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IVOA Spectral Energy Distribution (SED) Data Model

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…

Abstract

We present a data model for Spectral Energy Distributions (SED) by extending the existing IVOA Spectrum data model.

Status of This Document

This is an IVOA Note. The first release of this document was *YYYY Month DD*.

This is a draft for discussion among the relevant VAO and IVOA working groups.

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The Virtual Observatory (VO) is general term for a collection of federated resources that can be used to conduct astronomical research, education, and outreach.

The International Virtual Observatory Alliance (IVOA) (http://www.ivoa.net) is a global collaboration of separately funded projects to develop standards and infrastructure that enable VO applications.

A list of *current IVOA Recommendations and other technical documents* can be found at http://www.ivoa.net/Documents/.

Acknowledgements

"Ack here, if any"

Contents

1 Introduction

The IVOA has identified creation and analysis of spectral energy distributions as a key science capability desired in the VO. In this document we present a proposed abstraction for spectral energy distribution data and serializations in VOTABLE and FITS for use as a standard method of SED data interchange.

1.1 Change Log

2010 Nov 4   Initial draft.

2 Spectral Energy Distributions

A spectral energy distribution (SED) represents the energy output of an astronomical source over a wide spectral range. It differs from a traditional astronomical spectrum in that it is a composite data set which may be derived from (or in the case of a model SED, compared to) multiple instruments, telescopes and observational epochs.

Individual observations which go into the creation of an SED may be single photometry points or 1-D spectra with flux values at many spectral coordinates. Each of these observations has its own metadata describing the observational conditions, etc. We refer to these individual observations as segments.

We distinguish two main varieties of SED:

- An aggregate SED, consisting of a logical collection of segments together with each segment's metadata; no attempt is made at this stage to reconcile the data in the different segments.
- A uniform (or rebinned) SED, consisting of a single merged segment. To go from an aggregate to a uniform SED requires transforming each segment to provide uniform units for the spectral axis and for flux. To go from an aggregate SED to a binned SED further requires rebinning the data on a fixed wavelength or frequency grid and handling overlaps (for example, you may have a V photometry point overlapping an optical spectrum, or multiple V photometry points at different times).

Some SED science is done with uniform SEDs, which are the simplest to handle; some science requires you to work with the aggregate SED directly. This is the usual methodological dichotomy in astronomy between correcting your data to compare directly with a model, or folding your model through a simulation of the observation process and comparing the result with the data. Both kinds of SED may therefore have model (theoretical) counterparts, but we normally think of a model SED as being of the uniform kind.

One can also have an SED described by an analytic function; we consider this to be outside our scope, and assume that such representations will be instantiated as a finite, discrete array of flux and spectral coordinate values.

One special case is worth mentioning: a light curve consists of photometry points in the same band but at different epochs; this is a valid example of an aggregate SED, but if all the points are taken with the same instrumental conditions (same metadata except for time) it can be treated in similar ways to a uniform SED.

2.1 Scope

In modern instruments, photometry and spectra are often obtained by extraction from two- or higher-dimensional detectors; photometry points from CCD images, spectra from long slit images, Echelle datasets and spectra data cubes. The process of reducing such data to simple sets of flux-versus-spectral-coordinate arrays is out of our scope; we are only attempting at this stage to describe the extracted data, usually in calibrated form.

3 SED Data Model Summary

Our fundamental SED data model is as follows:

- An SED is either a single ‘segment’ (the uniform or binned SED) or an aggregation of ’segments’.

For an aggregate SED:

- Each segment is a photometry point, a time series or light curve (time-resolved photometry points in a single band) or a spectrum.
- A spectrum is described by the IVOA Spectrum data model with the spectral coordinate as the independent variable.
- A light curve is described by the IVOA Spectrum data model with time as the independent variable. The IVOA Photometry model, which is integrated into Spectrum, defines the photometric band observed.
- A photometry point is a limiting case of a light curve with a single photometric point, with a PhotCal object from the Photometry model defining the photometric band observed.

A light curve in a single band is a special case of a *time series*, which may record multiple spectral bands in a single observation.

The uniform SED is a single Spectrum instance; its metadata refer to the combined data points. For some use cases it is useful to be able to link to the individual segments of the aggregate SED from which the uniform SED is derived. This is a difficult problem, since a single point in the uniform SED may be a complicated function of points from multiple segments in the aggregate - either time averaging of photometry, or combining overlapping spectral segments and/or photometry points. Instead the aggregate SED as a whole is referenced with at most a mapping of SED data points onto segments. One would also like to record the algorithms used to create the uniform SED but this is beyond the scope of the current standard.

3.1 SED Metadata

Metadata is required to describe the overall, uniform SED object or "dataset", as well as the individual segments in the case of an aggregate SED. While metadata describing the overall SED dataset may not be required for analysis, it is required to be able to describe, index, discover, and access the SED via the generic mechanisms provided within the VO.

The SED data model extends Spectrum, retaining all Spectrum metadata while adding some SED-specific attributes. A SED segment including the uniform SED can be treated as an instance of Spectrum by client software, however to fully understand the dataset as a SED requires an understanding of the full SED data model. Data analysis client applications which understand Spectrum should recognize SED as a special case of Spectrum even if they ignore the SED-specific attributes.

The SED data model extends Spectrum and retains the same data model namespace, hence data model attributes share the same Utype namespace and prefix as the Spectrum data model. In the following tables the prefix "Spectrum." is omitted from the each Utype for brevity. Hence "spec:Spectrum.dataModel" would be the full Utype for the *DataModel* attribute shown in the first table, using "spec:" as the namespace prefix.

3.1.1 Dataset Metadata

The uniform (or rebinned) SED should contain the following global metadata attributes in addition to those defined or mandated by Spectrum (mandatory SED dataset fields are shown in bold text):

dataModel	"SED-1.0"
type	"SED" (the overall Dataset type as well as the segment type)
length	Number of data points in the uniform SED
nSegments	Number of segments in the aggregate SED
sedAggregate	URI to aggregate SED if applicable (FITS keyword: SEDORIG)

All attributes of the Spectrum data model for the uniform SED segment should refer to the overall SED dataset, e.g., the spatial, spectral, and time coverage of the overall SED should be characterized, and the dataset identification, curation, and access groups should refer to the overall SED dataset. For a full specification of the generic Dataset or Spectrum attributes please refer to the IVOA Spectrum and SSA standards.

3.1.2 Segment Metadata

Additional metadata beyond that defined by Spectrum is required to describe the data points in the uniform or binned SED since these data points are derived from segment information. Metadata may be SED-specific (*e.g., SegmentType*) or may be taken from the Spectrum model. Any attribute of Spectrum can be referenced as a data column in the uniform SED by prefixing the Utype with "Data.", *e.g.,* "Data.Target.pos" would allow the original observed position of a segment observation to be given in the data table in the uniform SED (note this is only possible where a single segment contributes to a given data point in the uniform SED).

Any of the following metadata attributes may be used as columns for the data table of the uniform SED. Selected Spectrum attributes are shown but many others are possible. Mandatory elements are shown in bold.

Data.segmentType	One of "photometry", "timeseries", "spectrum", or "composite".
Data.segments	The segment number, a comma-delimited list of segment numbers, or NULL if a more complex combination of segments are used to compute the given photometric value. The uniform SED is segment zero.
Data.Target.pos	The published observed position in the dataset reference frame.
Data.DataID.bandpass	The spectral bandpass (filter or bandpass name).
Data.DataID.title	Brief description of the data point or segment.
Data.SpectralAxis.value	Spectral coordinate for data points.
Data.SpectralAxis.publishedValue	The spectral coordinate of the original published observation in the same units as Data.SpectralAxis.Value.
Data.FluxAxis.value	Computed flux value for data point.
Data.FluxAxis.Accuracy.statError	Statistical error for flux value (see Spectrum for additional options to specify errors).
Data.FluxAxis.publishedValue	The original published flux value.
Data.FluxAxis.Accuracy.publishedStatError	The statistical error of the original published flux value.
Data.FluxAxis.publishedUnit	The unit for the published flux value and error.
Data.comments	Additional information about the computed data value or segment.

Any items appearing as table data in the uniform SED may also be given as metadata in the referenced segment, if any.

SegmentType is the same as *Spectrum.Type* for a reference to a single segment, but may have the value "composite" if multiple segments were used to compute the data point of the uniform SED. Where possible *Segments* should indicate the segment or segments used to compute the given data point. If no valid value can be specified for a given metadata attribute, for example in the case of a composite segment type, then a null value should be given.

3.1.3 Custom Metadata

The data provider may define additional custom metadata to describe their SED data products. These custom metadata attributes may differ for different data providers or data collections. Custom data provider-defined metadata attributes **must not** share the same namespace as the standard Spectrum and SED data models. In particular, any Utypes for custom data provider-defined attributes should not begin with "Spectrum", and the "spec:" and "sed:" namespace prefixes are reserved. Services and client software should if possible preserve such custom metadata and pass it through to applications.

Custom metadata may be inherently distinct, *e.g.*, specific to a given SED building application or data provider, or may be more general and hence a candidate for eventual inclusion in the standard model. Reserving the data model namespace to only metadata defined by the standard model is necessary to avoid name collisions and to allow changes as new attributes are added to the standard model, as well as make it clear to a data consumer where a given bit of metadata originates and is defined.

4 SED Serialization

We define two serializations of the SED data model: FITS and VOTable.

4.1 VOTable Serialization

An SED serialized as a VOTable is a dataset of type "SED", containing at least one RESOURCE element which in turn contains at least one TABLE element, the uniform (or binned) SED. While a uniform SED is required to define standard VO metadata for the overall SED dataset, it is optional whether or not the uniform SED contains any data points (the *length* attribute may be zero with TABLEDATA omitted).

Additional TABLE elements **may** be provided for segment data. Each TABLE element will contain a single segment of *segmentType*.

- A SED dataset consisting of only a uniform SED will contain a single TABLE element of type SED (the *segmentType* if provided should also be "sed"). A *sedAggregate* attribute may be provided to refer to a separate aggregate SED dataset.
- A SED dataset consisting of only an aggregate SED will contain a TABLE element defining metadata for the overall SED dataset (a uniform SED with no data points), followed by *nSegments* TABLE elements, one for each segment.
- A SED dataset containing both the uniform SED as well as the corresponding aggregate SED will contain an initial TABLE element for the uniform SED followed by *nSegments* TABLE elements, one for each segment.

An example follows, showing only the major VOTable elements.

```
<?xml version="1.0" encoding="UTF-8"?>
<VOTABLE version="1.1"
   xmlns:xsi=http://www.w3.org/2001/XMLSchema-instance
```

```
   xsi:noNamespaceSchemaLocation="xmlns:http://www.ivoa.net/xml/VOTable/VOTable-1.1.xsd"
   xmlns:spec=http://www.ivoa.net/xml/SpectrumModel/v1.01
   xmlns="http://www.ivoa.net/xml/VOTable/v1.1">
 <RESOURCE utype="spec:SED">
   <TABLE utype="spec:SED"></TABLE>
     <PARAM name="Segtype" utype="spec:Spectrum.segmentType" value="SED" … </PARAM>
   <TABLE utype="spec:photometry"></TABLE>
     <PARAM name="Segtype" utype="spec:Spectrum.segmentType" value="photometry" …
   <TABLE utype="spec:spectrum"></TABLE>
     <PARAM name="Segtype" utype="spec:Spectrum.segmentType" value="spectrum" …
  </RESOURCE>
  </VOTABLE
```

At the top level, both RESOURCE and the initial TABLE element specify the overall VO Dataset (object) type, in this case SED (for other types of datasets we would have Spectrum, TimeSeries, and so forth). Individual segments specify their object type separately as shown. In our case here, all allowable dataset or object types are defined by the Spectrum data model.

4.2 FITS Serialization

The uniform SED is serialized according to the VO Spectrum data model, with the additional optional metadata pointing to the aggregate SED from which it is derived:

- sedAggregate - URI to aggregate SED. FITS keyword SED ORIG.

[*details TBD*]

Appendix A: "Appendix Title"

Insert appendix here

References

[1] R. Hanisch, *Resource Metadata for the Virtual Observatory* , http://www.ivoa.net/Documents/latest/RM.html
[2] R. Hanisch, M. Dolensky, M. Leoni, *Document Standards Management: Guidelines and Procedure* , http://www.ivoa.net/Documents/latest/DocStdProc.html