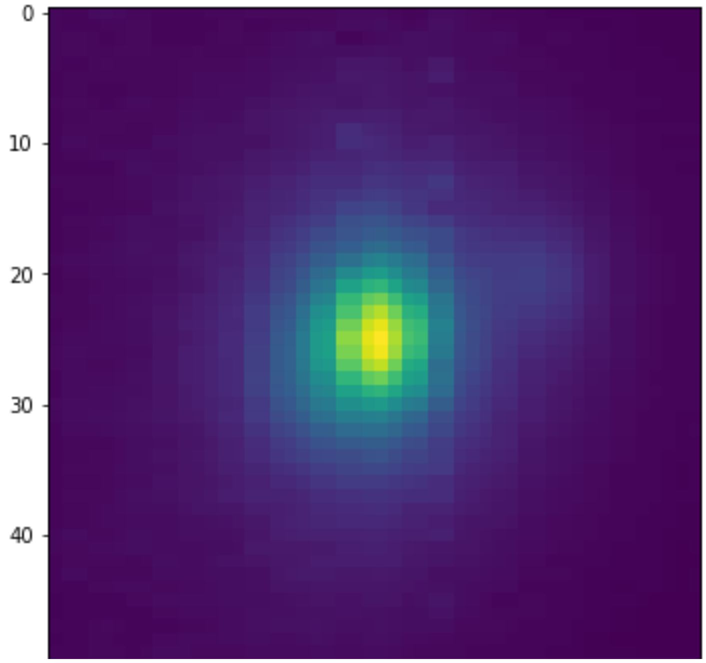
In [90]:
```
# 04/05/2022 - Trying out Gaussian MGE on J0037 by modifying fit_ngc4342 from
# from mge_fit examples

#################################################################

# import libraries
import numpy as np
np.set_printoptions(threshold=10000)
import matplotlib.pyplot as plt
import warnings
warnings.filterwarnings( "ignore", module = "matplotlib\..*" )
warnings.filterwarnings( "ignore", module = "plotbin\..*" )
from astropy.io import fits
from os import path

import mgefit
from mgefit.find_galaxy import find_galaxy
from mgefit.mge_fit_1d import mge_fit_1d
from mgefit.sectors_photometry import sectors_photometry
from mgefit.mge_fit_sectors import mge_fit_sectors
from mgefit.mge_print_contours import mge_print_contours
from mgefit.mge_fit_sectors_twist import mge_fit_sectors_twist
from mgefit.sectors_photometry_twist import sectors_photometry_twist
from mgefit.mge_print_contours_twist import mge_print_contours_twist

plt.rcParams["figure.figsize"] = (8, 6)

#################################################################
```

In [2]:
```
file_dir = '/data/raw_data/KECK_KCWI_SLACS_kinematics_shawn/CF_mosaics/SDSSJ0
obj_name = '/SDSSJ0037-0942'
```

In [3]:
```
# import image, center, and crop

file = file_dir + "/KCWI_J0037_icubes_mosaic_0.1457_2Dintegrated.fits"

hdu = fits.open(file)
img = hdu[0].data
header = hdu[0].header

# crop the image to ~ 50 pixels
central_pix = np.unravel_index(np.argmax(img, axis=None), img.shape)
central_pix_x = central_pix[1]
central_pix_y = central_pix[0]
crop_width = 50
half_width = int(crop_width/2)
img = img[central_pix_y - half_width:central_pix_y + half_width, central_pix_

plt.clf()
plt.imshow(img)
```

Out[3]:
```
<matplotlib.image.AxesImage at 0x7ff85d675d90>
```

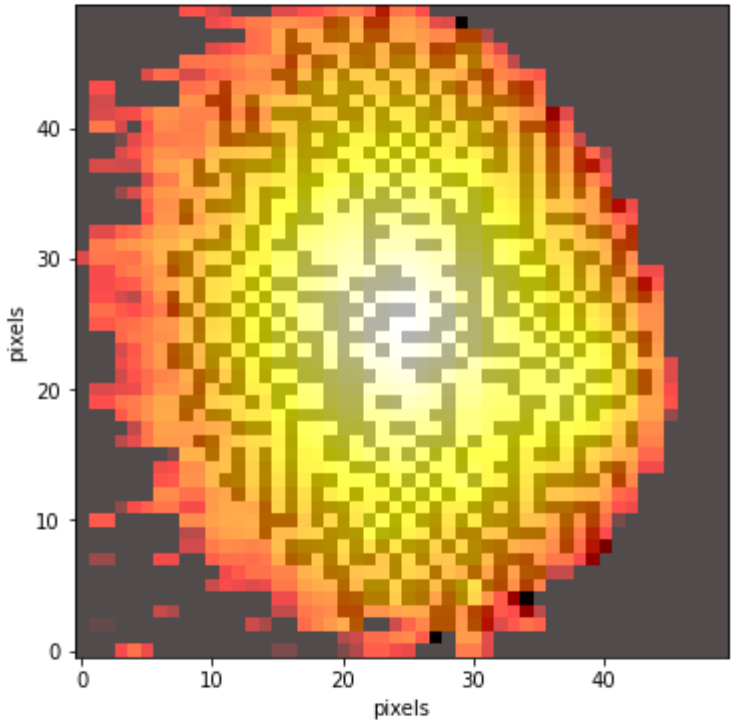

0
10
20
30
40

In [4]:

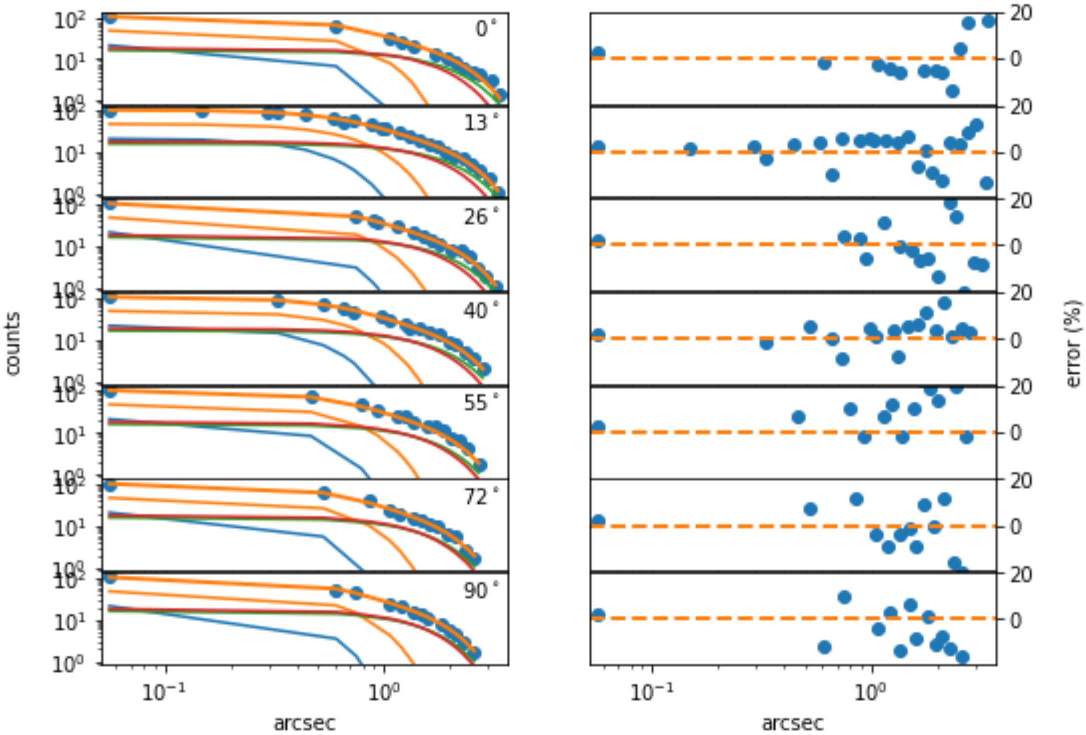
```
# check differences for different psf

# sky and psf?
scale = 0.147  # arcsec/pixel

#minlevel?
minlevel = 1  # counts/pixel
# exposure time
exp_time = 1.5 * 3600 # seconds
ngauss = 12

# Keck is typically 0.7-0.8
seeing_fwhm = 0.75 # arcsec
sigmapsf = seeing_fwhm / scale / 2.355 # pixels, 2.355 is fwhm/sigma
#print(sigma_psf)

################################################################3

# Here we use FIND_GALAXY directly inside the procedure. Usually you may want
# to experiment with different values of the FRACTION keyword, before adoptin
# given values of Eps, Ang, Xc, Yc.

# take different values of pixel fractions
lower, upper, steps = (0.06, 0.12, 7)
fractions = np.linspace(lower, upper, steps)

eps_list = []
theta_list = []
#cen_y_list = [] # don't need these, already centered it
#cen_x_list = []

for frac in fractions:
    #print(f'Calculating fraction {frac}')
    frac = np.around(frac, 2)
    mid = np.around((upper+lower)/2, 2)
    plt.clf()
    if (frac==lower) | (frac==mid) | (frac==upper):
        plot = 1
    else:
        plot = 0
    #plt.clf()
    f = find_galaxy(img, fraction=frac, plot=0, quiet=True)
    eps = f.eps
    theta = f.theta
    #cen_y = f.ypeak
    #cen_x = f.xpeak
    # assign to lists
    eps_list.append(eps)
    theta_list.append(theta)
    #cen_y_list.append(cen_y)
    #cen_x_list.append(cen_x)
    #if plot == 1:
    #    plt.title(f'{frac}')
    #    plt.pause(1)  # Allow plot to appear on the screen

eps_mean = np.mean(eps_list)
theta_mean = np.mean(theta_list)
#cen_y_med = np.median(cen_y_list)
```

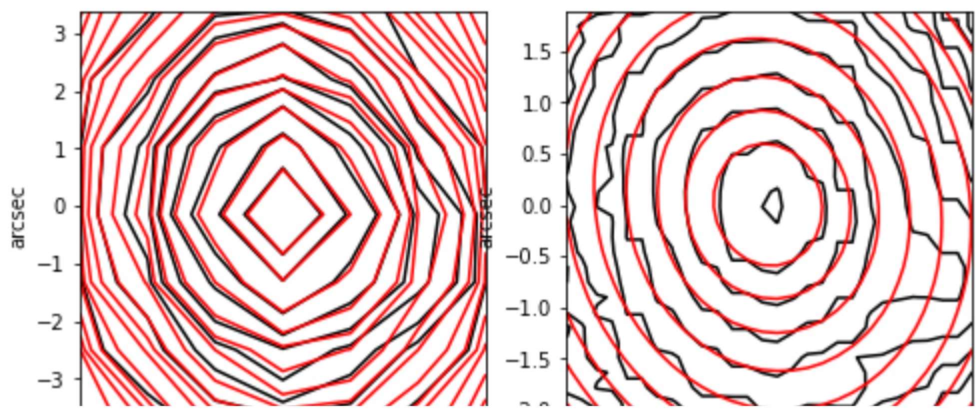
```
#cen_x_med = np.median(cen_x_list)

# Perform galaxy photometry
plt.clf()
s = sectors_photometry(img, eps_mean, theta_mean, f.xpeak, f.ypeak,
                       minlevel=minlevel, plot=1)
plt.pause(1)  # Allow plot to appear on the screen

# Do the actual MGE fit
# *********************** IMPORTANT ***********************************
# For the final publication-quality MGE fit one should include the line
# "from mge_fit_sectors_regularized import mge_fit_sectors_regularized"
# at the top of this file, rename mge_fit_sectors() into
# mge_fit_sectors_regularized() and re-run the procedure.
# See the documentation of mge_fit_sectors_regularized for details.
# *********************************************************************

plt.clf()
m = mge_fit_sectors(s.radius, s.angle, s.counts, eps_mean,
                    ngauss=ngauss, sigmapsf=sigmapsf, #normpsf=normpsf,
                    scale=scale, plot=1, bulge_disk=0, linear=0)

plt.pause(1)  # Allow plot to appear on the screen

# take the outputs
total_counts = m.sol[0]
sigma_pix = m.sol[1]
q = m.sol[2]
absdev = m.absdev

# calculate peak surface brightness of each gaussian
peak_surf_br = total_counts/(2*np.pi*q*sigma_pix**2)
# convert to johnson i band
# Here 20.840 is the photometric zeropint, 0.1 is a correction for infinite a
# for surface brightness measurements, and AI is the extinction in the I-band
# dust extinction ~ 0.05 from https://irsa.ipac.caltech.edu/workspace/TMP_lFD
AI = 0.05
iband_surf_br = 20.840 + 0.1 + 5 * np.log10(scale) + 2.5 * np.log10(exp_time)
# convert to surface density (L_sol_I pc-2)
M_sol_I = 4.08
surf_density = (64800/np.pi)**2 * 10**( 0.4 * (M_sol_I - iband_surf_br))
# convert sigma from pixels to arcsec
sigma = sigma_pix * scale

# Show contour plots of the results
plt.clf()
plt.subplot(121)
mge_print_contours(img.clip(minlevel), theta_mean, f.xpeak, f.ypeak, m.sol, s
                   binning=7, sigmapsf=sigmapsf, #normpsf=normpsf,
                   magrange=9)

# Extract the central part of the image to plot at high resolution.
# The MGE is centered to fractional pixel accuracy to ease visual comparson.

n = int(np.around(2/scale))
img_cen = img[f.xpeak-n:f.xpeak+n, f.ypeak-n:f.ypeak+n]
xc, yc = n - f.xpeak + f.xmed, n - f.ypeak + f.ymed
plt.subplot(122)
mge_print_contours(img_cen, theta_mean, xc, yc, m.sol,
```

```
                       sigmapsf=sigmapsf, #normpsf=normpsf,
                       scale=scale)
plt.pause(1)  # Allow plot to appear on the screen
```




```
Iteration:1  chi2: 2.747  Nonzero: 5/12
Iteration:11  chi2: 2.440  Nonzero: 4/12
Iteration:21  chi2: 2.436  Nonzero: 4/12
Nonzero Gaussians: 4/12
Eliminating not useful Gaussians...
Starting nonlinear fit...
Iteration:1  chi2: 2.428  Nonzero: 4/4
Nonzero Gaussians: 4/4
Eliminating not useful Gaussians...
All Gaussians are needed!
############################################
 Computation time: 0.41 seconds
  Total Iterations:  25
 Nonzero Gaussians:  4
  Unused Gaussians:  8
 Sectors used in the fit:  19
 Total number of points fitted:  287
 Chi2: 2.427
 STDEV: 0.09157
 MEANABSDEV: 0.07049
############################################
  Total_Counts  sigma_Pixels      q_obs
############################################
  8.050909e+02      1.62485     0.816537
  3.858726e+03      3.17038     0.786227
  6.682631e+03      7.92397     0.846848
  7.276328e+03      9.19698     0.780134
++++++++++++++++++++++++++++++++++++++++++++
```



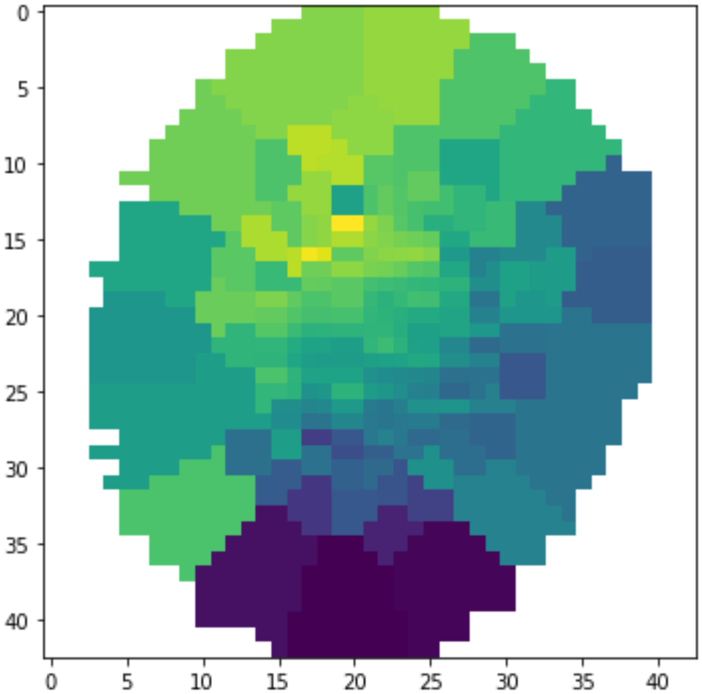


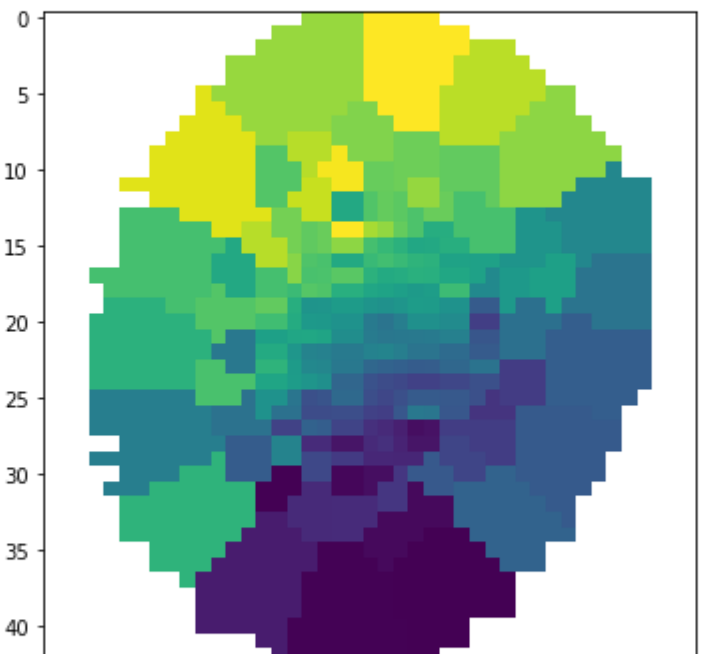
Try out JAM model step with the model that has psf 0.75

In [5]:

```
V = np.genfromtxt(file_dir + obj_name + '_V_2d.txt', delimiter=',')
dV = np.genfromtxt(file_dir + obj_name + '_dV_2d.txt', delimiter=',')
VD = np.genfromtxt(file_dir + obj_name + '_VD_2d.txt', delimiter=',')
dVD = np.genfromtxt(file_dir + obj_name + '_dVD_2d.txt', delimiter=',')
Vrms = np.sqrt(V**2 + VD**2)

plt.imshow(Vrms)
plt.figure()
plt.imshow(V)
```

Out[5]: <matplotlib.image.AxesImage at 0x7ff859f479d0>


0
5
10
15
20
25
30
35
40
0
5
10
15
20
25
30
35
40

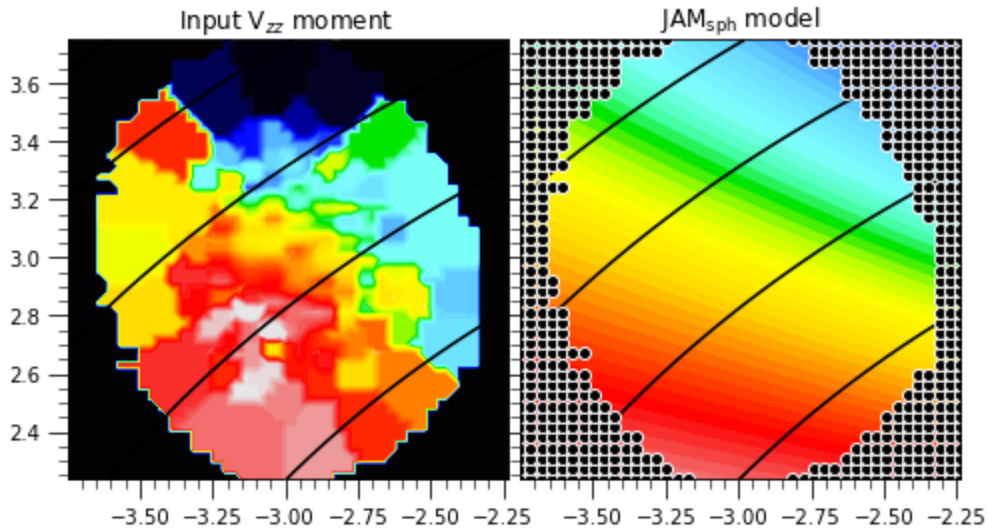

0
5
10
15
20
25
30
35
40

In [93]:
```
"""
    Copyright (C) 2019-2021, Michele Cappellari

    E-mail: michele.cappellari_at_physics.ox.ac.uk

    Updated versions of the software are available from my web page
    http://purl.org/cappellari/software

CHANGELOG
---------

V1.1.0: MC, Oxford, 16 July 2020
    - Compute both Vrms and LOS velocity.
V1.0.1: MC, Oxford, 21 April 2020
    - Made a separate file
V1.0.0: Michele Cappellari, Oxford, 08 November 2019
    - Written and tested

"""
import numpy as np
import matplotlib.pyplot as plt

from jampy.jam_axi_proj import jam_axi_proj
from jampy.jam_axi_proj import rotate_points
from plotbin.plot_velfield import plot_velfield

##############################################################################

#np.random.seed(123)
#xbin, ybin = np.random.uniform(low=[-55, -40], high=[55, 40], size=[1000, 2]

'''
What do I do for inclination?
'''
inclinations = np.arange(40,100,10)          # Assumed galaxy inclination

#r = np.sqrt(xbin**2 + (ybin/np.cos(np.radians(inc)))**2) # Radius in the pla
#a = 40                                                     # Scale length in a
#vr = 2000*np.sqrt(r)/(r + a)                               # Assumed velocity
#vel = vr * np.sin(np.radians(inc))*xbin/r                  # Projected velocit
#sig = 8700/(r + a)                                         # Assumed velocity
#rms = np.sqrt(vel**2 + sig**2)                             # Vrms field in km/

# Until here I computed some fake input kinematics to fit with JAM.
# Ina real application, instead of the above lines one will read the
# measured stellar kinematics, e.g. from integral-field spectroscopy

'''
Open kinematics maps
'''
V = np.genfromtxt(file_dir + obj_name + '_V_2d.txt', delimiter=',')
dV = np.genfromtxt(file_dir + obj_name + '_dV_2d.txt', delimiter=',')
VD = np.genfromtxt(file_dir + obj_name + '_VD_2d.txt', delimiter=',')
dVD = np.genfromtxt(file_dir + obj_name + '_dVD_2d.txt', delimiter=',')
# compute rms velocity
Vrms = np.sqrt(V**2 + VD**2)
dVrms = np.sqrt((dV*V)**2 + (dVD*VD)**2)/Vrms
```

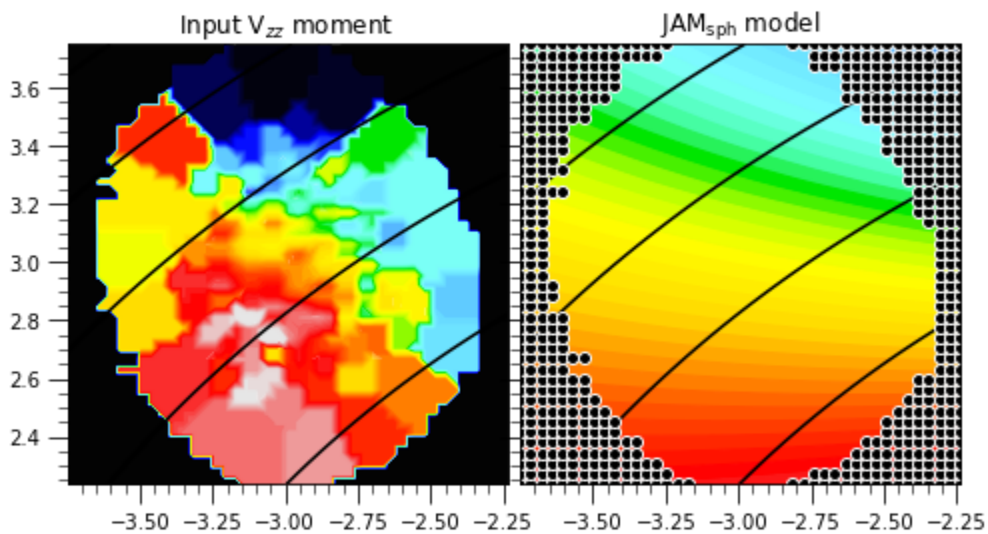
```
'''
x and y bins (pixels)
'''
# write the grid of xbins and ybins with (0,0) at the center and the x-axis c
# set x and y bins so that center is (0, 0)
size = V.shape[0]

xbin_arcsec = np.linspace(-np.floor(size/2), np.floor(size/2), size) * scale
ybin_arcsec = np.linspace(-np.floor(size/2), np.floor(size/2), size) * scale

# set PA from mean photometry fitting
PA = theta_mean

# set new arrays with the rotated coordinates
xbin_rot = np.zeros(size)
ybin_rot = np.zeros(size)

# rotate the coordinates and append to array
for i in range(len(xbin_arcsec)):
    for j in range(len(ybin_arcsec)):
        x_new, y_new = rotate_points(xbin_arcsec[i], ybin_arcsec[j], PA)
        xbin_rot[i] = x_new
        ybin_rot[j] = y_new

xbin, ybin = np.meshgrid(xbin_rot, ybin_rot)

'''
flatten data and bins
'''
V = V.flatten()
dV = dV.flatten()
VD = VD.flatten()
dVD = dVD.flatten()
Vrms = Vrms.flatten()
dVrms = dVrms.flatten()
xbin = xbin.flatten()
ybin = ybin.flatten()

'''
surface density
'''
# take the surface density, etc from mge
surf = surf_density # surf_dens_list[2] <- this was with psf 0.75
sigma = sigma #sigma_list[2]
qObs = q #q_list[2]

from astropy.cosmology import Planck18 as cosmo  # Planck 2018
# redshift, convert to angular diameter dist in Mpc
z = 0.195
distance = cosmo.angular_diameter_distance(z).value
mbh = 1e8 # Black hole mass in solar masses

# try different beta # TBD
#beta_list = [0.1,0.2,0.3,0.4,0.5]
beta = np.full_like(surf, 0.2)

# Below I assume mass follows light, but in a real application one
# will generally include a dark halo in surf_pot, sigma_pot, qobs_pot.
# See e.g. Cappellari (2013) for an example
```

```
# https://ui.adsabs.harvard.edu/abs/2013MNRAS.432.1709C

surf_lum = surf_pot = surf
sigma_lum = sigma_pot = sigma
qobs_lum = qobs_pot = qObs
sigmapsf = 0.75
sigmapsf = np.atleast_1d(sigmapsf)
sigmaX2 = sigma_lum**2 + sigmapsf[:, None]**2
sigmaY2 = (sigma_lum*qobs_lum)**2 + sigmapsf[:, None]**2
#normpsf = [0.7, 0.3]
pixsize = scale #0.8
goodbins = np.isfinite(Vrms) # take finite data

'''
run JAM
'''
# I use a loop below, just to higlight the fact that all parameters
# remain the same for the two JAM calls, except for 'moment' and 'data'
plt.figure(1)

reduced_chi_squared = np.zeros((len(inclinations)))
i=0
for inc in inclinations:
    print('####################################################')
    print(f'Inclination of {inc} degrees')
    #for moment, data, errors in zip(['zz', 'z'], [Vrms, V], [dVrms, dV]):
    #    print()
    #    print(f'Moment {moment}')
    moment = 'zz'
    data = Vrms
    errors = dVrms

    # The model is by design similar but not identical to the adopted kinemat
    m = jam_axi_proj(surf_lum, sigma_lum, qobs_lum, surf_pot, sigma_pot, qobs
                     inc, mbh, distance, xbin, ybin, plot=True, data=data, er
                     sigmapsf=sigmapsf, #normpsf=normpsf,
                     beta=beta, pixsize=pixsize,
                     moment=moment, goodbins=goodbins,
                     align='sph', ml=None, nodots=True)
    plt.pause(3)
    plt.figure(2)
    surf_pot *= m.ml  # Scale the density by the best fitting M/L from the pr
    reduced_chi_squared[i] = m.chi2
    i = i+1

# plot the inclinations
fig, axs = plt.subplots()
axs.plot(inclinations, reduced_chi_squared)
axs.set_ylabel(r'Reduced $\chi^2$')
axs.set_xlabel('Inclination')
```

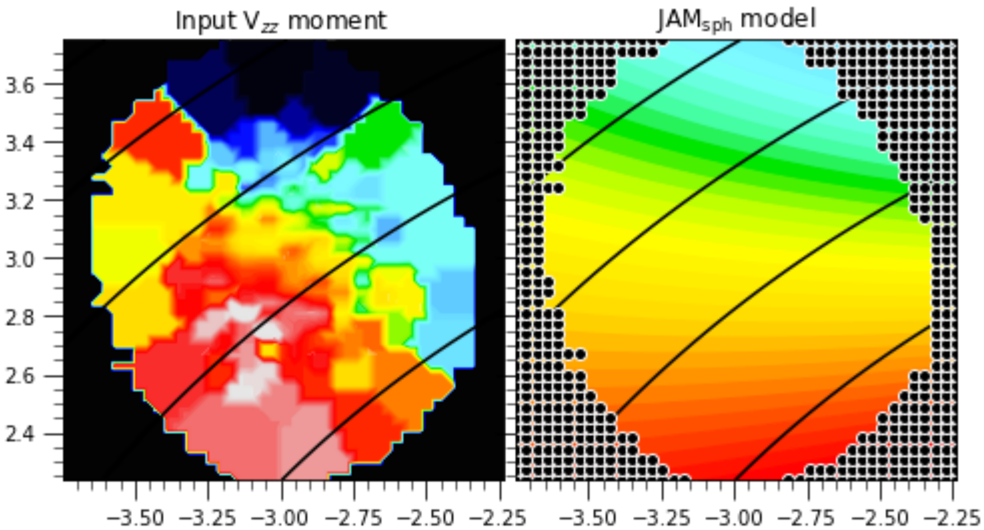
```
####################################################
Inclination of 40 degrees
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.74
inc=40.0; beta[0]=0.20; kappa=1.00; M/L=0.646; BH=6.5e+07; chi2/DOF=4.39
Total mass MGE (MSun): 1.720e+12
```



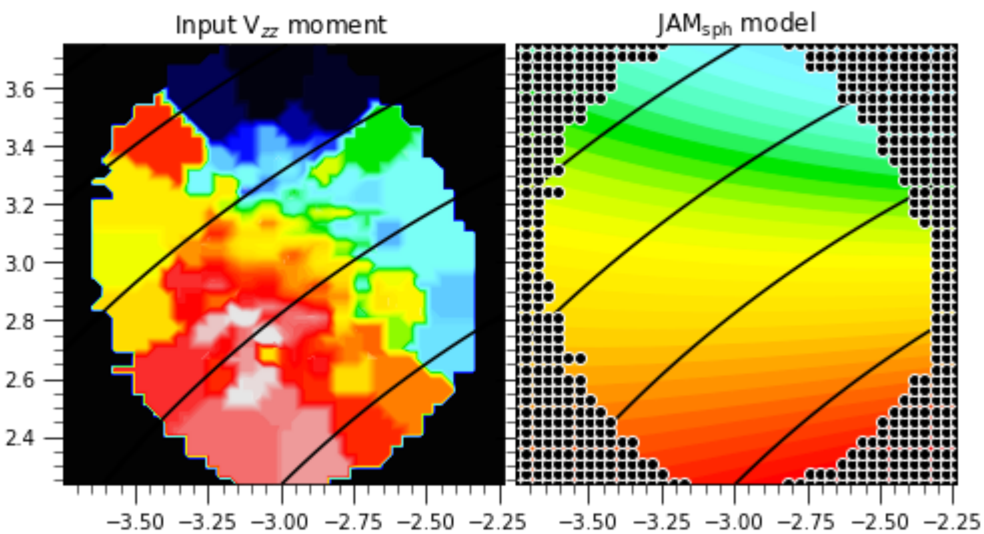

```
####################################################
Inclination of 50 degrees
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.70
inc=50.0; beta[0]=0.20; kappa=1.00; M/L=1.05; BH=1.0e+08; chi2/DOF=5.38
Total mass MGE (MSun): 1.804e+12
```



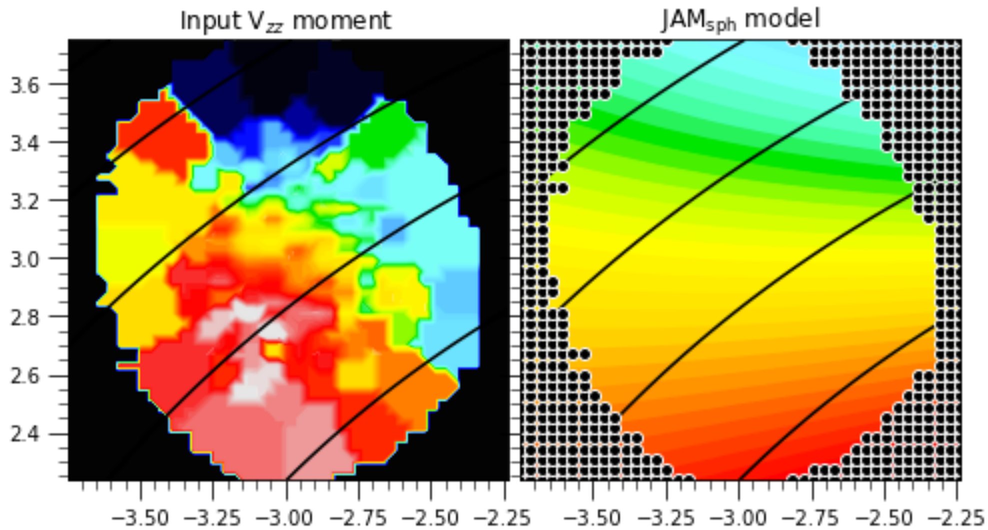

```
####################################################
Inclination of 60 degrees
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.60
inc=60.0; beta[0]=0.20; kappa=1.00; M/L=1.01; BH=1.0e+08; chi2/DOF=5.77
Total mass MGE (MSun): 1.817e+12
```



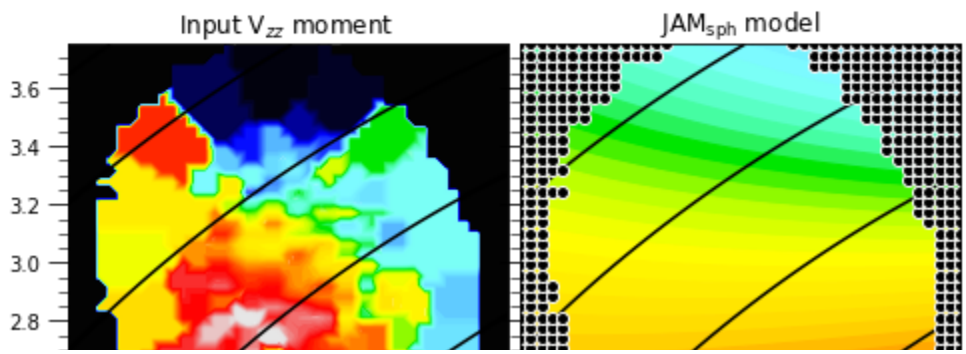

```
####################################################
Inclination of 70 degrees
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.35
inc=70.0; beta[0]=0.20; kappa=1.00; M/L=1.00; BH=1.0e+08; chi2/DOF=5.95
Total mass MGE (MSun): 1.821e+12
```




```
####################################################
Inclination of 80 degrees
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.31
inc=80.0; beta[0]=0.20; kappa=1.00; M/L=1.00; BH=1.0e+08; chi2/DOF=6.04
Total mass MGE (MSun): 1.823e+12
```




```
###################################################
Inclination of 90 degrees
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.34
inc=90.0; beta[0]=0.20; kappa=1.00; M/L=1.00; BH=1.0e+08; chi2/DOF=6.06
Total mass MGE (MSun): 1.824e+12
```



In [105…

```
# try for a different value of beta
"""
    Copyright (C) 2019-2021, Michele Cappellari

    E-mail: michele.cappellari_at_physics.ox.ac.uk

    Updated versions of the software are available from my web page
    http://purl.org/cappellari/software

CHANGELOG
---------

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"""
import numpy as np
import matplotlib.pyplot as plt

from jampy.jam_axi_proj import jam_axi_proj
from jampy.jam_axi_proj import rotate_points
from plotbin.plot_velfield import plot_velfield

##############################################################################

#np.random.seed(123)
#xbin, ybin = np.random.uniform(low=[-55, -40], high=[55, 40], size=[1000, 2]

'''
What do I do for inclination?
'''
inclinations = np.arange(40, 100, 10)         # Assumed galaxy inclination

#r = np.sqrt(xbin**2 + (ybin/np.cos(np.radians(inc)))**2) # Radius in the pla
#a = 40                                                    # Scale length in a
#vr = 2000*np.sqrt(r)/(r + a)                              # Assumed velocity
#vel = vr * np.sin(np.radians(inc))*xbin/r                 # Projected velocit
#sig = 8700/(r + a)                                        # Assumed velocity
#rms = np.sqrt(vel**2 + sig**2)                            # Vrms field in km/

# Until here I computed some fake input kinematics to fit with JAM.
# Ina real application, instead of the above lines one will read the
# measured stellar kinematics, e.g. from integral-field spectroscopy

'''
Open kinematics maps
'''
V = np.genfromtxt(file_dir + obj_name + '_V_2d.txt', delimiter=',')
dV = np.genfromtxt(file_dir + obj_name + '_dV_2d.txt', delimiter=',')
VD = np.genfromtxt(file_dir + obj_name + '_VD_2d.txt', delimiter=',')
dVD = np.genfromtxt(file_dir + obj_name + '_dVD_2d.txt', delimiter=',')
# compute rms velocity
Vrms = np.sqrt(V**2 + VD**2)
dVrms = np.sqrt((dV*V)**2 + (dVD*VD)**2)/Vrms
```
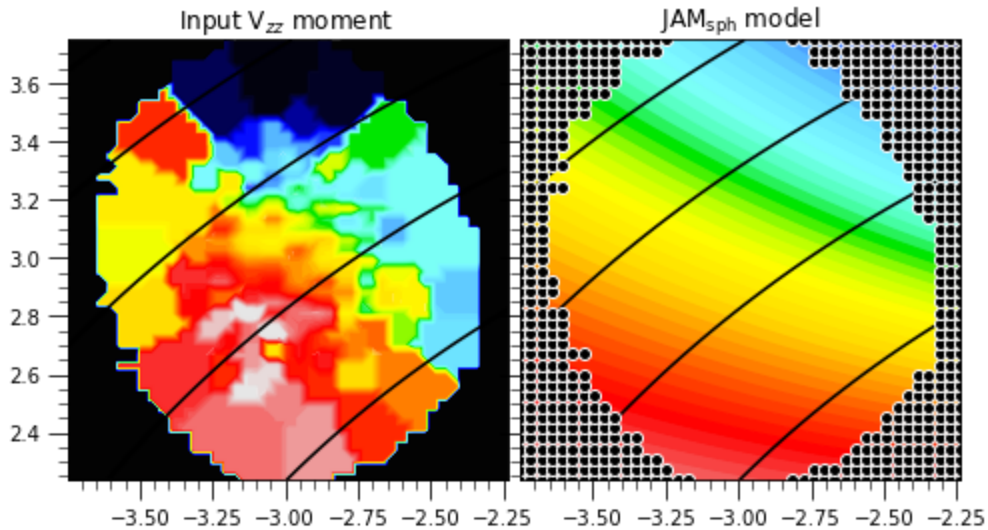
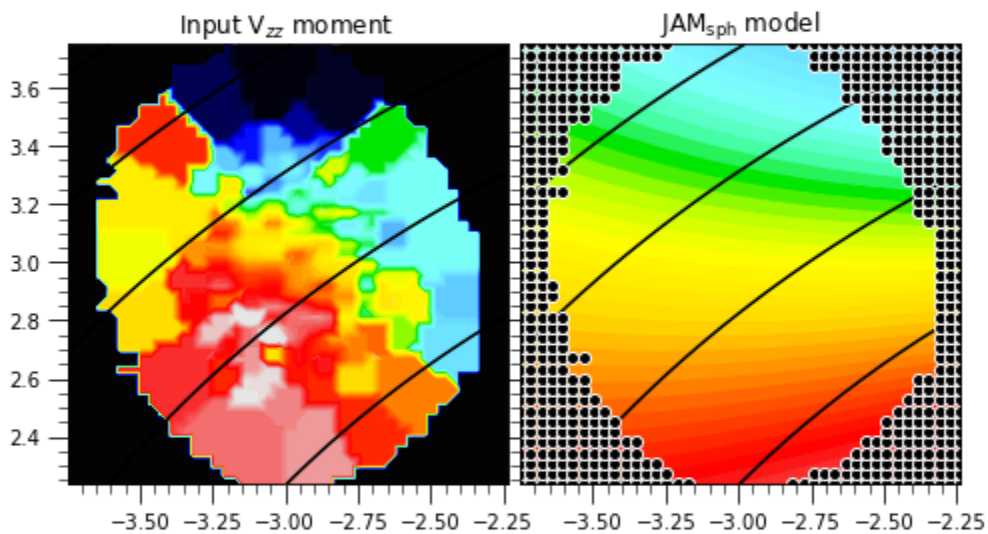

```
'''
x and y bins (pixels)
'''
# write the grid of xbins and ybins with (0,0) at the center and the x-axis c
# set x and y bins so that center is (0, 0)
size = V.shape[0]

xbin_arcsec = np.linspace(-np.floor(size/2), np.floor(size/2), size) * scale
ybin_arcsec = np.linspace(-np.floor(size/2), np.floor(size/2), size) * scale

# set PA from mean photometry fitting
PA = theta_mean

# set new arrays with the rotated coordinates
xbin_rot = np.zeros(size)
ybin_rot = np.zeros(size)

# rotate the coordinates and append to array
for i in range(len(xbin_arcsec)):
    for j in range(len(ybin_arcsec)):
        x_new, y_new = rotate_points(xbin_arcsec[i], ybin_arcsec[j], PA)
        xbin_rot[i] = x_new
        ybin_rot[j] = y_new

xbin, ybin = np.meshgrid(xbin_rot, ybin_rot)

'''
flatten data and bins
'''
V = V.flatten()
dV = dV.flatten()
VD = VD.flatten()
dVD = dVD.flatten()
Vrms = Vrms.flatten()
dVrms = dVrms.flatten()
xbin = xbin.flatten()
ybin = ybin.flatten()

'''
surface density
'''
# take the surface density, etc from mge
surf = surf_density # surf_dens_list[2] <- this was with psf 0.75
sigma = sigma #sigma_list[2]
qObs = q #q_list[2]

from astropy.cosmology import Planck18 as cosmo  # Planck 2018
# redshift, convert to angular diameter dist in Mpc
z = 0.195
distance = cosmo.angular_diameter_distance(z).value
mbh = 1e8 # Black hole mass in solar masses

# try different beta # TBD
#beta_list = [0.1,0.2,0.3,0.4,0.5]
beta = np.full_like(surf, 0.5)

# Below I assume mass follows light, but in a real application one
# will generally include a dark halo in surf_pot, sigma_pot, qobs_pot.
```

```
# See e.g. Cappellari (2013) for an example
# https://ui.adsabs.harvard.edu/abs/2013MNRAS.432.1709C

surf_lum = surf_pot = surf
sigma_lum = sigma_pot = sigma
qobs_lum = qobs_pot = qObs
sigmapsf = 0.75
sigmapsf = np.atleast_1d(sigmapsf)
sigmaX2 = sigma_lum**2 + sigmapsf[:, None]**2
sigmaY2 = (sigma_lum*qobs_lum)**2 + sigmapsf[:, None]**2
#normpsf = [0.7, 0.3]
pixsize = scale #0.8
goodbins = np.isfinite(Vrms) # take finite data

'''
run JAM
'''
# I use a loop below, just to higlight the fact that all parameters
# remain the same for the two JAM calls, except for 'moment' and 'data'
plt.figure(1)

reduced_chi_squared = np.zeros((len(inclinations)))
i=0
for inc in inclinations:
    print('####################################################')
    print(f'Inclination of {inc} degrees')
    #for moment, data, errors in zip(['zz', 'z'], [Vrms, V], [dVrms, dV]):
    #    print()
    #    print(f'Moment {moment}')
    moment = 'zz'
    data = Vrms
    errors = dVrms

    # The model is by design similar but not identical to the adopted kinemat
    m = jam_axi_proj(surf_lum, sigma_lum, qobs_lum, surf_pot, sigma_pot, qobs
                     inc, mbh, distance, xbin, ybin, plot=True, data=data, er
                     sigmapsf=sigmapsf, #normpsf=normpsf,
                     beta=beta, pixsize=pixsize,
                     moment=moment, goodbins=goodbins,
                     align='sph', ml=None, nodots=True)
    plt.pause(3)
    plt.figure(2)
    surf_pot *= m.ml  # Scale the density by the best fitting M/L from the pr
    reduced_chi_squared[i] = m.chi2
    i = i+1

# plot the inclinations
fig, axs = plt.subplots()
axs.plot(inclinations, reduced_chi_squared)
axs.set_ylabel(r'Reduced $\chi^2$')
axs.set_xlabel('Inclination')
```

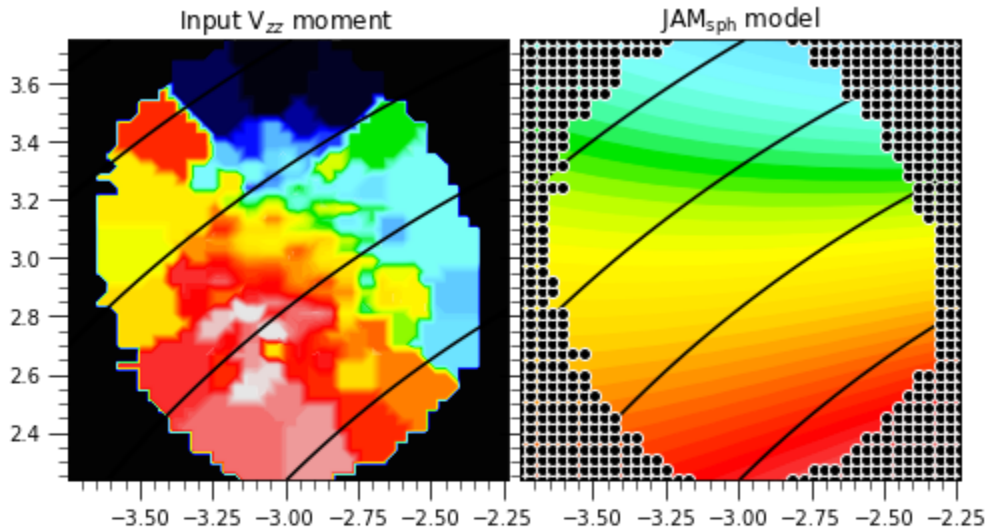
```
####################################################
Inclination of 40 degrees
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.59
inc=40.0; beta[0]=0.50; kappa=1.00; M/L=0.623; BH=6.2e+07; chi2/DOF=4.55
Total mass MGE (MSun): 1.996e+12
```



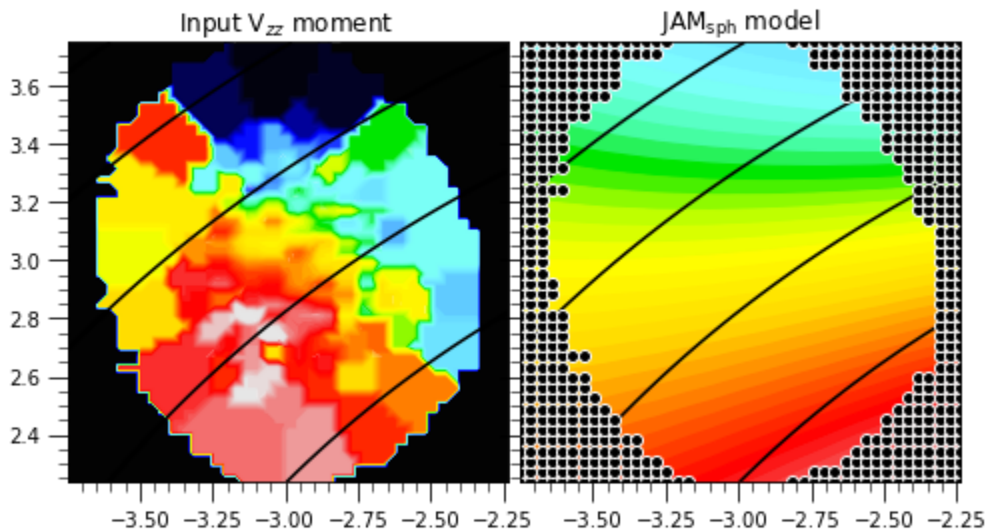

```
####################################################
Inclination of 50 degrees
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.71
inc=50.0; beta[0]=0.50; kappa=1.00; M/L=1.21; BH=1.2e+08; chi2/DOF=5.44
Total mass MGE (MSun): 2.416e+12
```



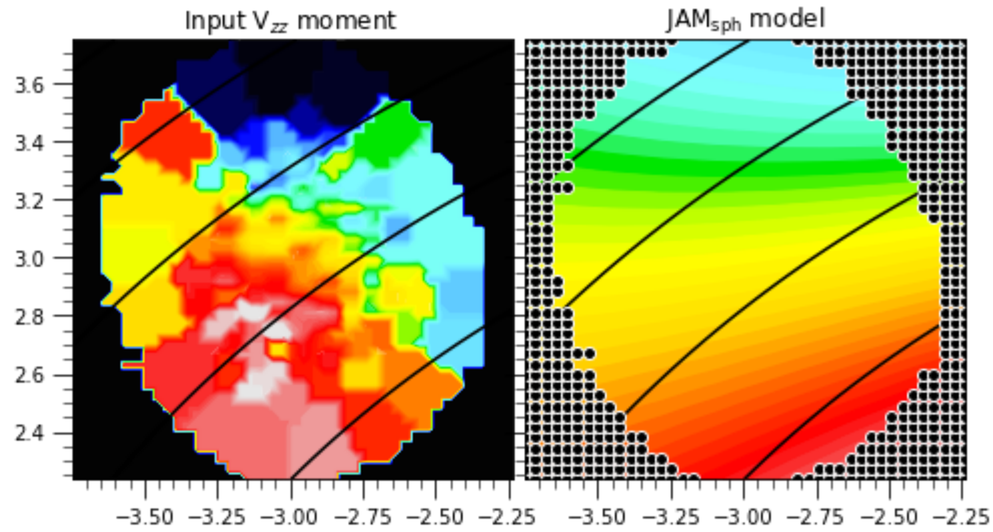

```
####################################################
Inclination of 60 degrees
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.46
inc=60.0; beta[0]=0.50; kappa=1.00; M/L=1.06; BH=1.1e+08; chi2/DOF=5.69
Total mass MGE (MSun): 2.557e+12
```



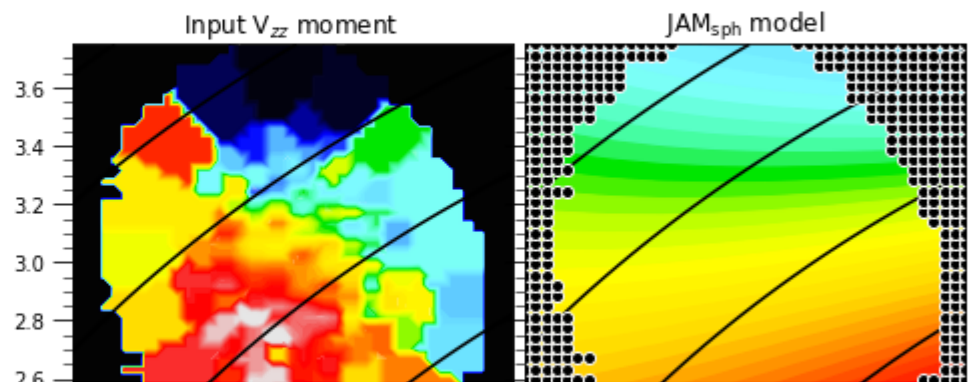

```
#####################################################
Inclination of 70 degrees
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.42
inc=70.0; beta[0]=0.50; kappa=1.00; M/L=1.03; BH=1.0e+08; chi2/DOF=5.80
Total mass MGE (MSun): 2.623e+12
```




```
#####################################################
Inclination of 80 degrees
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.46
inc=80.0; beta[0]=0.50; kappa=1.00; M/L=1.01; BH=1.0e+08; chi2/DOF=5.85
Total mass MGE (MSun): 2.655e+12
```




```
##################################################
Inclination of 90 degrees
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.51
inc=90.0; beta[0]=0.50; kappa=1.00; M/L=1.00; BH=1.0e+08; chi2/DOF=5.86
Total mass MGE (MSun): 2.664e+12
```



take it at 40 degrees and vary beta

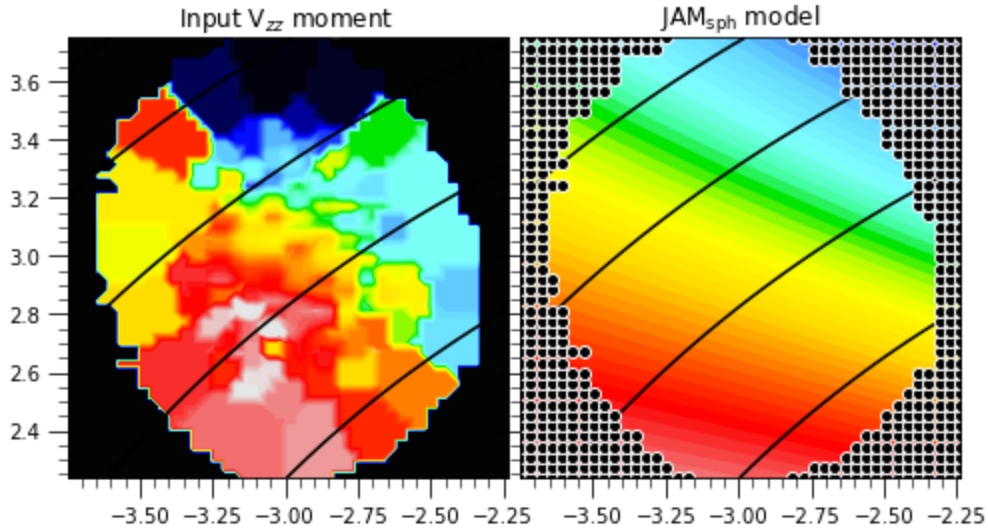
In [101…

```
# try for a different value of beta
"""
    Copyright (C) 2019-2021, Michele Cappellari

    E-mail: michele.cappellari_at_physics.ox.ac.uk

    Updated versions of the software are available from my web page
    http://purl.org/cappellari/software

CHANGELOG
---------

V1.1.0: MC, Oxford, 16 July 2020
    - Compute both Vrms and LOS velocity.
V1.0.1: MC, Oxford, 21 April 2020
    - Made a separate file
V1.0.0: Michele Cappellari, Oxford, 08 November 2019
    - Written and tested

"""
import numpy as np
import matplotlib.pyplot as plt

from jampy.jam_axi_proj import jam_axi_proj
from jampy.jam_axi_proj import rotate_points
from plotbin.plot_velfield import plot_velfield

##############################################################################

#np.random.seed(123)
#xbin, ybin = np.random.uniform(low=[-55, -40], high=[55, 40], size=[1000, 2]

'''
What do I do for inclination?
'''
#inclinations = [40.,45.,50.,55.,60.,65.,70.,75.,80.,85.,90.]          # Assu
inc = 40.

#r = np.sqrt(xbin**2 + (ybin/np.cos(np.radians(inc)))**2) # Radius in the pla
#a = 40                                                   # Scale length in a
#vr = 2000*np.sqrt(r)/(r + a)                             # Assumed velocity
#vel = vr * np.sin(np.radians(inc))*xbin/r                # Projected velocit
#sig = 8700/(r + a)                                       # Assumed velocity
#rms = np.sqrt(vel**2 + sig**2)                           # Vrms field in km/

# Until here I computed some fake input kinematics to fit with JAM.
# Ina real application, instead of the above lines one will read the
# measured stellar kinematics, e.g. from integral-field spectroscopy

'''
Open kinematics maps
'''
V = np.genfromtxt(file_dir + obj_name + '_V_2d.txt', delimiter=',')
dV = np.genfromtxt(file_dir + obj_name + '_dV_2d.txt', delimiter=',')
VD = np.genfromtxt(file_dir + obj_name + '_VD_2d.txt', delimiter=',')
dVD = np.genfromtxt(file_dir + obj_name + '_dVD_2d.txt', delimiter=',')
# compute rms velocity
Vrms = np.sqrt(V**2 + VD**2)
```

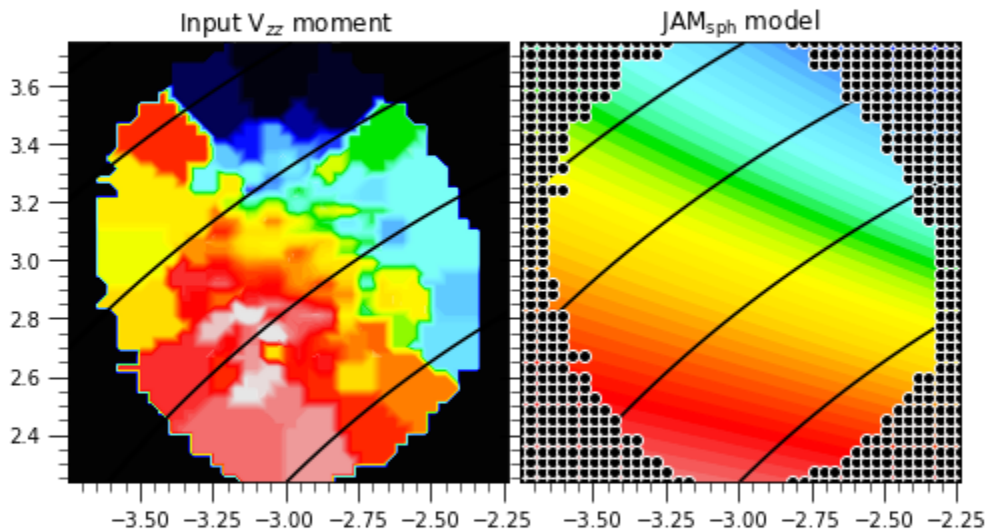
```
dVrms = np.sqrt((dV*V)**2 + (dVD*VD)**2)/Vrms

'''
x and y bins (pixels)
'''
# write the grid of xbins and ybins with (0,0) at the center and the x-axis c
# set x and y bins so that center is (0, 0)
size = V.shape[0]

xbin_arcsec = np.linspace(-np.floor(size/2), np.floor(size/2), size) * scale
ybin_arcsec = np.linspace(-np.floor(size/2), np.floor(size/2), size) * scale

# set PA from mean photometry fitting
PA = theta_mean

# set new arrays with the rotated coordinates
xbin_rot = np.zeros(size)
ybin_rot = np.zeros(size)

# rotate the coordinates and append to array
for i in range(len(xbin_arcsec)):
    for j in range(len(ybin_arcsec)):
        x_new, y_new = rotate_points(xbin_arcsec[i], ybin_arcsec[j], PA)
        xbin_rot[i] = x_new
        ybin_rot[j] = y_new

xbin, ybin = np.meshgrid(xbin_rot, ybin_rot)

'''
flatten data and bins
'''
V = V.flatten()
dV = dV.flatten()
VD = VD.flatten()
dVD = dVD.flatten()
Vrms = Vrms.flatten()
dVrms = dVrms.flatten()
xbin = xbin.flatten()
ybin = ybin.flatten()

'''
surface density
'''
# take the surface density, etc from mge
surf = surf_density # surf_dens_list[2] <- this was with psf 0.75
sigma = sigma #sigma_list[2]
qObs = q #q_list[2]

from astropy.cosmology import Planck18 as cosmo  # Planck 2018
# redshift, convert to angular diameter dist in Mpc
z = 0.195
distance = cosmo.angular_diameter_distance(z).value
mbh = 1e8 # Black hole mass in solar masses

# try different beta # TBD
betas = np.arange(0.05, 0.5, 0.05)

# Below I assume mass follows light, but in a real application one
# will generally include a dark halo in surf_pot, sigma_pot, qobs_pot.
```

```
# See e.g. Cappellari (2013) for an example
# https://ui.adsabs.harvard.edu/abs/2013MNRAS.432.1709C

surf_lum = surf_pot = surf
sigma_lum = sigma_pot = sigma
qobs_lum = qobs_pot = qObs
sigmapsf = 0.75
sigmapsf = np.atleast_1d(sigmapsf)
sigmaX2 = sigma_lum**2 + sigmapsf[:, None]**2
sigmaY2 = (sigma_lum*qobs_lum)**2 + sigmapsf[:, None]**2
#normpsf = [0.7, 0.3]
pixsize = scale #0.8
goodbins = np.isfinite(Vrms) # take finite data

'''
run JAM
'''
# I use a loop below, just to higlight the fact that all parameters
# remain the same for the two JAM calls, except for 'moment' and 'data'
plt.figure(1)

reduced_chi_squared = np.zeros((len(betas)))
i=0
for beta in betas:
    print('####################################################')
    print(f'Beta={beta}')
    beta = np.full_like(surf, beta)
    #for moment, data, errors in zip(['zz', 'z'], [Vrms, V], [dVrms, dV]):
    #    print()
    #    print(f'Moment {moment}')
    moment = 'zz'
    data = Vrms
    errors = dVrms

    # The model is by design similar but not identical to the adopted kinemat
    m = jam_axi_proj(surf_lum, sigma_lum, qobs_lum, surf_pot, sigma_pot, qobs
                     inc, mbh, distance, xbin, ybin, plot=True, data=data, er
                     sigmapsf=sigmapsf, #normpsf=normpsf,
                     beta=beta, pixsize=pixsize,
                     moment=moment, goodbins=goodbins,
                     align='sph', ml=None, nodots=True)
    plt.pause(3)
    plt.figure(2)
    surf_pot *= m.ml  # Scale the density by the best fitting M/L from the pr
    reduced_chi_squared[i] = m.chi2
    i = i+1

# plot the inclinations
fig, axs = plt.subplots()
axs.plot(betas, reduced_chi_squared)
axs.set_ylabel(r'Reduced $\chi^2$')
axs.set_xlabel(r'$\beta$')
```

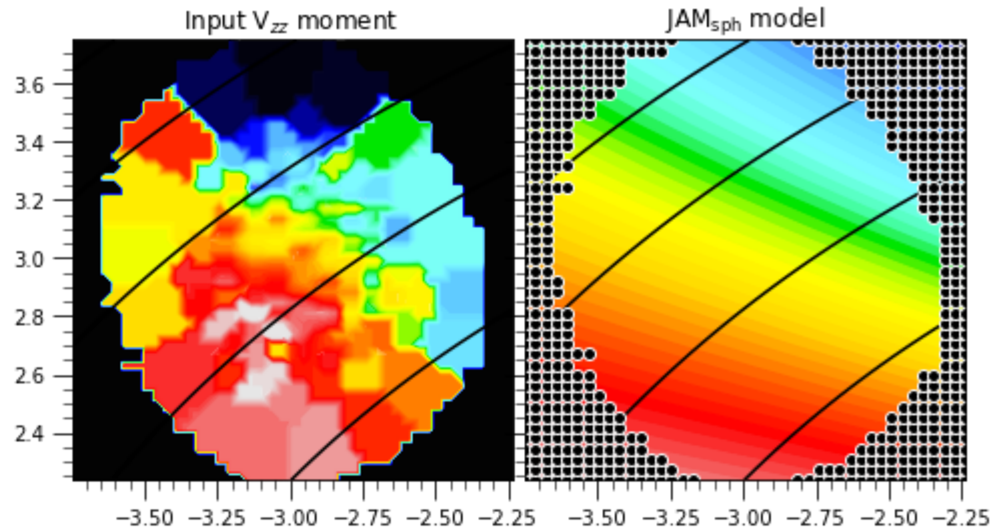
```
####################################################
Beta=0.05
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.69
inc=40.0; beta[0]=0.050; kappa=1.00; M/L=1.01; BH=1.0e+08; chi2/DOF=4.36
Total mass MGE (MSun): 1.648e+12
```



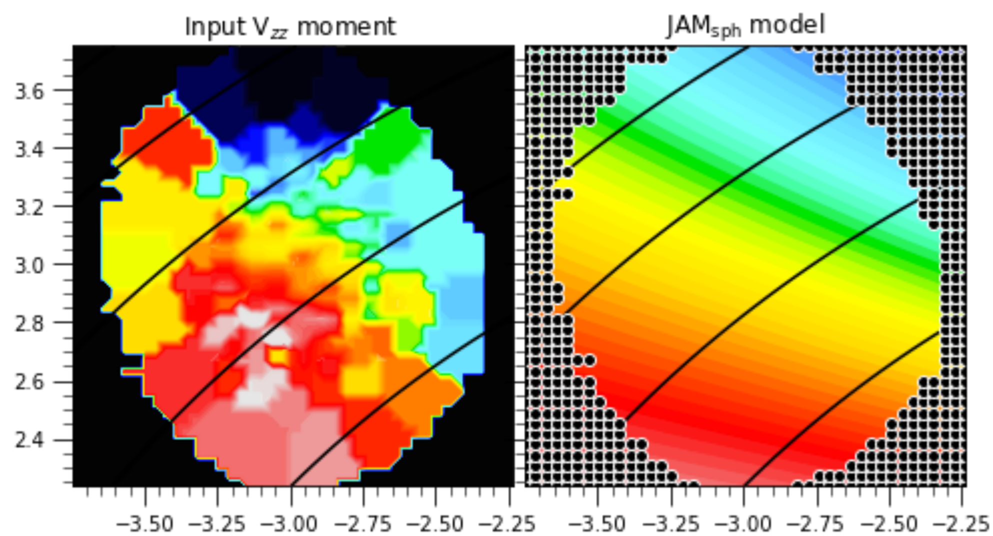

```
###################################################
Beta=0.1
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.74
inc=40.0; beta[0]=0.10; kappa=1.00; M/L=1.01; BH=1.0e+08; chi2/DOF=4.37
Total mass MGE (MSun): 1.669e+12
```



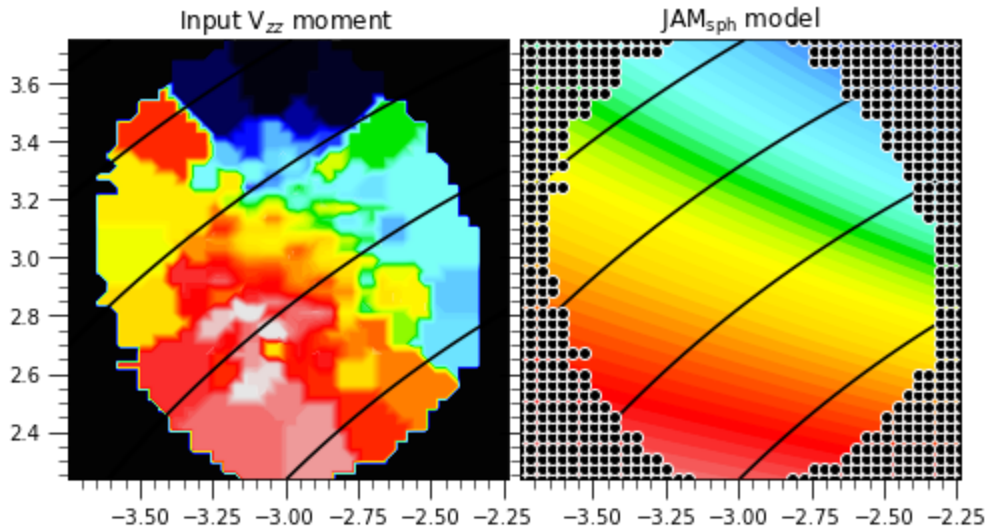

```
###################################################
Beta=0.15000000000000002
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.75
inc=40.0; beta[0]=0.15; kappa=1.00; M/L=1.01; BH=1.0e+08; chi2/DOF=4.38
Total mass MGE (MSun): 1.693e+12
```



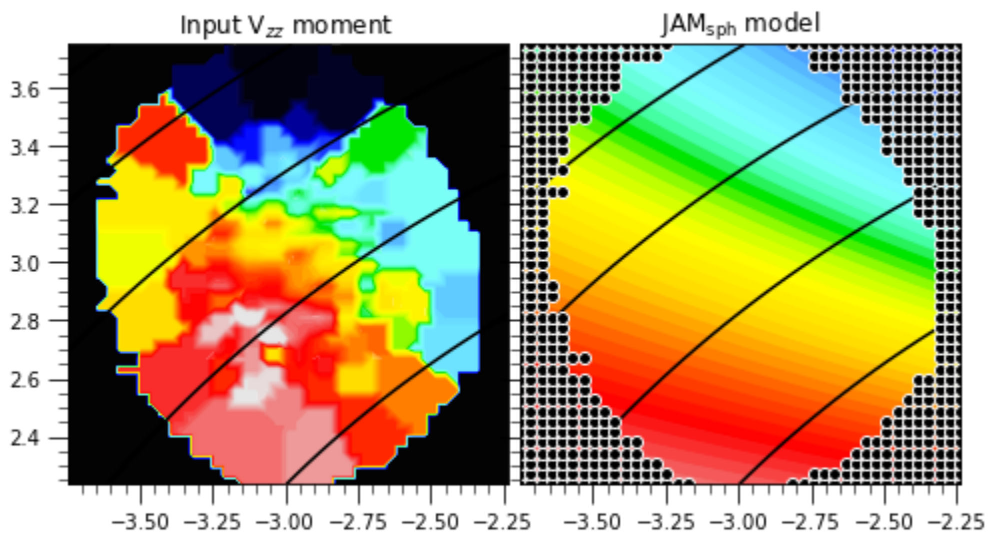

```
####################################################
Beta=0.2
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.86
inc=40.0; beta[0]=0.20; kappa=1.00; M/L=1.02; BH=1.0e+08; chi2/DOF=4.39
Total mass MGE (MSun): 1.720e+12
```



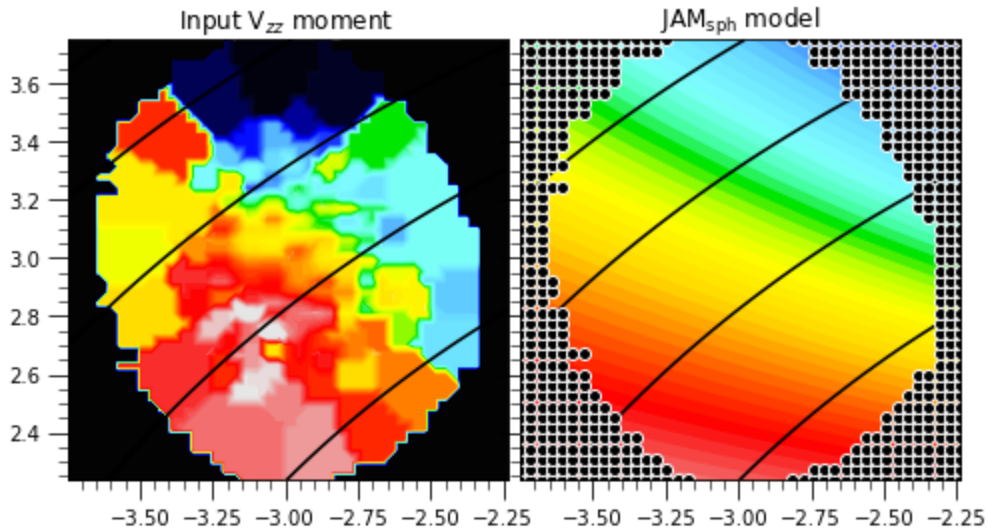

```
####################################################
Beta=0.25
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.72
inc=40.0; beta[0]=0.25; kappa=1.00; M/L=1.02; BH=1.0e+08; chi2/DOF=4.41
Total mass MGE (MSun): 1.751e+12
```



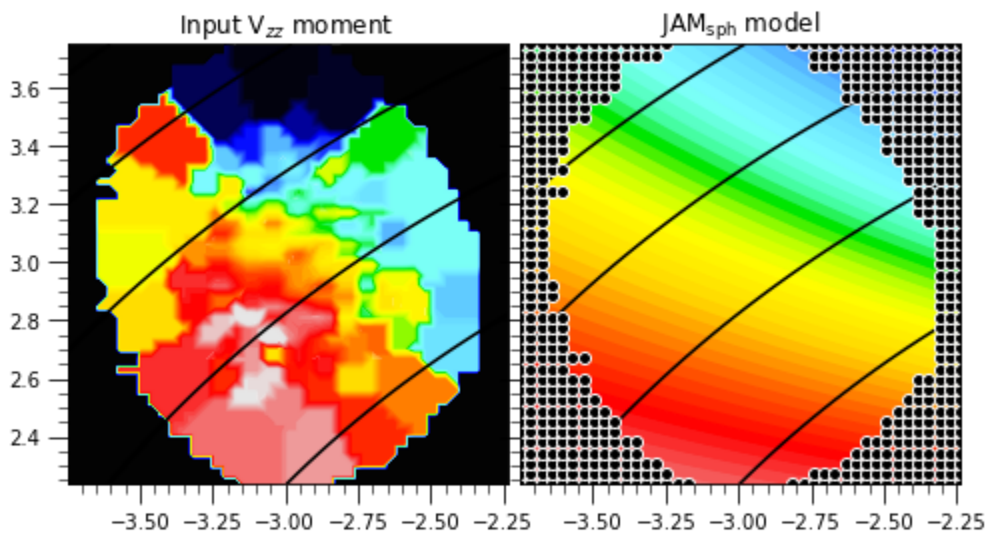

```
####################################################
Beta=0.3
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.68
inc=40.0; beta[0]=0.30; kappa=1.00; M/L=1.02; BH=1.0e+08; chi2/DOF=4.42
Total mass MGE (MSun): 1.786e+12
```




```
####################################################
Beta=0.35000000000000003
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.70
inc=40.0; beta[0]=0.35; kappa=1.00; M/L=1.02; BH=1.0e+08; chi2/DOF=4.45
Total mass MGE (MSun): 1.826e+12
```




```
#####################################################
Beta=0.4
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.76
inc=40.0; beta[0]=0.40; kappa=1.00; M/L=1.03; BH=1.0e+08; chi2/DOF=4.47
Total mass MGE (MSun): 1.874e+12
```

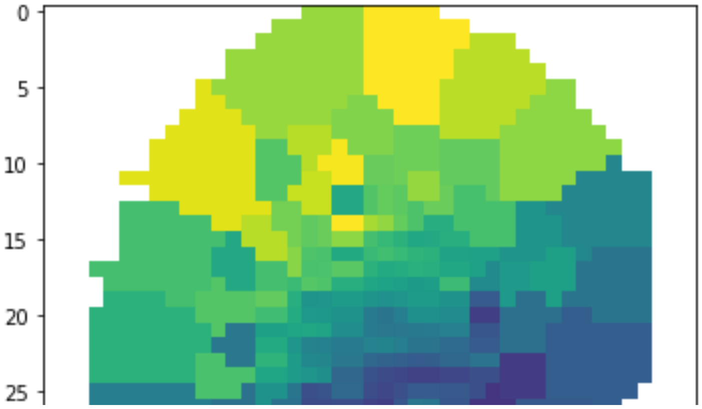



```
#####################################################
Beta=0.45
jam_axi_proj_sph_zz (analytic_los=False) elapsed time sec: 1.65
inc=40.0; beta[0]=0.45; kappa=1.00; M/L=1.03; BH=1.0e+08; chi2/DOF=4.50
```

In [31]:

```
V = np.genfromtxt(file_dir + obj_name + '_V_2d.txt', delimiter=',')
plt.imshow(V)
```

Out[31]: <matplotlib.image.AxesImage at 0x7ff85c8ce210>

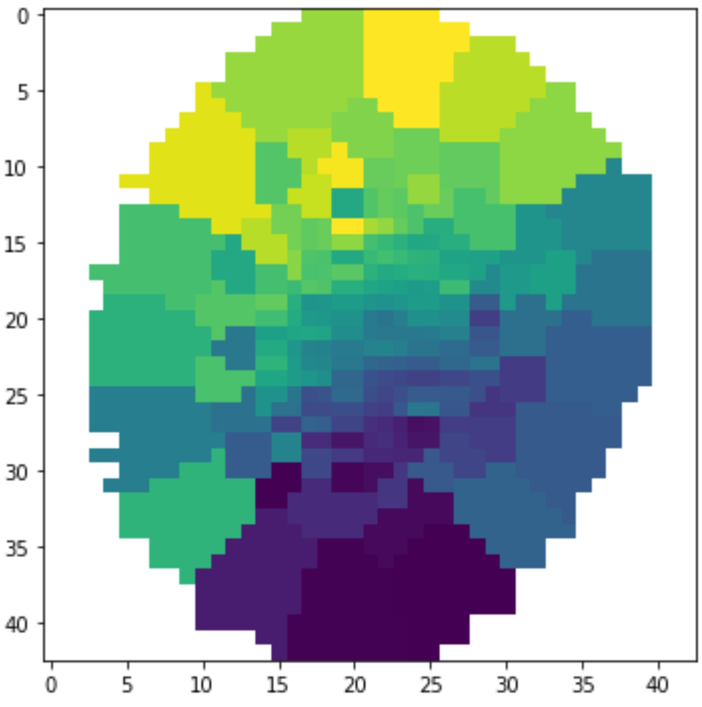


In [47]:
```
#The image is flipped vertically!!!
```

Out[47]: '\nThe image is flipped vertically!!!! This was so weird to try to figure ou
t.\n'

In [51]:
```
V = V.flatten()
V = V.reshape(43,43)
plt.imshow(V)

#Does it get flipped in JAM?
```

Out[51]: <matplotlib.image.AxesImage at 0x7ff85c285610>



In [ ]: