RAS Specialist Discussion Meeting

Progress in Astrophysics with Type Ia Supernovae third meeting (PATIAS-3)

Start	End	Speaker	Institute	Title
Session 1				
10:20	10:25			Welcome
10:25	10:50	Luciano Piersanti	INAF-Osservatorio Astronomico d'Abruzzo	The elusive nature of SNe Ia progenitors: a modeler point of view
10:50	11:02	Ryan Alexander	University of Hull	Constraining SN Ia progenitors from the observed Fe-peak elemental abundances in the Milky Way dwarf galaxy satellites
11:02	11:14	May Alruwaili	University of York	New experimental constrains on 16O(p,a)13N reaction rate for its role in SNIa explosive nucleosynthesis
11:14	11:26	James Munday	University of Warwick	The search for type Ia progenitors in our galactic neighbourhood
11:26	11:38	Anwesha Sahu	University of Warwick	Upper limits on radio emissions from AM CVn type stars - SNe Ia progenitors
11:38	11:50	Madeleine Ginolin	IN2P3 - CNRS	Type Ia supernovae standardisation for cosmology with the ZTF SN Ia DR2 sample
11:50	12:02	Tomás Müller Bravo	Trinity College Dublin	Understanding type Ia supernova through near-infrared observations
12:02	12:14	Or Graur	University of Portsmouth	Late-time observations of type Ia supernovae with the Hubble Space Telescope
12:14	12:50	Pilar Ruiz Lapuente	Instituto de F´ısica Fundamental	Type Ia supernovae: recent developments on their progenitors and their remnants

Lunch				
Session 2				
13:50	14:02	Georgios Dimitriadis	Lancaster University	The diversity in the thermonuclear SN population as observed from ZTF
14:02	14:14	Shubham Srivastav	University of Oxford	Early excess features linking peculiar sub-luminous and over-luminous type Ia supernovae
14:14	14:26	Charlotte-Grace Touchard-Paxton	Trinity College Dublin	SN 2023xwi: Evidence for a new progenitor system for Ca-rich supernovae
14:26	14:38	Fionntan Callan	Queen's University Belfast	Exploring the range of impacts of helium in the spectra of double detonation models for type Ia supernovae
14:38	14:50	Joshua Pollin	Queen's University Belfast	3D nebular phase radiative transfer calculations of double-degenerate double-detonation models for type Ia supernovae
14:50	15:02	Matthew Grayling	University of Cambridge	Environmental dependence of SN Ia secondary maximum in i-band
15:02	15:15	Lisa Kelsey	University of Cambridge	The local environments of type Ia supernovae: Supernova siblings
15:15	15:30			Closing remarks
End				

Meeting objectives

The aim of this Specialist Discussion meeting is to bring together researchers different research fields in astrophysics to promote interaction, networking and discuss strategies to progress our knowledge of type Ia supernova events. This meeting will be the third of a series started in November 2020 and continued in December 2022. As already done on those occasions, we plan to present a summary of the findings of the meeting in A&G.

SUGGESTED TWITTER HASTAG: #RASSNIa or #RASPATIAS3

Abstracts

Speaker: Luciano Piersanti
Institute: INAF-Osservatorio Astronomico d'Abruzzo
Title: The elusive nature of SNe Ia progenitors: a modeler point of view
Abstract: In spite of their pivotal role as standardized candles to probe the far Universe, type I Supernovae remain an intriguing mystery. In fact currently no clear consensus there exists about their progenitor systems and their evolution up to the explosion. In this talk I will review the possible evolutionary scenarios proposed so far and I will try to derive some constraints on the progenitor systems of these explosive phenomena according to the results of accurate stellar evolutionary models of CO WD in interacting binaries.

Speaker: Ryan Alexander
Institute: University of Hull
Title: Constraining SN Ia Progenitors from the observed Fe-peak Elemental Abundances in the Milky Way Dwarf Galaxy Satellites
Abstract: Nucleosynthesis yields from sub-Chandrasekhar (sub M-ch) and Chandrasekhar (M-ch) SN Ia progenitors have been discussed and debated for decades on their contributions to iron peak elements in the cosmos. Investigating SNe Ia in ultra-faint dwarf galaxies (UFDs) and dwarf spheroidal galaxies (dSphs) with different star formation and chemical enrichment histories may shed light on the progenitors in different environments. To this end, we incorporate metallicity dependent SN Ia yields from different progenitors within our novel inhomogeneous chemical evolution model, i-GEtool, and compare the predicted chemical abundances to observations in different UFD and dSph galaxies. While the observed [Mn/Mg] ratios increase towards higher metallicities both within single galaxies and when considering galaxies with different metallicity distributions, the observed [Ni/Mg] ratios show a weaker correlation. In my talk, I will show that our models for UFD and dSph can reproduce the observed trends along with their scatter without invoking any contribution from sub M-ch SN Ia progenitors, at variance with previous studies in the literature. I will discuss the implications of our findings for the observed iron peak elemental abundances in the Milky Way halo and disks, outlining our future plan.

Speaker: May Alruwaili
Institute: University of York
Title: New Experimental constrains on 16O(p,a)13N reaction rate for its role in SNIa explosive nucleosynthesis
Abstract: Previous studies of Ca, S, and Ar abundances in Type Ia supernovae (SNIa) remnants have revealed insights into nucleosynthesis processes and progenitor metallicities. The 16O(p,a)13N reaction is proposed as a key reaction influencing these abundance ratios, but its reaction rates suffer from large uncertainties. This study present new direct measurements of the 16O(p,a)13N reaction cross section at center-of-mass energies Ecm = 6.9-5.6 MeV using the MUSIC active-target detector at Argonne National Laboratory. Our results show a lower reaction rate than previous measurements by a factor of 2, reducing uncertainties significantly. The updated reaction rate demonstrates that 16O(p,a)13N alone cannot fully explain observed Ca/S abundance ratios across all SNIa metallicities. These new constraints contribute to improved modeling of SNIa nucleosynthesis and highlight the need for further investigation of competing reactions, particularly 16O+12C, during the oxygen burning stage in SNIa models.

Speaker: James Munday
Institute: University of Warwick
Title: The search for type Ia progenitors in our galactic neighbourhood
Abstract: I will discuss the recent and current observational efforts in the discovery of double white dwarf binary star systems, what remains unclear/unsolved and what can be expected from new missions such as the LSST, LISA, MOS observations and Gaia astrometry. The focus will be around

type Ia progenitors with comparison to binary population synthesis model predictions. During my talk, I will also speak about the double-lined double white dwarf (DBL) survey which is a targeted search for systems with total masses above ~1.0 solar masses that I lead. This includes the discovery of the most massive double white dwarf known to date (Porb~14hrs, 1.55 solar masses) and the most-compact near-Chandrasekhar mass double white dwarf binary (Porb ~4.5 hours, 1.3 solar masses).

Speaker: Anwesha Sahu
Institute: University of Warwick
Title: Upper Limits on Radio Emissions from AM CVn type stars - SNe Ia Progenitors
Abstract: Fundamental questions remain about the accretion and outflow physics of cataclysmic variable stars, and their compact binary counterparts, AM CVn systems. AM CVns are potential progenitors for Type Ia supernovae. Using observations from the Karl J. Jansky Very Large Array (VLA), I have obtained the deepest radio constraints to date, for two AM CVn systems: AM CVn and HP Lib. I am currently cross-matching these data and catalogue data, with large scale surveys such as LOFAR and VLASS to constrain the population of AM CVns, and investigate the radio emission mechanisms in accreting white dwarf binaries. In this talk, I will discuss how understanding outflows and radio emissions from accreting white dwarfs such as these may help constrain mass loss rates in Type Ia SNe progenitors.

Speaker: Madeleine Ginolin
Institute: IN2P3 – CNRS
Title: Type Ia Supernovae standardisation for cosmology with the ZTF SN Ia DR2 sample
Abstract: Type Ia Supernovae (SNe Ia) are the most precise probes used to infer distances in current cosmological analyses. Nevertheless, large samples of SNe Ia initially collected for cosmology can also give valuable insight into the characteristics of SNe Ia populations, as well as their dependence on astrophysical environment. I will introduce briefly the ZTF DR2 Type Ia supernovae sample, a single-survey sample containing more than 3,000 SNe Ia. I will then look at the distributions of SN Ia colour and stretch found in the ZTF DR2 volume limited sample. We find a complex relation between stretch, SN Ia host mass and local environmental colour around the SN Ia. Focusing on the colour distribution, we are able to select a sample where reddening due to dust is mitigated. I will finally present results on standardisation relations between SN Ia magnitudes and stretch/colour. In particular, the stretch-magnitude relation exhibits a strong non-linearity.

Speaker: Tomás Müller Bravo
Institute: Trinity College Dublin
Title: Understanding type Ia supernova through near-infrared observations
Abstract: Type Ia supernovae (SNe Ia) are among the most precise distance indicators in the local Universe and fundamental for the understanding of the cosmic expansion and dark energy. However, despite their use in cosmology, there is still a plethora of unanswered questions about these stellar transients. Having a better understanding of their progenitor systems and explosion physics can shed new light on known systematics affecting their standardisation. Fortunately, near-infrared (NIR) observations of SNe Ia offer unique advantages, such as reduced dust extinction and uniform peak luminosity, but more importantly, provide constraints on the internal composition and structure of their explosions. In this talk, I will present the largest compilation of SNe Ia with NIR data and some preliminary analysis. I explore correlations between light-curve parameters, such as time and magnitude of first and second peaks, and discuss their physical implications. I also examine the NIR spectral features and how these can help us constrain the explosion mechanism.

Speaker: Or Graur
Institute: University of Portsmouth
Title: Late-time Observations of Type Ia Supernovae with the Hubble Space Telescope

Abstract: Most Type Ia supernovae (SNe Ia) are only followed up for several weeks to, at most, a hundred days past maximum light. Over the last few years, late-time observations with the Hubble Space Telescope 800-2000 days past maximum have revealed fresh insights into the physics of the progenitors and explosions of these SNe. So far, we have shown that: (1) the optical and NIR light curves of normal SNe Ia slow down at ~800 days and once more at ~2000 days, consistent with the ejecta being heated by long-lived radioactive decay chains of iron-group elements; (2) there might be a correlation between the rate at which the light curves slow down and the intrinsic luminosity of the SNe Ia; (3) normal SNe Ia go through a year-long plateau in the NIR between 150-500 days post maximum; but (4) such a plateau is not observed in 1991bg-like SNe Ia. In my talk, I will summarize these discoveries and discuss their impact on our understanding of the progenitors and the explosion physics of SNe Ia.

Speaker: Pilar Ruiz Lapuente
Institute: Instituto de Física Fundamental
Title: Type ia supernovae: recent developments on their progenitors and their remnants
Abstract: The still unknown nature of Type Ia supernova progenitors and the mechanism of the explosions can be illuminated, hundreds or thousands of years later, by observations of their remnants. These do not only bear marks of the explosion mechanism in their chemical abundances, morphologies and dynamics, but their exploration can either reveal the presence of possible surviving companions or, on the contrary, establish their absence. I will review the current status of this research, in our Galaxy and in the Large Magellanic Cloud, as well as constraints coming from observations in other galaxies. I will also discuss other recent developments in the Type Ia supernova field.

Speaker: Georgios Dimitriadis
Institute: Lancaster University
Title: The diversity in the thermonuclear SN population as observed from ZTF
Abstract: The majority of thermonuclear explosions in the Universe seem to proceed in a rather standardised way, as explosions of carbon-oxygen (C/O) white dwarfs in binary systems, leading to the cosmologically useful, normal Type Ia supernovae (SNe Ia). However, our understanding of the SN physics has altered over the past few decades with the introduction of wide field, high-cadence, all-sky surveys. These surveys have not only increased the populations of established SN (sub)classes, allowing for large-scale statistical studies, they have also unearthed several new subclasses of events that deviate from normal SNe Ia in their observational properties, and which require different and not seldom more extreme progenitor systems. In this talk, I will present results from the Zwicky Transient Facility (ZTF), the current state-of-the-art discovery transient machine, and particularly the first homogeneous release of 3,628 SNe Ia, of all flavours, observed between March 2018 and December 2020. I will show the most detailed map of the SNe Ia diversity to date and discuss further research approaches into understanding how a WD explodes.

Speaker: Shubham Srivastav
Institute: University of Oxford
Title: Early excess features linking peculiar sub-luminous and over-luminous type Ia supernovae
Abstract: 02es-like Ia supernovae (SNe) constitute a peculiar subclass that show normal width light curves, but tend to be typically a magnitude fainter than normal SNe Ia, making them sub-luminous. 03fg-like SNe Ia on the other hand show slow-declining light curves and tend to be over-luminous. Photometric and spectroscopic differences notwithstanding, recently discovered SNe within both these rare subclasses have shown early excess features, a short-lived spike in the early light curve. Modeling the light curve suggests that a dense, nearby shell of circumstellar material (CSM) may best explain this feature, thereby suggesting a common origin for 02es-like and 03fg-like SNe Ia. The CSM could originate within a double-degenerate scenario involving a white dwarf merger. Other similarities in observed properties of the two subclasses include (typically) low ejecta velocities, weak

or absent secondary i-band maxima, and [OI] emission features in nebular spectra of some members of both subclasses. I will present early and late-time observations for a sample of recent Ia-02es and Ia-03fg and discuss the open questions surrounding the observed diversity within these subclasses and the nature of their progenitors.

Speaker: Charlotte-Grace Touchard-Paxton
Institute: Trinity College Dublin
Title: SN 2023xwi: Evidence for a New Progenitor System for Ca-rich Supernovae
Abstract: We present an extensive optical photometric and spectroscopic investigation into a newly-discovered Ca-rich supernova (SN) - SN 2023xwi. Observations from a variety of ground-based telescopes follow the SN from 8d pre-peak to 87d post-peak, covering both photospheric and nebular phases of the supernova. Objects of this class are characterised by nebular (late-time) spectra that are dominated by [Ca II] 12 7291, 7324 emission. SN 2023xwi displays a unique peculiarity in that its forbidden [Ca II] feature is visible in its peak spectrum - far earlier than current explosion models allow. This is the strongest and earliest detection of this feature in Ca-rich supernovae in photospheric-phase spectra. We investigate the velocity evolution of this spectral feature and confirm that it cannot be explained by any current explosion mechanism or progenitor system. From our observations, we propose a He-nova progenitor based on the AMCVn systems.

Speaker: Fionntan Callan
Institute: Queen's University Belfast
Title: Exploring the range of impacts of helium in the spectra of double detonation models for Type Ia supernovae
Abstract: In the double detonation scenario the ignition of a surface He detonation on a sub-Chandrasekhar mass white dwarf leads to a secondary core detonation. Double detonation models have shown promise for explaining Type Ia supernovae (SNe Ia) with a variety of luminosities. A key feature of such models is unburnt He in the ejecta, which can show significant variation in both its mass and velocity distribution. Many previous radiative transfer simulations for double detonation models have neglected treatment of non-thermal ionization and excitation, preventing them from robustly assessing whether He spectral features are expected to form. In this talk I will present results from a NLTE (non local thermodynamic equilibrium) radiative transfer simulation, including treatment for non-thermal electrons, for a double detonation model with a modest mass of He (0.04 $M_{\odot}$) ejected at reasonably low velocities (12000 km/s). Despite the simulation predicting no clear optical He features, a strong and persistent He I 10830 Å absorption feature forms that is significantly blended with the spectral contribution of Mg II 10927 Å. For some normal SNe Ia the Mg feature shows an extended blue wing, previously attributed to C I, however the simulated He feature shows its strongest absorption at wavelengths consistent with this wing. We therefore suggest this extended wing is instead a spectral signature of He. The He feature predicted by this particular model is too strong and persistent to be consistent with normal SNe Ia, however, this motivates further work to use this observable signature to test the parameter space for double detonation models.

Speaker: Joshua Pollin
Institute: Queen's University Belfast
Title: 3D Nebular Phase Radiative Transfer Calculations of Double-degenerate Double-detonation models for Type Ia supernovae
Abstract: The double-detonation of a sub-Chandrasekhar mass white dwarf is one of the leading models for Type Ia supernovae. Double-detonations could be triggered either via accretion or during the merger of white dwarf binaries. Most previous double-detonation explosion simulations have included only the primary white dwarf, but for white dwarf mergers, the fate of the secondary can have significant consequences. Recently, simulations fully accounted for the secondary white dwarf in 3D hydrodynamic explosion simulations of double-degenerate double-detonation mergers. We present the first multidimensional nebular phase radiative transfer calculations for the double-

degenerate double-detonation scenario, which utilises our full NLTE treatment of the plasma conditions. Similar to photospheric phase radiative transfer calculations, viewing angle variation is still important hundreds of days after the initial explosion. The range in viewing angle variation depends heavily on the level of asymmetry in the explosion models. Nebular phase radiative transfer modelling has revealed that the exact evolutionary endpoint of the binary system has significant observational consequences. Specifically, when the secondary white dwarf detonates, the viewing angle variation produces a greater range of features and Doppler shifts. Additionally, JWST observations have enabled detailed comparisons of the theoretical spectra to infrared data. Thus allowing for a deeper understanding of how the morphology of the models' innermost ejecta aligns with observations. These calculations demonstrate how radiative transfer calculations in the nebular phase can reveal key spectroscopic characteristics in explosion models compared to photospheric phase calculations and highlights the importance of multidimensional effects.

Speaker: Matthew Grayling
Institute: University of Cambridge
Title: Environmental dependence of SN Ia secondary maximum in i-band
Abstract: It has long been established that the properties of type Ia supernovae (SNe Ia) depend on their local environment, even after typical standardisation methods. This is typically referred to as the mass step, where SNe Ia in high-mass galaxies are on average brighter than their low-mass counterparts, although trends have been established with other environmental properties including colour, specific star formation rate and distance from the centre of the galaxy. There has been ongoing debate in the field about whether these differences are intrinsic or just the result of extrinsic effects i.e. dust. This mass step has typically been thought of as an overall magnitude offset between SNe Ia in different environments. However, recent analysis using BayeSN, a hierarchical Bayesian SED model for SNe Ia, has allowed for time- and wavelength-dependent differences between SNe Ia in different environments alongside differences in host galaxy dust. I will present results based on a variety of supernova surveys, demonstrating that we are consistently observing differences in intrinsic i-band absolute magnitude around the time of second maximum between SNe Ia in high and low-mass galaxies. These results demonstrate that there are intrinsic differences between SNe Ia in different environments and raise an interesting question about what spectral differences are causing these photometric results; understanding this result can help reveal the underlying physical cause of the environmental dependence of SNe Ia.

Speaker: Lisa Kelsey
Institute: University of Cambridge
Title: The Local Environments of Type Ia Supernovae: Supernova Siblings
Abstract: The use of type Ia supernovae (SNe Ia) as standardizable candles is complicated by an unresolved dependence on their environments: SNe Ia in high-mass galaxies are brighter than those in low-mass galaxies. This is a vital consideration for current and future cosmological surveys, as it is the largest systematic uncertainty in modern SN cosmology. In the current formalism for accounting for this dependence in cosmological analyses, sibling SNe Ia (which share a host galaxy) are treated in the same manner. If the remaining brightness dispersion in SNe Ia cosmology is entirely due to global host galaxy properties, siblings should be similar, with comparable intrinsic colours, stretches and Hubble residuals. However, prior studies have shown that this is not the case, and they are as different as any other random pair of SNe Ia, raising questions about the validity of global host galaxy corrections. It is crucial to improve our understanding of SN Ia correlations with environmental properties to ensure the most accurate cosmology in the era of the Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST). In this talk, I will present an overview of our current understanding of the importance of environmental correlations on SNe Ia cosmology, with a particular focus on local environmental properties and the importance of supernova siblings to disentangle the cause of this dependence. I will use as a case-study NGC 5468, a galaxy that hosts

six SNe, of which two are normal SNe Ia. Through obtaining high quality photometry of this galaxy using HST and JWST, I measure rest-frame galaxy colours, stellar masses, star formation rates and dust properties within small apertures around each SN and compare with their intrinsic properties. For this particularly prolific galaxy, we can both gain understanding into the preferences for different types of SNe to explode in different galactic environments, and if sub-galactic differences in environmental properties provide the solution to improving SNe Ia standardisation.