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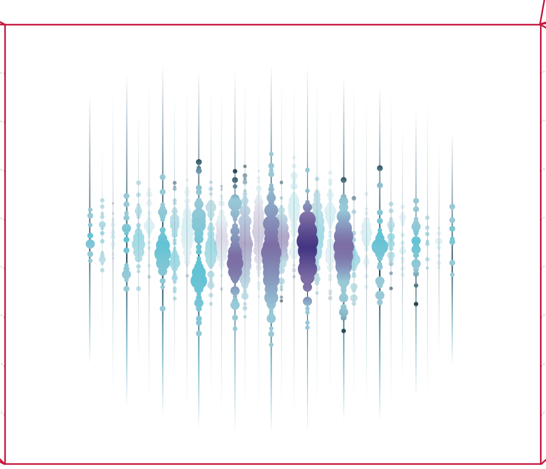
Neutrinos: Ice-Cold Detective Work

While searching for neutrinos as part of the IceCube experiment in Antarctica, Prof. Elisa Resconi and her team of researchers came across an extremely high-energy particle. Tracing it back, they realized they were dealing with an object that is 5.7 billion years old.

Physicist Elisa Resconi in a walk-in installation by conceptual artist Tim Otto Roth. The spheres symbolize the detectors of the IceCube experiment. The lights simulate the impact of a neutrino, similar to the measurements in the image below.



Picture credit: Juli Eberle; Graphics: ediundsepp (source: IceCube)

Kurzfassung

Physikalische Detektivarbeit: Herkunft hochenergetischer Neutrinos geklärt

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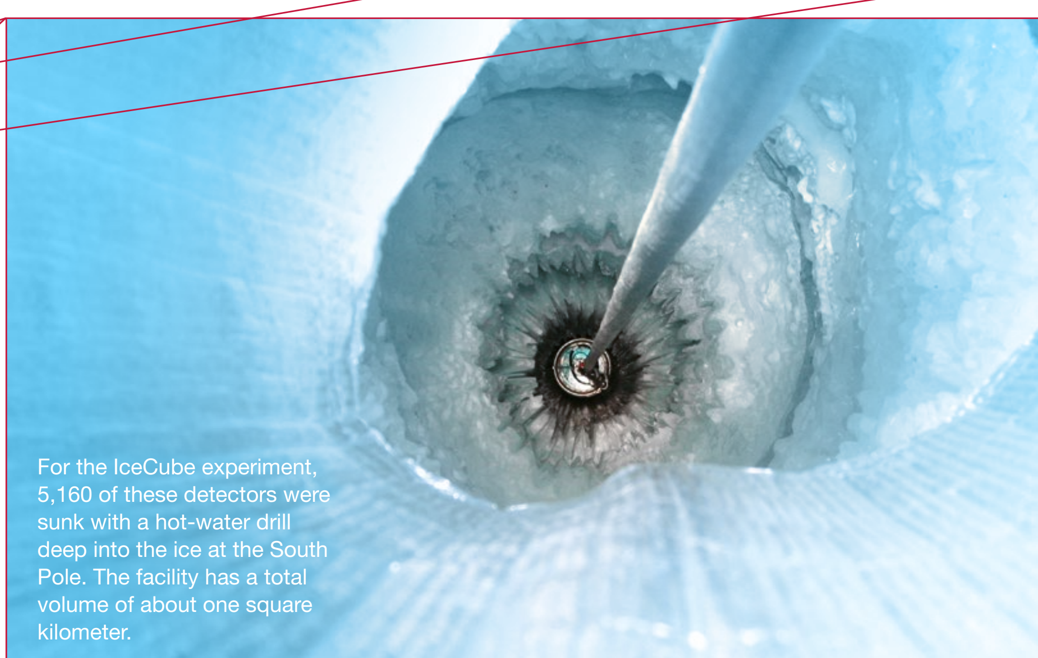
Am 22. September 2017 registrierten Sensoren im Experiment IceCube in der Antarktis ein hochenergetisches Neutrino. Seine Einfallsrichtung führte die Forscherin Prof. Elisa Resconi auf eine heiße Spur: Gemeinsam mit einem internationalen Forscherteam gelang es ihr nachzuweisen, dass das Neutrino von einem 5,7 Milliarden Lichtjahre entfernten Blazar stammte. Das Ergebnis erklärte *Science* zu einem der „Breakthroughs" des Jahres 2018.

Neutrinos haben keine Ladung und sind fast masselos, durchdringen Materie mühelos und werden von Magnetfeldern nicht abgelenkt. Für die Suche nach ihnen wurde im Eis der Antarktis das IceCube South Pole Observatory errichtet. Es weist Neutrinos indirekt nach: Stößt eines von ihnen mit einem Atomkern zusammen, kann ein Myon entstehen. Dieses sendet entlang seiner Flugbahn Photonen aus. 5160 Detektoren, die in einem Quadratkilometer Eis versenkt sind, detektieren diese. Aus den Messwerten berechnet man die Energie des Neutrinos und die Richtung seines Einfalls. Das am 22. September 2017 registrierte Teilchen hatte demnach eine Energie von 290 Tera Elektronenvolt (tausend Milliarden) und stammte aus Richtung des Sternbilds Orion.

In Zusammenarbeit mit Astronomen gelang es den IceCube-Forschern, den Herkunftsort des kosmischen Neutrinos zu lokalisieren: den Blazar TXS 0506+056, ein Schwarzes Loch im Zentrum einer aktiven Galaxie. Er erzeugt einen „Jet" hochenergetischer Strahlung, der auf die Erde gerichtet ist. Mit den Messungen konnte erstmals bewiesen werden, dass ein Blazar während Phasen erhöhter Aktivität nicht nur Röntgen- und Gammastrahlen, sondern auch hochenergetische Neutrinos erzeugt. □



For the IceCube experiment, 5,160 of these detectors were sunk with a hot-water drill deep into the ice at the South Pole. The facility has a total volume of about one square kilometer.

Via cables, the signals passed through the eternal ice from the detectors to the computer.

September 22, 2017

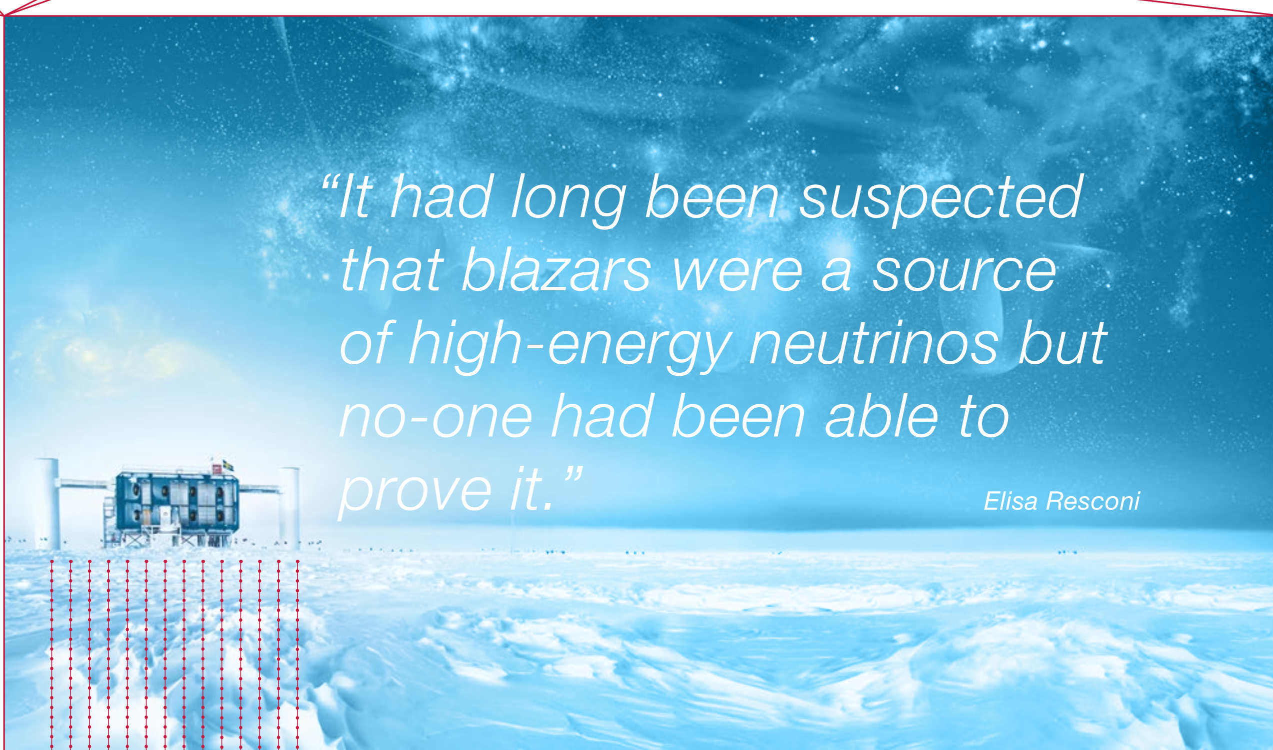
On Friday, September 22, 2017, 20:54 UTC, sensors near the South Pole detected a faint, bluish glow at a depth of more than 1,500 meters. Just a few minutes later, an alert popped up on Prof. Elisa Resconi's monitor in the TUM Department of Physics, 15,000 kilometers away.

The physicist still has a vivid recollection of the precise moment when she got the news: "I had been at a meeting and opened the mail as soon as I got back to my office. The data clearly indicated that the sensors in the IceCube South Pole Observatory had found evidence of a high-energy neutrino." She certainly waited a long time for this moment, having spent over twenty years tracking the tiny particles, which have barely any mass or charge, and pass through matter with ease. Along with research teams from twelve different countries, Elisa Resconi was involved in the IceCube project right from the start.

IceCube is the most unusual telescope in the world. The detector consists of 5,160 optical sensors, suspended from a total of 86 wires that are submerged into the Antarctic ice at depths of 1,500 to 2,500 meters. The sensors are connected by cable to the surface. The sensor field spans one cubic kilometer of ice (see Faszination Forschung 16, July 2015).

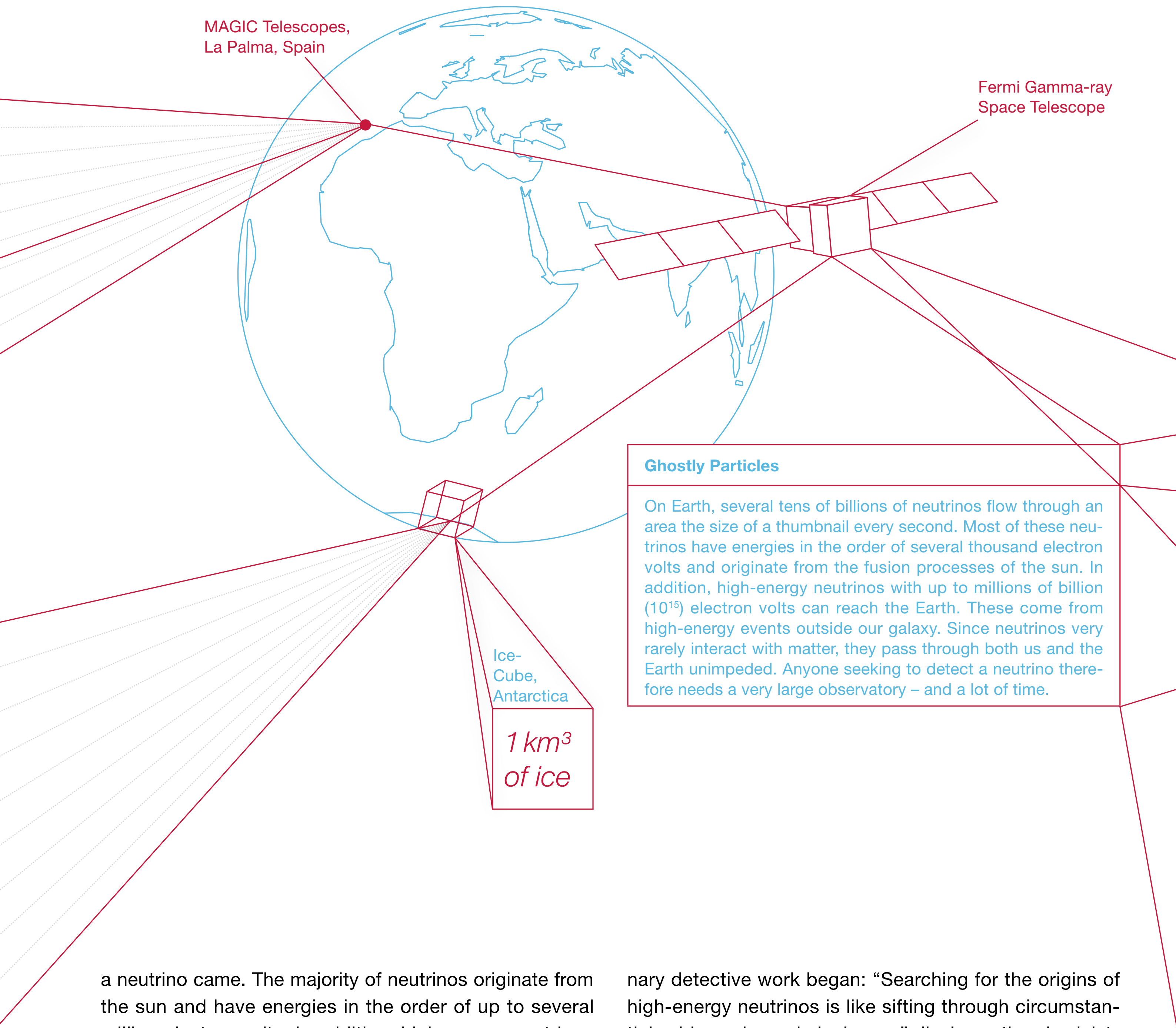
This Antarctic instrument can detect neutrinos indirectly. If one collides with an atomic nucleus in the ice, a muon can form. This charged elementary particle continues the trajectory of the neutrino, emitting a bluish glow due to Cherenkov radiation. The optical sensors in the ice detect the photons, and specially developed algorithms analyze the measurements. The number and intensity of photons can be used to determine a neutrino's energy, while the Cherenkov radiation trace indicates the direction from which ▷

Picture credit: IceCube/NSF; Freija Descamps, IceCube/NSF; Graphics: ediundsepp



5,160 detectors

In IceCube's laboratory building, the signals were collected and then sent all over the world. They also went to Paolo Padovani (top left) from the European Southern Observatory, to Paolo Giommi, then at TUM, and to the MAGIC Observatory in La Palma.



Ghostly Particles

On Earth, several tens of billions of neutrinos flow through an area the size of a thumbnail every second. Most of these neutrinos have energies in the order of several thousand electron volts and originate from the fusion processes of the sun. In addition, high-energy neutrinos with up to millions of billion (10^{15}) electron volts can reach the Earth. These come from high-energy events outside our galaxy. Since neutrinos very rarely interact with matter, they pass through both us and the Earth unimpeded. Anyone seeking to detect a neutrino therefore needs a very large observatory – and a lot of time.

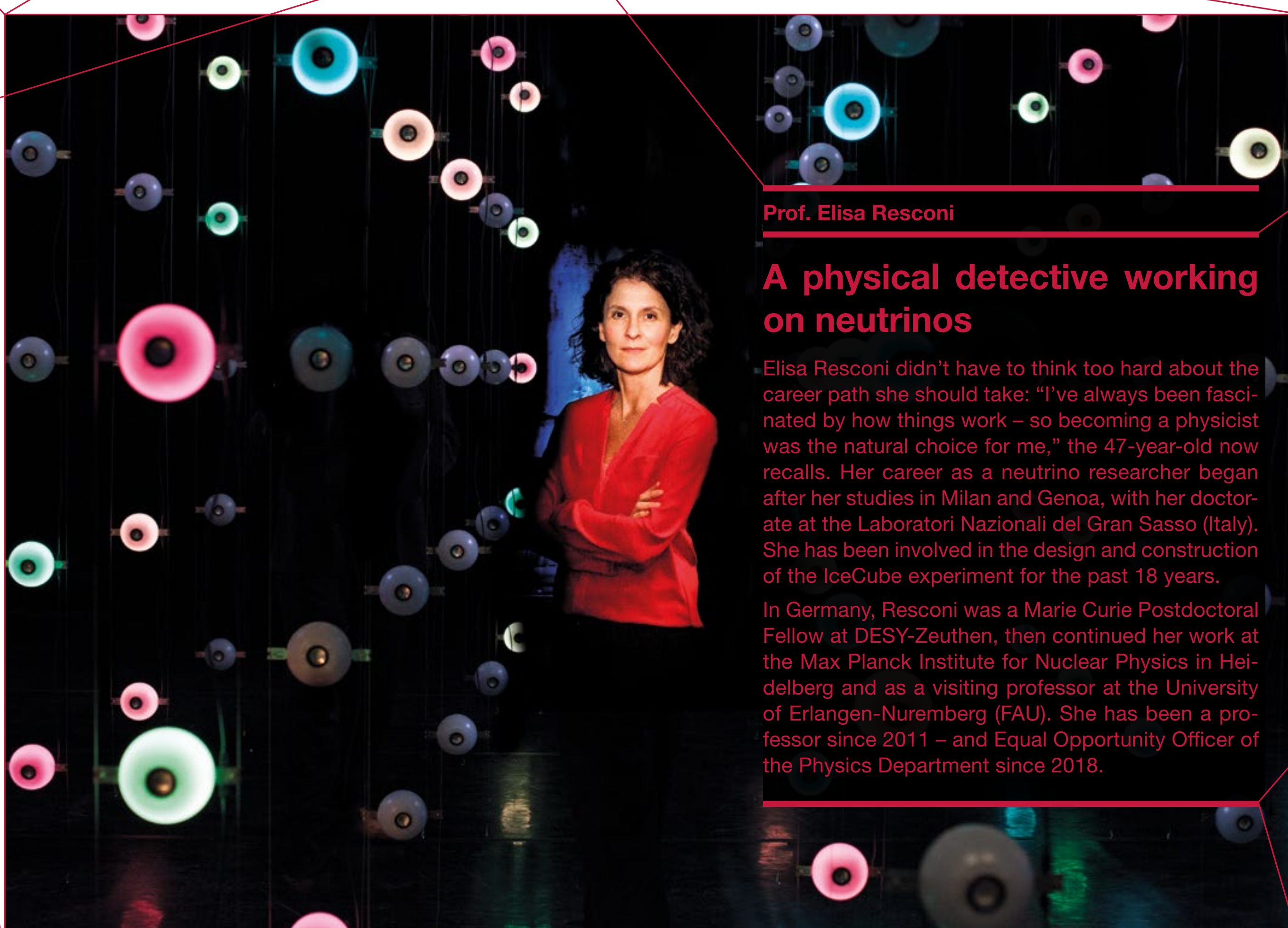
a neutrino came. The majority of neutrinos originate from the sun and have energies in the order of up to several million electron volts. In addition, high-energy neutrinos with up to millions of billion (10^{15}) electron volts – peta eV for short – reach the Earth. But only very rarely might one collide with an atomic nucleus in the exact cubic kilometer of Antarctic ice where the IceCube detector is located – as was the case on September 22, 2017.

Elisa Resconi stayed late in the office that evening. While she was busy scrutinizing the measurements, a dozen telescopes around the globe interrupted their routine programs due to the alert and set their sights on the Orion constellation. Calculations indicated that it was the source of the neutrino radiation. And so the interdisciplinary detective work began: "Searching for the origins of high-energy neutrinos is like sifting through circumstantial evidence in a criminal case," discloses the physicist. Observations by the Fermi Gamma-ray Space Telescope and the MAGIC gamma-ray telescope on La Palma (Canary Islands, Spain), and other telescopes pointed to a prime suspect: blazar number TXS 0506+056. This is located in the precise area of space from which the IceCube neutrino originated. Blazars are active galactic nuclei, black holes, which devour matter and produce jets of high-energy particles and electromagnetic rays directed towards Earth. On September 22, 2017, the jet of blazar TXS 0506+056 was particularly noticeable due to its increased radiation intensity. ▷

Picture credit: ESO; Eckert/TUM; Daniel Lopez/IAC; IceCube Collaboration; Graphics: ediundsepp

"That gave us a hot trail to follow," Resconi reports. "It had long been suspected that blazars were a source of high-energy neutrinos but no-one had been able to prove it."
A single neutrino, however, was obviously not enough to provide the necessary proof. So the researchers trawled the IceCube archive, looking for other evidence of particles coming from the same direction that were previously disregarded because their energy was lower. "When the data analysis results appeared on our screen, we all pretty much freaked out," recalls the physicist: "Over a dozen particles all pointed to the same place of origin."
But did they really come from blazar TXS 0506+056? To answer this question, Resconi needed to draw on the support of astronomers. "It was a lucky coincidence that two blazar researchers happened to work nearby at the time: Paolo Padovani, who works at the European Southern Observatory (ESO), and Paolo Giommi, then a fellow at TUM's Institute for Advanced Study."

July 13, 2018

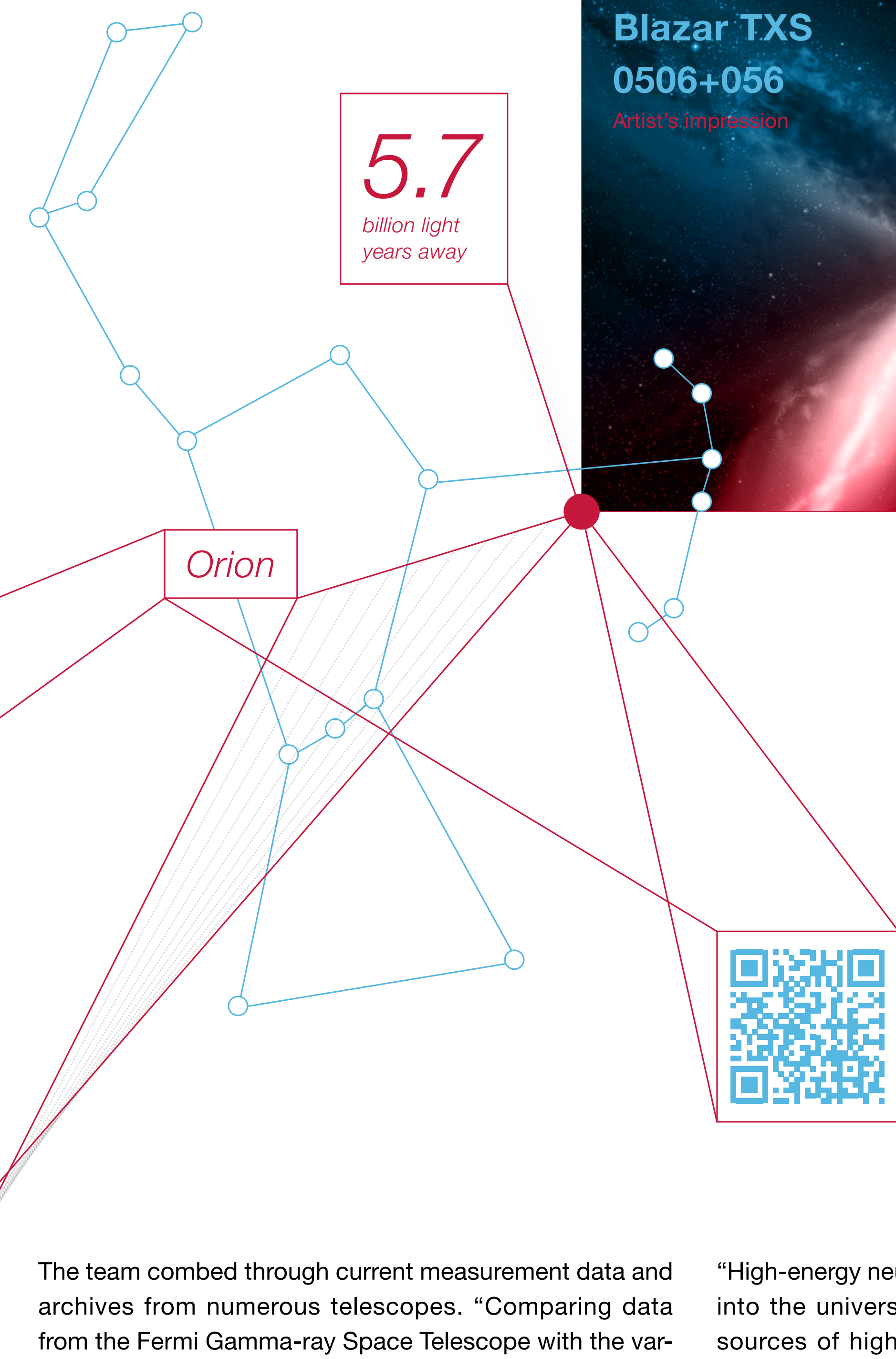


Prof. Elisa Resconi

A physical detective working on neutrinos

Elisa Resconi didn't have to think too hard about the career path she should take: "I've always been fascinated by how things work – so becoming a physicist was the natural choice for me," the 47-year-old now recalls. Her career as a neutrino researcher began after her studies in Milan and Genoa, with her doctorate at the Laboratori Nazionali del Gran Sasso (Italy). She has been involved in the design and construction of the IceCube experiment for the past 18 years.

In Germany, Resconi was a Marie Curie Postdoctoral Fellow at DESY-Zeuthen, then continued her work at the Max Planck Institute for Nuclear Physics in Heidelberg and as a visiting professor at the University of Erlangen-Nuremberg (FAU). She has been a professor since 2011 – and Equal Opportunity Officer of the Physics Department since 2018.



Finally, it turned out that the neutrino came from the blazar with the catalog number TXS 0506+056 in the constellation of Orion.

The news went around the world: “Science” put them on the front page and called this the “Breakthrough of 2018”; NASA made a movie about the discovery (see QR code).

Picture credits: Science Magazine, Cover, July 13, 2018. Reprinted with permission from AAAS; Juli Eberle; ESA/NASA/the AVO project/Paolo Padovani; Graphics: ediundsepp

The team combed through current measurement data and archives from numerous telescopes. “Comparing data from the Fermi Gamma-ray Space Telescope with the various IceCube measurements showed a clear connection between increased blazar activity and high-energy neutrino radiation,” reveals Resconi. “So, for the first time, we were able to assign that radiation to a cosmic object – 5.7 billion light-years away.” The findings were published on July 12, 2018, as the cover story in “Science” magazine. Not long after, “Science” named the IceCube researchers' discovery one of the biggest breakthroughs of 2018.

“High-energy neutrinos are now opening up a new window into the universe, allowing us to identify and research sources of high-energy radiation,” sums up Resconi – while admitting that this obviously still requires a lot more measurement data. That is why, together with teams from Canada, Russia and Europe, she is currently planning a global network of neutrino telescopes: “Implementing the planetary neutrino telescope (PLENUM) project will be a lot easier than all of our work thus far – because now we know what we are looking for.” ■ *Monika Weiner*