The current state on the GPS pulsars studies

Karolina Rożko[1], J. Kijak[1], K. Chyży[2]

[1] Janusz Gil Institute of Astronomy, University of Zielona Gora

[2] *Astronomical Observatory, Jagiellonian University*

June 15, 2023

Other collaboratores:

- W. Lewandowski, R. Basu: Janusz Gil Institute of Astronomy, University of Zielona Gora
- S. Seethapuram Sridhar, T. Shimwell: ASTRON
- A. Krankowski, L. Błaszkiewicz: Warmia and Mazury University in Olsztyn
- M. Curyło: Astronomical Observatory, The University of Warsaw
- D. Lorimer: West Virginia University, Morgantown, WV, US
- K. Rajwade: Netherlands Institute for Radio Astronomy, Dwingeloo, NL

Pulsars' spectra

The spectra of the majority of pulsars in the frequency range between 100 MHz and 10 GHz are well characterized by the single power-law function with a mean spectral index of -1.6 (Lorimer et al. 1995; Maron et al. 2000, Jankowski et al. 2018).

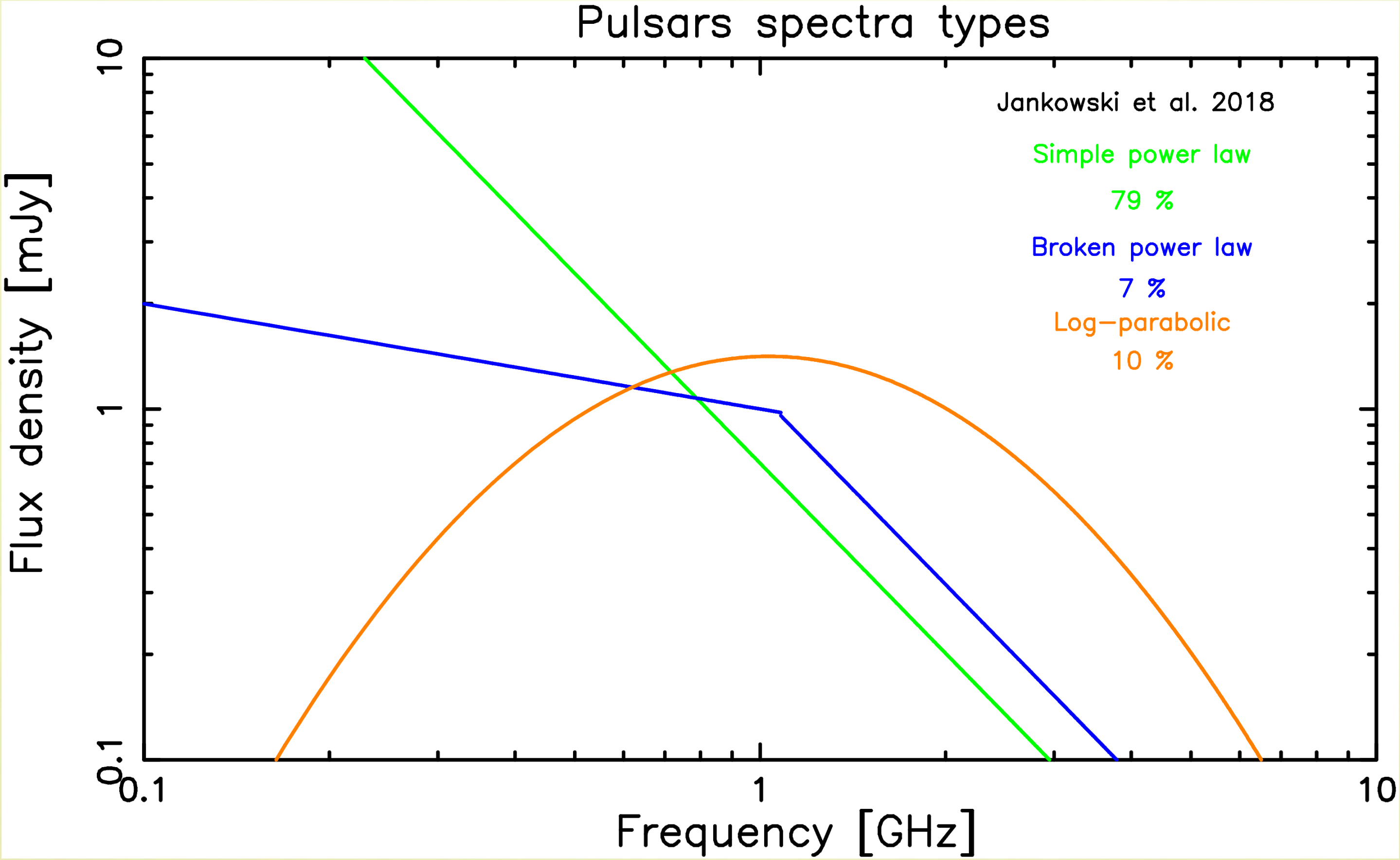

Figure 1: A schematic overview of different pulsars spectra types.

The Gigahertz-peaked spectra (GPS) effect in radio pulsars

Kijak et al. 2021:

33 confirmed GPS pulsars

(18 assosiated with SNR, PWN, H II or EGRET/HESS source)

- most have relatively high DM ($DM > 100$ pc cm^{-3})
- we identified 6 new GPS pulsars (+ 4 candidates) with peak frequencies between 370 MHz and 830 MHz
- the distribution of peak frequency is centered around 600-700 MHz

There is considerable evidence that an external mechanism is responsible for the spectral turnovers. The most compelling possibility is the thermal free-free absorption taking place in pulsar environments, described by function:

$$S_\nu = A \left(\frac{\nu}{10\ \mathrm{GHz}}\right)^\alpha e^{-B\nu^{-2.1}},$$

where: A - the pulsar intrinsic flux at 10 GHz,

α - the pulsar intrinsic spectral index

$B = 0.08235 \times T_\mathrm{e}^{-1.35}\ \mathrm{EM}$

(see Lewandowski et al. 2015, Rajwade, Lorimer & Anderson 2016, Basu et al. 2016 and Kijak et al. 2017, 2021).

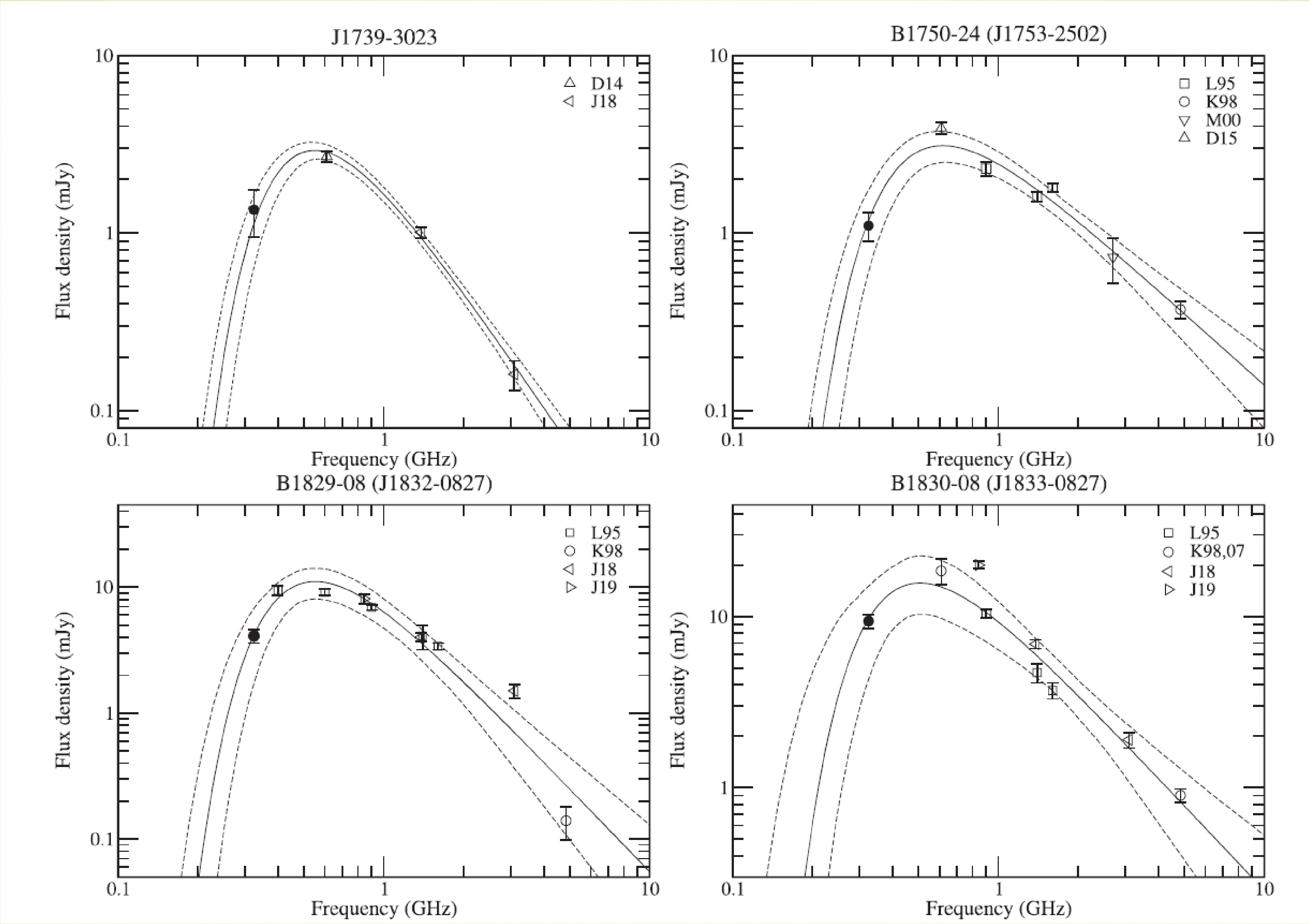

Figure 2: Example of the newly detected GHz-peaked spectra pulsars along with the free–free thermal absorption model fits (Kijak et al. 2021).

The LOFAR contribution

LC9_004 project: *Low frequency study of J1740+1000 using the interferometric imaging method*

9 hours of HBA observations that were co-observed with the LOFAR Tier I survey.

Calibration process:

- Standard facet calibration (Prefactor and factor)
- DR2 pipeline (DDFacet and killMS)

PSR J1740+1000:

Age ~11 thousand years

Period ~0.15 s

Distance: 1.23 kpc

Distance from the Galactic plane: 0.43 kpc

Farthest of all GPS pulsars!

Most likely it has the pulsar wind nebula (PWN) with a long tail.

(Kargaltsev et al., 2008; Kargaltsev & Pavlov, 2010)

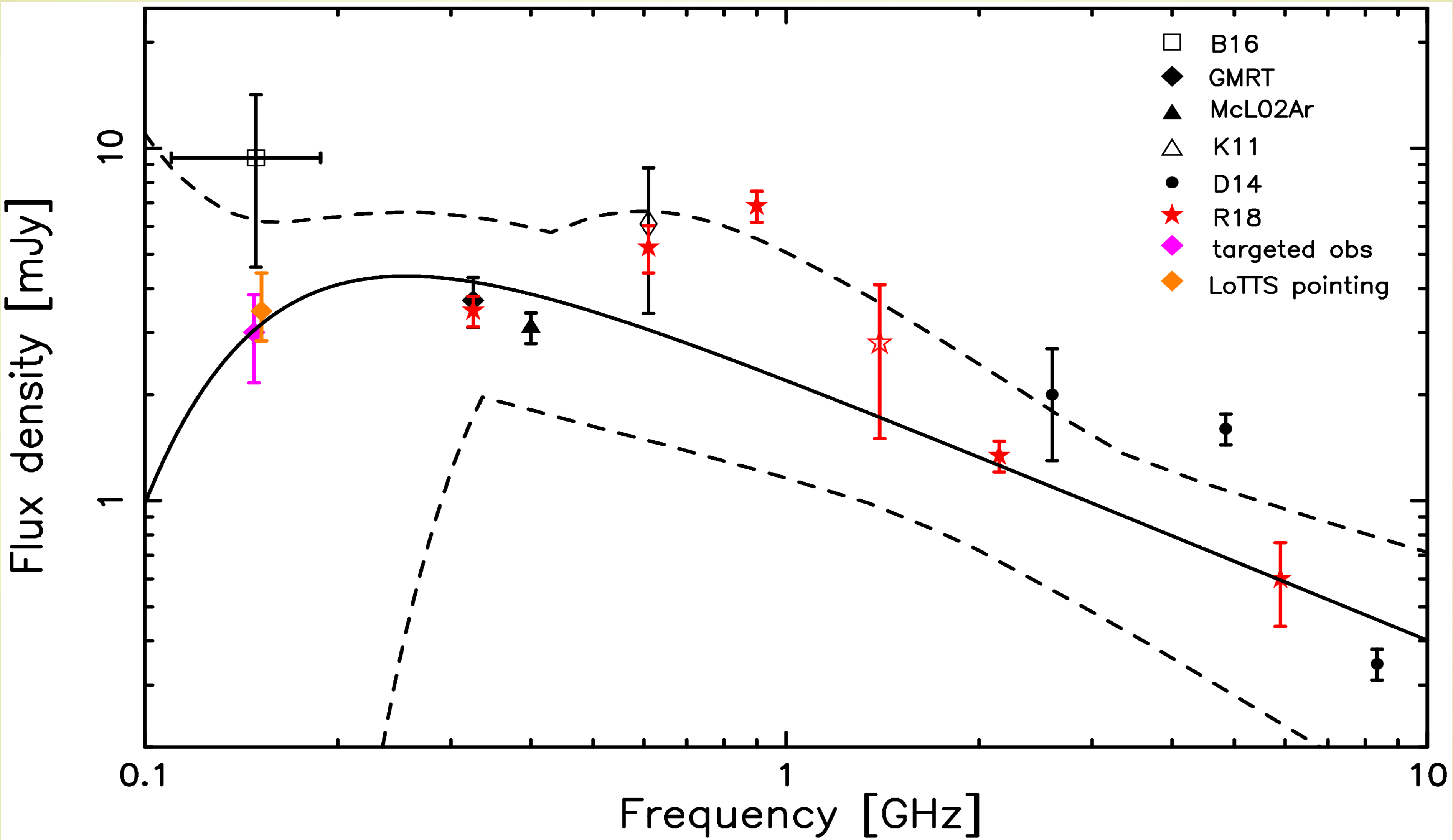

Figure 4: The pulsar spectrum with fitted free-free thermal absorption model based on all available flux density measurements.

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)

Wideband uGMRT observations

- Narrow-band observations:
  - 325 MHz
  - 610 MHz
  - 1280 MHz
- Wide-band observations:
  - Band-3 (250–500 MHz)
  - Band-4 (550–850 MHz)

Pulsar Flux Density Measurements

Frequency (MHz)	Pulsar Flux Density (mJy)		
	J1741−3016	J1757−2223	J1845−0743
325	1.8 ± 0.9	<1.05	1.8 ± 0.3
348	2.1 ± 0.4	<1.90	2.4 ± 0.2
392	2.5 ± 0.4	<1.45	2.5 ± 0.2
416	2.4 ± 0.3	<1.02	2.8 ± 0.1
441	2.3 ± 0.2	1.2 ± 0.5	2.7 ± 0.1
584	5.5 ± 0.5	1.8 ± 0.2	4.8 ± 0.4
610	3.2 ± 0.3	1.5 ± 0.2	4.3 ± 0.8
638	5.1 ± 0.5	1.6 ± 0.2	4.9 ± 0.4
691	5.3 ± 0.6	1.5 ± 0.2	4.6 ± 0.4
744	3.8 ± 0.4	1.7 ± 0.2	4.9 ± 0.4
791	3.8 ± 0.5	1.4 ± 0.2	4.6 ± 0.4
1280	2.6 ± 0.3	1.0 ± 0.1	3.0 ± 0.2

THE ASTROPHYSICAL JOURNAL, 922:125 (6pp), 2021 December 1 https://doi.org/10.3847/1538-4357/ac23dc

CrossMark

The uGMRT Observations of Three New Gigahertz-peaked Spectra Pulsars

K. Rożko[1], R. Basu[1,2], J. Kijak[1], and W. Lewandowski[1]
[1] Janusz Gil Institute of Astronomy, University of Zielona Góra, ul. Prof.Z. Szafrana 2, 65-516 Zielona Góra, Poland; k.rozko@ia.uz.zgora.pl
[2] Inter-University Centre for Astronomy and Astrophysics, Pune 411007, India
Received 2021 July 19; revised 2021 August 30; accepted 2021 September 3; published 2021 November 25

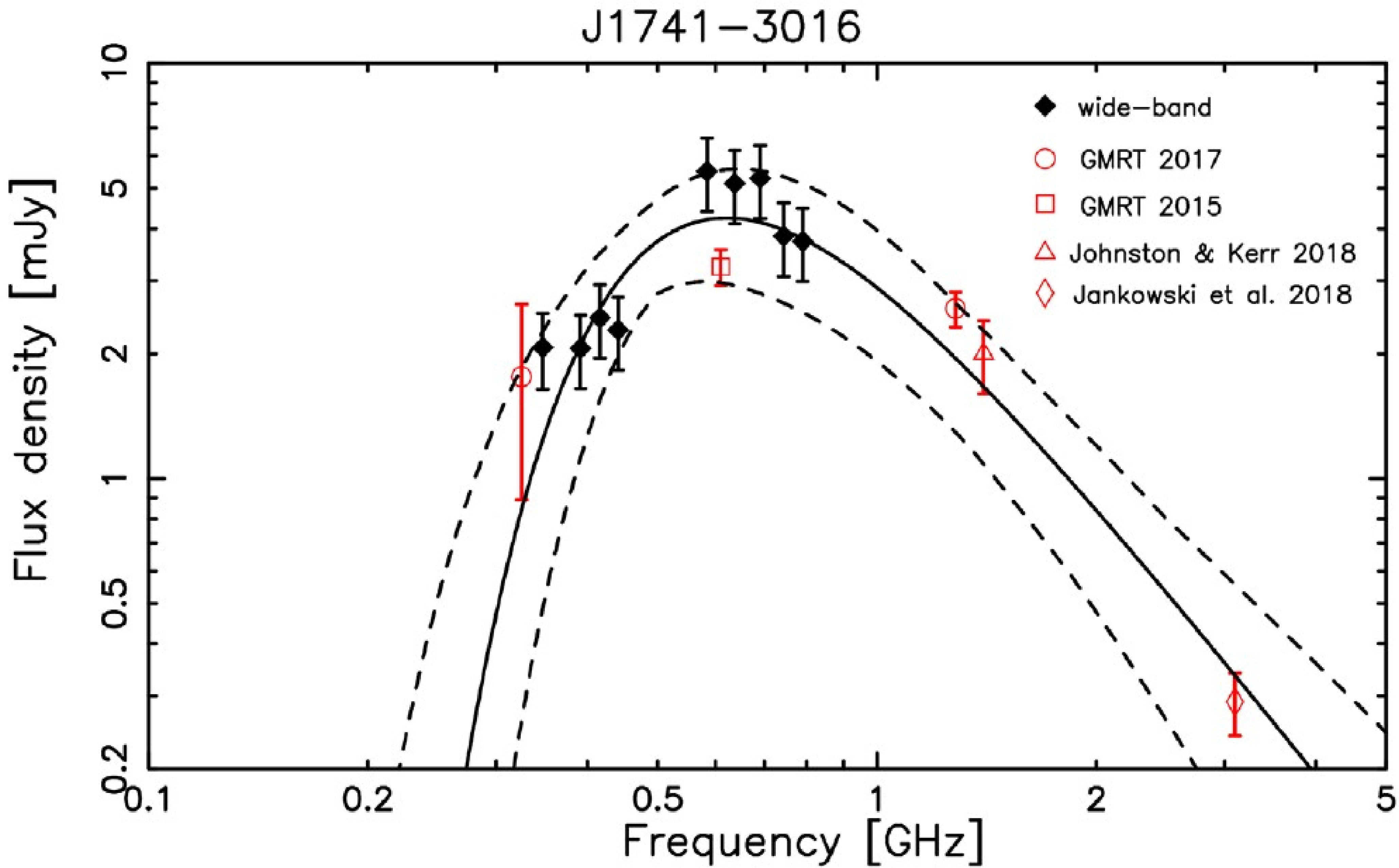

Figure 5: The PSR J1741-3016 spectrum with fitted free-free thermal absorption model. (Rożko et al. 2021)

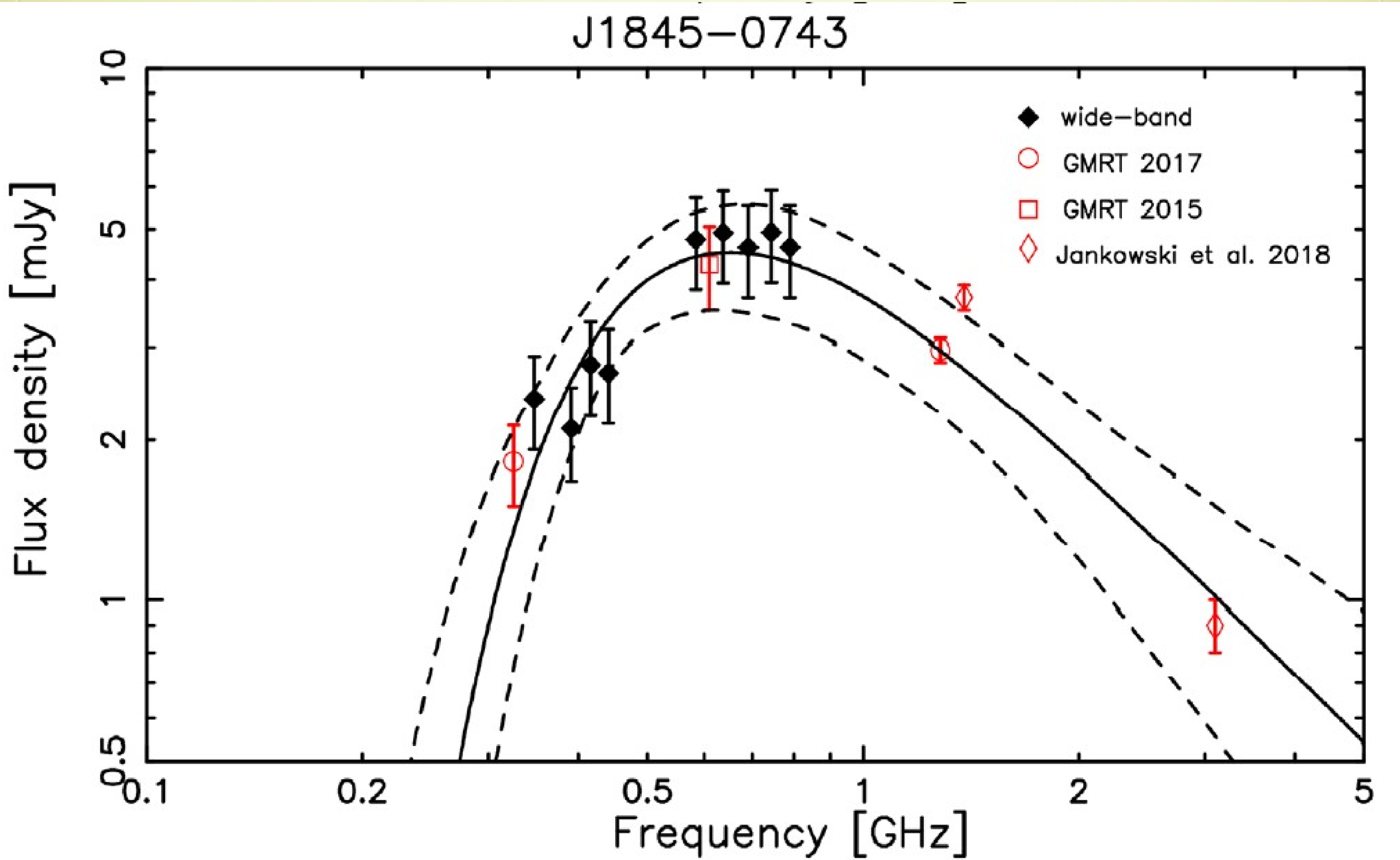

Figure 6: The PSR J1845-0743 spectrum with fitted free-free thermal absorption model. (Rożko et al. 2021)

The future work:

- Modelling of more complex spectral shapes e.g. two absorbers along the line of sight.
- 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 pulsars that should narrow down the physical constrains from homogeneous free-free thermal absorption model and help to model the inhomogeneous free-free thermal absorption.
- Looking for good candidates for observations at 300 MHz and below to catch spectral turnover in the 400-600 MHz range. Waiting for the SKA era!

Thanks for your attention!

The inhomogeneous free-free thermal absorption model

Bicknell et al. 1997 assumes that the screen is inhomogeneous, which is modelled by clouds with a power-law distribution of optical depths parametrized by p:

$$S_\nu = a(p+1)\gamma[p+1, \tau_\nu] \left(\frac{\nu}{\nu_0}\right)^{2.1(p+1)+\alpha}, \qquad (3)$$

where γ is the lower incomplete gamma function of order $p+1$, given by

$$\int_0^{\tau_\nu} e^{-x} x^p \, dx, \qquad (4)$$

and $\tau_\nu = (\nu/\nu_0)^{-2.1}$.

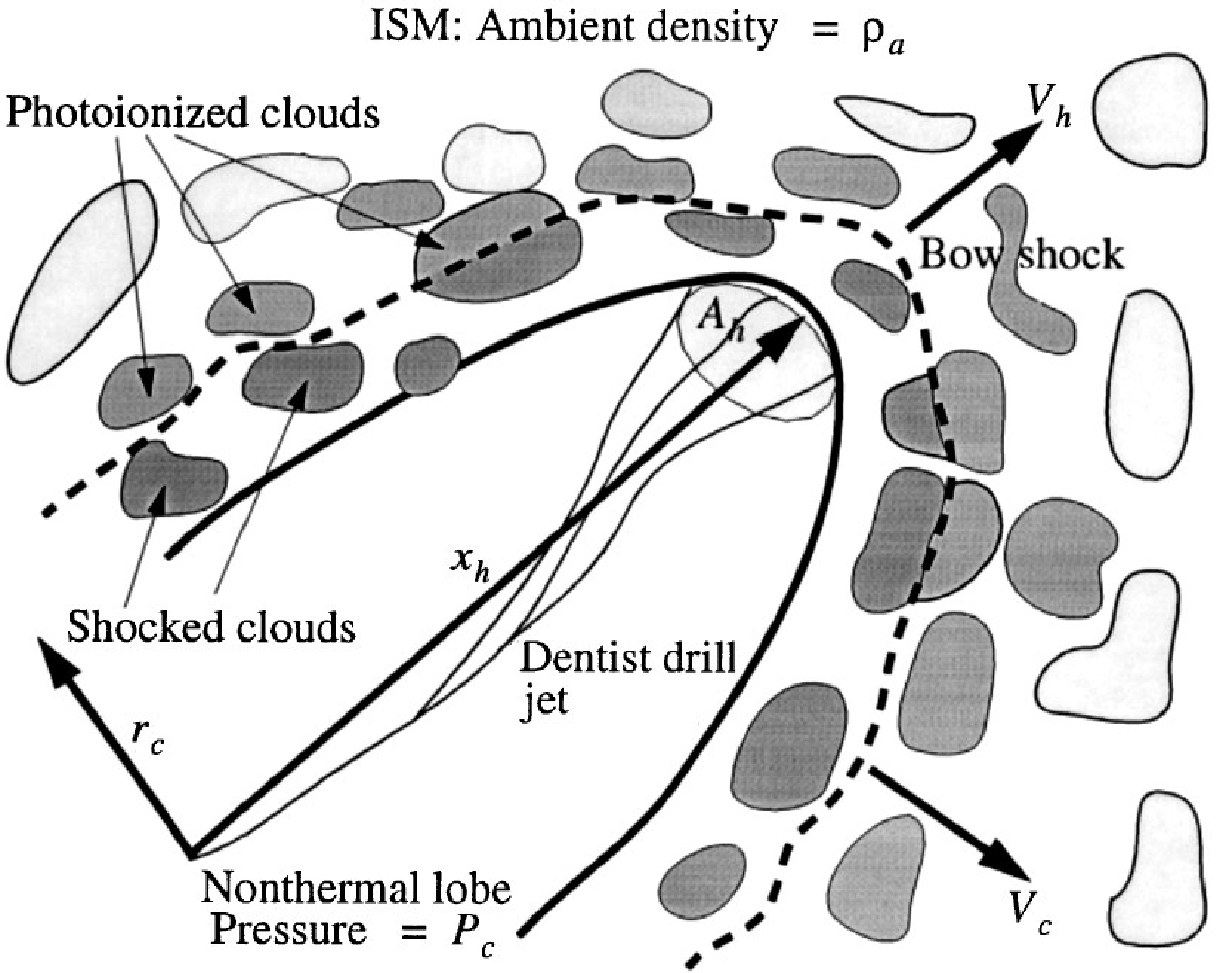

FIG. 1.—Illustration of the interaction of a jet-fed radio lobe with the dense interstellar medium. The radiative bow shock (*dashed line*) surrounding the radio lobe collisionally excites the ISM which is shown here as a two-phase medium permeated by dense clouds shown in light gray. The radiation from the shock also photoionizes clouds (*medium gray*) in the ISM in advance of the bow shock. The shocked clouds are shown as dark gray. When the ionized gas enveloping the radio lobe is sufficiently dense it can free-free absorb the radio emission at GHz frequencies. The ionized medium also forms a Faraday screen which depolarizes the radio emission.