lexi_tutorial

January 27, 2024

This Notebook will walk you through the process of using the LEXI code with the final goal of producing and saving x-ray data from LEXI spacecraft.

`LEXI`, in this context, is a package developed in Python to ingest the data from the LEXI spacecraft and produce x-ray data images in RA-DEC coordinate system.

0.1 LEXI package description

`LEXI` package has the following functions: - `get_spc_prams` - `get_exposure_maps` - `get_sky_backgrounds` - `get_lexi_images`

Details of each function are described in the following sections.

0.1.1 `get_spc_prams`

- `get_spc_prams`: to get the spacecraft's ephemeris data. It takes the following inputs:
- Required:
  - `t_range`: a list of two elements, the start and end time of the observation in UTC. The format of the time can be any of the following:
  - string: `YYYY-MM-DD HH:MM:SS`
  - float: Unix time or the number of seconds since 1970-01-01 00:00:00 UTC
  - datetime object: `datetime.datetime(YYYY, MM, DD, HH, MM, SS)`
  - Optional:
  - None The function returns the interpolated ephemeris data in a pandas dataframe. Output:
  - A pandas dataframe with the following columns:
  - `epoch_utc`: Time in UTC
  - `ra`: Right Ascension in degrees
  - `dec`: Declination in degrees
  - `roll`: Roll angle in degrees The interpolation is done internally on the ephemeris data using the `t_step` parameter. `t_step` is the time step in seconds at which the user desires to have look-direction computed. The default value is set to 5 seconds and is sufficient for most of the cases. The user can change it to a different value if needed.

0.1.2 `get_spc_prams`

- `get_exposure_maps`: The function to compute the exposure map for any given time interval. It takes the following inputs:
- Required:

  - `t_range`: a list of two elements, the start and end time of the observation in UTC. The format of the time can be any of the following:
  - string: `YYYY-MM-DD HH:MM:SS`
  - float: Unix time or the number of seconds since 1970-01-01 00:00:00 UTC
  - datetime object: `datetime.datetime(YYYY, MM, DD, HH, MM, SS)` Using the `t_range` parameter, the function will call `get_spc_prams` internally to get the ephemeris data.
- Optional:
  - `ra_range`: a list of two elements, the start and end RA of over which the user want the exposure maps to be computed. If not provided, the function computes the exposure map over the entire range of possible RA values (0 to 360 degrees).
  - `dec_range`: a list of two elements, the start and end Dec of over which the user want the exposure maps to be computed. If not provided, the function computes the exposure map over the entire range of possible Dec values (-90 to 90 degrees).
  - `ra_res`: the resolution of the RA bins in degrees. The default value is set to 0.1 degrees. The user can change it to a different value if needed.
  - `dec_res`: the resolution of the Dec bins in degrees. The default value is set to 0.1 degrees.
  - `nbins`: The number of bins to be used while computing the exposure map. It can be a single integer or a list of two integers. If a single integer is provided, the function will use the same number of bins for both RA and Dec. If a list of two integers is provided, the first element will be used for RA and the second element will be used for Dec. Note that if `ra_res` and `dec_res` are provided, the function will use the number of bins computed from the resolution values. However, if either of them is not provided, the function will use the number of bins provided by the user.
  - `t_step`: time step in seconds at which the user desires to have look-direction computed. The default value is set to 5 seconds and is sufficient for most of the cases. The user can change it to a different value if needed.
  - `t_integrate`: the integration time in seconds. This the length of time for wwhich each exposure map is computed. The default value is set to 600 seconds (10 minutes). If it is not provided by the user, the function will assume the time difference between the start and end time of the observation as the integration time. For example, if the provided `t_range` is `['2020-01-01 00:00:00', '2020-01-01 02:10:00']`, the function will assume the integration time to be 7800 seconds (2 hours and 10 minutes). However, if the user provides a different `integration_time`, let's say 600 seconds, the function will compute the exposure maps for 10 minutes each, there by producing 22 exposure maps.
  - `save_exposure_maps`: a boolean value to indicate whether the user wants to save the exposure maps as a PNG files. The default value is set to `False`. If the user wants to save the exposure maps, the function will save them in the a folder named `figures/exposure_maps/` in the current working directory. The function will also create a `.npy` file containing the the in a folder named `data/exposure_maps/` in the current working directory. The name of the `.npy` file will be `lexi_exposure_maps_Tstart_[YYYYMMDD_HHMMSS]_Tstop_[YYYYMMDD_HHMMSS]_RAstart_[RAstart]_`
  In the namefile, everything witihn the square brackets will be replaced by the actual values as computed by the function. For example, if the user provides the following inputs:
  - `t_range`: `['2020-01-01 00:00:00', '2020-01-01 02:10:00']`
  - `ra_range`: `[0, 360]`
  - `dec_range`: `[-90, 90]`

- `ra_res`: 0.1
- `dec_res`: 0.1
- `nbins`: [3600, 1800]
- `t_step`: 5
- `t_integrate`: 600 The function will save the exposure maps as `lexi_exposure_maps_Tstart_20200101_000000_Tstop_20200101_021000_RAstart_0_RAstop_360_I` in the `data/exposure_maps/` folder and the PNG files in the `figures/exposure_maps/` folder.

The function returns the following: - `exposure_maps`: a numpy array containing the exposure maps. The shape of the array is `(nbins_time, nbins_dec, nbins_ra)`. The `nbins_time` is the number of exposure maps computed for the given `t_range` and `t_integrate`. The `nbins_dec` and `nbins_ra` are the number of bins computed for the given `dec_res` and `ra_res` respectively. The unit of the exposure maps is `seconds` for each bin in the array. - `ra_arr`: a numpy array containing the RA values for the exposure maps. The shape of the array is `(nbins_ra,)`. - `dec_arr`: a numpy array containing the Dec values for the exposure maps. The shape of the array is `(nbins_dec,)`. - Images in the PNG format saved in the `figures/exposure_maps/` folder if `save_exposure_maps` is set to `True`.

0.1.3 `get_sky_backgrounds`

- `get_sky_backgrounds`: The function to compute the sky backgrounds for any given time interval using the ROSAT data. It takes the following inputs:
- Required:
  - `t_range`: a list of two elements, the start and end time of the observation in UTC. The format of the time can be any of the following:
  - string: `YYYY-MM-DD HH:MM:SS`
  - float: Unix time or the number of seconds since 1970-01-01 00:00:00 UTC
  - datetime object: `datetime.datetime(YYYY, MM, DD, HH, MM, SS)` Using the `t_range` parameter, the function will call `get_spc_prams` internally to get the ephemeris data. The function will also call `get_exposure_maps` internally to get the exposure maps.
- Optional:
  - `ra_range`: a list of two elements, the start and end RA of over which the user want the sky backgrounds to be computed. If not provided, the function computes the sky backgrounds over the entire range of possible RA values (0 to 360 degrees).
  - `dec_range`: a list of two elements, the start and end Dec of over which the user want the sky backgrounds to be computed. If not provided, the function computes the sky backgrounds over the entire range of possible Dec values (-90 to 90 degrees).
  - `ra_res`: the resolution of the RA bins in degrees. The default value is set to 0.1 degrees. The user can change it to a different value if needed.
  - `dec_res`: the resolution of the Dec bins in degrees. The default value is set to 0.1 degrees.
  - `nbins`: The number of bins to be used while computing the sky backgrounds. It can be a single integer or a list of two integers. If a single integer is provided, the function will use the same number of bins for both RA and Dec. If a list of two integers is provided, the first element will be used for RA and the second element will be used for Dec. Note that if `ra_res` and `dec_res` are provided, the function will use the number of bins computed from the resolution values. However, if either of them is not provided, the function will

use the number of bins provided by the user.
  - `t_step`: time step in seconds at which the user desires to have look-direction computed. The default value is set to 5 seconds and is sufficient for most of the cases. The user can change it to a different value if needed.
  - `t_integrate`: the integration time in seconds. This the length of time for wwhich each exposure map is computed. The default value is set to 600 seconds (10 minutes). If it is not provided by the user, the function will assume the time difference between the start and end time of the observation as the integration time. For example, if the provided `t_range` is `['2020-01-01 00:00:00', '2020-01-01 02:10:00']`, the function will assume the integration time to be 7800 seconds (2 hours and 10 minutes). However, if the user provides a different `integration_time`, let's say 600 seconds, the function will compute the exposure maps for 10 minutes each, there by producing 22 sky background images.
  - `save_sky_backgrounds`: a boolean value to indicate whether the user wants to save the sky background images as a PNG files. The default value is set to `False`. If the user wants to save the sky background images, the function will save them in the a folder named `figures/sky_backgrounds/` in the current working directory.

The function returns the following: - `sky_backgrounds`: a numpy array containing the sky backgrounds. The shape of the array is `(nbins_time, nbins_dec, nbins_ra)`. The `nbins_time` is the number of sky background images computed for the given `t_range` and `t_integrate`. The `nbins_dec` and `nbins_ra` are the number of bins computed for the given `dec_res` and `ra_res` respectively. The unit of the sky backgrounds is `counts` for each bin in the array. - `ra_arr`: a numpy array containing the RA values for the sky backgrounds. The shape of the array is `(nbins_ra,)`. - `dec_arr`: a numpy array containing the Dec values for the sky backgrounds. The shape of the array is `(nbins_dec,)`. - Images in the PNG format saved in the `figures/sky_backgrounds/` folder if `save_sky_backgrounds` is set to `True`.

0.1.4 `get_lexi_images`

- `get_lexi_images`: The function to compute the background corrected or uncorrected x-ray image from LEXI data. The function takes the following inputs:
- Required:
  - `t_range`: a list of two elements, the start and end time of the observation in UTC. The format of the time can be any of the following:
  - string: `YYYY-MM-DD HH:MM:SS`
  - float: Unix time or the number of seconds since 1970-01-01 00:00:00 UTC
  - datetime object: `datetime.datetime(YYYY, MM, DD, HH, MM, SS)` Using the `t_range` parameter, the function will call `get_spc_prams` internally to get the ephemeris data. The function will also call `get_exposure_maps` internally to get the exposure maps. The function will also call `get_sky_backgrounds` internally to get the sky backgrounds.
- Optional:
  - `background_correction_on`: a boolean value to indicate whether the user wants to apply the background correction to the x-ray image. The default value is set to `True`. If the user wants to apply the background correction, the function will subtract the sky backgrounds from the x-ray image.
  - `ra_range`: a list of two elements, the start and end RA of over which the user want the sky backgrounds to be computed. If not provided, the function computes the sky

backgrounds over the entire range of possible RA values (0 to 360 degrees).
- `dec_range`: a list of two elements, the start and end Dec of over which the user want the sky backgrounds to be computed. If not provided, the function computes the sky backgrounds over the entire range of possible Dec values (-90 to 90 degrees).
- `ra_res`: the resolution of the RA bins in degrees. The default value is set to 0.1 degrees. The user can change it to a different value if needed.
- `dec_res`: the resolution of the Dec bins in degrees. The default value is set to 0.1 degrees.
- `nbins`: The number of bins to be used while computing the sky backgrounds. It can be a single integer or a list of two integers. If a single integer is provided, the function will use the same number of bins for both RA and Dec. If a list of two integers is provided, the first element will be used for RA and the second element will be used for Dec. Note that if `ra_res` and `dec_res` are provided, the function will use the number of bins computed from the resolution values. However, if either of them is not provided, the function will use the number of bins provided by the user.
- `t_step`: time step in seconds at which the user desires to have look-direction computed. The default value is set to 5 seconds and is sufficient for most of the cases. The user can change it to a different value if needed.
- `t_integrate`: the integration time in seconds. This the length of time for wwhich each exposure map is computed. The default value is set to 600 seconds (10 minutes). If it is not provided by the user, the function will assume the time difference between the start and end time of the observation as the integration time. For example, if the provided `t_range` is `['2020-01-01 00:00:00', '2020-01-01 02:10:00']`, the function will assume the integration time to be 7800 seconds (2 hours and 10 minutes). However, if the user provides a different `integration_time`, let's say 600 seconds, the function will compute the exposure maps for 10 minutes each, there by producing 22 sky background images.

The function returns the following: - `lexi_images`: a numpy array containing the x-ray images. The shape of the array is `(nbins_time, nbins_dec, nbins_ra)`. The `nbins_time` is the number of x-ray images computed for the given `t_range` and `t_integrate`. The `nbins_dec` and `nbins_ra` are the number of bins computed for the given `dec_res` and `ra_res` respectively. The unit of the x-ray images is `counts` for each bin in the array. - `ra_arr`: a numpy array containing the RA values for the x-ray images. The shape of the array is `(nbins_ra,)`. - `dec_arr`: a numpy array containing the Dec values for the x-ray images. The shape of the array is `(nbins_dec,)`. - Images in the PNG format saved in the `figures/lexi_images/` folder.

0.2 Using the LEXI Code

0.2.1 Import the LEXI package from the `lexi` folder

NOTE: The following cell is only needed if you are running this notebook from the `examples` folder. This is beccause the code still uses `sample_lexi_pointing_ephem_edited.csv` and `sample_xray_background.csv` files from the to get the ephemeries and the x-ray background data.

[3]:
```
# Import LEXI
from lexi.lexi import LEXI
```

[4]:
```
# Check if lexi was imported correctly by printing the main LEXI docstring
print(LEXI.__doc__)
```

```
    A LEXI class for generating LEXI images based in either user input or
default parameters.

    Attributes:
        LEXI_FOV: float
            The LEXI field of view in degrees. It is a fixed value of 9.1
degrees.
        CDA_LINK: str
            The link to the CDAweb website, from which ephemeris data are
pulled.
        save_df: bool
            If True, save the dataframe to a file.
        filename: str
            Filename to save df to.
        filetype: str
            Filetype to save df to. Options: 'csv','pkl'
        interp_method: str
            Interpolation method used when upsampling/resampling ephemeris data,
ROSAT data. Options:
            'linear', 'index', 'values', 'pad'. See pandas.DataFrame.interpolate
documentation for
            more information. Default is 'index'.
        background_correction_on: bool
            Toggle background correction. Default is True. If False, background
correction is not
            applied to the LEXI images. If True, background correction is
applied to the final LEXI
            images.
        t_range: list
            Time range to consider. [start time, end time]. Times can be
expressed in the following
            formats:
                1. A string in the format 'YYYY-MM-DDTHH:MM:SS' (e.g.
'2022-01-01T00:00:00')
                2. A datetime object
                3. A float in the format of a UNIX timestamp (e.g. 1640995200.0)
                This time range defines the time range of the ephemeris data and
the time range of
                the LEXI data.
            Note that endpoints are inclusive (the end time is a closed
interval); this is because
            the time range slicing is done with pandas, and label slicing in
pandas is inclusive.
```

```
        t_step: float
            Time step in seconds for time resolution of the look direction
datum.
        t_integrate: float
            Integration time in seconds for lexi histograms and exposure maps.
This is the time that
            we integrate over to create the lexi histograms and exposure maps.
Default is 600
            seconds.
        ra_range: list
            RA (Right Ascension) range to plot, in degrees. [start RA, end RA].
Default is [0.0,
            360.0].
        dec_range: list
            DEC (Declination) range to plot, in degrees. [start DEC, end DEC].
Default is [-90.0,
            90.0].
        ra_res: float
            RA resolution to plot at, in degrees. Default is 0.1.
        dec_res: float
            DEC resolution to plot at, in degrees. Default is 0.1.
        nbins: int
            Alternative to ra_res/dec_res: nbins defines the number of bins in
the RA and DEC
            directions. Either a scalar integer or [ra_nbins, dec_nbins]. If
both nbins and
            ra_res/dec_res are specified, nbins will be used and ra_res/dec_res
will be ignored.
        save_exposure_maps: bool
            If True, save the exposure maps to a file of given filename and
filetype.
        save_sky_backgrounds: bool
            If True, save the sky background to a file of given filename and
filetype.
        save_lexi_images: bool
            If True, save the background corrected image to a file of given
filename and filetype.

    Methods:
        get_spc_prams:
            Gets spacecraft ephemeris data for the given t_range by downloading
the appropriate
            file(s) from the NASA CDAweb website.
        vignette:
            Function to calculate the vignetting factor for a given distance
from boresight.
        get_exposure_maps:
            Returns an array of exposure maps, made according to the ephemeris
```

```
data and the specified
            time/integration/resolution parameters.
            Shape: num-images * ra-pixels * dec-pixels, where num-images depends
on t_range and
            t_integrate, ra-pixels depends on ra_range and ra_res, and dec-
pixels depends on
            dec_range and dec_res.
        get_sky_backgrounds:
            Returns an array of ROSAT sky background images, corrected for LEXI
exposure time.
            Shape: num-images * ra-pixels * dec-pixels, where num-images depends
on t_range and
            t_integrate, ra-pixels depends on ra_range and ra_res, and dec-
pixels depends on
            dec_range and dec_res.
        get_lexi_images:
            Returns an array of LEXI science histograms.
            Shape: num-images * ra-pixels * dec-pixels,
            where num-images depends on t_range and t_integrate, ra-pixels
depends on ra_range and
            ra_res, and dec-pixels depends on dec_range and dec_res.
        array_to_image:
            Convert a 2D array from get_exposure_maps or get_lexi_images to an
image.
```

[5]:
```
# Set up the lexi instance using a dictionary of parameters and values as␣
 ↪follows:
# Refer to the LEXI docstring for a description of each parameter

lexi = LEXI(
    {
        "t_range": [
            "2024-07-08T21:43:41",
            "2024-07-08T21:47:48",
        ],
        "ra_range": [290, 360],
        "dec_range": [290, 360],
        "ra_res": 4,
        "dec_res": 3,
        "background_correction_on": False,
        "save_exposure_maps": True,
        "save_sky_backgrounds": True,
        "save_lexi_images": True,
    }
)
```

[6]:
```
# Get space params
df_space_params = lexi.get_spc_prams()
```

```
/home/vetinari/Desktop/git/Lexi-Bu/lexi/lexi/lexi.py:228: FutureWarning:
DataFrame.interpolate with object dtype is deprecated and will raise in a future
version. Call obj.infer_objects(copy=False) before interpolating instead.
  dfinterp = dfresamp.interpolate(method=self.interp_method)
```

[7]:
```
# Look at the space params
df_space_params.head()
```

[7]:

epoch_utc	epoch_utc	epoch_mjd	earth_ra	earth_dec	sun_ra	sun_dec	sco_ra	sco_dec	mp_az	mp_el	mp_ra	mp_dec
2024-07-08 21:44:00	Jul 08 2024 21:44:00.000000000	60499.905980	324.955849	-18.047999	108.192588	22.372788	244.982213	-15.640577	248.464172	37.481432	335.293995	-14.326040
2024-07-08 21:44:05	NaN	60499.906038	324.956541	-18.047728	108.192646	22.372781	244.982213	-15.640577	248.464264	37.481413	335.294663	-14.325745
2024-07-08 21:44:10	NaN	60499.906097	324.957233	-18.047457	108.192703	22.372775	244.982213	-15.640577	248.464357	37.481394	335.295330	-14.325450
2024-07-08 21:44:15	NaN	60499.906155	324.957924	-18.047186	108.192761	22.372768	244.982213	-15.640577	248.464449	37.481374	335.295998	-14.325155
2024-07-08 21:44:20	NaN	60499.906213	324.958616	-18.046915	108.192819	22.372762	244.982213	-15.640577	248.464542	37.481355	335.296665	-14.324860

[8]:
```
# Print a list of all the keys in the space params
df_space_params.keys()
```

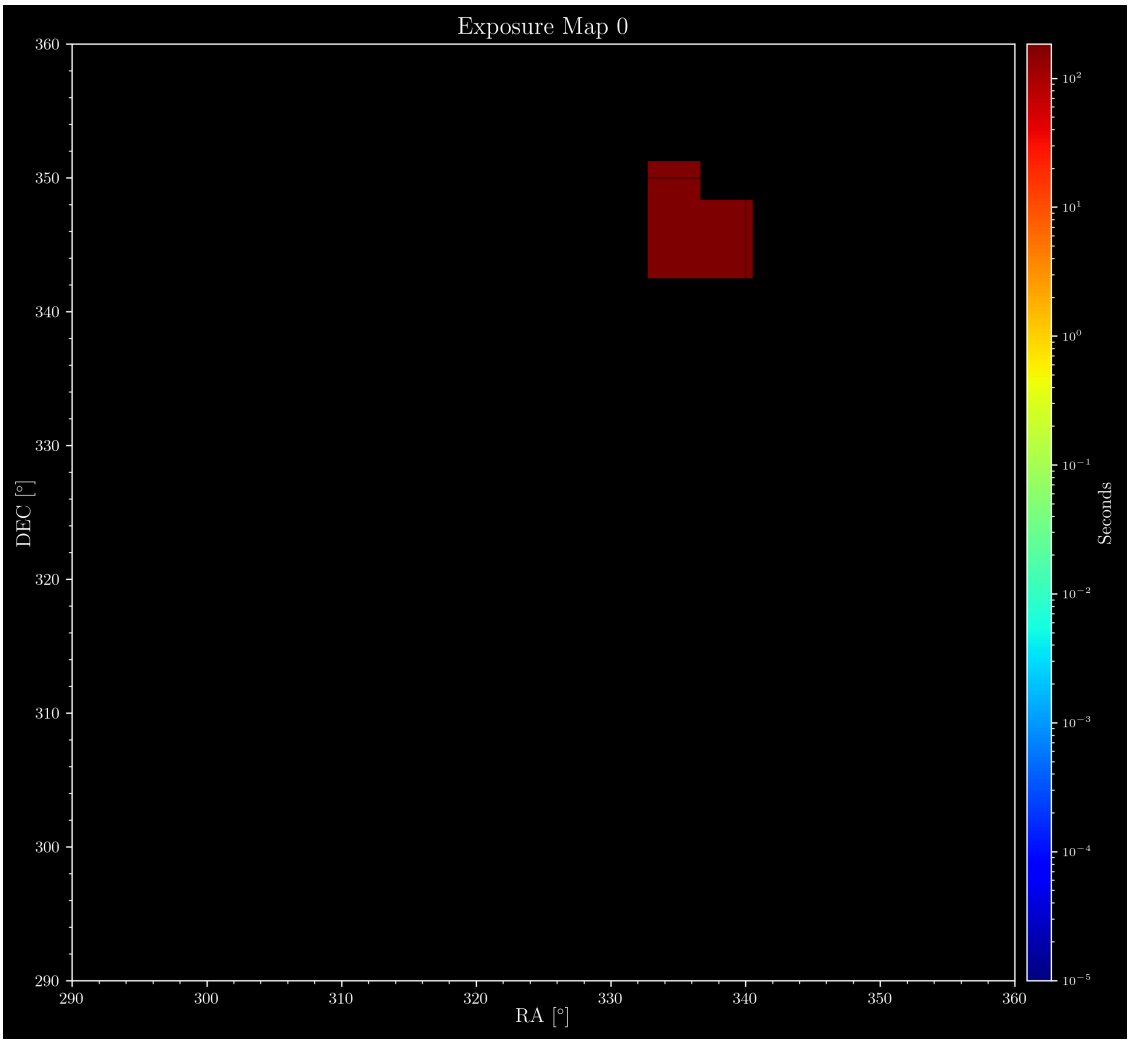
[8]:
```
Index(['epoch_utc', 'epoch_mjd', 'earth_ra', 'earth_dec', 'sun_ra', 'sun_dec',
       'sco_ra', 'sco_dec', 'mp_az', 'mp_el', 'mp_ra', 'mp_dec'],
      dtype='object')
```

[9]:
```
# Get exposure maps
expmaps, ra_arr, dec_arr = lexi.get_exposure_maps()
```

```
/home/vetinari/Desktop/git/Lexi-Bu/lexi/lexi/lexi.py:228: FutureWarning:
DataFrame.interpolate with object dtype is deprecated and will raise in a future
```

```
version. Call obj.infer_objects(copy=False) before interpolating instead.
  dfinterp = dfresamp.interpolate(method=self.interp_method)
```

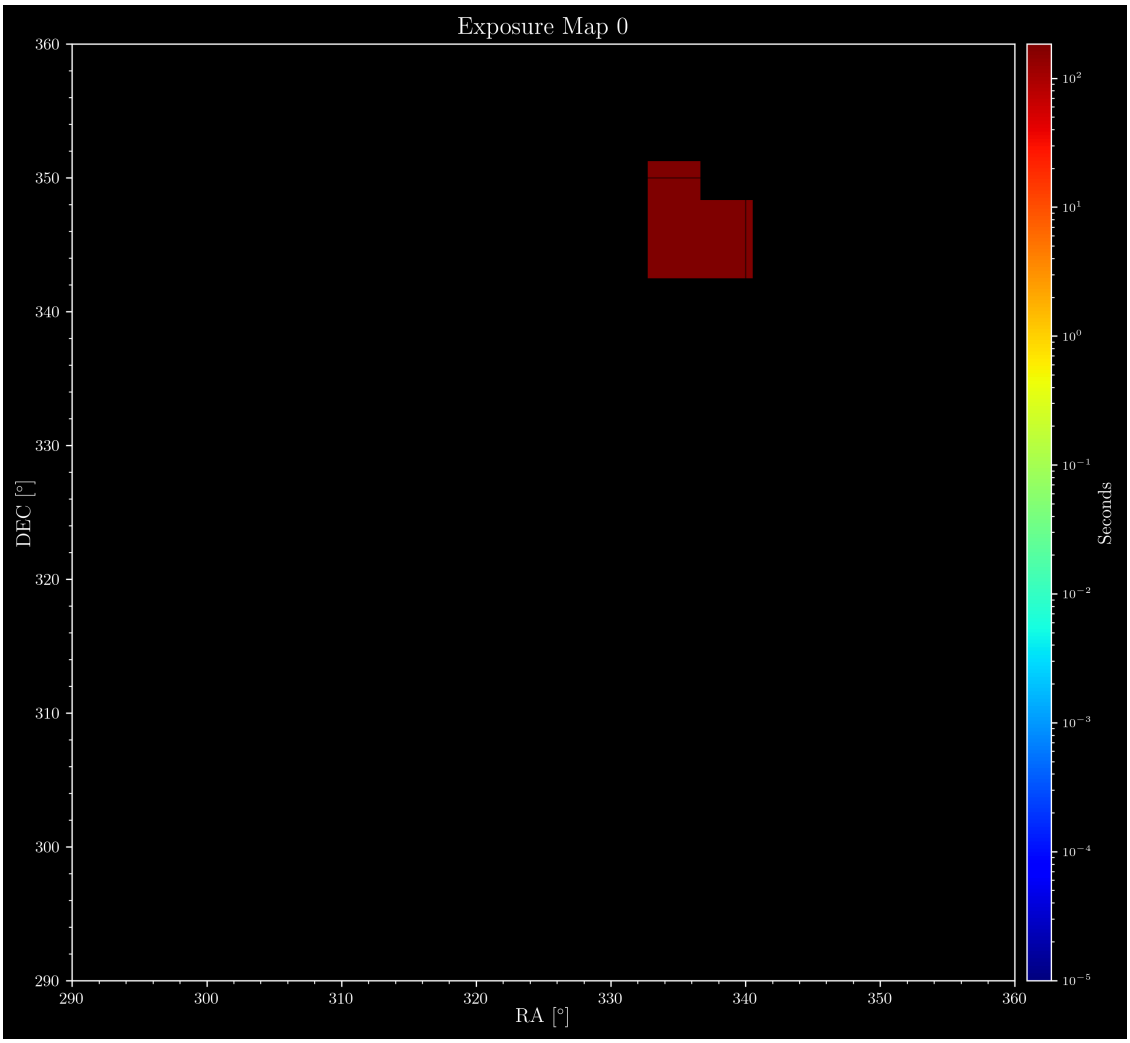
```
Exposure map loaded from file  /home/vetinari/Desktop/git/Lexi-Bu/lexi/data
/exposure_maps/lexi_exposure_map_Tstart_20240708_214341_Tstop_20240708_214748_RA
start_290_RAstop_360_RAres_4_DECstart_290_DECstop_360_DECres_3_Tint_247.npy

Saving exposure maps as images
Saved figure to figures/exposure_maps/exposure_map_0.png
```



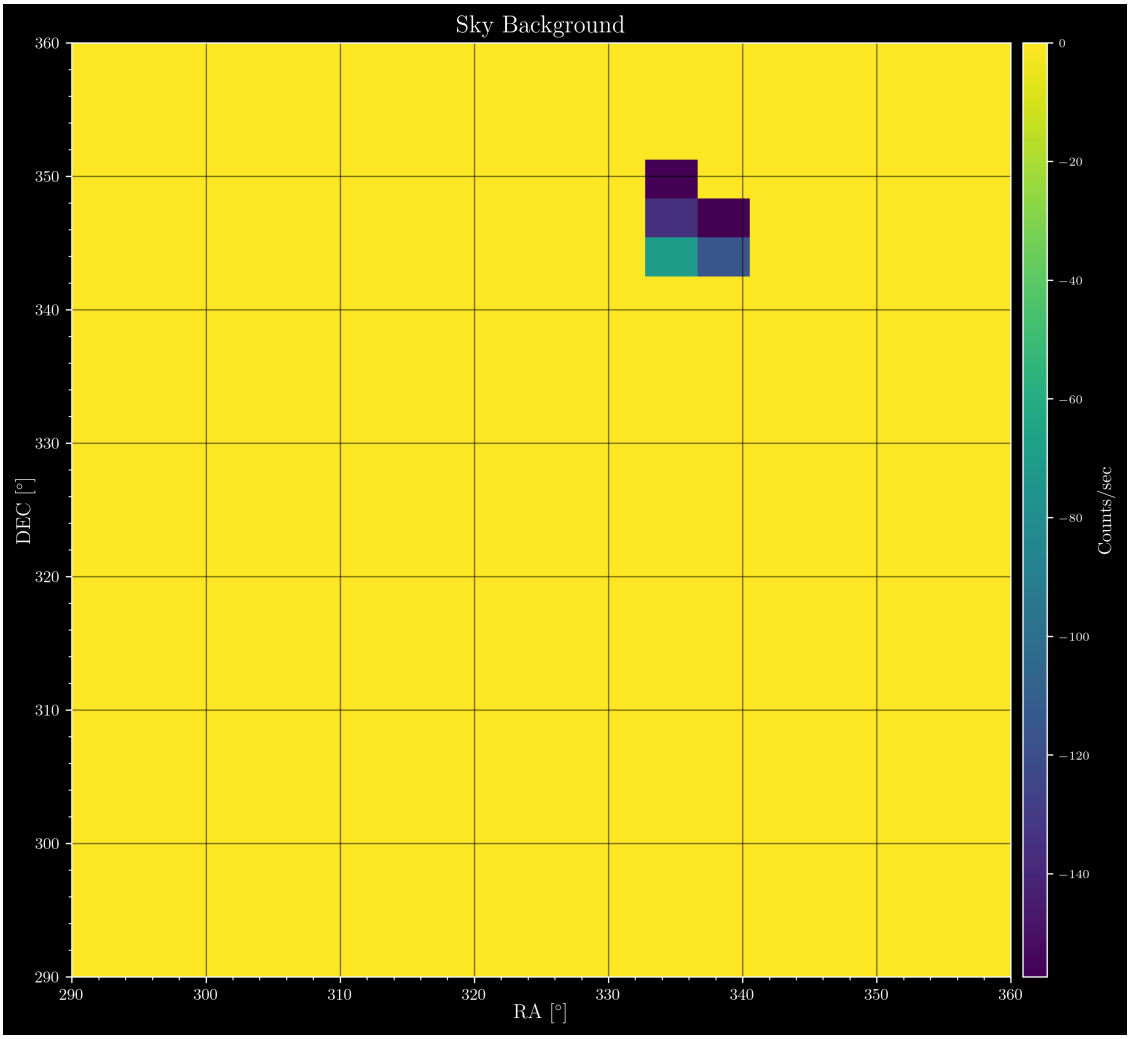
[10]:
```
# Get sky backgrounds
skybgs, ra_arr, dec_arr = lexi.get_sky_backgrounds()
```

```
/home/vetinari/Desktop/git/Lexi-Bu/lexi/lexi/lexi.py:228: FutureWarning:
DataFrame.interpolate with object dtype is deprecated and will raise in a future
```

```
version. Call obj.infer_objects(copy=False) before interpolating instead.
  dfinterp = dfresamp.interpolate(method=self.interp_method)
Exposure map loaded from file  /home/vetinari/Desktop/git/Lexi-Bu/lexi/data
/exposure_maps/lexi_exposure_map_Tstart_20240708_214341_Tstop_20240708_214748_RA
start_290_RAstop_360_RAres_4_DECstart_290_DECstop_360_DECres_3_Tint_247.npy

Saving exposure maps as images
Saved figure to figures/exposure_maps/exposure_map_0.png
```



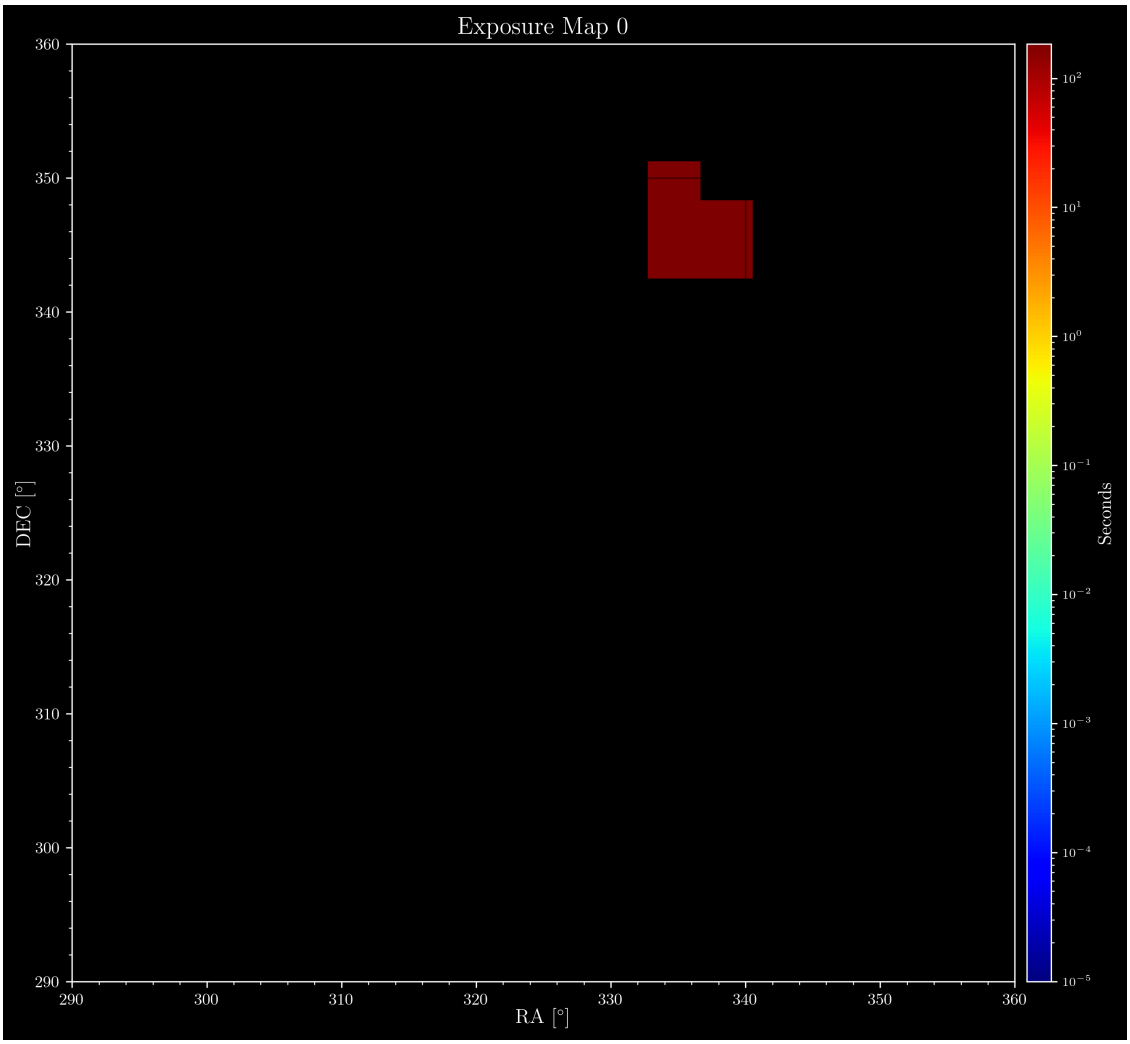

```
Saved figure to figures/sky_background/sky_background_0.png
```



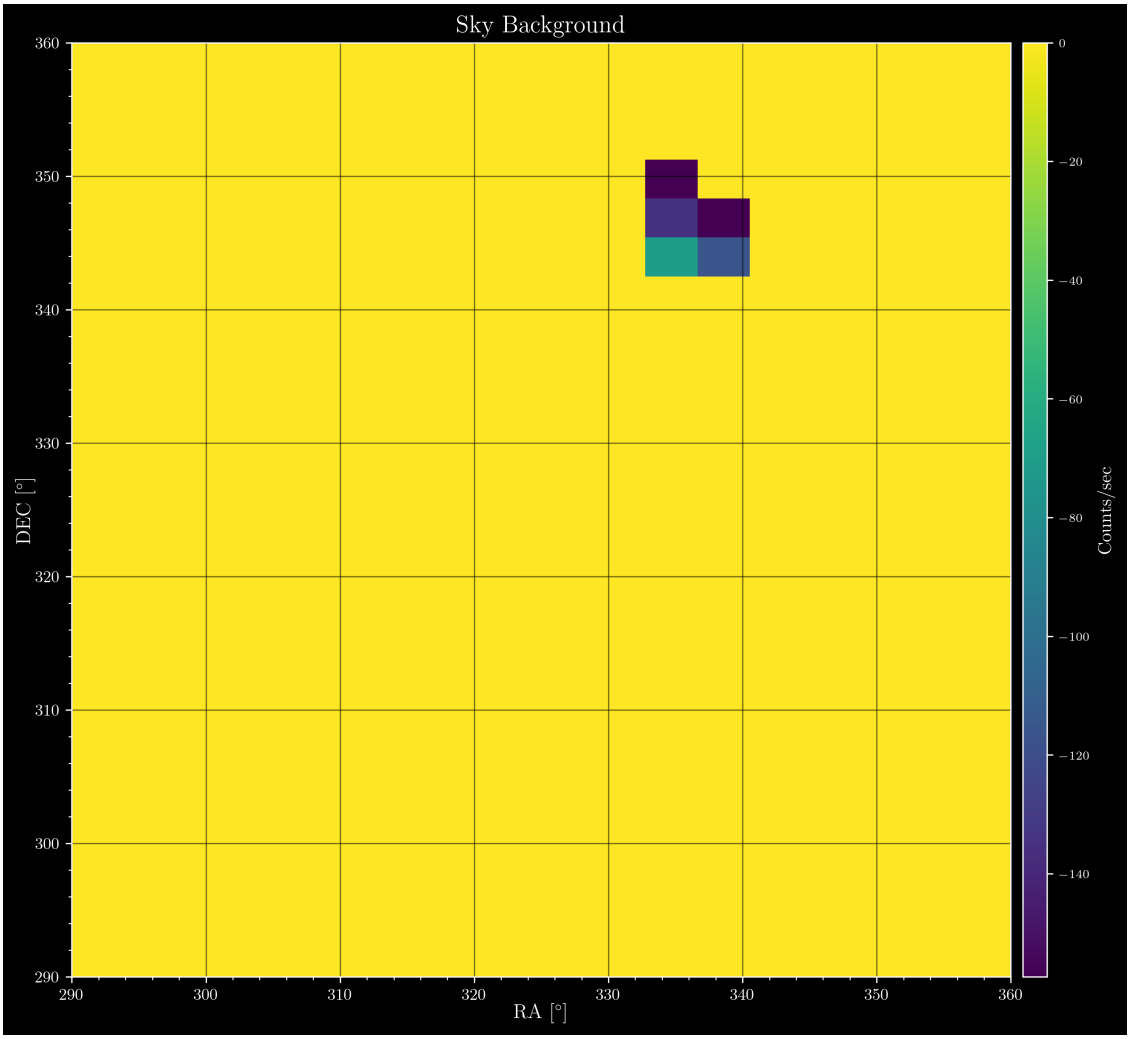
[11]:
```
# Get background corrected images
lexi_image, ra_arr, dec_arr = lexi.get_lexi_images()
```

```
Extrema: RA min -1102.979736328125, RA max 331.99212646484375, DEC min
-8373.873046875, DEC max 208.826904296875

/home/vetinari/Desktop/git/Lexi-Bu/lexi/lexi/lexi.py:228: FutureWarning:
DataFrame.interpolate with object dtype is deprecated and will raise in a future
version. Call obj.infer_objects(copy=False) before interpolating instead.
  dfinterp = dfresamp.interpolate(method=self.interp_method)

Exposure map loaded from file  /home/vetinari/Desktop/git/Lexi-Bu/lexi/data
/exposure_maps/lexi_exposure_map_Tstart_20240708_214341_Tstop_20240708_214748_RA
start_290_RAstop_360_RAres_4_DECstart_290_DECstop_360_DECres_3_Tint_247.npy

Saving exposure maps as images
```

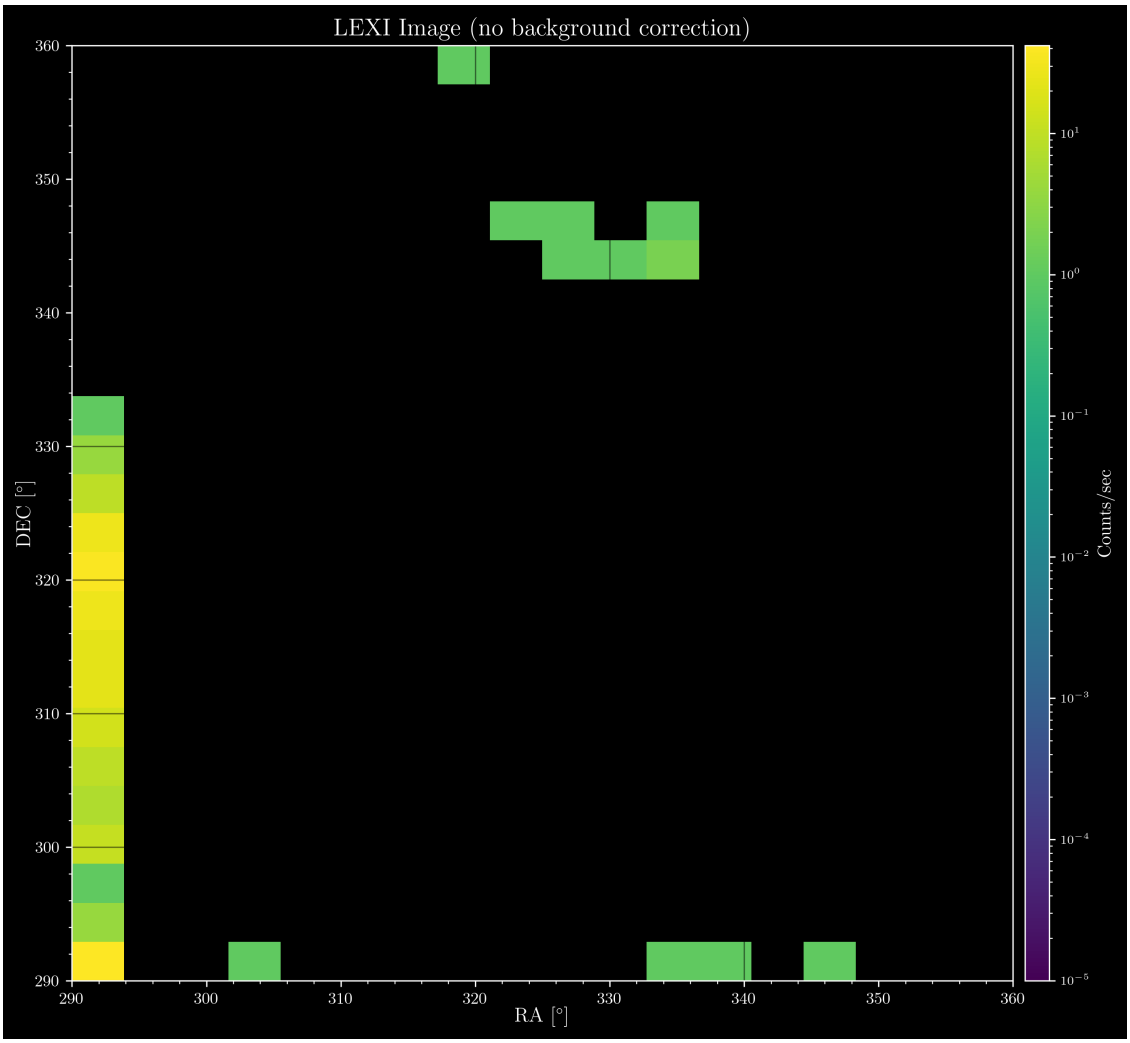
```
Saved figure to figures/exposure_maps/exposure_map_0.png
```




```
Saved figure to figures/sky_background/sky_background_0.png
```




```
Saved figure to figures/lexi_images/lexi_image_0.png
```



[12]:
```
lexi_image.shape
```

[12]: (18, 24)

[13]:
```
print(ra_arr.shape, dec_arr.shape)
```

```
(18,) (24,)
```

[ ]: