Pulsar-driven Jets in Supernovae, Gamma-Ray Bursts, LMXBs, SS 433, and the Early Universe

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The model of pulsar emission through superluminally induced polarization currents (SLIP) predicts that pulsations produced by such currents at many light cylinder radii by a rotating, magnetized body, will drive pulsations close to the axis of rotation. In SN 1987A, the possible Rosetta Stone for 99% of SNe, GRBs, ms pulsars, and SS 433, such highly collimated ($<10^{-4}$) 2.14 ms pulsations, and the similarly collimated jets of particles which they drove, including 10^{-6} $M_{\odot}$ with velocities ~0.95 c, were responsible for its very early light curve (days 3 - 20), "Mystery Spot," observed slightly later (0.5 to 0.3 c, at days 30-50 and after), and still later, in less collimated form, its bipolarity. The axially driven pulsations enforce a toroidal geometry onto all early SNR's, *rendering even SNe Ia unsuitable as standard candles.* The #s for Sco X-1's jet(s) are identical, while those for SS 433 are lower (0.26 c), because of the absence of velocity "boosting" via collisions of heavy elements with lighter ones, due to the nearly pure hydrogen content of the supercritical accretion. SLIP also drives positrons from SNe to high energies, possibly accounting for the excess seen by PAMELA at scores of GeV, and predicts that almost all pulsars with very sharp single pulses have been detected because the Earth is in a favored direction where their fluxes diminish only as 1/distance, and this has been verified in the laboratory as well as for the Parkes Multibeam Survey. SLIP also predicts that GRB afterglows will be 100% pulsed at 500 Hz in their proper frame. Finally, SLIP jets from SNe of the first stars may allow galaxies to form without the need for dark matter. This work was supported in part by the Department of Energy through the Los Alamos Directed Research Grant DR20080085.

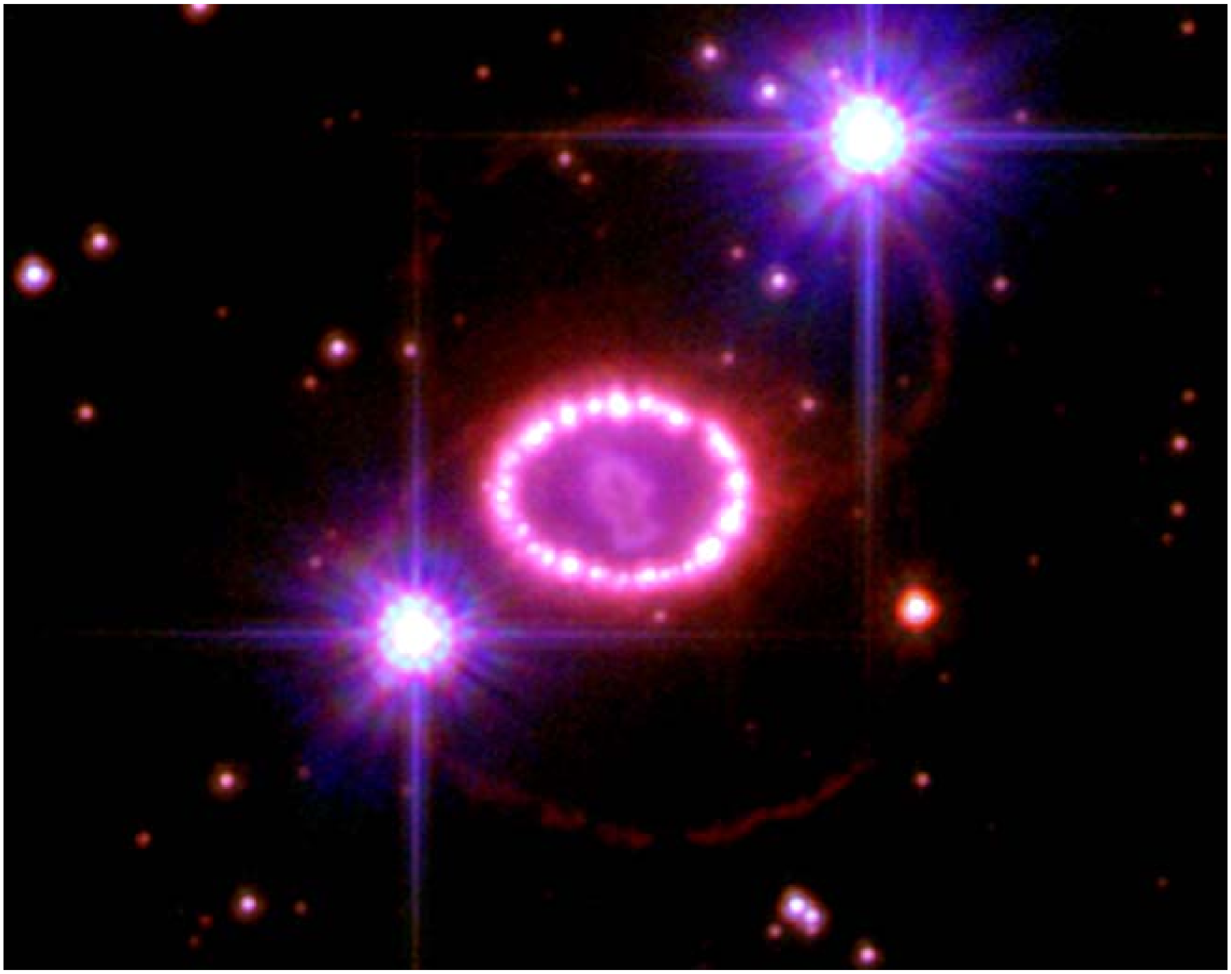


Fig. 1. SN 1987A as of December 2006, as viewed with the HST (NASA, P. Challis, & R. Kirshner, Harvard-Smithsonian Center for Astrophysics). North is up, east is to the left. The axis of the bipolarity corresponds to the "Mystery Spot" bearing of 194^o (the far-side [southern] minor axis of the equatorial ring has a bearing of 179^o). The pulsar within this remnant (and all other remnants as well) caused this bipolarity (see further below).

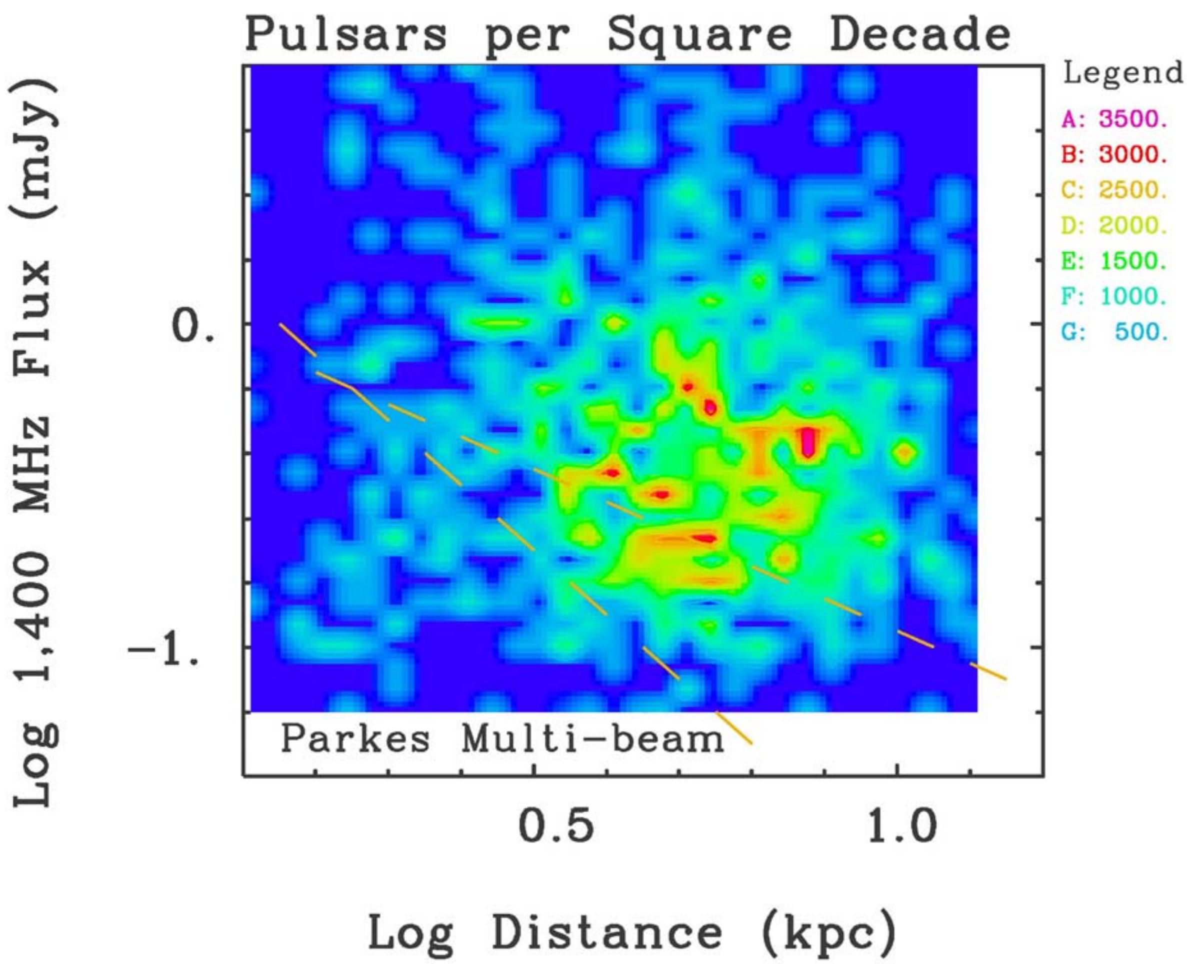
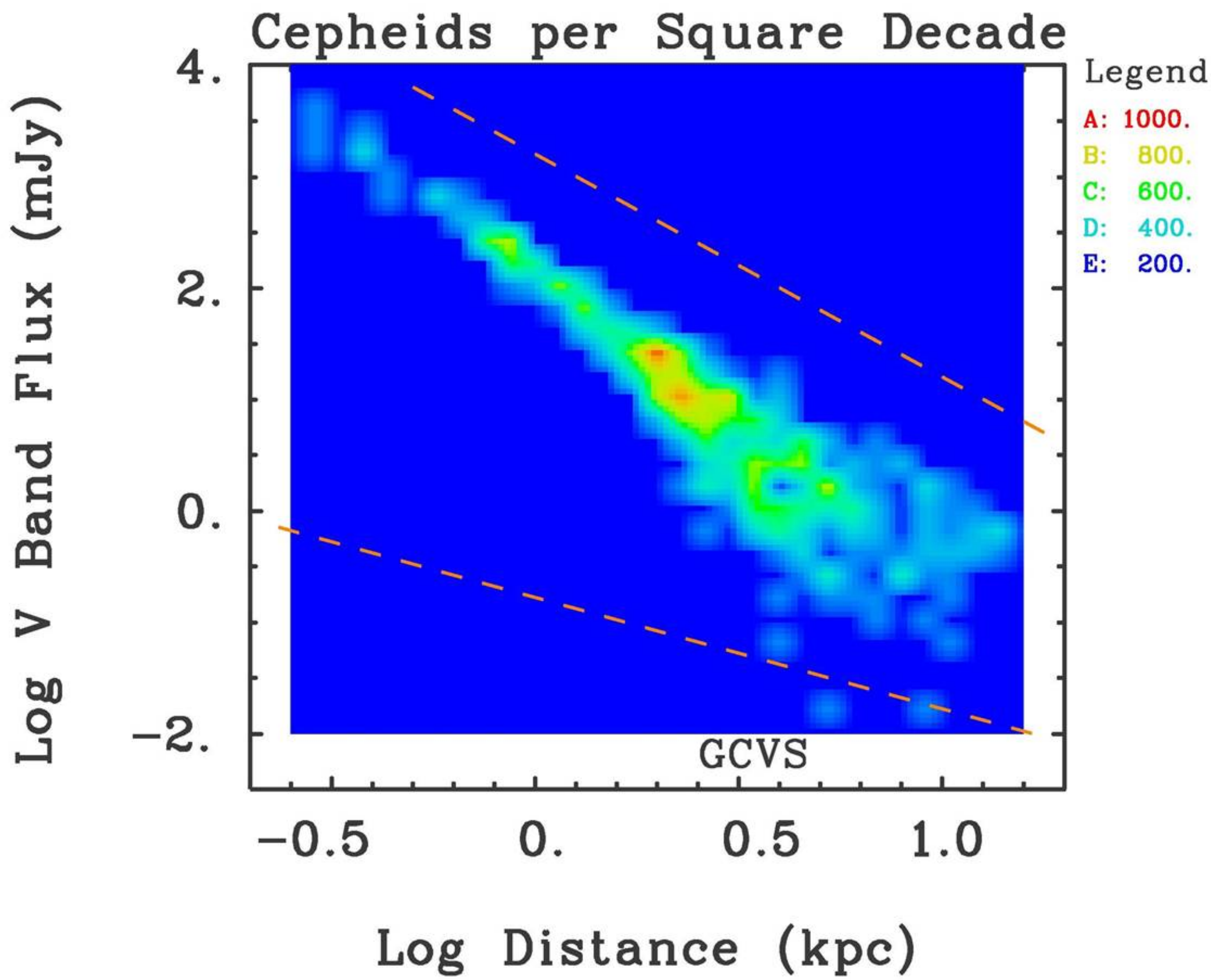


Fig. 2. Pulsars dim only as 1/distance in certain directions. This remarkable fact was *predicted* in H. Ardavan's Superluminally Induced Polarization Current Model (SLIP -- H. Ardavan, 1998, Phys. Rev. E., 58, 6659), but the effect has been known for decades ("Curved electromagnetic missiles"). This has been demonstrated in the field, and is also confirmed by the Parkes Multibeam Survey pulsars shown in this figure. There is no way that the steeper dashed line (with slope of -2) can bisect the nearby pulsar population and still bisect the distant pulsar population, even accounting for those pulsars which are undetected due to instrumental sensitivity (but lines of slope -1 and -1.5 can). In effect, there are too many faint, nearby pulsars for the overall distance law to be inverse square.



By contrast the Cepheids follow a distance law at least as steep as -2 (distances thanks to Eduardo Amores).

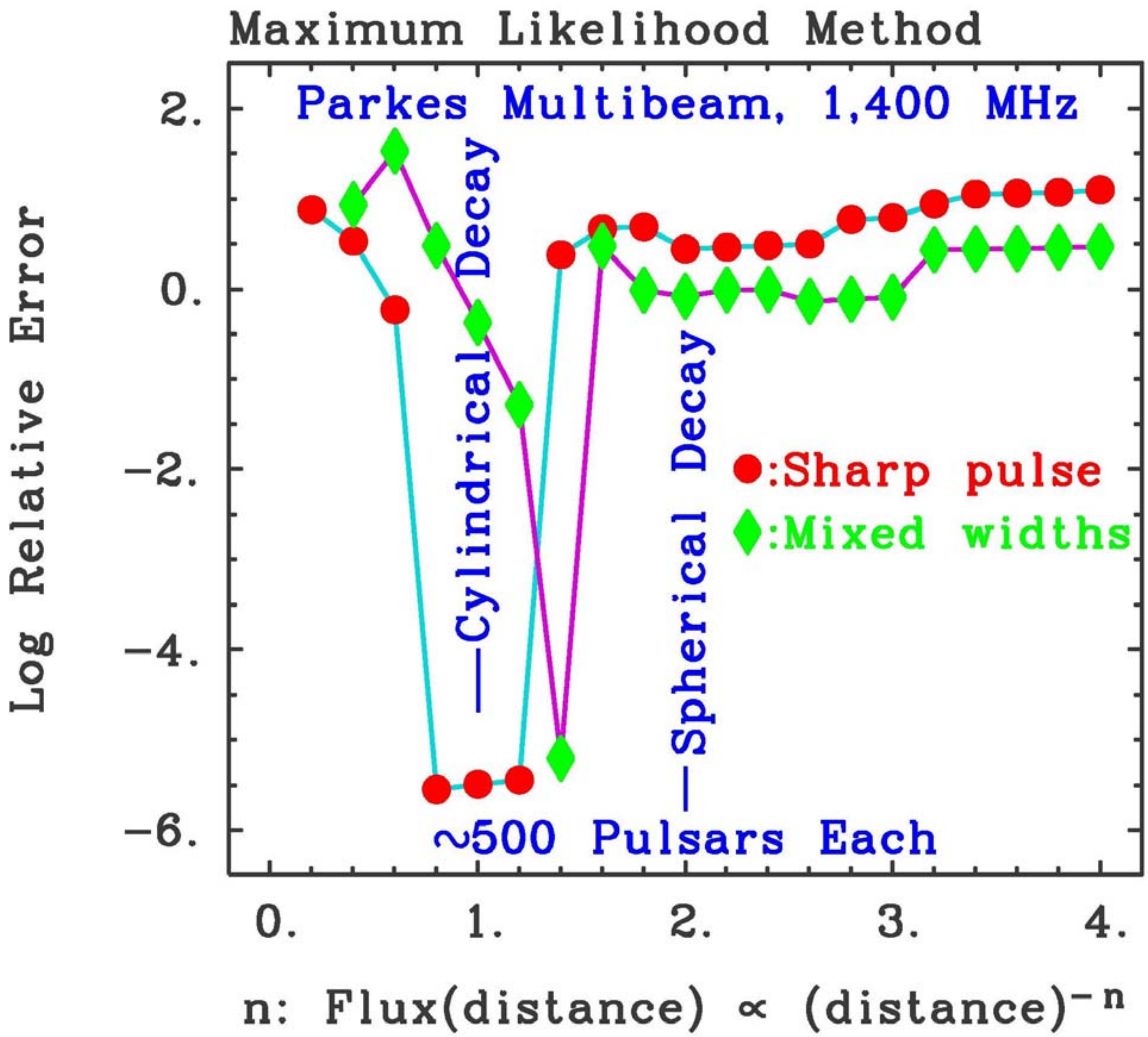


Fig. 3. The method of Efstathiou et al. (1988) as applied by Singleton et al. [arXiv:0912.0350] shows that those pulsars in the Parkes Multibeam Survey with sharp pulses (full width half maxima <3% of their periods) dim only as 1/distance, while those with wider pulses are displaced toward distance^{-2} as predicted by SLIP.

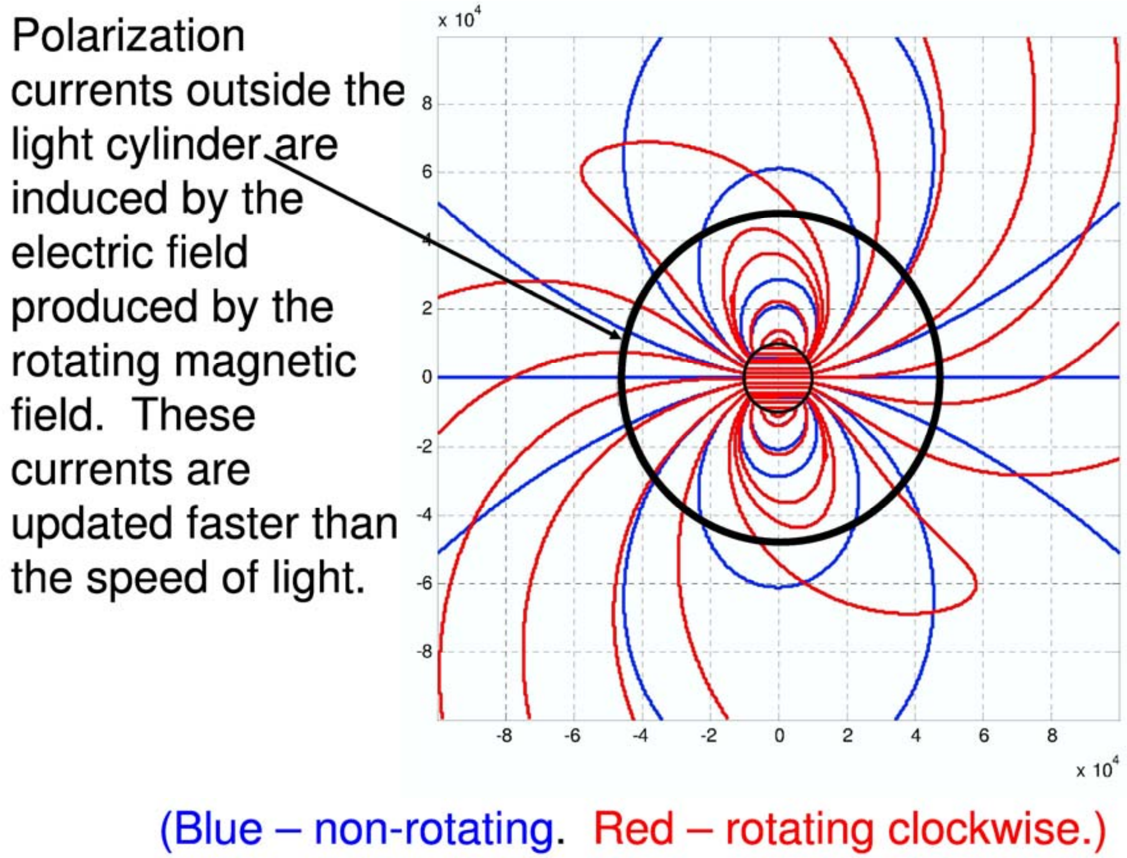


Fig. 4. A rotating, magnetized body produces a periodic disturbance, even beyond its light cylinder, which, if there is plasma available, induces polarization currents that are updated at a rate faster than the speed of light. There are no open field lines.

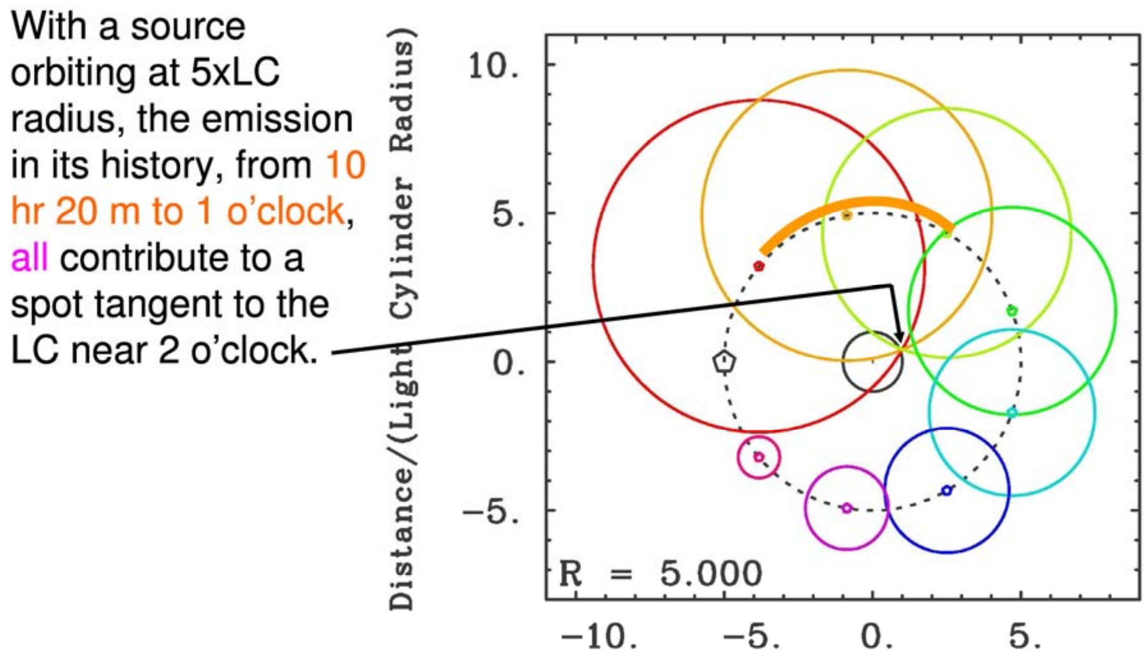


Fig. 4. A polarization current source, rotating clockwise, at 5 times the light cylinder radius. Contributions to the cusp run from 140^{o} to nearly 20^{o}, almost a third of an entire revolution. This is the well-known "cusp" of the SLIP model, whose intensity diminishes only as 1/distance due to temporal focusing. It is the circular analog of a shock wave. The range of sources contributing to the cusp (a single *point* of observer time) runs from 140^{o} to 20^{o}, a *third* of an entire revolution.

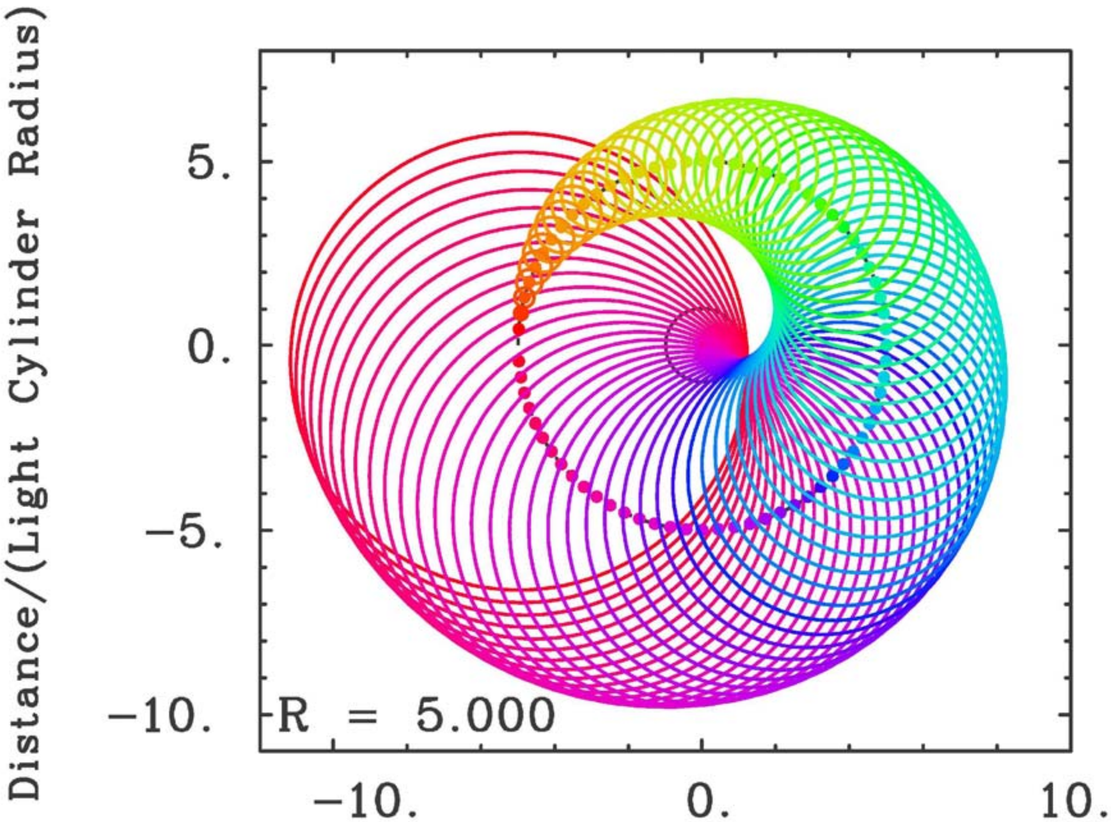


Fig. 5. A polarization current source, now rotating counterclockwise at 5 times the light cylinder radius, starting just >180^o, and ending at just <180^o, produces a pattern of emission (Huygens wavelets as colored circles) which is initially focused on its light cylinder (inner circle) just <360^o, and then progresses out of the plane with time (see next). The range of sources (dots), contributing to the cusp, runs from red through magenta to blue (180^o to 320^o), again a *third* of an entire revolution.

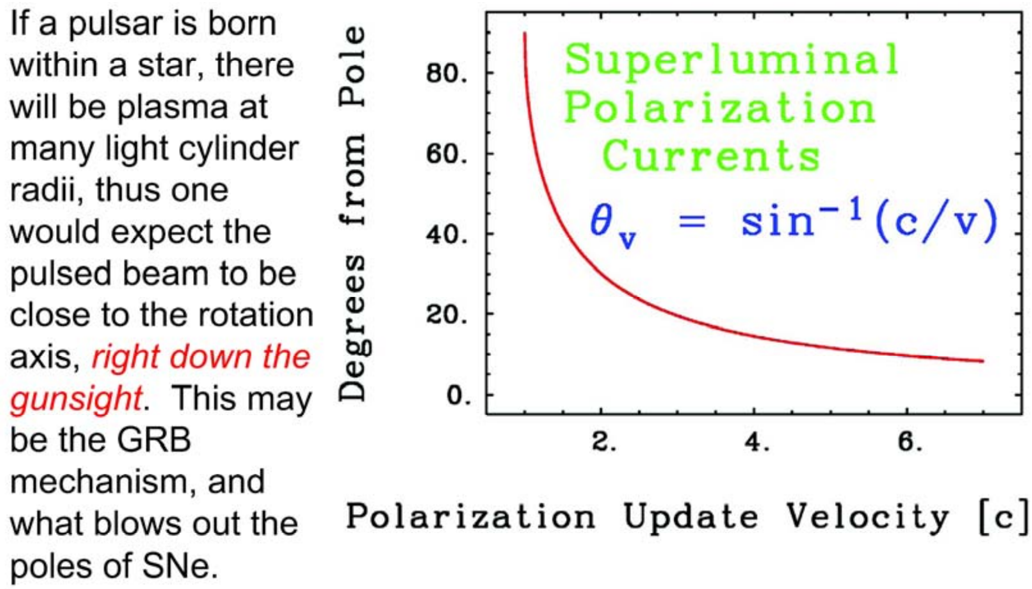


Fig. 6. The reason why SNe are bipolar is because of what the pulsar within them does in the 1st few months. Pulsars are a significant, and unignorable part of the SN process, and SN calculations are orders of magnitude more difficult than ever imagined.

The pulsations propagate out on the cone of half angle, θ_v, somewhat like a bedspring. This half angle may have caused the 30° misalignment between 87A's bipolarity and normal to its equatorial ring.

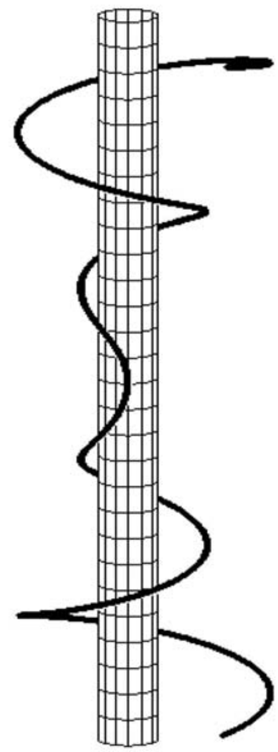


Fig. 6.5

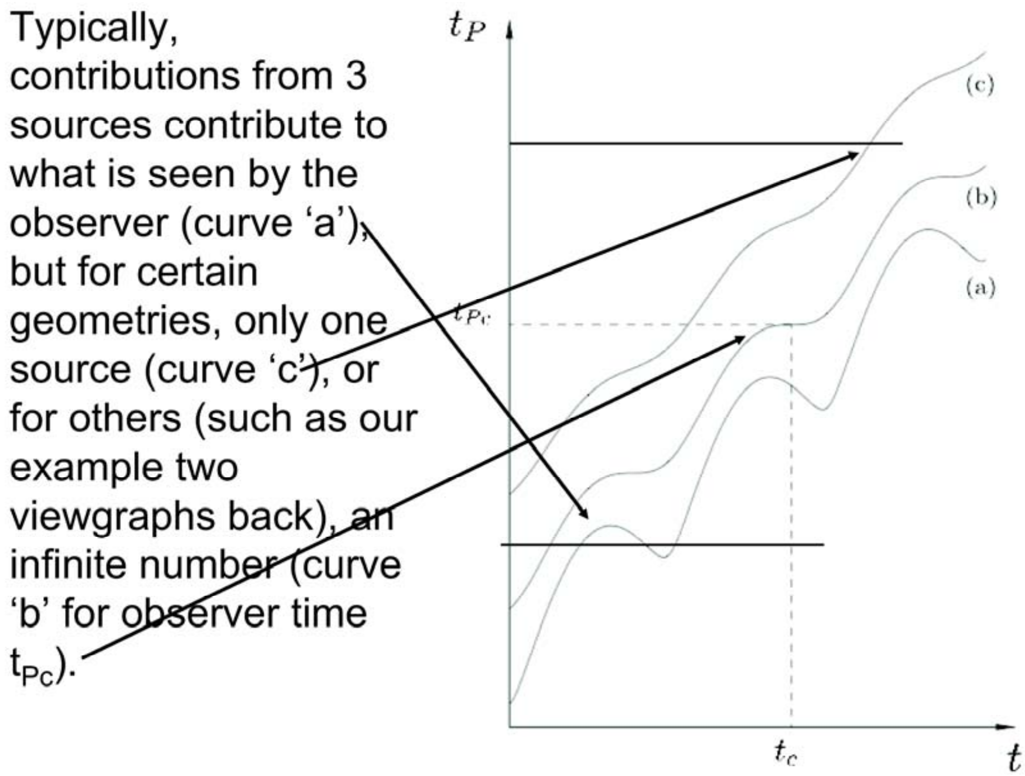


Fig. 7. For curve (b), a time source of finite dimension, (1) contributes to a single time (dimension 0) for an observer. Thus the 1/distance law goes on *forever* for the cusp -- the further away the observer, the more source contributes to the signal.

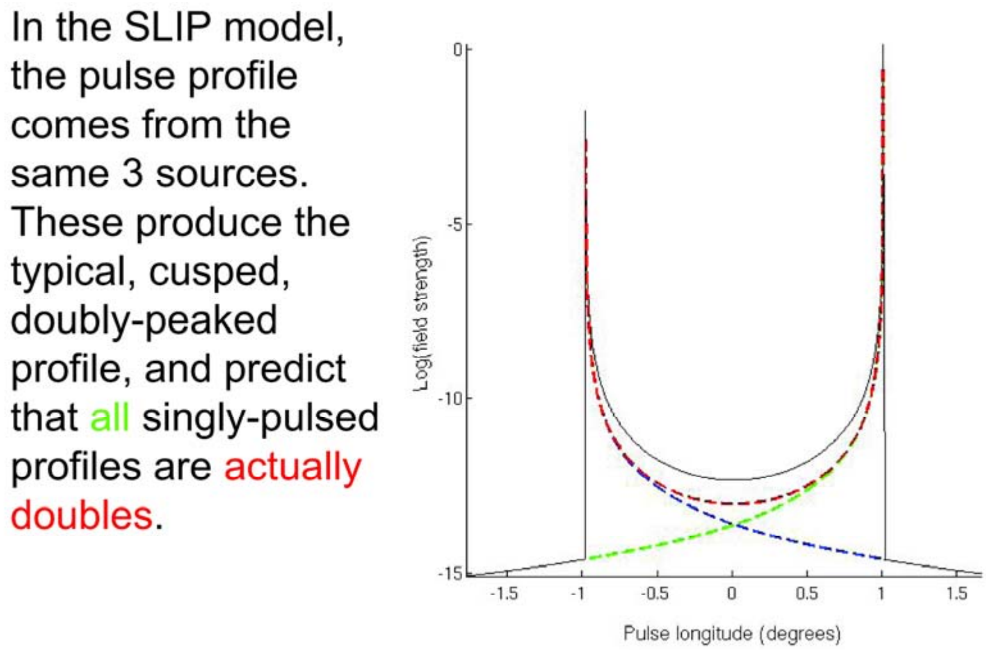

In the SLIP model, the pulse profile comes from the same 3 sources. These produce the typical, cusped, doubly-peaked profile, and predict that all singly-pulsed profiles are actually doubles.
0
-5
-10
-15
Log(field strength)
-1.5
-1
-0.5
0
0.5
1
1.5
Pulse longitude (degrees)

Fig. 8

The pulse profile of PSR J0537-6910 (16.1 ms) tends to progressively split, if allowed, over successive iterations which generate a new master fitting pulse each time, consistent with the prediction of the SLIP model. Proving this is meaningful will be the hard part.

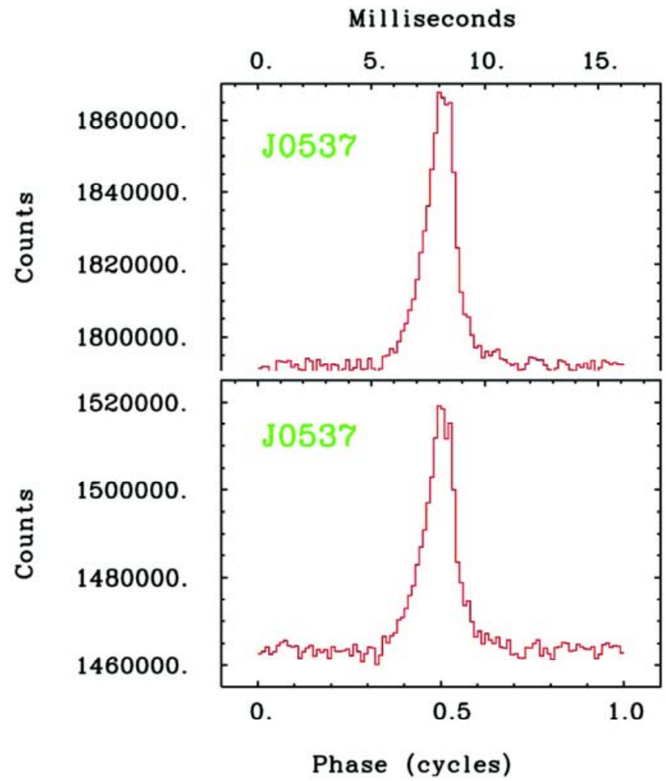


Fig. 9

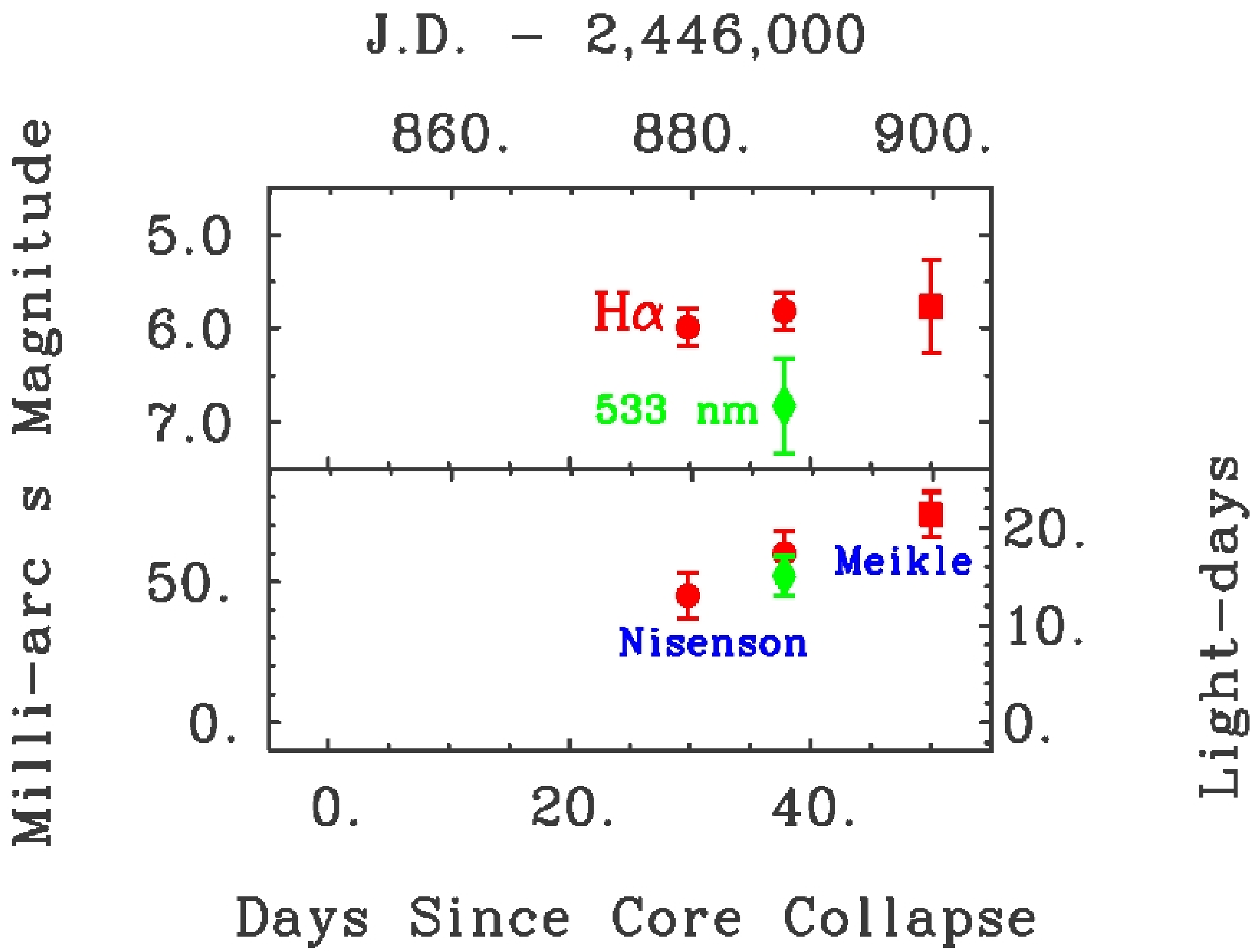


Fig. 10. Measurements of displacement (lower) and observed magnitude (upper) of the “Mystery Spot” (MS) from SN 1987A, at Hα and 533 nm, vs time, from Nisenson et al. 1987, ApJ, 320, L15, and Meikle et al. 1987, Nature, 329, 608.

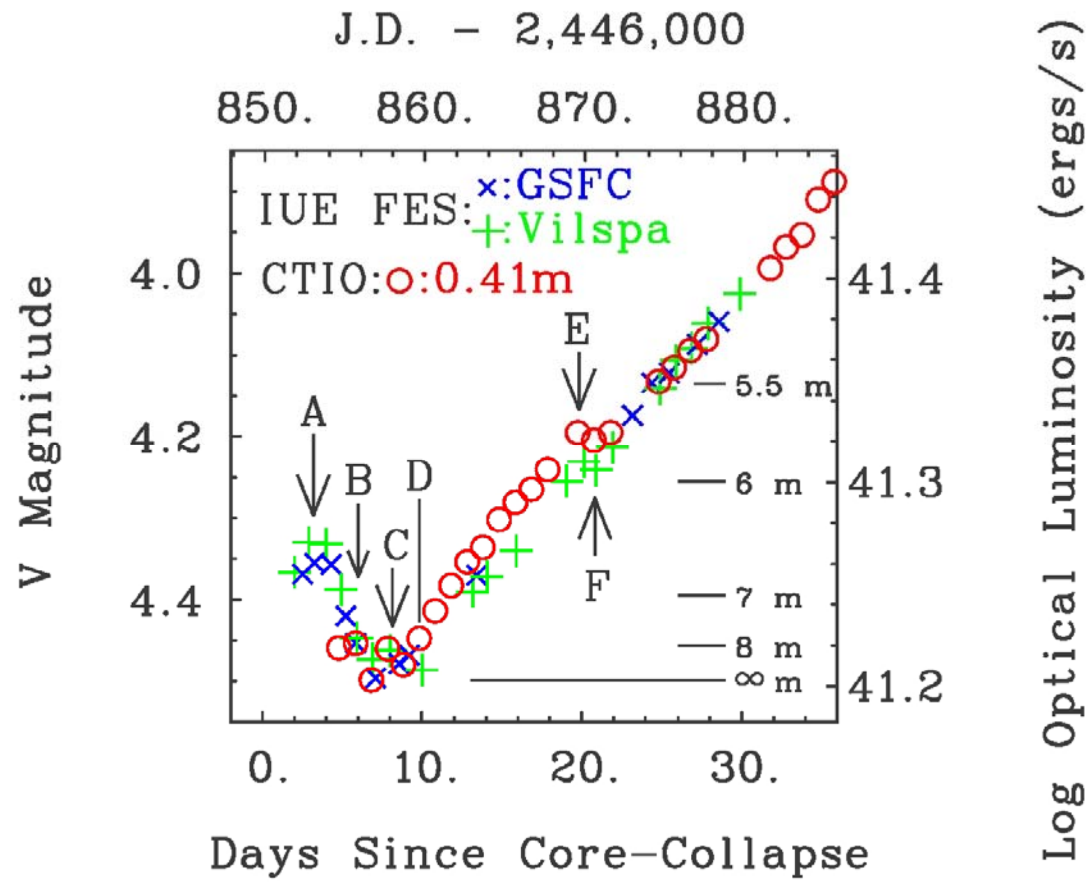


Fig. 11. After Hamuy & Suntzeff 1990, AJ, 99, 1146, and Wamsteker et al.1987, A&A, 177 L21, the very early luminosity history of SN 1987A as observed with the CTIO 0.41-m and the Fine Error Sensor of IUE. Data taken at Goddard Space Flight Center by Sonneborn & Kirshner, and the Villafranca Station in Madrid, are marked as blue x's, and green +'s, respectively. Various stages of beam/jet breakout and interaction with polar ejecta are labeled. The flux level near day 20 corresponds to 5.8 magnitudes above the day 7 minimum, the *same* (see Fig. 10) as that of the MS in Hα measured near days 30, 38, and 50.

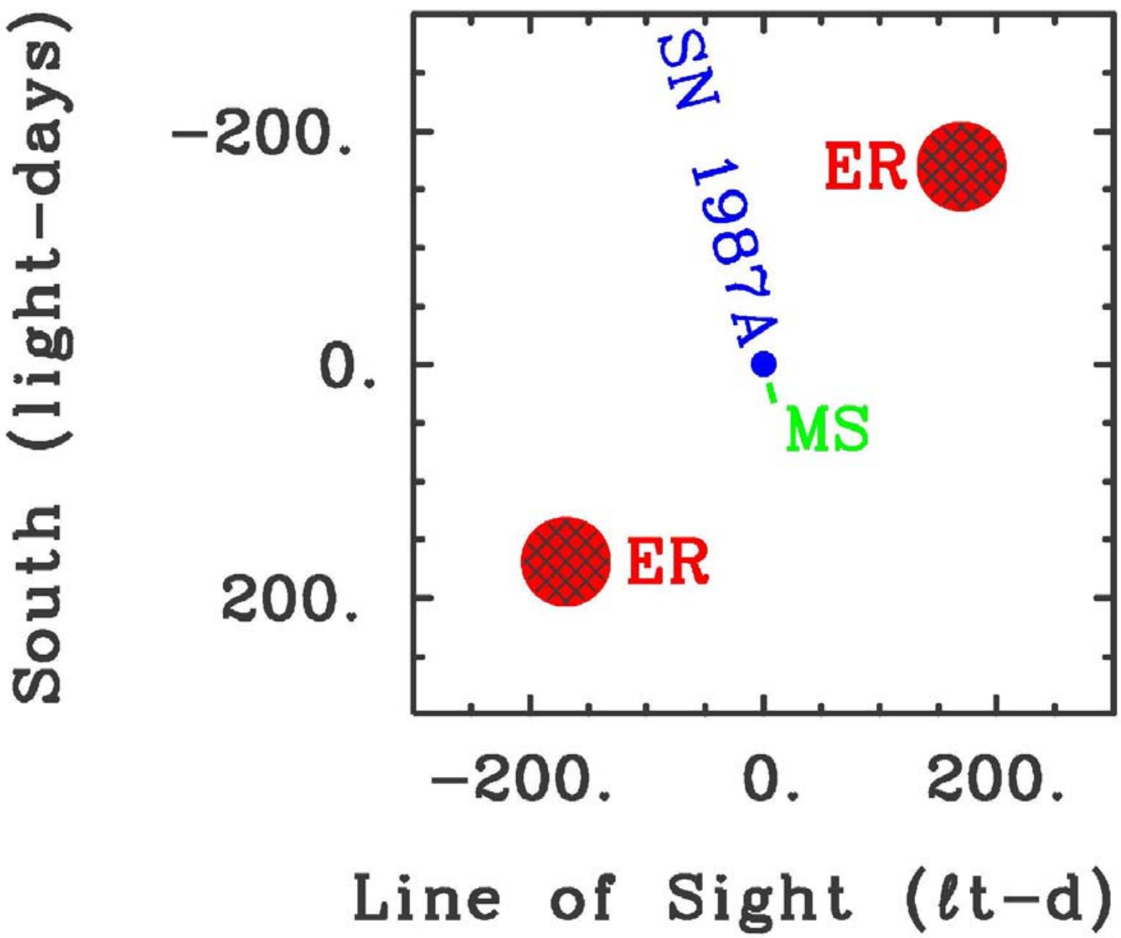


Fig. 12. The approximate path of the "Mystery Spot" (MS) relative to SN 1987A and the equatorial ring (ER -- shown in cross-section).

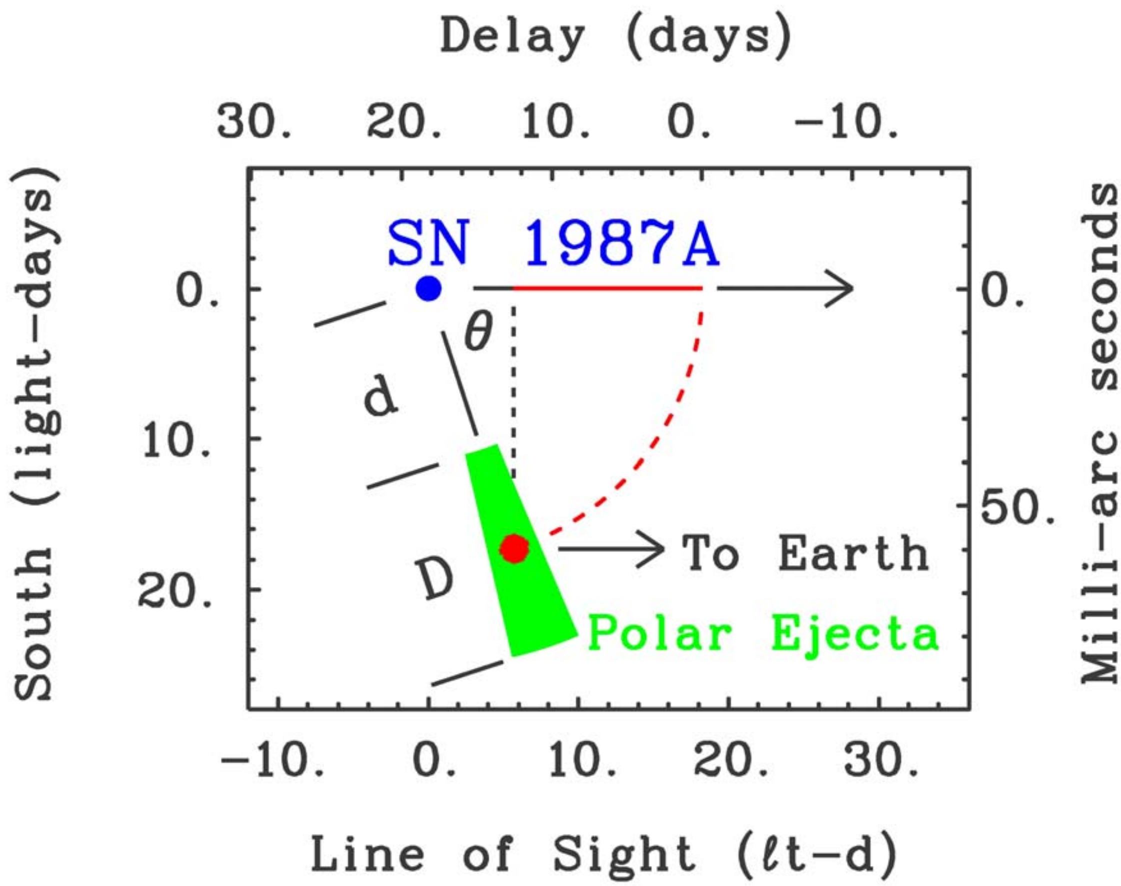


Fig. 13. The geometry of the "Mystery Spot," (MS – red dot) associated beam/jet, and direct line of sight from SN 1987A. It takes an extra *8* days for light from 87A to hit the polar ejecta (PE – an extra *13* days to the PE midpoint), and proceed on to the Earth. The distance from 87A to the MS, at day 30, is ~20 light-days. An offset by the 0.5^{o} half collimation angle of a GRB over this distance would delay the flux by about 100 s, the characteristic delay for long duration, soft spectrum GRBs (**ℓ**GRBs).

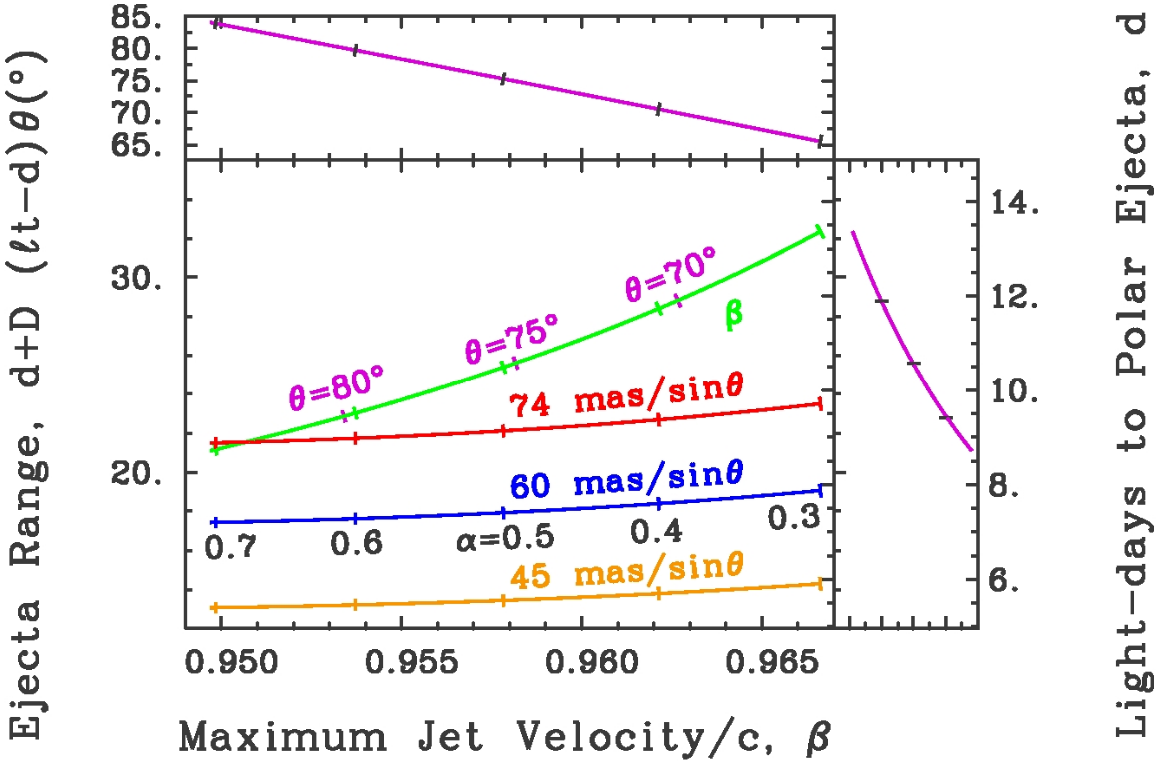


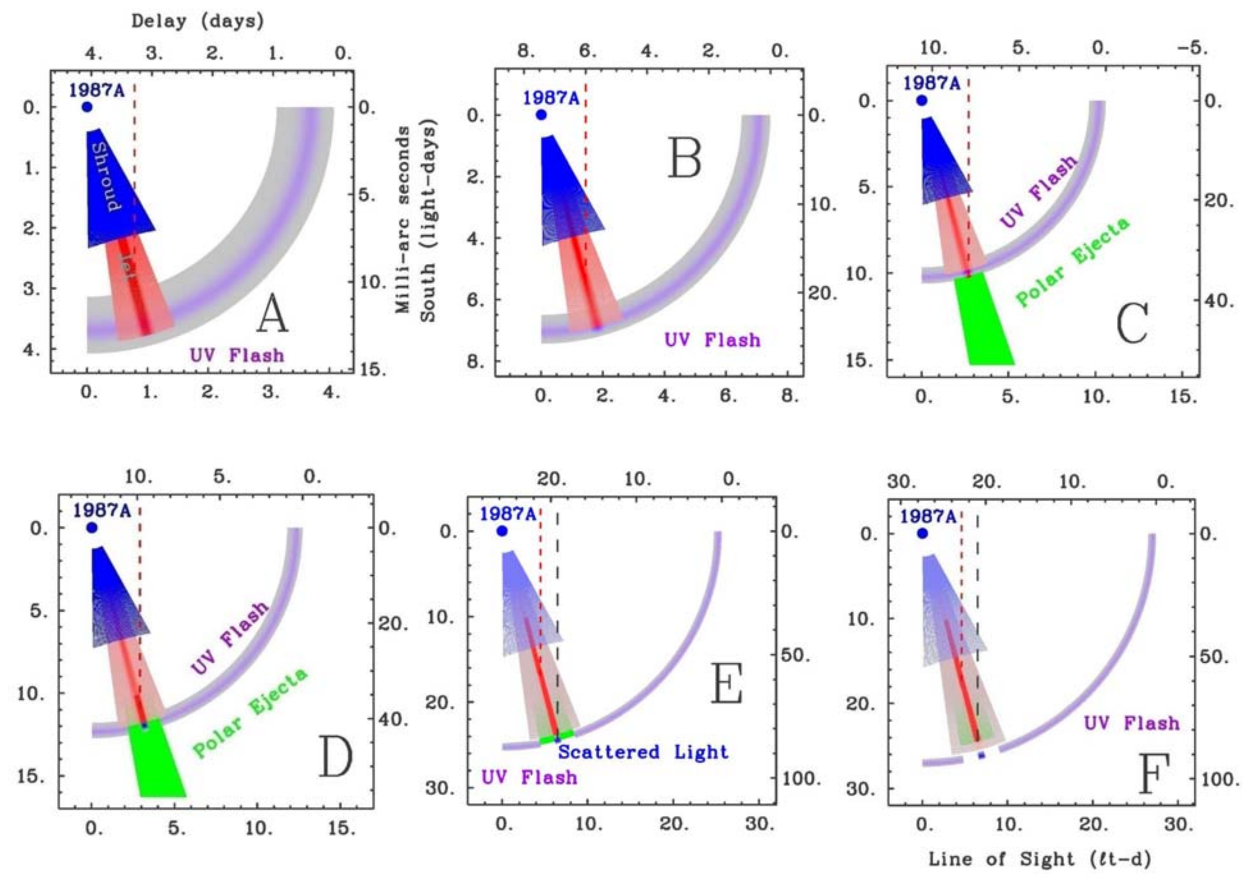
Fig. 14. We solve for the geometry of the beam/jet (green curve) from SN 1987A (as diagrammed in Fig. 13) using the constraints shown in Figs. 10 and 11. Here α is the fraction of the way through the polar ejecta that the Mystery Spot had penetrated at day 37.8, when its projected offset from SN 1987A was 0.060 arc s. The solution for α=0.5 gives:

$\theta = 75.193^{o}$,

d = 10.47738 ℓt-d,

D = 14.888 ℓt-d,

$\beta_{max} = 0.9578$.



The progression of the beam and jet from SN 1987A for times corresponding to Fig. 11. At ‘A’ the beam and jet expand freely. By ‘B’ the jet expands and cools, or loses the ability to do so, resulting in a diminishing luminosity. At ‘C’ the beam impacts the polar ejecta (PE) and reprocesses, producing an impulse of light. By ‘D’ the jet has penetrated into the PE, producing another uptick of light following the decay of the 1st uptick at day 7.8. By ‘E’ the beam has broken through the PE and scattered light produces yet another uptick of light around day 19.3 or so. In another day, the jet has cleared the PE, resulting in a decrement of the light near day 20.8. The 1 day lag out of in 20 means that the fastest jet particles are moving at 95% of the speed of light.

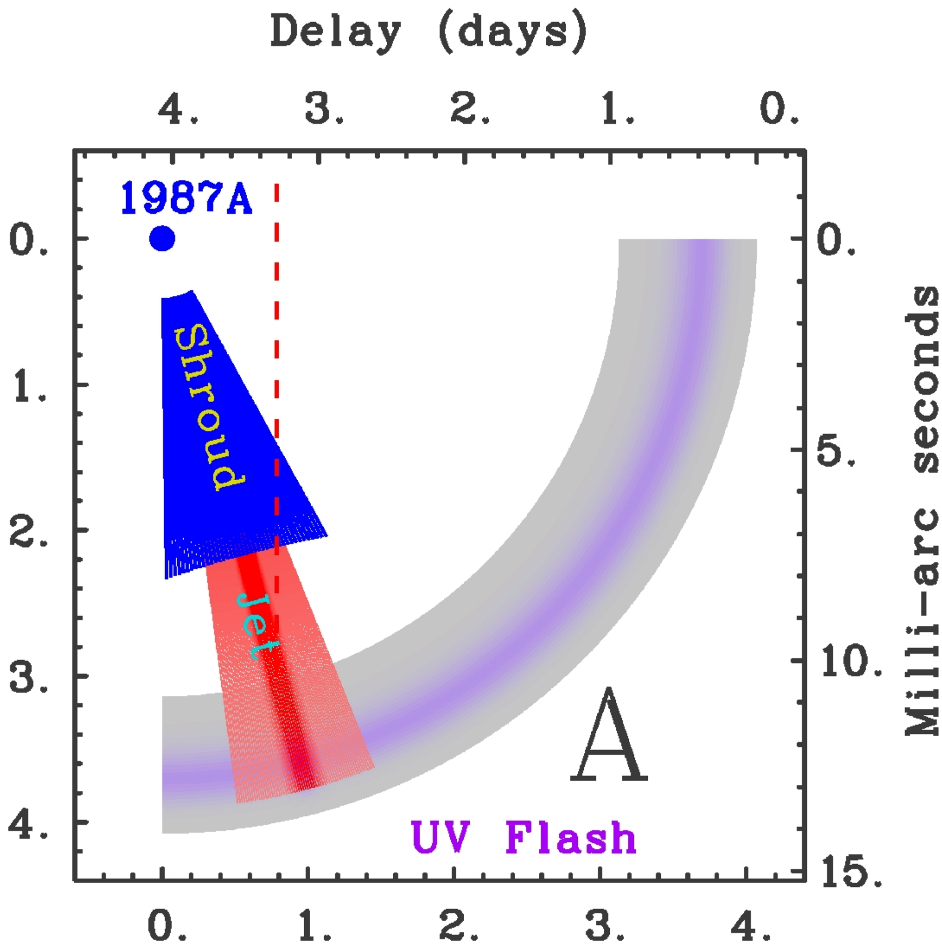


Fig. 15. The geometry of the 87A glowing beam/jet (BJ), initially opaque shroud, and UV Flash (which may have an enhanced beam of its own in the jet direction (here 75^o, down and to the right). The center of the emerging jet produces the rising luminosity shown in Fig. 11 at day 3.3 (read on the upper, delay scale). The maximum velocity of the jet is 0.95 c. That of the shroud, was arbitrarily set to 0.55 c. Because of the short time response of the luminosity shown in Fig. 11, the full angular width of the jet has been set to ~1^o.

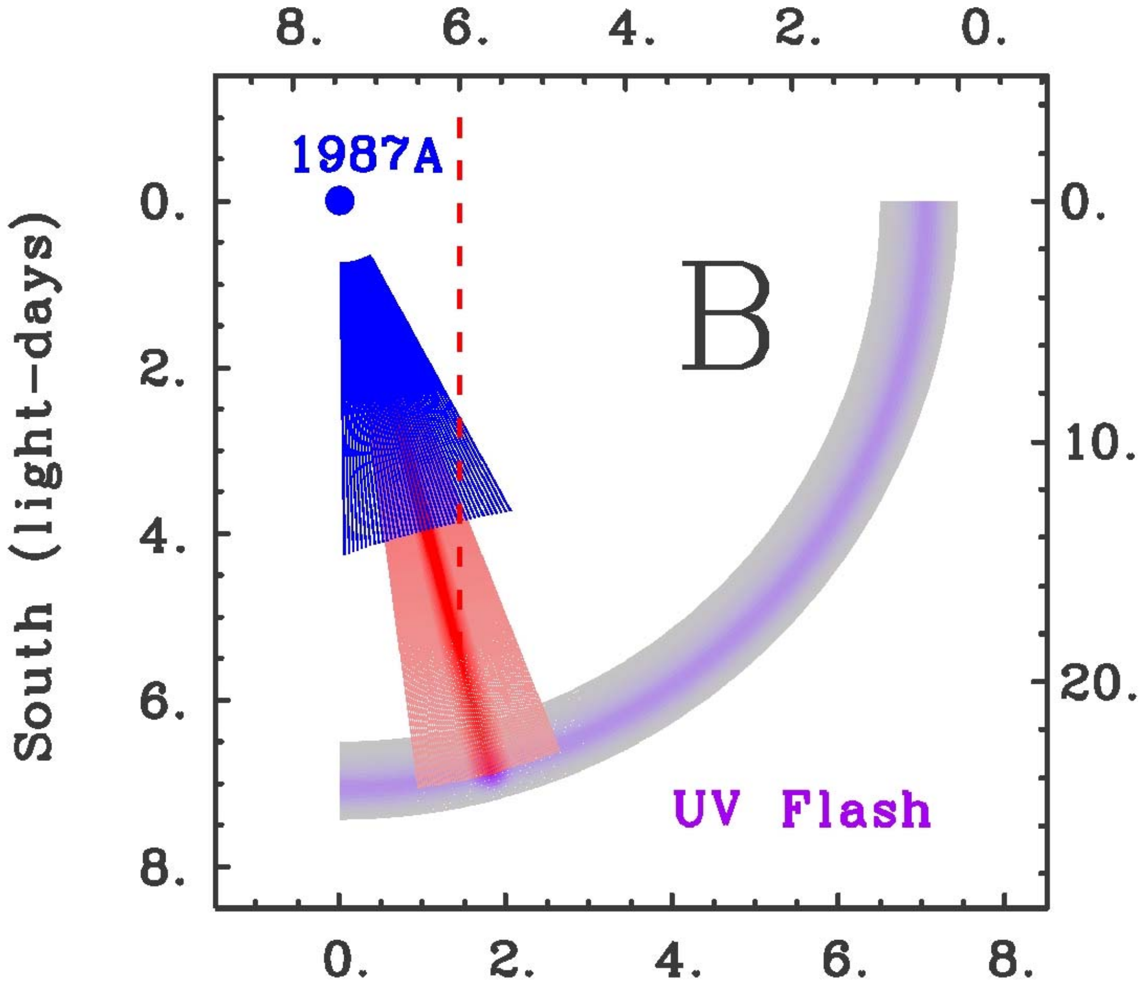


Fig. 16. The configuration in which the light from the center of the exposed part of the now fading jet lies on the dropping luminosity curve at day 6 (point ‘B’ in Fig. 11).

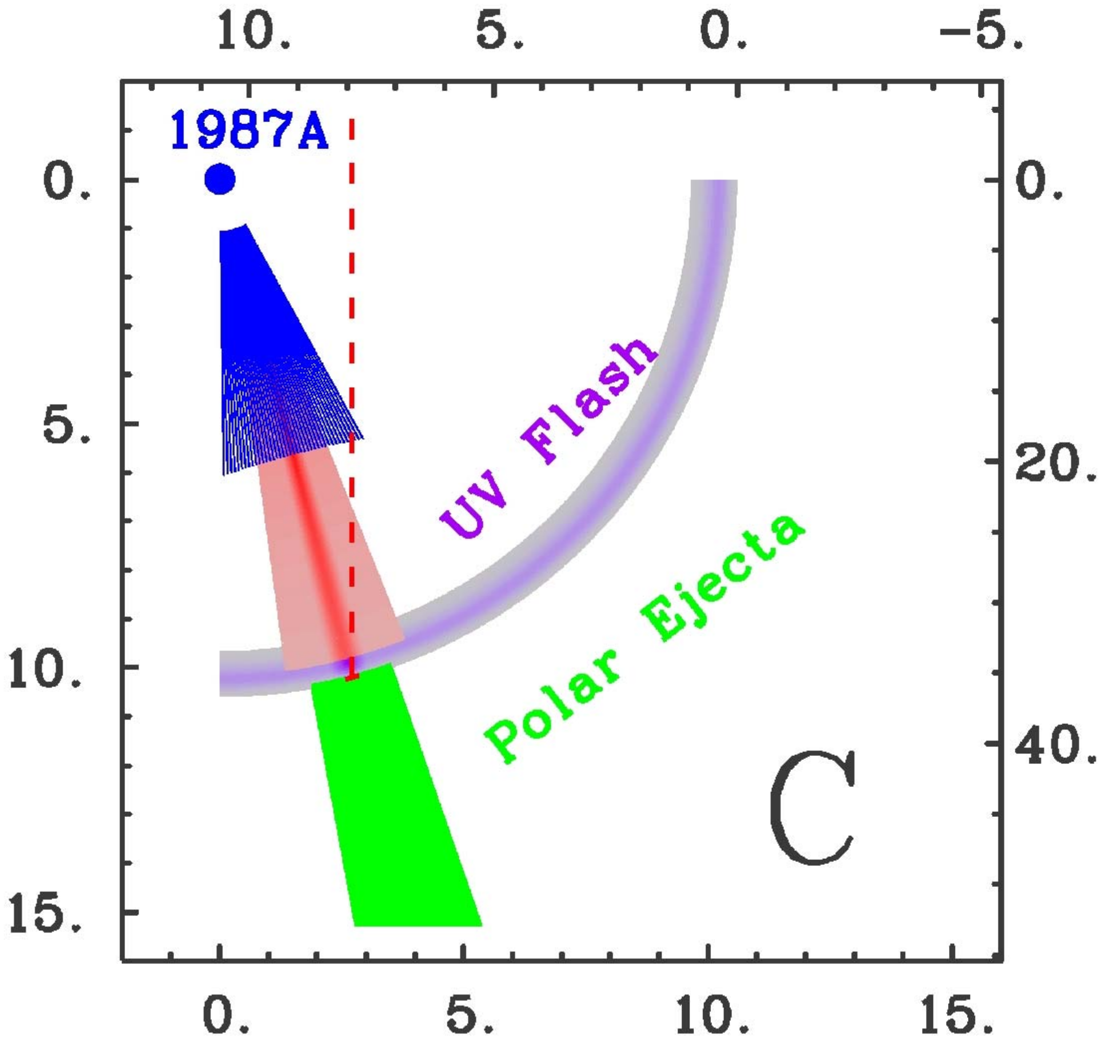


Fig. 17. The intense beam from the pulsar scatters and reprocesses off the polar ejecta (PE), producing the jump in luminosity at day 7.8 (top scale for the tiny red disk in the PE and ‘C’ in Fig. 11 – ~2x10^{39} ergs/s for a day). A polar ejecta density of 10^7 cm^{-3} would predict that the UV Flash part of the beam does not penetrate it deeply, and this is confirmed by the dropoff of luminosity near day 9 in Fig. 11. The tiny red disk corresponds to the highly collimated (~1^o) intense pulsed beam, and can not be much larger all because of the fast rise/drop in luminosity before/after day 8 in Fig. 11, and thus its collimation factor is >10^4.

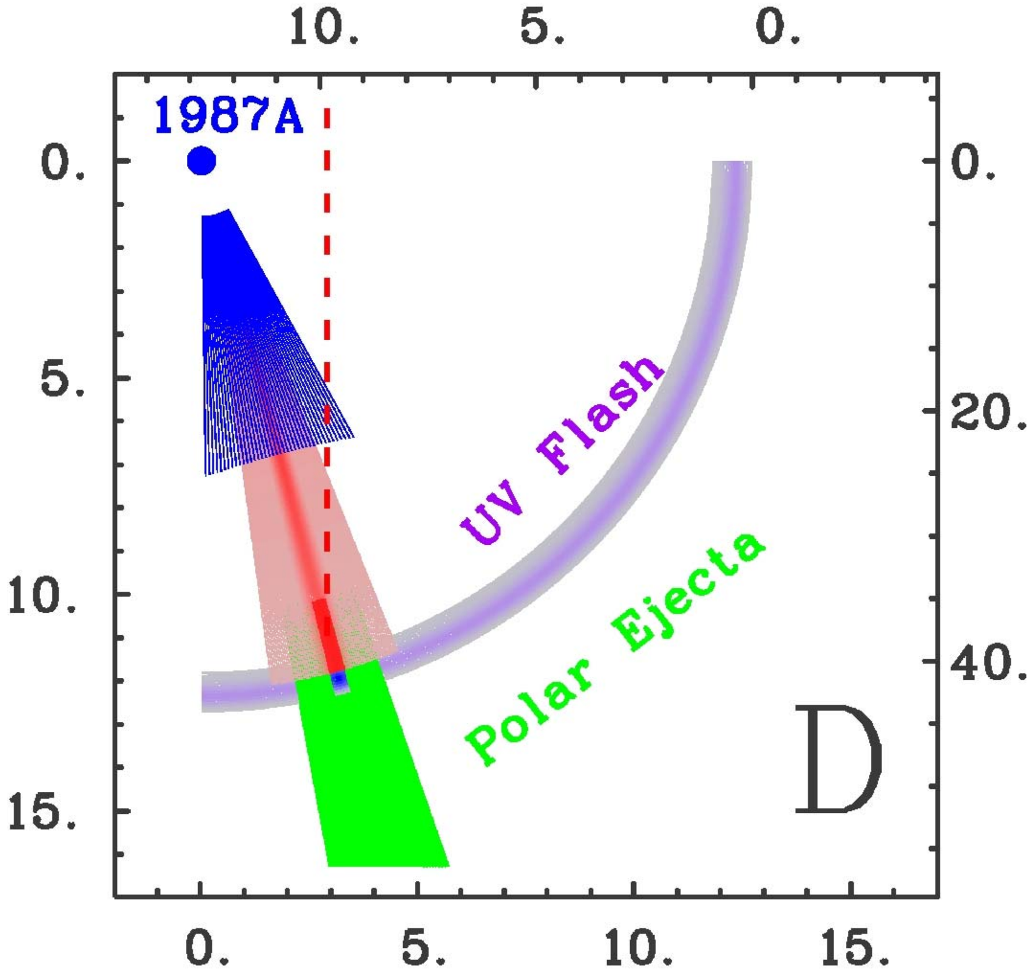


Fig. 18. The intense center (~1^{o}) of the jet begins to produce light (red) as it penetrates into the polar ejecta (green), producing the jump in luminosity at day 9.8 (again, top scale for the intense red column in this figure [18]), visible in Fig. 11 for the same time. The penetration may continue because the cross sections for this process are orders of magnitude smaller than for the UV Flash. The collimation factor for the jet is also $>10^4$.

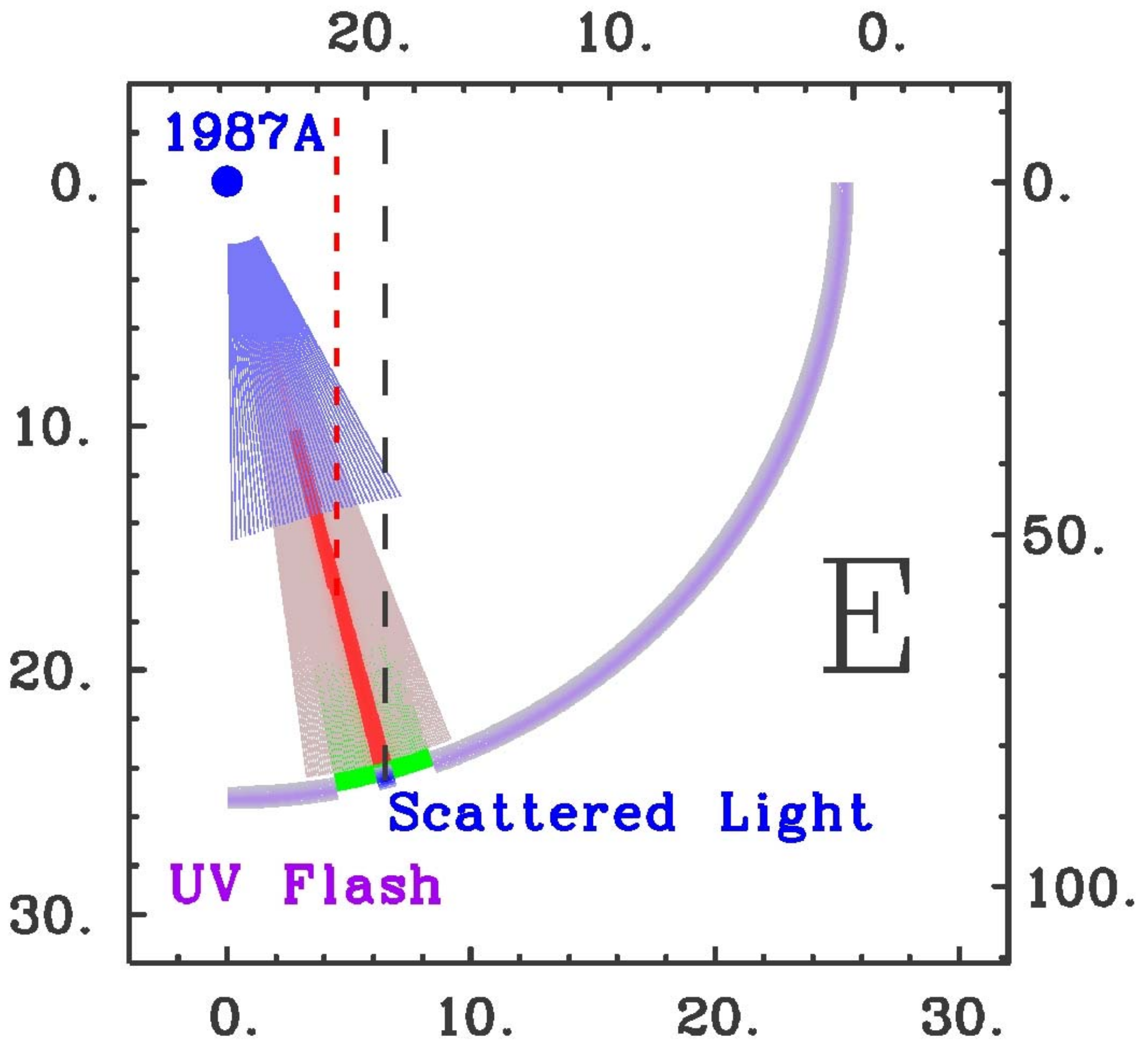


Fig. 19. After filtering through the polar ejecta, the enhanced pulsed beam breaks free, but still scatters off of some remaining clumps, producing excess light, in the B, R, and I bands observed near day 19.2 (black dashed line to upper delay scale), visible in the next figure.

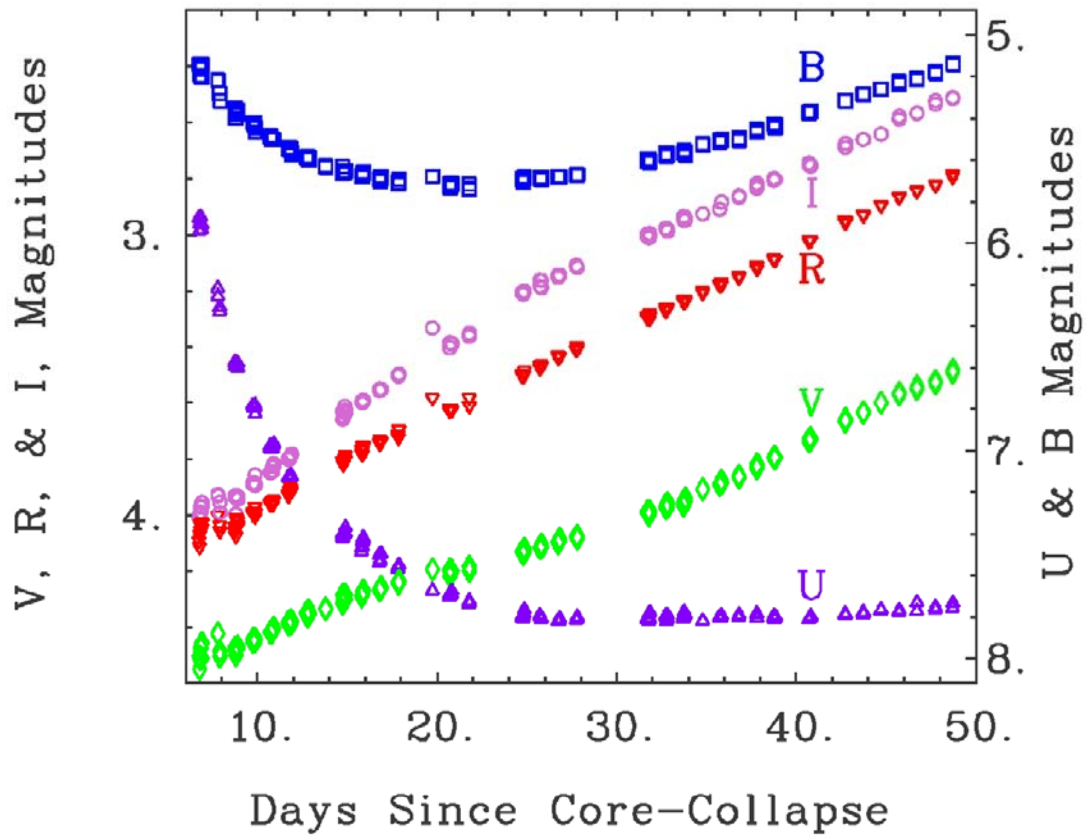


Fig. 20. The photometric data from the CTIO 0.4-m telescope plotted against time for days 6-50. Excess light in the B, R, and I bands was observed at day 19.8, but was also observed in the same bands in spectra taken by Menzies et al. (1987) on day 19.50, and Danziger et al. (1987) on day 19.76 (and this might have been the case for the previous day for which there is no available data). V band light is only slightly enhanced, and U band light is slightly suppressed. The R band light is associated with an enhancement of the Hα line, and the B and I band light matches the colors speculated for the 2.14 ms signal from SN 1987A seen by Middleditch et al. (2000). The excess light visible in Fig. 11 for day 19.8 can be used for a lower limit estimate for the isotropic luminosity of 10^{40} ergs/s for the 2.14 ms pulsations.

Scaling up 5th magnitude by just 1/distance from 8 Gℓt-y to 25 ℓt-d gives -22.7 m, 1/100th of solar radiation. Scaling 10^{40} ergs/s by 1/distance to 25 ℓt-d would be a solar constant of 600. At 41 ℓt-yr, by 1/distance, this would be reduced to one solar constant. Scaling this back to 8 Gℓt-y by 1/distance gives magnitude -6. On two occasions Howard Bond has seen two 2nd magnitude transients, which reddened as they faded, likely optical GRB AGs.

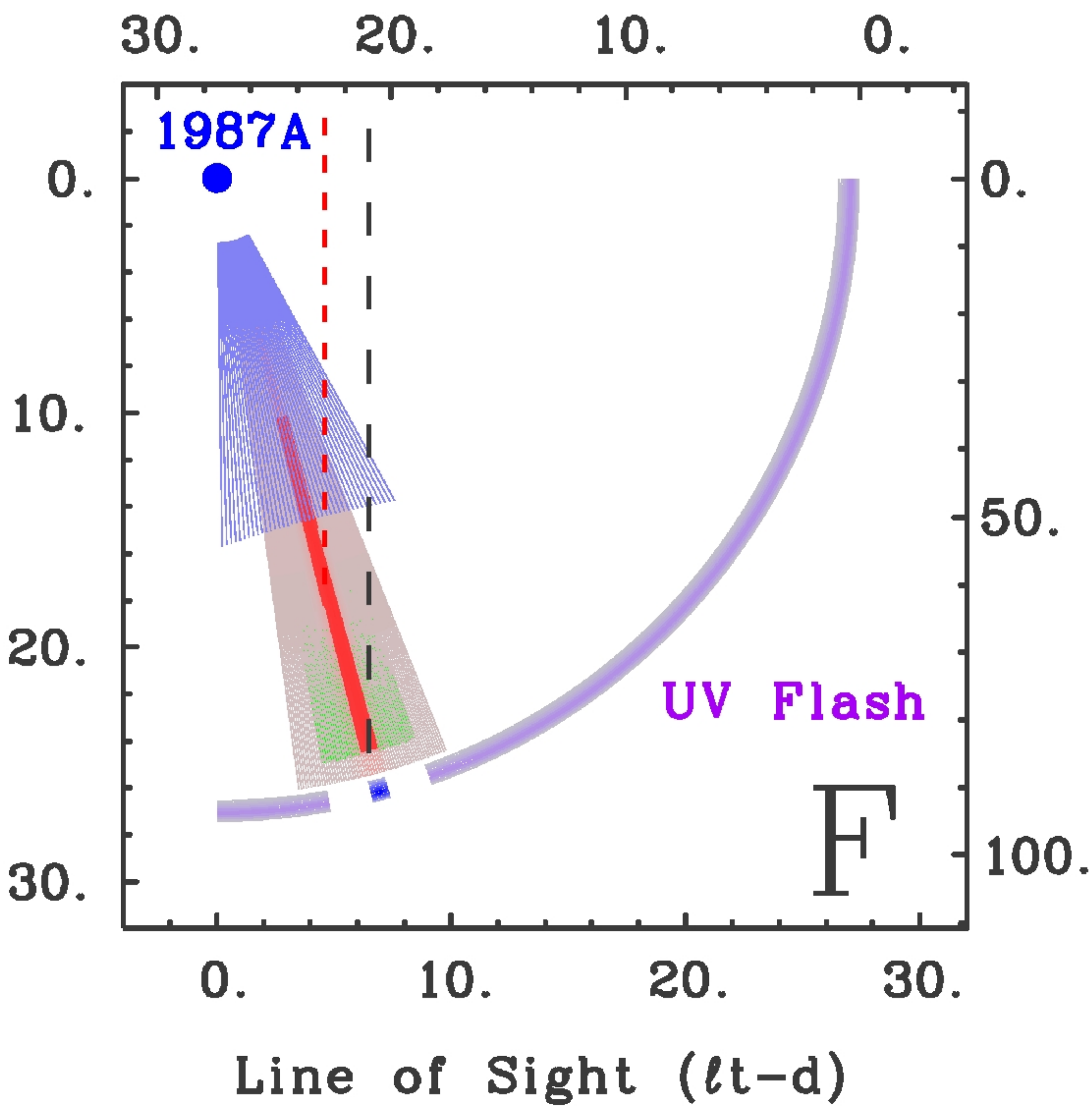
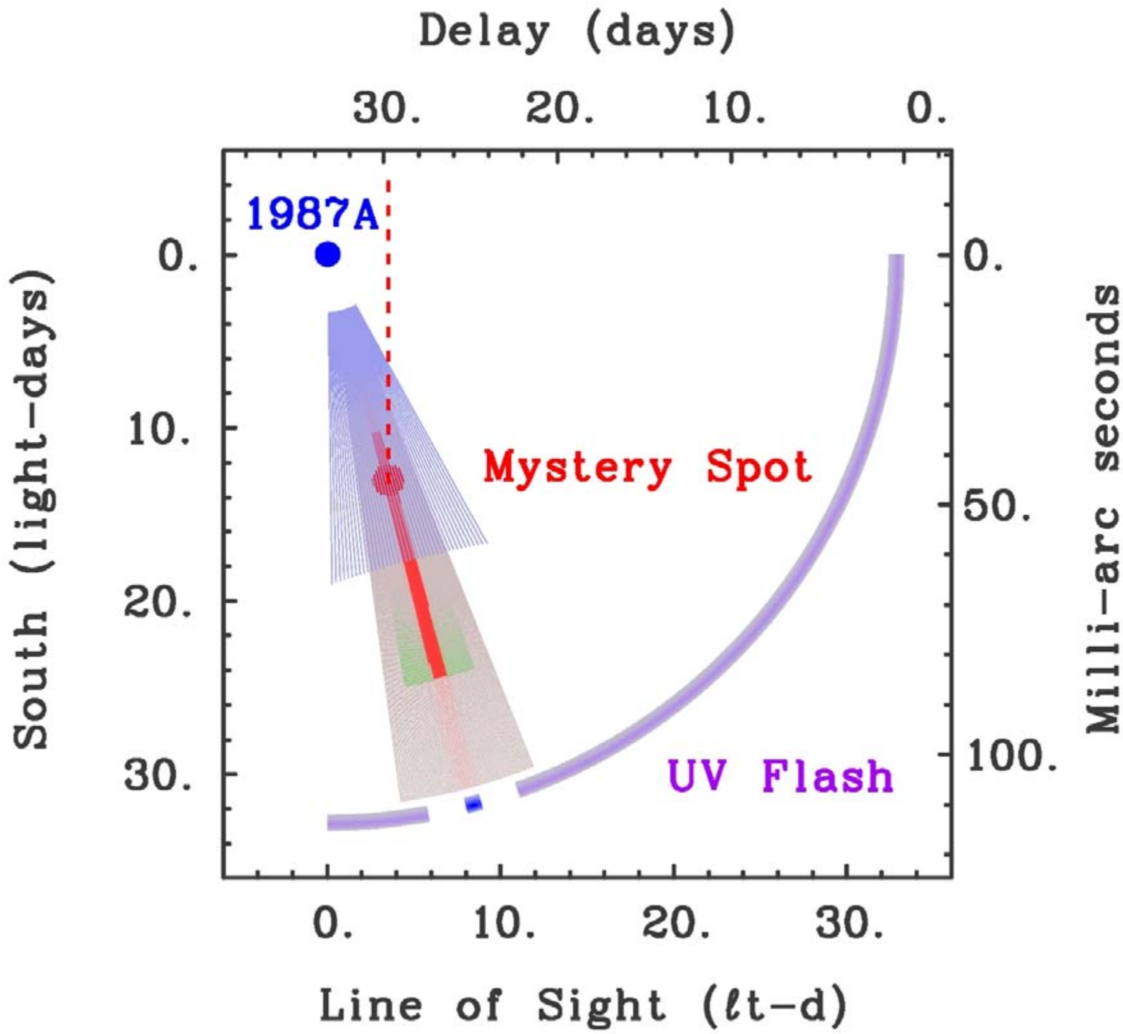
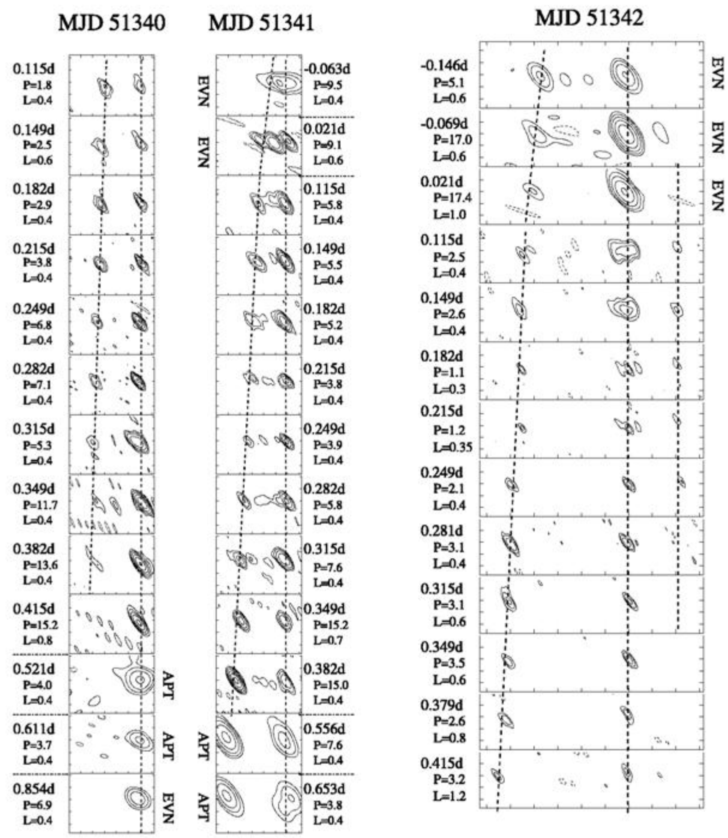


Fig. 21. Particles in the jet begin to clear the polar ejecta (mostly hidden green cone section), producing the decrement in luminosity visible in Fig. 11 near day 20.8 (top scale for the black dashed line in *this* figure [21]). A luminosity decrement, possibly indicating particles clearing the polar ejecta, appears in Fig. 11 just after this time (black, dashed line to top scale). Each of the polar jets contains as much as $2x10^{-5}$ $M_{\odot}$, and this can result in a spindown of 10^{-5} Hz/s for a pulsar spinning at 500 Hz.



Particles continue to inject energy into the Mystery Spot (MS) around day 30, where its offset from SN 1987A was 0.045 arc s. Rather than a luminous strip, the Mystery Spot has become a more spherical plume. Penetration into a very deep (~13-14 light-days) polar ejecta is consistent with the MS offset measures plotted in Fig. 10. There is no hard limit on its width at this late stage. The Mystery Spot was also observed on days 38 and 50. The mean velocity of the MS from day 30 to 38 was 0.5 c, from day 38 to day 50 was 0.35 c.

Sco X-1 is known to have a jet, (Fomalont et al. 2001, ApJ, 558, 283). Because of the short (18.9 hr) orbital period, the companion star is expected to be an m- or white-dwarf; the accretia will be supercritical and contain heavy elements, allowing boosting to occur. Its features move at 0.3 to 0.57 c, and energy must be transported at 0.95 c or greater. This is the same as the 87A Mystery Spot&jet!



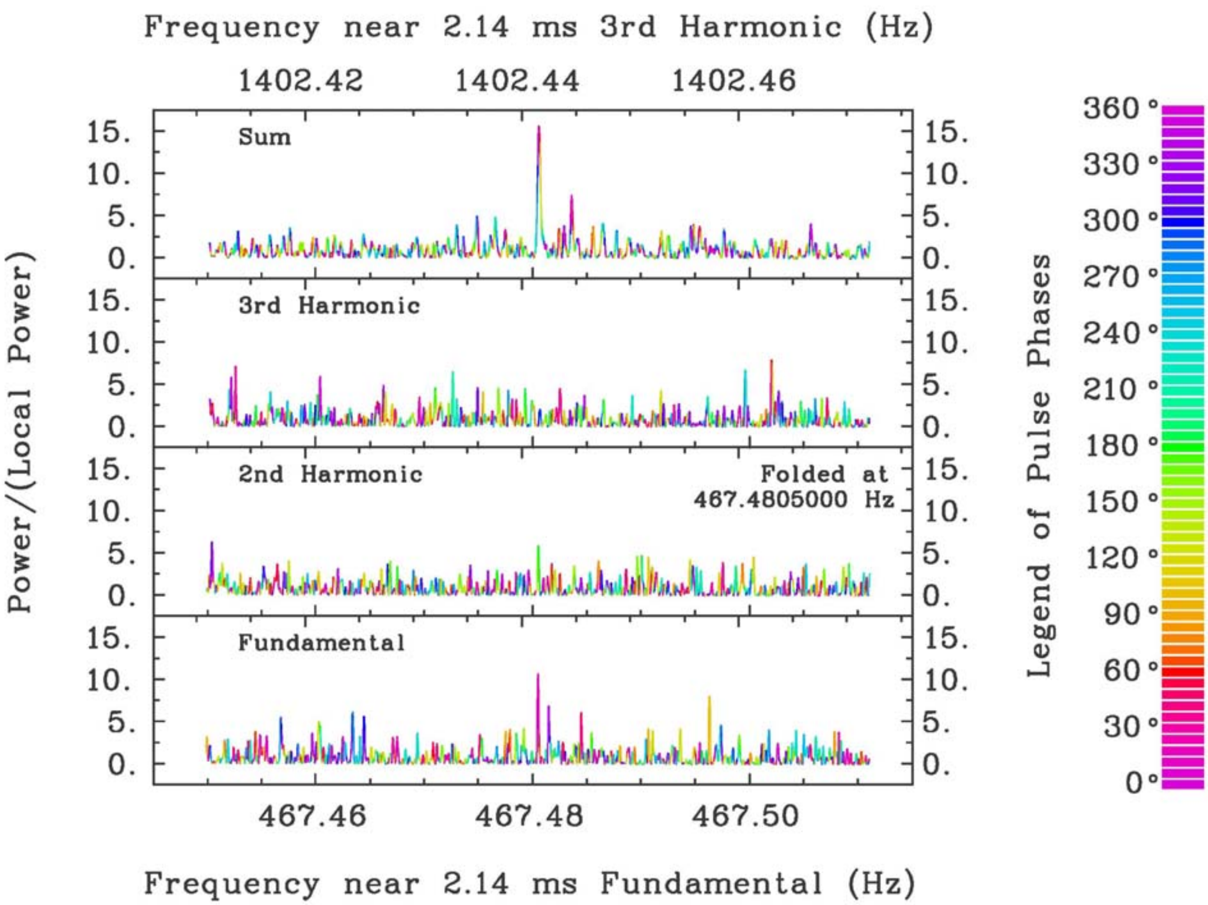
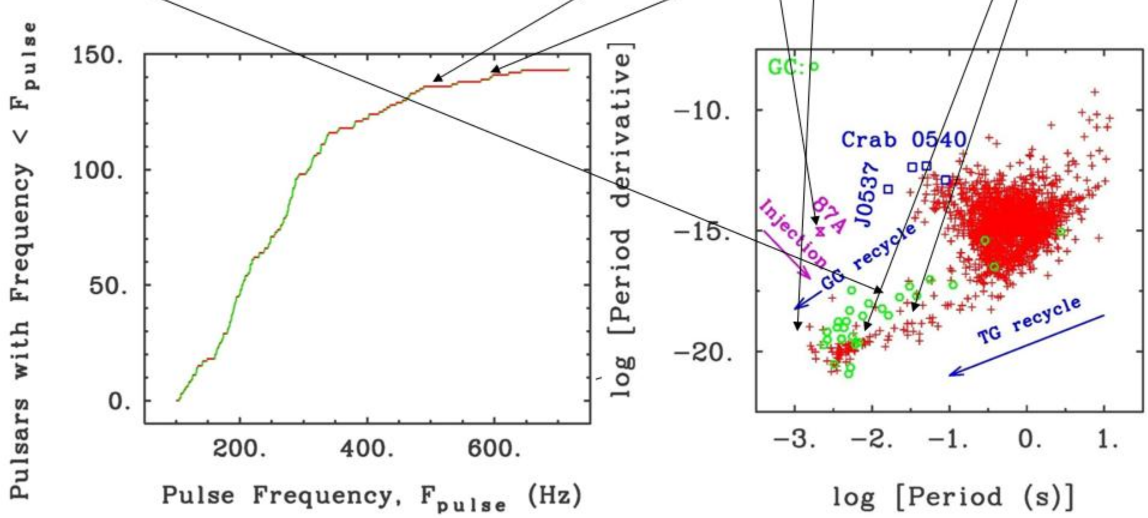
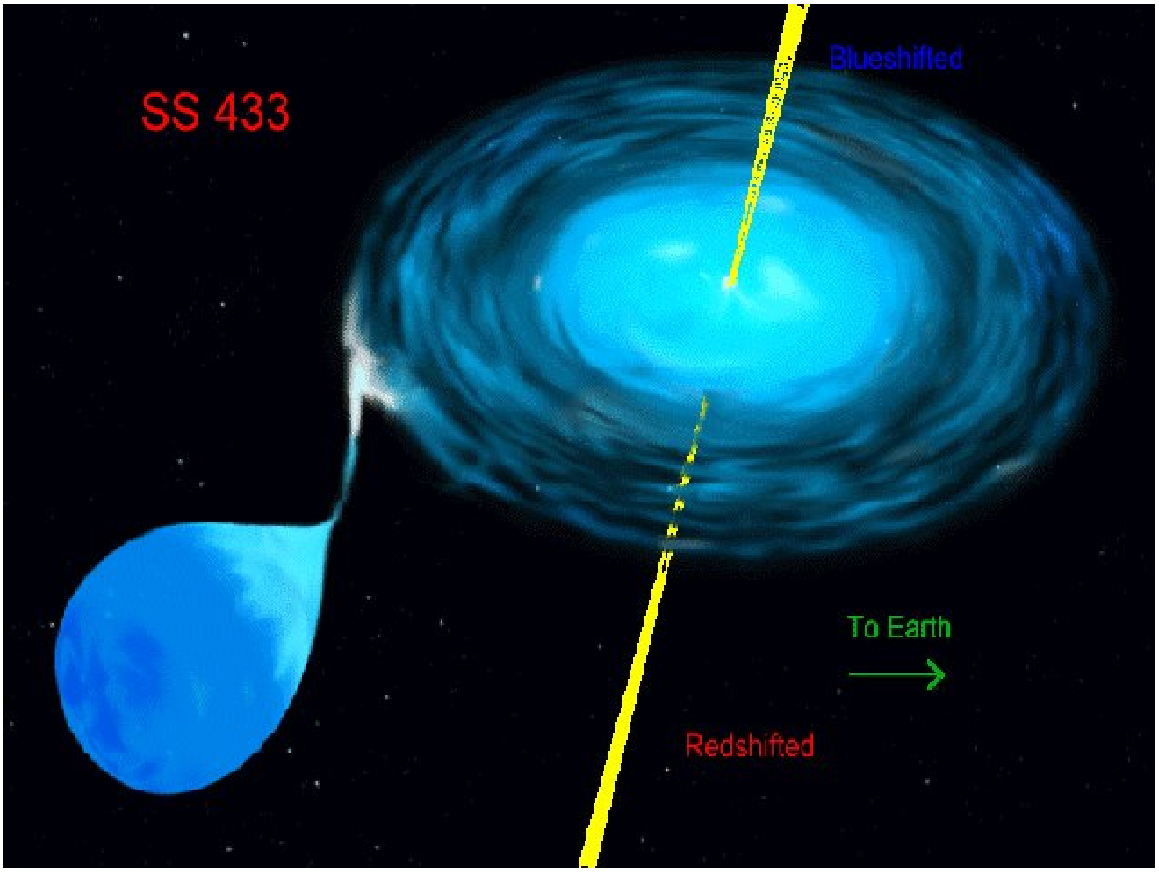


Fig. 23. The 2.14 ms signal (top = fundamental + 2nd harmonic), from observations with the Mt. Canopus 1-m Tasmania, was consistent with the LCO 2.5-m Wratten 87 magnitude of 21. After 1993, August 23, the probability that the 2.14 ms signal was not real was 10^{-10}. The fact that the pulsar is not visible now, in spite of any amount of wishful thinking on the part of many, only means that it ran out of plasma, and has entered the Cas A phase. That is the *boundary condition* for these objects, as 99% of SNe, near enough to tell, show no evidence of a non-thermal source at late times (1986J is the exception). The real questions to be answered were: Did a pulsar ever appear, and if so, when and why, and what did it do to the progenitor star? The SLIP model has answered these questions satisfactorily.

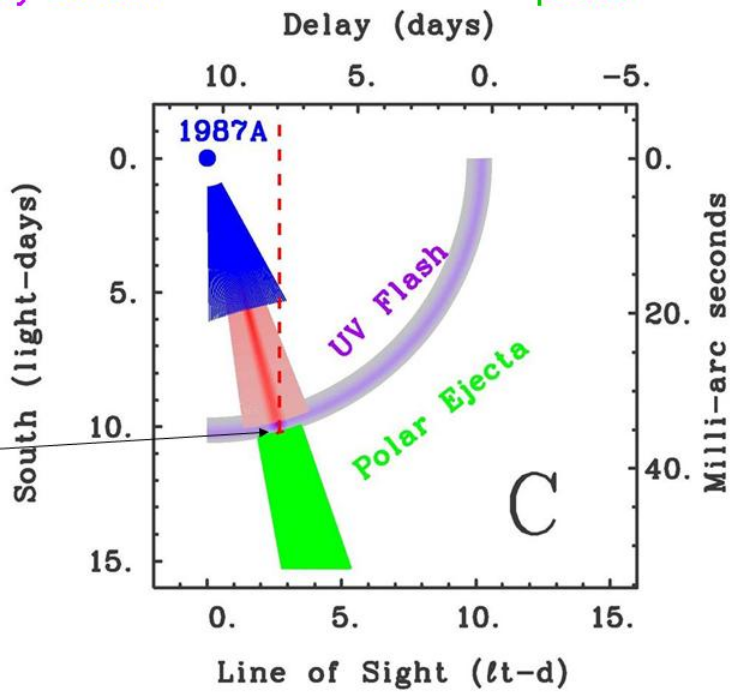
If the 2.14 ms signal from SN 1987A is real, most pulsars are born spinning with periods near 2 ms, and these may slow drastically during the first few months following the SN. The statistics of pulsars spinning faster than 100 Hz bear this out: there's a gap of nearly 45 Hz at 500 Hz. A few pulsars are recycled to spin rates > 500 Hz. Most just spin down. The main spinup/down paths differ:





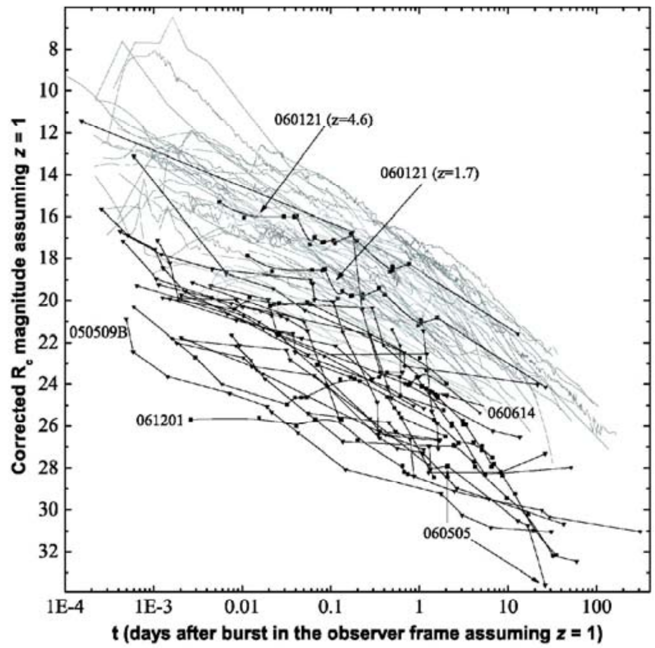
(From www.dstrange.freeserve.co.uk/ss433.htm)
Fig 23.5. SS 433's jets are likely also driven by a weakly magnetized millisecond pulsar, but unlike in SN 1987A, immersed in a hydrogen-dominated plasma, which limits the redshift to 0.26 c, when Lyman recombination to the ground state changes to L_α. The rarity of this object is due to a weakly-magnetized, millisecond pulsar being in a binary system with an early-type O or B star (ordinarily the companion to such a star would also have a high mass, ultimately producing a strongly-magnetized neutron star). The low mass X-ray binary, Scorpius X-1, also produces jets which, as with SN 1987A, also transport energy at velocities up to 0.95 c, because its neutron star's accretia may also be high in metals, again as with SN 1987A, because its companion may be an M-dwarf (estimated by size restrictions).

GRBs may be caused by scattering of the original pulsar-generated gamma-ray beam on the start of the polar ejecta, which acts as a flat screen. The excitation may spread, super-luminally, from the initial center of scattering, in concentric annuli of increasing radii -- Ardavan+Volegov. This pattern also produces an inversion of the distance law.



The T_{90} & small angle delay of ~100 s agree.

From Kann & Klose, Proc. 2007 Santa Fe GRB Conference. They write: "…, and once again, nearby afterglows were less luminous than more distant ones." Does this sound familiar? Afterglows are pulsars! The free lunch! Are GRBs themselves pulsed? Maybe not.

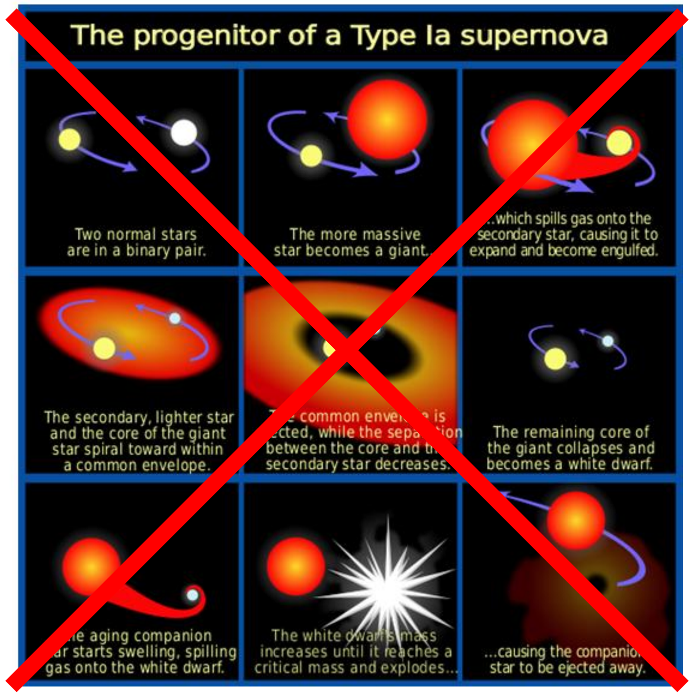


Pulsars, ALL!

Fig. 24. The premier prediction of the SLIP model is that gamma-ray burst afterglows will be essentially 100% pulsed.

The Demise of the Single Degenerate Paradigm

At ~5:30 p.m., on 21 Feb. 2007, at the SN 1987A 20 Years After, and Gamma-ray Burst Conference in Aspen, the question was posed: Is there any way of avoiding double-degenerate for these objects [Type Ia SNe]? There was no answer. Kirshner, Wheeler, & Fillipenko were all there. They also haven't said anything since then. This means that the thermo-nuclear mass left over from the merger can go to ZERO! No standard candle there until there's enough to encapsulate the ^{56}Ni e^+e^- γ-rays.



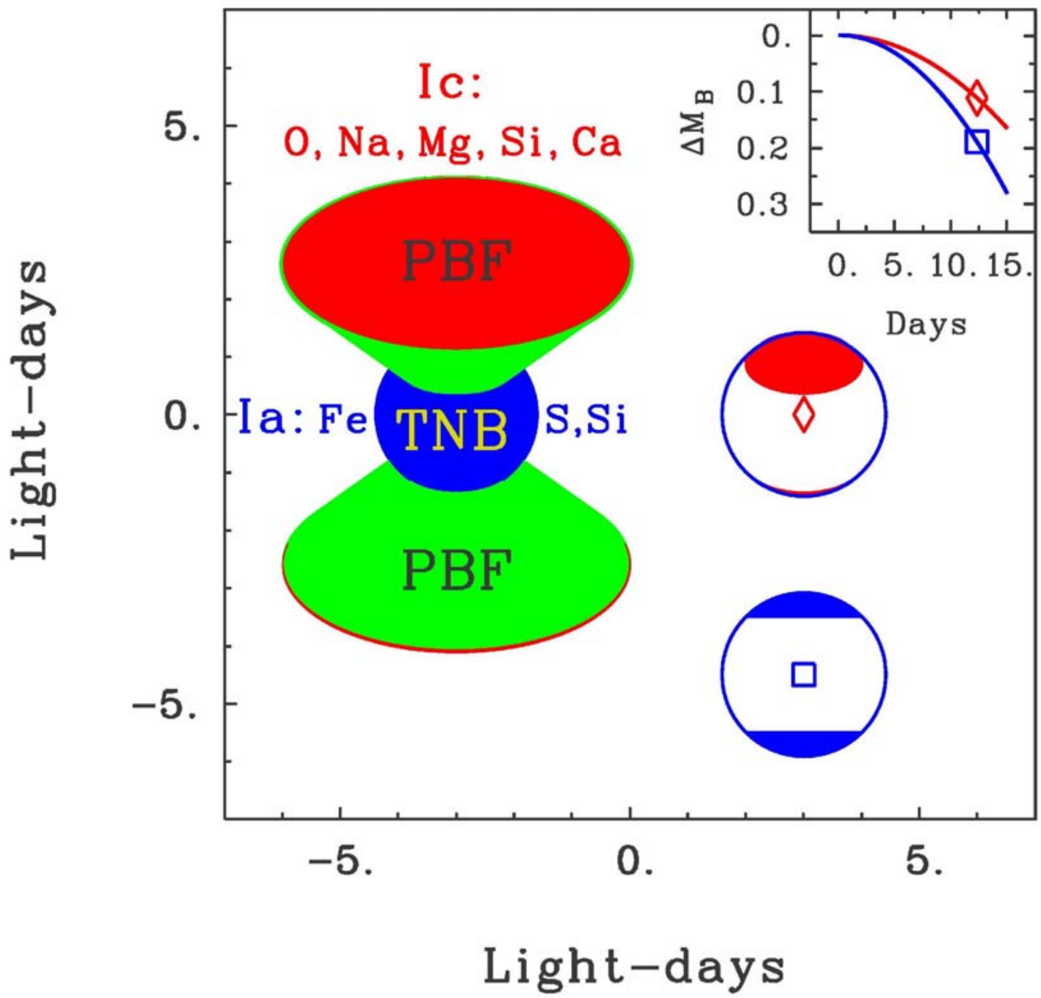


Fig. 25. In supernovae, the pulsar blows out the poles (PBF -- left hand figure), and it doesn't stop doing that until there is no material remaining around it. This is catastrophic to cosmology by Type Ia SNe, because the pulsar forces the thermonuclear ball (TNB) to remain *toroidal* for *all* of the lifetime of the SN, allowing much of the positron annihilation gamma-ray flux to escape from a much higher mass TNB than previously thought.

In addition, the width-luminosity magnitude drop is smaller than expected (still smaller than the red curve plotted in the upper right frame) because of the exposure of the rear, forward-looking face of the toroid, as the PBF thins in the weeks past maximum light of the SN.

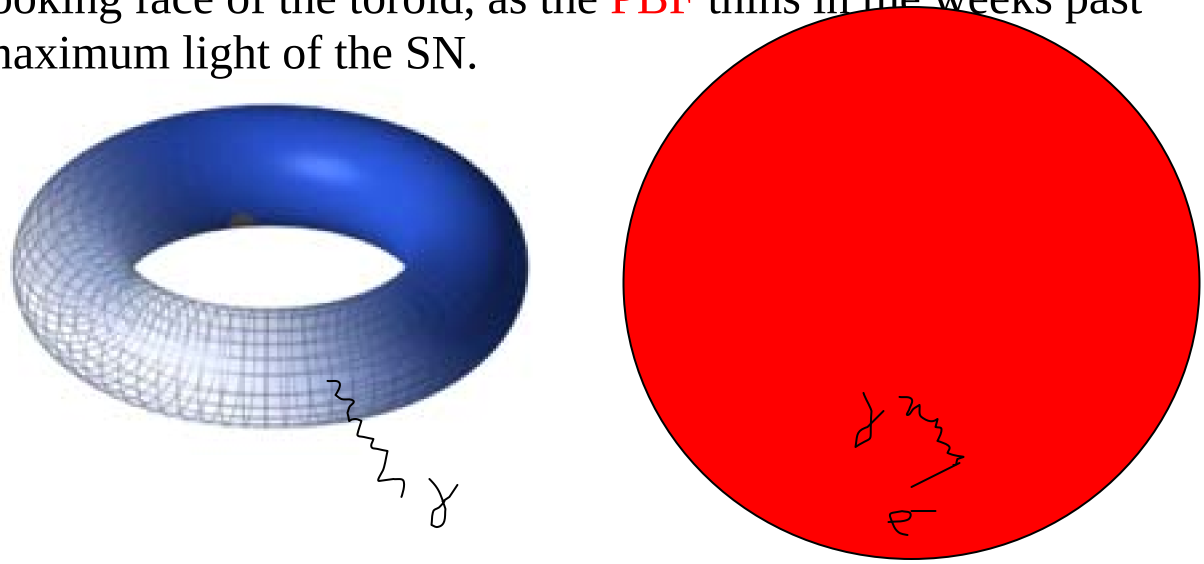
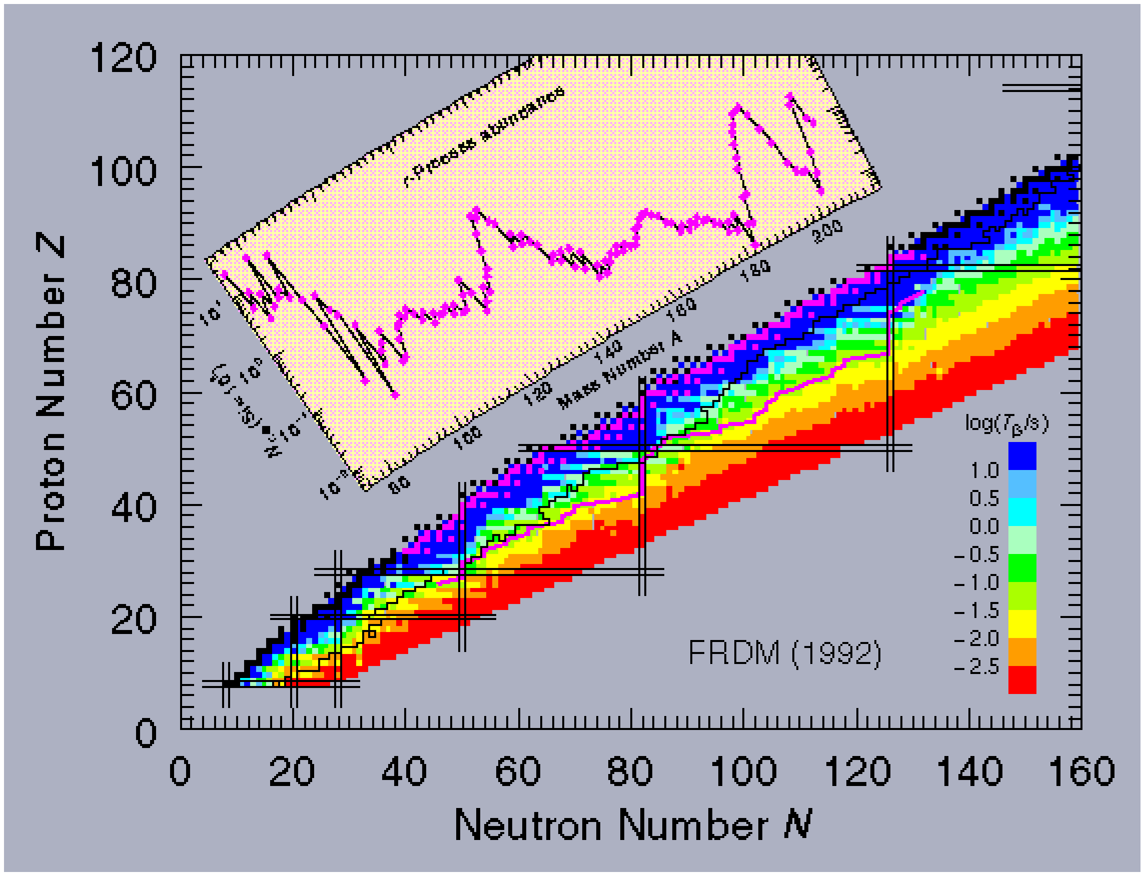


Fig. 26. SN Ia cosmology has failed because the equatorial toroid allows γ-rays to escape more readily than a spheroid of the same volume. Also, the material in excess of that lost to core-collapse can go to 0. Thus a population of Ia's exists that is not bolometric, and contaminates distant, but not local, samples.



Can pulsar-driven jets provide the r-process elements? Protons traveling at 0.95 c are destructive to heavy nuclei, resulting in spalled free neutrons, which, in turn, can be captured by other heavy nuclei, producing even heavier nuclei r-process elements. We don't know yet if the numbers work. (A plot of the nuclides contributing to the r-process and the resulting abundances is shown, superimposed on a representation of b-lifetimes. The small black squares are the stable isotopes, the black line represents the limit of the known nuclides on the neutron-rich side, and the magenta line below and to the right is a typical r-process contour. The small magenta squares show the nuclides that are produced when the r-process line decays.) Courtesy of Guided Tour of the Nuclear Information Service at Los Alamos

Positrons from the decay of ^{56}Ni to ^{56}Co in SNe are acclerated to multi-GeV energies by the directed pulsar beam (scattering) and jet (3 GeV protons, etc.) of a SLIP mechanism (figure from Adrianni et al. 2009, Nature, 458, pp 607-9).This could account for the excess observed above that expected from spallation of cosmic rays.

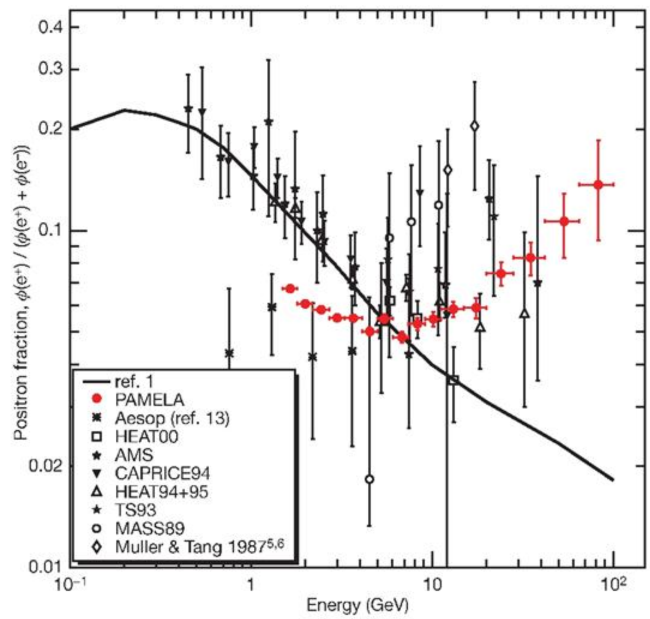
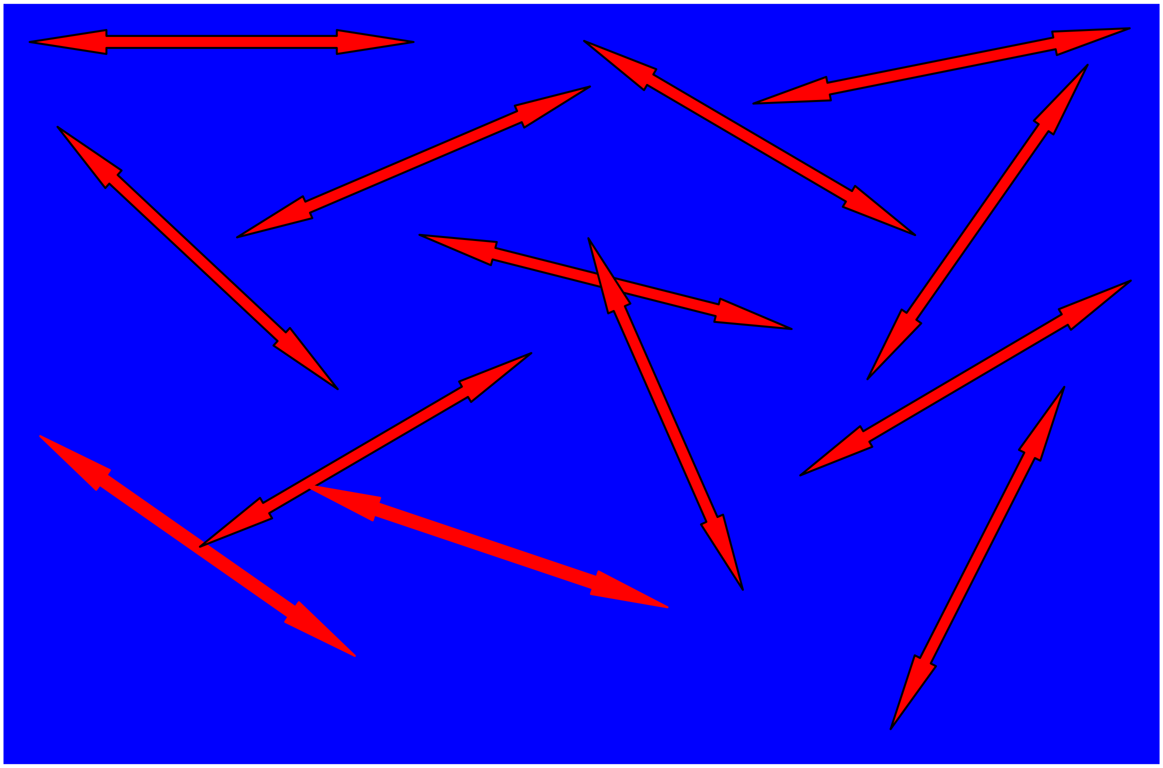
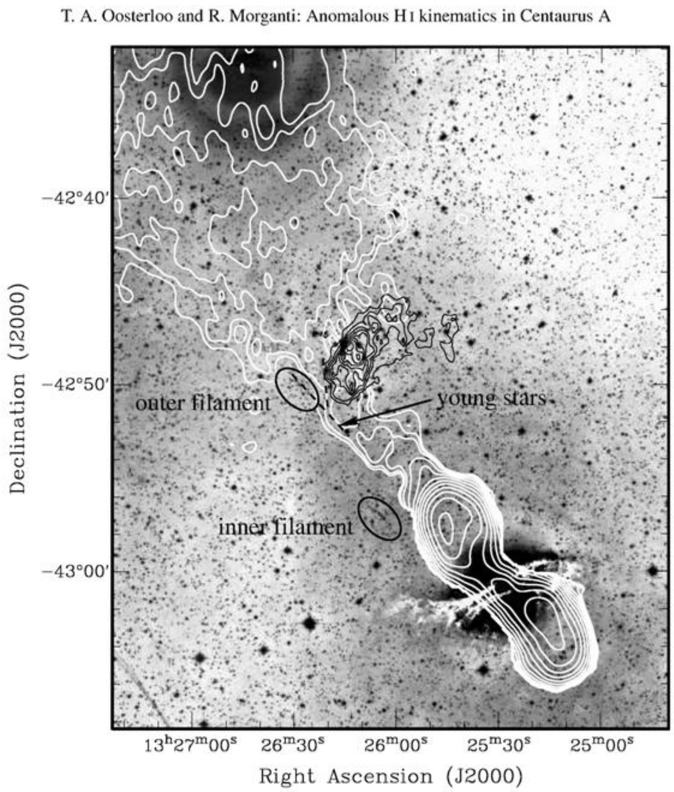


Figure 2 | PAMELA positron fraction with other experimental data and with secondary production model. The positron fraction measured by the PAMELA experiment compared with other recent experimental data (see refs 5–7, 11–13, 30, and references within). The solid line shows a calculation[1] for pure secondary production of positrons during the propagation of cosmic rays in the Galaxy without reacceleration processes. Error bars show 1 s.d.; if not visible, they lie inside the data points.



Do the jets from the pulsars produced by the 1st SNe allow the formation of galaxies within 500 million years? Maybe! They do trash a lot of entropy between stars. They inhibit star formation locally, but space is vast, and the pulsar-driven plumes (aka “Mystery Spot”), in addition to inducing star formation in lines along their paths, may plough up enough material to form stars at their endpoints.

There is plenty of evidence for jet-driven star formation in the present Universe. In the early Universe, it was much easier (also Dopita et al. 2007 Ap&SS, 311, 305; Tadhunter et al. 1989, MNRAS, 240, 225). The extent of the linear star formation is limited by the spreading of the jet – galaxy size is not unlikely. ~Linear star formations are then subject to gravitational attraction, forming galaxies in 500 Myr.



Conclusions

The model of pulsar emission by superluminally induced polarization currents (SLIP) provides a means by which spinning neutron stars can drive a highly collimated beam and relativistic jet which can account for SN 1987A's beam, jet, and "Mystery Spot," the bipolarity of all other SNe, the jets of Sco X-1 and SS 433, the multi-GeV e^+ excess, and possibly star formation in the early Universe. It predicts that gamma-ray burst afterglows will be pulsars, and that the pulsars within SNe will literally eviscerate the gaseous remnant into two polar jets and enforce a toroidal geometry on the remainder of the equatorial ejecta. This geometry and mechanism apply to all SNe observed so far, which makes it extraordinarily difficult to calculate, or to establish a representative local sample of any type of SNe, including Ia's. Because the local sample of Ia's was selected on the basis of obeying the width-luminosity relation, in which the e^+e^- γ-rays were well encapsulated, this sample undoubtedly lies at the high end of the range in mass, and hence is too luminous to be representative of a distant sample which could not be so carefully selected. The most likely interpretation of SNe Ia data is that there is no anomalous dimming of the distant sample, and therefore ***no direct evidence at all for the existence of dark energy***. And if dark energy goes, then there's no longer any sleazy numerical coincidence to argue for dark matter, so that goes as well. There is likely ***NO DARK STUFF*** affecting the Universe for the last 8 billion years, when gravity didn't matter and $\Omega_{Total} \sim 0.04$, even though $\Omega_{Total} = 1.0$ at the era of recombination, when gravity did matter – this is a deeper problem than many have been willing to admit.