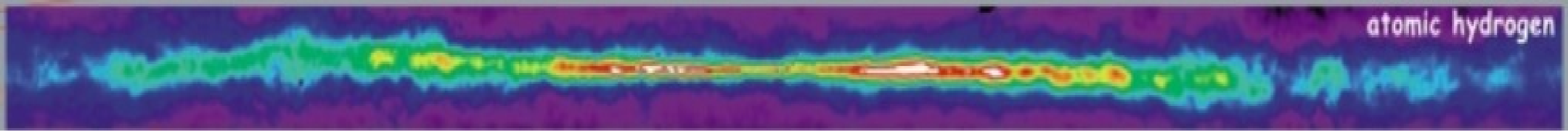


Leonardo Rossoni – 23/05/2024

DEV - RADIOASTRONOMY

Report number 5: 24 hours experiment

Experiment description
The goal of this experiment is to collect measurements on the Hydrogen Line by pointing towards a specific area of the sky for 24 consecutive hours (*220°N, 30° of elevation from the horizon*).
I expect to observe the passage of two different arms of the Milky Way during this period (*Perseus arm, Scutum-Centaurus arm and Galactic Bar*).
Additionally, measurements will be taken at a higher frequency (*1421MHz*) to determine if the same anomalies observed in previous test measurements are present.
The experiment started at 11:30AM (Rome time).

High-frequency measurements result
The same anomalies/peaks observed in previous tests were not detected. It is concluded that these were due to noise in the measurements rather than any particular astronomical objects.

Collected data
The data measured by the radio telescope were saved locally for a total of 24 hours, covering the entire predetermined duration and resulting in the collection of 132 measurement files. A preliminary examination of the collected data highlighted the need to develop a more sophisticated algorithm to extract useful information from the data. This necessity arises due to noise in the instrumentation, which caused the RTL-SDR dongle to record data with a specific shape—falling off at the extreme ends and skewed to the right across the spectrum, as you can see in the image down here.

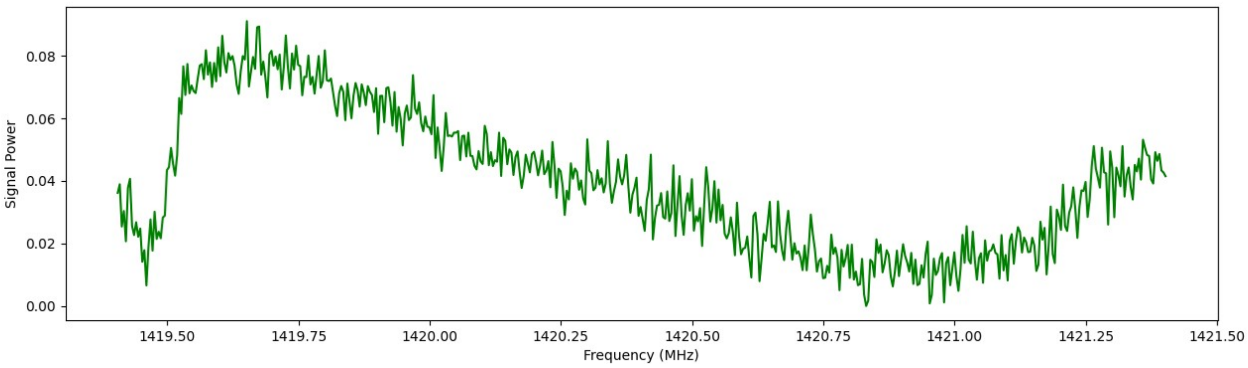


Figure 1: Raw data reading (1 out of 132)

At first glance, these data do not seem very interesting, especially when creating a map of these raw measurements, which results in a set of meaningless patches.

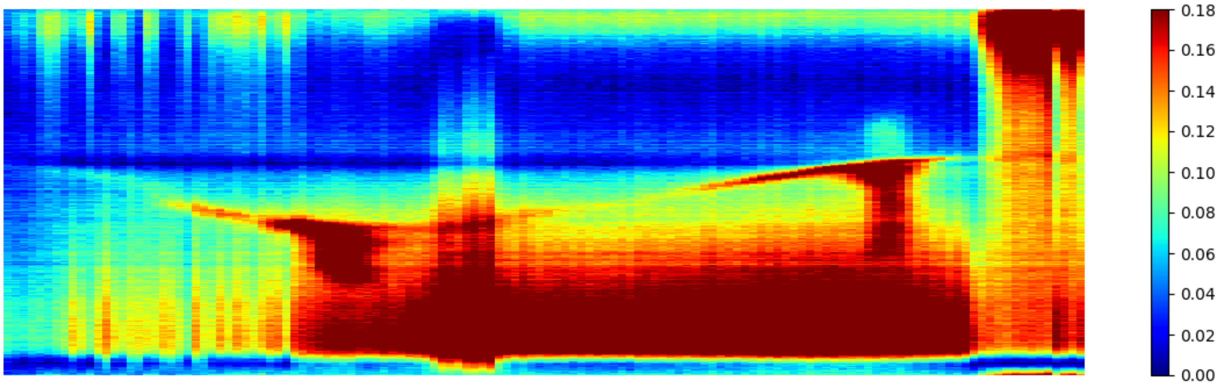


Figure 2: Raw data's heatmap (all 132 files used)

However, by manually inspecting the various collected measurements, it was possible to visually recognize the hydrogen peaks and determine their intensity.

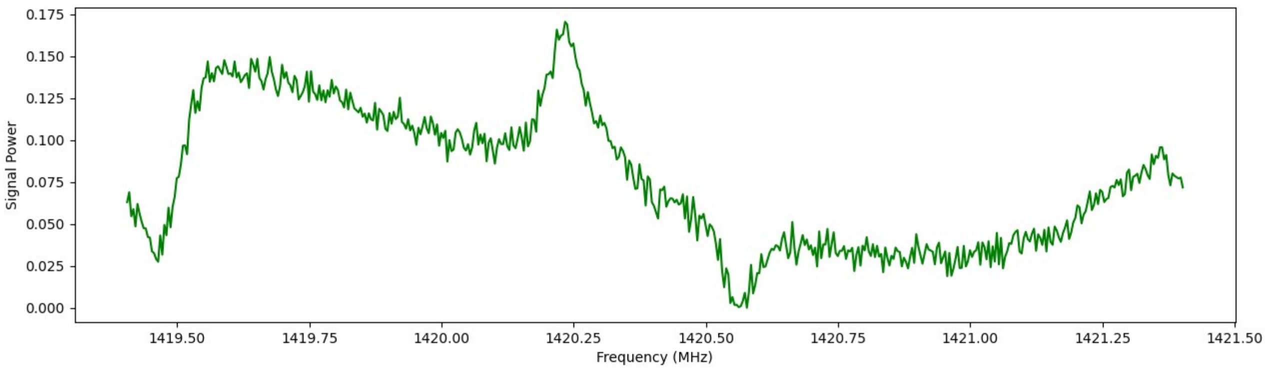


Figure 3: Example of visible hydrogen peak in one of the measurements

The algorithm

To extract useful information from these seemingly messy data, I wrote a signal processing algorithm in Python.

This algorithm employs various strategies and calculations to detect the presence of neutral hydrogen, reduce measurement noise, and amplify those peaks of interest for our data analysis.

The algorithm processes each collected measurement in sequence following these steps:

1. Trim Extreme Edges: cuts the extreme edges of the measurements to exclude the falling parts of the graph.
2. Generate a Smoothed Measurement Line: It creates a new measurement line by averaging the individual points of the graph, resulting in a much smoother and more homogeneous measurement/graph, without sudden peaks caused by noise.
3. Calculate Linear Regression Line: Using the results of the previous two steps, it calculates the linear regression line of these data. This line is then used to distinguish hydrogen peaks from background noise and to straighten the data from their skewed form to a flat form, without distorting the individual power values of the measured signals.
4. Create Amplification Coefficient: Through several calculations, an amplification coefficient proportional to the difference between the

linear regression line and the measurement power (from the result of step 2) is created. This amplifies the hydrogen peaks significantly, while smaller noise peaks remain negligible and do not affect the final result.

5. Display Final Result: The final result is displayed on a heatmap for easy interpretation (x-axis = time; y-axis = frequency; heat-color = signal power).

This method ensures the extraction of meaningful data from otherwise noisy and unorganized measurements.

(Please, click on this link to see an animated GIF on how the algorithm works to produce the results.)

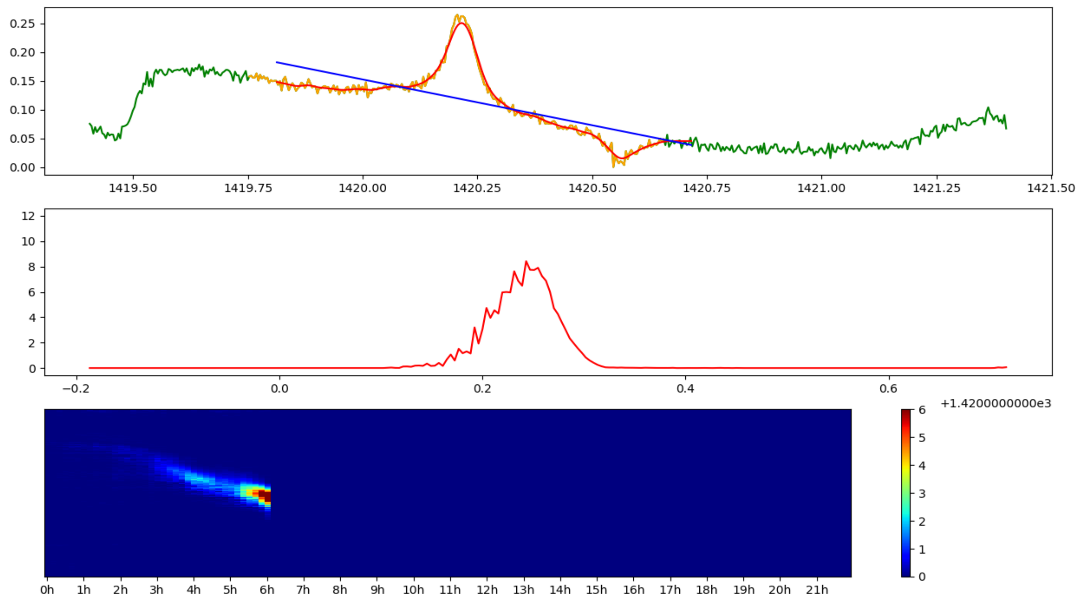


Figure 4: Example image of the algorithm

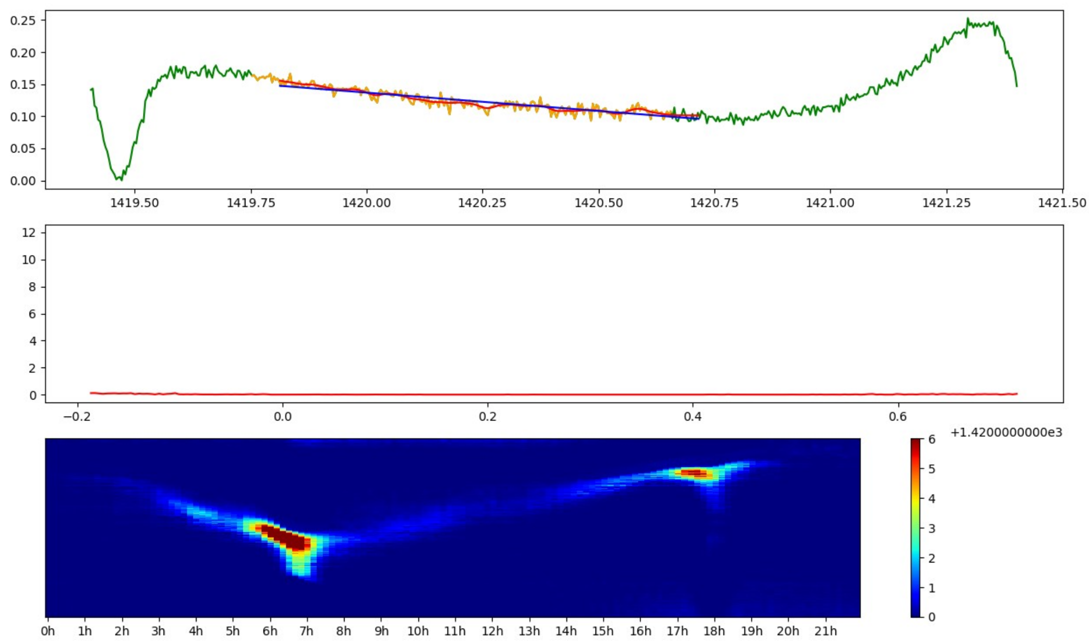


Figure 5: Example image of the algorithm

Analyzing the results
After applying the algorithm described, we were able to create a more interesting heatmap for analysis (heatmaps x-axis: time, y-axis: frequency).

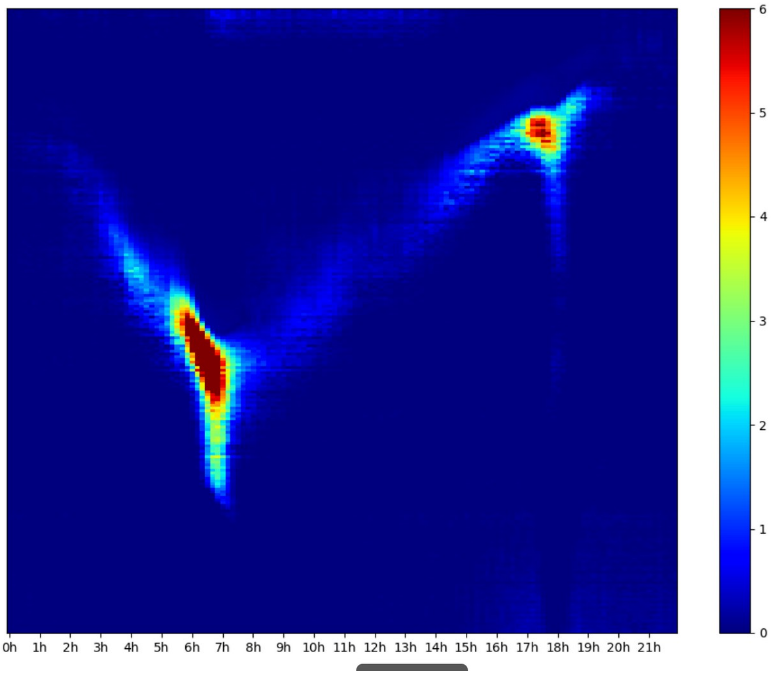


Figure 6: Final heatmap

Starting with an overview, we immediately notice the presence of two high-intensity spots:

- The first detected about 5 hours after the radio telescope was turned on, fading over the next 2 hours.
- The second detected about 17 hours after activation, also fading over the next 2 hours.

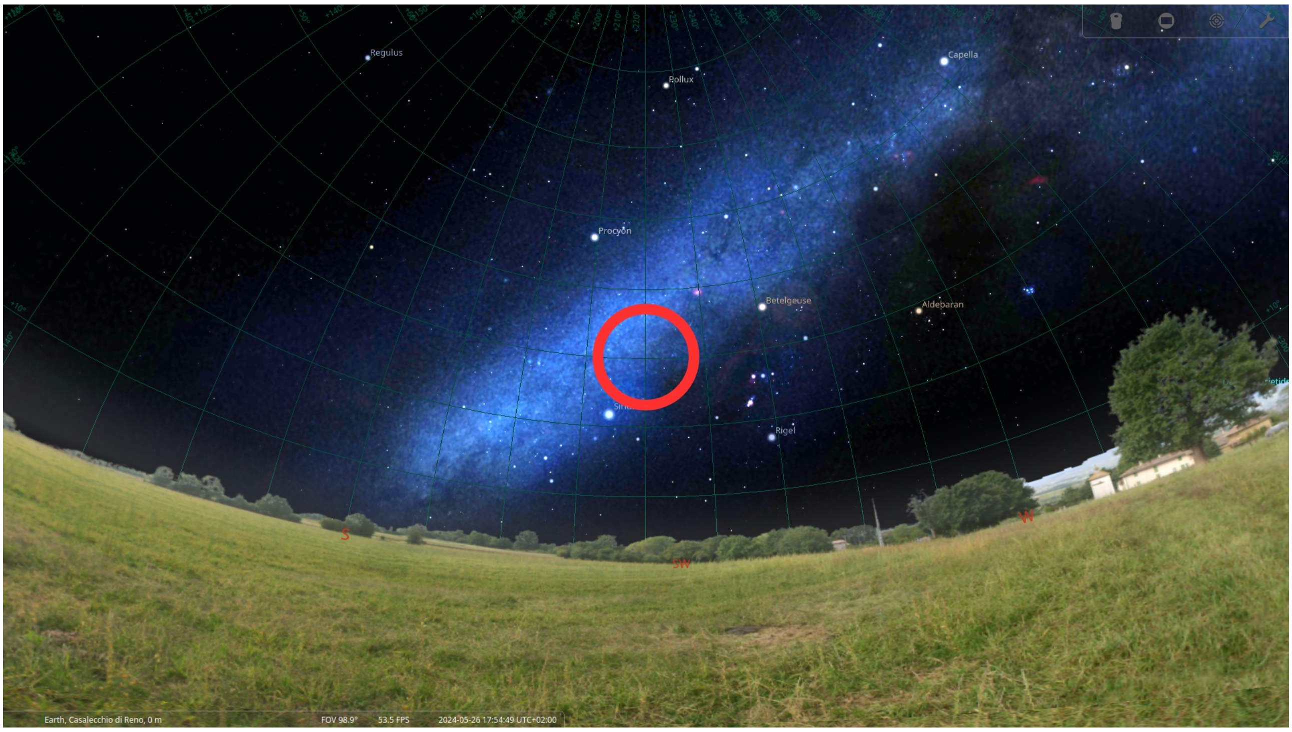


Figure 7: First passage through the Milky Way's plane, highlighting the galactic arm. Telescope focus indicated by red circle.

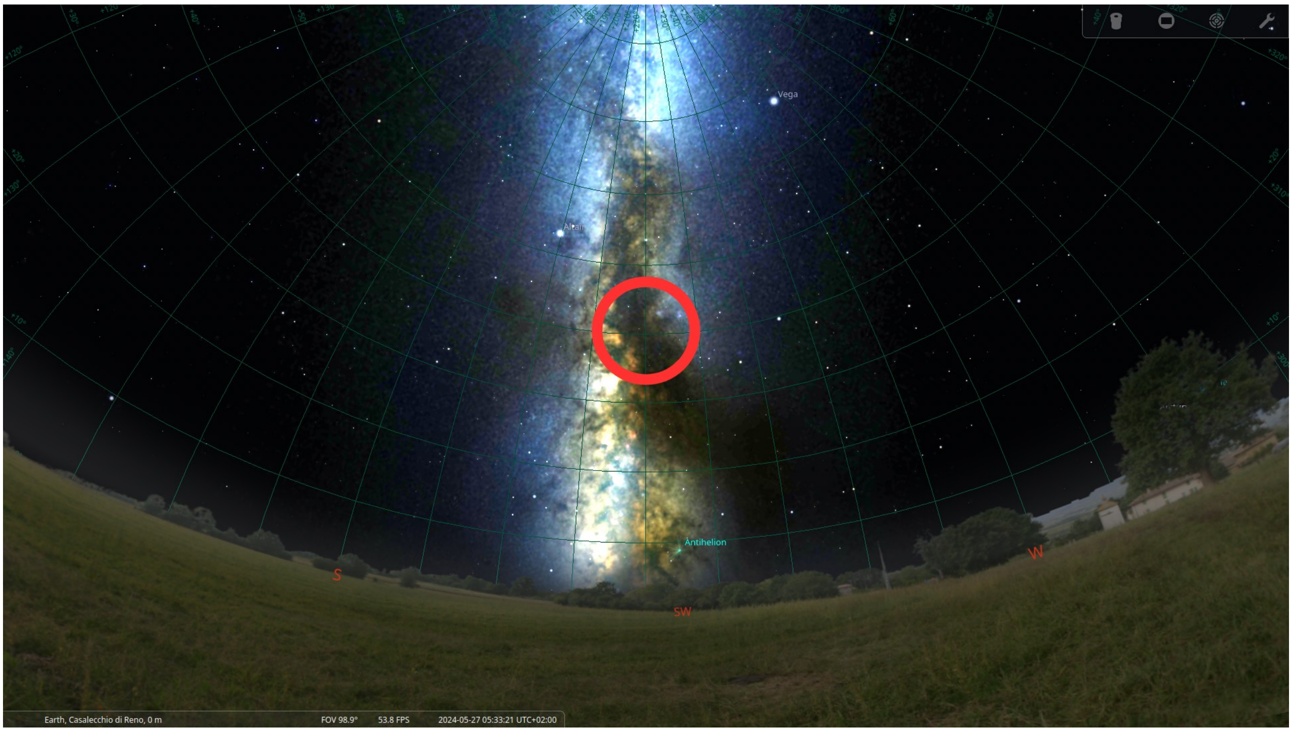


Figure 8: Second passage through the Milky Way's plane, highlighting the galactic arm. Telescope focus indicated by red circle.

Using the Stellarium software and observing the sky coordinates where the radio telescope was pointed, we can precisely correlate the two occurrences of the galactic arms with the reported times. This suggests that the data were processed correctly by the algorithm, which did an excellent job of separating the hydrogen signal from the background noise.
Note the difference between the two heatmaps.

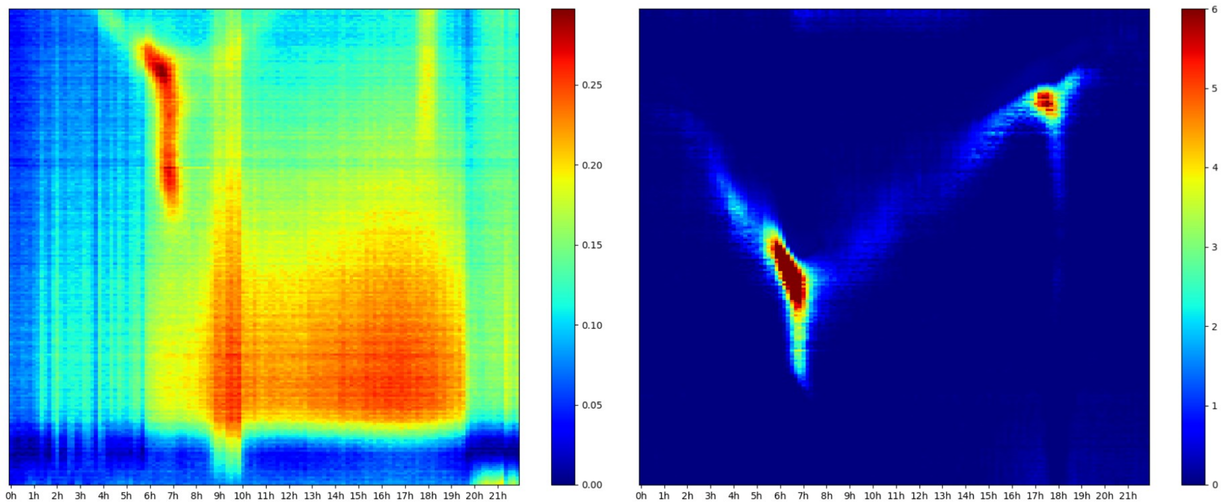


Figure 9: Heatmap before and after processing the data with the algorithm

Already at first glance, there's something quite intriguing, albeit somewhat subtle.
Observing the post-processed heatmap, it becomes evident that, even away from the peaks, traces of hydrogen radiation are consistently detected by the radio telescope throughout the duration of the measurements (notice the faint light blue shadow connecting the first to the second peak).
This demonstrates that hydrogen is not only prevalent within the galactic plane but also surrounds us in all directions.
It's fascinating to observe how this shadow almost entirely disappears exactly halfway between the first and second high-intensity spots, precisely when the telescope was pointing perpendicular to the galactic plane, towards deep space, where hydrogen radiation from our galaxy cannot be detected.
The same phenomenon is observable at the edges of the heatmap, approximately 12 hours away from the central region. Here, we observe a similar effect because we are still observing deep space perpendicular to the galactic plane, but this time in the opposite direction.

1. Analyzing the first spot

Let's now study in more detail what we are observing, starting with the analysis of the first high-intensity spot.

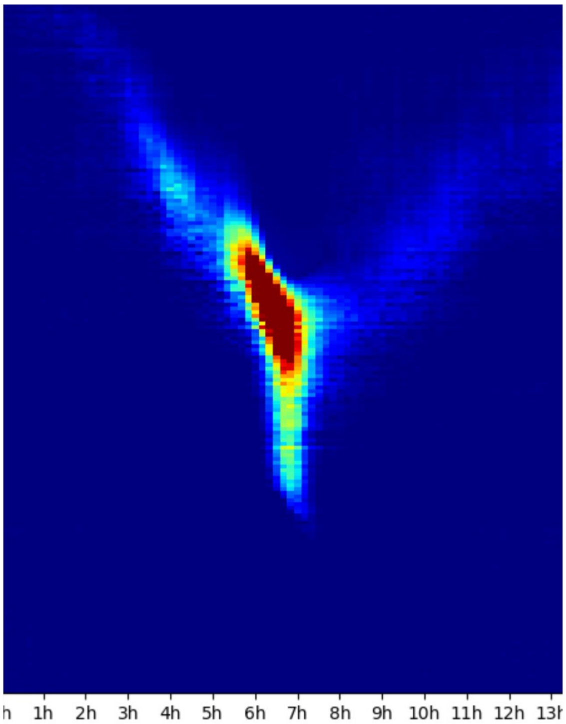


Figure 10: First high-intensity spot

This represents the first passage of the Milky Way's arms over Earth's skies since the radio telescope was activated.

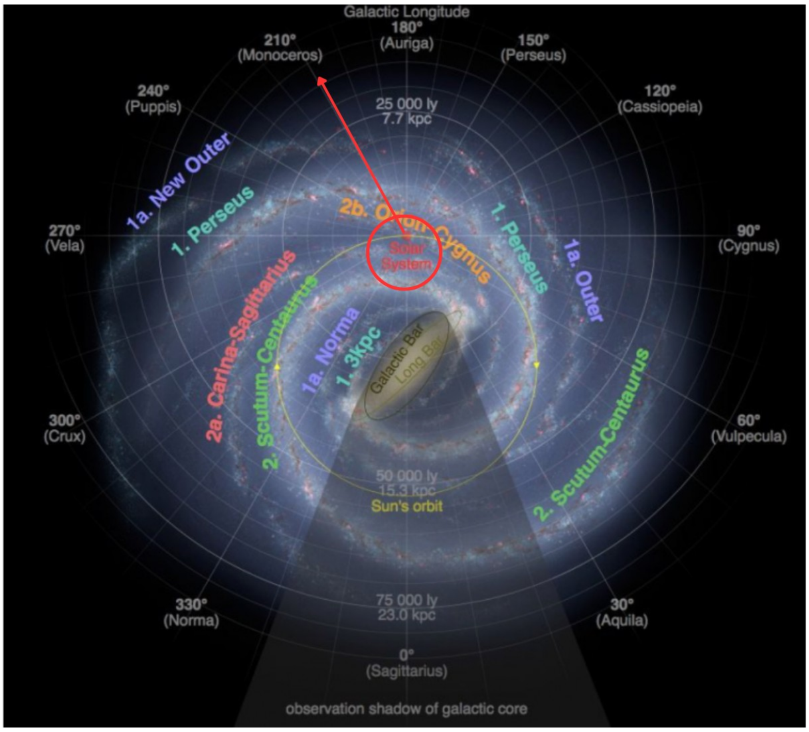


Figure 11: Milky Way map with constellations as reference. The red arrow shows the pointing direction fo the radiotelescope. The solar system is in the red circle

By looking at the map of our galaxy and orienting ourselves with the constellation we were pointing towards, Monoceros, we conclude that we are observing a region of the galaxy that is more external and farther from the core compared to Earth.

This implies that we should expect a certain redshift in the measurements, given that our relative velocity with respect to the clouds of neutral hydrogen in that area is quite high and directed in the opposite way (meaning we are moving away from that gas).

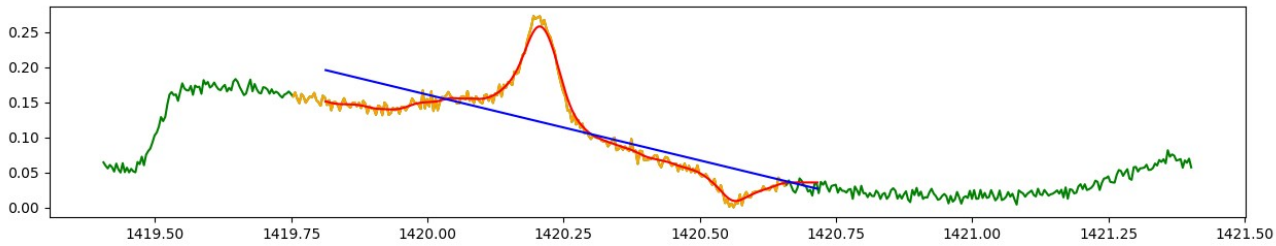


Figure 12: Data graph showing the hydrogen peak detected during the first passage of the galactic arm

Now, examining the spot on the heatmap and the various graphs of the data collected during those few hours, we can verify that the measured peak had a frequency around 1420.19 MHz (noting that the Hydrogen Line has a frequency of 1420.4057 Mhz).
In conclusion, what we are observing in the heatmap is the tail end of the Perseus Arm, which, looking from the Galactic Bar towards the solar system, is exactly behind us.

But there's more. In fact, upon closer examination of the spot from this first passage, it's possible to notice that when the telescope was pointing roughly towards the center of the galactic arm, a second peak, quite close to the first but with more red-shift, appears in the data.

This can be observed both in the heat map, where there is an intense green/yellow area lower than the rest of the spot (indicating lower frequency), and by examining the individual data graph.

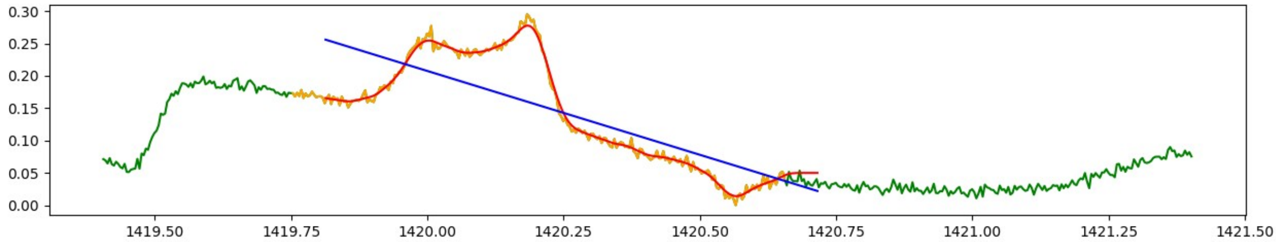


Figure 13: Data graph image showing secondary peak detection

Thanks to this greater red-shift effect, it can be concluded that this is neutral hydrogen located in even more outer regions of the galaxy and therefore, with even lower relative velocity compared to Earth. Since this secondary peak was recorded when the radio telescope was pointing as close to the galactic plane as possible, it's possible that these radiations may even originate from the New Outer arm, beyond the Perseus arm. These clouds of neutral hydrogen would be located approximately 20,000 light-years from Earth.

2. Analyzing the second spot

Let's now shift our focus to the second high-intensity spot.

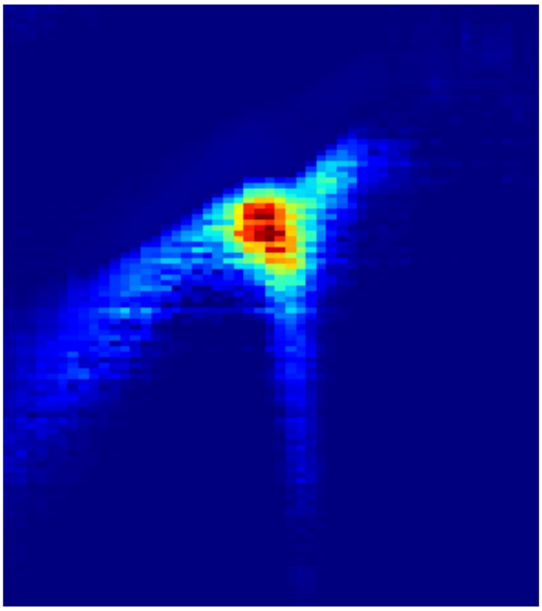


Figure 14: Second high-intensity spot

This time, the radio telescope was pointing in the opposite direction compared to before, towards the Aquila constellation.

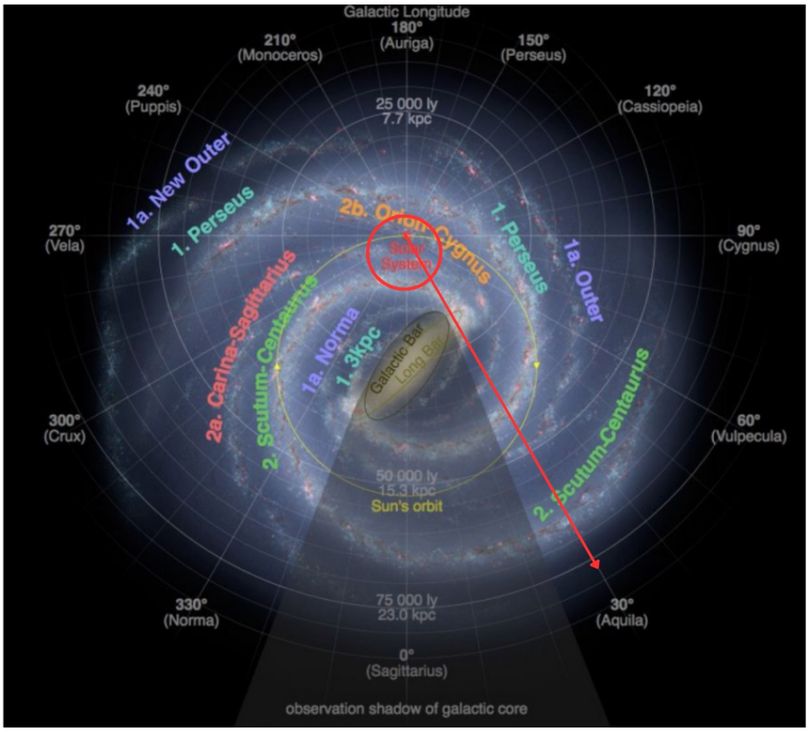
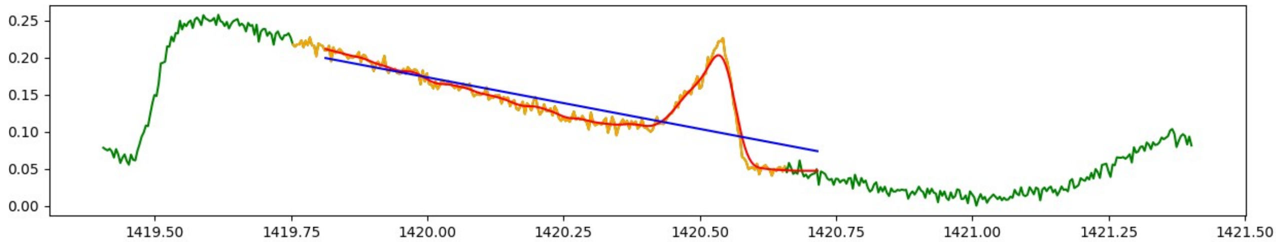


Figure 15: Milky Way map with constellations as reference. The red arrow shows the pointing direction fo the radiotelescope. The solar system is in the red circle

This time, we notice that we are pointing towards much more internal regions of the galaxy, almost directly towards the Galactic Bar. This implies that we would expect to observe a certain blue shift in the measurements since our relative velocity with respect to those areas, although not very high, is negative, indicating that we are approaching.



These assumptions are confirmed by the collected data, where a radiation peak around 1420.52 MHz was recorded.

Conclusions

In conclusion, the analysis of the radio telescope data, aided by this new signal processing algorithm, has provided valuable insights into the structure and dynamics of our Milky Way galaxy. By meticulously examining the high-intensity spots observed during the telescope's operation, I was able to discern the presence of galactic arms and their relative positions in the sky. Through careful analysis of the frequency shifts in the hydrogen line emissions, I identified regions of both inward and outward motion, shedding light on the complex kinematics of the galaxy. Furthermore, the correlation between the observed peaks and the known structure of the Milky Way, as confirmed by astronomical software such as Stellarium, underscores the accuracy of my findings. This study not only demonstrates the effectiveness of radio astronomy techniques but also highlights the ongoing quest to unravel the mysteries of our cosmic neighborhood.