Multi-Satellite Observation of Cen A

RXTE, INTEGRAL, Suzaku, Swift

Plus

XMM and Chandra

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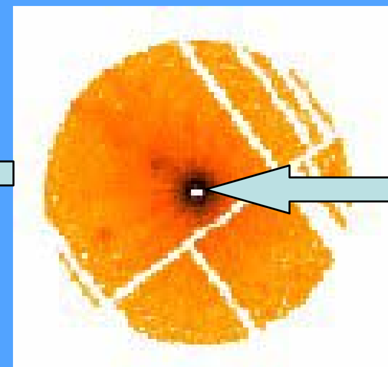
Instruments, Livetimes, and Rates

Instrument	Livetime (s)	Rate (0.5-2)	Rate (2-10)	Rate (20-100)
RXTE/PCU2	9,472		21.54 ± 0.06	
RXTE/HEXTE	6,073			4.62 ± 0.11
INTEGRAL/JEMX-1	42,080		1.27 ± 0.04	
INTEGRAL/ISGRI	83,160			6.59 ± 0.01
INTEGRAL/SPI	92,453			0.0115 ± 0.0009
Swift/XRT	10,086	0.127 ± 0.004	0.662 ± 0.008	
Swift/BAT	12,165			36.3 ± 1.9
Suzaku/XIS-FI	212,304	0.232 ± 0.001	4.51 ± 0.005	
Suzaku/XIS-BI	69,018	0.327 ± 0.002	3.84 ± 0.007	
Suzaku/PIN	154,000			0.471 ± 0.004
Suzaku/GSO	61,562			0.908 ± 0.013
Chandra/MEG	98,342	0.0165 ± 0.0009	0.635 ± 0.003	
Chandra/HEG	98,342		0.774 ± 0.003	
XMM/MOS1	18,900	0.557 ± 0.009	2.38 ± 0.01	
XMM/MOS2	18,911	0.583 ± 0.009	2.38 ± 0.01	
XMM/PN	16,664	1.77 ± 0.02	6.69 ± 0.02	

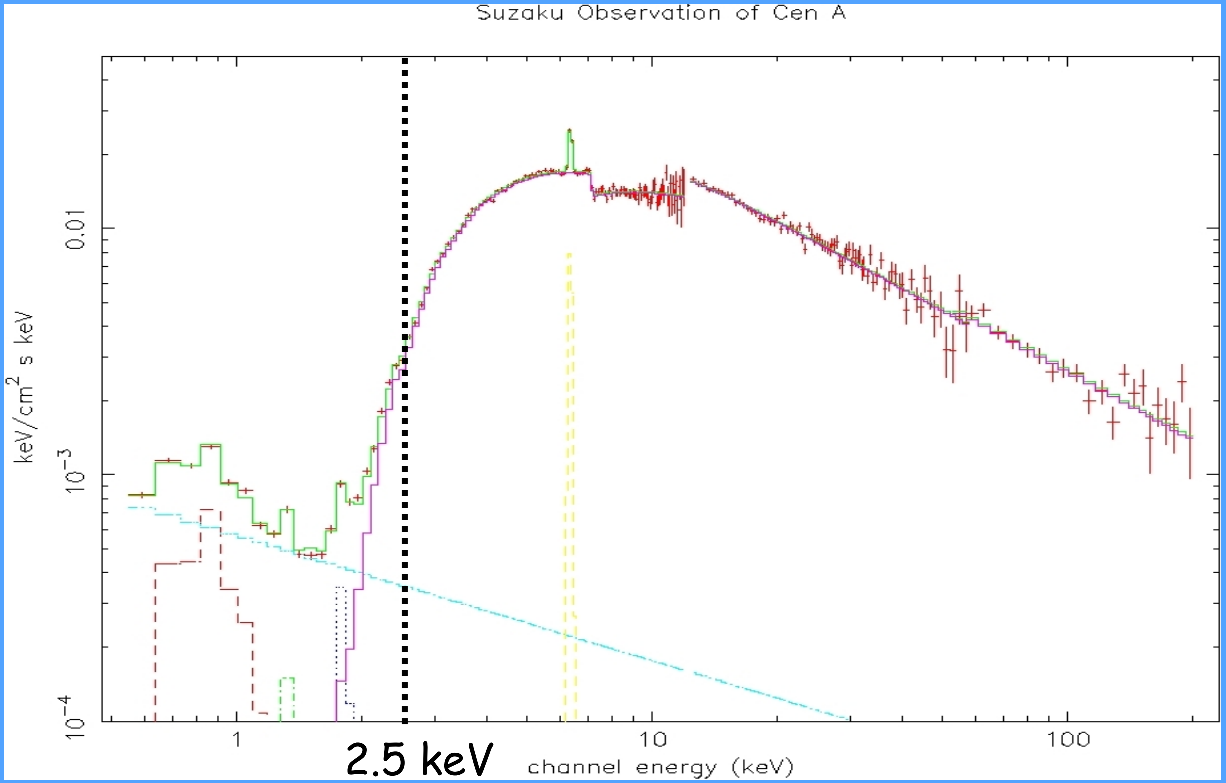
RXTE “Image”

XMM PN Image

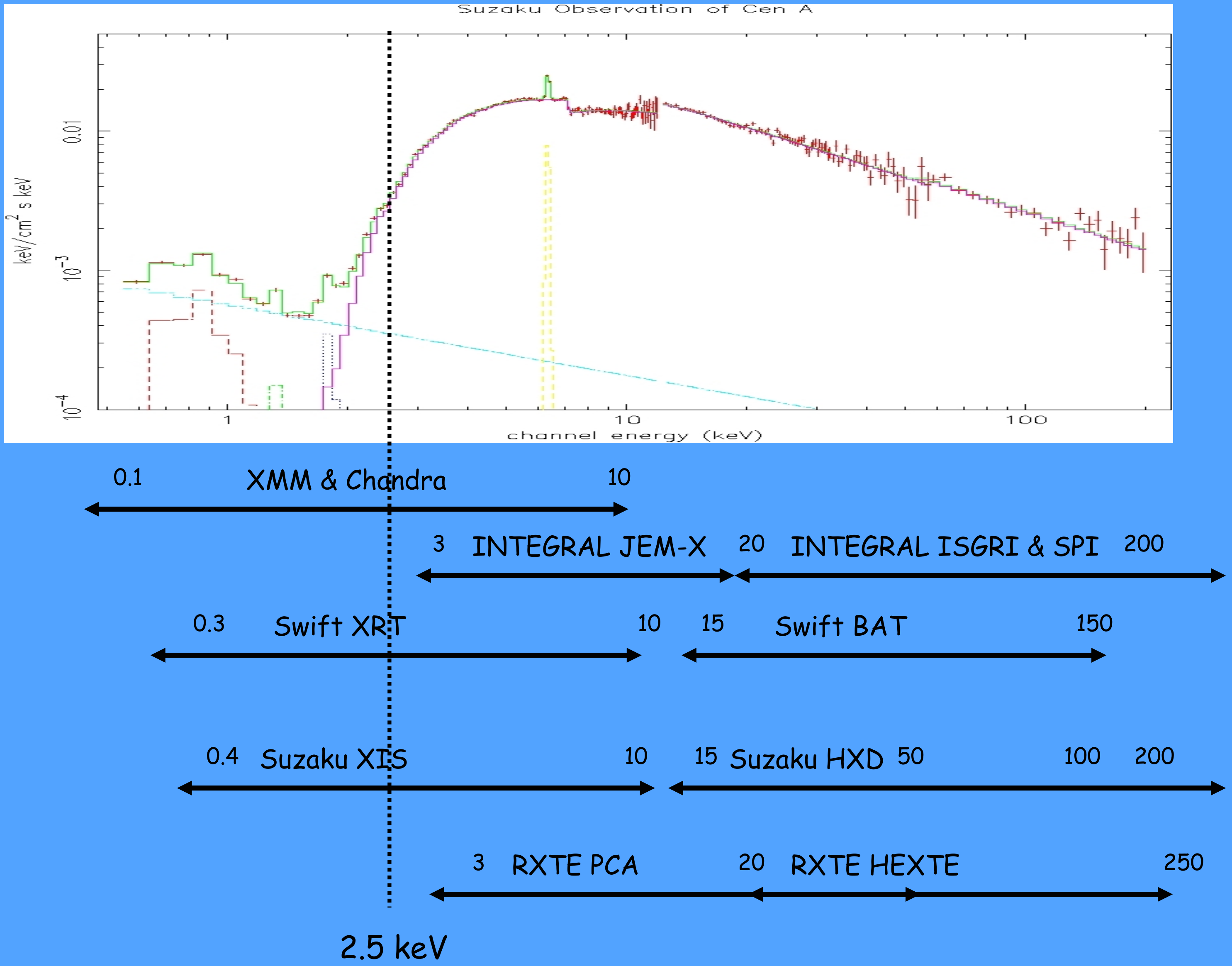


Chandra ACIS Image

Field of view and spatial resolution drastically affect what is included in “the spectrum of the nucleus of Cen A”.

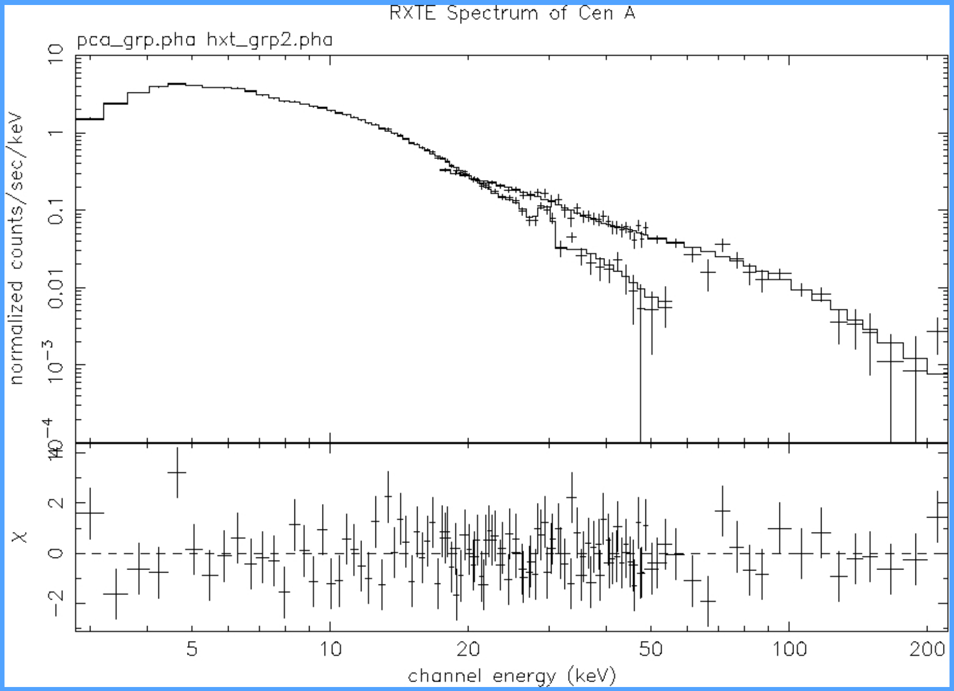


Energy range and energy resolution dramatically affect the modeled spectral components and thereby "the spectrum of Cen A"


Suzaku Observation of Cen A
keV/cm² s keV
0.01
10⁻³
10⁻⁴
1
10
100
channel energy (keV)
0.1 XMM & Chandra 10
3 INTEGRAL JEM-X 20 INTEGRAL ISGRI & SPI 200
0.3 Swift XRT 10
15 Swift BAT 150
0.4 Suzaku XIS 10
15 Suzaku HXD 50 100 200
3 RXTE PCA 20 RXTE HEXTE 250
2.5 keV

Cen A Spectrum Above 2.5 keV

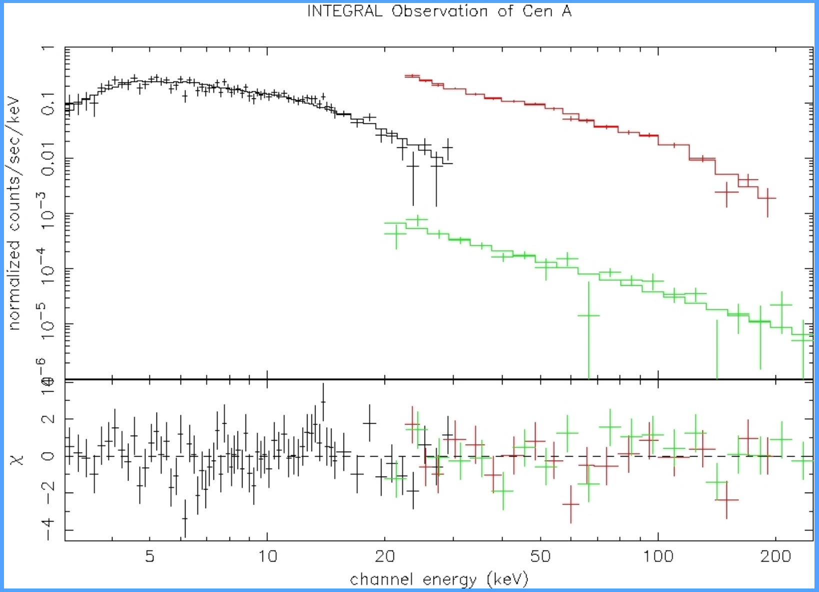
RXTE



	PCU2	HEXTE	RXTE
n_H	11.2 ± 0.03	---	11.2 ± 0.4
Γ	1.85 ± 0.02	1.83 ± 0.06	1.85 ± 0.02
$Norm_{2-10}$	389 ± 9	---	390 ± 8
$Norm_{20-100}$	---	500 ± 21	---
E(Fe)	6.32 ± 0.12	---	6.32 ± 0.12
F(Fe)	3.2 ± 0.8	---	3.2 ± 0.8
EW	82	---	81
χ^2_ν	67/61 = 1.09	33/48 = 0.69	100/110 = 0.91

Cen A Spectrum Above 2.5 keV

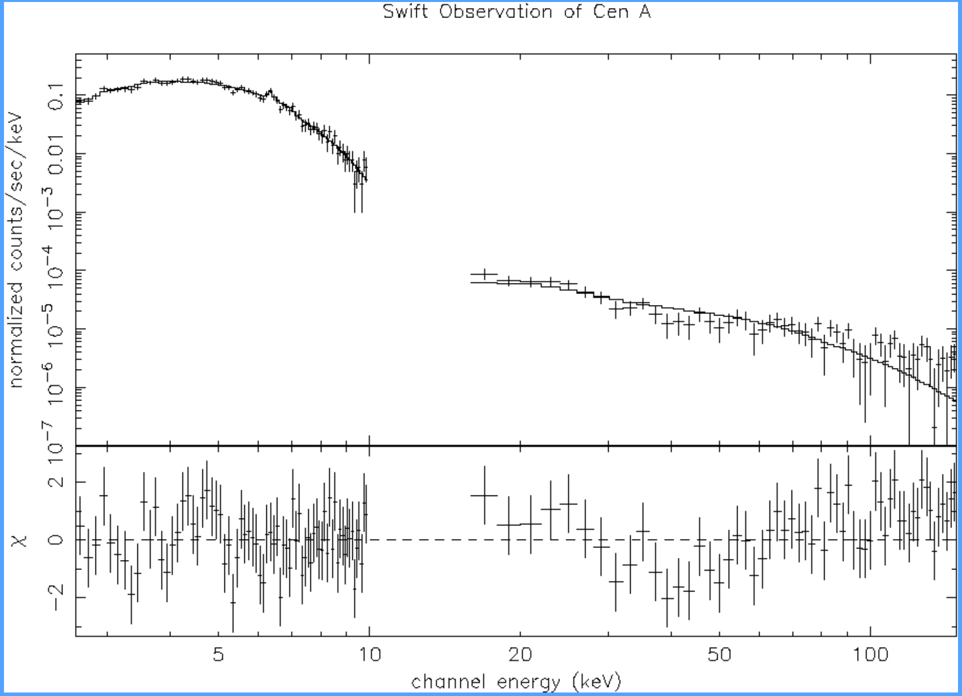
INTEGRAL



	JEMX	ISGRI	SPI	INTEGRAL
n_H	9.3 ± 3.2	---	---	$12.3 \pm^{0.7}_{1.9}$
Γ	1.80 ± 0.12	1.97 ± 0.05	1.76 ± 0.17	1.95 ± 0.02
$Norm_{2-10}$	361 ± 49	---	---	---
$Norm_{20-100}$	---	612 ± 12	817 ± 72	545 ± 29
E(Fe)	6.32	---	---	6.32
F(Fe)	≤ 2.0	---	---	≤ 1.9
EW	---	---	---	---
χ^2_ν	78/63 = 1.24	21/17 = 1.23	18/18 = 1.00	123/99 = 1.25

Cen A Above 2.5 keV

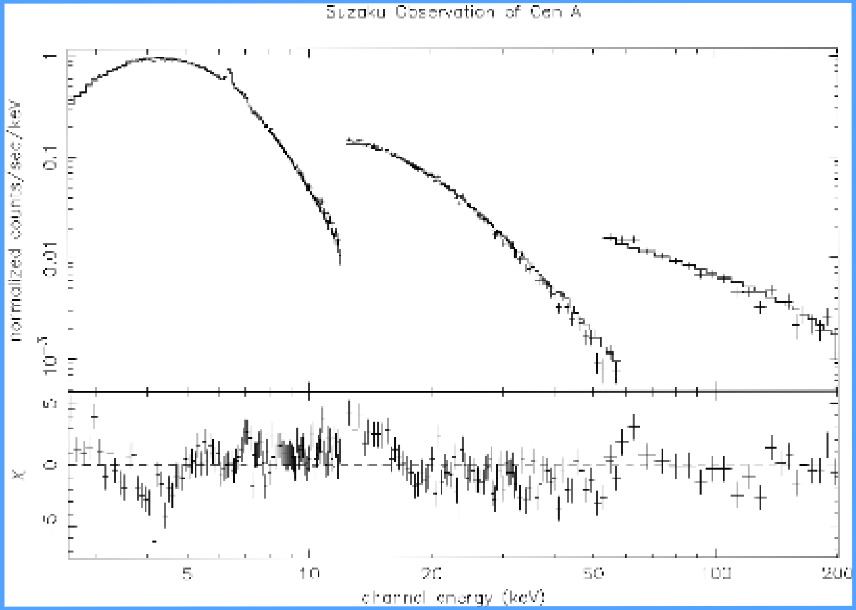
Swift



	XRT	BAT	Swift
n_H	9.8 ± 1.1	---	9.1 ± 0.9
Γ	1.83 ± 0.17	1.57 ± 0.18	1.71 ± 0.13
$Norm_{2-10}$	384 ± 29	---	369 ± 20
$Norm_{20-100}$	---	688 ± 54	---
E(Fe)	6.36 ± 0.04	---	6.35 ± 0.05
F(Fe)	3.2 ± 1.5	---	3.0 ± 1.5
EW	81	---	76
χ^2_ν	59/68 = 0.87	68/456= 1.22	131/125 = 1.05

Cen A Above 2.5 keV

Suzaku



	XIS-BI	PIN	GSO	Suzaku
n_H	9.8 ± 0.15	---	---	10.6 ± 0.13
Γ	1.57 ± 0.02	1.84 ± 0.03	1.97 ± 0.11	1.72 ± 0.02
$Norm_{2-10}$	289 ± 3	---	---	---
$Norm_{20-100}$	---	630 ± 15	641 ± 48	304 ± 2
E(Fe)	6.37 ± 0.01	---	---	6.38 ± 0.01
F(Fe)	2.6 ± 0.2	---	---	2.7 ± 0.2
EW	80	---	---	---
χ^2_ν	168/98 = 1.71	90/75 = 1.20	26/20 = 1.31	562/195 = 2.88

	XIS-FI
n_H	10.0 ± 0.1
Γ	1.68 ± 0.02
$Norm_{2-10}$	312 ± 2
E(Fe)	6.37 ± 0.004
F(Fe)	2.7 ± 0.1
EW	81
χ^2_ν	256/98 = 2.61

Cen A Above 2.5 keV

XIS BI & FI

Due to the higher energy resolution and sensitivity of the XIS telescopes, weaker features are significant.

Iron edge at 7.17 $\pm$ 0.04 keV with $\tau \sim 5\text{x}10^{-2}$

Another edge at 3.40 $\pm$ 0.03 keV with $\tau \sim 5\text{x}10^{-2}$

Emission line at 3.66 $\pm$ 0.03 keV with Flux of $5\text{x}10^{-5}$ $cm^{-2}s^{-1}$ or EW = 6 eV

These features and others need to be taken into account when calibrating high sensitivity instruments with good energy resolution, but they do not significantly affect continuum measurements.

Including them changed the fitted power law index by <1%.

Results from Continuum fitting above 2.5 keV

RXTE/PCU2 index of 1.85 ± 0.02 defines the continuum

-- Low index outliers:

BAT at 1.57 ± 0.18

XIS-BI at 1.57 ± 0.02

XIS-FI at 1.68 ± 0.02

-- High index outlier:

ISGRI at 1.97 ± 0.05

Suzaku/XIS defines iron line energy (6.37 ± 0.05 keV)

and line flux (2.7 ± 0.1 $cm^{-2}s^{-1}$)

All 4 missions agree with this within errors.

But what about low energy absorption?

Low energy telescopes and PCU2 disagree on n_H but this may be a function of the power law index in which they also do not agree.

Could it be the limited energy range of the telescopes? No!

Fitting PCU2 in the 2.5--12 keV range yields

$n_H = 11.6 \pm 0.5 \times 10^{22}$ cm^{-2}

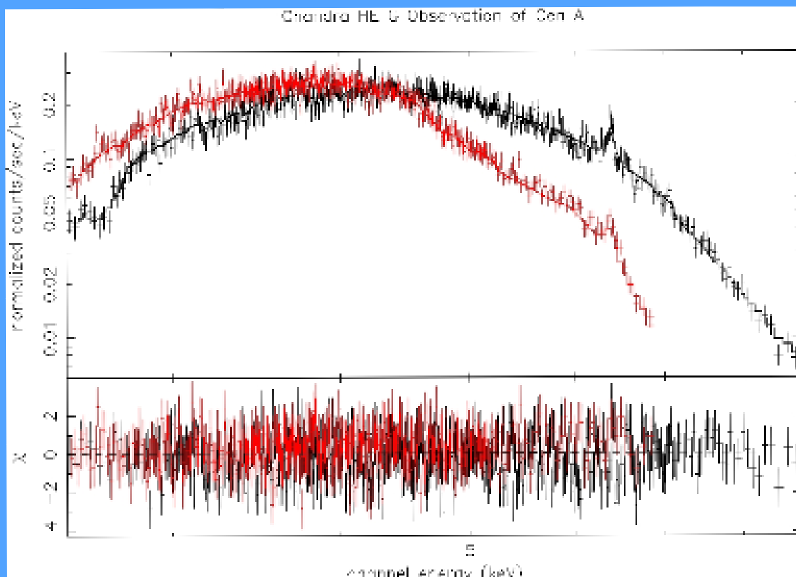
$\Gamma = 1.88 \pm 0.03$

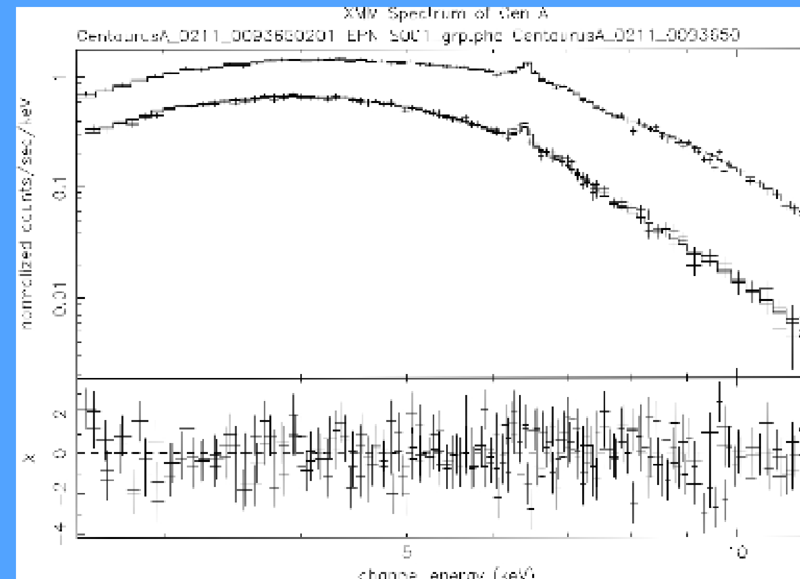
E(Fe) = 6.33 ± 0.13 keV

Flux(Fe) = $2.9 \pm 1.0 \times 10^{-4}$ cm^{-2}s^{-1}

Something is amiss in the telescope calibrations.

Do Chandra and XMM also fit to a flatter power law index --- YES!!





Chandra HETG:

$n_H = 9.9 \pm 0.3 \times 10^{22}\ cm^{-2}$

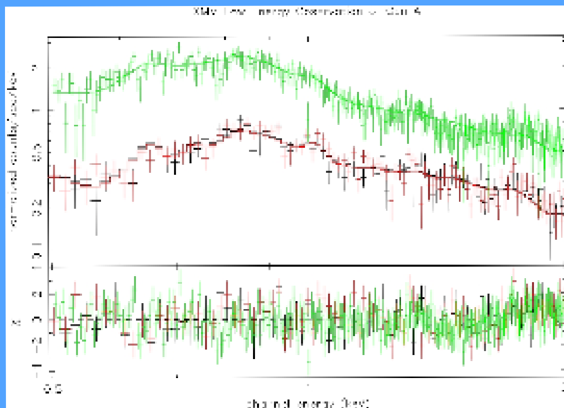
$\Gamma = 1.57 \pm 0.06$

$E(Fe) = 6.37 \pm 0.01$ keV

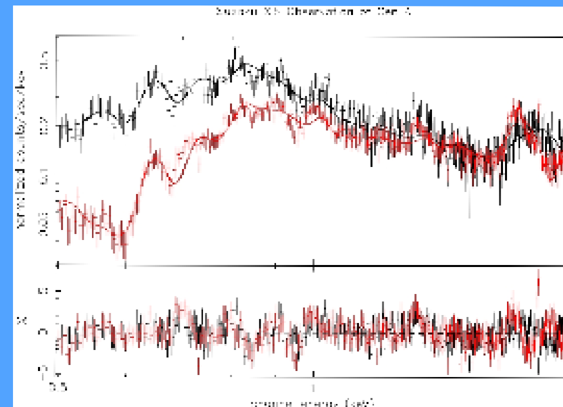
$F(Fe) = 3.1 \pm 0.5 \times 10^{-4}\ cm^{-2} s^{-1}$

XMM	MOS1	MOS2	PN
n_H =	8.4 ± 0.4	8.6 ± 0.4	8.6 ± 0.2
Γ=	1.56 ± 0.08	1.65 ± 0.08	1.69 ± 0.04
E(Fe) =	6.42 ± 0.02	6.38 ± 0.02	6.44 ± 0.02
F(Fe) =	3.4 ± 0.7	3.3 ± 0.7	2.5 ± 0.3

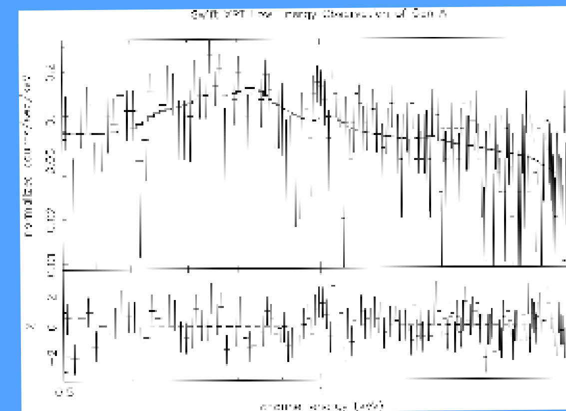
Cen A Below 2 keV



XMM



Suzaku



Swift

	XMM	Suzaku	Swift
Apec kT	0.64 ± 0.02	0.62 ± 0.01	0.42 ± 0.07
Apec Norm	$6.8 \pm 0.4 \times 10^{-4}$	$2.1 \pm 0.8 \times 10^{-4}$	$12.6 \pm 4.0 \times 10^{-4}$
Power Law Γ	1.01 ± 0.04	0.89 ± 0.06	0.84 ± 0.44
Flux(1 keV)	$2.01 \pm 0.03 \times 10^{-3}$	$0.56 \pm 0.01 \times 10^{-3}$	$2.1 \pm 0.5 \times 10^{-3}$
Line Energy	0.651 ± 0.012	0.641 ± 0.004	---
Line Flux	$1.5 \pm 0.5 \times 10^{-4}$	$0.38 \pm 0.07 \times 10^{-4}$	---
EW	33.5	27.0	---

Cen A Below 2 keV

Results below 2 keV appear to be very calibration and systematics dependent.

An Apec plus power law model can be the basis for beginning to understand the Cen A flux.

Variable abundances and better energy calibration may help with the additional lines required for each instrument.

Systematics associated with front or back illumination, variable contamination, instrumental lines, and sizes of extraction regions may very well dominate our detailed knowledge of emission processes below 2 keV.

Summary of the Inter-calibration above 2.5 keV

Power Law Index:

RXTE/PCU2:	1.85 ± 0.02
RXTE/HEXTE:	1.83 ± 0.06
INTEGRAL/JEMX:	1.80 ± 0.12
INTEGRAL/ISGRI:	1.97 ± 0.05
INTEGRAL/SPI:	1.76 ± 0.17
Swift/BAT:	1.57 ± 0.18
Suzaku/PIN:	1.84 ± 0.03
Suzaku/GSO:	1.97 ± 0.11

Swift/XRT:	1.83 ± 0.17
Suzaku/XIS-BI:	1.57 ± 0.02
Suzaku/XIS-FI:	1.68 ± 0.02
XMM/MOS1:	1.56 ± 0.08
XMM/MOS2:	1.65 ± 0.08
XMM/PN:	1.69 ± 0.04
Chandra/HETG:	1.57 ± 0.06

RXTE/PCU2 (2.5--10): 1.88 ± 0.03

RXTE:	1.85 ± 0.02
INTEGRAL:	1.95 ± 0.02
Swift:	1.71 ± 0.13
Suzaku:	1.72 ± 0.02

Power law index is probably 1.85 and steady.

Summary of Iron Line Measurements

RXTE/PCU2:	6.32 $\pm$ 0.12 keV	3.2 $\pm$ 0.03 x 10^{-4} cm^{-2} s^{-1}
Swift/XRT:	6.36 $\pm$ 0.04	3.2 $\pm$ 0.15
Suzaku/XIS-BI:	6.37 $\pm$ 0.01	2.6 $\pm$ 0.02
Suzaku/XIS-FI:	6.37 $\pm$ 0.004	2.7 $\pm$ 0.01
XMM/MOS1:	6.42 $\pm$ 0.02	3.4 $\pm$ 0.07
XMM/MOS2:	6.38 $\pm$ 0.02	3.3 $\pm$ 0.07
XMM/PN:	6.44 $\pm$ 0.02	2.5 $\pm$ 0.03
Chandra/HETG:	6.37 $\pm$ 0.01	3.1 $\pm$ 0.05

Line energy is most probably near 6.37 keV with a flux near 3.3 x 10^{-4} cm^{-2} s^{-1}

Summary of Using Cen A as a Calibration Source

1. Spectrum above 2.5 keV and up to at least 200 keV is an absorbed power law with an iron emission line and edge.
2. The line of sight absorption is variable between 1 and 1.5×10^{23} cm^{-2}, so that must be fit for each observation.
3. The power law photon index appears to be stable at 1.85 ± 0.01 over the last decade, as seen by RXTE and BeppoSAX.
4. While the 2-10 and 20-100 keV fluxes vary by as much as 50%, the power law index remains unchanged.
5. The iron line energy of 6.37 may be stable, but we do not have enough high resolution measurements to know for sure.
6. The iron line flux appears to be stable to 20% over the last decade.

BOTTOM LINE: Use the power law index for continuum calibrations with broad band instruments, but figure out why 2--10 keV measurements with focusing telescopes consistently derive indices $\Delta\Gamma \sim 0.2$ flatter.