OSSE OBSERVATIONS OF CENTAURUS A OVER 18 MONTHS

R.L. Kinzer, W.N. Johnson, J.D. Kurfess, M.S. Strickman,
J.E. Grove, R.A. Kroeger
E. O. Hulburt Center for Space Research, Naval Research Laboratory, Washington, D.C. 20375-5320

D.A. Grabelsky, W.R. Purcell, M.P. Ulmer
Deptartment of Physics and Astronomy, Northwestern University, Evanston, IL 60208

G.V. Jung
Universities Space Research Association, Code 7650, Naval Research Laboratory, Washington, D.C. 20375-5320

ABSTRACT

OSSE observed Centaurus A at energies between 0.05 and 10 MeV in 1991, 1992, and in 1993. During each observation, this AGN was found to be at relatively low intensities compared to previous observations. It exhibited roughly constant average intensity intervals of a few (5 to 8) days with abrupt (12 to 24-hour) intensity changes about the mean of as much as 60%. The spectral shape at low intensities can be represented by a single power-law up to about one MeV (1992); the more intense 1991 spectrum is best characterized by a broken power-law with a half-power steepening near 150 keV. Extrapolations to high energy, when compared with the EGRET upper limit for emission above 100 MeV, suggest a need for an additional spectral break above one MeV. The spectral behavior of the AGN in Cen A at energies below one MeV appears to be intermediate between that of flat-spectrum quasars such as 3C 273 and of steep-spectrum Seyferts such as NGC 4151.

INTRODUCTION

OSSE observed the AGN in the nearest (3-5 Mpc) radio galaxy Centaurus A (NGC 5128) on three occasions in 1991, 1992, and 1993. This source is among the brightest extragalactic objects above 100 keV. Prior to the launch of the Compton Gamma Ray Observatory (CGRO), Cen A was one of three AGN with detections up to and above about 100 keV (see e.g. Gehrels and Cheung, 1991), and was considerably the brightest of the class at these energies. Emission from this source has been found to be highly variable at X-ray energies. This paper describes OSSE observations of variability on time scales as short as 12 hours and of spectra and spectral shape variability in the 50 to 1000 keV range.

OBSERVATION AND EXPERIMENTAL RESULTS

OSSE comprises four identical and independent phoswich spectrometers which have a total area of 2620 cm^2 and an effective area of ~2000 cm^2 at 511 keV and which are sensitive between about 50 keV and 10 MeV (see Johnson et al. 1993 for an instrument description) . All four detectors were used in a two-minute source/background chopping mode to observe Cen A during three viewing periods in October 1991 (560,000 detector-s of

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1994**	2. REPORT TYPE	3. DATES COVERED **00-00-1994 to 00-00-1994**
4. TITLE AND SUBTITLE **OSSE Observations of Centaurus A Over 18 Months**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,E.O. Hulburt Center for Space Research,4555 Overlook Avenue, SW,Washington,DC,20375**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

source observing time), November 1992 (130,000 detector-s), and April 1993 (485,000 detector-s). For these observations, time-integrated count-rate spectra were accumulated in 512-channel energy spectra at 16 s resolution. During the 1991 and 1993 observations, the source was simultaneously observed by EGRET and COMPTEL.

1. VARIABILITY: OSSE observed Cen A at three relatively distinct intensity levels in observations in three consecutive calendar years. The 1991 observation had two distinct intensity levels; the 1992 and 1993 observations were at lower average intensity levels (Fig. 1), with significant and generally random variations about their mean intensity levels. During all of the observations, Cen A was at historically relatively low intensity levels, with the 1992 and 1993 observations being the near the lowest intensities yet reported for Cen A in the 50-100 keV region. Variability in the integral (50 keV to 500 keV) intensity of the three observations is shown in Fig. 1 on a one-day time scale.

The data provide compelling evidence for variability on a time scale of 12 to 24 hours. Much of the ~40% intensity change from the "high" to the "low" state in the 1991 observation occurred within 12 hours. This state change is also clearly present when similar analyses are made in narrow energy bands between 50 and 400 keV. Numerous 3-sigma variations of the integral intensity on a 12-hour time scale are present in the 3 observations. The average intensity in the observations monotonically decreased with time, with the 1992 observation (days 672-678) decreasing by a factor of ~2 in intensity relative to the "high" state observed in 1991. The 1993 observation (days 821- 825 and 831-839) are more variable, with an average intensity ~25% lower than that in 1992.

2. SPECTRAL ANALYSES: Time-integrated spectra for the 1991 low and high states and for the 1992, and 1993 observations had significantly different average intensities. Models fit to each spectrum were a double or broken power-law spectrum, a simple power-law spectrum, and a Sunyaev-Titarchuk Comptonization model spectrum (Sunyaev and Titarchuk, 1980). Fig. 2a and 2b show these fits for the 1991 high state (days 291-296) and low state (days 297-304). Uncertainties are shown at the one-sigma level; upper limits are plotted at the two-sigma intensity level. Spectral fits used single-channel data between 50 and 1000 keV; energy channels are combined for display. Table I gives the best-fit parameters for each model for the all four data sets.

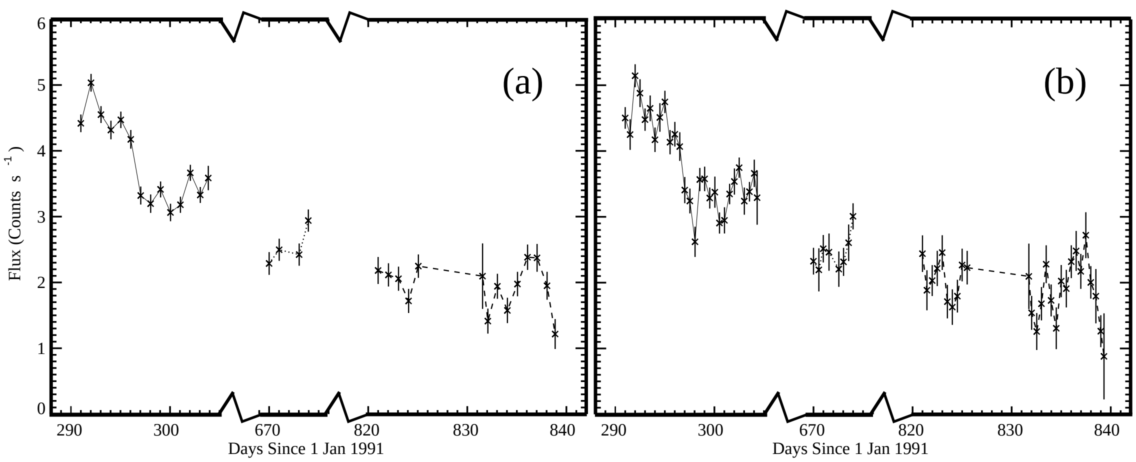

Figure 1. Intensity in the 60 to 500 keV energy band for the 1991,1992, and 1993 observations on 24 hour (a) and 12 hour (b) time scales.

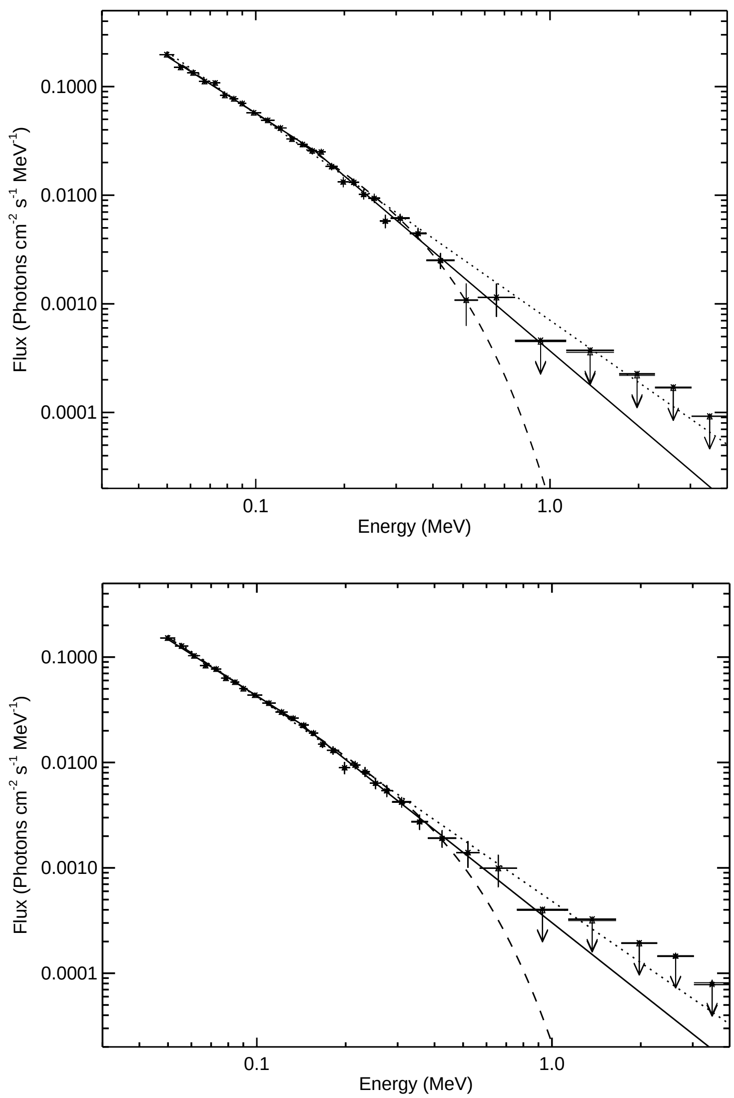

Fig. 2. Spectra for the 1991 observation. The high state (first 6 days) is shown in (a) and the low state (last 8 days) in (b). Best-fit models shown are a broken power-law (solid lines), a simple power-law (doted lines), and a single-temperature Sunyaev-Titarchuk Comptonization model (dashed lines).

There are significant differences between the time-integrated spectral shapes of the four observations at different intensities. The lower intensity observations (1992 and 1993) are reasonably well represented by a single power-law of index -1.9 over the full range observed. Broken power-law fits to these observations give statistically only marginally better fits than does a single power-law, but broken power-law fits give visually more satisfying fits. However, the fit parameters of the break are not as well defined, especially for the 1992 observation, suggesting that a spectral break may not be required to characterize these data. The Comptonization model gives fits statistically equivalent to the broken and single power-law fits for these data, but it fails in modeling the lower-significance high-energy points. However, the more intense emission observed in 1991 over a 14 day interval is not well-represented by a single power-law model. Both the 1991 high and low states are well-characterized by a broken power-law model with a half-power break in the 150 keV region; the higher-intensity spectrum has a slightly larger break at somewhat higher energy. Chi-squared mapping of the confidence levels of the break energy and the magnitude of the break show that the break is probably not abrupt, but occurs gradually over an energy range of ~50 keV. The Sunyaev-Titarchuk Comptonization model also gives a statistically acceptable fit to these data.

TABLE I: Model best-fit parameter values for 1991, 1992 and 1993 observations.

YEAR model	Amplitude (cm^2-s-MeV)	Break/Norm. Energy	Lower Ind./ Temp.(MeV)	Upper Ind./ Optical Dep.	Chi Sqr. prob.
1991 -- (high)					
BPL	0.0254 ±0.0047	0.159 ±0.016	-1.73 ±0.03	-2.30 ±0.11	0.86
PL	0.0558 ±0.0005	0.1	-1.90 ±0.02		0.05
ST	0.0565 ±0.0005	0.1	0.092 ±0.006	1.75 ±0.11	0.66
1991 -- (low)					
BPL	0.0238 ±0.0056	0.139 ±0.017	-1.78 ±0.04	-2.21 ±0.09	0.66
PL	0.0419 ±0.0004	0.1	-1.94 ±0.03		0.18
ST	0.0423 ±0.0004	0.1	0.103 ±0.011	1.51 ±0.14	0.35
1992					
BPL	0.0425 ±0.016	0.084 ±0.017	-1.47 ±0.28	-1.99 ±0.09	0.19
PL	0.0287 ±0.0006	0.1	-1.88 ±0.05		0.14
ST	0.0288 ±0.0006	0.1	0.137 ±0.043	1.24 ±00.34	0.14
1993					
BPL	0.0275 ±0.010	0.100 ±0.022	-1.72 ±0.13	-2.07 ±0.10	0.98
PL	0.0216 ±0.0004	0.1	-1.93 ±0.05		0.97
ST	0.0218 ±0.0004	0.1	0.112 ±0.024	1.41 ±0.27	0.97

DISCUSSION

OSSE's observations have confirmed the variable nature of Cen A previously reported at X-ray energies up to 100 keV, where intensities varying by a factor of ten have been seen (see e.g. Baity et al. 1981, or Gehrels et al. 1984 for historical summaries) . We have extended the variability range up to 500 keV and decreased the time-scales for intensity changes in the 100 keV range from months to as short as 12 hours. To a first approximation, the time-dependence of the variability is found to be similar for energies between 50 keV and 500 keV. An abrupt intensity change of ~30% was observed between roughly constant average intensity intervals of about one-week duration. OSSE's observed random intensity variations about the local mean of up to 60% in times as short as 12 hours. From simple light-travel arguments, these short intensity variations suggest that the emitting region is less than 10^{15} cm across.

Cen A exhibited different spectral shapes which may be intensity-related. A simple power-law represents the low-intensity data almost as well as does a broken power-law, but a broken power-law is needed to characterize the more intense 1991 spectra. For broken power-law fits (Table I), there is a trend for the break energy to move to lower energies and for the break to become less strong with decreasing intensity. Although a broken power-law represents the higher-intensity observations well, it is likely that a more physical model with a gradually steepening spectrum is a better model for Cen A's variable spectral shape.

The OSSE observations of Cen A, which are at historically low intensity levels, provide a new level of definition of the spectrum above 50 keV which is sufficiently precise to show spectral differences with intensity change, and to define the spectral shape up to about one MeV. Extrapolations of the OSSE spectra to the 100 MeV region are inconsistent with upper limits obtained by EGRET in simultaneous observations (Fichtel, 1993). This suggests that an additional break or roll-off in the few MeV region is present in the Cen A spectrum. No evidence for line emission was present in the OSSE data.

CONCLUSIONS

OSSE observed Cen A to exhibit highly variable hard X-ray and soft gamma-ray emission with average spectral behavior intermediate between that of the gamma-ray blazars like 3C 273 which have detectable gamma-ray emission extending from the keV to the GeV range (e.g. McNaron-Brown et al. 1994, Fichtel et al. 1993) and Seyfert galaxies, typified by NGC-4151 (Johnson et al. 1994) which have canonical low-energy spectra which roll off in the 100 keV range. Below about 100 keV, Cen A appears to exhibit spectra similar to the "canonical" AGN spectrum (Rothschild et al. 1983) with an index of around 1.7, but its spectrum does not roll off exponentially in the 50 to 200 keV range as do most X-ray Seyfert spectra (Johnson et al. 1994). In the OSSE energy range, power-law extrapolations to the MeV range appear appropriate. However, the roll off apparently required above an MeV by EGRET upper-limits cause this object to be unusual among extragalactic sources observed to date.

ACKNOWLEDGMENTS

This work was supported under NASA grant DPR S-10987C.

REFERENCES

Baity, W. A., et al.. 1981, Ap. J., **244,** 429.
Fichtel, C. E. 1993, private communication.
Fichtel, C. E. et al. 1993, AIP Conference Proceedings, **280**, 541
Fiegelson, E.D., et al. 1981, Ap. J., **251**, 31.
Gehrels, N., Cline, T., Teegarden, B.J., Paciesas, W.S., Tueller, J., Durouchoux, P. and Hameury, J., 1984, Ap. J., **278,** 112.
Gehrels, N., Cheung, C. 1991, AIP Conference Proceedings, **254**, 348
Johnson, W., Kinzer, R., Kurfess, J., Strickman, M., Purcell, W., Grabelsky, D., Ulmer, M., Hillis, D., Jung, G., Cameron, R. 1993, Ap. J. Suppl. **86,** 693.
Johnson, W. N. et al. 1994, this volume.
Mcnaron-Brown, K. et al. 1994, this volume.
Rothschild, R., Mushotzky, R., Baity, W., Gruber, D., Matteson, J., and Peterson, L. 1983, Ap J., **269**, 423
Sunyaev, R. A., Titarchuk, L. G. 1980, A & A, **86**, 121