Winds, Colliding Winds, Souped-up Winds, and GRB

David Eichler
Ben Gurion University

KITP Astro Plasmas, Sep 23, 2009

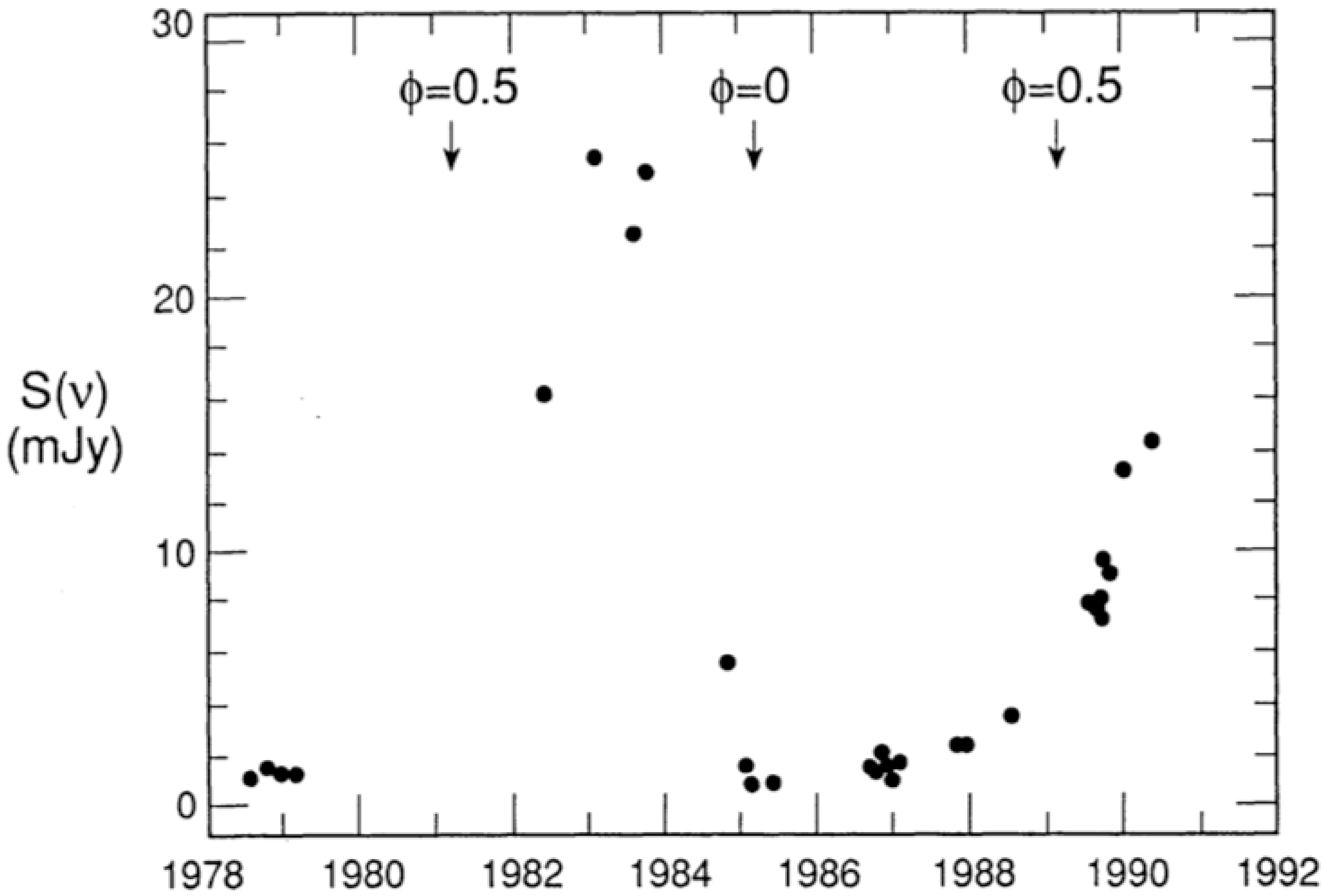

FIG. 2.—Radio light curve of WR 140 at the frequency $\nu = 5$ GHz. The orbital phase ϕ is shown by the arrows.

5.3. *Radio Luminosity and Radio Spectrum*

Substituting the parameters of WR 140 into equation (15) we obtain the following equation for the expected nonthermal radio luminosity from the region of stellar wind collision

$$L^{\rm rad} \simeq 5.4 \times 10^{31} \beta \left(\frac{\epsilon}{0.01}\right)\left(\frac{\zeta}{10^{-3}}\right) {\rm ergs\ s^{-1}}\ . \tag{25}$$

For reasonable values $\beta \sim 0.1$ and $\epsilon \sim 0.01$, this luminosity coincides with the observed value $L^{\rm rad}_{5\,\rm GHz} \simeq 5 \times 10^{29}$ ergs $\rm s^{-1}$ at 5 GHz at the radio high state ($\phi \simeq 0.7$) if $\zeta \sim 10^{-4}$. From equation (16) we can estimate the strength of the magnetic field in the region of stellar wind collision at the orbital phase $\phi = 0.7$ ($D \simeq 3.6 \times 10^{14}$ cm) as $B \simeq 0.03$ G. This magnetic field

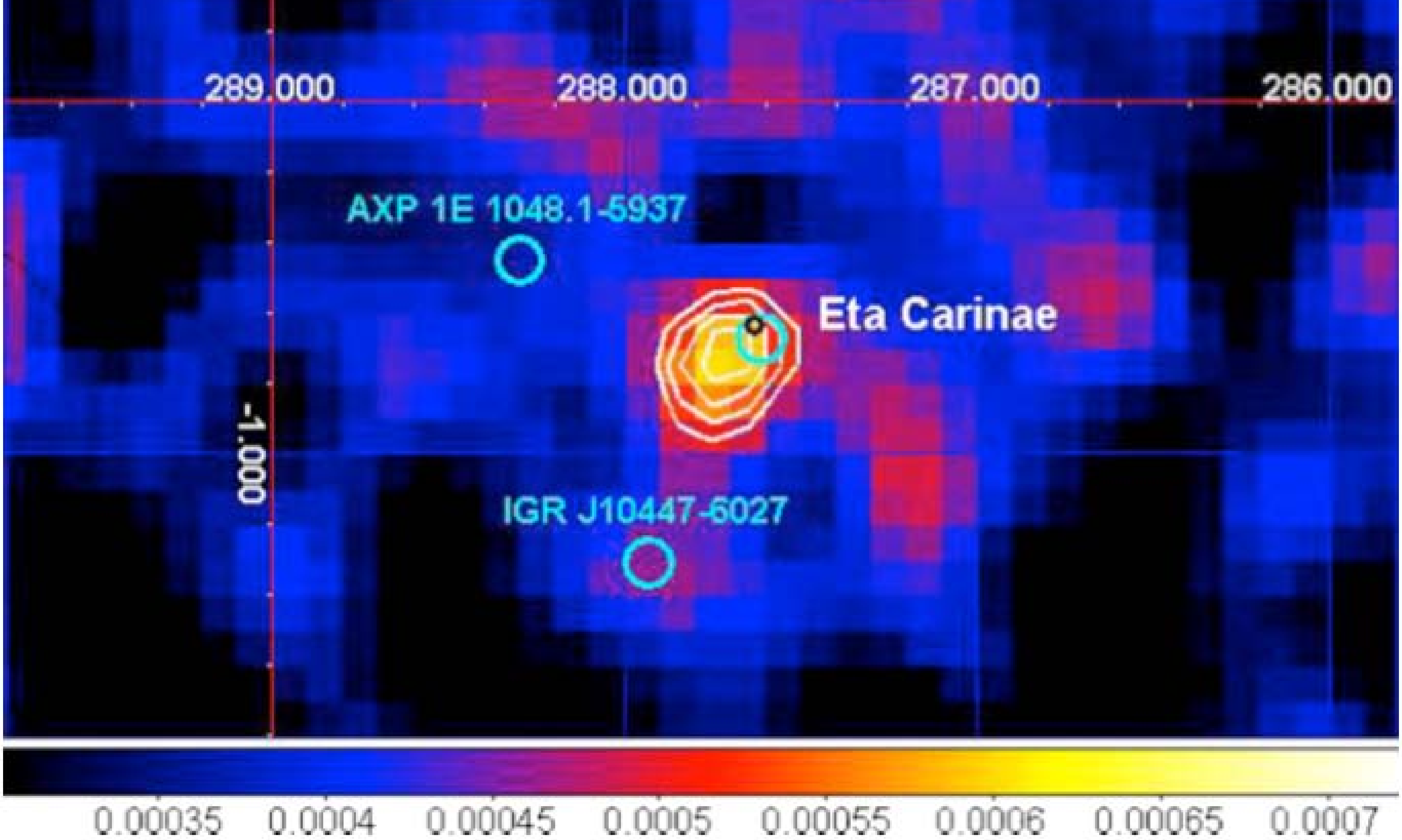

Figure 1. *AGILE* gamma-ray intensity map in Galactic coordinates of the η Car region above 100 MeV summing all data collected from 2007 July to 2008 October. The central gamma-ray source that can be associated with η Car is 1AGL J1043−5931; we also indicate the prominent nearby gamma-ray source AGL J1046−5832 which is associated with the radio pulsar PSR B1046−

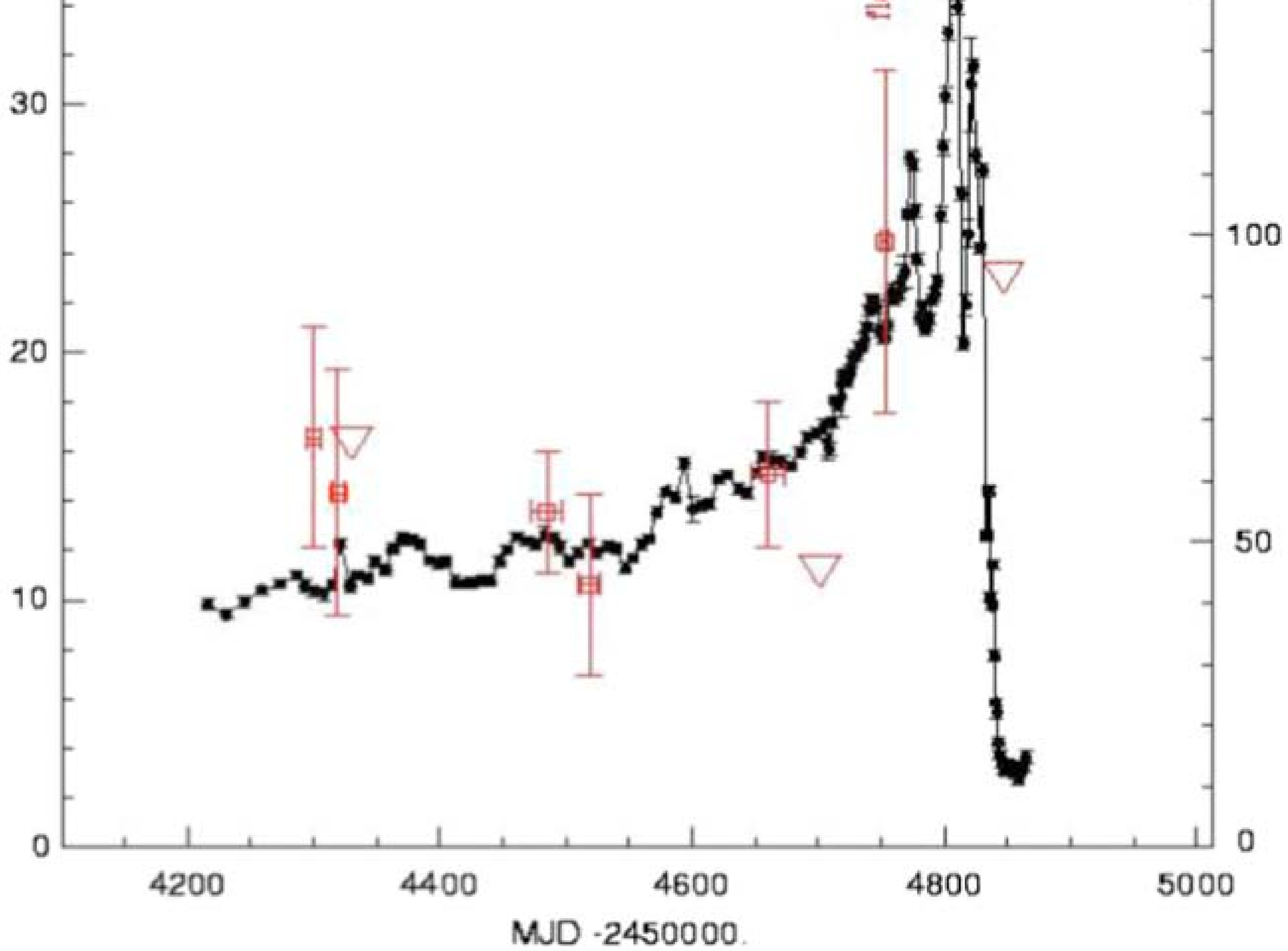

Figure 3. *AGILE* gamma-ray light curve of 1AGL J1043−5931 showing the fluxes above 100 MeV (right axis scale in units of 10^{-8}ph cm^{-2} s^{-1}) averaged

$$E_{\rm max} \simeq (4/3)E_{\rm UV}\gamma_{\rm max}^2 \simeq 4 \times 10^9 \eta \left(\frac{V_{\rm WR}^{\infty}}{2 \times 10^8\ {\rm cm\ s^{-1}}}\right)^2 \left(\frac{B}{\rm G}\right) \times \left(\frac{D}{10^{13}\ {\rm cm}}\right)^2 \left(\frac{L_{\rm bol}}{10^{39}\ {\rm ergs\ s^{-1}}}\right)^{-1} {\rm eV}\,, \quad (29)$$

where $E_{\rm UV} \simeq 10$ eV is the mean energy of UV photons radiated by the O4-5 star of which the effective temperature is $\sim$44,000 K (Williams et al. 1990). Using $L_{\rm bol} \simeq 1.7 \times 10^{39}$ ergs s^{-1}, $B \simeq 0.01$ G, $\eta \simeq 0.031$, and $D \simeq 3.6 \times 10^{14}$ cm, we have $E_{\rm max} \simeq 10^3$ MeV at $\phi \simeq 0.7$.

where β is the ratio the energy density of high-energy electrons to the total energy density of cosmic rays ($0 < \beta < 1$), and

$$\zeta \simeq \frac{t_f}{t_s} \simeq 2 \times 10^{-5} \gamma \left(\frac{B}{\mathrm{G}}\right)^2 \left(\frac{t_f}{10^4\ \mathrm{s}}\right) \simeq 4 \times 10^{-3} \eta^{1/2} \left(\frac{B}{\mathrm{G}}\right)^{3/2} \times \left(\frac{D}{10^{13}\ \mathrm{cm}}\right) \left(\frac{V^{\infty}_{\mathrm{WR}}}{2 \times 10^8\ \mathrm{cm\ s^{-1}}}\right)^{-1} \left(\frac{\nu}{5\ \mathrm{GHz}}\right)^{1/2} \quad (16)$$

is the fraction of the energy in high-energy electrons that is lost to synchrotron radiation, $t_s \simeq 5 \times 10^8 \gamma^{-1} (B/\mathrm{G})^{-2}$ s is the characteristic time of energy loss by a relativistic electron with the Lorentz factor γ via the synchrotron radiation,

$$t_f \simeq \frac{r_{\mathrm{OB}}}{V^{\infty}_{\mathrm{WR}}} \simeq 0.5 \times 10^5 \eta^{1/2} \left(\frac{D}{10^{13}\ \mathrm{cm}}\right) \left(\frac{V^{\infty}_{\mathrm{WR}}}{2 \times 10^8\ \mathrm{cm\ s^{-1}}}\right)^{-1} \mathrm{s} \quad (17)$$

is the flow time in the colliding wind region, and ν is the frequency of radio observations. The value of the dimension-

$$\gamma_{\max}^2 < \frac{3\pi e B c r_{\rm OB}^2}{\lambda \sigma_{\rm T} L_{\rm bol}} \left(\frac{V_{\rm WR}^\infty}{c}\right)^2 \simeq 3 \times 10^8 \eta \left(\frac{V_{\rm WR}^\infty}{2 \times 10^8 \text{ cm s}^{-1}}\right)^2 \times \left(\frac{B}{\rm G}\right)\left(\frac{D}{10^{13} \text{ cm}}\right)^2 \left(\frac{L_{\rm bol}}{10^{39} \text{ ergs s}^{-1}}\right)^{-1}, \quad (14)$$

with approximate equality obtaining in the absence of any other, stronger limits. Here $L_{\rm bol}$ is the bolometric luminosity of the OB star, $\sigma_{\rm T}$ is the cross section of Thomson scattering, e is the electron charge, and $\lambda \simeq 3$ is the ratio of mean free path to gyroradius. This limit follows from the condition that the inverse Compton loss rate not exceed the acceleration rate, which is given by

$$\Gamma \simeq \left(\frac{V_{\rm WR}^\infty}{c}\right)^2 \frac{\Omega_{ce}}{\gamma_{\max} \lambda},$$

where Ω_{ce} is the nonrelativistic electron cyclotron frequency.

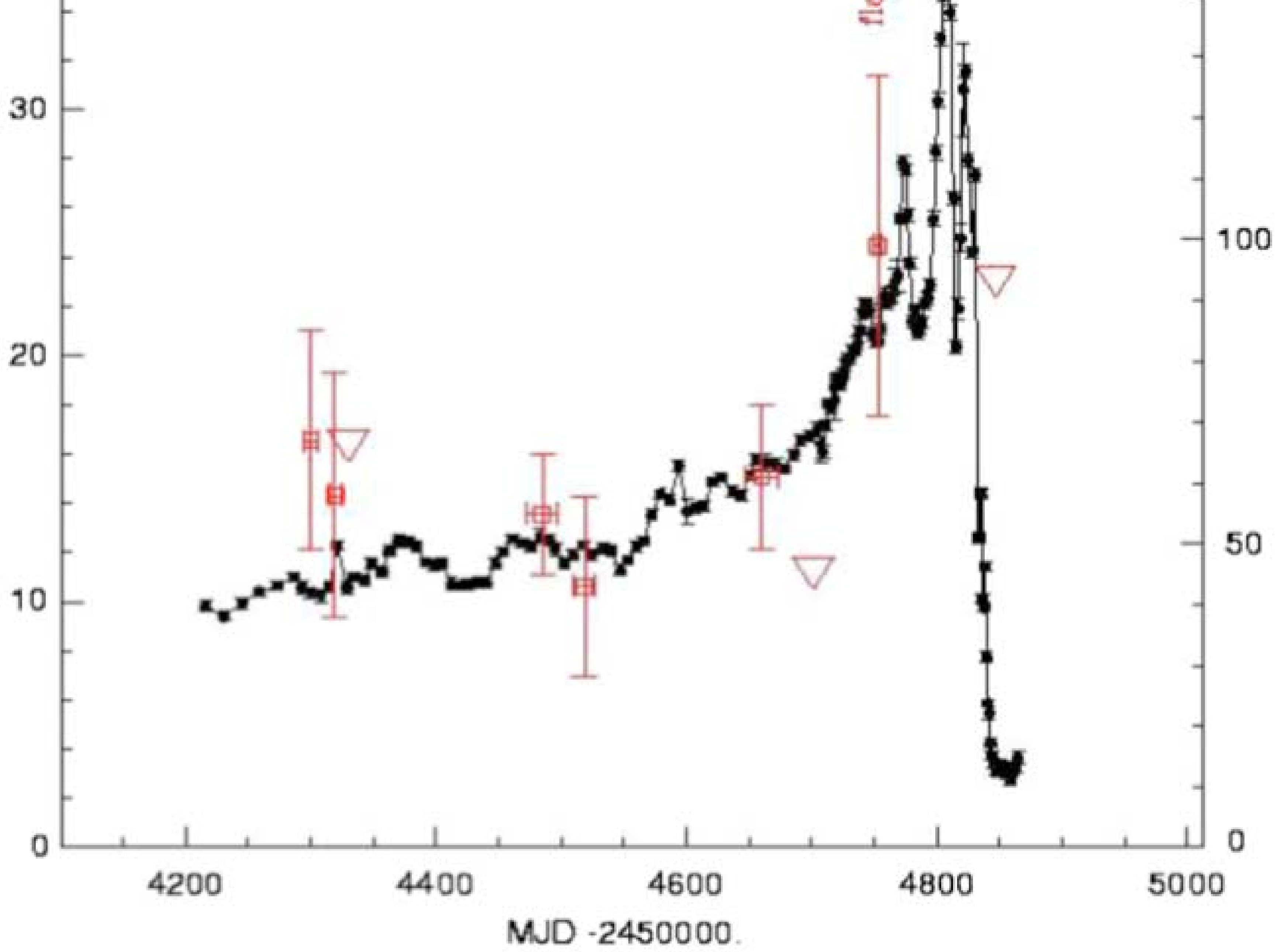

Figure 3. *AGILE* gamma-ray light curve of 1AGL J1043−5931 showing the fluxes above 100 MeV (right axis scale in units of 10^{-8}ph cm^{-2} s^{-1}) averaged