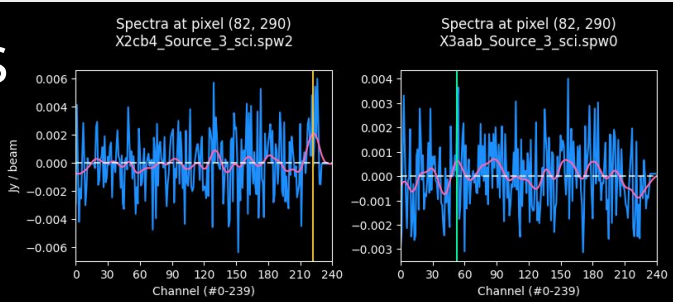
Source 4: CO4-5 @ 110.91GHz, CO3-4 @ 88.73GHz
z = 4.20

Source 6: CO4-5 @ 110.82GHz, CO3-4 @ 88.66GHz
z = 4.20

My Results







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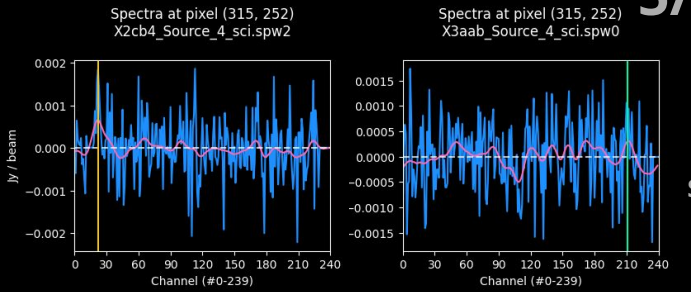

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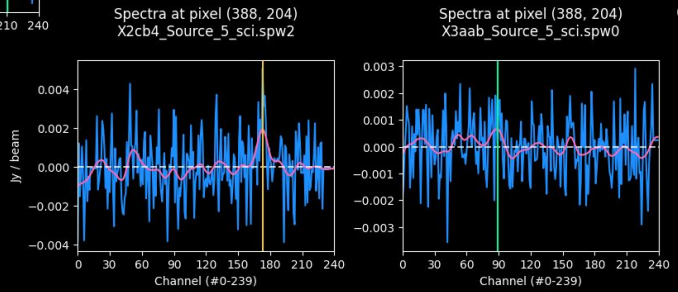

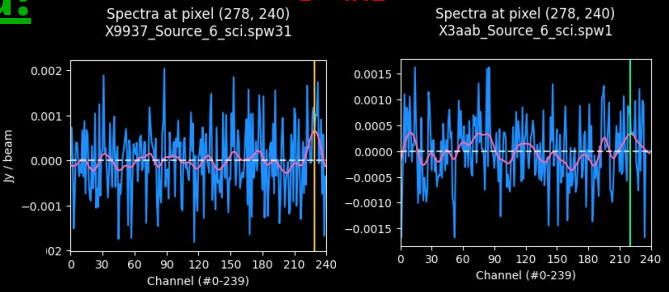

Source 6: CO4-5 @ 110.82GHz, CO3-4 @ 88.66GHz
z = 4.20

Source 2 is still unconfirmed...

Future Research

Closely examine **Source 2** to see if it is **truly not** in this protocluster

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Use my algorithm to look at **other protoclusters** of radio galaxies

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*Image Credit: Hubble/Ron Miller
https://www.scientificamerican.com/article/ancient-galaxy-clusters-offer-clues-about-the-early-universe/

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Do **more radio work** in general! I've never done radio astronomy before and am very new to all of this but quite enjoyed it, so I'll **certainly** be doing future projects **in radio!**

*Image Credit: ESO/D. Schreiner and S. Degezelle https://www.eso.org/public/images/img_1541/

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Thank you all for hosting me this summer! :)

Cheers,
Xander Jenkin

xanderjenkin@princeton.edu

Bonus Information Reference (Just in case):

6 Sources, each with 20 files, each file is 500x500 pixels, giving ~3,000 pixels with spectras (varies per file), giving a total of ~360,000 spectra to parse through, though the code deals with most of this for me!

Each pixel spans 0.01547 arcseconds^2 on the sky

Each spectra has 240 Ch's, Ch width is 0.008GHz

Source 1: CO4-5: 4.21 * sigma; CO3-4: 2.38 * sigma
Source 3: CO4-5: 4.06 * sigma; CO3-4: 1.82 * sigma
Source 4: CO4-5: 4.07 * sigma; CO3-4: 1.81 * sigma
Source 5: CO4-5: 4.17 * sigma; CO3-4: 2.67 * sigma
Source 6: CO4-5: 4.53 * sigma; CO3-4: 1.93 * sigma

S1: 21x CO3-4's, 42x Spectra
S2: 72x CO3-4's, 144x Spectra
S3: 1x CO3-4's, 2x Spectra
S4: 33x CO3-4's, 66x Spectra
S5: 35x CO3-4's, 70x Spectra
S6: 11x CO3-4's, 22x Spectra

Avg (Found): 40x

346x Total Spectra :)