Hercules X-1 X-Ray binary 1.7 days, Pulsar = 1.24 Seconds

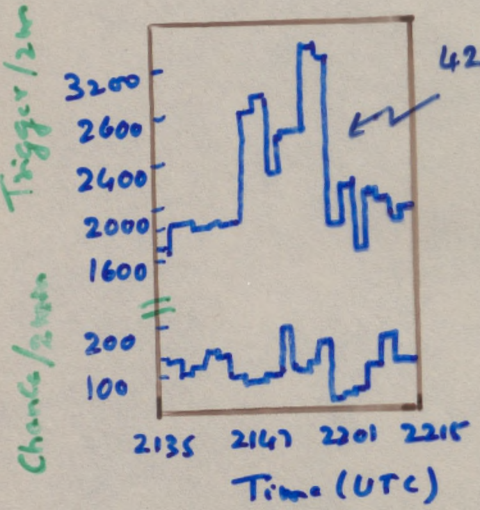
Neutron Star
Companion 2M⊙ + 35 day periodicity (precession?)
(11 days ON)

R.A. = 16h 56m
δ = +32°25'
distance = 4.5 kpc.

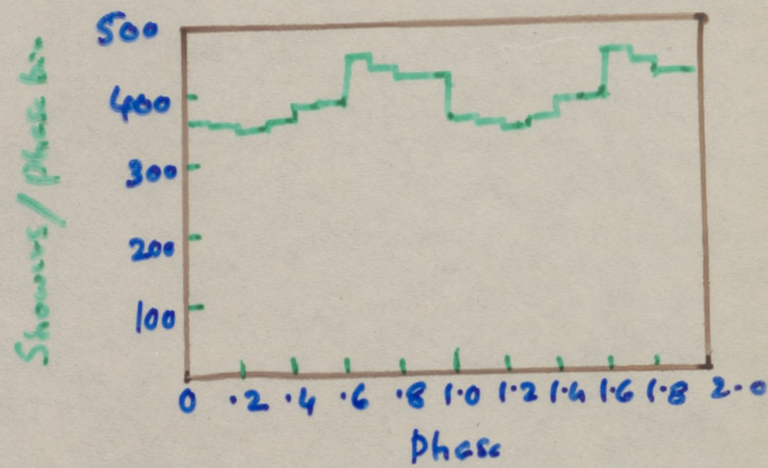
x-ray period = 1.2379

Tev γ-ray episodes of Her X-1

- Pachmarhi Viswanath et al. 11 Apr 86 14 mins.
- Whipple Lamb et al 11 June 86 >25 mins 1.2358
- Haleakala Resvanis et al 13th. May 86 15 mins 1.2359



Pachmarhi observations on 11/4/86.



Whipple Observatory.
11/5/86.

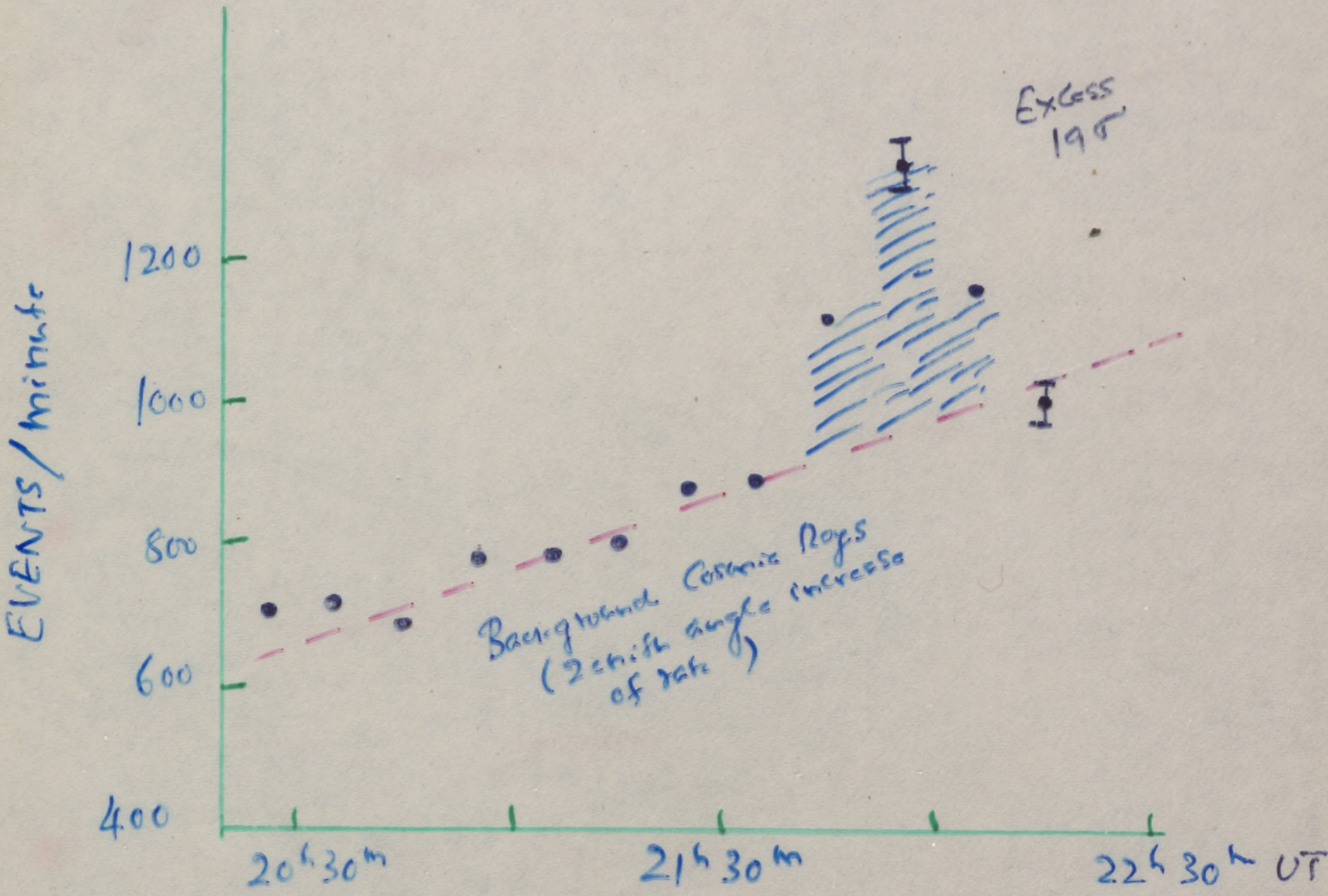
Tev Period Significantly different from x-ray period. Why?

(Model: particles accelerated in the neighbourhood of Neutron Star.
The TARGET is transient and detached.
episodal nature. Keplerian period of the target

Pev bursts from Her X-1 Los Alamos
(EAS array) July 23, 1986 Two bursts

(i) 9 observed 2.7 expected in 70 mins
(ii) 6 observed 1.4 expected in 15 mins.

PACHMARI - BURST ON April 11, 1986



HER X-1. OBSERVATIONS in High Energy γ-rays

* 1983. - • Durham group observed burst activity lasting about 3 mins in the TeV range from the direction of Her X-1 and with the 1·24 s. modulation.

April 1983.

Air Cerenkov

• The 3 min period coincided with the transition of Her X-1 from Low State to High State of activity in X-rays.

* About a month later, TENMA picked up HER X-1 in High State --- initially normal but later the flux diminished and the pulses began to shift in phase by 18 ms/hour.

X-rays

* 37 days after TENMA observations, EXOSAT was unable to detect Her X-1 in the expected High State.

X-rays

Approximately Eight 35-day cycles had to elapse to be seen in High State again

* During mid-July early in this expected Low State, Fly's Eye observed γ-rays of energy > 500 TeV during a 40 min interval

1983 July. Air Shower

* After the cessation of the Low Period Whipple observatory saw periodic emission similar to Durham observations. There was indication of persistent emission (weak) throughout 30 hrs observation. A fraction may be pulsed.

Mar-June 1984 observations.

4th. April 84	Flux $(5\cdot8 \pm 2\cdot1) \times 10^{-10}$ photons/cm²sec		>28 mins.
5th. May 84	$(6\cdot6 \pm 1\cdot2) \times 10^{-10}$	" "	>3hrs

$(E_\gamma > 150$ GeV$)$

Her X-1 (Summary)

April 1983 – Pulsed γ-rays of energy $> 10^{12}$ eV seen for 3 minutes by Durham group during transition of Her X-1 from Low State to High State.

May 1983 – TENMA picked up Her X-1 in X-rays – anomalous behaviour in usual High State – flux diminished – phase shifted by 18 ms/hr.

June-July 1983 – Exosat was unable to pick up Her X-1 in X-rays – for almost Eight 35 day Cycles.

Mid July 1983. – Fly's Eye observed γ-rays of $E_\gamma > 5\cdot10^{14}$ eV when Her X-1 was supposed to be in Low State.

May-June 1984 – Whipple observatory observed periodic emission in UHE γ-rays – Similar to Durham observations – 4th. April for 28 mins; 5th. May > 3 hrs. (> 150 GeV)

Anomalies:

① Mid July 1983. – Durham group in Dugway did not observe γ-rays $> 10^{12}$ eV during the period that Fly's Eye observed at $E_\gamma > 5\cdot10^{14}$ eV.

② Poor phase Correlations

Optical observations on HZ Hercules Confirm normal behaviour about X-ray production.

SS 433.

Galactic object (3 kpc.)
First Galactic object with Relativistic Jets.

* Strong Emission Lines of Hydrogen, Helium.
* X-Ray Source.
* Point Source in Radio — elliptical Cloud of gas sorrounding the Source Similar to SN remnant. (Is it with-in SN W50 ?)

The Most remarkable feature of SS 433 →

* presence of two sets of hydrogen and helium lines that move wildly back and forth across the spectrum
* (Only One of its kind in the Sky so far)
* While one set of lines moves to the red, the other moves to the blue — After many weeks they both reverse their directions — 163 day Cycle.

* The lines which are Stationary — close to the laboratory wavelengths — do not have 163 day period. — very small amplitude 13.1 day period similar to Spectroscopic binaries.

Optical Luminosity $B = 2.5 \times 10^{39}$ ergs
X-ray Luminosity 5×10^{35} ergs.

SS 433.

* The SN remnant W50 is basically circular with extensions to the East and West.
* In the centre of W-50 is the binary SS433 with an orbital period of 13 days – the secondary precessing with a period of 164 days
* SS433 is one of the few galactic sources that emit dual opposite relativistic beams that have been imaged in the radio and X-ray and
* the beam axis is aligned with the E-W extension of W-50; the beams may be responsible for the morphology of W-50.

* While HEAO-C reported very interesting line emissions in γ-rays of a few MeV the more recent observations by SMM (the Solar Maximum Mission) do not show these lines.

HEAO-C (JPL group)

* ① γ-ray lines at 1·5 and 1·2 MeV observed

Interpreted as blue shifted component of 24 Mg 1·368 MeV line. (1·5 MeV)

Red shifted line of 24 Mg 1·368 MeV li[ne] (1·2 MeV)

② The fluxes appeared to vary by a factor of 3 in periods of 2-3 days.

③ Average Flux: (46 days)

1·5 ± 0·3 flux units for blue

1·1 ± 0·2 " for red

(f.u. = 10^{-3} photons / $cm^2 s$)

SS433 contd.

* X-ray luminosity varies by a factor of 3 in time scales of several days, by 10-20% in time scales of 500-1000 seconds, and by less than 10% for time scale < 500 seconds.

* Flares in time scales of 1-2 days seen — some in association with Radio observed.

* X-ray luminosity drops to its lowest level and the spectrum softens at binary phase 0·3 — Companion star eclipses the accretion disk ?

The point X-ray source ~ 10^{13} cms since time variations < 300 seconds not observed.

Partial eclipse by companion star in the orbit of 13·1 days suggests that the companion star > 2×10^{12} cms ∴ > 20 $M_\odot$

Then the mass function for the compact object ~ 10 $M_\odot$. ∴ probably Black hole.

X-ray variability at 0·1 and 0·6 phase and also at 0·25.

(4) Some of the models for γ-ray emission of SS433 suggested a line at 6.1 MeV. HEAO-C reported weak evidence for this line emission also.

SMM Results on SS 433:

observations - 468 days during 80-85 (except during 83-84 which the tape recorders on board were not operating)

① SMM did not detect any shifted 1.3 MeV lines (with intensities comparable to HEAO-C)

② During the course of SMM observations, SS433 exhibited strong and weak Radio Flares - No instances of γ-emission.

③ Search for 6.1 MeV and 4.4 MeV lines proved negative.

④ Integral flux over 360 days atleast an order of magnitude lower than that reported by HEAO-C.

Either HEAO-C observations of γ-lines were just statistical fluctuations or there is time variability at γ-ray frequencies

However, it should be pointed out that to inhibit γ-ray transmission at 1.3 MeV - the density in the jets $n \sim 10^{14}$/c.c. is required.

Dominant γ-ray production Mechanisms

	Typical Energy (ev) of γ
Bremstrahlung	$\sim E_e$
Inverse Compton	$4 \times 10^{-12}\ \epsilon \cdot E_e^2$ ↓ energy of photon (ϵ)
e^+e^- annihilation	5×10^5 ev
Synchrotron	$2 \times 10^{-20}\ H E_e^2$ ↓ Mag Field (Gauss) (H)
Nuclear Transitions	$10^6 - 10^7$ (lines)
P_i^0 - Decay	Broad distribution with peak at 7×10^7 ev

Estimates of Intensities

* Galactic Center	$> 10^6$ ev	$> 5 \cdot 10^7$ ev	$> 10^9$ ev	
L:	$5 \cdot 10^{-5} - 10^{-6}$	3.2×10^{-4}	2×10^{-5}	photons $cm^{-2} sec^{-1} sr^{-1}$
* Crab Nebula →	$10^{-3} - 10^{-4}$	$10^{-5} - 10^{-9}$	$10^{-6} - 10^{-9}$	photons $cm^{-2} sec^{-1}$

Sources of γ-Ray Line Emission.

- Galactic Centre — 511 keV annihilation line
- Interstellar Space — 1.8 MeV line of Al^{26} → Radioactive Nucleosynthesis product.
- SS433 — 1.5 MeV and 1.2 MeV.

Doppler shifted lines of
Mg^{24} (1.369 MeV) or
N^{14} (1.38 MeV)

anomaly - not observed by SMM Satellite.

Variability ? ?

—

Galactic Gamma Ray Sources

Crab Pulsar
Cyg X-3
Geminga
ρ - Ophiuchi
Loop-I remnant.

Quasar 3C-47.

Optical photograph of 3C47 region -
The Star at the bottom in the slide is
5000 times brighter than the quasar in
the visible.

The X-ray picture made with Einstein
observatory shows how 3C47 stands out
in Comparison to the other Star.

If one wants to find more quasers, it
is obvious what should be done.

Hard X-Ray Astronomy

Mass estimates of Black holes at the Centre of galaxies depend on the total X-ray luminosity. In the case of AGN's no break is seen at 40 kev. Spectral determination beyond this energy is very important.

According to some theories, time delays in the range of tens of milliseconds expected between low energy and high energy X-rays (Ariel VI has measured delays of 7 ms).

Ultrafast temporal variability (less than millisecond) contains information on accretion process and angular momentum of the black hole. Hard X-rays would yield clearer signals in this respect.

Pulse phase spectroscopy =
In the case of Crab it has been found that the spectrum in the interpulse region is different from the spectrum in the peak regions. The two peak spectra are identical. The interpulse spectrum is much flatter and breaks at 200 kev.

Magnetic field of Pulsars — Cyclotron Features

Her X-1
4U0115+63
Gamma Ray Bursts

} Is collimation due to hole in the magnetosphere? (Near the magnetic poles of the neutron star?)

VELA X-1 distance ~ 500 pc.

Largest of the brightest S.N. Remnants 7°-8° Extent.
Most highly Polarised Radio Source.
Strong X-ray Source - also in Soft X-rays.
Pulsar PSR 0833-45 87 ms period.

VLA observations in Rado - April 1983
$\lambda = 6$ cms Emission Seen.
Pair of lobes 20" Separation on either side
flux ~ 150 μJy.
There is a faint but extended arc (40°N, 2°W
of the Source) peak flux of 200 μJy
The extended Source if associated with
Vela X-1 - very unlike the Surroundings
of other binaries
Reminescent of SCOX-1 with two lobes

There

The Galactic Ridge. GINGA Results

- Bright X-ray Sources Concentrated in the Galactic Plane - especially in the Galactic Ridge.

  $N_H = 10^{22}/cm^2$. So only > 2 keV can be seen.

1 Ginga - discovered many transient Sources and transient Pulsars.
2. - Strong Iron Line Emission towards Galactic Centre
3 - Significant X-ray flux from S.N. Remnants
4 - Many new faint Sources.

- $\frac{\text{Iron Line Intensity at Galactic Centre}}{\text{Intensity over the Ridge}} \sim 3.$

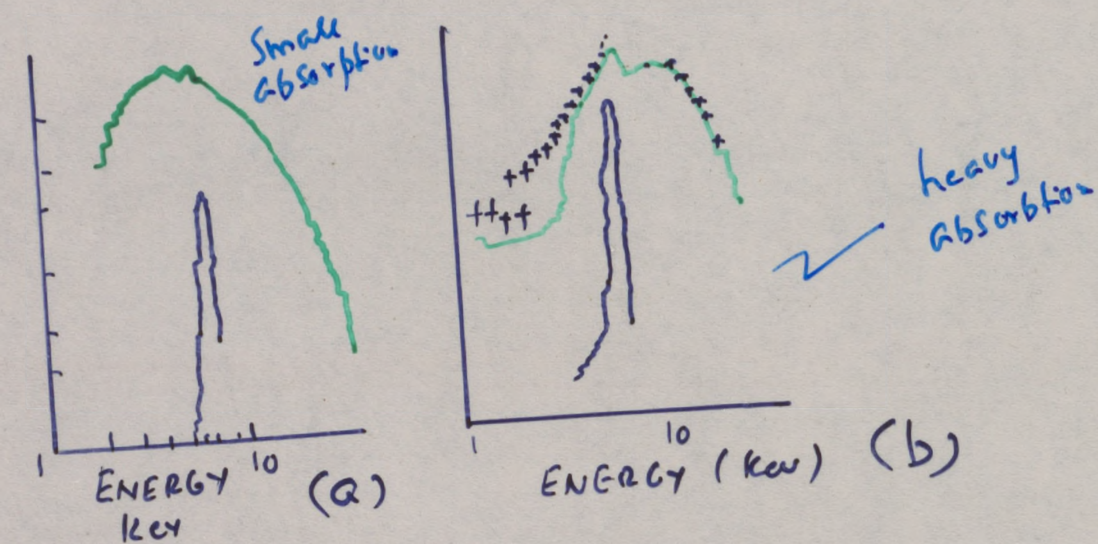
- This means either increased Iron abundance in G.C.
  or large emission measure.

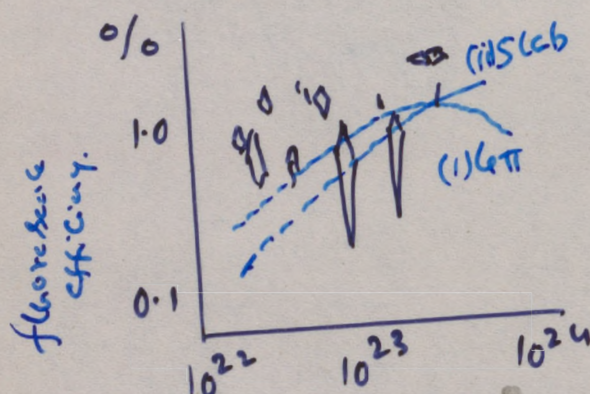
- The Spectral Features Show that the Galactic Ridge Emission is mostly due to RSCVn and Cataclysmic Variables
- The hard X-ray intensity may be from hidden Be Star Binaries
- The Galactic Ridge will be one of the new Frontiers of X-ray astronomy. Astro D is Specially designed from this point of view.

Iron emission line - pencil beam vs Fan beam

Iron Lines are prominent in most pulsars.

GSPC on TENMA - VELA X-1.





Observed fluoroscence efficiency vs absorption column n_H compared with expectations from (i) 4π shell (ii) extended slab behind source.

Iron line is found at 6.4 kev indicating fluorescence origin of the line.
A deep absorption trough at the K-edge of neutral iron (7.1 kev) is evident in (b)

$$\text{Fluorescence efficiency} = \frac{\text{Iron Line Intensity}}{(\text{Integrated Source intensity} > 7.1\ \text{kev})}$$

Detection of K-Iron Lines From Low mass binary X-ray Sources SCO X-1, 4U 1608-52.

GSPC on Tenma.

Source	Peak Energy (keV)	Equivalent width (eV)
SCO X-1	6.68 ± .06	36 ± 11
4U 1608-52	6.65 ± .06	40 ± 15

Since the discovery of SCO X-1, many attempts had been made to detect this Iron Line expected from hot plasma of 10^8 °K.

Einstein detected L-lines.

The TENMA observation of narrow K-Line indicates that the plasma which produces Helium Like Iron Lines (6.7 kev) is far outside the Neutron Star where plasma density is too low to broaden the lines.

Line Emission Studies (TENMA, EXOSAT)

* VELA X-1 – Narrow Iron Line at 6.4 kev intensity remains constant over the 283 Sc. phase

* Her X-1 6.4 kev Line.

* Sco X-1 } Fe emission lines (Broad)
  Sco X-2 } at 6.7 kev.
  Gx 17+2 } When Sco X-1 flares, no change in Iron line intensity

  ↑ New Burst Source detected by Japanese.

Gx 349+2 } 6.7 kev Iron Lines
Gx 5+1 }

* Perseus Cluster } EXOSAT reports Iron Line

NGC4151 Quasar } Intense Iron Line

X1636-536 } Line seen by TENMA at 4.1 ± 0.1 kev. This may be the doppler shifted Iron line of 6.7 kev in the gravitational field of the neutron star.

* Iron Line seen in the Galactic plane in regions away from known Sources. (TENMA)

Conclusion from fluoroscence efficiency Curve :

* The observed Iron Line is much too strong to be accounted for by a uniformly irradiated shell with X-rays of the observed intensity above 7.1 kev. (Iron Line intensity does not show significant pulsation)

* ∴ Much more intense beam are required to account for observed Iron Line Intensity

* ∴ in the Case of VELA atleast Pencil beam is indicated.

CEN X-3 UHURU Discovery
4.8 Second Pulsar
Orbital period = 2.1 days

Binary → High Mass Star + Neutron Star
young (old)

Very rare Combination!
Is the high mass Star born in the binary System?

Scenario → the object which is now Neutron Star started its life as a high mass Star and transferred its mass to its Companion converting it into a high mass star that is now bright in optical.

X-Rays From Stars. – $10^{27} - 10^{29}$ ergs/s

* Einstein has discovered X-ray emission from Stars in nearly every portion of H-R diagram – Changed our understanding of CORONA.

* Prior to Einstein – only RSCVn binaries, Late type dwarfs – α Cen, η boo, ξ boo, M-dwarfs in flares Vega, Sirius.

* Einstein detected X-rays from O, B, A – Contrary to expectation from all States, all ages.+

* The only region of H-R diagram from where X-rays have not been detected – K, M, Supergiants and giants.

* There is a factor of 300 Spread in Lx of Stars. – Same Spectral type and class – this means that temperature and gravity are <u>not</u> the main parameters determining the properties of Stellar Corona – dissipation of magnetic fields and generation of Shocks are important for the Non-thermal processes.

+ • Pre-Main Sequence Stars – T-Tauri – the young clusters in orion.. $L_x \sim 10^{30}$ ergs/s. Coronal Temperature $> 5 \times 10^6$ °K.
• M Dwarf Flare Stars YZ CMi, Proxima Cen, ..
• Luminous Cool Stars – G-giants, K-giants, ε sco $10^{28} - 10^{30}$ ergs/sec. α-boo, α-Tau.
• RSCVn binaries K0 and late G Star.
• Hot Stars O, B – brightest X-ray Sources

Three Decades of X-Ray Astronomy

1962 - 1989.

History of X-Ray Astronomy - The Sco X-1 Story

Early Rockets - Balloons -

X-Ray flares.

Time Variations.

Sco X-1 - QPO

Cyg X-1 — Black Hole

Her X-1 - multiple periods.

Tau X-1 (Neutron Star Story)

X-Ray Satellites - UHURU TO GINGA

X-Rays From Stars

X-Rays From S.N. Remnants

X-Ray Binaries -

X-Ray Lines -

X-Rays From S.N. 1987a. -

X-Rays From Extragalactic Sources

Diffuse X-Ray Background.

X-Ray Astronomy

Rocket Flight of 1962 - discovery of SCO X-1

62-70 : Rockets, Balloons - Cygnus X-1, Crab, ~~Her~~

70 : Launch of UHURU

↓

84 HEAO-1, SAS II, EINSTEIN (US)

ARIEL, ANS (Dutch)

(UK)

HAKUCHO, TENMA (Japanese)

EXOSAT - (European)

Soviet Satellites.

{ Failure of Indian Satellites - Aryabhata 75

{ Successful Balloon Programme. Bhaskara -

* γ-Ray Astronomy

* SAS II
  Cos B
* Balloons.

* UHY - Ground Based - * Night Air Cerenkov.
  * Air Showers.

US X-Ray Satellites + EUROPEAN Satellites

UHURU	1969
HEAO-1	1977
HEAO-2	1978 = EINSTEIN.
EXOSAT	1982 = Soft x-ray imaging Spectroscopy
ROSAT	1987 = Soft x-ray imaging, Spectroscopy
XTE	1988 = X-ray timing
AXAF	1990 = nearby galaxies;

JAPANESE

HAKUCHO	1979 = Burst Survey
TENMA	1983 - Spectra and Time Variations - Galactic
ASTRO-C	1986-87 - Time Variations of Extragalactic.

The Future of Astronomy -
80's, 90's

1. Space Telescope.

2. Space Platforms and dedicated Satellites -
AXAF, TXE, GRO, ...

3. Deep Underground, Under Water Experiments.

Proton Decay
Neutrino Astronomy
Heavy Photons

4. New Findings at accelerators

5. Ground Based High Energy Astronomies
UHE γ-ray Sources
Cosmic Ray Sources.

The Future

* Better Imaging over wider range
  - structure, angular size etc.

* Better Spectroscopy - Emission Mechanisms.
  Line Spectroscopy.

* Better Timing — bursts, pulsations etc.

Advanced X-ray Astronomy Facility (AXAF)

X-ray Luminosity functions for stars of all spectral types and luminosity class
physical conditions of Stellar Coronae - Composition by X-ray emission lines
Properties of stars in specific associations
Angular Resolution of globular cluster sources
Luminosity functions of clusters in the local group
Extended Supernova remnants - imaging, evolution, density, composition distribution
Young SNR; Fe XXV and Fe XXVI Line Confluence
Interstellar Medium
X-ray Emission from Planets
Detailed Source Counts of Virgo Cluster
Seyfert galaxies, BL Lac, N-type galaxies, radio galaxies, QSO's.

AXAF

Optical Configuration	6 nested pairs of Wolter type grazing incidence mirrors
Maximum Aperture	1.2 meters
Focal Length	10 meters
Plate Scale	50 μm /arc sec.
Diameter of Field of View	60 arc min (180 mm)
Energy Range	100 ev – 8 kev (1.5A° – 120 A°)
Encircled Energy (on axis)	60 % within 1" at 2.5 kev
	35 %. 5 kev.
	75 %. within 20" at 2.5 kev
	60 %. " " at 5 kev
Angular Resolution	0.5"

—

Detectors: possible candidates

Charge-Coupled Device
Negative Electron Affinity Detector
Micro-Channel plates
Imaging proportional Counters
Gas Scintillation Imaging proportional Counters

Rosat: (1987)

ALL SKY SURVEY with IMAGING TELESCOPE.

$> 10^5$ sources will be detected, "

1' accuracy in location.

Four Nested Mirrors 83 cms Aperture.

(0.1 - 2 kev). Field of view 2°. pointing ~ 30"

$\Delta E/E \sim 45\%$ at 1 kev.

Focal Plane - position sensitive proportional counter with Filter wheels

1987 10^{-3} milli crab Sensitivity 300 cm^2 area

Astro-c: (86-87)

Multi-Cell Proportional Counters 5000 cm^2

Time Variation of Extragalactic and galactic sources

> 300 galaxies expected to be measured.

XTE (1988): 10^{-1} milli crabs. 2-60 kev 5000 cm^2

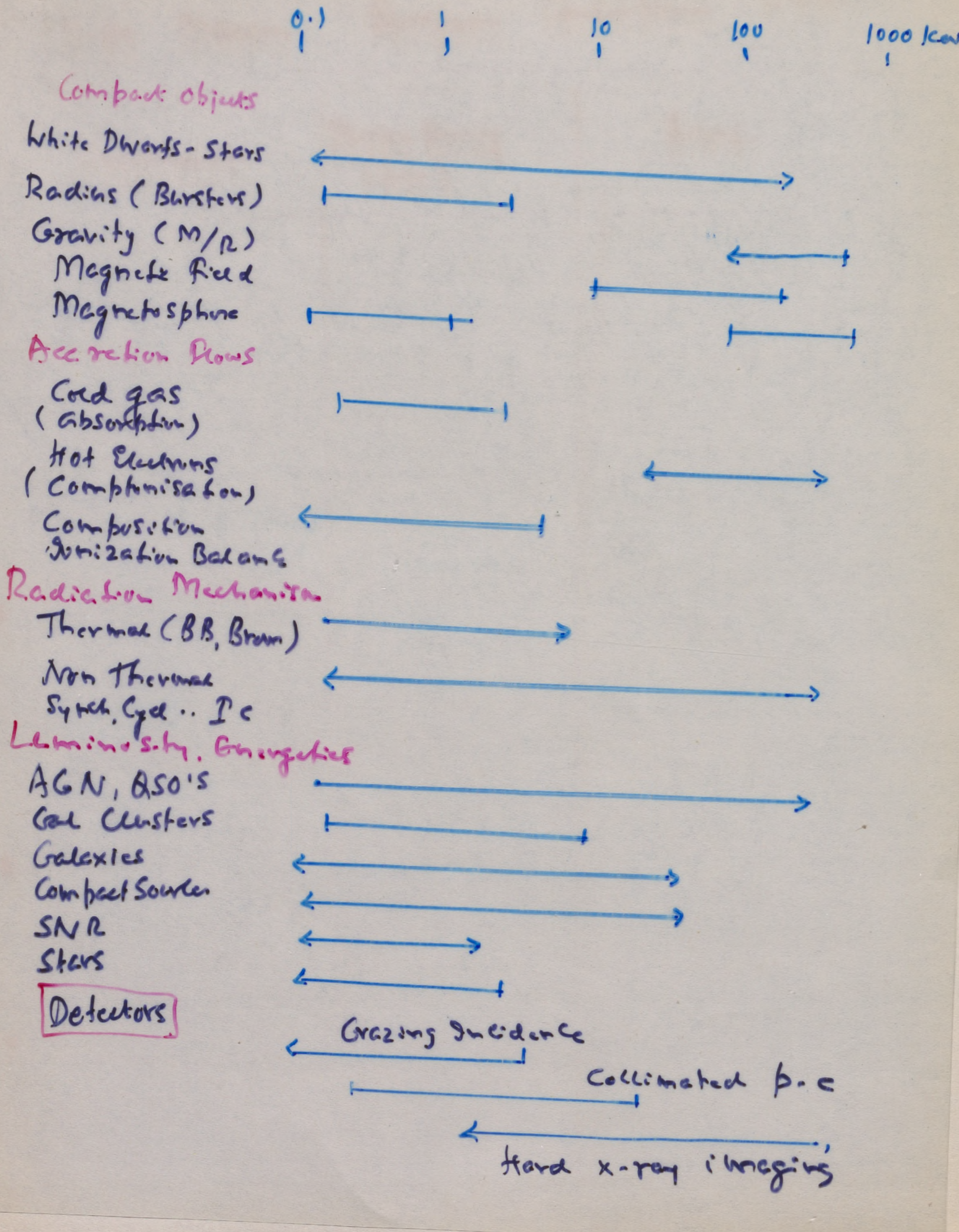
Soviet French ISPM

4-6 AU.

Hard X-rays 5 kev - 3000 kev.

Cosmic γ- bursts. - 100 kev - 10 Mev range.

Questions in X-ray Astronomy vs Energy.



X-80 Mission European Consortium ESA.

Instrument.	Photon Energy (kev)	Aims.
x Large Area Proportional Counter (LPAC) 2500 cm^2	1·2-20	Source Variability (1ms to days) Moderate Resolution Spectroscopy. Monitor for Crystal Spectrometer
x Wide Field (WFC) Cameras 4 units FOV ~1.4 Ster.	2-20 (imaging) 2-50 (timing)	Source Variability (Seconds to years) All Sky Monitor Localisation and Study of Transients X-ray and weak γ-ray bursts.
x Crystal Spectrometer 6 panels of 1000 cm^2 each	4 intervals in 0·5-10 kev (O, Si, S, Fe)	High Resolution Spectroscopy, Spectral Variability, Spectral mapping of extended sources
x Phoswich 650 cm^2	15-200	Source Variability Moderate Resolution Spectroscopy, Cyclotron line Spectroscopy
x γ-ray Burst Detector	40-130	Localisation of intense γ-bursts and hard x-ray transients.

HER X-1

Relation to 35 day Cycle phases

* 'The orbital phase' on 5th May when the data was acquired on Her X-1 was 0.53 - 0.61
on 4th April the phase was 0.42
Durham group saw it during 0.75
and Fly's eye 0.66.

'Anomalous dips' in X-ray ~ 0.55

No Strong Correlations in orbital phase

* Dips occur one or two cycles after 'turn on' in the 35 day cycle.
These are attributed to mass from Companion Star circulating around the accretion disk gradually relaxing on scale height over 20% of the orbit

* 5th May observations of Whipple observatory very close to the 'turn-on' as extrapolated from TENMA, EXOSAT (before extended Low)
Do they coincide with 'dips' in X-rays ?
If so target material available for γ-production and transient nature can also be understood.

* FLY'S Eye observations

The Fly's Eye observations - July 1983.

The detection of γ-rays of energy $> 5 \times 10^{14}$ ev from Her X-1 poses the following problems :
500 Tev γ-rays can arise only from the nuclear interactions of particles of energy $> 10^{15}$ ev
Since the rotation period of the neutron star is 1.24 s and the surface magnetic field 3.5×10^{12} gauss (from the Cyclotron Line observations of Trümper et al.)

according to most models the maximum energy of the accelerated particles is $\sim 2\cdot3 \times 10^{13}$ ev

Gunn and Ostriker's model also $\sim 10^{13}$ ev

* More recently there have been some models which do predict such high energies
(Eichler and Vestrand; Brecher and Shanmugam
Shock acceleration   uni-polar induction)
Kundt.

* As already pointed out .. Fly's Eye detection of γ-rays > 500 TeV was during July 1983. X-ray observations revealed that during the period June-Aug. 1983, the intensity was < 5 % of the normal peak intensities. This may support the kind of absorption suggested by these models.

* However optical observations on Hz Hercules - the companion star showed normal intensity variations - the optical variations are attributed to the heating of the side of the companion star by the X-rays from the pulsar. This observation therefore indicates that X-rays were being produced and impinging on the companion star.

This may be accounted for by the thickening of the accretion disc as pointed out by Delgado et al

* The observations of Durham group on the same night of mid July when Fly's eye detected γ-rays of $(E > 10^{15}$ ev$)$, did not show any burst activity in the TeV range though there was some indication of a feeble continuous emission throughout that night.

TIFR observations on Her X-1 from PACHMARI

5th. April – 14th. April 1986.

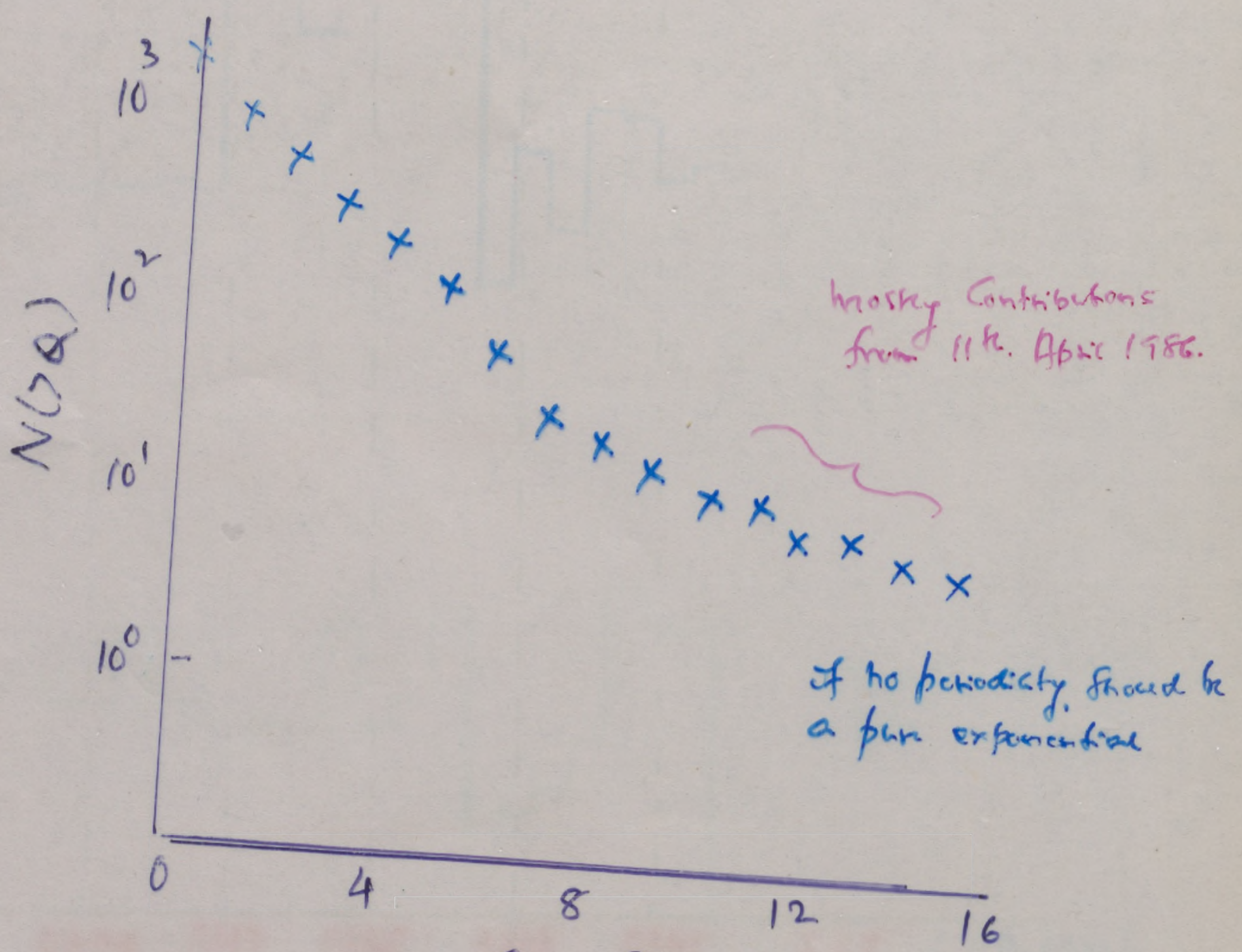
Data divided into 40 runs of 20 minute duration.

Period Range Searched – 1.23619 – 1.23931 s

X-ray Period = 1.23779200 s. $v \sin i$ = 169 km/s.

P_{orbit} = 1.70016799 days

P_{35d} = 34.928 days



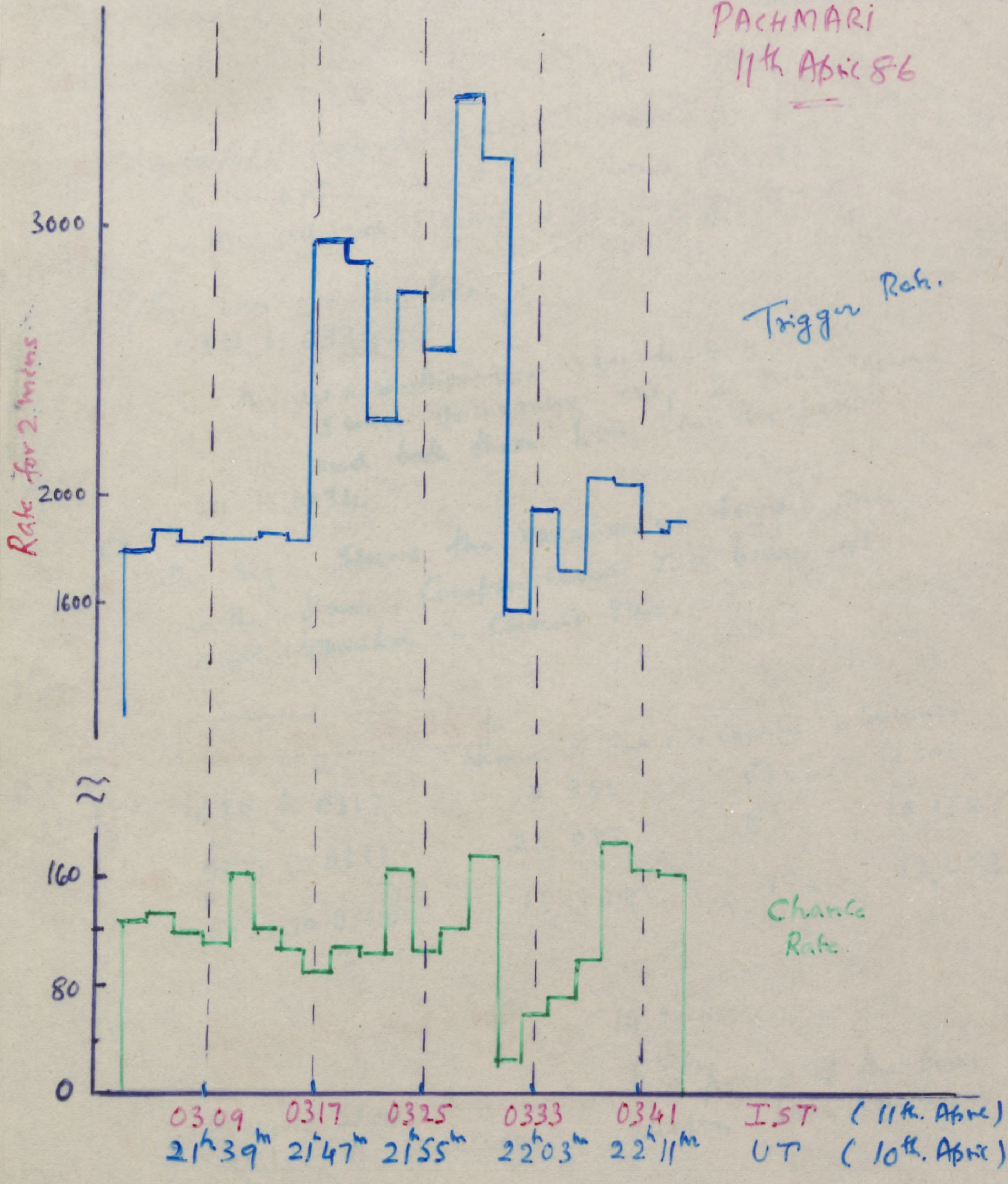
Q, Rayleigh Power

$$Q\,(RP) = \frac{1}{N}\left[\sum_{i=1}^{N}\left(\cos 2\pi\phi_i\right)^2 + \sum_{i=1}^{N}\left(\sin 2\pi\phi_i\right)^2\right]$$

ϕ_i = phase of each event. (after binary orbit correction)

N = Number of events in the run.

HER X-1
PACHMARI
11th April 86



TIFR (Pachmarhi)

Her X-1

- 15 hrs data in April 1986
- Data split into 40 intervals of 20 mins each.
- Data split around the X-ray period for period analysis.
- 40 periods around the X-ray period for period analysis
  ↓ in steps of .00008 and later .00032
- Only one interval showed high Rayleigh Power
  (> 10)
- This was on 11th April
  0311 to 0334.
- When the data ~~of this run 0311 to 0334~~ was split into 5 min miniruns, only 2 runs showed RP > 10 and both these were in the period 0311 to 0334.
- The fig shows the variation of trigger rate with time. Compare chance rate below. Not much variation in chance rate.

- **Data 0311 to 0344**

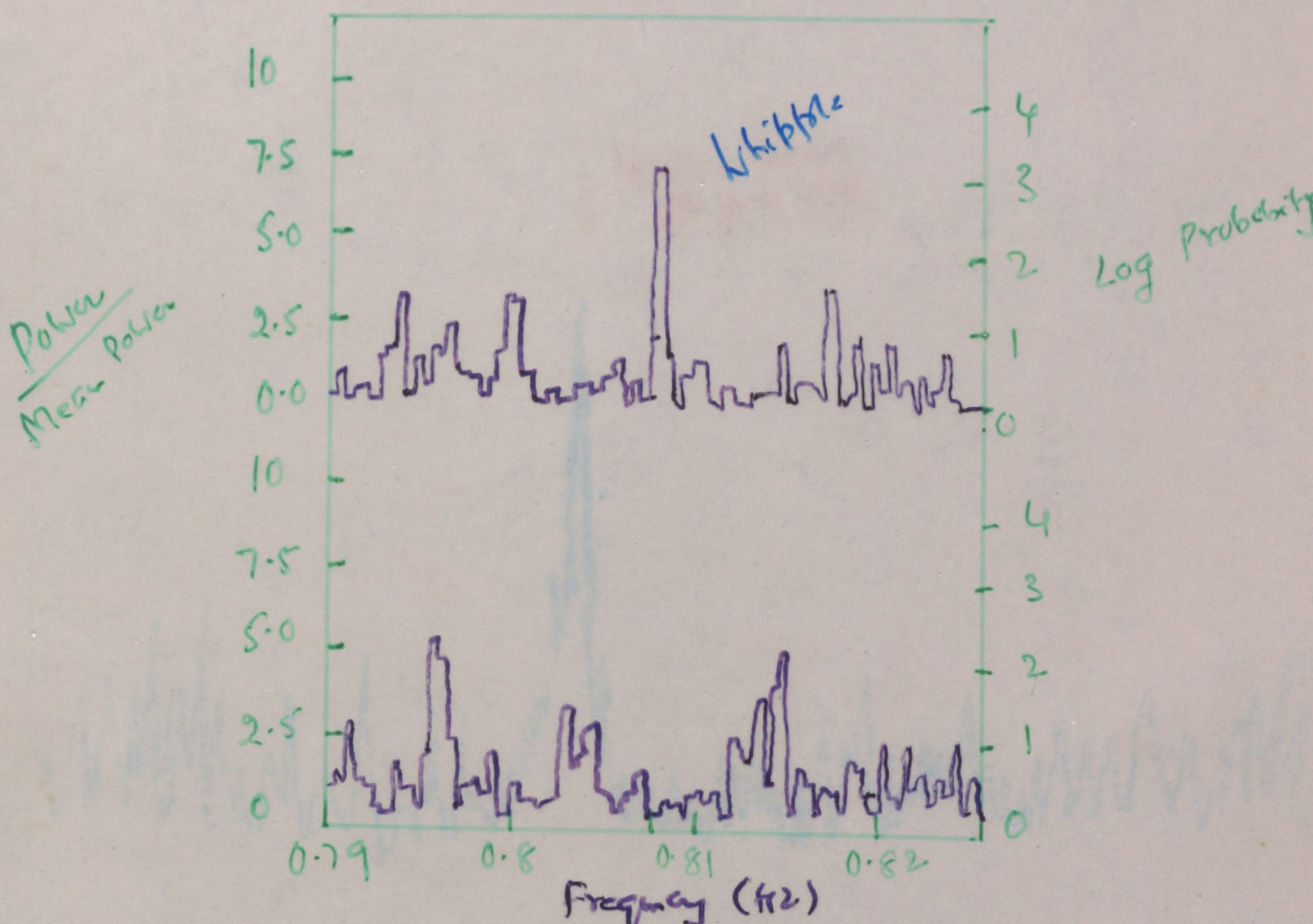
	Number of Events	Chance	Genuine
0311 to 0317	12,888	885	12,003
→ 0317 to 0331	20,035	879	19,156
0331 to 0345	13,269	776	12,493.

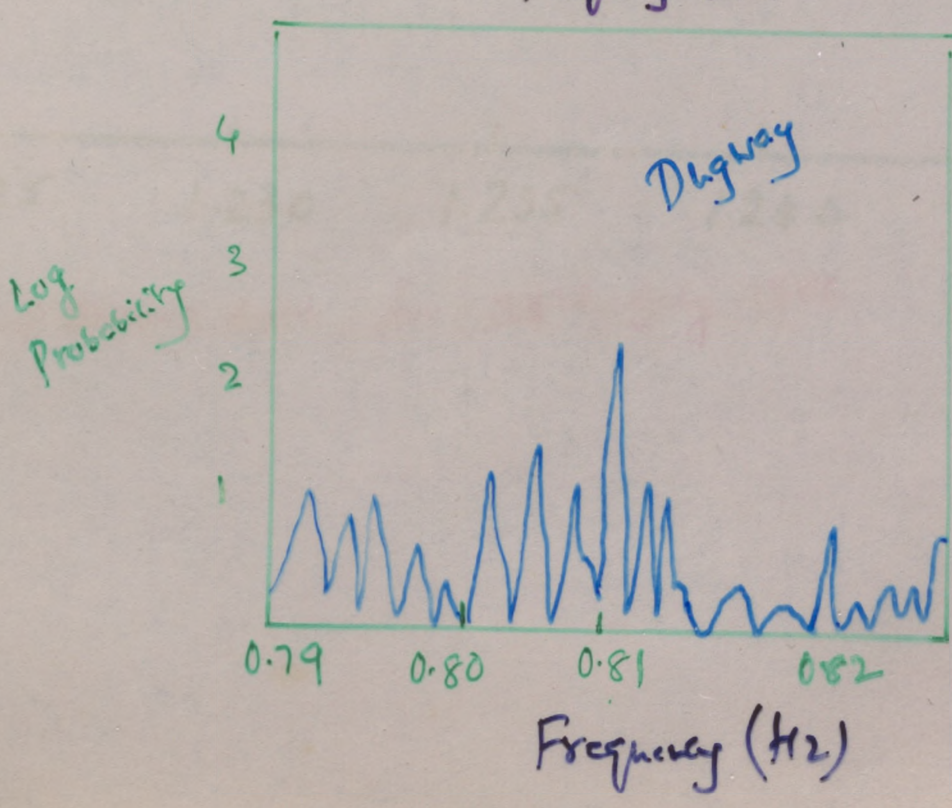
- Start of the burst 0317 }
  End 0331 } 14 mins.
- Analysis shows that during this period of the burst there is no significant pulsation which can be picked up.
- But outside this period there is evidence for pulsation as can be seen from the figure. In the beginning the period corresponds to X-ray period and in the end with the Whipple period.

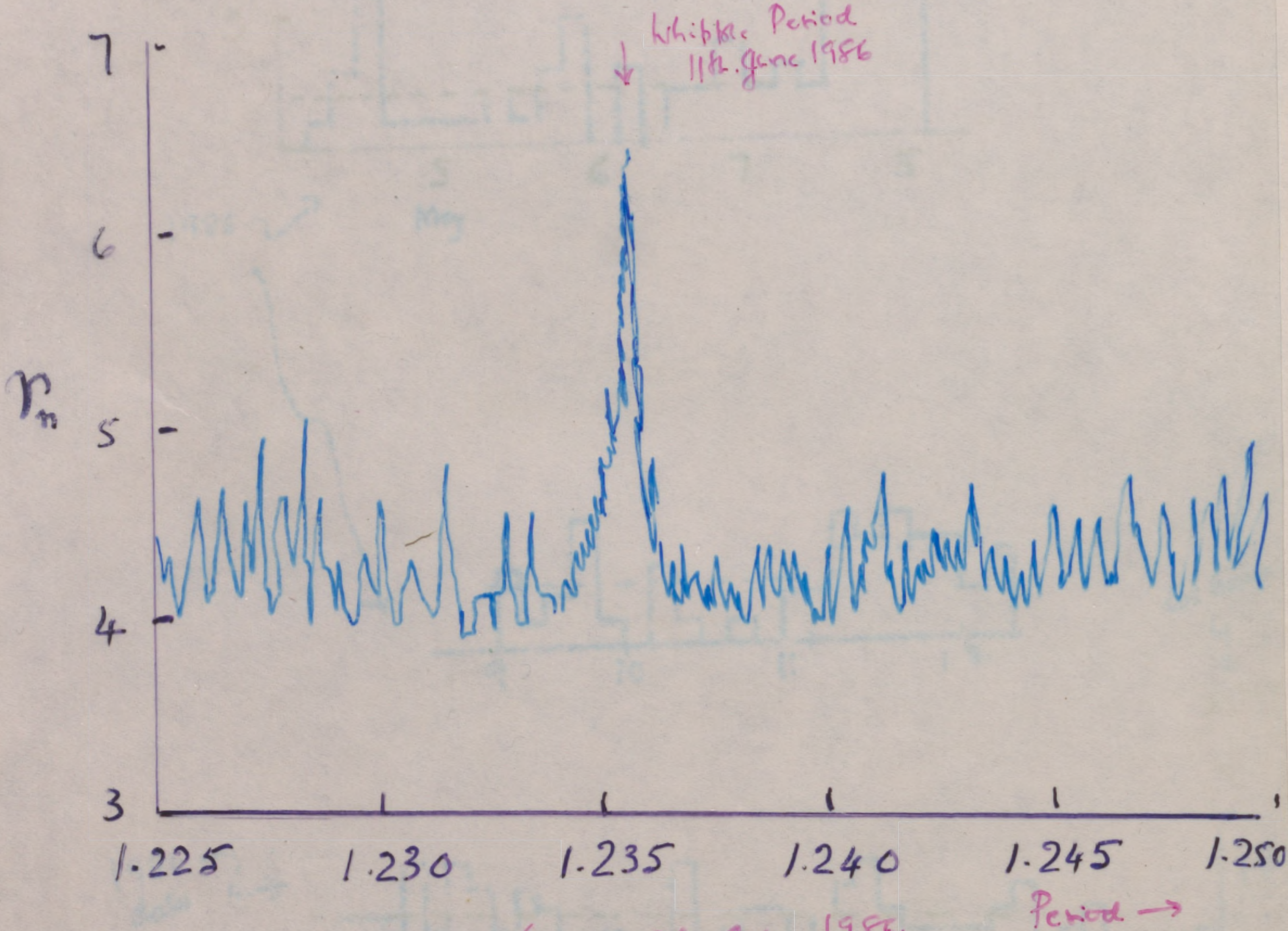
HER X-1

Simultaneous Observation in TEV Gamma rays

1984 April 4.42

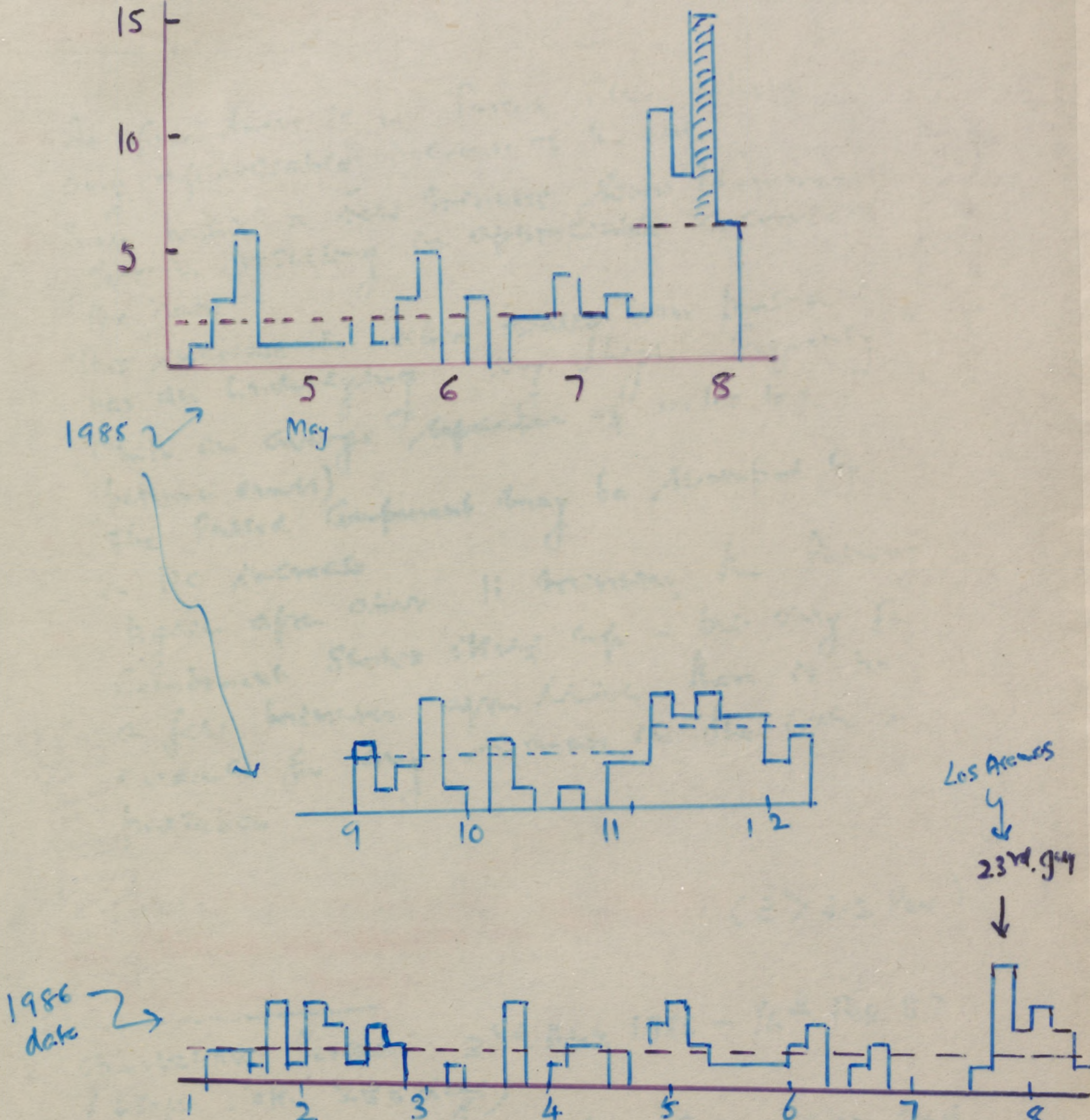






Los Alamos data for 23rd. July 1986.

Ohya/Tanashi arrays - 10^{16} eV - Her X-1.



Probable Scenario of Hercules Burst observed at Pachmari on 11.4.87.

- At first there is a Pulsed Flux without any appreciable increase of the rate.
- Then within a few minutes some phenomenon sets in resulting in appreciable increase of the rate
- This increase is either totally non-pulsed or has an underlying very high frequency (with an average separation of ~100 ms between events)
- The Pulsed Component may be swamped by a DC increase
- Again after about 11 minutes, the Pulsing Component shows itself up - but only for a few minutes after which there is no evidence for any increase in the rate or pulsation

—

Los Alamos observation on Her X-1. (E > 0.2 Pev) (Air Shower Array)

Observation Period 2nd. April 1986 - 16th. Feb 87.
(useful data 288 days)

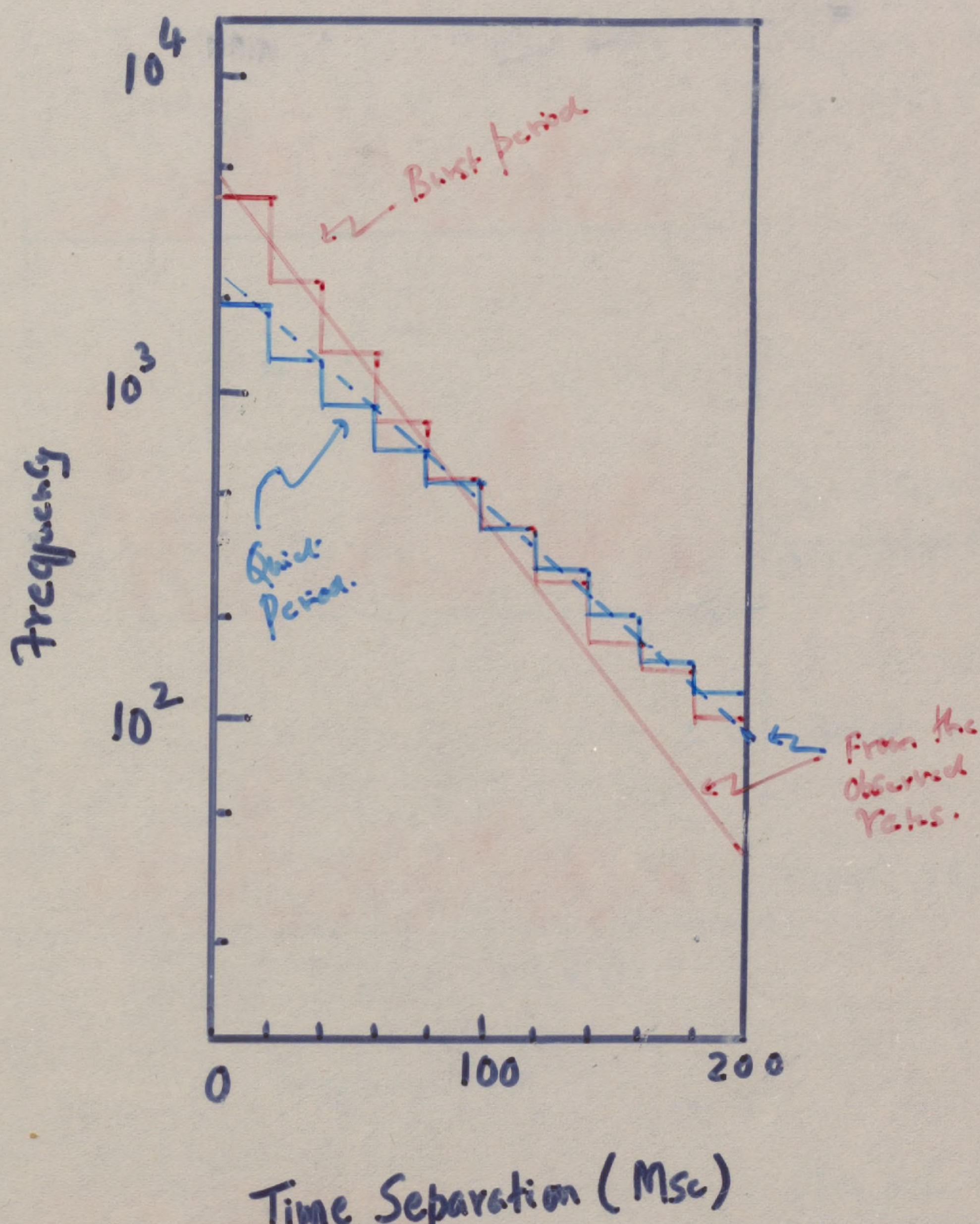
Each day's data examined for D.C. excess and burst (Kalmogorov - Smirnov Statistic)

10 out of 288 days had Combined Probability of < 1 % and examined further. (4 showed Periodicity at 1.24 s)

Periodic Emission at Probability $< 10^{-3}$ observed at the Whipple Period

Frequency vs time Separation of events

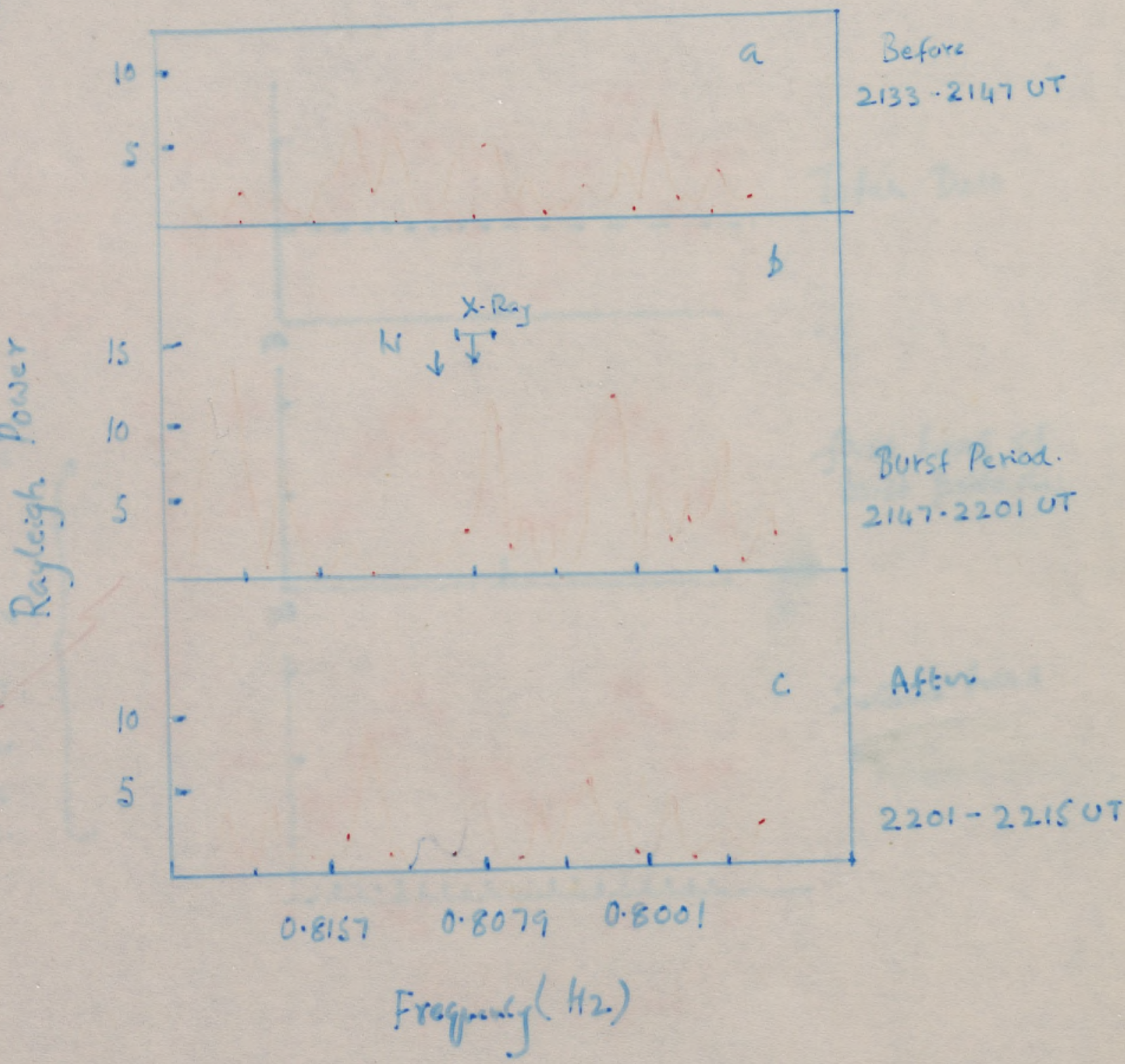
The increase in the frequency of closely separated events during the burst period is clear from this figure



Red - during burst period - Average Separation 41 ms.

Blue - Quiet period. Average Separation 62 ms.

Her X-1



Her X-1.

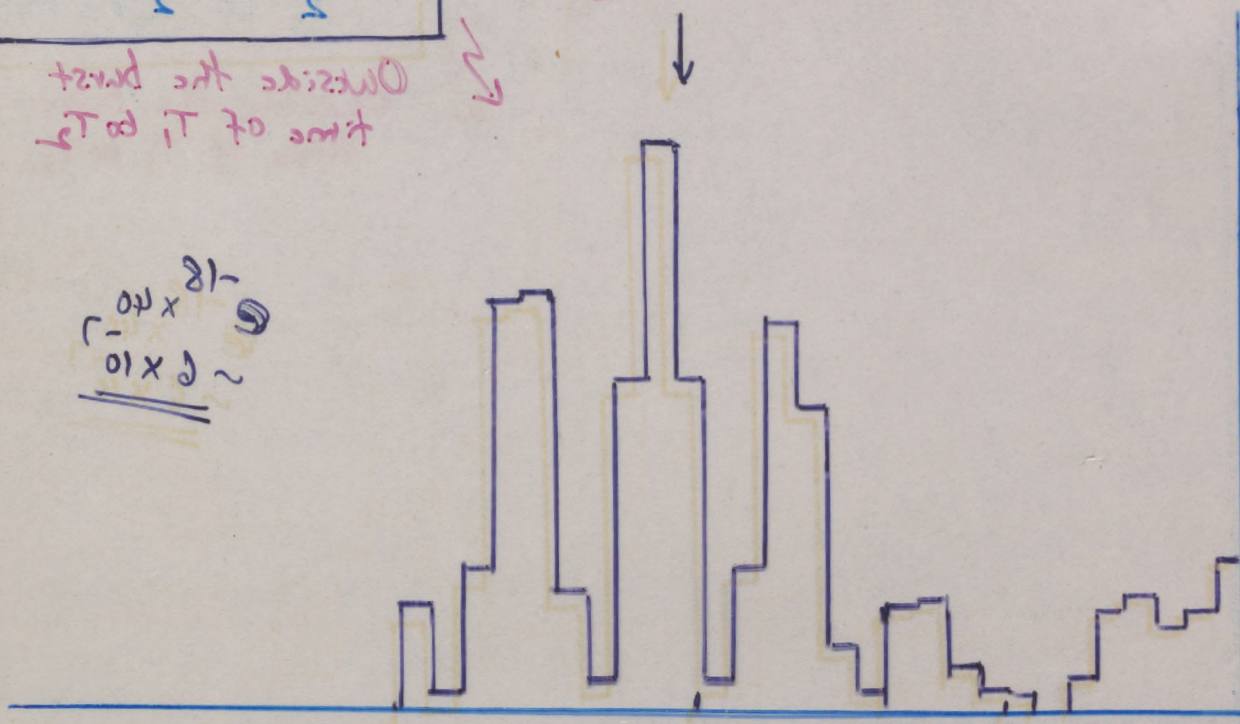
BURST.

(Similar behavior at optical frequencies have been reported by Middleditch et al 1976, 1988)

T_1 = Start of the Burst
T_2 = End of the Burst
$T_2 - T_1$ = 14 mins.

T_1 - 6 mins to T_1
and
T_2 to T_2 + 3 mins.

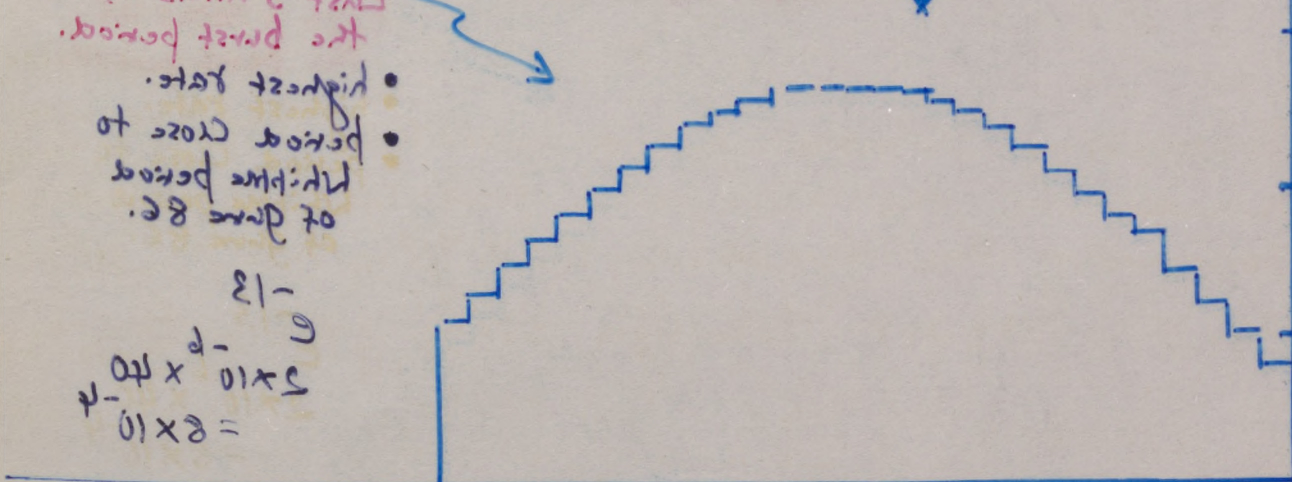
Outside the burst time of T_1 to T_2



$e^{-18} \times 40 \sim 6 \times 10^{-7}$

T_1 + 11m to T_2

Last 3 mins of the burst period.
- highest rate.
- period close to Whipple period of June 86.



e^{-13}
$2 \times 10^{-6} \times 40$
$= 8 \times 10^{-4}$

X-Ray period = 1.2377192 s

Steps of
0.00032 Seconds

Balloon X-Ray, γ-Ray Experiments of TIFR

1968 → 90

(68-73) Sco X-1, Cyg X-1, Cyg X-2, Cyg X-3, Tau X-1, Her X-1

- Sco X-1 → Spectrum, flare
- Cyg X-1 → Spectra, flares, Change of State, Variability.
- Tau X-1 → Occultation by moon
- Her X-1 → First detection of Source in hard X-rays. Spectrum.

• **Indo-Japanese Collaboration** on (i) diffuse background. (ii) Lunar occultation (iii) Simultaneous optical and hard X-rays from Sco X-1.

Oda, Hayakawa, Nishimura, Tanaka, Matsuoka, Makino, ..

• **Indo-Soviet Collaboration** - Anna-6, Natalya II - (>5 MeV) Gamma Rays - Spark Chamber. Crab, 2CG 195+04, 3C120

Fradkin, Kotov, ⋮

→ Photon Mission - ILTP.

• **TIFR - Calgary Collaboration** - Phoswich Detector Assembly

Sco X-1, Cyg X-1, GX 5-1, Cyg X-3, GX 1+4, GX 5-1 (QPO), 3C273.

Venkatesan ..

→ 2.93 ms pulsations

Till 1984

X-ray astronomy	53 flights.
γ-Ray astronomy	43 "
IR	7
Cosmic Ray Studies	112

* INDO-JAPANESE 69-74.

(I) Simultaneous observations on SCO X-1 in X-ray and optical. (Nizamia, Tokyo, Mount Stromlo

(ii) Lunar occultation of Crab (74-75)

(iii) γ-ray diffuse background

* TIFR-UNIVERSITY OF CALGARY. (75- present)

Phoswich NaI/CsI 400 cm² 16-120 kev.

Seyfert galaxy NGC 4151

X-ray flare of 8 minutes - in the direction of NGC 5608

Quasar 3C-273

SCO X-1 (Dec 1983 = first observation after 1978)

Crab, Geminga.

* INDO-SOVIET (75-83)

Gamma Ray Astronomy 5-300 Mev.

{ Altitude 4-7 gms/cm²

256 cm² (100 Mev) / ANNA-6
NATALIYA (440 cm²) (300 Mev) } Scintillation Counter + SPARK CHAMBER.

Crab Nebula → I_γ (5 Mev) = 9 ± 3 × 10^{-4} photons/cm² s.

2CG 195+04 → I_γ (>5 Mev) 7 ± 2 × 10^{-4} photons/cm² sec.

3C 120

INTERNATIONAL COLLABORATIVE PROGRAMMES USING HYDERABAD BALLOON FACILITY OF TIFR.

		No. flights	objectives
INDO-US	MARCH-APRIL 1961	24	Atmospheric Pollutants Radio Activity, ozone
INDO-US	MARCH-APRIL 1965	17	Cosmic Rays. & X-Ray Astronomy.
INDO-JAPANESE	1969-1974	13	X-RAY, GAMMA RAY ASTRONOMY.
TIFR-UNIVERSITY OF CALGARY	1975-present	9	X-RAY Astronomy
INDO-USSR	1977-1982	9	Gamma Ray Astronomy 5-300 Mev. Albedo

Historical- University of Rochester (Peters) - 1950. Heavy Primaries with emulsion sandwiches.

Tata-Bristol Stack- Tungsten. - High Energy jets

TIFR Cosmic Ray Experiments with Balloons

1948 – 1990.

1. Latitude Effect of the penetrating Component at high altitudes –
2. High Energy jets with Nuclear Emulsion Stacks
3. Primary Spectrum "
4. Primary Composition – Heavy Primaries .. (Li Be B)
5. The Primary Electrons
6. Primary Gamma Rays

Difficult to predict. but one should not hesitate — Nothing wrong in being wrong

Future ?

[Competition with Space Shuttle, Space Platforms]

* Primary Spectrum, Composition – open question at high energy

  Sophisticated electronic detectors. – using Cerenkov thresholds.

* Hard x-rays – High Pressure Counters / Large Area Phoswich. } time Variations

* Gamma rays. GRO background measurement / will tell whether satellites / will take over Mev γ-astronomy. }

* Long λ IR Astronomy

* Favourable SN Explosion in the Galaxy

* Surprises – (Remember discovery of Pulsars)

Geniuses are born of normal parents

{Much depends on breakthrough in Detector Technology – Cheap, Large Area, Light weight, high Sensitivity detectors that can be deployed in Space at Balloon Altitudes}

X-Ray Stars — Results from Einstein' Observatory.

SLIDE — EINSTEIN OBSERVATORY.

SUN : The recent observations at EUV, XUV and Soft X-rays have drastically changed our views on the <u>Solar Coronal Problem.</u>

* Solar Corona is Structured (loops)
    * All X-ray emission is from the loops ... which are magnetically closed.
    * No X-ray emission from other regions — 'magnetic field open' — Coronal holes.
    * Solar mass loss on the other hand is closely correlated with Coronal holes.

      Coronal activity and mass loss are anti correlated temporally and spatially.
    * Coronal heating is extremely inhomogeneous —

      Soft X-ray, EUV observations show strong correlation with surface magnetic fields
    * Local plasma heating inhomogeneous

      Serious constraints on acoustic heating mechanisms.

Stellar Observations with EINSTEIN.

* X-ray emission is ubiquitous -
  Occurs virtually throughout HR diagram.
  No need for special category → "X-ray Stars"

↓
Main Sequence, Giants, Supergiants,
Premain Sequence
White Dwarfs (?)

Exposure with Einstein $\sim 10^{3} - 10^{4}$ Seconds.
Typical Emission Detected (0.2-3 kev)
$10^{-12.5} - 10^{-13}$ ergs^{-1} cm^{-2} sc^{-1}

$L_x \sim 10^{32} - 10^{33}$ ergs/sc — Early 'O'
$< 10^{28}$ " — Late 'A'
Rises at — F
Drops to $10^{29} - 10^{28}$ — G, M

Late Type Dwarfs
Scatter by $\underline{\underline{10^{3}}}$
Evolved Stars RS CVn -
upper range of observed Luminosity.

* X-ray Emission and Stellar Rotation.

(i) No Strong Correlation between L_x and rotation rate for Early Type of Stars

(ii) But, there is Strong Correlation in the Case of "G" and Later.

$$L_x \sim 10^{27} (V \sin i)^2 \text{ ergs s}^{-1}$$

(iii) No Such Strong Correlation with 'Sin i' in the Case of RS CVn and dF Stars.

The Strong rotational dependence of X-ray emission argues against simple Coronal acoustic heating theories, and favours a Coupling mechanism between rotation and Coronal heating — magnetic field related Coronal heating processes.

X-ray Emission and Bolometric Luminosity.

(i) X-ray Luminosity L_X and Bolometric Luminosity L_{Bol} are Correlated within Spectral Type (O3 to A5) by a factor ~ 3.
$L_X \sim 10^{-7} L_{Bol}$.

(ii) X-ray emission is uncorrelated with mass loss - stellar wind for early type stars.
However small Correlation with the terminal wind velocity.

* ζ Pup and τ Sco - Same X-ray Luminosity but mass loss rates differ by 3 orders of magnitude and L_{Bol} by a factor 40.

* ζ Pup and 9 Sgr - Same Bolometric Luminosities.
But 9 Sgr has mass loss rate 10 times below that of ζ Pup and X-ray Luminosity larger by 3-10

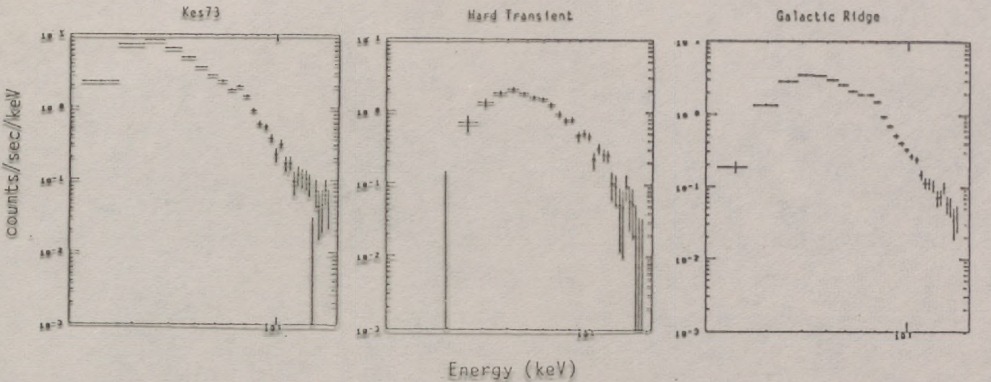


Fig.7 Typical X-ray spectra of the hard transient source, SNR (Kes 73) and diffuse galactic emission (l = 38°)

4-2 Origin of the Galactic Diffuse Emission

As regards the galctic diffuse emission, the 'hidden' Be star binaries reported in section 2 can not be a major contributor to the ridge emission (see van den Heuvel and Rapparort, 1986). The X-ray spectra of the hard transients were harder than the spectrum of the diffuse emission and contained no iron line at 6.7 keV. However, in the hard X-ray band , they can give a significant contribution. Based on the discovery of intense iron line at 6.7 keV , Koyama et al. (1986b) proposed that uncataloged SNRs can be a major contributor to the ridge emission. One argument against this idea is that the mean spectrum of known SNRs is generally softer than that of the galactic ridge emission . If the hard X-ray flux is biased by the Be star binaries , then the observed ridge emission can be harder than that of the mean spectrum of SNRs. Therefore, the above argument is relaxed.

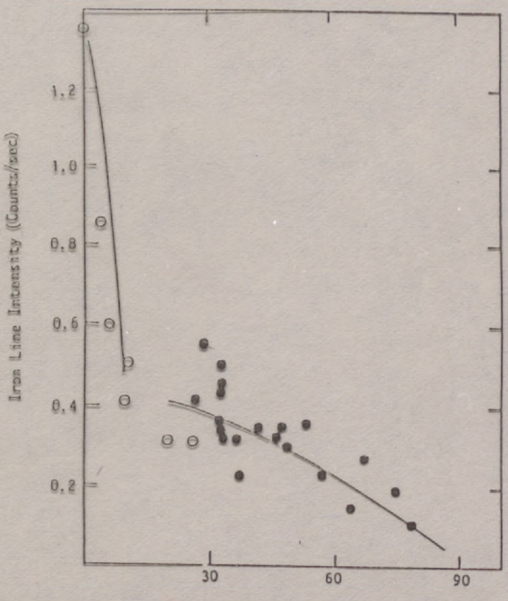


Fig.8 The intensity distribution of iron emission line from the galactic plane.

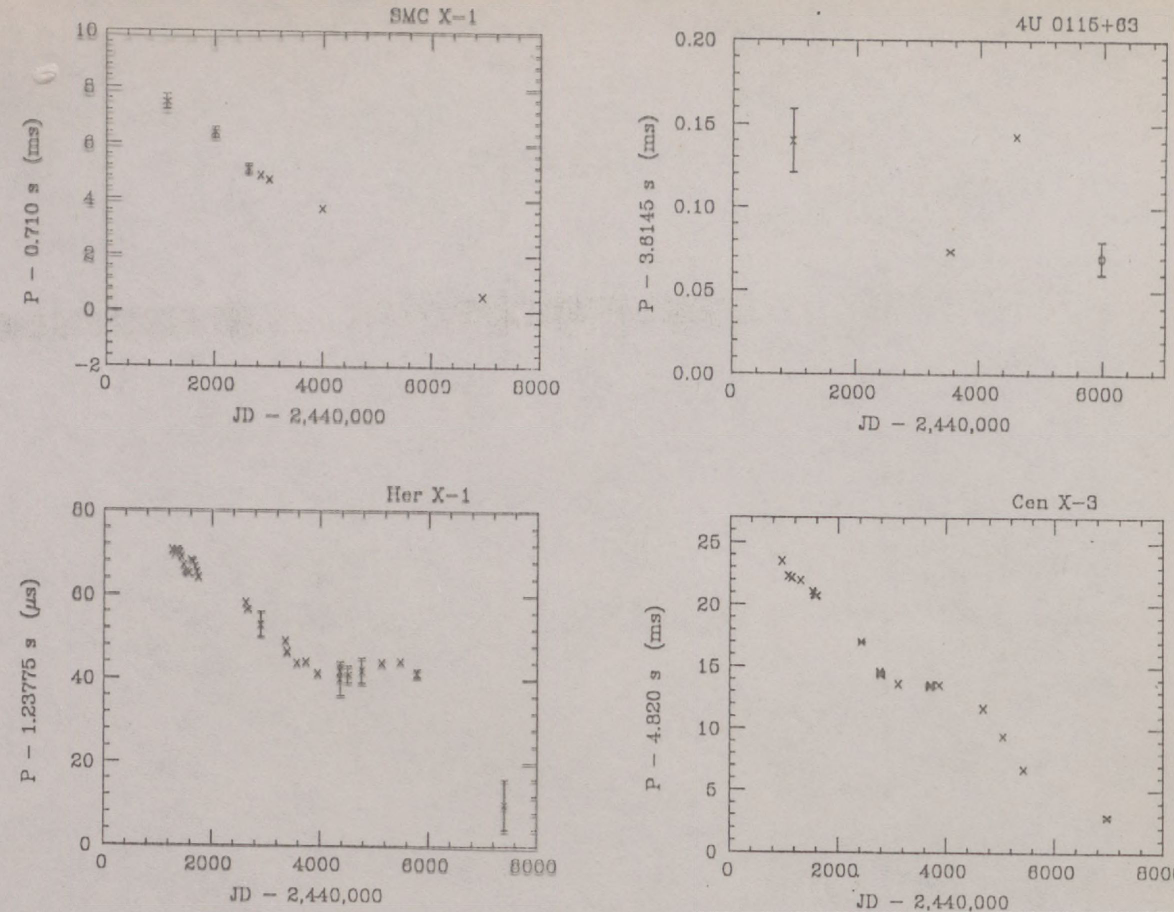
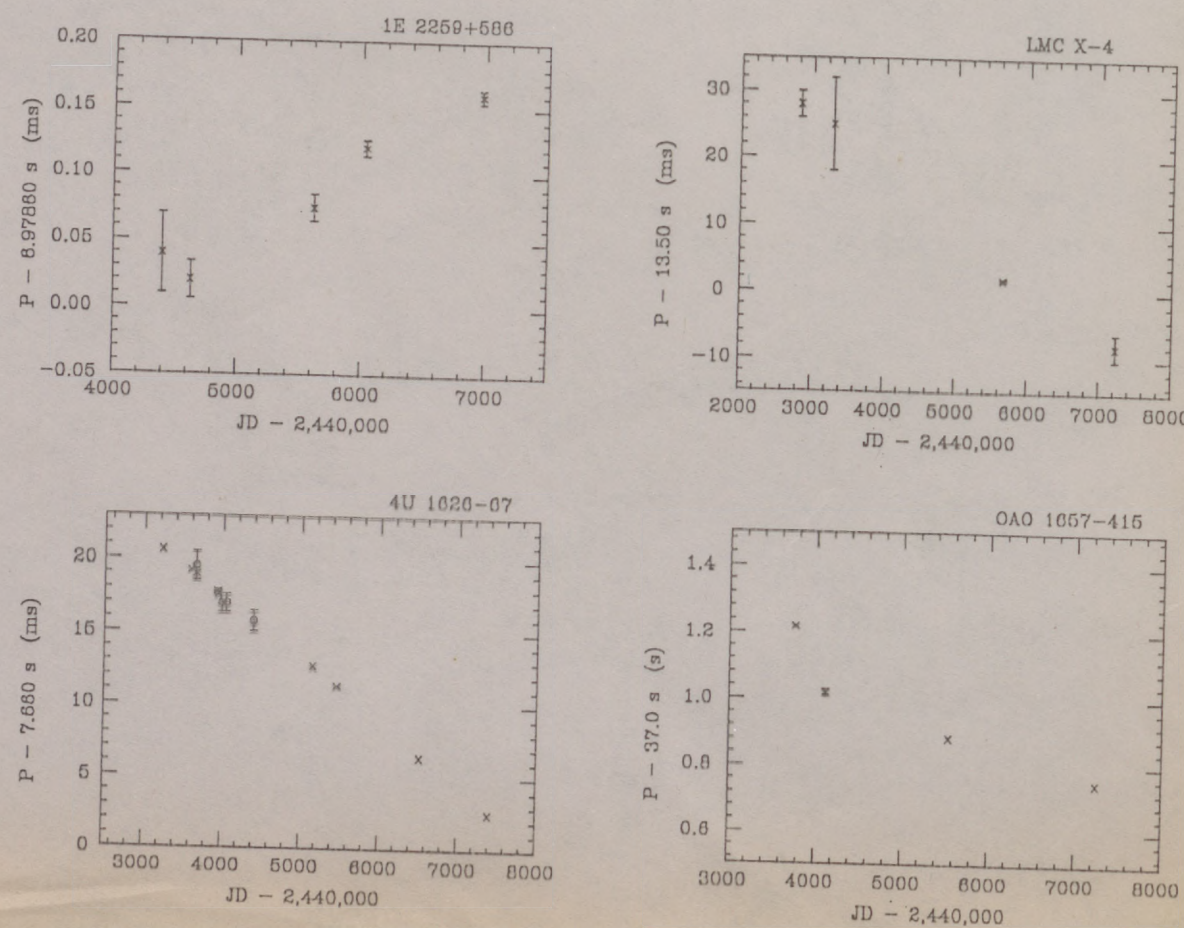


Fig. 11. See the legend on page 31.



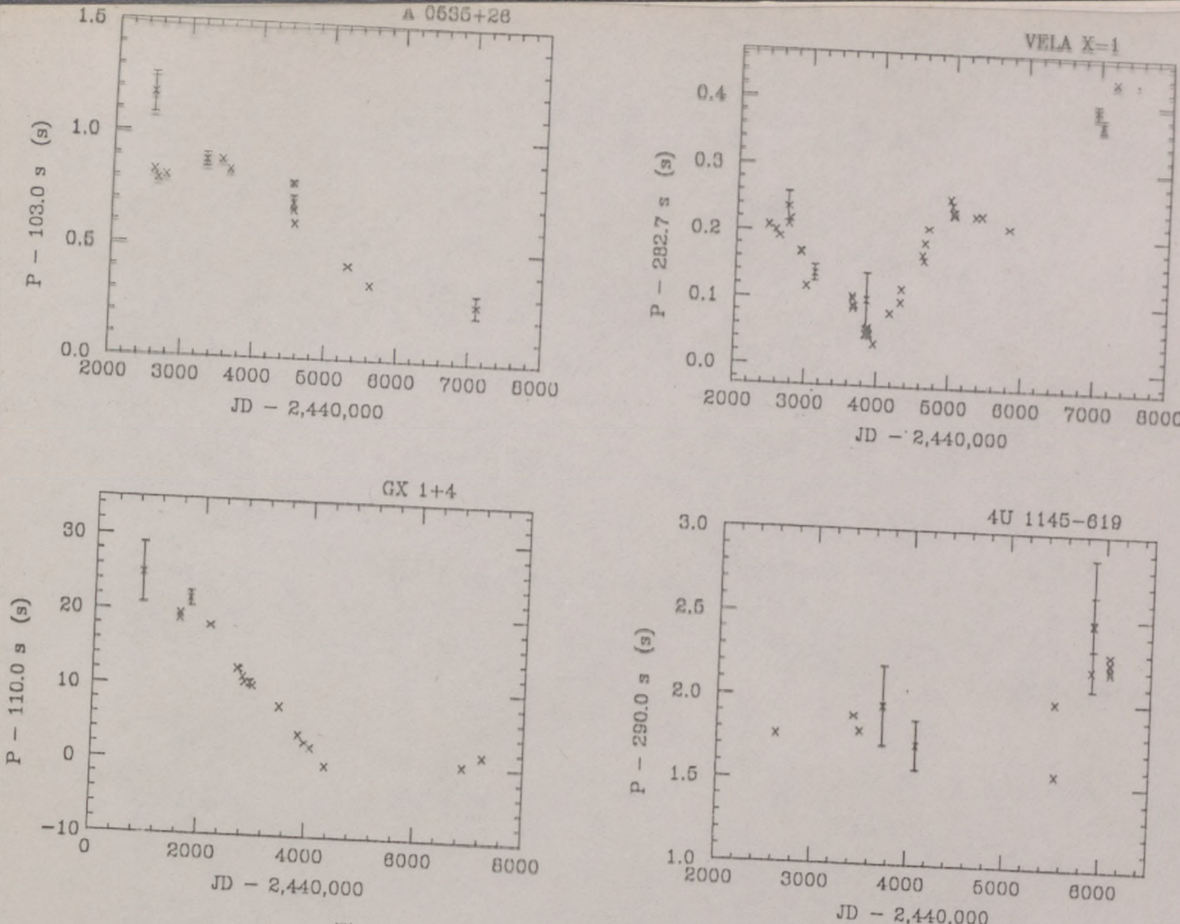


Fig. 11 (continued). See the legend on page 31.

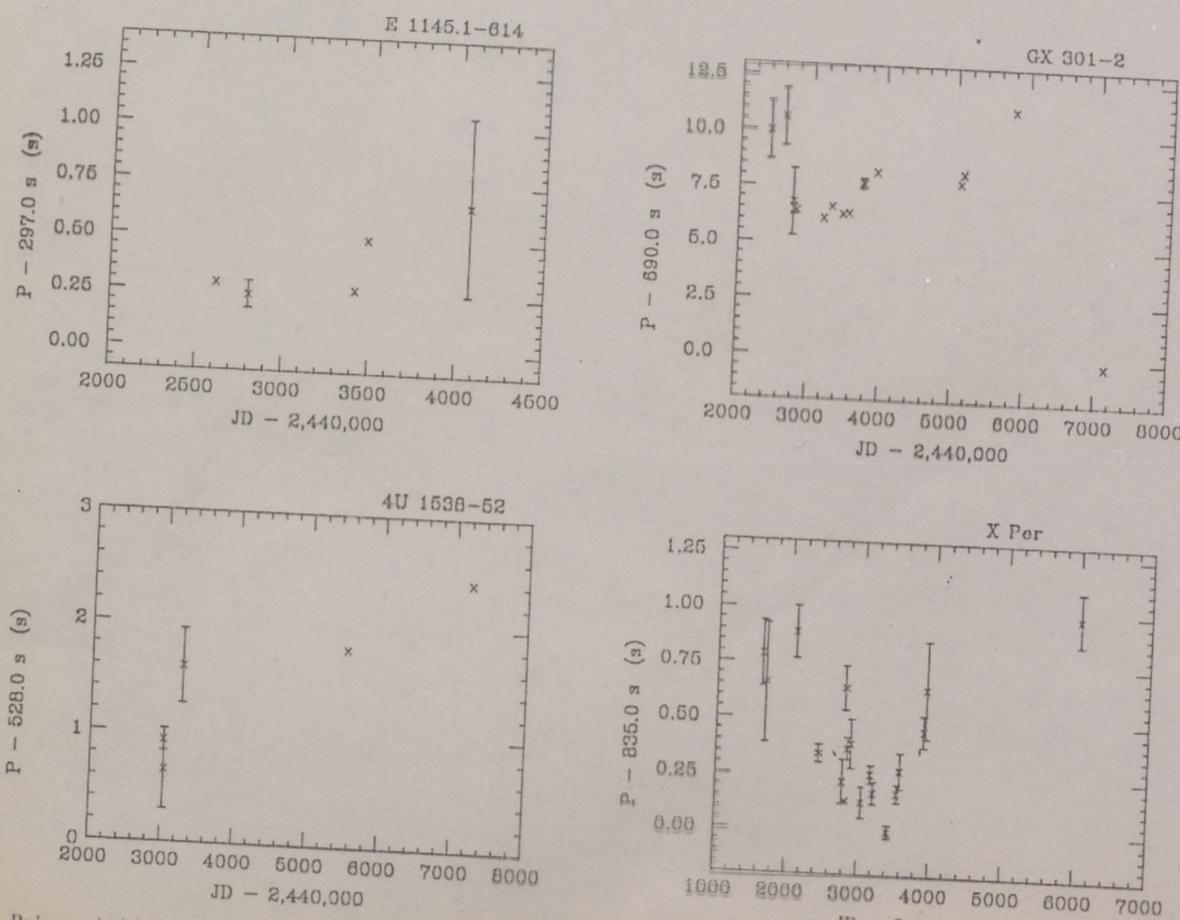


Fig. 11. Pulse-period histories for 16 X-ray pulsars. The numerical values for individual measurements are summarized in the Appendix together with the original references. The 1σ uncertainties in the period determination are shown only for those data with poor accuracy, otherwise the error bars determined are smaller than the size of symbols.

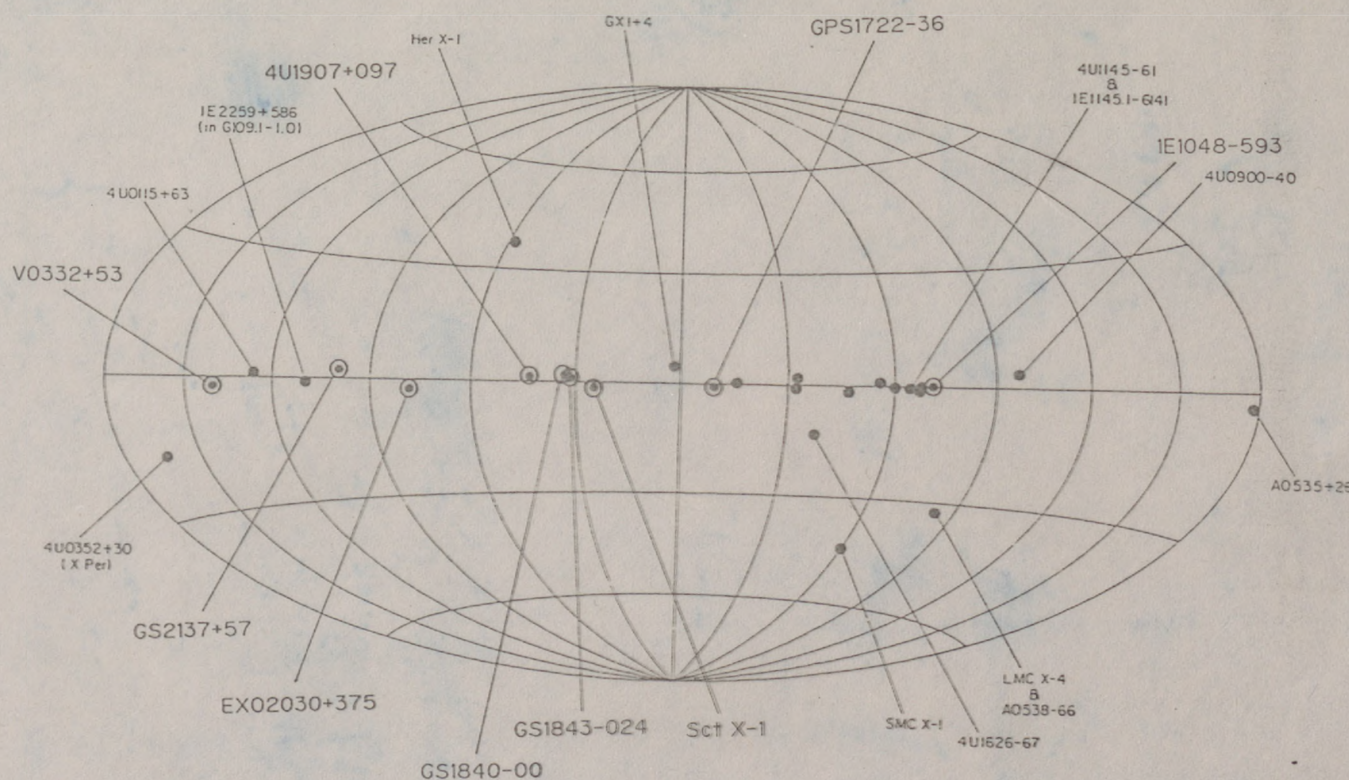
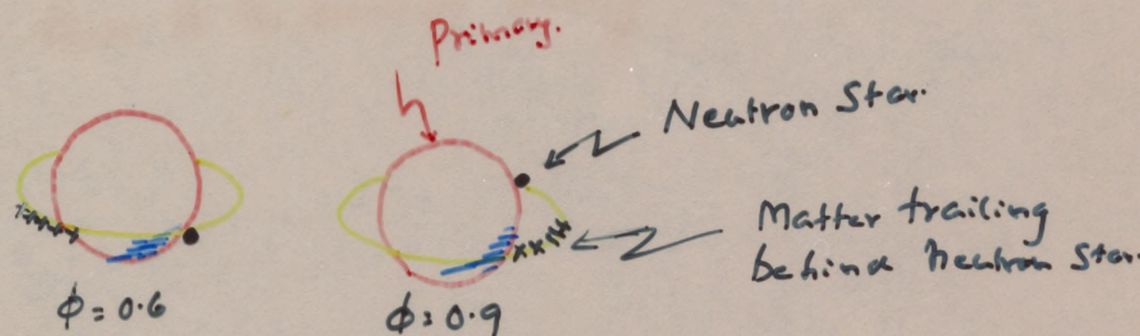


Fig. 2. Sky map of X-ray pulsars in galactic coordinates. The solid circles are taken from the review article by Joss and Rappaport (1984), whereas the dot-circles indicate pulsars discovered subsequently. Read GS 1843+00 for GS 1840−00.

UHE Gamma Rays From LMC X-4.

* LMC X-4 is a massive binary System with 1.408d period. In X-rays it has a high and a low State with 30 d period attributable to procession of the accretion disk.
* The inclination of the System is 66° and the X-ray Source is eclipsed between the phase 0.92 and 0.08
* The primary Star does not appear to fill its Roche Lobe and to have a rather low stellar wind (Huchings et al) Mass tranfer may occur through a trailing accretion stream which may feed the disk. Evidence for this Comes from the variable obscuration of the Companion Star between orbital phases 0.6 and 0.9 which could correspond to matter trailing behind the Neutron Star by between 0.2 and 0.3 phase.

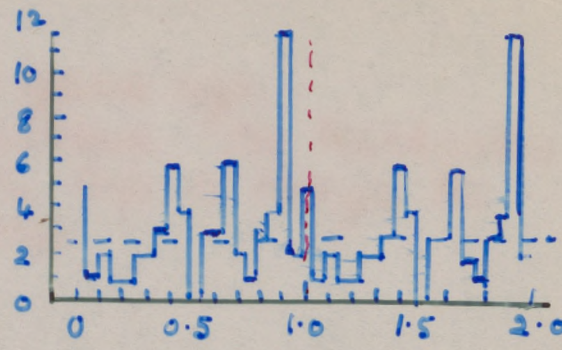


- Buck Land Park Array (Protheroe et al ICRC 19 Vol 1 p247 85)
- 63 Air Showers recorded within $\theta \sim 2.5°$ of LMC X-4 direction corresponding to $E > 10^{16}$ ev.

The phasogram (Ephemeris of Kelley et al) Shows peak in the phase bin 0.90 - 0.95

(Not Seen during .05 and 0.1 phase!)

Number of Events in the phase bin = 12 Compared to background rate of <u>2.65</u>



The model envisaged for γ-ray production of $E > 10^{16}$ ev is as follows:

Protons are accelerated in the vicinity of the neutron star and when these bombard the atmosphere of the Companion Star, in the nuclear interactions π^0 mesons are produced which decay into γ-rays. The γ-rays will be seen at the earth when the line of sight grazes the atmosphere of the Companion Star. If this mechanism operates then γ-rays should be seen in the phases 0.90-0.95 and also in the phas 0.05-0.1. While Buckland Park results show emission during 0.90-0.95 there is no emission during 0.05-0.1.

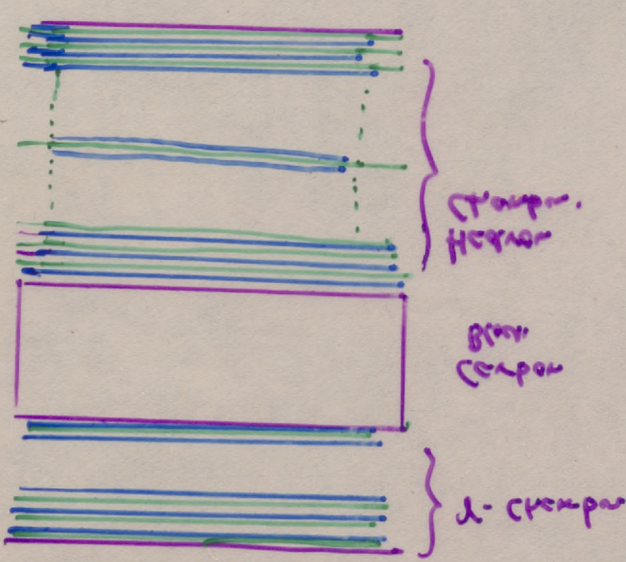
As we noted earlier, it is possible that a stream of gas is circulating behind the neutron star in the same orbit with a phase difference of 0.2-0.3. If this stream is the target material for γ-ray production, then the emission will be seen only in one phase.

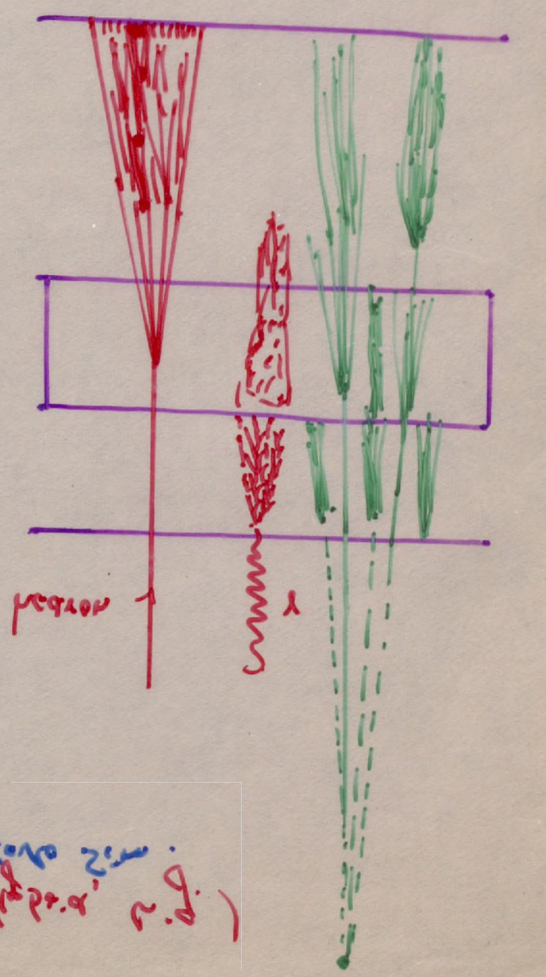
The Buckland Park results also seem to indicate the 30 day periodicity that is seen in LMCX-4 in the X-ray and optical wave lengths.

* One of the big anomalies is that γ-rays of energy $> 10^{16}$ ev should be attenuated very drastically due to interaction with 3° photons. — the attenuation mean free path ~ 10 Kpc.

Interactions deep down in the atmosphere
> 500 g/cm² (Emulsion Chambers, EAS, Hyd'a, e.g.)
+ Monte Carlo Sim.

• The Emulsion Chambers





Sandwich of
Lead and Emulsions
↓
X-ray Emulsions.

Carbon jets.
Atmospheric jets. — Nuclear Interaction
1-2 kms above the
observation level.

↓

• The Secondaries are spread out to
tens - cms separation.
• The nuclear emulsions provide
high spatial resolution.
• Photometric measurement of the
dark spots —
• Monte Carlo simulations for Calibration.

The instruments are
(1) Pamir
(2) Chacaltaya
(3) Mount Fuji
(4) Norikura.
(5) Kanbala.

Typically 20 m² in area.

1. Cosmic Rays discovered > 70 years ago. Still no definite Sources identified. No mechanism of acceleration established. The Hope is through the detection of UHE γ-ray Sources

2. 1953 - 4th. ICRC at Guanjuato, Mexico - Shklovsky → optically polarised emission from Crab → Synchrotron in $H = 10^{-3}$ gauss ∴ Electrons > 10^{12} ev.
If electrons of 10^{12} ev, why not protons of > 10^{12} ev?
If Protons of > 10^{12} ev, why not γ-rays of 10^{11} ev through π^0 - decay?

3. The BASJE Project - μ-poor EAS - } No positive
Air Cerenkov Technique by Soviet group } results.

4. Revival of interest in high energy γ-ray Studies with the discovery of Pulsars.
Neutron Stars with Magnetic Fields of ~ 10^{12} gauss - favourable environment for acceleration of particles.
Search for Pulsed UHE γ-rays - Crab Nebula.
Some indication of positive results - but marginal.

5. Discovery of Binary Accreting X-ray Sources with one of the Companions being a Neutron Star - B.H.
Tantalising Scenarios for acceleration of particles - interaction of the accelerated particles with matter surrounding the other object. Could give rise to γ-rays
Her X-1, Cyg X-3, Geminga, SS433, LMC X-4

6. Basic Methods : (i) EAS through timing } γ-rays.
(ii) Night Air Cerenkov Telescopes. }
Direction + Time of arrival (Tracking.)
(iii) Underground muons } Direction +
Single and multiple. } Time of arrival.