Simultaneous Observations of Radio and X-ray Variability in Radio Quiet Seyfert Galaxies

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The Restless Nature of AGN: 10 years later
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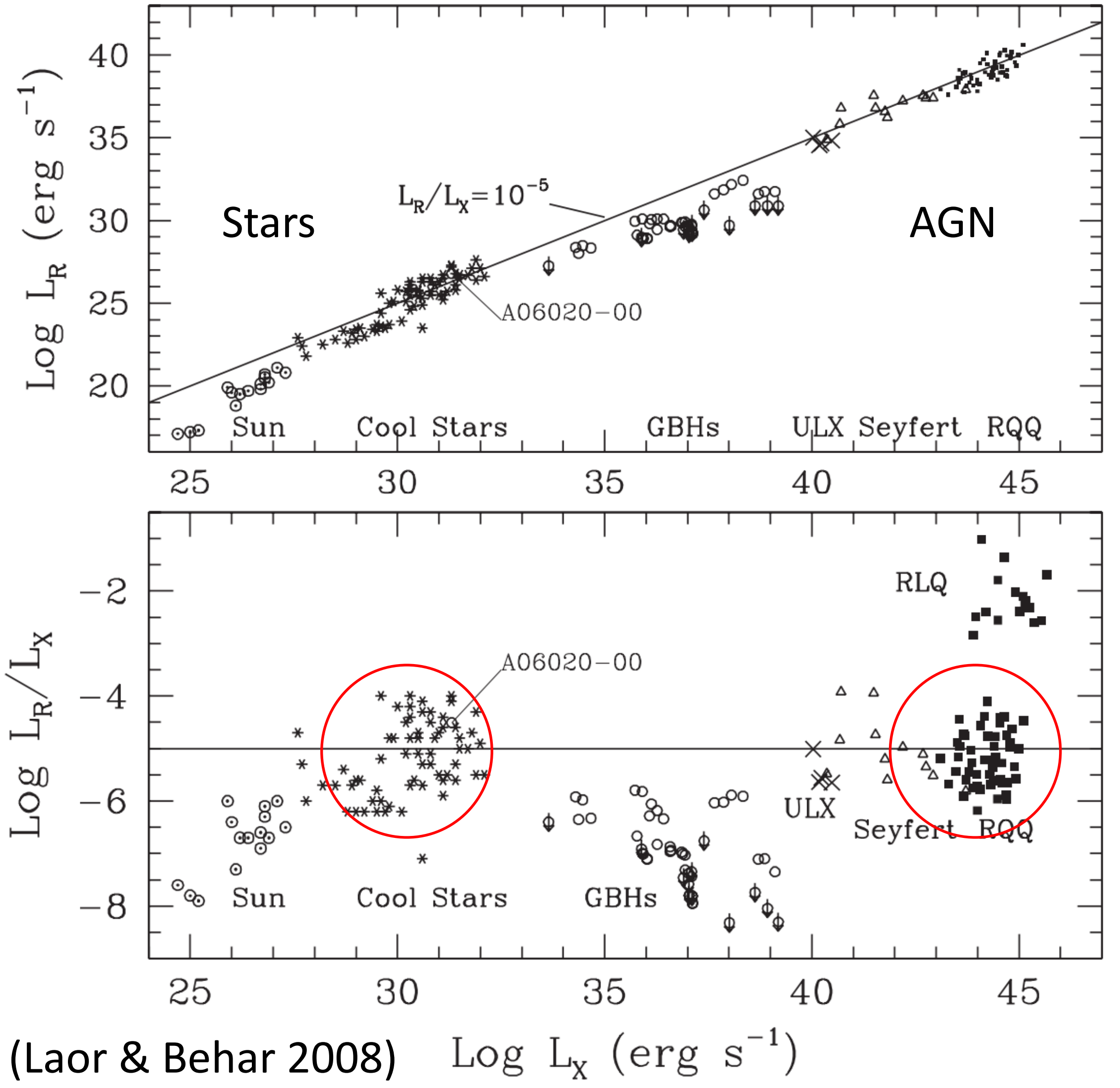
Radio and X-ray correlation

- A similar relation between radio and X-ray luminosities in both coronally active cool stars and RQ AGN

$$L_{\rm R}/L_{\rm X} \sim 10^{-5}$$

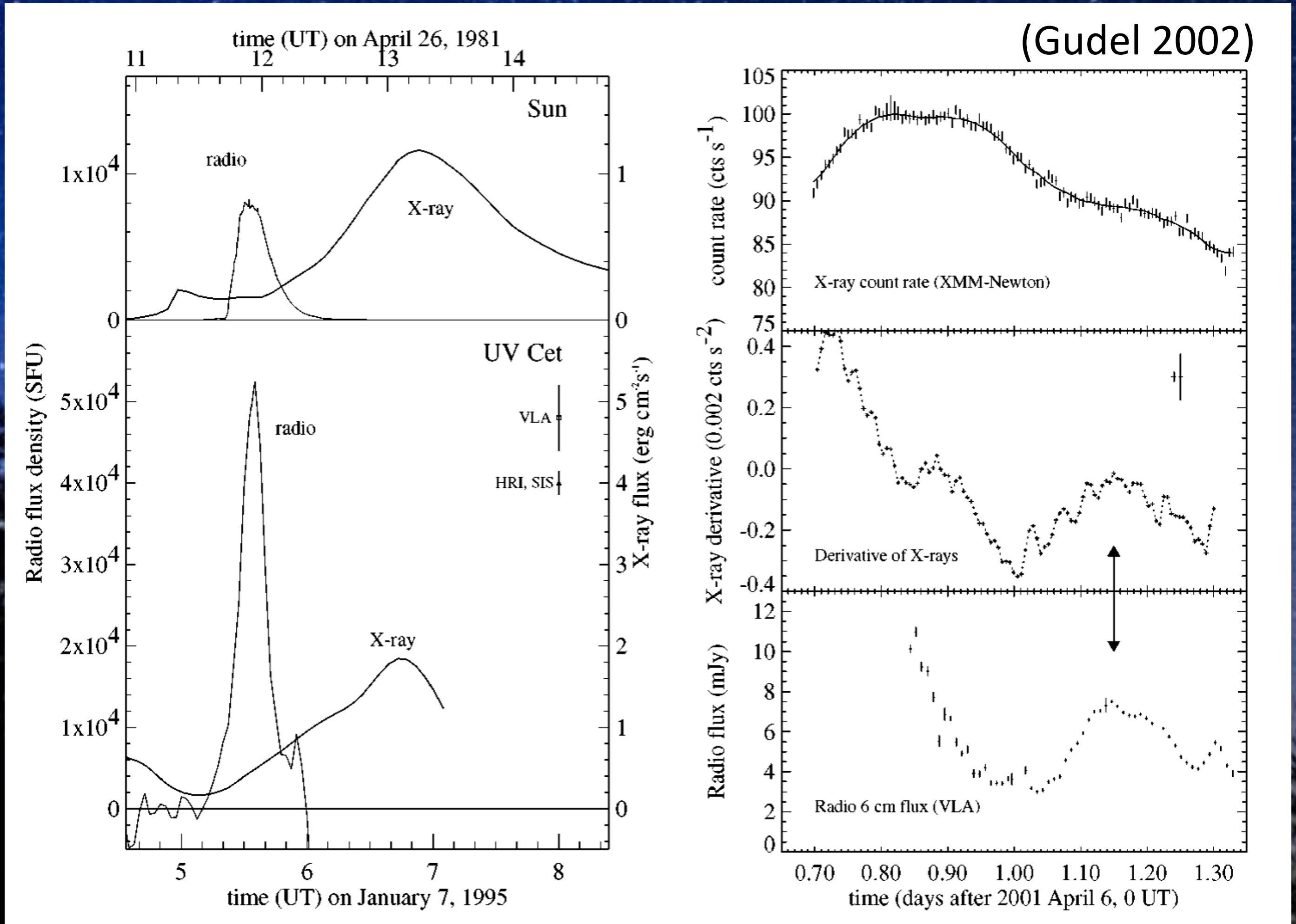
Radio emission from the corona in RQ AGN?



(Laor & Behar 2008)

Radio and X-ray variability in cool stars

The Neupert effect in stellar corona



- A radio flare is followed by a X-ray flare

$$L_{\rm R} \propto \frac{{\rm d}L_{\rm X}}{{\rm d}t}$$

Can we see such an effect in RQ AGN?

Simultaneous radio and X-ray monitoring

Three RQ Seyfert galaxies:

Mrk 110 (z=0.035), Mrk 766 (z=0.013), NGC 4593 (z=0.009)

Radio observation:

- VLA with A/B/D configurations at 8.5 GHz
- ~ 60 pointings over ~ 200 days

X-ray observation:

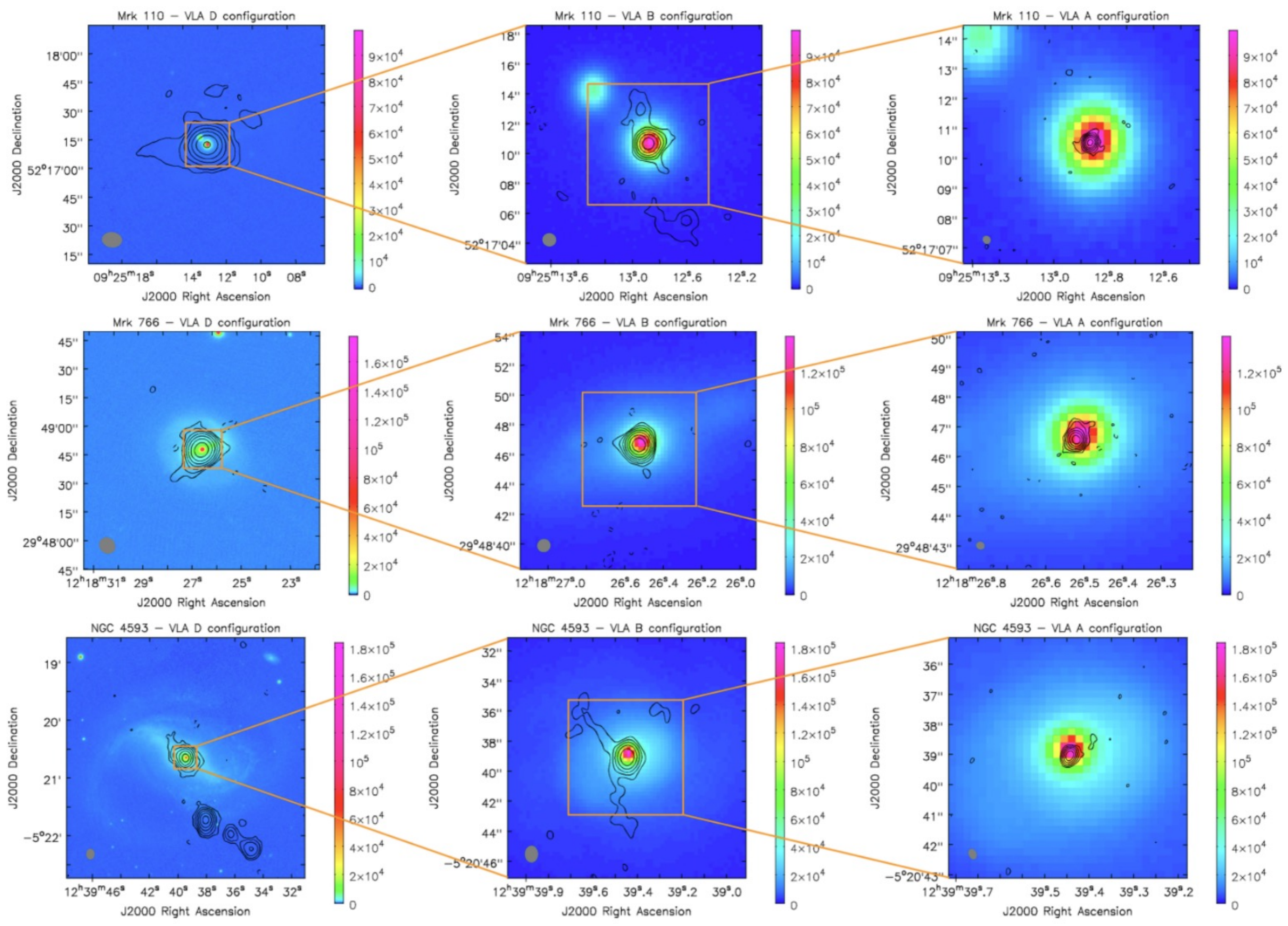
- Rossi X-ray Timing Explorer (RXTE) at 2-10 keV
- pointings every ~ 2-3 days over 6 years

Pan-STARRS color + VLA contour images

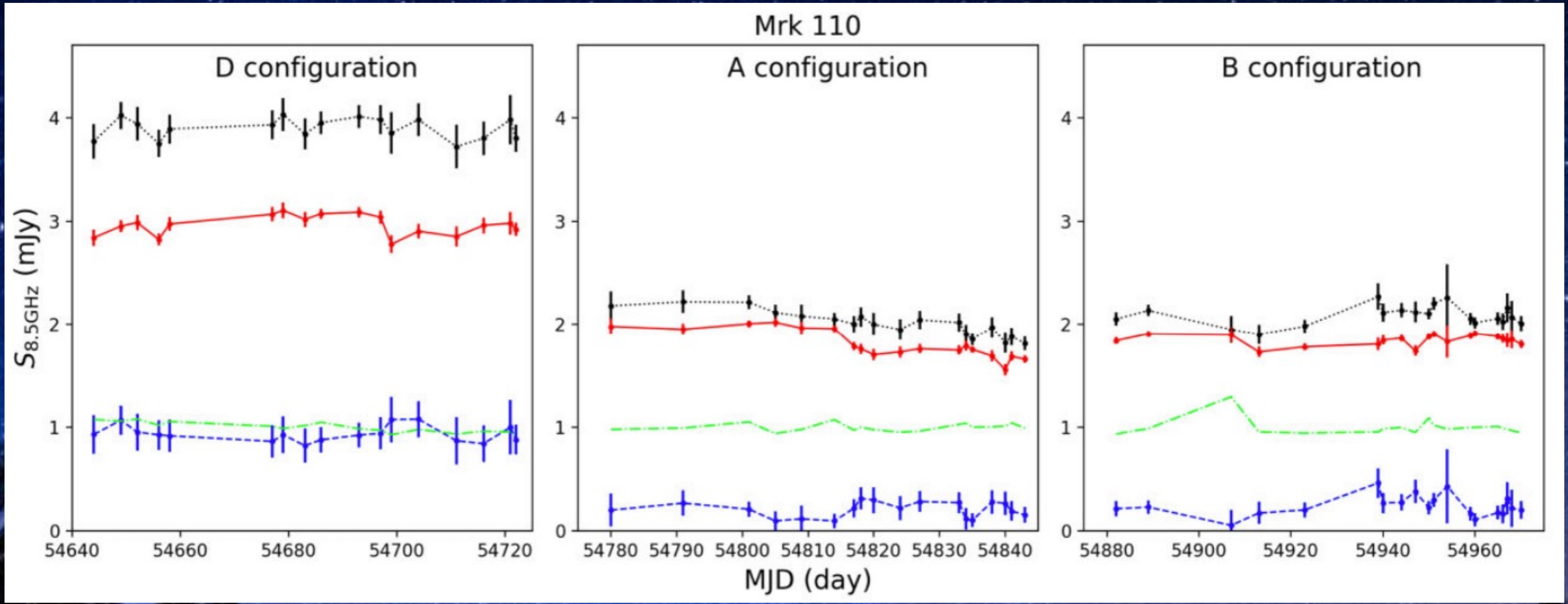
Mrk 110

Mrk 766

NGC 4593



Radio light curves of Mrk 110



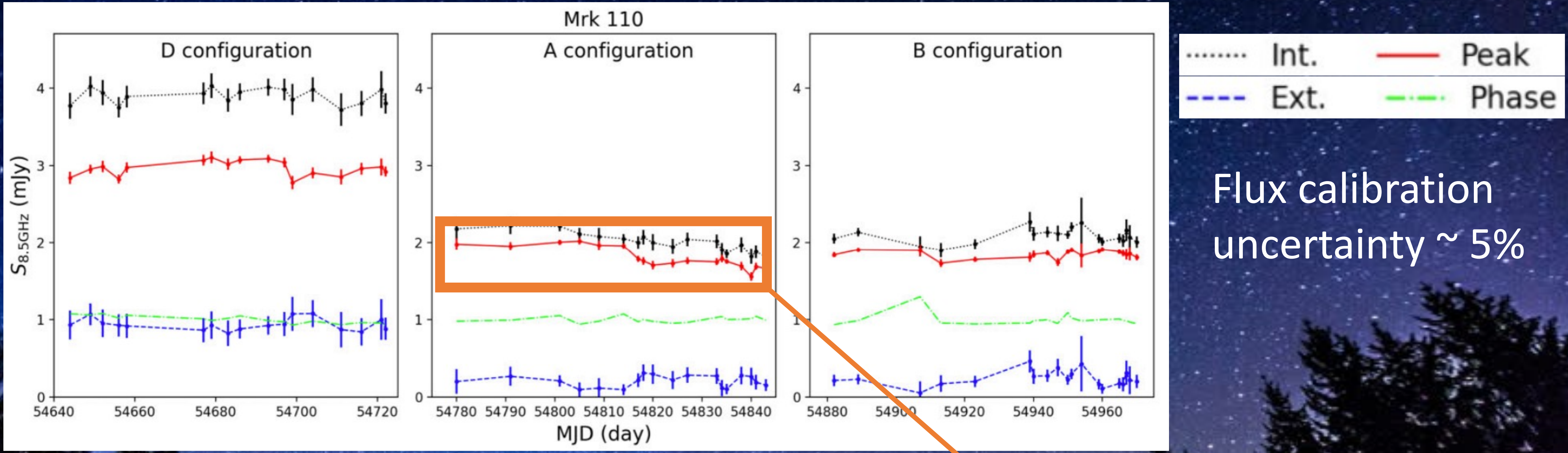
Flux calibration uncertainty ~ 5%

Variability amplitude

$$F_{\rm var} = \frac{\sqrt{\sum_{i=1}^{N}\left[(F_i - \langle F\rangle)^2 - \sigma_i^2\right]/N}}{\langle F\rangle}$$

	D	A	B
Integrated	-	3.0%	-
Peak	1.0%	6.3%	-
Extended	-	-	-

Radio light curves of Mrk 110

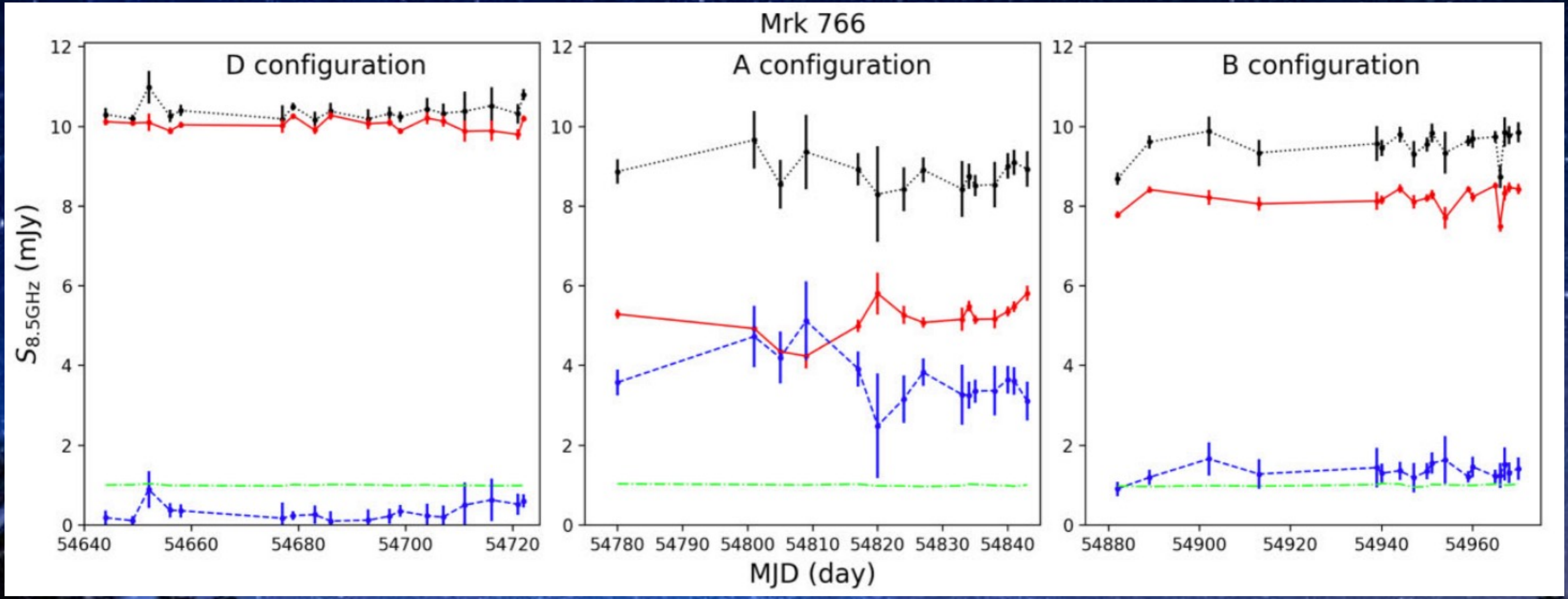


Flux calibration uncertainty ~ 5%

Variability detected!

	D	A	B
Integrated	-	3.0%	-
Peak	1.0%	6.3%	-
Extended	-	-	-

Radio light curves of Mrk 766

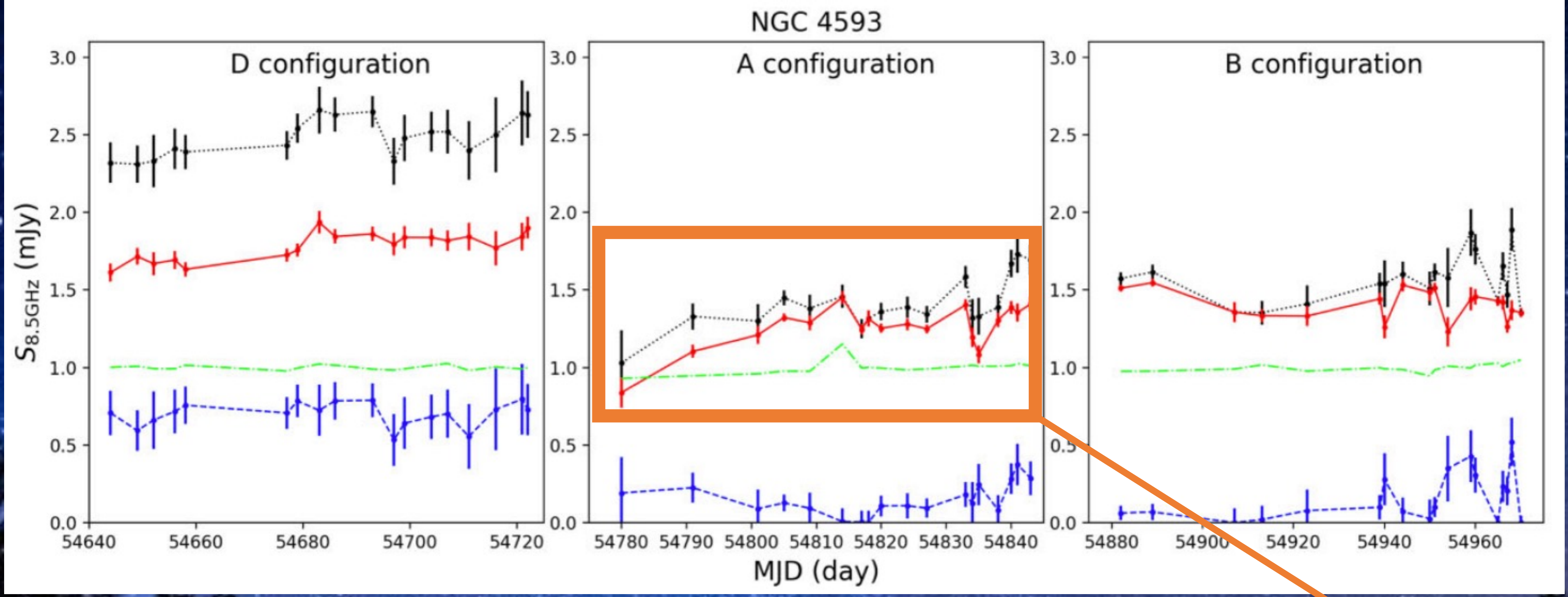


Flux calibration uncertainty ~ 5%

No variability!

	D	A	B
Integrated	-	-	1.7%
Peak	-	4.5%	2.5%
Extended	-	-	-

Radio light curves of NGC 4593

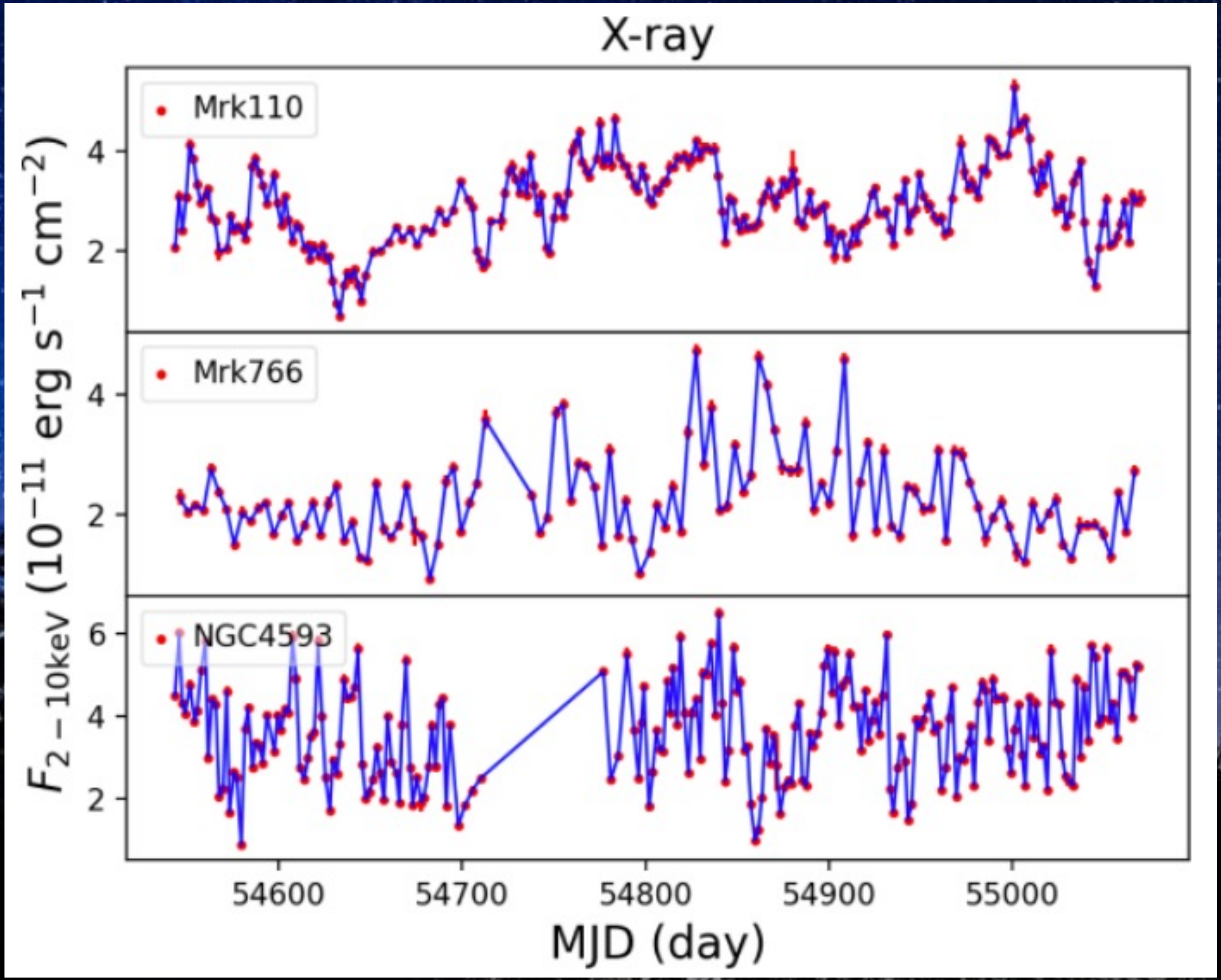


Flux calibration uncertainty ~ 5%

Variability detected!

	D	A	B
Integrated	-	9.0%	~~6.9%~~
Peak	1.9%	9.5%	4.2%
Extended	-	-	58.7%

X-ray light curves



$$F_{var} = \frac{\sqrt{\sum_{i=1}^{N}\left[(F_i - \langle F\rangle)^2 - \sigma_i^2\right]/N}}{\langle F\rangle}$$

Mrk110: 26.1%

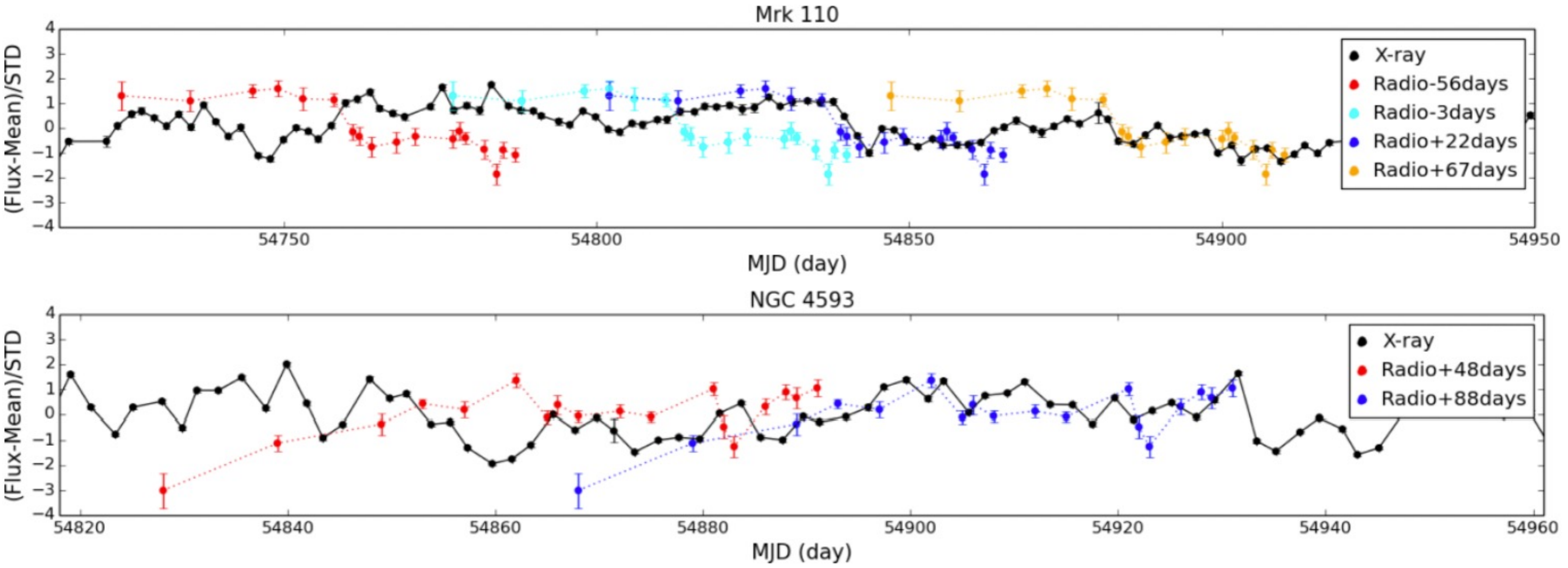
Mrk766: 32.3%

NGC4593: 31.9%

Radio versus X-ray delay

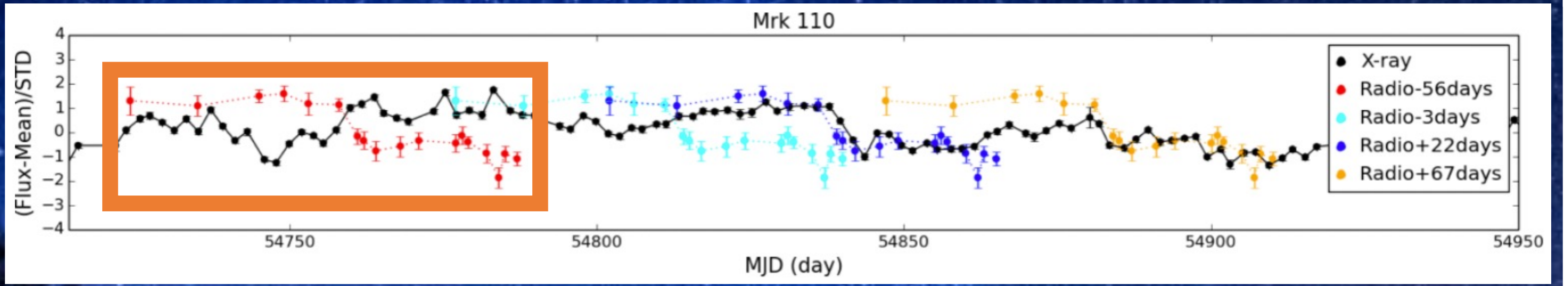
Pearson cross-correlation

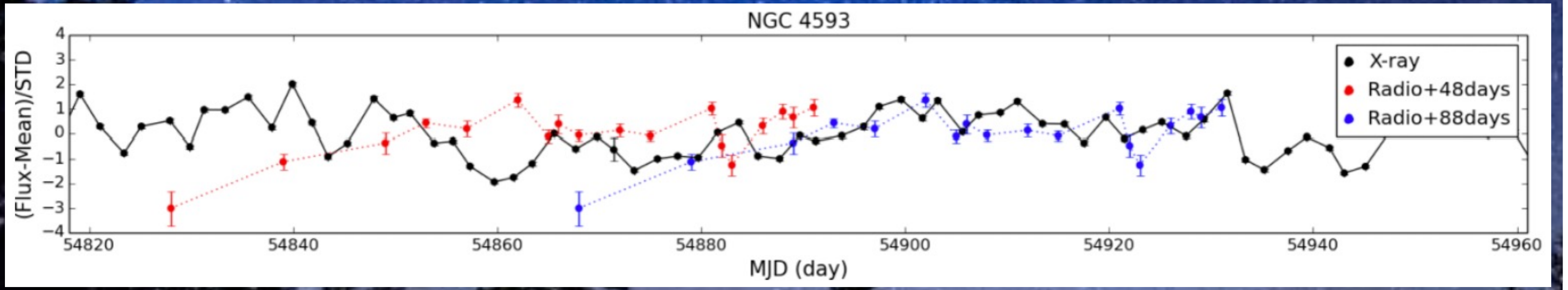
A time window of -100 and +100 days and a time step of one day



Radio versus X-ray delay

Is the correlation really highly significant?





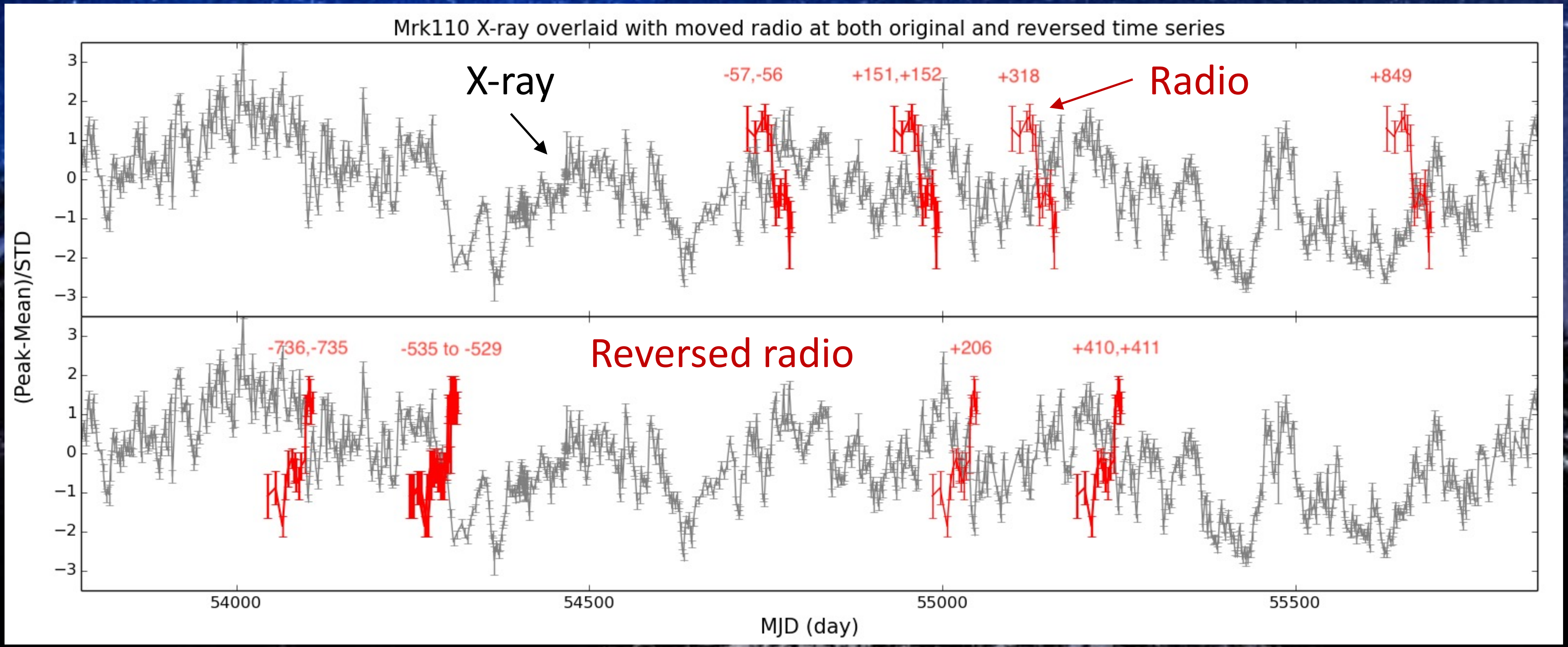
	Time lag (day)	*r*-value	*p*-value
Mrk 110	-56	-0.89	1.0×10^{-6}
	-3	-0.61	7.3×10^{-3}
	+22	0.74	4.7×10^{-4}
	+67	0.75	3.0×10^{-4}
NGC 4593	+48	-0.60	8.2×10^{-3}
	+88	0.59	9.5×10^{-3}

Positive time lags mean that the X-ray light curve lags the radio one, and vice versa.

Are the delays significant?

Look for delays over 6 years

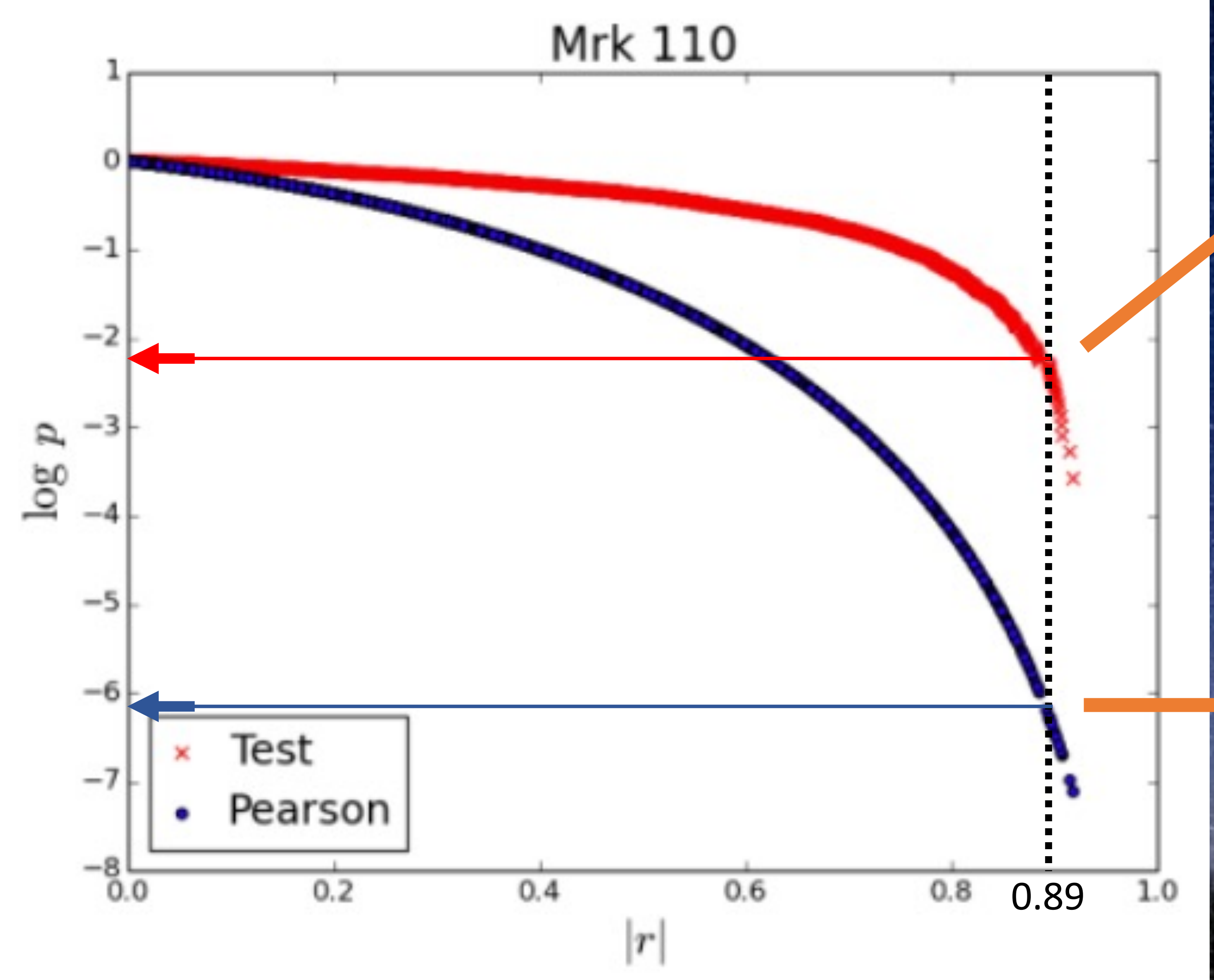
X-ray light curve ~ 2000 days



There are 20 possible delays with $|r| \geq 0.89$ *apparently highly significant*

Something is clearly wrong!

The $p(r)$ distribution for uncorrelated light curves



Observed:

$$p(r) = \frac{20}{3800} = 0.5\%$$

A factor of ~ 10^3 higher

Theorical (Pearson):

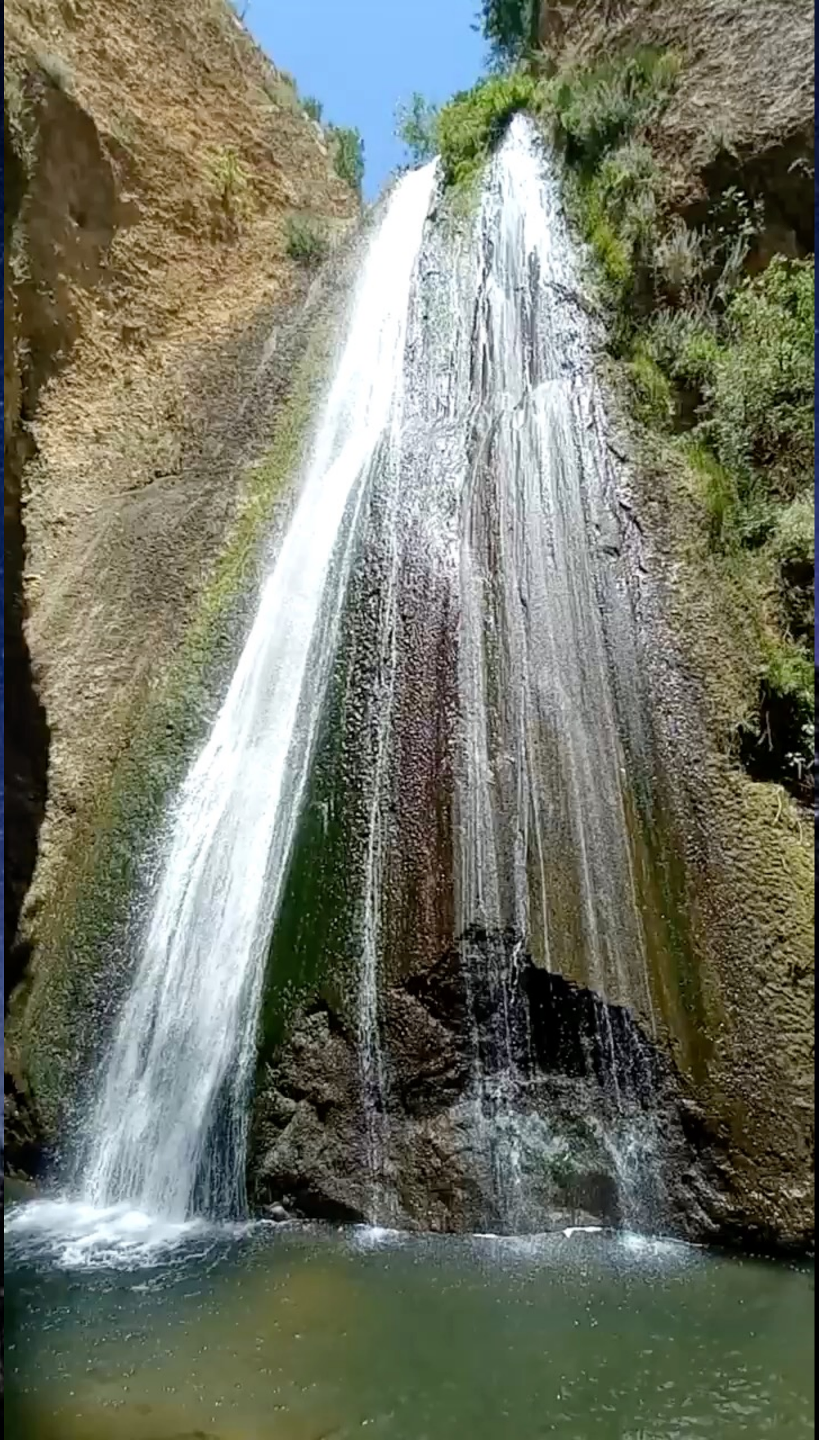
$p(r) = 1.0 \times 10^{-6}$

Why does the Pearson cross-correlation not yield the true distribution of *p*(*r*) for the physical uncorrelated data sets?

Pearson distribution assumes

- **"white noise"**

A time series of random numbers



Why does the Pearson cross-correlation not yield the true distribution of $p(r)$ for the physical uncorrelated data sets?

Radio and X-ray variability are

❖ **“red noise”**

The variability amplitude increases on longer time scales

Why does the Pearson cross-correlation not yield the true distribution of $p(r)$ for the physical uncorrelated data sets?

Radio and X-ray light curves are roughly
→ A single sinusoidal wave with a random phase

A certain delay when the two light curves are in phase
→ A high $|r|$ value

Conclusion:
Regular correlation cannot apply to test the significance of the correlation for "red noise" spectra (use Monte Carlo simulation).

Summary

- Radio variability observed in Mrk 110 and NGC 4593
- Tentative time lags between radio and X-ray fluxes in Mrk 110
- But the correlation is not significant ("red noise" spectra)

→ Need

1. A high resolution fixed radio array
2. A high sampling rate to resolve the variability

Is there a Neupert effect in RQ AGN?