Predicting the next local supernova

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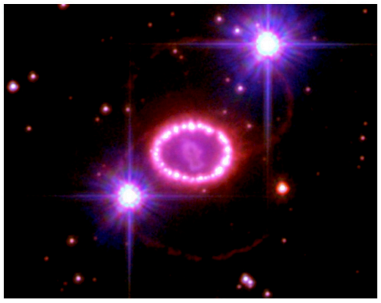
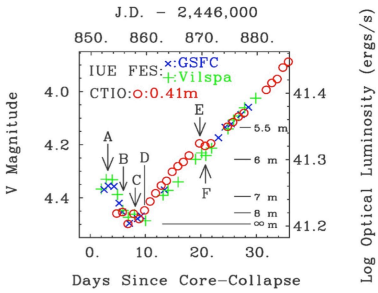
It has been over 31 years since Supernova 1987A, and we have learned many things from the neutrinos, light curve, evolving spectrum including the "Bochum Event" at day 19.2, the associated "Mystery Spot," the mixing, rings, X- and gamma-rays, polarization, and the 467.5 Hz pulsation and its associated ~1,000 s precession. Finally, our understanding of this event has progressed to the point where we have a time interval of a few months during which we can predict which supergiant star in our local neighborhood out to 5 Megaparsecs will be the next to die in a supernova explosion.

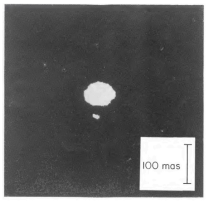


This poster is about how we can use what we've learned from Supernova 1987A to predict core-collapse in supergiants so we can observe this process as it happens.

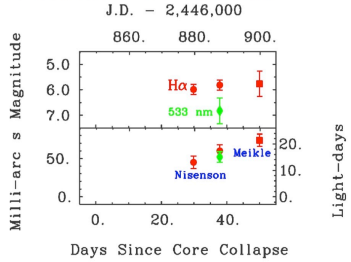


A: Luminous jet emerges. B: Jet cools.
C: Beam hits polar ejecta. D: Jet hits polar ejecta.
E: Beam clears polar ejecta. F: Jet clears polar ejecta.

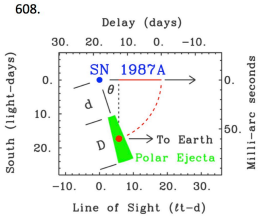
From Nisenson et al. (1987) the field around SN 1987A on day 30. Bright spot #1, aka the "Mystery Spot," is ~south of 87A and 45 milli-arc s distant (at 49.7 kpc and 0.287 ft-day/mas, this is 12.9 ft-day).



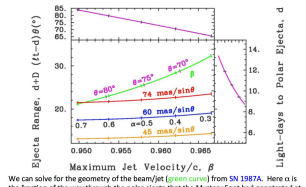
The jet from SN 1987A has driven circumstellar material in bulk to form this Mystery Spot.



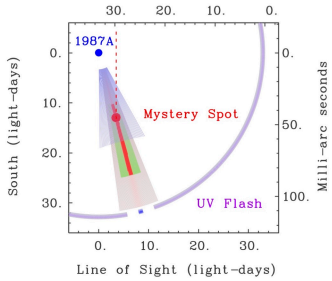
Measurements of displacement (lower) and observed magnitude (upper) of the "Mystery Spot" from SN 1987A, at Hα and 533 nm, vs time, from Nisenson et al. 1987, ApJ, 320, L15, and Meikle et al. 1987, Nature, 329, 608.



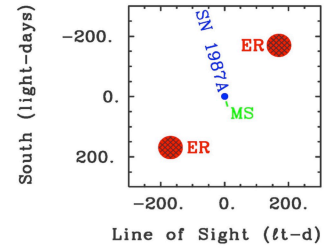
The geometry of the "Mystery Spot," (MS – red dot) associated beam/jet and direct line of sight from SN 1987A. It takes an extra *8* days for light from 87A to hit the polar ejecta (PE – an extra *13* days to the PE midpoint), and proceed on the the Earth. The distance from 87A to the MS, at day 30, is ~13 light-days.



We can solve for the geometry of the beam/jet (green curve) from SN 1987A. 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: θ = 75.193°, d = 10.47738 ft-d, D = 14.888 ft-d, β_{ave} = 0.9578. These kinematics, bulk feature motions of 0.2c - 0.6c, and energy transfer speeds > 0.95c, are identical to those found by Fomalont, Geldzahler, & Bradshaw (2001ApJ...553L..27F) in Sco X-1, a neutron star orbiting a late-type star (i.e., with at least C & O).



The Mystery Spot at day 30 projects to 0.045 arc s from SN 1987A.



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

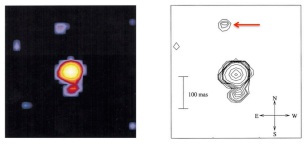
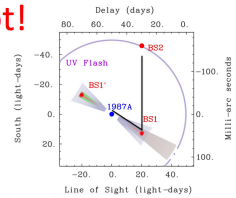


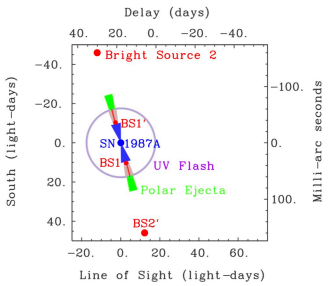
Fig. 1—New reconstructed image (left) and contour plot (right) of a 300 mas field around SN 1987A, from speckle data recorded with a 10 nm–wide filter centered at 655.0 nm. Note that two of the noise spikes (in the lower left and right) do not show up in the contour plot because their intensity falls below the lowest contour level (1%).

From Nisenson & Papaliolios (1999) the field around SN 1987A on day 30 *after an improved analysis*. Bright spot #1 is ~south of 87A and 45 milli-arcsec distant. Bright spot #2 is *exactly* opposite and *160* mas away.

Not!



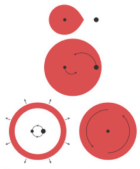
Nisenson & Papaliolios (1999) mentioned the possibility that BS2 was produced by SN 1987A. BS2 then appeared to be supraluminal on the sky (as would any source whose angle wrt the X axis was greater than 45°). However, this would mean that 87A, BS1, and BS2 *would not be colinear in three dimensions*, which must be considered unlikely. Also, the 87A – BS1 angle is off the solution by 43°.



This is the colinear geometry of 87A, BS1, BS1', and BS2 (at day 30) as required by the observations. BS2', the source opposite BS2 at day 6, had faded enough by day 30 so that it was not observed. BS2 had to have been produced before SN 1987A. But how?

Because of the rings, the mixing observed in the ejecta, the anisotropy of the expanding remnant, and the 467.5 Hz, weakly–magnetized pulsar remnant (Middleditch et al. 2000), SN 1987A is thought to have resulted from a merger of two ~0.7 $M_\odot$ mass electron degenerate cores within a common envelope.

It is thought that the star system originally contained 20 $M_\odot$, and shed 3 $M_\odot$ prior to core collapse, ejecting 15.5 $M_\odot$ from an ~1.3 $M_\odot$ neutron star remnant.



Key stages in a common envelope phase. Top: A star fills its Roche lobe. Middle: The companion is engulfed; the core and companion spiral towards one another inside a common envelope. Bottom: The envelope is ejected or the two stars merge.

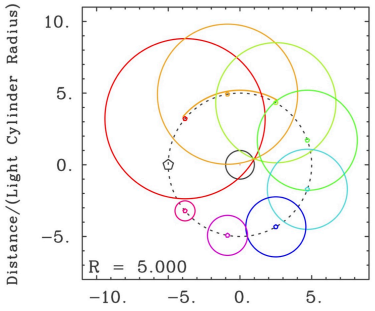
If r_{eq} represents the equatorial radius of Sk -69°202, the progenitor of 87A, a the separation of the two cores, P their orbital period, and v_{eq} the projection of the motion on the stellar equator (neglecting the rest of the material within the star), we have for R_{eq}, the ratio, of the orbital speed as projected out to the equator, to the speed of light, c:

$R_{eq} == v_{eq}/c = 2\pi\, r_{eq}/(Pc) = (r_{eq}/(2x10^7\ km)) / (a/(93{,}864\ km))^{3/2}$,

a = 93,864 km (r_{eq}/(2x10^7 km) x 1/R_{eq}))$^{2/3}$, and

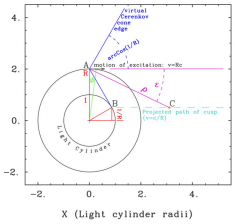
P =419.1 s (a/(93,864 km))$^{3/2}$.

For r_{eq} (the radius of Sk -69° 202) = 20 million km, the equatorial excitation velocity, v_{eq}, = c (R_{eq} = 1) for P = 419.1 s and a = 93,864 km (the circumference of Sk -69°202 is 419.1 ft-s).



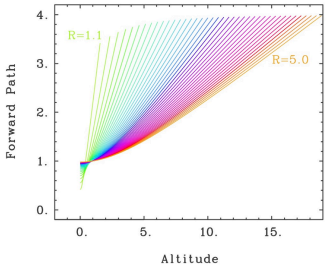
When R > 1, the excitations of polarization currents in an annulus coaxial with the rotation axis of the cores produces focused beams which start initially on the speed-of-light cylinder for the orbit.

The path of the focused beam must be on the "virtual Cerenkov cone"(in profile: the vCc edge + line AB, both extended) which has a half angle of arccos(1/R) where +X motion at point 'A' appears to be moving at exactly c. By solving for the Y which eliminates the φ^2 term at point 'C,' the result is the hyperbola:

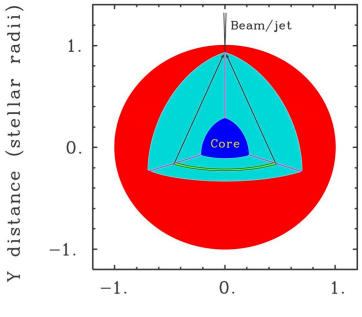


$Z = (R^2 - 1)^{1/2}\ (X^2 - 1 + 1/R^2)^{1/2}$; $Y = 1/R$.

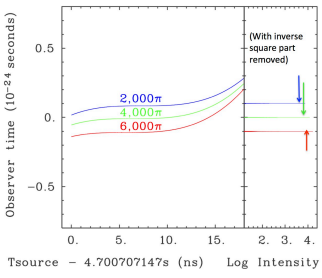
For the cores with decaying orbits, P can drop to 2 s, which makes R as big as 210. This leads to nearly polar focused beams, and source BS2:



The higher the relativity factor, R, the more polar the beam.

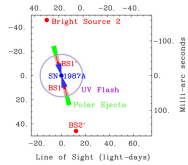


An annulus of polarization currents many light-radians outside the stellar core will direct its focused beam toward the poles, where it drives a beam and jet.



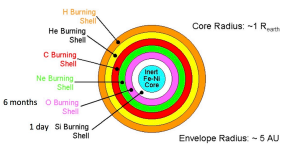
The power decay law for the focused beams is *1/distance*.

So how much time do we have to identify BS2 before core collapse? We know it took 50 days for BS1/ Mystery Spot to go 74 (projected) milli-arc s. Then another 4.3 ℓ t-d to get through to the end of the polar ejecta. Then another 21 ℓ t-d at 0.2 c. This amounts to 181 days. However, there is probably less material the first time thru.

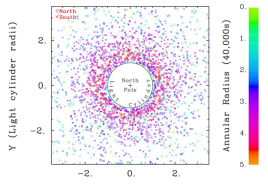


There is also, on average, 24 days of advance because BS2' will be seen before BS2. So it seems that there are about 4 months to detect it.

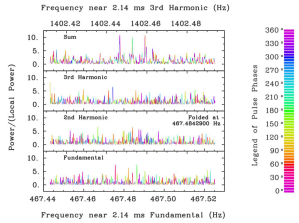
What about massive stars with a single core?



The Oxygen-burning core increases the density of the core, which reduces its moment of inertia, and, in consequence, increases its spin rate. If the spin period falls below about 19 minutes, then the excitation of the equatorial region becomes supraluminal, and the star begins to throw off matter, becoming more and more polar as the rotation period drops further. For a star of radius 200 million km, the transition occurs for a 70-minute period.



Then core collapse happens and the rotation rate increases by a factor of 1,000, to 500 Hz, and *R* rises to 200,000. This collimation is modified by precession to approximately 100, or what it used to be from the merger process. 2655/3930 beams emerge within +/-3.5 radians.



PSR1987A has been observed to precess at periods ranging from 870 to 1,430 s, so the effective collimation is more like 1:100

Where does this leave dark energy?

By 2007 it was clear that the anisotropy of SN disruption (and the untenability of single degenerate – ABSOLUTELY NO H or He lines) disqualifies SNe Ia as standard candles.

In late 1993, CTIO gave up on supporting observations of SN 1987A (we were still struggling, with a good candidate but uncertain about the best band to observe in), to concentrate on Mark Phillip's attempts to utilize SNe Ia as standard candles (the width-luminosity relation). Jerry Kristian was upset, as trying to exploit something not well understood, to prove something else about the Universe, was not the best way to do science. If SNe Ia were anything like SN 1987A (which turned out to be true), with the Mystery Spot, polarization, and other details as yet unexplained, then the method would almost certainly fail.

By the mid-90's, the automated and (HST) SN searches came online, and a few years later it was discovered that the distant SNe appeared to be underluminous by 0.25 magnitudes on average. Instead of questioning the systematics of the local sample (discovered by serendipity *before* the automated surveys can online), they said the expansion of the Universe was accelerating, folding in dark matter to exploit the coincidence, $\Omega_m + \Omega_{dm} + \Omega_{de} = 0.04 + 0.25 + 0.71 = 1.0$.

Whatever SNe were, they thought that Malmquist Bias would dominate any other types of bias that affected the measurements of SNe Ia (they were wrong, as we saw from previous slides).

So what recommendations would help to make progress in this subfield?

1. Never mind faster computers, we need more accurate computers – 256 bits or bust!
2. Continue to observe GRB afterglows in high time resolution.