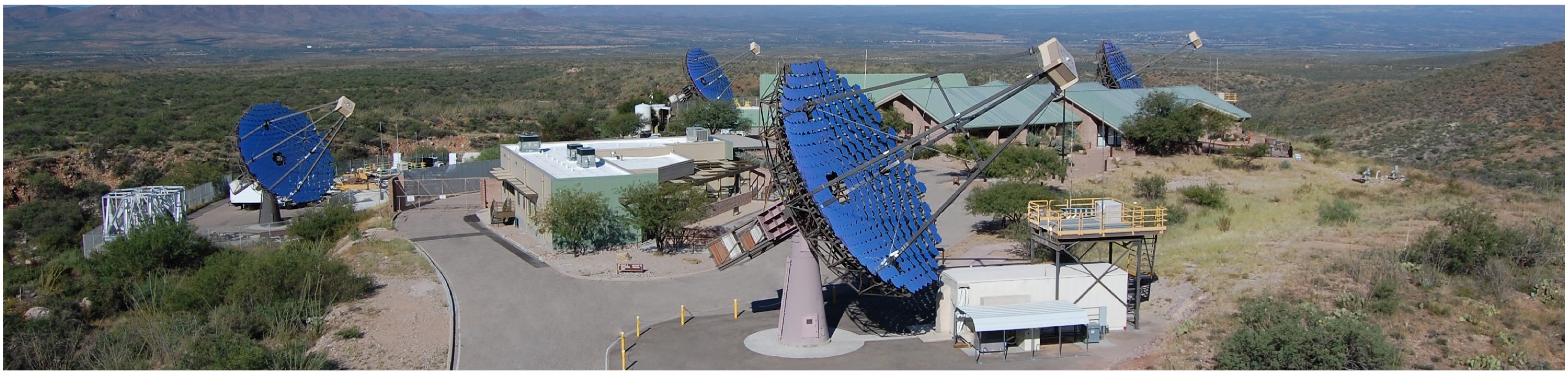

The search for short-term flares in extended VHE Crab Nebula observations with the Whipple 10 m telescope

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The Crab Nebula

Figure 1: Composite image of the Crab Nebula. Image credit: X-ray: NASA/CXC/SAO/F. Seward; Optical: NASA/ESA/ASU/J. Hester & A. Loll; Infrared: NASA/JPL-Caltech/Univ. Minn./R. Gehrz

The Crab Nebula was the first source detected at very high energies (VHE; $E > 100$ GeV) [1]. Since then, it has been considered a standard reference source of VHE astronomy, similar to its role in X-ray and high-energy gamma-ray astronomy, e.g., [2; 3].

In 2011, AGILE [4] and the *Fermi*-LAT [5] announced the discovery of short-term flares on the timescale of days at MeV – GeV energies. H.E.S.S., MAGIC and VERITAS have not detected evidence of any VHE flux enhancement during the flares [6–9].

Coverage of the known GeV flares with the Whipple 10 m telescope is unfortunately sparse. However, it is reasonable to assume that there have been flares from the nebula prior to the current gamma-ray satellite era. The Whipple telescope has a large archive of VHE data on the Crab Nebula. In this work, a ten-year data set collected with the Whipple 10 m telescope on the Crab Nebula from 2000 to 2010 is searched for flaring activity.

The Whipple 10 m telescope

The Whipple 10 m gamma-ray telescope was located at the Fred Lawrence Whipple Observatory in southern Arizona at an altitude of ~ 2.3 km above sea level. It was sensitive to photons with energies up to 20 TeV, with a nominal low-energy threshold of ~ 400 GeV for a Crab Nebula-like spectrum.

The telescope was of Davies-Cotton design, comprising a 10 m diameter reflector and a camera at the focal point to record the gamma-ray images. The reflector was composed of 248 tessellated hexagonal mirrors mounted on a spherical surface with a total reflecting area of $\sim 75\,\mathrm{m}^2$. The camera configurations used in this work each had a trigger field of view of $\sim 2.6^\circ$.

Figure 2: The Whipple 10 m telescope.

Observations

Due to local weather phenomena, an observing "season" was defined as beginning in September and lasting approximately until June. A data set was compiled using Crab Nebula observations from ten such seasons during the years 2000 – 2010. Data were taken in 28-minute observations in *paired mode*. Data were required to be accumulated under good weather conditions and at zenith angles $< 35^\circ$. A total of ~ 150 hours of quality-selected live time satisfied these criteria, including 328 observations taken on 243 separate nights.

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Bayesian-block analysis

A light curve of the Crab Nebula, binned by individual 28-minute observation is created for each observing season separately, as no interseason calibration has been applied. Each light curve is fitted with a constant rate to test for temporal stability. The source rate for each season is found to be consistent with a constant fit within $3\,\sigma$.

The data set is searched for variability using the Bayesian-block binning algorithm [10]. This modeling technique is used to obtain the best time-binned representation of the light curve. There is no lower or upper limit on the number of bins, and the bins can be of unequal size. A false-positive rate of $p_0 = 0.01$ is chosen for this analysis.

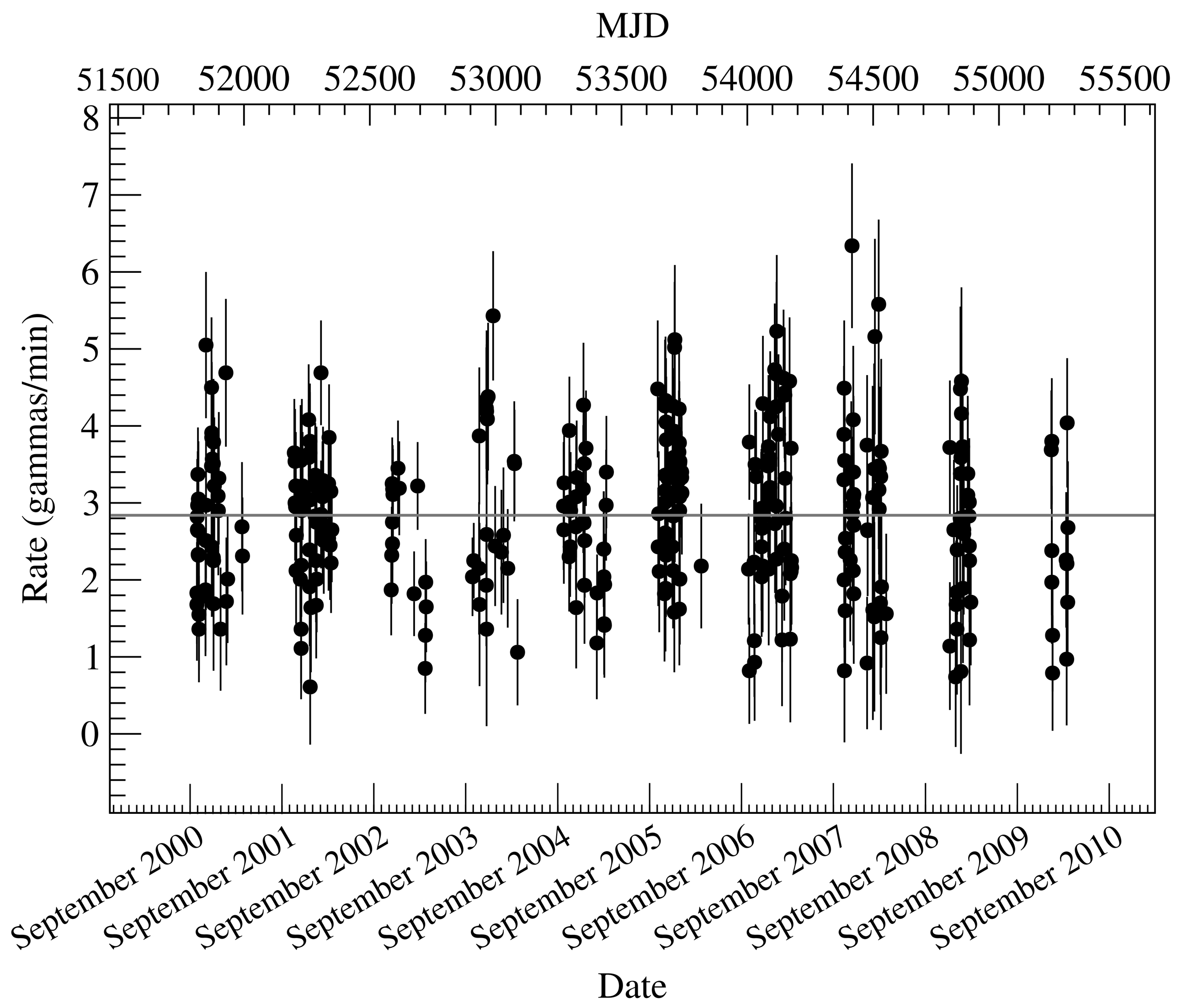

Figure 3: Ten-season light curve of the Crab Nebula covering the years 2000 – 2010, binned by individual 28-minute observation. The optimal temporal binning determined by the Bayesian-block analysis is a single bin spanning the entire data set, and is indicated by the solid gray line.

Upper limit on the frequency of flares

A toy Monte Carlo simulation was developed to simulate the light curve resulting from a single randomly-placed flare of known length and emission within an otherwise standard data set. A medium-duration flare of seven days was used for this study.

The simulation was run 10 000 times each for flare emission levels of five times, two times, and 1.5 times the average Crab Nebula flux. The Bayesian-block algorithm was used to analyze the resulting light curves. Based on the number of times a flare of a given level was detected by the algorithm, a 99% confidence level (CL) upper limit was calculated, using the method of [11], on the frequency of flares of that level that may be present in the data set. The following upper limits were found:

- Five-fold flares: 0.02 flares per year
- Two-fold flares: 0.27 flares per year
- 1.5-fold flares: detection rate consistent with false-positive rate of the analysis

Acknowledgments

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