High energy γ-emission from active red dwarf stars

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in 1947 flares of red dwarf star UV Cet were observed and its spectra studied. Later red dwarf flare stars of the UV Cet type were mentioned as a separate class of variable stars because of its photometric characteristics also with sporadic rapid flares of brightness up to hundred times 

\textbf{AND} Joy (1958), Gershberg (2005), Oskanjan (1964)

strong emission lines of hydrogen and calcium testifying to the powerful stellar chromospheres existence and non-thermal radio emission arises in stellar coronae

Similarity with solar flares? It registered up to several GeV!!!!!
Also detected in optical, radio and X-ray bands

!!!!!! supposing the concept of physical identity of activity of flared red dwarfs and Sun

Gershberg(1972), Hambaryan (2000)

!!!!!!!!! confirmed by UV Cet type stars flares observations by various experiments in radio and roentgen energy regions

Barthelmy (2014)
\(\gamma\)-emission with energy at least tens of a MeV was registered at confidence level better than 95% for B-class solar flares even if brightness of Sun during such events has small changes in optical band.

Arkhangelskaja 2009

During star flares **brightness changes up to hundred times**

Gershberg (2005), Oskanjan (1964)

This concept developing allows attempt of red dwarfs identification as high-energy \(\gamma\)-emission sources.

More high energy emission should be…

Recently gamma-emission with $E > 0.8$ TeV was detected by Cherenkov instrument SHALON in Tien-Shan mountains from red dwarfs V962 Tau and V1589 Cyg. These sources were registered by Fermi/LAT.

\[ I > 1\text{TeV} = (0.13 \pm 0.019) \times 10^{-12} \text{ cm}^{-2}\times\text{s}^{-1} \]

The spectral shapes have same power law indexes both in SHALON and Fermi/LAT bands!!!
Recently gamma-emission with $E > 0.8$ TeV was detected by Cherenkov instrument SHALON in Tien-Shan mountains from red dwarfs V962 Tau and **V1589 Cyg**. These sources were registered by Fermi/LAT.

**SHALON** spectrum

**Fermi/LAT** energy range

$E^2 \frac{dF}{dE}$, TeV cm$^{-2}$ sec$^{-1}$

$E$, eV

$E^2 \frac{dF}{dE} = (0.13 \pm 0.019) \times 10^{-12}$ cm$^{-2}$ sec$^{-1}$

Sinitsyna (2019)

**spectral shapes**

has same power law indexes both in **SHALON** and Fermi/LAT bands!!!
Recently gamma-emission with $E > 0.8$ TeV was detected by Cherenkov instrument SHALON in Tien-Shan mountains from red dwarfs V388 Cas and V780 Tau.

It were not active enough after 2008 to produce a significant detection by Femi-LAT launched in 2008.
GTSh10 CATALOGUE

- 5535 variable red dwarf stars with the solar-type activity
- stellar magnitudes in normal luminosity state (Johnson V-band magnitudes are given for 5396 stars but brightnesses in other bands are specified additionally), stars spectral types, equivalent widths of emission line Hα (318 objects), intensity in calcium emission (2487 stars). Also information about spotted photospheres, X-ray and radio emission presence are given and stars with registered flares in optical, X-ray and radio bands are marked.
Fermi gamma-ray space telescope experiment began operation since 2008 June 11. Fermi satellite was launched on into circular Earth orbit with an altitude of 565 km and inclination of 25.6°, and an orbital period of 96 minutes.

High energy gamma-emission registered by the Large Area Telescope (LAT) in energy band between 20 MeV and more than 300 GeV.

LAT is a pair-production telescope with an effective area ∼8000 cm⁻² at 1 GeV and field of view ~2.4 sr.

The 4FGL catalogue of high-energy γ-ray sources detected in the first eight years of the Fermi/LAT operation contain 5066 sources with flux in 1-100 GeV energy band from \( (8.8 \pm 4.5) \times 10^{-12} \text{ cm}^{-2} \text{s}^{-1} \) up to \( (9.2808 \pm 0.0043) \times 10^{-6} \text{ cm}^{-2} \text{s}^{-1} \).

270 sources from 4FGL catalogue reveal in ROSAT survey from 1007 objects radio-emission were detected.

More than 1323 sources are with absence of source type, 92 objects are with unknown one.
analysis results of GTSh10 and 4FGL catalogues

- Correlation for 56 and 37 objects at the distance less than 0.2° and 0.1° between sources.
- Five of 56 red dwarfs reveals in Ha band and 34 observed in calcium line range.
- Flux(1-100 GeV) from $(1.0259 \pm 0.2841) \times 10^{-11}$ up to $(4.474 \pm 0.4858) \times 10^{-9}$ cm$^{-2}$s$^{-1}$,
- V-band stellar magnitudes are in the range from 4.87 to 20.9.
2 types of 56 red dwarfs' associated objects high energy spectra shape:
- power law for 39 stars, flux (1-100) GeV from $(1.03 \pm 0.28) \times 10^{-11}$ up to $(6.90 \pm 0.12) \times 10^{-10} \text{cm}^{-2} \times \text{s}^{-1}$
- logparabola for 17 ones, flux (1-100) GeV from $(2.23 \pm 0.82) \times 10^{-10}$ up to $(4.47 \pm 0.49) \times 10^{-9} \text{cm}^{-2} \times \text{s}^{-1}$
- smaller fluxes for stars with power law spectral shape than ones with logparabola
2 types of 56 red dwarfs’ associated objects high energy spectra shape:

- power law for 39 stars,
- 5 flares observed in 1-100 GeV area (4FGL J0159.0+3313, 4FGL J0036.9+1832, 4FGL J1942.1+4011, 4FGL J0009.2+1745), flux changed up to $10^2$ times during flares
- logparabola for 17 ones

1 flare observed in 1-100 GeV area (4FGL J0433.0+0522), $I_{\text{flare}}/I_\sim 1.4 \times 10^3$
Recently $\gamma$-emission with $E>0.8$ TeV was detected by Cherenkov instrument SHALON for red dwarfs V388 Cas, V780 Tau, V962 Tau and V1589 Cyg. Moreover, spectral shapes of V962 Tau and V1589 Cyg has same power law indexes both in SHALON and Fermi/LAT energy.

We have found several other possible associations of active red dwarf stars from GTSh10 and high energy gamma sources from Fermi/LAT 4FGL catalogue: V* AK For and 4FGL J0330.7-2408 (∼0.042° distance), HD 12051 and 4FGL J0009.2+1745 (∼0.007° distance), etc. Also the source 4FGL J0009.2+1745 observed by Fermi/LAT in 10 GeV – 2 TeV energy range as 3FHL J0158.8+3314.

Preliminary results shows correlation for 56 and 37 objects at the distance less than 0.2° and 0.1° between sources GTSh10 and 4FGL catalogues correspondingly.
CONCLUSIONS

There are two types of 56 red dwarfs’ associated objects (distance less than 0.2°) high energy spectra shape: power law for 39 stars, flux (1-100) GeV from \((1.03 \pm 0.28) \times 10^{-11}\) up to \((6.90 \pm 0.12) \times 10^{-10}\) cm\(^{-2}\) s\(^{-1}\) 5 flares observed in 1-100 GeV area (4FGL J0159.0+3313, 4FGL J0036.9+1832, 4FGL J1942.1+4011, 4FGL J0009.2+1745), flux changed up to \(10^2\) times during flares logparabola for 17 ones flux (1-100) GeV from \((2.23 \pm 0.82) \times 10^{-10}\) up to \((4.47 \pm 0.49) \times 10^{-9}\) cm\(^{-2}\) s\(^{-1}\) 1 flare observed in 1-100 GeV area (4FGL J0433.0+0522), \(I_{\text{flare}}/I_{\sim} 1.4 \times 10^{3}\)

Such weak objects can be observed only if other more intensive gamma sources absent in immediate surroundings. For example, bright pulsar PKS 0019+058 with flux \((1.90 \pm 0.08) \times 10^{-9}\) photon/cm\(^2\)/s suppressed very weak source V*V Psc.

Thank you for attention!
Schematic diagram of the LAT. The telescope’s dimensions are $1.8 \text{ m} \times 1.8 \text{ m} \times 0.72 \text{ m}$. 

### Summary of LAT Instrument Parameters and Estimated Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value or Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy range</td>
<td>20 MeV–300 GeV</td>
</tr>
<tr>
<td>Effective area at normal incidence$^a$</td>
<td>9,500 cm$^2$</td>
</tr>
<tr>
<td>Energy resolution (equivalent Gaussian 1σ):</td>
<td></td>
</tr>
<tr>
<td>100 MeV–1 GeV (on-axis)</td>
<td>9%–15%</td>
</tr>
<tr>
<td>1 GeV–10 GeV (on-axis)</td>
<td>8%–9%</td>
</tr>
<tr>
<td>10 GeV–300 GeV (on-axis)</td>
<td>8.5%–18%</td>
</tr>
<tr>
<td>&gt;10 GeV (&gt;60° incidence)</td>
<td>≤6%</td>
</tr>
<tr>
<td>Single photon angular resolution (space angle)</td>
<td></td>
</tr>
<tr>
<td>on-axis, 68% containment radius:</td>
<td></td>
</tr>
<tr>
<td>&gt;10 GeV</td>
<td>≤0.15</td>
</tr>
<tr>
<td>1 GeV</td>
<td>0%</td>
</tr>
<tr>
<td>100 MeV</td>
<td>3:5</td>
</tr>
<tr>
<td>on-axis, 95% containment radius:</td>
<td>&lt; 3 × 68%</td>
</tr>
<tr>
<td>off-axis containment radius at 55°</td>
<td>&lt; 1.7 × on-axis value</td>
</tr>
<tr>
<td>Field of View (FoV)</td>
<td>2.4 sr</td>
</tr>
<tr>
<td>Timing accuracy</td>
<td>&lt; 10 μs</td>
</tr>
<tr>
<td>Event readout time (dead time)</td>
<td>26.5 μs</td>
</tr>
<tr>
<td>GRB location accuracy onboard$^b$</td>
<td>&lt; 10'</td>
</tr>
<tr>
<td>GRB notification time to spacecraft$^c$</td>
<td>&lt;5 sec</td>
</tr>
<tr>
<td>Point source location determination$^d$</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>Point source sensitivity (&gt;100 MeV)$^e$</td>
<td>$3 \times 10^{-9}$ ph cm$^{-2}$ s$^{-1}$</td>
</tr>
</tbody>
</table>

**Notes.**

$^a$ Maximum (as a function of energy) effective area at normal incidence. Includes inefficiencies necessary to achieve required background rejection. Effective area peak is typically in the 1 to 10 GeV range.

$^b$ For burst (<20 s duration) with >100 photons above 1 GeV. This corresponds to a burst of $\sim$5 cm$^{-2}$ s$^{-1}$ peak rate in the 50 – 300 keV band assuming a spectrum of broken power law at 200 keV from photon index of −0.9 to −2.0. Such bursts are estimated to occur in the LAT FoV $\sim$10 times per year.

$^c$ Time relative to detection of GRB.

$^d$ High latitude source of $10^{-7}$ cm$^{-2}$ s$^{-1}$ flux at >100 MeV with a photon spectral index of −2.0 above a flat background and assuming no spectral cutoff at high energy; 1σ radius; one-year survey.

$^e$ For a steady source after one-year sky survey, assuming a high-latitude diffuse flux of $1.5 \times 10^{-5}$ cm$^{-2}$ s$^{-1}$ sr$^{-1}$ (>100 MeV) and a photon spectral index of −2.1, with no spectral cutoff.
The SHALON instrument (!) consists of two imaging atmospheric Cherenkov telescopes located in Tien-Shan mountains at an altitude of 3340 m above the sea level. It is designed for observations of γ-ray sources in the energy range from 800 GeV to 100 TeV. Each of the telescopes has a composite mirror with an area of 11.2 m\(^2\). The detector has the largest field of view >8o among similar instruments.

The SHALON method of selection of γ-ray showers from the background cosmic-ray showers allows the rejection of 99.93% of the background events. The minimum detectable integral flux of γ-rays at 1 TeV is \(2.1 \times 10^{-13} \text{ cm}^{-2} \times \text{s}^{-1}\). In the energy range from 1 – 50 TeV the minimum detectable flux falls to the value of \(6 \times 10^{-14} \text{ cm}^{-2} \times \text{s}^{-1}\). The SHALON experiment has been in operation since 1992 providing the long-term observations of many different types of sources that are of interest for many areas of astroparticle physics. One of the goals of the SHALON long-term observational program is to search for γ-rays above 800 GeV from the active red dwarf stars.
<table>
<thead>
<tr>
<th>class</th>
<th>Amplitude at 1 a.u., Wt/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q (Q1-Q9)</td>
<td>$(1\div9.9)\times10^{-10}$ since 2009</td>
</tr>
<tr>
<td>S (S1-S9)</td>
<td>$(1\div9.9)\times10^{-9}$</td>
</tr>
<tr>
<td>A (A1-A9)</td>
<td>$(1\div9.9)\times10^{-8}$</td>
</tr>
<tr>
<td>B (B1-B9)</td>
<td>$(1\div9.9)\times10^{-7}$</td>
</tr>
<tr>
<td>C (C1-C9)</td>
<td>$(1\div9.9)\times10^{-6}$</td>
</tr>
<tr>
<td>M (M1-M9)</td>
<td>$(1\div9.9)\times10^{-5}$</td>
</tr>
<tr>
<td>X (X1-X30)</td>
<td>$&gt;10^{-4}$</td>
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</tbody>
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