MULTIWAVELENGTH MONITORING OF THE NUCLEUS IN PBC J2333.9-2343: THE GIANT RADIO GALAXY WITH A BLAZAR LIKE CORE

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INTRODUCTION

One example of the reactivation of AGN activity is from Giant Radio Galaxies (GRGs, Ishwara-Chandra & Saikia 1999 ; Lara et al. 2001), which are characterized by showing linear sizes larger than 0.7 Mpc from radio-lobe to radio-lobe. Some GRGs show multiple episodes of nuclear activity that can be observed in the same radio image at different spatial scales.

PBC J2333.9 −2343 is a GRG at z = 0.047 with a bright central core associated to a blazar nucleus (Hernández-García et al. 2017). If the nuclear blazar jet is a new phase of the jet activity, then the small orientation angle suggests a dramatic **change of the jet direction**. Fig. 1 shows the Very Large Array (VLA) image where the nucleus and the lobes can be observed, and the Very Long Baseline Array (VLBA), zooming into the nuclear región.

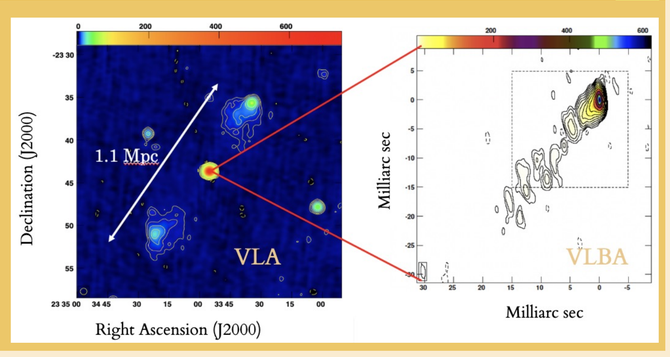

Fig. 1 : Left: VLA image of PBC J2333.9-2343 at kpc resolution Right: VLBA image at mas resolution where the nucleus and a jet can be

01 DATA: MULTIWAVELENGTH MONITORING

We performed a multiwavelength monitoring of the nucleus in 2018 with weekly cadence during four months, plus a daily monitoring with SMARTS-1.3m in 2019 during three months with the following instrumentation:

- **Effelsberg** -> Radio observations at 4.8, 8.5, 10.5, 20.4 GHz
- **SMARTS-1.3m** -> simultaneous NIR/optical in the K and I filters
- ***Swift*** (XRT/UVOT) -> X-ray (0.5-10 KeV) and UV observations (UVM2 filter)
- **Zwicky Transient Facility (ZTF)** -> optical observations in the g,r,i filters
- **Asteroid Terrestrial-impact Last Alert System (*ATLAS*)** -> optical in o,c filters

These data were complemented by archival data from:

- **Fermi** -> Integration at gamma-rays
- **Very Long Baseline Array (VLBA)** -> Radio observation at 15 and 24 GHz
- **Rapid ASKAP Continuum Survey** (**RACS**)-> Radio observation at 0.88 GHz
- **Very Large Array Sky Survey (VLASS)** -> Radio obsevation at 3 GHz

GAMMA-RAY SOURCE:

Fermi detected the source at a **6σ** of confidence level

SPECTRAL ENERGY DISTRIBUTION :

Fitted using JetSet (Tramacere et al. 2009, 2011)

JetSeT
Jets SED modeler and fitting Tool

CROSS CORRELATION :

The SMARTS-1.3m in the IR and optical during 2019 were cross correlated and we obtained a time delay of 1.02±1.45 days. Compatible with a jet origin.

IMPORTANT REMARKS

02 FIGURES

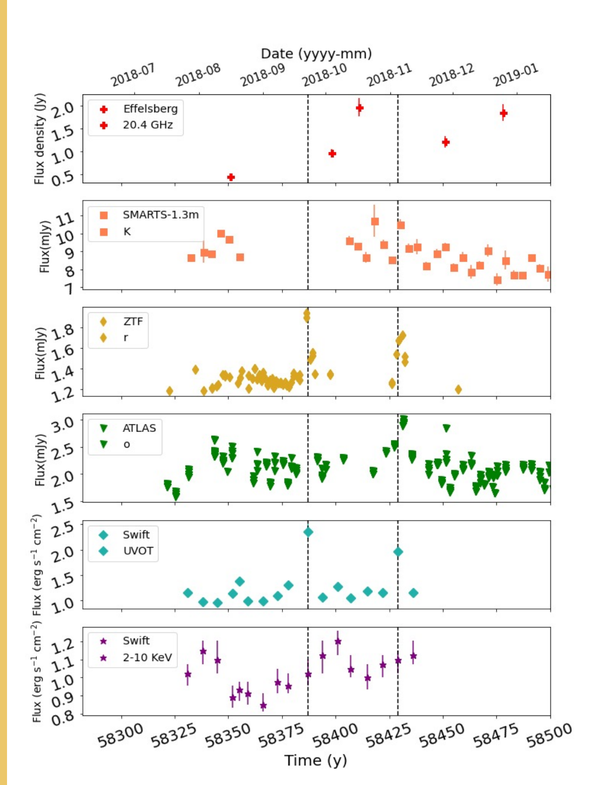

Fig. 2 : Multiwavelength light curve during 2018. Note that, for more clarity, only one light curve per instrument is plotted here. The grey dashed lines represent the peak of the first and second flares as observed by *Swift* / *UVOT* / UVM2 that occurred at MJD = 58387 and 58429.

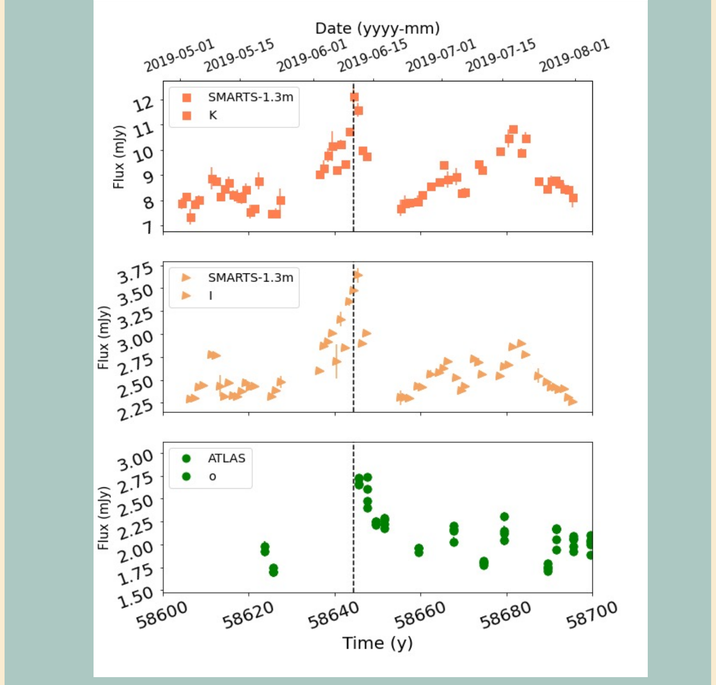

Fig. 3 : Multiwavelength light curve during 2019. Observations are only available with SMARTS-1.3 m and ATLAS. The grey dashed lines represent the peak of the third flare at MJD = 58644.5.

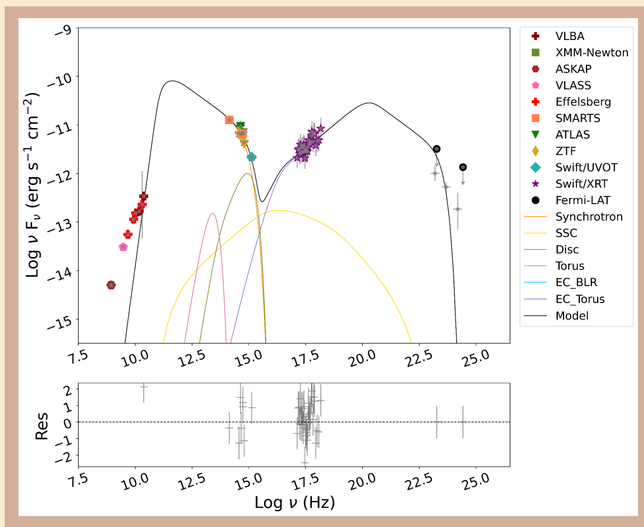

Fig. 4 : The observed frame SED using contemporaneous data from 2018 from the Effelsberg, SMARTS-1.3 m, ZTF, ATLAS, and *Swift* observatories. Additionally, we included data from VLASS, RACS (only for visualization), VLBA, and *Fermi-LAT* . The fit was done using the upper limits from *Fermi-LAT* , but for visualization we also include the 4FGL-DR3 detections.

The solid lines represent the different components of the fitted model: the orange line represents the synchrotron emission, the yellow line represents the synchrotron self-Compton (SSC), the pink line represents the dusty torus, the purple line represents the inverse Compton of the dusty torus, the green line represents the accretion disc, the blue line represents the inverse Compton from the broad line region and the black line is the sum of all the aforementioned components. The bottom panels include the residuals, which correspond to data with systematics.

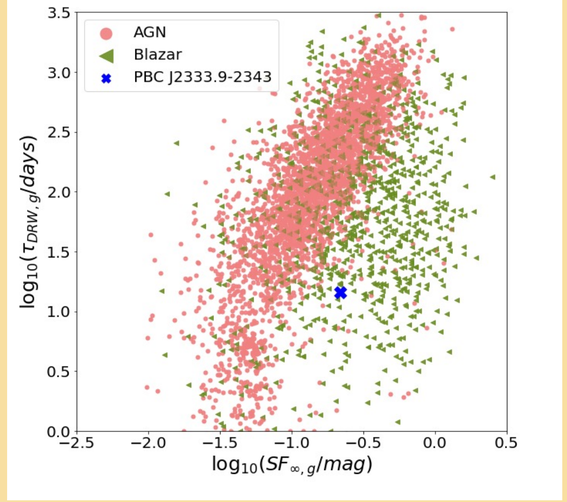

Fig. 5 : Distribution of the Damp Random Walk (DRW) parameters, *τDRW* (in days) against *SF* ∞ (in *mag*), in logarithmic scale, in the g-filter for the ALeRCE training set sample of non-blazar AGN (red circles) and blazars (green triangles). The parameters for PBC J2333.9-2343 are marked as a blue cross.

03 RESULTS/DISCUSSION

The main results obtained from this work are the following:

➔ In Fig. 2 we plot the multiwavelength light curves spanning between MJD = 58320 (2018 July 21st) and 58500 (2019 January 17th).
In Fig. 3, we plot the monitoring performed between MJD = 58600–58700 (2019 April 27th – August 5th).
➔ The observed flux variations show a flaring behaviour. Three events occurred during this monitoring (marked as dotted lines in Fig. 2 and 3) and were detected at different frequencies.
➔ We cross correlated the optical/NIR data from SMARTS-1.3m and obtained a delay of 1.02 ±1.45 days, i.e. compatible with these variations occurring quasi-simultaneously. Comparison with expected variability timescales at the black hole mass and accretion of this source reveals that these variations cannot be related to the NIR coming from a disk or a torus structure, but it is most probably related to jet emission.
➔The SED (Fig. 4) can be explained by an external compton (EC) dominated scenario coming from the dusty torus, with mild contribution of the synchrotron self-Compton (SSC) component at a jet angle of 3 degrees.
➔We used the ALeRCE (Förster et al. 2021, Sánchez-Sáez et al. 2021) light curve classifier repository to compute Damped Random Walk (DRW; Kelly, Bechtold & Siemiginowska 2009) parameters, which are known to be able to differentiate the variability properties of blazar and non-blazar populations of AGN (Ruan et al. 2012), with this galaxy being consisten with a blazar (Fig. 5).

04 CONCLUSION

In this work, we presented a **contemporaneous multiwavelength monitoring of the nucleus** in PBC J2333.9 −2343 that covered two periods, between 2018 September and 2019 January, and 2019 April–July. **Variations are found at all observed wavelengths** at significance larger than 6**σ**, except at X-rays where variations are detected at 2**σ** of confidence level within the four month monitoring period. The observed variations occur **in timescales shorter than a month** and with amplitudes larger than a factor of 2. The cross-correlation between optical/NIR also shows that the variations occur simultaneously in these bands. When comparing the optical variability features with large samples of non-blazar AGN and blazars, PBC J2333.9 −2343 shows characteristics more similar to the blazar population.

According to these results, we interpret the observed variations **as flaring events**. We constructed the SED, that we then fitted using a single-zone leptonic model. The SED shows two distinct peaks, the low energy one is well fitted by synchrotron emission, while the high energy peak is dominated by EC from the torus with some contribution from SSC. This SED was compared with the data already presented in Hernández-García et al. (2017) using VLBA and *XMM-Newton* , and we added *Fermi-LAT* data. **The jet angle in the fitted models is 3 degrees, indicative of a blazar**. These results and the gamma-ray detection at 6**σ** of confidence level strongly suggest the presence of a blazar-like nucleus at the centre of PBC J2333.9 −2343. This galaxy was previously classified as a GRG, suggestive of **a change in the direction of the jet** as previously proposed in Hernández-García et al. (2017). Further evidence in agreement with this scenario is the fact that no connection between the nucleus and the lobes is observed in the deepest radio images, and historical radio fluxes from the NRAO VLA archive survey revealed variations by a factor of seven about 30 yr ago, confirming the pronounced variability in the radio at 20.4 GHz shown in this work.

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