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Using cross-entropy optimization to model AGN light curves from VLBA MOJAVE images

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Abstract. We present in this article a new method to derive the observed properties of outbursts in relativistic jets. We use the VLBI MOJAVE maps to obtain the light curves, based on the principle that the variability of extragalactics sources, in this case 3C 279 and 4C +29.45, should appear in high resolution observations since 1996 until 2016. The use of the Cross Entropy method (CE) can accurately determine the ranges of parameters for a sequence of outbursts based on shock wave model (Marscher & Gear, 1985), where the decay/rise timescale ratio has a small spread and the use of an unique index 1.3 generates a good fit modeled by functions of outbursts (Valtaoja et al., 1999). With this, we can model the shock waves with reference to the distance at the core of AGN to obtain the brightness temperature, the Doppler factor, the Lorentz factor and the viewing angle of the jets. (Hovatta et al., 2009).

Resumo. Apresentamos neste artigo um novo método para derivar as propriedades observadas de explosões em jatos relativísticos. Utilizamos os mapas VLBI MOJAVE para obter as curvas de luz, com base no princípio de que a variabilidade das fontes extragalácticas, neste caso 3C 279 e 4C +29.45, devem aparecer em observações de alta resolução desde 1996 até 2016. O uso do método Cross Entropy (CE) pode determinar com precisão os intervalos de parâmetros para uma sequência de explosões com base no modelo de onda de choque (Marscher & Gear, 1985), onde a taxa de tempo de decaimento/subida "Rise Time" tem um intervalo de variação pequeno e o uso de um índice único 1,3 gera um bom ajuste na modelagem das funções de explosões (Valtaoja et al., 1999). Com isso, podemos modelar as ondas de choque com referência à distância do núcleo do AGN para estimar a temperatura de brilhância, o fator Doppler, o fator de Lorentz e ângulo de visualização do jatos. (Hovatta et al., 2009).

Keywords. galaxies: active – galaxies: jets – galaxies: nuclei – radio continuum: galaxies – techniques: interferometric – methods: statistical.

1. Introduction

The radio observations obtained from the MOJAVE (2 cm Survey) (Lister et al., 2009), $FERMI-LAT$ (Hayashida et al., 2015) and OVRO 40 m telescope monitoring program (Richards et al., 2011) show evidence of prominent structures or outbursts, propagating from high to low frequencies. Modelling the variability of blazars has been the subject of several studies. A general form of understanding the outbursts was made by Marscher & Gear (1985). Valtaoja et al. (1988) attempted to separate the quiescent from the flaring flux through multiwavelength flux-density curves (several frequencies from 4.8 to 90 GHz) where the authors examined the spectrum of each source at periods of minimum flux density between outbursts (what they considered as the 'constant' flux density of the jet) and a recent work (Liodakis et. al, 2017) presented a bimodal radio variability through OVRO 40m telescope. In this work we will demonstrate a similar behavior for the OVV blazar 3C 279 and the blazar 4C +29.45. An innovative method in this work is the use of a statistical accuracy algorithm, called Cross Entropy (CE) (Rubinstein, 1997), where it is possible to infer details of the behaviour of light curves. The peaks of outbursts observed in the light curves at 4.8, 8.0 and 14.5 GHz (UMRAO Database), 1.7, 22, 37, 90, 150, 230 and 375 GHz (Lindfors et al., 2006) show the individual outbursts as a sum of smaller peaks decomposed by the shock wave model. We started with 24 up to 33 outbursts, with this incremental coverage it is possible to be estimated the number of such events. In this article only the results for 33 outbursts will be shown. Another object shown in this work is the 1156+295 (4C +29.45), which also has VLBI maps available in the MOJAVE, whose period of observations are between 07/04/1995 until 02/11/2012. For this object we use 24 outbursts. In Hovatta (2009), the 1156+295 flux curve was decomposed into exponential outbursts at 22 GHz. The method of approach and decomposition of the outbursts for this object follow the same standards as described for 3C 279.

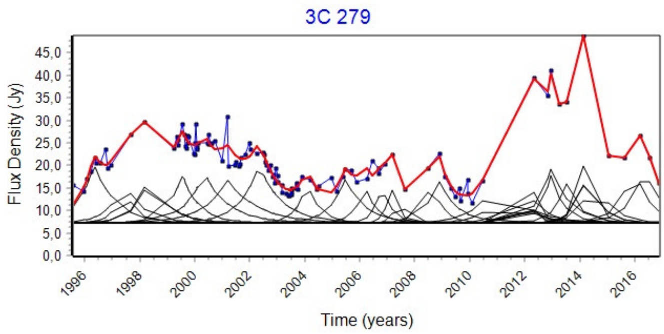

FIGURE 1. Results by the decomposition of about 33 outbursts for 3C 279. The main properties of light curve are observed.

2. Results

The figs. 1 and 2 show the results by the decomposition of about 33 outbursts for 3C 279 and ≈ 24 outbursts for 4C +29.45 respectively. The main properties of light curve are observed. Fig. 1 shows the fitting found for decomposition into smaller components based on self similar formations at 15.3 GHz.

Figures 1 to 5 showing the convergence of the parameters

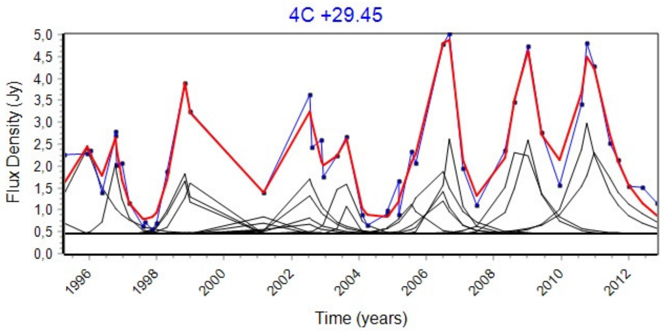

Figure 2. The CE method calculated the best fit for ≈ 24 outbursts for 4C +29.45.

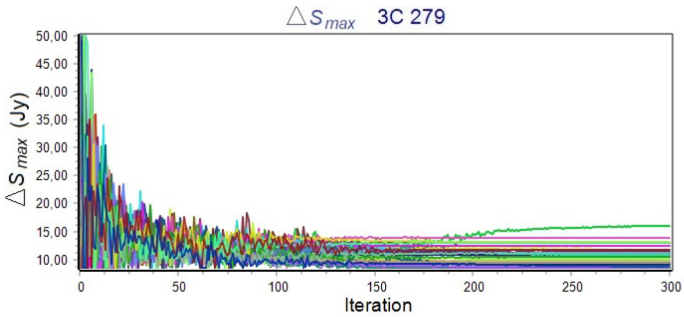

Figure 3. Convergence of ΔS_{max} values for each estimated outburst. The limits were fixed from 8.5 to maximum of 50.0 Jy. The CE found values between ≈ 8.5 to ≈ 16.02 Jy for individual outburst. Each line represents the evolution in the search for better results, in this case for ΔS_{max} of each shock wave. CE starts by varying values until it finds a better and more stable value. A stable value means that automatically the sigma value of each parameter for each outburst has decreased enough to obtain the best values when the variations end.

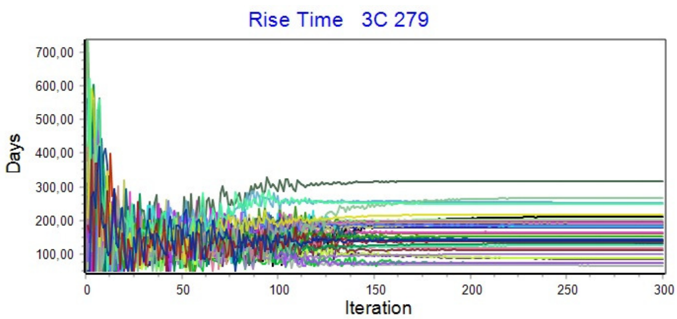

Figure 4. Interval found for the smallest and largest rise time for 3C 279 (MOJAVE), as a dispersion.

3. Conclusions

The decomposition of curves by a statistical method such as CE can be a useful tool to estimate both the amplitudes (flux density) as the rise time of the outbursts. The results obtained in this article show values close to those described in previous articles (Lindfors et al., 2006), where the variations of rise time are between 0.30 to 3.57 years at 43 GHz. The equations to obtain the Doppler and Lorentz factors are sensitive to $\log(T_b)$, which have imposed to CE a number of iterations enough to get a rise time. The brightness temperatures found in this work, at least for 3C 279, depending on the rise time, are in agreement with previous works (Hovatta et al., 2009).. For 4C +29.45 a minimum of ≈ **40** days was found for τ, and for this parameter the results are predominant in the range **100-230** days, suggesting a lower brightness temperature.

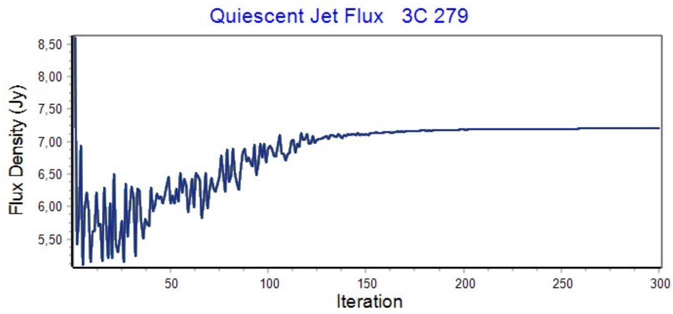

Figure 5. Calculation of convergence for the quiescent jet flux density.

Table 1. Values found by the CE method for $\mathrm{Log}(T_b)$, D_{var}, Γ_{var} and θ_{var} obtained by ΔS and τ minimum and maximum depending on the variation found by parameters of each outburst. The table also shows the results from (Prev.) analyses for comparison obtained from Hovata et al. (2009). The z values are 0.536 and 0.729 for 3C 279 and 4C +29.45 respectively.

Name	Ref.	$\mathrm{Log}(T_b)$	D_{var}	β_{app}	Γ_{var}	θ_{var}
3C 279	**Min.**	**14.82**	**23.71**	**20.64**	**20.86**	**2.39**
4C +29.45	**Min.**	**14.43**	**17.59**	**24.85**	**26.38**	**3.07**
3C 279	Max.	13.51	8.66	20.64	28.99	4.72
4C +29.45	Max.	13.27	7.22	24.85	46.47	4.25
3C 279	**Prev.**	**14.84**	**24.00**	**20.64**	**20.90**	**2.40**
4C +29.45	**Prev.**	**15.06**	**28.50**	**24.85**	**25.10**	**2.00**

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