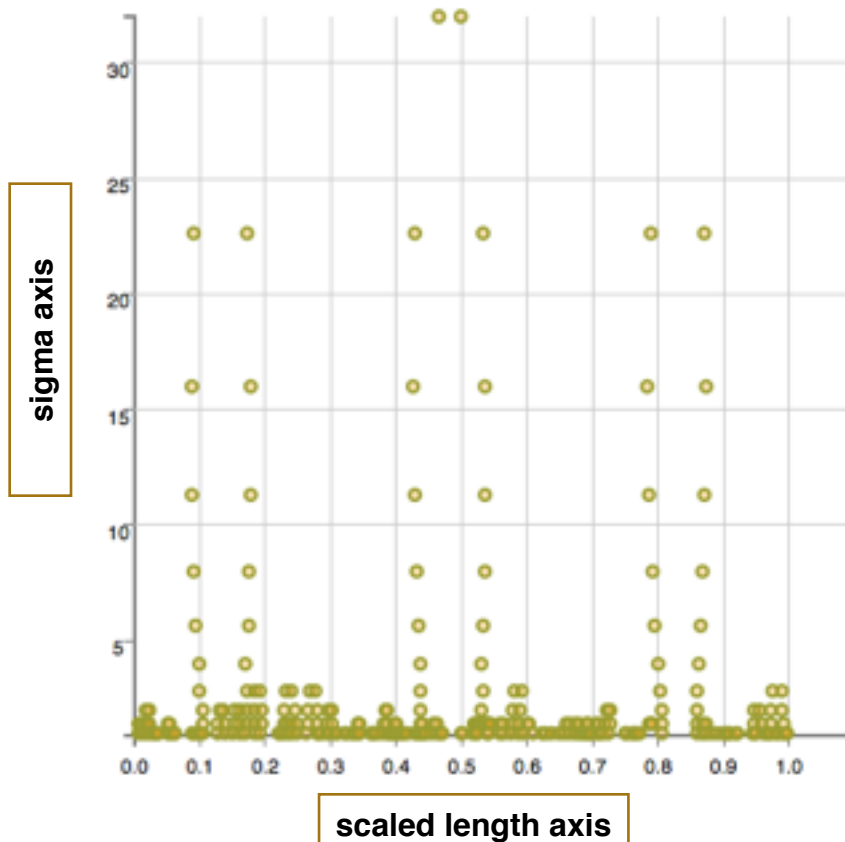


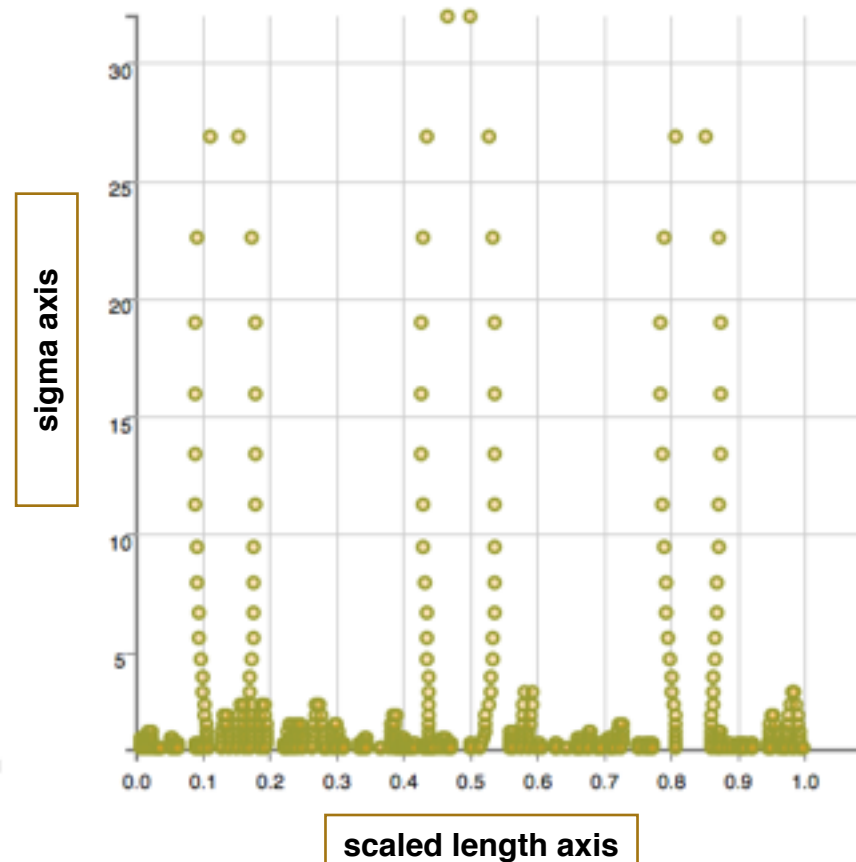
contour finder



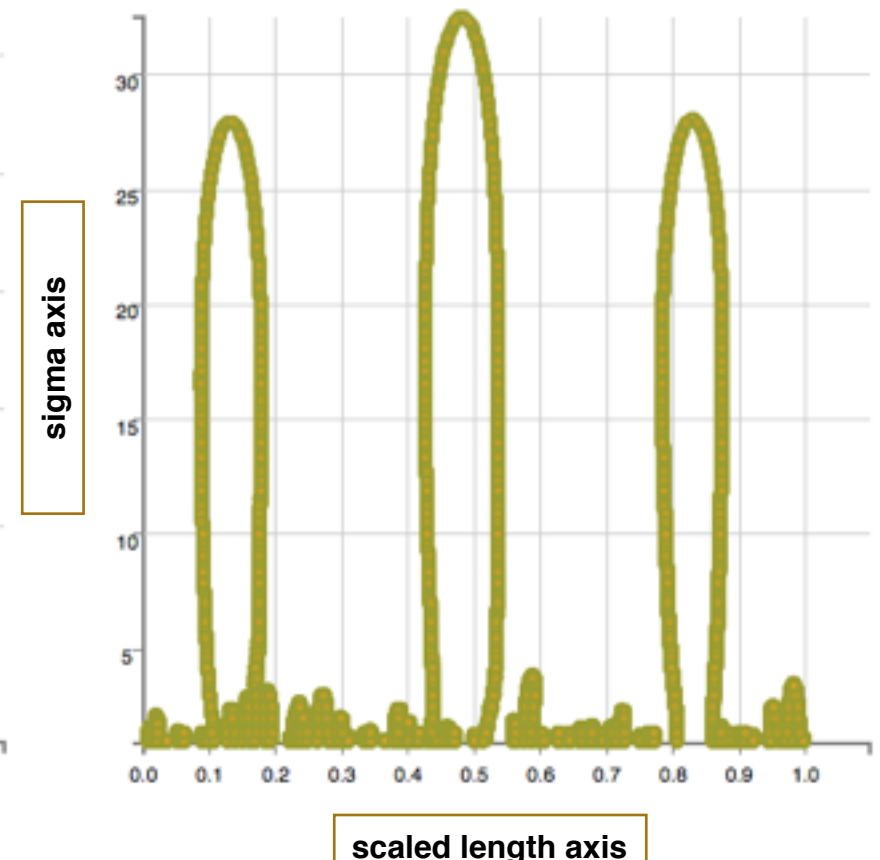
scale space image produced
for sigma factors of $\sqrt{2}$



scale space image produced
for sigma factors of $2^{1/8}$



scale space image produced
for sigma factors of $2^{1/128}$



There is an error in estimating the peak of a contour for fastest creation of scale space images ($\leq \sqrt{2}$). That error can be reduced overall, by having more contours in the final solution. For an error $< 10\%$ in determining a contour's peak height, one should choose a sigma factor of $2^{1/8}$ or smaller. It takes 2^3 more convolutions if the smaller sigma factor of $2^{1/8}$ is used instead of $2^{1/2}$.

Inflection points for $\sigma > 0$

Scale-Based Description and Recognition of Planar Curves and Two-Dimensional Shapes

FARZIN MOKHTARIAN AND ALAN MACKWORTH

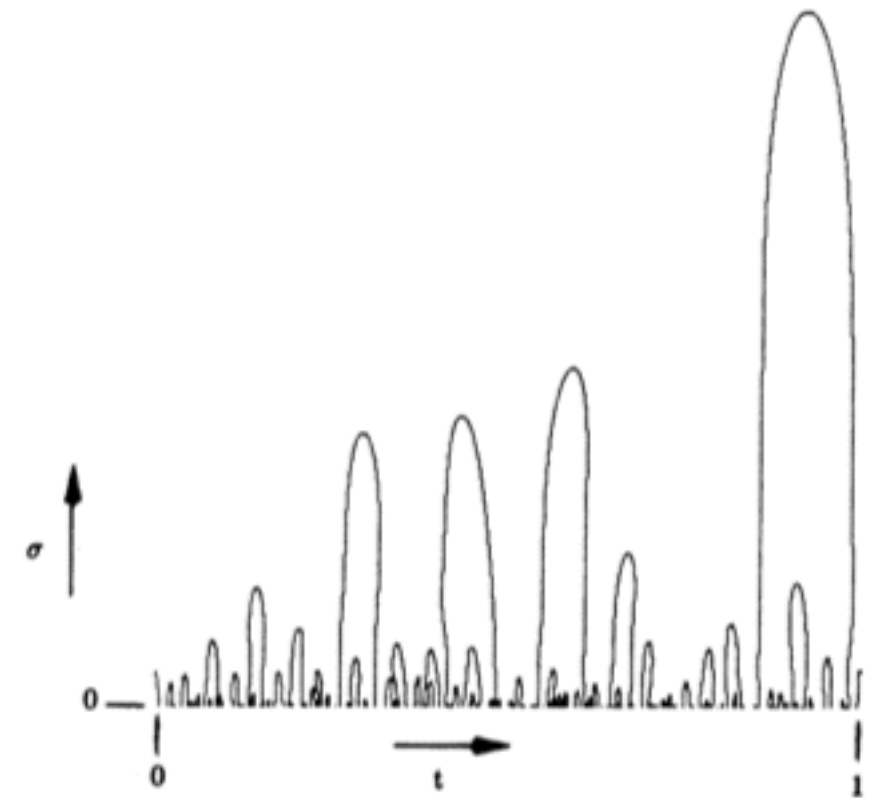
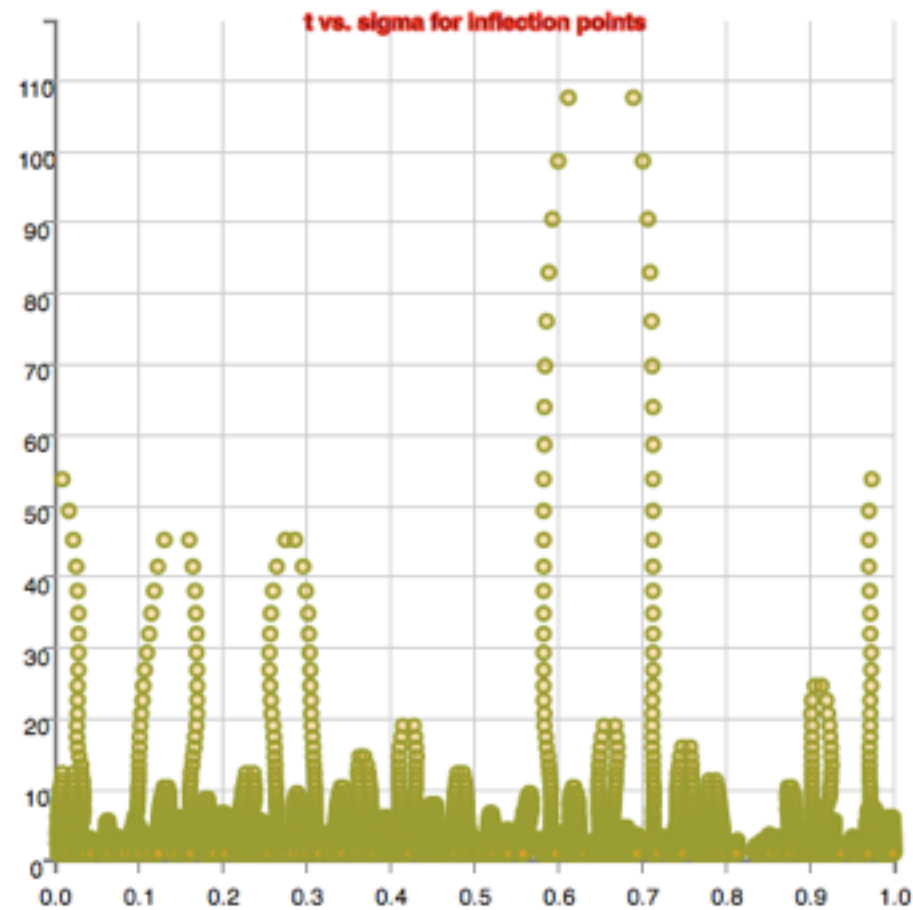
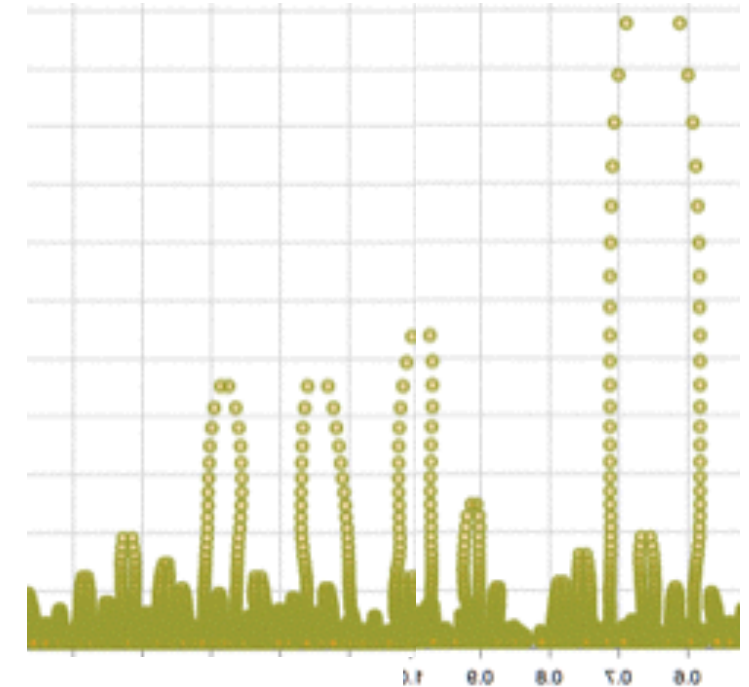


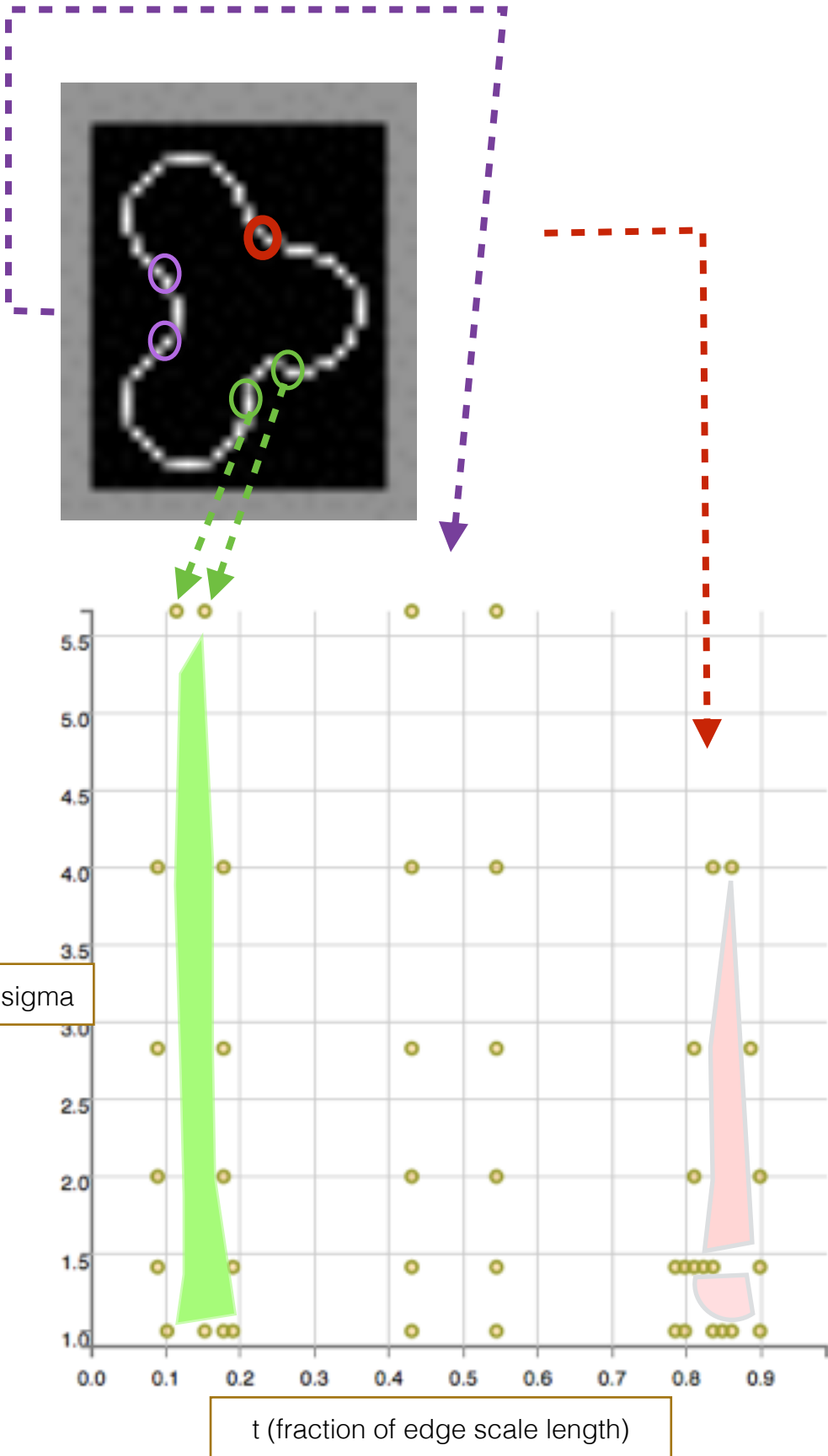
Fig. 3. Generalized scale space image of Africa.



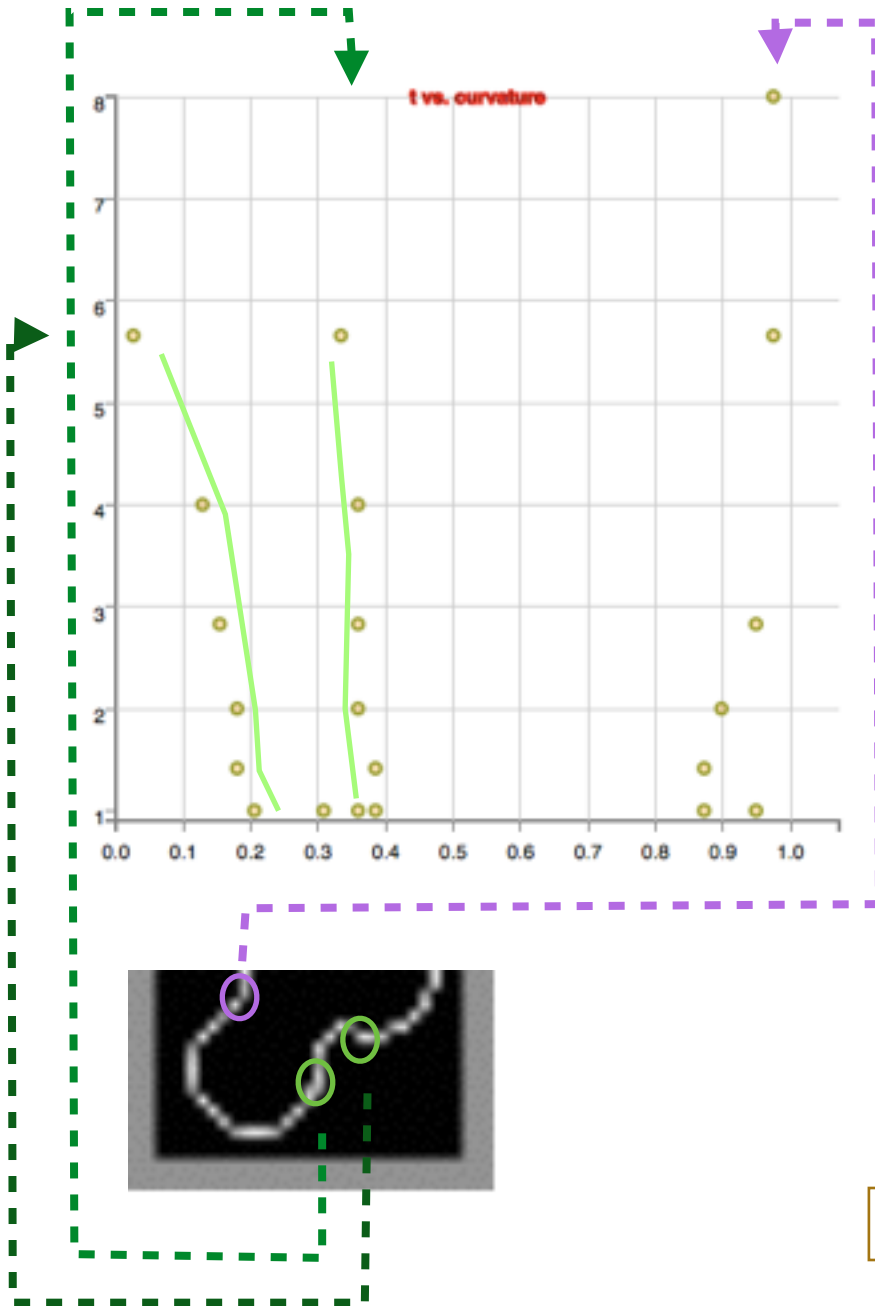
my scale space image
agrees with theirs

contour finder

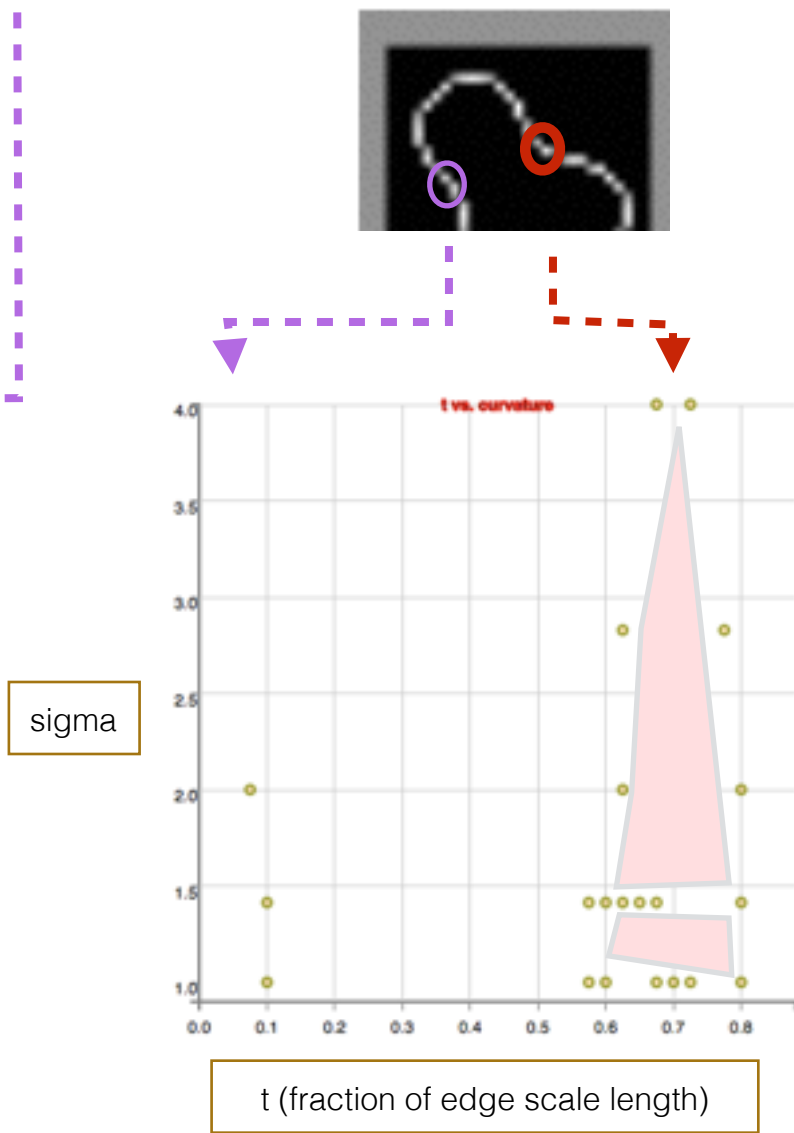
single closed curve's scale space image:



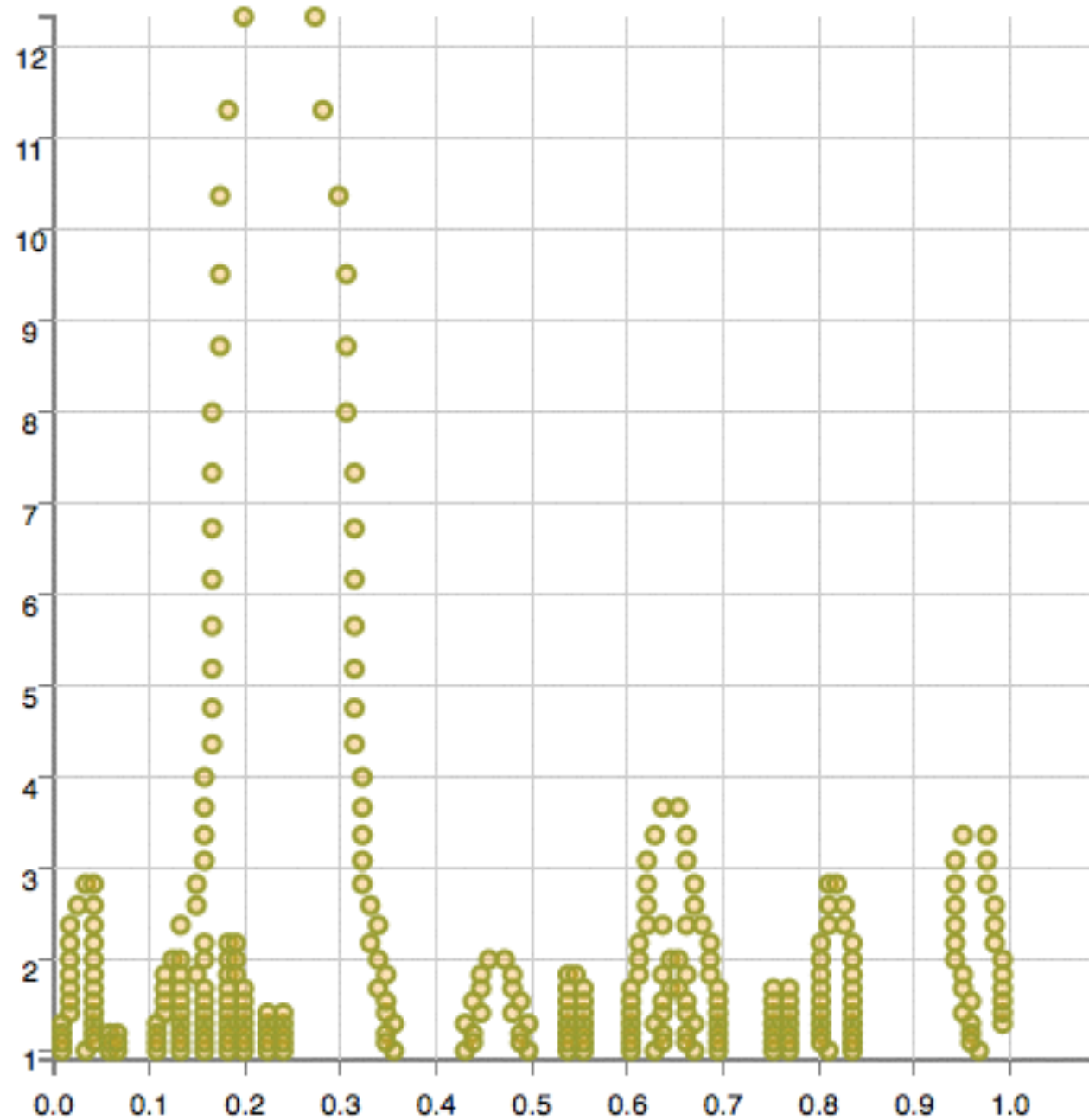
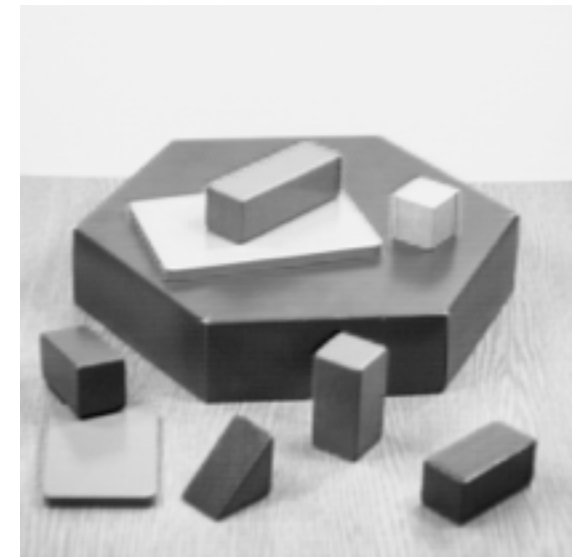
divided into 2 curves manually, then made into scale images (that is, 2 open curves possibly create open contours):



∴ open contours are hard to match in another image's scale images



contour finder



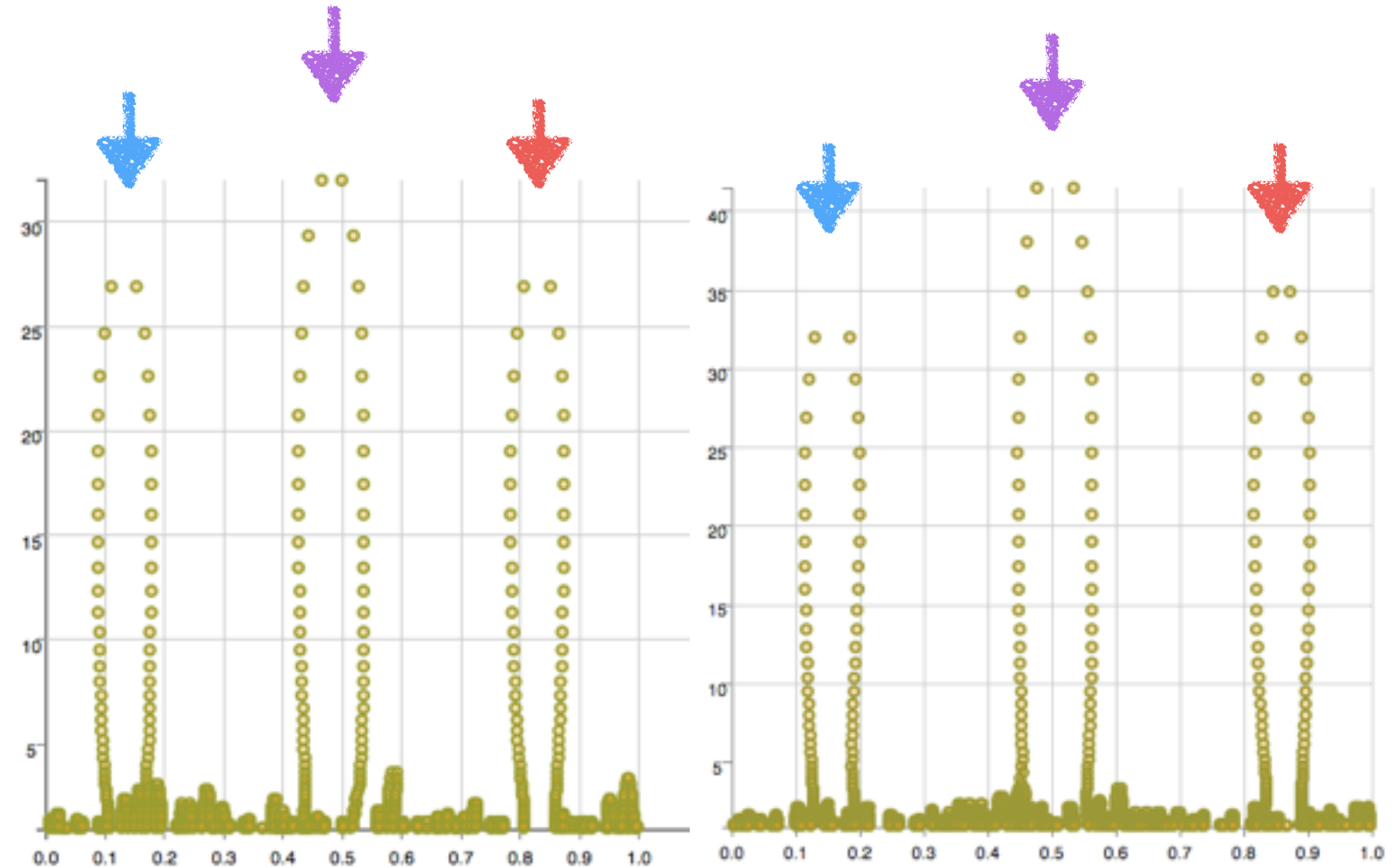
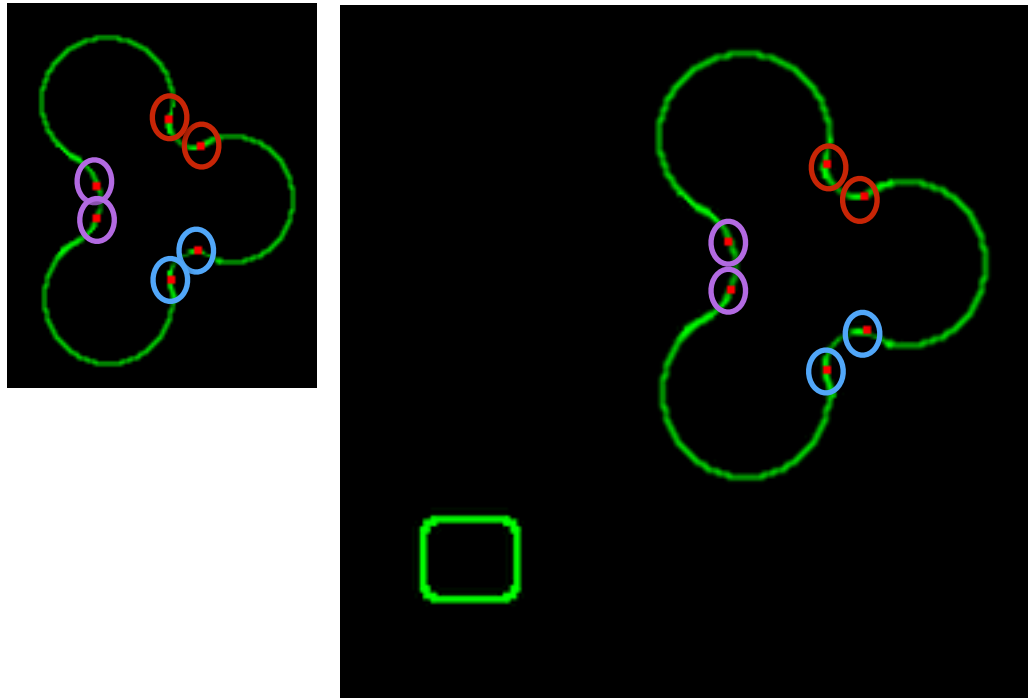
The contour finder looks for the peaks at the highest sigma and then follows the left and right branches down, subtracting that contour from the scale space image. each contour is found that way and subtracted to a lower threshold.

Then contours from one image are matched with the contours of another image (an image having the same content, that is).

Then euclidean transformation parameters rotation, scale, and translation are calculated from the matched contour peak coordinates.

Then, the parameters are refined with small changes and applied to the edges in image 1. The transformed closed curve edges from image 1 are compared to the closest matches in image 2 to find the best fitting transformation parameters.

coordinate transformation, after matching contours

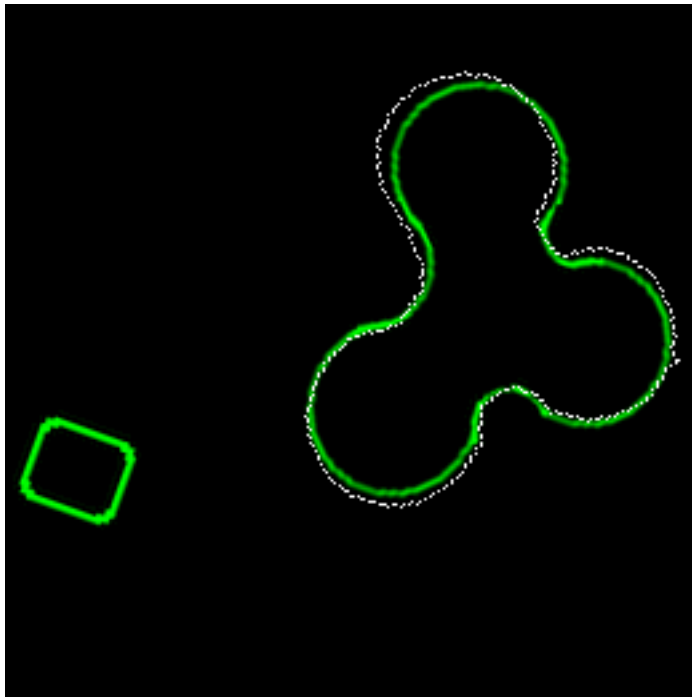


scale should be 1.3
rotation should be 360 - 20

Contour matcher solution scale=1.354256510734558
Contour matcher solution shift=-0.1688411384820938
CONTOUR PEAK1: (32.000237, 0.497126) (34, 78) (35, 72)
CONTOUR PEAK1: (26.908875, 0.146552) (70, 93) (61, 99)
CONTOUR PEAK1: (26.908875, 0.846264) (60, 45) (69, 54)
offsetImgX1=10 offsetImgY1=10
offsetImgX2=1 offsetImgY2=26
rotationInRadians=6.0030236
rotationInDegrees=343.94791799660214
scale=1.3542565
translationX=108.1361
translationY=15.72716

CONTOUR PEAK2: (43.336529, 0.504396) (157, 108) (159, 101)
CONTOUR PEAK2: (34.148750, 0.157143) (190, 143) (177, 150)
CONTOUR PEAK2: (34.896511, 0.859341) (200, 85) (209, 97)

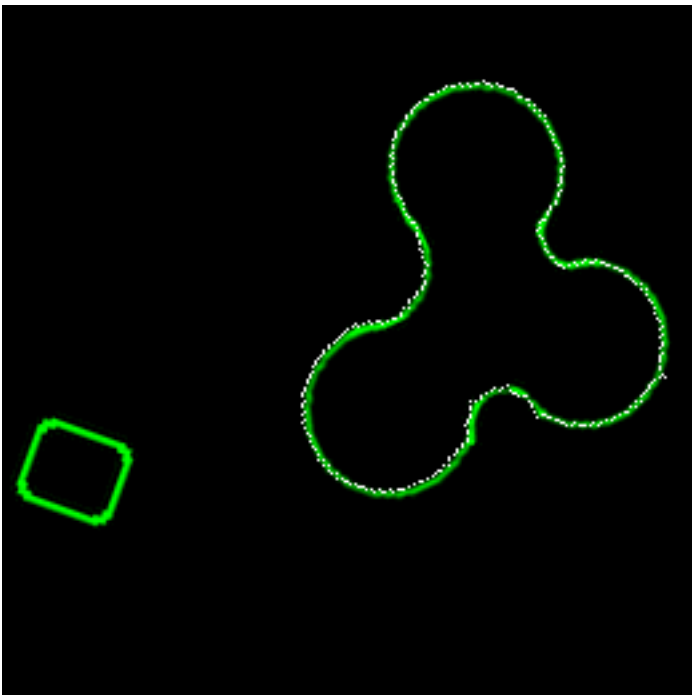
apply coordinate transformation



rotationInRadians=6.0030236
rotationInDegrees=343.94791799660214
scale=1.3542565
translationX=108.1361
translationY=15.72716

scale should be 1.3
rotation should be 360-20

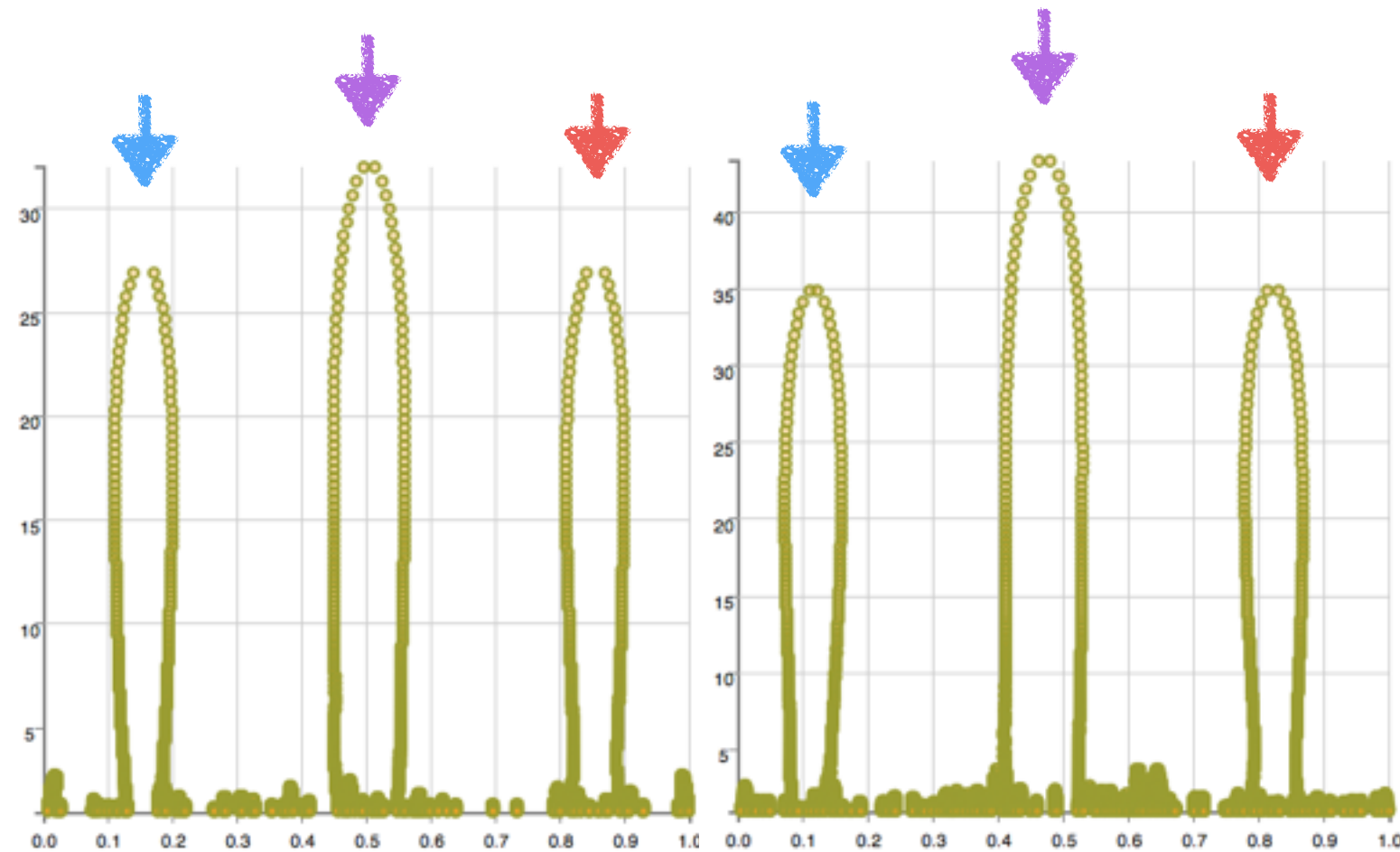
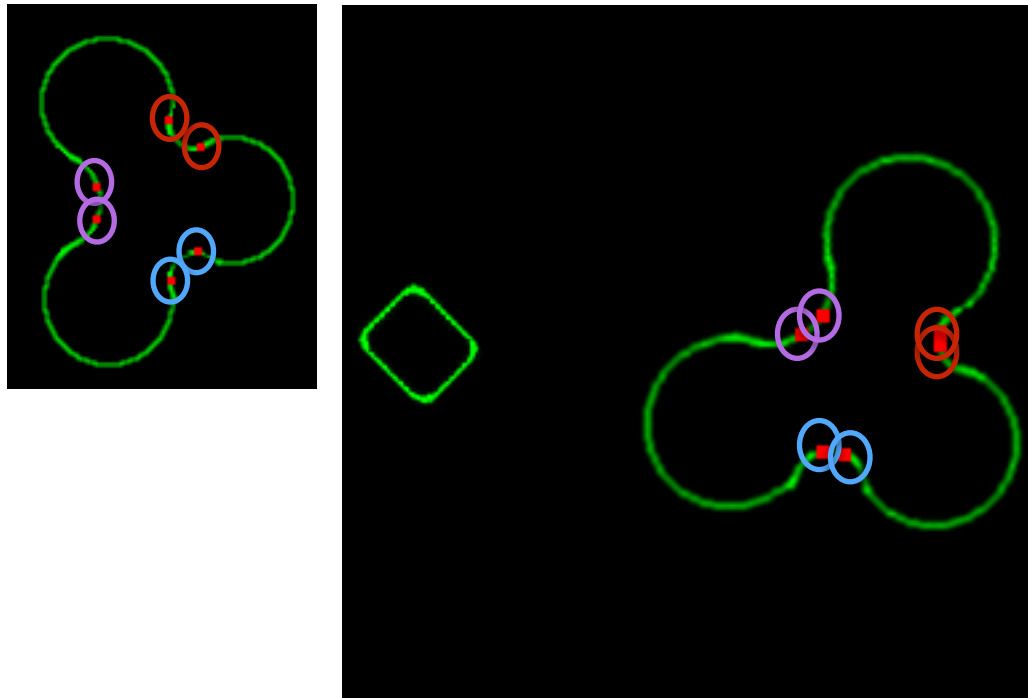
This shows that it's difficult to estimate scale unless some of the inflection points are further from the center of the shape



After Refinement

rotationInRadians=5.915757
rotationInDegrees=338.94791899582935
scale=1.3042566
translationX=111.0
translationY=20.0

coordinate transformation, after matching contours

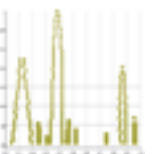


reversed to have CCW ordering

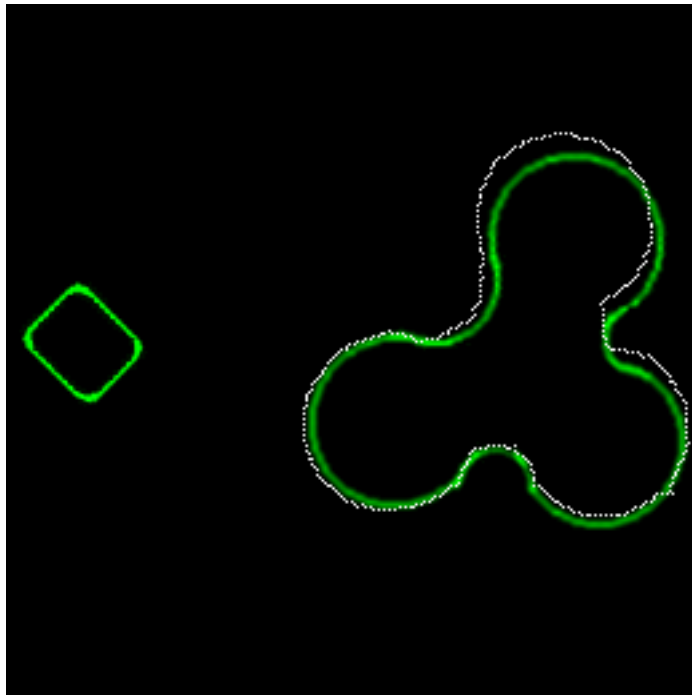
reversed to have CCW ordering

scale should be 1.3
rotation should be 360 - 45

Contour matcher solution scale=1.354256510734558
Contour matcher solution shift=-0.1425349861383438
CONTOUR PEAK1: (32.000237, 0.497126) (34, 78) (35, 72) CONTOUR PEAK2: (43.336529, 0.530702) (172, 123) (180, 116)
CONTOUR PEAK1: (26.908875, 0.146552) (70, 93) (61, 99) CONTOUR PEAK2: (34.896511, 0.179825) (188, 168) (180, 167)
CONTOUR PEAK1: (26.908875, 0.846264) (60, 45) (69, 54) CONTOUR PEAK2: (34.896511, 0.884868) (224, 122) (224, 127)
offsetImgX1=10 offsetImgY1=10
offsetImgX2=3 offsetImgY2=52
rotationInRadians=5.5627766
rotationInDegrees=318.7236195803948
scale=1.3542565
translationX=119.984764
translationY=39.13688

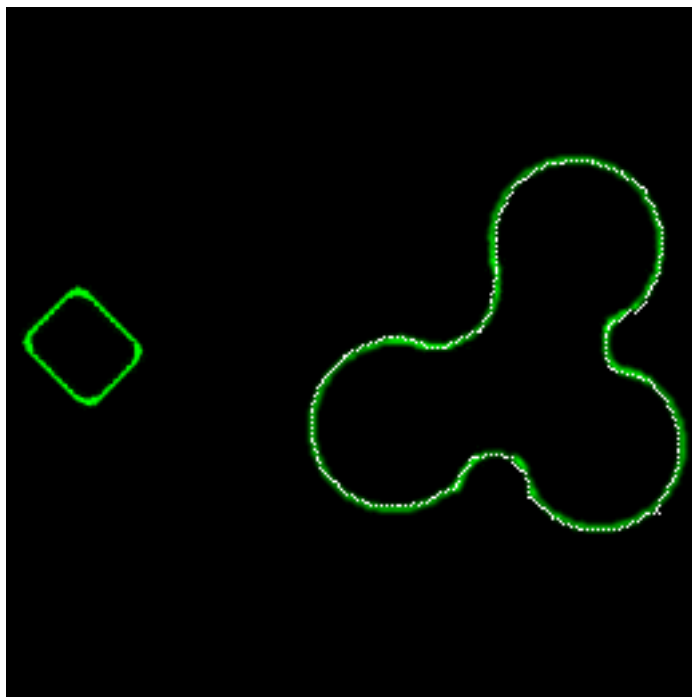


apply coordinate transformation



offsetImgX1=10 offsetImgY1=10
offsetImgX2=3 offsetImgY2=52
rotationInRadians=5.5627766
rotationInDegrees=318.7236195803948
scale=1.3542565
translationX=119.984764
translationY=39.13688

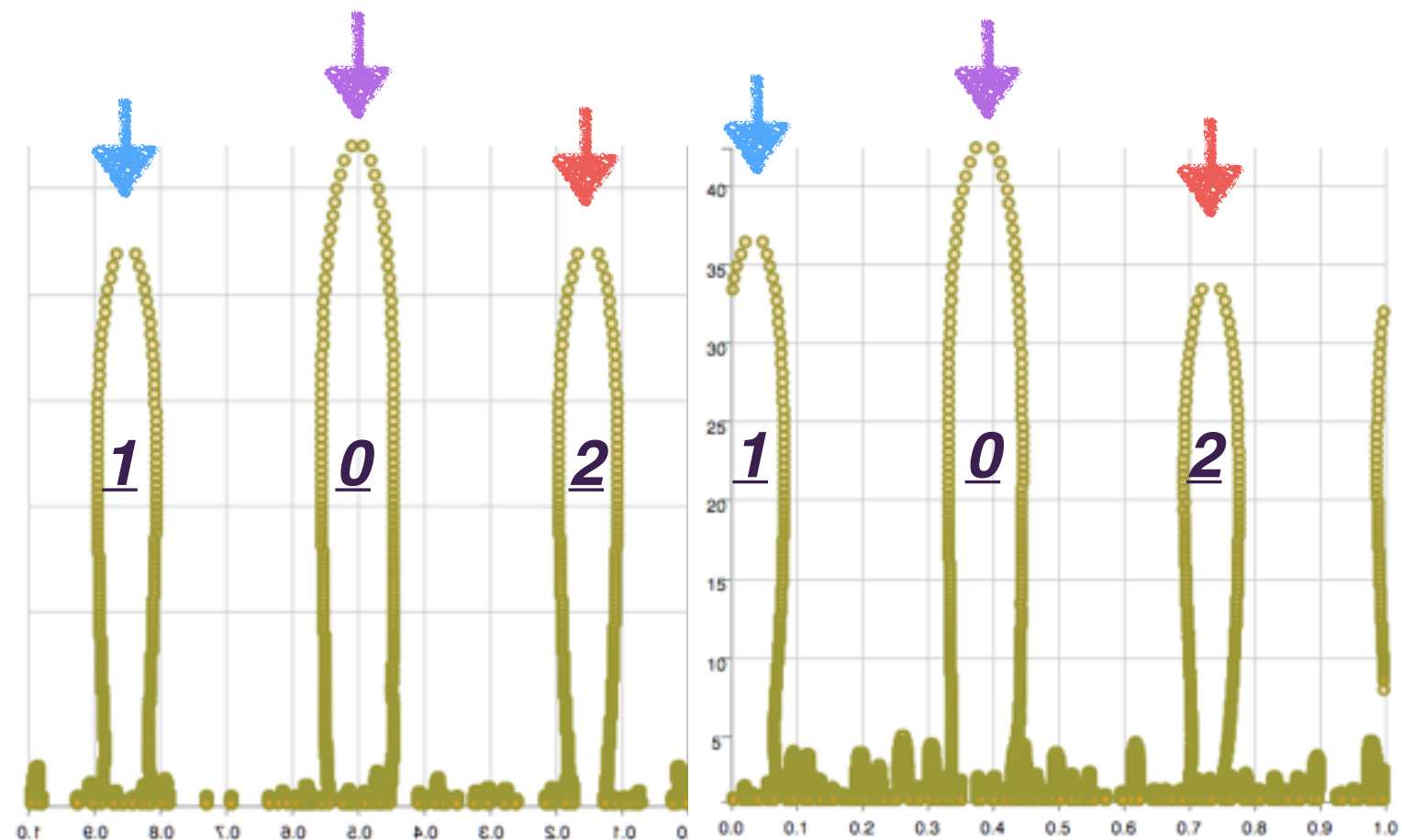
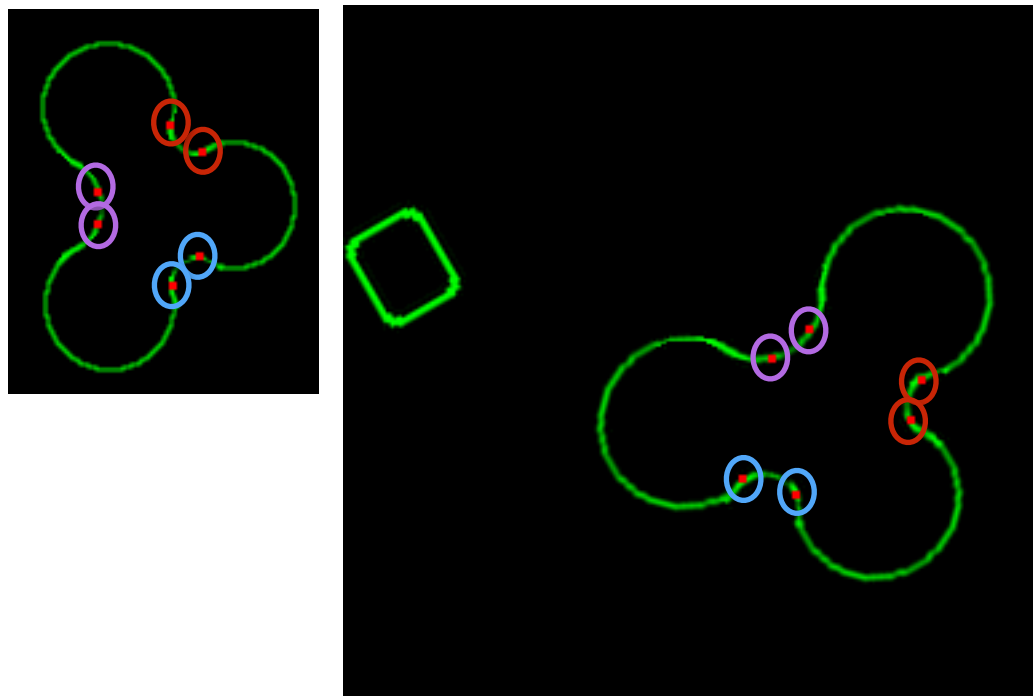
scale should be 1.3
rotation should be 360-45



After Refinement

rotationInRadians=5.47551
rotationInDegrees=313.72362057962204
scale=1.3042566
translationX=124.0
translationY=47.0

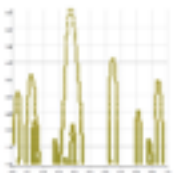
coordinate transformation, after matching contours



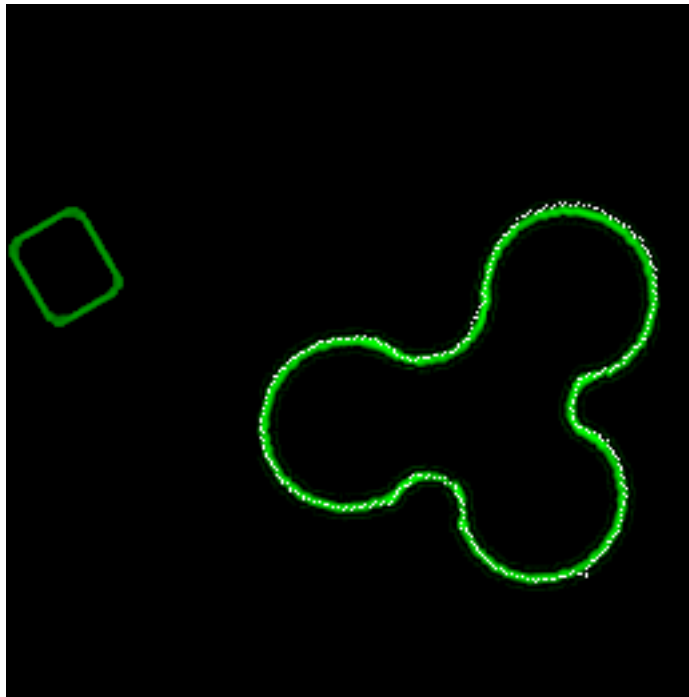
reversed to have CCW ordering

scale should be 1.3
rotation should be 360 - 60

Contour matcher solution scale=1.325237512588501
Contour matcher solution shift=-0.2715021073818207
CONTOUR PEAK1: (32.000237, 0.497126) (34, 78) (35, 72) CONTOUR PEAK2: (42.407913, 0.387309) (161, 133) (172, 126)
CONTOUR PEAK1: (26.908875, 0.146552) (70, 93) (61, 99) CONTOUR PEAK2: (36.441517, 0.035011) (168, 182) (157, 176)
CONTOUR PEAK1: (26.908875, 0.846264) (60, 45) (69, 54) CONTOUR PEAK2: (33.417011, 0.734136) (215, 143) (213, 156)
offsetImgX1=10 offsetImgY1=10
offsetImgX2=0 offsetImgY2=71
rotationInRadians=5.2398615
rotationInDegrees=300.2219485151509
scale=1.3252375
translationX=107.96625
translationY=59.87517

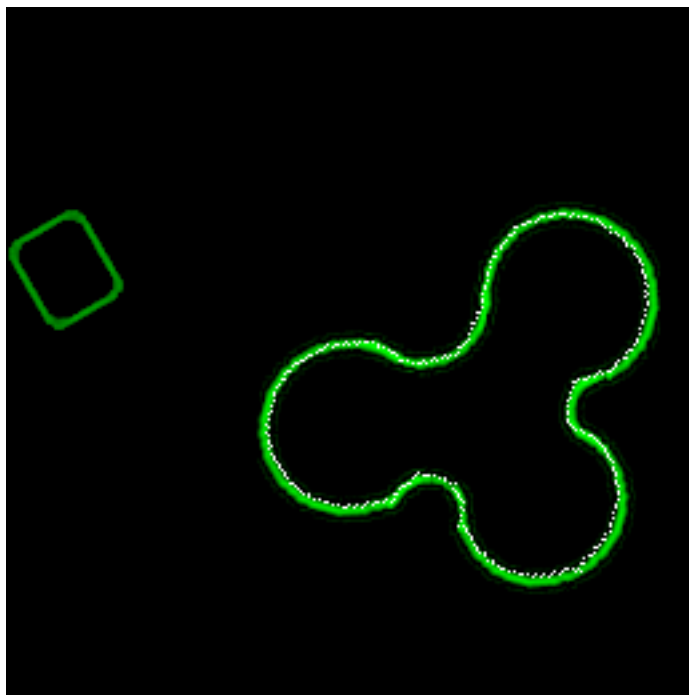


apply coordinate transformation



```
Contour matcher solution scale=1.325237512588501
Contour matcher solution shift=-0.2715021073818207
CONTOUR PEAK1: (32.000237, 0.497126) (34, 78) (35, 72)
  CONTOUR PEAK2: (42.407913, 0.387309) (161, 133) (172, 126)
CONTOUR PEAK1: (26.908875, 0.146552) (70, 93) (61, 99)
  CONTOUR PEAK2: (36.441517, 0.035011) (168, 182) (157, 176)
CONTOUR PEAK1: (26.908875, 0.846264) (60, 45) (69, 54)
  CONTOUR PEAK2: (33.417011, 0.734136) (215, 143) (213, 156)
offsetImgX1=10 offsetImgY1=10
offsetImgX2=0 offsetImgY2=71
rotationInRadians=5.2398615
rotationInDegrees=300.2219485151509
scale=1.3252375
translationX=107.96625
translationY=59.87517
```

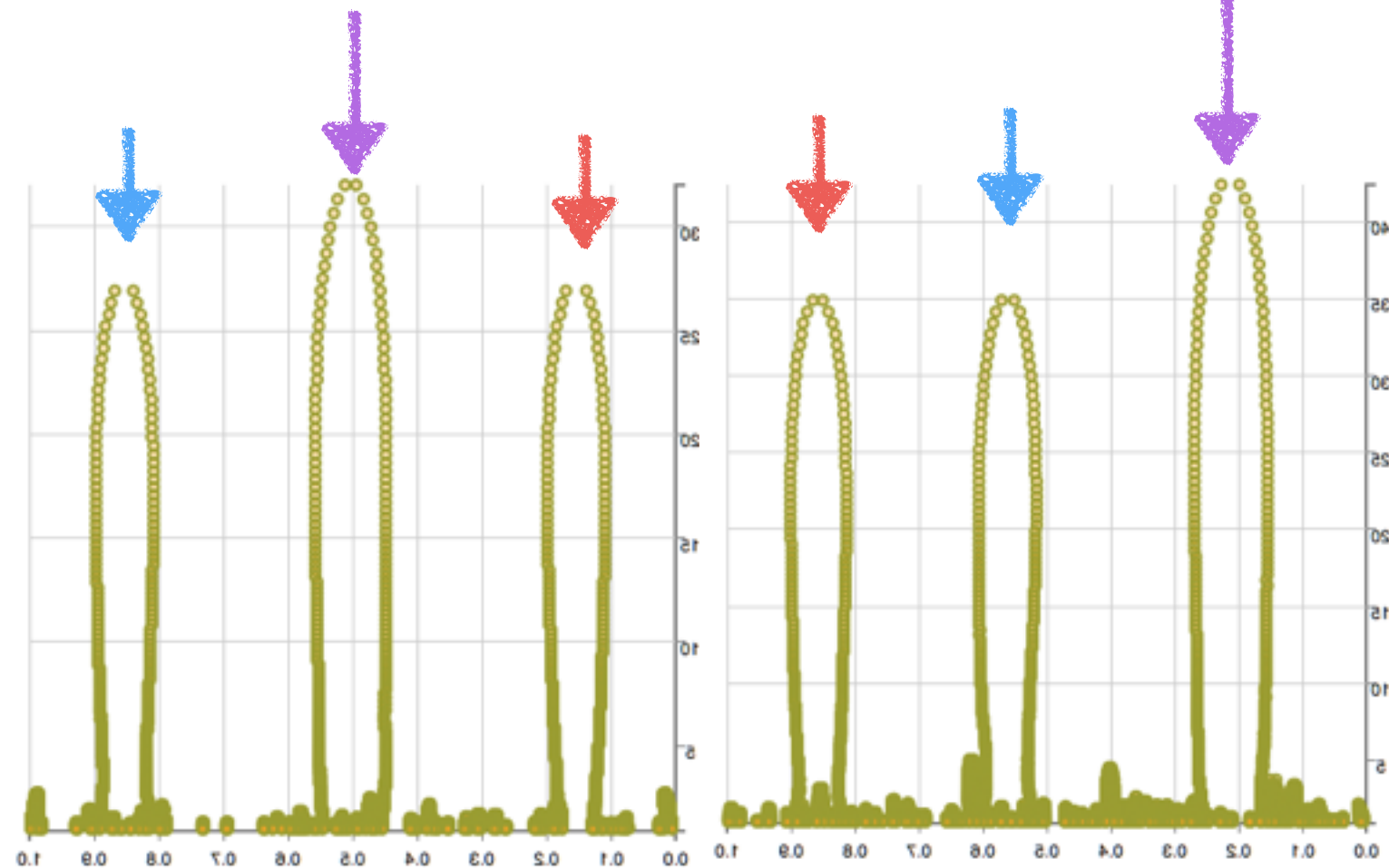
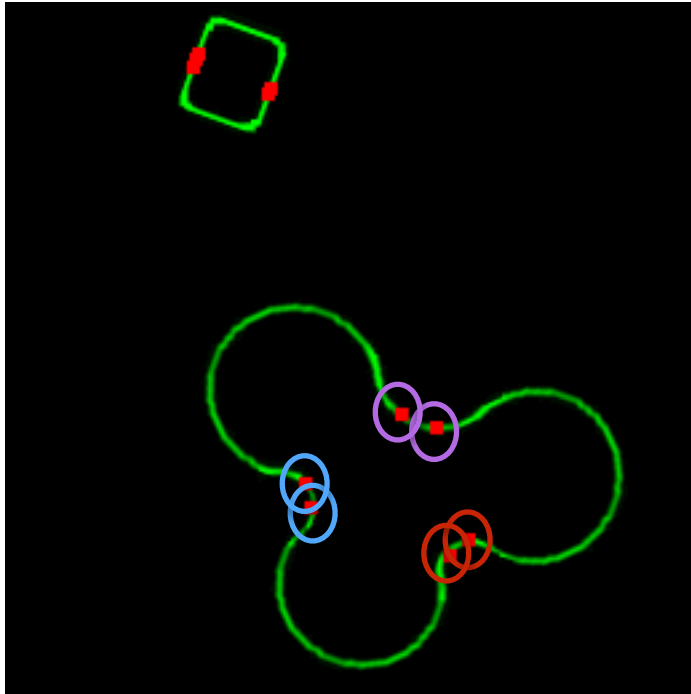
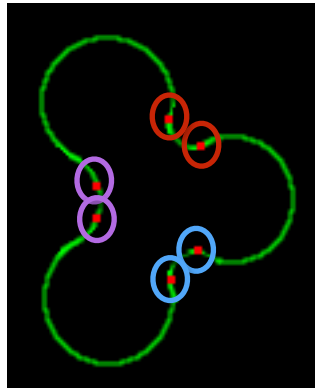
scale should be 1.3
rotation should be 360 - 60



After Refinement

```
rotationInRadians=5.2398615
rotationInDegrees=300.2219485151509
scale=1.2752376
translationX=110.0
translationY=63.0
```

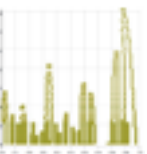
coordinate transformation, after matching contours



reversed to have CCW ordering

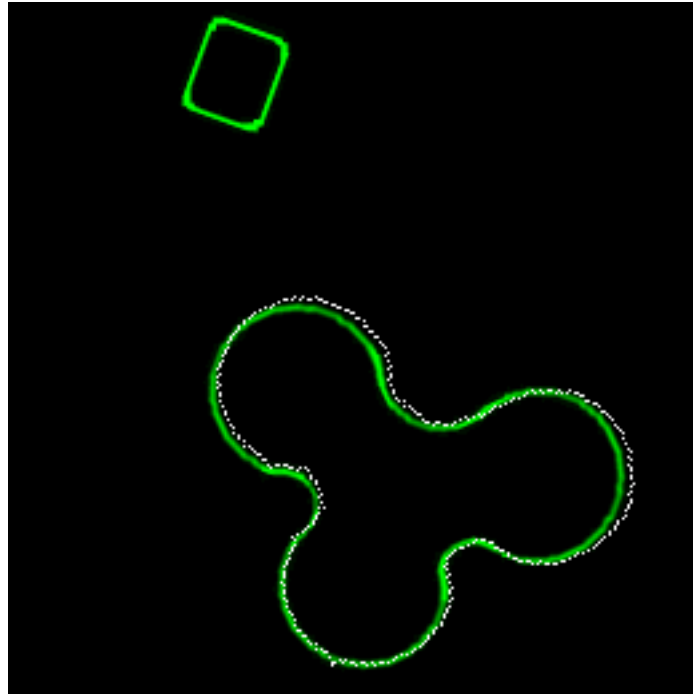
reversed to have CCW ordering

scale should be 1.3
rotation should be 360 -110



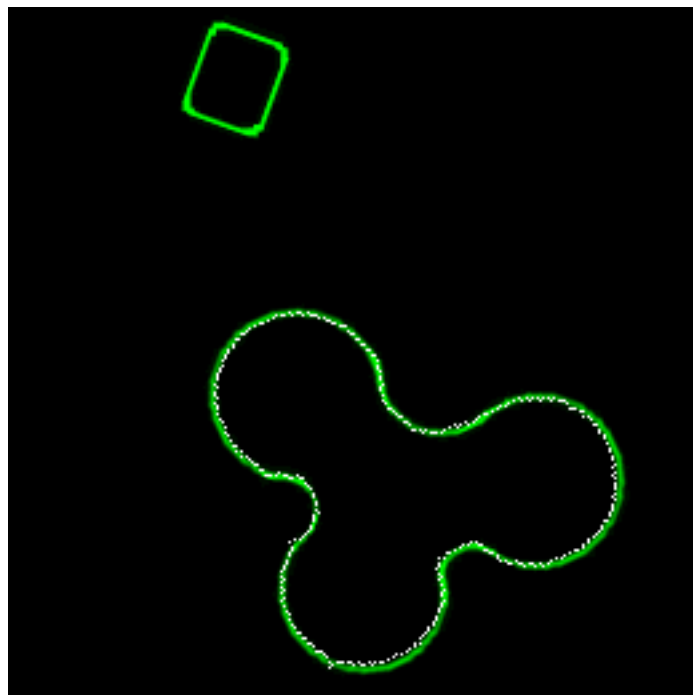
CONTOUR PEAK1: (32.000237, 0.497126) (34, 78) (35, 72) CONTOUR PEAK2: (42.407913, 0.787445) (148, 154) (161, 159)
CONTOUR PEAK1: (26.908875, 0.146552) (70, 93) (61, 99) CONTOUR PEAK2: (34.896511, 0.439427) (114, 189) (112, 180)
CONTOUR PEAK1: (26.908875, 0.846264) (60, 45) (69, 54) CONTOUR PEAK2: (34.896511, 0.142070) (173, 201) (166, 207)
offsetImgX1=10 offsetImgY1=10
offsetImgX2=62 offsetImgY2=1
rotationInRadians=4.336784
rotationInDegrees=248.47941332561248
scale=1.3252375
translationX=70.99721
translationY=91.054344

apply coordinate transformation



```
CONTOUR PEAK1: (32.000237, 0.497126) (34, 78) (35, 72)
CONTOUR PEAK2: (42.407913, 0.787445) (148, 154) (161, 159)
CONTOUR PEAK1: (26.908875, 0.146552) (70, 93) (61, 99)
CONTOUR PEAK2: (34.896511, 0.439427) (114, 189) (112, 180)
CONTOUR PEAK1: (26.908875, 0.846264) (60, 45) (69, 54)
CONTOUR PEAK2: (34.896511, 0.142070) (173, 201) (166, 207)
offsetImgX1=10 offsetImgY1=10
offsetImgX2=62 offsetImgY2=1
rotationInRadians=4.336784
rotationInDegrees=248.47941332561248
scale=1.3252375
translationX=70.99721
translationY=91.054344
```

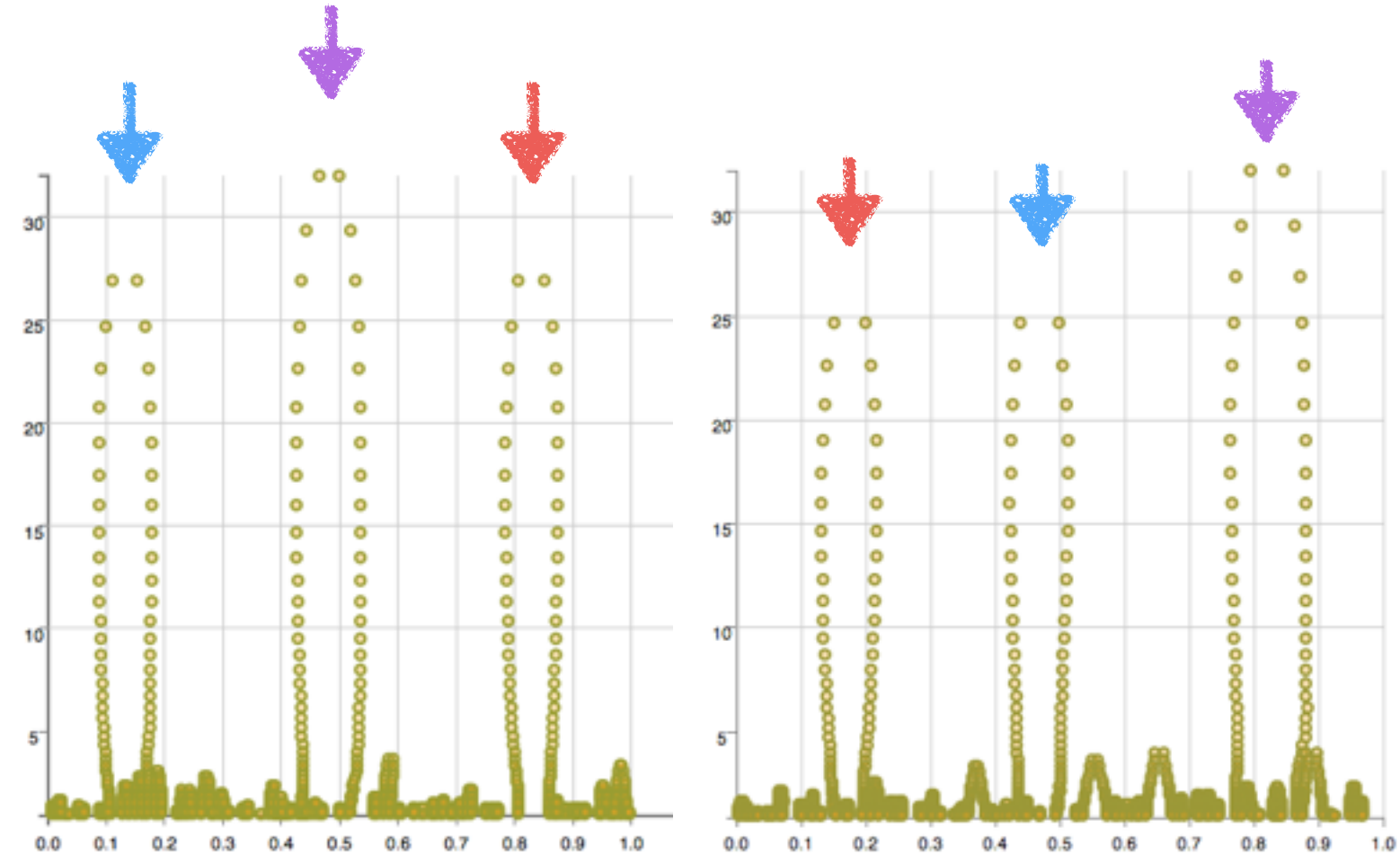
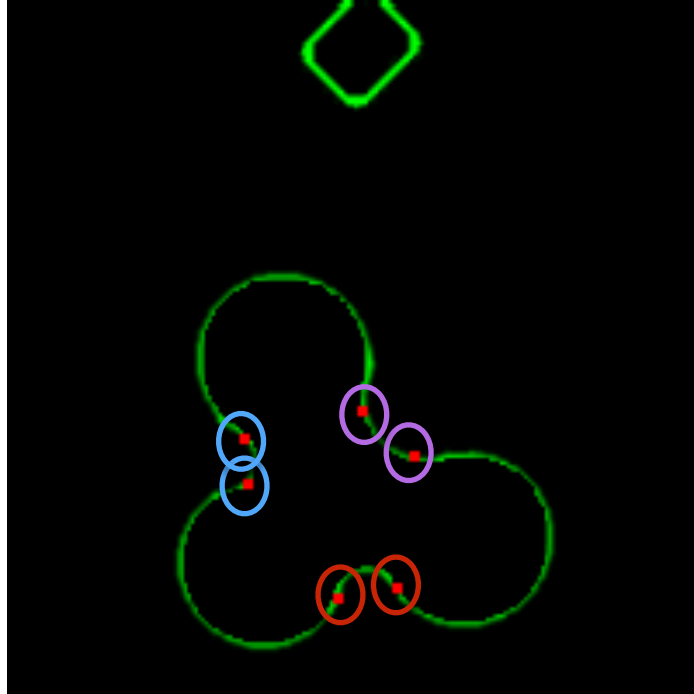
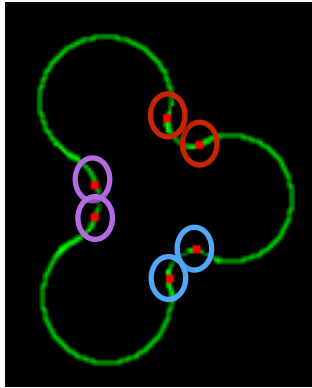
scale should be 1
rotation should be 360 - 110 (250)



After Refinement

```
rotationInRadians=4.354237
rotationInDegrees=249.4794076616157
scale=1.2752376
translationX=71.0
translationY=95.0
```

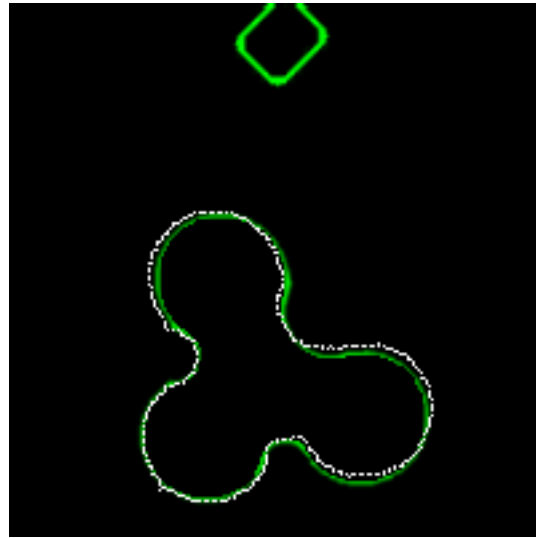
coordinate transformation, after matching contours



scale should be 1.3
rotation should be 360 - 135

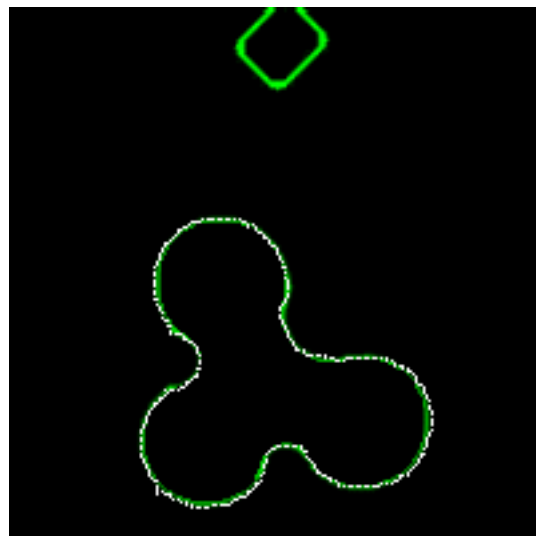
Contour matcher solution scale=1.0218971967697144
Contour matcher solution shift=0.3104316294193268
CONTOUR PEAK1: (32.000237, 0.497126) (34, 78) (35, 72) CONTOUR PEAK2: (32.700951, 0.818444) (103, 120) (115, 132)
CONTOUR PEAK1: (26.908875, 0.146552) (70, 93) (61, 99) CONTOUR PEAK2: (25.768024, 0.468300) (69, 136) (69, 127)
CONTOUR PEAK1: (26.908875, 0.846264) (60, 45) (69, 54) CONTOUR PEAK2: (25.768024, 0.175793) (105, 164) (97, 166)
offsetImgX1=10 offsetImgY1=10
offsetImgX2=46 offsetImgY2=0
rotationInRadians=3.9818497
rotationInDegrees=228.14318077005984
scale=1.0218972
translationX=32.712353
translationY=70.68979

apply coordinate transformation



```
offsetImgX1=10 offsetImgY1=10  
offsetImgX2=46 offsetImgY2=0  
rotationInRadians=3.9818497  
rotationInDegrees=228.14318077005984  
scale=1.0218972  
translationX=32.712353  
translationY=70.68979
```

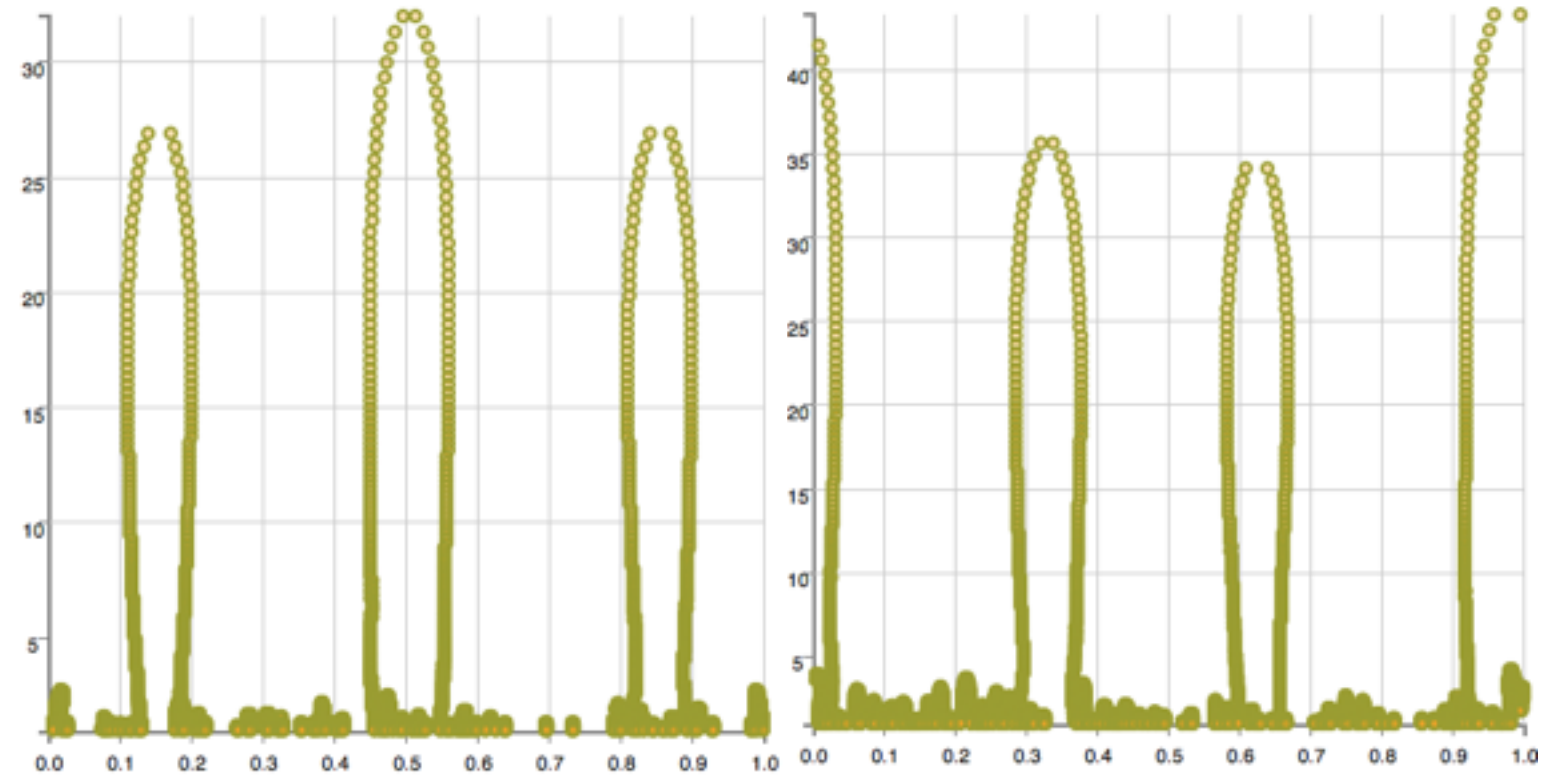
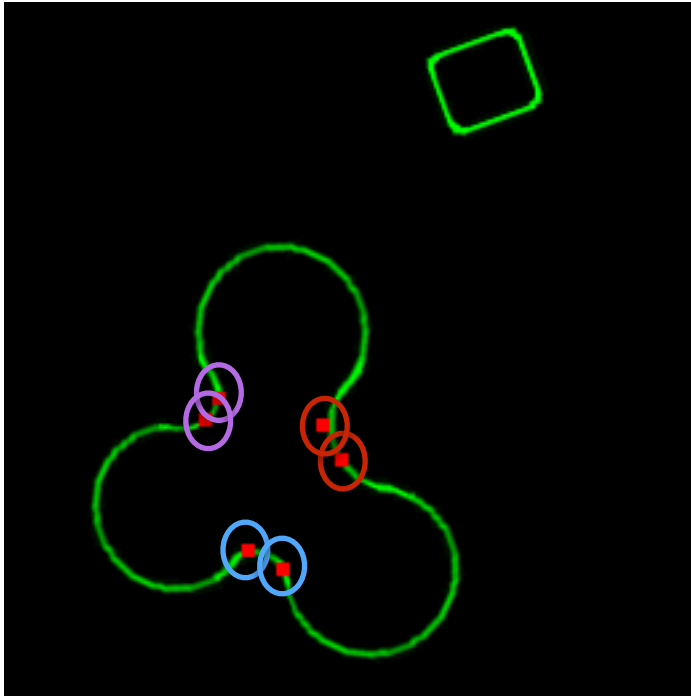
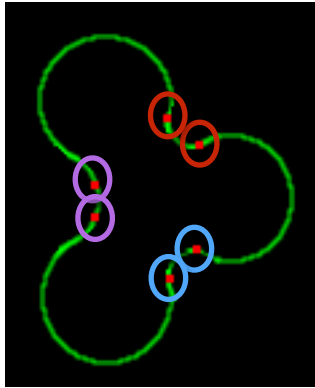
scale should be 1
rotation should be 360 - 135



After Refinement

```
rotationInRadians=3.9406004  
rotationInDegrees=225.77977139269535  
scale=1.0218972  
translationX=33.0  
translationY=72.0
```


coordinate transformation, after matching contours

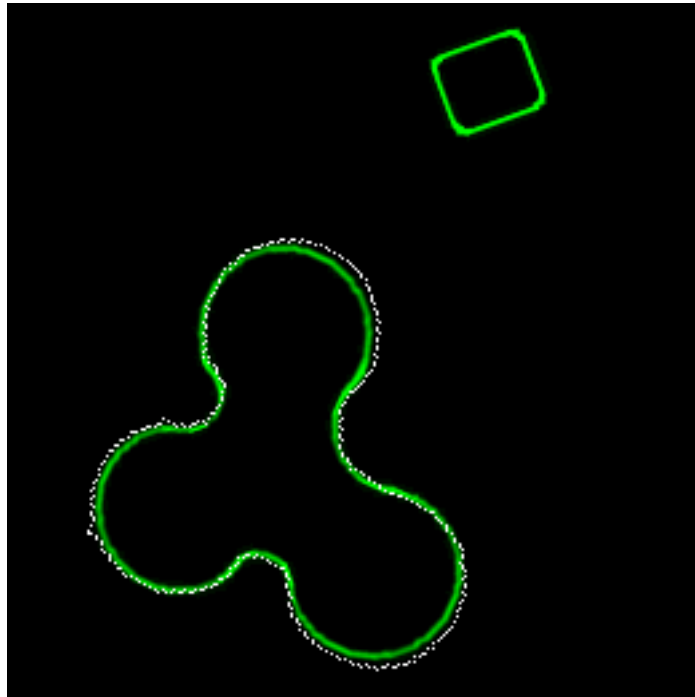


reversed to have CCW ordering

scale should be 1.3
rotation should be 360 - 160

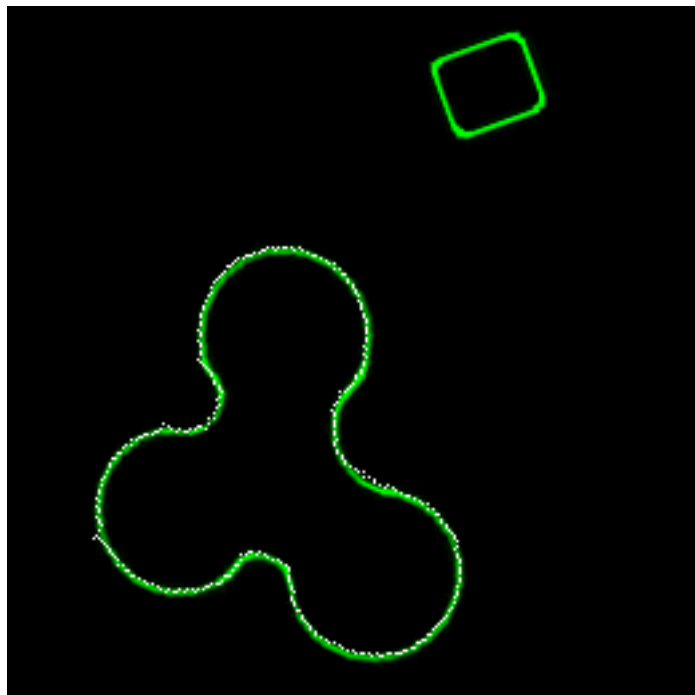
```
Contour matcher solution shift=-0.648127555847168
Contour matcher solution cost=3.0
CONTOUR PEAK1: (32.000237, 0.497126) (34, 78) (35, 72) CONTOUR PEAK2: (43.336529, 0.025109) (119, 158) (126, 171)
CONTOUR PEAK1: (26.908875, 0.146552) (70, 93) (61, 99) CONTOUR PEAK2: (35.660648, 0.672489) (75, 156) (80, 148)
CONTOUR PEAK1: (26.908875, 0.846264) (60, 45) (69, 54) CONTOUR PEAK2: (34.148750, 0.377729) (104, 212) (91, 205)
offsetImgX1=10 offsetImgY1=10
offsetImgX2=29 offsetImgY2=6
rotationInRadians=3.4556763
rotationInDegrees=197.995668339729
scale=1.3542565
translationX=17.566353
translationY=81.42969
```

apply coordinate transformation



rotationInRadians=3.4556763
rotationInDegrees=197.995668339729
scale=1.3542565
translationX=17.566353
translationY=81.42969

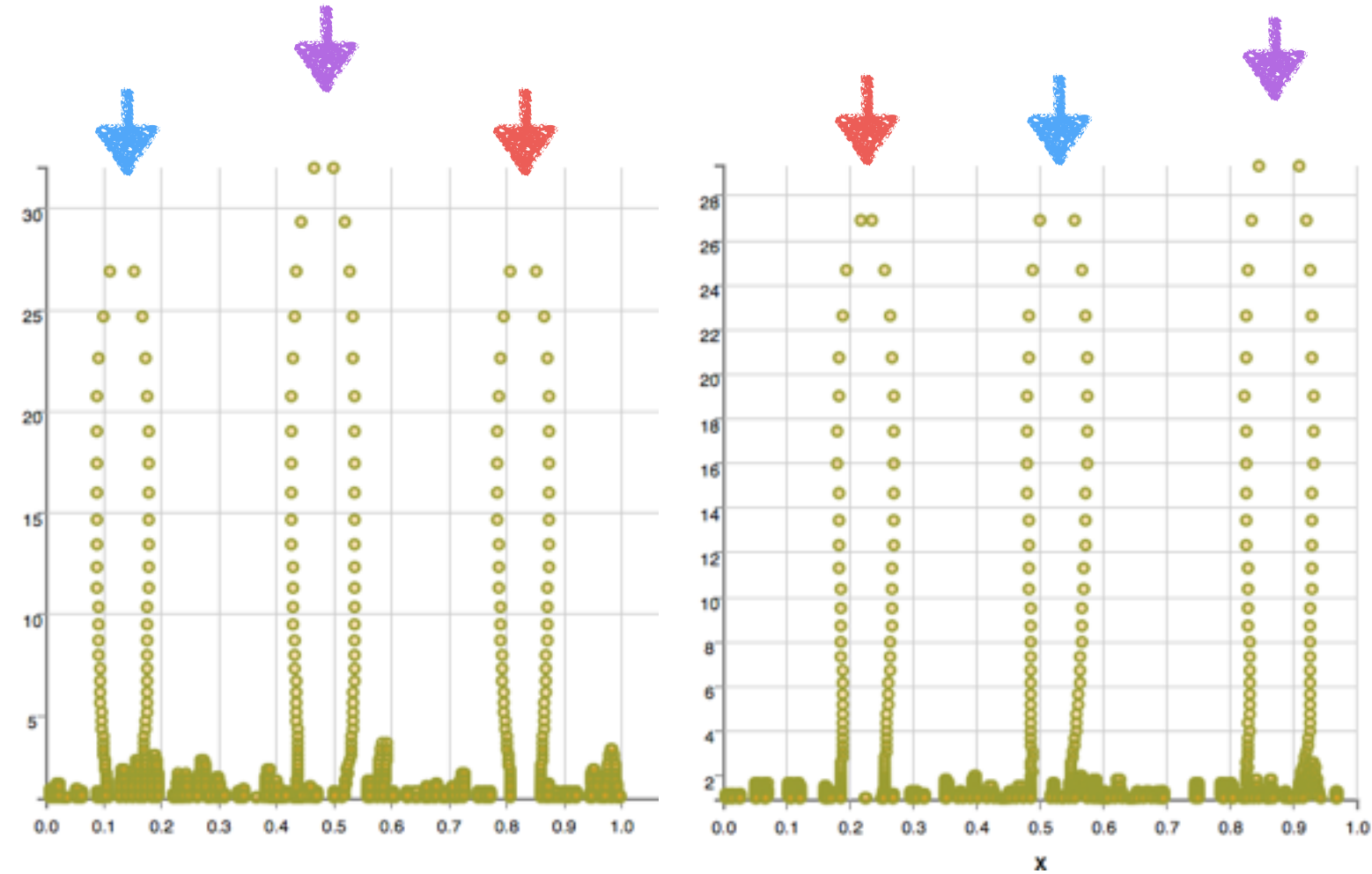
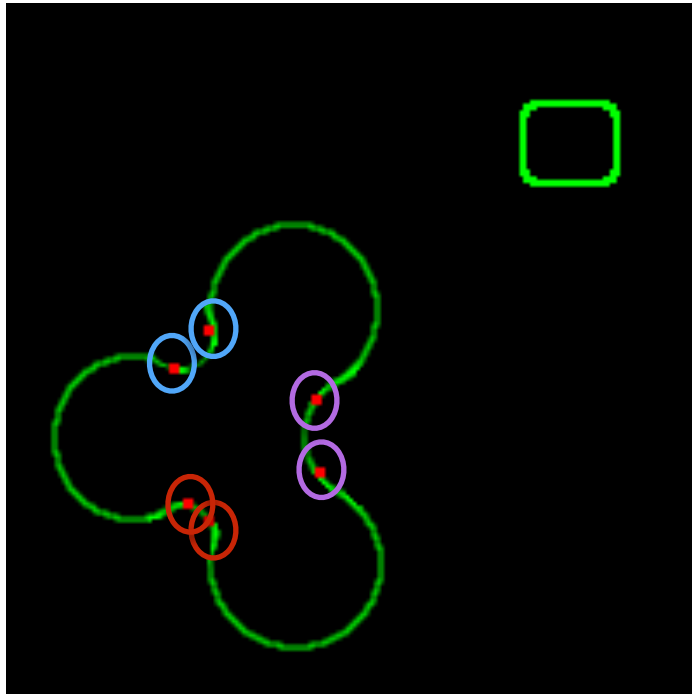
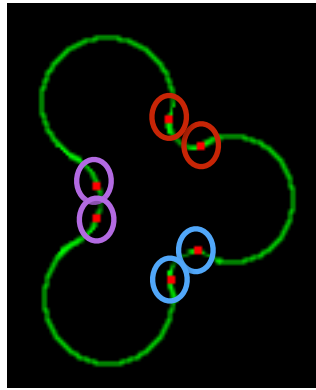
scale should be 1
rotation should be 360 - 160



After Refinement

rotationInRadians=3.4993095
rotationInDegrees=200.49566784011543
scale=1.3042566
translationX=20.0
translationY=84.0

coordinate transformation, after matching contours

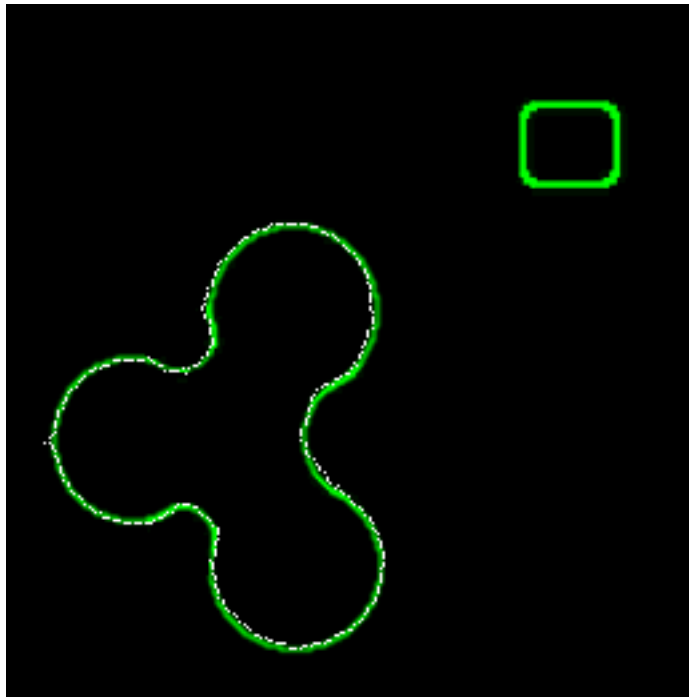


reversed to have CCW ordering

scale should be 1.3
rotation should be 180

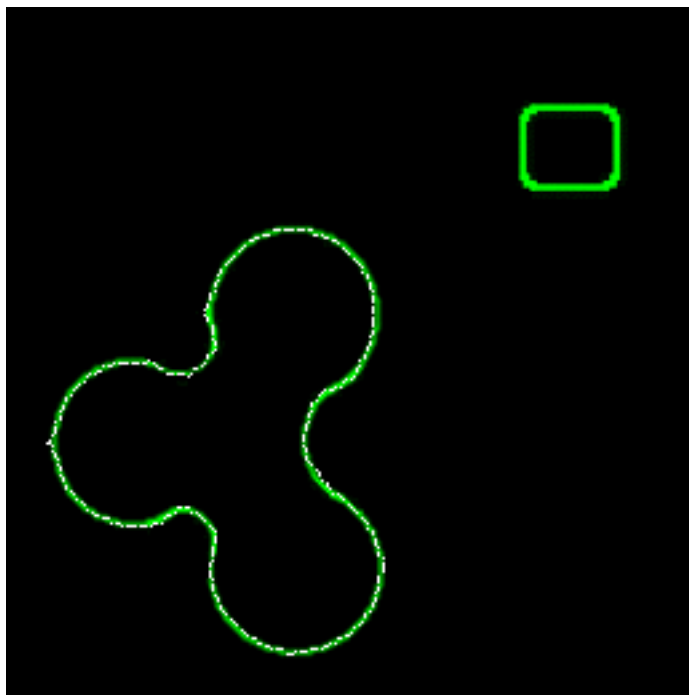
Contour matcher solution scale=1.2968404293060303
Contour matcher solution shift=0.22837476432323456
CONTOUR PEAK1: (32.000237, 0.497126) (34, 78) (35, 72) CONTOUR PEAK2: (41.499199, 0.873068) (111, 158) (112, 167)
CONTOUR PEAK1: (26.908875, 0.146552) (70, 93) (61, 99) CONTOUR PEAK2: (35.660648, 0.522075) (67, 137) (77, 127)
CONTOUR PEAK1: (26.908875, 0.846264) (60, 45) (69, 54) CONTOUR PEAK2: (34.896511, 0.222958) (75, 194) (69, 188)
offsetImgX1=10 offsetImgY1=10
offsetImgX2=14 offsetImgY2=33
rotationInRadians=3.1657186
rotationInDegrees=181.38231235356184
scale=1.2968404
translationX=5.891382
translationY=70.504585

apply coordinate transformation



```
offsetImgX1=10 offsetImgY1=10  
offsetImgX2=14 offsetImgY2=33  
rotationInRadians=3.1657186  
rotationInDegrees=181.38231235356184  
scale=1.2968404  
translationX=5.891382  
translationY=70.504585
```

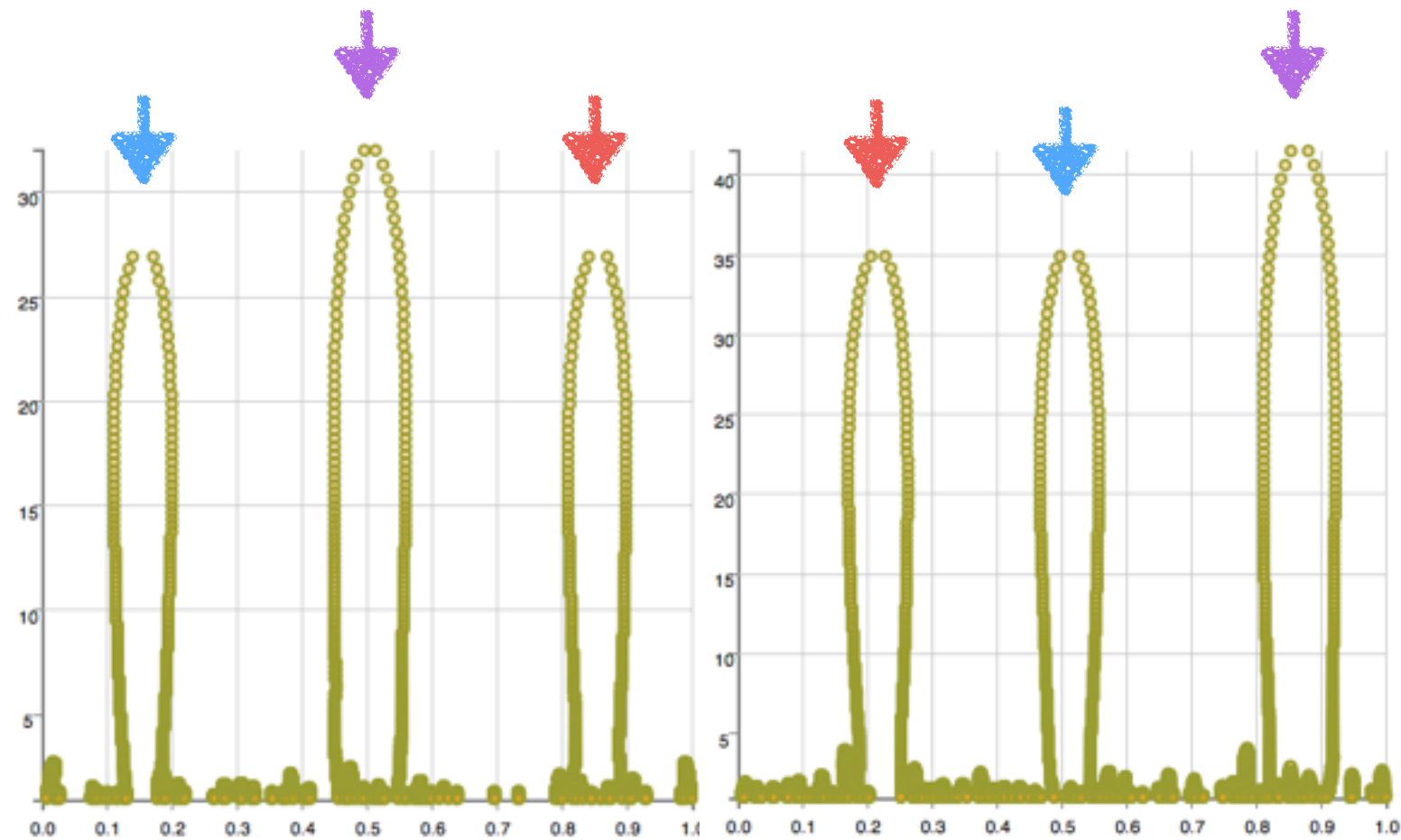
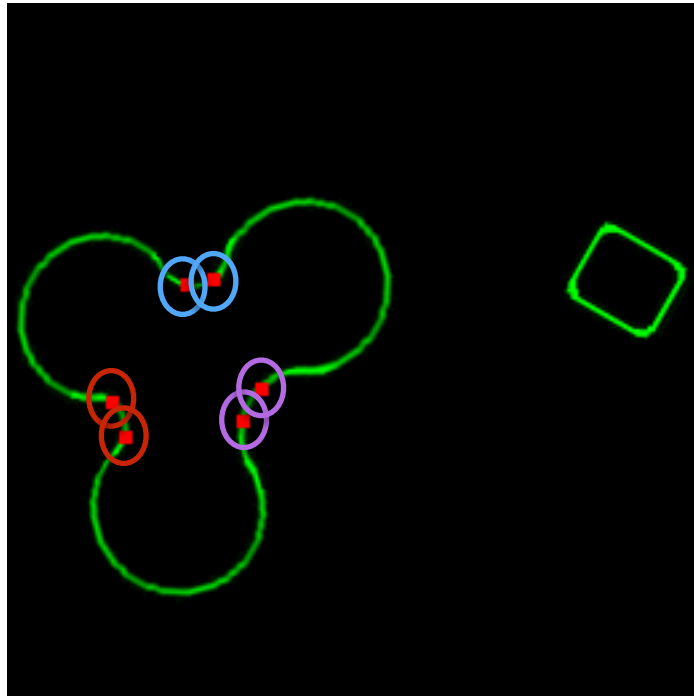
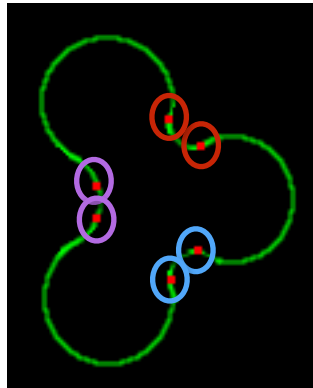
scale should be 1.3
rotation should be 180



After Refinement

```
rotationInRadians=3.1482654  
rotationInDegrees=180.38231801755862  
scale=1.2968404  
translationX=6.0  
translationY=71.0
```

coordinate transformation, after matching contours



reversed to have CCW ordering

reversed to have CCW ordering

scale should be 1.3
rotation should be 360 - 210

Contour matcher solution scale=1.2968404293060303
Contour matcher solution shift=-0.5097379088401794

CONTOUR PEAK1: (32.000237, 0.497126) (34, 78) (35, 72) CONTOUR PEAK2: (41.499199, 0.134956) (95, 144) (88, 156)

CONTOUR PEAK1: (26.908875, 0.146552) (70, 93) (61, 99) CONTOUR PEAK2: (34.896511, 0.785398) (67, 105) (77, 103)

CONTOUR PEAK1: (26.908875, 0.846264) (60, 45) (69, 54) CONTOUR PEAK2: (34.896511, 0.490044) (44, 162) (39, 149)

offsetImgX1=10 offsetImgY1=10

offsetImgX2=1 offsetImgY2=70

rotationInRadians=2.6591716

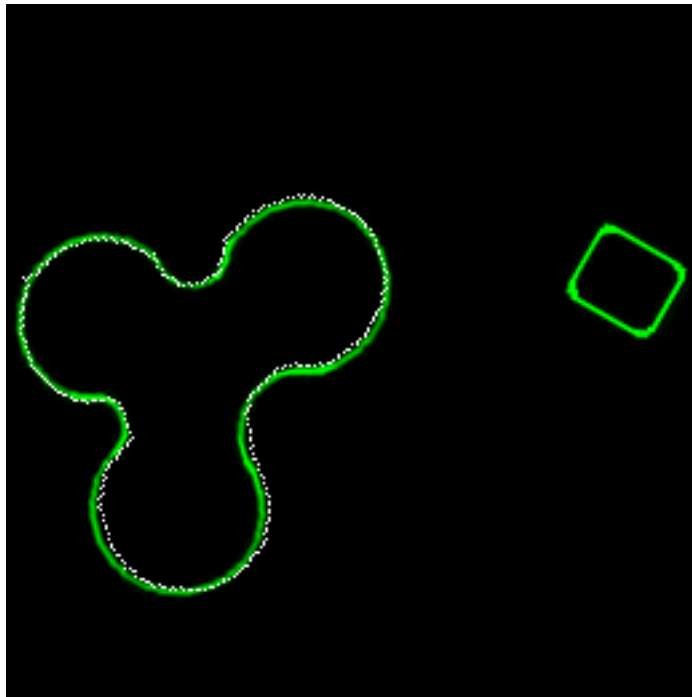
rotationInDegrees=152.3593086078036

scale=1.2968404

translationX=-10.876109

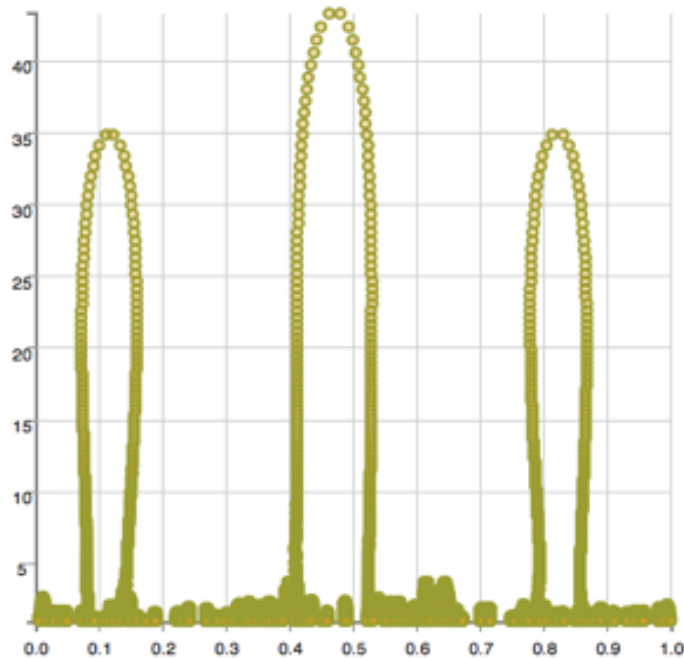
translationY=41.450577

apply coordinate transformation



```
offsetImgX1=10 offsetImgY1=10  
offsetImgX2=1 offsetImgY2=70  
rotationInRadians=2.6591716  
rotationInDegrees=152.3593086078036  
scale=1.2968404  
translationX=-10.876109  
translationY=41.450577
```

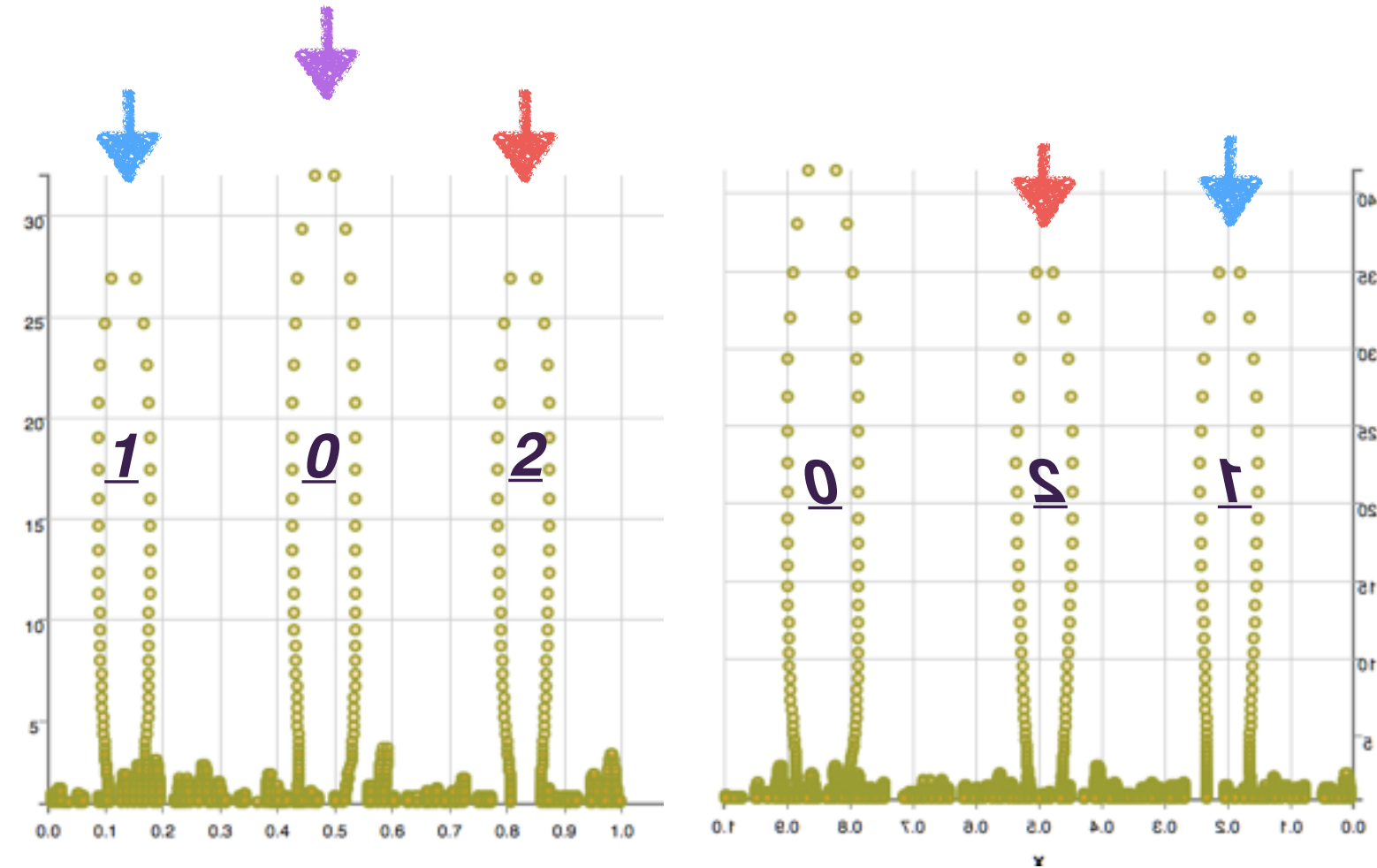
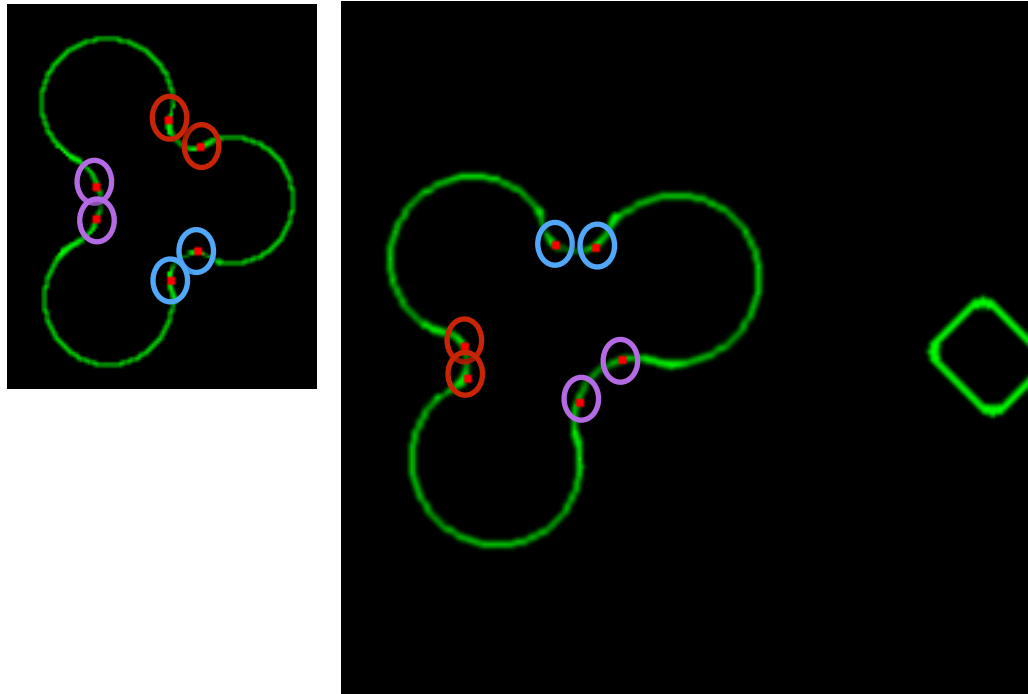
scale should be 1.3
rotation should be 360 - 210



After Refinement

```
rotationInRadians=2.6155384  
rotationInDegrees=149.85930910741718  
scale=1.2968404  
translationX=-12.0  
translationY=43.0
```


coordinate transformation, after matching contours

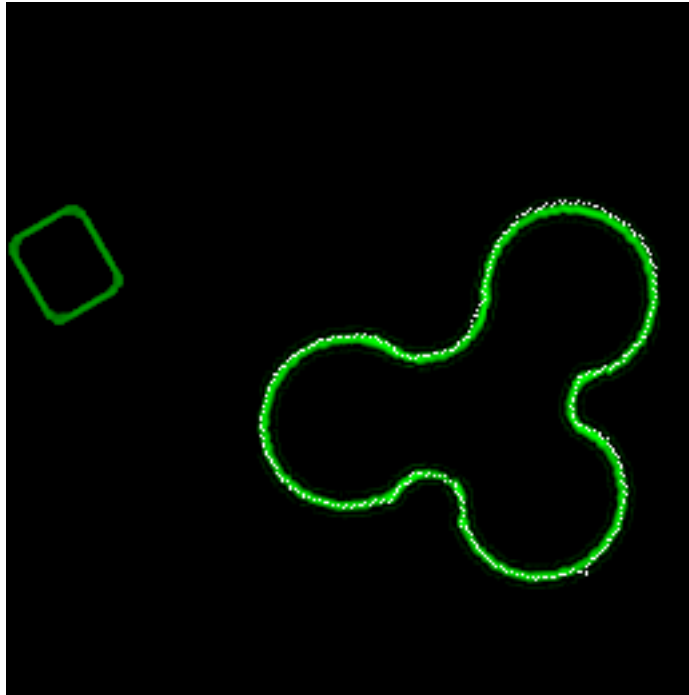


reversed to have CCW ordering

scale should be 1.3
rotation should be 360 - 225

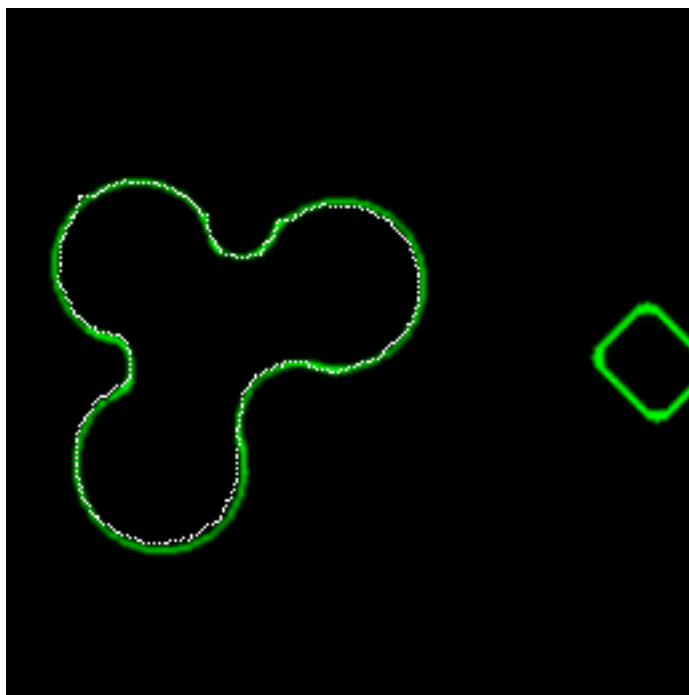
Contour matcher solution scale=1.325237512588501
Contour matcher solution shift=-0.5053889751434326
CONTOUR PEAK1: (32.000237, 0.497126) (34, 78) (35, 72) CONTOUR PEAK2: (42.407913, 0.153422) (98, 136) (91, 143)
CONTOUR PEAK1: (26.908875, 0.146552) (70, 93) (61, 99) CONTOUR PEAK2: (34.896511, 0.802428) (81, 91) (92, 92)
CONTOUR PEAK1: (26.908875, 0.846264) (60, 45) (69, 54) CONTOUR PEAK2: (34.896511, 0.508830) (46, 140) (45, 129)
offsetImgX1=10 offsetImgY1=10
offsetImgX2=14 offsetImgY2=61
rotationInRadians=2.4194849
rotationInDegrees=138.6262707153875
scale=1.3252375
translationX=-5.8268623
translationY=25.13414

apply coordinate transformation



offsetImgX1=10 offsetImgY1=10
offsetImgX2=14 offsetImgY2=61
rotationInRadians=2.4194849
rotationInDegrees=138.6262707153875
scale=1.3252375
translationX=-5.8268623
translationY=25.13414

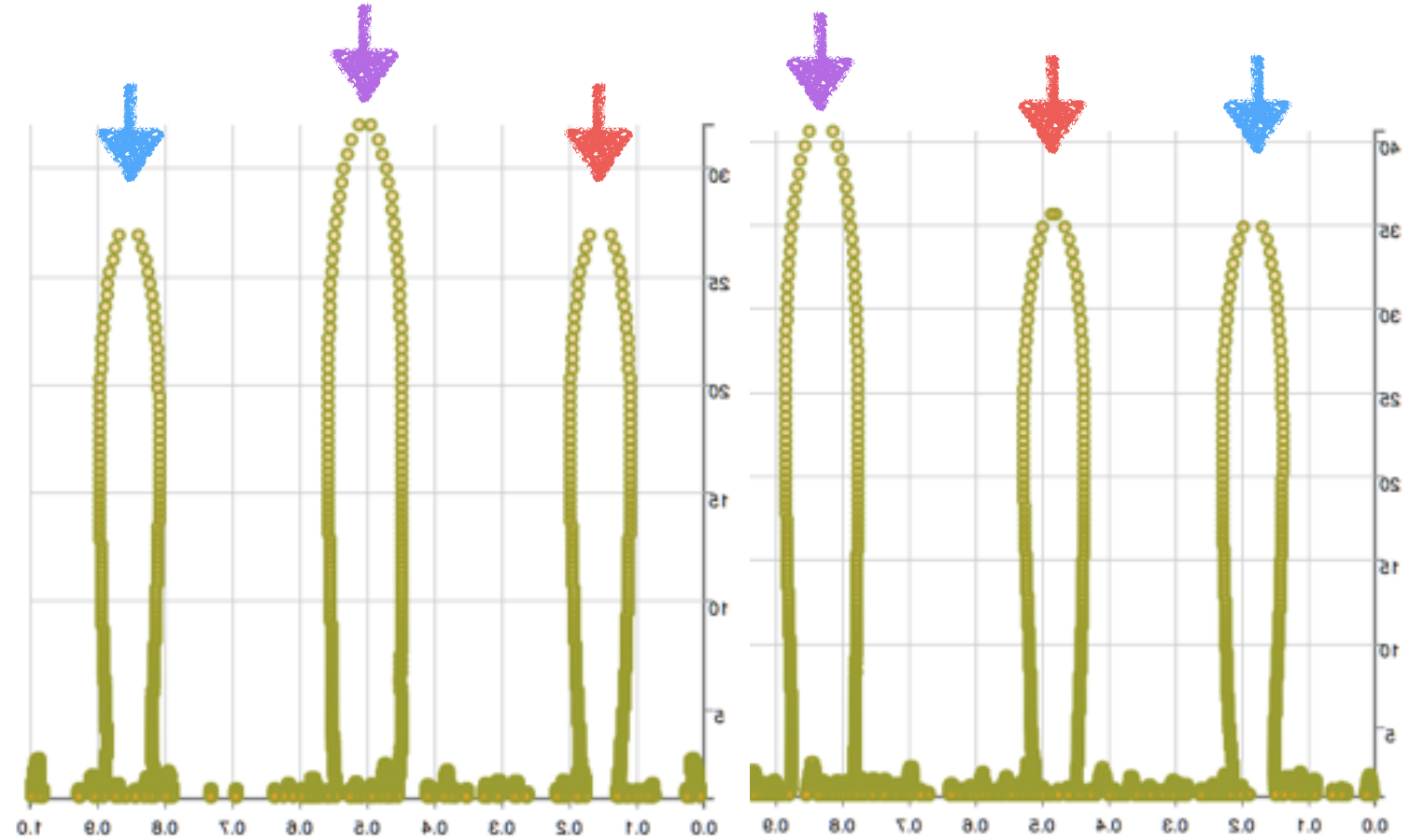
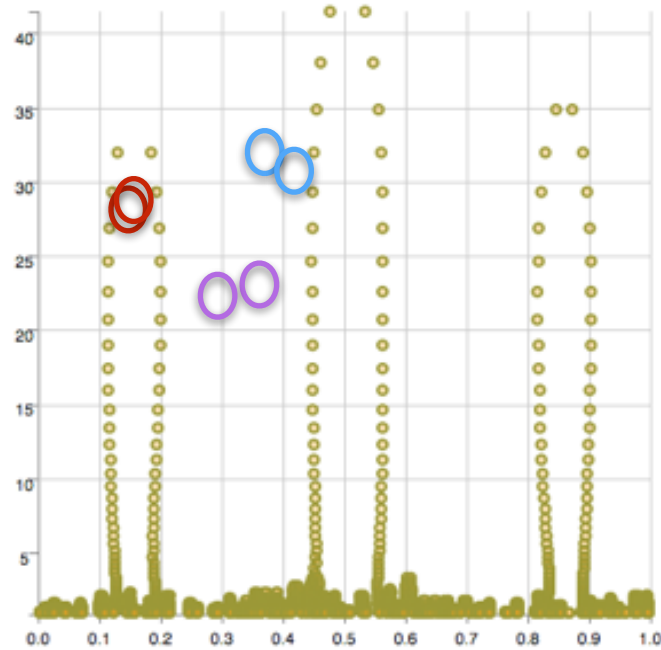
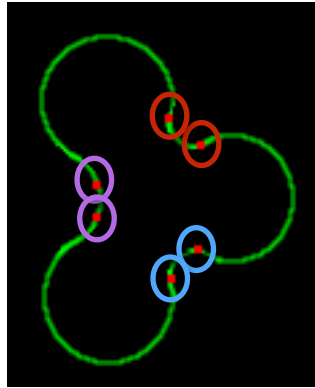
scale should be 1.3
rotation should be 360 - 225



After Refinement

rotationInRadians=2.3322184
rotationInDegrees=133.6262717146147
scale=1.2752376
translationX=-3.0
translationY=27.0

coordinate transformation, after matching contours



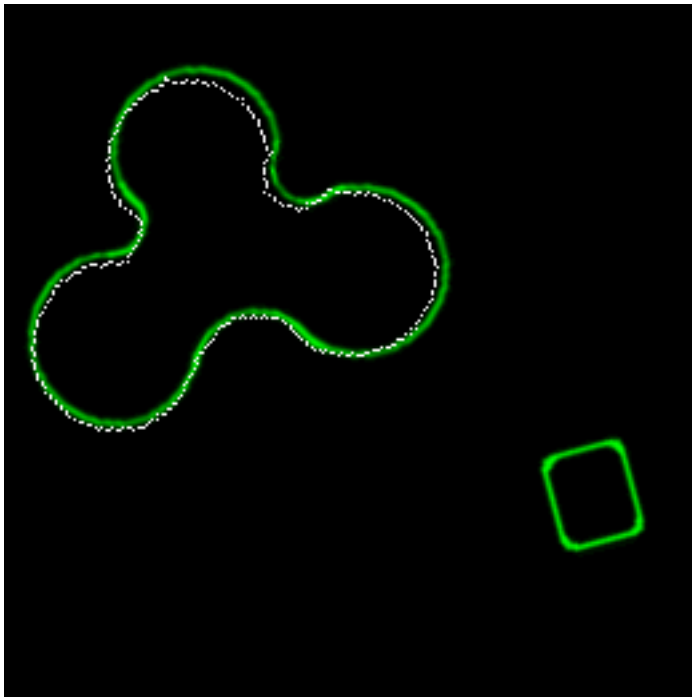
reversed to have CCW ordering

reversed to have CCW ordering

scale should be 1.3
rotation should be 360 - 255

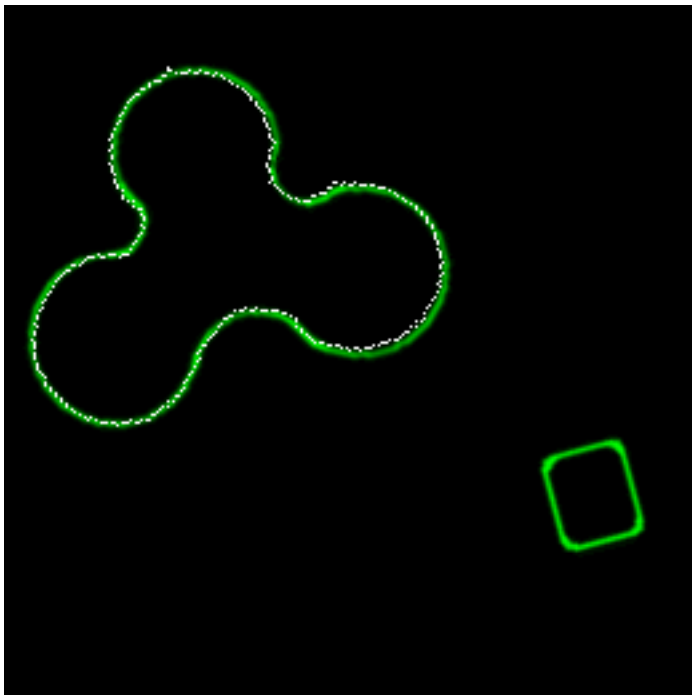
CONTOUR PEAK1: (32.000237, 0.497126) (34, 78) (35, 72) CONTOUR PEAK2: (40.609955, 0.168514) (98, 115) (82, 118)
CONTOUR PEAK1: (26.908875, 0.146552) (70, 93) (61, 99) CONTOUR PEAK2: (34.896511, 0.817073) (101, 65) (113, 73)
CONTOUR PEAK1: (26.908875, 0.846264) (60, 45) (69, 54) CONTOUR PEAK2: (35.660648, 0.517738) (49, 89) (51, 86)
offsetImgX1=10 offsetImgY1=10
offsetImgX2=5 offsetImgY2=20
rotationInRadians=1.8595577
rotationInDegrees=106.54481071213507
scale=1.2690517
translationX=3.6613295
translationY=-1.6037707

apply coordinate transformation



rotationInRadians=1.8595577
rotationInDegrees=106.54481071213507
scale=1.2690517
translationX=3.6613295
translationY=-1.6037707

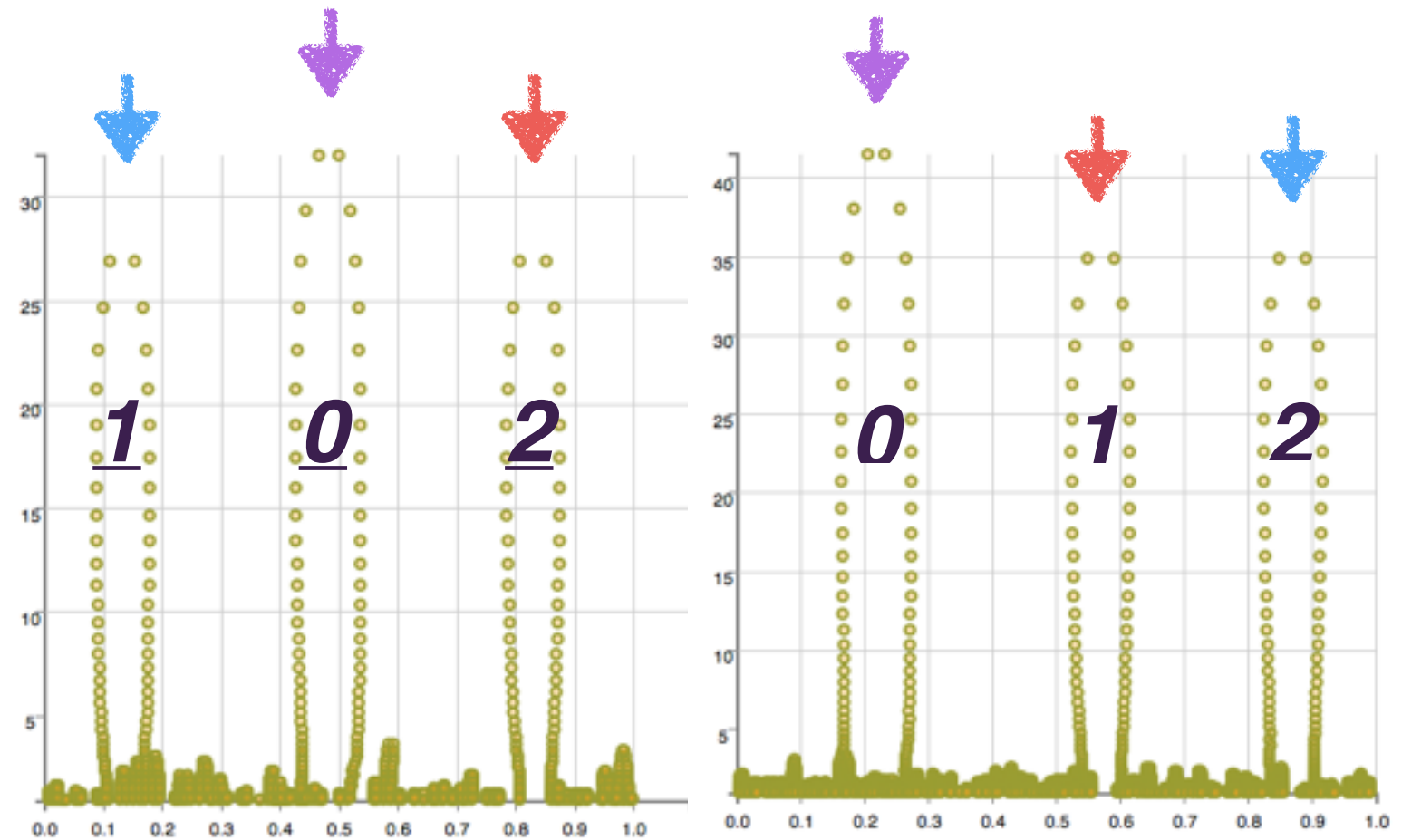
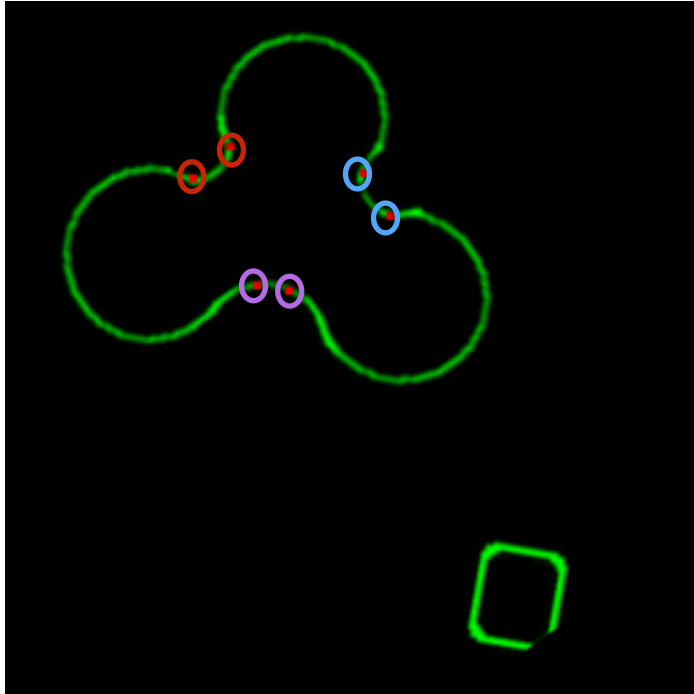
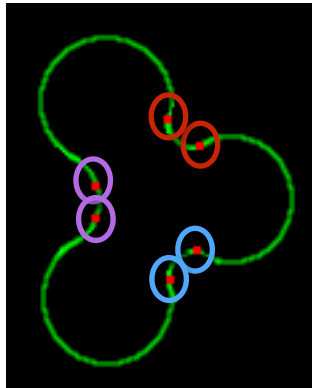
scale should be 1.3
rotation should be 360 - 255



After Refinement

rotationInRadians=1.8558925
rotationInDegrees=106.33480971591386
scale=1.2845517
translationX=4.0
translationY=-6.0

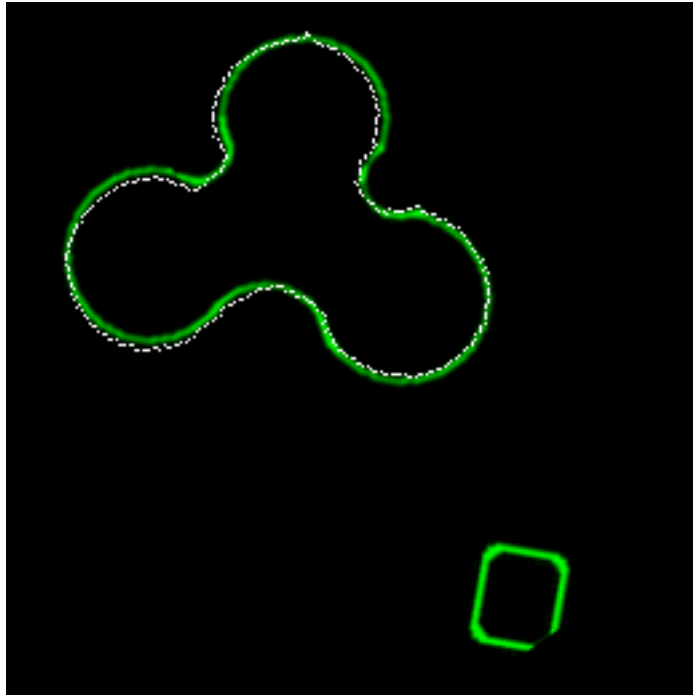
coordinate transformation, after matching contours



scale should be 1.3
rotation should be 360 - 280

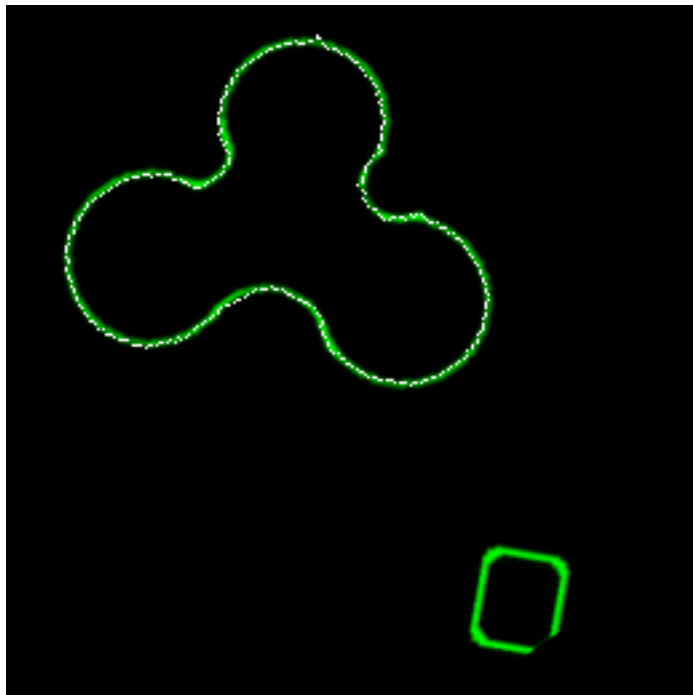
Contour matcher solution scale=1.2968404293060303
Contour matcher solution shift=-0.4310373365879059
CONTOUR PEAK1: (32.000237, 0.497126) (34, 78) (35, 72) CONTOUR PEAK2: (41.499199, 0.213656) (106, 108) (96, 106)
CONTOUR PEAK1: (26.908875, 0.146552) (70, 93) (61, 99) CONTOUR PEAK2: (35.660648, 0.865639) (134, 70) (137, 76)
CONTOUR PEAK1: (26.908875, 0.846264) (60, 45) (69, 54) CONTOUR PEAK2: (35.660648, 0.566079) (74, 67) (82, 60)
offsetImgX1=10 offsetImgY1=10
offsetImgX2=19 offsetImgY2=9
rotationInRadians=1.4486057
rotationInDegrees=82.9989903033234
scale=1.2968404
translationX=28.18638
translationY=-16.518988

apply coordinate transformation



offsetImgX1=10 offsetImgY1=10
offsetImgX2=19 offsetImgY2=9
rotationInRadians=1.4486057
rotationInDegrees=82.9989903033234
scale=1.2968404
translationX=28.18638
translationY=-16.518988

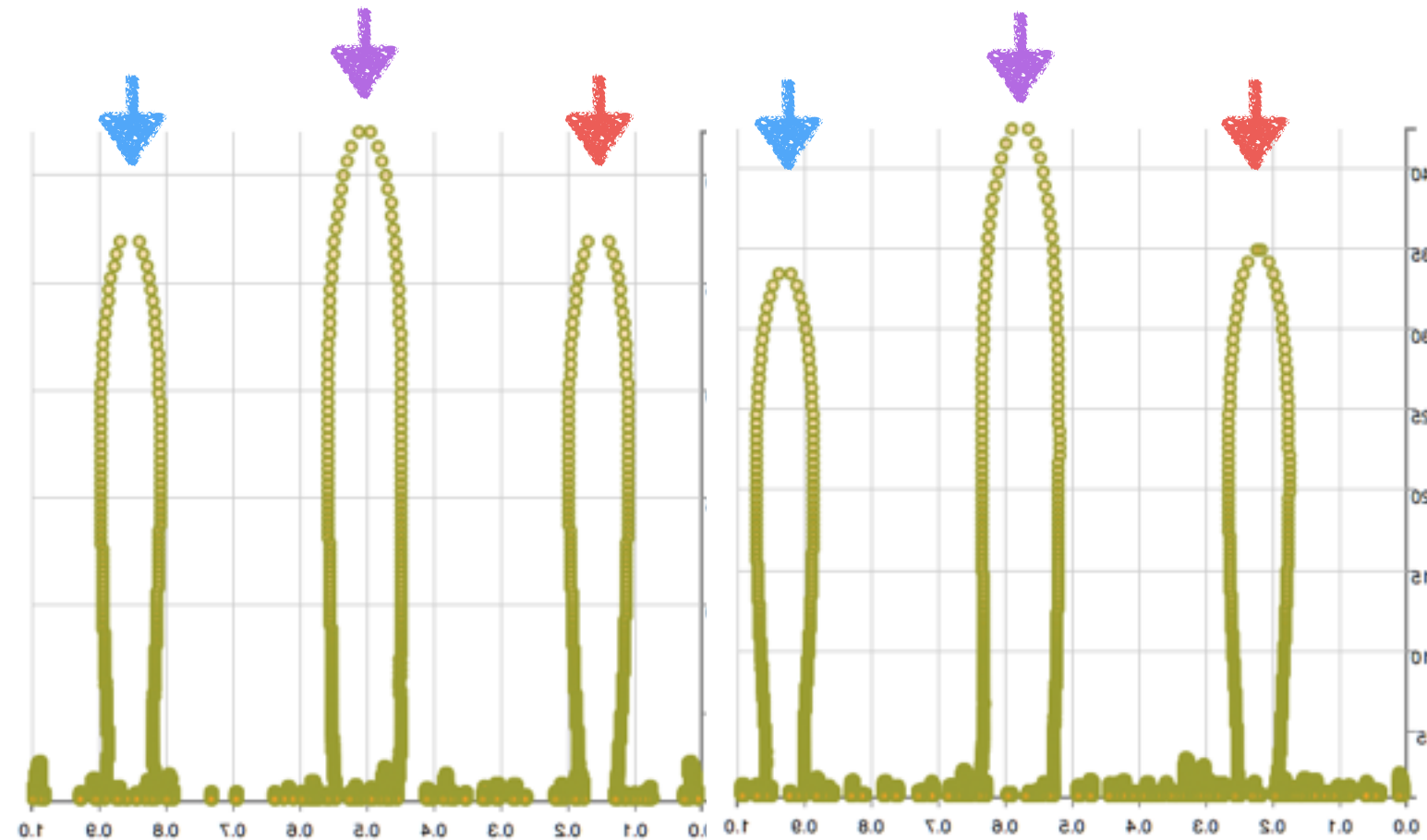
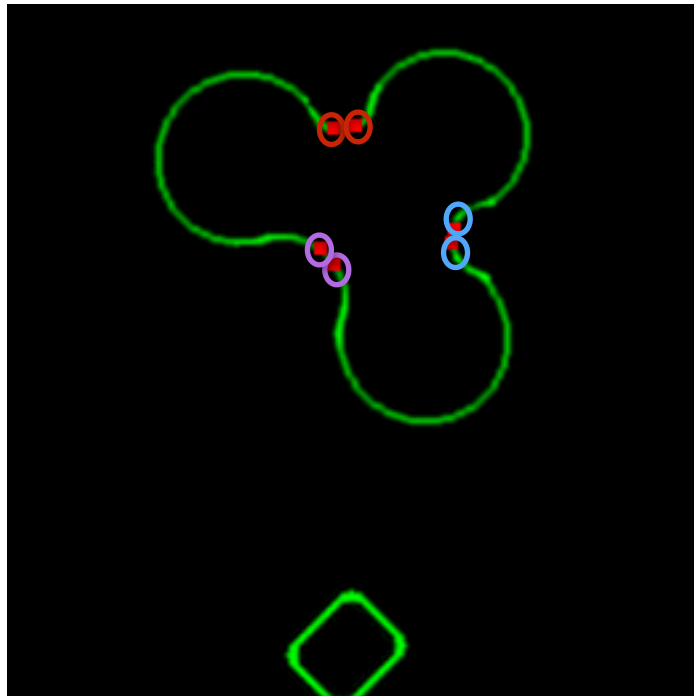
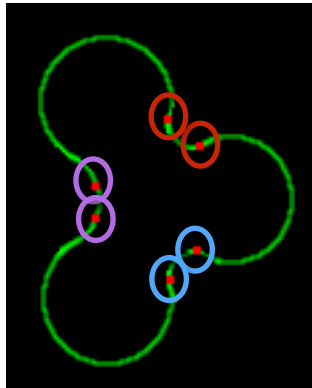
scale should be 1.3
rotation should be 360 - 280



After Refinement

rotationInRadians=1.4049724
rotationInDegrees=80.49899080293699
scale=1.2968404
translationX=29.0
translationY=-17.0

coordinate transformation, after matching contours



reversed to have CCW ordering

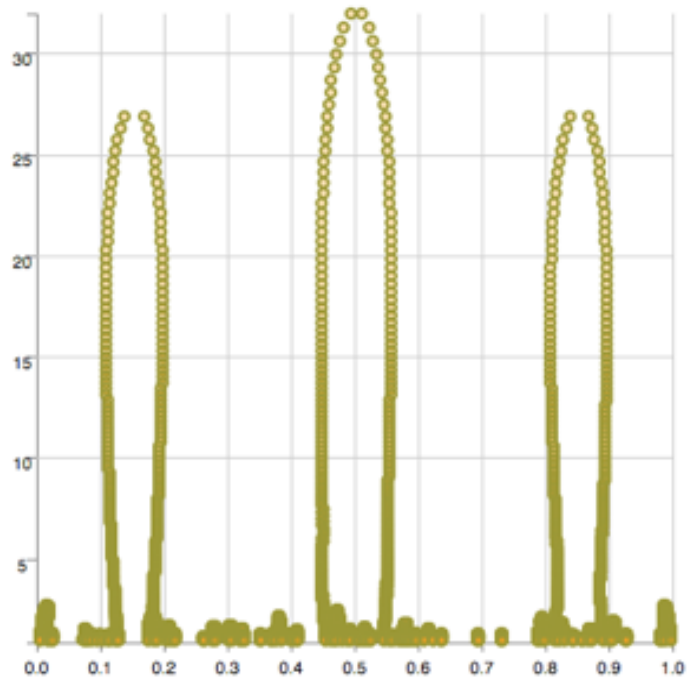
reversed to have CCW ordering

scale should be 1.3
rotation should be 360 - 315

Contour matcher solution scale=1.325237512588501
Contour matcher solution shift=-0.2311936765909195
Contour matcher solution cost=89.0
CONTOUR PEAK1: (32.000237, 0.497126) (34, 78) (35, 72)
CONTOUR PEAK1: (26.908875, 0.146552) (70, 93) (61, 99)
CONTOUR PEAK1: (26.908875, 0.846264) (60, 45) (69, 54)
offsetImgX1=10 offsetImgY1=10
offsetImgX2=52 offsetImgY2=14
rotationInRadians=0.7365556
rotationInDegrees=42.2015259002177
scale=1.3252375
translationX=60.744064
translationY=-25.366236

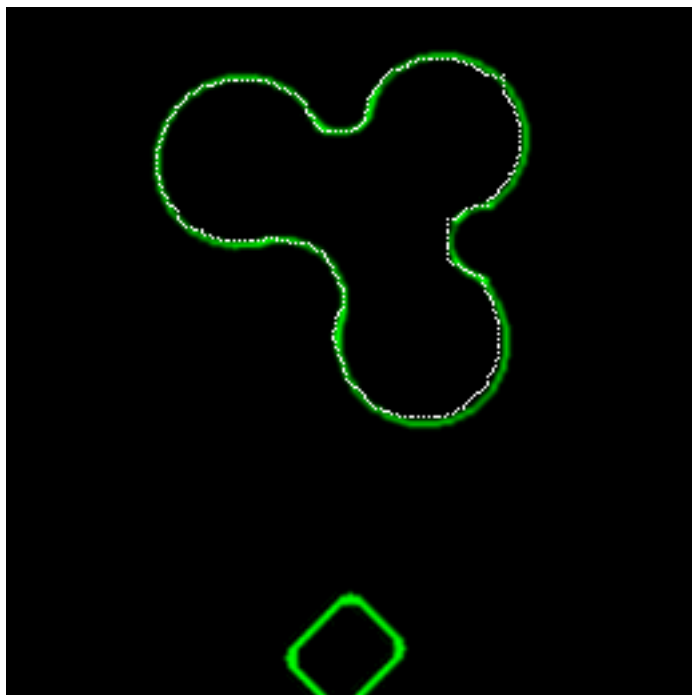
CONTOUR PEAK2: (42.407913, 0.427617) (125, 102) (112, 89)
CONTOUR PEAK2: (33.417011, 0.074610) (169, 80) (168, 93)
CONTOUR PEAK2: (34.148750, 0.783964) (120, 45) (132, 45)

apply coordinate transformation



offsetImgX1=10 offsetImgY1=10
offsetImgX2=52 offsetImgY2=14
rotationInRadians=0.7365556
rotationInDegrees=42.2015259002177
scale=1.3252375
translationX=60.744064
translationY=-25.366236

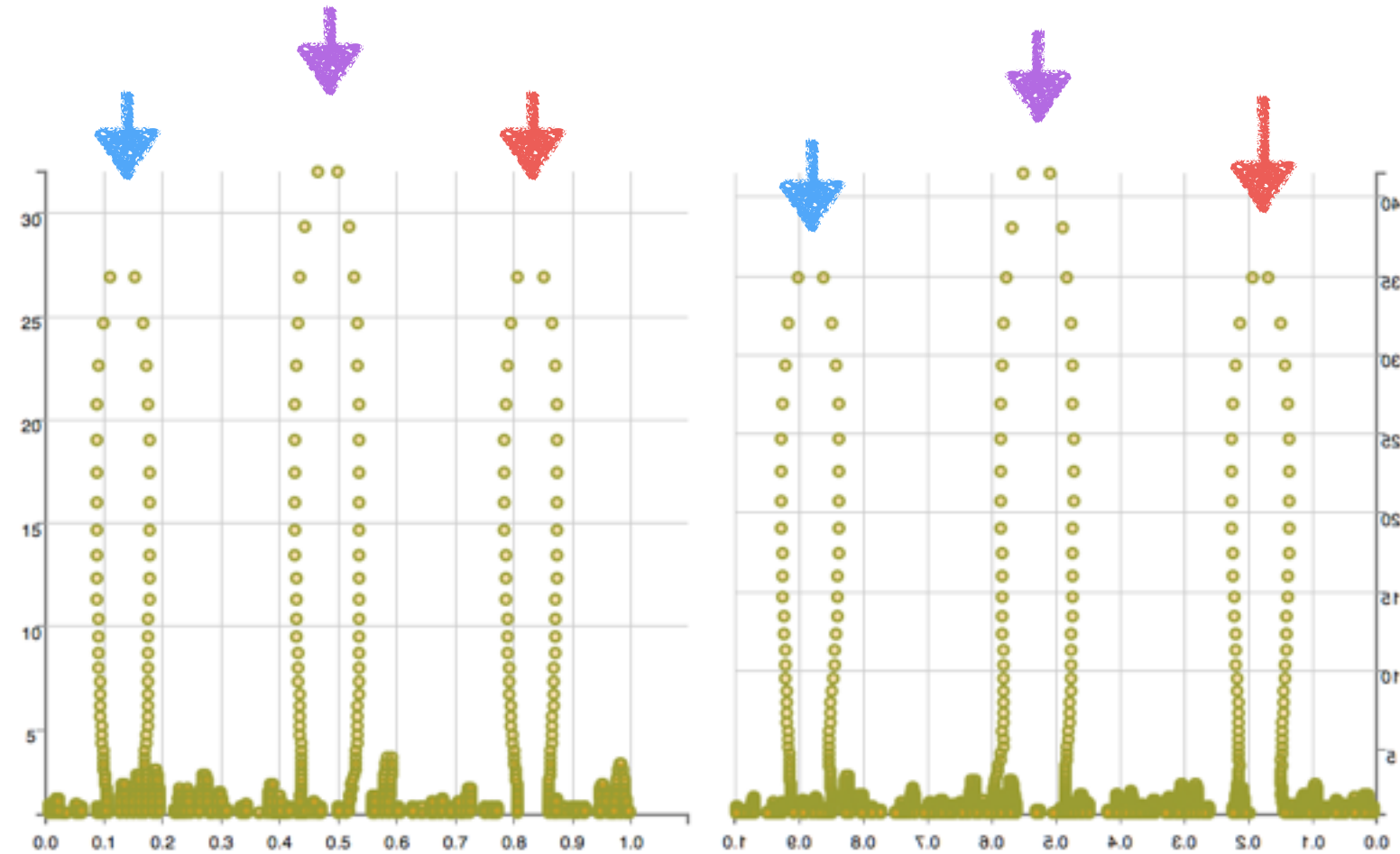
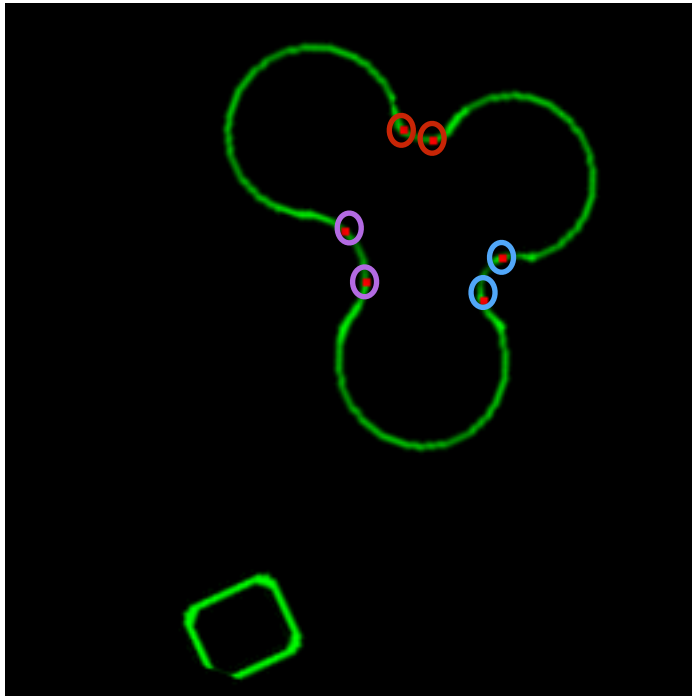
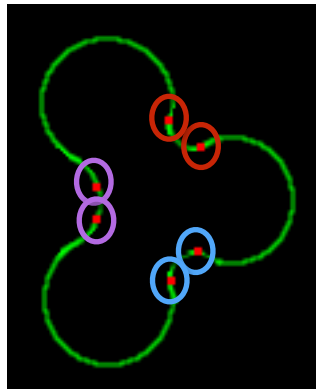
scale should be 1.3
rotation should be 360 - 315



After Refinement

rotationInRadians=0.7801888
rotationInDegrees=44.70152540060411
scale=1.2752376
translationX=65.0
translationY=-21.0

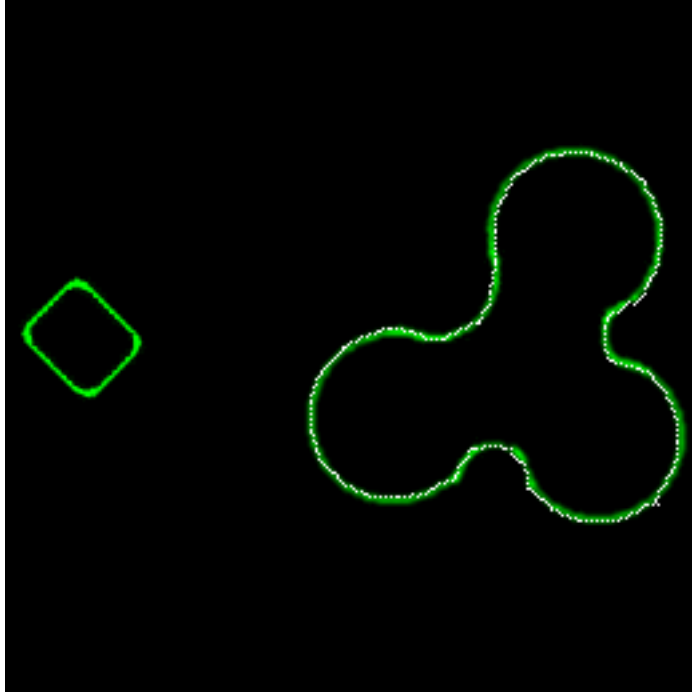
coordinate transformation, after matching contours



scale should be 1.3
rotation should be 360 - 335

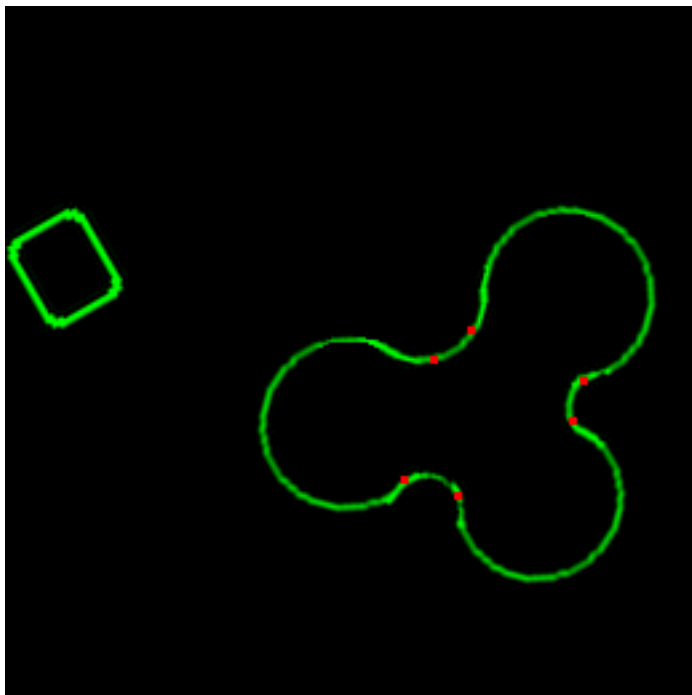
Contour matcher solution scale=1.325237512588501
Contour matcher solution shift=-0.19089026749134064
CONTOUR PEAK1: (32.000237, 0.497126) (34, 78) (35, 72) CONTOUR PEAK2: (42.407913, 0.467920) (134, 99) (131, 90)
CONTOUR PEAK1: (26.908875, 0.146552) (70, 93) (61, 99) CONTOUR PEAK2: (34.896511, 0.115044) (182, 98) (178, 106)
CONTOUR PEAK1: (26.908875, 0.846264) (60, 45) (69, 54) CONTOUR PEAK2: (34.896511, 0.818584) (150, 48) (158, 51)
offsetImgX1=10 offsetImgY1=10
offsetImgX2=63 offsetImgY2=12
rotationInRadians=0.43239865
rotationInDegrees=24.77461754427387
scale=1.3252375
translationX=81.613556
translationY=-16.98058

apply coordinate transformation



```
offsetImgX1=10 offsetImgY1=10  
offsetImgX2=63 offsetImgY2=12  
rotationInRadians=0.43239865  
rotationInDegrees=24.77461754427387  
scale=1.3252375  
translationX=81.613556  
translationY=-16.98058
```

scale should be 1.3
rotation should be 360 - 335



After Refinement

```
rotationInRadians=0.43239865  
rotationInDegrees=24.77461754427387  
scale=1.2752376  
translationX=85.0  
translationY=-14.0
```

coordinate transformation, after matching contours

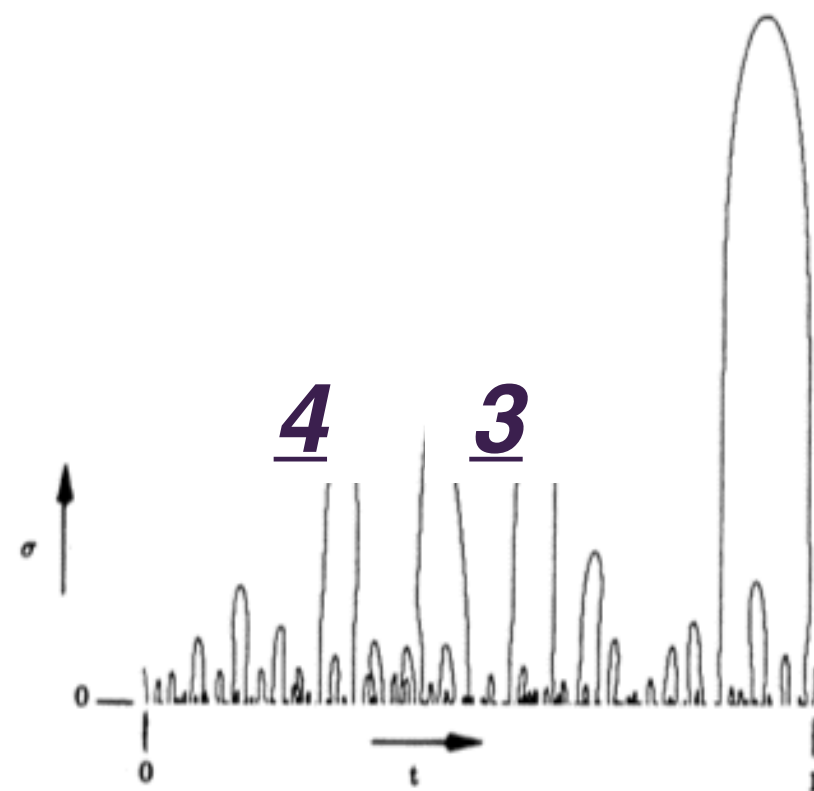
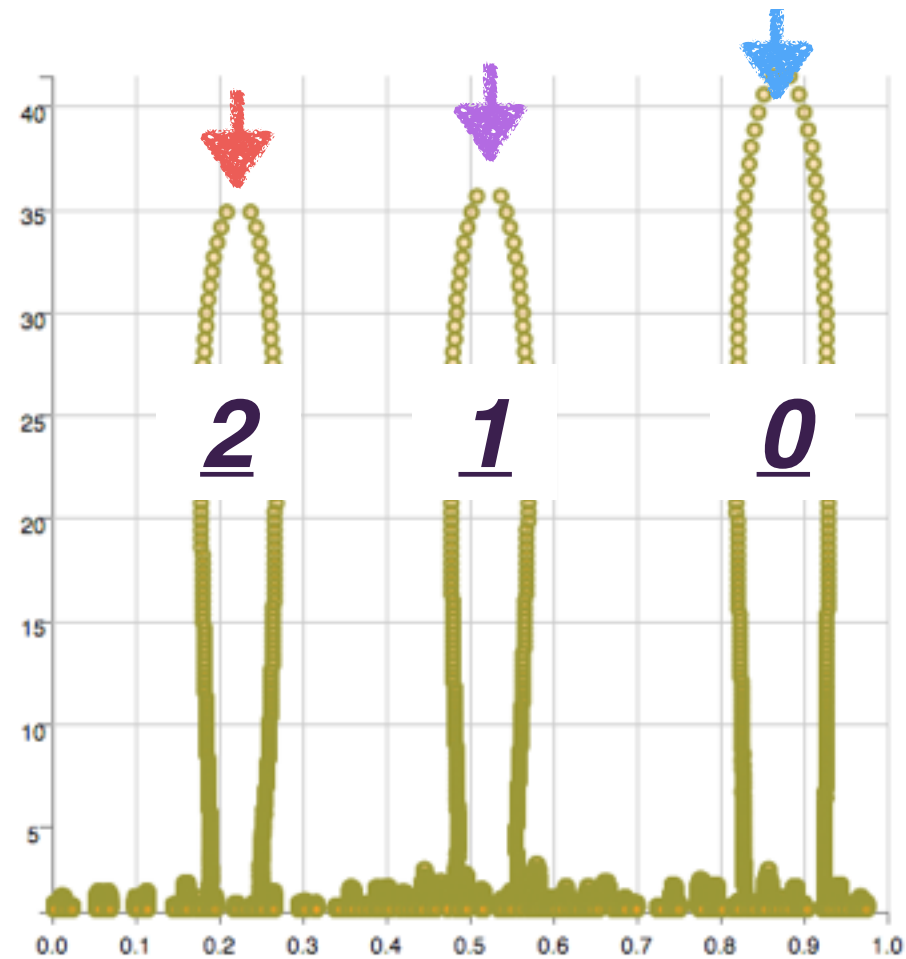
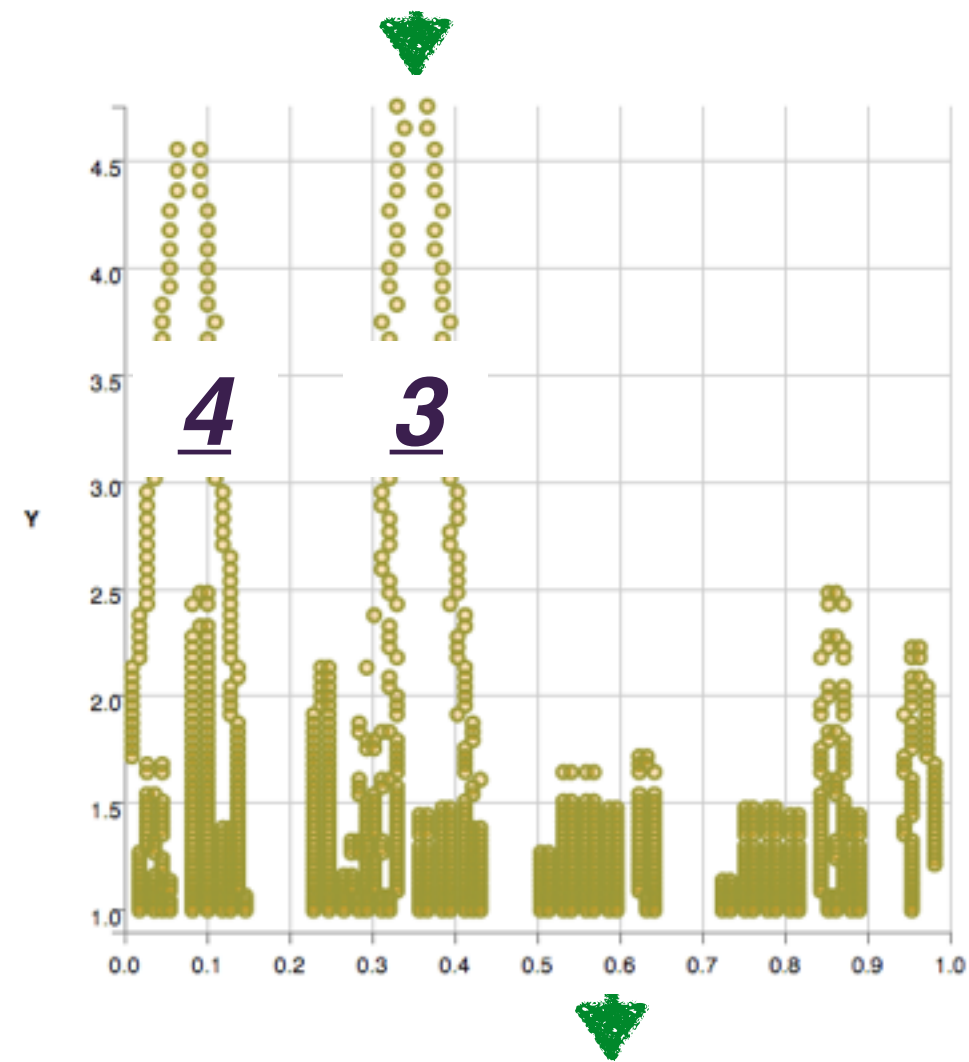
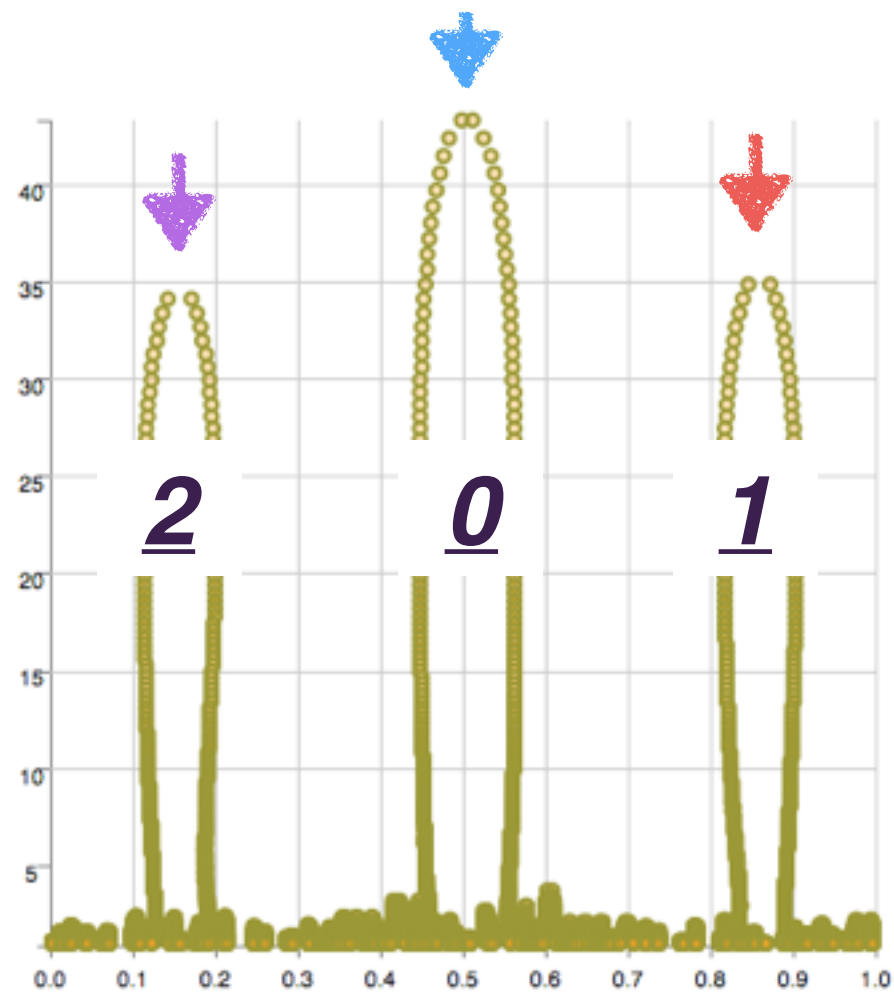


Fig. 3. Generalized scale space image of Africa.

scale should be 1.0
rotation should be 20 - 180