Honolulu, Hawaii, August 3 - 14, 2015

The possible evidence of the non-linear particle acceleration in Cas A from *Planck* data

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ABSTRACT

Planck Collaboration Int. XXXI (2014) have recently published their microwave survey of Galactic supernova remnants by using results of observations made by *Planck* telescope. The high frequency radio data obtained by *Planck* reveal obvious concave up form of spectrum of Galactic supernova remnant (SNR) Cas A. It is expected form of spectrum if non-linear diffuse shock acceleration (DSA) process is active. The radio spectral index ($S_\nu \propto \nu^{-\alpha}$) of Cas A at low and middle frequencies (<30 GHz) has value α=0.77. At higher frequencies (between 30 GHz and 353 GHz) this spectral index becomes flatter, α≈0.6. Under assumption of the test particle DSA, as the first approximation, the corresponding compression ratio should increase from 3 (α=0.77) to 3.5 (α=0.6). This represents a possible observational evidence for the existence of a modified shock wave.

INTRODUCTION

Cas A is a very bright and young supernova remnant, likely due to a historical supernova around 353-343 yr ago (Ashworth 1980; Fesen et al. 2006). Its estimated distance is 3.33±0.10 kpc (Alarie et al. 2014). Recently, this SNR was observed by *Planck* and the results were published in Planck Collaboration Int. XXXI (2014). It was shown that Cas A is a distinct compact source from 30 - 353 GHz but becomes confused with unrelated Galactic clouds at the highest *Planck* frequencies (545 and 857 GHz). The apparent excess radiation at 217 and 353 GHz is proposed to be due to coincidental peak in the unrelated foreground emission or to cool dust in the supernova remnant.

The slightly concave-up forms of radio-spectra were detected for some young SNRs (Reynolds & Ellison 1992). The main reason for high frequency concave-up curvature in radio-spectra of young SNRs should originate in non-linear diffuse shock particle acceleration (see Urošević 2014, and references therein). Due to the positive identification of the infrared synchrotron radiation from Cas A, Jones et al. (2003) gave indication that the radio-spectrum of this SNR should be concave-up.

This work focuses on the analysis of origin of the high-frequency curvature in radio-spectrum of Cas A.

DATA

There are various observations of SNR Cas A (Green 2014). Flux densities at different frequencies for SNR Cas A were taken from different papers. The data sample includes data from Planck Collaboration Int. XXXI (2014), Baars et al. (1977) and references therein as well as from Mason et al. (1999). The original data (data for original epochs) are taken from Table 2 of Baars et al. (1977), not the scaled ones. The flux densities were appropriately scaled to account for secular fading using the scaling proposed in Vinyaikĭn (2014):

$$d(\nu) = a - b\ln\nu_{[\mathrm{GHz}]} - c\,\nu_{[\mathrm{GHz}]}^{-2.1},$$
$$\Delta d(\nu) = \Delta a + \Delta b\,|\ln\nu_{[\mathrm{GHz}]}| + \Delta c\,\nu_{[\mathrm{GHz}]}^{-2.1},$$
$$a = (0.0063 \pm 0.0002),\ b = (0.0004 \pm 0.0001),$$
$$c = (0.0151 \pm 0.0016) \times 10^{-5}.$$

$$S_{t_2}(\nu) = S_{t_1}(\nu)\,(1 - d(\nu))^T\,,\ T = t_2 - t_1,$$
$$\Delta S_{t_2}(\nu) = S_{t_1}(\nu)\left(\frac{\Delta S_{t_1}(\nu)}{S_{t_1}(\nu)} + T\,\frac{\Delta d(\nu)}{1 - d(\nu)}\right).$$

where d(ν) is the secular decrease in the flux density at given frequency, Δd(ν) is its appropriate error estimate, $S_{t2}(\nu)$ and $\Delta S_{t2}(\nu)$ are flux density for the desired epoch (t_2) and its appropriate error estimate, respectively.

ANALYSIS AND RESULTS

The high-frequency radio-spectrum of Cas A is clearly curved (Figures 1-2) so it is not correct to be fitted by the pure power-law. It is more appropriate to represent radio-spectrum of young SNRs with approximative relation that represents varying power-law of the form (model 1):

$$S_{[\mathrm{Jy}]}(\nu) = S_{[\mathrm{Jy}]}(1\mathrm{GHz})\ \nu_{[\mathrm{GHz}]}^{-\alpha + a\log\nu_{[\mathrm{GHz}]}}$$

where α is the standard synchrotron spectral index and *a* is the parameter of spectral curvature which should be positive due to the non-linear behavior of DSA.

When low-frequency cut-off is taken into account previous model is adjusted in the following way (model 2):

$$S_{[\mathrm{Jy}]}(\nu) = S_{[\mathrm{Jy}]}(1\mathrm{GHz})\ \nu_{[\mathrm{GHz}]}^{-\alpha + a\log\nu_{[\mathrm{GHz}]}}\ e^{-\tau_0\nu_{[\mathrm{GHz}]}^{-2.1}}$$

where τ_0 represents the optical depth at 1 GHz.

The results (see Figures 1-2) show that the most probable scenario is that *Planck's* new data reveal the imprint of non-linear particle acceleration in the case of Cas A.

The estimated spectral curvature parameter *a*, although slightly higher, is not in disagreement with previous works (see Allen et al. 2008).

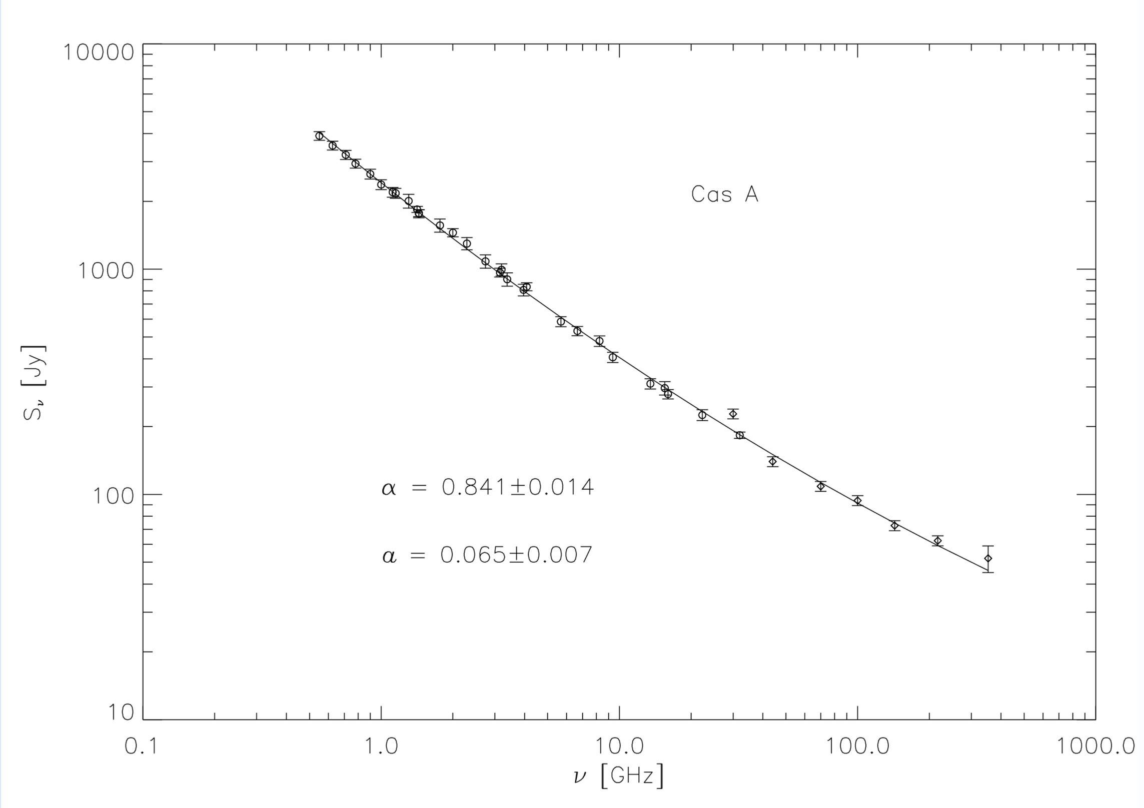

Figure 1. The weighted least-square fit to the data, for the varying spectral index model. Diamond symbols indicate *Planck's* data.

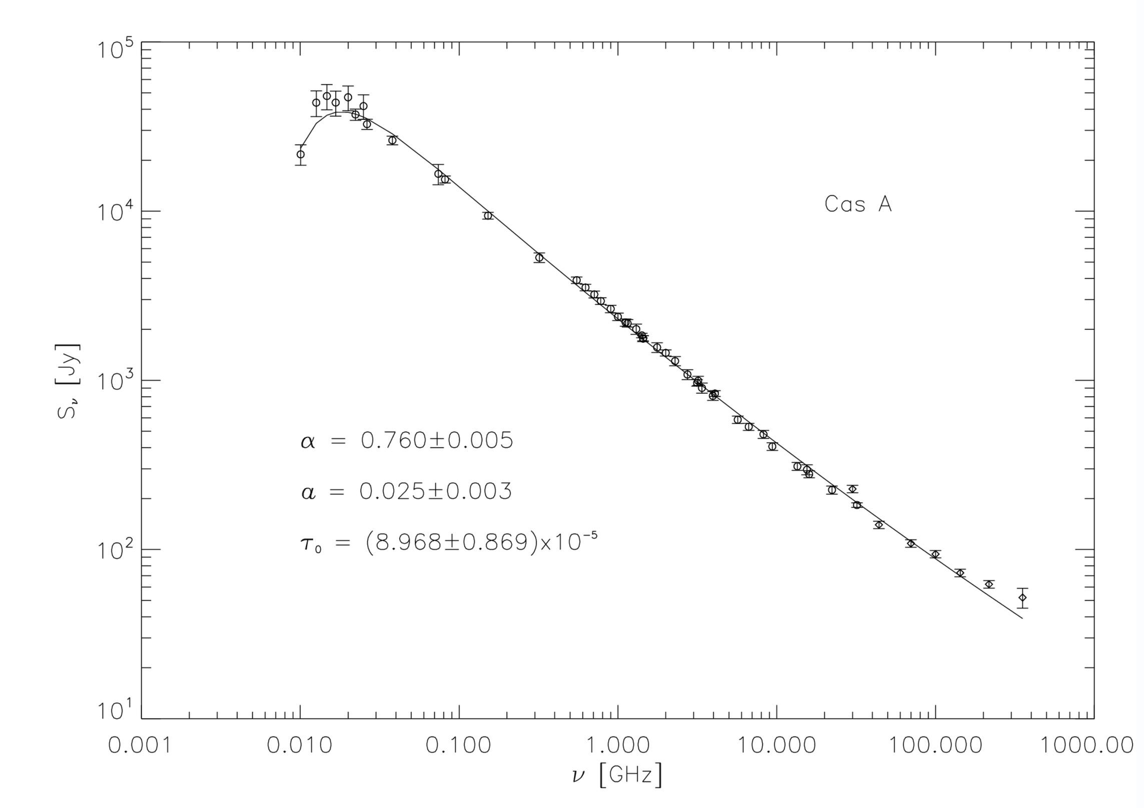

Figure 2. The weighted least-square fit to the data, for the varying spectral index model with low-frequency cut-off. Diamond symbols indicate *Planck's* data

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During the work on this paper, the authors were financially supported by the Ministry of Education and Science of the Republic of Serbia through the project 176005 "Emission nebulae: structure and evolution".