Travelling back through time

DR ASANTHA COORAY

With **Drs Julie Wardlow** and **Joseph Smidt** from his research group, **Professor Asantha Cooray** describes the areas of study by which they are seeking to expand knowledge of far distant galaxies and star formation

Can you begin by outlining your research goals?

Cooray: The first goal for my team is to search for the first galaxies in the distant, early Universe. The first galaxies are expected to be small in size and mass compared to later ones and their distance at almost the edge of the observable Universe makes them hard to see individually with existing observatories. So we look for signals in the sky that suggest their presence through aggregate effects, such as small variations in the total light emitted by them. Such searches for first galaxies are best done at short infrared wavelengths in the electromagnetic spectrum. A second research goal is to study the dust-enshrouded star formation in distant galaxies. Since optical light is absorbed by dust, such observations are best done at long infrared wavelengths again from space.

How will infrared wavelengths further understanding of star formation?

Wardlow: Optical light (that our eyes see) is absorbed by dust (think about trying to peer through a smoke-filled room), so that even the biggest optical telescopes cannot see into the densest regions of star-formation. However, infrared light can travel through this dust, so we use infrared telescopes to see through the dust and into the heart of star-formation regions. Infrared light is also particularly useful for studying galaxies that are millions of light-years away, in the distant universe.

FIGURE 1. A region of the sky as surveyed in near-infrared light by the Spitzer Space Telescope. Cooray group is using deep and wide images such as these to detect the integrated light from the first galaxies in the Universe.

Why is there a need to investigate zodiacal dust cloud? How does the Zodiacal dust, Extragalactic Background and Reionisation Apparatus (ZEBRA) mission concept study address this?

Smidt: Contributions from dust to astronomical observations are not always trivial. Zodiacal light is a main contaminant for total infrared background intensity experiments that we are doing to search for the cumulative signature of first galaxies at the edge of the Universe. For example, the Zodiacal dust cloud is a cloud of dust filling the inner regions of our Solar System that reflects light from the Sun, creating a bright diffuse glow across the sky. This glow needs to be subtracted out from infrared observations to correctly understand physics from outside the Solar system, as from extra-galactic sources.

Cooray: In principle, we would like to measure the total near-infrared background intensity, and look for the signatures of first galaxies in regions where the dust content is small. ZEBRA aims to travel to the outer Solar system, as part of a planetary mission to Jupiter or Saturn, to make astrophysical measurements related to the Universe without contamination from Zodiacal light.

What is the significance of gravitational lensing?

Wardlow: Gravitational lensing occurs when there is alignment of a background source

(like a galaxy), a foreground mass (such as another galaxy, or a cluster of galaxies) and our telescopes on Earth. The light from the background source has to pass through, or very close to, the foreground mass in order to reach us. However, as Einstein theorised, the path that light takes is affected by the intervening mass, in much the same way as light is deflected by the lens in spectacles. This deflection of the light from the background galaxy is called gravitational lensing. It enables us to see galaxies that are much fainter than we would normally even be able to detect and study them in much more detail than would otherwise be possible.

From your research, what do you consider the biggest revelation in the evolution of galaxy and star formation?

Wardlow: That is a tough one! Recently, we have been looking a lot at distant galaxies that are undergoing huge amounts of star-formation in very short timescales. We have been able to pinpoint these galaxies, detecting them at optical as well as infrared wavelengths, and calculate exactly how far away they are. These galaxies are strange: they are much more numerous in the distant Universe than nearby, and it is hard to discern how they fit into galaxy evolutionary scenarios and what could have caused such massive amounts of star-formation.

Smidt: Initially, it was hoped that the earliest stars and galaxies of the universe made the dominant contributions to the fluctuations in the infrared background light we measure. Instead, it has turned out that major contributor is the emission from previously unknown faint (dwarf) galaxies at much later times.

Cool science

The Cooray Group at the **University of California** in Irvine has a single mission: to discover how the original galaxies in the universe formed. Their programme of astrophysics research goes beyond the state-of-the-art

SINCE THE FIRST infrared space telescopes were sent into orbit in the 1980s, infrared technology in astronomy has transformed knowledge of the Universe. Able to capture heat energy even from exceedingly cool objects in space, infrared detection provides much more complete information than previous visible light technology: in space, visible light is scattered by dust and gases, which obscures images, but infrared can detect and display the tiny signs of galaxies and the birth of stars beyond the dust and gases.

The Cooray Group at the University of California Irvine campus studies the signatures of ancient galaxies detected with near-infrared light and measures clustering in star-forming galaxies detected with far-infrared light: "We would like to understand how galaxies first formed and what kind and amount of stars were present in those galaxies," states Asantha Cooray, Professor of Physics in the Department of Physics and Astronomy at the University of California and head and mentor of the Group.

The group has access to the massive datasets of the large space observing telescopes, including the Hubble Space Telescope, which uses ultraviolet and near-infrared and is 569 km from Earth; the European Space Agency's Herschel Space Observatory, which uses far-infrared and is usually about 1.5 million kilometres from Earth; and NASA's near- and mid-infrared Spitzer Space Telescope, which is currently nearly 160 million kilometres from Earth - this varies as Spitzer follows the Earth in its movements around the Sun. The Cooray Group, with collaborators at the NASA's Jet Propulsion Laboratory, also fly purpose-built small telescopes and instruments to the top of the atmosphere with rockets. This wide range of observing systems enables probes into previously uncharted parts of the universe: "For the first time, we can quantify in detail the number of galaxies that are hidden from traditional observations of the Universe at optical wavelengths, what the properties of such galaxies are and the rates at which stars are forming in them," Cooray asserts.

The team would like to understand how galaxies first formed in the Universe and what kind and amount of stars were present

The group aims to find the first ever galaxies in the Universe and to study the formation of new stars in far-off galaxies. Dr Julie Wardlow, a group member, studies distant galaxies that are undergoing huge bursts of star formation: "When we look at distant galaxies we are looking back in time,", she explains. "We have found that typical distant galaxies look different from typical nearby galaxies, which shows that there is some kind of evolution in galaxy types and star formation processes over the history of the Universe. Only by studying distant galaxies can we unravel the drivers behind this evolution and the physics that controls it," she enthuses.

As well as post-doctoral fellows, Cooray's Group comprises undergraduate and post-graduate students. Over the last five years the Group has produced more than 90 journal publications; the members work together and on some important international collaborative programmes in which Cooray is a key participant.

PIONEERING PROGRAMMES

Cooray is a member of the team from US that contributed to the UK-led Spectral and Photometric Imaging Receiver, known as SPIRE, one of the three instruments of the Herschel Space Observatory, and he participates in two major programmes on the Herschel platform.

The first is the Herschel multi-tiered extra-galactic survey (HerMES) studying the evolution of galaxies, the biggest project on the Space Observatory. Two undergraduates from his group co-authored some of the first science observation papers from the survey, an achievement of which Cooray is very proud.

The second major Herschel programme in which Cooray is the US (NASA) Principle Investigator is the Herschel-Astrophysical Terahertz Large Area Survey, known as H-ATLAS, carried out with five US and 25 European institutions to explore, with far-infrared and sub-millimetre wavelengths, further back in time than any previous mission – for this the H-ATLAS team managed to secure 600 hours' observing time on an area of the sky four times larger than all the other extra-galactic surveys combined – H-ATLAS was featured on the BBC's Bang Goes the Theory programme, in which Cooray explained the principles of gravitational lensing.

Cooray is also a member of the science team – alongside the astrophysicist Brian May, who is also known as a guitarist with Queen – in the Zodiacal dust, Extragalactic Background and Reionisation Apparatus (ZEBRA) mission concept study aimed at facilitating study of the creation of the solar system and the first stars in the Universe.

Cooray's involvement in these international programmes means that all members of his group are actively involved in seeking solutions to real issues in cosmology and astrophysics.

SOLVING PROBLEMS OF DUST, BACKGROUND LIGHT AND LENSING

Dr Joseph Smidt in the Cooray Group has been measuring Zodiacal light, using a purpose-built probe. For their sounding rocket experiment they used various spectrometers to measure the absorption lines of the Solar spectrum that are scattered from dust, as he elucidates: "The strength of the absorption lines allows us to quantify the total amount of dust in the Solar system in any one direction and understand the dominant sources of fluctuations in the infrared background. Such measurements are important for understanding the epoch of reionisation, when the first stars and galaxies were born in an otherwise neutral universe burning new pockets of ionised gas".

Interplanetary Zodiacal light in the Solar System is a major problem for the cosmological studies at infrared wavelengths. Zodiacal dust particles arise from the birth of planets and collisions between objects in space, such as comets and asteroids, and diffuse absorbed energy and reflected light from the Sun. This creates background noise in telescope images, especially at mid-infrared wavelengths. The obscuring effect of the diffused light from Zodiacal dust is compounded by Extragalactic Background Light, the total accumulated energy of all sources of light, the stars and galaxies, beyond our galaxy, over all time. The ZEBRA study aims to develop an instrument that can obviate contamination by both dust and background light by piggybacking onto a space mission into the outer Solar System within the next decade: "ZEBRA is an instrument that we have helped design with our collaborators," Cooray explains. "At distances of Jupiter and Saturn, the dust content in the Solar system is 100 times reduced. At such distances, we can make very clean measurements of the near-infrared background intensity from all galaxies in the universe without having to worry about Zodiacal light contamination".

Gravitational lensing is another focus for the group. Gravitational lensing allows much clearer infrared observation of a target galaxy through deflection of light around an interceding galaxy, which facilitates study: "The galaxy appears to be stretched and is spread out over a bigger area of sky, so we can see and study structures in the distant galaxy in much more detail than normally; and the distant galaxy appears much brighter than it would otherwise," Wardlow enthuses.

Cooray thinks that it is important that scientific achievements and principles are widely communicated; he delivers a course, that he hopes to eventually turn into a book, on Order of Magnitude Physics to science and non-science students alike: "It is aimed at solving day-to-day real world problems to a close approximation with simple order-of-magnitude mathematics, without the use of complex exact equations. It covers concepts in astrophysics, biophysics to geophysics. We can get an answer to almost all problems".

Members of the 2012 Cooray Group. From left: Sam Kim, Andrea Marchini,Colleen Nelson, Julie Wardlow, Hai Fu, Valentina Salvatelli, Asantha Cooray, Francesco De Bernardis, Cameron Thacker, Jae Calanog, Kristine Rezai, Joseph Smidt, Yan Gong and Jon O'Bryan.

INTELLIGENCE

NEAR- AND FAR-INFRARED BACKGROUND LIGHT AND THE ASTROPHYSICAL AND COSMOLOGICAL IMPLICATIONS

OBJECTIVES

To characterise the underlying astrophysical and cosmological information contained in the infrared background (IRB) spatial anisotropies at near- and far-IR wavelengths. In the near-IR regime, signatures of primordial galaxies in the background spatial fluctuations will be studied. At far-IR wavelengths, clustering information of dusty, star-forming galaxies will be measured. The main goal of this research programme is to expand the science case for anisotropy measurements of IRB and to provide a strong theoretical background to interpret these measurements just as the case has been with respect to CMB anisotropy experiments.

KEY COLLABORATORS AND PARTNERS

Herschel-SPIRE Instrument Science Team (PI: Matt Griffin, Cardiff, UK)

CIBER Team (PI: Jamie Bock, JPL, US)

ZEBRA Team (PI: Jamie Bock, JPL, US)

Spitzer Deep, Wide Field Survey Team (Dan Stern, JPL, US)

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ASANTHA COORAY is a Professor at University of California, Irvine. His research expertise is in the fields of space science, cosmology, and astrophysics. He is a member of teams that are using several space-based astrophysics missions and NASA sounding rocket experiments to understand the early universe, first stars, and galaxies.