Similarities and Differences between X-ray and H.E.S.S. Data Analysis

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Introduction and Motivation

H.E.S.S. data reduction

- **event reconstruction** (today) : leads to production of **DST** files
- **data analysis** proper (next two mornings) : subject of this talk

Two complementary aims

- illuminate HESS data analysis steps for X-ray observers
- introduce X-ray analysis tools and procedures to inspire possible new developments in HESS analysis

Outline

X-ray Data Analysis : Spectroscopic Imaging

Modern X-ray CCD detectors (e.g. *Chandra* ACIS, *XMM-Newton* EPIC cameras) produce **event lists** (in `FITS` format)

Event reconstruction done on-board (full images not telemetred); *pixel pattern* in CCD used to determine for each event:

- Event time
- **Sky coordinates**
- **Energy** estimator : `PI`
  (historical: position-invariant version of `PHA`)
- Event *grade*

Analysis : obtain **sky maps**, **spectra**...

H.E.S.S. Data Analysis

HESS event *reconstruction* : use shower images in the telescopes to reconstruct physical properties of the incident particle

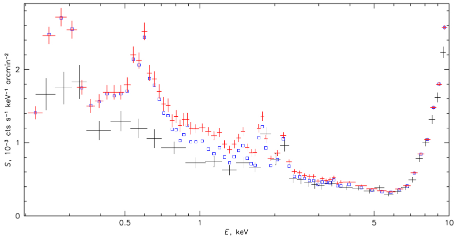
DST files contain for each event (among other things):

- Event GPS time stamp
- **Sky coordinates**
- **Energy** estimator
  (or relevant event parameters)
- **Discriminating variables** :
  Hillas parameters, model goodness, 3D width...

Analysis : obtain **sky maps**, **spectra**...

Chandra ACIS Background

- *some* background rejection done on-board
- background for standard (X-ray like) grades:
  - particle or non-X-ray background (NXB)
  - total with X-ray background
  - with *unresolved* X-ray background



- total rate : 0.27 s^{-1} (0.3 – 10 keV) per ACIS (FI) chip
  0.16 s^{-1} (0.5 – 7 keV)

Relative Importance of Background

Background Rates

- ACIS chip covers $7.5' \times 7.5'$ field of view
  $\Rightarrow$ background rate $\sim 2 \times 10^{-3}\ \mathrm{s}^{-1}\ \mathrm{arcmin}^{-2}\ \sim 10\ \mathrm{s}^{-1}\ \mathrm{deg}^{-2}$
- HESS event rate $\sim$ 300 Hz in $\sim 5^\circ$ diameter FOV
  $\Rightarrow$ raw background rate $\sim 10\ \mathrm{s}^{-1}\ \mathrm{deg}^{-2}$

  (coincidence : X-ray event rejection vs. much higher threshold)

Source photon fluxes

- typical ($\sim$ 10% Crab) HESS source : $\sim 10^{-2}\ \gamma/\mathrm{s}$
- $10^{-12}\ \mathrm{erg\ cm}^{-2}\mathrm{s}^{-1}$ (1-10 keV) X-ray source : $\sim 1\ \mathrm{count}/\mathrm{s}$

$\Rightarrow$ Importance of background rejection cuts

Selection Cuts : Influence on Acceptance

HESS data analysis

- selection cuts on **discriminating variables** (Hillas scaled parameters, model goodness, 3D width, X_{eff}, ...) reduce background by a large factor (> 90%)
- cost : non-negligible reduction in γ-ray acceptance (> 10%)

$\Rightarrow$ analysis must compute acceptance *after cuts*

Contrast : ACIS `VFAINT` mode

- for very faint sources, telemetry of more information per event
- allows additional background rejection (factor < 2)
- influence on X-ray acceptance negligible ($\sim$ 2%)

$\Rightarrow$ standard acceptances are normally used

Data Quality Selection

X-ray GTI's

- individual observations typically several hours (10's of ks) long
- must exclude periods of high particle background (*flares*), telemetry dropouts, etc.
- *Good Time Interval* (GTI) FITS extension in each data file
- used in exposure computation

HESS run selection

- observations divided into (typically) 28-minute runs
- must exclude periods of clouds, hardware problems, etc.
- currently done by excluding *entire runs*
- significant gain in useful exposure with GTI-like mechanism? (e.g. for clouds, well-defined by radiometer measurements)

Sky Maps and Background

Raw count map

- 2D histogram of event sky positions
- useful for fine detail in bright, compact X-ray sources

Background subtraction : excess map

- estimation and subtraction of (non-uniform) background
- requires some form of smoothing ; typical HESS maps

Significance map

- significance of excess relative to background fluctuations
- requires *oversampling* : N_{ON}, N_{OFF} in well-defined regions
- not typically used in X-rays : issue of oversampling scale

Sky Maps and Acceptance

Exposure correction : Flux map

- photon acceptance depends on position in FOV (*offset*)
  (also depends on other parameters: temperature, zenith angle...)
- X-rays : create *exposure map* according to pointing history and instrument sensitivity (bad columns, etc.)
- divide background-subtracted count map ($\equiv$ *excess* map) by exposure to obtain *flux map*

Issue : Energy dependence

- acceptance depends on photon energy
- exposure map created for a specific energy or spectrum : not appropriate for all sources or regions in FOV
- not typically used in HESS : would still be appropriate for extended sources without significant spectral variations
- alternative construction : *event-by-event* acceptance weighting?

Spectral Fitting Method

Forward folding : model spectrum vs data

- model spectrum $F(E_{\rm true} \equiv E)$ vs data $N_{\rm excess}(E_{\rm estim} \equiv E')$
- energy resolution $G(E, E')$: response matrix (RMF) file
- fold with exposure $A(E)$: ancillary response (ARF) file
- compare $\int F(E)\, A(E)\, G(E, E')\, dE'$ with $N(E')$

- implemented in standard program XSPEC
- many models, fit statistics ⇒ useful for HESS?

Issue : acceptance for extended sources

- $A(E)$ depends on position in FOV (*offset*)
- typical X-ray tools compute acceptance weighted by count map
- similar appoach (weighting by excess map) possible for HESS?

Summary and Prospects

Summary : Differences and Similarities

- Main difference between X-ray and Cherenkov gamma-ray data analysis lies in the **relative importance of background**.
- Much effort expended on **background rejection cuts**, with significant impact on γ-ray acceptance computation
- (Excess) **sky maps** and model **spectral fitting** otherwise similar

Outstanding issues and prospects for HESS

- Use of `GTI`-like mechanism for *partial run* selection?
- Computation of *flux* maps rather than *excess* maps?
  (Issues : spectral assumptions, smoothing scale)
- Spectral fitting:
  - Excess map weighting of acceptance for extended sources?
  - Use of `XSPEC` for flexibility and compatibility?