Time-dependent modelling of PKS 2155-304 in a low state: One- or two-zone emission modelling ?

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Abstract

One-zone radiation models have been widely used in modelling the steady-state multiwavelength (MW) spectra of blazars, having as main goal the determination of the physical conditions in the emitting region, such as the magnetic field strength, the species of radiating particles etc. Then, the results from one-zone stationary modelling are often used as a stepping stone for studying flaring events. Here we show that the application of steady-state one-zone models on intrinsic variable sources, even when these are in a low state, can be misleading. Although the one-zone SSC and proton synchrotron models succeed in fitting the time-averaged MW spectrum, they cannot easily (or at all) reproduce the small amplitude multifrequency variability. We show that a two-component leptonic model addresses both spectral and temporal observations more successfully, albeit at the expense of more free parameters.

Introduction

In the present work we apply three models: (i) One-component SSC model (**1-SSC**), (ii) leptohadronic proton synchrotron model (**LHs**) and (iii) two-component SSC model (**2-SSC**) to the MW observations of blazar PKS 2155-304 at redshift $z = 0.116$ in a low state [1], since (i) the blazar was for the first time monitored simultaneously in four energy bands (optical, X-rays, GeV and TeV γ-rays) and (ii) the blazar was observed in a low state with marginal variability at least at two energy bands (optical and GeV's) implying that the underlying physical conditions do not vary significantly.

Model description

Although the method we follow is similar to that described in [2], it has the novel feature of **time-dependent** fitting using a **leptohadronic model** (LHs) – application of **stationary** solutions within leptohadronic models on MW spectra of PKS 2155-304 can be found in [3]. Details about the numerical code we have used can be found in [4, 5].

In all cases we have used a two-step process: (**i**) Determine for which parameter values an acceptable fit to the average SED is obtained; (**ii**) *Vary one or more parameters* following the variability pattern observed in specific energy band(s). The amplitude of the parameter variations is determined by trial and error until an acceptable fit to one or more light curves is obtained. The only parameters that we have varied are: (i) maximum energy of electrons (1-SSC; 2-SSC; LHs) according to $\gamma^e_{\max} = \langle\gamma^e_{\max}\rangle\left(\alpha_1 F_X(\tau)/F_X^{\max}\right)^{\beta_1}$ and $\gamma^e_{\max} = \langle\gamma_e^{\max}\rangle\left(\alpha_2 F_{opt}(\tau)/F_{opt}^{\max}\right)^{\beta_2}$, where the subscripts 1, 2 refer to the first and second component respectively; (ii) electron/proton injection compactness (LHs) according to $\ell_{e,p} = \langle\ell_{e,p}\rangle\left(F_{opt}/F_{opt}^{\max}\right)/f_{e,p} + g_{e,p}$. The parameters used in our modelling are summarized in the Table below.

Variable	1-SSC	2-SSC		LHs
α_1, β_1	1.5,0.7	2.0, 1.8		2.0, 1.8
α_2, β_2	–	2.0,1.0		–
f_e, f_p	–	–		0.6, 0.5
g_e, g_p	–	–		0.0, 0.5
Fixed		1st	2nd	
B (G)	0.5	20	0.3	40
R (cm)	10^{16}	3×10^{15}	1.5×10^{16}	10^{16}
δ	34	18	34	28
$\gamma^e_{\rm min,max}$	$10^{3.6}, 10^{5.3}$	$10^{3.8}, 10^{4.8}$	$10^{3.6}, 10^{4.3}$	$10^{3.0}, 10^{4.7}$
ℓ_e	$10^{-4.3}$	$10^{-3.5}$	$10^{-4.2}$	$10^{-4.35}$
p_e	2.4	3.0	1.8	2.6
$\gamma^p_{\rm min,max}$	–	–	–	$10^7, 10^{9.9}$
ℓ_p	–	–	–	$10^{-6.5}$
p_p	–	–	–	2.4

References

[1] Aharonian F. et al. 2009, *ApJL*, **696**, L150-L155

[2] Krawczynski H. et al. 2002, *MNRAS*, **336**, 721-735

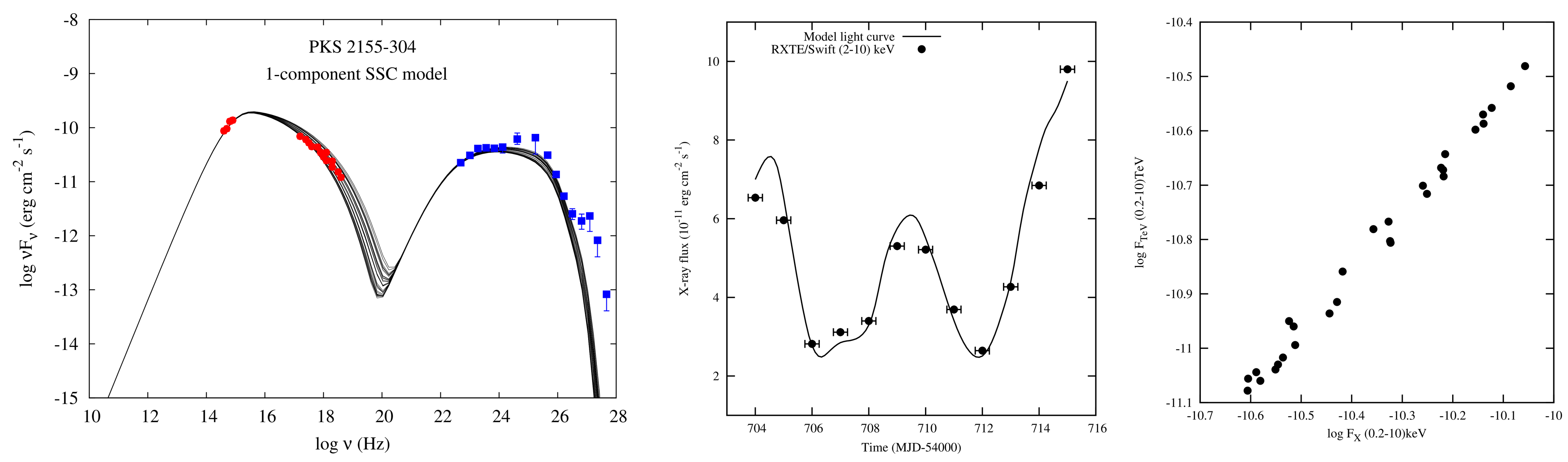
[3] Cerutti M. et al. 2012, *AIPC*, **1505**, 635-638

[4] Dimitrakoudis S. et al. 2012, *A&A*, **546**, 120D

[5] Mastichiadis A. et al. 2013, submitted in *MNRAS*

One-component SSC model

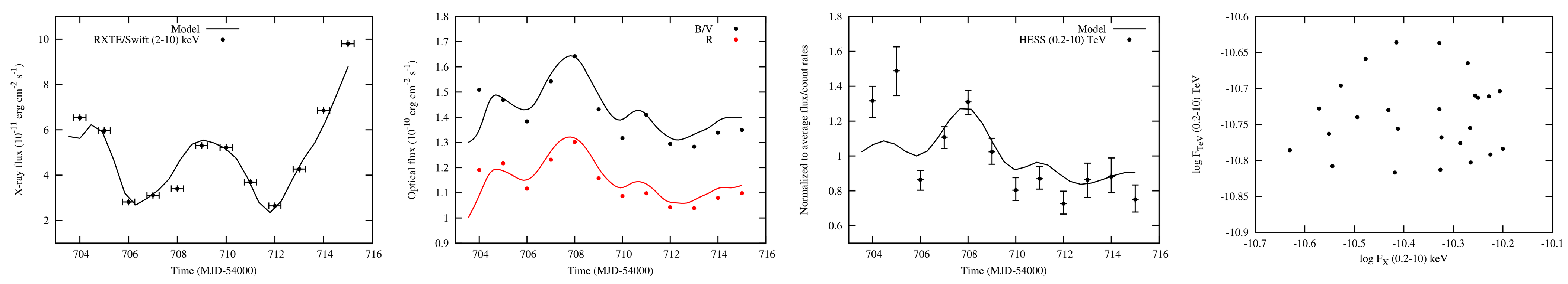
Left panel: Multiwavelength time dependent spectra during the period 54704-54715 MJD. Simultaneous observations with ATOM, RXTE, Fermi and H.E.S.S. (low-to-high frequencies) are shown with points. **Middle panel**: X-ray model lightcurve (solid line) and RXTE/*Swift* observations (points). **Right panel**: Log-log plot of the TeV-flux versus the X-ray flux obtained by our model.



- **Pros**: X-ray variability is fairly well reproduced with small amplitude variations of $\gamma^e_{\max}$: $\frac{\delta \log(\gamma^e_{\max})}{\langle\log\gamma^e_{\max}\rangle} = \frac{\max\log\gamma^e_{\max}}{\langle\log\gamma^e_{\max}\rangle} - 1 \simeq 0.02$.
- **Cons**: (i) Tight correlation of X-ray and TeV γ-ray fluxes which is not detected; (ii) the model does not reproduce the observed optical variability [1].

LHs model

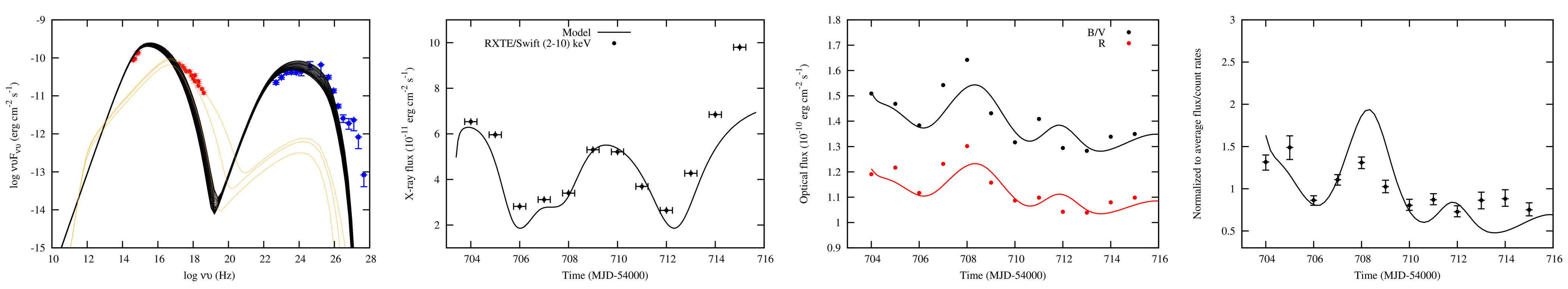
From left to right: X-ray model lightcurve (solid line) and RXTE/*Swift* observations (points); Optical model lightcurves (solid lines) and ATOM data (BV: black points; R: red points); Plot of the normalized model TeV flux (solid line) and H.E.S.S. photon count rate (points) with respect to their time-averaged values; Log-log plot of the TeV-flux versus the X-ray flux obtained by our model.



- **Pros**: (i) X-ray, optical and TeV variability are fairly well reproduced with small amplitude variations of the parameters; (ii) no significant correlation between X-ray and TeV flux is found, (iii) the maximum relative change of the GeV (logarithmic) flux with respect to its time-averaged value is ~ 0.01, which is compatible with an almost constant value.
- **Cons**: Fine tuning of three parameters, i.e. $\gamma^e_{\max}, \ell_e$ and ℓ_p, is required.

2-component SSC model

Here we show in addition to the lightcurves the MW spectra emitted by the 1st (orange lines) and 2nd (black lines) component. For clarity reasons, only three snapshots of the 1st component are plotted.



- **Pros**: (i) X-ray, optical and TeV variability are fairly well reproduced; (ii) no correlation between X-ray and TeV flux is found since the are produced by different unrelated components; (iii) for larger variations of the 2nd component, a correlation between X-rays and TeV gamma-rays is predicted.
- **Cons**: (i) The total number of free parameters is increased; (ii) small amplitude variations of $\gamma^e_{\max}$ cannot reproduce the high X-ray flux observations mainly due to the steep electron distribution.

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