SS 433
- a historical retrospect -

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- Early days
  - *Ariel V: A1909+04 (Seward et al 1976)*
  - *HEAO-A2; Ariel VI*
  - *Discovery and the 'kinematic model'*
    - *the binary system*
    - *the 'optical jet'*
    - *SS433 and W50*
- X-ray campaigns
  - *Einstein*
  - *EXOSAT*
  - *Ginga*
  - *ASCA*
  - *(ROSAT)*
- New results:
  - *Chandra*
  - *XMM-Newton*

A 1909 + 04 Ricketts et al.

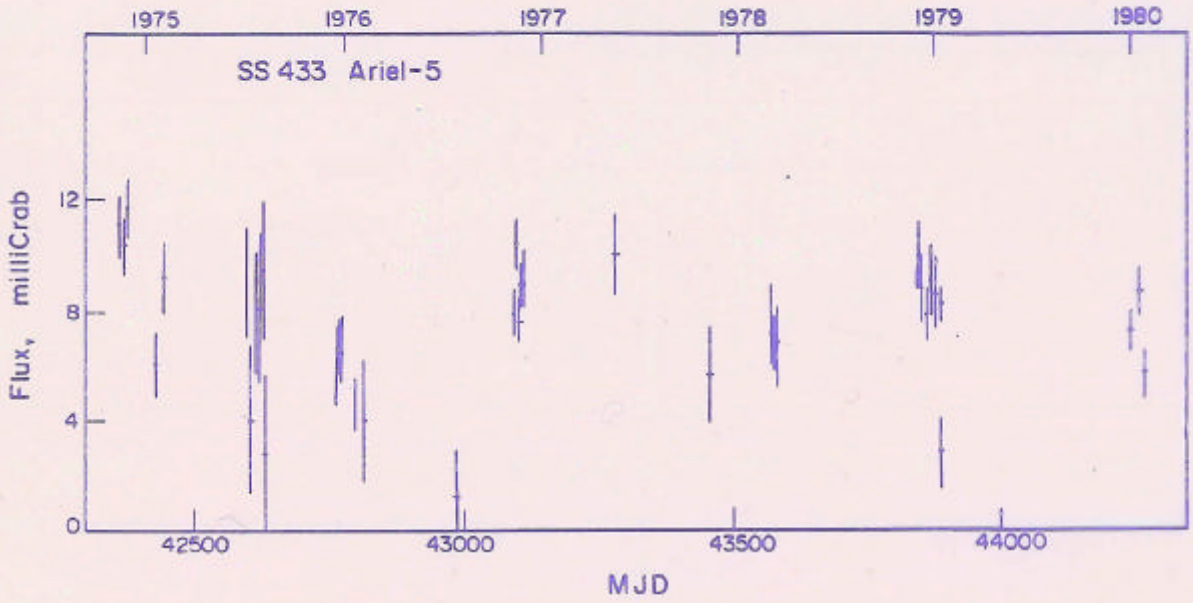
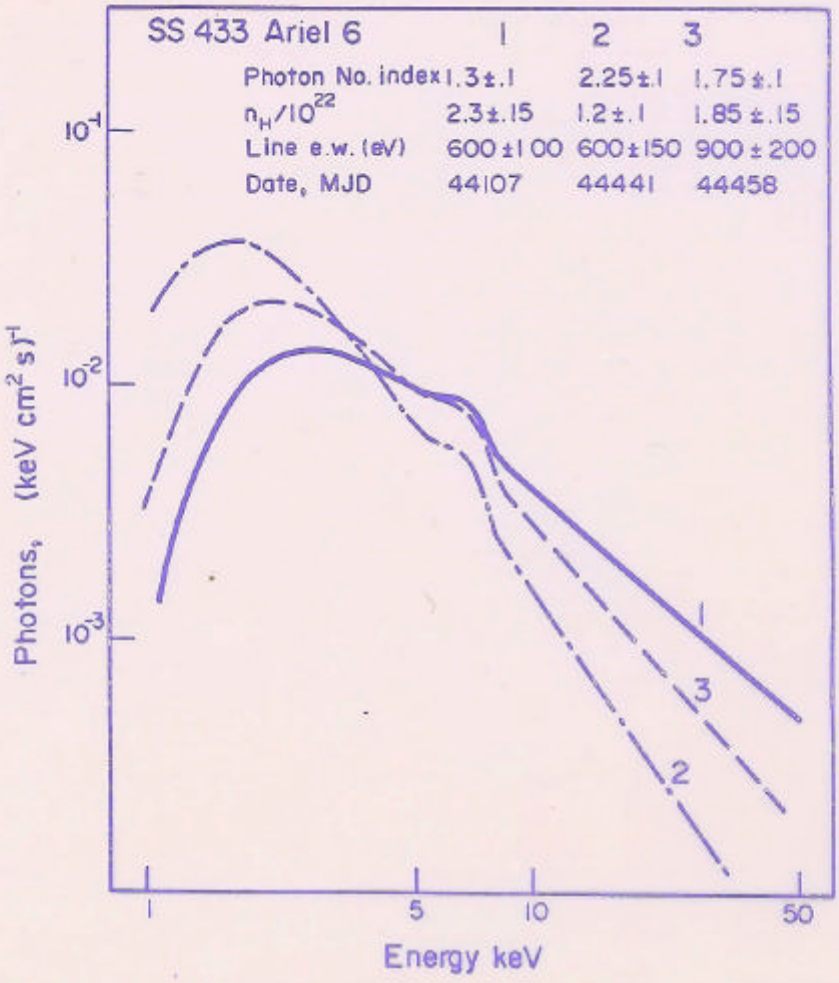


Fig. 1. The Ariel V SSI 2-15 keV flux measurements over the period 1974 October to 1980 January.



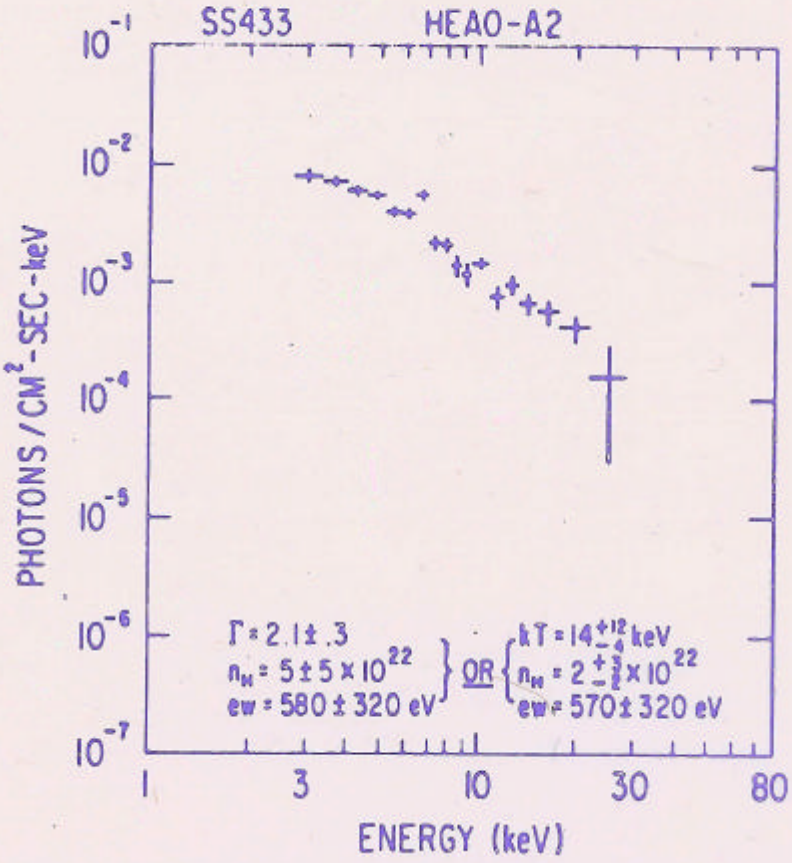
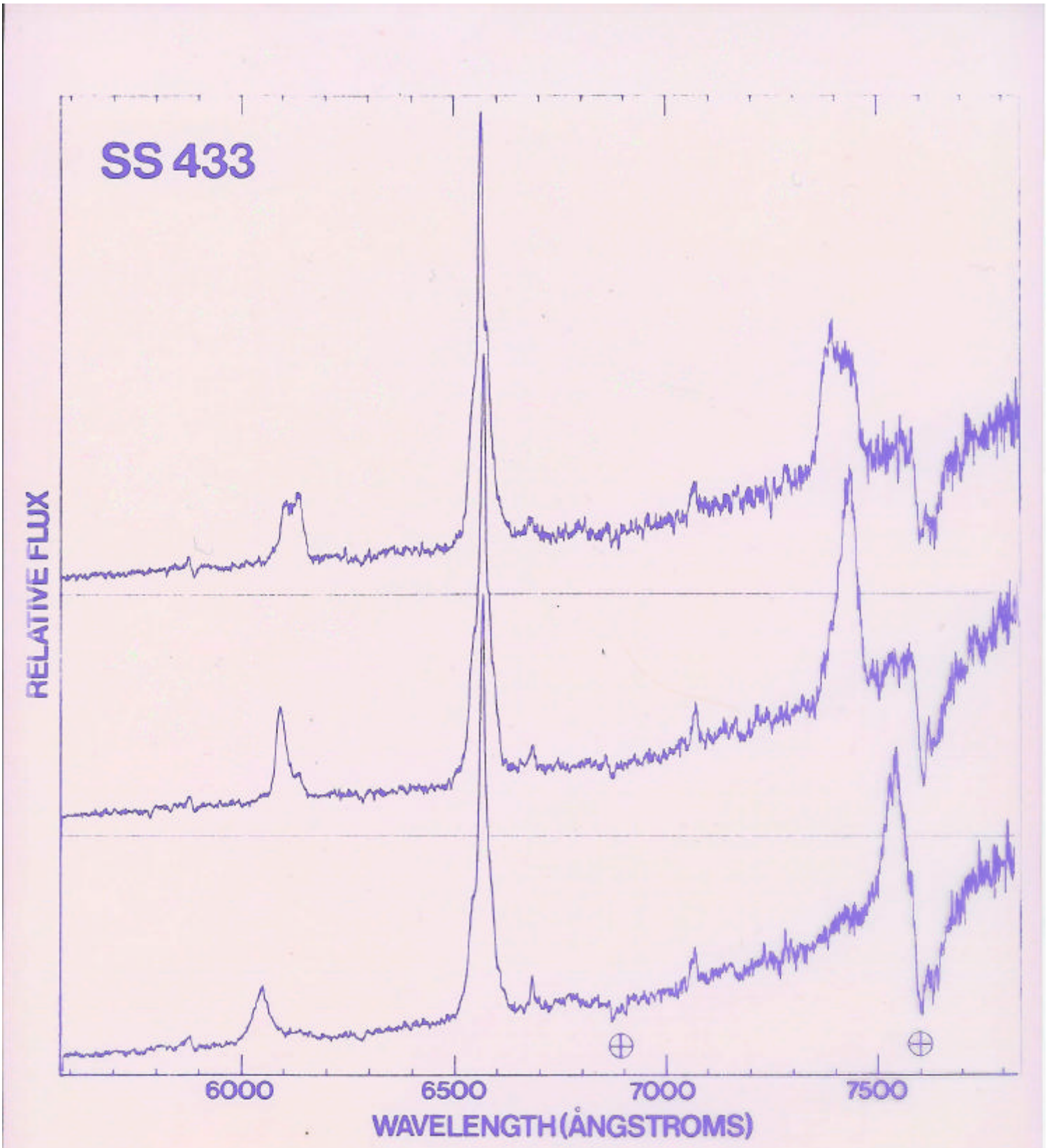


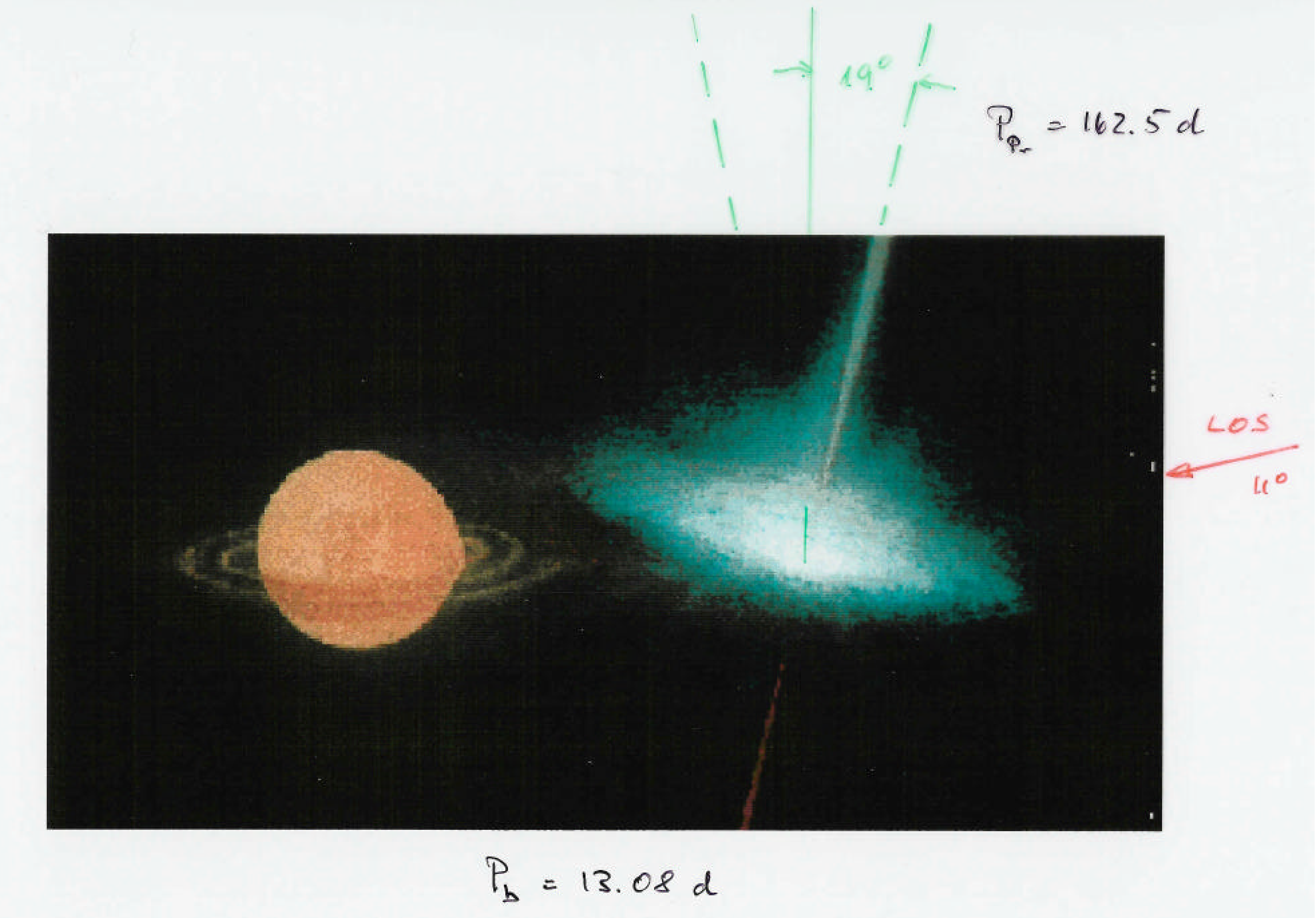
FIG. 3.—X-ray spectrum of SS 433 accumulated 1978 April 8–13. Best-fit parameters and 90% confidence error bars are given for two acceptable models.

fits, but the 90% confidence upper limit on n_H for either model is many times the amount in the direction of SS 433 deduced by Margon *et al.* (1979).

The addition of a ~575 eV equivalent-width 6.8 keV line to either model reduces χ^2 by 11 for the addition of one parameter. The equivalent width of the line is consistent with that produced by collisional equilibrium of a 14 keV gas of solar abundances (Raymond and Smith 1977), and so suggests that the thermal model may be more realistic than the power-law model.

Marshall et al. (1979)


SS 433
RELATIVE FLUX
6000
6500
7000
7500
WAVELENGTH (ÅNGSTROMS)



19°
P_{pr} = 162.5 d
LOS
11°
P_b = 13.08 d

$$(1+z) = \gamma(\pm v \sin\theta \sin i \cos\psi \pm v \cos\theta \cos i + 1). \qquad 1.$$

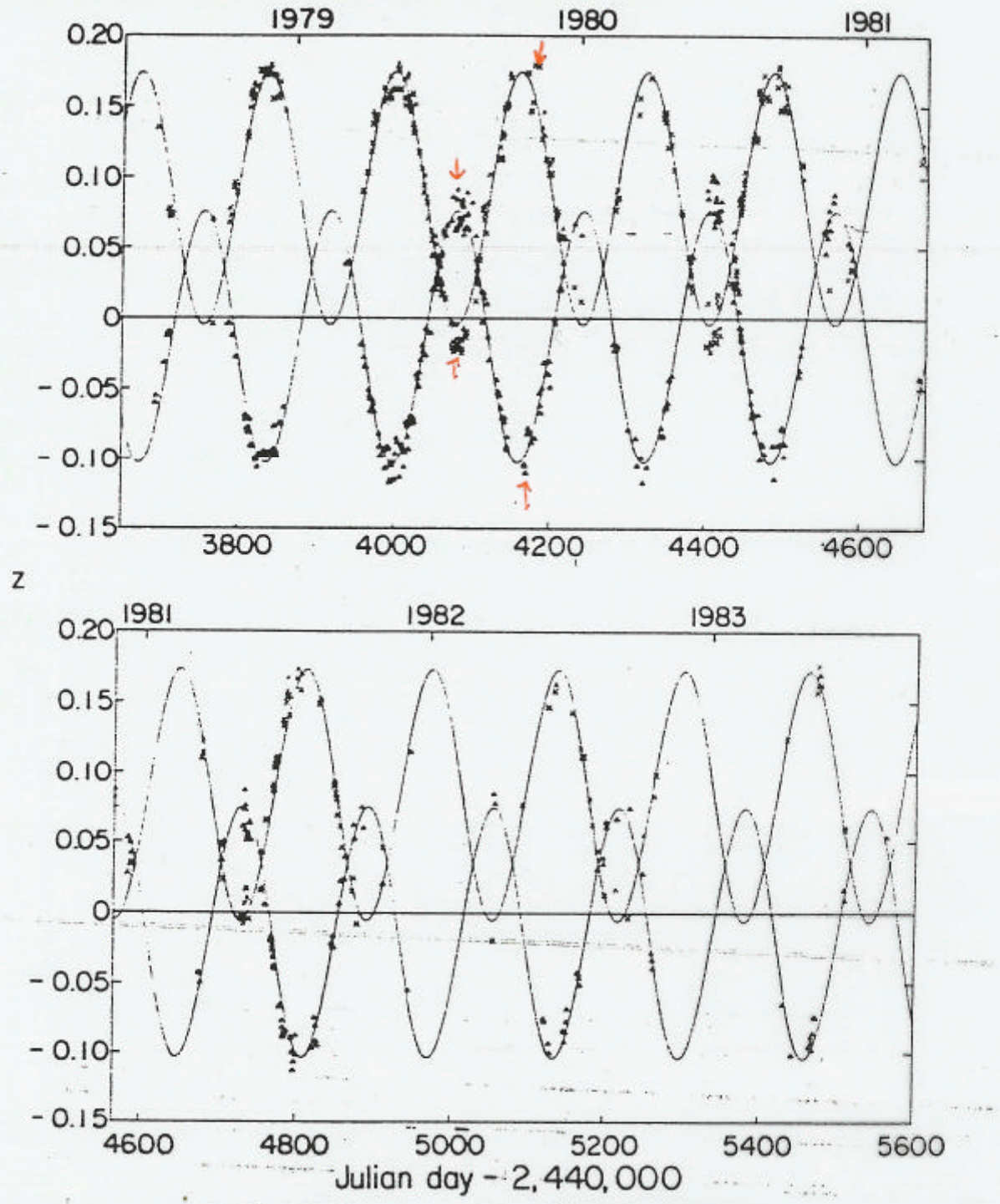


Figure 1 Doppler shifts of SS 433 on 450 nights in the period 1978–83. The majority of these data were obtained by the author and colleagues, supplemented by sources cited in (105). The solid curve is a least-squares best fit to the simple "kinematic model" (1). The free parameter values and their associated 1σ uncertainties (notation as in 105) for this fit are $v/c = 0.2601 \pm 0.0014$, $\theta = 19.80° \pm 0.18°$, $i = 78.82° \pm 0.11°$, $t_0 = \text{JD } 2{,}443{,}562.27 \pm 0.39$, $P = 162.532 \pm 0.062$ days.

Parameters of the 'optical' jets

- jet velocity: $v_j \sim 0.26$ c
  optical observations / kinematic model
- velocity-dispersion: $\Delta v/v \leq 0.04$
- opening angle $\Theta \leq 5^o$
  optical observations / velocity dispersion
- temperature $T \sim 10000$K
  no H_{II}, C_{II}, N_{II} lines
- density of the gas: $n_e > 10^7$ cm^{-3}
  no forbidden lines
- length of jets: $10^{12}\text{cm} \leq L \leq 7 \times 10^{14}$ cm
  black body radiation; variability
- kinetic energy of the flow:

$$\dot{E}_{kin} = \frac{L_{H\alpha}}{h\nu_\alpha} \times \frac{1}{2} m_H v^2 \leq 2 \times 10^{42}\ erg/sec$$

"moving line" system is highly variable !

Nature of binary system remains controversial

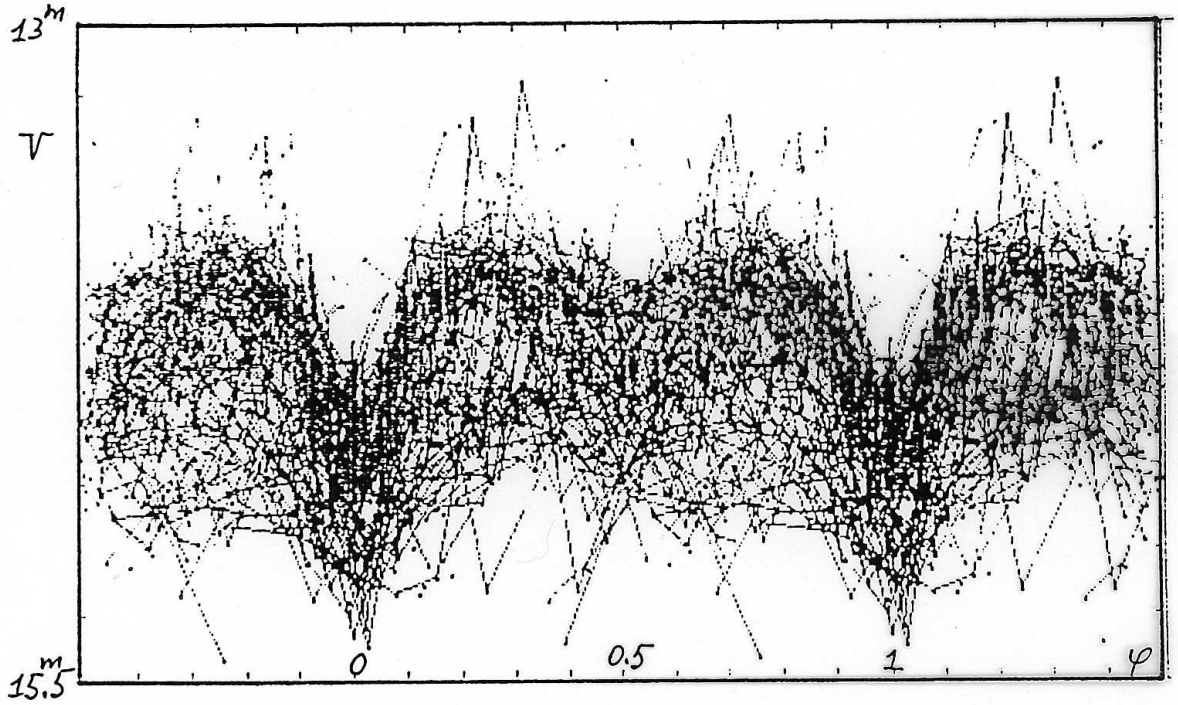


Fig. 2. The convolution of all photometric V observations of SS 433 with the orbital period 13.082 days.


SS433
STELLAR JETS

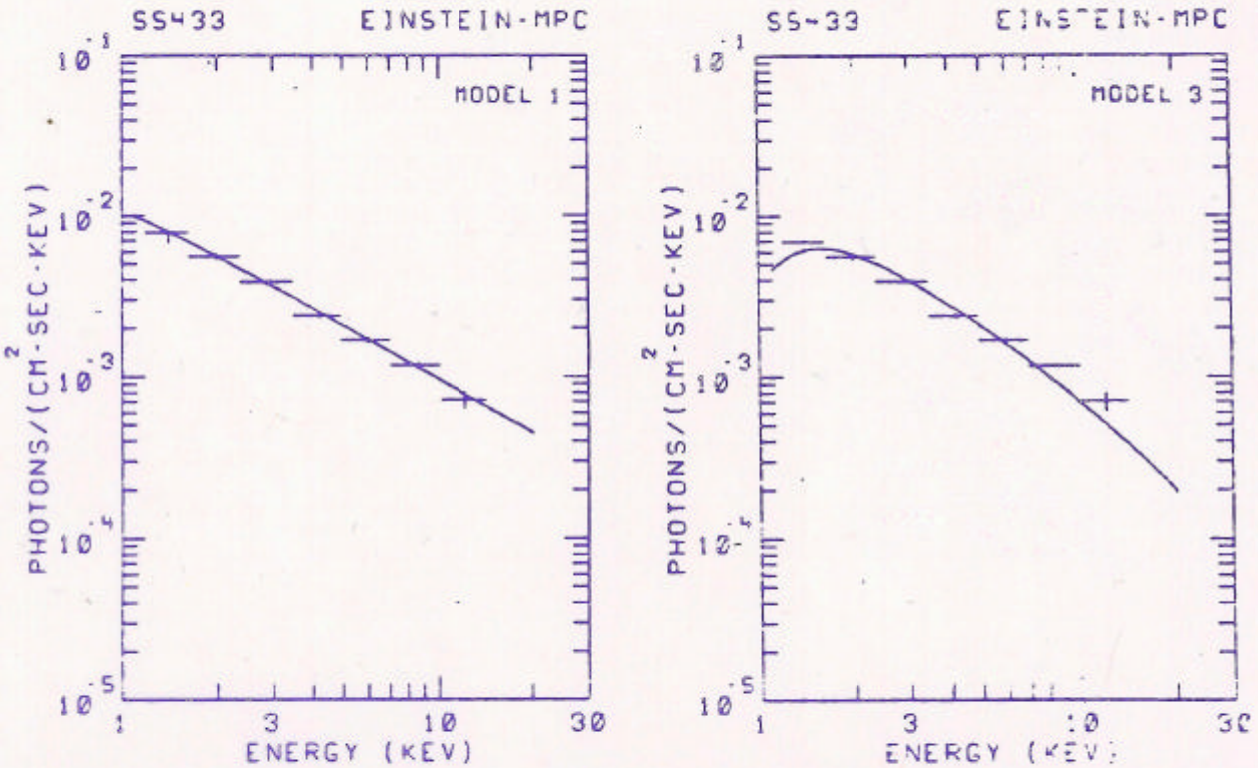
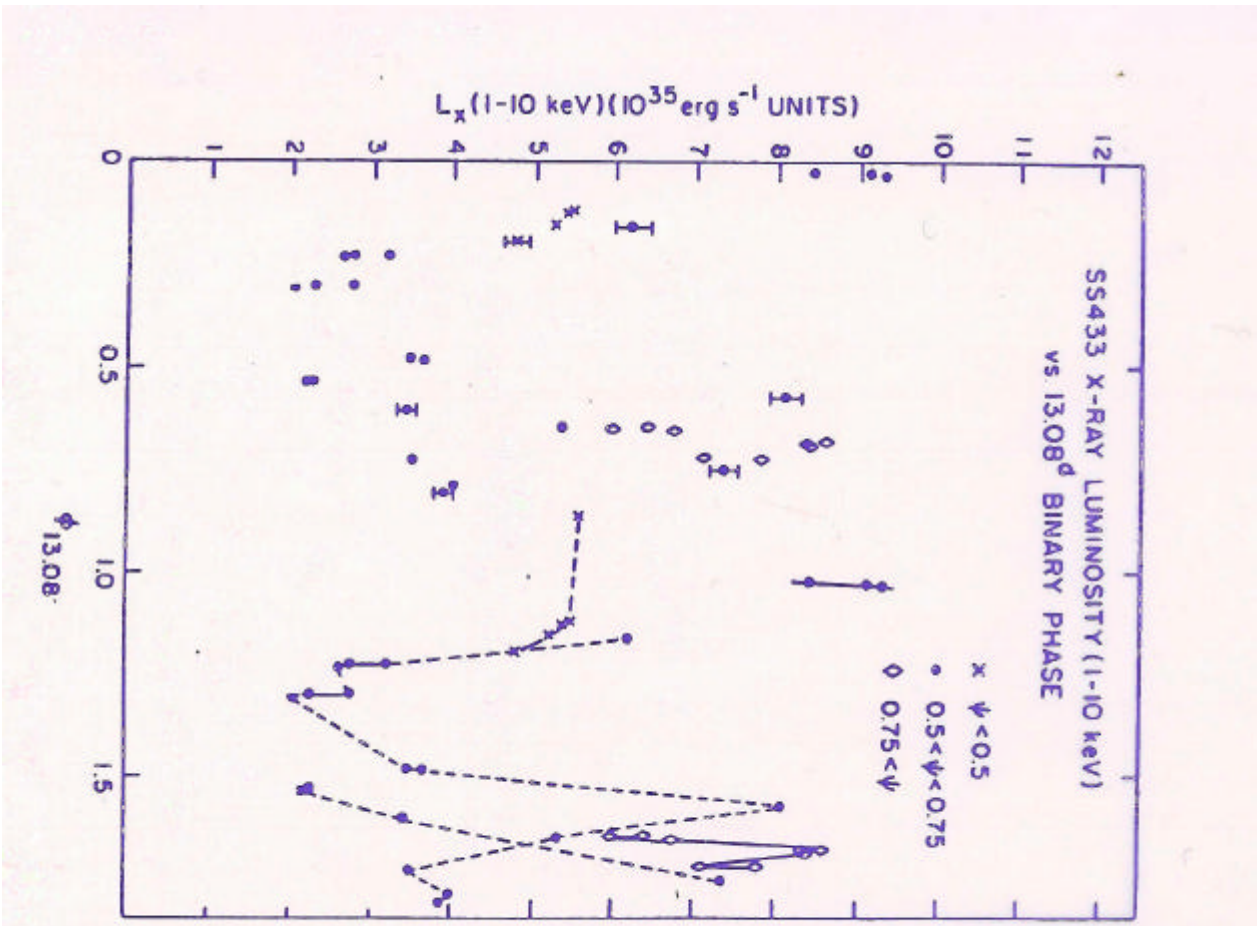
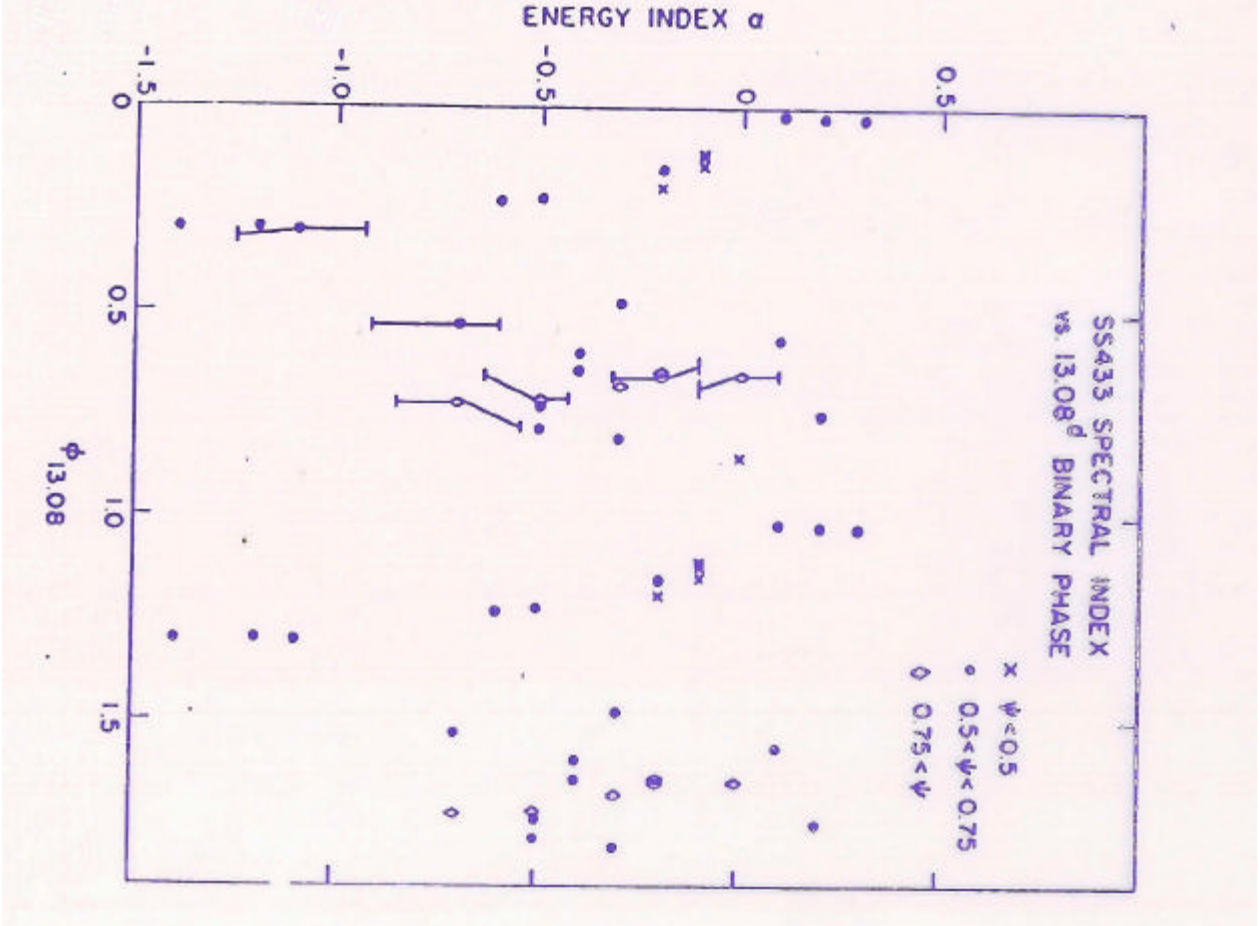


FIG. 1.—Best fit power-law vs. thermal bremsstrahlung models for a "typical" observation of SS 433 in the quiescent (i.e., nonflaring) state. The observation is at day no. 456.480 (see Table 1), and the two-parameter (spectral index or temperature vs. N_H) model fits yield values: $\alpha = -0.10^{+0.03}_{-0.03}$, $N_H = 1.3^{+0.3}_{-0.3} \times 10^{21}$ cm^{-2} and $\chi^2 = 3.3$ for the power-law vs. $kT \geq 30$ keV, $N_H = 8^{+7}_{-3} \times 10^{21}$ cm^{-2} and $\chi^2 = 29$ for the thermal bremsstrahlung fit.


L_x(1-10 keV)(10^{35}erg s^{-1} UNITS)
SS433 X-RAY LUMINOSITY (1-10 keV)
vs. 13.08^d BINARY PHASE
× ψ<0.5
• 0.5<ψ<0.75
◇ 0.75<ψ
$\phi_{13.08}$


ENERGY INDEX α
SS433 SPECTRAL INDEX
vs. 13.08^d BINARY PHASE
× ψ<0.5
• 0.5<ψ<0.75
◇ 0.75<ψ
$\phi_{13.08}$

2. Thermal spectrum with very high temperature (kT > 100 keV) and an N_H - value of typically $> 10^{22}$ cm^{-2}.

3. Sunyaev-Titarchuk Comptonization spectrum with kT = 3.6 keV, $r = 15.7$ and $N_H = 3.8 \times 10^{21}$ cm^{-2}.

In addition to the continuum we find in all cases very clearly an emission line $\sim I_l \times exp(-\frac{1}{2}(\frac{E-E_l}{\sigma})^2)$ with the following typical parameters:

$$I_l = 0.2,$$
$$E_l = 7.4\ keV,$$
$$FWHM = 0.4\ keV,$$
$$EW \simeq 800\ eV.$$

Figure one shows a power law fit to the total set of data. The emission line at $\simeq$ 7.4 keV is clearly visible as well as the fact that the fit is statistically unacceptable ($\chi^2_{dof} = 14$!).

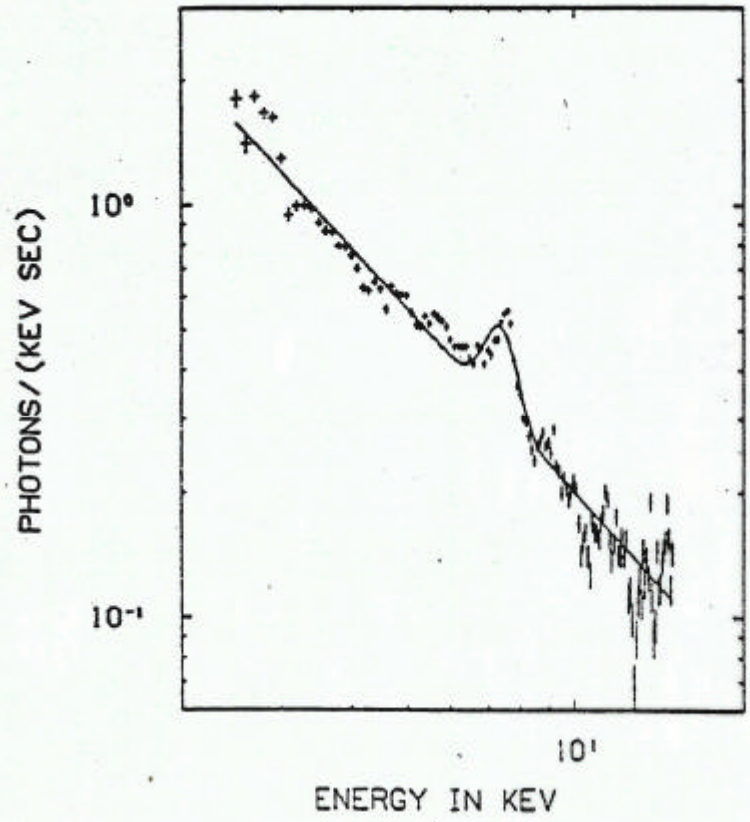
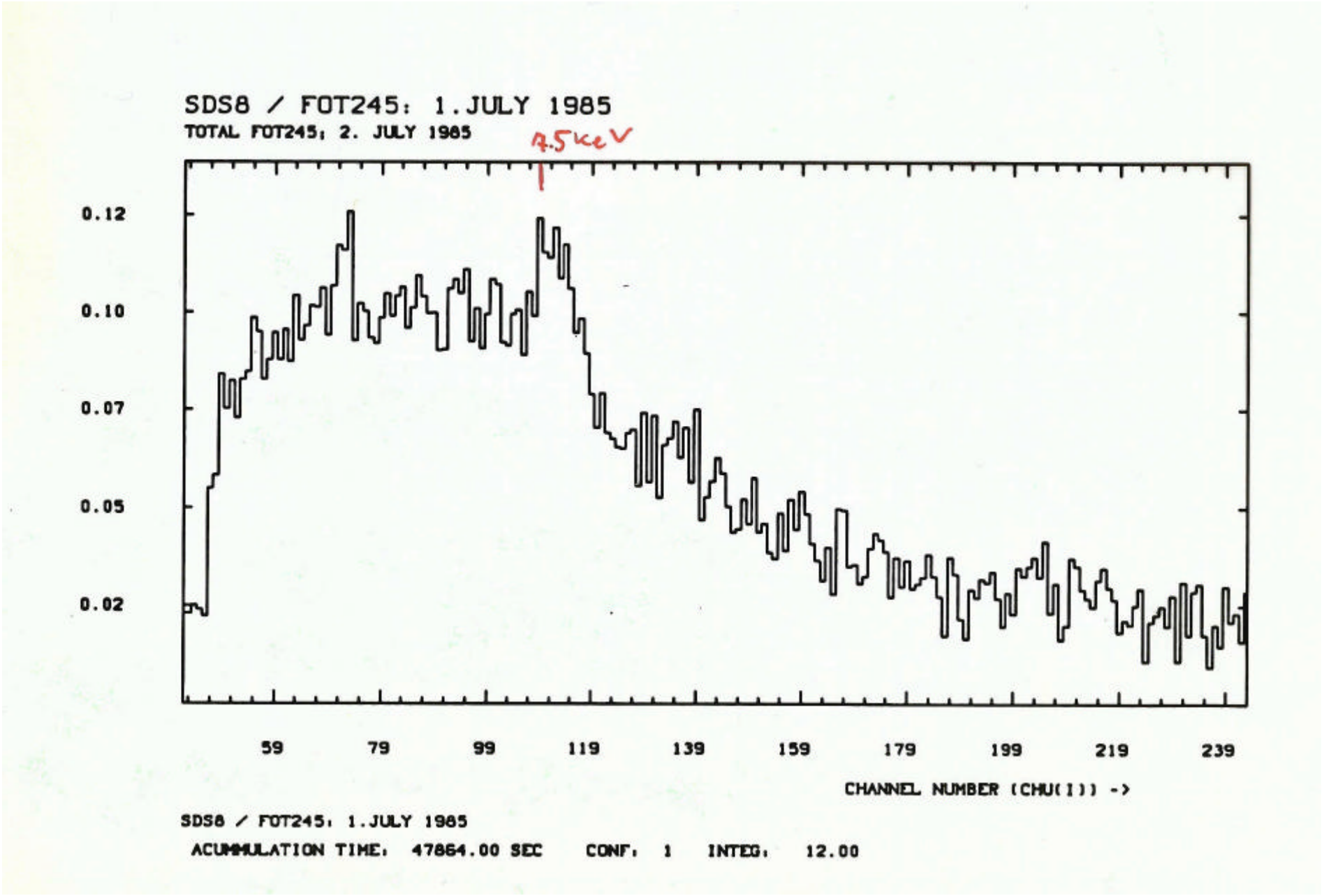
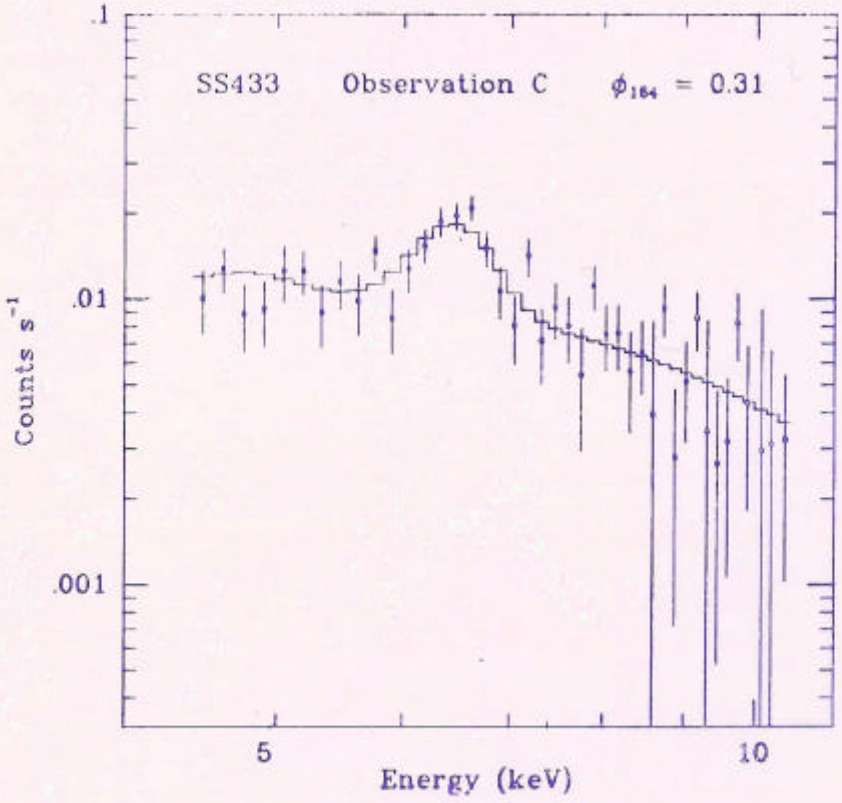


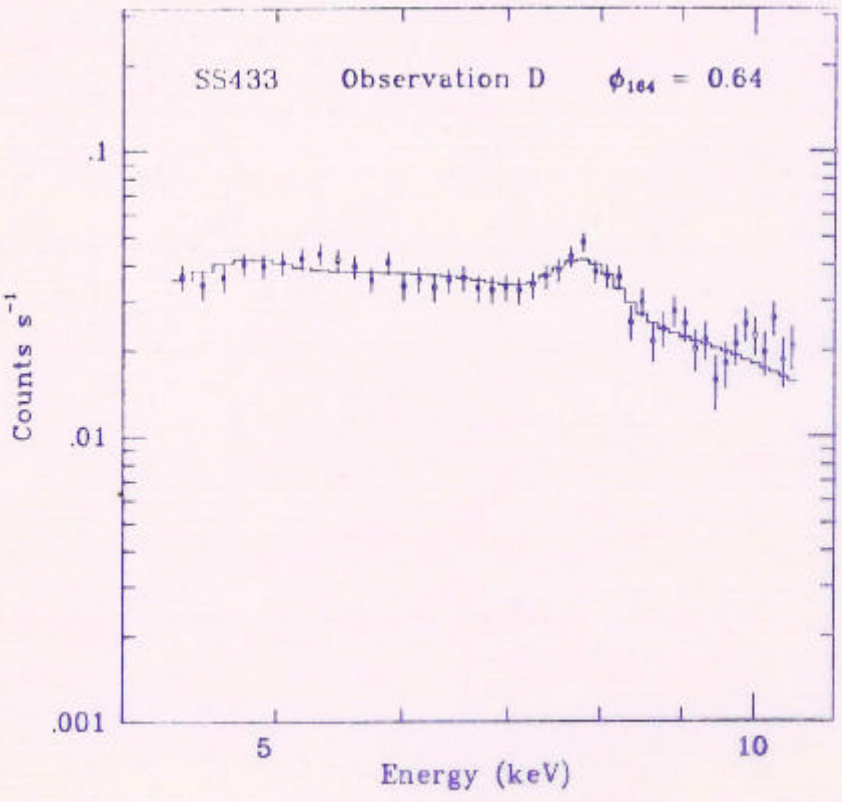
Fig.1: SS433 source spectrum with power law fit to the total data. Parameters are given in the text.

from: Proceedings of the 1984 Frascati WS on Vulcano

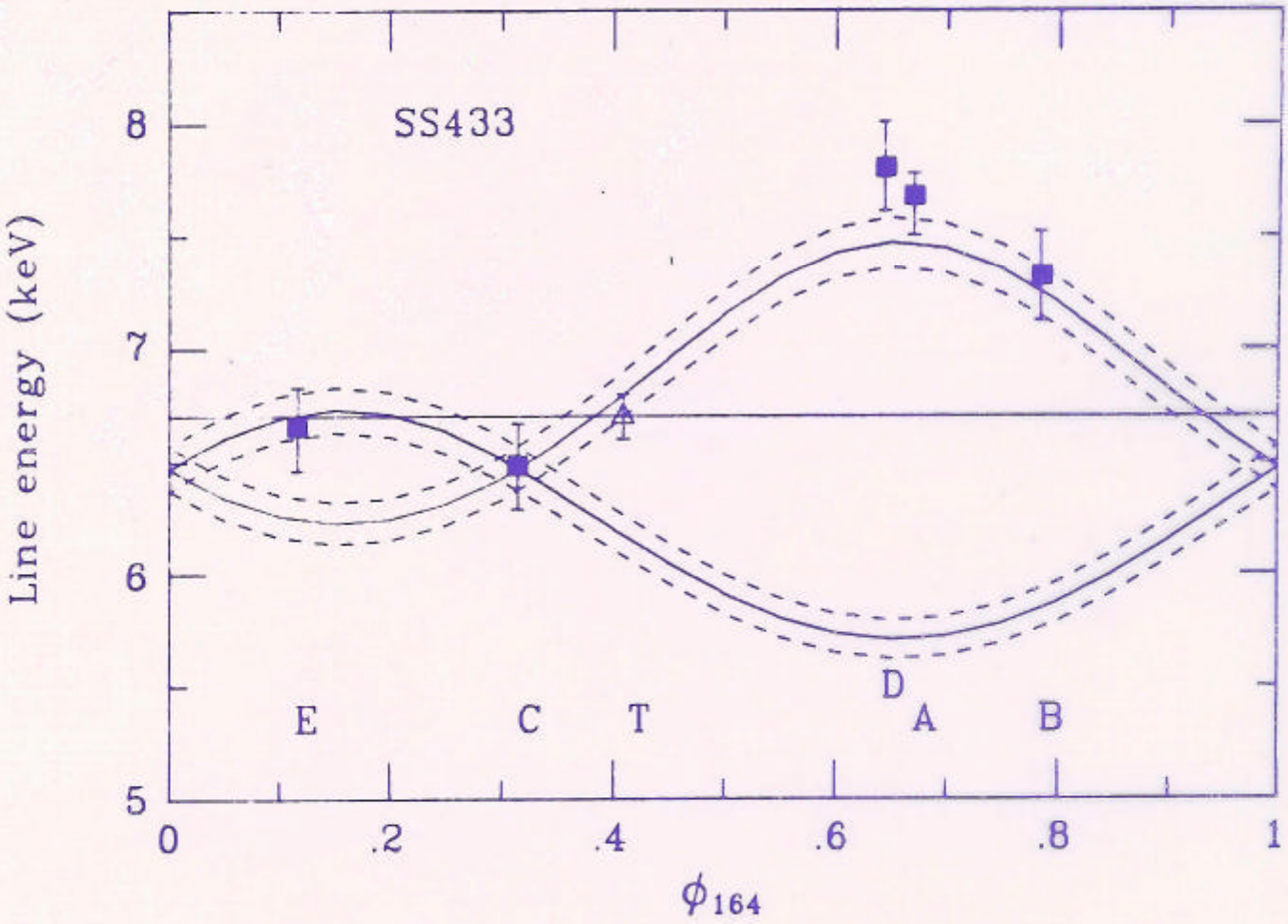

SDS8 / FOT245: 1.JULY 1985
TOTAL FOT245: 2. JULY 1985
4.5keV
0.12
0.10
0.07
0.05
0.02
59
79
99
119
139
159
179
199
219
239
CHANNEL NUMBER (CHU(I)) ->
SDS8 / FOT245: 1.JULY 1985
ACUMMULATION TIME: 47864.00 SEC
CONF: 1
INTEG: 12.00

Watson et al 1986





Watson et al '86



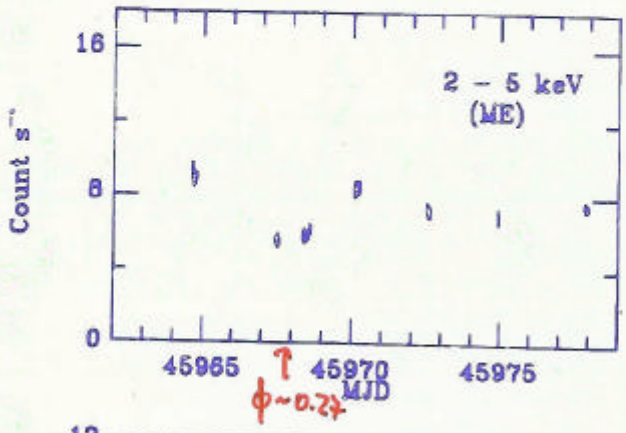
Parameters of the X-ray jets

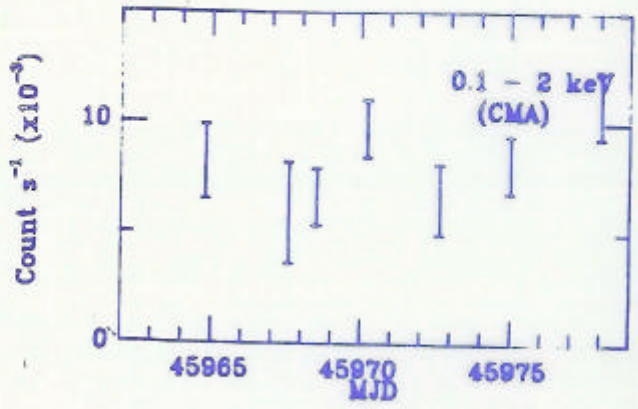
- hot gas, $T \geq 100$ *million* ^oK
  iron line, spectral fit, EW of line
- lenght of jet $L_x \leq 10^{12}$ cm
  no 'red' jet, dimensions of system
- cooling time of jets: $L_x/v \sim 100s$
- density of the hot gas $n_o \sim 10^{13}$ cm^{-3}
  cooling time $\sim n_e T/n_e^2\sqrt{(T)}$
- jet - radius: $r_o \sim several \times 10^{10}$ cm
  luminosity, density, cylindrical jet
- kinetic energy of outflowing matter:
  $\dot{E}_{kin} \geq 3 \times 10^{39}\ erg/sec$

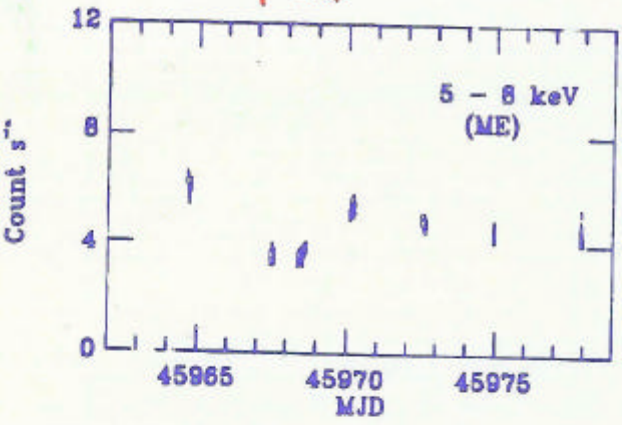
system parameters from long term monitoring
!

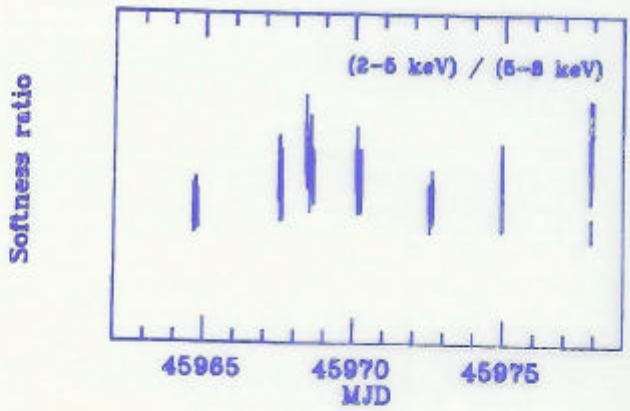
γ_{164} = 0.77 – 0.87

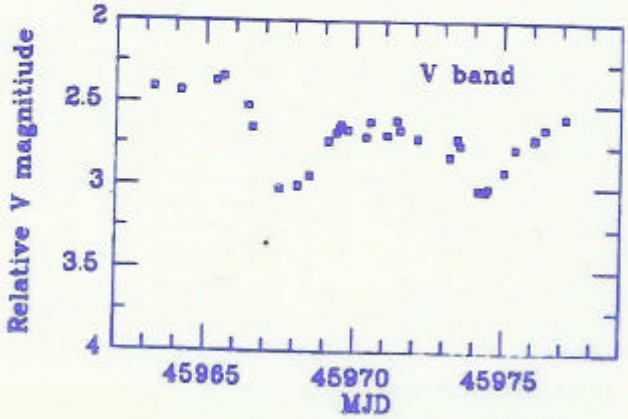
Stewart, Watson, LG
Matsuoka, ISAS
Brinkmann, MPE
Yagaku, Tokyo
Takagishi, Miyazaki
Omodaka, kagoshima
kemp
kenson } Oregon
kraus





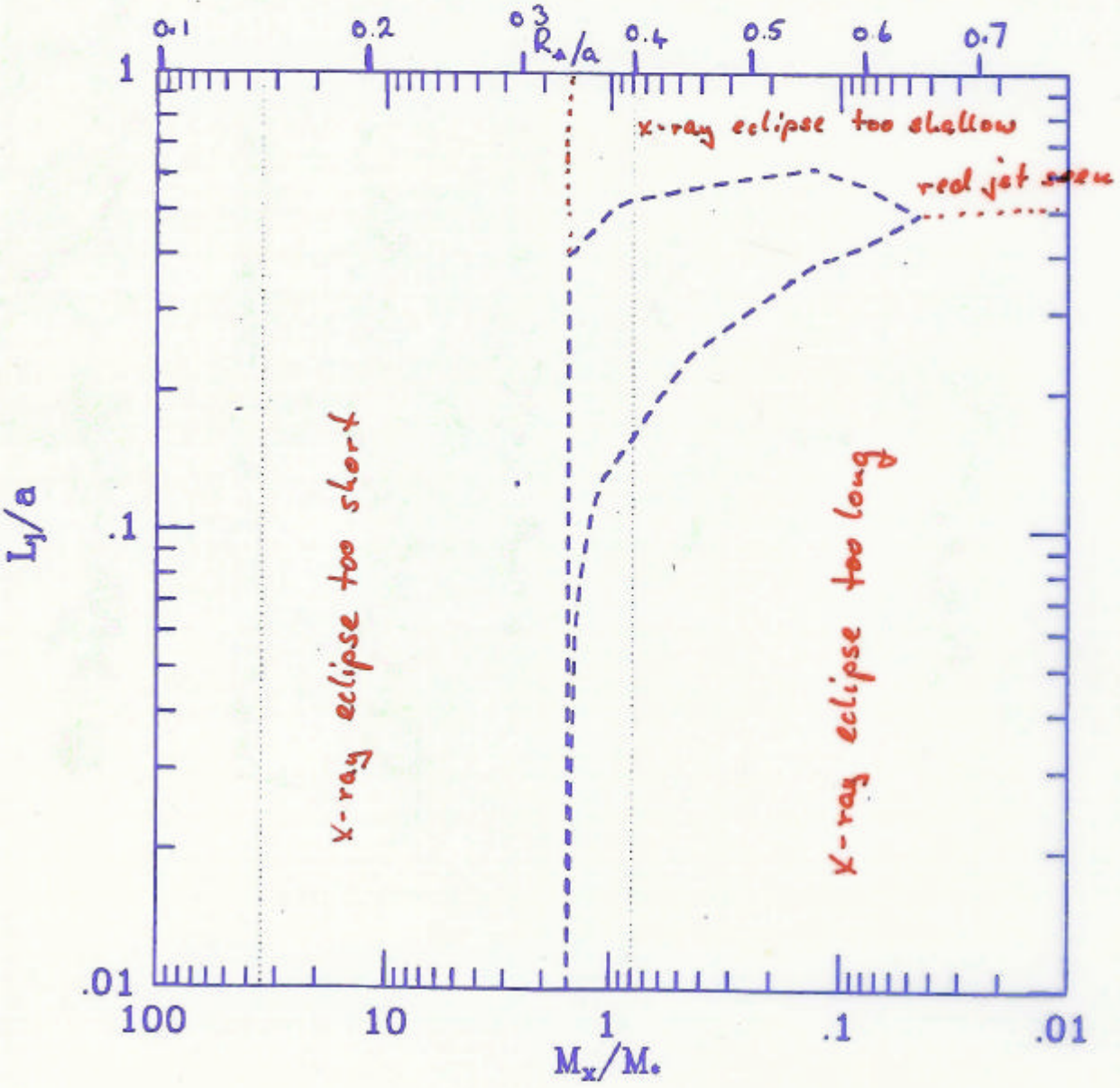






← Okayama Astr. Obs.
kagoshima Sp. Ct.
Hanna kea Obs.
Pine Mountain

Stewart et al 1987



$L_J \sim 10^{12}$ cm

$R^* \sim 3 \cdot 10^{12}$ cm

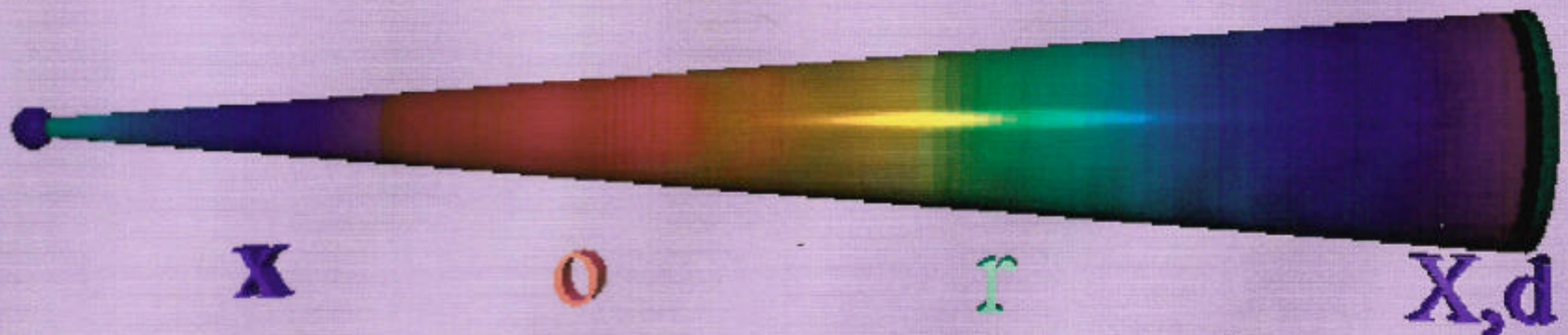
$q \sim 1$

$M_*, M_x \geq 10 M_\odot$

$q = 0.8$ $M_* \sim 35 M_\odot$ $M_x \sim 27 M_\odot$

$q = 1.5$ $M_* \sim 66 M_\odot$ $M_x \sim 100 M_\odot$

SS433 jet



$< 10^{12}$ cm

thermal !

10^{14-15} cm

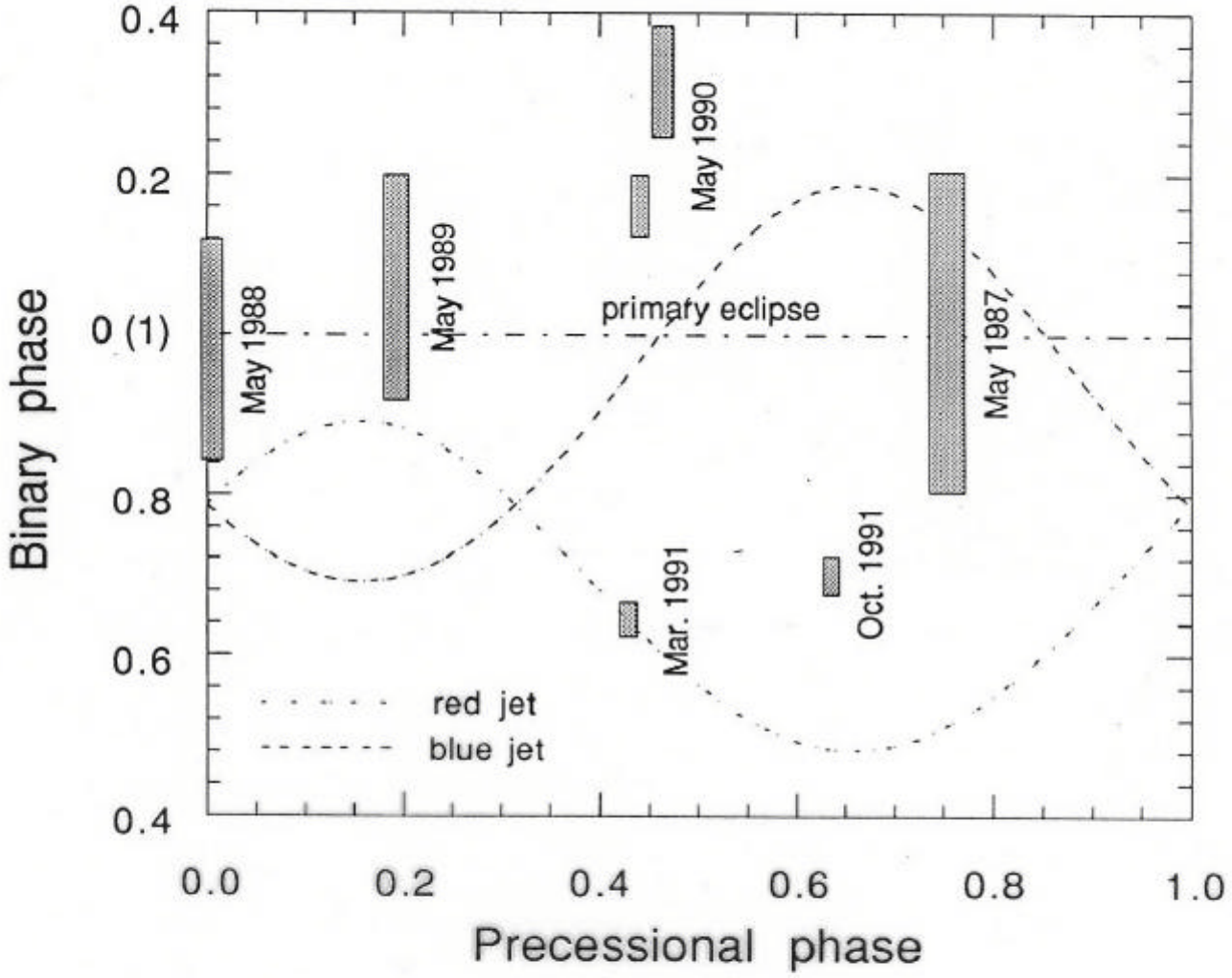
10^{15-17} cm

⇑

X-rays!
Chandra

$> 10^{18}$ cm

non thermal?



Yuan et al, 1995

Fig. 1

87 pe

SRF: R11211.SS433.SPEC(SUM1) SF.OB: 1.0
LAC SPEC SUBFILE: S8705190219 # 0 TARGET: SS433 287.34 4.90
COMMENT:

TIME: 87 5 18 14 29 50.062 - 87 5 18 22 58 38.052

TOTAL REAL TIME: 6976.00 SEC

TOTAL LIVE TIME: 6885.49 SEC/SENSOR

TOTAL EFFECTIVE TIME: 6747.98 SEC/SENSOR

SENSOR/LAYER: 3 3 3 3 3 3 3 3

MODE: MPC2 MPC1+2: YES

BACKGOUND SUBTRACTION: YES

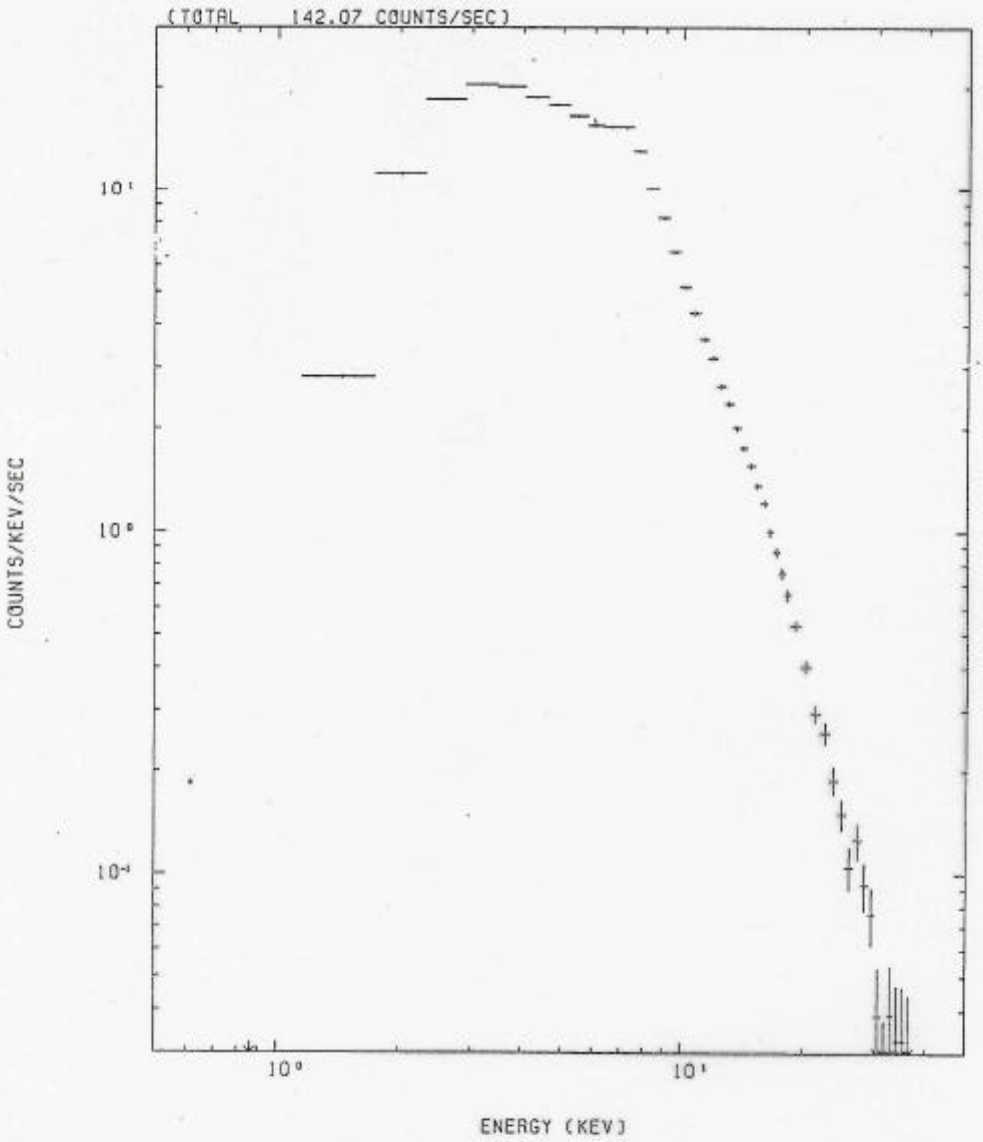
ASPECT CORRECTION: YES

DEAD TIME CORRECTION: YES

MODE:MPC2 E1:ON E2:ON BYPS:OF MEM:ON CAL3:OF CAL:OF

	HV	LVL	HK	INSEL LASVVE	CG	FG LASVVE	DISCRI LASVELMU	ANTI 12345678
LAC0	ON	9	1833	111000	0	444224	00000001	11111111
LAC1	ON	9	1824	111000	0	444224	00000001	11111111
LAC2	ON	9	1824	111000	0	444224	00000001	11111111
LAC3	ON	9	1830	111000	0	444224	00000001	11111111
LAC4	ON	9	1824	111000	0	444223	00000001	11111111
LAC5	ON	9	1823	111000	0	444224	00000001	11111111
LAC6	ON	9	1824	111000	0	333224	00000001	11111111
LAC7	ON	9	1823	111000	0	222224	00000001	11111111

TMP:	0A	0B	0C	1B	2A	2B	2C	3B	4B	5A	5B	6C	6B	7A	7B	7C
	11	9	8	10	12	11	8	10	13	14	15	16	16	14	15	16
	11	9	8	10	13	11	8	10	13	14	15	16	16	14	15	17
	11	10	8	11	13	11	9	11	14	14	16	16	[illegible]	14	16	17



88-08-15 15:46

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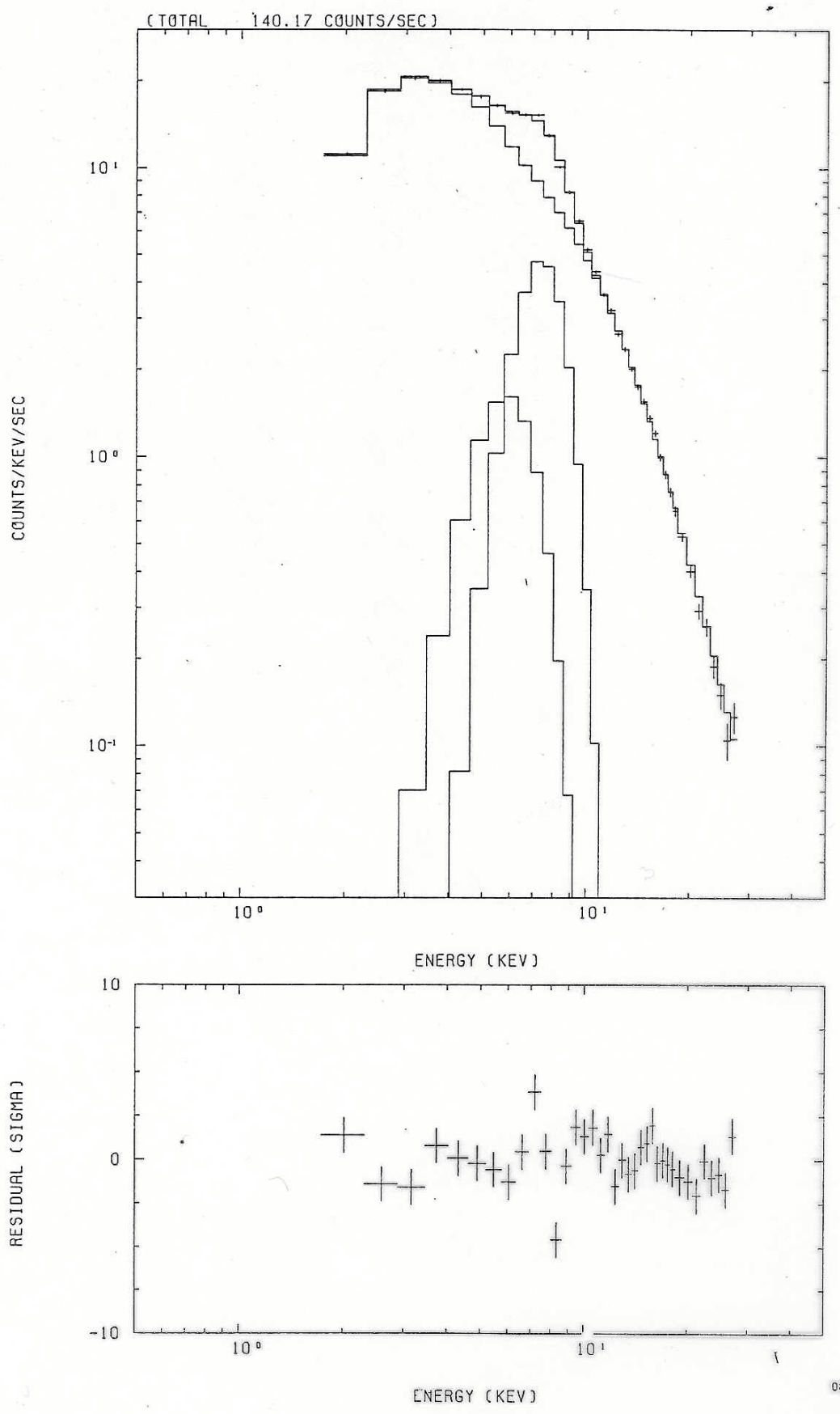
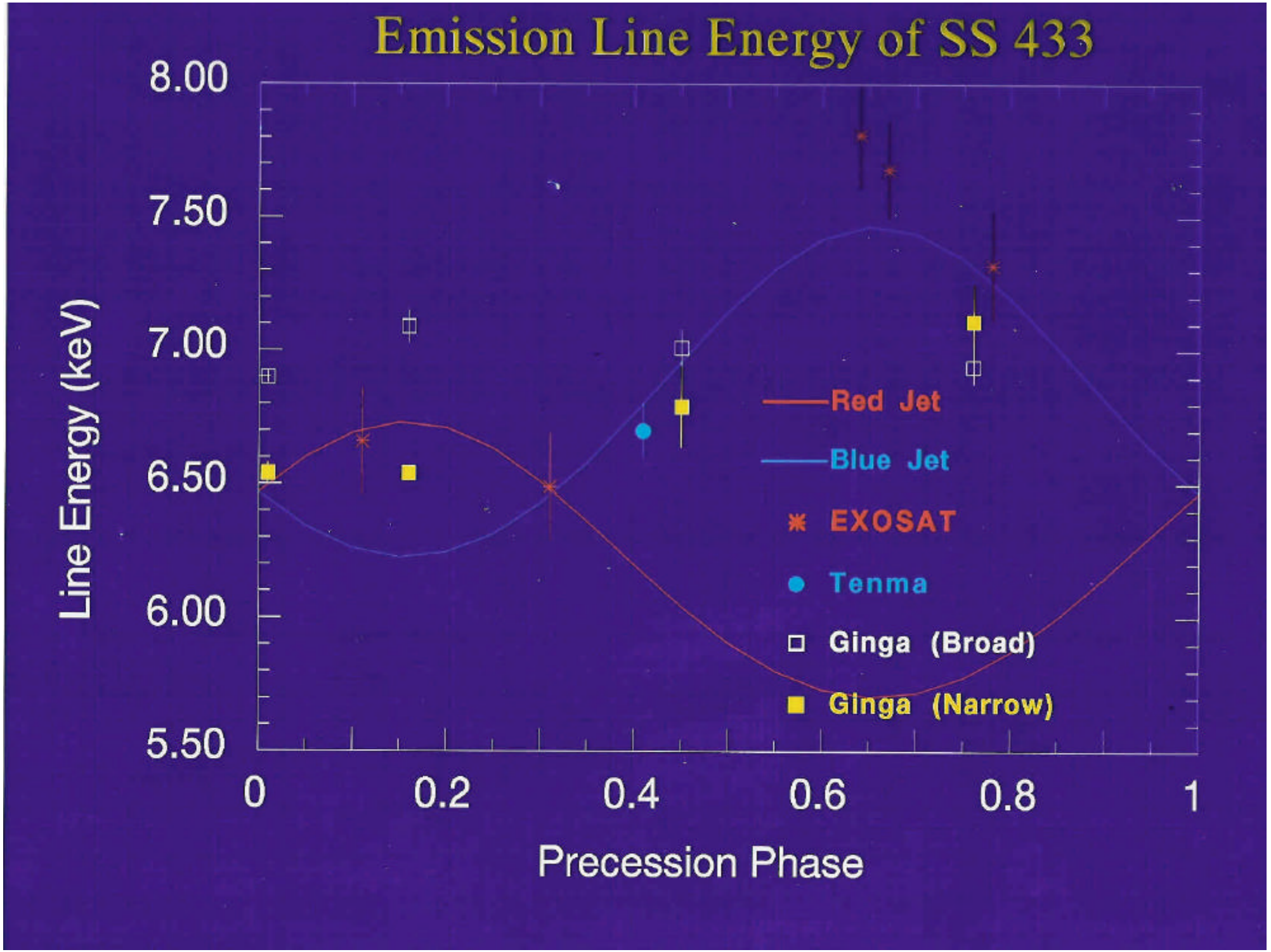


08-08-16

88-08-16 9:36


Emission Line Energy of SS 433
8.00
7.50
7.00
6.50
6.00
5.50
Line Energy (keV)
0
0.2
0.4
0.6
0.8
1
Precession Phase
Red Jet
Blue Jet
EXOSAT
Tenma
Ginga (Broad)
Ginga (Narrow)

TIME: 87 5 18 3 28 30.049 - 87 5 22 23 26 9.923

TOTAL REAL TIME: 72632.00 SEC

TOTAL LIVE TIME: 71914.20 SEC/SENSOR

TOTAL EFFECTIVE TIME: 42364.22 SEC/SENSOR

SENSOR/LAYER: 3 3 3 3 3 3 3 3

MODE: HPC2 HPC1+2: YES

BACKGOUND SUBTRACTION: YES

ASPECT CORRECTION: YES

DEAD TIME CORRECTION: YES

YLA TIME DELAY CORRECTION: NONE

MODE:HPC2 E1:ON E2:ON BTPS:OF MEM:ON CALS:OF CAL:OF

	HV	LVL	HK	INSEL LRSYVE	CG	FG LRSYVE	DISCRI LRSYELHU	ANTI 12345678
LAC0	ON	9	1832	111000	0	444224	00000001	11111111
LAC1	ON	9	1824	111000	0	444224	00000001	11111111
LAC2	ON	9	1824	111000	0	444224	00000001	11111111
LAC3	ON	9	1829	111000	0	444224	00000001	11111111
LAC4	ON	9	1823	111000	0	444223	00000001	11111111
LAC5	ON	9	1823	111000	0	444224	00000001	11111111
LAC6	ON	9	1824	111000	0	333224	00000001	11111111
LAC7	ON	9	1823	111000	0	222224	00000001	11111111

TMP:	0A	0B	0C	1B	2A	2B	2C	3B	4B	5A	5B	6C	6B	7A	7B	7C
	10	9	7	9	12	10	7	9	12	13	14	15	16	12	14	15
	11	9	8	10	12	11	8	10	13	14	15	15	16	14	15	16
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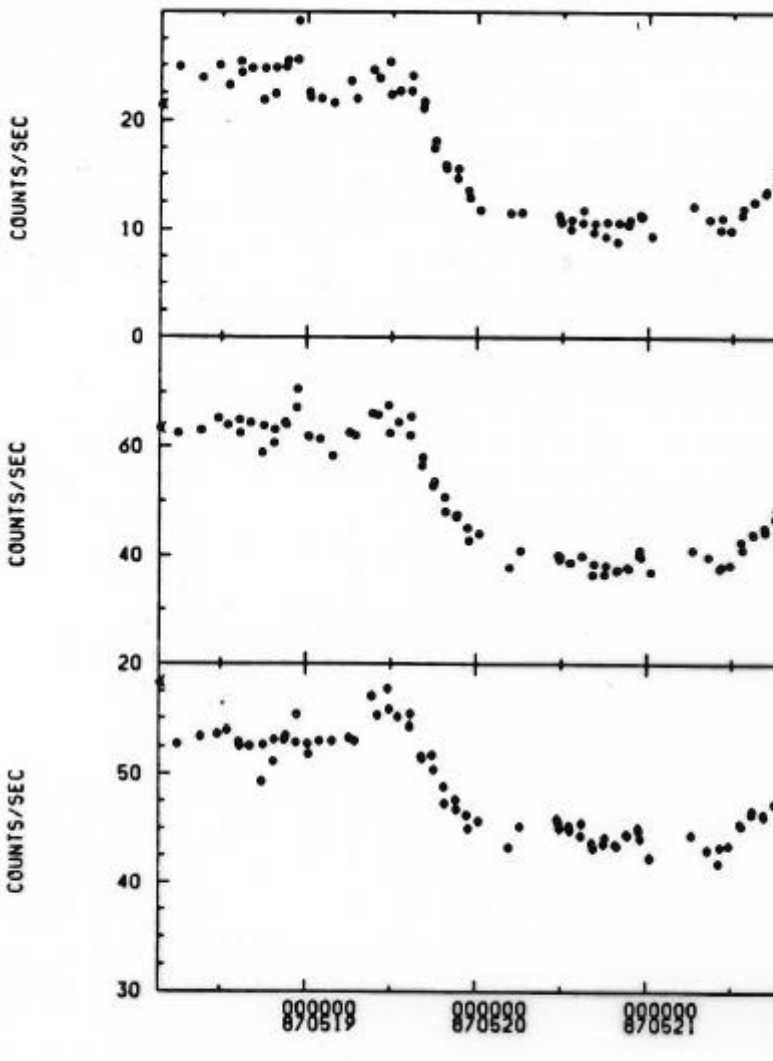
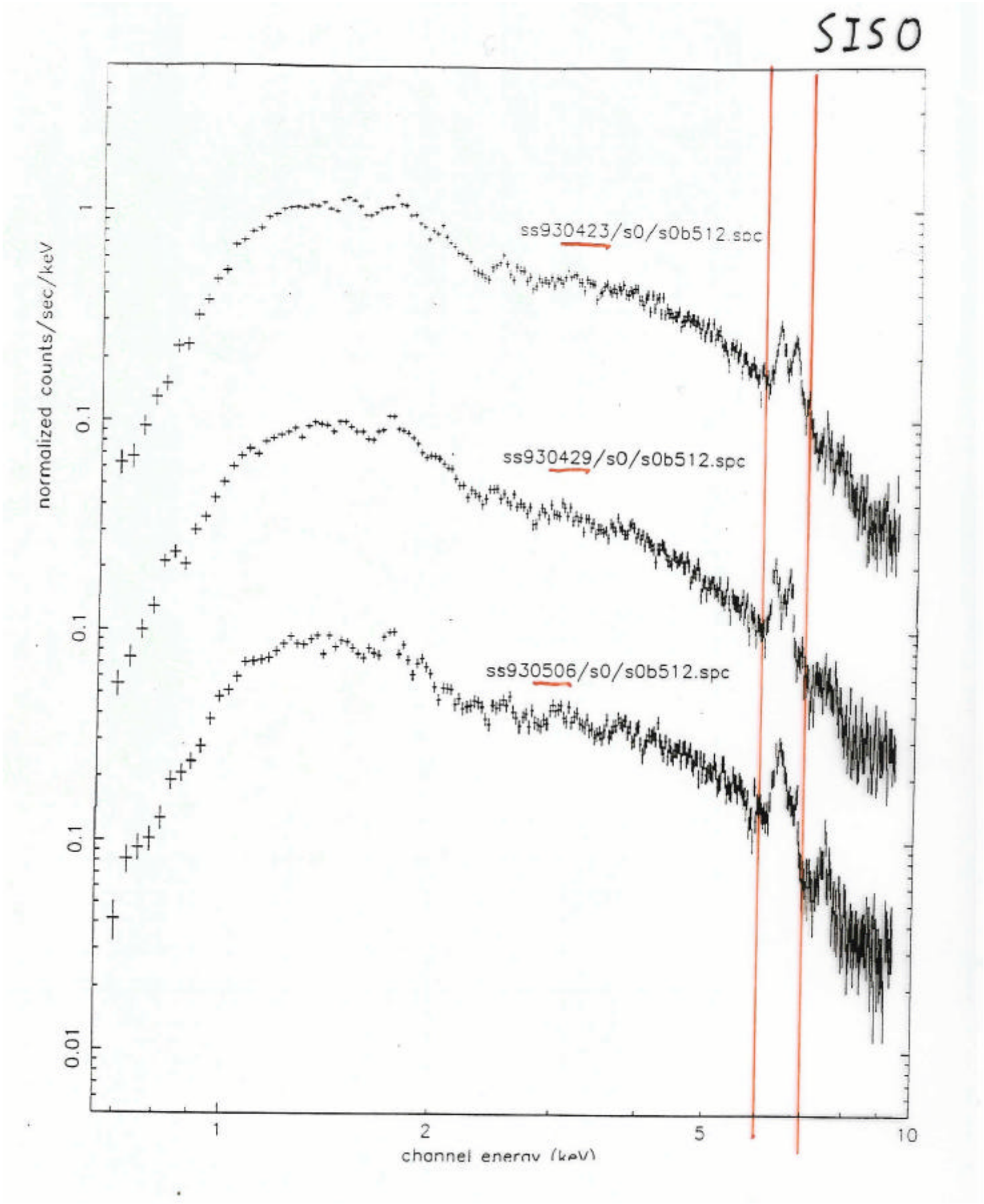
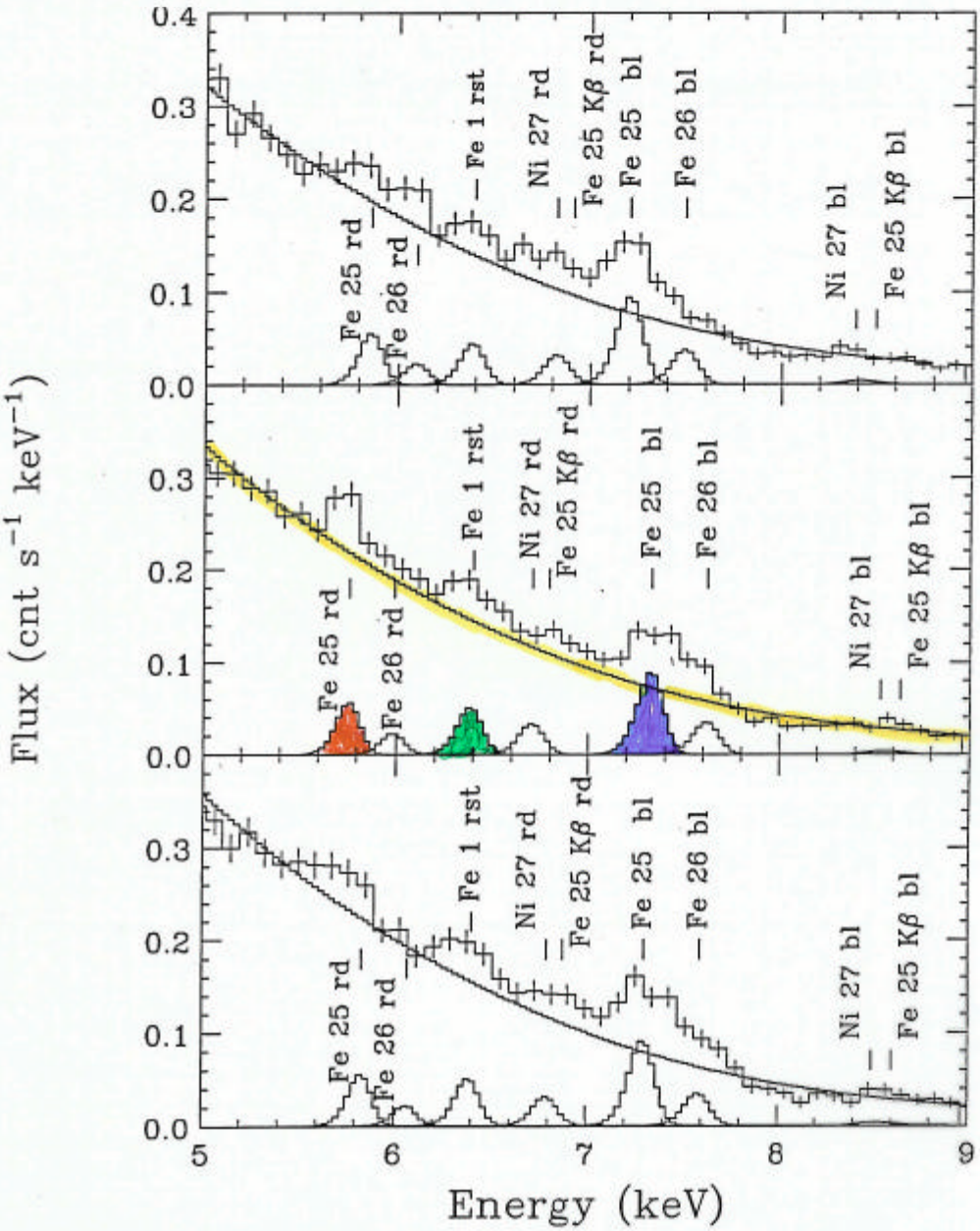



SIS0
ss930423/s0/s0b512.spc
ss930429/s0/s0b512.spc
ss930506/s0/s0b512.spc
normalized counts/sec/keV
1
0.1
0.1
0.1
0.01
1
2
5
10
channel energy (keV)

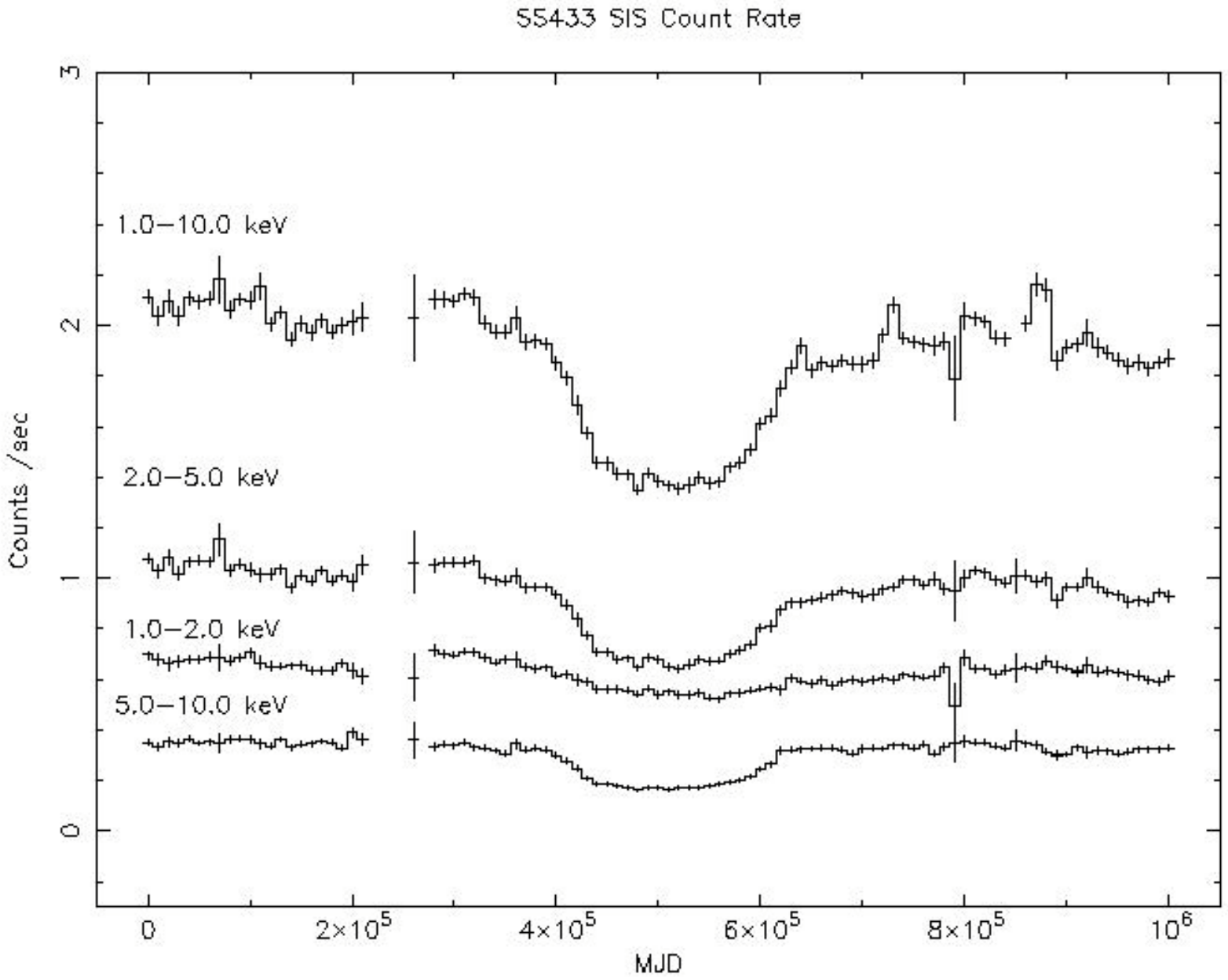


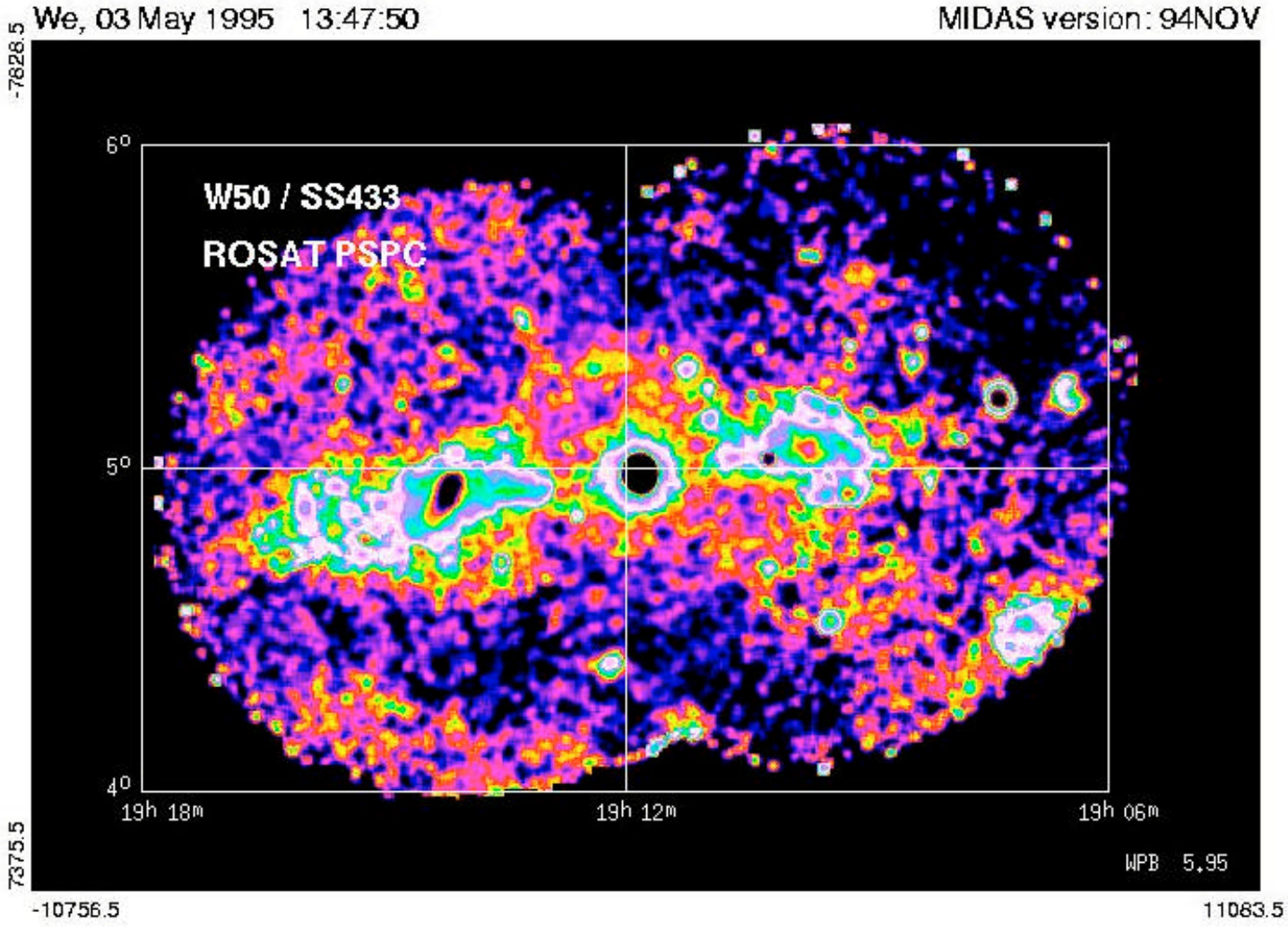
Oct 28 '94

Oct 29

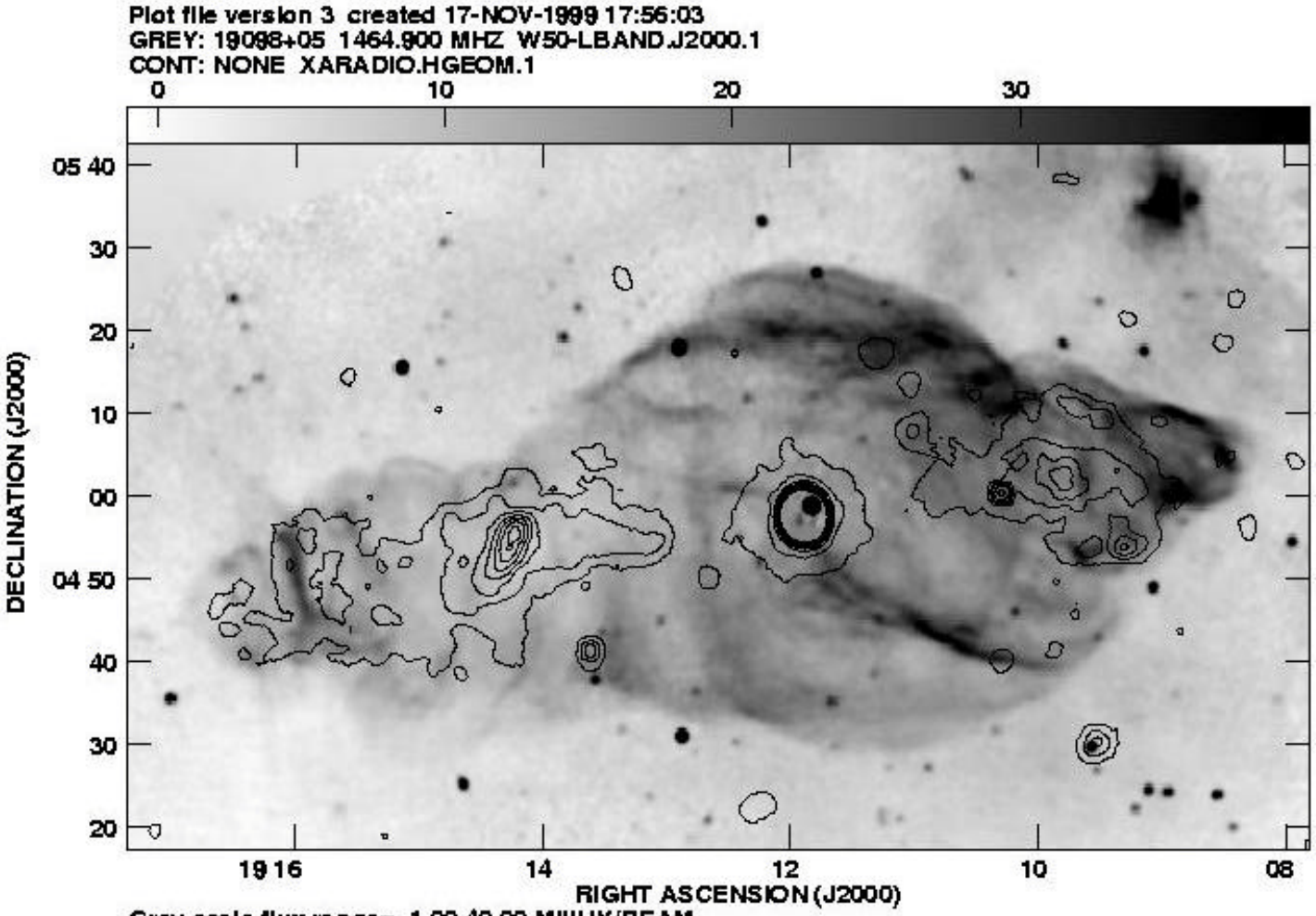
Nov 3

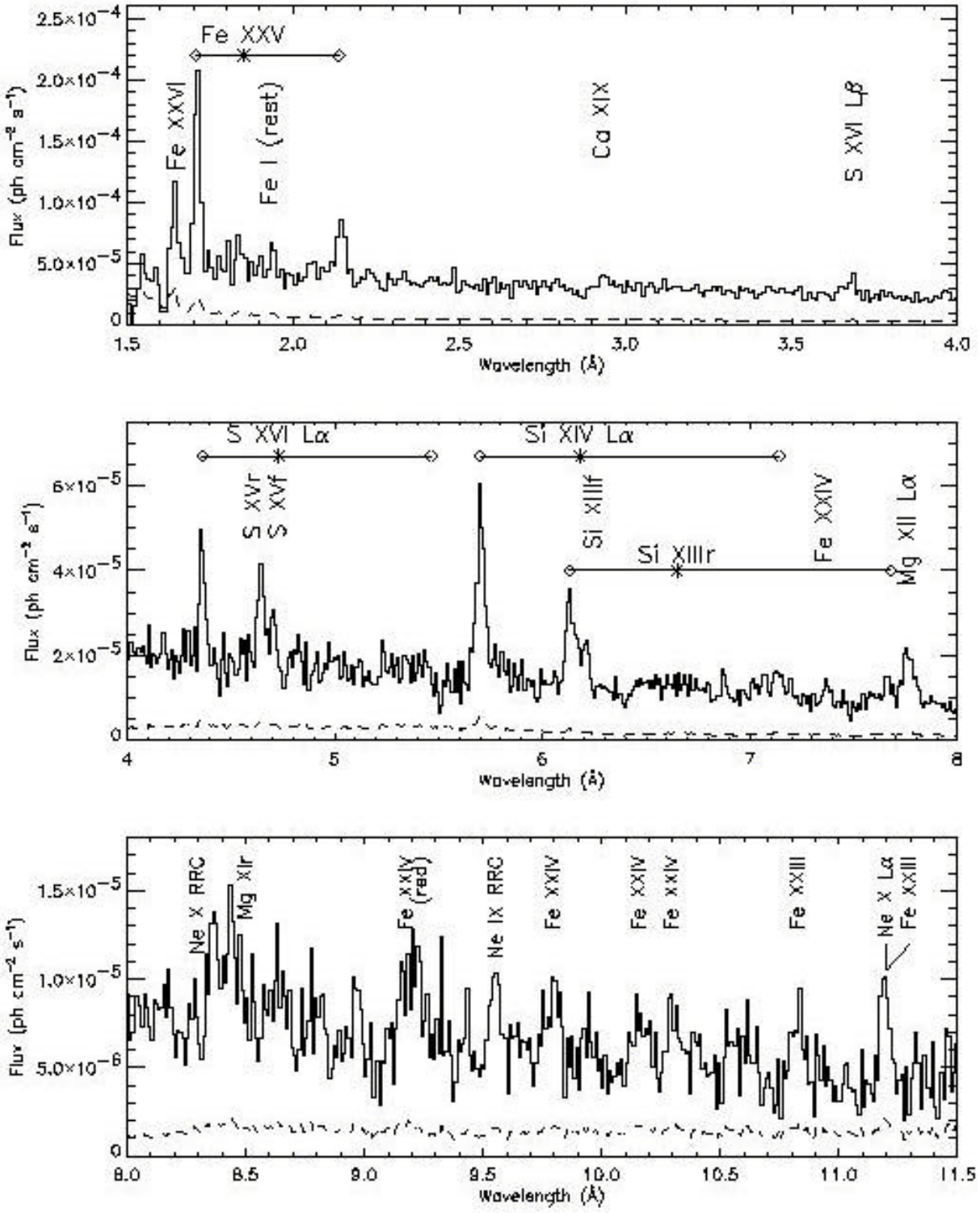
Kotani et al '96

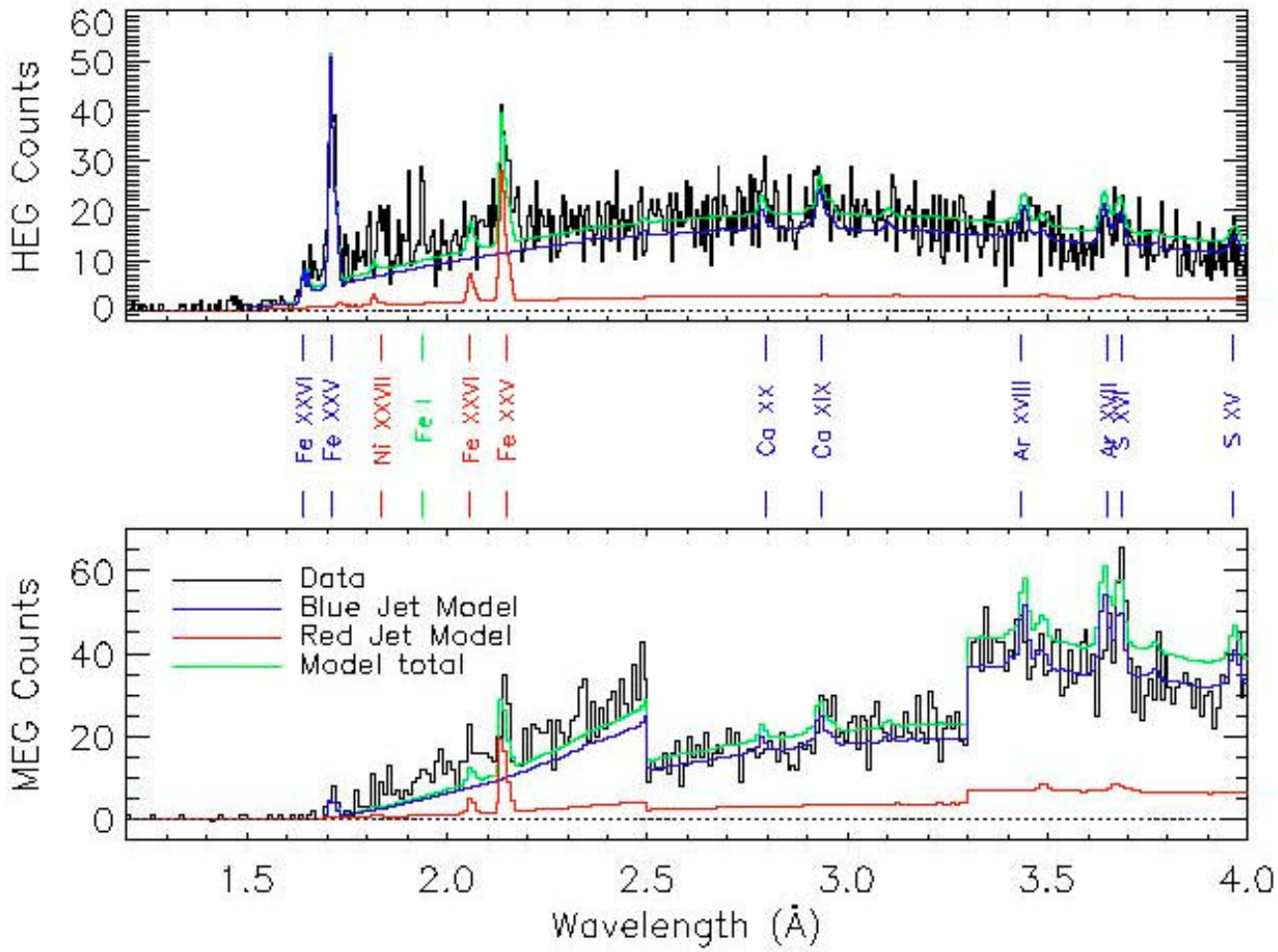

S5433 SIS Count Rate
1.0–10.0 keV
2.0–5.0 keV
1.0–2.0 keV
5.0–10.0 keV
Counts /sec
0
1
2
3
0
2×10^5
4×10^5
6×10^5
8×10^5
10^6
MJD

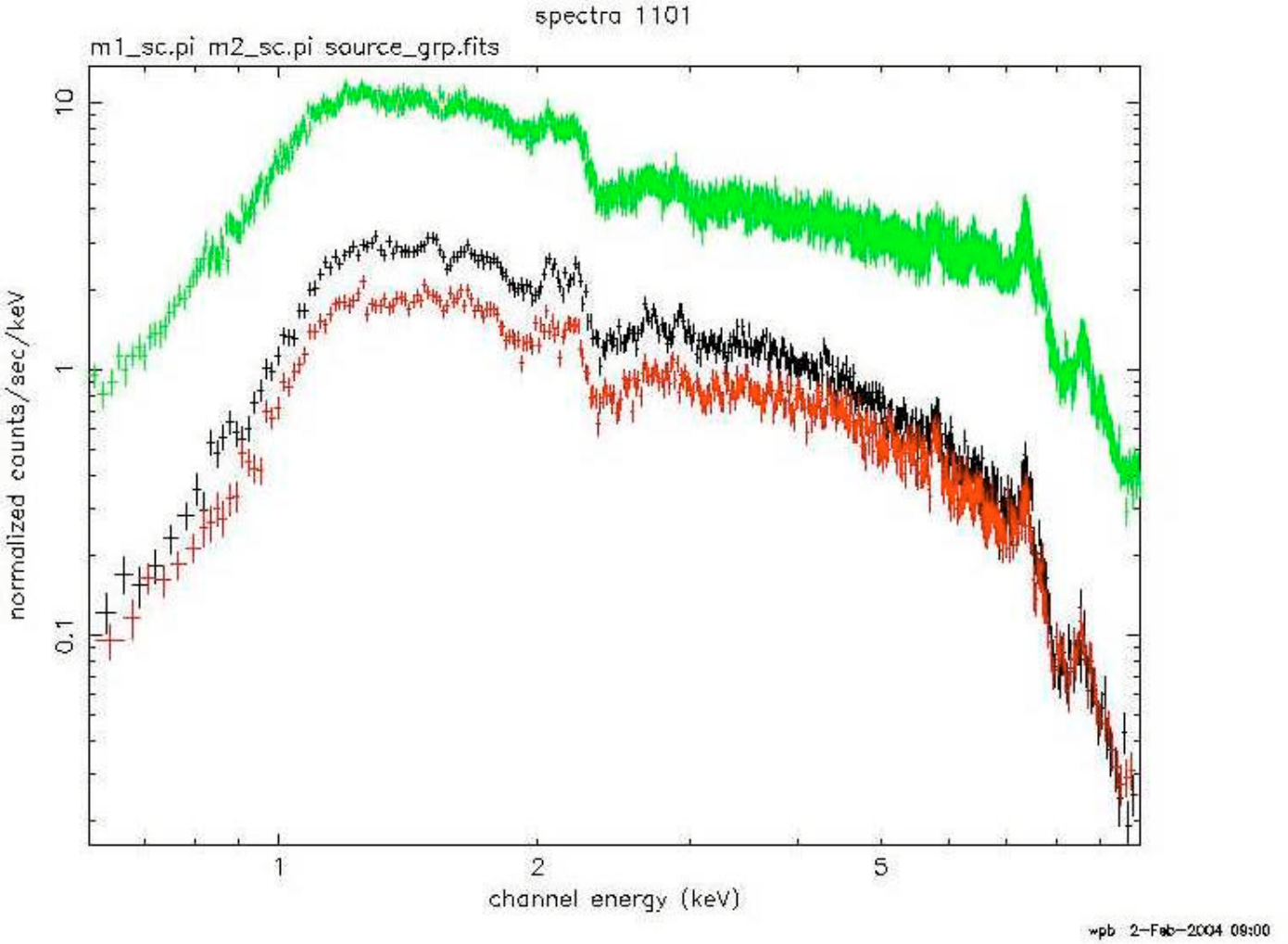

We, 03 May 1995 13:47:50
MIDAS version: 94NOV
-7828.5
W50 / SS433
ROSAT PSPC
6°
5°
4°
19h 18m
19h 12m
19h 06m
WPB 5.95
7375.5
-10756.5
11083.5

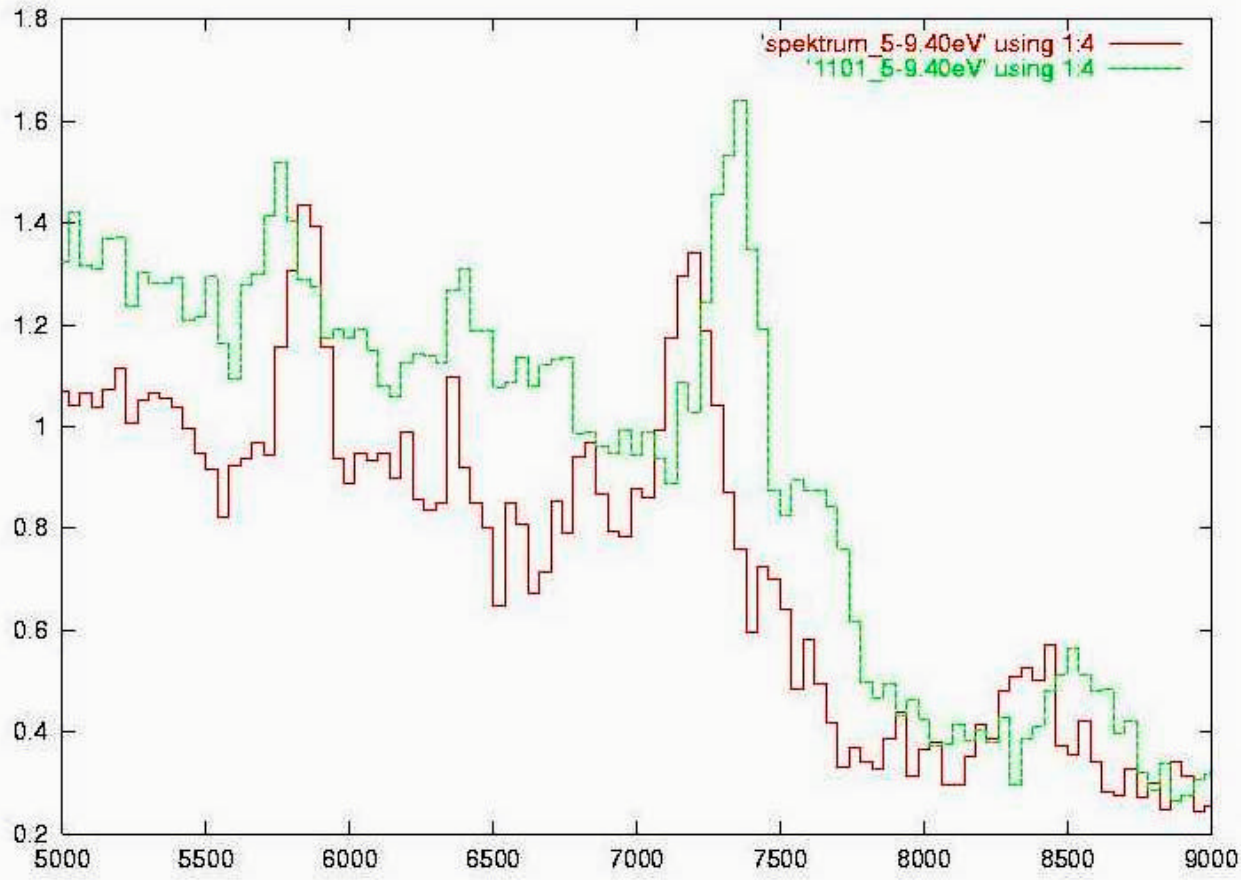
Frame imah a

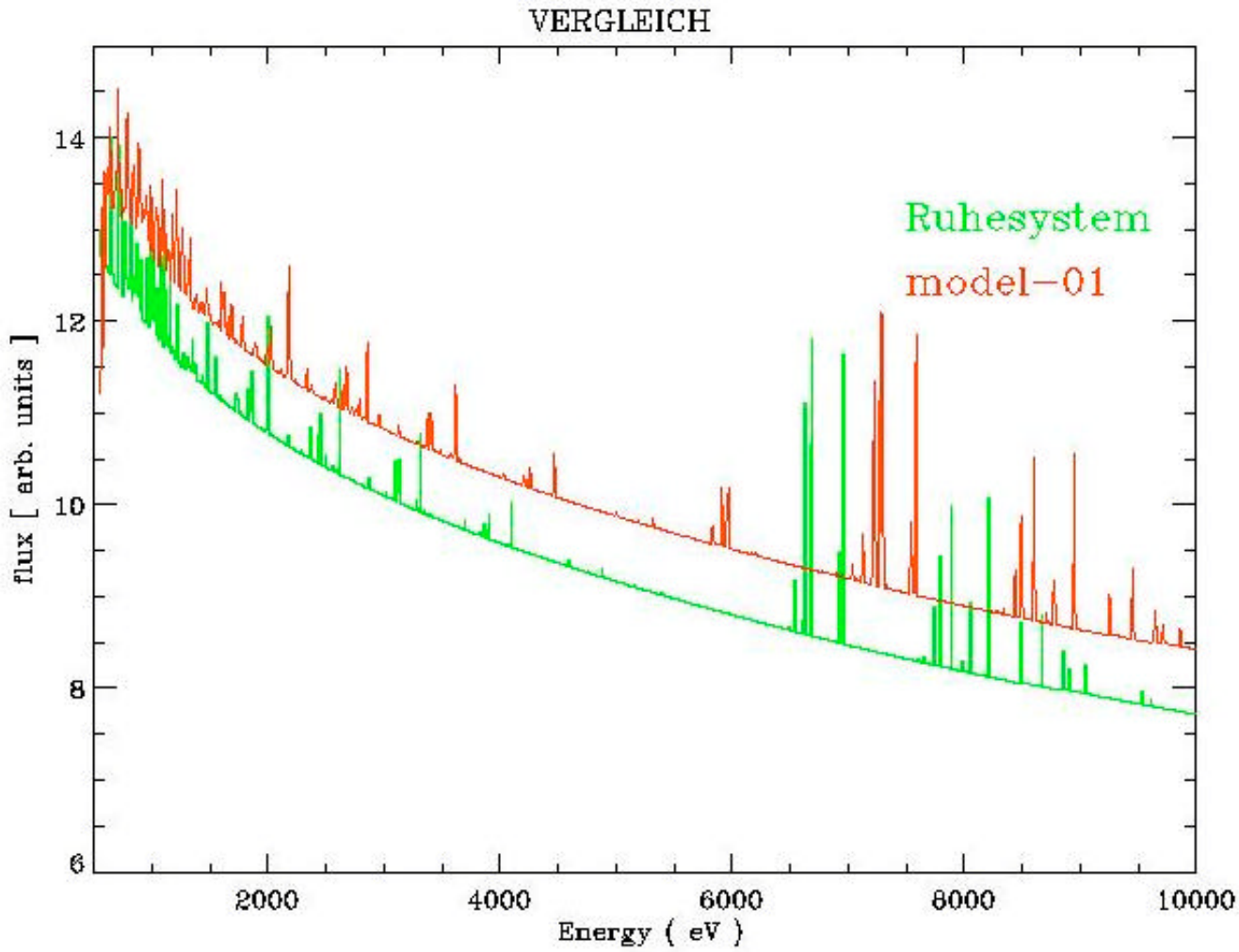

Plot file version 3 created 17-NOV-1999 17:56:03
GREY: 19098+05 1464.900 MHZ W50-LBAND.J2000.1
CONT: NONE XARADIO.HGEOM.1
0
10
20
30
05 40
30
20
10
00
04 50
40
30
20
DECLINATION (J2000)
19 16
14
12
10
08
RIGHT ASCENSION (J2000)
Grey scale flux range= -1.00 40.00 MILLIJY/BEAM
Peak contour flux = 5.7032E-03 COUNTS
Levs = 1.000E-04 * (0.500, 1, 1.500, 2, 2.500, 3,
3.500, 4, 4.500, 5)


Fe XXV
Fe XXVI
Fe I (rest)
Ca XIX
S XVI Lβ
Flux (ph cm⁻² s⁻¹)
Wavelength (Å)
S XVI Lα
S XVr
S XVf
Si XIV Lα
Si XIIIf
Si XIIIr
Fe XXIV
Mg XII Lα
Ne X RRC
Mg XIr
Fe XXIV (red)
Ne IX RRC
Fe XXIV
Fe XXIV
Fe XXIV
Fe XXIII
Ne X Lα
Fe XXIII


HEG Counts
60
50
40
30
20
10
0
Fe XXVI
Fe XXV
Ni XXVII
Fe I
Fe XXVI
Fe XXV
Ca XX
Ca XIX
Ar XVIII
Ar XVII
S XV
MEG Counts
60
40
20
0
Data
Blue Jet Model
Red Jet Model
Model total
1.5
2.0
2.5
3.0
3.5
4.0
Wavelength (Å)


spectra 1101
m1_sc.pi m2_sc.pi source_grp.fits
normalized counts/sec/keV
10
1
0.1
1
2
5
channel energy (keV)
wpb 2-Feb-2004 09:00


'spektrum_5-9.40eV' using 1:4
'1101_5-9.40eV' using 1:4
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
5000
5500
6000
6500
7000
7500
8000
8500
9000


VERGLEICH
Ruhesystem
model-01
flux [arb. units]
Energy (eV)
14
12
10
8
6
2000
4000
6000
8000
10000