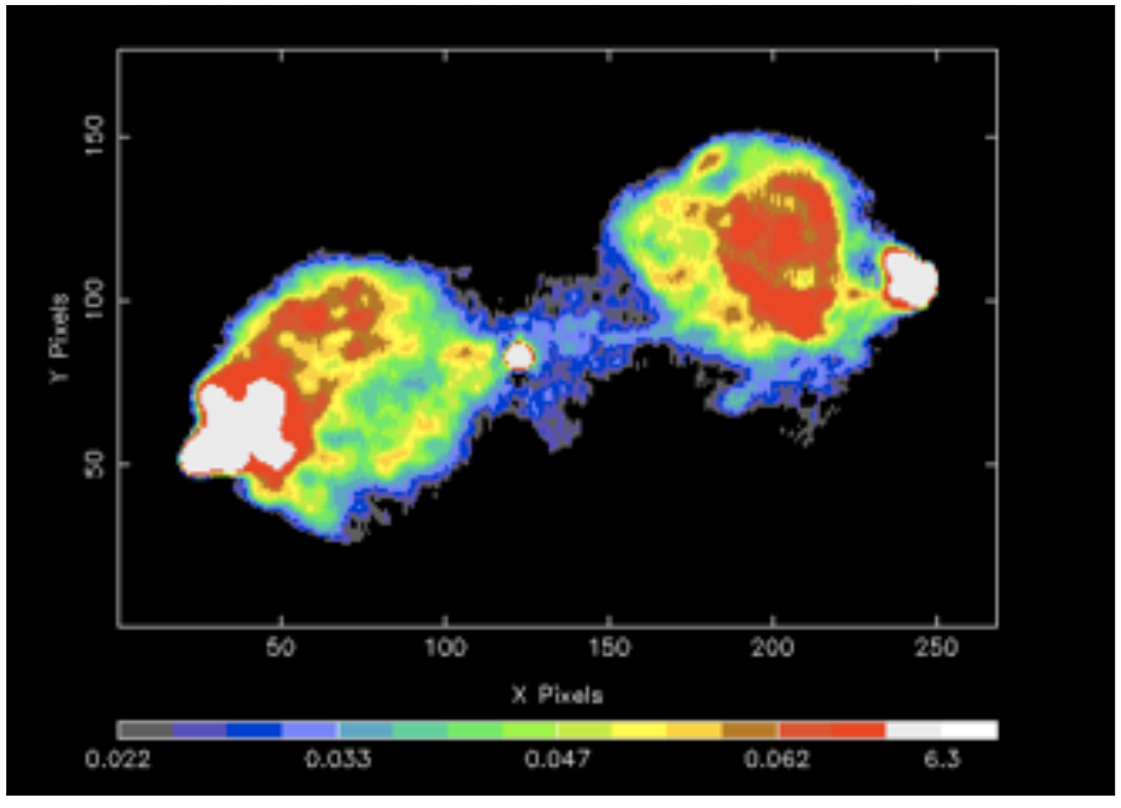
Pictor A with Chandra: jet and hotspot

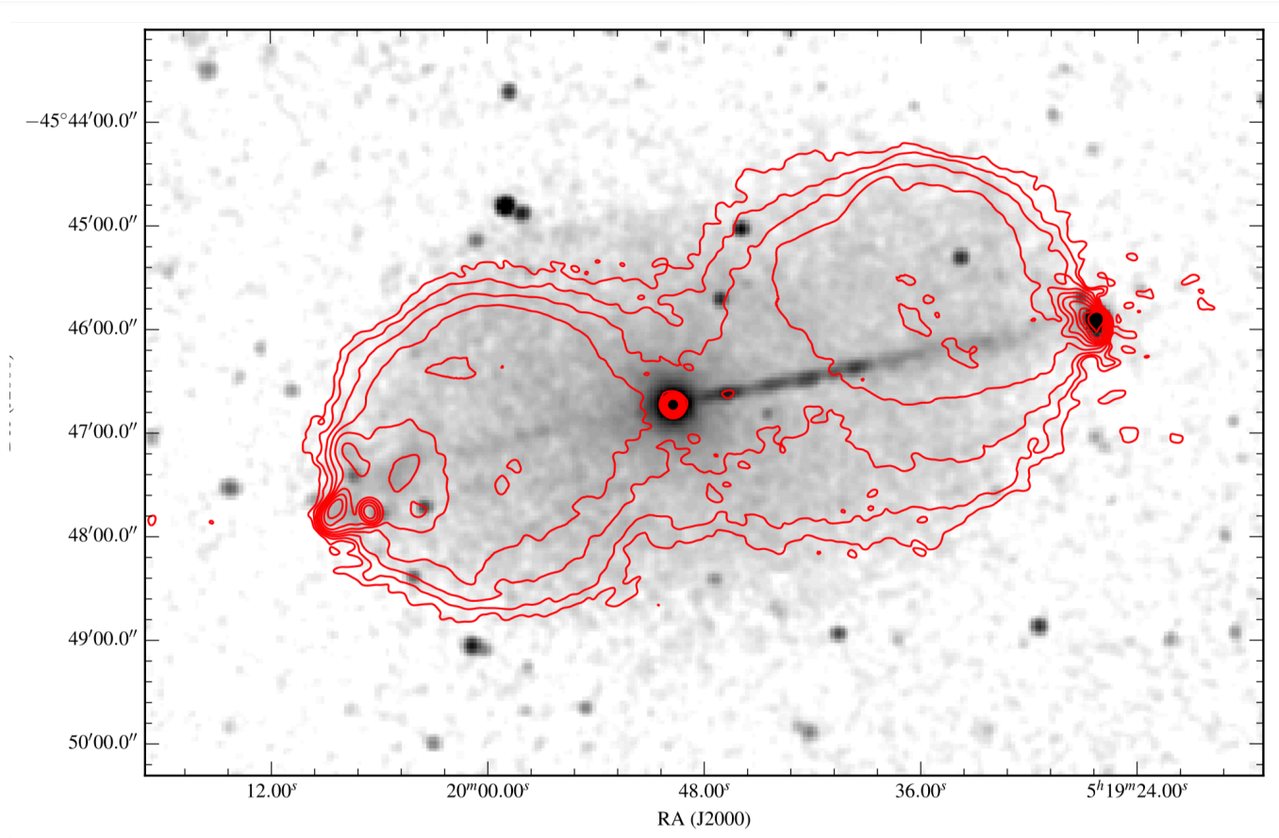
Pic A is a nearby (z =0.035) FRII radio galaxy optically classified as HERG (broad-line radio galaxy.

It is an isolated doubled-lobe radio source with a FRII morphology

VLA 20 cm



Chandra (0.5-5 keV) + 5.5 GHz contours

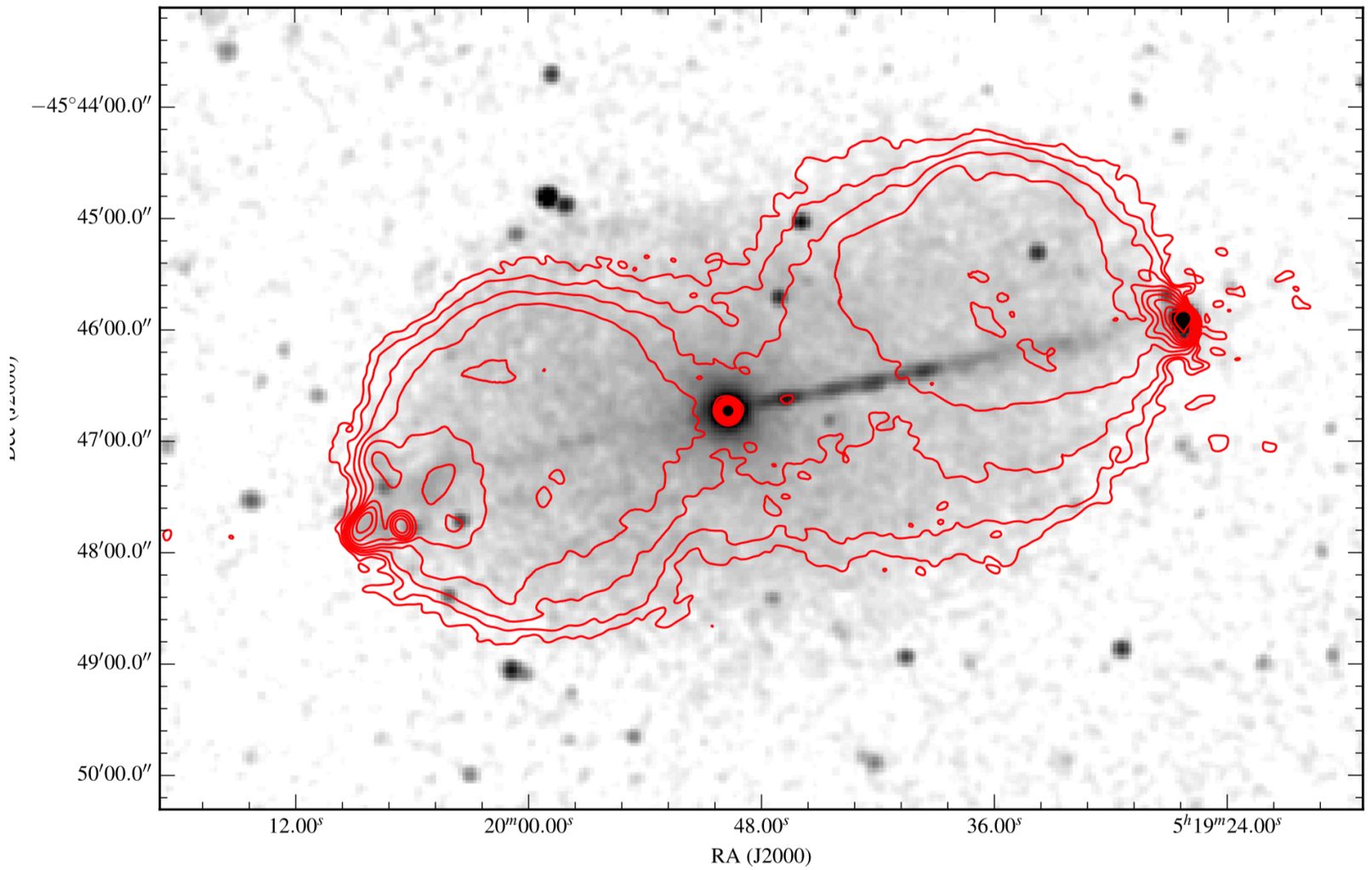


Analysis of the Chandra Observation: jet and Western hot spot

Merged Observation: morphological study

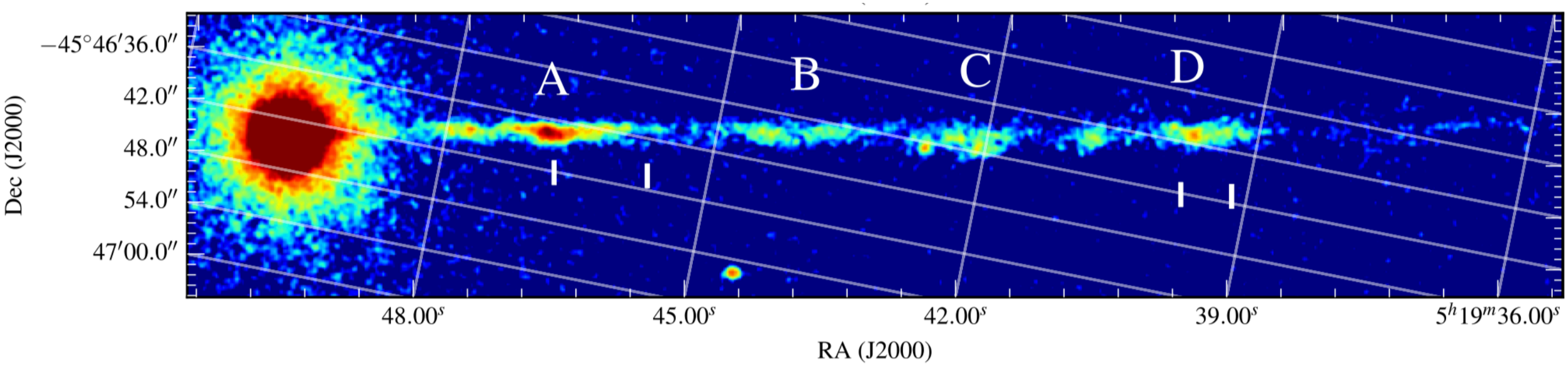
Datasets: merged file (mosaic) of 15 Chandra observations from 1999 to 2015, 466 ks exposure time

Superposition of the X-ray mosaic and radio images (DS9) to identify the regions for the X-ray analysis



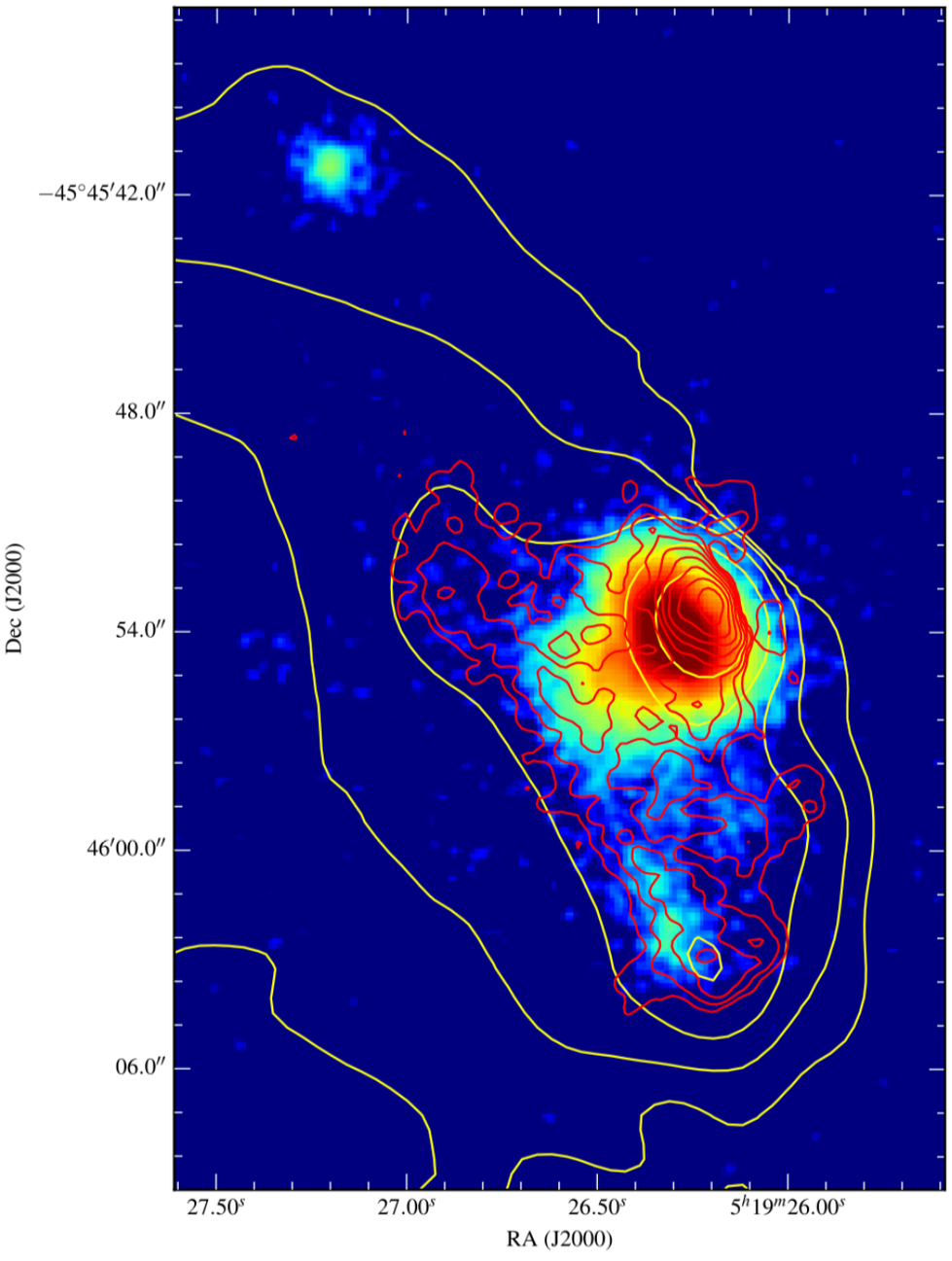
X-ray analysis of the Jet

Chandra mosaic image (0.5-5 keV)



- Extraction of the spectrum of the **entire jet** using the already reprocessed and longest observation, OBSID=14223;
- Extraction of the light curve of the jet: is the emission constant within the observation?
- Spectral analysis of the jet with XSPEC. Definition of the best data model: parameter uncertainties, confidence (68%, 90%, 99%) contour plots, flux and luminosity.

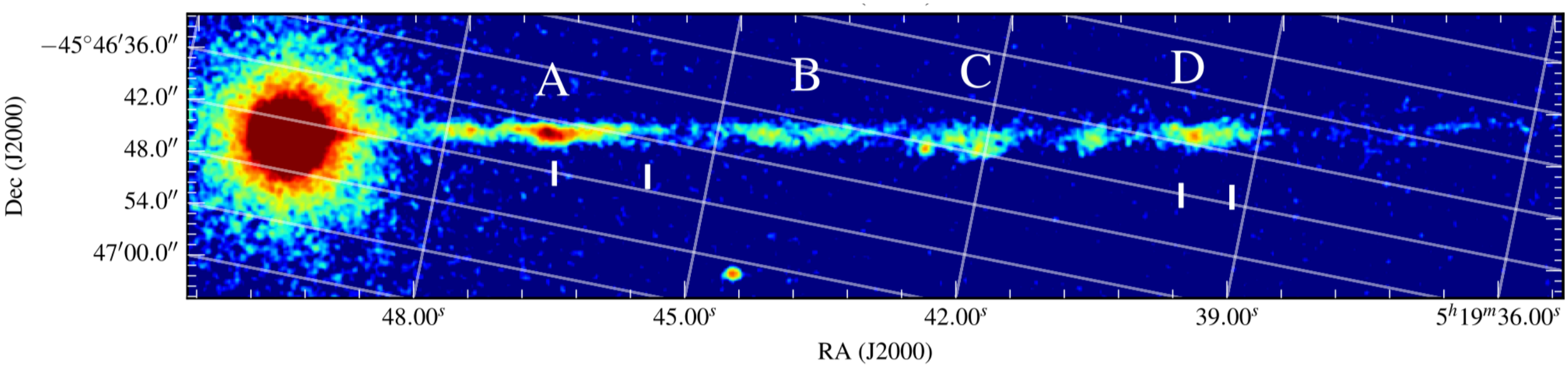
X-ray analysis of the Western hot spot



- Extraction and analysis of the light curve of the hot spot (position and size - elliptical vs. circular - provided to the students)
- Extraction of the spectrum of the hot spot (+rmf and arf)
- Spectral analysis with XSPEC. Definition of the best data model: parameter uncertainties, confidence (68%, 90%, 99%) contour plots, flux and luminosity;

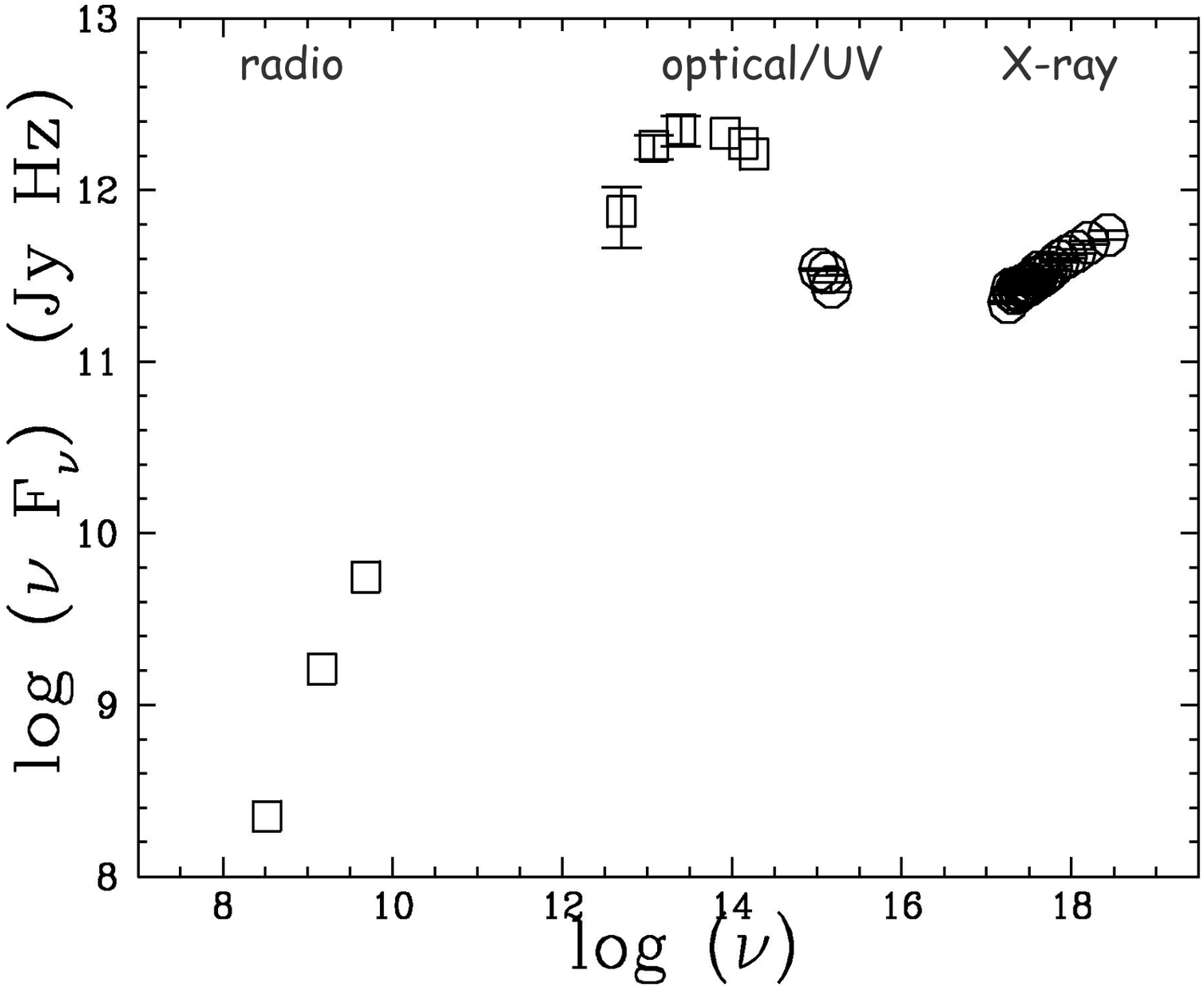
see http://adsabs.harvard.edu/abs/2016MNRAS.455.3526H

Optional (1): analysis of the jet knots



- Localization of knots A, B, C, D using the X-ray mosaic;
- Extraction of the spectrum of **knot A** (the brightest one) from the observation OBSID=14223 and spectral analysis with XSPEC (see above).

Optional (2): spectral energy distribution (SED of the hot spot)



Radio Data

SED HOT SPOT PICTOR A

λ (cm)	Flux (Jy)
2	1.6
3.6	1.5
6	2.1
20	5.3
90	16

HST Data

$\lambda(\mathring{A})$	$Flux(\mu Jy)$
2900	30
6130	104

We will give you more datapoints and/or the link to the website where you can retrieve them

Infrared

Meisenheimer et al. 1989 A&A 219,63

Table 2. Hot spot photometry at optical, near-infrared and millimetre wavelengths

Hot spot	λ [μm]	ν [Hz]	S_ν(obs) [μJy]	S_ν(corr)[a] [μJy]	Remarks
Pic A west	0.45	$6.67\,10^{14}$	68 ± 7		from Paper III
	0.67	$4.48\,10^{14}$	130 ± 15		$A_V = 0.00 \pm 0.03$
	1.25	$2.40\,10^{14}$	126 ± 25		
	1.63	$1.84\,10^{14}$	165 ± 43		
	2.20	$1.36\,10^{14}$	223 ± 35		

[a] Corrected for galactic extinction: The extinction E_{B-V} is taken from the maps of Burstein & Heiles (1982). We assume the standard extinction law given by Savage & Mathis (1979) with $A_V = 3.1E_{B-V}$.
[b] The value at $b_{II} = -10°$ is extrapolated to $b_{II} = -8.8°$ by using the HI column from Weaver & Williams (1973).

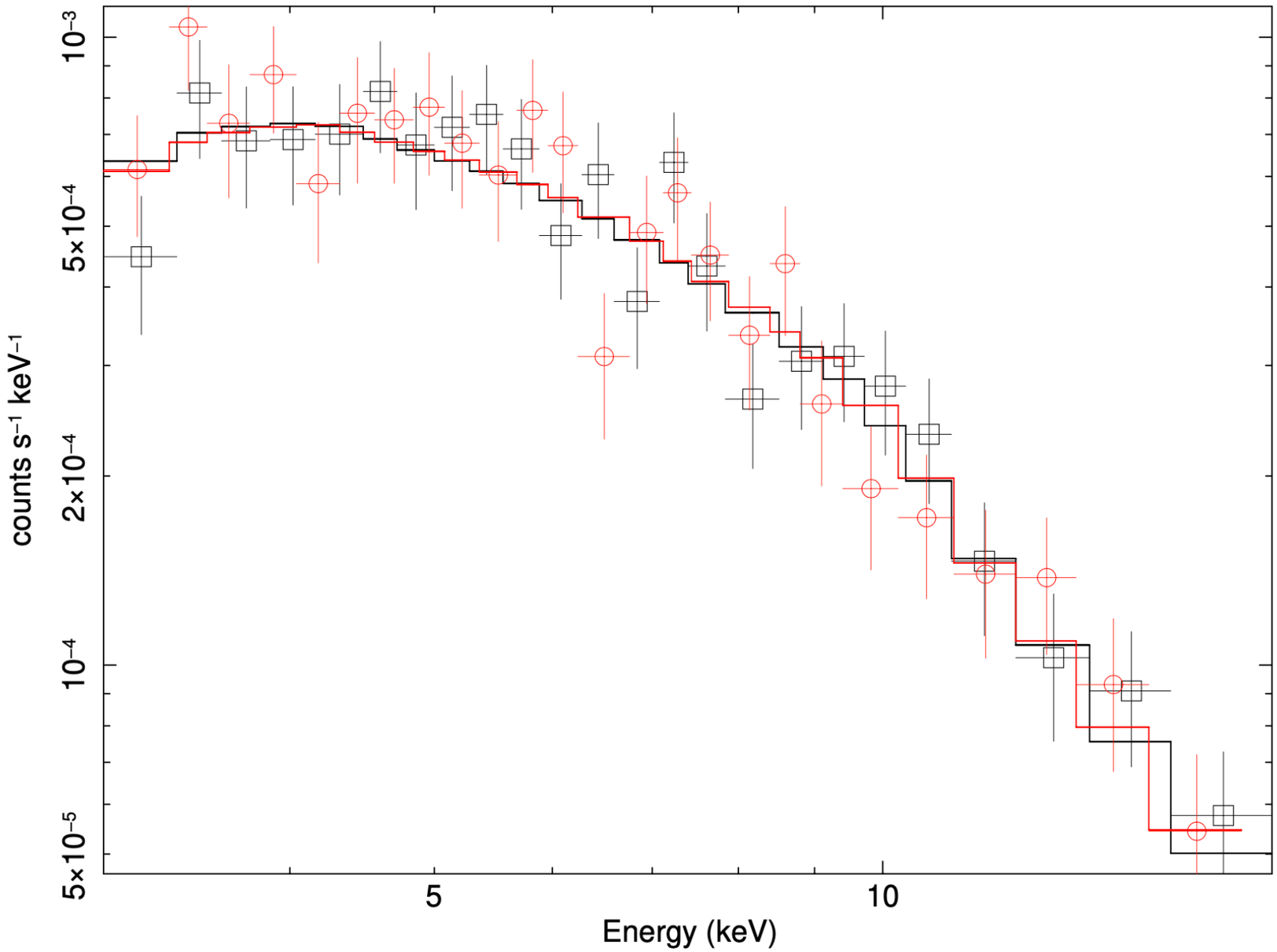
Table 1
WISE Properties of the West Hot Spot of Pictor A

Band	λ (μm)[a]	SN[b]	m (mag)[c]	F_ν (mJy)[d]	σ_{sys} (mJy)[e]	f_c[f]	f_r[g]
W1	3.35	45.8	13.368 ± 0.024	1.39 ± 0.03	0.03	0.992	1
W2	4.60	50.2	12.324 ± 0.022	2.02 ± 0.04	0.06	0.994	1
W3	11.56	35.7	9.569 ± 0.03	4.60 ± 0.13	0.21	0.937	1
W4	22.09	13.1	7.215 ± 0.083	9.98 ± 0.76	0.57	0.993	0.92

Notes.
[a] The isophotal wavelength of the *WISE* photometric band.
[b] The signal-to-noise ratio.
[c] The source magnitude in the Vega unit.
[d] The corresponding flux density.
[e] The systematic error of the *WISE* photometry (Jarrett et al. 2011).
[f] The color-correction factor for $\alpha = 1$.
[g] The additional correction factor for red sources (see Wright et al. 2010).

Isobe et al 2017
The Astrophysical Journal, 850:193 (7pp), 2017

Optional (3): NuSTAR spectral analysis of the Western hotspot



- Perform an X-ray spectral analysis using the already extracted FPMA and FPMB (two cameras) NuSTAR spectra of the hotspot. Derive main parameters including errors and contour plots.
- Compare the results vs. those in Sunada+22 and - if already obtained - with Chandra's.

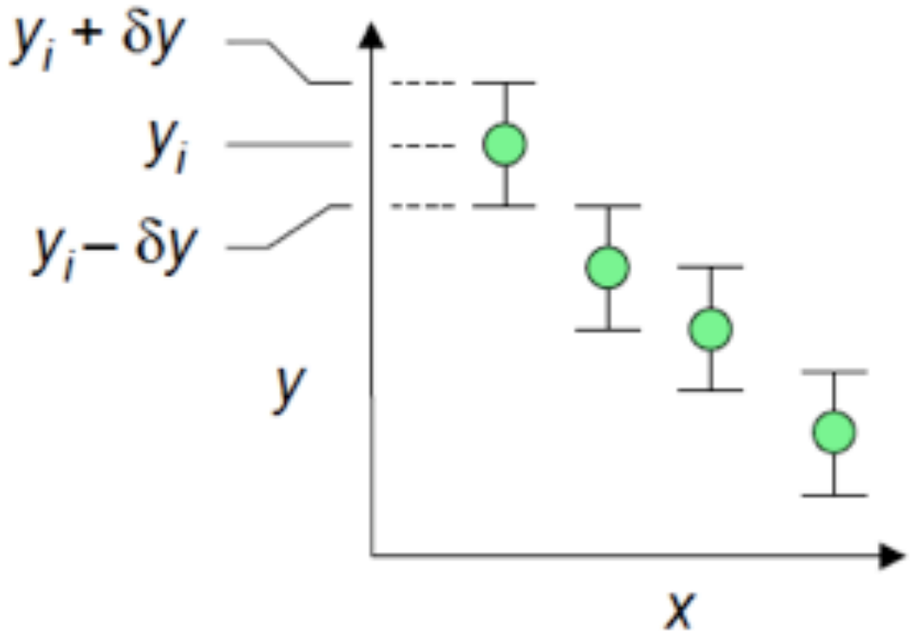
References

- Wilson et al. 2001, ApJ 547, 740
- Marshall et al. 2010, ApJL 714, 213
- Hardcastle et al. 2016, MNRAS 455, 3526
- Sunada et al. 2022, PASJ, 74, 602 (NuSTAR)

Logarithmic Error Bars

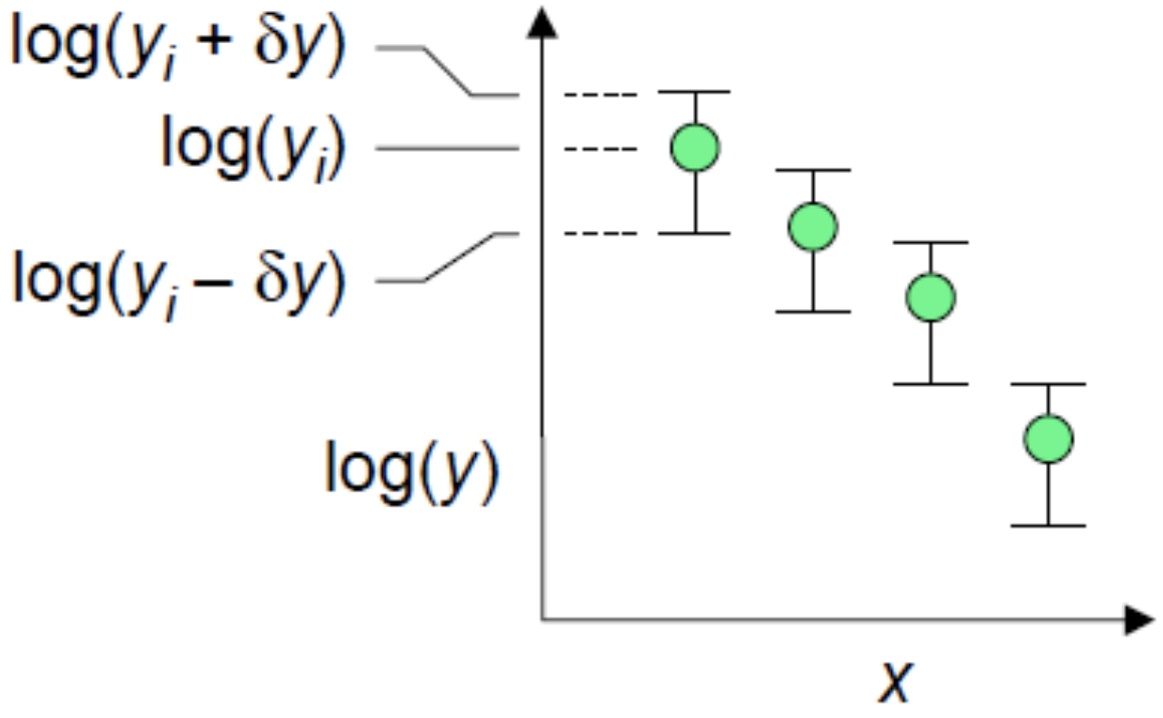
- Suppose that one has a sufficient number of measurements to make an estimate of a measured quantity y and report its error, $\pm \delta y$.

- The error, $\pm \delta y$, is represented on a Cartesian plot by extending lines of the appropriate size above and below the point y.



log Error Bars (cont.)

- If plotted on a logarithmic plot, however, this practice leads to asymmetric error bars.



log Error Bars (cont.)

- On the assumption of small errors, a differiential analysis can be used

$$\delta z \approx dz = d\left[\log(y)\right] = \frac{1}{2.303}\frac{dy}{y} \approx 0.434\frac{\delta y}{y}$$

- The error δz is thus given by the *relative error* in y

$$\delta z \approx 0.434\frac{\delta y}{y}$$

ln(10)