PhD second year report

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1 Research activity

During my PhD I am working with INAF Brera-OA Merate and the MAGIC Collaboration. *Extreme TeV Bl Lacs* are the main topic of my research activity.
In most cases the emission of a galaxy is dominated by the emission of its stars. *Active Galactic Nuclei* (AGN) outshine the host galaxy thanks to the bright emission of their central supermassive black holes. About 10% of the AGN are radio-loud, i.e. presents two-sided relativistic jets. *Blazars* are radio-loud AGN with a relativistic jet pointing towards the Earth. Blazar variability is generally extreme, moreover their spectral energy distribution (SED) ranges from radio to gamma rays and it is dominated by the non-thermal emission of the jet. For this reason the SED of blazars displays two broad humps, attributed respectively to synchrotron and inverse Compton mechanisms (for the latter one there is no general consensus yet) and amplified by the relativistic beaming.
Blazars can be classified using the position of the first peak, which ranges from the infrared to the x-ray band. Blazars whose first peak is in the x-ray band are called *Extreme Highly Peaked Bl Lacs* (EHBL). There is a subclass of EHBL, called extreme TeV Bl Lacs, which presents peculiar characteristics: i) the second SED peak beyond 1 TeV; ii) a hard sub-TeV intrinsic spectrum; iii) in most cases, the TeV emission is stable over years.
The standard phenomenological models based on a single shock acceleration are not able to reproduce these features, therefore many alternative models have been proposed, for example based on multiple shocks. The phenomenological models that leave the acceleration mechanism unspecified show that extreme TeV Bl Lacs present an extremely low magnetization. Recent 3D MHD simulations show that if the magnetization is low, the turbulence prevails after the first shock, preventing the formation of multiple shocks. Therefore we decided to elaborate a hybrid model where the non-thermal electrons are firstly accelerated through diffusive shock acceleration and then they are further energized by the turbulence through stochastic acceleration.
A first attempt was made supposing a constant turbulence spectrum and using the Synchrotron Self Compton (SSC) leptonic model, in which the photons emitted by synchrotron emission by the non-thermal electrons are then upscattered by the same electrons. Since the resulting SED was harder than the data of the prototypical extreme TeV Bl Lac object 1ES0229+200 and the magnetic energy density was much more lower than the electrons energy density, we deduce that the damping of the turbulence due to the non-thermal electrons was not negligible. Therefore we elaborated a more refined model which includes the interaction between electrons and turbulence. We calculated the electron and turbulence spectra solving a system of two non-linear Fokker-Planck equations and then we compute the emission spec-

trum using again the SSC model. The resulting SED is in good agreement with the data of 1ES0229+200 and the model parameters are in line with the theoretical expectations.
The model was improved adding lower order effects (e.g. Inverse Compton cooling for electrons) and new numerical algorithms were tested (e.g. Implicit-Explicit Runge Kutta). Moreover we tested the model with additional extreme TeV Bl Lac objects using Markov Chain Montecarlo sampling: the results confirm the theoretical predictions.

2 Attended courses and exams

- **Particle Physics and Multimessenger Astroparticles:** Exam attended and passed
- **Introduction to High Energy Astrophysics:** Exam attended and passed
- **Observational Astronomy:** Exam attended and passed
- **Artificial Intelligence for Astrophysical Problems:** Master course of Università degli studi dell'Insubria, exam attended and passed
- **International School of Physics "Enrico Fermi" - Course 208, Foundations of Cosmic Ray Astrophysics:** attended in place of a PhD course

3 Publications

[1] Fabrizio Tavecchio, Agnese Costa, and Alberto Sciaccaluga. **Extreme blazars: the result of unstable recollimated jets?** In: MNRAS (July 2022).

[2] Alberto Sciaccaluga and Fabrizio Tavecchio. **Extreme TeV BL Lacs: a self-consistent stochastic acceleration model**. In: MNRAS (Oct. 2022).

[3] Alberto Sciaccaluga and Fabrizio Tavecchio. **Extreme TeV BL Lacs: a self-consistent stochastic acceleration mode**. In: *Probing the Universe with Multimessenger Astronomy* (May 2023).

4 Conference presentations

- Speaker at "Hands On the Extreme Universe with High Energy Gamma Ray data", **Extreme TeV blazars: a phenomenological model**, Sesto Pusteria (Italy), 18-22 July 2022
- Speaker at "PASTO - Particle Acceleration in Astrophysical Object", **Extreme TeV blazars: a stochastic acceleration model**, Roma (Italy), 5-7 September 2022

- Speaker at "PUMA - Probing the Universe with Multimessenger Astrophysics", **Extreme TeV blazars: a stochastic model**, Sestri Levante (Italy), 26-30 September 2022

- Speaker at "Workshop Bologna&Friends", **Simulations of unstable recollimation shocks and Fermi-like particle acceleration**, Bologna (Italy), 1-2 March 2023

5 PhD Schools

- **International School of Physics "Enrico Fermi" - Course 208, Foundations of Cosmic Ray Astrophysics**, Varenna (Italy), 23-29 June 2022

- **The Transient Universe 2023**, Cargese (France), 30 May-9 June 2023