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Centaurus A at Hard X-Rays and Soft Gamma-Rays

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Abstract: Cen A, at a distance of less than 4 Mpc, is the nearest radio-loud AGN. Its emission is detected from radio to very-high energy gamma-rays. Despite the fact that Cen A is one of the best studied extragalactic objects the origin of its hard X-ray and soft gamma-ray emission (100 keV < E < 50 MeV) is still uncertain. Observations with high spatial resolution in the adjacent soft X-ray and hard gamma-ray regimes suggest that several distinct components such as a Seyfert-like nucleus, relativistic jets, and even luminous X-ray binaries within Cen A may contribute to the total emission in the MeV regime that has been detected with low spatial resolution. As the Spectral Energy Distribution of Cen A has its second maximum around 1 MeV, this energy range plays an important role in modeling the emission of (this) AGN. As there will be no satellite mission in the near future that will cover this energies with higher spatial resolution and better sensitivity, an overview of all existing hard X-ray and soft gamma-ray measurements of Cen A is presented here defining the present knowledge on Cen A in the MeV energy range.

Keywords: galaxies: individual (NGC 5128, Centaurus A) — X-rays: galaxies — gamma rays: observations

1 Introduction

The elliptical galaxy NGC 5128 is the stellar body of the giant double radio source Cen A that extends about 10° on the southern sky. In the inner region it contains a jet with a large inclination (~70°) to the line-of-sight which is detected in all wavelength bands where the spatial resolution is sufficient. The dust lane, which obscures the nucleus at optical wavelengths, is thought to be the remnant of a recent merger (10^7–10^8 years ago) of the elliptical galaxy with a smaller spiral galaxy (Thomson 1992). This merger and the subsequent accretion of gas and dust onto the central black hole gives rise to the observed activity of the nucleus (AGN). The supermassive black hole at the center has an estimated mass of 10^7 to 10^8 solar masses (Marconi et al. 2000, 2001; Silge et al. 2005; Cappellari et al. 2009).

Cen A as an active galaxy is usually classified as a FR I type radio galaxy, as a Seyfert 2 object in the optical (Dermer & Gehrels 1995), and as a 'misdirected' BL Lac type AGN at higher energies (Morganti et al. 1992). It is one of the best examples of a radio-loud AGN viewed from the side of the jet axis (Dufour et al. 1979; Graham 1979; Jones et al. 1996). Its proximity of <4 Mpc (Harris et al. 1984; Hui et al. 1993; Rejkuba 2004) makes Cen A uniquely observable among such objects, even though its bolometric luminosity is not large by AGN standards. It is the nearest active galaxy and therefore, NGC 5128 is very well studied and frequently observed in all wavelength bands (Israel 1998). Its emission is detected from radio to high-energy gamma-rays (Johnson et al. 1997; Israel 1998; Aharonian et al. 2009) making it the only radio galaxy detected in the hard X-ray and soft gamma-ray energy range (100 keV < E < 50 MeV), the MeV regime for short. All other AGN detected in MeV gamma-rays (and identified) are blazars (Collmar 2001).

Historically, Cen A has exhibited greater than an order of magnitude X-ray intensity variability that has been used to define a low, intermediate, and high-luminosity state in X-rays (Bond et al. 1996). In the MeV regime however, Cen A does not show a similar variability in intensity, but the spectral shape changes between the low and intermediate luminosity states as defined in the X-ray regime (Kinzer et al. 1995; Steinle et al. 1998). In contrast, in the X-ray energy range below ~100 keV no distinct change of the spectral index (1.7–1.8) is observed (Baity et al. 1981; Feigelson 1981; Morini, Anselmo & Molteni 1989; Maisack et al. 1992; Jourdain et al. 1993) when the luminosity state changes. It has to be noted, that the detections of variability in soft gamma-rays (and in most older X-ray observations) were made with instruments with spatial resolutions that make it impossible to resolve the components known today. Therefore the sources of the variability can only be determined by indirect methods. Israel 1998 argues that based on correlated variations at hard X-rays and millimeter wavelengths, this emission originates in the nucleus whereas correlated variability in soft X-rays and at 43 GHz point to an origin in the jet.

Observations of gamma-rays in general reveal the most powerful sources and the most violent events in the universe. While at lower energies the observed emission is generally dominated by thermal processes, the gamma-ray emission provides us with a view on the

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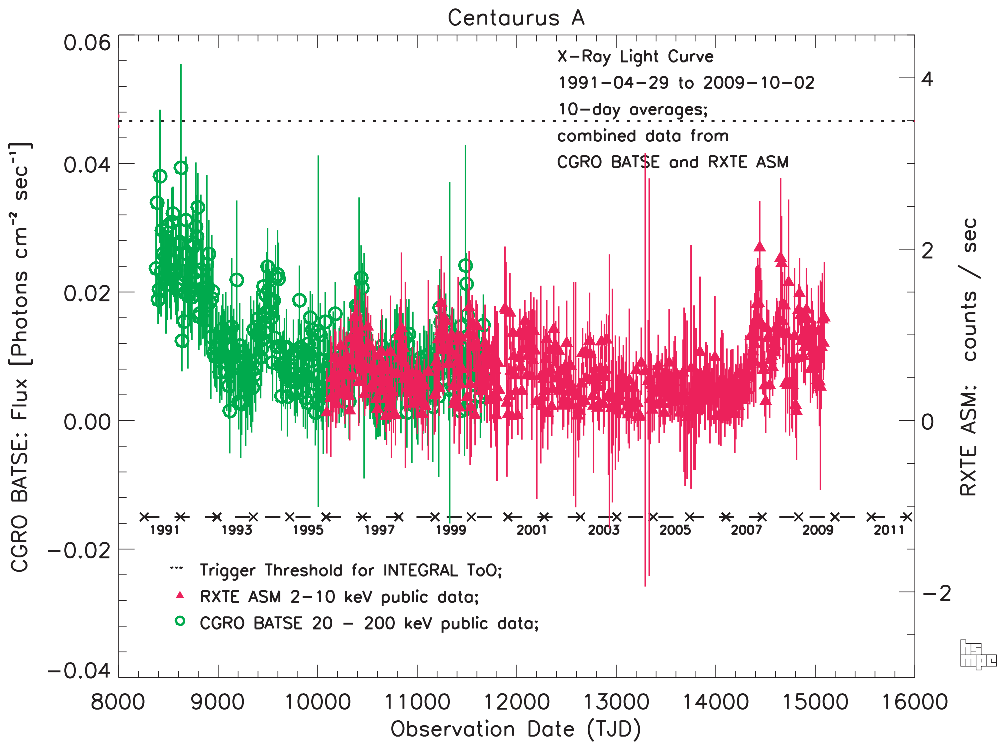

Figure 1 Combined *CGRO-BATSE* and *RXTE* X-ray light curve spanning 18 years from the launch of *CGRO* 1991 to the present (for more details see text). Each data point is a 10-day average.

non-thermal sources where particles are accelerated to extreme relativistic energies. It is therefore important for our understanding and subsequent modeling of the sources of the emission in AGN to measure the Spectral Energy Distribution (SED) over a wide energy range including gamma-rays and here especially the poorly sampled MeV regime.

Because Cen A is so close and modern instruments can resolve the inner part of this AGN in almost all wavelength bands down to parsec level, it has the potential to become a key object for AGN science where models can be uniquely tested. Therefore detailed observations of this galaxy across the electromagnetic spectrum are extremely valuable to improve our understanding of AGNs.

The existing MeV data will be for the near future the only measurements of Cen A in this energy range as no new satellite experiment sensitive in this energy range is beyond the conceptual phase. It therefore seems appropriate to summarize our present knowledge here and to provide references to all important results in this energy range.

As Cen A is such an unique object and so many observations exist, a dedicated web site[1] has been set up for this object at the Max Planck Institute for Extraterrestrial Physics (MPE) that provides among other information on Cen A an up-to-date and complete list of references. This web site, as all the others mentioned in this paper, is continuously updated and is guaranteed to exist for a longer period.

[1] `http://www.mpe.mpg.de/Cen-A/`

This paper is an extended version of a review presented at a dedicated conference that brought together theoreticians and specialists from all wavelength regimes to discuss 'The Many Faces of Centaurus A' in June 2009 in Sydney, Australia.

2 The MeV Energy Range

Compared to the energy ranges adjacent to the MeV regime, observations in the range 100 keV to 50 MeV have much less spatial resolution and the instruments used are less sensitive. In soft X-rays and high-energy gamma-rays a spatial resolution of arcseconds is possible today (*Chandra*, *Fermi*), but the best resolution in the MeV regime achieved so far is about 15 arcmin up to several hundred keV by the coded mask telescope *SIGMA* (Jourdain et al. 1993) and about 4 degrees in the energy range 1–30 MeV by the Compton telescope *COMPTEL* onboard the *Compton Gamma-Ray Observatory* (*CGRO*, Steinle et al. 1998). The main reason for this unfortunate situation, which prevents a clear identification of the MeV radiation sources, is due to the fact that the interaction probability of gamma-rays with matter in this energy range has a minimum (see figure 1 in Gehrels & Cannizzo 2009) and reflecting surfaces for telescopes can not be built. Although the interaction probability of MeV gamma-rays with matter is very small, the Earth atmosphere absorbs MeV gamma-rays and thus high altitude balloons or satellites are necessary (Pinkau 2009) to carry detectors above the absorbing atmosphere to detect MeV gamma-rays. In addition, the low interaction probability also implies, that detectors have to be massive and heavy, making satellite

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experiments very costly. As can be seen in figure 1 in Diehl et al. (2009), there is a 'sensitivity gap' in the MeV region which reflects the fact, that no second-generation experiment with improved sensitivity exists in this energy range. In the adjacent energy regions second- and third-generation instruments with orders of magnitude better sensitivity and resolution have been built. Compton telescopes like *CGRO-COMPTEL* or coded mask instruments like *SIGMA* and *INTEGRAL* are still the only proven technique in this energy band although new ideas for MeV telescopes exist (Bloser et al. 2009), but none of them will be realized in the near future.

One important feature of Cen A is, that the Spectral Energy Distribution has its second maximum in the MeV energy range (see Figure 5). Thus it is important to measure this region with high significance to derive the spectrum and possible time variability with high accuracy to enable tests of models of the high-energy emission of (this) AGN (e.g. Ghisellini, Tavecchio & Chiaberge 2005; Orellana & Romero 2009). In addition, a good spatial resolution to determine the sources of the MeV emission would be ideal, as this is a transition region where the contribution of various sources to the global luminosity changes. In soft X-rays the nucleus, jets, radio lobes and X-ray binaries all contribute to the total luminosity (see the very detailed X-ray images from *Chandra* (Kraft et al. 2001, 2003)), whereas at hard gamma-rays only the inner jet and nucleus and possibly the outer radio lobes are seen (Hardcastle et al. 2009; *Fermi*, Abdo et al. 2009; *H.E.S.S.*, Aharonian et al. 2009).

3 MeV Observations

Since the first satellites were launched in the early 1960s, a very large number of detectors sensitive to X-rays and gamma-rays were exposed to the radiation above the atmosphere. First hints to an extension of the spectrum of Cen A into the MeV range were obtained between 1972 and 1981 with various balloon experiments and satellites, when finally the MPI-Balloon Compton experiment detected emission up to 20 MeV from the direction to Cen A in October 1982 (von Ballmoos, Diehl & Schönfelder 1987 and references therein).

In 1990/91 the imaging coded mask telescope *SIGMA* on board the *GRANAT* satellite detected a point-like source at the position of the nucleus of Cen A with a spatial resolution of $\sim$15 arcmin and a positional uncertainty of 4 arcmin and measured a spectrum with a photon index of $\sim$2 in the energy range 40–400 keV (Jourdain et al. 1993). The most accurate spectral information between 50 keV and 10 GeV including the MeV regime so far was obtained by the instruments *OSSE*, *COMPTEL*, and *EGRET* onboard the *Compton Gamma-Ray Observatory*, that operated more than 9 years from April 1991 to June 2000. During this time, *OSSE* observed Cen A almost 100 times with a time resolution of about one day and a spatial resolution of 4–12° in the energy range 50 keV–10 MeV. *COMPTEL* has observed Cen A in the energy range 0.75–30 MeV during 40 *CGRO* pointings with a time resolution of 14 days and a spatial resolution of 4°. The highest energy range 50 MeV–10 GeV was covered by *EGRET* simultaneous to *COMPTEL*, but Cen A was only detected below 100 MeV. The *EGRET* time resolution was also 14 days and the spatial resolution several degrees. All this *CGRO* data have been entered into the NASA/IPAC Extragalactic Database (NED)[2] and are available to the public.

INTEGRAL, a satellite launched in October 2002 and still operational carries two instruments sensitive to MeV gamma-rays: the imager *IBIS* and the spectrometer *SPI*. Cen A was observed few times so far for about 6.5 days total but the sensitivities of both instruments do not allow measurements of Cen A beyond 500–600 keV in a reasonable length of observing time (Collmar 2001; Rothschild et al. 2006; Petry et al. 2009). Due to the relatively low sensitivity, the spatial resolution of nominal 12 arcmin of the imager *IBIS* could not be exploited for Cen A in the MeV regime to determine the origin of the gamma-ray emission.

3.1 Light Curves

X-ray intensity data from Cen A are available since the late 1960s and Cen A has exhibited variations greater than an order of magnitude in X-rays below 100 keV between 1973 and 1983 on time scales of years or less (Bond et al. 1996; Turner et al. 1997; Israel 1998). Later observations of Cen A have also shown variability on similar time scales (Grandi et al. 2003; Rothschild et al. 2006), but no high luminosity state was detected since 1985.

Jourdain et al. (1993) distinguish a long-term variability that lasts for years and defines the global luminosity state described above, and short intensity variations of the order of days that are superimposed on the long-term component.

X-ray monitoring of Cen A to define the luminosity state is still pursued today using the all-sky monitors (ASMs) onboard the *Rossi X-ray Timing Explorer* (*RXTE*; 2–10 keV) and on *Swift* (15–200 keV). Fortunately, during the time-span from 1995 to 2000, the luminosity of Cen A was monitored simultaneously with the *CGRO-BATSE* instrument in the energy range 20–200 keV and with *RXTE-ASM* in the energy range 1–10 keV so that a combination of both light curves could be achieved. To reduce the statistical noise in the daily data, averages over 10 days are formed for the data of both instruments which then show the long-term trends in the luminosity on timescales of months. In Figure 1 the combined data are shown. On the left ordinate the *CGRO-BATSE* flux is given whereas on the right ordinate the normalized *RXTE-ASM* counts are given. The *RXTE-ASM* counts were normalized in such a way, that the amplitudes of the variations are similar. No attempt was made to cross-calibrate the measured flux (counts) in the two energy bands.

By comparing the two light curves in the time span of the simultaneous monitoring, it could be verified that the

[2] The NASA/IPAC Extragalactic Database (NED) is at http://nedwww.ipac.caltech.edu/

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variations observed with the two instruments in different energy bands are almost identical and thus a combined light curve can be established. (A similar normalization is possible with the data simultaneously measured at present with the all-sky monitors on *RXTE* and *Swift*.) It is therefore possible to continue the monitoring and to combine the data sets to create continuous 10-day averages from 1991 to the present (and hopefully also in the future with *Swift*).

Also obvious from Figure 1 is the fact that only at the beginning of these monitoring observations in 1991 an intermediate luminosity state of Cen A was detected. Since then the source was found to be in a low state. Normalized to the flux at 100 keV (as in Jourdain et al. 1993 and Bond et al. 1996, which is also the middle of the energy ranges of *CGRO-BATSE* and *Swift*) the intermediate intensity state of Cen A has a flux of $\sim 6 \times 10^{-5}\,\mathrm{cm^{-2}\,s^{-1}\,keV^{-1}}$ and the low state has a flux of $\sim 2 \times 10^{-5}\,\mathrm{cm^{-2}\,s^{-1}\,keV^{-1}}$. The intermediate and low state luminosities in the energy range 40–1200 keV are $\sim 10^{43}\,\mathrm{erg\,s^{-1}}$ and $\sim 4 \times 10^{42}\,\mathrm{erg\,s^{-1}}$ respectively, assuming a mean single power law with index of 1.8 in this energy range (Bond et al. 1996), and ignoring the possible breaks in the spectrum discussed in Section 3.2 below.

Given the low spatial resolution of the instruments used to determine the flux from the direction of Cen A, it is possible that (superluminal) X-ray binaries in Cen A contribute significantly to the measured variability at the low energy X-rays that are used to monitor its luminosity state (Steinle, Dennerl & Englhauser 2000a; Kraft et al. 2001). Even in the MeV regime a contamination of the luminosity by such objects is possible as e.g. Cyg X-1, a galactic black hole candidate, is detected up to MeV energies (McConnell et al. 2000). The time scales of the variations in the monitoring data and that of typical X-ray binaries seem to be similar, supporting the possibility that at least some of the observed variations in the global luminosity may be caused by this class of objects. Although this possible contamination can not be determined for older measurements it is now possible to check the origin of a significant increase in the flux of Cen A as detected by the *ASMs* by taking contemporaneous high resolution X-ray images with the satellites *Chandra* or *Swift*. Therefore, X-ray monitoring is still a tool to define the actual luminosity state of Cen A.

Probably correlated with the luminosity state as defined by the X-ray monitoring with *BATSE* on board *CGRO* was the detection of spectral variability in the MeV range by *CGRO-COMPTEL* (see Section 3.2). This correlation is the main justification to use the X-ray monitoring as a tool to estimate the activity in the MeV energy band as in contrast to the spectral variability observed, no significant luminosity variation was detected with *CGRO-COMPTEL* in the MeV range as shown in Figure 2. Also *INTEGRAL* did not detect intensity variations in the observed energy range (Bouchet et al. 2005, 2008; Petry et al. 2009).

This non-detection of a luminosity variation in the total-energy band 1–30 MeV as opposed to the observed variation at 100 keV can be explained by the shift of the spectral breaks that change the shape of the spectrum in such a way that the integrated luminosity in the whole band is not affected.

3.2 Spectra

Spectra covering the MeV range are sparse. Jourdain et al. (1993) list only four measured spectra from the direction towards Cen A between 1968 and 1991 that reach beyond 500 keV. A balloon flight of the Rice University in 1974 reached 700 keV and found a single power law with an index of 1.9 (Hall et al. 1976). Spectra measured by the *HEAO 1* satellite in 1978 in the energy band 2 keV–2.3 MeV required the first broken power law: the index steepens from 1.6 below 140 keV to an index of 2.0 above (Baity et al. 1981). The first spectrum of Cen A reaching well above several MeV was measured with the MPI Compton telescope in October 1982. In a balloon flight of 4.5 h duration a power-law spectrum in the energy range 0.7–20 MeV was detected with a photon index of 1.4 ± 0.4 (von Ballmoos et al. 1987). This is a very hard spectrum, and the extrapolated luminosity in the 100 keV region of $10^{-4}\,\mathrm{cm^{-2}\,s^{-1}\,keV^{-1}}$ would indicate that it was taken during a high-luminosity state of Cen A in the definition of Bond et al. (1996). However, simultaneous measurements with the *SMM* satellite that was sensitive in almost exactly the same energy range as the balloon experiment could not verify such a high-luminosity state if it would have lasted longer than $\sim$8 days (Harris et al. 1993). In addition, in a re-analysis of the balloon data with improved analysis methods and using data on Cen A from the same balloon flight that were not included in the previous analysis it was found that the derived spectral slope remained unchanged, but the intensity of Cen A was much lower and had a large error so that the emission state could not be derived with certainty (M. Varendorff, private communication). This data are therefore not included in the final SED in Figure 5.

Observations in 1990/91 with the *SIGMA* satellite yielded the same power law in the energy band 35–200 keV with photon index $\sim$2 in both observations although in the second observation the intensity of Cen A had changed by a factor of $\sim$3 (Jourdain et al. 1993). This was the first hint of a constant power law index during changes of intensity below $\sim$200 keV.

Fortunately Cen A was among the first targets, when *CGRO* started regular observations (Steinle et al. 1998). The MeV range spectrum[3] shown in Figure 3 was measured during Viewing Period 12 (VP 12) in 1991 and it is the only intermediate state spectrum of Cen A measured simultaneous with all instruments on board *CGRO* covering 15 keV–10 GeV. After that, the source declined to its low-luminosity state that persists today. Breaks in the

[3] Following Gehrels (1997), all spectra are shown in the form of νF_ν plots giving the energy flux per logarithmic interval of frequency to ease the comparison of source luminosities in different wavelength bands — especially in SEDs.

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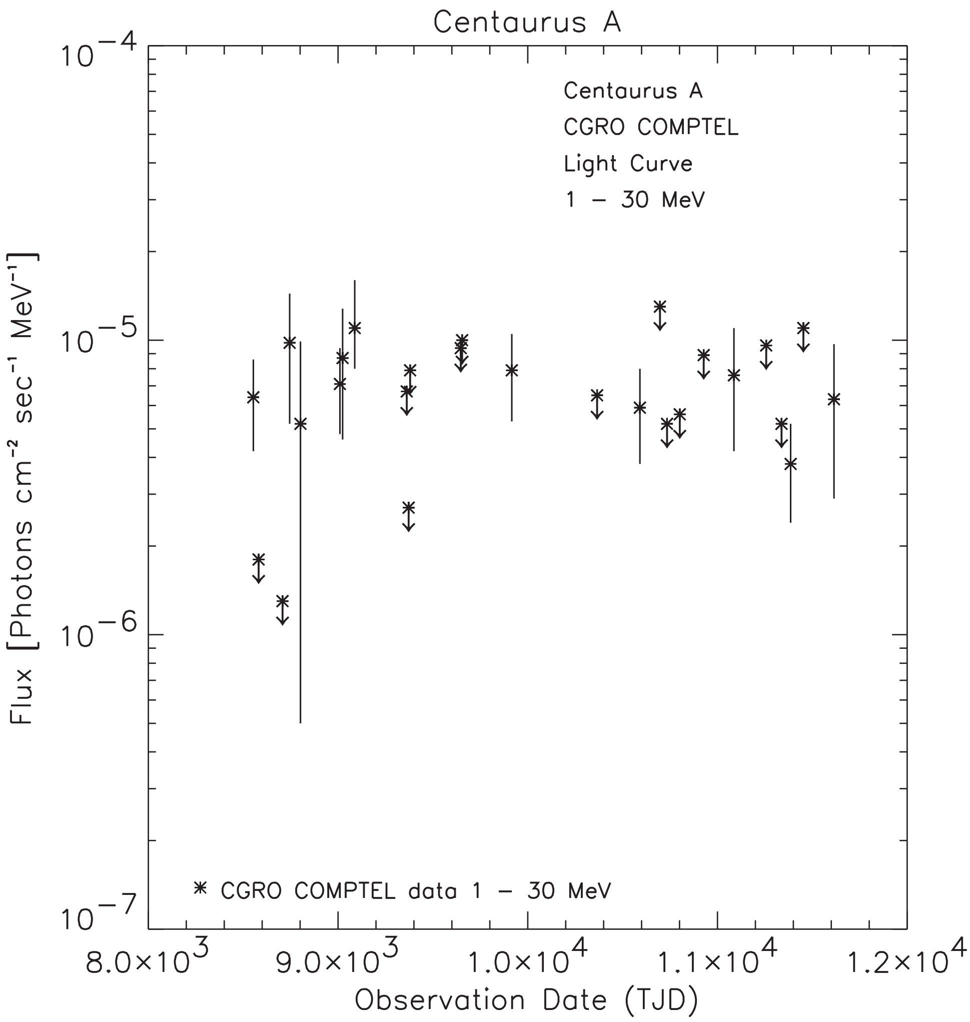

Figure 2 *CGRO-COMPTEL* light curve of Cen A in the range 1–30 MeV spanning 9 years from 1991 to 2000. The data points represent observations of 14-days duration each. Upper limits are two sigma. No significant variability is detected.

power law fit to the data are at 150 keV and 16.7 MeV. As obvious in this νF_ν plot, the maximum of the luminosity in this energy range is also at about 150 keV (3.6×10^{19} Hz).

The low-state spectrum of Cen A was measured much more often during the *CGRO* mission. It turns out that all those spectra are very similar and can be merged into the average low-state spectrum that is shown in Figure 4 together with the MeV range part of the multiwavelength campaign of 1995 that observed Cen A also in a low luminosity state. In this low state the breaks in the power law are at 140 keV and 590 keV and the maximum of the luminosity is shifted to about 600 keV (1.4×10^{20} Hz).

Although the errors in the position (i.e. energy) of break E_{b_2} during the intermediate state are very large (see Table 1) and this state was only observed once with *CGRO*, additional information supporting the shift of the break energy towards higher energies during the intermediate state compared to the low state is available. *CGRO-EGRET* detects Cen A with good statistics and determines the slope of a power law fit to be 2.85 ± 0.38 in its energy range 30–1000 MeV (Nolan et al. 1996). This is consistent within the errors with the spectral index of $\alpha_3 = 3.3 \pm 0.7$ above 16.7 MeV as determined from the whole spectrum in the energy range 30 keV–400 MeV (Figure 3). Together with the spectral index $\alpha_3 = 2.3 \pm 0.1$ above 150 keV this supports a significant shift in the break energy towards higher energies.

Table 1. Spectral properties of Cen A

Parameter	Intermediate state	Low state
E_{b_1}	$0.15^{+0.03}_{-0.02}$ MeV	$0.14^{+0.03}_{-0.03}$ MeV
E_{b_2}	$16.7^{+27.8}_{-16.3}$ MeV	$0.59^{+0.02}_{-0.02}$ MeV
α_1	$1.74^{+0.05}_{-0.06}$	$1.73^{+0.05}_{-0.05}$
α_2	$2.3^{+0.1}_{-0.1}$	$2.0^{+0.1}_{-0.01}$
α_3	$3.3^{+0.7}_{-0.6}$	$2.6^{+0.8}_{-0.6}$

In agreement with most previous measurements reaching higher energies beyond 100 keV, the power law slope below ~150 keV in the *OSSE* data shows no change of the spectral index (α ~1.7–1.8) below the break (i.e. at lower energies than 150 keV) when the intensity changes (e.g. Baity et al. 1981; Feigelson 1981; Morini et al. 1989; Maisack et al. 1992; Jourdain et al. 1993; Kinzer et al. 1995). *CGRO* for the first time showed that the spectral

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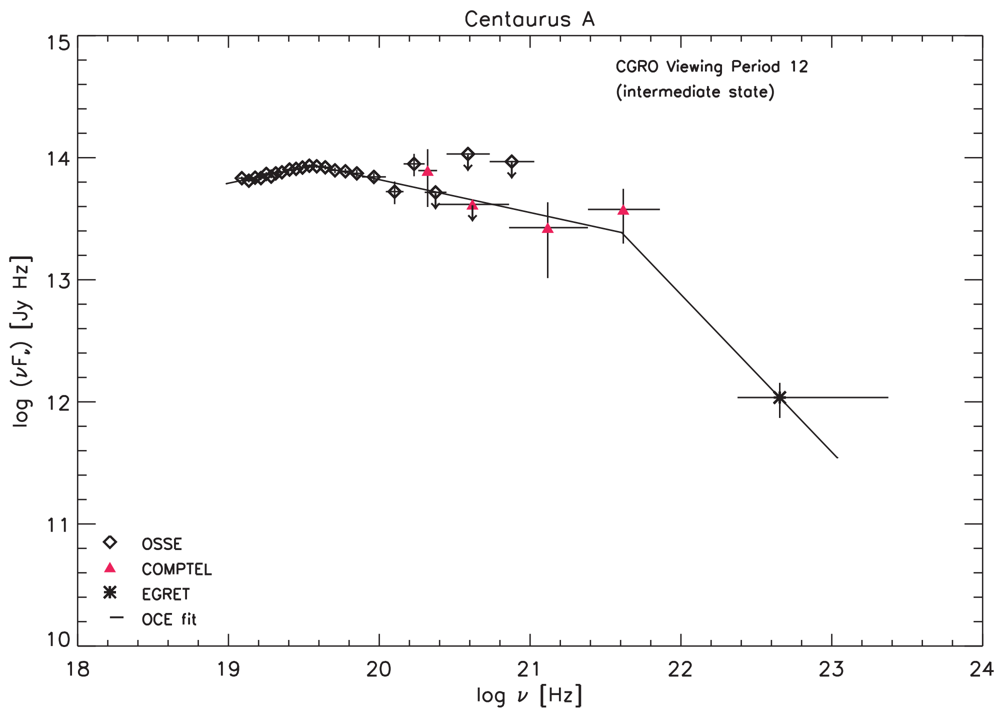

Figure 3 Intermediate-luminosity state spectrum of Cen A measured simultaneously with all instruments on board *CGRO*. (Viewing Period 12; October 17–31, 1991.) The data points from *OSSE*, *COMPTEL*, and *EGRET* together with a broken power law fit to the data are shown. See Table 1 for the fit parameter values.

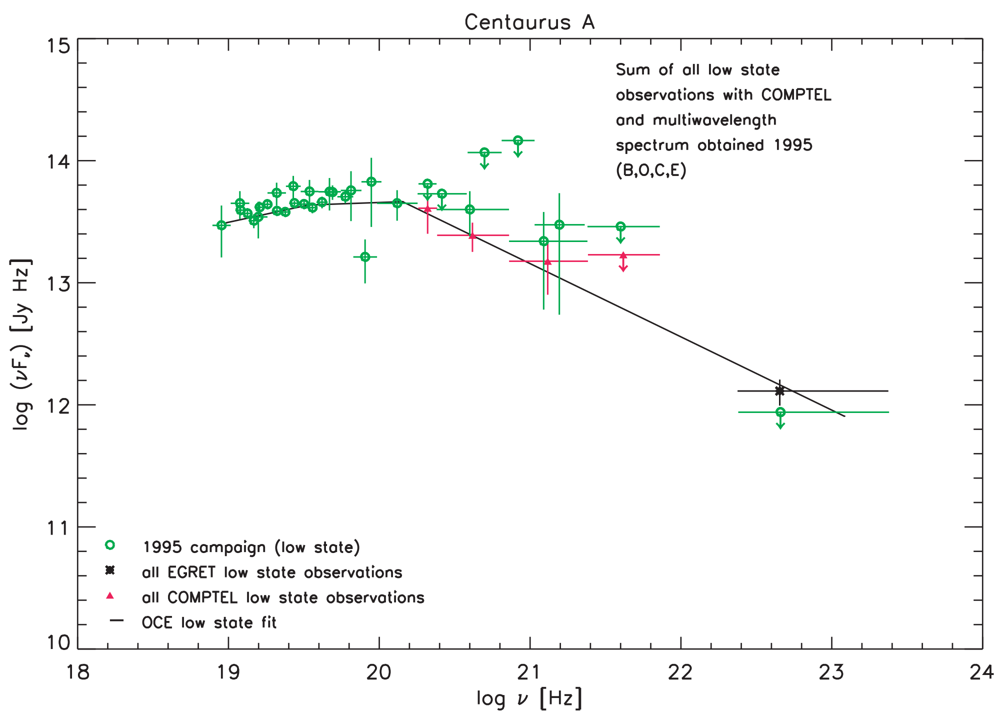

Figure 4 Cen A low luminosity state spectrum. All *CGRO* viewing periods except VP 12, data from the multi-wavelength campaign 1995, and the broken power law fit to the data are shown. See Table 1 for the fit parameter values.

shape above 150 keV changes between the low and intermediate states (Kinzer et al. 1995; Steinle et al. 1998).

The low energy low emission state spectra (3–100 (250) keV) measured with *INTEGRAL* and *RXTE* between 1996 and 2004 (Rothschild et al. 2006) confirmed the variability of the emission and the stability of the power law index of ~1.8–2.0. Petry et al. (2009) analyzed all *INTEGRAL* observations of the first four years (2003–2007) and produce an average spectrum for the *SPI* (25–1000 keV) and for the *ISGRI* (25–700 keV) data sets. Both spectra are in excellent agreement and the derived power law index is 1.8–1.9.

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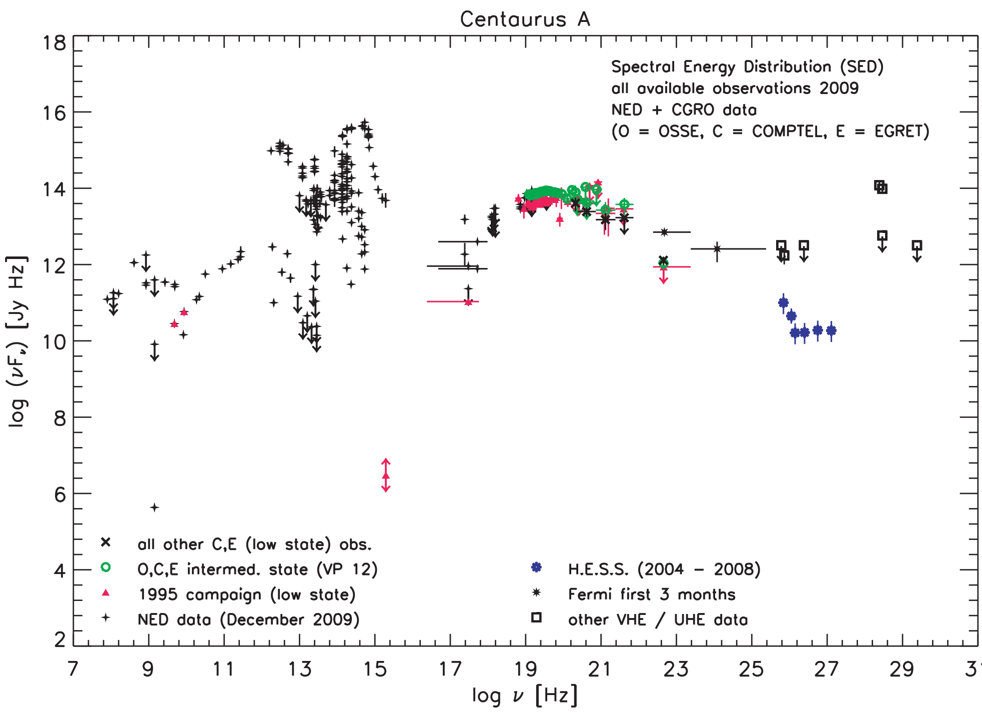

Figure 5 Spectral Energy Distribution (SED) of Cen A composed from all available data. It has to be noted, that the data in this SED are not contemporaneous. Only the data of the multiwavelength campaign 1995 shown in red filled triangles have been measured simultaneously.

To test models of the emission of AGN it is of great importance to measure the Spectral Energy Distribution over the widest possible range. Given the fact that Cen A is a very well observed object, its SED can be determined spanning almost 20 decades in energy. Figure 5 shows the final result by combining all measurements contained in the NED, in other publications, and the recently published *Fermi* (Abdo et al. 2009) and *H.E.S.S.* (Aharonian et al. 2009) very-high energy results. Indicated in the SED in Figure 5 is the fact, that only for the data in the MeV region discussed in this paper (i.e. 10^{19}–10^{23} Hz), the luminosity state is known and distinguished. For most of the other data, the luminosity state is not known. As Cen A is variable, the comparison of emission models and the SED requires simultaneous data and specific models for the different luminosity states. So far only one simultaneous data set from the 1995 multiwavelength campaign exists for a low luminosity state (Steinle et al. 1999).

4 Summary and Outlook

The detection of Cen A in gamma-rays up to GeV energies makes this AGN unique, as all other radio-loud AGN detected in high-energy gamma-rays are of the blazar type. As Cen A is viewed from a large angle with respect to the jet axis, it may well be, that we do not see jet emission from this AGN only (misaligned blazar) but also emission from the nuclear region and that we detect Cen A only because it is so close.

Observed in the MeV energy range with *CGRO* during more than 9 years, and in the following years up to now by *INTEGRAL*, Cen A did not show the large intensity variations in X-rays recorded in the past. Fortunately, at the beginning of the *CGRO* observations, Cen A was in an intermediate luminosity state before its intensity declined to the low luminosity state which lasted for the reminder of the mission and further on until today (October 2009). Only one MeV spectrum has been measured with *CGRO* in a luminosity state other than the low state. This intermediate state spectrum differs significantly from the average low-state spectrum. During changes in the X-ray luminosity states from intermediate to low, the luminosity in the MeV region stays constant, but in contrast to the stability of the spectral shape in the X-ray region, the spectral indices of the broken power law change in the MeV region.

The Cen A spectra measured with *CGRO* close the gap in the MeV energy range that is present in so many other SEDs of AGN due to the lack of high-energy measurements or too low sensitivity in this energy band. This energy band however is of specific interest, as almost all emission models of AGN show the second luminosity maximum of the SED to fall in this energy range. When analyzed together with data from other wavelength regimes the *CGRO* spectra allowed for the first time to derive a measured continuous Spectral Energy Distribution from the radio to the very-high gamma-rays providing a unique dataset for theoretical modeling of the emission of Cen A over 20 decades in frequency/energy. This SED contains data that were collected during very different X-ray luminosity states and it is very important to measure SEDs contemporaneously. Therefore a coordinated multiwavelength campaign was organized in 1995 to measure a simultaneous Cen A SED in a low luminosity state covering radio to GeV frequencies/energies (see Figure 5).

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Many interesting data on Cen A have been collected by the gamma-ray sensitive instruments on various satellites, but still many open questions exist and many important high-energy measurements still have to be made. Among the most interesting observations missing are simultaneous multiwavelength measurements of the SED in a high and intermediate X-ray luminosity state, and to determine any possible correlation with the spectral shape in the MeV region, as well as observations with high spatial resolution to resolve jet and nucleus in MeV gamma-rays and to determine the sources of the MeV emission.

To achieve this, second- or third-generation gamma-ray sensitive instruments are needed. In soft X-rays a comparable step was taken going from the *Einstein* and the *EXOSAT* satellites to the *Chandra* and *XMM/Newton* observatories. At high-energy gamma-rays this was the step from *COS–B* to *EGRET* and now to *Fermi*[4].

The outlook is not very encouraging. No new satellite experiment sensitive in the MeV energy range is accepted (*ASTRO–H* only reaches up to 600 keV) and only two proposals for large instruments covering the MeV range exist: *ACT*, the '*Advanced Compton Telescope*' is an optimized telescope sensitive in the 0.2–20 MeV energy band utilizing advances in detector technologies to improve sensitivity by two orders of magnitude, but the spatial resolution will still be only in the order of 1° (Boggs et al. 2008). *GRIPS* (Gamma-ray burst investigation via polarimetry and spectroscopy), mainly aiming towards high spectral resolution, would improve the sensitivity in the 200 keV–50 MeV range by a factor of 40 over *COMPTEL* but its spatial resolution would still only be 1.0–1.5° (Greiner et al. 2009).

As both projects will at best need many more years to be realized and new ideas like the ones listed in Bloser et al. (2009) need much more time, one will have to live for the next decades with what we have — the data presented in this overview.

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[4] A list of high-energy observatories is available from NASAs High Energy Astrophysics Science Archive Research Center (HEASARC): `http://heasarc.gsfc.nasa.gov/docs/corp/observatories.html`

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