X-ray Flare Evolution and Changing-Look Nature of the TeV Blazar OQ 334

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Objectives

Using multi-wavelength observations spanning MJD 58095 to 60580, with a focus on X-rays, we investigate:

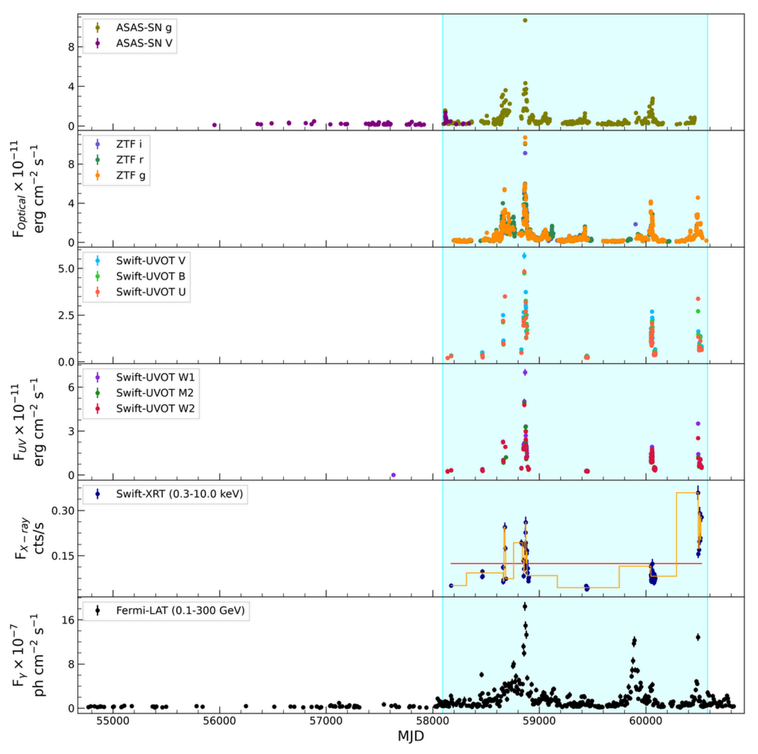
- The spectral evolution of the X-ray flares and the emission components driving them.
- The X-ray behaviour across the transitions between the FSRQ and BL Lac states.

Introduction

Blazars are divided into two classes by the rest-frame equivalent width (EW) of their broad emission lines [1]:

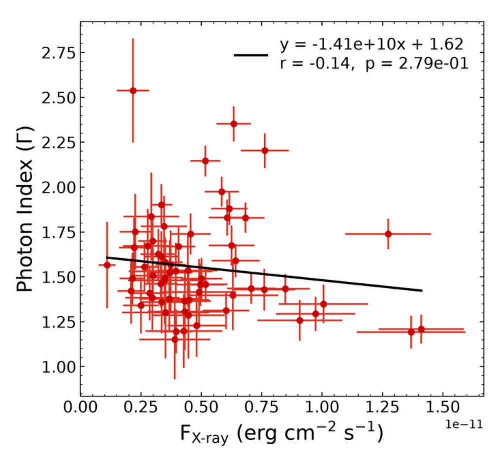
- **FSRQs (Flat Spectrum Radio Quasars)**: strong broad emission lines, EW > 5 Å
- **BL Lacs (BL Lacertae objects)**: weak or absent broad emission lines, EW < 5 Å

Changing-look blazars (CLBs) are sources observed in both states at different epochs, with the EW crossing the 5 Å boundary. The transition is attributed either to changes in the accretion rate or to the dilution of broad lines by enhanced jet continuum [2].



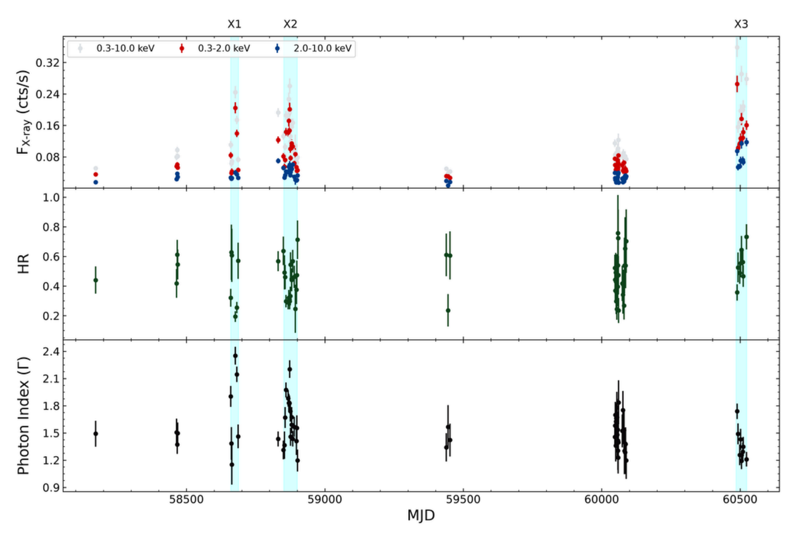
OQ 334 (B2 1420+326) has shown repeated transitions between FSRQ and BL Lac states in January 2018 [3]. Optical follow-up observations by MAGIC in January 2020 detected very high energy emission [4].

X-ray Analysis



Swift-XRT observation spectra are fitted with absorbed power-law, log-parabola, and broken power-law models.

- Most observations are best fit with absorbed power-law (47/64), with no strong requirement for curvature or breaks.
- Flux variations are not accompanied by systematic hardening or softening on long timescales.



- X-ray flaring epochs are selected with the Bayesian Blocks algorithm.

$$F_{\rm Flare} \geq 2\bar{F}$$

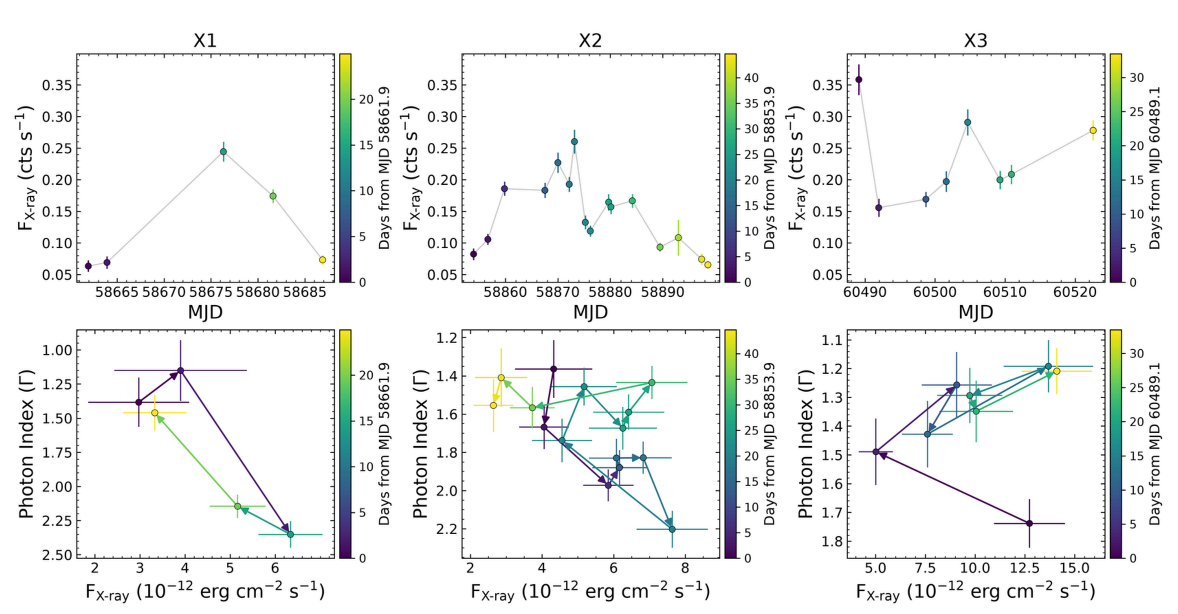
- Flares harden monotonically (X1 → X3):

Flare	Duration	HR	Γ
X1	$58660.0-58688.0$	0.323 ± 0.030	1.97 ± 0.09
X2	$58852.0-58900.0$	0.374 ± 0.019	1.71 ± 0.04
X3	$60485.0-60524.0$	0.554 ± 0.027	1.34 ± 0.06

The X-ray emitting region becomes increasingly populated by high-energy particles, indicating a physical transition through the flares.

Spectral Hysteresis: Loop-like strucutre in the flux vs hardness plane, which probes into the particle acceleration and radiative cooling mechanisms.

- Clock-wise (CW): soft lag, cooling dominated.
- Counter Clock-wise (CCW): hard lag, acceleration timescale comparable to cooling.

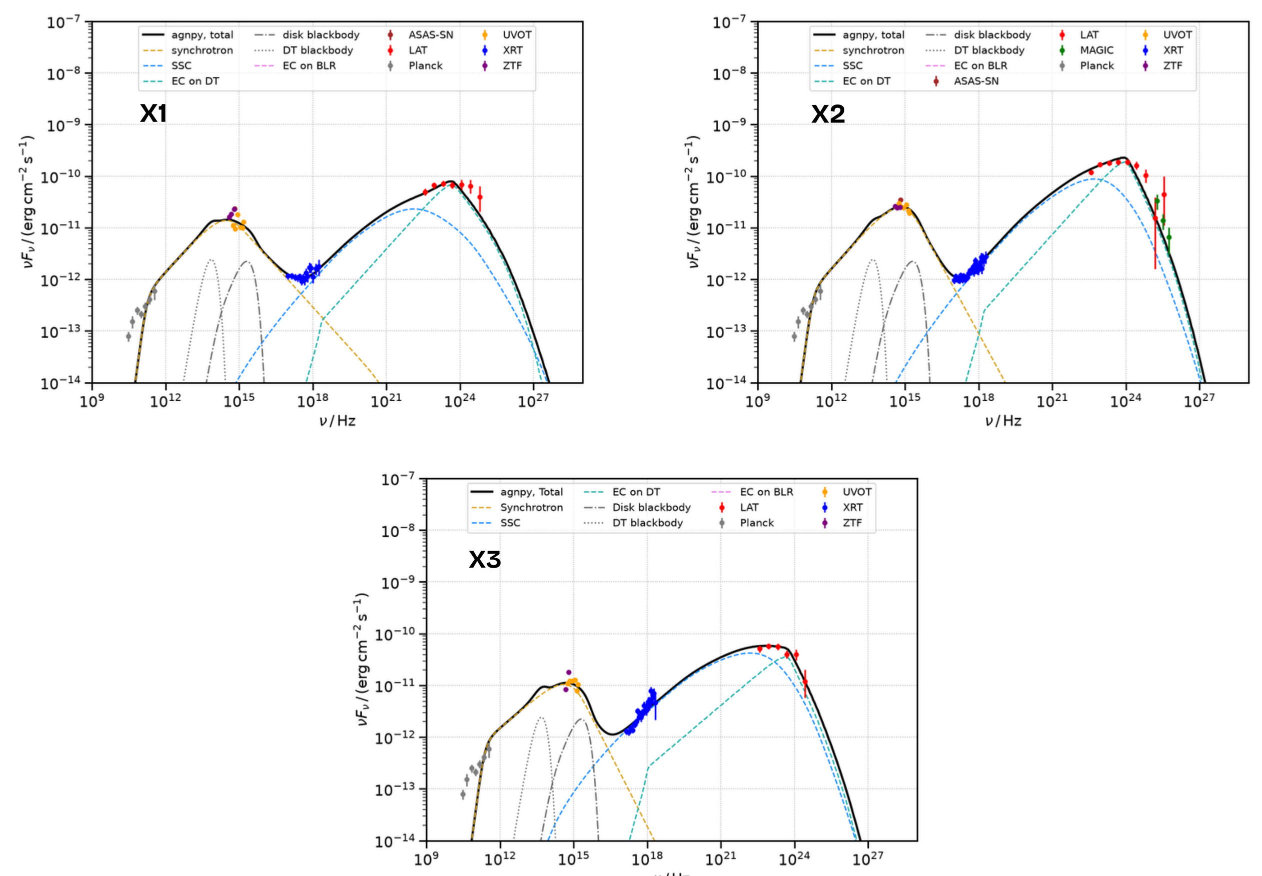


X1 is a CW cooling loop; X2 and X3 complex multi-loop trajectories, shifting acceleration/cooling balance.

Broad-Band SED

Spectral energy distribution (SED) modelling of the flares is performed in a one-zone leptonic framework with agnpy [5], assuming a broken power-law electron distribution. The radiative components are synchrotron, synchrotron self-Compton, and external Compton scattering (broad-line region and dusty torus).

The model reproduces all flares with a weak, nearly constant magnetic field (B ≈ 0.11-0.14 G), indicating that the flaring is driven by changes in the particle population.

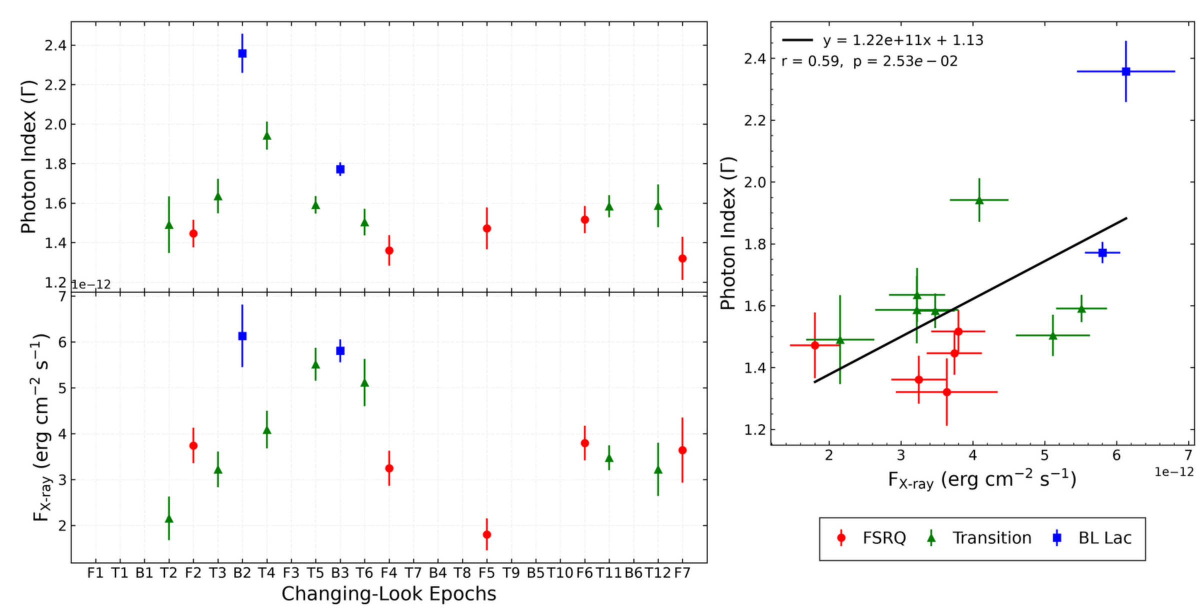


The Swift-XRT band lies in the valley between the synchrotron and IC humps, so its shape tracks their changing balance. X1 has synchrotron contribution, X2 hardens as the IC fraction grows, and by X3 the X-ray emission is dominated entirely by the IC component.

Changing-Look States

Adopting the CL epoch classifications of [6, 7], the X-ray spectral analysis separates the states in the flux-photon index plane.

State	Γ_γ (Ren et al. 2024)	Γ_X (this work)
FSRQ	$\gtrsim 2.2$	$1.32-1.52$
Transition	$2.0-2.2$	$1.49-1.94$
BL Lac	$\lesssim 2.0$	$1.77-2.36$



- Within the CL epochs, Flux and Photon Index (Γ_X) are positively correlated, producing a **softer-when-brighter** trend.
- The flares X1 and X2 coincide with BL Lac epochs: each follows a transition → BL Lac → transition sequence in the flare.
- X3, after the classified CL epochs, deviates from this trend: the flare shows the hardest spectrum (Γ_X = 1.34 ± 0.06), resembling FSRQ and transition states, suggesting no BL Lac state.

Summary

- The X-ray flares harden monotonically from X1 to X3, tracking a shift in the emission components from a combined synchrotron and IC contribution to full IC dominance, driven by the evolving electron population.
- Across the Changing-Look epochs, the X-ray spectra follow a softer-when-brighter trend. X3 breaks this trend: the brightest flare shows the hardest spectrum, suggesting no BL Lac state.

References

1. Urry C. M., Padovani P., 1995, PASP, 107, 803
2. Ruan J. J., et al., 2014, ApJ, 797, 19
3. Mishra H. D., et al., 2021, ApJ, 913, 146
4. MAGIC Collaboration, et al., 2021, A&A, 647, A163
5. Nigro C., et al., 2022, A&A, 660, A18
6. Ren S. S., et al., 2024, A&A, 685, A140
7. Ren S. S., et al., 2024, ApJ, 976, 124

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