Time Domain Astronomy

Studying transient skies

The UNIVERSE, far from being static, is an ever-changing, dynamic place. Time domain astronomy focuses on studying the evolution and changes of a wide variety of cosmic objects, particularly when the changes happen over "human" timescales: hours, days, to a year. These changes can be caused by several physical phenomena: starting from relatively benign flares on stars, to accretion of matter on compact objects, all the way to stellar mergers and explosions. These phenomena are commonly observed in binary stars, novae, supernovae, gamma ray bursts, active galactic nuclei, pulsars, and many more. These are aptly referred to as transients because when an event such as an explosion takes place, the electromagnetic signature radiated as a result is transient in nature. It appears as a flash in the sky for a period and then slowly fades away. By capturing these electromagnetic signatures, astronomers learn about the cosmic objects themselves and the physical processes that govern their evolution.

G.C. Anupama
Indian Institute of Astrophysics, Bengaluru, INDIA

Varun Bhalerao
IIT-Bombay
Mumbai, INDIA

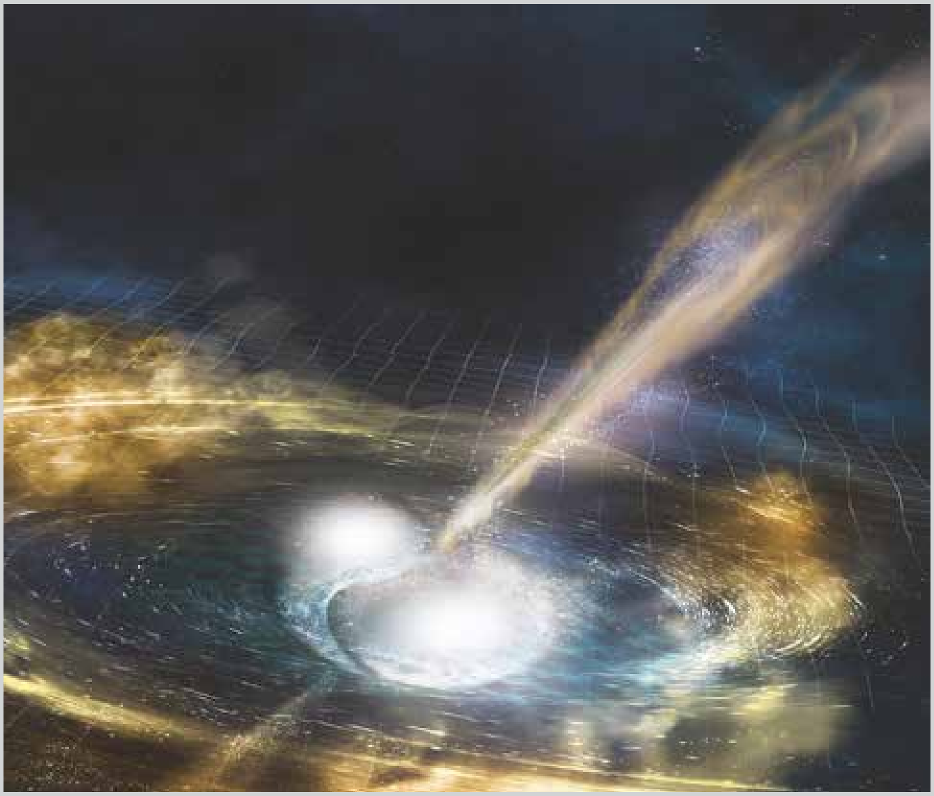
Exploring the dynamic cosmos

Transients often have tell-tale signatures in various electromagnetic wavelength bands. Astronomers leverage this fact to use telescopes sensitive to a variety of wavelengths – from gamma-rays to infra-red – to survey the night sky in search of transients. These surveys consist of scanning a part of the sky, moving on to other areas, and returning to the first part again and again. When the consecutive images are compared to the first image of that part of the sky, any sources that changed in brightness are detected. These changes can take the form of an increase or decrease in the brightness of a source seen in both images, or the appearance (or disappearance) of an object.

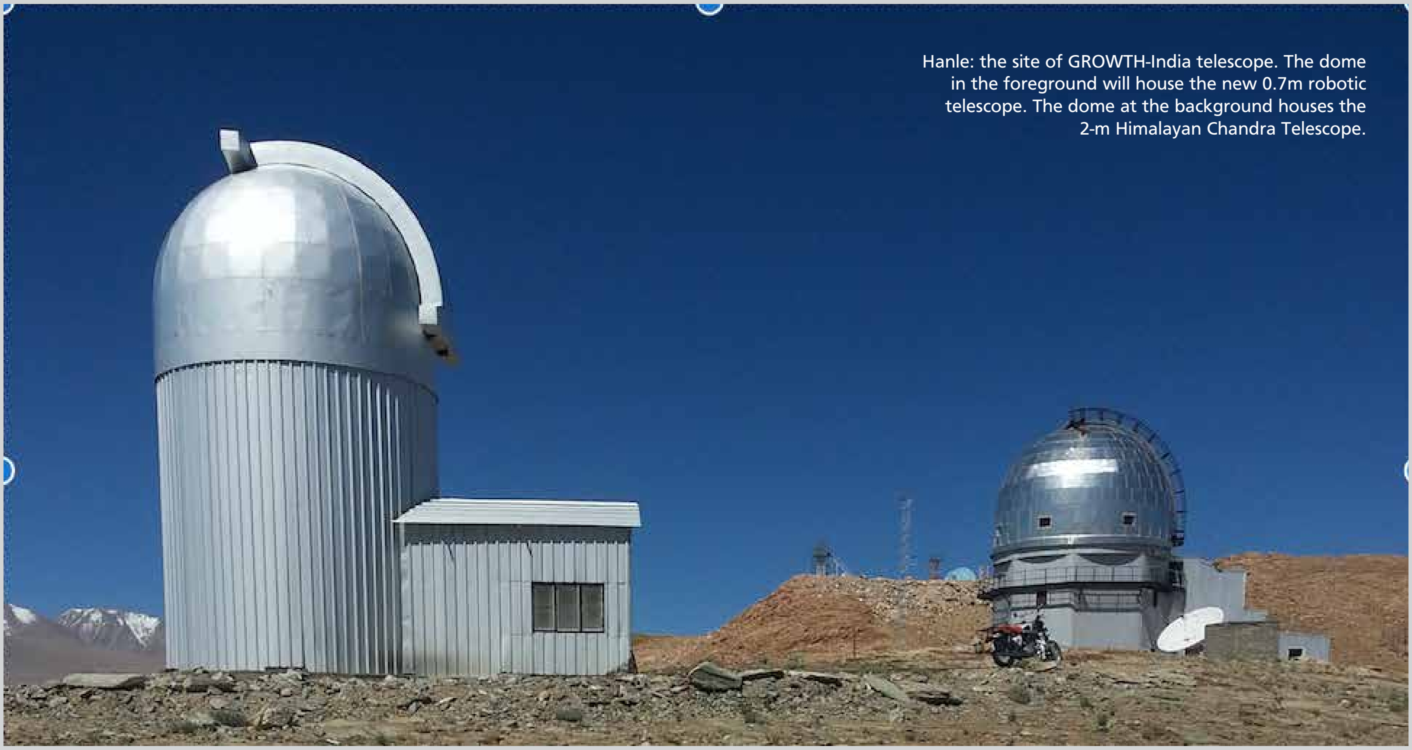
Finding such objects requires continuous monitoring of large areas of the sky. Hence, telescopes dedicated for such "transient surveys" are usually small, wide-field instruments, with a trade-off that they cannot see very faint object. Astronomers use automated and manual data processing to regularly check these surveys for transient sources. Promising candidates are selected for further study with larger, more sensitive telescopes. The most interesting objects are often studied at multiple wavelengths using earth-based and space-based telescopes.

Growth and the study of the transient universe

The Global Relay of Observatories Watching Transients Happen (GROWTH) is a network of observatories with a collection of telescopes around the world positioned in a way that allows the collaboration to observe a transient event uninterrupted by daylight. It is an international partnership created by researchers from seven countries pooling their resources towards common scientific goals. In the words of GROWTH's PI (Dr. Mansi Kasliwal, Caltech, USA), "GROWTH is primarily looking at optical transients from a host of different observatories to build a more complete picture of the physical processes of their evolution. We have a network of 18 observatories in the Northern Hemisphere. As Earth rotates and daylight creeps in at one of our locations, we switch observations to one of our facilities westward that is still enjoying night-time."


Artist's concept of the NS-NS merger. Credit: NSF/LIGO/Sonoma State University/A. Simonne

This is important not only because transients can be continuously monitored, but also because when a transient flashes in the sky, it is an entirely random event. With just one telescope to study it, the initial hours after detection may be missed if the detection happens close to daylight. On the other hand, with a global network, observations and follow up can start as soon as a transient is discovered. For many interesting events such as young supernovae and neutron star mergers, studies in the first 24 hours of explosion can give us the most information about the progenitor sources. Catching their fast-changing signals before they are gone is crucial for astronomers to understand origins and evolution mechanisms of these events.



Hanle: the site of GROWTH-India telescope. The dome in the foreground will house the new 0.7m robotic telescope. The dome at the background houses the 2-m Himalayan Chandra Telescope.

GROWTH India and its eye to the Universe

India has been very active in the GROWTH collaboration, with a wide range of contributions. We have developed optimal scheduling algorithms for follow-up observations which are being used by various partner observatories. We have used Indian facilities to participate in several observing campaigns. Traveling enabled by the project has been instrumental in communicating our results at international conferences as well as sending our students abroad for training. We have also hosted various visitors from GROWTH institutes.

GROWTH-India will get a major boost with the setting up of India's first fully robotic telescope, which will be dedicated for time domain astronomy. This 0.7-m wide-field "GROWTH-India" telescope is being set up with generous support of the Science and Engineering Research Board, Department of Science and Technology, and the Indo-US Science and Technology Forum. The telescope is equipped with a sensitive camera that can detect even the faintest transients found by our partner survey telescopes like iPTF and the Zwicky Transient Facility at Palomar, California.

The telescope is being programmed to directly communicate with various ground-based and space-based surveys that are searching for transient sources. Every transient source reported by any astronomer around the world is compared with our pre-defined criteria, designed to select specific transients like young supernovae, gamma ray bursts, gravitational wave events etc. If the transient matches our selection requirements, the telescope immediately swings into action, obtaining data without waiting for human intervention. The fast slewing design ensures that observations can commence within a few seconds of the transient report. In case of gravitational wave events where the exact source position is unknown, the telescope control software uses the smartest algorithms to find an optimal sequence in which to image different parts of the sky. Autonomous software process the data in real-time, looking for new sources in the images, calculating their positions and brightness.

In parallel, an alert is sent to the GROWTH-India team informing them of the details of observations being undertaken. All the data are also transferred to CREST (IIA) in Bangalore and to IIT Bombay. If a strong new source is found, another alert is dispatched. The core team has full control over the telescope and can switch from the autonomous control to manual control whenever desired. All the control software has been designed specifically for this project, and is giving good results in tests.

The telescope is being commissioned at Hanle, Ladakh and is expected to be operational by early 2018.

GROWTH strikes gold: GW170817

August 17, 2017 marks the dawn of multi-messenger era in astronomy. On this day, at 12:41:04 UTC, gravitational waves (GW) were detected by the Advanced LIGO and Advanced Virgo detectors. Almost within two seconds of the detection of this event, GW170817, the *Fermi* gamma-ray burst monitor independently detected a short, hard gamma-ray burst GRB170817A. The IceCube neutrino observatory reported detection of neutrinos within 500s of the GW event. GROWTH-India responded with immediate follow-up observations of the IceCube neutrino fields using the HCT, and ruled out the presence of any electro-magnetic (EM) counterpart in them. In the meantime, the LIGO collaboration localized the source to a sky region of 31 square degrees with an initial distance estimate of 40 8 Megaparsec, in the southern hemisphere, and with component masses consistent with neutron stars. The GROWTH collaboration identified 49 galaxies as potential hosts of the source. An extensive multi-wavelength observing campaign was then launched by various collaborations, to search the EM counterpart, leading to the discovery of a bright optical transient, nearly 11 hrs after the GW detection, in a nearby galaxy NGC4993, ranked 3rd in the list by GROWTH. This transient was also detected in the infrared and ultraviolet wavelengths. The global repertoire of GROWTH was key for complete characterization of this transient, and included contributions from HCT, AstroSat, and GMRT. The early ultraviolet observations revealed a blue transient that faded within 48 hours. Optical and infrared observations showed a redward evolution over ~10 days. Nine days after the GW event, an X-ray counterpart was identified, and fifteen days later, a radio counterpart was identified. The X-ray and radio emission appear to arise from a physical process that is distinct from the one generating the UV/optical/NIR emission. These observations support the hypothesis that GW170817 was produced by the merger of two neutron stars in NGC 4993, that was followed by a short gamma-ray burst and a kilonova/macronova powered by the radioactive decay of r-processed nuclei synthesized in the ejecta. These studies showed signatures of newly synthesized elements, confirming that such mergers are indeed the birthplaces of half of the elements heavier than iron – including most of the gold and platinum in the universe.

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