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Study of Synchrotron Emission of Crab Nebula Using Spectral Index Measurement

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***Abstract* - The present study deals with the spectral energy distribution (SED) of crab nebula covering energy regimes from radio to optical region, using the measurement of spectral index. We have obtained spatial variation of spectral index□α □ 0.5 in the range from radio spectral index,α_Radio=-0.31 to optical spectral indexα_Optical=-0.84 by applying fit function upon the available flux density data and obtained the synchrotron cooling break frequency around 10^14 Hz. Our results came out to be very close within the acceptance values with the observations and recorded results.**

***Index Terms* - Plerions, Radiation mechanism, Spectral index, Synchrotron emission.**

1.INTRODUCTION

The study of SED of crab nebula using spatial variation of spectral index becomes very important to understand the structure and dynamics of different physical mechanism which are taking place in the multi frequency band expansion of Crab nebula.

The Crab Nebula, Messier 1 (M1, NGC 1952) is the supernova remnant in the Milky way galaxy which was witnessed by the Chinese astronomers Wang Yei-te in 1054 A.D [1]-[3].It is also taken as the prototype of Pulsar Wind Nebulae (PWNe) or called Plerions which are known to be powered by a rotating neutron star at the centre, crab pulsar PSR B0531+21[Hester 2008].The crab pulsar together with the expanding parts of filaments and power-wind nebula makeup the Crab nebula [4].

It was first discovered as a bright radio source in the constellation of Taurus [5] at a distance of about 2 kpc from the earth [6]. The resultant synchrotron emission due to trapped highly energetic relativistic electrons [7] is extended from radio to x-ray wavelengths, accompanied with the same degree of polarization and the same orientation [8], obeying synchrotron power law with spectral index range between $0 < \alpha < 1.2$ steepening with the increasing frequency [9] and observed spectral break at high frequency $\leq 3 \text{ X } 10^{13}$ Hz [10] in optical region recorded. At higher frequencies > 10^{15} Hz, energies above 1GeV, spectral energy distribution in Crab nebula is explained by inverse Compton effect due to up-scattering of synchrotron photons by the relativistic electrons in the nebula [11][12]. The crab nebula was discovered in multi frequency bands from radio to gamma rays [13]. In this paper, we have introduced a new approach of applying a fit equation with GNU plot for calculating the spectral indices of Crab nebula's broad band SED ranging from radio to optical regions using the available data from the different sources consisting of earth-based telescopes utilities to satellite borne facilities. The measured results and the spatial variation of spectral index were compared and found in good agreement with the existing published results.

2. DATA COLLECTION

We have collected the flux density data ranging from radio to optical energy region from the different sources consisting of earth-based telescopes observations and satellite borne facilities results. The catalogues were accessed through Vizier/CDS and NED (NASA Extra-galactic Database).

The catalogues used: Swift Master Catlog, Radio Sources observed with Culgoora Circular Array [14] Planck Multi-frequency Cat. of Non-thermal Sources [15] 74MHz VLA Low-frequency Sky Survey Redux (VLSSr) [16] Texas Survey of radio sources at 365MHz [17] Supernova Remnants at Meter wavelengths [18] 22MHz flux densities of radio sources [19] Planck Catalogue of Compact Sources Release 1[20] SPECFIND V2.0 Catalogue of radio Apparao, K. M. (1973) continuum spectra [21] ground-based telescope Data [22]-[24].

3. METHODOLOGY USED

Crab nebula is a non-thermal radio source of synchrotron radiation extending over the frequency range of 15 MHz -300 GHz and above 10^4 GHz [22]-[23]. The spectral energy flux of the synchrotron emission is given by power law,

$$F(v) = K.v^{-\alpha} \quad (1)$$

Where flux density, $F(v)$ (Jansky or Jy) is a measure of strength of radiation emitting from a radio source, K is constant , v is the frequency and α is spectral index, ≥ 0 for non-thermal sources. The proposed fit equation was formulated taking flux density function [22] for calculating the spectral index:

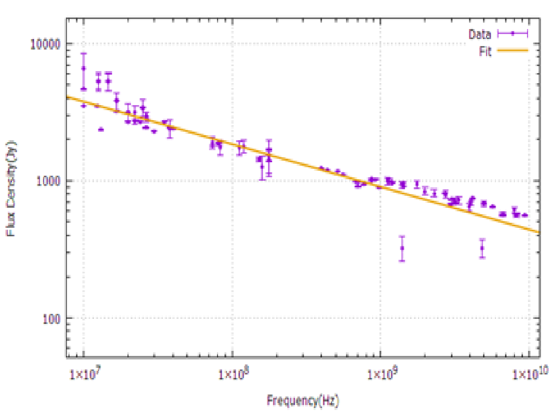
$$log f(Jy) = a + b\, log v[MHz] + c \log^2 v[MHz] (2)$$

$$f(v) = 10^{a+b\log(v)} \quad (3)$$

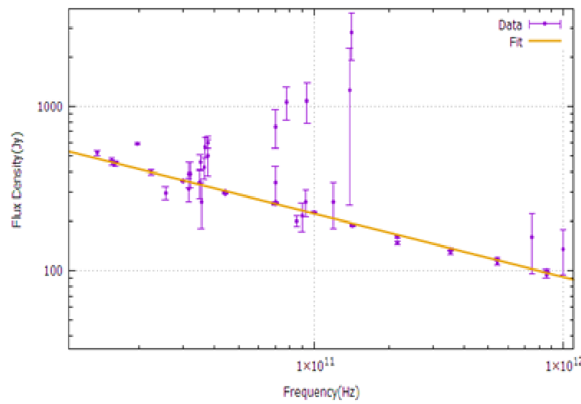
The fit equation using GNU plot was applied on the collected data of the different sources and the values of spectral parameters were calculated ranging from Radio to optical energy regions where spectral parameter “b” defined the spectral index value.

4. RESULT

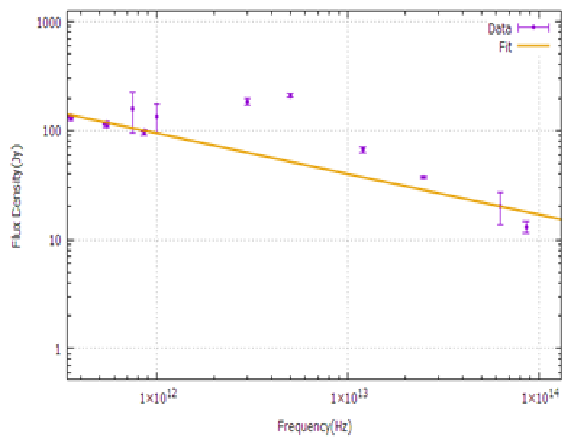
The net flux (Jy) is plotted against frequency (Hz) for different energy regimes namely radio, microwave, infrared and optical regions to determine the spectral index (Figure 1). The input values are taken from the available published data as mentioned above corresponding to different energy regions.



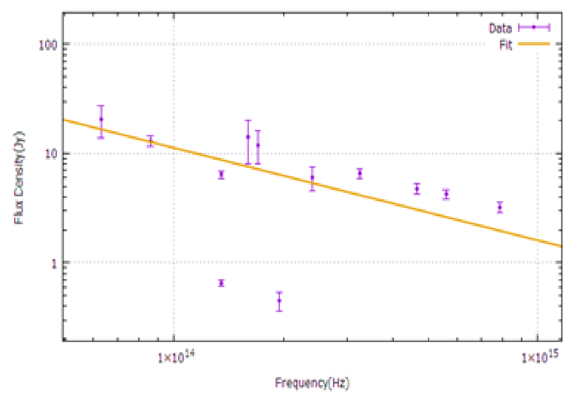
(a) Radio region, αR = - 0.31



(b) Microwave region, αMW = - 0.38



(c) Infrared region, α IR = - 0.37



(d) Optical region ,α_O = - 0.84

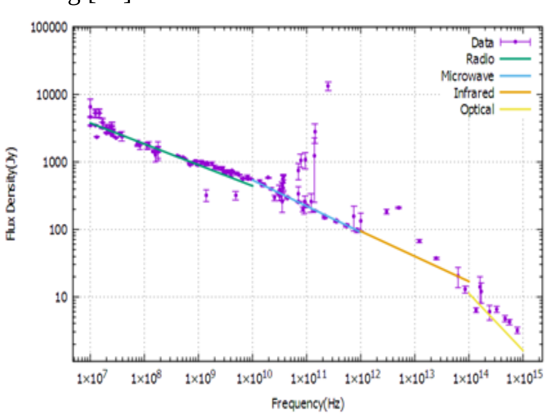
(Figure 1: Graph between Flux Density and Frequency (a) Radio region (b) Microwave region (c) Infrared region (d) Optical energy region)

An almost flat, continuum radio spectrum was obtained with a negative slope of α_R= -0.31097 ± 0.009 which is quite close to the reported value by the ground based telescopes observations on radio spectral index$\alpha = 0.28 \pm 0.05$[24], 0.299± 0.009 [22], α= -0.27 from 10MHz-to synchrotron break frequency near 10^4 GHz. [25]. In Microwave region, the spectral index α_{MW} =-0.385607 ± 0.0071was obtained using the recent data by Planck [20].

The spectral index value α_{IR} =-0.37248 ± 0.0299 was calculated in infrared region which is compatible with the literature. There is a significant variation in spectral index values from 0.3 to 0.8 in the Infrared region[26] caused by the steepening of spectral index values with distance from the central pulsar as a result of synchrotron losses.The spectral index was reported α=0.65 after applying extinction correction factor because of scattering and absorbing of radiations due to the presence of interstellar dust and gas [27]whereas the global synchrotron spectral index of the Crab Nebula was taken 0.5 [28].Hence our obtained spectral index value lies within this range and compatible with the literature.

The global (average) synchrotron spectral index of the Crab Nebula for the entire nebula at optical wavelengths was recorded 0.8 with the variations in a range from 0.6 to 1.0 in the optical region found [23]. The satellite 'Orbiting Astronomical Observatory' (OAO) made the ultraviolet observations [24] and measured corrected spectral index ≈ 0.8. Our fit function gave a spectral index of α_O =-0.8454 ± 0.07which is consistent with the accepted values.

Plotting the flux density data against frequency from the radio to optical energy regions, observed the steepening of curve with a change in the in spectral index $\Delta\alpha \approx 0.5$ consistent with [29] ranging spectral index values, $\alpha_{Radio} = -0.31$ to $\alpha_{Optical} = -0.84$, obtained a spectral break going from Radio to optical break around 10^{14} Hz which is close to the expected frequency of the spectral break due to synchrotron cooling [30].



(Figure 2: Graph between Flux Density and Frequency from Radio to Optical energy regimes)

Our results are within the acceptable values on comparison of recorded values as recorded the continuum radio spectrum exhibited a synchrotron power law with a spectral index−0.299 ± 0.009 [22] at higher frequency, above 10^4 GHz, the observation is also consistent with synchrotron emission with a power law of spectral index−0.73 [23].

The spectral variables with "b" being the spectral index, for the various different electromagnetic regimes are tabulated here.

EM region	Frequency region (Hz)	a	b	References
Radio	$10^7 - 10^{10}$	5.7547 ±0.074	-0.3109 ± .009	-0.299±0.009[22] -0.26[31]
Micro wave	$10^{10} - 10^{12}$	6.5869 ±0.075	-0.3856 ±0.007	-0.296 [8]
Infrare d	$10^{12} - 10^{14}$	6.4435 ±0.251	-0.3724 ±0.029	-0.3-0.8[26] -0.65[27] -0.296[8]
Optical	$10^{14} - 10^{15}$	12.886 ±0.907	-0.8454 ± 0.07	-0.6-1.0[23] -0.9 [31]

5. CONCLUSION

We first established that the obtained values of spectral indices are in agreement with the canonical model of crab nebula [22], according to which spectral energy distribution due to relativistic electrons is represented by a power law whereas the synchrotron emission takes place at low and high frequencies with dust components in infrared region and the energy is lost due to synchrotron emission as it progressed towards the outside [32].The obtained spectral index for radio region is ~0.3 flatter than the rest of the Nebula and the crab pulsar is the dominant accelerator of the relativistic electrons from radio to optical region. A clear change in the spectral index is noted between the optical and the radio regions indicating the synchrotron break frequency due to synchrotron cooling.

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access tool, CDS, Strasbourg, France (DOI: 10.26093/cds/vizier). The original description of the VizieR service was published in 2000, A\&AS 143, 23.

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