Background Estimation for a Balloon Borne Gamma-Ray Experiment (GRAPE)

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The Gamma Ray Polarimeter Experiment (GRAPE), a balloon borne polarimeter for 50~300 keV gamma rays, successfully flew in 2011 and 2014. GRAPE consists of collimated array of polarimeter modules. The primary goal of these balloon flights was to measure the gamma ray polarization of the Crab Nebula.A good background estimation is crucial for this measurement. GRAPE observed various different sky regions before crab was in the range of the instrument. It observed the sun, cygnus-X1 and two separate background regions in the sky where we had no known sources above our instrument's threshold. Additionally the cygnus-X1 and the sun were also not active and were below our instrument threshold. So these measurements were also treated as background measurements.The background depends on many flight and instrument parameters including altitude, instrument pointing, temperatures, etc. We wanted to use these parameters and the background measurements to get an estimate for the Crab observation. These parameters are varying throughout the flight so estimating the background for the Crab observation was quite challenging. We have developed a technique based on the Principle Component Analysis (PCA) to identify the influential parameters. We found that the background depended mostly on the atmospheric depth, pointing zenith angle and instrument temperatures. Incorporating Anti-coincidence shield data (which served as a surrogate for the background) was also found to improve the analysis. We used these influential parameters to estimate the background during the Crab observation.We present the technique and resulting background estimate using the PCA approach.

GRAPE

The Gamma RAy Polarimeter Experiment (GRAPE) is a balloon borne Compton polarimeter optimized for 50-500 keV gamma rays. GRAPE was flown initially in 2011. An improved version (with improved shielding and a larger detector array) was flown in 2014.

The configuration flown in 2014 had 24 detector modules (Figure 1). Each module consists of 36 plastic and 28 CsI(Tl) scintillator elements mounted on a multi-anode photo-multiplier tube (MAPMT). The grid of detector elements is designed to measure scattered photons. The distribution of the scattered photons provides a polarization measurement of the incident flux. **PC events**, The most dominant scatter event type, are defined as events that interact in one plastic element and one calorimeter (CsI(Tl)) element. Ideally, these are events in which a photon scatters from the plastic to the calorimeter. The module array rests on a motor that rotates the instrument in steps of 4º to achieve a full rotation (sweep). It takes 6 mins to complete a sweep. This helps us remove the anisotropy during the observation. This assembly is completely enclosed by both active shielding (plastic scintillator) and passive lead shielding (Figure 2). Lead collimators are used to define a 20° FoV. This instrument assembly is inside a pressure vessel that is maintained at 1 atm pressure and can be moved in elevation. An inertia wheel assembly is used to point the entire gondola in azimuth.

Figure 1:

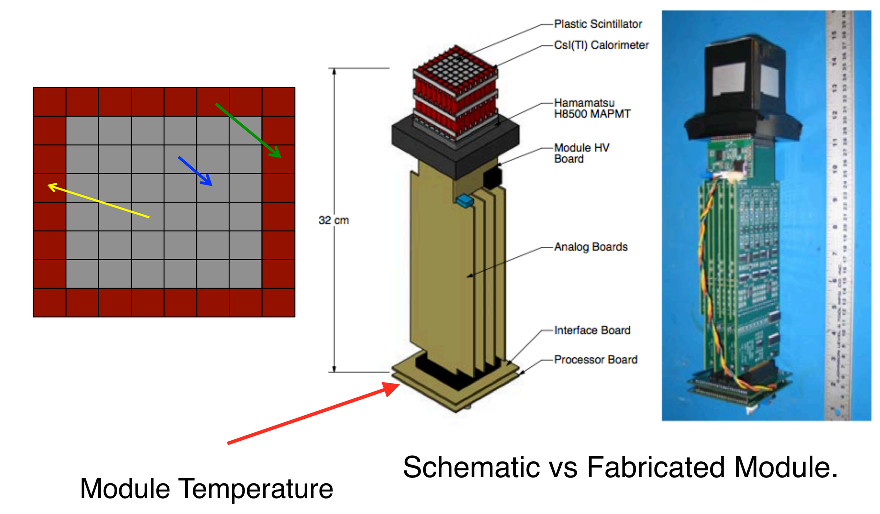


Figure 2:

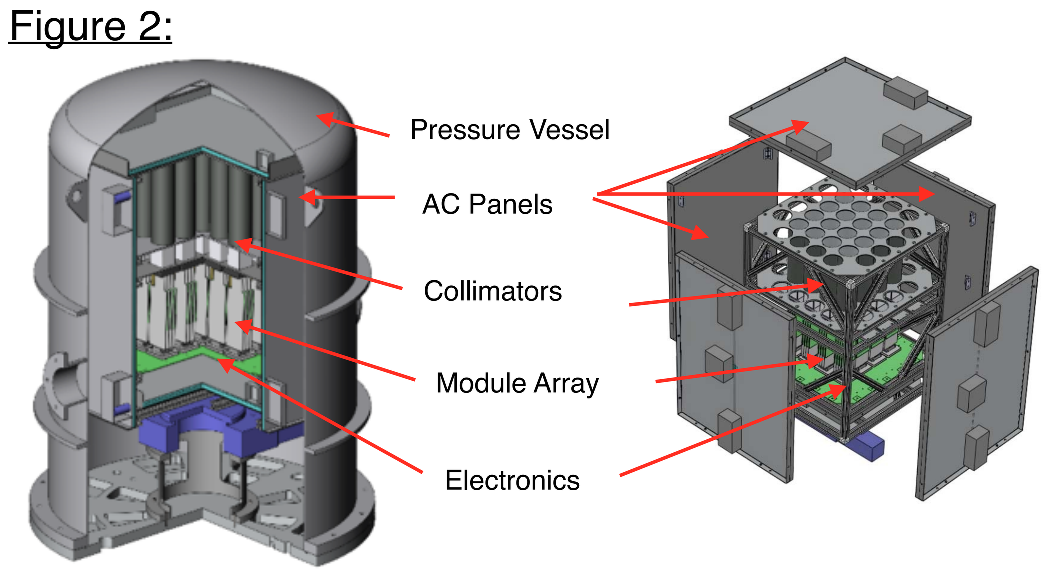
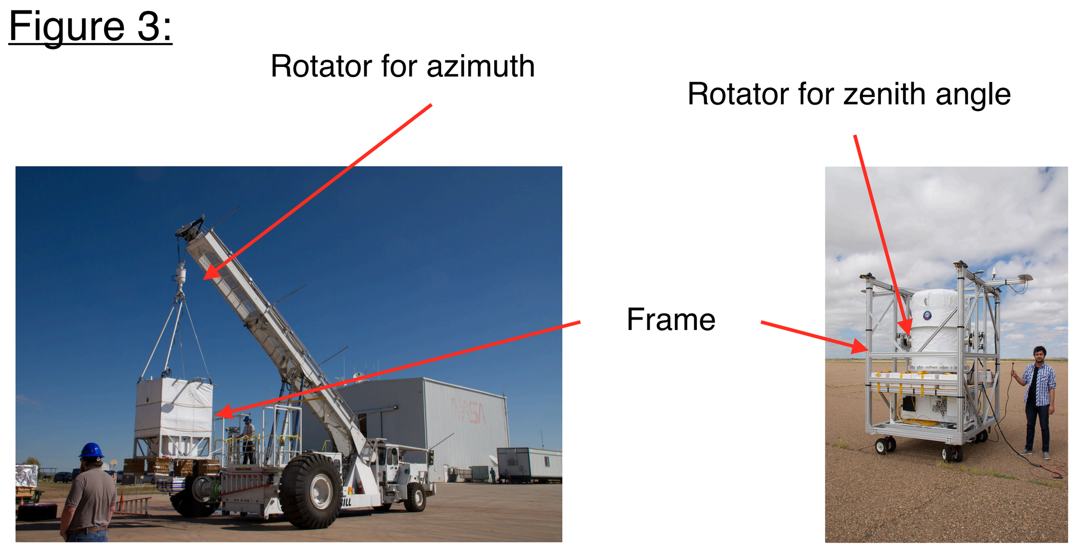


Figure 3:



2014 Flight

The GRAPE payload was launched on September 26th, 2014 from Fort Sumner, New Mexico. During the flight, GRAPE observed the Sun, Cygnus X-1 and the Crab, along with two background regions in the sky that we refer to as BGD2 and BGD4 . The background regions were regions in the sky that did not have known sources above our sensitivity threshold. During the flight, the Sun was not active and Cygnus X-1 was at a low intensity state (. So these data could also be used for estimating the background during the Crab observation (our primary scientific target). The payload spent 14.4 hours at float. The Crab was observed for only 1.8 hours because of the unfavorable wind. Our flight plan had included 8 hours of data on the Crab, but the flight was terminated before all of the data could be collected. The variation of PC rate with time for various observations is shown in figure 4.

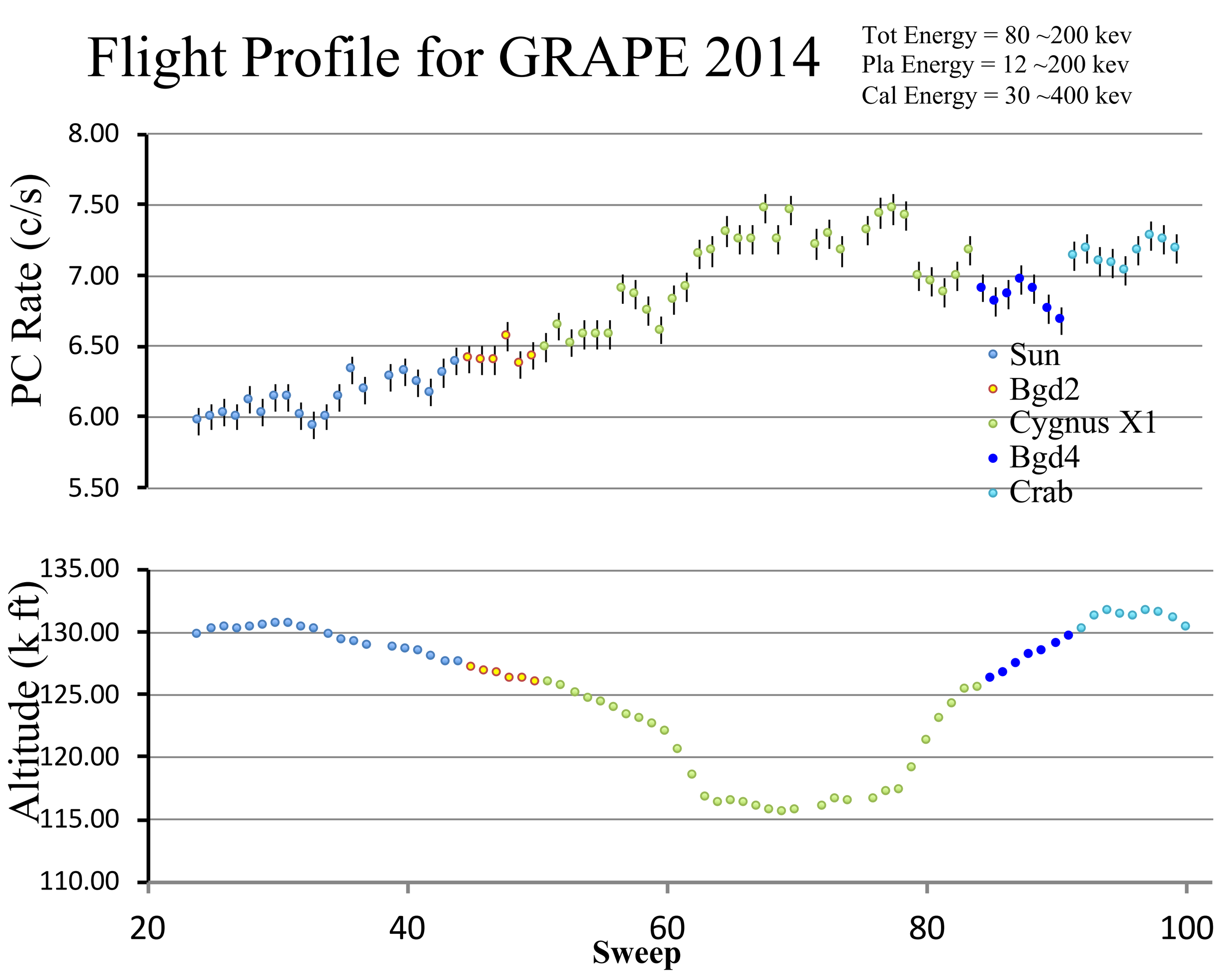


Figure 4: Flight profile of GRAPE 2014 showing the most dominant PC events.

Estimating the Background

The background depends on many flight and instrument parameters. These parameters are varying throughout the flight. Ideally, we would want a background measurement with the same flight parameters as the Crab observation. To achieve this we had planned to periodically take background measurements during the Crab observation. However, dude to the constricted time of the Crab observation due to the unfavorable wind, we were not able to achieve this traditional way. Secondly, we tried to find matching parameters of Crab observation with the background observations before we started looking at the Crab. Since there were plethora of variables varying throughout the flight, we could not find an agreeable flight parameters of the background observations comparable to the Crab observation. We would want to find the influential parameters that affect the background and use them to get an estimation for the Crab observation. We addressed this problem using Principle Component Analysis (PCA).

Principle Component Analysis

Principle Component Analysis (PCA) is a technique where it uses a linear combination of the input parameters to define new sets of orthogonal vectors called the principle components. Each of these principle components is associated with the correlation matrix of the input parameters. The relative magnitude of these eigenvalues provides the relative importance of the principle component to define the data [2][3]. We started with a total of 14 flight and instrument parameters for this analysis. We also included the AC rates from our active shielding as a surrogate for background estimation. These are shown in figure 5. The PCA helped us reduce this down to 5 principle components. These principle components are made up of linear combination of all the parameters, however, the influential parameters contribute the most and less influential parameters contribute the least in forming these principle components. We then used these components are did a regression analysis on the background measurements and further extrapolated it to the Crab observation. The result is shown in figure 6.

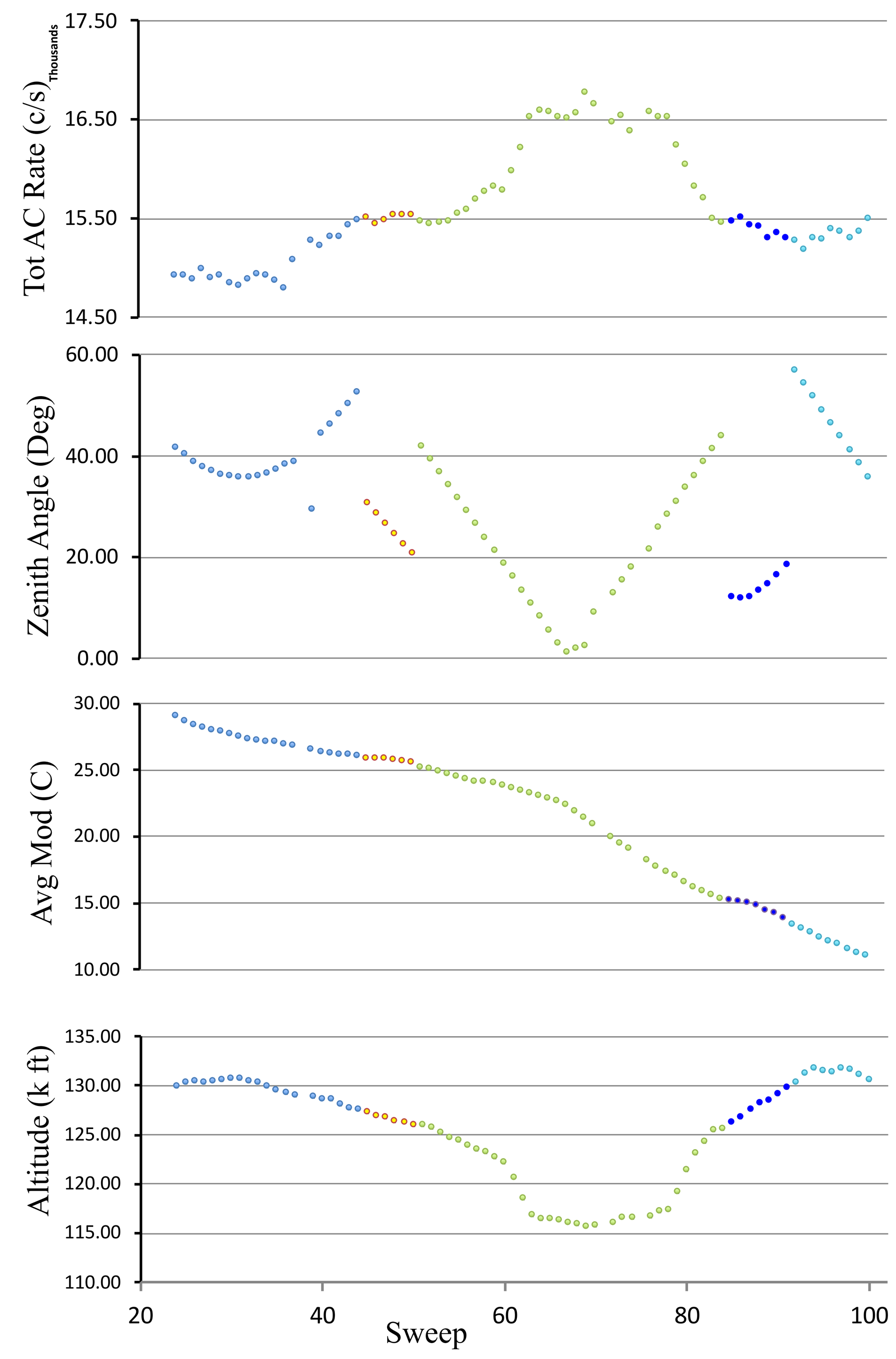


Figure 5: Various flight parameters

Summary

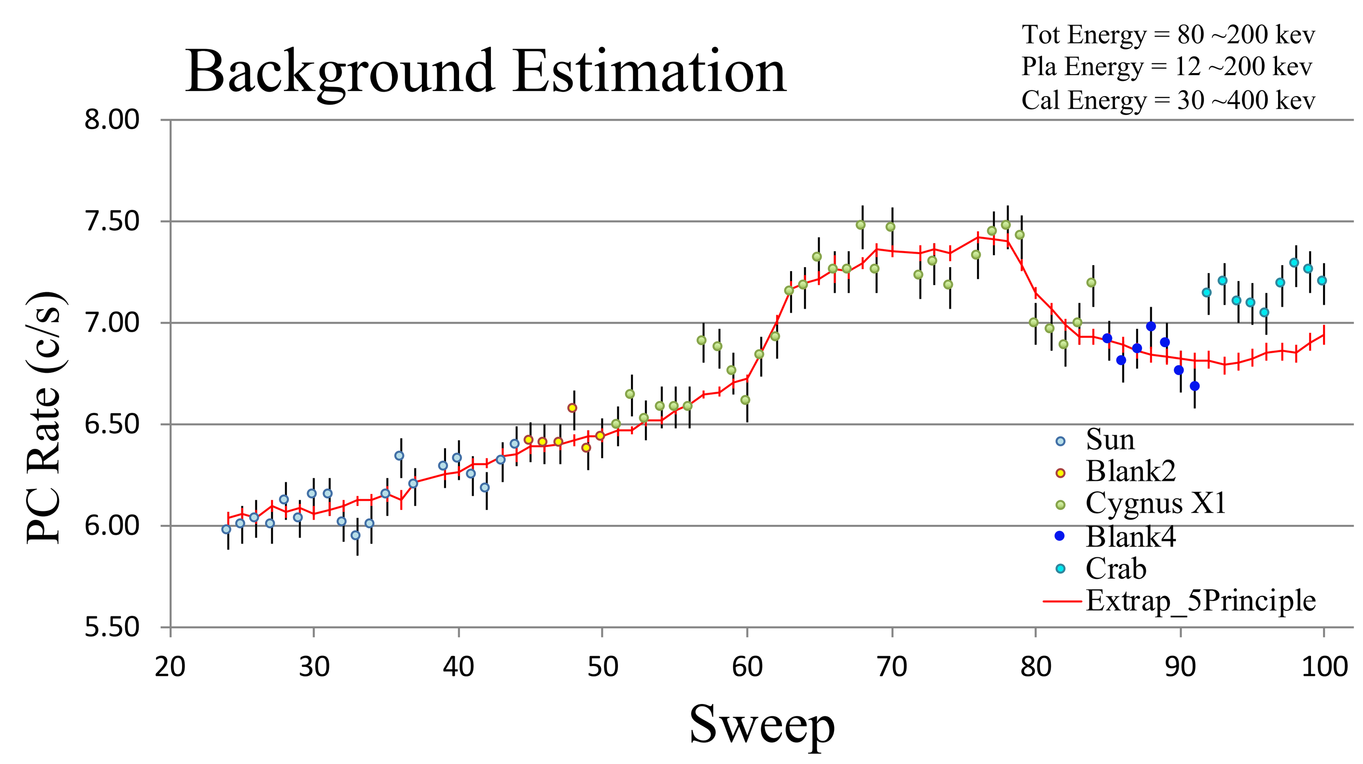


Figure 6: Using PCA and regression analysis to extrapolate background for Crab observation.

We can see in figure 6 that our approach provides a means to estimate the background for Crab. Here we have shown this approach for an energy range of 80-200kev. Our next step would be to use this for smaller energy ranges defined by our energy bins from energy loss spectrum and be used in conjunction with the response of the instrument to get an energy spectra.

[1] T. Mizuno, T. Kamae, G. Godfrey, T. Handa, D. J. Thompson, D. Lauben, Y. Fukazawa, and M. Ozaki. Cosmic-Ray Background Flux Model based on a Gamma-Ray Large-Area Space Telescope Balloon Flight Engineering Model. The Astrophysical Journal, 614(2):1113–1123, jun 2004.

[2]C. A. Whitney. Principal components analysis of spectral data. I - Methodology for spectral classification. Astronomy and As- trophysics Supplement Series, vol. 51, Mar. 1983, p. 443-461., 51:443–461, 1983.

[3] C. A. Whitney. Principal components analysis of spectral data. II - Error analysis and applications to interstellar reddening, lu- minosity classification of M supergiants, and the analysis of VV Cephei stars. Astronomy and Astrophysics Supplement Series, vol. 51, Mar. 1983, p. 463-478., 51:463–478, 1983.