The IceCube Collaboration sets the most restrictive constraints on relic magnetic monopoles from the early universe

March 10 2022, by Ingrid Fadelli

The IceCube laboratory at the South Pole. IceCube's 5160 optical sensors are buried under the ice between 1,5 and 2,5 km, instrumenting a total volume of 1 km^3. The direction and energy of the particles that cross the detector are reconstructed from the signals they produce in the optical sensors, and this information is sent through satellite link to the IceCube participating institutions for further analysis. Credit: Martin Wolf, IceCube/NSF.

Recent technological advances have enabled the development of increasingly advanced telescope and astrophysical instruments. This includes the IceCube telescope, which was originally built to detect and examine high-energy neutrinos in the universe.

High-energy neutrino telescopes, such as the IceCube telescope, are not only sensitive to neutrinos; they can also be used to detect other exotic particles, including magnetic monopoles. Magnetic monopoles are hypothetical elementary particles comprised of an isolated magnet with a single magnetic pole.

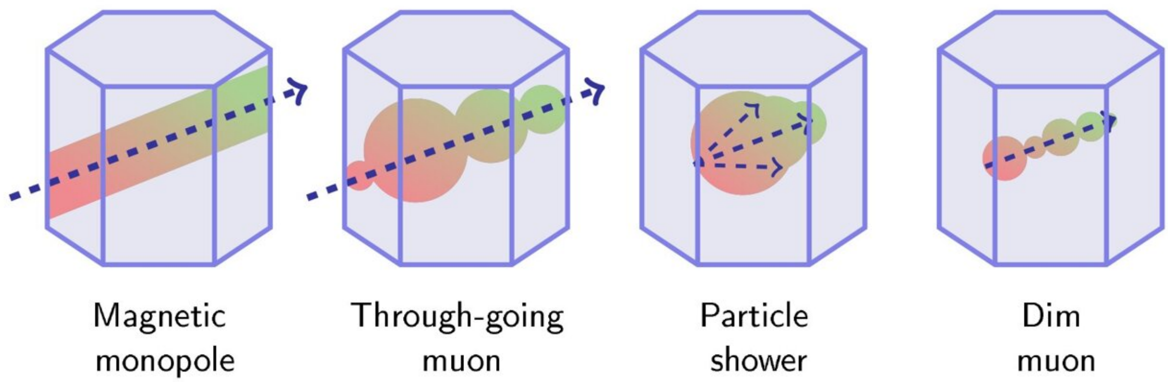
Using their high-energy neutrino telescope, the IceCube Collaboration recently set the most restrictive constraints on relativistic magnetic monopoles to date. The results of their study, published in *Physical Review Letters*, emphasize the potential of neutrino telescopes to search for exotic particles.

"A magnetic monopole with a speed near the speed of light (also-called relativistic monopole) would emit light, called Cherenkov radiation, as it traverses the ice where IceCube is deployed, leaving a very distinct signature in the detector: a very bright straight track crossing the detector," Carlos Perez de los Heros, one of the researchers who carried out the study, told Phys.org. "Our original idea was to search for very bright tracks in the eight years of accumulated data that we have from the IceCube telescope."

Grand unified theories are a set of theories that describe the evolution of the early universe, suggesting that, at the time, all known forces were unified into a single force. Similarly, today different electric and magnetic effects are assumed to originate from a single force, known as the electromagnetic force. Among other things, grand unified theories predict the existence of particles with one magnetic "pole" (i.e., monopoles).

"Currently, there are indications, although no proof, that the strong and nuclear forces were unified with the electromagnetic force in the early universe, and that they separated as different forces as the universe evolve," de los Heros said. "According to these theories, magnetic monopoles should have been created along with other matter just after the big bang."

As monopoles are theoretically stable, a gas of relic monopoles could still be permeating space today, yet no telescope has detected them so far. De los Heros and his colleagues hoped that the IceCube telescope could finally enable their detection.



Magnetic monopoles should display several distinct characteristics when traversing IceCube. This illustration shows a typical magnetic monopole event in comparison with other typical events in the IceCube detector (blue volume). The dashed lines represent particle trajectories, and the shaded areas around the trajectories represent the light pattern emitted by the different particle types. The color coding (red to green) represents the time of light production, from earlier to later. Credit: Abbasi et al. (IceCube Collaboration)

"The main objective of our analysis was to discover a cosmic flux of magnetic monopoles, with the monopole speed in the range from 0.75 to 0.995 times the speed of light," Alexander Burgman, another researcher involved in the recent study, told Phys.org. "There have been several previous analyses searching for a cosmic flux of magnetic monopoles, both using IceCube data and measurements with other facilities."

The IceCube collaboration has recently published data collected by their high-energy neutrino telescope over the course of eight years. This is a significantly longer observation time than that considered in previous monopole searches, which is around one year. Ultimately, the team hoped that, combined with advanced data analysis and reconstruction tools, this data will help them to detect monopoles and other exotic particles.

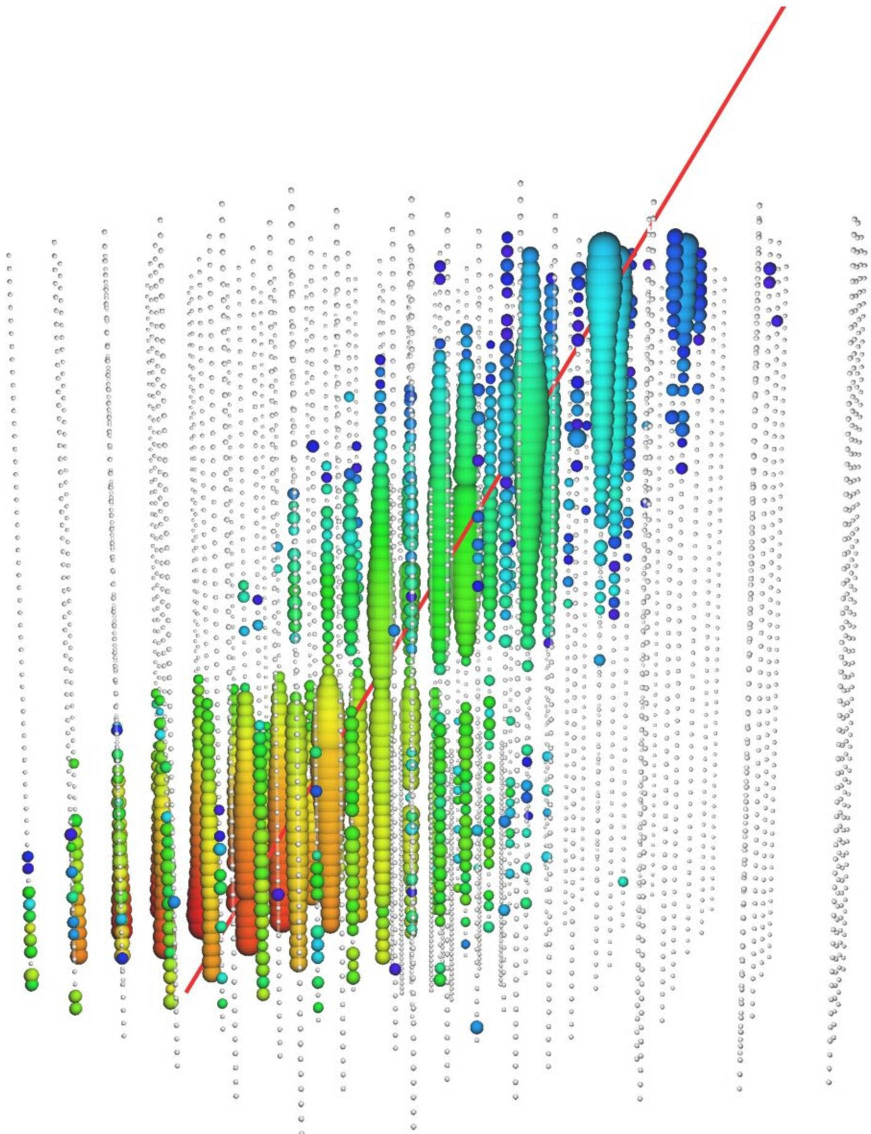
"In experimental physics, no signal is completely free of background noise (signals from other processes that mimic what you search for), and our search was no exception," de los Heros explained. "Although rarely, very high energetic neutrinos from far in the universe can interact near IceCube and produce a muon (a highly penetrating particle that resembles a heavy electron) that will cross the detector. These muons also produce Cherenkov radiation in the detector (this is how IceCube detects high-energy neutrinos) and can mimic a monopole track, although there are slight differences in the light emission pattern between a muon and a monopole."

The IceCube telescope can record around 2,700 particle "events" per second. These events can be caused by muons and neutrinos produced in the atmosphere, by neutrinos of an astrophysical origin, and, potentially, by a magnetic monopole traversing the detector.

"Initially, we determined some characteristics that would distinguish a magnetic monopole event from the regular events that we saw," Burgman said. "These include the amount of light that is detected in the event (magnetic monopoles produce a lot of light when propagating through ice) and the unevenness of the light output (monopoles would have a very smooth and even light output along their trajectory)."

As a first step, the researchers were able to reject most of the common events detected by the IceCube telescope simply based on their brightness. Subsequently, they trained a machine learning algorithm to classify the remaining "events" as either magnetic monopole- or neutrino-like, based on a series of relevant characteristics.

"We used machine learning combined with detailed computer simulations of the detector response to monopoles and muons to train the IceCube computer cluster to distinguish between muon tracks and monopole tracks," de los Heros said. "When the training was completed, the computers were fed the eight-year dataset (a total of 630 billion events) in the hope that they would identify one or more monopoles in the data."



A simulation of a magnetic monopole detection in the IceCube detector. Each sphere represents an individual light-detector module – the colored spheres represent modules that did detect light, and the grey represent modules that did not. The size of the sphere represents how much light was registered, and the color gradient (from red to blue) represents the detection time of the first registered photon in that module (from early to late). The red line represents the true trajectory of the magnetic monopole. Credit: Abbasi et al. (IceCube Collaboration)

In their analyses, de los Heros, Burgman and their colleagues from the IceCube Collaboration did not detect any events with the characteristics that would be associated with a magnetic monopole. Nonetheless, their results allowed them to set an upper limit on the cosmic monopole flux.

"Negative results are also important in physics, as they set constraints that theories must comply with," de los Heros said. "In this case, our results tell us that the number of relativistic monopoles in the universe is less than a specific value (approximately $2x10^{-19}$ per cm^2 second and stereoradian, which corresponds to less than 0.1 monopoles in a volume like the Earth at any given time). If the flux of relativistic monopoles would have been higher than that, we would have detected some, because our analysis was sensitive to a higher flux."

The new constraints set by the IceCube collaboration could have important implications for existing theories describing the evolution of the early universe. More specifically, their analyses suggest that the flux of relativistic magnetic monopoles cannot be higher than the limit they set.

"Our study contributes to the overall landscape of searches for magnetic monopoles," Burgman said. "Even though we did not find one, the results of our study will guide the next generation of searches. This type of incremental studies is a cornerstone for research on previously unobserved phenomena."

Remarkably, the limit on the relic flux of relativistic monopoles set by de los Heros, Burgman and their colleagues is currently the most restrictive one in existence. In addition to setting this important limit, their study demonstrates the versatility and wide research scope of the IceCube telescope, as well as other similar instruments. The IceCube collaboration is now searching for monopoles with lower speeds than those they searched for in this recent work.

"There is no favorite predicted speed range for monopoles," de los Heros added. "We searched for monopoles with speeds near the speed of light (relativistic monopoles) but the search continues for slower monopoles. On the other hand, as IceCube collects more years of data, the limit that we set can be made more stringent by adding more data to the analysis (if a monopole is not found)."

More information: R. Abbasi et al, Search for Relativistic Magnetic Monopoles with Eight Years of IceCube Data, *Physical Review Letters* (2022). DOI: 10.1103/PhysRevLett.128.051101

Citation: The IceCube Collaboration sets the most restrictive constraints on relic magnetic monopoles from the early universe (2022, March 10) retrieved 29 April 2024 from https://phys.org/news/2022-03-icecube-collaboration-restrictive-constraints-relic.html