GRIM: Gamma Ray Imaging Analysis

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ABSTRACT

The data analysis system set up in Hawaii for the Fred Lawrence Whipple Observatory 10 meter gamma ray telescope is described.

§1 Introduction

This is a description of the system which has been set up in Hawaii for the analysis of data from the 19 PMT imaging system on the FLWO 10m reflector at Mt. Hopkins, as part of the Smithsonian, Dublin, Iowa St., Durham, Hawaii collaboration.[1] The development of this data analysis system is still going on, but the major features which are discussed here are not expected to change significantly. Details, of course, will be changing right up to the day before we submit our final paper. This document, always in the computer, will be continually updated as changes are made. New versions will be distributed when the changes are significant. No attempt is made to make this a complete user's manual, but it can be used along with a program listing to figure out what is happening.

§2 GREED: Processing of Data Tapes

The data tapes from Mt. Hopkins contain the 64 byte event records in 16 event blocks.[2] The record format is given in Fig. 1. The tapes contain the observing runs in the sequence in which they were made, with different sources and calibration runs all intersperced on numerous files. The event records do not contain certain information, especially sidereal times, which are necessary for the data analysis. This information is in the form of Run Sheets filled out by the observers. The first step in the process is to read through the tape with the program GREED (for

Gamma Ray Read, of course) and interactively select out the runs desired for further analysis, add the Run Sheet data manually from a terminal, and create a file, or set of files, for each source. Currently this is accomplished with a separate pass through the tape for each source and takes about 15 min. a pass, including typing in the Run Sheet data. This is not excessive, and in fact is a useful exercise, giving the user a chance to go through the runs and decide if any should be discarded from the analysis. (Thus I do not recommend that a big effort be made to write these data on the tape.) The following information from the run sheets are entered: *Source, Date, Observing Mode, Sidereal Times (start, transit, finish), Elevation, Coincidence Level.* These are written at the beginning of each block of 16 events.

The user can specify the first run to be processed and the program will read until it finds that run. Thereafter he must step through all the runs, answering prompts from the computer on whether to process the run. Since there is no end-of-tape mark (that our VAX can recognize), the user must know when he has processed the last run.

Normally one file is created for each set of observations on a given source, so each source can be separately processed through the remaining system.

§3. GRIM: Processing of Events

The file created by GREED is processed by the main data reduction program, GRIM. First I will describe how the events are processed up to the point where the shower image is reconstructed.

3.1. Event Processing

The following parameters are read in (by Subroutine GRIN, of course):

- NEVMAX = MAX. NO. OF EVENTS TO BE PROCESSED EACH RUN.
- MPRT = MAX. NO. OF EVENTS TO PRINT OUT.
- IPRT = PRINT LEVEL: THE HIGHER, THE MORE YOU GET.
- MDL1 = MODEL OPTION FOR FIRST TRY IMAGE FIT
- MDL2 = MODEL OPTION FOR SECOND TRY IMAGE FIT.
- IDIN = RUN ID TO BE PROCESSED, IF ONLY ONE DESIRED.

different for different observing periods. GRIM reads it in from a specified file at the beginning of the pass on a given source.

Again, I guarantee there will be more added in the future, and others may become defunct. I will not bother to explain all these codes in detail. They are either self-explanatory or, at least, give the idea. The default process (no codes) is "normal" operation, although an END is still needed. For example, when we are looking at a run with the N2 Light Pulser, for calibration purposes, we would set PMTO,ALLE,BARE,NCUT and get the PMT output distribution for all triggers on the runs selected.

We also have the capability of processing Monte Carlo events through the system by creating an input file of the same format. This is currently done by typing in the data manually from printed Monte Carlo data from Durham. The codes for the Monte Carlo are :BARE,ALLE.

In normal operation (ALLE not set) we read through the data, unpacking the Trigger Code, until we find the first Trigger 7. This is the sideral minute indicator. The sideral time is then initialized to the value given as the Start Time on the Run Sheet, STZ. The value of the Universal Time clock is unpacked from the data and stored as UTZ.

After that, we read through the data event-by-event. Depending on the Trigger Code, we do as follows:

Trigger 6. This is the manual trigger at transit. Being human, it is unreliable. A message is printed out, but nothing further is done.

Trigger 7. If UPED is set, the PMT pedestals are reset to the PMT outputs. Otherwise we use the standard values read in at the beginning of the computer run (see above). A Sidereal Minute Counter, ST7, is incremented. This also is unreliable (low priority trigger) and is used only as a check.

Trigger 8. This is the Event Trigger. The event is processed and the data words are all unpacked from the 64 byte record and can be printed out. The sidereal time (in minutes) is calculated by

$$ST = STZ + 0.99726966(UT - UTZ)$$

where UT is the universal time from the hardware clock in minutes, corrected for clock rollovers, and the correction factor is the ratio of the unit time intervals for sidereal and universal times. ST is *not* zeroed at midnight, and so can exceed 1440. This is convenient for futher analysis and can always be computed MOD(1400).

If DRFT is set, the drift scan interval (before, transit, or after) is computed and counters for that interval (by run and sum over runs) are incremented. Thus the computer acts as a fancy scaler. Histograms of the time distribution (by run and sum over runs), PMT output distribution (if PMTO set), etc., are updated. We then proceed to reconstruct the image, as discussed in the next section.

Trigger 9. This highest priority trigger indicates the 1000 sec overflow of the universal time clock. The UT is updated accordingly.

3.2 Image Reconstruction

The fist step in the image reconstruction process is to determine the centroid and shower axis from the PMT outputs. Let N be the number of PMT's, x_i,y_i the coordinates (in degrees) of PMT i, and n_i the output in photoelectrons. Then the centroid is

$$x_c = \frac{1}{N}\sum_i n_i x_i \tag{1}$$

$$y_c = \frac{1}{N}\sum_i n_i y_i. \tag{2}$$

The *Principle Axis* is then defined by

$$\theta = \frac{1}{2} tan^{-1} \frac{2I_{xy}}{I_{yy} - I_{xx}} \tag{3}$$

where

$$I_{xx} = \sum_i n_i x_i^2 \tag{4}$$

$$I_{yy} = \sum_i n_i y_i^2 \tag{5}$$

$$I_{xy} = -\sum_i n_i x_i y_i. \tag{6}$$

Next we transform the coordinates to (x'',y'') so that the origin is at (x_c,y_c) and the x''-axis is in the direction θ, that is, along the principle axis. The shower

direction may be along the principle axis, or it may be at right angles. To decide which we compute

$$I''_{xx} = \sum_i n_i x''^2_i \tag{7}$$

$$I''_{yy} = \sum_i n_i y''^2_i \tag{8}$$

and take the shower axis to be along y'' if $I''_{yy} > I''_{xx}$. The shower coordinate system (x',y') then is defined so that x' is along the shower axis, in the direction of the longer tail; this is determined by choosing the sense of x' so that the third moment

$$I'_{xxx} = \sum_i n_i x'^3_i \tag{9}$$

is positive.

If FITI is set we carry on and attempt to improve on the reconstructed image by doing a least squares fit. The idea is to describe the shower photoelectron distribution in the image plane by a function $\check{n}(x',y')$, where x',y' is centered at x_o,y_o, location of the shower maximum in the image plane, and x' is along the shower axis. Using the centroid and shower axis directions discussed above as the initial conditions, the fit then minimizes

$$\chi^2 = \sum_i \frac{[n_i - \check{n}(x'_i, y'_i)]^2}{\check{n}(x'_i, y'_i) + 1} \tag{10}$$

Besides the three parameters giving the origin and direction of (x',y') there will be other parameters determined by the fit: $\check{n}_o$, the photoelecton maximum, and additional parameters describing the longitudinal and transverse distributions. In the latter case, a Gaussian width σ is used. In the case of the longitudinal distribution a number of things have been tried from a symmetric Gaussian to the form

$$\check{n}(x', y') = \check{n}_o \exp\left(-\frac{y'^2}{\sigma^2}\right)\left(\frac{x'}{pl} + 1\right)^p \exp\left(-\frac{x'}{l}\right) \tag{11}$$

where the longitudinal (x'-) distribution is parameterized in terms of a "length" l and a "power" p. A good value of p seems to be 3, and it is initialized to this value. It can also be fixed. The intial value of $\check{n}_o$ is taken as the highest PMT ouput. The initial width σ and length l are Gaussian standard deviations.

The choice of models used depends on the MDL1 and MDL2 parameters read in on input. If MDL1 fails, we try MDL2. Generally, the idea is that the shower axis may be indeterminate for a circular image, so one can try a simpler symmetric fit if a more general fit fails.

Currently this fitting process uses a general purpose minimizing routine MINER written by M. Peters of Hawaii.

I will not detail all the variations on the above which are currently available, first because they are likely to change and, second, because they do not seem to make any improvement over the simpler centroid plus principle axis reconstuction.

In the case where FITI is not set, only the centroid plus principle axis reconstruction is done, but the graphics output described below contains isophotes calulated according to MDL1.

Fig. 2 illustrates the basic idea and defines the coordinate systems and variable names used in the image reconstruction source program.

3.3 Event Selection

Next we can apply cuts which select only desired events. The algorithm we use will depend on Monte Carlo studies which have just begun. Currently I am cutting on ZENITH and IMPACT, defined in Fig. 2, in various combinations.

3.4 Output

GRIM has a variety of outputs. Beside details on each event, there are summaries and histograms at the end of each run, and for the sum over all runs processed. Some samples are included with this doucument. A graphics ability is also present on the Hawaii system. The user can plot the PMT pattern with the isophotes of the reconstucted image overlayed. An example is given in Fig. 3. Note that a data box of image parameters is also provided. These are named as in the source program, where $PEAK = \check{n}_o, WIDTH = \sigma, LENGTH = l, POWER = p$. The others are defined in Fig. 2, except for ***ENERGY***, which currently is the total number of photoelectrons predicted for the reconstructed image, including those which would have been detected by PMT's outside the field-of-view. That is,

$$ENERGY = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \check{n}(x', y')\, dx'\, dy'. \qquad (12)$$

§4 Setting up this System on your Computer

The tape reading program GREED should run on any VAX. It could be adapted for other computers, but the tape reading commands would have to be modified since these are non-standard. Every computer reads tapes its own way, and "foreign" tapes are always a hassle, so the non-VAX user will probably have to write his own version of GREED.

The main portions of the primary data analysis program GRIM should run with little trouble on another VAX. It should be possible to set them up on other computers, such as the Cyber, with some additional work. The Fortran used I believe is fairly standard, but I can predict a lot of trouble if one tries to set it up on the incredibly fussy IBM 370 or other machines with limited Fortran.

The Hawaii system has scientific utilities which are being used for output purposes. One of these is the set of CERN histogramming and plotting programs, HBOOK. If this is not available on your system, I assume you have something equivalent which can be interfaced, with moderate effort, to these programs. We also use the SLAC graphics system TOPDRAWER. This has proved invaluable in developing the image algortihms, and is good for PR, but is not essential to the basic statistical study of sources and can be deleted if necessary.

REFERENCES

1. W.F. Cawley *et al.*, Proc. Ooty Conference, 292 (1982).

2. D.J. Fegan *et al.*, Proc. 15th Conference on High Speed Photography and Photonics, San Diego (1982).

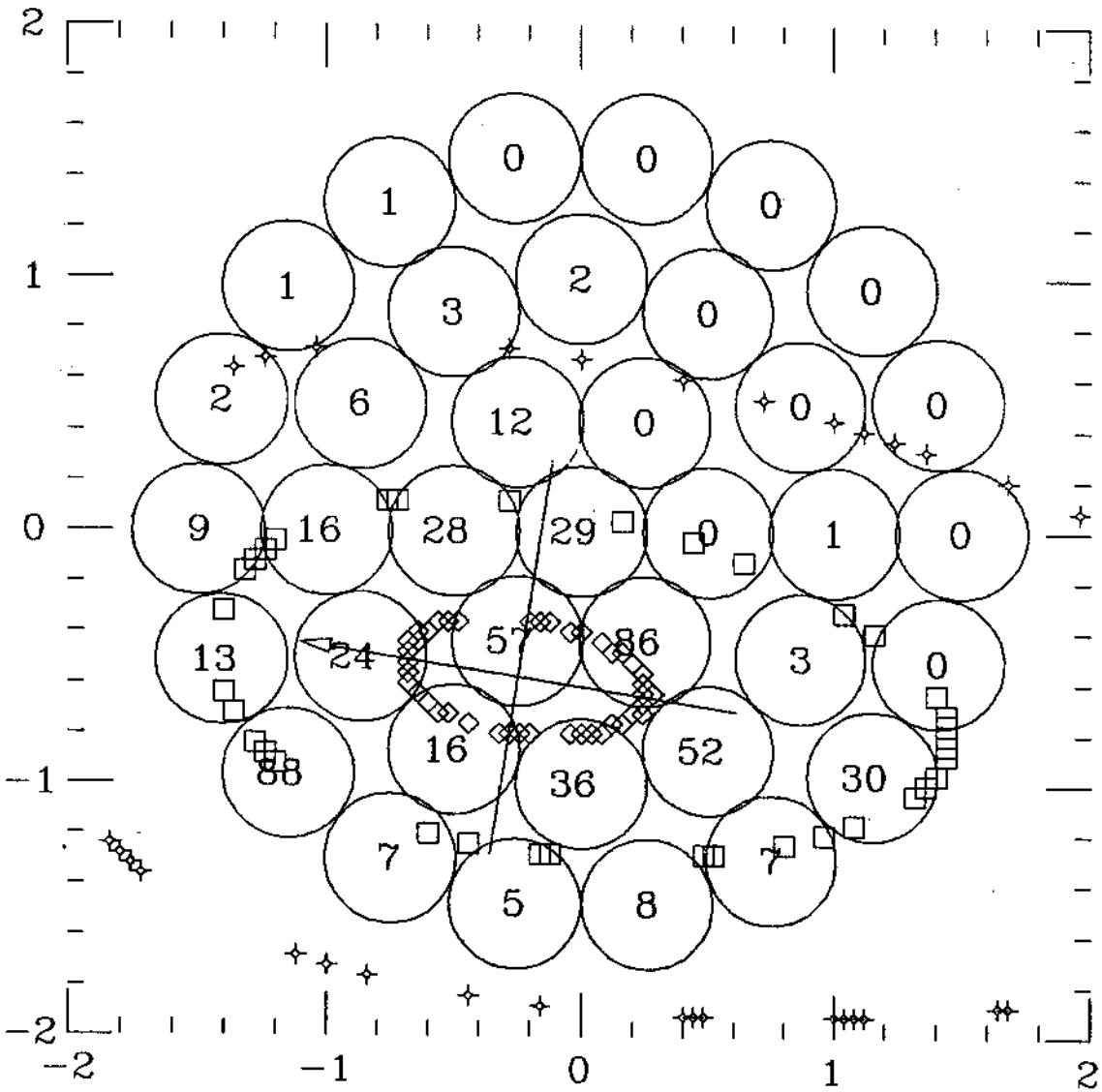
FIGURE CAPTIONS

1. Record format of 64 byte event.

2. Definitions of coordinate systems in image plane and image parameters, as used in GRIM.

3. Example of TOPDRAWER graphics output on an individual event. The circles represent the PMT's. The numbers in the circles the PMT outputs. The coordinate axes are those for the reconstructed shower image, with the arrow the direction of the shower, *opposite* x'. The isophotes shown correspond to the reconstructed image, as given for example by equation (11), for 0.95, 0.63 and 0.20 of the maximum. The data box on the right gives the image parameters.

EVENT 14 RUN 1 SID.TIME 0.00



MC

Fig. 3

IMAGE PARAMETERS	
MODEL	6
IER	0
CHISQ	0.00
X0	−0.25
Y0	−0.58
PEAK	88.00
WIDTH	0.71
LENGTH	0.86
AXIS	351.04
POWER	3.00
ENERGY	718.53
ZENITH	0.63
AZIMUTH	351.03
ASPECT	104.28
IMPACT	0.61

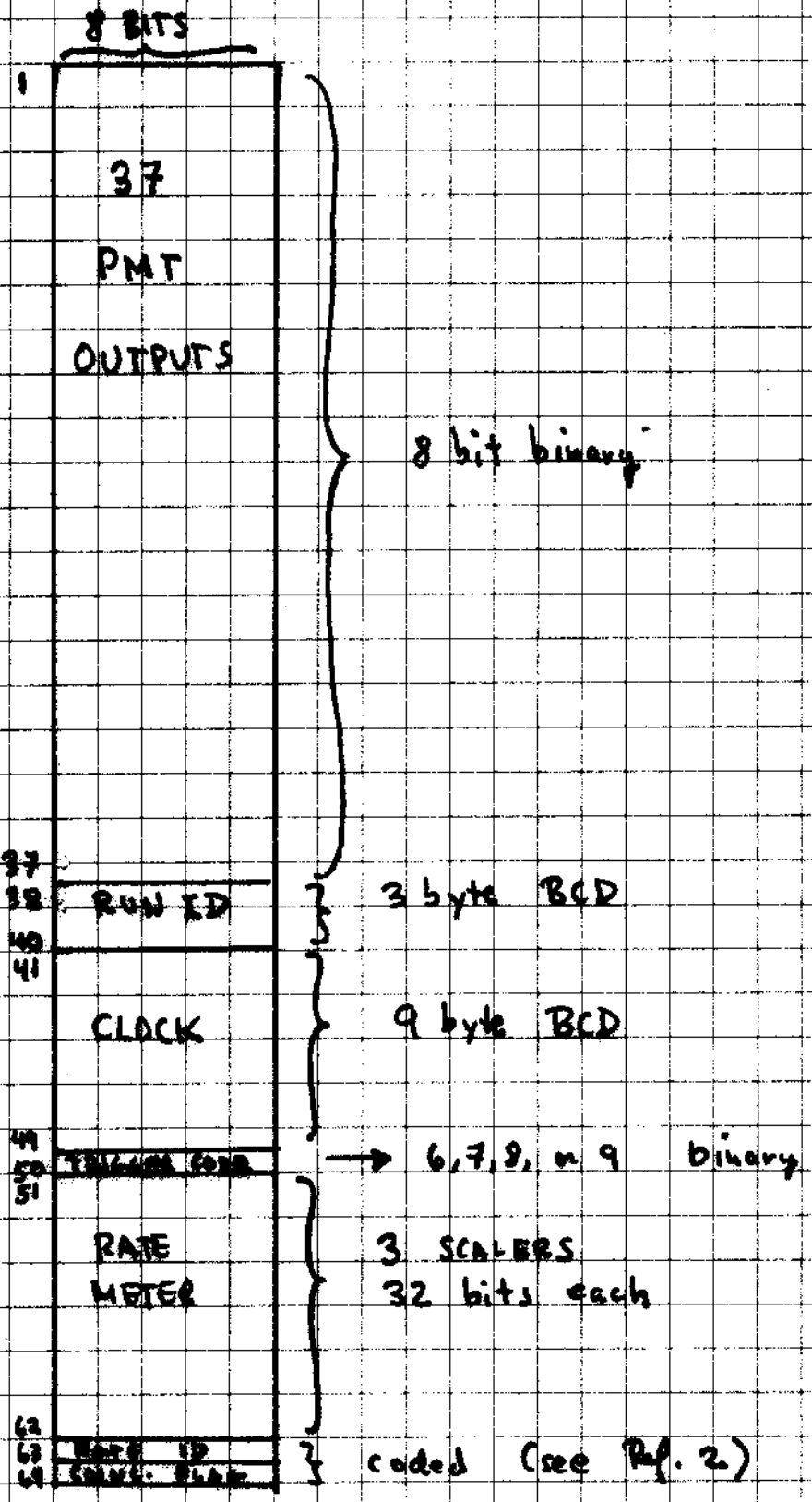

8 BITS
1
37
PMT
OUTPUTS
8 bit binary
37
38
RUN ED
39
40
41
CLOCK
3 byte BCD
9 byte BCD
49
50
51
→ 6, 7, 8, or 9 binary
RATE
METER
3 SCALERS
32 bits each
62
63
64
coded (see Ref. 2)

Fig. 1

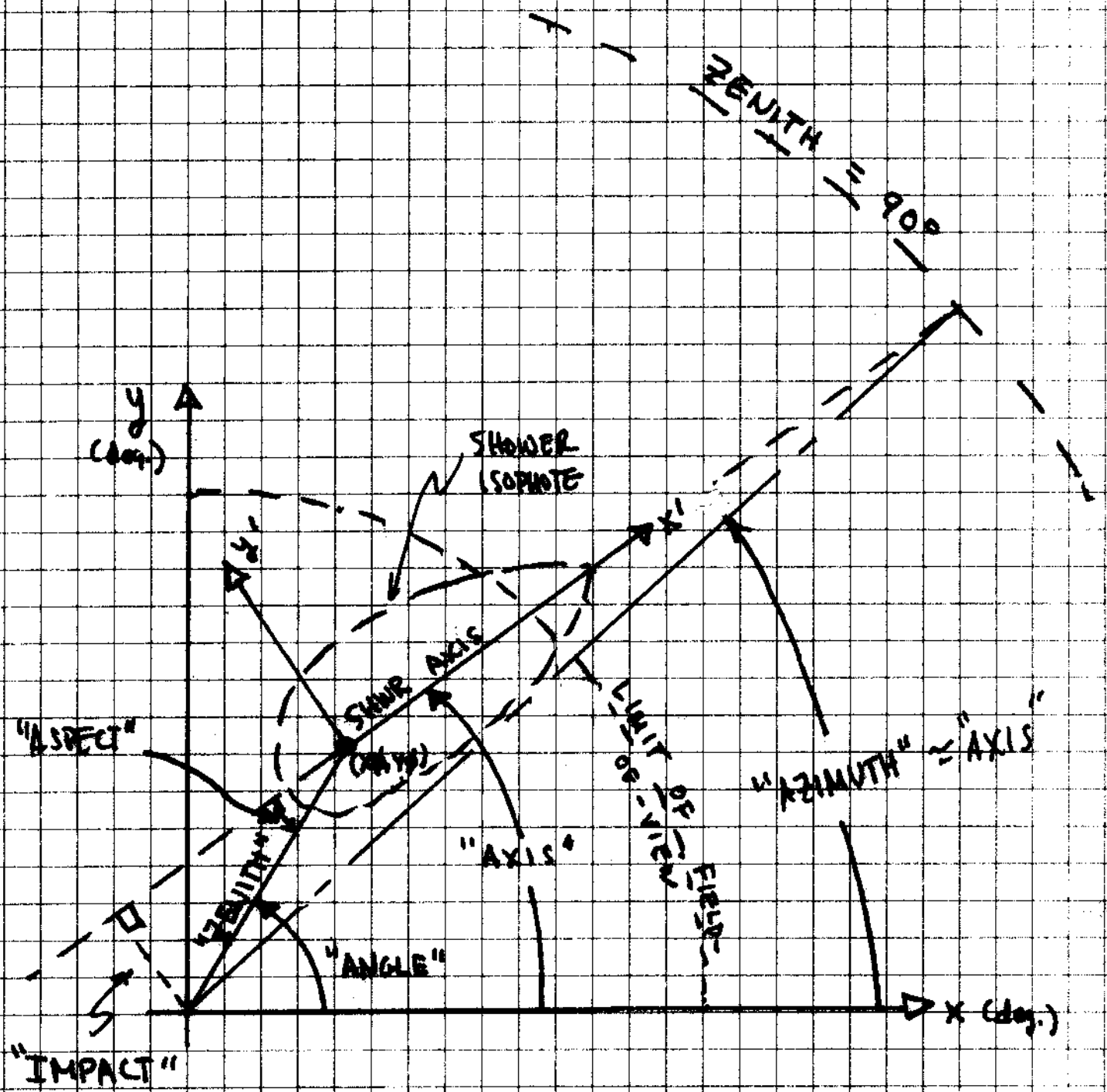

ZENITH = 90°
y (deg.)
SHOWER ISOPHOTE
y'
x'
SHWR AXIS
(x,y,z)
"ASPECT"
"ZENITH"
"AXIS"
"ANGLE"
"IMPACT"
LIMIT OF FIELD OF VIEW
"AZIMUTH" ≈ "AXIS"
x (deg.)

Fig. 2