ARCHIVING GEOSPATIAL METADATA IN HYPERSPECTRAL PLANETARY DATA WITH FITS AND PDS4.

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Introduction: Hyperspectral imaging is an essential tool in planetary science to perform detailed chemical and mineralogical analyses of planetary surfaces and atmospheres. Such kind of observations, as started in the late eighties; include the Cassini-Huygens mission to Saturn and its Visible and Infrared Mapping Spectrometer [1] (VIMS), followed by the VIRTIS family flying on board of Rosetta [2], Venus Express [3], and the Dawn [4] mission, OMEGA [5] on board of Mars Express, and CRISM [6] on Mars Reconnaissance Orbiter. Also, Bepi Colombo includes a Visible Infrared Hyperspectral Imager Channel for SIMBIO-SYS [7] (VIHI).

Adding geospatial information to hyperspectral data is a challenging task: due to instrument design and acquisition modes, surfaces are not regularly sampled and then pixel footprints cannot be described with simple analytic approximations. More generally spatial information is first provided for the Field of View boundaries of successive acquisitions (e.g. the four corners of each pixel).

Planetary Hyperspectral Data Formatting: Geospatially calibrated hyperspectral data are usually distributed as Band Interleaved per Lines (BIL) or Band Interleaved per Pixel (BIP) data cubes, following the order of the telemetry data flow. Scientific and geometric information are often archived in different files. Housekeeping parameters are stored in the scientific cube as side or back planes and geometry information is stored in a separate cube providing useful quantities such as coordinates and viewing angles for all observing sessions on a pixel basis.

The FITS TAB Projection: FITS [8] is an open digital standard, defined by the astronomical scientific community for data acquisition and archiving in astronomical observatories back in the late 70's, and is used for space telescope data too. FITS World Coordinate System (WCS) representation [9] is the standard way to describe spatial dependencies in FITS metadata.

To support look-up table coordinate representations in FITS metadata the TAB projection has been defined [10] with the correspondent algorithm linking pixel indexes to coordinates, allowing coordinate computation even for non-precomputed detector positions. In the TAB projection representation, coordinates are listed in a coordinate array, an indexing vector can be used to address coordinate array elements. Coordinates can then be sampled more or less coarsely depending on the behavior of the spatial reconstruction. Also, when the field is only partially filled by the planetary surface, coordinate array dimensions can be significantly reduced. TAB projection is implemented in the Calabretta `WCSLIB` [11], available in all major linux distribution.

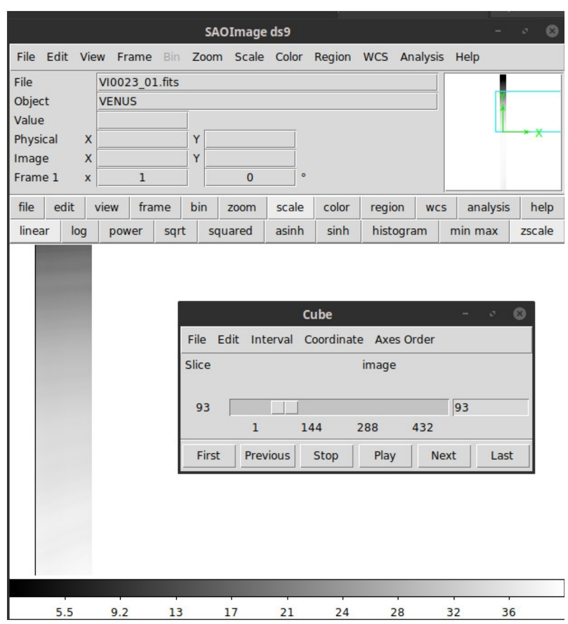
TAB Projection for Hyperspectral Data:

As an example, a geometrically calibrated product from the Mapping (M) channel of VIRTIS/Venus-Express has been converted in FITS format.

Multi Extension FITS (MEF) files are well suited for Multi Digital Object (MDO) data products. In our case a MEF scheme allows us to distribute together scientific and geometric information.

```
No.    Name       Type         Dimensions       Format
  0  PRIMARY     PrimaryHDU  (64, 1025, 432) float32
  1  WCS-TAB     BinTableHDU  1R x 1C    [131200J]
        …
  4  WAVELENGTH  BinTableHDU  432R x 3C [1E, 1E, 1E]
  5  INCIDENCE   ImageHDU    (64, 1025)  int32
  6  EMERGENCE   ImageHDU    (64, 1025)  int32
  7  PHASE       ImageHDU    (64, 1025)  int32
        …
 10  LOCAL TIME  ImageHDU    (64, 1025)  int32
```

The spectral data cube is the Primary extension, now stored as Band SeQuential (BSQ) simplifying direct surface visualization.



All geometric quantities (emission angle, incidence angle, etc.) are represented as extensions. Tabular information as, e.g. wavelength and coordinates, are stored in Binary Table extensions.

This representation has the advantage of making the file accessible and manageable by the high-level `astropy` [12] functions and the coordinate system compatible with FITS WCS standards. The link between the hyperspectral cube and the coordinate table is established in the cube header. Using, e.g., the `wcsware` tool, available from the `wcslib` library, we can easily convert pixel to world or world to pixel coordinates.

The FITS file has been produced using python sources available from github [13].

PDS4 TAB extension description: Due to the specific structure of the tabular WCS representation, particular attention must be given to the PDS4 description of the coordinate extension. Here a tentative solution is proposed mapping the principal FITS keywords into the PDS4 dictionary, using a VIRTIS/Venus-Express product.

```
Table_binary
   table_Base:records 1  #NAXIS2 : length of dimen-
sion 2

Record_Binary
   record:fields 1
   record:length 524800  #NAXIS1 : length of dimen-
sion 1

   Field_Binary
      field_binary:name 'COORDS  '        #TTYPE1
      field_binary:data_type signedMSB4   #TFORM1
      field_binary:field_length 524800    #TFORM1
      field_binary:unit 'deg     '        #TUNIT1
      field_binary:scaling_factor 0.0001 #TSCAL1
      field_binary:description
                  An array of 131200 signedLSB4
(from TFORM1  = '131200J ') grouped as a 64X1025 of
(long,lat) pairs ( from TDIM1   = '(2,64,1025)')
representing coordinates on the surface.
```

Future uses, conversion to GeoFITS: With a well described hyperspectral file, it should also be possible to map the geometric coordinates into a more GIS-friendly multi-band map projected representation. One must take care with this conversion, since this will require a resampling for all the spectral bands. The result of the conversion to a map projected coordinate system can then be stored back into the GeoFITS formats (FITS with a geospatial extension [14]). With support for reading and writing GeoFITS within the Geospatial Data Abstraction Library (GDAL), several GIS applications will be able to more readily display these hyperspectral cubes and if needed, convert to other hyperspectral formats which GDAL supports (e.g. GeoTiff).

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