

DeepTrack - Example 1b - Training

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Example 1b: Training of DeepTrack 1.0

Example code to train DeepTrack.

DeepTrack

DeepTrack - Example 1a - Tracking single particle 1.0 Digital Video Microscopy enhanced with Deep Learning version 1.0

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1. INITIALIZATION

```
In [1]: import deeptrack
```

2. DEFINE AND CHECK IMAGE GENERATION ROUTINE

Here, we simulate images of a variety of single particles. The particle position is chosen randomly from a normal distribution with mean of 0 and standard deviation of 1 pixel. The particle has a radius between 1.5 and 3 pixels, and a point-spread function obtained from Bessel function of the first kind of first or second order with positive or negative intensity. The image background, SNR and gradient intensity are randomly selected from a wide range of values. This results in particle images corresponding to dark or bright spots or rings of different intensities on a bright or dark background with varying SNR and gradient intensity.

This image generator was used to train the pretrained network saved in the file "DeepTrack - Example 1a - Pretrained network.h5".

Comments:

1. The `image_parameters_function` is a lambda function that determines the kind of particle images for which the deep learning network will be trained. Tuning its parameters is the simplest way to improve the tracking performance.
2. The `image_generator` is a lambda function that works as image generator. It does not need to be changed in most cases.
3. The parameter `number_of_images_to_show` determines the number of sample images that are shown.
4. The red symbol superimposed to the images represents the ground truth particle position.

```

In [2]: ### Define image properties
        %matplotlib inline
        from numpy.random import randint, uniform, normal, choice
        from math import pi

        image_parameters_function = lambda : deeptrack.get_image_parameters(
            particle_center_x_list=lambda : normal(0, 1, 1),
            particle_center_y_list=lambda : normal(0, 1, 1),
            particle_radius_list=lambda : uniform(1.5, 3, 1),
            particle_bessel_orders_list=lambda : [[randint(1, 3),], ], ],
            particle_intensities_list=lambda : [[choice([-1, 1]) * uniform(.2, .6, 1), ], ],
            image_half_size=lambda : 25,
            image_background_level=lambda : uniform(.2, .8),
            signal_to_noise_ratio=lambda : uniform(10, 100),
            gradient_intensity=lambda : uniform(0, 1),
            gradient_direction=lambda : uniform(-pi, pi),
            ellipsoidal_orientation=lambda : uniform(-pi, pi, 1),
            ellipticity=lambda : 1)

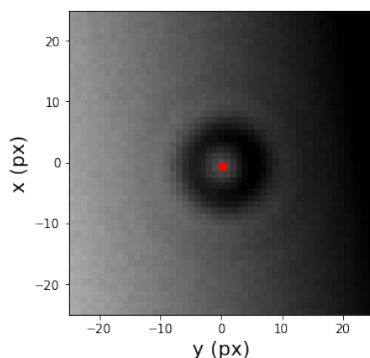
        ### Define image generator
        image_generator = lambda : deeptrack.get_image_generator(image_parameters_function)

        ### Show some examples of generated images
        number_of_images_to_show = 100

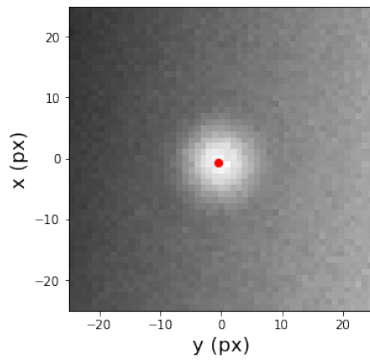
        for image_number, image, image_parameters in image_generator():
            if image_number >= number_of_images_to_show:
                break

            deeptrack.plot_sample_image(image, image_parameters)

```

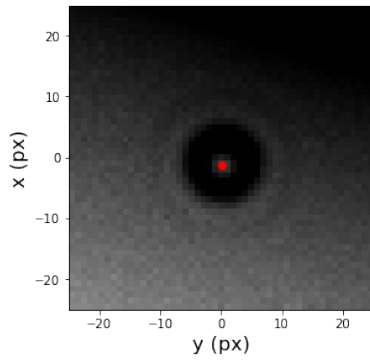


particle center x = -0.70 px	image half size = 25.00 px
particle center y = 0.29 px	image background level = 0.30
particle radius = 2.15 px	signal to noise ratio = 79.66
Bessel order = 2.00	gradient intensity = 0.92
particle intensity = -0.34	gradient direction = -3.00
ellipsoidal_orientation = 3.04	
ellipticity = 1.00	



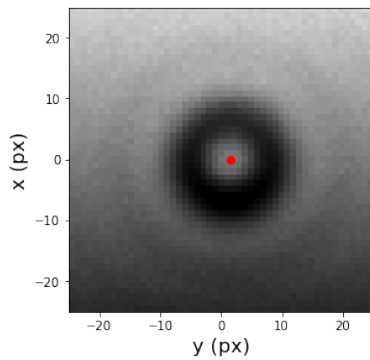
particle center x = -0.68 px
 particle center y = -0.44 px
 particle radius = 2.93 px
 Bessel order = 1.00
 particle intensity = 0.53
 ellipsoidal_orientation = -1.58
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.44
 signal to noise ratio = 45.81
 gradient intensity = 0.58
 gradient direction = -0.17



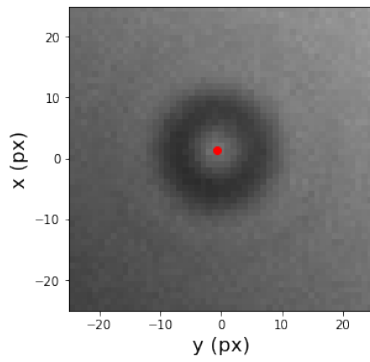
particle center x = -1.24 px
 particle center y = 0.24 px
 particle radius = 1.78 px
 Bessel order = 2.00
 particle intensity = -0.47
 ellipsoidal_orientation = 2.98
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.20
 signal to noise ratio = 34.04
 gradient intensity = 0.73
 gradient direction = -1.89



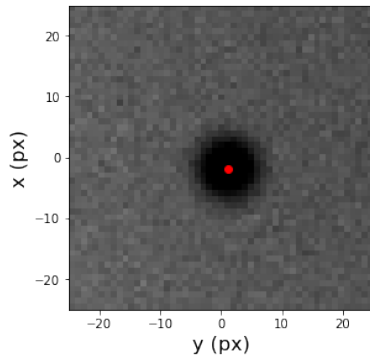
particle center x = -0.16 px
 particle center y = 1.51 px
 particle radius = 2.89 px
 Bessel order = 2.00
 particle intensity = -0.58
 ellipsoidal_orientation = -2.54
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.49
 signal to noise ratio = 65.18
 gradient intensity = 0.94
 gradient direction = 1.58



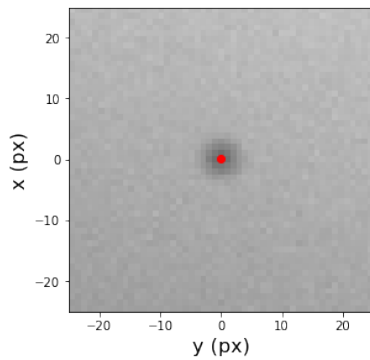
particle center x = 1.35 px
 particle center y = -0.63 px
 particle radius = 2.84 px
 Bessel order = 2.00
 particle intensity = -0.29
 ellipsoidal_orientation = -2.05
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.43
 signal to noise ratio = 59.72
 gradient intensity = 0.35
 gradient direction = 0.81



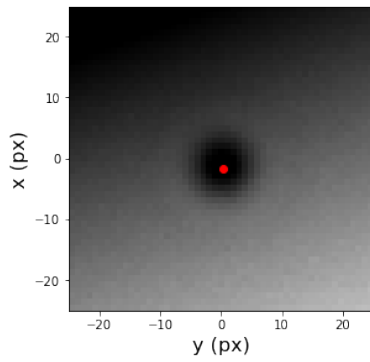
particle center x = -1.83 px
 particle center y = 1.17 px
 particle radius = 2.70 px
 Bessel order = 1.00
 particle intensity = -0.58
 ellipsoidal_orientation = 0.56
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.35
 signal to noise ratio = 20.90
 gradient intensity = 0.09
 gradient direction = -2.82



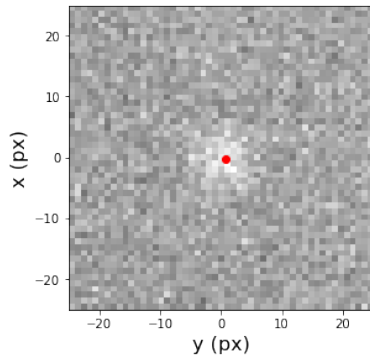
particle center x = 0.11 px
 particle center y = -0.01 px
 particle radius = 1.60 px
 Bessel order = 1.00
 particle intensity = -0.26
 ellipsoidal_orientation = 1.09
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.69
 signal to noise ratio = 72.82
 gradient intensity = 0.16
 gradient direction = 1.28



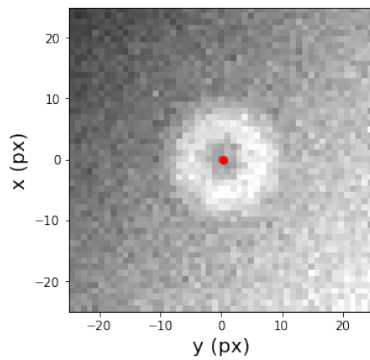
particle center x = -1.63 px
 particle center y = 0.38 px
 particle radius = 2.54 px
 Bessel order = 1.00
 particle intensity = -0.40
 ellipsoidal_orientation = -1.45
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.31
 signal to noise ratio = 99.06
 gradient intensity = 0.95
 gradient direction = -1.22



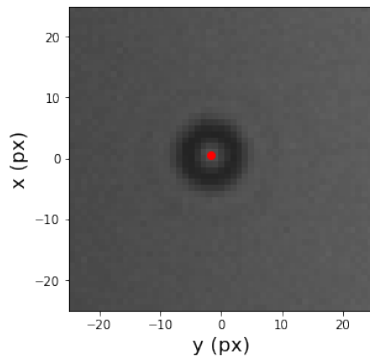
particle center x = -0.28 px
 particle center y = 0.68 px
 particle radius = 2.44 px
 Bessel order = 1.00
 particle intensity = 0.24
 ellipsoidal_orientation = 1.92
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.65
 signal to noise ratio = 11.31
 gradient intensity = 0.02
 gradient direction = 0.29



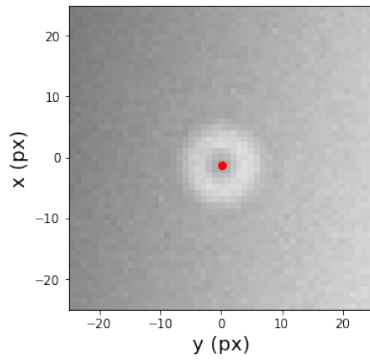
particle center x = -0.08 px
 particle center y = 0.33 px
 particle radius = 2.44 px
 Bessel order = 2.00
 particle intensity = 0.43
 ellipsoidal_orientation = -1.62
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.60
 signal to noise ratio = 16.89
 gradient intensity = 0.72
 gradient direction = -0.66



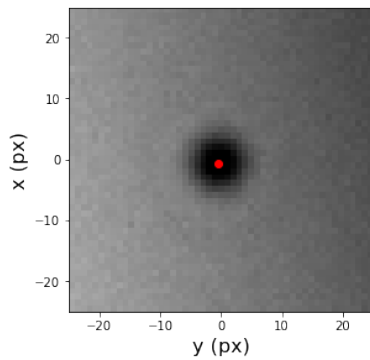
particle center x = 0.50 px
 particle center y = -1.70 px
 particle radius = 1.64 px
 Bessel order = 2.00
 particle intensity = -0.25
 ellipsoidal_orientation = 3.09
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.33
 signal to noise ratio = 98.20
 gradient intensity = 0.11
 gradient direction = 0.09



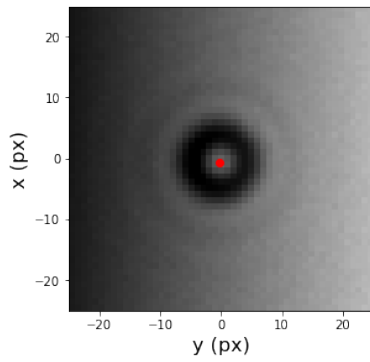
particle center x = -1.32 px
 particle center y = 0.07 px
 particle radius = 1.77 px
 Bessel order = 2.00
 particle intensity = 0.24
 ellipsoidal_orientation = 2.19
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.66
 signal to noise ratio = 79.85
 gradient intensity = 0.43
 gradient direction = -0.23



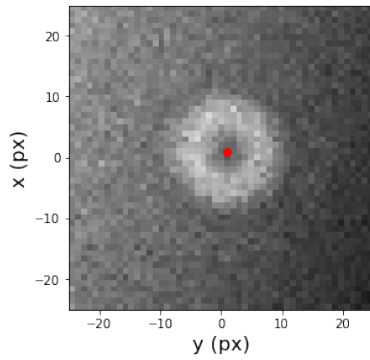
particle center x = -0.63 px
 particle center y = -0.51 px
 particle radius = 2.39 px
 Bessel order = 1.00
 particle intensity = -0.57
 ellipsoidal_orientation = 1.12
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.47
 signal to noise ratio = 54.66
 gradient intensity = 0.45
 gradient direction = -2.90



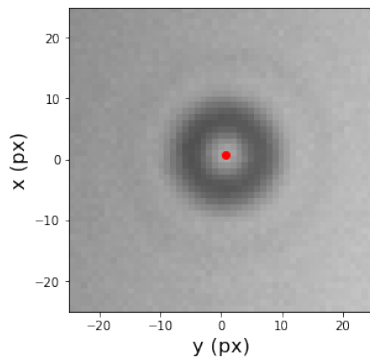
particle center x = -0.57 px
 particle center y = -0.18 px
 particle radius = 1.90 px
 Bessel order = 2.00
 particle intensity = -0.52
 ellipsoidal_orientation = -0.70
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.40
 signal to noise ratio = 89.83
 gradient intensity = 0.89
 gradient direction = -0.04



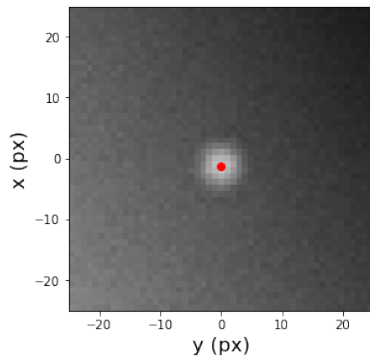
particle center x = 1.02 px
 particle center y = 0.99 px
 particle radius = 2.42 px
 Bessel order = 2.00
 particle intensity = 0.48
 ellipsoidal_orientation = 0.52
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.37
 signal to noise ratio = 15.31
 gradient intensity = 0.50
 gradient direction = 2.84



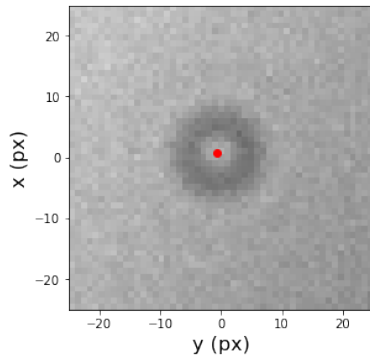
particle center x = 0.79 px
 particle center y = 0.77 px
 particle radius = 2.50 px
 Bessel order = 2.00
 particle intensity = -0.44
 ellipsoidal_orientation = 2.15
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.66
 signal to noise ratio = 92.28
 gradient intensity = 0.24
 gradient direction = -0.25



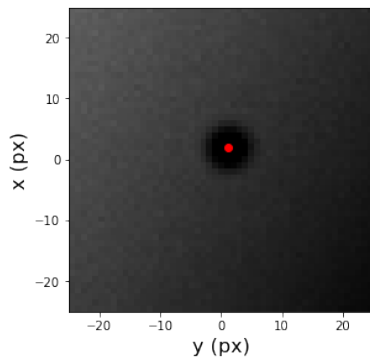
particle center x = -1.27 px
 particle center y = 0.01 px
 particle radius = 1.64 px
 Bessel order = 1.00
 particle intensity = 0.47
 ellipsoidal_orientation = 0.95
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.31
 signal to noise ratio = 48.97
 gradient intensity = 0.43
 gradient direction = -2.60



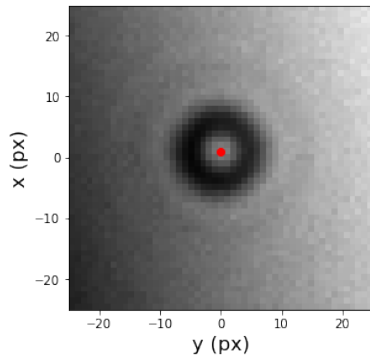
particle center x = 0.70 px
 particle center y = -0.57 px
 particle radius = 2.15 px
 Bessel order = 2.00
 particle intensity = -0.28
 ellipsoidal_orientation = 1.12
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.67
 signal to noise ratio = 35.49
 gradient intensity = 0.22
 gradient direction = 2.57



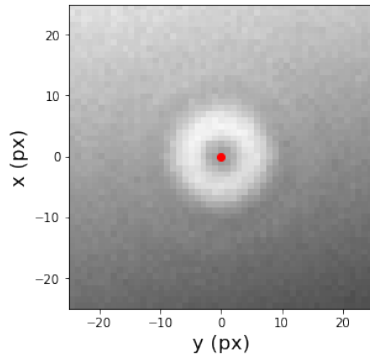
particle center x = 1.95 px
 particle center y = 1.23 px
 particle radius = 1.74 px
 Bessel order = 1.00
 particle intensity = -0.40
 ellipsoidal_orientation = -1.14
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.20
 signal to noise ratio = 60.90
 gradient intensity = 0.35
 gradient direction = 2.58



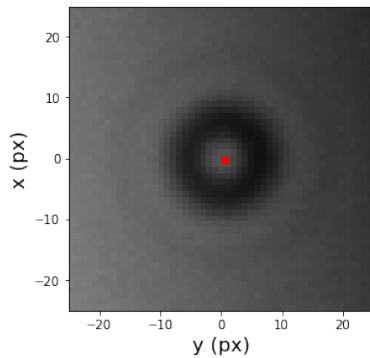
particle center x = 1.02 px
 particle center y = -0.12 px
 particle radius = 2.13 px
 Bessel order = 2.00
 particle intensity = -0.58
 ellipsoidal_orientation = 0.53
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.51
 signal to noise ratio = 48.91
 gradient intensity = 0.90
 gradient direction = 0.27



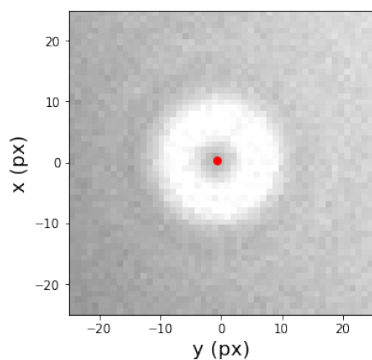
particle center x = 0.04 px
 particle center y = -0.05 px
 particle radius = 2.22 px
 Bessel order = 2.00
 particle intensity = 0.42
 ellipsoidal_orientation = 1.76
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.60
 signal to noise ratio = 65.15
 gradient intensity = 0.68
 gradient direction = 1.81



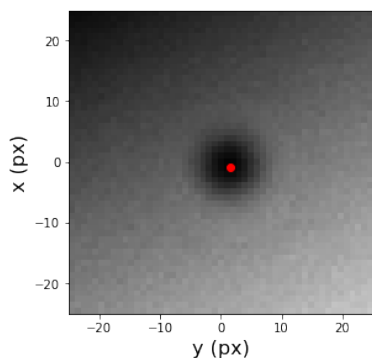
particle center x = 0.01 px
 particle center y = 0.36 px
 particle radius = 2.59 px
 Bessel order = 2.00
 particle intensity = -0.31
 ellipsoidal_orientation = 2.31
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.33
 signal to noise ratio = 99.67
 gradient intensity = 0.39
 gradient direction = -2.93



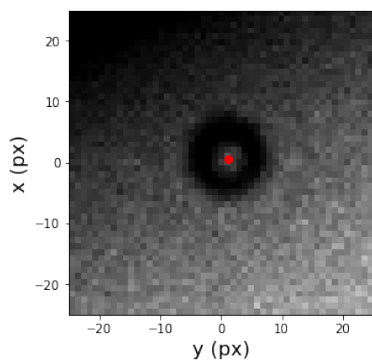
particle center x = 0.35 px
 particle center y = -0.73 px
 particle radius = 2.89 px
 Bessel order = 2.00
 particle intensity = 0.45
 ellipsoidal_orientation = -1.08
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.73
 signal to noise ratio = 46.59
 gradient intensity = 0.29
 gradient direction = 0.39



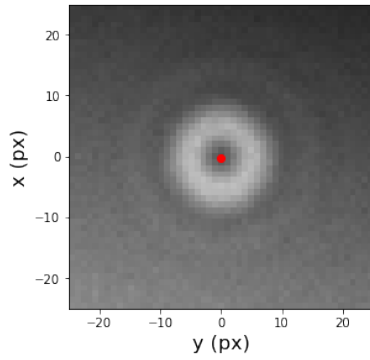
particle center x = -0.85 px
 particle center y = 1.53 px
 particle radius = 2.73 px
 Bessel order = 1.00
 particle intensity = -0.41
 ellipsoidal_orientation = -2.17
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.41
 signal to noise ratio = 60.56
 gradient intensity = 0.78
 gradient direction = -1.09



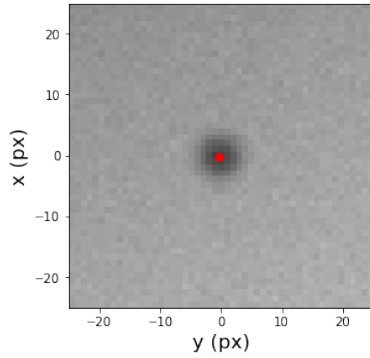
particle center x = 0.64 px
 particle center y = 1.25 px
 particle radius = 1.93 px
 Bessel order = 2.00
 particle intensity = -0.44
 ellipsoidal_orientation = 0.35
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.29
 signal to noise ratio = 13.30
 gradient intensity = 0.83
 gradient direction = -1.12



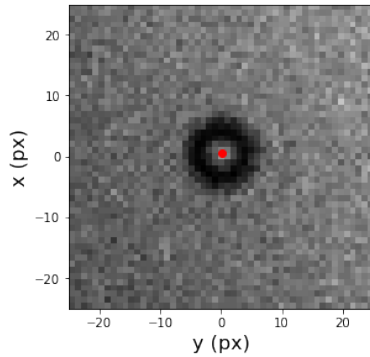
particle center x = -0.21 px
 particle center y = -0.05 px
 particle radius = 2.24 px
 Bessel order = 2.00
 particle intensity = 0.50
 ellipsoidal_orientation = 1.82
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.35
 signal to noise ratio = 60.16
 gradient intensity = 0.45
 gradient direction = -1.83



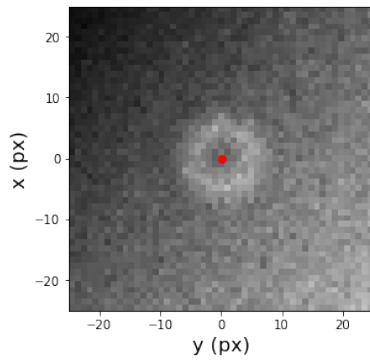
particle center x = -0.24 px
 particle center y = -0.25 px
 particle radius = 1.89 px
 Bessel order = 1.00
 particle intensity = -0.36
 ellipsoidal_orientation = 2.69
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.63
 signal to noise ratio = 53.54
 gradient intensity = 0.14
 gradient direction = -1.12



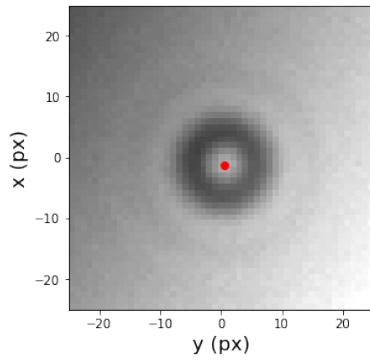
particle center x = 0.49 px
 particle center y = 0.09 px
 particle radius = 1.71 px
 Bessel order = 2.00
 particle intensity = -0.58
 ellipsoidal_orientation = -0.92
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.45
 signal to noise ratio = 10.91
 gradient intensity = 0.27
 gradient direction = 0.52



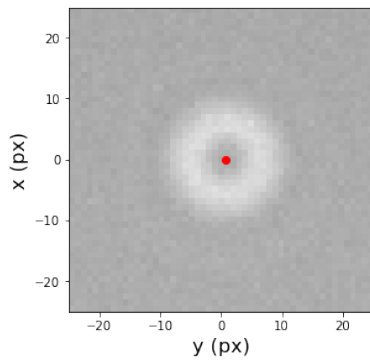
particle center x = 0.00 px
 particle center y = 0.23 px
 particle radius = 2.02 px
 Bessel order = 2.00
 particle intensity = 0.30
 ellipsoidal_orientation = 0.69
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.37
 signal to noise ratio = 16.38
 gradient intensity = 0.65
 gradient direction = -0.73



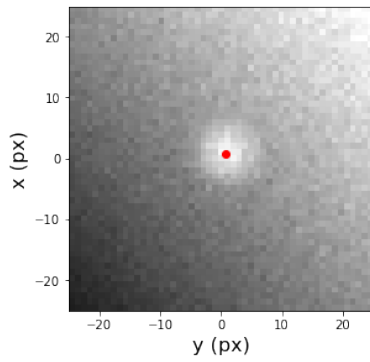
particle center x = -1.19 px
 particle center y = 0.61 px
 particle radius = 2.27 px
 Bessel order = 2.00
 particle intensity = -0.51
 ellipsoidal_orientation = 1.29
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.67
 signal to noise ratio = 90.24
 gradient intensity = 0.71
 gradient direction = -0.55



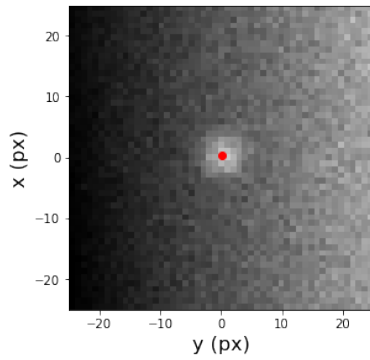
particle center x = 0.00 px
 particle center y = 0.77 px
 particle radius = 2.55 px
 Bessel order = 2.00
 particle intensity = 0.25
 ellipsoidal_orientation = -1.49
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.67
 signal to noise ratio = 77.05
 gradient intensity = 0.02
 gradient direction = -1.62



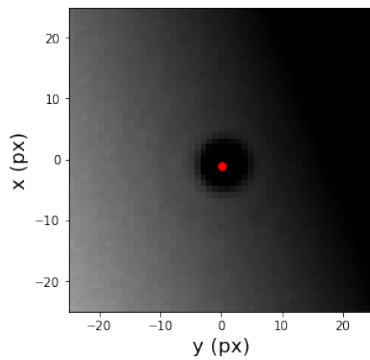
particle center x = 0.75 px
 particle center y = 0.78 px
 particle radius = 2.32 px
 Bessel order = 1.00
 particle intensity = 0.37
 ellipsoidal_orientation = 1.78
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.56
 signal to noise ratio = 28.94
 gradient intensity = 0.90
 gradient direction = 0.77



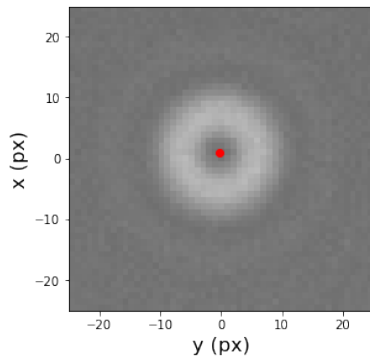
particle center x = 0.26 px
 particle center y = 0.23 px
 particle radius = 1.82 px
 Bessel order = 1.00
 particle intensity = 0.40
 ellipsoidal_orientation = 2.20
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.32
 signal to noise ratio = 16.52
 gradient intensity = 0.89
 gradient direction = 0.05



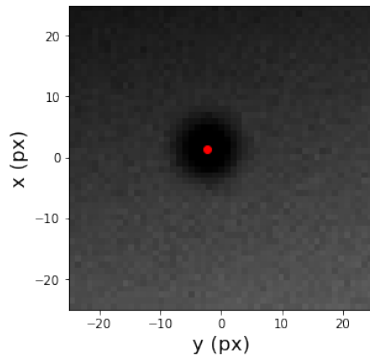
particle center x = -0.98 px
 particle center y = 0.23 px
 particle radius = 1.88 px
 Bessel order = 1.00
 particle intensity = -0.57
 ellipsoidal_orientation = -2.94
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.20
 signal to noise ratio = 98.57
 gradient intensity = 0.88
 gradient direction = -2.78



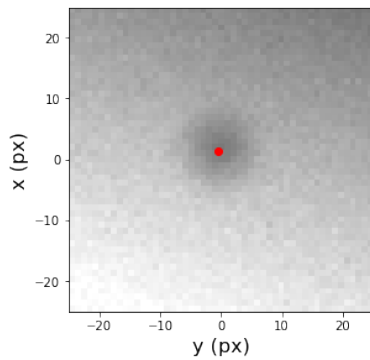
particle center x = 0.98 px
 particle center y = -0.34 px
 particle radius = 2.71 px
 Bessel order = 2.00
 particle intensity = 0.35
 ellipsoidal_orientation = -0.39
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.45
 signal to noise ratio = 84.26
 gradient intensity = 0.01
 gradient direction = -1.54



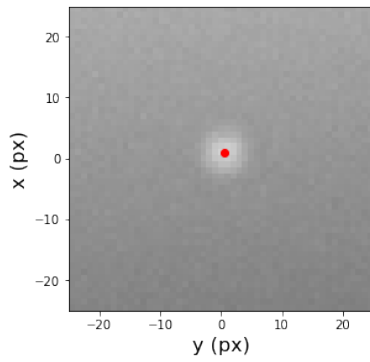
particle center x = 1.36 px
 particle center y = -2.27 px
 particle radius = 2.63 px
 Bessel order = 1.00
 particle intensity = -0.32
 ellipsoidal_orientation = -2.00
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.22
 signal to noise ratio = 36.25
 gradient intensity = 0.33
 gradient direction = -1.35



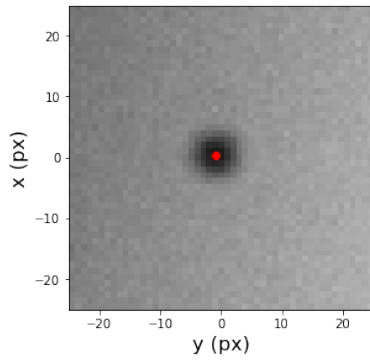
particle center x = 1.38 px
 particle center y = -0.36 px
 particle radius = 2.95 px
 Bessel order = 1.00
 particle intensity = -0.24
 ellipsoidal_orientation = 2.57
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.75
 signal to noise ratio = 51.64
 gradient intensity = 0.64
 gradient direction = -1.88



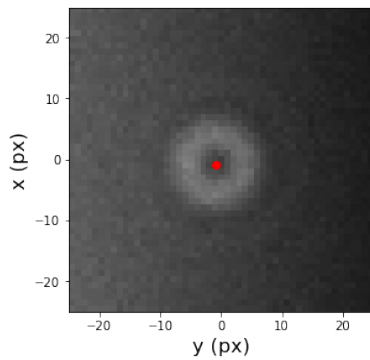
particle center x = 0.99 px
 particle center y = 0.58 px
 particle radius = 1.73 px
 Bessel order = 1.00
 particle intensity = 0.23
 ellipsoidal_orientation = 2.26
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.59
 signal to noise ratio = 97.29
 gradient intensity = 0.22
 gradient direction = 1.67



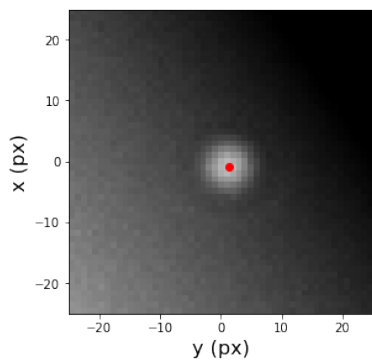
particle center x = 0.40 px
 particle center y = -0.91 px
 particle radius = 1.94 px
 Bessel order = 1.00
 particle intensity = -0.49
 ellipsoidal_orientation = -0.72
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.57
 signal to noise ratio = 47.06
 gradient intensity = 0.28
 gradient direction = -0.28



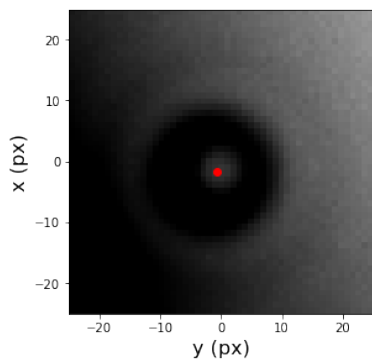
particle center x = -0.80 px
 particle center y = -0.90 px
 particle radius = 2.04 px
 Bessel order = 2.00
 particle intensity = 0.29
 ellipsoidal_orientation = -2.57
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.24
 signal to noise ratio = 40.11
 gradient intensity = 0.36
 gradient direction = -3.07



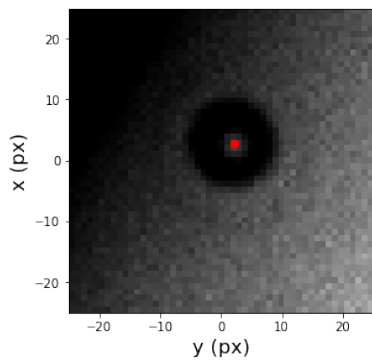
particle center x = -0.82 px
 particle center y = 1.30 px
 particle radius = 1.92 px
 Bessel order = 1.00
 particle intensity = 0.54
 ellipsoidal_orientation = -1.00
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.21
 signal to noise ratio = 56.42
 gradient intensity = 0.73
 gradient direction = -2.53



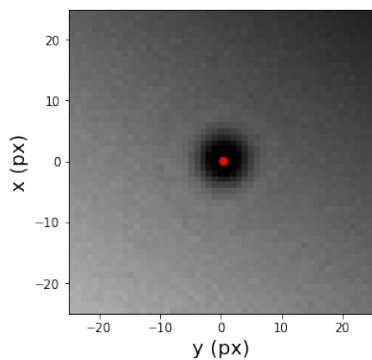
particle center x = -1.66 px
 particle center y = -0.63 px
 particle radius = 2.92 px
 Bessel order = 2.00
 particle intensity = -0.42
 ellipsoidal_orientation = -1.18
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.22
 signal to noise ratio = 61.66
 gradient intensity = 0.81
 gradient direction = 0.48



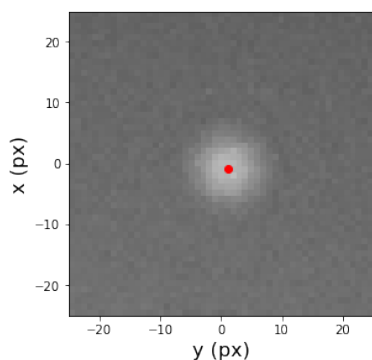
particle center x = 2.69 px
 particle center y = 2.14 px
 particle radius = 1.99 px
 Bessel order = 2.00
 particle intensity = -0.46
 ellipsoidal_orientation = -0.86
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.23
 signal to noise ratio = 18.03
 gradient intensity = 0.83
 gradient direction = -0.56



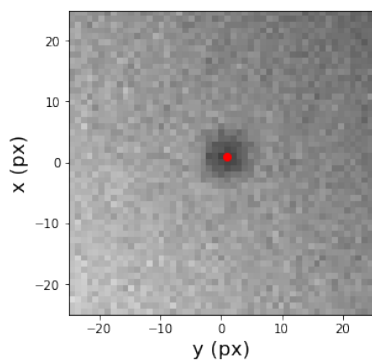
particle center x = 0.23 px
 particle center y = 0.42 px
 particle radius = 2.17 px
 Bessel order = 1.00
 particle intensity = -0.54
 ellipsoidal_orientation = -1.34
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.41
 signal to noise ratio = 76.27
 gradient intensity = 0.57
 gradient direction = -2.20



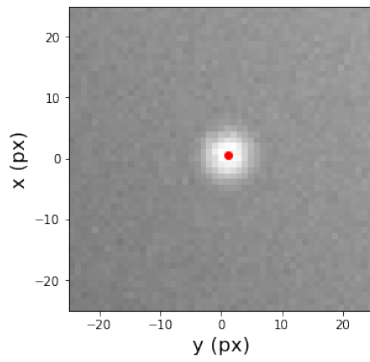
particle center x = -0.83 px
 particle center y = 1.10 px
 particle radius = 2.71 px
 Bessel order = 1.00
 particle intensity = 0.32
 ellipsoidal_orientation = -2.00
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.42
 signal to noise ratio = 61.03
 gradient intensity = 0.07
 gradient direction = -1.78



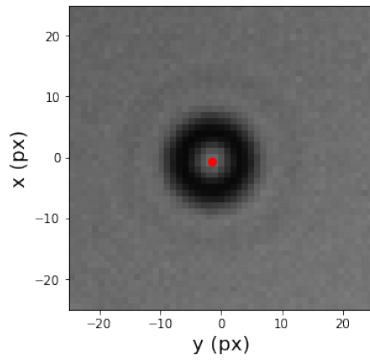
particle center x = 0.98 px
 particle center y = 0.91 px
 particle radius = 1.94 px
 Bessel order = 1.00
 particle intensity = -0.33
 ellipsoidal_orientation = 1.67
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.59
 signal to noise ratio = 21.02
 gradient intensity = 0.37
 gradient direction = -2.49



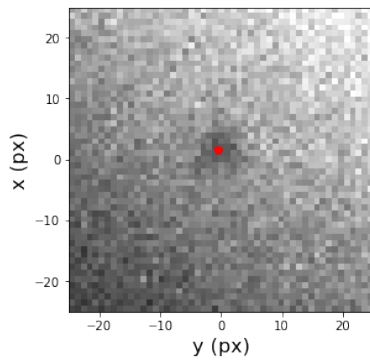
particle center x = 0.48 px
 particle center y = 1.13 px
 particle radius = 1.97 px
 Bessel order = 1.00
 particle intensity = 0.49
 ellipsoidal_orientation = -1.06
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.55
 signal to noise ratio = 57.52
 gradient intensity = 0.13
 gradient direction = 0.62



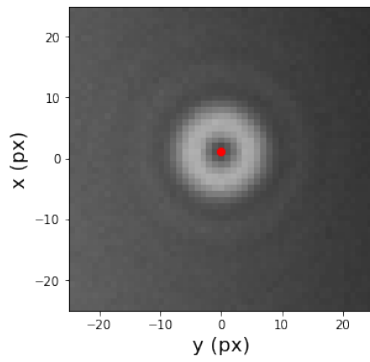
particle center x = -0.65 px
 particle center y = -1.57 px
 particle radius = 2.12 px
 Bessel order = 2.00
 particle intensity = -0.53
 ellipsoidal_orientation = -2.67
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.42
 signal to noise ratio = 61.24
 gradient intensity = 0.08
 gradient direction = -0.82



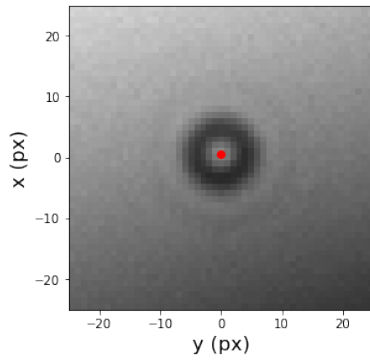
particle center x = 1.54 px
 particle center y = -0.54 px
 particle radius = 1.97 px
 Bessel order = 1.00
 particle intensity = -0.26
 ellipsoidal_orientation = 1.86
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.60
 signal to noise ratio = 11.20
 gradient intensity = 0.72
 gradient direction = 0.96



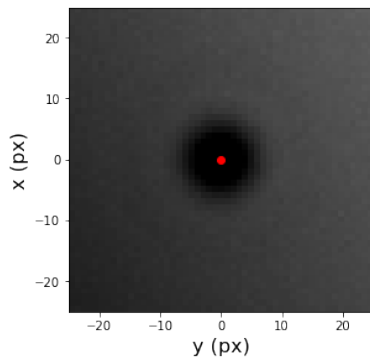
particle center x = 1.07 px
 particle center y = -0.08 px
 particle radius = 2.02 px
 Bessel order = 2.00
 particle intensity = 0.53
 ellipsoidal_orientation = -0.18
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.29
 signal to noise ratio = 85.84
 gradient intensity = 0.23
 gradient direction = -2.97



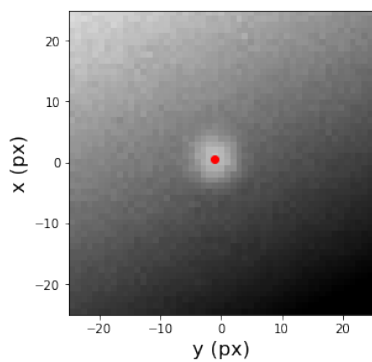
particle center x = 0.59 px
 particle center y = -0.05 px
 particle radius = 1.77 px
 Bessel order = 2.00
 particle intensity = -0.45
 ellipsoidal_orientation = -0.66
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.52
 signal to noise ratio = 76.63
 gradient intensity = 0.71
 gradient direction = 1.89



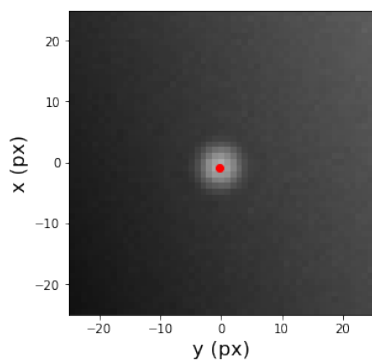
particle center x = 0.03 px
 particle center y = -0.07 px
 particle radius = 2.92 px
 Bessel order = 1.00
 particle intensity = -0.42
 ellipsoidal_orientation = 1.72
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.24
 signal to noise ratio = 91.55
 gradient intensity = 0.25
 gradient direction = 0.60



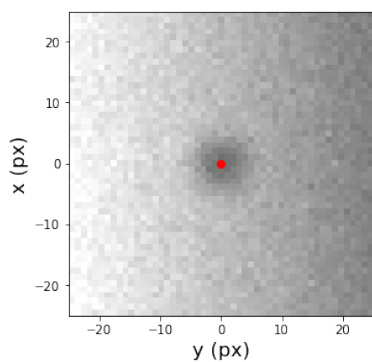
particle center x = 0.54 px
 particle center y = -1.02 px
 particle radius = 2.03 px
 Bessel order = 1.00
 particle intensity = 0.34
 ellipsoidal_orientation = -1.81
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.39
 signal to noise ratio = 54.29
 gradient intensity = 1.00
 gradient direction = 2.05



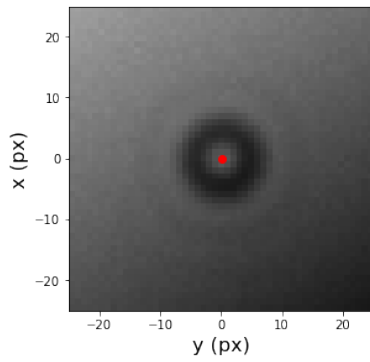
particle center x = -0.79 px
 particle center y = -0.21 px
 particle radius = 1.68 px
 Bessel order = 1.00
 particle intensity = 0.47
 ellipsoidal_orientation = 1.97
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.22
 signal to noise ratio = 91.02
 gradient intensity = 0.32
 gradient direction = 0.41



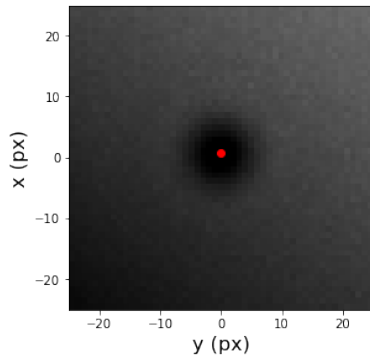
particle center x = -0.04 px
 particle center y = -0.11 px
 particle radius = 2.49 px
 Bessel order = 1.00
 particle intensity = -0.30
 ellipsoidal_orientation = 0.55
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.74
 signal to noise ratio = 31.21
 gradient intensity = 0.68
 gradient direction = -3.09



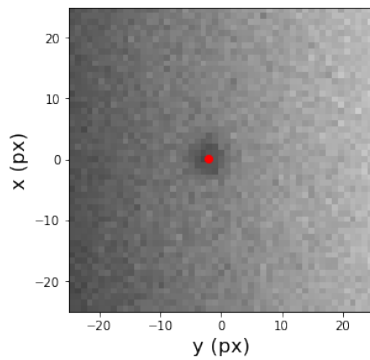
particle center x = -0.08 px
 particle center y = 0.18 px
 particle radius = 1.96 px
 Bessel order = 2.00
 particle intensity = -0.31
 ellipsoidal_orientation = -0.49
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.36
 signal to noise ratio = 90.19
 gradient intensity = 0.55
 gradient direction = 2.12



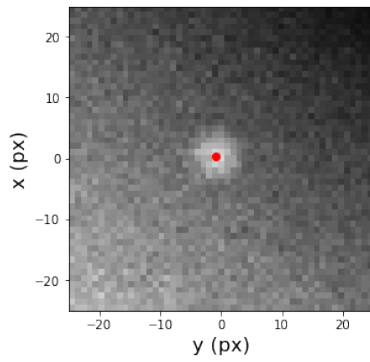
particle center x = 0.81 px
 particle center y = -0.04 px
 particle radius = 2.87 px
 Bessel order = 1.00
 particle intensity = -0.28
 ellipsoidal_orientation = -0.41
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.23
 signal to noise ratio = 62.35
 gradient intensity = 0.39
 gradient direction = 0.95



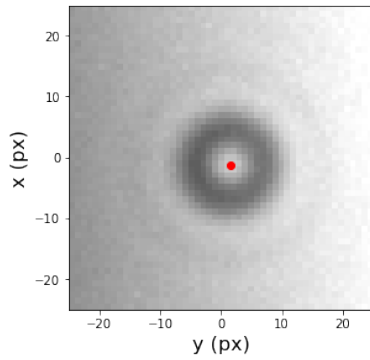
particle center x = 0.16 px
 particle center y = -2.11 px
 particle radius = 1.76 px
 Bessel order = 1.00
 particle intensity = -0.21
 ellipsoidal_orientation = -2.52
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.52
 signal to noise ratio = 26.34
 gradient intensity = 0.57
 gradient direction = 0.12



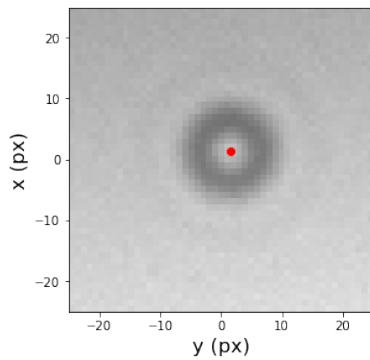
particle center x = 0.44 px
 particle center y = -0.85 px
 particle radius = 1.88 px
 Bessel order = 1.00
 particle intensity = 0.44
 ellipsoidal_orientation = -0.51
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.38
 signal to noise ratio = 15.73
 gradient intensity = 0.66
 gradient direction = -2.21



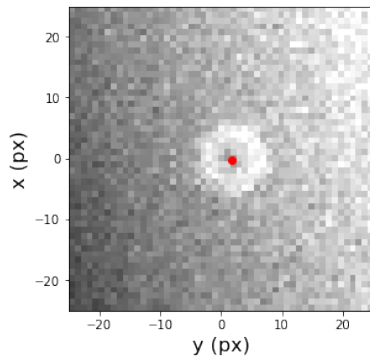
particle center x = -1.21 px
 particle center y = 1.48 px
 particle radius = 2.43 px
 Bessel order = 2.00
 particle intensity = -0.53
 ellipsoidal_orientation = -1.57
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.79
 signal to noise ratio = 76.65
 gradient intensity = 0.60
 gradient direction = 0.10



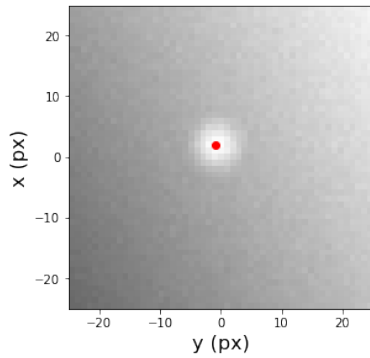
particle center x = 1.31 px
 particle center y = 1.52 px
 particle radius = 2.22 px
 Bessel order = 2.00
 particle intensity = -0.39
 ellipsoidal_orientation = -1.63
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.76
 signal to noise ratio = 90.07
 gradient intensity = 0.27
 gradient direction = -1.45



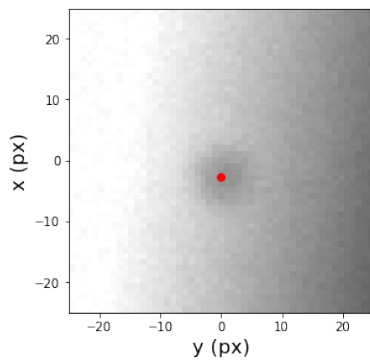
particle center x = -0.25 px
 particle center y = 1.75 px
 particle radius = 1.68 px
 Bessel order = 2.00
 particle intensity = 0.37
 ellipsoidal_orientation = -0.02
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.65
 signal to noise ratio = 13.39
 gradient intensity = 0.76
 gradient direction = 0.34



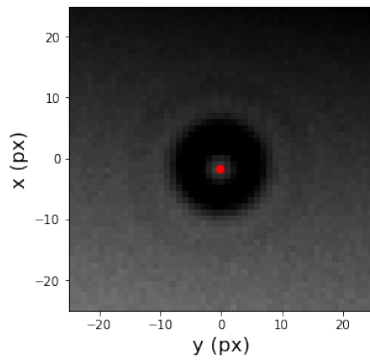
particle center x = 1.97 px
 particle center y = -0.77 px
 particle radius = 1.81 px
 Bessel order = 1.00
 particle intensity = 0.32
 ellipsoidal_orientation = 2.39
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.68
 signal to noise ratio = 92.25
 gradient intensity = 0.57
 gradient direction = 0.55



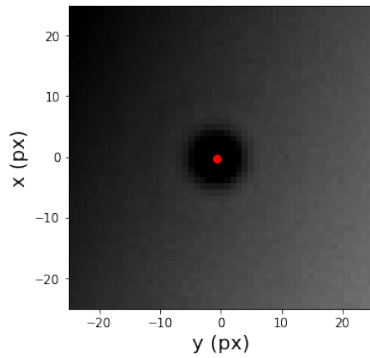
particle center x = -2.78 px
 particle center y = -0.02 px
 particle radius = 2.52 px
 Bessel order = 1.00
 particle intensity = -0.20
 ellipsoidal_orientation = 0.49
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.79
 signal to noise ratio = 77.42
 gradient intensity = 0.98
 gradient direction = 2.97



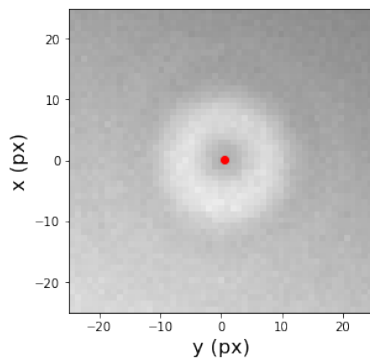
particle center x = -1.65 px
 particle center y = -0.26 px
 particle radius = 2.10 px
 Bessel order = 2.00
 particle intensity = -0.48
 ellipsoidal_orientation = 0.92
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.22
 signal to noise ratio = 48.60
 gradient intensity = 0.54
 gradient direction = -1.74



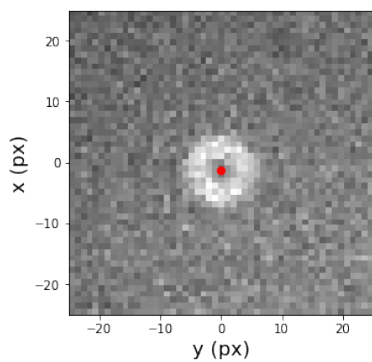
particle center x = -0.33 px
 particle center y = -0.65 px
 particle radius = 2.18 px
 Bessel order = 1.00
 particle intensity = -0.49
 ellipsoidal_orientation = -3.06
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.21
 signal to noise ratio = 82.55
 gradient intensity = 0.48
 gradient direction = -0.48



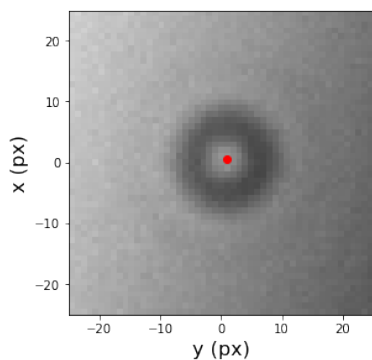
particle center x = 0.14 px
 particle center y = 0.57 px
 particle radius = 2.92 px
 Bessel order = 2.00
 particle intensity = 0.24
 ellipsoidal_orientation = -2.59
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.70
 signal to noise ratio = 84.28
 gradient intensity = 0.35
 gradient direction = -2.01



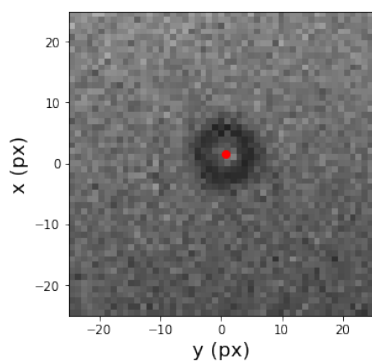
particle center x = -1.28 px
 particle center y = -0.04 px
 particle radius = 1.67 px
 Bessel order = 2.00
 particle intensity = 0.52
 ellipsoidal_orientation = -3.07
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.47
 signal to noise ratio = 11.01
 gradient intensity = 0.17
 gradient direction = -1.09



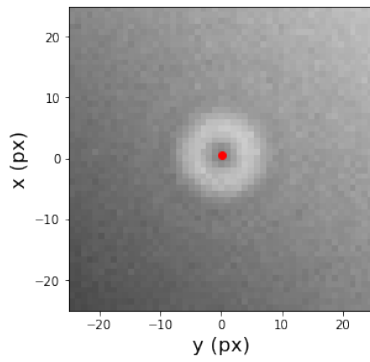
particle center x = 0.49 px
 particle center y = 0.86 px
 particle radius = 2.42 px
 Bessel order = 2.00
 particle intensity = -0.35
 ellipsoidal_orientation = 2.79
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.59
 signal to noise ratio = 63.56
 gradient intensity = 0.53
 gradient direction = 2.83



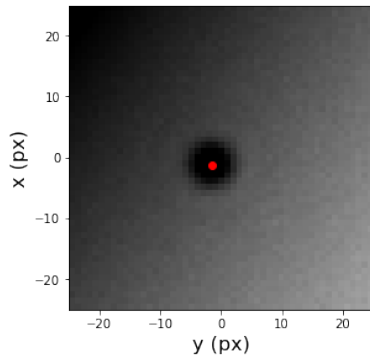
particle center x = 1.53 px
 particle center y = 0.75 px
 particle radius = 1.69 px
 Bessel order = 2.00
 particle intensity = -0.33
 ellipsoidal_orientation = 2.19
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.42
 signal to noise ratio = 12.75
 gradient intensity = 0.28
 gradient direction = 1.76



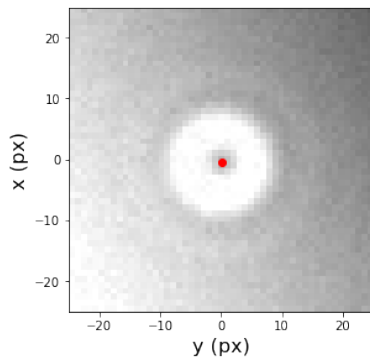
particle center x = 0.57 px
 particle center y = 0.09 px
 particle radius = 1.92 px
 Bessel order = 2.00
 particle intensity = 0.32
 ellipsoidal_orientation = -0.66
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.52
 signal to noise ratio = 53.09
 gradient intensity = 0.48
 gradient direction = 0.79



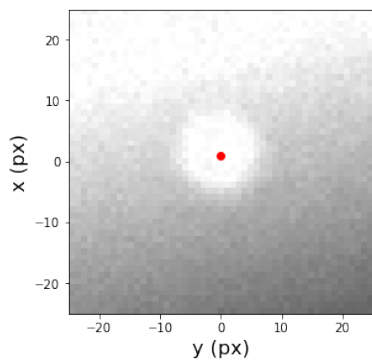
particle center x = -1.21 px
 particle center y = -1.57 px
 particle radius = 1.82 px
 Bessel order = 1.00
 particle intensity = -0.51
 ellipsoidal_orientation = 2.87
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.30
 signal to noise ratio = 68.85
 gradient intensity = 0.69
 gradient direction = -0.64



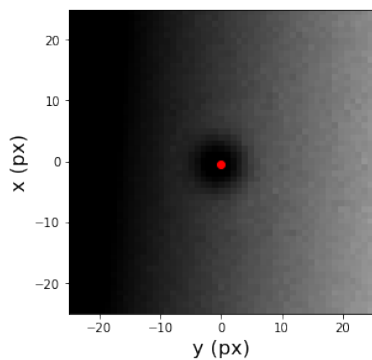
particle center x = -0.48 px
 particle center y = 0.10 px
 particle radius = 2.25 px
 Bessel order = 2.00
 particle intensity = 0.60
 ellipsoidal_orientation = 2.40
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.72
 signal to noise ratio = 53.85
 gradient intensity = 0.67
 gradient direction = -2.60



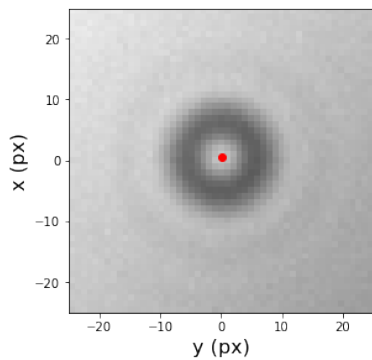
particle center x = 1.05 px
 particle center y = -0.12 px
 particle radius = 2.95 px
 Bessel order = 1.00
 particle intensity = 0.45
 ellipsoidal_orientation = 1.72
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.78
 signal to noise ratio = 50.07
 gradient intensity = 0.90
 gradient direction = 1.83



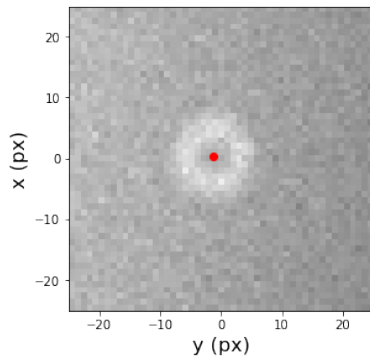
particle center x = -0.55 px
 particle center y = -0.16 px
 particle radius = 2.31 px
 Bessel order = 1.00
 particle intensity = -0.28
 ellipsoidal_orientation = 0.34
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.23
 signal to noise ratio = 61.25
 gradient intensity = 0.96
 gradient direction = -0.08



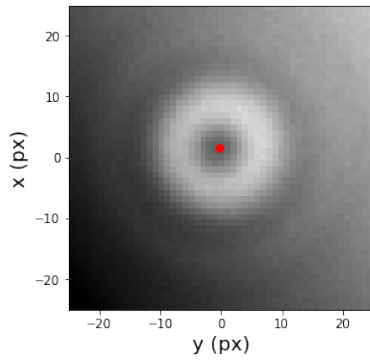
particle center x = 0.54 px
 particle center y = 0.05 px
 particle radius = 2.49 px
 Bessel order = 2.00
 particle intensity = -0.52
 ellipsoidal_orientation = -1.75
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.77
 signal to noise ratio = 95.76
 gradient intensity = 0.31
 gradient direction = 2.44



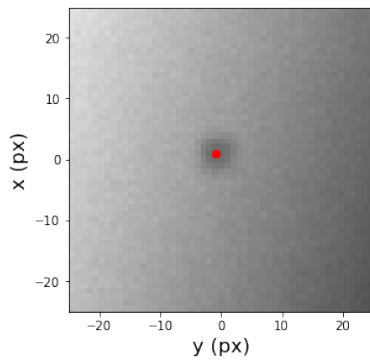
particle center x = 0.33 px
 particle center y = -1.26 px
 particle radius = 1.91 px
 Bessel order = 2.00
 particle intensity = 0.25
 ellipsoidal_orientation = -2.56
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.65
 signal to noise ratio = 26.75
 gradient intensity = 0.22
 gradient direction = 3.00



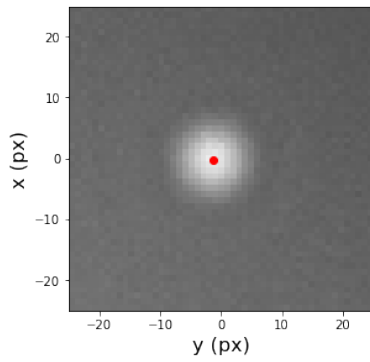
particle center x = 1.58 px
 particle center y = -0.32 px
 particle radius = 2.93 px
 Bessel order = 2.00
 particle intensity = 0.53
 ellipsoidal_orientation = -1.25
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.37
 signal to noise ratio = 84.93
 gradient intensity = 0.82
 gradient direction = 0.61



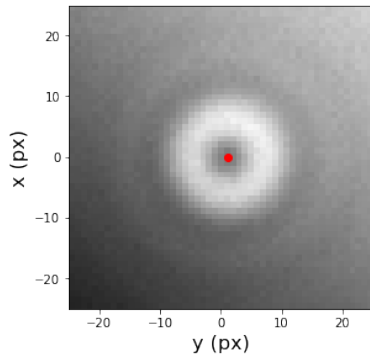
particle center x = 0.98 px
 particle center y = -0.79 px
 particle radius = 1.58 px
 Bessel order = 1.00
 particle intensity = -0.20
 ellipsoidal_orientation = -2.44
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.60
 signal to noise ratio = 82.19
 gradient intensity = 0.62
 gradient direction = 2.82



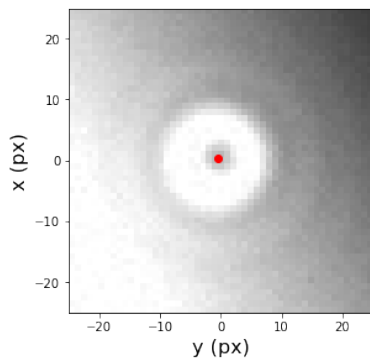
particle center x = -0.17 px
 particle center y = -1.37 px
 particle radius = 2.74 px
 Bessel order = 1.00
 particle intensity = 0.52
 ellipsoidal_orientation = 1.04
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.39
 signal to noise ratio = 74.93
 gradient intensity = 0.11
 gradient direction = -2.30



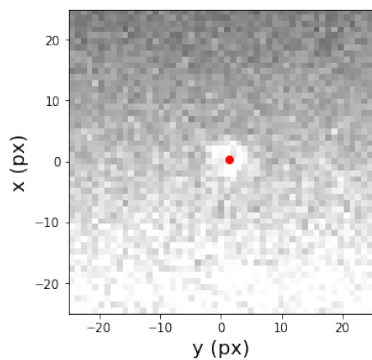
particle center x = -0.05 px
 particle center y = 1.17 px
 particle radius = 2.64 px
 Bessel order = 2.00
 particle intensity = 0.54
 ellipsoidal_orientation = -2.55
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.48
 signal to noise ratio = 78.95
 gradient intensity = 0.70
 gradient direction = 0.89



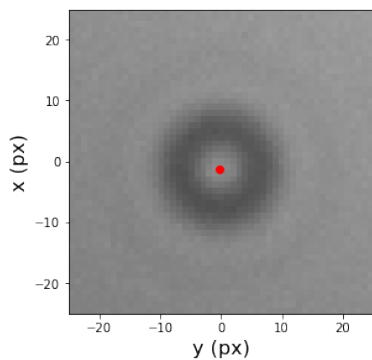
particle center x = 0.39 px
 particle center y = -0.49 px
 particle radius = 2.29 px
 Bessel order = 2.00
 particle intensity = 0.59
 ellipsoidal_orientation = -2.76
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.71
 signal to noise ratio = 70.60
 gradient intensity = 1.00
 gradient direction = -2.59



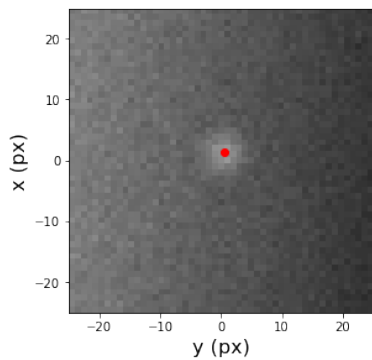
particle center x = 0.35 px
 particle center y = 1.40 px
 particle radius = 1.58 px
 Bessel order = 1.00
 particle intensity = 0.38
 ellipsoidal_orientation = -2.83
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.78
 signal to noise ratio = 15.27
 gradient intensity = 0.79
 gradient direction = -1.55



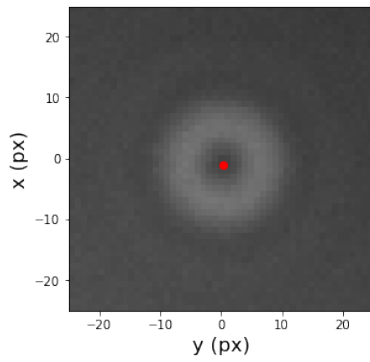
particle center x = -1.26 px
 particle center y = -0.21 px
 particle radius = 2.82 px
 Bessel order = 2.00
 particle intensity = -0.30
 ellipsoidal_orientation = -1.14
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.56
 signal to noise ratio = 98.77
 gradient intensity = 0.10
 gradient direction = 0.88



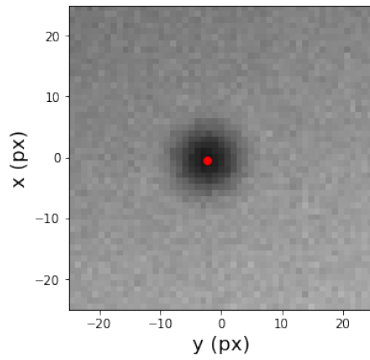
particle center x = 1.31 px
 particle center y = 0.58 px
 particle radius = 1.78 px
 Bessel order = 1.00
 particle intensity = 0.22
 ellipsoidal_orientation = -0.98
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.35
 signal to noise ratio = 28.20
 gradient intensity = 0.41
 gradient direction = 3.07



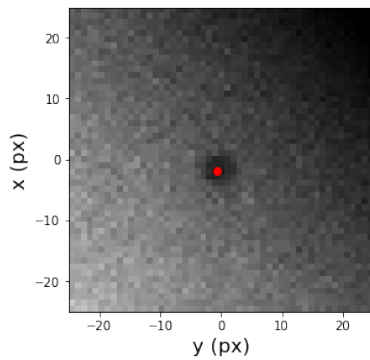
particle center x = -1.06 px
 particle center y = 0.30 px
 particle radius = 2.79 px
 Bessel order = 2.00
 particle intensity = 0.24
 ellipsoidal_orientation = 1.43
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.27
 signal to noise ratio = 87.02
 gradient intensity = 0.08
 gradient direction = -2.20



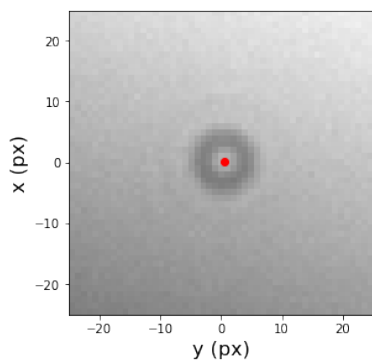
particle center x = -0.46 px
 particle center y = -2.33 px
 particle radius = 2.85 px
 Bessel order = 1.00
 particle intensity = -0.47
 ellipsoidal_orientation = -0.18
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.56
 signal to noise ratio = 35.41
 gradient intensity = 0.23
 gradient direction = -1.21



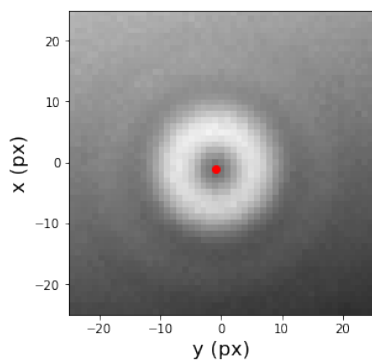
particle center x = -1.93 px
 particle center y = -0.60 px
 particle radius = 1.58 px
 Bessel order = 1.00
 particle intensity = -0.24
 ellipsoidal_orientation = -0.75
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.34
 signal to noise ratio = 17.66
 gradient intensity = 0.77
 gradient direction = -2.44



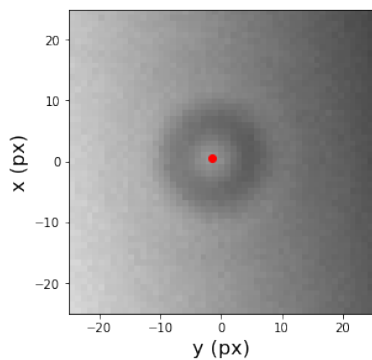
particle center x = 0.24 px
 particle center y = 0.48 px
 particle radius = 1.52 px
 Bessel order = 2.00
 particle intensity = -0.30
 ellipsoidal_orientation = 2.29
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.72
 signal to noise ratio = 95.29
 gradient intensity = 0.50
 gradient direction = 1.25



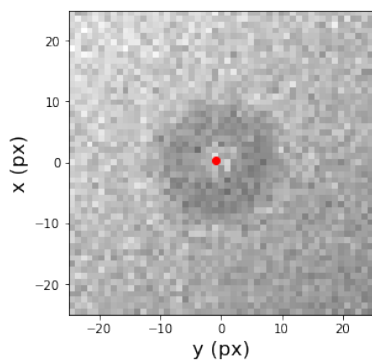
particle center x = -1.13 px
 particle center y = -0.93 px
 particle radius = 2.73 px
 Bessel order = 2.00
 particle intensity = 0.59
 ellipsoidal_orientation = 0.82
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.45
 signal to noise ratio = 82.15
 gradient intensity = 0.62
 gradient direction = 1.82



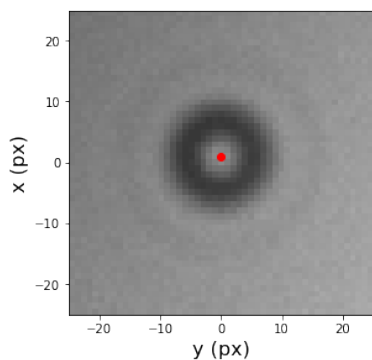
particle center x = 0.48 px
 particle center y = -1.38 px
 particle radius = 2.53 px
 Bessel order = 2.00
 particle intensity = -0.21
 ellipsoidal_orientation = -0.57
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.57
 signal to noise ratio = 90.70
 gradient intensity = 0.69
 gradient direction = -2.98



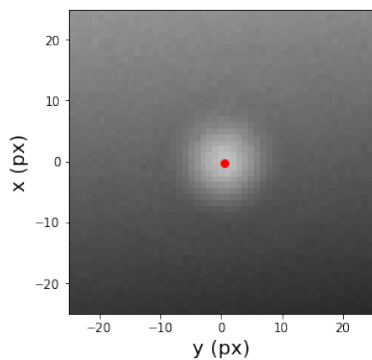
particle center x = 0.26 px
 particle center y = -0.83 px
 particle radius = 2.75 px
 Bessel order = 2.00
 particle intensity = -0.24
 ellipsoidal_orientation = 1.17
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.72
 signal to noise ratio = 14.97
 gradient intensity = 0.30
 gradient direction = 2.36



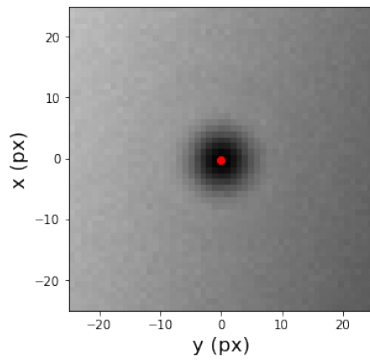
particle center x = 1.01 px
 particle center y = -0.14 px
 particle radius = 2.42 px
 Bessel order = 2.00
 particle intensity = -0.44
 ellipsoidal_orientation = -1.64
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.56
 signal to noise ratio = 77.14
 gradient intensity = 0.22
 gradient direction = -0.52



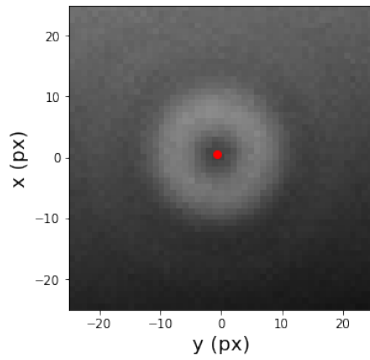
particle center x = -0.18 px
 particle center y = 0.53 px
 particle radius = 2.96 px
 Bessel order = 1.00
 particle intensity = 0.37
 ellipsoidal_orientation = 2.30
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.38
 signal to noise ratio = 97.88
 gradient intensity = 0.53
 gradient direction = 1.71



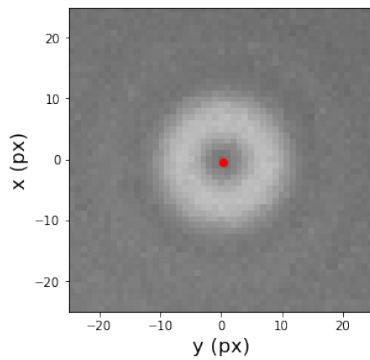
particle center x = -0.35 px
 particle center y = -0.08 px
 particle radius = 2.55 px
 Bessel order = 1.00
 particle intensity = -0.56
 ellipsoidal_orientation = 0.41
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.55
 signal to noise ratio = 84.65
 gradient intensity = 0.44
 gradient direction = 2.85



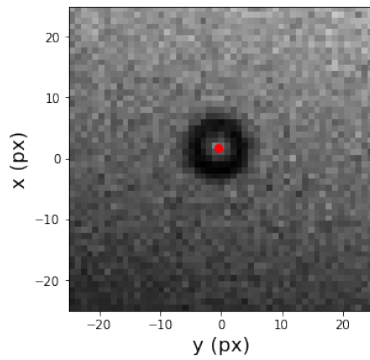
particle center x = 0.62 px
 particle center y = -0.76 px
 particle radius = 2.96 px
 Bessel order = 2.00
 particle intensity = 0.31
 ellipsoidal_orientation = -0.65
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.26
 signal to noise ratio = 59.42
 gradient intensity = 0.44
 gradient direction = 1.75



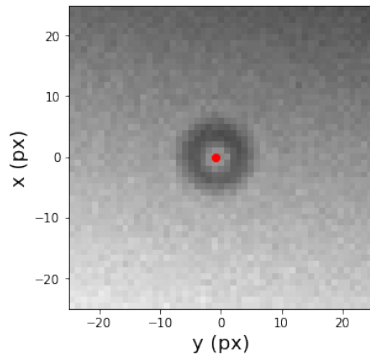
particle center x = -0.39 px
 particle center y = 0.36 px
 particle radius = 2.95 px
 Bessel order = 2.00
 particle intensity = 0.38
 ellipsoidal_orientation = 2.42
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.46
 signal to noise ratio = 62.75
 gradient intensity = 0.06
 gradient direction = -2.04



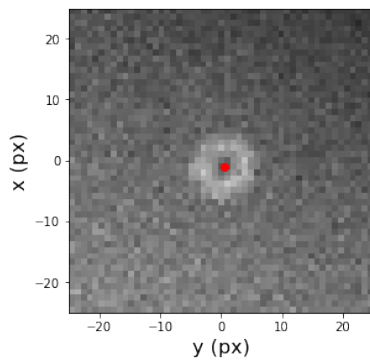
particle center x = 1.78 px
 particle center y = -0.49 px
 particle radius = 1.59 px
 Bessel order = 2.00
 particle intensity = -0.51
 ellipsoidal_orientation = 0.20
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.40
 signal to noise ratio = 12.65
 gradient intensity = 0.59
 gradient direction = 1.35



particle center x = -0.04 px
 particle center y = -0.81 px
 particle radius = 1.69 px
 Bessel order = 2.00
 particle intensity = -0.37
 ellipsoidal_orientation = -2.59
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.61
 signal to noise ratio = 39.57
 gradient intensity = 0.71
 gradient direction = -1.76



particle center x = -1.02 px
 particle center y = 0.46 px
 particle radius = 1.50 px
 Bessel order = 2.00
 particle intensity = 0.36
 ellipsoidal_orientation = 0.07
 ellipticity = 1.00

image half size = 25.00 px
 image background level = 0.39
 signal to noise ratio = 14.09
 gradient intensity = 0.35
 gradient direction = -1.96

3. CREATE AND COMPILE DEEP LEARNING NETWORK

The parameters of the deep learning network are defined and the network created. The summary of the network is printed where the output shape and number of parameters for each layer can be

visualized.

Comments:

1. The parameter `input_shape` determines the shape of the input image (x-pixels by y-pixels by color channels).
2. The parameter `conv_layers_dimensions` determines the number and size of convolutional layers.
3. The parameter `dense_layers_dimensions` determines the number and size of dense layers.

```
In [3]: ### Define parameters of the deep learning network
        input_shape = (51, 51, 1) # Change to determine the shape of the input image [x-pixels by y-pixels by color channels]
        conv_layers_dimensions = (16, 32, 64) # Change to determine the number and size of convolutional layers
        dense_layers_dimensions = (32, 32) # Change to determine the number and size of dense layers

        ### Create deep learning network
        network = deeptack.create_deep_learning_network(input_shape, conv_layers_dimensions, dense_layers_dimensions)

        ### Print deep learning network summary
        network.summary()
```

Using TensorFlow backend.

Layer (type)	Output Shape	Param #
conv_1 (Conv2D)	(None, 49, 49, 16)	160
pooling_1 (MaxPooling2D)	(None, 24, 24, 16)	0
conv_2 (Conv2D)	(None, 22, 22, 32)	4640
pooling_2 (MaxPooling2D)	(None, 11, 11, 32)	0
conv_3 (Conv2D)	(None, 9, 9, 64)	18496
pooling_3 (MaxPooling2D)	(None, 4, 4, 64)	0
flatten (Flatten)	(None, 1024)	0
dense_1 (Dense)	(None, 32)	32800
dense_2 (Dense)	(None, 32)	1056
output (Dense)	(None, 3)	99

Total params: 57,251

Trainable params: 57,251
Non-trainable params: 0

4. TRAIN DEEP LEARNING NETWORK

The parameters for the training of the deep learning network are defined and the network is trained. The sample size, iteration number, MSE, MAE and the time of each iteration is printed.

Comments:

1. The parameter `sample_sizes` determines the sizes of the batches of images used in the training.
2. The parameter `iteration_numbers` determines the numbers of batches used in the training.
3. The parameter `verbose` determines the frequency of the update messages. It can be either a boolean value (True/False) or a number between 0 and 1.

```
In [4]: ### Define parameters of the training
        sample_sizes = (8, 32, 128, 512, 1024)
        iteration_numbers = (4001, 3001, 2001, 1001, 101)
        verbose = .01

        ### Training
        training_history = deeptack.train_deep_learning_network(network, image_generator, sample_sizes, iteration_numbers, verbose)
```

Sample size	8	iteration number	1	MSE	2.48 px ²	MAE	1.23 px	Time
Sample size	8	iteration number	101	MSE	0.59 px ²	MAE	0.61 px	Time
Sample size	8	iteration number	201	MSE	0.35 px ²	MAE	0.50 px	Time
Sample size	8	iteration number	301	MSE	0.31 px ²	MAE	0.47 px	Time
Sample size	8	iteration number	401	MSE	0.63 px ²	MAE	0.63 px	Time
Sample size	8	iteration number	501	MSE	0.19 px ²	MAE	0.34 px	Time
Sample size	8	iteration number	601	MSE	0.30 px ²	MAE	0.43 px	Time
Sample size	8	iteration number	701	MSE	0.38 px ²	MAE	0.37 px	Time
Sample size	8	iteration number	801	MSE	0.10 px ²	MAE	0.26 px	Time
Sample size	8	iteration number	901	MSE	0.10 px ²	MAE	0.26 px	Time
Sample size	8	iteration number	1001	MSE	0.08 px ²	MAE	0.23 px	Time
Sample size	8	iteration number	1101	MSE	0.13 px ²	MAE	0.27 px	Time
Sample size	8	iteration number	1201	MSE	0.10 px ²	MAE	0.26 px	Time
Sample size	8	iteration number	1301	MSE	0.07 px ²	MAE	0.22 px	Time
Sample size	8	iteration number	1401	MSE	0.11 px ²	MAE	0.26 px	Time
Sample size	8	iteration number	1501	MSE	0.03 px ²	MAE	0.13 px	Time
Sample size	8	iteration number	1601	MSE	0.07 px ²	MAE	0.18 px	Time
Sample size	8	iteration number	1701	MSE	0.10 px ²	MAE	0.24 px	Time
Sample size	8	iteration number	1801	MSE	0.16 px ²	MAE	0.30 px	Time
Sample size	8	iteration number	1901	MSE	0.12 px ²	MAE	0.26 px	Time
Sample size	8	iteration number	2001	MSE	0.03 px ²	MAE	0.15 px	Time
Sample size	8	iteration number	2101	MSE	0.05 px ²	MAE	0.17 px	Time
Sample size	8	iteration number	2201	MSE	0.05 px ²	MAE	0.19 px	Time

Sample size	8	iteration number	2301	MSE	0.09 px ²	MAE	0.20 px	Time
Sample size	8	iteration number	2401	MSE	0.08 px ²	MAE	0.22 px	Time
Sample size	8	iteration number	2501	MSE	0.07 px ²	MAE	0.23 px	Time
Sample size	8	iteration number	2601	MSE	0.06 px ²	MAE	0.19 px	Time
Sample size	8	iteration number	2701	MSE	0.09 px ²	MAE	0.22 px	Time
Sample size	8	iteration number	2801	MSE	0.04 px ²	MAE	0.15 px	Time
Sample size	8	iteration number	2901	MSE	0.04 px ²	MAE	0.14 px	Time
Sample size	8	iteration number	3001	MSE	0.04 px ²	MAE	0.15 px	Time
Sample size	8	iteration number	3101	MSE	0.04 px ²	MAE	0.14 px	Time
Sample size	8	iteration number	3201	MSE	0.04 px ²	MAE	0.16 px	Time
Sample size	8	iteration number	3301	MSE	0.04 px ²	MAE	0.15 px	Time
Sample size	8	iteration number	3401	MSE	0.08 px ²	MAE	0.24 px	Time
Sample size	8	iteration number	3501	MSE	0.08 px ²	MAE	0.25 px	Time
Sample size	8	iteration number	3601	MSE	0.03 px ²	MAE	0.13 px	Time
Sample size	8	iteration number	3701	MSE	0.05 px ²	MAE	0.17 px	Time
Sample size	8	iteration number	3801	MSE	0.07 px ²	MAE	0.20 px	Time
Sample size	8	iteration number	3901	MSE	0.02 px ²	MAE	0.11 px	Time
Sample size	8	iteration number	4001	MSE	0.06 px ²	MAE	0.20 px	Time
Sample size	32	iteration number	1	MSE	0.05 px ²	MAE	0.18 px	Time
Sample size	32	iteration number	101	MSE	0.02 px ²	MAE	0.11 px	Time
Sample size	32	iteration number	201	MSE	0.04 px ²	MAE	0.16 px	Time
Sample size	32	iteration number	301	MSE	0.02 px ²	MAE	0.13 px	Time
Sample size	32	iteration number	401	MSE	0.05 px ²	MAE	0.18 px	Time
Sample size	32	iteration number	501	MSE	0.04 px ²	MAE	0.14 px	Time
Sample size	32	iteration number	601	MSE	0.03 px ²	MAE	0.13 px	Time
Sample size	32	iteration number	701	MSE	0.05 px ²	MAE	0.17 px	Time
Sample size	32	iteration number	801	MSE	0.03 px ²	MAE	0.13 px	Time
Sample size	32	iteration number	901	MSE	0.02 px ²	MAE	0.10 px	Time
Sample size	32	iteration number	1001	MSE	0.03 px ²	MAE	0.14 px	Time
Sample size	32	iteration number	1101	MSE	0.03 px ²	MAE	0.14 px	Time
Sample size	32	iteration number	1201	MSE	0.03 px ²	MAE	0.15 px	Time
Sample size	32	iteration number	1301	MSE	0.03 px ²	MAE	0.15 px	Time
Sample size	32	iteration number	1401	MSE	0.02 px ²	MAE	0.10 px	Time
Sample size	32	iteration number	1501	MSE	0.03 px ²	MAE	0.12 px	Time
Sample size	32	iteration number	1601	MSE	0.03 px ²	MAE	0.12 px	Time
Sample size	32	iteration number	1701	MSE	0.02 px ²	MAE	0.11 px	Time
Sample size	32	iteration number	1801	MSE	0.01 px ²	MAE	0.09 px	Time
Sample size	32	iteration number	1901	MSE	0.03 px ²	MAE	0.13 px	Time
Sample size	32	iteration number	2001	MSE	0.03 px ²	MAE	0.12 px	Time
Sample size	32	iteration number	2101	MSE	0.03 px ²	MAE	0.13 px	Time
Sample size	32	iteration number	2201	MSE	0.03 px ²	MAE	0.14 px	Time
Sample size	32	iteration number	2301	MSE	0.03 px ²	MAE	0.13 px	Time
Sample size	32	iteration number	2401	MSE	0.02 px ²	MAE	0.12 px	Time
Sample size	32	iteration number	2501	MSE	0.02 px ²	MAE	0.12 px	Time
Sample size	32	iteration number	2601	MSE	0.02 px ²	MAE	0.11 px	Time
Sample size	32	iteration number	2701	MSE	0.02 px ²	MAE	0.11 px	Time
Sample size	32	iteration number	2801	MSE	0.02 px ²	MAE	0.10 px	Time
Sample size	32	iteration number	2901	MSE	0.01 px ²	MAE	0.09 px	Time

Sample size	32	iteration number	3001	MSE	0.03 px ²	MAE	0.13 px	Time
Sample size	128	iteration number	1	MSE	0.02 px ²	MAE	0.12 px	Time
Sample size	128	iteration number	101	MSE	0.02 px ²	MAE	0.11 px	Time
Sample size	128	iteration number	201	MSE	0.02 px ²	MAE	0.11 px	Time
Sample size	128	iteration number	301	MSE	0.02 px ²	MAE	0.12 px	Time
Sample size	128	iteration number	401	MSE	0.02 px ²	MAE	0.11 px	Time
Sample size	128	iteration number	501	MSE	0.03 px ²	MAE	0.13 px	Time
Sample size	128	iteration number	601	MSE	0.01 px ²	MAE	0.09 px	Time
Sample size	128	iteration number	701	MSE	0.02 px ²	MAE	0.11 px	Time
Sample size	128	iteration number	801	MSE	0.02 px ²	MAE	0.11 px	Time
Sample size	128	iteration number	901	MSE	0.02 px ²	MAE	0.12 px	Time
Sample size	128	iteration number	1001	MSE	0.02 px ²	MAE	0.12 px	Time
Sample size	128	iteration number	1101	MSE	0.01 px ²	MAE	0.08 px	Time
Sample size	128	iteration number	1201	MSE	0.02 px ²	MAE	0.12 px	Time
Sample size	128	iteration number	1301	MSE	0.03 px ²	MAE	0.12 px	Time
Sample size	128	iteration number	1401	MSE	0.03 px ²	MAE	0.12 px	Time
Sample size	128	iteration number	1501	MSE	0.02 px ²	MAE	0.12 px	Time
Sample size	128	iteration number	1601	MSE	0.02 px ²	MAE	0.09 px	Time
Sample size	128	iteration number	1701	MSE	0.03 px ²	MAE	0.13 px	Time
Sample size	128	iteration number	1801	MSE	0.02 px ²	MAE	0.10 px	Time
Sample size	128	iteration number	1901	MSE	0.02 px ²	MAE	0.10 px	Time
Sample size	128	iteration number	2001	MSE	0.02 px ²	MAE	0.11 px	Time
Sample size	512	iteration number	1	MSE	0.03 px ²	MAE	0.13 px	Time
Sample size	512	iteration number	101	MSE	0.02 px ²	MAE	0.11 px	Time
Sample size	512	iteration number	201	MSE	0.01 px ²	MAE	0.09 px	Time
Sample size	512	iteration number	301	MSE	0.02 px ²	MAE	0.11 px	Time
Sample size	512	iteration number	401	MSE	0.02 px ²	MAE	0.11 px	Time
Sample size	512	iteration number	501	MSE	0.02 px ²	MAE	0.11 px	Time
Sample size	512	iteration number	601	MSE	0.01 px ²	MAE	0.08 px	Time
Sample size	512	iteration number	701	MSE	0.02 px ²	MAE	0.11 px	Time
Sample size	512	iteration number	801	MSE	0.01 px ²	MAE	0.09 px	Time
Sample size	512	iteration number	901	MSE	0.01 px ²	MAE	0.08 px	Time
Sample size	512	iteration number	1001	MSE	0.02 px ²	MAE	0.11 px	Time
Sample size	1024	iteration number	1	MSE	0.02 px ²	MAE	0.12 px	Time
Sample size	1024	iteration number	101	MSE	0.02 px ²	MAE	0.10 px	Time

5. PLOT LEARNING PERFORMANCE

The learning performance is plotted. The MSE, MAE, sample size, iteration number and iteration time are plotted against the number of timesteps.

Comment:

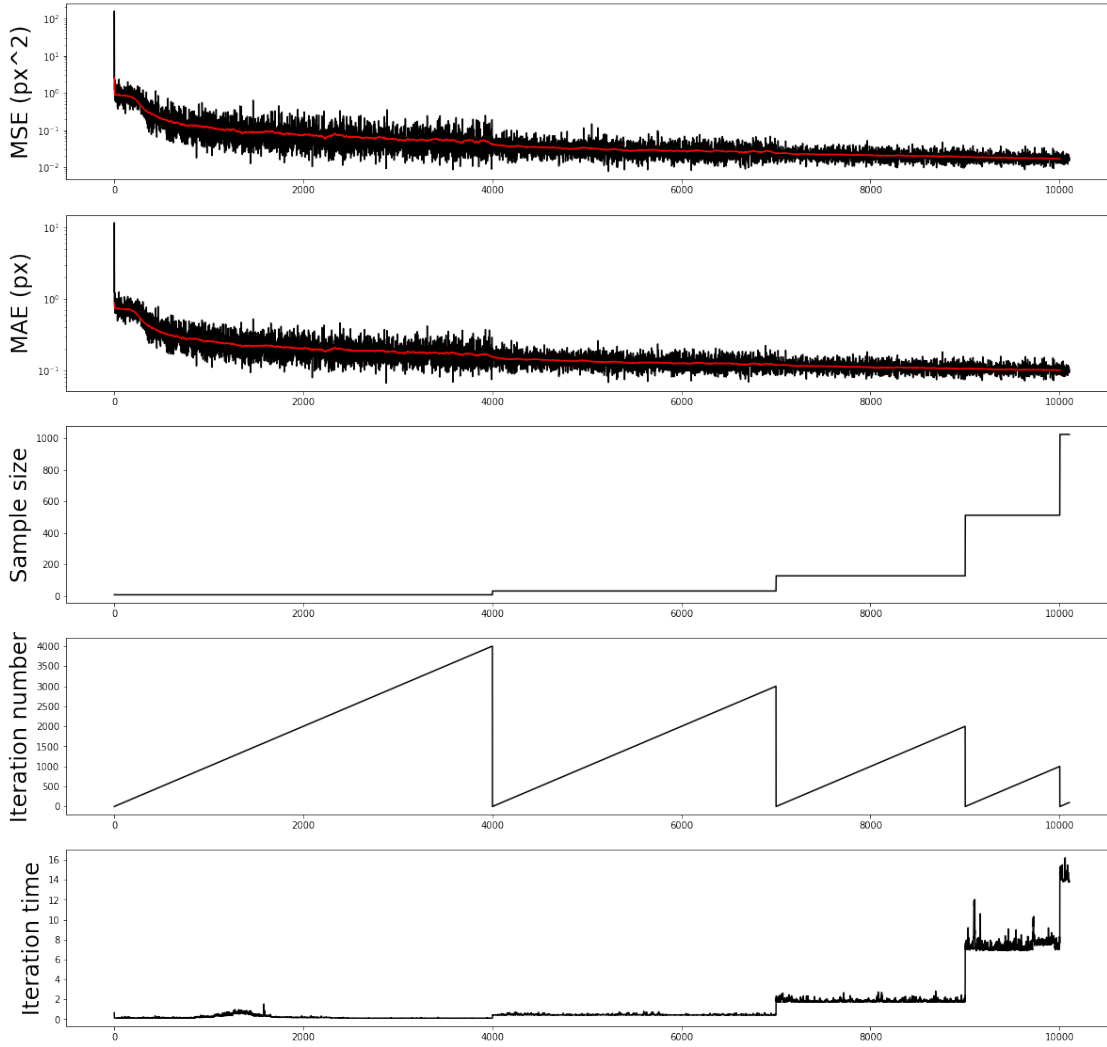
1. The parameter `number_of_timesteps_for_average` determines the length of the average. It must be a positive integer number.

In [5]: *### Plot learning performance*

```

number_of_timesteps_for_average = 100
deeptack.plot_learning_performance(training_history, number_of_timesteps_for_average)

```



6. TEST DEEP LEARNING NETWORK ON NEW SIMULATED DATA

The deep learning network is tested on new simulated data (parameters are defined in Section 2).

Comments:

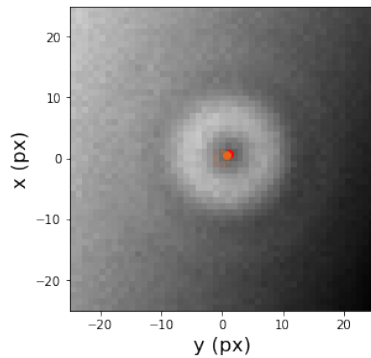
1. The parameter `number_of_predictions_to_show` determines the number of predictions that are shown.
2. The red symbol superimposed to the images represents the ground truth particle position.
3. The orange symbol is the deep learning network prediction for the position (x, y), and the circle is the prediction for the radial distance r.


```
In [6]: ### Test the predictions of the deep learning network on some generated images
        number_of_predictions_to_show = 10
```

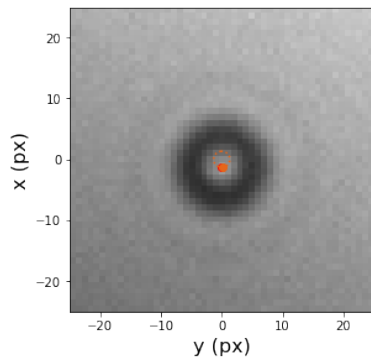
```
for image_number, image, image_parameters in image_generator():
    if image_number >= number_of_predictions_to_show:
        break
```

```
predicted_position = deeptack.predict(network, image)
```

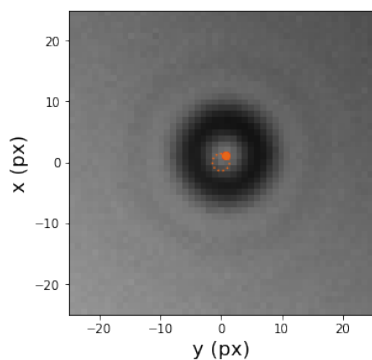
```
deeptack.plot_prediction(image, image_parameters, predicted_position)
```



```
particle center x = 0.72 px
particle center y = 1.07 px
particle radius = 2.56 px
Bessel order = 2.00
particle intensity = 0.41
ellipsoidal_orientation = 2.84
ellipticity = 1.00
predicted x = 0.55 px
predicted y = 0.85 px
predicted r = 1.15 px
image half size = 25.00 px
image background level = 0.40
signal to noise ratio = 50.22
gradient intensity = 0.86
gradient direction = 2.76 rad
```

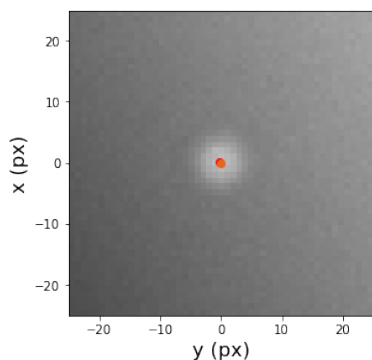


```
particle center x = -1.22 px
particle center y = 0.01 px
particle radius = 2.22 px
Bessel order = 2.00
particle intensity = -0.54
ellipsoidal_orientation = 1.51
ellipticity = 1.00
predicted x = -1.31 px
predicted y = 0.10 px
predicted r = 1.33 px
image half size = 25.00 px
image background level = 0.61
signal to noise ratio = 57.99
gradient intensity = 0.37
gradient direction = 1.13 rad
```



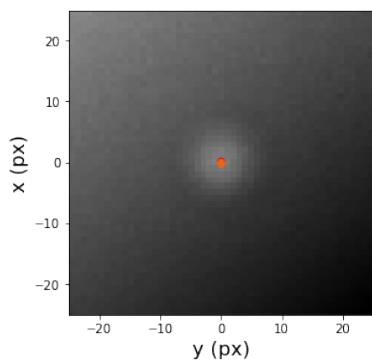
particle center x = 1.26 px
 particle center y = 0.70 px
 particle radius = 2.34 px
 Bessel order = 2.00
 particle intensity = -0.48
 ellipsoidal_orientation = 2.82
 ellipticity = 1.00
 predicted x = 1.16 px
 predicted y = 0.73 px
 predicted r = 1.41 px

image half size = 25.00 px
 image background level = 0.45
 signal to noise ratio = 92.84
 gradient intensity = 0.27
 gradient direction = -2.33 rad



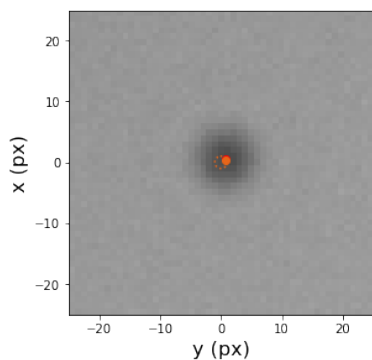
particle center x = 0.13 px
 particle center y = -0.16 px
 particle radius = 1.96 px
 Bessel order = 1.00
 particle intensity = 0.28
 ellipsoidal_orientation = -1.09
 ellipticity = 1.00
 predicted x = -0.05 px
 predicted y = -0.16 px
 predicted r = 0.26 px

image half size = 25.00 px
 image background level = 0.47
 signal to noise ratio = 96.49
 gradient intensity = 0.36
 gradient direction = 0.54 rad



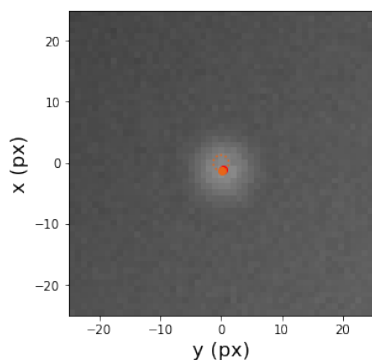
particle center x = 0.19 px
 particle center y = -0.04 px
 particle radius = 2.49 px
 Bessel order = 1.00
 particle intensity = 0.22
 ellipsoidal_orientation = -1.49
 ellipticity = 1.00
 predicted x = -0.04 px
 predicted y = -0.15 px
 predicted r = 0.25 px

image half size = 25.00 px
 image background level = 0.26
 signal to noise ratio = 92.79
 gradient intensity = 0.55
 gradient direction = 2.24 rad



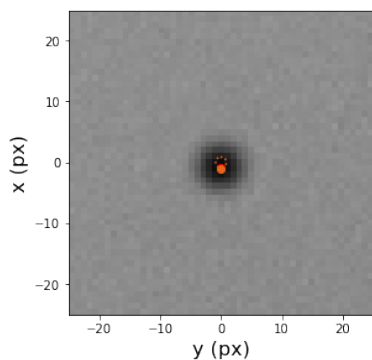
particle center x = 0.57 px
 particle center y = 0.82 px
 particle radius = 2.56 px
 Bessel order = 1.00
 particle intensity = -0.31
 ellipsoidal_orientation = -2.41
 ellipticity = 1.00
 predicted x = 0.42 px
 predicted y = 0.79 px
 predicted r = 1.01 px

image half size = 25.00 px
 image background level = 0.60
 signal to noise ratio = 91.16
 gradient intensity = 0.02
 gradient direction = -0.76 rad



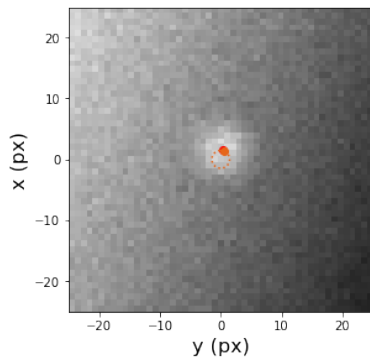
particle center x = -1.11 px
 particle center y = 0.30 px
 particle radius = 2.41 px
 Bessel order = 1.00
 particle intensity = 0.22
 ellipsoidal_orientation = -1.56
 ellipticity = 1.00
 predicted x = -1.24 px
 predicted y = 0.18 px
 predicted r = 1.28 px

image half size = 25.00 px
 image background level = 0.33
 signal to noise ratio = 68.06
 gradient intensity = 0.11
 gradient direction = -0.66 rad



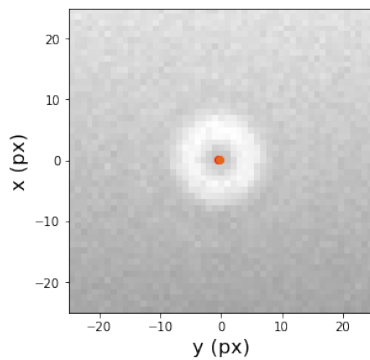
particle center x = -0.80 px
 particle center y = -0.13 px
 particle radius = 2.01 px
 Bessel order = 1.00
 particle intensity = -0.52
 ellipsoidal_orientation = -1.50
 ellipticity = 1.00
 predicted x = -0.98 px
 predicted y = -0.06 px
 predicted r = 0.88 px

image half size = 25.00 px
 image background level = 0.55
 signal to noise ratio = 62.59
 gradient intensity = 0.02
 gradient direction = 2.07 rad



particle center x = 1.51 px
 particle center y = 0.34 px
 particle radius = 2.27 px
 Bessel order = 1.00
 particle intensity = 0.34
 ellipsoidal_orientation = -0.64
 ellipticity = 1.00
 predicted x = 1.29 px
 predicted y = 0.45 px
 predicted r = 1.46 px

image half size = 25.00 px
 image background level = 0.48
 signal to noise ratio = 26.40
 gradient intensity = 0.76
 gradient direction = 2.75 rad



particle center x = 0.24 px
 particle center y = -0.38 px
 particle radius = 2.06 px
 Bessel order = 2.00
 particle intensity = 0.27
 ellipsoidal_orientation = 3.11
 ellipticity = 1.00
 predicted x = 0.18 px
 predicted y = -0.27 px
 predicted r = 0.41 px

image half size = 25.00 px
 image background level = 0.77
 signal to noise ratio = 59.34
 gradient intensity = 0.33
 gradient direction = 1.58 rad

7. SAVE DEEP LEARNING NETWORK

Comments:

1. The parameter save_file_name is the name of the file where the deep learnign network is saved.
2. By default, the network is saved in the same folder where DeepTrack 1.0 is running.

```

In [7]: ### Prepare file name
        from datetime import datetime as time

        save_file_name = 'Network ' + time.now().strftime('%Y-%m-%d-%H%M%S')

        save_file_name += ' C'
        for conv_layer_dimension in conv_layers_dimensions:
            save_file_name += '-' + str(conv_layer_dimension)

        save_file_name += ' D'
        for dense_layer_dimension in dense_layers_dimensions:
  
```

```

        save_file_name += '-' + str(dense_layer_dimension)

save_file_name += ' training'
for sample_size, iteration_number in zip(sample_sizes, iteration_numbers):
    save_file_name += '-' + str(sample_size) + 'x' + str(iteration_number)

save_file_name += '.h5'

### Save deep learning model
import os

if not os.path.exists(save_file_name):
    network.save(save_file_name)
    print('Saved deep learning network as:')
    print(save_file_name)

```

Saved deep learning network as:

Network 2019-03-08-185205 C-16-32-64 D-32-32 training-8x4001-32x3001-128x2001-512x1001-1024x101.

In []: