Pulsar-Driven Jets and the Universe

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CCS-3

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Four decades ago, in 1970 we (+Jerry Nelson, David Cudaback, & John Saarloos) searched for our first pulsar outside of our Milky Way galaxy, in Supernova 1970g, in the spiral galaxy, M101 (NGC 5457). We took data at 10 kHz with an analog tape recorder with timing marks and later redigitized and analyzed with Fourier transforms. We did not see any pulsar. Like every other extragalactic SN we observed until SN 1987A, the damn thing just sat out there and glowed.

So where the Hell was the pulsar?

Was it there at all?

If not was there a black hole?

Or was it too faint to see?

Because of material opacity?

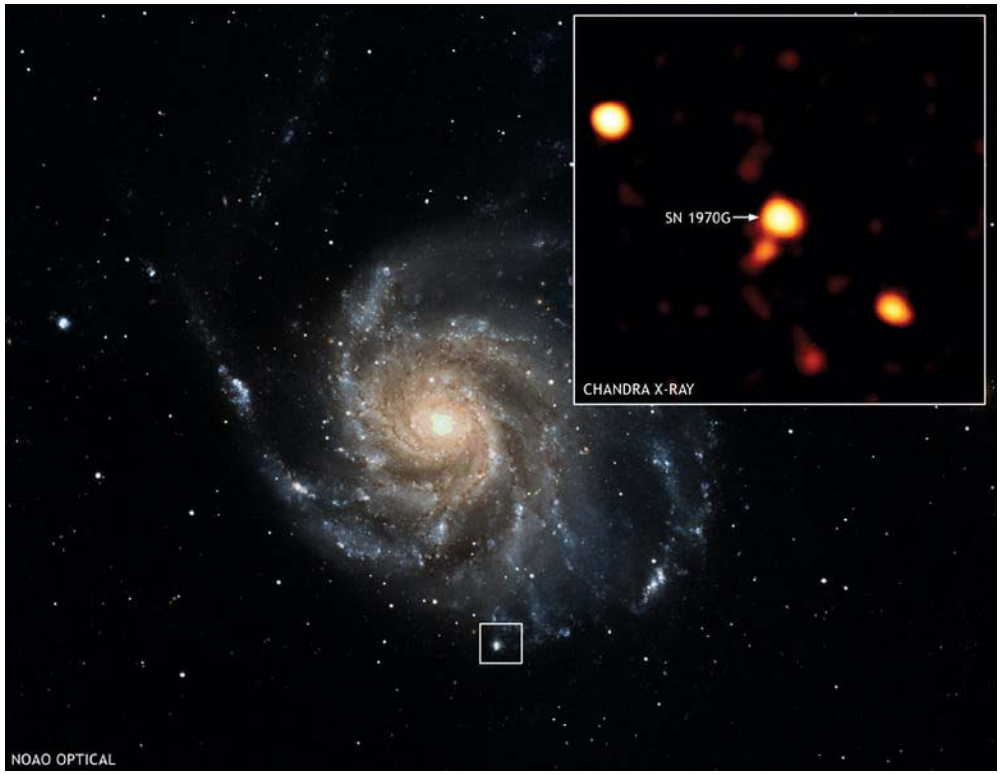
lines?

dust?

Because of beaming?

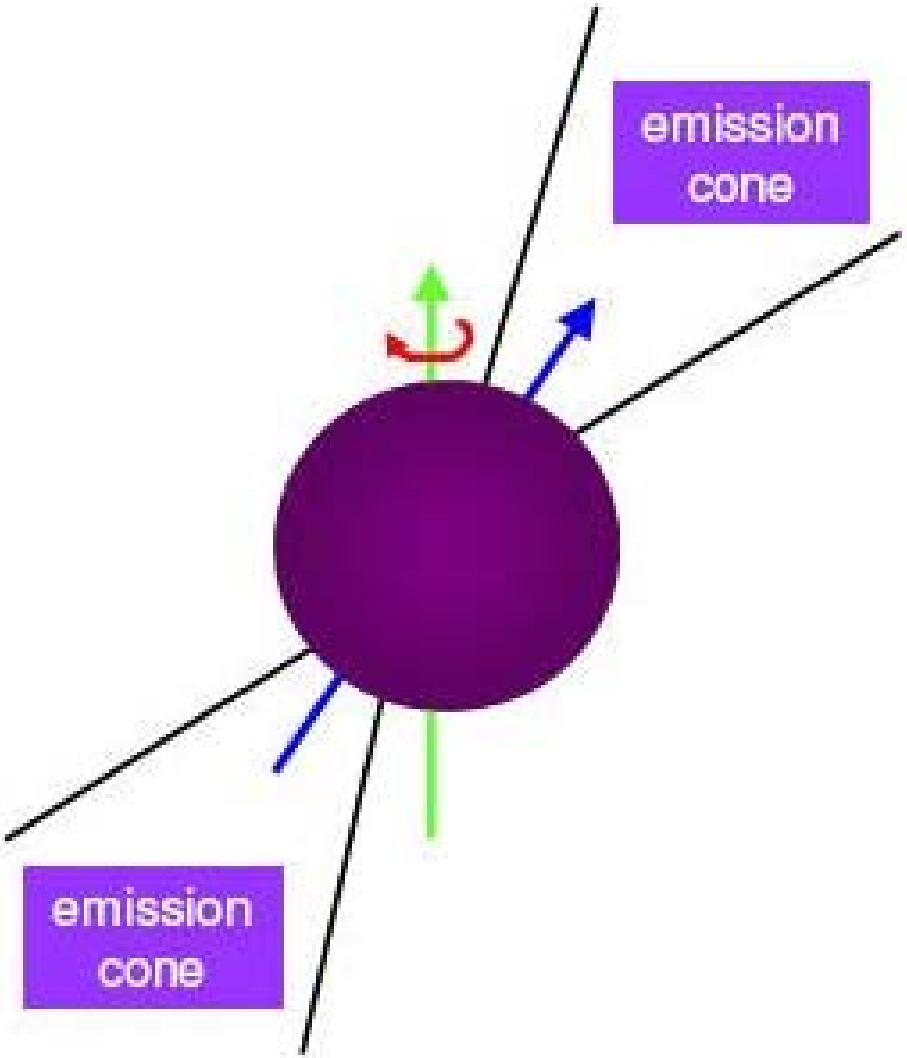
Because of source

conditions/emission mechanism?



Four decades later we know.

(Bad) Pulsar Emission Models



Pulsars are radio emitting & highly magnetized rotating neutron stars with periods ranging from 1.4 ms to 8.5 s

Problem: Explain radio emission mechanism

Werner Becker of the Max-Planck Institute said in 2006, "The theory of how pulsars emit their radiation is still in its infancy, even after nearly forty years of work."

In 1972 Vitaly Ginzburg and Boris Bolotovskii proposed a model for pulsar emission produced by polarization currents induced beyond the light cylinder ($|\underline{\Omega} X \underline{R}| > c$) by the influence of the magnetic field of the rotating neutron star. Because of this location, the modulation of these currents is faster than the speed of light (SuperLuminally Induced Polarization currents – SLIP).

This proposed model was motivated in part by the high brightness temperatures ($>10^{38}$ K) and polarization behavior observed from pulsars (more below).

Polarization Currents

Maxwell Equations

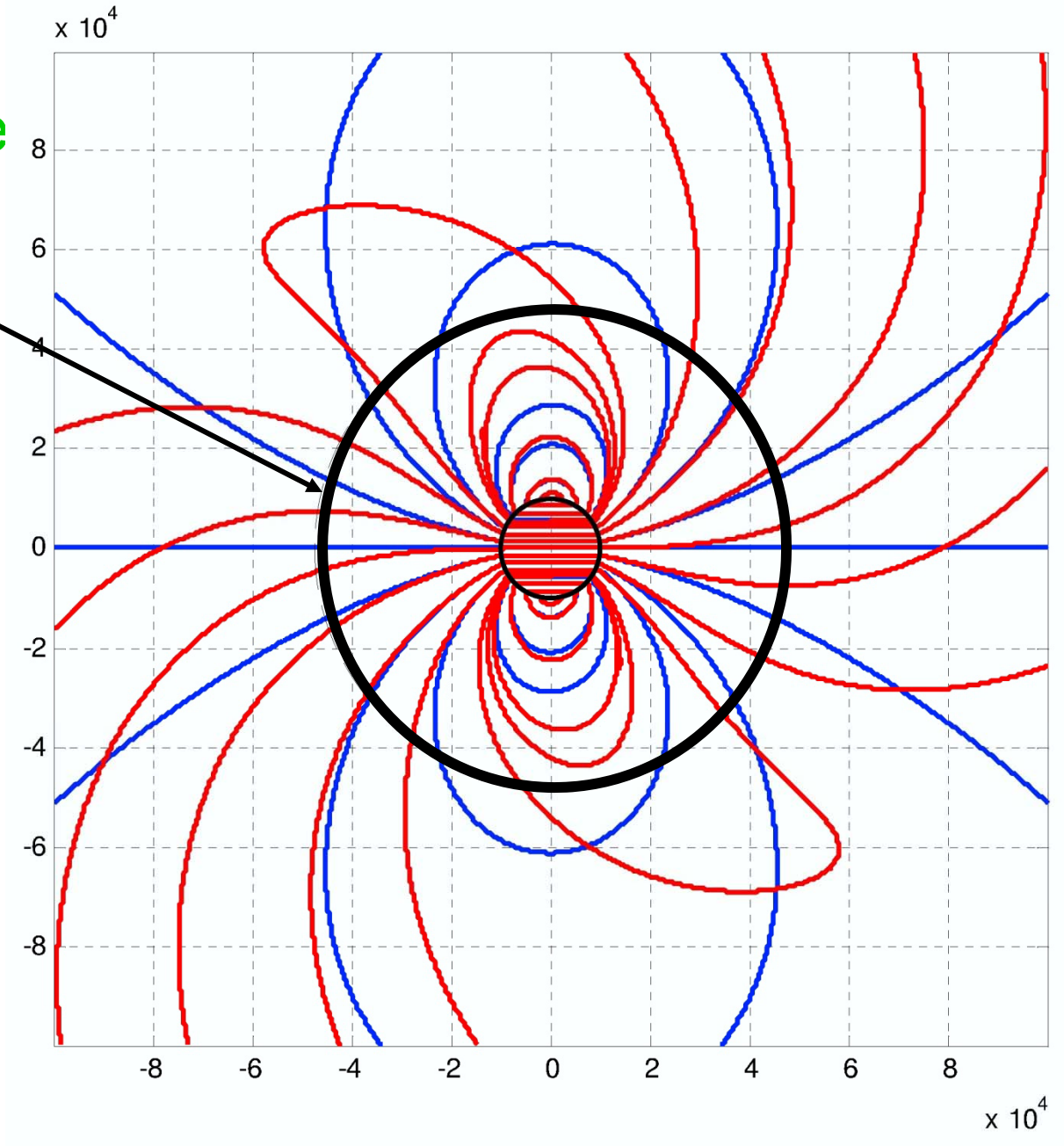
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{H} = \mathbf{J}_{\text{free}} + \epsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \frac{\partial \mathbf{P}}{\partial t}$$

- Propagation terms in green. Usual sources (aerials, synchrotrons) employ $\mathbf{J}_{\text{free}}$ of electrons, restricted to $v < c$.

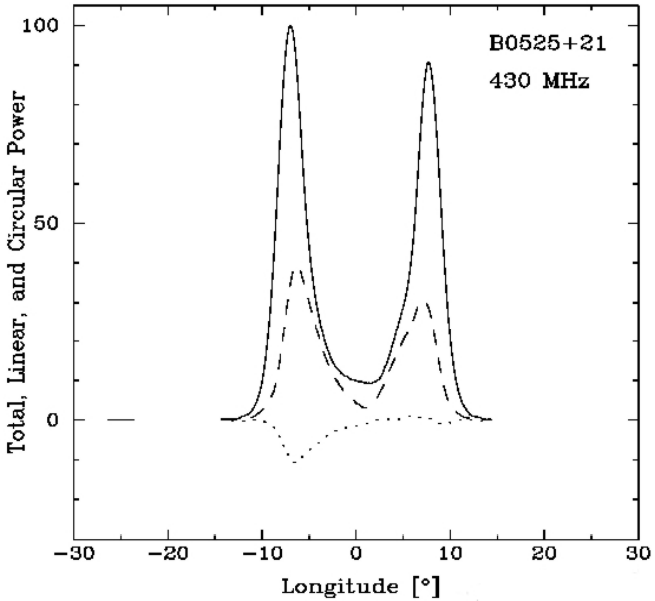
- The modulation of the *polarization current*, ($\partial\mathbf{P}/\partial t$), has no restriction on speed, could be $v > c$.

Polarization currents outside the light cylinder are induced by the electric field produced by the rotating magnetic field. These currents are updated faster than the speed of light. Emission mechanisms: cyclotron, strong plasma turbulence.

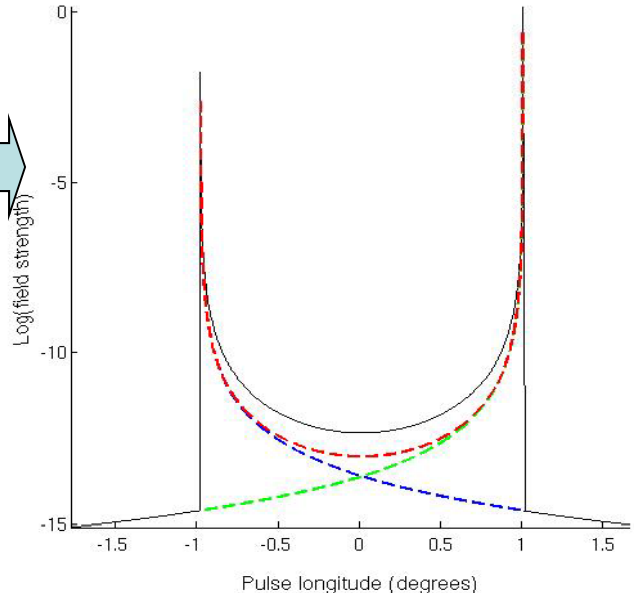


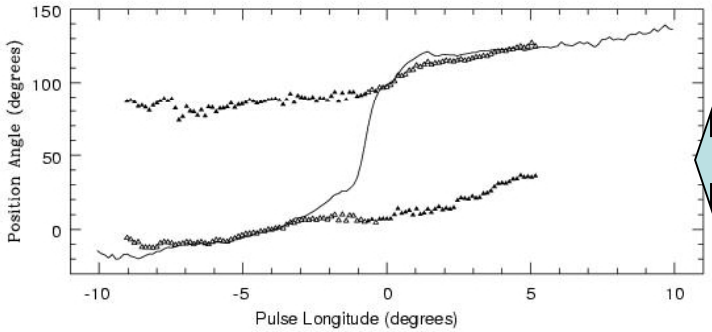
(Blue – non-rotating. Red – rotating clockwise.)

Pulsar Observations & Model

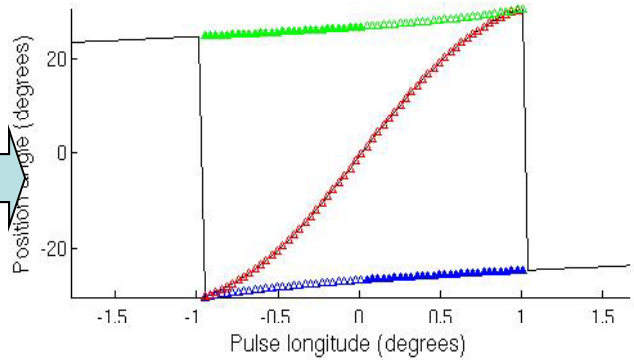


Emission Profile





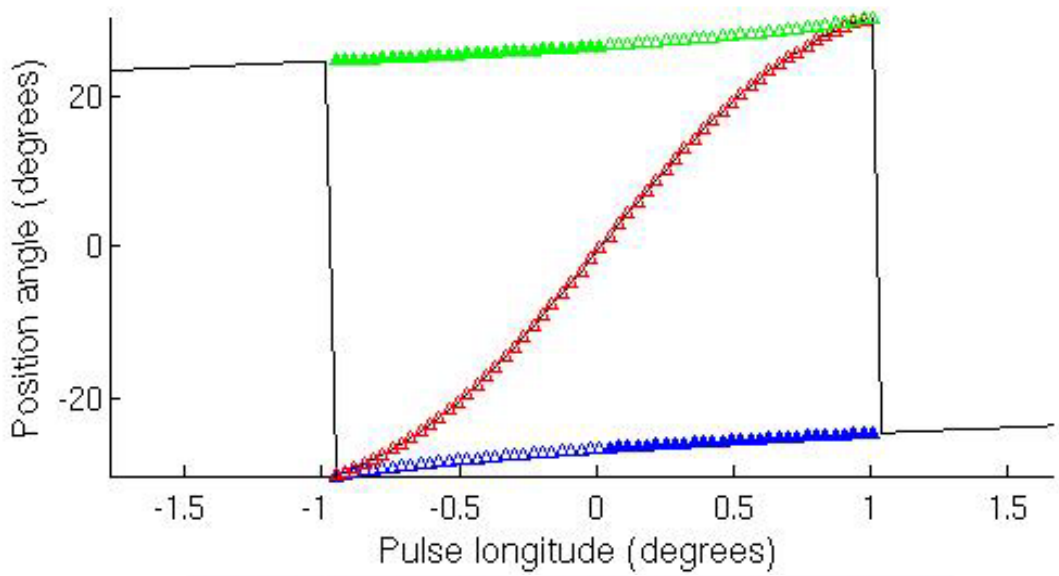
Position Angle

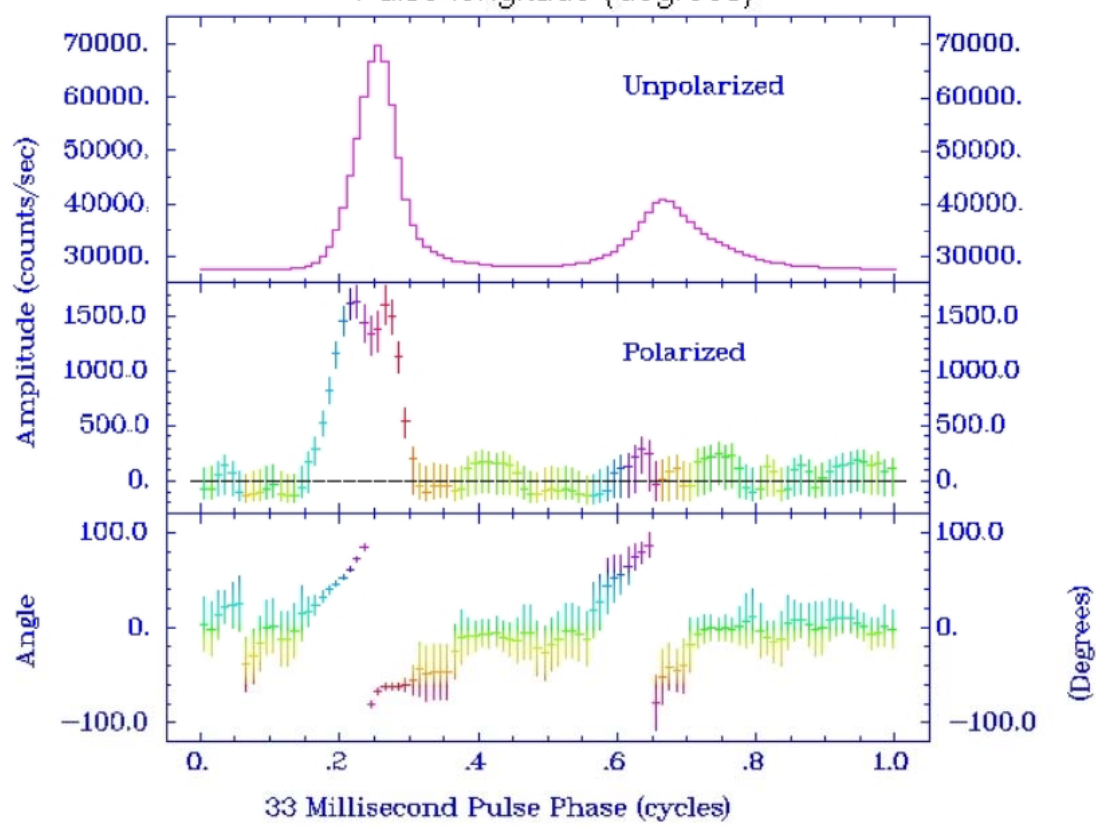


Observations: Hankins and Rankin (2006) & McKinnon (2003)

Model: Schmidt et al. (2006)

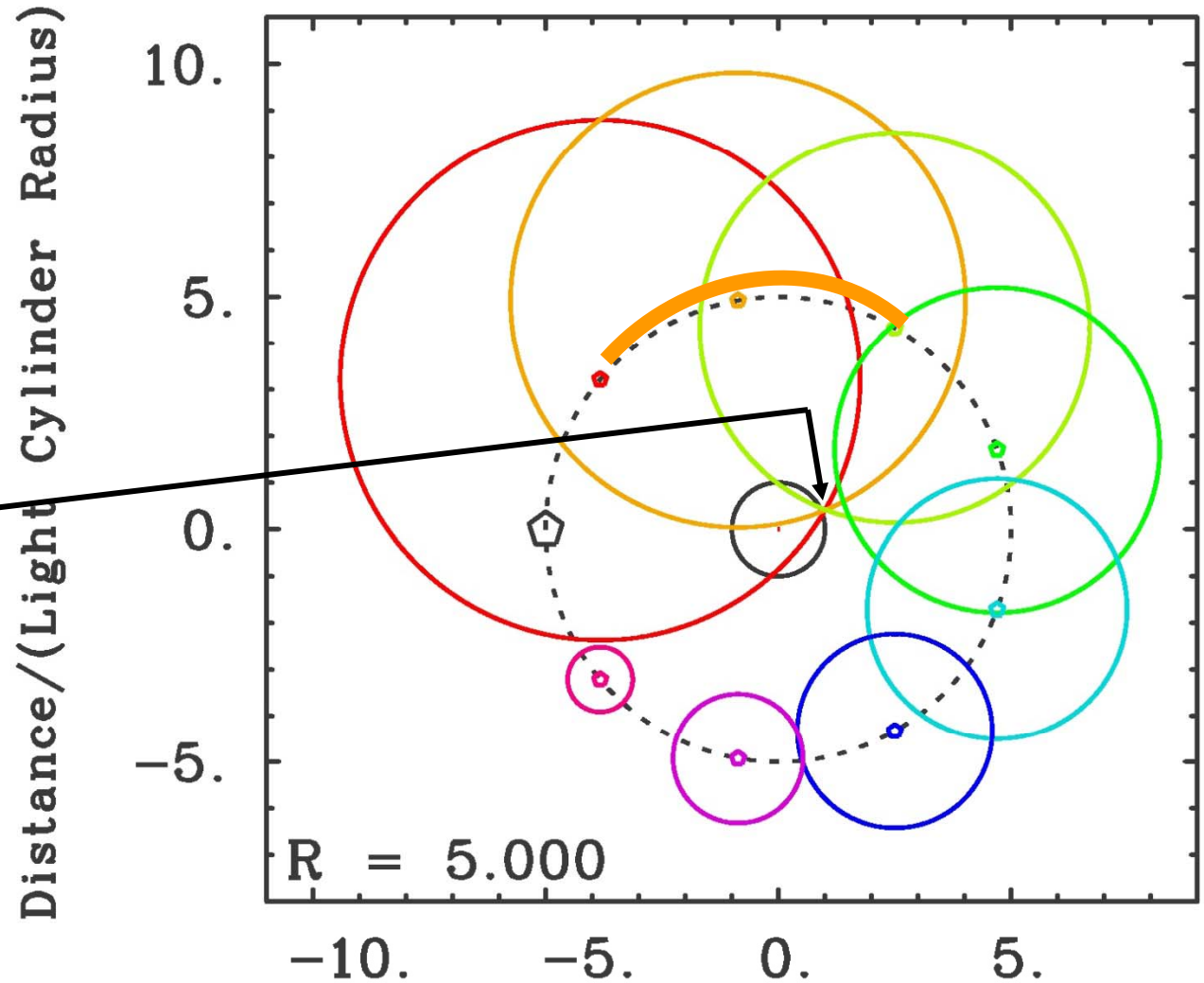
The 180° swing in polarization *across the pulse* is an easy, direct consequence of this model.





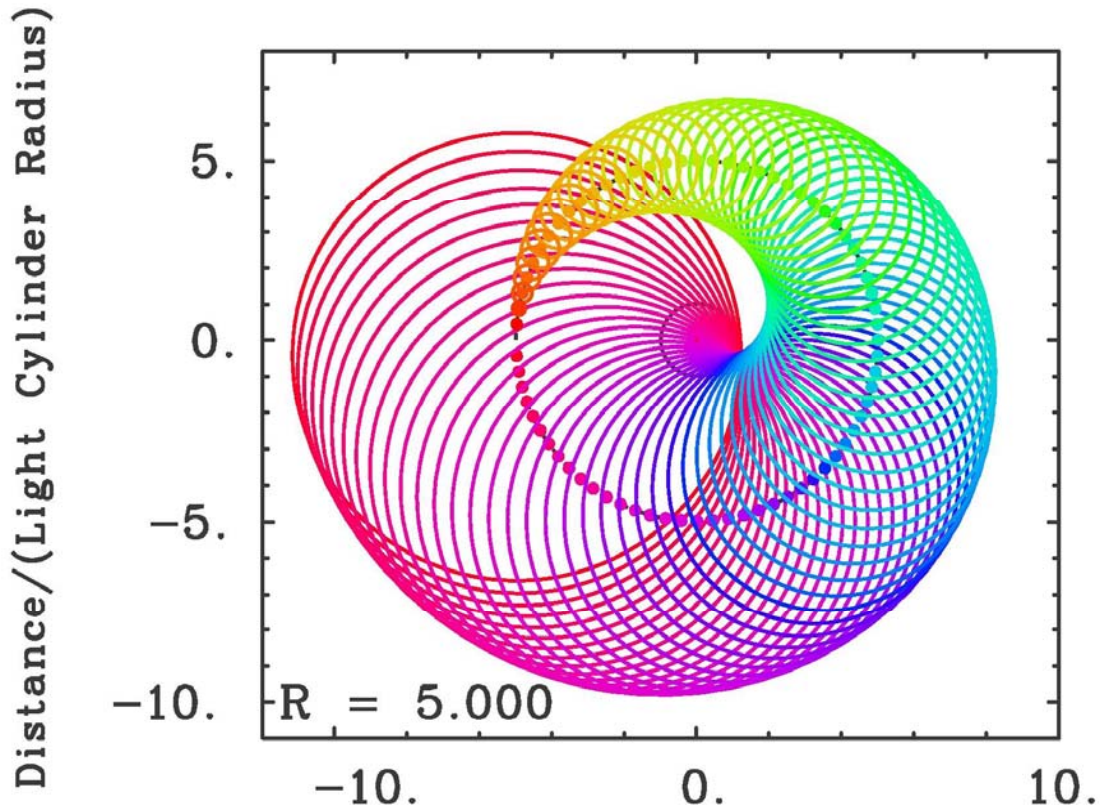
With a source orbiting at 5xLC radius, the emission in its history, from 10 hr 20 m to 1 o'clock, all contribute to a spot tangent to the LC near 2 o'clock.

This radiation at this spot evolves out of the plane with time, on a cone with an axis perpendicular to the page, of half angle $\sin^{-1}(1/5) = 11.5^{o}$.

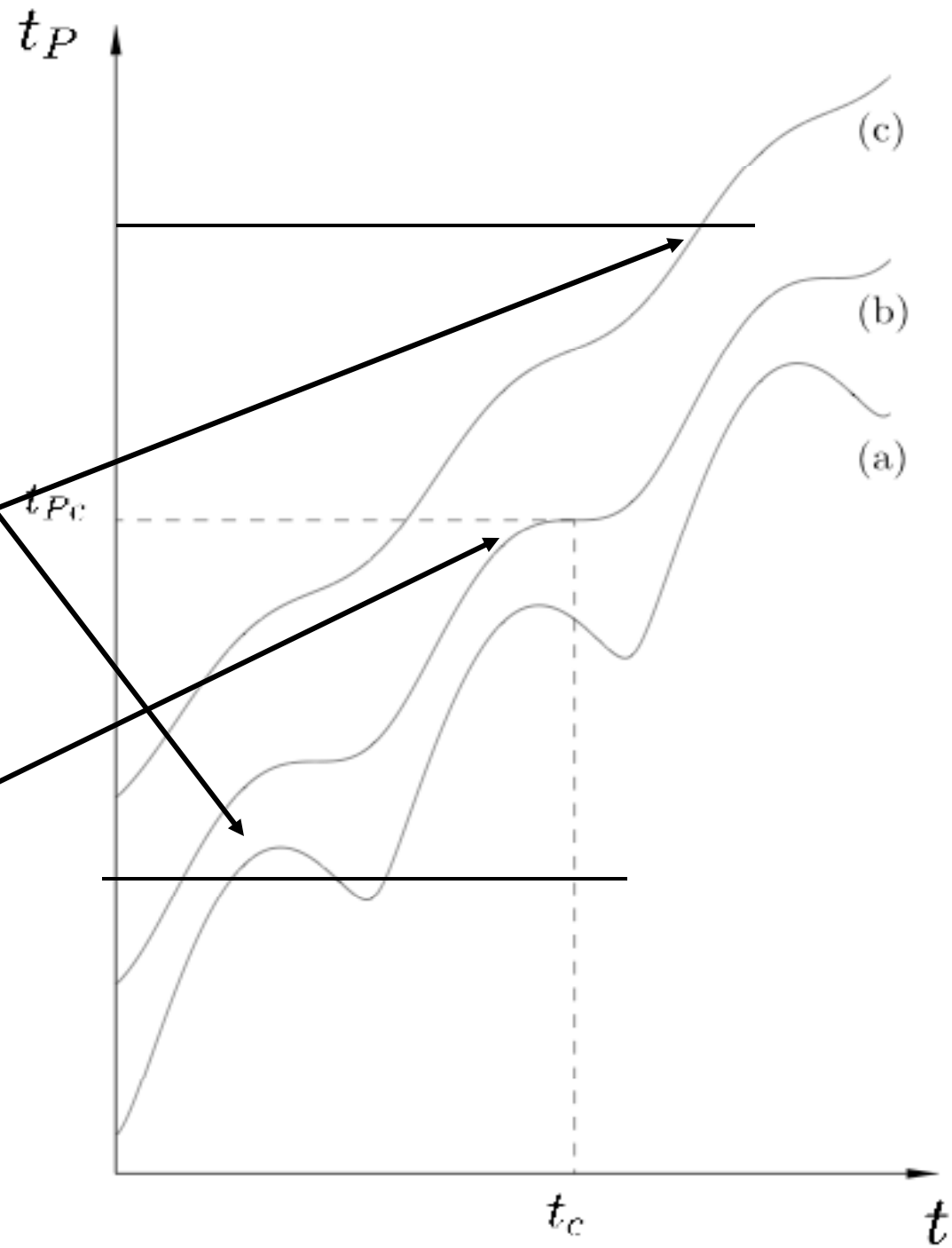


Again, with a source orbiting at 5xLC radius, now counter-clockwise, the emission in its history, from just >180°, and ending just <180°, all contribute to a spot tangent to the LC near 10°.

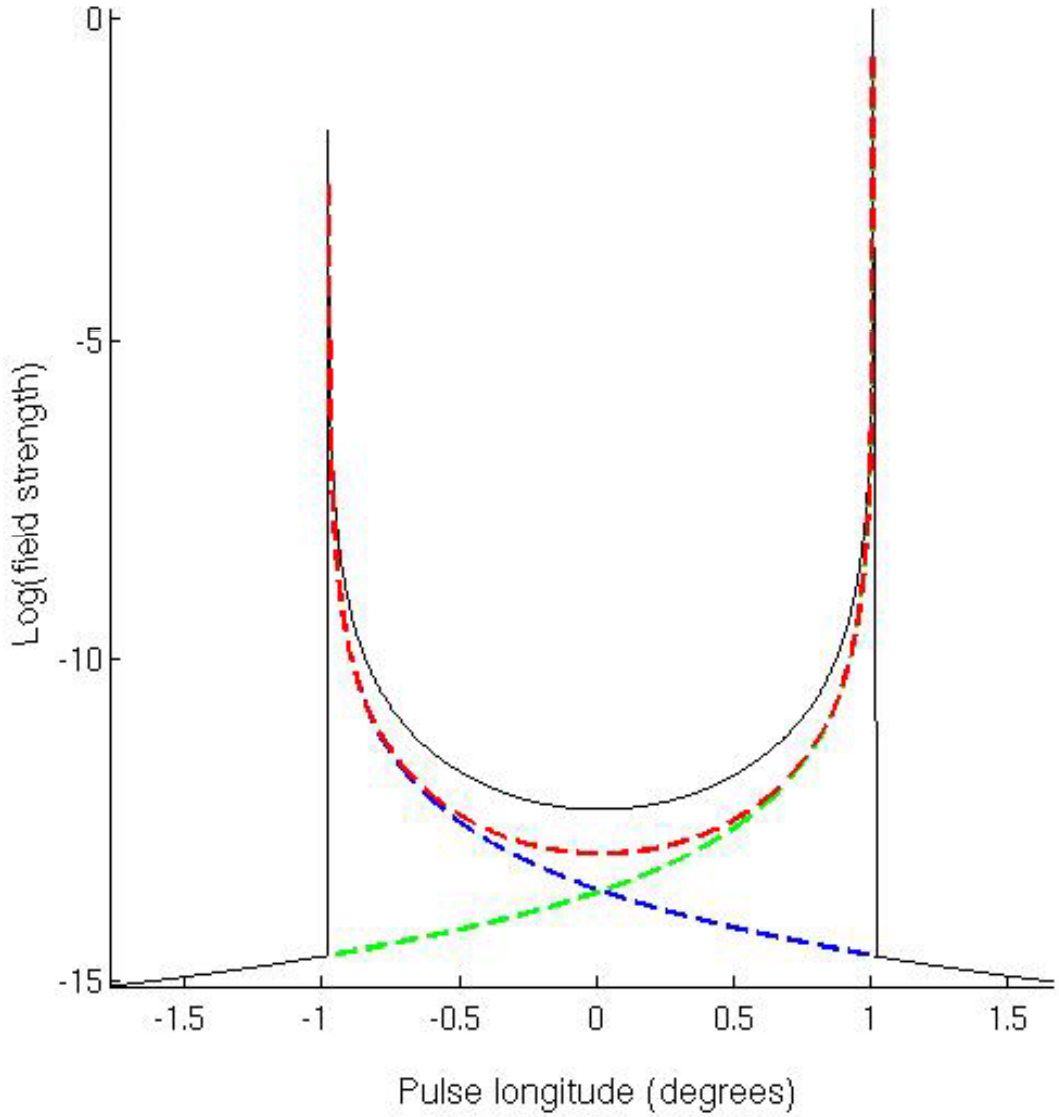
This is the classic "Picard Maneuver" – if you go faster than light, your enemy has many images of you to shoot at, and you have many opportunities to shoot at your enemy.



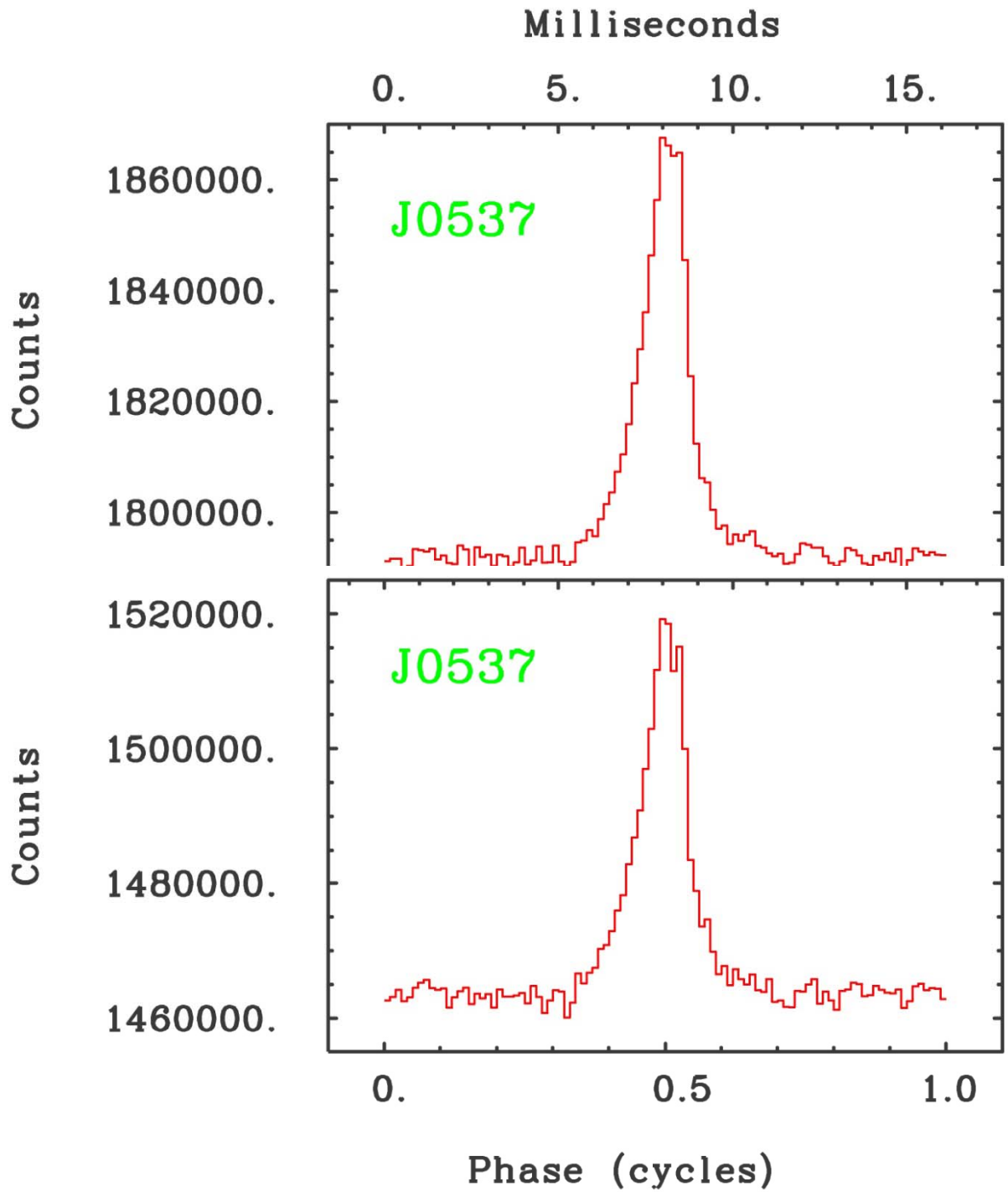
Typically, contributions from 3 sources contribute to what is seen by the observer (curve ‘a’), but for certain geometries, only one source (curve ‘c’), or for others (such as our example one & two viewgraphs back), an infinite number (curve ‘b’ for observer time t_{Pc}), and this is the “special” curve.



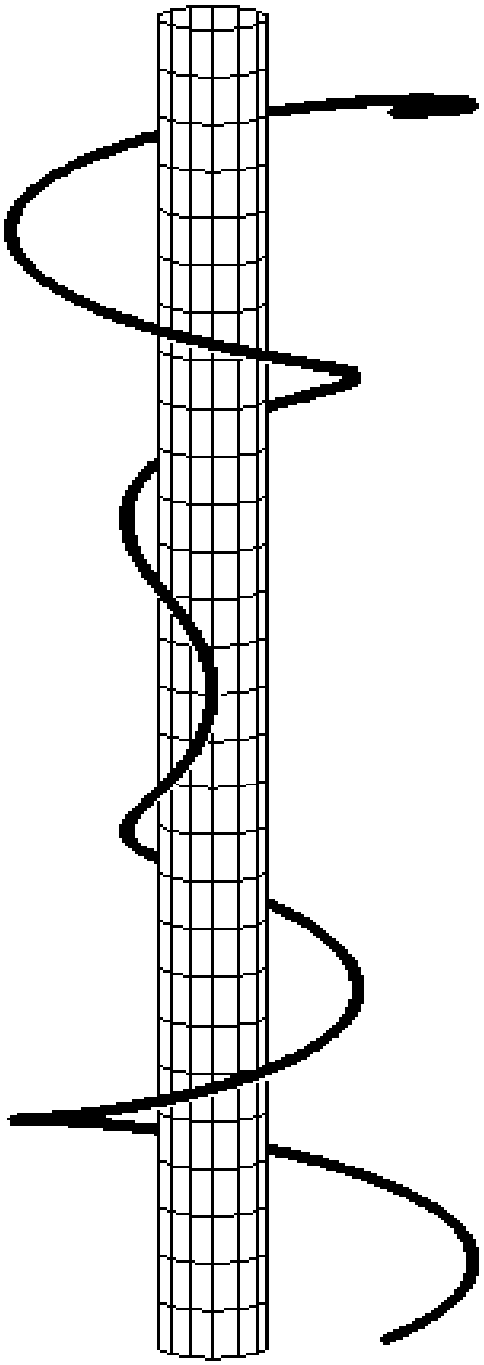
In the SLIP model, the pulse profile comes from the same 3 sources. These produce the typical, cusped, doubly-peaked pulse profile, and predict that all singly-pulsed profiles are actually doubles.



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.



The pulsations corresponding to the infinite number of sources propagate out on the cone of ½ angle, $\theta_v = \sin^{-1}(c/v)$, somewhat like a bedspring. This half angle may have caused the 30° misalignment between SN 1987A's jet bipolarity and the normal to its equatorial ring, but this is not yet clear. 30° seems too large for spin-orbit misalignment.



In this direction, $\Theta_{polar}=\sin^{-1}c/v$ = θ_V, pulsars dim only as 1/distance ("We should ***see*** that" – M. Perez):

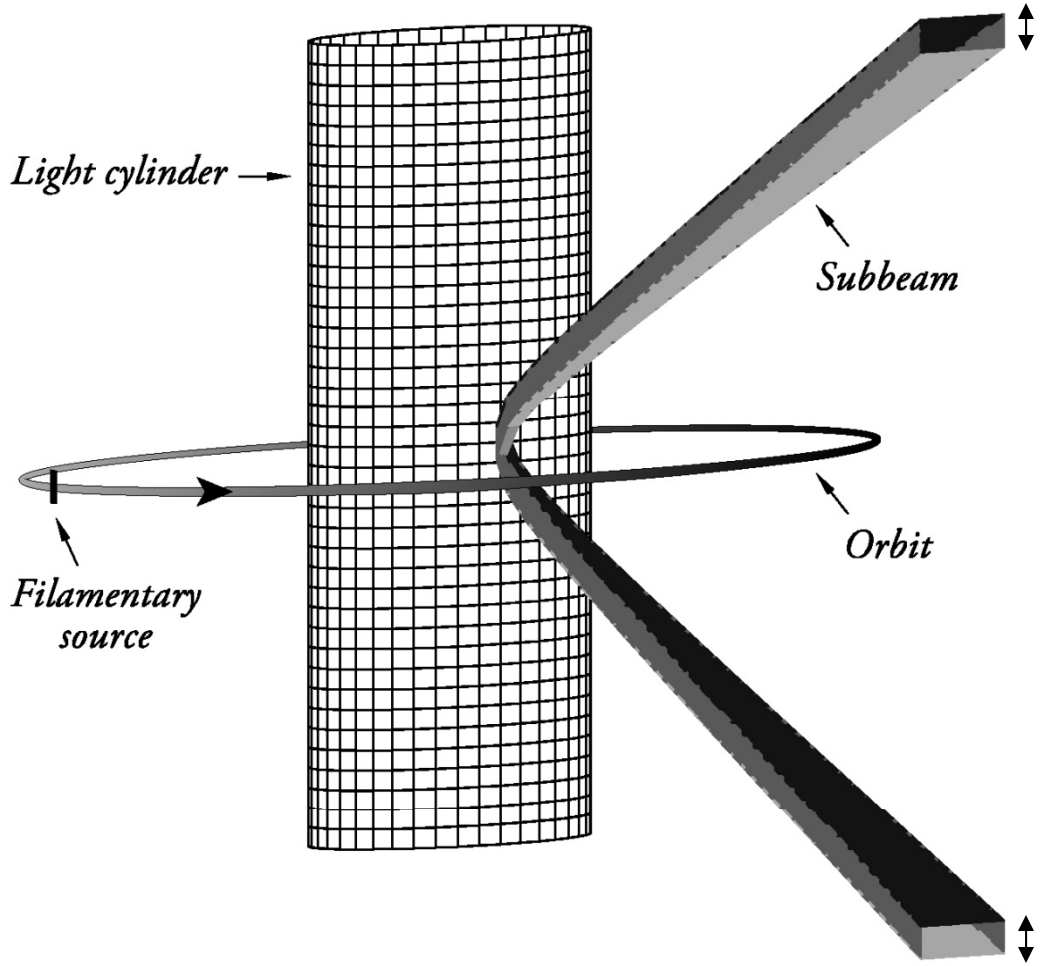
This remarkable aspect of SLIP was *predicted* in V. Ginzburg's Superluminal Polarization Current Model (SLIP -- H. Ardavan, 1998, Phys. Rev. E., 58, 6659, and later references). It's just mathematics … (but we're not getting into it here).

If this is true, then:

- We know how to survey.
- We know how long to look.
- We know when to quit.

But we don't have to survey, because there's a free lunch! (More below.)

How does the 1/distance relation happen? A sub-beam has a constant height in the polar direction, and thus the flux drops only as 1/distance. The pulsar angular beam width does not necessarily diminish at great distances because there are many, many subbeams. Also, the dimension of the favored directions is 1, whereas solid angle has a dimension of 2. Thus, as a fraction of the entire solid angle, that of the subbeams becomes vanishingly small. Still, as we will see below, it matters a great deal.

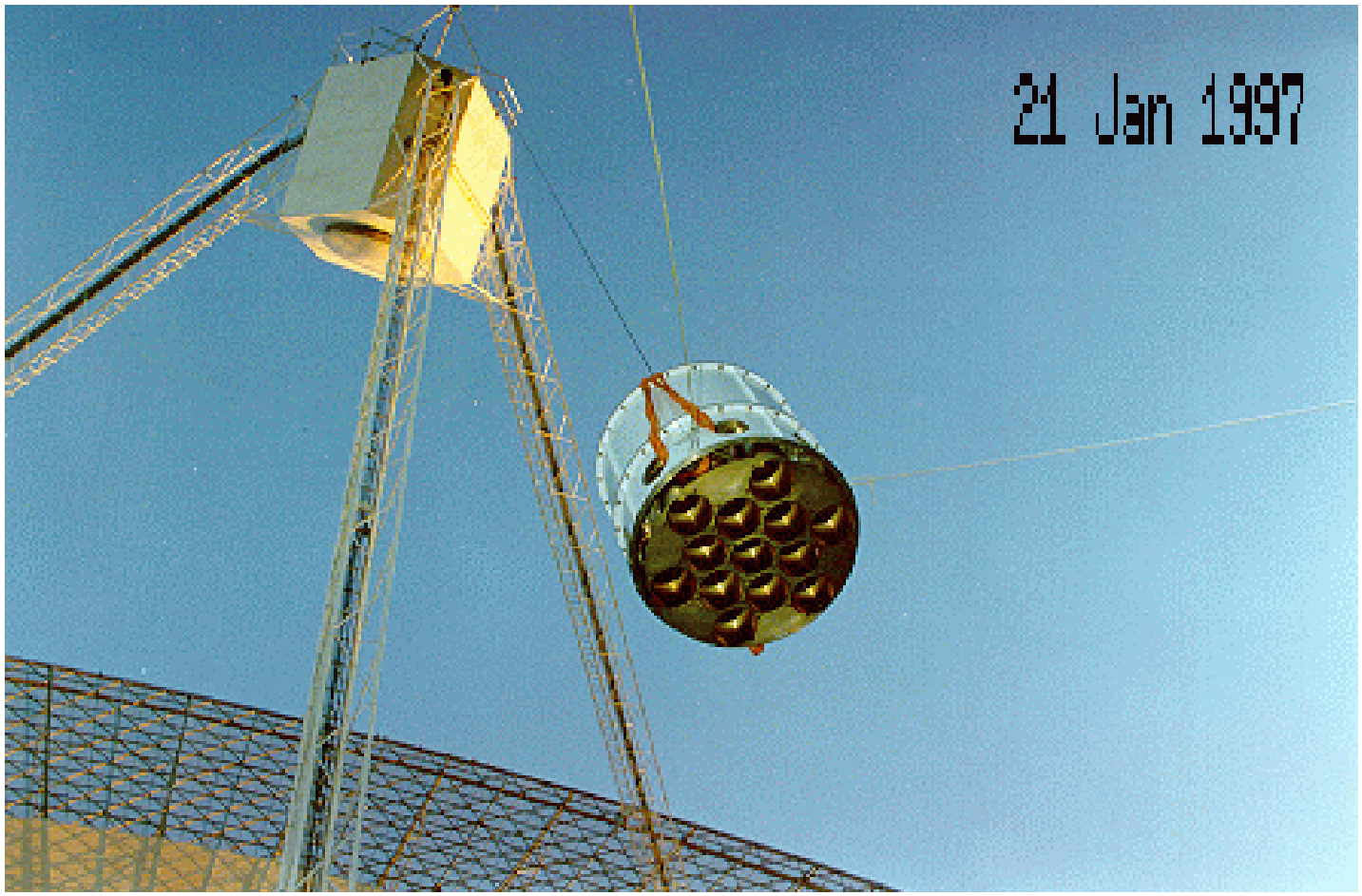


Does this *really* happen?

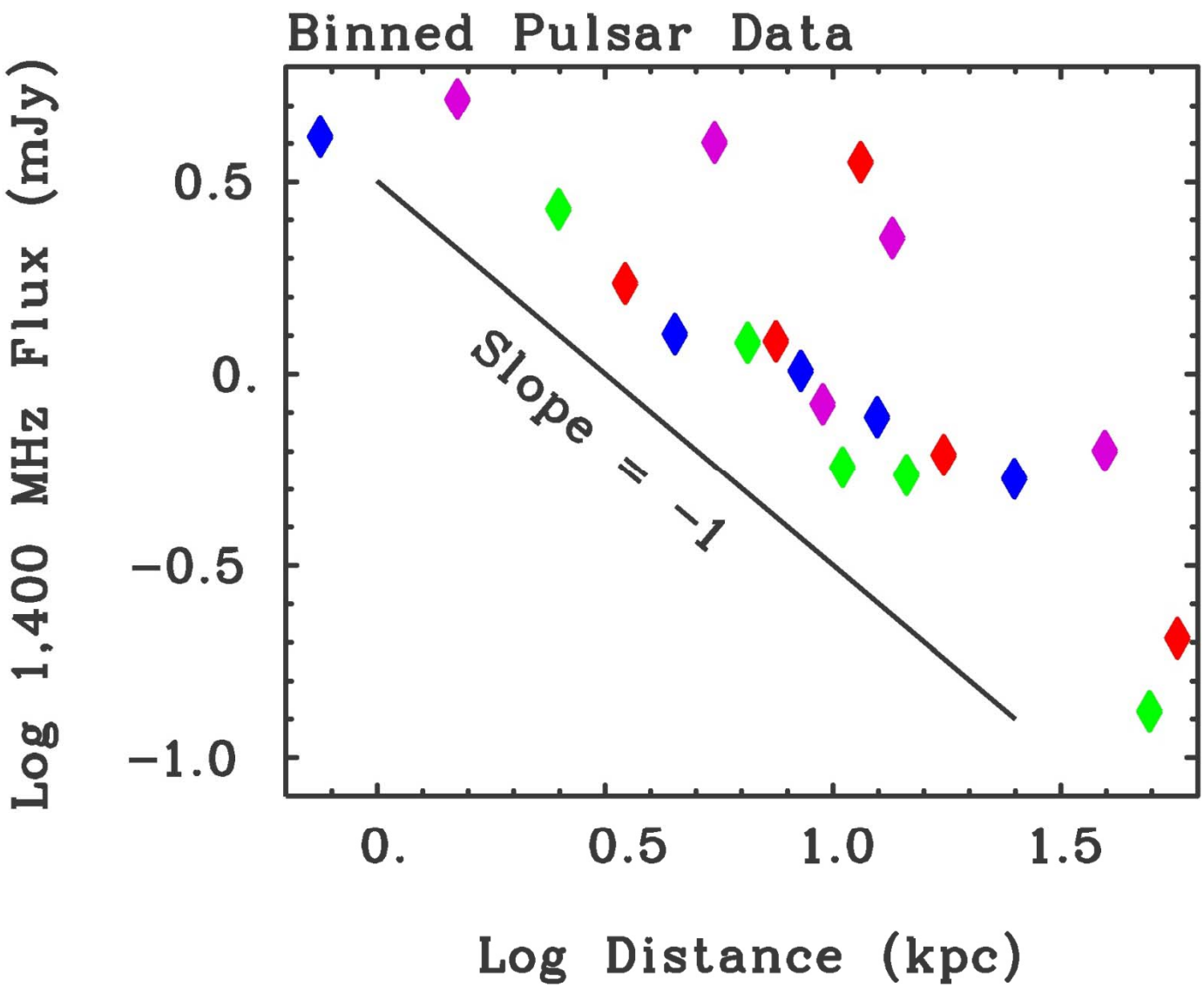
To test for this 1/distance law we need a sample of pulsars discovered in the most uniform survey possible – the Parkes Multibeam Survey:

- The Parkes Multibeam *Pulsar* Survey is the creation of Richard Manchester of the Australian National Telescope Facility.
- The survey has:
- a 64-meter dish
- 13 separate beams
- a 20 cm band center
- a 288 MHz bandwidth
- covered 261 to 51° Galactic longitude (8.5 < RA < 19.6 hr) and |Galactic latitude| < 5°
- discovered ~1,000 pulsars

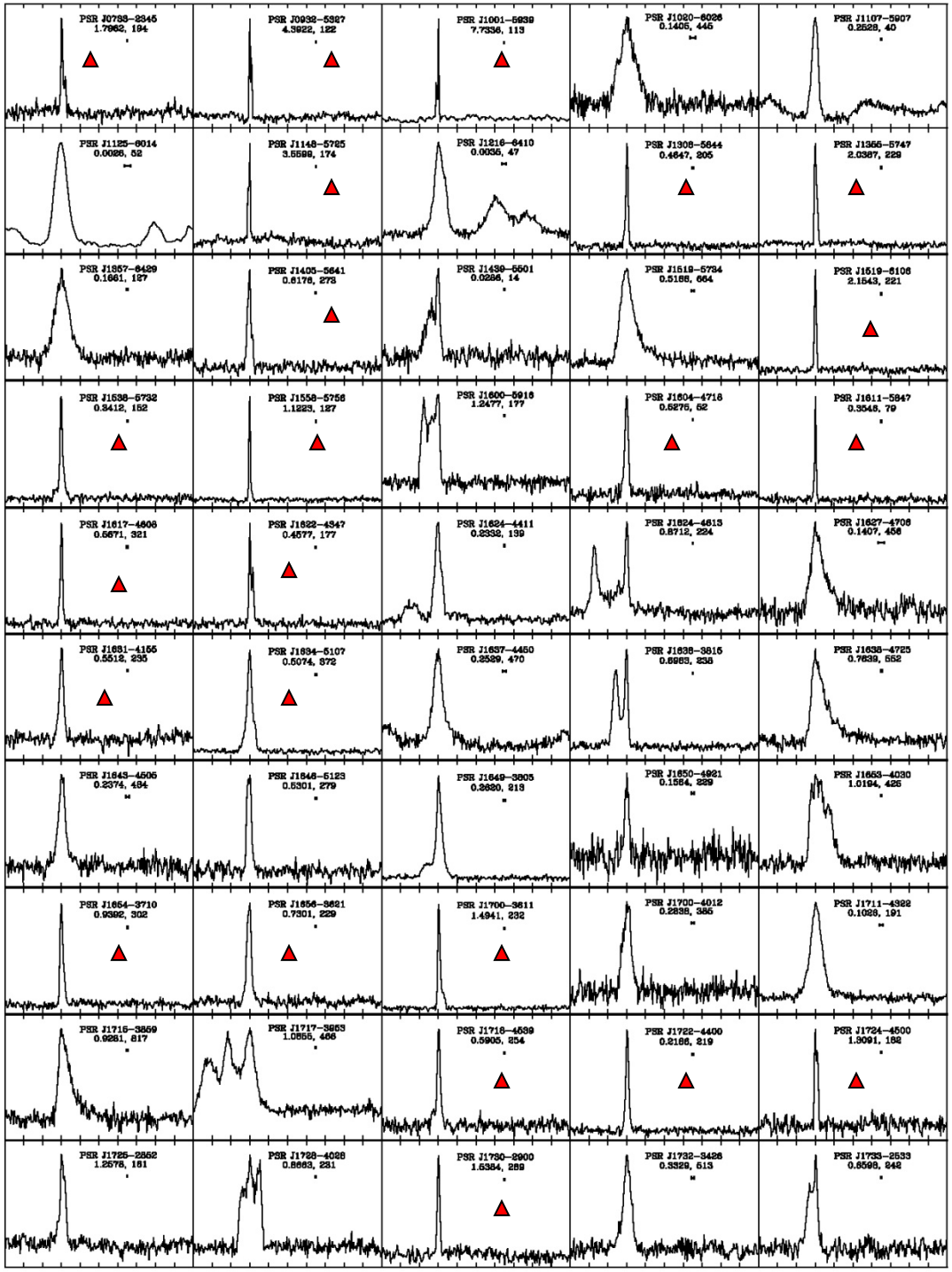
The Parkes Multibeam Pulsar Survey – the 13 element detector. Single dish radio telescopes don't make exquisite images, so filling the center beam area with multiple detectors sacrifices nothing.



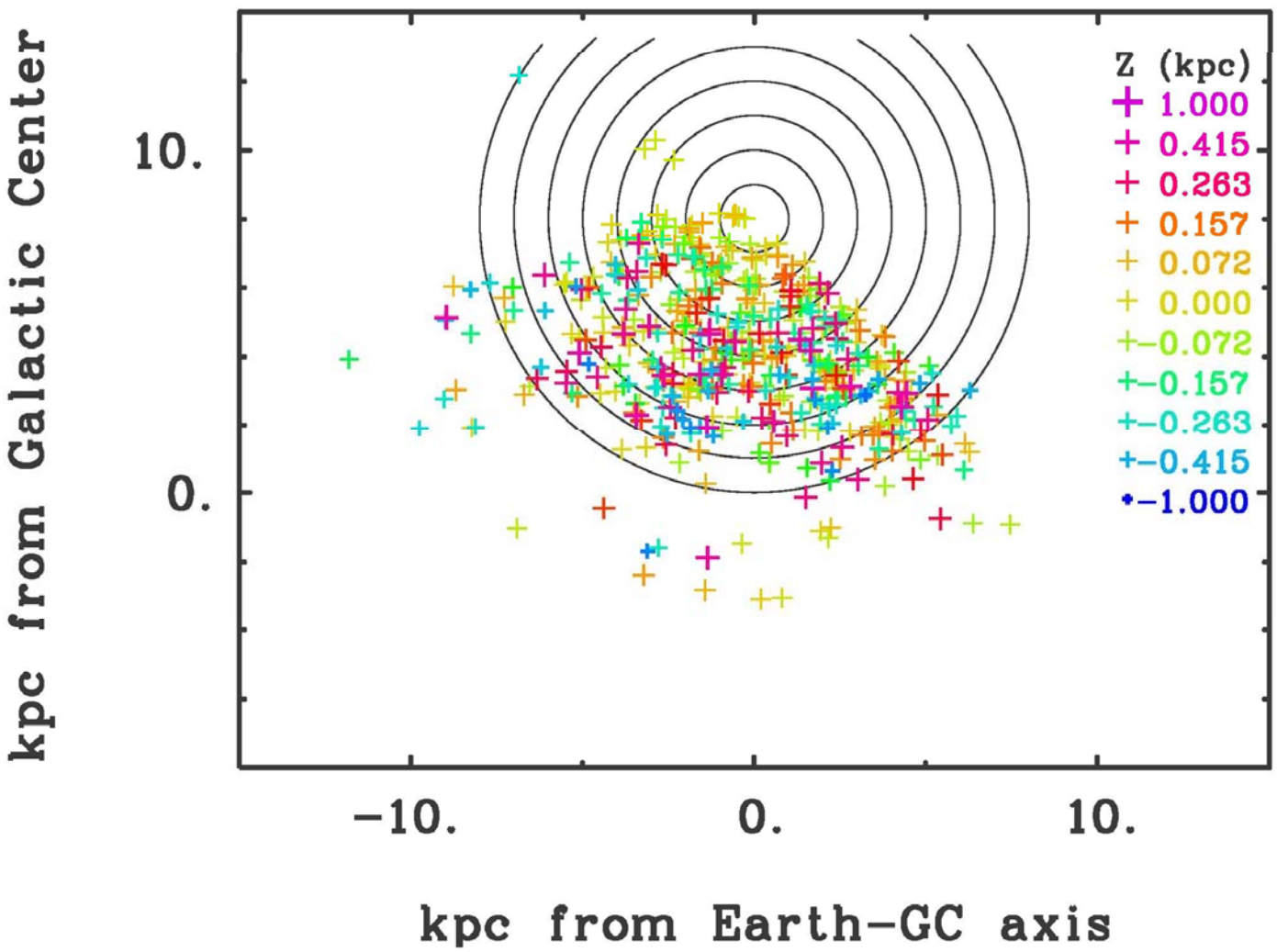
Mario binned the Parkes MB pulsars into discrete distances, averaged, and got the result below. No way is it 1/distance^2, but the luminosity function of the population is a complicating factor.



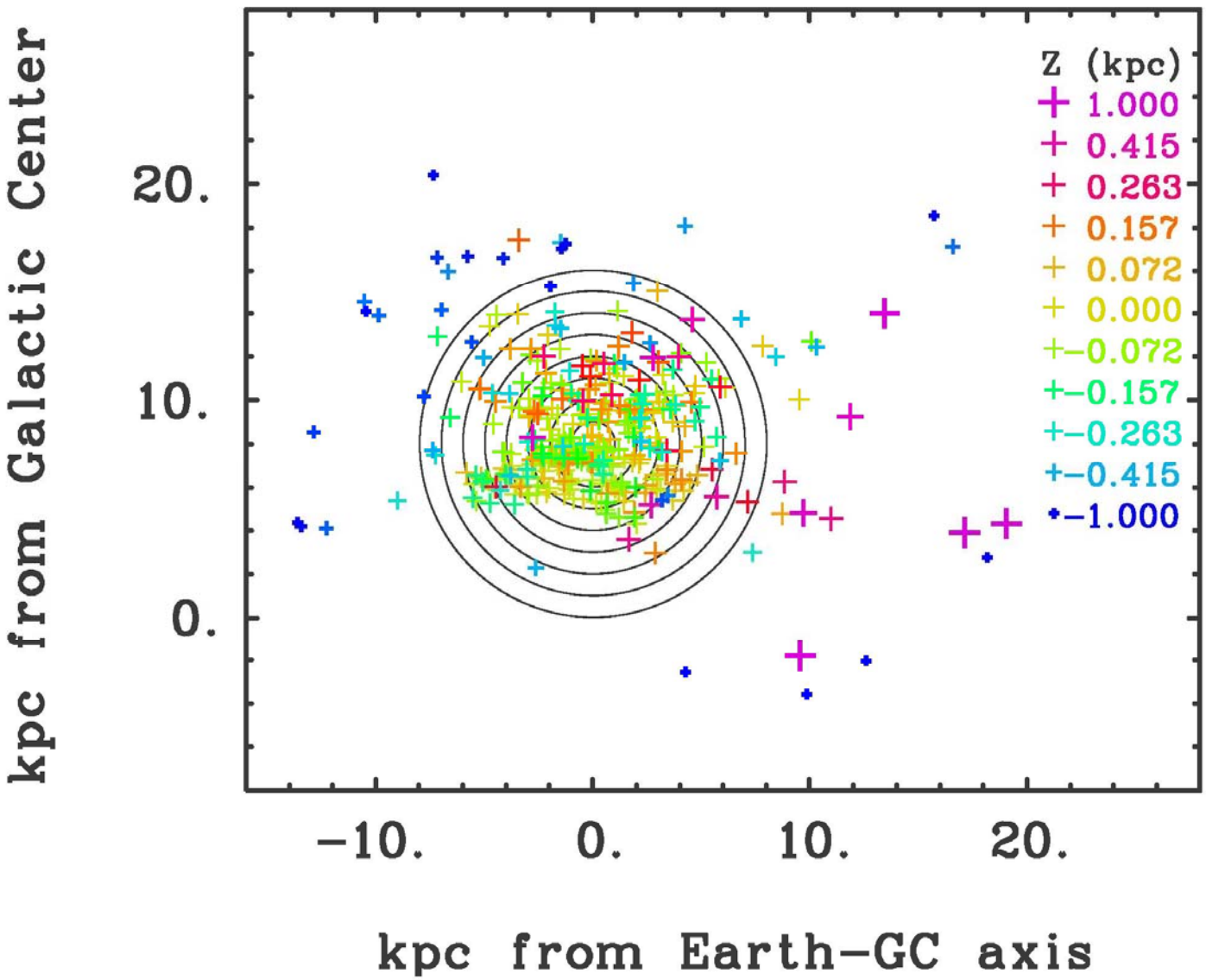
From Lorimer et al. (2006, MNRAS, 372, 777), 140 pulsars discovered in the Parkes Multibeam Survey. Half of these have pulse profiles consisting of a single, very narrowly peaked pulse.



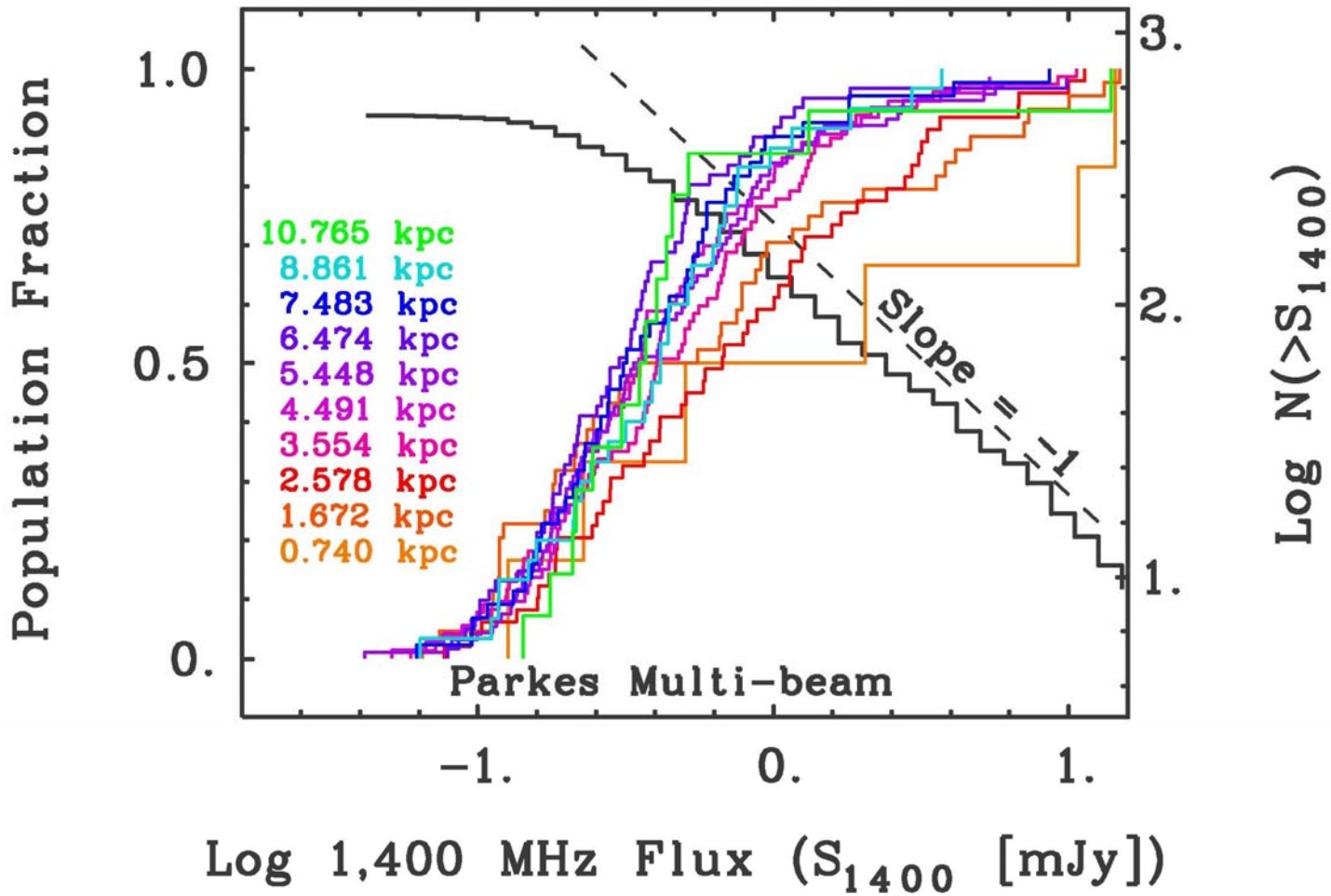
The distribution of the 497 narrowly-peaked pulsars of the Parkes MB Survey in space. Earth is at (0,8) kpc.



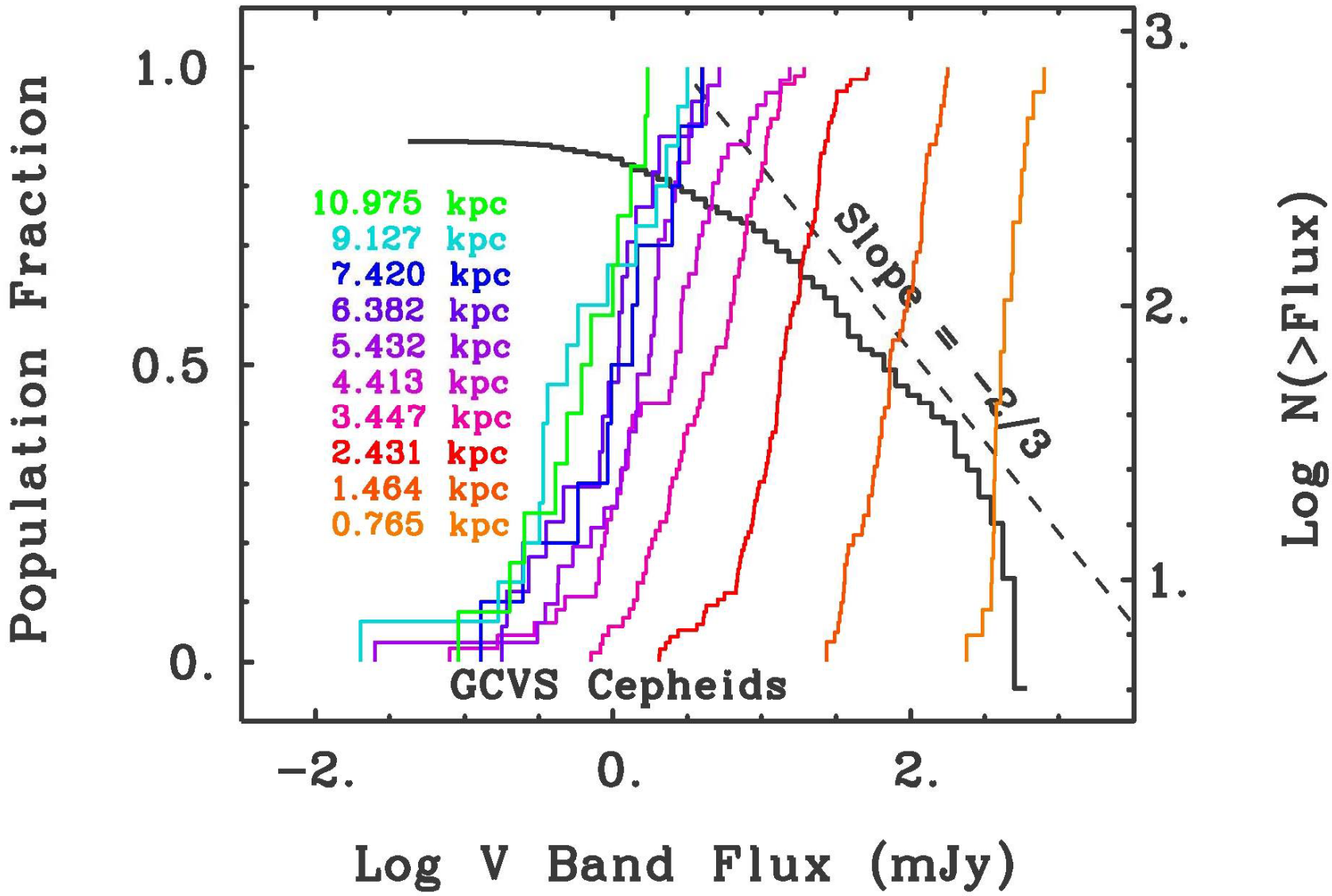
The distribution of 407 Cepheid variables from the General Catalog of Variable Stars, for which we have distances, in space. Earth is at (0,8) kpc.



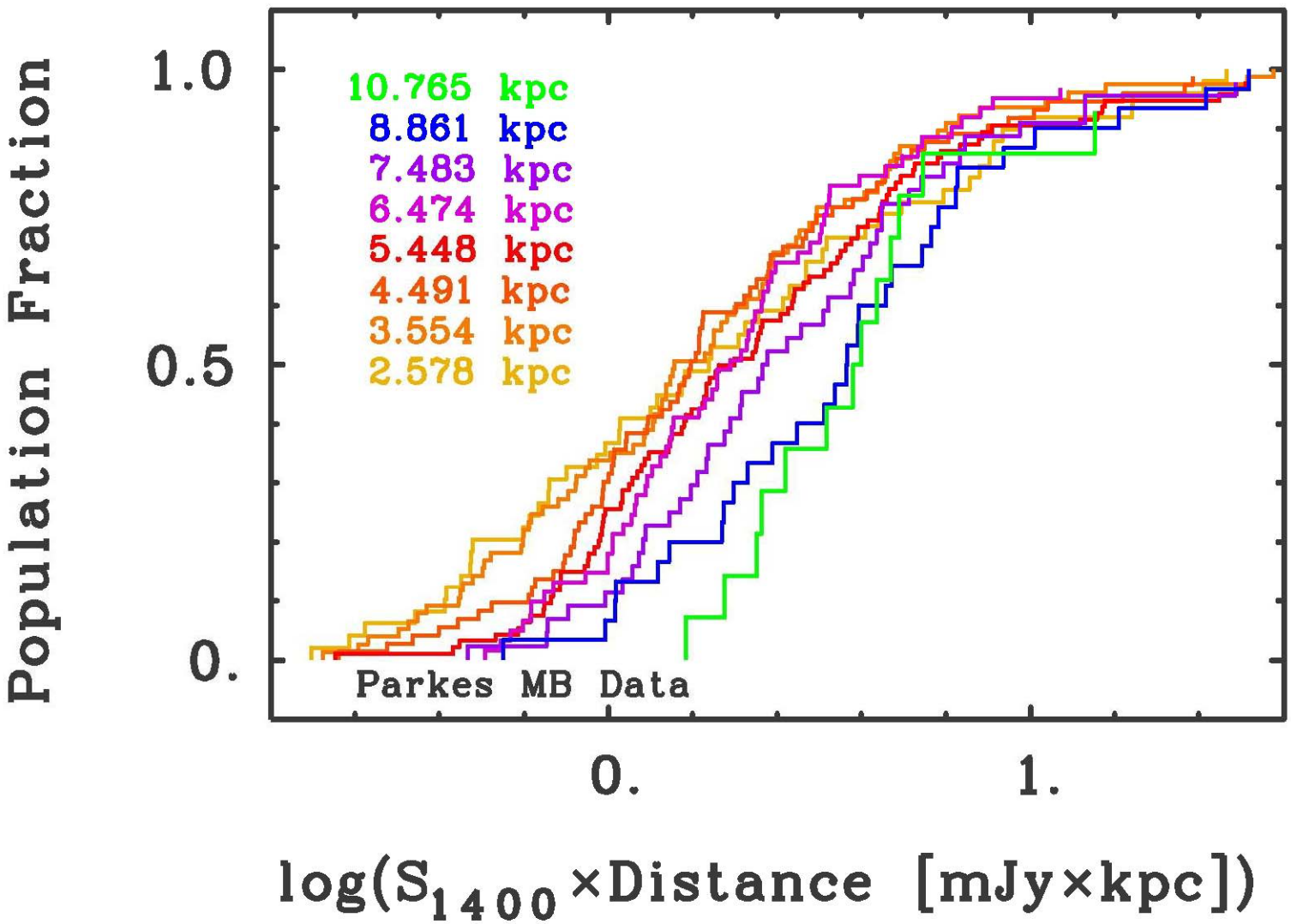
To deal with the complicating factor of the luminosity function, we plot the cumulative distributions vs luminosity for pulsars selected at different distances. We have also selected the 497 pulsars with pulse FWHM < 3% of the pulse period, because SLIP predicts that these are the ones for which the Earth is in their 1/distance sub-beams. The results show a detection limited sample at the faint (left hand) end, but a sample clearly not 1/distance² at the bright (right hand) end:



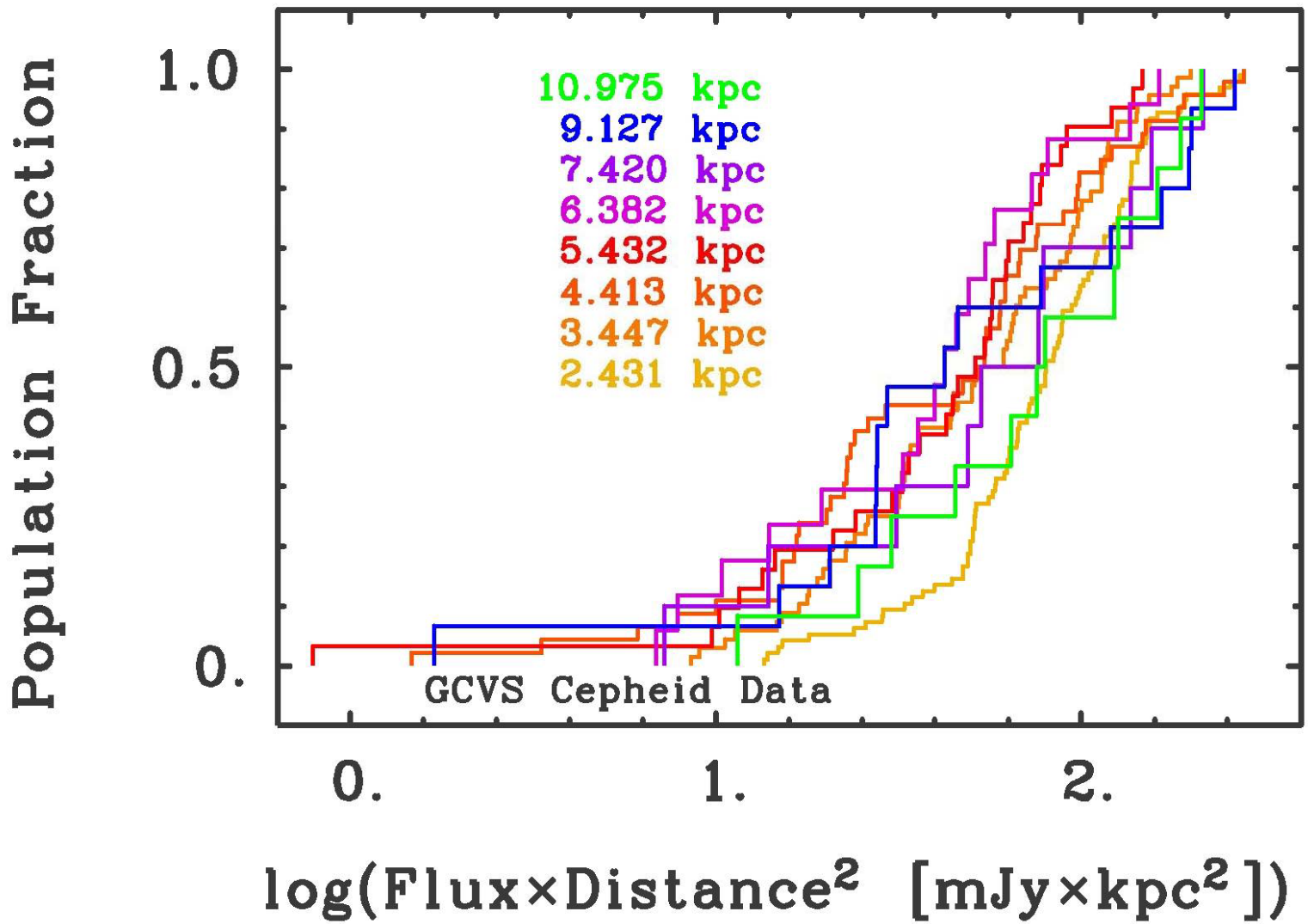
By contrast, the population of Cepheids is clearly very close to a distance^{-2} law. We also can not penetrate very far into our Galaxy to see Cepheids, we have to go around, thus the population slope differs from that of the pulsars.



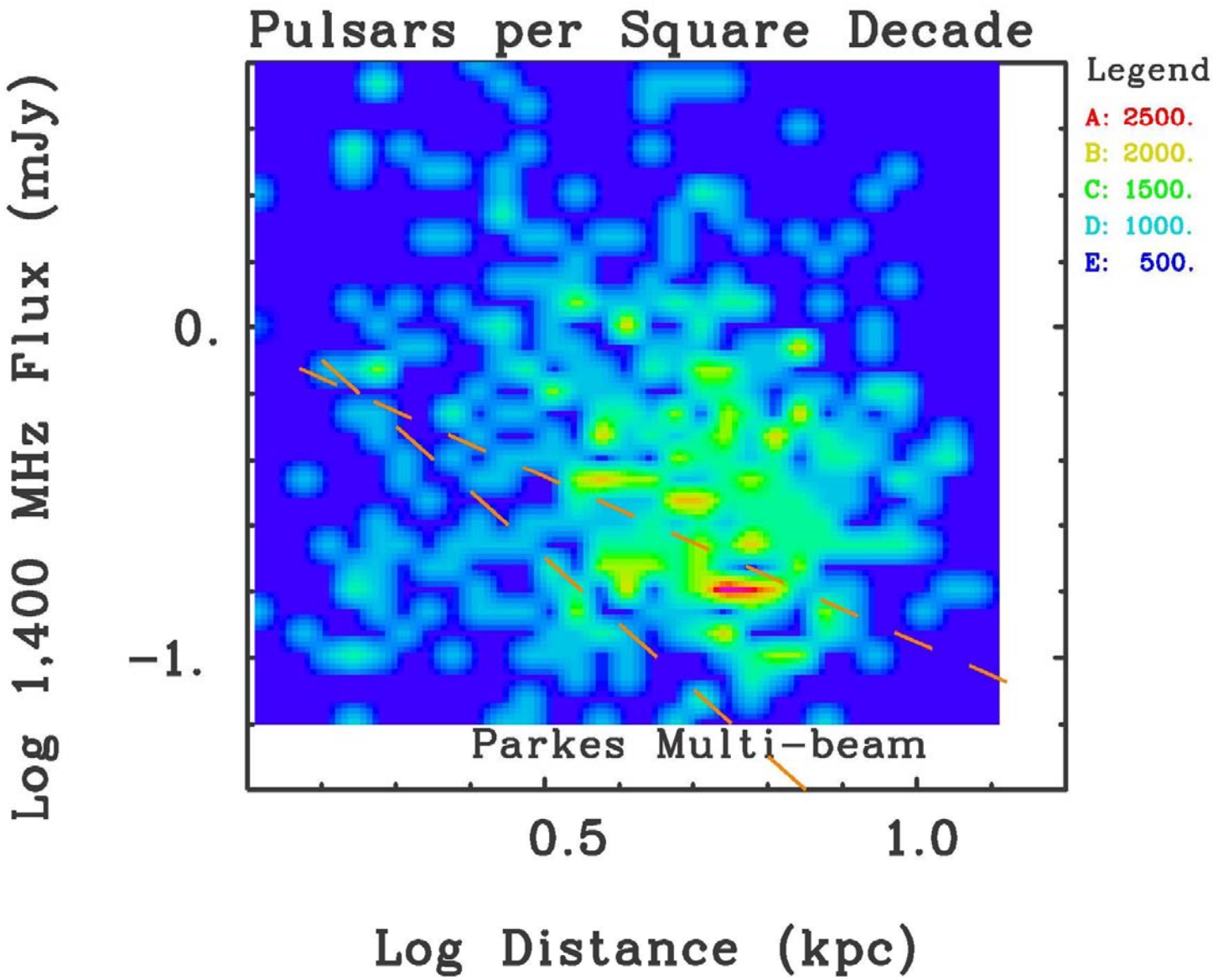
When we plot the cumulative population of pulsars at various distances vs their flux times one power of distance, the real data sample collapses in width at the high end. So again, the real pulsar data follow a 1/distance law.



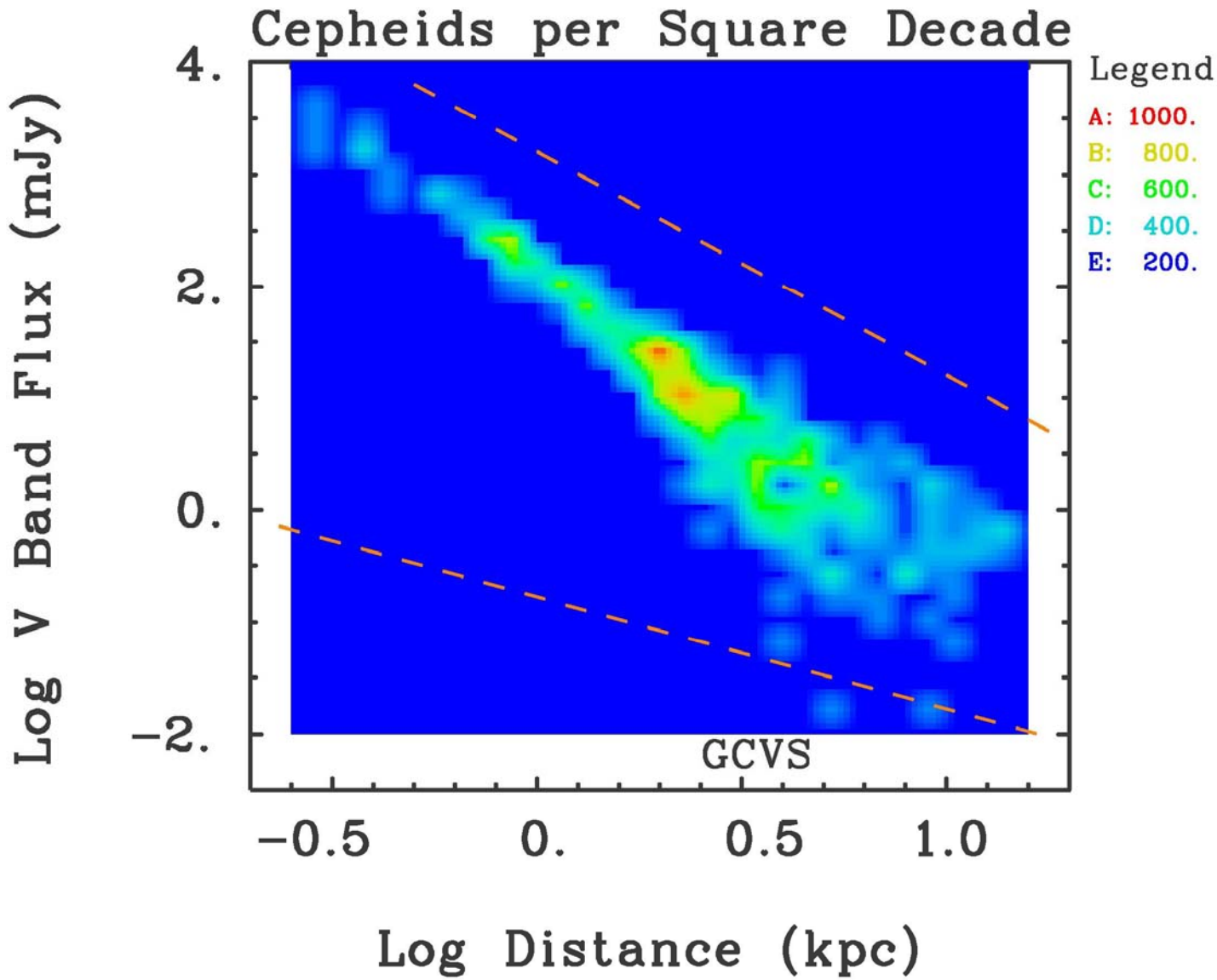
When we plot the cumulative population of Cepheids at various distances vs their flux times distance^2, the sample collapses in width. So again, the cepheid data follow a distance^{-2} law. Unlike the Parkes MB pulsars, this population is NOT flux-limited.



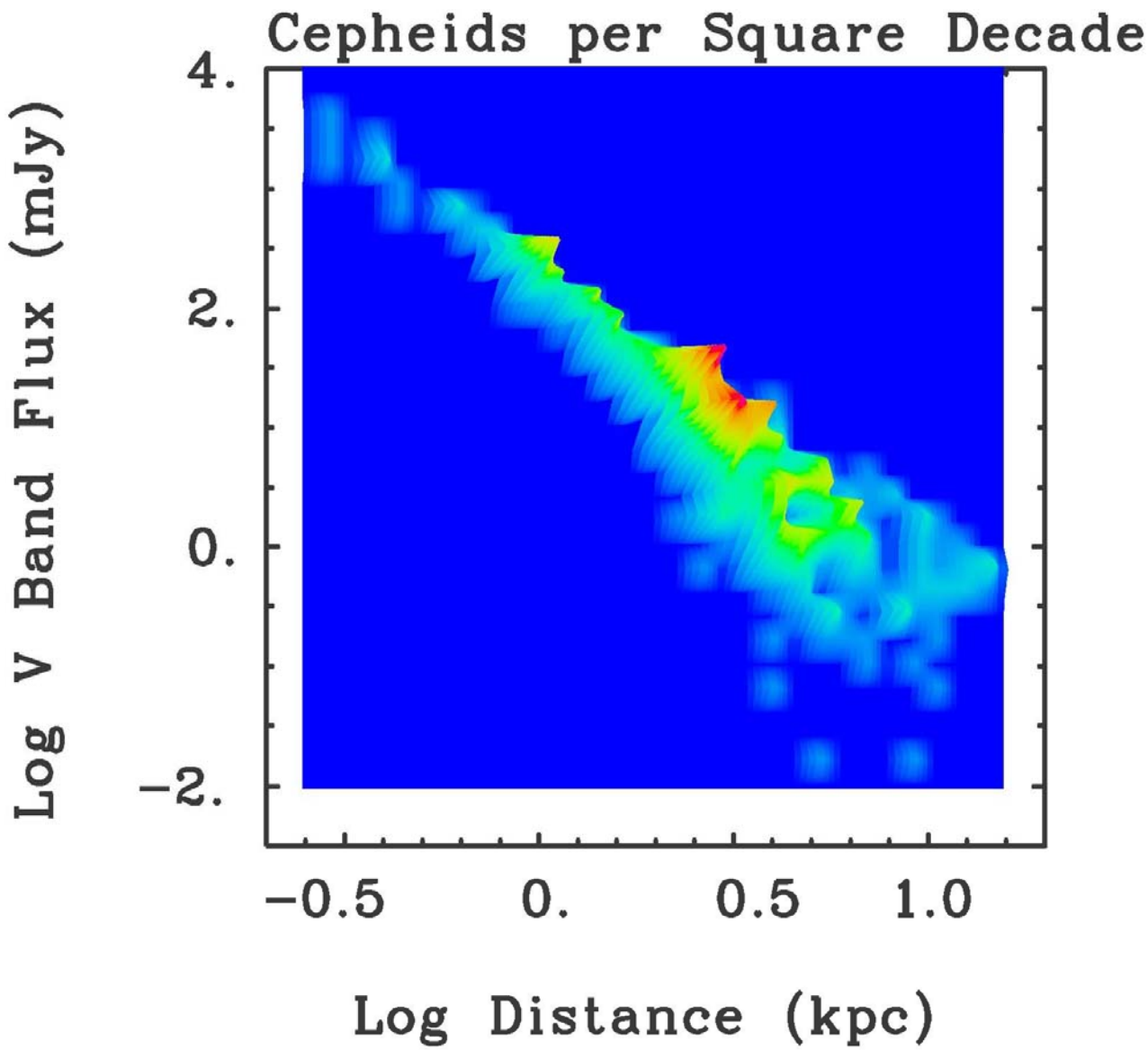
The unusual nature of this population can be seen on the log [distance-flux] plane. Here a line with a slope of -1 bisects the populations at different distances much more easily than does a line of slope -2. However, there remains the problem of the undetected parts of the distributions (497 pulsars). There are too many faint, nearby pulsars.



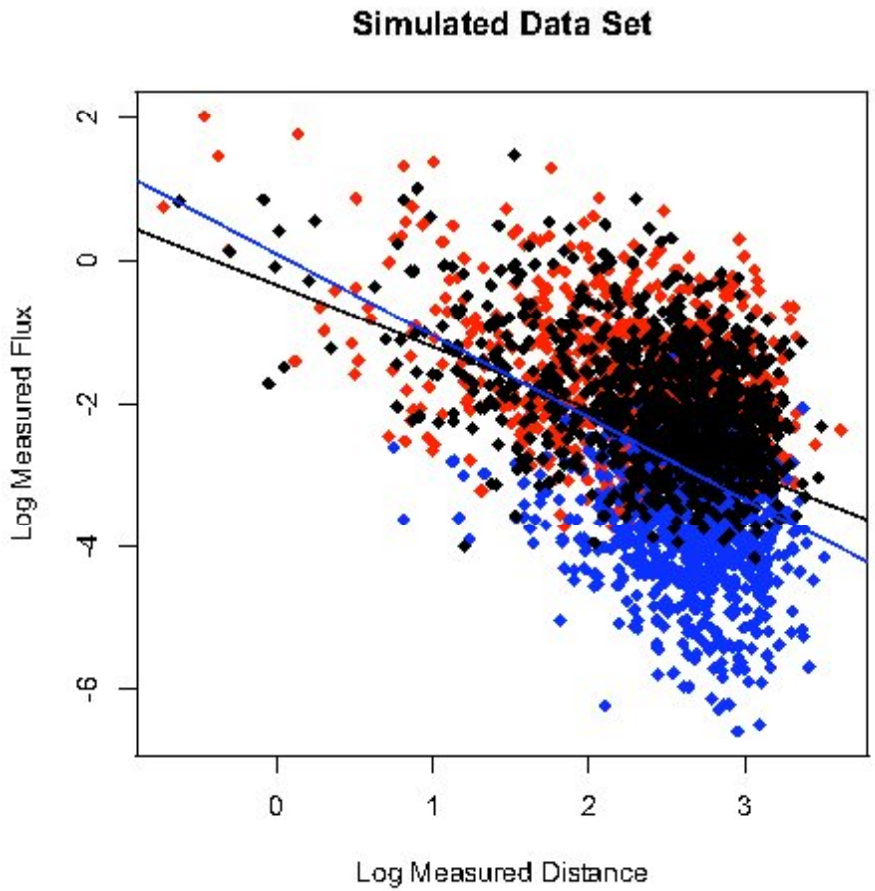
By contrast, the Cepheids follow a distance law at least as steep as -2 (distances thanks to Eduardo Amores).

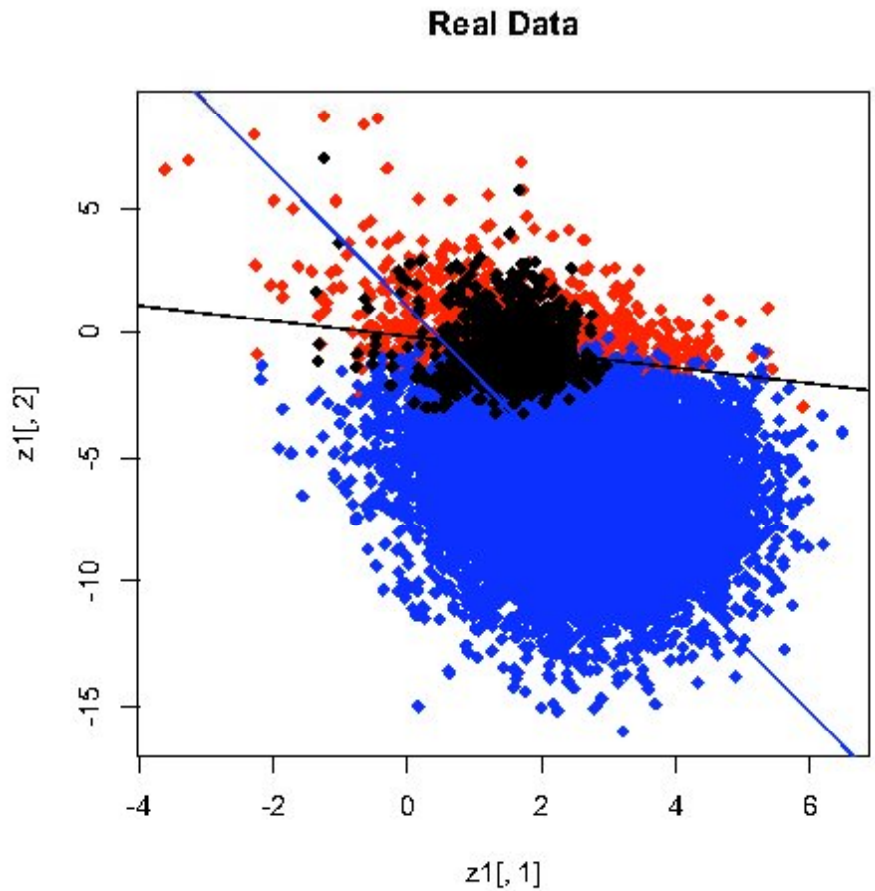


For those who prefer mountains:

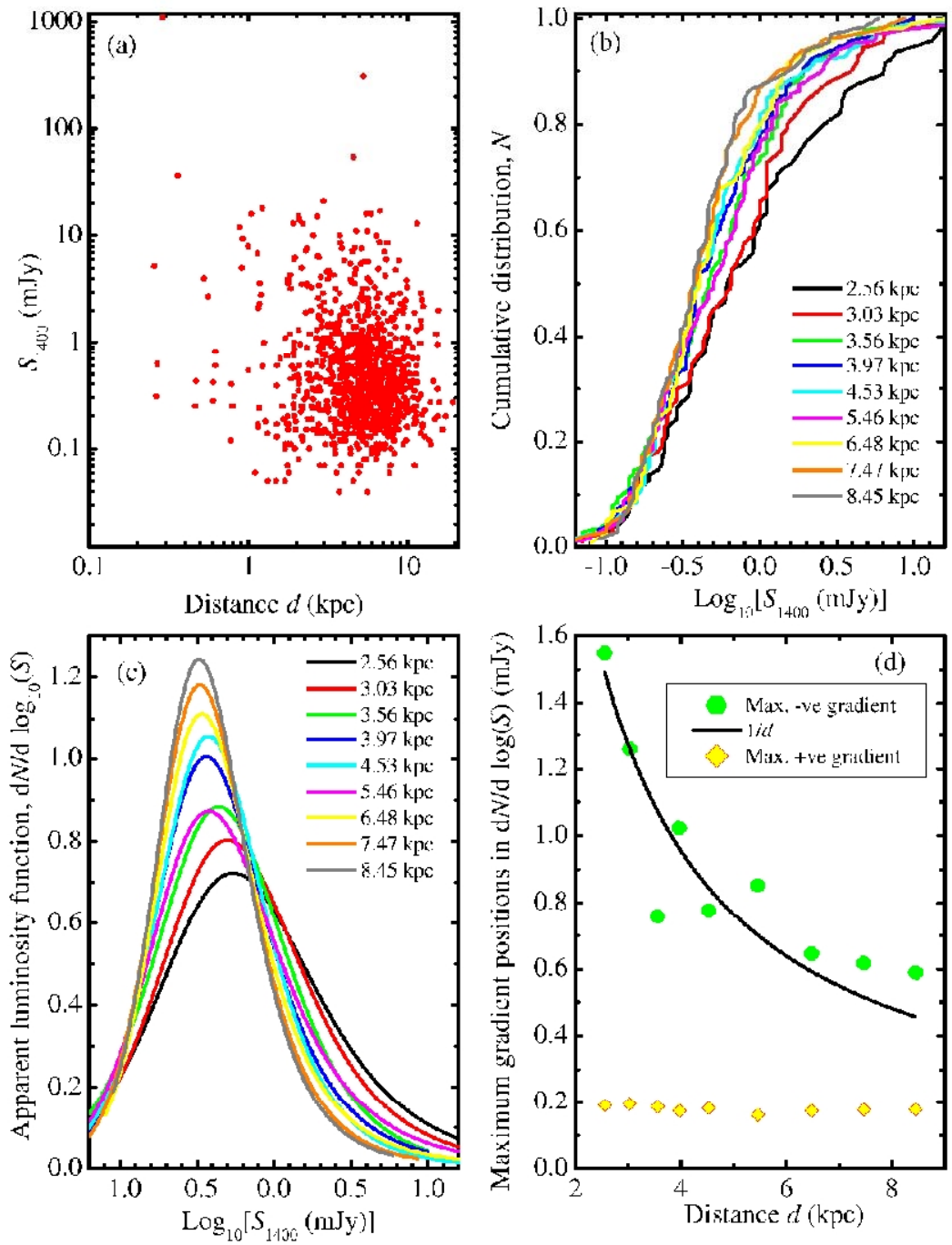


These plots show how complicated the problem really is. The real data set was not selected for narrowly peaked pulse profiles (~1,000 pulsars).





By fitting the cumulative population distributions to a smooth function, and differentiating three times to find the maximum negative slope of the differential population distribution (as high in S_{1400} as possible, so as to avoid instrumental cutoff), Singleton was able to extract a nearly monotonic series of peaks, which followed the 1/distance law closely. The maximum positive slopes clearly show the instrumental cuttoff (~1,000 pulsars – NOT pulse width selected).



Efstathiou, Ellis, & Peterson (1988) developed a stepwise maximum-likelihood method (a method already insensitive to Malmquist bias), which did not rely on a single functional form for the luminosity function, φ(L), to measure the exponent of the distance law for galaxy redshift survey samples.

We (Pinaki) applied this method to our sample of 497 Parkes MB Survey pulsars with narrow peaks,

2.1.3 Stepwise maximum-likelihood method

In this section, we develop a maximum-likelihood technique which does not rely on the assumption of a simple functional form for $\phi(L)$. Let us parameterize the luminosity function as N_p steps:

$$\phi(L)=\phi_k, \qquad L_k-\Delta L/2<L<L_k+\Delta L/2, \qquad k=1,\ldots,N_p. \tag{2.8}$$

As in expressions (2.5) and (2.6), the likelihood is

$$\ln \mathfrak{L}=\sum_{i=1}^{N} W(L_i-L_k)\ln\phi_k-\sum_{i=1}^{N}\ln\left\{\sum_{j=1}^{N_p}\phi_j\Delta L H[L_j-L_{\min}(z_i)]\right\}+\text{const}, \tag{2.9}$$

where N is the total number of galaxies in the sample and

$$W(x)=\begin{cases}1, & -\Delta L/2\leqslant x\leqslant\Delta L/2;\\ 0, & \text{otherwise}.\end{cases} \tag{2.10a}$$

$$H(x)=\begin{cases}0, & x\leqslant-\Delta L/2\\ (x/\Delta L+1/2), & -\Delta L/2\leqslant x\leqslant\Delta L/2\\ 1, & x\geqslant\Delta L/2.\end{cases} \tag{2.10b}$$

Now, since the likelihood function involves ratios of the ϕ_k, some sort of constraint must be imposed to fix the otherwise arbitrary normalization constant. A constraint is essential if the results from different samples are to be directly compared. We adopt a constraint of the form

$$g=\sum_k \phi_k(L_k/L_f)^{\beta}\Delta L-1=0, \tag{2.11}$$

where L_f is a fiducial luminosity and β is a constant. The constraint is introduced into the likelihood equation using a Lagrangian multiplier λ, thus we maximize $\ln\mathfrak{L}'=\ln\mathfrak{L}+\lambda g(\phi_k)$ with respect to the ϕ_k and λ.

The likelihood equation then yields

$$\phi_k\Delta L=\frac{\sum_i W(L_i-L_k)}{\sum_i\left\{H[L_k-L_{\min}(z_i)]\Big/\sum_{j=1}^{N_p}\phi_j\Delta L H[L_j-L_{\min}(z_i)]\right\}}, \tag{2.12}$$

together with condition (2.11) and the requirement that $\lambda=0$. The constraint therefore does not affect the shape of the maximum likelihood estimate of ϕ but it does play a role in the error estimates. The constant β may be chosen to give 'minimum variance' in a way which will be made precise in Section 2.2 below. The parameters ϕ_k may be rapidly determined from equation (2.12) by iteration.

To estimate errors we use the property that the maximum-likelihood estimates ϕ_k are asymptotically normally distributed with covariance matrix

$$\text{cov}\,(\phi_k)=\mathbf{I}^{-1}(\phi_k), \tag{2.13a}$$

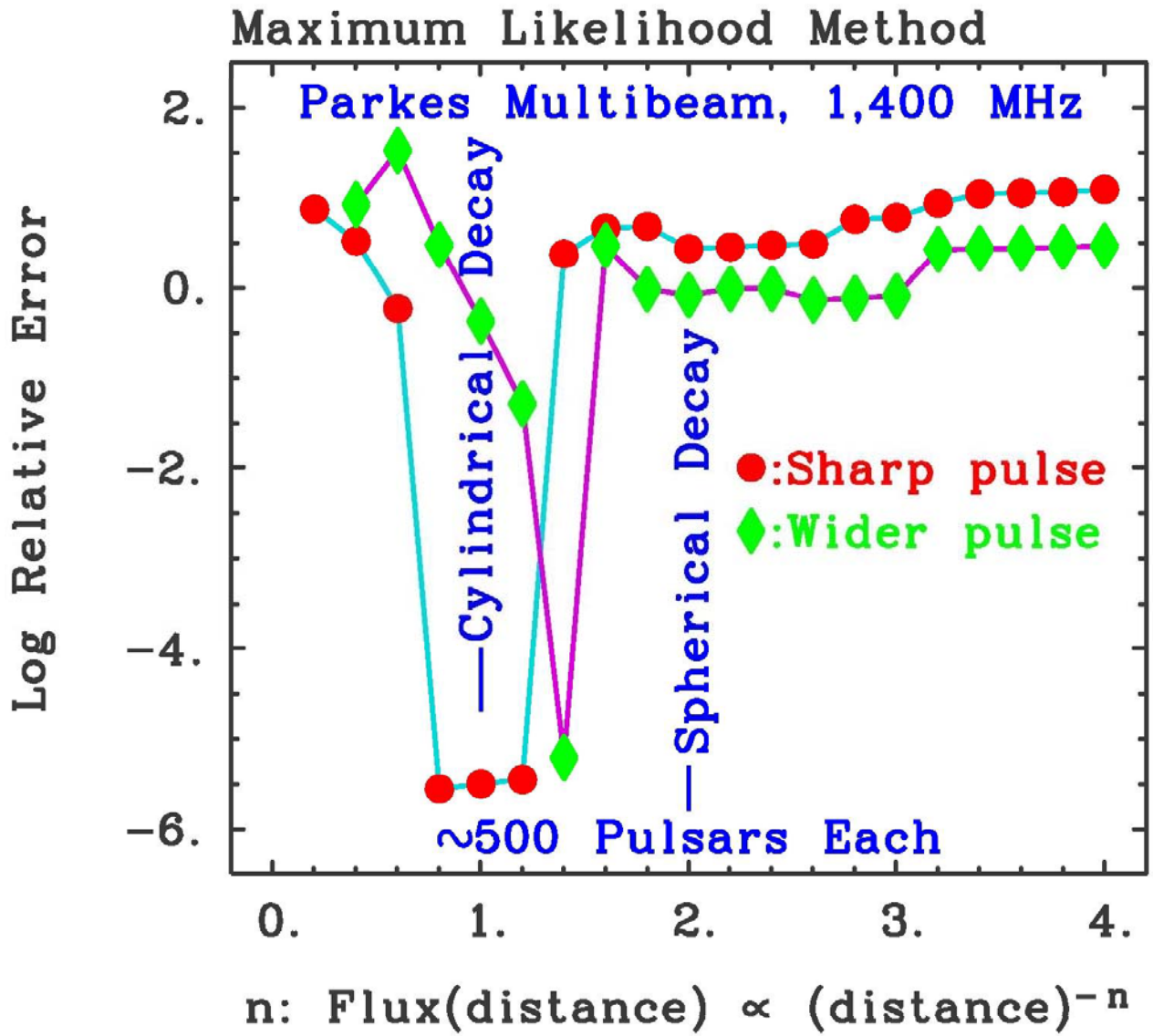
where $\mathbf{I}(\phi_k)$ is the information matrix given by

$$\mathbf{I}(\phi_k)=-\begin{bmatrix}\partial^2\ln\mathfrak{L}/\partial\phi_i\partial\phi_j+(\partial g/\partial\phi_i)(\partial g/\partial\phi_j) & \partial g/\partial\phi_j\\ \partial g/\partial\phi_i & 0\end{bmatrix}_{\phi=\phi_k}. \tag{2.13b}$$

(see Eadie *et al.* 1971). Notice the inclusion of the term $(\partial g/\partial\phi_i)(\partial g/\partial\phi_j)$ which renders the information matrix non-singular. The convergence of the covariance matrix to the asymptotic expression (2.13) is considered in Section 2.2.

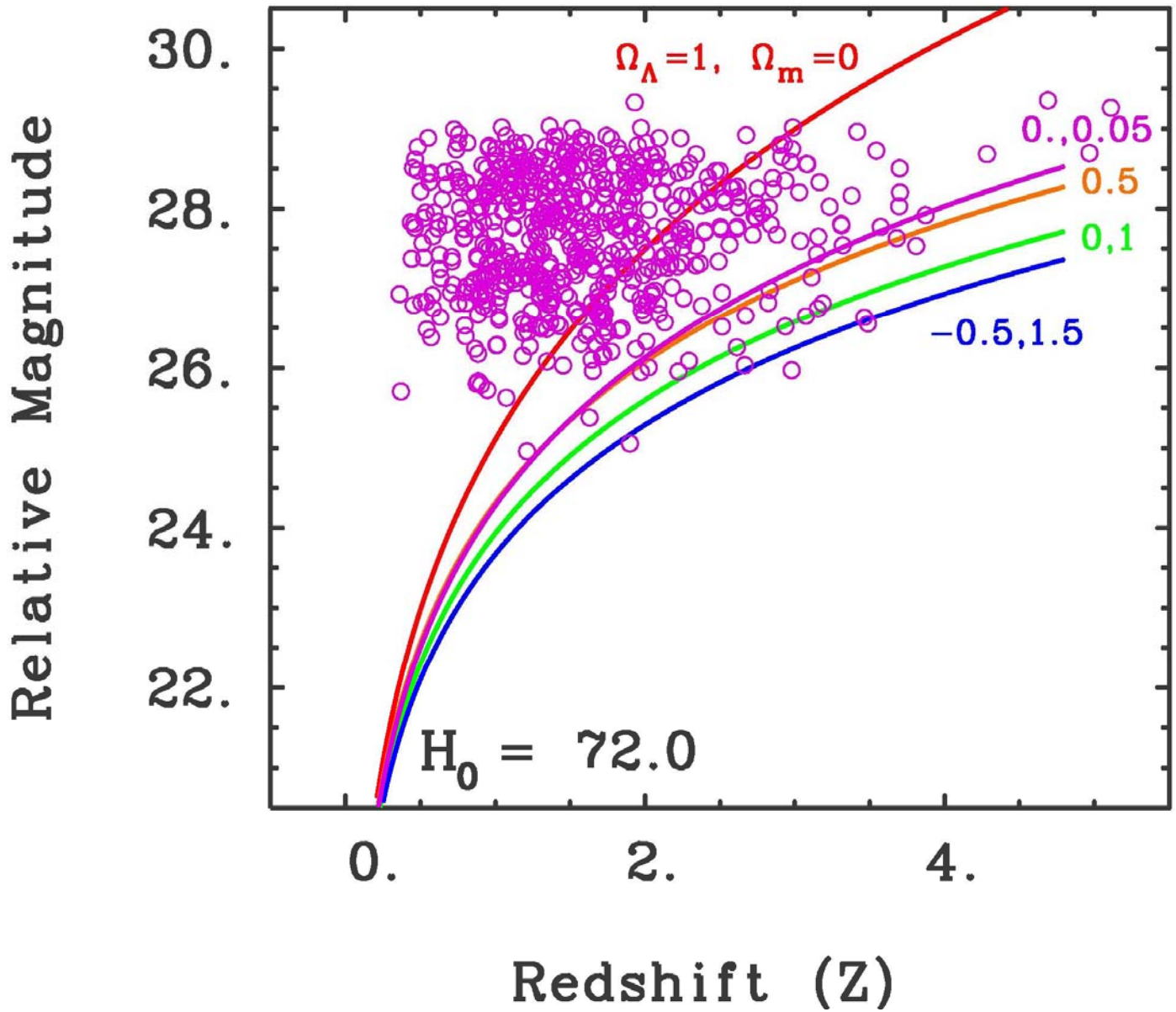
The estimator (2.12) is a generalization of the C-method of Lynden-Bell (1971; see also

… and the results were spectacular – it's just math!



This is the most definitive result for any population in astronomy, ever. So, SLIP **IS** the correct model for isolated pulsars.

Quasars have NO distance law. Are they the product of more than one superluminal excitation?



So the 1/distance law holds!!!!!!!!!!

The Ginzburg/Bolotovskii model ***IS*** the model for most rotation-powered pulsars.

This is beaming, *on Steroids*.

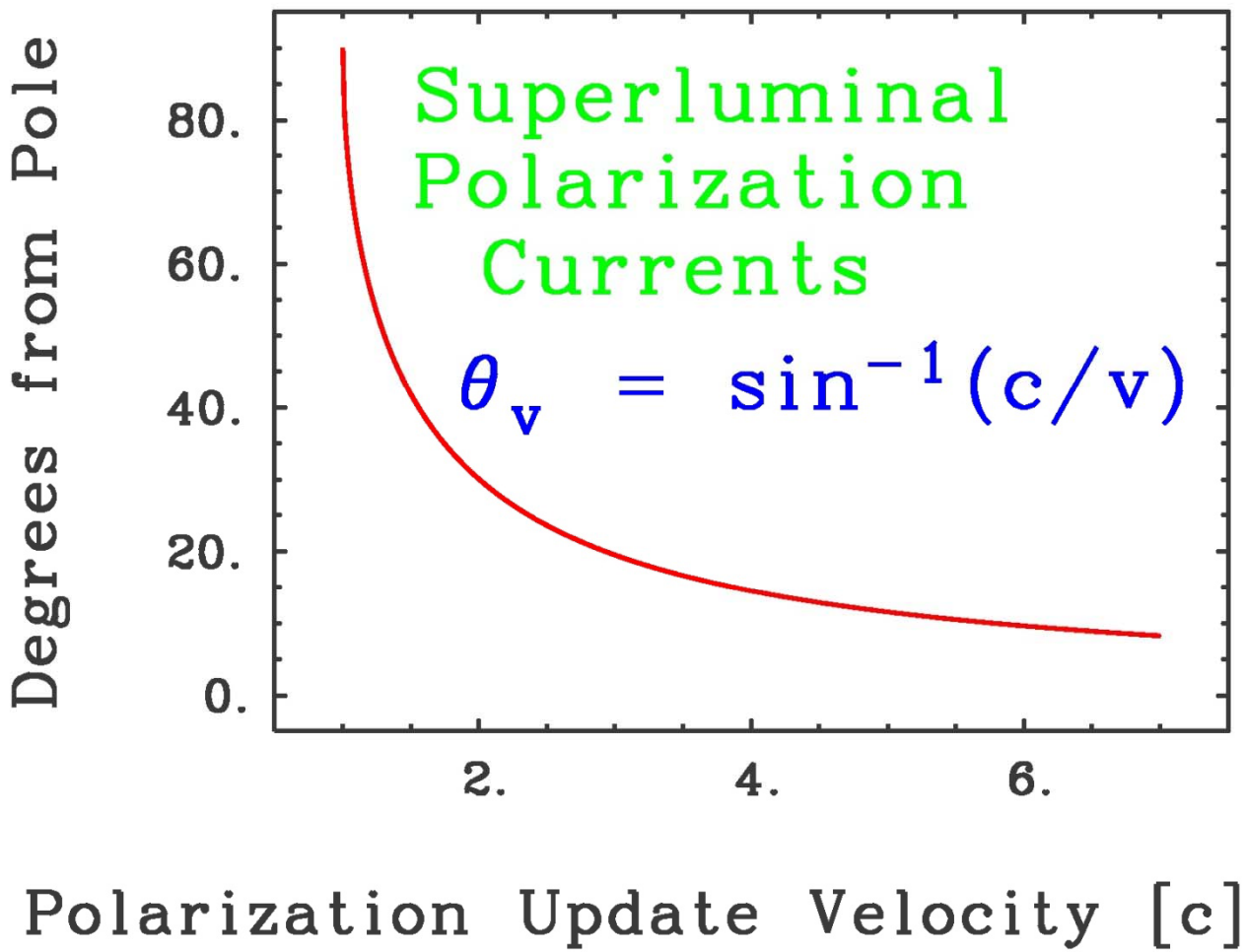
The usual rules don't hold:

A pulsar doesn't need much excuse to show up or go away. Changes in the plasma outside of the light cylinder are enough. Strong, otherwise unexplained instances of pulsations should always be published. 23.1 ms in the Cygnus Loop; 104 Hz optical pulsations in 4U1728-24.

Luminosity conundra are suspended. Most, if not all, of the transient events at cosmological distances are the result of a superluminal excitation with a distance law inversion.

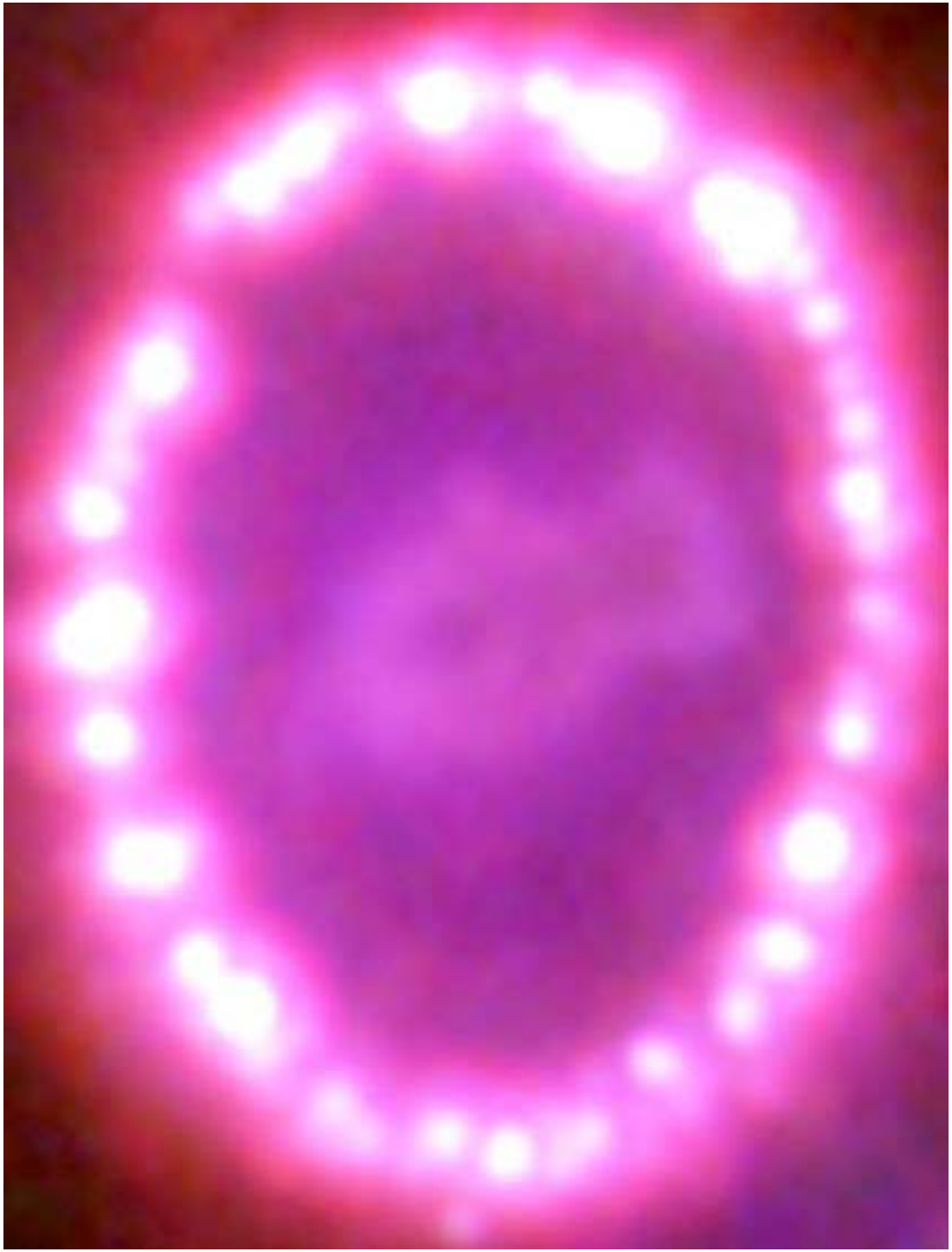
What about the other detail of the prediction, namely that the direction of this favored emission lies on a cone of ½ angle, $\theta_v = \sin^{-1}(c/v)$?

If a pulsar is born within a star, there will be plasma at many light cylinder radii, thus one would expect the pulsed beam to be close to the rotation axis, *right down the gunsight*. This may be the central engine of the GRB mechanism, and what blows out the poles of SNe.

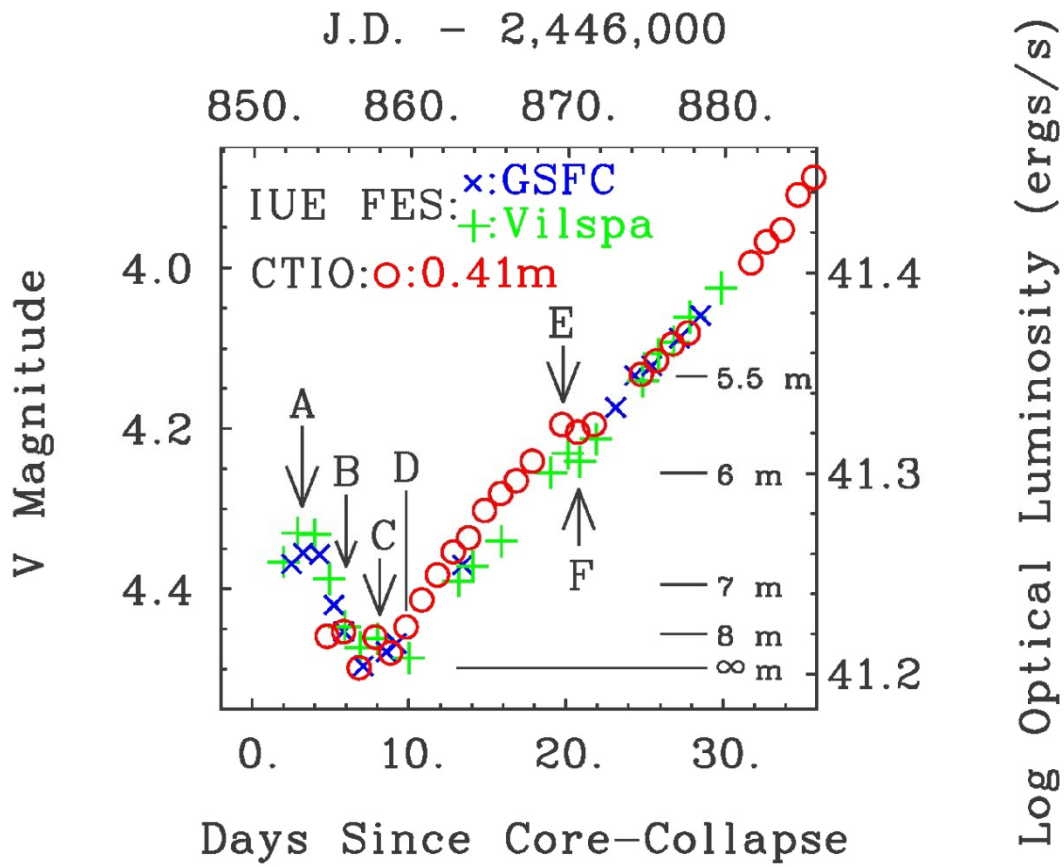


There's a reason why SNe appear as they do, and that reason is what the pulsar does in the first few months. Pulsars are a significant, and non-ignorable part of the SN process, and modelers have never accounted for this. Pulsars eviscerate their progenitors until there is little progenitor left. The evidence:

SN 1987A is clearly bipolar. It is thought to have been due to a merger of the cores of two 8-10 $M_\odot$ stars. All other SNe measured are also consistent with this bipolarity to some degree. These are 21st century objects, and it is no wonder that λ spectrophotometry alone has not made much progress understanding them.

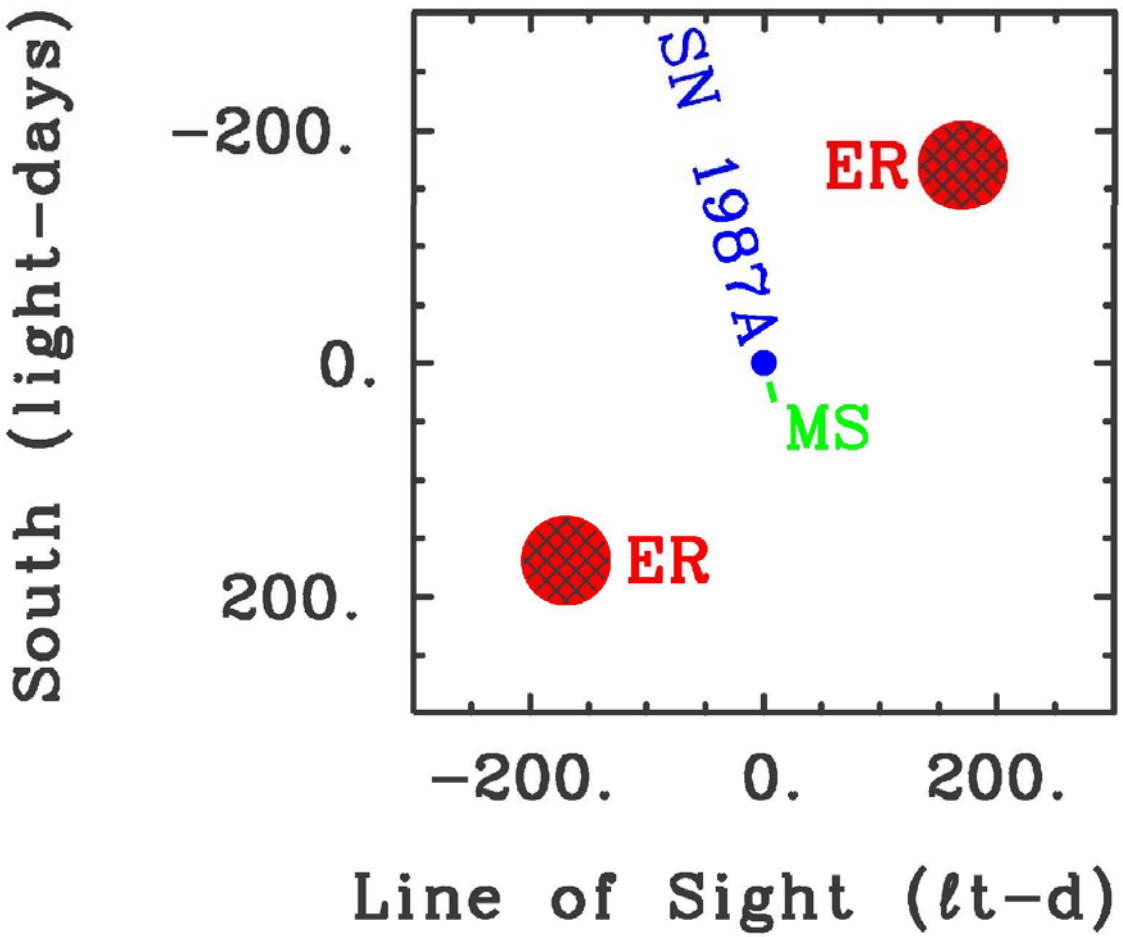


SN 1987A is the Rosetta Stone for a pulsar-driven jet. Its early light curve indicates an impulsive ejection of particles with a maximum velocity of 0.95 c, penetrating polar ejecta ~11 ℓt-days away, and ~14 ℓt-d thick. However, measurements of the "Mystery Spot" (MS) indicate a continued ejection of ~0.5 c particles (for at least a month) not unlike the Crab pulsar or Sco X-1.

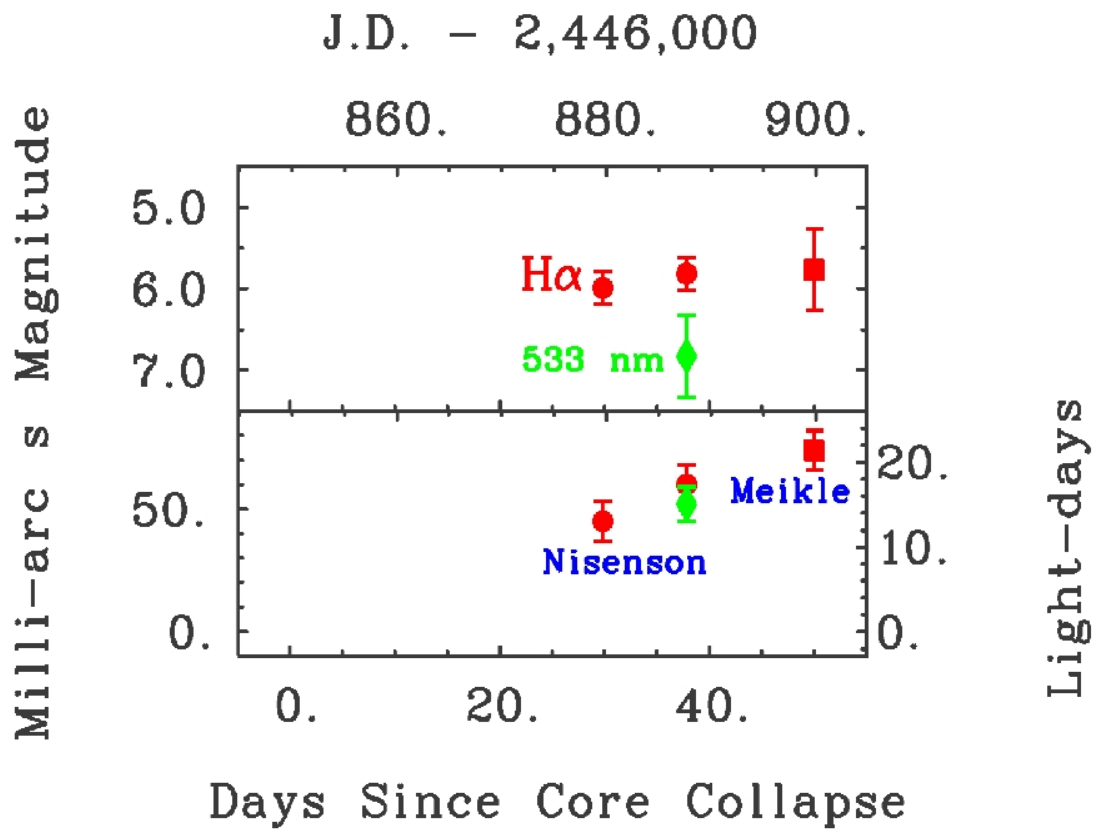


A: Emergence of a luminous jet
B: Cooling (or spreading) of the jet
C: UV Superflash/(pulsed beam) hits polar ejecta
D: Jet ~2 ℓt-d into14 ℓt-d of polar ejecta
E: Breakout of the pulsed beam from the polar ejecta
F: Particles of jet begin to clear the polar ejecta

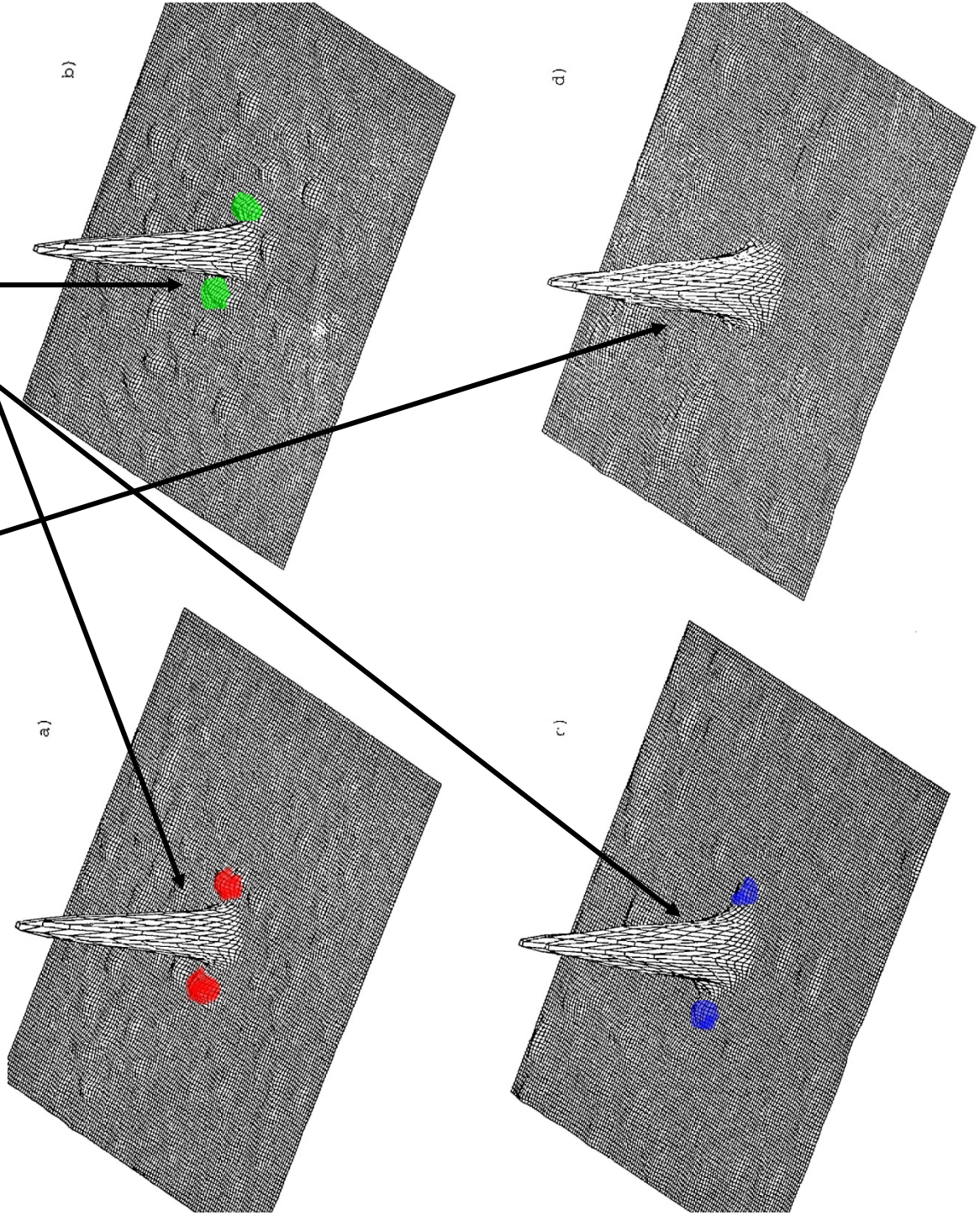
The approximate path of the "Mystery Spot" (MS -- now in green) relative to **SN 1987A** and the equatorial ring (ER -- shown in red, hatched cross-section). The large angle to the bipolarity may have been the reason that optical pulsations were not seen until years 5.0 – 6.5. The plasma had to thin so that the 1/distance beam could be more equatorial.



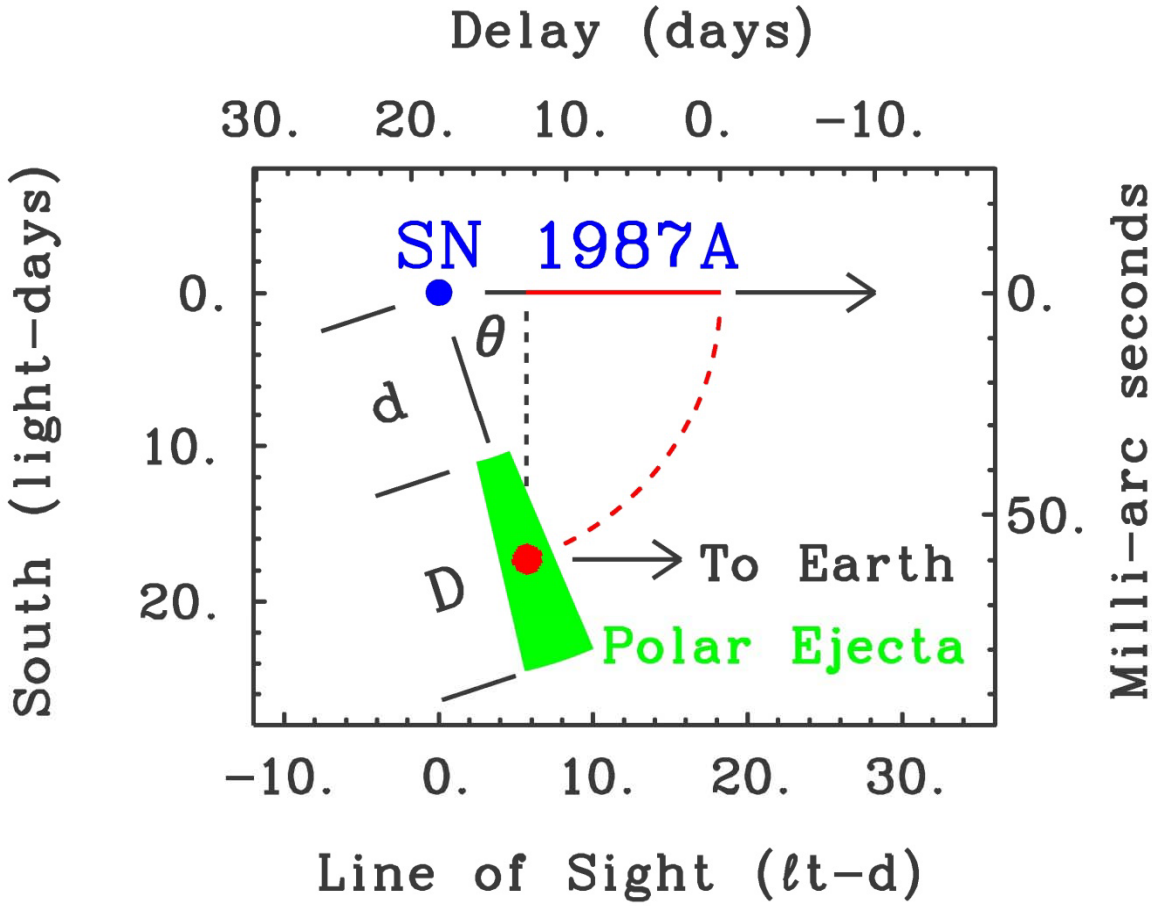
Measurements of displacement (lower) and observed magnitude (upper) of the "Mystery Spot" (MS) from **SN 1987A**, at Hα and 533 nm, vs time, from Nisenson et al. 1987, ApJ, 320, L15, and Meikle et al. 1987, Nature, 329, 608. In Hα, the MS represents about 8% of SN 1987A proper.



Here are the speckle data for the mystery spot in Hα (lower left), 533 nm (upper left), 450 nm (lower right), and the normal star, ν Doradus (upper right). There is a 180° ambiguity in the display. We could have used speckle starting on day 2!



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 0.5º 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 (ℓGRBs).



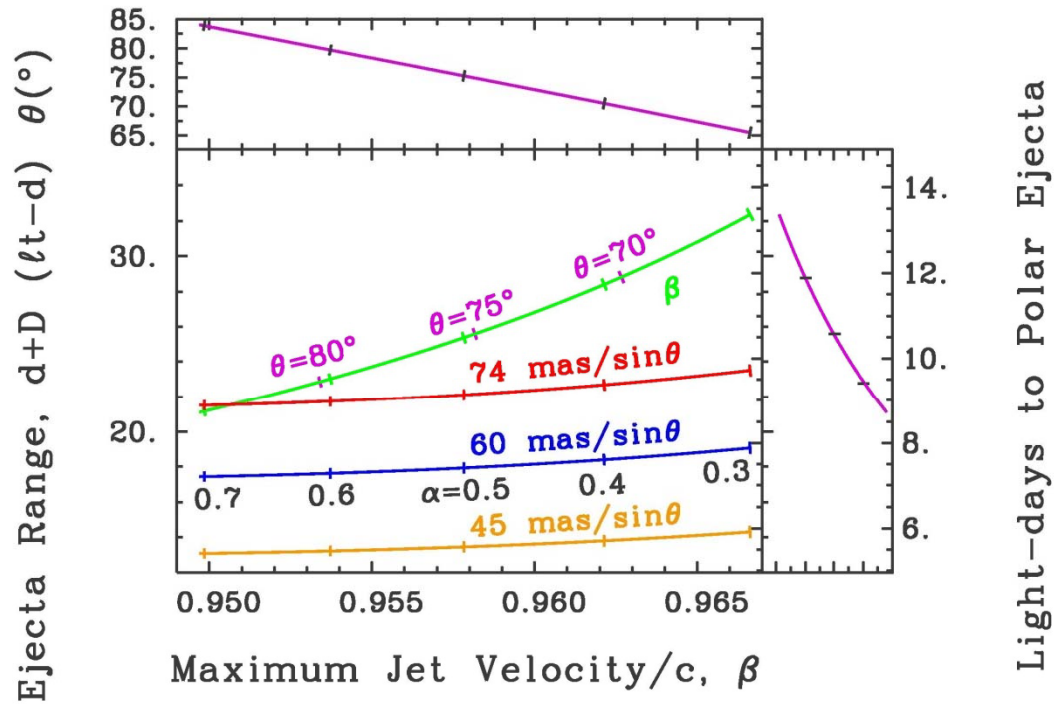
We solve for the geometry of the beam/jet (green curve) from SN 1987A using the constraints. Here α is the fraction of the way through the polar ejecta that the Mystery Spot had penetrated at day 37.8, when its projected offset from SN 1987A was 0.060 arc s. The solution for α=0.5 gives:

θ = 75.193º,

d = 10.47738 ℓt-d

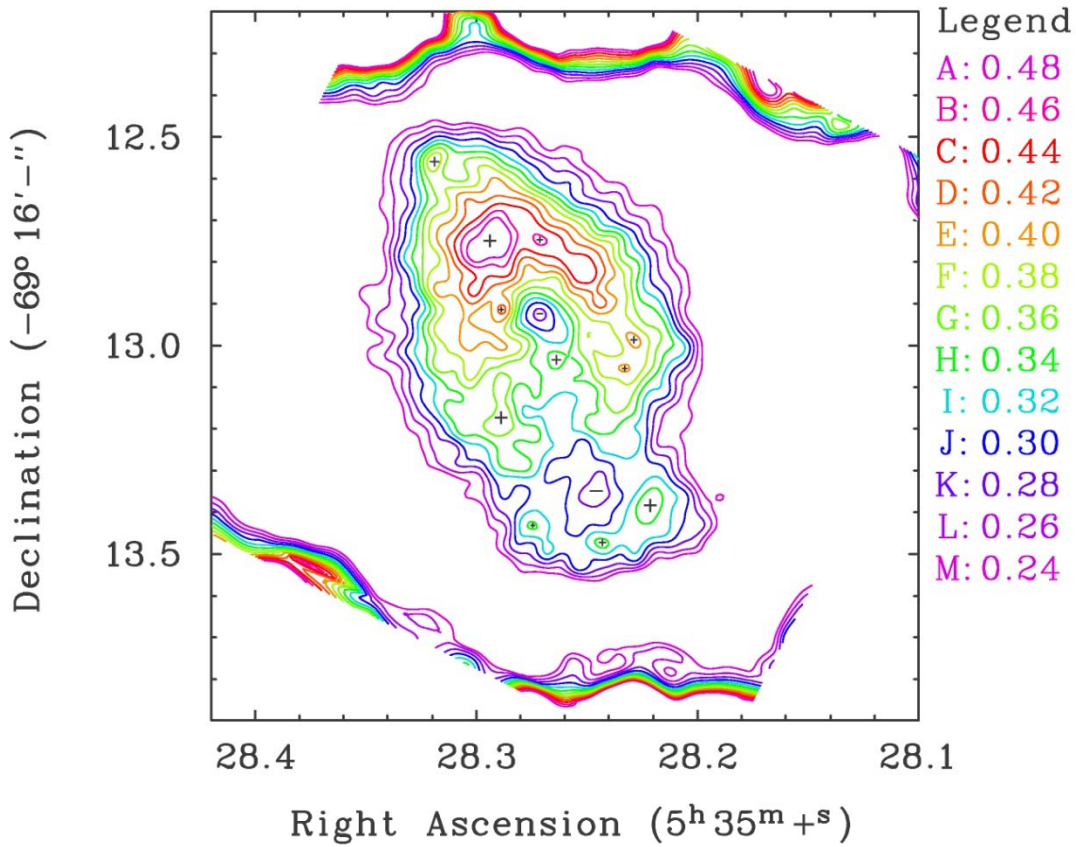
D = 14.888 ℓt-d,

β_{max} = 0.9578.

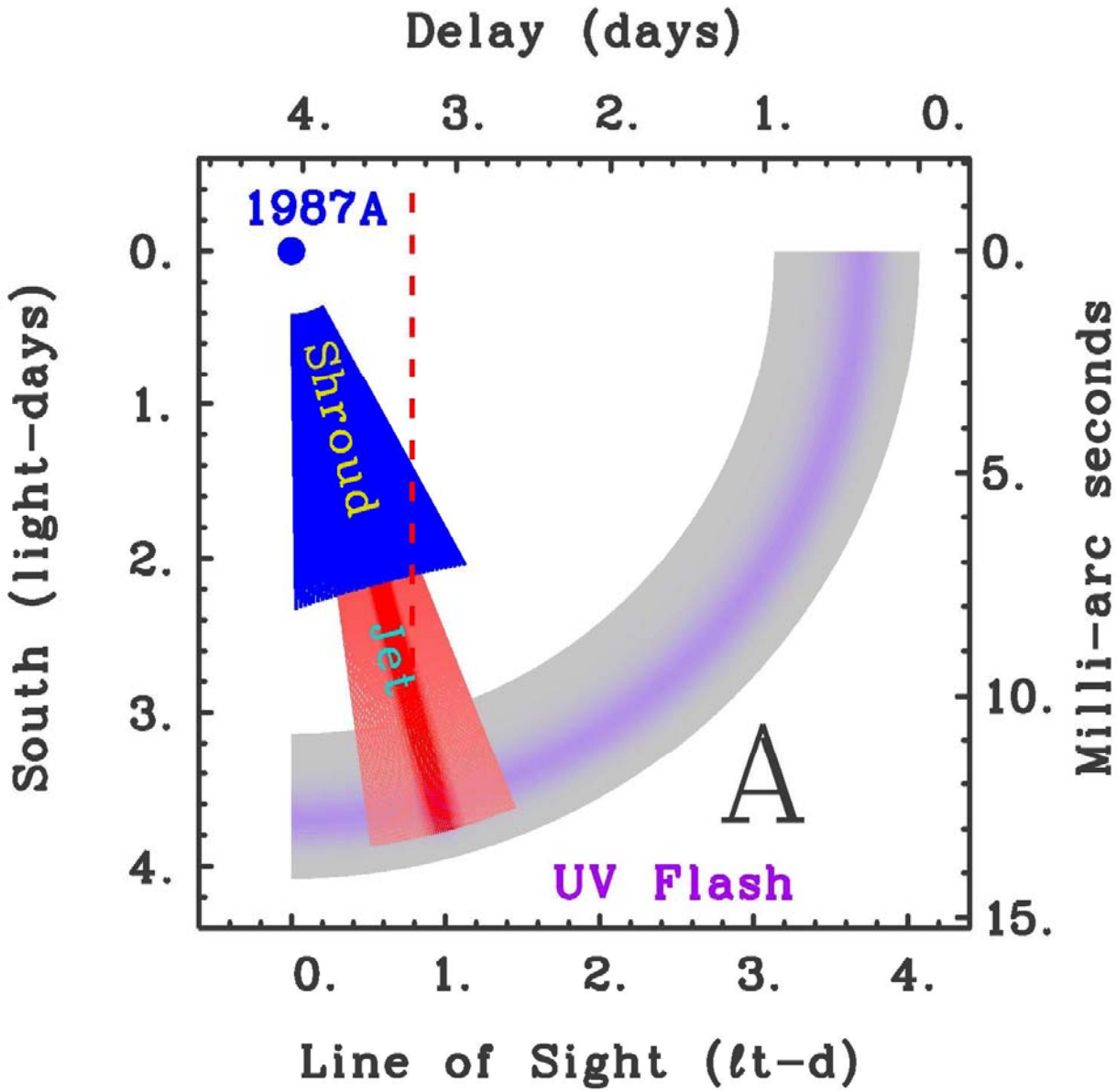


How can the beam accelerate jet H atoms to 0.95 c? Easy, by just the standard SN mechanism whereby heavier elements hit progressively lighter ones (buy the toy at Ottowi Station). This is important when we discuss the jets in SS 433, which has a β of only 0.26 c (further below). Since single particle Thompson cross sections go like 1/mass^2, electrons and positrons can be accelerated to very, very high energies, maybe up to the TeV range (uncollimated).

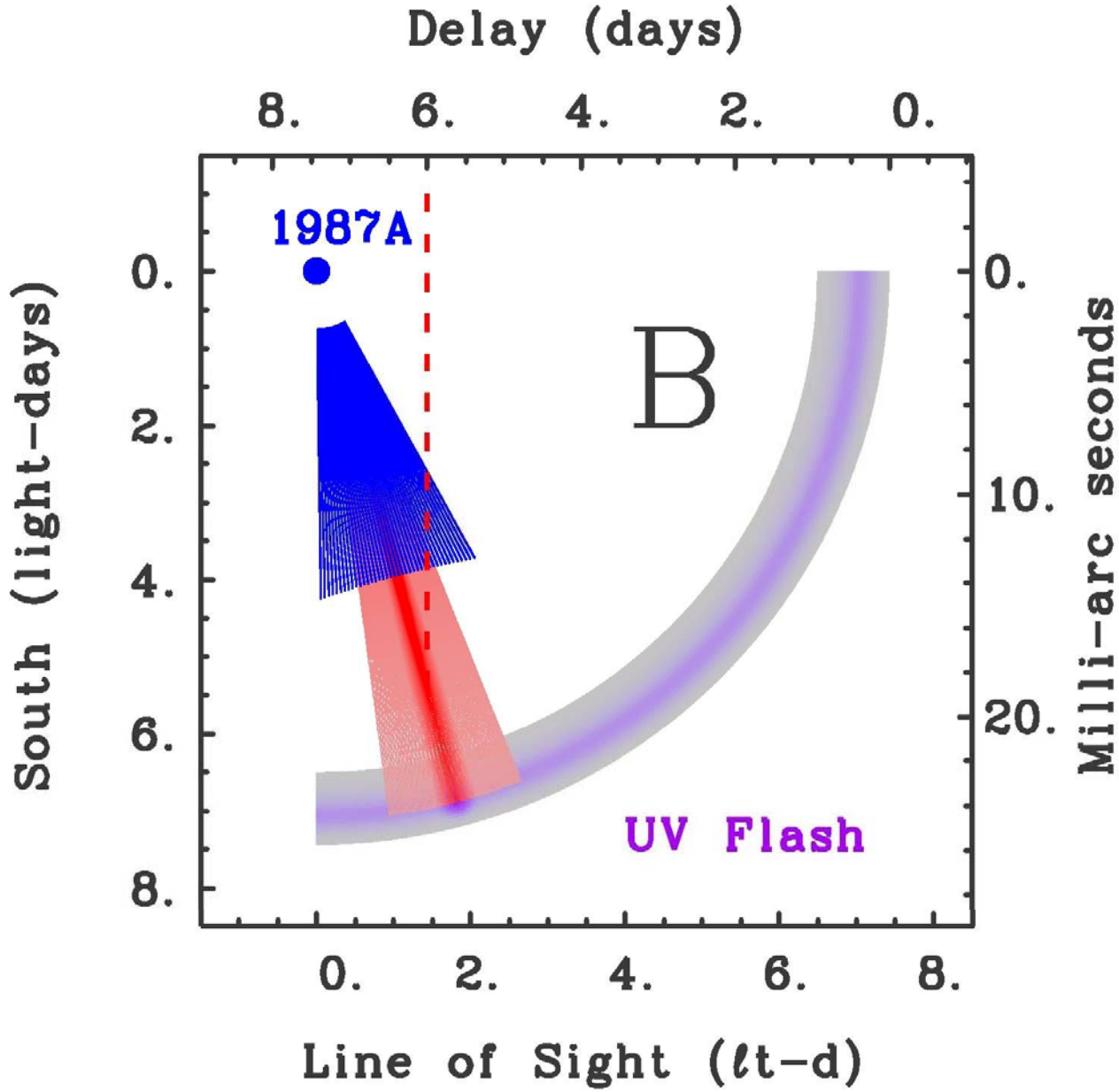
Having done the math, the angle of the 87A bipolarity to our line of sight is 75°, and thus the angle between the normal to the plane of the equatorial ring and the bipolarity is ~30°. This is way too much for spin-orbit in the merger, but may indicate plasma only out to ~2 LC radii in the SLIP model, but this is inconsistent with the collimation. So ????



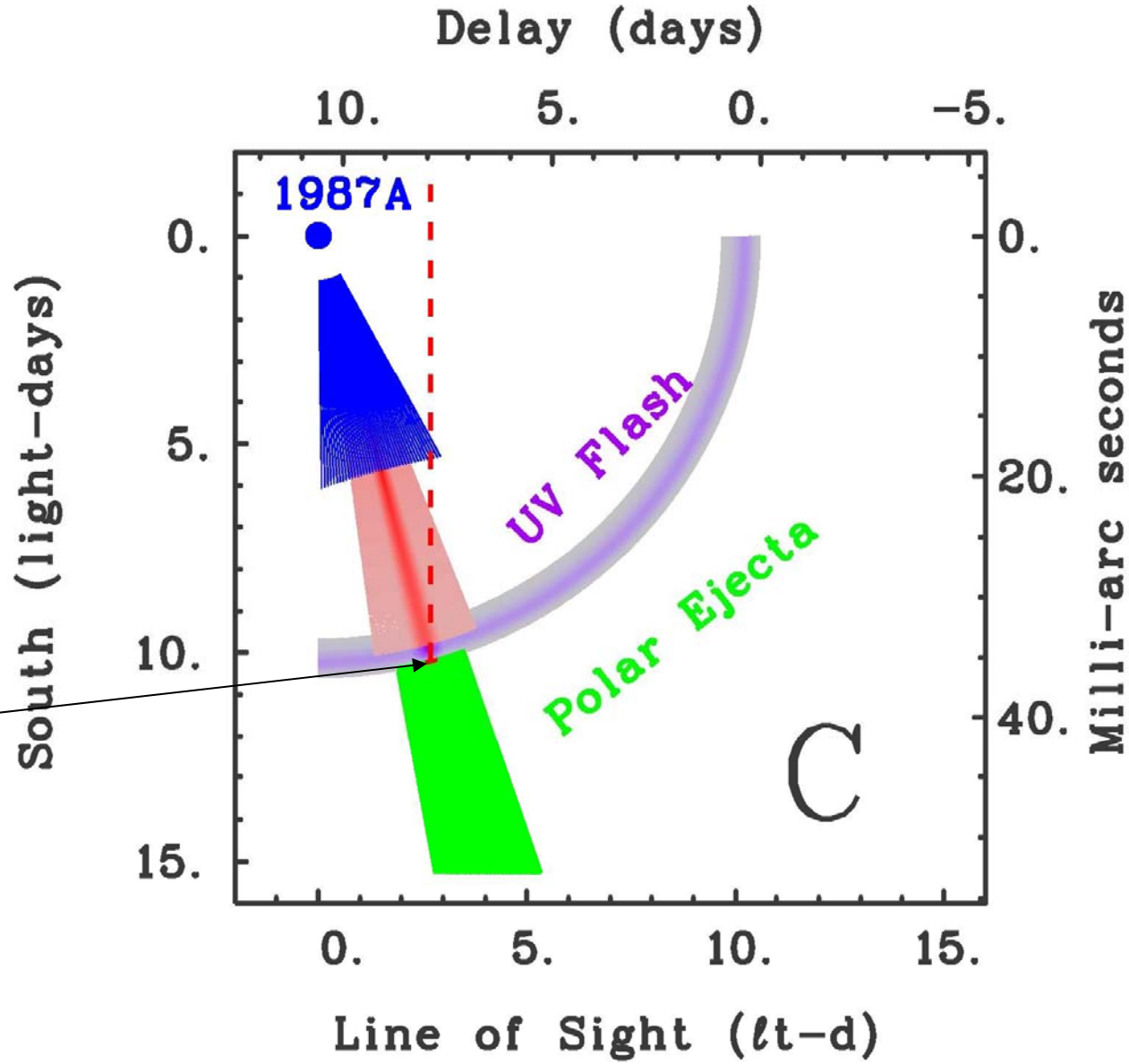
The geometry of the 87A glowing beam/jet (BJ), initially opaque shroud, and UV Flash (which may have an enhanced beam of its own in the jet direction (here 75º, down and to the right). The center of the emerging jet produces the rising luminosity shown in a previous slide at day 3.3 (read on the upper, 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 an earlier slide, the full angular width of the jet has been set to ~1º.



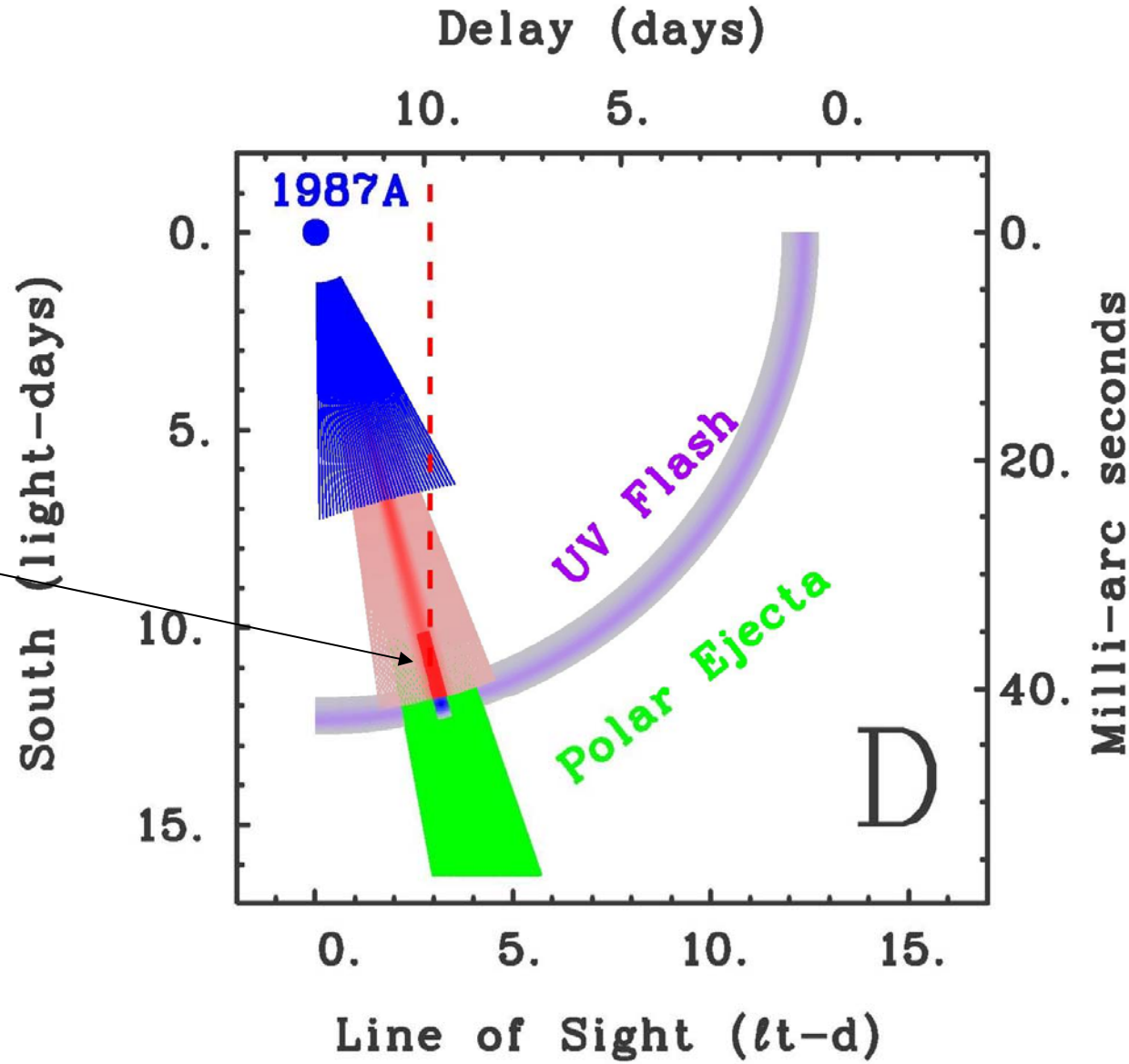
The configuration in which the light from the center of the exposed part of the now fading jet lies on the dropping luminosity curve at day 6.



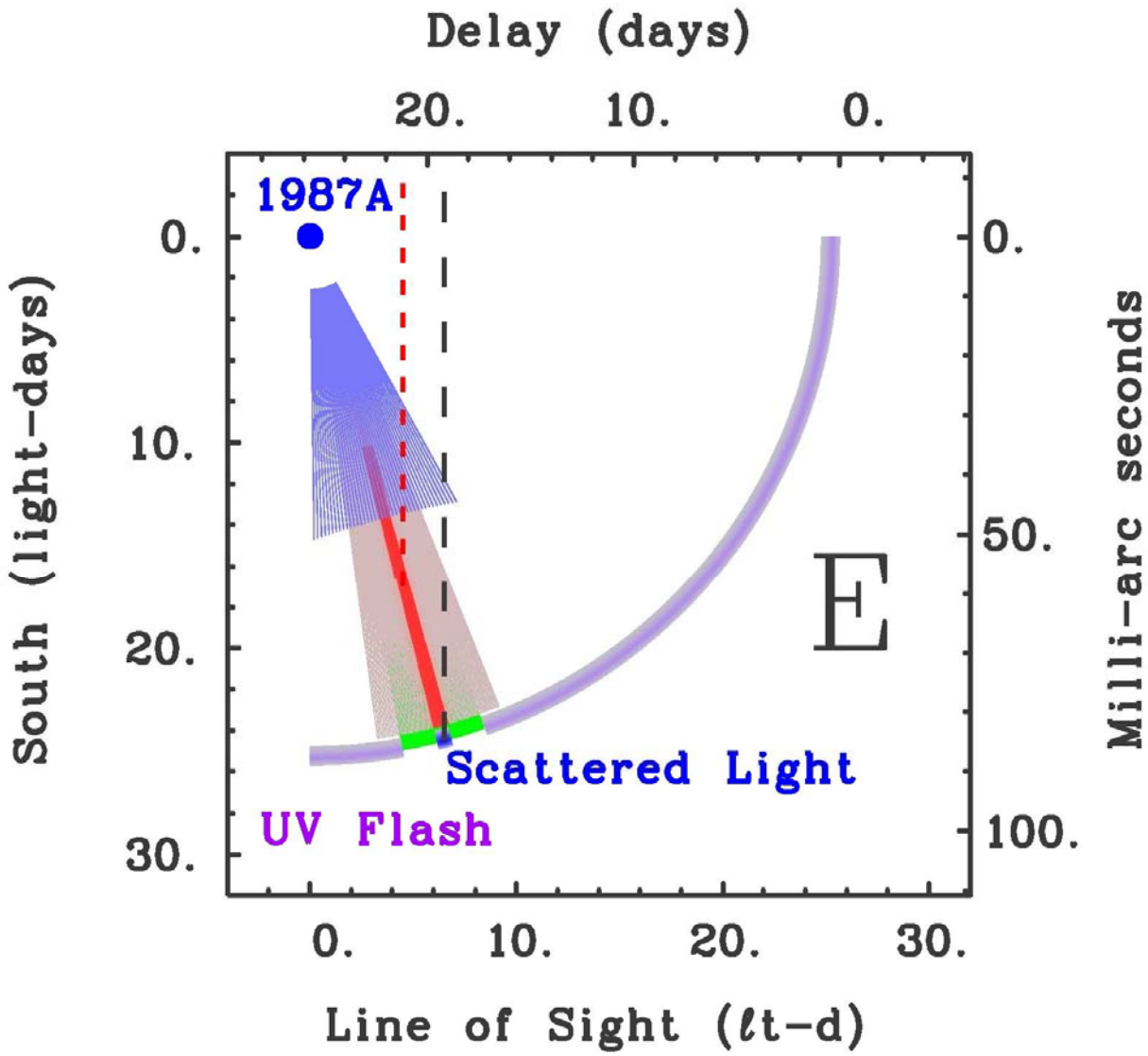
The intense beam from the pulsar scatters and reprocesses off the polar ejecta (PE), producing the jump in luminosity at day 7.8 (top scale for the tiny red disk in the PE – ~2×10^{39} ergs/s for a day). A polar ejecta density of 10^7 cm^{-3} would predict that the UV Flash part of the beam does not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



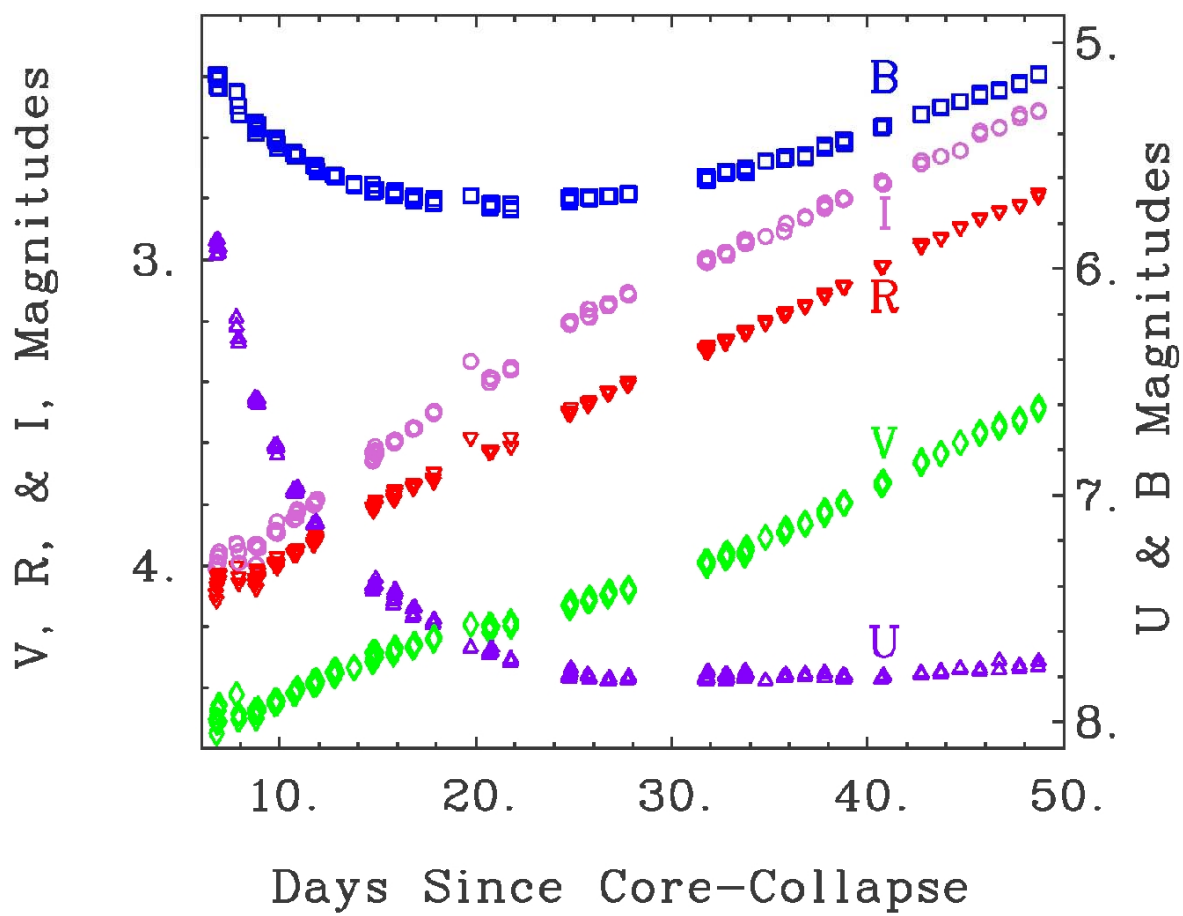
The intense center (~1°) of the jet begins to produce light (intense red) as it penetrates ~2 ℓt-d into the polar ejecta (green), producing the jump in luminosity at day 9.8 (again, top scale for the intense red column). The penetration may continue because the cross sections for this process are orders of magnitude smaller than for the UV Flash. The collimation factor for the jet is also >10^4.



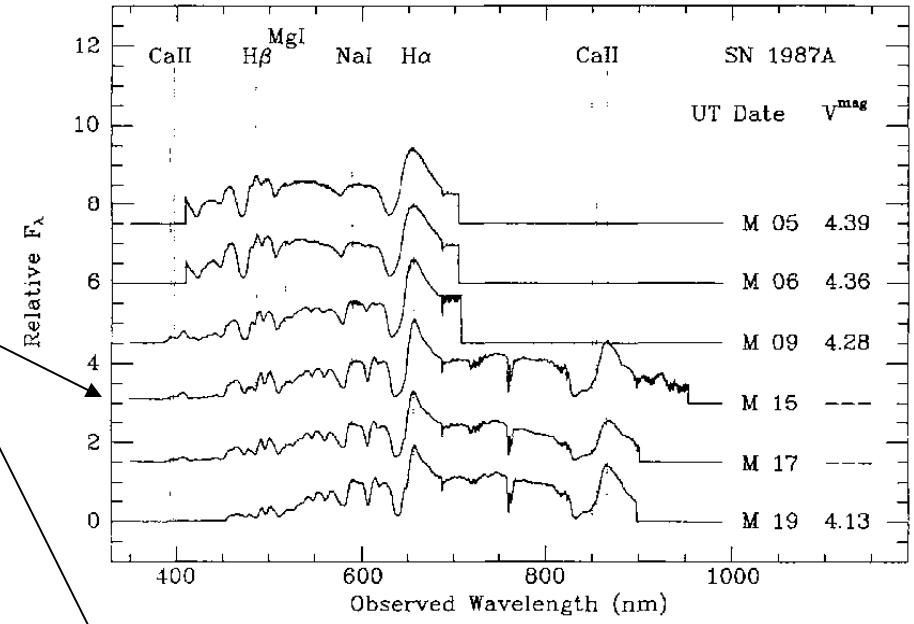
After filtering through the polar ejecta, the enhanced pulsed beam breaks free, but still scatters off of some remaining clumps, producing excess light, in the B, R, and I bands observed near day 19.2 (black dashed line to upper delay scale), visible in the next slide.

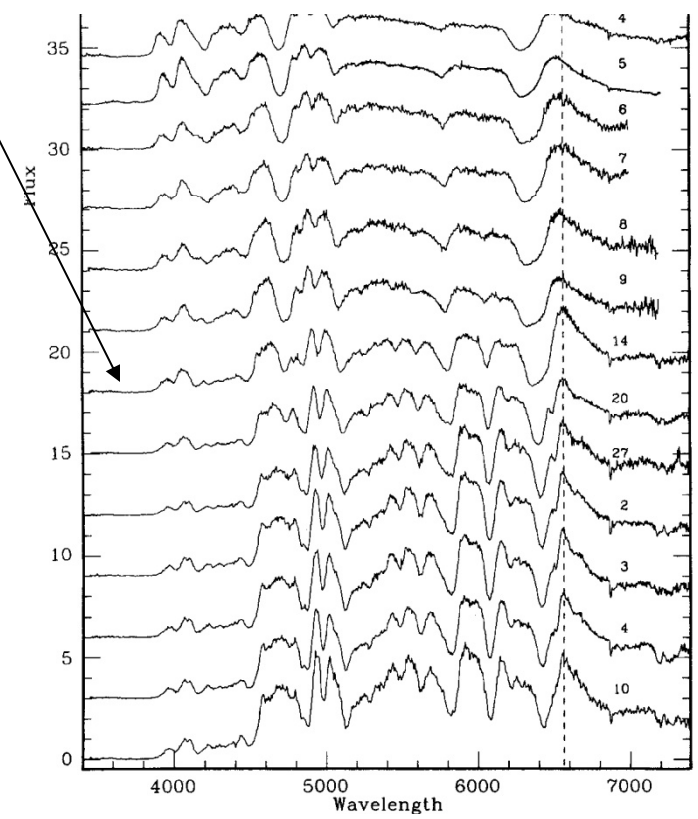


The photometric data from the CTIO 0.4-m telescope plotted against time for days 6-50. Excess light in the B, R, and I bands was observed at day 19.8. The R band light is associated with an enhancement of the Hα line, and the B and I band light matches the colors speculated for the 2.14 ms signal from SN 1987A seen by Middleditch et al. (2000). The excess light 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. The kinetic energy in each jet is estimated to be near 5×10^{49} ergs. This represents 2.5×10^{52} protons, each with a KE of 0.002 ergs, assuming $\beta=0.9$. Over 10^6 s, this would represent 5×10^{40} ergs/s, using Meikle et al.'s estimate of 0.001 for the efficiency of converting pulsar output into Mystery Spot luminosity . A 500 Hz pulsar would lose 10 Hz at a mean rate of -10^{-5} Hz/s during this interval.



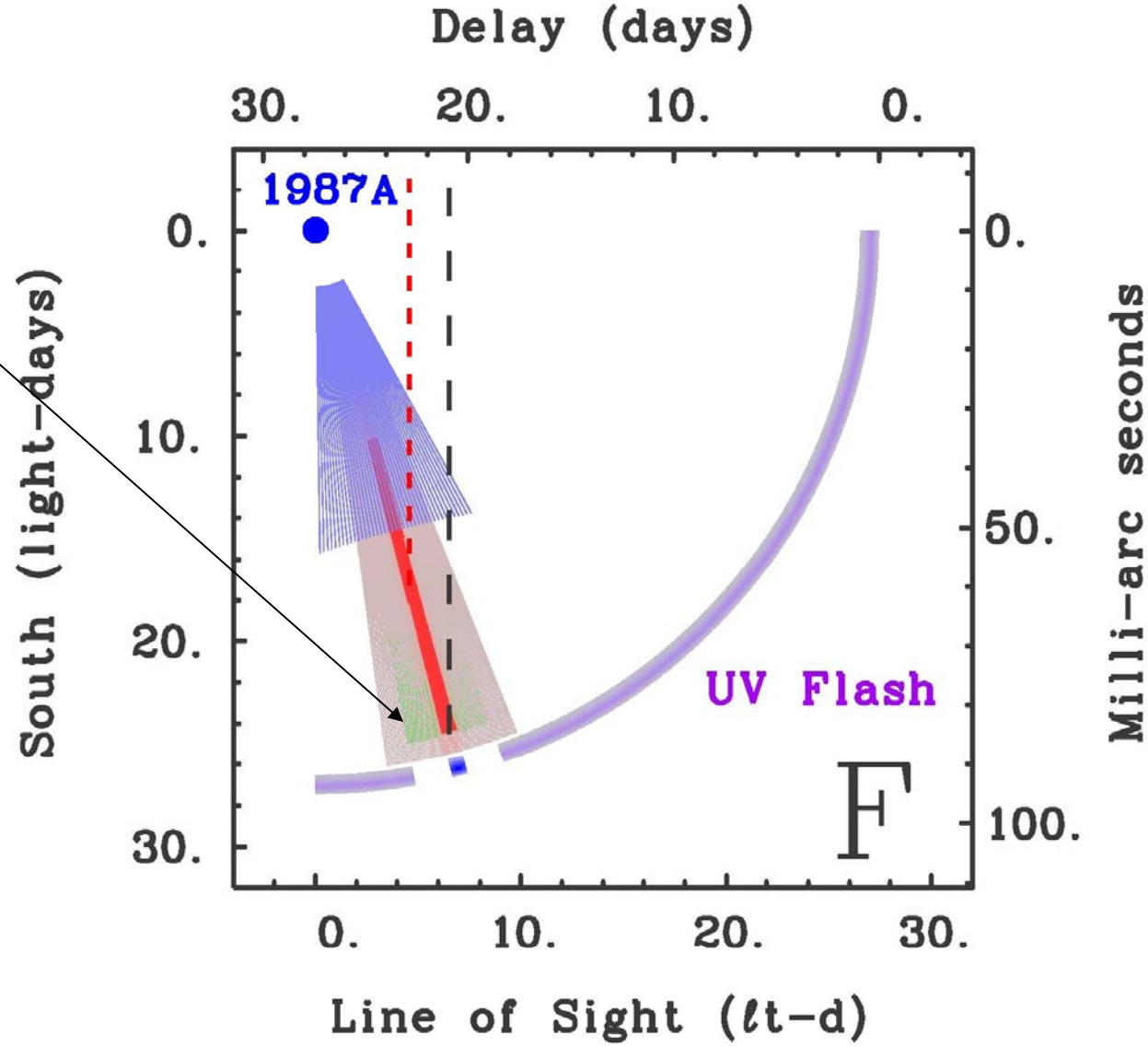
These excursions in the B, R, & I bands have their counterparts in the spectra taken at the same time by Menzies et al. (1987, MNRAS, 227, 39P) and Danziger et al. (1987, A&A, 177, L13), and are caused by the beam/jet hitting a partly cloudy end to the polar ejecta around 14/15 March 1987. The B band is the 2nd cyclotron harmonic of the I band. An Hα *P-Cygni* enhancement dominates the R band, while a similar Ca II triplet (λλ849.8, 854.2, 866.2 *nm*) enhancement dominates the I band.

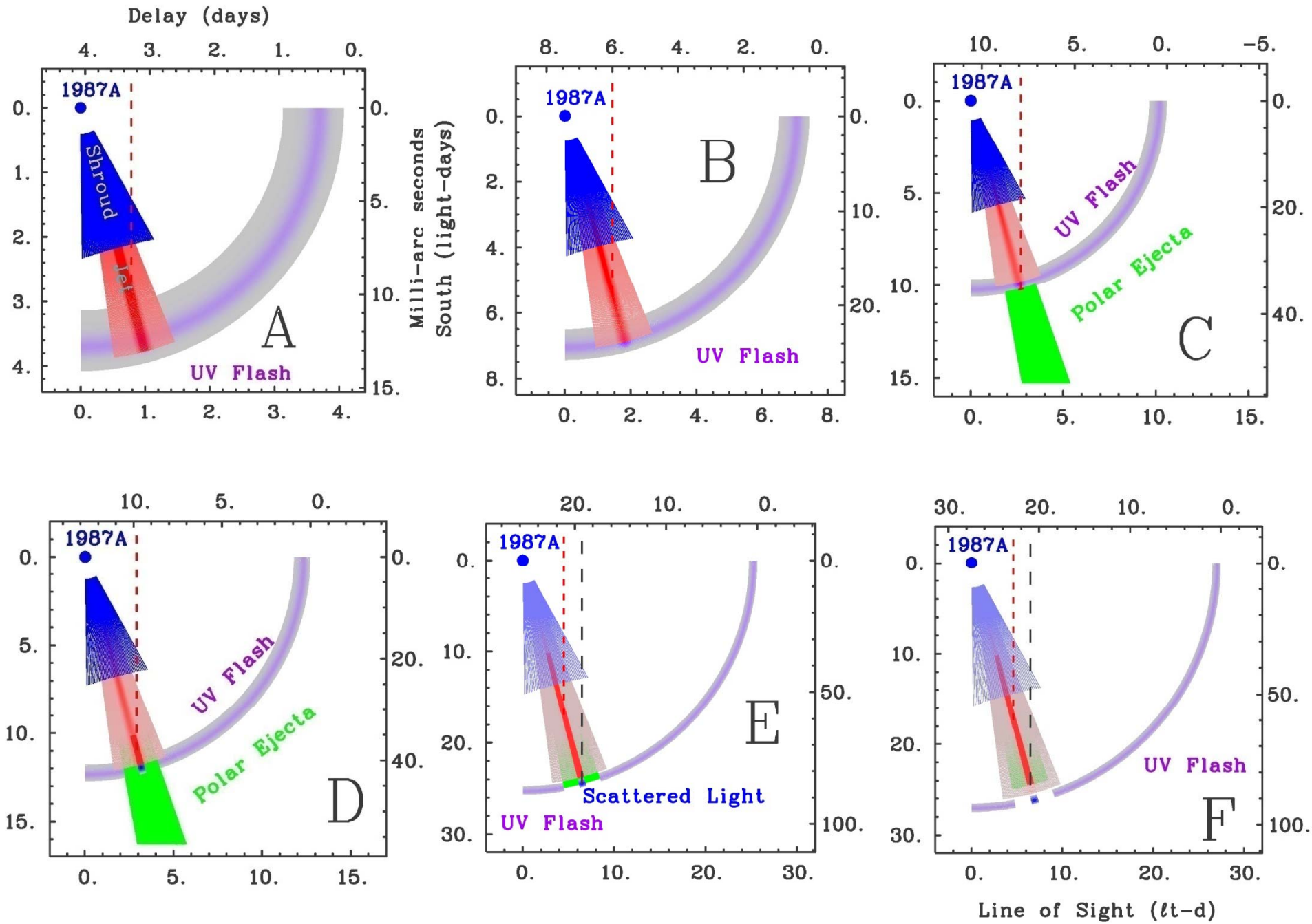




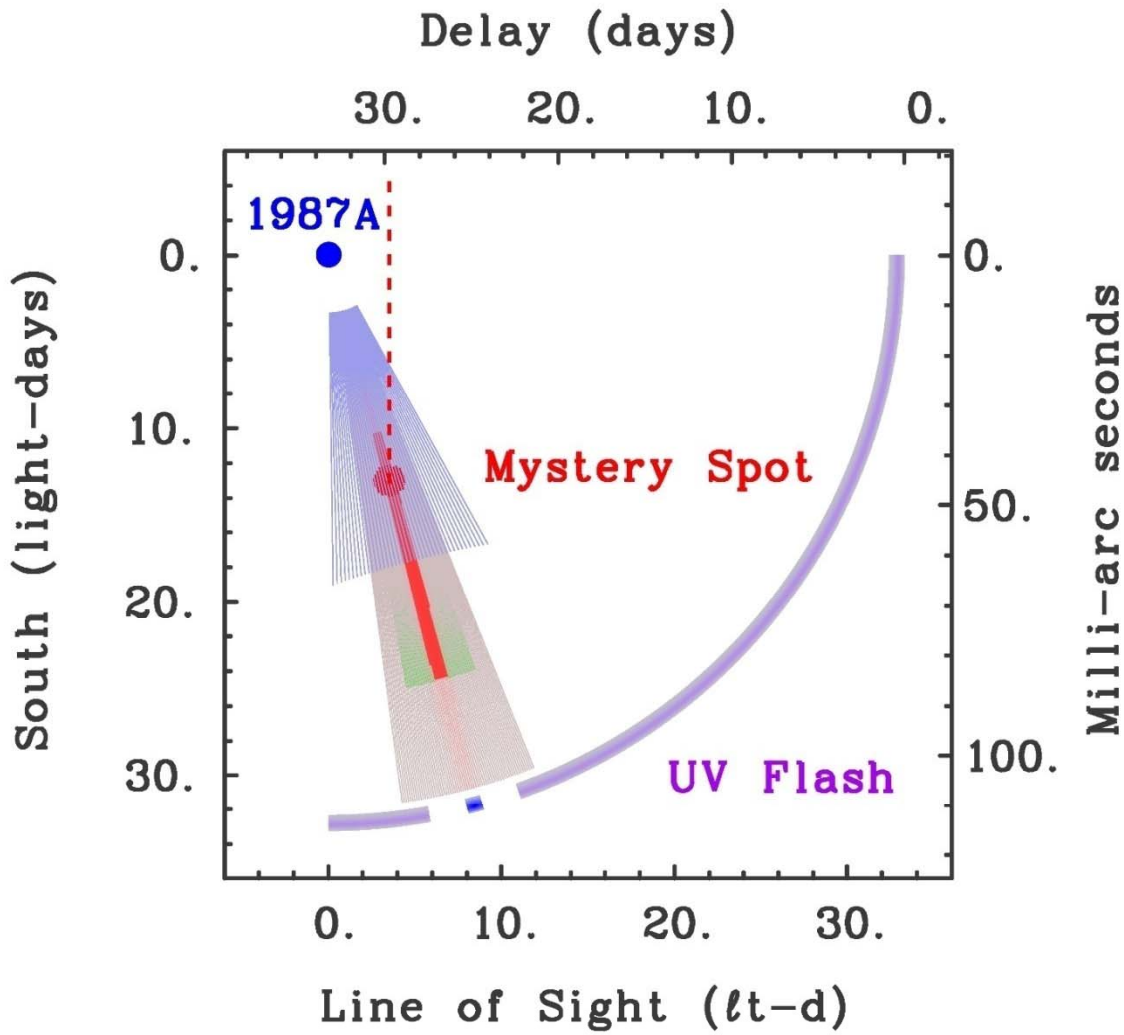
Scaling up 5th magnitude by just 1/distance from 8 Gℓt-y to 25 ℓt-d gives -22.7 m, 1/100th of solar radiation. Scaling 10^{40} ergs/s by 1/distance to 25 ℓt-d would be a solar constant of 600. At 41 ℓt-yr, by 1/distance, this would be reduced to one solar constant. Scaling this back to 8 Gℓt-y by 1/distance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

Particles in the jet begin to clear the polar ejecta (mostly hidden green cone section), producing the decrement in luminosity near day 20.8 (top scale for the black dashed line). Each of the polar jets contains as much as 2×10^{-5} $M_{\odot}$, and this can result in a spindown of 10^{-5} Hz/s for a pulsar spinning at 500 Hz.

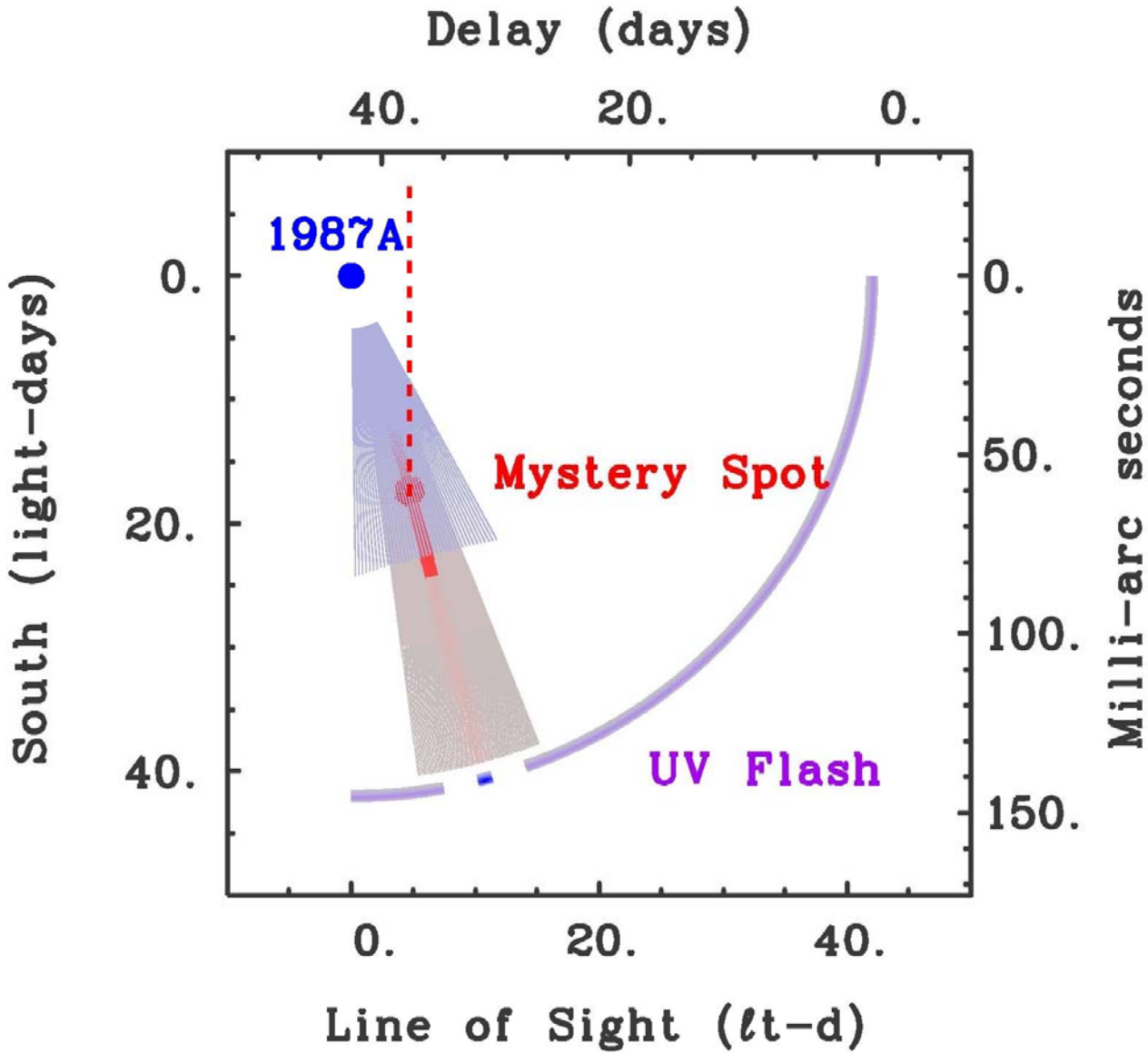



Delay (days)
Milli-arc seconds South (light-days)
Line of Sight (ℓt-d)
1987A
Shroud
Jet
UV Flash
Polar Ejecta
Scattered Light
A
B
C
D
E
F

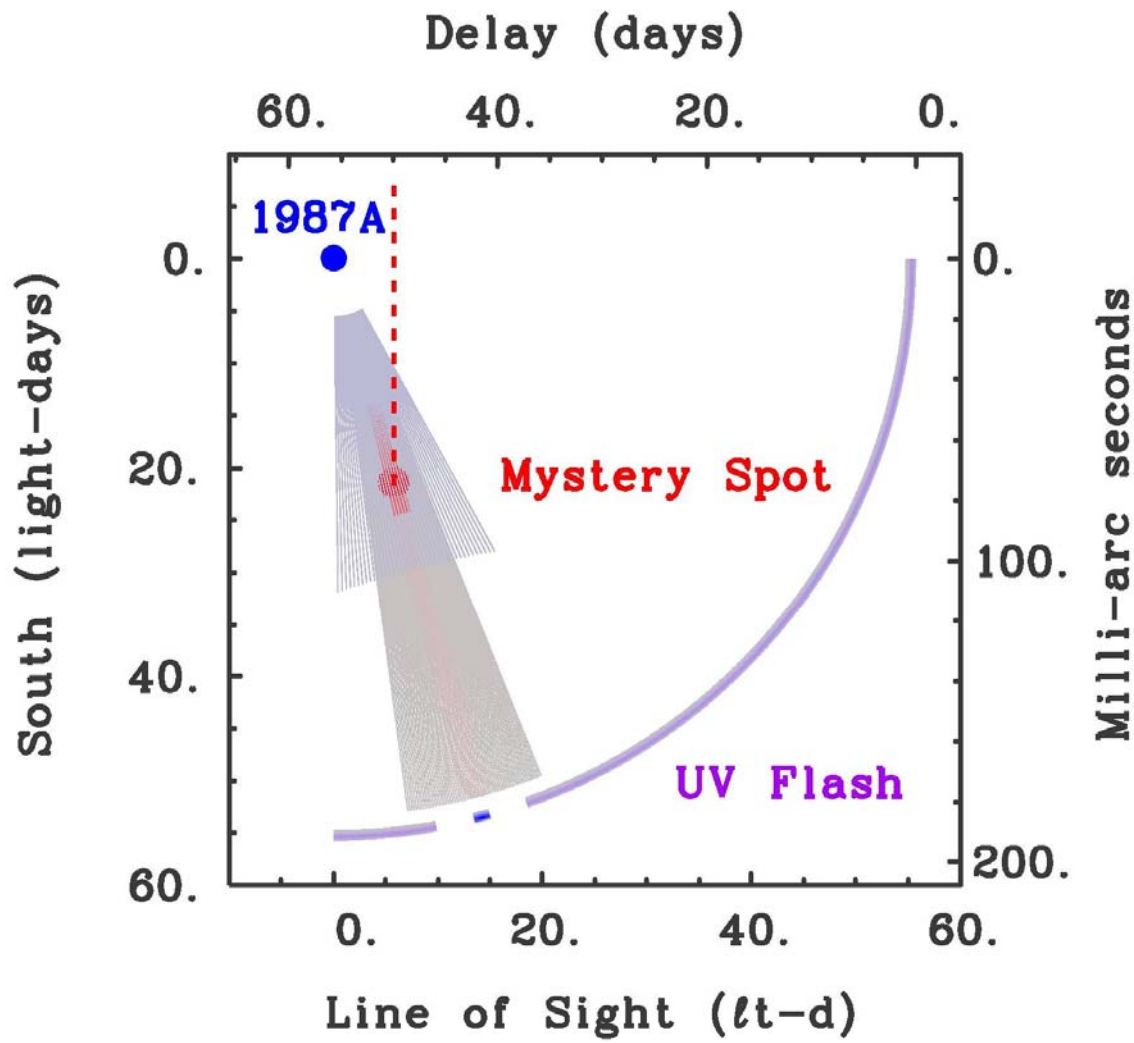
Particles continue to inject energy into the Mystery Spot around day 30, where its offset from **SN 1987A** was 0.045 arc s. Rather than a luminous strip, the Mystery Spot has become a more spherical plume. Penetration into a very deep (~13-14 light-days) polar ejecta is consistent with the Mystery Spot offset measures plotted earlier. There is no hard limit on its width at this late stage.



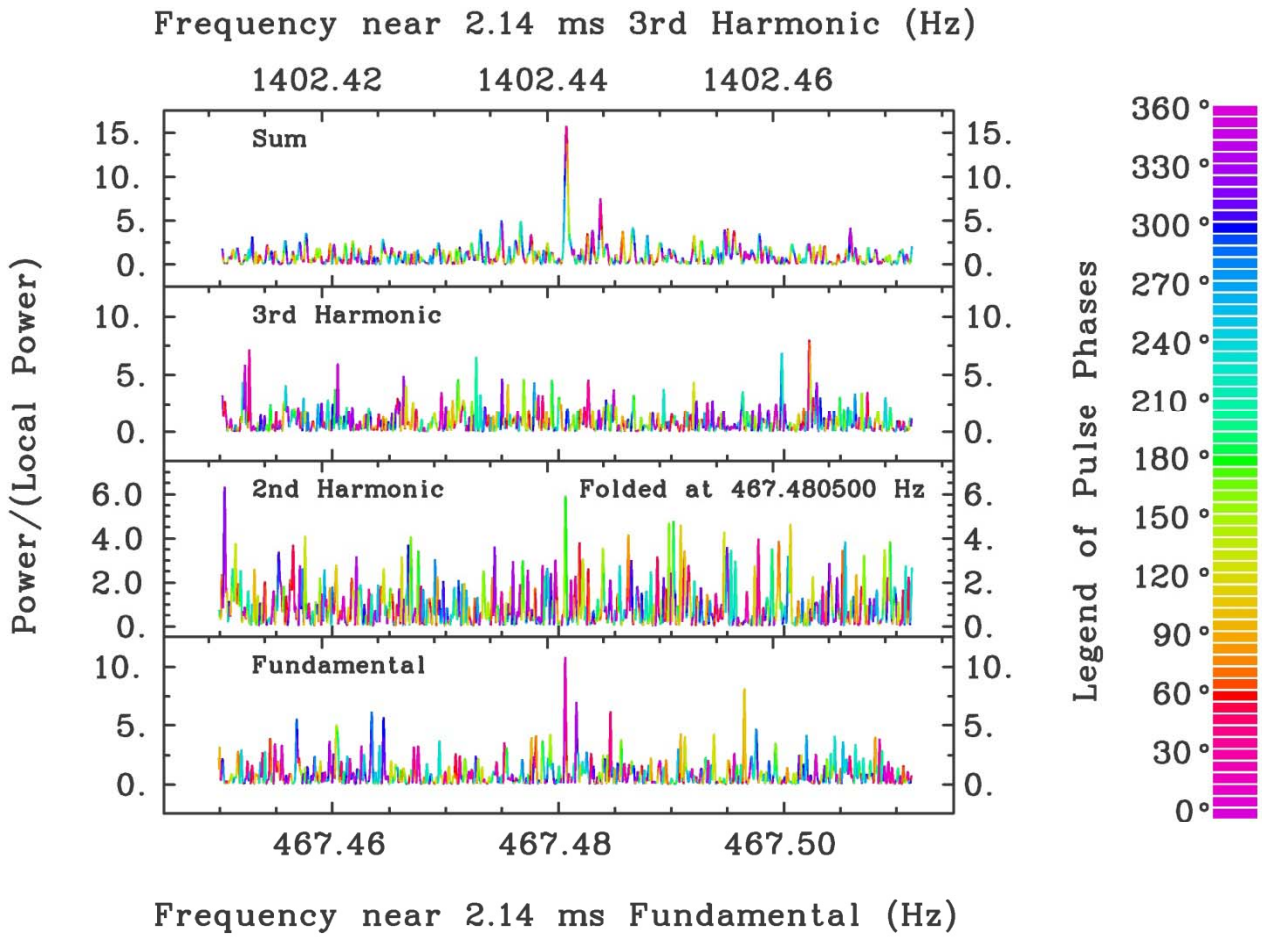
Particles continue to inject energy into the Mystery Spot around day 38, where its offset from **SN 1987A** was 0.060 arc s. The mean velocity from day 30 to day 38 (this slide) was 0.5 c.



Particles continue to inject energy into the Mystery Spot around day 50, where its offset from **SN 1987A** was 0.074 arc s. The mean velocity from day 38 to day 50 (this slide) was 0.35 c.



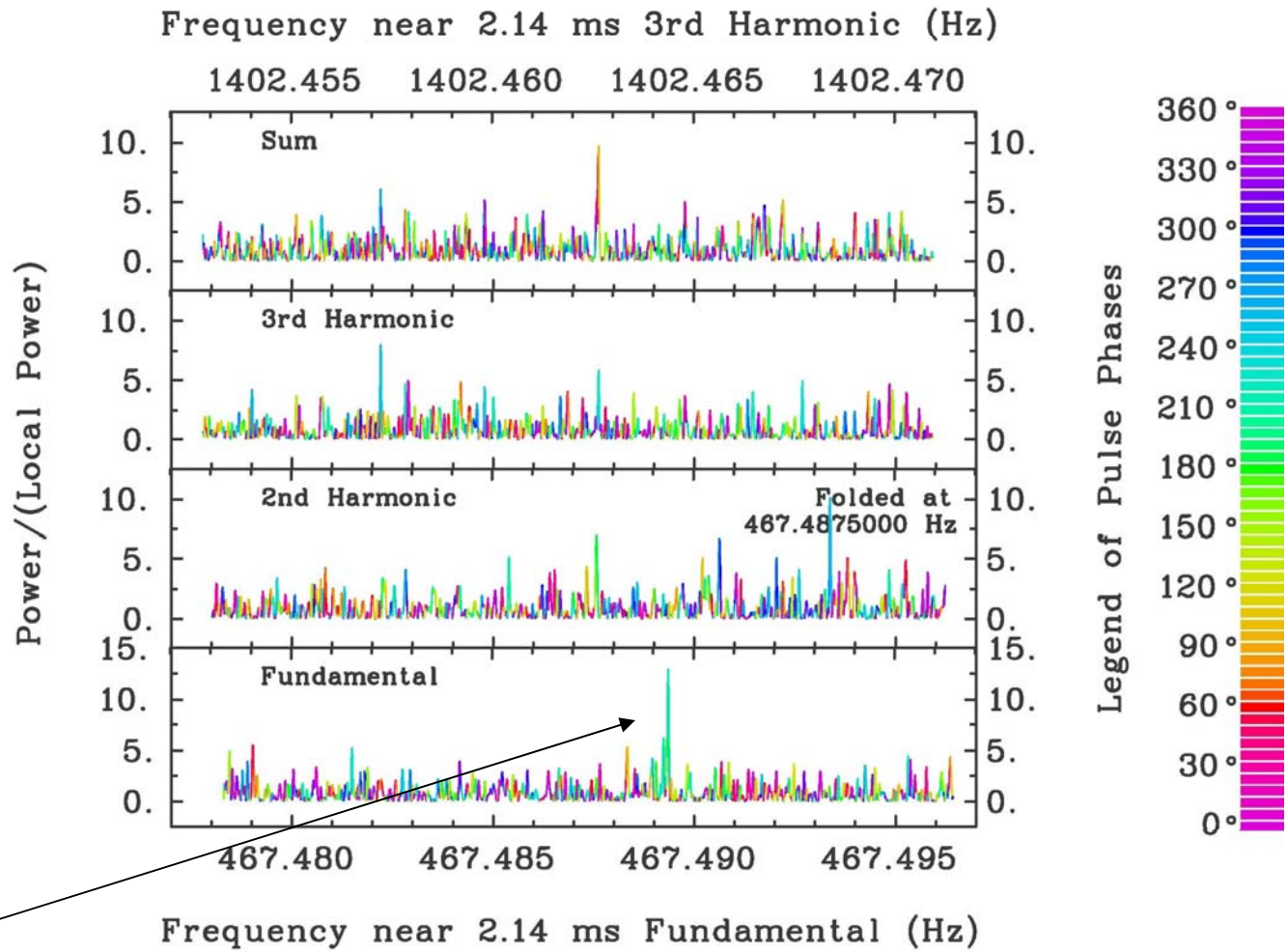
The 2.14 ms signal hammered the Tassies as hard as possible, without being inconsistent with our Wratten 87 magnitude of 21. Their band at their 1-m scope had B, but little U or I.

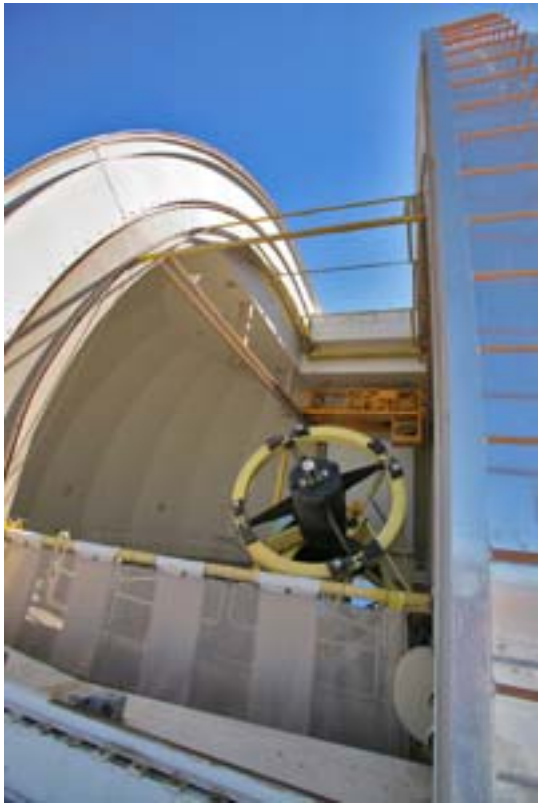


After 1993 August 23, the probability that the 2.14 ms signal was not real, was 10^{-10}. We are not off 8 orders of magnitude! This is real, and the result 99% of the time (Fe catastrophe in massive stars accounting for only 1%). We can get redshifts from these objects (below).

What about other teams not detecting the signal? The team at the ESO La Silla 3.6-m had a night in common with us at the LCO 2.5-m. We saw something and requested their data. The answer "We don't see much." "That's not real helpful," said Kristian. They clearly had written over this data within 4.5 months!

By standards, ***we*** didn't see much. But we saw something! The ESO signal could easily have twice this power, and it wouldn't be "much". Of the power in the lowest frame, Kristian said 4.5 months earlier: "There's a lot of power there!". It was sideband power.





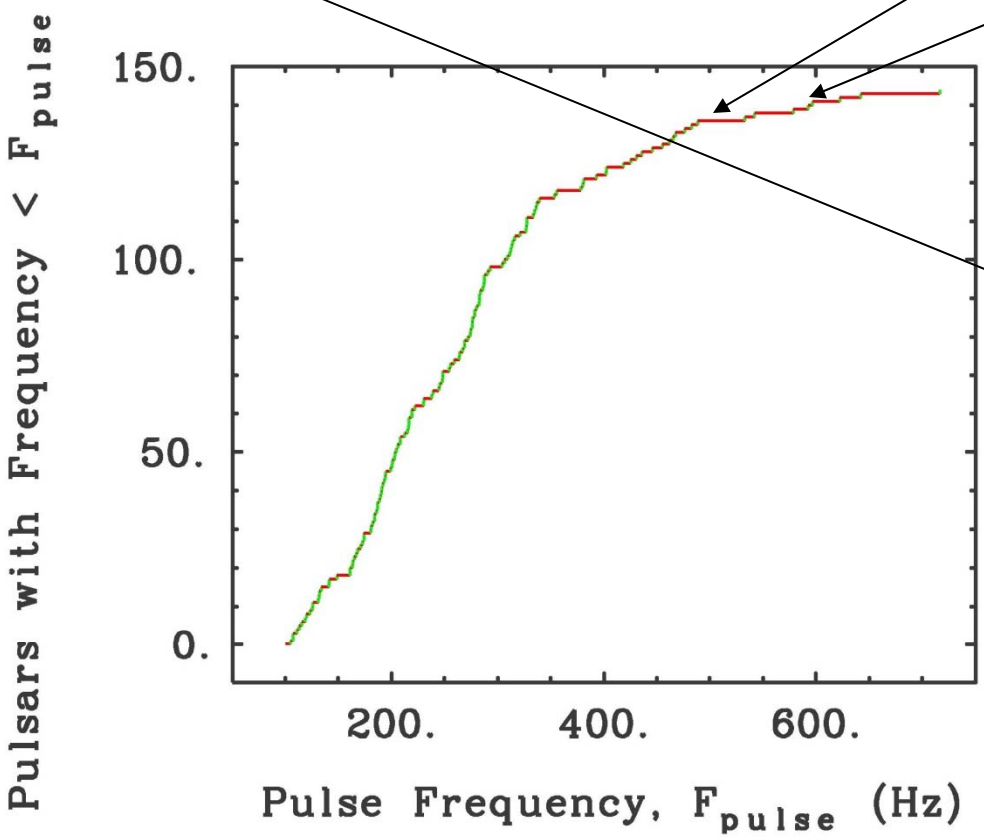
Both scopes used the same phototube on the same night, Nov. 5/6 1992, and were separated by only ~25 miles, mostly with Las Campanas north, and ESO south. The sky had some cirrus cloud, but just enough to keep the seeing sharp.

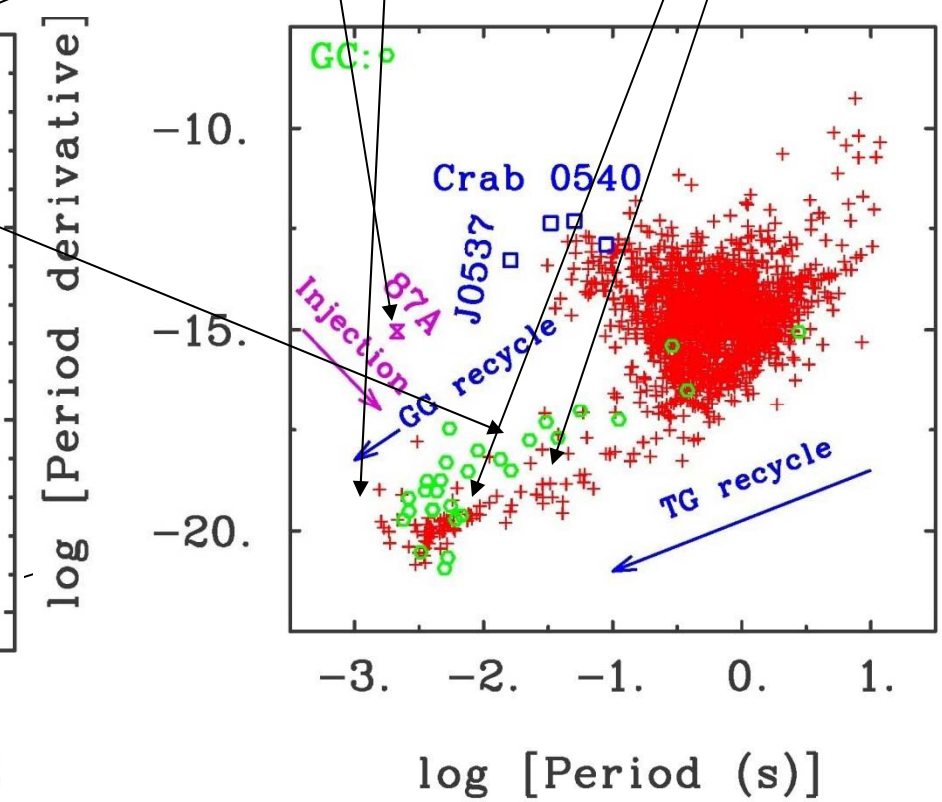
Dupont 2.5-m: 1-m secondary
5.45 m^2 clear area
3.77 arc circular aperture
Wratten 87 filter (800-900 nm)

ESO 3.6-m: 1.2-m 2^{ndary}
8.86 m^2 clear area
4 arc s square aperture
GG 495 filter (500-900 nm)

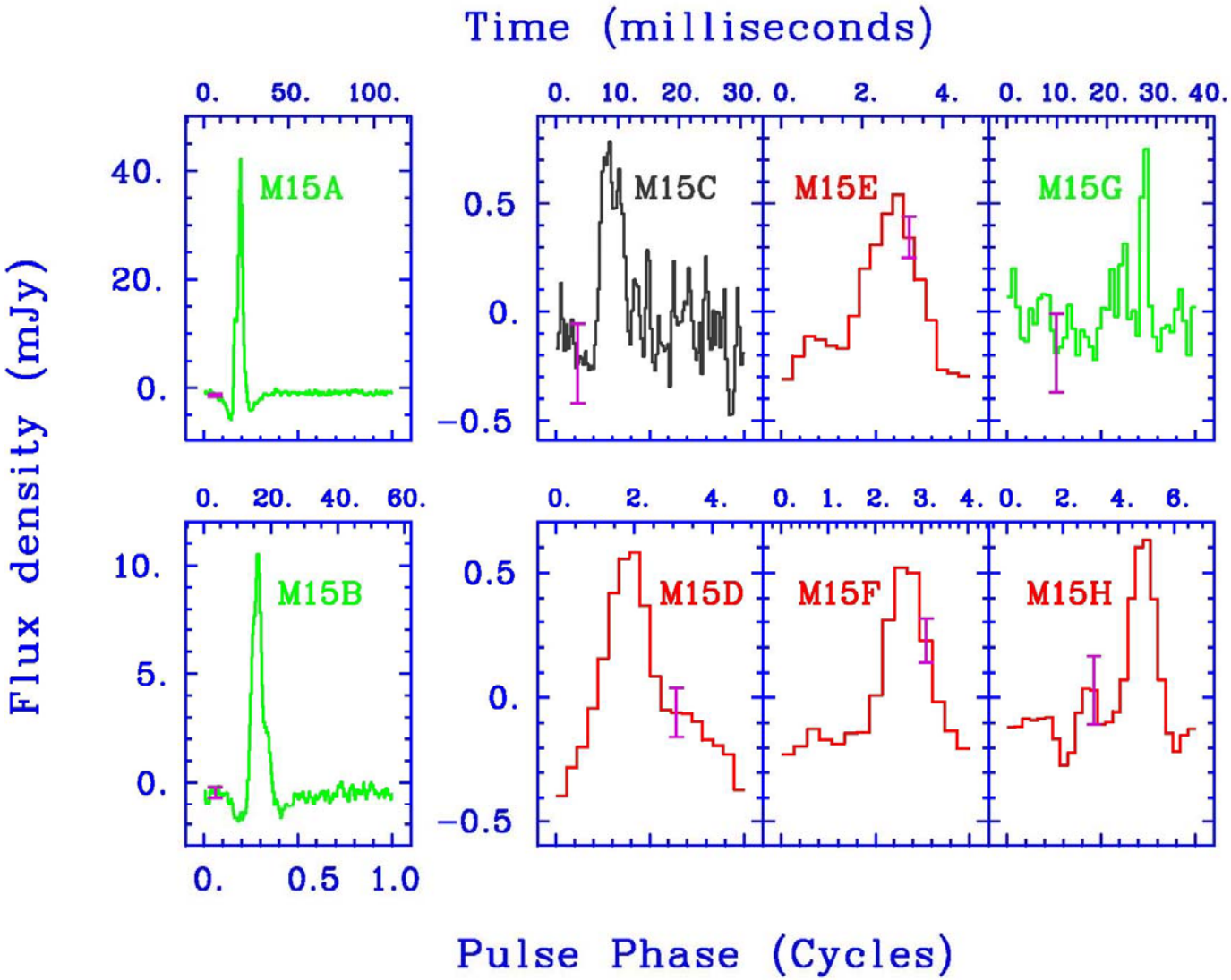
The difference in count rate between a Wratten 87 (I band) and a GG 495 filter was nearly exactly a factor of 10. Thus if the 2.14 ms pulsations were present in the entire GG 495 filter, ESO would see 11.3 times as much power. If restricted to the W87 band, LCO gets 8.8 times as much power. The results were comparable.

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:





Of the pulsars in M15, we are seeing A, B, C, and G, and possibly C favorably, and not D, E, F, or H (provided the pulse profiles for these hold up at faster sampling). C is wide only because the ephemeris is slightly bad.



If pulsars are so good at ejecting material outside of the light cylinder, how do any of them manage to accrete material? The answer must be that those pulsars with the smallest effective dipole moment are the ones that do manage to accrete material. Clearly the neutron stars in the low mass X-ray binaries do manage to accrete material. Do accretion stresses migrate the magnetic poles toward the rotation axis, thereby reducing the effective dipole? What is the crossover between rotation-powered and accretion-powered pulsars?

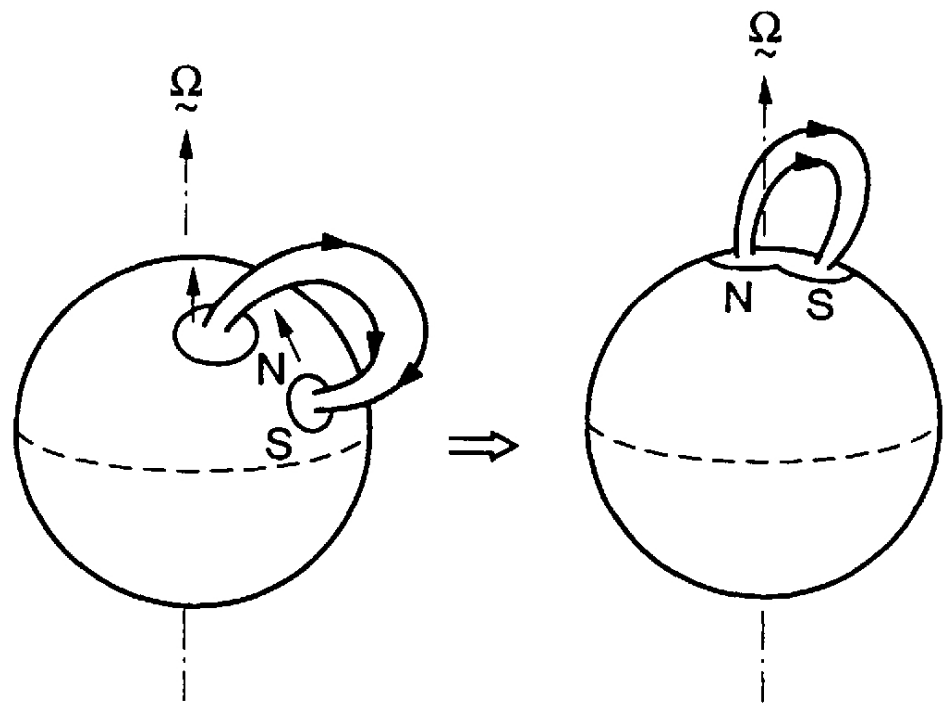
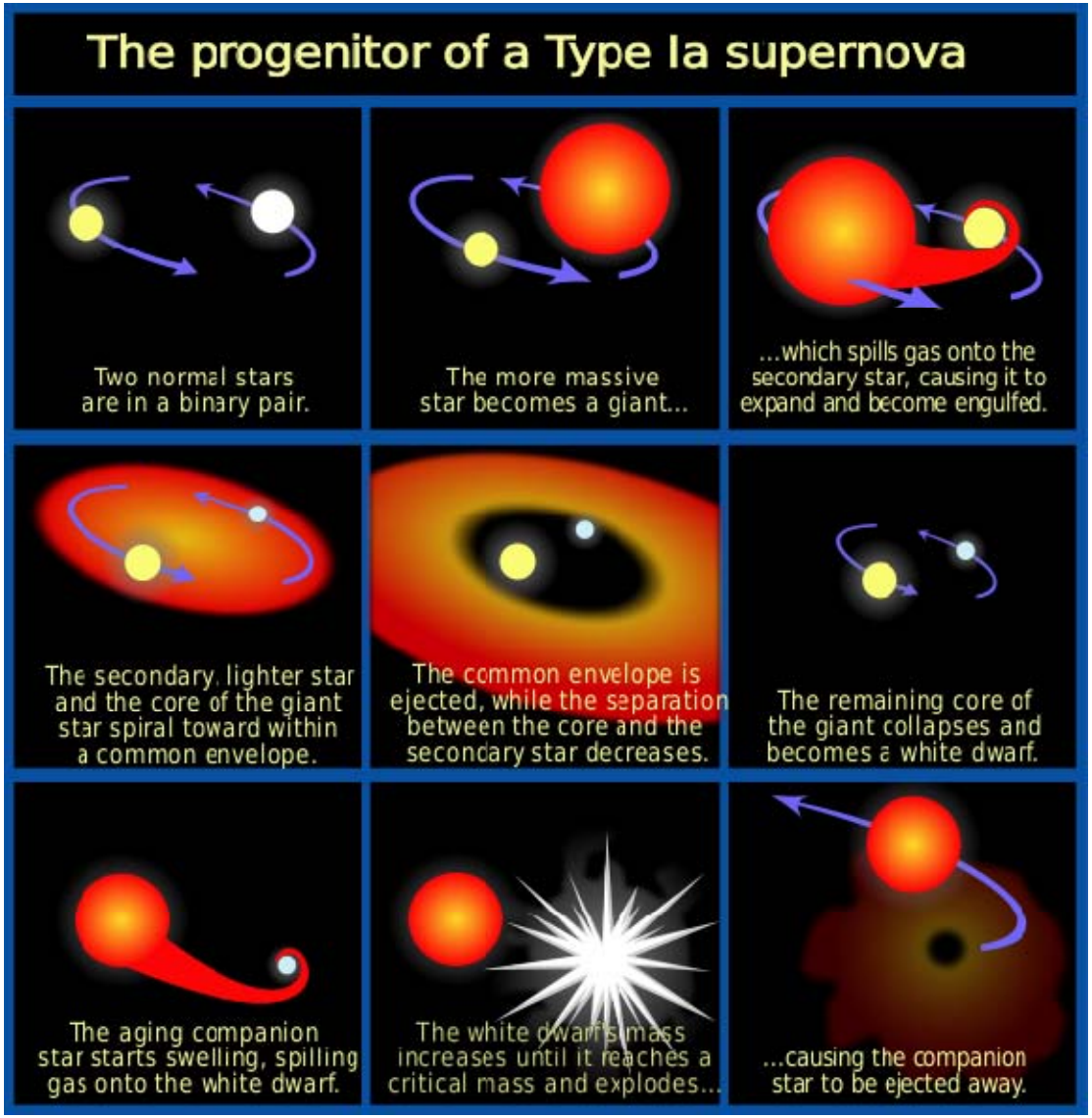


FIG. 2.—Evolution of the magnetic field of a short-period spinning-up neutron star when all flux leaving a hemisphere reenters the same hemisphere.

Chen & Ruderman 1993

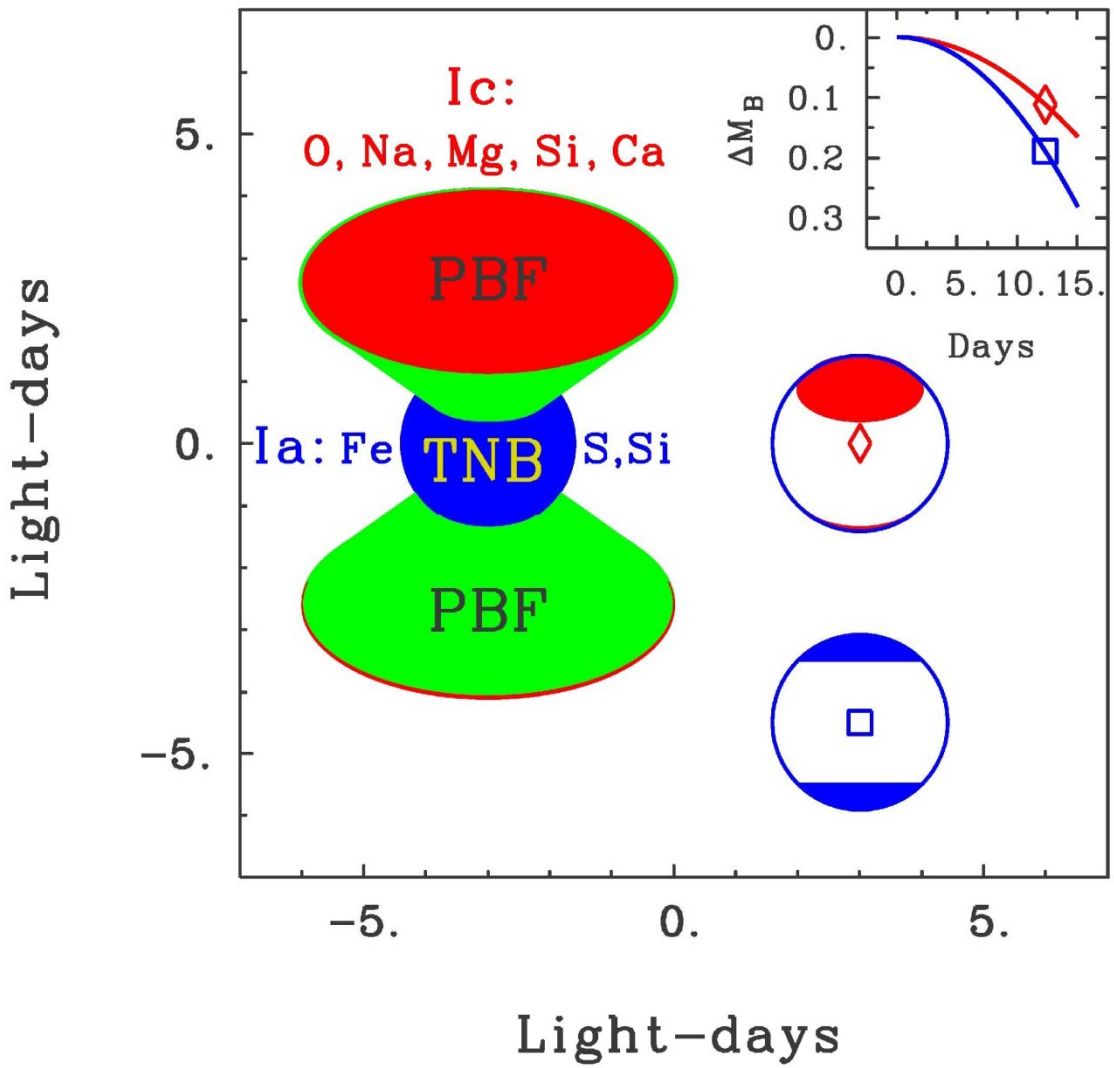
The Demise of the Single Degenerate Paradigm

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.

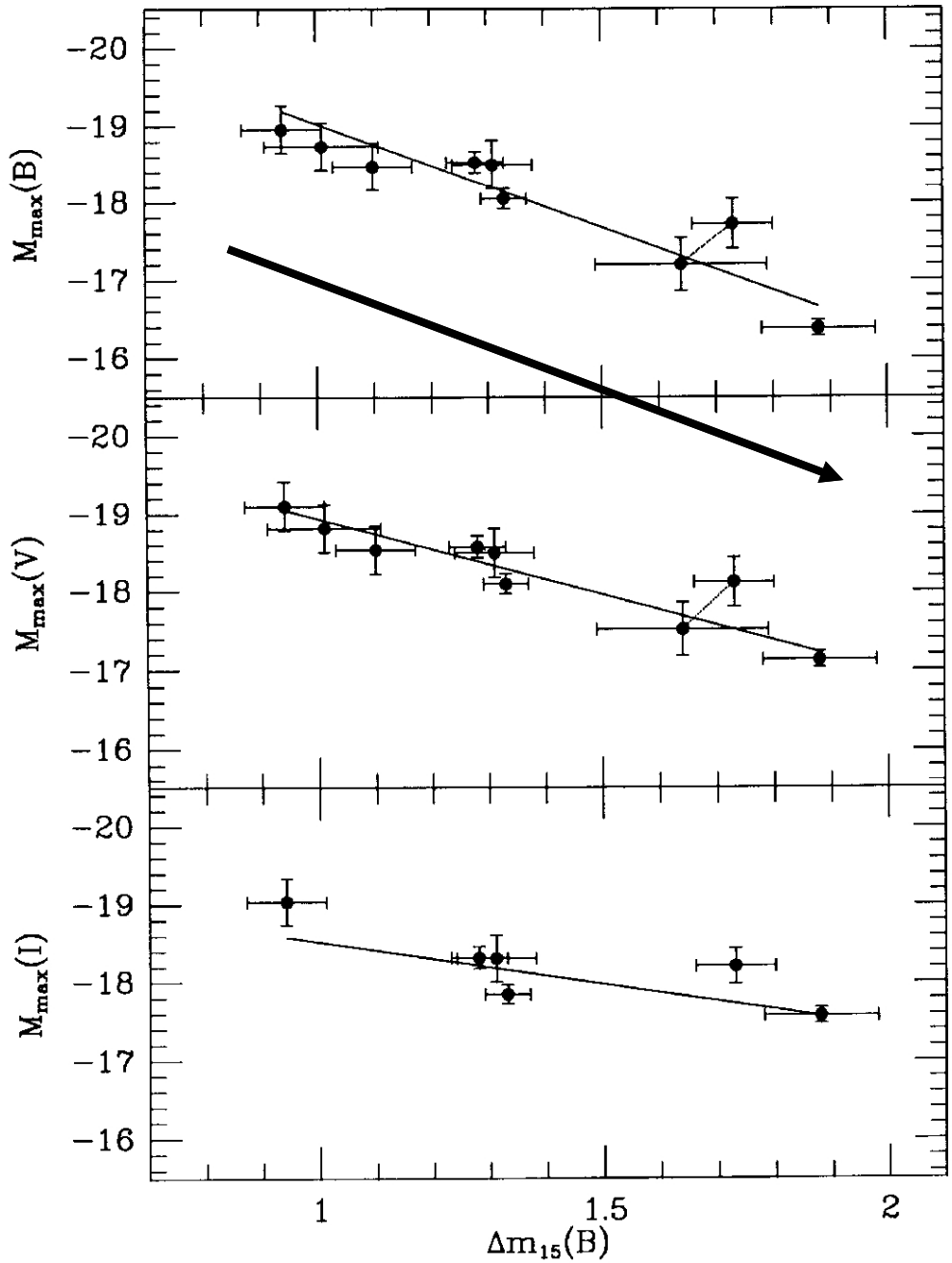


Haven't heard of this? They haven't been very candid about this, have they? They have not had the courage to stop the runaway train of bad science known as Dark Energy, and after WMAP everyone just assumes that the continued belief in this result is justified, when, in actuality, it isn't.

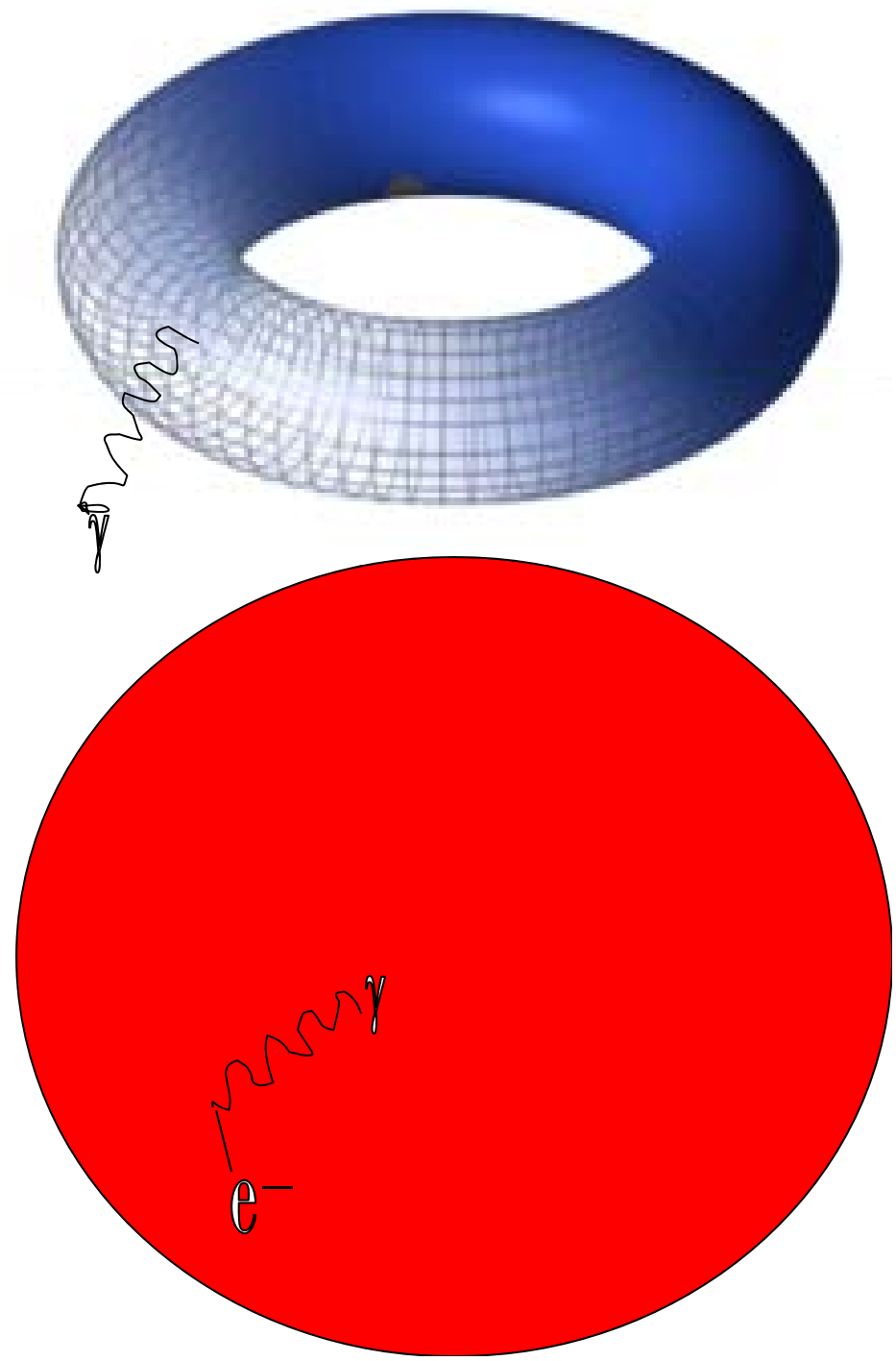
In supernovae, the pulsar beams and jets blow out the poles (PBF -- left hand figure), and do not stop doing that until there is no material remaining around it. The demise of the single-degenerate paradigm, ***plus this***, are catastrophic to cosmology by Type Ia SNe, because the matter in excess of that lost to core-collapse can go to 0, and 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.



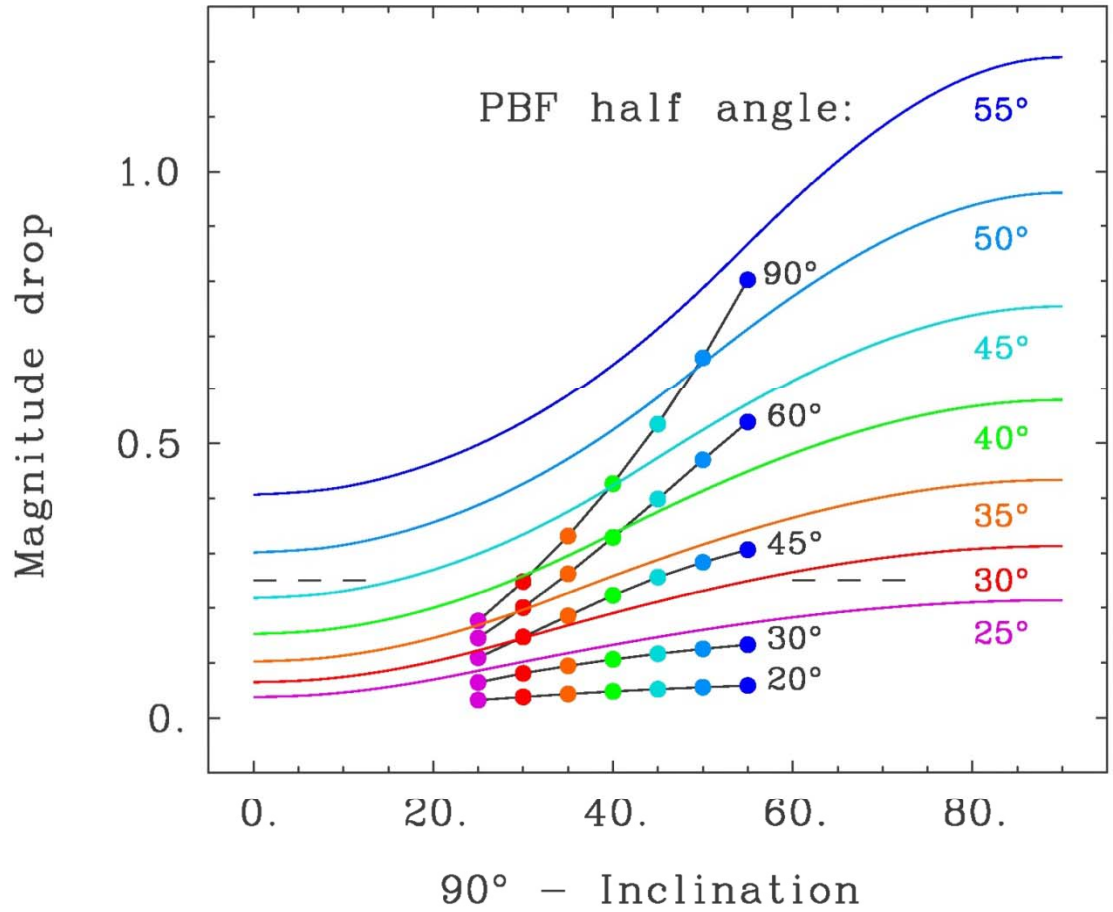
The width-luminosity relation (w-ℓ), posited in 1993 by Mark Phillips. The problem is that there are SNe recognized as Ia's which are two magnitudes or more below this relation. These are not in the local sample (by definition), but impossible to exclude from the distant sample. Thus the log of the systematics can be 10 times the log of 1+(the small effect), *in the same direction*. This can swamp even Malmquist bias, the largest systematic in the other direction!



The equatorial toroid allows γ-rays to escape much more readily than a spheroid of the same volume. Also, from above, 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, even in the w-ℓ sense, and contaminates the distant, but **not** the local, sample, because of the method by which the local sample was chosen (satisfies the width-luminosity [w-ℓ] relation). The mean measured effect is 28% faint (0.25m), but Ia's exist 2 mag below w-ℓ, **an order of magnitude more *logarithmically***! The expansion of the Universe is **NOT** accelerating!

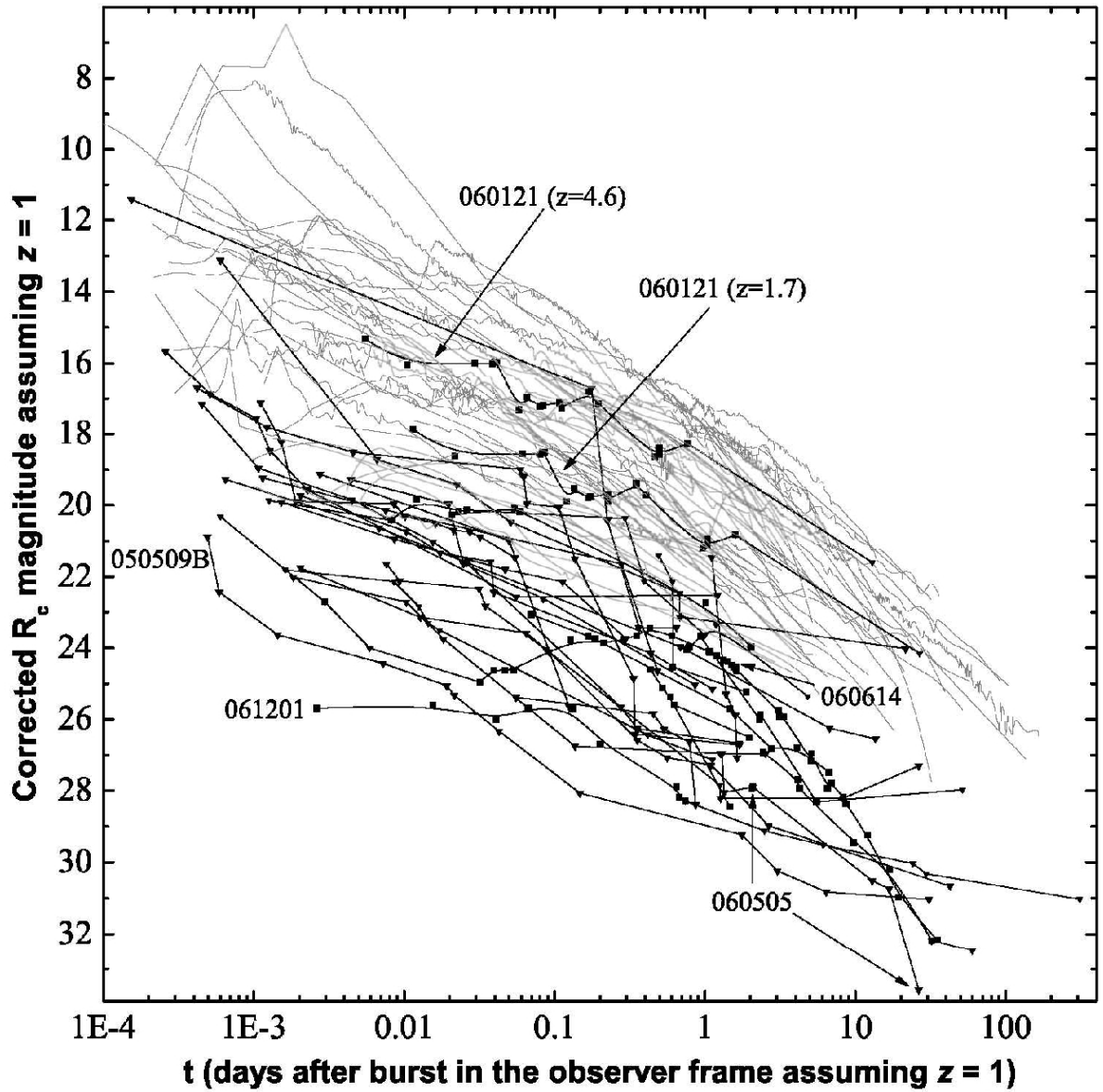


Finally, the width-luminosity magnitude drop is smaller than expected (still smaller than the red curve plotted in the upper right frame) because of the exposure of the rear, forward-looking face of the toroid, as the PBF thins in the weeks past maximum light of the SN. The situation is worse than plotted, as the calculations were done for a sphere, not a toroid.



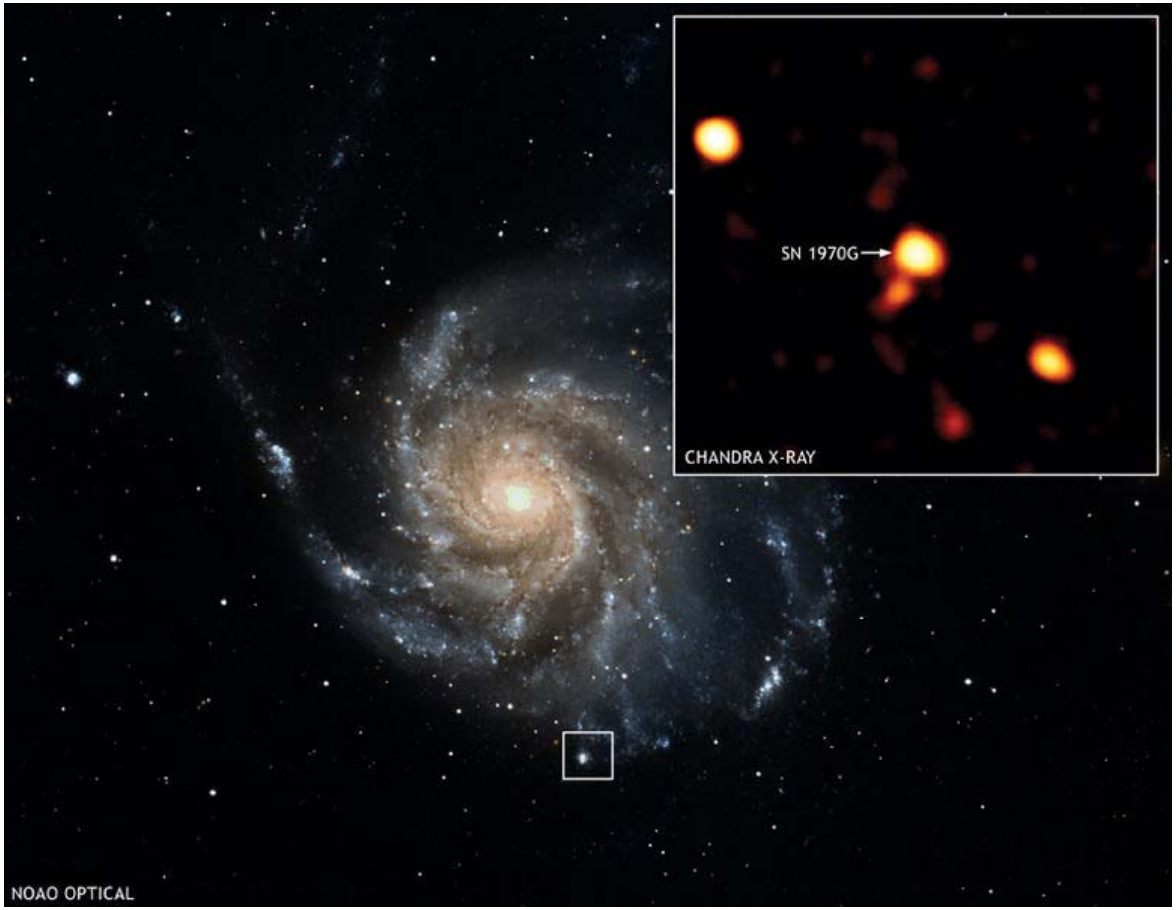
From Kann & Klose, Proc. 2007 Santa Fe GRB Conference. They write: "…, and once again, nearby afterglows were less luminous than more distant ones." Does this sound familiar? GRB Afterglows are pulsars! The free lunch! z=P/(2 ms)-1.

Are GRBs themselves pulsed? Maybe not.



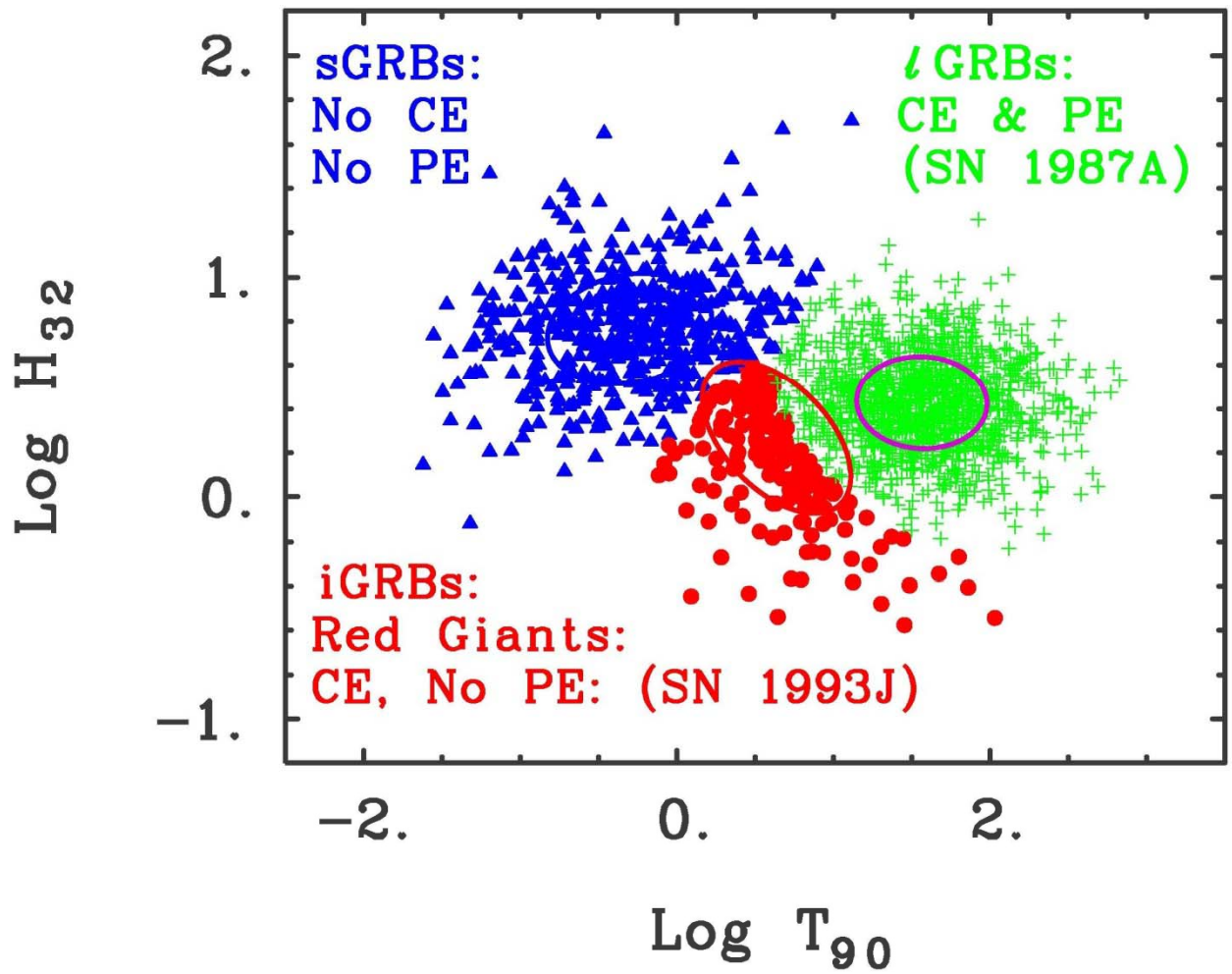
Pulsars, ALL!

We see GRB afterglows because they are 100% pulsed and we are in the very narrow cone where the intensity drops only as 1/distance. Thus the pulsar in SN 1970g will be someone else's GRB at some other end of the Universe a very long time from now (let's hope they're not as stupid as we are). At one SN/s in the Universe, a collimation factor near 10^{-5} is needed to balance the SN rate with the observed GRB rate. This only requires plasma out to 224 R_{LC}, which is no problem for a ms pulsar in a SN.

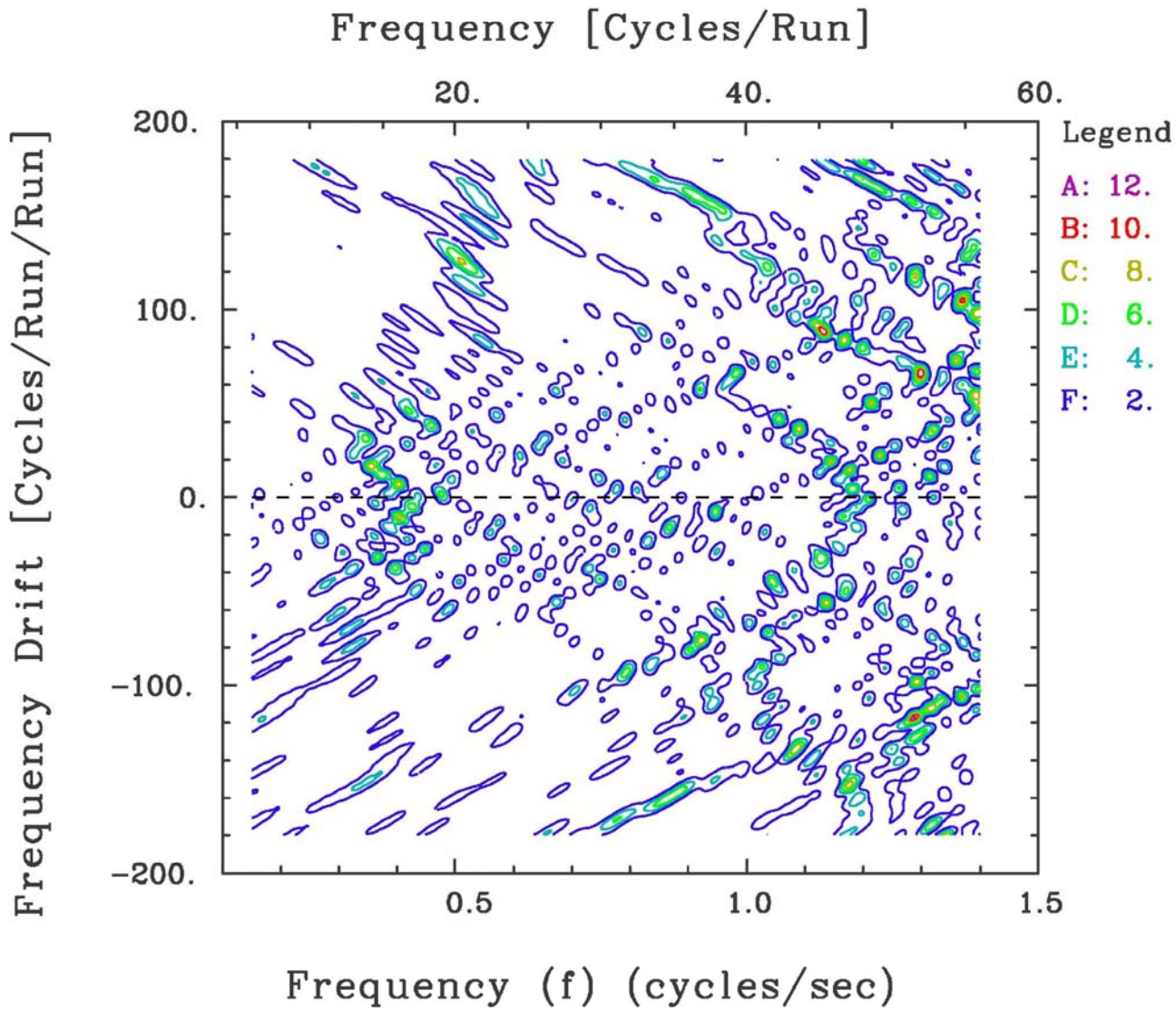


Most, if not all of the transient events in the distant Universe will be the result of a superluminal excitation of one kind or another.

Long duration, (ℓ)GRBs, then, are initiated, at least, by merger-induced core-collapse. These events far exceed neutron star-NS mergers *anywhere*, even in elliptical galaxies. Thus sGRBs are also due to merger-induced core-collapse, most likely naked white dwarf-white dwarf merger in the ellipticals' globular clusters, which explains the offset observed from their centers. A 3rd class of GRBs may or may not exist, as this doesn't show up in a more recent sample (though this is a smaller sample than BATSE). Do GRBs from strongly magnetized NSs differ from those due to weakly magnetized NSs?

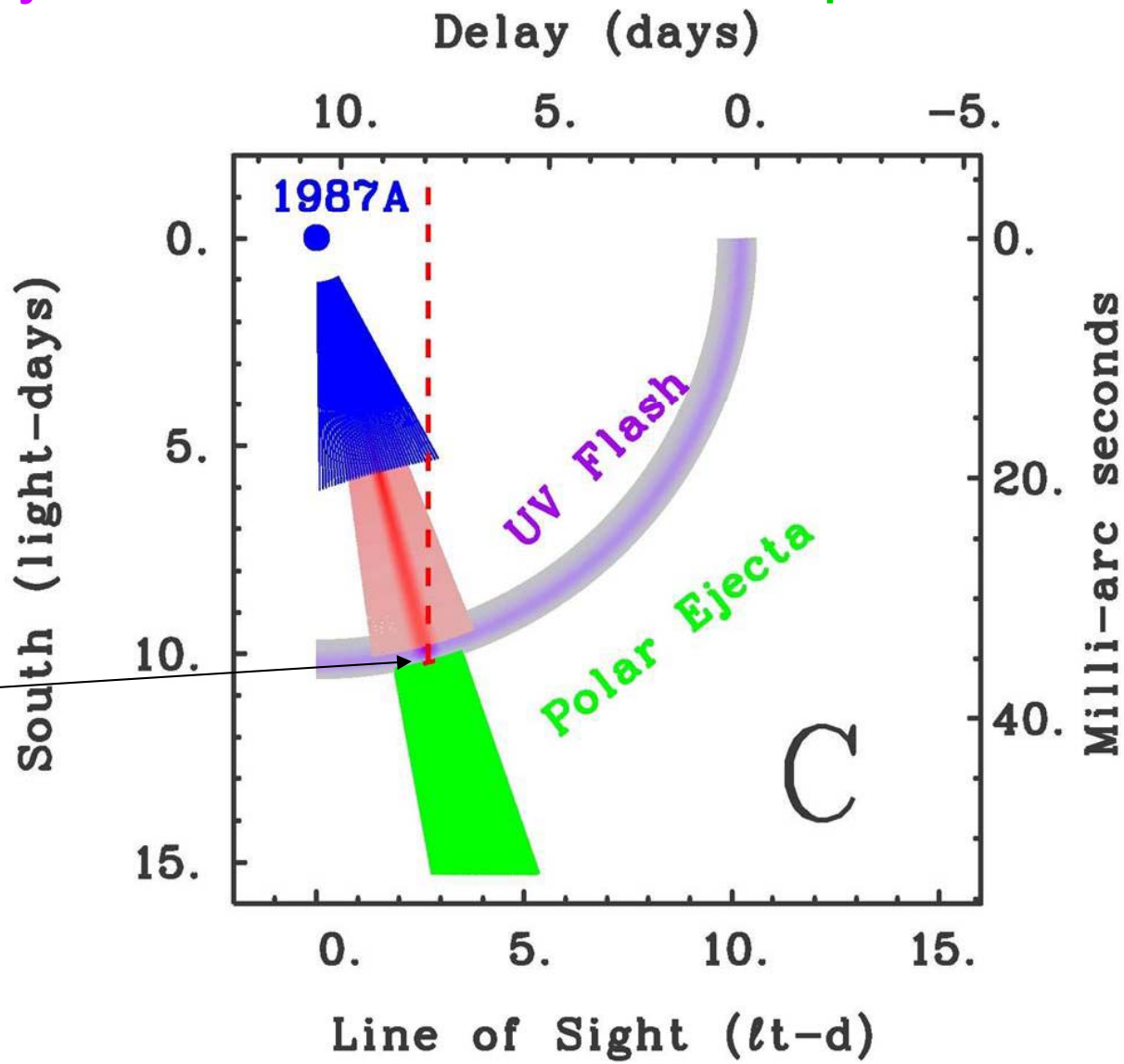


Are GRB's themselves pulsed? Not obviously and probably not (see below). If we Fourier transform the 1st 40 s of GRB 9602016 and plot the power on the f-df/dt plane, no dominant chirp & frequency appears. However, the chirp of core-collapse could be enormous and complex.



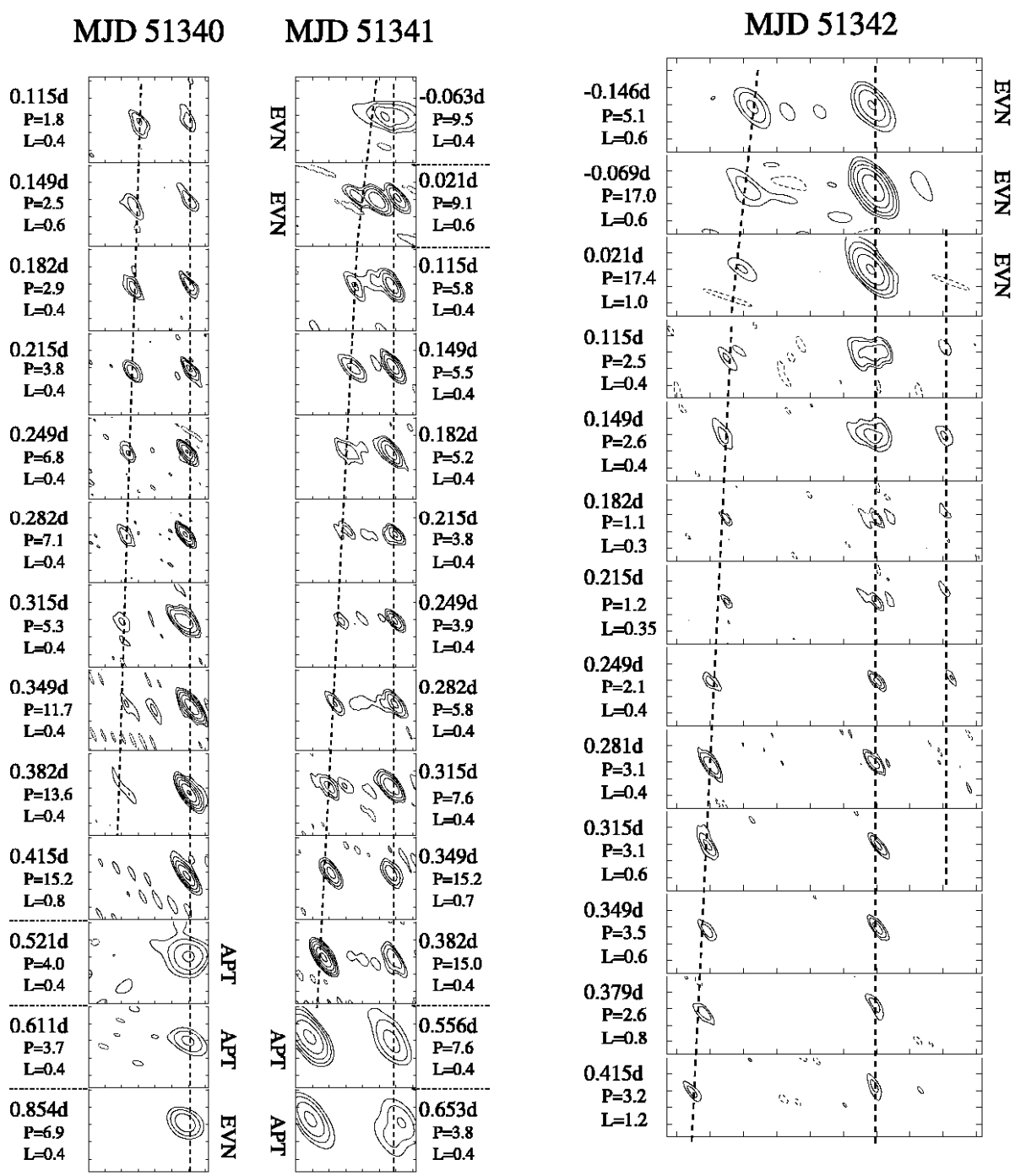
GRB 960216 (BATSE Trigger 4898)

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.

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!



In this jet features are known to travel between 0.3 and 0.57 c, and within which energy must be transferred at up to 0.95 c (attributed to electrons). However, SN 1987A moves protons that fast (a non-neutral beam would not maintain its collimation). The fast jets in Sco X-1 are weak because, unlike SN 1987A, where the elements are stratified, Sco X-1's accretia is not stratified.

SCORPIUS X-1: THE EVOLUTION AND NATURE OF THE TWIN COMPACT RADIO LOBES

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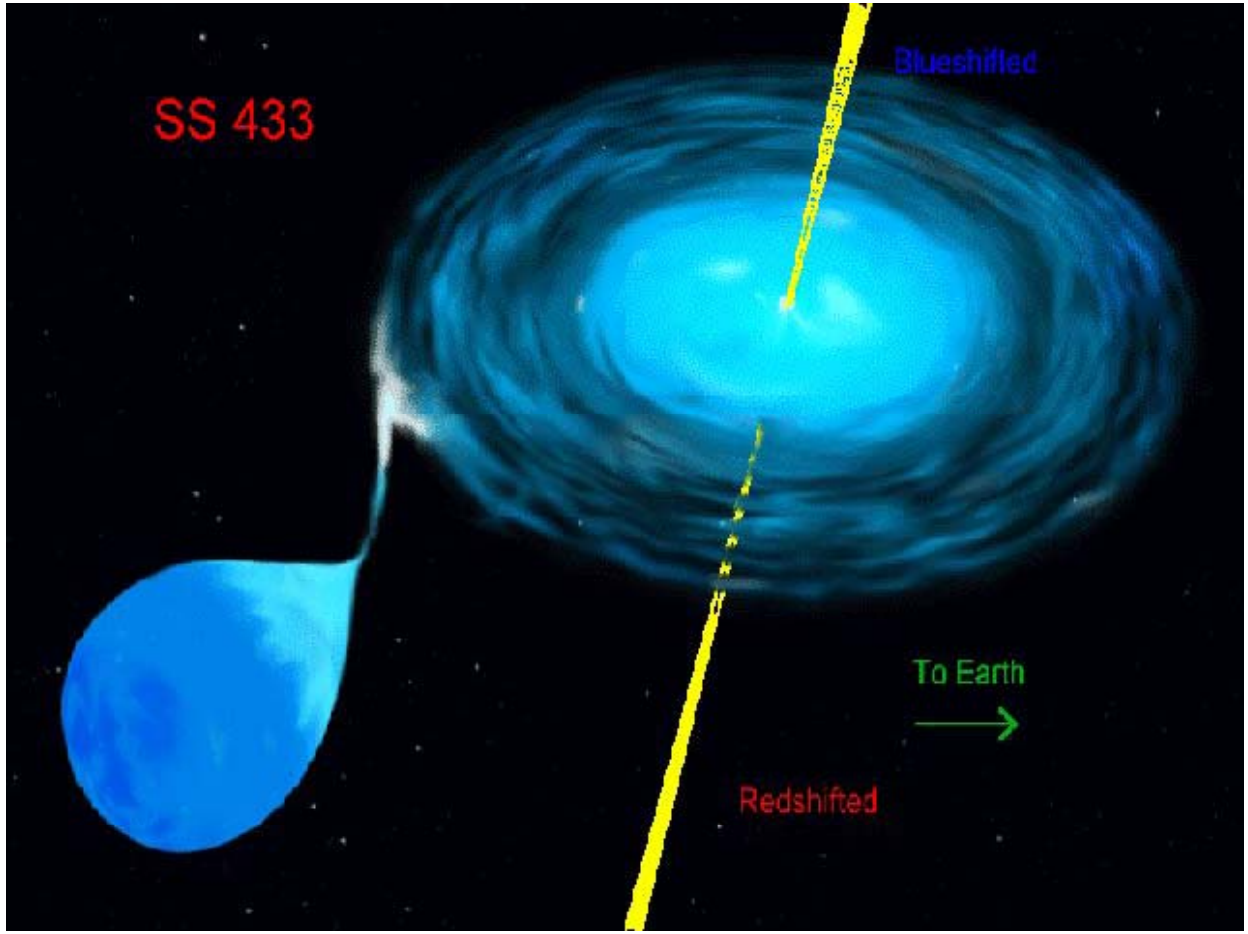
ABSTRACT

The motion and variability of the radio components in the low-mass X-ray binary system Sco X-1 have been monitored with extensive VLBI imaging at 1.7 and 5.0 GHz over 4 yr, including a 56 hr continuous VLBI observation in 1999 June. We detect one strong and one weak compact radio component, moving in opposite directions from the radio core. Their relative motion and flux densities are consistent with relativistic effects, from which we derive an average component speed of $v/c = 0.45 \pm 0.03$ at an angle of $44° \pm 6°$ to the line of sight. This inclination of the binary orbit suggests a mass of the secondary star that is less than 0.9 $M_\odot$, assuming a neutron star mass of 1.4 $M_\odot$. We suggest that the two moving radio components consist of ultrarelativistic plasma that is produced at a working surface where the energy in dual-opposing beams disrupt. The radio lobe advance velocity is constant over many hours, but differs among lobe-pairs: 0.32*c*, 0.46*c*, 0.48*c*, and 0.57*c*. A lobe-pair lifetime is less than 2 days, with a new pair formed near the core within a day. The lobe flux has flux density that is variable over a timescale of 1 hr, has a measured minimum size of 1 mas (4×10^8 km), and is extended perpendicular to its motion. This timescale and size are consistent with an electron radiative lifetime of less than 1 hr. Such a short lifetime can be caused by synchrotron losses if the lobe magnetic field is 300 G or by adiabatic expansion of the electrons as soon as they are produced at the working surface. The lobes also show periods of slow expansion and a steepening radio spectrum. Two of the core flares are correlated with the lobe flares under the assumption that the flares are produced by an energy burst traveling down the beams with a speed greater than 0.95. The radio morphology for Sco X-1 differs from most other Galactic jet sources. Possible reasons for the morphology difference are that Sco X-1 is associated with a neutron star, it is a persistent X-ray source, and the source is viewed significantly away from the angle of motion. However, the lobes in Sco X-1 are similar to the hot spots found in many extragalactic radio double sources. Scaling the phenomena observed in Sco X-1 to extragalactic sources implies radio source hot-spot variability timescales of 10^4 yr and hot-spot lifetimes of 10^5 yr.

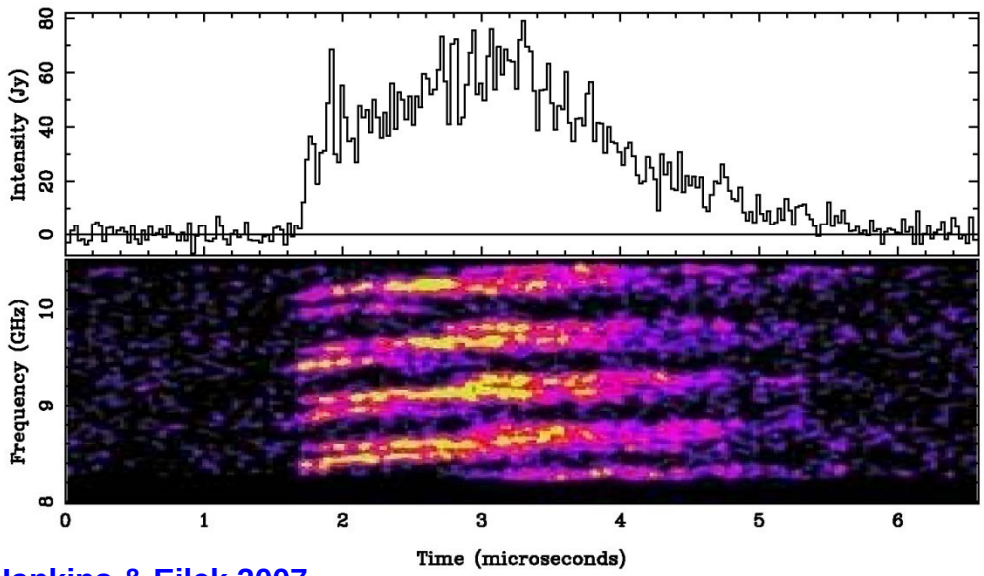
Subject headings: radio continuum: stars — stars: individual (Scorpius X-1) — X-rays: individual (Scorpius X-1)

SS 433 has two Hα jets which travel at 0.26 c. The companion may be an early type star, thus there are NO heavy elements in the accretia, and there is NO boost mechanism.

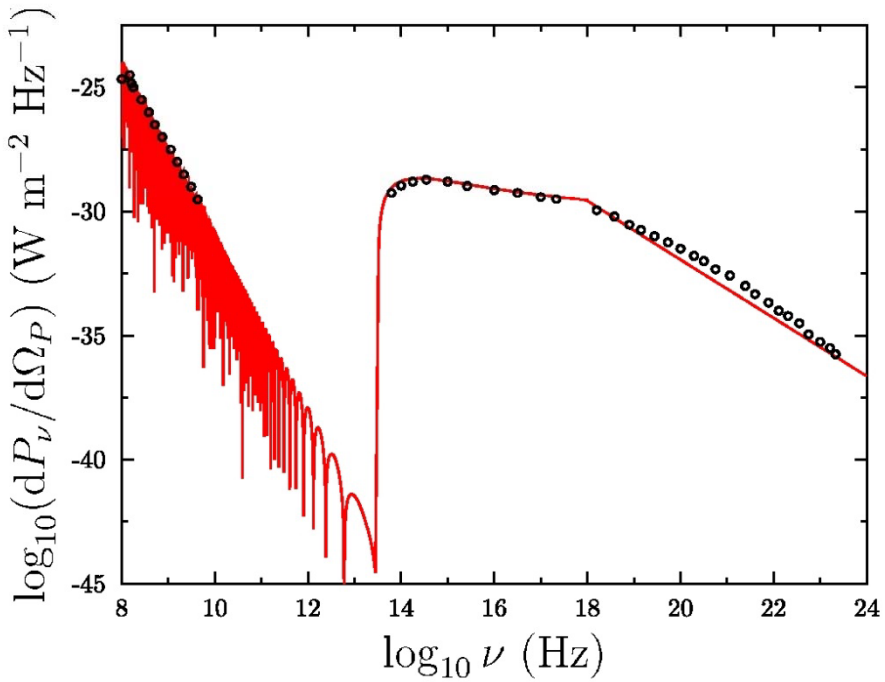


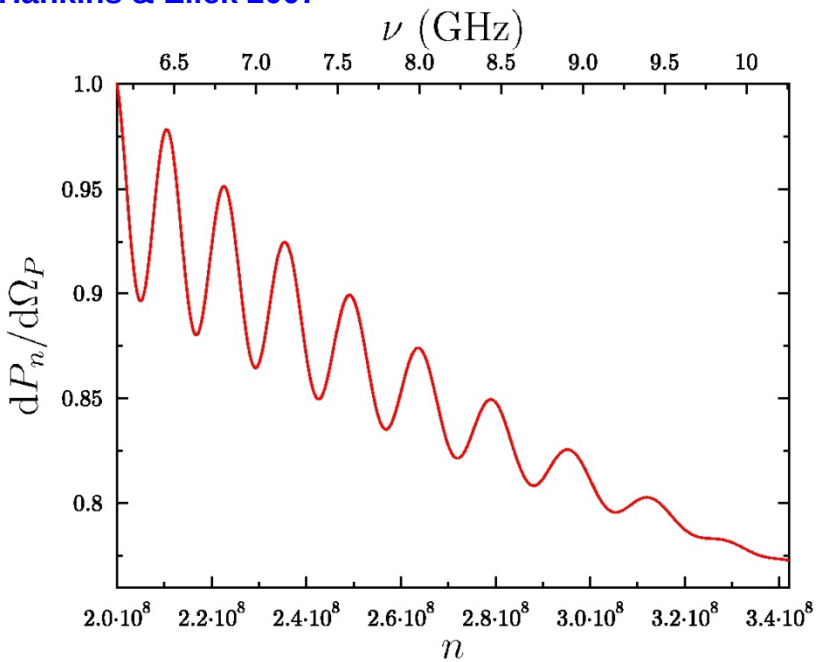
The velocity is limited by the redshift of Ly_∞ to Lyα, or to 0.28 c. However, some finite bandwidth is needed to accelerate the jet particles, so the saturation velocity is 0.26 c. Multiple Hα excitations occur from the SLIP mechanism and excite moving lines.

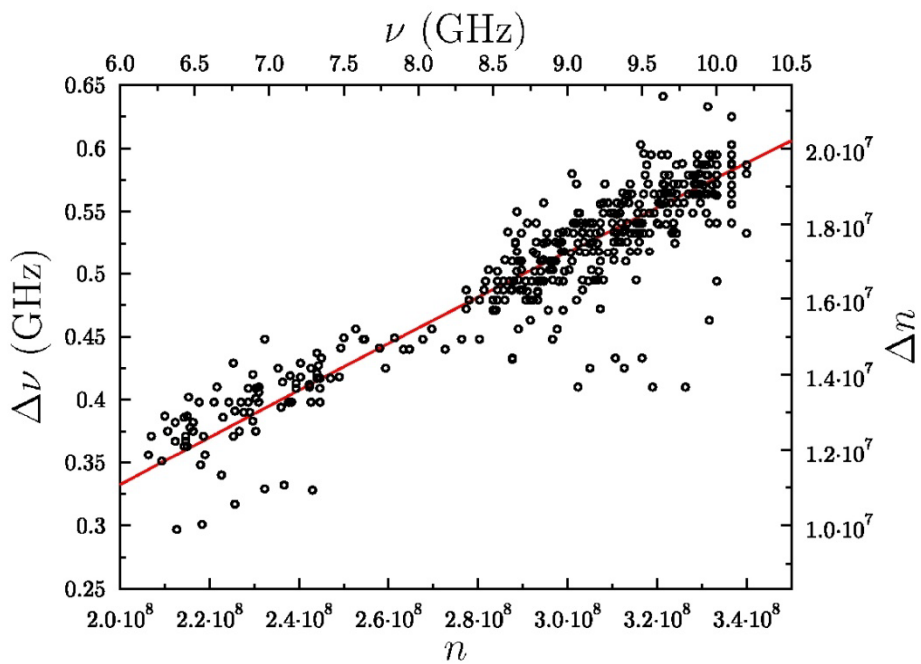
SLIP explains the spectrum of the Crab giant interpulse in detail:



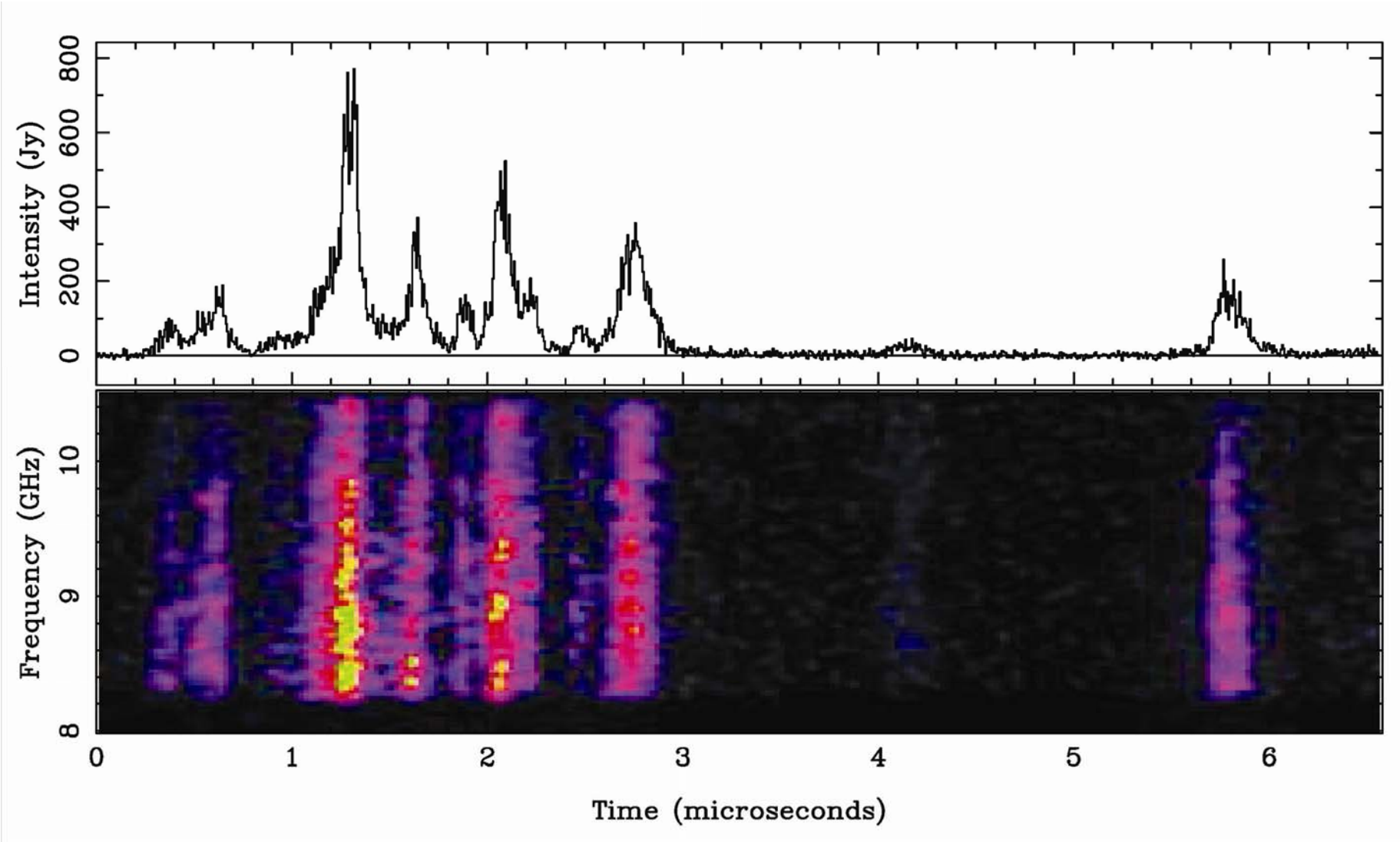
Hankins & Eilek 2007



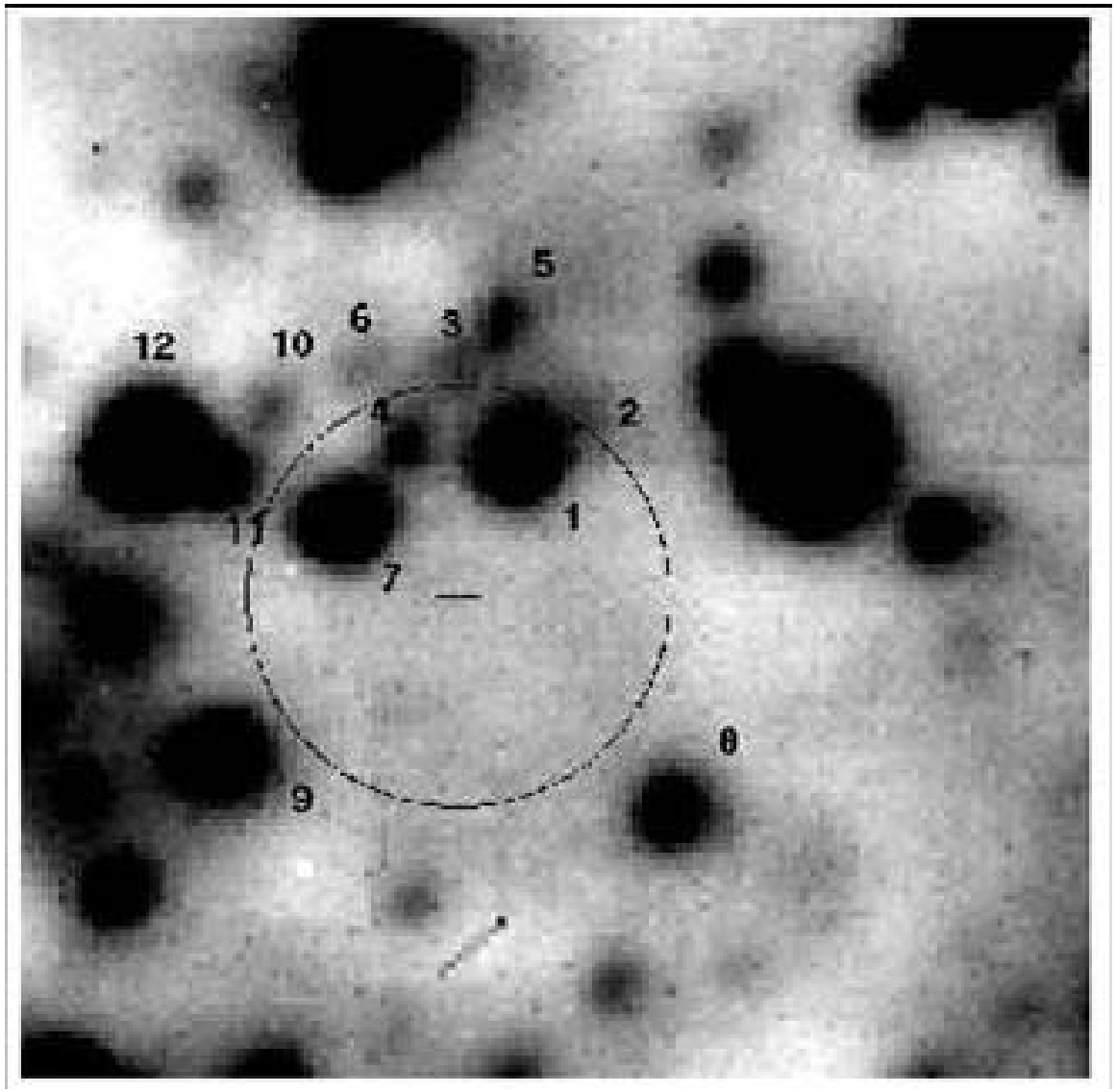




But the Crab giant main pulse does not have the bands and therefore does not shine by the same mechanism: · Hankins & Eilek 2007

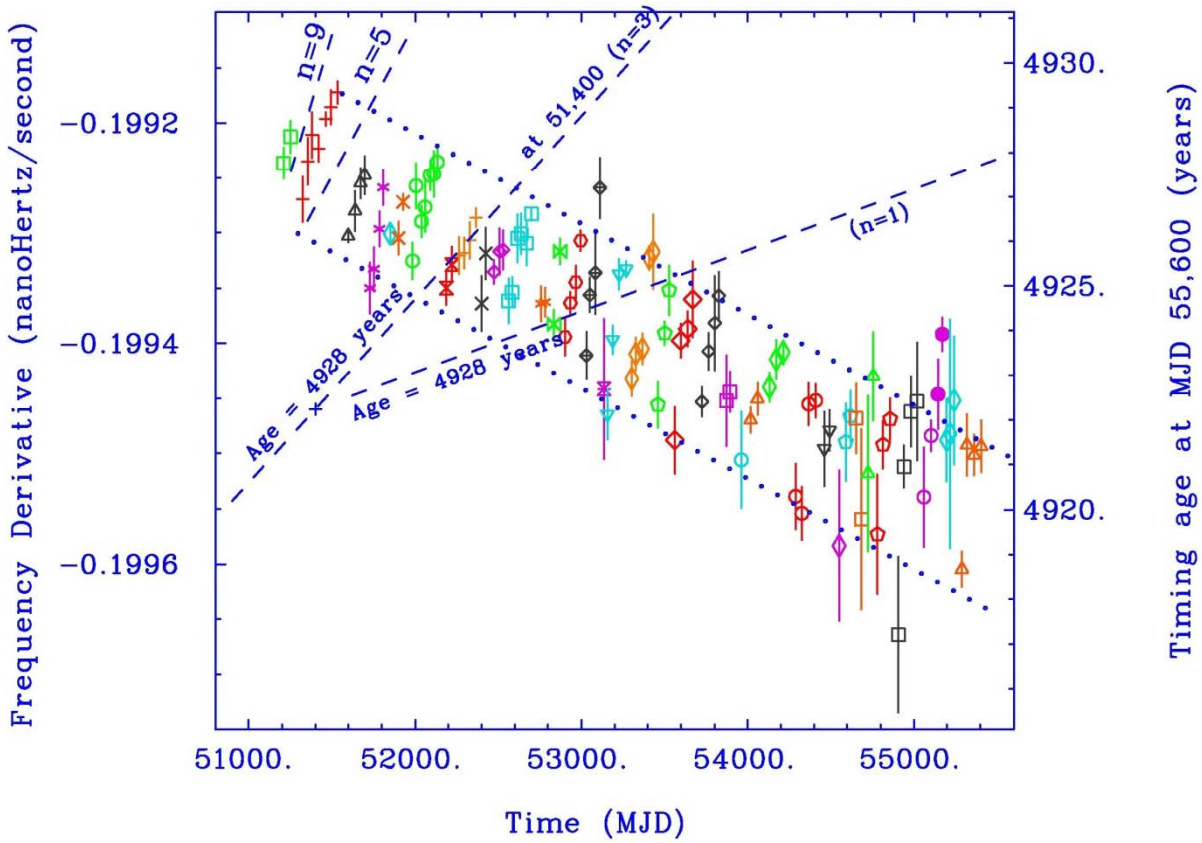


SLIP also explains many other facets of pulsars, and whether or not pulsed radiation is seen in any particular band. For isolated pulsars, SLIP says that the pulsations come from just outside of the light cylinder, where gravity from the neutron star has concentrated the ISM plasma to its maximum density. As an example, the 62 Hz pulsar in the Large Magellanic Cloud is NOT an optical pulsar. This is because although it only has an effective dipole field of ~1 TG, since it is an oblique rotator, its actual field is as strong as that of the Crab or 0540, 3-5 TG, or even stronger.



But J0537 spins at 62 Hz, so the magnetic field just outside of its light cylinder (which is <½ the size) is an order of magnitude larger than that of the Crab or B0540, and the cyclotron frequency there is also an order of magnitude (or more) higher than for the Crab or B0540.

Since cyclotron frequencies only have higher harmonics (and no sub-harmonics), the J0537 radiation has a much shorter wavelength than the optical, and so it is mostly just an X-ray pulsar.



The increasing spindown of J0537

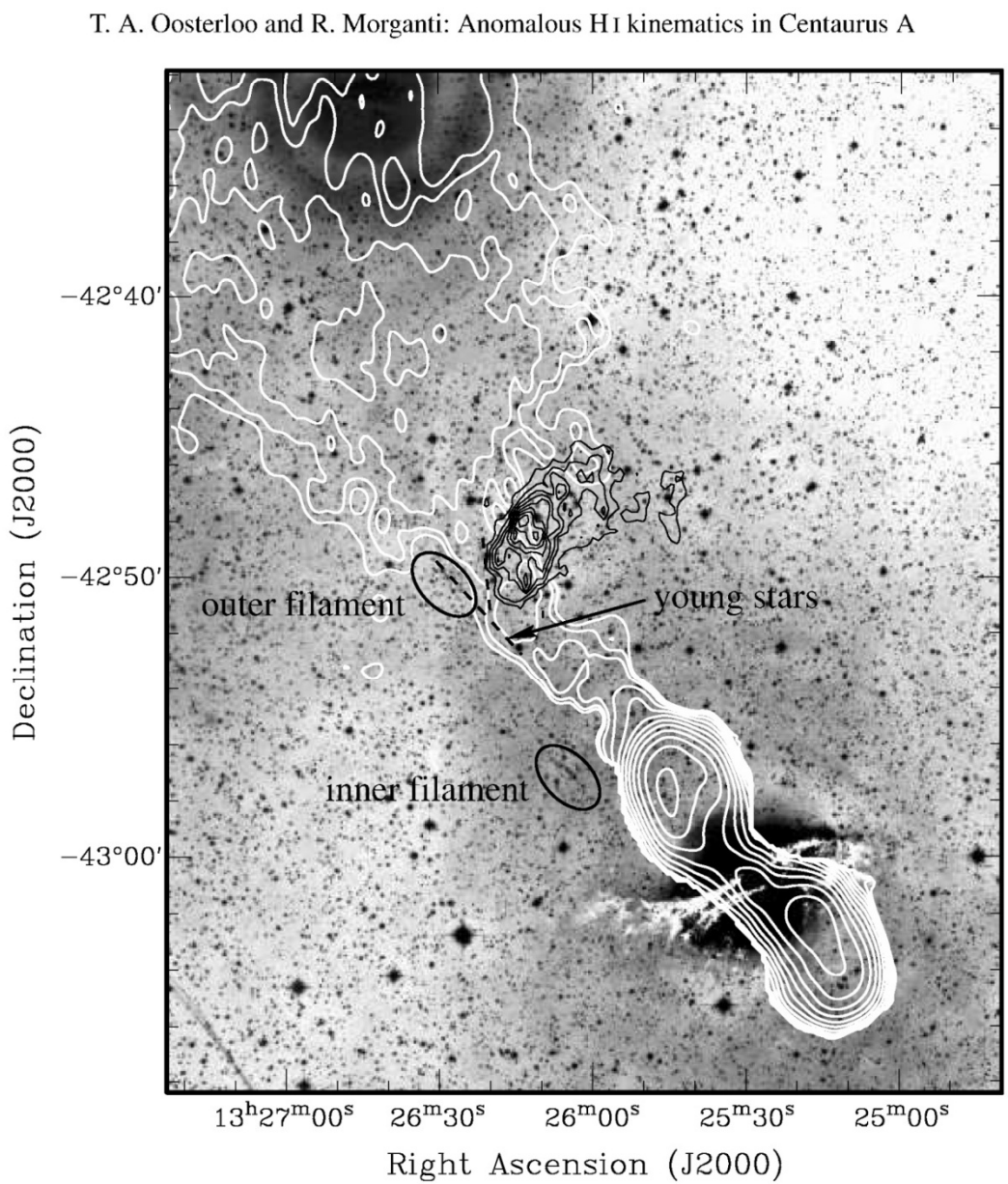
What have we learned about pulsar jets?

These jets eviscerate their progenitors in supernovae; they dominate the extreme end of the kinetic spectrum.

It is very likely that dark energy does not exist.

But if there is no dark energy, then there's no sleazy numerical coincidence to argue for dark matter. (Trust me, they're both garbage.)

There is plenty of evidence for jet-driven star formation in the present Universe. In the early Universe, it was much easier (Oosterloo & Morganti 2005, 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.



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.

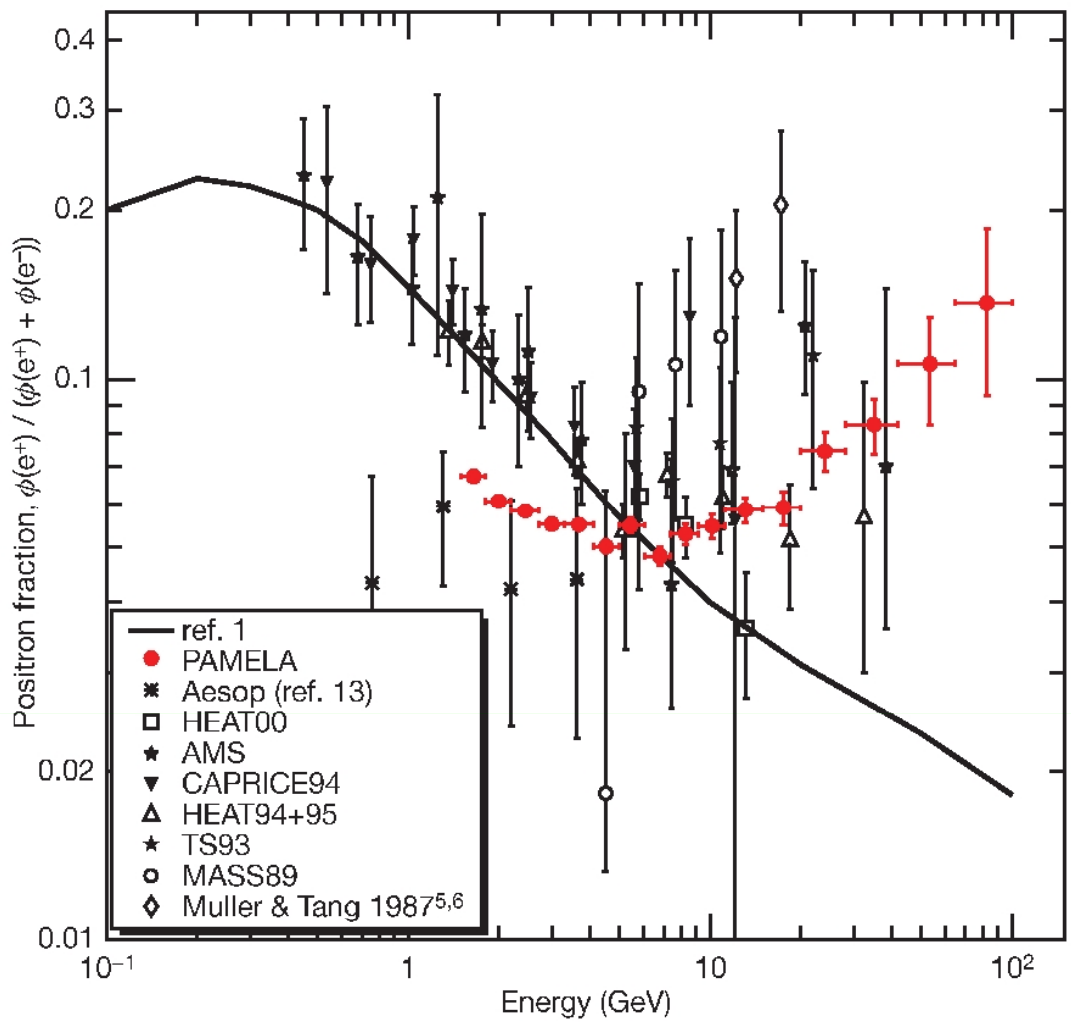
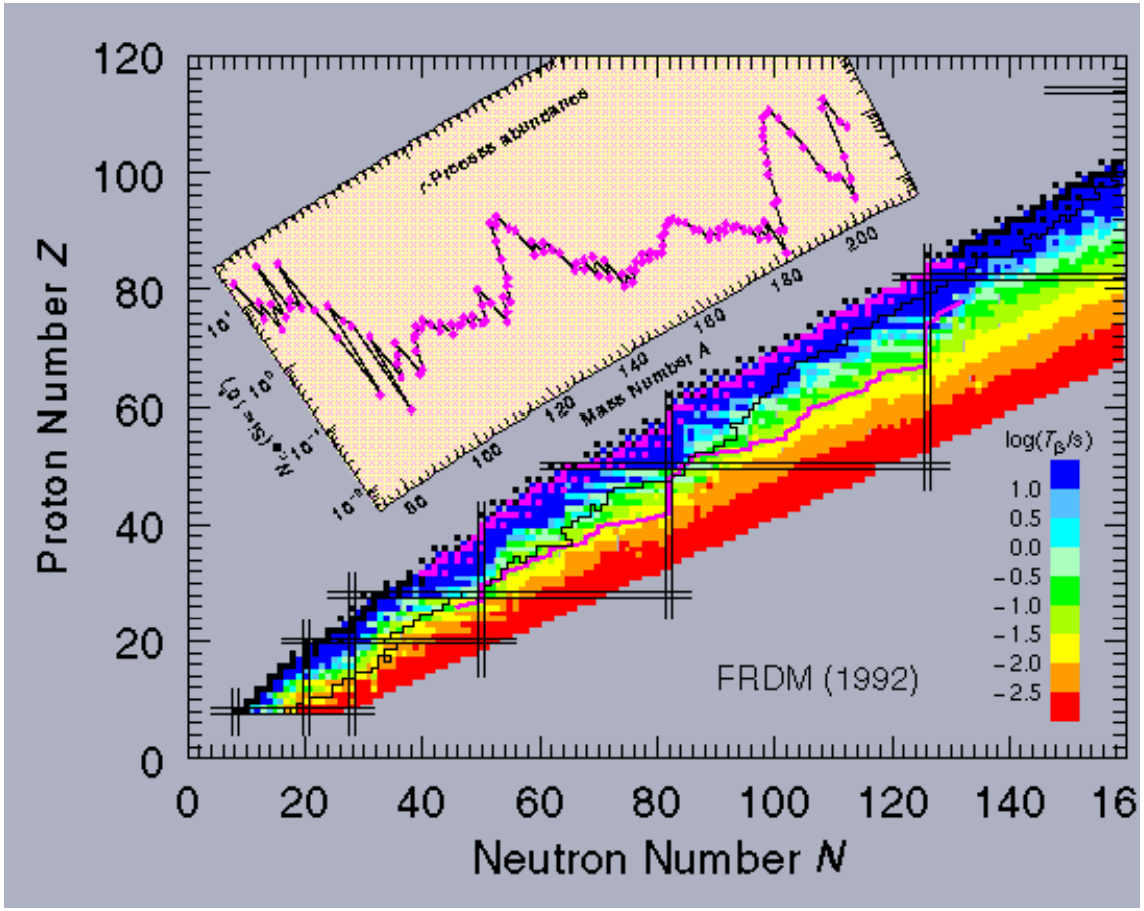


Figure 2 | PAMELA positron fraction with other experimental data and with secondary production model. The positron fraction measured by the PAMELA experiment compared with other recent experimental data (see refs 5–7, 11–13, 30, and references within). The solid line shows a calculation[1] for pure secondary 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.

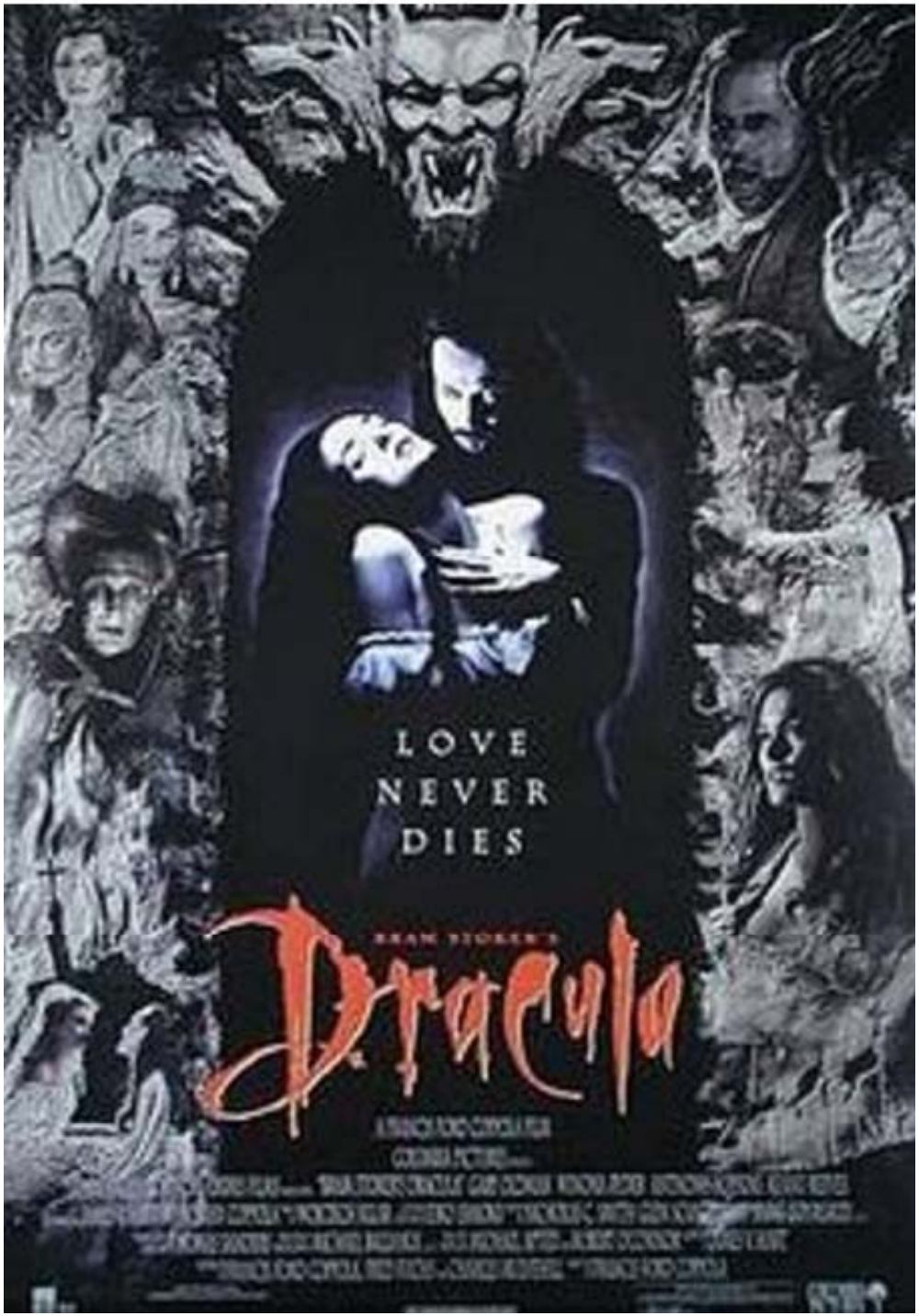
Can pulsar-driven jets provide the r-process elements? Protons traveling at 0.95 c are destructive to heavy nuclei, resulting in spalled free neutrons, which, in turn, can be captured by other heavy nuclei, producing even heavier, r-process nuclei. We don't yet know if this works.



(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

The anomalous dimming of distant SNe is therefore likely to be only a systematic effect, and observers have been aware of this since 2007, or before. But they haven't retracted the result, and very many astronomers still want to believe it. Thus it persists as an *undead* result, and like Dracula, has been sucking the lifeblood out of other aspects of astronomy, by distorting observing, instrumentation, and funding priorities.

(Credit: Francis Ford Coppola and Fred Fuchs, *Dracula*, 1991)



What are the RULES for pulsars now?

The luminosity rules are abnormal.

For all but the largest mass progenitors, pulsars eviscerate their remaining gaseous remnant stars with their pulsations, until very little is left. Mass up to 75 $M_\odot$: no He mixed into C, O, Ne, & Si layers by binary merger, ∴ lots of ^{56}Ni, e.g. SNe 06gy & 07bi will have high B pulsars. SNe 06gy & 07bi have declines consistent with 3 & 6 $M_\odot$ of ^{56}Ni.

They *can* make jets, so DO NOT invoke black holes when neutron stars will do (lack of pulsations can not be invoked)! Make better use of Occam's Razor (or *START* using it!).

We are now at this stage:

Dark energy is a never-ending snipe hunt of bad science. It is highly probable that there is no effect in the distant SN Ia population, thus no dark energy.

"If we keep out mouths shut about this, we can milk it forever."

Physics is hard enough without starting with invalid assumptions. The probability of getting things right when starting with the wrong assumptions is $e^{-\infty}$.

If we do keep our mouths shut about this, candor is impossible and we'll make no progress at all.

When I ***knew*** I had a spurious result, I retracted it. By not retracting dark energy, the SN observers have done a great disservice to science.

Glaciers are melting, but much of the astronomical community think it's their God-given right to start their physics with the wrong assumptions.

The evidence for dark matter nowadays

Is tenuous at best:

1. Clusters of galaxies – their velocities appear larger than cluster-size Keplerian because they formed while falling in from a much greater distance.
2. Velocity curves of spirals – spirals are accretion disks: stuff falls in and stuff flies off. Of course the outer velocites are >Keplerian. The Universe is never in equilibrium.
3. The bullet cluster has an alternate explanation. There is no evidence for dark matter in any of the 103 known cases of isolated ring galaxies.
4. Gravity mattered at the epoch of recombination. It doesn't now. So one can not invoke dark matter now because of what one sees at z~1,300, when gravity mattered. Is this a deeper problem? See below.

Pulsars and the Universe

There may be a way out of the need for dark matter to make galaxies form.

This way is to exploit the non-spheroidal pulsar eviscerations of the first stars by the pulsars they give birth to, which seed the Universe with moving plumes of material, which in turn, seed star formation in lines.

Pulsars are entropy destroyers.

Most, if not all, of the transient events in the Universe are due to superluminal excitations.

Recommendations:

We should exploit pulsed GRB afterglows as soon as possible, while Swift is still operating.

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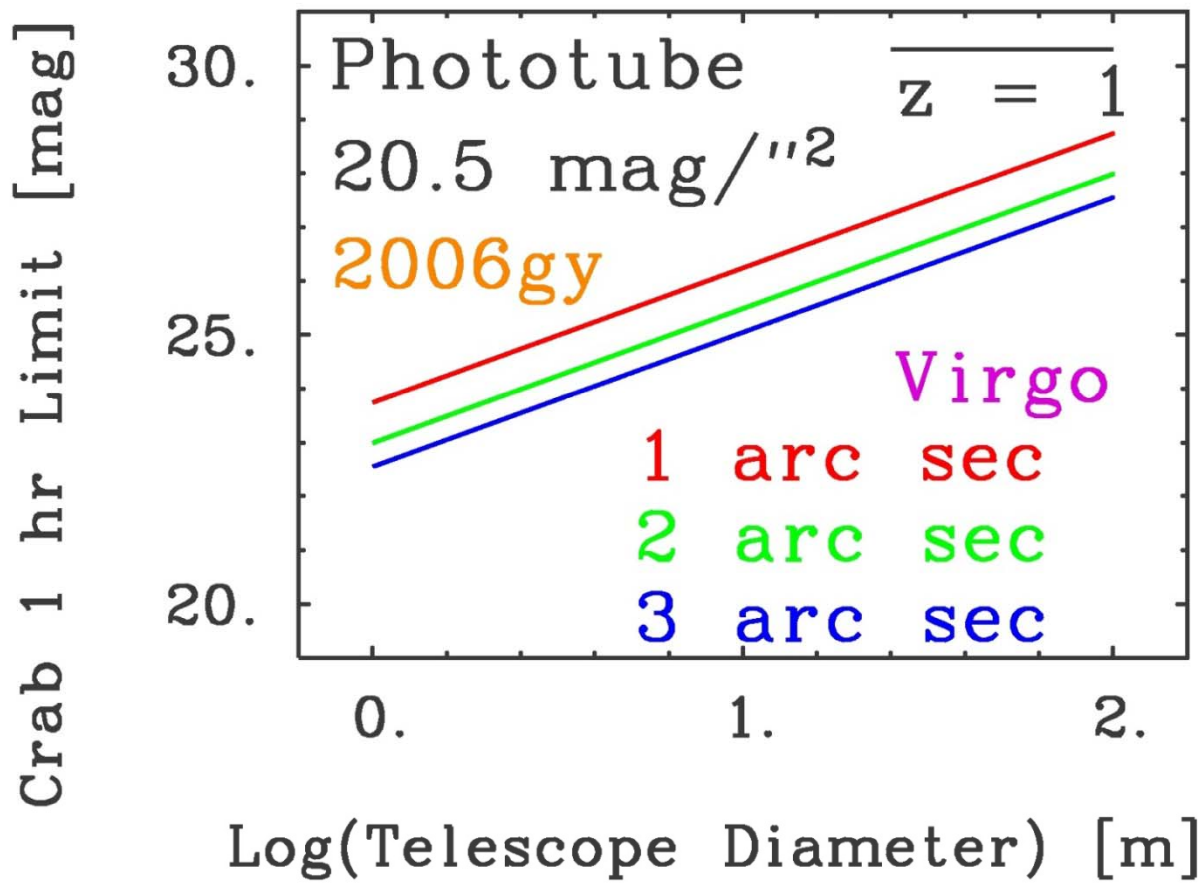
Otherwise one could prove:

$$2 + 2 \neq 4$$

So what do we do if we can't study dark energy or dark matter? There are enough problems on SN 1987A to put everyone to work. Then there are the pulsed GRB afterglows, with which we can study cosmology and pulsars at the same time.

"You study the Universe that you do live in, not the one that you wished you lived in."

Since pulsars dim only as 1/distance in certain directions, they are already accessible in the Virgo cluster with Keck-, Gemini-, & Magellan-class telescopes. SN 2006gy with some effort. z=1 is accessible with synthetic apertures < 0.5”, telescopes with diameters 30 m or more, and single-photon-counting detectors with higher quantum efficiencies. We need 30-m class scopes to study GRB afterglows in the near IR with single-photon-counting detectors, such as the SSPM.



- We needed fast pulse counting instruments *a few years ago*. Every large, (and even many smaller) telescope(s) on the planet should have this option.
- At least four groups have fast polarimeters and/or photometers: GASP (Galway Automated Stokes Polarimeter), and the South African Large Telescope (Salticam, 0.1 ms). Also Ozzy Sigmund's photon-counting Berkeleycam, and Cesare Barbieri and Padua/Asiago's avalanche photodiode instruments.
- With GPS, recording fast data has never been easier: a simple, cheap, photon-counting instrument could be developed.
- The complexity (precession, etc.) of the time signature of an infant neutron star will require support software to ease interpretation, particularly for the casual observer who opts to observe an afterglow in high time resolution. I'll have to write it.

- With the engineering planned for giant telescopes we can detect pulsars out to z ~ 1.
- GRB afterglows may be blazingly bright pulsars, detectable to well beyond (z ~ 8). No Eddington limit applies!
- We can learn about infant neutron stars, GRBs, and SNe, and do cosmology at the same time!
- Because 99% of SNe are mergers, like 87A, these will be standard frequency candles, and we automatically get the redshift, z, as: [(measured pulse period)/(2.14 ms)] - 1.
- Detecting the chirps in GRB afterglows may help LIGO detect GR signatures of SNe.

Pulsars will save Astronomy from itself. (Pulsars Rule the Universe!)

- Sooner or later, the general public will catch on that dark energy and dark matter are just so much pimped-up astroBS (I guarantee you this will happen).
- When that happens, pulsars out to the end of the Universe will be the new (and more lasting) legacy of Astronomy.
- THE END (and the BEGINNING!).

This research was supported by Los Alamos National Laboratory directed research grant, LDRD 20080085DR.

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