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Handling 3D data in the Virtual Observatory

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Abstract. 3D spectroscopy is a modern and promising observational technique, that allows spectra to be obtained for a contiguous area of the sky, resulting in a 3-dimensional data structure or 'data cube' containing spectral and spatial information. During the last 15 years a considerable amount of 3D data was obtained on large optical, sub-mm and radio telescopes.

We are making an effort to define the standard way of describing and handling complex datasets, such as 3D data, in the VO framework. The most general and self-sufficient description of the observational and theoretical data will be handled eventually by the forthcoming Observation Data Model, and the physical characterisation of the data in the parameter space will be done using the Characterization DM, which is one of the most important parts.

We present the characterisation of the 3D datasets obtained with Integral-Field-Unit (IFU) spectrographs. The proposed metadata structure allows to query the different datasets' attributes, such as spectral and spatial sampling and resolution and retrieve the data using the power of extensible IVOA Simple Spectral Access Protocol (SSAP)

1. Introduction

Integral field (or 3D) spectroscopy is a modern technique in astrophysical observing that was proposed by Georges Courtés in the late 60's. The idea is to get a spectrum for every point in the field of view of a spectrograph.

One of the approaches is to use a scanning Fabry-Perot interferometer. In this case after reducing the data, one gets a set of narrow-band direct images with slightly overlapping bands, or a so-called data cube – a three dimensional structure, containing spatial and spectral information – a short spectrum for every spatial pixel. Resulting data cubes have wide spatial dimensions and relatively narrow spectral ones. A similar approach has been used in radio astronomy for a couple of decades, and their datasets look nearly the same.

Another approach is to slice a field of view using a micro-lens array or special image slicer device (Integral Field Unit, or IFU) and feed a "classical" spectrograph (see review in Pécontal-Rousset et al., 2004 for a description of different image slicing techniques). The resulting datasets are normally smaller in spatial dimensions than Fabry-Perot datasets, however the spectral dimension is usually one to two orders longer.

The first implementations of 3D spectrographs came in the 1980s and immediately demonstrated great benefits of this technique for studying both extended and point sources. Presently, there are more than a dozen 3D spectrographs being operated on nearly every large telescope all over the world. A growing amount of 3D data is being produced by these instruments, and the question of dissemination of these data in the Virtual Observatory has become an important challenge.

Creating the archive implies the following necessary metadata to be defined: **Data Description**, **Data Storage Format**, and **Query Interface and Data Retrieval**. While there is a good and interoperable solution for the data storage format, the Euro3D FITS Format developed within Euro3D research training network (Kissler-Patig et al. 2004), the two other aspects rely on the Virtual Observatory community.

2. Characterisation Data Model of IVOA

An abstract, self-sufficient and standardised description of the astronomical data is known as a data model. Such a description is supposed to be sufficient for any sort of data processing and analysis. The Data Modelling working group of the International Virtual Observatory Alliance (IVOA) is responsible for defining data models for different types of astronomical data sets, catalogues, and more general concepts e.g. "quantity". The most general description of any sort of observational or theoretical data sets will be given by the forthcoming Observational DM (McDowell et al. 2004). Its main subclasses are: Observation, DataCollection, Curation, Provenance and Characterisation. The latter one gives a physical insight to the dataset, while others provide more instrument-specific or sociological information. Characterisation was reorganised as a separate data model (McDowell et al. 2005), which is now being intensively developed.

Characterisation DM is a way to say where, how extended and in which way the Observational or Simulated dataset can be described in a multidimensional parameter space, having the following axes: **spatial**, **temporal**, **spectral**, **observed** (e.g. flux), **polarimetric**, as well as other arbitrary axes. For every axis, there are three characterisation properties: **coverage**, **resolution**, and **sampling**. Every axis also contains a specific **axisFrame** subclass used for error assessment and including some general axis-specific metadata. Four levels of characterisation, reflecting different levels of details in the description can be given for every axis:

1. **location** or **reference value**, giving average position of the data on a given parameter axis
2. **bounds**, providing a bounding box

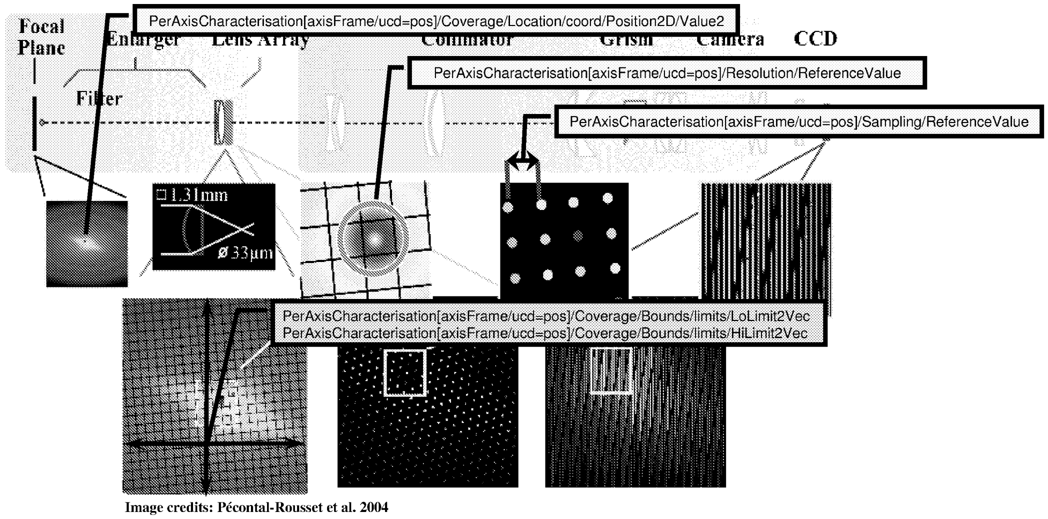

Figure 1. Characterisation of the spatial axis for IFU datasets

3. **support**, describing more precisely regions on a parameter axis as a set of segments
4. **map**, showing a detailed sensitivity map, containing the absolute transmission factor for every volume element in the parameter space

The first two levels of characterisation provide basic information that usually already exists in the metadata given by the different data processing pipelines, or is easy to compute from science-ready datasets. These levels can be easily provided as searchable criteria by the data access services (e.g. Simple Spectral Access Protocol (Tody et al. 2005) admits service-specific parameters).

3. Characterising 3D Datasets

Due to the complexity of 3D datasets we propose that data centres give only the first two levels of characterisation for the whole dataset. Further levels can be given optionally for every spectral segment (in case of IFU data) or image plane (in case of Fabry-Perot or radio data cube).

We present a way of characterising IFU datasets (actually other types of 3D data can be characterised in a similar way). On Figure 1 and Figure 2 we demonstrate how to compute characterisation metadata for spectral, spatial, and observable axes from the real dataset. We have developed a software package for computing characterisation metadata for IFU datasets stored in the Euro3D format. We also suggest some modifications to Euro3D FITS format for storing temporal and resolution-specific information.

A "live" example of the first two levels of the characterisation metadata for the data, obtained with the Multi-Pupil Fiber Spectrograph based on the Russian 6m telescope at SAO RAS, in the XML format can be found here: **http://www.sai.msu.su/~ chil/VO/CharMPFS.xml**

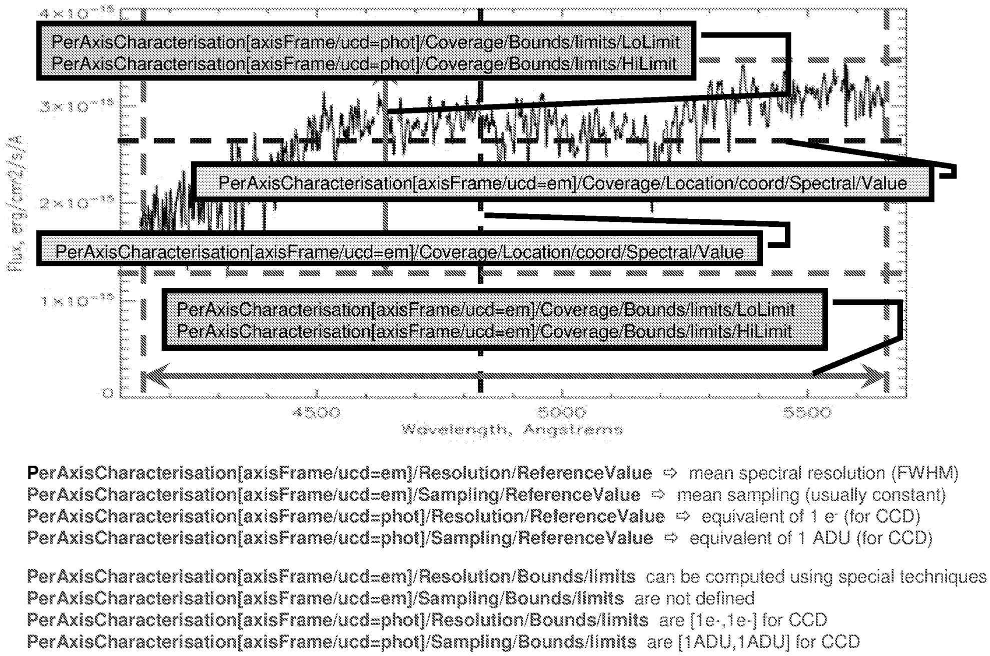

Figure 2. Characterisation of the spectral and observed axes for IFU datasets. The procedure has to be run over all the spectral segments.

4. Summary

The data modeling is a crucial point for building VO-compliant data archives and tools for data processing and analysis. Characterisation DM has sufficient flexibility and completeness to be applied for such complex datasets as 3D data.

Considering the Characterisation DM and the extensibility of the Simple Spectral Access Protocol, we conclude that all the necessary infrastructural components exist for building VO-compliant archives of science-ready 3D data and tools for dealing with them. We expect the first 3D archives to appear in the beginning of 2006.

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