Rapid TeV and GeV Variability in AGNs as Result of Jet-Star Interaction

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Outline

1. VHE short variability and MAIN Ingredients (Jet&Star)
2. A low power jet (M87)
3. A powerful jet and heavy cloud (3C454.3)
4. Conclusions
The observed parameters of the PKS 2155–304 flares (H.E.S.S. data)

\[ L_\gamma \approx 10^{47} \text{erg s}^{-1} \]
\[ \tau \approx 200 \text{ s} \]
\[ L_X \sim 10^{46} \text{erg s}^{-1} \]

(Aharonian et al 2007)
What are the Blobs in Powerful Jets?

There are a lot of hypothetical blobs

Internal Shocks, Magnetic Reconnection, Change in Accretion, Instabilities....
**Fundamental Requirements on the blob properties**

**BLOBS MUST BE SMALL AND CONTAIN A LOT OF ENERGY (OR BE ABLE TO TRIGGER POWERFUL INTERACTION)**

<table>
<thead>
<tr>
<th>Instabilities</th>
<th>Accretion</th>
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<tr>
<td>can be very small</td>
<td>hydrodynamical scale</td>
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<td>no energy</td>
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<th>Shocks</th>
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<td>very intensive interaction</td>
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</table>

(Nagoya University)  JRGI and rapid $\gamma$-ray variability in AGNs  5th *Fermi* Symposium
Blobs of external origin

- If blobs have external origin, they can be very small as compared to the hydrodynamical scale of the jet.....
- External blobs contain no energy (as compared to the jet)
- I.e. external blobs must be able to trigger an intensive interaction. To be heavy?
- Compact and heavy, i.e DENSE: stars, BLR clouds?

Specific realization of such blob formation:

*Jet-Red Giant Interaction Scenario*
Main Ingredients

### AGN jet
- Relativistic outflow ($\Gamma_{\text{bulk}} \sim 10 - 100$, likely depends on the distance)
- Narrow: typically one adopts $\theta \simeq \Gamma^{-1}$, i.e.,
- Cross section:

  \[ \omega \simeq 10^{17} \Gamma_{1.5}^{-1} R_{\text{pc}} \text{cm} \]

### Stars around BH
- Moves with Keplerian velocity:
  \[ V_* \simeq 600 M_{\text{BH}}^{1/2} R_{\text{pc}}^{-1/2} \text{km/s} \]
- Density (quite uncertain): $\rho_* \simeq \rho_0 R^{-a}$

### Mass injection between $10^{-2}$ and $10^{-1}$ pc:

\[
\dot{M}_* \simeq 2 \times 10^{-5} \frac{\rho_0 M_{\text{BH}}^{1/2}}{\Gamma_{1.5}} \int_{0.01}^{0.1} x^{1/2-a} \, dx \text{ [pc}^3 \text{ yr}^{-1}] ,
\]
Probability to get a star to a jet

Murphy et al. 1991
- It was revealed that "a" spans a quite broad range depending on the mass accumulated in the central parsec.
- It was obtained that $a = \frac{7}{2}$ for $\bar{\rho} = 10^6 M_\odot pc^{-3}$ and $a = \frac{1}{2}$ for $\bar{\rho} = 10^8 M_\odot pc^{-3}$.

Mass injection appears to depend very weakly on $a$

$$\dot{M}_* \simeq 2 \times 10^2 M_{BH,8}^{1/2} M_\odot \Gamma^{-1} \text{yr}^{-1}$$

for $10^{-2} < R_{pc} < 0.1$

One can expect HUNDREDS of stars entering per year which can contain a few Red Giants or young stars per year...
VHE variability in M87
Several flashes were observed in 2006, 2008, 2010.

Variability on scales $t \sim 1\text{day}$

The flux $L_\gamma \sim 10^{42}\text{ergs s}^{-1}$, $E_{\gamma,max} \sim 20\text{TeV}$.

(Aharonian et al 2006; Abramowski et al. 2011; Aliu et al. 2011)
Cloud/Star — Jet interaction

(a) Shocked obstacle
Bow shock
Disrupted RG
Jet
Accretion disc

(b) Cloud

(Barkov et al 2010, 2012b)
Star envelope evolution (Numerical results)

(Bosch-Ramon et al 2012)
p-p interaction
The cloud density can be very high making the \( pp \) interactions to be the most plausible mechanism for the gamma-ray production in the RG-jet interaction scenario: in this case the characteristic cooling time for \( pp \) collisions is

\[
t_{pp} \approx \frac{10^{15}}{c_f n_c} = 10^5 n^{-1}_{c,10} c_f^{-1} \text{s} \quad \chi \equiv \frac{E_\gamma}{E_p} = 0.17 [2 - \exp(-t_v/t_{pp})]
\]
VHE light curves and spectra (Numerical model)

$\xi = 0.5$ and $Q_p(E) \propto E^{-2}$

(Barkov et al 2012b)
Fast variability in GeV blazars (3C454.3)
3C454.3 observations

The observed parameters of the 3C454.3 flares (*Fermi* data)

\[ L_\gamma \approx 2 \times 10^{50} \text{erg s}^{-1} \]

\[ \tau_r \approx 4.5 \text{ h} \]

\[ L_X \sim 5 \times 10^{47} \text{erg s}^{-1} \]

(Abdo et al. 2011; Vercellone et al. 2011)
3C454.3 observations (2010 November)

(Abdo et al 2011)
Sketch and Plateau model

\[ \dot{M}_* \approx 10^{24} L_{\gamma,49} \xi^{-1} \Gamma_{j,1.5}^{-3} \text{ g/s}. \]

The cosmic ray/X-ray excite stellar wind (Basko et al. 1973; Dorodnitsyn et al. 2008),

\[ \dot{M} \approx 10^{24} \alpha_{-12} R_{*,2}^{5/2} M_{*,0}^{-1/2} \chi P_{0,6} \text{ g s}^{-1} \]

which providing limitations on the stellar radius

\[ R_{*,2} > 2 \left( \frac{2F_e M_{0,*}^{1/2}}{\alpha_{-12} \chi} \right)^{2/5}. \]
The Model Solution for the Main Flare

\[ D \equiv \frac{L_j r_c^2}{4 \theta^2 \Gamma_j^3 Z_0 c^3 M_c} \quad \Rightarrow \quad L_j \geq 10^{48} \text{ erg s}^{-1} \]

\[ M_{\text{BH}} \approx 10^9 M_\odot \quad \delta_b \approx 20 \]
Radiation Model: Proton synchrotron + secondary synchrotron

\[ t_{\text{acc}} / (2\Gamma_b^2) \approx 5 \text{ h.} \]
Radiation Model: Geometry

Radio

X-ray (IC)

Optic (Syn)

Gamma

Jet

10 pc

0.1 pc

(Nagoya University)

JRGI and rapid $\gamma$-ray variability in AGNs

5th Fermi Symposium
Radiation Model: limitations

\[ B_j = z_0^{5/4} \xi^{-1/2} \chi^{1/2} \bar{B} \]

\[ B_j' = z_0^{5/4} \xi^{-1/2} \chi^{1/2} \bar{B} \]

\[ L_{\text{ph,EIC}} = \kappa f \xi^{-1} z_{0,17}^{-3/2} \bar{L} \]

\[ t'_{\text{cool}} = z_{0,17}^{17/8} \xi^{3/4} \chi^{-3/4} E_{\gamma,\text{GeV}}^{-1/2} \bar{t} \]

\[ t'_{\text{acc}} = z_{0,17}^{1/2} \bar{t} \]
Radiation Model: Light curve + cooling time
Conclusions

- The jet can blow-up some RG envelope fragments and accelerate them up to Lorentz factors of $\Gamma_j (\sim 10 – 30)$.
- In the case of 3C454.3 the radiation in the GeV energy range can be effectively produced through proton synchrotron radiation, Jitter or EIC in the Thompson regime.
- The model can explain hour scale GeV flares and the minute-scale TeV flares on top of a longer (typical time-scales of days) gamma-ray variability.
- The process can render suitable conditions for energy dissipation and proton acceleration, which could explain the detected day-scale TeV flares in 2010 from M87 via proton-proton collisions.
Based on:

- V. Bosch-Ramon, M. Perucho and MVB, (M87); A&A (2012) 539, 69
Thank you!!!