VELOCITY CURVE AND MAP OF THE MILKY WAY

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INTRODUCTION

The velocity curve of a galaxy displays the velocity at which an object moves at a given distance from the center, assuming it follows a circular trajectory. Such curves require radio astronomical observation using the 21 cm emission line of hydrogen. Velocity curves further served as a main argument in favor of the existence of what is called “Dark Matter” [2]. In this work, such a curve was constructed to investigate the relation with different models for the mass distribution of the Milky Way.

WORKING PRINCIPLE OF THE ANTENNA AND METHOD

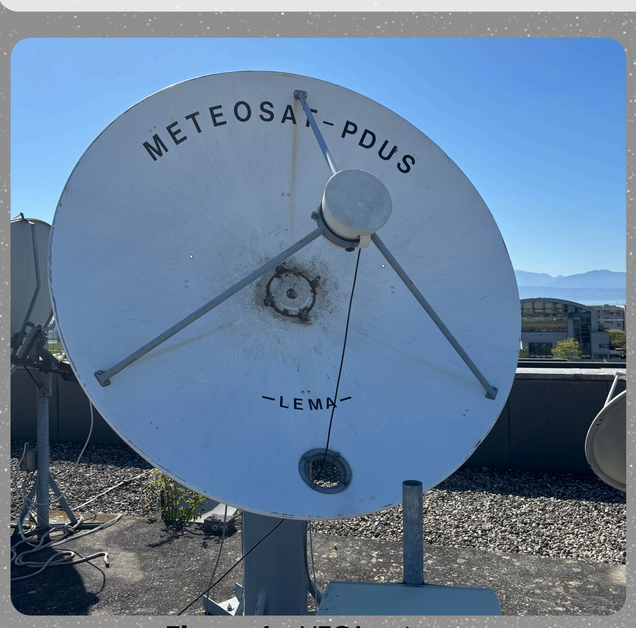

Figure 1 : VEGA antenna

H21 emission line :

- Spin flip of the electron : rare event
- BUT large abundance of hydrogen in Universe

VEGA (Very Elegant Galactic Antenna) :

- Receiver : copper helical antenna around non-conducting rod inside aluminum pan
- Feed : electronic components (amplifiers, filters, bias tee)
- Recorder : electrical → digital converter

Signal processing :

- Obtain a **P**ower **S**pectral **D**ensity curve
- First uniform filtering of the PSD signal
- Substracting the noise

CALIBRATION

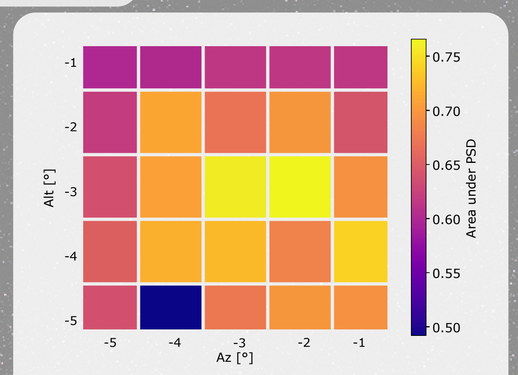

Figure 2 : Calibration of the antenna

- Pointing antenna to the exact coordinates of the Sun
- Calculating the area under the PSD curve
- Repeating the operation with an offset on the Az/Alt coordinates to find maximum received power
- As seen on the figure, best offset is $(-2^\circ, -3^\circ)$ Az/Alt

21 CM SIGNAL

- Hydrogen Emission Line at $f_0 = 1420.405751\ \text{MHz}$ [3]
- Movement of the emitting source (hydrogen cloud) $\Rightarrow$ Doppler shift observed
- Radial velocity (along line of sight): $v_r = c\dfrac{f_{obs} - f_0}{f_{obs}}$ (Doppler formula)
- Formation of a clearer peak for $b \to 0^\circ$ (more emission in the milky way than in outer space)

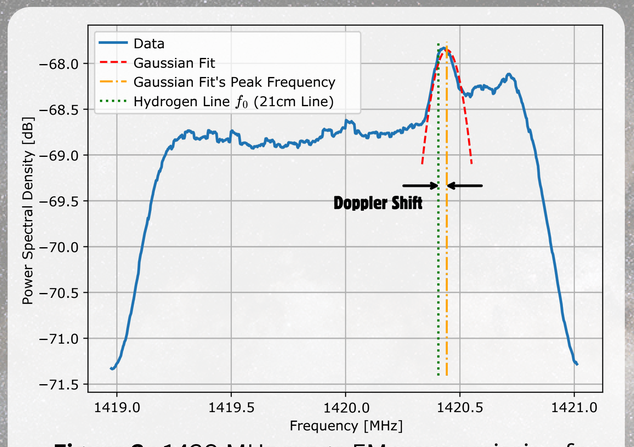

Figure 3 : 1420 MHz range EM wave emission for $(90^\circ, -1^\circ)$ Az/Alt

GALACTIC MAP

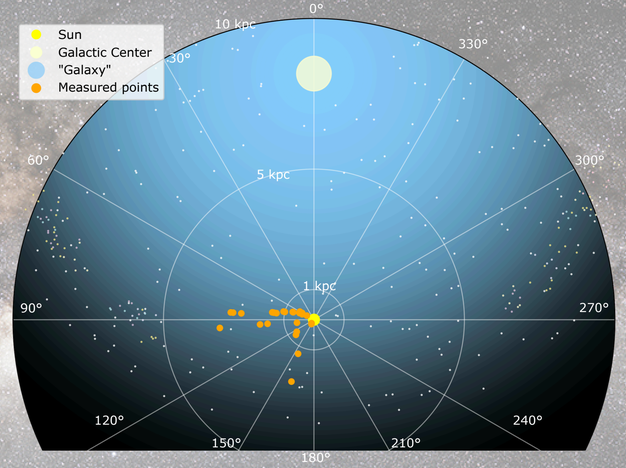

Figure 4 : Schematic map of the Galaxy with points measured in this work (local Galactic disk : distance to the Sun <5kpc)

Velocity-Vector Method :

- Approximation for Sun-Cloud distance :

$$d = \left| \frac{v_r}{A \sin(2l)} \right|$$

- From cosine law :

$$R = \sqrt{R_0^2 + d^2 - 2R_0 d \cos(l)}$$

→ Oort constant : $A = (14 \pm 1)\ \text{km} \cdot \text{s}^{-1} \cdot \text{kpc}^{-1}$

→ Galactic longitude : $l \in [60^\circ, 160^\circ]$ and latitudes $b = \{-1, 0, 1\}$

→ Distance Sun - Galactic Center : $R_0 \approx 8.17\ \text{kpc}$

VELOCITY CURVE

Experimental velocity :

- From velocity-vector method :

$$v_{circ} \cos\left(\angle(v_r, v_{circ})\right) = v_r + v_0 \sin(l)$$

$$\Rightarrow v_{circ} = \frac{R}{R_0}\left(\frac{v_r}{sin(l)} + v_0\right)$$

→ Sun’s velocity around GC : $v_0 \approx 220\ \text{km.s}^{-1}$ [4]

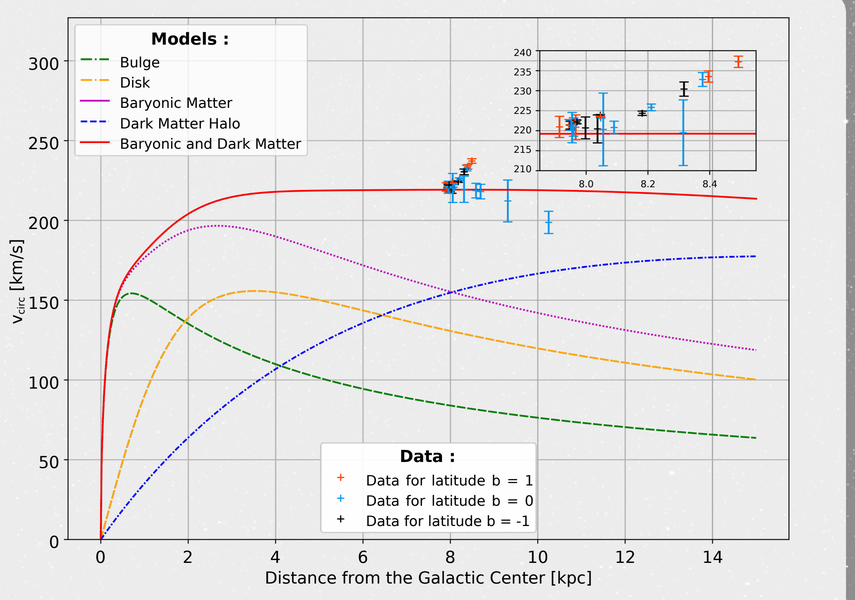

Figure 5 : Velocity curve for measured points and theoretical models

Theoretical velocity profiles [5]:

- Circular motion $\Rightarrow$ acceleration : $a = \dfrac{v^2}{r}$

  gives velocity : $v = \sqrt{-r\dfrac{\partial \phi}{\partial r}}$

- Bulge model (Hernquist) : $v_b = \sqrt{r\dfrac{GM_b}{(r_b + r)^2}}$

- Disk model (Plummer) : $v_d = \sqrt{\dfrac{GM_{0,d}r^2}{[r^2 + (r_d + z_d)^2]^{3/2}}}$

- Dark Matter Halo model (Einasto) : $v_h = \sqrt{\dfrac{GM_{0,h}}{r \cdot r_h^3}\int_0^r r'^2 e^{-\left(\frac{r'}{r_h}\right)^\alpha} dr'}$

- Total theoretical velocity curve : $v_{circ,th} = \sqrt{v_b^2 + v_d^2 + v_h^2}$

Normalized masses

length scales

CONCLUSION

In this work, the 21 cm emission line from neutral hydrogen was observed, using the VEGA antenna. This HI line was shown to be a powerful tool for tracing the structure and dynamics of galaxies, including the Milky Way. The former was roughly mapped in the Galactic Map, while the latter was studied through a velocity curve.
These results show the potential of radio observations, even with rather modest instrumentation, to explore large-scale Galactic properties. Further observations at more longitudes would allow for a more complete velocity curve since one of the problems found in this work is the lack of measurements further away from the Galactic Center.

REFERENCES

[1] Background image : ESO/S. Brunier ; [2] Rubin et al., *Rotational properties of 21 SC galaxies with a large range of luminosities and radii,* 1980 ; [3] M. Moazzenzadeh, J. T. Firouzjaee, *Searching for the hydrogen 21 cm line in cosmos*, 2021 ; [4] Horellou et al, *SALSA project documentation : Mapping the Milky Way, 2015*
[5] Xiaowei Ou et al, *The dark matter profile of the Milky Way inferred from its circular velocity curve,* 2023