

Constraining the origin of dark energy through measurements of exploding stars

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‘Ordinary matter’ such as galaxies, planets and the desk you might be reading this at, makes up just 5% of the mass-energy of the universe, and dark matter . However, 70% has been shown to be in the form of ‘dark energy’, and understanding the origin of this mysterious quantity is one of the fundamental questions that exists about our Universe. The presence of dark energy was first discovered at the end of the last century from measurements of distant exploding stars [1] [2] and it was a completely unexpected result. Since then numerous theoretical models for the origin of dark energy have been put forward, including the presence of vacuum energy, even more exotic physics; or alterations to the general theory of relativity. Understanding this dark energy is a major area of astrophysical research and a key goal of current and future cosmology surveys.

The most successful probe to date of the origin of dark energy are measurements of a particular type of exploding star, called a Type Ia supernova. Type Ia supernovae are the luminous deaths of small dense stars called white dwarfs and for many months after explosion they can be bright enough to outshine their host galaxies. The 2011 Nobel Prize in Physics was awarded to two groups for the discovery of dark energy using distant Type Ia supernovae and substantial effort is ongoing to build new higher precision samples of Type Ia supernovae to constrain the properties of dark energy. However, if we want to be able to distinguish between the leading theoretical models of dark energy, it has become clear that we need to understand better the supernova explosions themselves and this is the aim of my research proposal.

During my summer research project, I plan to analyse Type Ia supernova data from a leading telescope, the Zwicky Transient Factory based at the Palomar Observatory, to investigate the link between supernova explosions and the properties of the different types of galaxies they explode in. There are two main broad classes of galaxies in the Universe: young galaxies with many young stars and old galaxies with many old stars and Type Ia supernovae have been found to explode in both types of galaxy. Understanding the link between the subtle variations seen in Type Ia supernovae and their host galaxy properties is very important because it can be used to design cleaner samples of Type Ia supernovae to study dark energy. There is a hint from older data that it may be easier to calibrate Type Ia supernovae exploding in galaxies with large populations of old stars, e.g. the measurements of supernovae in these galaxies produce tighter constraints on the measurements of dark energy. Therefore, subsamples using only Type Ia supernovae from galaxies with old stars may be better to use in future cosmological surveys, such as the next-generation Large Synoptic Survey Telescope, which will be built to make precision measurements of dark energy to distinguish between the proposed theoretical models.

A state-of-the-art precursor sample of Type Ia supernovae is currently being obtained by the Zwicky Transient Factory of which my supervisor, Prof. Kate Maguire, is the leader of the Type Ia supernova physics group within the collaboration. The key difference between this sample of Type Ia supernovae, and previous samples that have been obtained, is that this is the first time that a large number of exploding stars (approx. 100 events) have been caught within hours to days after explosion. Most previous surveys were limited in how soon after explosion they could discover Type Ia supernovae and so discovered them only 10 – 20 days after explosion. Data in the first hours to days after explosion are really interesting because theoretical modelling has suggested that this is time when subtle signatures of how exactly the stars explode can be studied (e.g. Kasen 2010 [3], Piro et al. 2013 [4], Magee et al. 2018 [5]).

During my research project, I will link these subtle signatures of the supernova explosions to the properties of the galaxies (obtained from telescope images from the Zwicky Transient Factory) to determine if sub-samples of events can produce cleaner samples for cosmology. The main part of my project during the first summer will be writing code to analyse the Zwicky

Transient Factory galaxy images and determine their properties by fitting available galaxy models to my data and obtain the best match model for each galaxy. This will allow me to determine properties of my galaxy sample such as the amount of on-going star formation and the quantity of heavy elements (such as iron and calcium) that have enriched each galaxy. These values will then be compared to the properties of the supernova explosions from the early light curves that are currently being measured by a PhD student in Prof. Maguire's group. From this combined sample, I will then apply some machine learning outlier detection algorithms to be able to determine if there is a sub-sample of Type Ia supernovae that could be used in future cosmological samples for providing higher precision constraints on the origin of dark energy. If I confirmed a connection between the subtle supernova properties and the host galaxy properties in this new sample, this would also be very exciting because it would help us understand how exactly the stars explode in greater detail than previously possible.

Finally, in my second summer, I will visit the research group of Dr. Melissa Graham at the Astronomy Department at the University of Washington, USA and apply the code developed in Summer 1 to the next-generation cosmology survey, the Large Synoptic Survey Telescope. Dr. Graham is a research scientist with the Large Synoptic Survey Telescope team and is heavily involved in research in the use of Type Ia supernovae in cosmological measurements of dark energy. This will be an amazing opportunity to not only be at the core research institute at a key time in the development of the Type Ia supernova cosmology plan of Large Synoptic Survey Telescope but also to potentially influence the survey strategy.

References

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