MNRAS 000, 1–13 (2015) Preprint 29 October 2021 Compiled using MNRAS LATEX style file v3.0

Spectral States of OJ 287 blazar from Multi-wavelength Observations with *AstroSat*

K. P. Singh,[1,7]* P. Kushwaha,[2]†‡ A. Sinha,[3,6] Main Pal,[4,8] A. Agarwal, [5]
G. C. Dewangan[6]

[1] *Department of Physical Sciences, Indian Institute of Science Education and Research Mohali, Knowledge City, Sector 81, SAS Nagar, Punjab 140*
[2] *Aryabhatta Research Institute of Observational Sciences (ARIES), Manora Peak, Nainital 263001, India*
[3] *Laboratoire Univers et Particules de Montpellier, Université de Montpellier, CNRS/IN2P3, CC 72, Place Eugène Bataillon, F-34095 Montpellier*
[4] *Centre for Theoretical Physics, Jamia Millia Islamia, New Delhi-110025, India*
[5] *Raman Research Institute, C. V. Raman Avenue, Sadashivanagar, Bengaluru 560080, India*
[6] *Inter-University Centre for Astronomy and Astrophysics, Ganeshkhind, Pune 411 007, India*
[7] *Department of Astronomy and Astrophysics, Tata Institute of Fundamental Research, 1 Homi Bhabha Road, Mumbai 400005, India*
[8] *Department of Physics, Ramjas College, University of Delhi, New Delhi-110007, India*

Accepted XXX. Received YYY; in original form ZZZ

ABSTRACT

We present *AstroSat* soft X-ray, near-UV (NUV) and far-UV (FUV) observations of a blazar, OJ 287, carried out in 2017, 2018, and 2020. The simultaneous observations with NuSTAR in 2017 provide a broad-band look encompassing NUV, FUV, soft and hard X-rays. Captured in three different broadband spectral states in three observations, the X-ray spectrum is found to be the hardest during 2018, while the high-energy-end of the simultaneous optical-FUV spectrum shows a steepening that is modeled with a broken power-law spectrum. The spectral energy distribution (SED) in 2017 shows a relatively flatter optical-FUV and soft X-ray spectra, implying an additional emission component. The 2020 optical-FUV spectrum is harder than in 2017 and 2018, with an extremely soft X-ray spectrum and a hardening above ∼1 GeV, similar to the SEDs of High-energy-peaked BL Lac objects (HBL), thereby establishing that this additional emission component has HBL-like properties. The *AstroSat* multi-wavelength observations trace the spectral evolution from the end-phase of the HBL component in 2017 to its disappearance in 2018 followed by its revival in 2020. A single zone leptonic model reproduces the 2018 broadband spectrum while the 2017 and 2020 SEDs require an additional HBL-like emitting zone. The spectral evolution of the high-energy-end of optical-UV spectrum, revealed by the FUV observations in 2017 and 2018, strongly suggests that X-ray spectral changes in the normal broadband spectral state of OJ 287 are primarily due to the evolution of the optical-UV synchrotron spectrum.

Key words: BL Lac objects: individual: OJ 287 – galaxies: active – galaxies: jets – radiation mechanisms: non-thermal – gamma-rays: galaxies – X-rays: galaxies

1 INTRODUCTION

BL Lac type objects are a special class of active galactic nuclei known as blazars, that are powered by accretion on to a super-massive black-hole (SMBH) and have a super-luminal relativistic jet directed almost along the line-of-sight to us. The radiation from such objects covers the entire range of electromagnetic spectrum from radio to very high energy (VHE, E > 100 GeV) γ-rays and can be highly polarised. The entire emission originates almost exclusively within the jet and exhibits a broad spectral energy distribution (SED) with two distinct humps ascribed to synchrotron and inverse-Compton processes, and with their peaks shifting towards lower frequencies with increasing bolometric luminosity thus giving rise to a spectral sequence that has been clubbed into three classes known as Low-frequency-peak BL Lac (LBLs), intermediate-frequency-peak BL Lacs (IBLs), and high frequency peak BL Lacs (HBLs) (Fossati et al. 1998; Abdo et al. 2010). X-ray emission from blazars is either due to Synchrotron (Sy) process from highly energetic electrons (or protons) or due to Synchrotron Self-Compton (SSC) process where low frequency photons are boosted in energy by the inverse Compton (IC) process from the same electrons that produced the Sy emission. Radiation from these objects is highly variable in intensity and spectral shapes on time-scales of minutes to years, indicative of highly compact yet powerful sub-parsec size for the emission regions powering these objects.

OJ 287 is an archetypal BL Lac object with red-shift, z,

* E-mail: kpsinghx52@gmail.com (KPS)
† pankaj.kushwaha@aries.res.in (PK)
‡ Aryabhatta Postdoctoral Fellow