Understanding the Most Violent Explosions in the Universe!

Adam Higgins is a third year Astrophysics PhD student in the Department of Physics and Astronomy looking at some of the universe's most luminous and violent explosions – Gamma-ray Bursts and Supernovae. Although most of these events are only short lived they give an unparalleled look into the distant universe and its most extreme environments.

Wonders of the universe

The universe is home to some of the brightest and most energetic physical phenomena imaginable. Many of these phenomena come from massive stars reaching the end of their lives – but out of their loss come unique opportunities to observe the distant universe and put our most extreme physical theories to the test!

For thousands of years, we have gazed upon the heavens with huge curiosity searching to explain the origin of our species and the universe itself. We have long observed the stars in the sky – bright, celestial objects, powered by nuclear fusion of hydrogen creating light elements such helium. However, current telescopes only allow us to resolve single stars within our own galaxy, meaning we cannot directly observe most of the stars in other galaxies, leaving billions of individual sources of light within the universe shrouded in mystery. This provides two big questions; how can we explore the distant universe and how can we probe the environments in which these distant stars exist?

> “The earliest reports of explosive astrophysical transients date back to 185 CE.”

In 185 CE, Chinese astronomers observed what they thought was a new star, something they described as a ‘guest star’. It was present in the sky for about eight months before fading away and eventually vanishing. This might be the first ever recording of what is classed as a transient event – a new source of light typically varying in brightness on timescales of seconds to months before disappearing again. Several more such events were reported throughout the first millennium, in 386 CE and 393 CE, and this trend continued into the second millennium. Today, transient astronomy is a huge field within astrophysics, with thousands of these short-lived events being detected every year.

The extreme nature of transient astronomy

Some of the most explosive events in the universe result from the death of massive stars. When a star begins to run out of hydrogen fuel, it can no longer sustain its core against gravity. The star collapses under its own mass while the core’s temperature and pressure dramatically increase. Within a few seconds, the collapse rebounds and outer layers of the star are ejected into space accompanied by a huge amount of energy in an event known as a Supernova, leaving behind a dense core. Supernovae are one of the few events in the universe with temperatures great enough to produce rare heavy metals, such as gold and platinum. If the star is sufficiently large (greater than 10x the mass of the sun), then the remnant core may form into a neutron star or black hole – some of the most dense and extreme physical environments currently known. Lingering gas and dust can be funnelled into this dense core via a mechanism known as accretion, producing jets of energy called Gamma-ray Bursts.

> “For the short time they exist, Gamma-ray Bursts outshine the rest of the universe in gamma-ray light”

La Silla Observatory - Credit: Klaas Wiersema

Gamma-ray bursts are some of the most luminous events in the entire universe. The amount of gamma-ray produced in a few seconds outshines the rest of the universe, equivalent to the total energy output of our sun in its entire 10-billion-year lifetime! As Gamma-ray Bursts are so bright, they can be used to probe the distant universe. One event that was observed on 29th April 2009, aptly named GRB090429, is the most distant transient ever seen, measured to have a distance greater than 13 billion light years. Incredibly, at vast distances such as these, the light we receive is 13 billion years old – acting as a time machine with a window to the early universe. Transient events are therefore an incredible tool to test the most extreme physical environments that we could not possibly observe on Earth.

> "These events are so bright they light up the darkest corners of the universe"

My current work aims to characterise these explosive events and the environments in which they exist. Part of my work involves using the EFOSC2 instrument on-board the New Technology Telescope in La Silla, Chile. EFOSC2, an acronym for The European Southern Observatory Spectrograph and Camera (v2), is a versatile scientific instrument that can be used to take follow-up optical images of recently detected astrophysical objects in short amounts of time. I am interested in EFOSC2's capability to measure the optical polarisation - the preferred orientation of visible light waves - from a host of transient sources. This property is useful for uncovering the internal mechanics of explosive events. Polarisation provides a unique way to probe the properties of transients and can even aid in mapping out the environments of newly detected Supernovae or Gamma-ray Bursts. In 2019, a new observatory called the Large Synoptic Survey Telescope (LSST) will begin observing the skies. LSST, which will continuously scan the sky and have a much larger field of view than EFOSC2, is expected to detect thousands of new explosive transients every night. Prompt follow-up analysis of these events may be key to understanding the physics of many of these sources, helping us to continue expanding our understanding of the high-energy universe.

> "Gamma-ray Bursts can act as a time machine – showing us parts of the universe only a few hundred million years after the big bang"

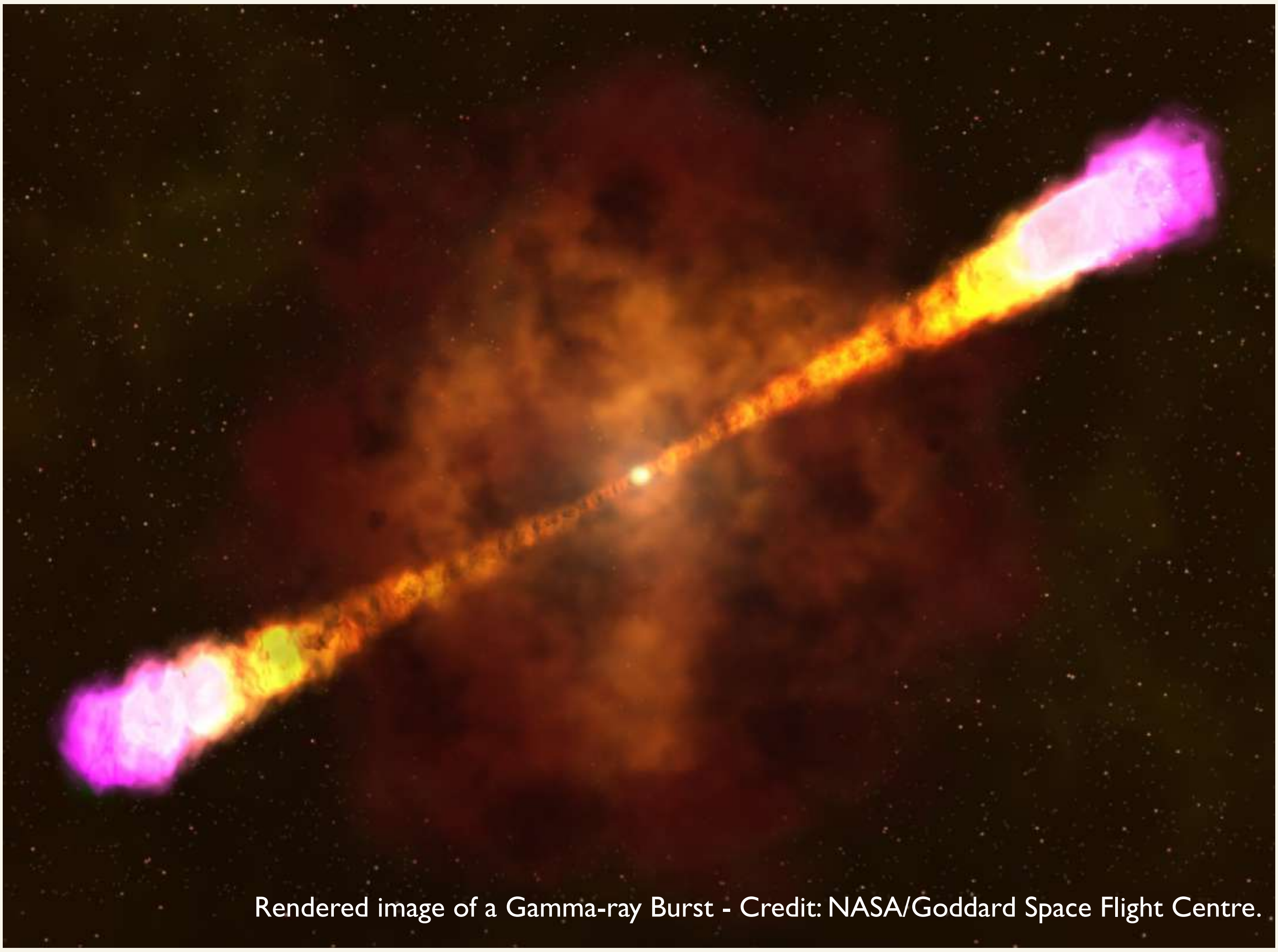
Can polarised light play a part?

I, along with collaborators here at the University of Leicester and the University of Warwick, have led an investigation in creating a sample of approximately 50 transient sources using follow-up observations with EFOSC2. Within this sample we have observed a dozen Supernovae and numerous Active Galactic Nuclei (AGN) – where activity in the centre of galaxies causes a large increase in brightness. The AGN we observed typically exhibited large values of polarised light (up to 20 percent or so) implying that the centre of these galaxies may have violent, chaotic environments made up of very ordered magnetic fields, the acceleration of high energy particles or vast amounts of dust. We also observed numerous uncommon events such as a Tidal Disruption Event where a star passing too close to a black hole is disrupted and ripped apart. In a similar fashion to the Gamma-ray burst, some of the gas is then funnelled into a disk around the black hole and powers large scale jets. Only a couple of polarisation measurements of these events have previously been acquired.

The most important part of our investigation was the proof of concept – could we use the polarisation of light to help identify sources of transients with potentially interesting science value? Within the sample, we have shown that high levels of polarisation hint at potentially interesting sources and environments that may warrant further, more in-depth investigations. I have also helped produce semi-automated data-reduction pipelines that can output almost real-time science results from EFOSC2 and can be easily adapted to work with several similar instruments.

> "Transients possess some of the most extreme physical environments that can exist in the universe!"

The New Technology Telescope (NTT) at La Silla
Credit: Adam Higgins.



Rendered image of a Gamma-ray Burst - Credit: NASA/Goddard Space Flight Centre.

“We can use the polarisation of light as an alternative observational tool to pick out sources of real scientific interest!”

Looking to the future

The gravitational wave binary neutron star merger event on August 17th 2017 excited the world, by showcasing both the power and reach of transient astronomy. With the advent of bigger and more sophisticated telescopes and satellites coming online over the next few years, it truly is a very exciting time to be involved in astronomy! Alternative methods to filter out the sources of real scientific interest from the large number of new detections are urgently needed. This research project was a pilot study to show the potential of polarimetry and has shown this technique has a significant role to play in the future of transient observations. I returned to Chile in August 2018 for another observing run using EFOSC2 to further cement the effectiveness of our polarisation survey.

Inside the NTT - Credit: Klaas Wiersema.