Death of Massive Stars: Supernovae and Gamma-Ray Bursts
Proceedings IAU Symposium No. 279, 2012
P. Roming, N. Kawai & E. Pian, eds.

doi:10.1017/S1743921312013117

Concluding Remarks

Elena Pian[1], Nobuyuki Kawai[2], and Peter W. A. Roming[3]

[1]Scuola Normale Superiore di Pisa, Piazza dei Cavalieri 7, I-56126 Pisa, Italy
email: elena.pian@sns.it

[2]Department of Physics, Tokyo Institute of Technology, 2-12-1 Ookayama,
Meguro-ku, Tokyo 152-8551, Japan

[3]Southwest Research Institute, Space Science & Engineering Division,
PO Drawer 28510, San Antonio, TX 78228-0510, USA

Abstract. At the end of IAU Symposium 279, Shri Kulkarni delivered the concluding remarks. This paper presents a summary of his comments as interpreted by the Chairs of the Science Organizing Committee.

Keywords. supernovae: general, gamma rays: bursts

This symposium confirmed the existing general consensus that stellar deaths do not represent an incomplete chapter, but rather an unfinished book. Not only are we not clear about stellar paths that lead to certain classes of progenitors, but the ingredients that take part in this evolution - such as mass loss, angular momentum, magnetic fields - are also obscure, debated and controversial. The core-collapse progenitor "spectrum" defines a nice sequence that goes from red/blue supergiants and Wolf-Rayet stars, all presumably ending their lives as neutron stars (NS); to Type IIn SNe and massive stripped stars, probably producing black holes (BH); to the most luminous known explosions, super-luminous supernovae, likely proceeding from massive stars with large radii; and finally pair-instability supernovae, thermonuclear explosions originating from the most massive stars in the Universe (more than $100\,M_\odot$). While the boundary between white dwarfs and neutron stars is rather well determined, the gap between neutron stars and black holes is still debated, and may hide a variety of compact objects - described by a range of equations of state - that may account for the diversity we see in the electromagnetic display of stripped envelope supernovae (SNe) and gamma-ray bursts (GRBs).

During this conference, we saw the clear emergence of numerous questions and controversies such as:

- What (rare) type of massive stars end their lives as GRBs?
- What is the mass spectrum of Population III stars ($40\,M_\odot$ versus $400\,M_\odot$)
- What factors produce NS versus BH?
- What factors genreate NS versus magnetars?
- Are stellar collisions important for certain outcomes?
- Are there some long GRBs without SNe?
- Is there a fundamental difference between GRB 980425 - the close-by (35 Mpc) prototype of GRB-SN association - and classical GRBs, i.e. those at "cosmological" redshifts?

In parallel, other questions and puzzles were raised with answers that are very likely to be complex in nature:

- What factors determine mass loss rates?

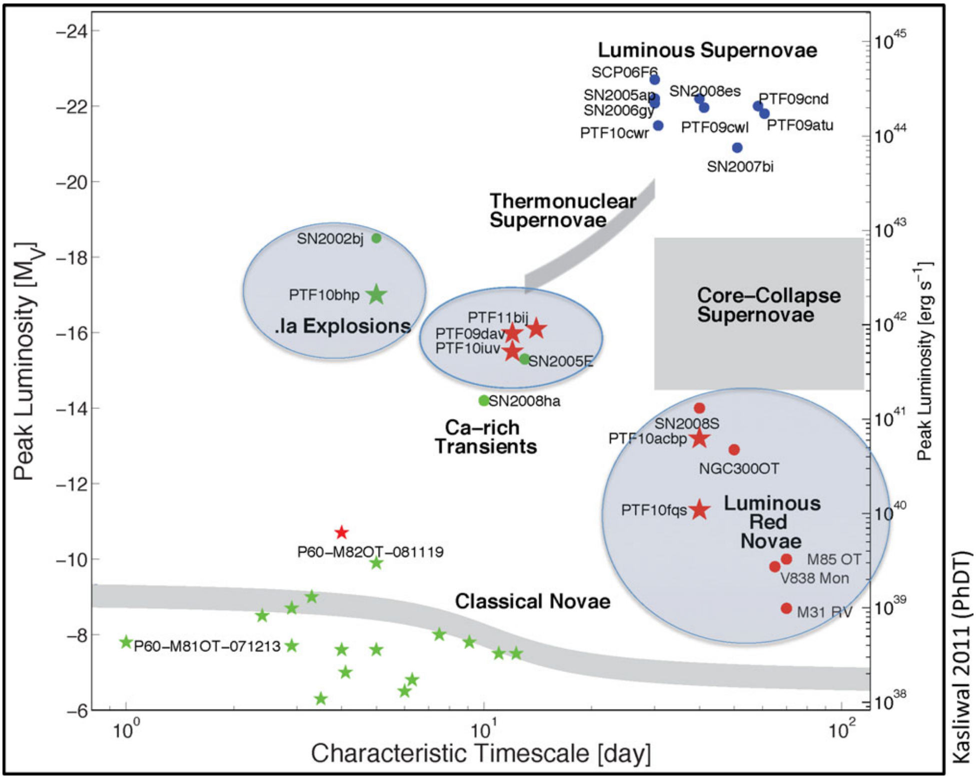

Figure 1. The transient zoo from Kasliwal (2011). Reprinted with permission.

- How does the environment shape the IMF?
- What is the role of metallicity?
- What determines the retaining (or radiating) of angular momentum?
- Do (slowly rotating) BH outcomes produce detectable SNe?
- The explosion mechanism(s) issue for core-collapse SNe is rapidly escaping a general approach, because numerous peculiarities arise. The behavior of SN 2010jp was a case in point. Are there many cases which require bipolar explosion mechanism?
- The "Christmas burst", GRB 101225A, characterized by an early prominent thermal component and possibly related to the explosion of a helium star in a binary system, is a clear reminder that we are wandering in a heterogeneous zoo, still without solid diagnostic tools at hand to recognize and interpret diversity and variety (see Figure 1).
- How is energy carried in long GRBs?
- Are relativistic jets Poynting dominated?
- What determines the jet opening angles?
- Are ultra-high energy cosmic rays produced by stellar deaths?
- What re-ionized the early Universe?

Recently, the importance of the standing accretion shock instability (SASI) has been recognized as a fundamental ingredient (although probably not necessary, but certainly sufficient) to create asymmetry in the explosion. This was nicely simplified and represented during the conference in a shallow water analogue that explains the basic properties of the phenomenon by keeping it close to our "everyday life" experience and common sense.

Zooming out from explosion sites, we saw many attempts at investigating stellar deaths through the analysis of their environments: star forming regions and host galaxies. Cumulative distributions of light in galaxies provide hints toward identifying similarities and differences in GRB and SNe progenitors, and clearly GRB hosts are akin to those of Type Ic SNe, the most stripped type of core-collapse supernova, i.e. associated with the death of a massive star core that has lost both its hydrogen and helium envelopes. While this is not completely unexpected (because whenever a supernova is identified in association with a GRB or XRF, this is usually of Type Ic), it suggests that Type Ic SNe may be the true parent population of long GRBs. A number of them are likely the most energetic and perhaps more will be identified that are able to produce "engines", i.e. jets. How we can distinguish the signature of these engines (which are expected to have non-thermal spectra, but may occasionally have a thermal component leading to a cocoon) from that of shock breakout emission (the classical blast wave following collapse stalling and rebouncing) is one of the current challenges of exploration in this field.

A frontier of the observational approach is represented by polarimetry at high energies (the detection of gamma-ray polarimetry in GRB 100826A by the Japanese experiment IKAROS/GAP is pioneering in this sense) and non-electromagnetic messengers (neutrinos, cosmic rays, gravitational waves).

Finally, particular attention deserves the issue of metallicity: massive stars exist locally (examples abound in our own Galaxy and in the Magellanic Clouds, in isolated clusters or in large star-forming complexes), and we know beyond a doubt that their final fate depends on metallicity. How exactly this parameter governs and determines the explosion and how prominently it shapes the small and large scale environment of the GRB is a matter of hot debate, because the observational information is still too limited to allow a satisfactory quantitative analysis that can provide objective conclusions.

Reference

Kasliwal, M. M. 2011, Bridging the Gap: Elusive Explosions in the Local Universe, PhD Dissertation, California Institute of Technology (http://resolver.caltech.edu/CaltechTHESIS:05162011-09434522)

https://doi.org/10.1017/S1743921312013117 Published online by Cambridge University Press

https://doi.org/10.1017/S1743921312013117 Published online by Cambridge University Press

https://doi.org/10.1017/S1743921312013117 Published online by Cambridge University Press

https://doi.org/10.1017/S1743921312013117 Published online by Cambridge University Press

https://doi.org/10.1017/S1743921312013117 Published online by Cambridge University Press