sunpy

The community-developed,
free and open-source solar data analysis
environment for Python.

Laura A. Hayes[1]
on behalf of **The SunPy Community**

22 April 2020 PyAstro

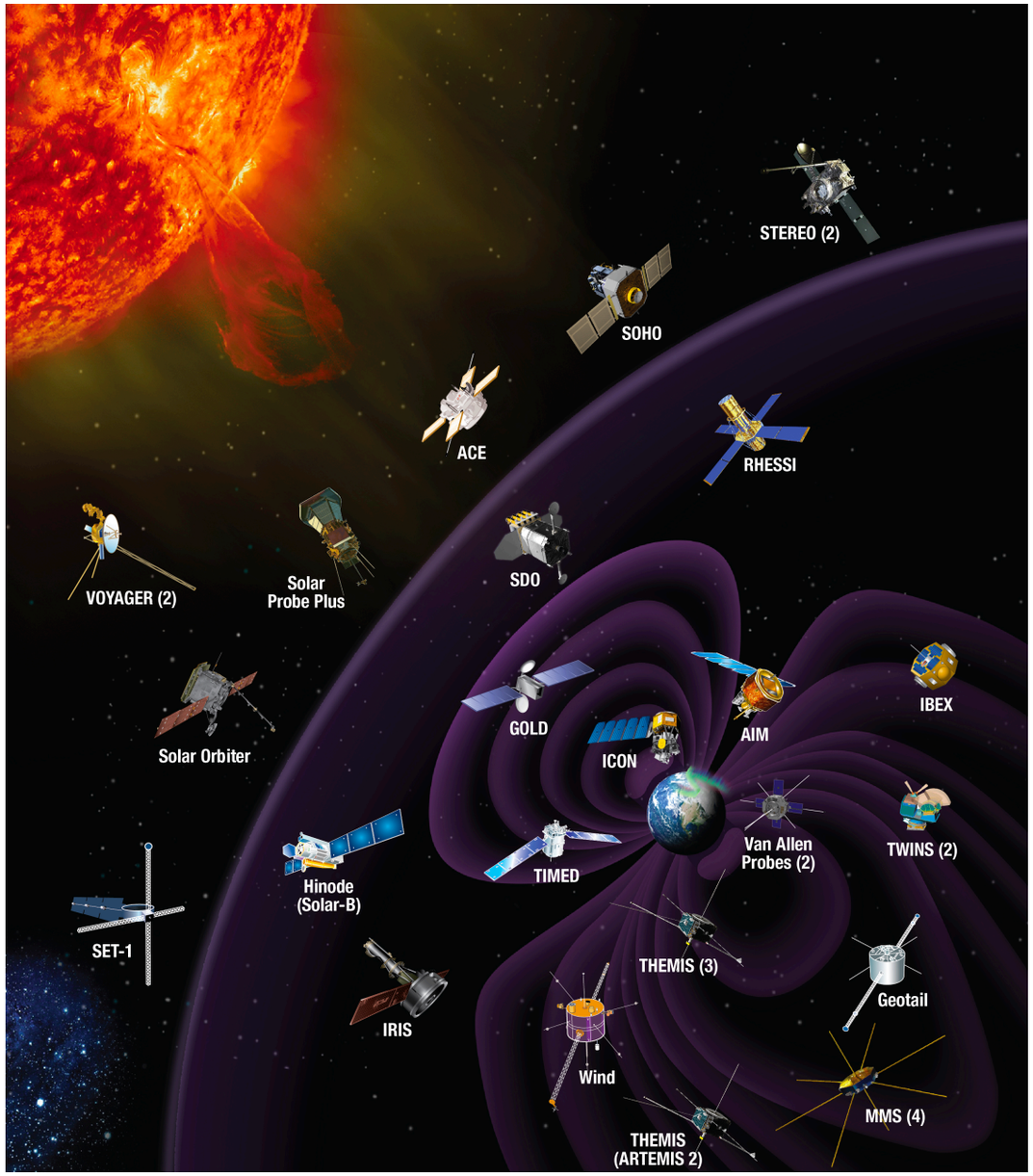
sunpy.org
https://github.com/sunpy/sunpy

[1]*NASA Goddard Space Flight Center/USRA*

Solar Physics

What do solar physicists do? What do we need in software?

- **Study of the Sun**
  - *solar events (flares, coronal mass ejection), Sun-as-a-star, space weather, 'plasma lab in the sky'*
- **Detailed measurements**
  - From both *space- and ground- based instruments* - lots of data!
  - Images, time-series, spectra
- **What software do we need?**
  - Download data, read in data into standard format, deal with different coordinates systems and transformations
  - Data exploration/visualisation e.t.c



Heliophysics system observatory *credit NASA*

Software in Solar Physics

Whats currently available?

SolarSoftWare (SSW) *Interactive Data Language (IDL)*

- 2+ decades of instrument specific software
- Large amount of software (4 million lines code! 16GB)
- Open sourced, but closed development
- Not version controlled, not coordinated/organized, conflicts

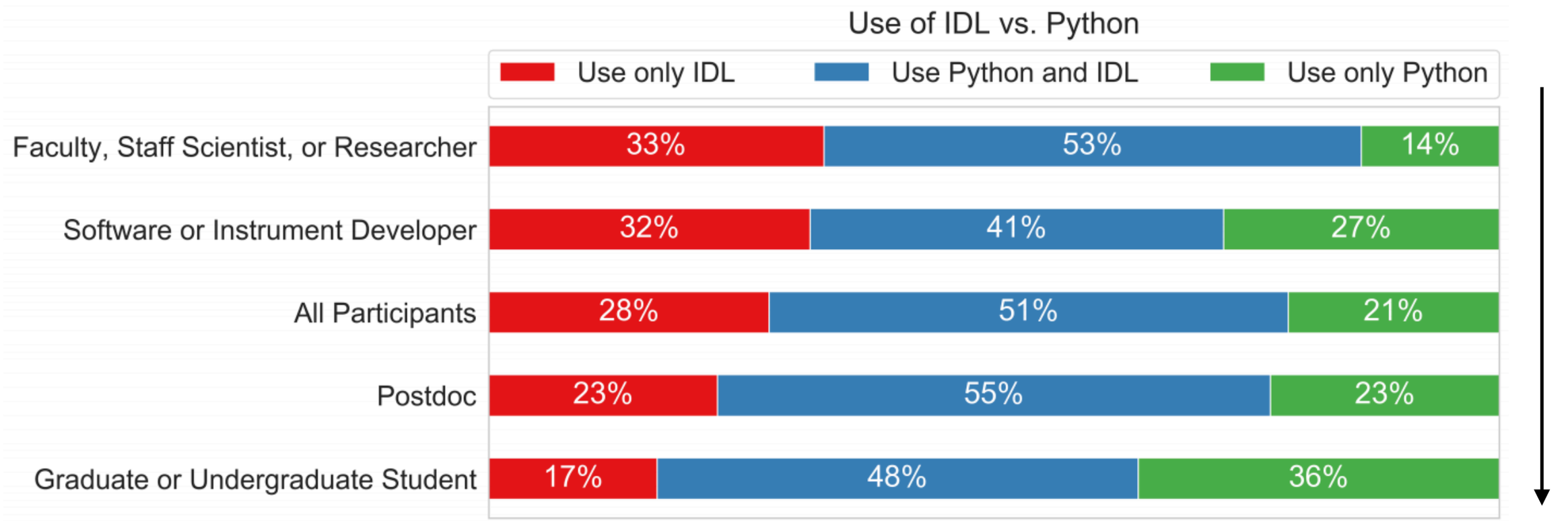
SunPy *Python*

- More to come in this talk ;)

Software in Solar Physics

Community Survey

- 13-question survey to understand the software and hardware usage of the solar physics community (364 people, across 35 countries took part)
- Compared to astrophysics - **IDL is still very common**, especially with faculty, staff researchers etc.



Bobra, Monica G., et al. "A Survey of Computational Tools in Solar Physics." arXiv preprint arXiv:2003.14186 (2020).

SunPy

What is SunPy?

NUMFOCUS
OPEN CODE = BETTER SCIENCE

Python in
Heliophysics (PyHC)

The SunPy project facilitates and promotes the use and development of several community-led, free, and open source data analysis software packages for solar physics based on the scientific Python environment.

Functionality

- Provide Python tools specific to solar data analysis
- Focus on calibrated high level data
- Provide standardized gateway for solar data into the scientific python environment
- Support other solar packages outside the scope of SunPy core

Cultural

- Open-source community and inclusive of everyone (anyone can contribute!)
- Coordinate development
- Code testing and code review
- Version control
- Standardized and discoverable documentation

SunPy

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The SunPy project facilitates and promotes the use and development of several community-led, free, and open source data analysis software packages for solar physics based on the scientific Python environment.

Functionality

- Provide Python tools specific to solar data analysis - gateway into ecosystem
- Focus on calibrated high level data
- Leverage mature and maintained code from other field (e.g. `astropy`)
- Support other solar packages (affiliated) outside the scope of SunPy core

Cultural

- Open-source community and inclusive of everyone (anyone can contribute!)
- Coordinate development
- Code testing and code review
- Version control
- Standardized and discoverable documentation

SunPy Organization

The SunPy Community

SunPy Board

Up-to 10 people, guides overall direction of sunpy project by voting on SunPy Enhancement Proposals (SEPs) - anyone can propose

Lead-Developer

Leads development core team and community developers and affiliated packages

Deputy Lead-Developer

Assists lead developer

Sub-package maintainers

Assist lead devs with maintaining sub-packages

Community Roles

Summer of Code students

Users

Community Developers

https://sunpy.org/project/

Contributing to SunPy

What does this look like?

Anyone can contribute! 🌞

Guidelines in place to ensure new code meets quality standard:

Lots of assistance given to newcomers!

Style Guide

All code and docs must comply with widely used style guides (e.g. Pep8)

Docs

New features require documentation - code comments, docstrings and guide, examples

Unit tests

All code must provide unit tests that cover functionality

Within Scope

All code must be within scope and approved by at least 2 members of dev community

Automated testing on GitHub (incl. different op systems, building docs, plots, code-coverage etc). Use of Azure, CircleCI, Codecov and Travis CI

Where is SunPy now?

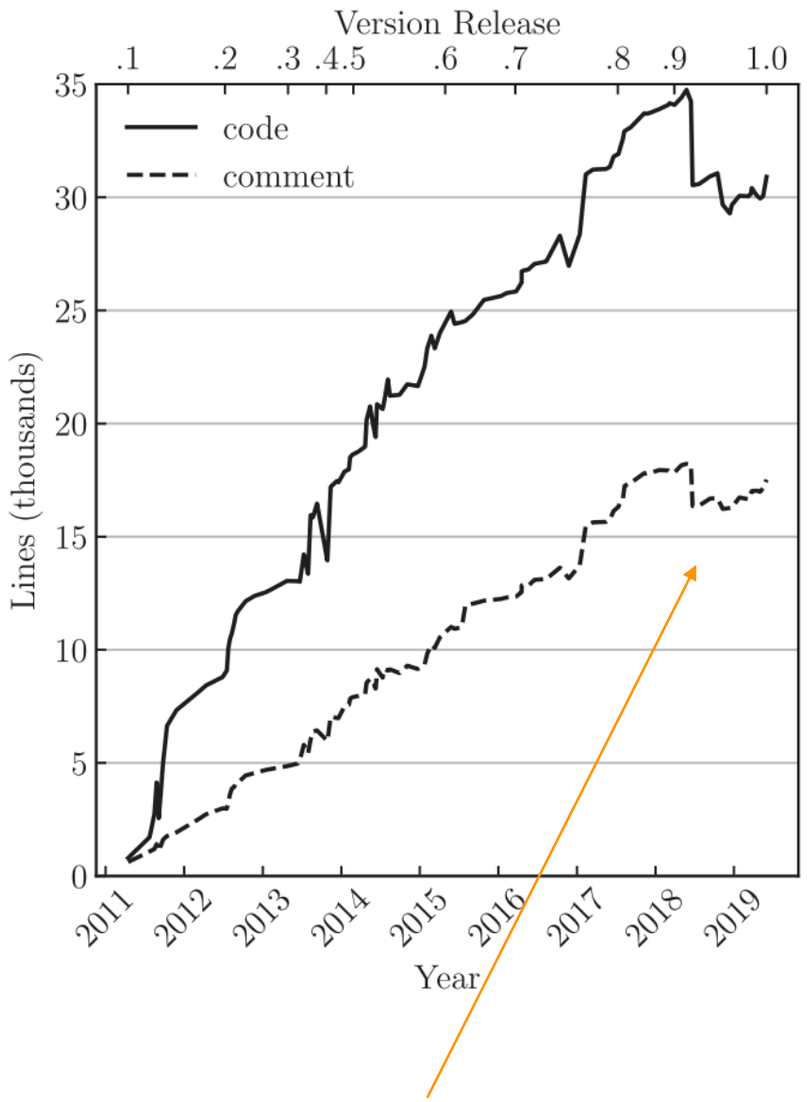
Current Status

- Project officially founded in March 2014, began in March 2011 (9 years ago!)
- **Released SunPy 1.1** (1.0 first stable release 🎉 🥳)
- Now release schedule - twice a year

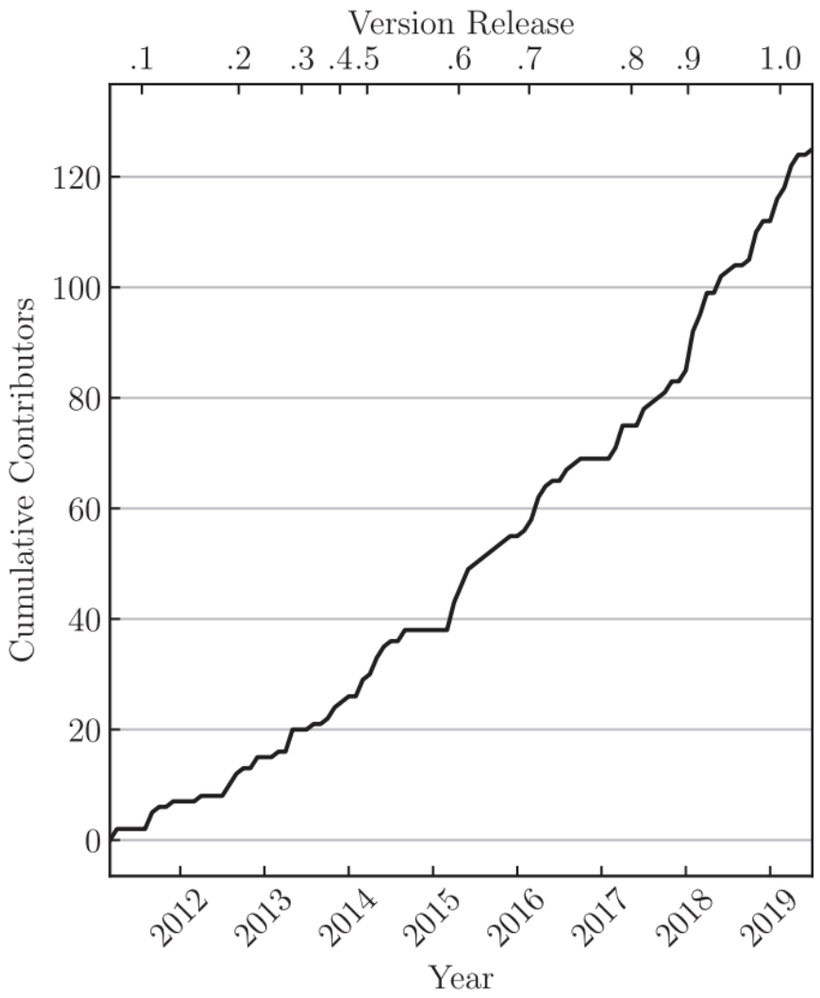
- ~50,000 lines of code (incl. comments & docs), 134 unique contributors
- Published paper and code:
  - *The SunPy Community, et al. "The sunpy project: Open source development and status of the version 1.0 core package." The Astrophysical Journal 890.1 (2020): 68.*
  - *Mumford, Stuart, et al. "SunPy: A Python package for Solar Physics." Journal of Open Source Software 5.46 (2020).*

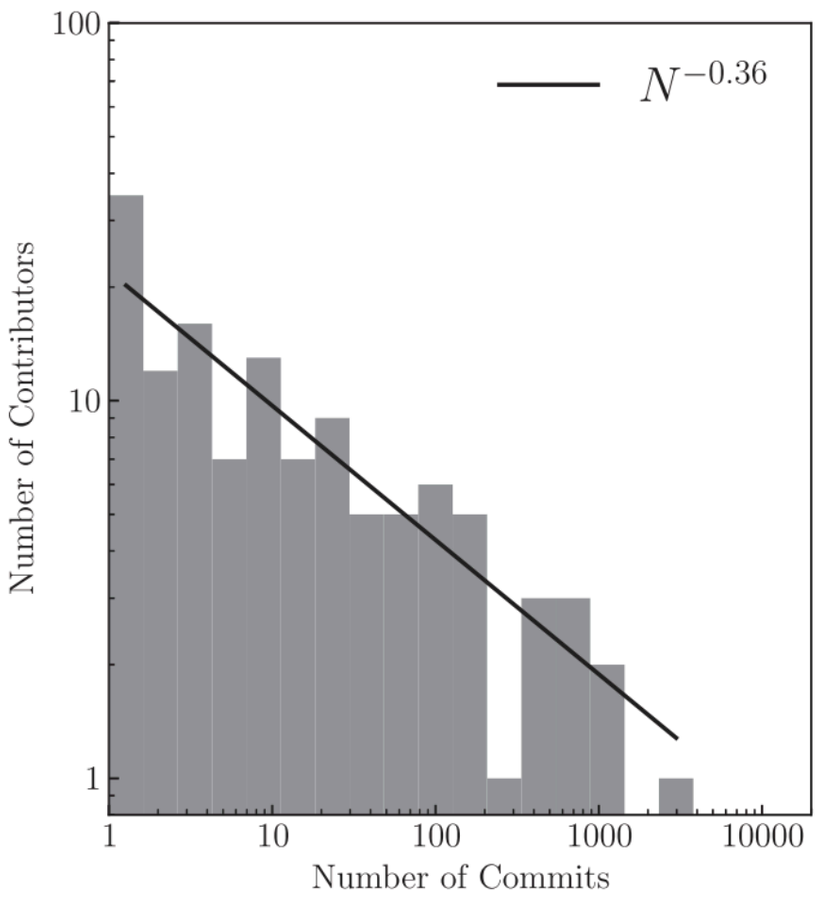
Where is SunPy now?

Current Status



Major tidy up for 1.0





Slope quite steep
hope to flatten this

SunPy 1.0 +

Overview and Highlights

- **Headline core changes**:
  - Major clean up of core
  - Improved download capabilities (`parfive`)
  - Improved Coordinates functionality - Sun-specific transformation stack and coordinate frames
  - Full adoption of astropy time
  - Logging system

Data Retriever

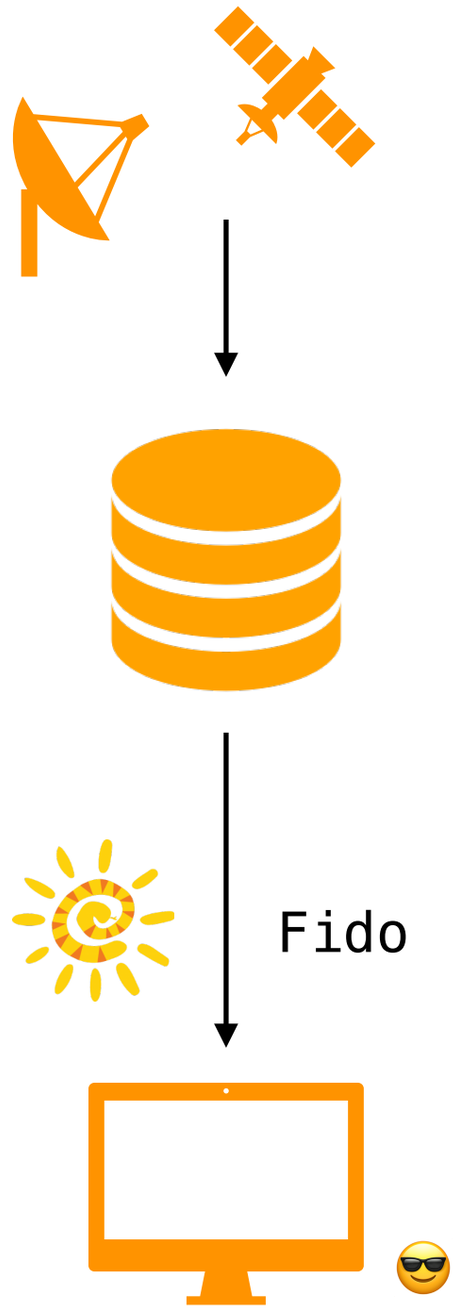
sunpy.net and `Fido`

- `Fido` Unified API for searching and downloading solar data from various search engines and data sources (e.g. VSO, JSOC, https, ftp)

```
In [5]: from sunpy.net import Fido, attrs as a

In [6]: result = Fido.search(a.Time('2012/3/4', '2012/3/6'), a.Instrument('XRS'))

In [7]: result

Out[7]: Results from 1 Provider:

3 Results from the XRSClient:
Table length=3
```

Start Time	End Time	Source	Instrument	Wavelength
str19	str19	str4	str4	str3
2012-03-04 00:00:00	2012-03-04 23:59:59	nasa	goes	nan
2012-03-05 00:00:00	2012-03-05 23:59:59	nasa	goes	nan
2012-03-06 00:00:00	2012-03-06 23:59:59	nasa	goes	nan

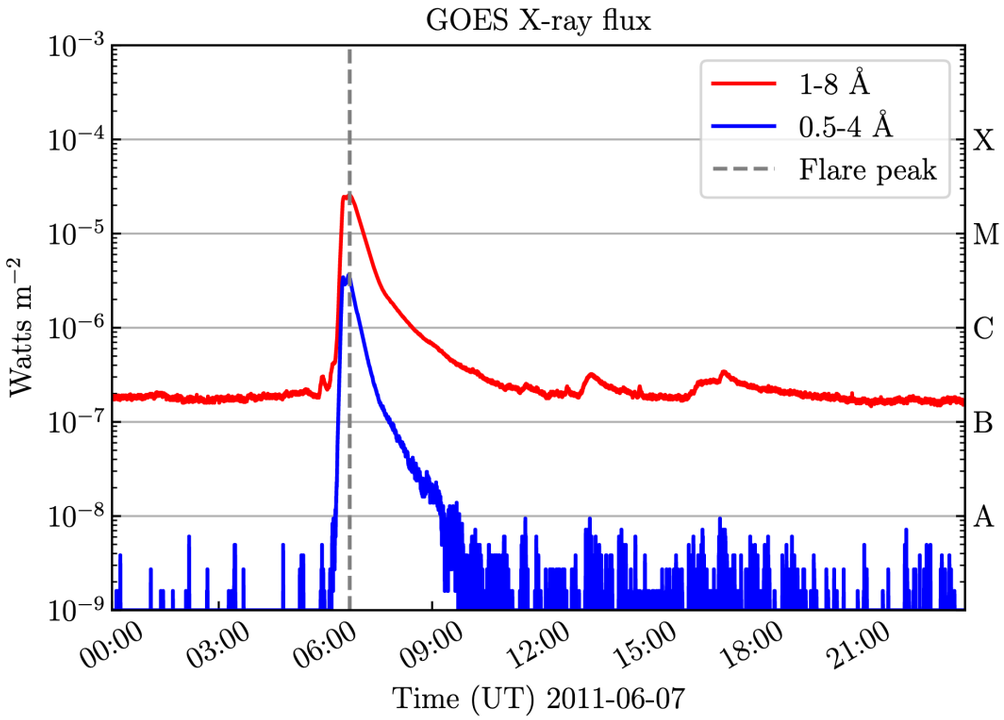
```
In [*]: Fido.fetch(result, path='./{file}')

Files Downloaded: 33%  1/3 [00:00<00:00, 2.90file/s]
```



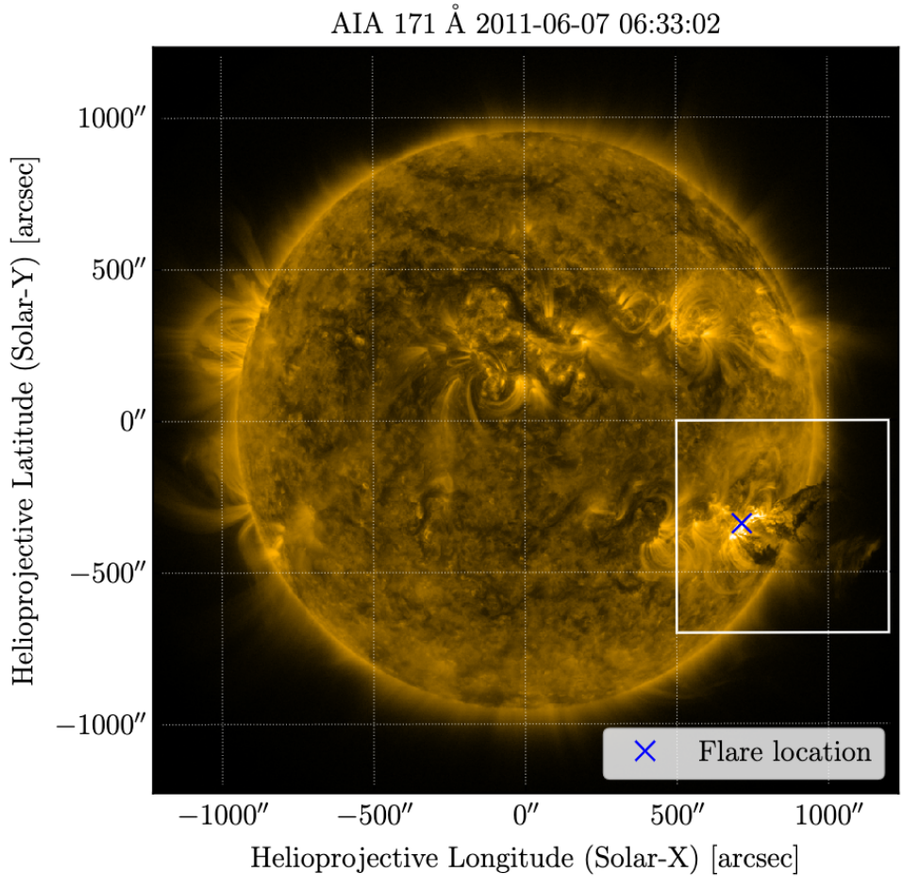
Data Containers

`TimeSeries` and `Map`

- SunPy provides general, **standard and consistent interface** for loading and representing solar data across different instruments and missions.



`TimeSeries`: 1D temporal data



`Map`: 2D image data

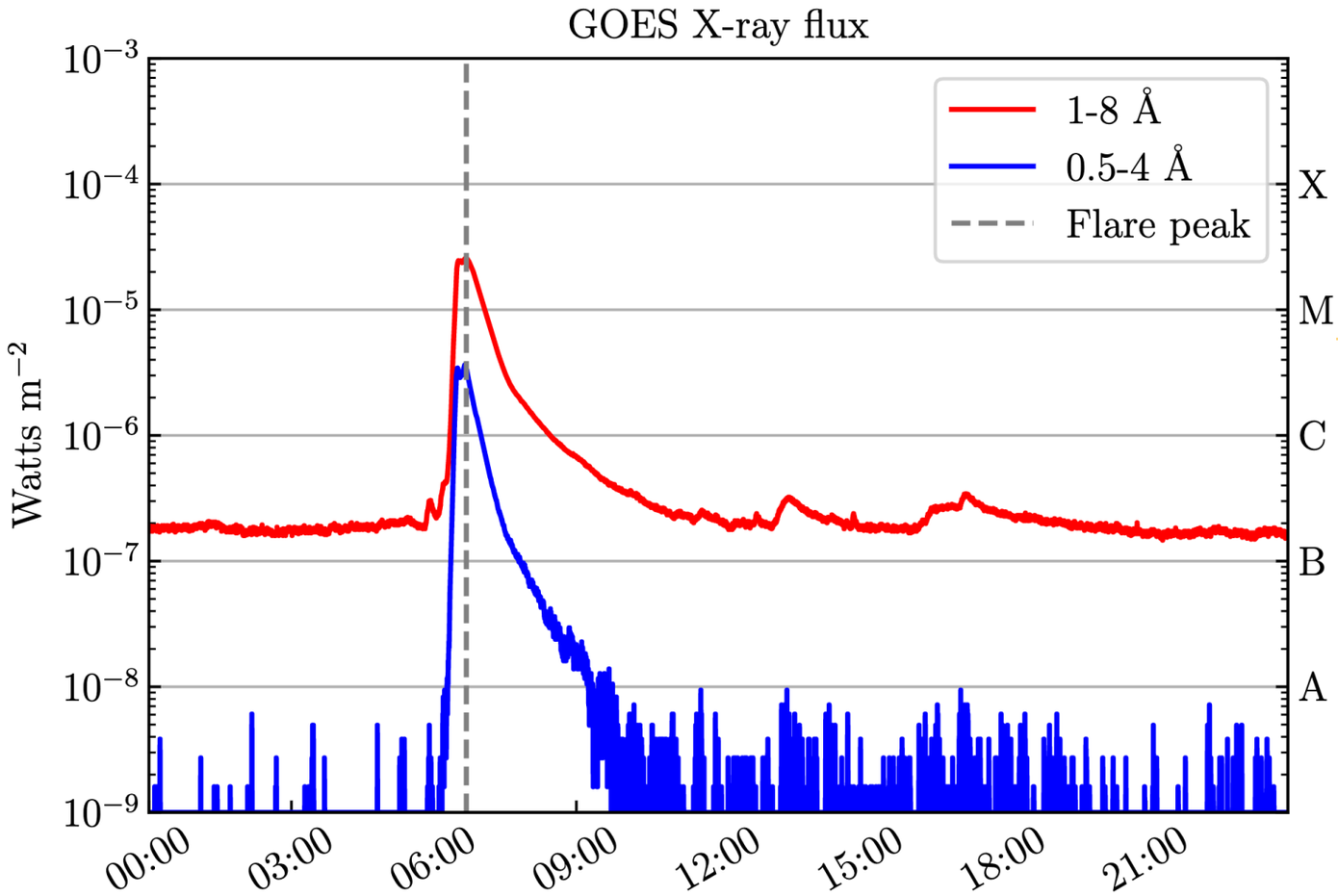
TimeSeries

Data Containers

- MetaData container to hold information from different files, instruments e.t.c

- Identify metadata that corresponds to given times and columns

- Truncate, concatenate, resampling, plot

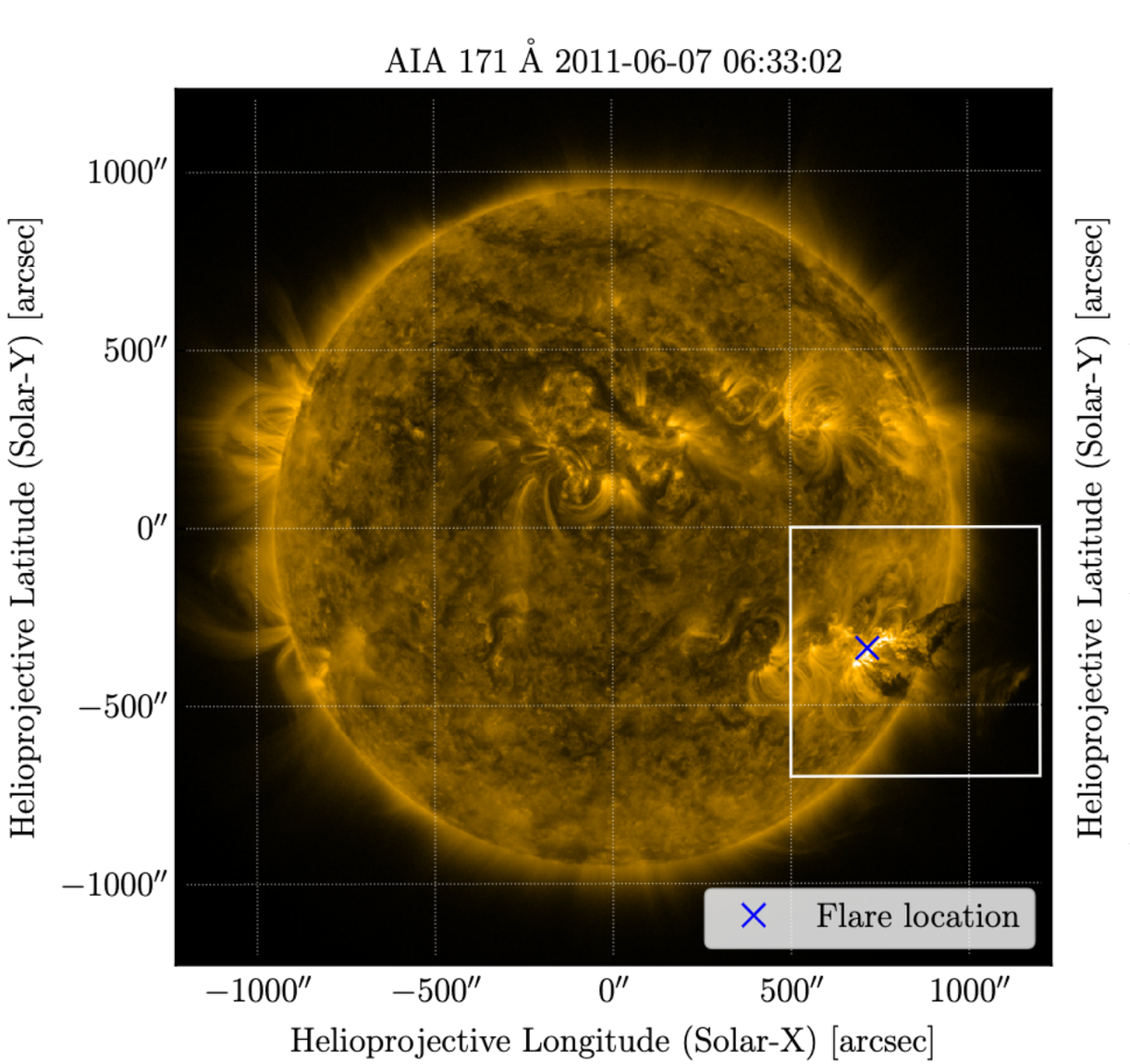


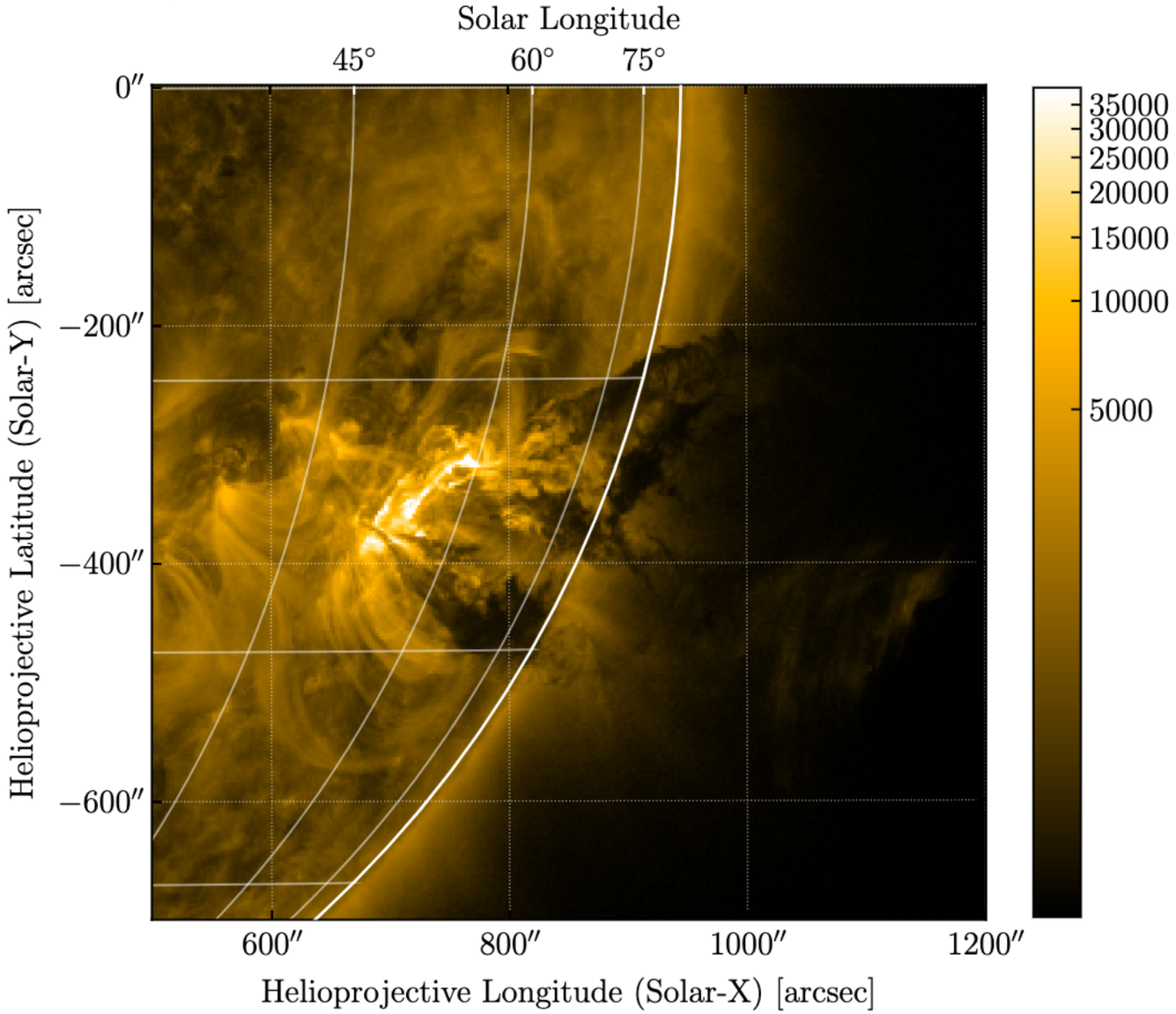

```
In [2]: from sunpy import timeseries as ts

In [3]: goes_ts = ts.TimeSeries('go1520120304.fits')

In [4]: goes_ts.units

Out[4]: OrderedDict([('xrsa', Unit("W / m2")), ('xrsb', Unit("W / m2"))])

In [5]: goes_ts.meta

Out[5]:
|-----------------------------------------------------------------------------------------------------|
| TimeRange                    | Columns          | Meta                                          |
|-----------------------------------------------------------------------------------------------------|
| 2012-03-03 23:59:58.438999   | xrsa             | simple: True                                  |
|              to              | xrsb             | bitpix: 8                                     |
| 2012-03-04 23:59:56.301999   |                  | naxis: 0                                      |
|                              |                  | extend: True                                  |
|                              |                  | date: 26/06/2012                              |
|                              |                  | numext: 3                                     |
|                              |                  | telescop: GOES 15                             |
|                              |                  | instrume: X-ray Detector                      |
|                              |                  | object: Sun                                   |
|                              |                  | origin: SDAC/GSFC                             |
|                              |                  | ...                                           |
|-----------------------------------------------------------------------------------------------------|
```

Map

Data Containers

- Standardized interface to coordinate aware 2-D images
- Uses WCSAxes for plotting functionality

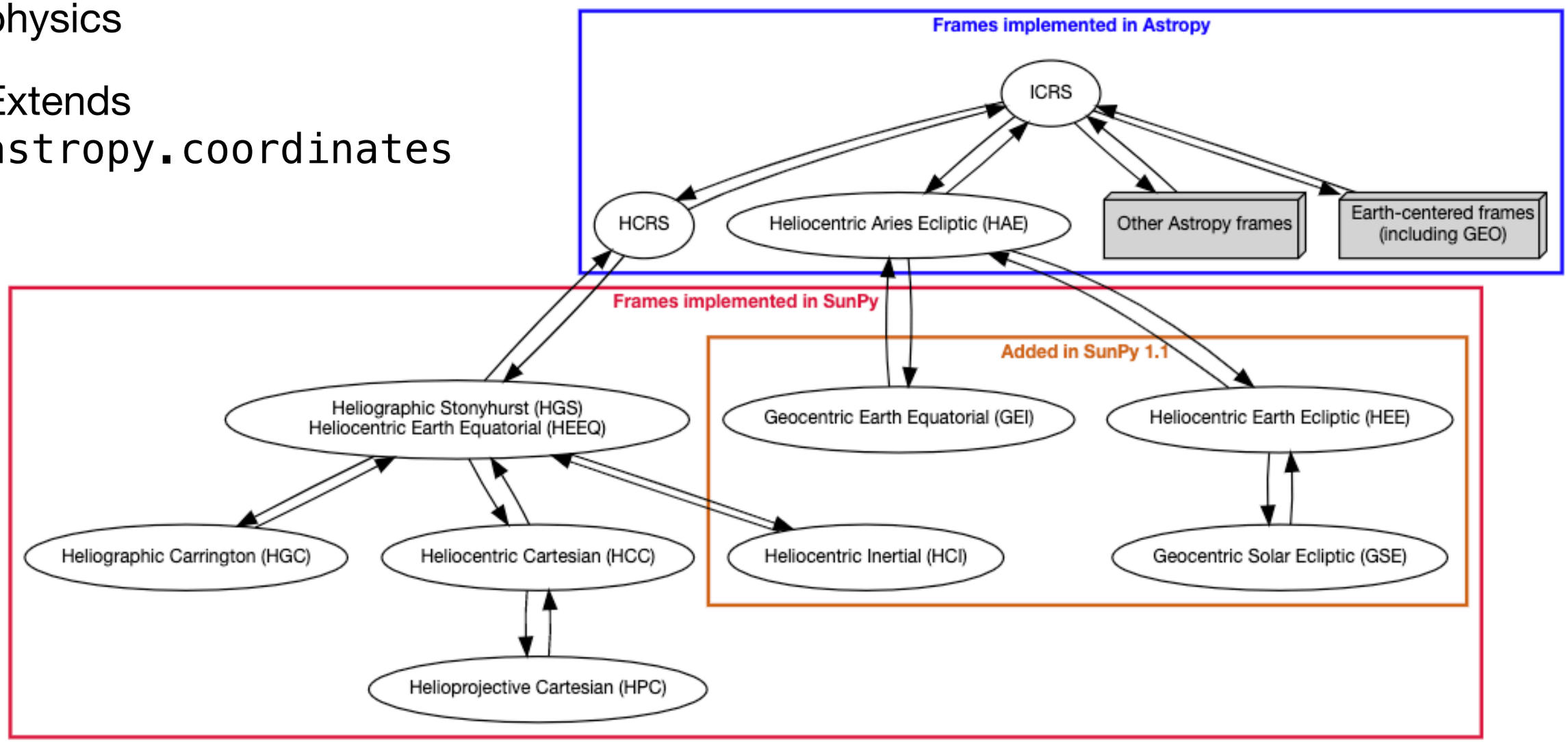




Coordinates

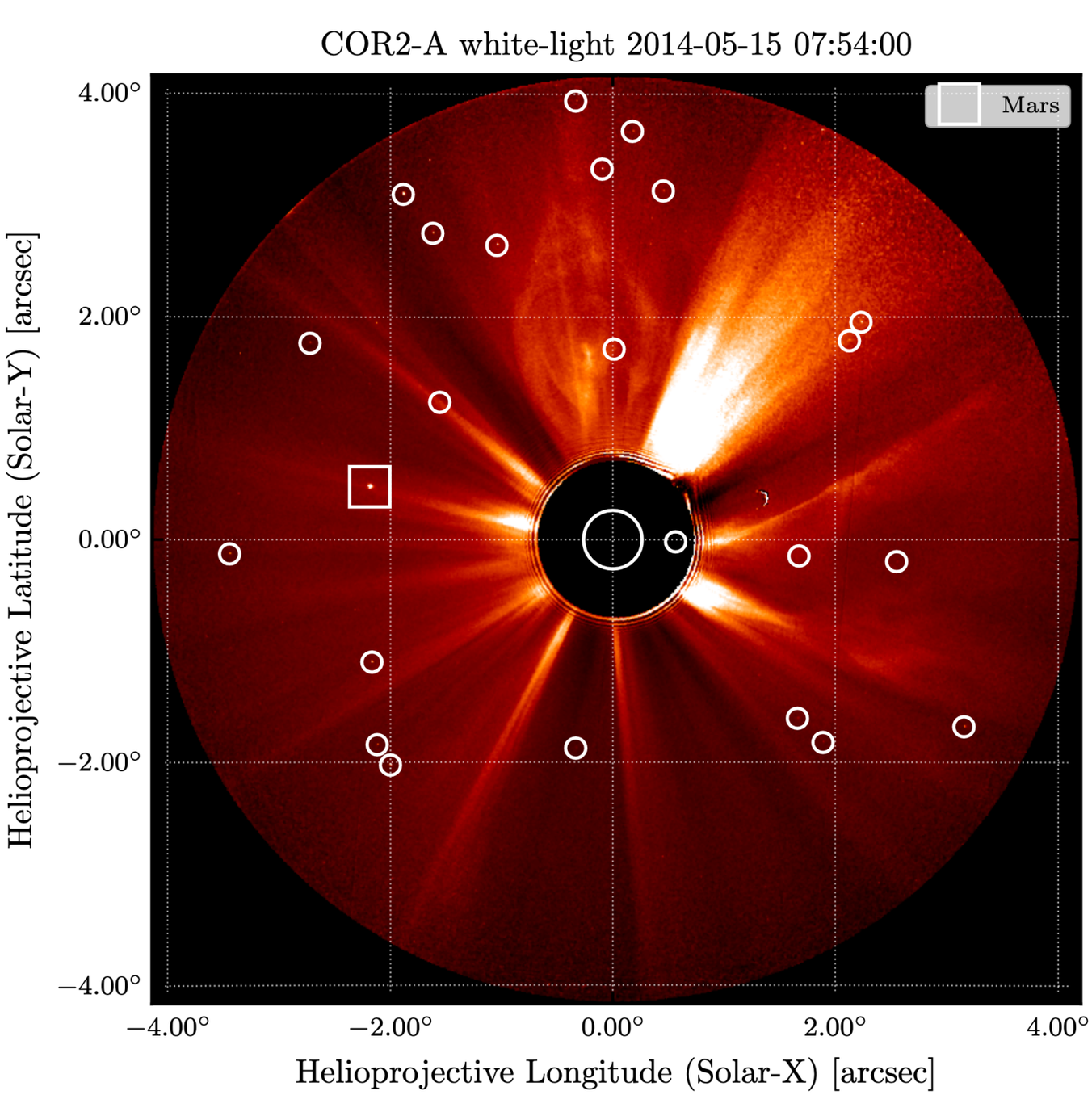
Solar Coordinates

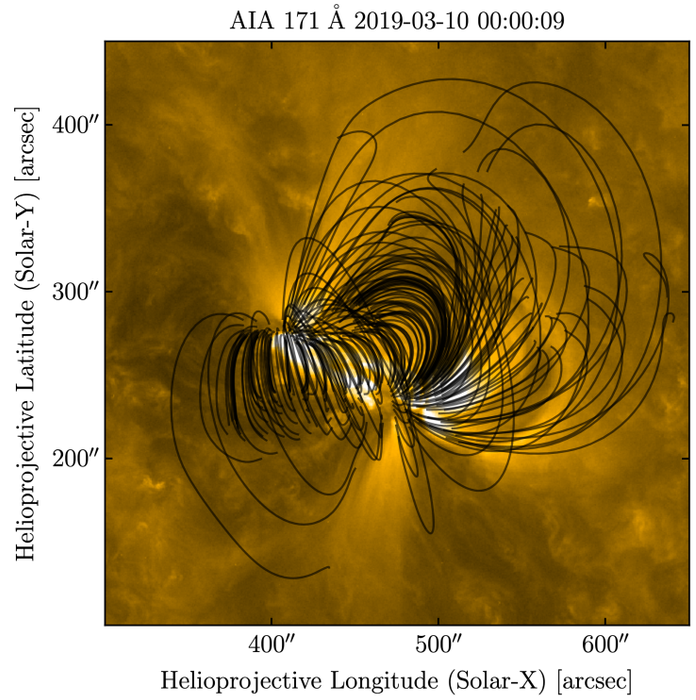
- `sunpy.coordinates` for representing and **transforming** coordinates used in solar physics
- Extends `astropy.coordinates`

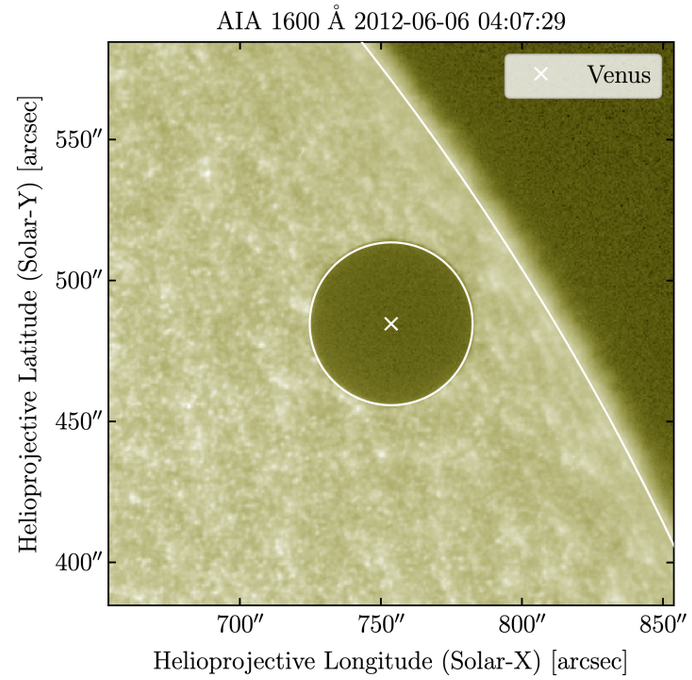


Coordinates

Some Examples

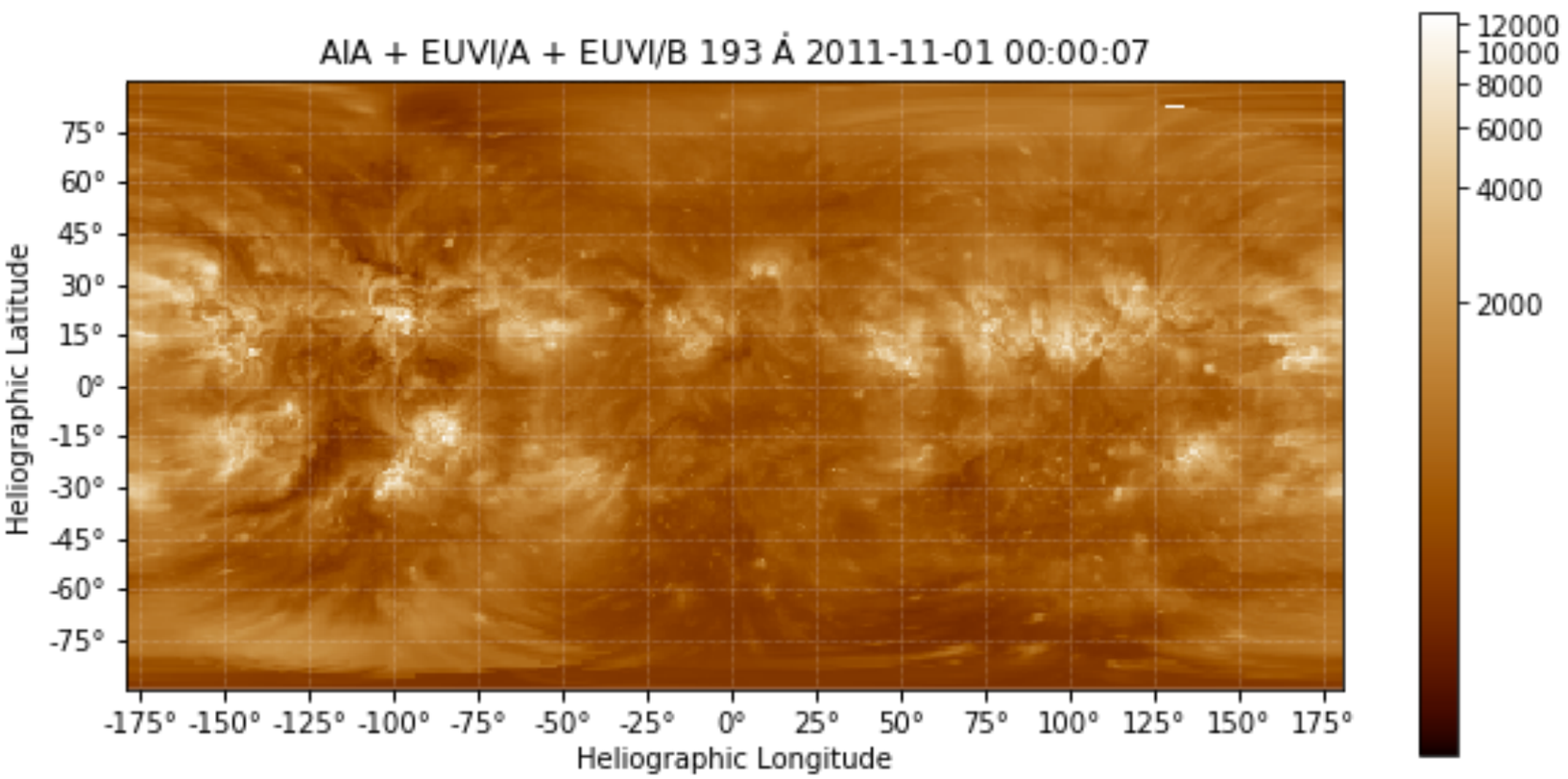






Coordinates

Full map of Sun using different spacecraft



Creation of full Sun map from SDO/AIA and STEREO A & B

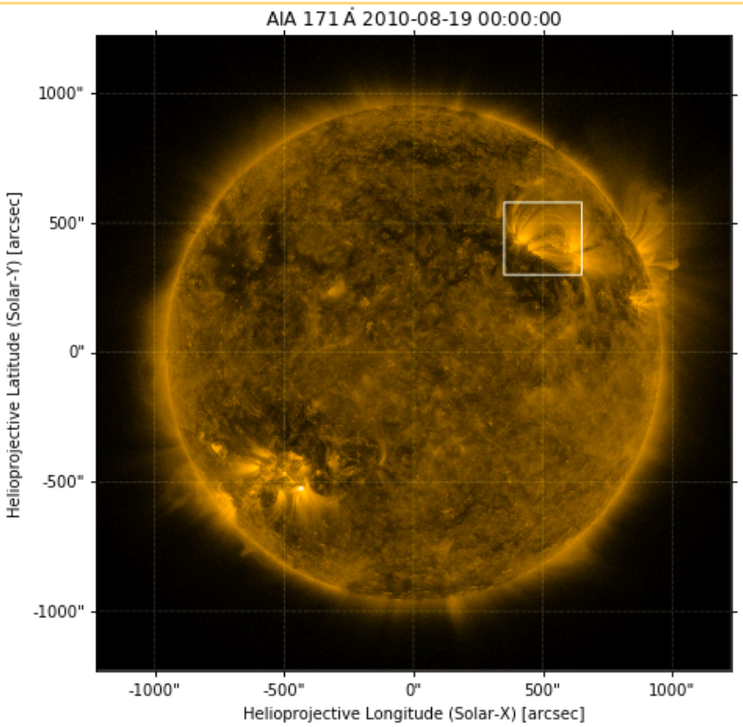
Check this out in our example gallery!
https://docs.sunpy.org/en/stable/

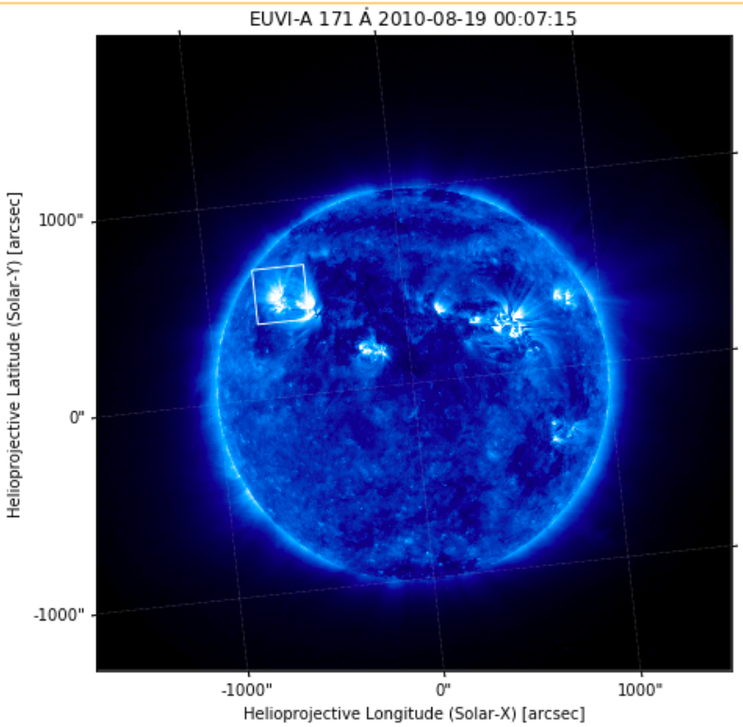
using `reproject` package

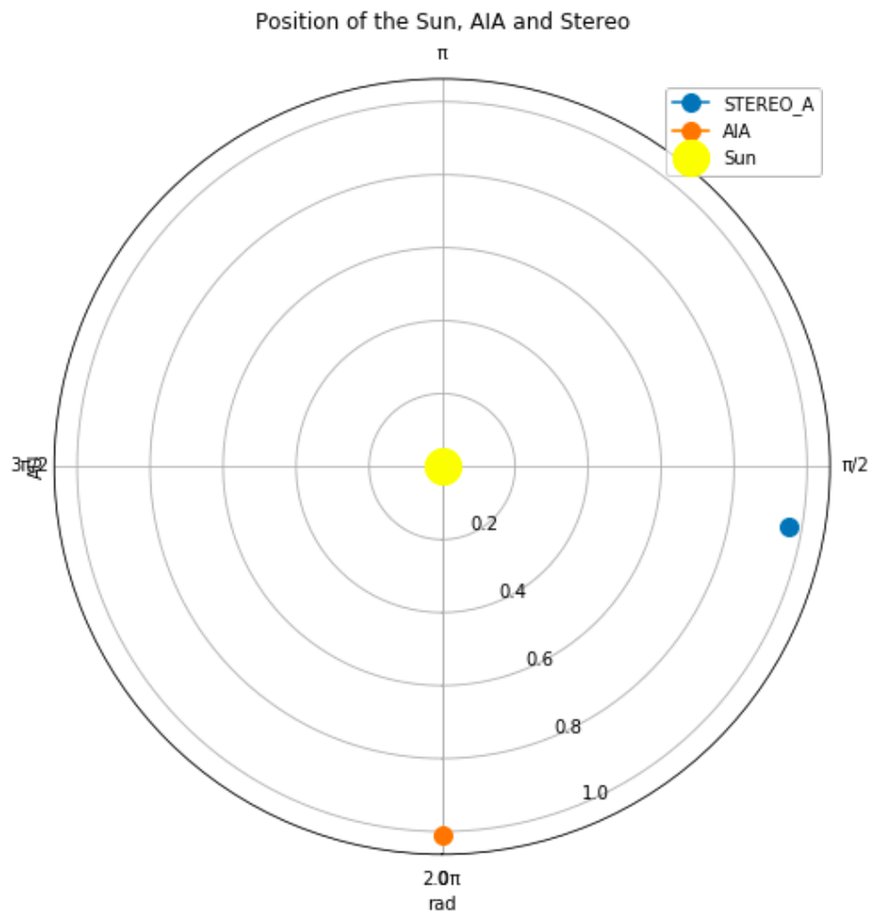
Positions of satellites

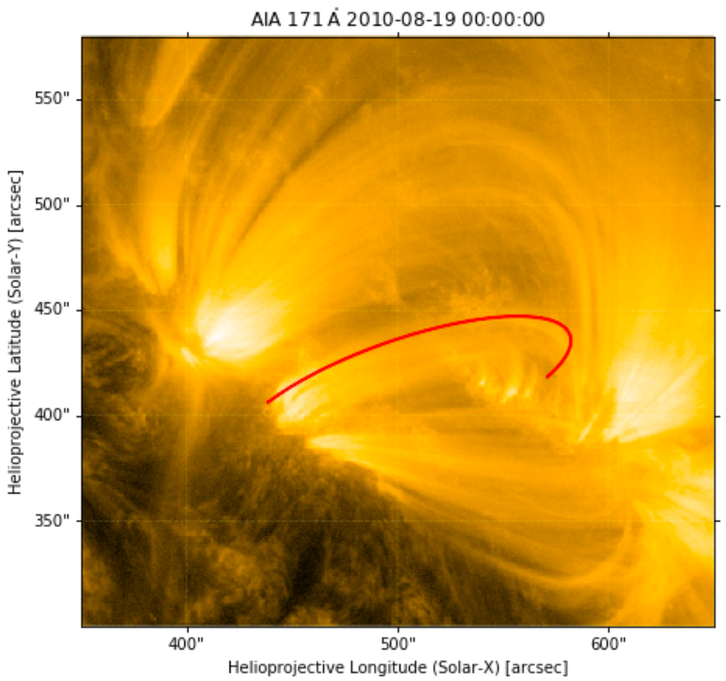
Coordinates

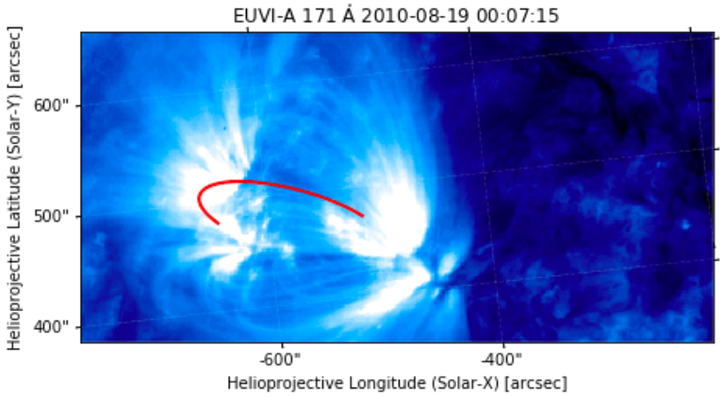
Finding regions of interest









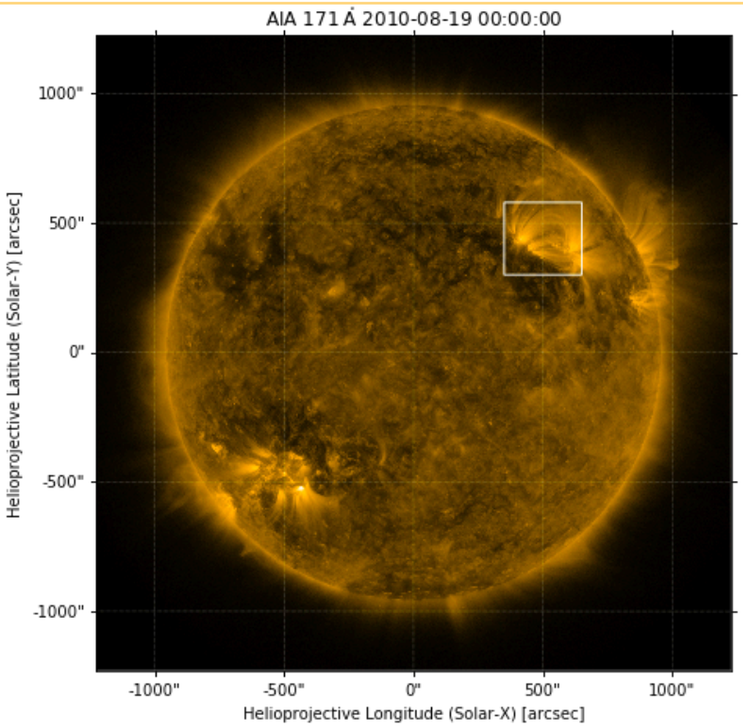


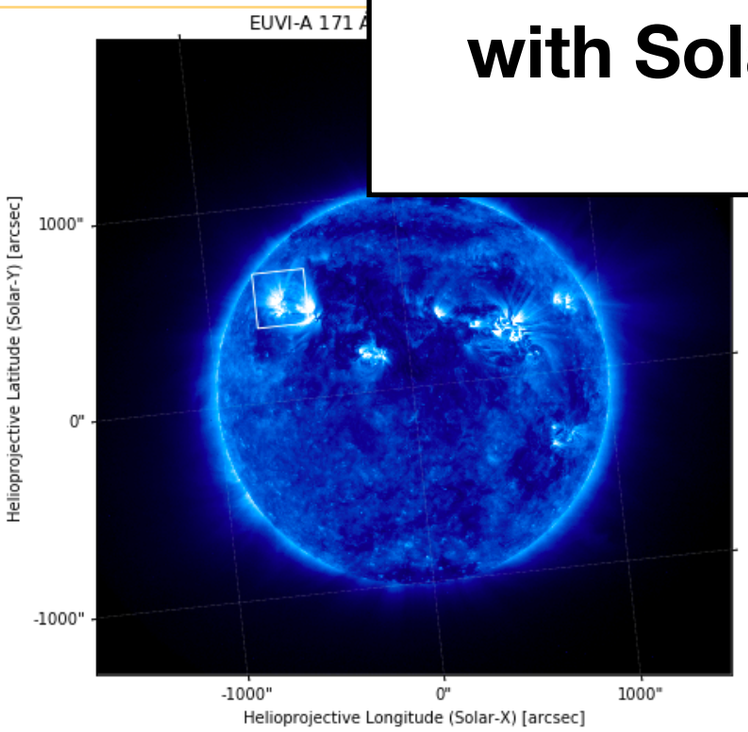
Positions of satellites

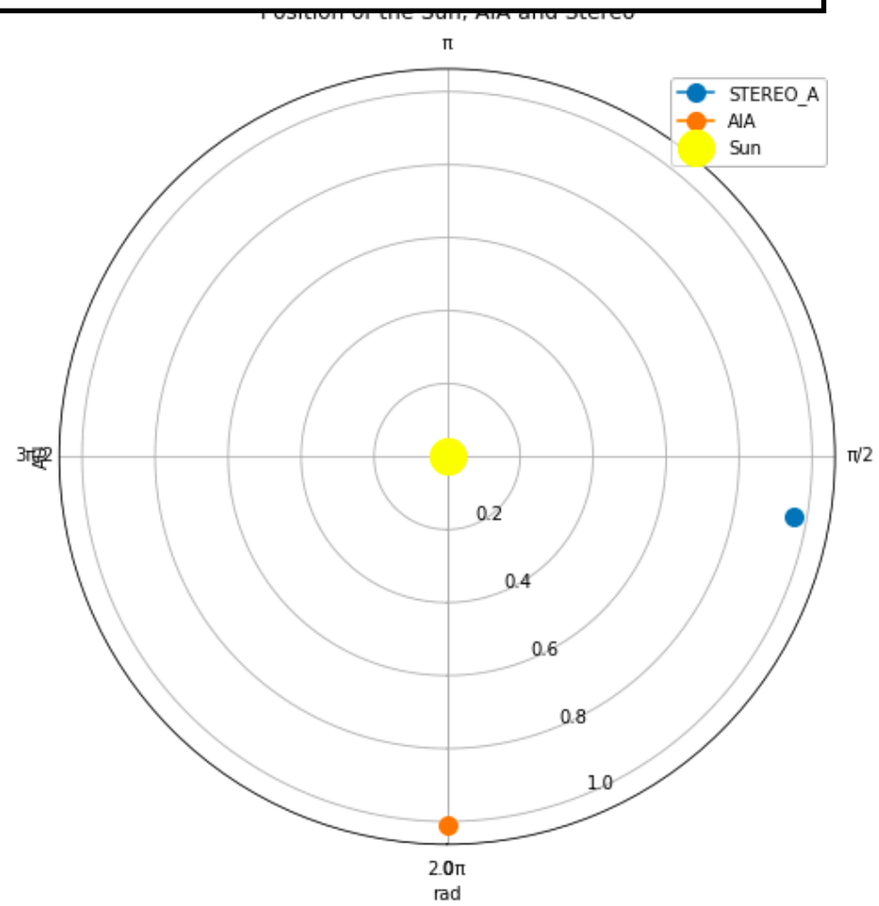
Coordinates

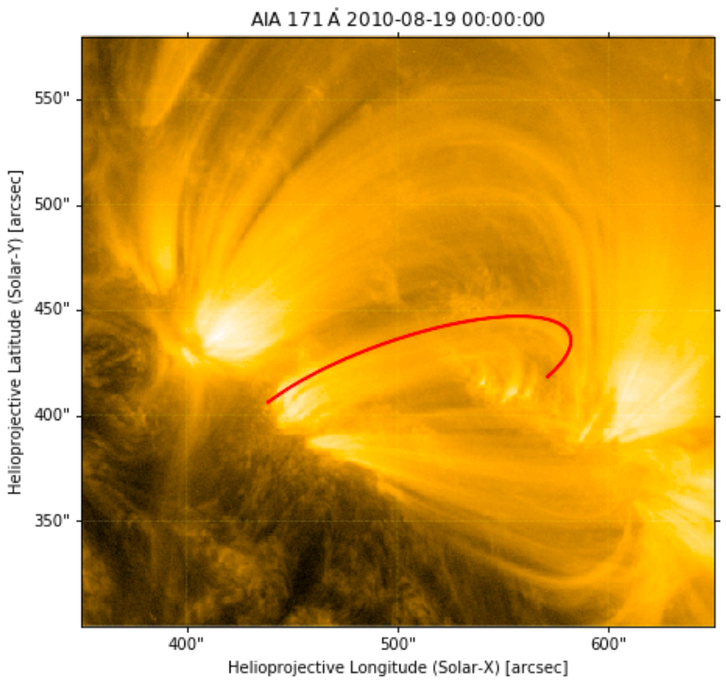
Finding regions of interest

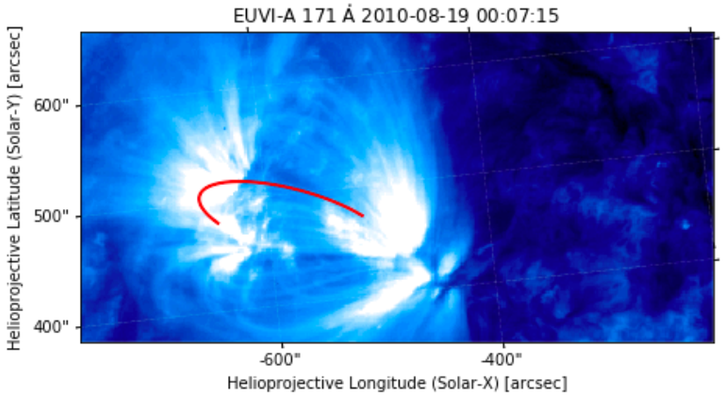
Really important to have this functionality for new observations with Solar Orbiter and Parker Solar Probe!









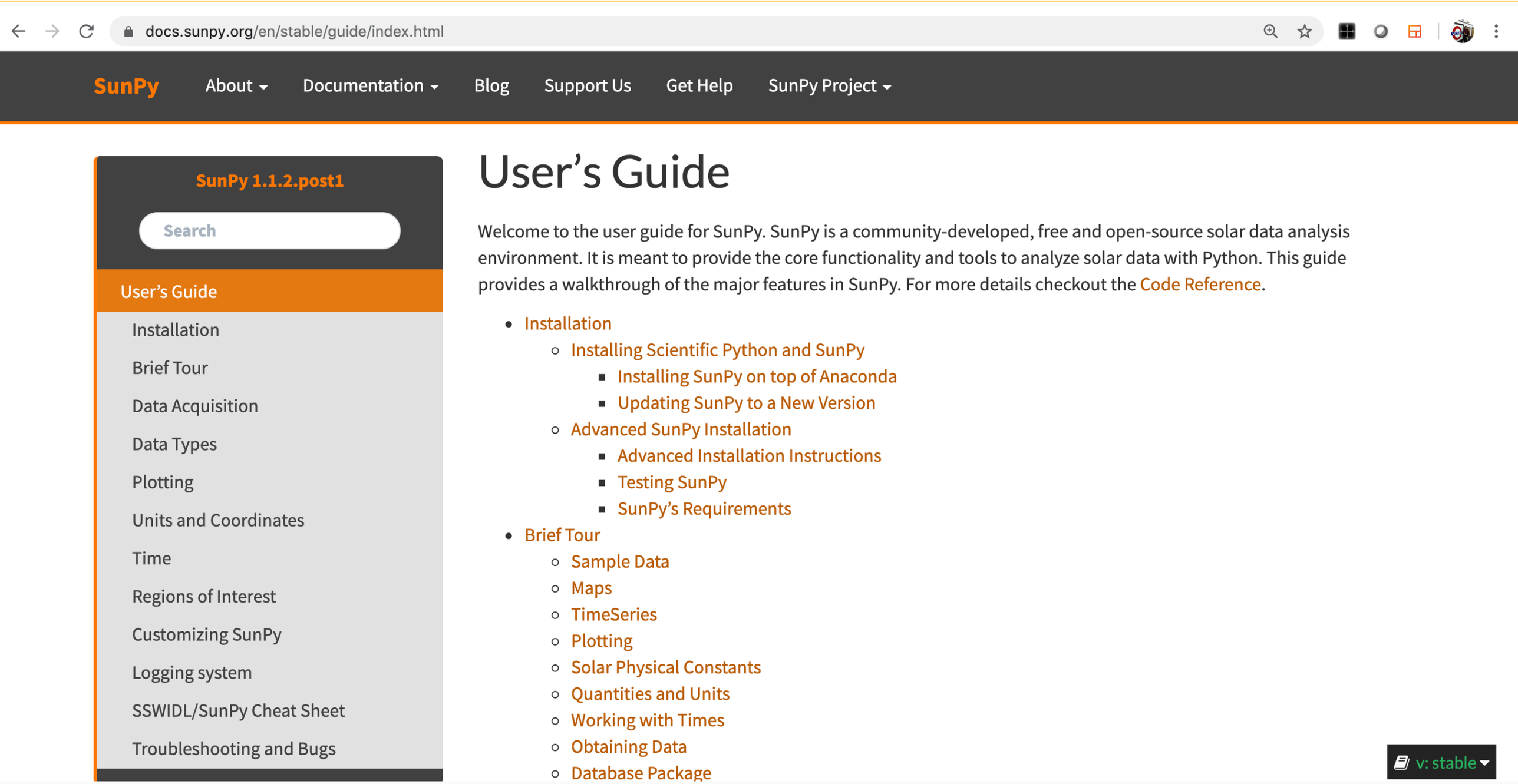


Positions of satellites

Documentation

User Docs

https://docs.sunpy.org/en/stable/



Documentation

Example Gallery

https://docs.sunpy.org/en/stable/

docs.sunpy.org/en/stable/generated/gallery/index.html

Map

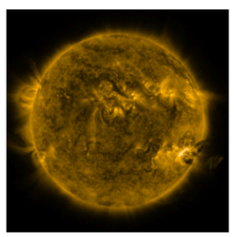
This section contains any examples which showcase how SunPy's **Map** can be used to with solar data.

Rotating a Map

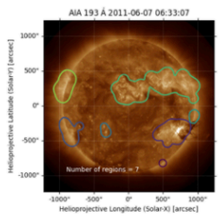
Resampling Maps

Finding the brightest pixel

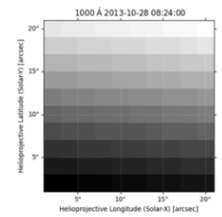
Cropping a Map



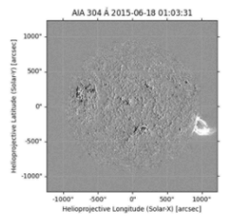
Plotting a Map without any Axes



Finding bright regions with ndimage



Generating a map from data array



Plotting a difference image

v: stable

Documentation

Example Gallery

https://docs.sunpy.org/en/stable/

docs.sunpy.org/en/stable/generated/gallery/index.html

Go and try it out!

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SunPy 1.1.2.post1

Search

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    - Downloading and plotting an HMI magnetogram
    - Sample data set overview
  - Map
    - Rotating a Map
    - Resampling Maps
    - Finding the brightest pixel

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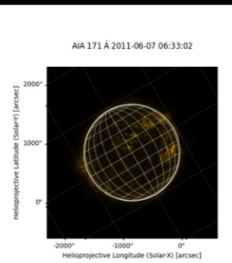
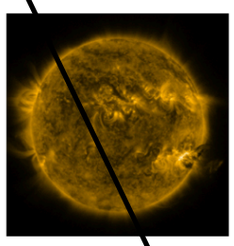
Github

Map

This section contains any exa



Rotating a Map



Plotting a Map without any Axes

Click here to download the full example code

Rotating a Map

How to rotate a map.

```
import astropy.units as u

import matplotlib.pyplot as plt

import sunpy.map
import sunpy.data.sample
```

We start with the sample data

```
aia_map = sunpy.map.Map(sunpy.data.sample.AIA_171_IMAGE)
```

`GenericMap` provides the `rotate` method which accepts an angle. This returns a rotated map and does not rotate in place. The data array size is expanded so that none of the original data is lost due to clipping. Note that subsequent rotations are not compounded. The map is only rotated by the specified amount from the original maps orientation.

```
aia_rotated = aia_map.rotate(angle=30 * u.deg)
```

Affiliated Packages

SunPy affiliated packages

Package Name	Description	Documentation	Maintainer
ndcube	A base package for multi-dimensional (non)contiguous coor-dinate-aware arrays	ndcube docs	Daniel Ryan
drms	Access HMI, AIA and MDI data with Python	drms docs	Kolja Glogowski
radiospectra	This package aims to provide support for some type of radiospec-tra on solar physics	radiospectra docs	David Pérez-Suárez
IRISPy	A package for handling data from the IRIS satellite	IRISPy docs	Daniel Ryan

sunraster *

Generalized to slit-spectrograph instruments

Affiliated Packages

SunPy affiliated packages

Check up hack-day discussion lead by Monica Bobra about review process for affiliated packages!

Package Name	Description		
ndcube	A base package for multi-dimensional (non)contiguous coor-dinate-aware arrays	ndcube docs	Daniel Ryan
drms	Access HMI, AIA and MDI data with Python	drms docs	Kolja Glogowski
radiospectra	This package aims to provide support for some type of radiospec-tra on solar physics	radiospectra docs	David Pérez-Suárez
IRISPy	A package for handling data from the IRIS satellite	IRISPy docs	Daniel Ryan

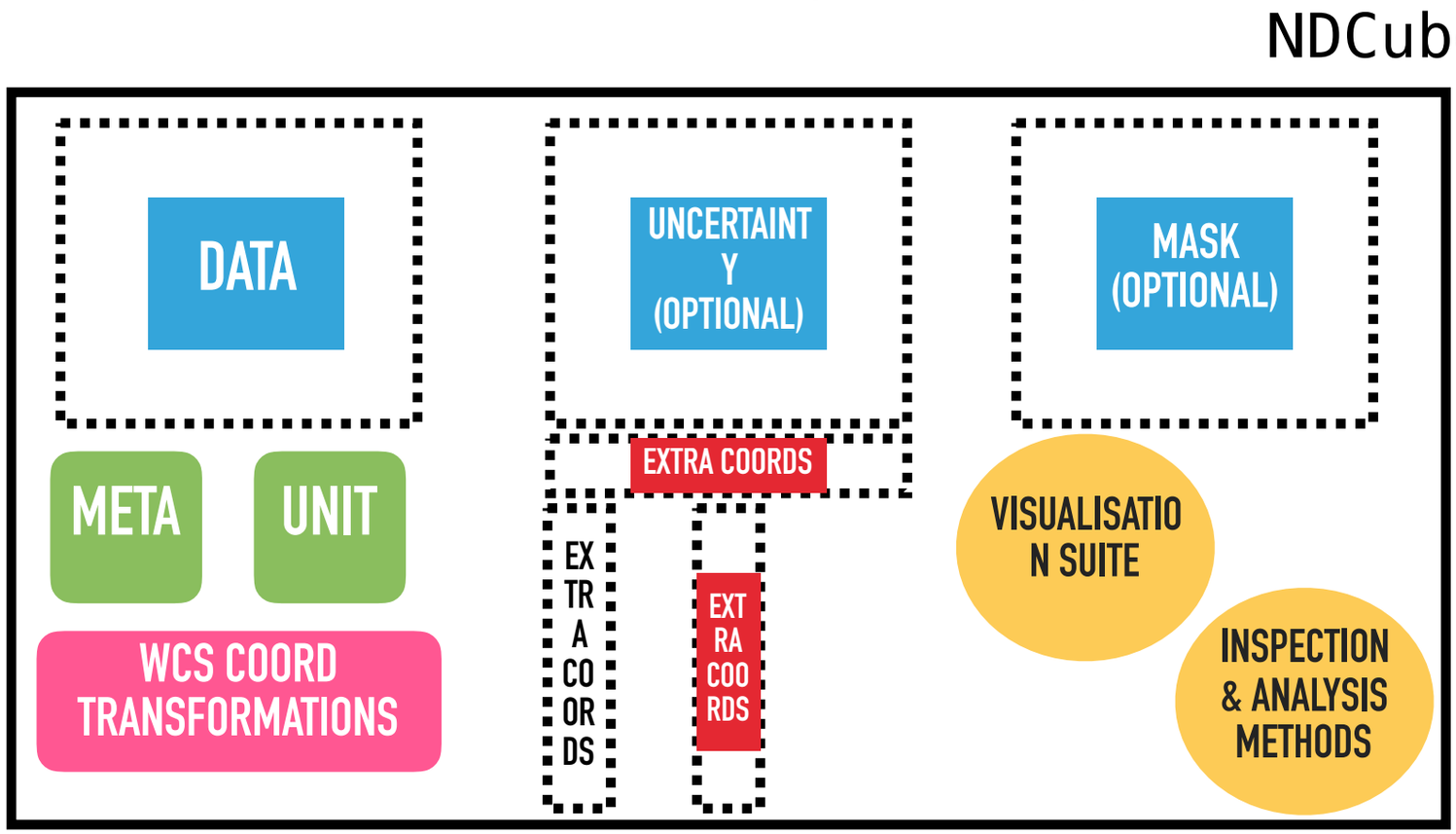
sunraster *

Generalized to slit-spectrograph instruments

NDCube

SunPy affiliated package

- Provides base classes for ND astronomical and solar data
- Unified slicing, coordinate transformation, data mask, unit, uncertainties, visualization
- Planned for base class for Map in SunPy 3.0



Lead developer
Dan Ryan
https://github.com/sunpy/ndcube

Looking ahead

Roadmap and future plans

- Two new releases now planned per year - SunPy 2.0 in May 🌞
- Future development and roadmap plan:
  - `NDCube` for `Map`
  - Improved support for data with spectral axes and multi-dimensional data sets
  - standardized approach to metadata
  - Package template for affiliated packages - incubator for instrument teams?
- Hope to **grow community involvement** - feedback from users, users —> contributors

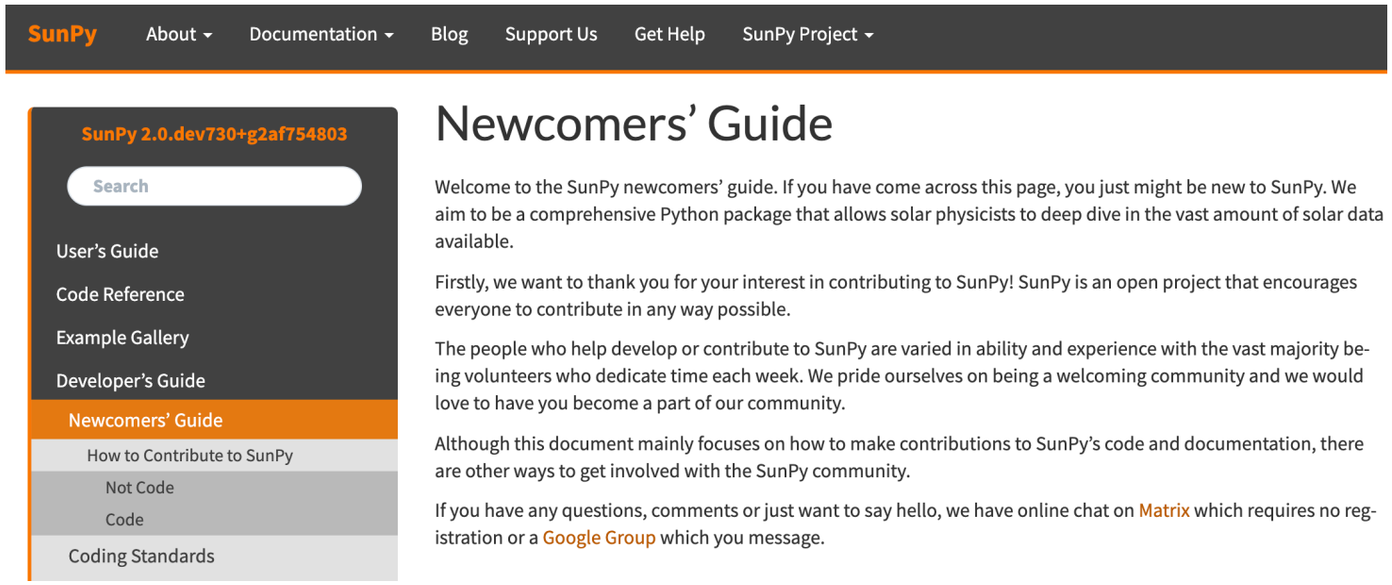
Get Involved

Please!

- Get involved in the community and contribute!
- Don’t need to contribute code - give feedback, report bugs, request features and examples!

sunpy.org

https://github.com/sunpy/sunpy



- Get in touch on Github, mailing list, matrix channel or this week!