Working with PUNCH Data

A How-To Guide

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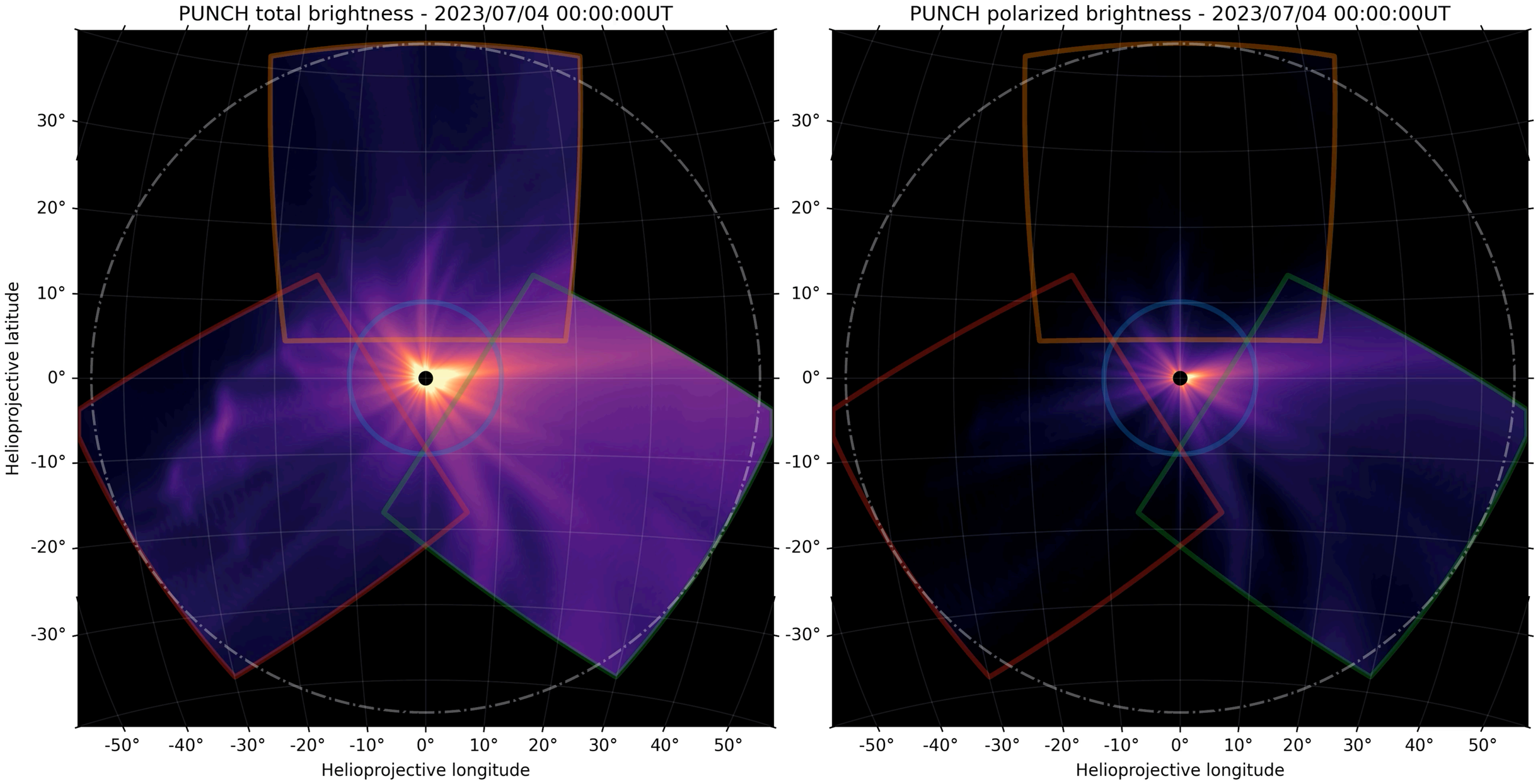
Southwest Research Institute
PUNCH 5 meeting

Southwest Research Institute

What is PUNCH?

What is PUNCH Data?


PUNCH total brightness - 2023/07/04 00:00:00UT
PUNCH polarized brightness - 2023/07/04 00:00:00UT
Helioprojective latitude
30°
20°
10°
0°
-10°
-20°
-30°
-50°
-40°
-30°
-20°
-10°
0°
10°
20°
30°
40°
50°
Helioprojective longitude

Data design principles

Data and metadata

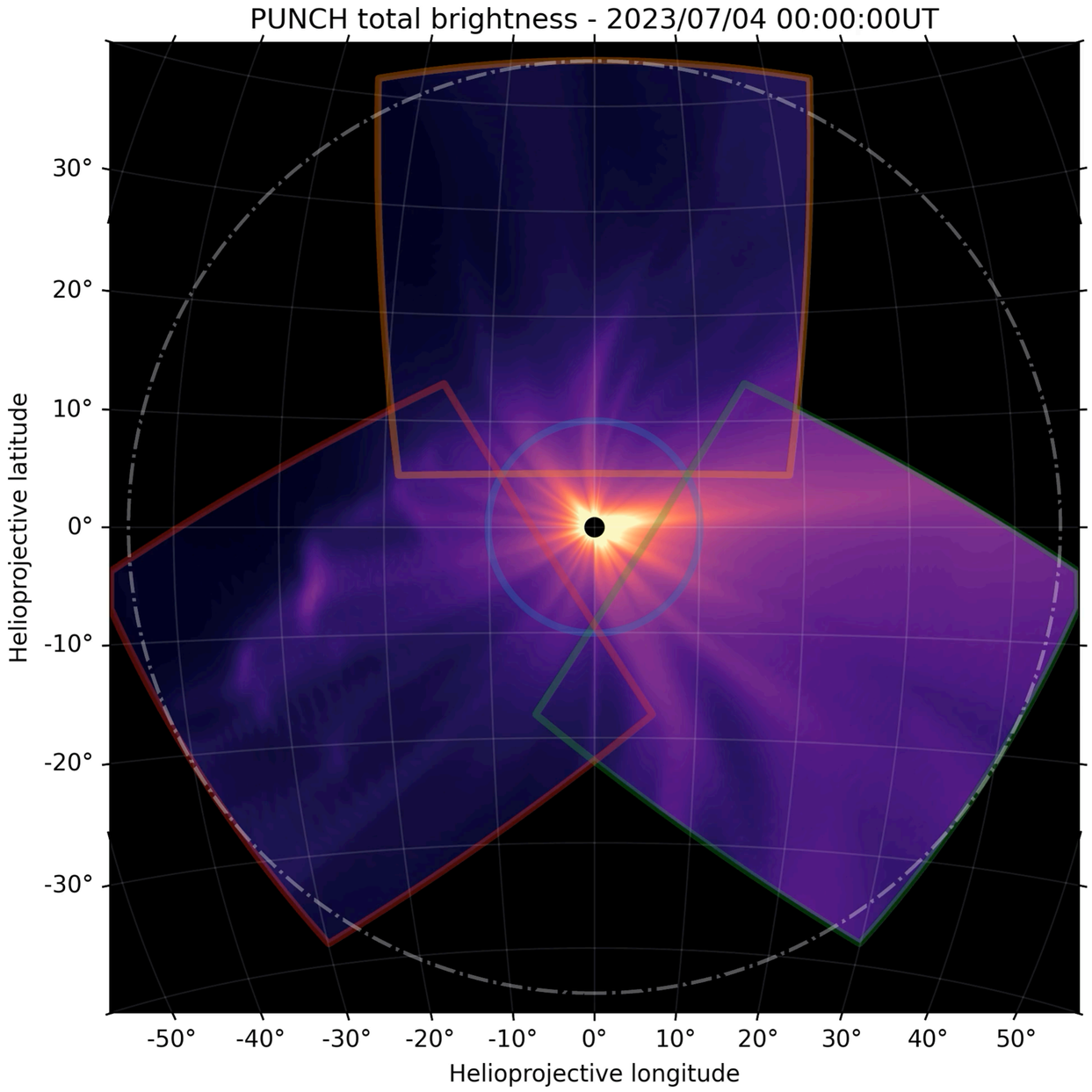
- Built on NDCube
  - Bundles data with associated uncertainties, world coordinate system (WCS), and metadata
- Transparent & self-describing metadata
- Fully standards (FITS 4.0) compliant
- Human *enjoyably* readable
- Uses FITS's multidimensional data capabilities to represent polarization, uncertainty, etc.

```
COMMENT ----- Documentation, Contact, and Collection Metadata ------------------
DOI     = 'https://doi.org/TBD' / Data reference DOI
PROJECT = 'PUNCH   '
TITLE   = 'PUNCH Level-3 Polarized Low Noise Mosaic'
KEYVOCAB= 'Unified Astronomy Thesaurus Keywords'
KEYWORDS= 'Solar Corona (1483), Solar K Corona (2042), Solar F Corona (1991), &'
CONTINUE  'Solar Coronal Streamers (1486), Solar Coronal Plumes (2039), Solar &'
CONTINUE  'Wind (1534), Fast Solar Wind (1872), Slow Solar Wind (1873), Solar &'
CONTINUE  'Coronal Mass Ejection (310), Heliosphere (711), Polarimetry (1278)'
LICENSE = 'Creative Commons Attribution 4.0 International | CC BY 4.0'
DESCRPTN= 'PUNCH Level-3 data, Composite mosaic in output coordinates'
DOC_URL = 'https://punch.spaceops.swri.org'
COMMENT ----- File Type and Provenance ----------------------------------------
FILENAME= '' / Name of file
LEVEL   = '3       '           / Product Level
OBSTYPE = 'Polarized low noise mosaic' / Plain text observation
TYPECODE= 'PA      '           / Observation product type code
OBSCODE = 'M       '           / Observatory spacecraft code
PIPEVRSN= '' / PUNCHPipe software version number
FILE_RAW= '' / Raw telemetry filename
ORIGIN  = 'SwRI    '           / Institution responsible for creating the file
COMMENT ----- Temporal Information -------------------------------------------
TIMESYS = 'UTC     '           / Principal time system
DATE-BEG= '2024-06-20T00:00:00.000' / UTC time observation
DATE-OBS= '2024-06-20T00:00:00.000' / UTC reference time
DATE-AVG= '2024-06-20T00:16:00.000' / UTC reference time
DATE-END= '2024-06-20T00:32:00.000' / UTC time of observation end
DATE    = '2024-06-20T12:32:00.000' / UTC file generation date and time
COMMENT ----- Instrument and Spacecraft State ----------------------------------
WAVELNTH=                  530 / [nm] average peak response
WAVEUNIT= 'nanometer'          / Unit of observation measurement
OBS-MODE= 'Polar_BpB'          / Image Mode (Unpolarized, Polar_MZP, Polar_BpB)
OBSLAYR1= 'Polar_B '           / Image Mode for first datacube layer
OBSLAYR2= 'Polar_pB'           / Image Mode for second datacube layer
INSTRUME= 'WFI+NFI Mosaic'     / Instrument name
TELESCOP= 'PUNCH 1-2-3-4'      / Satellite name
OBSRVTRY= 'PUNCH   '           / Observatory name
OBJECT  = 'Heliosphere white light' / Object observed
COMMENT ----- World Coordinate System ----------------------------------------
WCSAXES =                    3 / Number of coordinate axes
CRPIX1  =               2047.5 / Pixel coordinate of reference point
CRPIX2  =               2047.5 / Pixel coordinate of reference point
CRPIX3  =                  0.0 / Pixel coordinate of reference point
PC1_1   =                  1.0 / Coordinate transformation matrix element
PC1_2   =                  0.0 / Coordinate transformation matrix element
PC1_3   =                  0.0 / Coordinate transformation matrix element
PC2_1   =                  0.0 / Coordinate transformation matrix element
PC2_2   =                  1.0 / Coordinate transformation matrix element
PC2_3   =                  0.0 / Coordinate transformation matrix element
PC3_1   =                  0.0 / Coordinate transformation matrix element
PC3_2   =                  0.0 / Coordinate transformation matrix element
PC3_3   =                  1.0 / Coordinate transformation matrix element
CDELT1  =               0.0225 / [deg] Coordinate increment at reference point
CDELT2  =               0.0225 / [deg] Coordinate increment at reference point
CDELT3  =                  1.0 / Coordinate increment at reference point
CUNIT1  = 'deg     '           / Units of coordinate increment and value
CUNIT2  = 'deg     '           / Units of coordinate increment and value
CUNIT3  = '' / Units of coordinate increment and value
CTYPE1  = 'HPLN-ARC'           / Coordinate type codezenithal/azimuthal equidist
CTYPE2  = 'HPLT-ARC'           / Coordinate type codezenithal/azimuthal equidist
CTYPE3  = 'STOKES  '           / Coordinate type
CRVAL1  =                  0.0 / [deg] Coordinate value at reference point
CRVAL2  =                  0.0 / [deg] Coordinate value at reference point
CRVAL3  =                  0.0 / Coordinate value at reference point
```

Data pipeline

Overview

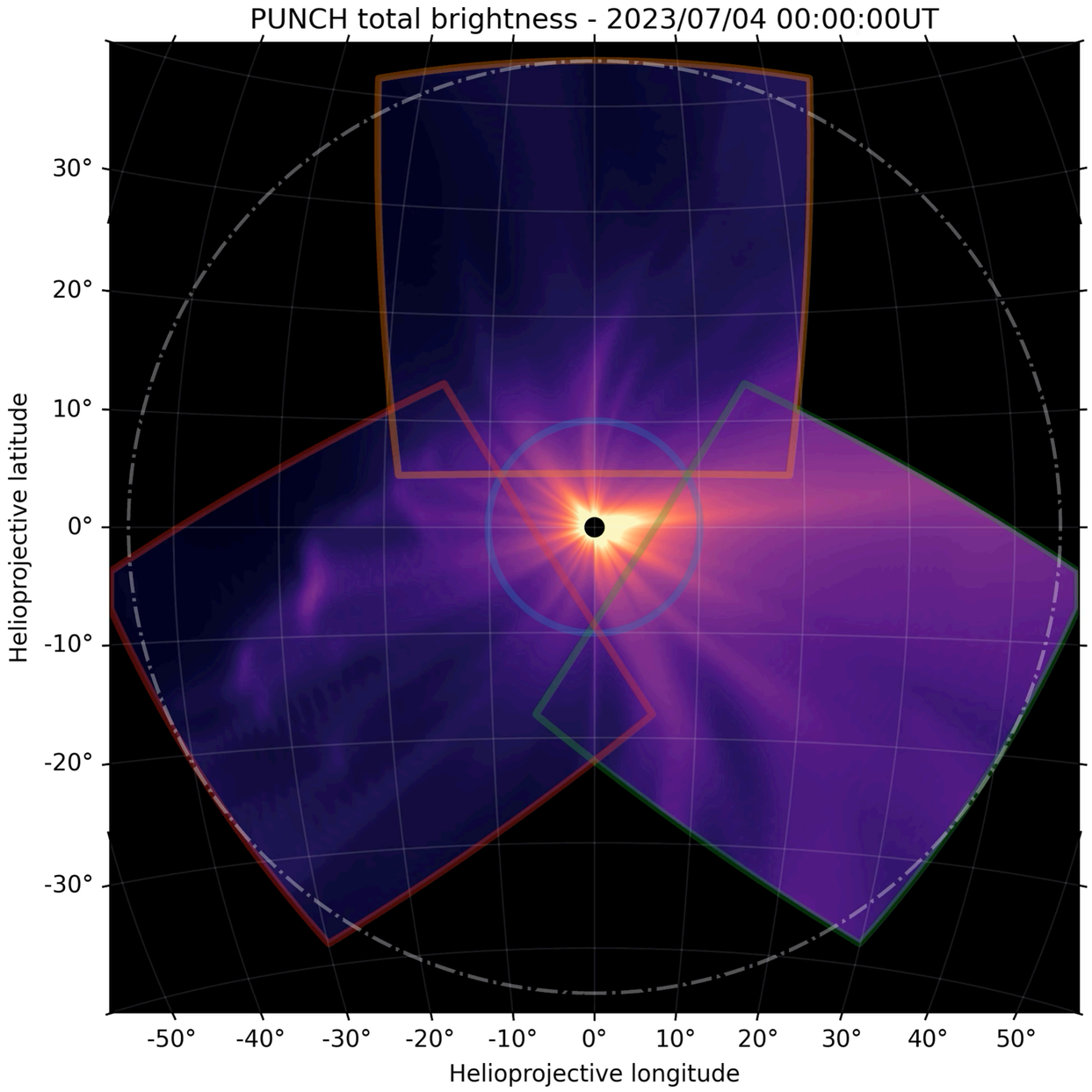
- Combining observations from four satellites into one virtual observatory with modern pipeline tools
- *Prefect* for pipeline orchestration
- *NDCube* for data handling
- Ease of use / extensibility
- Robust documentation



Data products

Overview

- Preliminary synthetic PUNCH data generated from GAMERA model data
- Simulates real PUNCH Level 3 data
- Does not include a starfield or F-corona
- The next iteration of this data will include realistic noise



Data products

Filenames

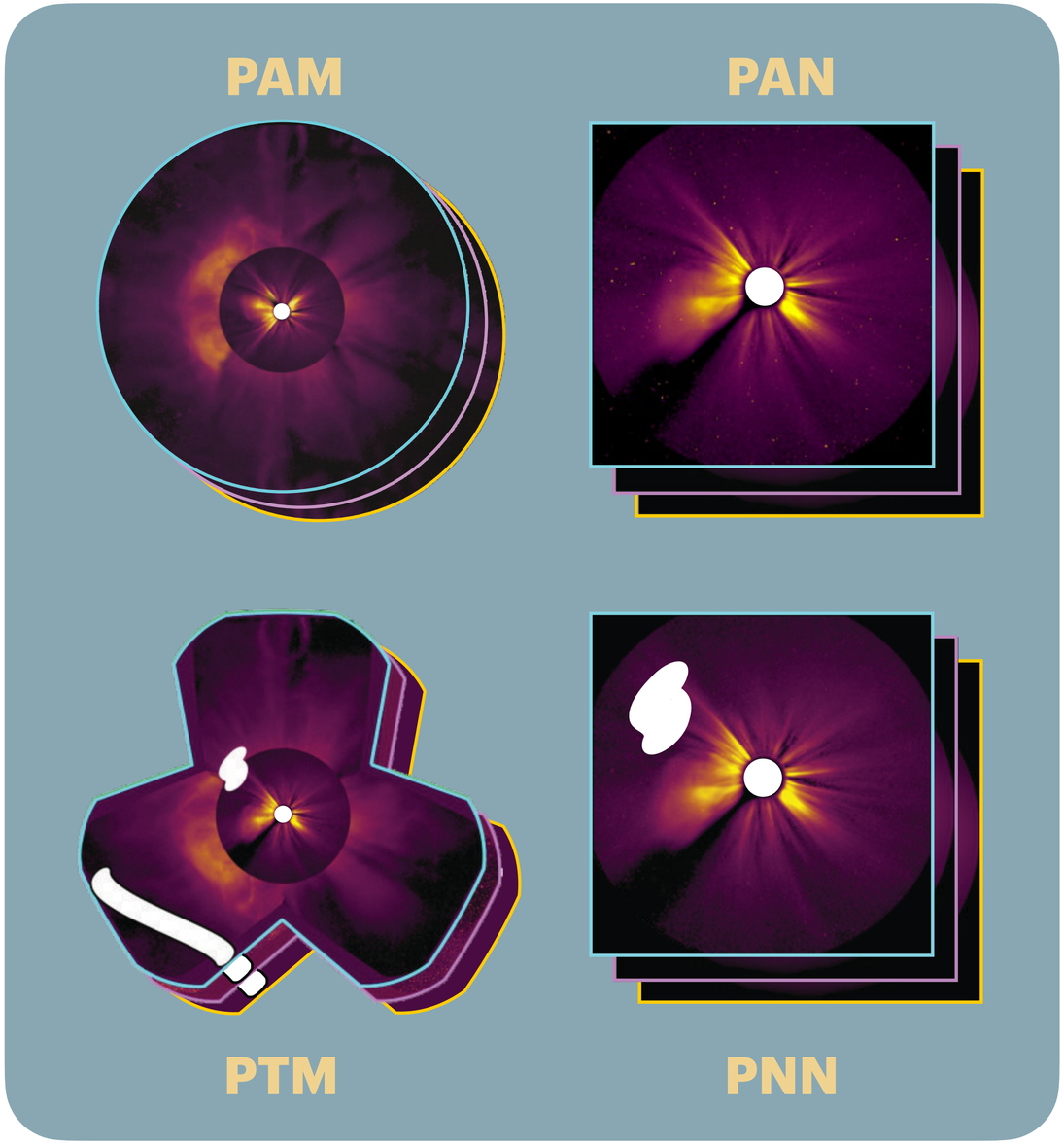
PUNCH_L3_PAM_20230704000000_v1.fits

- PUNCH: Spacecraft
- L3: Data level
- PAM: Product code
- 20230704000000: Timestamp
- v1: Version number for reprocessing
- .fits

Data products

Primary data

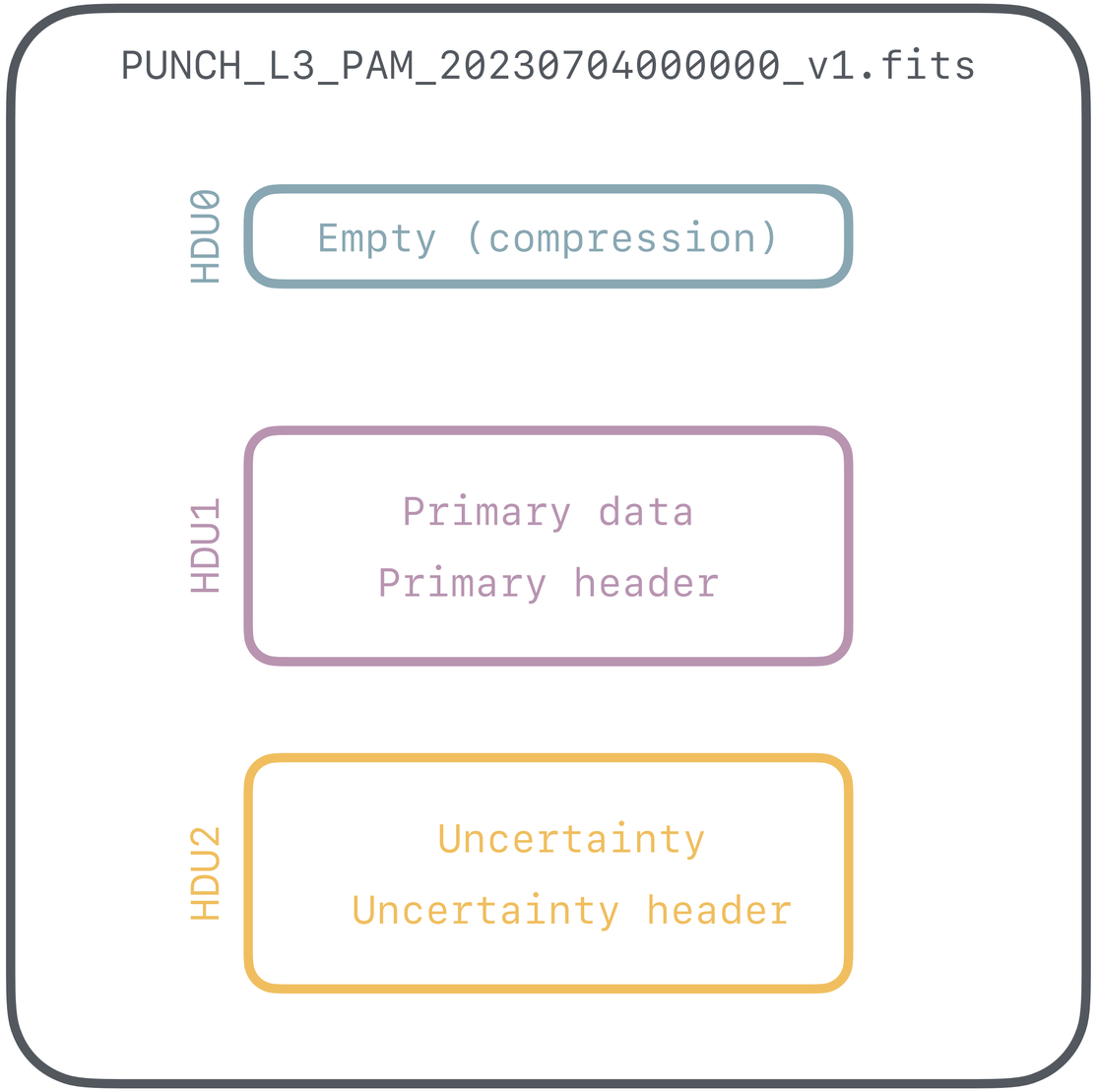
- L3 - Level 3 total brightness and polarized brightness
  - **PAM** - Polarized Low Noise Mosaic – 32 minutes
  - **PAN** - Polarized Low Noise NFI Image – 32 minutes
  - **PTM** - Polarized Trefoil Mosaic – 4 minutes
  - **PNN** - Polarized NFI Image – 4 minutes
- Corresponding clear data (**CXX**) also generated in data pipeline



Data products

Overview

- Data is RICE compressed, with primary data / header in the second HDU and uncertainty in the third HDU
- Data can be read with astropy FITS frameworks
- Bespoke data handler capable of reading PUNCH data and bundling the data and WCS information will be available at https://github.com/punch-mission
- A sample IDL script for reading PUNCH data is under development at: https://github.com/punch-mission/PUNCH_IDL_Tools



A notebook example

```
# Load libraries

import matplotlib.pyplot as plt
from matplotlib.colors import LogNorm
import numpy as np

from astropy.io import fits
from astropy.wcs import WCS

import astropy.units as u

from sunpy.map import Map

from ndcube import NDCube
```

```
# Specify data filepath

filename = 'PUNCH_L3_PAM_20240620000000.fits'


# Open the HDU list, and read out the appropriate data
# As the data is RICE compressed, the *second* HDU contains the main data frame

with fits.open(filename) as hdul:
    data = hdul[1].data
    header = hdul[1].header
    uncertainty = hdul[2].data
```

```
# Take a look at the data and uncertainty
array shapes
# For this data product, total brightness and
polarized brightness and stacked along the
first dimension
# The uncertainty array corresponds on a
pixel-to-pixel basis with the data array

data.shape, uncertainty.shape
```

```
((2, 4096, 4096), (2, 4096, 4096))
```

```
# Take a look at the header for these data

header
```

```
COMMENT ----- FITS Required ------------------------------------------------------
EXTNAME = 'PRIMARY DATA ARRAY' / Name of this binary table extension
LONGSTRN= 'OGIP 1.0'           / The OGIP long string convention may be used
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TELESCOP= 'PUNCH 1-2-3-4'      / Satellite name
OBSRVTRY= 'PUNCH   '           / Observatory name
OBJECT  = 'Heliosphere white light' / Object observed
COMMENT ----- World Coordinate System ----------------------------------------
...
COMMENT ----- Fixity ------------------------------------------------------------
CHECKSUM= 'EWh3HVh2EVh2EVh2'   / HDU checksum updated 2024-04-06T21:54:50
DATASUM = '1089768418'         / data unit checksum updated 2024-04-06T21:54:50
COMMENT ----- History ----------------------------------------------------------
HISTORY Records of processing from pipeline
```
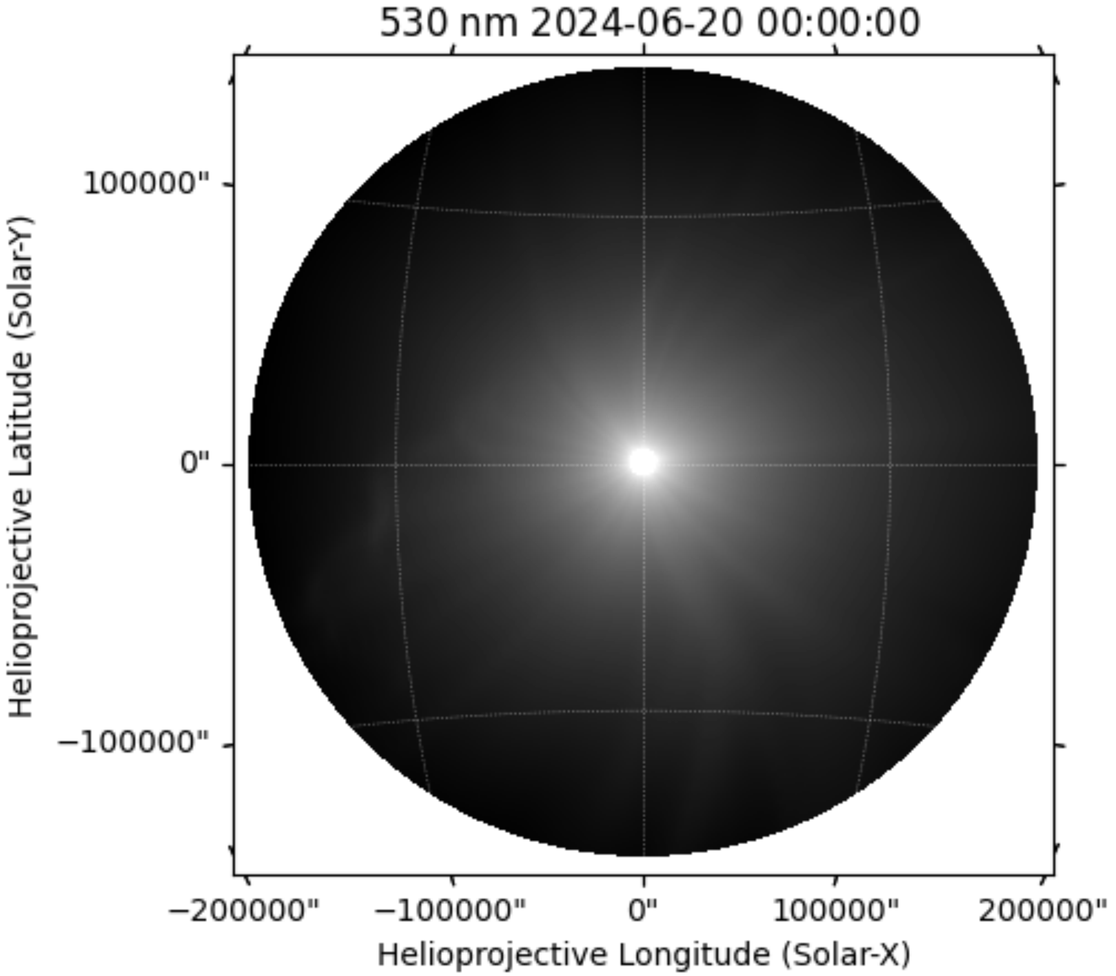

```
# The header information can be converted
into an AstroPy WCS object
# Note that due to the stacked nature of this
data, there is an additional STOKES axis

data_wcs = WCS(header);

data_wcs
```

```
WCS Keywords

Number of WCS axes: 3
CTYPE : 'HPLN-ARC' 'HPLT-ARC' 'STOKES'
CRVAL : 0.0 0.0 0.0
CRPIX : 2047.5 2047.5 0.0
PC1_1 PC1_2 PC1_3  : 1.0 0.0 0.0
PC2_1 PC2_2 PC2_3  : 0.0 1.0 0.0
PC3_1 PC3_2 PC3_3  : 0.0 0.0 1.0
CDELT : 0.0225 0.0225 1.0
NAXIS : 4096  4096  2
```

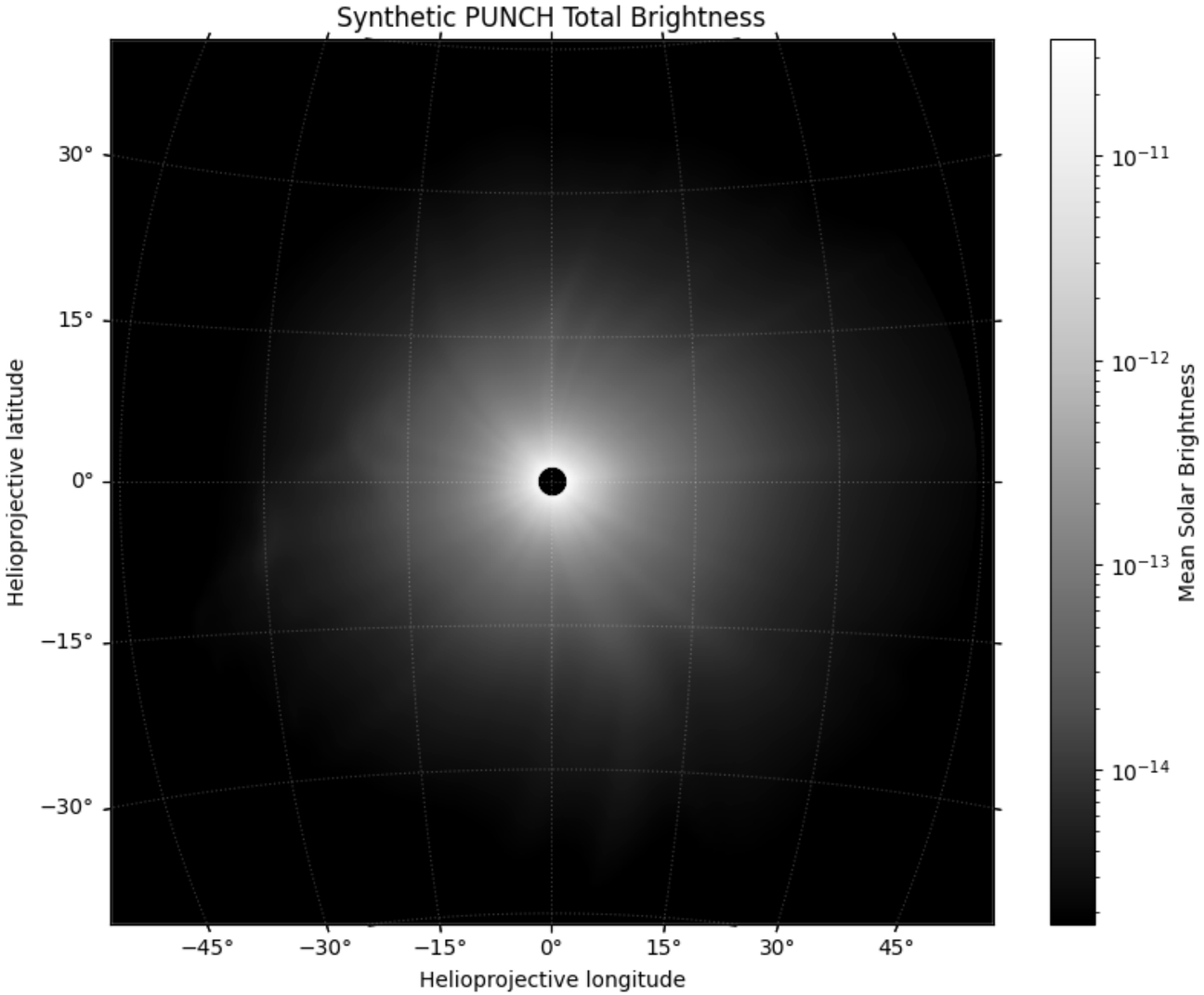
```
# Construct a SunPy Map object of out this data

data_map = Map(data, header)

# Plot the data using the SunPy Map object
plotting function

data_map.plot(norm='log')
```



```
# Construct an NDCube object out of this data

data_ndcube = NDCube(data, wcs=data_wcs,
meta=header)

data_ndcube
```

```
<ndcube.ndcube.NDCube object at 0x17f9c31d0>
NDCube
------
Dimensions: [2.000e+00 4.096e+03 4.096e+03]
  pix
Physical Types of Axes:
  [('phys.polarization.stokes',),
  ('custom:pos.helioprojective.lon',
  'custom:pos.helioprojective.lat'),
  ('custom:pos.helioprojective.lon',
  'custom:pos.helioprojective.lat')]
Unit: None
Data Type: float32
```

```
# Plot the data using matplotlib manually

plt.figure(figsize=(9.5, 7.5))
ax = plt.subplot(111, projection=data_wcs[0,:,:])

plt.imshow(data[0,:,:], cmap='Greys_r',
norm=LogNorm(vmin=1.77e-15, vmax=3.7e-11))

lon, lat = ax.coords
lat.set_ticks(np.arange(-90, 90, 15) * u.degree)
lon.set_ticks(np.arange(-180, 180, 15) * u.degree)
lat.set_major_formatter('dd')
lon.set_major_formatter('dd')
ax.set_facecolor('black')
ax.coords.grid(color='white', alpha=.25,
ls='dotted')

plt.xlabel("Helioprojective longitude")
plt.ylabel("Helioprojective latitude")
plt.title('Synthetic PUNCH Total Brightness')
plt.colorbar(label='Mean Solar Brightness')
```



Notebook / sample data

https://github.com/punch-mission/punch-5-meeting