The multi-colour dynamic Universe explored

The BlackGEM project brings a wide-field robotic optical telescope array with outstanding image quality, sensitivity and field-of view to the Southern Hemisphere to explore the multi-colour explosive Universe, explains Principal Investigator Paul Groot.

Exploration of the dynamic and explosive Universe is pushing into the minutes-to-hours regime. The detection of counterparts to gravitational wave events[1] is foremost in these phenomena, but shock breakouts from supernovae, explosive events associated with white dwarf binaries, fast radio bursts and fast X-ray transients show just how diverse this regime of time-domain astronomy is. The sub-day timescale is waiting to be explored, preferentially using a multi-messenger and/or multi-band approach.

Early models of the expected electromagnetic signals from gravitational wave mergers (see, for example, ref. [2]) formed the basis for the development of the BlackGEM array in 2012. Coupled with the expected sensitivity of the Advanced LIGO and Virgo detectors, these models show that detecting the optical signals from mergers requires a telescope able to scan a ~100 deg^2 error box, down to the 23rd magnitude on a timescale of ~2 hours, preferably in multiple optical bands to distinguish the mergers from other explosions. These requirements were not met by an existing Southern Hemisphere facility, hence the need for BlackGEM. The Phase 1 array consists of three telescopes, each with a 65-cm main aperture. Using a Harmer–Wynne optical design, a flat and achromatic focal plane of 100 mm x 100 mm is created with an exceptionally stable point-spread function: from the optical axis to the corner of the field the image quality degrades by less than 0.3′′. With a telescope focal ratio of *f*/5.5 and a 110 Mpx CCD, a field of 1.65° x 1.65° (2.7 deg^2) is sampled at 0.56′′ per pixel. A six-filter wheel holds an optimized SDSS filter set (*u*,*g*,*r*,*i*,*z*) as well as a broadband filter: *q*, 440–720 nm. Filter changes take <3 s. Operations are robotic, and reaction times to gravitational wave alerts are on the order of one minute.

The high-quality optical design requires an equally high-quality carbon-fibre telescope assembly, heat accounting, site and housing. All heat sources are glycol-cooled, in particular the counterweight that doubles as the electronics cabinet. The telescopes are in clam-shell enclosures, on top of 5-m towers that are double cylinders: the inner cylinder holds the telescope, the outer one the dome with louvres in the floor that open during the night (Fig. 1). Solar ground heating is reduced by a cover of white quartz, reducing the night-time turbulent ground air layer, resulting in sub-arcsecond image quality over the full field. The site at La Silla can house the 15 telescopes that are the objective of Phase 2. A further expansion to southern Africa and Australasia would complete a Southern Hemisphere 24/7, wide-field coverage.

The BlackGEM prototype-telescope MeerLICHT was installed in South Africa in mid-2017. It is now in nightly operation and will soon start shadowing the MeerKAT radio array to create an 'always-on' radio–optical synoptic survey. MeerLICHT has a detection zero-point (1 $e^- s^{-1}$) of $q = 24.0$ mag, demonstrating the very high throughput of the optical system. The installation of the first three BlackGEM telescopes started in August 2019, with an expected first light in early 2020. All data from the BlackGEM array will be processed and hosted in the cloud, in collaboration with Google.

The science programme of BlackGEM is dominated by the identification of gravitational wave counterparts. To enable this, the BlackGEM array will create a deep, 22nd magnitude, six-filter survey of the full Southern sky with 1′′ image quality. This BlackGEM Southern All Sky Survey will be co-hosted with the European Southern Observatory. To understand and explore the behaviour of celestial sources at minute-to-hour timescales, the BlackGEM array will undertake two more surveys: the BlackGEM Local Transient programme, which will target a selection of nearby (<100 Mpc) mass concentrations on a 3-hr timescale in three bands (*u*,*q*,*i*), including a wider *q*-band bi-nightly survey; and the BlackGEM Fast Synoptic Survey, which will take single deep-drilling fields (2.7 deg^2) and stay on a given field continuously for 2–4 weeks in three bands (*u*,*q*,*i*) with a cadence of minutes.

Fig. 1 | The first two BlackGEM telescopes installed in their clam-shell enclosures at the European Southern Observatory's La Silla Observatory in August 2019. The third tower is awaiting the third dome, which was shipped to Chile in November 2019.

The BlackGEM project is a collaboration between NOVA (the Netherlands Research School for Astronomy), Radboud University and KU Leuven, with participation from the University of Manchester, Tel Aviv University, the Hebrew University of Jerusalem, the Weizmann Institute, the University of Potsdam, Texas Tech University, the University of California at Davis, the Technical University of Denmark, Trinity College Dublin and the University of Valparaiso, in collaboration with the European Southern Observatory. ❐

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