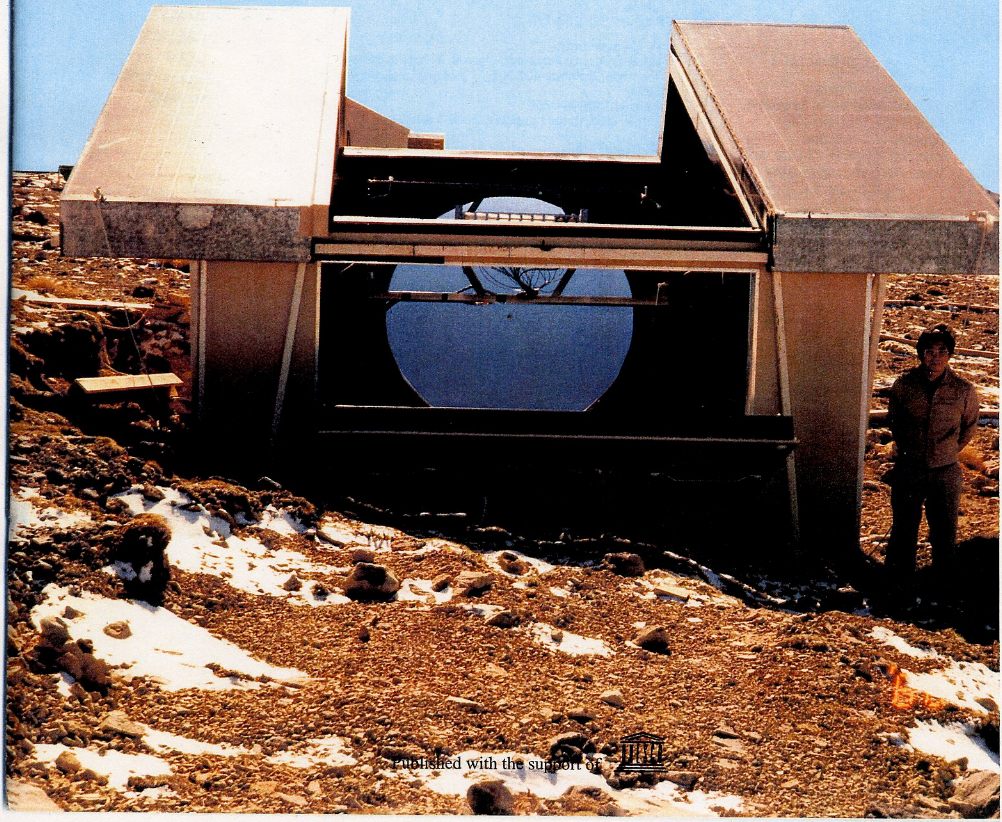
# AAPPS BULLETIN

VOL. 3, NO. 4, DECEMBER 1993

ISSN: 0218-2203



Published with the support of

# The JANZOS Project

This is a brief description and history of the JANZOS (Japan Australia New Zealand Observation of Supernova) project which has been running for six years. Some results are described, and future prospects briefly mentioned.

Philip Yock

## Introduction

An observatory was constructed at Black Birch in the South Island of New Zealand during the winter of 1987. Construction was carried out by some forty staff and students from Japan, Australia and New Zealand, with assistance from the Ministry of Works and the Marlborough Electric Power Board. The project was undertaken following a cabled request for assistance from Tokyo University and the National Laboratory for High Energy Physics in Japan to study the supernova SN1987A which appeared in the Large Magellanic Cloud on February 23 of that year. In view of the special nature of the event – this was the first supernova in 400 years that was visible to the naked eye – some effort was made to provide the assistance that had been requested. Black Birch was selected as the most suitable site in Australia or New Zealand, and construction of the observatory was completed in five months. Data taking commenced in October 1987.

Theories about supernovae have been developed over the past 40 years to explain what happens in the interior of massive stars that causes them to explode and how nuclear reactions fuel the stars through their lifetimes.[1] The theory of nucleosynthesis predicts that stellar nuclear reactions make elements that are heavier than helium and then eject these elements into the interstellar medium to make new stars and planets. If this theory is correct, the known chemical elements were synthesized in the core of a star and then released to make the Earth. The study of a close supernova can give us a detailed look at the processes that presumably made our elements billions of years ago.

The major goal of the JANZOS project when it was set up in 1987 was to find out if a supernova is a significant source of cosmic rays in the first few years following the explosion. Cosmic rays are high speed particles (mostly protons) travelling through the Galaxy. The total energy of these particles is significant, about the same as the total energy of starlight in the Galaxy. Hence it is of interest to determine their origin. Experimental and theoretical studies of cosmic ray particles had been carried out in the three partner countries of JANZOS prior to the supernova explosion.[9] This experience was called on in 1987 to evaluate the potential significance of observations which could be made.

The observatory that was built includes three "air Cerenkov" telescopes (front cover) and an array of plastic scintillators (Figure 1). A list of participants of the project is given at the end of the paper. Professor Muraki, whose telegram initiated the collaboration, appears in Figure 2.

## The Goals of JANZOS

The initial task of the JANZOS project was to see if a supernova emits significant numbers of cosmic rays in the first few years after the explosion. This task is made difficult by the fact that cosmic rays do not travel in straight lines. Being charged particles, their trajectories in the Galaxy are bent by the galactic magnetic field. Thus it is not possible to locate their sources from their arrival directions at the Earth. It has long been recognized, however, that sources of cosmic rays may also be sources of gamma rays, and that it may be possible to pinpoint sources through the gamma rays, because these are undeflected by magnetic fields. In the JANZOS project we have looked for sources of cosmic rays through the associated gamma rays.

The problem of the origin of cosmic rays is especially pressing for those with energies above 100 TeV. The bulk of

Figure 1. University of Auckland physics students David Hirst, Peter Norris and Mark Conway installing scintillation detectors at Black Birch in 1987. Evidence for inter-galactic 3K photons from the Big Bang was obtained with these detectors.

Philip Yock is Associate Professor in Physics Department, The University of Auckland, Auckland, New Zealand. This paper originally appeared in The Australian & New Zealand Physicist, Vol. 30, No. 8, August 1993.

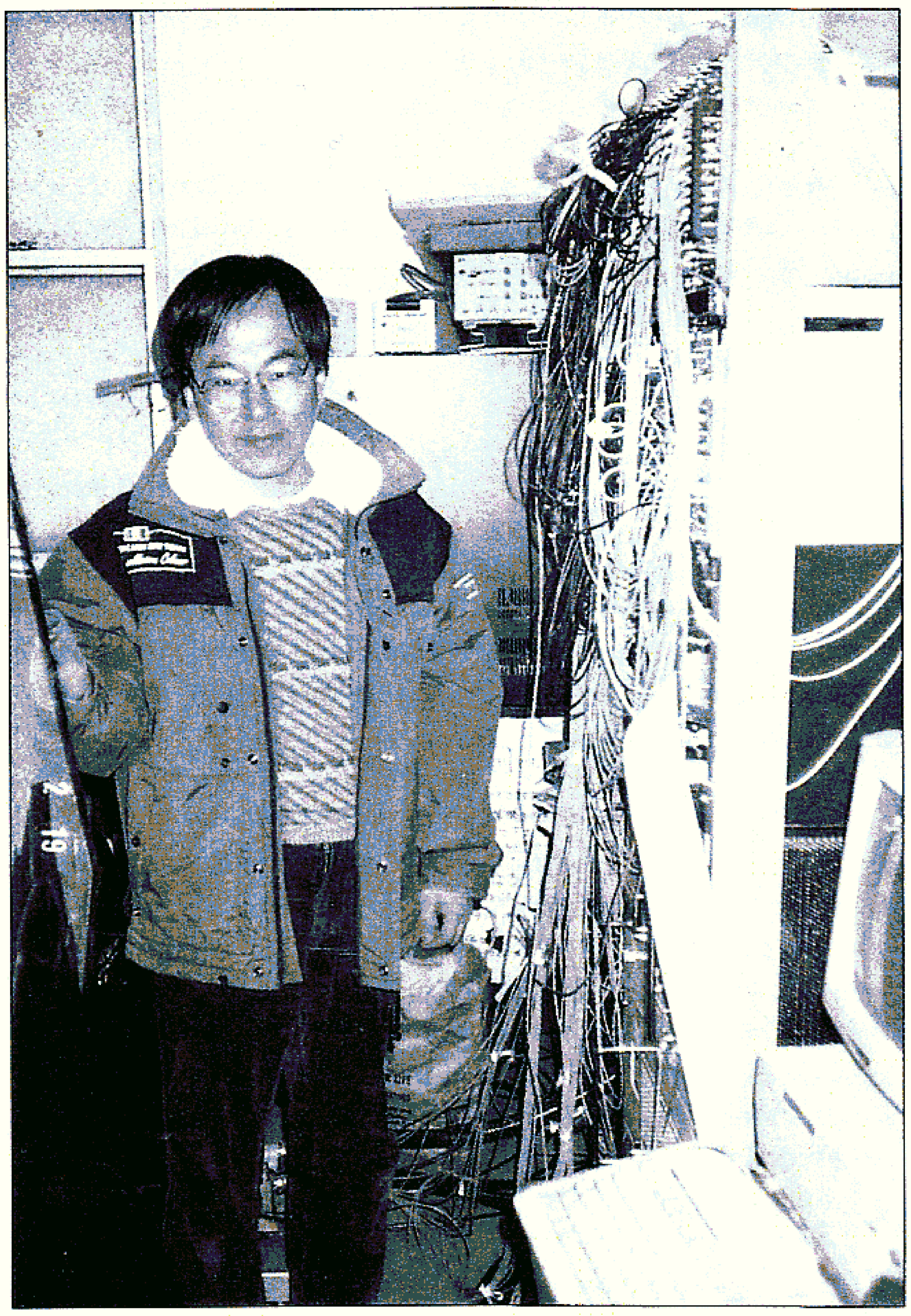


Figure 2. Professor Muraki, an originator of the JANZOS project, checking a solar neutron detector of novel design at Mt. Norikura cosmic ray laboratory (February 1993).

cosmic rays below this energy are believed to originate in blast waves of old supernova remnants, through a process originally proposed by Fermi in which macroscopic kinetic energy of moving magnetized clouds is transferred to individual particles.[2] It can be shown, however, that supernova blast waves cannot be sites of cosmic ray acceleration via the Fermi process to energies beyond about 100 TeV. Gamma ray searches at these ultra-high energies may be especially useful in locating the sites of cosmic ray acceleration.[3] Some of the work done by JANZOS at these energies, in particular on the supernova, is described here.

The search for gamma rays provides a second general goal for JANZOS. This is the exploration of a new window in the electromagnetic spectrum. Detailed observations have been carried out by astronomers over a wide range of the spectrum, from radio wavelengths to X-ray energies. More recently, the gamma ray region has been extensively explored, from MeV to GeV energies. This has led to the observation of mysterious "gamma ray bursts" all over the sky, and to the observation of intense gamma ray emission from the nuclei of active galaxies.[4] The JANZOS observatory is sensitive in the TeV to PeV region, and it is hoped that the observations can be correlated with those made at lower energies. In fact, a substantial effort (described here) has already been made by JANZOS to study the nucleus of the galaxy Centaurus A. This is the nearest active galaxy to the Earth, and it passes overhead at the JANZOS site.

Further motivation for JANZOS arises from the emerging field[5] of "particle astrophysics". This growing symbiosis is at the frontier between high energy astrophysics, cosmology and particle physics, and it is possible that experiments such as the JANZOS one can contribute. Indeed, a contribution has recently been made by JANZOS in the area of cosmology. Lastly, we mention here the mountain altitude location of JANZOS (1635m). This is the highest altitude of any observatory in Australasia and has provided the opportunity to follow up, with higher statistical accuracy, observations[6] which were made from sea-level sites in Australia in the 1970's and 1980's. This is a result of the greater fluxes which are observed at higher altitudes because of reduced atmospheric absorption.

## Experimental Techniques

A schematic diagram of the JANZOS observatory appears in Figure 3. A gamma ray from supernova SN1987A is shown striking the earth's atmosphere. A shower containing many particles is formed, and this propagates through the atmosphere at very nearly the speed of light. The shower particles are mostly electrons and positrons, and they are detected by the scintillators shown in Figures 1 and 3. As the shower particles propagate through the atmosphere, they generate a flash of (bluish) "Cerenkov" light, because they exceed the speed of light in air. The flash is detected by the telescopes shown in front cover and Figure 3.

Directional information is obtained by timing measurements. Clearly, for the shower shown in Figure 3, the detectors on the left will be struck several nanoseconds earlier than those on the right. The angular resolution of the timing technique is limited to about one degree, because of the curvature and diffuseness of the shower front shown in the figure, and because of the sampling procedure used to detect the shower front. The resolution of one degree is similar to that attained by other groups. In the JANZOS setup, the timing

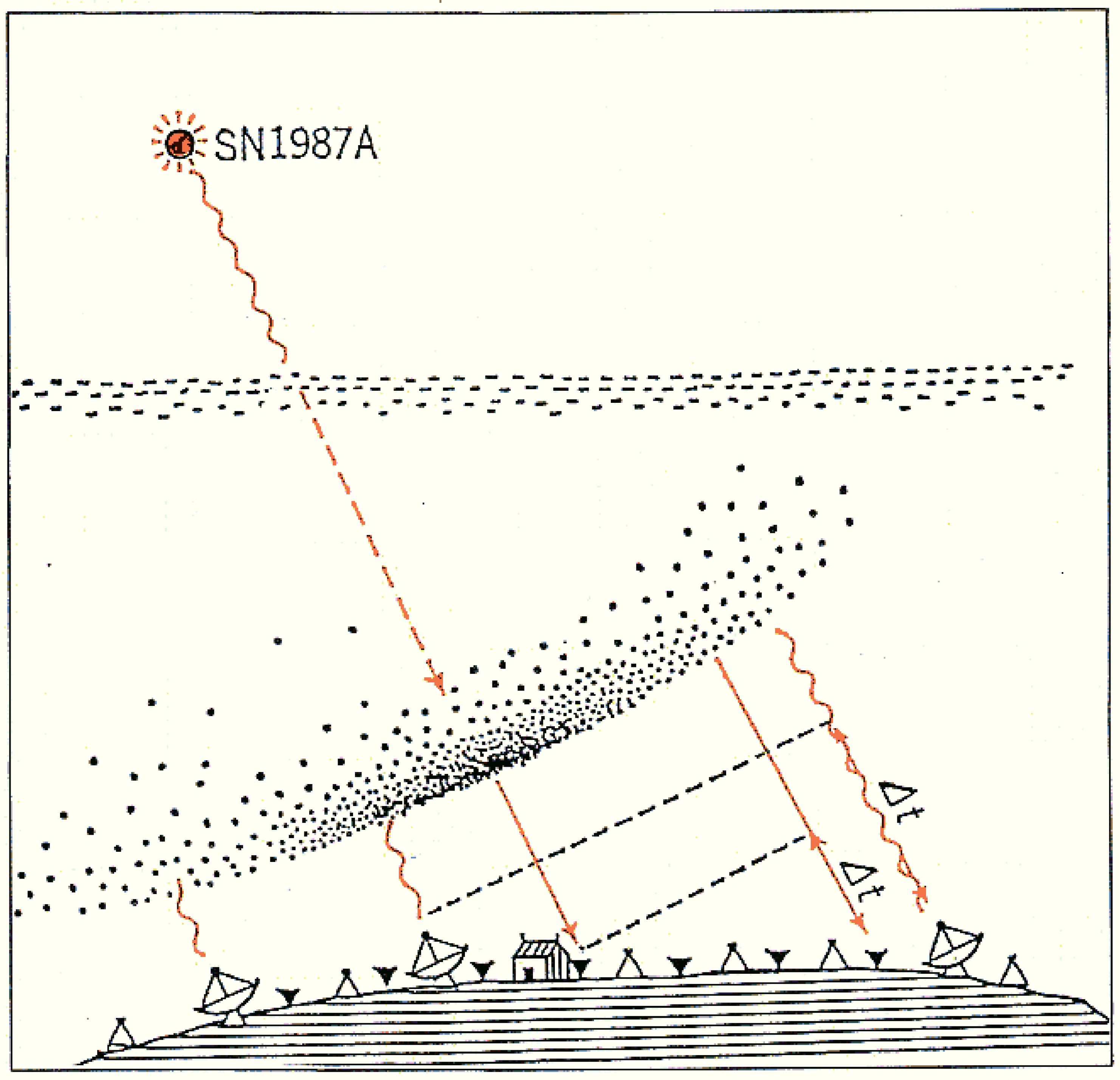



Figure 3. Side view of the JANZOS setup. A gamma ray from the supernova is shown producing a shower of particles in the atmosphere. The shower is detected by the three telescopes and the array of scintillators shown as triangles. The signals are routed to the eleclranic hut in the centre.

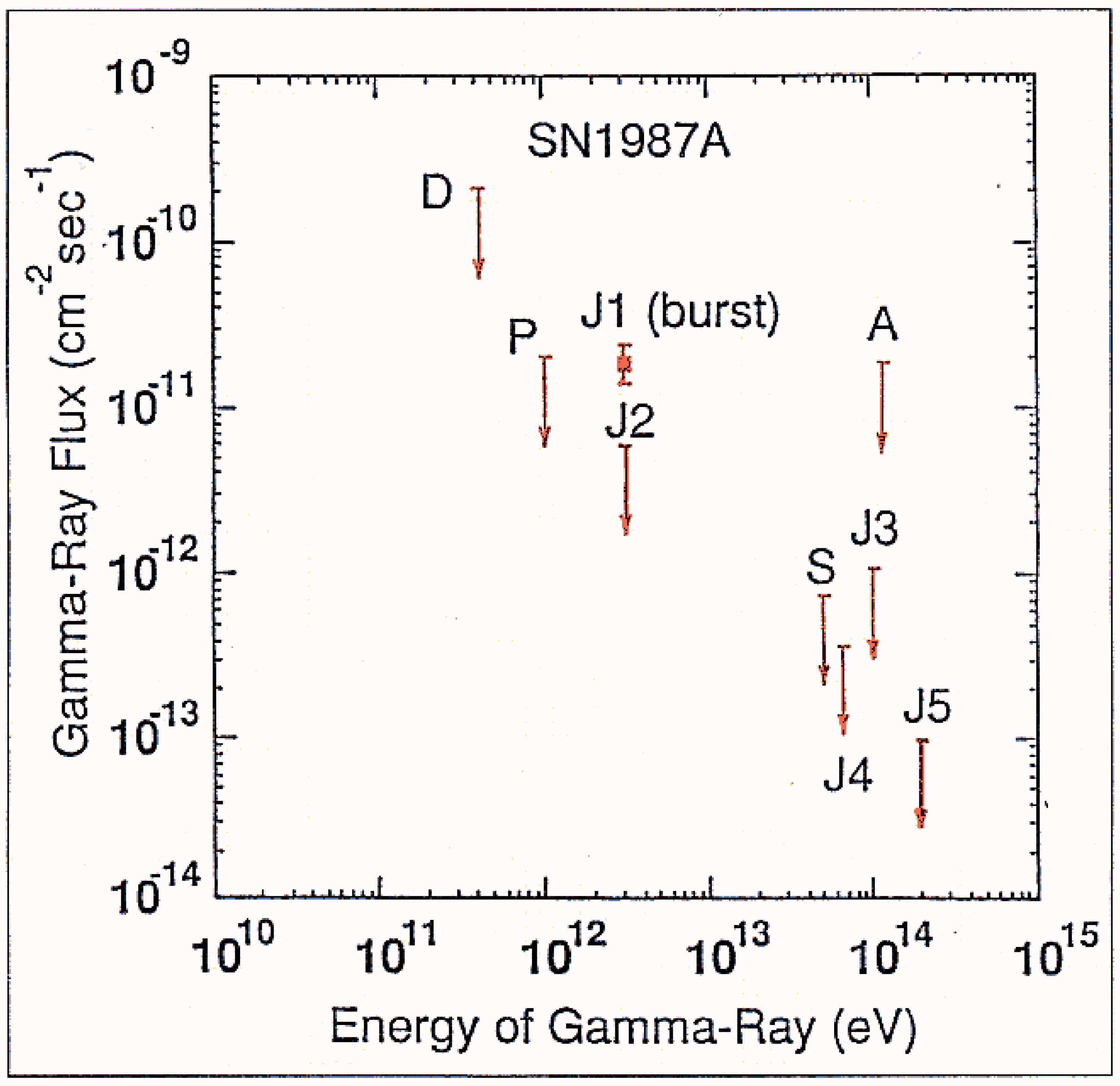



Figure 4. Gamma ray fluxes from the supernova as measured by various groups.[7] Measurements by JANZOS are labelled Jl-J5. Measurements by Durham, Potchefstroom, South Pole and Adelaide groups are labelled D, P, S and A respectively. The Durham group observes from New South Wales.

measurements are calibrated with a pulsed laser and a system of optical fibres which illuminate the detectors simultaneously. Energies of incident particles are determined from shower sizes. A threshold energy of 1 TeV is required to trigger the Cerenkov telescopes, and for the scintillators the threshold is about 50 TeV. The Cerenkov telescopes can only be used on clear, moonless nights, and they view a limited region of sky at any one time (approximately 150 square degrees). The scintillators, on the other hand, operate day and night as an "all-sky-camera". This is a significant advantage, because some possible sources of ultra-high energy gamma rays and cosmic rays are variable objects. Further details on the experimental techniques used by JANZOS have been given elsewhere.[7]

## Some Results of the JANZOS Project

Some representative results obtained by JANZOS to date are described here. Three objects only are discussed, the supernova SN1987A, a recently discovered millisecond pulsar, and the active galaxy Centaurus A. Details of the observations have been published.[7] The publications also describe other work which has been carried out, including a survey of the southern sky.

### SN1987A

Several observations have been made of the supernova, both by JANZOS and by other high energy gamma ray groups working in South Africa, in Australia, and at the South Pole. The results of all groups have been collated in Figure 4. Some features are apparent. Firstly, except for a burst in the TeV region reported by JANZOS,[8] no signal has been detected in the TeV to PeV region. All the other measurements shown in Figure 4 are for average fluxes over long periods, and they are clearly consistent. The most sensitive measurements at ultra-high energies are those by the South Pole and JANZOS groups.

The observations that were made about one year after the supernova explosion are especially useful, since at that time the ejecta of the supernova formed a target of optimal thickness (approximately one nuclear mean free path) for conversion of cosmic rays to gamma rays.[9] The limits obtained on the gamma ray flux at that time yield quite model independent limits on the cosmic ray luminosity of a young, compact, supernova remnant. The limit obtained by JANZOS above 100 TeV is of order 10E33 watts.[10] This compares with the power, about 10E32 watts,[3] required to energize cosmic rays in the Galaxy above this energy. This is about the power of a million stars like the Sun. Clearly, the result obtained by JANZOS can be used to constrain theories which would attempt to ascribe a large fraction of ultra-high energy cosmic ray production at any one time to a few, young, compact supernova remnants. Assuming SN1987A was a standard supernova explosion, we can conclude that, at a supernova rate of one per century in the Galaxy, the power output of supernovae in the first few years is insufficient to energize all ultra-high energy cosmic rays.

A more restrictive, but model dependent, result can be deduced from the burst seen at TeV energies. This was very faint, and could not be unambiguously distinguished from background. It was, however, interpreted as possibly due either to a collision of material ejected from the supernova with surrounding circumstellar material, or to a pulsar of unexpectedly low power, about 10E30 watts.[11] A supernova explosion is normally expected to produce a compact star, known as a pulsar, at the explosion site. The pulsar is highly magnetized and spins fast. As it spins it radiates beams of energy, and these appear as pulses like a lighthouse. The best known pulsar is the Crab pulsar. This was produced as the aftermath of a supernova explosion observed as a "guest star" by Chinese astronomers in 1054AD. The power of the Crab pulsar, which may be regarded as a standard, is twenty times higher than that deduced above for a possible pulsar remnant of SN1987A. This suggests that SN1987A was not a typical supernova explosion. Simiiar conclusions have been reached through observations of SN1987A at other wavelengths.[12]

### PSRJ0437-4715

As a second example of observations by JANZOS we consider here a nearby, millisecond pulsar (termed PSRJ0437-4715) which was discovered recently with the Parkes radio telescope in Australia.[13] Millisecond pulsars are old pulsars with companion stars from which angular momentum has been transferred. They spin very fast, but their magnetic fields have decayed, and they do not radiate as strongly as young pulsars like the Crab. The radio signal from PSRJ0437-4715 is clear, and the estimated distance is only 400 light years. The declination of the pulsar (47^S) takes it almost directly over the JANZOS site. The pulsar is in a binary orbit with a low-mass companion star, and the orbital period is 5.7 days. It was suggested by the Parkes group that this object may be a gamma ray source. Consequently, we searched the JANZOS data base from 1987 to 1992 in the direction of the pulsar. Our results[7] are plotted in Figure 5 in the form of a phaseogram at the orbital period. This is a sensitive technique which has been used by various groups. As the figure shows, we obtain no evidence for emission from this object at ultra-high energies. The upper limit obtained by JANZOS on the flux above 100 TeV is less than 10E-13 photons cm$^{-2}$ sec$^{-1}$. At a distance of 400 light years, this

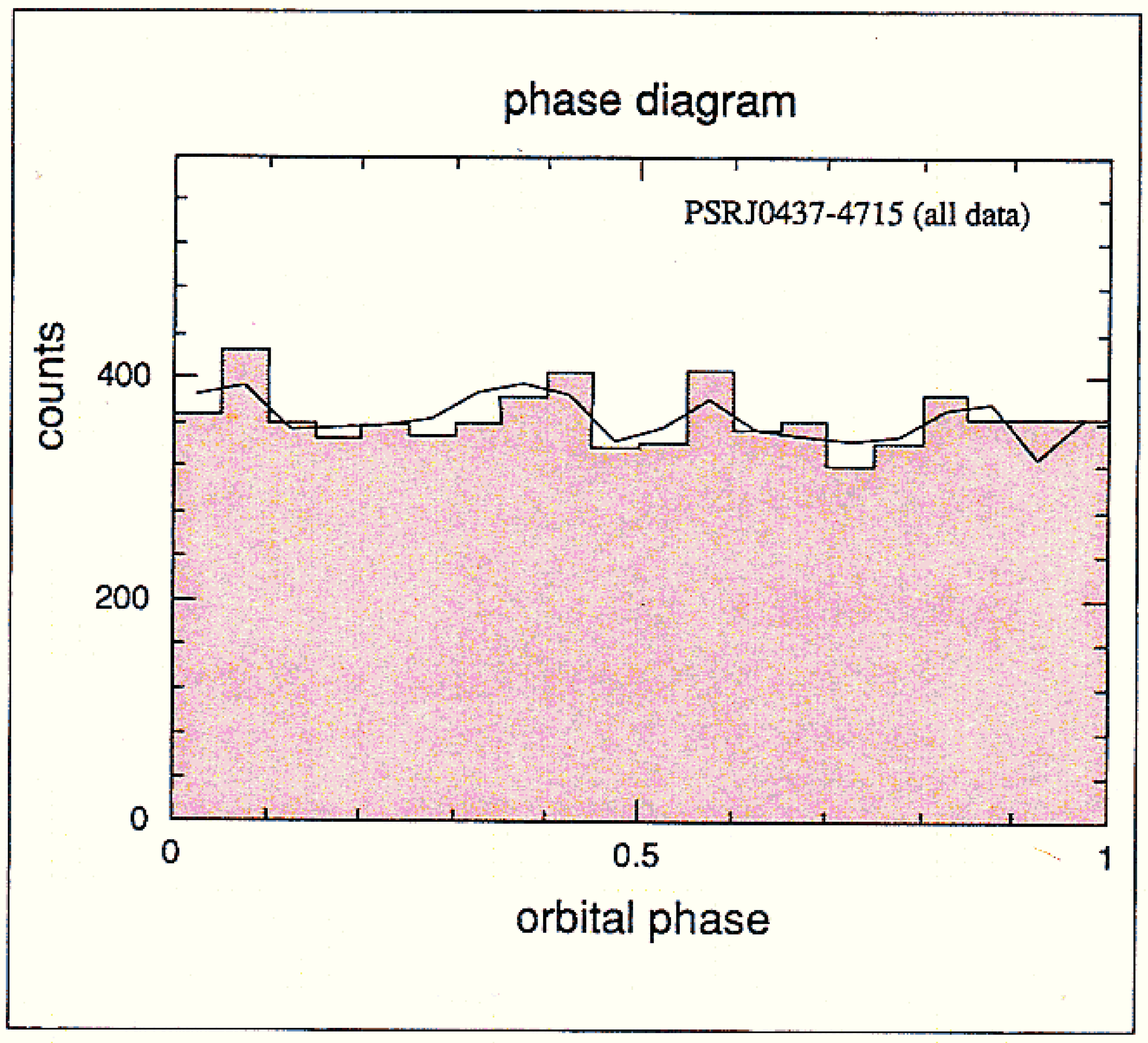



Figure 5. Phaseogram of binary, millisecond pulsar PSRJ0437-4715 at ultra-high energy. The line denotes the cosmic ray background. No significant excess above the background is seen.

corresponds to an upper limit on the power of 10E25 watts above 100 TeV. Because the pulsar is radiating energy, it spins more slowly with time. The "spin-down" has been measured and it corresponds to a total radiated power at all frequencies of 3 x 10E27 watts.[13] We conclude that less than 1% of the spin-down energy of a millisecond pulsar is emitted as ultra-high energy photons.

## Centaurus A

As a final example, some recently obtained results on the galaxy Centaurus A are summarized here. This is the nearest active galaxy and it passes overhead at the JANZOS site. The nuclei of active galaxies are the most powerful emitters of radiation in the known Universe. It is thought that these objects contain supermassive black holes at their centres, and that they are powered by gravitational energy from matter falling towards the black hole. This process may account for their prodigious power from radio wavelengths to gamma ray energies, for their small sizes, and for the frequent occurrence of jets of material seen emanating from them.[14] It has been suggested that protons are accelerated to ultra-high energies near their nuclei through a variant of the Fermi process. It is possible that some of these escape from the acceleration region as a result of nuclear interactions, and subsequently produce gamma rays. Several versions of this general scenario have been proposed.[5]

The X-ray powers of active galaxies range from about 10E36 watts to about 10E40 watts. Centaurus A is at the lower end of the scale. However it is the closest active galaxy and this is an important consideration for ultra-high energy gamma ray astronomy, because gamma rays with energies above a few hundred TeV are expected to be absorbed in inter-galactic space by interactions with remnant 3K photons from the Big Bang. The process which causes absorption is the collision of an ultra-high energy gamma ray and a 3K photon producing an electron-positron pair. The threshold and absorption length for the process are about 2 PeV and 30,000 light years, respectively. Gamma rays with energies below 2 PeV may also be absorbed, because the 3K photon field follows the Planck distribution, but the absorption length is greater.[16]

The distance of Centaurus A is approximately 15 million light years, and the JANZOS data collected from the direction of the nucleus between 50 TeV and 1 PeV have been examined. Previous studies of Centaurus A at X-ray energies had revealed a typical outburst period of 50 days at a power of 10E36 watts. In our data base for 1987 to 1992 we found evidence, at a significantly high level of confidence, for one outburst at ultra-high energy of similar duration and similar power.[7] A contour plot of the region is shown in Figure 6. The signal appears to have been present amongst events below 200 TeV, but absent above this energy. This is the expected behaviour due to the absorption process on the 3K photon field in a distance of 15 million light years. The observation of the absorption feature in the spectrum provides direct evidence for the existence of inter-galactic 3K photons. It is remarked here that the above described results are new. The emission of ultra-high energy gamma rays has not been observed before from an active galaxy, and direct, observational evidence for inter-galactic remnant radiation from the Big Bang has been lacking. In view of the novel nature of the results, it is hoped that further observations may be made with improved precision and confidence. Such observations may elucidate details of particle acceleration in active galaxies, and provide information on the strength of the inter-galactic magnetic field.[7]

There is, of course, no reason to suppose that Centaurus A is an unusual example of an active galaxy. Presumably results obtained with this galaxy apply in a general sense to all active galaxies.

The active galaxy Markarian 421 in the northern sky has recently been found to be an emitter of 500 GeV gamma rays.[17]

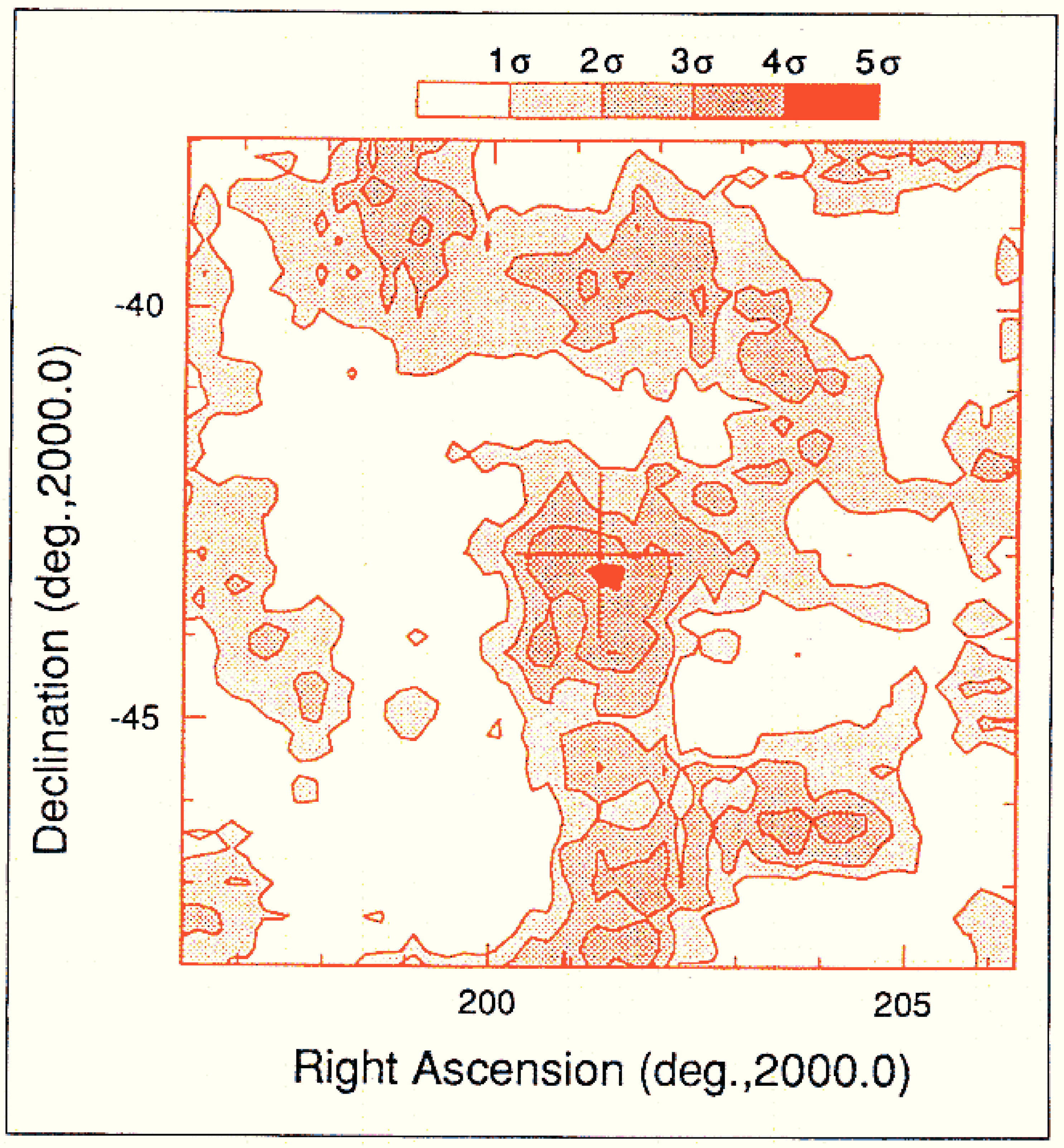



Figure 6. Contour map in the region of Centaurus A obtained in the period 14 April 1990 to 3 June 1990. The data are for events with energies between approximately 50 and 200 TeV. The nucleus ofCentaurus A is denoted by the cross. No signal was seen in the data above 200 TeV.

Further information on high energy processes which occur in the nuclei of active galaxies may be obtained with neutrino telescopes which are presently under construction at Hawaii and at the South Pole,[18] and with various gamma ray telescopes in operation around the globe.

## Summary

The request from Japan for assistance to carry out gamma ray studies of SN1987A has led to some fruitful results. An observatory was built with state-of-the-art performance. It is the only high-altitude observatory of its type at a mid southern latitude. This enables unique observations to be made. The work is of relevance to cosmic ray physics, to high energy astrophysics, and to cosmology. Measurements have been made on southern objects with greater precision than was previously possible. The main physics results obtained to date are:

1. Experimental evidence that supernovae do not energize all ultra-high energy cosmic rays in the first few years.
2. Experimental evidence that active galaxies emit ultra-high energy gamma rays. The power is similar to the X-ray power.
3. Experimental evidence that remnant radiation from the Big Bang is present in inter-galactic space.

Several physics students from the University of Auckland contributed significantly towards the project. They also learned much working alongside experts at a frontier of a developing field.

The observatory is still operational after six years of continuous running. It is hoped that, with support, further observations may be carried out.

## Acknowledgements

The JANZOS project has been carried out as a team effort to date. The author of this article would like to take this opportunity to express his sincere thanks to his family and friends for support throughout the project.

He is also most grateful for hospitality extended to him by colleagues at Nagoya University where this article was written, and to Ed Budding, John Humble and Jack Storey for commenting on the manuscript.

## Participants of Janzos

**Carter Observatory, New Zealand**
Allen W.H., Budding E. Wadsworth A.

**University of Auckland**
Bond I.A., Camilleri M., Conway M.J., Daniel A., Lythe G.D., Norris P.M., Spencer M., Storey J.R., Woodhams M.D., Yock P.C.M.

**University of Tasmania**
Fenton K.B., Humble J.E.

**National Laboratory for High Energy Physics, Japan**
Fujii H., Kabe S., Miura Y., Mori M., Watase Y.

**Nagoya University**
Fujii Z., Maehara O., Matsubara Y., Muraki Y.

**University of Tokyo**
Hayashida N., Hibino K., Honda M., Kifune T., Mitsui K., Nagano M., Saito To., Teshima M., Yuda T.

**Kanagawa University**
Kasahara K., Torii S.

**Kyoto University**
Masaike A., Nakamura T., Sato H., Shimizu H.M.

**Konan University**
Nishizawa M., Sakata M., Yamamoto Y.

**Tokyo Institute of Technology**
Ogio S., Tanimori T.

## References

1 S.E. Woolsley and T. Weaver, Scientific American, p24, August (1989); C.H. Atwood, Chemistry in Britain, p423, May (1990).

2 W.I. Axford, Proc. 17th Int. Conf. Cosmic Rays **12**, 155 (1981); M.S. Longair, *High Energy Astrophysics* (CUP 1992).

3 T.K. Gaisser, *Cosmic Rays and Particle Physics* (CUP 1990)

4 G. F. Bignami, Nature, 360, 416 (1992)

5 F. Close et al, *The Particle Explosion* (OUP 1987); B. Sadoulet and J.W. Cronin, Physics Today, p53, April (1991).

6 R.W. Clay et al, Aust. J. Phys. **37**, 91 (1984); R.J. Protheroe et al, Astro. J. **280**, L47 (1984); R.J. Protheroe and R.W. Clay, Nature **315**, 205 (1985); D. Ciampa et al, Astro. J. **346**, 151 (1989); R. Meyhandan et al, Astro. J. 391,236 (1992); R.W. Clay et al, Astron. Astrophys. **255**, 167 (1992).

7 W.H. Allen et al, Astro. J. **403**, 239 (1993); W.H. Allen et al Astro. J. **405**, 554 (1993); W.H. Allen et al, Phys. Rev., **1**, 296 (1993); W.H. Allen et al, Astroparticle Phys., **D48**, 466 (1993) W.H. Allen et al, *Proc. 23 Int. Conf Cosmic Rays*, **1**, 227 and 349 (1993).

8 I.A. Bond et al, Phys. Rev. Letters **61**, 2292 (1988).

9 H. Sato, Prog. Theor. Physics **58**, 549 (1977).

10 I.A. Bond et al, Phys. Rev. Letters **61**, 1110 (1988).

11 M. Honda et al, Prog. Theor. Physics **82**, 315 (1989); V.S. Berezinski and T. Stanev, Phys. Rev. Letters **63**, 1035 (1989).

12 R.A. Chevalier, Nature **360**, 628 (1992).

13 S. Johnston et al, Nature **361**, 613 (1993).

14 M.S. Longair, reference 2; R. Ruthen, Scientific American, p 18, December (1992).

15 F.W. Stecker et al, Phys. Rev. Letters **66**, 2697 (1991); R.J. Protheroe and A.P. Szabo, Phys. Rev. Letters **69**, 2885 (1992); V.J. Stenger, *High Energy Neutrino Astrophysics* (World Scientific 1992).

16 R.J. Protheroe and R.W. Clay, reference 6; M. Honda, Astro. J. **339**, 629 (1989).

17 M. Punch et al, Nature **358**, 477 (1992).

18 D.M. Lowder et al, Nature **353**, 3 31 ( 1991 ).