Summary of the Thermonuclear Explosions Working Group

Michael Zingale and Daniel Bardayan

1 Type Ia supernovae

1.1 Recent Accomplishments

Over the past decade a large number of supernovae have been observed. We have detailed spectra and lightcurves of many events. These observations have shown that there is a lot of diversity in events, and looking at the properties of Ias with host galaxy have led to the argument that there may be distinct populations or multiple progenitor mechanisms at work. Finally, some observations suggest that explosions involving progenitors of more than a Chandrasekhar mass were involved.

Of the three main progenitor models for Ias (the single-degenerate Chandrasekhar mass model, merging white dwarfs, and the sub-Chandra model), the Chandrasekhar mass model has seen the most attention in the past decade. Models of the explosion have shown that to produce a realistic-looking explosion, a deflagration-to-detonation transition is needed. The precise mechanism for this transition is not understood, although models that put in an ad hoc transition once a critical density threshold is reached can be tuned to match observations well. Alternate models include the breakout of a bubble to the surface, driving waves to the opposite pole where a detonation may be ignited. Progress was made in studying the onset of the explosion by modeling the final hours of convection, and suggests that off-center ignition may be realized. Advanced nucleosynthesis is currently modeled in these events through particle post-processing. Radiative transfer has evolved to the point of being able to produce realistic spectra and light curves of these models, making comparisons with observations feasible. Some work has argued that hints of the progenitor model is encoded in the light curve.

Models of merging white dwarfs have seen renewed interest, owing to the increasing diversity shown by observations. In special cases (equal masses or head-on collisions), models show that explosions can be realized. For the general case of unequal mass white dwarfs merging, the simulations are not yet to the point of producing explosions (if possible).

Finally, the sub-Chandra model (and .Ia) have seen a lot of recent activity. These may explain some low luminosity events and much effort has been done on exploring just how much He is needed to initiate the detonation while not overproducing heavy nuclei at the surface.

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1.2 Observational Needs

The biggest observational need is to provide constraints on the progenitor. This is difficult due to the rarity of these events. New telescopes will open windows in the IR. This is interesting because SN Ia are more similar in the IR and distinct lines can be seen here. More observations of polarization can help distinguish between models (for example, mergers may be expected to have high polarization). It is also possible that isotopic information can be obtained from these observations.

New surveys (like PTF and soon LSST) will find a large number of transients. Are these new objects or extreme examples of our existing models? Detailed observations on these new transients will be needed.

Finally, new telescopes will allow for extensive and complete datasets for individual SN—these are needed to constrain models.

1.3 Theory Needs

Chandrasekhar mass single degenerate models are mature, to the point that vast parameter studies building up a library of models are possible. This work should continue with improved nuclear rates. Binary white dwarf mergers have seen less attention, although several groups are working on them. The primary issue in those models is whether the merger can proceed in a fashion so to avoid an accretion-induced collapse to a neutron star. This needs more attention through multi-dimensional simulation. As different methods have different strengths, a variety should be used to understand the sensitivity of the merger outcome to modeling. Also, improved models of sub-Chandra events can help us understand whether these are realized in nature.

1.4 Nuclear Experiment Needs

Rates identified with the greatest uncertainties are $^{12}C(\alpha,\gamma)^{16}O$, $^{12}C+^{12}C$, and $^{12}C+^{16}O$. Improved rates for charged-particle rates on ^{48}Ca are also needed—this can be a possible discriminator of progenitor models. Finally, while much progress has been made over the past decade in measuring weak interactions, the steps of converting this experimental data into the products that can be used by modelers is incomplete. Updated weak rates for modelers would allow for much better models, and would help to elucidate ^{56}Ni production in the various models. Gamow-Teller strengths of FP-shell nuclei are an important ingredient to such rate estimates, and experimental measurements of these using (p,n) reactions on exotic nuclei are needed.

2 Novae

2.1 Recent Accomplishments

Models of novae have been advancing over the last decade. One-dimensional models can produce explosions, but the inputs necessary (in particular, enrichment of the H envelope) do not match observations. Multi-dimensional models have focused on the role of convection in producing the necessary enrichment, and have shown some success. Recent radio observations show multiple mass loss episodes in novae, perhaps indicating multiple outbursts. There is also some very recent evidence of gamma-ray photons associated with nova. Experimentally, the first direct measurements of proton capture on radioactive nuclei of interest to novae have been made in the past decade, but significant work is still needed.

2.2 Observational Needs

Key questions that can be answered by (difficult) observations include: Are WDs that exhibit nova growing in mass? Gamma-ray photons associate with nova need explanation. We need precise WD masses in nova systems—none thus far have Keplerian masses. Perhaps IR observation will help here. We also need isotopic abundances. More sensitive gamma-ray telescopes would allow for detections of ^{18}F and ^{22}Na, and diffuse ^{26}Al.

2.3 Theory Needs

When does mixing occur in the event (early during accretion, late stages?) and how can we shut down the mixing. Convective undershoot is a likely candidate, but more modeling work is needed. Understanding mixing is a key question, and requires multidimensional modeling. Most modeling has focused on the runaway itself, but what about the interaction of the blast wave with the

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companion or the accretion itself. These need to be explored. Refined multidimensional models may be key to understanding the dynamics of the mixing, but algorithms can have trouble right at the H envelope boundary since numerical mixing may artificially enhance the burning. Algorithmic sensitivity studies are needed to understand what is real and what is unphysical. Also, the effects of magnetic fields on the explosion process have not been explored in any depth. Sensitivity studies of the explosion energetic to new rates (and their uncertainties) is needed, as well as sensitivity studies of the hydrodynamic models themselves. Current models do not predict the correct ejecta mass—what are we missing in OUR understanding. Parameter studies exploring the sensitivity to reaction rates are needed.

2.4 Nuclear Experiment Needs

A nice feature of nova is that the temperature in the runaway occurs in regimes where cross-sections can be measured in the lab. Improved experimental measurements of the bottleneck and hot-CNO breakout rates are needed to make more precise measurements. Additionally, improved experimental measurements of radionuclide production would help interpret the ejecta. Key reactions include ^{18}F$(p,\alpha)^{15}$O, ^{25}Al$(p,\gamma)^{26}$Si, AND ^{30}P$(p,\gamma)^{31}$S. Measurements at the Facility for Rare Isotope Beams should be able to determine the majority of the nuclear reaction rates needed to understand nova nucleosynthesis.

3 X-ray bursts

3.1 Recent Accomplishments

Over the last decade, we've realized that there is a large variety in bursts: long and short bursts, intermediate (deep He) long bursts, and superbursts. A wealth of observational data has been produced and new catalogs (like MINBAR) allow for detailed exploration of these observations. One-dimensional models can reliably produce bursts with the recurrence times and energetic observed. These models can include a large number of nuclei and give detailed information about the nucleosynthesis. Photosphere expansion bursts have been recognized as potential sources with which radii can be measured. Multi-dimensional models of the propagation of and expansion of parameterized burning across the surface showed the importance of rotation in localization.

3.2 Observational Needs

There are a large variety of bursts, and we need to study this variety in more detail. In particular, we need to observe the precursor bursts of superbursts. We need a greater catalog of burst observations such that detailed comparisons and classifications can occur. Further observations could also elucidate whether enriched material is ejected. An observations of lines during these events would greatly help with interpretations.

3.3 Theory Needs

In remains unsolved how enough C can be produced in a year to ignite a superburst. Perhaps a different explosion mechanism is required? What are the double peaked bursts—is it simply nuclear waiting points or more complex dynamics? What is the ash composition after multiple bursts? and can he bring any of these ashes up to the photosphere? Ignition is likely localized (burst oscillations support this), but thus far, models have not explained the ignition mechanism—this is a multi-dimensional problem that needs more attention. These models could also potentially explain how

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the burning front propagates through the envelope. Finally, little work on MHD in models has been done to date—this should be explored.

3.4 Nuclear Experiment Needs

Basic nuclear data is required as many of the nuclei involved in rp-process burning have scarcely been studied in the laboratory. Masses and halflives are needed, and there is a real possibility that this can be realized during the next decade. Pinning down the rates of proton and helium induced reactions is also important especially near waiting points and bottlenecks. A significant reduction in the nuclear physics uncertainties would leave the hydrodynamical and astrophysical environments as the key uncertainties. This could allow for the production of a set of model templates to match to observations.

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