

EXTENDED DIFFUSE RADIO HALO AROUND BLAZARS

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INTRODUCTION

Blazars constitute intriguing subclass of the active galactic nuclei (AGNs), for which the total radiative output is dominated by a Doppler-boosted and highly variable emission of a nuclear relativistic jet, observed at small viewing angle. The blazars' family includes BL Lacertae (BL Lac) objects and flat-spectrum radio-loud quasars (FSRQs) [1]. Among them, some objects possess diffuse radio structures from milliarcseconds to

arcminutes scales, which origin is still not fully explained.

A group of blazars with prominent radio halos have been analyzed to disclose the nature of their extended radio emission. The sample has been chosen from formerly reported VLA and WSRT observations of AGNs [2][3][4]. Here we show two examples: 3C 371 and Mrk 0421, which are surrounded by extended radio halos.

ANALYSIS

Some of the examined blazars have proven to be characterized by spectral energy distribution significantly increasing in the low-frequency radio regime. This could suggest the existence of two different radio components which make up the total radio flux: a flat-spectrum central element and a steep-spectrum diffuse halo. Radio spectra of 3C 371 and Mrk 0421 are presented in Figs 7, 8, respectively.

to a common scale to obtain spectral index map. Regions with flux density values below 3σ have been blanked.

We have used the 1.4 GHz NVSS [5] and 0.3 GHz WENSS [6] images to create spectral index ($S_{\nu} \sim \nu^{-\alpha}$) maps of 3C 371 and Mrk 0421. At the beginning, the higher resolution map has been convolved to the resolution of the WENSS map. Since misalignment of the total-power map at two frequencies could produce systematic errors in the spectral index map, we have co-registered the positions of the central point source and several bright point-like field sources on both maps. Further, both maps have been brought

The final 3C 371 and Mrk 0421 color maps of the spectral index are shown in Figs 4 and 6, respectively. They reveal that radio spectrum steepens monotonically from the center towards outer regions. The spectral index near the position of the blazar core is 0.1 and 0.2 in case of 3C 371 and Mrk 0421, respectively. The mean spectral index over the entire diffuse halo of 3C 371 and Mrk 0421 is about 1.0 and 0.6, respectively. High values of the spectral index at some points on the outskirts of these sources might be due to the missing flux in the 1.4 GHz interferometric maps. The presence of an evident outwards radial steepening of the radio halos' spectra indicates monotonic ageing of the electron population.

3C 371

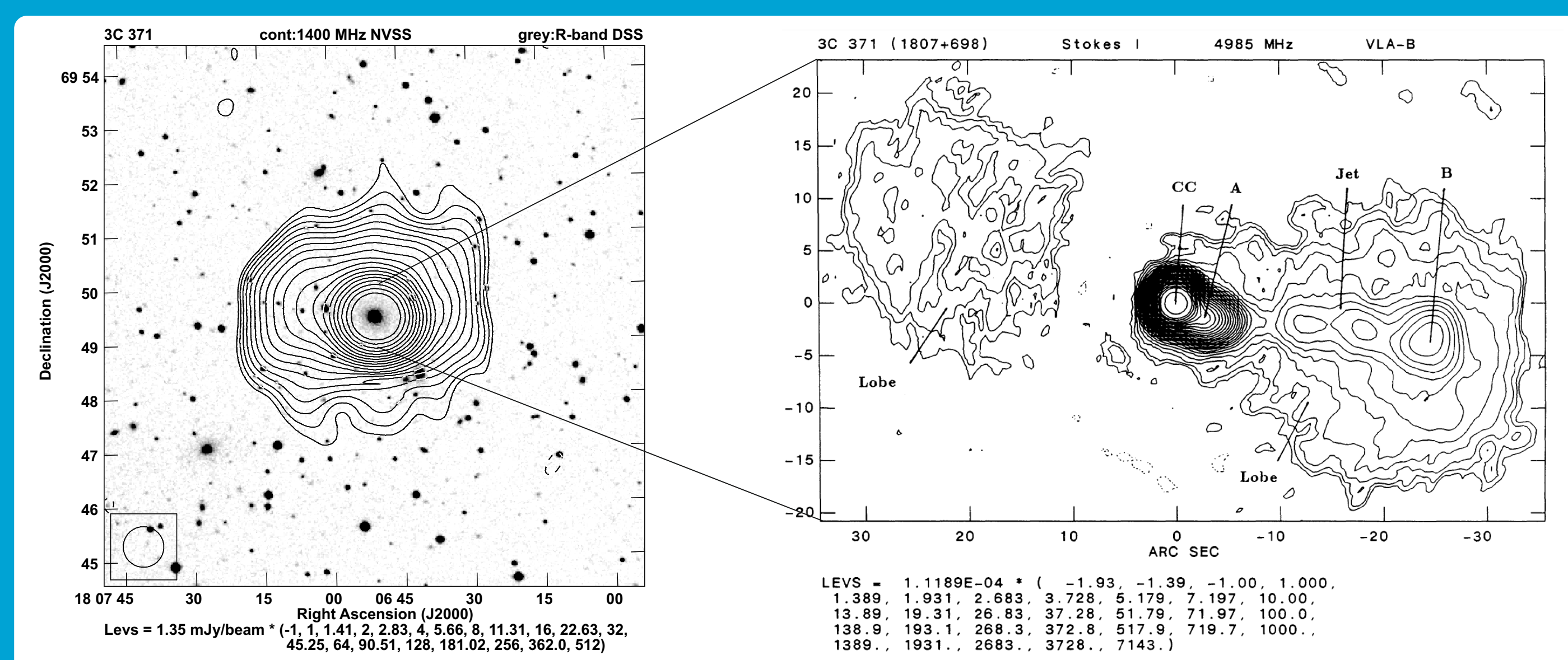


Fig. 1: 3C 371 grey scale DSS [7] with NVSS contour plot, starting from 3σ and scaled of $\sqrt{2}$ (left panel). Inner part of 3C 371 VLA B – configuration contour plot (this figure is taken from Wrobel & Lind (1990)) [8] (right panel).

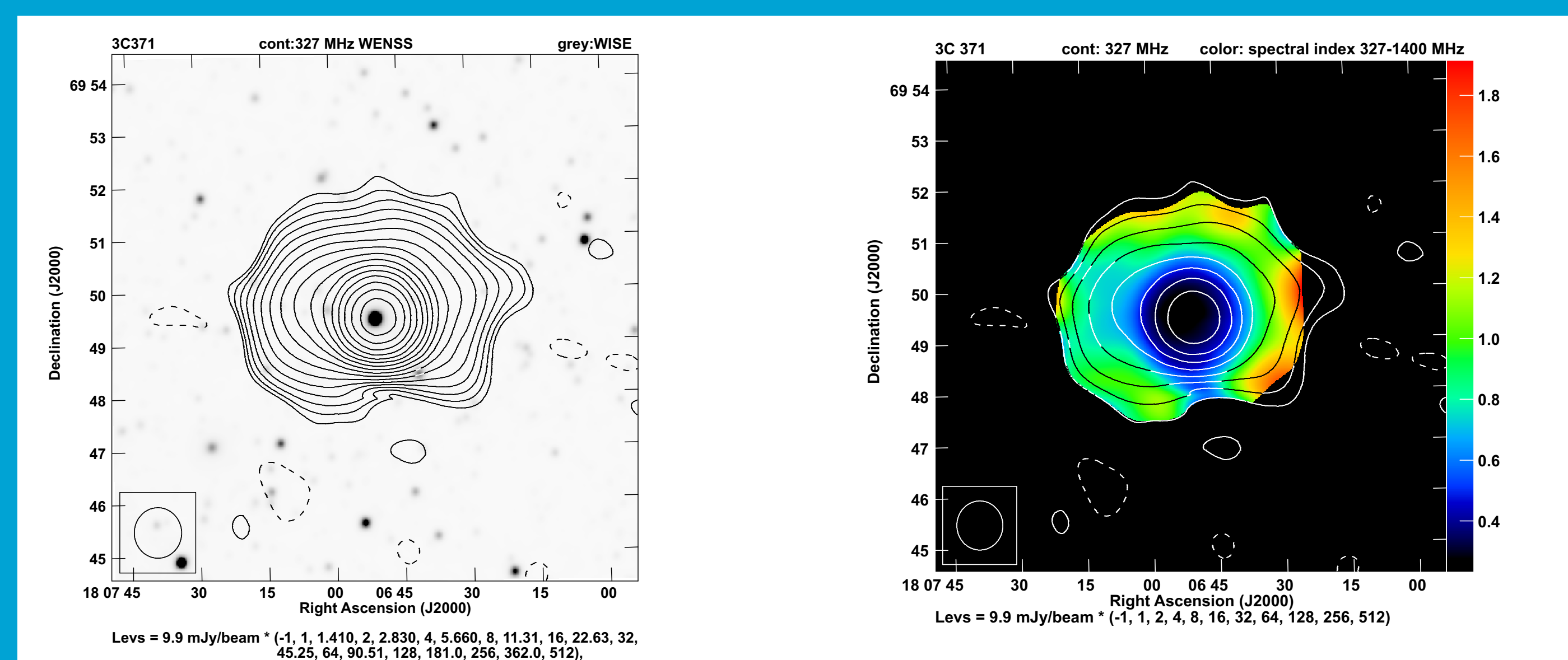


Fig. 3: 3C 371 grey scale WISE (3.4 μm) with WENSS contour plot, starting from 3σ and scaled of $\sqrt{2}$.

Fig. 4: 3C 371 spectral index with WENSS contour plot, starting from 3σ and scaled of $\sqrt{2}$.

3C 371 is a BL Lac type object in the northern sky with redshift of about 0.05 (1 arcminute corresponds to 61 kpc). It has been reported as one of the more unusual blazars with stellar line optical spectrum and a nonthermal continuum. Its emission lines are similar to those in some giant elliptical galaxies [10]. VLA observations have exhibited double-lobed structure of this source residing in the large halo extending over 4 arcminutes in declination [8] (see Fig. 1).

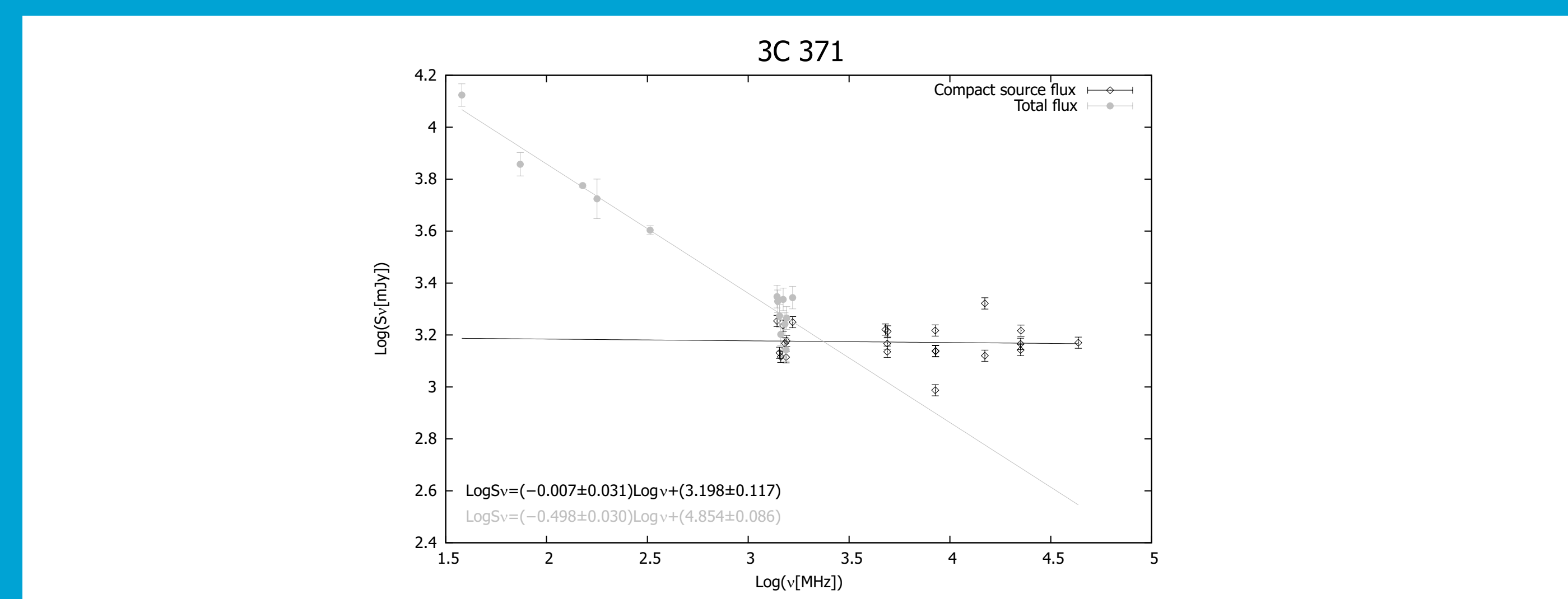


Fig. 7: Radio spectrum of 3C 371. The total radio flux (grey) is a composition of a flat-spectrum central source (black) and a steep-spectrum diffuse halo.

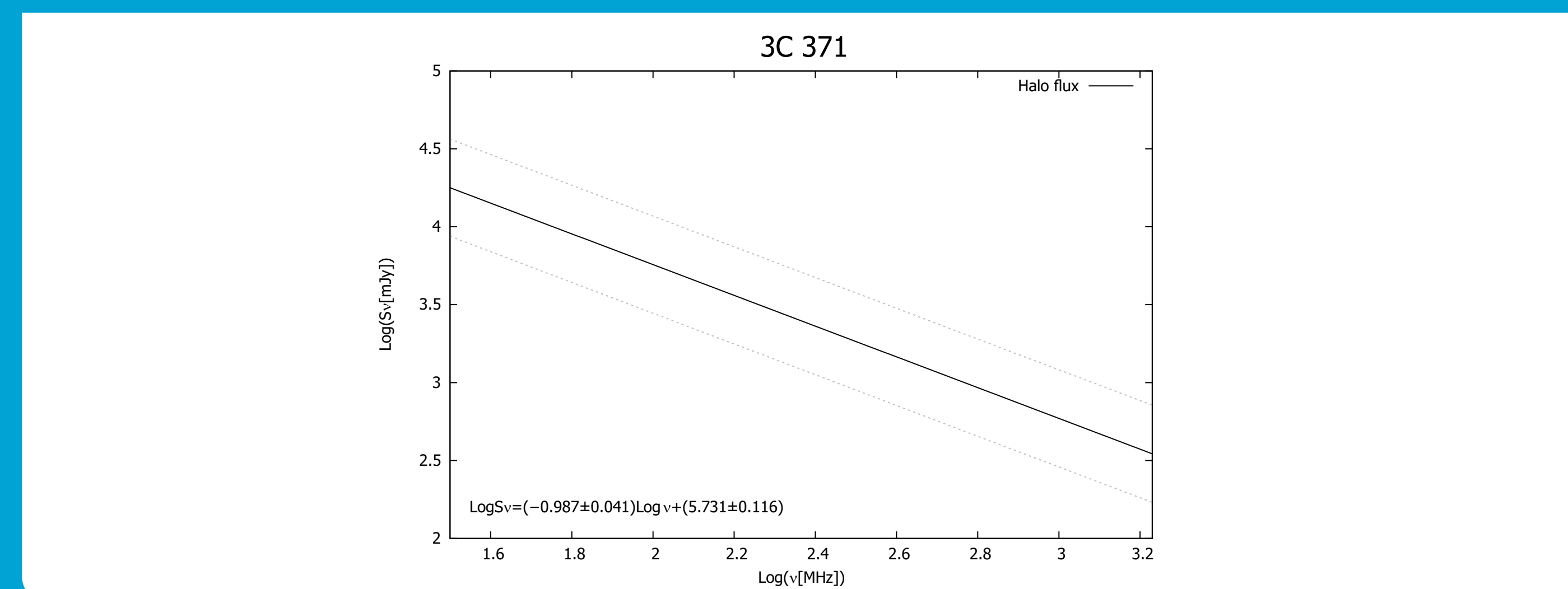


Fig. 9: Radio spectrum of 3C 371 halo (black line) obtained from the fitted values of total and compact source flux densities (as in Fig. 7). The dashed lines represent the error ranges.

Mrk 0421

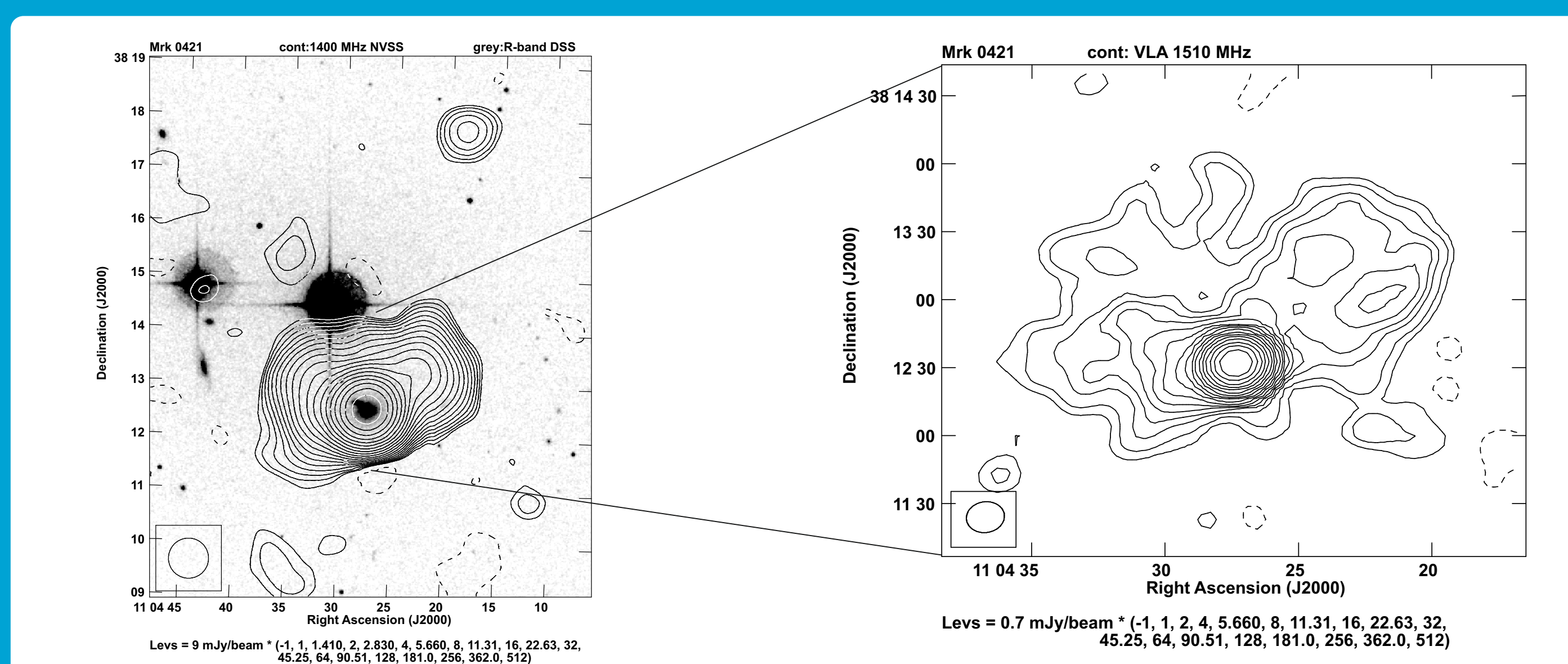


Fig. 2: Mrk 0421 grey scale DSS with NVSS contour plot, starting from 3σ and scaled of $\sqrt{2}$ (left panel). Mrk 0421 VLA C – configuration contour plot, starting from 3σ and scaled of $\sqrt{2}$ (right panel) [9].

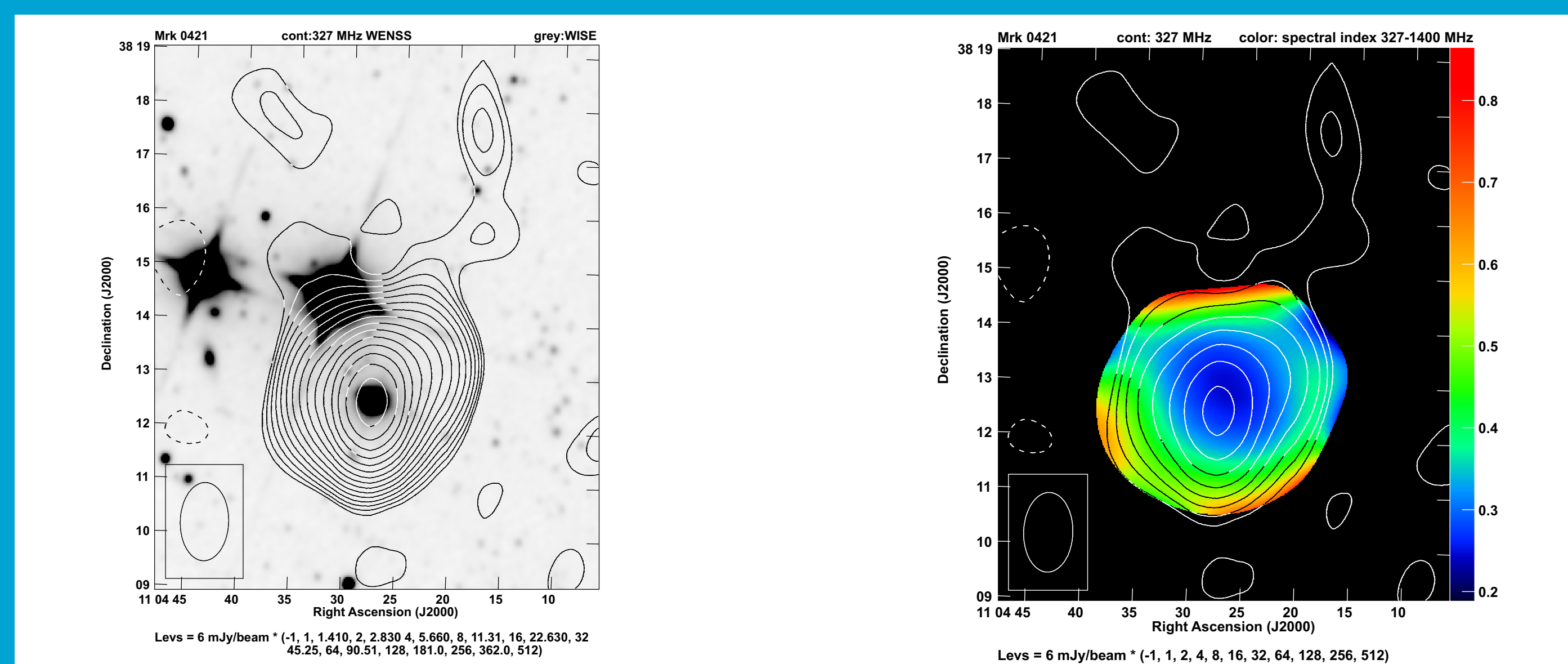


Fig. 5: Mrk 0421 grey scale WISE (3.4 μm) with WENSS contour plot, starting from 3σ and scaled of $\sqrt{2}$.

Fig. 6: Mrk 0421 spectral index with WENSS contour plot, starting from 3σ and scaled of $\sqrt{2}$.

Mrk 0421 is a high-synchrotron-peaked BL Lac object with redshift of about 0.03 (1 arcminute corresponds to 36 kpc). It belongs to the brightest X-ray blazars. Furthermore, Mrk 0421 was the first extragalactic source detected in the very high energy gamma rays regime. Its bright elliptical parent galaxy shows a nonthermal and highly polarized nuclear region [11]. Similar to 3C 371, it is characterized by a rapid flux variability at different wavelengths [10][12]. This source is surrounded by a diffuse radio structure exceeding 3 arcminutes in declination (see Fig. 2).

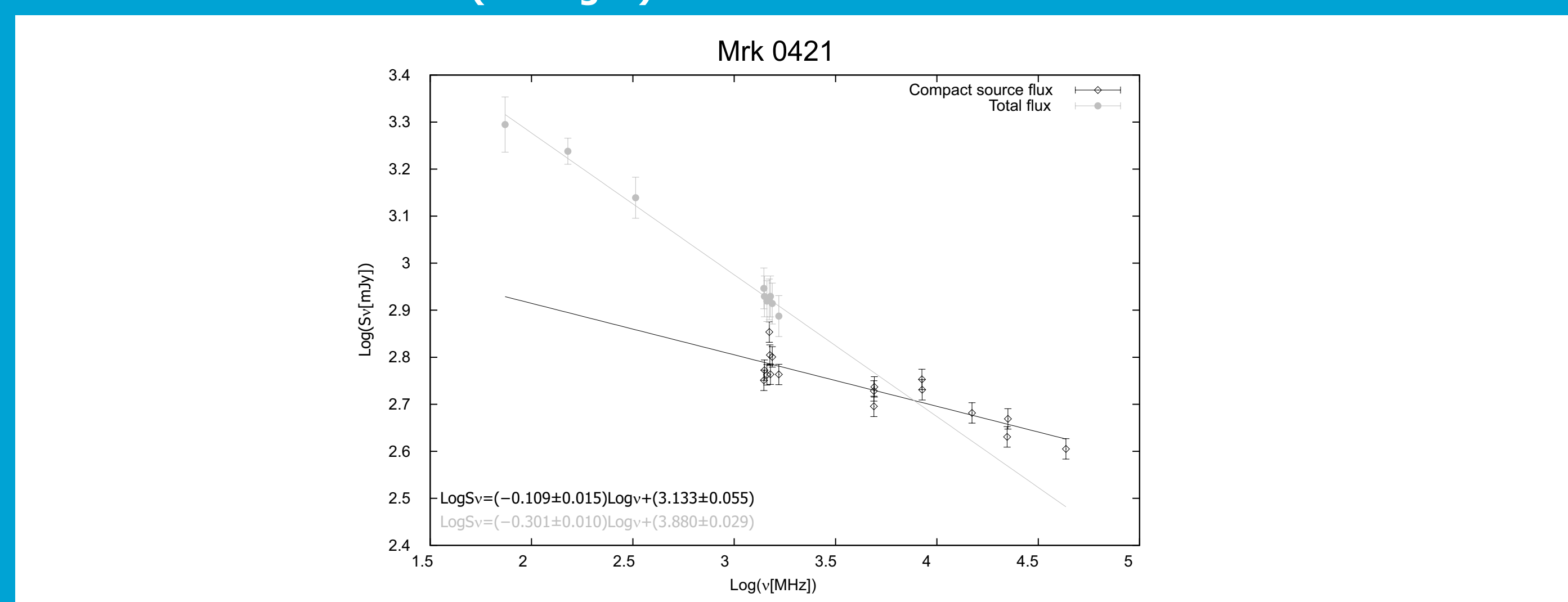


Fig. 8: Radio spectrum of Mrk 0421. The total radio flux (grey) is a composition of a flat-spectrum central source (black) and a steep-spectrum diffuse halo.

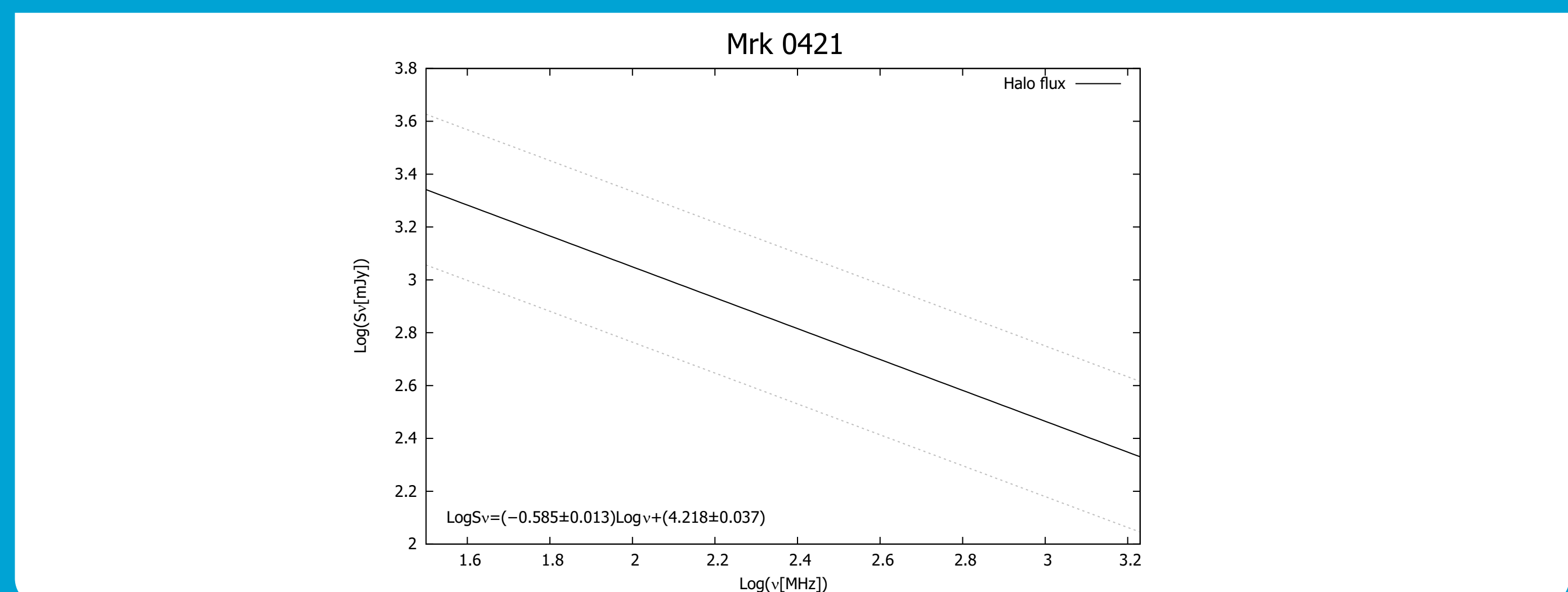


Fig. 10: Radio spectrum of Mrk 0421 halo (black line) obtained from the fitted values of total and compact source flux densities (as in Fig. 8). The dashed lines represent the error ranges.

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Acknowledgments
Work by UP, MJ and MO, LS is supported in part by Polish NSC grants DEC-2013/09/B/ST9/00599 and DEC-2012/04/A/ST9/00083, respectively.