

naima: a Python package for inference of particle distribution properties from nonthermal spectra

Víctor Zabalza

University of Leicester, University Road, Leicester, LE1 7RH, United Kingdom

Email: Victor.Zabalza@le.ac.uk

The ultimate goal of the observation of nonthermal emission from astrophysical sources is to understand the underlying particle acceleration and evolution processes, and few tools are publicly available to infer the particle distribution properties from the observed photon spectra from X-ray to VHE gamma rays.

We present **naima**, an open source Python package that provides models for nonthermal radiative emission from homogeneous distribution of relativistic electrons and protons, as well as tools to infer their properties from nonthermal spectra.

Features of **naima**

- Open source (3-clause BSD style license), modular Python package.
- Extensive use of **astropy** (Astropy Collaboration et al., 2013) features such as physical units and data table management.
- **Radiative models** using established parametrizations of the processes with selection of particle distribution function:
 - Synchrotron (Aharonian et al., 2010).
 - Inverse Compton scattering of graybody seed photon fields (Khangulyan et al., 2014).
 - Nonthermal bremsstrahlung (Haug, 1975; Baring et al., 1999).
 - Neutral pion decay (Kafexhiu et al., 2014; Kelner et al., 2006).
- **Tools to fit these radiative models to observed nonthermal spectra.** This is done through MCMC sampling (with the **emcee** package; Foreman-Mackey et al. 2013) of a likelihood function that assumes Gaussian, independent uncertainties on the flux measurements. The sampling allows to obtain in a single run:
 - The Maximum Likelihood (ML) parameters.
 - The posterior distribution of the free parameters, from which marginalised median values and uncertainties can be derived.
 - The posterior distribution of secondary values such as the total energy content in particles for a given energy.
- **Tools to analyse and plot the results of the MCMC run.**
- Wrappers for the radiative models to be used in the **sherpa** spectral analysis package (Freeman et al., 2001).

How to get it and use it

You can install **naima** in any scientific Python installation with:

```
$ pip install naima
```

And start using with the example analysis scripts in the documentation.

The documentation is available at <http://naima.readthedocs.org>



The source code and issue tracker at <http://github.com/zblz/naima>

Example application: VHE γ -ray spectrum of RX J1713–3946

As an example application of **naima**, we use a power law with a high-energy exponential cutoff as the particle distribution function (`naima.models.ExponentialCutoffPowerLaw`) and compare the results for a leptonic (`naima.models.InverseCompton`) or hadronic (`naima.models.PionDecay`) radiative model. The models are fit to the 2007 H.E.S.S. spectrum of the shell-like supernova remnant RX J1713–3946 (Aharonian et al., 2007) using the **naima** function `naima.run_sampler`. The inferred particle distribution parameters can then be used to discuss the feasibility of a given model considering the acceleration and cooling physics of the source.

Leptonic model

In a leptonic scenario where the seed photon fields are known, the particle spectrum can be inferred directly from the gamma-ray spectrum. Here we consider the Cosmic Microwave Background Radiation and a galactic far infrared component ($T = 27$ K, $u = 0.4$ eV cm⁻³, from GALPROP; Porter et al. 2006) as seed photon fields.

Inferred particle distribution parameters (median and 1σ uncertainty):

- $\Gamma_e = 2.6 \pm 0.1$
- $E_{e,cutoff} = 51^{+15}_{-12}$ TeV
- $W_e(E_e > 1\text{TeV}) = (1.07 \pm 0.08) \times 10^{47}$ erg

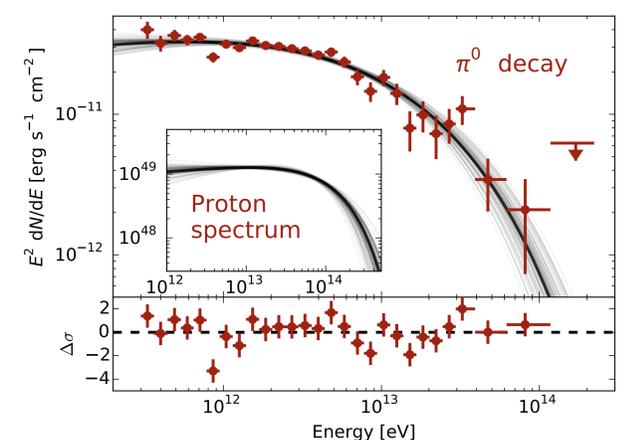
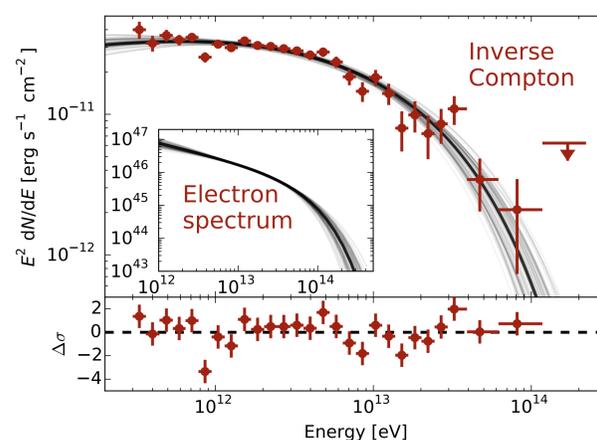
Hadronic model

In a hadronic scenario the gamma-ray emissivity is proportional to both the energy in relativistic protons and the density of the target gas clouds. In addition, the gas density is bound to be inhomogeneous over a complex remnant such as RX J1713–3946, so we can only infer the normalization of the proton spectrum times the average gas density.

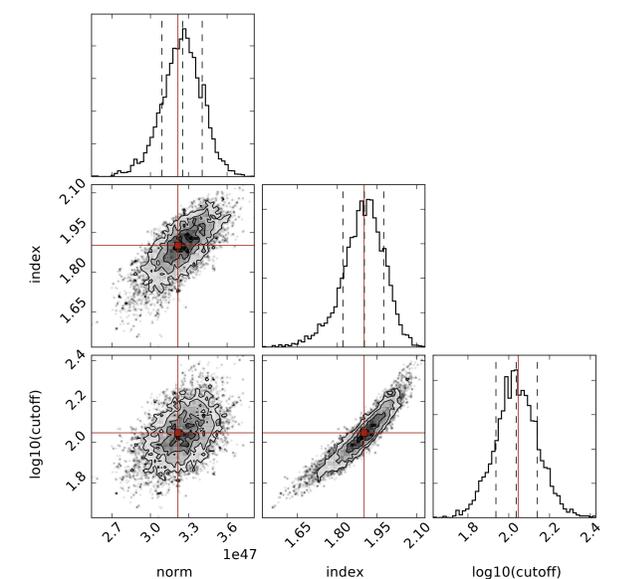
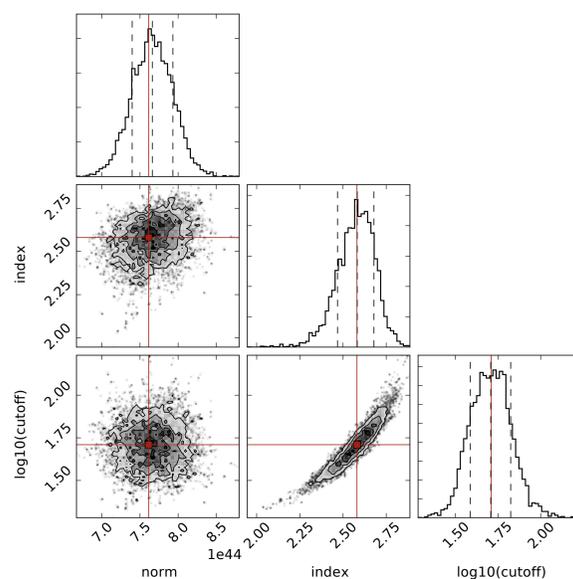
Inferred particle distribution parameters (median and 1σ uncertainty):

- $\Gamma_p = 1.90 \pm 0.08$
- $E_{p,cutoff} = 109^{+30}_{-20}$ TeV
- $W_p(E_p > 1\text{TeV}) = (6.1 \pm 0.2) \times 10^{49}$ erg

H.E.S.S. spectrum and radiative output of the model



Posterior distribution of the free particle spectrum parameters



References

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