Long term lightcurve of the BL Lac object 1ES 0229+200 at TeV energies with H.E.S.S.

G. Cologna [1†], M. Mohamed [1†], S. J. Wagner [1], A.Wierzcholska [1‡], C. Romoli [2]
for the H.E.S.S. Collaboration
and O. Kurtanidze [3,1]

1 Landessternwarte, Heidelberg, Germany
2 DIAS, Dublin, Ireland
3 Abastumani Observatory, Abastumani, Georgia

1ES 0229+200

- HBL at a redshift $z = 0.1396$
- bright in optical and X-rays:
  - synchrotron emission reaches 100 keV and possibly up to 200 keV [1]
- faint in radio and γ-rays:
  - detected above 580 GeV with H.E.S.S. in 2006 [2]
  - detected between 1 - 300 GeV in 2011 [3]
- little flux variability:
  - stable optical emission [4]
  - factor ~ 2 variations in X-rays [4]
  - no variability reported by H.E.S.S. [2]
  - hints of variability claimed by VERITAS [5]
- peculiar γ-ray characteristics:
  - hard TeV spectrum with $\Gamma \sim 2.5$ [2]
  - reaches $\sim$ 10 TeV

Astrophysical importance

Thanks to its peculiar γ-ray properties together with its distance, 1ES 0229+200 is a key source for deriving constrains

- on the extragalactic background light (EBL) at near- and mid-infrared wavelengths (2 - 20 μm) at high optical depths ($\tau = 1$ - 6). Low EBL levels have been determined [2].
- on the intergalactic magnetic field (IGMF). Lower limits of the order of 10^{-17}-10^{-15} Gauss have been calculated (e.g. [6; 7; 8; 3]). They normally rely on the assumption of a steady TeV flux (for more details, please refer to the proceeding).

H.E.S.S. observations

Dataset

- almost yearly observations between 2004 and 2013
- total livetime of 133 hours after quality cuts
- mean zenith angle of 45.2° and mean offset of 0.51°
- inhomogeneous exposure over the years

Data analysis

- data reduction performed using the Model analysis [9] with *Standard* cuts.
- background evaluation using a reflected region model
- power-law (PL) spectral fits performed on different data subsets
- lightcurves above 580 GeV (Fig. 1, top two panels) derived using a photon index of 2.9

Results

- detection with a significance of 18.1 σ
- no significant spectral variability
- monthly flux variability above 580 GeV: χ^2/d.o.f. 84.3/22, probability 5×10^{-9} $F_{var} = 0.60 \pm 0.15$
- monthly variability also between 0.58 to 1 TeV and above 1 TeV (probability of 1×10^{-4} and 2×10^{-5}, respectively).
- yearly flux variabiltity: χ^2/d.o.f. 33.3/7, probability 2×10^{-5} $F_{var} = 0.39 \pm 0.11$

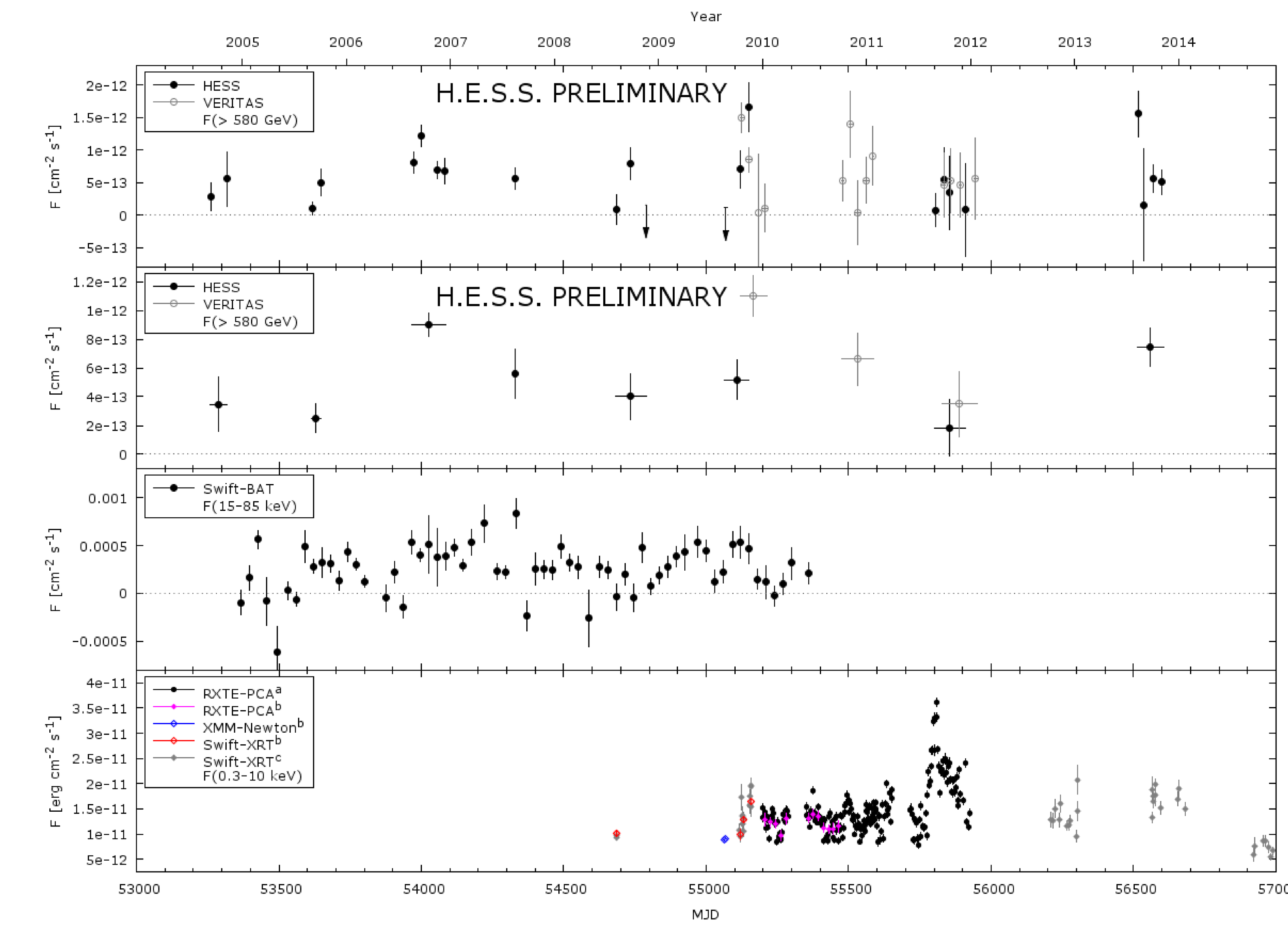

Figure 1 : Lightcurves of the BL Lac object 1ES 0229+200 in different energy bands between 2004 and 2013. From *top* to *bottom*: monthly and yearly H.E.S.S. lightcurves above 580 GeV - the VERITAS values from [5] are also depicted as comparison; *Swift*-BAT hard X-rays monthly lightcurve between 15 and 85 keV from the Palermo BAT Catalogue [10]; soft X-ray lightcurve between 2 and 10 keV for different instruments: $^{a)}$ 2010-2012 *RXTE* dataset from [11], $^{b)}$ XMM-*Newton*, *Swift*-XRT and *RXTE* data from [4], $^{c)}$ *Swift*-XRT data analysed in this work. The source is clearly variable in all energy bands. The discrepancy between the H.E.S.S. and VERITAS points in 2009 is explained by the non identical observation windows of the two instruments. Three point at MJD 53831, 55331 and 55377 have been removed for clarity from the *Swift*-BAT plot because of their large negative fluxes or error bars.

Multiwavelenght data

Very high energies

- VERITAS flux values taken from [5] and rescaled above 580 GeV
- VERITAS reported hints of variability on yearly and monthly timescales.

High energies

- *Fermi*-LAT data from August 4, 2008 to April 27, 2015
- 1ES 0229+200 detected between 100 MeV and 500 GeV with a significance of 10.5 σ
- the low flux does not permit detailed temporal studies on monthly timescales
- the variability index $TS_{var} = 2\Sigma_i[\log\mathcal{L}_i(F_i) - \log\mathcal{L}_i(F_{const})]$ of the monthly lightcurve indicates variability at the 5 σ level.

X-rays

- *Swift*, *RXTE* and XMM-*Newton* data from the literature are shown in Fig. 1, third and fourth panels
- all available *Swift*-XRT data between 2008 and 2015 are (re-)analysed for this work
- The soft X-ray lightcurve shows a flux variability of a factor ~ 2

Optical

- optical monitoring in R and B band carried out between 2007 and 2012 with ATOM [12]
- R band observation collected with the 70 cm telescope of the Abastunami Observatory (Georgia) in 2013
- The R and B bands are constant within the errors and do not show any variations

MWL campaigns

- August 21 and 23, 2009 with XMM-*Newton* and ATOM;
- October 1, 5 and 11, 2013 with *NuSTAR*, *Swift*-XRT, MAGIC and VERITAS.

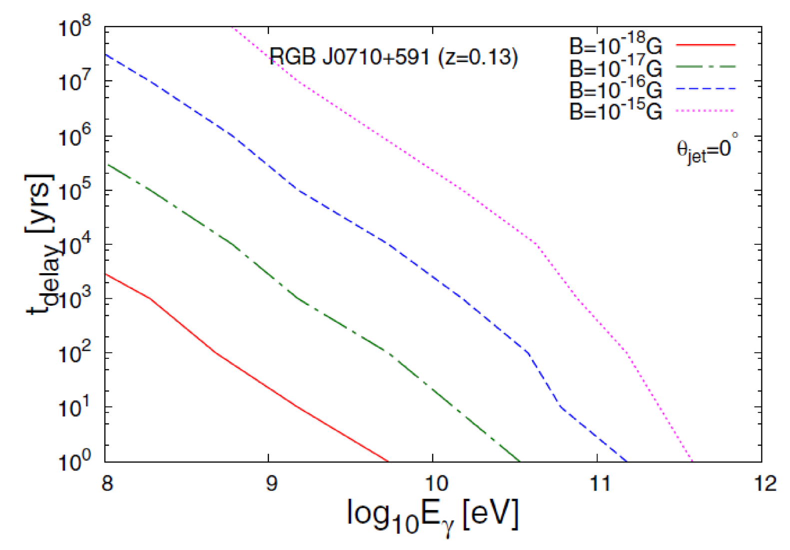

Figure 2 : Mean time delay in the arrival time of reprocessed radiation as function of the photon energy for different strength of the IGMF. The plot is taken from [8].

Results and discussion

Lightcurves

- contemporaneous observations with H.E.S.S. and VERITAS in 2009: measurements consistent with a flux that reaches its maximum just before MJD 55150 and then decreases
- 2009 MWL campaign (MJD $\sim$55065):
  - source in very low state for both H.E.S.S. and XMM-*Newton*
  - flux increase in the soft/hard X-ray and TeV bands of a factor of 2 to 3 in the following three months
  - subsequent flux decrease in all energy bands
- the three periods of low TeV flux in 2008 and 2009 are mirrored also in the *Swift*-BAT hard X-ray band
- 2013 MWL campaign (MJD $\sim$56570): source relatively bright in X-rays and on its average value in TeV

X-ray - TeV correlation is expected by the SSC model, implying that the two components are generated by the same electron population.

The big *RXTE* peak in 2011 (MJD $\sim$55800) has no clear correspondence in TeV. This could be explained by:

- the very low H.E.S.S. exposure
- a period of high activity of one of the many X-ray sources in the field of view of *RXTE*
- the presence of a second X-ray emitting zone, not related to any γ-ray emission and/or affected by Klein-Nishina suppression

Implications

- VHE monthly variability affects the limits on the IGMF
- the detected variability at $\sim$600 GeV allows a measurement of the IGMF if this emission consists of secondary photons ("maximal" case in [8])
- extrapolating Fig. 2 to shorter time delays, the IGMF is measured to be $B_{IGMF} \sim 3 \times 10^{-16}$ G
- proton-cascade models which require a constant TeV emission consisting of secondary radiation only (e.g. [13]) are strongly challenged by the monthly variability above 1 TeV (as well as "maximal" type cascade models in general)

Conclusions

- The 10 years long H.E.S.S. monitoring of the blazar 1ES 0229+200 between 2004 and 2013 has been presented for the first time in a MWL context.
- Clear variability is detected on monthly and yearly timescales.
- Hints of correlation between TeV and X-ray emission come from the contemporaneous observations with XMM-*Newton* and *Swift* in 2009: the fluxes increase in all energy bands in similar way over four months.
- This supports an SSC emission model in this source.
- The VHE monthly flux variability affects the derivation of lower limits on the IGMF. Assuming the emission at $\sim$600 GeV to be of secondary photons, one can actually obtain a measurement of the IGMF of $B_{IGMF} \sim 3 \times 10^{-16}$ G.
- Future studies investigating further the energy dependent variability will allow the contribution of the cascade emission to the flux to be probed more deeply for both hadronic and leptonic models.

Acknowledgements

Please see standard acknowledgement in H.E.S.S. papers, not reproduced here due to lack of space.
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† Member of the International Max Planck Research School for Astronomy and Cosmic Physics at the University of Heidelberg (IMPRS-HD) and the Heidelberg Graduate School of Fundamental Physics (HGSFP).
‡ Mobility Plus Fellow.

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