The SN 1987A Link to Others and Gamma-Ray Bursts

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ABSTRACT

Early measurements of SN 1987A can be interpreted in light of the beam/jet (BJ), with a collimation factor $>10^4$, which had to hit polar ejecta (PE) to produce the “Mystery Spot” (MS), some 24 light-days distant. Other 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 (ℓGRB) upon hitting the PE, thus DD can produce ℓGRBs. Because DD must be the overwhelmingly dominant merger/SN mechanism in elliptical galaxies, where only short, hard GRBs (sGRBs) have been observed, DD without CE or PE must also produce sGRBs, and thus the pre-CE/PE impact photon spectrum of 99% of *all* GRBs is *known*, and neutron star (NS)-NS mergers may not make GRBs as we know them, and/or be as common as previously thought. 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 the centers of elliptical galaxies. The many details of Ia's strongly suggest that these are also DD initiated, and the single degenerate total thermonuclear disruption paradigm is now in serious doubt as well. This is a cause for concern 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. As a DD-initiated 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, such as “collapsars,” to account for GRBs.

Subject headings: cosmology:observations–gamma-rays: bursts–pulsars:general—white dwarfs—stars: Wolf-Rayet—supernovae: general—supernovae: individual (SN 1987A)

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1. Introduction

In Supernova 1987A (87A), Nature has provided an unparalleled opportunity to learn the details of one of the most frequent, and violent events in the Universe. Although confirming some early expectations of theorists (Chevalier 1992a,b), even from the first, features which would never have been seen at ordinary extra-galactic distances, appeared in the early light curve, which at that time defied easy explanation.

The most remarkable feature[1] of 87A was the "mystery spot" (MS), with a thermal energy of 10^{49} ergs, even 50 days *after* the core-collapse (CC) event (Meikle et al. 1987; Nisenson et al. 1987) and separated from the SN photosphere "proper" (PP) by some 0.06 arc s, with about 3% of this energy eventually radiated in the optical band. The possibility that this enormous energy implied for the MS might somehow link it gamma-ray bursts (GRBs) generally went unnoticed at the time.

GRBs, particularly long, soft GRBs (ℓGRBs), appear to be the most luminous objects in the Universe, occurring at the SN rate of one per second, given a collimation factor near 10^5, yet we still know very little about them (see, e.g., Mészáros 2006 and references therein). Although some have been found to be associated with SNe, others, mostly those lasting only a fraction of a second, with slightly harder spectra (sGRBs), 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 sGRBs, and exotic objects such as "collapsars" (MacFadyen & Woosley 1999) for ℓGRBs. The prime physical motivation for these is the enormous energy of up to 10^{54} ergs implied for an isotropic source. However, given that the data from 87A presented herein support a beam/jet (BJ) collimation factor (CF) $>10^4$ in producing its MS (see §3), there is no need for such a high energy.

This letter offers a simple explanation for 99% of SNe, MSPs, and GRBs,[2] in the context of the DD SN 1987A, its BJ and MS (Middleditch 2004, hereafter M04). It further argues that these start as sGRBs, and only later are some modified to ℓGRBs (and one other type – see §4), by interaction with the common envelope (CE) and/or polar ejecta (PE). It also argues that many, possibly all SNe Ia are caused by DD (merger-induced) CC, the single

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[1] Not counting, for the moment, the 2.14 ms pulsed optical remnant, which also revealed a ~1,000 s precession (Middleditch et al. 2000a,b – hereafter M00a,b). Since a prototypical, dim, thermal neutron star remnant (DTN) has been discovered in Cas A (Tananbaum et al. 1999), representing what PSR 1987A will look like after another 300 years, and other pulsars have since been observed to precess (Stairs et al. 2000), this candidate is no longer controversial.

[2] All except Soft Gamma Repeater [SGR] GRBs, which are estimated to amount to less than 5% of sGRBs and 1.5% of the total (Palmer et al. 2005).

degenerate (SD) paradigm (total thermonuclear disruption) being now admittedly in serious doubt (Siegfried 2007). Thus Ia Cosmology has not yet successfully challenged the Standard Model, and the burden of proof, for an accelerating expansion of the Universe, lies with the challenging model, the convenience of Concordance Cosmology amounting to only that.

2. The SN 1987A Bipolarity and "Mystery Spot"

SN 1987A is clearly bipolar (NASA et al. 2007; Wang et al. 2003). A "polar blowout feature" (PBF – a needed candidate for the r-process, e.g., Arnould et al. 2007) approaches at ∼45° off our line of sight, partially obscuring an equatorial bulge/ball (EB), behind which 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 §5).

A binary merger of two electron degenerate stellar cores (DD – in isolation these would be white dwarfs [WDs]) has been proposed for 87A (Podsiadlowski & Joss 1989), and the triple ring structure has recently been calculated in this framework (Morris & Podsiadlowski 2007). Many other details of 87A, including the mixing (Fransson et al. 1989), the blue supergiant progenitor, the early polarization (Schwarz & Mundt 1987; Barrett 1988), and the 2.14 ms optical pulsations (M00a,b), strongly support this hypothesis.

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 (Lyne et al. 1987), in the non-core-collapsed (nCCd) globular cluster (GC) M28. Subsequently many more were found in the nCCd GCs, such as 47 Tuc, over the next 20 years, and attributing these to recycling through X-ray binaries has never really worked (Chen et al. 1993), by a few orders of magnitude.[3]

The 0.059 arc s offset of the MS from the PP *coincides* with the PBF bearing of 194° (and thus *along the axis of its DD merger*),[4] some 45° off our line of sight, corresponding to 24 light-days (ℓt-d), or 17 ℓt-d in projection, it taking light from 87A only *eight* extra days to reach the Earth after hitting the MS, and there is evidence for exactly this delay (see below). In addition, the typical 0.5° collimation for an ℓGRB, over the 24 ℓt-d from 87A to its PE, produces ∼100 s of delay, within the range of the non-prompt components of ℓGRBs.

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[3] Relatively slowly rotating, recycled pulsars weighing 1.7 $M_\odot$, in the CCd GC, Ter 5 (Ransom et al. 2005), have removed high accretion rate from contention as a alternative mechanism to produce the MSPs in the nCCd GCs. The three MSPs in Ter 5 with periods < 2 ms, Ter 5 O, P, and ad (Hessels et al. 2006), may have been recycled starting with periods near 2 ms. There are four in this sample with periods between 2.05 and 2.24 ms, and another, the first from Arecibo ALFA, at 2.15 ms (Champion 2007).

[4] The far-side (southern) minor axis of the equatorial ring has a bearing of 179°.

3. The Early Luminosity History of SN 1987A

The early luminosity histories of 87A taken with the Cerro Tololo Inter-American Observatory (CTIO) 0.41-m (Hamuy & Suntzeff 1990) and the Fine Error Sensor (FES) of the International Ultraviolet Explorer (IUE) (Wamsteker et al. 1987), both show such evidence of the BJ and MS (Fig. 1).[5]

Following the drop from the initial flash, the luminosity rises again to a maximum ('A' in Fig. 1) of magnitude 4.35 at day 3.0, interpretable as the hotter, more central part of the BJ shining through/running ahead of the cooler, roughly cylindrical outer layers which initially shrouded it. This declines ('B') to magnitude 4.48 around day 7.0, interpretable as free-free cooling of, or the loss of the ability to cool for, an optically thin BJ. The initial flash should scatter in the PE at day 8, and indeed 'C' shows $\sim 2 \times 10^{39}$ ergs/s in the optical for a day at day 8.0, and a decline *consistent with the flash* after that, indicating a flash CF $>10^4$. A linear ramp in luminosity starting near day 10 indicates particles from the BJ penetrating into the PE, with the fastest traveling at >0.9 c, *and* a particle CF $>10^4$. A decrement[6] of $\sim 5 \times 10^{39}$ ergs s^{-1} appears in both data sets near day 20 ('D'). The CTIO point just before the decrement can be used as a rough upper limit for the MS luminosity, and corresponds to an excess above the minimum (near day 7.0) of 5×10^{40} ergs s^{-1}, or magnitude 5.8, the *same* as that observed in $H\alpha$ for the MS at days 30, 38, and 50.

4. The SN 1987A link to GRBs

Without the H and He in the envelope of the progenitor of 87A, Sk -69°202, the collision of the BJ with its PE (which produced the MS) might be indistinguishable from a full ℓGRB (Cen 1999).[7] This realization, together with the observation that no ℓGRBs have been found in elliptical galaxies, and the realization that the DD process *must* dominate (as always, through binary-binary collisions) by a large factor the NS-NS mergers in these populations, even when requiring enough WD-WD merged mass to produce CC, leads to the *inescapable* conclusion that the DD process produces sGRBs in the absence of CE and PE, the means

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[5] The CTIO V band center occurs at 5,500 Å, as opposed to 5,100 Å for the FES, and in consequence, the FES magnitudes have been diminished by 0.075 in Fig. 1 to account for the resulting luminosity offset.

[6] This is preceded by a spike of up to 10^{40} ergs s^{-1} in the CTIO data, with the unusual colors of B, R, and I, in ascending order. Optical pulsations were not seen during this early period (R. N. Manchester, private communication, 2007). The possibility of less-than-coherent pulsations, though, is harder to eliminate.

[7] Otherwise it would just beg the question of what distant, on-axis such objects would look like.

by which they would otherwise become ℓGRBs. Given that the sGRBs in ellipticals are due to mergers of WDs, we can conclude that: 1) the pre-CE/PE impact photon spectrum of ℓGRBs is *known*, 2) sGRBs are offset from the centers of their elliptical hosts because they are WD-WD mergers in their hosts' GCs (to produce most of their MSPs – Gehrels et al. 2005), and 3) NS-NS mergers may not make GRBs as we know them, and/or be as common as previously thought.[8] This is a disappointment to the Earth-based gravitational observatories such as LIGO, because sGRBs may not flag NS-NS merger events.

Through their interaction with the overlaying CE and/or PE, BJs produce the wide variation in GRB/X-ray flash properties observed from DD SNe of sufficiently low inclination to the line of sight, and the flavors of the 99% of GRBs due to DD depend only on observer inclination, CE and/or PE mass, extent, and abundance. Of the *three* different classes of GRBs, ℓGRBs, sGRBs, and the intermediate time, softest GRBs (iGRBs), as recently classified by Horváth et al. (2006, see also Middleditch 2007), most sGRBs occur from DD WD-WD merger without CEs or PE, ℓGRBs pass through at least the PE (necessary for small angle deviations to produce $\sim$100 s of delay), and usually the CE (which, in addition to the PE, can soften the burst), while iGRBs pass through red supergiant (RSG) CEs, but little or no PE, possibly the result of a merger of two stars with very unequal masses, the possible cause of SN 1993J, which had an RSG progenitor (Podsiadlowski et al. 1993).[9] The $\sim$10 s limit for T_{90}, and its substantially negative slope (tradeoff) with H_{32} for the iGRBs, are consistent with an RSG CE, but no PE.[10] As in the case of ℓGRBs, the pre-CE impact photon spectrum of iGRBs is also known.

5. DD in Type Ia/c SNe

The list of good reasons against SD for Ia's is long: (1 & 2) no SN-ejected or wind-advected H/He (Marietta et al. 2000; Lentz et al. 2002), (3) ubiquitous high velocity features (Mazzali et al. 2005a), (4 & 5) SiII/continuum polarization (CP) both inversely propor-

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[8] Without ejected matter these merge within a few ms, far shorter than sGRBs (Eicher et al. 1989).

[9] At 1.6% and 1.0% (Trammell et al. 1993) the early polarization of SN 1993J was *twice* that of the 0.9% and 0.4% observed from 87A, consistent with even *more* axiality than that of 87A.

[10] The fluence of *both* the non-prompt and prompt parts of off-axis ℓGRBs are suppressed, the first by scattering in the PE, the second by being off axis by the time it emerges from the CE, frequently leaving both roughly equally attenuated. This scenario also explains why the two ("precursor" and "delayed") have similar temporal structure (Nakar & Piran 2002). Negligible spectral lag for late ($\sim$10–100 s) emission from "spikelike" bursts (Norris & Bonnell 2006) can be explained in terms of small angle scattering off the PE, without invoking extreme relativistic Γ's.

tional to luminosity (IPL – Wang et al. 2006; Middleditch 2006), (6) no radio Ia SNe (Panagia et al. 2006), (7) *four* Ia's within 26 years in the merging spiral/elliptical galaxies comprising NGC 1316 (Immler et al. 2006), (8) >1.2 $M_\odot$ of ^{56}Ni in SN 2003fg (Howell et al. 2006), (9) cataclysmic variables are explosive (Scannapieco & Bildsten 2005), and (10) DD SNe are needed to account for the abundance of Zinc (Kobayashi et al. 2006).

No observation of *any* recent SN other than SN 1986J[11] and SN 2006gy, including all *ever* made of Type Ia SNe, is inconsistent with the bipolar geometry of 87A. Thus, especially in the light of SD's serious problems, it seems likely that Ia's are also DD-initiated SNe, of which some still produce TN yield, but with all producing weakly magnetized MSPs.

Further, it seems likely that Ia's and Ic's form a continuous class, classified as Ic's when viewed from the merger poles, if sufficient matter exists, in excess of that lost to CC, to screen the Ia TN products (a rare circumstance in ellipticals), because this view will reveal lines of the r-process elements characteristic of Ic's.[12] All this complicates the use of SNe Ia in cosmology, because many Ia/c's in actively star-forming galaxies (ASFGs) belong to the continuous class, and Ia's in ellipticals (and some in ASFGs) may not produce enough ^{56}Ni to be bolometric (Pinto & Eastman 2001), lying as much as two whole magnitudes below the width-luminosity (W-L) relation (the faint SNe Ia of Benetti et al. 2005).

A "missing link" of Ia's must exist, more luminous than 'faint' SNe, which fall below the W-L relation by a tenth to a whole magnitude, may still be largely absent from the local sample, but may *not* be easily excluded by the TiII $\lambda\lambda$ 4,000-4,500 Å shelf. There is a more luminous class of Ia's, found almost exclusively in ASFGs, that may be attributed to CE Wolf-Rayet stars (see, e.g., DeMarco et al. 2003, Howell et al. 2001, and the data in Górny & Tylenda 2000), and a less luminous "leaner" class, found in both ellipticals and ASFGs (Hamuy et al. 2000; Sullivan et al. 2006; Wang et al. 2006), which can be attributed to CO-CO WD mergers. In the DD paradigm, the Ia mass, above the 1.4 $M_\odot$ lost to CC, determines the optical luminosity. Since optical afterglows have been found in sGRBs with no

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[11] This SN, in the edge-on spiral galaxy, NGC 0891, exceeds the luminosity of the Crab nebula at 15 GHz by a factor of 200 (Bietenholz et al. 2004), and thus is thought to have occurred because of iron photodissociation catastrophe (FePdC), 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 a massive progenitor to an Fe core is related).

[12] As with 87A-like events, it would again beg the question of "What *else* they could possibly be?," and "delayed detonation" (Khokhlov 1991), or "gravitationally confined detonation" (Plewa et al. 2004), do not produce the IPL polarization. And unless the view *is* very near polar, this geometry can produce split emission line(s) on rare occasions, as was seen in SN 2003jd (Mazzali et al. 2005b), and thus again there is no need to invoke exotica, or an entire population (III) to account for GRBs (Conselice et al. 2005; M04).

SNe (Gal-Yam et al. 2006; Fynbo et al. 2006; Della Valle et al. 2006; Gehrels et al. 2006), DD Ia's can be very lean indeed. It is not at all clear if SD *ever* happens.

If Ia/c's are indeed the result of the same process that underlay 10–15 $M_\odot$ in 87A, but which instead only underlay 0.5 $M_\odot$, the outcome will be even more extreme than the geometry of the SN 1987A remnant. The PBFs will have higher velocities, and the equatorial/thermonuclear ball (TNB) will be much brighter, due to the greater concentration of ^{56}Ni. Thus PBFs form linearly extended structures, whose brightness pales in comparison to that of the spheroidal TNBs, which explains why Ia continuum and SiII polarization are both IPL (Wang et al. 2006; Middleditch 2006), and also indicates that part of these lines must originate from the sides of the Ia/c PBFs.

Ia/c PBFs depart and/or thin out quickly because of their high velocities and limited masses, potentially exposing a fraction of the TNBs during the time interval when $\Delta m_{15}(B)$ is measured. Ia/c's with PBFs initially showing r-process lines, because of views closer to the poles of the DD merger, are frequently excluded from the local sample as part of overdiligent attempts to select a "pure" sample of Ia's. This selection doesn't work as effectively on the distant sample, and the result will be distant SNe which are too faint for the redshift of their host galaxies. Figure 3 of Middleditch (2007) shows how this effect could spuriously produce half of Ω_Λ=0.7 for a co-inclination (co-i) of 30° and a PBF of half angle of 45°. More realistic TNBs which begin as toroids could produce a big effect even for low co-i's.

6. Conclusion

We have argued that the DD SN 1987A, its beam/jet, Mystery Spot, and possible 2.14 ms pulsar remnant, are intimately related to as many as 99% of GRBs, MSPs, and other SNe, including all Type Ia SNe, a grave concern for Ia Cosmology. The time lags, energetics, and collimation of ℓGRBs are consistent with those of 87A's BJ and MS, and there is no need to invent exotica, such as collapsars, to satisfy them, the expansion of the Universe may not be accelerating, and there may be no Dark Energy. Recent observations have also cast significant doubt on the existence of dark matter as well (Nelson & Petrillo 2007).

Given this new, very complex picture of Ia's, any sample, with a very low dispersion in magnitude, is hardly reassuring. A rigorous treatment of Ia data rules out all cosmologies (Vishwakarma 2005). A straightforward argument indicates that NS-NS mergers may not make *any* GRBs as we know them, and/or occur nearly as frequently as previously thought. Models of SNe to date are flawed because neither the DD process, nor strong magnetic fields have been included, developments that may still be at least a decade away. Certainly, no relatively nearby FePdC SN has been well studied, SN 1986J having occurred during 1983.

The DD mechanism ensures that nearly all SNe are born from a maximally rotating, post-merger WD with a rotation period near 1.98 s, thus rapid rotation can not be invoked as an unusual circumstance, for the case of SN 2003fg, to justify "super-Chandrasekhar-mass" WDs (SCMWDs). The >1.2 $M_\odot$ of ^{56}Ni it produced may only mean that CC underneath mixed TN fuel can initiate very efficient combustion/detonation,[13] the paltry amounts of ^{56}Ni associated with Ib's and at least 90% of IIs being the result of dilution of their TN fuel with He and/or H due to the DD merger process. Thus SN 2006gy may not be a pair-instability SN (Smith et al. 2006),[14] only a massive FePdC SN, which may have produced $\sim$20 $M_\odot$ of ^{56}Ni, *and* a strongly magnetized NS remnant, a prediction which can be tested soon.

Although it would appear that a Universe without collapsars, pair instability SNe, SCMWDs, and frequent NS-NS mergers which make sGRBs, is much less "exotic" than previously thought, SNe themselves are plenty exotic enough, with 1% producing a strongly magnetized NS remnant/pulsar, and the remaining 99% caused by DD, producing $\sim$2 ms pulsars, and BJs which can incinerate half the planet from a great distance with little or no warning. *This* is what we will spend a good deal of the first half of this century figuring out.

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REFERENCES

Arnould, M., Goriely, S., & Takahashi, K. 2007, preprint, arXiv/0705.4512

Barrett, P. 1988, MNRAS, 234, 937

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[13] The spectroscopic demands of a significant mass of unburned fuel, such as O, being invalid because of the invalid paradigm under which such estimates were made.

[14] The inner layers of all FePdC SNe, possibly *many* $M_\odot$ of Si, Ne, O, and C, have not been diluted with H and/or He by DD, and thus may ignite/detonate upon CC, and burn efficiently. SN modelers therefore face the unenviable choice of calculating FePdC SNe, which involve strong magnetic fields, or DD SNe, which involve a great deal of angular momentum and *demand* GRBs as an outcome (see §4).

Benetti, S., et al. 2005, ApJ, 623, 1011 (B05)

Bietenholz, M. F., Bartel, N., & Rupen, M. P. 2004, Science, 304, 1947

Cen, R. 1999, ApJ, 524, L51

Champion, D. 2007, NAIC Arecibo Obs. News., No. 41, 17

Chen, K., Middleditch, J., & Ruderman, M. 1993, ApJ, 408, L17

Chevalier, R. A. 1992a, Nature, 355, 691.

Chevalier, R. A. 1992b, Nature, 360, 628

Conselice, C. J., et al. 2005, ApJ, 633, 29

Della Valle, M., et al. 2006, Nature, 444, 1050

DeMarco, O., Sandquist, E. L., Low, M-M M., Herwig, F., & Taam, R. E. 2003, RMxAC, 18, 24

Eicher, D., Livio, M., Piran, T., & Schramm, D. N. 1989, Nature, 340, 126

Fransson, C., Cassatella, A., Gilmozzi, R., Kirshner, R. P., Panagia, N., Sonneborn, G., & Wamsteker, W. 1989, ApJ, 336, 429.

Fynbo, J., et al. 2006, Nature, 444, 1047 (astro-ph/0608313)

Gal-Yam, A., et al. 2006, preprint (astro-ph/0608257)

Gehrels, N., et al. 2005, Nature, 437, 851

Gehrels, N., et al. 2006, Nature, 444, 1044

Górny, S. K., & Tylenda, R. 2000, A&A, 362, 1008

Hamuy, M., & Suntzeff, N. B. 1990, AJ, 99, 1146

Hamuy, M., Trager, S. C., Pinto, P. A., Phillips, M. M., Schommer, R. A., Ivanov, V., & Suntzeff, N. B., 2000, AJ, 120, 1479

Hessels, J. W. T., Ransom, S. M., Stairs, I. H., Freire, C. C., Kaspi, V. M., & Camilo, F. 2006, Science, 311, 1901

Horváth, I., Balázs, L. G., Bagoly, Z, F. Ryde, & A Mézáros, A. 2006, A&A, 447, 23

Howell, D. A., Höflich, P, Wang, L., & Wheeler, J. C. 2001, ApJ, 556, 302

Howell, D. A., et al. 2006, Nature, 443, 308

Immler, S., Gehrels, N. F., & Nousek, J. A. 2006, http://www.science.psu.edu/alert/Swift11-2006.htm

Khokhlov, A. M. 1991, A&A, 245, 114

Kobayashi, C., Umeda, H., Nomoto, K., Tominaga, N, & Ohkubo, T. 2006, ApJ, 653 1145

Lentz, E. J., Baron, E., Hauschildt, P. H., & Branch, D. 2002, ApJ, 580, 374

Lyne, A. G., Brinklow, A., Middleditch, J., Kulkarni, S. R., & Backer, D. C. 1987, Nature, 328, 399

MacFadyen, A., I., & Woosley, S. E. 1999, ApJ, 524, 262

Marietta, E., Burrows, A., & Fryxell, B. 2002, ApJS, 128, 615 No. 3548, 1

Mazzali, P., et al. 2005a, ApJ, 623, L37

Mazzali, P., et al. 2005b, Science, 308, 1284

Meikle, W. P. S., Matcher, S. J., & Morgan, B. L. 1987, Nature, 329, 608

Mészáros, P. 2006, Rep. Prog. Phys., 69, 2259

Middleditch, J. 2004, ApJ, 601, L167 (M04)

Middleditch, J. 2006, preprint (astro-ph/0608386)

Middleditch, J. 2007, in Supernova 1987A: 20 Years After, Supernovae and Gamma-Ray Bursters, ed. S. Immler, K. W. Weiler, & R. McCray (New York:AIP) 107, also preprint, arXiv/0705.3846

Middleditch, J., et al. 2000a, preprint (astro-ph/0010044)

Middleditch, J., et al. 2000b, New A, 5, 243

Morris, T., & Podsiadlowski, Ph. 2007, Science, 315, 1103

Nakar, E., & Piran, T. 2002, MNRAS, 331, 40

NASA et al. 2007, http://hubblesite.org/gallery/album/entire/_collection/pr2007010a.

Nelson, E., & Petrillo, K. 2007, BAAS, 39, 1, 184

Nisenson, P., Papaliolios, C., Karovska, M., & Noyes, R. 1987, ApJ, 320, L15

Norris, J. P., & Bonnell, J. T. 2006, ApJ, 643, 266

Palmer, D., et al. 2005, Nature, 434, 1107

Panagia, N., Van Dyk, S. D., Weiler, K. W., Sramek, R. A., Stockdale, C. J., & Murata, K. P.. 2006, ApJ, 646, 959

Pinto, P. A., & Eastman, R. G. 2001, New A, 6, 307

Plewa, T., Calder, A. C., & Lamb, D. Q. 2004, ApJ, 612, L37

Podsiadlowski, Ph., Hsu, J. J. L., Joss, P. C., & Ross, R. R. 1993, Nature, 364, 509

Podsiadlowski, Ph., & Joss, P. C. 1989, Nature, 338, 401

Ransom, S. M., Hessels, J. W. T., Stairs, I. H., Freire, P. C. C., Camilo, F., Kaspi, V. M., & Kaplan, D. L. 2005, Science, 307, 892

Schwarz, H. E., & Mundt, R. 1987, A&A, 177, L4

Scannapieco, E., & Bildsten, L. 2005, ApJ, 629, L85

Siegfried, T. 2005, Science, 316, 195

Smith, N. et al. 2006, preprint, astro-ph/0612617

Stairs, I. H., Lyne, A. G., & Shemar, S. L. 2000, Nature, 406, 484

Sullivan, M., et al. 2006, ApJ, 648, 868

Tananbaum, H., & The Chandra Observing Team 1999, IAU Circ., No. 7246, 1

Trammell, S. R., Hines, D. C., & Wheeler, J. C. 1993, ApJ, 414, L21

Vishwakarma, R. G. 2005, preprint (astro-ph/0511628)

Wamsteker, W., et al. 1987, A&A, 177, L21

Wang, L., Baade, D., & Patat, P. 2006, Science, 315, 212

Wang, L., et al. 2003, ApJ, 591, 1110

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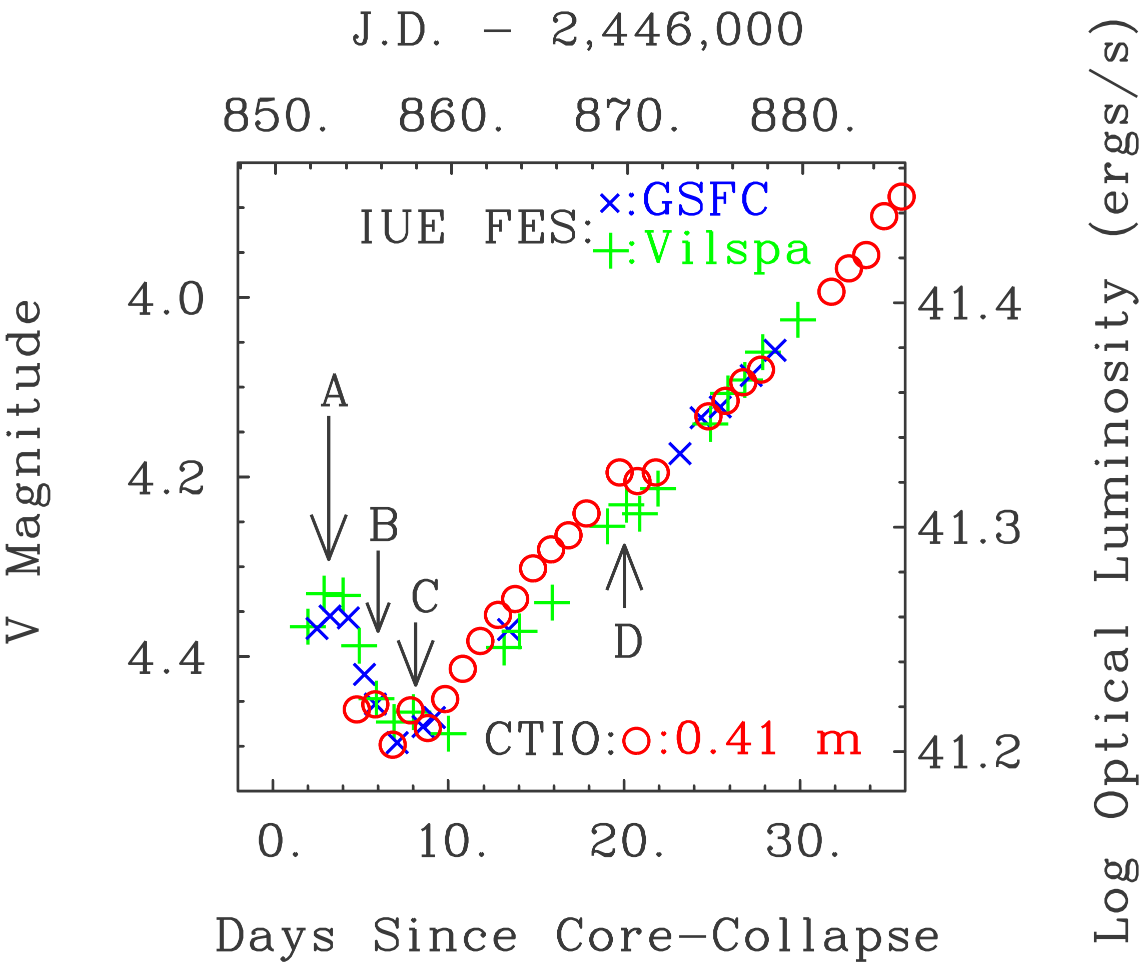

Fig. 1.— The very early luminosity history of SN 1987A as observed with the Fine Error Sensor of IUE and the 0.41-m at CTIO. Data points taken at Goddard Space Flight Center by Sonneborn & Kirshner, the Villafranca Station in Madrid, Spain, are marked (see §3).