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SCHOOL ON
NON-ACCELERATOR PHYSICS
25 April - 6 May 1988

VERY HIGH ENERGY GAMMA RAY ASTRONOMY

by

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Bombay
India

VERY HIGH ENERGY
GAMMA RAY
ASTRONOMY

— P. R. Vishwanath

VERY HIGH ENERGY γ RAY ASTRONOMY

1. Introduction → Brief History
2. Sources: Where to look
3. Detection: How to find them:
4. Results
   (a) PULSARS : CRAB (vela)
   (b) X-ray Binaries : HER X-1, CYG X-3

— P.R. Vishwanath
Tata Institute
BOMBAY

Table 1

Gamma-Ray Energy Ranges

nergy Range (eV)	Greek	Classification	Technique	Observation Platform
$.1.10^5$–1.10^7	0.51–10 MeV	Low/Nuclear	NaI crystal	Satellite
$.10^7$–3.10^7	10–30 MeV	Medium	Compton telescope	Satellite
$.10^7$–10^{10}	30 MeV–10 GeV	High "100 MeV"	Spark Chamber	Satellite
10–10^{14}	~~10~~ 100 GeV–100 TeV	Very High "TeV"	Atmospheric Cherenkov	Ground level Mountain *
^{14}–10^{17}	100 TeV–100 PeV	Ultra High "PeV"	Air Shower Array	Ground level Mountain
^{17}–10^{19}	100 PeV–100 EeV	Extremely High "EeV"	Air Shower Array	Ground level Sea level

Table 3

Principal Ground-based Gamma-Ray Observatories Reporting Results Prior to 1980

nstitution	Location	Epoch	Energy Threshold (TeV)
tmospheric Cherenkov			
ebedev Institute, U.S.S.R.	Crimea	1960–64	5
.E.R.E., U.K.; U.C.D., Ireland	Glencullen, Ireland; Malta	1964–70	2 – 5
mithsonian Institution U.S.A.	Mt. Hopkins	1967–76	0.2
ata Institute, India	Mukurthi; Ootacamund	1969–	0.5 – 2
rimean Astrophysical Observatory, U.S.S.R.	Crimea	1969–	2
niversity of Sydney/ Smithsonian	Narrabri	1972–74	0.5
r Shower Array			
ASJE Collaboration	Mount Chacaltaya, Bolivia	1962–67	100 – 100,000
lish-French Collaboration	Lodz, Poland	1964–66	1000 – 100,000

VERY HIGH ENERGY GAMMA RAYS

WHY STUDY THEM ?

(1) Highest energy photons (>100 GeV)

Important to observe a source at all wavelengths
What is the limit to the energy of photons emitted by a source ?
Are there different processes at different energies

(2) ORIGIN OF COSMIC RAYS

Cos. Rays → Charged ptls extending to 10^{20} eV
But where do Cos Rays come from ?
Cos. Rays affected by magnetic field and direction is lost. But
p + matter → π^0 → 2γs
γ direction is preserved
If γ rays are seen from any direction, Cos Rays must be there
(Morrison, 1958) → BIRTH OF γ ray Astronomy

VHE (>100 GeV) UHE (>100 TeV)

1953 Atmospheric Cer. Technique (ACT) ~1950 EAS technique
Large Uncertainty in angle determination

1958-1960 Idea of γ ray astronomy

1963 First ACT expt - First Disappointment
EAS - μ poor technique

1968 Pulsars discovered!
New Hope!!
Look for signature

CP1133 VHE γ rays seen (219, Nature)
CP0532 " " Not " (220, ")

1968-1980 MeV γ rays from pulsars
(satellite observns)

CRAB YES (3-4σ)
No, May be
CRISIS situation

1982 I WORKSHOP ON γ ray Astro. at OOTY
No Standard Candle
Only BRIEF CANDLES

1982-1987 Conscious perusal of Transient Phenomena
1983 → CYG X3 > 100 TeV

High level (>5σ) fluxes from crab
Switch over to X ray binaries
} More and more UHE expts
HER X-1, CYG X-3 (4-5σ)

1986 II Workshop on γ ray astro. Durham
↳ Mostly transients

1987 Very High level Signal from Her X-1 (~40σ)

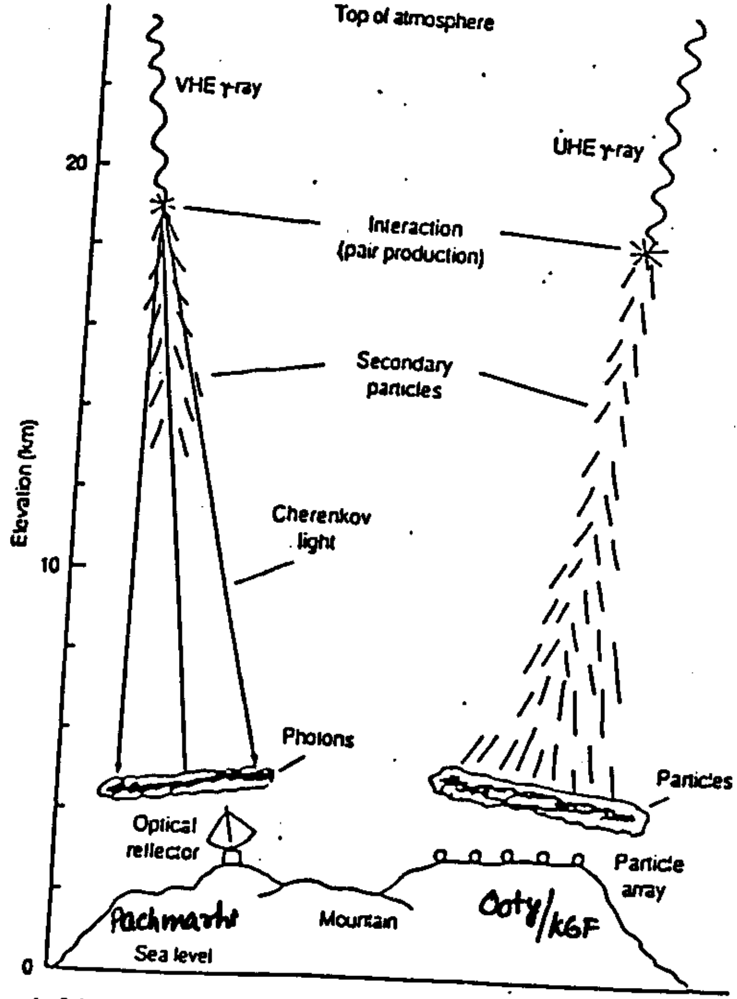
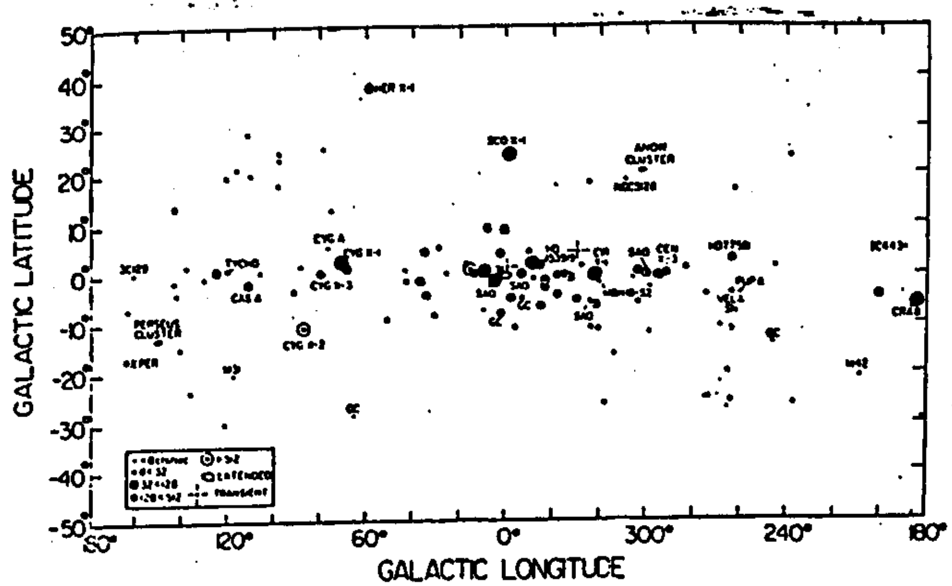


Fig. 1. Schematic view of two air showers created in the atmosphere. The VHE gamma ray is detected by the Cherenkov light emitted from the relativistic electrons and positrons of the shower. The higher energy UHE gamma ray creates numerous particle secondaries that penetrate to ground-based particle detector arrays.

11 DECEMBER 1987



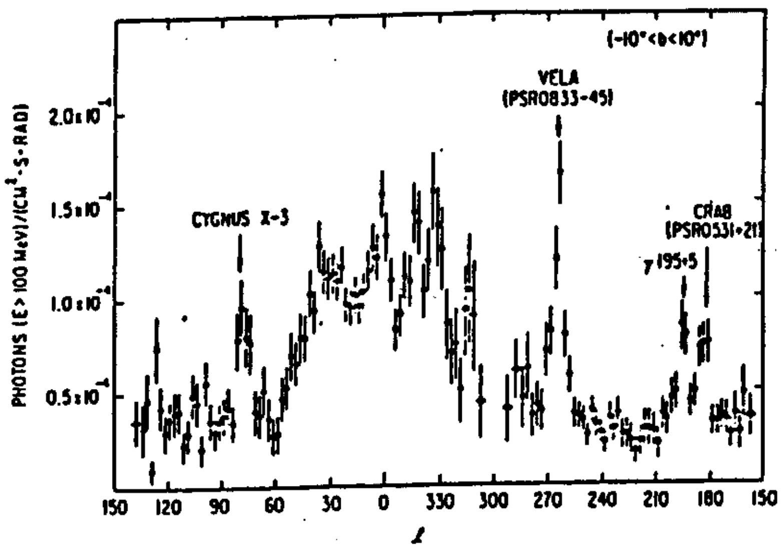


FIG. 9.7. SAS-2 measurements of the distribution of gamma ray emission (ϵ > 100 MeV) along the Galactic plane. (From Hartman *et al.* 1979, p. 599.) © (1979) The American Astronomical Society.

Radio Pulsars

Isolated magnetized neutron star

Period: CRAB 0.0331340.. sec

Narrow light Curves

Period increases

$\dot{P} = +\ 422.43\ ns/day$

Rotational Energy loss
$\sim I\Omega\dot{\Omega}$
$\sim 3\times10^{46}\ \dot{P}\ P^{-3}$
$\sim 10^{38}$ ergs/sec

Low Energy (Mev-Gev) γ Ray Luminosity

CRAB $\sim 10^{35}$ ergs/sec.

X-RAY BINARIES

Mag. neutron star around a massive ($\gtrsim 2M_\odot$) Companion

Her X-1 1.237792 sec

Broad light Curves (changes shape)

Period decreases (sometimes erratic)

$\dot{P} = -17280 \pm 8640$ ns/day

Gain in Rotnal energy

Fall (accretion) of matter from Main Star to neutron star → gives ang. mom to n.star

$\frac{dm}{dt} \lesssim 10^{-10} M_\odot$/year

10% Conversion eff. to X rays

X ray Lum = 10^{37-38} ergs/sec

TECHNIQUE

VHE γ RAY → E.M.CASCADE → CERENKOV LIGHT

Electrons are absorbed
but Cer light penetrates the atmosphere

LIGHT POOL
$\sim$ $>10^6$ photons
Spread over Dist.s >100m
lasts for $\lesssim 10$ns

300 GeV γ $\sim$ Density of ~ 10 photons/m^2 at core

Single Mirror (few m^2 area) Can detect the light
Collected and focussed onto a Photomultiplier

In front of PM mask (1°–4° diameter)
$\because$ of finite emission angle
Source $\sim$ 1°–2° dia
Mostly search light mirrors

BACKground

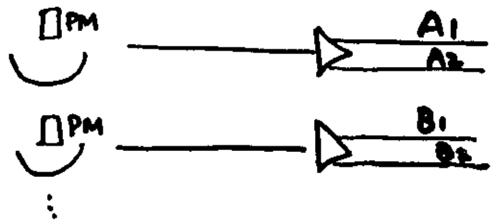
NIGHT SKY — use more mirrors and take Coincidence

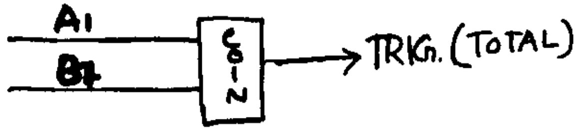
Cosmic Rays # ALSO PRODUCES SAME Phenomenon
More in number
→ THE NOISE

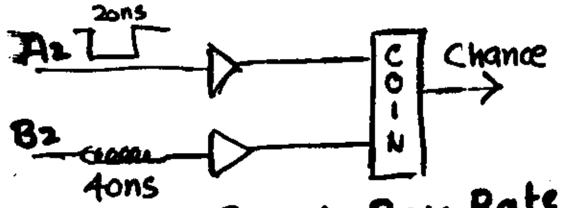
CER LIGHT weak
needs cloudless, moonless nights
$\therefore$ Duty cycle small

>50 GeV Satellite Detectors not practical
1 m^2 on satellite for 1 yr → 32 γ rays >1 TeV

BASIC TRIGGER SYSTEM







Chance $= 2R_1R_2T$

Cosmic Ray Rate (Cerenkov) = Total − Chance

	TRIG(Tot) Rate	Chance Rate	Cosmic Ray Rate
Lightning, Stars etc	✓	✓	✗
HT increase	✓	✓	✓

Chance monitors the ambient light level

Usually chance % $\sim$ 5–10

	VHE (>100 GeV)	UHE (>100 TeV)
what is detected?	Cer light	Particles
How detected?	Mirrors	Scintillators
Duty cycle	Moonless nights (Low)	24 hrs
Direction	Source can be tracked	no tracking; use arrival time at detectors to find direction
Background (noise)	Cosmic Rays	Cosmic Rays
Counting rate	400-800/min	~ 30-60/min
Threshold	Equate CR rate to what is expected Reda ± 50%	
Proton? γ?	No le Detectors	(1) le Detectors for a possible differentiation (2) Age of the shower

Accurate time needed for Pulsar analysis

Info. recorded

1. Time of the evt.
2. Various Scaler readings
3. Pulse hts. ADC
4. Arrival time. TDC

Cerenkov

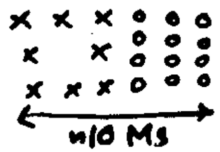
1. Align to a bright star
2. Move to source and track it

Good night – 4-5 hrs on a source
2-3 sources per night.

VARIOUS CONFIGURATIONS

× 1.5 m Dia
○ 0.9 m Dia

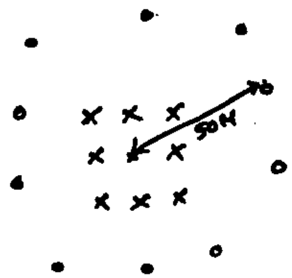
[redacted]



COMPACT ARRAY

RAJ Bhavan, OOTY

Sometimes ½ mirrors track comparative region

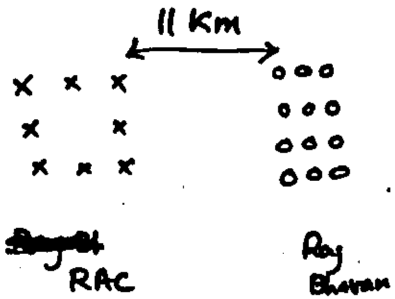


DISTRIBUTED ARRAY

Determine arrival direction

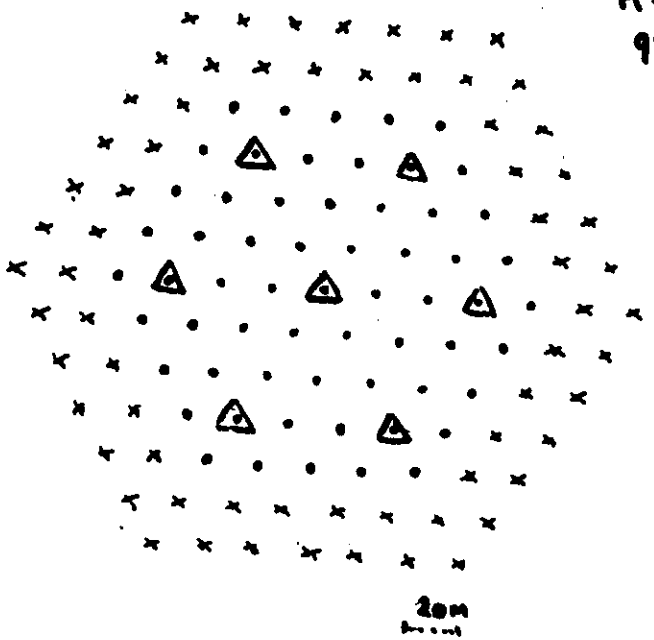
RAC, OOTY

SEPERATED ARRAYS



		ENG. THRESH. (CRAB)
COMPACT ARRAY	78-80	1.5 TeV
	83-84	0.6 TeV
	>86 Pachmarhi	0.4 TeV
DISTRIBUTED ARRAY	80-82	~ 1 TeV
SEPERATED ARRAYS	84-85	1TeV/2TeV

K.G.F.
920 $g\,cm^{-2}$



• 1 m^2 scintillator Timing + Density
× 1 m^2 Scintillator Density only (from February 1987)

Δ 28.8 m^2 Muon ($E_\mu > 1$ GeV) [from June '86]

<u>Trigger</u>: 3 fold of 20m Equilateral Triangle
and 1.5 / 0.5 particles each (slow) / (fast)
Detectors 1 – 61.

Rate of trigger ~ 60/min.
Record, after software cuts: ~ 40/m.

Tata Institute efforts

<u>ATMOS. CER. Technique</u>

OOTY. S. India
69-71 early obsons (2 mirrors)
76-85 obsvns with increasing sensitivity
(10 mirrors → 12 → 18 mirrors)

OOTY - poor viewing Crab 10 nights/year.
Shifted to Pachmarhi

Pachmarhi C. India >86 Several Configurations (Transp)
Crab 40 nights/yr.

76-85 P.N. BHAT, S.K. GUPTA, P.V. RAMANAMURTHY, B.V. SREEKANTAN, S.C. TONWAR, PRV
>86 BHAT, RAMANAMURTHY, SREEKANTAN, PRV.

<u>EAS TECHNIQUE</u>

Arrays at OOTY (hadron related) since ~'60
KGF (Muon ")

>83 <u>KGF</u> 121 scintillators 1 m^2
7 Mu Stations each ~ 30 m^2
(prop. counters)

>83 <u>OOTY</u> 25 scintillators 1 m^2
>88 " ~ 80 Scintillators
Mu detectors proposed
also cloud chamber.

<u>KGF</u> P.N. Bhat, M.R. Rajeev, S. Sinha, MVS Rao, S.C. Tonwar, B.V. Sreekantan, B.S. Acharya, PRV.

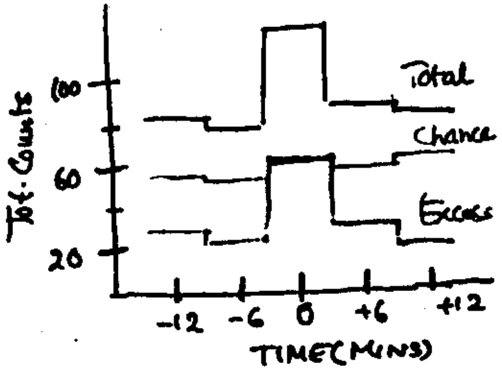
<u>OOTY</u>, S K Gupta, M.R. Rajeev, B.V. Sreekantan, S.C. Tonwar.

I Method - Directional Excess

CERENKOV: Keep telescope stationary } Variation is the ON-OFF technique
Let the source drift in

EAS: Find the arrival direction. Compare it with neighbouring RA bins

Good for all sources; only method for sources which have no signature.

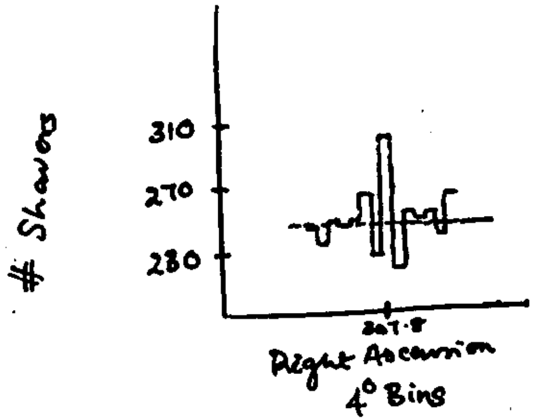


Probably the very first $\boxed{VHE}$ γ rays seen (S'reengnin et al 1968)

~ 3.2σ effect

↑ CP1133

CYGNUS X-3



84-86

Some of the Most recent $\boxed{UHE}$ γ rays seen (S.C. Tonwar et al 1988)

OOTY.

Average 247 ± 1.6

OBSVD. 300

~ 3.4σ effect

For unknown periods use circular statistics ......

If p is the phase of the event

RP (Rayleigh Power)

$$= \frac{\left(\sum^{N} \cos 2\pi p\right)^2 + \left(\sum^{N} \sin 2\pi p\right)^2}{N}$$

$$P(>R) = e^{-R}$$

Resultant of N unit vectors each oriented at angle $2\pi p_i$ wrt a particular dirn

Advantages

a) Independent of # of bins

b) does not depend on choice of phase origin.

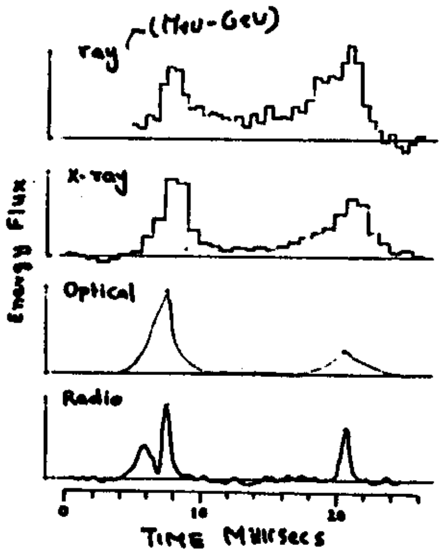
Disadvantages

a) gives low RP for narrow peaks

b) " double peaks.

Gaussian	RP	Prob.
4σ	10.5	$3 \cdot 10^{-5}$
5σ	15	$3 \cdot 10^{-7}$
6σ	20	$3 \cdot 10^{-9}$

TRACKING MODE



CRAB PULSAR SIGNATURE
IN 4 E.M. Windows
Optical, Radio 1969
Xray
Same Basic Shape
Sepn between Main and Inter Pulse $\sim$ 13.4 ms
$\simeq$ .40 phase

IP/MP = .65 (430 MHz) } Radio
= .20 (1664 MHz) }
= .59 optical
$\sim$ 1.2 Xray 1.5 – 200 KeV
→ Varies lower γray

FOR VHE γ
RECORD Time Accurately. Get the Phase of the Evt.
At t_1 — #cyc c_1, t_2 → #cyc c_2

at t - #cyc = $\frac{c_2-c_1}{t_2-t_1}(t-t_1)$ PHASE is frac Part

advantages!
(i) No necessity of Comparing with an OFF region
(2) S/N is higher

If $\sim$ 19 γs/hr (steady) find 3σ in 40 hrs with phase anal, in 800 hrs with Drift scan

EAS → Random Phase
γ → Definite Phase

Phase Plot → EAS + γ
If γ exists, expect Peaks in phase plots.

Two types of statistical tests.

1. EPOCH FOLDING

ARR. Times ⟶ phase Φ
Should know P, $\dot{P}$ etc
Epoch of zero phase should be known for absolute phase

Bin Φ in a histogram.
Ideal for narrow light curves eg: Crab Pulsar
Dis adv: Try different bin widths.
4σ Peak $\sim 3.10^{-5}$ Prob due to chance
5σ $\sim 3.10^{-7}$

2. Circular statistic (Rayleigh)

Represent N phases (N = # evts) by N unit vectors, each oriented at angle $2\pi\phi_i$ wrt a particular dirn
Rayleigh Statistic = length of the Resultant Vector Divided by N

$$R = \frac{\left(\sum_1^N \cos 2\pi\phi\right)^2 + \left(\sum_1^N \sin 2\pi\phi\right)^2}{N}$$

$$P(>R) = e^{-R}$$

Ideal for broad light curves eg: Her X-1
4σ $\sim$ R $\sim$ 10.5
5σ $\sim$ 15

CRAB

a favourite Cosmic ray source for long time

1960 p + matter $\rightarrow \pi^0 \rightarrow 2\gamma$

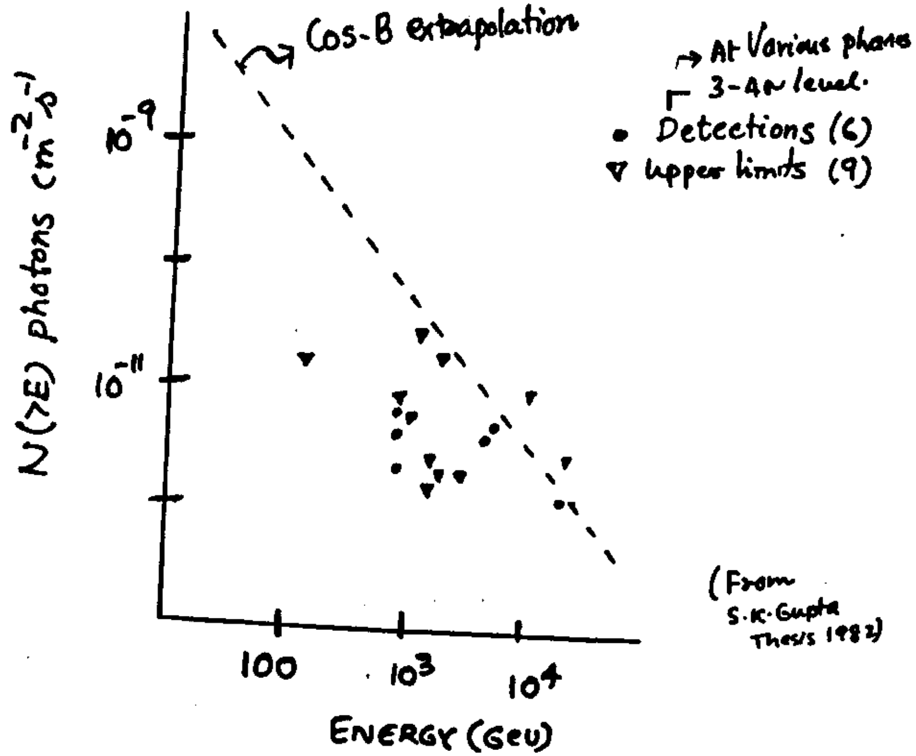
1 TeV flux = $10^{-7}\ \gamma/cm^2\,sec$

1963 Chudakov et al (USSR)
First full scale TeV experiment
Only upper limit $< 10^{-11}\ \gamma/cm^2\,sec$.

1969 Discovery of Crab Pulsar
(1) fastest (till recently)
(2) youngest (~ AD 1000)
(3) emits at all energies
(4) Northern hemisphere
(5) For HE γ expts, S/N could be high.

CRAB PULSAR (1970-1980)

Time Averaged Flux



PORTER + Weekes 1979 Review Paper
1) Situation unsatisfactory
2) UHE γ rays MAY have been detected
3) Spectrum has to steepen.

CRISIS Point ~ 1980

EXPECTATIONS : CRAB PULSAR

(A) HIGH Flux ~10^{-10} at 1 TeV
(Low En γ extrapolations)
NO Flux > $5 \cdot 10^{-11}$ was reported any time

(B) Non Reproducibility, conflicting results

ARE There no VHE γ rays at all?

ARE They time Variable?

Expected Steady Continuous emission
Belief in STANDARD CANDLE

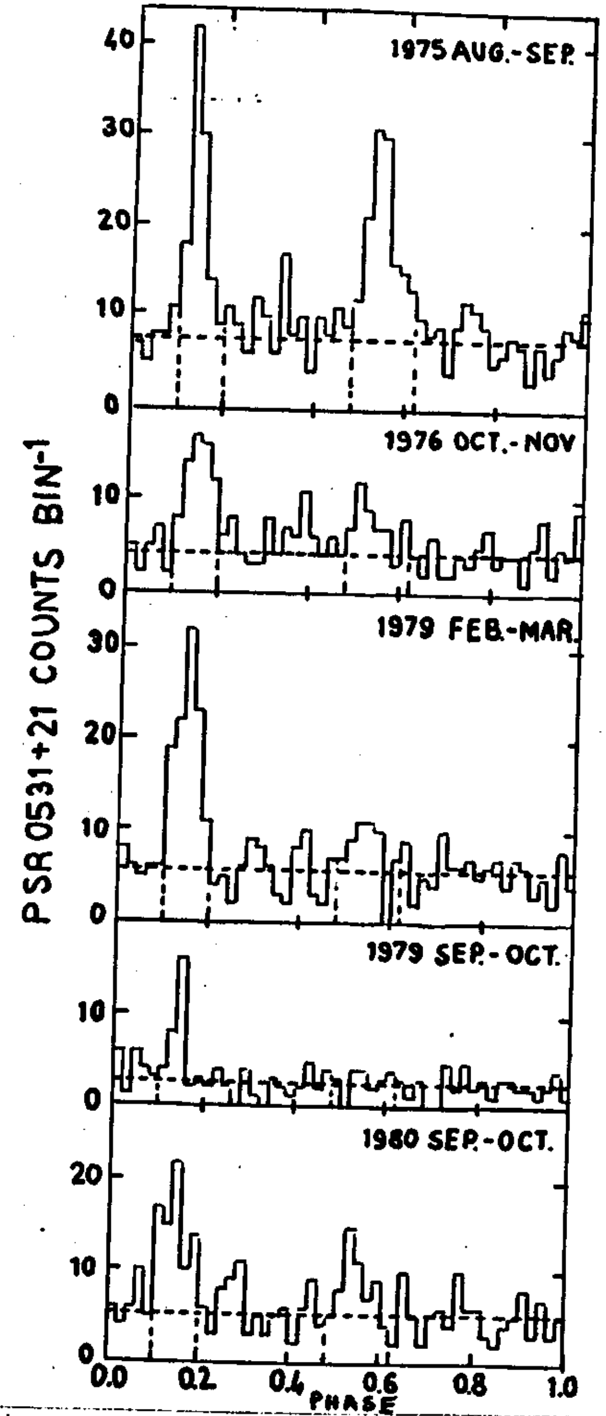
Data added up to get time averaged fluxes

What if there are only BRIEF CANDLES at these energies

Depending on
how brief the Candle flickered
how bright " "
During the obsvn time
↳ upper limit or Signals!

1982 OOTY 1st Intl. Workshop on VHE γ rays

Conscious persnal of Transient phenomena



LOW ENERGY DATA
Cos B
MeV-GeV

CRAB PULSAR

Three of these time periods had overlapping X ray Obsvns.
No change in the light Curve of X ray was observed.

TRANSIENT PHENOMENA
- Several approaches

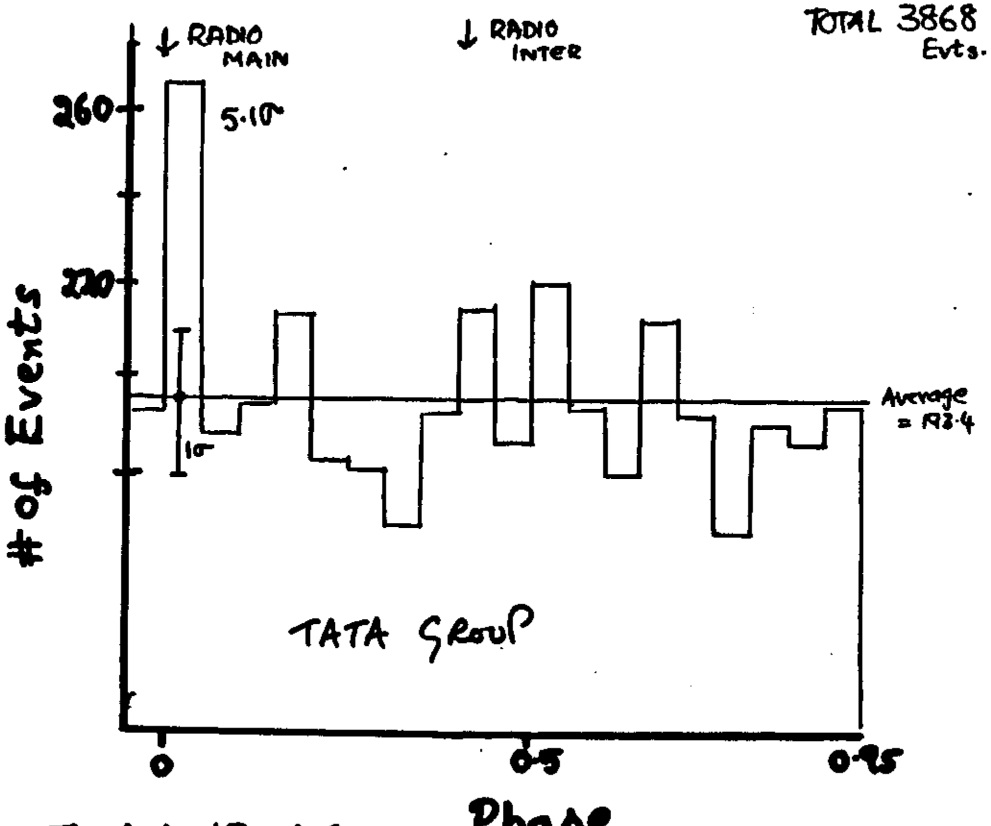
[1] Counting rate increases because of gamma rays. Inspect moments of high rate [Durham]

[2] Divide data into miniruns of duration 't' minutes. Look at light curves of all miniruns [TIFR ↳ CRAB]
OR subject each minirun to a Period Analysis (period not known exactly) [Whipple ↳ X ray binaries]

[3] Signal is weak. Temporary increase in S/N when noise (cos. Rays) undergoes a downward statistical fluctuation [TIFR ↳ CRAB]

1 → High Level transients - Rare
3 → Low level transients - May be more typical.

23 Jan 85 1711-1726 UTC
CRAB PULSAR



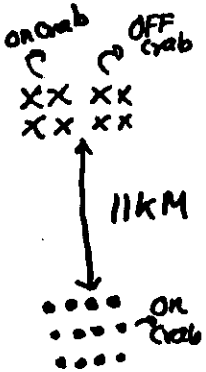
~70 γs in 15 mins

P.N. Bhat, P.V. Ramanamurthy, B.V. Sreekantan and P.R. Vishwanath Nature, 319, 127 (1986)

∴ Characteristics of the 15 min burst — 5

(a) 5.1σ peak coincident with radio main in array A_1 looking at Crab

(b) narrow ~ 1.65 msec



(c) no unusual behaviour from array A_2 looking at $8°$ south of Crab

(d) Array B, at a higher threshold and looking at Crab, agrees with A_1 $\sim 2/3$ of the time

(e) 10,000 wrong periods do not reproduce 5σ peak in any bin

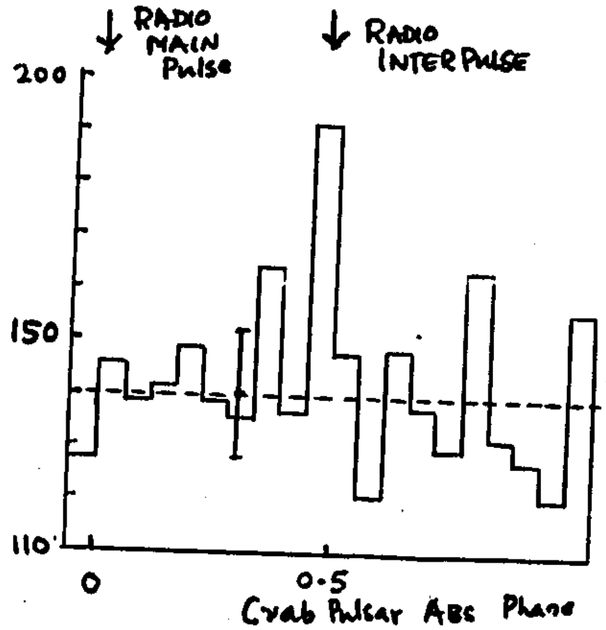
(f) Pois Prob $\sim 7.8 \times 10^{-3}$ any bin
3.8×10^{-4} at radio peak

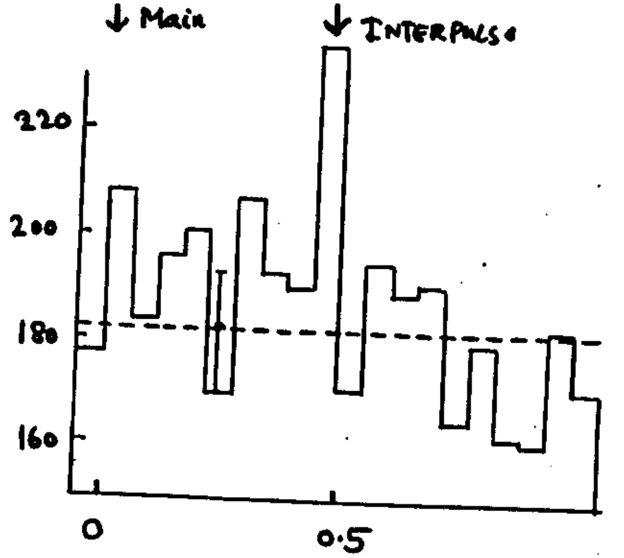
(g) Transient flux over 15 min duration
$= 2.5 \pm .5 \; 10^{-10} \; \gamma/cm^2/sec$

Similar bursts (2) seen by Durham group in Oct 81

a) duration ~ 15 mins
b) Broad — width 6ms FWHM
c) one of them similar flux
d) absolute phase not known.

VHE γ ray signal at radio
→ At least some VHE γ ray phenomenon similar to those at lower energies.





86-87

435 miniruns of 15 minute duration

Pachmarhi

Farewell Gift of the year

TWO BURSTS ON 31 DEC 86
UT $19^h 18^m - 19^h 33^m$
$18^h 19^m - 18^h 34^m$

No. of Trials
435×15
Prob $> 4\sigma = 2 \times 10^{-5}$
∴ Prob of
1 Burst = .14
2 " = .02
not very small

Pick out minutes which have uneven phasograms
(χ^2 criterion)

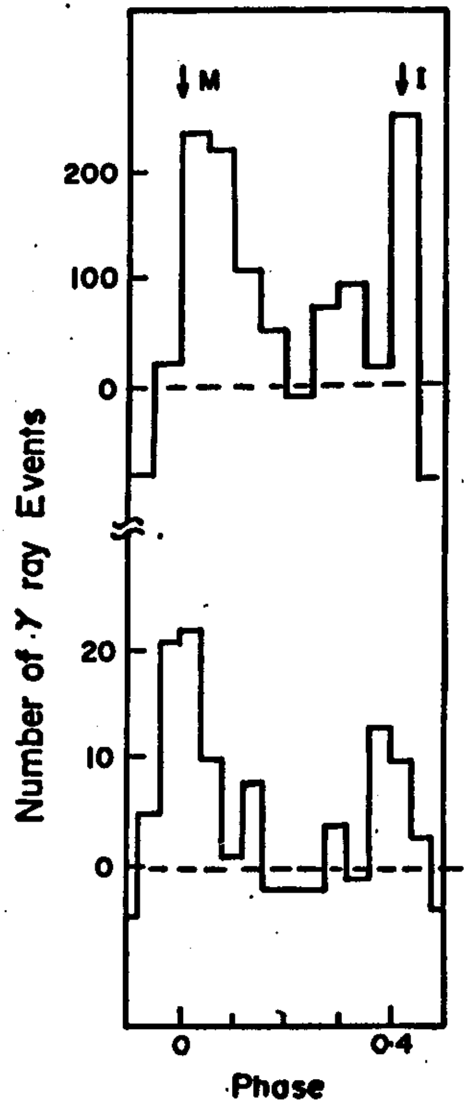


Fig. 3

Collection of One minute intervals

(a) VHE γ rays
(>600 GeV)
Only 82-83
84-85

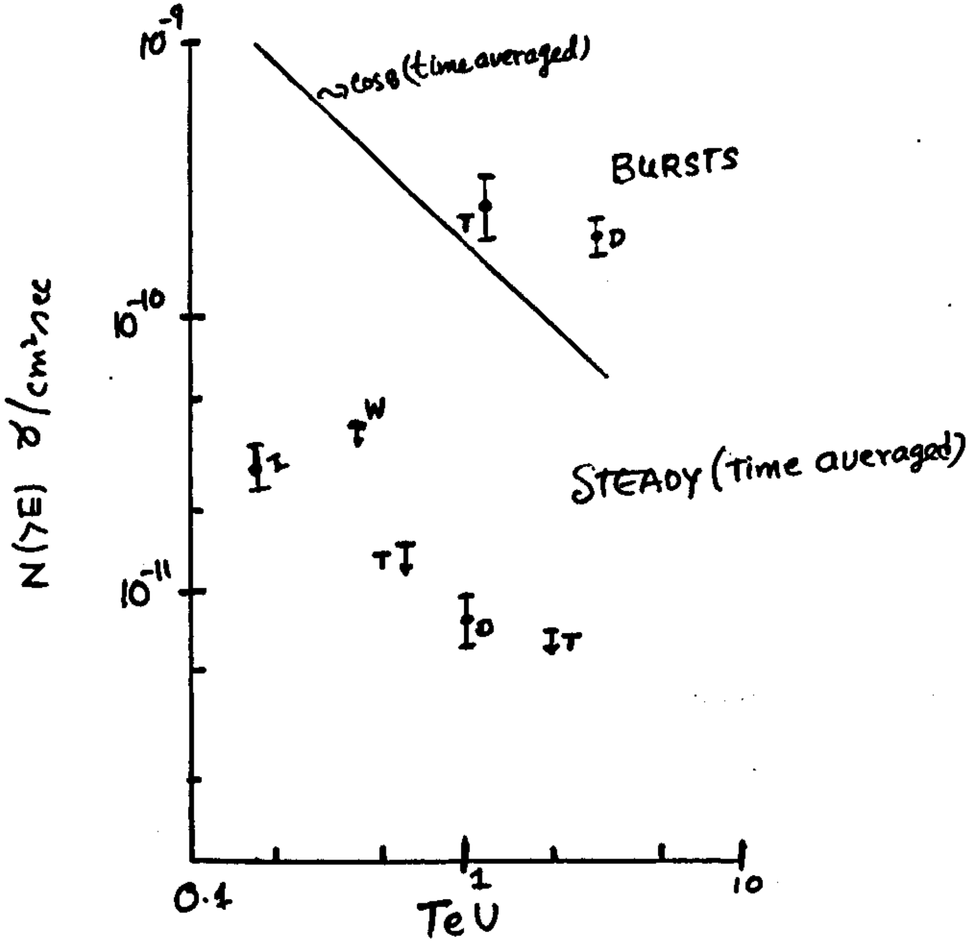
(b) HE γ rays
(50-3000 MeV)
Cos-B

PRV. J. Astrophys. Astron '87

STEADY Emission
Spectrum has to
steepen

CRAB PULSAR
(>1980)

D Durham
W Whipple
T Tata
I Towa JPL



VELA PULSAR (PSR 0833-45)

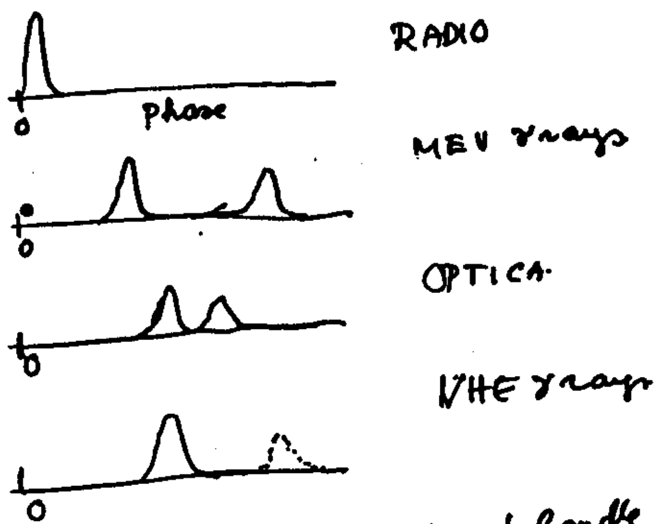
Southern hemisphere
Brightest MeV γ ray Source
Expected Flux 1 TeV $5 \cdot 10^{-9}$ /cm² sec
(Crab $\sim 10^{-10}$)

1974 Grindlay ~ 4.5σ at optical Main Pulse position

1974-80
Combined 82-83 } TIFR " "
84-85

78-79 TIFR ~ 4σ } ABS phase
80-81 TIFR ~ 4σ } unknown).

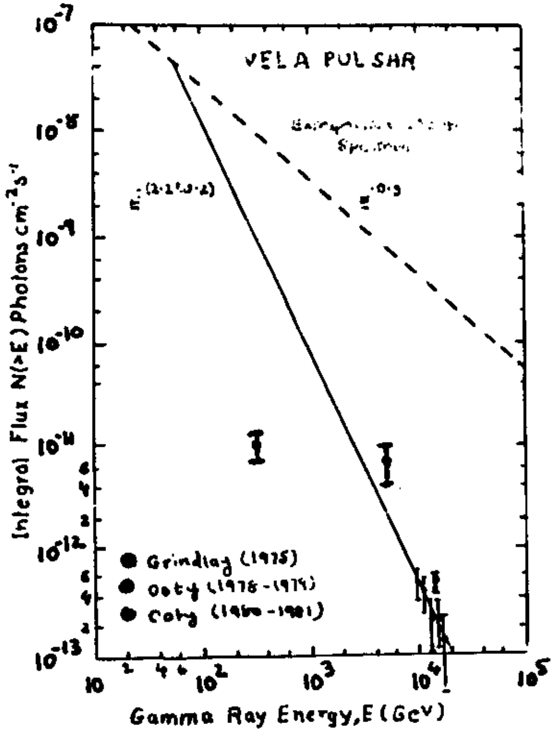
\# Spectrum steepens
\# Better Obson in Southern hemisphere



BEST BET for a standard Candle

Time Averaged Flux

28
27



OOTY- ABS phase not known

OOTY 78-79
80-81

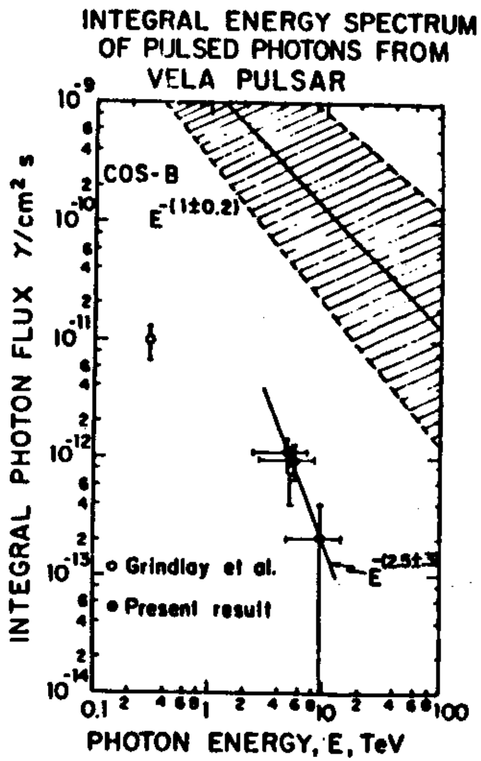


Figure 5.

Integral energy spectrum of VHE gamma rays from PSR 0933-45. The filled circles are from the present results whereas the open circles are the results of an earlier observations by Grindlay et al.(1975). Even though these authors stated that the signals reported were to be considered as upper limits, Grindlay (1982) indicated them as positive fluxes as shown in this figure. The straight line is a least square fit to our measurements and has a slope of -(2.5±0.3).

OOTY 79-80
82-83
84-85

Grindlay 1975

VHE γ ray peak Coincides with OPTICAL MAIN.

Bhat et al Astron. Astrophy. 1987

X RAY- BINARIES

PULSAR ORBITING around a companion star

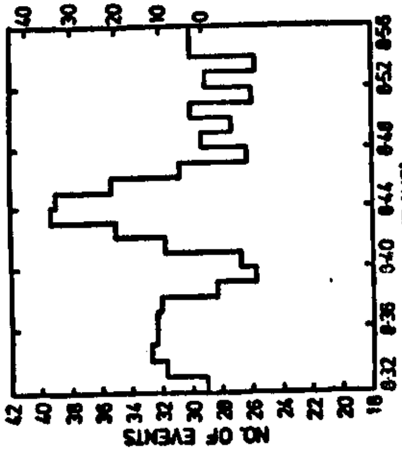
	CYG X-3	Her X-1
Pulsar period	12.6ms?	1.24s
Orbital period	4.8hr	1.7day
Other periods	19d? 34d?	35days
Comp. mass	?	$\sim 2 M_\odot$
Distance	11KPC?	5KPC
Xray luminosity	$10^{37}-10^{38}$	$10^{35}-10^{37}$
VHE γ ray lumi.	$10^{35}-10^{37}$	$10^{35}-10^{37}$

Xray binaries γ ray luminosity is $\sim 10^{-2}$ of total luminosity

Pulsars 2×10^{34} Crab $\sim 10^{-4}$ " "

HER X-1
CYG X-3 } MOST CREDIBLE SOURCES
$\sim$ 4 Groups (TeV)
$\sim$ 3 Groups (PeV)

Hercules X1 >1 TeV – Durham



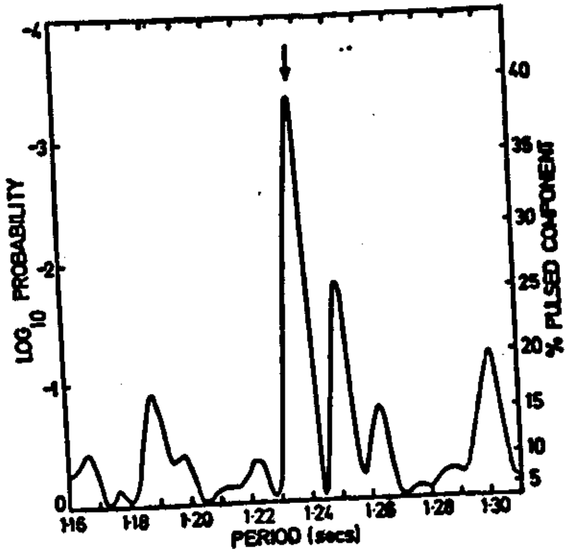
17 AP'83
Excess in Counting Rate
~ 3 mins

γray flux ~ 10^{-9}/cm²sec

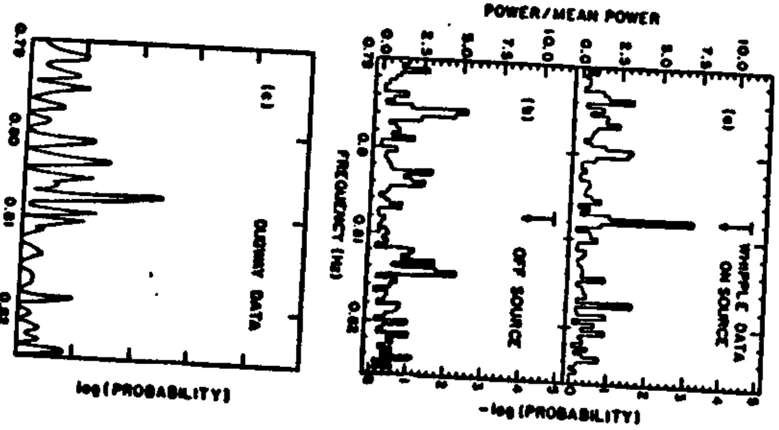
$\phi_{orb} = .76$

$\phi_{35d} = 0.0$

26



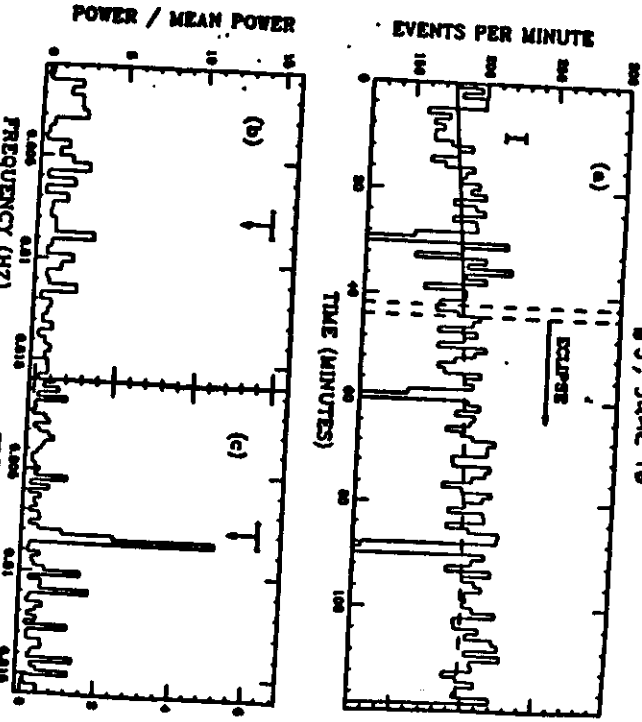
Simultaneous Obsn
Utah – Arizona



Whipple Observatory

18

'85, June 16



8 Detections by
Whipple Gp (84-86)

1986 Sep

Durham Intl. workshop on
UHE and UHE γ

(1) Still, there is no single UHE γ ray source which can be called a Standard Candle

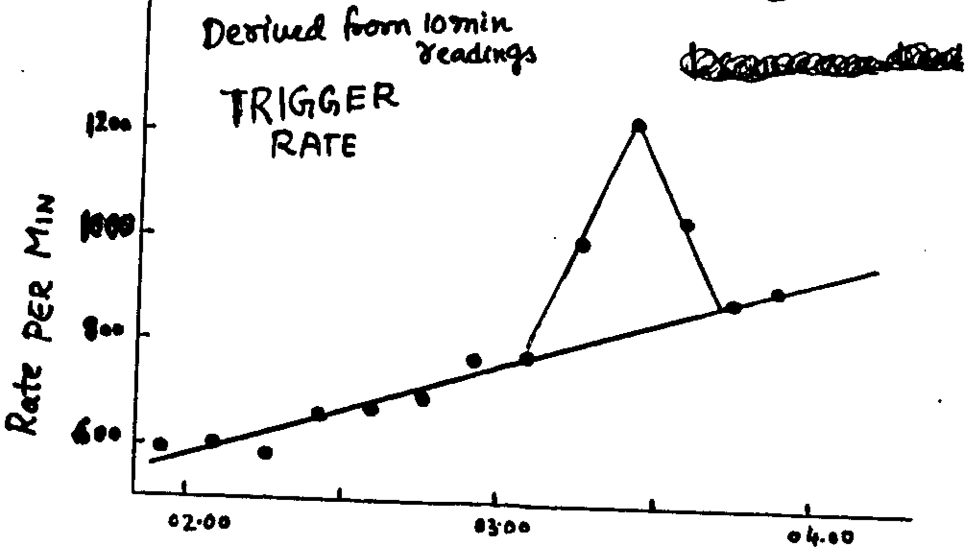
- Crab pulsar 2 groups — Bursts? yes But either very weak or no steady emission
- Cygnus X-3 >3 gps — Till ~83, nearest to a std. candle But now → variable 12 MS pulsar?
- Vela Pulsar 2 groups — Very weak emission
- Hercules X-3 atleast 2 gps — Transient
- 4 AU 011+63 atleast 2 gps — needs more study

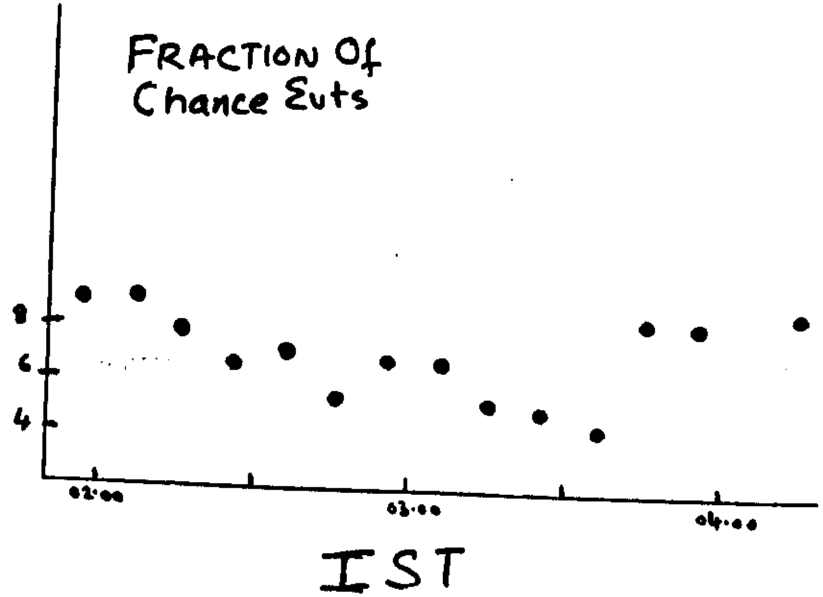
(2) Previously at 3-4σ level; Now in Burst activities >5σ level; Still critics ask why not ~10σ?

(3) Is it right to expect a standard candle at these energies? Weekes — (a) even in xray astronomy, there are variations by ~10⁴
(b) difficult to conceive of a natural particle accelerator which will act like a std. candle ∴
(c) target material is also a variable
steady flux must be the exception rather than the rule

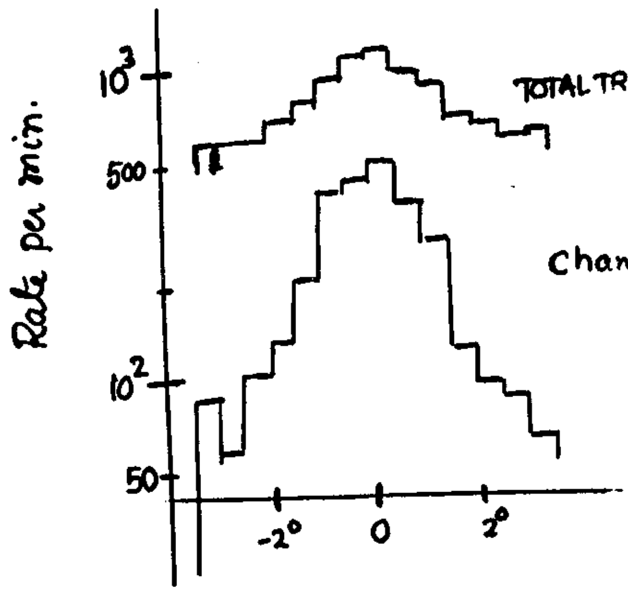
Log Book Information

APRIL 12, '86
{ HER X-1
Pachmarhi

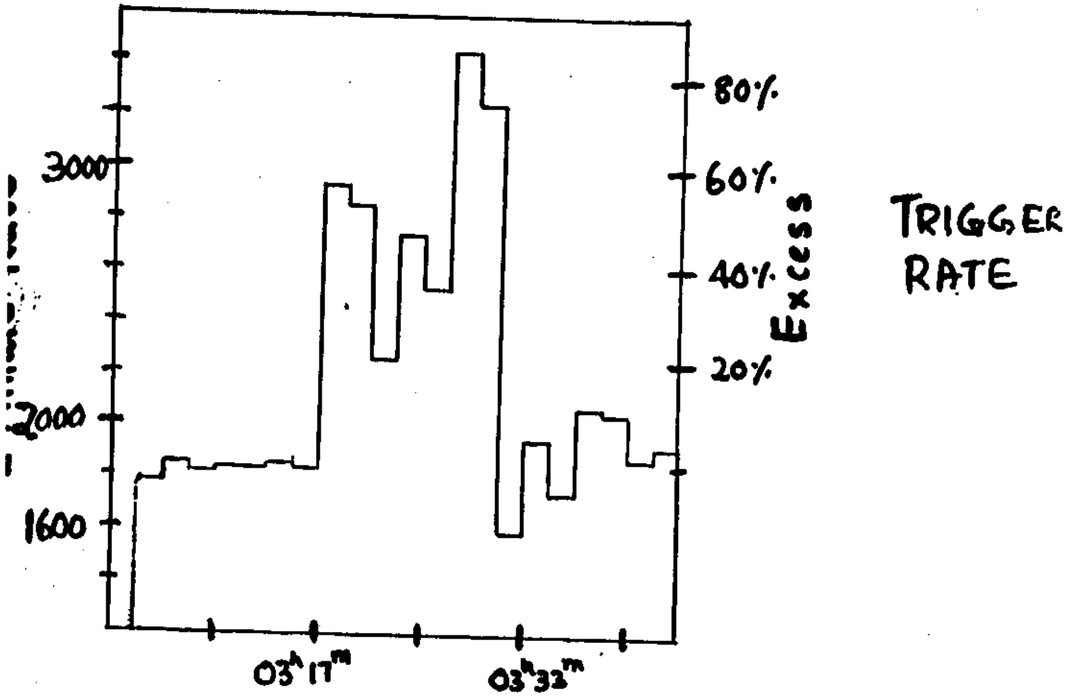


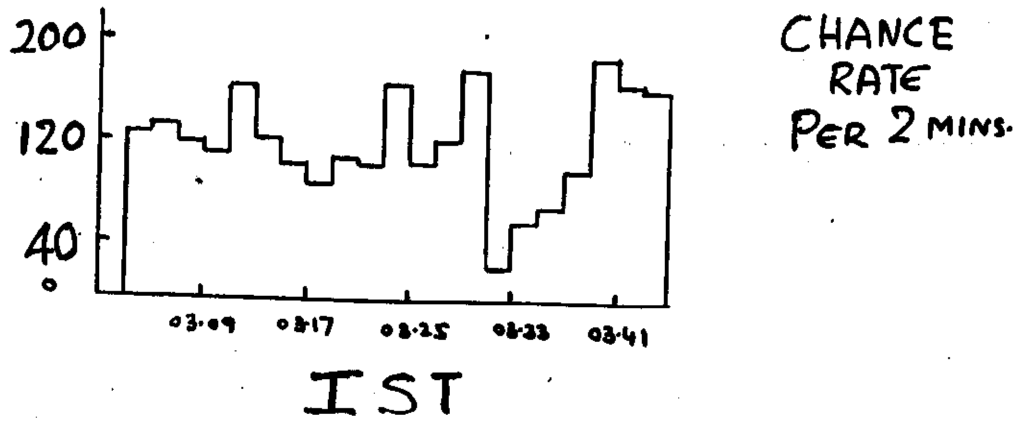


ENTRY OF A BRIGHTSTAR (2·6 Mag)



BURST: 03·17-03·31 APRIL 12,86
IST Tapedata





	TOTAL	CHANCE	
UT 2133-2147	13254	905	A
2147-2201	20367	873	B
2201-2215	13826	790	C

EXPECTED # $\frac{A+C}{2}$ 12692±85

OBSVD # B 19494±146

EXCESS EVTS Due to Burst

6802±169 → 40σ effect

IMP: CHANCE DOES NOT GO UP

Unless source has bright optical flashes which can mimic Cerenkov pulses (flash < 10ns)

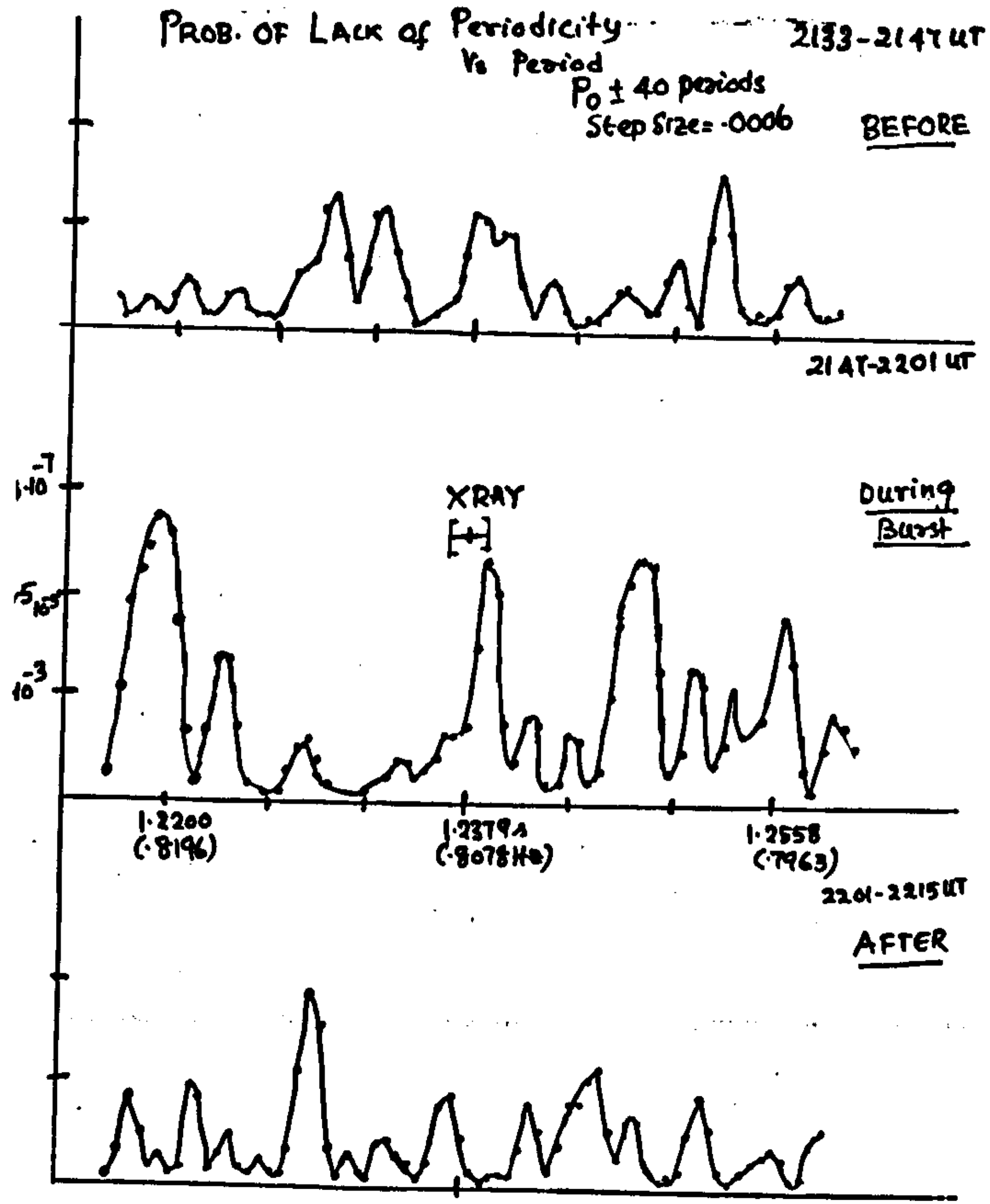
Excess has to be attributed to UHE γ rays.

Flux = $1.80 \pm .05$ $\gamma/cm^2 sec$ $(\times 10^{-8})$

Luminosity ~ $9 \cdot 10^{36}$ ergs

Energy Threshold ≈ 500 GeV

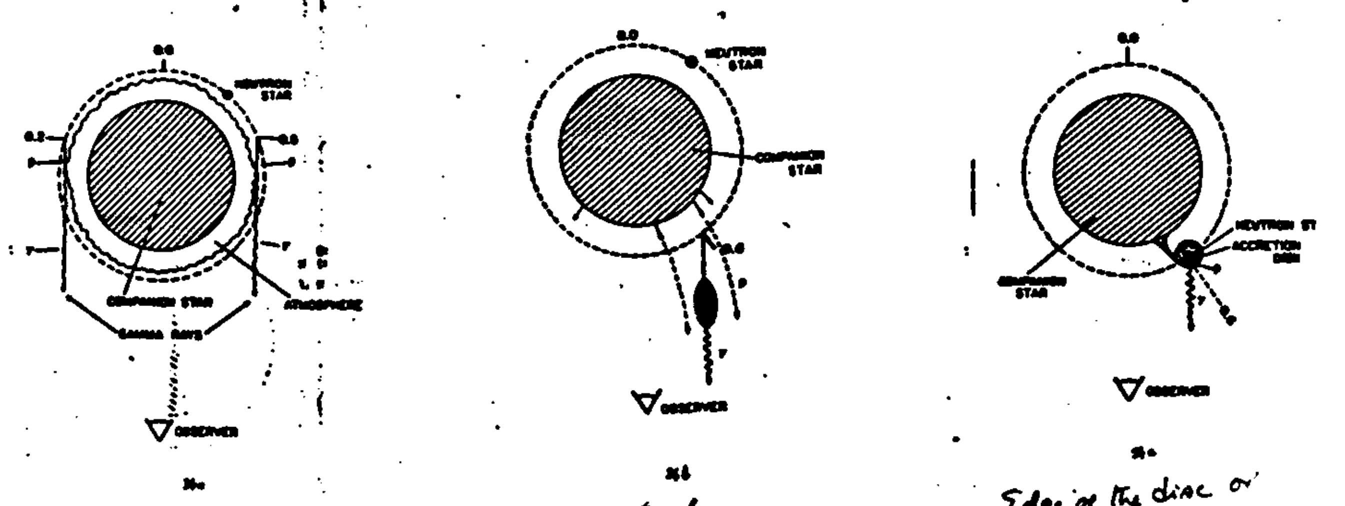
It is the Highest signal seen in γ ray astronomy till now.



VESTRAND + Eichler

1 · Pulsar accelerates Primary Protons
2 · Favourable Orientation of HE ptles and a suitable target
OPTIMUM thickness of target ~50gm/cm²
< no intn > absorption.

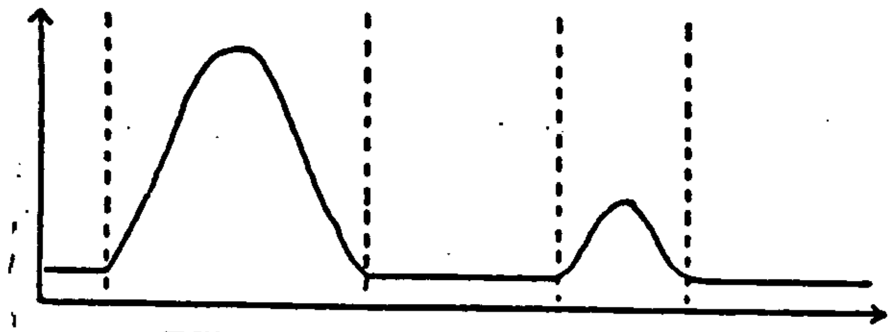
First put out for Cygnus X-3



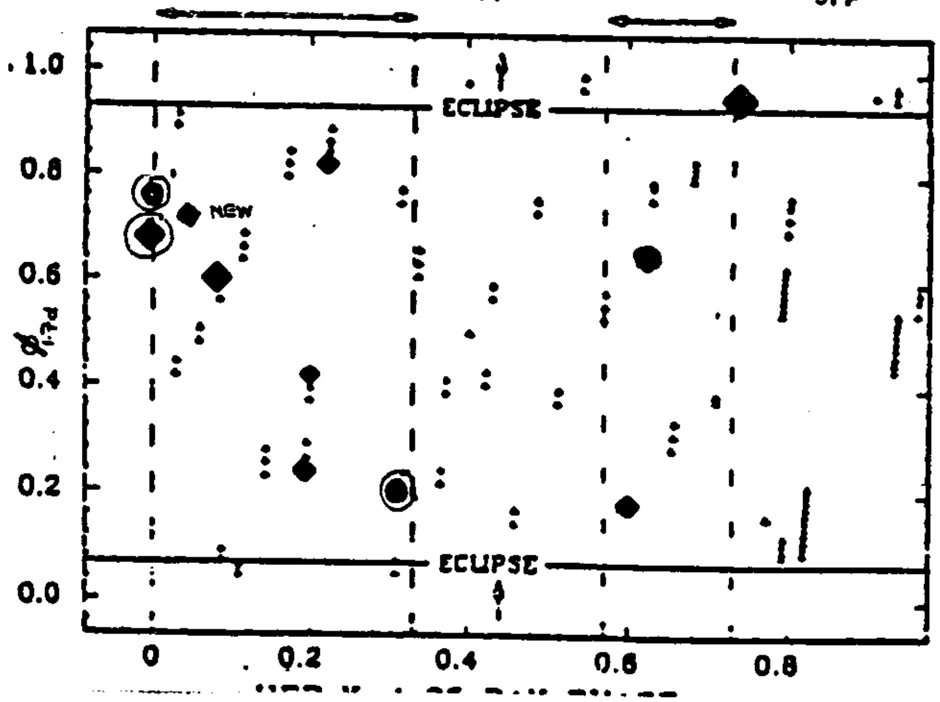
0.2, 0.8
Gas of the Companion

0 · 6
HE ptls — Companion
— Drives off material which acts as beam Dump

Edge of the disc or a bulge in the Disc
Line of sight Thickness close to 50gm.
Where neutron star enters and leaves the



35day period due to a precessing absorbing accretion Disc.



● DURHAM
♦ WHIPPLE
● FLY'S EYE
● PRESENT RESULT

35day on-off occurs always around orbital phase of ·2 or ·7

Her x-1 PeV (UHE) energies – Preliminary reports

KGF (84 Sep–85 June) 200 days

Los Alamos (" 86) 400 days.

Directional excess

For each day, calculate background and see whether there is any excess from source direction.

{ KGF – 2 days Prob < 10^{-4} May, June 85

{ Los Alamos – 1 Run " 23 Jul 86

KGF expect $200 \times 10^{-4} = 2 \times 10^{-2}$ # days

L.A $400 \times 10^{-4} = 4 \times 10^{-2}$ # days.

∴ Prob = .02 expect see 2 KGF

.04 — 1 L.A

KGF Both bursts in orb phase .7–.8

Los Alamos

Period analysis → Peak at the frequency seen by Whipple, Haleakala.

Prob of peak ~ 10^{-2}

Muons – Muon Content is anomalously Large }

KGF → Sporadic flux ~ 10^{-12}/cm²sec.

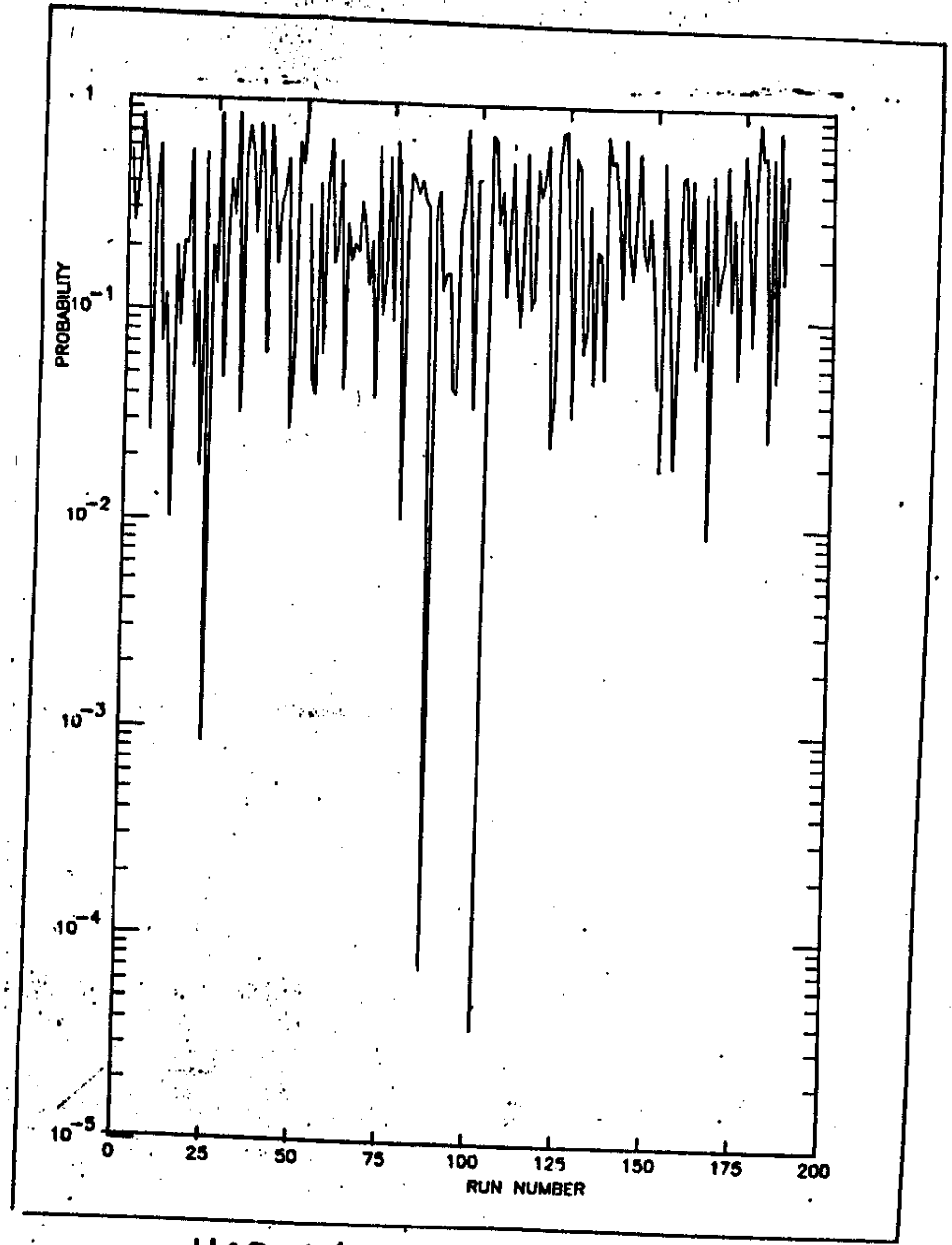
Lum → $5 \cdot 10^{37}$ ergs/sec.

no TeV obsvn by Durham

[40 minute burst seen by Fly's eye

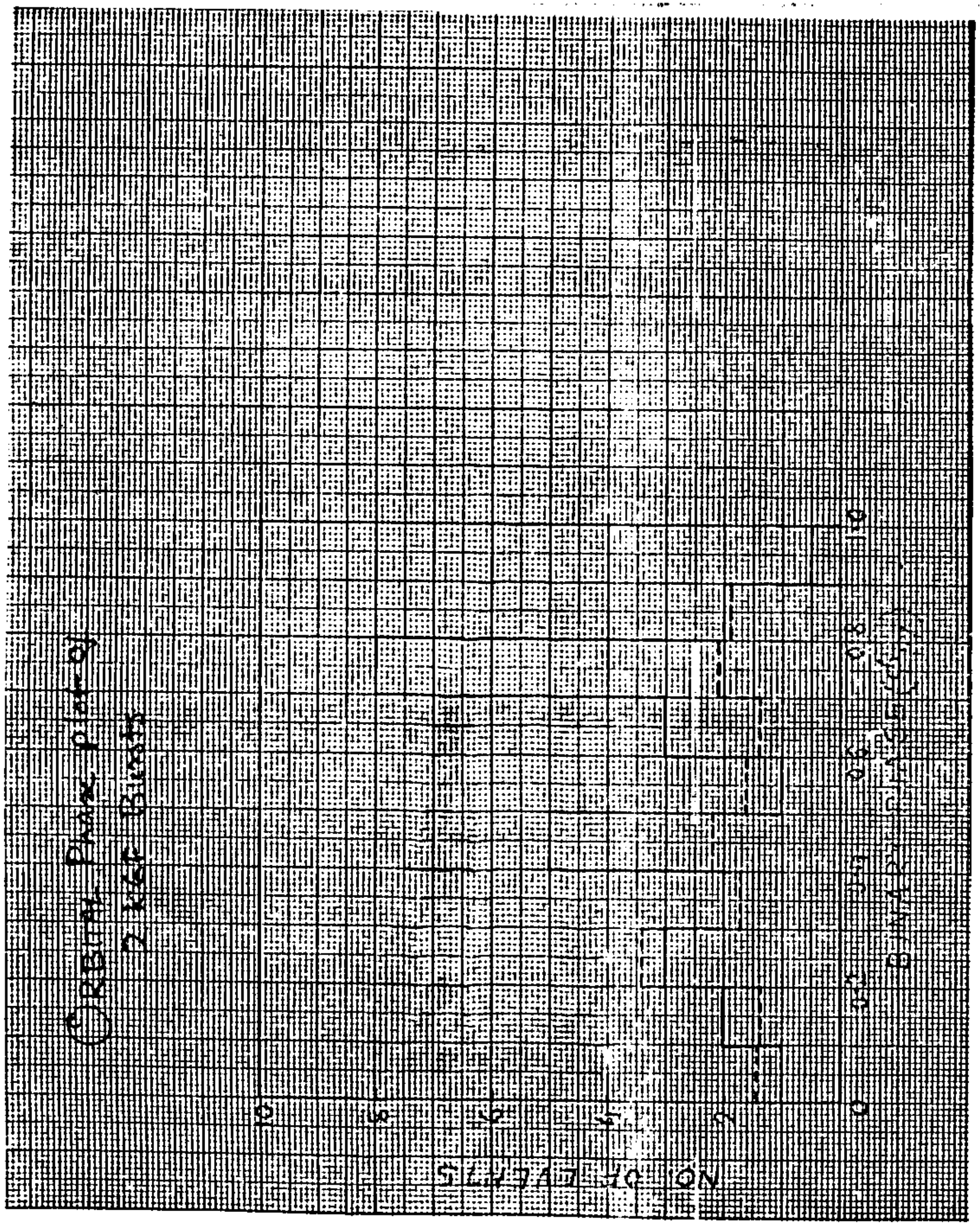
orb Phase = 0.67

Flux = 3.3 ± 1 10^{-12}/cm²sec



HER x-1

PROB. OF OBSERVING the obsvd no. of cnts. from source compared to background



Hercules X-1

(1) Seen by all the groups working in northern hemisphere in VHE

(2) Signal levels 4-40σ

(3) Flux ~ 10^{-10} - 10^{-8} γ/cm²sec

(4) VHE γ ray period - some near X ray
some far
(optical: sometimes different periods)
γ ray may be produced at a different location

(5) Needs more observation.

Most of these statements apply to Cygnus X-3 also.

(6) Also a PeV γ ray emitter.

CYGNUS X-3

VHE:
- SEP 72 — Huge Radio Bursts - - - -
- 72-80 — Crimean Obsons (STEPANIAN)
- 81-82 — USA, UK obsons
- ~82 — Finally a standard Candle !!
- 83-85 — Whipple Obs. → no emission.
- 85 — A 12ms pulsar ? (Durham)

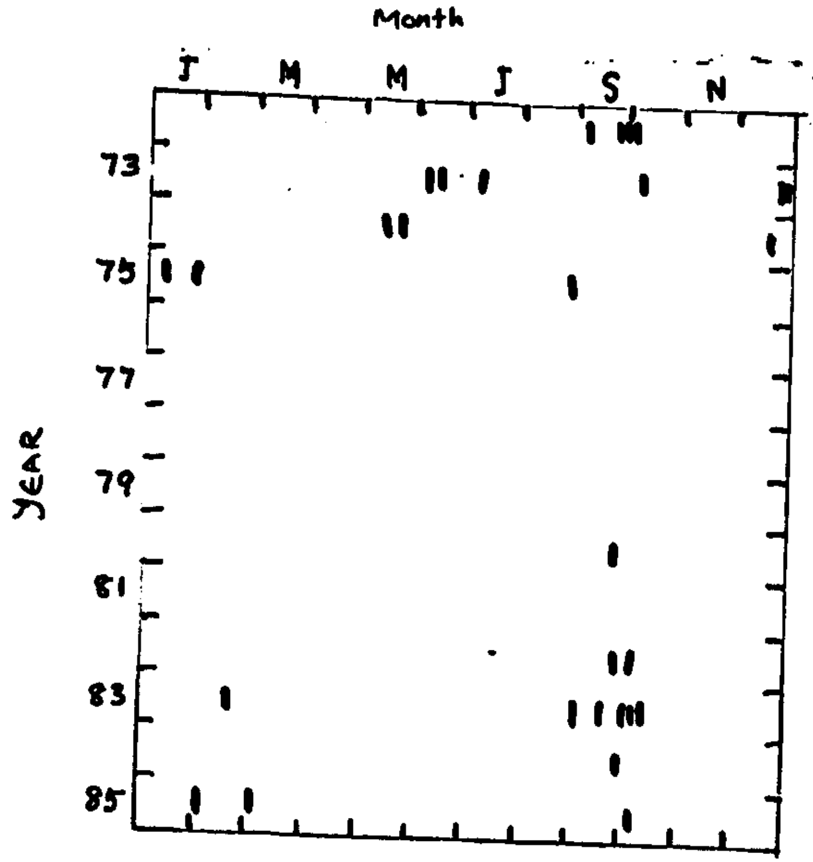
~82 — UHE γ rays (from Kiel)

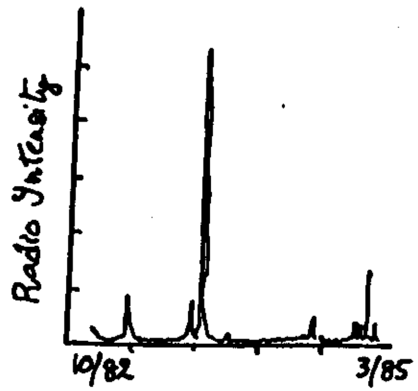
~83 — " Haverah Park

>83 — Many EAS arrays
(a) newly established
(b) older arrays refitted with timing

83-88 — Most Expts have not seen any steady flux - only Ooty 84-86

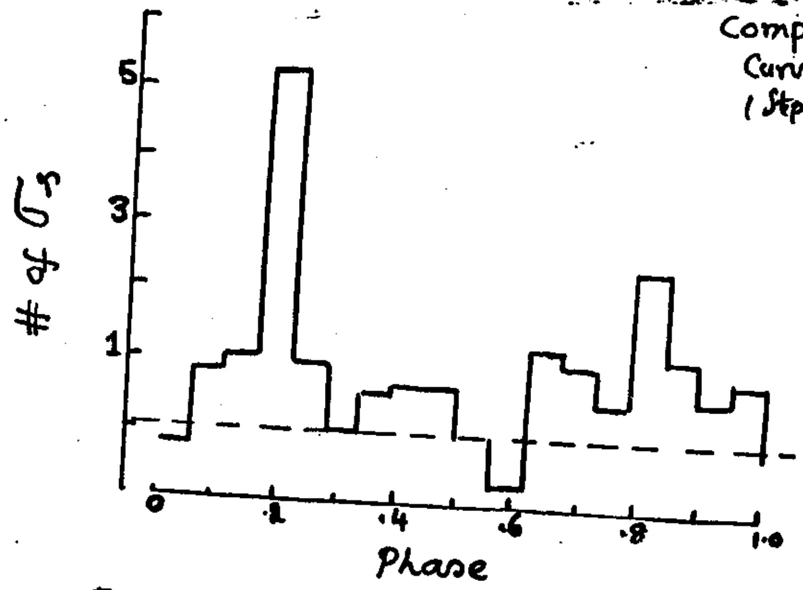
Like in TeV, concentrating on Bursts





Cygnus X-3 Radio Activity
Johnston et al

CRIMEA
1972-1980
Composite light Curve
(Stepanian '82)



First Obsvn
few weeks/months after giant radio outburst of Sep 2, 1972
Reported in Denver Cosmic Ray meet 1973

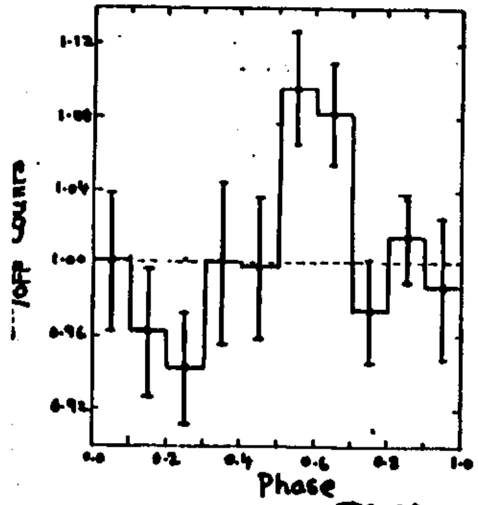
(1) Period measured independently 4·8 hrs

DC (2) Net excess = 3.9σ from CX-3 dirn.

(3) Light Curve was not Constant : times when emission at later phases was more significant than at 0.2 phase

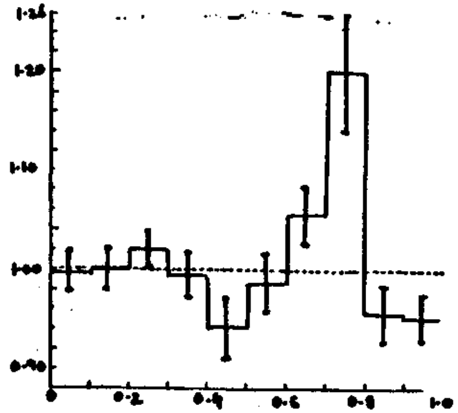
first to give period accurately
4.792416 hrs
later Confirmed by X-ray

1981



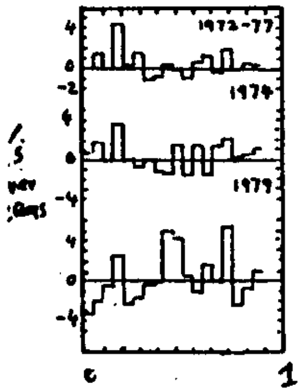
IOWA

1981

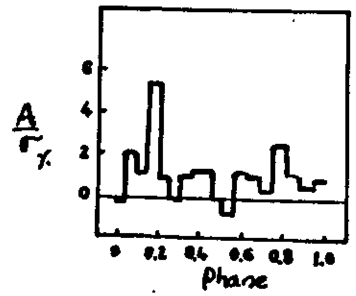


CYGNUS X-3

DUBLIN
– Smith et al
>1000 TeV



CRIMEAN



1972-1980
Crimea

USES DRIFTSCAN (ON/OFF)
16 MIN ON,
16 OFF

SLIDE

STEPANIAN first to give period accurately (4·792416 hrs)

KIEL RESULT 76-80

Angular accuracy $\pm 1\frac{1}{2}^{\circ}$

Choose age parameter > 1.1

so called flat showers

Developing early in the atmosphere.

Directional excess (D.C)

Expect 15 showers

Obsvd CYG X-3 $\pm 1.5^{\circ}$ } 30 " 4.4σ

ONLY OTHER EXPT TO have seen D.C excess

Tonwar et al (OOTY) 84-86

Expect 247 showers ± 2

Obsvd CX-3 $\pm 4^{\circ}$ } 300 3.4σ

Phase analysis

Kiel, Haverah Park, OOTY (78-82)

Time Avg. Kiel DC Flux

$> 2 \cdot 10^{15}_{ev}$ = (7.4 ± 3.2) 10^{-14}/cm^{2}sec

OOTY DC Flux

$> 2 \cdot 10^{14}_{ev}$ = (7.2 ± 3.2) 10^{-13}

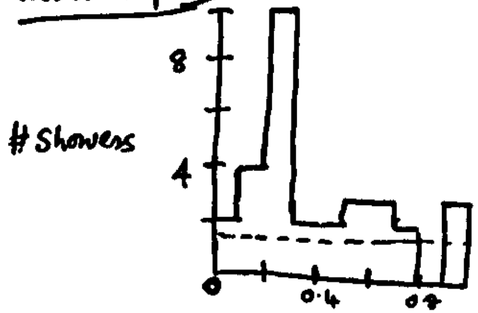
$> 2 \cdot 10^{15}_{ev}$ = ~~1 ± 4~~ $(1.0 \pm .4)$ 10^{-13}

HP Pulsed

$> 3 \cdot 10^{15}$ = $(1.5 \pm .3)$ 10^{-14}

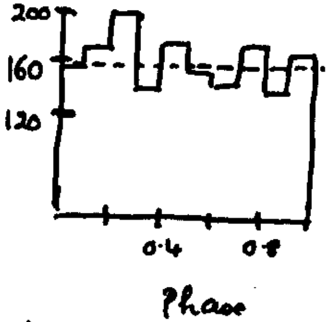
CYGNUS X-3

Mason ephemeris 0.2-0.3



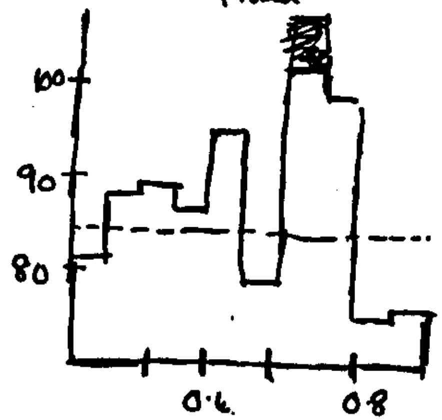
Kiel Age cut

.02% Prob that it is chance



0.2-0.3 Haverah Park No age cut

1% Prob that it is chance



OOTY age cut

~ 2σ effect 0.6-0.8

TEV also ≤ 1980 peak .2-.3

> 1980 — .6-.7

OOTY size cut $> 5 \cdot 10^5$ gives ~ 4.7σ

age > 1.4

Problems

(1) Are γ ray showers flatter than proton showers?

OOTY, KIEL do the shower cut

But many calculations show no significant differences between γ and P

(2) Muon content of Kiel showers high

Expected (for γ) = μ/e = 10%

Obsvd = 77±9%

Are more muons produced?

(3) Protheroe ('87) lists 9 EAS arrays doing UHE γ ray work 85-87

AKENO, BAKSAN, FLY's eye, HP, KGF (397 Exp, 387 obsvd), OOTY

Los Alamos, MOSCOW SU, Tienshan.

ONLY OOTY shows steady flux

All are upper limits.

Bursts reported by

BAKSAN	14-18 oct'85 (Radio Burst) → many phases and in '86 →	0.5-0.8
Los ALAMOS	April - May 86	0.6-0.7
Fly's eye	Jun - Aug 85	"

OTHER SOURCES

VHE γ rays	4AU 0115 (Xray Bi.)	Durham, Whipple, TIFR
	PSR 1509-58	Potchefstroom
	PSR 1953+29 6ms pulsar	Durham
UHE γ rays	Vela x-1	Adelaide, BASJE
	LMCX-4	"
	CYG x-1	Moscow

Traditional EAS arrays being used

Tien Shan,

Old Barge data

Table 21a

Very High Energy Gamma-Ray Experiments
(Atmospheric Cherenkov)

#	Location	Country	Organization	Location Lat. (deg)	Long. (deg)	Elev. (km)	Energy (TeV)	Operational
*a	Potchefstroom	South Africa	Potchefstroom	-27	27E	1.4	1	1985
*b	White Cliffs	Australia	Adelaide	-32	143E	0.16	1	1986
c	Narrabri	Australia	Durham	-31	145E	0.21	0.3	1986
*d	Haleakala	U.S.A.	Wisconsin+	21	156W	3.0	0.5	1985
*e	Albuquerque	U.S.A.	Riverside+	35	107W	1.5	0.2	1986
f	Mt. Hopkins	U.S.A.	Smithsonian+	32	111W	2.3	0.3	1983
*g	Themis	France	Saclay+	43	1W	1.5	0.1	1986
h	Crimea	U.S.S.R.	C.A.O.	45	34E	S.L.	1	1986
i	Pachmarhi	India	Tata	23	78E	1.1	0.5	1987
j	Gulmarg	India	[redacted] BARC	35	77E	2.7	1	1985
k	Beijing	China	Acad. Sinica	40	117E	1.0	1	1987
l	Delingha	China	Acad. Sinica	37	97E	3.2	1	1990

** After 1986
* After 1985

Many more arrays for UHE γ rays.

FUTURE

1. MORE HIGH LEVELS SHOULD BE SEEN
2. There is a steady flux from pulsars at 1 GeV. But ~ 500 GeV, only transients
   ∴ Steady flux disappears - Spectrum steepens.
   At what energies? why?
   ∴ Go To Lower energies. Use more area
   Are Processes different?
3. A better job of discriminating against Cosmic Ray Background
   - use lateral distribution (TeV)

A Mercedes Benz approach to γ ray Astronomy?

VHE (France)

UHE (Chicago, Mich, Fly's eye)

4. Whither smaller groups?
   Smaller Groups Can take up monitoring activity.
   γ ray Astro → more and more a search for bursts
   Bigger Groups may tire out
   - Conglomeration of smaller Univs / Developing Countries Can take over.

In Search of Loud Bells

(Pulsars to X ray Binaries)

ANTHONY HEWISH
Jostling with a BELL .
found another bell
which was rather mewish

It rang
regularly with a twang
but very rarely
with a Bang

Ricardo Giaconi
no relation to Coconi
or to the Giani
recommended an X-crony

His name is Hercules
And he is a dumbbell
but as a bell
He may be Swell