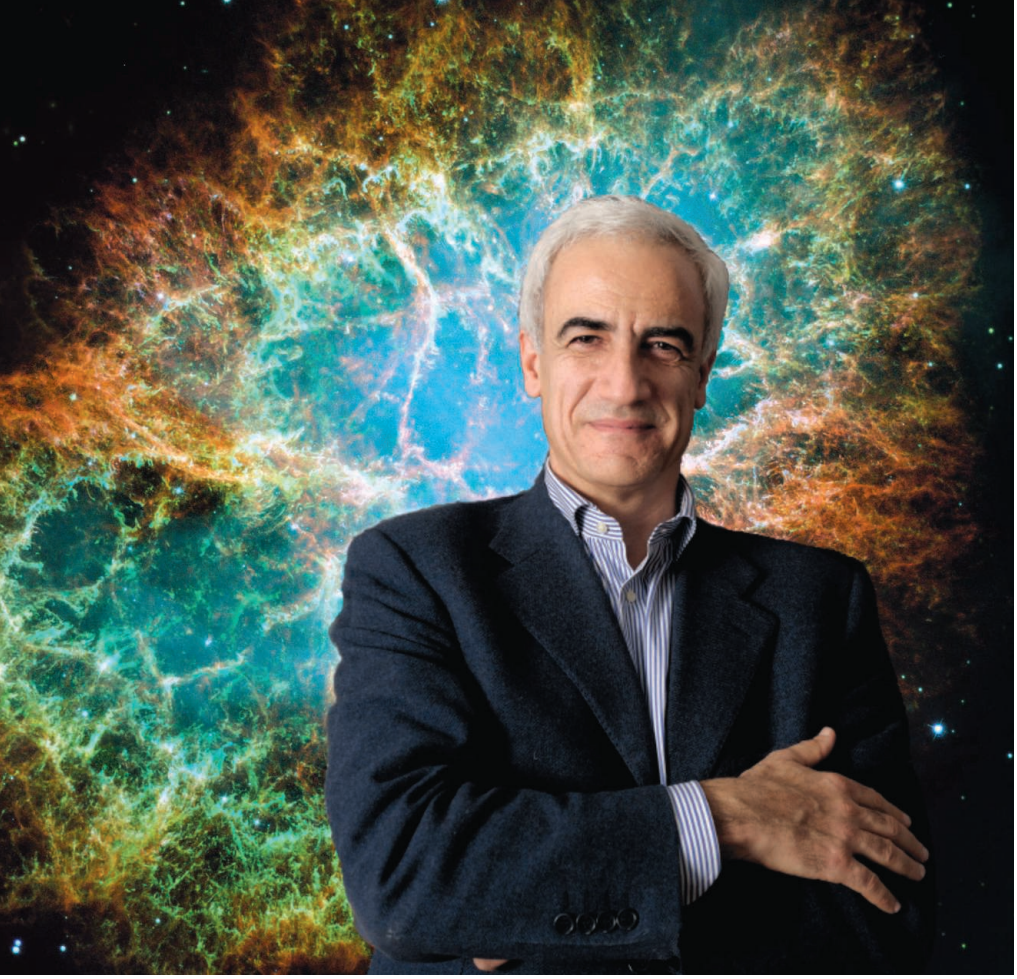

Flare? Where? AGILE PI Tavani in photo composite with the unexpectedly assertive Crab.

ASTRONOMY

The Crab That Roared

The Crab nebula was famous for its rock-steady output of radiation. So when it began spewing gamma rays, at first researchers couldn't believe their instruments

On an October morning in 2007, Marco Tavani took a train from Rome to Bologna to attend a meeting of the scientific team behind AGILE, a gamma ray telescope launched earlier that year by the Italian Space Agency. A researcher at Italy's National Institute for Astrophysics, Tavani had led the AGILE mission since it was conceived in 1997. Now that the observatory was finally in orbit, he and his colleagues were keen to start doing real science. First, however, they had to spend a few months confirming that AGILE was working as planned.

As the train sped toward Bologna, Tavani switched on his laptop and got to work. A trim 57-year-old with silver hair and bushy eyebrows, Tavani has a ready laugh, but his equine face is engraved with deep frown lines. He was frowning as he stared at the slides he'd prepared for the meeting. The irritant was a map of the sky based on observations taken by AGILE in the last week of September, showing three bright gamma ray sources. Each is a rapidly spinning neutron star known as a pulsar: the Vela pulsar, a thousand light-years from Earth; the Geminga, some 500 light-years away; and the Crab, which spins at the center of the iconic Crab nebula, about 6000 light-years away.

For decades, the three pulsars had emitted radiation so steadily that astronomers had come to rely on them as cosmic standards to calibrate their instruments—AGILE included. Geminga, being closer, normally shines brighter than the Crab. But in the AGILE map, the Crab blazed brighter and larger than Geminga. The anomaly raised the troubling prospect of a flaw in the telescope's detectors. Tavani wanted to wish it away.

At the meeting in Bologna, attended by some two dozen researchers, Tavani delivered a technical talk on the satellite. Then he showed the audience the problematic slide. Several scientists expressed surprise. "This is very strange," said Marco Feroci, an astrophysicist at the Institute of Space Astrophysics and Cosmic Physics in Rome. "I have never seen anything like this before." But Tavani had more pressing problems to attend to. "For the moment, we put this week of observations in our drawer," he told the group. "And we do not talk about this to anybody."

Tavani had passed up—for the moment—a chance to make a textbook-changing discovery about one of the most familiar objects in the heavens.

The Crab burst into human awareness in the year 1054, when astrologers in China reported seeing in the constellation Taurus a brilliant star that appeared out of nowhere and then faded away over several months. Centuries later, astronomers recognized the sighting as a massive stellar explosion, a supernova. The blast spread a bright, shiny blob of gas, or nebula, some 11 light-years across space, and in 1968, radio astronomers detected a pulsar at its center.

That pulsar—which sets the entire nebula aglow—formed when the massive star that exploded into the 1054 supernova collapsed into a dense neutron star barely 20 kilometers across, spinning fast and powerfully magnetized. Those magnetic fields cause jets of particles accelerated to nearly the speed of light to shoot out from the star's magnetic poles, generating powerful beams of radiation across different energy bands that sweep Earth 30 times a second. Telescopes see the pulsar as a strobe light flashing with the unwavering precision of a cosmic metronome.

Astrophysicists prize the Crab because it is the only nebula they can trace to its originating event, allowing them to figure out and confirm the physics of how it developed over time. Tavani saw its image in one of his first astronomy textbooks. Later he studied the Crab pulsar along with other neutron stars while working on his doctorate in theoretical astrophysics at Columbia University. In the 1990s, as a postdoctoral researcher, Tavani returned to the Crab nebula yet again in work aimed at understanding how the powerful winds of charged particles gusting from near the pulsar interact with the surrounding gas.

In 1997, he moved back to his native Italy to begin working at the Institute of Space Astrophysics and Cosmic Physics in Milan. The Italian Space Agency had just put out a call for small missions, and Tavani and colleagues immediately started drafting a proposal for an observatory with a gamma ray imager and an x-ray detector on board.

When AGILE was launched, in April 2007, the Crab nebula wasn't on Tavani's list

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of targets to study. It was too familiar and "boring," Tavani says—far less exciting than the exotic new gamma and x-ray sources he expected AGILE to discover.

A year after the Bologna meeting, Carlotta Pittori, a researcher in Tavani's group, met with him to discuss her project: a catalog of the gamma ray sources that AGILE had observed in its first year. There were about four dozen of them. For each, Pittori had calculated the average gamma ray emission observed between July 2007 and June 2008. Scanning the numbers, Tavani's eyes homed in on the value for the Crab. "This cannot be so high," he remarked, noting that Pittori's number was 30% higher than readings NASA's Compton Gamma Ray Observatory had recorded in the 1990s. "See? It's not possible."

The suspect value stemmed from data collected during the anomalous week in September 2007. The pulsar's recorded emissions then had been high enough to skew the average for the entire year. Tavani suggested that the gamma ray detector had temporarily malfunctioned, but Pittori was skeptical. "I would like to publish this table as is, without eliminating anything, with a note saying that this point is under investigation," she said.

"No," Tavani replied. "We have to cut that week out." Scientists would normally frown on such an omission, but Tavani deemed it appropriate for data from a newly launched satellite still in its early phase of observation.

The revised data set brought the emission value back in line with what astronomers were accustomed to seeing from the Crab. Tavani was satisfied. In a concession to Pittori, the paper on the catalog included a sentence stating that the average emission from the Crab had been found to be higher than usual when the researchers merged all the observations from 2007.

The cryptic note went unnoticed when the paper appeared online in *Astronomy & Astrophysics* in September 2009. So did a figure that the authors later realized they had included by mistake. It was an image showing the Crab outshining Geminga—the same slide Tavani had shown his colleagues at the October 2007 meeting in Rome.

In October 2009, Tavani was wracked with anxiety. He'd just got word that AGILE's reaction wheel—the device that helps point a satellite—had failed. Engineers at the Italian Space Agency had tried to restart it, but in vain.

To salvage the mission, Tavani and his colleagues put AGILE into a spin. Every 7 minutes, it made a full rotation, its wide field of view sweeping out a circular band of the sky. The maneuver converted AGILE from a point-and-shoot imager to a sky survey, and by early 2010 the mission was back on track.

To follow the latest observations, the researchers created a website onto which a fresh map of the gamma ray sky, as seen by AGILE, was uploaded every few hours. Tavani got in the habit of accessing it on his iPhone morning, noon, and night.

Shortly before midnight on 20 September 2010, Tavani clicked on the link one last time before going to bed. On the map he saw a bright, yellow spot, right in the position of the Crab nebula. "Who knows what this is?" he said excitedly to his wife, showing her the screen. The Crab was at it again.

The next morning, Tavani hurried to his office at the institute, where a 2-day conference for AGILE team members was about to begin. Before the morning session, he stopped by the office of his graduate student, Edoardo Striani, who was responsible for conducting fast analyses on AGILE data, and asked Striani to take a look at the Crab.

Striani carried his laptop into the conference and settled down in a corner. His attention drifted in and out of the presentations. Analyzing the satellite's observations—downloaded every hour and a half by a receiver in Kenya, then relayed to the AGILE data center—he checked whether the emission from the Crab had been changing over the past few days.

By the afternoon, Striani had confirmed that the emission had been rising. He and Tavani were witnessing a flare. "It immediately occurred to me that we had seen this in 2007," Tavani says. "At that moment, I knew the phenomenon was real."

By the next morning, the Crab's emission had started to go back down, although it was still more than twice as high as normal. After the meeting's morning presentations, Tavani and Striani worked straight through the lunch break, plotting the pulsar's emission. Tavani was scheduled to give a "surprise talk" after lunch. He had planned to discuss a different gamma ray source, but now he had something meatier to present. "We have this phenomenon again," he announced, flashing his freshly made slides. "What do we do now?"

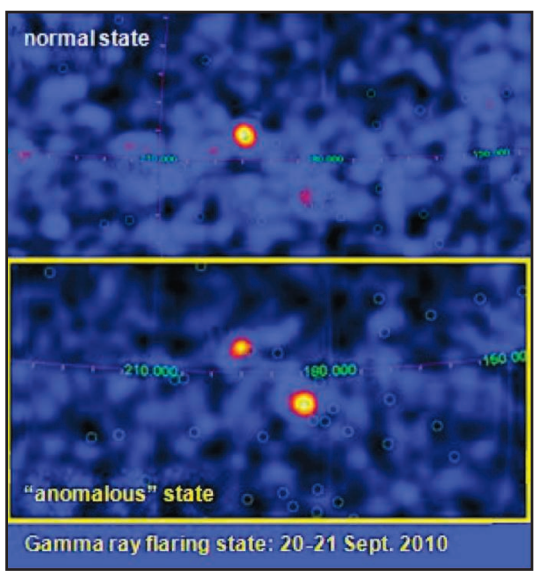
Any postprandial lethargy in the room evaporated instantly. Pittori was jubilant. "Do you remember the note we put in the catalog?" she asked, grinning. It was the day before her birthday.

A few hours later, the researchers put out an astronomical telegram announcing the flare to the broader community. The following day, researchers with NASA's Fermi gamma ray observatory reported that they had seen evidence of the flare in their archived data from the same dates. The teams described the flares in papers in *Science* a few months later (11 February 2011, pp. 736 and 739).

Since 2010, AGILE and Fermi have both seen more flares in the Crab—one or two a year, each lasting a few days. In January, the American Astronomical Society awarded Tavani and the AGILE team its Bruno Rossi Prize "for a significant contribution to High Energy Astrophysics" for the discovery.

What's causing the flares is still a mystery. The data show that the pulsar doesn't emit more energy than usual during the flaring episodes and that it gets brighter only in the gamma ray band of the electromagnetic spectrum, not at optical wavelengths. Tavani and others speculate that the wind of charged particles emanating from near the pulsar could be slamming into the surrounding plasma in a way that destabilizes regions of it. These plasma instabilities could be causing a runaway acceleration of particles that produces the spike in high-energy gamma radiation seen during a flare.

But this explanation and others are still preliminary, says Bruno Coppi, a physicist at the Massachusetts Institute of Technology in Cambridge. "I think it would be unfair to call them theories," he says. Perhaps the solution is lurking in data that's already been collected, waiting to be recognized as such by a receptive mind. **–YUDHIJIT BHATTACHARJEE**



Flash! Normally (*top*) Geminga far outshines the Crab in gamma rays. But in 2010 (*bottom*), the Crab blazed forth.

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