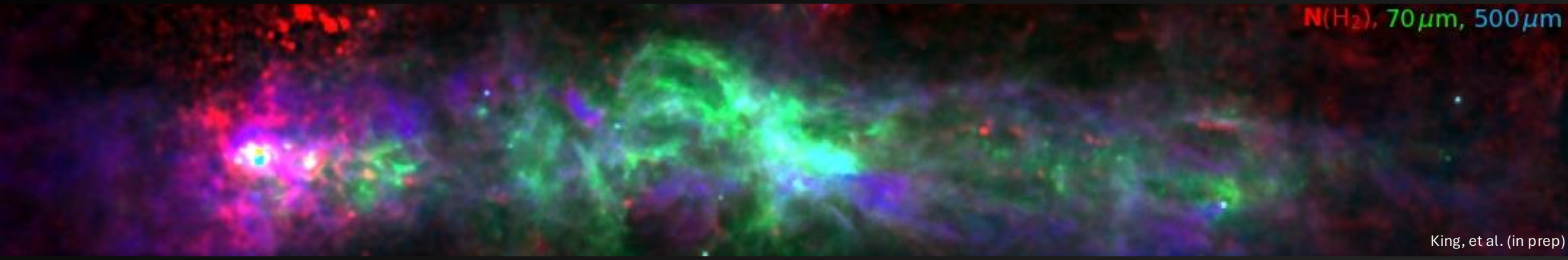

King, et al. (in prep)

Isolating The Central Molecular Zone Using Fourier Filtering Techniques

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About Me

- **Stevie King (She/They) – I like cats**
  - Cat rescue volunteer
- **Educational Background**:
  - 3rd year PhD Candidate at the Astrophysics Research Institute, Liverpool John Moores University
  - MPhys in Astrophysics at The University of Liverpool
- **Research Focus**:
  - Star Formation in the Central Molecular Zone (CMZ) of the Milky Way
- **Current Project:**
  - To develop a method to deconvolve the CMZ and Spiral Arm signals, detected in the JCMT CHIMPS2 Survey's CMZ data (^{12}CO & ^{13}CO: J = 3 → 2)
  - To analyse each component and compare the physical parameters of molecular gas in the CMZ to the nearby Spiral Arms
- **Contact Information**:
  - Email: arisking@ljmu.ac.uk

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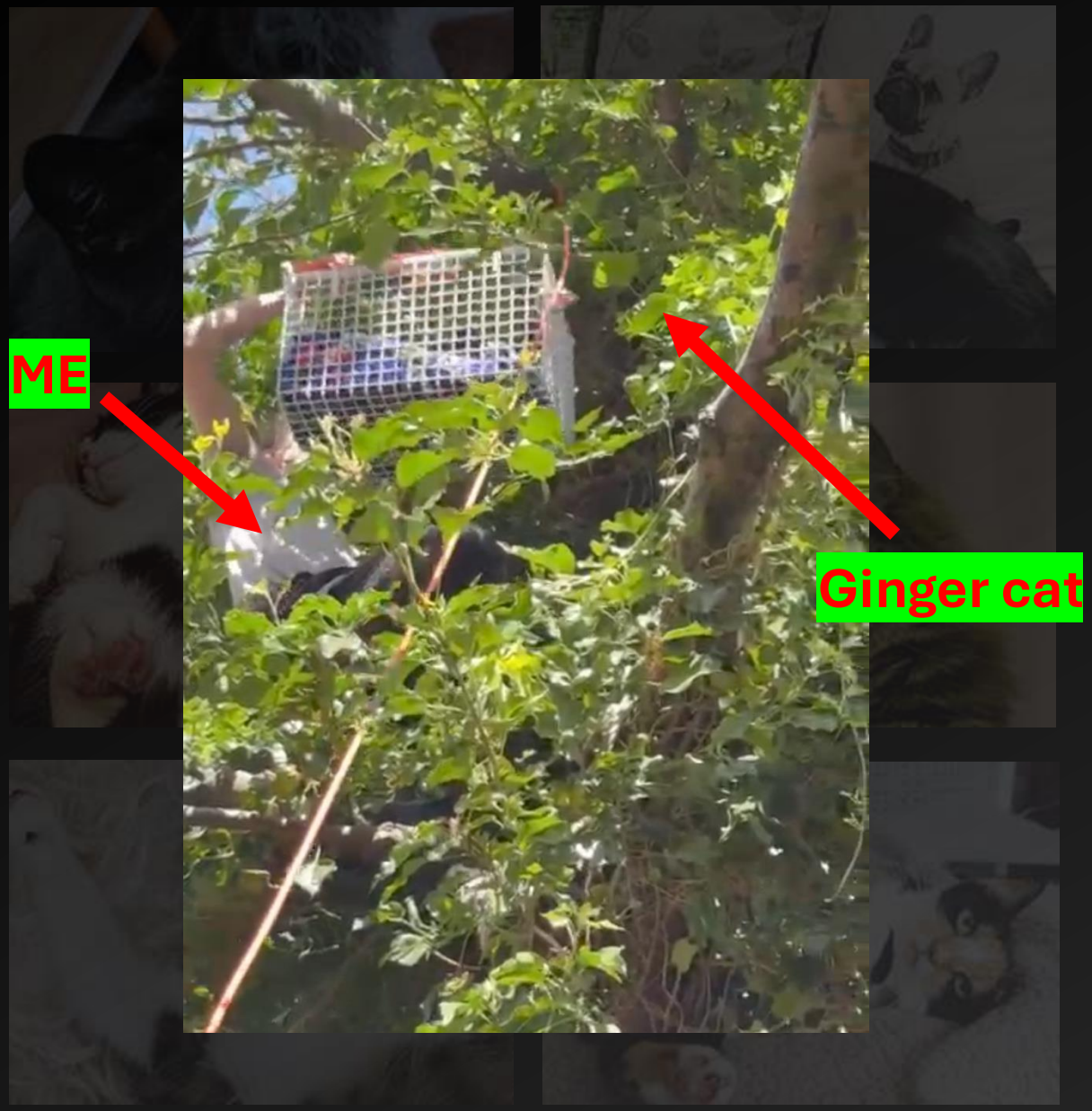

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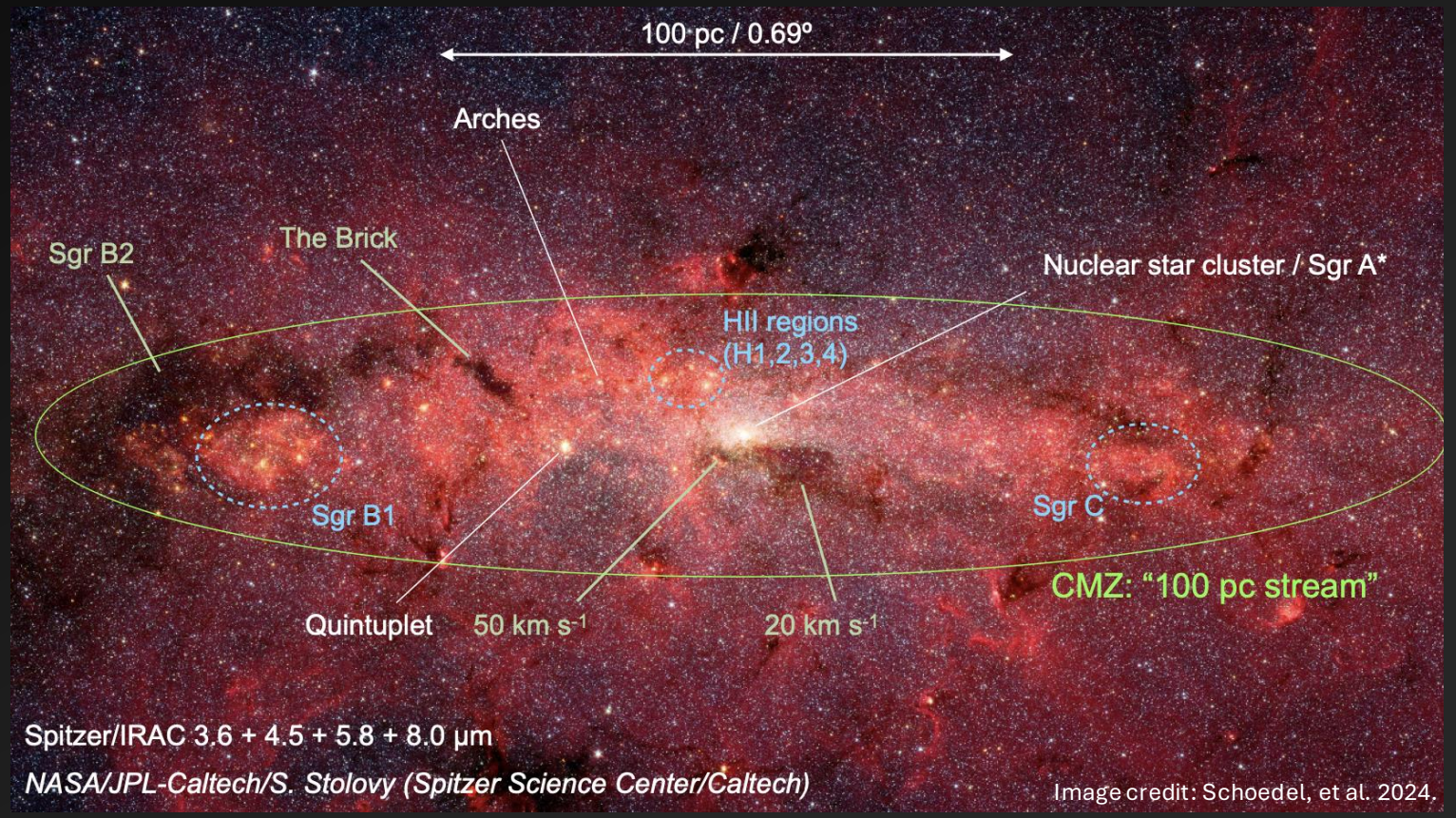
The Central Molecular Zone

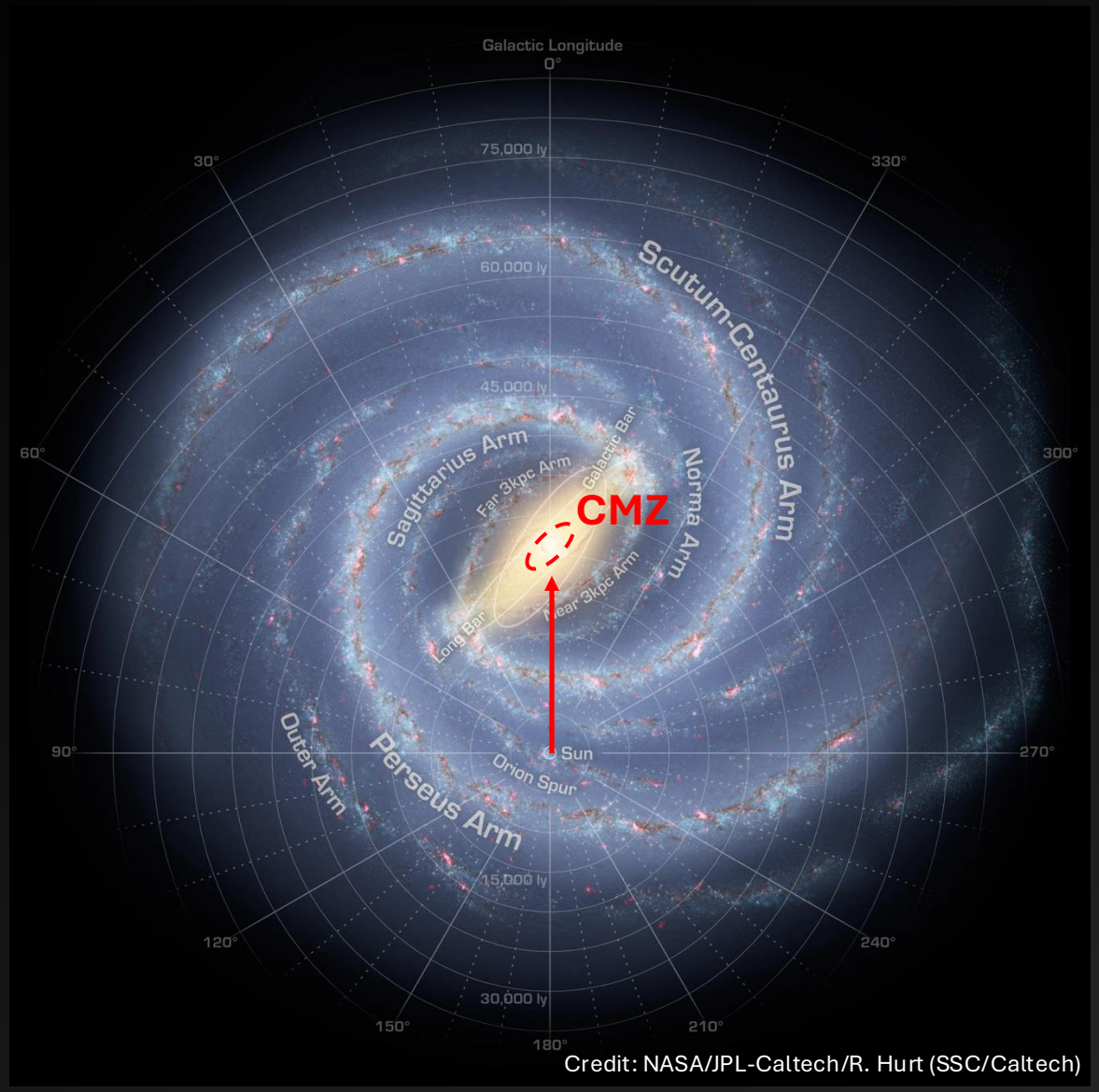
- The Central Molecular Zone is a region ~8kpc from the Sun at the centre of of the Galaxy containing ~$10^7 M_\odot$ of molecular gas

- The CMZ is turbulent, and chaotic, molecular line widths are broad typically between ~15-50 $\mathrm{km\ s^{-1}}$ (Rathborne, et al. 2009)

- The Star Formation Rate per unit dense gas is an order of magnitude lower in the CMZ compared to regions in the Spiral Arms (Longmore, et al. 2013)



The Galactic Spiral Arms



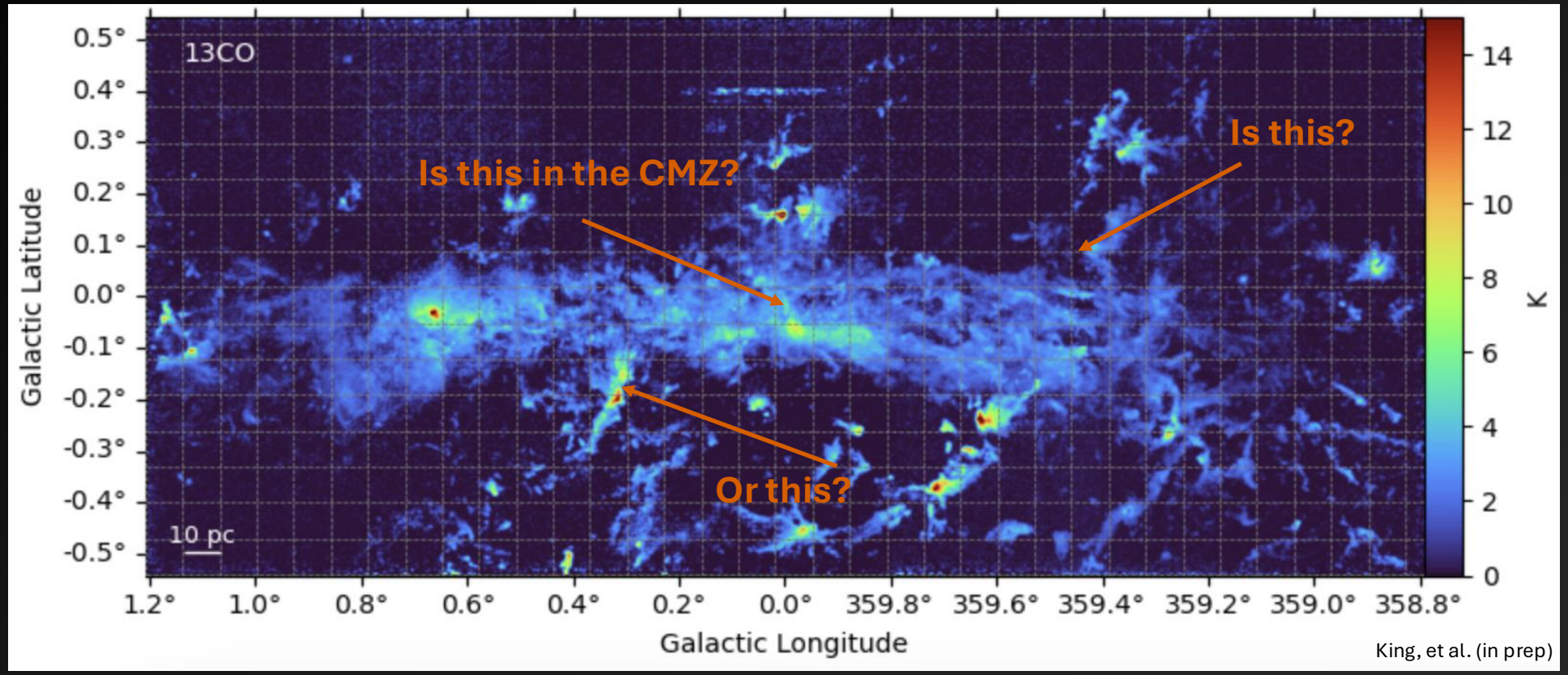
Credit: NASA/JPL-Caltech/R. Hurt (SSC/Caltech)

- The Galaxy has two major arms (Scutum-Centaurus and Perseus), and two minor arms (Norma and Sagittarius) located between the major arms

- The Near and Far 3 kpc arms are much closer to the CMZ

- Typical line widths in the Spiral arms can reach up $\sim 1 - 10\ \mathrm{km\ s^{-1}}$ (3 – 5× smaller than in the CMZ) (Mills, et al. 2017)

The Problem



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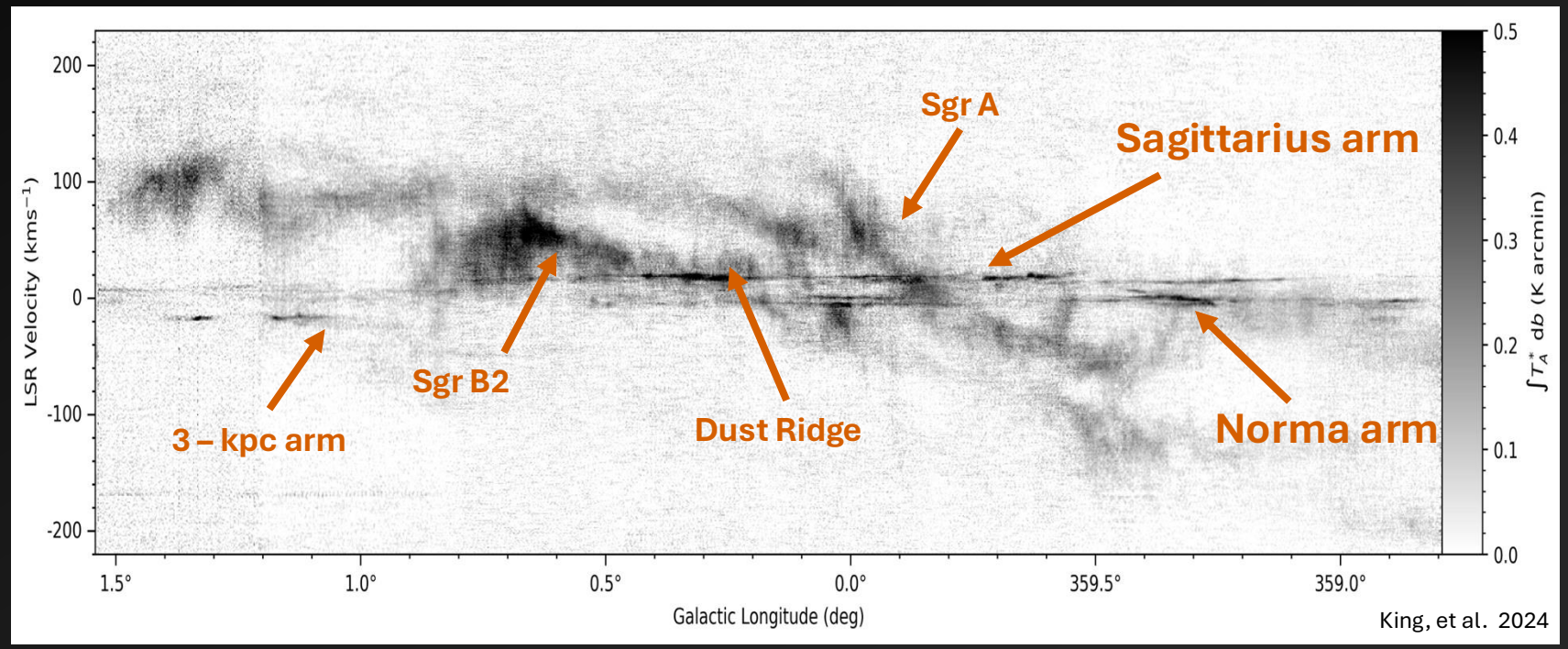
- Our position in the Galaxy means observations of the CMZ are littered with contamination from dust and gas which is contained in the Spiral Arms making it difficult to determine accurate measurements of the CMZ's physical properties e.g. Total H_2 mass, Temperature, and kinematics.

The CMZ in P-V space

In Position-Velocity space the CHIMPS2 - CMZ data shows two interesting characteristics;

- Spatially compact emission from a large quantity of high velocity gas ($v_{LSR} \pm 200\ km\ s^{-1}$) typical of material in the CMZ
- A spatially extended signal with a low velocities ($v_{LSR} \pm 20\ km\ s^{-1}$) characteristic of slower moving gas in the spiral arms



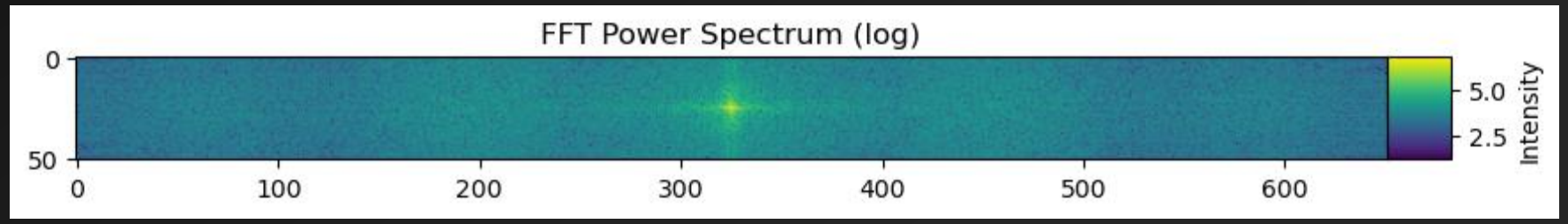
How can we separate the two mixed signals?

Fourier transforms in P-V space

- The Fourier Transform for Position-Velocity data is given by:

$$\mathrm{F(k,\,l)} = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} \mathrm{f(m,\,n)} \cdot e^{-2\pi i\left(\frac{km}{M}+\frac{ln}{N}\right)}$$

- Where:
- f(m, n) is the data in P-V space at coordinates (m, n)
- F(k, l) is the result in Fourier space at coordinates (k, l)
- M and N are the dimensions of the data
- k and l are the indices in the frequency domain

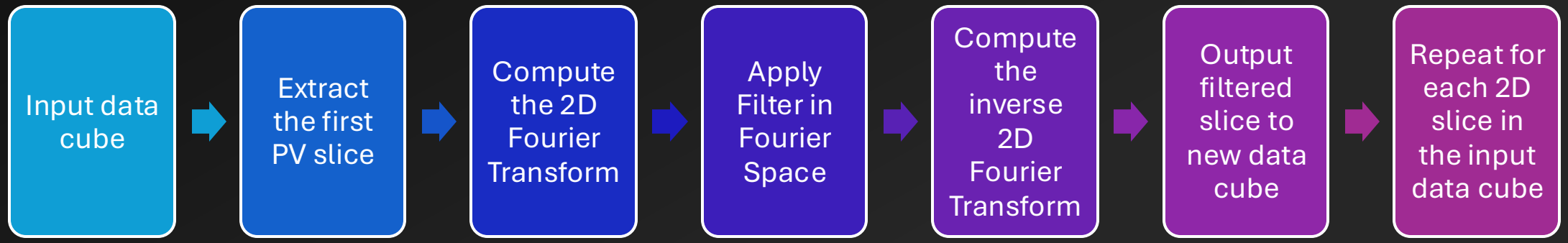


Fourier-filtering process

- The process requires applying a Bessel filter to the data in Fourier Space to attenuate specific spatial and velocity frequencies based on input cutoff frequencies.

- A Bessel filter is a type of analogue filter that is designed to have a maximally flat group delay.
  - This ensure that:
    - The filter's phase response is as linear as possible,
    - It preserves the wave shape of signals within the passband
    - Has a slower roll-off compared to other filtering methods
      - More gradual filtering at edges.

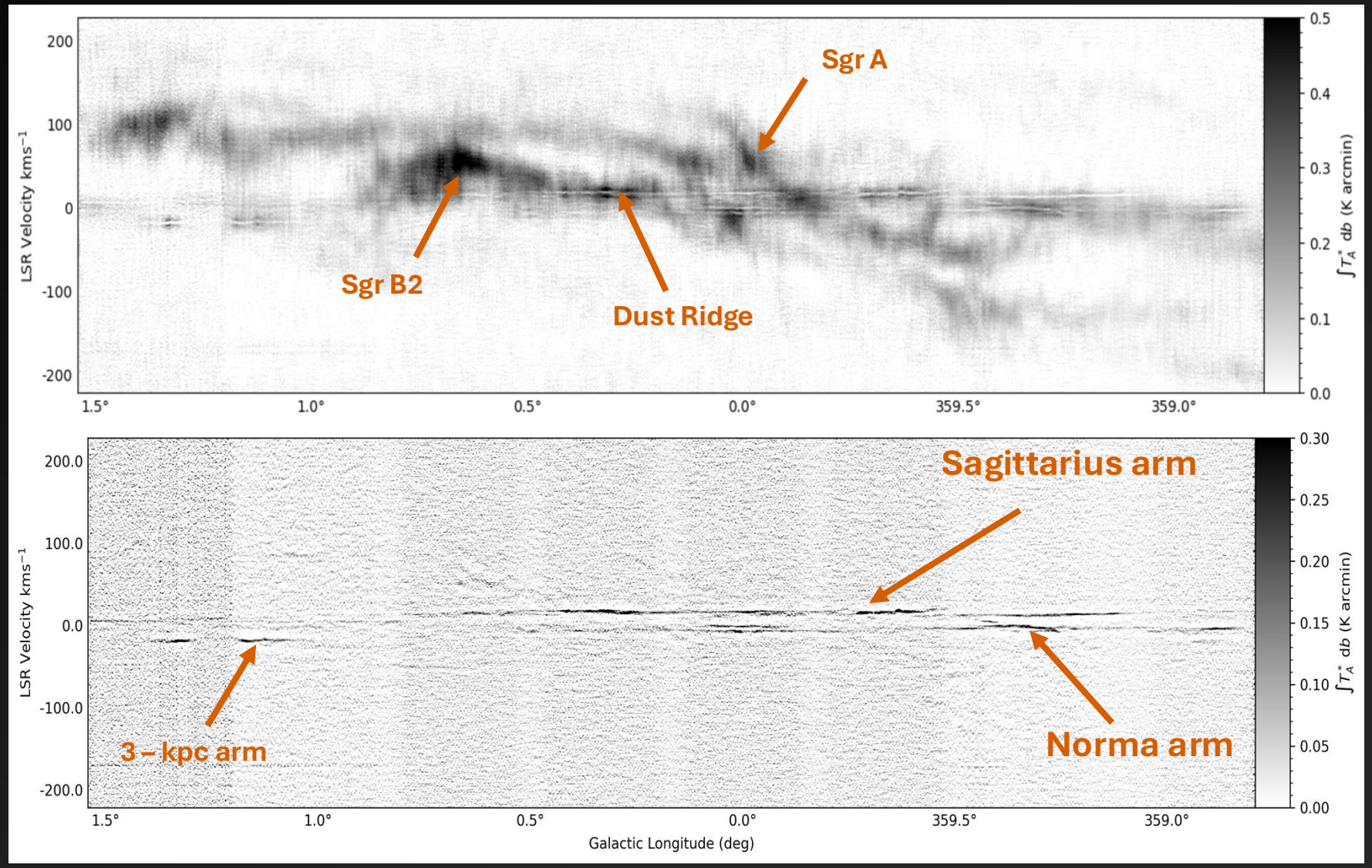
- Other filters that can be used include Butterworth and Chebyshev filters



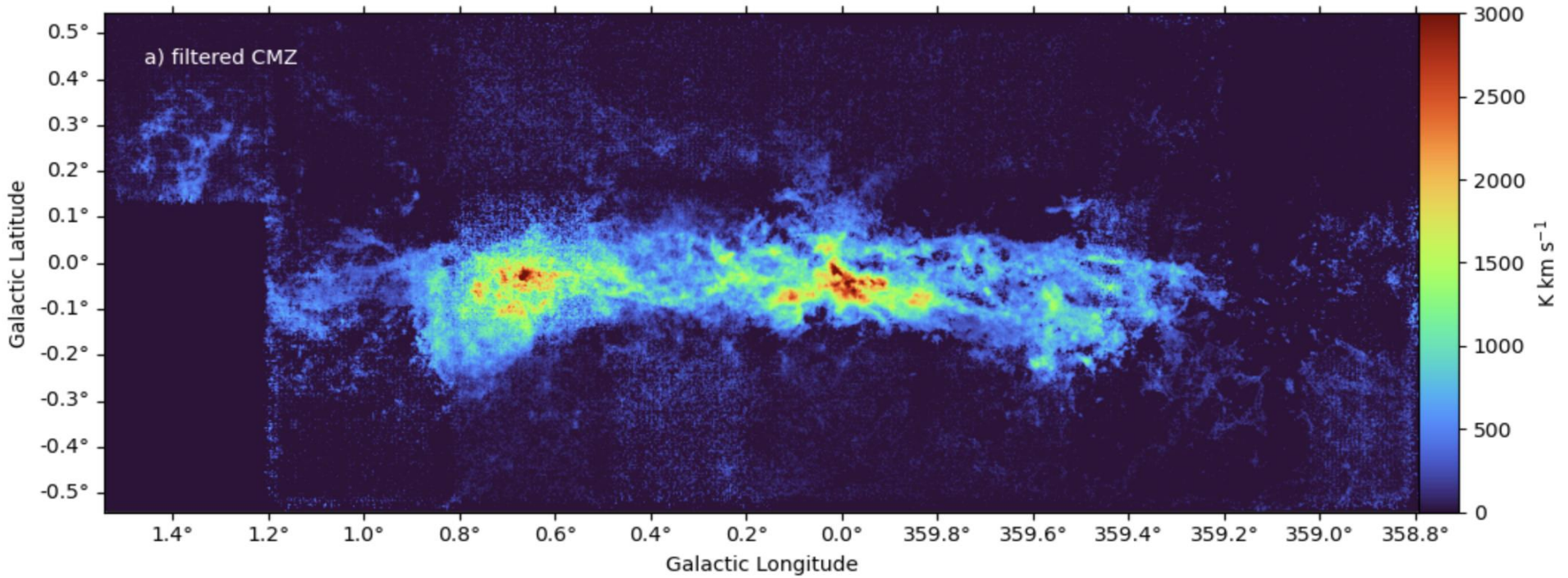
Initial results

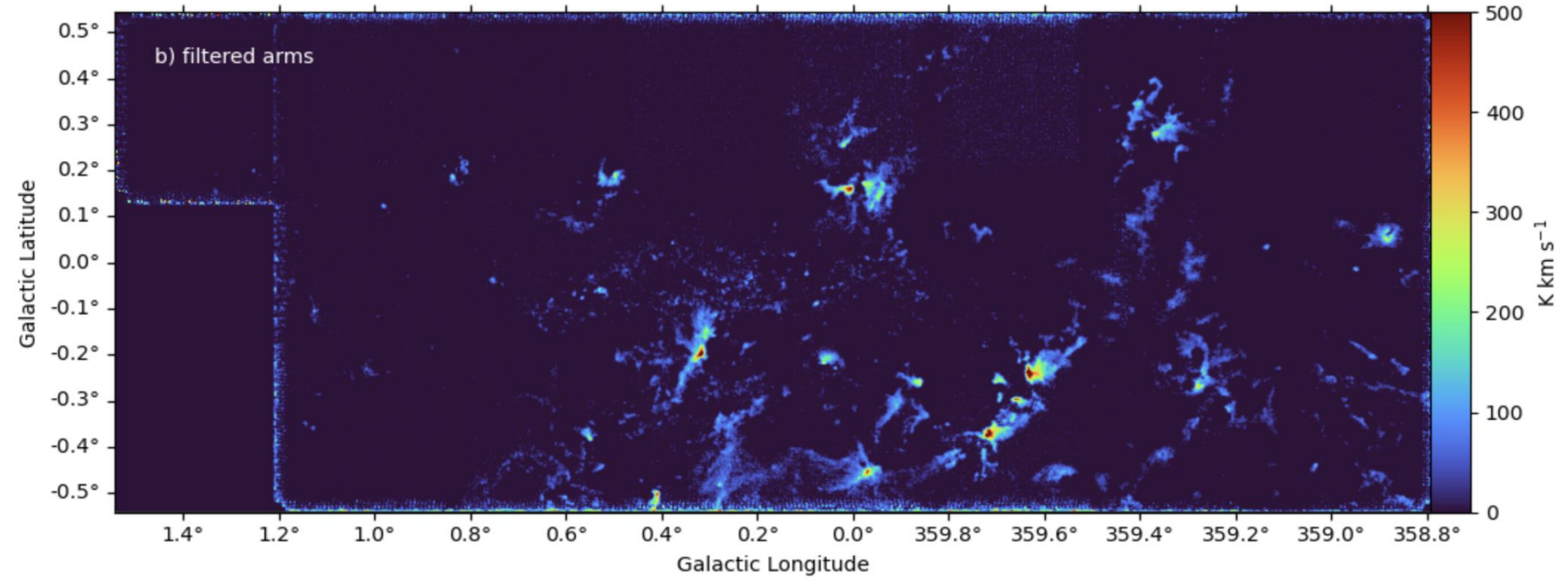
- In Position-Velocity space, the first Fourier Filtered cube now shows only emission extended in velocity

- The second Fourier Filtered cube only signals with spatially extended, low velocity emission.



- We can now see the clear structure of the CMZ, and spiral arms separately.
  - Some residual artifacts are present in both the filtered data cubes
- Refining the filtering process, using stricter input frequencies, or masking techniques could yield better results.





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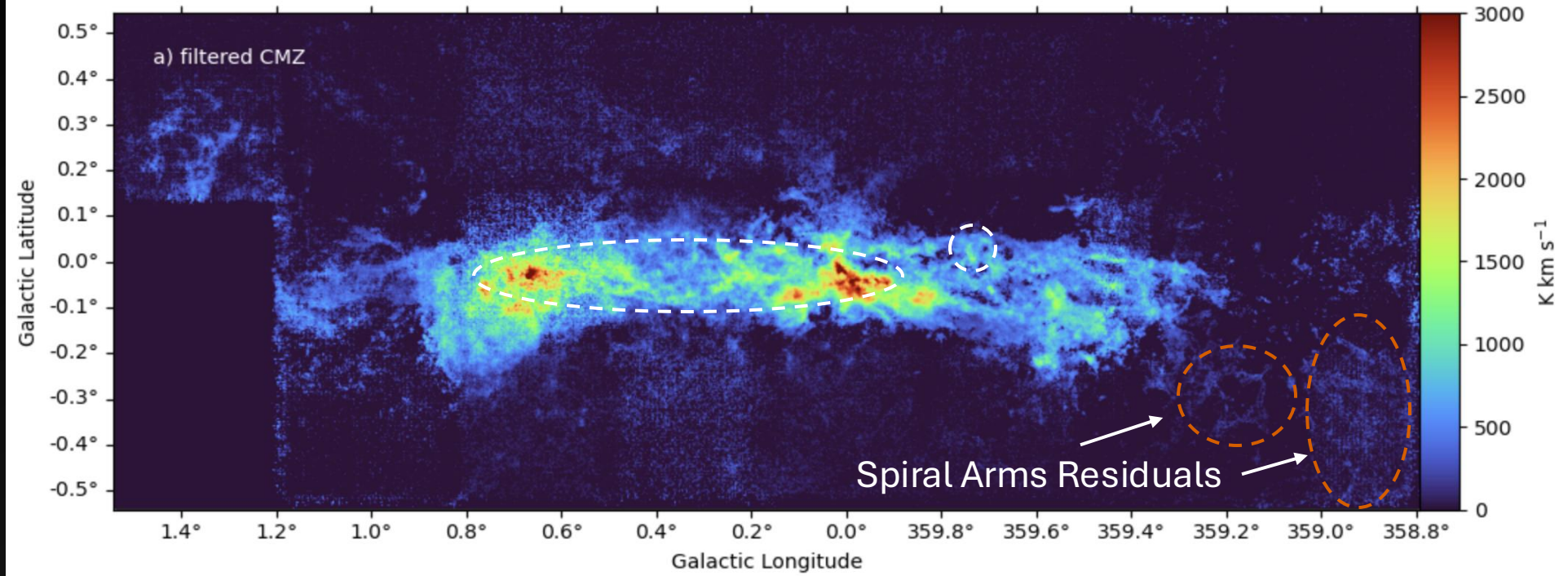
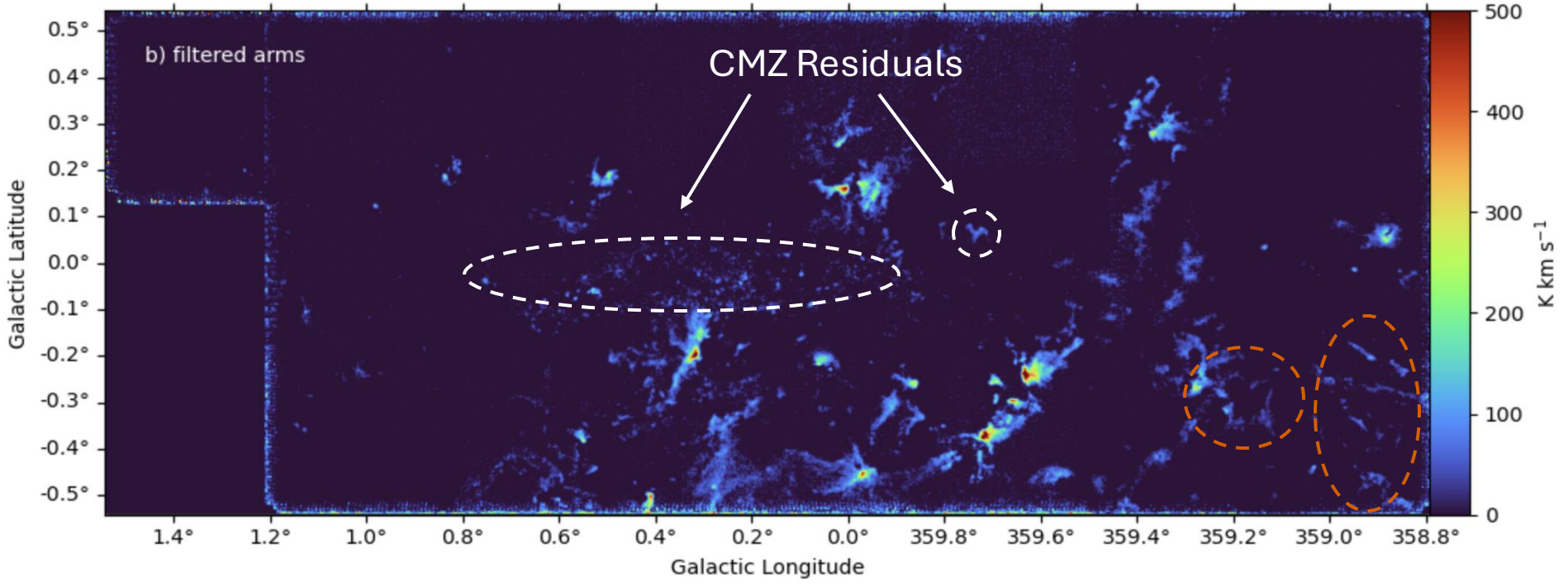
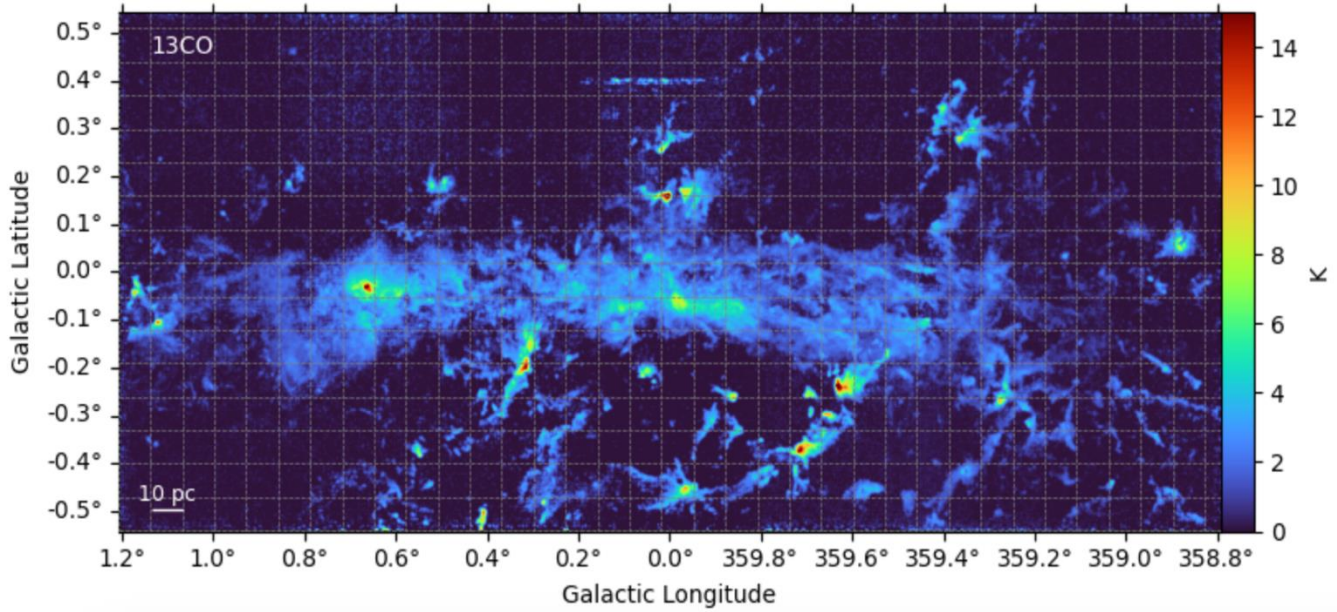
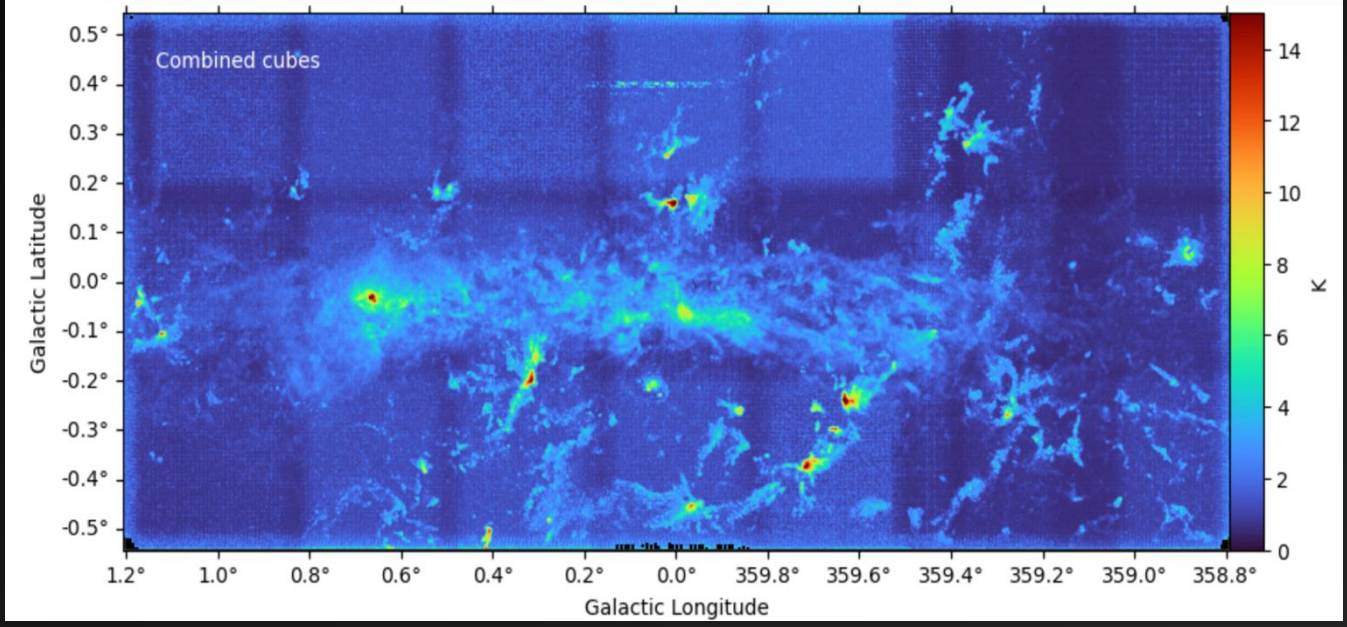
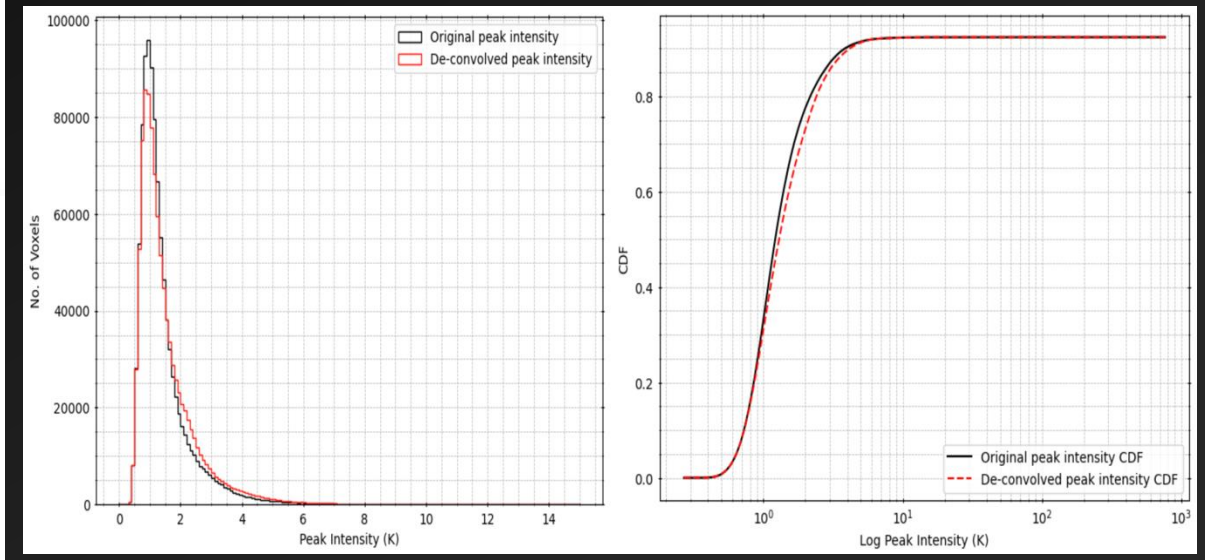








- The two combined cubes show the same morphological structure as seen in the peak intensity map
- Noise in the combined cubes is also combined



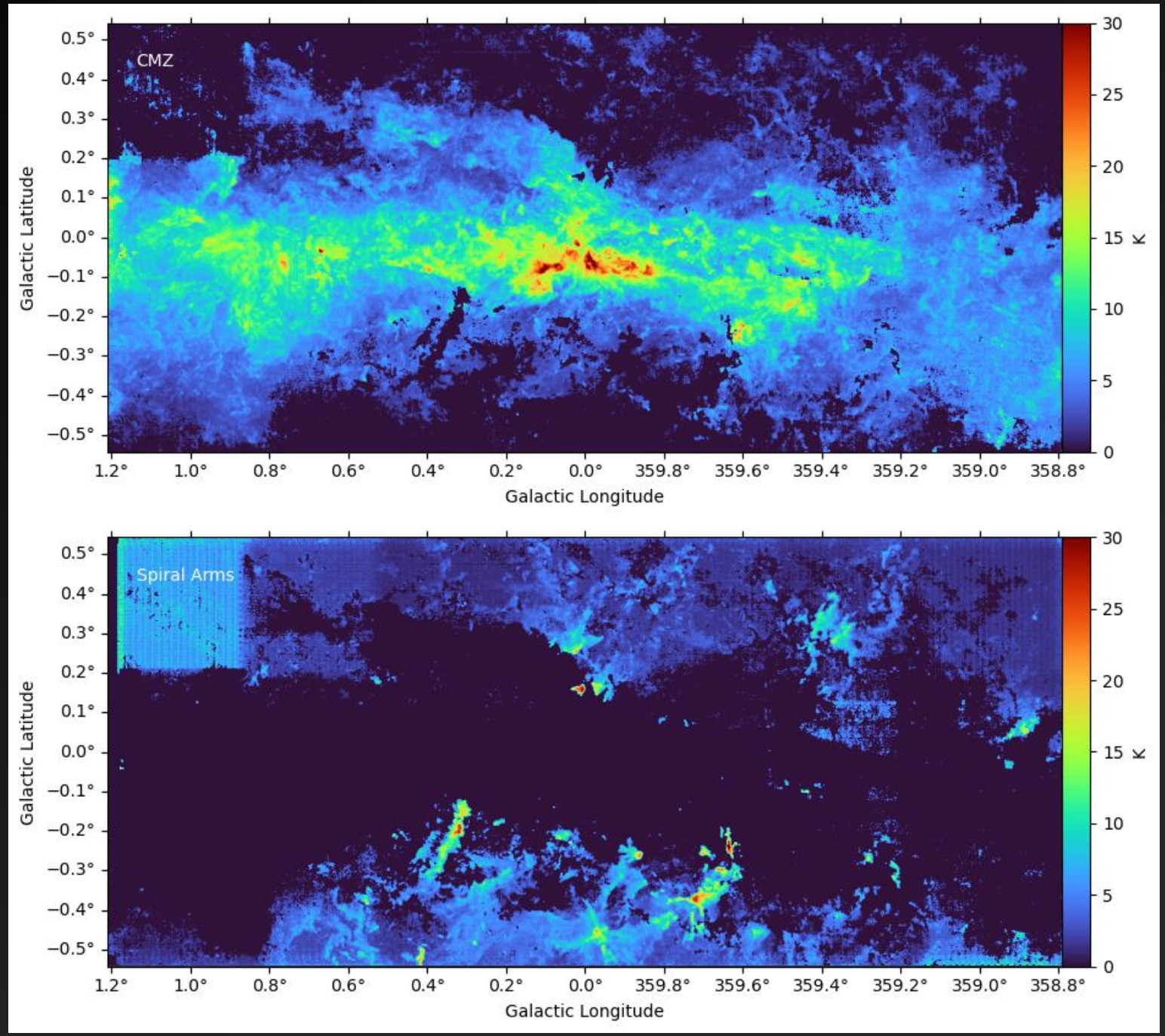
- The distribution in pixel intensities, and their Cumulative Distribution Functions is nearly identical

What about ^{12}CO ?

- Comparing the filtered image with the original peak intensity image shows the Spiral Arms can be extracted from the ^{12}CO data.

- Low intensity emission in the spiral arm regions is also removed – further refinement is needed to retain it

- Like ^{13}CO, there are residual signals in the filtered images and further refinement is needed to remove them



Conclusion

- Initial results demonstrate that Fourier Filtering the CHIMPS2 data is a viable method to separate the Spiral Arms from the CMZ
- Once refined, successful deconvolution using Fourier filtering will allow for the individual study of the Spiral Arms and CMZ, and will allow for direct comparison of their physical properties
- Future work will involve:
  - Refining the filtering process to reduce noise and remove residual signals in the deconvolved cubes
  - Determining the viability of wavelet analysis as an alternative method to Fourier Filtering
  - Further refining the process for the CHIMPS2 $^{12}\mathrm{CO}$ and extending it to our new JCMT $^{12}\mathrm{CO}$ observations as well as SEDIGISM $^{13}\mathrm{CO}$ CMZ data
  - Multi-line analysis of both the separated CMZ and Spiral Arm data cubes
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