The SN 1987A Link to Gamma-Ray Bursts

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Abstract. Early measurements of SN 1987A can be interpreted in light of the beam/jet (BJ) which had to hit polar ejecta (PE) to produce the “Mystery Spot” (MS), some 22 light-days distant. It takes an extra eight days for the SN flash to hit the MS, and early measurements confirm $2 \times 10^{39}$ ergs/s in the optical for a day at day 8, before dropping off by day 8.5. A linear ramp in luminosity starting near day 10 indicates particles from the BJ hitting the PE, with the fastest particles traveling at 0.8 c, and an upper limit for the optical luminosity of the MS of $5 \times 10^{40}$ ergs/s, about 23% of the total of $2.1 \times 10^{41}$ ergs/s at day 20. The many details of SN 1987A strongly suggest that it resulted from a merger of two stellar cores of a common envelope (CE) binary, i.e. a “double degenerate” (DD)-initiated SN. Without having to blast through the CE of Sk -69° 202, it is likely that the BJ would have caused a full, long-soft gamma-ray burst ($\ell$GRB) upon hitting the PE, thus DD is a mechanism which can produce $\ell$GRBs. A 0.5° offset, the typical collimation for a GRB, over the 22 light-days from SN 1987A to its PE, produces $\sim 100$ s of delay, matching the observed delay of the non-prompt parts of $\ell$GRBs. Because DD must be the overwhelmingly dominant SN mechanism in elliptical galaxies (EGs), where only short, hard GRBs (sGRBs) have been observed, DD without CE or PE must also produce sGRBs, and thus the initial photon spectrum of 99% of all GRBs is known, and neutron star (NS)-NS mergers may not make GRBs as we know them. Millisecond pulsars (MSPs) in the non-core-collapsed globular clusters are also 99% DD-formed from white dwarf (WD)-WD merger, consistent with their 2.10 ms minimum spin period, the 2.14 ms signal seen from SN 1987A, and sGRBs offset from EGs. The many details of Ia’s strongly suggest that these are also DD. This is a concern for systematics in Ia Cosmology, because Type Ia SNe will appear to be Ic’s when viewed from their DD merger poles, given sufficient matter above that lost to core-collapse (otherwise it would just beg the question of what else they could possibly be, and other mechanisms, such as “delayed detonation” or “gravitationally confined detonation,” don’t produce the inverse relation between polarization and luminosity). As a DD-initiated SN, SN 1987A appears to be the Rosetta Stone for 99% of SNe, GRBs and MSPs, including all recent nearby SNe except SN 1986J, and the more distant SN 2006gy. There is no need to invent exotica to account for GRBs.

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Introduction

Gamma-ray bursts (GRBs) are the most luminous objects in the Universe, yet we still know very little about them (see [1] and references therein), although some have been found to be associated with SNe but others, mostly those lasting only a fraction of a second, with slightly harder spectra, produce only “afterglows,” sometimes extending down to radio wavelengths. A large number of models have been put forth to explain GRBs, including NS-NS mergers for some, and many flatout inventions, such as “collapsars,” “hyperfervae,” and “supranovae,” for others. This work offers a simple explanation for 99% of SNe, GRBs, and MSPs, in the context of a phenomenon that Nature has already provided, namely SN 1987A (87A).
The explosion of 87A is clearly bipolar \[2, 3\]. A “polar blowout feature” (PBF – the prime suspect for the r-process) approaches at about 45° off our line of sight. It partially obscures an equatorial bulge/ball (EB), behind which a part of the opposite, receding PBF is visible. The 87A PBFs and EB are approximately equally bright, in contrast to what polarization observations imply for Type Ia SNe (see below).

A binary merger scenario of two electron degenerate stellar cores (double degenerate, or DD) has been proposed for 87A, and the triple ring structure has recently been consistently calculated \[4\]. The many other details of 87A, including the mixing, the blue supergiant progenitor, and the 2.14 ms pulsed optical signature, strongly support this hypothesis. Prior to and during this time no measurement of any SN other than SN 1986J\[1\] or of any GRB other than SGRs, has been inconsistent with this geometry.

The first clear evidence for DD-formed MSPs coincidentally came in the birth year of 87A, with the discovery of the 3 ms pulsar, B1821-24 \[6\], in the non-core-collapsed (nCCd) globular cluster (GC) M28. This discovery was followed by many, many more in the nCCd GCs, such as 47 Tuc, over the last 20 years, and attributing these to recycling through X-ray binaries has never really worked \[7\], by a few orders of magnitude\[2\]. Other works \[8, 9\] have explored DD more recently.

The most remarkable feature \[3\] of 87A was the “mystery spot” (MS – Fig. 1), with a thermal energy of 10\[49\] ergs, even 50 days after the CC event and separated from the SN photosphere “proper” by some 0.06 arc s along the axis of its DD merger toward the Earth, some 45° off our line of sight, with about 3% of this energy eventually radiated in the optical band. The geometry is such that it takes light only about eight extra days to hit it and continue on to be observed from the Earth (Fig. 1).

The approaching polar beam/jet produced by 87A, which blasted through the CE of Sk -69° 202 and collided with what is thought to be PE some 22 light-days distant from the SN along this axis, may be generic to the DD process. Through its interaction with the overlaying CE and/or PE it produces the wide variation in GRB/X-ray flash properties observed from DD SNe of sufficiently low inclination to the line of sight. Thus the flavors of the 99% of GRBs due to DD depend on CE and/or PE mass (Fig. 2, 1

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1 This SN occurred in the edge-on spiral galaxy, NGC 0891, and exceeds the luminosity of the Crab nebula at 15 GHz by a factor of 200, and is thus thought to have occurred because of the iron photodissociation catastrophe (Fe PdC) mechanism, thereby producing a strongly magnetized NS (the origin of magnetic fields in NSs is still poorly understood, though it is believed that thermonuclear [TN] combustion in the massive progenitor to an Fe core is related). As a corollary, we note that models of SNe to date have not taken DD into account, and certainly have not been calibrated to an Fe PdC SN, such as 1986J. The inner layers of all Fe PdC SNe, possibly many M\[\odot\] of Si, C, and O, have not been diluted with H and/or He by DD, and thus may ignite upon core-collapse and burn efficiently to \[56\]Ni, making a strongly magnetized remnant a possibility even for SN 2006gy \[5\], which may have produced \~20 M\[\odot\] of \[56\]Ni.

2 Recycled pulsars weighing 1.7 M\[\odot\] in the CCd GC, Ter 5 (Scott Ransom 2006), have removed high accretion rate from contention as an alternative mechanism to produce the MSPs in the nCCd GCs.

3 Not counting, for the moment, the 2.14 ms pulsed optical remnant, which also revealed a \~1,000 s precession \[10, 8\]. Since a prototypical, dim, thermal neutron star remnant (DTN) has been discovered in Cas A \[11\], representing what PSR 1987A will look like after another 300 years, and other pulsars have since been observed to precess \[12\], this candidate is no longer controversial. 

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FIGURE 1. (Left) The distance of the MS from 87A at Hα and 533 nm vs time, from [13, 14] (M87/N87). (Center) The MS geometry and cross-sections of the equatorial ring (ER). (Right) The lines of sight from 87A to the Earth directly/through the MS (which takes an extra 8 days).

left). The restricted T_{90} range of the new iGRB class is consistent with DD events within RSGs, and the early polarization of SN 1993J [17], at 1.6% and 1.0%, being twice that of 87A (0.9% and 0.4% [18]). Since (per the Abstract) DD also produces sGRBs, it is not clear if any of these result from NS-NS mergers, bad news for the Earth-based gravitational observatories. Without circum-merger material, this process completes in a few milliseconds, shorter than the shortest sGRBS, out of range of Fig. 2, left.

Following the initial flash, very early data on 87A (Fig. 2, right) shows the breakout of the hotter, central part of the BJ by day 3, then cooling (or losing the ability to do so) until day 8, when the flash scatters in the PE (etc., per the Abstract).

DD in Type Ia/c SNe

Every observation of Type Ia SNe ever made is consistent with the bipolar explosion geometry of 87A, thus it seems reasonable to suggest that these too are DD-initiated SNe, which still produce TN yield, but also leave weakly magnetized MSPs, rather than single degenerate, disrupting TN blasts. The list of good reasons supporting the DD hypothesis for Ia’s is long: (1 & 2) no SN-ejected or companion wind-advected H/He, (3) ubiquitous high velocity features (HVFs), (4 & 5) SiII/continuum polarization (CP) both ∝ luminosity (IPL), (6) no radio Ia SNe, (7) four Ia’s/(26 years) in the merging spiral/elliptical galaxies comprising NGC 1316, (8) >1.2 M_⊙ of ^{56}Ni in SN 2003fg, (9) cataclysmic variables are explosive, & (10) DD SNe are needed to account for the abundance of Zinc – see the references in [21].

Thus Ia’s appear to be similar to the bipolar explosion of 87A, except that their TN/EB (TNB) dominates their luminosity over the PBFs, hence the very low, but still IPL CP (~0.0-0.5%). The primary effect of Ia PBFs is likely to be their shading of the TNBs.
These PBFs have higher velocities than in 87A because of lighter overlayers, assuming that the DD mechanism does not differ underneath, as seems reasonable.

Ia’s in old populations are almost exclusively due to CO-CO WD merger. In younger populations they can also be merging CE binary WR stars [22]. Occam’s Razor and the extreme bipolarity of Ia’s implied by their HVFs and IPL polarizations would suggest that Ia’s observed from the DD merger poles are Type Ic SNe, given enough overlayer to shroud the TN ashes of Si, S, & Fe (otherwise per the Abstract). Thus Ia/c’s form a continuous class of SNe, varying only by overlayer mass and observer co-i.

This is a concern for Ia Cosmology, as small levels of Ibc contamination can spuriously produce a high fraction of the $\Omega_\Lambda = 0.7$ [23]. Figure 3 shows how a fraction of the bright TNB can be exposed by the departing (and relatively dark) PBFs during the interval when $\Delta M_{15}$ is being measured, producing a SN which appears to be too faint for the redshift of its host galaxy, due to inadequate correction. The effect for a 30° co-i and PBFs with 1/2 angles of 45°, as drawn in Fig. 3 (left), accounts for half of $\Omega_\Lambda = 0.7$, even though this difference is scarcely apparent to the eye (the dashed line segments at 0.25 mag in Fig. 3, right, represent the whole effect). More realistic TNBs which begin as toroids may produce a big effect even for low co-i’s.

Have overdiligent attempts to select a local sample of Ia’s “uncontaminated” by Ic’s, excluded events in error by a tenth to a whole magnitude, which are not routinely excluded from distant samples? There appears to be a gap between the Ia’s underluminous by 1-2 whole magnitudes [24], which are easily excluded by the TiII $\lambda \lambda$ 4,000-4,500 Å shelf, and the others in the local sample. Are there Ia’s in this gap which may not be so easily excluded from the distant samples? Time will tell.

In conclusion, 87A is the Rosetta Stone for 99% of SNe, GRBs, and MSPs, and NS-NS mergers may not make GRBs as we know them. I thank the Observatories of the Carnegie Institution of Washington for support (see [21] for further acknowledgments).
FIGURE 3. (Left) The geometry for type Ia/c SNe, as viewed 30° off the merger equator, with PBFs sketched as cones of half-angle 45°. The two circles at the right/lower right show the maximum PBF footprints on the much brighter TNBs, which can be exposed as the PBFs quickly depart, for merger co-inclinations (co-i’s) of 0° (square) and 30° (diamond). These effects are compounded with a parabolic $\Delta M_{B,15}$ of 0.5 m in 15 days (inset). (Right) The maximum drop in magnitude from exposure of PBF footprints on the TNB as a function of co-i for PBF half angles of 25°-55° in 5° steps (curves without dots), and the excess drops over 0° for co-i’s of 20°, 30°, 45°, 60°, and 90° (curves with dots), plotted at the abscissa values equal to their PBF half angles.

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