Spectrum and variability of the Crab Nebula with H.E.S.S.

Floriana Zefi
J. Hahn, M. Holler, V. Marandon, C. Mariaud, M. de Naurois & D. Parsons
for the H.E.S.S. collaboration

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Motivation

- Crab always considered as a “standard candle” in $\gamma$-ray astronomy
- But... Several flares reported by Fermi-LAT
- Search for TeV flux variations, taking into account atmospheric conditions
- Study long-term variability using 10yr of H.E.S.S. I data
H.E.S.S. observations of the Crab Nebula

- Crab Nebula is visible to H.E.S.S. at zenith angles $\theta > 45^\circ$
  $\rightarrow$ prone to larger systematics

- Visibility periods: September – March

  Rainy season
  + fire bushes
Crab Nebula Data Set

Crab Nebula commonly used for instrument studies:

- Large zenith angles: 45 – 65°
- Large off-axis angle spread: 0.5 – 3.0°

For spectrum & variability studies:

- Zenith angles < 55°
- Offset angles < 0.8°
- + the standard run quality selection

41.5 hr
Crab Nebula energy spectrum fit:
[0.464 – 68.129] TeV

Best fit log-parabola:

\[
\frac{dN}{dE} = N_0 \left( \frac{E}{E_0} \right)^{-\alpha - \beta \ln \left( \frac{E}{E_0} \right)}
\]

- \( N_0 = 3.443 \pm 0.035 \times 10^{-11} \text{ cm}^{-2} \text{ s}^{-1} \text{ TeV}^{-1} \)
- \( E_0 = 0.994 \text{ TeV} \)
- \( \beta = 0.117 \pm 0.011 \)
- \( \alpha = 2.375 \pm 0.02 \)
Crab Nebula SED

- Spectral Energy Distribution of Crab Nebula

![Graph showing the Spectral Energy Distribution of Crab Nebula with data points from Fermi-LAT, MAGIC, VERITAS, and HESS.]
Long term variability

- 2004-13 run by run (28 min) lightcurve

$\chi^2/\text{NDF} = 582.6/134$

Excess variance = 17%
Long term variability

- 2004-13 run by run (28 min) lightcurve

\[ \chi^2/NDF = 582.6/134 \]
Excess variance = 17%

- Some runs with particularly low fluxes
  → Non-optimal atmospheric conditions?
Transparency coefficient (TC)

- Transparency coefficient (TC) is a measure of the quality of the atmosphere

\[ T \equiv \frac{1}{N \cdot k_N} \sum_i t_i. \]  

(Hahn et al. 2013)

- Telescope-averaged transparency coefficient

\[ T = \frac{\sum_i \frac{t_i^2}{\sigma_i^2}}{\sum_i \frac{1}{\sigma_i^2}} \]

- Designed to be independent from instrument behavior & observation strategy
TC impact on the Crab Nebula flux

- Runs grouped by mean TC value: 0.85, 0.925, 0.975, 1.025
- Integral flux for each run group

- Runs with low reconstructed flux correspond to low TC
Long-term lightcurve – good TC

- 2004-13 run by run lightcurve for runs with TC > 0.9

\[ \chi^2/\text{NDF} = 191.3/97 \]

Excess Variance = 13%
TC-correction of flux

- Selecting runs with good TC
  → Improved fit, reduced systematics
  at the expense of statistics

- TC correction
  → Keep more data, and correct flux for “bad” runs
  → Larger handle on variability studies

- Correction attempts:
  - Linear correlation: Flux/TC
  - Non-linear relation (requires calibration)

![Graph showing Flux vs. TC with a linear correlation]

Flux $\propto$ TC$^\alpha$

$\alpha \approx 1.7$
Long-term TC-corrected lightcurve

Uncorrected lightcurve: $\chi^2/NDF = 582.6/134$

Corrected lightcurve: $\chi^2/NDF = 430.2/134$
Conclusions and prospects

- Using transparency coefficient allows to:
  - Recover data taken under non-optimal atmospheric conditions
  - Reduce flux systematics

- Large H.E.S.S. I data set used to investigate variability of the Crab Nebula
  - No variability found at run-by-run level
  - Systematic uncertainty (excess variance)

- Outlook
  - Correct energy instead of flux (low transparency → underestimated energy)
  - Investigation of other time-scales
Backup