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A cosmic chameleon escapes classification

Blazars are active galaxies that emit narrow jets of ionised matter from their centres, aimed towards Earth. Depending on properties of the electromagnetic radiation emitted by the jets, astronomers divide such objects into different, clearly defined classes. However, with the BL Lacertae blazar, located in the background of the Lizard constellation, things turn out to be not quite so simple.

Once again, the distant cosmos has surprised researchers. Until now, it seemed that blazars – active galaxies emitting jets of matter towards us – could be divided into fairly distinct groups according to the electromagnetic radiation they generate. This hitherto clear situation has just become very complicated. In the prestigious astronomical journal *Astronomy & Astrophysics*, a Polish-German team of scientists from the Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) in Cracow and the University of Heidelberg (HU) report recent observations of a blazar which, for unknown reasons, escapes the current classification.

The object now known as BL Lacertae was discovered in 1929 in the background of the Lacerta (Lizard) constellation. Initially, astronomers regarded it as one of many variable stars in our galaxy. However, later observations led to a surprising discovery: what looked like a star in fact appeared to lie as far as 900 million light years away – so it certainly could not be a star.

Of the hundreds of billions of galaxies visible within the observable Universe, some are active galaxies. These are galaxies whose nuclei emit large amounts of electromagnetic radiation, presumably as a result of the complex processes that occur when matter falls into the central supermassive black hole. In some galaxies, narrow jets of ionised matter ejected from near the poles of the black hole over gigantic distances, in extreme cases even exceeding a million light-years, are a spectacular sign of activity. If the jet runs towards Earth, astronomers call the galaxy producing it a blazar. BL Lacertae turned out to be just such an object.

“Blazars are interesting for many reasons, not least because the orientation of the jets and the enormous velocities of their particles, close to the speed of light, lead to a variety of effects described by the theory of relativity. Emission from blazars is observed at various electromagnetic wavelengths, ranging from radio to very high-energy gamma rays,” explains Dr. Alicja Wierzcholska (IFJ PAN) and specifies: *“We focused on the analyses of the energy of electromagnetic radiation emitted by one of the earliest discovered blazars: BL Lacertae. Why did we focus on this particular one? Because of its activity in recent years and some interesting features of the radiation emitted by it, which we had already noticed during earlier observation sessions.”*

The reported observations took place in 2020-2023. They were carried out in orbit around the Earth with instruments from the American Neil Gehrels Swift Observatory satellite; only in the hard X-ray range were they complemented by data from the NuSTAR space telescope. In addition to the X-ray range which was of most interest to the Polish-German researchers, the optical and ultraviolet regions of the spectrum were also recorded. This is because the electromagnetic radiation produced by blazars extends from the radio range through the optical, ultraviolet and X-ray regions to gamma radiation of the highest energies.

Blazars are subdivided into flat spectrum radio quasars and BL Lacertae objects (BL Lacs), which are characterised by weaker emission lines and whose name is derived precisely from the BL Lacertae blazar. Within the BL Lacs, a further division is possible. Indeed, diagrams showing the entire energy spectrum of blazars resemble volcanic cones: they have two peaks separated by an arched depression. If the spectral 'volcano' is shifted towards the high-energy side, the BL Lacertae object is classified as HBL (High-frequency peaked BL Lac), if towards the low-energy side – as LBL (Low-frequency peaked BL Lac), while objects with an intermediate shift are referred to as IBLs (Intermediate BL Lacs).

"BL Lacertae objects lend themselves quite unambiguously to being assigned to a specific type. Blazar BL Lacertae has so far been considered a representative of the intermediate class, the IBL. It was therefore with no small degree of surprise that we noticed that in the X-ray range it looked like an HBL at some phases of the observation period, at others like an LBL, and at other times 'politely' gave the impression of an IBL-type object. As if this were not enough, these sorts of changes occurred very quickly. This is unusual behaviour, the physical basis of which we are not yet able to explain," says Dr. Wierzcholska, and emphasises that there were more surprises: the recorded X-ray activity of the blazar turned out to be a record in the entire history of its observations.

It is currently assumed that separate physical phenomena involving different populations of particles in the jet are responsible for the existence of the two peaks in the spectra of blazars. Many astrophysicists agree with the assumption that the low-energy peak is related to electrons and the synchrotron radiation they emit. There is no consensus of opinion for the second peak. Perhaps it too is a consequence of the electrons' behaviour, for example, their collisions with low-energy photons, which would result in an increase in the photons' energy (this is known as inverse Compton scattering). However, other hypotheses have also been put forward, for example those involving hadrons (i.e. clusters of quarks such as protons or neutrons). But in order to explain the behaviour of the BL Lacertae blazar, it would be necessary to point to something more: not only the physical processes responsible for the formation of the two peaks, but above all the mechanism responsible for their rapid switching. One could venture to say that before this happens, many an astrophysicist-theorist will spend many a sleepless night.

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The Henryk Niewodniczański Institute of Nuclear Physics (IFJ PAN) is currently one of the largest research institutes of the Polish Academy of Sciences. A wide range of research carried out at IFJ PAN covers basic and applied studies, from particle physics and astrophysics, through hadron physics, high-, medium-, and low-energy nuclear physics, condensed matter physics (including materials engineering), to various applications of nuclear physics in interdisciplinary research, covering medical physics, dosimetry, radiation and environmental biology, environmental protection, and other related disciplines. The average yearly publication output of IFJ PAN includes over 600 scientific papers in high-impact international journals. Each year the Institute hosts about 20 international and national scientific conferences. One of the most important establishments of the Institute is the Bronowice Cyclotron Centre (CCB), which is an infrastructure unique in Central Europe, serving as a clinical and research centre in the field of medical and nuclear physics. In addition, IFJ PAN runs four accredited research and measurement laboratories. IFJ PAN is a member of the Marian Smoluchowski Kraków Research Consortium: "Matter-Energy-Future", which in 2012-2017 enjoyed the status of the Leading National Research Centre (KNOW) in physics. In 2017, the European Commission granted the Institute the HR Excellence in Research award. As a result of the categorization of the Ministry of Education and Science, the Institute has been classified into the A+ category (the highest scientific category in Poland) in the field of physical sciences.

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LINKS:

http://www.ifj.edu.pl/
The website of the Institute of Nuclear Physics, Polish Academy of Sciences.

http://press.ifj.edu.pl/
Press releases of the Institute of Nuclear Physics, Polish Academy of Sciences.

IMAGES:

IFJ250312b_fot01s.jpg **HR:** http://press.ifj.edu.pl/news/2025/03/12/IFJ250312b_fot01.jpg
Blazar BL Lacertae is an active galaxy, emitting from its core a plasma jet that is directed towards Earth (artistic image).
(Source: NASA/JPL-Caltech)