Investigating noise patterns in the JWST/MIRI detector

A signal processing analysis using FFTs and clustering

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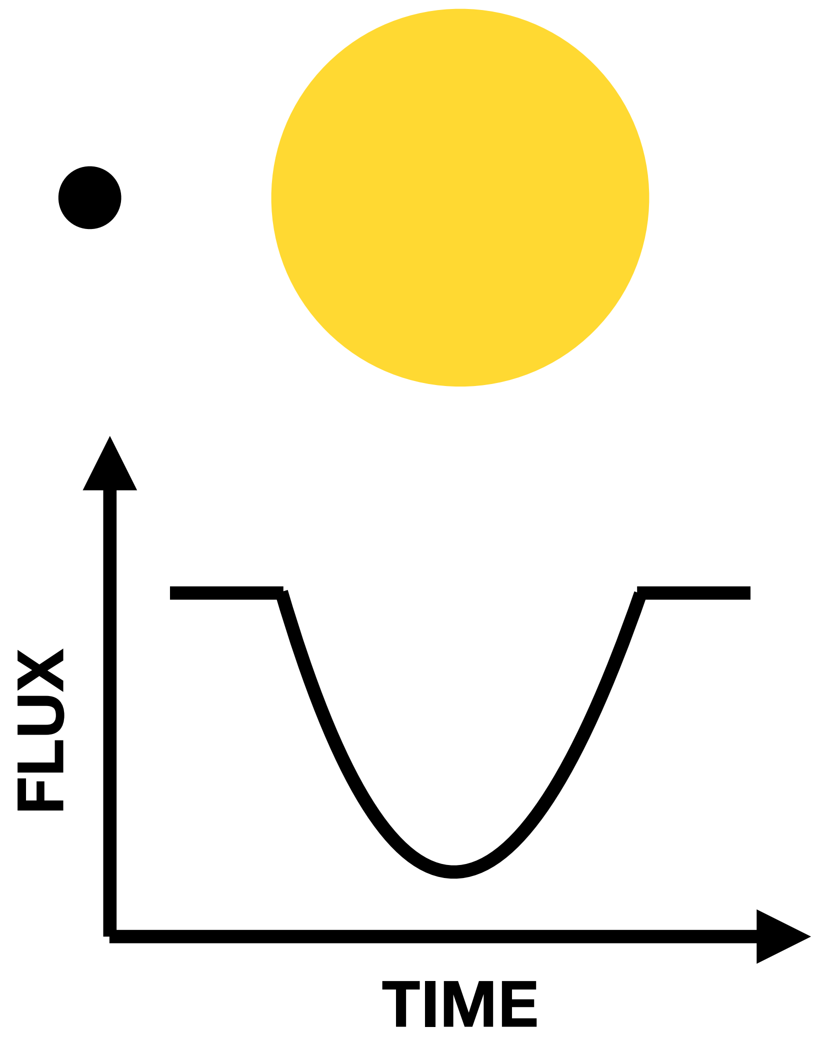
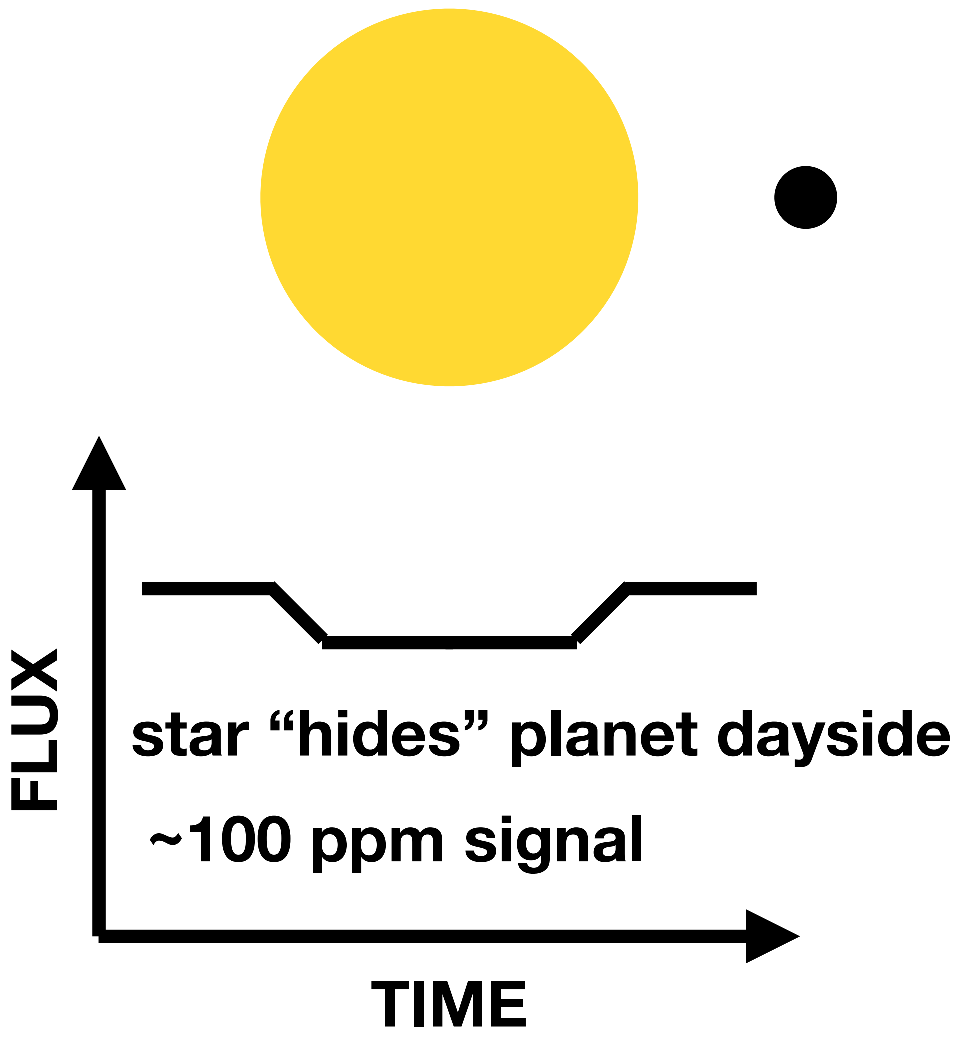
Outline

- **Introduction** : Exoplanets, JWST and the MIRI detector
- **Data** : From images to pixel time-series
- **Method** : Frequency analysis and clustering
- **Results I & II** : MIRI is great, pixels can be funky
- **Conclusions**

Introduction

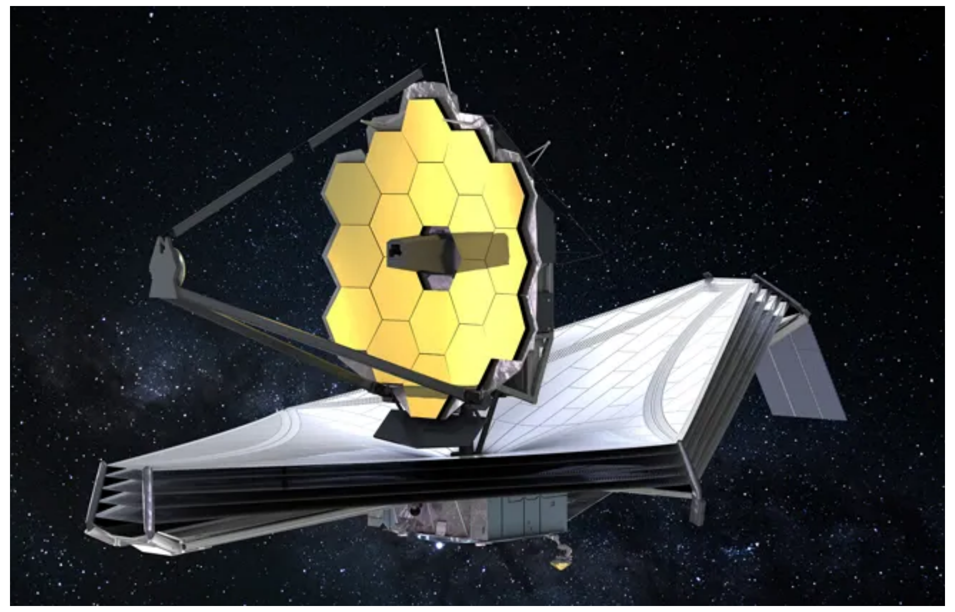
Exoplanets, JWST and MIRI





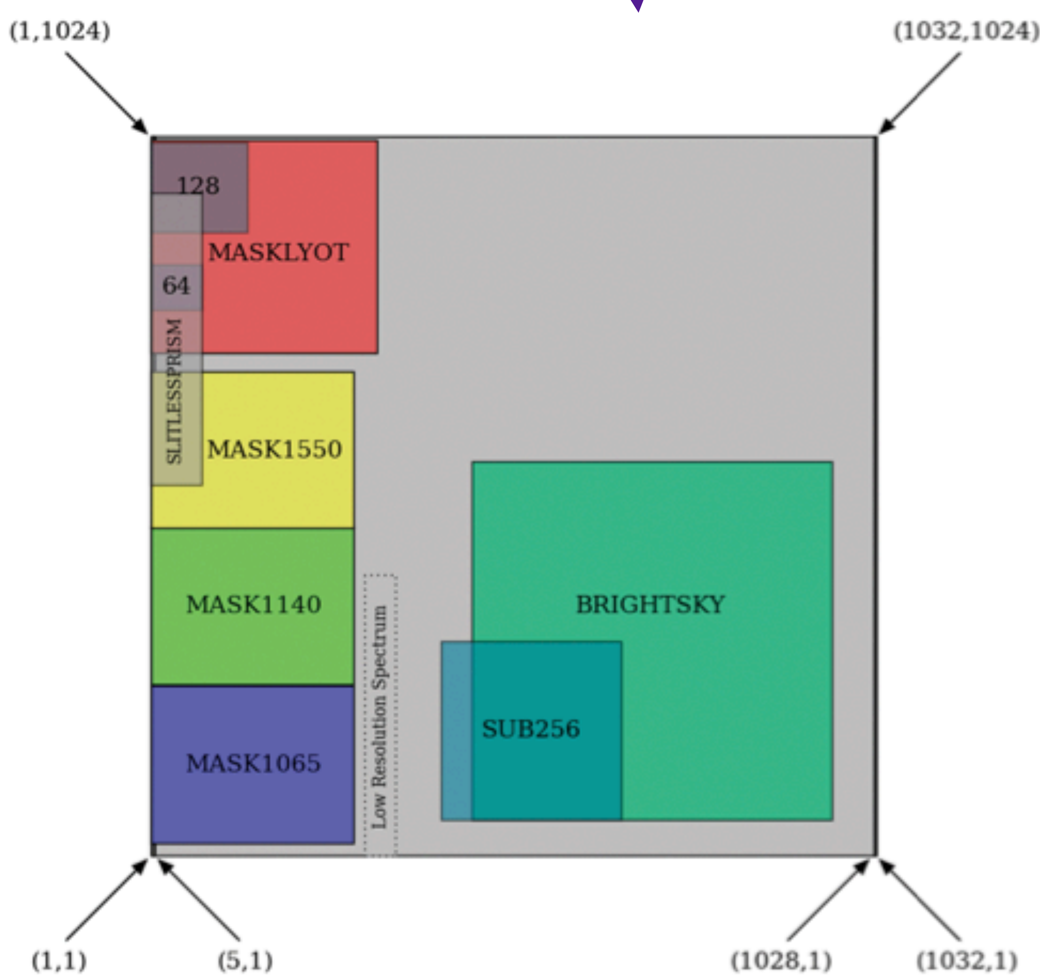
Are there noise/systematics ***patterns across the detector*** *I can identify (and perhaps remove) beforehand?*

star (point source)



JWST

MIRI detector & subarrays

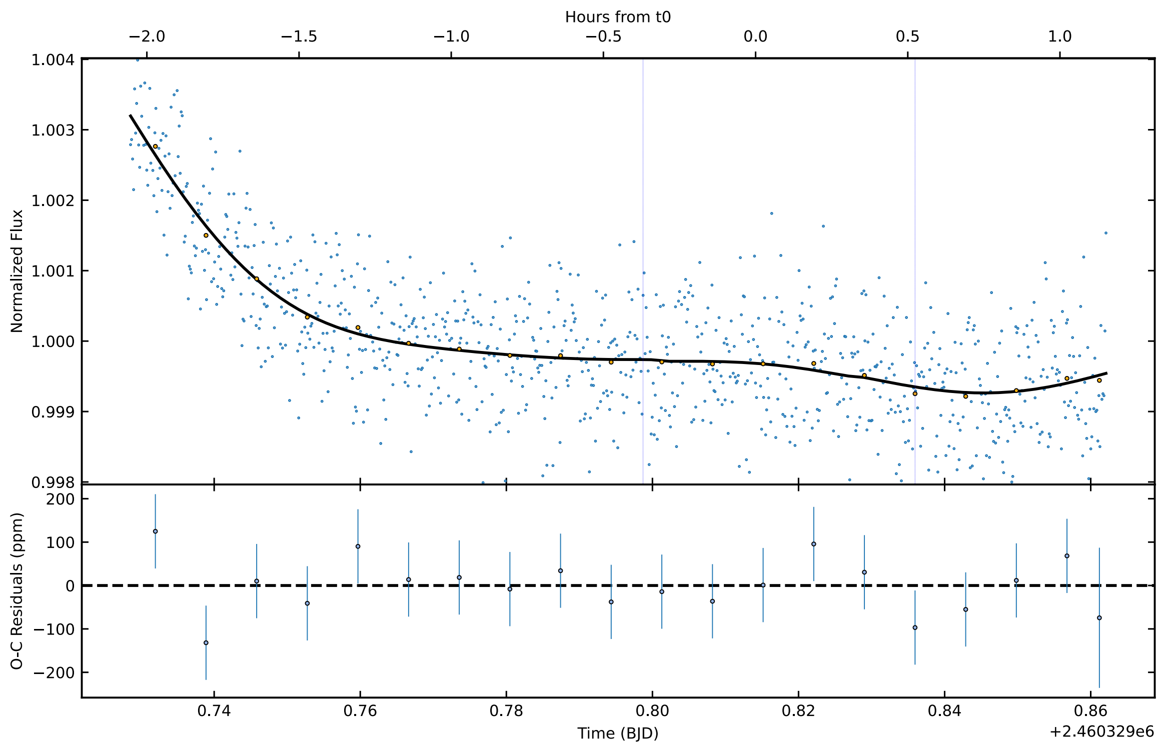


NEW INSTRUMENTS

not much experience yet

lots of image/data processing…

light-curve

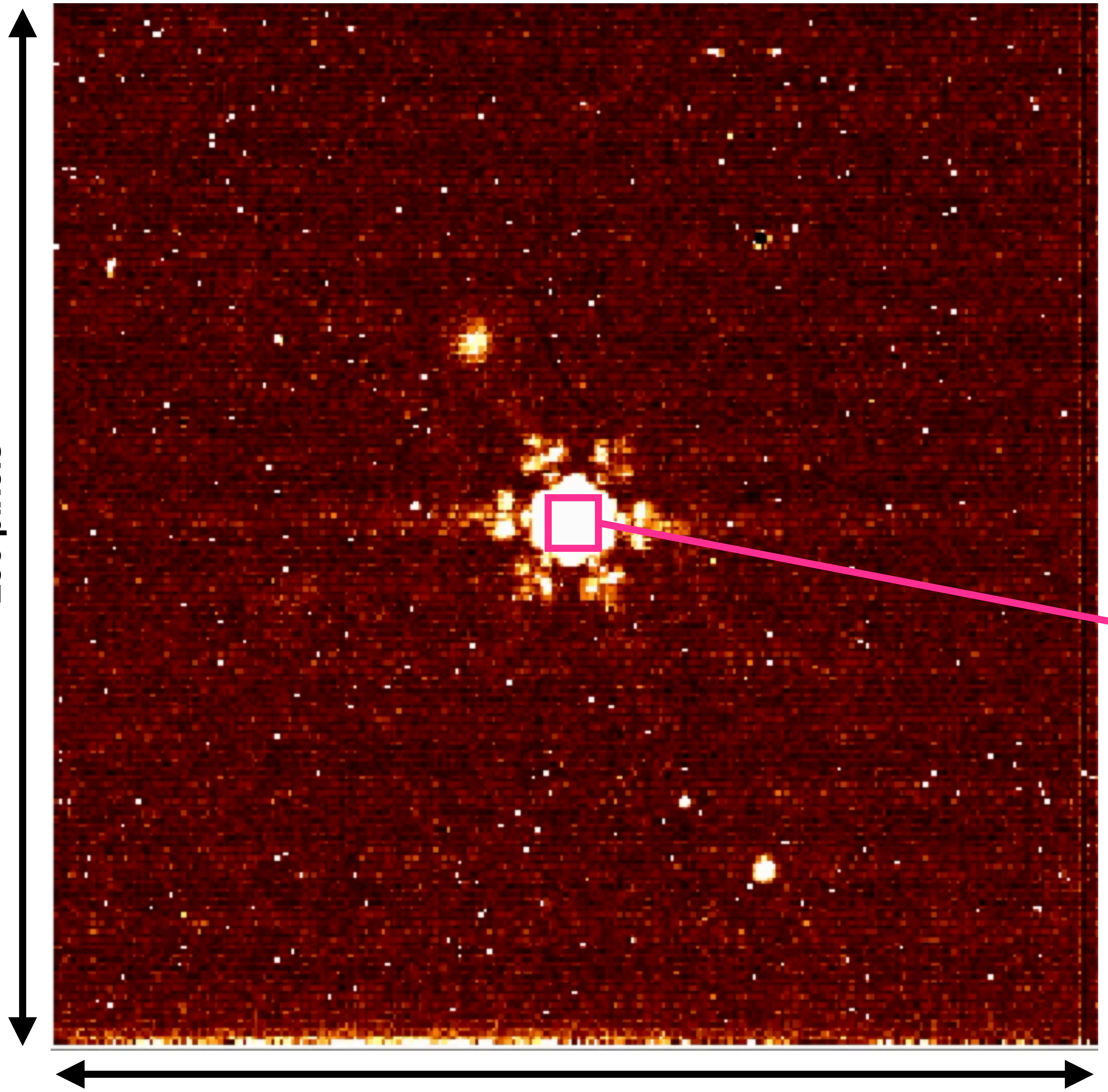


modeling, …

scientific interpretation

The data

From images to pixel time-series



Main ideas:

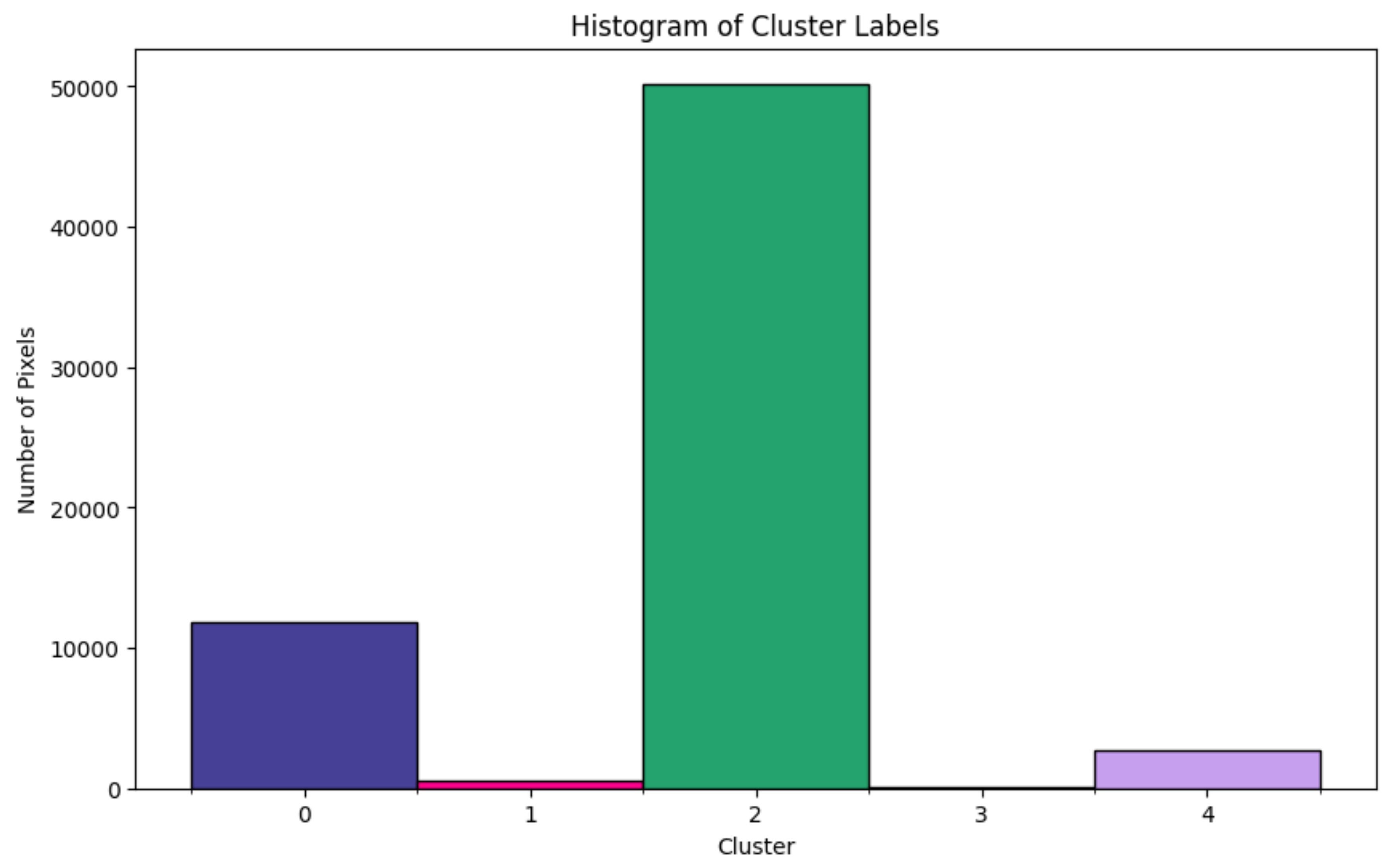
- Cluster pixels to find **patterns**
- **Signal processing** inspired approach
- Passage to **Fourier space** + normalised power spectra + freqs > 0

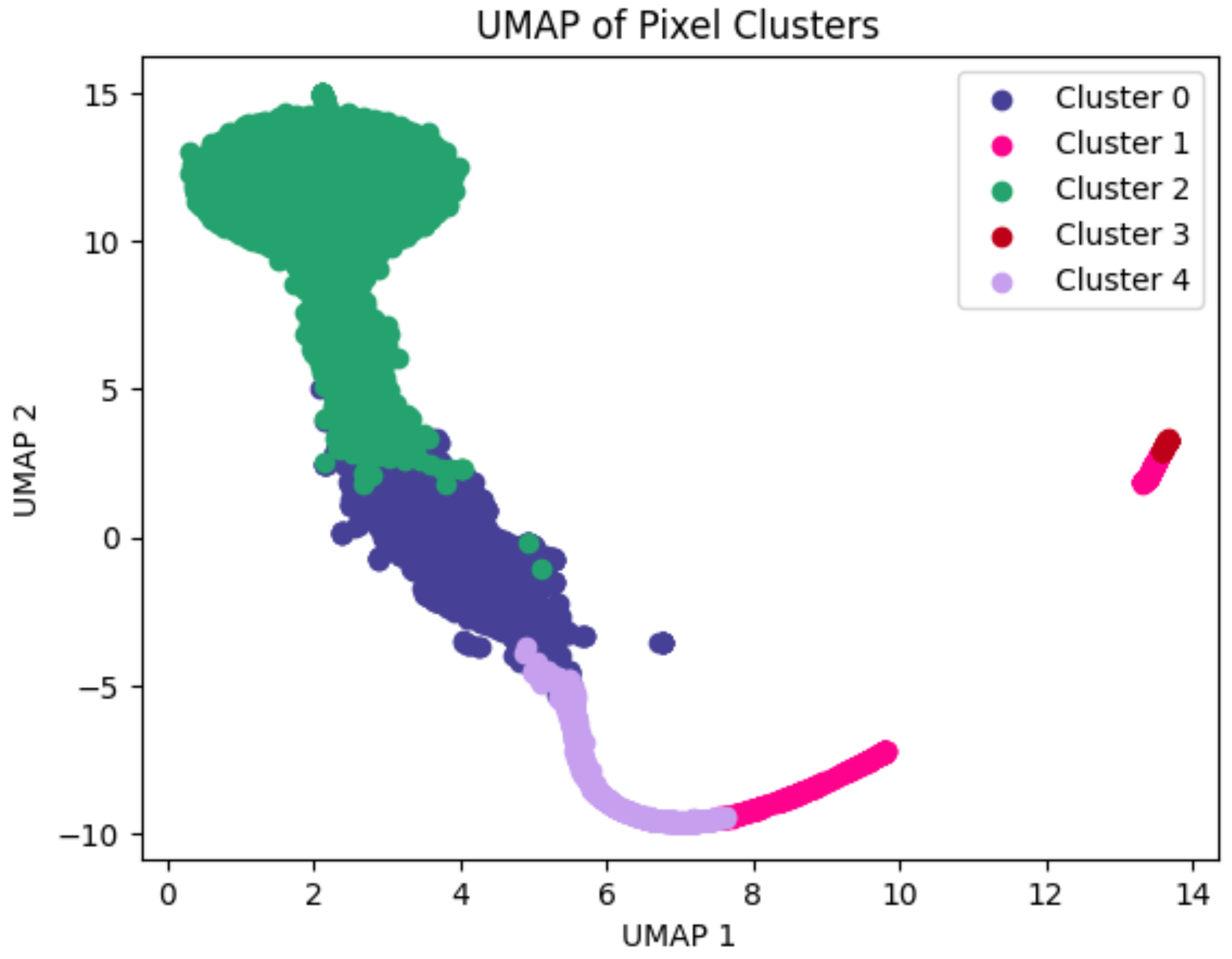
First attempt(s)

Example with 5 clusters

- Tried different **algorithms, n. clusters, hyper-parameters**
- KMeans seemed to work best, but very **unbalanced clusters**
- UMAP & PCA : bit of **structure**, but **no obvious "blobs"**

What does this look like spatially/on the detector?

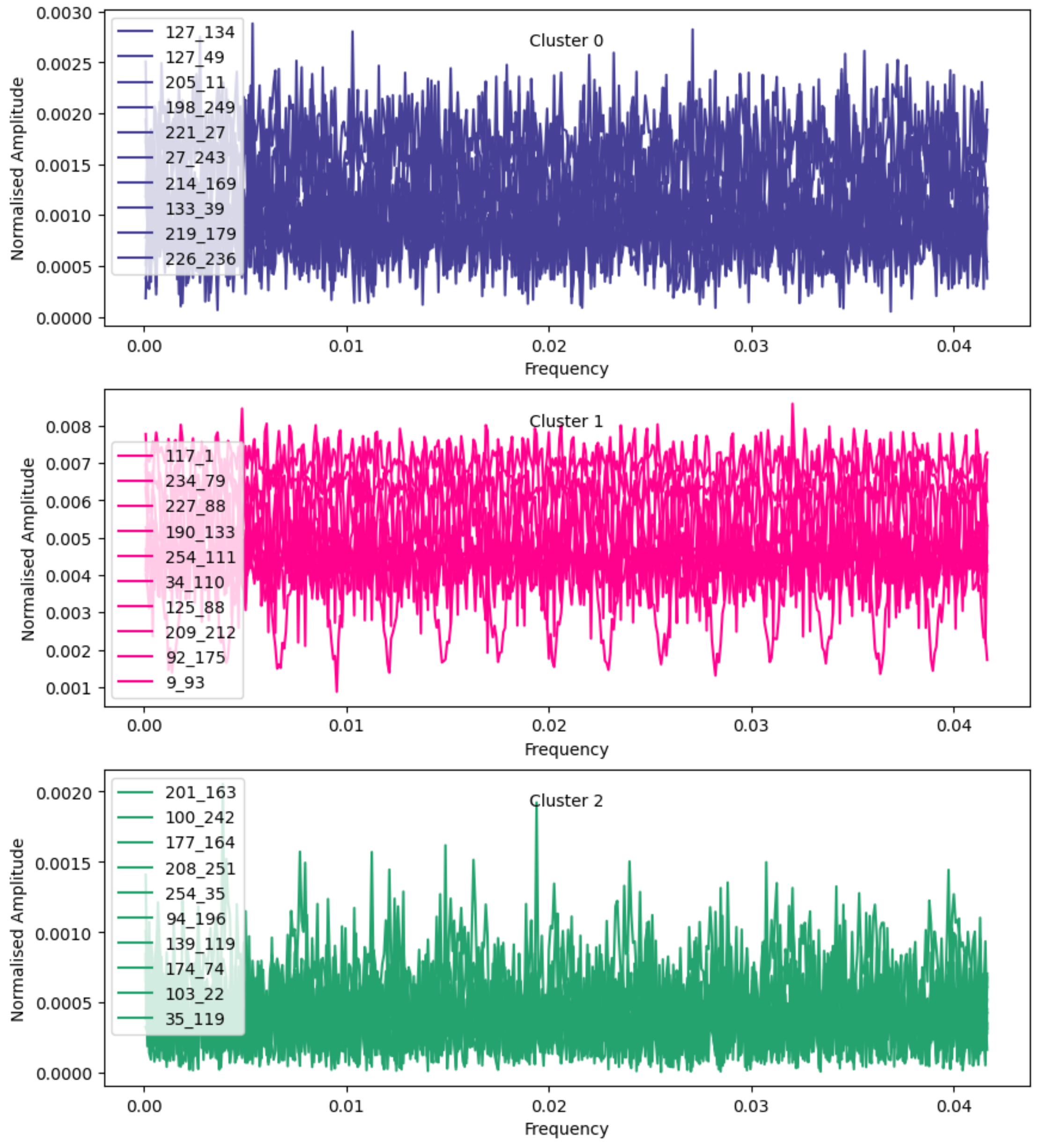




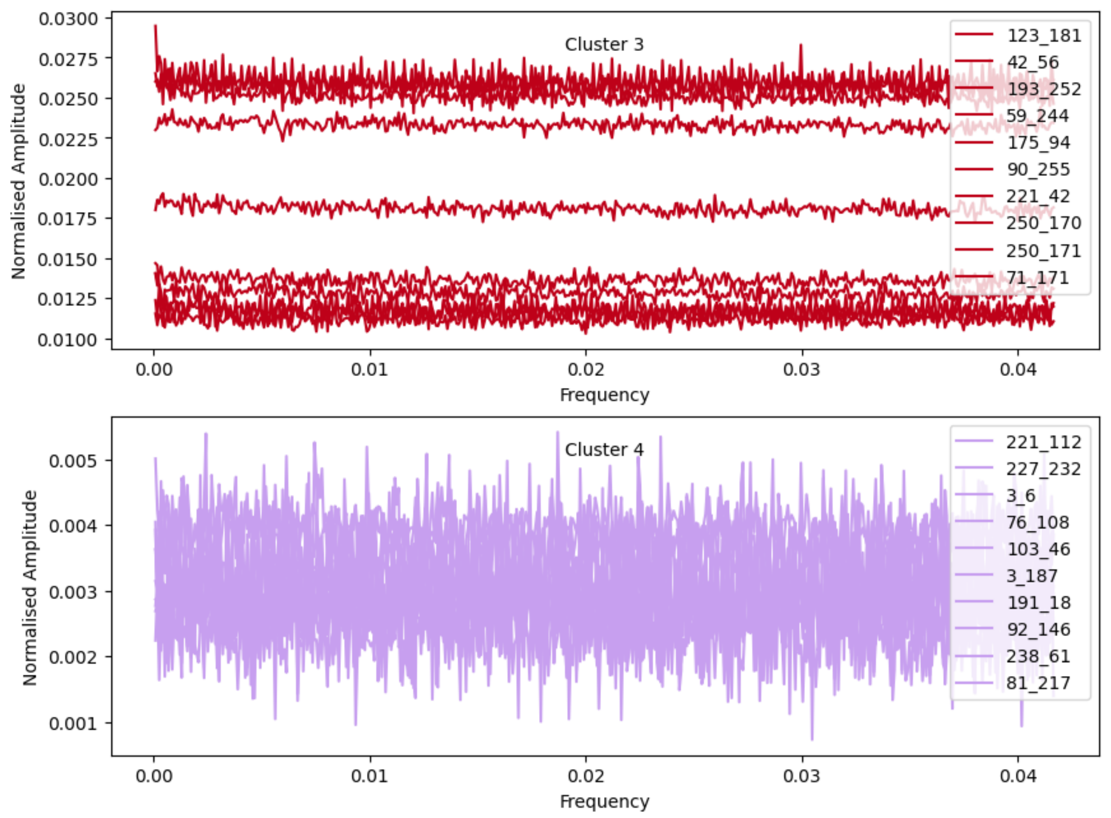
First attempt(s)

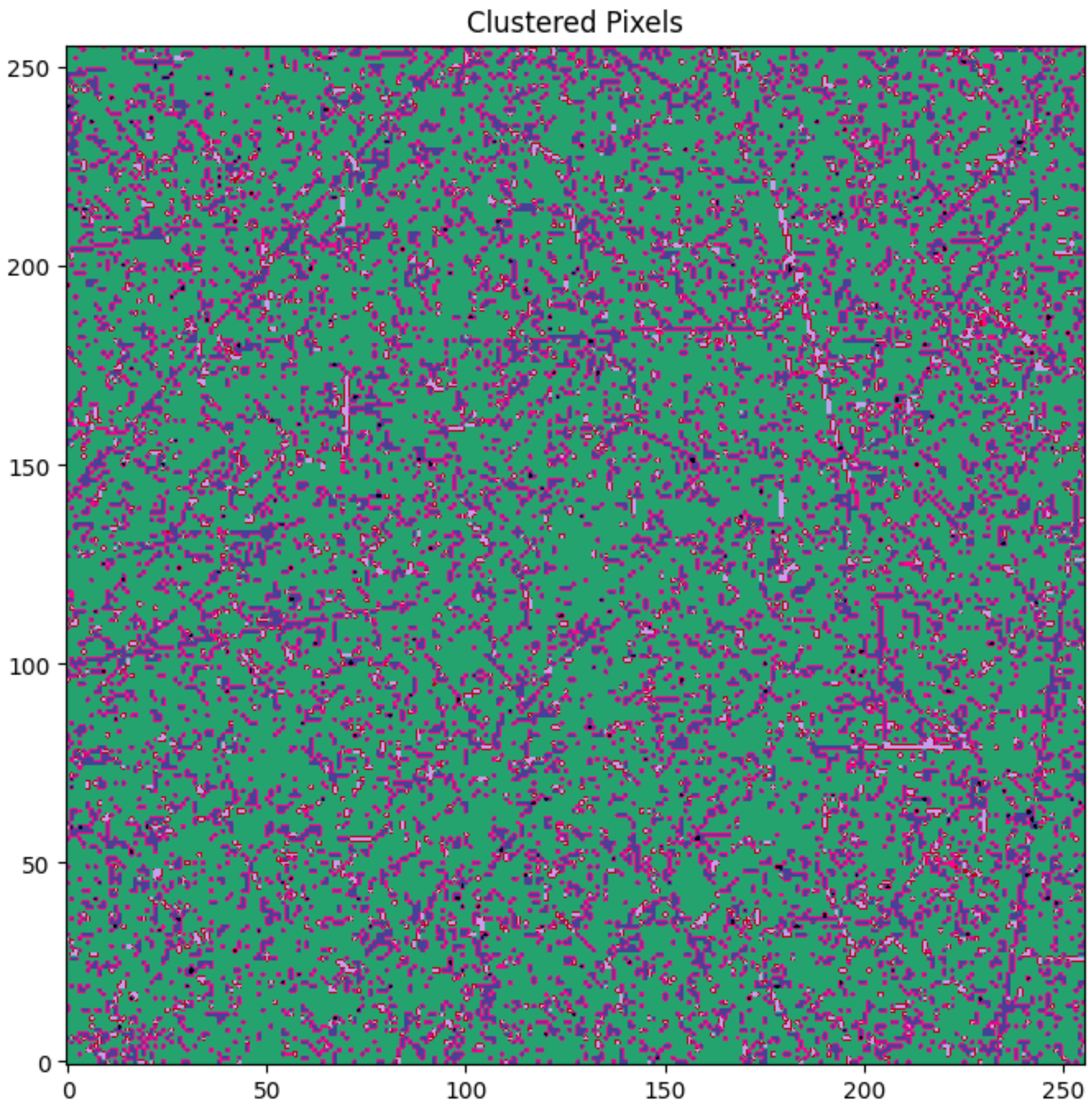
5 clusters

What does this look like spatially/on the detector?



10 random draws of FFTs per cluster



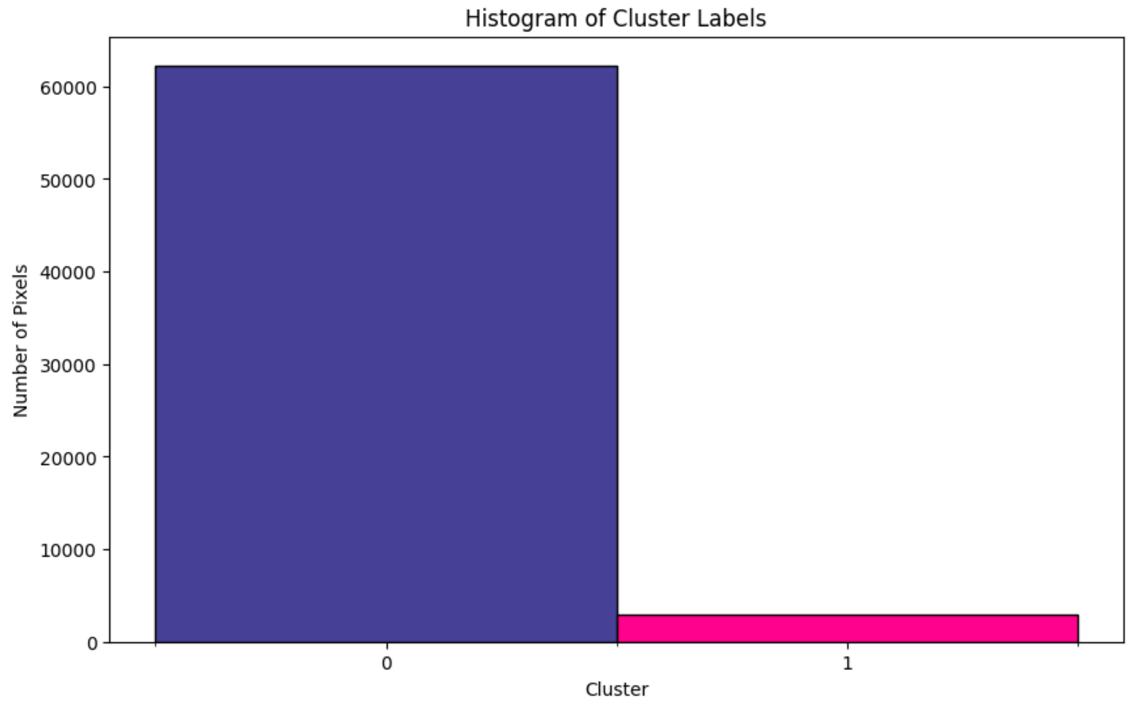


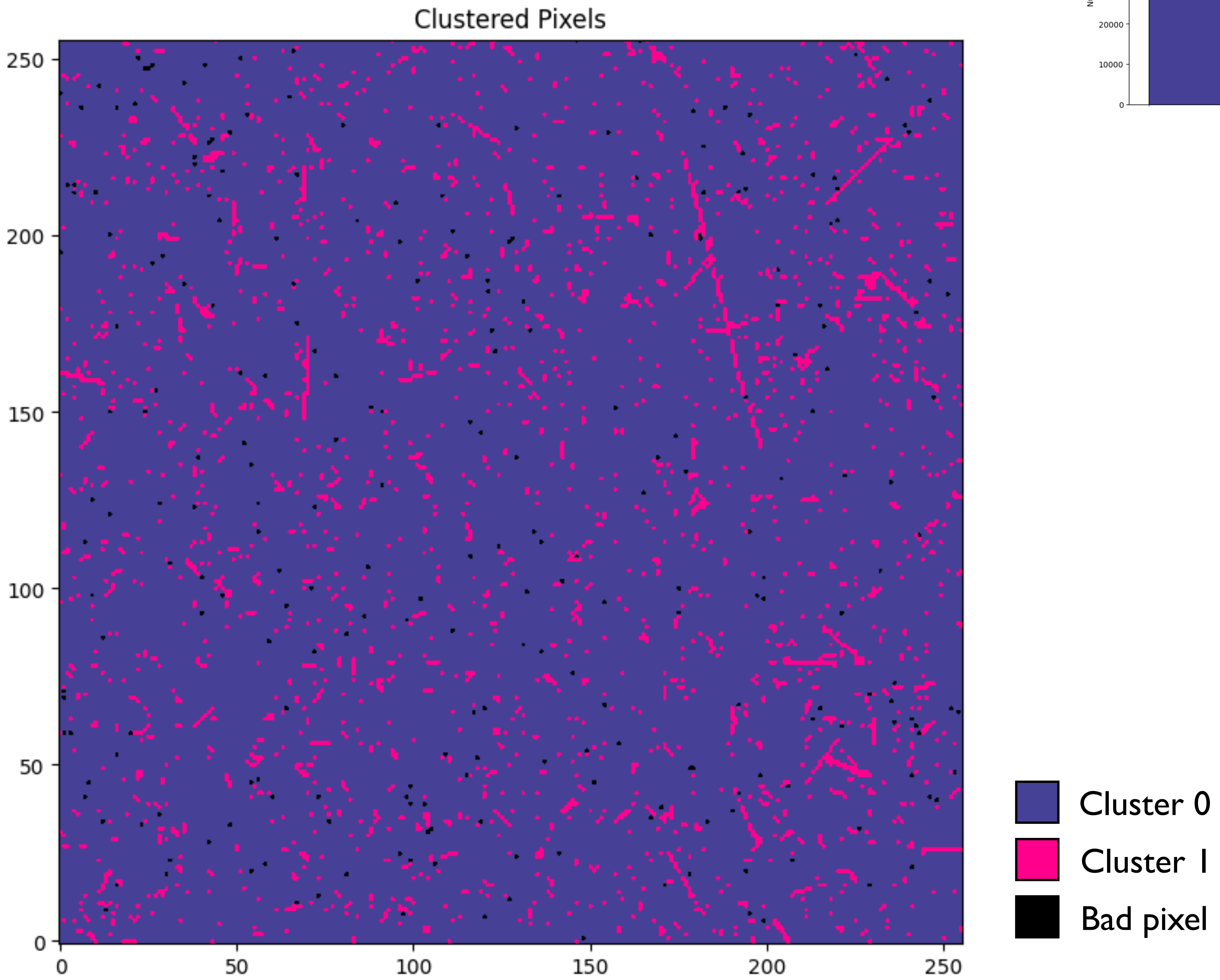
MIRI seems to work pretty well.

(which is reassuring for a $10 billion project)

2 clusters

Quick look

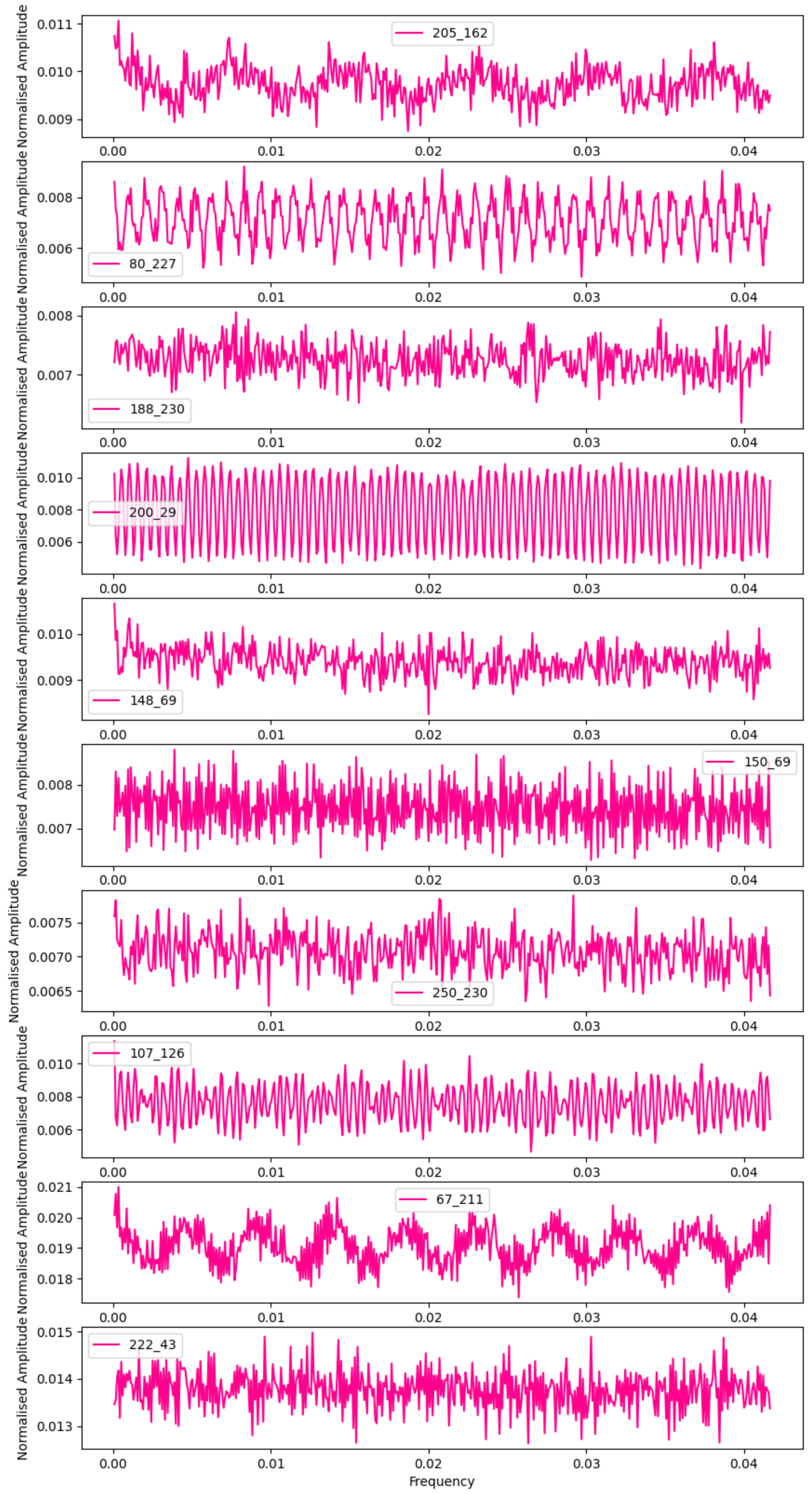


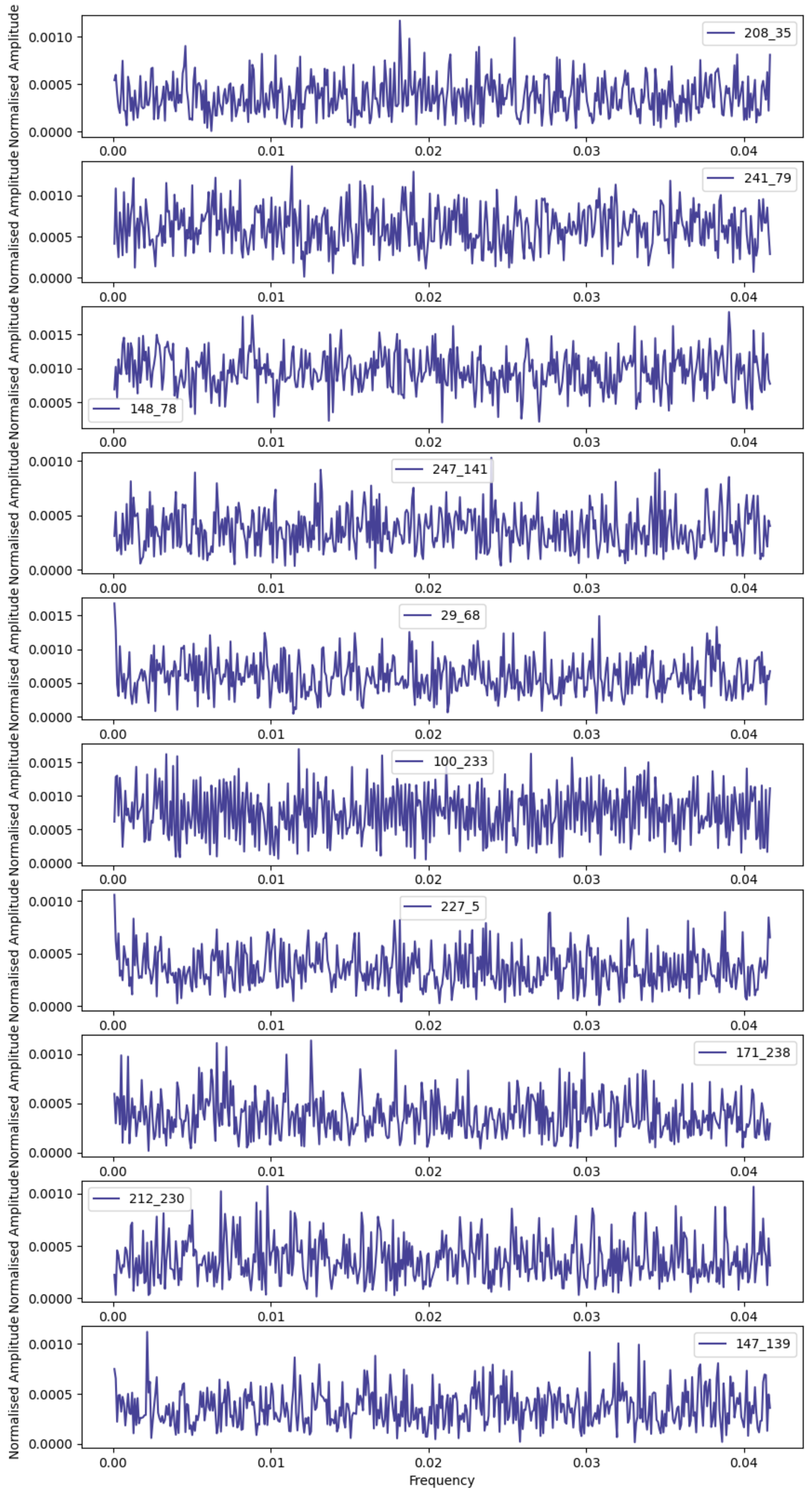


FFTs

2 clusters

More random?
Smaller amplitudes?

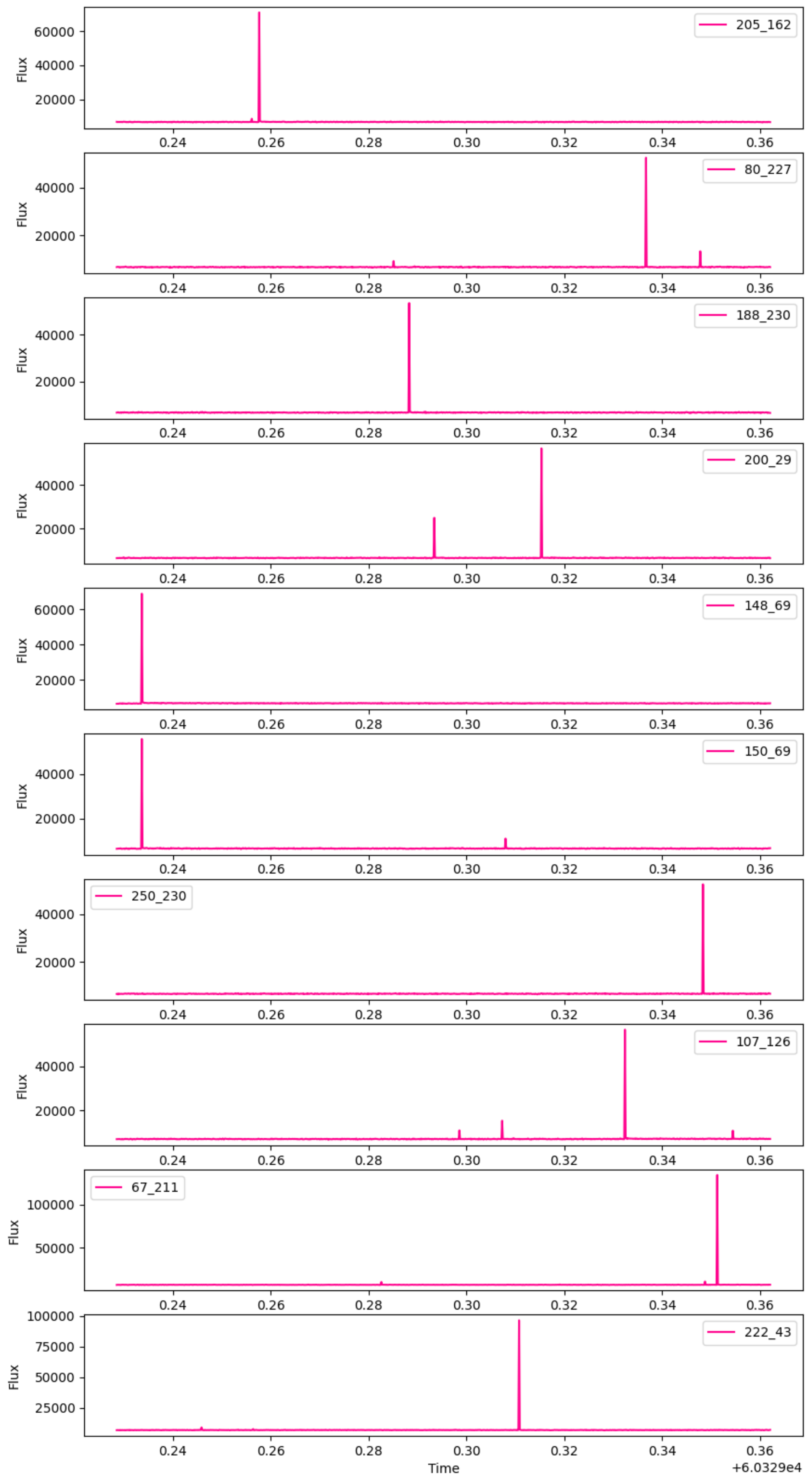




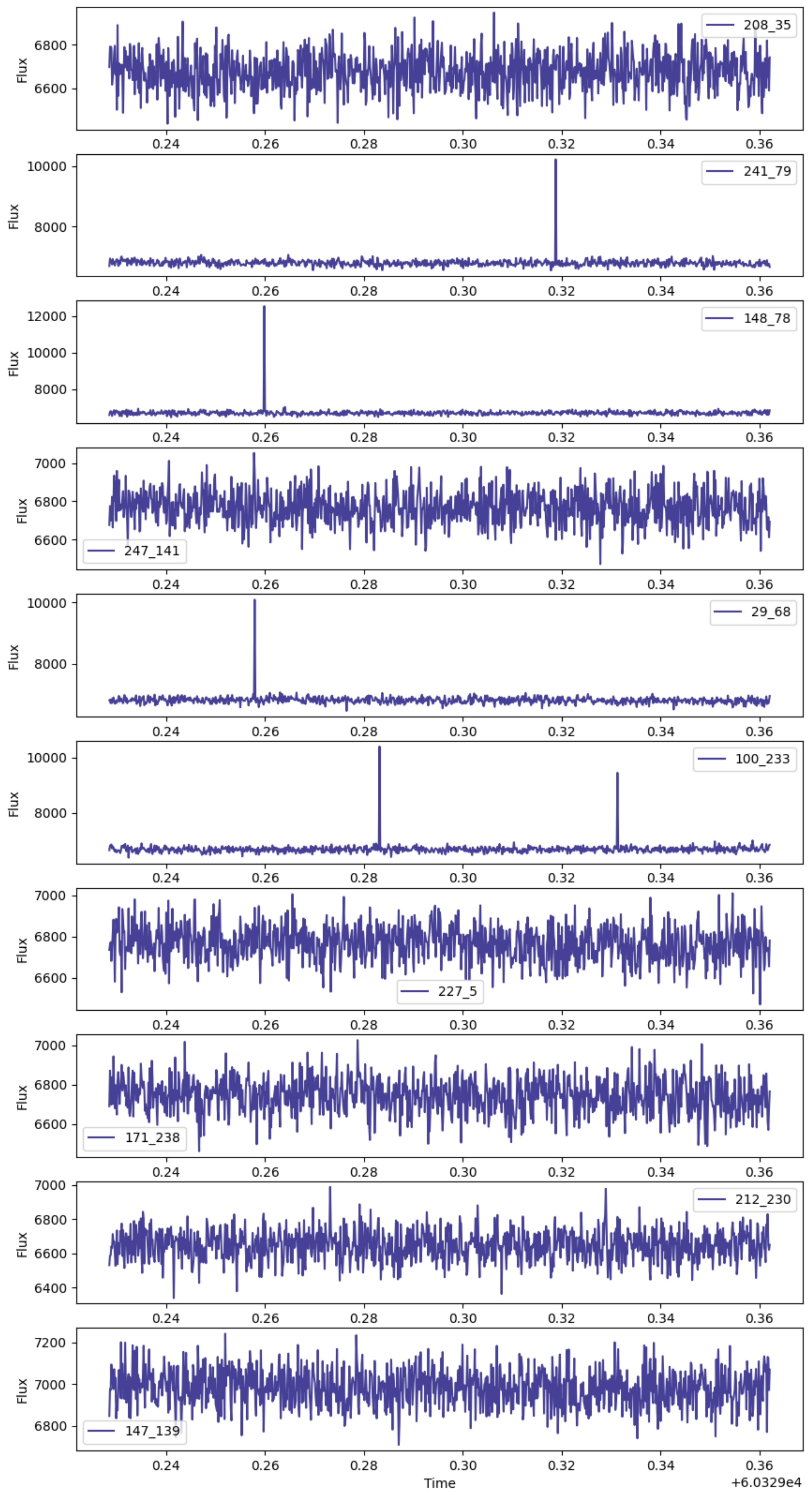
Structure? Larger amplitudes?

Lightcurves

2 clusters



(Strong) cosmic ray impacts



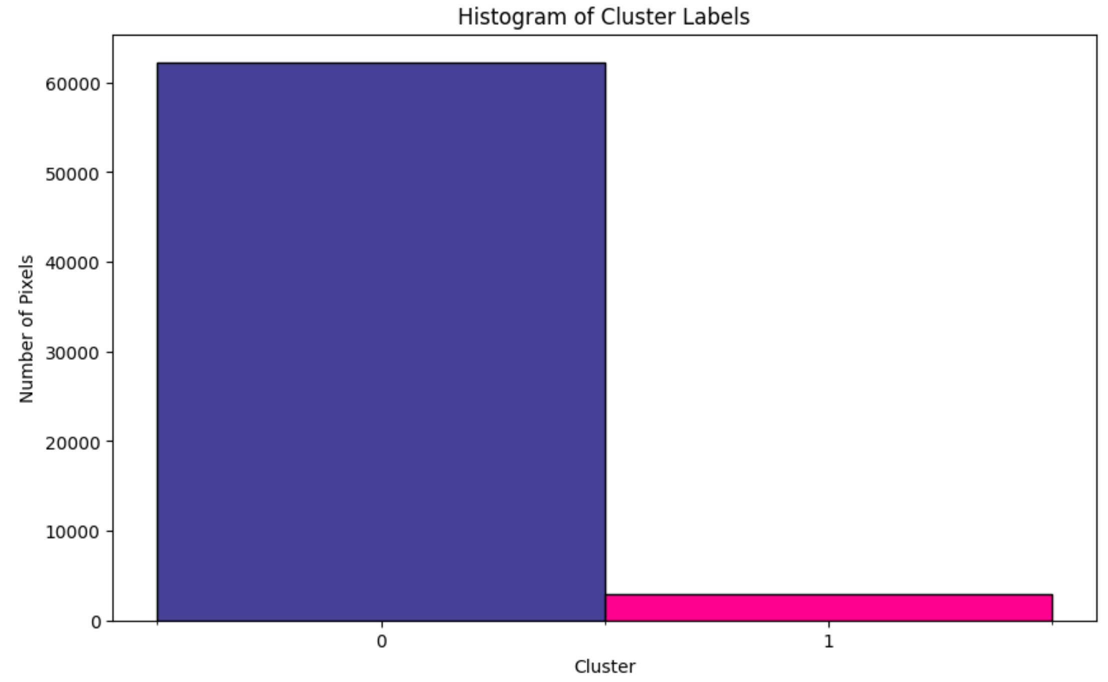
No/small cosmic ray impacts

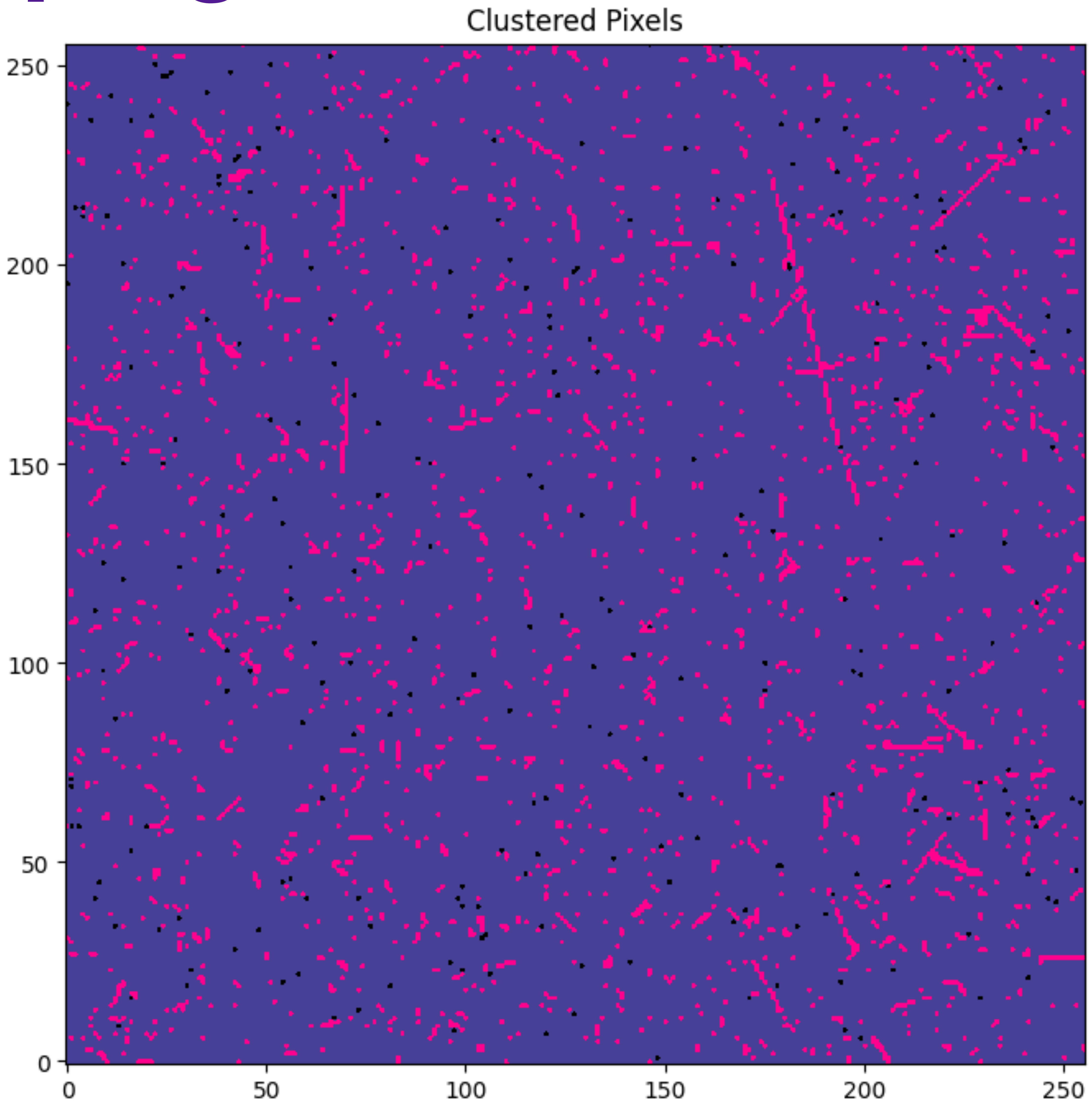
=> clip out cosmics & replace by median of the flux

Maybe it's just picking up on the actual **Fourier space signature** of the cosmic?

Cosmic clipping

2 clusters





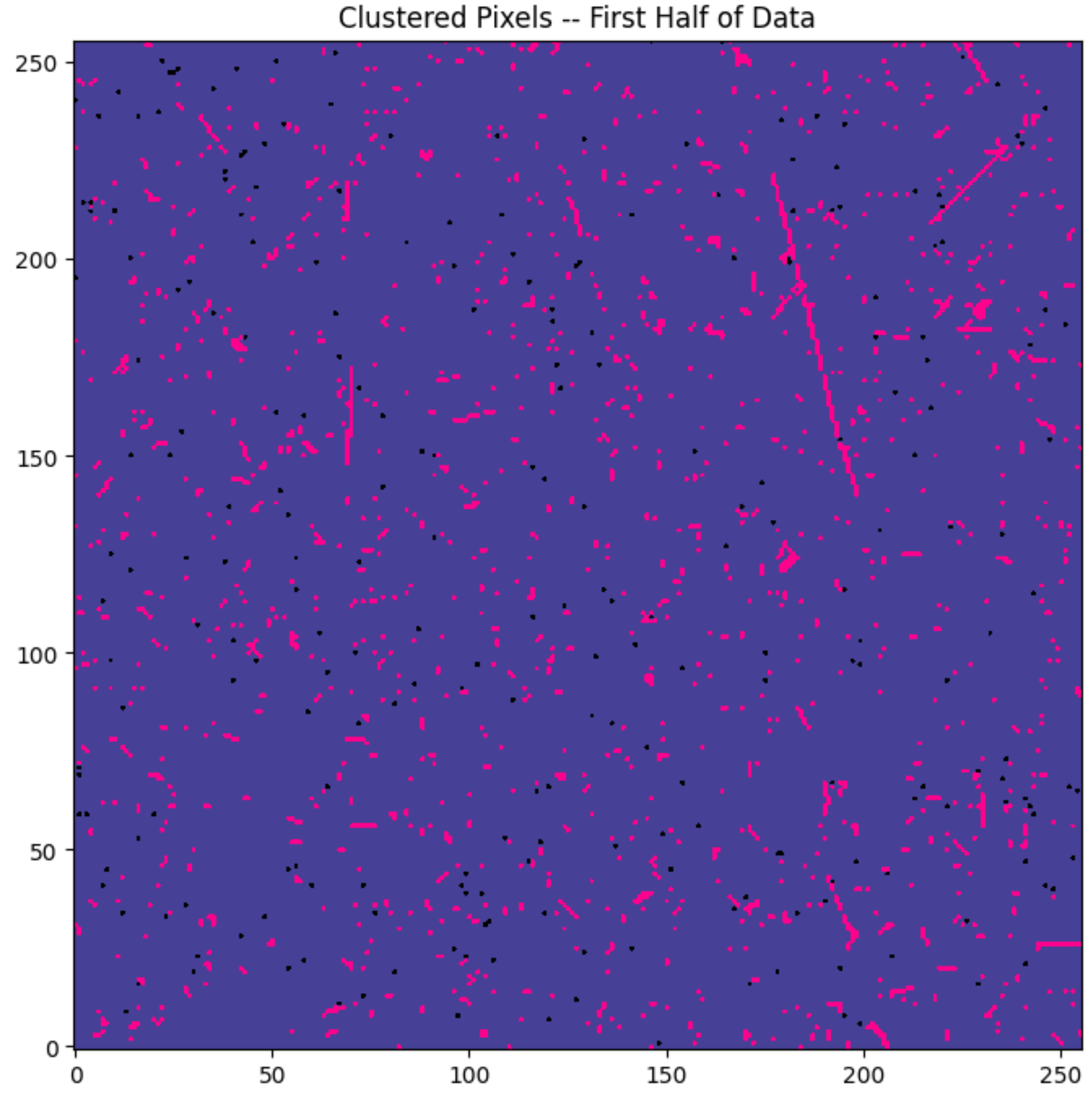
Clustering still "finds" them **even after they're removed!**

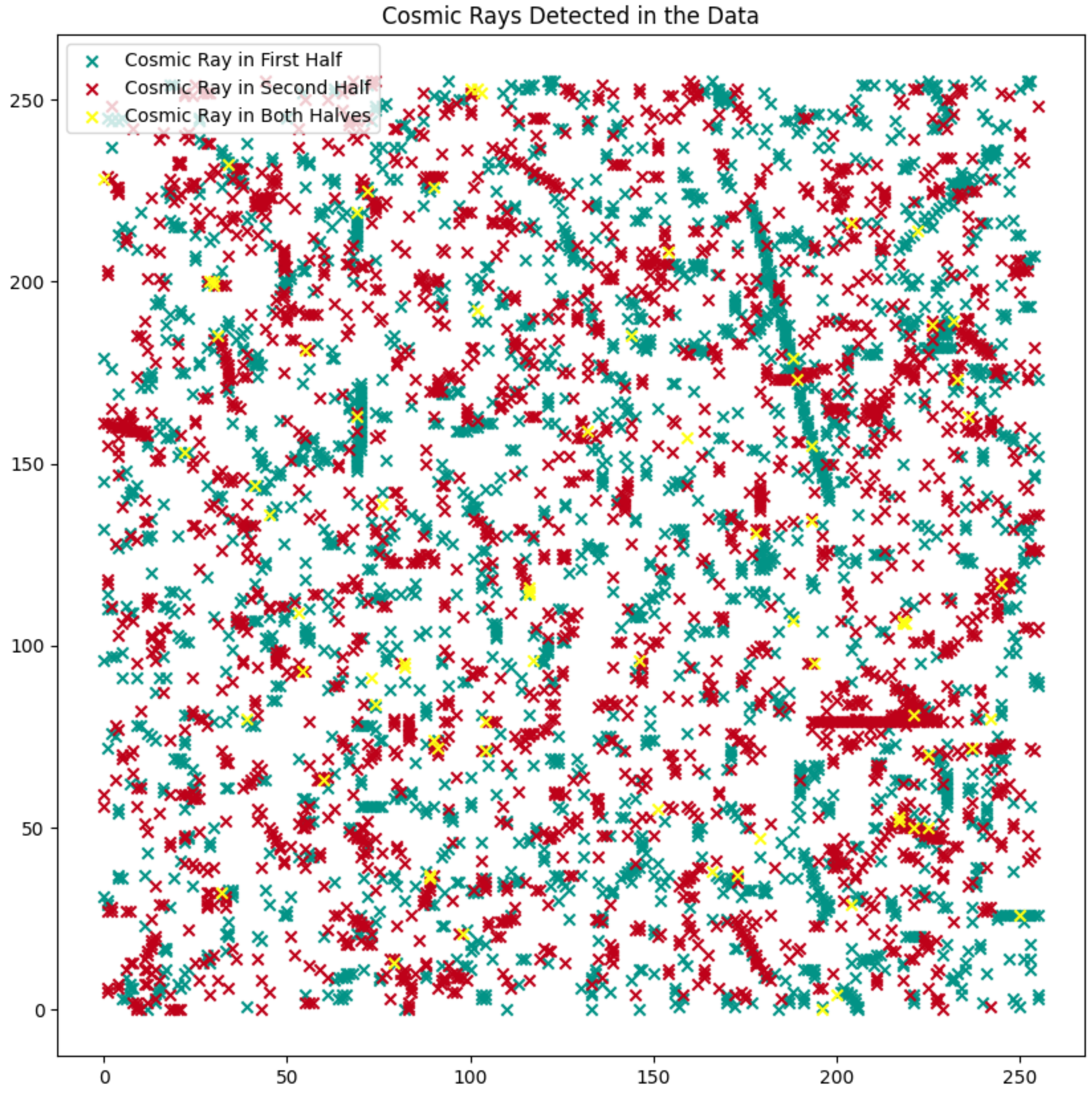
Let's do a last test and **split the data in 2…**

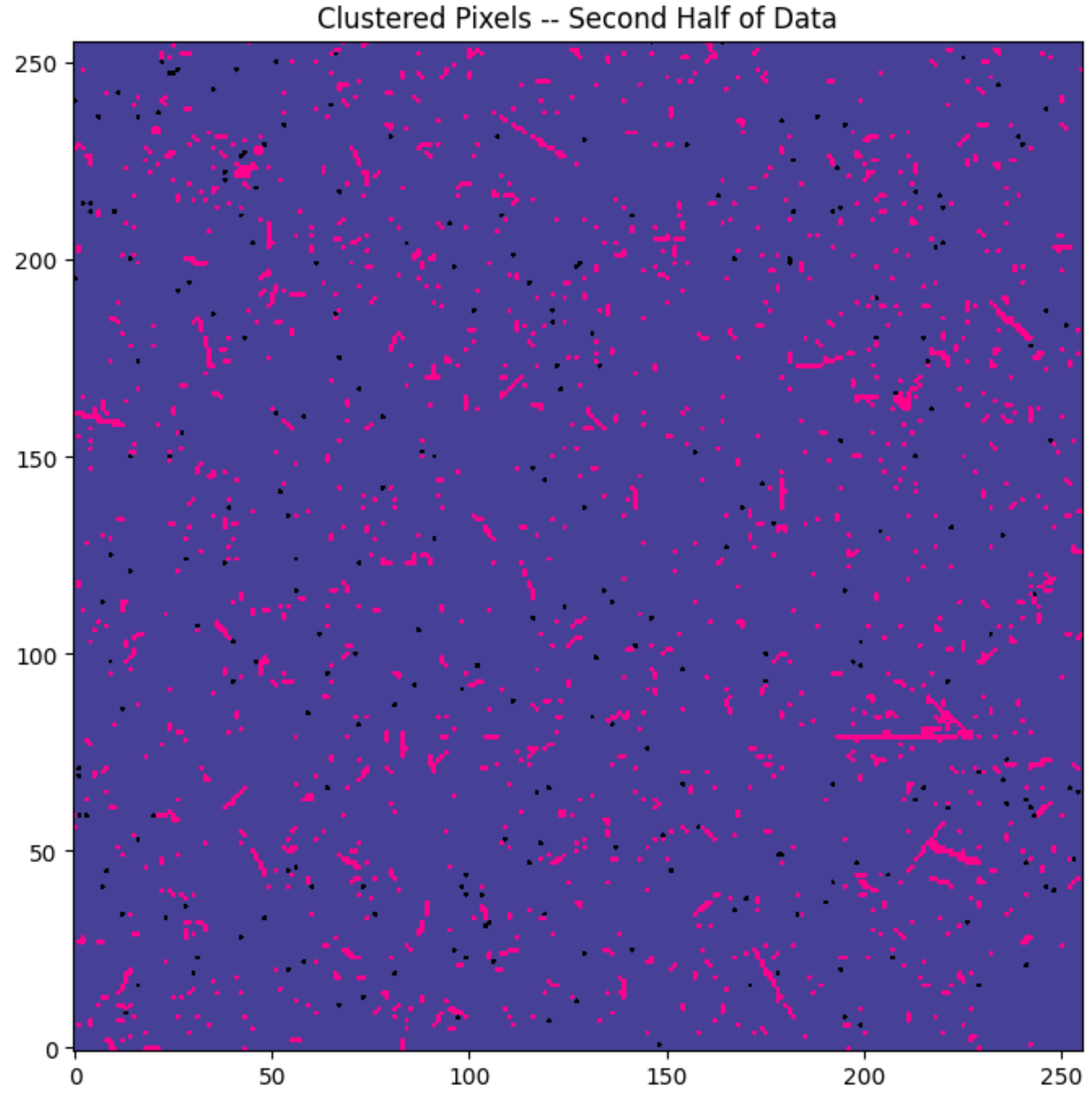
Clustering the FFTs in halves

Splitting the lightcurves

- cosmic ray in **first half**
- cosmic ray in **second half**
- cosmic ray in **both**

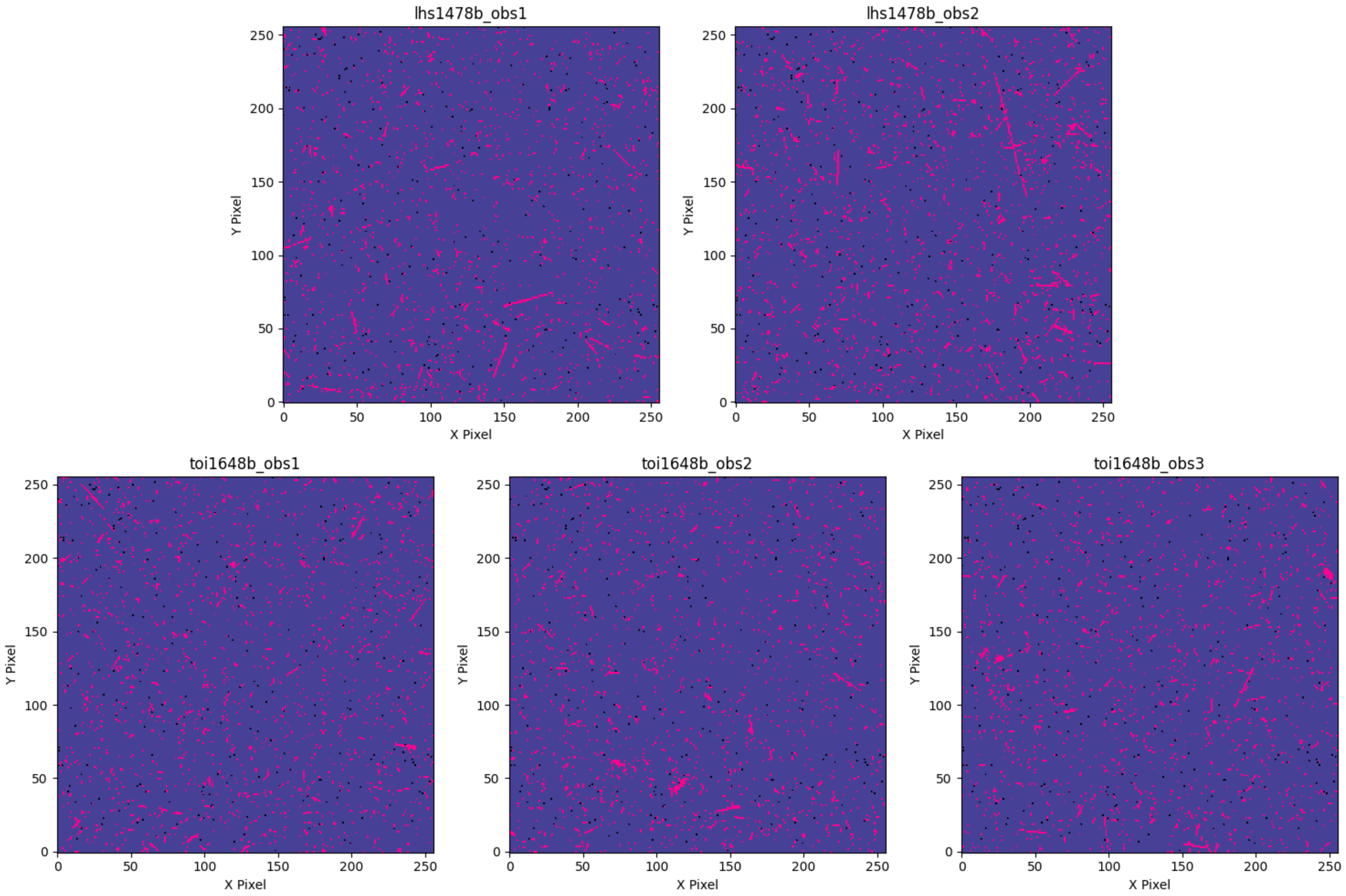






Other observations

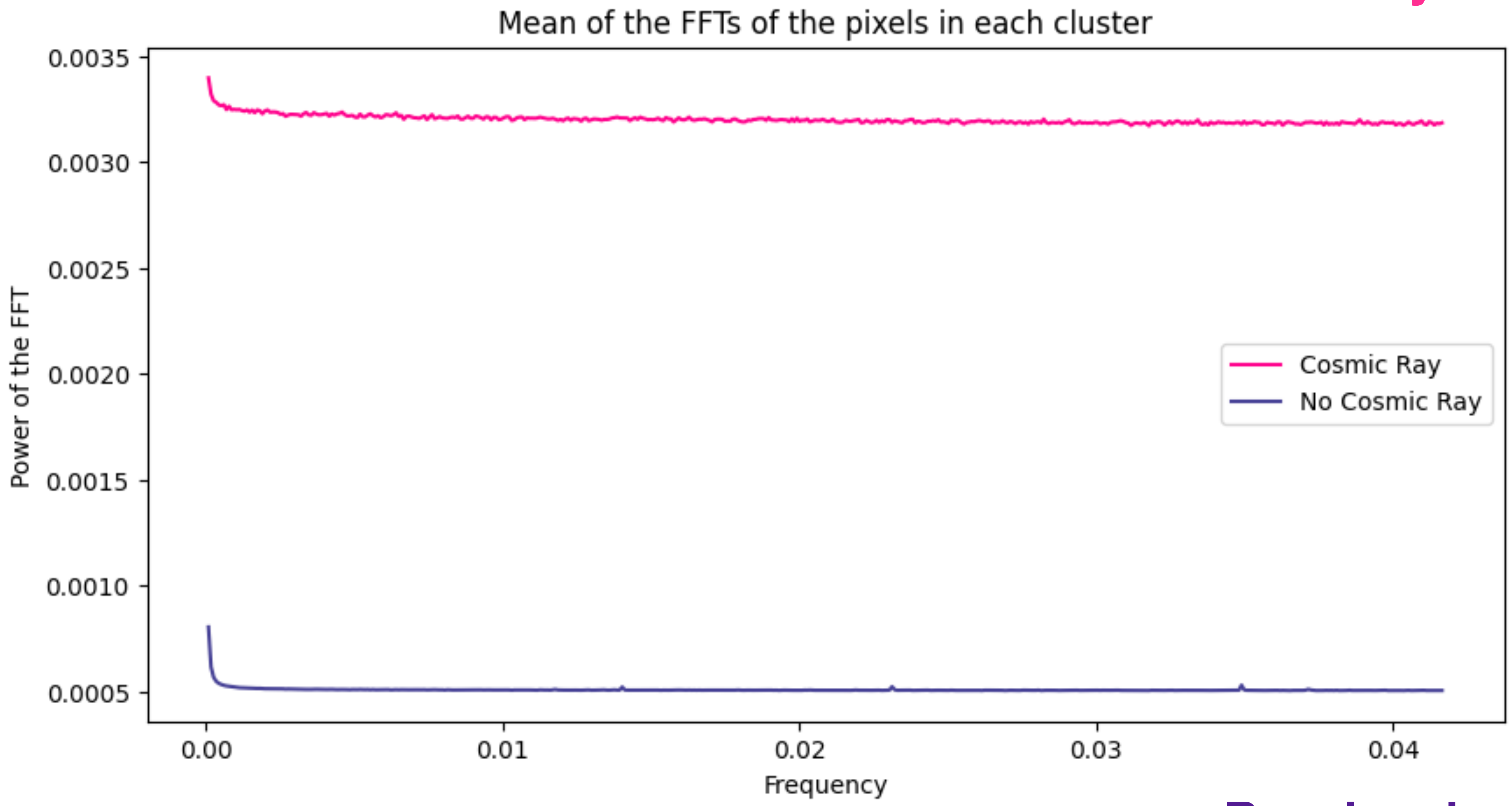
1st visit of LHS-1478b + 3 visits of TOI-1648b



Average of the FFTs in each cluster

Are large cosmics “shocking” pixels?

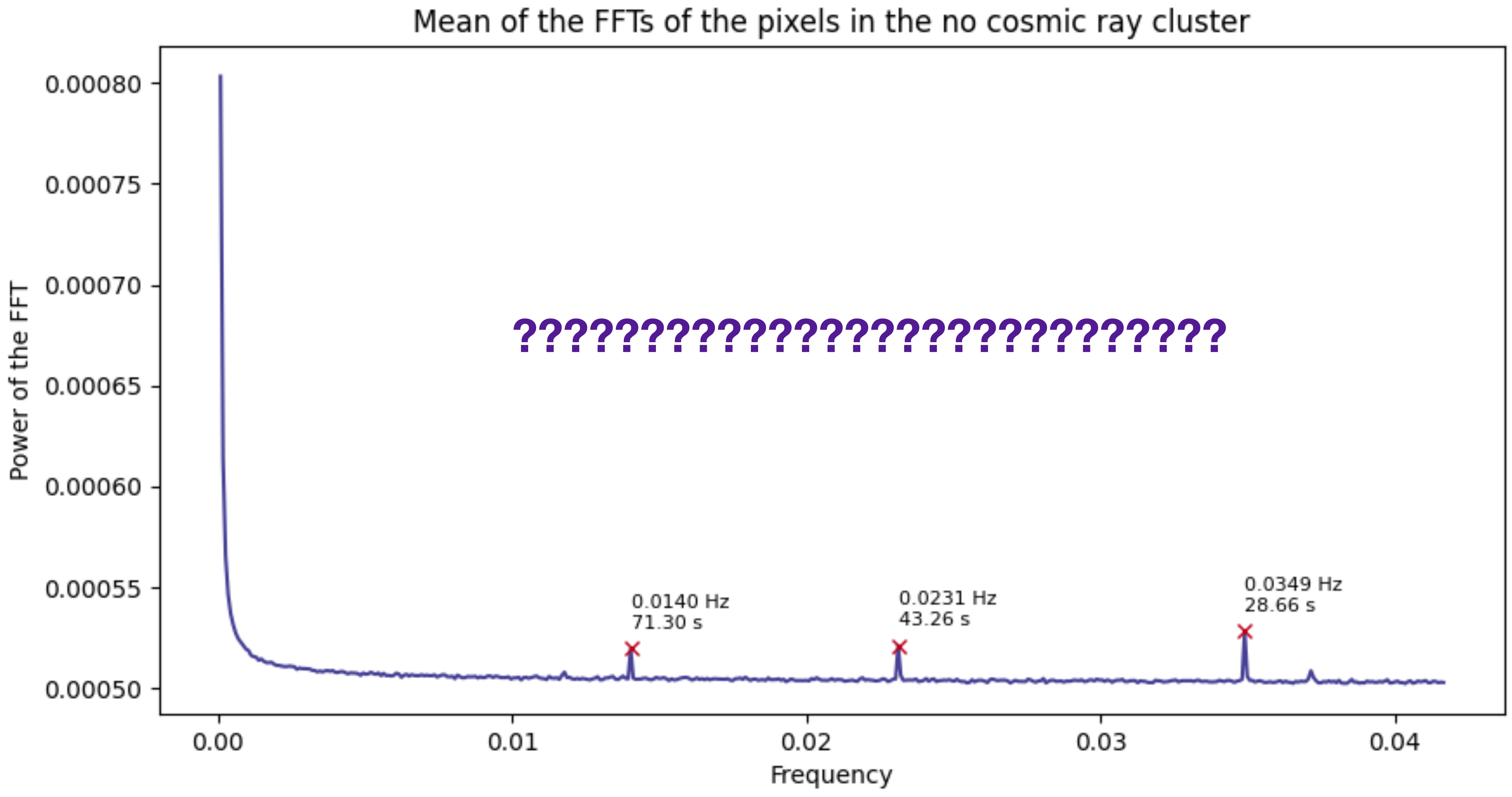
Cosmics make the pixels go a little cray cray



Regular pixels are more calm… although there are some peaks?

Average of the FFTs in each cluster

Is there an intrinsic detector pattern here?



What is this??
Should I be worried?

Seems to be below noise level

Conclusions

Research often means wasting time on useless things

- **ML did not really solve my problems**
- **BUT** it helped me identify new things to worry about!
- Learned a lot of potentially interesting things about the detector behaviour, which **I wouldn't necessarily have identified without**
- **MIRI pixels have a "PTSD" response to cosmics/polluters**
- **MIRI pixels might have an intrinsic frequency pattern**

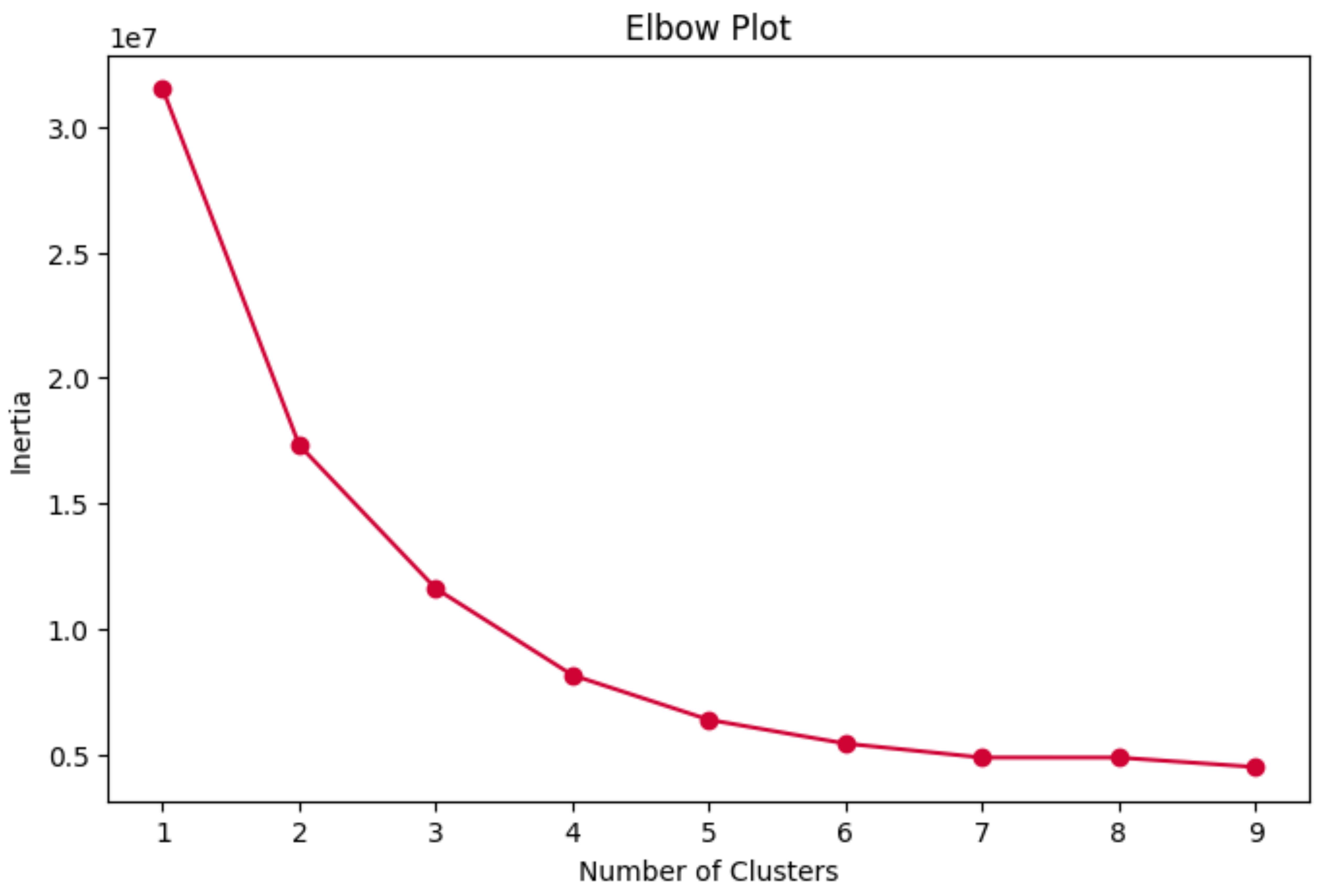
DTU UNIVERSITY OF COPENHAGEN

All members contributed evenly

Here is an appendix

Elbow plot

For LHS-1478b observation 2



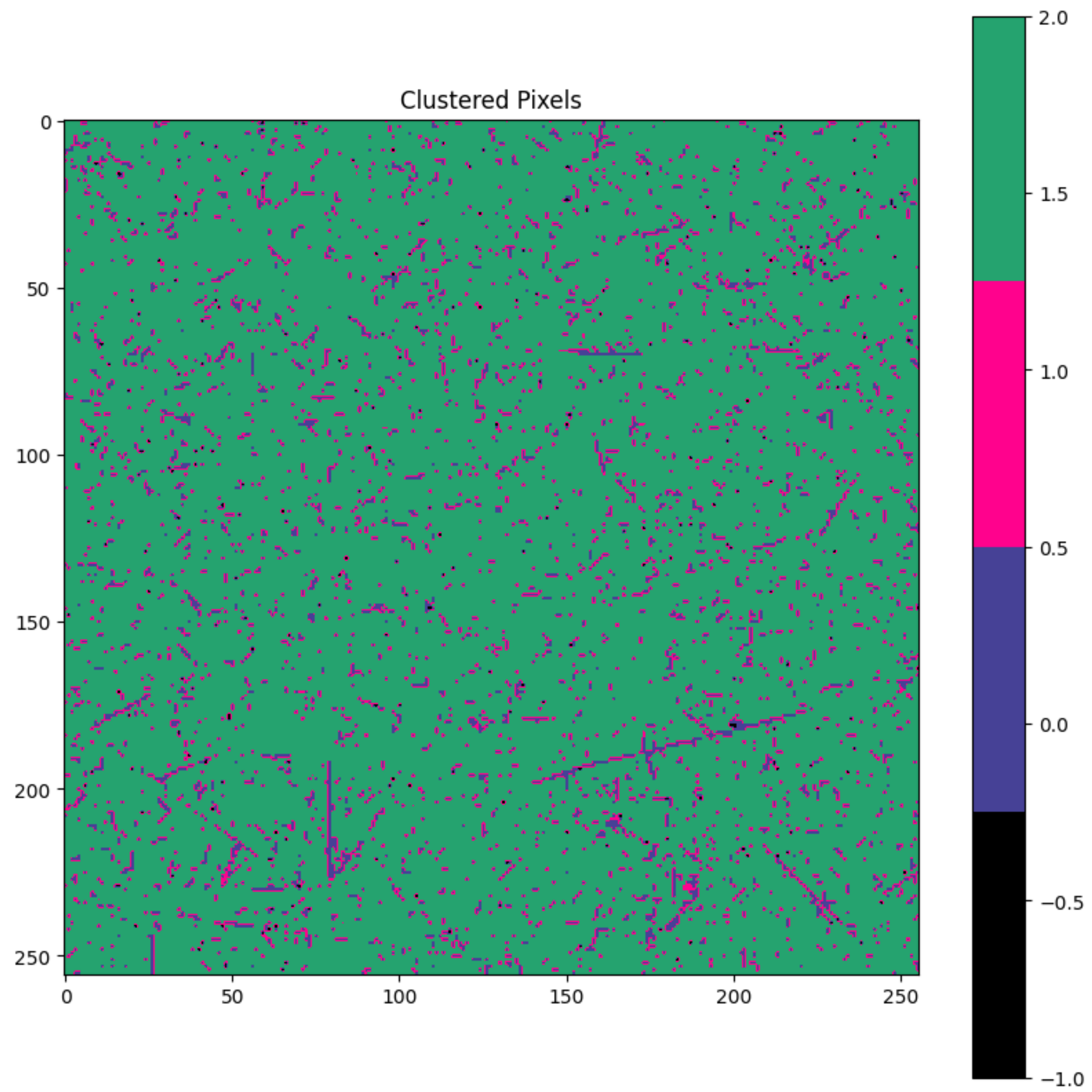
No clear "elbow", 2 seemed the best option

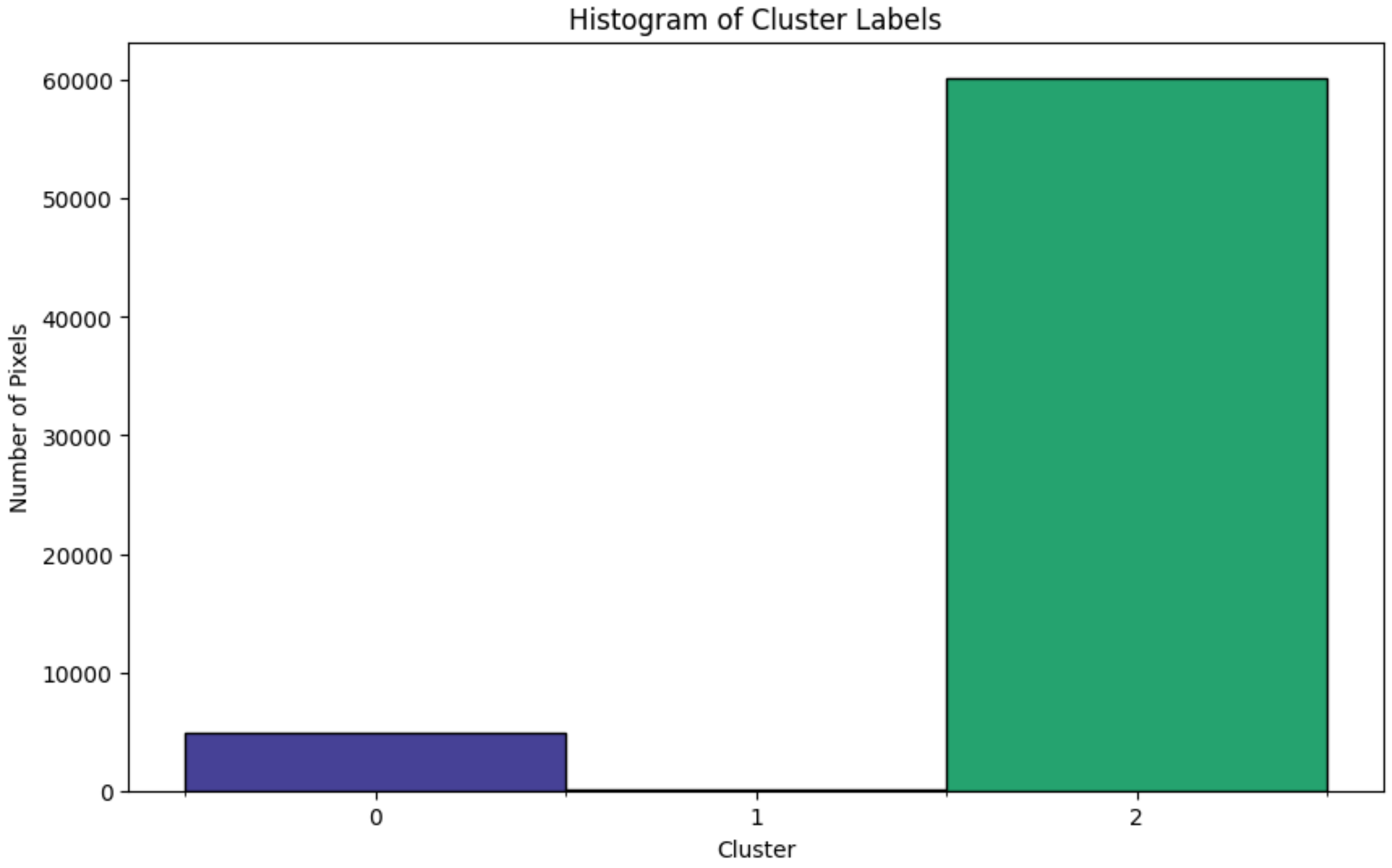
Maybe could've tried with 9 clusters but unclear. (Classification of cosmics?)

Clustering the FFTs

3 clusters

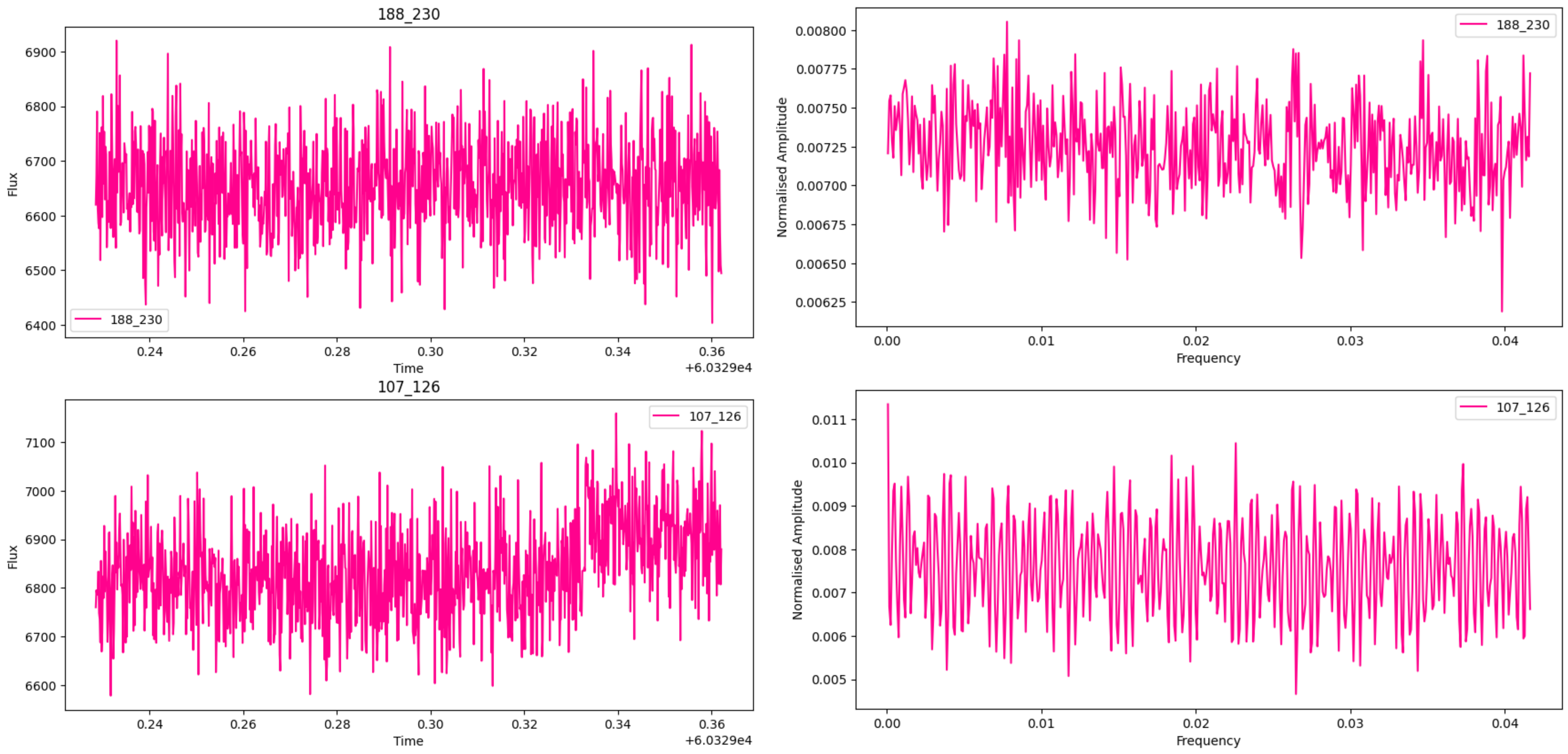
Almost seems to highlight the strongest parts of the "cosmics" (NB what we refer to as cosmics are sometimes just bright asteroids or other polluters)





Cosmic response

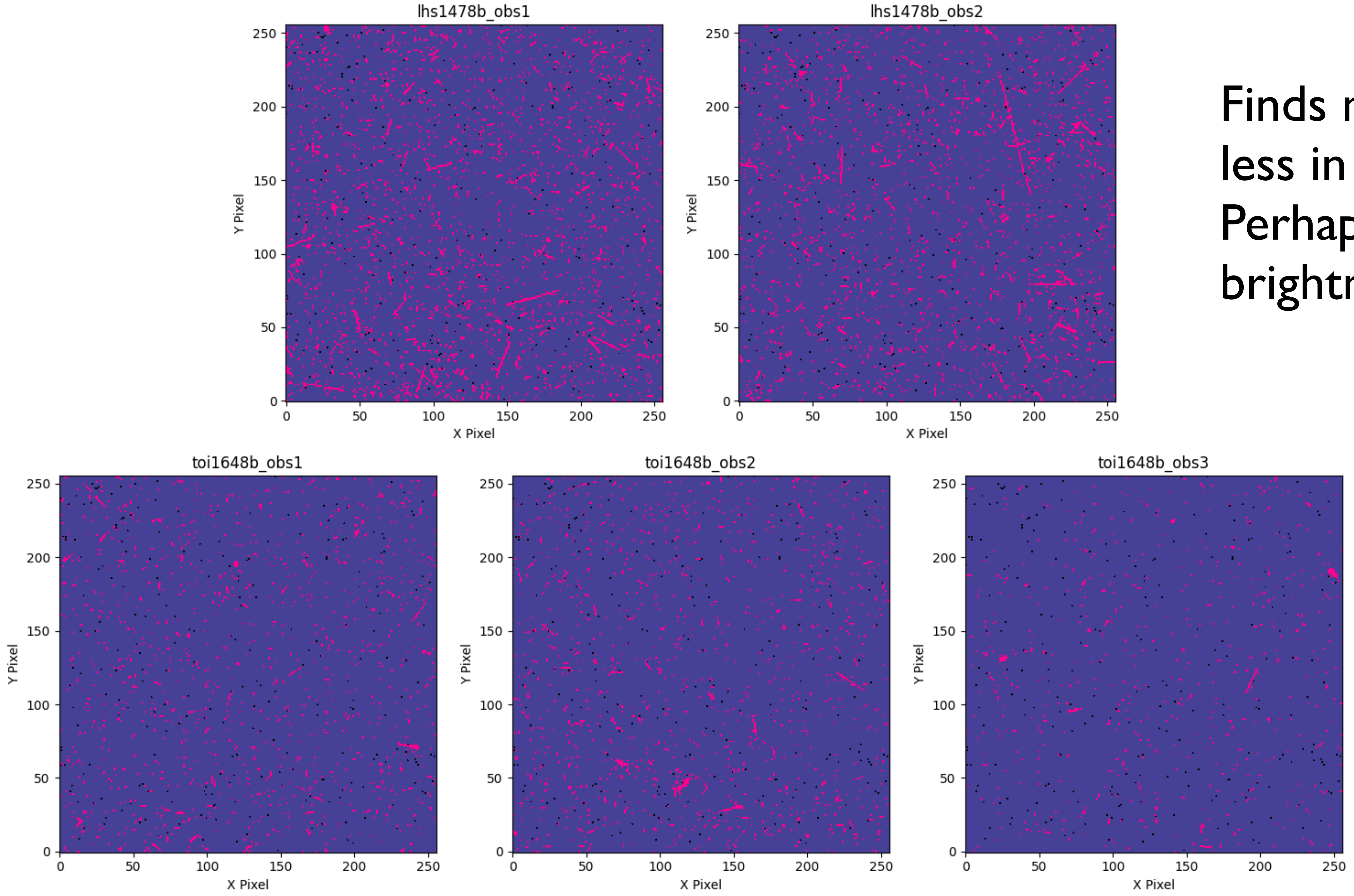
Cosmics can leave “imprints” — but not always



Another point of investigation would have been to see if these “cosmics” can be separated into different categories.
Do cosmics have different signatures on the detector than, i.e., asteroids?
Can ML identify different classes of “polluters”?

Other observations

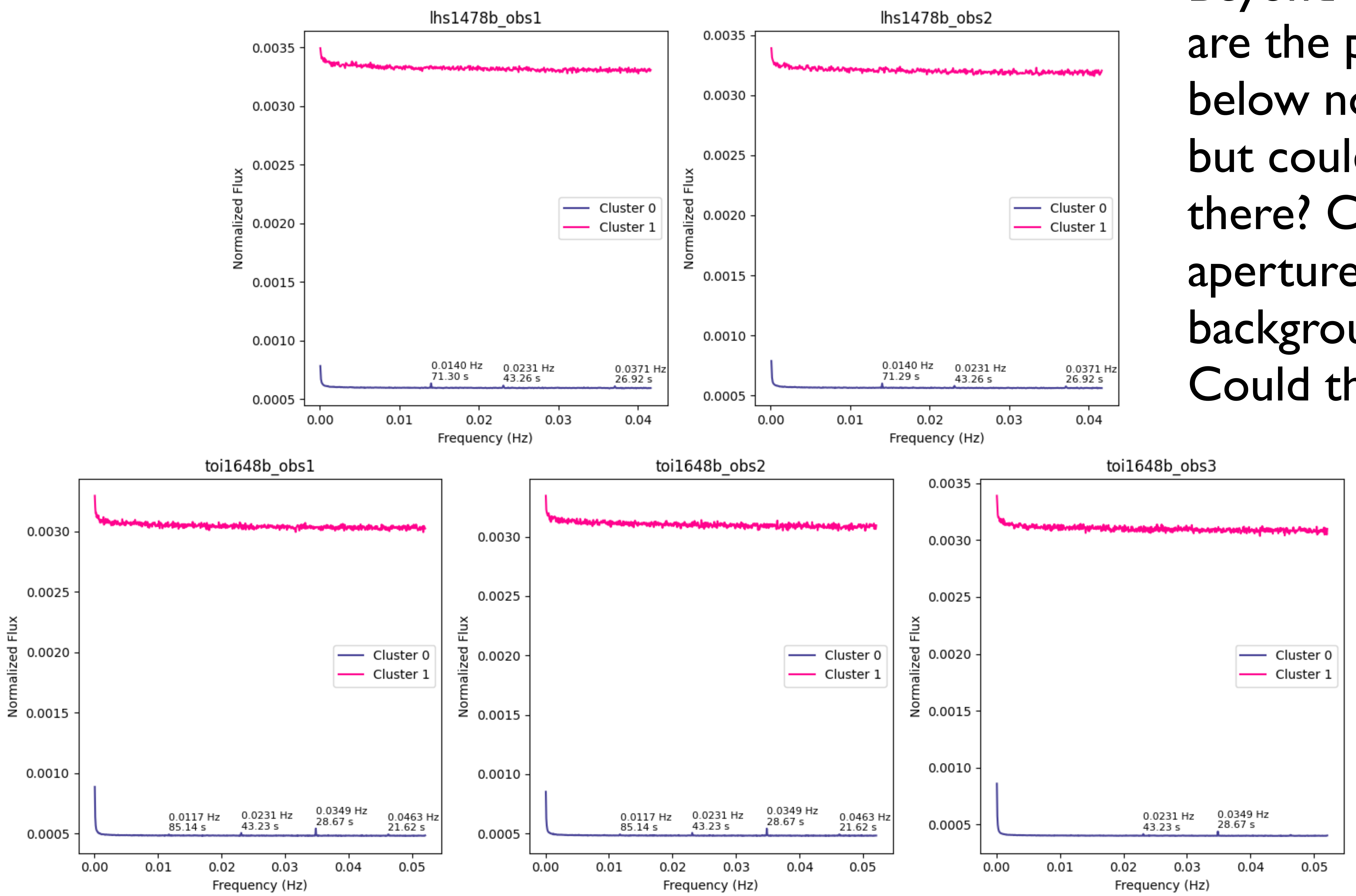
All datasets analysed together as one big dataset



Finds more cosmics in LHS-1478b target and less in TOI-1648b.
Perhaps that's due to the sampling & overall brightness differences? Perhaps something else.

Average of the FFTs in each cluster

For each dataset

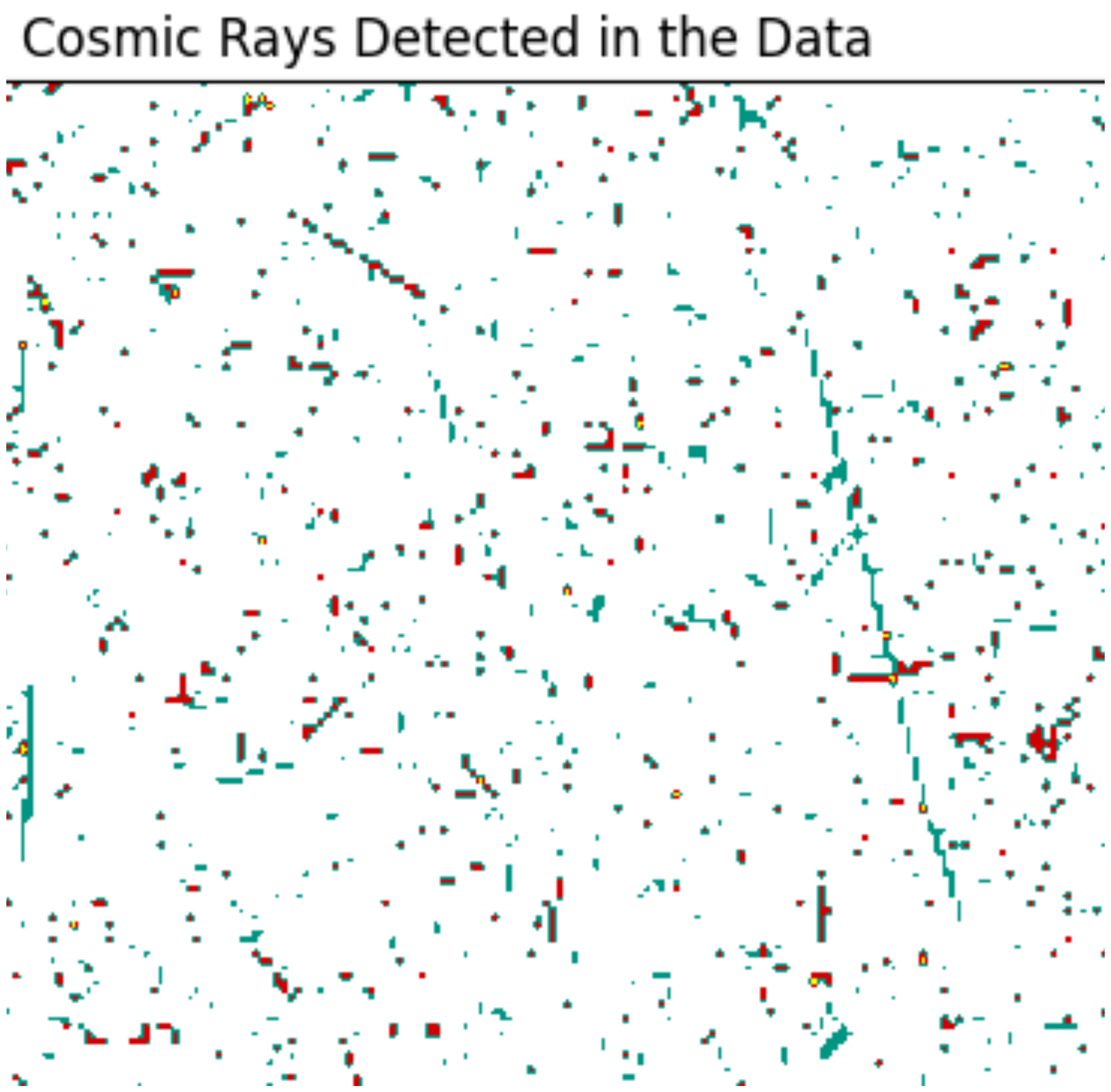


Beyond the obvious cosmic/no cosmic divide, what are the peaks in the background? They probably are below noise level and just show up once stacked, but could there be an intrinsic instrumental effect there? Could it matter for small signals when doing aperture photometry on 5x5 pixel circles? And background subtraction?

Could this introduce red noise?

“PTSD” response of pixels

Might affect neighbouring pixels too



If I look at this again, it seems the big bright green stripe has only a few pixels getting hit but is much thicker on the clustered pixels. So neighbouring ones might also be “shocked” and have this vibrating response even though they didn’t directly receive the cosmic ray hit. Is this because of flux leak? Or is it really some sort of “vibration/PTSD” response on the detector itself?