Addendum to VERITAS Proposal

Summary

In March, 1999 the proposal to build VERITAS, the Very Energetic Radiation Imaging Telescope Array System, was submitted to the U.S. Department of Energy by Iowa State University, Purdue University, the Smithsonian Astrophysical Observatory, and Washington University. Copies were also sent to the Smithsonian Institution, to the National Science Foundation (by the University of Chicago and the University of Utah), to PPARC in the United Kingdom (by the University of Leeds) and to Enterprise Ireland (by University College, Dublin). At DOE's request the proposal was reviewed by SAGENAP (the Scientific Assessment Group for Experiments in Non-Accelerator Physics); it was also sent by DOE for review by external referees.

The reviews were very positive and we have been encouraged to proceed with the project. A slightly revised and abbreviated proposal is now being submitted to these agencies. Further encouragement comes from the progress in the field as reported in the Proceedings of the Workshop on the "TeV Astrophysics of Extragalactic Sources" in Cambridge, MA in October, 1998 (Astroparticle Physics, vol. 11) and of the Workshop on "GeV-TeV Astrophysics" in Snowbird, UT in August, 1999 (in press). In this Addendum we address some of the concerns raised during the reviewing process in greater detail than was possible in the main body of the proposal. The Addendum includes:

1. Summary of the Report of Review by a Panel of Experts on the Optical and Mechanical Design of the Telescopes and Camera
2. Summary of the Report of Review by a Panel of Experts on the Electronics of the Camera
3. Observation Plan for the first three years of VERITAS
4. VERITAS Design Justification
5. Flash ADC Development
6. VERITAS Management Structure
7. VERITAS Work Breakdown Schedule (WBS) Summary

1 Mechanics & Optics Review of VERITAS

1.1 Overview

Purpose

A technical review of the mechanical and optical system proposed for VERITAS was held on August 28, 1999 in Tucson at the Steward Observatory. This review was requested by S. Criswell, Project Manager, and T. Weekes, Project Scientist, to evaluate the conceptual design of the optical collector and make recommendations. Members of the VERITAS Working Groups provided documentation describing components of the reflector and gave presentations of work in progress, summarizing the various options pursued, the choices made and their justification.

Reviewers

Jingquan Cheng	NRAO Telescope Mechanical Engineer
Jeff Kingsley	NRAO Telescope Mechanical Engineer
Steve Miller	SO Mirror Laboratory Manager
David Vaughn	NOAO Optic Shop Manager
J. T. Williams	SO 6.5 m Project Engineer (chair)

Presenters

Steve Criswell	SAO	Optics Support Structure (OSS) & Pedestal
Jim Gaidos	Purdue University	Mirrors & Mounting
Kevin Harris	SAO	Present 10*m* Reflector
Frank Krennrich	Iowa State University	Optical Design
Trevor Weekes	SAO	Overview of VERITAS

Consultants: Phone Contact

Joe Antebi*	Simpson Gumpertz & Heger
Tom Hoffman*	Hoffman Design & Development

**Responsible for the engineering design and construction of the 10 m reflector and for carrying out a preliminary engineering analysis of the proposed VERITAS telescopes.*

1.2 Review

1.2.1 Mechanical Mount

Off-the-shelf pedestal
Azimuth/Elevation mount
Type of motors

The reviewers agreed that an AZ/EL pedestal already produced and tested is the best approach and recommended that a pointing and tracking budget be specified, identifying practical tradeoffs. No specific recommendations beyond using the existing 10 m drive motors other than to evaluate anti-backlash preload motors to reduce the allowable 0.05° backlash.

1.2.2 Optics Support Structure

f-number
Davies-Cotton optical design
Tube steel space-frame for OSS
OSS diameter

The reviewers commented that a good case was made for the $f/1.2$ Davies-Cotton design; however, the additional costs due to the longer camera arms await evaluation. Steel is the preferred structural material with possible space-frame and quad-arm cross bracing to suppress low frequency oscillations. Some wind tests can be carried out on the 10 m. Further evaluation of distortions of the OSS by wind and gravity are needed in order to achieve the light imaging specifications. No recommendations for a larger OSS other than the possibility of reducing stray light through baffling. The system as presented warrants an end-to-end stray light analysis.

1.2.3 Mirror Facets

Mirror facet size
Circular/hexagonal mirror facets
Float glass mirrors
Mirror mountings
Mirror coatings
Mirror alignment

The reviewers concurred with the conclusions of the Mirror Working Group that the optical specifications of the mirrors are best satisfied by hexagonal 60 cm mirrors made with a float glass substrate. These mirrors can be produced by the slumping technique in an accurately machined mold which is cost effective in large quantities. The reviewers noted that the specification of substrate quality by reflected flux at the radius of curvature is a good fit for this project: >85% of the reflected flux from a point source at the radius of curvature should fall within a 15 mm diameter circle at the point source. This corresponds to a 7.5 mm blur on the camera for a point source at ∞ and is $\sim$ 25% of the pixel diameter.

Two methods for mounting mirrors were presented: (1) drill 3 $\sim$15 mm holes in a triangular pattern for mounting onto three fine screws with adjusting nuts; (2) a gimbal mount to which the mirror is affixed with a high quality elastomeric adhesive. The motion of the gimbals is effected by high precision stepping motors controlled remotely. Scheme (1) is currently used on the 10 m and allows access from the front with a cherry-picker. The reviewers saw merit in both approaches and recommended that more effort be devoted to exploring the mounting designs and developing prototypes.

The reviewers agreed with the proposal of the Mirror Working Group to coat the mirrors with an on-site facility, including aluminization for high reflectance and anodization to protect the surface. They recommended a more precise system be developed for measuring and monitoring reflectance.

The reviewers suggested using the center photomultiplier to check mirror alignment whether using mounting method (1) or (2) described above.

1.3 Summary (by the Review Committee)

"The committee wishes to stress that the VERITAS system, as presented, is above all sound. Most concepts are proven. The change in $f/\#$ and evolution to an array is the natural next step. The system will work and produce good science, and it is cost effective. The VERITAS team is well educated on the limits of related technology and has a good plan to go forward."

2 VERITAS Electronics Review

2.1 Overview

Charge

"We would like a brief technical review of the electronics and data acquisition plans for an astrophysics project called VERITAS. VERITAS is a ground-based array of seven telescopes for detecting high energy gamma-ray showers induced in the atmosphere. These telescopes essentially consist of a 10 m diameter mirror with a cluster of 500 PMTs in the focal plane. These are planned to be instrumented with 500 MHz high dynamic range FADCs. We would like to have an external group of people look at our design plans for the hardware and provide some critique for our approach. We are eager to listen to your expertise in developing our instrumentation."

Logistics

The VERITAS Electronics Review took place on October 27, 1999 at the University of Chicago. The Panel consisted of three experts on electronics at Fermi National Accelerator Laboratory. It was attended by 14 members of VERITAS. After a day of presentations the Panel submitted a written report on November 19, 1999 which is summarized here.

Reviewers

Peter Cooper	Fermilab
Mike Crisler	Fermilab
Bob Tschirhart	Fermilab

Presenters

Introduction	Rene Ong	Chicago
Photomultipliers	John Finley	Purdue
Preamplifiers	Stephane LeBohec	Iowa State
Cables	Dave Kieda	Utah
Optical Fiber Cables	Joachim Rose	Leeds
Constant Fraction Discriminators	Dave Kieda	Utah
Pattern Trigger	Stella Bradbury	Leeds
DOT Boards	Joachim Rose	Leeds
FADC Overview	Jim Buckley	Washington
FADC Board	Paul Dowkontt	Washington
Reflective Memory	Simon Swordy	Chicago
Data Acquisition	John Quinn	Dublin
Array Trigger	Rene Ong	Chicago
High Voltage	Simon Swordy	Chicago
Environmental Issues	Dave Kieda	Utah

2.2 Review

"In general, the committee was impressed with the technical expertise and well thought out design concepts. We can identify no serious problems. Overall this design, if well executed as described, should just work. The biggest risk in this project appears to be schedule delays. We have identified a few areas where inattention or lack of decision making from project management could risk the schedule of the project. Specific comments for individual systems follow below."

2.2.1 Photomultipliers

The committee was favorably impressed that the photomultiplier situation was well in hand. Detailed studies have been performed on relevant performance specifications such as anode pulse rise time, transit time spread, and afterpulse fraction. An affordable candidate PMT has been identified, and an appropriate voltage divider and associated preamplifier electronics have been developed. All the right things have been done, and the committee saw no significant technical, cost, or schedule risk associated with the photomultipliers. We did note that all members of the committee have had experiences with thermal issues in close packed arrays of PMT's and recommend that an analysis be performed of the heat load on the PMT's both from the voltage divider and from the associated electronics.

2.2.2 High Voltage

The baseline solution for providing high voltage to the PMT array is the commercial LeCroy 1440 high voltage system. This will clearly work, but is costly. Largely because the 1440 system provides significantly more computer control capability than is actually required given that voltage changes are likely to be infrequent. The most important requirement on the high voltage is the ability to reduce the gain on tubes when the light level is high. The committee notes that there are other less expensive solutions available. An example would be a voltage divider equipped with a trim pot to adjust the voltage of an intermediate dynode. This is an old-fashioned way of balancing gains which preserves uniform timing from tube to tube and requires only the distribution of a single common high voltage to the array. Such a base can be equipped with a relay or other electronic switch to change to a lower gain when necessary. Clearly either approach will work. A custom system might be cheaper and potentially more robust, but would of course require development effort. The committee recommends that the collaboration look at the cost versus benefit for the two approaches before finalizing a decision to buy a commercial system.

2.2.3 Preamplifier

The Analog Devices AD8009 amplifier is a sensible choice for the front end amplifier. General concerns include:

a) Control of gain and offset variation due to temperature and other environmental effects. The required experimental control of gain and offsets was not clear.

b) A coherent grounding plan is advisable, and was not present at time of the review. Ground loops are a common problem of large extended systems such as the one proposed. Careful attention to minimizing ground loops and maintaining one clear system ground reference will go a long way in reducing noise and improving stability.

2.2.4 Environmental Issues

The electronic systems of the complexity proposed REQUIRES reliable and sufficient environmental control for successful operation: keep it cool and keep it dry, don't try to save money here. Debugging and maintaining these systems will require reliable access and operation during hot days.

2.2.5 Cables

The large number of cables and connectors in the system will likely play a role in the reliability of the system. Connectors are a notorious source of reliability problems in systems of this complexity.

2.2.6 Optical Fiber Cables

The proposed optical fiber cable replacement for the baseline conventional cables is a great solution and significant improvement; if it works. There is substantial risk here. The design is based upon the analog properties of a VCSEL laser which is commercially produced as a digital product. The vendor does not specify the analog characteristics so changes in the design or fabrication process could render the part useless in this application with no recourse.

This upgrade is a challenge for the VERITAS project management. Some clear, objective, decision process will have to be developed, and honored, to determine when and how to adopt or abandon this solution in favor of the baseline conventional cable solution.

2.2.7 Constant Fraction Discriminators

The CFDs proposed look fine. This solution is not what the committee would choose but this is clearly only a matter of taste.

2.2.8 Pattern Trigger

The pattern trigger described is based on the existing trigger from the Whipple 10 m telescope. The goal of lowering the threshold by about a factor of 2 at constant trigger rate is clearly well motivated. The system proposed does and will work. The electronic implementation in CAMAC modules with a specialized ECL signal splitter isn't really consistent with the 9U VME boards being developed everywhere else in the system. The committee has some concern that this system might become a long term problem in terms of maintenance and flexibility. Perhaps you should consider going with the proposed design for the first telescope and upgrade, soon, to a 9U VME solution based on large logic arrays. A new design with 3 or 4 modern FPGAs on a single board should be able to perform that same task as a high powered CAMAC crate full of the system as presently designed.

2.2.9 DOT Boards

The scheme presented for fiber optic digital data transfer to bring the signals from individual telescopes to a central point is sensible and seems a good choice. The ground isolation provided by a photonic link is a definite plus given the certainty of lightning strikes to the array. An analysis of the ground path for a lightning strike to one telescope with the goal of minimizing the risk to the whole array might be wise.

2.2.10 FADCs

The high speed flash encoder system will provide a dramatic increase in the information available, and will no doubt be a powerful tool in reducing the energy threshold and raising the general performance of the experiment. The proposed system is clearly the "technology frontier" of the experiment. General concerns include:

a) There didn't appear to be a frequency bandwidth consensus in the analog signal path chain from the preamplifier to the flash encoder input. The system stability will be improved by operating all the analog subsystems at the minimum required bandwidth.

b) It wasn't clear what the required linearity relationship is between the pulse voltage, which fires the trigger discriminators, and the charge integral data provided by the flash encoder. Since the experiment endeavors to run at the lowest possible threshold, it's likely that this relationship will be relevant in understanding the low energy data.

c) Simultaneous digitization and acquisition: A common problem of encoders that acquire and digitize simultaneously (buffered operation) is acquisition induced corruption of the digitization. The designers stated that buffered operation will be supported but is not required for successful operation of the system.

d) Power consumption: The flash encoder system presents a large thermal load, and sufficient cooling AND cooling system interlocks are a MUST in a system like this.

e) Schedule issues: The proposed system is largely based around very high speed multi-layer analog/digital printed circuit boards. The designers have allowed effectively two prototype iterations, which seems like an aggressive schedule for a board of this complexity. Fortunately the designers are working closely with the printed circuit board vendor, which has delivered prototype boards in a timely way.

2.2.11 Data Acquisition

The data acquisition system is built around high performance commercially available hardware and software, and appears to be a sensible and robust design. The issue of how front-end "busies" are serviced wasn't clear, and in general the system needs to be able to handle and recover from data backups at every stage.

2.2.12 Array Trigger

The array trigger appears well thought out and robust. The only comment here is that the event number that is fanned out to data streams should be generated by one simple hardware module, that fans a hardware event number to the data sub-streams.

2.3 Summary

"Overall the VERITAS electronics and data acquisition design concepts the committee has reviewed are sound and well conceived. The designs are well thought out and the collaboration appears to have the necessary skills and experience to execute them in a timely and successful way. The biggest risk to the project is schedule delay. The FADC development schedule is aggressive and could cause significant delays if more design iterations than now planned are required. The Optical Cable decision is a challenge to project management. The potential benefits of this enhancement justify the effort to develop this technology. The criteria for accepting or forgoing this option and the timing of this decision should be thoughtfully planned."

3 Observation Plan for VERITAS Years 1–3

3.1 Whipple Collaboration Observation Selection Procedure

The Whipple Collaboration uses an internal peer–review process to establish the yearly observing program. Observers from within the collaboration submit observing requests consisting of a 1-2 page document detailing the scientific motivation for the observation, the amount of time requested for the observation, and the strategy for acquiring the observations (e.g., how the time should be spread out, any constraints on elevation, etc.). A Telescope Allocation Committee, consisting of one representative from each collaborating institution, reviews each proposal and ranks them according to the compelling nature of the science, suitability for the 10 m telescope, and the chance for success. The program for the observing season is drawn from the rank–ordered list of proposals until the anticipated observing time for the season is filled. In addition to the observers program a small fraction of the telescope time ($\sim$ 10%) is reserved for engineering purposes as well as discretionary observations (e.g., an AGN which is in a high, or active, state). The actual allocation of the telescope is carried out by the local group in Tucson and is determined by the local sidereal time in any given dark period (i.e., roughly the time between last quarter of the Moon and first quarter of the Moon).

3.2 VERITAS: the Boundary Conditions

Based upon 30 years of experience on the ridge of Mt. Hopkins $\sim$800 clear, moon-less hours can be expected in any year on average. The baseline VERITAS site in the Montosa Canyon, owing to its lower elevation compared to the Mt. Hopkins ridge, is expected to yield $\sim$900 clear, moon-less hours a year on average. The first three years of operation of the full VERITAS array would then have $\sim$2,700 hours of clear, moonless conditions to carry out its scientific program. We identify four distinct modes of the full VERITAS array: mode **A** trains all seven telescopes on the scientific target to achieve the highest sensitivity and lowest energy threshold observations; mode **B1** divides the full array into two sub-arrays (one sub-array consists of four telescopes and the second sub-array consists of three telescopes) so that two scientific programs can be carried out in parallel; mode **B2** consists of two sub-arrays, each of three telescopes, for carrying out two scientific programs simultaneously while a single telescope monitors variable sources; mode **C** utilizes each telescope as a separate instrument to search for new sources and to monitor sources in active states.

3.3 VERITAS Scientific Program

The proposed three year program for the full VERITAS array is outlined in Table 1 below.

Table 1: Proposed 3 Year Observation Program of VERITAS

Mode	Scientific Program	Allocation	Hours	Total
B1/B2	Galactic Plane Survey	80 nights @ 8 hrs/nt	640	640
A	Survey follow–up	20 sources @ 10 hrs/src	200	840
A	XBL AGN†	30 w/ $z < 0.3$ @ 10 hrs/AGN	300	1140
A	EGRET AGN†	top 20 @ 10 hrs ea.	200	1340
A	Neutralino search	30 hrs/yr for 2 yrs	60	1400
A	Pulsars††	top 5 @ 50 hrs/pulsar	250	1650
B1/B2	Supernova Remnants†††–shell type	top 10 @ 25 hrs/SNR	250	1900
B1/B2	Supernova Remnants†††–plerionic	top 10 @ 25 hrs/SNR	–	1900
B1/B2/C	AGN Monitoring†††	brightest– 50 hrs/yr	–	1900
A	Gamma-Ray Bursts†	50 hrs/yr	150	2050
any	Discretionary/Target of Opportunity	100 hrs/yr	300	2350
–	Engineering	10% total	300	2650

†Scientific goals depend on sensitivity and energy threshold of the full VERITAS array.

††Scientific goals are compromised without the full VERITAS array.

†††These programs can be carried out in parallel so additional targets do not increase observing time.

3.3.1 Galactic Plane Survey

This program will be a path finder for new source classes in the Galaxy and will concentrate on the first quadrant of the Galactic plane (i.e., $0^\circ < l_{II} < 90^\circ$) spanning Galactic longitudes of $|b_{II}| \leq 2^\circ$ at full sensitivity. The visibility of the Galactic plane restricts observations to no more than 4 months per year so the entire survey will require 3 years to complete. The portion of sky surveyed will include 19 young, energetic pulsars, 12 unidentified EGRET sources, numerous supernova remnants of varying ages, several X-ray binaries, and at least one Galactic microquasar. The full 360 square degree survey will be carried out by observing each imaging location several times to maximize the coverage of potentially variable sources and to permit variability studies of the brightest sources. During the survey, time will be allocated to follow-up any new or possible source detections.

3.3.2 XBL AGN

This is the group of X-ray selected BL Lac objects which are the only confirmed extragalactic sources above the GeV range. It is anticipated that VERITAS will detect between 20 and 30 of the sources depending somewhat on the source spectra and the amount of attenuation above energies of 300 GeV. Table 2 lists the 33 known XBL AGN which are visible with VERITAS and have a cosmological redshift $z \leq 0.5$. As the ROSAT all sky survey analysis is completed the number of candidate sources is expected to increase.

Table 2: XBL AGN with $z \leq 0.5$ visible to VERITAS.

#	Name	R.A. (J2000)	Dec. (J2000)	z
1	1ES 0120+340	$01^h\ 23'\ 08''.6$	$+34^\circ\ 20'\ 47''.5$	0.272
2	1ES 0145+138	$01^h\ 48'\ 29''.7$	$+14^\circ\ 02'\ 18''.0$	0.125
3	1ES 0158+003	$02^h\ 01'\ 06''.3$	$+00^\circ\ 34'\ 00''.0$	0.299
4	3C 66A	$02^h\ 22'\ 39''.6$	$+43^\circ\ 02'\ 08''.0$	0.444
5	1ES 0229+200	$02^h\ 32'\ 48''.6$	$+20^\circ\ 17'\ 17''.0$	0.139
6	RGB 0326+024	$03^h\ 26'\ 14''.0$	$+02^\circ\ 25'\ 16''.0$	0.147
7	1ES 0347-121	$03^h\ 49'\ 23''.2$	$-11^\circ\ 59'\ 27''.0$	0.188
8	1H 0413+009	$04^h\ 16'\ 52''.4$	$+01^\circ\ 05'\ 24''.0$	0.287
9	1ES 0446+449	$04^h\ 50'\ 07''.2$	$+45^\circ\ 03'\ 12''.0$	0.203
10	1H 0506-039	$05^h\ 09'\ 38''.1$	$-04^\circ\ 00'\ 46''.0$	0.304
11	1ES 0525+713	$05^h\ 31'\ 41''.7$	$+71^\circ\ 22'\ 17''.0$	0.249
12	MS 0737.9+7441	$07^h\ 44'\ 05''.7$	$+74^\circ\ 33'\ 58''.0$	0.315
13	1ES 0806+524	$08^h\ 09'\ 49''.2$	$+52^\circ\ 18'\ 58''.4$	0.138
14	1ES 0927+500	$09^h\ 30'\ 37''.6$	$+49^\circ\ 50'\ 26''.0$	0.188
15	1ES 1011+496	$10^h\ 15'\ 04''.2$	$+49^\circ\ 26'\ 00''.0$	0.200
16	RGB 1031+508	$10^h\ 31'\ 18''.5$	$+50^\circ\ 53'\ 35''.8$	0.239
17	Markarian 421	$11^h\ 04'\ 27''.3$	$+38^\circ\ 12'\ 31''.8$	0.031
18	RGB 1120+422	$11^h\ 20'\ 48''.1$	$+42^\circ\ 12'\ 12''.5$	0.124
19	Markarian 180	$11^h\ 36'\ 26''.4$	$+70^\circ\ 09'\ 27''.3$	0.046
20	1H 1219+301	$12^h\ 21'\ 21''.9$	$+30^\circ\ 10'\ 37''.1$	0.182
21	MS 1229.2+6430	$12^h\ 31'\ 31''.4$	$+64^\circ\ 14'\ 18''.4$	0.170
22	1ES 1255+244	$12^h\ 57'\ 31''.9$	$+24^\circ\ 12'\ 40''.0$	0.141
23	1E 1415+2557	$14^h\ 17'\ 56''.7$	$+25^\circ\ 43'\ 25''.0$	0.237
24	1H 1430+423	$14^h\ 28'\ 32''.6$	$+42^\circ\ 40'\ 21''.1$	0.130
25	RGB 1442+120	$14^h\ 42'\ 48''.2$	$+12^\circ\ 00'\ 41''.0$	0.162
26	MS 1552.1+2020	$15^h\ 54'\ 24''.1$	$+20^\circ\ 11'\ 25''.4$	0.222
27	1ES 1553+113	$15^h\ 55'\ 43''.2$	$+11^\circ\ 11'\ 21''.0$	0.360
28	Markarian 501	$16^h\ 53'\ 52''.2$	$+39^\circ\ 45'\ 36''.6$	0.033
29	I Zw 187	$17^h\ 28'\ 18''.6$	$+50^\circ\ 13'\ 10''.5$	0.055
30	1ES 1741+196	$17^h\ 43'\ 57''.5$	$+19^\circ\ 35'\ 10''.0$	0.083
31	1ES 1959+650	$19^h\ 59'\ 59''.9$	$+65^\circ\ 08'\ 55''.0$	0.048
32	1ES 2326+174	$23^h\ 29'\ 03''.3$	$+17^\circ\ 43'\ 30''.0$	0.213
33	1ES 2344+514	$23^h\ 47'\ 04''.8$	$+51^\circ\ 42'\ 18''.0$	0.044

3.3.3 EGRET AGN

The AGN detected by EGRET that are visible in the Northern Hemisphere are given in Table 3 below in order of detected flux. The first 3 years of operation of the full VERITAS array will allow us to survey the top 20 of these GeV AGN at the highest sensitivity. Subsequent years will allow us to survey the group as a whole with additional direction from the GLAST observatory. At a minimum we anticipate detection of some 17 of these GeV AGN.

3.3.4 Fundamental Physics – Neutralino Search

VERITAS will provide unique measurements important to fundamental physics through the observation of photons from fundamentally important objects or through propagation effects on electromagnetic radiation resulting from new physics. In the first years of VERITAS we will focus on the issue of neutralinos since they are the prime candidate for the cold dark matter component of the universe. Observations of 60 hours carried out with the full array will probe a significant portion of the allowed phase space of neutralino and dark matter parameters.

Table 3: 20 Brightest EGRET AGN Visible to VERITAS

Name	RA	DEC	Flux 10^{-8} photons cm^{-2} s^{-1}	z
3EG J1255-0549	$12^h\ 55'\ 55''$	$-5^\circ\ 49'\ 12''$	179.7	0.54
3EG J0340-0201	$3^h\ 40'\ 10''$	$-2^\circ\ 1'\ 12''$	118.8	0.85
3EG J0442-0033	$4^h\ 42'\ 12''$	$0^\circ\ -33'\ 0''$	79	0.84
3EG J0237+1635	$2^h\ 37'\ 26''$	$16^\circ\ 35'\ 24''$	65.1	0.94
3EG J2254+1601	$22^h\ 54'\ 2''$	$16^\circ\ 1'\ 12''$	53.7	0.86
3EG J1200+2847	$12^h\ 0'\ 29''$	$28^\circ\ 48'\ 0''$	50.9	0.73
3EG J0422-0102	$4^h\ 22'\ 36''$	$-1^\circ\ 2'\ 24''$	50.2	0.92
3EG J0852-1216	$8^h\ 52'\ 38''$	$-12^\circ\ 16'\ 12''$	44.4	0.57
3EG J1605+1553	$16^h\ 5'\ 12''$	$15^\circ\ 53'\ 24''$	42	0.36
3EG J2202+4217	$22^h\ 2'\ 24''$	$42^\circ\ 17'\ 24''$	39.9	0.07
3EG J1733-1313	$17^h\ 33'\ 50''$	$-13^\circ\ 13'\ 48''$	36.1	0.9
3EG J0743+5447	$7^h\ 43'\ 19''$	$54^\circ\ 48'\ 0''$	30.3	0.72
3EG J0204+1458	$2^h\ 4'\ 26''$	$14^\circ\ 58'\ 12''$	23.6	0.41
3EG J1744-0310	$17^h\ 44'\ 5''$	$-3^\circ\ 10'\ 48''$	21.9	1.05
3EG J2232+1147	$22^h\ 32'\ 26''$	$11^\circ\ 48'\ 0''$	19.2	1.04
3EG J0222+4253	$2^h\ 22'\ 48''$	$42^\circ\ 54'\ 0''$	18.7	0.44
3EG J1512-0849	$15^h\ 12'\ 41''$	$-8^\circ\ 49'\ 48''$	18	0.36
3EG J1727+0429	$17^h\ 27'\ 53''$	$4^\circ\ 30'\ 0''$	17.9	0.3
3EG J0721+7120	$7^h\ 21'\ 43''$	$71^\circ\ 21'\ 0''$	17.8	$\sim$0.3
3EG J0828+0508	$8^h\ 28'\ 10''$	$5^\circ\ 8'\ 24''$	16.8	0.18
3EG J0737+1721	$7^h\ 37'\ 53''$	$17^\circ\ 21'\ 0''$	16.4	$\geq$0.424
3EG J0958+6533	$9^h\ 58'\ 29''$	$65^\circ\ 33'\ 36''$	15.4	0.37
3EG J1229+0210	$12^h\ 29'\ 0''$	$2^\circ\ 10'\ 12''$	15.4	0.16
3EG J1104+3809	$11^h\ 4'\ 24''$	$38^\circ\ 9'\ 0''$	13.9	0.03
3EG J1224+2118	$12^h\ 24'\ 26''$	$21^\circ\ 18'\ 36''$	13.9	0.44
3EG J2036+1132	$20^h\ 36'\ 43''$	$11^\circ\ 32'\ 24''$	13.3	0.6
3EG J1230-0247	$12^h\ 30'\ 36''$	$-2^\circ\ 47'\ 24''$	12.7	1.05
3EG J1339-1419	$13^h\ 39'\ 22''$	$-14^\circ\ 19'\ 12''$	11.8	0.54
3EG J1222+2841	$12^h\ 23'\ 0''$	$28^\circ\ 42'\ 0''$	11.5	0.1
3EG J0853+1941	$8^h\ 53'\ 41''$	$19^\circ\ 40'\ 48''$	10.6	0.31
3EG J0952+5501	$9^h\ 52'\ 2''$	$55^\circ\ 1'\ 12''$	9.1	0.9

3.3.5 Gamma–Ray Pulsars

One of the outstanding questions in gamma-ray astrophysics pertains to the origin of the pulsed emission in neutron stars. The EGRET instrument aboard the Compton Gamma-Ray Observatory has detected pulsed GeV gamma rays from six young, spin powered neutron stars. Spectral measurements in the 10–300 GeV range will provide decisive data to sort out the issue of the seat of the acceleration in these systems. VERITAS, with its good sensitivity above 50 GeV, will probe the cutoff region of the gamma-ray pulsars and solve the mystery of the accelerator mechanism. Table 4 below lists the top five targets which VERITAS will initially pursue.

Table 4: Five pulsars which will be observed with VERITAS.

PSR	RA	DEC	$\dot{E}/\mathrm{D}^{2\dagger}$	Comments
B0531+21	$5^h\ 31'\ 31''.4$	$21^\circ\ 58'\ 54''.3$	112	Crab Pulsar, EGRET pulsed source
B0630+18	$6^h\ 33'\ 54''.0$	$17^\circ\ 46'\ 11''.5$	3.24	GEMINGA, EGRET pulsed source
B1951+32	$19^h\ 52'\ 58''.3$	$32^\circ\ 52'\ 40''.5$	0.59	CTB 80 pulsar
B0656+14	$6^h\ 59'\ 48''.1$	$14^\circ\ 14'\ 21''.5$	0.42	EGRET pulsed source
J0538+2817	$5^h\ 38'\ 25''.0$	$28^\circ\ 17'\ 11''.0$	0.2	

$^\dagger\dot{E}/\mathrm{D}^2$ is a measure of gamma-ray visibility where $\dot{E}$ is the spin down power in units of 10^{36} erg s^{-1} and D^2 is the square of the distance in units of kiloparsecs.

3.3.6 Supernova Remnants

Two types of supernova remnant are morphologically recognized; shell type and center filled. As outlined in the VERITAS proposal the full array should detect ∼20 Galactic supernova remnants within 4 kpc of the Earth if the diffusive shock emission models are indeed correct. Table 5 lists the top 20 candidate targets of VERITAS with both a shell and center filled morphology.

Table 5: SNRs to be observed with VERITAS.

Name	RA (hr min)	DEC (deg min)	Size (arcmin)	Morphology†
W44	$18^h\ 53'$	$1^\circ\ 18'$	35x27	S
W51	$19^h\ 21'$	$14^\circ\ 0'$	30	S
Cygnus Loop	$20^h\ 49'$	$30^\circ\ 30'$	230x160	S
γ Cygni	$20^h\ 19'$	$40^\circ\ 15'$	60	S
W63	$20^h\ 17'$	$45^\circ\ 20'$	95x65	S
HB21	$20^h\ 43'$	$50^\circ\ 25'$	120x90	S
CAS A	$23^h\ 21'$	$58^\circ\ 32'$	5	S
Tycho	$0^h\ 22'$	$63^\circ\ 52'$	8	S
G156.2+5.7	$4^h\ 54'$	$51^\circ\ 47'$	110	S
IC443	$6^h\ 14'$	$22^\circ\ 36'$	45	S
W28	$17^h\ 57'$	$-23^\circ\ 25'$	42	C
SN AD386	$18^h\ 8'$	$-19^\circ\ 26'$	4	C
G21.5-0.9	$18^h\ 30'$	$-10^\circ\ 37'$	1.2	F
KES 75	$18^h\ 43'$	$-3^\circ\ 2'$	3	C
G32.1-0.9	$18^h\ 50'$	$-1^\circ\ 12'$	40	C
G54.1+0.3	$19^h\ 28'$	$18^\circ\ 46'$	1.5	F
CTB 80	$19^h\ 51'$	$32^\circ\ 45'$	80	$*$
CTB 87	$20^h\ 14'$	$37^\circ\ 3'$	8x6	F
CTA 1	$0^h\ 4'$	$72^\circ\ 30'$	90	S
3C58	$2^h\ 1'$	$64^\circ\ 35'$	9x5	F

†S = shell; F = filled; C = Composite; $*$ complicated

3.3.7 Additional Targets

Time will be allocated within the standard observing schedule for targets which cannot be pre-scheduled due to their intrinsically variable nature. These are targets such as AGN in outbursts which are to be monitored (utilizing a single telescope in the **B2** mode of operation), gamma-ray bursts, and discretionary targets such as flaring Galactic black hole candidates or transient X-ray binary targets. Of course, as with all observatories, a certain amount of engineering time will be required. Experience has shown that a 10% allotment is usually sufficient once stable operation has been achieved.

3.4 Summary

We have put forward here a very ambitious program of observations for the first three years of the full VERITAS array, but the flexibility of the seven telescopes of VERITAS make such an ambitious program manageable. The fact that two, and in some cases three, scientific programs can be pursued in parallel is one of the compelling strengths of VERITAS. The results of the first 3 years of operation will also point us in the appropriate scientific directions for the out years of VERITAS. Given the large discovery space available to VERITAS a full and rich scientific program can be expected for many years beyond the initial three years described here.

4 Justification of VERITAS Design

4.1 Introduction

The performance characteristics required of the VERITAS array of imaging Cherenkov telescopes are derived from its scientific goals. VERITAS was designed to optimize sensitivity and flexibility for observing a variety of sources, each of which may require a different subset of capabilities (e.g., continuous monitoring, large field of view, good flux sensitivity, large collection area, accurate angular resolution, low energy threshold, accurate energy resolution, prompt response, or broad energy coverage). With these features, VERITAS can observe known and anticipated sources in several observing modes. In addition, the array permits flexible reconfiguration to pursue unanticipated discoveries. Briefly summarized, the VERITAS scientific objectives are:

AGN studies: The highly variable flaring activity observed in known TeV sources suggests that continuous monitoring of many AGN, even using instruments with somewhat reduced capabilities, may be an efficient means of detecting these objects. The determination of energy spectra and study of short timescale variability require the best energy resolution and the largest collection area achievable. Extending the energy range to below 100 GeV is crucial for detecting high redshift objects and additional classes of AGN with cutoffs below a few hundred GeV.

Galactic plane survey: A large field of view, good flux sensitivity, large collection area are required to discover stable and variable sources through a large area survey. Also, broad energy coverage will increase sensitivity to objects with a variety of emission spectra. Because this requires substantial observing time, this survey can be accomplished most efficiently if the array can be split into subarrays.

Unidentified EGRET sources: Accurate angular resolution (for source position reconstruction), wide field of view (for poorly constrained source positions), and low energy threshold (to detect previously unknown pulsars) are essential to understanding the nature of the unidentified EGRET sources.

Supernova remnants: Excellent sensitivity in the 200 GeV - 2 TeV energy range is needed for this task. Also required is excellent angular resolution to study these extended sources and accurate spectra over a broad energy range to resolve contributions to the emission.

EBL studies: Accurate energy spectra from sources at a range of redshifts are needed to resolve the effects of attenuation of γ-rays by pair-production with extragalactic background light (EBL). Large photon statistics (i.e., large effective area) and good energy resolution are needed for accurate spectral measurements. Also, spectroscopy in the region around 100 GeV is of particular importance for estimating the EBL spectral density in the whole wavelength range from 0.1-100 μm because the amount of absorption from the EBL is expected to rapidly decrease there.

GRBs: Prompt response to detect a rapidly decreasing flux, a large field of view for poorly located sources, and the ability to operate below 100 GeV to extend the visibility range to high redshifts are desired.

Dark matter candidates: Broad energy coverage, good energy resolution and good flux sensitivity are the most important requirements for detecting a neutralino annihilation line whose specific energy and flux is not well-constrained.

Pulsars: Operation below 100 GeV is required due to the expected spectral cutoffs in these objects.

The energy ranges of these areas of interest as well as the range of sensitivity of γ-ray telescopes is shown in Figure 1.

4.2 Technicalities

For this sub-section, we assume the baseline VERITAS array is seven 10 m telescopes positioned on a hexagonal grid with 80 m sides operated in a trigger mode requiring at least three adjacent pixels in three telescope cameras to exceed a 4.2 photoelectron (pe) threshold. We define a sub-array as three telescopes located on an equilateral triangle with $\sqrt{3} * 80$ m separation. The sub-array trigger requires all three telescopes to detect >4.2 pe per pixel in at least 3 adjacent pixels.

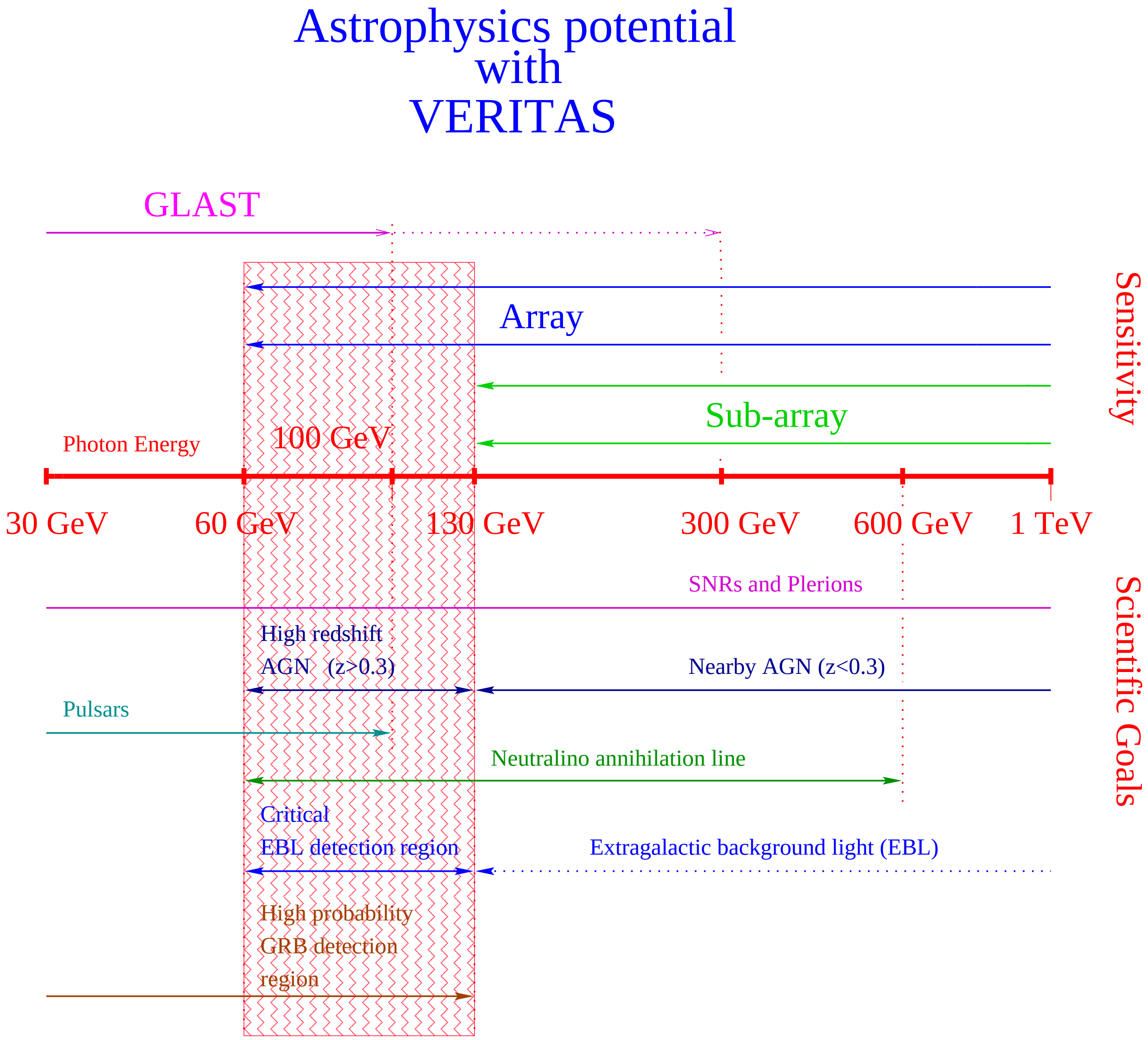

Figure 1: Energy ranges covered with good sensitivity by the seven-telescope VERITAS (Array), a three-telescope array (Sub-array), and GLAST compared to the relevant energy ranges for studying some scientific topics of interest to VERITAS. The hashed area emphasizes the region not covered by the three-telescope sub-array.

4.3 Design Considerations

To achieve the greatest scientific return with VERITAS, the required characteristics of the chosen design for VERITAS are low energy operation ($\lesssim$100 GeV), large array collection area, and the ability to split the array into sub-arrays.

In general, the multiple stereoscopic view of the sky afforded by an array has several significant advantages over a single telescope. For example, the angular origin of the primary γ-ray can be determined to better than about 0.1° which may be crucial for mapping extended sources such as SNR and eliminating source confusion when there are several possible candidates within the field of view. It dramatically reduces the background from isotropically distributed cosmic-ray protons and electrons. Also, the shower core location can be found to better than 10 m which, when combined with the light in the shower striking several telescopes, allows one to reconstruct the energy with a factor of three better resolution than a single telescope. In principle, two telescopes are sufficient for stereoscopic reconstruction of a shower, but only a relatively small fraction

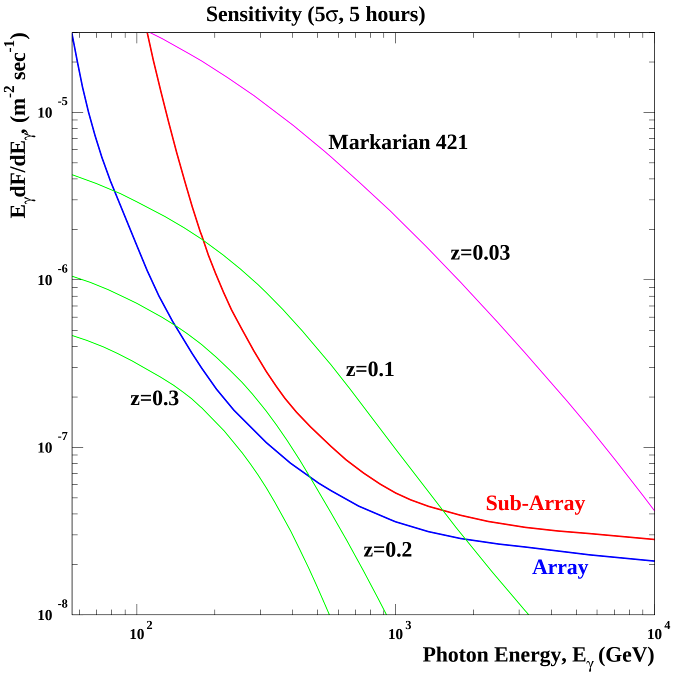

Figure 2: The flux sensitivity, expressed as $E * dF/dE$, for the full VERITAS array (seven telescopes) and the sub-arrays (three telescopes) for a five-hour exposure. For reference, the spectrum of Markarian 421 as seen on May 7, 1996 is shown, with an extrapolation of the spectrum below 400 GeV. We also show the flux which would be seen if the source were at different redshifts, where the flux is reduced by distance and attenuated by extragalactic absorption.

of the showers are sufficiently near both telescopes to trigger them simultaneously, yet far enough away from the line joining the telescopes to permit good angular reconstruction. Thus, a three-telescope array is the minimum practical size. As more telescopes are added, the gain in sensitivity comes mostly through reducing the energy threshold at which meaningful measurements can be made. The joint requirements of adequate light from a single shower at the telescopes (implying a small separation) and angular reconstruction of the shower (implying a large separation) gives an optimal separation of about 80 m for the telescope spacing. The collection area of an array grows more slowly beyond three telescopes and is related to the area of the shower (about 250 m in diameter) folded with the area of the array.

The VERITAS configuration was chosen (after extensive simulations) for the reasons outlined in the remainder of this sub-section.

4.3.1 Low Energies

Although high sensitivity measurements in the energy region above 130 GeV will be accessible with a smaller array of 10 m telescopes (e.g., 3 or 4 telescopes), *the energy range from 60 GeV to 130 GeV is only accessible with the full array of seven telescopes.* Some cosmic sources (e.g., γ-ray pulsars or possibly γ-ray bursts) may be detectable *only* in the lowest energy range which is accessible with the full seven-telescope array. However, energy measurements on *all* sources will benefit from having meaningful spectral measurements over a wide range of energies. The differential flux sensitivity is defined as the flux level over an energy interval of 1/4 of a decade over which an energy measurement can be made to the 20% level in 50 hours of observation. This is the meaningful level for astrophysical measurements. The flux sensitivity for the full array is shown in Figure 2 where it is contrasted with the flux sensitivity for a three telescope array (Sub-array).

The energy band from 60 GeV to 130 GeV is a particularly interesting one for many astrophysical measurements:

- It is the critical region for the study of AGN with z from 0.3 to 1.0. As seen in Figure 3, sensitivity in this region allows the study of objects like Mrk 421 beyond redshifts of 0.3. Also, many EGRET-detected AGN are expected to have intrinsic spectral cut-offs in this energy region.

- This region is most important for measurements of the cutoff in γ-rays from extragalactic sources due to pair production on the EBL.
- It is the region with the greatest possibility for the detection of pulsars as illustrated in Figure 4 where the extrapolated spectrum of PSR 1951+32 is shown for cutoffs of 50 GeV and 75 GeV.
- Sensitivity at these low energies provides the highest probability of γ-ray burst detection due to their large redshift. Information on the high energy spectra of GRBs is scarce but in Figure 5 we show the extrapolated spectra from EGRET measurements using an extragalactic infrared density model of Primack and assuming a distance to the burst source of z=0.94. If the fraction of high mass stars created during the epoch of star formation is low, the attenuation will be considerably less. A one minute duration is assumed for the very high energy emission and the sensitivity is a $5\,\sigma$ detection per 1/8 decade of energy. In Figure 6 the simulated relative response of a hard-spectrum GRB is shown for the full Array and the Sub-array.
- This band covers a large portion of the allowed phase space for neutralino line emission.
- Broad-band spectral energy measurements of supernova remnants are essential to resolve the emission mechanisms at work in these objects. Effective combination of VERITAS with GLAST will provide energy spectra over 6 magnitudes in γ-ray energy. GLAST will be able to detect γ-rays out to 300 GeV, but its primary sensitivity range will be below about 100 GeV due its small effective area. With energy coverage significantly below 100 GeV, VERITAS will permit accurate cross-calibration with GLAST, maximizing the scientific return of combined measurements with these instruments.

4.3.2 Versatility

As discussed in § 3, the observing program for VERITAS can only be accomplished in a timely fashion if the array can be divided in two or more sub-arrays for simultaneous monitoring of different regions of the sky. A sub-array of three or four telescopes is very powerful and performs almost as well as the full array for the detection of new sources and measurement of established sources above ~250 GeV. Above ~250 GeV, a sub-array also has comparable angular resolution to the full array and provides excellent performance for spectral studies. Some scientific studies, such as the long-term variability of AGN, can *only* be accomplished with a sub-array dedicated to monitoring one particular object for extensive time periods. It is anticipated that the array will be operated as two independent sub-arrays at least 50% of the time.

4.3.3 Flexibility

Experience has shown that the full potential of an atmospheric Cherenkov telescope is only realized *after* the detection of γ-ray sources. Therefore, we anticipate that, with operating experience, significant improvements will be made in the achievable flux sensitivity of VERITAS by varying both the observing techniques and the telescope hardware. The multi-telescope configuration of VERITAS presents the maximum adaptability in this regard.

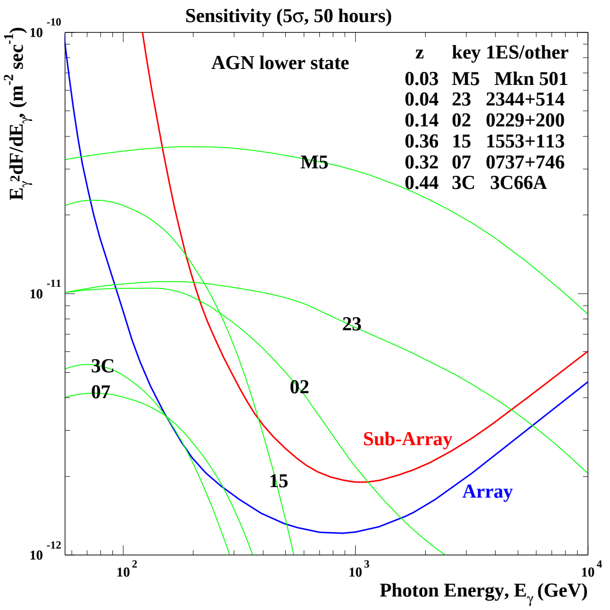

Figure 3: The flux sensitivity, expressed in units of $E^2 * dF/dE$, for the full VERITAS array (seven telescopes) and a sub-array (three telescopes) for a 50 hour exposure. The measured spectrum of Mrk 501 from 1997 is shown, with an extrapolation below 250 GeV, as well as model spectra for some other similar type of AGN at different redshifts.

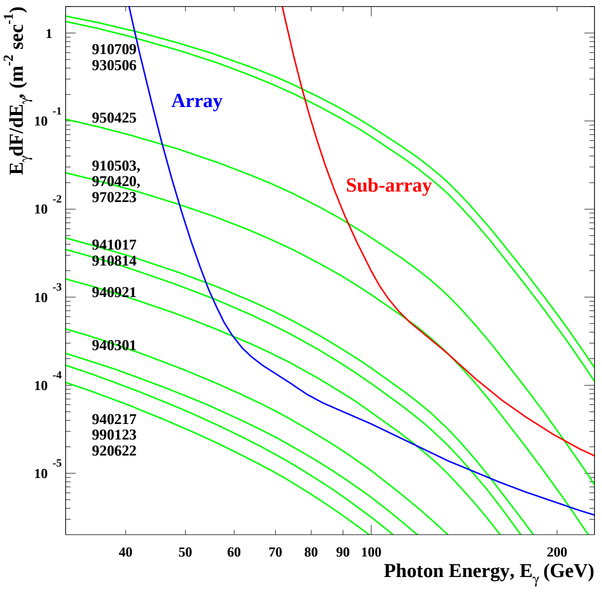

Figure 5: The flux sensitivity, expressed in units of $E * dF/dE$, for the full VERITAS array (seven telescopes) and a sub-array (three telescopes) for a 1 minute exposure. An extrapolation of the spectra measured by EGRET for several GRBs is shown after attenuating the γ-ray emission from interaction with the extragalactic background light.

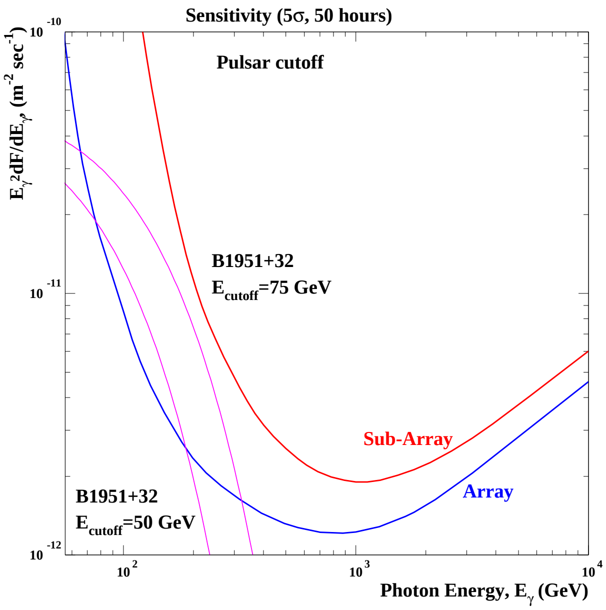

Figure 4: The flux sensitivity, expressed in units of $E^2 * dF/dE$, for the full VERITAS array (seven telescopes) and a sub-array (three telescopes) for a 50 hour exposure. The spectrum of PSR B1951+32 is shown extrapolated from EGRET energies with exponential cut-offs at 50 GeV and 75 GeV.

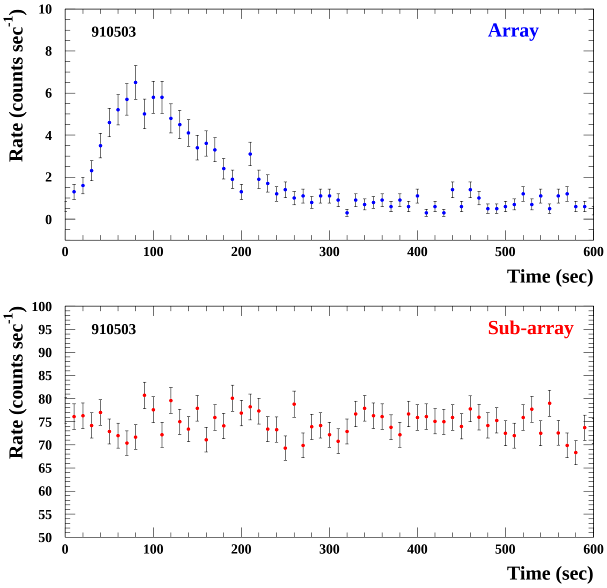

Figure 6: Simulated lightcurves (without background subtraction) measured by the full VERITAS array between 55 and 180 GeV (top) and a sub-array of three telescopes between 100 and 240 GeV (bottom) for GRB 910503 if the spectrum follows that indicated in Fig. 5. The background dominates the sub-array measurements because the data must be accumulated much closer to the lower end of its sensitive energy range.

5 FADC Subproject Update

5.1 Update on FADC/CFD System

Since the original VERITAS proposal was submitted, the design of the VERITAS FADC board has been completed. Printed circuit board (PCB) fabrication and gate-array programming are complete, stuffing and testing of the first 10 channel boards are now in progress. The FADC data acquisition scheme has been revised, and now includes reflective memory to merge data and provide a high-speed interconnection between crates. We have analyzed data taken with the prototype one-channel FADC system, and have used simulations to more rigorously justify the use of a 500 mega-sample per second (Msps) digitization rate. We have also developed a detailed plan for the complete fabrication of the boards by sub-contractors, and for the testing and maintenance of the boards throughout the construction phase of the project. The main points covered are summarized below:

- The FADC system for one telescope now consists of 51 10-channel 9U VME boards, with 17 located in each of 3 crates. High power Wiener crates with CERN v430 backplane will be used. A clock/trigger board in each crate will provide synchronous clear, trigger, and 500 MHz clock signals over a custom J3 backplane. This board will also latch the universal event number received by the DOT and presented on the ECL header. The J3 backplane will also supply busses for additional power.
- The FADC board serves as a motherboard for the Constant Fraction Discriminators (CFDs), providing DACs for threshold control, a singles rate scaler, buffering of the hit pattern programmable trigger delay and VME interface. The CFD design effort has been decoupled by putting the discriminator circuit on a mezzanine board with SIP connector pin-outs compatible with existing commercial CAEN CFD boards. This will allow alternate schemes for the discriminator to be explored.
- The total cost per channel for the finished, tested FADC/CFD boards will be <\$585 including the current CFD design.
- Each crate will contain a CPU and reflective memory module for readout control, event building and buffering.
- The FADCs will use the D32 Chained Block Transfer (CBLT) to efficiently transfer variable length data distributed among the 17 modules over the VME bus.
- FADC boards include a local SRAM (one on each 10-channel board) which is capable of on-board buffering of event data (initiated by the trigger signal) before data is read by the VME CPU over the backplane.
- The closest viable commercial device, the Acquiris Model DC265 CompactPCI/PXI 500 MHz FADC, is more than twice as expensive as the combined FADC/CFD board (the quote for VERITAS is ~\$1250 per channel), has a much lower channel density (4 per board, 8 boards per PCI backplane) requiring many more CPUs, no ability to extend the dynamic range above 8 bits, no ability to latch the CFD hit pattern, and lacks the ability to *chain* data transfers, resulting in a much larger read-out dead time.
- Simulations indicate an improvement in the signal to noise ratio and charge reconstruction quality factor of at least 11% in going from 250 Msps to 500 Msps. However, this requires significant real time processing to perform a sinc function interpolation. Without this processing, the difference is even larger, ~34%.
- Tests of the one-channel FADC board on Whipple indicate an improvement in the signal to noise ratio (for image reconstruction) of $\sim \sqrt{2}$ compared with the existing GRANITE-III electronics based on measurements of light pulser signals (signal) and pedestal variances (noise).
- The FADC board also stores the CFD state *for every 4 samples* in the same channel ring buffer used to store the FADC data. This provides a record of the triggering pixel hit pattern for every triggering event up to any trigger rate at which the telescope can be operated (e.g., a 1 MHz telescope trigger rate).

- Use of a hardware CFD trigger provides a low time jitter gate which is required to produce an optimal charge measurement for on-board zero-suppression and to minimize the data window (and hence the data rate).

5.2 FADC Subproject Management Plan

S. Swordy is the Group Coordinator for the camera/electronics task and, working with the VERITAS Project Manager, will oversee the project ensuring that the work stays on schedule and within budget, and that the interface requirements and other specifications of the FADC are met.

J. Buckley (Faculty, Washington University) working with Paul Dowkontt (electrical engineer, Washington University) will jointly complete the design of the electronics, and will oversee the FADC subproject. The Washington University electrical engineer will be responsible for the design and entry of the electronics schematics (for the FADC board, clock/trigger board, and J3 backplane), but will work with an outside consulting firm (Avid Technologies Inc) to do the printed circuit board (PCB) layout. Parts ordering, oversight of PCB manufacturing and layout, final electronic and mechanical assembly, and automated board testing will be the responsibility of an electronics technician, G. Simburger.

J. Buckley and a graduate student will design the elements of the data acquisition software required for designing the FADC data interface, and for designing the automated test setup.

The University of Chicago will take responsibility for the design of the FADC data acquisition computer and reflective memory which will merge the data from the three FADC crates, and will provide a high speed buffered interface to the data acquisition hardware. The University of Utah will build the CFD daughter boards or will work with CAEN to produce these. The University of Utah will also work on the thermal control system for the FADC electronics.

Figure 7 shows a flow chart of the FADC/CFD system design and fabrication.

The design starts with J. Buckley and is passed to P. Dowkontt who completes the detailed schematics. This design is passed on to Avid Technologies who complete the PCB layout working closely with P. Dowkontt. G. Simburger will oversee the remainder of the project. G. Simburger will order components for the boards, and initiate work at Sovereign Circuits who will fabricate and test PCBs. G. Simburger will send PCBs and Components to Libra Industries, who will machine stuff the boards. The completed boards will be returned to G. Simburger for final mechanical and electronic assembly and testing using an automated test station consisting of Wiener NIM and VME racks with a crate CPU. D. Kieda will supply CFD daughter cards, and S. Swordy will supply reflective memory modules, CPUs and Wiener Crates to be assembled at Washington University before shipping to Arizona.

5.2.1 Experience

The procedure described in the FADC design flowchart is similar to the procedure followed for the development of the one-channel FADC prototype and is almost identical to the procedure followed by the Washington University technical staff (led by P. Dowkontt) working on other projects. The FADC/CFD motherboards are 9U×400 mm format VME cards with ∼4000 components. The Washington University group has designed a 9U board with 3000 components which is quite similar in complexity and which has been used successfully in a balloon experiment (HEAT). As for the FADC boards, Avid Technologies did the layout, Sovereign manufactured the PCBs, and Libra Industries stuffed these boards.

The Washington University technical group also developed space-qualified electronics for the readout of image intensifiers on the CRIS instrument on-board the ACE satellite, has developed 6U VME pulse height analysis modules for balloon experiments as well as 3U VME discriminator boards which formed a multi-thousand channel system for MAPMT readout of scintillating fibers at an accelerator run in 1999. The design of the MAPMT discriminator boards also made use of P. Dowkontt, G. Simburger, Avid Technologies, and Libra although a PCB prototyping house (Nashua Circuits) was used for PCB fabrication.

Wiener Plein und Baus Corporation has extensive experience building VME crates for applications in high energy physics.

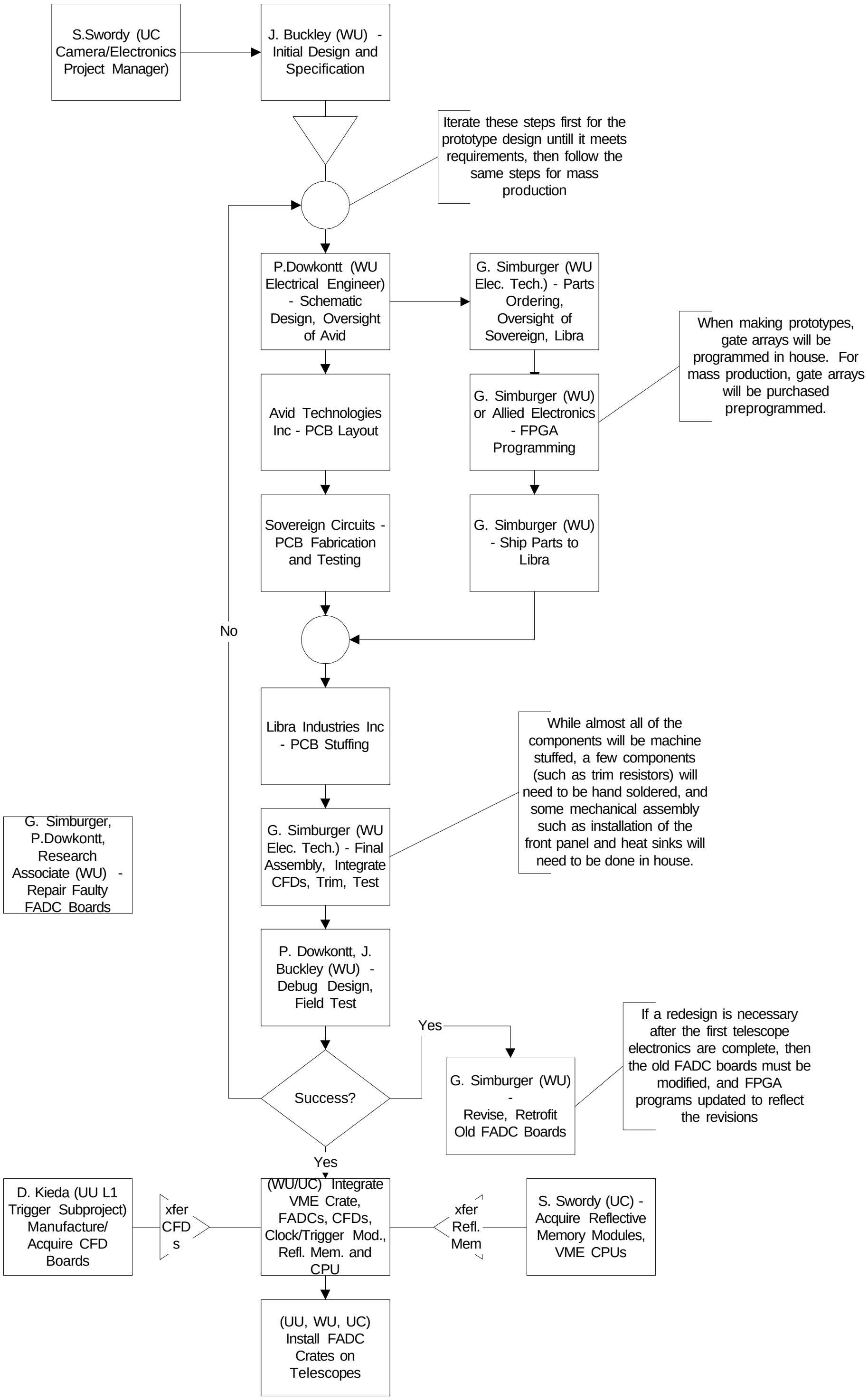

Figure 7: FADC subproject design/fabrication flowchart and management scheme .

5.3 Description of the 10 Channel FADC/CFD board

Figure 8 shows a simplified schematic of one FADC/CFD board, and indicates how 17 of these boards are integrated with other electronics into one of the three crates which make up the complete FADC system for

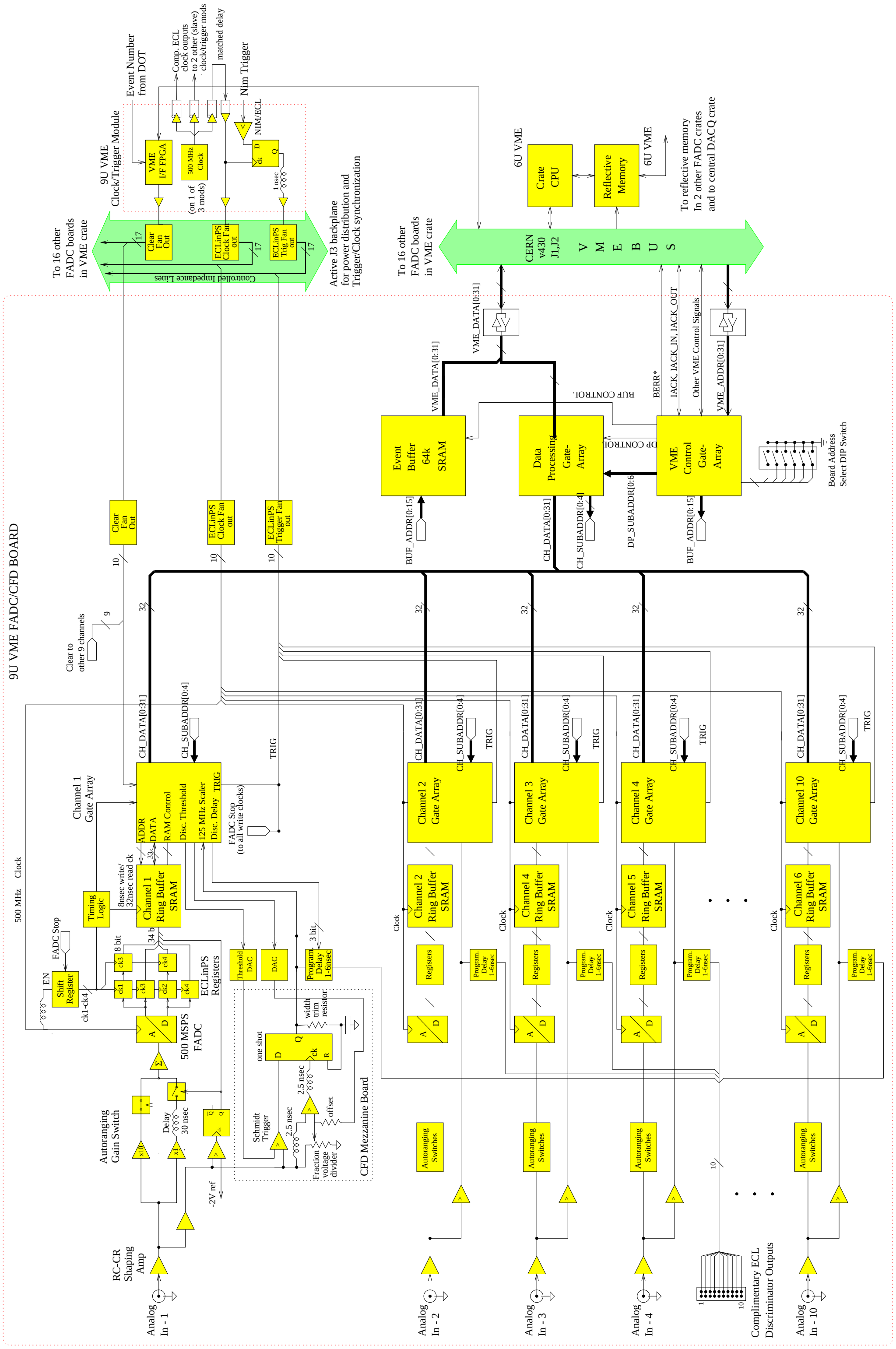

Figure 8: VERITAS FADC/CFD electronics.

one telescope.

5.4 Custom versus commercial units

The best commercial alternative to the custom FADC design is manufactured by Acquiris which uses a very high quality 500 Msps or 1Gsps FADC IC manufactured by Thomson. The Acquiris DC265 is a CompactPCI card with 4 FADC channels with sampling rates of 500 Msps and an analog bandwidth of 150 MHz. For the quantity required for VERITAS Acquiris is quoting $1250 per channel. Acquiris also makes an 8 slot CompactPCI crate (CC108) which could be used. These cards have a very high speed data interface, the ability to read out a small amount of data at a specified boundary in RAM and most of the other essential features needed for the mode of operation required for VERITAS.

The Acquiris FADC is, however, more than twice as expensive as the custom combined FADC/CFD board; the price difference in custom and commercial electronics has been and remains to be one of the principle drivers for the custom development. If these commercial units were to be used, we would need to purchase separate fan-outs, commercial CFDs, fan-out cables, and singles rate scalers which would result in an even larger price difference. While the Acquiris boards appear to be the best commercial choice (especially for applications which require 1 Gsps) there are a number of disadvantages for their application to VERITAS. The lower channel density of 32 channels per crate (4 per board, 8 boards per crate) compared with 170 channels per VME crate requires more than 5 times as many (albeit 6U form factor) crates, CPUs and other hardware (such as reflective memory modules) compared with the custom units. These FADCs have no ability to extend the dynamic range above 8 bits or to latch the CFD hit pattern. While DMA from a single card is supported, currently these cards lack the ability to *chain* data transfers. This results in a significant amount of dead-time since the CPU has to do the readout sequencing, and the CPU latency will dominate the dead-time.

6 VERITAS Project Organization

6.1 Organization Chart

With eight collaborating institutions, five potential funding sources/agencies, three countries, and a budget that is a factor of ten above previous investments in γ-ray projects of this nature, VERITAS requires a complex management structure. We have settled on a structure in which the ultimate authority rests with a representative Executive Committee, in which the daily management is vested in a Project Scientist/Spokesperson and Project Office, and in which the project is divided into eighteen Sub-projects. Each Sub-project has an individual Leader and Manager; Sub-projects that closely overlap are grouped together with Group Coordinators.

The project will be organized as shown in the Figure 9.

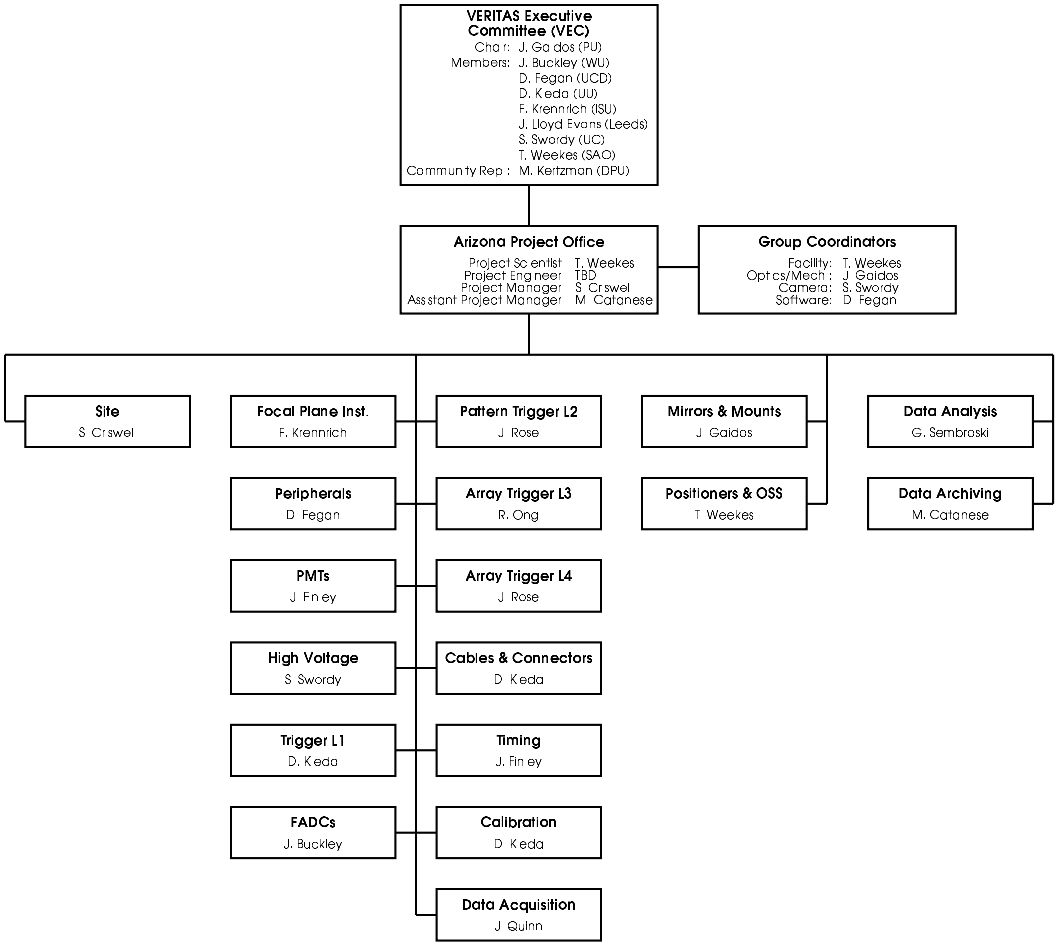

Figure 9: The organizational structure of the VERITAS project.

6.2 VERITAS Executive Committee

6.2.1 Responsibilities

The VERITAS Executive Committee (VEC), with the assistance of the Project Manager and Project Scientist, will be responsible for the following tasks:

- providing scientific leadership to the project,
- determining the membership of the collaboration,
- drawing up the overall project plan and yearly plans,

- outlining the technical work to be pursued during that year,
- determining the availability of resources to accomplish the proposed work,
- assigning detailed responsibility for carrying out such work, thereby defining Sub-project teams, Group Coordinators and updating the list of Sub-projects as necessary, and
- selecting successors to the Project Scientist and Project Manager, when necessary, in agreement with the Director of SAO.

6.2.2 Membership

Each major contributing institution will appoint one member to the VEC, to serve for three years. At the beginning of each calendar year, the VEC will elect one of their members to act as Chairman for the year.

The Membership of the Collaboration may be modified with a two-thirds vote of the VEC. Other decisions of the VEC will be decided by simple majority; in the event of a tie the Chairman shall have the casting vote.

The Project Scientist and Project Manager will be non-voting members of the VEC (except when they also serve as representatives of Collaboration groups).

6.3 Project Office

6.3.1 Responsibilities

The Project Office, under the direction of the VEC, will be responsible for the following tasks:

- providing local scientific leadership and providing the day-to-day management of the project,
- drawing up the overall project specifications, project plan and yearly plans for approval,
- assessing the work accomplished to date; monitoring progress at frequent intervals,
- outlining the technical work to be pursued during that year and estimating the cost of such work,
- determining the availability of resources to accomplish the proposed work,
- assigning detailed responsibility for carrying out the tasks, monitoring the tasks and ensuring that they are within agreed schedule and budget, and
- monitoring the task interfaces.

To aid the Project Office, each institution will provide to it timely reports specifying in some detail both past expenditures and future plans regarding finances and personnel. These reports will be due to the Project Office one year from the signing of this agreement, and yearly thereafter. The Project Office will issue its report within 60 days after the end of each year's activities.

The Project Office will be located at the VERITAS site 40 miles south of Tucson, Arizona. The Project Office will avail of the general administrative services of the Whipple Observatory Administrative Office nearby.

6.3.2 Personnel

The Project Office will consist of the following positions.

Project Scientist: The Project Scientist will report directly to the VEC and will be responsible for ensuring that their policies are followed and their instructions are carried out. He/she will be responsible for the Project Office and will act as Spokesperson for the project.

Project Manager: The Project Manager will report to the Project Scientist and will manage the Project Office. He/she will provide project management for the total project. He/she will monitor all Sub-projects and assist in their fiscal planning and scheduling; problems (fiscal and schedule) will be identified, and solutions evaluated and implemented. Annual agency funding to the various collaborating institutions will be recommended based on discussions with Group Coordinators and on the present status and future projections of each Sub-project. Overall spending will be monitored and project costs will be controlled. Cost-to-complete analyses will be done yearly. The Project Manager will serve on the vendor selection committee of all major procurements. He/she will coordinate the involvement of off-site service organizations at the parent organizations.

Assistant Project Manager: He/she will provide assistance to the Project Manager and act as Project Manager during his/her absence. He/she reports to the Project Manager.

Project Engineer: The Project Engineer will provide project engineering and system engineering for the project. He/she reports to the Project Manager. He/she will have special responsibility for quality control, system engineering, task interfacing, and site coordination.

Administrative Assistant: This person will maintain the project schedule and WBS.

6.4 Groups and Sub-Projects

The project has been been broken up into four Groups and 18 Sub-projects. The Sub-projects are the working units and it is the responsibility of the Sub-project Leader to ensure that the Sub-project completes its task in a timely and economic fashion. The Sub-project Leader reports to the Project Office on matters of finance, schedule and quality. The Group Coordinator has the responsibility for coordination of activities and technical interfaces between Sub-projects within the Group. The following Group Coordinators and Sub-project Leaders have been identified.

Group	Sub-project	Group Coordinator	Sub-project Leader
Facility Group		T. Weekes	
	Site		S. Criswell
Optics and Mechanics Group		J. Gaidos	
	Mirrors and Mounts		J. Gaidos
	Pedestals and OSS		T. Weekes
Camera Group		S. Swordy	
	Focus Plane Instrumentation		F. Krennrich
	Peripherals		D. Fegan
	PMT's		J. Finley
	High Voltage		S. Swordy
	Trigger L1		D. Kieda
	FADC		J. Buckley
	Pattern Trigger L2		J. Rose
	Central Array Trigger L3		R. Ong
	Central Array Trigger L4		J. Rose
	Cable and Connectors		D. Kieda
	Timing		J. Finley
	Calibration		D. Kieda
	Data Acquisition		J. Quinn
Software Group		D. Fegan	
	Data Reduction		G. Sembroski
	Data Archiving		M. Catanese

7 Work Breakdown Schedule Summary

Breakdown by Funding Agency and Institution

The table below shows a breakdown of the spending for VERITAS by funding agency and collaborating institution.

		Data					
Funding Org	Funded Org	*Sum of 2000*	*Sum of 2001*	*Sum of 2002*	*Sum of 2003*	*Sum of 2004*	*Sum of All Years*
DOE	IS	$144,059	$262,817	$404,837	$395,635	$393,807	$1,601,155
	PU	$790,268	$434,657	$522,063	$376,951	$226,332	$2,350,271
	SAO	$1,103,449	$576,508	$136,229	$141,041	$143,205	$2,100,430
	WU	$486,049	$42,281	$382,727	$371,651	$42,281	$1,324,989
DOE Total		$2,523,825	$1,316,262	$1,445,855	$1,285,278	$805,625	$7,376,845
EI	UCD	$64,260	$30,870	$25,620	$25,620		$146,370
EI Total		$64,260	$30,870	$25,620	$25,620		$146,370
NSF	UC	$248,308	$230,161	$868,257	$695,687	$761,589	$2,804,003
	UU	$175,288	$987,024	$827,166	$827,029	$327,152	$3,143,658
NSF Total		$423,596	$1,217,185	$1,695,423	$1,522,716	$1,088,741	$5,947,661
PPARC		$219,455	$173,678	$91,305	$272,833	$170,661	$927,931
SI A&M	SAO	$224,206			$0		$224,206
SI A&M Total		$224,206			$0		$224,206
SI MC	SAO			$947,554	$3,335,717		$4,283,271
SI MC Total				$947,554	$3,335,717		$4,283,271
SI MSI	SAO	$43,549	$59,787	$676,356	$665,462	$416,655	$1,861,809
SI MSI Total		$43,549	$59,787	$676,356	$665,462	$416,655	$1,861,809
Grand Total		$3,498,890	$2,797,782	$4,882,112	$7,107,626	$2,481,681	$20,768,092

Breakdown by Sub-project

The table below shows the breakdown of the spending for VERITAS by Sub-project.

Team	Sub Team	2000	2001	2002	2003	2004	All Years
A Facility (Weekes)		**$309,348**		**$947,554**	**$3,335,717**		**$4,592,619**
	1 Pioneer Facility	$309,348					$309,348
	2 Final Facility			$947,554	$3,335,717		$4,283,271
B Mirrors, Coating & Mounts (Gaidos)		**$602,858**	**$472,604**	**$477,179**	**$404,273**	**$486,330**	**$2,443,243**
	Mirrors Year 0	$602,858					$602,858
	Mirrors Year 1		$472,604				$472,604
	Mirrors Year 2			$477,179			$477,179
	Mirrors Year 3				$404,273		$404,273
	Mirrors Year 4					$486,330	$486,330
C OSS/Covers & Positioners (Weekes)		**$835,380**	**$927,345**	**$879,120**	**$879,120**		**$3,520,965**
	OSS/Pos. 2 & 3		$927,345				$927,345
	OSS/Pos. 4 & 5			$879,120			$879,120
	OSS/Pos. 6 & 7				$879,120		$879,120
	OSS/Pos. 1	$835,380					$835,380
D Peripherals (Fegan)		**$64,260**	**$30,870**	**$25,620**	**$25,620**		**$146,370**
	Peripherals 1	$32,760					$32,760
	Peripherals 2 & 3	$10,500	$30,870				$41,370
	Peripherals 4 & 5	$10,500		$25,620			$36,120
	Peripherals 6 & 7	$10,500			$25,620		$36,120
E Photo Multiplier Tubes & Bases (Finley)		**$250,979**	**$241,817**	**$242,649**	**$243,481**	**$244,313**	**$1,223,239**
	PMTs & Bases Year 0	$250,979					$250,979
	PMTs & Bases Year 1		$241,817				$241,817
	PMTs & Bases Year 2			$242,649			$242,649
	PMTs & Bases Year 3				$243,481		$243,481
	PMTs & Bases Year 4					$244,313	$244,313
F High Voltage (HV) (Swordy)		**$123,039**	**$208,018**	**$208,018**	**$208,018**		**$747,093**
	HV 1	$123,039	$0				$123,039
	HV 2 & 3		$208,018				$208,018
	HV 4 & 5		$0	$208,018			$208,018
	HV 6 & 7				$208,018		$208,018

G Focalplane Instrumentation (Krennrich)	**$67,892**	**$126,457**	**$262,155**	**$246,315**	**$237,515**	**$940,333**
Focalplane Instr. 1	$67,892	$126,457				$194,349
Focalplane Instr. 2 & 3			$262,155			$262,155
Focalplane Instr. 4 & 5				$246,315		$246,315
Focalplane Instr. 6 & 7					$237,515	$237,515
H Trigger (L1) (Kieda)		**$46,499**	**$87,239**	**$87,239**	**$87,239**	**$308,216**
CFD daughter board 1		$46,499				$46,499
CFD daughter board 2 & 3			$87,239			$87,239
CFD daughter board 4&5				$87,239		$87,239
CFD daughter board 6&7					$87,239	$87,239
I FADC (Buckley)	**$611,317**	**$42,281**	**$826,110**	**$815,034**	**$759,585**	**$3,054,328**
FADC's 1	$611,317	$42,281	$0	$0	$0	$653,599
FADC's 2 & 3	$0	$0	$826,110	$0		$826,110
FADC's 4 & 5				$815,034	$0	$815,034
FADC's 6 & 7					$759,585	$759,585
J Pattern Trigger Level 2 (Rose)	**$165,375**	**$173,678**	**$75,370**	**$171,522**	**$146,333**	**$732,277**
Pattern (L 2) Triggers 1	$165,375	$41,963				$207,338
Pattern (L 2) Triggers 2 & 3		$131,715	$44,315			$176,030
Pattern (L 2) Triggers 4 & 5			$31,055	$143,400		$174,455
Pattern (L 2) Triggers 6 & 7				$28,122	$146,333	$174,455
K Central (Array) Trigger (L3) (Ong)			**$172,570**			**$172,570**
Array Trigger (L3)			$172,570			$172,570
L Array (Pat) Trigger (L4) (Rose)	**$54,080**		**$15,935**	**$101,311**	**$24,328**	**$195,654**
Array (Pat) (L4) 1	$54,080					$54,080
Array (Pat) (L4) 2 & 3			$15,935			$15,935
Array (Pat) (L4) 4 & 5				$72,258		$72,258
Array (Pat) (L4) 6 & 7				$29,053	$24,328	$53,381
M Cables & Connectors (Kieda)		**$40,148**	**$71,145**	**$71,007**	**$71,007**	**$253,308**
Cables 1		$40,148				$40,148
Cables 2 & 3		$0	$71,145			$71,145
Cables 4 & 5		$0		$71,007		$71,007
Cables 6 & 7		$0			$71,007	$71,007
N Timing (Finley)		**$17,774**	**$22,235**	**$22,235**	**$22,235**	**$84,480**
Timing 1		$17,774				$17,774
Timing 2 & 3			$22,235			$22,235
Timing 4 & 5				$22,235		$22,235
Timing 6 & 7					$22,235	$22,235
O Calibration (Kieda)	**$175,288**	**$161,029**	**$85,154**	**$85,154**	**$15,387**	**$522,011**
Calibration 1	$175,288	$111,044				$286,331
Calibration 2 & 3		$49,985	$35,169			$85,154
Calibration 4 & 5			$49,985	$35,169		$85,154
Calibration 6 & 7		$0		$49,985	$15,387	$65,372
P DACQ (Quinn)	**$43,549**	**$35,058**	**$107,549**	**$92,954**	**$87,914**	**$367,022**
DACQ 1	$43,549	$35,058				$78,607
DACQ 2 & 3			$107,549			$107,549
DACQ 4 & 5				$92,954		$92,954
DACQ 6 & 7					$87,914	$87,914
Q Data Archiving (Catanese)		**$31,647**	**$86,602**	**$17,566**		**$135,815**
Data Archiving 1		$31,647				$31,647
Data Archiving 2 & 3			$73,260			$73,260
Data Archiving 4 & 5			$13,342			$13,342
Data Archiving 6 & 7				$17,566		$17,566
R Data Analysis (Sembroski)		**$9,500**	**$11,000**	**$14,000**	**$0**	**$34,500**
Data Analysis 1		$9,500				$9,500
Data Analysis 2 & 3			$11,000			$11,000
Data Analysis 4 & 5				$14,000		$14,000
Data Analysis 6 & 7					$0	$0
S Project Office (Criswell)	**$195,525**	**$233,057**	**$278,911**	**$287,061**	**$299,497**	**$1,294,051**
Project Office Year 0	$167,090					$167,090
Project Office Year 1	$28,435	$233,057				$261,492
Project Office Year 2			$278,911			$278,911
Project Office Year 3				$287,061		$287,061
Project Office Year 4			$0		$299,497	$299,497
Grand Total	**$3,498,890**	**$2,797,782**	**$4,882,112**	**$7,107,626**	**$2,481,681**	**$20,768,092**