The Titan UVIS Library User Guide

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The Titan UVIS Library is a compilation of the Cassini-Ultraviolet Imaging Spectrograph (UVIS) observations of Titan made between 2005 and 2017. The dataset includes the raw and calibrated data and processed detector images in FITS format, along with three associated types of documents: 1) an averaged spectra per observation, 2) a geometry movie per observation and 3) geometry snapshots of each record of an observation sequence per observation. All UVIS observation sequences have been combined per day, meaning that each FITS file contains the entire sequence of observations taken on a particular day. Data presented in this archive were calibrated using the 2017 version of the cube_generator software, which is a Cassini-UVIS team tool.

The Titan UVIS Library is organized per UVIS channels. The data_derived and the document folders each contain one Extreme Ultraviolet (EUV) folder and one Far Ultraviolet (FUV) folder. Within each folder, data and documents have been organized by calendar year. The data_derived folder directly contains the data FITS files under each calendar year sub-folder, while the document folder is further divided into an AveragedSpectra and a Geometry folder under each calendar year. A set of quasi-simultaneous EUV and FUV observations were usually taken, and you will find a corresponding EUV FITS file to each FUV FITS file for most cases.

The UVIS detector

The UVIS instrument, described in detail by Esposito et al. (2004), is composed of two-dimensional CODACON detectors that provide simultaneous spectral and one-dimensional spatial images. The EUV channel covers wavelengths from 56.1 nm to 118.2 nm. The FUV channel covers wavelengths from 111.5 nm to 191.2 nm. The detector format for each channel is 1024 spectral pixels by 64 spatial pixels. Each spectral pixel is 0.25 mrad projected on the sky and each spatial pixel is 1.0 mrad projected on the sky. Using the low-resolution slit in the FUV gives a spectral resolution of 0.48 nm and a spatial FOV of 1.5 mrad in the spectral dimension for example. General information regarding the UVIS instrument can be found on the Planetary Data System (PDS) Cassini-UVIS webpage. Furthermore, the Titan UVIS Library should be consulted in parallel with the Titan EUV/FUV Book available at the PDS.

Nomenclature

Each observation file's name starts with the channel used (either EUV or FUV), followed by the date of observation in the format YYYY_DOY_HH_MM_SS, followed by the instrument's name "UVIS", the revolution (orbit) number around Saturn and the body targeted (TI for Titan). Then, a code describes the type of observation ("EUVFUV" for example) and if the instrument was prime or not. If not prime, the file name ends with the instrument's name that was prime (See for example observation EUV2013_254_23_21_48_UVIS_197TI_EUVFUV001_ISS, where the

ISS instrument was prime). Data FITS files contained the word "_combined" at the end of the file name to indicate that all available UVIS data on the day have been combined into one single data file.

Data structure

UVIS FITS data files, located in the data_derived folder, are divided into 10 Binary Table Header/Data unit (HDU) components listed below:

No.	Name	Ver	Type	Cards	Dimensions
0	PRIMARY	1	PrimaryHDU	18	()
1	CAL	1	BinTableHDU	13	1R x 1C
2	CONFIG	1	BinTableHDU	55	1R x 10C
3	DATA	1	BinTableHDU	19	85R x 2C
4	DETECTOR_IMG_FUV	1	BinTableHDU	37	85R x 7C
5	FOV_GEOM	1	BinTableHDU	57	85R x 11C
6	KERNELS	1	BinTableHDU	37	1R x 7C
7	SC_GEOM	1	BinTableHDU	53	85R x 11C
8	TARGET_GEOM	1	BinTableHDU	45	85R x 9C
9	TIME	1	BinTableHDU	17	85R x 2C
10	WAVELENGTH	1	BinTableHDU	13	1024R x 1C

The primary HDU contains general information related to data file, such as the date of observation, mission, mission phase and instrument used, as well as the name of the satellite targeted during the observation (e.g Titan).

The CAL HDU contains the calibration matrix called 'CAL_FACTOR' to allow users to reapply the calibration to the raw data if necessary.

The CONFIG HDU contains 10 variables describing the type of windowing and spectral/spatial binning that was applied during the observation:

- OBS_SECONDS provides the observation start time in seconds,
- OBS_TICKS provide the start time in subseconds (units of seconds/65536.) for more precision.
- IMG_XMIN indicates the detector left edge of valid window,
- IMG_XMAX indicates the detector right edge of valid window,
- IMG_YMIN indicates the detector lower edge of valid window,
- IMG_YMAX indicates the detector upper edge of valid window,
- IMG_XBIN indicates the image binning factor along the spectral dimension,
- IMG_YBIN indicates the image binning factor along the spatial dimension,
- INT_TIME is the integration time in seconds,
- NUMBER_OF_SAMPLES is the number of samples/records contained in the observation.

The DATA HDU contains the raw data, named 'rawcounts' and the calibrated data, named 'UVIS_Calibrated'. Each matrix is of dimension: number_of_samples x 3 x 1024 x 64. The second dimension (3) account for the data taken at the start time of the observation, taken in the middle of the time period of the observation and taken at the end of the observation. On observation sequences lasting several hours, the geometry can significantly change over the course of the observation, thus requiring the need to divide the data into three time periods (start, middle and end). On most observations shorter than 2 hours, the middle portion of the observation is representative of the entire sequence. The 1024 dimension represents the spectral dimension. The 64 dimension is the spatial dimension across the 64 pixels of the slit.

The DETECTOR_IMG_FUV contains seven binary tables that can each be used to recreate detector images at specific wavelengths. Further description of the wavelength ranges used can be found in the 'UVIS Detector images' section hereafter. If the processed file contained data taken with the EUV channel of the instrument, this HDU will be labeled DETECTOR_IMG_EUV. Each DETECTOR_IMG binary table is of dimension number_of_sample x 64.

The FOV_GEOM contains information related to the geometry of the field of view. The HDU is structured into 10 variables:

- RA is the right ascension coordinate for the corners and center of each pixel. It is of dimension number_of_samples x 3 x 64 x 5. The dimension 5 includes the information for the 4 corners of a pixel plus its center,
- DEC is the declination coordinate for the corners and center of each pixel, of same dimension as RA,
- LAT represents the latitude on target body for the corners and center of each pixel, of same dimension as RA,
- LON represents the longitude on target body for the corners and center of each pixel, of same dimension as RA,
- SOLAR_HOUR_ANGLE is the solar hour angle for the corners and center of each pixel, of same dimension as RA,
- LOS is the Line of Sight or distance from the spacecraft to the target body for each pixel, of dimension number_of_samples x 3 x 64,
- RAYHEIGHT is the minimum separation between the look vector and the surface, also of dimension number_of_samples x 3 x 64,
- EMISSION_ANGLE is the angle between the line of sight and the local surface normal of the target body at each pixel center. It is of same dimension as LOS,
- INCIDENCE_ANGLE is the angle between the Sun and the local surface normal of the target body at each pixel center. It is of same dimension as LOS,
- PHASE_ANGLE is the angle between the Sun and the Line of Sight. It is of same dimension as LOS.

The KERNEL HDU contains the list of all kernels used to retrieve the geometry. Kernel files are publicly available on [the NAIF website.]()

The SC_GEOM includes the spacecraft geometry. It is structured into 11 variables, each one of dimension numer_of_samples x 3.

- SUB_SC_LAT is the sub-spacecraft latitude in the Saturn fixed frame,
- SUB_SC_LON is the sub-spacecraft latitude in the Saturn fixed frame,
- SUB_SOLAR_LAT is the sub-solar latitude in the Saturn fixed frame,
- SUB_SOLAR_LON is the sub-solar longitude in the Saturn fixed frame,
- SC_ALTITUDE is the distance (in km) between the spacecraft and the center of body target,

- VEL_X_SC_RATE is the x velocity of the spacecraft (in km/s) with respect to the planet,
- VEL_Y_SC_RATE is the y velocity of the spacecraft (in km/s) with respect to the planet,
- VEL_Z_SC_RATE is the z velocity of the spacecraft in km/s) with respect to the planet,
- VX_SC is the x location of the spacecraft with respect to the planet,
- VZ_SC is the y location of the spacecraft with respect to the planet,
- VZ_SC is the x location of the spacecraft with respect to the planet.

The TARGET_GEOM HDU includes 9 variables related to the geometry of the target of observations:

- TARGET_RA is the right ascension of the target body related to the spacecraft and is of dimension number_of_samples x 3,
- TARGET_DEC is the declination of the target body related to the spacecraft and is of same dimension as TARGET_RA,
- TARGET_PHASE_ANGLE is the phase angle at the sub-spacecraft point and is of same dimension as TARGET_RA,
- TARGET_INCIDENCE_ANGLE is the solar incidence angle at the sub-spacecraft point and is of same dimension as TARGET_RA,
- TARGET_EMISSION_ANGLE is the emission angle at the sub-spacecraft point and is of same dimension as TARGET_RA,
- PHI is the azimuth angle and is of dimension number_of_samples x 3 x 64.
- RAM_LON is the longitude of the leading edge point of the target and is of same dimension as PHI,
- RAM_LAT is the latitude of the leading edge point of the target and is of same dimension as PHI,
- SATURN_LOCAL_TIME (in hour) represents the position of Titan along its orbit around Saturn and is of same dimension as TARGET_RA.

The TIME HDU contains two arrays of dimension number_of_samples x 3, displaying a time conversion from ET to UTC:

- TIME_ET is the start time of observation using the ephemeris time (J2000),
- TIME_UTC is the start time of observation converted to UTC time.

The WAVELENGTH HDU contains an array with the default wavelength scale. Data file taken with the FUV channel of the instrument contain the FUV wavelength array while data file taken with the EUV channel of the instrument contain the EUV wavelength array.

UVIS Detector images

Each FITS file includes a higher order product called detector images (DETECTOR_IMG_EUV or DETECTOR_IMG_FUV, described above). Each image is done at a particular wavelength or wavelength range. Fourteen wavelength sets (a set of seven in the EUV and a set of seven in the FUV) were chosen as a function of the most prominent airglow spectral features at Titan.

The EUV channel contains the following selected wavelengths:
- the Carroll-Yoshino (C-Y) bands between 870 and 1020Å,

- the NII atomic emission at 919Å,
- the NI atomic emission at 953Å,
- the Lyman beta emission at 1026Å,
- the NII atomic emission at 1085Å,
- the NI atomic emission at 1134Å and,
- the scattered Lyman alpha emission beyond 1134Å

The FUV channel contains the following selected wavelengths:
- the Lyman alpha emission at 1216 Å,
- the Lyman–Birge–Hopfield (LBH) bands between 1270 and 1505Å,
- the N_2 LBH emission at 1356Å,
- the LBH emission at 1464Å,
- the NI atomic emission at 1493Å
- the reflected solar light between 1740 and 1895Å and
- the summed emissions between 1100 and 1900Å

Detector images, shown in Figure 1, display the temporal variation of the information on the UVIS-slit during an entire observation. The x-axis represents the spatial pixels of the detector, usually 64. The y-axis represents the time, either in samples # or in UTC time. A sample (or record) corresponds to one integration during an observation. On a detector image, samples are stacked over each other to form an image. The color provides information on the brightness of what is in the field of view in units of R/A. Some images are a true temporal variation of a same geographic zone (Example of the T32 flyby on June 13, 2007), while other images, like in Fig. 1, show a spatial variation during a certain time frame. However, most images are a mix of spatial and temporal variations at Titan, and it can be difficult to disentangle both components in them.

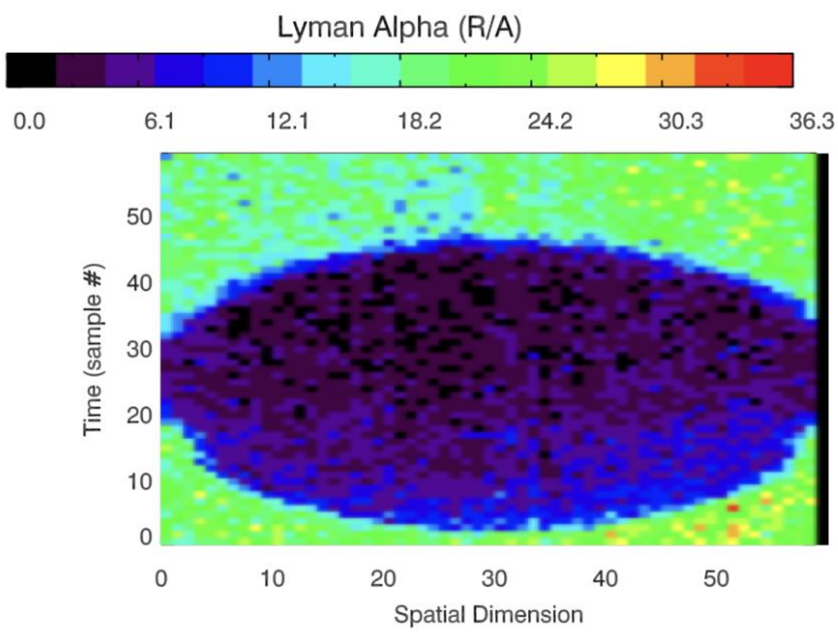


Figure 1 – Lyman Alpha detector image for observation FUV2006_140_04_53_39_UVIS_024 TI_EUVFU001_PRIME. The dark areas show the optically thick disk of Titan at 121.6 nm. The disk appears non-spherical due to the geometry used during the sequence of observation.

UVIS spectra

In the document folder, the AveragedSpectra sub-folder contains one averaged spectra figure per observation, as displayed in figure 2. The spectrum is averaged on all spatial pixels and all samples. Titan airglow spectra are mainly composed of the LBH band system, atomic Nitrogen emissions, reflected sunlight, and the Vegard-Kaplan (VK) band system. Typical other features are the Lyman alpha at 1216Å and solar reflected light long-ward 1650Å. The intensity is given in kR/Å.

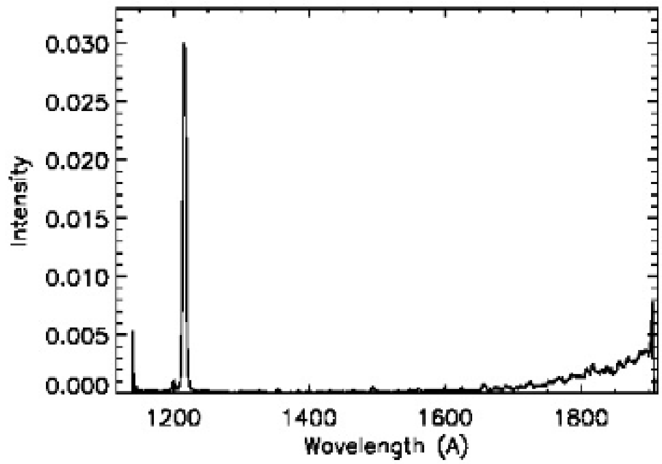


Figure 2 – Averaged spectrum for observation FUV2006_140_04_53_39_UVIS_024TI_EUV FU001_PRIME.

More information on the architecture of the UVIS data cubes is available in the UVIS user's guide.

Geometry

The Geometry folder is sub-divided in two folders: the mp4 subfolder and the pngSnaphot subfolder. The mp4 folder contain MPEG-4 movies of the geometry corresponding to each data FITS file. The movies show Titan, its phase angle (the dark grey color on the disk indicates the night side, while the light grey color indicates the day side) and how the UVIS slit is positioned across Titan's disk for the entire duration of the observation sequence. Additional information, such as the longitude and latitude of the sub-solar and sub-observer points, etc… can be found on the right margin of the movie. The pngSnapshot folder contains snapshots from the geometry MPEG-4 movies, as shown in Figure 3. Snapshots are taken for each step in time during the observation (called a sample, or a record) and their main purpose is to display the position of the UVIS slit across Titan's disk to better interpret the detector images. The pixel numbers are displayed at the edge of the slit, for orientation purpose.

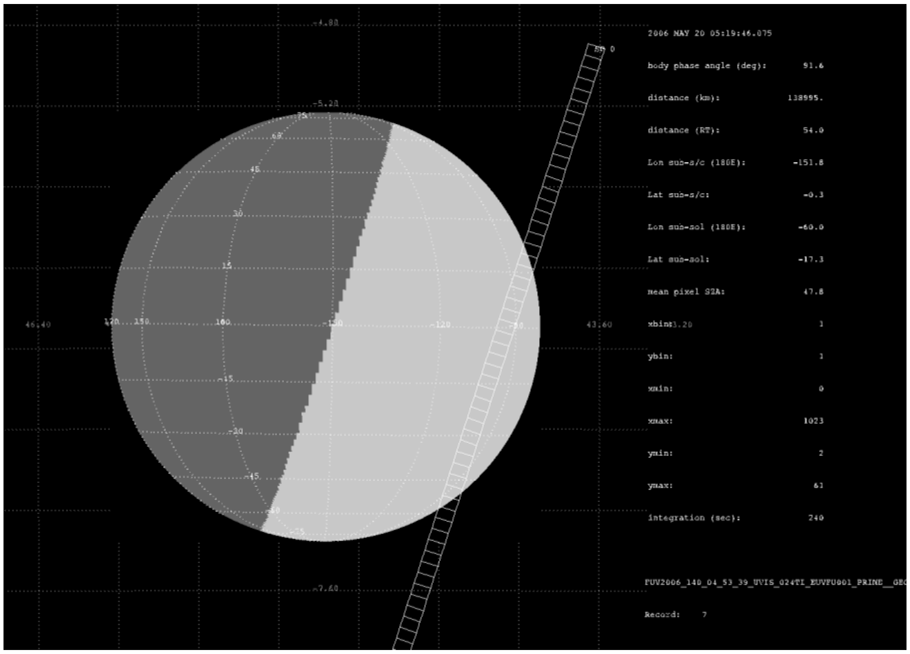


Figure 3 – Geometry snapshot of record 7 for observation FUV2006_140_04_53_39_UVIS_024 TI_EUVFU001_PRIME. The UVIS slit is placed across the dayside of Titan. When correlated with the detector image in Figure 1, we see that each end of the slit is looking at the interplanetary Lyman alpha emission, while the middle portion of the slit is looking at Titan's disk. The right margin indicates that titan's phase angle was 91.6º at the time of observation.

References

Esposito, L.W. et al., 2004. The Cassini ultraviolet imaging spectrograph investigation. Space Sci. Rev. 115, 299–361.

Python reader for data FITS files

The Python code below requires the installation of the Astropy library, which installation instructions and general information can be found at this address: https://www.astropy.org.

We are proving below a view of the Jupyter notebook that reads the data FITS files. The notebook itself can be downloaded from [github.](github)

jupyter TitanLibraryReader Last Checkpoint: 11/29/2023 (unsaved changes) Logout

File Edit View Insert Cell Kernel Widgets Help Not Trusted Python 3 (ipykernel)

Run Code

Python Reader for the Titan UVIS Library

The code below allow to open and read the main elements of the Titan UVIS Library FITS files. Examples are given to obtain the data general information, to retrieve specific parameter values, to graph a spectrum and to display a detector image.

Importing the libraries and opening the data

In [1]:

```
import numpy as np
import scipy
import matplotlib.pyplot as plt
from astropy.io import fits


hdulist = fits.open('/Users/eroyer/Desktop/cassini-uvis_titan-library/data_derived/FUV/2011/FUV2011_109_07_44_36
```

In [2]:

```
# Printing the general information about the data file
# This displays the name of each HDU
hdulist.info()
```

```
Filename: /Users/eroyer/Desktop/cassini-uvis_titan-library/data_derived/FUV/2011/FUV2011_109_07_44_36_UVIS_147TI_EU
VFUV001_PRIME_combined.fits
No.    Name          Ver    Type        Cards   Dimensions   Format
  0  PRIMARY           1 PrimaryHDU      18   ()
  1  CAL               1 BinTableHDU     13   1R x 1C    [65536E]
  2  CONFIG            1 BinTableHDU     47   1R x 10C    [K, J, J, J, J, J, J, J, E, E]
  3  DATA              1 BinTableHDU     19   81R x 2C    [196608E, 196608E]
  4  DETECTOR_IMG_FUV     1 BinTableHDU      37   81R x 7C    [64D, 64D, 64D, 64D, 64D, 64D, 64D]
  5  FOV_GEOM          1 BinTableHDU     57   81R x 11C    [960D, 960D, 960D, 960D, 960D, 960D, 192D, 192D, 192D, 192D,
192D]
  6  KERNELS           1 TableHDU        37   3R x 7C    [A12, A12, A29, A17, A23, A25, A15]
  7  SC_GEOM           1 BinTableHDU     53   81R x 11C    [3D, 3D, 3D, 3D, 3D, 3D, 3D, 3D, 3D, 3D, 3D]
  8  TARGET_GEOM        1 BinTableHDU      45    81R x 9C    [3D, 3D, 3D, 3D, 3D, 192D, 192D, 192D, 3D]
  9  TIME              1 BinTableHDU     17   81R x 2C    [3D, 78A]
 10  WAVELENGTH        1 BinTableHDU     13   1024R x 1C    [E]
```

In [3]:

```
# To print the Primary header
hdulist[0].header
```

Out[3]:

```
SIMPLE  =                    T / conforms to FITS standard
BITPIX  =                    8 / array data type
NAXIS   =                    0 / number of array dimensions
EXTEND  =                    T
FILENAME= 'FUV2011_109_07_44_36_UVIS_147TI_EUVFUV001_PRIME_combined.fits' / nan
PROD_ID = 'FUV2011_109_07_44'  / PDS product ID
DATE    = '2023-02-04T00:03:03.509936' / date this file was written (yyyy-mm-dd)
MISSION = 'Cassini '           / Mission name = Cassini
INSTRUME= 'ULTRAVIOLET IMAGING SPECTROGRAPH' / instrument used to acquire data =
VERSION =                  1.0 / File version number
OBS_ID  =               136337 / Numerical Observation ID
MPHASE  = 'XXM     '           / Mission Phase (Ground, Prime,Solstice, Equinox)
TRGTNAME= 'TITAN   '           / Target name ("Titan","Saturn", ...)
ORBNUM  =                  147 / Orbit number = REV number
OBS_ET  =    356471149.3276016 / Observation ephemeris time seconds (J2000)
OBS_UTC = '2011-04-19T07:44:43.142000+00:00' / Observation start UTC date/time s
END_UTC = '2011-04-19T08:00:43.142000+00:00' / Observation end UTC date/time str
CHANNEL = 'FUV     '           / FUV or EUV channel
```

Retrieveing parameter values

In [4]:

```
# the two functions below allow to
# - display the names of each parameter with an HDU with col_name() and,
# - return the value of the parameter with fits_data()

def col_name(hdulistNum):
    names = hdulist[hdulistNum].data.columns
    return names

def fits_data(hdulistNum, col_name):
    table = hdulist[hdulistNum]
    value = table.data.field(col_name).squeeze()
    return value
```

In [5]:
```python
# Example to retrieve the column names of HDU #9 (TIME)
# The TIME HDu has two variables, called TIME_ET and TIME_UTC
col_name(9)
```

Out[5]:
```
ColDefs(
    name = 'TIME_ET'; format = '3D'; dim = '(3)'
    name = 'TIME_UTC'; format = '78A'; dim = '(26,3)'
)
```

In [6]:
```python
# printing the value of TIME_ET
time_et = fits_data(9,'time_et')
print('shape of time_et:' , time_et.shape)
print('First row of the time_et array:' , time_et[0])
```

```
shape of time_et: (81, 3)
First row of the time_et array: [3.5647110e+08 3.5647098e+08 3.5647122e+08]
```

In [7]:
```python
# Example to retrieve the column names of HDU #2 (CONFIG)
col_name(2)
```

Out[7]:
```
ColDefs(
    name = 'OBS_SECONDS'; format = 'K'; null = 999999
    name = 'OBS_TICKS'; format = 'J'; null = 999999
    name = 'IMG_XMIN'; format = 'J'; null = 999999
    name = 'IMG_XMAX'; format = 'J'; null = 999999
    name = 'IMG_YMIN'; format = 'J'; null = 999999
    name = 'IMG_YMAX'; format = 'J'; null = 999999
    name = 'IMG_XBIN'; format = 'J'; null = 999999
    name = 'IMG_YBIN'; format = 'J'; null = 999999
    name = 'INT_TIME'; format = 'E'
    name = 'NUMBER_OF_SAMPLES'; format = 'E'
)
```

In [8]:
```python
# Example to retrieve the values of the OBS_SECONDS, IMG_XBIN and NUMBER_OF_SAMPLES parameters
print(fits_data(2,'obs_seconds'))
print(fits_data(2,'IMG_XBIN'))
print(fits_data(2,'number_of_samples'))
```

```
1681893179
1
81.0
```

In [9]:
```python
# printing the array sizes of the rawcounts and uvis_calibrated data parameters
print(fits_data(3,'rawcounts').shape)
print(fits_data(3,'uvis_calibrated').shape)
```

```
(81, 3, 1024, 64)
(81, 3, 1024, 64)
```

In [10]:
```python
# printing the first sample of the calibrated data, for the middle of the observation
# a value of -1000 indicated missing data
data = fits_data(3,'uvis_calibrated')
data[0,1,:,:]
```

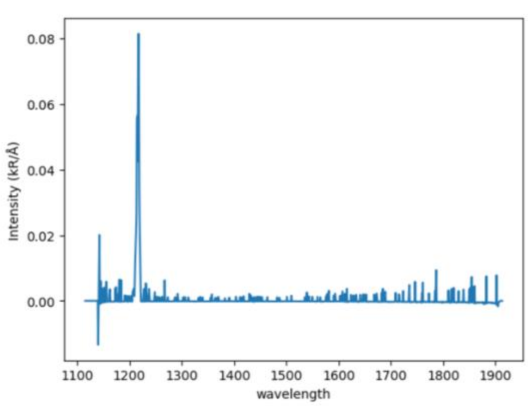
Out[10]:
```
array([[    0.,     0.,     0., ..., -1000., -1000., -1000.],
       [    0.,     0.,     0., ..., -1000., -1000., -1000.],
       [    0.,     0.,     0., ..., -1000., -1000., -1000.],
       ...,
       [    0.,     0.,     0., ..., -1000., -1000., -1000.],
       [    0.,     0.,     0., ..., -1000., -1000., -1000.],
       [    0.,     0.,     0., ..., -1000., -1000., -1000.]],
      dtype=float32)
```

Graphing a spectrum

In [11]:
```python
# Let's look at the first sample of the observation and at the begnning of the time period (first time stamp):
sample1 = data[0,1,:,:]
print(sample1.shape)
wavelength = fits_data(10,'wavelength_fuv')

# printing the spectrum for spatial row 32 on the slit
plt.plot(wavelength,sample1[:,32])
plt.xlabel('wavelength')
plt.ylabel('Intensity (kR/Å)')
```

```
(1024, 64)
```

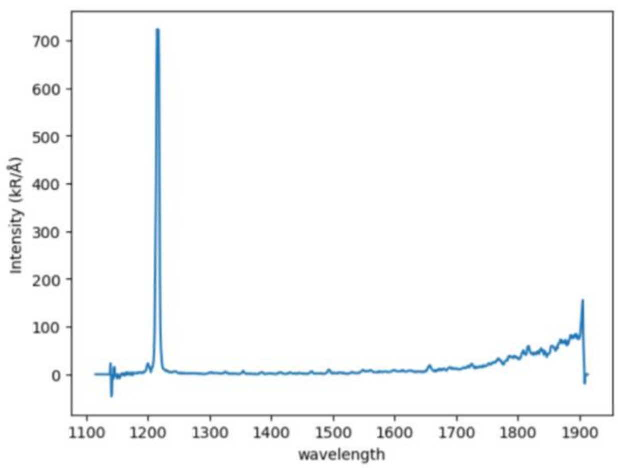
Out[11]:
```
Text(0, 0.5, 'Intensity (kR/Å)')
```



In [12]:
```python
# Graphing the average spectrum over the entire observation:
# - over the three time periods and,
# - over all the samples and,
# - over all the spatial pixels

# Set the -1000 values to zero
index = np.where(data == -1000)
data[index] = 0.0

# Averaging the spectrum acroos the spatial and temporal dimensions
avg_spectrum = np.sum(data, axis=(0,1,3))
print(avg_spectrum.shape)

# This graph corresponds to the information stored in the AveragedSpectra file
plt.plot(wavelength,avg_spectrum)
plt.xlabel('wavelength')
plt.ylabel('Intensity (kR/Å)')
```

```
(1024,)
```

Out[12]:
```
Text(0, 0.5, 'Intensity (kR/Å)')
```



Displaying detector images

The detcetor images are located in the DETECTOR_IMG_FUV HDU, which contains a set of 7 binary table, each diplaying an image detector at a particular wavelength or wavelength range.

In [13]:
```python
col_name(4)
```

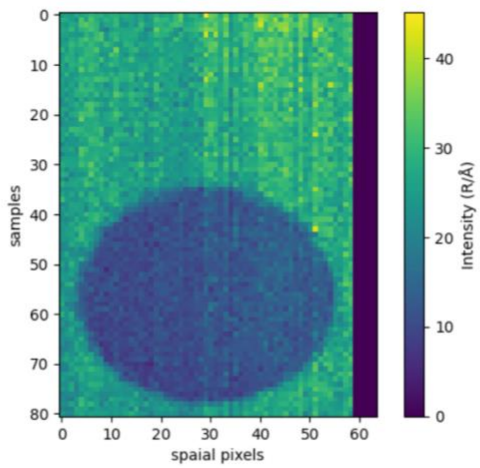
Out[13]:
```
ColDefs(
    name = 'LYMAN_ALPHA'; format = '64D'; dim = '(64)'
    name = 'LBH_1270_1505A'; format = '64D'; dim = '(64)'
    name = 'N2_LBH_1356A'; format = '64D'; dim = '(64)'
    name = 'LBH_1464A'; format = '64D'; dim = '(64)'
    name = 'NI_1493A'; format = '64D'; dim = '(64)'
    name = 'REFLECTED_SOLAR_1740_1895A'; format = '64D'; dim = '(64)'
    name = 'SUMMED_1100_1900A'; format = '64D'; dim = '(64)'
)
```

In [14]:
```python
# let's look at the Lyman alpha image
lyman = fits_data(4,'Lyman_alpha')
print(lyman.shape)
```

```
(81, 64)
```

In [15]:

```
im = plt.imshow(lyman)
plt.xlabel('spaial pixels')
plt.ylabel('samples')

cbar = plt.colorbar(im)
cbar.set_label("Intensity (R/Å)")
```



In [16]:

```
# Displaying the LBH emission band system from 1270 to 1505 Å
lbh = fits_data(4,'LBH_1270_1505A')
im = plt.imshow(lbh)
plt.xlabel('spaial pixels')
plt.ylabel('samples')

cbar = plt.colorbar(im)
cbar.set_label("Intensity (R/Å)")
```