# SIMPUT
# A File Format for Simulation Input

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## SUMMARY

We present a standard format for source input files to be used in simulations of astronomical observations. Each source file contains a catalog with one or multiple sources, which are described by specific properties such as position, brightness, energy spectrum, as well as optional characteristics such as time variability, polarization, and spatial extent.

This file format defines a common basis to exchange data between different software packages and scientific groups. It was developed in particular for the simulation of X-ray telescopes, but can also be used in different wavelength domains.

# LOG OF SIGNIFICANT CHANGES

| **R**elease **D**ate | **S**ections Changed | **B**rief Notes |
|---|---|---|
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DRAFT

# 1   Introduction

In X-ray astronomy, simulations of existing and future telescopes are used both to estimate the scientific capabilities provided by an instrument and to understand particular phenomena in measured data. Therefore there are a growing number of different simulation tools for particular issues, each implementing its own particular format for simulation input data.

X-ray point sources may be modeled using coordinates given either on the command line or in a separate file. For extended sources there are also various approaches parameterizing the observable shape or specifying an input image. The range of possible input formats extends even further when additional parameters such as the spectral shape or brightness variability have to be considered.

Due to the large number of existing input formats it is difficult to use data generated for one particular simulation within another software package. We address this issue by introducing a common input data format for simulations of astronomical X-ray telescopes based on the Flexible Image Transport System (FITS) file format defined by Hanisch et al. (2001) and Pence et al. (2010). The format enables modeling of all relevant source properties starting with source positions, spatial shapes for extended sources, energy spectra, polarization of the emitted radiation, as well as time-variable features such as brightness, spectral, and spatial variations. It can be regarded as an interface between different simulations and different scientific groups, for example the users of a simulation and a Magnetohydrodynamic (MHD) modeler providing the input data. The use of this format simplifies the conversion processes needed to prepare for a simulation and provides a clear and flexible way to describe all relevant features to model X-ray sources.

Although the file format has been developed in particular for simulations of X-ray telescopes, it can also be used in different wavelength domains of astronomy by adjusting the required units. The usage of physical units within this format is based on the specification defined by George & Angelini (1995) and Pence et al. (2010).

# 2   File Format

A SIMPUT FITS file contains several different types of extensions with the formats described in this section. The main file must contain one source catalog extension defining the individual sources. Of course, the catalog can also consist of a single source. Additional data such as spectra, light curves, or images can be stored in separate extensions in the same file or in other FITS files. An example for the basic structure of a SIMPUT file is shown in Fig. 1.

The file format can describe point-like and spatially extended sources with either constant or time-variable brightness. The spectral shape, spatial extension, or polarization of the emitted photons might also be time-dependent. The emitted radiation can have a particular polarization. By combining different features of the presented format, one can describe nearly all astronomical sources. For instance a spatially extended source, which has different emission regions with particular spectra, can be described as the superposition of several separate source images with appropriate spectra. In addition each of these spectra can have different polarization.

In the following part of this section the format of the individual extension types is defined. The proposed order of columns in binary tables is not mandatory, but can be modified. Additional columns are allowed. Undefined string entries in a table are denoted by the FITS NULL value.

Figure 1: A SIMPUT file ('main.fits') contains one source catalog extension with the basic description of one or multiple sources. Additional data such as spectra, light curves, and images can be stored in separate HDU s or even in separate FITS files ('additional.fits'). The individual entries in the source catalog refer to the required extensions.

## 2.1 Source Catalog Extension

**Description**    The main extension in a SIMPUT FITS file is a source catalog providing the basic properties of individual sources. It defines source characteristics such as the position and brightness. Additional information about the source spectrum, light curve, and spatial extension may be stored in separate FITS file HDU s. The entries in the catalog contain links to the corresponding extensions using the extended filename syntax (Pence, 1999).

In order to be used as simulation input, a SIMPUT FITS file must contain exactly one source catalog extension, even if it describes only a single source. The name of this extension is **SRC_CAT**.

**Extension Header**    The following keywords are mandatory:

- HDUCLASS - contains the string HEASARC
- HDUCLAS1 - contains the string SIMPUT
- HDUCLAS2 - contains the string SRC_CAT
- HDUVERS = '1.0.0' - giving the version of the format
- EXTNAME - contains the string SRC_CAT
- RADESYS - reference coordinate system, e.g. FK5
- EQUINOX - reference coordinate system, e.g. 2000.0

The usage of the RADESYS and EQUINOX keywords is described by Calabretta & Greisen (2002) and Pence et al. (2010).

**Data Format**    The data within the extension are organized as a BINTABLE with the following columns:

1. *ID*, an **integer** value containing a unique identifier for each entry.
   The FITS column name is **SRC_ID**.
   (unitless).
   This column is required.

2. *Name*, a **string** containing the name of the source (need not be unique, as a single source might be modeled by several entries).

The FITS column name is **SRC_NAME**.
(unitless).
This column is optional.

3. $\alpha$, a **floating point** value containing the right ascension of the source.
The FITS column name is **RA**.
The recommended units are deg.
This column is required.

4. $\delta$, a **floating point** value containing the declination of the source.
The FITS column name is **DEC**.
The recommended units are deg.
This column is required.

5. $\rho$, a **floating point** value containing the rotation angle (measured in the direction N-E-S-W) around the reference point for extended sources and of the polarization vector for polarized sources respectively (see notes below). This quantity is only defined for extended or polarized sources.
The FITS column name is **IMGROTA**.
The recommended units are deg.
This column is optional.

6. *Image Scale*, a **floating point** value containing the inverse linear scaling factor for extended sources (see notes below). This quantity is only defined for extended sources.
The FITS column name is **IMGSCAL**.
(unitless).
This column is optional.

7. $E_{\min}$, a **floating point** value specifying the lower value of the reference energy band.
The FITS column name is **E_MIN**.
The recommended units are keV.
This column is required.

8. $E_{\max}$, a **floating point** value specifying the upper value of the reference energy band.
The FITS column name is **E_MAX**.
The recommended units are keV.
This column is required.

9. *Flux Density*, a **floating point** value containing the source flux density in the specified reference energy band.
The FITS column name is **FLUX**.
The recommended units are $\mathrm{erg\,s^{-1}\,cm^{-2}}$.
This column is required.

10. *Spectrum*, a **string** containing a reference to a FITS file HDU describing the energy spectrum of the source. The reference is given via the extended filename syntax (see notes below). If source spectra are defined in the light curve extension (see Sec. 2.4.1) this field must be NULL.
The FITS column name is **SPECTRUM**.
(unitless).
This column is required.

11. *Image*, a **string** containing a reference to a FITS file HDU with an image of the source. The reference is given via the extended filename syntax (see notes below). For a point source or if several source images are defined in the light curve extension (see Sec. 2.4.1), this field must be NULL.
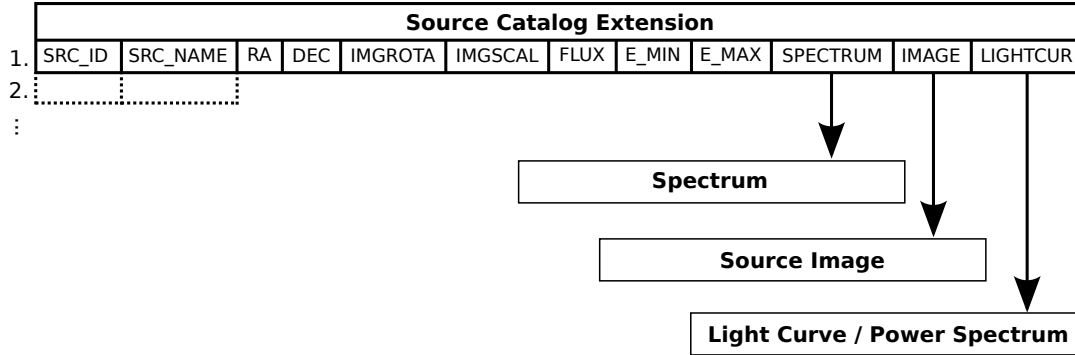The FITS column name is **IMAGE**.

Figure 2: Layout of the source catalog extension. Apart from basic source properties such as the position or energy flux density each source must refer to a spectrum extension. The specification of a light curve or PSD and a source image is optional. If the spectrum or the spatial shape of a source is time-dependent, the corresponding fields in the source catalog must be NULL. In that case the light curve must contain links to the respective spectra or images.

(unitless).
This column is optional.

12. *Light Curve*, a **string** containing a reference to a FITS file HDU defining the time-dependence of the source brightness. As described in Sec. 2.4 this can be either a light curve or a Power Spectral Density (PSD). The reference is given via the extended filename syntax (see notes below). For a constant source this field must be NULL.
The FITS column name is **LIGHTCUR**.
(unitless).
This column is optional.

The basic scheme of the source catalog extension is displayed in Fig. 2.

**Points to note & Conventions**

- The reference energy band defined in the E_MIN and E_MAX columns must be covered by the assigned source spectrum.

- Links to additional FITS file HDU s containing spectra, light curves, or images are given according to the extended filename syntax (Pence, 1999) by the name of the corresponding file, the extension name (EXTNAME), extension version (EXTVER), and required additional selectors such as the table row containing a particular spectrum or the corresponding name, in case the spectrum table contains a NAME column. For instance the spectrum in row number 4 within the HDU with EXTNAME = SPECTRUM and the EXTVER = 3 stored in the file data.fits is identified by the reference data.fits[SPECTRUM,3][#row==4].

  If the spectrum table contains the optional column NAME (see Sec. 2.2.1), the particular spectrum, which has the value 'powerlaw2.1' in its NAME field, is identified with the reference data.fits[SPECTRUM,3][NAME=='powerlaw2.1']. The latter syntax is more flexible in terms of the table structure, since spectra can be rearranged without taking care of their row numbers.

  References to data residing within the current file are given without the filename, in order to avoid inconsistency problems, when the file is renamed: [SPECTRUM,3][#row==4]

- In order to model a time-variable source, multiple energy spectra or images might be required to describe the temporal evolution of the system. In that case the source must refer to a light curve containing a SPECTRUM or IMAGE column with links to the corresponding FITS file HDU s (see Sec. 2.4.1), and the SPECTRUM or IMAGE fields in the source catalog must be NULL.

- A single extended source with different energy spectra for different emission regions can be described by multiple entries in the source catalog with different images and spectra. The superposition of the individual entries in the simulation results in the complete image of the extended source.

- Different source entries in the catalog can refer to the same spectrum, light curve, or source image. It is possible to apply individual scales to spectra or images through the FLUX, IMGSCAL, and IMGROTA columns in order to match the respective sources. For instance, the flux density given for a particular entry in the catalog determines the absolute flux for this source, providing the possibility to use the same spectral shape for multiple sources with different brightness.

  In a similar way extended sources, which are either characterized by a source image or by a photon list, can be rotated and scaled in size using the columns IMGROTA and IMGSCAL. The rotation is performed around the reference point of the source image or photon list in N-E-S-W direction. The angular extent $\gamma$ of the image or photon list is scaled as follows in order to obtain the simulated source extent $\gamma'$:

$$\gamma' = \frac{1}{\text{IMGSCAL}} \cdot \gamma \tag{1}$$

  The rotation angle is also applied to the polarization direction defined in a spectrum.

## 2.2 Spectrum Extension

In SIMPUT files there are three different basic ways to describe the energy spectrum of a source. Each entry in the catalog must refer to at least one such spectrum extension. Several sources with different brightness can refer to the same spectrum, which is scaled according to the particular energy flux density of the respective entries in the catalog.

A time-variable source can also have multiple spectra specified in the assigned light curve extension (see Sec. 2.4.1). The spectra valid for the different points of time or phases during the simulated time interval are stored separately in different rows of a spectrum extension or even in different HDU s. In order to have a continuous spectral variation, the simulation software might, e.g., apply a linear interpolation for the time intervals in between two specified spectra.

Each spectrum extension can contain information about the polarization of the emitted radiation by specifying the following optional keywords:

- STOKES1 - Stokes parameter
- STOKES2 - Stokes parameter
- STOKES3 - Stokes parameter
- RADESYS - reference coordinate system, e.g. FK5
- EQUINOX - reference coordinate system, e.g. 2000.0

The keywords STOKES1, STOKES2, and STOKES3 define the 2nd, 3rd, and 4th component of the normalized Stokes vector (Stokes, 1852) specifying the polarization of the emitted radiation. The information about the absolute intensity of the measured radiation is neglected, such that the first component of the normalized Stokes vector (STOKES0) has always a value of 1, and therefore does not have to be specified explicitly. The absolute intensity is given by the particular source brightness. The keywords RADESYS and EQUINOX define the coordinate system the polarization direction refers to.

In order to be able to reuse the same spectrum for different source entries in the catalog, the polarization direction can be modified by the IMGROTA value in the catalog. For each individual source the polarization direction is rotated by this angle in N-E-S-W direction.

### 2.2.1   Mission-Independent Spectrum

This is the preferred format for the description of a source spectrum, because it is mission-independent and physically accurate at the same time. It can therefore be used for simulations of different telescopes covered by the specified energy range.

**Description**   The spectrum extension describes one or multiple energy spectra in a mission- (and therefore effective area-) independent way giving the photon flux density distribution in a particular energy range. In order to determine the observed photon spectrum for a specific telescope, it has to be multiplied with the corresponding effective area (George & Zellar, 1995) or Ancillary Response File (ARF) (George et al., 1998, 2007) respectively.

Similar to Pulse Height Amplitude (PHA) II files (Arnaud et al., 2009; George & Arnaud, 2004) multiple spectra can be stored in a single binary table HDU. Each single spectrum is stored in a single row using vector columns. The spectra in the table can be either identified by their row number or by a unique name defined in the corresponding optional column.

**Extension Header**   The following keywords are mandatory:

- HDUCLASS - should contain the string HEASARC
- HDUCLAS1 - should contain the string SIMPUT
- HDUCLAS2 - should contain the string SPECTRUM
- HDUVERS = '1.0.0' - giving the version of the format

If applicable the following optional keyword can be used to specify the spectral model and parameters the spectrum has been generated from:

- MODEL - filename refering to the spectral model and parameters

**Data Format**   The data within the extension are organized as a BINTABLE with the following columns:

1. *Name*, a **string** containing a unique case-sensitive designator for each individual spectrum.
   The FITS column name is **NAME**.
   (unitless).
   This column is optional.

2. *Energy*, a **floating point** fixed or variable length array containing the grid of photon energy values.
   The FITS column name is **ENERGY**.
   The recommended units are keV.
   This column is required.

3. *Flux Density Distribution*, a **floating point** fixed or variable length array containing the photon flux densities at the respective energies. The number of entries in the array must be the same as

the number of entries in the array contained in the ENERGY column.
The FITS column name is **FLUX**.
The recommended units are $\mathrm{photon\,s^{-1}\,cm^{-2}\,keV^{-1}}$.
This column is required.

**Points to note & Conventions**

- The energy flux density can be easily obtained by multiplying the photon flux density with the corresponding photon energy.

- Each array in the ENERGY column should have ascending order.

- In order to refer to a particular spectrum in the table via the extended filename syntax, the filename and the HDU have to be specified in combination with either the respective row number or the unique name of the spectrum, in case the NAME column is present.

### 2.2.2  PHA File

The source spectrum can also be modeled by a standard PHA file (Arnaud et al., 2009; George & Arnaud, 2004) either of type I or type II. The latter may contain multiple spectra within a single HDU table.

**Points to note & Conventions**

- PHA files contain the convolution of the source spectrum with a mission-dependent detector response matrix. Since the convolution with the response matrix is a non-invertible process, the original spectrum cannot be uniquely reconstructed from these data. This has to be taken into account when using PHA files to describe source spectra for input to a simulation.

  The specification of a PHA spectrum might be useful, if an existing observation of a source with a particular telescope must be simulated for a different telescope and the energy resolution of the telescope the PHA file was made for is comparable or better than the resolution of the telescope in the simulation. The approximate unfolding can be done, e.g., with the procedure described by Nowak et al. (2005).

  The mission-independent spectral format (Sec. 2.2.1) is preferred in terms of simulation input data.

- Using PHA II files multiple spectra can be stored in a single HDU, each occupying one row in the binary table. The entries in the source catalog can refer to the individual spectra via the extended filename syntax specifying the respective row number.

- In order to be able to determine the photon energies corresponding to the channels used in the PHA file, an appropriate detector response file containing an EBOUNDS extension has to be specified via the RESPFILE header keyword in the PHA file.

### 2.2.3  Photon List

**Description**  The energy spectrum of an X-ray source can also be described by specifying a sample of photons distributed according to the respective spectrum. This approach can be useful if the photon sample is obtained, e.g., from a complicated MHD simulation.

**Extension Header**  The following keywords are mandatory:

- HDUCLASS - contains the string HEASARC
- HDUCLAS1 - contains the string SIMPUT
- HDUCLAS2 - contains the string PHOTONS
- HDUVERS = '1.0.0' - giving the version of the format
- RADESYS - reference coordinate system, e.g. FK5
- EQUINOX - reference coordinate system, e.g. 2000.0
- REFRA - right ascension of reference point in deg
- REFDEC - declination of reference point deg

The usage of the RADESYS and EQUINOX keywords is described by Calabretta & Greisen (2002) and Pence et al. (2010).

In addition a photon list with information about the arrival time of the photons must contain the following time definition keywords, even if the energy spectrum is not time-dependent:

- MJDREF - MJD for reference time
- TSTART - start time
- TSTOP - stop time
- TIMEZERO - zero time
- TIMESYS - the system used to define the time
- TIMEUNIT - unit for TSTART, TSTOP, TIMEZERO. The recommended units are s.
- CLOCKCOR - if time is corrected to UT

The usage of the time definition keywords is described by Angelini et al. (1994).

**Data Format**  The data within the extension are organized as a BINTABLE with the following columns:

1. *Time*, a **floating point** value containing the arrival time of the photon (relative to the offset given by the header keyword TIMEZERO).
   The FITS column name is **TIME**.
   The units are defined by the header keyword TIMEUNIT.
   This column is optional.

2. $\alpha$, a **floating point** value containing the right ascension of the origin of the photon.
   The FITS column name is **RA**.
   The recommended units are deg.
   This column is required.

3. $\delta$, a **floating point** value containing the declination of the origin of the photon.
   The FITS column name is **DEC**.
   The recommended units are deg.
   This column is required.

4. *Energy*, a **floating point** value containing the energy of the photon.
   The FITS column name is **ENERGY**.
   The recommended units are keV.
   This column is required.

5. *Polarization Angle*, a **floating point** value containing the polarization angle of the photon.
   The FITS column name is **POLANG**.

The recommended units are deg.
This column is optional.

**Points to note & Conventions**

- The main advantage of photon lists is that event lists obtained from observations can be easily converted to this format and therefore be used as input for simulations of different telescopes.

- A photon list is capable of describing the energy spectrum of a source, the spacial distribution of the emitted photons, and also time-dependent phenomena in case the optional TIME column is used. For time-independent photon lists the simulation software can randomly select entries. In that case no sorting of the list is required. For time-dependent photon lists it is up to the simulation to apply an appropriate algorithm to select photons without destroying the time-dependent features.

- The number of photons in the list should be sufficiently large for the statistical purpose of the simulation. Depending on the applied algorithm not every photon in the list will be used in a simulation, but only some of them will be selected by a randomization process. The number of actually required photons depends on the particular source flux density, the effective area of the selected telescope and the length of the simulated time interval. If $N$ is the number of photons in the list with an energy in the reference range and $T$ is the simulated time interval, the photon rate required for the simulation of a particular source should be at least by a factor of 5 smaller than $N/T$ in order to guarantee a sufficiently large number of photons. The simulation software has to make sure that this criterion is fulfilled.

- In order to be able to reuse the same photon list extension for different entries in the source catalog, the direction of each photon in the simulation is obtained from its right ascension and declination value with respect to the reference point defined by the REFRA and REFDEC keywords and its position in the source catalog. For each catalog entry the refence point is translated to match the position in the source catalog, and the angular distances of the individual photons with respect to the reference point are scaled by a factor 1/IMGSCAL. In addition the photon positions are rotated around the reference point in N-E-S-W direction according to the angle given in the IMGROTA column.

- Each photon in the list can have a polarization defined by the optional POLANG column. The angle is determined with respect to the north pole of the reference coordinate system via the eastern direction. For the special case of a photon coming directly from one of the poles the angle is measured with respect to the meridian corresponding to RA=0. In order to be able to reuse the same photon list for different sources, the polarization angle can be adjusted by the IMGROTA value in the source catalog. This value, which can be different for each source, is added to the IMGROTA angle in order to obtain the polarization direction.

  The specification of an explicit polarization angle overrides the polarization characteristics defined by the header keywords STOKES1, STOKES2, and STOKES3.

## 2.3 Image Extension

**Description** Extended sources are described by an image obtained from an observation or from a simulation. The image represents the spatial distribution of the flux density. The coordinates of the image are given via World Coordinate System (WCS) keywords.

If the spatial shape of a source is time-dependent, this can be described by several images valid for particular points of time or phases in case of a periodic system. The relation between the time or phase of the system and the corresponding images is defined in the light curve extension (see Sec. 2.4.1).

**Extension Header**   The following keywords are mandatory:

- HDUCLASS - should contain the string HEASARC
- HDUCLAS1 - should contain the string SIMPUT
- HDUCLAS2 - should contain the string IMAGE
- HDUVERS = '1.0.0' - giving the version of the format

The image coordinates are defined by an appropriate set of WCS header keywords, as described by Greisen & Calabretta (2002), Calabretta & Greisen (2002) and Pence et al. (2010). For instance one can use the following keywords:

- CTYPE1 - WCS axis type
- CTYPE2 - WCS axis type
- CUNIT1 - units of CRVAL1 and CDELT1
- CUNIT2 - units of CRVAL2 and CDELT2
- CRPIX1 - reference point in pixels
- CRPIX2 - reference point in pixels
- CRVAL1 - coordinate value at reference point
- CRVAL2 - coordinate value at reference point
- CDELT1 - coordinate increment at reference point
- CDELT2 - coordinate increment at reference point
- RADESYS - reference coordinate system, e.g. FK5
- EQUINOX - reference coordinate system, e.g. 2000.0

In addition the following optional header keyword can be used to specify the normalization of the flux represented by the source image:

- FLUXSCAL - scaling factor (see below)

If FLUXSCAL is not given as a header keyword, it is calculated by summing up all pixel values.

**Data Format**   The source image is a FITS image representing the spatial flux distribution. The photon flux density for a particular pixel $F(\text{pixel})$ is obtained from the reference flux density in the source catalog $F_{\text{catalog}}$, the pixel value $f(\text{pixel})$, and the value of FLUXSCAL via the following relation:

$$F(\text{pixel}) = \frac{f(\text{pixel})}{\text{FLUXSCAL}} \cdot F_{\text{catalog}} \tag{2}$$

In order to be able to reuse the same image for multiple sources in a catalog, the absolute position of the image in the sky defined by the WCS header keywords, is neglected. Instead of that, the reference point given by the CRPIX1 and CRPIX2 header keywords is translated to match the position of the individual source specified by the corresponding RA and DEC values in the source catalog. In addition to this translation the image can be rotated and linearly scaled using the optional columns IMGROTA and IMGSCAL in the source catalog. The rotation angle around the reference point is defined in the direction N-E-S-W. The linear scale of 1/IMGSCAL is applied to the angular extent of the image.

| Light Curve | | |
|---|---|---|
| **PHASE** | **FLUX** | **SPECTRUM** |
| 0.1 | 0.82 | spectra.fits[SPECTRUM,1][#row==1] |
| 0.2 | 1.15 | spectra.fits[SPECTRUM,1][#row==2] |
| ⋮ | ⋮ | ⋮ |

Figure 3: The light curve shown in this figure represents a periodic system with a spectral evolution during the transition between the different phases of the oscillation. The spectrum corresponding to each phase is given in a table column, such that the specification of a spectrum for this particular source in the source catalog table is not applicable. In the same way different source images can be assigned to particular phases or points of time in the light curve using the optional IMAGE column.

**Points to note & Conventions**

- A spatially extended source with different emission regions characterized by particular spectra can be modeled by a superposition of different images in combination with the spectra describing the particular emission features of the corresponding regions. An example of that is shown in Sec. 3.2.

## 2.4   Time Variability Extension

Brightness variability of a source can be modeled either by an explicit light curve or by a PSD, which can be used to simulate a light curve.

### 2.4.1   Light Curve

**Description**   The time-dependence of the flux density of a source can be explicitly described by a light curve. If the variability is periodic, one can also specify the phase of the oscillation instead of the time in the light curve.

A light curve can be used to model, e.g., the pulse profile of the Crab pulsar, or to implement time-dependent source spectra and images. If a source is oscillating between a hard and a soft spectrum, it can be described by a light curve specifying the brightness variation during the different phases of this oscillation and giving references to the corresponding spectra (see Fig. 3 and Sec. 3.2).

**Extension Header**   The following keywords are mandatory:

- HDUCLASS - should contain the string HEASARC
- HDUCLAS1 - should contain the string SIMPUT
- HDUCLAS2 - should contain the string LIGHTCUR
- HDUVERS = '1.0.0' - giving the version of the format
- MJDREF - MJD for reference time
- TSTART - start time
- TSTOP - stop time
- TIMEZERO - zero time
- TIMESYS - the system used to define the time

- TIMEUNIT - unit for `TSTART, TSTOP, TIMEZERO`. The recommended units are s.
- CLOCKCOR - if time is corrected to UT
- PERIODIC - flag whether the light curve is periodic (`1`) or not (`0`)

The usage of the time definition keywords is described by Angelini et al. (1994).

If the light curve describes a periodic system, the following additional keywords are required:

- PHASE0 - phase of periodic oscillation at TIMEZERO (recommended value between 0 and 1)
- PERIOD - duration of one oscillation period (units given by TIMEUNIT)

In addition the following optional header keyword can be used to specify the normalization of the flux represented by the light curve:

- FLUXSCAL - scaling factor (see below)

If FLUXSCAL is not given as a header keyword, it is assumed to be unity.

**Data Format**    The data within the extension are organized as a BINTABLE with the following columns:

1. *Time*, an **floating point** value containing the time (relative to the offset given by the header keyword TIMEZERO). If this column exists, the table must not contain a PHASE column.
   The FITS column name is **TIME**.
   The units are defined by the header keyword TIMEUNIT.
   This column is optional (either TIME or PHASE column must exist).

2. *Phase*, a **floating point** value containing the phase in a periodic system. If this column exists, the table must not contain a TIME column.
   The FITS column name is **PHASE**.
   (unitless, value in the interval from 0 to 1).
   This column is optional (either TIME or PHASE column must exist).

3. *Relative Flux*, a **floating point** value containing the relative source flux density with respect to the reference value given in the source catalog.
   The FITS column name is **FLUX**.
   (unitless).
   This column is required.

4. *Spectrum*, a **string** containing a reference to the FITS file HDU describing the energy spectrum of the source valid for this particular point of time or phase respectively. The reference is given via the extended filename syntax (see Sec. 2.1). Entries in this column might be NULL (see notes below).
   The FITS column name is **SPECTRUM**.
   (unitless).
   This column is optional.

5. *Image*, a **string** containing a reference to the FITS file HDU with an image of the source valid for this particular point of time or phase respectively. The reference is given via the extended filename syntax (see Sec. 2.1). Entries in this column might be NULL (see notes below).
   The FITS column name is **IMAGE**.
   (unitless).
   This column is optional.

The table must contain either a TIME or PHASE column.

The absolute source flux density $F(t)$ for a particular time $t$ is obtained from the reference flux density in the source catalog $F_{\mathrm{catalog}}$, the light curve value $l(t)$, and the value of FLUXSCAL via the following relation:

$$F(t) = \frac{l(t)}{\mathrm{FLUXSCAL}} \cdot F_{\mathrm{catalog}} \tag{3}$$

**Points to note & Conventions**

- The TIME and PHASE column are mutually exclusive. A light curve extension may contain only one of them. For periodic systems the PHASE column should be used instead of the TIME column.

- The TIME and PHASE columns should have ascending order.

- A complex time-variable system with time lags or independent variability in different energy bands can be modeled by a superposition of multiple entries in the source catalog, each having its own spectrum and light curve.

- The SPECTRUM and IMAGE columns are only used for sources with time-dependent spectrum or spatial extent. Otherwise the spectrum and image for a particular source should be defined in the source catalog (see Sec. 2.1).

- If the light curve has a very high resolution, references to the spectra or images might not be given for all time bins. Some entries in these columns might be NULL. In that case the simulation must interpolate between the given spectra or images.

- It is up to the simulation software to make sure that the required time interval is covered by the light curve. Otherwise the source can, e.g., be either considered to be in an off-state or a warning for the user can be produced.

### 2.4.2 Power Spectral Density

**Description**   Instead of giving an explicit light curve the time-variability of a source can be described by a PSD, which can be converted to a light curve in the simulation itself, e.g. by using the algorithm presented by Timmer & König (1995). In contrast to a light curve a PSD can be used to describe statistically-independent brightness variations such as noise for different sources with only one data set.

**Extension Header**   The following keywords are mandatory:

- HDUCLASS - should contain the string HEASARC
- HDUCLAS1 - should contain the string SIMPUT
- HDUCLAS2 - should contain the string POWSPEC
- HDUVERS = '1.0.0' - giving the version of the format

**Data Format**   The data within the extension are organized as a BINTABLE with the following columns:

1. *Frequency*, a **floating point** value containing the frequency.
   The FITS column name is **FREQUENC**.
   The units are Hz.
   This column is required.

2. *Power*, a **floating point** value containing the power spectral density with the normalization defined by Miyamoto et al. (1992).
   The FITS column name is **POWER**.
   The units are $\mathrm{rms\,Hz}^{-1}$.
   This column is required.

**Points to note & Conventions**

- The FREQUENC column should have ascending order from low frequencies to high.

- The PSD can be converted into a light curve using the algorithm presented by Timmer & König (1995).

# 3 Examples

In order to illustrate the structure of the SIMPUT file format, this section lists two examples. One of them describes a simple system of two single X-ray point sources with constant brightness each having its own spectrum. The other one describes an extended X-ray source with different polarized emission regions and a point source oscillating between two states.

## 3.1 Simple Example

The following example describes a simple system of two single point-like X-ray sources. Both sources have a constant brightness and each of them has its own spectrum. All data are combined in one FITS file 'simple.fits' with three HDU s (one empty primary, one source catalog, and one spectrum extension containing both spectra).

### 3.1.1 simple.fits

The primary HDU is empty and therefore neglected here.

**HDU 2** This HDU contains the source catalog.

```
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                   61 / width of table in bytes
NAXIS2  =                    2 / number of rows in table
```

```
PCOUNT  =                      0 / size of special data area
GCOUNT  =                      1 / one data group (required keyword)
TFIELDS =                     10 / number of fields in each row
TTYPE1  = 'SRC_ID  '            / label for field    1
TFORM1  = 'J       '            / data format of field: 4-byte INTEGER
TTYPE2  = 'SRC_NAME'            / label for field    2
TFORM2  = '8A      '            / data format of field: ASCII Character
TTYPE3  = 'RA      '            / label for field    3
TFORM3  = 'E       '            / data format of field: 4-byte REAL
TTYPE4  = 'DEC     '            / label for field    4
TFORM4  = 'E       '            / data format of field: 4-byte REAL
TTYPE5  = 'E_MIN   '            / label for field    5
TFORM5  = 'E       '            / data format of field: 4-byte REAL
TTYPE6  = 'E_MAX   '            / label for field    6
TFORM6  = 'E       '            / data format of field: 4-byte REAL
TTYPE7  = 'FLUX    '            / label for field    7
TFORM7  = 'E       '            / data format of field: 4-byte REAL
TTYPE8  = 'SPECTRUM'            / label for field    8
TFORM8  = '21A     '            / data format of field: ASCII Character
TTYPE9  = 'IMAGE   '            / label for field    9
TFORM9  = '4A      '            / data format of field: ASCII Character
TTYPE10 = 'LIGHTCUR'            / label for field   10
TFORM10 = '4A      '            / data format of field: ASCII Character
EXTNAME = 'SRC_CAT '            / name of this binary table extension
HDUCLASS= 'HEASARC '
HDUCLAS1= 'SIMPUT  '
HDUCLAS2= 'SRC_CAT '
HDUVERS = '1.0.0   '
RADECSYS= 'FK5     '
EQUINOX =                  2000.
TUNIT3  = 'deg     '
TUNIT4  = 'deg     '
TUNIT5  = 'keV     '
TUNIT6  = 'keV     '
TUNIT7  = 'erg/s/cm**2'
END
```

| | SRC_ID | SRC_NAME | RA | DEC | E_MIN |
| | | | deg | deg | keV |
|---|---|---|---|---|---|
| 1 | | 1 SIMPLE-1 | 2.3469999E+01 | -8.1199999E+00 | 1.0000000E+00 |
| 2 | | 2 SIMPLE-2 | 2.3920000E+01 | -7.8800001E+00 | 5.0000000E-01 |

| | E_MAX | FLUX | SPECTRUM | IMAGE | LIGHTCUR |
| | keV | erg/s/cm**2 | | | |
|---|---|---|---|---|---|
| 1 | 1.0000000E+01 | 5.3299999E-12 | [SPECTRUM,1][#row==1] | NULL | NULL |
| 2 | 1.2000000E+01 | 2.1799999E-11 | [SPECTRUM,1][#row==2] | NULL | NULL |

**HDU 3** This HDU contains the spectra of both sources in the catalog. The spectrum of the first source is stored in the first row, the spectrum of the second source in the second row. The spectra do not have explicit names. In the source catalog they are therefore identified by their row numbers.

```
XTENSION= 'BINTABLE'              / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                 1592 / width of table in bytes
NAXIS2  =                    2 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                    2 / number of fields in each row
TTYPE1  = 'ENERGY  '            / label for field   1
TFORM1  = '199E    '            / data format of field: 4-byte REAL
TTYPE2  = 'FLUX    '            / label for field   2
TFORM2  = '199E    '            / data format of field: 4-byte REAL
EXTNAME = 'SPECTRUM'            / name of this binary table extension
HDUCLASS= 'HEASARC '
HDUCLAS1= 'SIMPUT  '
HDUCLAS2= 'SPECTRUM'
HDUVERS = '1.0.0   '
EXTVER  =                    1
TUNIT1  = 'keV     '
TUNIT2  = 'photon/s/cm**2/keV'
END

        ENERGY          FLUX
        keV             photon/s/cm**2/keV
     1  1.5000001E-01   2.4728054E-31
        2.5000000E-01   6.2420354E-06
        3.5000002E-01   9.5439591E-02
        4.4999999E-01   1.7395179E+00
        5.5000001E-01   3.5762501E+00
  ...
     2  1.5000001E-01   1.3464495E+00
        2.5000000E-01   6.6499883E-01
        3.5000002E-01   4.2314768E-01
        4.4999999E-01   2.8910592E-01
        5.5000001E-01   2.2885039E-01
  ...
```

## 3.2  Elaborate Example

The following example file contains an extended X-ray source with two different polarized emission regions described by two separate images, and a point source oscillating between two states, one with a hard spectrum and low intensity and one with a soft spectrum and high intensity.

In the source catalog the extended source is split up in two separate entries, each with a specific spectrum and image of the particular emission regions. The periodic point source consists of a single entry in the catalog with a periodic light curve and two spectra for the different states. The source catalog and the light curve of the second source are stored in the file 'elaborate.fits', the spectra and images in the separate file 'data.fits'.

### 3.2.1   elaborate.fits

The primary HDU is empty and therefore neglected here.

**HDU 2**   This HDU contains the source catalog.

```
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                   93 / width of table in bytes
NAXIS2  =                    3 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                   12 / number of fields in each row
TTYPE1  = 'SRC_ID  '           / label for field   1
TFORM1  = 'J       '           / data format of field: 4-byte INTEGER
TTYPE2  = 'SRC_NAME'           / label for field   2
TFORM2  = '10A     '           / data format of field: ASCII Character
TTYPE3  = 'RA      '           / label for field   3
TFORM3  = 'E       '           / data format of field: 4-byte REAL
TTYPE4  = 'DEC     '           / label for field   4
TFORM4  = 'E       '           / data format of field: 4-byte REAL
TTYPE5  = 'IMGROTA '           / label for field   5
TFORM5  = 'E       '           / data format of field: 4-byte REAL
TTYPE6  = 'IMGSCAL '           / label for field   6
TFORM6  = 'E       '           / data format of field: 4-byte REAL
TTYPE7  = 'E_MIN   '           / label for field   7
TFORM7  = 'E       '           / data format of field: 4-byte REAL
TTYPE8  = 'E_MAX   '           / label for field   8
TFORM8  = 'E       '           / data format of field: 4-byte REAL
TTYPE9  = 'FLUX    '           / label for field   9
TFORM9  = 'E       '           / data format of field: 4-byte REAL
TTYPE10 = 'SPECTRUM'           / label for field  10
TFORM10 = '21A     '           / data format of field: ASCII Character
TTYPE11 = 'IMAGE   '           / label for field  11
TFORM11 = '18A     '           / data format of field: ASCII Character
TTYPE12 = 'LIGHTCUR'           / label for field  12
TFORM12 = '12A     '           / data format of field: ASCII Character
EXTNAME = 'SRC_CAT '           / name of this binary table extension
HDUCLASS= 'HEASARC '
HDUCLAS1= 'SIMPUT  '
HDUCLAS2= 'SRC_CAT '
HDUVERS = '1.0.0   '
RADECSYS= 'FK5     '
EQUINOX =                2000.
TUNIT3  = 'deg     '
TUNIT4  = 'deg     '
TUNIT5  = 'deg     '
TUNIT7  = 'keV     '
TUNIT8  = 'keV     '
```

```
TUNIT9  = 'erg/s/cm**2'
END
```

| | SRC_ID | SRC_NAME | RA | DEC | IMGROTA |
|---|---|---|---|---|---|
| | | | deg | deg | deg |
| 1 | 1 | EXTENDED-1 | -1.0500000E+01 | -3.0999999E+00 | 3.0000000E+01 |
| 2 | 2 | EXTENDED-2 | -1.0500000E+01 | -3.0999999E+00 | 3.0000000E+01 |
| 3 | 3 | PERIODIC | -9.6999998E+00 | -4.1999998E+00 | 0.0000000E+00 |

| | IMGSCAL | E_MIN | E_MAX | FLUX |
|---|---|---|---|---|
| | | keV | keV | erg/s/cm**2 |
| 1 | 8.9999998E-01 | 5.0000000E-01 | 1.0000000E+01 | 7.6999998E-14 |
| 2 | 8.9999998E-01 | 5.0000000E-01 | 1.0000000E+01 | 9.9999998E-14 |
| 3 | 0.0000000E+00 | 1.0000000E-01 | 1.5000000E+01 | 5.6999998E-11 |

| | SPECTRUM | IMAGE | LIGHTCUR |
|---|---|---|---|
| 1 | data.fits[SPECTRUM,1] | data.fits[IMAGE,1] | NULL |
| 2 | data.fits[SPECTRUM,2] | data.fits[IMAGE,2] | NULL |
| 3 | NULL | NULL | [LIGHTCUR,1] |

**HDU 3** This HDU contains the light curve of the periodic source.

```
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                   43 / width of table in bytes
NAXIS2  =                   10 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                    3 / number of fields in each row
TTYPE1  = 'PHASE   '           / label for field    1
TFORM1  = 'E       '           / data format of field: 4-byte REAL
TTYPE2  = 'FLUX    '           / label for field    2
TFORM2  = 'E       '           / data format of field: 4-byte REAL
TTYPE3  = 'SPECTRUM'           / label for field    3
TFORM3  = '35A     '           / data format of field: ASCII Character
EXTNAME = 'LIGHTCUR'           / name of this binary table extension
HDUCLASS= 'HEASARC '
HDUCLAS1= 'SIMPUT  '
HDUCLAS2= 'LIGHTCUR'
HDUVERS = '1.0.0   '
EXTVER  =                    1
MJDREF  =               48043.
TSTART  =                   0.
TSTOP   =                   0.
TIMEZERO=                   0.
TIMESYS = 'MJD     '
TIMEUNIT= 's       '
CLOCKCOR= 'YES     '
```

```
PERIODIC=                      1
PHASE0  =                   0.31
PERIOD  =                283680.
FLUXSCAL=                     1.
END
```

```
         PHASE              FLUX             SPECTRUM

      1   0.0000000E+00   1.4700000E+00  data.fits[SPECTRUM,3][NAME=='hard']
      2   1.0000000E-01   1.3802379E+00  NULL
      3   2.0000000E-01   1.1452379E+00  NULL
      4   3.0000001E-01   8.5476196E-01  NULL
      5   4.0000001E-01   6.1976200E-01  NULL
      6   5.0000000E-01   5.2999997E-01  data.fits[SPECTRUM,3][NAME=='soft']
      7   6.0000002E-01   6.1976206E-01  NULL
      8   6.9999999E-01   8.5476196E-01  NULL
      9   8.0000001E-01   1.1452380E+00  NULL
     10   8.9999998E-01   1.3802379E+00  NULL
```

### 3.2.2 data.fits

**HDU 1** This HDU contains one of the two emission region images of the first source.

```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =                  -32 / number of bits per data pixel
NAXIS   =                    2 / number of data axes
NAXIS1  =                    3 / length of data axis 1
NAXIS2  =                    3 / length of data axis 2
EXTEND  =                    T / FITS dataset may contain extensions
COMMENT   FITS (Flexible Image Transport System) format is defined in 'Astronomy
COMMENT   and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
EXTNAME = 'IMAGE   '
HDUCLASS= 'HEASARC '
HDUCLAS1= 'SIMPUT  '
HDUCLAS2= 'IMAGE   '
HDUVERS = '1.0.0   '
EXTVER  =                    1
CTYPE1  = 'RA---CAR'
CTYPE2  = 'DEC--CAR'
CUNIT1  = 'deg     '
CUNIT2  = 'deg     '
CRPIX1  =                   2.
CRPIX2  =                   2.
CRVAL1  =                   0.
CRVAL2  =                   0.
CDELT1  =                 0.25
CDELT2  =                 0.25
RADECSYS= 'FK5     '
EQUINOX =                2000.
FLUXSCAL=                  0.8
```

```
END
```

**HDU 2**   This HDU contains the other emission region image of the first source.

```
XTENSION= 'IMAGE   '              / IMAGE extension
BITPIX  =                    -64 / number of bits per data pixel
NAXIS   =                      2 / number of data axes
NAXIS1  =                      3 / length of data axis 1
NAXIS2  =                      3 / length of data axis 2
PCOUNT  =                      0 / required keyword; must = 0
GCOUNT  =                      1 / required keyword; must = 1
EXTNAME = 'IMAGE   '
HDUCLASS= 'HEASARC '
HDUCLAS1= 'SIMPUT  '
HDUCLAS2= 'IMAGE   '
HDUVERS = '1.0.0   '
EXTVER  =                      2
CTYPE1  = 'RA---CAR'
CTYPE2  = 'DEC--CAR'
CUNIT1  = 'deg     '
CUNIT2  = 'deg     '
CRPIX1  =                     2.
CRPIX2  =                     2.
CRVAL1  =                     0.
CRVAL2  =                     0.
CDELT1  =                   0.25
CDELT2  =                   0.25
RADECSYS= 'FK5     '
EQUINOX =                  2000.
FLUXSCAL=                   0.18
END
```

**HDU 3**   This HDU contains the emission spectrum of the first source corresponding to the first image
in HDU 1.

```
XTENSION= 'BINTABLE'              / binary table extension
BITPIX  =                      8 / 8-bit bytes
NAXIS   =                      2 / 2-dimensional binary table
NAXIS1  =                   4003 / width of table in bytes
NAXIS2  =                      1 / number of rows in table
PCOUNT  =                      0 / size of special data area
GCOUNT  =                      1 / one data group (required keyword)
TFIELDS =                      3 / number of fields in each row
TTYPE1  = 'NAME    '             / label for field   1
TFORM1  = '11A     '             / data format of field: ASCII Character
TTYPE2  = 'ENERGY  '             / label for field   2
TFORM2  = '499E    '             / data format of field: 4-byte REAL
TTYPE3  = 'FLUX    '             / label for field   3
```

```
TFORM3  = '499E    '              / data format of field: 4-byte REAL
EXTNAME = 'SPECTRUM'              / name of this binary table extension
HDUCLASS= 'HEASARC '
HDUCLAS1= 'SIMPUT  '
HDUCLAS2= 'SPECTRUM'
HDUVERS = '1.0.0   '
EXTVER  =                      1
TUNIT2  = 'keV     '
TUNIT3  = 'photon/s/cm**2/keV'
STOKES1 =                     0.
STOKES2 =                     1.
STOKES3 =                     0.
RADECSYS= 'FK5     '
EQUINOX =                  2000.
END

        NAME          ENERGY          FLUX
                      keV             photon/s/cm**2/keV
      1 cutoffpl1.6   1.1993988E-01   3.0327507E+01
                      1.5981963E-01   1.8991982E+01
                      1.9969940E-01   1.3242880E+01
                      2.3957916E-01   9.8731565E+00
                      2.7945894E-01   7.7058897E+00
      ...
```

**HDU 4** This HDU contains the emission spectrum of the first source corresponding to the second image in HDU 2. This emission spectrum has a different shape and polarization than the spectrum in HDU 3.

```
XTENSION= 'BINTABLE'             / binary table extension
BITPIX  =                     8 / 8-bit bytes
NAXIS   =                     2 / 2-dimensional binary table
NAXIS1  =                  4003 / width of table in bytes
NAXIS2  =                     1 / number of rows in table
PCOUNT  =                     0 / size of special data area
GCOUNT  =                     1 / one data group (required keyword)
TFIELDS =                     3 / number of fields in each row
TTYPE1  = 'NAME    '             / label for field    1
TFORM1  = '11A     '             / data format of field: ASCII Character
TTYPE2  = 'ENERGY  '             / label for field    2
TFORM2  = '499E    '             / data format of field: 4-byte REAL
TTYPE3  = 'FLUX    '             / label for field    3
TFORM3  = '499E    '             / data format of field: 4-byte REAL
EXTNAME = 'SPECTRUM'             / name of this binary table extension
HDUCLASS= 'HEASARC '
HDUCLAS1= 'SIMPUT  '
HDUCLAS2= 'SPECTRUM'
HDUVERS = '1.0.0   '
EXTVER  =                     2
TUNIT2  = 'keV     '
TUNIT3  = 'photon/s/cm**2/keV'
```

```
STOKES1 =                    -1.
STOKES2 =                     0.
STOKES3 =                     0.
RADECSYS= 'FK5       '
EQUINOX =                  2000.
END
```

```
         NAME          ENERGY          FLUX
                       keV             photon/s/cm**2/keV
      1 cutoffpl2.0   1.1993988E-01   3.5723953E+01
                      1.5981963E-01   1.9869173E+01
                      1.9969940E-01   1.2651364E+01
                      2.3957916E-01   8.7613888E+00
                      2.7945894E-01   6.4260769E+00

      ...
```

**HDU 5** This HDU contains the two spectra assigned to the periodic point source. The soft spectrum in row 1 corresponds to phase 0.0 of the oscillation, the hard spectrum in row 2 corresponds to phase 0.5. The spectra have explanatory names, which are used to identify them.

```
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                 7996 / width of table in bytes
NAXIS2  =                    2 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                    3 / number of fields in each row
TTYPE1  = 'NAME    '           / label for field   1
TFORM1  = '4A      '           / data format of field: ASCII Character
TTYPE2  = 'ENERGY  '           / label for field   2
TFORM2  = '999E    '           / data format of field: 4-byte REAL
TTYPE3  = 'FLUX    '           / label for field   3
TFORM3  = '999E    '           / data format of field: 4-byte REAL
EXTNAME = 'SPECTRUM'           / name of this binary table extension
HDUCLASS= 'HEASARC '
HDUCLAS1= 'SIMPUT  '
HDUCLAS2= 'SPECTRUM'
HDUVERS = '1.0.0   '
EXTVER  =                    3
TUNIT2  = 'keV     '
TUNIT3  = 'photon/s/cm**2/keV'
END
```

```
         NAME ENERGY          FLUX
              keV             photon/s/cm**2/keV
      1 soft   1.0995996E-01   0.0000000E+00
              1.2987988E-01   0.0000000E+00
              1.4979979E-01   2.9488223E-31
              1.6971973E-01   2.9728314E-21
```

```
            1.8963963E-01    6.3448235E-15
      ...
    2 hard  1.0995996E-01    0.0000000E+00
            1.2987988E-01    0.0000000E+00
            1.4979979E-01    4.2622720E-32
            1.6971973E-01    4.6921411E-22
            1.8963963E-01    1.0827691E-15
      ...
```

# 4   Summary

The presented format provides a common standard to define elaborate models of astronomical sources as input for simulation programs. It comprises approaches to specify simplistic point sources up to detailed descriptions of time-variable spatially extended systems with polarized emission. Although it has been developed in the context of X-ray astronomy, it provides sufficient flexibility to be suitable for other wavelengths.

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# A  List of Acronyms

**ARF**      Ancillary Response File

**FITS**     Flexible Image Transport System

**HDU**      Header and Data Unit

**MHD**      Magnetohydrodynamic

**PHA**      Pulse Height Amplitude

**PSD**      Power Spectral Density

**WCS**      World Coordinate System