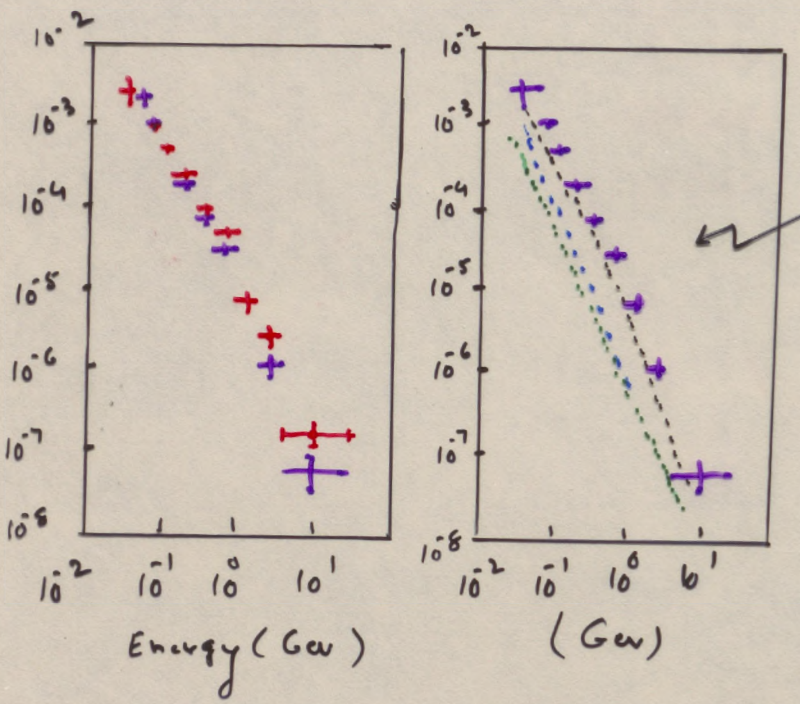
V1 p140

EGRET ~~BATSE~~ RESULTS

Gamma Rays From Molecular Clouds:

$346° \leq l < 10°$
$1° < b \leq 26°$

- Ophiuchus Cloud Complex – 125-160 pc. Consists of large tangled molecular clouds associated with Scorpio-Centaurus OB association.
- The molecular matter surveyed in CO shows five separate cloud complexes with elongated filamentary structures and a number of smaller clouds.
- The gamma ray emission from such clouds could be due to cosmic ray electron and proton interactions with matter and to a lesser extent with radiation.
- Contributions from bremstrahlung, nuclear interactions and inverse Compton.



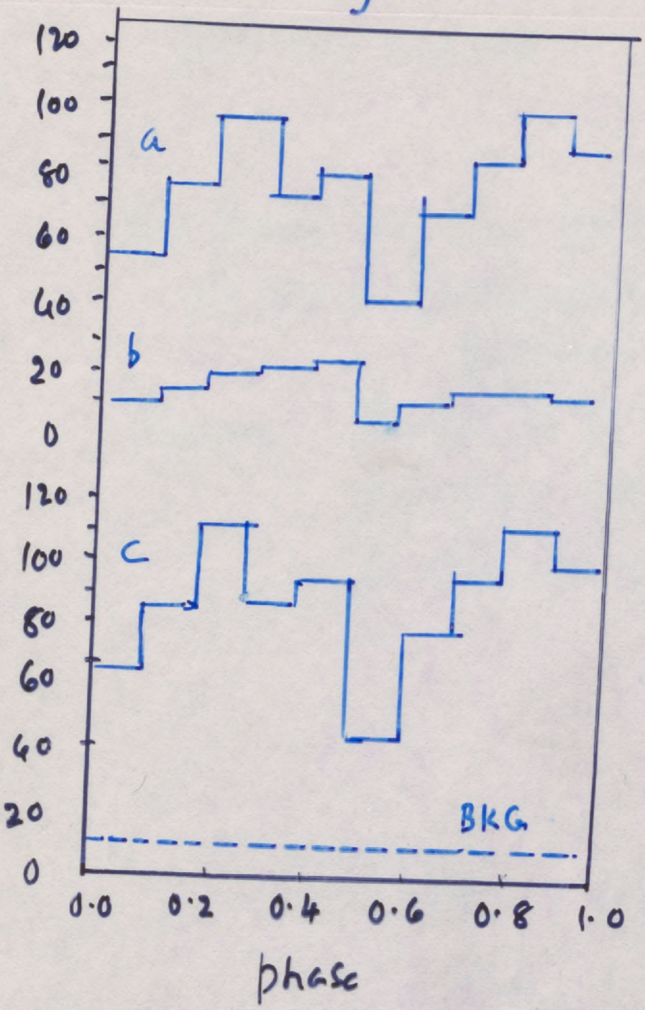
+ West Spectrum
+ East Spectrum.

East region spectrum.
(the dashed lines are the calculated contributions from bremstrahlung, inverse Compton and nucleon-nucleon interactions.

→ ⟨o⟩ Proton and Electron intensity and spectrum at the distance of Ophiucus (~150 pc) is not different from the immediate neighbourhood. — No evidence for any radical difference.

- Similar results on SMC, LMC.

Geminga

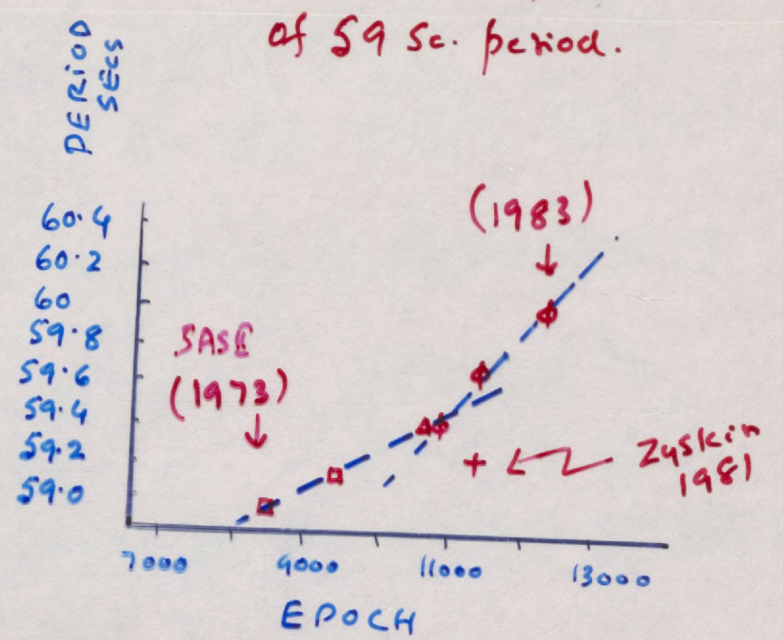


a EINSTEIN IPC March 1981 (810 events)
P = 59.737

b HRI data (91 events)

c. Sum of IPC + HRI

Secular Variation of 59 Sc. period.



SAS 1973
COS B 1975 ; Einstein 1979; Zyskin 79
Zyskin 1981 Einstein 1981
Exosat 1983

Zyskin	1979	59.46 ± .01 Sc
	1981	59.28 ± .01 Sc.
Einstein	1981	59.73 ± .05 Sc.
Exosat	1983	60.06

Geminga – (i) Source from kev to Tev. P ~ 59 Seconds.
(ii) high and rapidly increasing period derivative.

(iii) Isolated Neutron Star ?
Difficulty with energy budget if the observed P and $\dot{P}$ are due to spin down of pulsar.
$\dot{E} = I\omega\dot{\omega} = 10^{32-33}$ ergs.s. – Even with $\eta = 1$,
the distance < several tens of parsecs.
May be consistent with x-ray absorption.

There is no other evidence.
Precession of a Neutron Star axis ?

No other periodicity found with Einstein data.

③ OOTY Results on Geminga
DEC 84 - Feb 85 — two Cerenkov arrays at Ooty separated by 11 kms. (64 m^2 and 14 m^2 - mirror areas)

No peak at the period 60.25 s [expected according to predictions of Bignami et al]

Search $P = 60.15\ s - 60.35\ s$ — $\Delta P = 6 \times 10^{-4}\ s$

$P = 59 - 60.8\ s$ — $\Delta P = 1.8 \times 10^{-3}\ s$.

$\dot{P}$ can be ignored for the duration of observation

Flux Limits
$< 1.0 \times 10^{-10}/cm^2 s$ for $E_\gamma \geq 0.8$ TeV
$< 3.8 \times 10^{-11}/cm^2 s$ for $E_\gamma \geq 1.7$ TeV.

④ Whipple observatory results. (Cawley et al ICRC 19.

Nov 84 - Feb 85
No significant flux either as pulsed or as a steady source.

3 σ upper limits on flux ($> 10^{12}$ eV)
$< 5 \times 10^{-11}/cm^2 s$ steady
$< 2 \times 10^{-11}/cm^2 s$ pulsed.

The flux limits given by Whipple observatory is a factor of 6 less than that given by Mukanov et al at the same energy.

The Event of AD 437 and Geminga.

Chinese Records

on 26th. Jan 437 A.D

"A Star was seen by day between 3 and 5 P.M in the Lunar Mansion TUNG CHING"

Stephenson (Q. Jr. Ast. Soc. 17 121, 1976) translates this event to $l = 195^\circ$, $b = +5^\circ$ (with large uncertainities)

This agrees with the position of Geminga.

If true and $\ddot{P}$ same throughout — 1500 yrs old

$\tau = \frac{P}{2\dot{P}} \sim 400$ yrs. May be $\ddot{P}$ was less.

Stephenson and Clark (Mongr. Ast. 5 4(1978))

Not a Supernova

A Relatively Short optical flash reaching an optical magnitude of -4.

Geminga - A binary System ?

* More flexibility in the interpretation.
  Better fit with optical observations.
  G-Type star + Collapsed object. (neutron Star)

  [a model similar to that of Vestrand and Eichler for Cyg X-3]

  ↓

* a beam of ultra high energy particles created in the vicinity of neutron star and hits the surface of the primary.
* Radiative Collisions (bremsstrahlung and π^0 production) reprocess the incident beam to produce the observed kev - Tev photons
* For a given angular width of the primary beam, with scattering during reprocessing, the possibility exists for the reprocessed radiation to be observed together with the direct ultra high energy beam.
* Co-rotation of the processing region produces a beat period between the reprocessed and direct one, the difference between the two being the orbital frequency

* Geminga : 1981 ultra high point period 59.28 sc.
  beat period = 59.46 sc.
  orbital period = 160 mins.

Uhf Component (10^{12} ev) - two period values will be present.

* EXOSAT observations can be summarised as

① Peak at 59.74 s ; ② No peak outside 58 - 60 s.

③ Light curve of Einstein (901 events) - 50 % pulsed. 50 steady.
EXOSAT (435 ") Less significant.

④ Secular variations of P

73.79 $\dot{P} = 2.4 \times 10^{-9}\ ss^{-1}$
79.83 $4.7 \times 10^{-9}\ ss^{-1}$

} * has $\dot{P}$ changed by a factor of 2 between 73-79 and 79-83 ?

Very High Energy γ-rays.

① Helmken and Weekes searched for VHE γ-rays with Mt. Hopkins 10 m. dish. (Ap. J. 228, 53 1979)
No periodic signal $< 1.5 \times 10^{-10}$ photons / $cm^2 s$. [$E_\gamma > 0.2$ TeV]
$< 6.7 \times 10^{-11}$ " " [$E_\gamma > 1$ TeV]

② Zyskin and Mukanov et al (18th ICRC 1, 122 (1983)
Makanov et al ($E_\gamma > 10^{12}$ eV) (19th ICRC (1985)

29th Jan - 1st Feb (79) P = 59.46 s (Chance Probability
144 mins 6×10^{-2})

5th Feb - 6th Feb 81, P = 59.28 s (")

9th Dec 27th Dec 83 P = 59.49 s

[Rate on source 24.88 / min
off source 24.03 / min]

3.5 ± 0.44 % Excess

$7.0 \pm 4.5 \times 10^{-11}$ photons / $cm^2 s$.

Period of Geminga.

SAS II (75)	59.0074
Cos B	59.1969 (?)
Exosat (83)	59.745
Zyskin (81)	59.28
" (83)	59.49

* Cos B - Retraction (Mashou et al 17th ICRC, Paris, 1 177, 1981)

> 4 months exposure.
Search around SAS II parameters $P, \dot{P}$
$\Delta P = 5.4 \times 10^{-5}$ s ; $\Delta \dot{P} = 8.3 \times 10^{-11}$ ss^{-1}
"No Evidence for Periodicity" was the Conclusion.

* X-Ray observations (Bignami et al Ap. J. Lett 272 L-9 1983)

• Analysis of Einstein Data (IPC, HRI)
10^4 s 2.5×10^3 s

4 Sources in the γ-ray error box
Brightest IE 0630+178 proposed as Candidate.

① $L_x / L_v \sim 1000$; ② No temporal Variability ③ No Radio Counterpart ④ Soft Spectrum $\Rightarrow N_H = 10^{19}$-$10^{20}$/cm^2
$\simeq 100$ pc

⑤ $F_x = 2 \times 10^{-12}$ ergs/cm^{2}s.

⑥ Within 2" HRI Error Box - a faint blue object $m_v \sim 23$
(ESO 1.5m Telescope + CCD)

• Exosat Observations (Caraveo et al Nat. 310, p481 (1984))
Exposure 3.4×10^4 s (Sept 83)
Essentially Confirm Einstein Results
No Variability over 10 hrs
Periodicity Search (Bignami et al) 310, 464 1984)
↓ 59.4 - 59.8 s in Steps of .02 s

For P = 59.745 $\chi^2 = 3.94$ for 9 degrees of freedom
Chance Probability $5 \times 10^{-5} \times 20 = 10^{-3}$ s

[In a further refinement 20 Steps $\Delta P = 1 \times 10^{-6}$ s
$\chi^2 = 4.26$ (for 9 df)
objected to by Buccheri et al]
(Nat 316, 131 1985)]

Geminga $\alpha = 6h\,30m\,59{\cdot}15''$ l^{II} $195 \pm {\cdot}04$

$\delta = 17^\circ 48' 33''$ b^{II} $4{\cdot}2 \pm {\cdot}04$

(Gemini Constellation Gamma Ray Scource)

Second brightest in Cos B γ-ray sources (25)

Flux : $4{\cdot}8 \times 10^{-6}$ photons / cm^2 sc.

$2{\cdot}4 \times 10^{-9}$ ergs / cm^2 sc.

Distance : Controversial by 8 orders of magnitude

X-ray ~ 100 pc

Radio ~ $1{\cdot}1 \times 10^4$ Mpc

Radio 0630+180 { 60 ± 20 mJy, $\alpha = -0{\cdot}11$

{ Quasar Z = 1·2

optical Counterpart. No x-ray object in this region.

* SAS-II on Geminga (Ap. J. 198 p163, 1975) Fichtel et al

Point Sources → "Crab, Vela, ... and a region few degrees north of Galactic Plane around 190-195° longitude"

... Bennet et al (NASA Symposium 1976); Swanenberg et al Confirmed the Source. "Error Box too big to make any identification".

Thomson et al (Ap. J. 213, 1977) — based on 121 events in 3 different weeks of observation gave

$P = 59{\cdot}0074$ Seconds
$\dot{P} = 2{\cdot}23 \times 10^{-9}\ ss^{-1}$ } $T_0 = J.D\ 2441656$

Commented " Large Number of trials. Evidence not Compelling; worth watching in future experiments.

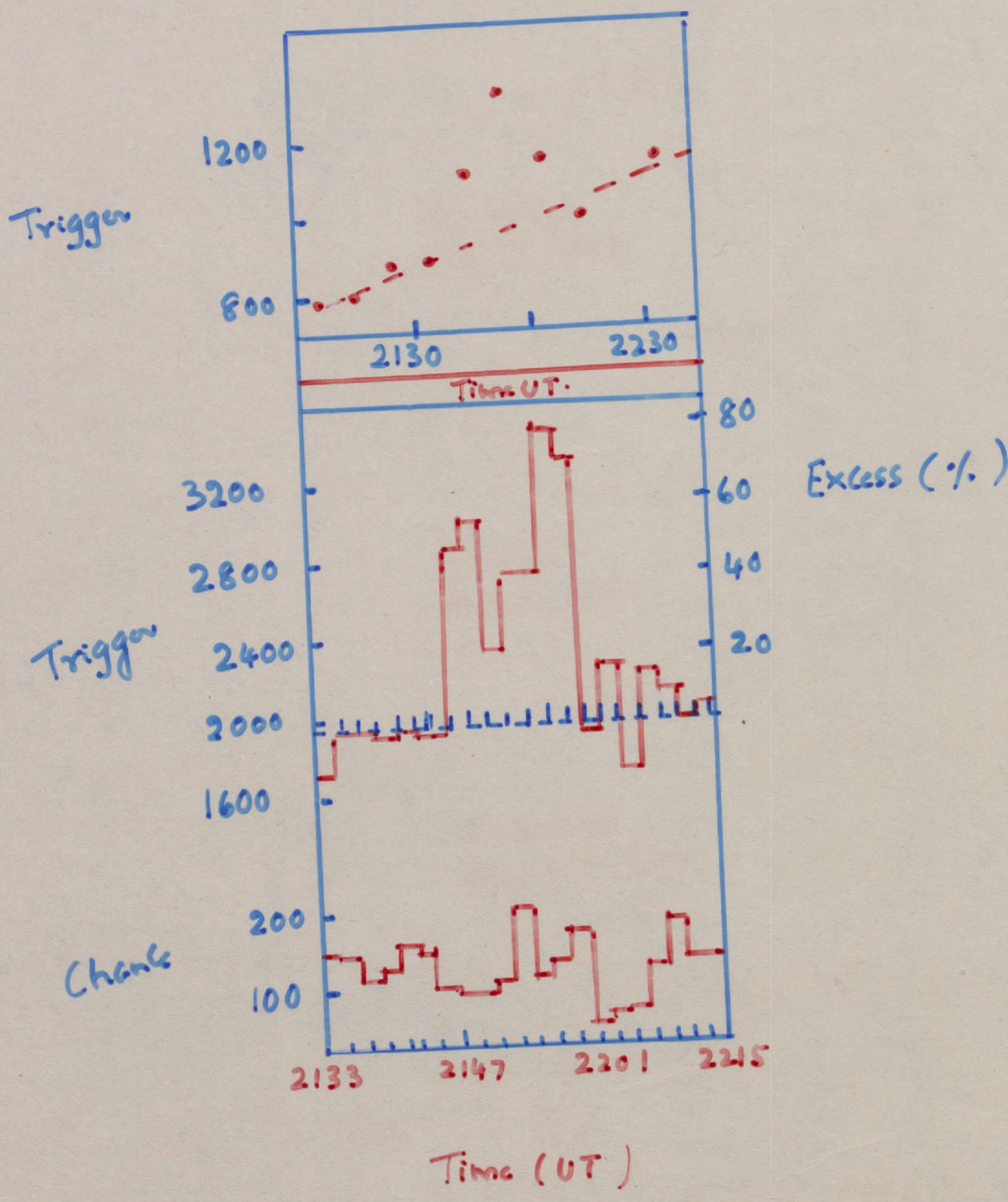
* Cos B Claim (Masnou et al 12th. Eslab Symp. p33 1977)

488 events in one month's observation

$P = 59{\cdot}1969\ s$
$\dot{P} = 1{\cdot}39 \times 10^{-9}\ ss^{-1}$

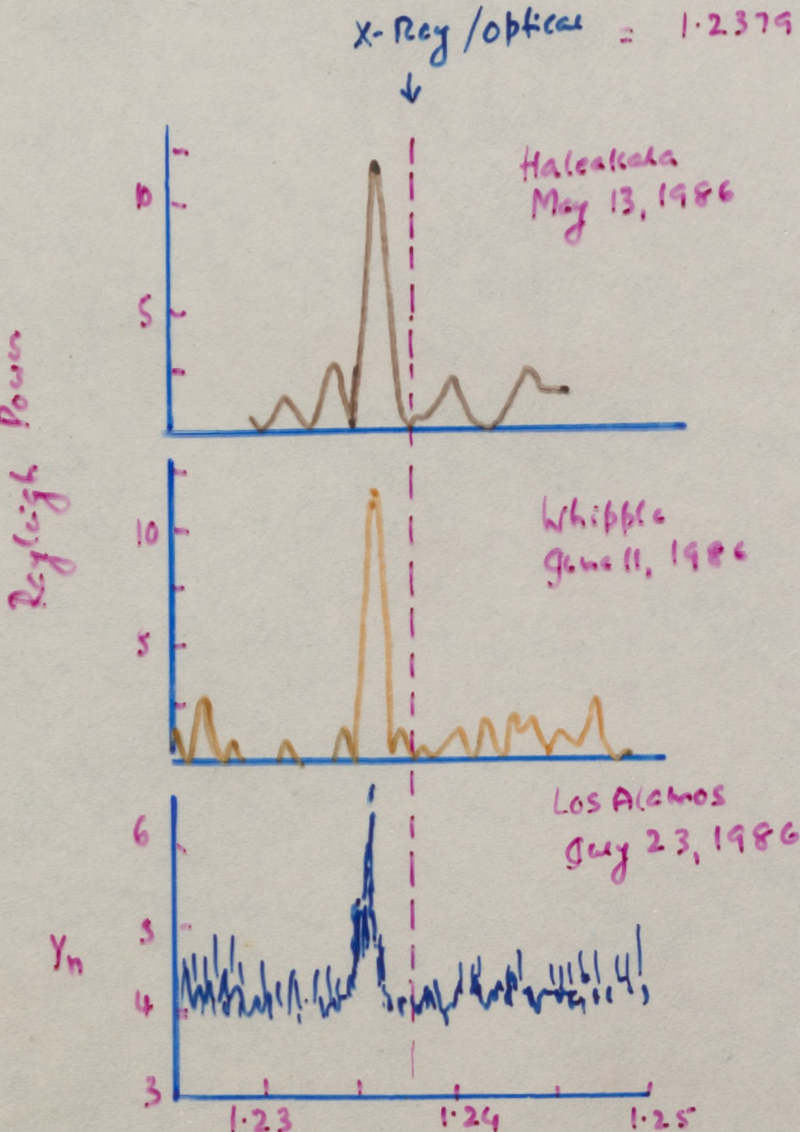
$\chi^2 = 43{\cdot}6$ for 19 degrees of freedom.

Chance Probability $\leq 1\%$.



Trigger
1200
800
2130
2230
Time UT.
80
Excess (%)
60
40
20
3200
2800
Trigger
2400
2000
1600
200
Chance
100
2133
2147
2201
2215
Time (UT)

Her X-1
BURST.



TeV — 1·2359 — 35 day phase = 0·25, orbital = 0·81

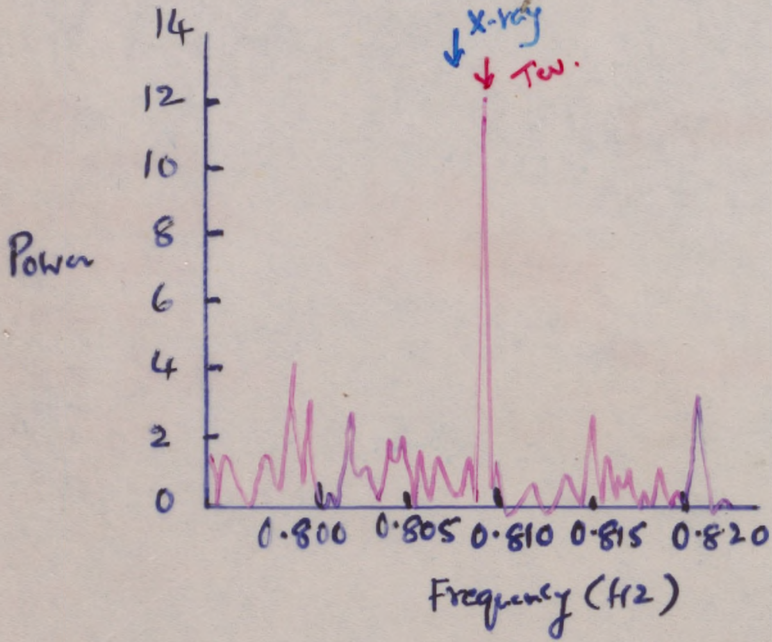
TeV — 1·2358 — 35 day phase = 0·00, orbital = 0·70

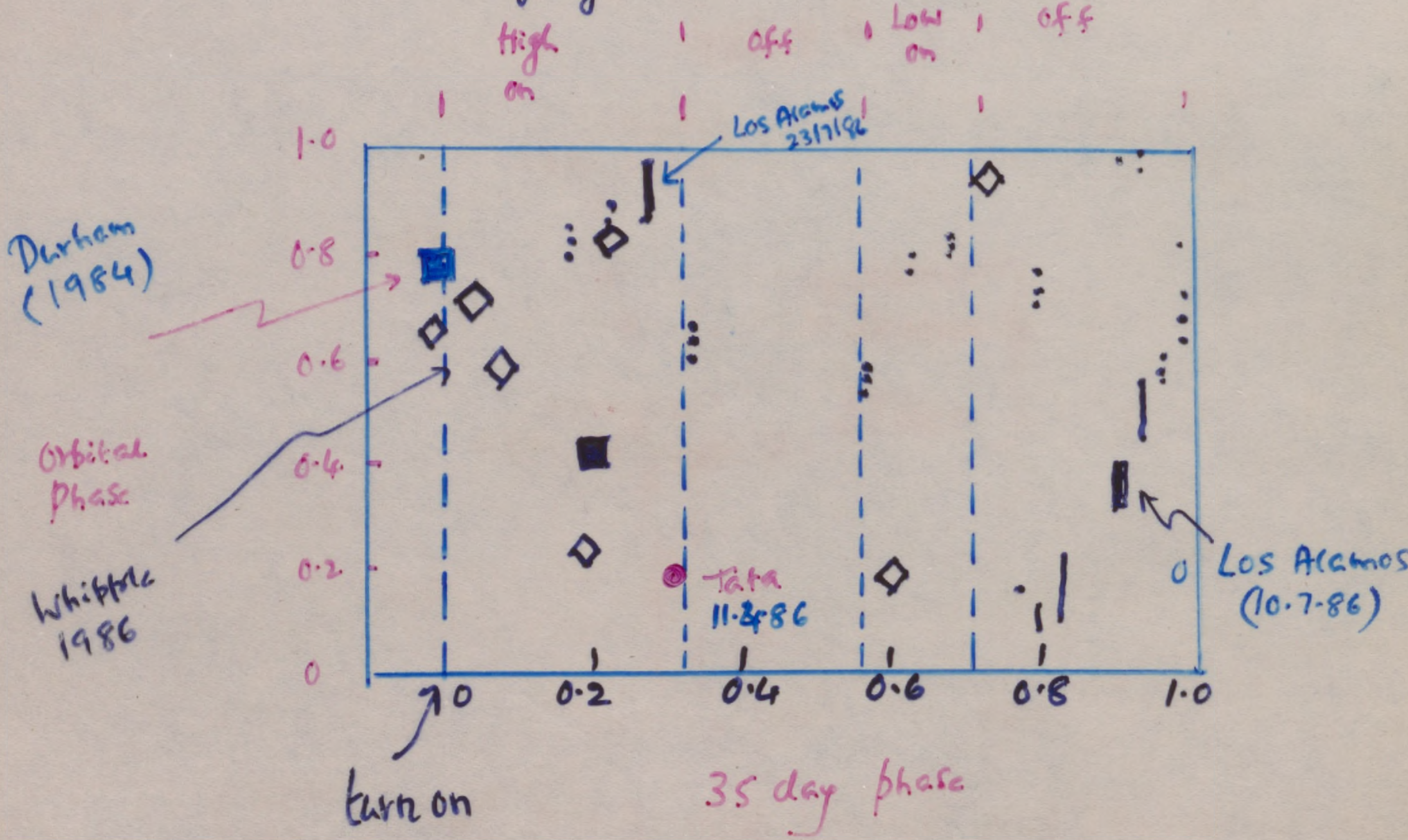
PeV — 35 day phase = 0·22 - 0·27, orbital = 0·84 — 1·2357

Ooty Air Showers } Bursts seen on { August 8 and August 9, 1986 } { July 1 and Nov 21, 1986 }

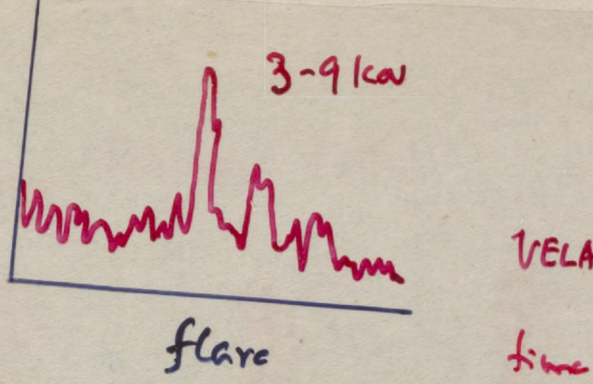
- PeV Showers Contain Muons same as in Hadron Showers.
- PeV } TeV } Showers - Pulsar Period is distinctly different from optical / x-ray.

HER X-1
Whipple Observatory (1986)

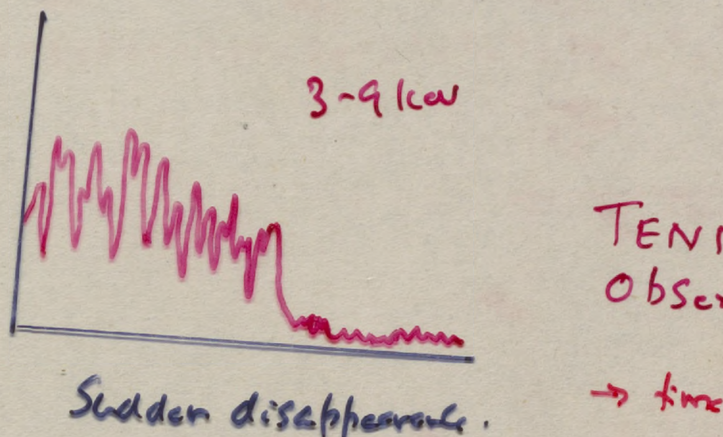


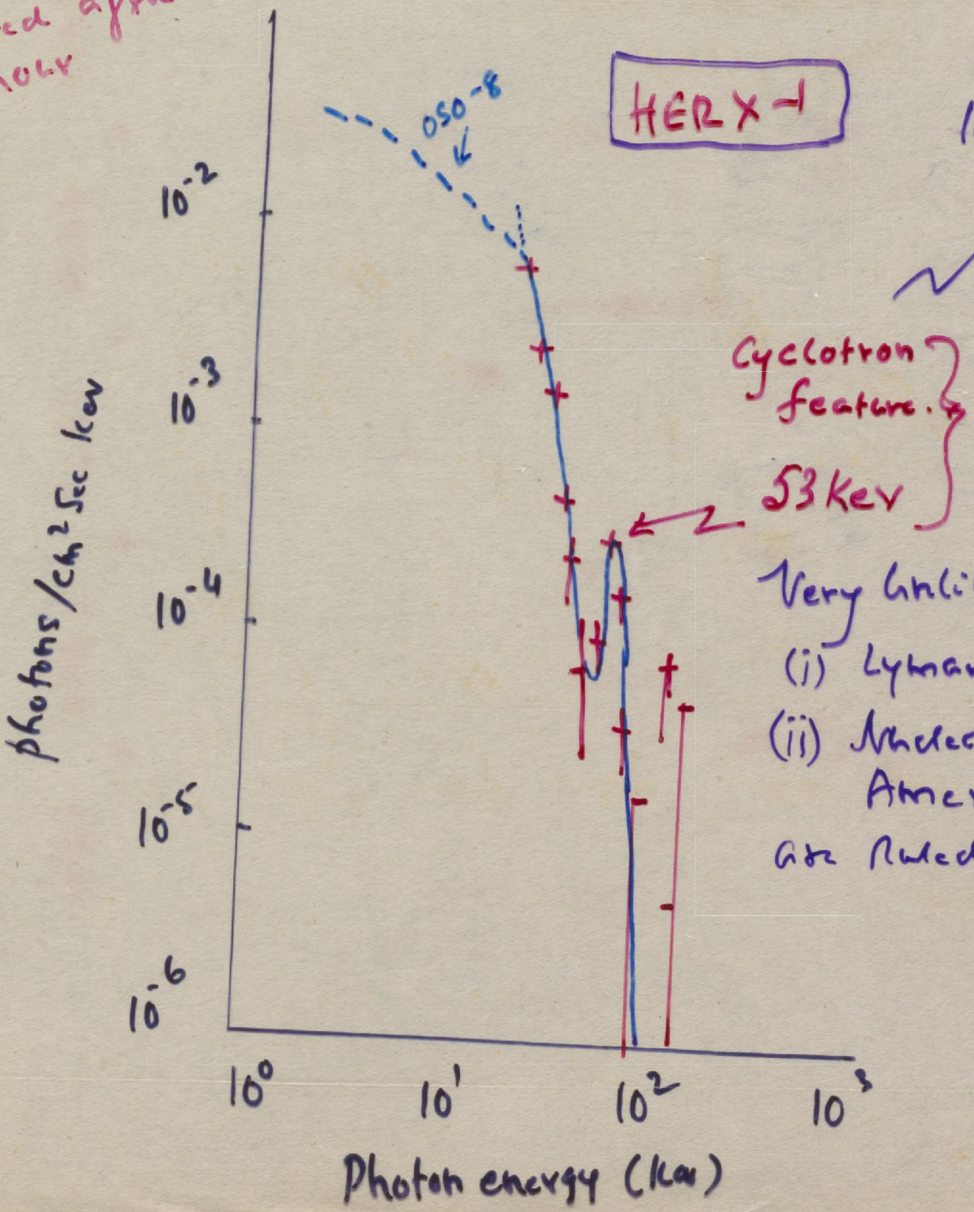


Pulse Profile Variations of Vela X-1



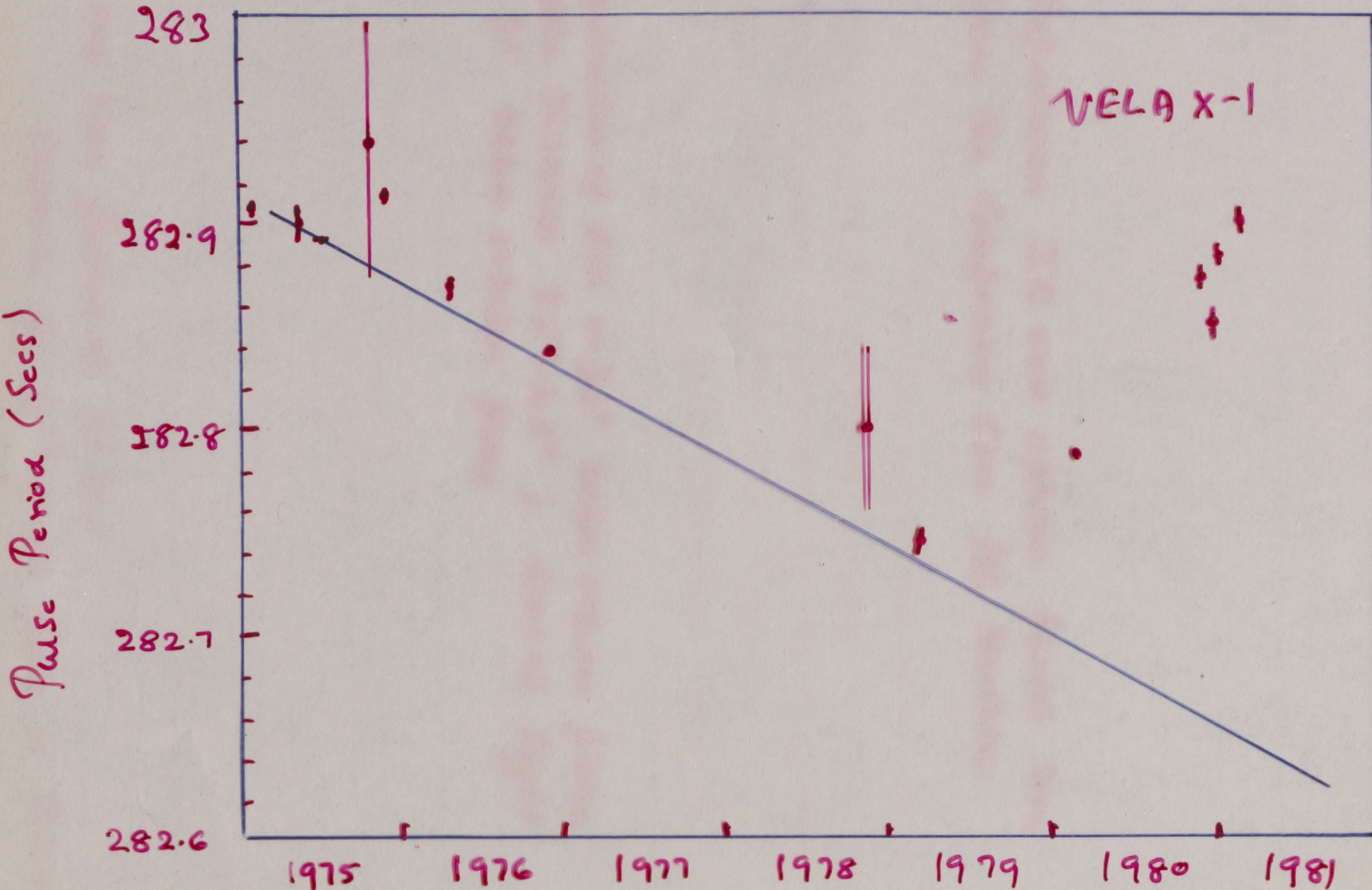
Sudden disappearance or Considerable attenuation of Vela X-1 or beam Shifted Out of Sight.
Returned to normal then Sighted after an hour





Evidence for 10^{12} gauss on Neutron Star.

Very unlikely possibilities
(i) Lyman α of Platinum 77
(ii) Nuclear γ-line of Americium 241.
are Ruled out.


VELA X-1
Pulse Period (Secs)
283
282.9
282.8
282.7
282.6
1975
1976
1977
1978
1979
1980
1981

HERCULES X-1

SLIDE

* HER X-1 is a binary pulsar in X-Rays with 3 periodicities 1·24 seconds ; 1·7 day ; 35 days
(Neutron Star) Pulsar — binary

* 35 day modulation -
11 days High 19 days Low
(5 days Intermediate high)

* Reprocessed I.R and optical pulses seen from the Companion star HZ Hercules.

* While there is no clear-cut explanation of the 35 day period, one of the favoured models is that the modulation is produced by the varying aspect of an accretion disc that is suitably inclined and precesses about the X-ray pulsar.

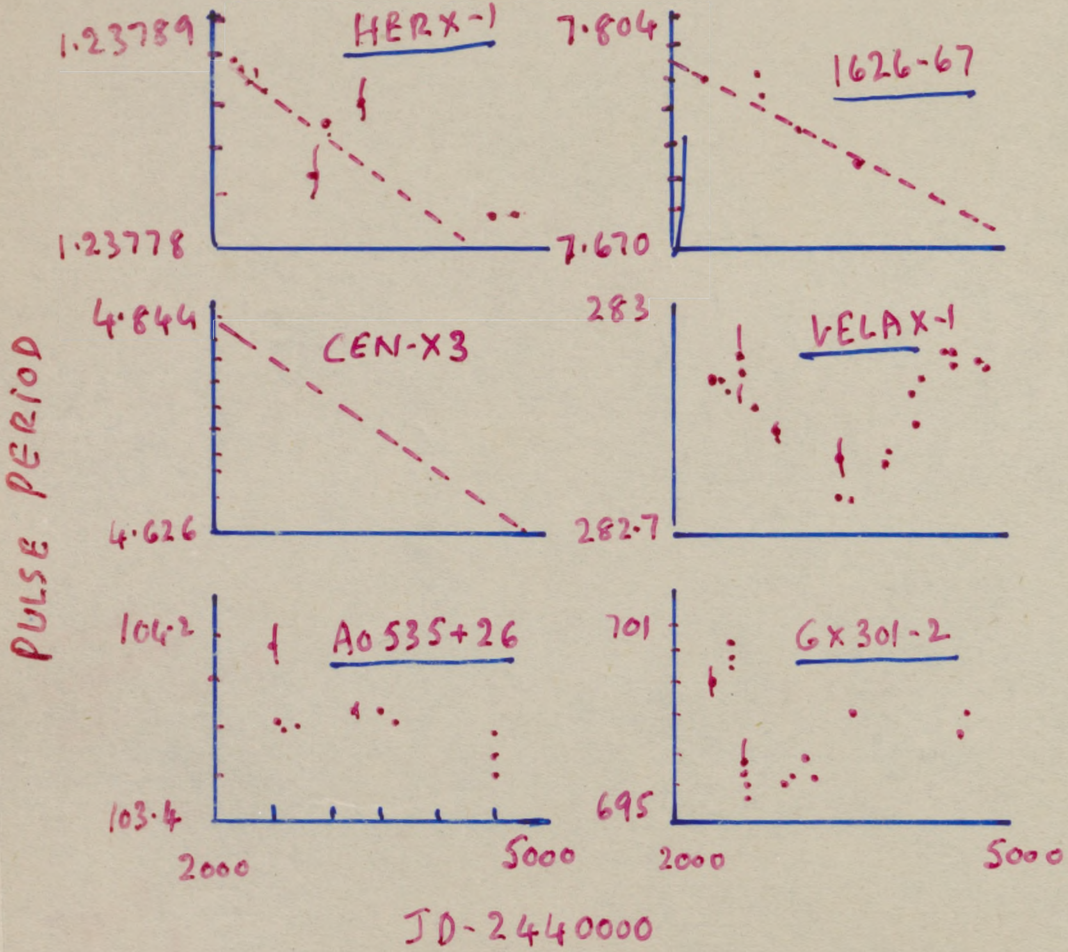
* Inclination of disc ~ 30° below orbital plane; disc thickness 25°-45° ; line of sight ~ 3° below orbital plane

* * the 11 day high State occurs - when no observation
* the 19 day Low State - when it is observed
* the 5 day intermediate State - when the line of sight is grazing the disc partially obscured by the Corona

* Cyclotron Line feature at 53 keV
- Evidence for 10^{12} gauss field on Neutron Star.

Her X-1 (1972 UHURU)

- 1.24 Sec pulsar
- 1.7 day binary
- 11 days on out of 35 days cycle
- Cyclotron line
- 13 Mag. Star with UV excess.
- Photographic plates going back to 1890 Show 1.7 d. orbit for 80 years.
- distance ≈ 6 kpc
- $L_x \approx 10^{37}$ ergs/sec.
- Pulse profile change



Pulse Period Variations of Pulsars.

* Secular trend in Spin-up seen in SMC X-1, X 1627-67, GX 1+4

* However recent results show significant deviations as shown above in Vela X-1, A0 535+26, GX 301-2.

* Vela X-1 - had been persistently slowing down. Now this trend has changed. Fast variations in time intervals of weeks - Spin up and Spin-down noticed. (different from glitches).

Time Variability of Some Extragalactic Sources.

Source	Lx erg/s	$\frac{\Delta L_x}{L_x}$	Δt sc.	$c\Delta t$ cms
CEN A	10^{43}	0·25	7×10^{3}	2×10^{14}
Mk 421	10^{44}	2·0	1×10^{5}	3×10^{15}
NGC 6814	10^{43}	1·5	2×10^{2}	6×10^{12}
0x 169	10^{44}	1·5	6×10^{3}	$1{\cdot}8\times10^{14}$
3C 273	$1{\cdot}7\times10^{46}$	0·1	6×10^{3}	$1{\cdot}8\times10^{14}$
NGC 4151	5×10^{42}	3·0	10^{3}	3×10^{13}

Nearest brightest QSO → 3C 273

Type I Seyfert galaxy → NGC 4151

CEN A – X-rays

Variable – factor of 3 in 3–4 years

40 % increase in 6 days

Low Energy cut off

$N_H = 1{\cdot}35\times10^{23}$ atoms/cm^2

Power Law $\alpha = 0{\cdot}8$

3C 273 – $>10^7 M_\odot$ Black hole ?

gas temp $\sim 10^9$ °K

Seen in hard X-rays

CEN A – 4 Mpc. 4' dia – obscuring dust lane which contains IR source.

Outer two lobes – separated by 8° – far beyond visible contours

Inner lobes 7' separation

Nucleus – radio source $< \cdot001''$

Questions to be answered about Pulsars:

(I) Are these disk fed or wind fed

(ii) How do they reach long periods and persist? the mechanism of spin down.

(iii) What are the causes of Period variations

(iv) Role of magneto-sphere and surface plasma in defining the spectra

(v) What are the surface magnetic fields and dipole moments?

(vi) What is the equation of state of very high density matter?

(vii) What are the internal dynamical properties of neutron stars

Questions about Galactic Bulge Sources:

(i) The Bulge Sources are binaries. How are they formed? Capture?

(ii) Why never more than one bright compact X-ray source in a globular cluster?

(iii) How large are the surface magnetic fields?

Extragalactic X-ray Astronomy

(i) Nearby galaxies
(ii) Active galaxies
(iii) Clusters of galaxies

Our galaxy

- X-ray : 2×10^{39} ergs/sec
- Visible = 4×10^{45} ergs/sec.
- X-ray Sources ~ 200
- Stars ~ 10^{11}

Nearby galaxies:
- LMC – 10^{38} ergs/sec.
- SMC
- M·31 – nearest Spiral 2×10^{39} ergs/sec.

Einstein has resolved about 200 point Sources

X-ray Sources →

Galaxy	D	M	Binaries I	Binaries II	SNR	?
LMC	55 kpc	$10^{10} M_\odot$	8		~40	~20
SMC	65 kpc	1.5×10^{9}	3		~5	~15
M31	750 "	3×10^{11}		20 globs, 19 bulge		~47
M33	750 "	4×10^{10}				~9
M101	6 Mpc	$10^{11} M_\odot$				~5
M100	15 Mpc	$10^{11} M_\odot$				~2

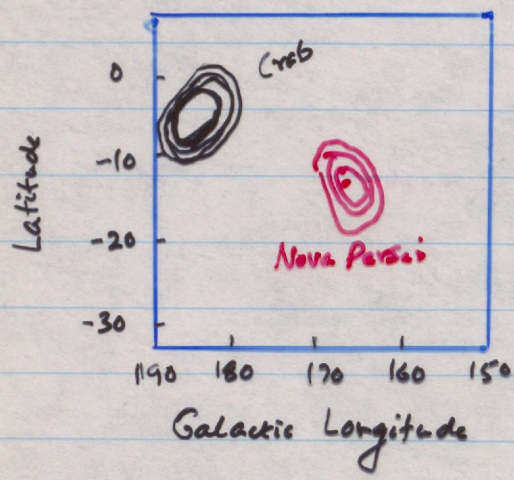
- M31 has 20 globular cluster Sources and 19 bulge Sources very much more than our galaxy. Why?

Black Hole Candidates

NOVA PERSEI

J0422+32.

This Nova was discovered by BATSE on Aug 5, 1992. Within a few days the intensity increased to 3 Crab, in the 20-300 kev. range. Later decreased exponentially with e-folding rate of 41 days.



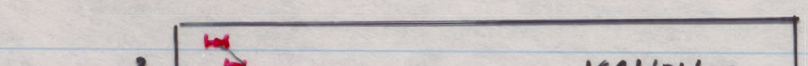
The Crab is close by. So analysis difficult. Spectrum from OSSE shows it to be similar to Cyg X-1

Black Hole Candidate?

Optical observations seem to indicate this possibility.

NOVA MUSCAE

GRS 1124-684. Black Hole Candidate



SIGMA on-board GRANAT has measured the Spectrum of Nova Muscae 35-1300 kev.

* During the outburst of Jan 20, 1991, two intense gamma ray line features were observed at 200 kev and 480 kev.

The 480 kev line is interpreted as the red shift of 511 kev line and the 200 kev as the Compton back scattered line. (Hua and Lingenfelter)

480 kev line 6.01×10^{-3} cm^{-2} s^{-1}

200 kev " 1.8×10^{-3} "

B.H. Candidate Mass 3.07 ± 0.4 M⊙ (optical photometry and spectroscopy)

H and L set the limit $(4.3 - 7.0)$ M⊙

GINGA

$L_x > 10^{38}$ ergs.

Spectral class C, D.

MK-type: late K-type.

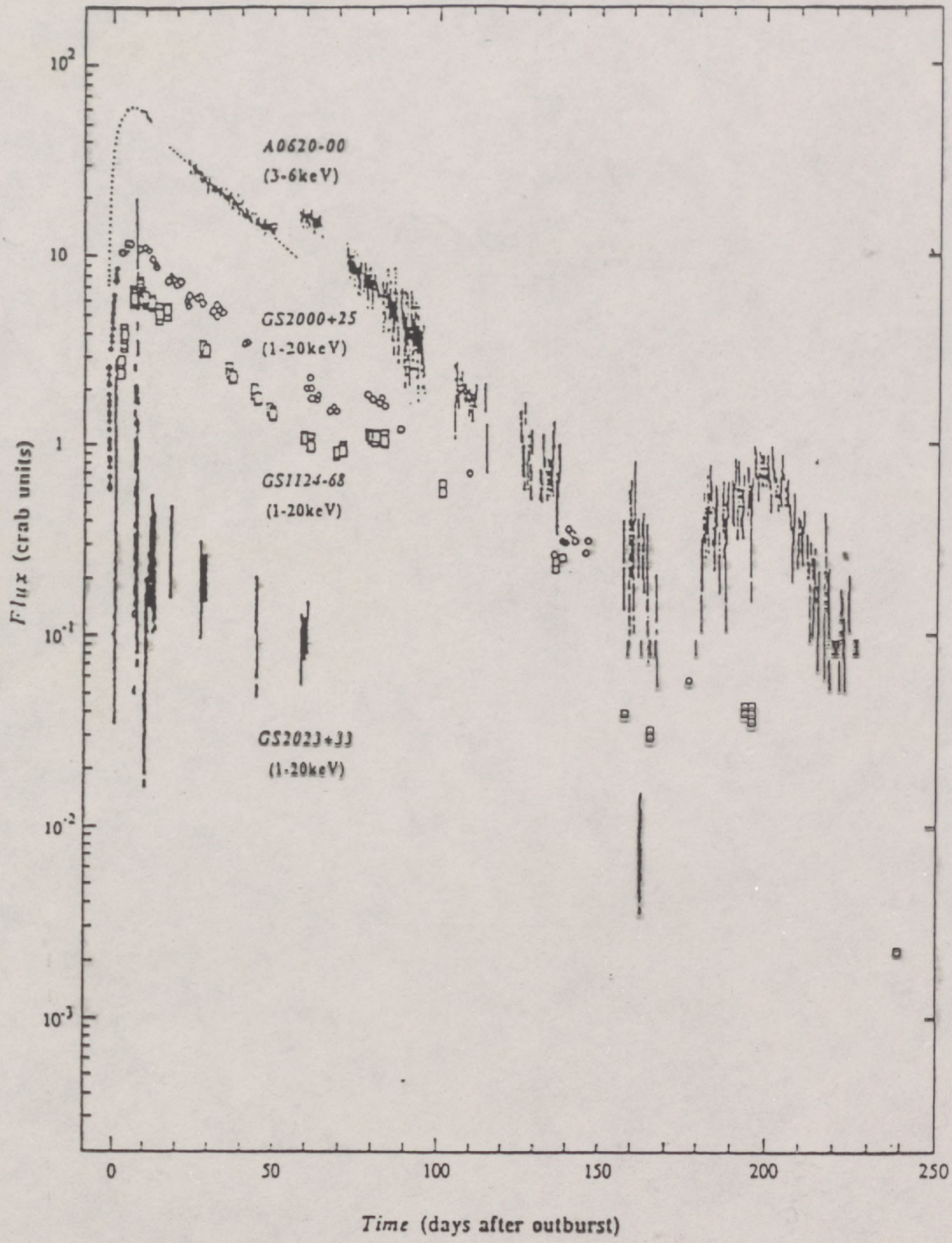
$d = 3$ kpc (?)

$m_v = 20.4$

K (km/s) $= 411 \pm 21$

P (days) $= 0.43$

FLUX IN CRAB UNITS



DAYS AFTER OUT-BURST

Figure 5. X-ray light curves of GS2000+25, GS2023+33, and GS/GRS1124-68, together with that of A0620-00 (Kaluzienski *et al.* 1977).

Accreting Black Hole Binaries — "Ginga Transients" (Binaries)

Estimated Number of Black Holes} in the Galaxy 100 - 3000 ~ about the same as Neutron Stars

* Origin of Low Mass Black Hole binaries remains a mystery. Why are they transient?

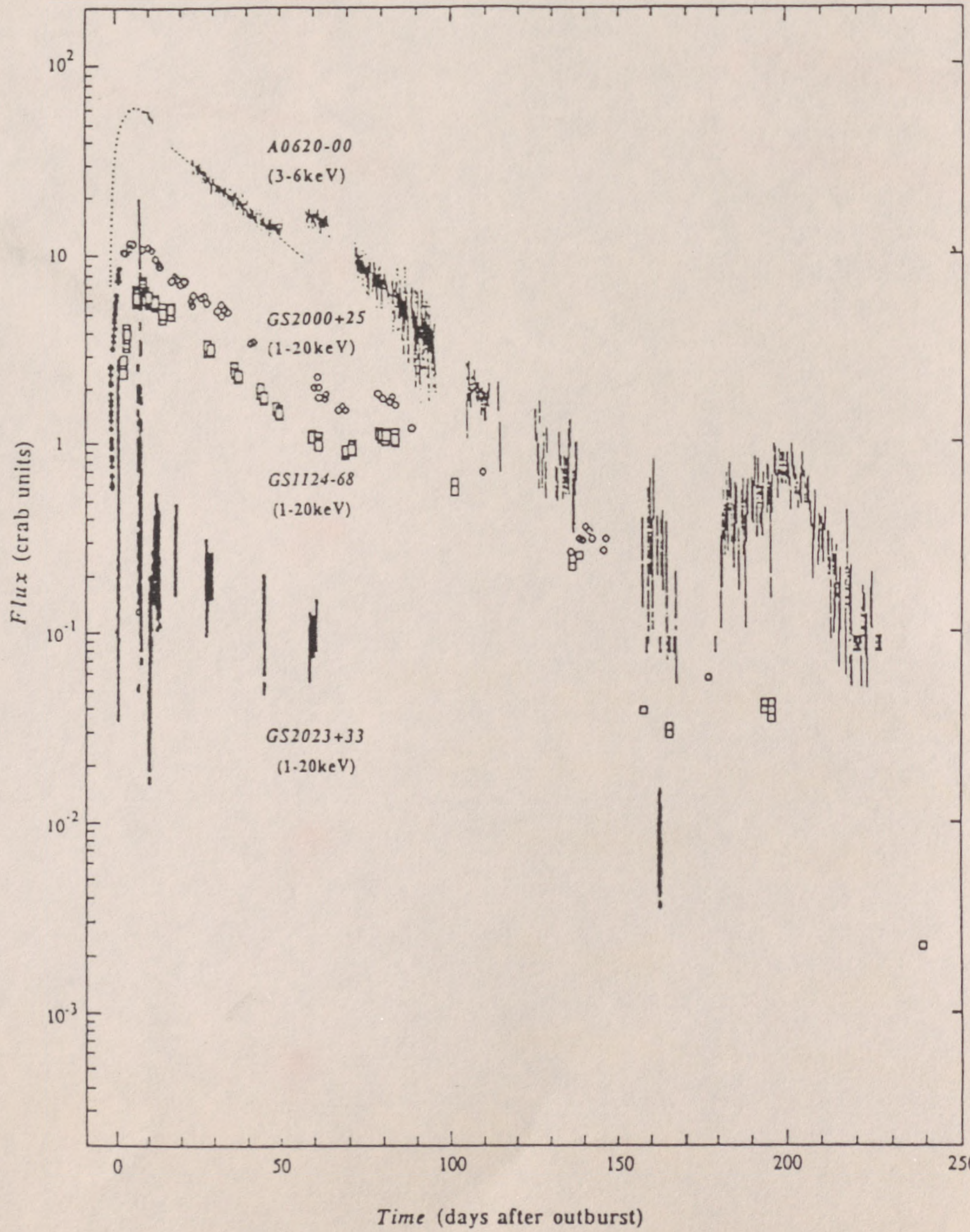


Figure 5. X-ray light curves of GS2000+25, GS2023+33, and GS/GRS1124-68, together with that of A0620–00 (Kaluzienski *et al.* 1977).

(1992)

↑

BLACK HOLE BINARIES (GINGA)

Steady Sources

		Binary Period	Lx
CYGNUS X-1	(HM)	5.6 days.	2×10^{37} ergs
LMC X-3	(HM)	1.7 days	3×10^{38} ergs
LMC X-1	(HM)	4.2 days	2×10^{38} ergs
GX 339-4	(LM)	Highly variable	

HM = High Mass Companion

Transients + "Ginga Transients" (Candidates for BH)

4U 1630-7
4U (1543-62)
A 1524-47
A 0620-00 Nova-Mon
H 1705 -25 Nova-oph
H 1743 -32
GS 1354-64
GS 2000 +25 Nova-Vul
GS 1124 -68 Nova Muscae

} Low Mass Companion Systems.


Nith----------ya kal ---------------------ya------------------ni
1
ni--ga-ma-----------rtha san-----------cha-------------rini
3
Ni----------thya---kal--------------------ya---------------------------ni
5
ni--ga-ma---------rtha------------san-------------cha------ri ni
7

Transient Source V0 332 + 53.

BLACK HOLE BUT PULSAR ?

* Transient Source V0 332+53 observed during 83 by both TENMA and EXOSAT.
* Orbital period = 34.25 days.
* Random fast X-ray Variations Similar to Cyg X-1.

In the weak State 4.375 Sc. period pulsation observed.

* In X-ray $\frac{L_{peak}}{L_{Quiscent}} \sim 500$.

* Optical Candidate 15 OB Star ; B-V = 2.3

Asiago observatory of Padova University made observations during Nov 23rd 83 – Mar 6 84

18 Spectrograms in different phases

34 day binary period Confirmed.

EXOSAT: 4.4 Sc. pulsation in X-rays.
Power Law Spectrum $\alpha = 0.5$
High Energy Cut off 20 kev.
Outbursts in X-rays Centred on Periastron passage. (eccentricity ≥ 0.34).

Binary X-ray Sources.

Population I

* Massive Binaries
  Primaries O, B Stars
  Main Sequence - Supergiants.
* Mostly in Galactic arms.
* Young Systems
* Most of them X-ray Pulsars

Population II

* Primaries $\lesssim 1 M_\odot$
* Mostly in the galactic Centre
  ∴ galactic bulge Sources.
* Also found in globular Clusters
  ∴ typically old Systems.
* Generally not Pulsars
  (Exceptions X1627-67, GX1+4(?))
* Many of them produce Bursts.

* In General no X-ray Pulsar produces bursts and no burst source pulsates
* But, there is Now an important exception
  Transient V0332+53

Young Neutron Stars possess Strong Magnetic Fields
Old Neutron stars - Magnetic Field Considerably Weakened.

Spectra of Supernova Remnants

- Einstein, Tenma, Exosat have provided (i) High Resolution Imaging (ii) High Resolution Spectra and (iii) broad band energy coverage on Supernova remnants - Cas A, Puppis A, Kepler, Tycho.
- Young remnants Cas A, Kepler, Tycho, SN1006 are still maintaining circular shells.
- X-ray and Radio Images match very well. Radio Bright knots coincide with X-ray bright.

The FPCS (Focal Plane Crystal Spectrometer) and the SSS (Solid State Spectrometer) on Einstein have shown that NEI (Non Equilibrium Ionization) may be present in many remnants - even in Cygnus Loop.

(time for plasma ionization equilibrium $\sim 10^4/n_e$ yrs

$n_e \sim 1$ to $10/cm^3$. $T_{eq.} > 10^3$ yrs)

- But NEI models do not explain the broad band high energy spectra observed with EXOSAT.
- ROSAT with energy coverage 0.3 - 10 keV and high angular resolution (20") will throw further light on this problem.

Collisional Equilibrium Ionizations vs Non Equilibrium Ionization.

- * Thermal Origin established by Fe-K lines, Mg, Si, S, Ar, Ca.

Conclusions From Spectra of S. N. Remnants.

- 1. Spectrum – Superposition of two Component plasma
  Low Temp 0.2 - 0.5 kev; High Temp ~ few kev
- 2. In Cas A – a third high temperature
  Component ~ 30 kev. (Some Controversy exists)
  EXOSAT does not show.
  Sensitivity ?
- 3. Elemental Abundances :
  Si, S, Ar and Ca overabundant Compared with Solar Composition
  Fe tends to be less than Solar.
- 4. X-ray Emitting Mass.
  Even young remnants Contain large x-ray emitting
  mass. In Cas A ≳ 15 $M_\odot$
  Tycho ≳ 15 $M_\odot$

Questions

- Is the emitting plasma in thermal equilibrium ?
- thermal equilibrium between electrons and ions ?
- electrons have a Maxwellian Velocity distribution ?
- Plasma parameters homogeneous over the remnant ?

General opinion: NEI
Non-Equilibrium Ionisation.

Indian Programme in X-Ray Astronomy

- Balloon flights from Hyderabad 1968 —
  by TIFR, PRL.
- Soft X-Ray Rocket flights from TERLS, SHAR.
  CENTAUR, RH 560. – TIFR.
  ISRO.
- X-Ray Telescope on Aryabhata, Bhaskara. – No Results.
- TIFR. CALGARY — Phoswhich Detectors. –
- INDO-JAPANESE – occultation of Crab.
  SCOX-1 – Simultaneous optical.
- INDO-SOVIET – Gamma Ray Telescope – Spark Chamber
  ↓
- INDO-SOVIET – SATELLITE Expt. (ILTP)
  PHOTON MISSION – 1992.
  X-Ray, γ-Ray Telescopes.
- TIFR- ISRO X-RAY SATELLITE
  (ASLV ?)
- GUEST OBSERVATIONS – EINSTEIN.
- Optical observations on X-ray Sources –
  Rangapur, Kavalur, Nainital.

(4) The space-time dimensions involved in collisions of $5 \cdot 10^{15} - 2 \cdot 10^{16}$ eV with nuclei: $\Delta x \lesssim 3 \cdot 10^{-17}$ cms, $\Delta t \lesssim 3 \times 10^{-28}$ s.

(5) This may indicate the possibility of production of particles of mass ~ 400 GeV/c^2

(6) These new particles might decay into $W^{\pm}$, Z, muons and neutrinos thus depriving energy to the hadron and electromagnetic cascades.

(7) Such a process also leads to a "break" in the primary spectrum – the Cosmic Ray 'Knee'

(8) The new particles are H-bosons ?

From Biller's Thesis

"The data did not indicate the presence of a signal; so we had to apply statistics" Anon.

"Outcome, n. a particular type of disappointment" Ambrose Bierce.

"Was there a choice a priori? Mm...m. I would rather not answer that question" Anon.

"Sim-u-late / "sim-yə-lāt / vb : To assume the outward qualities or appearances of, usually with the intent to deceive"

Webster's Dictionary.

"I see the world in very fluid, contradictory, emerging, interconnected terms, and with that kind of circuitry, I just don't feel the need to say what is going to happen or will not happen

Governor - Jerry Brown.

"The wonderful thing about science is that you get such a wholesale return of conjecture for such trifling investment of fact"

Mark Twain.

"I deserve respect for the things I did not do"

Dan Quayle

"It is no exaggeration to say that the undecideds could go one way or another" George Bush

"There are three kinds of lies - lies, damned lies and statistics" Mark Twain.

"The Signal must be detected above the intrinsic noise associated with the detector system i.e. Cavity, amplifier, Coaxial feeds, graduate Students etc" Ed. Kolb and Mike Turner

Search for High Energy Cosmic Ray Sources.

- Brief Historical Perspective on Cosmic Rays
- Clues on possible Sources from Optical, Radio, X-ray γ-ray astronomies → SN remnants, Pulsars, Accreting Binaries, AGN's, γ-ray burst Sources
- Brief Summary of Relevant results from CGRO
- Current Status of Tev, Pev, Eev astronomies (as of Calgary Conference 1993)
- Future Trends – { Muon, Neutrino Astronomies. – Simultaneous observations
- New Types of arrays. Milagro, Amanda, Dumand, Horizontal Muons, Upward Showers.

Mysterious Leakage of Charge from Charged Metal Spheres - electroscopes - puzzle from time of Coulomb

1897 Discovery of Radioactivity → Ionization phenomenon

1912 Discovery of Cosmic Rays - Penetrating, Ionizing Radiation

Ramification of phenomenology of Cosmic Rays - Altitude, Latitude, Longitude, E-W effects - Soft and penetrating Components - Showers - The Millikan - Compton Controversy

1932 Discovery of positron

1937 Discovery of muon, EAS

1946 Proton is the primary particle,

1947 Discovery of pion, kaon, Λ_0

Discovery of Heavy Primaries.

} ERA OF PARTICLE PHYSICS

Strangeness QM.

T-θ puzzle → Parity Breakdown.

Bremsstrahlung, pair production, Cascade Showers, Meson production, Nuc. Component.

Isotropization of Charged primaries by Mag. fields. $10^6 - 10^{21}$ eV

Search for CR Sources begins here. →

1950 EAS arrays. Direction determination by timing the shower front.

1954

* New Mexico Conference on CR - optical polarization of Crab → Synchrotron - High Energy - Electrons → High Energy Protons - π_0's → γ's.

(Super Nova Remnants CRAB.)

BASJE - (μ-poor) Search for high energy γ-rays from Crab and other S.N. remnants.

1963. Crimean Air Cerenkov Expts Search for γ-rays in the TeV region. NEGATIVE RESULTS.

1958 Prediction of γ-ray Line Emissions from Celestial Sources - Not feasible with Detectors of that time!

1962 Discovery of Discrete X-ray Sources and Diffuse Background.

Discovery of 3° radiation and its implications to CR Spectrum

1967 Discovery of Diffuse Galactic plane Gamma ray background.

1968 Discovery of Pulsars - The Crab - an X-ray Source, Pulsar.

Air Cerenkov Experiments to detect TEV pulsations.

EAS experiments to detect PeV pulsations.

Controversial Results on Crab, Vela Pulsar, Cyg X-1, Her X-1, CYG X-3, . .

Focus on accreting binary system with neutron star, black hole companions

1973 Discovery of γ-ray bursts

Discovery of Neutron Stars.

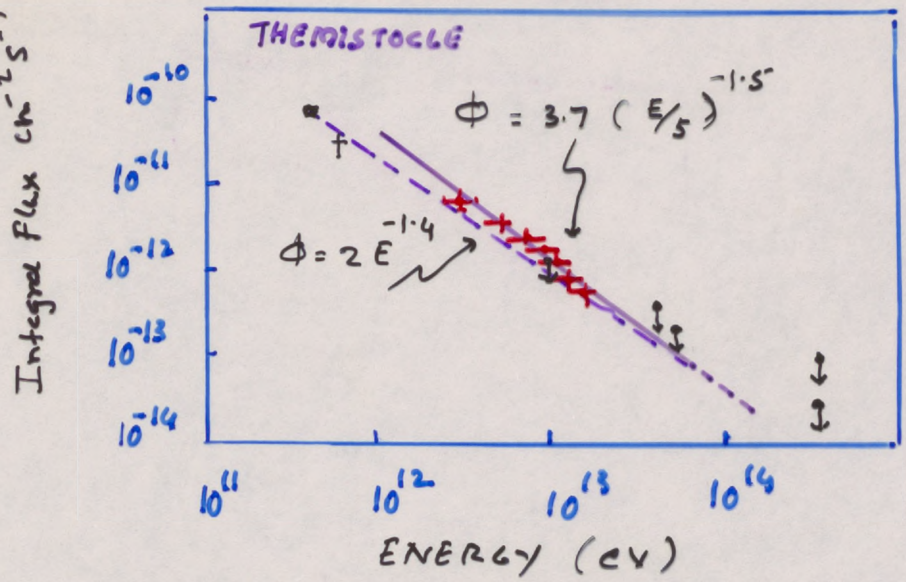
1987 88 First definitive results on (Whipple) Crab as a Steady TeV Source.

Line emissions in γ-rays Show presence of 10^{12} gauss fields.

1990 GRO - Fresh Focus on (results upto few GeV) γ-ray bursts, γ-ray pulsars, AGN's, Galactic Sources, . . .
↓
(Mrk 421)

1993 Current Status of TeV, PeV, EeV astronomy

CRAB NEBULA TeV - PeV

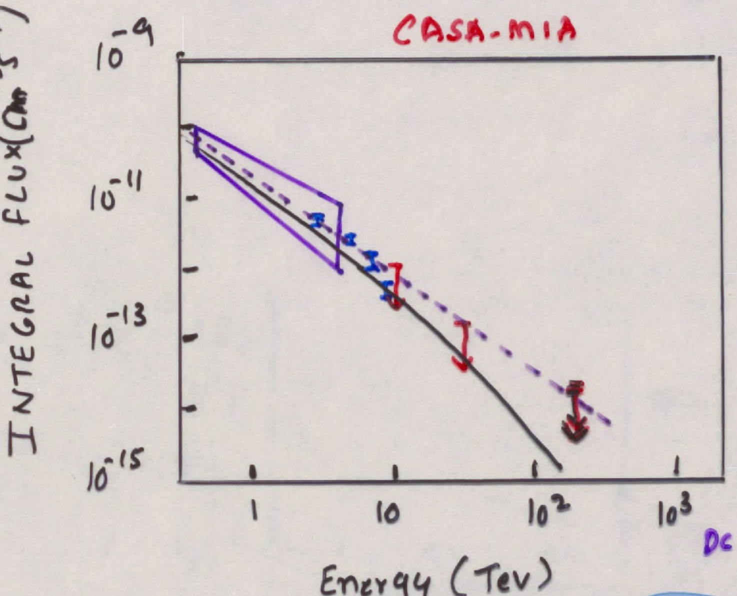


Spectrum over the range 3-15 TeV from THEMISTOCLE

$$\Phi = (3.7 \pm 0.5) \cdot 10^{-12} \, (E/5)^{-1.5 \pm 0.20} \; cm^{-2} s^{-1}$$

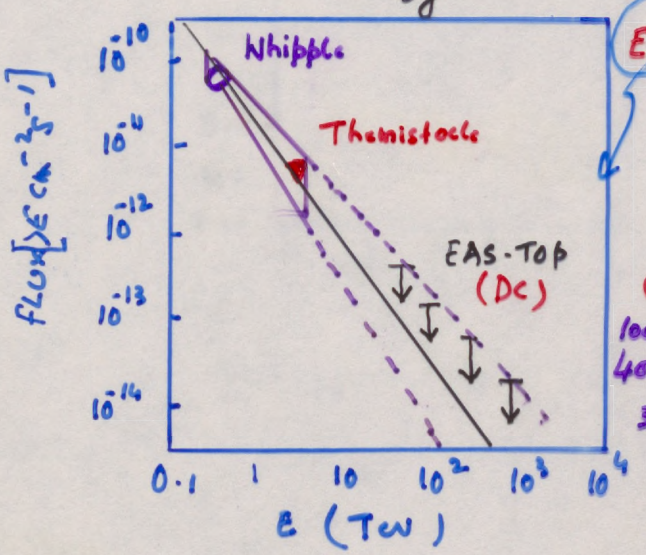
CERENKOV Expt.

CASA-MIA



- ▱ Whipple.
- - - - Extrapolated Flux of Whipple
- I Flux given by THEMISTOCLE
- I Tibet Air Shower Expt.
- I CASA-MIA - (μ-poor)
- — Theoretical model Curve of de Jager and Harding (inverse Compton Model)

DC { ⊙ Upper limit from BAKSAN 0.2 PeV $< 1.1 \times 10^{-13} \, cm^{-2} s^{-1}$
⊙ Upper limit by HEGRA SCINTILLATOR ARRAY = > 48 TeV $< 1.23 \times 10^{-13} \, cm^{-2} s^{-1}$ }



EAS-TOP.

⊙ No evidence for Pulsed Flux in EAS-TOP, CANGAROO, OOTY, CYGNUS HEGRA,

⊙ PULSED flux reported by DURHAM

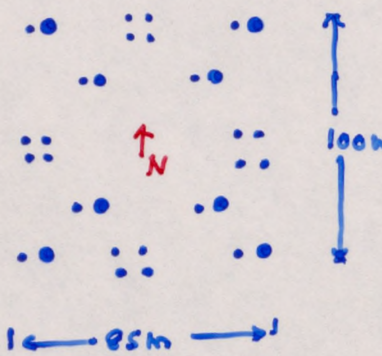
1000 GeV → 81-83	$0.8 \times 10^{-11} \, cm^{-2} s^{-1}$	(Peak) $20 \times 10^{-11} \, cm^{-2} s^{-1}$	}
400 GeV → Oct 88-89	< 5	"	
3000 GeV → 90-91	< 0.1	"	

* PACHMARI - (See next Transparency)

* Upper Limit on Crab at EeV $< 1.4 \times 10^{-17} \, cm^{-2} s^{-1}$

CRAB

Pachmarhi Cerenkov Array (Cerenkov)



• = 0.9m dia

● = 1.5m dia.

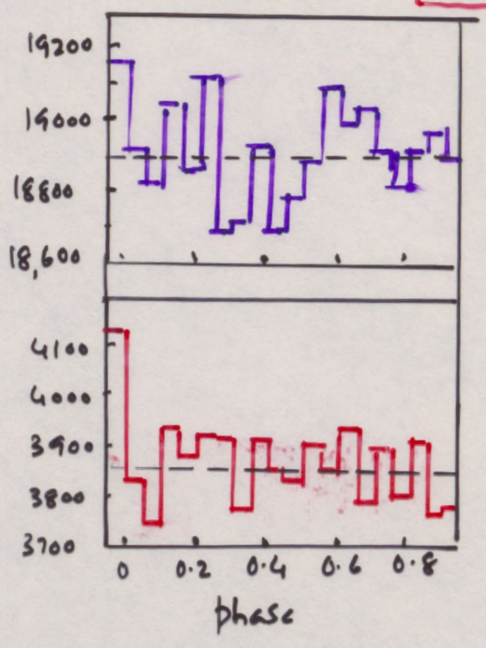
Coverage -38° to $+38^\circ$ in declination.

event time accuracy 1 μs ≠ Relative accuracy 100 nanoseconds.

Global Position Satellite Clock

Shape of the lateral distribution of Cerenkov photons can be used to discriminate between photon induced and hadron induced showers.

CRAB Jan.-March 92.



all data — 1.8σ Signal

↓

with LD-cut. $V < 0.5$ — 4.5σ Signal.

p_i = normalized amplitude of Cerenkov Pulse.

$\langle P \rangle$ = average of p_i $\frac{\Sigma p_i}{N}$

Criterion $V = \frac{1}{N} \sum_{i=1}^{N} \left[P_i - \langle P \rangle \right]^2$ → Compute for each shower.

V is chosen to be < 0.5 for all the selected showers.

Preliminary analysis.

Q Why only one peak ?

1/4 of the data only is useful.

HER X-1

$4.11 \times 10^{-6} \left(E / 274\ \text{MeV} \right)^{-2.15}$ / $cm^{-2}\ sec^{-1}\ MeV^{-1}$

- Her X-1 is an X-ray binary consisting of 1.24 s Pulsar and 2.2 $M_{\odot}$ Companion.
- Has 3 periodicities – 1.24 s, 1.7 binary period and 35 day cycle. The X-ray source is eclipsed for 5.6 hrs during each 1.7 day period. In X-rays it has a High and a Low State.
- Cyclotron line emission → $H = 3.5 \times 10^{12}$ gauss
  Not seen in Radio. Not seen in GeV gamma rays.
- Episodic emissions reported in TeV – PeV domains. Some of the positive 1.24 s. Pulsar emissions showed a distinct difference in the period compared to X-ray period, by as much as 0.016 %. [Whipple, Cygnus, Ooty] Pachmarhi ↳ (40σ D.C. reported in 1987)

- **Current (93) upper limits**

• HEGRA	PeV	$< 3.4 \times 10^{-13}\ cm^{-2} s^{-1}$
• BAKSAN	0.2 PeV	$< 1.1 \times 10^{-13}$ "
• CASAMIA	140 TeV	$< 1.3 \times 10^{-12}$ "
	μ-poor	$< 5.9 \times 10^{-13}$ "
• Nottingham		$< 2.1 \times 10^{-13}$ "
• Pachmarhi		$< 10^{-11}$ "
• CYGNUS		
• Tibetan Collaboration	> 10 TeV	$\leq 5.8 \times 10^{-13}$ "
	≥ 30 TeV	$\leq 1.4 \times 10^{-13}$ "

* No results from CGRO reported so far. But GAMMA-1 has reported positive results. (~ 50 MeV)

Positive result reported by Adelaide group →

⊙ UNIVERSITY OF ADELAIDE - Woomura Cerenkov Telescope.

3 mirrors - each 12 m² - three p.m. at each focus.

Her X-1 Culminates at an elevation of 23°.

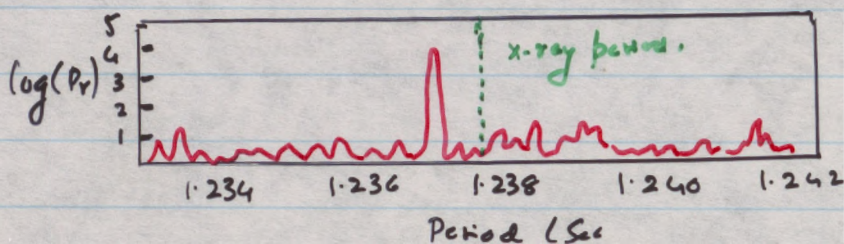
∴ Threshold is 25 TeV. Collecting area ~ 10^6 m².

γ-ray flux F_γ (> 50 TeV) ~ 10^{-12} cm⁻² s⁻¹

The emission is correlated with eclipse ingress.

This suggests that the limb of the Companion Star (HZ Her) is the site for the Conversion of the accelerated particles to γ-rays.

- The period is blue shifted by 0.053 % from the x-ray period. (Whipple, CYGNUS, Ooty have reported similar shifts of the period)



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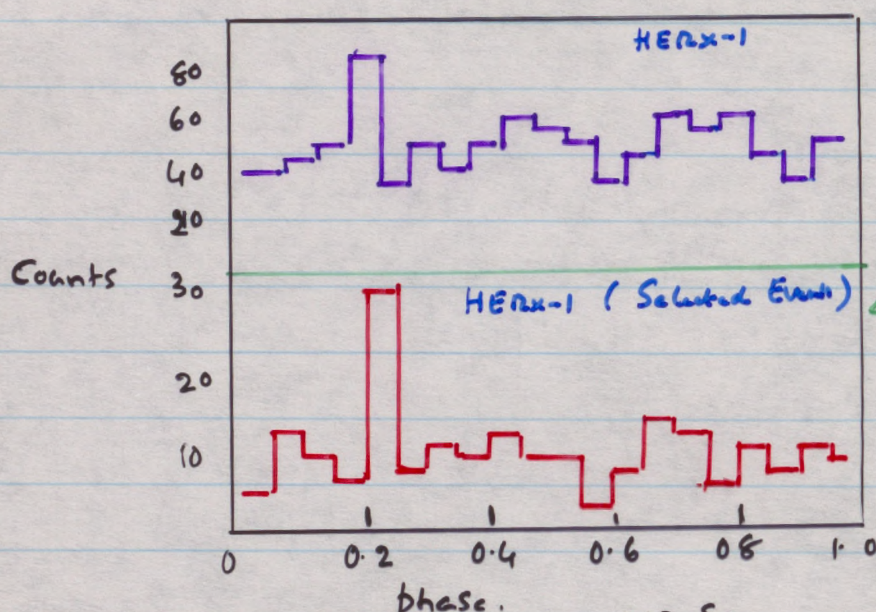
* RESULTS ON HERX-1 FROM GAMMA-1 TELESCOPE (~ 50 MeV)
Dec 1990 - Jan 1991 and June 1991

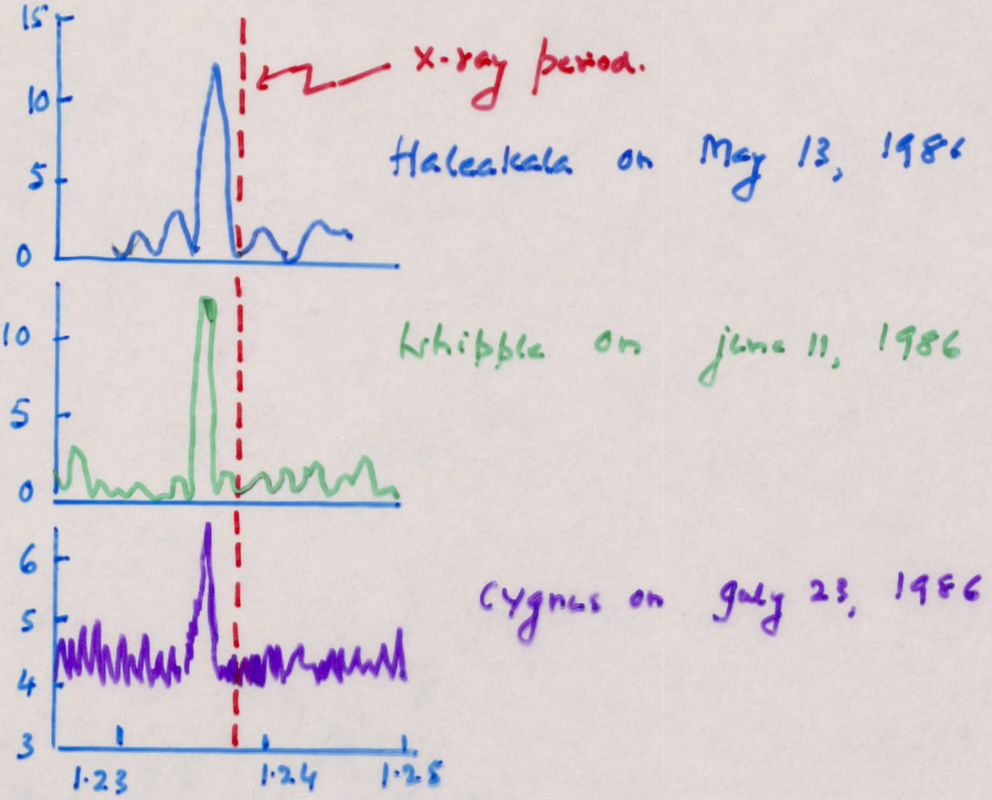


$F(>50\,MeV) = 6.3\times10^{-6}$ cm⁻² s⁻¹

← Stopping muon background removed. The count rate comes down, but the significance of the signal goes up (7 σ)

Period = 1.2377513 s.

HER X-1.



Period

Evidence For:

TeV period being substantially different from x-ray period — from May – July 1986.

Similar result reported by Ooty air shower group.

Search For Tev } Counterparts of Gamma Ray Bursts.
Pev }

BATSE is discovering Gamma Ray Bursts at the rate of 1 per day. - ~ 7×10^{-7} bursts / Sr. Sc.

Are there Tev Counterparts of these ?

Whipple Telescope - expected rate of overlap
= 0.02 events/~~day~~ year.

Solid angle = ·01 Sr. }
Time of observation } The probability of Coincident detection is very small.

- If BATSE lasts for 8 years, and all the Cerenkov Telescopes in the world look for Coincidence, then a few Coincident bursts may be recorded.
- Extensive Air Shower arrays operate with 100 % duty Cycle and Cover π-Steradians. However the threshold energy is 100 Tev and Collecting area $10^8 cm^2$.

Search with Whipple.

April 1991 - March 1992

BATSE ~ 262 bursts.

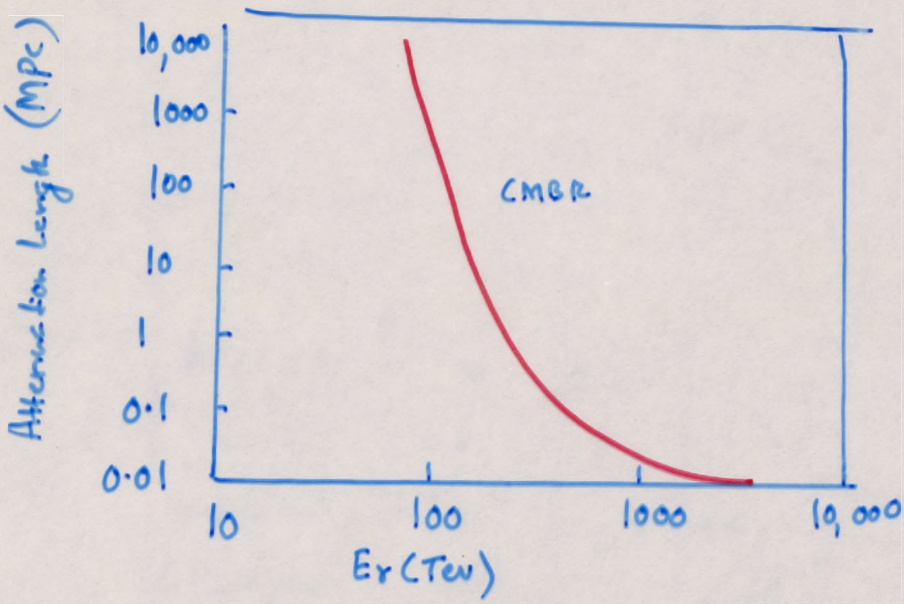
Whipple ~ 13 BATSE Burst were recorded during the operation time of Whipple.
The angular Separation between Whipple pointing direction and BATSE burst ranged from 32° to 148°.
Nothing Seen.

There Could be bursts unique to Tev domain - that may not be detected by BATSE.
(Primordial Black Hole Explosions, Non-Super Conducting Cosmic Strings ..

Search is on. OOTY, CYGNUS have set limits in EAS domain.

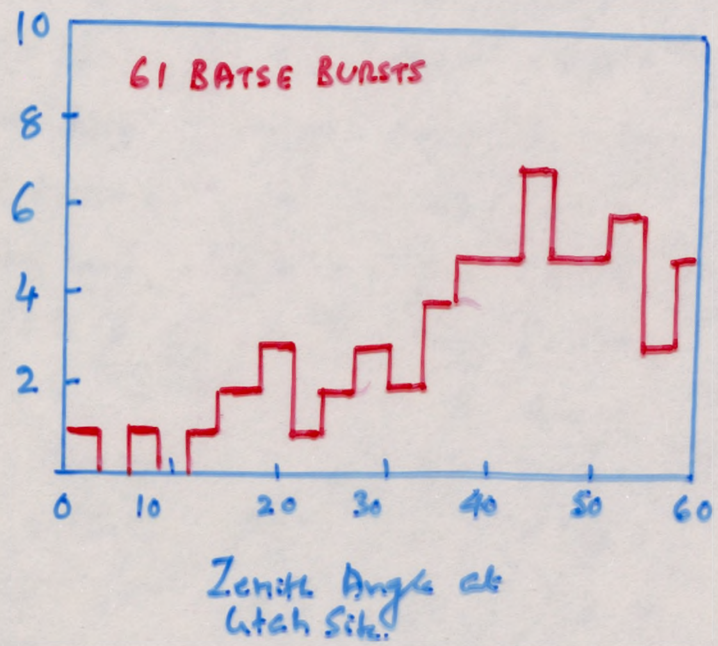
(BATSE + EAS) restricts the distance of the γ-burst source

Can EAS observations resolve the question of galactic vs extragalactic and cosmological?



$\gamma\gamma \to e^+e^-$

Interaction with 3° Radiation



BATSE recorded 260 γ-bursts during the period 21st April 91 to March 5, 92.

Out of these 61 burst directions were such that they would have been observed by CASAMIA had the spectrum extended up to a TeV

(Chicago + Michigan) >100 TeV.

The plot shows the zenith angle distribution at UTAH of these BATSE recorded bursts.

Unfortunately CASAMIA was not operational during this period.

It shows the potential of CASA-MIA to record.

CASAMIA threshold is 100 TeV. If +ve correlation is seen for any burst, then extragalactic origin can be ruled out.

[May 3rd. burst of BATSE $J(E) = 8.7\,E^{-2.29}$ photons/cm²s.MeV

When extrapolated to 100 TeV, $J(>100\,\text{TeV}) = 8.4 \times 10^{-10}$ photons/cm²s.

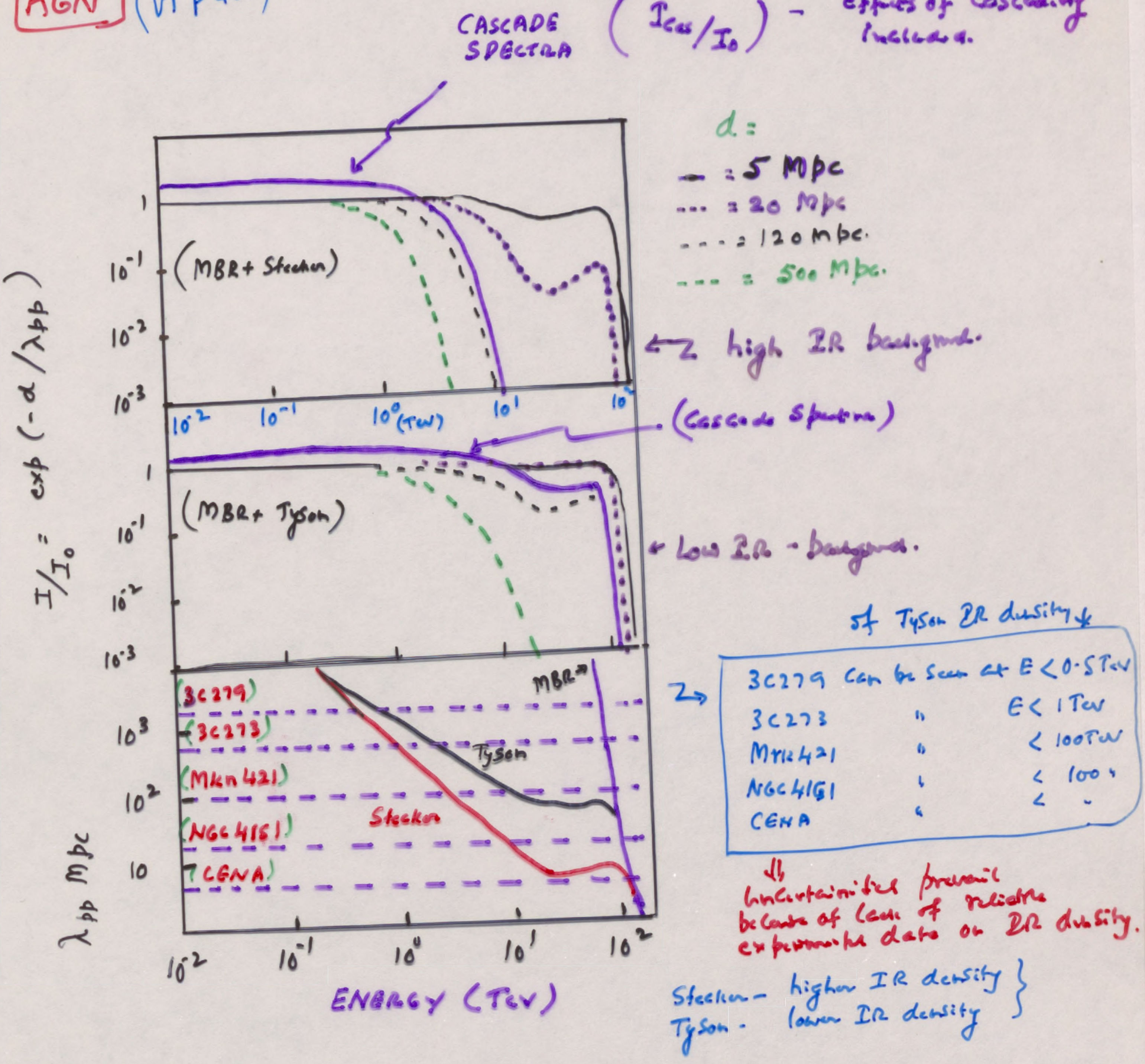
CASAMIA area $\approx 2.3 \times 10^9\,\text{cm}^2$ } ∴ 4 photons of 100 TeV will be recorded against a background of 0·04 photons.

10^{45-48} ergs/s. — for isotropic emission $10^{45-48} \times f$ where f = beaming factor

- **AGN's** that have been detected by CGRO - EGRET (*) in the Mev - 10 Gev range and that have been searched for Tev, Pev emissions so far.

	AGN	Type	z	Whipple < Tev	Others Tev, Pev.
*	MRK 421	BL Lac	0.031	1.5×10^{-11} $cm^{-2}s^{-1}$	NO (CYGNUS, CASA, HEGRA, TIBET)
	MRK 501	"	0.069	$< 0.71 \times 10^{-11}$ "	
	I2W 187	"	0.055	< 4.4 "	
	VR042.22.01	"	0.69	< 0.73 "	
*	QS00716+714	"		< 2.8 "	NO (CYGNUS)
	OJ 287	"	0.31	< 2.7 "	
	ON 325	"	0.24	< 2.9 "	
	NGC 1275	Seyfert	0.018	< 1.5 "	
	PG 2304+042	"	0.042	< 1.9 "	
	MRK 1048	"	0.043	< 2.2 "	
*	3C454.3	"	0.859	< 1.2 "	NO (CYGNUS)
	3C111	"	0.049	< 2 "	
	4U0241+61	"	0.044	< 4.3 "	
*	PKS0528+134	QSO	2.06	< 3.0 "	NO (CYGNUS, CASA)
*	QS00836+710	"	2.17	< 2.3 "	NO (CASA)
*	3C273	"	0.158	< 2 "	NO (CYGNUS, CASA, HEGRA, TIBET) Durham
*	3C279	"	0.538	< 0.76 "	NO (CYGNUS, CASA, HEGRA, TIBET) Durham,
	4C31.04	Gal pair	0.059	< 1.1 "	
*	4C38.41	OVV	1.81	< 0.45 "	NO (CYGNUS)

AGN (V1 p 453)

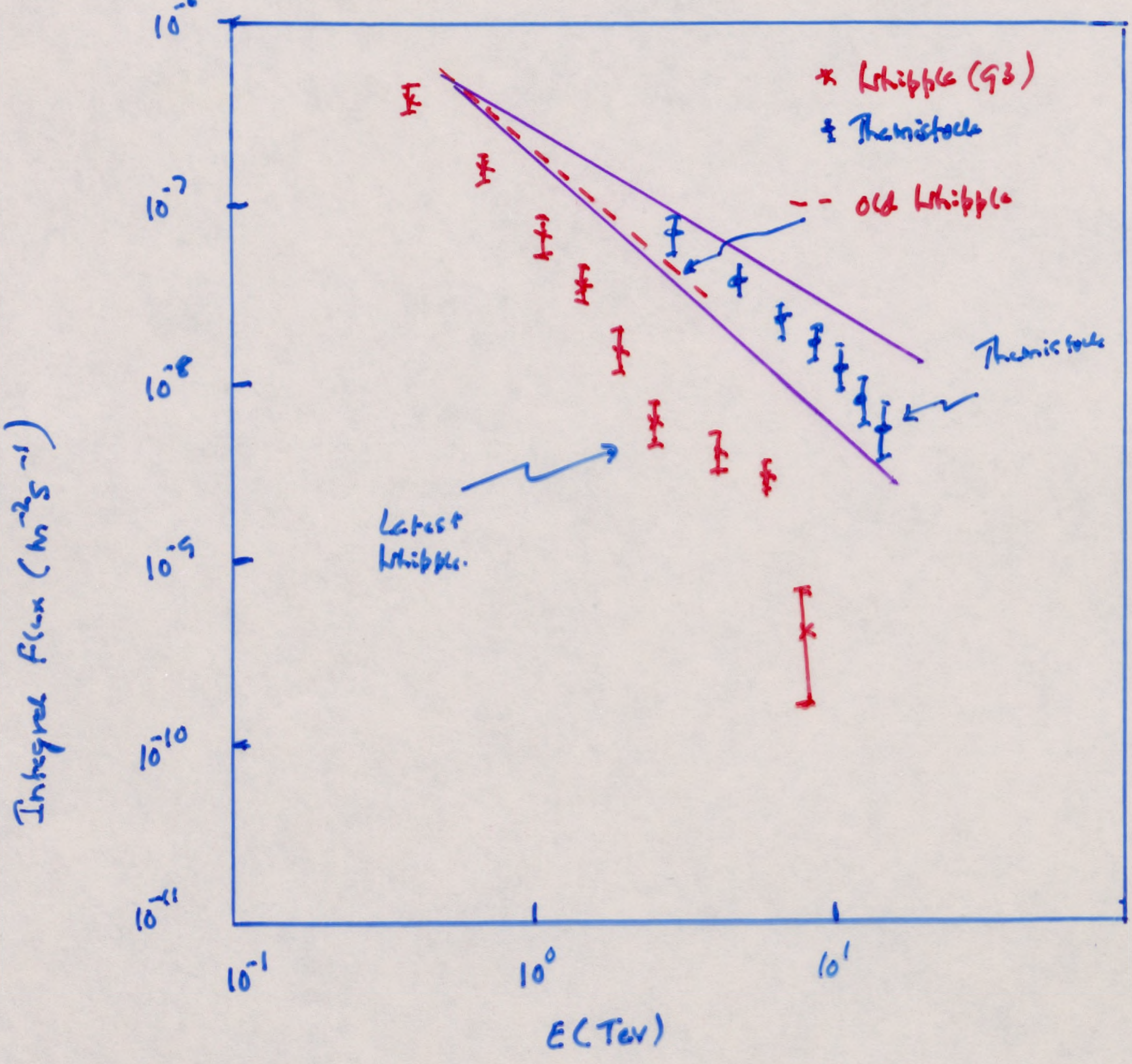


Absorption of γ-rays by MicroWave, Infrared and Optical background Radiations (Two models of IR/O background Stecker and Tyson are used since no reliable measurements are available)

[Aharonian, Coppi, Volk]

Cascade Spectra: The γ-rays interacting with the background photons produce cascades through pair production. The spectra calculated assume no deflection of e^+, e^- by mag. fields. → HALO - PAIRS around Sources →

CRAB



$$\text{Whipple: } N(>E) = (0.88 \pm 0.24) \times 10^{-11} \left(E/_{TeV}\right)^{-1.69 \pm 0.3} \ cm^{-2}s^{-1}$$

$$\text{Themistocle: } = (4.1 \pm 0.5) \times 10^{-11} \left(E/_{TeV}\right)^{-1.5 \pm 0.20.}$$

[EGRET Slope for the integral Spectrum 50 MeV - 10 GeV is -1.15 (Pulsed Component)]

flatter than the D.C. Component Slope of -1.5.

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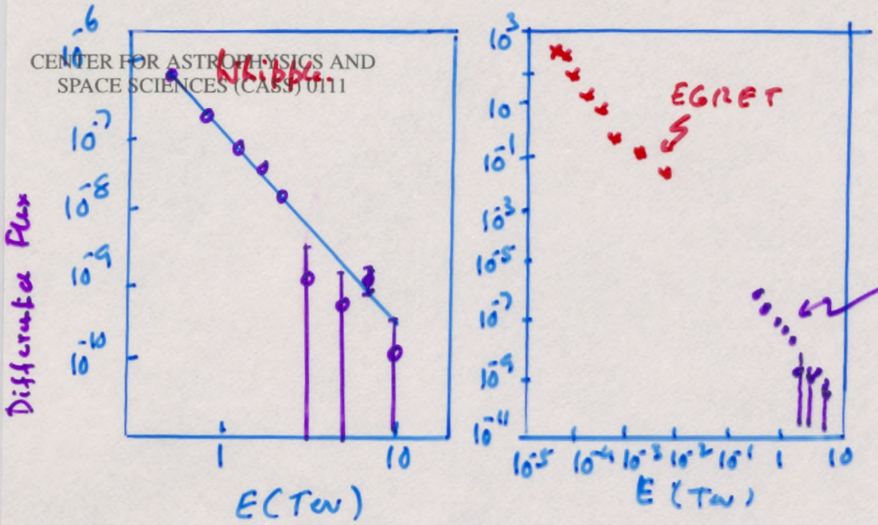
CRAB (1988-89 data set)



• Latest Flux given by Whipple: (Steady)
(1993)

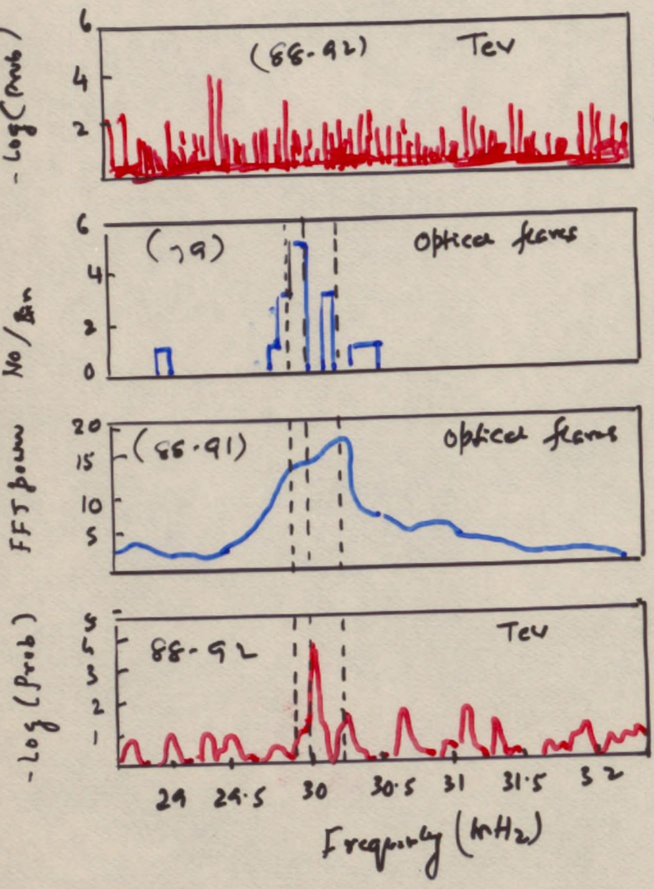
$$\frac{dN(E)}{dE} = (1.48 \pm 0.09 \pm 0.41) \times 10^{-7} \left(\frac{E}{TeV}\right)^{-(2.69 \pm 0.3)} \text{photons } m^{-2} s^{-1} TeV^{-1}$$

AE Aquarii (X-ray Binary)

CR Source Candidate.

Southern Source.

Cataclysmic Variable discovered in 1938 by Zinner.
Close binary with a period of 9.88 hrs.
Magnetic White Dwarf spinning with a period F_0 of
30.23 mHz (33.08 seconds) – Surface Mag. field ~ 6×10^{4} gauss.
No spin up or spin down known ($\dot{P} < 10^{-14} ss^{-1}$)
X-ray emission with period 33.08 s. detected.



Incoherently combined power spectrum of all TeV γ-ray data.

Density of occurrence of peaks in optical flares. (Patterson)

Optical flares power spectra (Meintjes et al)

TeV γ-ray power spectrum in a narrow range around persistent optical frequencies during optical flares.

The dashed lines indicate the most prominent QPO features.

- The Durham Group has reported emission in TeV range during Oct 1990 and August 1991 – the emission was observed in the 2nd. Harmonic of F_0. Bursts with pulsed emission at F_0 and $2.F_0$ have also been reported.

⟹ AE Aqurii – an object for intense study during World Astronomy Day in October 93. (Did it happen?)

Galactic Sources

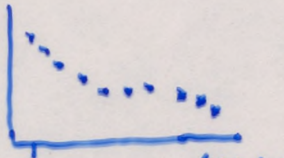
CEN X-3

CR Source Candidate

- Typical High Mass X-ray binary
- Pulse Period = 4.8 hrs. Orbital period = 2.087 days.

Southern Source.

Over a period of 5, the Pulsar Period Changed from 1987-92 4.823 s → 4.818 s. GINGA March 89 → ~~4.823 s~~. 4.84 s.



period Variation of CENX-3.

① Durham group observed Tev gamma rays in the phase 0.75 - 0.84.

$F = 3\times10^{-11}$ photons $cm^{-2}s^{-1}$ at 300 Gev.

$F_{peak} = 13\times10^{-11}$ photons $cm^{-2}s^{-1}$

② SA group (Potchefstroom)

2.4 σ in the phase (0.52 - 0.76)

③ Janzos upper limit $< 3.6\times10^{-11} cm^{-2}s^{-1}$ (1 Tev)

④ South Pole Air Shower group Negative.

PSR 1957+20 Millisecond Pulsar

PSR 1957+20 is a millisecond Pulsar in a binary System with a period of 9 hrs.

The Pulsar is ablating the White Dwarf Companion through a Strong Pulsar wind.

- Tev emission reported by SA group from the Lagrangean Point L-4. Not very convincing evidence yet.
- KGF Air Shower array $> 5\cdot10^{14}$ ev. } 3.3 σ Signal in 1990

CYG X-3

- UHURU discovered CYG X-3 as a 4.8 hr. period X-ray binary.
- Controversial evidence from COS-B.
- Normally Radio Quiet. But occasionally roughly once a year flares up and the flares persist for several days. Became an interesting object for Cosmic Ray Scientists because of
- (i) report of detection at air shower energies by Stepanian et al (1976-79), Samorski and Stamm and Lloyd-Evans et al. in 1983.
- (ii) Detection of high energy muons in the underground experiments - Soudan and Mt. Blanc.
- (iii) Bursts of high energy muons associated with Radio Flares by several groups Soudan, KGF, ; IMB,
- (iv) Bursts in TeV - PeV (Alexeenko, et al, Bhat et al, Tonwar et al, Dingus et al)
- (v) 12.6 ms periodicity claimed by Durham group at TeV. (12.5908 ms)

EeV ($>10^{18}$ eV) Claims by Fly's Eye Akeno

A very highly variable source?

Has the activity come down after 1981?

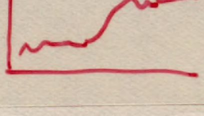
Update 1993 on Cyg X-3

- **COMPTEL** finds no evidence for a source at the location of CYG X-3. The 2σ upper limits set are

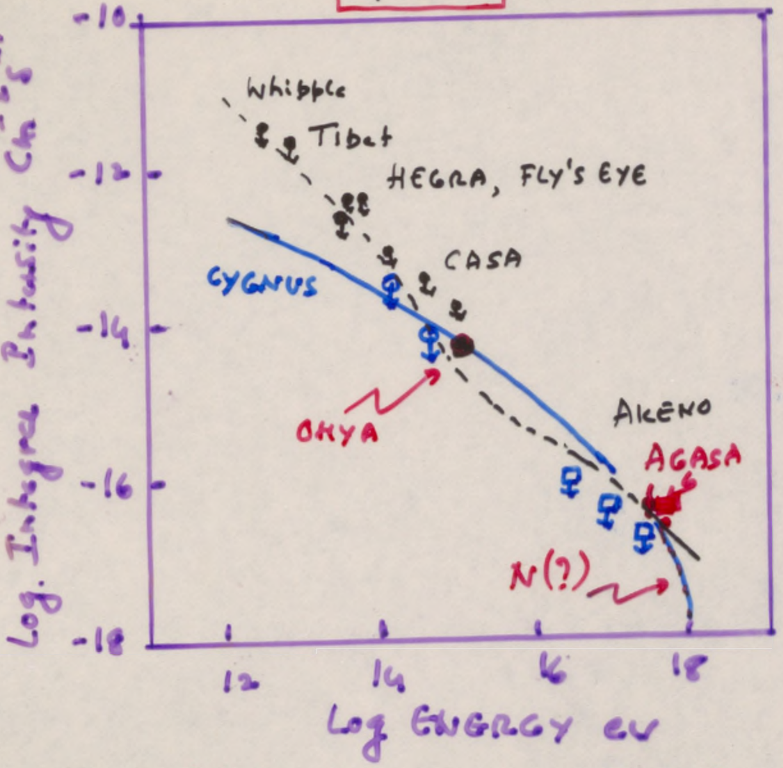
0.75 - 1.0 MeV	6.0×10^{-4} $cm^{-2} s^{-1}$
1 - 3.0 "	8.1×10^{-5} "
3 - 10 "	6.7×10^{-6} "
10 - 30 "	6.0×10^{-7} "

- **EAS** (Upper Limits)
  - CYGNUS 70 TeV $< 3.1 \times 10^{-14}$ $cm^{-2} s^{-1}$
  - BAKSAN 200 TeV $< 1.0 \times 10^{-13}$ $cm^{-2} s^{-1}$
  - MITSUISHI $N_e > 10^4$, $\mu > 10$ GeV. No signal.
  - CASAMIA 140 TeV $< 1.3 \times 10^{-12}$ $cm^{-2} s^{-1}$; μ-poor $< 5.8 \times 10^{-13}$ "
  - OHYA $N_e > 10^5$, $\mu > 10$ GeV: episodic 3 to 4σ during 89-91.

3σ Cumulative excess seen by KGF at 10^{14} eV



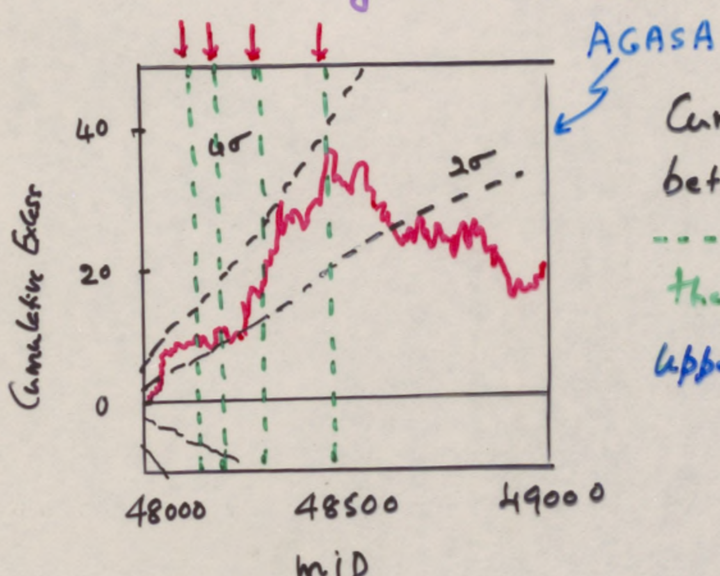
CYG X-3



The dashed line = 90 % Confidence Upper Limits (1991) by Whipple, Tibet, HEGRA, CYGNUS, Fly's Eye, CASA and AGASA (AKENO)

The OHYA point at 10^{15} eV and of AGASA at 10^{17} eV represent positive Signals from Cyg X-3.

* At 10^{17} eV - Neutrons from Cyg X-3 Can arrive without large fractions decaying.



Cumulative Excess of Cyg X-3 between Jan 1990 and Feb 1993

- - - Radio Flares occurred on these days - exceeding 10 J

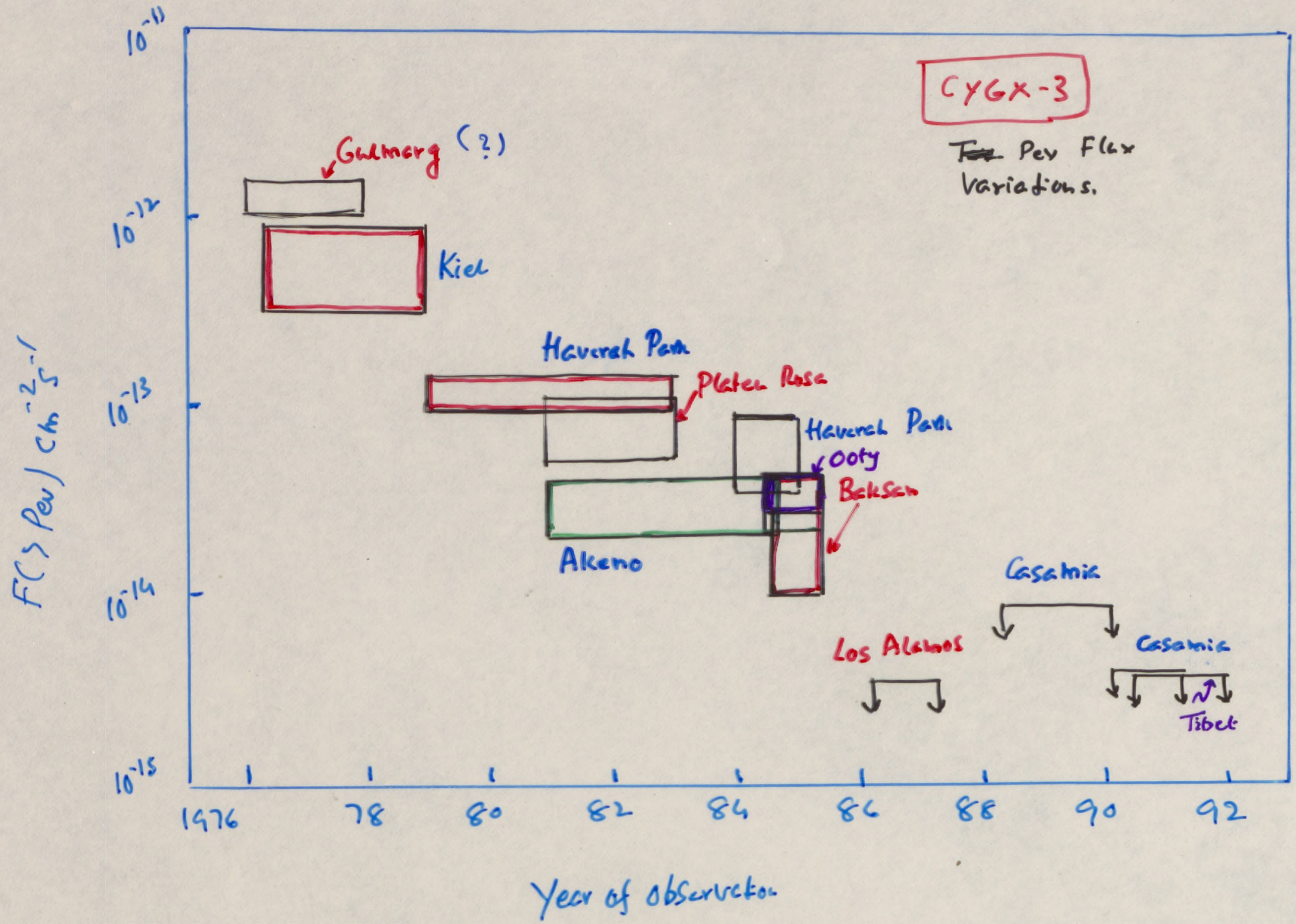
Upper limit of flux (Steady) $= 1.5 \times 10^{-17} cm^{-2} s^{-1}$ at 3×10^{17} eV

*

Group	ENERGY (eV)	Flux $cm^{-2}s^{-1}$	Period	E x F
FLY'S EYE	5×10^{17}	2×10^{-17}	Nov 81 - May 88	10
Lawrence et al	5×10^{17}	$< 4 \times 10^{-18}$	Jan 74 - July 87	< 2.0
Teshima et al	5×10^{17}	1.8×10^{-17}	Dec 84 - July 89	9.0
Hayashida et al	3×10^{17}	3.4×10^{-17}	Jan 90 - July 91	10.2
Chiba et al	3×10^{17}	$< 1.5 \times 10^{-17}$	Jan 90 - Feb 93	< 4.5

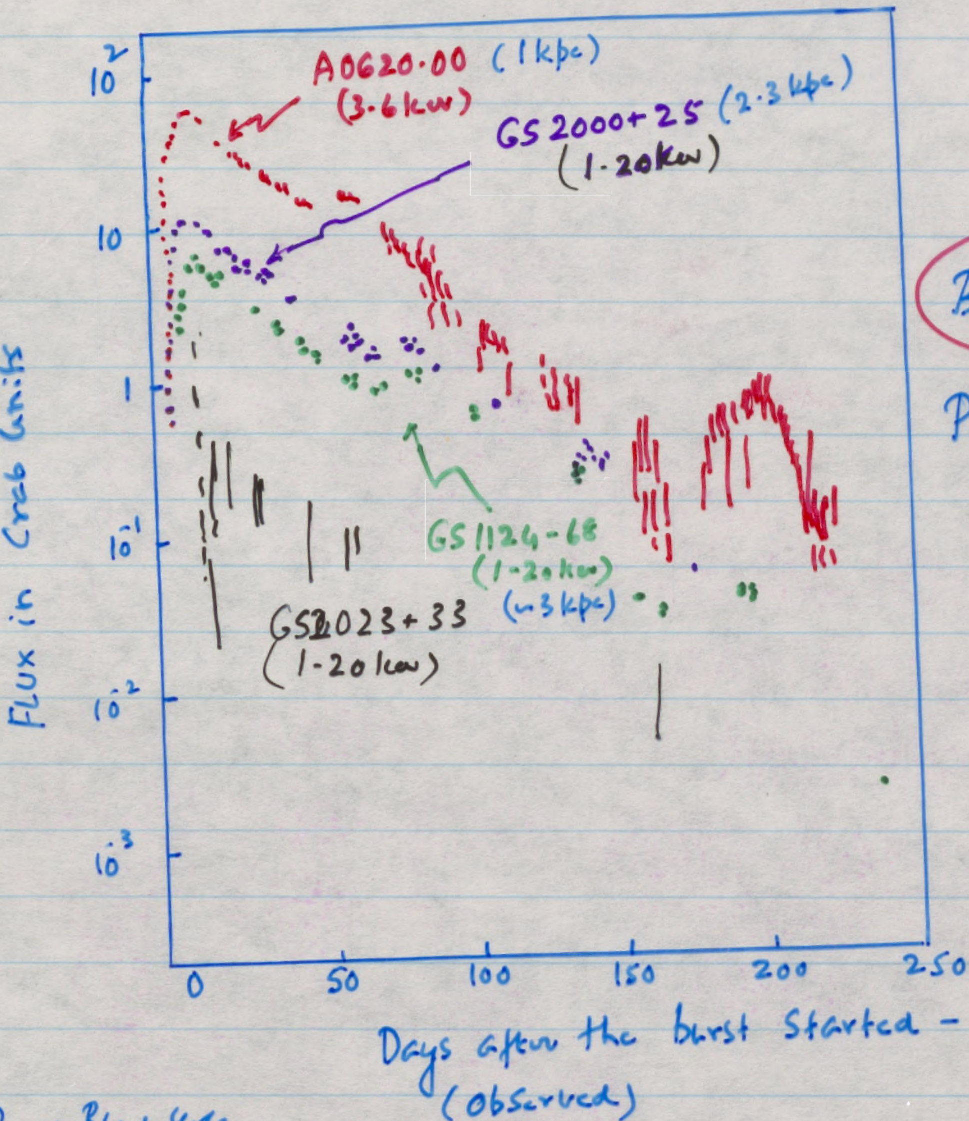
EeV BURSTS } ↓ Neutral Particles (?)

⊙ → Search for bursts at $E > 10^{17}$ eV using the Kolmogolov Smirnov test revealed only 3 regions. One of these three regions fall in the direction of Cyg X-3.



CYGX-3
PeV Flux
Variations.
Gulmarg (?)
Kiel
Haverah Park
Plateu Rosa
Haverah Park
Ooty
Baksan
Akeno
Casamia
Los Alamos
Casamia
Tibet
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
F(> PeV) cm^{-2} s^{-1}
1976
78
80
82
84
86
88
90
92
Year of observation

GINGA BURSTS - TRANSIENTS



Binaries.

Black Hole Candidates.

Peak Luminosities ~ 10^{38} ergs.

Best Black Hole Candidate (Mass > 3 M⊙)

A0620+00 (Nova-Mon) - reported by Kaluzienski et al in 1977.
peak observed intensity in 3-6 kev - 30 Crab Units
Show a secondary increase around 60-70 days and a tertiary increase after 170 days.

The other 3 Sources discovered by GINGA Satellite show similar behavior.

* There have been Claims of occasional Tev-Pev emissions from the black hole Candidate Cyg X-1 (2.5 kpc)

Accelerator Experiments:

- Cosmotron - Bevatron — CERN — Colliders — FNAL --> SSC (?)
  early 50's — 60's — 70', 80's — 90's.

- Characteristics of interactions:

  pp upto ~ 10^{15} eV.

  p-Nucleus ~ 3×10^{11} eV

  Nucleus-Nucleus ~ 2×10^{11} eV.

  Fragmentation region —

- Even within the Frame-work of the Standard Model —

  Top, Higgs, τ_{Neutrino} and other flavours (?)

  SUSY particles? Quark-Gluon-Plasma (?)

- Non-accelerator particle physics Expts.

  Proton Decay (?) upto 10^{32} yrs.

  Magnetic Monopoles (?)

  Axions,

  Neutrino Mass (?),

  Quark States - Nuggets.

  ← The Rise and Fall of 17 keV Neutrino — by DRO Morrison Nature Nov. 4, 93.

- Anomalies in Cosmic Ray investigations:

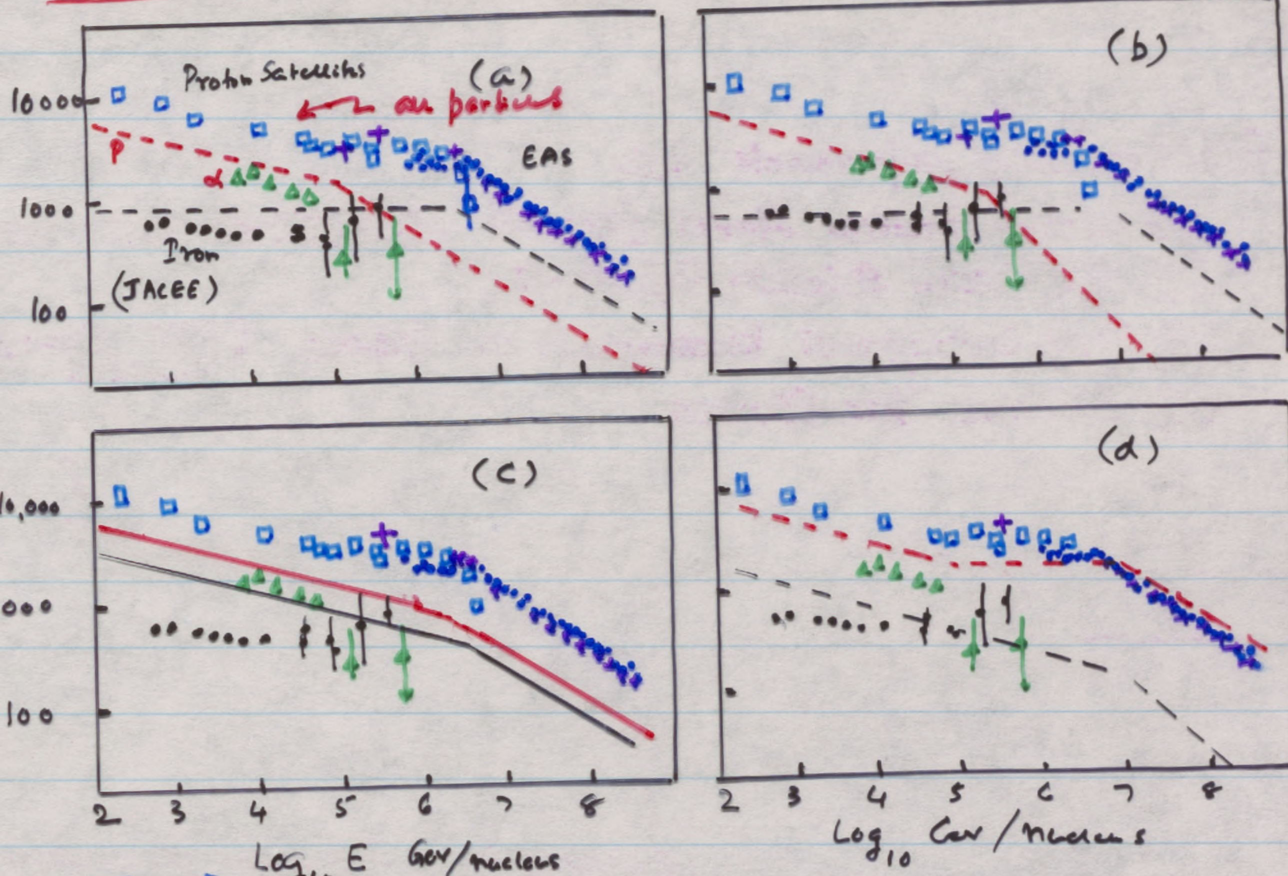
  Only at very high (>10^{12} eV) energies.

  Primary Composition
  ↓
  Characteristics of High Energy Interactions
  ↓
  Primary Composition
  ↓
  ⋮

  The early Credentials of Cosmic Ray investigations in this field →

Gaisser p 108.
Stanev.

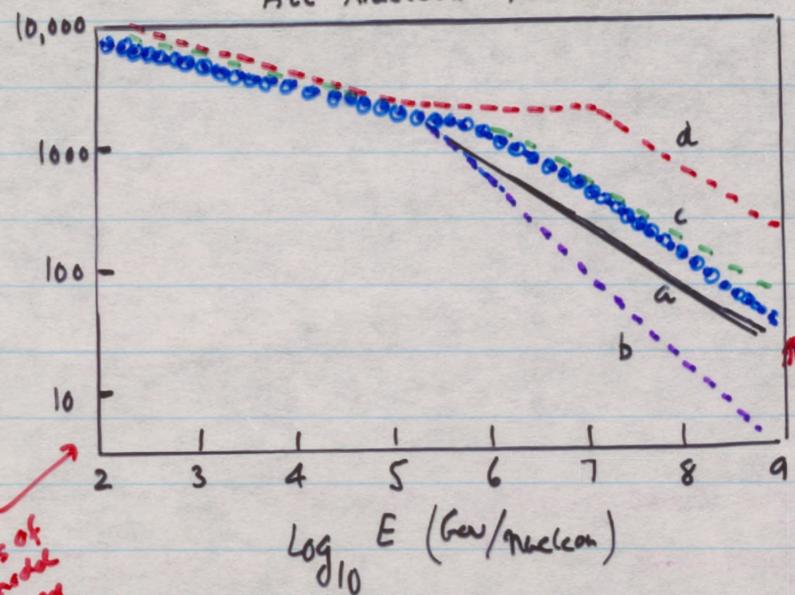
Cosmic Ray Spectrum and Composition



Total Energy

(a) p-poor model. (b) Maryland (c) Constant mass (d) Linsley.

All Nucleon Spectrum Consistent with direct flux measurements and high energy muon spectrum.



- What is responsible for the Steepening ?
- Rigidity Cut off ?
- Change in interaction Characteristics ?
- Is there a Change of Composition ?

Predictions of various model over the energy range 10^{11} - 10^{18} eV (Gaisser and Stanev)

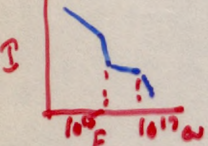
Direct measurement are available only up to 10^{14} eV (JACEE)

Best fit to all the experimental data including data on high energy muons.

Structure in Cosmic Ray

Primary Spectrum and Composition at high energies – (10^{9} – 10^{21} ev)

- Conventional Wisdom vs Recent Trends
  ↓ Based on early experiments with



  (i) Nuclear Emulsion Stacks flown to Stratospheric altitudes.
  (ii) the Russian Satellite Experiments (Proton Series)
  (iii) Deep Underground Measurements on Muons. (KGF · 8000 ft → 16,000 ft)
  (iv) Extensive Air Showers (–2.6, –2.7)

- The all particle Spectrum which is a power law with a slope (–2.6, –2.7) Steepens around 10^{16} - 10^{15} ev (The 'Knee' of CR Spectrum) → Density Spectrum showed this first. and flattens beyond 10^{17} ev.
- The primary Composition is Proton dominant before the bend.
- The bending is due to a "Rigidity Cut off" – particles (Peters 1959) escaping from the galaxy beyond this rigidity defined by the galactic magnetic field. [Change in Interaction Characteristics ?]
- The Inability of SN remnants, Neutron Stars with magnetic field of ~ 10^{12} gauss to accelerate particles beyond 10^{15} ev or so.
- The particles beyond 10^{17} ev – predominantly 'protons' of extragalactic origin. Heavies will be disintegrated.
- A Sharp Cut off to the primary Spectrum was expected beyond ~ 10^{19} ev due to interaction with the photons of the 3° Universal Radiation. Consequently the CR Sources had to be within the Super Cluster of galaxies, if 3° radiation is Universal.

- This entire picture has changed Considerably due to
  (i) New Large Scale Experiments – Balloon, Satellite, ground
  (ii) New ideas on acceleration and Sources. → { Plasma Shocks, Galactic Wind, Reacceleration, AGN's, Jets · ·, Collision of galaxies, Cosmic Strings → 10^{19} ev or higher even }
  (iii) Evaporation of Primordial { Black Holes directly into CR particles; Topological Relics } (No acceleration)

The field of high energy Cosmic Ray Research has again opened up for more sophisticated investigations –

* The question of change in interaction Characteristics has cropped up again.

In the

First Talk: (Sources within the Galaxy)

<•> Summary of the Current Status of TeV, PeV, EeV searches for Cosmic Ray Sources in the Galaxy – S.N. remnants, Pulsars, X-ray binaries – especially those that have been seen in the MeV-GeV range by the instruments on the Compton observatory (CGRO).

<•> Among them the only source that is established with certainty is the Crab Nebula – in the TeV range. The anomaly still is that the Crab is a D.C. source in the TeV range, while the pulsed mode is dominant at all the lower energies. The PeV observations also indicate a pulsed emission though on occasions

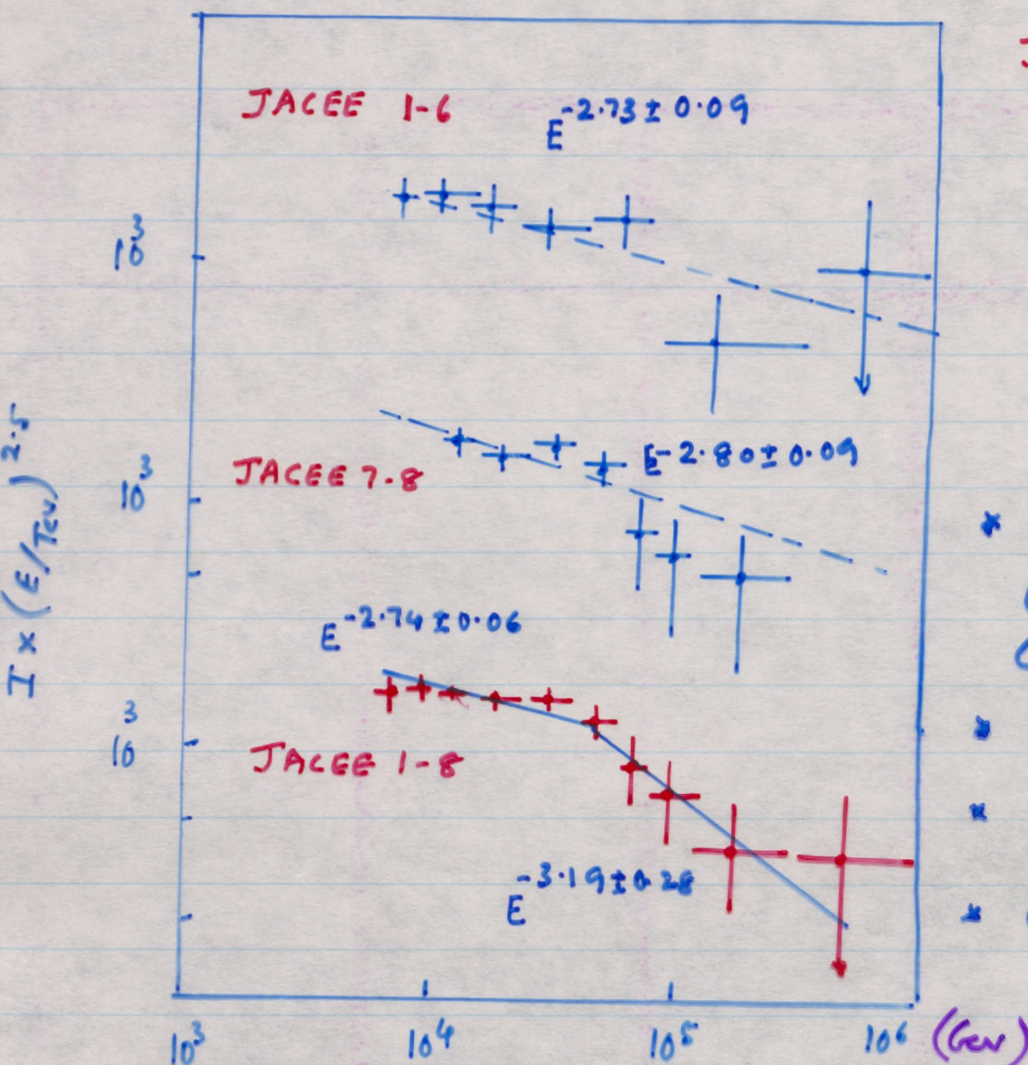
<•> The other galactic sources, which are tantalizing, but still far from being established on a firm basis are Her X-1, Cyg X-3, CEN X-3, AE Aquarii, Geminga, Sco X-1, Cyg X-1, PSR 1957+20 – the millisecond Pulsar., and the Vela Pulsar. These have been seen at the level of 3 to 5 σ on occasions and sometimes in the burst mode. CYG X-3 remains enigmatic in several respects.

<•> Before discussing the searches for extragalactic sources let us see what the current status is regarding the structure in the primary spectrum and composition which is closely related to the question of cosmic ray sources – galactic vs extragalactic.

<•> The possibility of young S.N. remnants like Geminga contributing to Cosmic Ray Flux upto ~ 10^{15} eV was discussed.

Primary Proton Spectrum.

JACEE (1993)



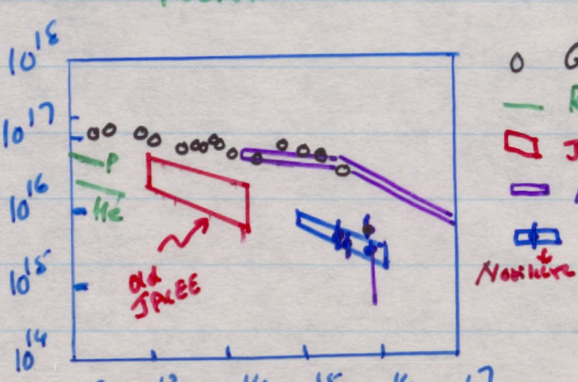
* Primary Composition undergoes a Radical Change around 1 TeV
* Becomes Heavy Dominant.
* Around 10^{16} - 10^{17} Iron Could be dominant
* Only beyond 10^{19} does it become all protons (?)

Steepening of the Proton Spectrum around 40 TeV

Composition: %

	P	He	CO	NeS	Z>17
45 TeV	35±8	30±6	16±4	9±1	10±1
370 TEV	14±9	23±10	26±11	13±7	24±1

Proton Fluxes



o Grigorov et al (Proton Satellite)
— Ryan et al
▭ JACEE (Dublin 91) Emulsion Stack at Balloon altitudes.
▭ AKENO Air Shower
▭ Fuji & Kanbala. - [Hybrid (EAS + EC) at Norikura]
↓ Primary proton flux 10^{15} - 10^{16} derived from hybrid experiment at Norikura.

• CONFLICT WITH LATEST JACEE ?

Japan-US Collaboration

JACEE BALLOON FLIGHTS

Flight NO	Date of Launch	Site of Launch	Alt mbar	Time hrs	Exposure {Area cm^2 × Units}
JACEE 0	5/79	Japan	8.0	29	1(40×50)
1	9/79	Texas	3.7	25.2	4 (40×50)
2	10/80	Texas	4.0	29.6	4 (40×50)
3	6/82	S. Calif	5.0	39	1 (50×50)
4	9/83	Texas	5.0	59.5	4 (40×50)
5	10/84	Texas	5.0	15	4 (40×50)
6	5/86	Texas	4.0	30	4 (40×50)
7	1/87	Australia	5.5	150	3 (40×50)
8	2/88	Australia	5.0	120	3 (40×50)
9	10/90	New Mexico	4.0	44	4 (40×50)
→ 10	12/90	ANTARTICA	3.5	204	2 (30×40)

JACEE-11
258 ? E>10^{14} ev
Total upto date = 54

BALLOON FLIGHTS FROM (ANTARTICA 93)

E > 10^{12}/nucleon or Total E > 10^{14} eV.

Two flights 6 Units for 400 hrs (258)

Expected Events	(Tev/Nucleon) 1	5	10	50	100	500	E>10^{14} ev Tot
P			2580	140	43	3	43
He			410	27	7	0.5	83
C-O	988	65	21	1			36
Ne-S	338	24	5	0.5			33
18<Z<24	28	8					14
Fe (E$^{-2.5}$)	78	26	2				49

Cosmic Ray Sources. (VI p 365)

The Whole Sky Survey at Eev (10^{18} ev) by AGASA

AGASA is extension of AKENO (100 km^2 array)
111 Scintillators – 1 km. apart.
Threshold 10^{17} ev . angular resolution 3-4°

Declination 0° - 60° } in 1° Steps
~~Az~~ RA 0 - 360° }

The number of positions showing probability $< 10^{-3}$ is 27 among 21,600 trials. (360 × 60). Not all independent.

TABLE below gives the location of 3 independent clusters and the probabilities P_{ch} associated with them.
What is interesting is that Cyg x-3 is one among them.
(307.65, 40.78)

	RA	Dec	gl^{II}	gb^{II}	log P_{ch}
	17 ± 2	52 ± 2	126 ± 2	-10 ± 2	-3.55
(Cyg x-3) →	309 ± 2	40 ± 2	80 ± 2	1 ± 2	-3.48
	332 ± 2	56 ± 2	101 ± 2	0 ± 2	-3.95

Cumulative Excess seen by AGASA during the period 47,950 MJD — 48,500 MJD during which 4 Radio flares were observed. (Jan 19, 91 — Feb 93)

Cosmic Ray Observations: Tev → Eev

Tev (10^{12} ev)	Pev 10^{15} ev	Eev (10^{18} ev)
50 Gev - 50 Tev.	50 Tev - 5×10^{17} ev	> 10^{17} ev - 10^{21} ev.
Air Cerenkov	Extensive Air Showers	Extensive Air Showers.
Dublin Whipple (USA) Pachmarhi, Ooty, Gulmarg } (India) Durham (UK) Adelaide (Australia) HEGRA (Germany) Crimea, Tienshan (Soviet) South Africa Themistocle (France)	CYGNUS (USA) KGF, Ooty (India) Haverah Park (UK) CASA-MIA (USA) EAS-TOP (CERN) TIBET JANZOS (Japan-NewZealand) CANGAROO Moscow State University (Soviet)	Fly's Eye (USA) Haverah Park SUGAR (Australia) YAKUTSK (Siberia) AKENO, AGASA (Japan)

- Sources tracked
- Angular Resolution ~ 1°
- Observation possible only on cloudless, moonless nights ∴ overall efficiency ~ 10%
- Threshold ~ 50 Gev.
- Effective area ~ 10^4 m².
- Pulse Shape rejection (Muon Rejection.)

- No Tracking. Angle determined by timing measurement. Best resolution ~ 0.5°-1°
- Effective Area depends on the size of the array and on the size of shower. (10^3 – 10^{12} particles)
- 100% efficiency above threshold.
- Scintillators, Water Cerenkov Detectors + Muon and Hadron Detectors.

(P. A. Johnson p.362)
V2-362 (Adelaide)

* Cosmic Rays From Geminga Supernova ?

The Second Closest Pulsar.

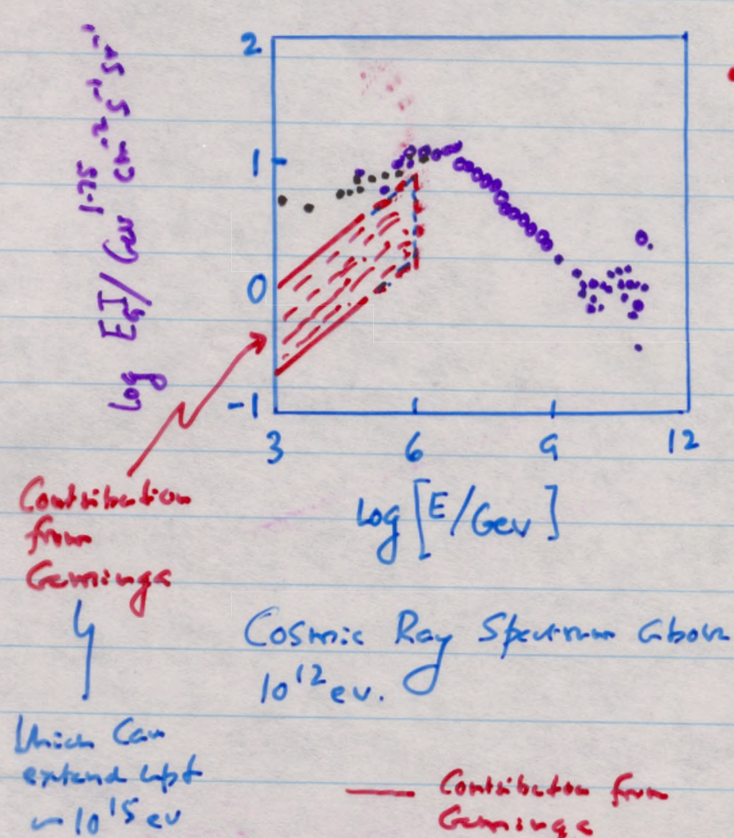
Geminga Pulsar formed ~ 4×10^5 years ago. – ($\dot{P}$ measurement)
(237 ms.)

distance : γ-flux < 380 pc.
Vela like γ-efficiency leads to ≃ 40 pc }
optical Companion speed of 0.17 arcsec/yr ~ 100 pc.

It has been suggested that the Earth is within the Bubble formed by the explosion of the Catacylsmic Variable that exploded and lead to Geminga.

Such an young S.N. remnant can accelerate particles upto 10^{14} eV
(Shock acceleration)

Energy Release assumed ~ 10^{51} ergs }
Acceleration period ~ 1000 yr }

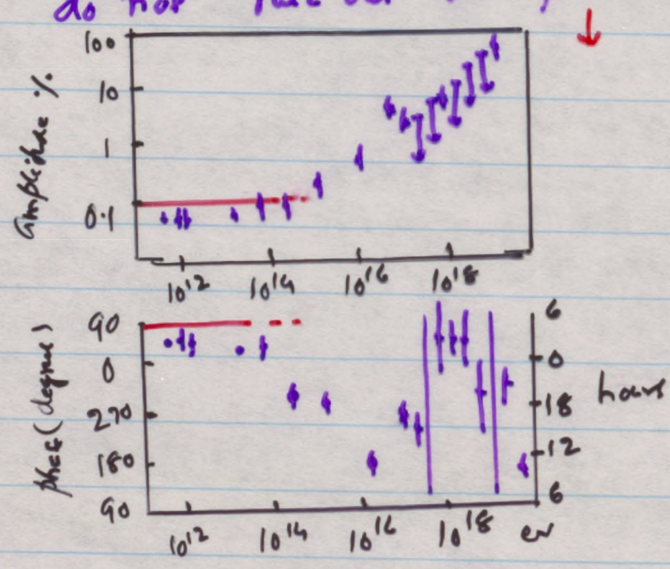


Cosmic Ray Spectrum above 10^{12} eV.

— Contribution from Geminga

• Particle acceleration in the young SN remnant could be responsible for a large fraction of the present day CR flux upto the knee-region.

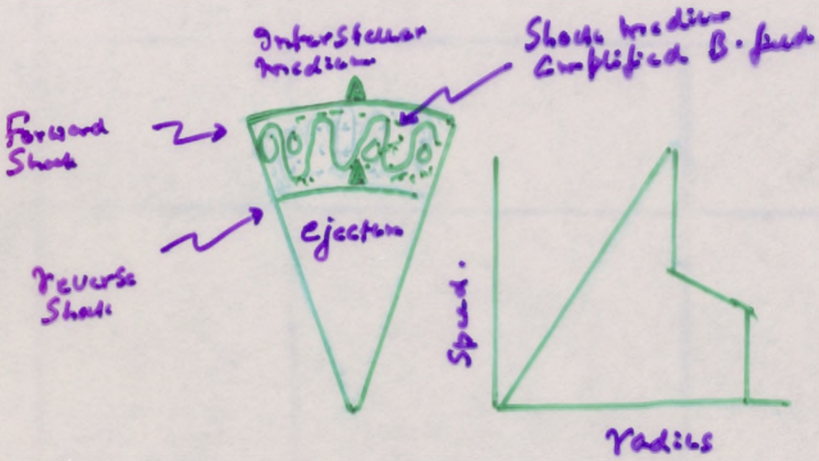
• Cosmic ray anisotropy measurements do not rule out this possibility ↓



(Ming Zhang) p 32. Chicago.

* The Role of Supernova Reverse Shocks in Cosmic Ray Acceleration
(Composition may remain same upto very high energies 10^{17}–10^{18} eV)

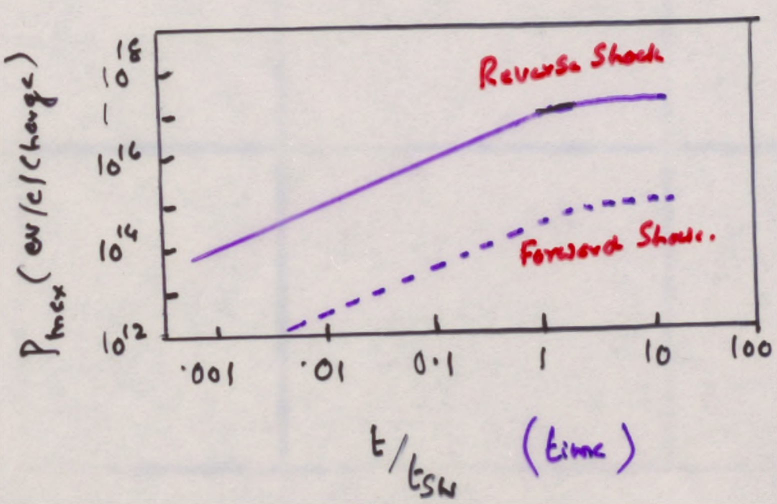
- Shock waves in SN remnants – Source of CR upto 10^{15} eV. This upper limit comes from the lifetime of SN compared to acceleration time.
- Reverse shocks have been observed in various SN remnants and the reverse shocks are expected to be formed at the same time as the formation of the forward shock.



Interstellar medium magnetic field (mean) } 3 μG

- Maximum Energy as a function of time due to acceleration by the forward shock is given by the dashed line. – 10^{15} eV.

The sweep-up time t_{sw} ~ few hundred to few thousand years.



t_{sw}: Sweep up time.

- The reverse shock amplifies the field to ~ 9×10^2 μG inside the SN shell.

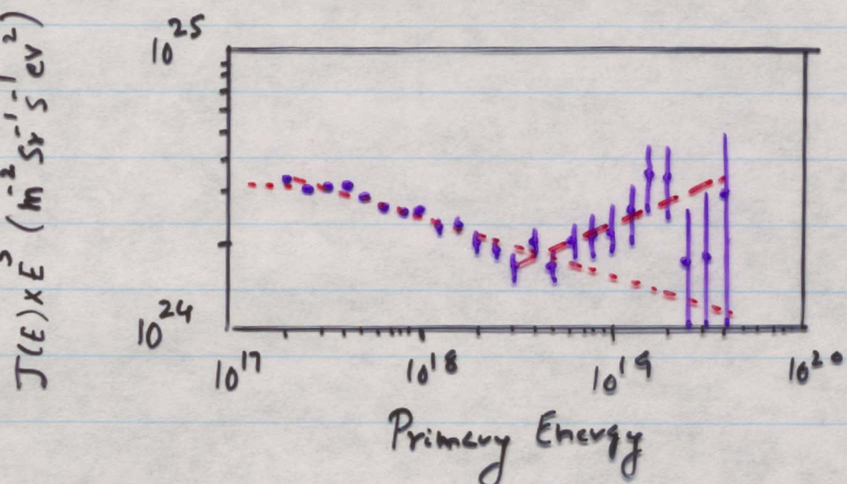
The Maximum Energy of particles accelerated by reverse shock ~ 2×10^{17} eV/charge. This can be pushed to 10^{18} eV if the diffusion coefficient is smaller. – In the case of Iron, this mechanism can lead upto 2.6×10^{19} eV.

- The acceleration time much less than loss due to Synchrotron, Inverse Compton, and other losses – Coulomb collision, ionization etc.
- Particles injected into reverse shocks may come from preaccelerated particles by the forward shock. ∴ the composition may remain the same as at lower energies.

Model	Energy Spectrum	Anisotropy	Composition
Galactic Wind	$7\text{-}10 \times 10^{19}$ eV Cut off	Slight (~5%) Enhancement	Light - Heavy
Compact Object Acc. Disk	10^{18} - 10^{19} eV Cut off	Galactic plane enhancement	Protons only
Multiple SNR	10^{18} - 10^{20} eV Cut off	Isotropic	Light - Heavy
Compact Nebula	10^{18} - 10^{19} eV Cut off	Galactic plane enhancement	Light - Heavy
Extra galactic Cosmic Strings	6×10^{19} eV Cut off Bump before Cut off	Isotropic	Protons only
Extragalactic EGRJ's < 100 Mpc	6×10^{19} eV Cut off Bump before Cut off	Isotropic	Light - Heavy
Extragalactic AGN'S, EGRJ's > 100 Mpc.	6×10^{19} eV Cut off Bump before Cut off.	Isotropic	Protons only

Predictions of Very High Energy (Eev) models on Energy Cut off, anistropy and Composition.

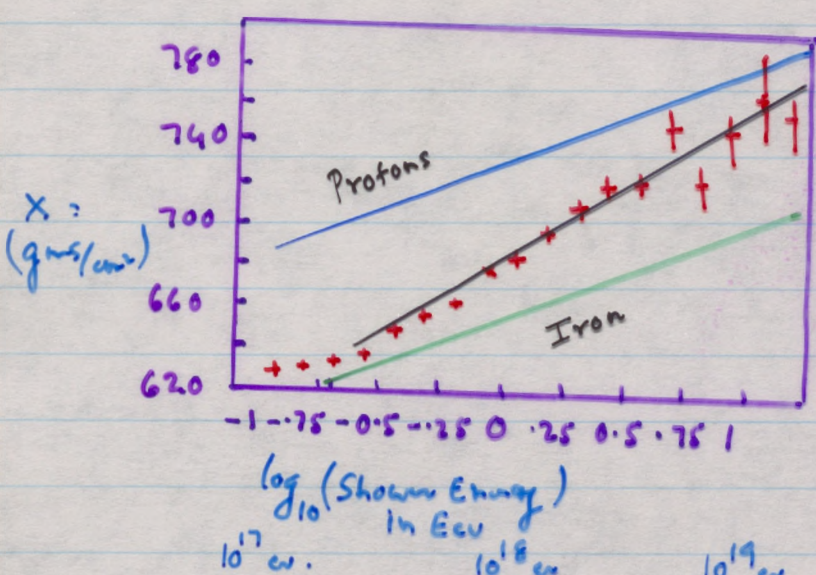
⊙ The Cosmic Ray Spectrum at Very High Energies $> 10^{17}$ ev.



	γ
$10^{17.3} - 10^{19.6}$ ev	$-3.18 \pm .01$
$10^{17.3} - 10^{18.5}$ ev	-3.27 ± 0.02
$10^{18.5} - 10^{19.6}$ ev	-2.71 ± 0.10

- The Fly's Eye Spectrum shows an upward trend beyond $10^{18.5}$ ev.
- { There is no evidence for the Steepening of the Spectrum due to 3^0 radiation expected if the Sources are Extragalactic.

⊙ Cosmic Ray Composition at Very High Energies.



X = Elongation Rate = Rate of Change of the average depth of Shower Maximum per $\log_{10}$ of Shower energy in Eev (10^{18} ev)

- Pure Proton and Pure Iron are clearly ruled out
- At the low energy end - a Significant mixture of Iron is required.
- At the high energy end ($\sim 10^{19}$ ev) higher proportion of protons required.

<In the Knee region and beyond, the Composition is heavy dominant.>

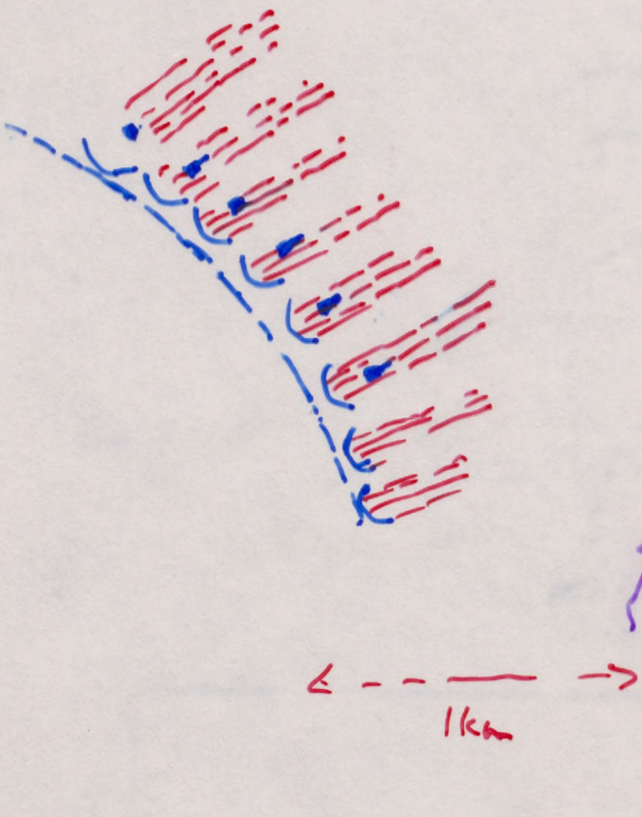
The Fly's Eye

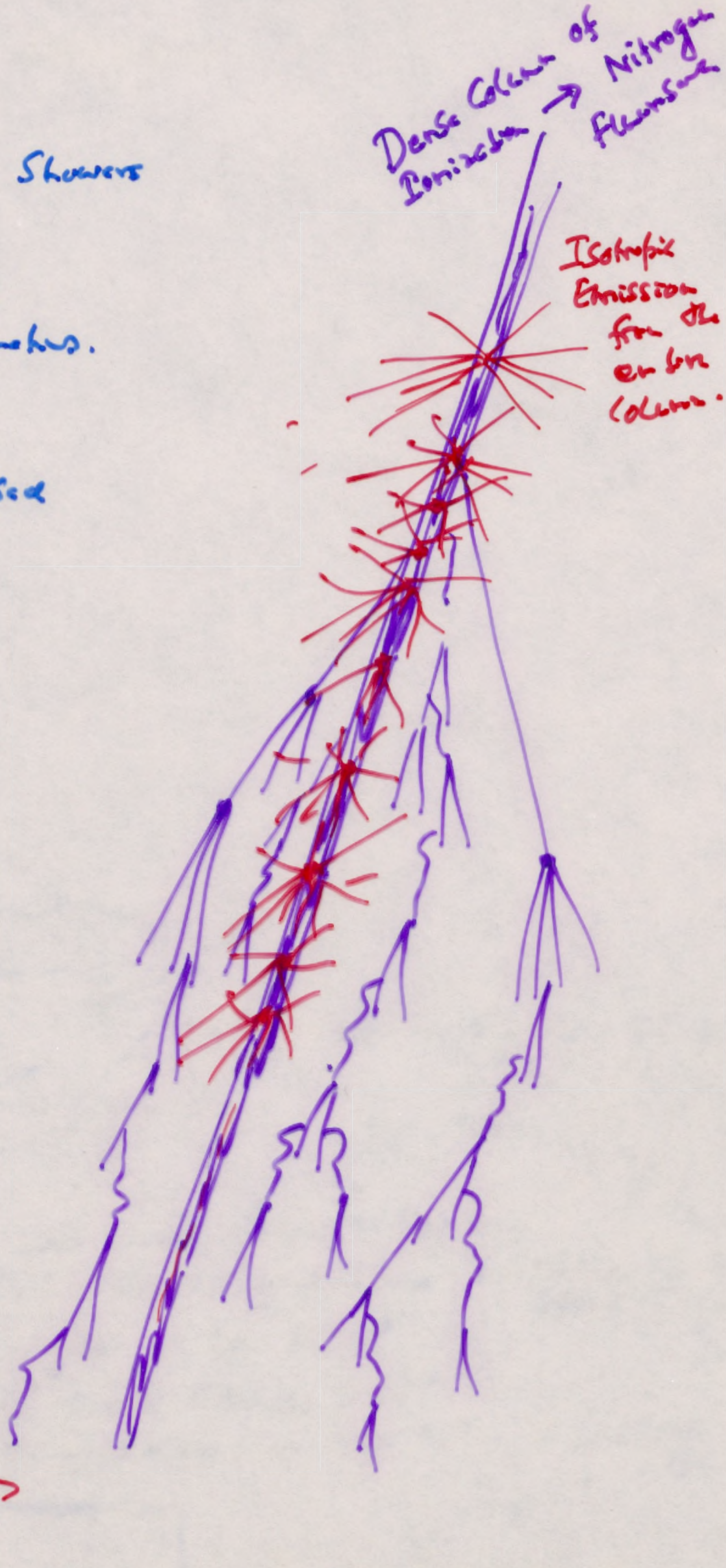
Longitudinal Development of Air Showers Measured

The effective distance of the Core Can even be several kilometers.

Threshold $\geq 10^{17}$ eV.

The Same mirrors Can also be used As Cerenkov Counters.

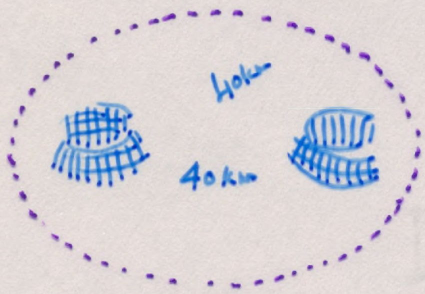


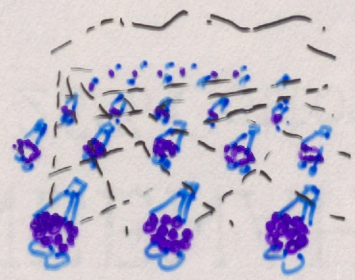


TELESCOPE ARRAY PROJECT.

(USA - JAPAN)
↓
Utah

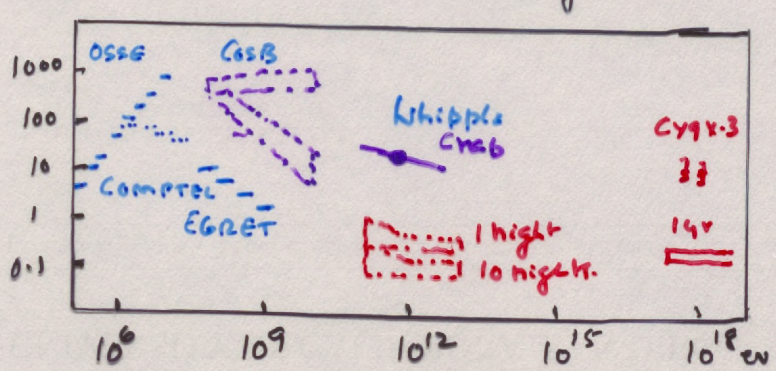
- Two Stations Separated by 30-40 km.
- Each Station : 120 imaging telescopes of 3 m dia + 69 telescopes of 1 m dia
- Coverage 2π Steradians
  Area × Sr for 10^{20} ev ~ 40,000 km² Sr.
- For Tev γ-rays. Combined 6×10^9 cm²
- FLY's Eye Technique - Combination of Cerenkov and Air Scintillation.





- Angular Accuracy with 20 telescopes 0.02°
- proton rejection 99.90 %.

- The Telescopes are Separated by 50 m over 600 m × 600 m.
- The Imaging Camera — 16 multianode photomultiplier (HAMAMATSU + ICRR, Tokyo)
  Each photomultiplier: 5" Square FOV 10°×10°
  1024 anode Cells of 0.25°
  Charge deposit on each Cell read separately.



Relative Sensitivities of Various arrays :

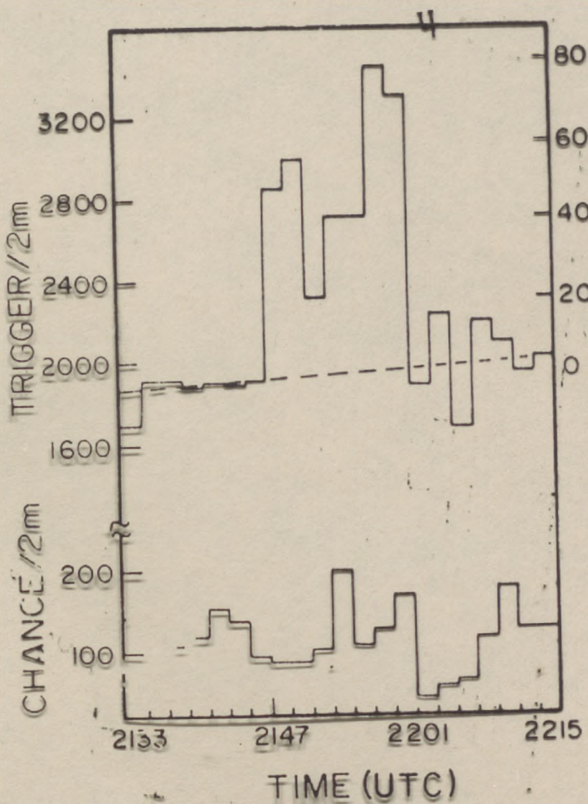
Red — TELESCOPE ARRAY

* In the Search for Cosmic Ray Sources, the following lessons from X-ray, γ-ray and Radio astronomies may be important.

1. The Source may not be Spectacular in other bands of the e.m. Spectrum – (Sco X-1 example)
2. Wide Variations in intensity and Spectra on time Scales from milliseconds – Seconds – min. hours – days may occur
3. Sources may be modulated for long periods – days, months, years – from Complete obscuration to gigantic flaring activity by Several orders of magnitude – Cyg X-3 in radio, Her X-1, the rapid burster
4. The Pulsed Frequency may vary Systematically and erratically. – Her X-1
5. There Can be large phase difference in the pulsations at different bands of the Spectrum – PSR 1509-58
6. Transient Sources lasting from Seconds to months may reveal either Neutron Stars with high magnetic fields or black holes as part of accreting binaries – which could be Sources of Cosmic rays. (Ginga Transients)
7. Simultaneous observations – in different energy ranges. and by different laboratories are a great help in establishing genuineness of Signals and in identification of Sources. From this point of view as well as from the point of view of getting maximum information, it is important to keep track of the events with high timing (Absolute) accuracy. [S.N. 1987a]

0 minute duration covering ... OFF source scan of same duration, spanning the same zenith angle range. No evidence of steady emission form Her X-1 was seen in the entire 16 hours' data collected during June 1988. Based on the average ON/OFF ratio of 1.01 ± 0.01, a 99% confidence level upper limit on the steady flux of γ-rays of energy ≥ 3 TeV from Her X-1 is placed at 1.6 × 10^{-11} γ/cm² s. However, one 15 minute long duration of episodic emission was noticed to occur on June 12, 1988 at 21:05 UT when the data were subjected to neutron star periodicity analysis. The observed pulsation period is consistant with the contemporary X-ray period. The 35 d cycle phase for the episode is 0.02, a phase close to the on-set time of 'high on' state in the X-ray flux and the 1.7 d orbital phase is 0.66. The time averaged flux works out to be $(4.7 \pm 1.2) \times 10^{-10}$ γ/cm² s at ≥ 3 TeV which corresponds to a source luminosity of ~ 10^{35} erg/s.

The binary system, Cygnus X-3, in the constellation of Cygnus is known to flare up occasionally producing an increase by a few orders of magnitude in the radio flux density.



Transient emission from Her X-1

Figure 3. The trigger rate and the chance coincidence rate per 2 minutes on 1986 April 11, during observations on Her X-1. The broken line represents the expected trigger rate due to cosmic ray showers. The right-hand side scale shows the excess over the cosmic ray background rate as a percentage of the background rate.

In his paper on "Subjective Foundation of Science: Language, Consciousness and Reason" Sunder Sarukkai makes the following points.

- While objectivity is the hallmark of Science, it has to be conceded that this objectivity has to be Subjective in Character. Culled out of experience which is How this objective knowledge is generated from Subjective human activities is certainly a matter of Concern in discerning the foundation of Science
- In his paper entitled "Subjective Foundations of Science: Language, Consciousness and Reason" dwells on how these are connected to the issue of objectivity of Science.
- "The Human Reason is a curious thing. Although manifested in individuals, it seems to behave in a similar way in almost all individuals – even among Cross cultures. The belief that objectivity lies in the world of objects is false … the objectivity of the world can be known only by human intervention"
- The Subjectivity-objectivity divide makes no sense.
- Husserl: Objectivity is the essence of pure subjectivity.
- Beauty is an exemplar of subjectivity. Beauty has a role in Science
- Beauty in Science is appreciated only by the Community of Scientists while in Arts it is appreciated by all.
- In Science aesthetic considerations play a significant role in accepting certain theories
- [A beautiful theory may be killed by an ugly experiment.]
- Symmetry, a characteristic of beauty, plays a significant role in Science.
- "It is more important to have ~~beauty~~ beauty in One's equations than to have them fit experiments" — ~~Heisenberg~~ ~~Weyl~~. Dirac

- Einstein emphasized on "Principles of Simplicity and Beauty" as guides in his theories.
- Copernican theory replaced Ptolemy's theory of because of aesthetic considerations
- For arts beauty is an end whereas for Science beauty is the beginning.
- It is the clash between the human individual will and the collective will of Science that is the fulcrum of clash between subjectivity and objectivity in Science.
- Scientific methodology is to be understood not in terms of objective and subjective divisions alone, but by other elements which are subjective in nature, yet an integral part of scientific method and practice.
- Two such elements are
  - (i) ritualisation of epistemological practice
  - (ii) discursive practices with language
- The idea of "Form" plays a fundamental role in the growth of Science.
  - Structure of DNA, sequences and codes embedded
  - Notations of chemical equations
  - representation of molecular shapes
  - ⋮
  - Form plays a role in the writing of Science and writing plays a role in a coherent creative understanding of Science – definite shape from prisms of logic, theories and models
  - In Bohr's formulation of the atomic theory, the shape from the form of a continuously spiralling in orbit to discrete set of orbits played a very important role. and laid the foundation of quantum theory.

- The idea of writing similarity is fundamental to the writing of discourse in science.

- Writing strategies based on formal similarity in the written form, as also in the figures, graphs etc. generate new knowledge

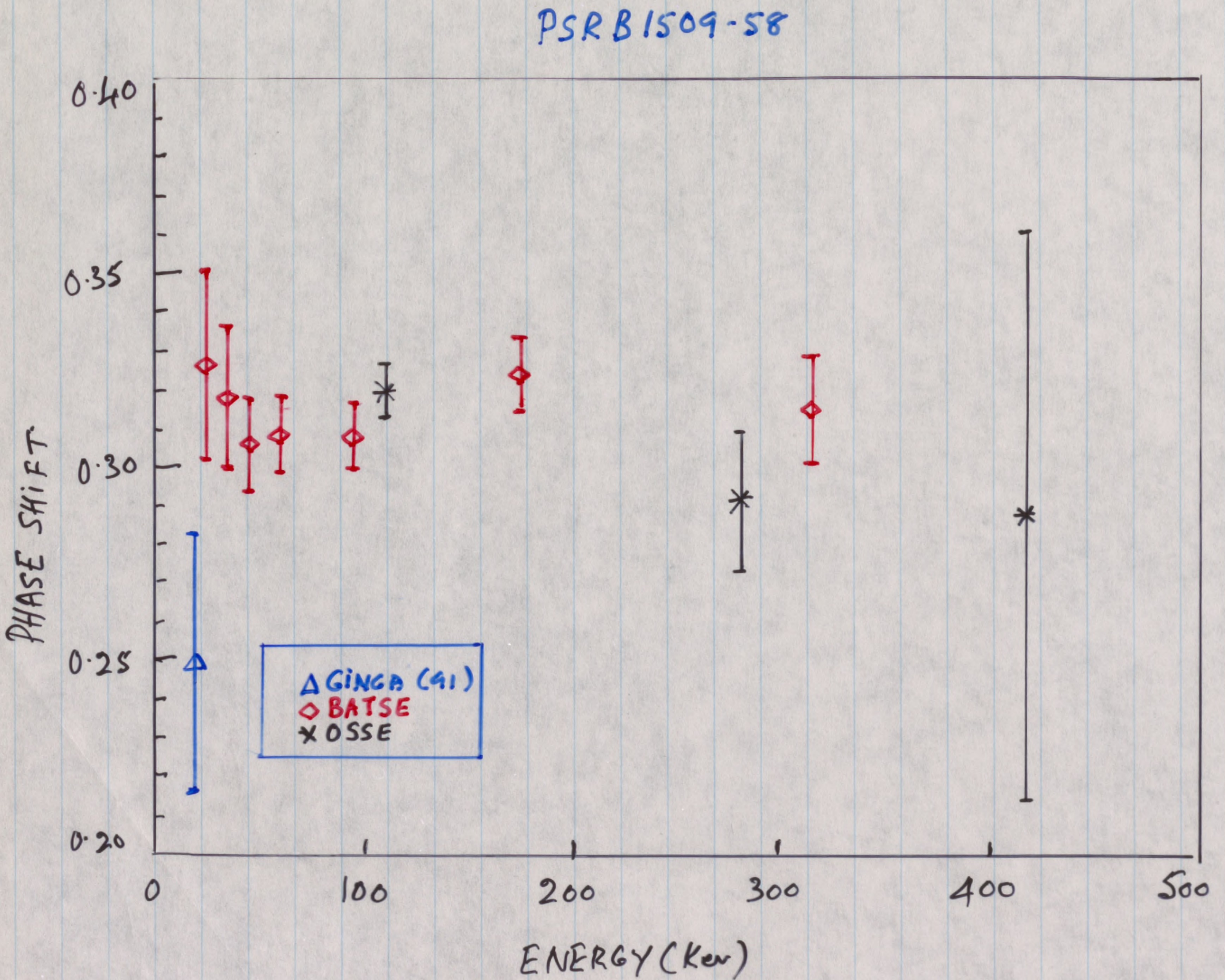
- New structures, insights and theories are made possible not by experiments or deductive logic alone, but also by certain strategies of writing discourse. These discursive strategies also generate new particles! This is exemplified in many theories of particle physics

NIAS

- My First Encounter with Vikram Aug 3, 1948. Ammu Swaminathan's place.
  Selected as an R.A. for PRL.
- Annual Cosmic Ray Symposia. - Ahmedabad.
- London Conference. - Aug. 1965. - urges me to change my field
  then I went to NRSP. Encounter with U.R. Rao at London.
- Dec. 22nd. 1971 Ahmedabad. } 10 years ~~of~~ profile of
- Dec 27th. 1971 Trivandrum. } Space Astronomy.

  Last Darshan.

Modern Astronomy. - Radio, IR, optical, UV... Pev - Neutrino.
μ-meson Expts.


PSR B1509-58
PHASE SHIFT
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100
200
300
400
500
ENERGY (Kev)
Δ GINGA (91)
◇ BATSE
✕ OSSE