The SunPy Ecosystem

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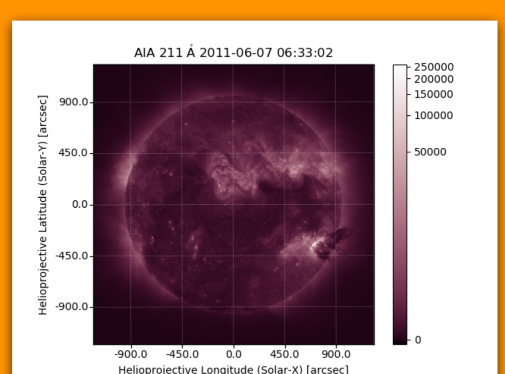
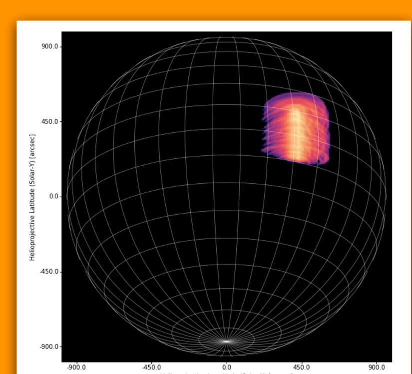
SunPy

SunPy (SunPy Community et al., 2015) is a Python-based project that **enables the analysis of solar data** in the scientific Python data analysis environment. It is built using capabilities from other packages such as Astropy, Numpy, Scipy, pandas and matplotlib. Some of SunPy's features are highlighted below. See **sunpy.org** for more.

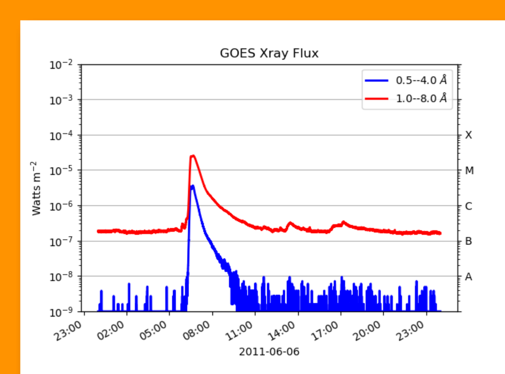
Data objects `Map` and `TimeSeries` make it easy to hold and manipulate the same types of data from different instruments.



co-ordinate aware spatial data



re-projected coronal loop simulations using `Map`



uses `pandas` DataFrames

SunPy's `Fido` **data search & download client** now uses the `drms` package to query the petabyte-scale Solar Dynamics Observatory Joint Science Operations Center (SDO JSOC) image archive.

```
from sunpy.net import Fido, attrs as a
result = Fido.search(a.jsoc.Time('2014-01-01T00:00:00', '2014-01-01T01:00:00'),
                     a.jsoc.Series('hmi.v_45s'), a.jsoc.Notify('my@myemailaddress.org'))
print(result)

Results from 1 Provider:

81 Results from the JSOCClient:
         T_REC          TELESCOP  INSTRUME  WAVELNTH CAR_ROT
         str23            str7     str10    float64   int64
----------------------- -------- ---------- -------- -------
2014.01.01_00:00:45_TAI  SDO/HMI HMI_FRONT2   6173.0    2145
2014.01.01_00:01:30_TAI  SDO/HMI HMI_FRONT2   6173.0    2145
2014.01.01_00:02:15_TAI  SDO/HMI HMI_FRONT2   6173.0    2145
2014.01.01_00:03:00_TAI  SDO/HMI HMI_FRONT2   6173.0    2145
```

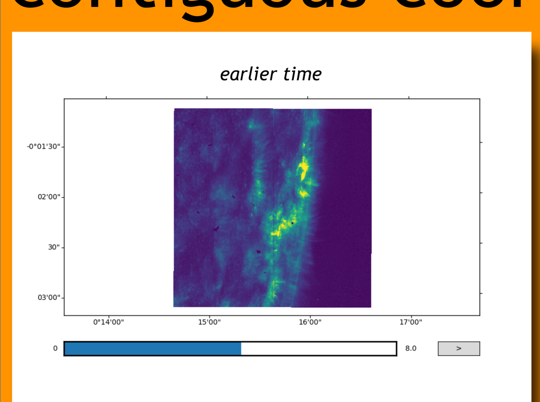
Transformation between solar and astrophysical co-ordinate systems is simple, implemented using `Astropy coordinates`.

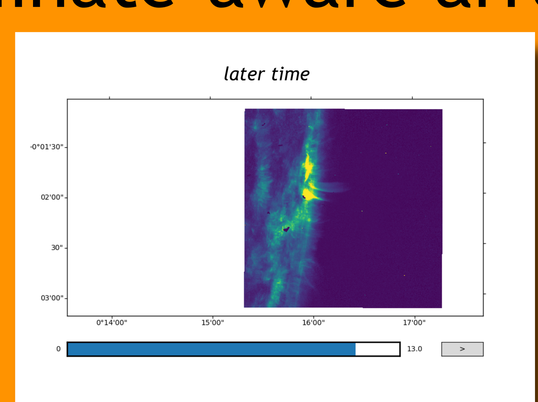
```
import astropy.units as u
from astropy.coordinates import SkyCoord
import sunpy.coordinates
import sunpy.map
from sunpy.data.sample import AIA_193_IMAGE
m = sunpy.map.Map(AIA_193_IMAGE)
point = SkyCoord(123*u.arcsec, 456*u.arcsec, frame=m.coordinate_frame)
print(point) # Helioprojective Cartesian
print(point.transform_to('heliographic_stonyhurst')) # Heliographic Stonyhurst
print(point.transform_to('icrs')) # International Celestial Reference System

<SkyCoord (Helioprojective: obstime=2011-06-07 06:33:07.840000, rsun=696000000.0 m, observer=<HeliographicStonyhurst
Coordinate (obstime=2011-06-07 06:33:07.840000): (lon, lat, radius) in (deg, deg, m)
    (0., 0.048602, 1.51846027e+11)>): (Tx, Ty) in arcsec
    (123., 456.)>
<SkyCoord (HeliographicStonyhurst: obstime=2011-06-07 06:33:07.840000): (lon, lat, radius) in (deg, deg, km)
    (8.50035688, 28.75970887, 695999.9999963)>
<SkyCoord (ICRS): (ra, dec, distance) in (deg, deg, km)
    (230.18600357, 2.18397588, 947137.58662574)>
```

SunPy Ecosystem

Use of SunPy has prompted the development of packages (some of which are outlined below) that support other types of solar physics studies. Efforts are also underway **now** to agree a framework leading to **interoperable data analysis packages for all heliophysical domains** (heliopython.org).

`IRISpy` provides support for data from the Interface Region Imaging Spectrograph (IRIS) via the `ndcube` package. `ndcube` supports multi-dimensional contiguous and non-contiguous coordinate-aware arrays.

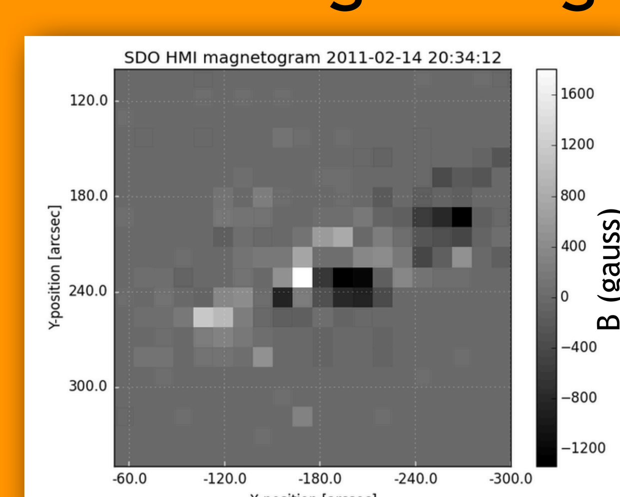




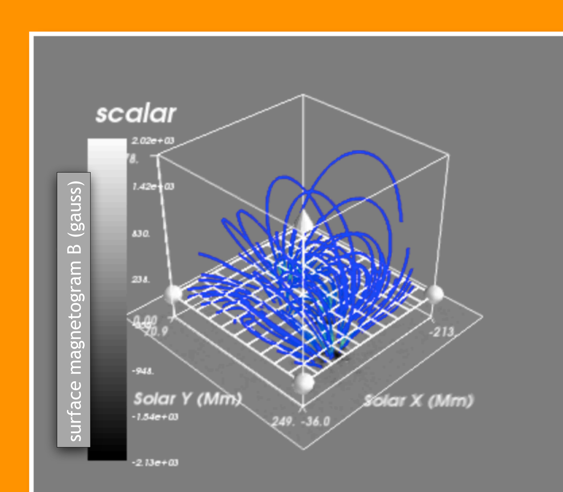
IRIS data is natively 4 dimensional (2 space, time and energy) requiring multi-dimensional coordinate aware arrays for efficient, flexible and intuitive representation and manipulation.

Example 1330Å bandpass IRIS slit jaw images showing rastering over the solar limb, using `IRISpy`. Original data is stored in a three dimensional FITS file.

`solarbextrapolate` provides support for extrapolating the magnetic field of portions of the solar surface from observations of the line-of-sight magnetic flux



downsampled SDO Helioseismic Imager data of the line-of-sight magnetic flux used as input to `solarbextrapolate`

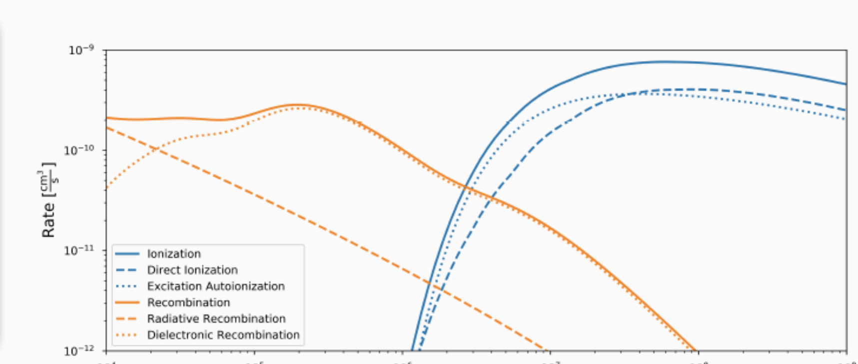


extrapolated magnetic field using the potential field source surface approach

`fiasco` provides support for CHIANTI atomic database - details of emission lines from multiple elements at many ionization stages.

```
>>> import fiasco
>>> import numpy as np; import astropy.units as u
>>> t = np.logspace(4,8,100)*u.K
>>> ion = fiasco.Ion('Fe 16', temperature=t)
# Equivalently
>>> fiasco.Ion('Fe +15', t), fiasco.Ion('iron 16', t);
# Basic metadata
>>> ion.element_name, ion.atomic_symbol, ion.atomic_number
('iron', 'Fe', 26)
>>> ion.ion_name, ion.ionization_stage, ion.charge_state
('Fe 16', 16, 15)
```

```
>>> ion.ionization_rate()
<Quantity [  2.18538687e-258,   1.84291825e-236, ...] cm3 / s>
>>> ion.recombination_rate()
<Quantity [  2.11925041e-10,   2.08729127e-10, ...] cm3 / s>
```



SunPy Community et al., 2015, Computational Science & Discovery, 8(1), 014009

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