Optical and Radio Observations of Seven Flat Spectrum Radio Quasars (FSRQ)

Abstract: Optical and radio observations of seven Flat Spectrum Radio Quasars (FSRQs) are examined to determine the possible amplitude correlation of the radio and optical spectra for each object. Each FSRQ exhibits a different correlation ranging from generally correlated (the amplitudes of the spectra rise or fall together), partially correlated (some parts of the amplitudes rise or fall together while other parts do not), uncorrelated (no discernible amplitude correlation) or indeterminate (no definitive conclusions can be made). Additionally, the correlations may be offset with the radio spectrum preceding the optical spectrum or vice versa. We examine FSRQs OJ 248, PKS 1222+216, 3C 273, 3C 279, B2 1611+34, S4 1633+38, and 3C 345. Preliminary conclusions are that the optical and radio spectra of PKS 1222+216, 3C 273, and 3C 279 are generally correlated, while the remaining four are weakly correlated or indeterminate.

1. Introduction and Background

Active Galactic Nuclei (AGN) are energetic astrophysical sources powered by accretion onto supermassive black holes in galaxies, and present unique observational signatures that cover the full electromagnetic spectrum over more than twenty orders of magnitude in frequency from radio waves to gamma rays. As shown in Figure 1, AGN constitutes a few percent of all galaxies and can be divided into two categories; radio quiet and radio loud. Radio quiet AGN accounts for 85%-95% while radio loud AGN accounts for 5%-15%. Within the radio loud portion of AGN, one subcategory is known as blazars, accounting for less than 5% of all AGN. A blazar is an active galactic nucleus with a relativistic jet (a jet composed of ionized matter traveling at nearly the speed of light) directed very nearly towards an observer. Relativistic beaming of electromagnetic radiation from the jet makes blazars appear much brighter than they would be if the jet were pointed in a direction away from the observer. Blazars are powerful sources of emission across the electromagnetic spectrum and are observed to be sources of high-energy gamma ray photons. Blazars are highly variable sources, often undergoing rapid and dramatic fluctuations in brightness on short timescales (hours to days). Some blazar jets exhibit apparent superluminal motion, another consequence of material in the jet traveling toward the observer at nearly the speed of light. Blazars can be further subdivided into BL Lac and FSRQ components. BL Lacs (BL Lacertae-type objects) are compact quasi-stellar objects showing almost continuous spectra with weak emission and absorption lines and relatively rapid irregular light changes with amplitudes. Flat Spectrum Radio Quasars (FSRQ) are distinguished by high energy jets pointed directly at earth. The AGN radio configuration as described by the Unified AGN Model is shown in Figure 2.

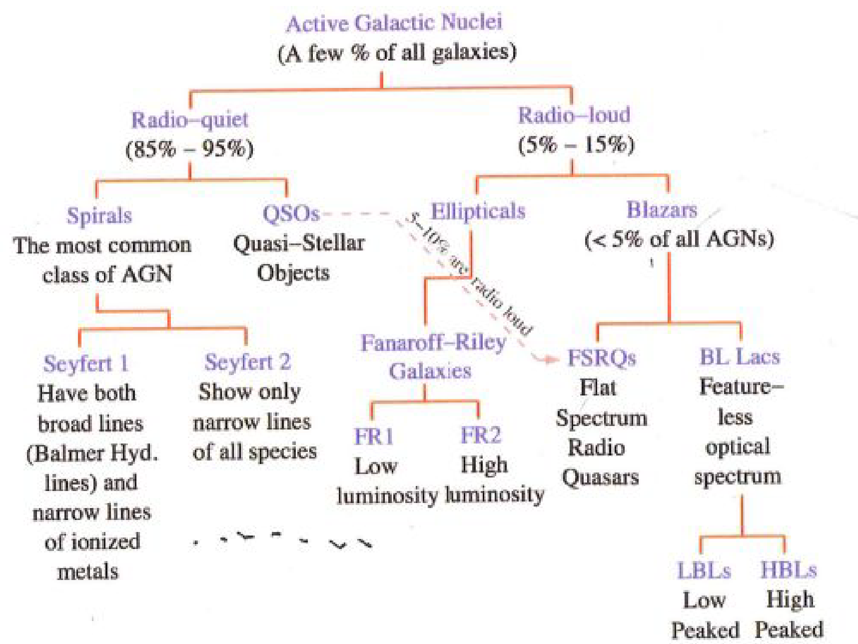

Figure 1: AGN Morphology

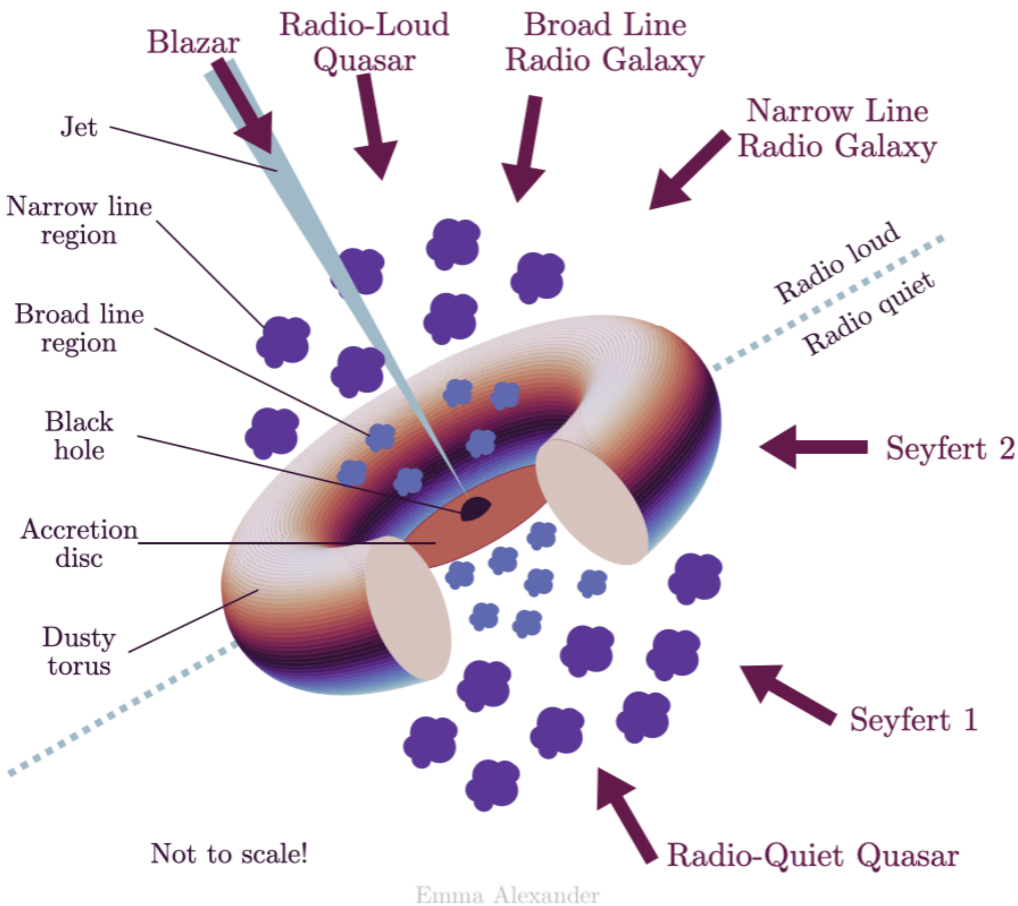

Figure 2: Unified AGN Model

2. Methods

In general, there are relatively few continuous, long term radio observations that can be correlated with continuous, long term optical observations. Most radio observations are at a few discrete frequencies which are taken over a short period of time (hours to a few weeks). Typically, these observations indicate the maximum/peak radio flux at a given frequency over the observation period. Optical observations, in comparison, are typically taken over years or decades across numerous optical and infrared bands. Additionally, there are relatively few radio telescopes that are used to obtain radio data while there are numerous optical telescopes that can obtain optical data.

However, one very significant long term radio study of blazars has been performed by the National Institute for Astrophysics (INAF) in Italy. This is summarized in

Marchili, N., et al. 2025, Astronomy & Astrophysics, arXiv:2509.04577v1 4 Sep 2025, "Twenty years of blazar monitoring with the INAF radio telescopes". These long term radio observations can be directly correlated over the twenty year period with optical observations over that same period, specifically JD2453000-JD2461000 (12/26/2003-11/20/2025). These radio observations are of both BL Lac and FSRQ blazars. This study looks at seven specific FSRQ objects: OJ 248, PKS 1222+216, 3C 273, 3C 279, B2 1611+34, S4 1633+38, and 3C 345. All objects were observed at the 5 GHz, 8 GHz, 24 GHz, and 43 GHz radio bands. Optical observations were made at ASAS-SN V, ASAS-SN G, Cousins R, Cousins I, Johnson V, Johnson B, Sloan G, Sloan I, Sloan R, ZTF zg, ZTF zr, ZTF zi, ZTF zi', and visual wavelengths. All optical wavelengths are in the 400 nm to 900 nm range. The ZTF wavelengths are in the near infrared band of 1600 nm to 1800 nm.

All of the optical and infrared photometry files outlined above were downloaded and composite light curves were generated by the American Association of Variable Star Observers (AAVSO) VStar software (Benn, D. 2012, Algorithms + Observations = VStar, Journal of the AAVSO (JAAVSO), v40, n2, pp.852-866). Time-series data can be obtained from time-series photometry with the periodic variability of the star's brightness as a function of time. This is the star's composite light curve. Given the wide range of wavelengths in the composite light curve, the AGN optical properties and characteristics are better determined for comparison with the radio wavelengths than would be possible from only a single optical wavelength.

3. Analysis and Results

Presented below is the analysis of the correlation between optical and radio spectra for seven FSRQ objects. It should be noted that this correlation is determined only by visual inspection of the light curves and not through any rigorous mathematical or statistical analysis.

OJ 248 (0827+243)

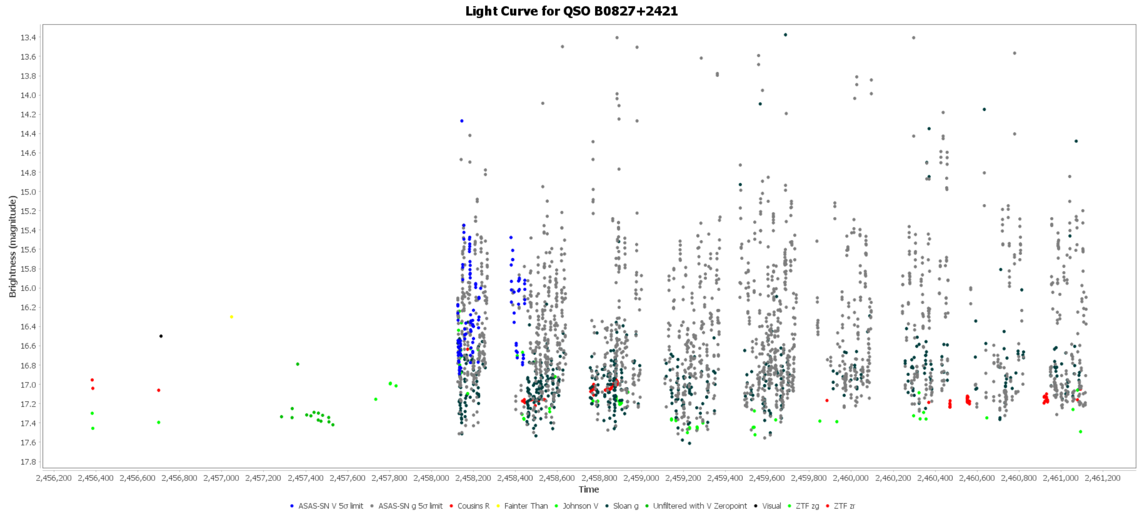

Figure 3: OJ 248 (0827+243) Composite Optical Light Curve

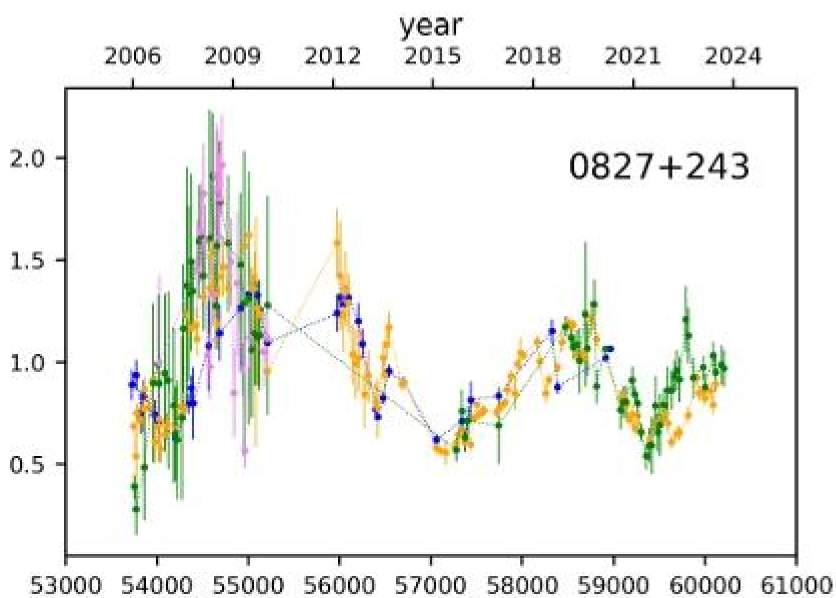

Figure 4: OJ 248 (0827+243) Composite Radio Light Curve

For OJ 248 (QSO B0827+2421), the radio peaks are at JD 54000-55000, JD 56000, JD 58000-59500, and JD 60000. The optical peaks are indeterminate, therefore nothing conclusive can be said about this object.

PKS 1222+216 (1222+21)

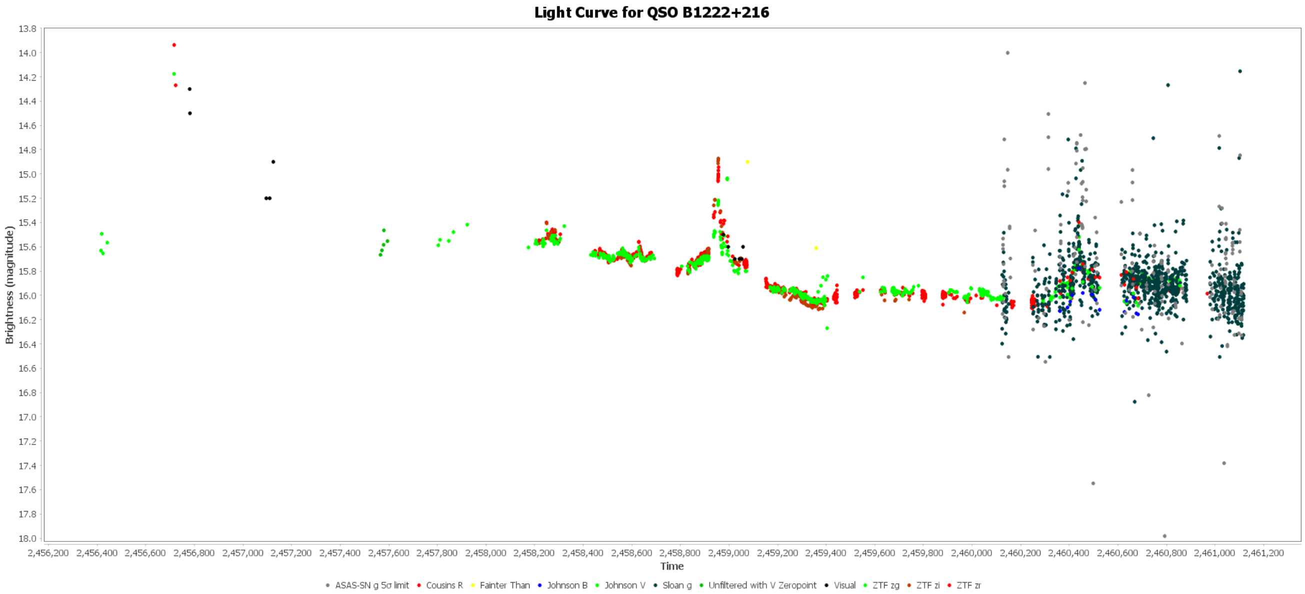

Figure 5: PKS 1222+216 (1222+21) Composite Optical Light Curve

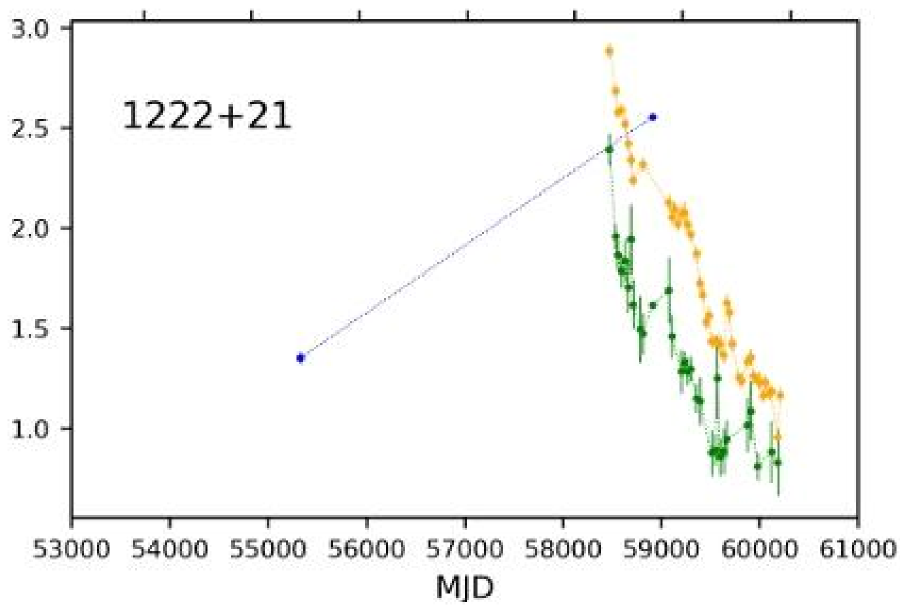

Figure 6: PKS 1222+216 (1222+21) Composite Radio Light Curve

For PKS 1222+216 (QSO B1222+216), there is relatively little radio data. The radio peak is JD 58000-58500. The optical peaks are JD 58900, JD 56600-56800, and JD 60500. There is a positive correlation around JD 58000-60000.

3C 273 (1226+023)

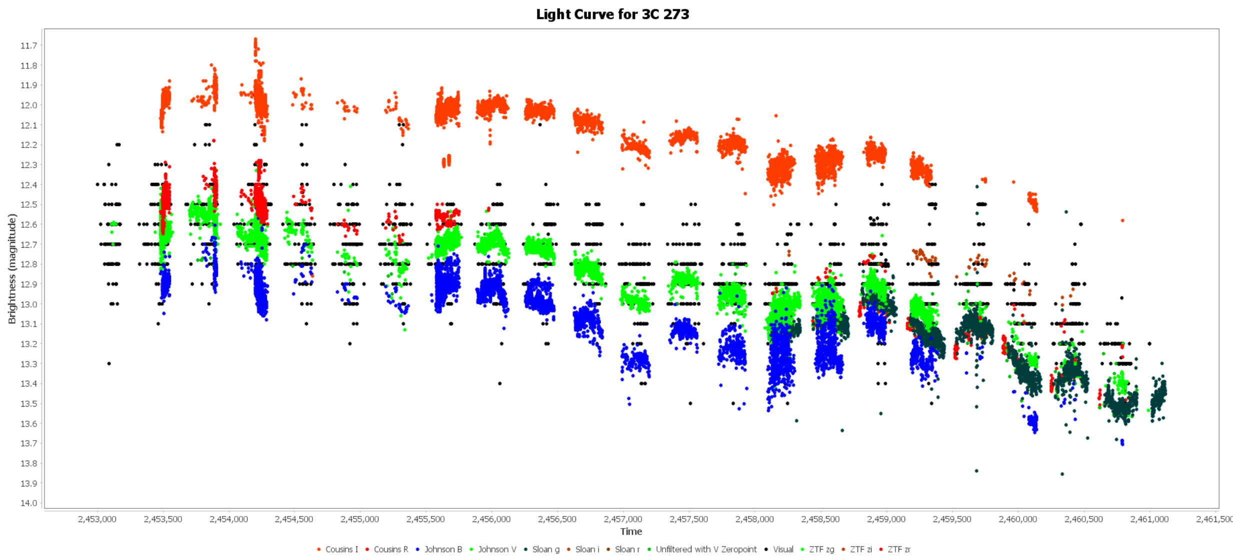

Figure 7: 3C 273 (1226+023) Composite Optical Light Curve

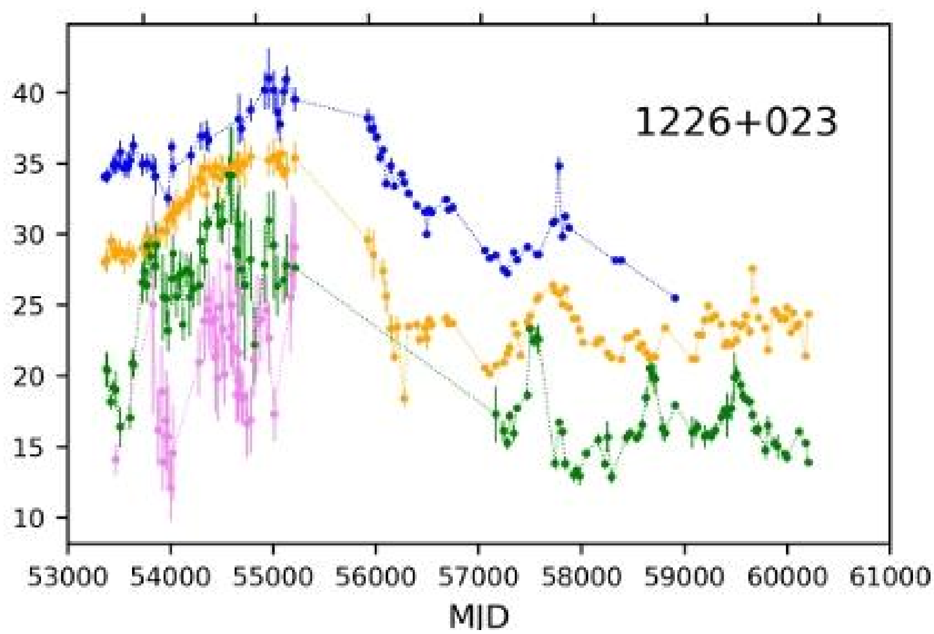

Figure 8: 3C 273 (1226+023) Composite Radio Light Curve

For 3C 273, there are radio peaks at JD 54000-55000, and JD 58000. There are multiple optical peaks in this time interval. Additionally, there seems to be an overall decrease with time between JD 53000-66100 for both radio and optical spectra. This object appears to have a good general positive correlation between spectra.

3C 279 (1253-055)

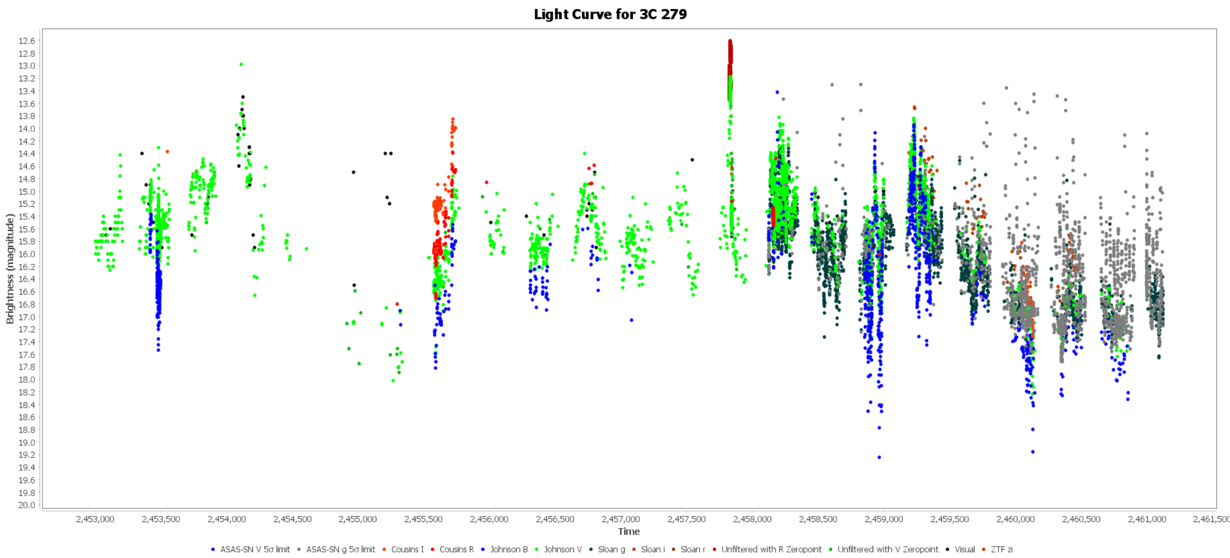

Figure 9: 3C 279 (1253-055) Composite Optical Light Curve

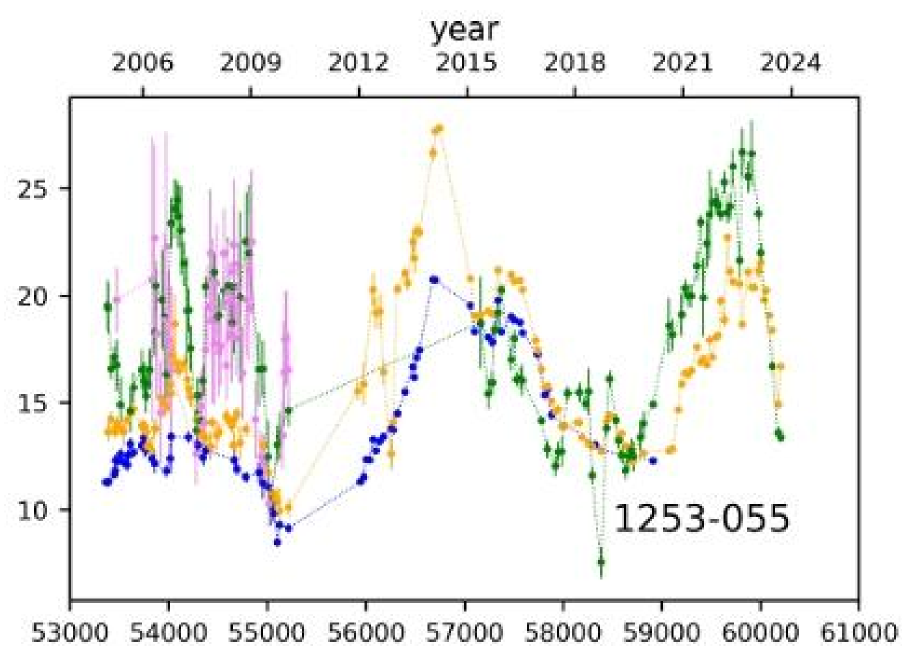

Figure 10: 3C 279 (1253-055) Composite Radio Light Curve

For 3C 279, there are radio peaks at JD 54000-55000, JD 56500, JD 59000-60000. The optical peaks occur at JD 54000, JD 55500, JD 56500, JD 58000, JD 58250, and JD 59500. This object appears to have a good general positive correlation between spectra.

B2 1611+34 (1611+343)

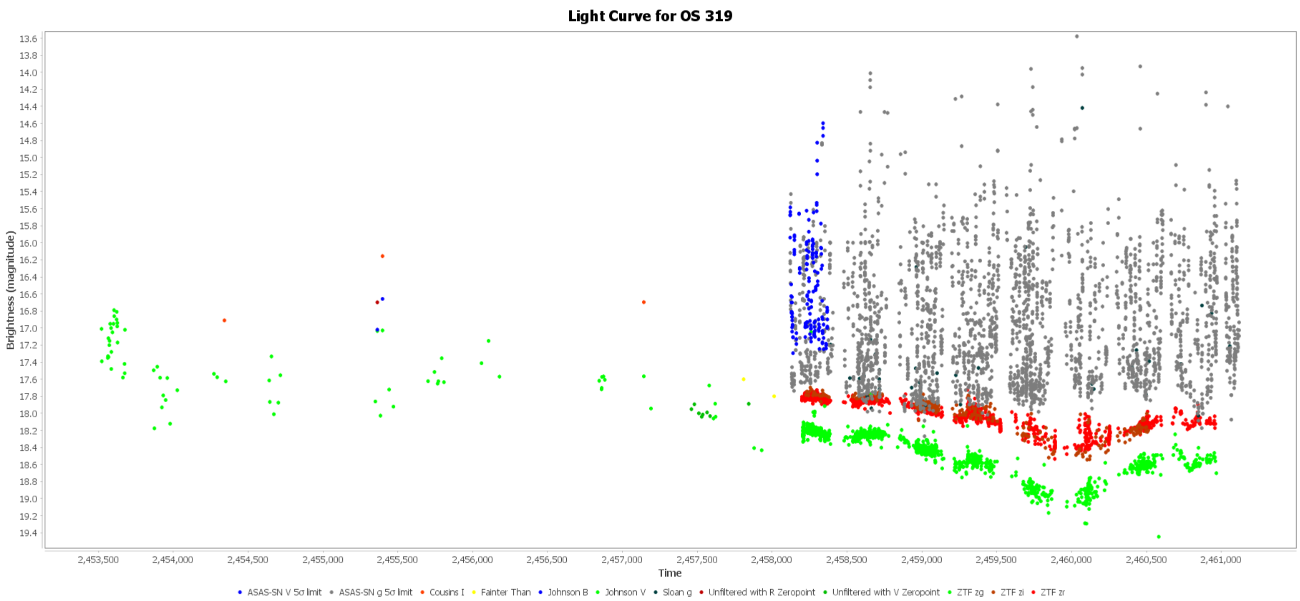

Figure 11: B2 1611+34 (1611+343) Composite Optical Light Curve

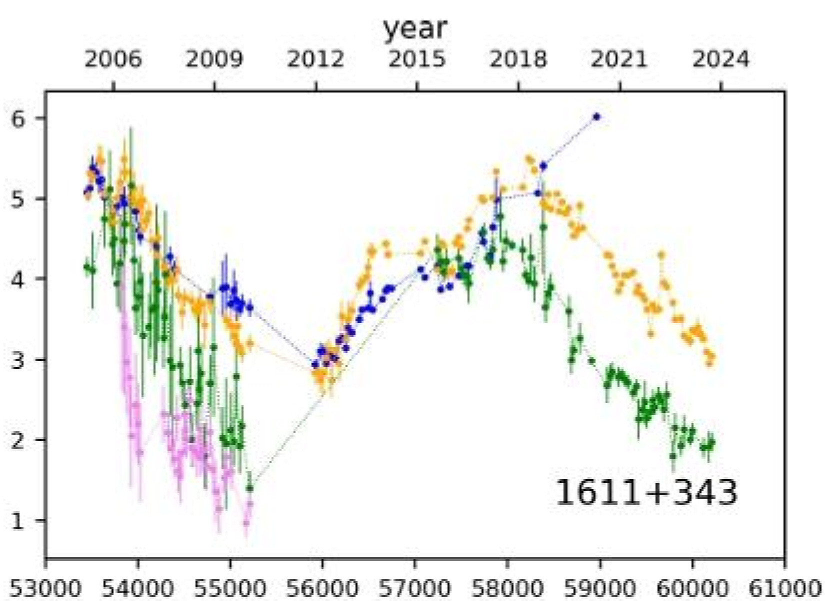

Figure 12: B2 1611+34 (1611+343) Composite Radio Light Curve

For B2 1611+34 (OS 319), there are radio peaks at JD 53500, JD 57000-59000 (this radio spectrum is relatively broad). The optical peaks occur at JD 58250-60000. There is some positive correlation in the JD 57000-60000 band.

S4 1633+38 (1633+382)

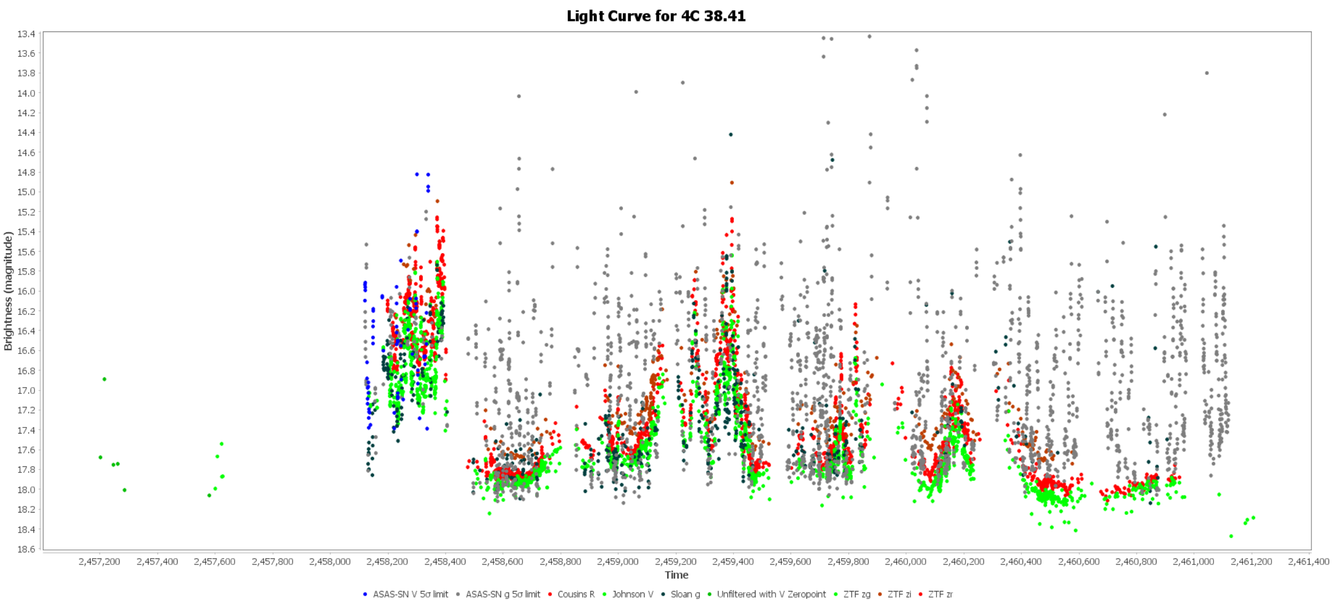

Figure 13: S4 1633+38 (1633+382) Composite Optical Light Curve

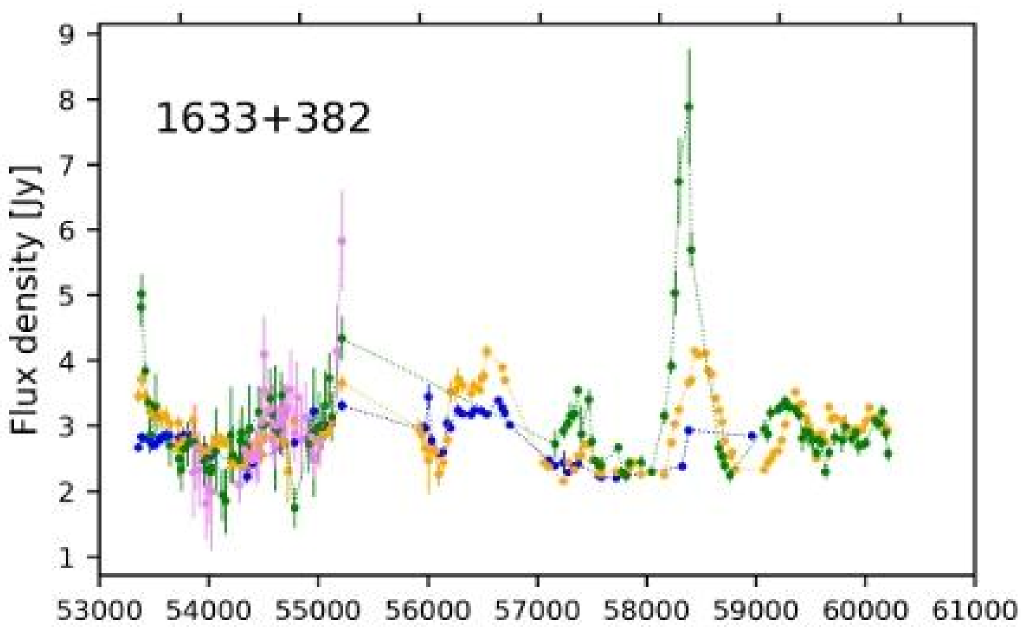

Figure 14: S4 1633+38 (1633+382) Composite Radio Light Curve

For S4 1633+38 (4C 38.41), there are radio peaks at JD 53500, JD 55000, and JD 58500. These peaks are quite narrow and sharp. The optical peaks occur at JD 58200-58400, JD 59400, JD 59800, and JD 60200. There is positive correlation in the JD 58400, but other bands are indeterminate due to the lack of optical data at the earlier dates.

3C 345 (1641+399)

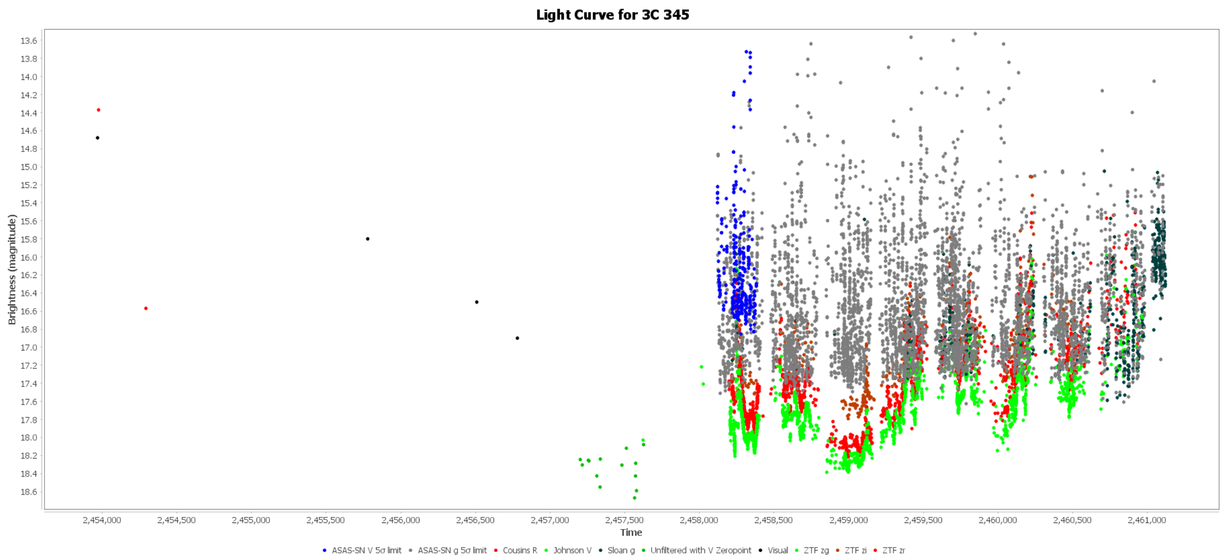

Figure 15: 3C 345 (1641+399) Composite Optical Light Curve

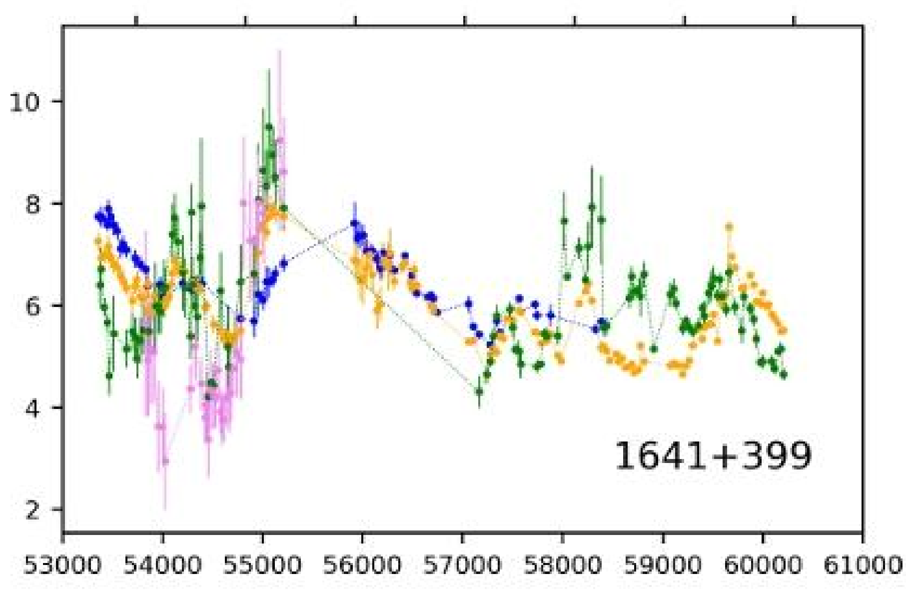

Figure 16: 3C 345 (1641+399) Composite Radio Light Curve

For 3C 345, there are radio peaks at JD 55000, JD 58500, and JD 60000. The optical peak occurs at JD 58250. There is moderate correlation in this band.

4. Discussion

The above analysis shows that FSRQs can significantly differ with respect to the correlations between optical and radio spectra. There are several potential reasons for this variability, including position offsets, emission mechanisms, and central engine dynamics. So, what is the correlation between active galactic nuclei radio and optical spectra? The correlation between radio and optical spectra in active galactic nuclei is real but complex, and it depends strongly on the physical component being probed—jets, accretion disks, or circumnuclear environments. The literature points to several distinct relationships. Radio and optical emission in AGN correlate only weakly and often indirectly, because they arise from different physical regions (jets vs. accretion disk). When correlations do appear, they typically reflect deeper connections to black hole mass, accretion rate, or jet power, but not a direct spectral link.

Radio spectra in AGN are dominated by synchrotron emission from jets or compact cores. Recent high-resolution VLA/VLBA studies show:

- Flat or inverted radio spectra ($\alpha \gtrsim -0.5$ to >0) are associated with compact, VLBA-detected cores and active jets.
- Steep radio spectra ($\alpha \approx -0.7$) correspond to optically thin synchrotron emission from extended or resolved jet/lobe structures.
- Spectral index correlates with source size: more compact sources tend to have steeper spectra, likely due to energy losses or absorption processes.
- These radio properties trace jet strength, compactness, and evolutionary stage.

Optical emission in AGN is dominated by the accretion disk, broad-line region, and reprocessing structures. Long-term optical variability studies show that optical variability correlates strongly with black hole mass and accretion disk thermal timescales. No significant correlation exists between optical variability and X-ray properties. Only a weak anticorrelation is found between optical variability and radio parameters (e.g., radio flux, radio loudness). This suggests jet activity does not dominate long-term optical variability. Thus, optical behavior is largely disk-driven, not jet-driven.

5. Conclusions

Most studies find no strong direct correlation between radio spectral index and optical spectral/variability properties.The correlation is weak or indirect. This is because radio probes jets while optical probes the accretion disk. These components can evolve semi-independently. However, accretion rate links both. Some AGN classes (e.g., changing-look AGN) show a source-by-source anticorrelation between radio emission and accretion rate with lower accretion indicating stronger radio jet power and higher accretion indicating weaker radio jet activity. But this is not a population-wide trend. Jet-Disk coupling exists but is subtle. Radio-loud AGN often show strong jets (flat/inverted radio spectra) and distinct optical spectral signatures (e.g., broader lines, different variability patterns). But these are broad demographic trends, not tight spectral correlations. In summary, there is no strong universal correlation between AGN radio and optical spectra. Instead, both bands trace different physical processes that can be coupled through deeper parameters like black hole mass, accretion rate, and jet evolution.

6. Acknowledgements

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Lambert and Secrest, 2024, “VLBI Position Variability of AGNs Is Inversely Correlated with Their Photometric Variability.”

Marchili, N., et al. 2025, Astronomy & Astrophysics, arXiv:2509.04577v1 4 Sep 2025, "Twenty years of blazar monitoring with the INAF radio telescopes".

Secrest, 2022, "Optical-Radio Position Offsets Are Inversely Correlated with AGN Photometric Variability."

Shappee et al. (2014) and Kochanek et al. (2017).

Databases

- **FIRST: Faint Images of the Radio Sky at Twenty-cm; The VLA FIRST Survey**
- **NRAO: data.nrao.edu**
- **CIRADA: cirada.ca**
- **NASA IPAC Extragalactic DatabaseFrankfurt Quasar Monitoring**
- **Whole Earth Blazar Telescope**
- **Frankfurt Quasar Monitoring**