Fitting the spectral energy distributions of blazars with the JetSeT code

JetSeT

Jets SED modeler and fitting Tool

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https://jetset.readthedocs.io/en/latest/
https://github.com/andreatramacere/jetset
https://www.facebook.com/jetsetastro/
JetSeT functionalities and scope

- handling observed data (groping, definition of data sets, etc...)
- definition of complex radiative models SSC/EC IC against CMB/BLR/DT, plus analytical and template models
- constraining of the model in the pre-fitting stage, based on accurate and already published phenomenological trends
- fitting of multiwavelength SEDs using both frequentist approach (iminuit/scipy) and Bayesian MCMC sampling (emcee)
- reproduction of the temporal evolution of the plasma under the effect of radiative and accelerative processes. Both first order and second order (stochastic acceleration) processes.
- Currently used by large collaborations MAGIC/FERMI (CTA under test) and single researchers and for didactic in universities ~ 10 users
- I will a Hands-on session at the MultiMessenger School in Asiago next week
Notebooks that cover the content of the following slides

- Notebooks for the Asiago MultiMessenger School
- https://github.com/andreatramacere/jetset/tree/master/notebooks

Jetset User guide

In this paper, we propose a phenomenological approach to study the properties of blazars. The analysis is based on the spectral features of the rising part of the IC component.

The paper is organized as follows: In Section 1, we discuss the physical setup for the analysis. In Section 2, we describe the sample of objects and their properties. In Section 3, we compare the numerical trends with theoretical predictions. Finally, in Section 4, we present the results and discuss their implications.

We work in a leptonic SSC framework. The rationale of our analysis is intuitive and based on the effectiveness of the method in deriving the acceleration time and the escape time. The data used are from the Fermi-LAT and Swift/BAT observations.

In Section 3, we investigate how the hard X-ray photon index depends on the range of the hard X-ray spectral window. We also examine the case of HSPs for a SSC scenario.

The figure shows how the Fermi-LAT and Swift/BAT observations sample the IC component for FSRQs and LBLs. The top and middle panels of the same figure show the typical SEDs of FSRQs.
Beamed Emission

\[ t_{\text{obs}} \sim t_{\text{em}} / \delta \]

\[ \nu_{\text{obs}} \sim \nu_{\text{em}} \delta \]

\[ \Omega_{\text{obs}} \sim \Omega_{\text{em}} / \delta^2 \]

\[ L \sim \nu \Omega^{-1} t^{-1} \rightarrow L_{\text{obs}} \sim \delta^4 L_{\text{em}} \]

rest frame: isotropic emission

Observer frame: beamed

Beaming factor:

\[ \delta = \Gamma / (1 - \beta \cos(\theta)) \]

\[ \theta = 1 / \Gamma \]

\[ \nu_{\text{obs}} = \delta \nu_{\text{em}} \]

\[ L_{\text{obs}} = \delta^4 L_{\text{em}} \]
Variability and emitting region size $R$

$$R \leq c \frac{\Delta t \delta}{(1+z)}$$
X-ray SPECTRAL DISTRIBUTION OF HBLs (stochastic acceleration)

\[ S(E) = S_p \times 10^{-b \left( \log\left( E/E_p \right) \right)^{2}} \]

- \( b \): curvature at peak
- \( E_p \): peak energy
- \( S_p \): SED height @ \( E_p \)
HBL: Fermi I+II Fermi II Mrk 421 2006

LP+PL spectra
Synch index ~ [1.6-1.7] => s ~ [2.2-2.4]

Lemoine, Pelletier 2003 FI multip.

Ball+ 2019 magnetic reconnection (PIC)
distance, we set a reference value of
is the Schwarzschild radius for a BH mass
flaring SSC emission. The red and blue thick dotted lines correspond to the
BAT data represent the five year fluxes discussed in Section
Figure 24. (a) analyzing the UVOT data of PKS
UVOT (filled circles) during March
exposure (JD
exposure (JD
a) suggesting a di
peak seems to be delayed with respect
the random walk of atoms and ions within the emitting region,
this is another proof of the fact that the rapid increase of the op-
therefore such increase of the degree of polarization is a clear
the NIR data for the same SED are collected by REM at JD
M
−
5
17
<
M
−
12
14
<
M
−
5
⊙
ν

erg s
−
ν
2008
×
10
−
1998
×
10
−
1998
×
10
−
1998
×
10
−
1998
×
10
⋅
0.1
(\text{Ghisellini et al.} (2009))

The red solid circles correspond to simultaneous optical

Instead, the SED of PKS 1510
Fig. 6.

Differences between the SED of the low-energy part of the spectrum constructed with

Upper panel: the SEDs for the different values of the high-

Lower panel: optical

suggesting a di

1510
could be partially due to the fact that it is more di

and a significant rise of the spectrum at UV due to the accretion

between 18 and 26 March 2009. Similarly to the harder-when-

disk emission, as already observed on 20–22 March 2008. On

confirmation the evidence of thermal signatures in the optical

contribution in the optical part likely due to the little blue bump

energy branch of synchrotron emission depending on the activity

are likely due to pure synchrotron, as shown in Fig.

The NIR data for the same SED are collected by REM at JD

March 18, 2009
March 23, 2009
March 25–26, 2009

FSRQs
SED shaping and constraining the electron distribution

![Graphical representation of SED shaping and constraining the electron distribution](image-url)
Synchrotron emission Estimate of $\gamma_p^s$ from $\nu_p^s$

$$\nu_p^{Sync} \sim 3.2 \times 10^6 \ (\gamma_{3p})^2 \ B \ \delta$$

$$S_{p}^{Sync} \sim \frac{dN(\gamma)}{d\gamma} \gamma_{3p}^3 \ B^2 \ \delta^4$$
Synchrotron emission Estimate of $\gamma_{min}$ from spectral index
Synchrotron emission Estimate of $s$ from spectral index
Adding the IC emission SSC case
IC emission TH/KN regime and peak freq.

\[ \nu_{p\ IC} / \nu_{p\ S} \sim (4/3) \gamma_p^2 \equiv \gamma_{p\ IC}^2 \] is true only in TH regime
IC emission TH/KN regime and peak curvature

\[ \gamma \]

\[ \gamma_{\text{min}} \]

\[ r \]

\[ r_{\text{lower}} \]

\[ r_{\text{higher}} \]
External Compton Scenario

\[ I_{\nu} = \frac{1}{4\pi} \int d\Omega' \delta^3 I_{\nu'}(\nu'/\Gamma) \]

\[ = \Gamma \frac{L_{\text{bne}}}{4\pi R^2} f_{\nu'}(\nu'/\Gamma, T_{\text{ext}}) \]

\[ u'_{\text{ext}} \simeq \Gamma^2 u_{\text{ext}} \]

\[ L_{\text{ERC}} \simeq \Gamma^6 U_{\text{ext}} \]

\[ \eta = \frac{\dot{\gamma}/I_C}{\dot{\gamma}/\text{sync}} = \frac{U_{\text{ph}}}{U_B} \]

\[ \epsilon^{-3} I_{\epsilon} \quad \text{and} \quad \epsilon^{-2} j(\epsilon, \Omega) \]

\[ \frac{u(\epsilon, \Omega)}{\epsilon^3} = \frac{u'(\epsilon', \Omega')}{\epsilon'^3} = \text{inv.} \]
External Compton Scenario and TH/KN
External Compton Scenario and external seed photons energy

\[ \nu_{p, EC} \sim \left(\frac{4}{3}\right) \gamma^2 \nu''_{p, ext} \delta \Gamma / (1+z) \]

\[ \nu'_{\text{seed-IC}} = \nu''_{p, ext} \Gamma \]
JetSeT models

base model

parameter

Value
ModelParameterArray
ModelParameter

base_model

jet_model

numerical

ModelParameter → JetParameter
Model → Jet
ElectronDistribution

log_log_poly_model

analytical

ModelParameter → PolyParameter
Model → LogLogModel
LogLinear
LogCubic
LogParabolaEp
LogParabolaPL

template_model

template
JetSeT jet model definition

- jet_kernel (C/engine)
- third party models
- JetSpecComponent
- JetParameter
- ElectronDistribution
JetSeT SED shaping: log-log fit and peaks

<table>
<thead>
<tr>
<th>Model: sync-shape-fit</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Type</td>
</tr>
<tr>
<td>b</td>
<td>curvature</td>
</tr>
<tr>
<td>c</td>
<td>third-degree</td>
</tr>
<tr>
<td>Ep</td>
<td>peak freq</td>
</tr>
<tr>
<td>Sp</td>
<td>peak flux</td>
</tr>
<tr>
<td>nuFnu_p_host</td>
<td>erg cm^-2 s^-1</td>
</tr>
<tr>
<td>nuFnu_scale</td>
<td>erg cm^-2 s^-1</td>
</tr>
<tr>
<td>nu_scale</td>
<td>Hz</td>
</tr>
</tbody>
</table>

**SED shaping**

- $E_p$, $S_p$, $b$
- $E_p^{IC}$, $S_p^{IC}$

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**Best fit parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>best-fit value</th>
<th>best-fit err</th>
<th>best-fit err - start value</th>
<th>fit boundaries</th>
</tr>
</thead>
<tbody>
<tr>
<td>b</td>
<td>-1.63463e-01</td>
<td>1.27406e-02</td>
<td>-1.61576e-01</td>
<td>[-1.000000e+00, 0.000000e+00]</td>
</tr>
<tr>
<td>c</td>
<td>-1.10232e+01</td>
<td>1.47859e+01</td>
<td>-1.18331e+01</td>
<td>[-1.000000e+00, 0.000000e+00]</td>
</tr>
<tr>
<td>Ep</td>
<td>1.07138e+01</td>
<td>5.01725e+02</td>
<td>1.05994e+01</td>
<td>[-0.000000e+00, 0.000000e+00]</td>
</tr>
<tr>
<td>Sp</td>
<td>-9.68052e+00</td>
<td>3.721703e+03</td>
<td>-9.68052e+00</td>
<td>[-3.000000e+00, 0.000000e+00]</td>
</tr>
<tr>
<td>nuFnu_p_host</td>
<td>2.54478e+02</td>
<td>2.83984e+04</td>
<td>1.000000e+00</td>
<td>[-5.000000e+00, 0.000000e+00]</td>
</tr>
<tr>
<td>nuFnu_scale</td>
<td>6.17387e+01</td>
<td>5.01725e+02</td>
<td>6.17387e+01</td>
<td>[-0.000000e+00, 0.000000e+00]</td>
</tr>
<tr>
<td>nu_scale</td>
<td>6.17387e+01</td>
<td>5.01725e+02</td>
<td>6.17387e+01</td>
<td>[-0.000000e+00, 0.000000e+00]</td>
</tr>
</tbody>
</table>

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**Class:** HSP

**sync** nu_p = 1.07138e+01 (err = 5.61725e+02) nuFnu_p = -9.68052e+00 (err = 3.721703e+02) curv. = -1.
JetSet SED model constraining: SSC

```python
from jetset.obs_constrain import ObsConstrain
from jetset.model_manager import FitModel
from jetset.minimizer import fit_SED

sed_observ=ObsConstrain(beam=25,
    B_range=[0.001, 0.1],
    distr_e='plc',
    t_var_sec=3e86400,
    nu_cut=1e13,
    SEDShape=my_shape)

jet=sed_observ.constrain_SSC_model(electron_distribution_log_values=False)
pl=jet.plot_model(sed_data=sed_data)
pl.rescale(x_min=-15, x_max=29)
```

Model constraining

We pass the `sed_shape` object
JetSeT model fitting: SSC

from jetset.model_manager import FitModel
jet.set_gamma_grid_size(200)

fit_model = FitModel(jet=jet, name='SSC-best-fit', template=my_shape.host_gal)
fit_model.freeze('z_cosm')
fit_model.parameters.gmax.fit_range=[1E5, 1E8]
fit_model.freeze('R')
fit_model.parameters.nuFnu_p_host.frozen=True
fit_model.parameters.nu_scale.frozen=True
fit_model.show_pars()
JetSeT model fitting MCMC

model_manager

mcmc

mcmcSampler

minimizer

ModelMinimizer
LSBMinimizer
Minimizer
LSMinimizer
FitResults
MinutMinimizer
JetSeT temporal evolution

IC cooling and equilibrium

$R = 1 \times 10^{15}$ cm

$R = 5 \times 10^{13}$ cm

Tramacere +2011
Pile-up and hard spectra

Mrk 501 2014 Flare
MAGIC paper (accepted)
backup slides