GAMMA RAY ASTRONOMY FROM SATELLITES AND BALLOONS

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1. Introduction. This rapporteur talk deals with the field of gamma ray astronomy from satellites and balloons and therefore is restricted to energies below about 10 GeV. Ground based gamma ray observations (E_γ > 1 TeV) will be covered by the rapporteur talk of Dr. Watson.

Gamma ray astronomy provides the opportunity to study high energy phenomena in space. Many of these phenomena are directly related to questions of cosmic ray research, so gamma ray astronomy plays a central role for cosmic ray research.

Gamma ray astronomy has become a rather broad field. The different topics can be grouped under the following headings:

- gamma ray bursts
- gamma ray line spectroscopy
- galactic gamma ray sources
- broad scale distribution of galactic gamma ray emission
- extragalactic gamma ray astronomy (extragalactic sources and diffuse cosmic gamma ray background)

All these topics were covered during the conference (by in total 62 papers), and in my presentation I shall follow this subdivision.

2. Gamma Ray Bursts. During the time of their bursts cosmic gamma ray bursters are the by far brightest gamma ray sources in the sky. Our entire knowledge on bursters is essentially based on the measurement of four different properties of their bursts. These are

- their light curves
- their energy spectra
- the location of the burster in the sky
- recently, for very few gamma ray burst sources, a correlated observation in the optical range

Additional information on each of these four observational aspects was provided at the conference:

The durations of gamma ray bursts typically range from a few tenths of a second to tens of seconds. Some are as short as 10^{-2} sec, others as long as 100 sec. It seems that there is no uniform structure in the light-curves of different bursts. Some bursts show single spikes only, others very complex structures. Cline (OG 1.2-6) has speculated that all complex long duration bursts might be characterised as superposition of single spikes, which are similar for all bursts.

The energy spectra of gamma ray bursts in many cases show a thermal bremsstrahlung spectrum $N(E)dE \sim E^{-1} \exp(E/kT)$ with kt ≈ 300 keV. Recently, however SMM-measurements (Matz et al., 1985) have shown that high energy gamma ray emission above 1 MeV is a common feature of bursts. This conclusion was confirmed by HEAO-1 observations (Hueter and Matteson, OG 1.1-1). Many bursts show power law spectra at least up to 6 MeV and are in conflict with the normal thermal model burst spectra.

Our knowledge on burster positions in the sky is mainly - with the exception of a very few measurements with position sensitive burst detectors - based on triangulation from different spacecraft locations. An overview on

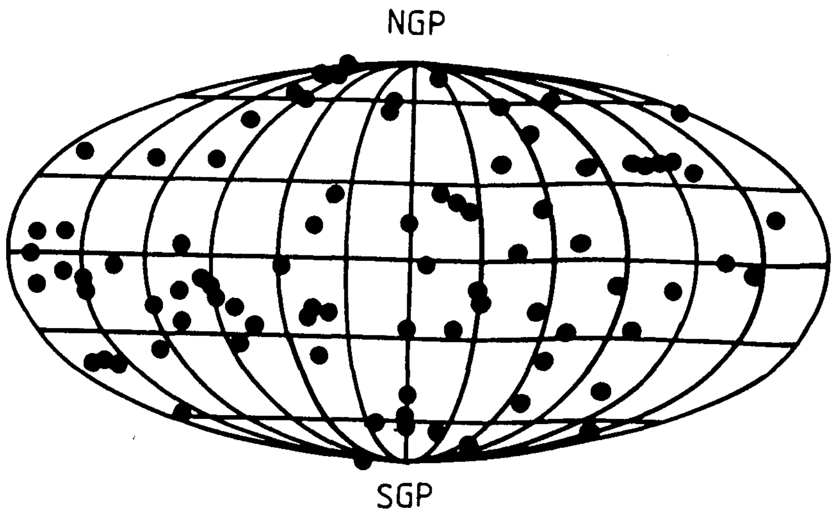

Fig. 1 Distribution of 86 bursters on the sky (from Atteia et al., OG 1.2-1).

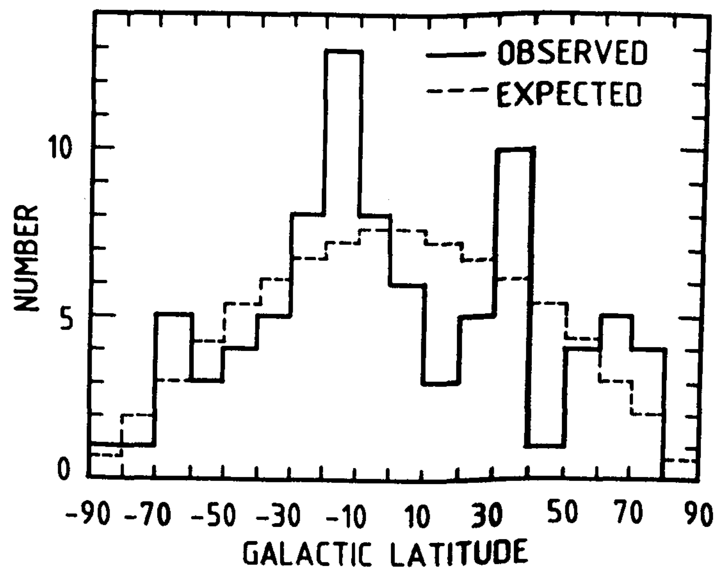

Fig. 2 Latitude distribution of the 86 bursters of Fig. 1. The dashed line is the distribution expected on the basis of isotropy (from Atteia et al., OG 1.2-1).

our present state of knowledge was given at the conference (Atteia et al. (OG 1.2-1). Fig. 1 displays the distribution of 86 bursters in the sky. Fig. 2 shows the latitude distribution of these locations as well as that expected, if the distribution is isotropic. It is clear: the observed burster distribution is consistent with isotropy.

Extensive efforts to find out whether optical phenomena are associated with gamma ray bursters were finally successful. At the positions of 3 different gamma ray bursts optical flashes could be found on archival photographs. The optical flashes occurred in 1901, 1928 and 1944 and are correlated with the gamma ray bursts of Nov. 5, 1979, Nov. 19, 1979, and January 1, 1979, respectively (Schaefer et al., 1984). The optical flashes had durations of typically 1 sec. From statistical considerations it was estimated that the recurrence time scale of the optical flashes of a burster is about 1 year. The energy emitted in gamma-rays was estimated to be about 1000-times larger than in the optical flashes. We do not yet know, whether optical and gamma-ray bursts occur simultaneously. A detailed analysis of the bursts of the Second Interplanetary Network (Atteia et al., OG 1.2-5) came to the important conclusion that the best lower limit to the repetition rate of gamma ray bursts from one and the same source is 100 months. So far only two examples of repetition are known at all (one of which is the burster with the famest outburst on March 5, 1979). Further searches for counterparts of gamma ray bursters in the optical and infrared region so far remained unsuccessful (Gehrels et al., OG 1.1.-7, Seetha et al., OG 1.1-8, and Schaefer and Cline OG 1.1-9). Such counterpart searches will definitely play an important role in gamma ray burst astronomy of the near future.

More observational "facts" on cosmic gamma ray bursters are now urgently needed in order to come to an understanding about their nature. So far, more than 40 models have been suggested to explain the origin of the bursts. During the last few years a certain consensus about the nature of the burst sources has been achieved. First, it is now generally agreed that the burst sources are contained within the Milky Way and second, there is strong evidence that a neutron star is somehow involved in the sources. Both these conclusions have to be discussed in more detail:

The galactic origin of most of the gamma ray bursts so far was mainly derived from the log N (> S) - log S diagram, which shows a -1.5-slope at high fluences (time integrated gamma ray flux) S and a flattening at lower fluences. This shape has been generally interpreted as evidence for the galactic origin of bursts: it is expected from an isotropic burster distribution up to about 300 pc distance and a disk like distribution for larger distances, if all bursts are assumed to have the same intrinsic gamma ray luminosity. Such an interpretation, however, is inconsistent with the distribution of measured burst positions on the sky (see Fig. 1 and 2), which show complete isotropy. Many people have worked on this problem. It has been shown that a halo-distribution of bursts can also reproduce the observed log N (> S) - log S curve, if a proper luminosity distribution is assumed (for a review see Jennings, 1984). In case of an extragalactic origin the log N (> S) - log S curve should have the -1.5-slope over the entire range and should show much more structure, because the bursters would be expected to be clustered in certain galaxies. In addition, it is difficult to explain the resulting very high luminosities of typically 10^{46} erg instead of typically 10^{38} erg for a galactic origin.

During the conference strong arguments were put forward that the flattening of the fluence distribution at low fluences actually is only an observational selection effect due to variations in durations and energy spectra of different bursts (Higdon and Lingenfelter, OG 1.2-3 and Nishimura and Yamagami, OG 1.2-10). The selection effect on duration is due to the fact that burst detectors do not trigger on a minimum fluence, but on a minimum flux increase within a fixed time. Similarly, different energy spectra of bursts lead to a selection effect, because a given burst detector samples only a limited energy band and not the entire energy range of the burst. The result of the energy selection effect is illustrated in Fig. 3. Here the peak

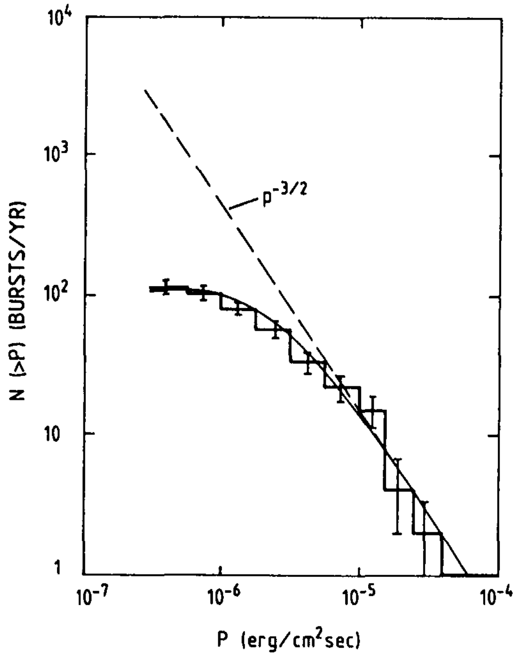

Fig. 3 Burst size-frequency distribution of peak energy flux, N (> P) as function of P. Measuring points are from Venera-data. Solid line is derived from an isotropic burst distribution with a certain assumed intrinsic energy distribution. The flattening of the solid curve at low P-values is caused by spectral selection biases of the burst-detectors (from Higdon and Lingenfelter, OG 1.2-3).

energy flux P is used instead of the fluence S, because P is more directly related to the burst detector response than the fluence and because the influence of variations in burst duration is minimised, if P is used. In Fig. 3 the size frequency distribution for bursts observed by Venera is compared with that expected from an isotropic distribution of sources, which have a certain assumed distribution of energy spectra. As can be seen, spectral selection biases can indeed account for the observed deviation from the simple -1.5 power law distribution. The flattening of the size frequency distribution therefore no longer seems to be an argument for the galactic origin. The strongest arguments for the galactic origin at present are the luminosity argument and the neutron star hypothesis.

Why do we believe that a neutron star is somehow involved in the burst sources? First, there is some observational evidence: namely the existence of absorption lines between 30 to 70 keV, which are interpreted as cyclotron lines and, therefore, require magnetic field strengthes which are available only on the surface of a neutron star. Furthermore, about 7% of all bursts show an emission line at about 420 keV, which is interpreted as red-shifted annihilation line in the gravitational field of a neutron star. In addition to these (and a few other) observational evidences there are also some good theoretical reasons, why neutron stars should be involved: it is easy to account for the observed energy release by means of their gravitational and/or magnetic field energy, and the high magnetic field density provides a means to confine the source region against the radiation pressure of the gamma-rays.

Essentially four different classes of models exist, in which a neutron star is the main cause of the gamma ray bursts: The four causes are:

- accretion of matter onto the surface of a neutron star (either from interstellar space or from a companion star). The material is heated and may lead to an explosion after some reservoir of accreted matter has reached a critical mass (nuclear flash model).
- star quakes, which generate shocks
- magnetic instabilities near the surface of the neutron star
- impact of a comet or asteroid onto the neutron star surface.

It is quite clear that further observations are needed to confirm the neutron star hypothesis and to distinguish between these models. The future aspects of gamma ray burst astronomy are quite promising: once, due to the burst capabilities of GRO and then due to efforts which are presently undertaken to observe large numbers of correlated optical flashes.

3. Gamma Ray Line Astronomy. Gamma ray line astronomy is no longer a field for theoreticians only. Gamma ray lines by now have been detected from solar flares, from gamma-ray bursts and transient sources, and from some steady sources. In the following I shall restrict myself to line-emission from steady sources only (solar flare gamma ray line emission will be discussed in the SH-session). Three such sources are listed in Table 1:

Table 1: Sources of Gamma Ray Line Emission

galactic center	511 keV-annihilation line
interstellar space	1.8 MeV-line from radioactive Al^{26}
SS 433	lines at 1.5 MeV and 1.2 MeV

New results on each of the sources were presented at the conference: The 511 keV-line from the galactic center region has first been detected in the 1970's and since then has turned out to be variable in intensity on a time scale of about half a year. A new attempt of the joint Bell/Sandia gamma-ray astronomy group to detect the line in a balloon flight in November last year was not successful. The source was still in the "off"-state (MacCallum and Leventhal, OG 2.5-5). Considering the large flux of the line, the rapid variability, the line width (< 2.5 keV FWHM), and the absence of other nuclear gamma ray lines from the center region a black hole model provides the easiest and most natural explanation for the origin of the line.

The 1.809 MeV line from Al^{26} in interstellar space is the first line from a radioactive nucleosynthesis product. The line was first detected by HEAO-3 (Mahoney et al. 1984) and now also by SMM (Share et al., OG 3.2-1). The HEAO-3 line profile is shown in Fig. 4 (from Mahoney et al., OG 3.2-3). Al^{26} is a long lived isotope of half-life $1.4 \cdot 10^6$ years. Therefore the presently observed line intensity is the sum emission over more than a million years. The observed abundance ratio Al^{26}/Al^{27} is a factor of 10 too high to be explained by supernovae alone. It therefore is concluded that most of the Al^{26} is produced in novae (Clayton, 1984). Other possible contributors are massive stars and red giants (Prantzos et al., OG 3.2-5). In order to better understand the origin of the line it would be necessary to measure the angular distribution of the line: whereas the novae-distribution is strongly peaked towards the galactic center, supernovae and massive stars have a much broader distribution.

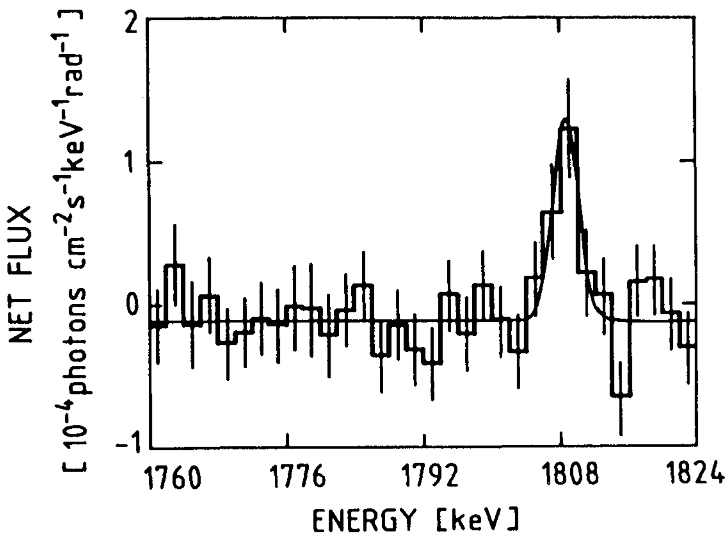

Fig. 4 The 1.809 MeV-line in the diffuse galactic gamma ray emission from the center region as observed by HEAO-3 (from Mahoney et al., OG 3.2-3).

Gamma ray line emission at 1.5 and 1.2 MeV from the binary system SS 433 was reported by HEAO-3 (Lamb et al., 1983 and Wheaton et al. OG 2.4-9). These two lines were interpreted as Doppler shifted lines from Mg^{24} (1.369 MeV) or from N^{14} (1380 MeV). The SMM-investigators (Geldzahler et al. OG 2.4-11) have analysed 468 days of their data, during which SS 433 was within the field-of-view. The line is not seen! The upper limits derived by SMM are at least an order of magnitude below the fluxes of HEAO-3. Either SS 433 shows unusual variability at gamma ray energies or statistical/systematic fluctuations were misinterpreted by the HEAO-3 group. The HEAO-3 group believes the latter possibility to be very unlikely, at least for the 1.5 MeV line.

In addition to the three lines discussed so far, other line observations are reported in the literature. However, most of them are at the limit of statistical significance. We therefore have to wait for more sensitive observations. The intensities of so far detected lines are in the range of $10^{-3}/cm^2$ sec or somewhat lower. GRO will be able to detect line intensities down to $10^{-5}/cm^2$ sec. A next generation of high resolution gamma ray spectroscopy instruments with senstivities down to $10^{-6}/cm^2$ sec will be needed, however, to open the full potential of gamma ray line spectroscopy.

4. Galactic Gamma Ray Sources. Most of the known galactic gamma ray sources are contained in the second COS-B catalog. So far only 3 sources of

this catalog are identified, namely the quasar 3C 273; the only extragalactic object in this catalog, and the two radio pulsars Crab and Vela. A fourth source 2CG 353+16 which was tentatively identified with the ρ -Ophiuchi cloud has been resolved in the meantime (Hermsen, 1983). Not contained in this catalog is the Orion nebula which covers a field of the sky of a few hundred square degrees and which was resolved by COS-B.

The remaining 21 sources of the catalog are still unidentified in spite of tremendous efforts to find counterparts in other spectral ranges. Because nearly all sources are located along the galactic plane, it is obvious that most of them are galactic. The attempt to identify some of the sources by observation of correlated time variability in different spectral ranges so far was not successful (Caraveo et al. OG 2.5-9). A third issue of the COS-B catalog is in preparation. Pollock et al. (OG 3.1-9) presented results from a new point source search along about half of the galactic plane. So far this analysis was restricted to high energies only (> 300 MeV). An extension to all energies and to the rest of the galactic plane is in preparation.

During the conference new results were presented on some of the COS-B sources and on a few others as well.
These are
- Crab pulsar
- Cyg X-3
- Geminga
- ρ -Ophiuchi
- Loop I remnant
- the unidentified COS-B sources in general

Each of these objects will now be discussed separately.

Crab-pulsar. The Riverside group (White et al. OG 2.3-8) presented final results from a balloon flight which was carried out already in 1978 with their Compton telescope. The derived pulsar spectrum in the 1 to 30 MeV range follows the single power law spectrum $\sim E^{-2.2}$ which is generally observed between about 50 keV and 2 GeV. The new fluxes agree well with previous values obtained by Graser and Schönfelder (1982) in the same energy range. The final analysis of the balloon flight did not confirm the results of a preliminary analysis on the existence of MeV-lines in the pulsar spectrum, which were presented at the Bangalore conference (Long et al., 1983).

Cyg X-3. Cyg X-3 is a binary X-ray source with a periodicity of 4.8 hours. The situation of Cyg X-3 in the gamma ray range around 100 MeV is controversial. The SAS-2 experimenters had claimed the detection of this source above 35 MeV (Lamb et al., 1977). They identified the total excess observed in the Cyg-region with Cyg X-3 and found the total excess to be pulsed with the 4.8 hour period. COS-B has looked at the Cygnus region seven-times from 1975 to 1982. No evidence for pulsed emission with the 4.8 hour period was found. The 2 σ upper limits are an order of magnitude below the flux reported by SAS-2. The COS-B analysis has shown that the emission in the Cygnus-region is structured and that it can be explained as being the sum of a diffuse emission in interstellar space plus a contribution from two point-like gamma ray sources as illustrated in Figure 5 (from Hermsen et al., OG 2.2-2). There is no excess emission at the position of Cyg X-3 which is indicated by the cross at the time of the COS-B observations. To resolve the contraversy it is recommended to the SAS-2 experimenters to repeat their analysis of the Cygnus region using all the information on molecular hydrogen which is now available - more than 10 years after the first analysis. Gamma ray observations of Cyg X-3 at ultrahigh energies are discussed in the rapporteur talk of Dr. Watson.

Geminga (2CG-195+04). The Geminga gamma ray source was discovered by SAS-2 (Thompson et al., 1977); it is one of the strongest gamma ray sources in the sky. Based on 121 detected gamma-ray photons the SAS-2 observers had claimed the existence of a 59 sec-period emphasizing, however, that this periodicity would have to be confirmed with better statistics.

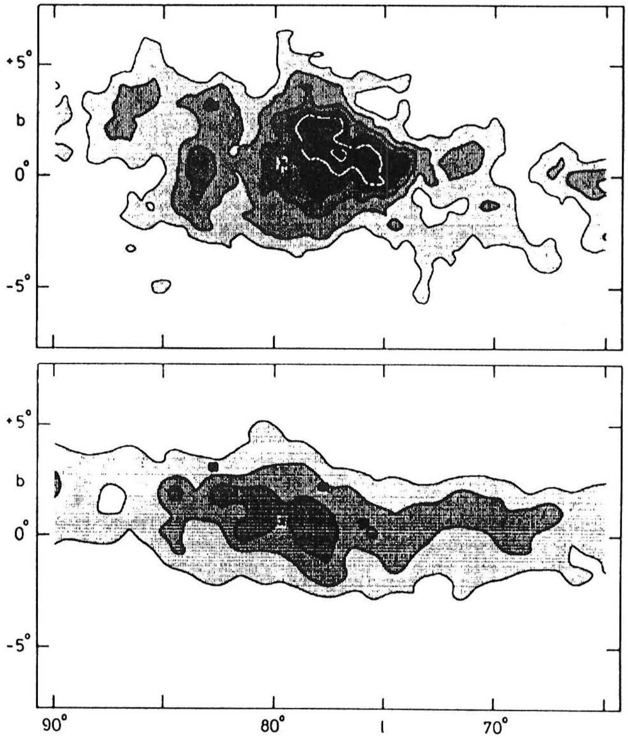

Fig. 5 Gamma ray intensity distributions in the Cygnus-region above 500 MeV as observed by COS-B (from Hermsen et al, OG 2.2-2). Upper half: contours as measured by COS-B. Lower half: estimated from total gas distribution (HI and CO-data). Position of Cyg X-3 is indicated by X. The positions of 3 γ-ray sources are also indicated (●).

Recently, Bignami, Caraveo and Paul (1985) reported that they have identified the gamma-ray source with the X-ray source 1E 0630+178. They found the X-ray source, which was observed by the EINSTEIN- and EXOSAT-satellites, to show a 50% periodic emission at a period of about 59 sec. The coincidence of the temporal signature was used for the identification of Geminga with the X-ray source. Buccheri et al. (1985) have reviewed the statistical significances of all reported detections and conclude that the identification cannot be made. The COS-B collaboration ((Buccheri et al., OG 2.4-3) has now performed a comprehensive analysis of all their Geminga data (214 days of observation). The analysis does not confirm the presence of a 59 sec pulsation with the characteristics reported by SAS-2. A sinusoidal signal at this period, however, at present cannot be excluded. The identification of Geminga is still open.

ρ-Ophiuchi. Whereas the analysis of the gamma ray data from the Orion complex has shown that the nebula is penetrated by a cosmic ray density equal to that observed near the Sun, the conclusion is different for the ρ - Oph complex: if the observed gamma-ray emission from the direction of ρ - Oph is linked to the gas in the cloud, then an increase of the cosmic ray density inside the cloud by a factor of about 2 is needed. Montmerle and Feigelson (OG 2.5-1) have looked for possible X- and radio objects, which are not correlated with ρ -Oph, but could explain the observed excess in gamma-ray intensity from this direction. They do not find such a source and therefore conclude that the most probable explanation of the excess remains the interaction of cosmic rays of enhanced density with the cloud.

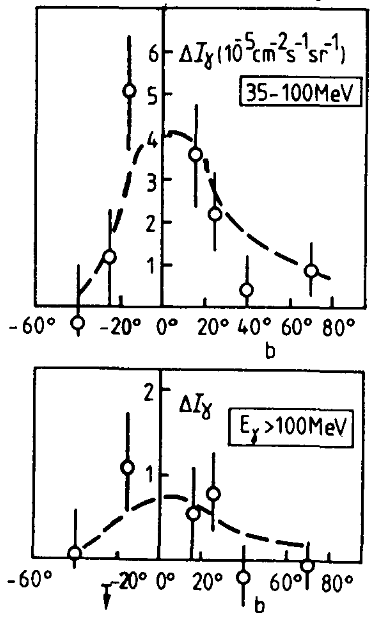

Fig. 6 Excess gamma ray intensity (using SAS-2 data) associated with Loop I as function of galactic latitude. For details see text. From Bhat et al., (OG 3.1-10).

Loop I Supernova Remnant. The Loop I SNR, which is clearly visible in radio synchrotron radiation and known as North Polar Spur, is only ~ 130 pc away; its radius is about 115 pc. Evidence for enhanced gamma-ray emission from the remnant was found by three different groups independently (Bhat et al., OG 3.1-10, Lebrun and Paul OG 3.1-1 and Strong et al. OG 3.1-3). Fig. 6 shows the excess gamma-ray intensity from the direction of Loop I as a function of b^{II}: ΔI_γ is the difference between observed and expected intensity for the Loop region minus the same quantity outside the Loop. The dashed curve corresponds to the 408 MHz radio intensity, which shows the same behaviour. There is clear indication of enhanced gamma-ray emission along the Loop. It is most interesting to note that the cosmic ray density within the remnant which is required to explain the observed ΔI_γ is consistent with the one needed, if the bulk of cosmic rays with energies below 100 GeV is produced in galactic supernova remnants.

Unidentified COS-B sources. The understanding of the unidentified COS-B sources remains an unsolved puzzle. The low luminosity of the sources in all other spectral ranges in comparison to the gamma-ray luminosity is a constraint for the object behind these sources. Fast radio pulsars, SNR's, giant HII-regions and giant molecular clouds (very often in combination with SNR's) are possible candidates. Theoreticians nowadays concentrate on molecular clouds in combination with SN's. In most cases the mass of molecular clouds is not large enough to produce the required gamma-ray emission in the environment of a cosmic ray density equal to the one near the Sun. Indeed, recently Pollock et al. (1985) reported that only 3 out of the 8 COS-B sources in the first quadrant (2CG 036+01, 2CG 065+00, 2CG 095+04) may simply reflect the clumpiness of the interstellar gas. For the other 5 sources, either a large enhancement of the cosmic ray density within the cloud is needed or these sources are independent of the gas. Since shock waves appear to be an efficient means to accelerate cosmic rays, the combination of interstellar clouds with shocks is of special interest. The shock may come from SN's either inside or outside the cloud. Stephens (OG 2.5-2 and OG 2.5-3) has investigated a scenario, in which SN envelopes explode into dense clouds, and Montmerle (OG 2.5-4) has looked for correlations between gamma-ray sources and giant HII-regions which contain SNR's or stars with strong stellar winds. He proposes that 10 of the unidentified COS-B sources in the second and third quadrant may be of this tpye.

5. Large Scale Galactic Gamma Ray Distribution. The large scale distribution of high energy gamma ray emission - say above 50 MeV - within the Milky Way is of fundamental importance for cosmic ray research. It is expected to give an answer to the important question, how cosmic rays are distributed within the Galaxy.

It is now generally agreed that the diffuse galactic gamma-ray emission at high energies mainly results from interactions of cosmic ray nuclei and electrons with interstellar matter via π^0-decay and via bremsstrahlung, respectively. The production of gamma-rays by inverse Compton scattering of cosmic ray electrons with the ambient photon field is believed to play a minor role - however cannot be neglected totally (Bloemen, OG 3.1-2).

The gamma-ray emission from interactions of cosmic ray nuclei and electrons with interstellar matter is determined by

$$(1) \qquad \Delta I_{\gamma,ISM} = \int \frac{q(r)}{4\pi}\, n_{H,tot}(r)\, dr$$

where $q(r)/4\pi$ is the gamma-ray emissivity at distance r in units of gamma-rays produced per H-atom sec ster and $\int n_{H,tot}(r)\, dr$ is the column density of interstellar hydrogen. The production rate at distance r is proportional to the cosmic ray density at this distance:

$$(2) \qquad q(r) = q_o \frac{n_{CR}(r)}{n_{CR}(r = o)}$$

Therefore, by measuring the gamma-ray intensity $\Delta I_{\gamma,ISM}$, the distribution of cosmic rays within the galaxy can be inferred, if the local gamma-ray production rate q_o and the total interstellar hydrogen density is known.

The determination of $\Delta I_{\gamma,ISM}$ has some problems: First, the contribution of discrete sources has to be subtracted from the measured overall gamma-ray intensity. Second, the instrumental and cosmic background has to be known accurately in order to be subtracted, too. Indeed, small errors in the background may introduce significant errors in the broad scale distribution of $\Delta I_{\gamma,ISM}$. A better understanding of the total COS-B background was achieved only recently. Third, the inverse Compton component has to be estimated and then to be subtracted, too.

The local gamma-ray emissivity q_o is normally determined by interpretation of the diffuse galactic gamma-ray emission at medium galactic latitudes $|10^o| < b < |20^o|$. The total hydrogen column density is determined from galaxy count data. Because gamma-rays from this medium latitude range are produced within the next - say 0.5 kpc - it is justified to take a constant value of q, which then by definition is the local one. Strong et al. (OG 3.1-3) applied this method in a more elaborated way to derive local q_o-values for atomic and molecular hydrogen separately. Lebrun and Paul (OG 3.1-1) question the usefulness of this method. They found that the detectability of galaxies - and hence the galaxy count rate - strongly depends on the field star density in the corresponding part of the sky. When correcting for this effect, they find significant variations in the emissivity from one direction to the other and therefore conclude that the definition of an average emissivity in the solar neighbourhood appears rather meaningless.

The largest uncertainty in the interpretation of the gamma-ray data is caused by our poor knowledge on the total interstellar hydrogen column density. Whereas the distribution of neutral hydrogen (HI) is known reasonably well from observations of the 21 cm line, the situation of molecular hydrogen (H_2) is controversial. The H_2 column density cannot be measured directly, but is normally obtained indirectly by observation of interstellar CO which is excited by collisions with H_2-molecules.

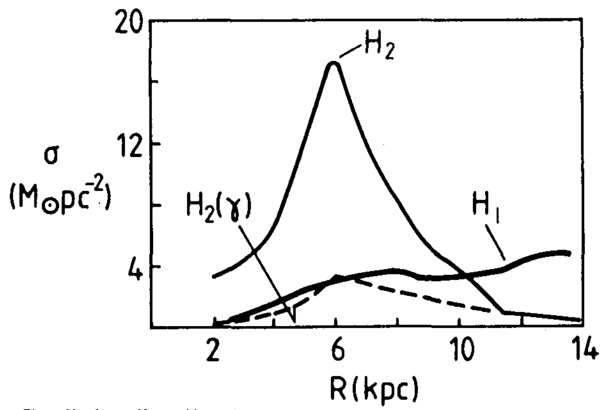

Fig. 7 Radial distribution of neutral and molecular hydrogen in the Milky Way (from Bhat et al., 1985).

Fig. 7 shows two rather extreme cases of the molecular hydrogen content within the Milky Way. The high H_2-curve is from Sanders, Solomon and Scoville (1984), and the lower dotted one from the Durham group. At 6 kpc from the galactic center both H_2-distributions differ by a factor of about 6. The neutral hydrogen density is also indicated.

It is quite clear that such differences in the gas distributions must have a significant effect on the interpretation of the gamma-ray data. The standard way to determine the gamma-ray volume emissivity within the galaxy so far was based on an unfolding of the gamma-ray longitude distribution under the simplifying assumption of cylindrical symmetry. Stecker and Harding (OG 3.1-4) again followed this approach using the complete set of SAS-2 and COS-B data and new CO-data. They found a maximum of the cosmic ray density - for both electrons and nuclei - at about 5 kpc from the center, where the density of supernovae remnants and pulsars is greatest. Goned and Wahdan (OG 3.1-5) came to a similar conclusion.

The Durham group (Bhat et al., OG 3.1-8) took a different approach: They used the distribution of supernova remnants as probable distribution of the cosmic ray density in the galaxy and then determined the gas distribution from the gamma-ray data. Due to the assumed high cosmic ray density in the inner part of the galaxy (a factor of 2.5 higher at 6 kpc than at 10 kpc) they derive the low H_2-density shown in Fig. 7. The factor of 6 difference in their H_2-density compared to that of Sanders, Solomon and Scoville (1984) is explained by them by different conversion factors between the measured CO-intensity and the derived H_2-column density. With their new and very low mass estimate of the interstellar gas in the Milky Way the Durham group found wide attention. It is one of the rare astronomical results which was reported in the Frankfurter Allgemeine Zeitung (FAZ from April 24, 1985).

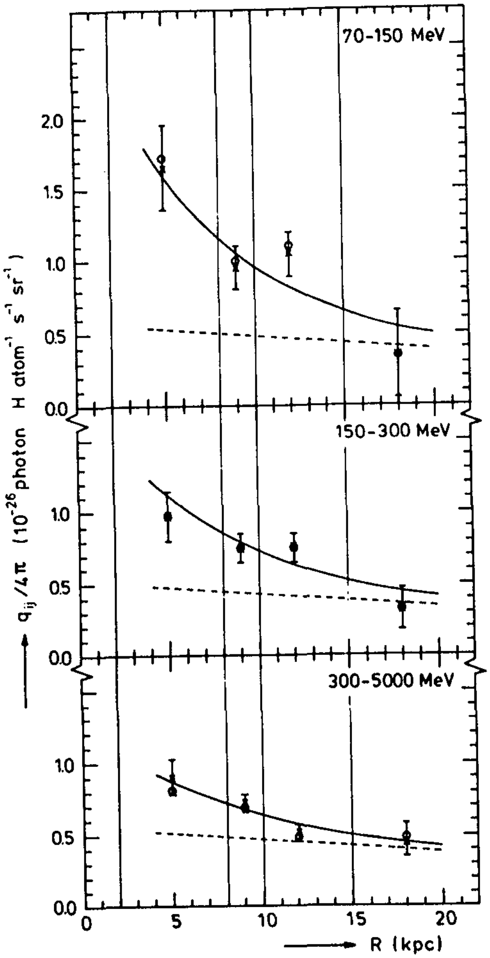

Fig. 8 Galactocentric distribution of the gamma ray emissivity for 3 energy intervals. The dashed lines indicate the π^0-decay contribution from cosmic ray nuclei only (from Bloemen et al., (OG 3.1-6).

Again a different approach was taken by the COS-B collaboration (Bloemen et al., OG 3.1-6). They made a maximum likelihood fit of the gamma-ray intensity (observed in $1^o x 1^o$ bins) to the entire data of HI and

CO. The emissivity parameter of HI, the conversion factor between CO-intensity and H_2-column density, and the total instrumental and cosmic background were free parameters. The total line of sight was subdivided into 4 galactocentric distance intervals. The velocity information of the HI- and CO-lines was used as distance indicator. The result of this analysis is shown in Fig. 8, where the emissivity per H-atom is plotted as a function of galactocentric distance. At 10 kpc the q-values are consistent with the ones derived by Strong et al. (OG 3.1-3) from medium galactic latitudes. In each energy interval the emissivity increases towards the inner part of the galaxy. The gradient is stronger at lower than at higher energies. Because the contribution of electron bremsstrahlung to the total gamma-ray emission dominates at lower energies (as we know from the gamma-ray energy spectrum), it is concluded (and derived quantitatively) that the observed overall gradient in the low energy interval is mainly due to electrons. The lower energy gradient is consistent with the electron gradient derived from non-thermal radio measurements. The density of cosmic ray nuclei, however, is found to be practically constant throughout the entire galaxy (dashed line). The same conclusion was already earlier derived by the COS-B collaboration, when analysing gamma-ray data from the anticenter region alone in a similar way. The analysis of the anticenter is in so far easier, as the uncertainty in the contribution of H_2 does not exist, because of its relatively low contribution in this part of the galaxy.

With this conclusion the old question, whether the bulk of cosmic rays is galactic or extragalactic is open again. Though the gradient in the distribution of cosmic ray electrons confirms their galactic origin, the constancy of the cosmic ray nuclei component either requires a large galactic halo distribution or cosmic ray nuclei of predominantly extragalactic origin. In case of a galactic origin the cosmic ray nuclei density does not follow the distribution of supernovae in the Galaxy.

I think the battle on the interpretation of the broad scale galactic gamma ray distribution will continue for quite a while. New data on H_2, and also future gamma-ray data will definitely stimulate further discussions. GRO will not only provide more precise gamma-ray data from our own galaxy, it will also provide information on the interstellar gamma-ray emission in our neighbouring galaxies (see also Berezinsky et al., OG 2.7-15).

6. Extragalactic Gamma Ray Astronomy.

Extragalactic gamma ray astronomy may - at some time in the near future - turn out to be the astronomy of active galactic nuclei and quasars. These two classes of objects at present belong to the most interesting objects in astronomy and astrophysics. Due to their high luminosity and their extreme compactness it is supposed that an accreting black hole is the powering engine in the center of these galaxies.

Although COS-B has devoted nearly one third of its observation time to extragalactic pointings ($|b| > 15^o$), only one source, the quasar 3C 273, could be detected. For other potential sources like normal galaxies in the local group, Seyfert galaxies, BL-lac objects, and other quasars only upper limits to the gamma ray flux could be derived.

The quasar 3C 273 has its maximum of luminosity at energies of a few MeV, as can be derived from an interpolation of its X-ray and high energy gamma ray spectrum. Many other galaxies, especially Seyferts should also have their maximum of luminosity in the range between several 100 keV and a few MeV, as can be concluded from their hard X-ray spectra in combination with the existing upper limits at gamma ray energies above 35 MeV. Hard X-ray and low energy gamma ray observations are therefore expected to provide special insight into the source mechanism of these objects.

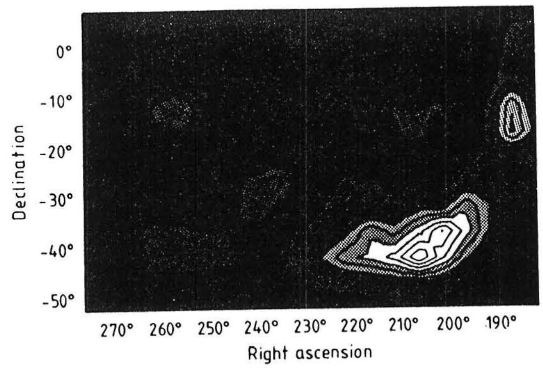

Fig. 9 Observation of Cen A with the Compton-telescope of MPI-Garching between 1 to 20 MeV (from v. Ballmoos et al., OG 2.7-7).

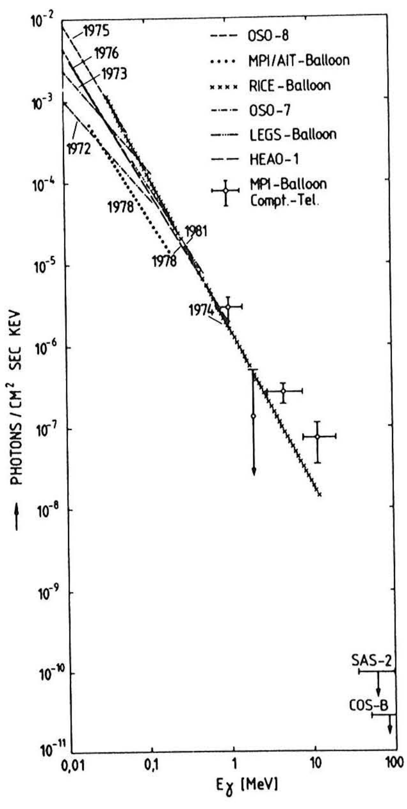

Fig. 10 The energy spectrum of Cen A from X-ray to gamma ray energies (from v. Ballmoos et al., OG 2.7-7).

During this conference my own group (v. Ballmoos et al., OG 2.7-7) reported on an observation of Centaurus A at MeV-energies. Cen A is the nearest active galaxy in the sky. Fig. 9 shows a reconstructed image of the part of the sky which we observed during a balloon flight with our Compton-telescope. The contour lines are a measure of the likelihood for the existence of a source. The likelihood is greatest near Cen A. A detailed analysis showed that the statistical significance of the source detection at the position of Cen A was 4.1σ. The derived energy spectrum is shown in Fig. 10. It is seen that the spectrum at MeV-energies well connects to the X-ray spectrum with practically constant slope. This fact, together with the position of the excess in the previous figure seems to indicate that the observed gamma ray emission is related to Cen A.

Assuming the validity of the upper limits above 35 MeV from SAS-2 and COS-B also for the time of the balloon flight, it has to be concluded that the Cen A spectrum must steepen rapidly somewhere beyond 8 or 20 MeV in order to meet the upper limits. This spectral shape, which again places the maximum of luminosity of Cen A in the MeV-range, allows interesting discussions on the source size and the radiation mechanism involved.

Damle et al. (OG 2.7-8) reported on a balloon observation of another active galaxy, namely the Seyfert galaxy 3C 120 at gamma ray energies above 5 MeV. The detection of the source had a statistical significance of $2.75\ \sigma$ only, and therefore definitely needs confirmation.

Let me finally turn to the topic of the diffuse cosmic gamma ray background, which has been of special interest since the very early beginning of gamma ray astronomy. It is now generally agreed that unresolved active galaxies to some extend contribute to the cosmic gamma ray background. The degree of this contribution, however, still contains considerable uncertainties.

Gruber et al. (OG 3.1-12) presented new results on the diffuse cosmic X- and gamma-ray energy spectrum between 15 keV to 4 MeV from HEAO-1 observations. Their new results agree with the compilation of experimental data between 2 keV and 200 MeV, as shown in Fig. 11. Whereas the X-ray background below 1 keV is mostly galactic, the galactic contribution above 2 keV is only a few percent of the measured flux. The high degree of isotropy, especially in the 2 to 10 keV range, is evidence for its extragalactic origin.

As can be seen from Fig. 11, there is much structure in the spectrum. Between 3 to 50 keV a thermal bremsstrahlung spectrum of $kT = 40$ keV fits the data quite well. Though the spectrum between 40 keV and 400 keV gives a smooth connection to the lower energy range, it does not follow the thermal bremsstrahlung shape. In the MeV-range all the existing measurements (including the new HEAO-1 results of OG 3.1-12) show the existence of a bump above the extrapolation from X-ray energies. Above about 5 MeV the spectrum becomes very steep.

Unresolved normal galaxies make only a minor contribution to the background flux (see Lichti et al., 1978). A significant contribution of unresolved active galaxies, however, especially Seyferts, is generally accepted around 100 keV (Rothschild et al., 1983).

The contribution of unresolved quasars to the high energy gamma ray background (> 35 MeV) was estimated from SAS-2 data by Lau and Young (OG 2.7-10) to be about 25% of the total observed flux. After more than 100 quasars have been observed at X-ray energies by the EINSTEIN observatory, estimates of the quasar contribution to the 1 to 3 keV X-ray background range from 25% to 100%. If all quasars would have the same spectral shape as 3C 273 between 1 keV and 800 MeV, then their summed contribution at 100 MeV would supersede the observed gamma-ray flux by more than a factor of 10. It must therefore be concluded that the spectrum of 3C 273 cannot be typical for most of the other quasars. The typical quasar spectrum should break off already below 100 keV, otherwise it would be in conflict with the well established contribution of Seyferts at 100 keV.

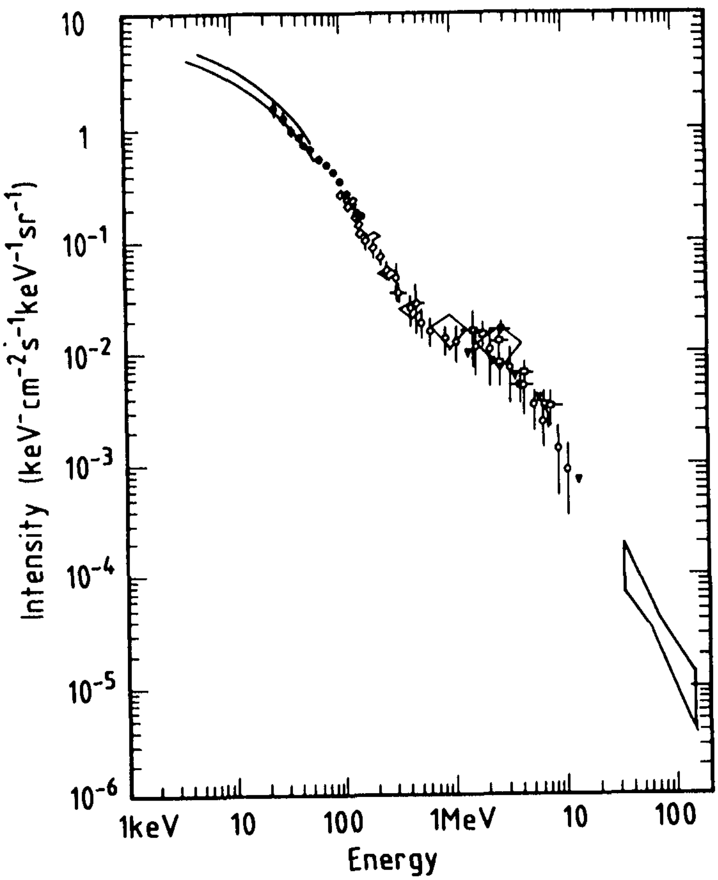

Fig. 11 The energy spectrum of the diffuse cosmic X- and gamma-ray background. The X-ray measurements are from HEAO A-2 and A-4, the low energy gamma ray measurements are from Apollo, the two Compton-telescopes at Riverside and MPI-Garching and a shutter type telescope at Nagoya. The high energy gamma-ray spectrum is from SAS-2.

In view of this discussion it is perhaps not surprising that no single power law dependence is observed over the entire X- and gamma-ray range, since different types of galaxies may contribute and dominate at different energies. The question of a remaining really diffuse component like the one from matter-antimatter annihilation in a baryon symmetric universe can only be answered if much more information on the X- and gamma-ray emission of active galaxies and quasars is available. Only then will it be possible to derive that part of the background spectrum that cannot be explained by unresolved sources.

7. Conclusions. The major conclusions at the Cosmic Ray Conference in the field of gamma ray astronomy were:

- MeV-emission of gamma-ray bursts is a common feature. Variations in duration and energy spectra from burst to burst may explain the discrepancy between the measured log N - log S dependence and the observed isotropy of bursts.
- The gamma-ray line at 1.809 MeV from Al^{26} is the first detected line from a radioactive nucleosynthesis product. In order to understand its origin it will be necessary to measure its longitude distribution in the Milky Way.
- The indications of a gamma-ray excess found from the direction of Loop I is consistent with the picture that the bulk of cosmic rays below 100 GeV is produced in galactic supernova remnants.
- The interpretation of the large scale distribution of gamma rays in the Milky Way is controversial. At present an extragalactic origin of the cosmic ray nuclei in the GeV-range cannot be excluded from the gamma ray data.
- The detection of MeV-emission from Cen A is a promising step towards the interesting field of extragalactic gamma ray astronomy.

It is obvious: each new result raises new questions. The future of gamma-ray astronomy will be very exciting!

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