The Road to and Success of VERITAS

Imagining what could be

The pursuit of sites and funding

Events on the ground

The payoff and ongoing success

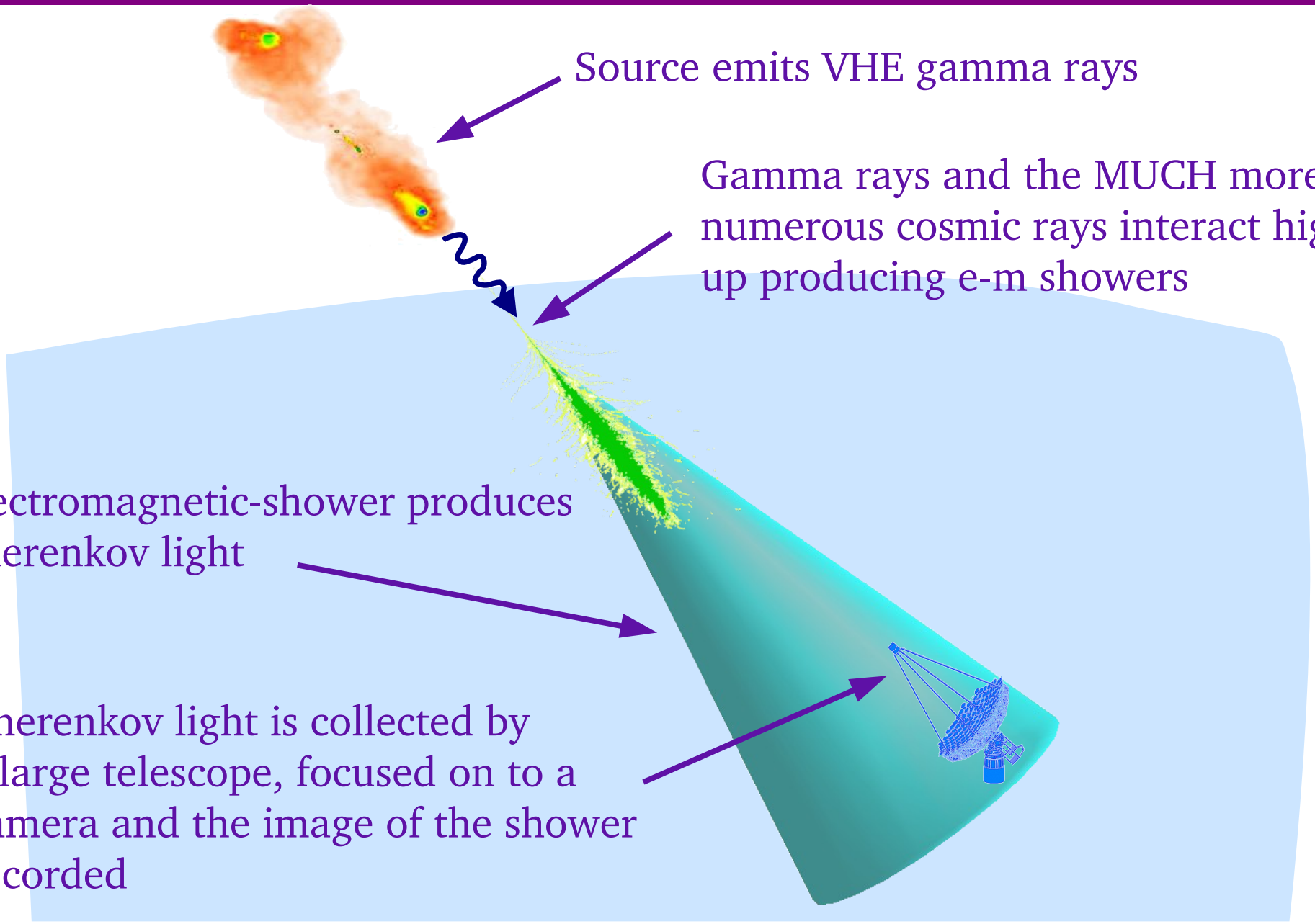
VERITAS

VERITAS “the collaboration” is composed of more than 100 scientists from 20 institutions in 5 countries, plus on the order of 50 associated scientists.

VERITAS “the detector” consists of four Imaging Atmospheric Cherenkov Telescopes, forming a single instrument and designed to study astrophysical sources of Very High Energy gamma rays.

VERITAS “my opinion” is the most robust, reliable and sensitive observatory now and for the next 5 years.

IACT in one slidet



A slow start

In the Fall of `84:

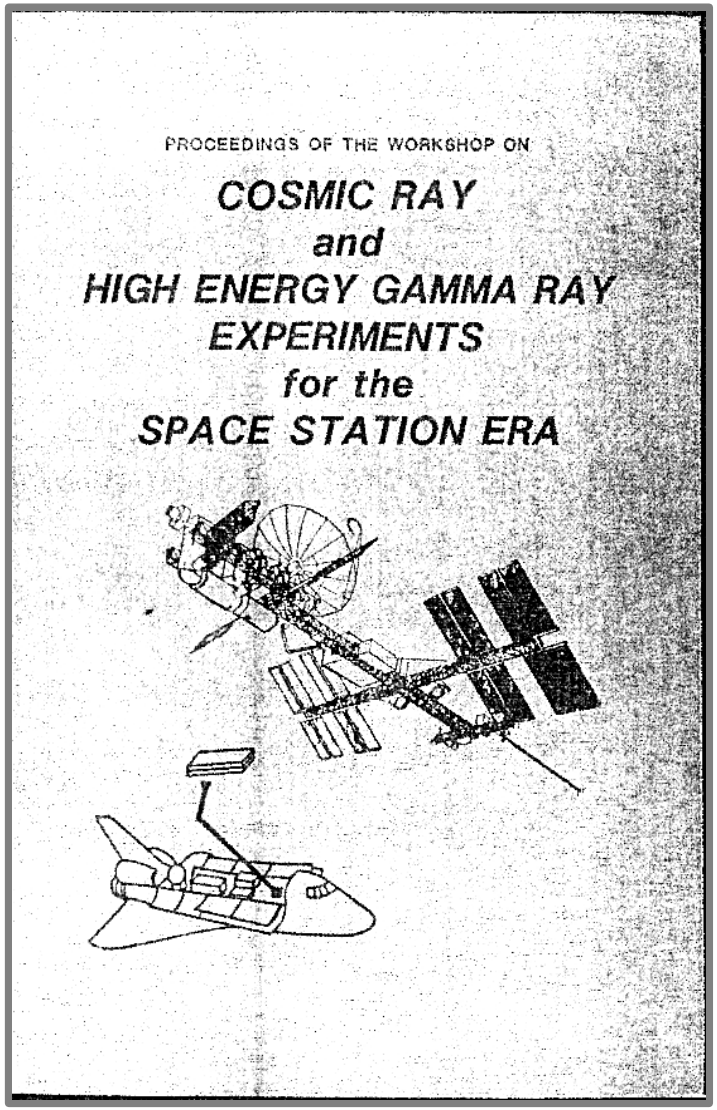
- The 37-pixel camera had just the season before been installed on the 10M on Mt. Hopkins
- Hillas had completed his simulations and introduced his eponymous image parameters
- Hercules X-1 and Cygnus X-3 seemed both to exhibit periodic signals, but nothing from the Crab Nebula

Why wasn't imaging working?

It would be two years before evidence that imaging did work emerged and three more (in 1989) before the first convincing results were published.

Nonetheless ...

Imagining what could be



A THIRD GENERATION VHE GAMMA RAY OBSERVATORY

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ABSTRACT

An atmospheric Cherenkov experiment that parallels the developments in sensitivity at gamma ray energies in the MeV-GeV region expected in the Space Station Era is described. It consists of seven 10 - 15 m aperture optical reflectors in an array of spacing 75 m at a high mountain altitude (3.5 km). Each reflector is equipped with a camera similar to that currently in use at the Whipple Observatory. The flux sensitivity will be a factor of ten better than that achievable with the current camera and will be competitive with the anticipated sensitivity of space-borne calorimeters in the TeV energy range. The effective energy threshold could be as low as 10 GeV. A colocated particle detector array consisting of 61 scintillators of 1 m^2 area will give coverage from 10^{14} to 10^{17} eV so that six magnitudes of the electromagnetic spectrum can be simultaneously monitored.

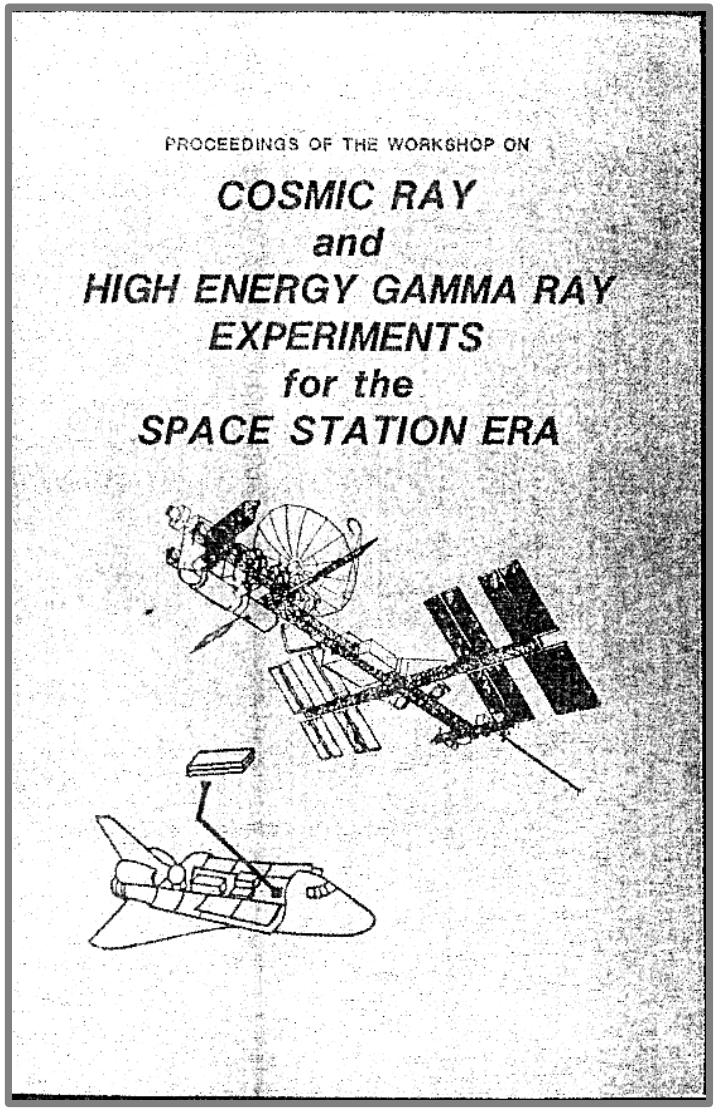
1. Introduction

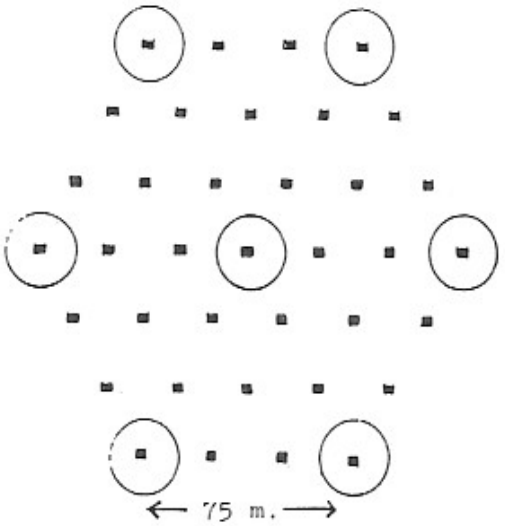
The discovery that Cygnus X-3 was a source of gamma rays at energies ranging from 10^{12} to 10^{16} eV is probably the most significant observation in cosmic ray astrophysics in the past decade; it is a clear indication that gamma ray astronomy must play an important role in unravelling the origin of the cosmic radiation since nothing prior to these observations would have suggested that Cygnus X-3 was a major source of high energy particles.

These observations were made using ground-based instrumentation which was remarkable for its lack of sophistication. The combined budgets of the various groups involved probably represented a small fraction of a major high energy satellite experiment during the same period.

Louisiana State University, Baton Rouge, October, 1984.

A blueprint for VERITAS





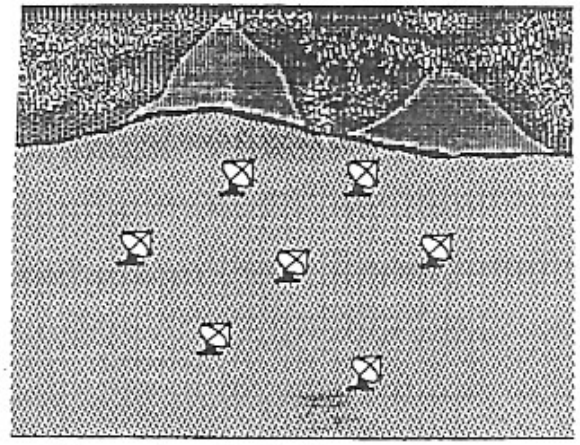
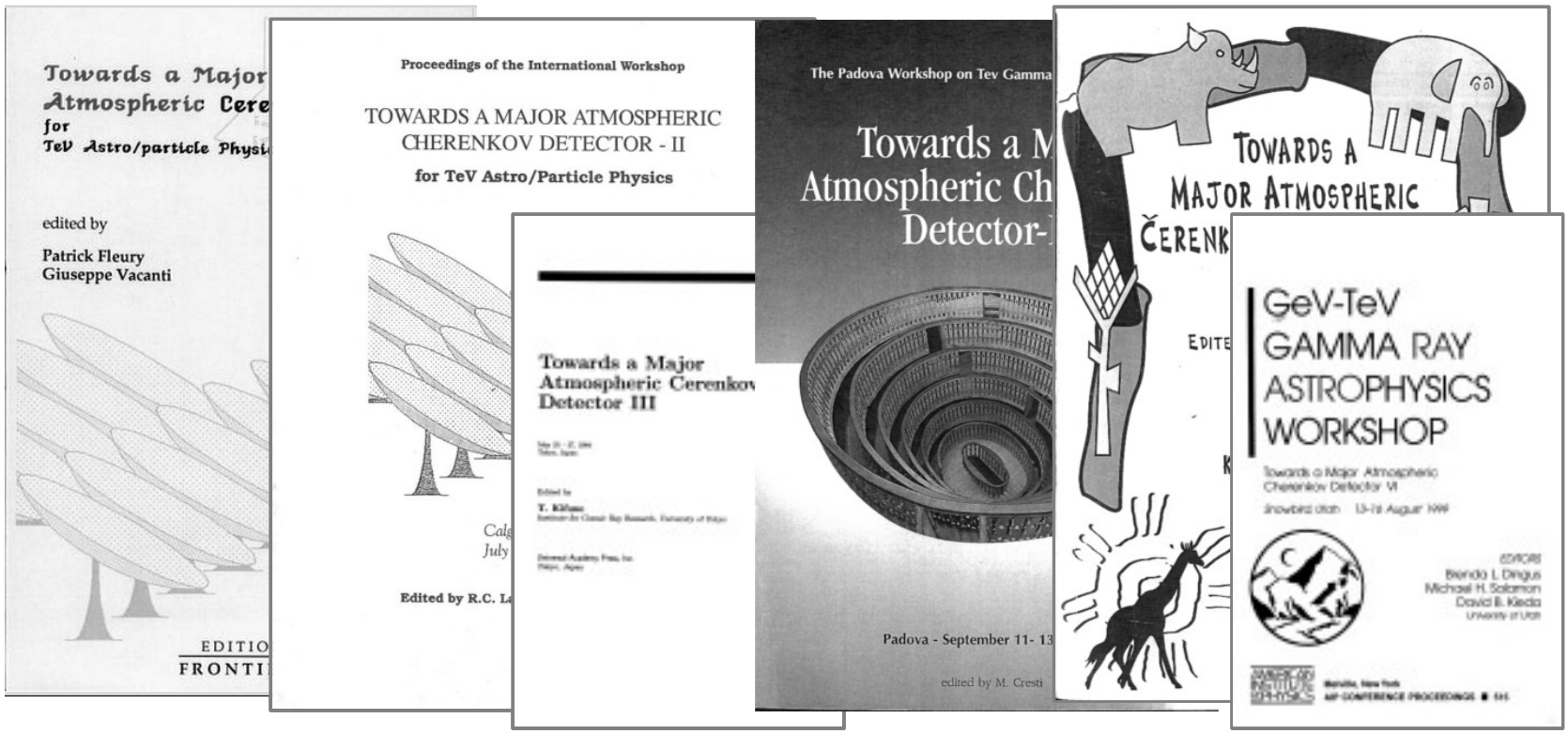


Figure 1a. Artist's concept of VHE Gamma Ray Observatory showing seven 15 m aperture atmospheric Cherenkov cameras with spacing of 75 m.

Figure 1b. Plan of combined VHE and UHE Observatory. Squares are scintillators of 1 m^2 area and spacing of 25 m. Circle are 15 m aperture cameras at spacing of 75 m.

Louisiana State University, Baton Rouge, October, **1984**.

Six “Quo vadis?” conferences in the `90s



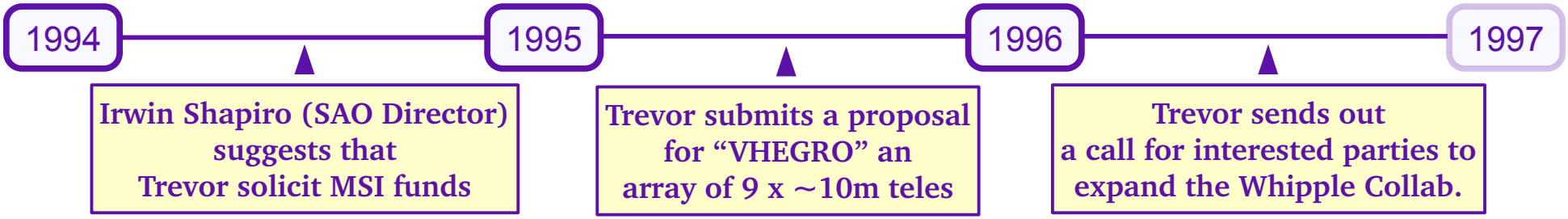
- Additional sources (& source classes) presented
- A number of techniques explored: imaging, fast timing, lateral light distribution
- Advantage of stereo imaging demonstrated by HEGRA
- First MAGIC, then HESS and VERITAS introduced

“The Road”

(and a long and winding one it was!)

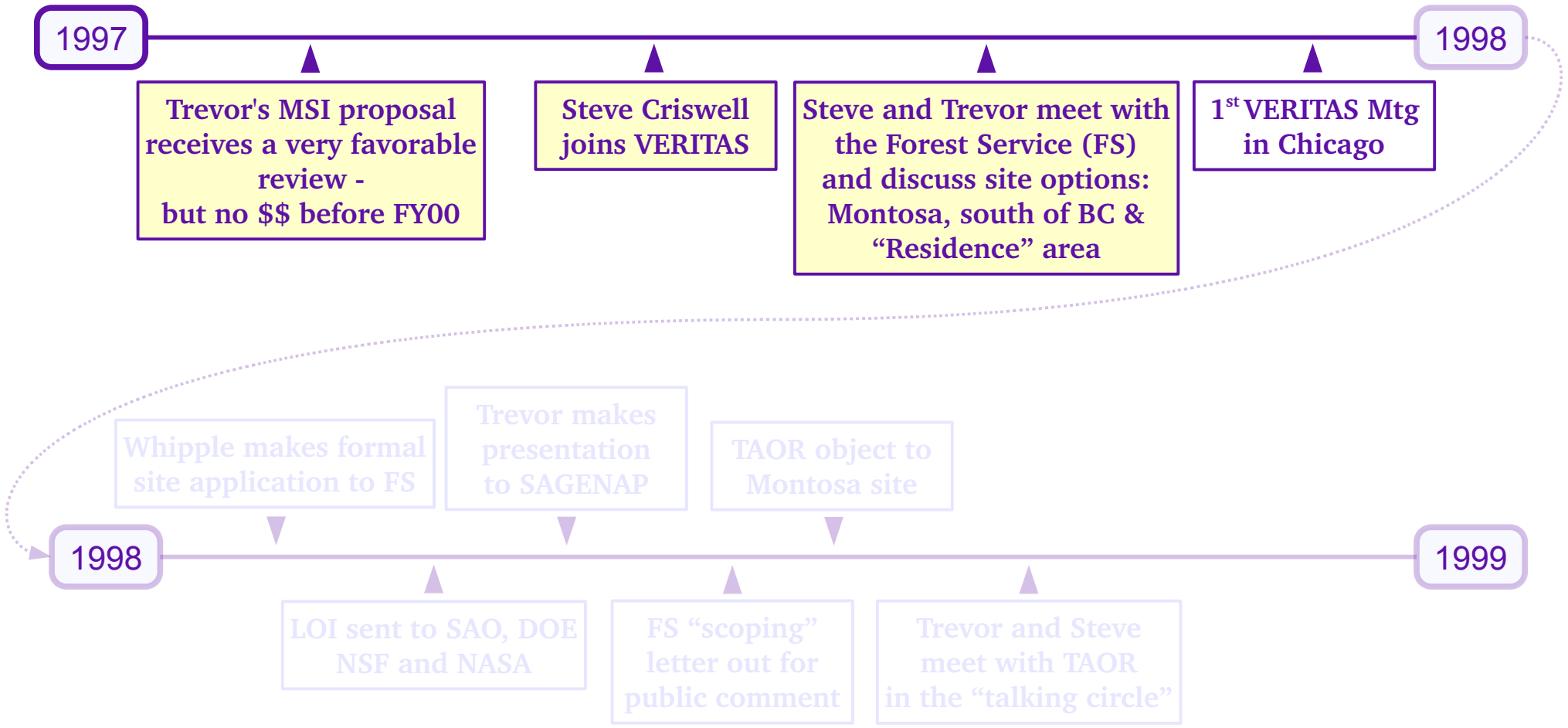
In the early part of the `90s Whipple had consolidated its position as a leader in the field: refining the analysis, improving the hardware, identifying new sources and attracting an outstanding group of graduate students and postdocs.

However, the field (including the competition) was evolving and it became time to move on!



A search for both a site and funding

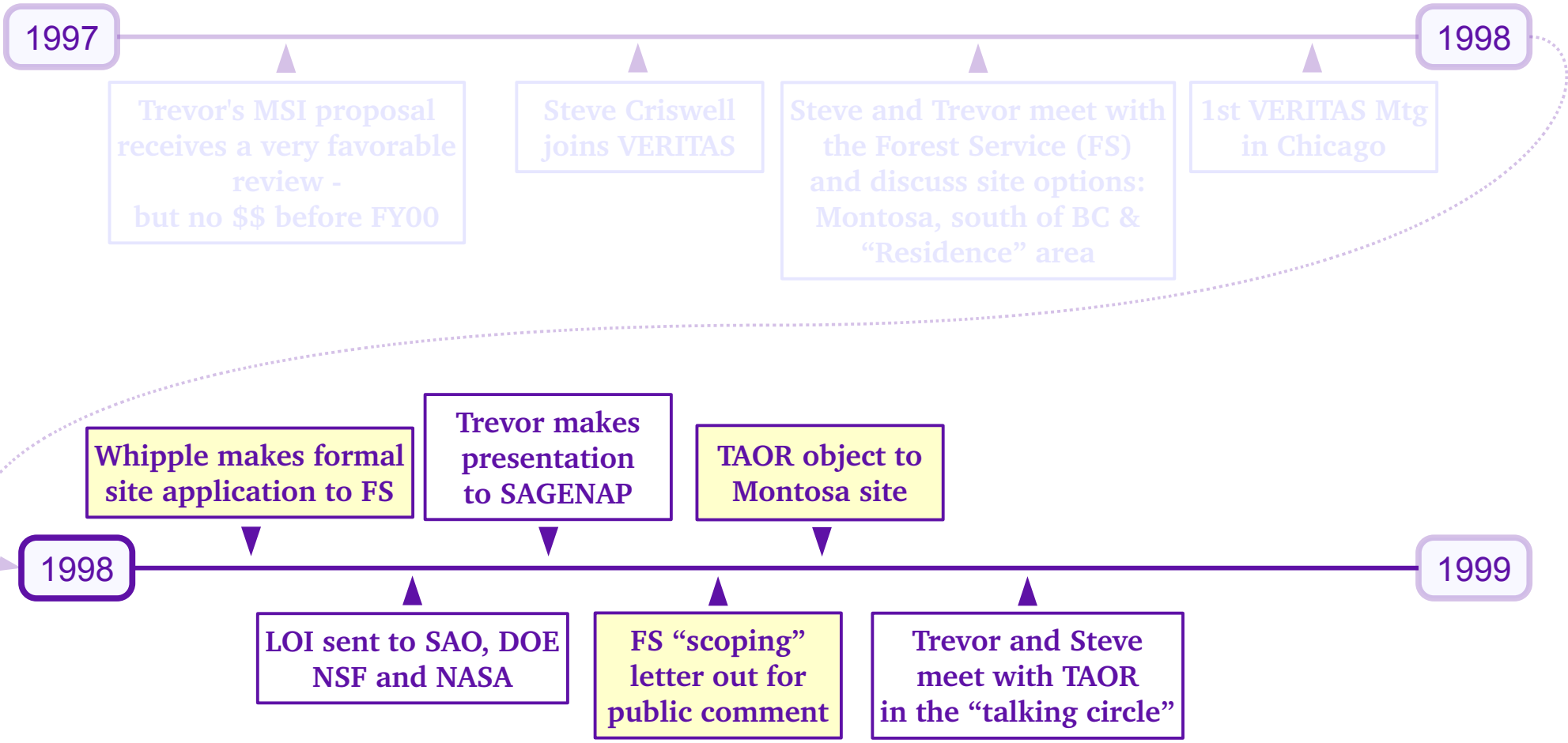
(only the beginning)



FLWO Basecamp

Reviews and Montosa Cyn

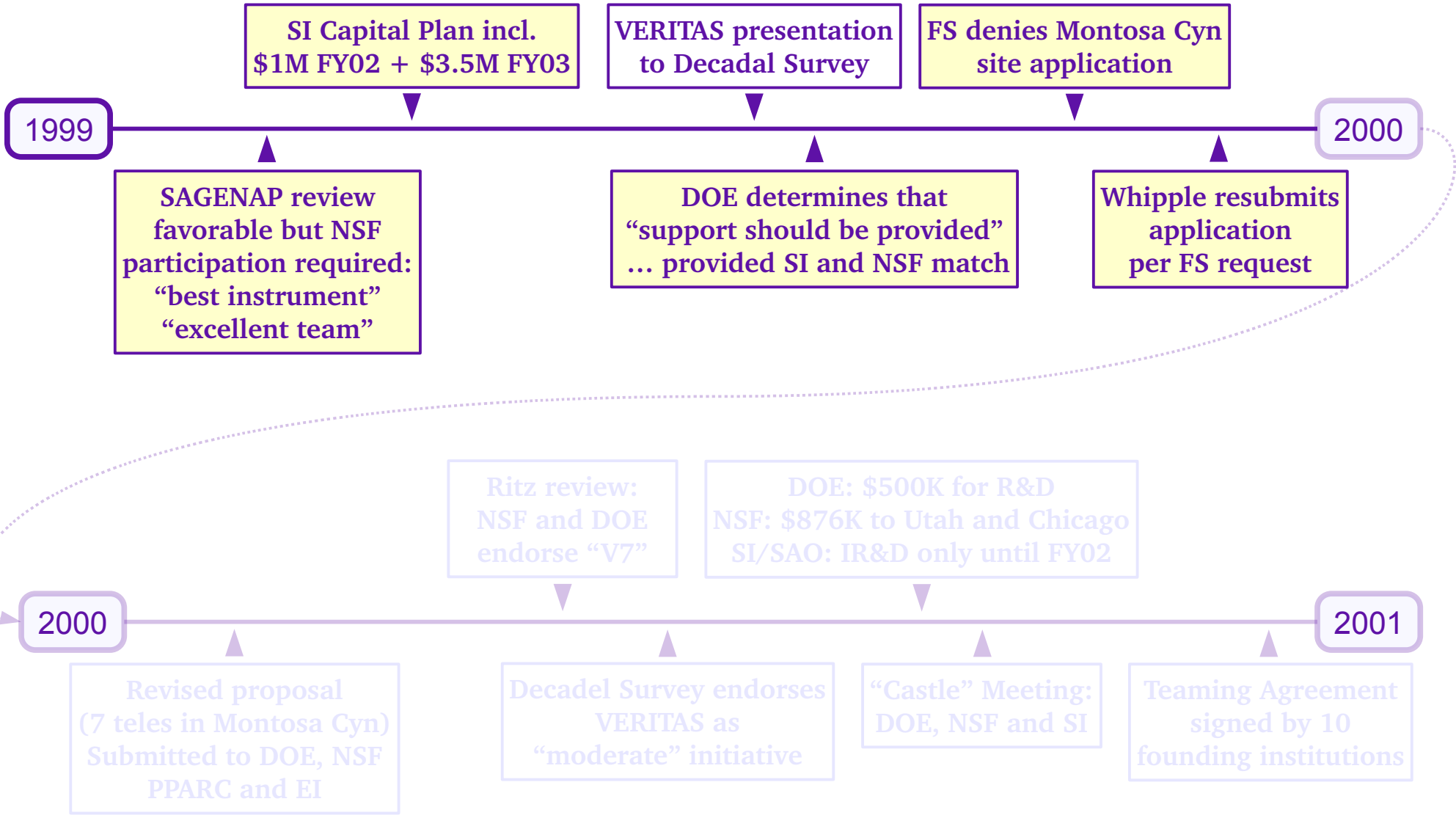
(the first of many, reviews and canyons)



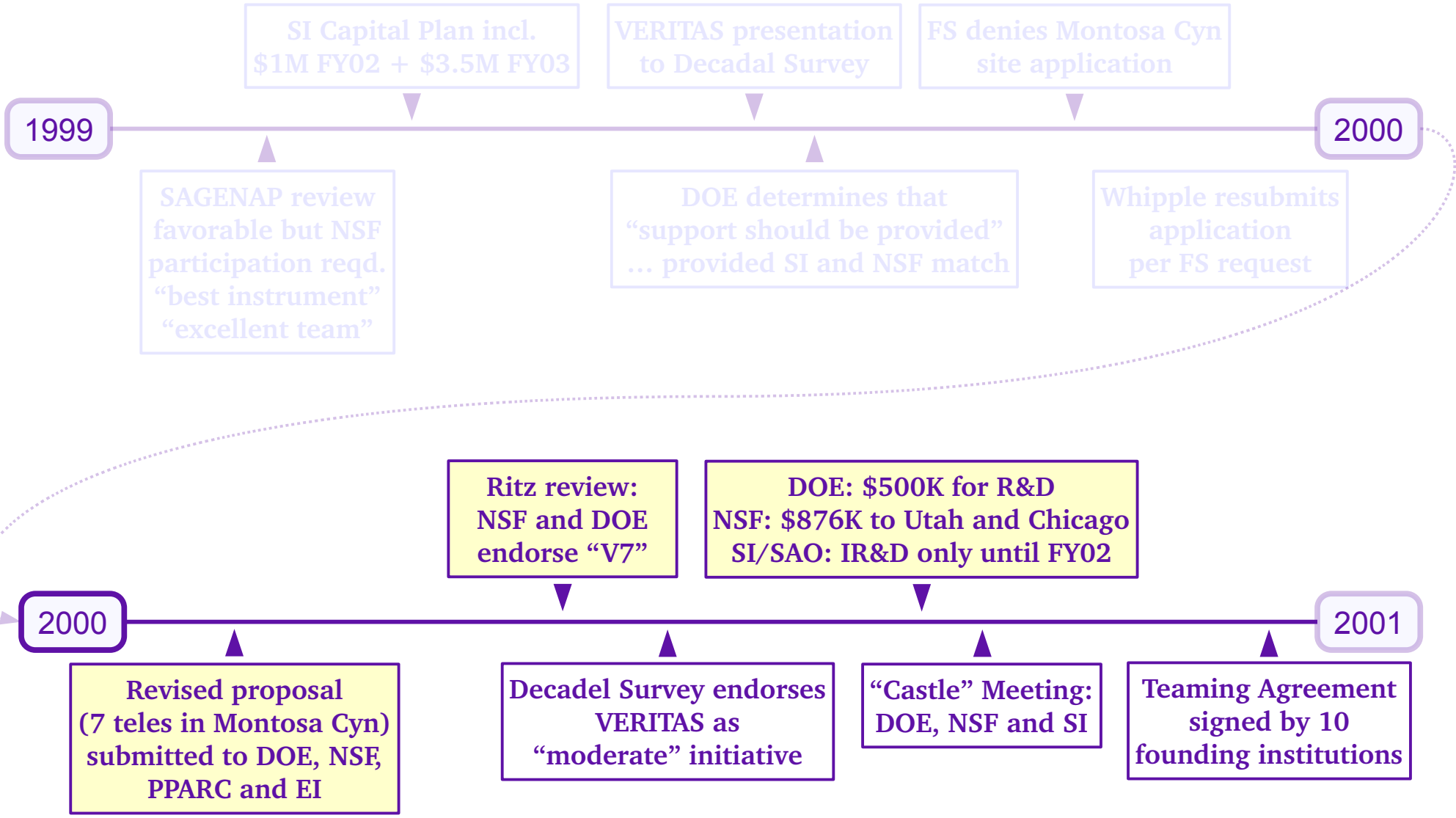
TAOR: To All Our Relations - a community program providing sweatlodge and other American Indian ceremonies.

SI Funding on the horizon

(albeit, the distant horizon)

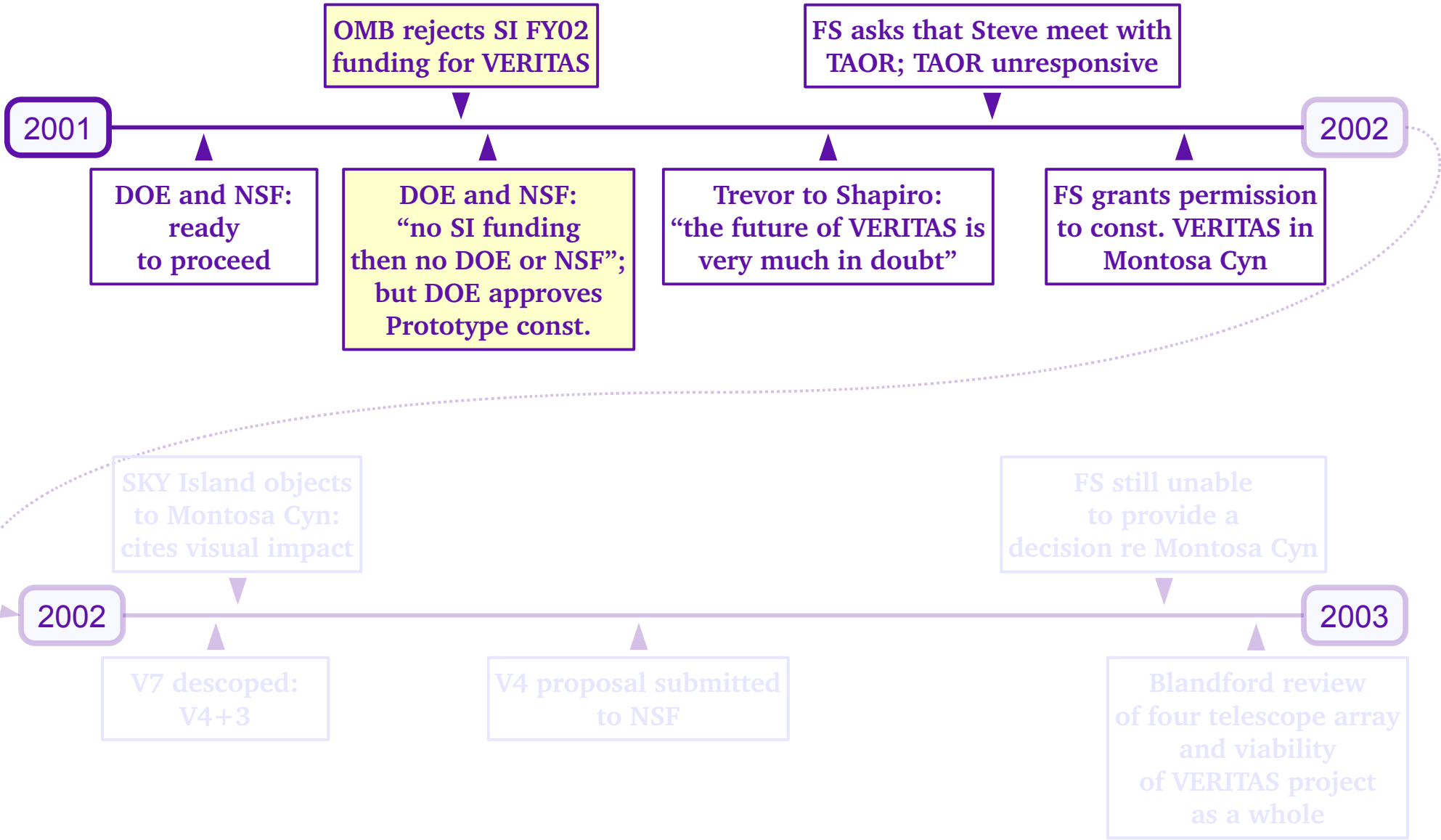


Yet more reviews and some funding



No SI funding but site progress

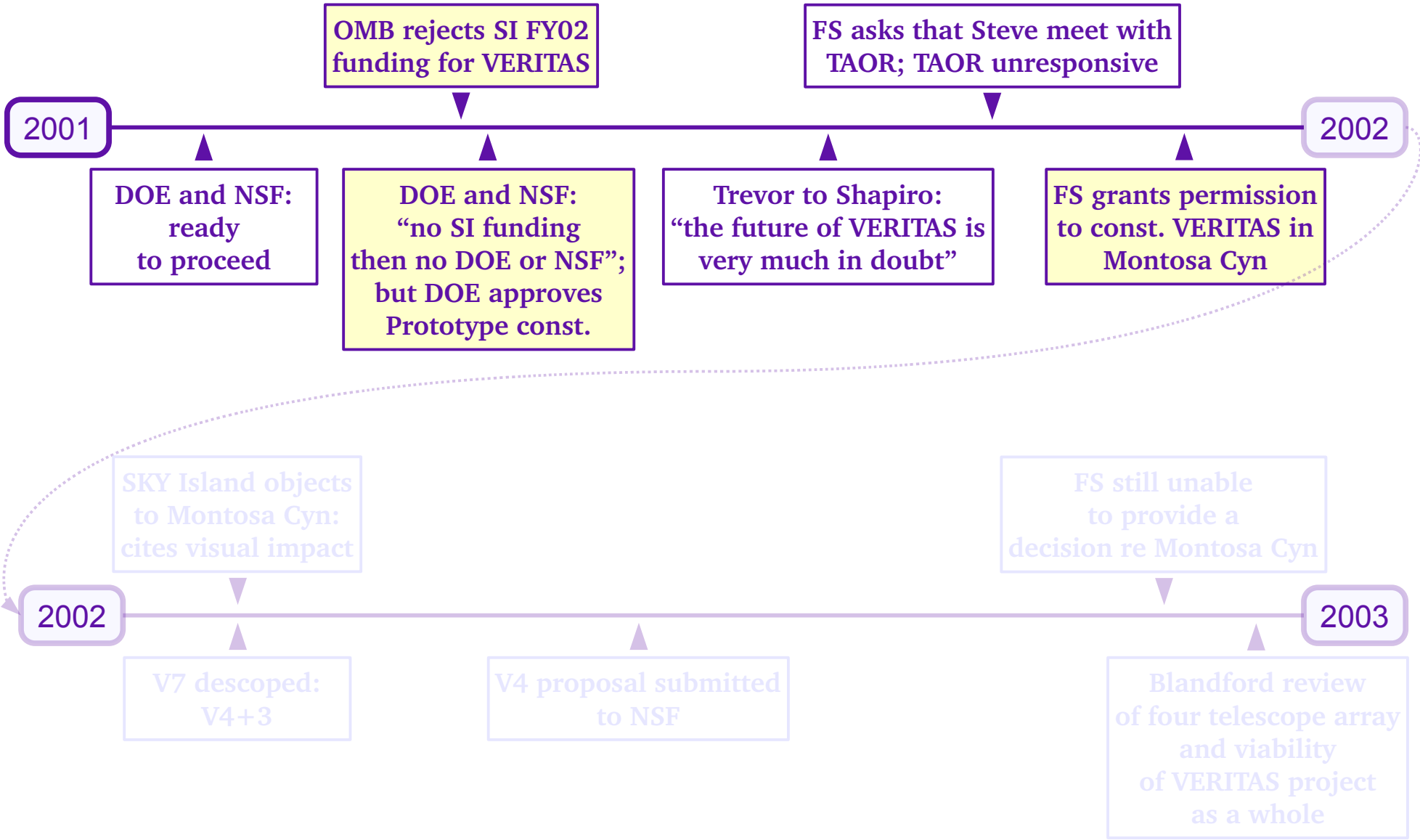
(a very shaky "three legged [funding] stool")



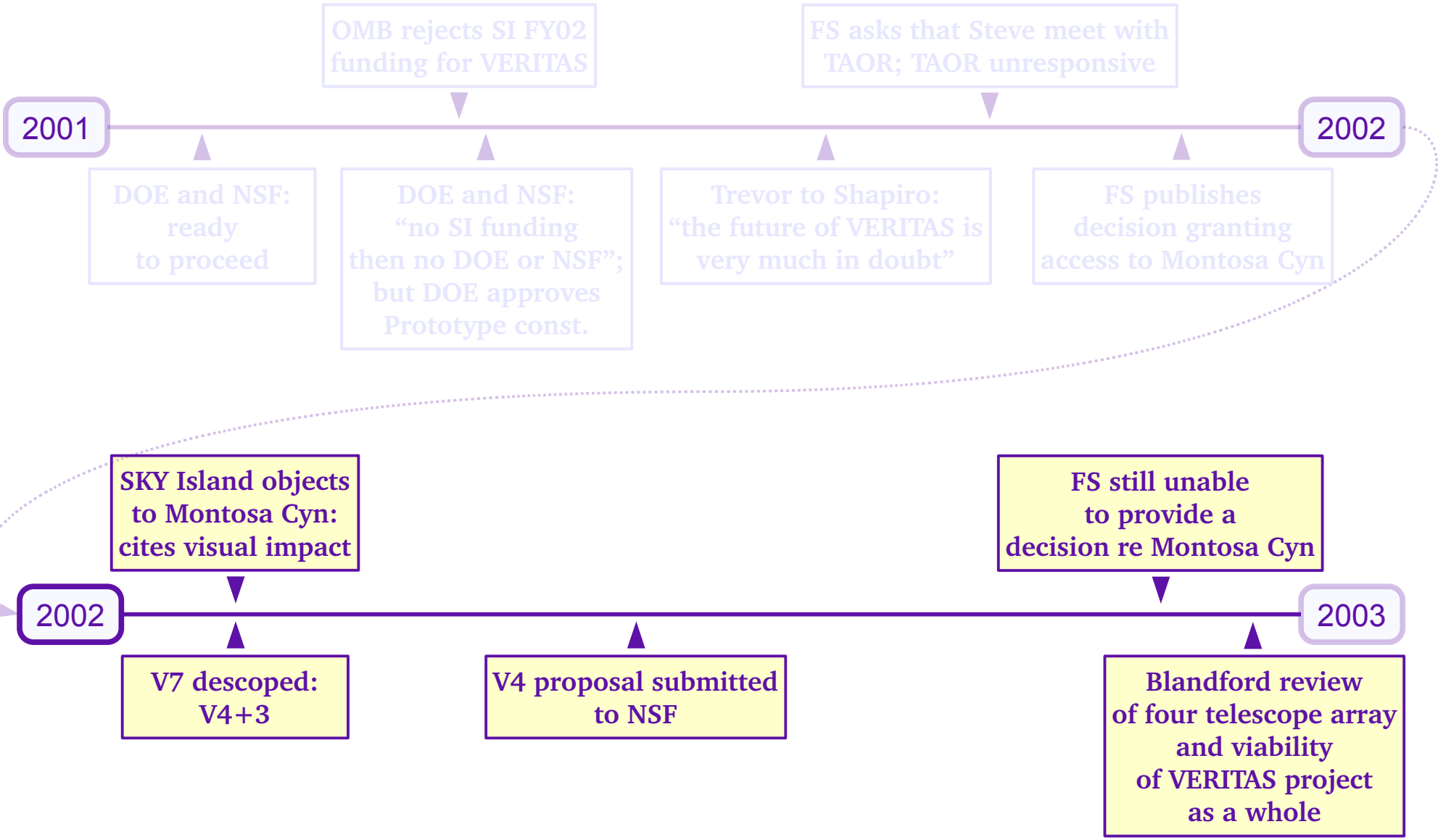
A meeting of the Project Office

No SI funding but site progress

(a very shaky "three legged [funding] stool")

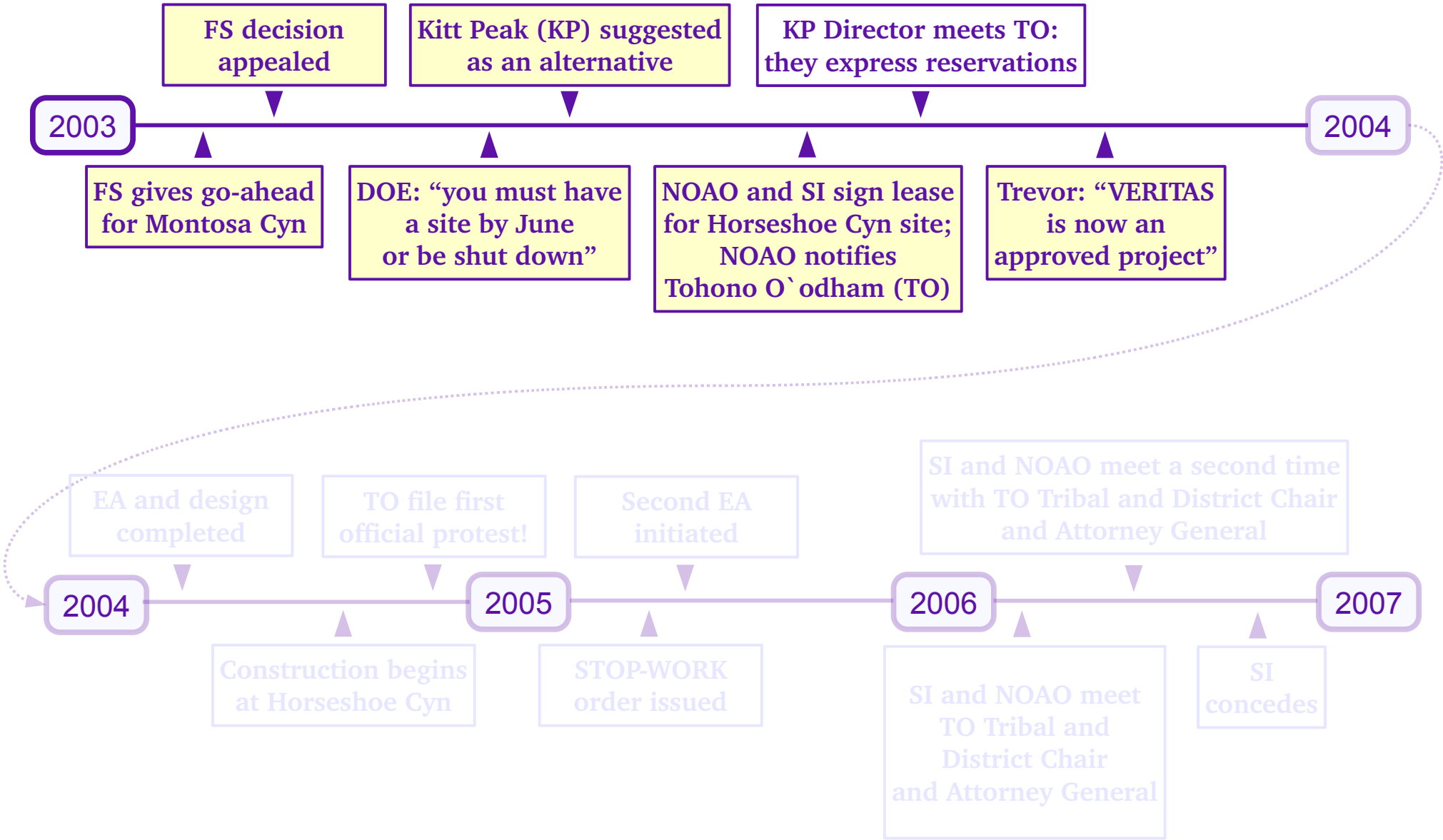


… or no site progress?



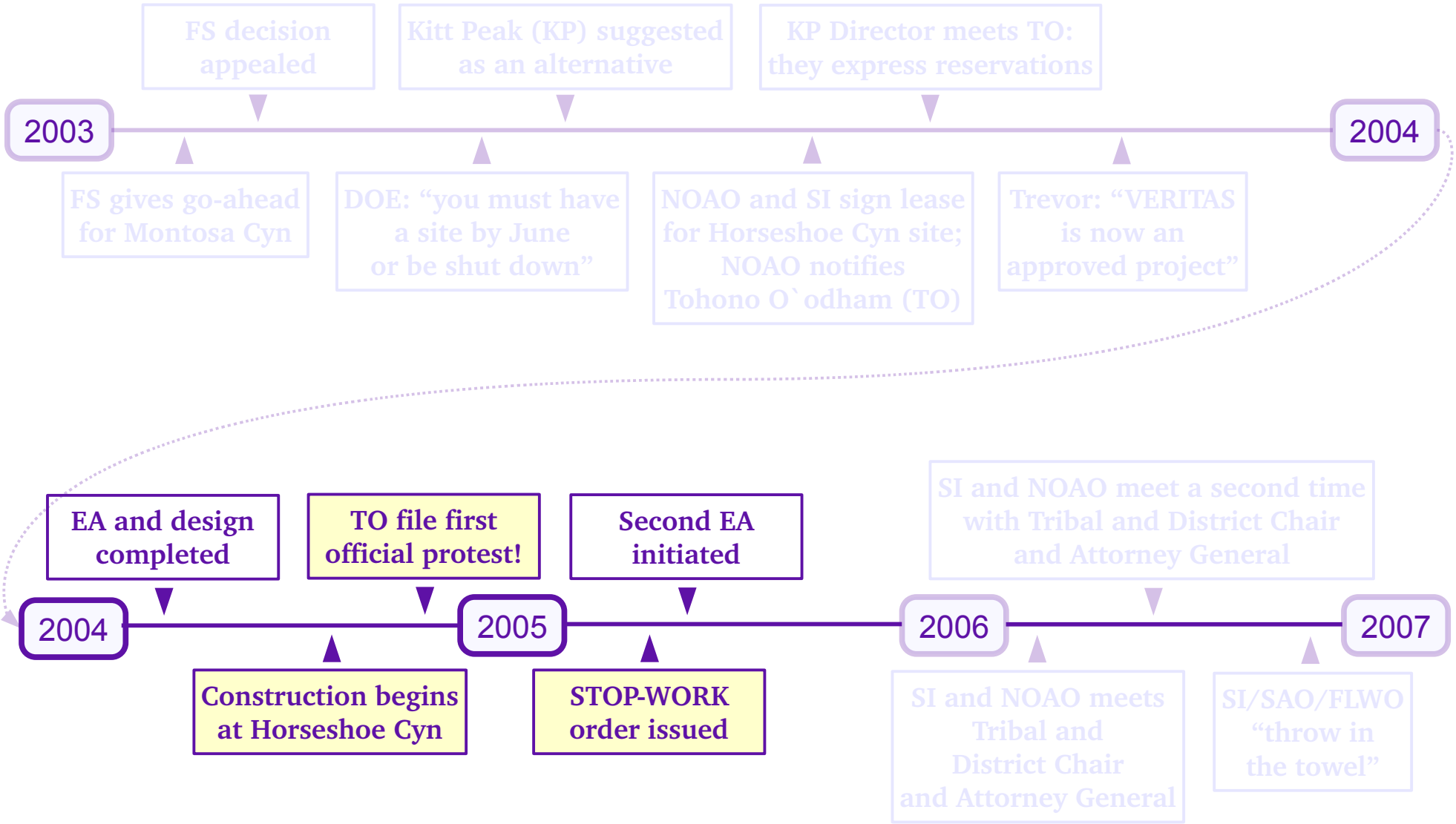
Kitt Peak (NOAO) throws a lifering

(the natives are friendly, and anyway there is the lease)



HORSESHOE CYN

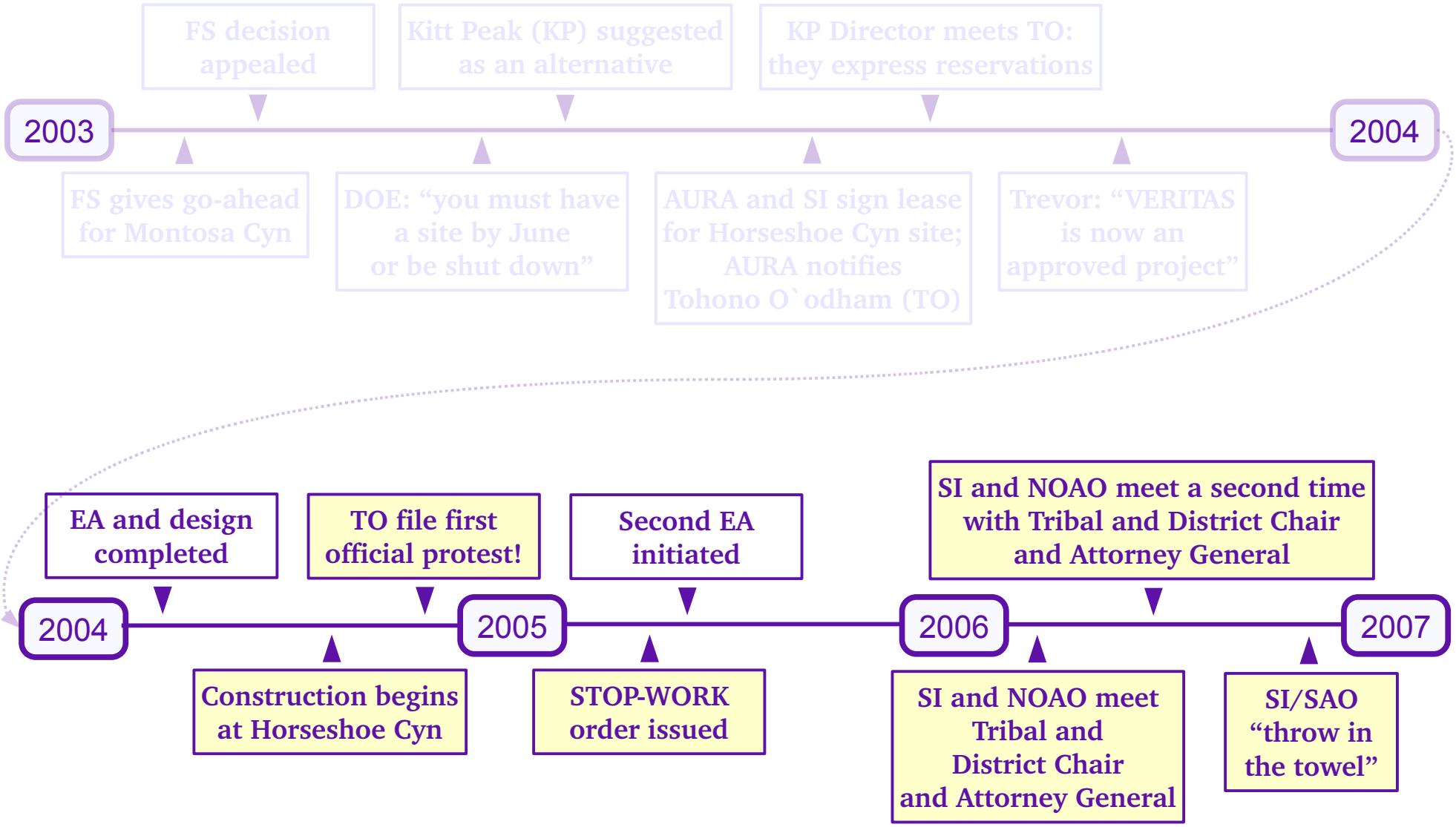
… which falls short



Horseshoe Cyn construction

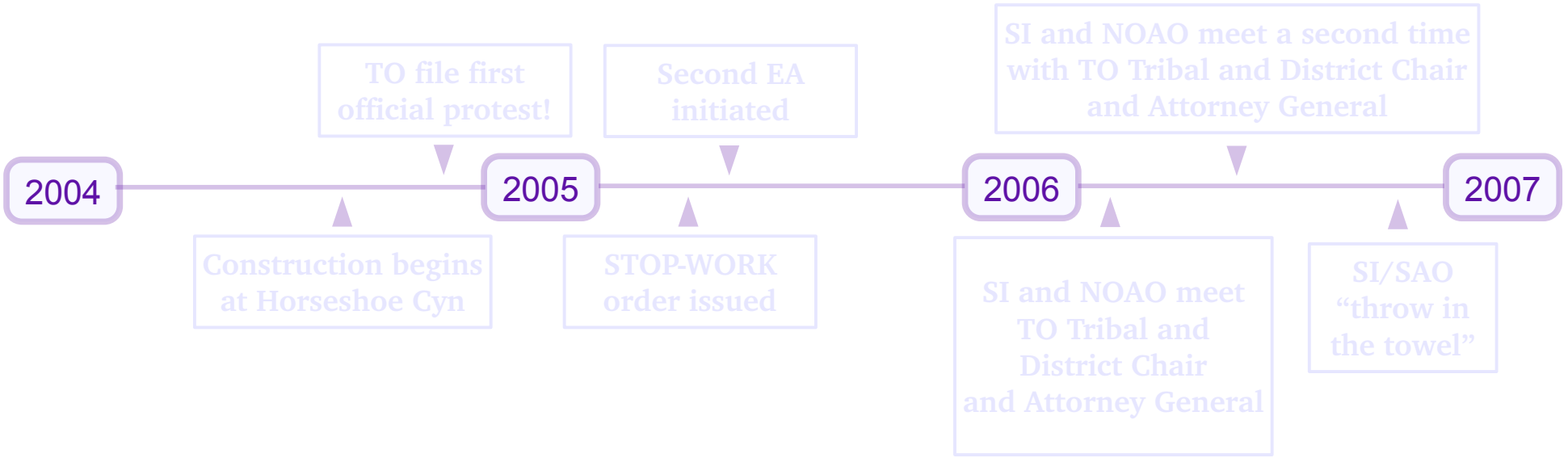
… which falls short

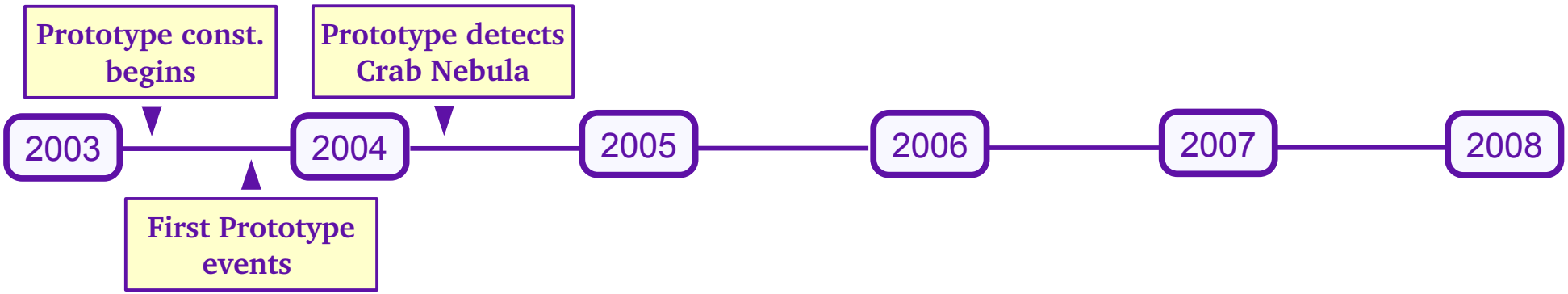
(NSF was “dissappointed)



Events on the ground ...

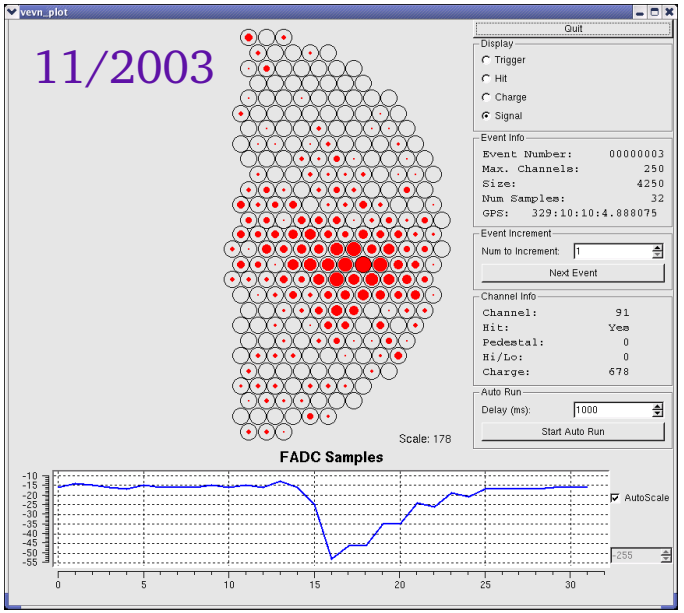
(meanwhile, back at the Basecamp ...)

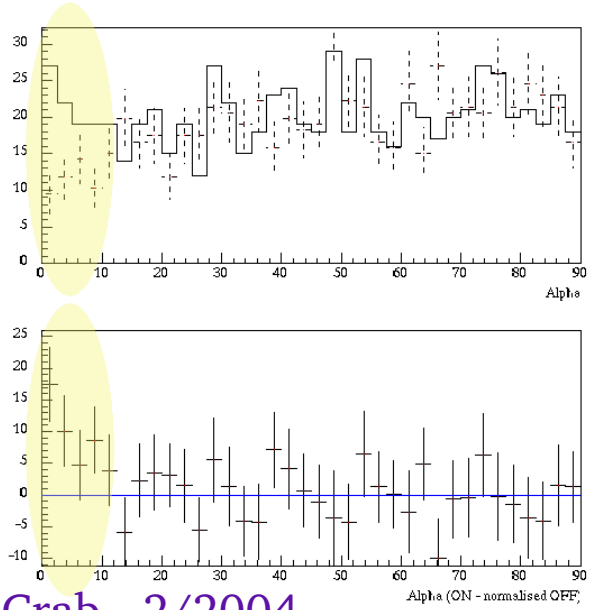




Prototype completed

(half the mirror facets, half the camera)

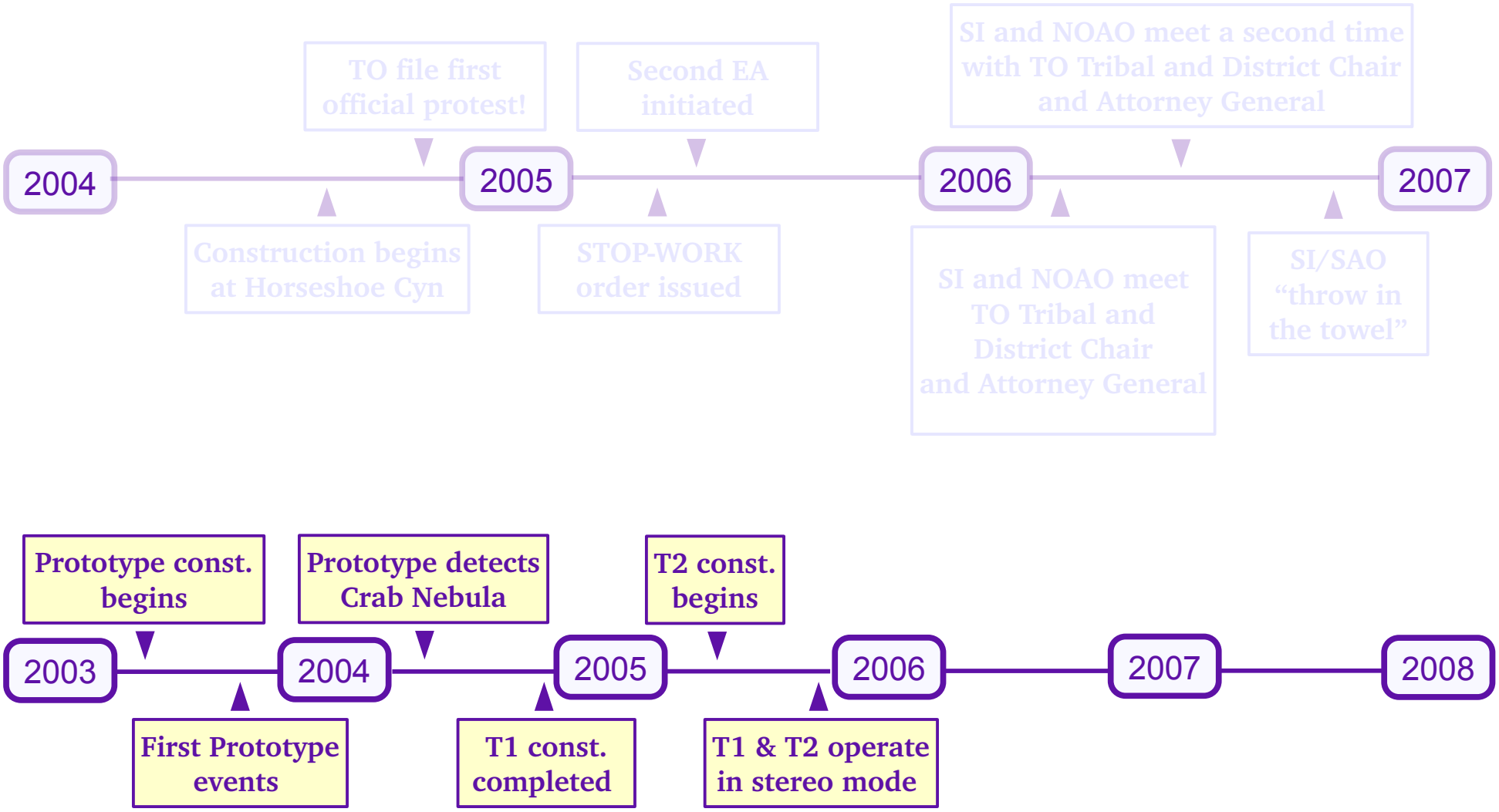




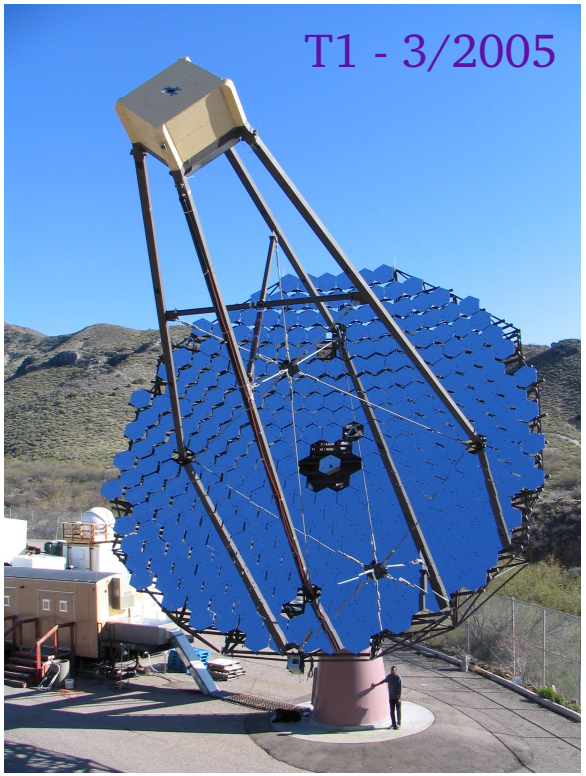
Crab - 2/2004

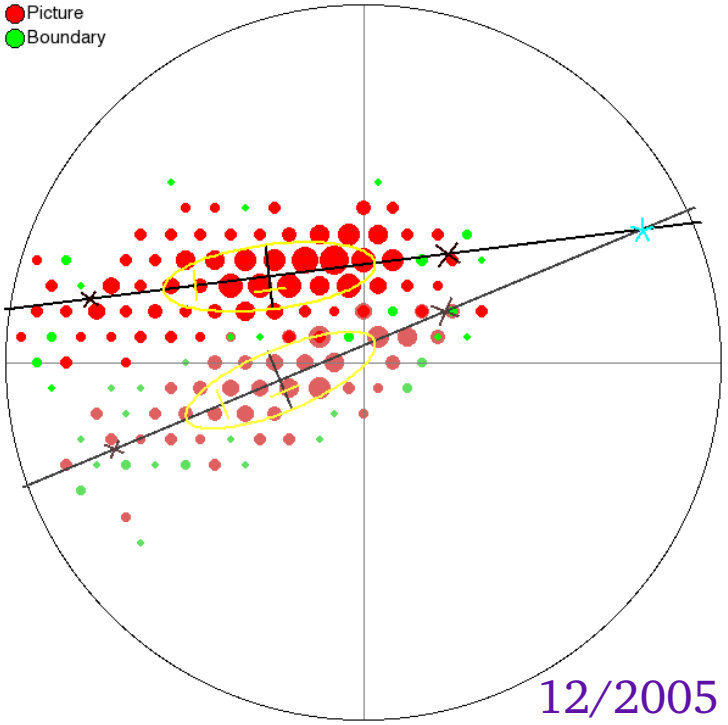
Two teles to test the array ...

(two to tango)

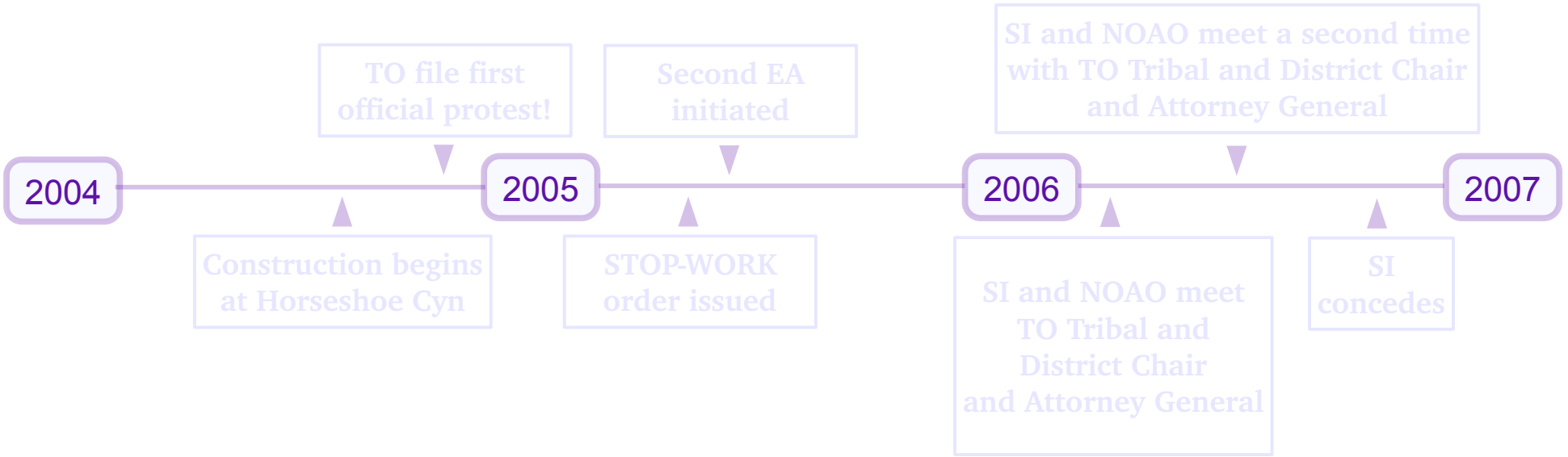


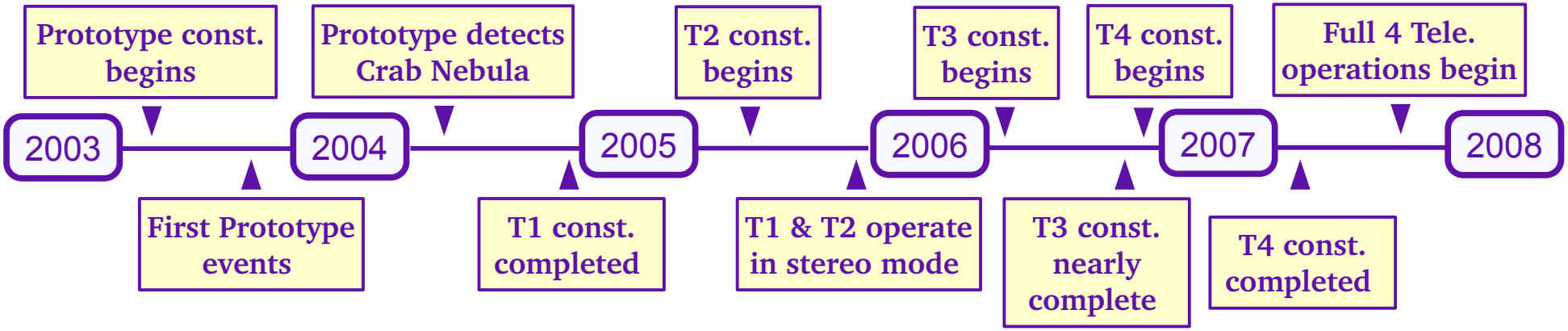
T2 joins T1 at the Basecamp





And then there were 4 ...





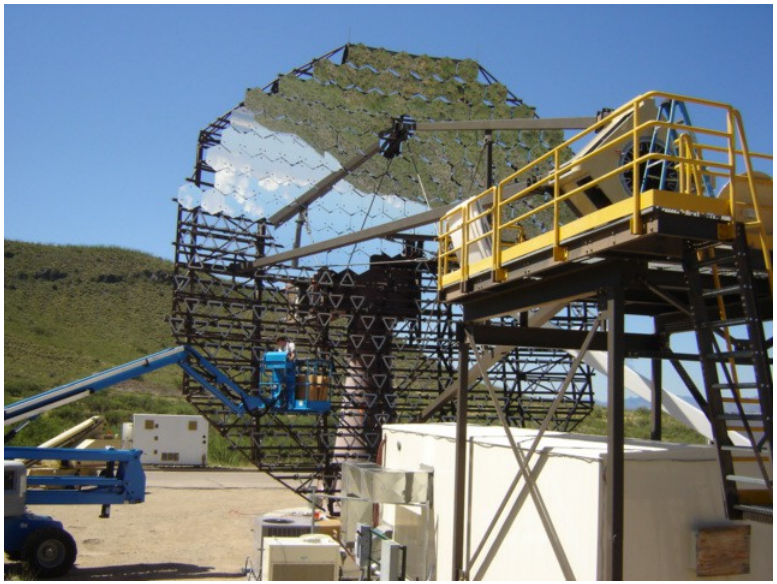
T3 and T4 come together quickly

(we were really getting rather good at this)

VERITAS at FLWO – June 2006

Summer 2009 – T1 relocated

(soup to nuts in under 4 months)



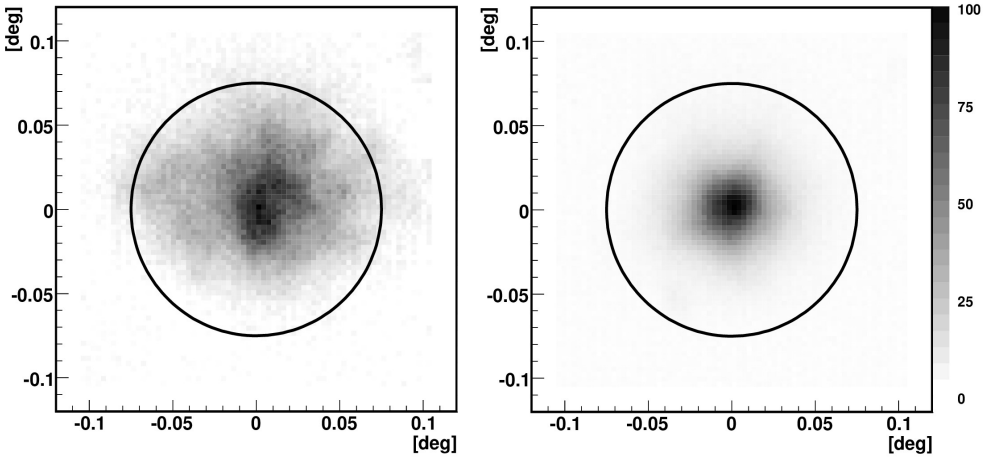
Summer 2009 – T1 relocated

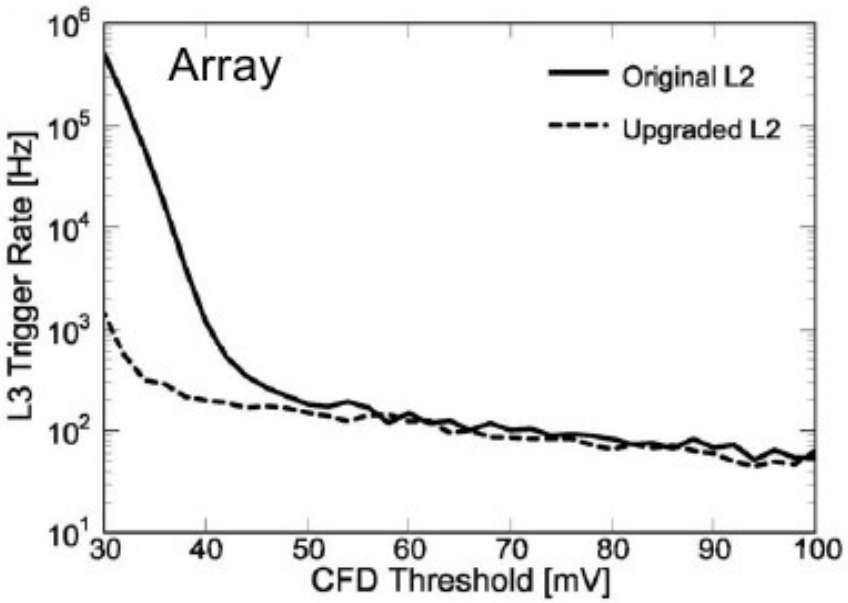
The result, a significant increase in sensitivity:

- At low energies a source with a flux of 1% of the “Crab” could be detected in ~1/2 the time (30 vs 50 hours)
- The Crab Nebula itself was detectable in less than 80 seconds!

Further refinements

Vastly improved mirror alignment technique produced much better light concentration

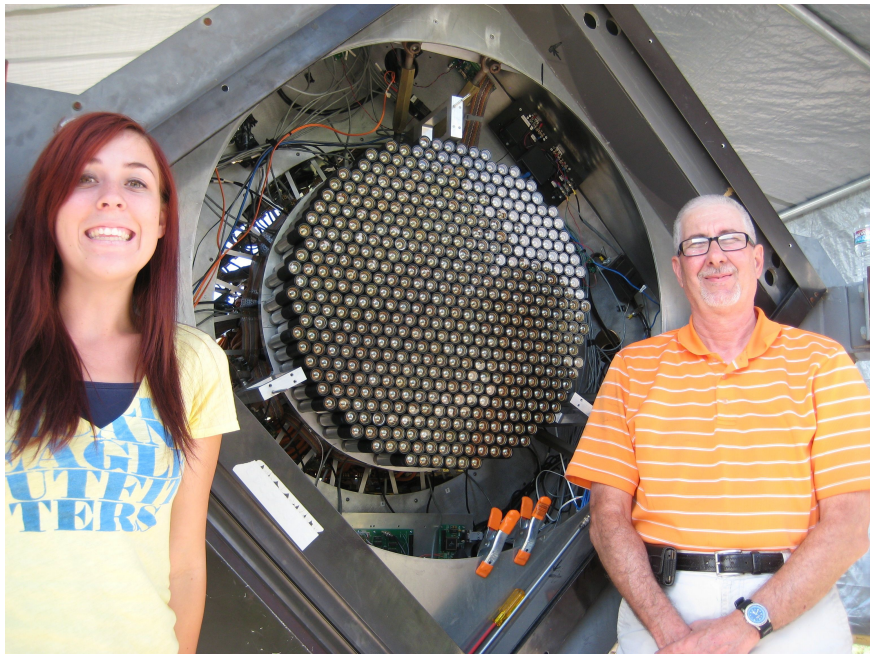




Replaced the original `90's era telescope trigger with a system which provided tighter timing (trigger) constraints, more flexibility and increased reliability

Developed the capacity to observe under the full Moon using UV filters & reduced HV adding >15% more hours

Upgraded PMTs in Summer 2012



Replace all 2000 of the the original “lowest-bidder” photo-multipliers with new high-efficiency (~2x) photo-tubes.

The ultimate result of the trigger and photo-tube upgrades is still TBD but at first glance:

- A 30% decrease in energy threshold to ~70 GeV
- Further increase in sensitivity so that a given source can be detected in ~1/2 the time

The payoff is data

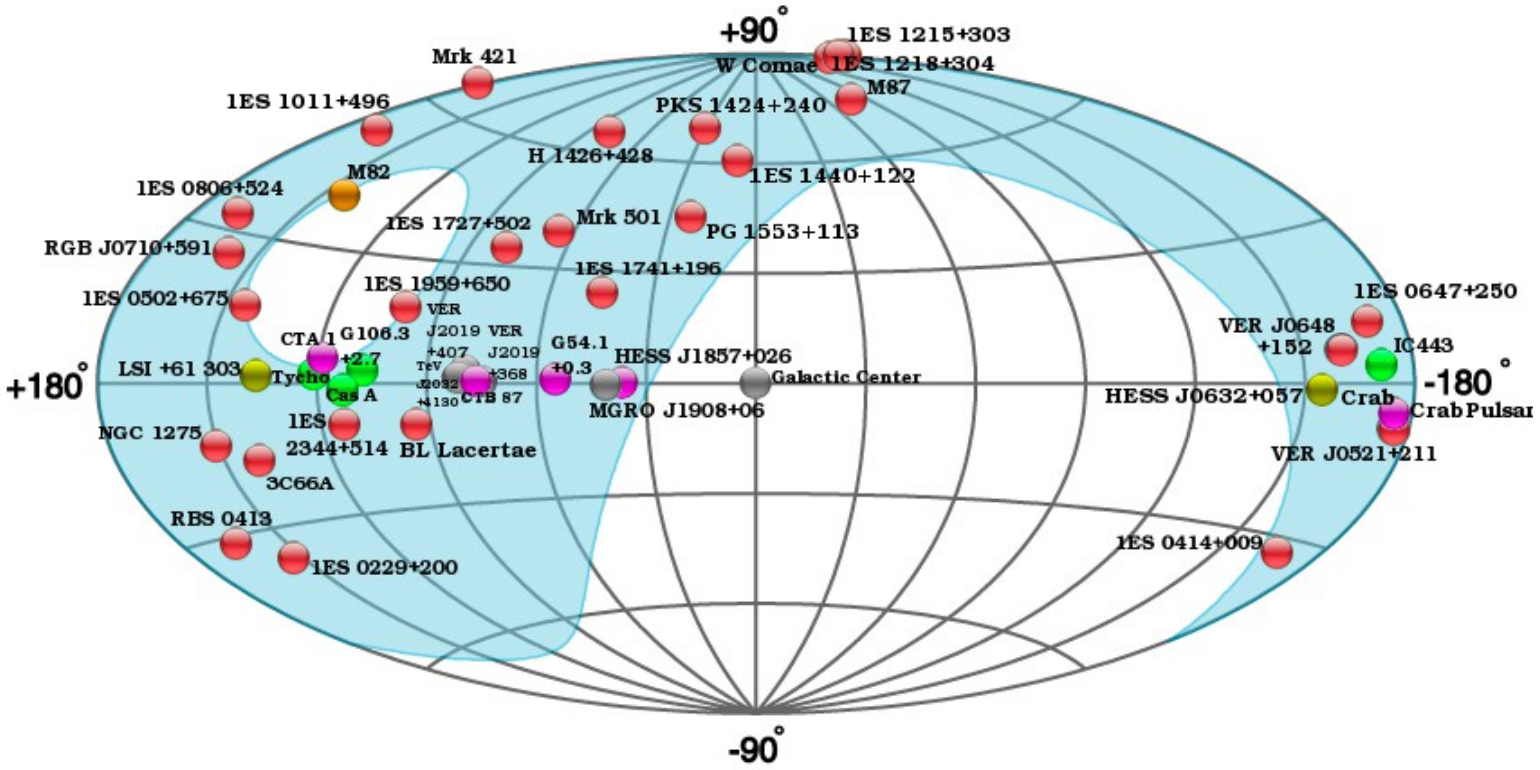
VERITAS has been full-scale operation since 2007 (with T1 down for only 2 months during its relocation and with no down time for the PMT upgrade).

Typically VERITAS observes ~1100 hours/year and more than 1300 hours when the UV-filter/low-HV data are included. This represents about 60% of all available hours (losses due to weather, calibration, engineering).

VERITAS probably enjoys unmatched reliability: 92% of the data are with all four telescopes and 99% of the cameras.

The payoff is a torrent of high quality data. Even so, too much to do (too many sources of interest), and to little time (available observing time is heavily over subscribed).

The success of VERITAS



VERITAS† has detected 45 sources from 8 astrophysical classes: 25 blazars, 5 pulsar wind nebulae, 4 supernova remnants, 2 radio galaxies, a starburst galaxy, the Crab pulsar, 2 x-ray binaries and 5 unidentified objects.

† As of summer 2013

Everyone's favorite result (a poll)

1es1218+30 / W Comae / 1es1215+30: a taste of CTA's future

Cisne: a challenging region of multiple point and extended sources

Crab pulsar: “the holy grail of TeV astronomy”

HESS J0632+057 and LSI +61 303: x-ray binaries

M82: a cosmic ray accelerator outside our galaxy

M87: a resolvable AGN

Mrk 421: an old favorite, flaring, again

PKS 1424+240: the first Fermi-LAT motivated VHE discovery

TeV J2032+43: a Fermi-LAT pulsar with no unpulsed emission

Segue I: Dark Matter limits from a target outside of our Galaxy

Tycho SNR: a cosmic ray accelerator inside our Galaxy

My selections ...

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M82 – a Starburst Galaxy

Tidal encounter with M81 created a compact region of dense gas and dust where the rate of star formation is ~10x normal.

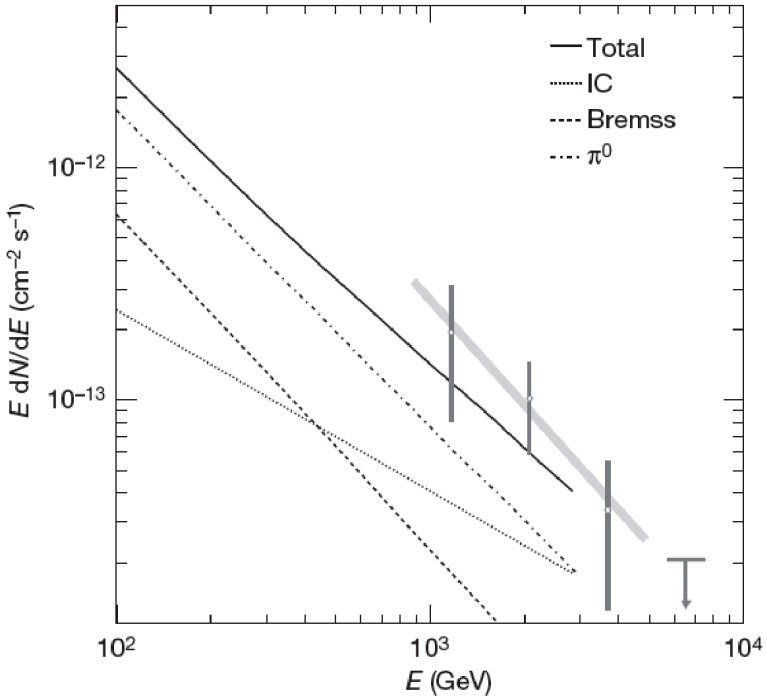
Massive stars and associated winds, and supernovae are abundant there, as are the shocks they produce.

M82 – a Starburst Galaxy

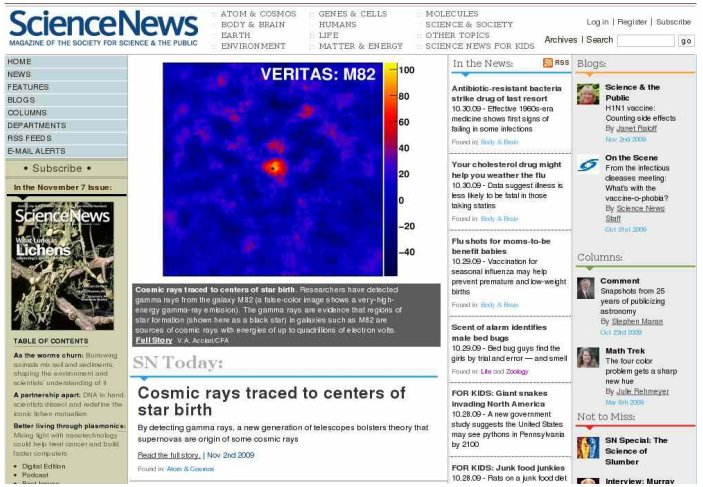
Fermi predicted that such shocks within our galaxy are likely the origin of most of the cosmic rays we observe — and Fermi-LAT and recent VHE observations support this connection. But each local source is likely to exhibit its own peculiarities. M82 is an object where the Fermi process operates (or should operate) in spades and the complications associated with modeling individual sources ironed out in the mean.

As a result theorist predicted that M82 would be an ideal candidate for making the “Fermi” connection and that it should be a source of VHE gamma rays, though very near the threshold of detectability by present day observers.

… and indeed it was!



In 2009 VERITAS confirmed the expected … and the press went wild!



Beyond confirming Fermi's insight, this result served to demonstrate the remarkably sensitive and robust nature of the technique.

The data consisted of >95 million (mostly background) events collected over ~130 hours. Standard analysis rejected 99.999% of the background.

The result was a flux 0.9% that of the Crab: less than 1 event/hour!

M87 – A nearby AGN

Active galaxies (AGN) — of the blazar variety — are far and away the most common VHE gamma-ray sources. Blazars are "simply" active galaxies in which the relativistic jet generated by the central super-massive black hole is pointed or beamed in our direction.

Beaming causes blazars to appear especially bright and their flux levels and spectra can be measured across a wide range of energies.

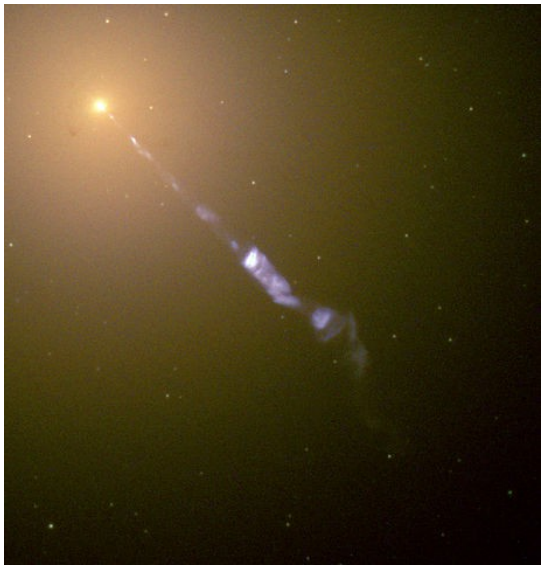
Such multi-wavelength observations are key to understanding AGN and VHE observations may provide the strongest constraints on the nature of the source regions.

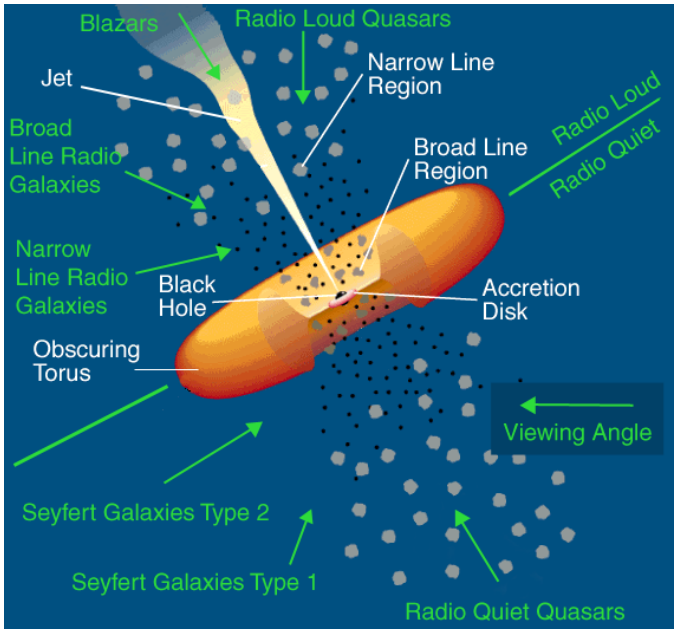
Modeling the spectrum of blazars is an industrial occupation among some theorists, and a successful one.

But, because blazars are viewed "end on" candidate source regions are stacked along the line of sight. Some perspective is needed.

M87 – A nearby AGN

(a blazar than can't shoot straight)



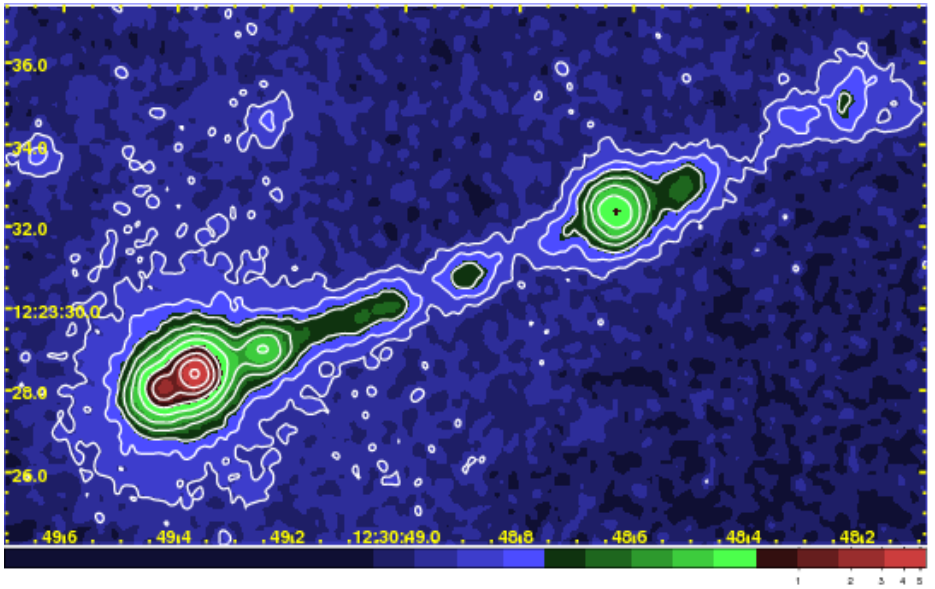


M87's provides that perspective: its jet is seen in profile and the jet and the area near the core are resolvable at radio, optical and x-ray wavelengths.

It is sensible to assume that contemporaneous transients observed at different wavelengths are produced in the same region — this is the handle for locating the VHE emission.

In 2005 HESS observed a brief flare which seemed to coincide with a (years long) flare seen by Chandra in x-rays in a “knot” in the jet called HST-1.

… in 2008 more flare episodes …



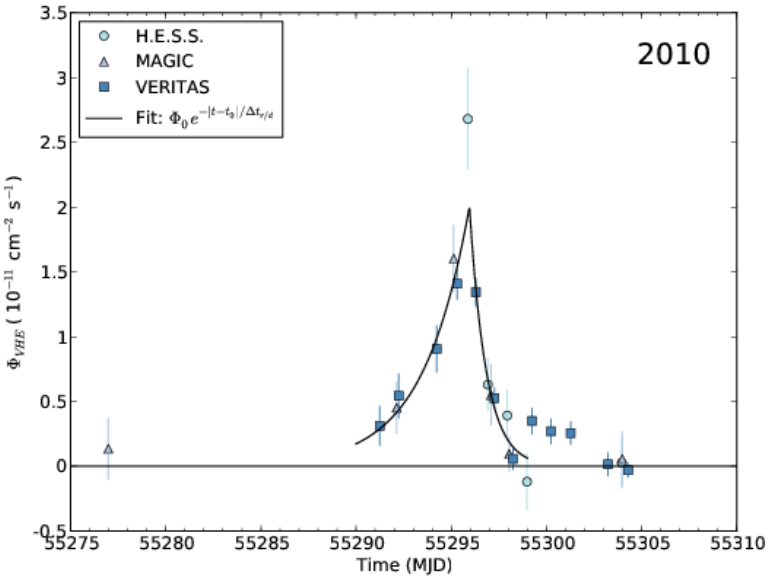
In 2008 HESS, MAGIC and VERITAS jointly observed M87 for a total of 120 hours.

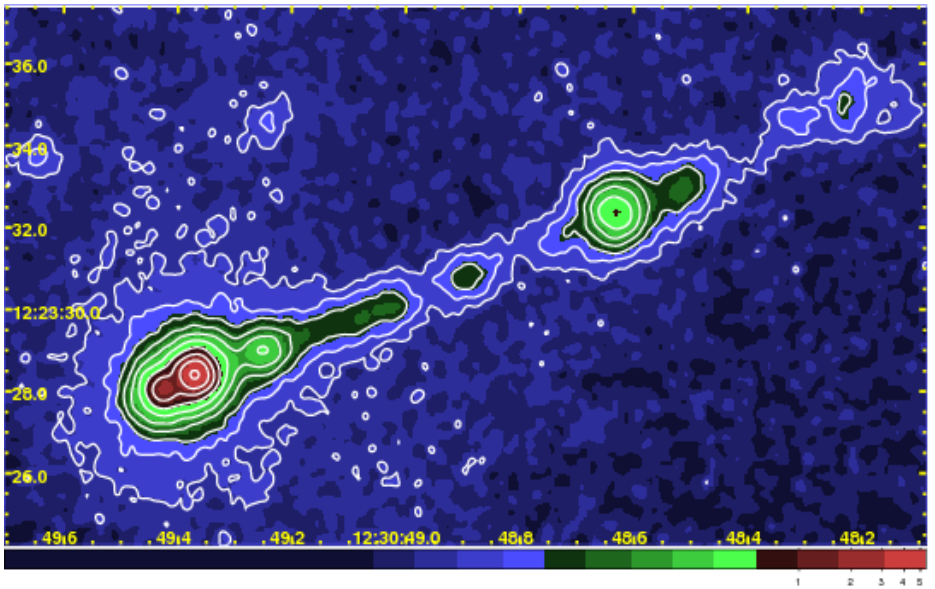
During this period VLBA and Chandra also monitored the source.

A flare was detected by MAGIC in February, followed by a stronger flare in April seen by all three VHE observatories. This time:

- Unlike the 2005 flare, HST-1's x-ray emission was in a relatively low state
- But the core of M87 reached the highest flux level ever measured by Chandra two days prior to the April flare
- Radio emission in the core also rose and reached the highest level ever observed in M87 by the VLBA

… and a third episode!





In April 2010 VERITAS, MAGIC and HESS again detected a very rapid flare in M87. This time:

- The x-ray emission from the core doubled after the VHE flare
- No increase in the core's radio emission was detected

All the VHE flares exhibit similar flux levels, spectra and timescales: but no unique signature at other wavelengths.

Confusing? Yes! But it may be the best opportunity to understand blazars!

The Crab Nebula and Pulsar

Formed by a supernova of 1054 it was observed by the Earl of Rosse in 1844 who referred to it as the "Crab Nebula" (he later decided that it did not look anything like a crab).

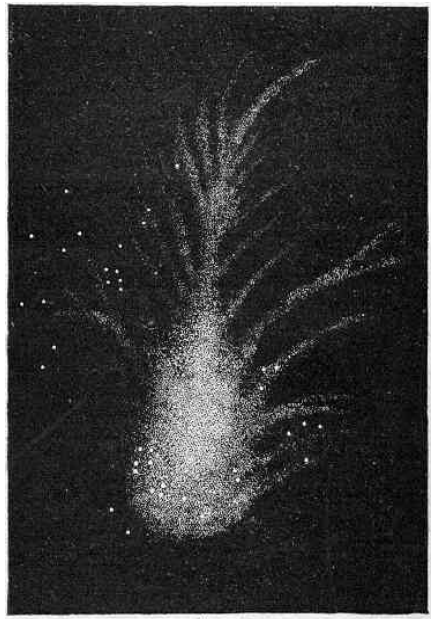


Fig. 438.

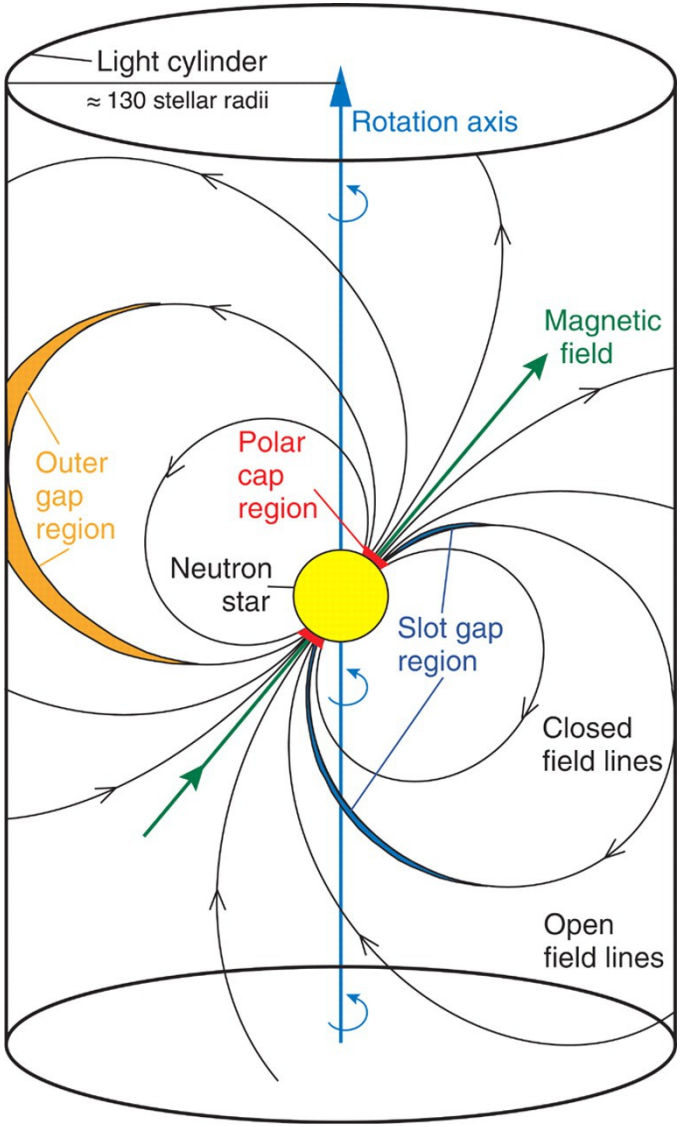
A typical pulsar wind nebula in which the central pulsar powers a relativistic wind which excites a shock which in turn produces non-thermal emission.

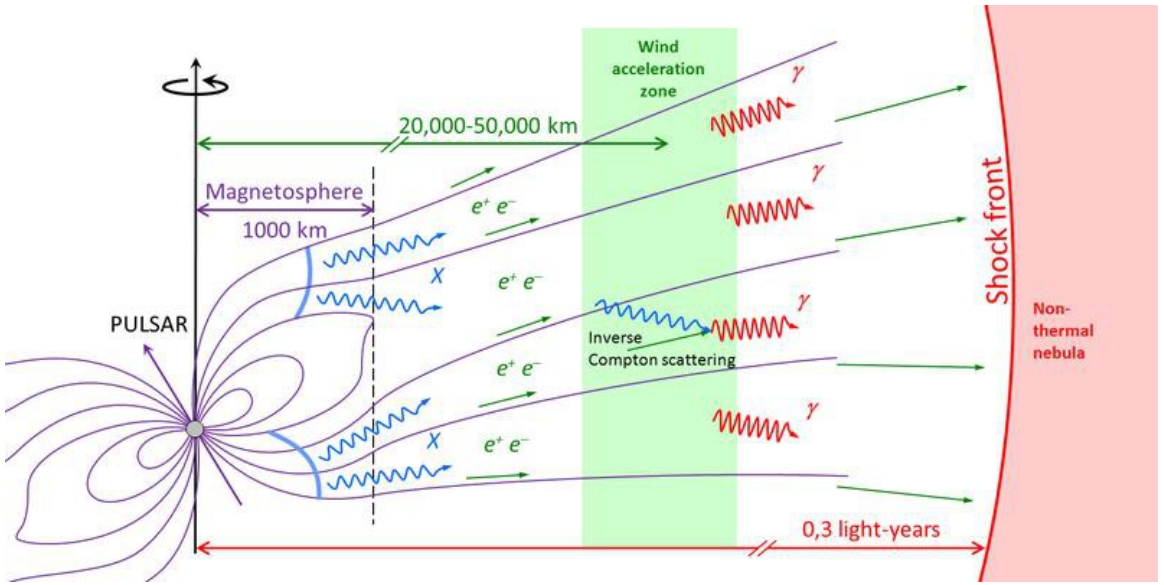
Neither the Crab pulsar or the nebula are particularly unique, other than being younger and brighter than most.

Conventional wisdom is that pulsed radio to GeV emission can be produced within the co-rotating magnetosphere (though where is still unanswered).

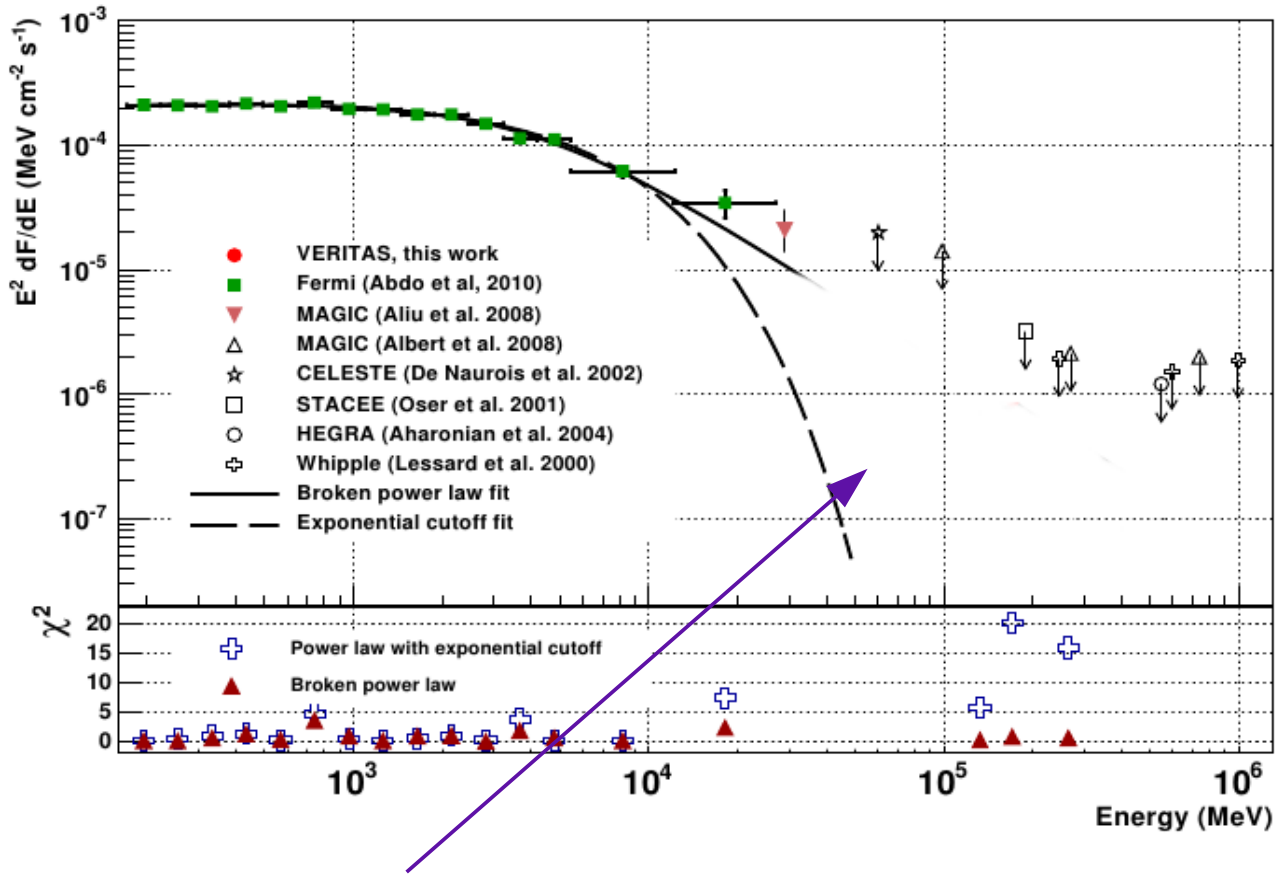
At higher energies, whatever the process is, it breaks down, and only non-pulsed VHE emission from the nebula should be observed.

The models


Light cylinder
≈ 130 stellar radii
Rotation axis
Magnetic field
Outer gap region
Polar cap region
Neutron star
Slot gap region
Closed field lines
Open field lines

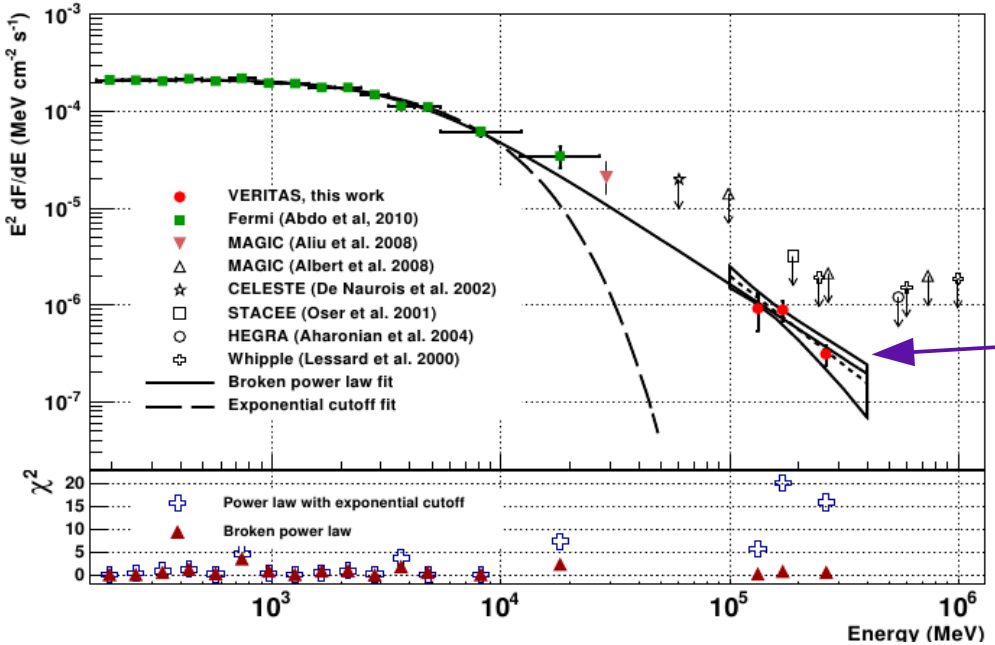

Wind acceleration zone
20,000-50,000 km
Magnetosphere
1000 km
PULSAR
Inverse Compton scattering
Shock front
Non-thermal nebula
0,3 light-years

Conventional wisdom ...

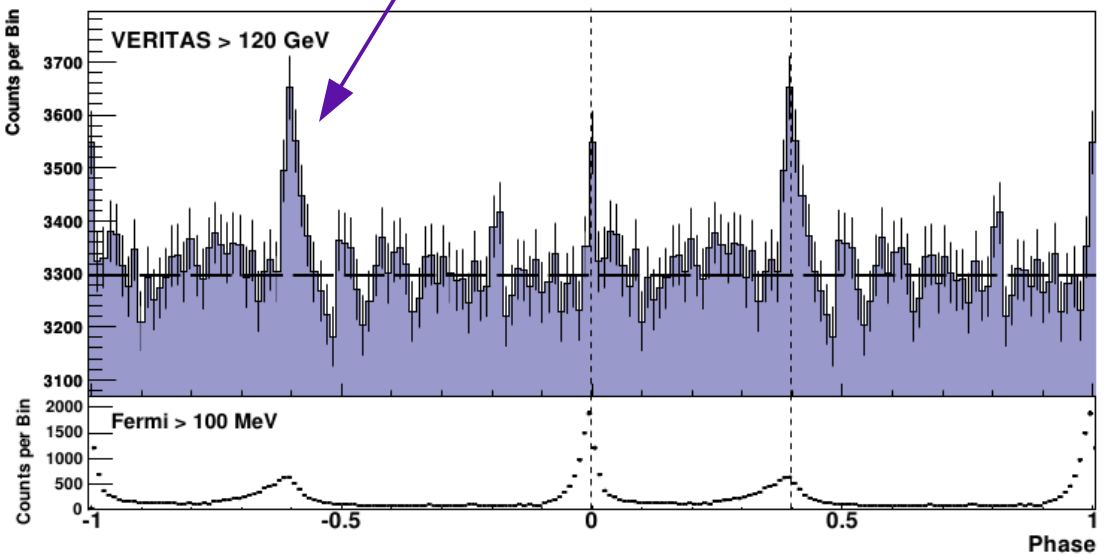


At high energies models (tmk) argue that the pulsed emission should drop off exponentially between a few 10s and 100 GeV

Conventional wisdom … takes a vacation



But clearly the message was not received!



And the press goes wild, again!

The VHE Crab Pulsar … what it means

Trevor was quoted as saying “[the Crab pulsar] is the holy grail of VHE gamma-ray astronomy!”

The VHE Crab Pulsar … what it means

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I think of it as the “holy hand grenade” of VHE gamma-ray astronomy … since it exploded the conventional wisdom.

Everyone's favorite result (a poll)

1es1218+30 / W Comae / 1es1215+30: a taste of CTA's future

Cisne: a challenging region of multiple point and extended sources

Crab pulsar: “the holy grail of TeV astronomy”

HESS J0632+057 and LSI +61 303: x-ray binaries

M82: a cosmic ray accelerator outside our galaxy

M87: a resolvable AGN

Mrk 421: an old favorite, flaring, again

PKS 1424+240: the first Fermi-LAT motivated VHE discovery

TeV J2032+43: a Fermi-LAT pulsar with no unpulsed emission

Segue I: Dark Matter limits from a target outside of our Galaxy

Tycho SNR: a cosmic ray accelerator inside our Galaxy

VERITAS' unsung heros

Steve Criswell — the very definition of unperturbable who just rolled with the punches and whose long (and no doubt painful) experience with SI and the Forest Service was utterly critical

Grace Alegria — for whom the impossible just takes a little bit longer

Danny West and Cesar Lopez — demonstrated again and again that practical experience trumps those silly physicists every time (and many a time saved our bacon)

Emmet Roache, Jack Musser and George Jones — the glue that holds VERITAS the detector together. Without their (often overlooked) efforts the whole enterprise would grind to a halt

Our program managers at the funding agencies — Jim Stone and Kathy Turner, and Vern Pankonin: often a pain, but surprisingly resolute supporters

The face of VERITAS

For me this will always be the face of VERITAS
and of VHE gamma-ray astronomy.