A hydrodynamical model for the Fermi-LAT $\gamma$-ray light curve of Blazar PKS 1510-089.

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Jets at all scales.

- Highly collimated and in most cases two-sided.
- Originate in compact objects.
- Show evidence of accretion of matter into the central source via an accretion disc.
- Highly relativistic Jets.

**Fig 1.** Morphological similarities between the accretion-ejection mechanism for three different astrophysical objects: \(\mu\)-quasars, quasars and long Gamma ray bursts.
Fig 2. When a fast velocity flow 2 moves over a slow velocity flow 1, a working surface (represented with a curved line) moving with velocity $v_{ws}$ is generated as a result of the interaction.

The model

The formation of shocks waves in relativistic jets.

- Inhomogeneities in the surrounding media, deviations and precessions in the jets and time fluctuations in the ejection parameters.
- Time variations in the speed produce initial discontinuities since fast flow overtakes slow one.
- Ballistic approximation is assumed and so, radiation time scales are small with respect to the dynamical time.
Model

- The injected energy at the base of the jet is radiated away as the working surface moves:
  \[ E_0 = \int_{\tau_1}^{\tau_2} \dot{m}(\tau) \gamma(v(\tau)) c^2 d\tau, \]  
  \( \quad \) (1)

- Energy \( E_{ws} \) of the material inside the working surface:
  \[ E_{ws} = mc^2 \gamma_{ws}, \]  
  \( \quad \) (2)

- Assuming the energy loss along the jet \( E_r = E_0 - E_{ws} \) is completely radiated away, then the luminosity of the working surface is given by: \( L = \frac{dE_r}{dt} \).
Example: a constant discharge flow $\Rightarrow \dot{m} = \text{const.}$

- Injected velocity given by:
  \[ v(\tau) = v_0 + \eta^2 \sin(\omega \tau) \quad (3) \]

- The model accurately fits observations of lGRB (Mendoza et al. 2009).

- The model only depend of four parameters:
  - Background velocity $v_0$
  - Fixed speed $\eta^2$
  - Frequency $\omega$
  - Mass ejection rate $\dot{m}$
PKS 1510-089

Features

- Gamma-ray blazar detected in MeV-GeV band by EGRET.
- High polarized blazar.
- Redshift $z = 0.361$.
- Apparent velocities $\gtrsim 10c$ observed in multiepoch VLBA observations.
- Angle between line of sight and jet axis: $\sim 3^\circ$.

Fig 3. AGILE detection of a bright and persistent gamma-ray flare from the blazar PKS 1510-089
Fig 4. Fermi-LAT light curve of blazar PKS 1510-089 (from 0.2-300 GeV) obtained from 2008 August to 2012 May. The outburst identification number (ID) labelled in the figure stands for the different flares. The $3\sigma$ noise level is represented by the red horizontal line.
PKS1510-089

- Light curve fit by periodic variations in velocity (Cabrera, Coronado, et. al. 2013).
- ∀ peaks, background velocity: $v_0 = 0.9984c$, and so: $\Gamma(v_0) = 18$.

**Fig 5.** fit to the observational data in Gamma-rays of PKS 1510-089, by multiple periodic variations in velocity for each peak. Observational data from Fermi telescope.
Fig 6. Fit to observational data of 2011, by a periodic variation in velocity, note that the peak 30 is three times larger than the maximum outburst in 2009.

- Total luminosity in $\gamma$-rays is obtained by:
  \[ L = F 4\pi D_L^2 \delta^{-(3+\alpha)} \]
  where the relativistic beaming $\delta \sim 18$.

- We take a luminosity distance of $D_L = 1919$ Mpc and select the index $\alpha \sim 3$ for all the bursts (Wu et. al. 2011).

- Fits are performed by normalising the Luminosity to the peak of the LC and the time to the FWHM of the LC. With this, $\dot{m}$ and $\omega$ do not appear in the description of the LC in this normalised system.

- The parameter $\eta^2$ is then obtained by a $\chi^2$ statistical test.
A0620-00

**Fig 7.** Fit to the observational data in X-rays of the \( \mu \)-quasar A0620-00, by periodic variations in velocity and mass discharge for the second peak. Observational data courtesy of McClintock private communication.

- Fit to the light curve of A0620-00, by periodic variations in velocity and mass discharge.
- The periodic variation in velocity for the mean peak assume a background velocity \( v_0 = 0.9 \) c.
- Periodic variations in the mass discharge are used to model the 2nd peak.
Conclusions

Relativistic shocks

- PKS1510-089 gamma-ray LC was fitted with the hydrodynamical model by Mendoza et al. (2009).
- $\dot{m} \sim (2 - 25) \times 10^{-3} M_\odot \text{yr}^{-1}$, $\omega^{-1} \sim (0.3 - 2.6) \times 10^3 \text{s}$ and $\Gamma \sim 10 - 380$. A clear scaling from lGRB (Mendoza et al. 2009) counterparts arise: $\dot{m} \sim 10^{-1} - 10^{-2} M_\odot \text{s}^{-1}$, $\omega^{-1} \sim 10\text{s}$ and $\Gamma \sim 50 - 500$.
- The model has also been tested for a $\mu$-qsr (A0062-00).
- The fact that the same physical model can be applied to lGRB, Blazars and $\mu$-qsr’s is a step forward to the unified physical model of relativistic astrophysical jets.