
pfsspy Documentation

pfsspy contributors

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pfsspy is a python package for carrying out Potential Field Source Surface modelling. For more information on the actually PFSS calculation see [this document](#).

Note: pfsspy is a very new package, so elements of the API are liable to change with the first few releases. If you find any bugs or have any suggestions for improvement, please raise an issue here: <https://github.com/dstansby/pfsspy/issues>

pfsspy can be installed from PyPi using

```
pip install pfsspy
```


CHAPTER 1

Citing

If you use pfsspy in work that results in publication, please cite the archived code at *both*

- <https://zenodo.org/record/2566462>
- <https://zenodo.org/record/1472183>

Citation details can be found at the lower right hand of each web page.

For the main user-facing code and a changelog see

2.1 pfsspy Package

2.1.1 Functions

<code>load_output(file)</code>	Load a saved output file.
<code>pfss(input)</code>	Compute PFSS model.

load_output

`pfsspy.load_output(file)`

Load a saved output file.

Loads a file saved using `Output.save()`.

Parameters

file [str, file, `Path`] File to load.

Returns

:class:‘Output‘

pfss

`pfsspy.pfss(input)`

Compute PFSS model.

Extrapolates a 3D PFSS using an eigenfunction method in r, s, p coordinates, on the dumfric grid (equally spaced in $\rho = \ln(r/r_{sun})$, $s = \cos(\theta)$, and $p = \phi$).

The output should have zero current to machine precision, when computed with the DuMFriC staggered discretization.

Parameters

input [*Input*] Input parameters.

Returns

out [*Output*]

2.1.2 Classes

<i>FieldLine</i> (x, y, z, output)	A single magnetic field line.
<i>Grid</i> (ns, nphi, nr, rss)	Grid on which the solution is calculated.
<i>Input</i> (br, nr, rss)	Input to PFSS modelling.
<i>Output</i> (alr, als, alp, grid)	Output of PFSS modelling.

FieldLine

class pfsspy.**FieldLine** (x, y, z, output)

Bases: astropy.coordinates.sky_coordinate.SkyCoord

A single magnetic field line.

Parameters

x :

y :

z :

output [*Output*]

Attributes Summary

<i>expansion_factor</i>	Magnetic field expansion factor.
<i>is_open</i>	Returns True if one of the field line is connected to the solar surface and one to the outer boundary, False otherwise.
<i>polarity</i>	Magnetic field line polarity.

Attributes Documentation

expansion_factor

Magnetic field expansion factor.

The expansion factor is defined as $(r_{\odot}^2 B_{\odot}) / (r_{ss}^2 B_{ss})$

Returns

exp_fact [float] Field line expansion factor. If field line is closed, returns None.

is_open

Returns True if one of the field line is connected to the solar surface and one to the outer boundary, False otherwise.

polarity

Magnetic field line polarity.

Returns

pol [int] 0 if the field line is closed, otherwise sign(B_r) of the magnetic field on the solar surface.

Grid

class pfsspy.**Grid**(*ns, nphi, nr, rss*)

Bases: `object`

Grid on which the solution is calculated.

The grid is evenly spaced in ($\cos(\theta)$, ϕ , $\log(r)$).

Attributes Summary

<i>dp</i>	Cell size in ϕ .
<i>dr</i>	Cell size in $\log(r)$.
<i>ds</i>	Cell size in $\cos(\theta)$.
<i>pc</i>	Location of the centre of cells in ϕ .
<i>pg</i>	Location of the edges of grid cells in ϕ .
<i>rc</i>	Location of the centre of cells in $\log(r)$.
<i>rg</i>	Location of the edges of grid cells in $\log(r)$.
<i>sc</i>	Location of the centre of cells in $\cos(\theta)$.
<i>sg</i>	Location of the edges of grid cells in $\cos(\theta)$.

Attributes Documentation**dp**

Cell size in ϕ .

dr

Cell size in $\log(r)$.

ds

Cell size in $\cos(\theta)$.

pc

Location of the centre of cells in ϕ .

pg

Location of the edges of grid cells in ϕ .

rc

Location of the centre of cells in $\log(r)$.

rg

Location of the edges of grid cells in $\log(r)$.

sc

Location of the centre of cells in $\cos(\theta)$.

sg

Location of the edges of grid cells in $\cos(\theta)$.

Input

class pfsspy.Input (*br, nr, rss*)

Bases: `object`

Input to PFSS modelling.

Parameters

br [2D array, `sunpy.map.Map`] Boundary condition of radial magnetic field at the inner surface. If a SunPy map is automatically extracted as `map.data` with *no* processing.

nr [int] Number of cells in the radial direction.

rss [float] Radius of the source surface, as a fraction of the solar radius.

Methods Summary

<code>plot_input([ax])</code>	Plot a 2D image of the magnetic field boundary condition.
-------------------------------	---

Methods Documentation

plot_input (*ax=None*)

Plot a 2D image of the magnetic field boundary condition.

Parameters

ax [Axes] Axes to plot to. If *None*, creates a new figure.

Output

class pfsspy.Output (*alr, als, alp, grid*)

Bases: `object`

Output of PFSS modelling.

Parameters

alr : Vector potential * grid spacing in radial direction.

als : Vector potential * grid spacing in elevation direction.

alp : Vector potential * grid spacing in azimuth direction.

grid [Grid] Grid that the output was calculated on.

Attributes Summary

<code>al</code>	Vector potential times cell edge lengths.
<code>bc</code>	B on the centres of the cell faces.
<code>bg</code>	B as a (weighted) averaged on grid points.
<code>source_surface_br</code>	Br on the source surface.

Methods Summary

<code>plot_pil(ax)</code>	Plot the polarity inversion line on the source surface.
<code>plot_source_surface(ax)</code>	Plot a 2D image of the magnetic field at the source surface.
<code>save(file)</code>	Save the output to file.
<code>trace(x0[, atol, rtol])</code>	Traces a field-line from $x0$.

Attributes Documentation

al

Vector potential times cell edge lengths.

Returns $ar * L_r$, $as * L_s$, $ap * L_p$ on cell edges.

bc

B on the centres of the cell faces.

bg

B as a (weighted) averaged on grid points.

Returns

br [array]

bs [array]

bp [array]

source_surface_br

Br on the source surface.

Methods Documentation

plot_pil (*ax=None*, ***kwargs*)

Plot the polarity inversion line on the source surface.

The PIL is where $Br = 0$.

Parameters

ax [Axes] Axes to plot to. If *None*, creates a new figure.

****kwargs** : Keyword arguments are handed to *ax.contour*.

plot_source_surface (*ax=None*)

Plot a 2D image of the magnetic field at the source surface.

Parameters

ax [Axes] Axes to plot to. If *None*, creates a new figure.

save (*file*)

Save the output to file.

This saves the required information to reconstruct an Output object in a compressed binary numpy file (see `numpy.savez_compressed()` for more information). The file extension is `.npz`, and is automatically added if not present.

Parameters

file [str, file, `Path`] File to save to. If `.npz` extension isn't present it is added when saving the file.

trace (*x0*, *atol*=0.0001, *rtol*=0.0001)

Traces a field-line from *x0*.

Uses `scipy.integrate.solve_ivp`, with an LSODA method.

Parameters

x0 [array] Starting coordinate, in cartesian coordinates.

dtf [float, optional] Absolute tolerance of the tracing.

rtol [float, optional] Relative tolerance of the tracing.

Returns

fl [`FieldLine`]

2.2 Changelog

2.2.1 0.1.3

- `pfsspy.Output.plot_pil()` now accepts keyword arguments that are given to Matplotlib to control the style of the contour.
- `pfsspy.FieldLine.expansion_factor` is now cached, and is only calculated once if accessed multiple times.

for usage examples see

2.3 pfsspy examples

Note: Click [here](#) to download the full example code

2.3.1 Dipole source solution

A simple example showing how to use pfsspy to compute the solution to a dipole source field.

First, import required modules

```
import astropy.constants as const
import matplotlib.pyplot as plt
import matplotlib.patches as mpatch
import numpy as np
import pfsspy
```

Set up a 1degree by 1degree grid in theta and phi

```
nphi = 360
ntheta = 180
```

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```
phi = np.linspace(0, 2 * np.pi, nphi)
theta = np.linspace(-np.pi / 2, np.pi / 2, ntheta)
theta, phi = np.meshgrid(theta, phi)
```

Define the number of radial grid points and the source surface radius

```
nr = 50
rss = 2.5
```

Compute radial component of a dipole field

```
def dipole_Br(r, theta):
    return 2 * np.sin(theta) / r**3

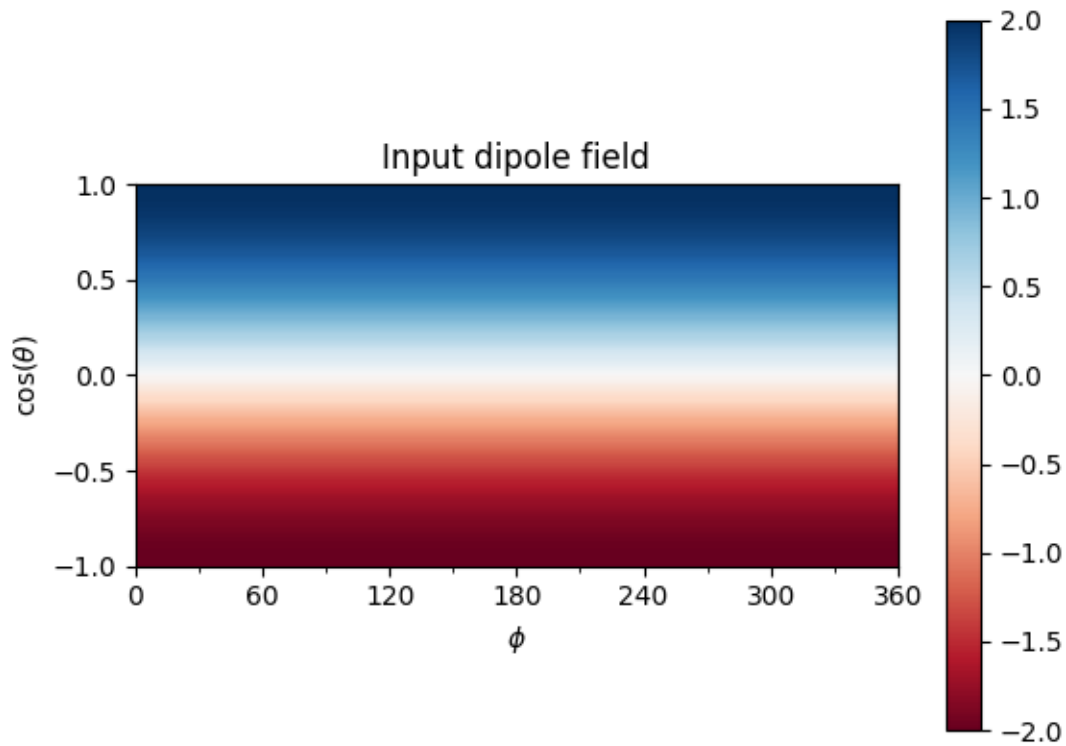
br = dipole_Br(1, theta).T
```

Create PFSS input object

```
input = pfsspy.Input(br, nr, rss)
```

Plot input magnetic field

```
fig, ax = plt.subplots()
mesh = input.plot_input(ax)
fig.colorbar(mesh)
ax.set_title('Input dipole field')
```

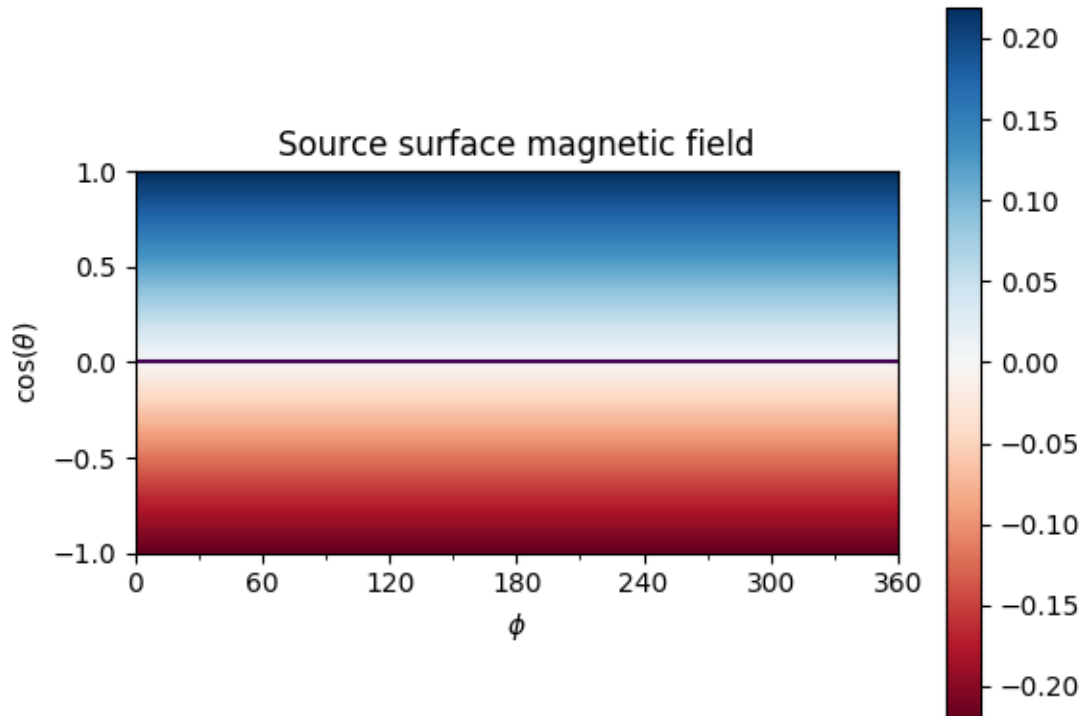


Calculate PFSS solution

```
output = pfsspy.pfss(input)
```

Plot output field

```
fig, ax = plt.subplots()
mesh = output.plot_source_surface(ax)
fig.colorbar(mesh)
output.plot_pil(ax)
ax.set_title('Source surface magnetic field')
```



Trace some field lines

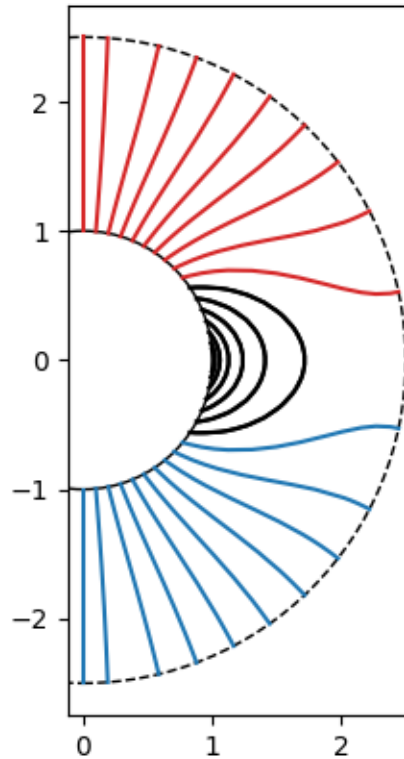
```
br, btheta, bphi = output.bg

fig, ax = plt.subplots()
ax.set_aspect('equal')

# Take 32 start points spaced equally in theta
r = 1.01
for theta in np.linspace(0, np.pi, 33):
    x0 = np.array([0, r * np.sin(theta), r * np.cos(theta)])
    field_line = output.trace(x0)
    color = {0: 'black', -1: 'tab:blue', 1: 'tab:red'}.get(field_line.polarity)
    ax.plot(field_line.y / const.R_sun,
            field_line.z / const.R_sun, color=color)

# Add inner and outer boundary circles
ax.add_patch(mpatch.Circle((0, 0), 1, color='k', fill=False))
ax.add_patch(mpatch.Circle((0, 0), input.grid.rss, color='k', linestyle='--',
                           fill=False))
ax.set_title('PFSS solution for a dipole source field')
plt.show()
```

PFSS solution for a dipole source field



Total running time of the script: (0 minutes 13.686 seconds)

Note: Click [here](#) to download the full example code

2.3.2 GONG PFSS extrapolation

Calculating PFSS solution for a GONG synoptic magnetic field map.

First, import required modules

```
import os
import astropy.constants as const
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D
import numpy as np
import pfsspy
import sunpy.map
```

If a gong magnetic field map isn't present, download one

```
if not os.path.exists('gong.fits') and not os.path.exists('gong.fits.gz'):
    import urllib.request
    urllib.request.urlretrieve(
```

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```
'https://gong2.nso.edu/oQR/zqs/201901/mrzqs190108/mrzqs190108t1114c2212_050.
↪fits.gz',
    'gong.fits.gz')

if not os.path.exists('gong.fits'):
    import gzip
    with gzip.open('gong.fits.gz', 'rb') as f:
        with open('gong.fits', 'wb') as g:
            g.write(f.read())
```

Use SunPy to read the .fits file with the data

```
map = sunpy.map.Map('gong.fits')
nr = 60
rss = 2.5
```

Extract the data, and remove the mean to enforce $\text{div}(\mathbf{B}) = 0$ on the solar surface

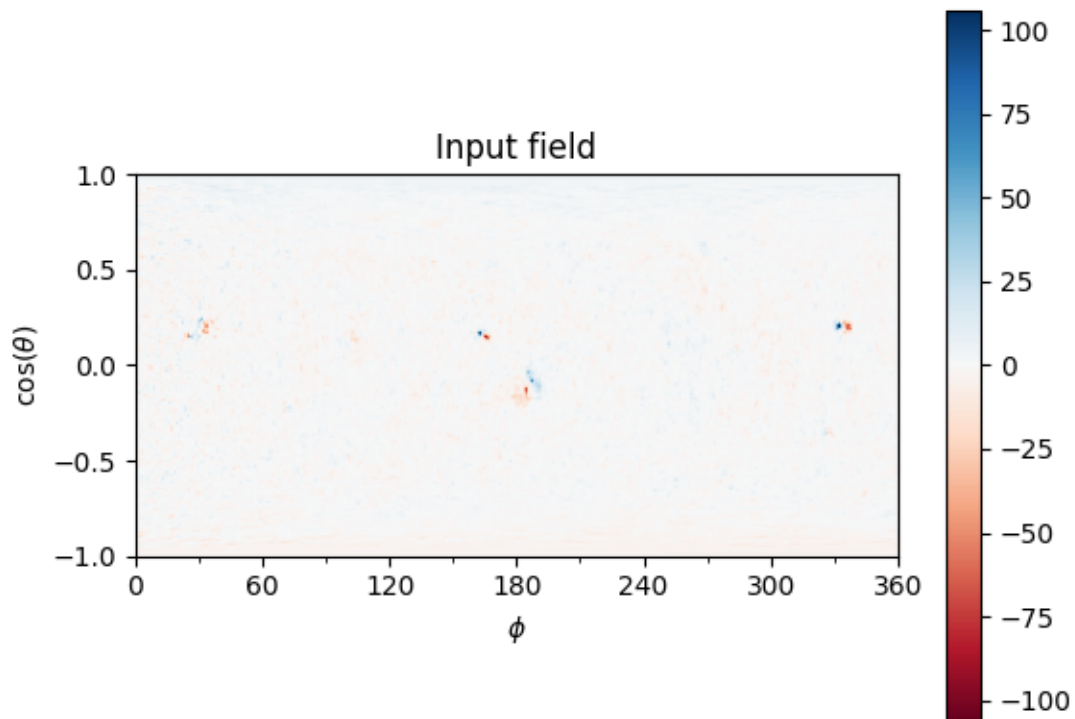
```
br = map.data
br = br - np.mean(br)
```

Create PFSS input object

```
input = pfsspy.Input(br, nr, rss)
```

Plot input magnetic field

```
fig, ax = plt.subplots()
mesh = input.plot_input(ax)
fig.colorbar(mesh)
ax.set_title('Input field')
```

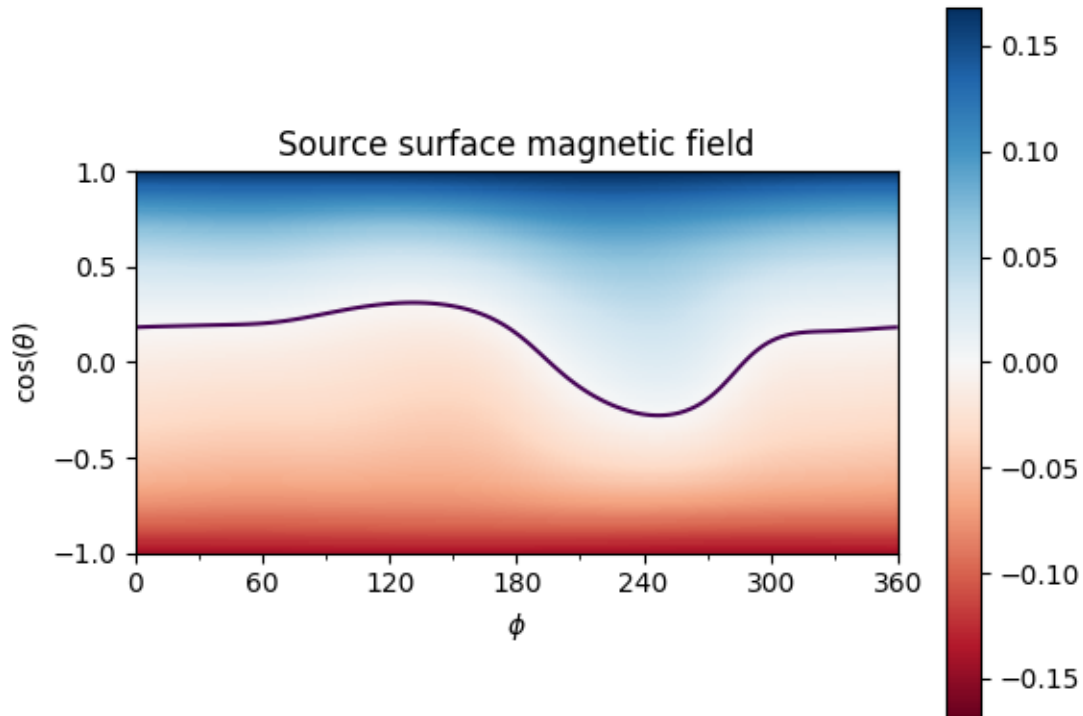


Calculate PFSS solution

```
output = pfsspy.pfss(input)
output.plot_pil(ax)
```

Plot output field

```
fig, ax = plt.subplots()
mesh = output.plot_source_surface(ax)
fig.colorbar(mesh)
output.plot_pil(ax)
ax.set_title('Source surface magnetic field')
```



Trace some field lines

```
br, btheta, bphi = output.bg

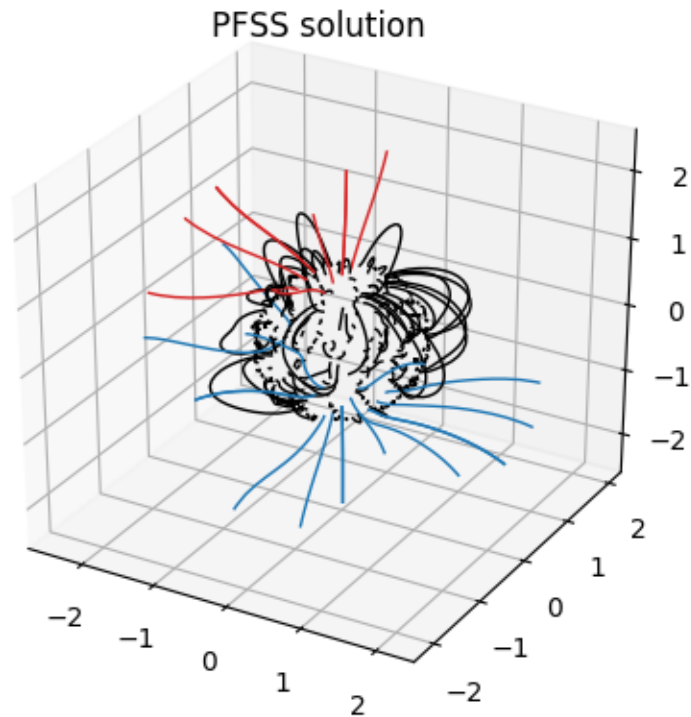
fig = plt.figure()
ax = fig.add_subplot(111, projection='3d')
ax.set_aspect('equal')

# Loop through 16 values in theta and 16 values in phi
r = 1.01
for theta in np.linspace(0, np.pi, 17):
    for phi in np.linspace(0, 2 * np.pi, 17):
        x0 = np.array([r * np.cos(phi),
                        r * np.sin(theta) * np.sin(phi),
                        r * np.cos(theta) * np.sin(phi)])
        field_line = output.trace(x0)
        color = {0: 'black', -1: 'tab:blue', 1: 'tab:red'}.get(field_line.polarity)
        ax.plot(field_line.x / const.R_sun,
                field_line.y / const.R_sun,
                field_line.z / const.R_sun,
                color=color, linewidth=1)

# Add inner and outer boundary circles
ax.set_title('PFSS solution')
plt.show()
```

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```
# sphinx_gallery_thumbnail_number = 3
```



Total running time of the script: (0 minutes 26.434 seconds)

and for the helper modules (behind the scene!) see

2.4 Helper modules

2.4.1 pfsspy.plot Module

Functions

`contour(phi, costheta, field, levels[, ax])`

Parameters

`radial_cut(phi, costheta, field[, ax])`

contour

`pfsspy.plot.contour(phi, costheta, field, levels, ax=None, **kwargs)`

Parameters**phi :****costheta :****field :****levels :****ax** [Axes, optional] Axes to plot to. If `None` a new figure is created.****kwargs :** Keyword arguments are handed to `ax.contour`.**radial_cut**`pfsspy.plot.radial_cut(phi, costheta, field, ax=None)`**2.4.2 pfsspy.coords Module**

Helper functions for coordinate transformations used in the PFSS domain.

The PFSS solution is calculated on a “strumfric” grid defined by

- $\rho = \log(r)$
- $s = \cos(\theta)$
- ϕ

where r, θ, ϕ are spherical coordinates that have ranges

- $1 < r < r_{ss}$
- $0 < \theta < \pi$
- $0 < \phi < 2\pi$

The transformation between cartesian coordinates used by the tracer and the above coordinates is given by

- $x = r \sin(\theta) \cos(\phi)$
- $y = r \sin(\theta) \sin(\phi)$
- $z = r \cos(\theta)$

Functions

<code>cart2strum(x, y, z)</code>	Convert cartesian coordinates to strumfric coordinates.
<code>strum2cart(rho, s, phi)</code>	Convert strumfric coordinates to cartesian coordinates.

cart2strum`pfsspy.coords.cart2strum(x, y, z)`

Convert cartesian coordinates to strumfric coordinates.

strum2cart

`pfsspy.coords.strum2cart` (*rho, s, phi*)

Convert strumfric coordinates to cartesian coordinates.

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