Periodicity Search in AGN using Bayesian Inference:
Study of Blazar OJ287 Radio Lightcurve

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Introduction

Blazar OJ 287 (z=0.304) is one of the best-known candidates to host the SMBH Binary at its center (SMBHB) emitting nano Hertz Gravitational Waves (nHz GWs). Its optical light curve exhibits unique quasi-periodic high-brightness flares (outbursts) with a period of 12 years and shows a long-term variation in its apparent magnitude with a period of 60 years. According to the SMBHB central engine model, secondary BH is orbiting the more massive primary BH in a relativistic eccentric orbit with a redshifted orbital period of 12 years and the longer 60-year timescale is associated with the advance of the periastron. The double-peaked flares occur due to the impacts of the secondary BH on the accretion disk of the primary BH twice during each orbit. This model has accurately predicted the flares during the years 2005, 2007, 2015, and 2019. In this project, we are probing the SMBHB central engine signatures in radio wavelengths.

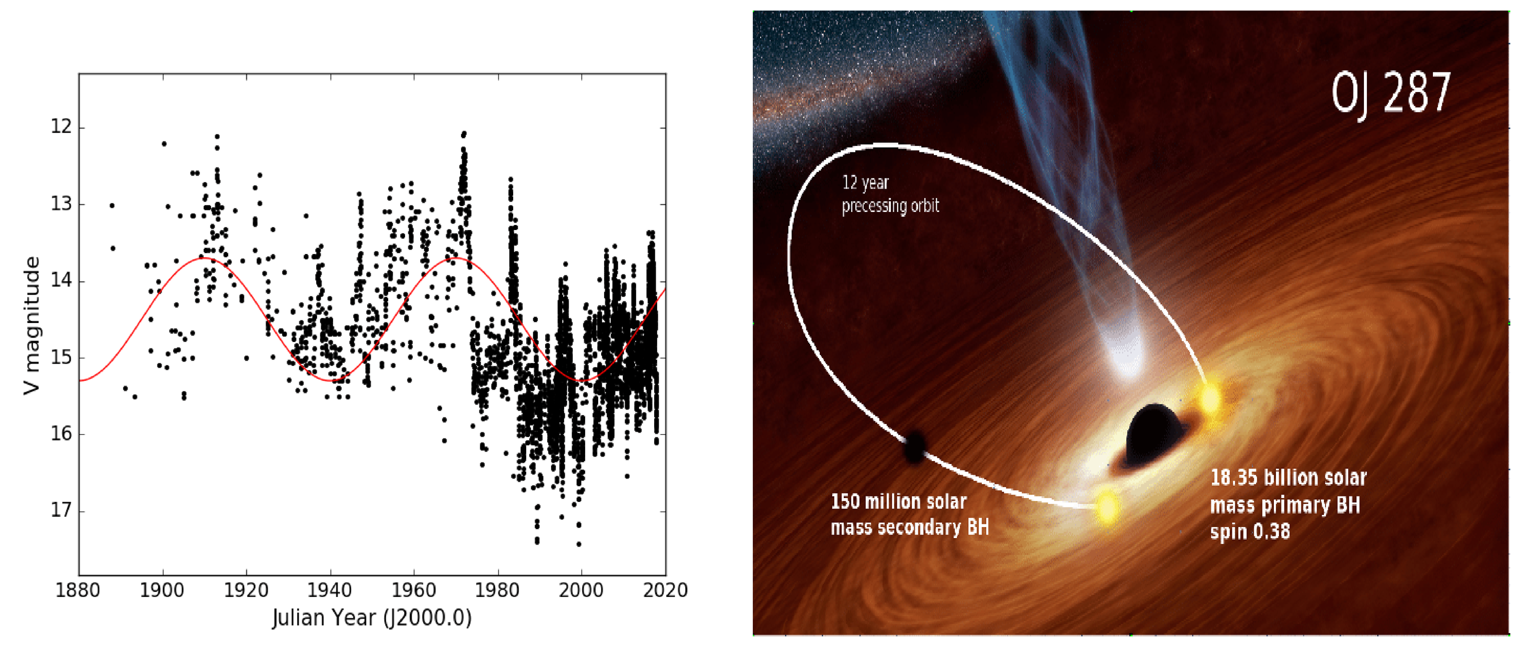

Figure 1: Historic V band Optical Lightcurve of OJ287 (left) & Artistic illustration of OJ287 SMBHB model (right)

Method

Bayesian Inference framework described in Zhu & Thrane 2020. can be used to successfully model deterministic signals in the presence of red noise. Bayesian Inference is a method in which the Bayes theorem is used to get the posterior probability distribution of the parameters of a model for the given data.

In our context, the Bayes theorem states that

$$P\left(\vec{\theta}|\mathbf{d},\mathcal{H}\right) = \frac{\mathcal{L}(\mathbf{d}|\vec{\theta},\mathcal{H})P(\vec{\theta}|\mathcal{H})}{Z(\mathbf{d}|\mathcal{H})}$$

We assume stationary Gaussian noise whose Likelihood function is given by

$$\mathcal{L}\left(\mathbf{d}|\vec{\theta},\mathcal{H}\right) = \frac{1}{\sqrt{(2\pi)^N \det[\mathbf{C}]}}\exp\left[-\frac{1}{2}(\mathbf{d}-\mathbf{m}-\mathbf{s})^T\mathbf{C}^{-1}(\mathbf{d}-\mathbf{m}-\mathbf{s})\right]$$

$$\mathbf{C} = \mathbf{C}_w + \mathbf{C}_r \quad \text{and} \quad \mathbf{C}^w_{ij} = (EFAC * \sigma_i)^2\,\delta_{ij}$$

For our initial analysis we are considering three simple cases:

Only Red noise

$$\mathbf{C}^r_{ij} = \frac{1}{2}\hat{\sigma}^2\tau_0 exp\left[\left(\frac{\tau_{ij}}{\tau_0}\right)^{\gamma}\right] \quad \text{and} \quad \tau_{ij} = |t_i - t_j|$$

Sine + Red noise

$$\mathbf{s}(t) = Asin\left(\frac{2\pi t}{T_0} + \phi\right) \quad \text{and} \quad \mathbf{C}^r_{ij} = \frac{1}{2}\hat{\sigma}^2\tau_0 exp\left[\left(\frac{\tau_{ij}}{\tau_0}\right)^{\gamma}\right]$$

QPO + Red noise

$$\mathbf{C}^r_{ij} = \frac{1}{2}\hat{\sigma}^2\tau_0\exp\left[\left(\frac{\tau_{ij}}{\tau_0}\right)^{\gamma}\right] cos\left(\frac{2\pi\tau_{ij}}{T_q}\right)$$

Data

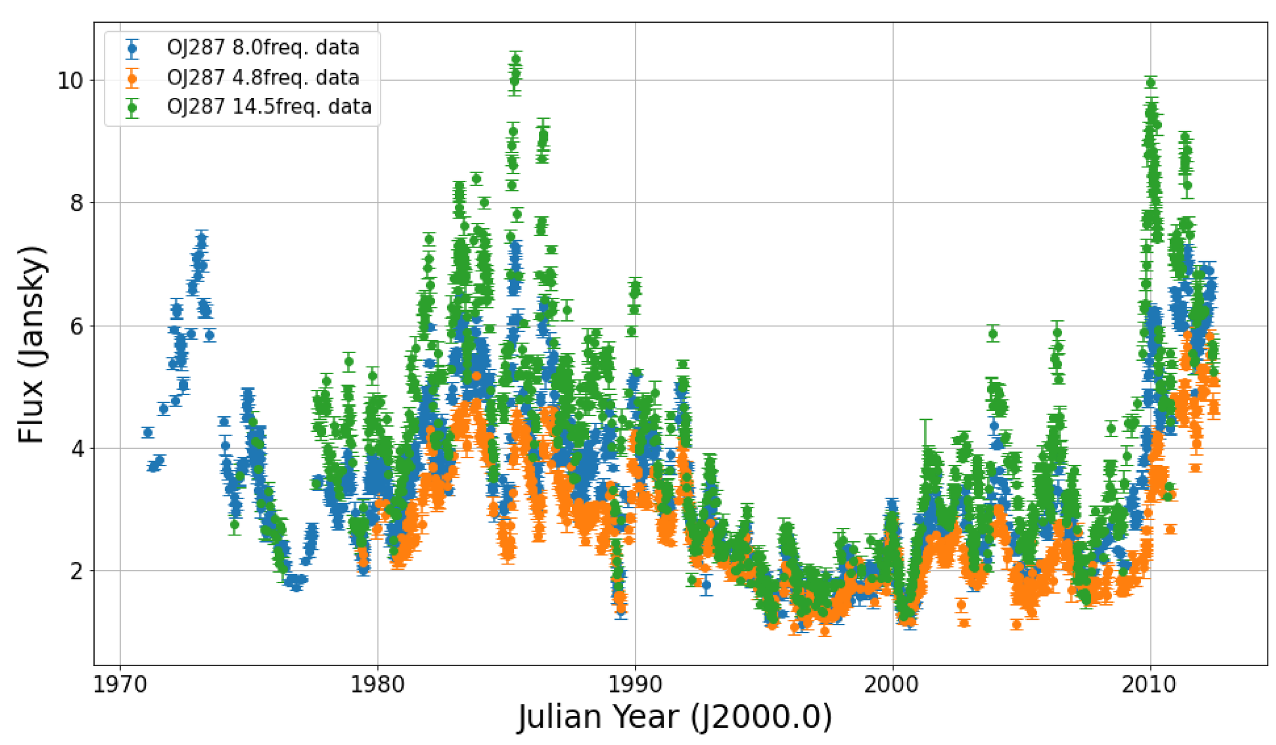

Figure 2: Radio Lightcurve of OJ287 from UMRAO Database (Margo F. Aller, University of Michigan). We are using three frequencies, i.e., 4.8 GHz (33.22 yrs), 8.0 GHz(41.29yrs), and 14.5 GHz(38 yrs).

Results

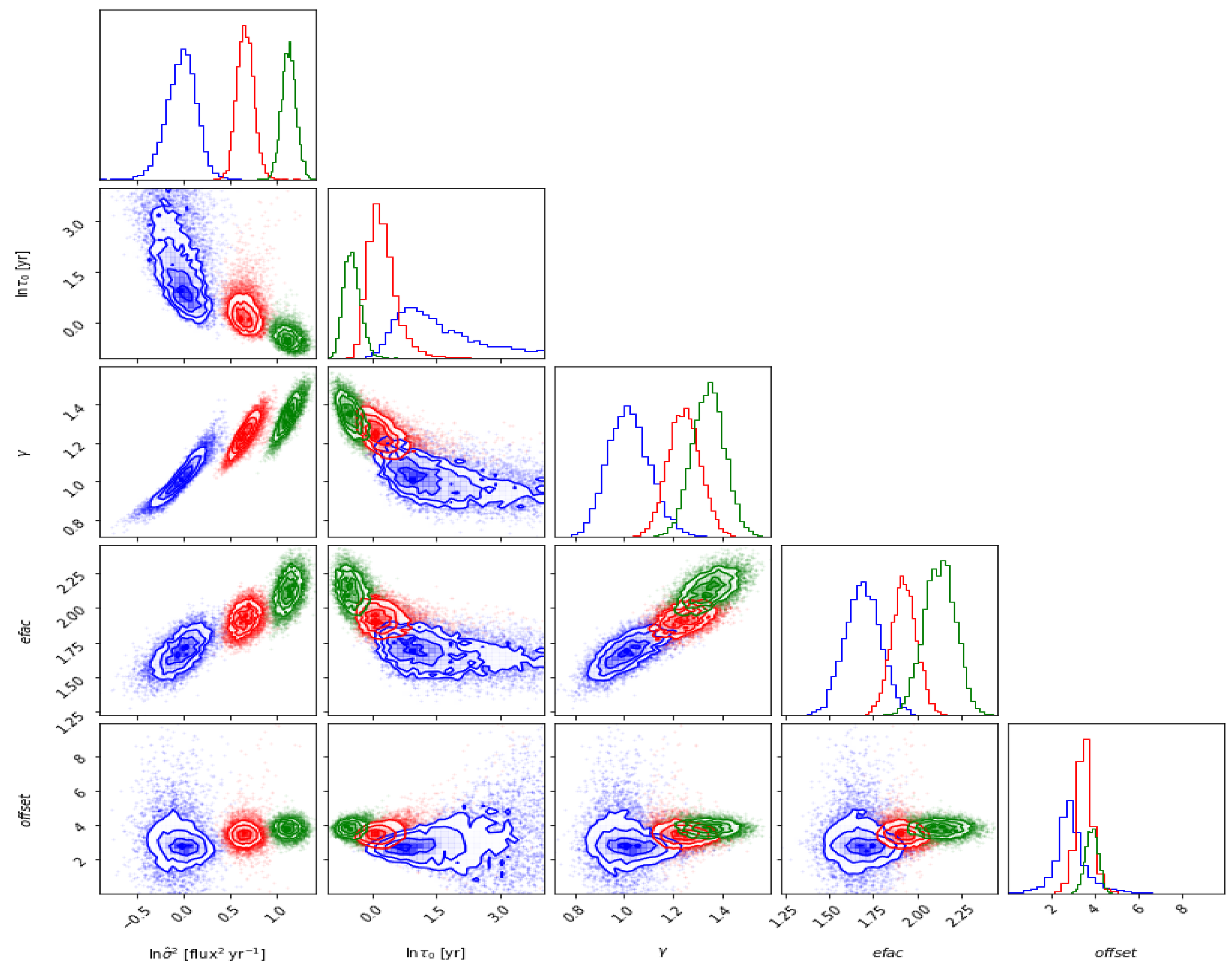

Figure 3: Posterior Probability Distribution of Red noise model parameters for 4.8GHz (blue), 8.0GHz (red) and 14.5GHz (green) data

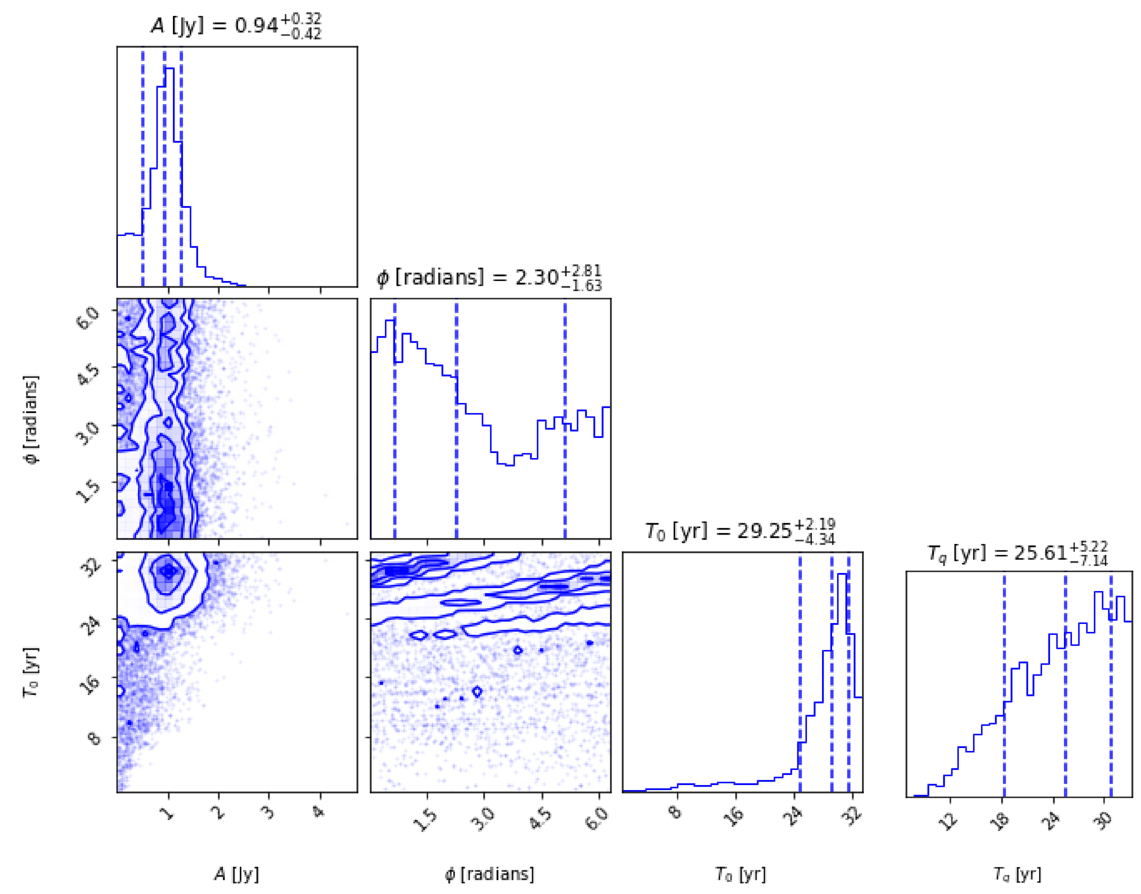

Figure 4: Posterior Probability Distribution of sine parameters (left) and QPO parameters (right) for 4.8GHz data. (Here red noise parameters are not shown)

Conclusions

The red noise-only model gives a good convergence and the posteriors are different for different bands. The red noise + sin model for 4.8GHz data shows a period of 29.25 yrs which is unreliable as it is comparable to the data span. The red noise + QPO model for 4.8GHz data doesn't show any period within the data span implying it is equivalent to the red noise only method. It is observed that the above simplistic model doesn't represent the data completely. So, we want to use the theoretical jet precession model due to SMBHB for further analysis. This technique is computationally expensive so currently developing a computationally efficient code using the algorithm given in Lentati et.al. 2013. It enables us to try various complicated models. We can use this technique to compare the binary central engine model of OJ287 with a single SMBH model using the Bayes factor.

References

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