

**THE APPLICATION OF TWO-DIMENSIONAL IMAGING
TO VERY HIGH ENERGY GAMMA RAY ASTRONOMY**

**THE U.S. DEPARTMENT OF ENERGY
AGREEMENT NO. DE-FG02-91ER40635**

ANNUAL REPORT

For the period 1 May 1991 through 30 April 1992

Principal Investigator

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December 1992

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**The Smithsonian Astrophysical Observatory
is a member of the
Harvard-Smithsonian Center for Astrophysics**

I. INTRODUCTION

(1) Overview

Astronomy has traditionally progressed by exploiting every band of the electromagnetic spectrum with maximum sensitivity; the vast band covered by "gamma rays" obviously has tremendous potential. While the lower energy part of the band has begun to be explored (and is producing many surprises), even the mighty EGRET on the Compton GRO can only report signals up to energies of 10 GeV.

Some feeling for the fascination that very high energy gamma rays sources hold for the physicist can be obtained by considering the equivalent "laboratory" sources here on earth. It is comparatively easy to make a test source for calibrating an astronomical instrument in every band of the electromagnetic spectrum short of the gamma-ray band. Although radioactive sources can be found for the lower energy gamma rays, when we come to 100 MeV and beyond we have to look to particle accelerators to provide the relativistic particle beams which, on collision, produce secondary gamma rays. Particle accelerators are arguably the most sophisticated man-made machines ever built (certainly they are the most expensive e.g. the SSC). It is sobering to note that even the SSC will not produce gamma rays of the energies now under investigation in gamma ray astronomy experiments.

The quest in very high energy gamma-ray astronomy can be simply stated as the quest for cosmic particle accelerators, Cosmic Super Colliders (CONTRACTUAL's), that produce the cosmic rays that fill the galaxy, and perhaps the universe, and provide us with a laboratory that can never be duplicated on earth. These CONTRACTUAL's are probably the most interesting objects in the universe, of interest to the astronomer because they provide a new ingredient to an already complex universe, to the astrophysicist because they give an insight into some unbelievably complex astrophysical processes, to the cosmic ray physicist because they provide positive evidence of the

acceleration of cosmic particles, and to the particle physicist because they provide the only particle beam with such great energies.

Despite the tremendous activity in gamma-ray astronomy at energies of 1 TeV and above, it is still true that this is a science that is only just beginning. Large detector arrays have given hints of possible sources with energies up to 1 EeV; however most observers would now agree that the highest energy region where one can, with confidence, believe that sources have been established with any certainty is in the 0.4 to 10 TeV energy region. This is, however, a start; it provides the TeV astronomer with a standard candle to enable the techniques to be improved and provides an encouragement to widen the search for sources; it also serves as an incentive to the PeV and EeV astronomers to improve their techniques to the point where their sensitivities meet a reasonable extrapolation of the TeV fluxes.

The steady TeV gamma-ray emission from the Crab Nebula was used to optimize the sensitivity of the Whipple 10m telescope. Using this method, which is of order 20 times more sensitive than the standard method using a simple non-imaging detector, it is possible to detect the Crab Nebula at a significance level in excess of 6 standard deviations (σ) in under one hour on source (with a corresponding time observing a background comparison region); a source one tenth the strength of the Crab Nebula can be detected at the 4 σ level after 40 hours on the source (and 40 hours on a background region). A variety of sources were monitored using this technique over the period 1988 to 1991 but none were detected apart from the Crab Nebula. Some of these sources may be detectable with the GRANITE system which comprises the 10m and 11m cameras acting in tandem. The full sensitivity of this system has yet to be determined but it is certainly better than the two telescopes acting alone. The configuration of the telescopes on the 2.3 km ridge of Mount Hopkins is shown in Figure 1.



Figure 1. The 11m and 10m telescopes at the Whipple Observatory.

(2) Status of Collaboration.

The institutional membership of the collaboration is unchanged since last year. A formal request for membership by the Ecole Polytechnique group was rejected pending a clearer picture of the future direction that the collaboration wished to take vis-a-vis the development of a third-generation system.

The education of students in physics continues as a high priority with the Smithsonian gamma-ray group. Two graduate students, Stephen Fennell and Michael Punch completed one and two years respectively as Smithsonian Predoctoral Fellows and returned to their home institution (University College, Dublin) in October, 1992. Adrian Rovero (from the University of Buenos Aires, Argentina) was reappointed a Smithsonian Predoctoral Fellow (second year). Mark Chantell and Terry Whitaker, both from the Physics Department of the University of Arizona, continued full-time research. Eduardo Colombo (University of Buenos Aires, Argentina) returned to the Whipple Observatory for three months to complete work on the observational part of his dissertation, the observation of cataclysmic variables.

(3) Collaboration Membership

The Whipple Observatory Gamma-ray Collaboration c. Dec. 1992

Smithsonian Astrophysical Observatory

T.C.Weekes	Astrophysicist	Smithsonian
M.A.Lawrence	Post-doc.	DOE
K.Harris	Engineer	DOE
T.Lappin	Observer	NASA
A.Rovero	Pre-doc(UBA)	Smithsonian
M.Chantell	Grad. Stud. (UA)	DOE/Schol.Stud.
T.Whitaker	Grad. Stud. (UA)	DOE
E.Colombo	Grad. Stud. (UBA)	Buenos Aires
M.Calaluca	Phys. Sci. Aide	DOE

Iowa State University

R.C.Lamb	Professor	ISU/DOE
D.A.Lewis	Assoc. Prof.	ISU/DOE
A.Kerrick	Post-doc.	DOE
G.Mohanty	Grad. Stud	DOE

University of Michigan

C.A.Akerlof	Professor	UM/DOE
D.Meyer	Professor	UM/DOE
M.Schubnell	Post-doc.	DOE

Purdue University

J.Gaidos	Professor	PU/DOE
C.Wilson	Post-doc	DOE
G.Sembroski	Post-doc	DOE

University College, Dublin

D.J.Fegan	Stat. Lect.	UCD
N.A.Porter	Prof. Emeritus	
K.O'Flaherty	Grad. Stud.	UCD
M.Punch	Grad. Stud.	UCD
S.Fennell	Grad. Stud.	UCD
V.Connaughton	Grad. Stud.	UCD
J.Hagen	Grad. Stud.	UCD

St. Patrick's College, Maynooth

M.F.Cawley	Lecturer	SPC
J.Murphy	Grad. Stud.	SPC

University of Leeds

A.M.Hillas	Professor	UL
Pending	Post-doc	SERC
M.West	Grad. Stud.	SERC

II. RESEARCH REPORT.

In this report we cover progress made since our last report (dated December, 1991); of necessity, much of the work described here is still work in progress. Research at the Whipple Observatory Gamma Ray Project is the result of a collaboration of seven organizations, all of whom contribute to the overall result; emphasis is given here to the work of the Smithsonian group although inevitably their efforts overlap with those of the other groups. The P.I. of this proposal acts as spokesperson for the collaboration and, as such, has responsibility for the overall coordination of the project. Because all the observational work is carried out at the Whipple Observatory he is also responsible for the day-to-day management of the program. Although other collaborators pay a User's Fee to the Whipple Observatory as a contribution to the utilities, etc, the Smithsonian group assumes the responsibility for the local operating expenses of the two telescopes.

Most of the most important results of the work of the collaboration has been reported in papers submitted to journals or conference proceedings. Rather than repeat this text, the most important papers will be attached as an appendix and the results will be very briefly summarized here.

(1) Observations.

(a) The HRC Summary paper.

One of the major publications of the collaboration this year was a paper which summarized all the results of the observations made with the 10m High Resolution Camera in the epoch 1988-91. The paper "Survey of Candidate Gamma-ray Sources at TeV Energies Using a High Resolution Cherenkov Imaging System: 1988-91" by Reynolds et al. will appear in the February 10, 1993 issue of the Astrophysical Journal (see Appendix). In this paper upper limits were presented which in many instances are a factor of 10 below the flux of the Crab Nebula.

(b) Cygnus X-3.

This important source was the origin of much of the current

activity in VHE and UHE gamma-ray astronomy. It appears that the level of activity observed between 1973 and 1985 has not been sustained. The upper limits from the Whipple observations between 1988 and 1990 are the best at TeV energies and are at least a factor of ten below the earlier detections; our results were published in the *Astrophysical Journal* on September 10, 1992 ("A Search for TeV Emission from Cygnus X-3" by O'Flaherty et al.; see Appendix).

(c) Markarian 421.

One of the most exciting results in VHE gamma-ray astronomy in recent years was the detection of Markarian 421 by the Whipple HRC in 1992; this was published as a Letter to Nature ("Detection of TeV Photons from the Active Galaxy Markarian 421" by Punch et al. 1992; see Appendix). The significance of this detection, the first direct evidence for TeV activity, was such that it merited a Nature commentary in the same issue ("Catching Photons from Hell" Francis Halzen, *Nature*, 358, 452. (1992); see Appendix).

(d) AGN's: General Survey.

Unlike the Crab Nebula, which is almost unique as a galactic source, Markarian 421 does not appear to have any properties which suggest that it alone of all the AGN's should be a TeV gamma-ray source. It is true that it is the closest of the EGRET-detected AGN's but there are other closer AGN's which have not been detected by EGRET (or Whipple); also it is only barely detected by EGRET whereas it is a strong source at TeV energies. Hence it seems possible that there may be a population of such extragalactic objects of similar or even greater intensity. Following the detection of Markarian 421 we extended our survey of EGRET-detected AGN's to include AGN's with similar properties and small redshifts. The first results of this survey were presented at the Compton GRO Symposium in St. Louis, October 1992 ("Search for TeV Gamma-ray Emission from AGN's using the Whipple Imaging Telescope" by Fennell et al.; see Appendix).

(e) Crab observations: pulsar outburst.

Although an exhaustive search through our large data-base of

observations on the Crab Nebula does not show any evidence for a significant contribution from the Crab pulsar (PSR0531), we did find evidence for one unusual short-term outburst of emission. Lasting for just 29 minutes, this periodic emission had a significance > 99% of being a genuine signal. It was reported at the Taos Workshop on Isolated Pulsars ("Observations of Pulsars with the Whipple Imaging Telescope" by Punch et al.; see Appendix).

(f) Geminga.

The discovery of pulsations in the X-ray and gamma-ray signals from Geminga led to an intense analysis of the Whipple data-base on this source. Since our d.c. analysis had given evidence for a signal that was just below statistical credibility, our hope was that the added sensitivity that comes with periodicity analysis at a known period would give clear evidence for a TeV signal. This was not the case; we find no evidence for periodic TeV emission at our present level of sensitivity. This result was presented at the Compton GRO Symposium in St. Louis (October, 1992); ("Search for TeV Gamma-ray from Geminga" by Fegan et al.; see Appendix).

(g) AE Aqr.

This is the only cataclysmic variable that has been detected as a TeV gamma-ray source. The two groups reporting the detection find evidence for periodic emission during flares. In the fall of 1992 we have accumulated a total of 40 hours of observation on this system. For some of these nights we made simultaneous observations with a CCD camera on the nearby 1.3m aperture optical telescope in an attempt to detect optical flares from the source. This data is currently being analyzed.

(h) Bursts.

On the assumption that gamma-ray bursts might originate in the halo of our galaxy (one of three possibilities), that they might have a flat energy spectrum (some bursts certainly do extend out to GeV energies) and that M31 might have a similar component (a reasonable assumption), an attempt was made to detect TeV gamma-

ray bursts from M31 or its halo (which exactly filled the field of view of the 10m camera). No bursts were detected and an upper limit was derived; an upper limit to TeV emission from any source within the galaxy was also derived. These results were presented at the Compton GRO Symposium in St. Louis in October, 1992 ("A Method for Searching the Whipple Observatory Gamma-Ray Data-Base for Evidence for GRB's" by Chantell et al.; see Appendix).

(i) ARTEMIS.

Following a visit in January-February, 1992 by our French collaborators, the observing plan for the ARTEMIS experiment was finalized. A quartz filter with a solution of Nickel Sulphate and Cobalt Sulphate was used to provide a sharp cutoff for light outside the near uv range. The effect of the filter is to reduce the noise from the full moon at a distance of 1° by a factor of ten; the actual noise level is then about that for the visible camera under a dark sky. The uv signal from the air showers is only reduced by 20%. The new focus box was designed and built at the Ecole Polytechnique; it was installed in August, 1992 and tested on the moon in September, 1992. The focus box included a rotating camera head of 109 pmt's (to compensate for the rotation of the field during observations) and a scintillator shield (to provide a veto signal when a cosmic ray traversed the pmt's). The cosmic ray veto works with an efficiency of 80%; the other 20% apparently penetrate the pmt's without traversing the scintillators. The rotation has been found to be very useful in keeping the moon at a fixed orientation relative to the pmt's in the camera.

A duplicate focus box has been built for the visible camera and the interchange between the two cameras (at the beginning and end of each dark run) is straightforward and requires only half a day. Marcel Urban (the P.I. for this project from the Ecole Polytechnique) is spending the 1992/93 academic year on sabbatical at the Whipple Observatory. Routine ARTEMIS observations were begun in October, 1992 and the data is currently being analyzed. When the moon is not high enough for

useful ARTEMIS observations, gamma-ray observations have been made with the uv camera, in moonlight, of the Crab Nebula. Previous observations of the Crab with the uv camera indicate a detection at the 4 sigma level. It is planned to observe with the uv camera on all the 12 nights per month when the moon prevents gamma-ray observations with the visible camera. The objective of this winter is to observe the proton shadow and to determine the observing strategy for observing the anti-proton hole in subsequent years.

(j) Muon Telescope.

The absolute calibration of ground-based gamma-ray telescopes is a long-standing problem. An elegant solution to the measurement of the energy threshold comes from the analysis of the recorded Cherenkov ring images from local muons in the high resolution camera; these muons are detected by a separate muon telescope which triggers the 10m camera. With the assistance of a Smithsonian Visiting Scientist, Jiang Yinlin (Institute of High Energy Physics, Beijing), a series of measurements were made with the 10m reflector. The measured value of energy threshold was not significantly different from that estimated previously. This result was described in a paper presented at the St. Louis Symposium on the Compton GRO ("Calibration of an Atmospheric Cherenkov Telescope using Muon Ring Images") by Rovero et al.; see Appendix).

Technical developments

(a) 11m Telescope:dedication.

Much of the physical installation of the 11m telescope and its associated electronic 37 pixel camera was completed in 1991. The telescope was officially commissioned in a small ceremony on the mountain that was attended by all the P.I.'s, their heads of department, representatives of D.O.E., representatives of the Smithsonian Institution and members of the gamma-ray community. The official dedication was performed by Dr. Homer Neal, Regent of the Smithsonian Institution and Chairman of the Physics Department at the University of Michigan (Figure 2).

The dedication was followed by a two day workshop on the imaging technique; this was held in the newly completed Visitor Center of the Whipple Observatory Basecamp and was attended by some 35 scientists (Figure 3). An informal proceedings was produced and distributed in the scientific community.

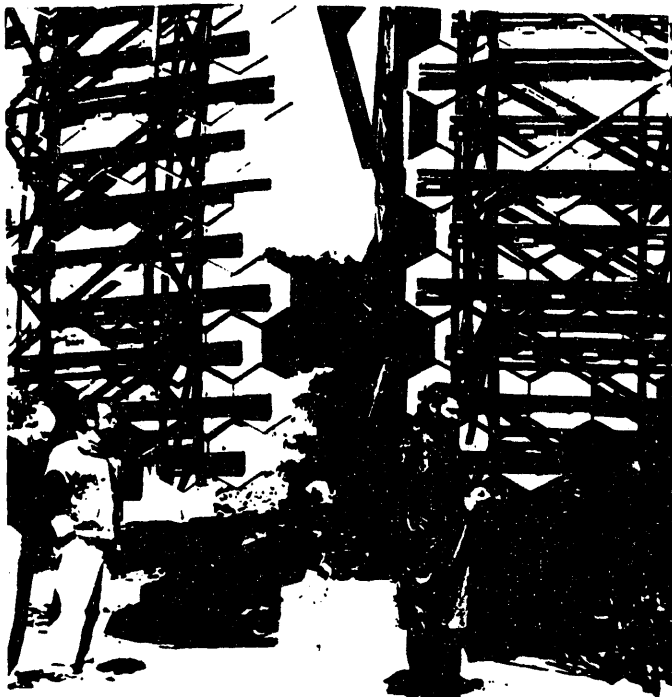


Figure 2. Professor Homer Neal, Smithsonian Regent, performs the official dedication of the 11m gamma-ray telescope (January 22, 1992).



Figure 3. Atmospheric Cherenkov Imaging Workshop, January 23-4, 1992.

(b) 11m Telescope:performance.

Most of the technical efforts of the collaboration were devoted to bringing the 11m telescope on-line and interfacing it with the 10m telescope. As much as possible this was accomplished without disturbing the operation of the 10m which was used routinely in the observing program described above. The performance of the new camera generally met with expectations; the preliminary performance is described in the paper "GRANITE - A Stereoscopic Imaging Cherenkov Telescope System" by Schubnell et al. which was presented at the Compton Symposium in St. Louis in October, 1992 (see Appendix).

The principal features of the telescope are listed below:

- 1). Optical Quality: the image size is within design specifications; the FWHM is 0.18° . The method of mounting the mirrors is quite satisfactory and stable; the alignment procedure is straight-forward and requires only one night of effort. The mirrors have shown no obvious deterioration in one year of exposure.
- 2). Sensitivity: because of the high quality of the reflectivity of the mirrors and the absence of any time delay in the optics of the parabolic mirror the camera (with light-cones installed; see below) can be operated independently at a trigger rate (any 2 out of 37 pmt's) of 20 Hz ((High Trigger). This corresponds (probably) to an energy threshold of 0.2-0.3 TeV; the precise level of the Low 1/37 (coincidence with 10m) trigger is not yet determined but is of order half of this. This performance is significantly better than that of the 10m reflector when it had a 37 pixel camera.
- 3). Tracking: the tracking program that came with the solar mount was successfully converted to sidereal tracking the accuracy was determined to be $\pm 0.1^\circ$ when all the necessary correction constants were determined (these arise from the offset from true pointing in the mount axes and slumping in the mount as a function of elevation).

4). Data Acquisition: the basic system was that used in the Sandia experiment by the Michigan group was adapted for the initial testing of the 11m. Images were successfully recorded; their parameter distribution matched that from the 10m telescope.

5). Performance: in the spring of 1992 the 11m was successfully employed to observe both the Crab Nebula and Markarian 421 with High Level Trigger. Poor weather conditions (the worst winter and spring in 20 years!), some technical problems (see below), and the limited resolution (only 37 pixels) limited the scientific value of the data obtained. The overlap with the 10m (stereo operation) was only possible at the High level of triggering where the results were inconclusive; the Low level trigger was implemented in November at both telescopes and the results are now being evaluated.

Although in principle the 11m camera is a duplicate of the 10m camera, in practice it has many innovative features which required some work to implement fully. These features are necessary for the wholly integrated camera and will be introduced into the 10m camera also. Technical problems that were encountered and that have been solved (or will be solved shortly) are as follows:

1) Mount motion: the mount has been found to shift its axis as it settles on its pier. This is a fundamental feature of its design (not its foundation or installation: a collar is being manufactured to prevent further slippage. The installation of the CCD camera (January, 1993) will make monitoring and correcting the pointing much easier.

2). Absolute Positioning: the magnetic sensors used are simple but unreliable. The computer interface is more complex than it need be (it was originally designed to drive 100 telescopes!) and the computer needs to be upgraded. As outlined below both the computer and sensors will be replaced by a more modern system.

3) Computer Interface: the computer-CAMAC interface is erratic and is being replaced (see below) for greater reliability. It will also provide reduced dead-time, give greater flexibility and

produce on-line diagnostics. The computer is being upgraded to a VAXstation 4000.

4) Resolution: the major limitation of the current system is the low resolution of the 37 pixel camera; this will be addressed in the upcoming upgrade.

(c) 10m mount control.

As the angular resolution of the technique has improved, so has the necessity for more accurate positioning of the reflectors. An important first step in this direction was the replacement of the 10 m Apple II control computer with a PC386. An extra set of synchro-to-digital converters removed the ambiguity inherent in reading the mount position and effectively converted the system to "absolute encoders". The mount control program was completely rewritten (in C) and a parallel program was written for use with ARTEMIS.

(d) CCD cameras.

The video cameras used on both reflectors to determine source pointing, sky clarity, etc. are being replaced by state-of-the-art ccd cameras. The first of these was installed on the 10m reflector in August, 1992. The camera makes a continuous record of the position of stars in the field of the camera and their brightness. Its wide dynamic range, large field of view, good resolution, digital read-out and reliability, ensure much higher quality house-keeping. In January, 1993 a similar camera will be installed on the 11m reflector and the outputs of the two devices will be displayed side-by-side in the 10m control room. The CCD camera is also essential for the ARTEMIS project where it co-rotates with the camera head and monitors the position of the moon on the edge of the field. These devices and their control and analysis software have been developed by our collaborators at St. Patrick's College, Maynooth.

(e) Light cones.

The deadspace between the active photocathode area in the focal plane of the cameras is considerable, about 37% for the High Resolution Camera on the 10m reflector and at least 50% for

the 37 element camera on the 11m reflector. Although the incident light angles are large, some improvement can be made by the use of light cones. Aluminized plastic light cones were made at the University of Michigan and installed on both cameras. The increase in counting rate (relative to sky noise) was a factor of 2.0 for the 11m and 1.25 for the 10m; for the former the reduction in energy threshold is about 60%. The light cones are now a permanent feature of both telescopes.

(f) Filters.

It had been hoped that a similar reduction might be achieved by the use of filters. Although previous experience with the 10m reflector had not encouraged the use of filters (the gain never matched the theoretical gain, probably due to reflection losses), the ARTEMIS quartz liquid container permitted an inexpensive way to test the use of liquid filters. A solution of Nickel Sulphate was calculated to provide the maximum gain in signal-to-noise for the 10m camera but the actual gain was significantly less than 1.0. For the moment we do not plan to use filters on the 10m camera.

(g) GRANITE Upgrade.

The first phase of the GRANITE upgrade was undertaken by the Purdue group and involved the replacement of the 11m data acquisition system which had been adapted from the previous Michigan Sandia experiment and which was not ideally suited for the present experiment. The new system involves the installation of Hytec ethernet CAMAC Crate Controllers and List Sequencers. The List Sequencer allows rapid read-out of the events (which is now in excess of 20Hz and may go to 50Hz) and hence minimizes dead-time. This part of the upgrade has been the responsibility of the Purdue group.

The List Sequencers are state-of-the-art devices which required new data acquisition software. At this point the software to communicate with the ethernet Crate Controller has been installed. The Controller and List Sequencer work with the present data acquisition system. In December it is hoped to

permanently install the new system; in the New Year it will be expanded to include the 10m camera (which up to now has relied on an outdated and well-worn LSI-11 computer).

The use of the new Crate Controller also required new software to control the High Voltage system; this has been the responsibility of the ISU group and has been completed.

(h) Trigger configuration.

In the spring of 1992 the two telescopes were operated in parallel but with independent 2/91 and 2/37 triggers. Although both telescopes showed overlap in off-line analysis, operation at this high threshold did not give any improvement in source signal-to-noise. To maximize the gain from the two telescope overlap, the trigger at both telescope was significantly reduced; at the 11m this was accomplished by using two sets of discriminators for all channels and demanding High and Low 2/37 coincidences. This was not possible at the 10m but was approximated using two coincidence levels (3/91 (High) and 1/91(Low)). These are just now being implemented; some preliminary rates at the two telescopes are shown in Table 1. The energy of the Low coincident events should be in the range 0.1 to 0.3 TeV; that of the High events is > 0.3 TeV.

Table 1.

Trigger Rates.

10 m Telescope			11m Telescope		
High	Low	Low(coinc)	High	Low	Low(coinc)
9.16Hz ^a	(10kHz)*	0.66Hz	16.37Hz ^b	(1kHz)*	0.77Hz

* not recorded

^a 25% in coincidence with the 11m

^b 15% in coincidence with the 10m

(i) Mirror Coatings.

The aluminizing and coating of the mirrors of the 10 reflector continued. Some time was lost when the chamber was contaminated because of a pump failure. High values of reflectivity were obtained with good consistency; all but one third of the mirrors now need to be recoated and these will be done this winter. The

coating process was described in a paper presented at the Ecole Polytechnique Workshop on Large Cherenkov Arrays in June, 1992 ("Mirror Coating and Anodization at the Whipple Observatory" by Harris et al.; see Appendix).

(j) Lightning Protection.

Following a disastrous lightning strike in September, 1991 which caused upwards of \$10,000 worth of damage to the electronics of the experiment (as well as numerous less serious strikes over the past 25 years), it was resolved to better protect the equipment using the most advanced technology. A lightning consultant, (Dr. P. Krider, Director, Atmospheric Physics Research Institute, University of Arizona) was engaged who recommended a number of fairly drastic measures which are currently being implemented. These included grounding all coaxial cables to the external ground before entering the building, installing a 75 foot high lightning conductor to provide a protective canopy over the 10m building and the gamma-ray building (Figure 4 and 5), and extending the ground plane around the experimental area.

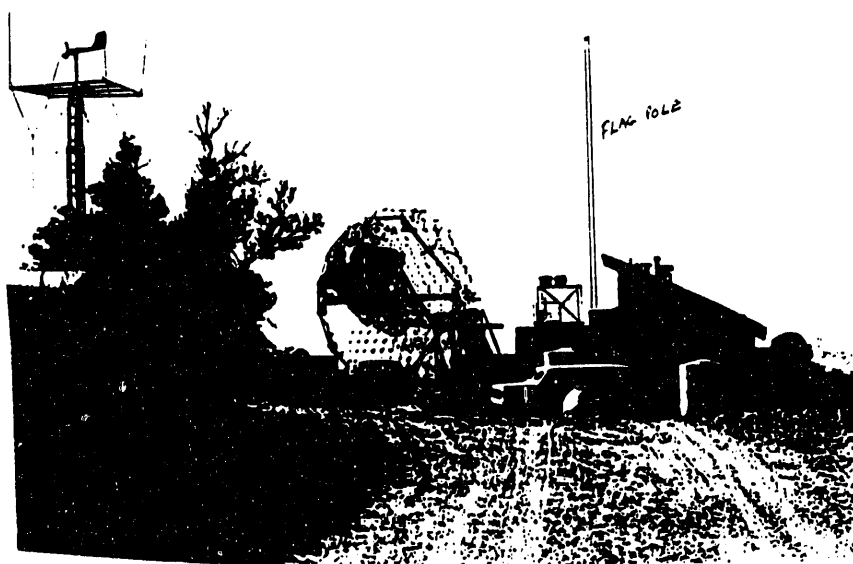
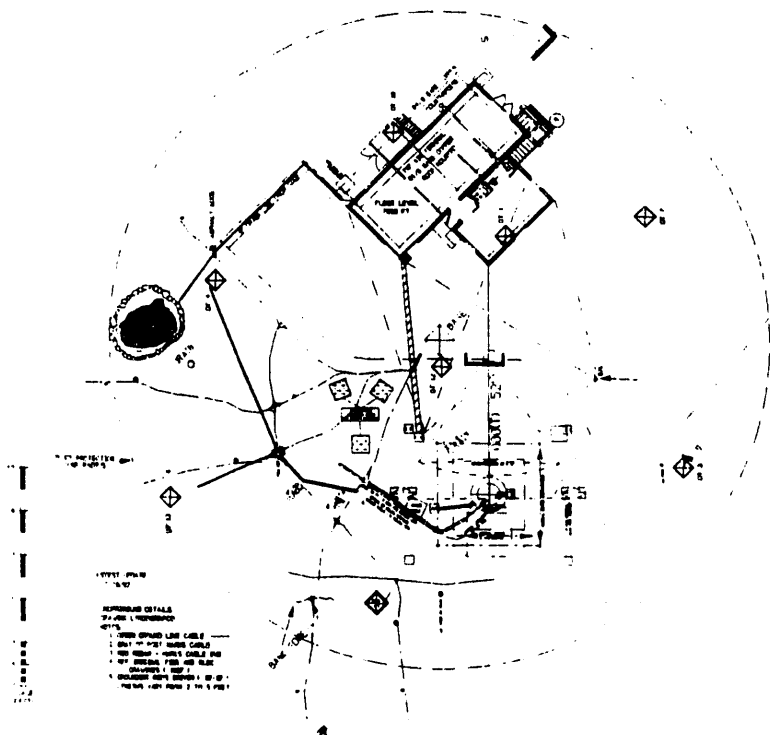


Figure 4. The 75 foot flag-pole that will provide lightning protection for the 10m telescope and the gamma-ray building.

Figure 5. Plan of area around telescope and building.



(3) Data Analysis

(a) Quick Look.

The detection of Markarian 421 was possible because of a new capability within the collaboration of rapid data-analysis which permitted the observers to quickly detect that there was an apparent signal from this source (out of the ten that were on the observing list) that were being observed. By concentrating our observations on this one source we were able to amass enough observations (despite poor observing weather) to get a statistically significant signal. At the end of each night of observing the data from both telescopes is transferred to the Tucson computers where it is analyzed that morning by non-observing personnel for Quick-Look analysis (using the well-established Supercuts routines).

(b) Optical Disk Archive.

To permit all members of the collaboration to have instant access to the data, we store all data taken in a given observing

dark period on an optical disk which can be accessed by internet by our collaborators in the U.S. and overseas. The larger data load from the two telescopes operated at low threshold will necessitate the acquisition of a second optical disk.

(c) False Source Method.

The standard method of observing is limited to ideal observing conditions which are generally not too unusual at our Arizona site. However a method has been devised in collaboration with Valery Fomin, a Smithsonian Visiting Scientist from the Crimean Astrophysical Observatory, whereby observations can be made under poor weather conditions. In this method the "OFF" observations are made simultaneously with the "ON" observations, thus minimizing the effect of sky non-uniformity. A paper describing this method is in preparation.

(4) Infrastructure

(a) Offices.

The scientific offices of the gamma-ray group are part of the complex of offices supplied to the Whipple Observatory by the University of Arizona on their Tucson campus; for sometime our space has been severely limited. This year, thanks to the completion of a new astronomy building, our office space has more than doubled, giving adequate facilities for resident staff and visitors.

(b) Building Extension.

This year the Smithsonian commissioned a local firm of architects to draw up three design concepts for the Gamma Ray Building Extension. A committee consisting of the P.I., Mark Lawrence (postdoc), Kevin Harris (technician) and Steve Criswell (Facilities Manager) drew up the initial requirements. After consultation with other members of the collaboration and local staff, one of the designs was chosen as optimal.

(c) Transportation.

With the increase in activity and the number of project personnel our demands on local transportation have increased dramatically. The Smithsonian has provided us exclusive use of a

sedan for transport between Tucson and the Basecamp; this is supplemented by private cars. For mountain travel outside normal "shuttle" times, the observatory has provided a four-wheel drive vehicle.

(5) REVIEWS

As a measure of the increasing interest in VHE gamma-ray astronomy various members of the collaboration have been invited to review the field at numerous workshops and meetings. The reviews given by the P.I. in the past year are listed below; many of these will ultimately be published. (Because they are repetitious, only one is included in the Appendix).

- (0) Texas-PASCOS '92, Meeting, Berkeley, California, December 13-18, 1992, INVITED TALK, "VHE Gamma Ray Astronomy".
- (1) 70th Anniversary, Chinese Astronomical Society, October 30 - November 3, Beijing, China. INVITED TALK. "Very High Energy Gamma Ray Astronomy"
- (2) International School on Astrofundamental Physics, Erice, Italy, September 6-13, 1992. INVITED LECTURE "Sources of TeV Gamma Rays" (to be published).
- (3) 4th Rencontre de Blois, Particle Astrophysics, June 15-21, 1992, Blois, France. INVITED TALK. "TeV Gamma Ray Astronomy" (to be published).
- (4) Workshop, "Towards a Large Cherenkov Array", Ecole Polytechnique, France, June 11-12, 1992, SUMMARY TALK "Quo Vadis?" (in press).
- (5) Workshop on Isolated Pulsars, Taos, New Mexico, February 24-28, 1992. INVITED TALK. "TeV Observations of Pulsars" (to be published).
- (6) Nuclear Physics Division, American Physical Society, October 24, 1991. East Lansing, Michigan. INVITED PLENARY LECTURE. "TeV Gamma Ray Astronomy"

(6) ANNIVERSARY

— In September, 1992 we marked the 25th anniversary of gamma-ray astronomy on Mount Hopkins.

APPENDIX

List of papers included here.

- (a) "Survey of Candidate Gamma-ray Sources at TeV Energies Using a High Resolution Cherenkov Imaging System: 1988-91" by Reynolds et al. Astrophysical Journal (in press)
- (b) "A Search for TeV Emission from Cygnus X-3" by O'Flaherty et al. Astrophysical Journal, 396, 674 (1992).
- (c) "Detection of TeV Photons from the Active Galaxy Markarian 421" by Punch et al. Nature, 358, 477 (1992).
- (d) "Search for TeV Gamma-ray Emission from AGN's using the Whipple Imaging Telescope" by Fennell et al. Compton GRO Symposium, St. Louis, October, 1992 (in press).
- (e) "Observations of Pulsars with the Whipple Imaging Telescope" by Punch et al.; Workshop on Isolated Pulsars, Taos, February, 1992 (in press).
- (f) "Search for TeV Gamma-ray from Geminga" by Fegan et al.; Compton GRO Symposium, St. Louis, October, 1992 (in press).
- (g) "A Method for Searching the Whipple Observatory Gamma-Ray Data-Base for Evidence for GRB's" by Chantell et al.; Compton GRO Symposium, St. Louis, October, 1992 (in press).
- (h) "Calibration of an Atmospheric Cherenkov Telescope using Muon Ring Images" by Rovero et al.; Compton GRO Symposium, St. Louis, October, 1992 (in press).
- (i) "GRANITE - A Stereoscopic Imaging Cherenkov Telescope System" by Schubnell et al.; Compton GRO Symposium, St. Louis, October,

1992 (in press).

(j) "Mirror Coating and Anodization at the Whipple Observatory"
by Harris et al.; Workshop on Large Cherenkov Arrays, Ecole
Polytechnique, June, 1992 (in press).

(k) International School on Astrofundamental Physics, Erice,
Italy, September 6-13, 1992. INVITED LECTURE "Sources of TeV
Gamma Rays" (to be published).

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