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Present status of very high energy gamma ray astronomy and plans for an imaging gamma ray telescope in India

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Abstract. The unequivocal detection of the Crab Nebula as the first-ever standard candle in the VHE bracket, made possible by the recently-developed Cerenkov Imaging Technique, marks a water-shed in the 20 year-old history of the TeV γ-ray astronomy. It gives hope that, as with the Crab today, future detections in the field, too, will be on a firm statistical footing and the attendant investigations, more comprehensive in their content and range. The present mood in the field is one of cautious optimism. This paper gives an overview of the contemporary observational scene in the ground-based gamma-ray astronomy. It closes with an introduction to TACTIC, the first Indian Imaging gamma-ray telescope, presently under-development.

Key words : γ-ray astronomy—VHE γ-ray telescopes—Cerenkov imaging technique

1. Introduction

Very High Energy (VHE) γ-ray astronomy, which deals with cosmic photons in the energy bracket 0.1-10 TeV, opens a new window on the universe. It gives information on astrophysical objects and the intervening space which not only supplements the clues provided by other electromagnetic probes about the cosmic jigsaw puzzle, but is also unique in several important respects (Lamb 1989). The likely cosmic sources/production sites for these photons in the galaxy may be of a compact type, like pulsars (young and recycled), Supernova remnants, binary systems with a compact primary (neutron star/white dwarf), or of a non-compact type, viz., galactic plane, cosmic-ray-irradiated molecular clouds and the primary electron component (Weekes 1992). The extragalactic candidate objects and emission features include normal galaxies, seyferts, Active Galactic Nuclei, quasars and the general metagalactic space. The main gamma-ray emission modes are (i) steady or d.c., (ii) persistent-periodic, and (iii) sporadic or episodic. Emissions of variant (iii) may exhibit a periodic or quasi-periodic modulation and can include VHE gamma-ray transients (Ramana Murthy & Wolfendale 1986; Bhat *et al.* 1986; Vahia 1993) expected to be produced in primordial black-hole and Supernova outbursts, solar flares (?) and in the astrophysical processes manifesting themselves as the Vela-class gamma-ray bursts.

2. Cerenkov imaging technique

As with γ-rays belonging to other energy brackets, VHE photons too are blocked from reaching the earth's surface by the atmospheric mantle. Unlike at lower energies, however, TeV γ-rays cannot be detected directly, outside this mantle, in a satellite-borne experiment, because the signal flux is generally too small, translating to a typical value of < 1 photon m^{-2} (50 days)$^{-1}$ above 1 TeV primary energy. What saves the day, mercifully, is the beneficial transducing role of the terrestrial atmosphere at these (and higher) energies, which permits to undertake astronomical studies at TeV energies in a viable manner through the Atmospheric Cerenkov Technique (ACT) because of the following two important reasons (Weekes 1988) : (i) The large lateral extent of the Cerenkov wavefront helps to boost the effective detection area by a factor of ~ 10^4 compared with the actual physical area of a typical light collector. (ii) The collimated nature of the Cerenkov light helps to essentially preserve information regarding the arrival direction of the primary particle. However, the method also extracts a heavy price for offering these practical advantages. The useful observation time is restricted to the clear, dark portion of a night, leading to a duty-cycle of < 15% only. This, combined with the fact that γ-ray induced atmospheric Cerenkov events (γ-ACE), severely undermines the detection sensitivity of a conventional atmospheric Cerenkov telescope. For example, the 3 σ-flux sensitivity limit, in 50 h of on-source observations, works out to be as high as ~ 3×10^{-11} photons cm^{-2} s^{-1} at photon energies > 2 TeV for the Gulmarg system (Koul *et al.* 1989). As a consequence, d.c. point-sources and diffuse emission regions are more or less out of the scope of investigations of a generation-I system (Weekes 1988). In the case of periodic sources, off-line searches in the recorded database for the anticipated modulation feature have helped sometimes to circumvent the sensitivity problem.

There is therefore a crying need to boost the sensitivity limits of the detection technique if TeV γ-ray astronomy has to be in serious business and its reach has to be more comprehensive, both, in overall range and depth (Lamb 1989, Bhat *et al.* 1993). This stipulation happens to be the principal goal of generation-II systems, a few of which have been commissioned recently (Vladimirsky *et al.* 1989; Weekes 1991), while several others are presently in various stages of development in different parts of the world (Lamb *et al.* 1989; Nikolsky *et al.* 1989; Aharonian *et al.* 1991; Ebisuzaki *et al.* 1991). Different prescriptions are being attempted for improving the detection sensitivity, the underlying common theme in all of them being to reject a substantial fraction of p-ACE from the recorded data through appropriate hardware and/or software procedures. One such filtering procedure, referred to as the Cerenkov Imaging Technique (CIT), has already met with impressive success in attaining this 'Holy-Grail' objective—it has helped to detect the Crab Nebula as a d.c. γ-ray source at a hitherto unsurpassed statistical significance of ~ 30σ in ~ 60 h of on-source observations, to be compared with ~ 1000 h of observations required for the conventional (non-imaging) Whipple system (Weekes 1992 & references therein). Another first (Vacanti *et al.* 1991), CIT has made it possible to measure successfully the differential energy spectrum of this source in the TeV energy range (0.4-4 TeV) and, finally, it has also convincingly demonstrated (Akerlof *et al.* 1991a) that it is possible to achieve an angular resolution of ~ 6 arcmin at TeV γ-ray energies, which is comparable with, or even better than that achieved by direct satellite-borne experiments, used in the MeV-GeV γ-ray region (Weekes 1991).

CIT seeks to exploit the differences which, according to detailed simulation studies of γ- and hadron atmospheric cascades, exist in shape and orientation of Cerenkov images of

γ- and p-ACE (Hillas & West 1991). Speaking in general terms, while the 2-dimensional γ-ACE images, detected in the image plane of a Cerenkov telescope, are compact ellipses having their major axes pointed in the direction of the (point) source, the p-ACE images are comparatively more extended and fuzzier, with no preferred orientation. These differences are quantified by a set of imaging parameters, of which the AZWIDTH-cut has been found to be the most sensitive in rejecting background events from the Crab Nebula direction. A very reassuring feature of CIT is the complete congruency of the simulation predictions with the results of actual observations on the Crab Nebula (Weekes 1991). Further improvement in the figure of merit of CIT has been made possible by 'a posteriori'-developed filtering procedure, called SUPERCUTS (Punch *et al.* 1992) and by the use of 'cluster masks' and neural-nets (Hillas & West 1991; Halzen *et al.* 1991). The pioneering experimental work in using and improving CIT has been carried out at the Whipple Observatory in Arizona, U.S.A., and the remarkable success achieved by this group is undoubtedly related to the replacement of the non-imaging-type focal plane instrumentation of the 10m Whipple telescope with a high-resolution, 108-pixel Cerenkov imaging camera (Weekes 1988, 1992). Apart from the Crab Nebula, the new-look Whipple system, backed up with the SUPERCUTS pattern recognition methodology, has detected the active galaxy MK421 as a TeV γ-ray source at a $\sim 7\sigma$ significance in only 15 h of total observations time (Punch *et al.* 1992). Surprisingly, however, it has consistently 'failed' when applied to several other databases, including the one from Her X-1, where a pulsed signal has been claimed at a reasonably high significance level from an analysis of the overall raw data (Weekes 1992).

The apparent 'dichotomic' behaviour of imaging parameters can be plausibly attributed to the following main factors (Weekes 1992) : (i) The significance levels of previous detection claims have been overestimated—a hypothesis difficult to accept on a universal basis. (ii) The claimed 'signal' is produced by a hitherto unknown, neutral particle—an overstretched possibility admittedly, for which there are few takers among the particle physicists. (iii) Our present knowledge of the pattern recognition methodology is not complete and all the underlying subtleties (exact source spectrum and zenith angle, earth's magnetic field, background star-fields etc.) have not yet been completely folded into the simulation package (e.g. Lewis *et al.* 1991; Bowden *et al.* 1992a; Kornienko *et al.* 1993). Be that as it may, it will be only prudent to evolve other prescriptions for background filtering, including those based on tractable differences expected to exist in the spectral and temporal features of γ- and p-ACE (Vladimirsky *et al.* 1989; Konopelko *et al.* 1991). Such background rejection procedures can also help in γ-ray studies involving non-compact emission regions, for here, discrimination is not possible using image-orientation parameters like AZWIDTH and ALPHA.

3. Observational status

In order to have a better appreciation of the emission behaviour of a given candidate source, we shall somewhat exceed our 'brief' and refer in this section to the results obtained on a given candidate-source in the ultra high energy (UHE) region alongside those obtained in the TeV energy bracket. Unlike the picture prevailing up to late eighties, when detection claims involving several genres of cosmic objects were made by various groups, more recent investigations, some of them made with higher-sensitivity detectors, have, generally speaking, drawn a blank. In what follows, we shall illustrate the contemporary observational scene on a case-by-case basis, and, wherever possible, try to provide a logical perspective for this apparent old versus new 'generation gap'.

3.1. *Crab region*

This region contains the supernova remnant, Crab Nebula, and the 33 ms – pulsar, PSR 0531 + 21, filling up the centre of this well-known plerion. Both these sources have attracted sustained attention from the very inception of the ground-based gamma-ray astronomy in late 1960's and this has recently culminated in the Nebula becoming the first-known standard cosmic candle in the VHE region (Weekes 1991). Turning to figure 1 (upper panel), it is seen that TeV emission history of the Crab Nebula is characterised by an essential constancy of flux over the last 20 years of observations; the Whipple Imaging system has provided convincing evidence for this steadiness being valid down to time-scales of even months

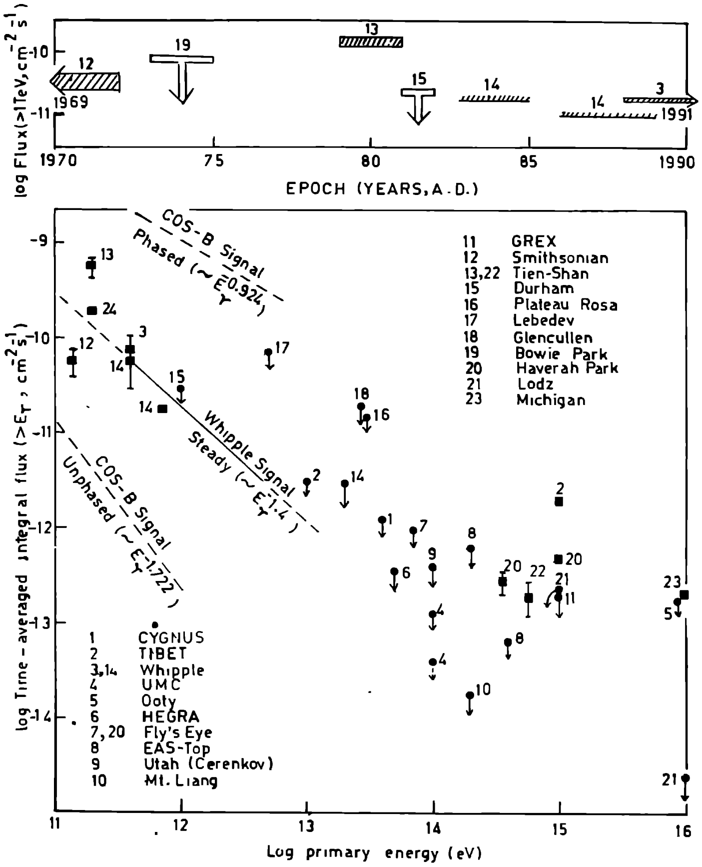

Figure 1. *Upper panel* : TeV flux values and 3σ upper limits of Crab Nebula, arranged chronologically, to show the near constancy of this flux over the past 20 years.
Lower panel : Integral photon spectrum of Crab Nebula in the energy bracket 0.1 TeV-10 PeV. All upper limits are normalized to the 3σ confidence level.

(Cawley *et al.* 1989). Furthermore, the Whipple data have also yielded the first-ever differential photon number spectrum for a TeV source; as shown in figure 1 (lower panel), it is consistent with an exponent of ~ 2.4 and this, 100% unpulsed emission, is believed to be of Compton synchrotron origin (de Jager & Harding 1991). The situation is less clear in the PeV energy region, with new experiments (e.g. Gibbs *et al.* 1991) yielding upper limits, some of which severely constrain the detection claims made in the past.

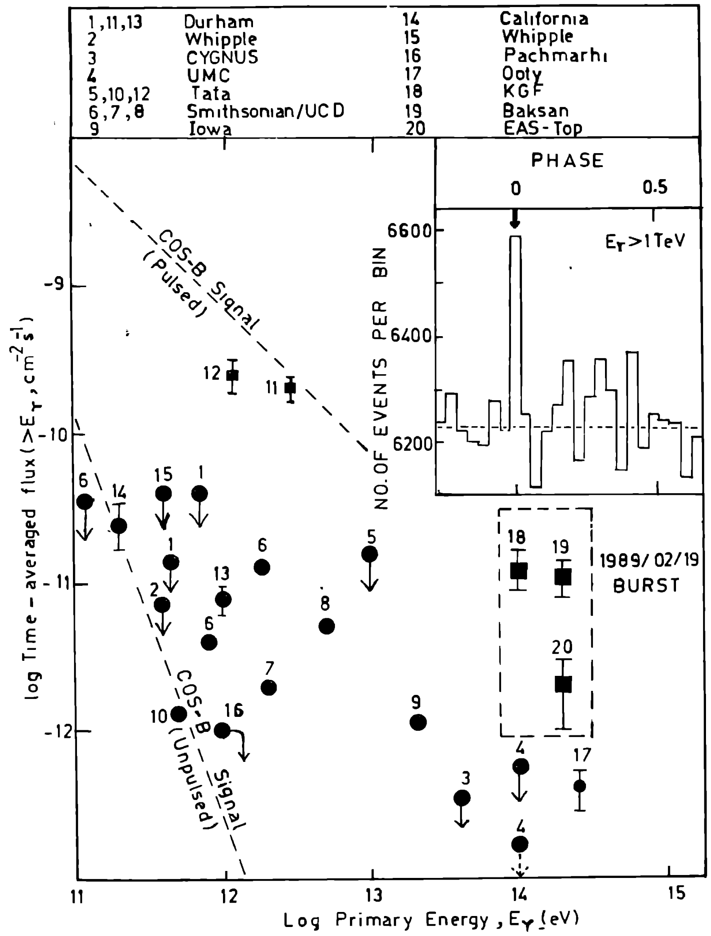

Figure 2. Flux measurements of the 33 ms pulsar PSR 0531 + 21 in TeV and PeV energy brackets; ● persistent-pulsed, ■ episodic pulsed. The box encloses the flux values derived for the first-ever PeV energy burst detected in time-correlation from the Crab direction by the KGF, Baksan and EAS-Top groups.
Inset : γ-ray light curve of PSR 0531 + 21 as derived by the Durham group for the period 1982 September-1983 November. The position of the radio peak is shown by the thick arrow at the phase zero.

Figure 2 gives an overview of the corresponding observational situation in case of the Crab pulsar; here the signal (if detected) is linked to this source on the basis of an expected 33 ms modulation, characteristic to PSR 0531 + 21 (see inset). This pulsed emission has been reported either in the form of strong, relatively short-duration bursts or as a low-level persistent activity. A careful examination of the figure shows that the spectral form for both these emission modes is compatible with an integral exponent $\gamma_I \sim 0.92$, reliably inferred for the pulsed component at the COS-B satellite energies (Weekes 1988). The recently obtained upper limits are consistent with such a projection.

3.2. *Cygnus X-3*

This enigmatic object continues to spring surprises, the latest one being its reported detection in the EeV energy region (1 EeV = 10^{18} eV) by 3 independent groups (Cassiday *et al.* 1989; Teshima *et al.* 1990; Efimov *et al.* 1991), with an equally significant null result from the Haverah Park group (Lawrence *et al.* 1989). If the reported signal is indeed of Cyg X-3 origin, the associated primary particle at these energies can even be the normally unstable neutron. Implications on the acceleration processes and the central engine responsible for driving this system are obvious. A note of caution here : the EeV signal seems to have faded in the last 2 years (Weekes 1992).

At lower energies, the source has been more or less under constant scrutiny of different groups since early 70's. Most of the signals reported here exhibit the 4.8 h—modulation period, characteristic of this binary system (Weekes 1988), though a sporadic component is also occasionally detected, usually following a major radio outburst from the source. A ~ 12.6 ms periodicity, attributed to the (recycled) pulsar within this binary system, has also been reported at TeV energies by the Durham group (several times; Bowden *et al.* 1992b) and Adelaide group (once; Gregory *et al.* 1990), with an equally emphatic null result from the Whipple group (Fegan *et al.* 1989; O'Flaharty *et al.* 1992), backed up with additional support from the Haleakala, Pachmarhi and Gulmarg experiments (Weekes 1992; Tickoo *et al.* 1993).

Figure 3 presents the results of various flux measurements reported in literature on Cyg X-3 in the TeV and PeV energy brackets. The important thing to note here is that, in sharp contrast to the past results summarized in Bhat *et al.* (1986), essentially all the recent measurements have yielded only upper limits, despite the significantly higher sensitivity levels of the new experiments (e.g. Ong *et al.* 1991; Alexeenkov *et al.* 1991). What is to be made of this rather unexpected turn of events? We turn to figure 4 to seek a possible explanation. Here, various flux values and more restrictive upper limits, reported so far in the TeV, PeV and EeV energy brackets, are plotted, after appropriate energy-scaling, as a function of the corresponding epoch of observation. The PeV data are also corrected for flux attenuation effects caused by the intervening 3°K microwave radiation background (source

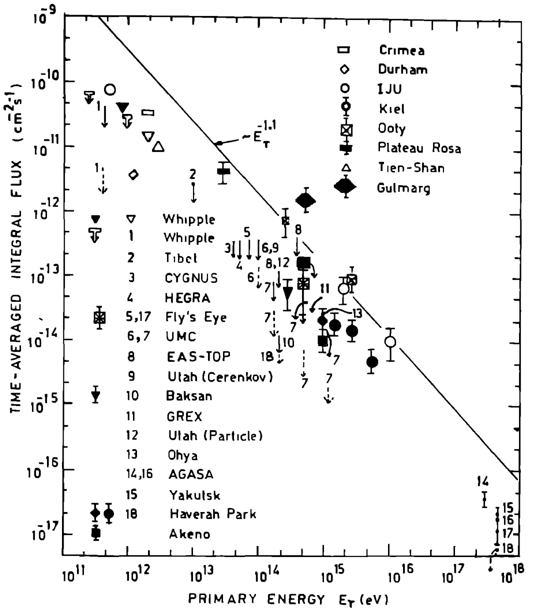

Figure 3. Results of Cyg X-3 observations between 0.1 TeV-1 EeV. Arrowheads represent 3σ upper limits : (most of them are comparatively recent). ↓ : raw data, ⇣: data with an imaging or muon cut.

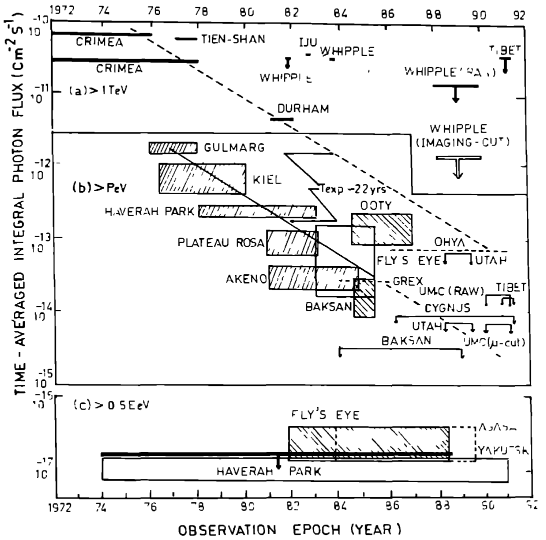

Figure 4. Evidence suggesting a sharp secular decrease of Cyg X-3 luminosity at TeV and PeV energies. Previous flux values and recent 3σ upper limits are compatible with an e-folding time constant of ~ 2-3y in both the energy brackets.

distance ~ 11.6 kpc). The central panel in figure 4 suggests that the luminosity of the PeV source in Cyg X-3 is experiencing a secular waning with an e-folding time-constant, T_e ~ 2.2 years. This inference was first drawn by Bhat *et al.* (1986), based on an analogous examination of pre-1985 Cyg X-3 PeV data. The strongly constraining recent upper limits from CYGNUS, UMC and Baksan experiments are in agreement with this suggestion. Examination of the upper panel in figure 4 now indicates that the measurements from Crimea, Tien Shan and Durham, representing long-term TeV flux averages (> 1 year), and the recent Whipple upper limit (with imaging cut), also mirror a remarkably similar long-term trend, thereby reinforcing the above viewpoint, with all its likely profound implications. The apparent source behaviour at balloon/satellite γ-ray energies is also consistent with this picture (Rana *et al.* 1984), and the latest Compton Observatory results on Cyg X-3 are eagerly waited to further clarify this position. It may be noted that this projection about the long-term behaviour of Cyg X-3 has started receiving serious attention now (Weekes 1992). It is too premature at this stage to opine about the corresponding (still-confused) situation at EeV energies.

3.3. *Hercules X-1*

This represents another, extensively studied source at TeV and PeV energies (Weekes 1988, 1992). Figure 5 represents the overall observational scene. The following features about the emission behaviour of the source are noteworthy : (i) In general, a Her X-1 signal manifests itself in the form of a short-duration pulsed burst. (ii) In nearly half such episodes, the pulsation period is significantly blue-shifted with respect to the contemporaneous X-ray period of the neutron star primary (inset). The dashed line, drawn across the figure, has a symbolic significance only. It represents the approximate epoch (December 1986) beyond which only 3 statistically weak detections have been reported—from Halekala, Gulmarg and Durham. In contrast, 12 non-detections have been reported during the corresponding period, including two by Bhat *et al.* (1990a) from Pachmarhi and Akerlof *et al.* (1990) from γ* experiment (not shown in figure). The following tentative picture emerges about the long-term γ-ray emission behaviour of this largely episodic emitter : Her X-1 may have lapsed into a state of relative quiescence in late 1986.

3.4. *4U 0115 + 63*

Also referred to as Cassiopia γ -1, this X-ray binary system has been observed at TeV and PeV energies since early 70's (figure 6). In the VHE bracket, sporadic and persistent-pulsed emissions have been reported by the Crimean, Durham and Pachmarhi groups, while Whipple, Pachmarhi (repeat observations) and Gulmarg groups have quoted upper limits on, both, steady and pulsed emissions from the source. In the UHE region, the Tien Shan group alone have claimed the detection of a pulsed signal, while comparatively more sensitive experiments like, CYGNUS, EAS-Top and Baksan array have provided quite stringent upper limits. As at lower (X-ray) energies, 4U 0115 + 63 may be displaying a sporadic (pulsed) emission behaviour at γ-ray energies. More observations are required to draw a firm conclusion.

3.5. *Cataclysmic variables*

Characterised by a magnetic white-dwarf compact primary, this promising class of cosmic objects has only recently gained a foothold in the 'catalogue' of γ-ray candidate sources.

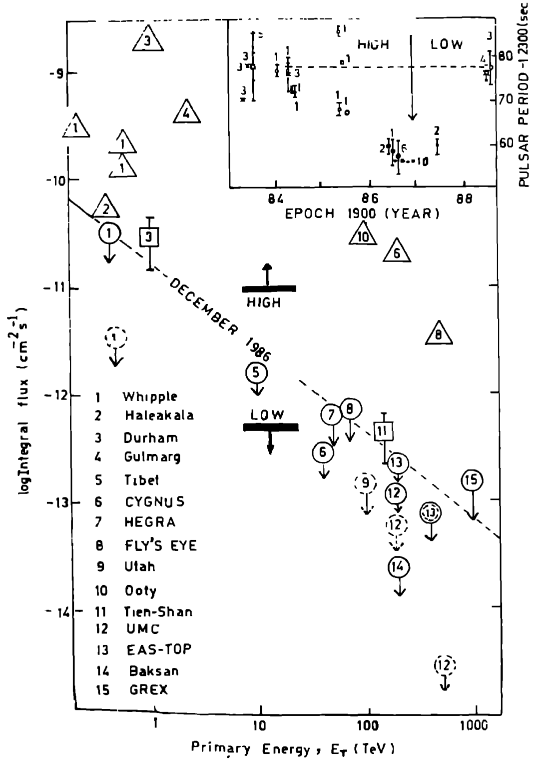

Figure 5. Reported flux values and 3σ upper limits from Her X-1. The source seems to have switched over to a low flux state around December 1986.
Inset : γ-ray period plotted against observation epoch. Dotted line represents the corresponding X-ray period.

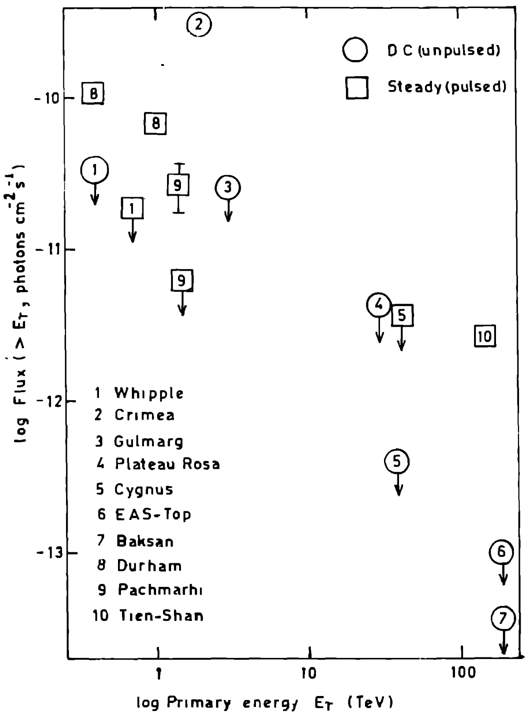

Figure 6. Results of observations made by various groups on 4U 0115 + 63 in TeV and PeV energy regions are compared. Sporadicity, a hall-mark of the source in other regions of the electromagnetic spectrum, may be extending to the VHE region also.

Potchefstroom (Meintjes *et al.* 1991) and Durham (Bowden *et al.* 1991a) groups have presented independent evidence, suggesting episodic-pulsed TeV γ-ray emission from the DQ-Her system AE-Aqr. The work of the Gulmarg group, likewise, hints at the prototype polar AM-Her being a γ-ray source at TeV and (possibly PeV) energies (figure 7). Whileas the Gulmarg case for a TeV signal (Bhat *et al.* 1991) is based on the detection of, both, a 3σ dc excess and a strong 3.1 h (source-related) phase modulation, the PeV claim (Bhat 1990) is not as strong and is based on the observation of a phase-dependent modulation only. Recently, 4 groups have presented null results from their AM-Her observations at TeV and PeV energies. The corresponding upper limits, based on d.c. signal searches, are shown in figure 7 along with the Gulmarg results. An upper limit, derived by us from the Whipple raw data (without any imaging cut), is also shown in the figure, to account for the possibility that this cut does not apply universally. The revised Whipple upper limit is still incompatible with the Gulmarg results, as is also the strongly constraining CYGNUS upper bound. A reconciliation is possible, however, by invoking a flux time-variability, a quite plausible scenario for accretion fed systems like AM-Her (Kaul *et al.* 1993).

3.6. *Geminga*

This, second-brightest COS-B catalogue source, has staged a come-back in the γ-ray domain, following its 'rediscovery' by the ROSAT X-ray satellite (Hallpern & Holt 1992) and the

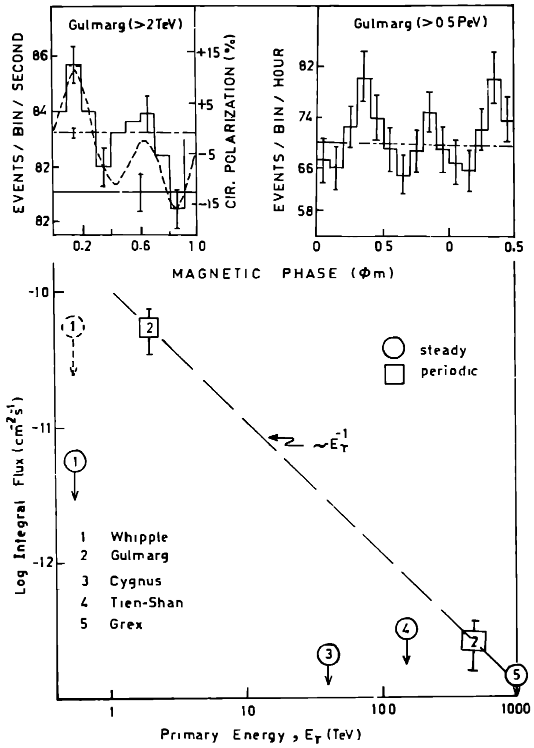

Figure 7. *Upper panel* : TeV and PeV light curves of AM Her, as suggested by Gulmarg Cerenkov observations, are compared. TeV light curve (histogram) displays a strong morphological similarity with the circular polarization curve of the source (superimposed dashed curve) and is anti-correlated with the corresponding PeV phasogram. *Lower panel* : Gulmarg TeV flux value and the PeV upper limit compared with the recently reported results from 4 other experiments. The dashed circle labelled '1' is the upper limit for the Whipple raw data.

EGRET experiment on the Compton γ-ray Observatory (Bertsch *et al.* 1992) as a 237 ms-period X-ray pulsar. Earlier, it was reported to exhibit a ~ 59s period (see Kaul *et al.* 1989 for an updated Gulmarg picture). Following this important revelation, the Durham group (Wolfendale, private communication) have carried out a periodicity search of their 1983 Dugway data using the EGRET timing parameters. The results given in figure 8 are self-explanatory, though the following caveats are in order : (i) The statistical significance of the overall VHE detection is $< 3\sigma$. (ii) Again, the Whipple imaging system (Akerlof *et al.* 1991b) has failed to detect the implied d.c. excess, despite sustained observations on Geminga (flux < 0.2 Crab above 0.4 TeV).

3.7. *Markarian 421*

The active galaxy MK 421 (distance : 124 Mpc) happens to be the second d.c. source, after the Crab Nebula, which has been detected at TeV energies through CIT. The Whipple detection (Punch *et al.* 1992) followed the discovery of this source as a gamma-loud active galaxy by the EGRET experiment (Michelson *et al.* 1992). Using the SUPERCUTS-discriminant routine, first perfected on the Crab Nebula database, the source was revealed at a 6.6σ confidence level in only 7.5 h of on-source observations (figure 9). The photon flux is estimated to be 1.5×10^{-11} cm^{-2} s^{-1}, corresponding to a source luminosity of ~ 10^{43} erg s^{-1}

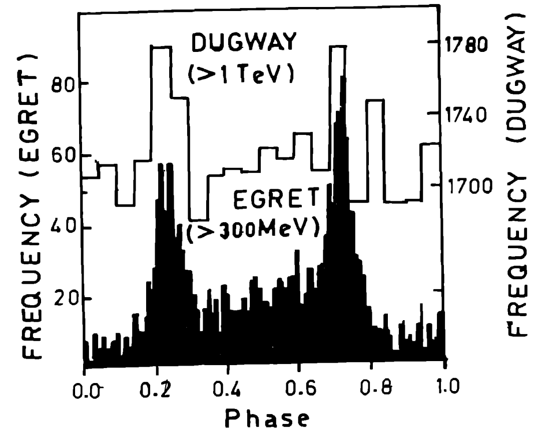

Figure 8. γ-ray light curves of Geminga in High Energy (EGRET) and Very High Energy (Dugway) brackets are shown. Both sets of data are folded with the recently discovered 237 ms period of the source (ref : Wolfendale 1992. pvt. commn.).

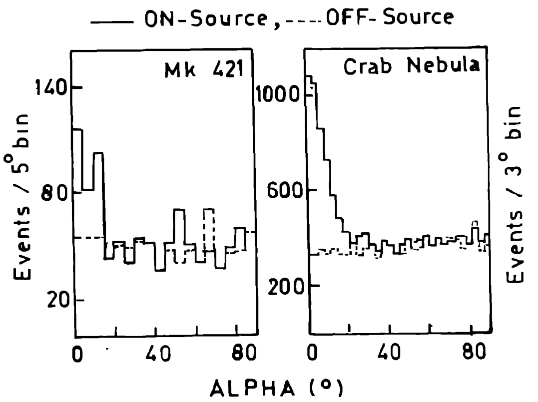

Figure 9. Evidence for a clear excess of γ-rays from the direction of the active galaxy. MK 421 (on-source). The Image-orientation parameter ALPHA is used as a discriminant. Reference data from the Crab Nebula are shown for a comparison.

(4π emission). Some other (comparatively stronger) γ-ray-loud galaxies from the EGRET list have failed to show up in the Whipple system, presumably because γ-γ absorption effects become important at TeV energies for these more distant systems (Punch *et al.* 1992; Stecker *et al.* 1992).

3.8. *Other important observations*

The radio-pulsar PSR 0355 + 54 (period : 156 ms) was first reported as a pulsed TeV source by the Pachmarhi group (Bhat *et al.* 1990b) based on their 1987 December observations. The emission had a duty-cycle of < 3% and the excess corresponded to a time-averaged flux of (7.9 ± 2.0) × 10^{-12} cm^{-2} s^{-1} at photon energies beyond 1.3 TeV: The source was revisited in 1989 October-1990 January by the Pachmarhi, Whipple and Gulmarg groups (Lamb *et al.* 1991 & references therein; Senecha *et al.* 1993). No d.c. or pulsed signal was detected this time, leading to the Whipple upper limits of < 0.2 Crab and < 0.03 Crab for the two emission modes respectively, beyond 0.4 TeV primary energy.

Four prominent Southern hemisphere candidate-sources are Vela X-1, Cen A, Sco X-1 and SN 1987A. In the case of Vela X-1, the discovery result belongs to Protheroe *et al.* (1984), who reported an apparent orbital phase excess from an analysis of their PeV data. Subsequently, it was detected in the TeV energy range by Potchefstroom and Durham groups (Caraminani *et al.* 1989 and references therein), while JANZOS collaboration have reported an upper limit (Allen *et al.* 1993). All the three results are mutually compatible. The detection of TeV photons from Cen-A (closest galaxy) was first reported by Grindlay *et al.* (1975). Recent TeV observations by the Durham and JANZOS groups have not confirmed this detection (Caraminani *et al.* 1990; Allen *et al.* 1993). There is a marginal evidence for PeV emission from the source (Clay *et al.* 1991). New results of observations on Sco X-1 have been reported by the Ooty, BASJE and Chacaltaya groups in the multi-TeV energy range. The Ooty group (Gupta *et al.* 1991a) have reported a detection for the period 1986 March-May, corresponding to a flux of (6.4 ± 1.6) × 10^{-12} photons cm^{-2} s^{-1} at > 250 TeV energy. However, their overall database (1984-87) does not show the presence of a significant signal. BASJE (Kaneko *et al.* 1991) and Chacaltaya (Inoue *et al.* 1991) groups, too, have reported null results.

Finally, upper limits have also been published on TeV γ-ray emission from SN 1987A by Durham (Bowden *et al.* 1991b), and SPASE (Finnemore *et al.* 1991) groups. The TeV limit (Durham) corresponds to a value of 2.8×10^{-10} cm^{-2} s^{-1} at > 0.4 TeV.

An important departure, made feasible by the higher sensitivities of the Whipple and UMC systems, is the scanning of nearby molecular clouds for VHE/UHE γ-ray emission. An upper limit of 1.8×10^{-11} cm^{-2} s^{-1} at > 0.5 TeV photon energy has been quoted for the Taurus cloud (Akerlof *et al.* 1991b). The UMC collaboration have also given flux upper limits for this and Cygnus cloud with a typical value of $< 3 \times 10^{-14}$ cm^{-2} s^{-1} above 0.2 PeV (Covault *et al.* 1991).

4. Indian plans for imaging γ-ray telescope

Plans are afoot for an indigeneous development of a high-sensitivity γ-ray telescope, keeping in mind the severe limitations of the conventional telescopes and the encouraging experience of the Whipple group with their imaging system. Called TACTIC, after the 'TeV Atmospheric Cerenkov Telescope with an Imaging Camera', this system will involve a total of 4×10 m^2 alt-azimuth-mounted light collectors, which are suitably instrumented to obtain concurrent on- and off-source images of γ- and p-ACE and, in addition, record their spectral (ultraviolet/visible) content as also their time profiles (for supplementary background discrimination). Details of the design philosophy and instrumentation of TACTIC are discussed in accompanying

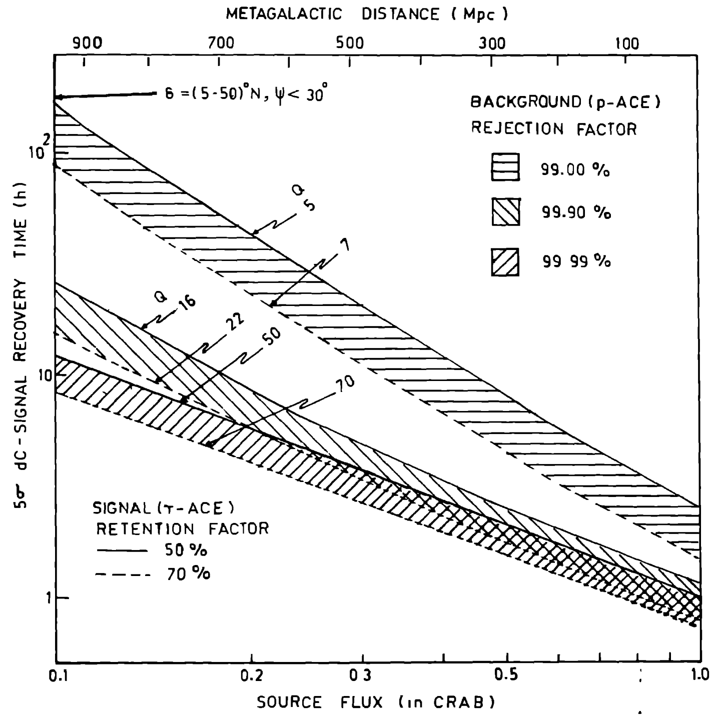

Figure 10. An estimate of the detection sensitivity of TACTIC—an extragalactic source giving a flux of 1 Crab (in the absence of recessional and γ-γ attenuation effects) can be detected to distances of ~ 900 Mpc within 10-180 h of observations (one observing season for a typical source from Gurushikar). The source zenith angle ψ is supposed to remain within 30° during observations.

papers (Bhat *et al.* 1993, Koul *et al.* 1993). Attention is drawn here to the following main design goals for the system : (i) To achieve a background (p-ACE) rejection of > 99.9% without losing, at the same time, more than 50% γ-ACE. This yields a sensitivity figure Q > 25 for TACTIC, enabling it thereby to detect a Crab Nebula-like galactic source (flux ~ 4.5×10^{-11} photons $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ at > 0.5 TeV) in < 1 h of total (ON + OFF) observations at a 5σ confidence level. Equivalently, as shown in figure 10, such an extragalactic source can be detected out to distances of ~ 900 Mpc in ~ 10-180 h of observations, after accounting for the attenuation of the incident γ-ray beam due to recessional effects and absorption by the intervening infrared photon field. (ii) To provide for an efficient and reliable monitoring of all the three emission modes—d.c., periodic and episodic and also for γ-ray emission from non-compact regions like the galactic plane and nearby molecular clouds and supernova remnants.

A proper observatory site at Gurushikar, Mt. Abu, (1700m asl), has been identified for locating the TACTIC experiment (Sapru *et al.* 1993). The first unit is expected to be installed there by early 1994. The full-scale TACTIC (4 units) is scheduled to see 'first light' by the end of 1995.

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