

CHARM

2.1

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Chapter 1

CHARacterization Algorithm for Radius Measurements (CHARM)

Python script to characterize a black-hole image, measure its diameter and FWHM, as well as characterize its visibility map. This version of the script does not assume a known center of the black-hole shadow but instead finds first the center of the image by minimizing an appropriate measure of the variance of diameters along different azimuthal cross sections.

This version is also meant to be applied to images reconstructed from real and synthetic data, i.e., without substantial substructure. For this reason the algorithm does not apply any filtering to the images.

The script runs in batch mode, by characterizing all images in files that end with '.fits' found in the directory given in variable 'path'

To execute, go to the /data directory and give: `python ../src/charm.py`

Upon completion, the script will generate a diagnostic plot for each of the images, as well as an ASCII file with name given in variable 'outfile' that contains, for each image, the following parameters:

```
rad25 a float with the 25th percentile value of the radius
rad50 a float with the 50th percentile value of the radius
rad75 a float with the 75th percentile value of the radius
FWHM25 a float with the 25th percentile value of the FWHM
FWHM50 a float with the 50th percentile value of the FWHM
FWHM75 a float with the 75th percentile value of the FWHM
fracCirc a float with the fraction of the ring circumference with brightness above the floor
zFirstHor the baseline length of the first horizontal visibility minimum in Glambda
zFirstVer the baseline length of the first vertical visibility minimum in Glambda
```

Author

UofA Group (F. Ozel, D. Psaltis, S. Dougall, T. Trent)

Version

2.1

Date

October 13, 2021

Bug No known bugs

Warning

No known warnings

Todo Nothing left

Chapter 2

Todo List

page [CHaracterization Algorithm for Radius Measurements \(CHARM\)](#)

Nothing left

Namespace [charm](#)

Nothing left

Global [charm.char_image](#) (label, movieframe, Npixels, X, Y, I)

Nothing left

Global [charm.FilterImage](#) (Npts, X, Y, I, dX, Npadfact=16)

Nothing left

Global [charm.findcenter](#) (Npixels, X, Y, ImageFilter, Dmax=25., ND=50, Ngrid=Ngrid, Nslice=Nslice, i↔
Floor=iFloor, radmin=15)

Nothing left

Global [charm.ImageParams](#) (Npixels, X, Y, ImageFilter, d0X=d0X, d0Y=d0Y, Ngrid=Ngrid, Nslice=Nslice, i↔
Floor=iFloor, radmin=5.)

Nothing left

Global [charm.zcr](#) (x, y)

Nothing left

Namespace [plotParams](#)

Nothing left

Global [plotParams.setPlotParams](#) ()

Nothing left

Chapter 3

Bug List

page [CHARacterization Algorithm for Radius Measurements \(CHARM\)](#)

No known bugs

Namespace [charm](#)

No known bugs

Global [charm.char_image](#) (label, movieframe, Npixels, X, Y, I)

No known bugs

Global [charm.FilterImage](#) (Npts, X, Y, I, dX, Npadfact=16)

No known bugs

Global [charm.findcenter](#) (Npixels, X, Y, ImageFilter, Dmax=25., ND=50, Ngrid=Ngrid, Nslice=Nslice, i↔
Floor=iFloor, radmin=15)

No known bugs

Global [charm.ImageParams](#) (Npixels, X, Y, ImageFilter, d0X=d0X, d0Y=d0Y, Ngrid=Ngrid, Nslice=Nslice, i↔
Floor=iFloor, radmin=5.)

No known bugs

Global [charm.zcr](#) (x, y)

No known bugs

Namespace [plotParams](#)

No known bugs

Global [plotParams.setPlotParams](#) ()

No known bugs

Chapter 4

Namespace Index

4.1 Namespace List

Here is a list of all documented namespaces with brief descriptions:

charm	Python script to characterize a black-hole image This version finds first the center of the image and does not invoke any filtering	9
plotParams	Defines matplotlib parameters for the plots	16

Chapter 5

Namespace Documentation

5.1 charm Namespace Reference

Python script to characterize a black-hole image This version finds first the center of the image and does not invoke any filtering.

Functions

- def `zcr` (x, y)
Finds zero crossings.
- def `findcenter` (Npixels, X, Y, ImageFilter, Dmax=25., ND=50, Ngrid=Ngrid, Nslice=Nslice, iFloor=iFloor, radmin=15)
Finds the center of the image by minimizing the spread of the radii measured along different azimuthal slices
- def `FilterImage` (Npts, X, Y, I, dX, Npadfact=16)
(In principle) filters an image and returns its visibility map
- def `ImageParams` (Npixels, X, Y, ImageFilter, d0X=d0X, d0Y=d0Y, Ngrid=Ngrid, Nslice=Nslice, iFloor=iFloor, radmin=5.)
Measures the diameter and FWHM of a ring-like image.
- def `char_image` (label, movieframe, Npixels, X, Y, I)
function char_image(label,movieframe,Npixels, X,Y,I)

Variables

- float **d0X** = 0.0
- float **d0Y** = 0.0
- int **convert** = 1./206.26
- float **RadMax** = 50.0
- int **Ngrid** = 256
- int **Nslice** = 128
- float **iFloor** = 0.01
- list **listoffiles** = [x for x in os.listdir(path) if ((x.endswith(".fits")))]
- int **index** = 1
- **hdulist** = fits.open(path+file_name)
- **hdu** = hdulist[0]
- **array** = hdu.data

- float **pixel** = np.abs(hdu.header['CDEL1'])*3.6e9
- **Npts** = np.shape(array)[0]
- tuple **FOV** = (np.float(Npts-1))*pixel
- **X** = np.linspace(-FOV/2,FOV/2,num=Npts,endpoint=True)
- **Y** = np.linspace(-FOV/2,FOV/2,num=Npts,endpoint=True)
- **I** = array
- **label1** = file_name.replace('_', ' ')
- **label** = label1.replace('.fits','')
- **movieframe** = str(index).zfill(4)
- **rad25**
- **rad50**
- **rad75**
- **FWHM25**
- **FWHM50**
- **FWHM75**
- **fracCirc**
- **zFirstHor**
- **zFirstVer**
- list **listResults** = [file_name, 2.*rad50, 2.*rad25, 2.*rad75, FWHM50, FWHM25, FWHM75,fracCirc,zFirst↵
Hor,zFirstVer]
- string **res** = " ".join([str(i) for i in listResults])

5.1.1 Detailed Description

Python script to characterize a black-hole image This version finds first the center of the image and does not invoke any filtering.

Author

UofA Group

Version

2.1

Date

October 19, 2021

Bug No known bugs

Warning

No known warnings

Todo Nothing left

5.1.2 Function Documentation

5.1.2.1 char_image()

```
def charm.char_image (
    label,
    movieframe,
    Npixels,
    X,
    Y,
    I )
```

function char_image(label,movieframe,Npixels, X,Y,I)

main function to characterize an image of Npixels by Npixels, stored in the 2D array I, with horizontal and vertical coordinates stored in arrays X and Y. Image characterization subroutine

Given a square image of Npixels per side, with coordinates in X and Y, and brightness in I, this subroutine first filters the image (not in this script), find its center, measures the distribution of "radii" and "widths" for a grid of Nslice azimuthal slices, and plots all of the above together with two cross section of the visibility map of the image.

Besides returning a lot of these parameters, it also generates a 6-panel diagnostic plot, labeled with the input string 'label'.

The plot is saved as a PNG file with name movieframe+".png" If 'movieframe' corresponds to an increasing integer, the resulting files can be easily combined into a movie with ffmpeg.

@label a string to be placed on the image, for recognition @movieframe a string for the name of the plot file

Parameters

<i>Npixels</i>	the number of points per dimension (assuming square image)
<i>X</i>	a 1D array of Npts points with the X-coordinates
<i>Y</i>	a 1D array of Npts points with the Y-coordinates
<i>I</i>	a 2D array of Npts*Npts points with the image brightness

Returns

rad25 a float with the 25th percentile value of the radius
rad50 a float with the 50th percentile value of the radius
rad75 a float with the 75th percentile value of the radius
FWHM25 a float with the 25th percentile value of the FWHM
FWHM05 a float with the 50th percentile value of the FWHM
FWHM75 a float with the 75th percentile value of the FWHM
fracCirc a float with the fraction of pi with brightness above the floor
zFirstHor the baseline length of the first horizontal visibility minimum in Glambda
zFirstVer the baseline length of the first vertical visibility minimum in Glambda
nothing

Author

UofA Group

Version

2.1

Date

October 22, 2021

Bug No known bugs**Warning**

No known warnings

Todo Nothing left**5.1.2.2 FilterImage()**

```
def charm.FilterImage (
    Npts,
    X,
    Y,
    I,
    dX,
    Npadfact = 16 )
```

(In principle) filters an image and returns its visibility map

For this version of the script, there is no filtering.

Given a square image of Npts per side, with coordinates in X and Y and brightness in I, the subroutine just returns the visibility map of the image.

Npadfact is the multiplicative padding factor for calculating the 2D Fourier transform of the image with default Npadfact=16

Parameters

<i>Npts</i>	the number of points per dimension (assuming square image)
<i>X</i>	a 1D array of Npts points with the X-coordinates
<i>Y</i>	a 1D array of Npts points with the Y-coordinates
<i>I</i>	a 2D array of Npts*Npts points with the image brightness
<i>dX</i>	a float with the pixel width in uas

Returns

FilterImage a 2D Npts*Npts array with the filtered image
uGrid a 2D Npts*Npts array with the u-coordinate grid in Glambda
vGrid a 2D Npts*Npts array with the v-coordinate grid in Glambda
Visibility a 2D Npts*Npts array with the complex Visibility

Author

UofA Group

Version

1.0

Date

September 13, 2018

Bug No known bugs**Warning**

No known warnings

Todo Nothing left**5.1.2.3 findcenter()**

```
def charm.findcenter (
    Npixels,
    X,
    Y,
    ImageFilter,
    Dmax = 25.,
    ND = 50,
    Ngrid = Ngrid,
    Nslice = Nslice,
    iFloor = iFloor,
    radmin = 15 )
```

Finds the center of the image by minimizing the spread of the radii measured along different azimuthal slices

Given a square image of Npixels per side, with coordinates in X and Y and brightness in ImageFilter, it finds its center by searching through a square grid of NDxND points in the range [-Dmax,Dmax] along each orientation. The two parameters are inputs but defaults are Dmax=25 and ND=50.

The remaining default parameters are from the global variables.

In this version of the script, there is no image filtering; any mention of filtering is for compatibility with other script versions.

All image coordinates and distances are in the native units of the image provided.

v2.0 There is now a minimum radius requirement for the ring stored in 'radmin'. Introducing this ensures that the algorithm doesn't focus on compact knots. This value can be different between the centering and the characterization function, with the former typically being larger.

Parameters

<i>Npixels</i>	the number of points per dimension (assuming square image)
<i>X</i>	a 1D array of Npts points with the X-coordinates
<i>Y</i>	a 1D array of Npts points with the Y-coordinates
<i>ImageFilter</i>	a 2D array of Npts*Npts points with the image brightness

Returns

d0X a float with the x-displacement of the center
d0Y a float with the y-displacement of the center

Author

UofA Group

Version

2.0

Date

October 19, 2021

Bug No known bugs

Warning

No known warnings

Todo Nothing left

5.1.2.4 ImageParams()

```
def charm.ImageParams (
    Npixels,
    X,
    Y,
    ImageFilter,
    d0X = d0X,
    d0Y = d0Y,
    Ngrid = Ngrid,
    Nslice = Nslice,
    iFloor = iFloor,
    radmin = 5. )
```

Measures the diameter and FWHM of a ring-like image.

Given a square image of Npixels per side, with coordinates in X and Y, brightness in ImageFilter, and image center at d0X and d0Y, measures the distribution of "radii" and "widths" of the image for a grid of Nslice azimuthal slices with a distance up to RadMax

It only considers slices for which the max brightness is larger than iFloor*iFilterMax, which is important for, e.g., CLEAN images that have a substantial central floor.

v2.0 There is now a minimum radius requirement for the ring stored in 'radmin'. Introducing this ensures that the algorithm doesn't focus on compact knots. This value can be different between the centering and the characterization function, with the former typically being larger.

Parameters

<i>Npixels</i>	the number of points per dimension (assuming square image)
<i>X</i>	a 1D array of Npts points with the X-coordinates
<i>Y</i>	a 1D array of Npts points with the Y-coordinates
<i>ImageFilter</i>	a 2D array of Npts*Npts points with the image brightness
<i>d0X</i>	a float with the x-displacement of the center
<i>d0Y</i>	a float with the y-displacement of the center

Returns

sliceangle a 1D array with the angles (from horizontal) of the slices
 radii a 1D array with the peak brightness radii of the individual slices
 radiusL a 1D array with the radius of the half point on the left
 radiusR a 1D array with the radius of the half point on the right

Author

UofA Group

Version

2.0

Date

October 19, 2021

Bug No known bugs

Warning

No known warnings

Todo Nothing left

5.1.2.5 zcr()

```
def charm.zcr (
    x,
    y )
```

Finds zero crossings.

Given two arrays of the x- and y- coordinates of a function it returns an array of the x-coordinates of the zero crossings

the x-coordinates are assumed to be in order

Parameters

<i>x</i>	a float array with the x-coodinates
<i>y</i>	a float array with the y-coordinates

Returns

a float array with the locations of the zero crossings

Author

UofA Group

Version

1.0

Date

September 13, 2018

Bug No known bugs

Warning

No known warnings

Todo Nothing left

5.2 plotParams Namespace Reference

defines matplotlib parameters for the plots

Functions

- def [setPlotParams](#) ()
Sets matplotlib parameters.

5.2.1 Detailed Description

defines matplotlib parameters for the plots

Author

UofA group

Version

2.0

Date

October 11, 2019

Bug No known bugs

Warning

No known warnings

Todo Nothing left

5.2.2 Function Documentation

5.2.2.1 setPlotParams()

```
def plotParams.setPlotParams ( )
```

Sets matplotlib parameters.

Sets a number of matplotlib parameters (using rcParams) to create plots.

It requires latex fonts on python.

Returns

nothing

Author

UofA group

Version

2.0

Date

October 11, 2019

Bug No known bugs

Warning

No known warnings

Todo Nothing left

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