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Gazing at galaxies from the edge of space

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Forty days and forty-five nights at space's edge

The SuperBIT telescope spent more than a month being carried through the stratosphere by a scientific balloon, imaging space from above 99.5% of the Earth's atmosphere.

In April 2023, the 0.5 metre, 2 tonne SuperBIT telescope was lifted to the stratosphere by a helium balloon the size of a small stadium (Fig. 1). For 40 days and 45 nights (crossing the international date line five times) SuperBIT obtained high-resolution, diffraction-limited optical and near-UV imaging from a vantage above 99.5% of Earth's atmosphere. When it landed in Argentina, it had mapped the distribution of dark matter in 30 galaxy clusters.

Fig. 1 | SuperBIT on the launch pad in Wanaka, New Zealand. The balloon mission was being prepared for flight on 16 April 2023.

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Dark matter is invisible but can be detected via gravitational lensing: the deflection of light from galaxies behind the dark matter, which distorts the galaxies' apparent shapes. Measurements of the shapes of distant galaxies therefore reveal the distribution of nearby dark matter. However, resolving the shapes of the smallest, faintest lensed galaxies is only possible above Earth's atmosphere, where telescopes are freed from the 'seeing' that blurs ground-based images. The sky above the stratosphere is also very dark and transparent, especially at shorter wavelengths, 300–700 nm (ref. 1), benefitting observations. SuperBIT's 15' × 23' field-of-view is designed to encompass merging pairs of galaxy clusters, which are naturally occurring dark matter particle colliders[2]. SuperBIT also used its wide-field, diffraction-limited imaging to address additional science goals through near-ultraviolet imaging of nearby galaxies, dwarf galaxies and the shells of material thrown off Wolf-Rayet stars.

The balloon travelled wherever the wind took it, but the telescope pointing could be controlled. As the balloon blew around the Earth on seasonal polar winds, on-board software used global positioning satellites to autonomously update the observing schedule. Pendulation of the telescope under the balloon was corrected by motion control in azimuth, elevation and roll. This stabilized the pointing of star-tracking cameras to 0.34'' rms over long exposures. A fast-steering mirror in the optical path further stabilized images to 0.055'' rms on the sky: easily sufficient to maintain the 0.5 metre telescope's 0.3'' diffraction limit. The pointing stabilization system performed extremely well, even during the weekly rollercoaster ride through turbulence above the Andes.

To operate at an altitude of 33 kilometres, SuperBIT needed to be robust, lightweight, and largely autonomous. The telescope and other components were carefully temperature-controlled, varying by only 0.1° C between the hot days and cold nights. Power was provided by solar panels, with batteries to last through the nights. Data and commands were communicated via several satellite networks including, for the first time on a balloon mission, Starlink. But data were also physically backed up off-site: we copied everything to flash drives that were separately dropped on parachutes when over land, with tracking hardware to help locate them[3]. This low-tech 'download' became more important when the Starlink antenna failed two weeks into the flight. Although a wild Argentinian cougar 'inspected' one of the descended parachutes, we still managed to recover all the data, and analysis is now underway.

SuperBIT cost much less than a satellite, and could be recovered and upgraded over multiple launches. Performance milestones were achieved during four overnight test flights: from telescope stability up to space-quality imaging[4,5]. Components and code that failed to work first time could be repaired or replaced. New parts, often low-cost off-the-shelf hardware, were tested. And thanks to the low cost and short timeline, PhD students led most of this development. Such iterative engineering enabled SuperBIT to exploit the very latest technology.

Funding has already been secured for the 1.4 m GigaBIT telescope, which will improve on SuperBIT's sensitivity and resolution. With bands from near-UV to red, GigaBIT will be open for any astronomer to submit an observing proposal. SuperBIT and GigaBIT augment the capabilities of the current generation of mainly infrared space telescopes, while testing technology and training personnel for the next generation.

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