Investigating Pulsar Spectral Turnover in the Gum Nebula: Insights from the Murchison Widefield Array

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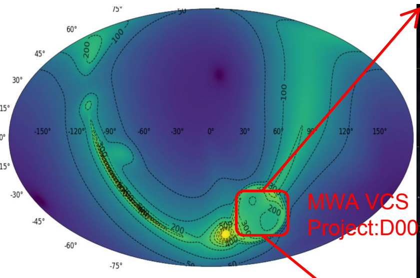
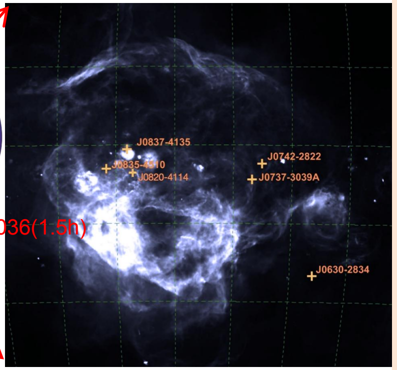
Abstract

The pulsar spectral turnover in low frequencies below 300 MHz may be caused by absorption in the magnetosphere, loss of efficiency of the emission mechanism, or interstellar effects. The usual physical mechanisms explaining turnover are synchronous self-absorption (SSA), free-free absorption (FFA), or superposition. Therefore, we selected pulsars within the Gum Nebula as targets for studying turnover. We employed MWA-VCS to utilize 12 coarse (2.56 MHz) channels spanning from 75 MHz to 240 MHz, including polarimetric information, conducting a more thorough investigation into the distribution of interstellar medium in this area. This study will aid in understanding interstellar absorption near the Gum Nebula and clarifying the absorption mechanism of the pulsar spectral turnover phenomenon, as well as the properties of the magneto-ionic interstellar medium (ISM).





Pulsars detected in the field of view (FOV) of the proposed observation are shown in the table.

Pulsar	R.A. (J2000)	Dec. (J2000)	Period (s)	DM (cm^{-3} pc)	Distance (kpc)	S400 (mJy)
J0630-2834	06:30:49.40	-28:34:42.78	1.2444	34.43	0.320	206
J0737-3039A	07:37:51.25	-30:39:40.71	0.0227	48.92	1.100	*
J0742-2822	07:42:49.06	-28:22:43.76	0.1668	73.73	2.000	296
J0820-4114	08:20:15.46	-41:14:35.20	0.5454	113.40	0.571	65
J0835-4510	08:35:20.61	-45:10:34.87	0.0893	67.77	0.280	5000
J0837-4135	08:37:21.19	-41:35:14.56	0.7516	147.20	1.500	197

Theoretical model of pulsar spectral turnover

Synchrotron self-absorption model

Synchrotron radiation emerges as relativistic electrons traverse uniform and straight magnetic field lines, embodying a process that includes both emission and absorption. Recognized as the particles' spontaneous transitory radiation, synchrotron self-absorption can be calculated by considering the established radiation power and the interplay of Einstein coefficients. According to Sieber's model, the synchrotron self-absorption is represented as follows:

$$S(\nu) = b(\frac{\nu}{\nu_0})^{\beta}(1 - e^{-c(\frac{\nu}{\nu_0})^{\alpha-\beta}})$$

where b is the scaling factor of the intrinsic flux of the pulsar, the parameters c, α and β are values fitted from measurements..

Free-free absorption model

Free-free absorption occurs when electrons collide with ions. In this process, they absorb photons and move from lower to higher kinetic energy states. Kijak et al. (2017) proposed that spectral turnovers in the interstellar medium result from free-free thermal absorption. They analyzed the spectra of all known pulsars and used observational data to constrain the properties of the absorbing materials, helping to identify different absorption sources. Assuming a single power law for the intrinsic spectra of pulsars, they estimated the optical depth using an approximate formula for free-free thermal absorption:

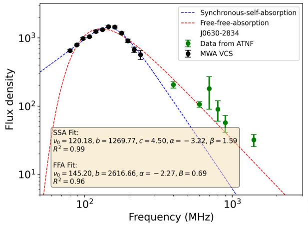
$$S(\nu) = b(\frac{\nu}{\nu_0})^{\alpha} e^{-B(\frac{\nu}{\nu_0})^{-2.1}}$$

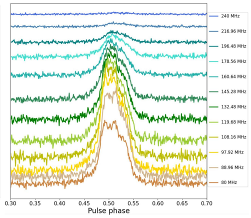
b is the pulsar's intrinsic flux scaling factor, α is its intrinsic spectral index, and the frequency v is measured in GHz. The formula $B = 0.08235 \times T_e^{-1.35} EM$ calculates B, where T_e is the electron temperature and EM is the emission measure along the line of sight to the pulsar. The Levenberg-Marquardt least squares algorithm is used to achieve the best fit for the observed spectrum.

Sieber et al. (1973) represented the free-free thermal absorption model as follows:

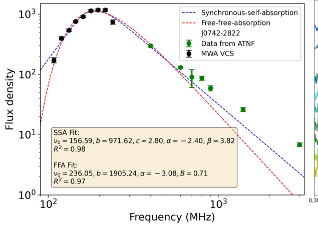
$$S(\nu) = b(\frac{\nu}{\nu_0})^{\alpha} e^{-\tau})$$
$$= b(\frac{\nu}{\nu_0})^{\alpha} exp\{-3.014 \times 10^4 \times EM \times T^{-1.5}\nu^{-2} \times \ln(49.55 \times T^{1.5}\nu^{-1})$$

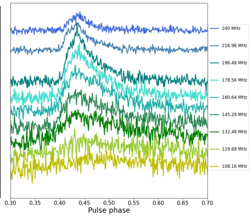
where T represents the temperature of the absorbing cloud in Kelvin, EM represents the emission measure along the line of sight to the pulsar, with units of cm^{-6}pc, and v is in units of MHz.

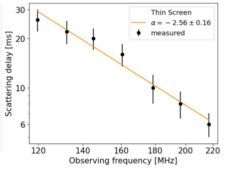


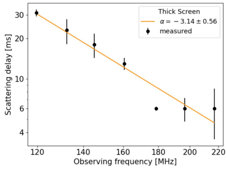


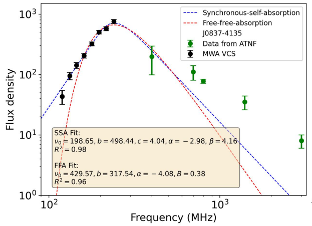
- J0630-2834: turnover likely due to synchrotron self-absorption, as no scattering delays are observed.
- J0742-2822: scattering tail delays suggest external medium absorption likely causes low-frequency turnover.
- J0837-4135:the alpha value closer to a Kolmogorov spectrum supports external medium absorption's influence on turnover.

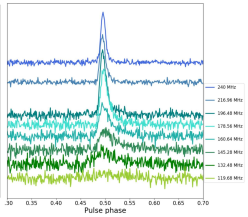


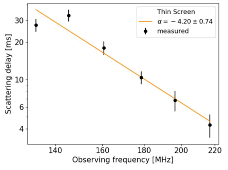


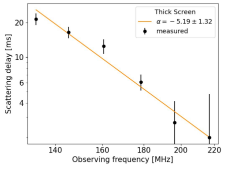


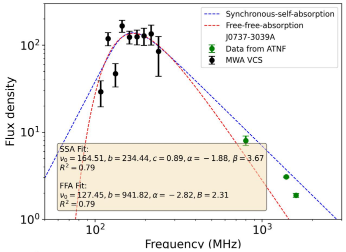


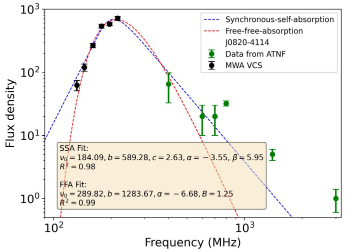












Discussion and Future Research

- J0737-3039A: Part of a pulsar binary with no significant scattering. Future studies will incorporate polarization to further validate the value of B in free-free absorption.
- J0820-4114: Due to its weak signal and indistinct scattering, no scattering fit was performed. Future research will include polarization to further validate the value of B in free-free absorption.
- J0835-4510: Scattering affects the entire pulse profile, causing substantial deviations in flux calculations from the time domain. Future studies will use imaging to obtain more accurate flux measurements and explore polarization further.

reference

Sieber W. A&A, 1973, 28: 237

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