The ablation of gas clouds by blazar jets and the long-lasting flare in CTA 102

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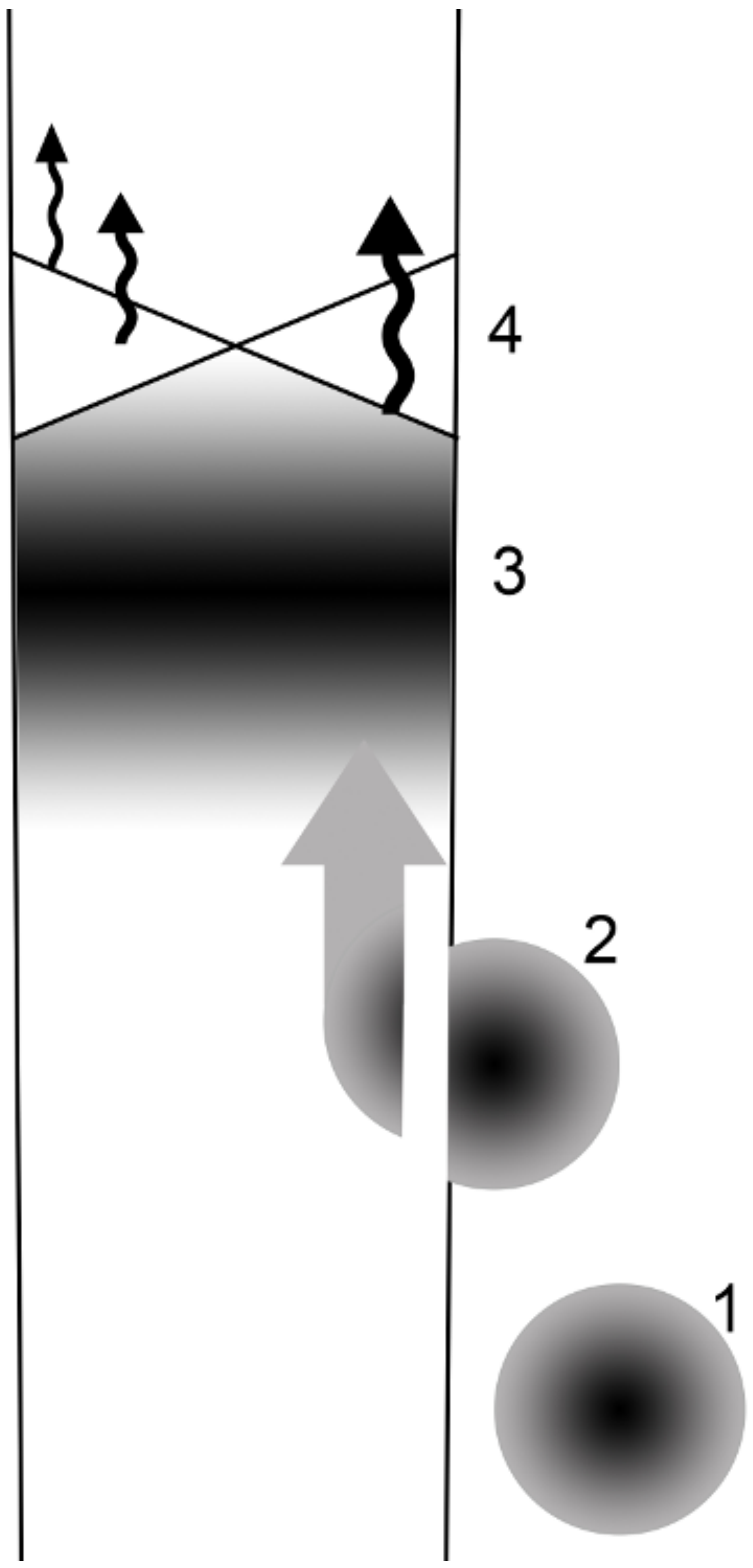
Abstract
Long-lasting, very bright multiwavelength flares of blazar jets are a curious phenomenon. The interaction of a large gas cloud with the jet of a blazar may serve as a reservoir of particles entrained by the jet. The size and density structure of the cloud then determine the duration and strength of the particle injection into the jet and the subsequent radiative outburst of the blazar. In this presentation, a comprehensive parameter study is provided showing the rich possibilities that this model offers. Additionally, we use this model to explain the 4-months long, symmetrical flare of the flat spectrum radio quasar CTA 102 in late 2016. During this flare, CTA 102 became one of the brightest blazars in the sky despite its large redshift of z=1.032.



The cloud ablation model

(1) An isothermal, self-gravitating gas cloud slowly approaches the relativistic jet of a blazar. The density structure $n(r)$ as function of radius r is:

$$n(r) = \frac{n_0}{1 + \left(\frac{r}{r_0}\right)^2}$$

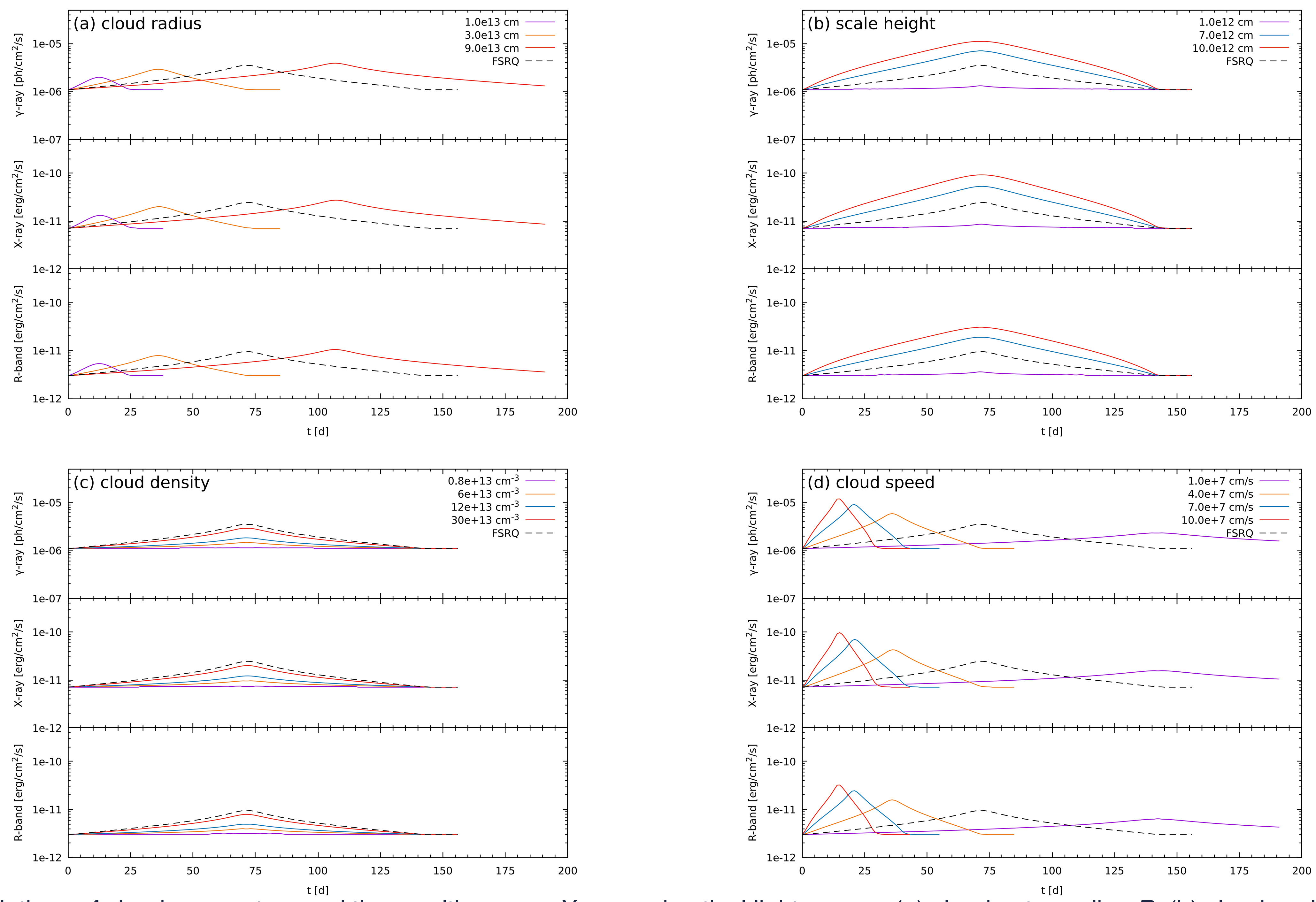
with the scale height $r_0 \propto \sqrt{T/n_0}$, the temperature T and central density n_0 of the cloud. We set an outer radius R, where the cloud ends.

(2) The ram pressure of the jet ablates the cloud volume that has penetrated the jet

(3) The slow ablation process along with the density structure of the cloud result in a specific density profile being added to the jet flow

(4) At a shock in the jet, the increased density causes a flare with a characteristic flux evolution

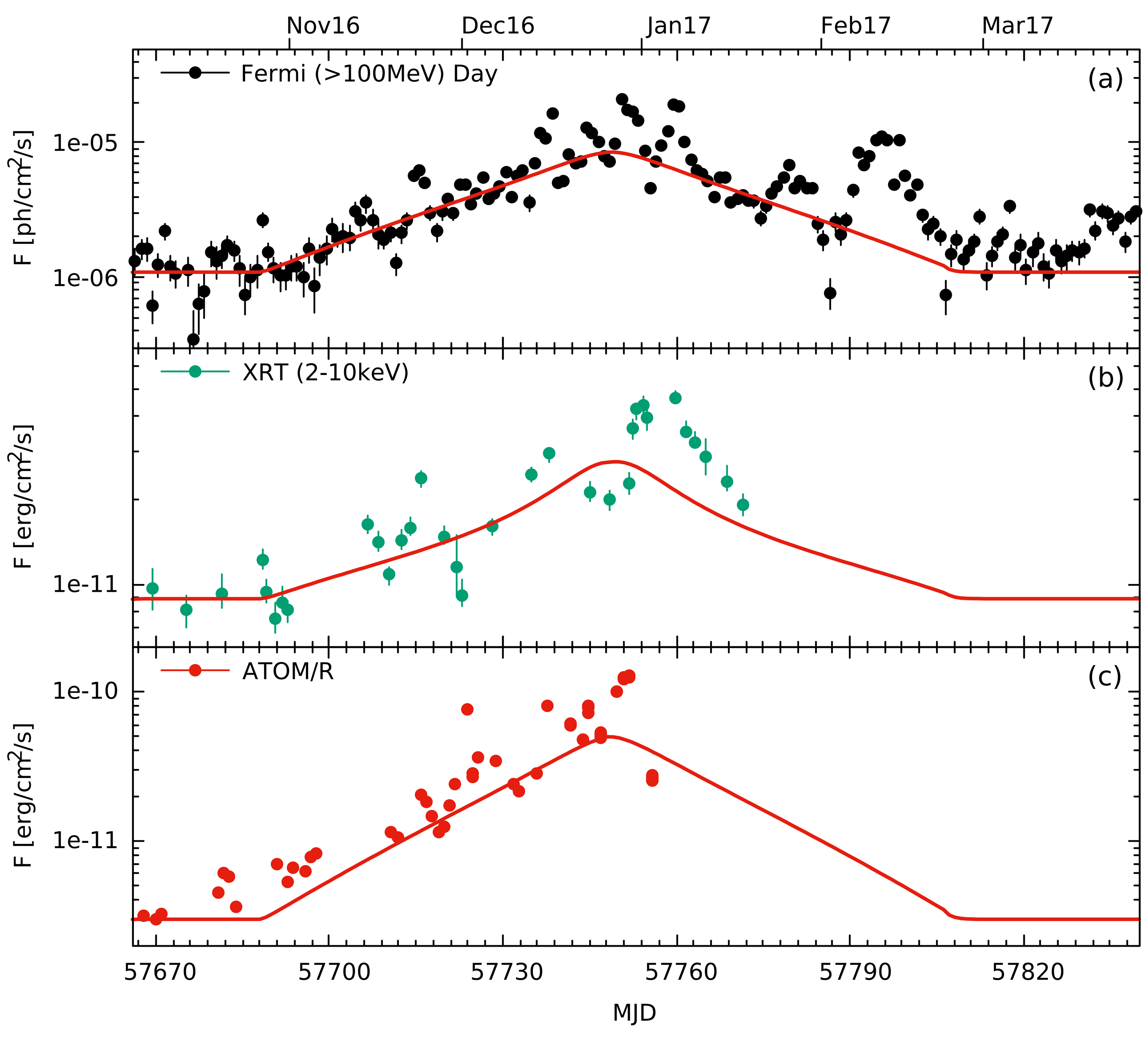
The following light curves are derived within a leptonic jet emission scenario (similar results can be obtained with a hadronic scenario). They show the rich variety of flaring profiles, which can be realized within this model.



Variations of cloud parameters and the resulting γ-ray, X-ray and optical light curves: (a) cloud outer radius R, (b) cloud scale height r_0, (c) cloud entral density n_0, and (d) cloud speed v. Note the logarithmic scaling of the y-axes.
In Heil & Zacharias (2020), we further discuss the influence of jet parameters and expected lightcurves for various cloud types.

The curious flare of CTA 102

- CTA 102 is an FSRQ at $z = 1.032$.
- In 2016/2017 is exhibited a 4-months long, quasi-symmetric flare becoming one of the brightest γ-ray objects in the sky and being visible to the human eye through small telescopes.
- The plot on the right shows the light curves and an application of the "cloud ablation" model using a leptonic jet emission scenario (Zacharias et al. 2017).
  The emission components are:
  - γ rays: inverse Compton scattering of BLR photons (data from *Fermi*-LAT)
  - X-rays: inverse Compton scattering of BLR photons; during the peak, SSC becomes important explaining the deviation from the "triangular" shape of the light curve (data from Swift-XRT)
  - R band: synchrotron emission (data from ATOM)
  - A hadronic emission scenario provides equally good fits (Zacharias et al. 2019).
- The reproduction of the long-term trend is excellent.
- From the modeling we can deduce the cloud parameters. The density value is derived under the assumption that all cloud electrons contributed to the flare emission. However, (i) not all particles will be accelerated in the jet, and (ii) most particles will be lost in the ablation process. While this is not quantifiable, the density will be a lot higher than the value given below. In turn, the temperature will also increase significantly.
  - $R = 1.3 \times 10^{15}$ cm, $r_0 = 1.6 \times 10^{14}$ cm, $v = 5.1 \times 10^8$ cm/s, $n_0 \geq 2.5 \times 10^8\,\mathrm{cm}^{-3}$, $T \geq 0.5$ K
- The cloud parameters correspond to clouds from star forming regions. Less likely options are BLR clouds or astospheres of giant stars.



γ-ray, X-ray and optical light curve of CTA 102. The red lines show the cloud ablation model using a leptonic emission scenario (synchrotron, SSC, and inverse Compton of BLR photons). Note the logarithmic scaling of the y-axes. (Zacharias et al. 2017)

Bibliography

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