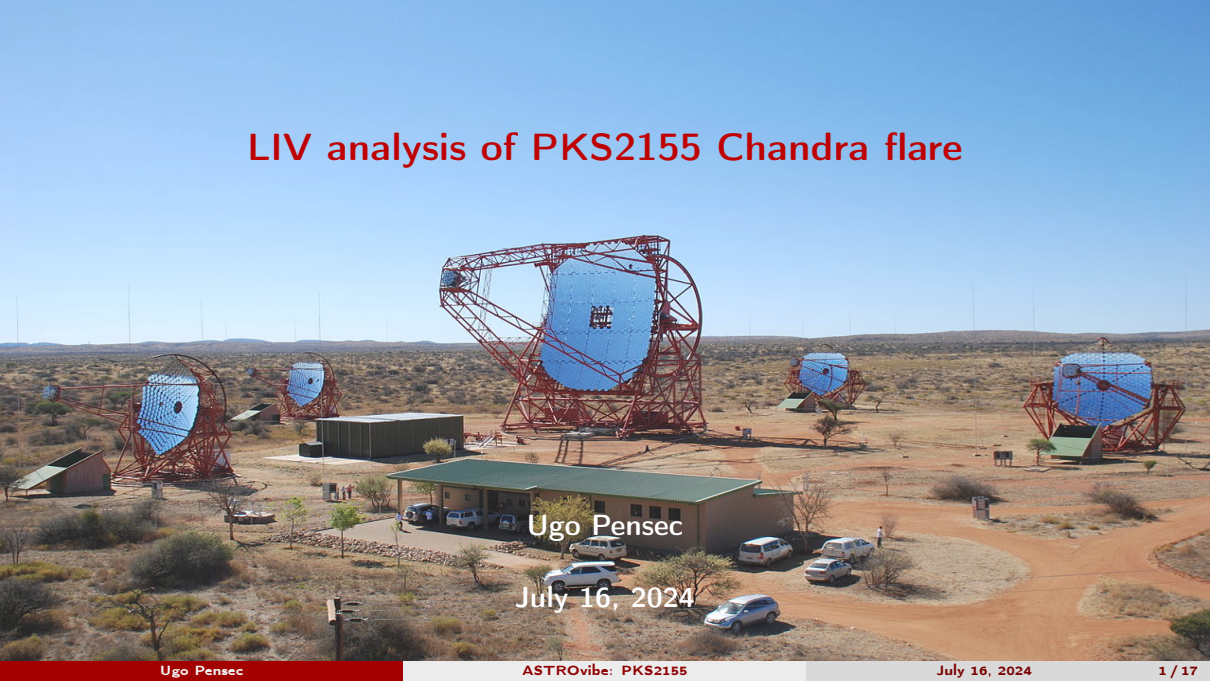
LIV analysis of PKS2155 Chandra flare



Ugo Pensec

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Outline

1. HESS telescope
2. PKS2155 Chandra flare
3. Templates
4. Reconstruction of the lag
5. Results from real data
6. Conclusion

Fig. 1. High Energy Stereoscopic System in Namibia

A first look at PKS 2155 Chandra flare data

Why the Chandra flare?

- Huge data set, not yet analysed for a LIV search
  - Full night of observation, 15 runs, 32612 excess events, 254σ
  - Zenith angle varied from 53° to 8° to 50°
  - Variability timescale down to $\sim$2 minutes
- Possibility for a good limit on E_{QG} & Contribute to the combined limit

The MW analysis of this night was published in [Aharonian *et al.* 2009 A&A]

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- The plan is to use HESS public data set on PKS2155-304 Chandra Night flare (29-30/07/2006) as a benchmark and provide a reproducible/example analysis for new LIVelihood users

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- This source is interesting to test the code in a case where the IRFs change a lot

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Spectrum

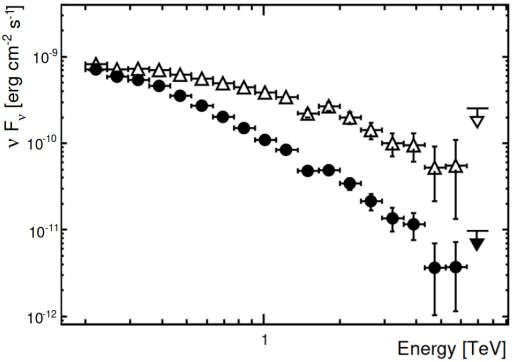


Fig. 2. Spectrum from PKS2155-304 Chandra flare taken from the original paper (cut T200), black dots are the original points and triangles accounts EBL deabsorption.
PL fit: $\Gamma = 3.25 \pm 0.01$
LogP: $\alpha = 3.69 \pm 0.05$ $\beta = 0.78 \pm 0.07$

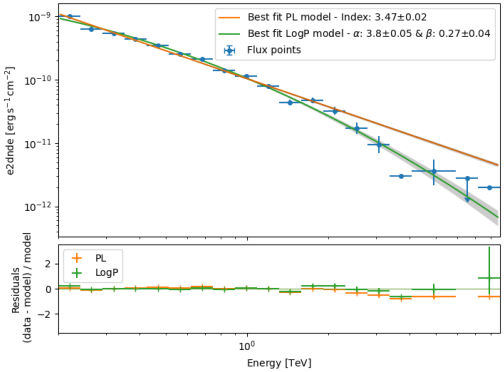


Fig. 3. Spectrum from the PKS2155-304 Chandra flare (public data with Gammapy) with same T200 cut

Lightcurves

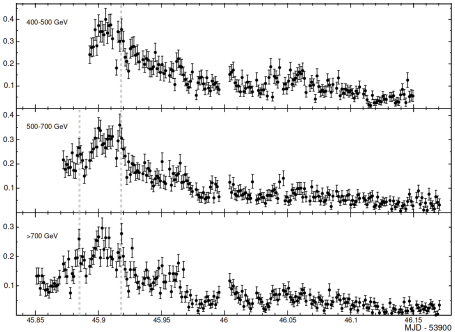


Fig. 4. Lightcurves taken from the original paper [Aharonian *et al.* 2009]

To compute the time lag, we need a **template** lightcurve (low energy photons) to compare to high energy photons

$\Longrightarrow$ arrange the photons into low and high energy parts, by taking the median energy (with the full flare $E_{med} = 0.61\text{TeV}$)

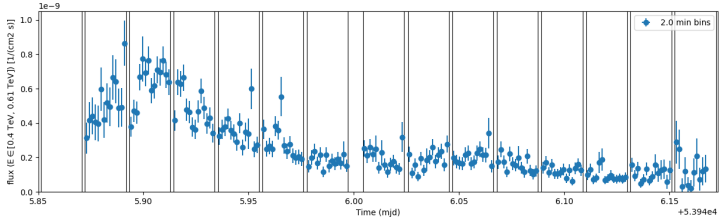
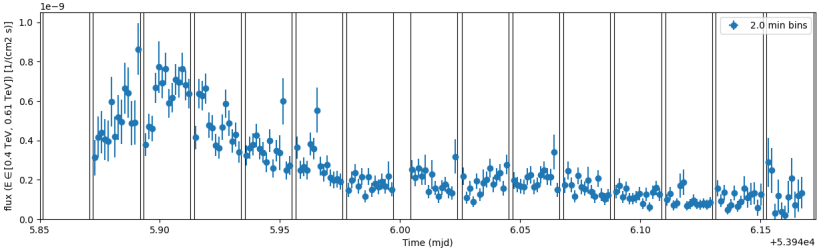


Fig. 5. Lightcurve from public data at low energies. Vertical lines separate runs.

Template lightcurve (preliminary)

But hard to fit the whole lightcurve because of the many free parameters



Template lightcurve (preliminary)

But hard to fit the whole lightcurve because of the many free parameters
$\longrightarrow$ reduce the analysis to the **4th run** as a first step

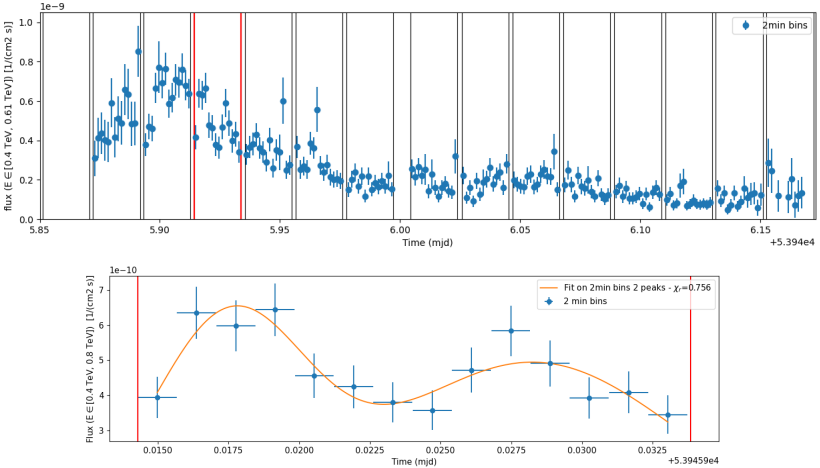


Fig. 6. Analytical fit of the light curve on low energies (in this run [0.4,0.79] TeV)

Likelihood technique

Likelihood formula [Martinez & Errando, 2008 Astrop.Phys.]

$$\frac{dP}{dE_m dt} = \frac{w_s}{N_s} \int A(E_t, \epsilon) M(E_t, E_m) F_s(E_t, t; \lambda) dE_t + \text{bkg. contrib.} \quad (1)$$

A is the effective area, M the energy migration matrix, and F_s is the flux
λ is the likelihood parameter

$$L(\lambda) = -\sum_i \log\left(\frac{dP}{dE_m dt}(E_m, i, t_i; \lambda)\right) \quad (2)$$

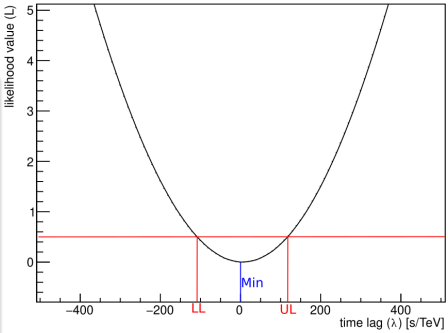


Fig. 7. Likelihood computed from a list of simulated photons following the template time distribution

Reconstruction of the lag from simulations

Process

- **Simulate** high and low energy photons from this template lightcurve at low energies and the energy spectrum
- Compute the likelihood curve for the **time lag parameter** λ
- Find the **minimum** and the lower and upper limits at 1σ

Sanity check: Distribution for $\lambda = 0$

Repeat 1000 simulations to get the distribution of reconstructed lags (for the J&P model and in the n=1 case)

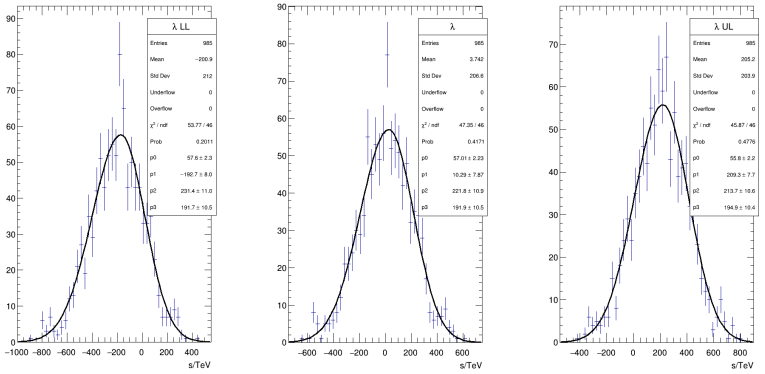


Fig. 8. Distribution of the reconstructed lags from 1000 simulations, with 0 injected lag. Left and right panels are the lower and upper limits of the confidence interval (1σ).

Reconstruction of the lag

Repeat with injected lag in the simulated dataset

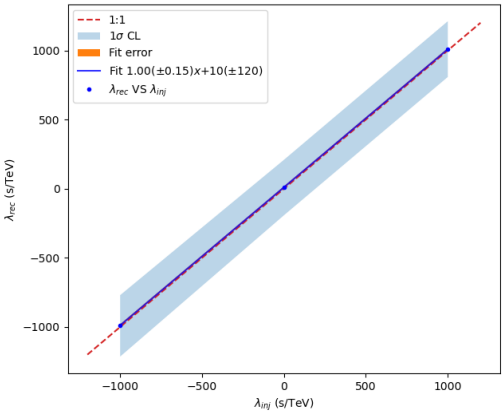


Fig. 9. Plot of the reconstructed VS injected lag

Everything works nicely!

Now let's try on real data

Likelihood from real data

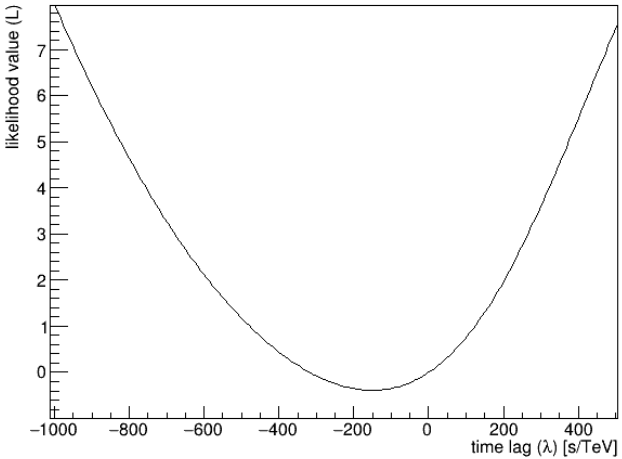


Fig. 10. Likelihood computed from real data

- Minimum: -146 s/TeV
- LL: -426 s/TeV
- UL: 84.8 s/TeV

Calibrated statistical error

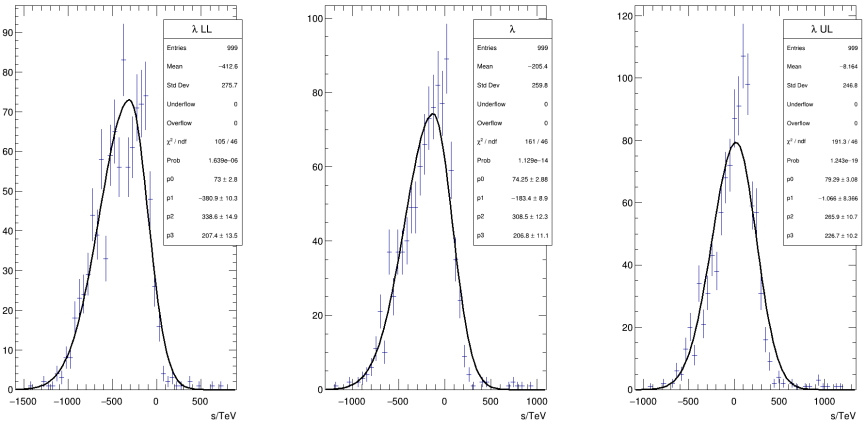


Fig. 11. Simulations based on real data → extract the **statistical error**

Systematic errors

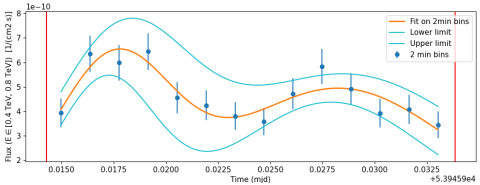


Fig. 12. Errors on lightcurve parameters

Spectral index	Redshift	Background	Energy Scale
± 0.02	$\pm 10^{-5}$	$\pm 20\%$	$\pm 10\%$

$$L(\lambda, \vec{\theta}) = L_S(\lambda) + L_{template}(\vec{\theta_{LC}}) + L_\gamma(\theta_\gamma) + L_B(\vec{\theta_B}) + L_{ES}(\theta_{ES}) + L_z(\theta_z) \tag{3}$$

with

$$L_x(\vec{\theta_x}) = \sum_i \frac{(\theta_{x,i} - \bar{\theta}_{x,i})^2}{2\sigma^2_{x,i}}, \tag{4}$$

assuming a normal distribution.

Then, re-do the whole process with these nuisances → get a mean value + errors → get a limit

Results

Limits

- J&P $\lambda_1 = -146 \pm \binom{182}{198}_{stat} \pm \binom{412}{405}_{syst}$
  $E_{QG,1} = 0.31\text{e}18$ GeV (95% CL)

Big flare	2.1e18 GeV
Chandra flare (1run)	0.31e18 GeV

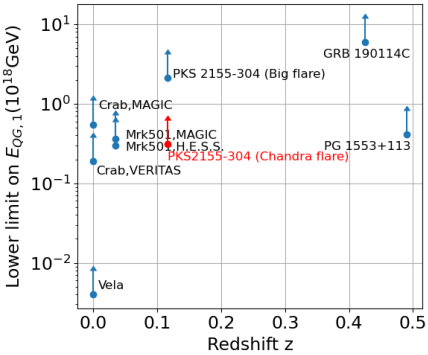


Fig. 13. Current limits on $E_{QG,1}$

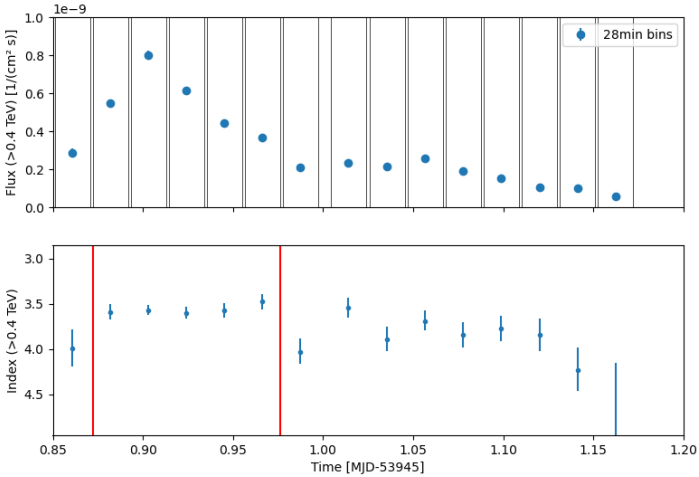
Conclusions and next steps

- Good limit obtained with only one run
- Analysis of the whole dataset is ongoing
- It should strengthen the limit obtained here, with only one run
- The final result should be published and then be used in the HESS/MAGIC/VERITAS/LST-1 working group
- During summer: first tests of a combination of real data sets: Chandra flare + LST BL Lac observations
- Combine this result with other results in the γLIV working group in preparation for the second paper

Thank you!

Template lightcurve (preliminary)

Hard to fit the whole lightcurve → focus the analysis to the main flare, where the spectral index is constant



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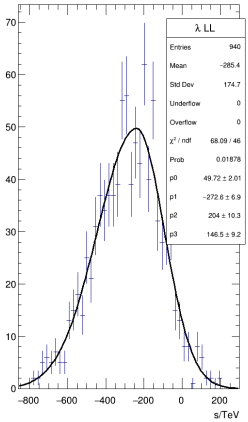

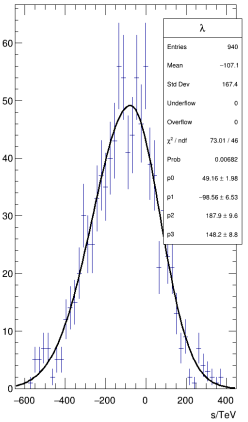

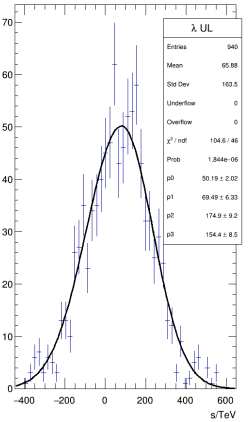

Fig. 15