Combining 3-PCU, 4-PCU and 5-PCU Spectra

Recipes from the RXTE Cook Book

Introduction

In March 1996, PCU3 and PCU4 (if you start counting from 0; PCU4 and PCU5 if you count from 1) began to discharge. Since then, these two PCUs - individually or together - are turned off now and again to prevent further damage. Observers, therefore, should not be surprised to find that their data have been collected with three, four or five PCUs, or a combination of these.

The turning on and off of PCUs 3 & 4 is sometimes scheduled and sometimes automatically triggered. Since it obviously has an important impact on data analysis, you should check your observation against the SOF's *XTE PCA High-Voltage History*. It is also essential to plot the PCU-related columns from the filter file (see below).

Before looking at the recipe, we should first consider how the spectra, background and responses should be combined.

In general, arrival times are lost when a spectrum is extracted, so a spectral fitting program like xspec can't "know" whether the counts in a PHA file were collected when three PCUs were on or five. This means that should only combine spectra when arrival times don't matter, i.e. when the source was in the same spectral state. Of course, this is usually the scientifically prudent thing to do anyway.

Combining the PHA files, source and background, is straightforward: the total counts is the sum of the individual counts, while the total exposure is the sum of the individual exposures. Less obvious, perhaps, is that the corresponding responses should be be combined by weighting them by background-subtracted counts, rather than by exposure. To see why, consider the extreme example of an observation conducted half the time with all five PCUs and half the time with just one PCU. In this case, five times more incoming photons experience the all five PCUs than experience one PCU. Accordingly, the 5-PCU response should carry five times the weight as the 1-PCU response, rather than the equal weight implied by the exposures. Background-subtracted counts are used in the weighting because the response is applied to background-subtracted spectra.

Extracting 3-PCU, 4-PCU and 5-PCU Spectra

General instructions for extracting spectra can be found in the recipe *Reduction and Analysis of PCA Spectra*. Here, we simply emphasise the aspects that pertain to mixed-PCU observations.

1. **Examine the filter file:** In general, the filter file tells you the status of the satellite and its instruments during your observation and can be used to identify periods of good data. In particular, the column `NUM_PCU_ON` will tell you *how many* PCUs were on during the observation. To see *which* if PCUs were off, plot the columns:

   ```
   PCU0_ON
   PCU1_ON
   PCU2_ON
   PCU3_ON
   PCU4_ON
   NUM_PCU_ON
   ```

   or the columns containing the count rates from the individual PCUs:

   ```
   evXEgood_PCU0
   evXEgood_PCU1
   evXEgood_PCU2
   evXEgood_PCU3
   evXEgood_PCU4
   ```

2. **Create GTI files with maketime:** If you find, for example, that your observation has periods when all five PCUs are on and periods when only PCUs 0-2 are on, you can generate GTI files containing these periods using maketime:

   ```
   kaah[21]% maketime
   Name of FITS file and [ext#][] realtime_go.xfl
   Name of output FITS file[] pcus_01234.gti
   Selection Expression[] NUM_PCU_ON.eq.5
   Column containing HK parameter names[NAME]
   Column containing HK parameter values[VALUE]
   Column containing HK parameter times[TIME] Time
   Flag, yes if HK format is compact[yes] no
   ```

   and

   ```
   kaah[21]% maketime
   Name of FITS file and [ext#][realtime_go.xfl]
   Name of output FITS file[pcus_01234.gti] pcus_012.gti
   Selection Expression[NUM_PCU_ON.eq.5] NUM_PCU_ON.eq.3
   Column containing HK parameter names[NAME]
   Column containing HK parameter values[VALUE]
   Column containing HK parameter times[Time]
   Flag, yes if HK format is compact[no]
   ```

3. **Create column selection files:** If extracting Standard-2 data then you should create column selection files corresponding to the PCUs and anodes you want. See the recipe *Selecting PCA Data by PCU, Layer and Anode* for more details. [Note, however, that this is not strictly necessary if you use GTI files to identify the 3-PCU and 5-PCU periods. This is because saextrct does not accumulate exposure from columns with no data in them.]

4. **Extract the source and background spectra, make the response matrices**: The recipe *Reduction and Analysis of PCA Spectra* explains how. Each 3-PCU, 4-PCU and 5-PCU spectrum should have a corresponding background file. And you should make responses for 3-PCU, 4-PCU and 5-PCUs.

Combining 3-PCU, 4-PCU and 5-PCU Spectra

In this example, we'll combine the following two sets:

```
                    3-PCU                  5-PCU

     SOURCE    quiescence_012.pha     quiescence_01234.pha
 BACKGROUND    back_012.pha           back_01234.pha
   RESPONSE    p012_L1R1_970218.rsp   pca_L1R1_970218.rsp
```

1. **Change the headers of the source files:** The ftool addspec will combine spectra, but first we should write the names of the background and response files into headers of the source files. Several different ftools can be used to this. With grppha:

   ```
   kaah[66]% grppha quiescence_012.pha
   Please enter output filename[] !quiescence_012.pha
   .
   .
   .
   GRPPHA[] chkey BACKFILE back_012.pha
   GRPPHA[] chkey RESPFILE p012_L1R1_970218.rsp
   GRPPHA[] exit
   ```

   The exclamation mark before the output filename causes the program to overwrite the input file, which is what we want.

2. **Run addspec to combine the spectra:**

   1. First create an ASCII file listing the source PHA files you want to add. In our example, `combine_pha.list` contains:

      ```
      quiescence_012.pha
      quiescence_01234.pha
      ```

   2. Run addspec:

      ```
      kaah[73]% addspec
      ** ADDSPEC 1.1.1
      ***** THIS IS A BETA_TEST VERSION (check your o/p) *****
      Input ASCII filename[] combine_pha.list
      Root of Output filename(s)[] quiescence_combo
      Combine any corresponding RMF datasets ?[no] yes
      Create background file (if possible) ?[no] yes
      ```

   Here, addspec:

   - created the source PHA file `quiescence_combo.pha` by combining `quiescence_012.pha` and `quiescence_01234.pha`;

   - created the combined background PHA file `quiescence_combo.bak` by combining `back_012.pha` and `back_01234.pha`;

- created the combined response file `quiescence_combo.rsp` by combining `p012_L1R1_970218.rsp` and `pca_L1R1_970218.rsp`; and
- wrote `quiescence_combo.bak` and `quiescence_combo.rsp` into the header of `quiescence_combo.pha`.

3. **Combine the response matrices:** Since addspec weights responses by exposure rather than by counts, we'll have to regenerate `quiescence_combo.rsp` with addrmf:

   1. Delete the incorrectly weighted `quiescence_combo.rsp`. [In case you're wondering, there are two reasons why we created it in the first place. First, addspec wrote its name into the header of `quiescence_combo.pha`, so if we choose the same name for the correct version, xspec will find it automatically. Second, due to a bug, addspec only assigns certain keywords when a response is generated.]

   2. Determine the weights. To get the total counts in each PHA file, run the ftool fstatistic on the `COUNTS` column, for example:

      ```
      kaah[55]% fstatistic quiescence_012.pha COUNTS
      Range of rows to include[-]
       The sum of the selected column is    1906007.0
      ```

      In our example, we have:

      ```
      quiescence_012.pha       1906007.0
      quiescence_01234.pha     4100638.0
      back_012.pha               15664.278
      back_01234.pha             33093.738
      ```

      which yields the weights 0.3173 for the 3-PCU response and 0.6827 for the 5-PCU response. [Note that the background spectra have non-integer total counts because they were extracted from model data generated by pcabackest.]

   3. Create an ASCII file, `combine_rsp.list`, say, containing the responses and weights:

      ```
      p012_L1R1_970218.rsp  0.3173
      pca_L1R1_970218.rsp   0.6827
      ```

   4. Run addrmf to combine the matrices:

      ```
      kaah[75]% addrmf
      ADDRMF vers 1.10  10 April, 1997.
      Name of ascii file listing input RMFs or input RMF filenames[@rsp.txt] @
      Summing ...
       3.173E-01 * p012_L1R1_970218.rsp
       6.827E-01 * pca_L1R1_970218.rsp
      Name of output RMF file[pca_L1R1_970218.rsp] quiescence_combo.rsp
       RMF #    1 : p012_L1R1_970218.rsp       0.32
                    XTE         PCA         PCU0        NONE        PHA
       RMF #    2 : pca_L1R1_970218.rsp        0.68
                    XTE         PCA         PCU0        NONE        PHA
      ```

4. **Test your results:** If the combination worked correctly, then you should find that when you fit the same model in xspec to the combined spectrum, i.e. with:

   ```
   XSPEC> data quiescent_combo.pha
   ```

   you should obtain a similar fit with the individual spectra:

   ```
   XSPEC> data quiescent_012.pha quiescent_01234.pha
   ```

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