New observations of Crab Nebula and pulsar reveal polarised emissions

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The view from the gondola at 40 km altitude during a Crab observation. Credit: SSC

New observations of polarised X-rays from the Crab Nebula and Pulsar, published today in *Scientific Reports*, may help explain sudden flares in the Crab's X-ray intensity, as well as provide new data for modeling – and understanding – the nebula.

Since it was first observed little more than a thousand years ago, the Crab Nebula has been studied by generations of astronomers. Yet new observations by researchers in Sweden show this "cosmic lighthouse" has yet to give up all of its secrets.

The researchers' observations of polarised X-rays from the Crab Nebula and Pulsar, published today in *Scientific Reports*, may help explain sudden flares in the Crab's X-ray intensity, as well as provide new data for modeling – and understanding – the nebula.

The polarisation of Crab X-rays reveals how and where they are produced in the extreme environment of the nebula, says Mark Pearce, Professor of Physics at KTH Royal Institute of Technology and lead author of the study.

"Our measurements indicate that the X-rays come from an organized region in the vicinity of the pulsar at the centre of the nebula," Pearce says. "Electrons gyrating around magnetic field lines in this region produce the X-rays. The measurements are made in an unexplored energy range, so they provide new information which will help to solve the puzzle of how high energy radiation is generated."

The PoGO+ gondola developed by SSC containing the X-ray telescope and pointing system developed by DST Control. The PoGO+ flight team is lined up in the foreground. From left to right: Jan-Erik Strömberg (DST Control), Nagomi Uchida (Hiroshima Uni.), Christian Lockowandt (SSC), H.-G. Florén (Stockholm Uni.), Mark Pearce (KTH), Victor Mikhalev (KTH), Hiromitsu Takahashi (Hiroshima Uni.), Maxime Chauvin (KTH), Mette Friis (KTH), Takafumi Kawano (Hiroshima Uni.), Mózsi Kiss (KTH), Theodor-Adrian Stana (KTH). Credit: Mark Pearce, KTH

In 1054 CE, Chinese astronomers recorded the appearance of a new bright star on the sky - an event we now refer to as a supernova, or exploding star. The aftermath of this cataclysmic event was a rapidly rotating neutron star: the Crab pulsar, barely 15 km in diameter but with a mass equal to our solar system's Sun, surrounded by an expanding

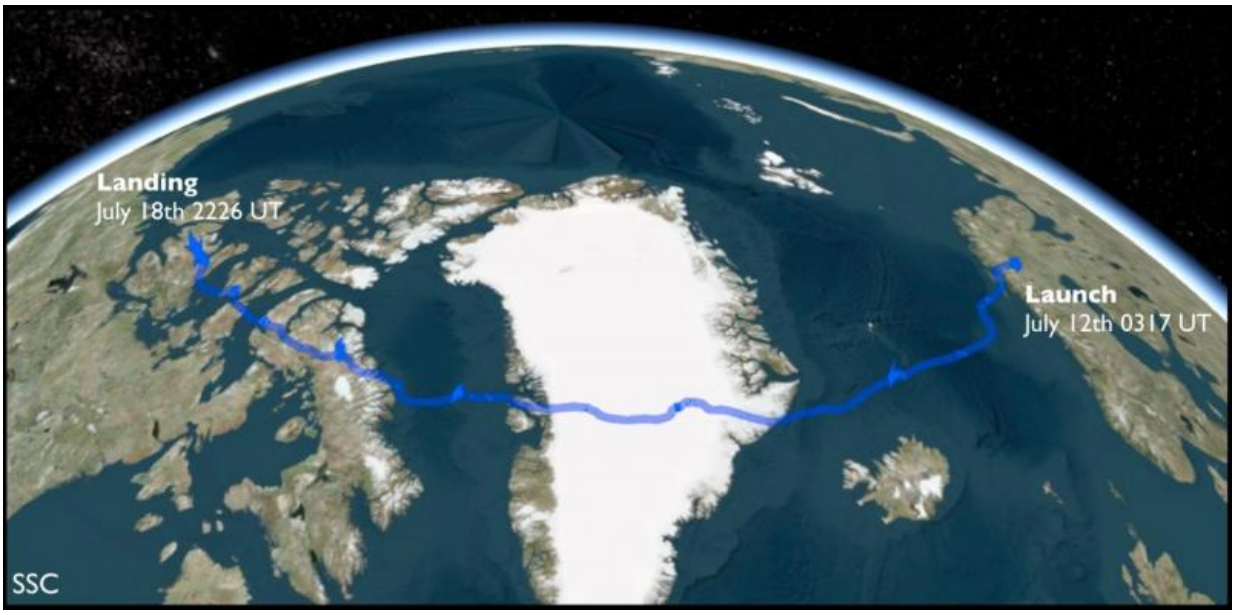
nebula of particles and radiation.

Neutron stars are a kind of ultra-dense zombie sun that forms when a star exhausts its fuel and collapses upon itself due to the force of its own gravity. If they were any denser, they'd be black holes.

Pearce says that while detecting the Crab's X-rays is routine business for research satellites, examining the polarisation of these emissions—that is, the plane in which the radiation waves oscillate—is new territory.

"Neutron stars are fascinating objects," Pearce says. "The Crab pulsar rotates around an axis 30 times per second producing flashes of X-rays – a sort of cosmic lighthouse. The X-rays arise from the acceleration of electrons in intense magnetic fields (10 trillion times stronger than the earth's magnetic field), up to energies typically a hundred times higher than obtainable at the LHC accelerator."

In the paper published in *Scientific Reports* on August 10th 2017, new light is shed on the pulsar through novel measurements conducted by a balloon-borne telescope, PoGO+ ("PoGO plus"), flown at the top of the atmosphere in summer 2016.



The flight path of the PoGO+ balloon. Credit: SSC

Just like visible light or radio waves, X-rays are electromagnetic and they can be polarised, or in other words, the electric field can oscillate in a specific plane. Usually, the polarisation cannot be measured by X-ray telescopes, so researchers miss out on some of the information carried by these X-ray messengers, Pearce says. The PoGO+ mission was developed specifically to measure the polarisation of X-rays from the Crab and other celestial bodies, with the aim of opening a new observational window on these objects.

Since X-rays are readily absorbed by the earth's atmosphere, observations need to take place high in the stratosphere. In the early hours of July 12 2016, an enormous, 1.1 million-cubic-metre helium balloon carrying a specially built telescope was released from the SSC Esrange Space Centre, near Kiruna in northern Sweden, to do just that.

The PoGO measurements are the first-made in the so-called "hard X-ray" band, covering the energy range 20-160 keV, and provide new data for Crab modeling. Results from the PoGO missions are the first from a dedicated X-ray polarimetry mission in more than 40 years. PoGO+ reveals that a relatively high fraction, 21 percent, of Crab X-rays are polarised even though observations encompassed both the pulsar and topologically complex nebula.

Pearce says that this indicates the X-rays originate from a compact region with a well-ordered magnetic field. "The angle of the polarisation plane is aligned to the rotation axis of the pulsar, as expected for electrons which generate X-rays through synchrotron processes while trapped in toroidal trajectories around the pulsar," he says. "By accurately determining the arrival time of X-rays, PoGO+ was able to distinguish between X-rays which originate from the nebula and pulsar."

The overall emission was found to be dominated by the nebula. Comparing the measured nebula polarisation angle with that measured at optical wavelengths also indicates that the emission site is associated with the torus – a donut shaped luminous structure in the inner part of the nebula. Pearce says that the lower polarisation angle seen for the pulsar is in line with results at optical wavelengths - an important confirmation that these more straight-forward measurements are a reasonable proxy for X-ray models.The PoGO+ polarisation results are compatible with those obtained in 2013 from the PoGOLite Pathfinder.

The consistency between these results may help to elucidate the cause of sudden increases in the Crab X-ray intensity which were recently observed. Such flares were unexpected for an object which was long considered to be a celestial standard candle for X-rays.

More information: M. Chauvin et al. Shedding new light on the Crab with polarized X-rays, *Scientific Reports* (2017). DOI:

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