Fifty-One Ergs 2019

An International Conference on the Physics and Observations of Supernovae and Supernova Remnants

May 20th - 24th 2019

Abstracts

NC STATE UNIVERSITY

Monday, May 20$^{\text{th}}$

Georges Meynet, *University of Geneva*

Angular momentum transport processes in stars

In this talk, I shall first discuss the various physical processes that can transport angular momentum in stars and how they are presently implemented in stellar models. I shall then discuss the observational constraints that can be used to infer the efficiency of this transport in stars. The case of low and high mass star will be presented. Finally I shall report on various recent attempts to fit these observational constraints and discuss some future lines of research.

Sung-Chul Yoon, *Seoul National University*

Issues on the evolution and properties of stripped-envelope supernova progenitors

Evolution of massive stars is affected by mass loss via stellar winds and/or binary interactions. The so-called stripped-envelope supernovae, including Type IIb, Ib and Ic supernovae, provide excellent observational constraints on the mass-loss history of massive stars. Many previous studies argued that a large fraction of their progenitors have a binary star origin, but details of their evolutionary paths and their exact nature are still a matter of debate. In this talk, I will address the following issues. 1) How can the binary scenario explain the diversity of stripped-envelope supernovae? 2) Are progenitors of Type Ic supernovae really helium-deficient? 3) Was the progenitor of the Type IIb supernova 1993J really a cool supergiant? I will conclude the talk by discussing uncertainties in the current stellar evolution theory implied by these issues.

Mojgan Aghakhanloo, *Florida State University*

Using Gaia to constrain late-stage evolution of massive stars

Using Gaia parallaxes and proper motions we place fundamental constraints on stellar evolution. Gaia parallaxes provide the most accurate luminosity and mass estimates, while the proper motions will provide kinematic age estimates. Our goal is to constrain all phases of late-stage evolution; as a first case study we first constrain the fundamental parameters and ages of luminous blue variables (LBVs). We examine parallaxes and distances to individual Galactic LBVs and find that nearly half of the new Gaia inferred distances are significantly closer than previous estimates in the literature. For the remaining half of the sample, the

DR2 distances are formally consistent within the uncertainty, either because there is little change or because the large uncertainty encompasses a wide range of values. We find the birth associations for these LBVs and use the combined statistics to place even tighter constraints on distance to LBVs. Furthermore, we begin characterizing the dynamics of the LBVs and birth associations to derive kinematic ages.

Diego López-Cámara, *Instituto de AstronomíÂa, UNAM*

How self-regulating jets may play a key role during the common-envelope phase

Many of the highly-energetic and transient phenomena in the Universe are the result of stellar binary interactions in which the common envelope (CE) phase. Even though the CE phase has been studied for decades, its overall understanding and some key questions remain to be fully understood. In this talk I will show how self-regulated jets launched from a compact object (CO), immerse in the common envelope (CE), may play a key role in the evolution of the system. Specifically, I will show the results from a set of three-dimensional hydrodynamic simulations in which we follow the evolution of a jet that is self-consistently powered by a fraction of the mass accretion rate that reaches the CO, through the CE. Depending on the accretion efficiency the jet may be quenched, it may present variable behavior, or it may even deposit enough energy (∼0.01 FOE) to unbind the outer layers of the CE (giving rise to a grazing envelope configuration).

Susanna Vergani, *l'Observatoire de Paris*

Host properties of long GRBs, SLSNe and SNe Ic-BL: implications for progenitors

I will present the results of a series of studies carried out by our group over the last years on the host galaxies of long gamma-ray bursts (LGRBs), super-luminous supernovae (SLSNe) and broad-line Ic supernovae (Ic-BL SNe) to obtain indirect information on the key properties of their progenitor stars, leading to these different types of explosions. We find unbiased observational evidence that metallicity is the key driver for LGRBs. In general we find similar properties for LGRB and type-I SLSN host galaxies. The differences we highlight for the properties of Ic-BL SN host galaxy allow us to support the scenario of a genuine Ic-BL SN population not associated with LGRB explosions.

Albino Perego, *University of Trento*

Modelling of binary neutron star mergers and of their kilonovae

Katerina Chatziioannou, *Flatiron Institute*

Studying neutron stars with gravitational waves

The first detection of a merger of two neutron stars with gravitational waves has already offered novel insights on supranuclear matter. In this talk I will describe how the gravitational wave data can be used to infer the radius and the equation of state of the merging bodies and how these constraints can be combined with nuclear experimental data. I will further discuss future prospects for equation of state constraints from upcoming observing runs, improved gravitational wave detectors, as well as the post-merger part of the gravitational wave signal.

Kenta Kiuchi, *Albert Einstein Institute*

Revisiting on the lower bound of tidal deformability constraint derived by AT 2017gfo

Avishay Gal-Yam, *Weizmann Institute of Science*

New observations of infant SN explosions from ZTF

For the past year, the Zwicky Transient Facility (ZTF) has been conducting a high-cadence (approximately 6 images per night) extragalactic survey over 1800 square degrees of sky. During routine operations, this survey finds about 1-2 supernova (SN) explosions within 1-2 days from first light; we refer to such events as “infant SNe”. I will review the exciting science opportunities offered by observations of infant SNe, show preliminary results from the first ZTF season, and share short- and long-term prospects.

Mansi Kaslival, *California Institute of Technology*

The Dynamic Infrared Sky

The dynamic infrared sky is hitherto largely unexplored. The infrared is key to understand elusive stellar fates that are opaque, cold or dusty. The infrared unveiled the otherwise opaque heavy element nucleosynthesis in neutron star mergers. I will describe multiple projects to chart the time-domain in the infrared. I will begin with the SPitzer InfraRed

Intensive Transients Survey (SPIRITS) — a systematic search of 194 nearby galaxies within 30 Mpc, on timescales ranging between a week to a year, to a depth of 20 mag with Spitzer's IRAC camera. SPIRITS has already uncovered over 131 explosive transients and over 2536 strong variables. Interpretation of these new infrared discoveries may include (i) deeply enshrouded supernovae, (ii) stellar mergers with dusty winds, (iii) 8–10 solar mass stars experiencing e-capture induced collapse in their cores, (iv) the birth of massive binaries that drive shocks in their molecular cloud, or (v) formation of stellar mass black holes. Motivated by the treasure trove of SPIRITS discoveries, we just commissioned Palomar Gattini-IR - a new 25 sq deg J-band camera to robotically chart the dynamic infrared sky. We have also begun building WINTER - a new 1 sq deg yJH-band camera on a new 1m telescope at Palomar Observatory.

Deanne Coppejans, *Northwestern University*

Multi-wavelength studies of fast-evolving blue optical transients

In recent years surveys have identified a new class of luminous transients with an extremely rapid rise to maximum (a few days) and blue colours. These transients, refered to as Fast Blue Optical Transients (FBOTs), have properties that challenge traditional supernova models. Based on optical data, a number of physical scenarios have been suggested for FBOTs, but the mechanism/s in the class are still unknown. Multi-wavelength observations of the recent FBOT AT2018cow demonstrated how important radio and x-ray observations are to determining the physics. In particular, these wavelengths probe the fast-moving material and consequently sample the environment density and blast-wave dynamics. In this talk I will discuss the results of our ongoing multi-wavelength campaign on AT2018cow and how we can use multi-wavelength observations to determine the nature of this enigmatic class of transients.

Emmanouela Paraskeva, *Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing (IAASARS)*

Early high-cadence observations of supernovae: revealing features of variability and identifying their diversity

Ashley Villar, *Harvard University*

CCSNe studies in the age of LSST

LSST will annually discover a million of new supernovae, including exotic CCSNe subtypes. With this deluge of new data, we need to understand how to extract the most science from the sample of LSST light curves which received no additional followup. In this talk, I will describe a new photometric SN classification pipeline which has been trained on light curves from the Pan-STARRS Medium Deep Survey and how similar pipelines will be essential to classify CCSNe in the future. I will then discuss how we can meaningfully model populations of (classified) exotic CCSNe, using a population of simulated LSST Type I SLSN light curves as an example.

Jennifer Barnes, *Columbia University*

Kilonovae and r-process nucleosynthesis

Sherwood Richers, *North Carolina State University*

Neutrino quantum kinetics in compact objects

Neutrinos play a critical role of transporting energy and changing the lepton density within core-collapse supernovae (CCSNe) and neutron star mergers. The possibility of flavor or angular instabilities in the neutrino distributions have the potential to revolutionize our understanding of the CCSN explosion mechanism and neutrino signals. However, understanding these effects will require yet-undeveloped technology to simulate the neutrino quantum kinetic equations (QKEs). I will present a method for extending existing neutrino interaction rates long used in CCSN simulations to full QKE source terms for use in numerical calculations. To demonstrate the effects of a complete set of neutrino interaction physics, I will show the results of simulations of the full isotropic QKEs in conditions relevant to core-collapse supernovae and neutron star mergers. I will demonstrate that in isotropic calculations, electron scattering, nucleon-nucleon bremsstrahlung processes, and four-neutrino processes dominate flavor decoherence in the protoneutron star (PNS), absorption dominates near the shock, and all of the considered processes except elastic nucleon scattering are relevant in the decoupling region. Finally, I will present an effective decoherence opacity that at most energies predicts decoherence rates to within a factor of 10 in our model PNS and within 20% outside of the PNS.

Xilu Wang, *University of Notre Dame*

Sandblasting the r-process: spallation of the r-process nuclei ejected from a NS-NS event

Neutron star mergers are r-process nucleosynthesis sites, which eject materials at high velocity ranging from 0.1c to 0.3c for different regions. Thus the r-process nuclei ejected from a neutron star merger event are sufficiently energetic to have spallation nuclear reactions with the interstellar medium particles. The spallation reactions tend to shift the r-process abundance patterns towards the solar data, and smooth the abundance shapes. The spallation effects depend on both the initial r-process nuclei conditions, which is determined by the astrophysical trajectories and nuclear data adopted for the r-process nucleosynthesis, and the propagation process with various ejecta velocity and spallation cross section.

Sanjana Curtis, *North Carolina State University*

Examining the treatment of neutrino-matter interactions in neutron star merger simulations

Neutrinos play an important role in the nucleosynthesis, post-merger evolution, and electromagnetic transients produced in binary neutron star mergers. To reliably model these effects, we need accurate neutrino transport in merger simulations. However, it is prohibitively expensive to evolve the Boltzmann transport equation directly and simulations rely on various approximate methods instead. In order to understand how to interpret simulation results, we need to understand the errors associated with approximate transport schemes. To this end, we use the time-independent Monte Carlo neutrino transport code Sedonu to calculate the neutrino distribution function, along with the heating, leptonization and neutrino pair-annihilation rates, for a number of post-merger snapshots. The snapshots are taken from dynamical merger simulations with M0 transport, spanning a range of binary mass ratios, equations of state and merger outcomes. I will first identify the major discrepancies between our results and those obtained with M0 transport for the same set of weak reactions. I will then present our full calculations that include, for the first time, the effects of inelastic neutrino-electron scattering in the merger case. Finally, I will discuss the implications of our results for the treatment of neutrinos in future dynamical simulations.

Tuesday, May 21st

Dario Carbone, *Texas Tech University*

Multi-messenger exploration of the transient radio sky: GW170817 and the future

Rodrigo Fernandez, *University of Alberta*

Long-term GRMHD simulations of neutron star merger accretion disks

Neutron star mergers result in the formation of an accretion disk that evolves on timescales much longer than the orbital time, thereby ejecting mass that contributes to the r-process kilonova transient. It is widely accepted that angular momentum transport in astrophysical disks is mediated by magnetic turbulence, but thus far very few simulations of these disks have included this effect. I will present results of three-dimensional GRMHD simulations of neutron star merger accretion disks around Kerr black hole remnants, evolved for long enough to achieve completion of mass ejection far from the disk. Comparing to viscous hydrodynamic simulations, we find that inclusion of magnetic fields result in a factor of two more mass ejected, at higher velocities, and with a wider electron fraction distribution. Given our initial magnetic field geometry, we also obtain a powerful relativistic jet capable of powering a short gamma-ray burst and its non-thermal afterglow.

Paul Duffell, *Harvard-Smithsonian Center for Astrophysics*

Jet dynamics in compact object mergers

We use relativistic hydrodynamic numerical calculations to study the interaction between a jet and a homologous outflow produced dynamically during binary neutron star mergers. We quantify how the thermal energy imparted by the jet and the ability of the jet to escape the ejecta depend on the parameters of the jet engine and the ejecta. Under our assumptions, a collimated jet initiated at early times compared to the engine duration, we show that successful breakout of the forward cocoon shock necessitates a jet that successfully escapes the ejecta. This is because the ejecta is expanding, and the forward shock from a failed jet stalls before it reaches the edge of the ejecta. This conclusion can be circumvented only for very energetic wide angle jets, with parameters that are uncomfortable given short-duration GRB observations. For successful jets, we find two regimes of jet breakout from the ejecta: early breakout on timescales shorter than the engine duration, and late breakout well after the engine shuts off. A late breakout can explain the observed delay between gravitational waves and gamma rays in GW170817. We show that for the entire parameter space of jet parameters surveyed (covering energies $\sim 10^{48} - 10^{51}$ erg and opening angles $\sim$ 0.07-0.4) the thermal energy deposited by the jet is less than that produced by r-process heating on second timescales by at least an order of magnitude. Shock heating is thus energetically subdominant in setting the luminosity of thermally powered transients coincident with neutron star mergers (kilonovae).

Steven Fahlman, *University of Alberta*

HMNS disk outflows and the blue kilonova from GW1701817

The recent detection of the first neutron star merger in gravitational and electromagnetic waves allows us to compare observational data to theoretical predictions. The observed kilonova from GW170817 was powered by the decay of r-process elements ejected from the system, with the light curve dependent on the velocity, mass, and composition of the ejecta. Standard kilonova fits require a separate blue component from lanthanide-poor ejecta. The existence of this component has been used as evidence for a hypermassive neutron star (HMNS) remnant in GW170817. I will present results from long-term hydrodynamic simulations of the accretion disk around a HMNS that for the first time scan a wide range of plausible parameters compatible with GW170817. We find that large outflow velocities ($\sim$0.25c) in the lanthanide-poor ejecta, needed to account for the blue kilonova component, cannot be reproduced by a combination of neutrino heating, viscous angular momentum transport, and nuclear recombination. Viable resolutions to this problem are inclusion of magnetic stresses in long-term disk simulations, improved radiative transfer models for kilonova light curve fitting, or enhancements in the dynamical ejecta from merger simulations.

Chad Hanna, *Penn State University*

Advanced LIGO's third observing run

Rosalba Perna, *Stony Brook University*

Electromagnetic counterparts from mergers of compact object binaries

Paolo D'Avanzo, *INAF, Brera Astronomical Observatory*

The evolution of the afterglow of GW 170817 / GRB 170817A: evidence for a structured relativistic jet

Tyler Parsotan, *Oregon State University*

Numerical simulations of the dynamics and radiative properties of gamma-ray burst jets

Gamma Ray Bursts are the most energetic events in the universe that cover a range of photon energies, from gamma rays, produced by the prompt emission near the compact object, all the way to radio waves, produced in the afterglow of the GRB. Modeling these various energies can shed light on the radiation mechanism at play in the GRB jet and the structure of the jet, both of which are not well understood after decades of research. We use our novel Monte Carlo Radiative Transfer (MCRaT) code to analyze the prompt photospheric emission from synthetic GRBs simulated using the FLASH code. Additionally, we delve into the modeling of the afterglow from synthetic GRBs. We show what our agreements with observed prompt and afterglow observations means for understanding the dominant radiation mechanism in GRBs and the structure of GRB jets.

Hannah Klion, *UC Berkeley*

Effects of jet-ejecta interaction on kilonova light curves

Recent observations have confirmed that the neutron star merger detected by LIGO in August 2017 had a jet. If there is ejecta surrounding the merger remnant, the interaction of a jet with the ejecta can influence the associated optical and infrared light curves. Using Sedona, a Monte Carlo radiation transport code, we examine the viewing angle-dependence of the effect of the jet on the light curves, as well as the relative influence of jet shock and r-process heating on the observations.

Ore Gottlieb, *Tel Aviv University*

What have we learnt from the EM signals in GW170817?

Following a Neutron star merger a jet propagates and interacts with the outflowing ejecta that surrounds the merger. As a result matter is pushed around the jet to form a hot cocoon which applies pressure on the jet and potentially collimates it. The cocoon envelops the jet as long as the jet propagates within the dense ejecta. After the jet breaks out, the cocoon expands and emits radiation over large angles throughout the entire electromagnetic spectrum, from γ-rays to radio. In GW170817 the cocoon is a leading candidate to be the source of the observed γ-ray emission and dominated the first $\sim$2 months of the afterglow emission, until the jet decelerated enough to become visible. Likewise, observations of future double NS merger events are also expected to be dominated by the cocoon emission due to the beaming of the jet emission. Furthermore, it is possible that some jets are choked inside the ejecta, in which cases the cocoon becomes the leading candidate to produce the entire prompt and afterglow emissions. In this talk I will present the different mechanisms of emission from the cocoon and discuss what we learned about the GW170817 jet-cocoon system from the entire set of EM observations. I will end with what it tells us about future double Neutron star merger joint detections during the upcoming Advanced LIGO/Virgo observation run O3.

Thomas Janka, *Max Planck Institute for Astrophysics*

3D Core-collapse Supernova Modeling: Where do we Stand?

The talk will briefly review the current state of core-collapse supernova simulations, in particular the progress in three dimensions. It will also address still unsettled questions connected to the initial conditions in the progenitor stars, the numerical resolution dependence of 3D calculations, and the implications of fully multidimensional neutrino transport.

Tomoya Takiwaki, *Kyoto University*

Neutrino radiation hydrodynamic simulation of an ultra-stripped Type Ic supernova

Ultra-striped supernovae are considered to play an important role in the formation of double neutron star systems that attract special interest due to the gravitational wave detection of binary neutron star merger. We investigate the dynamics of ultra-stripped supernova by 2 dimensional simulation with the new neutrino reaction rate of Horowitz et al 2017. We found that 0.02 solar mass of Ni is ejected in our model. The amount of Ni is comparable to dark supernovae of PRF10iuv and sn2010X.

Quintin Mabanta, *Florida State University*

Convection-aided explosions in one-dimensional core-collapse supernova simulations

A primary goal of core-collapse supernova (CCSN) theory is to predict which stars explode. One-dimensional (1D) CCSN simulations typically do not explode, while three-dimensional (3D) simulations sometimes do; yet 3D simulations take ∼100,000 more computing resources than 1D to produce a successful supernova. To properly explore the parameter space of explodability, simulations must be completed at a much faster pace than the current generation of multi-dimensional simulations. We show that neutrino-driven convection enables explosions in the multi-dimensional simulations. Based upon this work, we develop a convection model and include it in one-dimensional simulations. This 1D+ scheme reproduces the explosion conditions of multi-dimensional simulations but in a fraction of the time. We will further calibrate this model using more nuanced, radiation-hydrodynamic simulations and follow with a statistical analysis of explodability for thousands of progenitors.

Sarah Gossan, *California Institute of Technology*

On wave heating from protoneutron star convection and the core-collapse supernova explosion mechanism

Our understanding of the core-collapse supernova explosion mechanism is incomplete. While the favoured scenario is delayed revival of the stalled shock by neutrino heating, it is difficult to reliably compute explosion outcomes and energies, which depend sensitively on the complex radiation hydrodynamics of the post-shock region. For computational efficiency, many simulations mask out the inner regions of the proto-neutron star (PNS), from which nearly all the PNS binding energy and hence explosion energy originates. We show that gravity waves excited by core PNS convection can couple with outgoing acoustic waves that present an appreciable source of energy in the post-shock region. Using one-dimensional simulations, we estimate the gravity wave energy flux excited by PNS convection and the fraction of this energy transmitted upward to the post-shock region as acoustic waves. We find wave energy fluxes near $10^{51}\,\mathrm{erg\,s^{-1}}$ likely persist for ~ 1s post-bounce, well after neutrino heating rates have greatly decreased. The wave pressure on the shock may exceed 10% of the thermal pressure, potentially contributing to shock revival and, subsequently, a successful and energetic explosion. We discuss how future simulations can better capture the effects of waves and more accurately quantify wave heating rates.

Shunsaku Horiuchi, *Virginia Tech*

Diffuse supernova neutrino background from extensive core-collapse simulations

The diffuse supernova neutrino background (DSNB) will enter an era of signal-dominated search with the completion of the gadolinium upgrade at Super-Kamiokande, motivating a re-investigation of its theoretical predictions. We focus in particular on recent advances in core-collapse simulations that shed light on supernova diversity—namely, the progenitor dependence of core-collapse supernova neutrino emission. We report DSBN predictions based on the detailed variations in the neutrino emission over the entire mass range 8–100 $M_\odot$, based on (i) a long-term simulation of the core collapse of an ONeMg core progenitor, (ii) over 100 simulations of iron core collapse to neutron stars, and (iii) half a dozen simulations of core collapse to black holes (the 'failed channel').

MacKenzie Warren, *Michigan State University*

Correlated multi-messenger signals from the landscape of core-collapse supernovae

With the advent of modern neutrino and gravitational wave detectors, the promise of multi-messenger detections of the next galactic core-collapse supernova has become a certainty. These detections will give insight the core-collapse supernova mechanism, the structure of the progenitor star, and may even resolve longstanding questions in fundamental physics. Using CCSN simulations, we have explored multi-messenger neutrino and gravitational wave signals from the landscape of CCSN progenitors from 9-120 $M_\odot$. We have found that the neutrino and gravitational wave signals from a galactic CCSNe will have strong correlations with the structure of the progenitor star and protoneutron star. Additionally, the two signals will be strongly correlated with each other, which may give insight into neutrino flavor mixing that occurs in core-collapse supernovae.

Wednesday, May 22nd

Laura Chomiuk, *Michigan State University*

A shocking shift in paradigm for classical novae

The discovery of GeV gamma-rays from classical novae has led to a reassessment of these garden-variety explosions, and highlighted their importance for understanding radiative shocks, particle acceleration, and dust formation in more exotic, distant transients. Recent collaboration between observers and theorists has revealed that shocks in novae are energetically important, and can even dominate their bolometric luminosity. Shocks may also explain long-standing mysteries in novae such as dust production, super-Eddington luminosities, and complex optical light curves. I will review these recent developments and look forward to exciting future prospects.

Jordi Jose, *Universitat Politècnica de Catalunya*

Classical novae, recurrent novae, and the mass of the underlying white dwarf

Classical novae are thermonuclear explosions that take place in the H-rich envelopes of accreting white dwarfs in stellar binary systems. The material piles up under degenerate conditions, driving a thermonuclear runaway. The energy released by the suite of nuclear processes operating at the envelope heats the material up to peak temperatures of (100 - 400) MK. During these events, about 10-7 - 10-4 solar masses, enriched in CNO and, sometimes, other intermediate-mass elements (e.g., Ne, Na, Mg, Al) are ejected into the interstellar medium. In this talk, we present new multidimensional simulations of mixing at the core-envelope interface during classical novae, for different masses and chemical compositions of the underlying white dwarf, and explore the dynamic stages of the explosion through remaping of the 3D results obtained with the FLASH code into the 1D SHIVA code. New nucleosynthesis results will be presented. We will also present recurrent nova models, in which the mass of the accreting white dwarf should be very close to the Chandrasekhar value, as imposed by their short recurrence periods. Models suggest that the white dwarf hosting recurrent nova explosions grows in mass, becoming likely candidates for thermonuclear supernovae.

Sumner Starrfield, *Arizona State University*

Classical nova explosions: SN Ia progenitors and lithium factories

We report on studies of Classical Nova (CN) explosions where we follow the evolution of thermonuclear runaways (TNRs) on Carbon Oxygen (CO) white dwarfs (WDs). We vary both the mass of the WD (from 0.6$M_\odot$ to 1.35$M_\odot$) and the composition of the accreted material. Our simulations rely on the results of multi-dimensional studies of TNRs in WDs that find sufficient mixing with WD material occurs after the TNR is well underway, reaching levels of enrichment that agree with observations of CN ejecta abundances. We use NOVA (our 1-dimensional hydrodynamic code) to accrete solar matter until the TNR is ongoing and then switch from the solar composition to a mixed composition (either 25% WD material and 75% solar or 50% WD material and 50% solar). Because the amount of accreted material is inversely proportional to the initial ^{12}C abundance, by first accreting solar matter the amount of material taking part in the outburst is larger than in those simulation where we assume a mixed composition from the beginning. We find large enrichments of ^{7}Be in the ejected gases implying that CO CNe may be responsible for a significant fraction ($\sim$ 300 $M_\odot$) of the $\sim$1000 $M_\odot$ we determined for the total amount ^{7}Li in the galaxy. Finally, these simulations eject less material than accreted. We predict, therefore, that the WD is growing in mass as a consequence of the accretion/ CN outburst/ accretion cycle. This result implies that CO CNe may be a channel of Supernova Ia progenitors and not the Super-soft X-ray sources as has been assumed previously.

Kojiro Kawana, *University of Tokyo*

Emission from thermonuclear explosions in white dwarf TDEs

In tidal disruption events (TDEs) of a white dwarf (WD) by a black hole (BH), the WD is not only tidally disrupted but possibly ignites nuclear burning with the help of tidal compression. MacLeod et al. (2016) show that emission from thermonuclear explosion in a TDE of a CO WD with 0.6 $M_\odot$ is reminiscent of Type I supernovae. However, nucleosynthesis and dynamics of tidal debris in WD TDEs have a large variety depending on BH/WD mass and orbital parameters (Kawana et al. 2018). Here, we study a variety of emission emerging from thermonuclear explosion in WD TDEs by performing hydrodynamic simulations coupled with nuclear reactions and post-process radiative transfer calculations. We find that emission from WD TDEs of a He WD is significantly different from that of CO WDs. Because of lower mass of unbound debris, it shows short timescale and blue color, which is similar to fast transients.

Ashley Ruiter, *University of New South Wales Canberra*

SN Ia subclasses and progenitor origin

It has become clear over the last decade that the progenitors of Type Ia supernovae originate from at least 2 (likely more) formation channels. However, it is still uncertain what the different SN Ia progenitors are in terms of exploding white dwarf mass, nature of the mass-losing companion star, and how these are connected to the observed sub-classes of SNe Ia (e.g. 'normal', 91bg-like, Type Iax, etc.). Binary evolution models can constrain the ages (delay times), birthrates, and evolutionary channel origins of SNe Ia and other thermonuclear transients. I will discuss how metallicity and other evolutionary factors influence the rate of sub-Chandrasekhar mass and Chandrasekhar mass explosions among different stellar populations. For example: the Chandrasekhar mass scenario involving a hydrogen-stripped, helium-burning star donor - a favoured candidate for SN Iax transients - is more favourable by number than the canonical hydrogen-rich donor channel over the tested metallicity range with an increasing relative frequency toward low metallicity.

Hiroya Yamaguchi, *JAXA/ISAS*

X-ray view of Type Ia supernova remnants

Despite decades of intense efforts, many fundamental aspects of thermonuclear supernovae (SNe Ia) remain elusive. X-ray observations of SN Ia remnants offer unique opportunities to study the detailed nature of progenitor's evolution and explosion, although the number of observables is limited. I will review recent observational results on Galactic and Magellanic SN Ia remnants focusing on key issues that can best be addressed by X-ray studies: a large scale distribution of the ambient medium, asymmetricity and clumpiness of the SN ejecta, and composition of the Fe-peak elements. Prospects for future X-ray missions, such as XRISM, Athena, Lynx, and AXIS will also be discussed.

Ken Shen, *UC Berkeley*

Confirmation of the D6 Type Ia supernova scenario with hypervelocity white dwarfs in Gaia DR2

The binary companion and mechanism responsible for triggering the explosion of a white dwarf (WD) as a Type Ia supernova (SN Ia) have been the subject of intense research for decades. In the "dynamically driven double-degenerate double-detonation" (D6) scenario, the binary companion is another WD that begins to undergo unstable mass transfer. The violence of this dynamical accretion leads to a helium detonation on the primary WD's surface that then triggers a carbon core detonation and subsequent SN Ia. One possible outcome of the D6 model is that the secondary WD survives the explosion and flies away from the SN Ia site with its pre-explosion orbital velocity of ¿1000 km/s. We performed a search for such hypervelocity runaway WDs in Gaia's second data release and found three very intriguing stars whose characteristics, derived from follow-up observations, match many of the predictions of the D6 model. These potential D6 survivors are the strongest evidence to date of a successful SN Ia progenitor scenario, and future work may confirm the hypothesis that the D6 model is responsible for the majority of all SNe Ia.

Nahliel Wygoda, *Yale University*

The physical width-luminosity relation(s) for type Ia supernovae favor sub-Chandrasekhar and collision models

The width-luminosity relation among type Ia supernovae (slower is brighter) [Phillips 93] is critical for using Ia's as standard candles and is one of the best studied properties of this type of events, and yet its physical basis has not been identified convincingly. The 'luminosity' is known to be related to a clear physical quantity - the amount of 56Ni synthesized, but the 'width' has not been quantitatively linked yet to a physical time scale. We demonstrate that there are two robust fundamental time scales which 1. Can be calculated using simple physical considerations based on integral quantities of the ejecta and 2. Can be inferred from observations. Two physical width-luminosity relations are obtained that can be used to test explosion models with little dependence on radiation transfer modelling. The first is the gamma-ray deposition time t0 which determines the long term evolution of the bolometric light curve and the second is the recombination time of 56Fe and 56Co from doubly ionized to singly ionized states which sets the long term color evolution of the emitted light. When compared to observations, these width-luminosity relations are found to be consistent with central core detonations and collisions of sub-Chandrasekhar mass white dwarfs (WDs) but not with delayed detonation models for explosions of Chandrasekhar mass WDs. We further explore how simulated, directional light curves, in the collisions model, differ from simple one dimensional estimates.

Melina Bersten, *Instituto de Astrofísica de La Plata*

Hydrodynamical models of core-collapse supernovae and shock breakout

Francisco Forster, *U. de Chile*

Shock breakout delay due to circumstellar material seen in most SNe II

Athira Menon, *University of Amsterdam*

The explosion of blue supergiants: SN1987A and other peculiar Type II supernovae

The most well-observed supernova of all time, SN 1987A, allows us to study two exotic phenomena: a peculiar Type-II supernova and a stellar merger that produced its blue supergiant progenitor, which was observed prior to its explosion. In this talk, I will present blue supergiant pre-supernova models for peculiar Type-II supernovae, focusing especially on SN 1987A. Our study encompasses three initial parameters- the primary mass, the secondary mass, and the most crucial one, the fraction of the He shell that is set to be dredged up from the He core during the merger. Of the 84 pre-SN models computed, 59 are blue supergiants and 6 of these match the position of the progenitor of SN 1987A in the HR diagram, its lifetime until its explosion and the composition of the triple-ring nebula. We also exploded these models with a 1D hydrodynamic, radiative-transfer explosion code to obtain their light curves and constrain the progenitor and explosion parameters for SN 1987A, SN 1998A and SN 2006V.

Eric Lentz, *University of Tennessee*

Core-collapse supernova models with Chimera

We present recent progress in multi-dimensional modeling of core-collapse supernovae using the Chimera supernova code. We focus on the growing range of initial conditions of models in 3D and 2D and on the variations in explosions, ejecta, and multi-messenger signals from neutrinos and gravitational waves.

Lars Bildsten, *UC Santa Barbara*

Type IIP supernova: inferring explosion energies and ejecta masses

Jennifer Andrews, *Steward Observatory*

Observations of a luminous asymmetric Type II SN from 1 - 400 days post-explosion

We present UV, optical, and IR data on a luminous, nearby Type IIP supernovae from hours after discovery through the first 400 days. Modeling indicates the SN was discovered within a day of explosion, and high-resolution spectra taken 6 hours after discovery show the presence of only narrow H-alpha and no other flash spectroscopy features. The high maximum and post-plateau luminosity suggests a massive progenitor, circumstellar interaction, or both. Prominent multi-peaked emission lines of H-alpha and [O I] appear in the nebular phase indicating that asymmetries may be present, and spectropolarimetry shows a rise in the polarization $\sim$30 days before the nebular phase. Late-time spectra indicates this object is also extremely calcium rich, with [Ca II]/[O I] $\sim$8. Overall the observational data suggests we have either a massive (¿ 20 Sun) RSG progenitor with non-spherical 56Ni, or a less massive progenitor surrounded by a dense disc of circumstellar material with which it is interacting.

Melissa Shahbandeh, *Florida State University*

Near-infrared spectroscopy of stripped envelope core-collapse supernovae

We present 109 near-infrared (NIR) spectra of 40 Stripped Envelope Core Collapse Supernovae (SECCSNe), also referred to as Types Ib, Ic, IIb and Ic-BL, obtained by Carnegie Supernova Project II (CSP-II). This diverse dataset constitutes the largest NIR sample of core collapse explosion of massive stars. NIR spectroscopy provides a unique probe for SN cosmology with several advantages over observations in the optical. Specifically, helium, carbon and oxygen lines are stronger in the NIR. This advantage combined with our large sample allow us to address many long-standing questions, e.g. whether SNe Ic are the explosion of C-O-Si-Fe core or similar to SNe Ib but with the difference of their helium shell not being sufficiently excited by gamma-rays to produce strong optical He lines. We find that all subclasses show a strong He I profile at 1.083 micron, which indicates significant amount of helium shells. We also find that many of our SNe show He I profile at 2.058 micron. We compare measures of line strength, equivalent width and velocity of He I lines through the entire sample. We also compare helium lines in the optical to the ones in the NIR in velocity space. We show how doppler shift of helium, carbon, oxygen can be used to probe the nature of progenitors and long gamma-ray bursts.

Ioana Boian, *Trinity College Dublin*

Predictions of early-time spectroscopic properties of core-collapse supernovae and impostors

Powerful explosions of massive stars, such as supernovae (SNe) or impostors, that interact with their progenitor's winds or circumstellar media (CSM) provide many constraints on both the explosion and the pre-explosion properties of their progenitors. Using their post-explosion spectra, progenitor mass-loss rates, wind velocities and surface abundance can be determined and thus our understanding of both the late-stages of massive star evolution and the links between supernovae and their progenitors can be significantly improved. However, early-time observations of these events and prompt spectroscopic follow-up are crucial, since many events will only show interaction for a brief period ranging from a few hours to a few days after explosion (e.g. SN 2013fs). Recent surveys, such as PTF or iPTF, have already identified a considerable number of early-time interacting supernovae and shed a light on the importance of such events. Forthcoming time domain surveys such as ZTF or LSST promise an increasing number of early-time observations of transient events, thus posing the need for theoretical advances and predictions. In our work we explore the early spectroscopic properties of interacting SN and impostors, by building an extensive library of synthetic spectra. We employ the non-LTE radiative transfer code CMFGEN and cover a wide range of progenitor mass-loss rates (5e-4 to 1e-2 $M_{\odot}$/yr), surface abundances (solar, CNO-processed, and He-rich) and SN luminosities (2e8 to 2e10 Lsun). Our results show that the spectra are mainly affected by the SN luminosity and the CSM density. Three main classes of spectra are identified based on the ionisation levels, i.e. high-ionisation (showing emission of HeII or OVI), medium-ionisation (showing CIII and/or NIII) and low-ionisation (emitting HeI, Fe II/III or NII). The abundances could be well constrained depending on the lines present in the spectra, and they can be used to link the SN to their progenitors, provided they have evolved as a single star. Our models also put a limit on the observability of these events, as progenitors with a mass-loss rate lower than 5e-4 $M_{\odot}$/yr will not show signs of interaction in their spectra. Our library is publicly available and thus can be used to fit the newly observed events in a timely fashion.

Thursday, May 23rd

JJ Eldridge, *University of Auckland*

A double look at supernovae with BPASS

Massive stars are predominantly found in binary stars with many of them in orbits close enough that they will interact and thus experience very different evolution to that expected for single stars. In the BPASS (Binary Population and Spectral Synthesis) project we have investigated many aspects of supernovae and their progenitors. Both from studying the progenitors themselves, simulating the lightcurves as well as reproducing the rates across cosmic history. We will outline our latest results, including implications from gravitational wave transients, and present the consistent picture how much of what we observe in supernova arises from the fact that most stars exist in binaries

Eva Laplace, *University of Amsterdam*

The size of stripped-envelope supernovae progenitors and its impact on gravitational waves events

Stripped-envelope and ultra-stripped envelope supernovae mark the death of massive stars that have lost their H-rich envelope and are related to exotic events such as long gamma-ray burst progenitors and to the formation of gravitational waves sources. The progenitors can result from binaries that experience one or more phases of mass transfer and lead to a variety of events, some of which are very fast and faint. New fast cadence and deep surveys are expected to dramatically increase the number of detected events in the near future. At present, theoretical predictions for their light curves based on self consistent binary evolutionary models are still very scarce. We present a new extended grid of full binary evolutionary models and the resulting light curves computed using hydrodynamic simulations (MESA and SNEC). We study their properties as a function of initial mass and metallicity. At high metallicity, we find that practically all the hydrogen is removed and low-mass systems can evolve to large sizes. At low metallicity, a substantial amount of hydrogen is left and the progenitors can in principle expand to giant sizes or fill their Roche lobe a second time. In particular, we show that the prescriptions commonly used in population synthesis models underestimate the radius by up to two orders of magnitude and that this impacts the number of gravitational waves sources from double neutron star mergers. We are planning to release a large library of theoretical light-curves of stripped-envelope supernovae in anticipation of the up-coming transient surveys such as ZTF, LSST, and Pan-STARRS.

Gaston Folatelli, *Instituto de Astrofísica de La Plata*

Progenitors of stripped-envelope supernovae

A key open question in astrophysics is how massive stars evolve before they produce a core-collapse supernova explosion. Mass-loss processes are particularly important in this respect. The kind of core-collapse supernovae that show no or very little signs of hydrogen, also known as stripped-envelope supernovae (SE SNe), can provide crucial insight on this fundamental question. I will talk about ongoing efforts that aim at characterizing the progenitors of SE-SNe either through direct detections or via modeling of light curves and spectra. With focus on the relevant cases of SNe 2011dh, iPTF13bvn, SN 2016gkg, and other events from the literature, I will summarize our current understanding of their progenitor nature and the role of binary interaction in the mass-loss process.

Ryosuke Hirai, *University of Oxford*

The appearance of companion stars after supernova in binaires

Many supernovae are known to occur in binary systems. After the explosion, the supernova ejecta can inject part of its kinetic energy into the envelope of the companion star. Most of its energy will be deposited around the surface, driving the star out of thermal equilibrium. This energy excess can bloat the star up and change its appearance for a decade or so. Here I will discuss a model to estimate this effect, derived from a large grid of 2D hydrodynamical simulations. I will also discuss possible applications to some observed supernovae (iPTF13bvn, SN2006jc) which can in turn be used to constrain its pre-supernova binary evolution.

Mariangelly Diaz-Rodriguez, *Florida State University*

Progenitor mass distribution for core-collapse supernova remnants

We infer the progenitor mass distribution for 100 core-collapse supernovae. In particular, we infer the age of stellar populations surrounding 94 supernova remnants (SNRs) in M31 and M33. From these ages, we infer the progenitor mass distribution. Assuming each progenitor evolved as a single star, we find that the minimum mass is $M_{min} = 7.33^{+0.02}_{-0.16}$ $M_{\odot}$, the slope of the progenitor distribution is $\alpha = -2.96^{+0.45}_{-0.25}$, and the maximum mass is greater than $M_{max} > 38$ $M_{\odot}$. The accuracy on the minimum mass may provide tight constraints on stellar evolution. The steep distribution suggests that the most massive stars are either not exploding with the same frequency as the stars near the minimum mass, or SNR catalogs are biased against the youngest SF regions. If there is a bias on the SNR catalogs, it will most likely only affect the slope. This bias will not affect the minimum mass or the lower limit on the maximum mass. In the future, we will infer the progenitor ages and masses for thousands of SNRs, placing unique and robust constraints on which stars explode as CCSNe.

Avishai Gilkis, *University of Cambridge*

Leftover hydrogen in stripped massive stars

Most massive stars evolve in interacting binary systems before exploding as core-collapse supernovae (CCSNe). Uncertainties in the efficiency of mass transfer by Roche-lobe overflow (RLOF) and the subsequent mass loss through stellar winds make it difficult to predict the material and angular momentum content in the system at its final stages. I will present binary stellar evolution simulations with decisively different assumptions for these key processes and discuss the implications for CCSNe, with special focus on the post-RLOF mass loss by stellar winds and supernovae of types IIb and Ib, for which little or no hydrogen is left in the stellar envelope. I will underscore the significant sensitivity of the stellar evolution models to the assumed mass-loss rates and the need to develop a better theoretical understanding of stellar winds.

Anders Jerkstrand, *Max-Planck-Institute for Astrophysics*

Nucleosynthesis yields and progenitor constraints from nebular-phase supernova spectra

I present techniques and results for inferring nucleosynthesis yields and ejecta morphologies from nebular-phase spectra. I focus on recent progress in analysis of both hydrostatic (oxygen) and explosive (stable nickel) burning in core-collapse supernovae, and what these results tell us about the supernova progenitor landscape and explosion process. I also present the first results on modeling spectral signatures of 3D simulations.

Miho Ishigaki, *Tohoku University*

Element production by supernovae across the cosmic time probed by metal-poor stars

Supernova explosions have been a dominant contributor of metals in the Universe. Thanks to recent large spectroscopic surveys of metal-poor stars in our Milky Way Galaxy, unprecedentedly large data sets of elemental abundances in the atmosphere of metal-poor, and thus likely very old, stars are now available. Statistical properties of the measured elemental abundances have put useful constraints on nucleosynthetic yields of supernovae of different generations of stars. I would like to review what we can learn from comparison between observed elemental abundances in metal-poor stars and theoretical supernova yield models, including core-collapse supernovae of the very first generation of stars and Type Ia supernovae of various progenitor metalicities. Prospects for future large spectroscopic surveys in the outskirt of the Milky Way will also be discussed.

Samaporn Tinyanont, *California Institute of Technology*

First silicate dust detection in an interacting SN 2014C

Core-collapse supernovae (CCSNe) that interact with their environment provide us insights into the nature of their progenitor and its last stage of the mass loss history. Strongly interacting SNe show strong narrow recombination lines (Type IIn) from the unshocked, dense gas in their circumstellar medium (CSM) getting ionized radiatively by the shock front. Luminous blue variables (LBVs) are a prime suspect to produce these SNe IIn because Galactic LBVs (e.g. eta Carinae) are known to have massive eruptions, producing dense CSM around them. Moreover, these LBVs are known to produce an oxygen rich CSM with abundant silicate dusts, which have strong emission features around 10 micron. Mid-infrared (mid-IR) observations of all past SNe IIn, however, show spectral energy distributions (SEDs) and spectra consistent with no silicate features. Here we present a detection of SN 2014C at 9.7 micron with Subaru/COMICS. We show, from dust model fitting to the IR SED, that the flux at 9.7 micron, along with photometry at 1-5 micron, is best described by a dust component with 50% graphite and 50% silicate. In addition, we present a 3-4 micron medium resolution spectrum of SN 2014C from Gemini/GNIRS, showing the lack of emission feature from polycyclic aromatic hydrocarbons (PAHs) at 3.3 micron, suggesting an oxygen-rich environment. We note that SN 2014C was distinct from most other SNe IIn in that it exploded as a normal hydrogen-poor SN Ib and ran into a hydrogen-rich CSM ~1 year later. We will discuss the implication of this silicate dust detection and the lack of PAHs on the possible identification of an LBV as a progenitor to SN 2014C.

Tuguldur Sukhbold, *The Ohio State University*

Missing red supergiants and carbon burning

Charlie Kilpatrick, *UC Santa Cruz*

The population of Type II supernova progenitor stars with new mid-infrared limits

Red supergiants are robustly predicted to be the progenitor stars of most Type II supernovae through supernova spectra and photometry, population synthesis, and the direct detection of over a dozen supernova progenitor stars. However, all of the red supergiant progenitors of Type II supernovae appear to have bolometric luminosities below log L = 5.2, despite the fact that Galactic red supergiants extend up to log L = 5.6. This is the so-called red supergiant problem. There remain many open questions as to whether this represents a genuine limit on the maximum mass of supernova progenitor stars, and to what extent red supergiant models, circumstellar dust, and the available data bias our interpretation of these stars. I will present new analysis of the current population of Type II supernova progenitor stars, which incorporates previously unused archival Spitzer/IRAC imaging. Spitzer/IRAC probes the mid-infrared from 3-10 microns where warm and cool circumstellar dust around supernova progenitor stars can be observed. I will discuss the implications for the current population of supernova progenitor stars and future directions for this science in the upcoming era of JWST.

Justyn Maund, *University of Sheffield*

Exploring the progenitors of Type Ibc supernovae using resolved stellar populations

Pre-explosion observations of Type IIP SNe have repeatedly shown the progenitors of these explosions to be red supergiants. Despite similar quality pre-explosion imaging being available, this success has not been replicated for the progenitors of Type Ibc SNe. Candidate progenitors have been detected in only two cases, yet analyses of these observations have been contradictory. The paucity of direct constraints on the progenitors of these SNe has a major impact on our understanding of the fates of the most massive stars with Minit ¿ 40 $M_{\odot}$; which some explosion models predict do not produce SNe at all. I will present Hubble Space Telescope observations of the sites of 23 stripped envelope SNe and new results from a dedicated UV survey of SNe locations with HST. I will show that it is possible to discriminate between high mass progenitors of these SNe, and lower mass systems in which the progenitor evolves as part of a binary - and discuss the role of migration of the progenitor from the location of its birth. Unlike spectroscopy of the host regions or normalized pixel statistic methods, in which large stellar populations are unresolved, this technique provides a direct connection between the often complex star formation histories of these regions and the properties of the exploding stars.

Ben Davis, *Liverpool John Moores University*

What red supergiants do before they die

I will review the recent work of our group in which we study the appearance and mass-loss behaviour of RSGs in the years before supernova. I will show that RSGs evolve to very red colours as the age, which almost completely explains the “RSG Problem”. However, I will also show that current estimates of how much mass is lost in the RSG phase are wildly overestimated. This suggests that RSG winds alone are unable strip the H-envelope, and implies that the single-star channel for Ibc SNe can only be viable for very massive (¿50 $M_{\odot}$) stars.

Asier Castrillo Varona, *Universidad Autónoma de Madrid*

Supernova rate statistics in nearby galaxies from integral-field spectroscopy data

Parameterize the delay-time distribution (DTD) model of the different supernova (SN) types can shed light on the timescales of chemical enrichment and the feedback processes. Here, we present an approach to recover the SN DTD base on the integral field spectroscopy technique. We reconstruct the star formation history (SFH) in every spaxel of the galaxy and compute the supernovae rate (SNR) of the different DTD models for type Ia, II and Ib/c SN. We use a statistical analysis of a sample of 116 galaxies with one registered SN event. That allows us to adjust the different parameters of the DTD models. We find the best Ia DTD fit for a power law of exponent -1.2 and a time delay of 150 My without SN events. For the type II SN, the data suggest a best fit for the late core-collapse SN DTD propose by Zapartas et al. (2017), that takes into account a binary ccSN population. For the type Ib/c SN we observed a good correlation for a Gaussian DTD model. The integral field spectroscopy opens a new way of studying the DTD models in the local universe.

Manos Zapartas, *University of Geneva*

Binary stars as progenitors of hydrogen-rich, core-collapse supernovae

As many young massive stars are found in close binaries, many core-collapse supernova progenitors are expected to experience binary interaction before exploding. Although possible binary channels are usually taken into account for stripped-envelope SNe, binarity is generally considered less when studying the properties and diversity of hydrogen-rich, type II supernovae (SNe). We employ simple analytical estimates as well as more sophisticated population synthesis simulations to quantify the expected fraction of hydrogen-rich SN progenitors with binary interaction history. In all our simulations, each for different assumptions, we find that around 1/2 to 1/3 of all type II SN progenitors experience some kind of mass exchange with a companion, including mass accretion, common envelope evolution and/or merging. Comparing with observations, we argue that the variety of the binary evolutionary scenarios may potentially help explain the diversity in the observed properties of type II SN and may account for a portion of some peculiar type II subclasses. We find that a significant fraction even of type II-P SNe (which show a plateau in their light curves), commonly linked to single star progenitors, are expected to have had mass exchange with a companion prior to explosion. We discuss the expected surrounding environments of type II progenitors and the predicted absence of close-by companions at the moment of explosion. We also study the impact of this binary history on the final pre-SN core mass distribution, putting our findings in the context of the red supergiant problem, i.e., the lack of direct observational detections of high mass progenitors of Type II SNe (e.g., Smartt et al. 2009).

Friday, May 24$^{\text{th}}$

Tea Temim, *STScI*

Progenitor and explosion properties of core-collapse supernova remnants

Connecting supernova remnants (SNRs) to their stellar progenitors and characterizing their supernova (SN) explosion properties remains a challenge. While a number of methods exist for distinguishing SNRs resulting from Type Ia from those of core-collapse explosions, ascertaining additional progenitor and explosion properties has been possible for only a handful of young SNRs, particularly those for which which light echoes have been observed. Observations of young SNRs allow us to resolve and study in detail the material expelled in the SN explosion, offering crucial information on the ejecta dynamics, composition, and mixing, as well as on the formation of dust; such information can, in turn, also provide constraints on the SN progenitor. I will review some observational studies of core-collapse SNRs that led to insights on the SNe that produced them, emphasizing recent work on SNRs that contain young pulsar wind nebulae (PWNe). These serve as powerful probes of the deepest SN ejecta layers and not only shed light on the SN progenitor properties but also on the degree of mixing in the explosion.

Salvatore Orlando, *INAF, Osservatorio Astronomico di Palermo*

Evolving core-collapse supernovae to supernova remnants through 3D MHD simulations

Massive stars end their lives with catastrophic supernova (SN) explosions. Their outcomes are the supernova remnants (SNR) whose emission encode information on the explosion processes and on the progenitor stars. Deciphering the observations, however, is hampered by the complex morphology of the remnants, which also reflects the interaction of the shock wave with the inhomogeneous ambient medium. In this talk, we will report on the recent progress in simulating the long-term evolution of SN 1987A from SN to SNR at the age of 50. The comparison between the model results and the observations allowed us to constrain the physical and geometrical properties of the asymmetric explosion responsible for the Doppler shifts in the emission lines of heavy elements observed in SN 1987A and for the asymmetries observed in the distribution of ejecta. Furthermore it has been possible to demonstrate that the SNR observations are better reproduced considering a scenario of binary merger for the evolution of the progenitor star.

Samayra Straal, *NYU Abu Dhabi*

What do pulsar wind nebulae tell us about supernovae?

The majority of core-collapse supernovae are believed to produce a neutron star.Â The rotational energy of this neutron star powers an ultra-relativistic outflow, called a pulsar wind, which is confined by the supernova remnant (SNR) produced in this explosion.Â The evolution of this pulsar wind nebula (PWN) is strongly dependent on the birth properties of its associated pulsar and the energetics of the progenitor explosion.Â As a result, one can derive these quantities by fitting the properties of a PWN with a model for its evolution. From modelling a sample of PWNe we find a surprising range of initial spin periods, supernova explosion energies and ejecta masses. I will present the initial results of this study and how they relate to our current understanding of core-collapse supernovae.

Don Warren, *RIKEN*

The (missing) link between SNe and SNRs

The study of supernova remnants (SNRs) can resolve such important mysteries as the type of the supernova (SN), the nature of the progenitor system, and possibly even the explosion mechanism that produced the SN. Historically, this work happened independently from the study of SNe. While state-of-the-art simulations of SNe are now fully 3-D, simulations of SNRs are tied to their 1-D past. Many SNR simulations that use 2 or 3 dimensions still rely on a 1-D model for the initial conditions of the ejecta, largely ignoring the work done by the SN modeling community. In this paper we report on a first attempt to bridge this gap. The output from a 3-D SN simulation was used as the input for a 3-D SNR simulation, allowing us to follow the evolution of an SN/SNR system, from ignition till well into the remnant phase, in full 3-D. We find significant departures from traditional SNR simulations that rely on a spherically symmetric initial state, due the multidimensional nature of the supernova. These differences suggest that the SN part of SNR simulations leaves an imprint hundreds of years into the SNR phase, and that we should interpret observations of SNRs with this lesson in mind.

Om Sharan Salafia, *INAF, Osservatorio Astronomico di Brera*

Punching through the diversity of gamma-ray burst jets

The properties of GRB progenitors appear to be rather standard: GRB-SNe are very similar to each other, pointing to similar progenitors; the masses of NSs in binaries seem to be distributed in a narrow range. Despite this, the luminosity distributions of both long and short GRBs span several orders of magnitude. How can this vast diversity be produced? The answer may be that GRB jets appear very different depending on the viewing angle. Following this line of thought, I present a detailed semi-analytical model of the propagation of a relativistic jet in either a static or a moving ambient medium, with a recipe to compute the jet structure (i.e. the angular distribution of kinetic energy and Lorentz factor) that develops as the jet punches through it. I then compare the long and short GRB luminosity distributions to a population of structured jets constructed using such model, assuming identical progenitors and narrow distributions of the jet properties at launch.

Kate Alexander, *Northwestern University*

New insights into engine-driven stellar explosions from GRB 161219B

Long-duration gamma-ray bursts (GRBs) are unique laboratories for studying high-energy astrophysics ranging from stellar death to relativistic jets and particle acceleration. Although they are the most energetic explosions in the Universe, many of their fundamental properties remain mysterious, including the mechanism responsible for the production and collimation of their relativistic jets. Clues to this process can be gleaned from modeling of the afterglow emission produced as the GRB jet decelerates in the ambient medium. I will present results from our multi-wavelength studies of the nearby GRB 161219B, revealing the explosion energy and jet collimation, a low circumburst density, and weakly magnetized ejecta. Our dataset includes the first ALMA light curve of a GRB afterglow and multi-frequency radio observations taken with the VLA. The first four days of VLA data exhibit sharp spectral peaks and minutes-timescale large-amplitude variability, consistent with strong scattering of the radio emission by the turbulent ionized Galactic interstellar medium. Interestingly, the scattering properties require an emission region much smaller than expected at early times, possibly indicating substructure in the jet, a slightly off-axis viewing angle, or the need for updates to the standard fireball model.

Chris Irwin, *Tel Aviv University*

The propagation of choked relativistic jets in power-law external media

Observations of both gamma-ray bursts (GRBs) and active galactic nuclei (AGNs) point to the idea that some relativistic jets are suffocated by their environment before we observe them. In these "choked" jets, all the jet's kinetic energy is transferred into a hot and narrow cocoon of near-uniform pressure. We consider the evolution of an elongated, axisymmetric cocoon formed by a choked jet as it expands into a cold power-law ambient medium $\rho \propto R^{-\alpha}$. The evolution proceeds in three stages, with two breaks in behavior: the first occurs once the outflow has doubled its initial width, and the second once it has doubled its initial height. Using the Kompaneets approximation, we derive analytical formulae for the shape of the cocoon shock, and obtain approximate expressions for the height and width of the outflow versus time in each of the three dynamical regimes. The asymptotic behavior is different for flat ($\alpha \leq 2$), intermediate ($2 < \alpha < 4$), and steep ($\alpha \geq 4$) density profiles. Comparing the analytical model to numerical simulations, we find agreement to within $\sim 15\%$ out to

45 degrees from the axis, but discrepancies of a factor of 2–3 near the equator. We discuss potential applications to GRB-SNe, emphasizing how the shape of the cocoon shock upon breakout affects the early SN light. Observational constraints on the shock geometry provide a useful diagnostic of the jet properties, even if the jet was quenched well before breakout.

Manos Chatzopoulos, *Louisiana State University*

Synthetic spectra of pair-instability supernoave in 3D

Pair-Instability Supernovae (PISNe) may signal the deaths of extremely massive stars in the local Universe or massive primordial stars after the end of the Cosmic Dark Ages. The properties of these explosions have been explored via hydrodynamics simulations done in 1D, 2D and 3D geometry that reveal the strong dependence of mixing in the PISN ejecta on dimensionality. This chemical rearrangement is mainly driven by Rayleigh-Taylor instabilities that start to grow shortly after the collapse of the carbon-oxygen core. We investigate the effects of such mixing on the spectroscopic evolution of PISNe by post-processing explosion profiles with the radiation diffusion-equilibrium code SNEC and the implicit Monte Carlo direct diffusion Monte Carlo (IMC-DDMC) radiation transport code SuperNu. The first 3D radiation transport calculation of a PISN explosion is presented yielding viewing angle-dependent synthetic spectra and lightcurves. We find that while 2D and 3D mixing does not significantly affect the lightcurves of PISNe, their spectroscopic and color evolution is impacted. Strong features of intermediate mass elements dominated by silicon, magnesium and oxygen appear at different phases and reach different intensities depending on the extent of mixing in the silicon/oxygen interface of the PISN ejecta. On the other hand, we do not find a significant dependence of PISN lightcurves and spectra on viewing angle. Our results showcase the capabilities of SuperNu to handle 3D radiation transport and highlight the importance of modeling time-series of spectra in identifying PISNe with future missions.

Conor Omand, *University of Tokyo*

Submillimetre constraints on the pulsar-driven supernova model

It has been widely argued that Type-I super-luminous supernovae (SLSNe-I) are driven by powerful central engines with a long-lasting energy injection after the core-collapse of massive progenitors. One of the popular hypotheses is that the hidden engines are fast-rotating pulsars with a magnetic field of B $\sim 10^{13} - 10^{15}$ G. Murase+ (2016) and Omand+ (2018) proposed that non-thermal pulsar wind nebula (PWN) emission could be detected in certain SLSN remnants at submillimetre wavelengths at $\sim$ 1-3 years after the explosion. We observed two SLSNe, SN2015bn and SN2016ard, in two bands with ALMA and one SLSNe, SN2017egm, in one band with NOEMA; all to a flux below the lower limit of our model. We did not detect any sources consistent with SN2015bn or SN2016ard, and while we detected emission from the host galaxy of SN2017egm, there was no significant signal from the SN remnant. I discuss the implications of these non-detections, as well as the recent detection of 6 GHz emission from PTF10hgi (Eftekhari (2019+)), on the pulsar-driven SN model.

Poster Abstracts

Iminhaji Ablimit, *Kyoto University*

Evolution of Magnetized White Dwarf Binaries to Type Ia Supernovae

With the increasing number of observed magnetic white dwarfs (WDs), the role of magnetic field of the WD in both single and binary evolutions should draw more attentions. In this study, we investigate the WD/main-sequence star binary evolution with the Modules for Experiments in Stellar Astrophysics (MESA code), by considering WDs with non-, intermediate and high magnetic field strength. We also consider normal MS stars and He stars as the WD's donor. We mainly focus on how the strong magnetic field of the WD (in a polar-like system) affects the binary evolution towards type Ia supernovae (SNe Ia). The accreted matter goes along the magnetic field lines and falls down onto polar caps, and it can be confined by the strong magnetic field of the WD, so that the enhanced isotropic pole-mass transfer rate can let the WD grow in mass even with a low mass donor with the low Roche-lobe overflow mass transfer rate. In this talk, I will show some detailed evolutions of the highly magnetized WD + MS and highly magnetized WD + He star binaries to SNe Ia. The results under the magnetic confinement model show that both initial parameter space for SNe Ia and characteristics of the donors after SNe Ia are quite distinguishable from those found in pervious SNe Ia progenitor models. The predicted natures of the donors are compatible with the non-detection of a companion in several SN remnants and nearby SNe.

Denis Leahy, *University of Calgary*

Models for Galactic supernova remnants in the VGPS survey

We apply new SNR evolution models to observations of Galactic supernova remnants (SNR) in the VGPS survey which have known distances. The models include evolution of SNR forward and reverse shocks, and yield forward and reverse shock X-ray emission measures vs. time. Application of the models to SNRs with measured X-ray spectra yields estimates of explosion energy, age and ejecta mass for a significant set of SNRs and can tell which ones likely occur inside stellar wind environments. The results are used to obtain some constraints on the Galactic SNR population.

Denis Leahy, *University of Calgary*

Constructing models for supernova remnant evolution using numerical simulations

The evolution of supernova remnants is followed using numerical simulations, with the public PLUTO code (Mignone et 2012). The full evolution from days after explosion to late in the adiabatic phase is calculated. For these calculations we consider spherically symmetric evolution and "power-law plus core" ejecta. Before the reverse shock encounters the core, the evolution agrees with the Chevalier self-similar results. For the late evolution the existence of finite ejecta mass causes significant differences from the standard Sedov solution. Analytic fits for a number of quantities of interest, including shock radii and emission measures, are derived.

Akihiro Suzuki, *National Astronomical Observatory of Japan*

Radiation hydrodynamic simulations of supernova ejecta interacting with circumstellar disks

Circum-stellar media (CSM) are believed to play important roles in various types of supernova (SN) explosions. The collision between the SN ejecta and the CSM sometimes gives rise to very bright thermal emission, which is considered to be the main power source for for specific types of SNe. Type IIn SNe are among the most important class of such interacting SNe. In the extreme case of superluminous type IIn SNe, CSMs as much as $\sim$10 solar mass are suspected to be around the progenitor star. The biggest question related to interacting SNe is when and how such massive CSM are produced. In addition, some type IIn SNe are known to exhibit unusual polarization and spectroscopic signatures indicating aspherical CSMs. Such aspherical geometry of CSMs may be a key to understanding the mechanism that massive stars shed their envelopes prior to the core-collapse explosion. Recently, I carried out some 2D radiation-hydrodynamic simulations of SN ejecta interacting with spherical and disk-like CSMs. In this presentation, I report some results of our simulations and discuss observational signatures of SNe interacting with aspherical CSMs.

Takei Yuki, *University of Tokyo*

Constructing a Light Curve Model for Interaction-Powered Supernovae Using Radiative Transfer Simulations

Type IIn Supernovae (SNe IIn) exhibit narrow hydrogen emission lines in their spectra, which indicates that the progenitor experiences extremely intense mass loss at its final stage of evolution. Thus SNe IIn occur in a dense circumstellar medium (CSM). They are much more luminous than other normal SNe because collision between the ejecta and the dense CSM can dissipate a large amount of the kinetic energy of the ejecta to thermal radiation energy through shock waves. We are trying to investigate this process by solving the internal structure of the shocked region and calculate the radiation from this region. To calculate the structure of the shocked region, we assume steady states in the rest frame of each of the shocks and numerically solve equations for the conservations of mass, momentum, energy, and simplified radiative transfer equations to satisfy boundary conditions at the contact surface. We can obtain the velocities of the shocks as the eigen values. With these velocities, we can follow the movement of the shock fronts and describe the temporal change of the structure in the shocked region. Radiation emitted from the shocked region diffuses out in the dense unshocked CSM. We also solve radiative transfer equations in the unshocked CSM with given luminosities at the forward shock as boundary conditions. We will present the results and discuss how the internal structure of the shocked region and the CSM affect the temporal evolution of the luminosity.

Leonardo Enrique García García, *Instituto de Astronomía, UNAM*

The evolution of a relativistic and collimated jet through a magnetized medium

The recently detected merger of two neutron stars produced gravitational waves and a short gamma ray burst (GW/sGRB170817). The product after the fusion was a compact object (CO) which to date is not clear whether it is a hyper-massive neutron star (HMNS), or a low mass black hole (LMBH). Since the distribution of the ambient medium and its magnetic field distribution is different in both cases, the evolution of the relativistic and collimated sGRB-jet through it would be different. Thus, the objective in this work is to follow the evolution of a relativistic jet through an ambient medium with different magnetic field distributions, via two-dimensional relativistic-magneto-hydrodynamical simulations in order to be able to differentiate between the HMNS and LMBH scenario.

Toshiki Sato, *RIKEN*

The Origin of the X-ray clumpy structures in a Type Ia supernova remnant

In this study, for the first time, the genus statistic has been applied to a famous type Ia remnant, Tycho (SN 1572) to understand the formation of the ejecta clumps by comparing with hydrodynamical models. X-ray-emitting clumpy structures are generally observed in young Type Ia supernova remnants although the origin is still obscure. There are two candidates for explaining the formation of clumps; initial clumpiness in ejecta at the explosion (i.e., clumpy ejecta model) or hydrodynamic instabilities made from smooth ejecta profile (i.e., smooth ejecta model). This information should reflect the initial ejecta structure of SNe Ia, so it is important for understanding the Type Ia explosion itself. Our preliminary investigations into constraining the structure of SN Ia remnants using Fourier and wavelet-transform analyses did not turn out to be sufficiently powerful at discriminating the two hydro models and the observed Tycho image from each other. This led us to investigate an approach that would be more sensitive to patterns in the distribution of clumps and holes in the images, such as the "genus statistic". As a result, we found the genus curve of Tycho's SNR strongly indicates a skewed non-Gaussian distribution of the ejecta clumps and is similar to the genus curve for the simulation with initially clumped ejecta. In contrast, the simulation of perfectly smooth ejecta where clumping arises from the action of hydrodynamic instabilities produced a genus curve that is similar to a random Gaussian field, but disagrees strongly with the genus curve of the observed image. Our results support a scenario in which the observed structure of SN Ia remnants arises from initial clumpiness in the explosion and demonstrate usefulness of the genus statistics for this field.

Seong Hyun Park, *Seoul National University*

Effects of the envelope structure of cool supergiant progenitors on the early-time light curves of Type IIb supernovae

Progenitors of some Type IIb supernovae (SNe IIb) like SN1993J and SN2013df have been identified as cool supergiants in the pre-SN images. Their light curves and spectra bear evidence that their progenitors have a relatively low-mass hydrogen-rich envelope. This implies that the progenitors undergo strong mass-loss via stellar winds and/or binary interactions during their pre-supernova evolution. There exist many theoretical studies on the SN IIb light curves and spectra, but the effect of the hydrogen-rich envelope structure on SNe IIb has not been fully explored yet. We systematically investigate how the early-time light curves of SNe IIb are affected by the density profiles of the hydrogen-rich envelope of cool supergiant progenitors, using the radiation-hydrodynamics code STELLA. We find that with a steeper density profile of the hydrogen-rich envelope, the post-breakout emission in the optical reaches its peak earlier, and thereafter its luminosity declines more rapidly. However, with a flat density profile predicted by recent SN IIb progenitor models where the effect of envelope inflation due to the iron opacity bump is taken into account, the post-breakout emission declines too slowly after its peak, compared to observations. This indicates that the early-time light curves of SNe IIb of SN1993J and SN2013df are not compatible with the most recent predictions of stellar evolution models. We discuss implications of our results for the nature of SN IIb progenitors.

Takashi Moriya, *National Astronomical Observatory of Japan*

Circumstellar properties of Type Ia supernovae with helium star donors

We investigate predicted circumstellar properties of Type Ia supernova progenitor systems with non-degenerate helium star donors. A system with a carbon+oxygen white dwarf and a helium star has been suggested to lead to Type Ia supernova explosions. Among all, Type Ia supernovae with short delay times are particularly dominated by this helium star donor channel. Binary evolution models predict that such progenitor system in either a stable

He-shell burning phase or a weak helium-shell flash phase at the time of the explosion. By taking the binary evolution model of Wang et al. (2009), we show that a large fraction of the progenitor systems have low enough density to explain the current non-detection of radio emission from Type Ia supernovae.

Dieter Hartmann, *Clemson University*

The Cosmic Neutrino Background

We discuss the cosmic neutrino background in the MeV regime, predominantly due to core collapse supernovae (ccSNe), and prospects for future multi-messenger observations of these events in the local volume (D ¡ 10 Mpc).

Haruo Yasuda, *Kyoto University*

Time evolution of broadband non-thermal emission from supernova remnants in different circumstellar environments

Supernova remnants (SNRs) are thought to be one of the major acceleration sites of galactic cosmic rays (CRs) and an important class of objects for high-energy astrophysics. SNRs produce multi-wavelength, non- thermal emission via accelerated particles at collisionless shocks generated by the interactions between the SN ejecta and the circumstellar medium (CSM). Although it is expected that the rich diversities observed in supernovae (SNe) and their CSM can result in distinct very-high-energy (VHE) electromagnetic signals in the SNR phase, there are only a handful of SNRs observed in both GeV and TeV γ-rays so far. A systematic understanding of particle acceleration at SNRs in different ambient environments is therefore limited. Here, we explore non-thermal emission from SNRs in various circumstellar environments up to 5000 yrs from explosion using hydrodynamical simulations coupled with efficient particle acceleration. We find that time-evolution of emission characteristics in the VHE regime is mainly dictated by two factors; the number density of the target particles and the amplified magnetic field in the shocked medium.

Taiki Morinaga, *Waseda University*

Collective neutrino flavor conversion vs. collisional decoherence under axisymmetric supernova models with full Boltzmann transport

In dense neutrino environments around proto-neutron stars, neutrino flavor conversions are induced by the self-interactions of neutrinos when electron lepton number angular distributions cross the zero. In contrast, the collision terms in the kinetic equations for neutrinos suppress the neutrino oscillations. In this study, we compare the timescales of these effects in the supernova models obtained by the full Boltzmann transport simulations and show each of them can be treated independently in supernova simulations since their timescales are greatly separated.

Fernando Rivas, *University of Tennessee*

Multi-dimensional vast network SNIa double detonations

Type Ia supernovae stem from thermonuclear disruption of carbon-oxygen white dwarfs (WD). Though there are several possible progenitor scenarios, one of the mechanisms of explosion that has regained a measure of attention is the sub-Chandrasekhar mass Scenario (subCh): a sub-Chandrasekhar mass carbon-oxygen core accretes helium from a binary companion until helium burning temperatures are reached, this in turn causes a dynamical process of thermonuclear runaway in the helium shell, causing the shocked core to begin carbon burning and unbind the system. Given the dynamical characteristics of the scenario, high-dimensional models must be used. Further, energy release due to helium burning in the system can make or break the second ignition in the core, requiring the interaction of a reaction network with the dynamical detonation shock over the core. To this end, we perform multi dimensional hydrodynamic simulations of detonating helium layers over carbon-oxygen white dwarfs run concurrently with a vast (over 200 species) reaction network.

Akira Harada, *University of Tokyo*

Neutrino Distributions for a Rotating Core-collapse Supernova with a Boltzmann-neutrino-transport

With the Boltzmann-radiation-hydrodynamics code, which we have developed to solve numerically the Boltzmann equations for neutrino transfer, the Newtonian hydrodynamics equations, and the Newtonian self-gravity simultaneously and consistently, we simulate the collapse of a rotating core of the progenitor with a zero-age-main-sequence mass of 11.2 solar mass and a shellular rotation of 1 rad/s at the center. We pay particular attention in this talk to the neutrino distribution in phase space, which is affected by the rotation. By solving the Boltzmann equations directly, we can assess the rotation-induced distortion of the angular distribution in momentum space, which gives rise to the rotational component of the neutrino flux. We compare the Eddington tensors calculated both from the raw data and from the M1-closure approximation. We demonstrate that the Eddington tensor is determined by complicated interplays of the fluid velocity and the neutrino interactions and that the M1-closure, which assumes that the Eddington factor is determined by the flux factor, fails to fully capture this aspect, especially in the vicinity of the shock. We find that the error in the Eddington factor reaches $\sim$20% in our simulation. This is due not to the resolution but to the different dependence of the Eddington and flux factors on the angular profile of the neutrino distribution function, and hence modification to the closure relation is needed.

Christopher Kolb, *NC State University*

Evolution of Type IIb supernovae in the binary circumstellar medium

The presence of slow, dense stellar wind in binary systems can produce a highly asymmetric circumstellar medium (CSM), particularly for systems with a mass outflow velocity comparable to the binary's orbital velocity. Mass loss in such a system is significantly enhanced in the equatorial plane, with a resulting polar-to-equatorial density contrast of 10 to ∼300. We aim to better understand this asymmetric CSM in the context of supernovae IIb progenitors and to study the impact on supernova morphology and resulting observational signatures. We model the asymmetric wind and subsequent supernova explosion with full 3D hydrodynamics using the shock-capturing hydro code VH-1 on a spherical yin-yang grid. We investigate a range of CSM parameters including companion-to-primary mass ratios spanning 1.0-2.5, asymptotic wind speeds between 15-25 km/s, and orbital-to-wind velocity ratios ranging 1.0-2.0. For each, the resulting CSM is used to evolve a blastwave out to a few tens of years. In some cases the blastwave remains quite asymmetric with a polar-to-equatorial radius ratio ¿2.5. We discuss this morphology and the observational implications of the resulting data, with a focus on radio brightness from a few weeks to months.

Chinami Kato, *Waseda University*

Effects of nucleon recoils for neutrino spectra in core-collapse supernovae

One of the most favorable mechanisms for supernova explosions is a "neutrino heating mechanism". In this scenario, neutrinos emitted from PNS surface give energy to the stalled shock wave and help the explosion. Then, neutrino spectra behind the shock wave is critical for the explosion. Although it is known that nucleon recoils in neutrino-nucleon scatterings are one of the important factors for making neutrino spectra, it is difficult to take them into numerical simulations due to their small energy exchange. In our study, we investigate the effects of nucleon recoils for neutrino spectra using new neutrino transport code with Monte Carlo methods and suggest the way to incorporate them in the dynamical SN simulations.

Abigail Polin, *UV Berkeley*

Do sub-Chandrasekhar mass white dwarf explosions occur in nature?

Carbon-oxygen WDs accreting a helium shell have the potential to explode in the sub-Chandrasekhar mass regime through the double detonation scenario, when a helium shell ignition propagates a shock wave into the the core of the WD causing a central ignition. I will present the results of a recent numerical parameter survey of hydrodynamic and radiative transport models of sub-Chandrasekhar mass white dwarf explosions. I examine a relationship between SiII velocity and luminosity which, for the first time, identify a subclass of observed supernovae that are consistent with these models. I will also discuss the distinct observational signatures of sub-Chandrasekhar mass WD explosions predicted for early time, peak and nebular observations. I will also discuss the discovery of the peculiar Type I supernova, SN2018byg: the first observed sub-Chandrasekhar mass mass white dwarf explosion triggered by the ignition of a massive helium shell.

Michael Sandoval, *University of Tennessee*

Extending core-collapse supernova simulations: from the onset of explosion to shock breakout

As well as contributing to star formation, core-collapse supernovae (CCSNe) are the richest astrophysical producers of heavy elements. As the explosion progresses, the evolution of the nuclear species synthesized in the early-time of the explosion is strongly coupled with the hydrodynamics. Hydrodynamic instabilities, specifically Rayleigh-Taylor instabilities, affect the distribution of material most strongly. Our aim is to understand how the instabilities in the central engine drive inhomogeneities in the ejecta, leading to the observed elemental distribution. To achieve this understanding, and to accurately replicate the observed asymmetries, multi-dimensional simulations of the supernova explosion must be carried beyond the initial seconds where the central engine operates and the nucleosynthesis occurs. We have therefore performed simulations with the FLASH code that follow the progression of the explosion throughout the entire star, starting from neutrino-radiation hydrodynamic simulations of the first seconds performed with the CHIMERA code. At present, we have performed two-dimensional and three-dimensional FLASH simulations starting from two-dimensional CHIMERA models of a 9.6 $M_\odot$ zero-metallicity progenitor, and a 10 $M_\odot$ solar metallicity progenitor, all simulated until shock-breakout while tracking the 160 nuclear species evolved in the CHIMERA models. We are presently exploring differences that result when three-dimensional CHIMERA models are used as the initial conditions.

Chloe Keeling-Sandoval, *University of Tennessee*

The effects of stellar collapse on subsequent supernovae

Using both Modules for Experiments in Stellar Astrophysics (MESA) and CHIMERA, a multi-dimensional neutrino-radiation hydrodynamics code, we studied the effects of stellar evolution and collapse on the subsequent supernovae. MESA was used to create 3 different one-dimensional 20 $M_\odot$ progenitors each ending at different epochs of stellar collapse. The 1D progenitors were mapped into two dimensions and simulated using CHIMERA.

Saku Iwata, *University of Tokyo*

The diversity of young neutron stars determined by fallback accretion onto and energy deposition from the central object in supernova

In core-collapse supernovae, a fraction of ejecta generally falls back onto a newborn compact object. While the compact object can deposit energy into the fallback matter via magnetic dipole radiation if rapidly rotating neutrton star is formed as a central object. If spherically symmetric and power-law energy deposition rate are assumed, the repulsive flow of the fallback matter can be described by self-similar solutions(Shigeyama & Kashiyama 2018). The self-similar solutions have the critical accretion rate above which there is no solution when the adiabatic index is equal to or less than 4/3. The results also indicate that some solutions may be subject to the Rayleigh-Taylor instability. Thus we have performed two dimensional relativistic hydrodynamics simulations to investigate these effects. In this paper, we compare these spherically symmetric self-similar solutions and results of 2D relativistic hydrodynamics simulations for the corresponding flows to investigate effects of the Rayleigh-Taylor instability. We find the critical accretion rates derived from 2D simulations are much smaller than in spherical symmetry. Finally, combining a condition of whether fallback matter bury the surface magnetic field into the crust, we discuss the impact of these effects on the diversity of young neutron stars.

Kazimierz Borkowski, *NC State University*

Infrared light echos of core-collapse supernovae in close binaries

The ambient circumstellar medium (CSM) around core-collapse supernova (SN) progenitors in close binaries is expected to be asymmetric as revealed by our 3D hydrodynamical simulations (see presentation by C. Kolb at this conference). A fraction of the SN radiation is absorbed by dust that is present in this CSM, with the absorbed radiation reradiated as an infrared (IR) light echo. We model light curves and spectra of IR light echos produced by asymmetric CSM density distributions predicted by our 3D simulations. We discuss prospects for detection of the asymmetric CSM around Type II SNe in binaries with Spitzer and JWST.

Dean Townsley, *University of Alabama*

Making normal Type Ia supernovae with double detonations

The double detonation scenario in which a white dwarf (WD) is incinerated by a sequence of detonations, first in the surface helium shell and successively in the carbon-rich interior, has emerged as a promising sub-Chandrasekhar mass scenario for Type Ia Supernovae (SNe Ia). Previous work on this scenario has shown that a helium shell that is too thick will produce spectral peculiarities that are not seen in SNe Ia. I will discuss two dimensional simulations targeted at determining the characteristics of the He shell, such as mass and enrichment, that are required for an explosion to produce a spectroscopically normal SNe Ia. The results of this comparison will inform future work on dynamic ignition of helium detonations by determining the range of characteristics of the helium shell that must ignite. I will also explore how aspects of SN Ia spectroscopic diversity might be understood within the double detonation scenario.

Noah Wolfe, *NC State University*

Characterizing gravitational wave signals from core-collapse supernovae

Core-collapse supernovae (CCSNe) are the explosive deaths of massive stars, and multi-messenger events which produce signals including gravitational waves, neutrinos, isotope abundances, and light in a multitude of wavelengths. With the next-generation of gravitational wave telescopes (Advanced LIGO/VIRGO), it may soon become possible to detect gravitational waves originating from CCSNe. Here, we compute the gravitational wave eigenfrequencies for a set of CCSNe models based on the PUSH method. The models span a range of progenitor zero-age main sequence masses and two different nuclear equations of state (DD2 and SFHo). We will discuss the influence of the progenitor compactness and the equation of state on the gravitational wave signal, as part of a comprehensive set of multi-messenger predictions from our 1-D models.

Sam Flynn, *NC State University*

Detectability of Non-Standard Interactions in Supernovae Neutrino Signals

In addition to being an immense source of light, supernovae are prolific sources of neutrinos. Given the copius neutrino flux from a core-collapse supernova, they are an ideal laboratory for probing the properties of neutrinos. It has been shown that if neutrinos are allowed to undergo non-standard interactions (NSI), with couplings to the quarks and electrons beyond the standard model of particle physics, they experience new oscillation effects. In order to be able to perform neutrino astronomy for supernovae, it is critical that we understand how these new effects alter the signal seen in Earth based neutrino detectors. In particular, we examine whether supernova neutrinos can help place new bounds on the non-standard interactions. In this poster, I will show how I have expanded on previous calculations to a multi-energy neutrino spectrum and a more realistic supernova profile. The neutrinos are evolved all the way to Earth, and then the flux is turned into a detector signal with the SNoWGLoBES code. I will give a review of the effects of non-standard interactions in single energy calculations, and then show that these effects are preserved in a multi-energy scenario. Additionally, I will show that the NSI induced effects lead to differences in the anti-neutrino fluxes at Earth which differ from the no NSI case in a detectable way.

Yukari Ohtani, *National Astronomical Observatory of Japan*

Nebular emission line of core-collapse supernova exploded by neutrino heating mechanism

The emission lines shown in the nebular phase of a supernova are known as the probe of the morphology of the ejected matter, which reflects the explosion mechanism. The recent observations indicate that several tens of percent supernovae have double-peaked emission lines instead of single-peaked lines (e.g., Taubenberger et al. 2009). The theoretical studies implied such features can be produced by asymmetric distributions of the ejected matter (e.g., Maeda et al.2008). However, in the previous studies, the evolution of fluid dynamics have been traced with artificially injected energy. In this study, we calculate the shapes of the emission lines of striped core-collapse supernovae to investigate the relations of the distribution of ejecta. The hydrodynamics are calculated by using the 3DnSEP code (developed by Takiwaki et al.), and the initial conditions are the profiles of Nakamura et al. (2015) model in which the neutrino transport is solved. We derive the shape of the emission line assuming that the relative strength of the line is simply proportional to the density and mass fraction of each element. The wavelength is determined by considering the radial velocity of the matter. In this presentation, I will show the resultant spectra.

Luke Shingles, *Queen's University Belfast*

Late-phase radiative transfer of Type Ia supernovae

Type Ia supernovae are well-studied objects, largely because of their usefulness as precise distance indicators for cosmology and their role in the production of Fe-peak elements for chemical evolution. However, while Type Ia supernovae almost certainly involve the thermonuclear explosion and unbinding of a carbon-oxygen white dwarf, understanding the possible role of a binary companion and the mechanism of explosion remain open problems in supernova research. Multi-band observations including radio and X-ray have placed deep upper limits on the density of the surrounding medium and disfavour most scenarios involving a non-degenerate companion. Several other scenarios remain, and thanks to theoretical developments in the last decade, we now have a variety of 3D hydrodynamic explosion models available. These can can be tested with nucleosynthesis and radiative transfer simulations to compare to observational light curves and spectra. We present recent work to improve the physics of the ARTIS radiation transport code to extend its validity to late times (¿100 days in the nebular phase) for application to existing 3D explosion models. The code developments are initially tested with 1D models, including the well-known W7 fast-deflagration model, and then applied to sub-Chandrasekhar mass detonation models that account for the effect of gravitational settling in the progenitor white dwarf. We also outline the next step to three-dimensional radiative transfer simulations of 3D hydrodynamic explosion models.

Yongje Jeong, *Seoul National University*

The role of dense circumstellar medium in type IIb supernova light curves and implications for the progenitor of SN1993J

Progenitors of type IIb supernovae, which behave like type II supernovae in their early phase and evolve to type Ib-like phase, are believed to be supergiant stars retaining a small amount of the hydrogen envelope (M_{env} ~0.01–0.5 $M_\odot$). In previous observational and theoretical studies, the progenitor of SN1993J had been suggested as a red supergiant. However, we find that supernova light curve simulations using the most recent red supergiant progenitor models and the multi-group radiation hydrodynamics code STELLA fail to predict early time features of SN 1993J. Instead, supernova models using a compact progenitor, whose stellar radius is less than 20 $R_\odot$, with a dense wind-driven circumstellar matter about 0.1 $M_\odot$ can reproduce early time light curve properties like strong U-band magnitude and stiff luminosity drop after post-shock peak. Our result gives new insights into type IIb progenitors and their mass loss history.

Roberto Iaconi, *Kyoto University*

Speaking with one voice: simulations and observations discuss the common envelope alpha parameter

Common envelope (CE) is the primary physical mechanism that, from large orbital separation binary stars, produces close binaries. As such is the formation channel for a variety of close binary objects and phenomena, such as Type Ia SN, low- and high-mass X-ray binaries, double neutron star, double black holes and mergers producing detectable gravitational waves. In the last few years great progress has been done in understanding this complex phenomenon, yet many aspects of the CE interaction remain to be investigated. In this work we focused on the evolution of the CE ejecta after the binary separation has already decreased and all the stellar envelope has been ejected from the potential well of the system. We show that as there is no more injection of energy in the CE once the orbital separation of the binary levels up, the expanding debris' dynamic slowly transitions from chaotic to an homologous expanding distribution. Approximating such expansion to the analytical, kinematic homologous model may open the doors for the computation of the light emitted by the CE ejecta in the late phases of the expansion.

Harim Jin, *Seoul National University*

Light curve and color evolution models with circumstellar medium for the Type Ic supernova LSQ14efd

A bright post-breakout emission was detected for a Type Ic supernova (SN Ic) LSQ14efd, which was among the first for SNe Ic. To explain the early-time light curve and color evolution, the effects of the circumstellar medium (CSM) are investigated. Four main parameters, CSM mass, CSM radius, nickel distribution, and explosion energy, are systematically explored in multi-group radiation hydrodynamics simulations. Matching the model light curves and color evolution with the observation, we could constrain the parameter space and find out the best fit models. Our results imply that the progenitor suffered a strong mass loss of $\sim$0.1 $M_\odot$ shortly before the explosion (i.e., $\sim$ 1 yr).

Benjamin Wehmeyer, *Konkoly Observatory, Budapest & Univ of Hertfordshire*

Influence of key SN properties on Galactic Chemical Evolution

Galactic chemical evolution (GCE) is a great tool to probe the influence of various astrophysical sites on the observed abundances of stars. We use the high resolution ((20 pc)^3 /cell) inhomogeneous GCE tool 'ICE' to estimate the impact of two key supernova (SN) properties on observed stellar abundances: Firstly, we will show that supernova yields need to be metallicity dependent in order to explain the observed alpha element abundances. Secondly, we show that SN explosion energies have a significant impact on the mixing of the interstellar medium. We further use pedicted SN explosion energies to constrain under which circumstances SNe 'fail', i.e., collapse to a black hole instead of leaving behind a neutron star. We then use these predictions to estimate if black hole – neutron star mergers might be a second, earlier acting rapid neutron capture (r-) process production site. Lastly, we speculate whether a rare sub class of supernovae (magnetorotationally driven supernovae) can act as an additional and earlier r-process site and conclude that our simulations with an adequate combination of these two sites successfully reproduce the observed r-process elemental abundances in the Galactic halo.

Ken'ichi Sugiura, *Waseda University*

Linear Analysis of Shock Instability in Core-collapse Supernova

We investigated the possible influences of the inner boundary conditions on the linear stability of the standing accretion shock in core-collapse supernovae (CCSNe). More specifically, we imposed a time-dependent, oscillating condition at the inner boundary, having in mind the injection of acoustic power by an oscillating proto-neutron star. We also considered possible correlations between the inner and outer boundary conditions as invoked in the argument for Lepton-number Emission Self-sustained Asymmetry (LESA). We conduct the linear stability analysis based on Laplace transform. We found that the acoustic power enhances the standing accretion shock instability (SASI), especially when the luminosity is low. On the other hand, the correlation between the fluctuations of neutrino luminosity at the neutrino sphere has little influences on the instability, changing the amplitudes of eigenmodes only slightly. We further investigated steady solution of perturbation equations, being motivated by LESA, and concluded that not the difference but the sum of the fluxes of electron-type neutrinos and anti-neutrino is the key ingredient to production of the self-sustained steady perturbed configuration.

Payel Mukhopadhyay, *Stanford University*

Neutrino-Driven winds and breezes in CC-Supernova- a fresh look

We study the presence of winds and breezes in core-collapse supernovae. We study the basic physics and map the parameter space of transition from winds to breezes in supernova explosions.