Keeping watch over the whole sky

A Flash of Insight

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In *The Jungle Book*, Baloo the Bear taught Mowgli to constantly stay on his guard since the most interesting things always happen unexpectedly. That notion lies at the heart of the search for gamma ray bursts – far-off cosmic explosions of staggering magnitude

It was around 7 AM on Wednesday, 19 March 2008: at home preparing breakfast, I glanced with one eye at my laptop screen where a computer in Chile was displaying status information about our robotic telescope, called "Pi of the Sky." The telescope was collecting images of a section of the sky where a gamma ray burst had been detected by the Swift satellite about a half an hour previously. Since the position was visible in the southern hemisphere, Pi of the Sky had automatically turned its cameras to have a look.

"Something strange is going on. Looks like we just got a second alert," my PhD student, Kasia Małek, wrote in the communicator window. Indeed, seconds later my cell phone received another message from the satellite, signaling an unusual situation – a second burst registered in space shortly after the first. "I wonder how the system will handle it." We decided to ask Lech Piotrowski from the University of Warsaw to start downloading images taken from the two bursts and quickly departed for work.

An eye on the entire sky

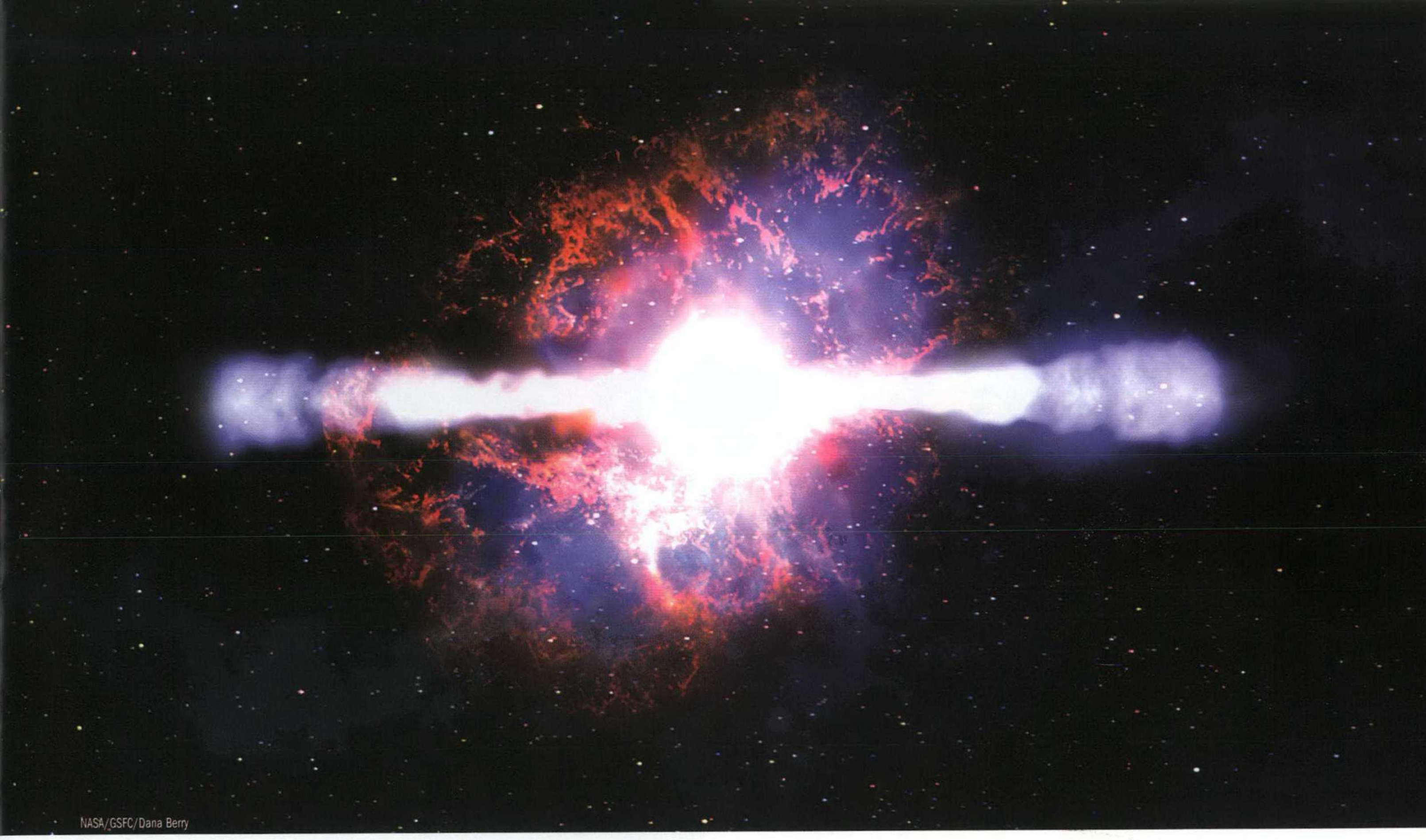
Gamma ray bursts (GRBs) were first discovered back in the 1960s, but another 30 years passed before successive generations of satellites became able to pinpoint their position in the sky, linking their occurrence to observations in other parts of the spectrum. Then GRBs frequently turned out to be accompanied by an afterglow in the optical and radio bands. Calculations of their distance and the sum total of energy emitted led to the amazing conclusion that these mysterious explosions lasting less than a minute release more energy than a star like our Sun emits over its entire lifetime!

For many years, scientists debated where gamma ray bursts actually occurred. Thanks to precise satellite measurements we now know that they are evenly distributed across the map of the sky, evidence that they do not occur within our own Galaxy. All the signs are that the radiation from these bursts travels billions of light years to reach us.

Nevertheless, we are still a long way from grasping the true nature of these powerful explosions. They are thought to occur when a massive star runs out of fuel and collapses, forming a black hole, or when neutron stars collide. A better explanation will require more observational data, and so scientists have built up an extensive system on Earth and in space designed to "hunt" for gamma ray bursts. This is the GRB Coordinate Network, known as the GCN for short, a network of satellites and terrestrial observation stations linked by Internet, exchanging information about the position of discovered bursts.

Clues to the mechanism involved in gamma ray bursts lie hidden in the properties of radiation observed just after their explosion

Since no one knows where or when the next burst will happen, the best strategy is to observe a relatively large section of the sky continuously. In practice that means using instruments with a smaller focal length, only able to register a flash in its initial, brightest stage – although that is the stage of most interest. The constant vigilance required to find such a needle-in-


NASA/GSFC/Dana Berry

a-haystack makes it necessary to analyze and process vast amounts of data. That therefore requires equipment that works automatically and alerts researchers only when something interesting is observed.

The concept of constantly watching the sky for the optical afterglows that accompany gamma bursts was put forward by the late Professor Bogdan Paczyński, a preeminent Polish astrophysicist from Princeton University. His idea that we should build such a detector was well-founded, as Polish researchers have made considerable world-class achievements using automatic data processing in astronomy. The most well-known project is OGLE (Optical Gravitational Lensing Experiment), directed by Professor Andrzej Udalski from the Warsaw University Astronomical Observatory, which constantly monitors tens of millions of stars looking for gravitational lensing effects signaling the presence of extraterrestrial planets. Another experiment, ASAS (All Sky Automatic Survey) built by Dr. Grzegorz Pojmański also from the Warsaw University Astronomical Observatory, has used small automatic telescopes to discover tens of thousands of variable stars. The novelty of our experiment, in turn, lies in the concepts of constantly observing the whole sky at once and rapidly analyzing successive images immediately upon receipt so as to quickly identify brief bursts.

These factors made it necessary to cope with a very large data stream. Since we had previously studied elementary particle physics (together with Grzegorz Wrochna from the Sołtan Institute for Nuclear Studies and Aleksander Filip Żarnecki from Warsaw University's Institute of Experimental Physics), observing the sky did pose a new challenge for us but we were not intimidated by analyzing large flows of data. In designing our robot telescope we decided to harness the experience gained in Warsaw when constructing detectors for elementary particle physics experiments, including for DESY and CERN. Aware that Grzegorz Pojmański frequently complained about the quality of instrumentation purchased abroad, and facing a similarly restricted budget precluding the purchase of truly first-rate hardware, we therefore decided to build our equipment ourselves. We realized that the know-how so developed could lay the foundation for a new Polish research specialization – designing and utilizing small robotic detectors for continuous observation of the sky. We set to work after borrowing $10,000 from Prof. Paczyński, via the Foundation for Polish Astronomy, but before long we also managed to obtain a Polish Interior Ministry grant of 50,000 zlotys. We decided to start by developing a small device that would pave the way for subsequent construction of a large detector

A long gamma ray burst occurs when a supermassive star explodes. Its core collapses, forming a black hole, and the matter in the vicinity forms a disc being dragged inward. Some of that matter, however, manages to escape along the rotational axis of the star, throwing out jets that emit X-ray and gamma radiation

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The prototype "Pi of the Sky" apparatus, installed at the Las Campanas observatory in Chile's Atacama Desert

with a range covering practically the entire sky. Steradians, or units of angle in three-dimensional space, can be used to express field of vision. The field available for observations from any given point on the Earth's surface is somewhat more than π (3.14...) steradians, hence the name of our experiment: "Pi of the Sky."

The necessary CCD cameras had to be very sensitive instruments. Just how sensitive? Let's imagine bags of money, containing around a million coins each. Our job is to build a device that can detect how much money is in each bag without ever being more than 100 coins off the mark, while testing about a million bags a second. We were fortunate enough to find a master's student at the Institute of Electronic Systems (Warsaw University of Technology) who proved to be a genius with CCD cameras. Now Grzegorz Kasprowicz is finishing his doctorate in electronics at the CERN international nuclear physics laboratory in Geneva.

Designing and building our own CCD cameras was not our only problem. Any camera has to have a shutter. Because gamma ray bursts are of quite short duration - the longest lasting just a few minutes - we decided to photograph the sky with a 10-second exposure time. Typical commercial shutters can withstand around 100,000 closures and would therefore break down after a month of use. We needed to have engineers from Warsaw University's Institute of Experimental Physics construct special shutters able to withstand more than a million such cycles.

Autonomous detector

Thanks to Prof. Paczyński's support, our prototype detector was installed at the Las Campanas observatory in Chile's Atacama Desert. It selects its own program of observation for a given night, based on information from the GCN network about the orientation of satellites. Twice a night the cameras systematically sweep the whole sky looking for the flashes of new stars, while the rest of the time they follow the field of vision of one of the satellites looking for gamma ray bursts. Artificial intelligence technology enables the detector to analyze data on its own and to detect optical bursts not observed by the GCN satellites. Software developed in part at the Sołtan Institute for Nuclear Studies also enables it to react to typical malfunctions and fix itself without human intervention.

The observations gathered by the Pi of the Sky detector at times when "nothing interesting is happening" make it possible to trace the history of some 10 million stars for which some 2 billion observations have been made. A collaborative relationship initiated last year with IBM Polska, which has granted us cost-free access to its latest database software, has provided material for several master's theses written in IT at Warsaw universities. Pi of the Sky offers students of electronics and physics an extraordinary opportunity to contribute to a real project, and young programmers a chance to work with state-of-the-art commercial IT tools.

Pi sees a flash

So what happened on that memorable morning of 19 March 2008? I went off to my lecture and it was only a text message from Kasia that made me realize our team had been involved in one of the most spectacular discoveries in the history of astronomy. Our cameras, fortunately aimed at just the right bit of sky, registered an unidentified optical flash at 7:12 AM. Two seconds later a powerful gamma radiation impulse reached the Swift satellite, which sent out an alert to ground-based telescopes 17 seconds later. The alert reached our detector, which in the meantime had taken two more exposures clearly showing an ever-brighter dot. The optical flash was so bright it should have been visible to the naked eye. The observations were joined by "Tortora" - an ordinary video camera mounted on the Italian REM telescope located in the neighboring observatory La Silla. It supplied around half a minute of observations with a resolution in the tenths of a second.

Terrestrial telescopes that had been alarmed by Swift began to turn towards the burst, which several minutes later was the most closely observed spot in the sky. Observations were recorded over practically the entire optical spectrum, and in gamma and X rays. After several hours the results of red-shift measurements by large telescopes became known: they indicated a distance of some 7.5 billion light years! That means the burst occurred long before the Earth was ever formed, and before reaching Pi of the Sky's camera the photons had covered a distance more or less equal to half the dimensions of the visible Universe.

Due to its strength and the good fortune of its being captured in the field of view of both Pi of the Sky and Tortora, 20080319B is the best-studied gamma ray burst in history. A film we posted on the Internet, comprised of several Pi of the Sky exposures, had within a few days become famous as the "first-ever film of a black hole's birth." But true analysis of the data had only just begun. A consortium of more than a dozen teams affiliated with the telescopes and satellites that had observed the burst was set up, and we were invited to take part. As it turns out, the standard models of gamma ray flashes have come up short against this much more precise new data, and now need to be adjusted and developed.

GRB080319B will continue to inspire the imaginations of astronomers and astrophysicists for a long time to come. Work is now nearing completion on a large detector consisting of 32 cameras mounted on 8 mobile assemblies, funded by the Polish Ministry of Science. This new detector will be able to observe nearly π steradians and to detect flashes irrespective of signals coming in from satellites or other telescopes. With this detector, we are truly making Prof. Paczyński's ideas a reality. That is certainly something we owe him. ■

Further reading:

http://grb.fuw.edu.pl/pi/ot/grb080319b/news_pl.html
http://grb.fuw.edu.pl/pi

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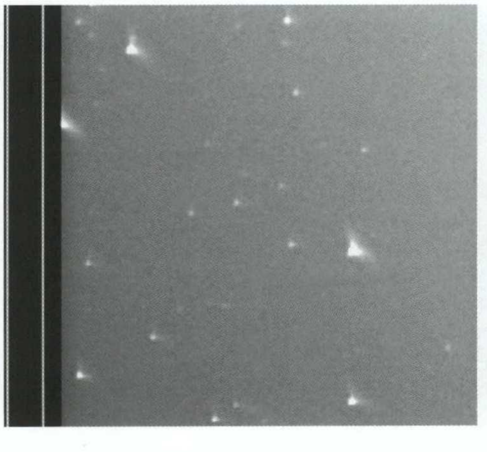

The first two images taken of the GRB 080319B burst by the "Pi of the Sky" detector. In the image to the left the burst is still weakly visible, while in the next it is nearly brighter than the stars surrounding it. Image distortion is due to the fact that the burst fell near the edge of the lens's field of view