**////Title: Studying Blazars with Multiwavelength and Multi-messenger Astronomy**

**////Standfirst:**

Blazars [blay-zaars] are some of the brightest and most vibrant objects known to astronomers: emitting high-velocity jets of matter, and producing gamma rays which outshine almost all other sources in the known universe. To study these phenomena, astronomers must use the latest techniques to observe blazars simultaneously at different wavelengths of electromagnetic radiation, while also capturing the elusive neutrinos they emit. In a recent article, Dr Markus Böttcher [Bert-yer], an astronomer at North-West University on Potchefstroom [Potch-uhf-strome], South Africa, presents an overview of the latest advances in these ‘multiwavelength’ and ‘multi-messenger’ techniques – and where they could lead in the near future.

**////Main text:**

Blazars can be found in the compact, extremely bright regions at the centres of some galaxies, and are widely thought to form as material is accreted by supermassive black holes – which are often billions of times more massive than our Sun. Although their brightness is highly variable, and often fluctuates on extremely short timescales, blazars emit light across the entire electromagnetic spectrum. Alongside this radiation, they also emit colossal jets of charged particles that travel through intergalactic space at close to the speed of light.

Astronomers now propose that the radiation emitted by blazars is triggered by a variety of different mechanisms. According to current theories, their lower-frequency light is produced by relativistic electrons, which are forced to change direction as they pass through strong magnetic fields. In contrast, higher-frequency radiation is thought to emerge as photons are scattered by the same relativistic electrons, gaining energy in the process. The light produced in this way is now well known among astronomers as the brightest persistent source of gamma rays in the entire sky.

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In his recent publication, Dr Böttcher describes how much of our understanding of the gamma rays emitted by blazars comes from observations by NASA’s Fermi Gamma-Ray Telescope, as well as from ground-based instruments, including HESS, MAGIC, and VERITAS. Since blazars emit wavelengths across the entire electromagnetic spectrum, he explains that it is important to correlate these observations with other wavelengths emitted at the same time – a technique named ‘multiwavelength astronomy’. Unfortunately, since blazar emissions at different wavelengths are not always correlated with each other, this can often be extremely difficult.

One alternative technique arises from neutrinos. Neutrinos are chargeless, almost massless particles that may also be emitted by blazar jets. Through ‘multi-messenger astronomy’, detections of astronomical neutrinos can be correlated with flashes of light originating from blazar jets – allowing astronomers to glean important insights into their physics.

Neutrinos are notoriously difficult to detect, but have been picked up by facilities such as the IceCube Neutrino observatory at the South Pole. This instrument uses detectors positioned throughout a vast block of Antarctic ice to detect tiny flashes of light, produced by high-energy neutrinos as they interact with particles in the ice.

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Despite the limitations of these techniques, several recent observations have provided fascinating insights into the physical properties of blazars, and the mechanisms by which they produce electromagnetic radiation. This radiation includes very-high-energy gamma rays, which fluctuate on timescales as short as a few minutes, and often – though not always – show a clear correlation between gamma rays and lower-energy X-rays. Perhaps most intriguingly, astronomers have identified one particular blazar as the likely source of one of the highest-energy neutrinos detected by IceCube.

According to Dr Böttcher, each of these important discoveries has enabled astronomers to gain a better theoretical understanding of blazars, and the radiation they emit. So far, this has led to several differing theories to explain the possible causes of variability in blazar brightness – including shocks and turbulence within their jets, and collisions between jets and stars or dust clouds. Alongside this work, astronomers have also used theoretical techniques to study polarisation in the light produced by blazars – whereby electromagnetic waves become aligned in one particular direction.

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Despite the many important advances made through these previous studies, there are still many questions surrounding the nature of blazars and their emissions that astronomers have yet to answer. Through future advances in the capabilities of multiwavelength and multi-messenger astronomy, Dr Böttcher hopes that three key questions in particular could soon be answered. Firstly, what is the material composition of blazar jets, and what types of particles are responsible for the highest-energy gamma rays they emit? Answering this question could lead to major new insights into the energy loaded onto and launched by the jets.

Secondly, what are the shapes of the magnetic fields that surround blazars, and what are their roles in accelerating jets to close to the speed of light? Answers to this question could lead to a better understand how the jets flow, and the mechanisms underlying their acceleration. Finally, where along the jets are high-energy gamma rays actually being produced? If astronomers could identify the mechanisms most likely to be responsible for this radiation, Dr Böttcher proposes that their findings could hint at evidence for processes that go beyond our current understanding of particle physics.

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Dr Böttcher and his colleagues may not have to wait too long before they can begin to answer these questions. On December 9th, 2021, NASA launched the IXPE [I-X-P-E]: the first space observatory designed to measure the polarisation of high-energy X-rays originating from sources across the universe, including those emitted by blazars. By the mid-2020s, the Cherenkov Telescope Array is also scheduled to come online. This worldwide project is developing a new generation of ground-based, high-energy gamma ray detectors – distributed across two arrays of telescopes in Chile and the Canary Islands.

These arrays will be some 10 times more sensitive than HESS, MAGIC, or VERITAS – providing astronomers with unprecedented opportunities to study blazars through the gamma rays they emit. Together, Dr Böttcher hopes that these cutting-edge instruments could prove to transform the capabilities of multiwavelength and multi-messenger astronomy – providing answers about the nature of blazars, and the radiation they emit, which has eluded astronomers for decades.

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This SciPod is a summary of the paper ‘Progress in Multiwavelength and Multi-Messenger Observations of Blazars and Theoretical Challenges’, from MDPI. [doi.org/10.3390/galaxies7010020](https://doi.org/10.3390/galaxies7010020)

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