Long (and short) **term,**
(X-ray/)**optical/UV time-lags in AGN**

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(WORK IN PROGRESS)

In AGN, optical/UV variations are correlated, and are lagging behind the X-ray variations.

But, there are some exceptions.

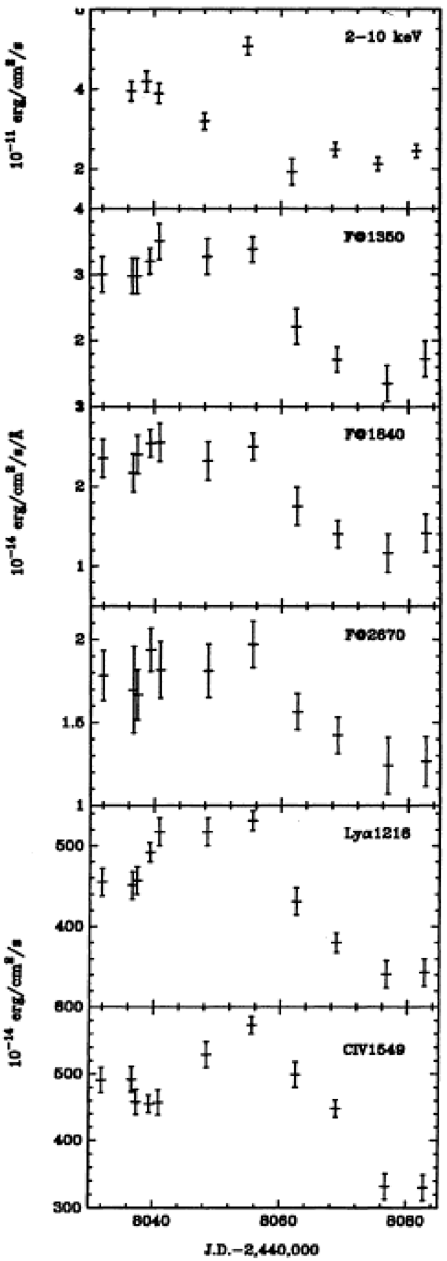


FIG. 1.—*Top to bottom:* light curves of the integrated 2–10 keV flux, the continuum at 1350, 1840, and 2670 Å, and the Lyα λ1216 and C IV λ1549 emission lines. Fluxes are represented with their associated errors.

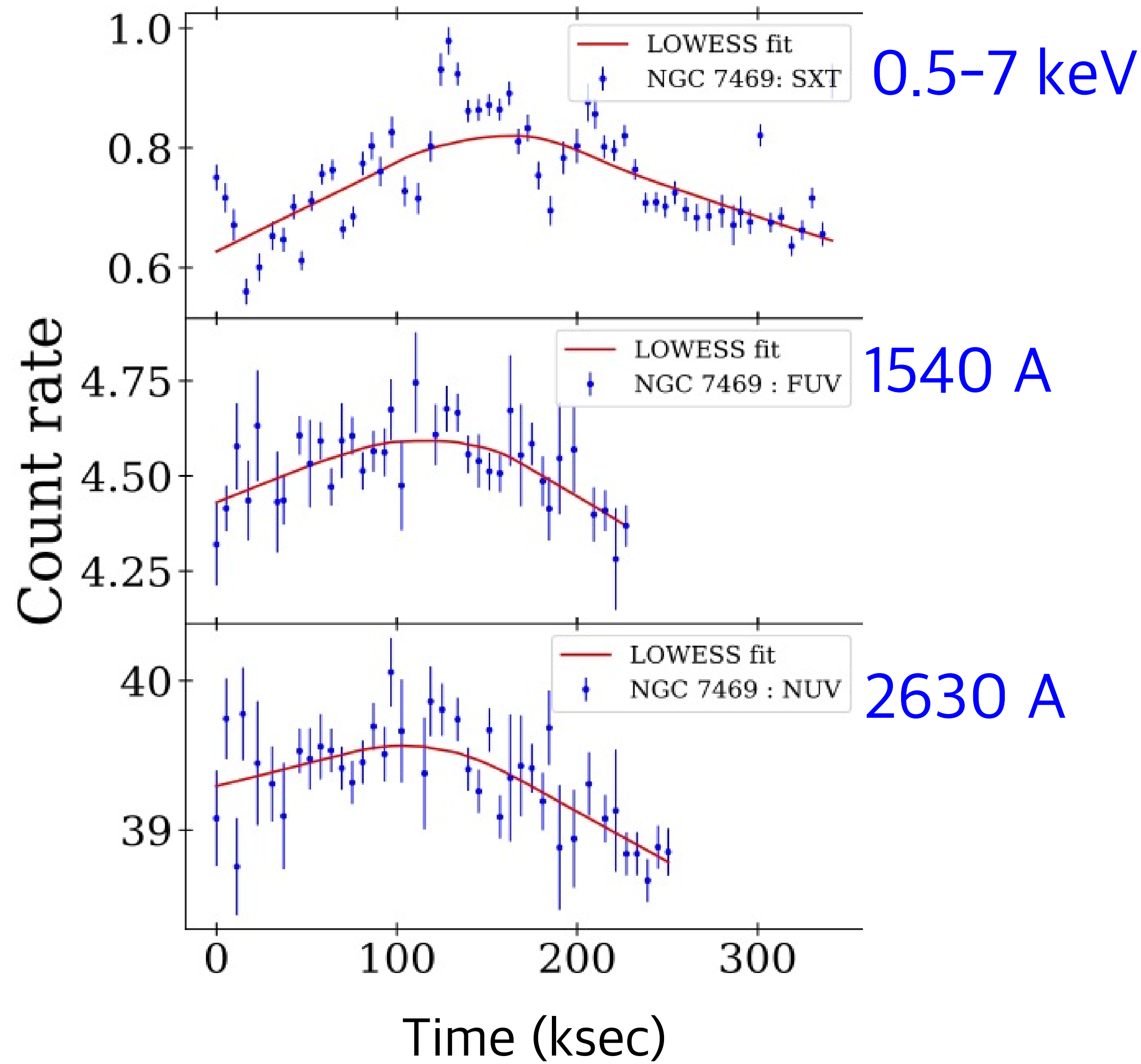
NGC 5548

Clavel et al (1992)

NGC7469

AstroSat observations

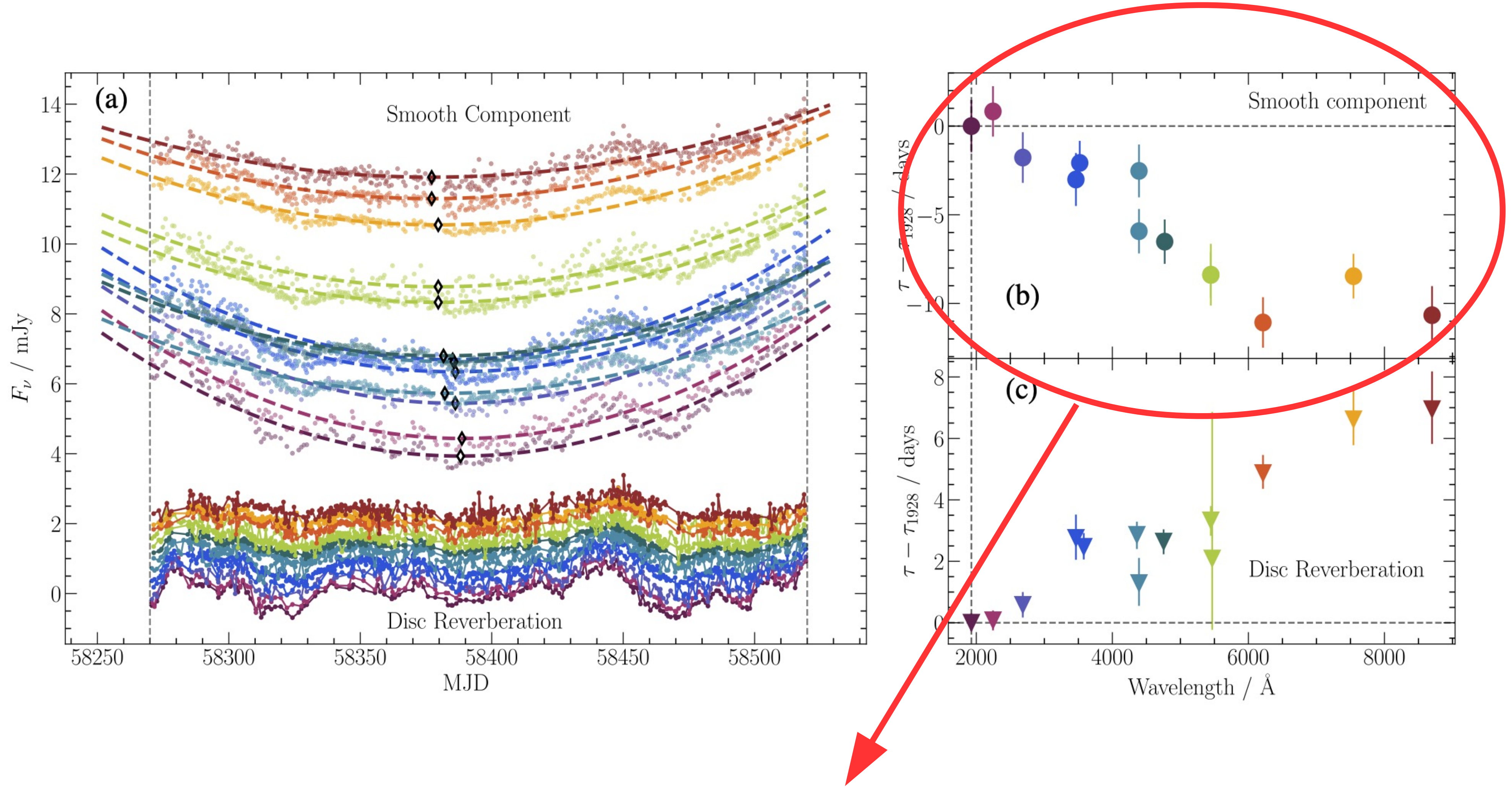
(see also Pahari etal, 2020)



(Kumari et al 2023)

But also Fairall 9

(Santisteban et al, 2020 & Yao et al, 2022)



“Negative” time lags at long time scales

Is there an objective way to measure time lags at long time scales, without assuming (arbitrarily) some function?

We studied "negative", long term time lags, following a simple method:

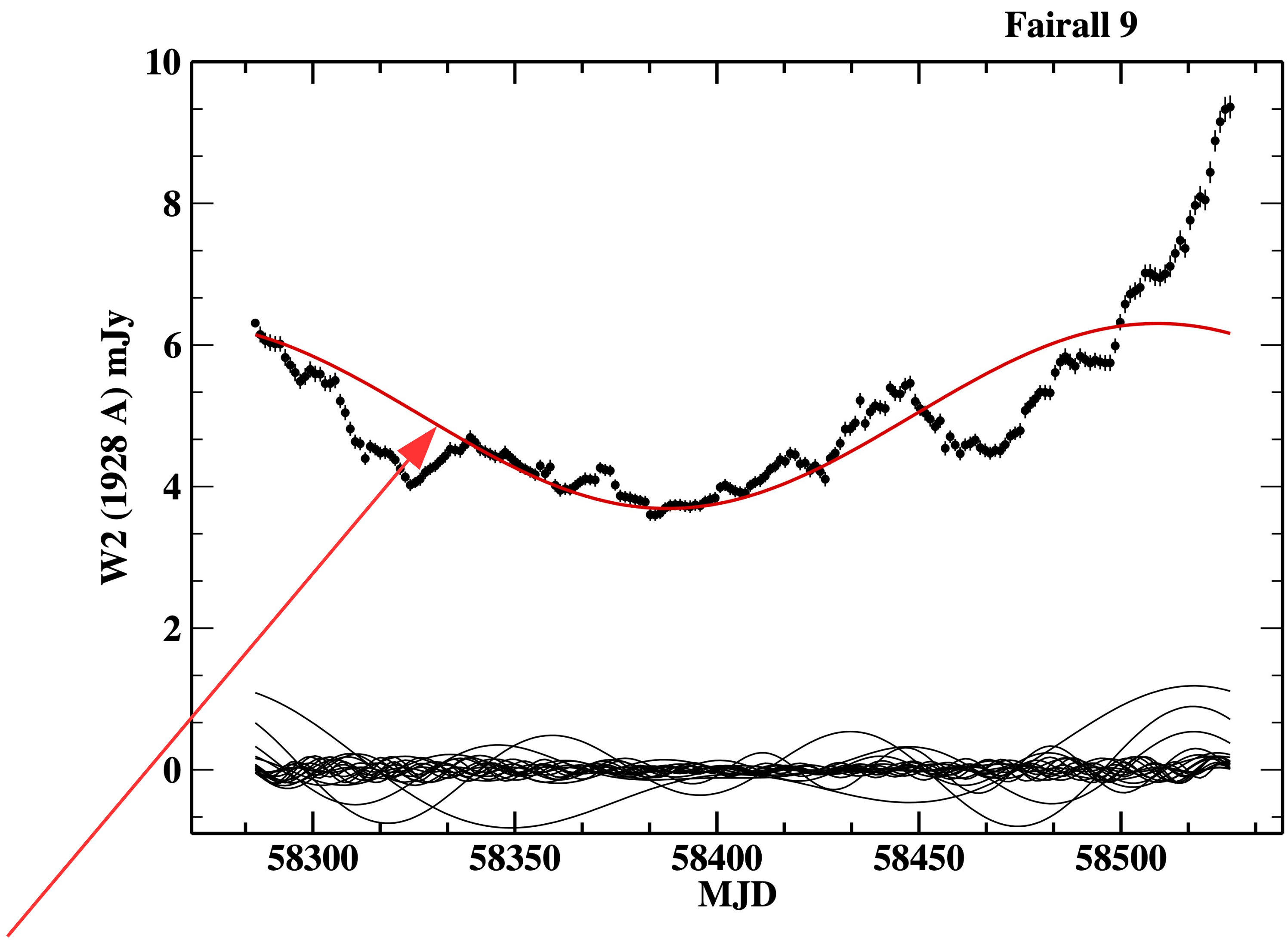
1) Compute the Fourier transform of the light curves in all bands:

$$X_n = \sum_{t=0}^{N-1} x(t) e^{i2\pi t\left(\frac{n}{N}\right)}$$

where $n = -\frac{N}{2}, \ldots, \frac{N}{2}$.

Obviously, the inverse transform gives the original light curve:

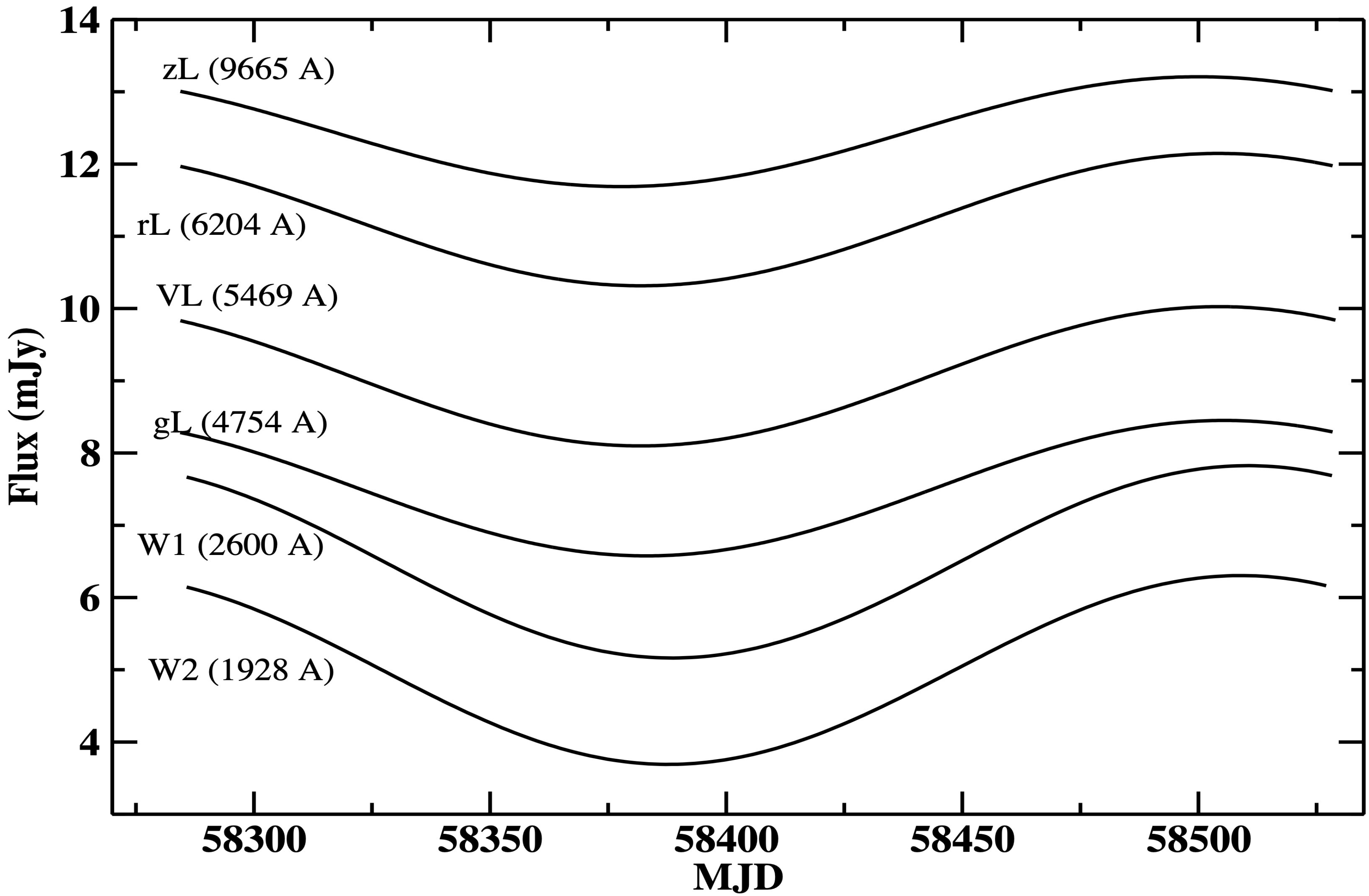
$$x(t) = \frac{1}{N} \sum_{n=-N/2}^{N/2} X_n e^{-i2\pi t\left(\frac{n}{N}\right)}$$



This is the longest Fourier sinusoid that we observe in the W2 light curve.

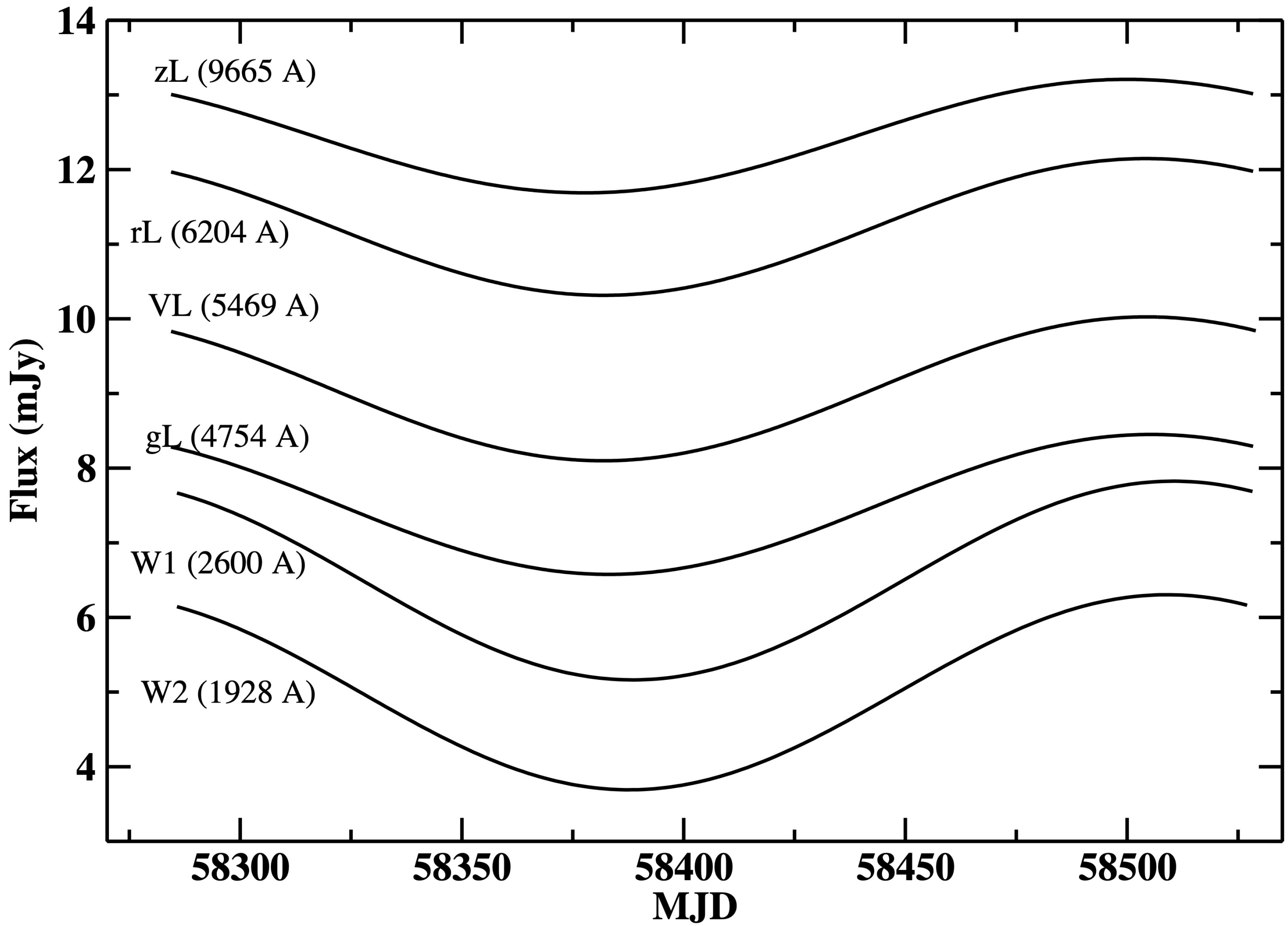
This shows the intrinsic variations that operate on a time-scale of ~250 days in the source.

Fairall 9



In the same way we can determine the longest variations in all wavebands.

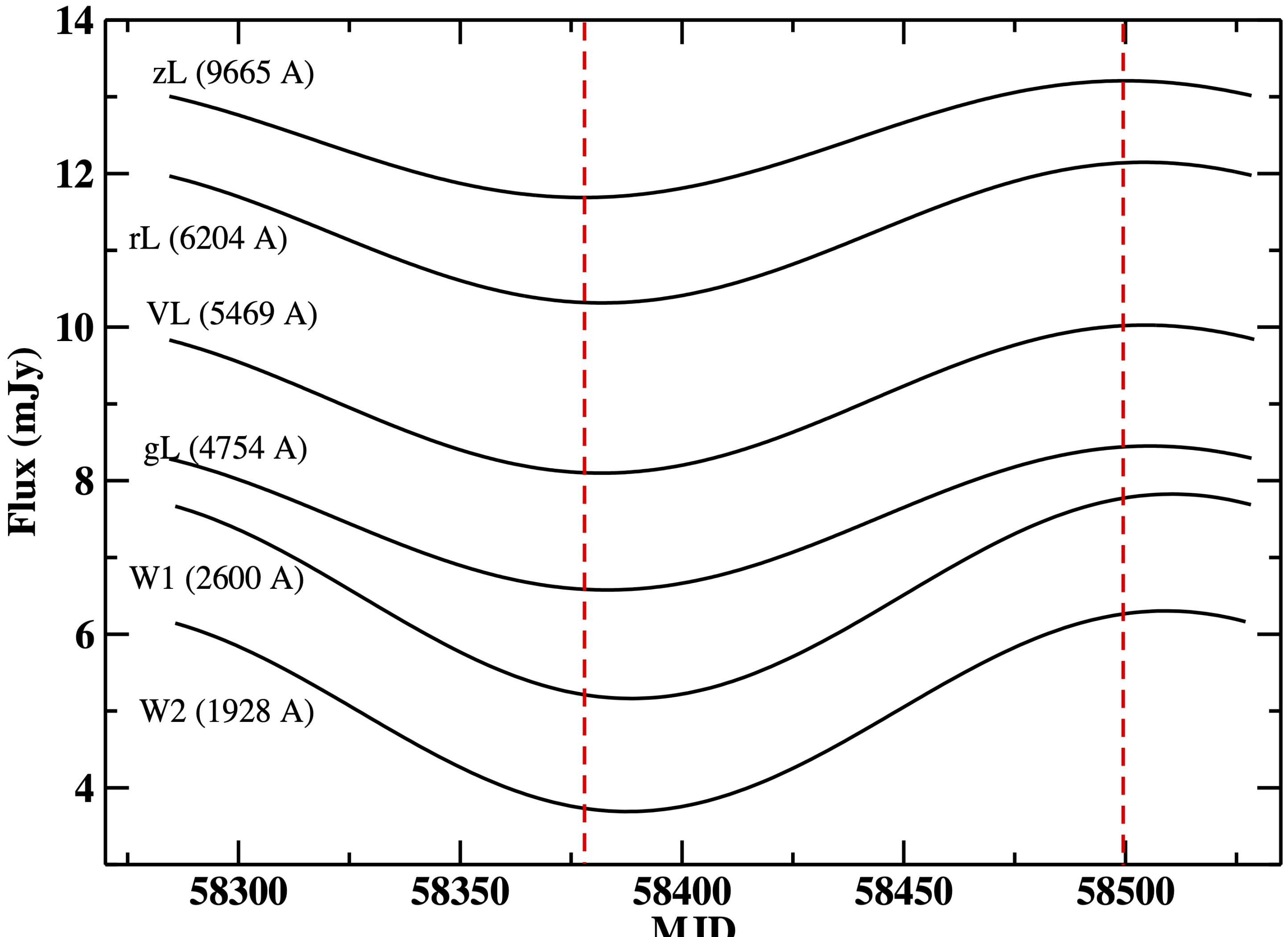
Fairall 9

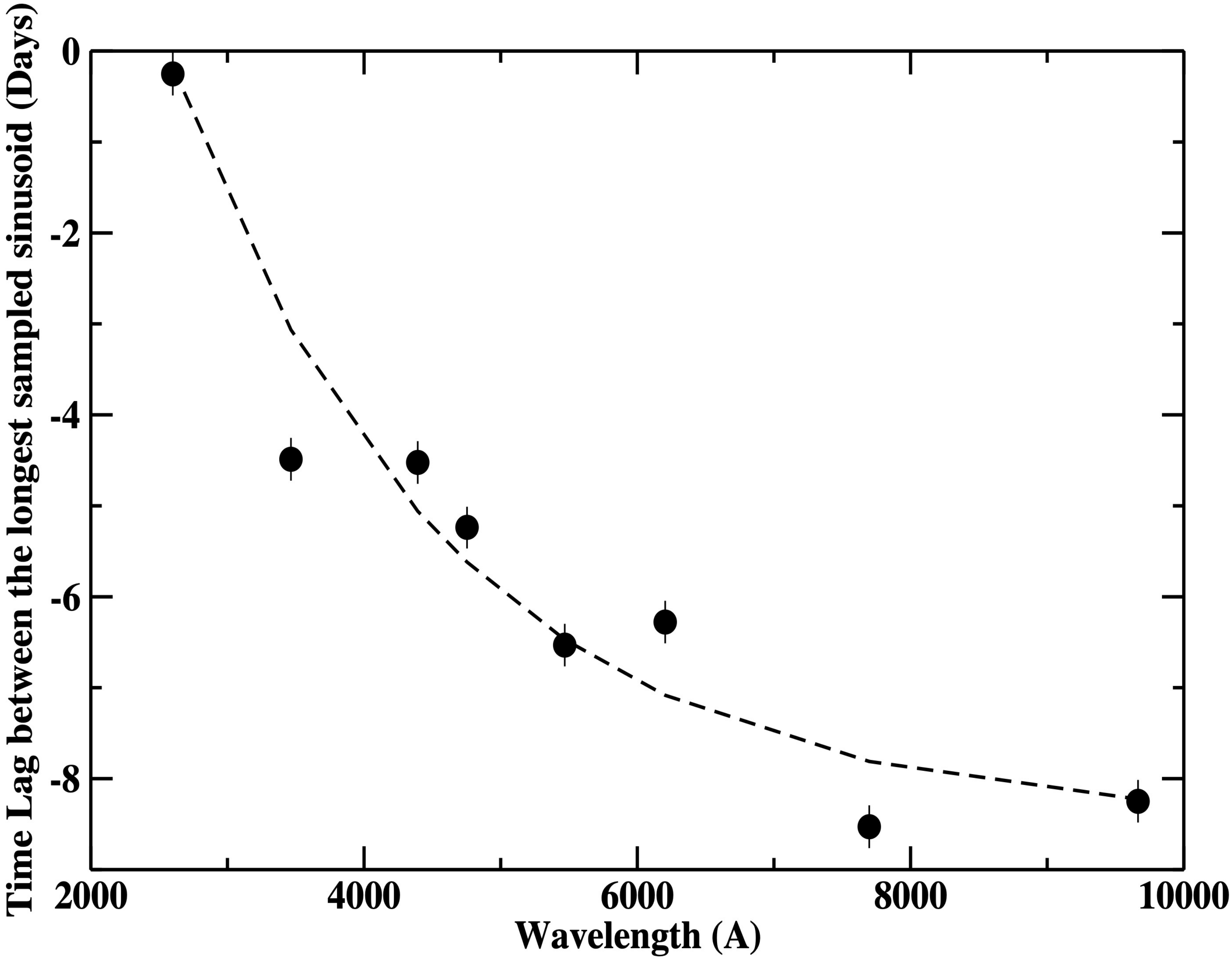


The ~250 day sinusoids appear very similar, in all bands.

The variability amplitude increases from the longest to the shortest wavelength.

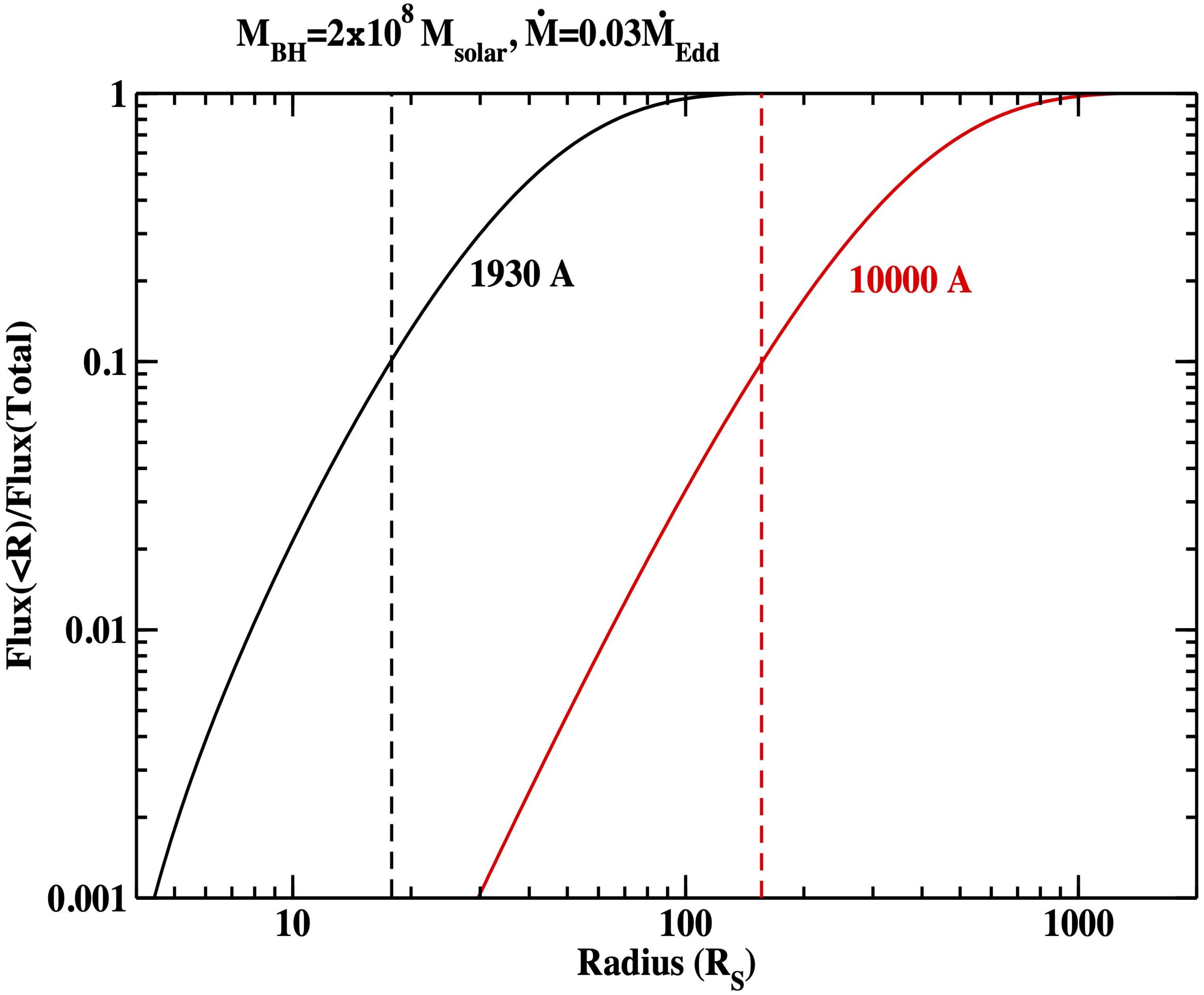
2) We can now compute the cross correlation of the "longest" sinusoids in the light curves to measure the delays and see if they are negative, and how they depend on wavelength.





These are the delays between the longest variations sampled in the light curves ("negative" time lags).

The negative time-lags could be due to accretion rate fluctuations, which propagate from the outer to the inner disc. But we must remember that:



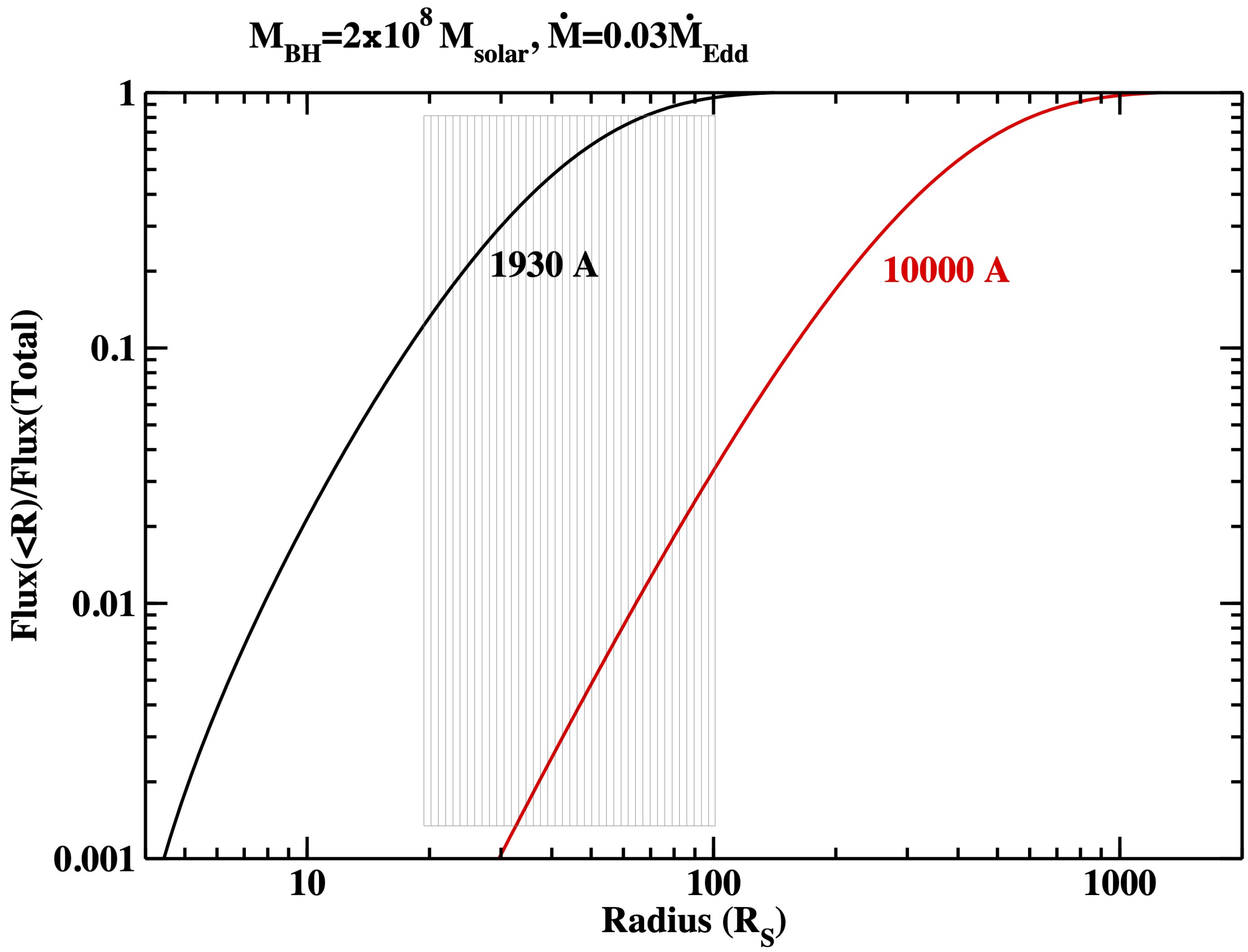
The flux we detect in each filter is emitted from a large area of the accretion disc.

So:

1) What are the variations we detect in the z-band on a time-scale of ~ 250 days?
The viscous time scale at distances larger than ~200 R_S are a few tens of thousand days.

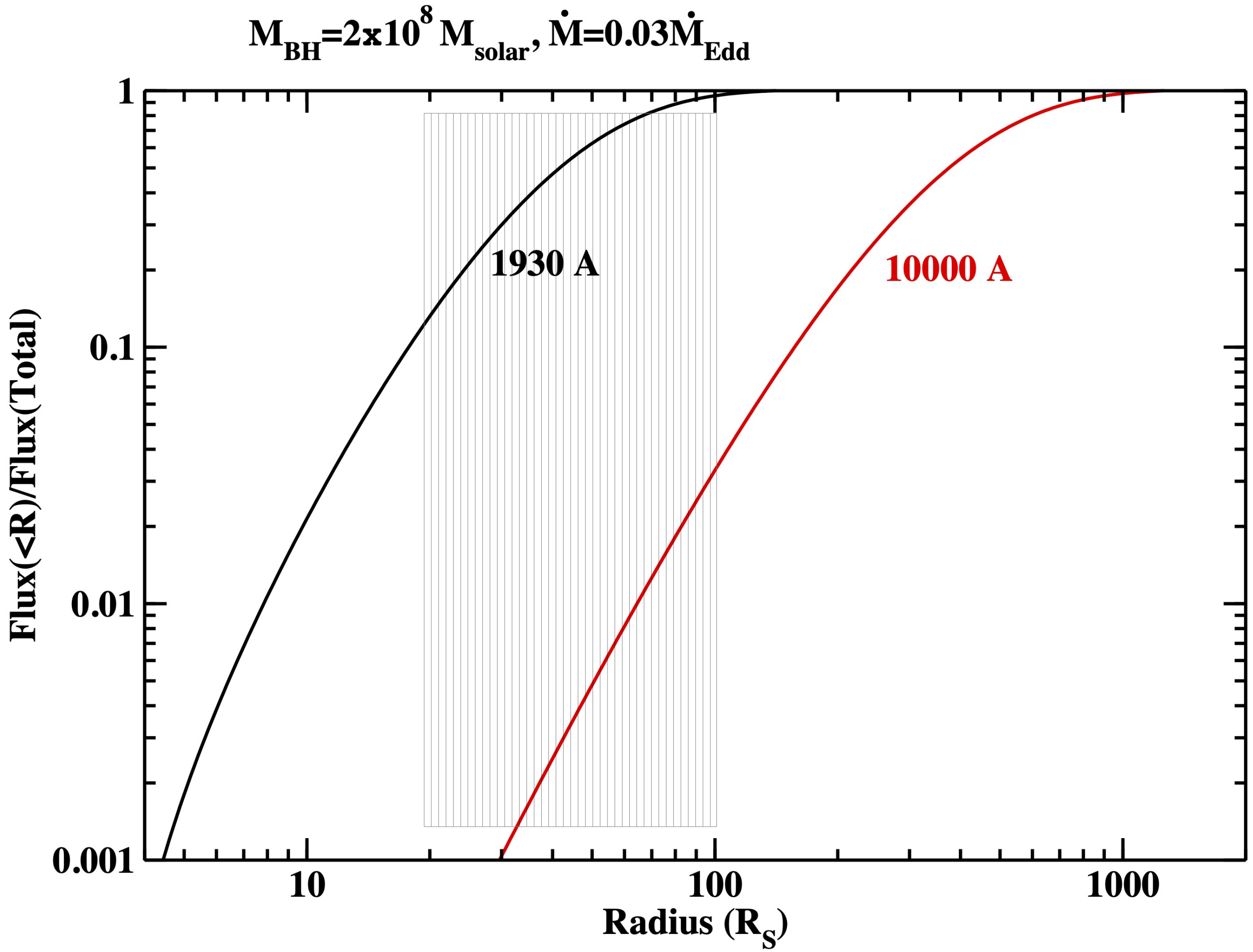
2) If we observe accretion rate variations which propagate from R~250 R_S to ~25 R_S, the timescales of the mass inflow are very long, and the delays should be of the order of thousands of days.

(Perhaps) sinusoids at the same frequency are affected by variations that happen at more or less the same radii:



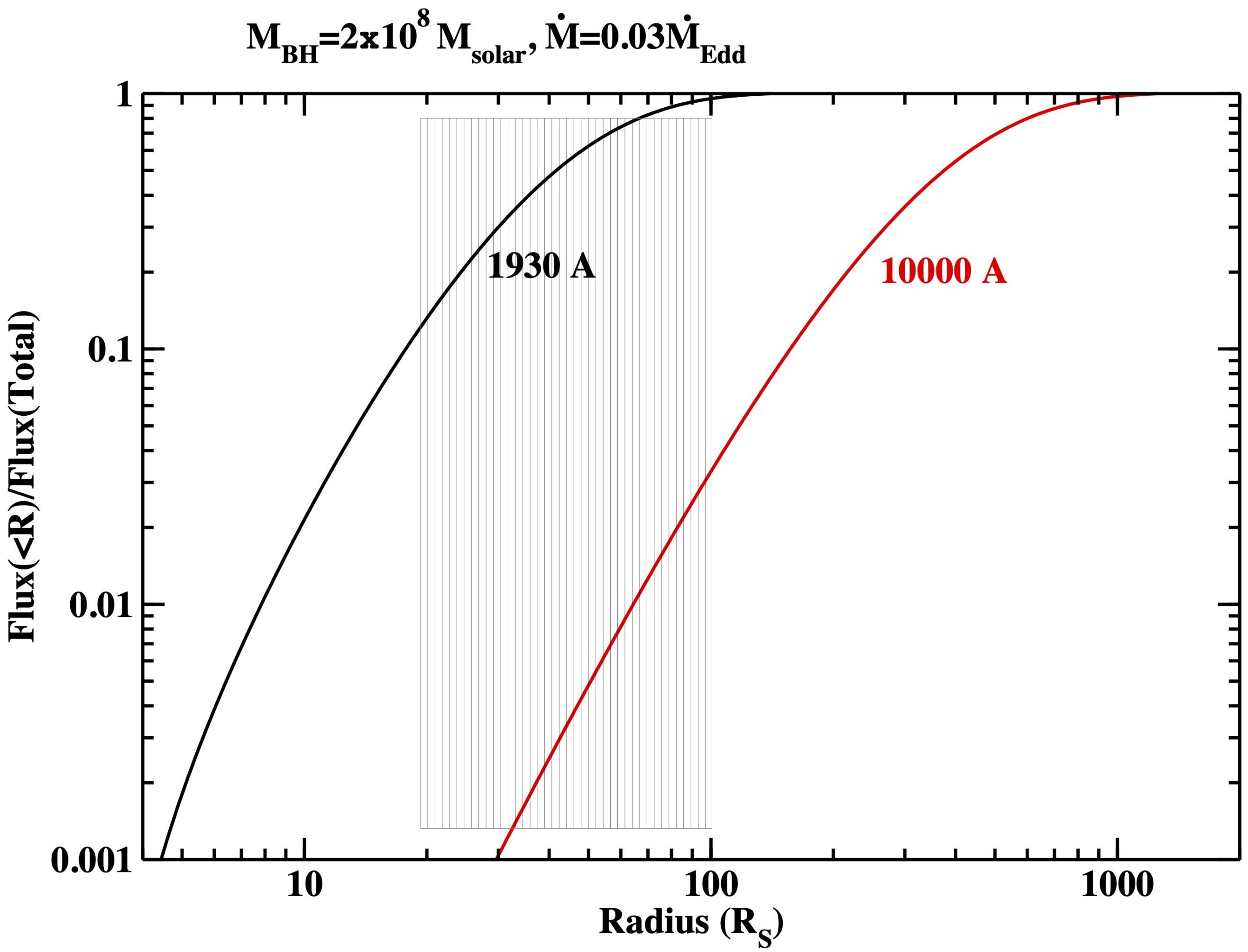
This would explain why the longest Fourier sinusoids are the same in all wavebands, and why the variability amplitude decrease with increasing wavelength.

Variations at larger R either do not propagate inward, or if they do, their period is very long so they cannot affect the sinusoids with periods ~ 250 days.

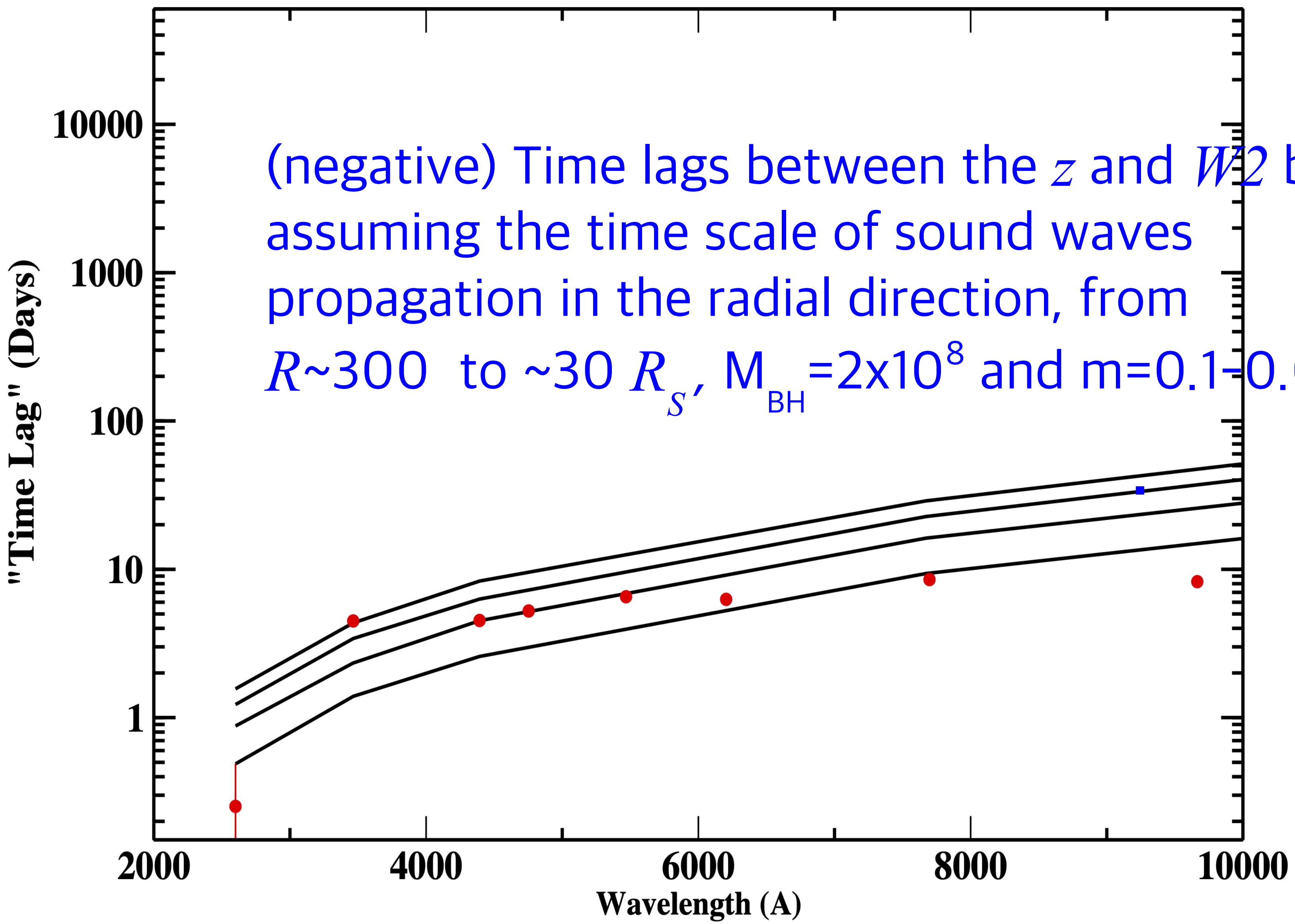


Variations at small R may be of small amplitude (so cannot affect either the ~ 250 days variations).

Viscous time scale is smaller than ~ 2500 days at $R<15\ R_S$ for a $2x10^8$ solar mass BH.

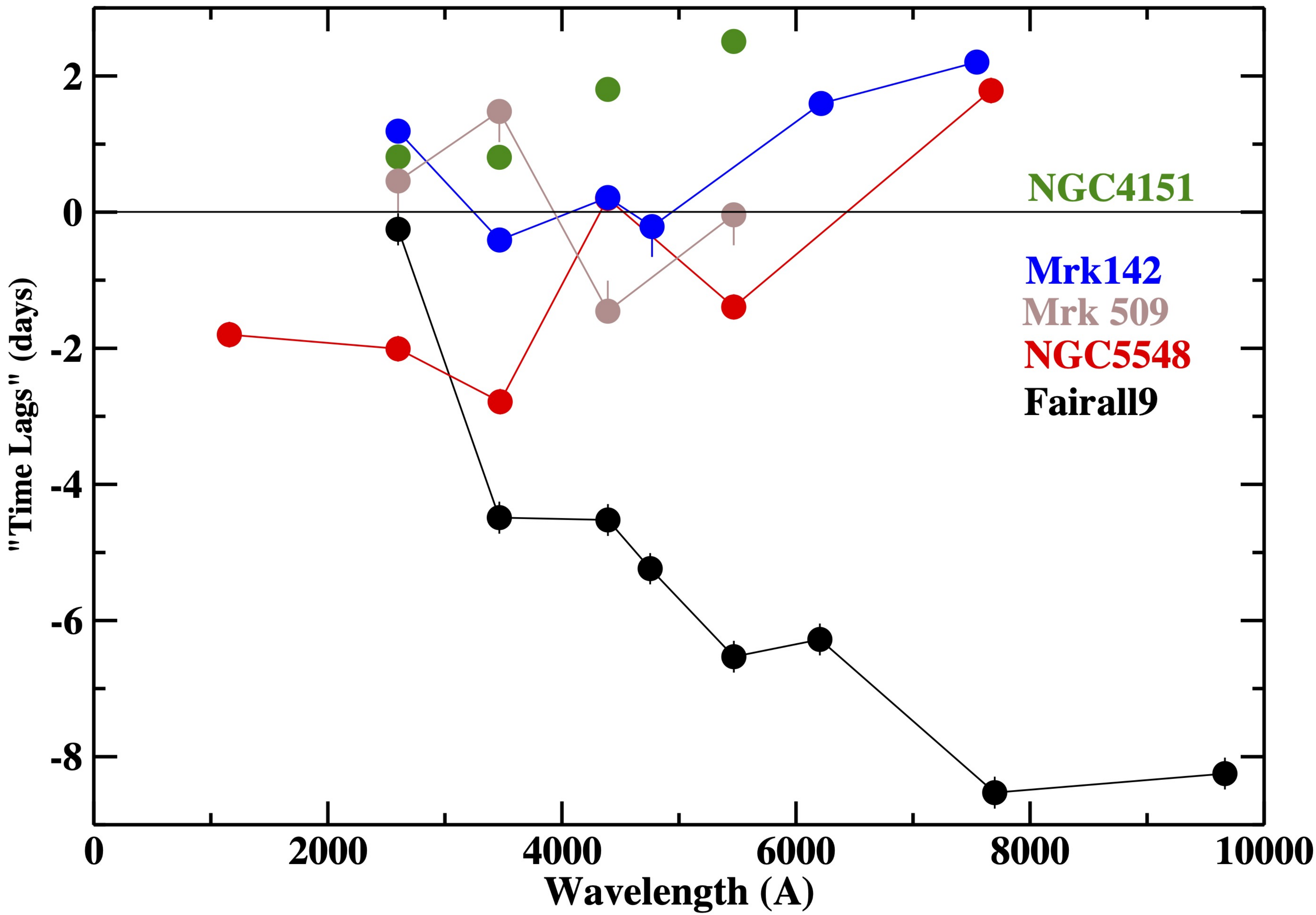


Perhaps density waves which propagate inward?



(negative) Time lags between the z and $W2$ bands, assuming the time scale of sound waves propagation in the radial direction, from R~300 to ~30 R_S, M_{BH}=2x10^8 and m=0.1-0.01

What about other AGN?



NGC4151
Mrk142
Mrk 509
NGC5548
Fairall9
"Time Lags" (days)
Wavelength (A)
2
0
-2
-4
-6
-8
0
2000
4000
6000
8000
10000

The non-detection of "negative time-lags" at long time scales in the other AGN (with the exception, perhaps, of NGC 5548) may be due to the fact that,

the disc reverberation variability amplitude is stronger than the intrinsic disc variability amplitude in these objects.

(Depends on spin, corona height, accretion rate…)

(Kammoun et al, ApJ, 2021)

- Fourier transform of the observed light curves can be used to determine the longest variations in a light curve, in a quantitative way, without assuming an adhoc function to model these variations.

- “Negative” time lags at long time scales are observed in Fairall9 and NGC 5548 (perhaps) and are of the order of a few days.

- Reverberation variability amplitude stronger in most AGN (?).

- Difficult to interpret as propagating accretion rate fluctuations.

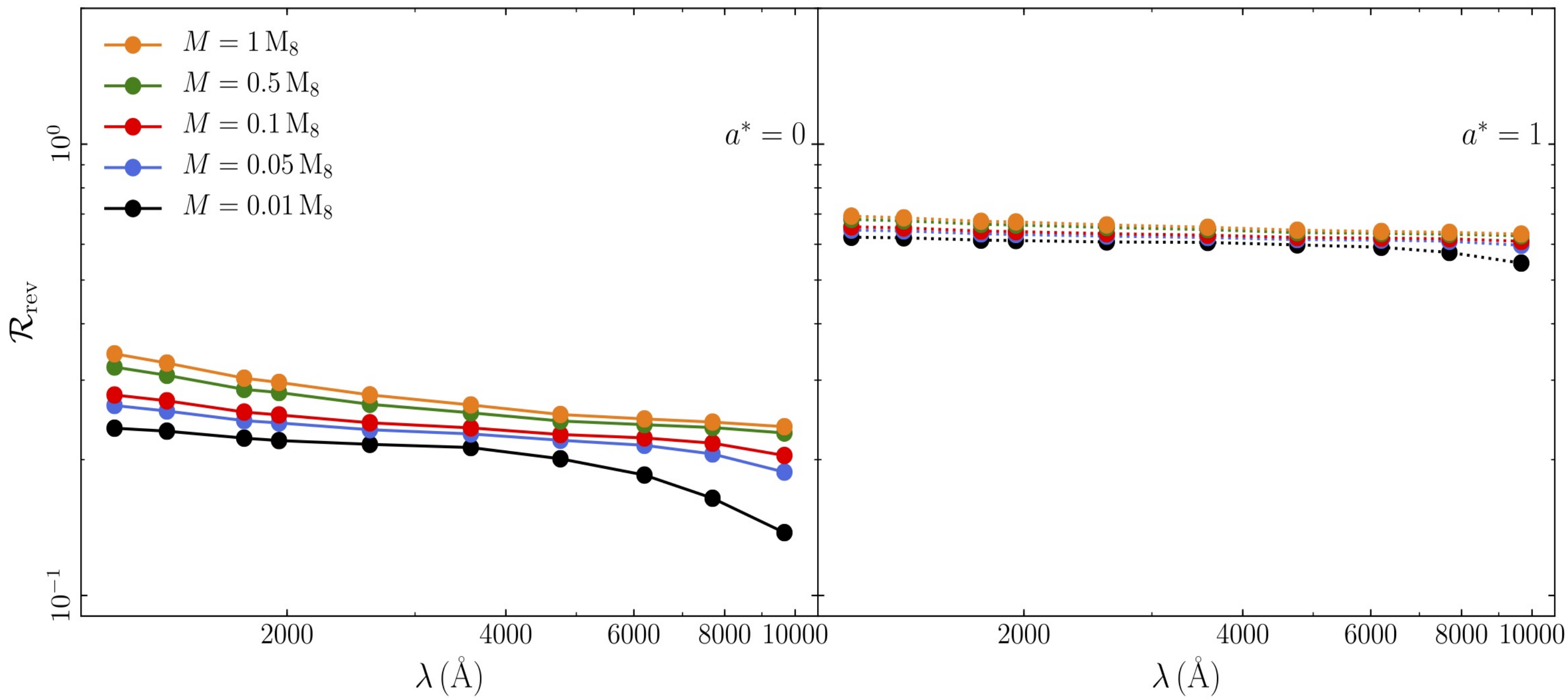


Figure 24. The reverberation fraction plotted as a function of the wavelength for different values of BH mass, considering spins of 0 and 1 (left and right panels, respectively).

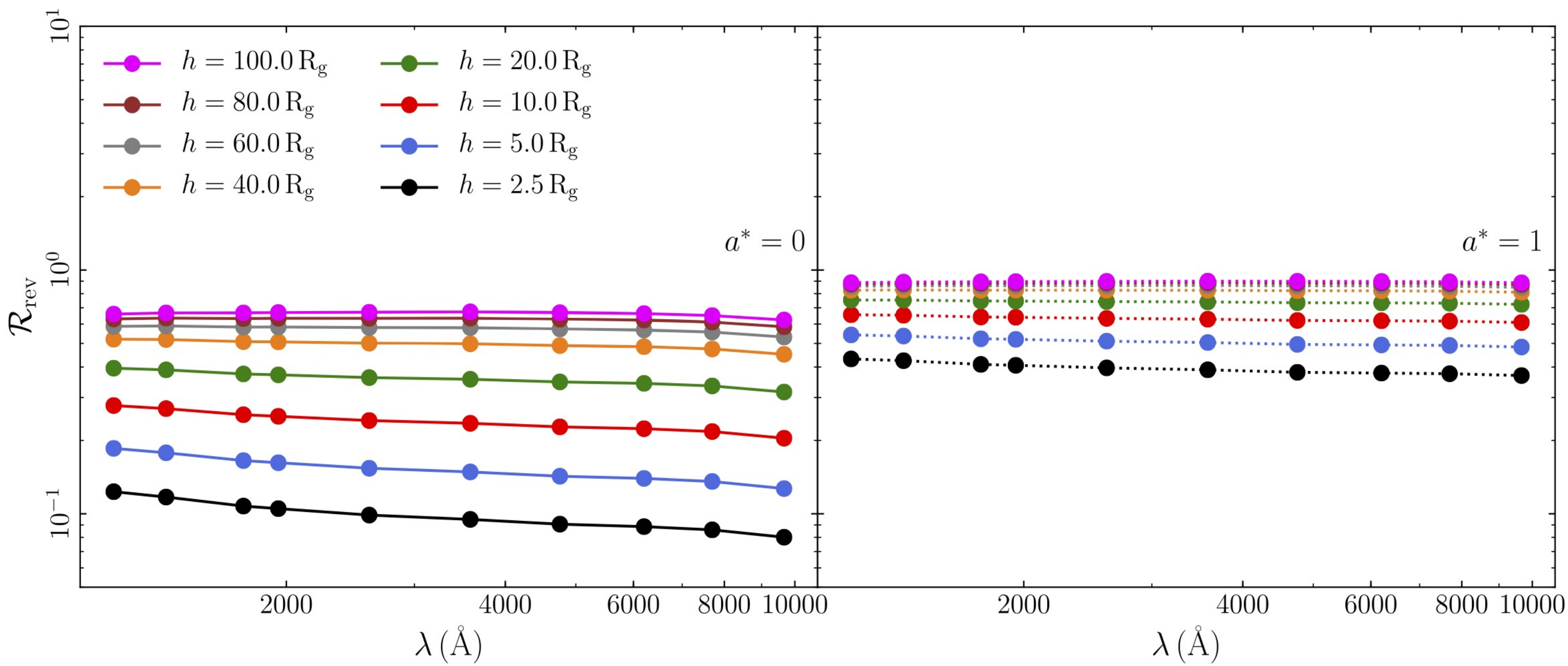


Figure 26. Same as Figure 24 but for the lamp-post height.