MeV quasar observations with the COMPTON Gamma Ray Observatory

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Zusammenfassung

Als am 5. April 1991 das COMPTON Gammastrahlen Observatorium (CGRO) vom Space Shuttle Atlantis in die Erdumlaufbahn gebracht wurde, waren im Strahlungsbereich oberhalb 1 MeV ($\lambda <$ 0.0012 nm) nur drei extragalaktische Objekte bekannt: der Quasar 3C 273, die aktive Radiogalaxie Cen A und NGC 4151, eine Galaxie vom Typ Seyfert I. Eineinhalb Jahre später, nach Beendigung der ersten kompletten Himmelsdurchmusterung in diesem Spektralbereich, waren die meisten der gefundenen permanenten Gammastrahlungsquellen aktive Galaxien (AGN) oder Quasare. Mehr als 25 dieser Objekte wurden bisher vorläufig identifiziert, und die Zahl wächst ständig.

Typische Beobachtungen mit dem COMPTON Observatorium dauern zwei bis drei Wochen, in denen der Satellit ständig auf eine bestimmte Richtung am Himmel ausgerichtet ist. Da zwei (EGRET und COMPTEL) der vier Meßinstrumente, die sich auf CGRO befinden, ein sehr großes Gesichtsfeld von ca. 50° Durchmesser haben, werden viele der entdeckten Objekte von diesen Instrumenten immer wieder über einen längeren Zeitraum kontinuierlich beobachtet, auch wenn sich die Ausrichtung des Satelliten geändert hat. Man kann schon fast von einer Überwachung sprechen. Sehr starke Gammaquellen im Energiebereich unter 1 MeV können von einem dritten Meßinstrument auf CGRO, das für Strahlung aus allen Richtungen empfindlich ist, überwacht werden. Dieser Gamma-Burst Detektor (BATSE) registriert kontinuierlich die Intensität starker Quellen und erzeugt so fast lückenlose Lichtkurven. So wurden z.B. von Cen A und NGC 4151 Lichtkurven über einen Zeitraum von mehreren Monaten mit einer Auflösung von einem Tag erstellt.

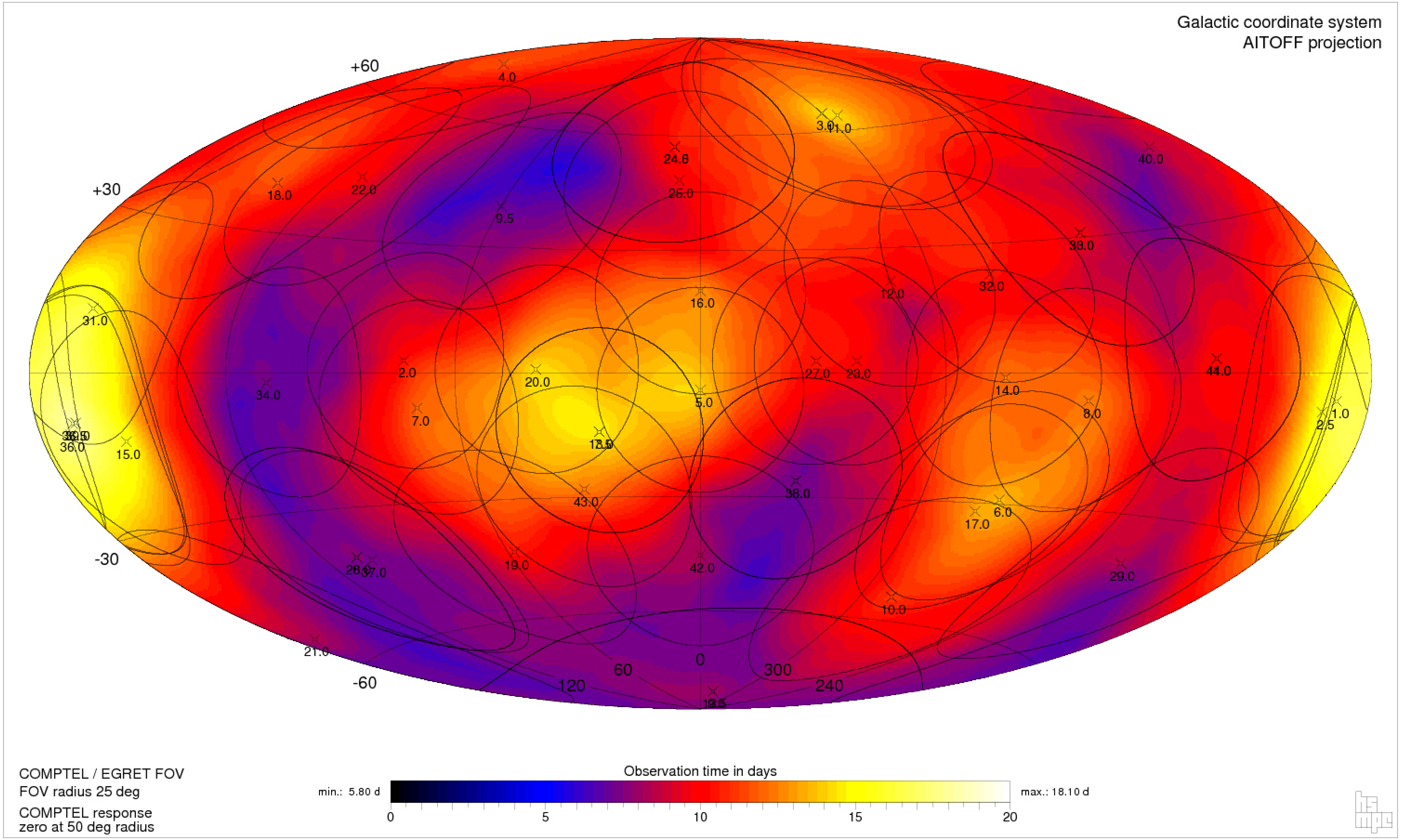
Wie oben bereits bemerkt, ist eine eindeutige Identifizierung der gefundenen Gammastrahlungsquellen noch nicht erfolgt. Dies ist nur möglich durch den Nachweis korrelierter Änderungen der Strahlung dieser Objekte im Gammabereich und in einem anderen Wellenlängenbereich, in dem eine Identifizierung schon vorliegt. Dazu ist es aber notwendig, möglichst lückenlose Lichtkurven dieser Quasare und AGN in vielen Wellenlängenbereichen zur Verfügung zu haben, da auch zeitverzögerte Variationen von diversen Theorien der Strahlungsentstehung vorhergesagt werden. Gleichzeitige Beobachtungen aller bisher im Gammabereich entdeckten Objekte und möglicher Kandidaten wurden bereits versucht. So wurden gezielt Radiobeobachtungen durchgeführt, und einige Objekte über einen Zeitraum von zwei mal 14 Tagen simultan mit CGRO vom Calar Alto Observatorium aus im Optischen beobachtet. Im Verlauf von zwei, seit einiger Zeit laufenden Quasar Monitoring Programmen, wurden für einige der entdeckten Gamma-Quasare zufällig schon relativ vollständige optische Lichtkurven erhalten. Diese unter der Leitung der Hamburger und der Heidelberger Sternwarten durchgeführten Beobachtungsreihen bilden eine erste, noch grobe Datenbasis zur möglichen Identifizierung der im Gammabereich aktiven Objekte.

Nach dem für Juni 1993 geplanten Anheben der CGRO Umlaufbahn auf 450 km über der Erdoberfläche, wird die geschätzte Lebensdauer des Satelliten noch 6 bis 8 Jahre betragen. Während dieser Zeit werden mit dem COMPTON Observatorium alle entdeckten Quasare und AGN weiter überwacht, und eine große Datenbasis für Gammastrahlen-Lichtkurven wird entstehen. Die Fortführung und der Ausbau der optischen Überwachung von Quasaren (auch am Südhimmel) ist für die Gammaastronomie von großer Bedeutung. Genaue Lichtkurven geben außerdem wichtige Informationen zur Geometrie und Physik dieser Objekte, deren Strahlung in dem riesigen Frequenzbereich von der Radio- bis zur höchsten Gamma-Strahlung ausgesandt wird. Mechanismen, die solch enorme Energiemengen freisetzen, sind noch völlig unerforscht.

Proc. 1st MEGAPHOT workshop, Hamburg 1993

COMPTON Gamma Ray Observatory

Phase I Sky Survey Completed 1992-11-17



1 Introduction

Extragalactic gamma-ray astronomy barely existed prior to the launch of the COMPTON Gamma Ray Observatory (CGRO) but there were good indications that this is a potentially very promising field of research. Particularly good indicators were the detections of 3C 273 by the COS-B satellite at energies above 50 MeV (suggesting a peak energy output in the MeV range) and the detections of Cen A and NGC 4151 at MeV energies (Hermsen et al. 1981, von Ballmoos et al. 1987, Perotti et al. 1981). Since most of the COS-B observations were concentrated along the galactic plane, there was some hope that the CGRO pointings away from the plane might show additional active galactic nuclei (AGNs). This expectation has been borne out, since the four instruments on CGRO have detected a surprisingly large number (> 35) of active galactic nuclei during the first two years of the mission.

In accordance with the topic of the workshop, only observations of time variability in the gamma-ray and optical emission of the AGNs and quasars will be addressed in the following.

2 The COMPTON Gamma Ray Observatory

The COMPTON Gamma Ray Observatory, as one of NASA's Great Observatories, provides for the first time coordinated observations over six decades of energy in the gamma-ray range. Four instruments cover, with some overlap, the energy band from few keV up to 30 GeV (Kniffen 1989, 1991; Hurley 1992).

BATSE is an omnidirectional sensitive gamma-ray burst detector with one detector module mounted on each of the eight corners of CGRO (Fishman et al. 1989). During the first year, techniques have been developed to monitor strong gamma-ray sources continously using earth occultations.

COMPTEL is an imaging Compton Telescope working in the energy range 750 keV to 30 MeV (Schönfelder et al. 1993). Its location accuracy is about half a degree for strong (Crab-like) sources and few degrees for weaker sources. Given the large field-of-view of about 1 steradian, COMPTEL observes a large part of the sky containing several gamma-ray sources in each pointing of CGRO. It is the first time that an instrument sensitive in this MeV gamma-ray range is flown on a satellite.

EGRET has a similar field-of-view as COMPTEL and points also along the Z-axis of CGRO (Thompson et al. 1993). The energy range covered is 20 MeV up to photon

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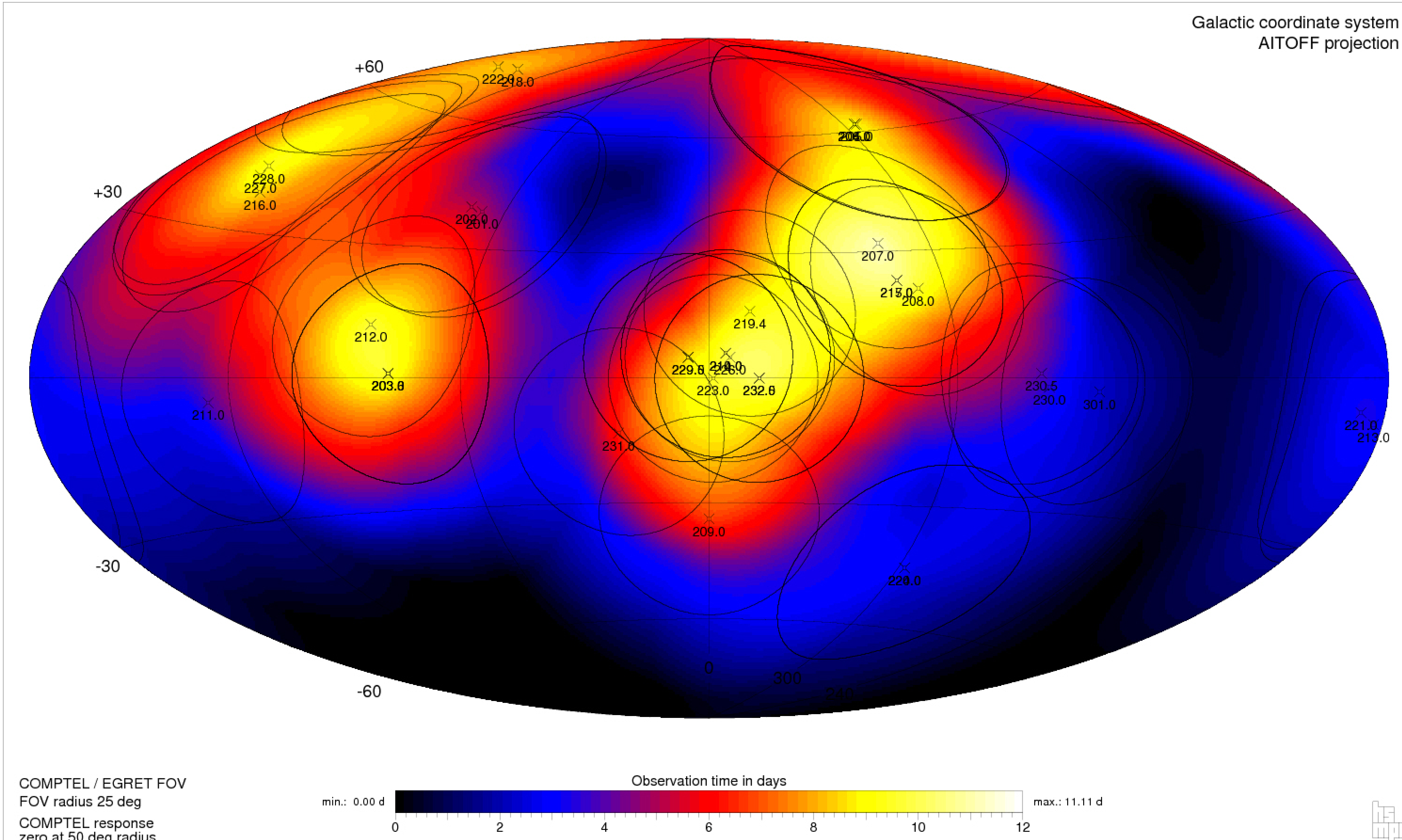
Figure 1: *(previous page)* Estimated effective observing time in units of days for the COMPTEL instrument aboard CGRO after the completion of the sky survey period. AITOFF projection and galactic coordinate system (II) are used. Each of the 44 viewing directions is indicated by an "circle" of 25° radius

COMPTON G R O PHASE II

Final (actually observed) viewing plan as of 1993-09-07.
COMPTEL predicted effective observing time; TDRS coverage 70% assumed.



energies > 30 GeV. Its predecessor COS-B had mapped — with much lower sensitivity — the galactic plane and EGRET now for the first time has surveyed the complete sky in the high-energy gamma-ray range.

OSSE is the instrument on CGRO with the smallest field-of-view (Kurfess et al. 1991). Its four detector modules, which view an $4^\circ \times 11^\circ$ area on the sky, can be pointed in pairs towards interesting regions on the sky which lie in the X-Z plane of CGRO, thus allowing to measure several objects during one fixed CGRO pointing. The energy range covered is 100 keV to 10 MeV.

3 Observation periods

After its launch with space shuttle Atlantis on 1991 April 5 and an initial check-out phase, CGRO begun an all sky survey on 1991 May 16. This first phase ended 1992 November 17 with the completion of the 44^{th} pointing. Each pointing in the sky survey period on the average lasted 14 days. The overlaping pointings resulted in a coverage of the entire sky (as seen by the wide field-of-view instruments COMPTEL and EGRET) with a minimum of $\sim$ 6 days effective observing time and a maximum of $\sim$ 20 days. The goal of more than 5 days effective observing time at each point on the sky and a reasonable homogeneous coverage of the sky was fully achieved with an average viewing time of about 12 days (see Fig. 1).

In the following phases of the CGRO observations, which will last about one year each, more time will be spent on single objects which are of specific interest and/or have been detected during the sky survey. Thus e.g. phase II covers only a fraction of the sky but interesting quasars are very often in the field-of-view of EGRET and COMPTEL (see Fig. 2). Also more and more time will be given to guest observers (phase II: 30%; phase III: 60%).

4 Observed gamma-ray light curves of AGNs and quasars

In total more than 35 AGNs have been detected by COMPTON during the first two years of it's mission (Table 1 and Fig. 3). Almost all of the detected AGNs show variations in intensity.

Out of the surprisingly large number (> 25) of active galactic nuclei detected by EGRET above 50 MeV, the majority are quasars and four are usually classified as BL Lacertae objects. All are radio loud and have a flat radio spectrum (Fichtel et al. 1993). Depending on the strength of the gamma-ray source, flux variations can be observed between different observations (e.g. CTA 102, Fichtel et al. 1993) or during single observations (see Fig. 4). PKS 0528+134 is shown in Fig. 5 which has been

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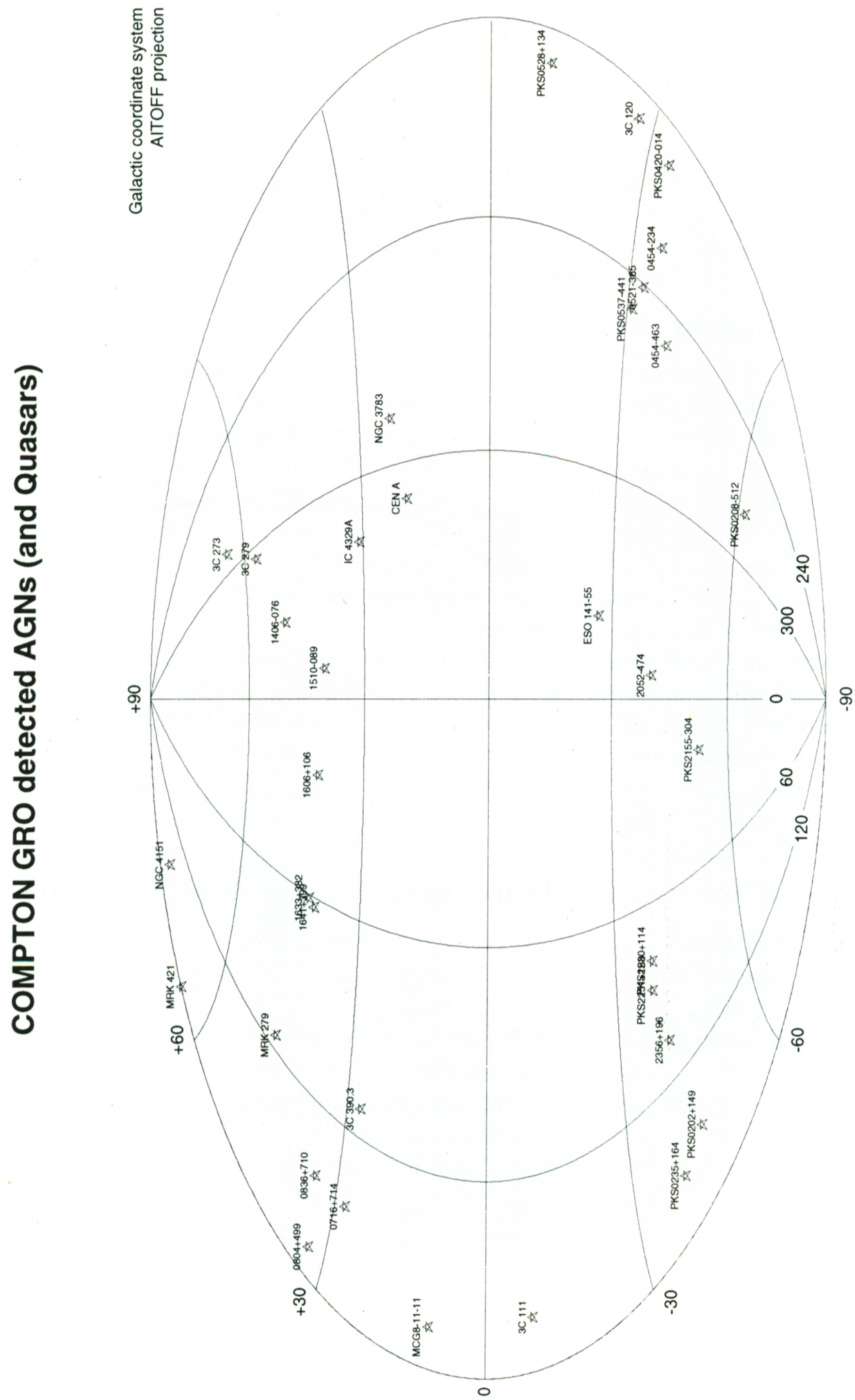
Figure 2: *(previous page)* Estimated effective observing time in days for COMPTEL aboard CGRO in phase II. As in Fig. 1, AITOFF projection and galactic coordinate system (II) are used. The viewing directions are indicated by a "circle" of 25° radius


COMPTON GRO detected AGNs (and Quasars)
Galactic coordinate system
AITOFF projection
+90
+60
+30
0
-30
-60
-90
0
60
120
240
300
PKS0528+134
3C 120
PKS0420-014
0454-234
PKS0537-441
0521-365
0454-463
NGC 3783
CEN A
PKS0208-512
IC 4329A
3C 273
3C 279
1406-076
ESO 141-55
1510-089
2052-474
1606+106
PKS2155-304
NGC 4151
MRK 421
MRK 279
2356+196
3C 390.3
0836+710
0716+714
0804+499
PKS0235+164
PKS0202+149
MCG8-11-11
3C 111

repeatedly observed over an interval of about 60 days and shows variations in the gamma-ray flux on long and short time scales.

No Seyfert galaxy has been detected by EGRET (above 50 MeV), but OSSE has detected several AGNs of this type at energies below 300 keV. As an example the light curve of NGC 4151 over one observation of 14 days is shown in Fig. 6.

The "middle energy instrument" COMPTEL has so far detected four AGNs (Collmar et al. 1993). Three of them are also seen by EGRET (3C 273, 3C 279, PKS 0528 +134) and two are seen by OSSE (3C 273, Cen A).

BATSE is continously monitoring the gamma-ray emission of bright AGNs by using the earth-occultation technique to identify them (Paciesas 1993a). Fig. 7 shows the count rate of Cen A in the energy interval 35 – 100 keV over a time span of 50 days. Variations by a factor of four are visible.

The observation of variability in the emission from active galactic nuclei from hard X-rays to high energy gamma rays has important implications for the understanding of the physical properties of these sources.

5 Gamma-ray monitoring and correlated observations

Typical observations with the COMPTON Gamma Ray Observatory last two to three weeks. During this time, the satellite is pointing towards a fixed position at the sky. As two (EGRET and COMPTEL) of the four instruments aboard CGRO have a rather large field-of-view of about 25° radius, many of the interesting objects are observed more than once. Even if the pointing of the satellite has changed, objects may still be in the field-of-view and can be monitored over a larger time interval. In addition, BATSE can monitor strong gamma ray sources continously using the earth-occultation technique. High quality light-curves from Centaurus A and NGC 4151 have been obtained already covering several months with a resolution of one day.

Although all the gamma-ray sources mentioned above have been tentatively associated with the AGNs (quasars and blazars) given in Table 1, no real identification has been made so far, as the location accuracy of all instruments is one to several degrees. An identification is only possible, if a correlated variation in gamma rays and any other wavelength region, where an identification has been made, is observed. It is therefore necessary to obtain continous light curves in as many wavelength regions as possible, as also delayed variations are predicted by theory.

Simultaneous optical observations of gamma-ray quasars and possible candidates have been carried out already in two 14-day periods in early 1992. All candidates

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Figure 3: *(previous page)* Distribution of all 35 quasars and AGNs on the sky which have been detected so far with CGRO instruments. AITOFF projection and galactic coordinate system (II) are used. See Table 1 for more details

Table 1: Detected Gamma-Ray Quasars and AGNs. The symbols mean: "+": detected, "=": not detected, "?": uncertain, ".": not analysed

Name	l	b	Type	BATSE	OSSE	COMPTEL	EGRET	Ref.
PKS 2155−304	17.732	−52.244	Sy-1	.	?	.	.	2
1606+106	22.755	41.447	BL Lac	.	.	.	+	1
1633+382	61.089	42.344	OVV	.	.	.	+	1
1641+399	63.000	41.000	OVV	.	.	.	+	3
PKS 2230+114	77.432	−38.579		.	.	.	+	1
PKS 2251+158	86.123	−38.187	OVV	.	.	.	+	1
2356+196	106.001	−41.000		.	.	.	+	3
3C 390.3	111.438	27.075	Sy-1	.	+	.	.	2
MRK 279	115.044	46.865	Sy-1	.	+	.	.	2
0836+710	143.542	34.425	OVV	.	.	.	+	1
0716+714	143.980	28.018	BL Lac	.	.	.	+	1
PKS 0202+149	147.221	−44.620		.	.	.	+	1
NGC 4151	155.062	75.063	Sy-1	+	+	=	.	2,5,6
AO 0235+164	155.937	39.745	BL Lac	.	.	.	+	1
3C 111	161.677	−8.819	Sy-1	.	+	.	.	2
MCG 8-11-11	165.725	10.400	Sy-1	.	+	.	.	2
0804+499	169.000	32.998		.	.	.	+	1
MRK 421	179.861	65.032	BL Lac	.	.	.	+	1
3C 120	190.373	−27.398	Sy-1	.	?	.	.	2
PKS 0528+134	191.371	−11.008	OVV	.	.	+	+	1,2
PKS 0420−014	194.827	−33.866	OVV	.	.	.	+	1
0454−234	223.435	−35.560		.	.	.	+	3
0521−365	241.001	−33.000	BL Lac	.	.	.	+	3
PKS 0537−441	250.089	−31.094	BL Lac	.	.	.	+	1
0454−463	252.011	−39.133		.	.	.	+	1
PKS 0208−512	276.110	−61.781		.	.	.	+	1
NGC 3783	287.453	22.941	Sy-1	.	?	.	.	2
3C 273	289.945	64.359		+	+	+	+	1,2,4,5
3C 279	305.093	57.062	OVV	?	+	+	+	1,2,4,5
CEN A	309.525	19.418	Sy-2	+	+	+	=	2,3,5,6
IC 4329A	317.497	30.921	Sy-1	.	+	.	.	2
1406−076	333.994	50.002		.	.	.	+	3
ESO 141-55	338.183	−26.712	Sy-1	.	?	.	.	2
1510−089	350.997	40.002		.	.	.	+	3
2052−474	353.000	−40.004		.	.	.	+	3

References:
1 Fichtel et al. 1993
2 Cameron et al. 1993
3 Fichtel 1993
4 Hermsen et al. 1993
5 Paciesas et al. 1993a
6 Steinle et al. 1993

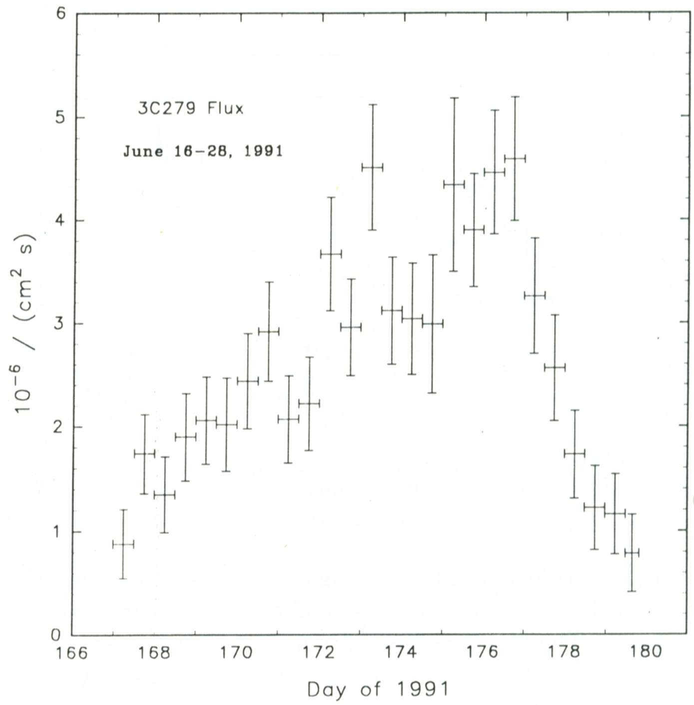

Figure 4: 3C 279 flux variation during the EGRET observation June 16–28, 1991 for gamma-ray energies $>$100 MeV. This is the largest flux increase and fastest flux decrease observed in gamma rays from an AGN within one observation of 13 days duration (Kniffen 1993b)

within the field-of-view of EGRET and COMPTEL had been monitored from the Calar Alto observatory (Spain). Also, by chance, some of the gamma-ray quasars are included in two long term monitoring programs carried out under the leadership of the observatories in Heidelberg and Hamburg (Germany). Two examples of optical light curves are given in Figs. 8 and 9. These observations are the first coarse data base for an attempt to identify the detected gamma-ray quasars. The two examples also demonstrate the necessity to obtain continuous data with a good time resolution in all energy bands, so that comparisons on a solid basis are possible.

6 Future observations

During two weeks in June 1993, CGRO will be lifted again to it's nominal orbit of 450 km. The estimated life time will be 6 to 8 years from then on. During this time all of the gamma-ray quasars will be monitored by CGRO and a large data base for gamma-ray light curves will be collected. Therefore the continuation or even extension (southern skies) of the optical monitoring programs seems to be mandatory from the point of view of the gamma-ray astronomy.

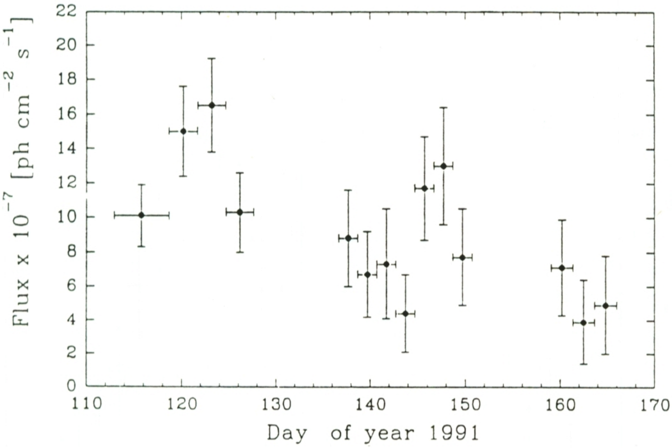

Figure 5: PKS 0528+134 flux variation during an eight week period in 1991 for gamma-ray energies > 100 MeV. During these eight weeks, PKS 0528+134 was observed by EGRET three times. The first two observations lasted two weeks each, the third one was of only one week duration (Hunter et al. 1993). Day 115 is April 25

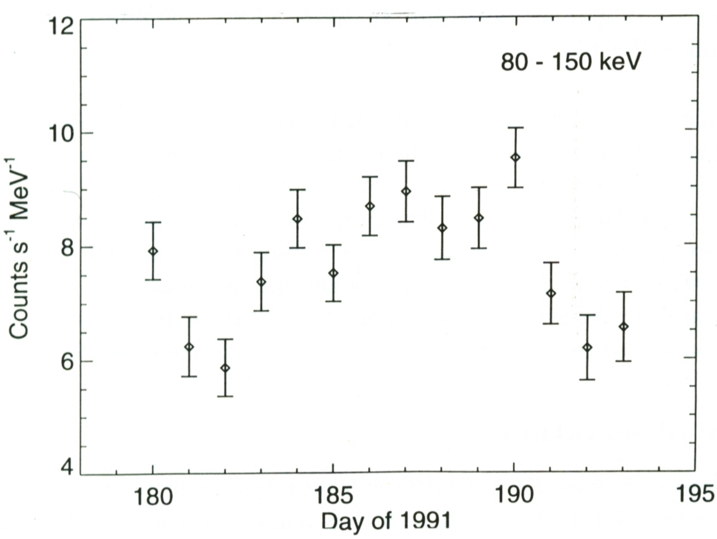

Figure 6: NGC 4151 count rate in the 80 – 150 keV energy interval as observed by OSSE in 1991 (day 180 is June 29). Variations of ~ 25% are observed (Maisack et al. 1993)

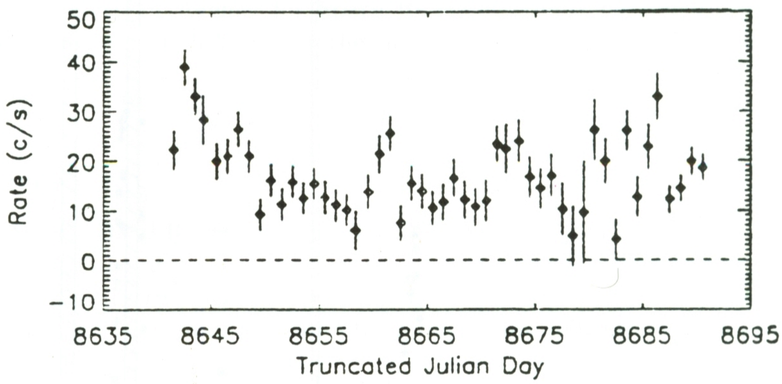

Figure 7: Cen A count rate in the 35 – 100 keV energy range as monitored by BATSE in 1992. The source shows relatively constant intervals of 5 – 10 days of low intensity, interrupted by flares where the count rate increases by as much as a factor of four (Paciesas et al. 1993b). TJD 8635 is Jan. 14, 1992

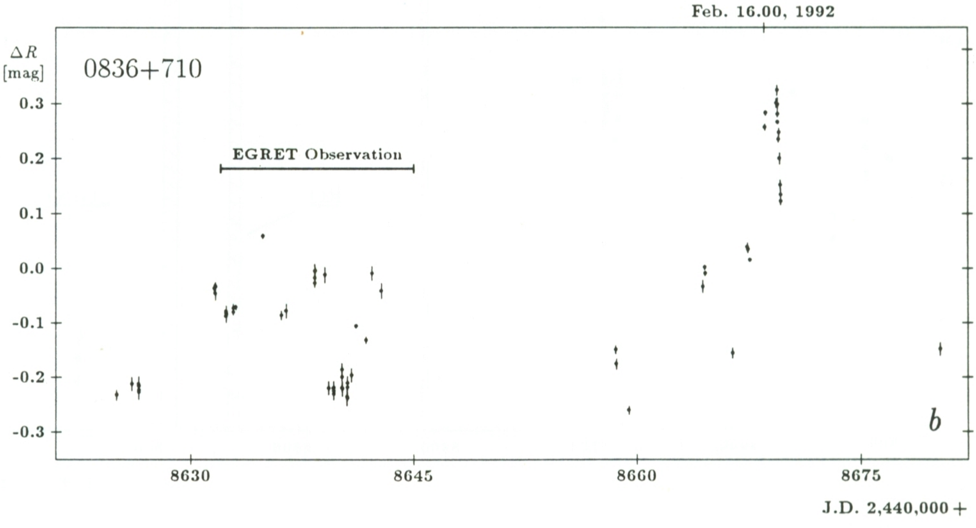

Figure 8: 0836+710 optical light curve in Jan./Feb. 1992 (a lightcurve from 1990 to 1993 is plotted in the contribution of Borgeest). The major part of the Januar observations were simultaneously with the CGRO observation (von Linde et al. 1993). Unfortunately the gamma-ray source is rather weak so that no gamma-ray light curve with satisfying resolution is available to date. The optical flare one month after the simultaneous measurements is evident

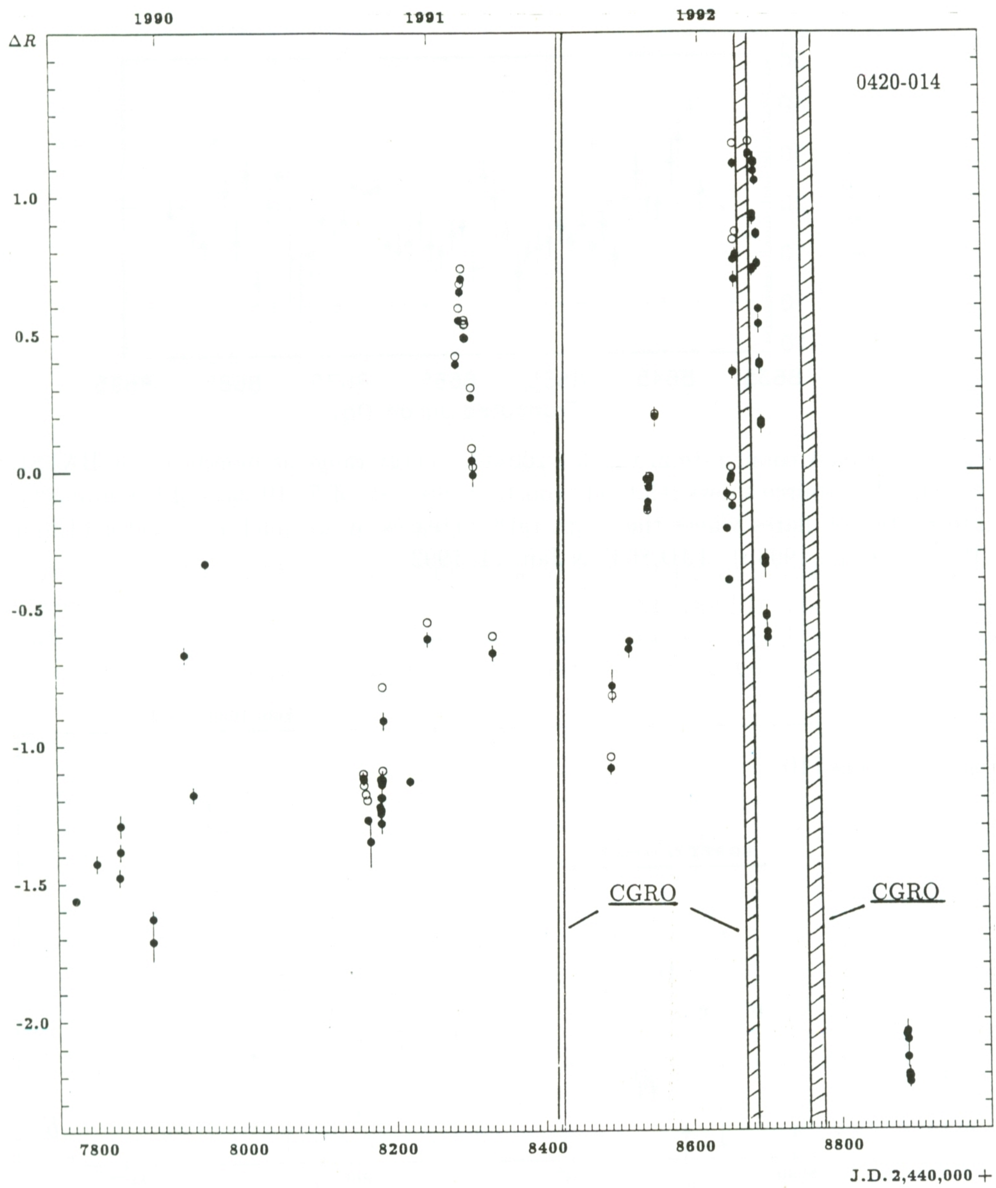

Figure 9: 0420–014 optical light curve covering two years (Borgeest 1993, cf. also the contribution by Borgeest). A steady increase with large flaring periods is clearely seen. Three CGRO observations of this region fall in this time interval and are indicated. Only in the last observation, the gamma-ray source is within the field-of-view of EGRET and clearely detected. In the other two observations, 0420–014 is just few degrees outside the field-of-view of EGRET and a coarse analysis gave no result. Judged from the optical data, results from the second observation should be very interesting

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