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Study suggests a paradigm shift in our understanding of gamma ray bursts

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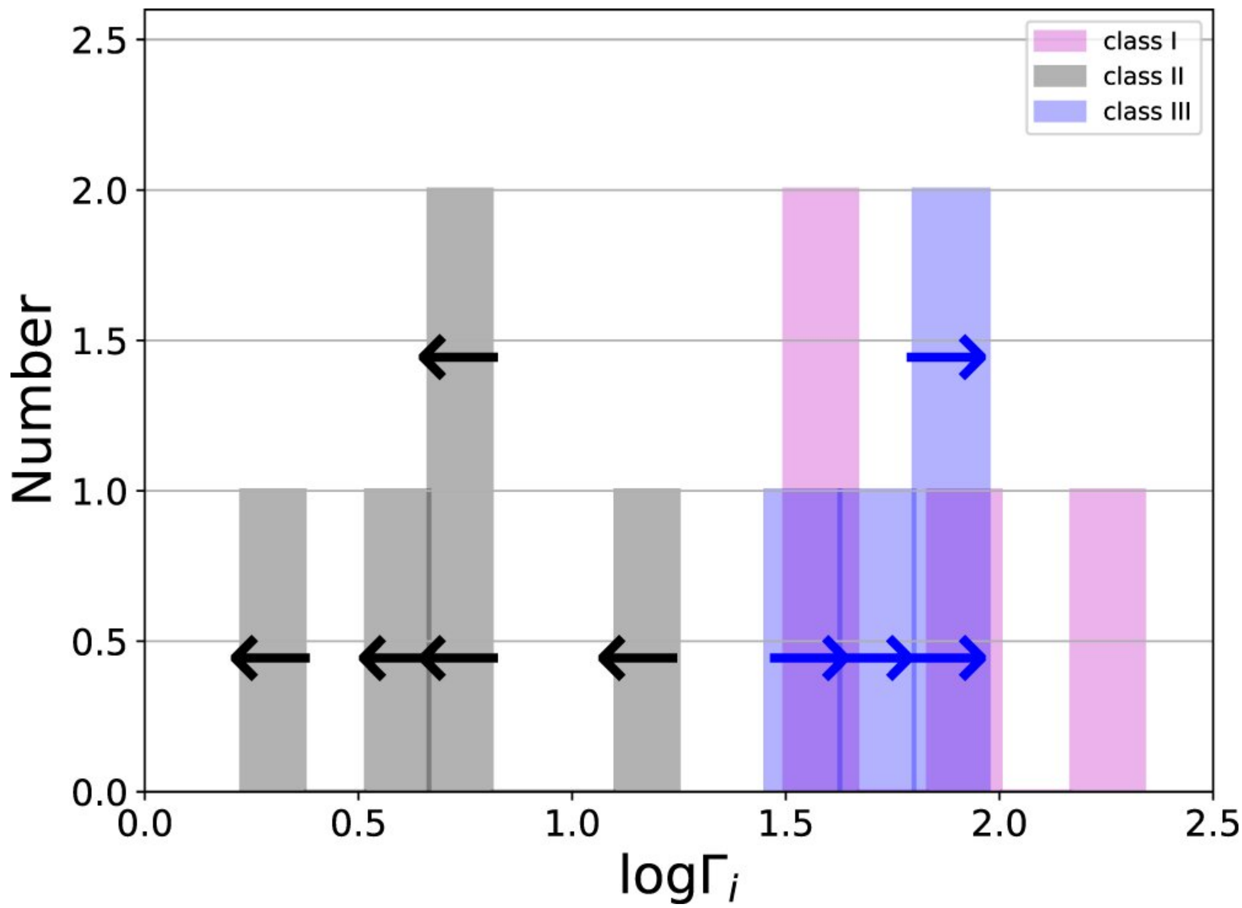

Histogram of the initial jet Lorentz factors for the 13 GRBs in our sample. These values are obtained by assuming that the fraction of energy in the magnetic field is $\epsilon_B = 10^{-3}$. The purple bars represent values deduced directly from the data (class I), the black bars are upper limits (class II) and the blue bars are lower limits (class III). Upper and lower limits are also marked by arrows. The average value of the initial GRB jet Lorentz factor is $\langle\Gamma_i\rangle \approx 51$ (median is 32), although the range span is between $1.7 \lesssim \Gamma_i \leq 218$ (see Table 3). We point out that GRB 080607 which has the highest value of Γ_i has a large gap in its X-ray LC between the plateau and self-similar phases. Furthermore, GRB 171205A which has the lowest value of Γ_i is associated with SN 2017iuk, therefore, both the optical plateau and self-similar slopes of this burst are effected by the SN bump. Credit: *Nature Communications* (2022). DOI: 10.1038/s41467-022-32881-1

Matter outflows in the form of jets are observed in astronomical systems at fast, medium and slow speeds. The fastest jets are highly relativistic, and travel very close to the speed of light. The origin, as well as many properties of the jets, is uncertain. Jet velocities seem to have a bi-modal distribution—some very fast and others slow, with a gap in velocities in between, which has long challenged experts. Bar-Ilan University researchers re-examined the data and have now seemingly solved the puzzle.

In many different galactic and extragalactic systems, emission of matter is commonly observed in the form of jets. The speed at which this occurs greatly varies. Alongside relatively slow jets associated with neutron stars or binary star systems, very fast, relativistic jets are seen at speeds very close to the speed of light. The fastest known jets are associated with a phenomenon known as gamma-ray bursts.

This phenomenon is characterized by an initial flash of gamma rays lasting for a few seconds, in which a strong emission of gamma radiation is visible. It is then followed by an afterglow lasting a much longer period of hours, days and even months. During this epoch, the emission subsequently fades and is observed as lower wavelengths, X-rays, ultraviolet, optical, infrared, and radio frequencies very late in the process.

Beyond the question of why jets from these objects are so rapid, is a seemingly unrelated mystery as to what happens during the intermediate period of hundreds to thousands of seconds, in which the emission either fades or remains constant. In some cases, after a few tens of seconds, X-ray emission decays considerably, as would be expected from a relativistic burst colliding with the matter and radiation that exist in the space between the stellar systems in a galaxy.

However, in about 60% of the observed cases, the visible emission doesn't fade but rather remains constant. This observation has long been a source of confusion to researchers, and no convincing explanation has been found for it since this phenomenon was discovered approximately 18 years ago.

Researchers from the Department of Physics at Bar-Ilan University have now proven that this visible, perpetual emission is a natural consequence of jet velocity, which is significantly lower than what was commonly assumed, and fills the gap between velocities measured from other sources. In other words, lower initial jet speed can explain lack of decay and more visible and perpetual emission.

The researchers showed that previous results, from which high speeds were deduced in these objects, are not valid in these cases. This changes the old paradigm and proves that jets are formed in nature at all speeds. The study was published in the journal *Nature Communications*.

One of the main open questions in the study of gamma ray bursts is why in a significant percentage of cases, X-rays, which are visible for up to several days, take a long time to fade. To answer this question, the researchers began a careful mapping of the data, which are numerous but scattered and "noisy."

After thorough literature research, they created a sample of high-quality data. Following an examination of explanations for the phenomenon in existing literature, they found that all existing models, without exception, make additional assumptions that are not supported by the data. What is more significant is that none of the models offered a convincing explanation for the clean data.

Therefore, the researchers returned to the basic model and tried to understand which of the basic assumptions isn't valid. They discovered that changing just one assumption, about the initial speed of the jets, was sufficient to explain the data. The researchers continued and examined the data that led other astrophysicists to conclude that the jets must be highly relativistic (that is, traveling very close to the speed of light = extremely fast), and discovered, to their surprise and delight, that none of the existing arguments was valid in the cases they studied. From there, they quickly concluded they were most likely in the right direction.

Prof. Asaf Pe'er, who led the theoretical part of this research, describes himself as a theorist who enjoys working with data. "Astrophysical systems in general are characterized by great complexity, and often theoretical models, inherently more simplistic, may miss key points," he explains. "In many cases, careful examination of the data, as we performed here, shows that existing ideas simply don't work. This is what led us to come up with new ideas. Sometimes the simplest, least complex idea is sufficient."

Prof. Pe'er's partners in this research are the study's first author, Dr. Hüsne Déréli-Begue, from the Bar-Ilan research group, and Prof. Felix Ryde, from KTH Royal Institute of Technology in Stockholm. While Pe'er focused on theory, his collaborators focused on analyzing the data that stimulated and supported the theory he proposed.

"It took us a while to develop the understanding, and once I realized that one parameter in total needed to be changed, everything worked out just like a puzzle," Prof. Pe'er says. "So much so that from some point, every time we brought up a new potential problem, it was clear to me that the data would be in our favor, and, indeed, they were."

Astrophysics research by its very nature is basic research. If, indeed, the researchers are correct, the results have far-reaching implications that can lead to a paradigm shift in the field, as well as in understanding the physical processes that produce jets. It is important to note that the origins of the phenomenon still aren't fully known, but it is clearly related to the collapse of a star (or pair of stars) into a black hole. The research results are very important in understanding these mechanisms, as well as the type of stars that end their lives in a way that produces strong gamma radiation.

"Scientific research is fascinating. New ideas are constantly born and tested. Since the data are often inconclusive, people often publish their ideas and move on," says Prof. Pe'er. "Here was a unique case, in which, after examining many ideas, I suddenly realized that the explanation could be very simple. After I proposed the explanation, we checked it again and again against the existing data, and it passed test after test. So sometimes, the simplest explanation is also the most successful one."

More information: Hüsne Dereli-Bégué et al, A wind environment and Lorentz factors of tens explain gamma-ray bursts X-ray plateau, *Nature Communications* (2022). DOI: 10.1038/s41467-022-32881-1

Provided by Bar-Ilan University