Gigahertz-peaked spectra pulsars

Karolina Rożko

in collaboration with

Wojciech Lewandowski, Jarosław Kijak, Rahul Basu

The University of Zielona Góra

Janusz Gil Institute of Astronomy, Poland

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(Radio) Pulsars and their spectra

Rapidly rotating highly magnetised neutron stars

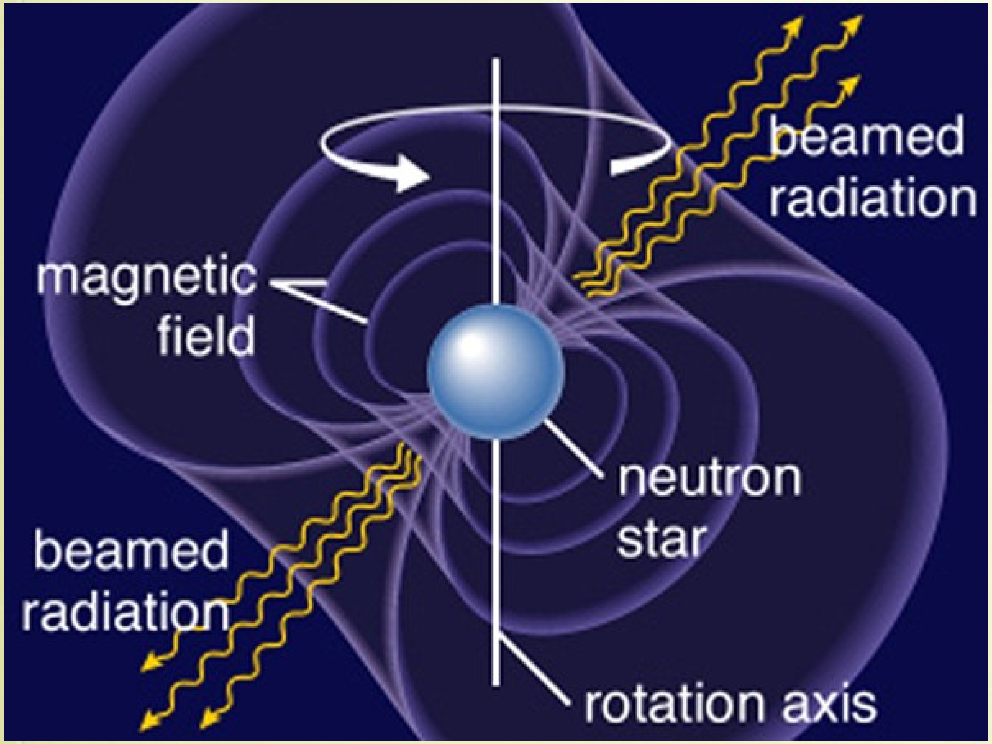


Figure 1:The model of the pulsar magnetosphere.
Picture from: http://astronomy.nmsu.edu.

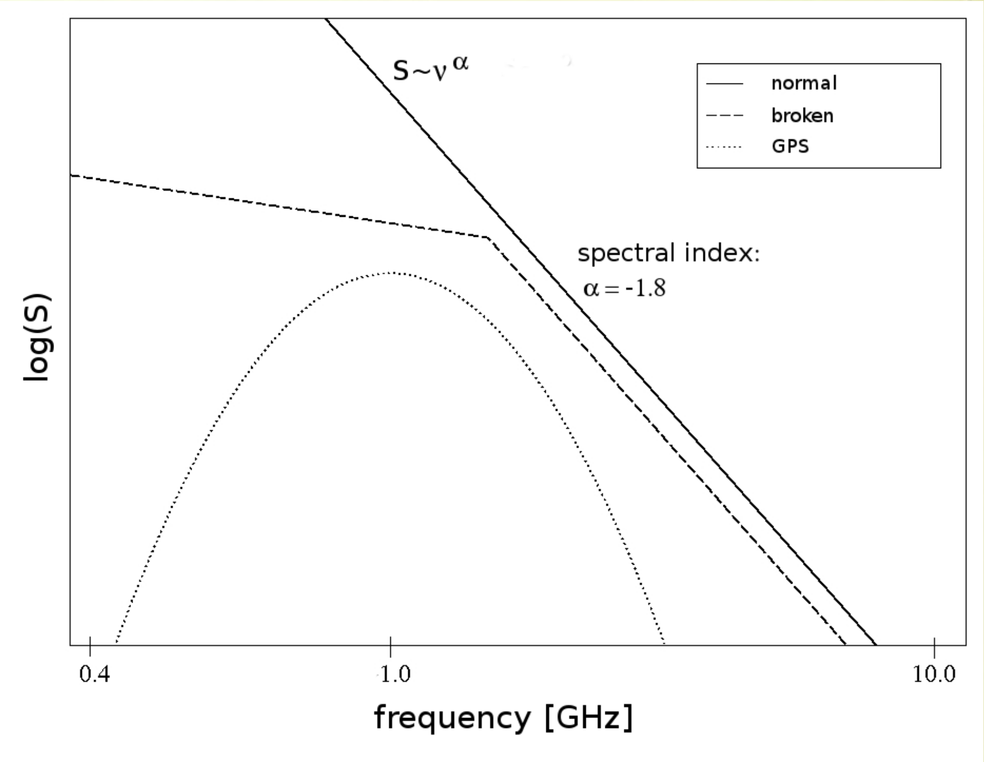


Figure 2: The morphological classification of the pulsar's radio spectra in the frequency range 100 MHz – 10 GHz.

A case of B1259-63 + Be star

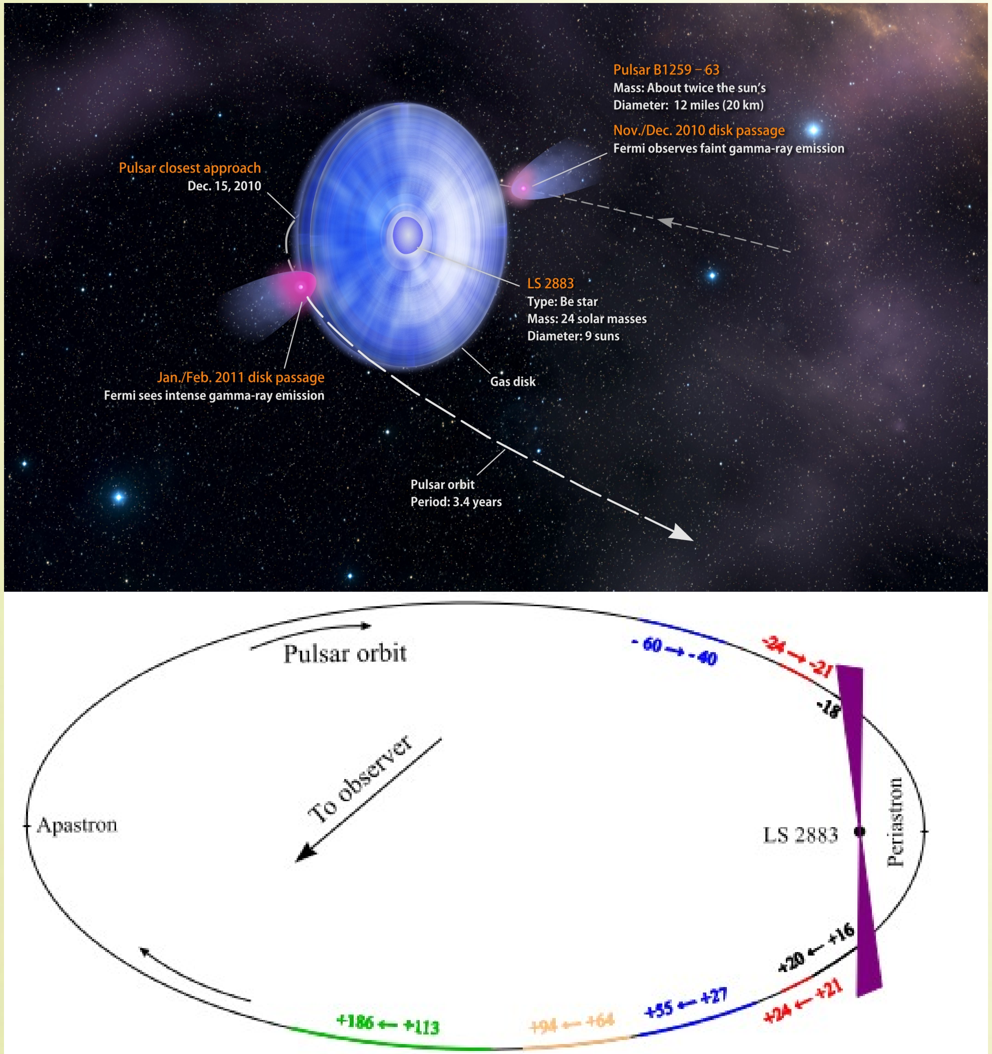


Figure 3: Top: The view of a binary pulsar B1259-63 with Be star LS 2883 from Earth (image credit: www.nasa.gov).
Bottom: Scheme of the orbital epochs over which the spectra were averaged (Kijak et al. 2011).

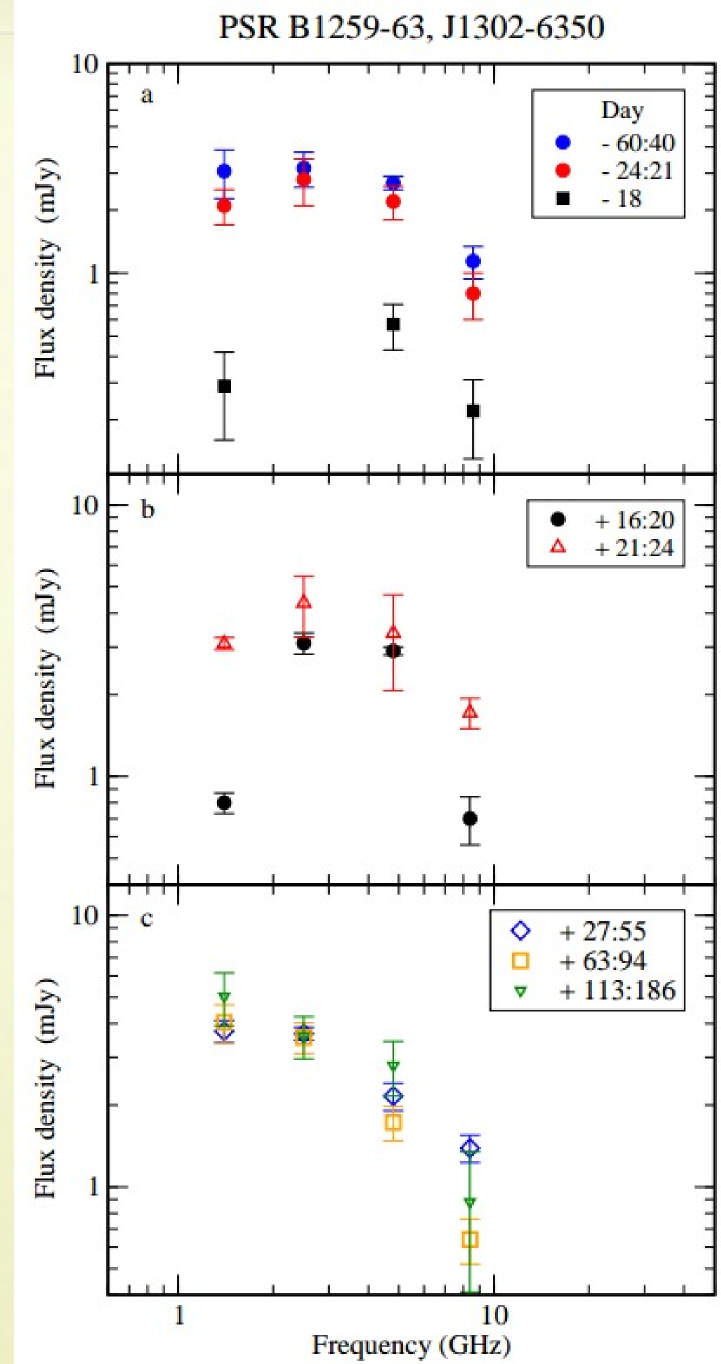


Figure 4: The spectra of PSR B1259-63 averaged over each orbital epoch (Kijak et al. 2011)

The observations of GPS pulsars

2021: 30 confirmed GPS pulsars

(18 assosiated with SNR, PWN, H II or

EGRET/HESS source)

J. Kijak, W. Lewandowski, O. Maron, Y. Gupta, A. Jessner 2011 - introduced the term gigahertz-peaked spectra (GPS) pulsars as analogy to GPS extragalactic sources.

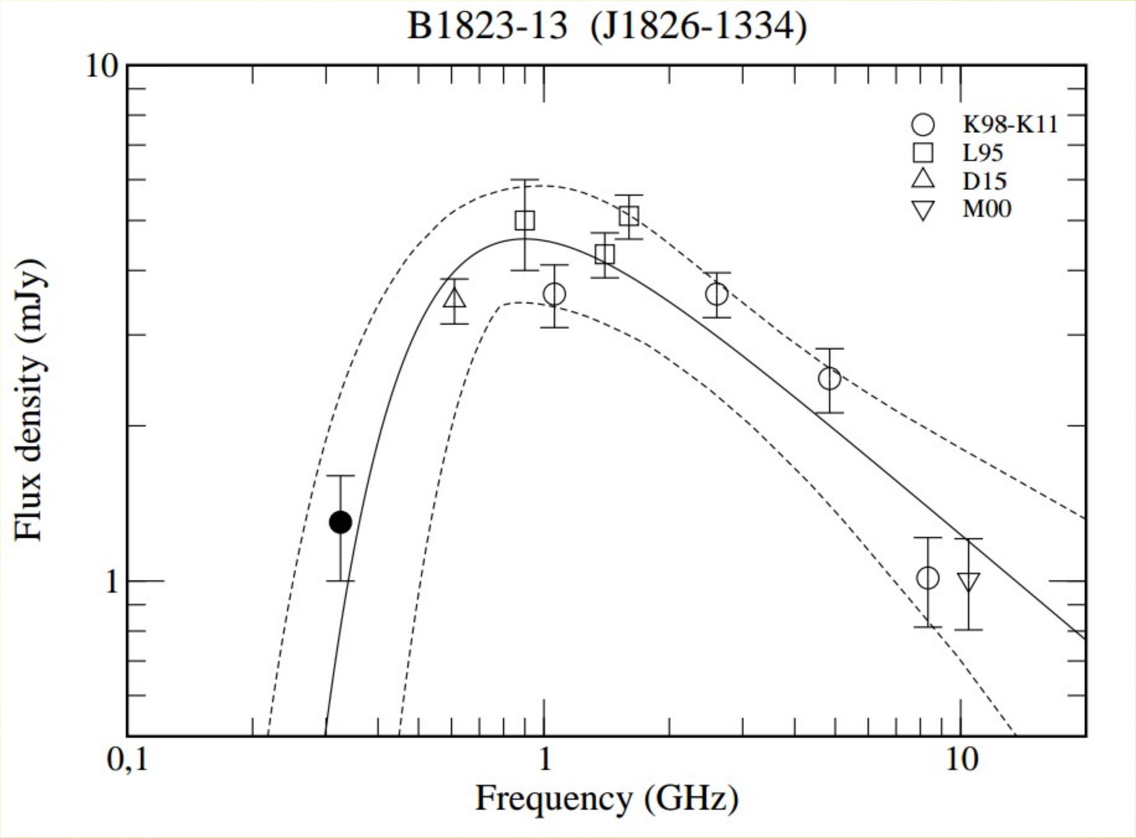


Figure 5: Example of GPS pulsar (Kijak et al. 2017a).

SGR J1745-2900 – SGR A* magnetar

1. The absorption in the electron material ejected during the magnetar outburst.

<u>Our assumptions:</u>

- The temperature drops adiabatically.
- Magnetar is located in the hot, dense environment.

2. An external absorption.

The thickness = 1 pc

$n_e = 500\ cm^{-3}$, T = 200 K

Conclusion: the free-free thermal absorption model may explain the observed spectrum evolution.

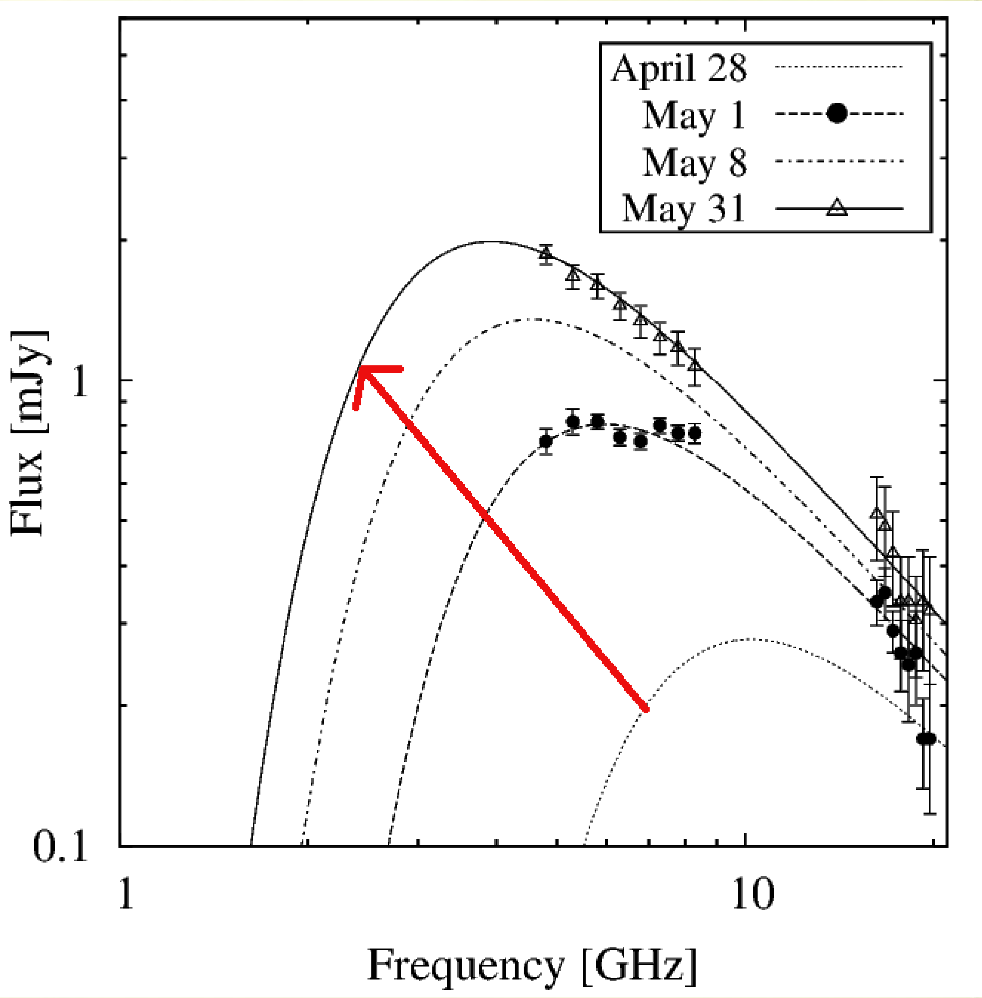


Figure 6: Spectra of the radio-magnetar SGR J1745-2900 with fitted free-free thermal absorption model. All values are taken from Figure 4 in Shannon & Johnston 2013. (Lewandowski, **Rożko** et al. 2015)

B1800-21 – Vela-like pulsar near W30 complex

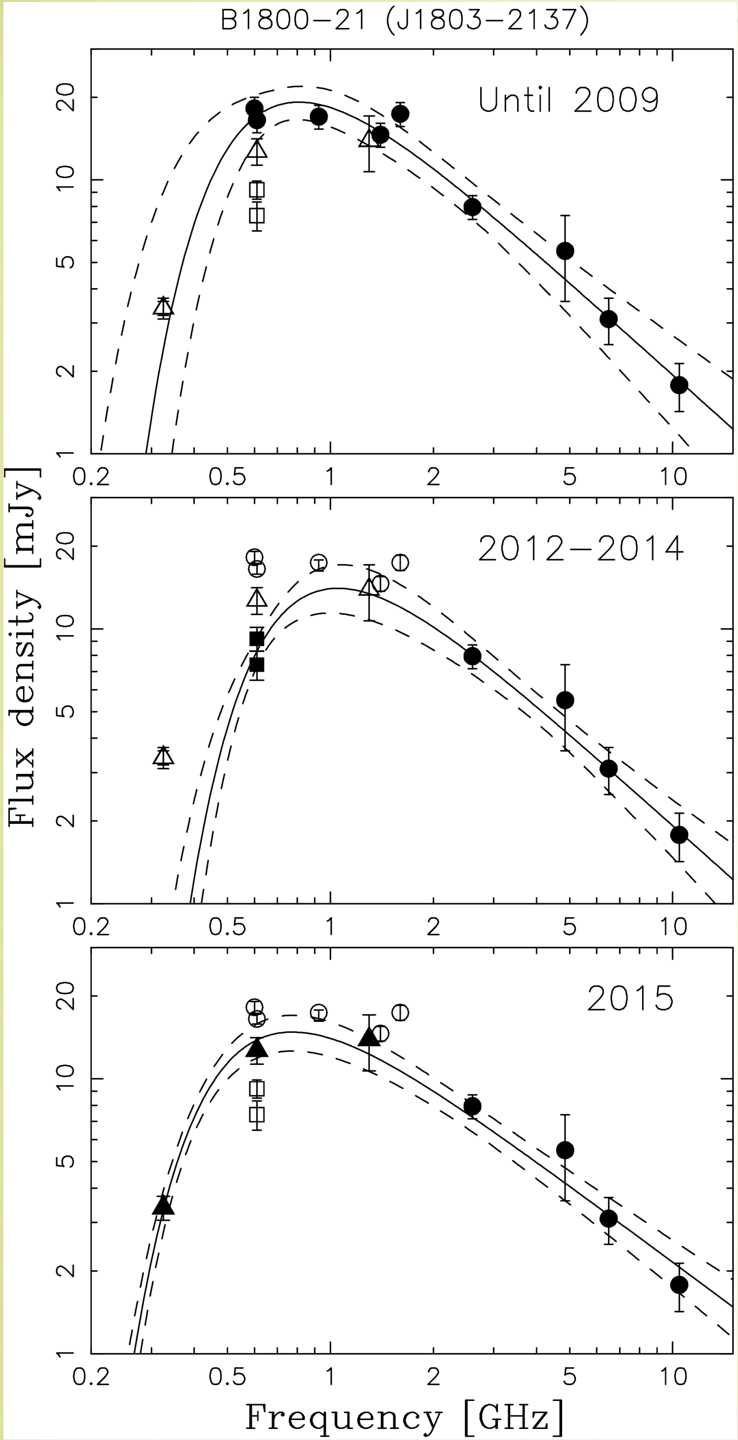


Figure 7: Basu, **Rożko** et al. 2016

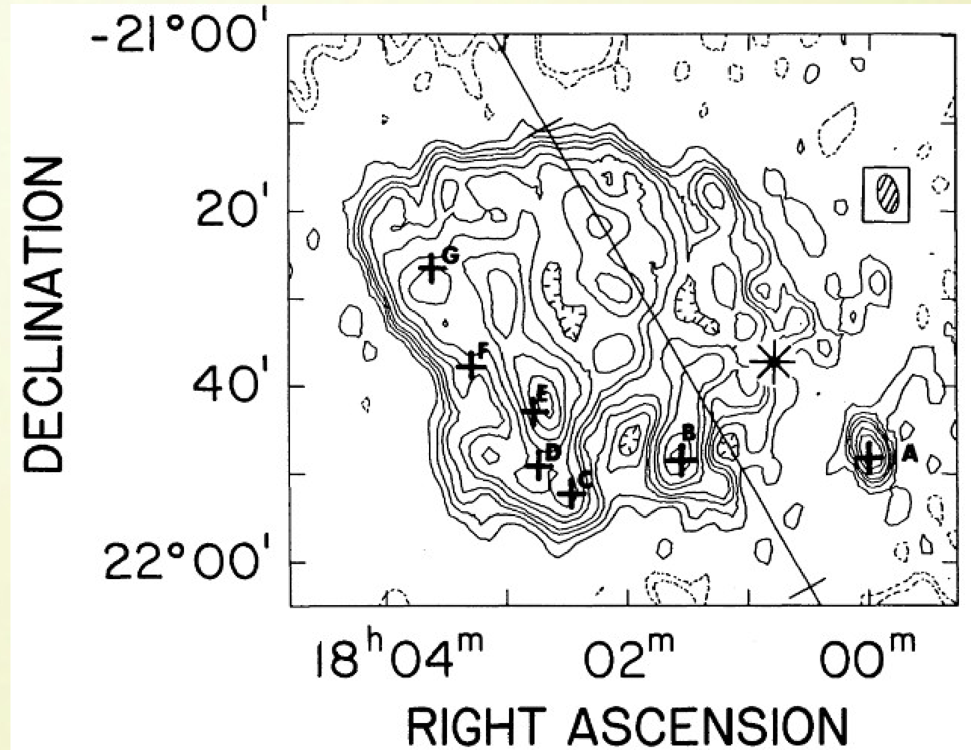


FIG. 1.—Contour map, corrected for primary beam attenuation, of the W30 complex at 90 cm wavelength (330 MHz). The half-power beamwidth of 4.′1 × 2.′8 at P.A. 11° is shown in the upper right-hand corner. Contour levels are at (−0.50, −0.25, 0.25, 0.50, 0.75, 1.00, 1.50, 2.00, 3.00, . . . , 7.00) × 0.5 Jy beam^{-1}, with the peak brightness in the map being 3.76 Jy beam^{-1} at the position $\alpha = 18^h02^m38^s$, $\delta = -21°42'00''$. The brightness temperature scale is 1 Jy beam^{-1} ≈ 302 K. The position of PSR 1800−21 is marked with a star (*), and the positions of known H II regions are marked with plus (+) signs and letter designations A–G. The Galactic plane is shown with tick marks at $l = 8°$ and $l = 9°$, with Galactic latitude increasing to the northeast.

Figure 8: Kassim & Weiler 1990.

J1740+1000 – the young pulsar far from the galactic plane

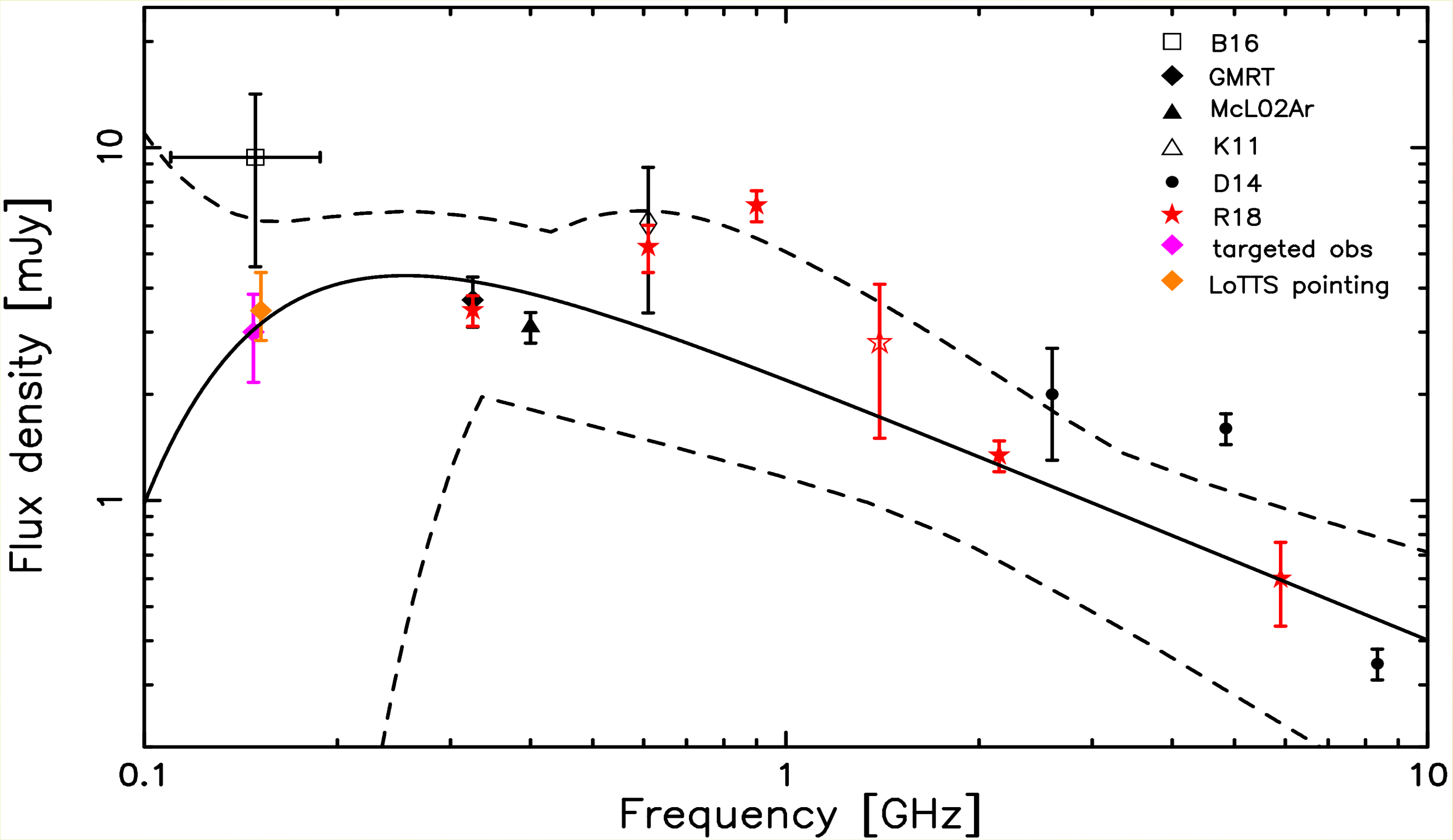
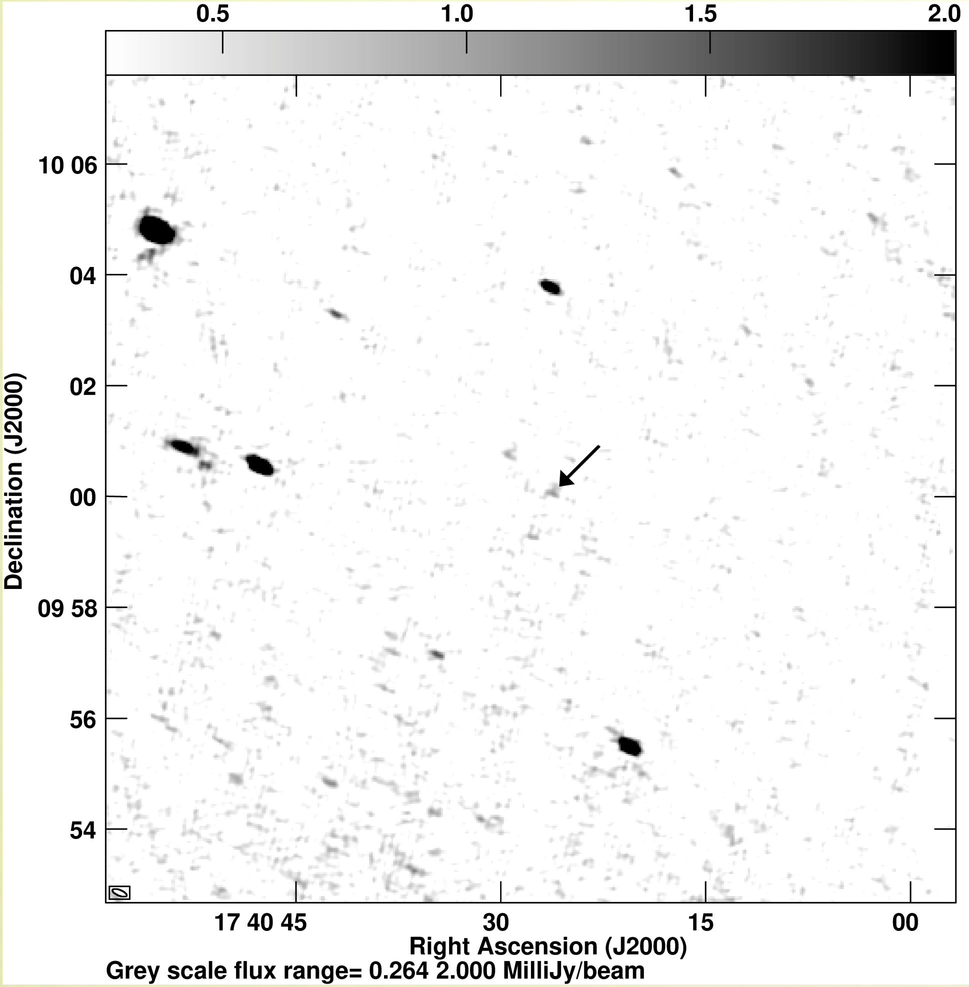


Figure 9: The pulsar spectrum with fitted free-free thermal absorption model based on all available flux density measurements.

The acronyms mean the following publications: B16 - Bilous et al. (2016), GMRT - our interferometry measurements published in Rożko et al. (2018), McL02Ar - McLaughlin et al. (2002), K11 - (Kijak et al. 2011b), D14 - Dembska et al. (2014), R18 - Rożko et al. (2018). (Figure from **Rożko** et al. 2020)

LOFAR observations of PSR J1740+1000



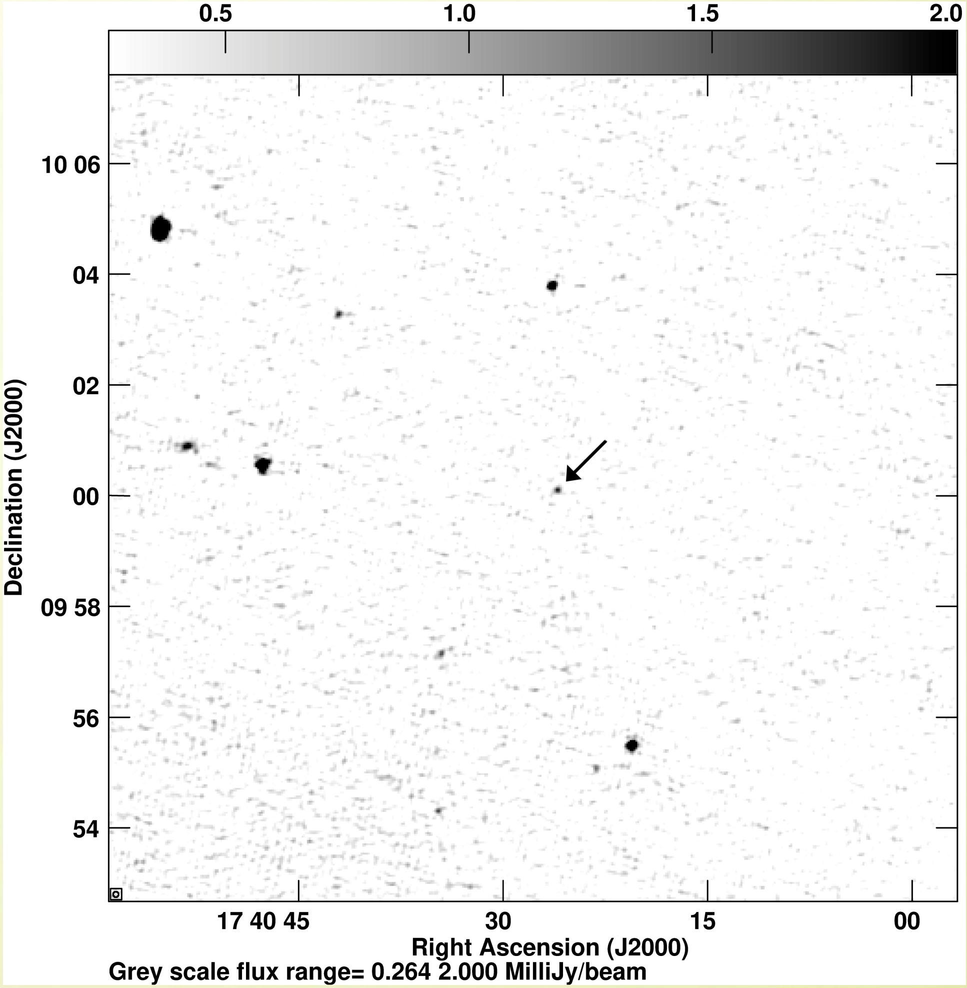


Figure 10: Grayscale images showing the total intensity maps centered at the region around PSR's J1740+1000 position (the black arrow marks the pulsar position). Both maps were obtained from the targeted observations. Left: results from the Factor pipeline. Right: results from DDF-pipeline. The map resolution is 16.5″ × 6.2″ and 6″ × 6″, respectively. (Figure from **Rożko** et al. 2020)

Wideband uGMRT observations of GPS candidates

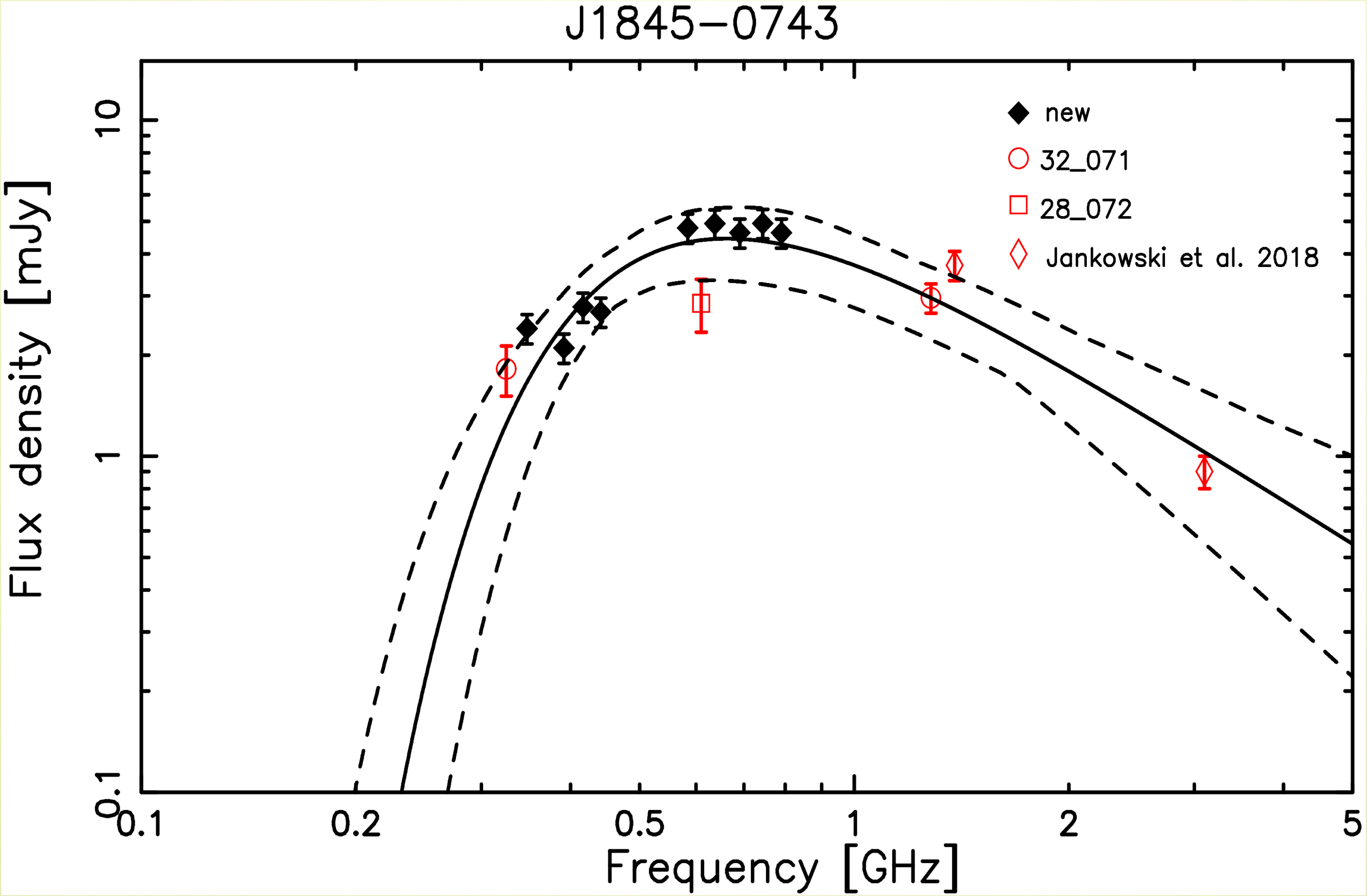


Figure 11: The PSR J1845-0743 spectrum with fitted free-free thermal absorption model. (Rożko et al. 2021, in preparation)

Future challenges

- Modelling of more complex spectral shapes:
- two absorbers along the line of sight?
- Or maybe we observed both: pulsar and pulsar wind nebulae emission?
- Comparison of the free-free thermal absorption model and synchrotron self-absorption model in cases when observed emission may come not only from pulsar but also from the Pulsar Wind Nebulae.
- Continuation with the wideband observations of the GPS candidates.

Thank you for your attention!

Our model:

$$I = Amp \times ((freq/10.)^{\alpha}) \times \exp(-1 \times freq^{-2.1} \times B)$$

Fitting procedure

The Levenberg-Marquard algorithm.

We fitted three parameters:

Amp - amplitude

α - spectral index

$B = 8.235 \times 10^{-2} (\frac{T_e}{\mathrm{K}})^{-1.35} \frac{\mathrm{EM}}{\mathrm{pc\ cm^{-6}}}$

Errors estimation

3D χ^2 mapping: we calculate the matrix of χ^2 values for the fitted parameters and the values that are inside 1 sigma contour.

The constraints from DM

Table 5. Estimating the fitting parameters for the Gigahertz-peaked spectra using the thermal absorption model

PSR	Amp	B	α	χ^2	ν_p (GHz)
J1740+1000	$0.132^{+0.275}_{-0.094}$	$0.22^{+0.11}_{-0.12}$	$-1.61^{+0.66}_{-0.63}$	4.27	0.55
B1800−21	$1.65^{+1.52}_{-1.05}$	$0.26^{+0.15}_{-0.10}$	$-1.00^{+0.39}_{-0.49}$	8.94	0.76

$$B = 8.235 \times 10^{-2} \left(\frac{T_e}{K}\right)^{-1.35} \frac{EM}{pc\ cm^{-6}}$$

Table 6. The constraints on the physical parameters of the absorbing medium.

PSR	Size (pc)	n_e (cm^{-3})	EM (10^2 pc cm^{-6})	T_e (K)
J1740+1000	0.1	119.48 ± 0.13	14.277 ± 0.030	106^{+42}_{-45}
	1.0	11.948 ± 0.013	1.4277 ± 0.0030	$19.3^{+7.6}_{-8.2}$
	10.0	1.1948 ± 0.0013	0.14277 ± 0.00030	$3.5^{+1.4}_{-1.5}$
B1800−21	0.1	1169.95 ± 0.25	1368.78 ± 0.58	2680^{+1100}_{-770}
	1.0	116.995 ± 0.025	136.878 ± 0.058	488^{+199}_{-140}
	10.0	11.6995 ± 0.0025	13.6878 ± 0.0058	89^{+36}_{-25}

From DM we can estimate n_e .

Using n_e we can calculate EM.

Using EM we can from parameter B calculate T_e.

And check if this has the physical sense.

- The SNR filament:

  size 0.1 pc

  electron density 7000 cm^{-3}

  electron temperatur 5000 K

- The bow-shock PWN:

  size 1.0 pc

  electron density 50-250 cm^{-3}

  electron temperatur 1500 K

- The cold HII region

  size 10.0 pc

  electron density a few thousand cm^{-3}

  electron temperatur 1000-5000 K

Low-frequency turnover

Sieber (1973):

synchrotron self-absorption vs free-free thermal absorption

The case of PSR B0329+54

(K. Rajwade. D.R. Lorimer & L.D. Anderson 2015):

- the turn over frequency is around 200 MHz.
- the estimated EM is ~0.052 cm^{-6}, for that value the fitted electron temperature is 0.18 K (which is contradicted to the assumed 5000 K - the typical temperature of the Warm Ionized Medium).

Conclusion: different mechanism may be responsible for the turnover at lower and higher frequency

Problem: thermal absorption could also cause turn over ~200 MHz, so it is hard to determine which model is correct one (it requires very good quality of pulsar spectrum)