The Road to VERITAS

John P. Finley*

Department of Physics and Astronomy

Purdue University

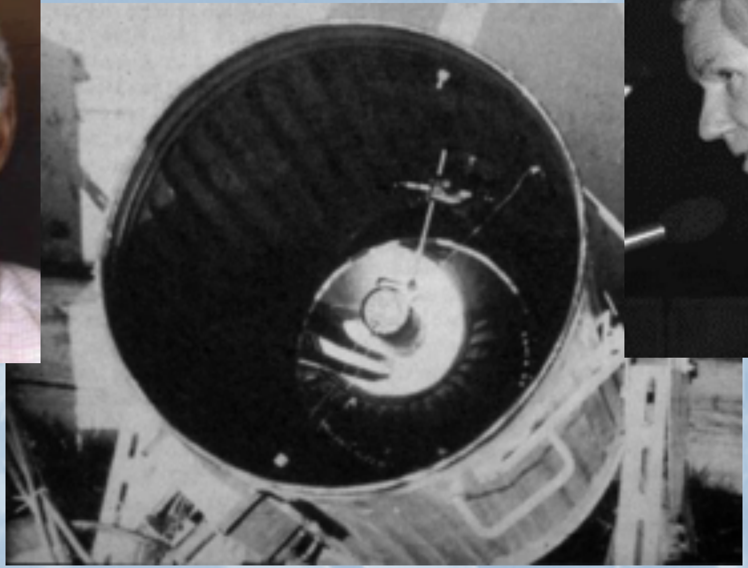
- 50's – 70's
- 80's
- 90's and beyond

* Channeling David Fegan

VERITAS

Very Energetic Radiation Imaging Telescope Array System

"Reflections in a Trashbin" – Galbraith & Jelley (52-53)



"In 1948, Blackett' suggested that a contribution approximately 10^{-4} of the mean light of the night-sky might be expected from Cerenkov radiation [2] pro duced in the atmosphere by the cosmic radiation."

- First instance of detection of light pulses coincident with cosmic-rays
- Could not distinguish if the pulses were a result of Cherenkov radiation or ionization in the atmosphere

Light Pulses from the Night Sky associated with Cosmic Rays

IN 1948, Blackett[1] suggested that a contribution approximately 10^{-4} of the mean light of the night-sky might be expected from Čerenkov radiation[2] produced in the atmosphere by the cosmic radiation. The purpose of this communication is to report the results of some preliminary experiments we have made using a photomultiplier, which revealed the

• • •

NATURE February 21, 1953 VOL. 171

thank Mr. W. J. Whitehouse and Dr. E. Bretscher for their encouragement, and Dr. T. E. Cranshaw for the use of the extensive shower array.

W. GALBRAITH
J. V. JELLEY

Atomic Energy Research Establishment,
Harwell, Didcot, Berks.
Nov. 19.

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Meanwhile in the U.S.S.R. (Crimea) – A. Chudakov (60-63)

"It seems to us that showers from primary photons with energy E ~ 10^{12} ev, in a solid angle Ω ~ 10^{-3} sr, can be registered more reliably and with much simpler means by using the Cerenkov radiation produced by the shower in the atmosphere. For this purpose, the light flash should be registered with a photomultiplier placed at the focus of a large parabolic mirror. The angular resolution of such a system can be reduced to ± 1°."

- 12 parallel oriented parabolic mirrors – light buckets
- Used in time coincidence to discriminate from background in addition to coincident particle counters

SOVIET PHYSICS JETP VOLUME 14, NUMBER 2 FEBRUARY, 1962

Letters to the Editor

METHOD OF FINDING LOCAL SOURCES OF HIGH-ENERGY PHOTONS

G. T. ZATSEPIN and A. E. CHUDAKOV

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

lower energy can be registered. At high energies, the ratio of the photon effect to the cosmic-ray background can be improved by using penetrating-particle detectors connected for anticoincidence.

An advantage of the proposed method, in addition to the possibility of placing the apparatus at sea level, is the relatively large effective area of shower registration (on the order of 10^5 m^2), so that high statistical accuracy can be attained; the latter is very important, since the optimistic estimates given in [1] for the intensity of the high

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Image Intensifier Work at 10^{15} eV– Porter and Hill (61-64)

Neil A. Porter

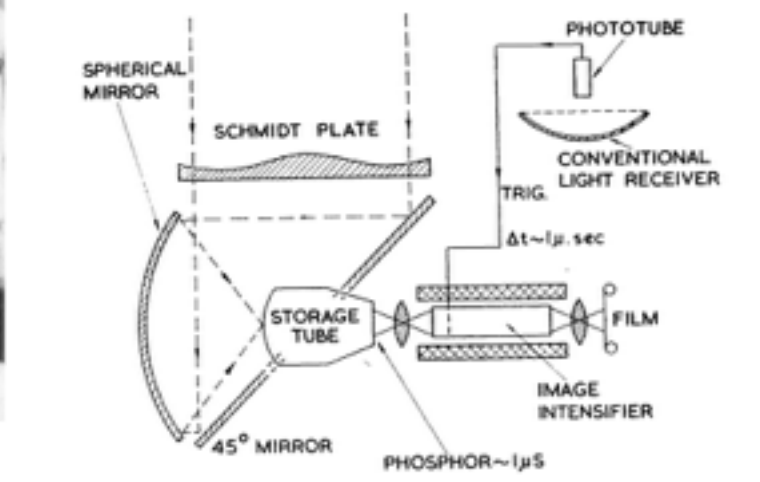
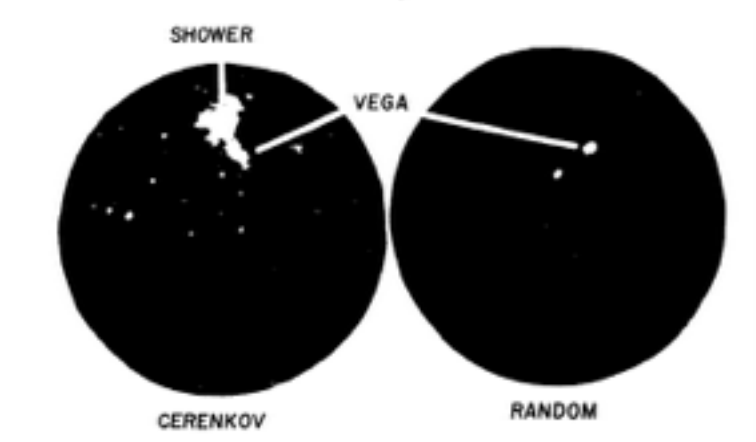


Fig. 3. The essential features of an image intensifier system with phosphor storage.

D. A. Hill

- First photgraphs of EAS at 10^{15} eV
- Zenith pointed, recorded 4 photos/hr
- First indication of utility of shower shape in discrimination and in shower localization both on the sky and the ground
- Abandoned by Porter circa '64 to pursue radio detection of EAS



(a) A Čerenkov light flash photographed against the background light of the night-sky, using an image intensifier with phosphor storage, ref. (52). *Left*—with the intensifier triggered from a conventional light receiver, showing the patch of Čerenkov light, and the star Vega. *Right*—with the intensifier triggered at random.

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A Landmark Publication - First Hint at a Way Forward

Jelley and Porter, 63

Čerenkov Radiation from the Night Sky, and its Application to γ-Ray Astronomy

J. V. Jelley and N. A. Porter

QJRAS, 4R, 275, 1

Neil A. Porter

The existing light receiver installation at A.E.R.E., Harwell. The bank of three-foot f/0·5 mirrors is mounted equatorially for drift scans.

John V. Jelley

Discussed both PMT and Intensifier systems

PMT systems

- Noted essential differences between γ-ray initiated versus nuclear initiated showers
- Shower development is fast
- High angular resolution is desirable
- Temporal coincidence in multiple systems reduces background from random noise pulses

Intensifier systems

- Schmidt optics; wide FOV and high angular resolution
- Shapes give information on arrival direction and impact point
- Two separated telescopes operating stereoscopically enhance the effects

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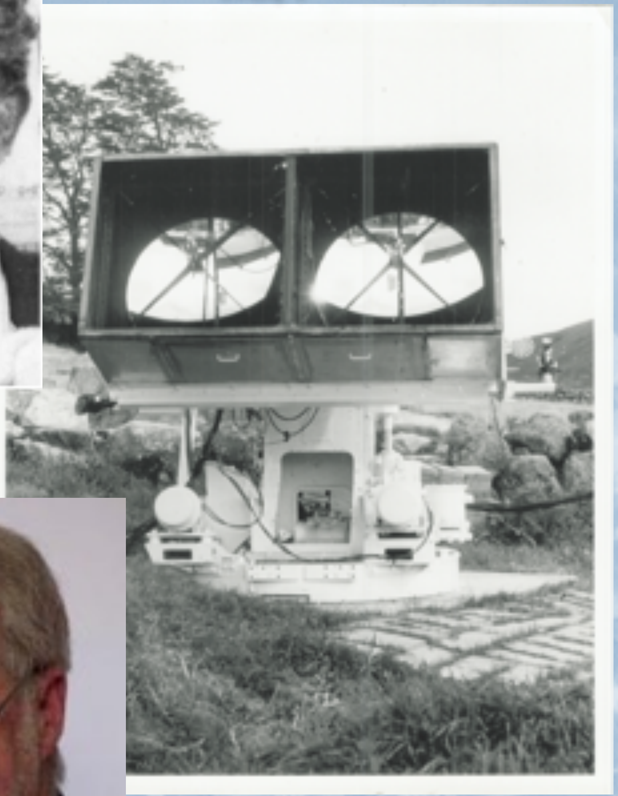
Meanwhile in Ireland and the UK – Harwell/UCD
Glencullen and Malta 63 - 72

Neil A. Porter

David J. Fegan

Mk I



Mk II

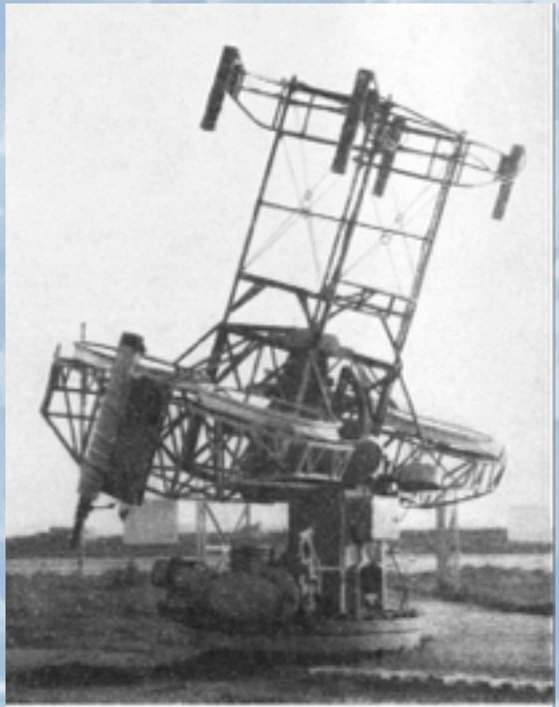


Fig. 6. The Čerenkov γ-ray installation operated jointly by the Atomic Energy Research Establishment, Harwell, and University College, Dublin. This installation consists of four 90 cm diameter f/2 mirrors and is sited at Qrendi, Malta.

OG - 10 *Proc. 11th Int. Conf. on Cosmic Rays, Budapest 1969*

SEARCHES FOR HIGH ENERGY GAMMA-RAYS FROM PULSARS USING A FAST NIGHT SKY ČERENKOV DETECTOR*

W. N. CHARMAN, J. H. FRUIN, J. V. JELLEY
Atomic Energy Research Establishment, Harwell, England

D. J. FEGAN, D. M. JENNINGS, E. P. O'MONGAIN, N. A. PORTER, G. M. WHITE
University College, Dublin, Ireland

Mk I at Glencullen, Co. Dublin

- 2 mirror fast coincidence system
- Operated from 63 – 66
- Yielded only upper limits and a thesis for T. C. Weekes

Mk II at Malta

- Developed at Glencullen but eventually moved to Malta
- Very fast integration and coincidence times with a narrow FOV – exploit the fast annulus
- Operated from 69 – 73; only upper limits

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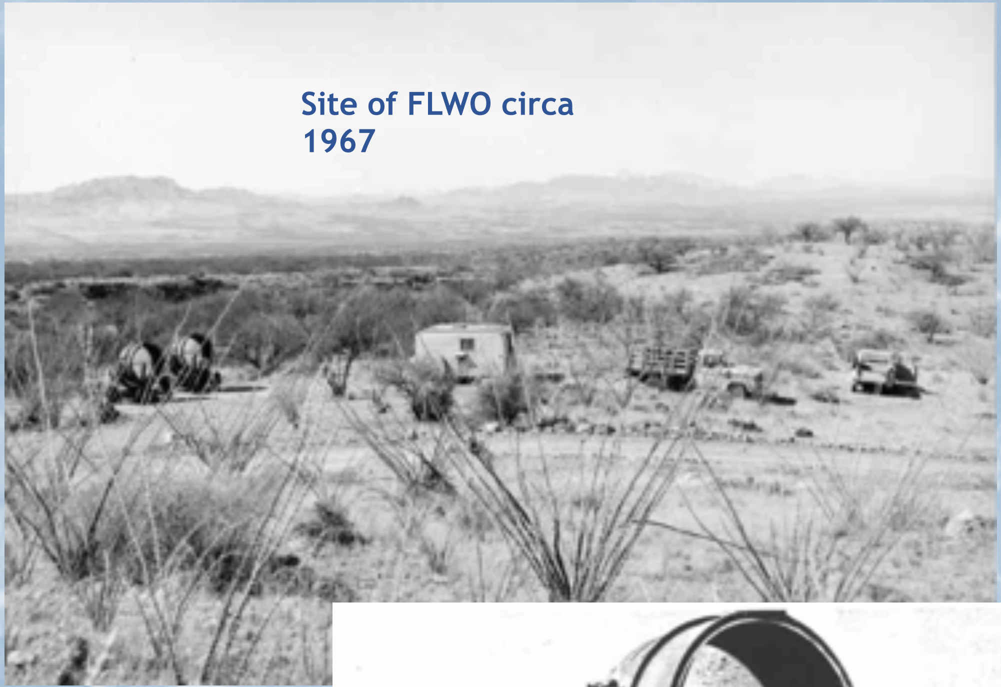
Meanwhile in the U.S.A. – SAO
Mt. Hopkins, AZ 67 - 78

Giovanni Fazio

10th ICRC, Calgary, 1967

- After pursuing and advancing γ-ray astronomy at lower energies Giovanni Fazio along with Henry Helmken decide to give ground based detection a try
- Solar furnace at Natick, MA
- Exploratory effort in 65 – 66
- SAO agrees to build a large optical reflector for γ-ray astronomy in 1966
- Trevor Weekes hired on as an NAS-NRC postdoc for the effort
- Efforts commence on building the 10m telescope and developing the Mount Hopkins Observatory - 67

Meanwhile in the U.S.A. – SAO
Mt. Hopkins, AZ 67 - 73

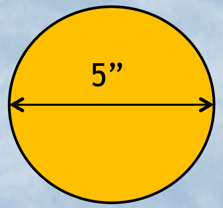


Site of FLWO circa 1967

Work on the Mt. Hopkins Observatory proceeds at an astonishing pace. The laser and Baker-Nunn systems are now installed and operating and the large optical reflector is scheduled to arrive by the end of next month. In preparation for the LOR installation, Trevor Weekes (above, left) and George Rieke have conducted seeing tests with two movable searchlight reflectors. Look carefully – some outcroppings at the base of Mt. Hopkins are visible upside-down in the reflector.

Trevor Weekes and George Rieke with a searchlight mirror

The 10m telescope at the Mt. Hopkins ridge



The 10m camera circa 1968

- 10m telescope completed and Mount Hopkins Observatory dedicated – 68
- Despite the large mirror area the 10m was still a simple counting instrument
- The focal plane detector was a 1 pixel camera
- Observations continued until 78 although sporadically after 73

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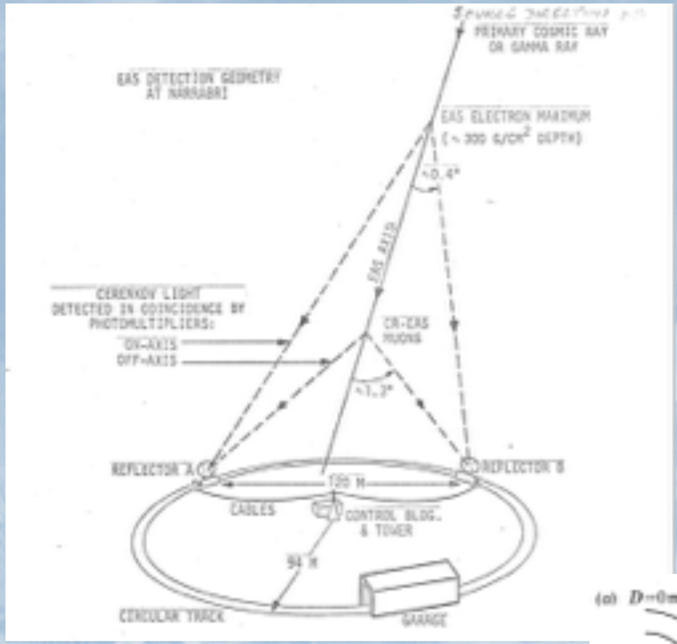
The Pause That Refreshes – early 70's to early 80's



- Josh Grindlay demonstrates the utility of stereo – SAO and Narrabri 70 - 75

Grindlay, J. E., *Smithsonian Astrophysical Observatory Spec. Rep. no. 334*, 1971
Grindlay, J. E., *Phys. Rev. D*, 11, 517, 1975

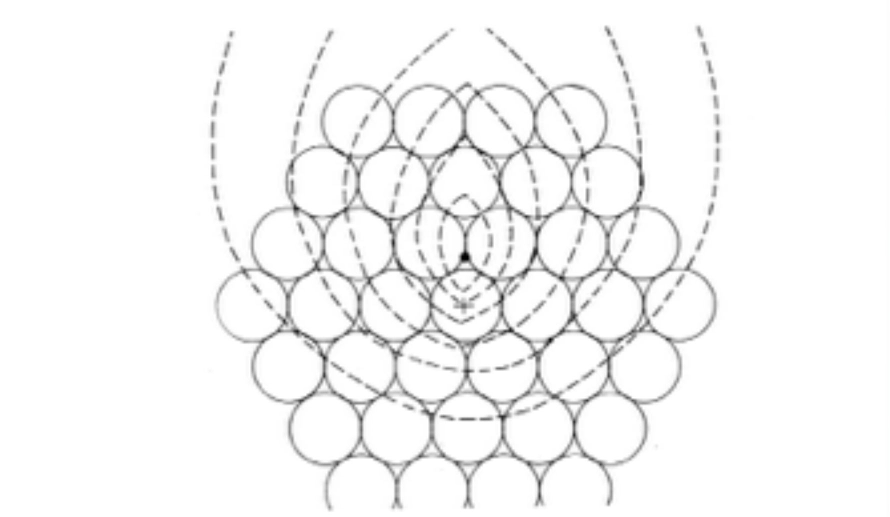


FIGURE 11a. The proposed configuration of 37 phototubes on the M.H.O. 10 m reflector shown superimposed on the Cherenkov image of a shower with $d = 50$ m; its arrival direction is the centre of the phototube array.

- Lead to the conceptual design of a 37 pixel camera to be deployed at the Whipple Observatory 10m

- More sophisticated simulations of air showers and the Cherenkov light distributions

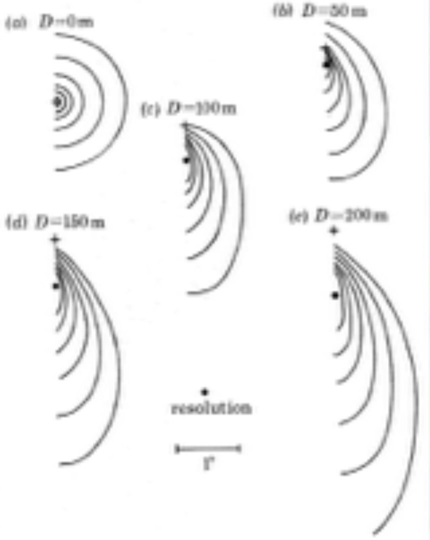


FIGURE 10. Predicted shapes of Cherenkov light images as a function of the separation between parallel shower and detector axes. (Rieke 1969.)

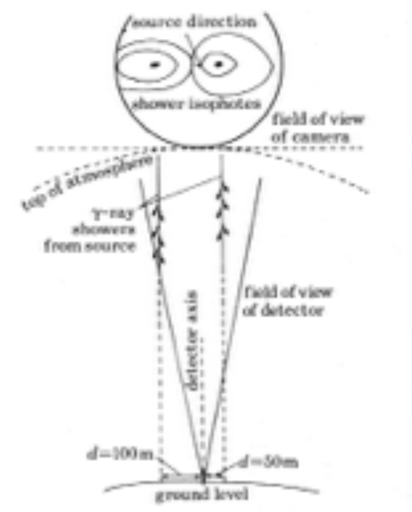


FIGURE 9. The geometry of Cherenkov image detection showing how the 'elliptical' images in figure 8 are produced.

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The Pause That Refreshes – early 70's to early 80's

Phil. Trans. R. Soc. Lond. A **301**, 615–628 (1981) **615**
Printed in Great Britain

Gamma-rays above 100 GeV

BY K. E. TURVER† AND T. C. WEEKES†‡§
† *Department of Physics, The University, Science Laboratories, South Road, Durham DH1 3LE, U.K.*
and ‡ *The Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, East Sussex BN27 1RP, U.K.*

The Cherenkov light technique for the ground-based detection of ultra-high energy γ-rays is described and some of the most significant measurements are reported. Improvements in experiments leading to increases in sensitivity are outlined and the aims of future work are discussed.

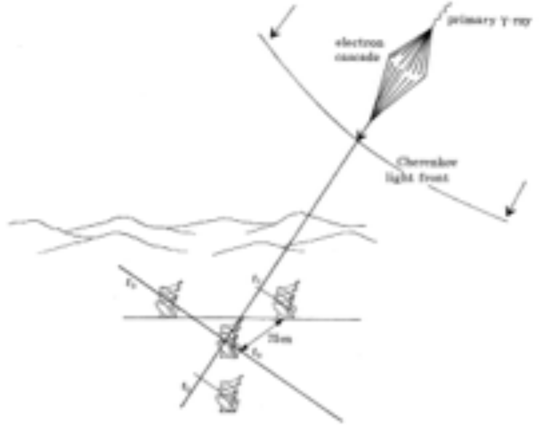

FIGURE 7. The University of Durham fast timing detector array. The accurate times of arrival of the light signal at each detector (t_1, t_2, t_3, t_4) allow the arrival direction to be precisely determined.

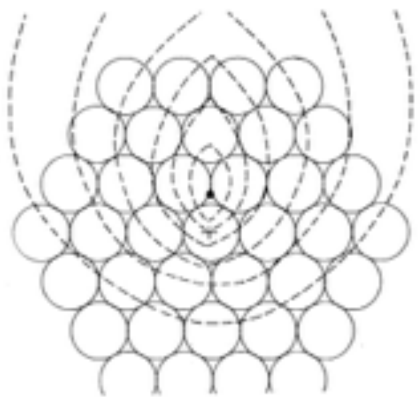

FIGURE 11a. The proposed configuration of 37 phototubes on the M.H.O. 10 m reflector shown superimposed on the Cherenkov image of a shower with $d = 50$ m; its arrival direction is the centre of the phototube array.

- During a visit to UCD in 78 Weekes, Fegan and Porter decide that an imaging instrument needs to be developed
- Worked commenced at UCD, largely a paper study, on how to develop a 2D imaging system
- Weekes took a sabbatical in Durham during 80 and discussed the future of ground-based γ-ray astronomy which led to a seminal work that first appeared in an ESALab symposium but later published in PTRSL in 81
- In addition to Turver's shower front timing a 2D imaging camera was described

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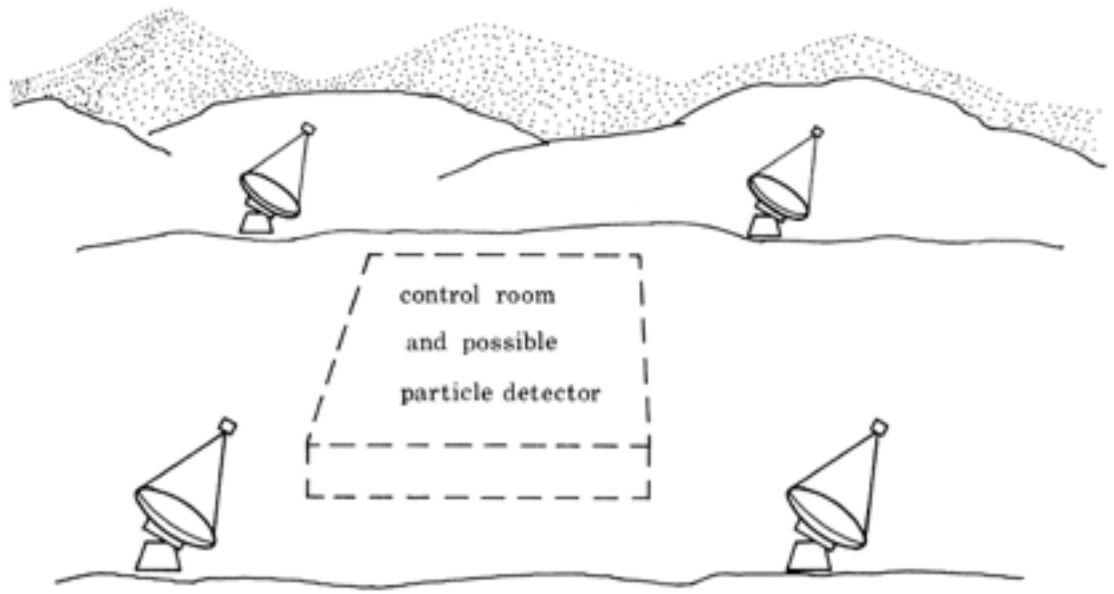

Figure 13. The proposed configuration of a Cherenkov experiment that would cover the energy range 10^{10}–10^{13} eV by using the imaging and timing techniques discussed above; each reflector would have an aperture of 10–15 m and the separation would be 50–100 m.

- In that same paper in the section titled "Energy Region Below 10^{11} eV" a four telescope system was described.
- The caption reads "...each reflector would have an aperture of 10-15 m and the separation would be 50-100 m."

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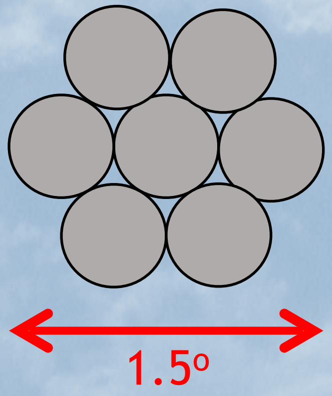
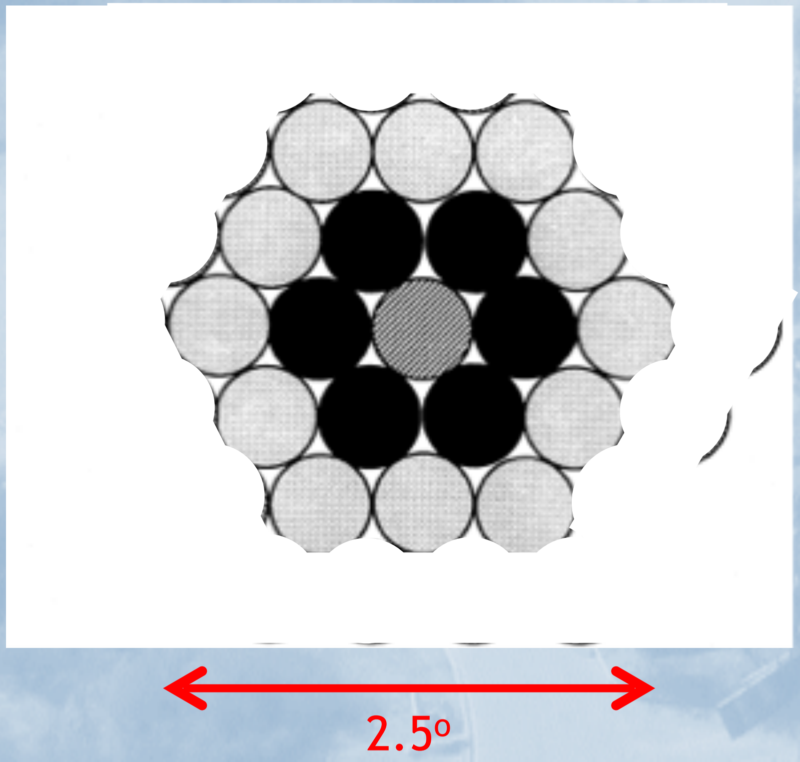
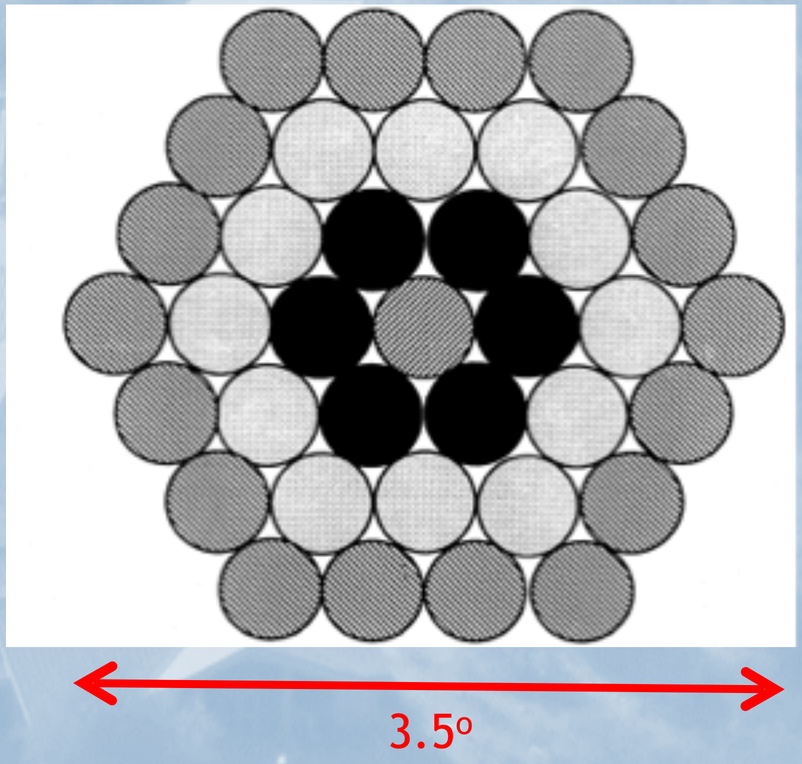
The Decade of the 80's – Birth of a New Astronomy





- Despite a lack of funding work on building the first camera commenced in 1980 at SAO and UCD
- The first camera was a 7 pixel system ; 5 cm PMTs on a 0.5° spacing.
- In 1981 it was desired to expand the collaboration and ISU, Durham, U of Hawaii, and Hong Kong were added – became the Whipple Collaboration as the observatory was renamed in honor of Fred Whipple
- 82-83 season saw the use of a 19 pixel camera
- 83 the camera was expanded to 37 pixels



VERITAS
Very Energetic Radiation Imaging Telescope Array System

The Decade of the 80's – Birth of a New Astronomy

- All the pieces were in place in 1983 and now other difficult aspects raised their heads
  - How should the system be calibrated
  - How should one deal with noise and varying sky brightness
  - What should be the normalization procedure
  - How should gains be normalized and monitored
  - How do you pick out a γ-ray from the large cosmic ray background
  - This was a difficult struggle for a small group of people
  - Upon invitation from Weekes Hillas visited Tucson in 84 to present a talk at a AAS meeting on Cyg X-3
  - Hillas was doing simulations for EAS arrays and was intrigued with the Whipple telescope
  - Upon return to Leeds he began a detailed simulation study specifically for the 10m system
  - A close collaboration and exchange between the groups led to a set of selection criteria

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The Decade of the 80's – Birth of a New Astronomy

445

OG 9.5-3

CERENKOV LIGHT IMAGES OF EAS PRODUCED BY
PRIMARY GAMMA RAYS AND BY NUCLEI

A. M. Hillas
Physics Department
University of Leeds, Leeds LS2 9JT, UK.

ABSTRACT

It is shown that it should be possible to distinguish very effectively between background hadronic showers and TeV gamma-ray showers from a point source on the basis of the width, length and orientation of the Cerenkov light images of the shower, seen in the focal plane of a focusing mirror, even with a relatively coarse pixel size such as employed in the Mt. Hopkins detector.

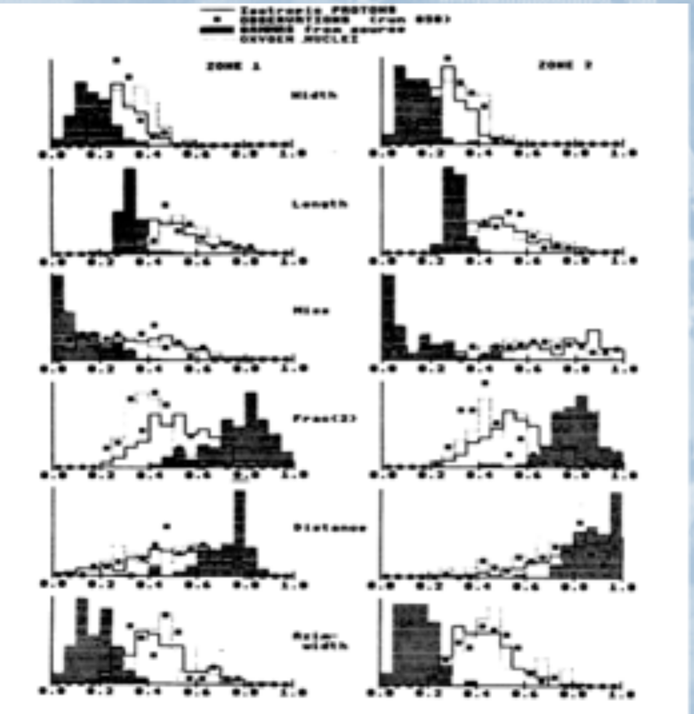
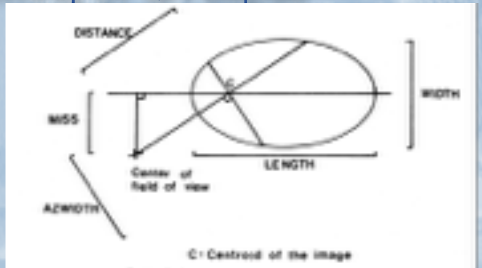


Figure 2: histograms of image characteristics. (vertical showers)

- 1985 ICRC at La Jolla
- Hillas presents data selections based on the moment fitting of an ellipse



- This set of selections would prove to be the first set of imaging selections that yielded an increased sensitivity
- The next 2 years observing would be crucial for the field

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The Decade of the 80's – Birth of a New Astronomy

THE ASTROPHYSICAL JOURNAL, 342:379–395, 1989 July 1

OBSERVATION OF TeV GAMMA RAYS FROM THE CRAB NEBULA USING THE ATMOSPHERIC CERENKOV IMAGING TECHNIQUE

T. C. WEEKES,[1] M. F. CAWLEY,[2] D. J. FEGAN,[3] K. G. GIBBS,[1] A. M. HILLAS,[4] P. W. KWOK,[1] R. C. LAMB,[5] D. A. LEWIS,[5] D. MACOMB,[5] N. A. PORTER,[3] P. T. REYNOLDS,[1,3] AND G. VACANTI[5]

Received 1988 August 1; accepted 1988 December 9

ABSTRACT

The Whipple Observatory 10 m reflector, operating as a 37 pixel camera, has been used to observe the Crab Nebula in TeV gamma rays. By selecting gamma-ray images based on their predicted properties, more than 98% of the background is rejected; a detection is reported at the 9.0 σ level, corresponding to a flux of 1.8×10^{-11} photons cm^2 s^{-1} above 0.7 TeV (with a factor of 1.5 uncertainty in both flux and energy). Less than 25% of the observed flux is pulsed at the period of PSR 0531. There is no evidence for variability on time scales from months to years. Although continuum emission from the pulsar cannot be ruled out, it seems more likely that the observed flux comes from the hard Compton synchrotron spectrum of the nebula.

Subject headings: gamma rays: general — nebulae: Crab Nebula — pulsars — radiation mechanisms

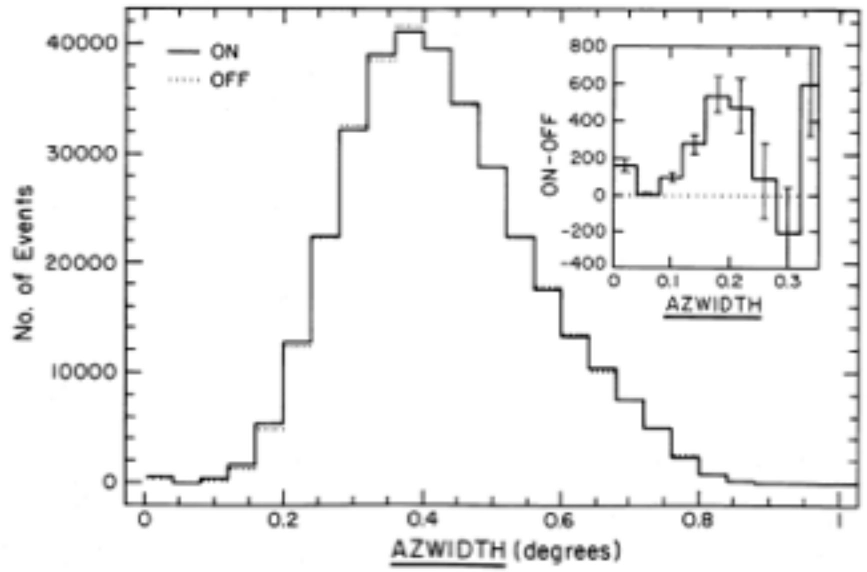

FIG. 6.—Distribution of "all" ON and OFF *azwidth* parameters (with z < 30°) for image zones 1 and 2 combined, with the differences in the two distributions in the gamma-ray domain shown in the inset.

- 1989 saw the publication of the first clear detection of extra-terrestrial gamma rays above an energy of 10^{11} eV – the Crab Nebula
- Using the imaging selections proposed by Hillas (now known as Hillas parameters) the Crab nebula was detected at ~ 9σ
- The largest excess (i.e. the most sensitive) was the Azwidth parameter
- The new field of ground-based VHE gamma ray astronomy was established

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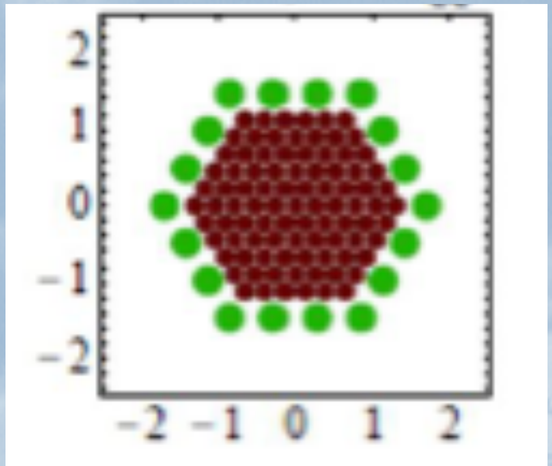
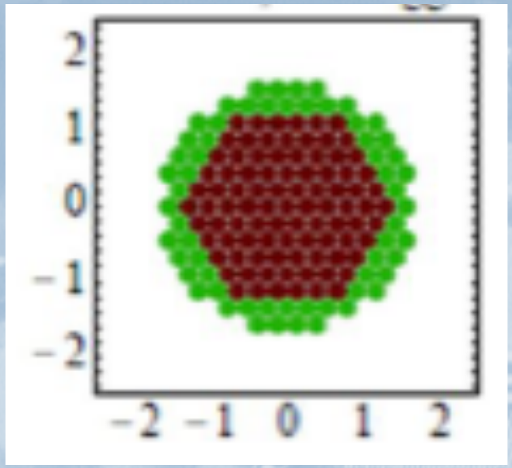
The Decade of the 90's and Beyond– Growth and Rapid Advancement

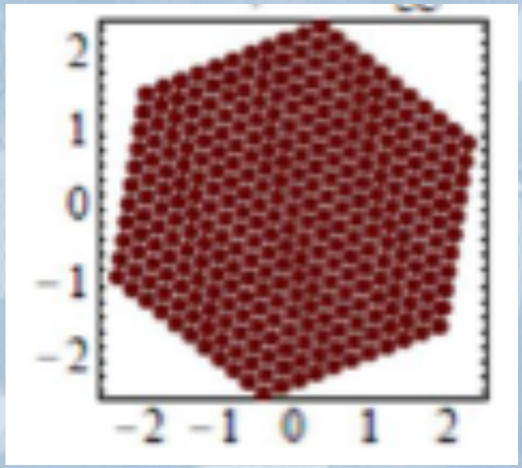
109 pixel camera
88 - 93



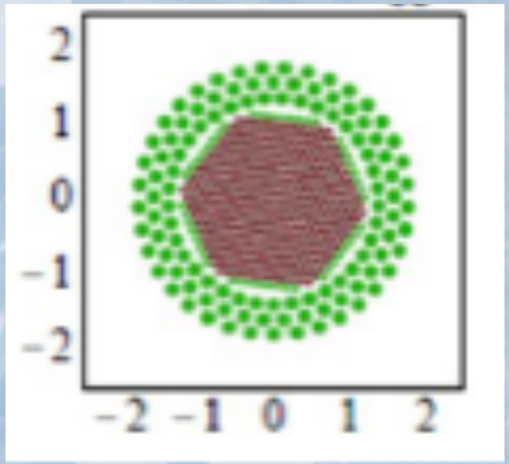
151 pixel camera
96 - 97



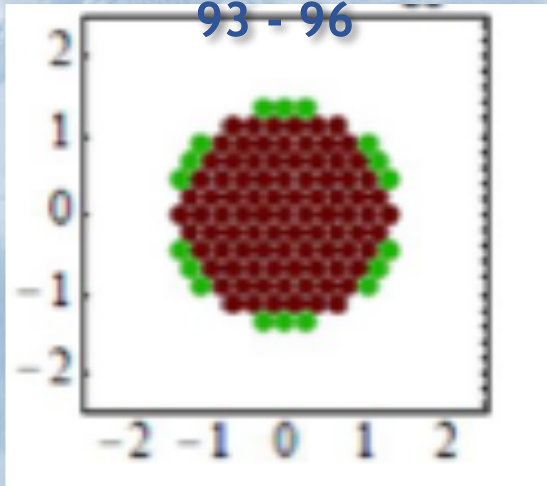
331 pixel camera
97 - 99



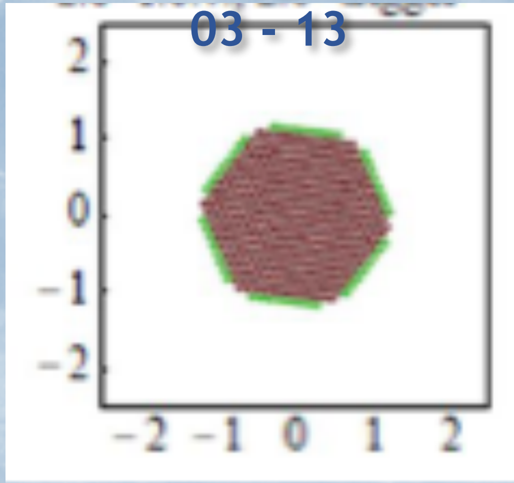
490 pixel camera
99 - 03



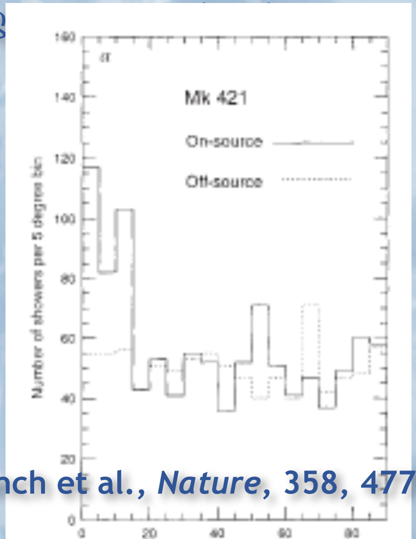
109 pixel camera
V2
93 - 96



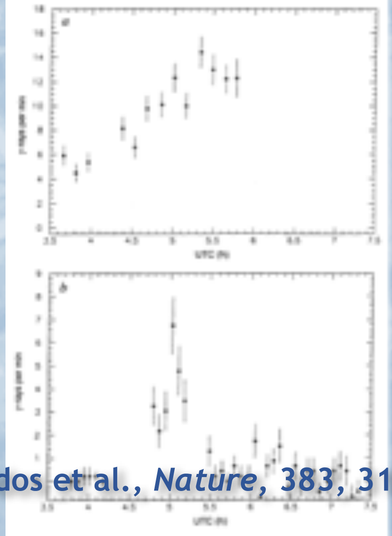
379 pixel camera
V2
03 - 13



- Rapid progress was the hallmark of the 90's – increasingly more sensitive instrumentation
- Results



Punch et al., *Nature*, 358, 477, 1992



Gaidos et al., *Nature*, 383, 319, 1996

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The Decade of the 90's and Beyond- Growth and Rapid Advancement

- Including stereo observations with the 10m and 8m at Mount Hopkins

ELSEVIER
Astroparticle Physics 8 (1998) 213-221
Astroparticle Physics

Stereoscopic observations of gamma rays at the Whipple observatory

F. Krennrich[a,*], C.W. Akerlof[b], J.H. Buckley[d], J. Bussóns-Gordo[f], D.A. Carter-Lewis[a], M.F. Cawley[e], M.A. Catanese[a], V. Connaughton[f], D.J. Fegan[f], J.P. Finley[g], J.A. Gaidos[g], K.H. Harris[d], A.M. Hillas[c], R.C. Lamb[a], M.J. Lang[h], G. Mohanty[a], J. Quinn[f], A.J. Rodgers[c], H.J. Rose[c], A.C. Rovero[i], M.S. Schubnell[b], G.H. Sembroski[g], T.C. Weekes[d], C. Wilson[g]

- 5.45 hours of ON/Off data collected in 1996 demonstrating the increase in sensitivity with a stereo system

146 m

- By this time, 1996, VERITAS was a proposed next generation system

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Very Energetic Radiation Imaging Telescope Array System

"The Road"

(and a long and winding one it was!)

Ken Gibbs

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!

1994 — 1995 — 1996 — 1997

Irwin Shapiro (SAO Director) suggests that Trevor solicit MSI funds

Trevor submits a proposal for "VHEGRO" an array of 9 x ~10m teles

Trevor sends out a call for interested parties to expand the Whipple Collab.

VERITAS

Very Energetic Radiation Imaging Telescope Array System

A search for both a site and funding

(only the beginning)

Ken Gibbs

1997 — 1998

- Trevor's MSI proposal receives a very favorable review - but no $$ before FY00
- Steve Criswell joins VERITAS
- Steve and Trevor meet with the Forest Service (FS) and discuss site options: Montosa, south of BC & "Residence" area
- 1st VERITAS Mtg in Chicago

1998 — 1999

- Whipple makes formal site application to FS
- LOI sent to SAO, DOE NSF and NASA
- Trevor makes presentation to SAGENAP
- FS "scoping" letter out for public comment
- TAOR object to Montosa site
- Trevor and Steve meet with TAOR in the "talking circle"

VERITAS

Very Energetic Radiation Imaging Telescope Array System

Reviews and Montosa Cyn

(the first of many, reviews and canyons)

Ken Gibbs

1997 – 1998

- Trevor's MSI proposal receives a very favorable review - but no $$ before FY00
- Steve Criswell joins VERITAS
- Steve and Trevor meet with the Forest Service (FS) and discuss site options: Montosa, south of BC & "Residence" area
- 1st VERITAS Mtg in Chicago

1998 – 1999

- Whipple makes formal site application to FS
- LOI sent to SAO, DOE NSF and NASA
- Trevor makes presentation to SAGENAP
- FS "scoping" letter out for public comment
- TAOR object to Montosa site
- Trevor and Steve meet with TAOR in the "talking circle"

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

VERITAS

Very Energetic Radiation Imaging Telescope Array System

SI Funding on the horizon

(albeit, the distant horizon)

Ken Gibbs

1999

- **SAGENAP review favorable but NSF participation required: "best instrument" "excellent team"**
- **SI Capital Plan incl. $1M FY02 + $3.5M FY03**
- **VERITAS presentation to Decadal Survey**
- **DOE determines that "support should be provided" … provided SI and NSF match**
- **FS denies Montosa Cyn site application**
- **Whipple resubmits application per FS request**

2000

2000

- Revised proposal (7 teles in Montosa Cyn) Submitted to DOE, NSF PPARC and EI
- Ritz review: NSF and DOE endorse "V7"
- Decadel Survey endorses VERITAS as "moderate" initiative
- DOE: $500K for R&D
  NSF: $876K to Utah and Chicago
  SI/SAO: IR&D only until FY02
- "Castle" Meeting: DOE, NSF and SI
- Teaming Agreement signed by 10 founding institutions

2001

VERITAS

Very Energetic Radiation Imaging Telescope Array System

Yet more reviews and some funding

Ken Gibbs

1999

SI Capital Plan incl.
$1M FY02 + $3.5M FY03

VERITAS presentation
to Decadal Survey

FS denies Montosa Cyn
site application

2000

SAGENAP review
favorable but NSF
participation reqd.
"best instrument"
"excellent team"

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submitted to DOE, NSF,
PPARC and EI

Decadel Survey endorses
VERITAS as
"moderate" initiative

"Castle" Meeting:
DOE, NSF and SI

Teaming Agreement
signed by 10
founding institutions

VERITAS
Very Energetic Radiation Imaging Telescope Array System

No SI funding but site progress

(a very shaky “three legged [funding] stool”)

Ken Gibbs

2001

- DOE and NSF: ready to proceed
- OMB rejects SI FY02 funding for VERITAS
- DOE and NSF: “no SI funding then no DOE or NSF”; but DOE approves Prototype const.
- Trevor to Shapiro: “the future of VERITAS is very much in doubt”
- FS asks that Steve meet with TAOR; TAOR unresponsive
- FS grants permission to const. VERITAS in Montosa Cyn

2002

2002

- V7 descoped: V4+3
- SKY Island objects to Montosa Cyn: cites visual impact
- V4 proposal submitted to NSF
- FS still unable to provide a decision re Montosa Cyn
- Blandford review of four telescope array and viability of VERITAS project as a whole

2003

VERITAS

Very Energetic Radiation Imaging Telescope Array System

… or no site progress?

Ken Gibbs

2001

- DOE and NSF: ready to proceed
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- DOE and NSF: "no SI funding then no DOE or NSF"; but DOE approves Prototype const.
- Trevor to Shapiro: "the future of VERITAS is very much in doubt"
- FS asks that Steve meet with TAOR; TAOR unresponsive
- FS publishes decision granting access to Montosa Cyn

2002

2002

- SKY Island objects to Montosa Cyn: cites visual impact
- V7 descoped: V4+3
- V4 proposal submitted to NSF
- FS still unable to provide a decision re Montosa Cyn
- Blandford review of four telescope array and viability of VERITAS project as a whole

2003

VERITAS

Very Energetic Radiation Imaging Telescope Array System

Kitt Peak (NOAO) throws a lifering

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

Ken Gibbs

2003

- FS gives go-ahead for Montosa Cyn
- FS decision appealed
- DOE: “you must have a site by June or be shut down”
- Kitt Peak (KP) suggested as an alternative
- NOAO and SI sign lease for Horseshoe Cyn site; NOAO notifies Tohono O`odham (TO)
- KP Director meets TO: they express reservations
- Trevor: “VERITAS is now an approved project”

2004

2004

- EA and design completed
- Construction begins at Horseshoe Cyn
- TO file first official protest!

2005

- STOP-WORK order issued
- Second EA initiated

2006

- SI and NOAO meet TO Tribal and District Chair and Attorney General
- SI and NOAO meet a second time with TO Tribal and District Chair and Attorney General
- SI concedes

2007

VERITAS

Very Energetic Radiation Imaging Telescope Array System

… which falls short

Ken Gibbs

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- SI and NOAO meets Tribal and District Chair and Attorney General
- SI and NOAO meet a second time with Tribal and District Chair and Attorney General
- SI/SAO/FLWO "throw in the towel"

2007

VERITAS

Very Energetic Radiation Imaging Telescope Array System

… which falls short

Ken Gibbs

2003

FS decision appealed

FS gives go-ahead for Montosa Cyn

Kitt Peak (KP) suggested as an alternative

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SI and NOAO meet Tribal and District Chair and Attorney General

SI and NOAO meet a second time with Tribal and District Chair and Attorney General

SI/SAO "throw in the towel"

2007

VERITAS

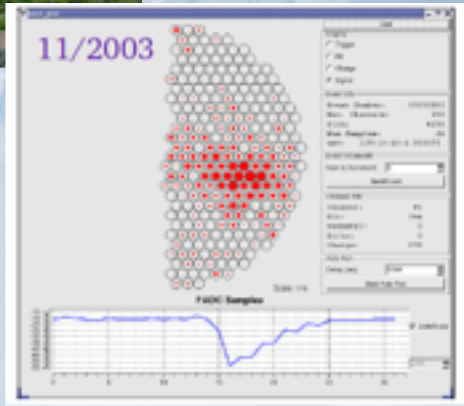
Very Energetic Radiation Imaging Telescope Array System

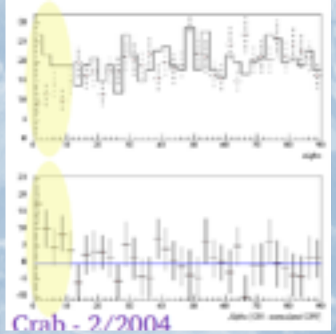
Events on the ground ...

(meanwhile, back at the Basecamp ...)

Ken Gibbs

- 2003
- Prototype const. begins
- First Prototype events
- 2004
- Prototype detects Crab Nebula
- T1 const. completed
- 2005
- T2 const. begins
- T1 & T2 operate in stereo mode
- 2006
- T3 const. begins
- T3 const. nearly complete
- T4 const. begins
- 2007
- T4 const. completed
- Full 4 Tele. operations begin
- 2008





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The first VERITAS telescope

J. Holder [a,*], R.W. Atkins [b], H.M. Badran [c], G. Blaylock [d], S.M. Bradbury [a], J.H. Buckley [e], K.L. Byrum [f], D.A. Carter-Lewis [g], O. Celik [h], Y.C.K. Chow [h], P. Cogan [i], W. Cui [j], M.K. Daniel [i], I. de la Calle Perez [k], C. Dowdall [i], P. Dowkontt [e], C. Duke [l], A.D. Falcone [m], S.J. Fegan [h], J.P. Finley [j], P. Fortin [n], L.F. Fortson [o], K. Gibbs [p], G. Gillanders [q], O.J. Glidewell [a], J. Grube [a], K.J. Gutierrez [e], G. Gyuk [o], J. Hall [b], D. Hanna [r], E. Hays [f,s], D. Horan [p], S.B. Hughes [e], T.B. Humensky [s], A. Imran [g], I. Jung [e], P. Kaaret [t], G.E. Kenny [q], D. Kieda [b], J. Kildea [r], J. Knapp [a], H. Krawczynski [e], F. Krennrich [g], M.J. Lang [q], S. LeBohec [b], E. Linton [s], E.K. Little [p], G. Maier [a], H. Manseri [b], A. Milovanovic [a], P. Moriarty [u], R. Mukherjee [n], P.A. Ogden [a], R.A. Ong [h], D. Petry [x], J.S. Perkins [e], F. Pizlo [j], M. Pohl [g], J. Quinn [i], K. Ragan [r], P.T. Reynolds [v], E.T. Roache [p], H.J. Rose [a], M. Schroedter [g], G.H. Sembroski [j], G. Sleege [g], D. Steele [o], S.P. Swordy [s], A. Syson [a], J.A. Toner [q], L. Valcarcel [r], V.V. Vassiliev [h], S.P. Wakely [s], T.C. Weekes [p], R.J. White [a], D.A. Williams [w], R. Wagner [f]

VERITAS

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VERITAS today

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