# Small RNA dataset

Luis Ángel Rodríguez García

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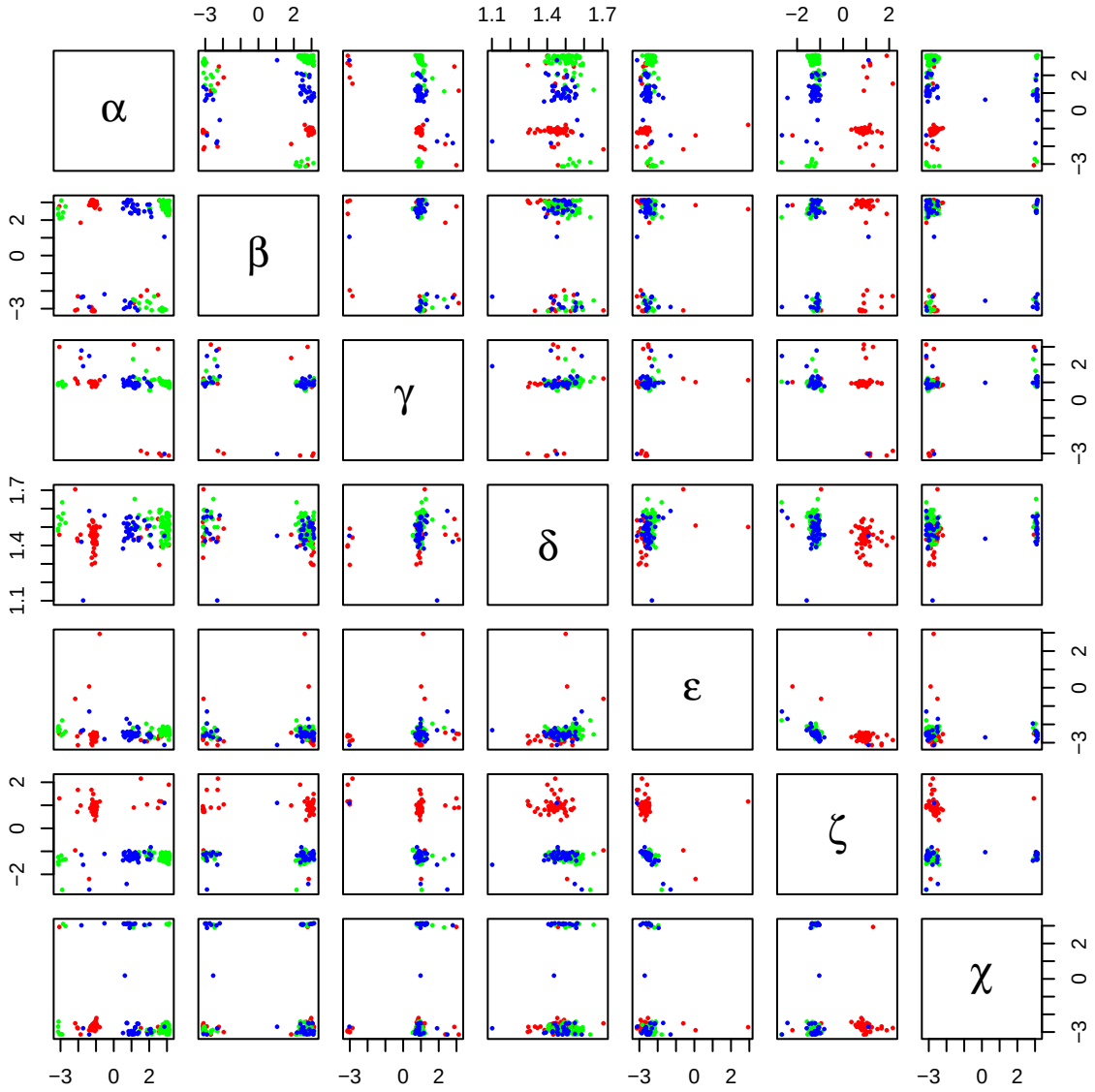
The objective in this case study is to recover clusters identified in `smallrna$clusters` using only the information on `smallrna$angles`, a 7-dimensional matrix of angles (i.e., data on $(\mathbb{S}^1)^7$)). The clusters have been constructed using the information in `smallrna$torsion`. If a dimension-reduction technique is able to successfully identify clusters, then it will be doing a good job in terms of identifying the underlying structure of the data. Section 5.2 in Zouboulоglou et al. (2021) describes the history of the "Small RNA" dataset and its construction.

Let's begin by importing the data.

```
# Load package
library(pscsne)
stopifnot(packageVersion("pscsne") >= "0.0.1.900005")

# Load dataset
data("smallrna")
original_clusters <- smallrna$clusters

# Visualize original data
pairs(smallrna$angles, col = rainbow(3)[original_clusters],
      cex = 0.5, pch = 16,
      labels = c(expression(alpha), expression(beta), expression(gamma),
                 expression(delta), expression(epsilon), expression(zeta),
                 expression(chi)))
```




We can now run psc-SNE. First, we transform the data and obtain the $\rho$'s giving the prescribed perplexity.

```
# Data to Cartesian coordinates
smallrna_X <- sphunif::Theta_to_X(Theta = smallrna$angles)

# Obtain rhos for given perplexity
rho_psc_list <- rho_optim_bst(x = smallrna_X, perp_fixed = 30)
```

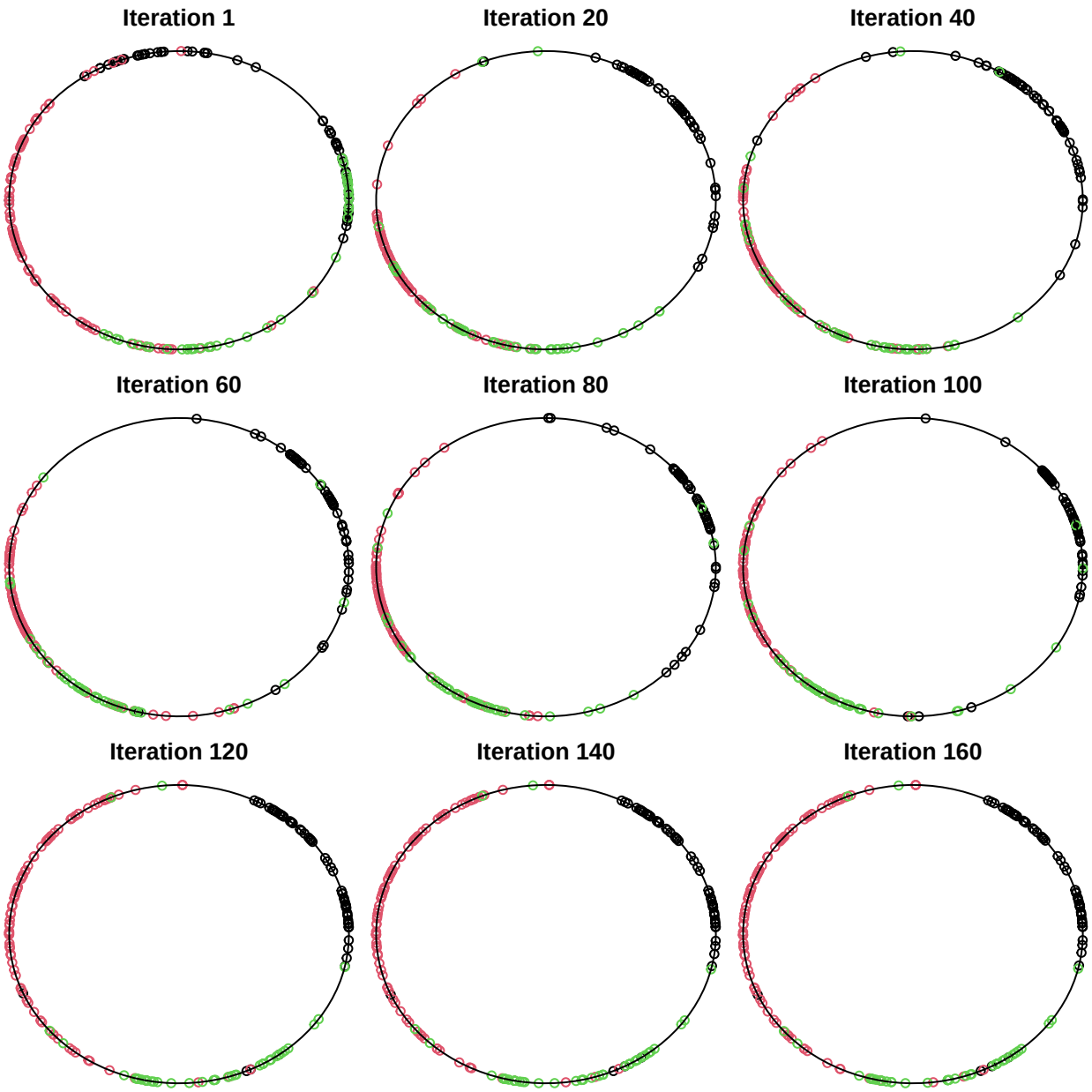
```
## Time difference of 1.196058 secs
```

We run psc-SNE for $d = 1$ with its default $\eta$.

```
# Default
fit_1 <- psc_sne(X = smallrna_X, d = 1, rho_psc_list = rho_psc_list,
                 eta = 200, maxit = 1e3, tol = 1e-6, show_prog = 10,
                 colors = original_clusters)
```

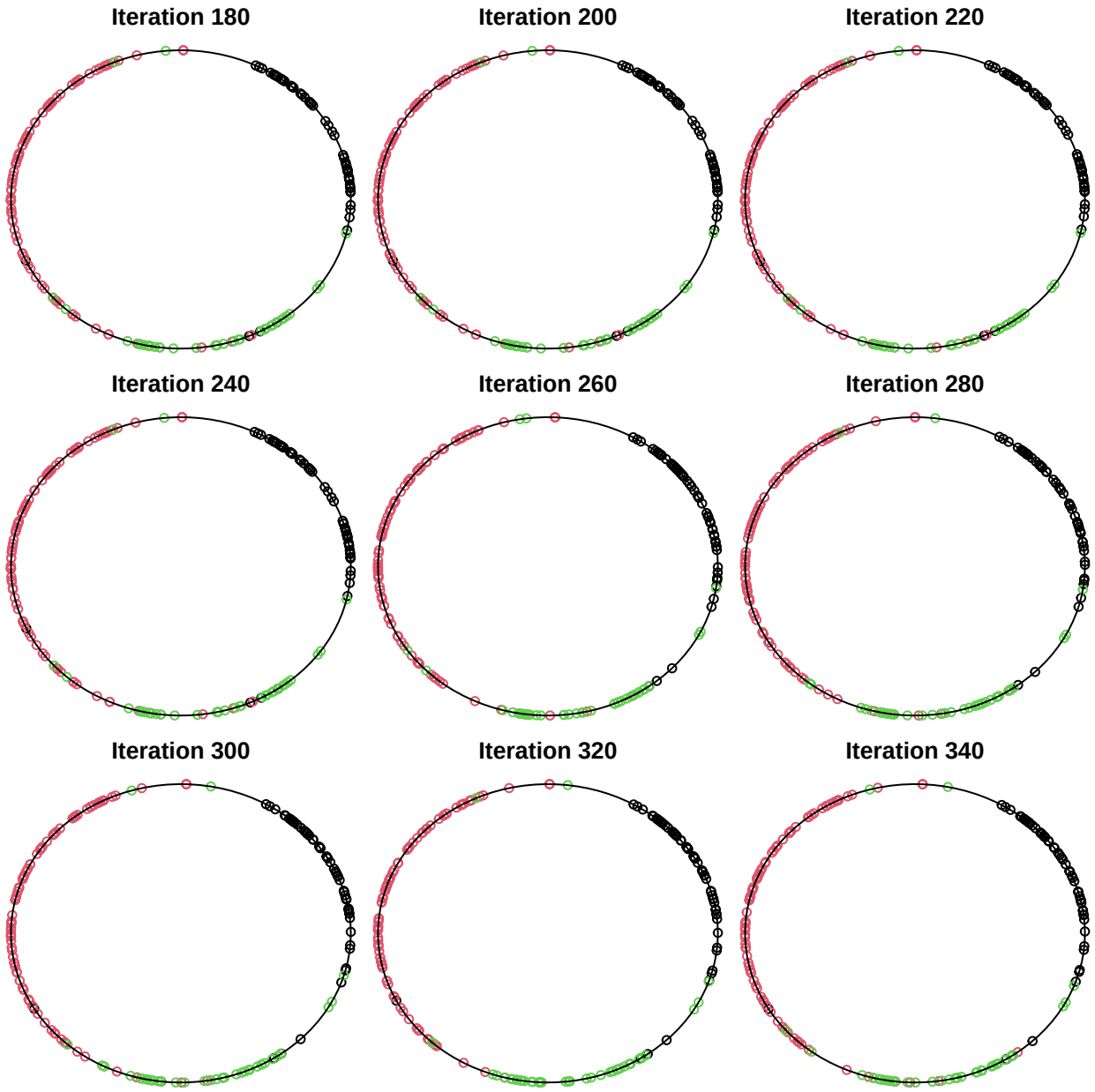
```
## It: 1 (best: 1); obj: 1.20e+01 (best: 1.20e+01); abs: 0.0e+00; rel: 0.0e+00; norm: 3.2e-01; mom: 0.0e+00
## It: 10 (best: 6); obj: 1.05e+01 (best: 1.05e+01); abs: 1.7e+00; rel: 1.4e-01; norm: 2.6e-01; mom: 7.7e+00
## It: 20 (best: 14); obj: 1.05e+01 (best: 1.03e+01); abs: 1.8e+00; rel: 1.4e-01; norm: 2.5e-01; mom: 7.8e+00
## It: 30 (best: 14); obj: 1.05e+01 (best: 1.03e+01); abs: 1.8e+00; rel: 1.5e-01; norm: 2.6e-01; mom: 7.5e+00
## It: 40 (best: 14); obj: 1.07e+01 (best: 1.03e+01); abs: 1.5e+00; rel: 1.2e-01; norm: 2.5e-01; mom: 7.4e+00
```

```
## It: 50 (best: 14); obj: 1.06e+01 (best: 1.03e+01); abs: 1.6e+00; rel: 1.3e-01; norm: 2.5e-01; mom: 7.6e+00
## It: 60 (best: 14); obj: 1.05e+01 (best: 1.03e+01); abs: 1.9e+00; rel: 1.6e-01; norm: 2.5e-01; mom: 7.7e+00
## It: 70 (best: 14); obj: 1.04e+01 (best: 1.03e+01); abs: 2.0e+00; rel: 1.6e-01; norm: 2.4e-01; mom: 7.6e+00
## It: 80 (best: 14); obj: 1.04e+01 (best: 1.03e+01); abs: 2.0e+00; rel: 1.6e-01; norm: 2.5e-01; mom: 7.6e+00
## It: 90 (best: 14); obj: 1.04e+01 (best: 1.03e+01); abs: 2.1e+00; rel: 1.7e-01; norm: 2.4e-01; mom: 7.7e+00
## It: 100 (best: 14); obj: 1.05e+01 (best: 1.03e+01); abs: 1.9e+00; rel: 1.5e-01; norm: 2.6e-01; mom: 7.5e+00
## It: 110 (best: 101); obj: 1.15e+00 (best: 1.08e+00); abs: 2.3e-02; rel: 2.1e-02; norm: 8.8e-02; mom: 4.4e+00
## It: 120 (best: 101); obj: 1.15e+00 (best: 1.08e+00); abs: 2.0e-02; rel: 1.7e-02; norm: 8.9e-02; mom: 4.4e+00
## It: 130 (best: 101); obj: 1.15e+00 (best: 1.08e+00); abs: 2.2e-02; rel: 1.9e-02; norm: 8.8e-02; mom: 4.4e+00
## It: 140 (best: 101); obj: 1.15e+00 (best: 1.08e+00); abs: 1.5e-02; rel: 1.4e-02; norm: 8.9e-02; mom: 4.5e+00
## It: 150 (best: 101); obj: 1.15e+00 (best: 1.08e+00); abs: 2.2e-02; rel: 1.9e-02; norm: 8.8e-02; mom: 4.4e+00
## It: 160 (best: 101); obj: 1.15e+00 (best: 1.08e+00); abs: 1.5e-02; rel: 1.3e-02; norm: 8.9e-02; mom: 4.5e+00
## It: 170 (best: 101); obj: 1.15e+00 (best: 1.08e+00); abs: 2.2e-02; rel: 1.9e-02; norm: 8.8e-02; mom: 4.4e+00
## It: 180 (best: 101); obj: 1.15e+00 (best: 1.08e+00); abs: 1.5e-02; rel: 1.3e-02; norm: 8.9e-02; mom: 4.5e+00
```



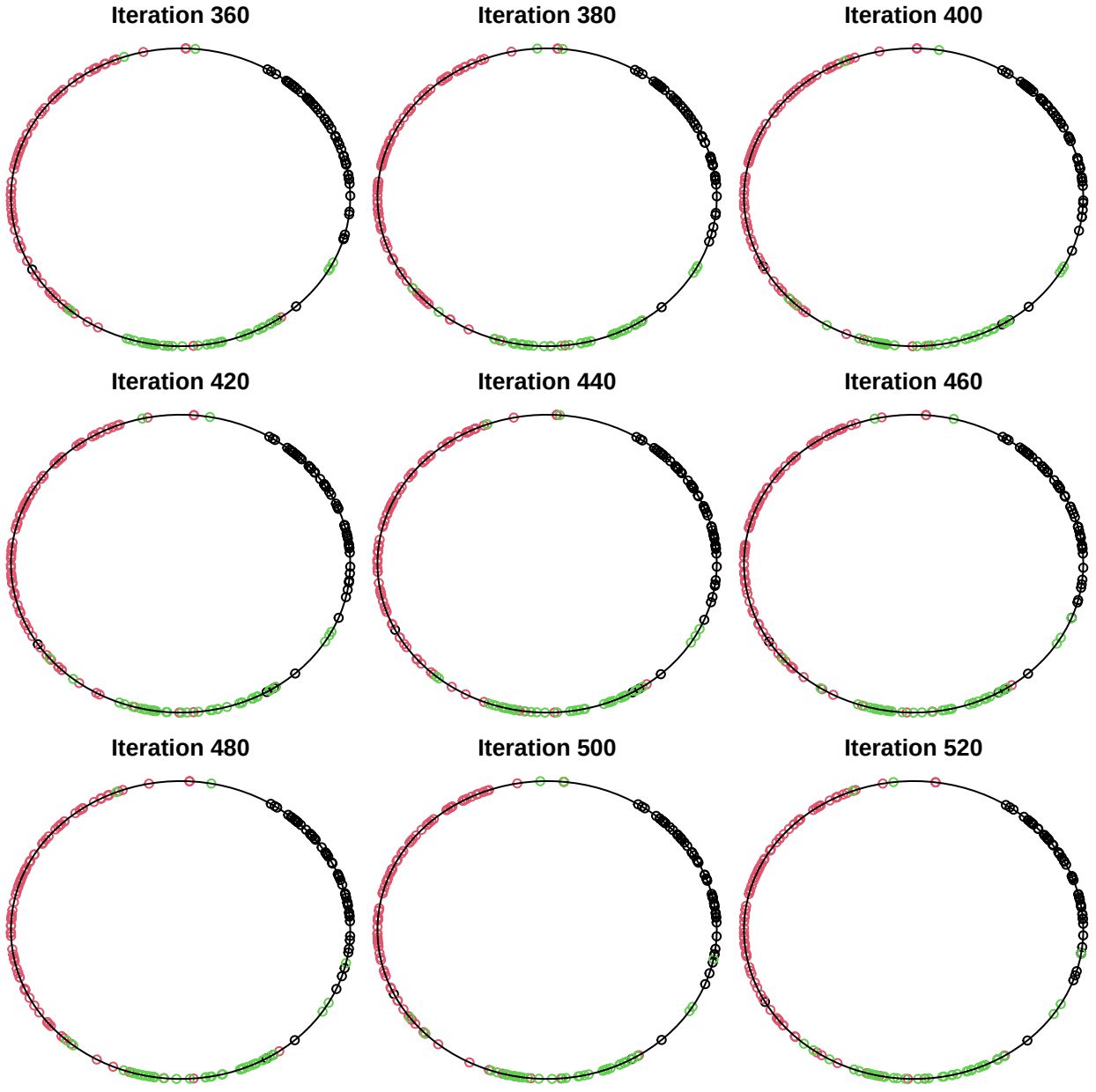

```
## It: 190 (best: 101); obj: 1.15e+00 (best: 1.08e+00); abs: 2.2e-02; rel: 1.9e-02; norm: 8.8e-02; mom: 4.4e+00
## It: 200 (best: 101); obj: 1.15e+00 (best: 1.08e+00); abs: 1.5e-02; rel: 1.3e-02; norm: 8.9e-02; mom: 4.5e+00
## It: 210 (best: 101); obj: 1.15e+00 (best: 1.08e+00); abs: 2.2e-02; rel: 1.9e-02; norm: 8.8e-02; mom: 4.4e+00
## It: 220 (best: 101); obj: 1.15e+00 (best: 1.08e+00); abs: 1.5e-02; rel: 1.3e-02; norm: 8.9e-02; mom: 4.5e+00
## It: 230 (best: 101); obj: 1.15e+00 (best: 1.08e+00); abs: 2.2e-02; rel: 1.9e-02; norm: 8.8e-02; mom: 4.4e+00
## It: 240 (best: 101); obj: 1.15e+00 (best: 1.08e+00); abs: 1.5e-02; rel: 1.3e-02; norm: 8.9e-02; mom: 4.5e+00
## It: 250 (best: 250); obj: 1.02e+00 (best: 1.02e+00); abs: 1.1e-01; rel: 9.4e-02; norm: 8.8e-02; mom: 7.1e+00
## It: 260 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 6.7e-03; rel: 6.1e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 270 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 4.3e-03; rel: 3.9e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 280 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 9.3e-03; rel: 8.5e-03; norm: 8.7e-02; mom: 6.1e+00
## It: 290 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 7.3e-03; rel: 6.7e-03; norm: 8.7e-02; mom: 6.1e+00
## It: 300 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 3.3e-03; rel: 3.0e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 310 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 4.2e-03; rel: 3.8e-03; norm: 8.6e-02; mom: 6.2e+00
```

```
## It: 320 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 1.1e-02; rel: 9.8e-03; norm: 8.7e-02; mom: 6.1e+00
## It: 330 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 5.3e-03; rel: 4.8e-03; norm: 8.7e-02; mom: 6.1e+00
## It: 340 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 2.0e-03; rel: 1.8e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 350 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 2.8e-03; rel: 2.6e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 360 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 2.8e-03; rel: 2.6e-03; norm: 8.6e-02; mom: 6.1e+00
```



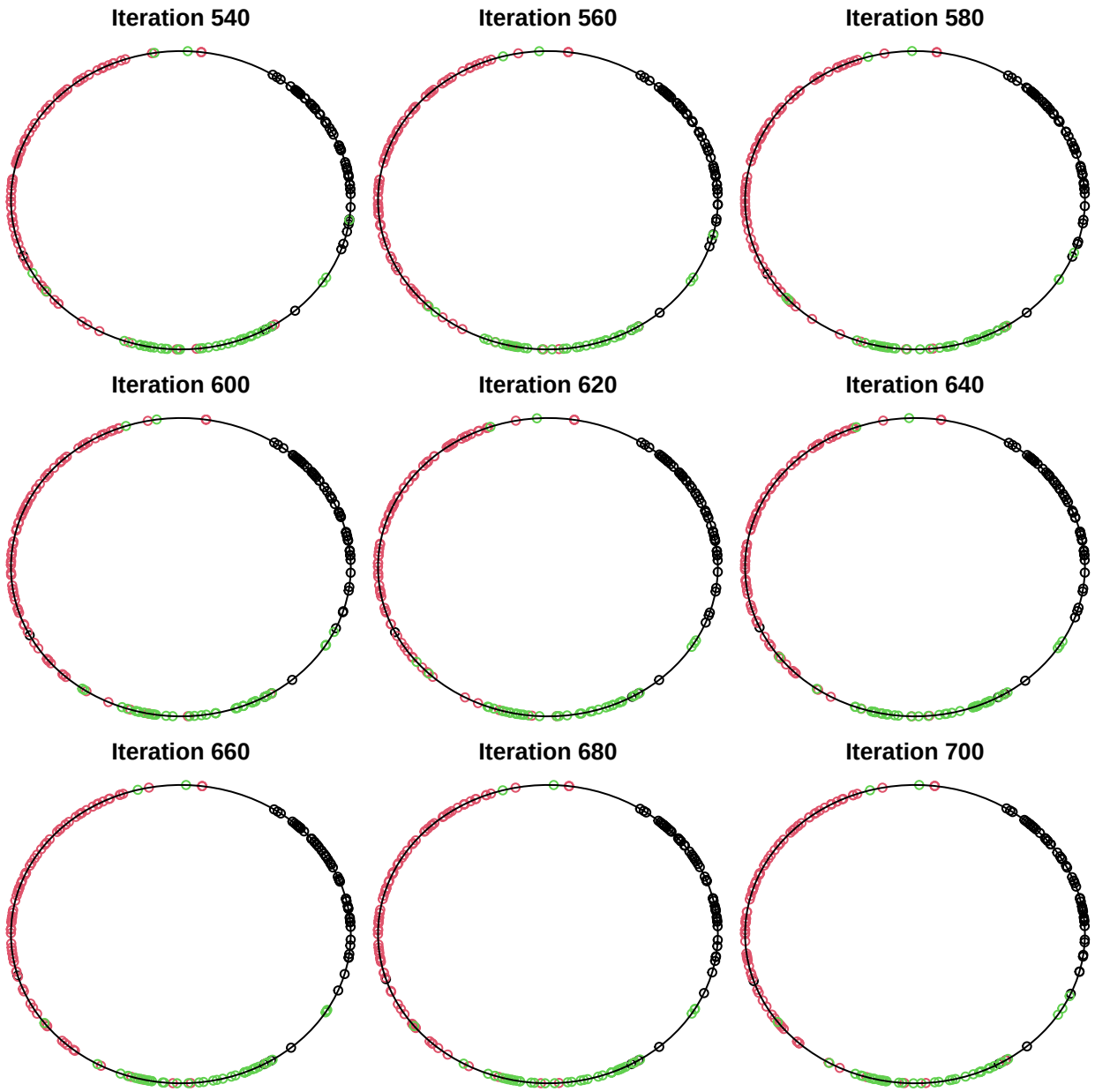

```
## It: 370 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 3.5e-03; rel: 3.2e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 380 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 7.9e-03; rel: 7.3e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 390 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 4.6e-04; rel: 4.3e-04; norm: 8.6e-02; mom: 6.1e+00
## It: 400 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 1.2e-02; rel: 1.1e-02; norm: 8.6e-02; mom: 6.1e+00
## It: 410 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 1.0e-02; rel: 9.2e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 420 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 2.3e-03; rel: 2.1e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 430 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 4.2e-04; rel: 3.8e-04; norm: 8.6e-02; mom: 6.1e+00
## It: 440 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 5.3e-03; rel: 4.9e-03; norm: 8.6e-02; mom: 6.0e+00
```

```
## It: 450 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 2.6e-04; rel: 2.4e-04; norm: 8.6e-02; mom: 6.1e+00
## It: 460 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 1.3e-04; rel: 1.2e-04; norm: 8.6e-02; mom: 6.1e+00
## It: 470 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 2.6e-03; rel: 2.4e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 480 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 1.9e-03; rel: 1.7e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 490 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 2.3e-03; rel: 2.1e-03; norm: 8.7e-02; mom: 6.1e+00
## It: 500 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 6.4e-03; rel: 5.8e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 510 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 9.8e-03; rel: 9.0e-03; norm: 8.7e-02; mom: 6.1e+00
## It: 520 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 9.6e-03; rel: 8.8e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 530 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 2.9e-03; rel: 2.6e-03; norm: 8.7e-02; mom: 6.1e+00
## It: 540 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 7.3e-03; rel: 6.7e-03; norm: 8.7e-02; mom: 6.1e+00
```



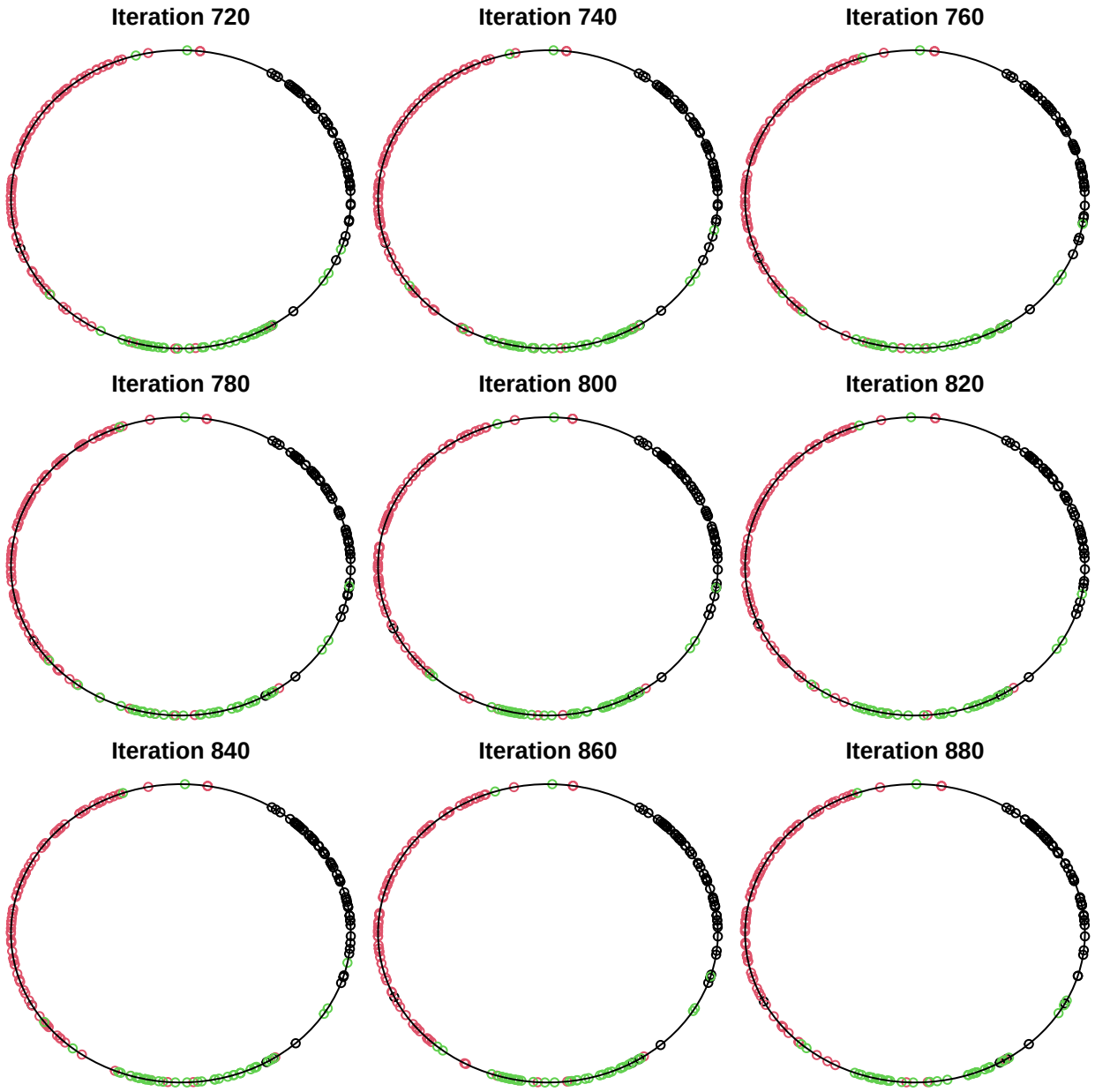

```
## It: 550 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 6.9e-03; rel: 6.3e-03; norm: 8.7e-02; mom: 6.1e+00
## It: 560 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 8.0e-03; rel: 7.3e-03; norm: 8.7e-02; mom: 6.1e+00
## It: 570 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 3.2e-03; rel: 2.9e-03; norm: 8.7e-02; mom: 6.1e+00
```

```
## It: 580 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 5.2e-04; rel: 4.8e-04; norm: 8.6e-02; mom: 6.1e+00
## It: 590 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 1.1e-02; rel: 1.0e-02; norm: 8.6e-02; mom: 6.2e+00
## It: 600 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 3.1e-03; rel: 2.8e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 610 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 4.1e-03; rel: 3.8e-03; norm: 8.6e-02; mom: 6.2e+00
## It: 620 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 5.5e-03; rel: 5.1e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 630 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 9.0e-04; rel: 8.2e-04; norm: 8.6e-02; mom: 6.1e+00
## It: 640 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 4.5e-03; rel: 4.1e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 650 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 8.2e-03; rel: 7.5e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 660 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 4.9e-04; rel: 4.5e-04; norm: 8.6e-02; mom: 6.1e+00
## It: 670 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 7.6e-03; rel: 7.0e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 680 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 1.4e-04; rel: 1.3e-04; norm: 8.6e-02; mom: 6.1e+00
## It: 690 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 6.8e-03; rel: 6.3e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 700 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 4.7e-04; rel: 4.3e-04; norm: 8.6e-02; mom: 6.1e+00
## It: 710 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 3.0e-03; rel: 2.8e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 720 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 2.7e-03; rel: 2.5e-03; norm: 8.6e-02; mom: 6.1e+00
```



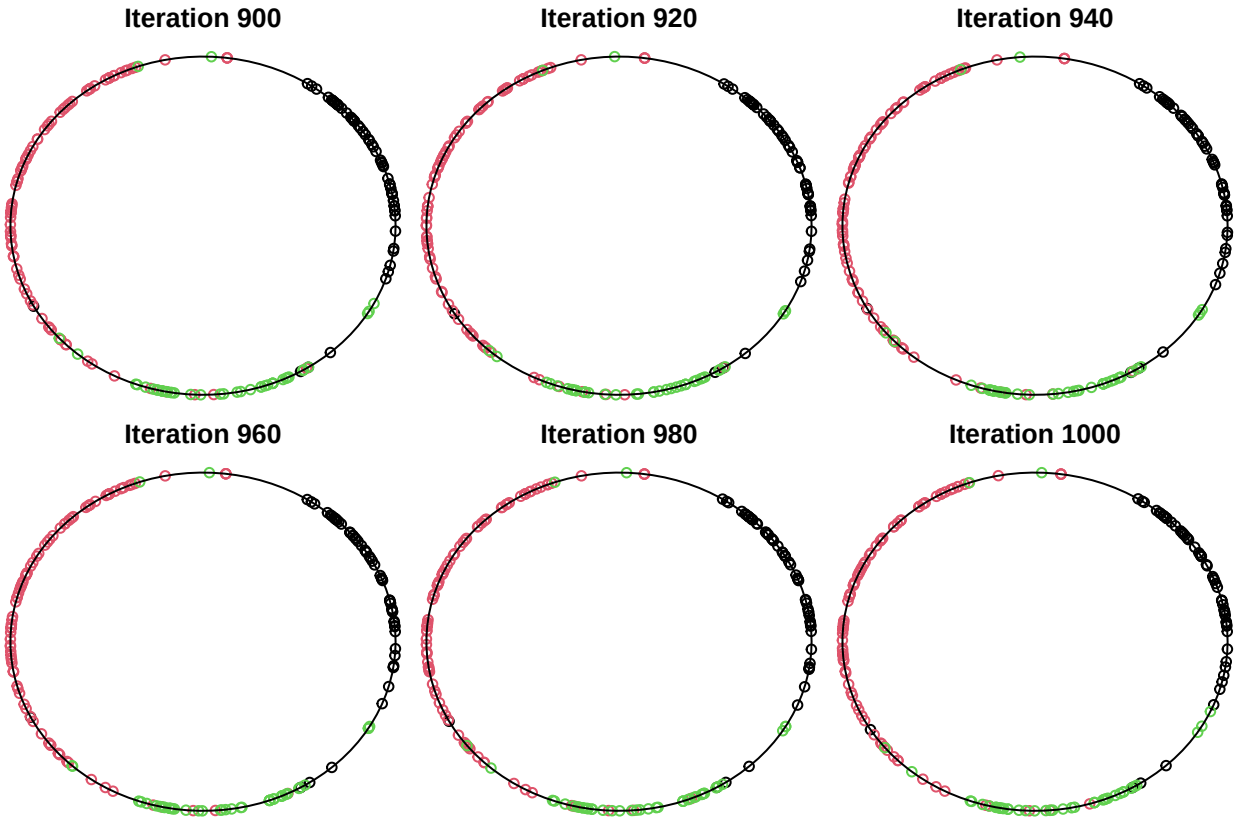

```
## It: 730 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 6.3e-03; rel: 5.8e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 740 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 1.1e-03; rel: 9.9e-04; norm: 8.6e-02; mom: 6.1e+00
## It: 750 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 7.0e-03; rel: 6.5e-03; norm: 8.6e-02; mom: 6.0e+00
## It: 760 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 6.6e-03; rel: 6.0e-03; norm: 8.7e-02; mom: 6.1e+00
## It: 770 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 4.7e-03; rel: 4.3e-03; norm: 8.7e-02; mom: 6.1e+00
## It: 780 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 3.9e-03; rel: 3.6e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 790 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 5.1e-04; rel: 4.7e-04; norm: 8.6e-02; mom: 6.1e+00
## It: 800 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 8.9e-04; rel: 8.2e-04; norm: 8.7e-02; mom: 6.1e+00
## It: 810 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 6.9e-03; rel: 6.3e-03; norm: 8.7e-02; mom: 6.1e+00
## It: 820 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 4.3e-03; rel: 4.0e-03; norm: 8.6e-02; mom: 6.0e+00
## It: 830 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 1.1e-02; rel: 9.7e-03; norm: 8.7e-02; mom: 6.2e+00
## It: 840 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 1.3e-03; rel: 1.2e-03; norm: 8.7e-02; mom: 6.1e+00
## It: 850 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 2.2e-03; rel: 2.1e-03; norm: 8.6e-02; mom: 6.1e+00
```

```
## It: 860 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 2.3e-03; rel: 2.1e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 870 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 7.6e-03; rel: 7.0e-03; norm: 8.7e-02; mom: 6.1e+00
## It: 880 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 2.6e-03; rel: 2.4e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 890 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 7.7e-03; rel: 7.1e-03; norm: 8.7e-02; mom: 6.1e+00
## It: 900 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 6.9e-03; rel: 6.4e-03; norm: 8.6e-02; mom: 6.1e+00
```




```
## It: 910 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 5.8e-03; rel: 5.3e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 920 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 6.1e-04; rel: 5.6e-04; norm: 8.6e-02; mom: 6.1e+00
## It: 930 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 4.5e-03; rel: 4.2e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 940 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 2.1e-03; rel: 1.9e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 950 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 5.4e-03; rel: 4.9e-03; norm: 8.6e-02; mom: 6.1e+00
## It: 960 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 1.3e-02; rel: 1.2e-02; norm: 8.6e-02; mom: 6.1e+00
## It: 970 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 3.5e-03; rel: 3.2e-03; norm: 8.6e-02; mom: 6.0e+00
## It: 980 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 9.3e-03; rel: 8.5e-03; norm: 8.6e-02; mom: 6.1e+00
```

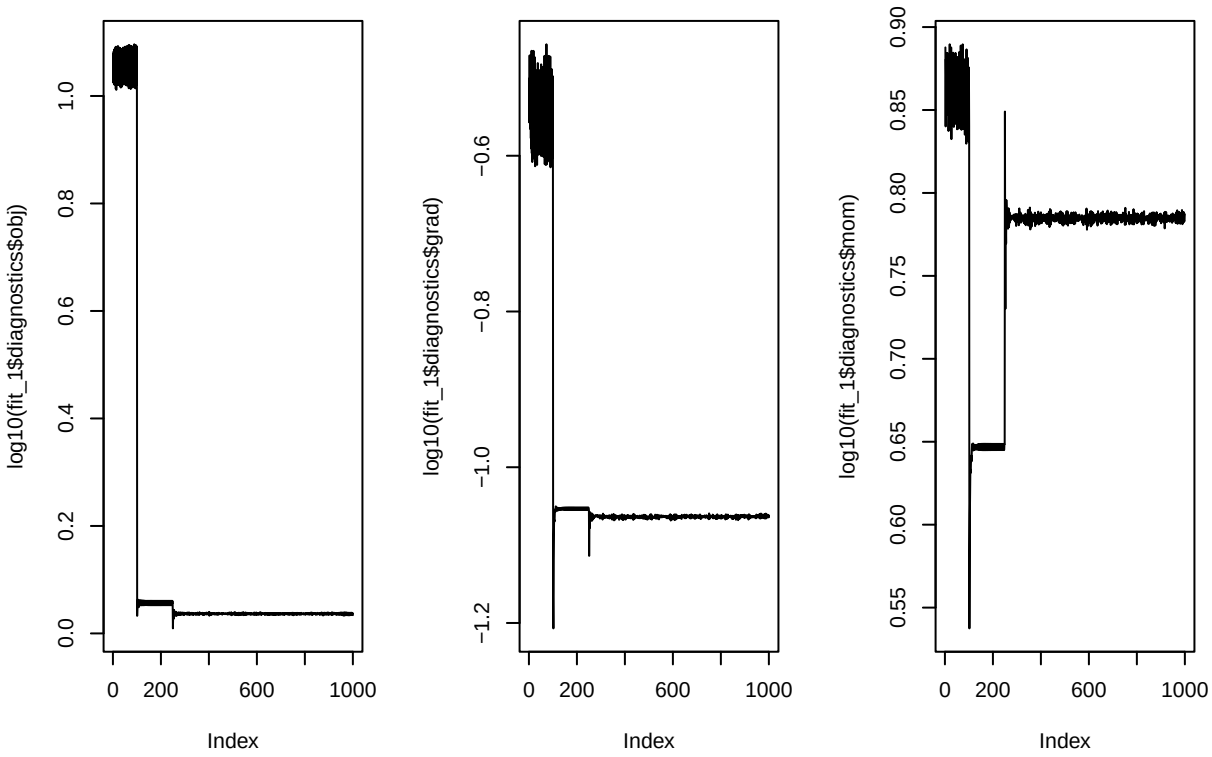
```
## It: 990 (best: 250); obj: 1.09e+00 (best: 1.02e+00); abs: 7.6e-04; rel: 7.0e-04; norm: 8.6e-02; mom: 6.0e+00
## It: 1000 (best: 250); obj: 1.08e+00 (best: 1.02e+00); abs: 9.7e-03; rel: 8.9e-03; norm: 8.6e-02; mom: 6.1e+00
## **NO** CONVERGENCE. Decrease eta? Change init? Increase maxit?
```




```
# Does not converge
fit_1$convergence
```

```
## [1] FALSE
```

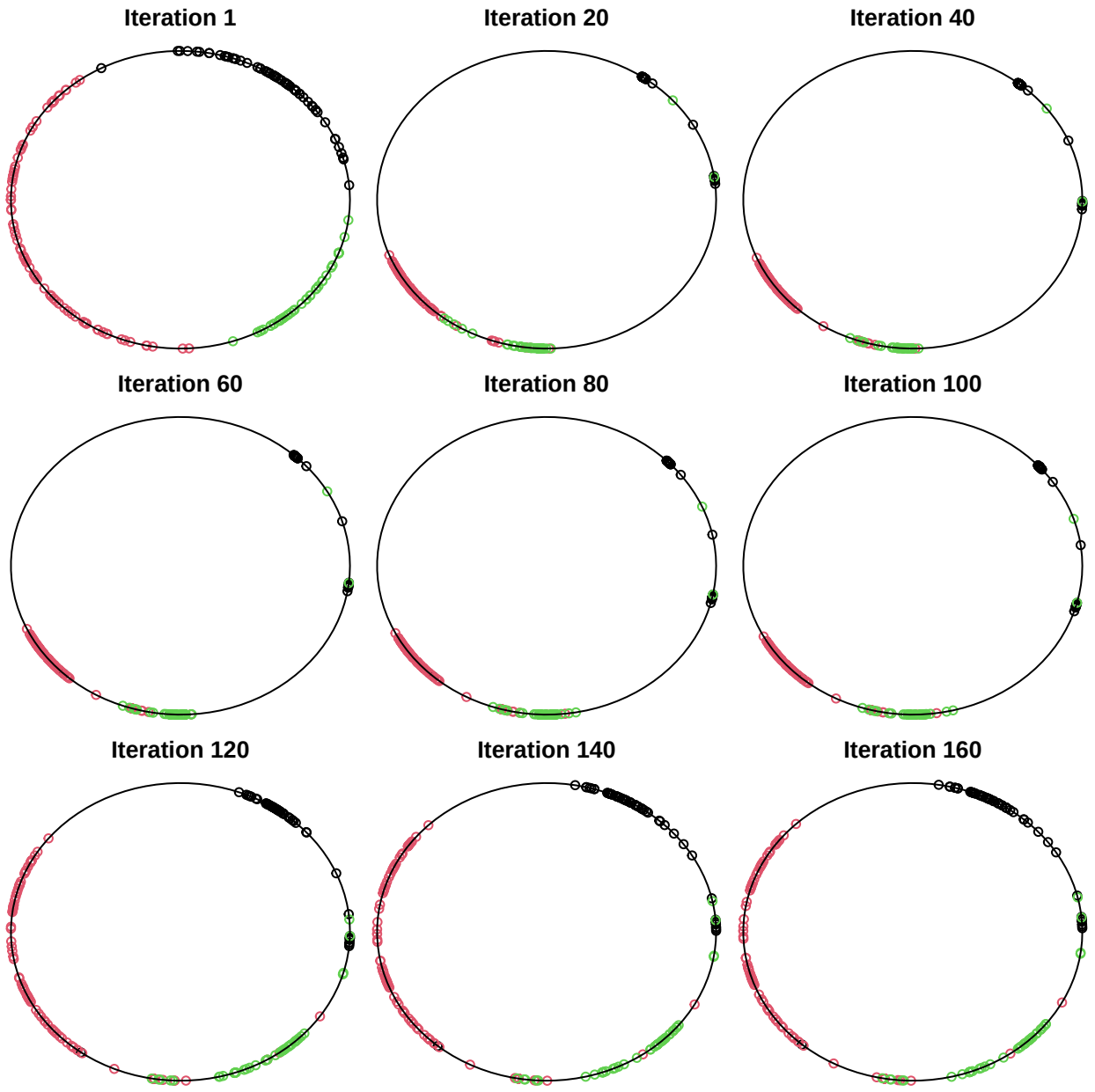
```
par(mfrow = c(1, 3))
plot(log10(fit_1$diagnostics$obj), type = "l")
plot(log10(fit_1$diagnostics$grad), type = "l")
plot(log10(fit_1$diagnostics$mom), type = "l")
```



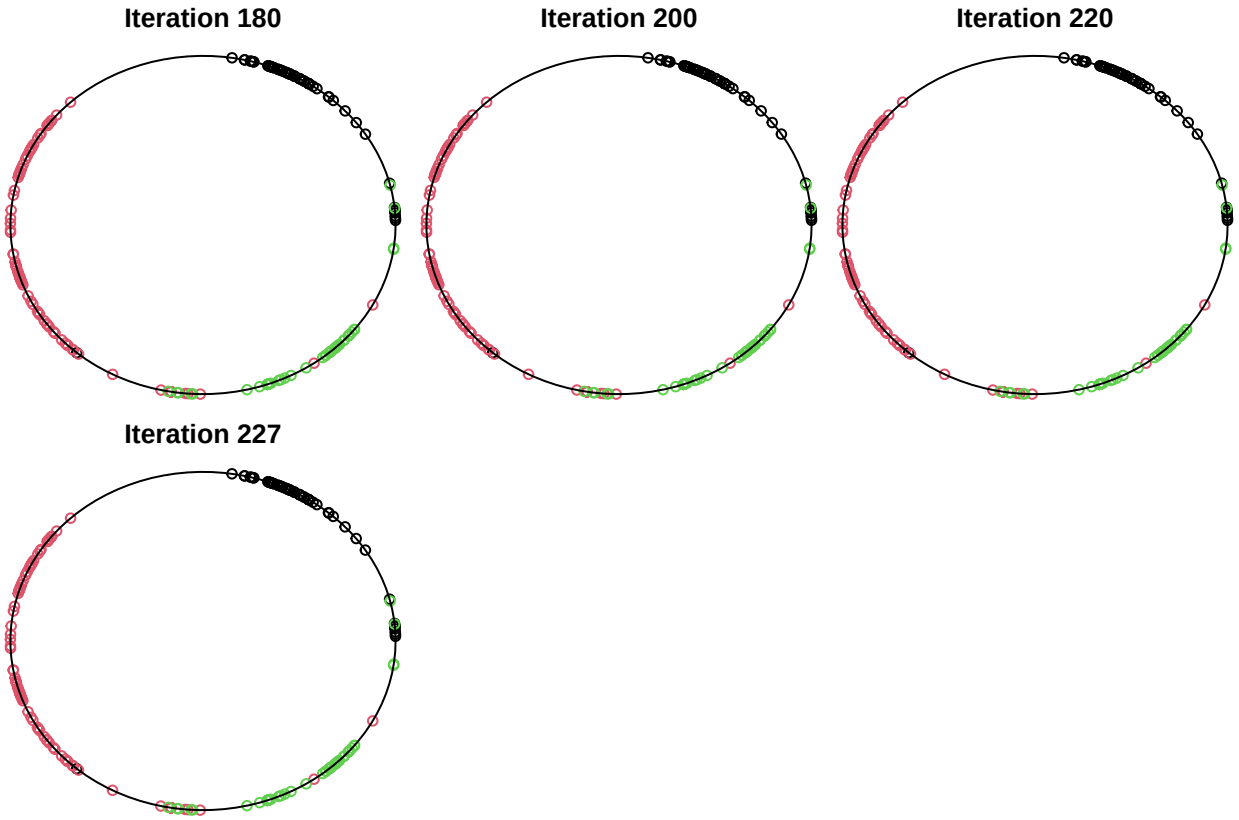

The employed $\eta$ seems to be too large. Let's reduce it.

```
# Lower eta
fit_2 <- psc_sne(X = smallrna_X, d = 1, rho_psc_list = rho_psc_list,
                 eta = 10, maxit = 1e3, tol = 1e-6, show_prog = 10,
                 colors = original_clusters)
```

```
## It: 1 (best: 1); obj: 1.03e+01 (best: 1.03e+01); abs: 0.0e+00; rel: 0.0e+00; norm: 3.2e-01; mom: 0.0e+00
## It: 10 (best: 10); obj: 9.62e+00 (best: 9.62e+00); abs: 1.1e-02; rel: 1.2e-03; norm: 6.0e-02; mom: 4.8e-01
## It: 20 (best: 13); obj: 9.68e+00 (best: 9.57e+00); abs: 1.1e-03; rel: 1.1e-04; norm: 2.0e-02; mom: 2.0e-01
## It: 30 (best: 13); obj: 9.64e+00 (best: 9.57e+00); abs: 1.9e-03; rel: 1.9e-04; norm: 2.3e-03; mom: 2.5e-02
## It: 40 (best: 13); obj: 9.63e+00 (best: 9.57e+00); abs: 2.2e-05; rel: 2.3e-06; norm: 1.9e-03; mom: 1.9e-02
## It: 50 (best: 13); obj: 9.63e+00 (best: 9.57e+00); abs: 1.2e-04; rel: 1.2e-05; norm: 1.8e-03; mom: 1.8e-02
## It: 60 (best: 13); obj: 9.64e+00 (best: 9.57e+00); abs: 1.5e-04; rel: 1.5e-05; norm: 1.6e-03; mom: 1.6e-02
## It: 70 (best: 13); obj: 9.64e+00 (best: 9.57e+00); abs: 1.8e-04; rel: 1.9e-05; norm: 1.5e-03; mom: 1.5e-02
## It: 80 (best: 13); obj: 9.64e+00 (best: 9.57e+00); abs: 2.4e-04; rel: 2.5e-05; norm: 1.3e-03; mom: 1.3e-02
## It: 90 (best: 13); obj: 9.64e+00 (best: 9.57e+00); abs: 3.1e-04; rel: 3.2e-05; norm: 1.1e-03; mom: 1.2e-02
## It: 100 (best: 13); obj: 9.65e+00 (best: 9.57e+00); abs: 3.5e-04; rel: 3.6e-05; norm: 9.7e-04; mom: 1.0e-02
## It: 110 (best: 110); obj: 8.89e-01 (best: 8.89e-01); abs: 5.4e-03; rel: 6.1e-03; norm: 1.6e-02; mom: 2.0e-01
## It: 120 (best: 120); obj: 8.66e-01 (best: 8.66e-01); abs: 1.1e-03; rel: 1.3e-03; norm: 7.3e-03; mom: 8.4e-02
## It: 130 (best: 130); obj: 8.61e-01 (best: 8.61e-01); abs: 2.0e-04; rel: 2.4e-04; norm: 3.1e-03; mom: 3.8e-02
## It: 140 (best: 140); obj: 8.60e-01 (best: 8.60e-01); abs: 2.9e-05; rel: 3.4e-05; norm: 1.2e-03; mom: 1.4e-02
## It: 150 (best: 150); obj: 8.60e-01 (best: 8.60e-01); abs: 4.3e-06; rel: 5.0e-06; norm: 4.5e-04; mom: 5.5e-03
## It: 160 (best: 160); obj: 8.60e-01 (best: 8.60e-01); abs: 6.5e-07; rel: 7.6e-07; norm: 1.8e-04; mom: 2.1e-03
## It: 170 (best: 170); obj: 8.60e-01 (best: 8.60e-01); abs: 1.0e-07; rel: 1.2e-07; norm: 6.9e-05; mom: 8.4e-04
## It: 180 (best: 180); obj: 8.60e-01 (best: 8.60e-01); abs: 1.6e-08; rel: 1.8e-08; norm: 2.7e-05; mom: 3.3e-04
```



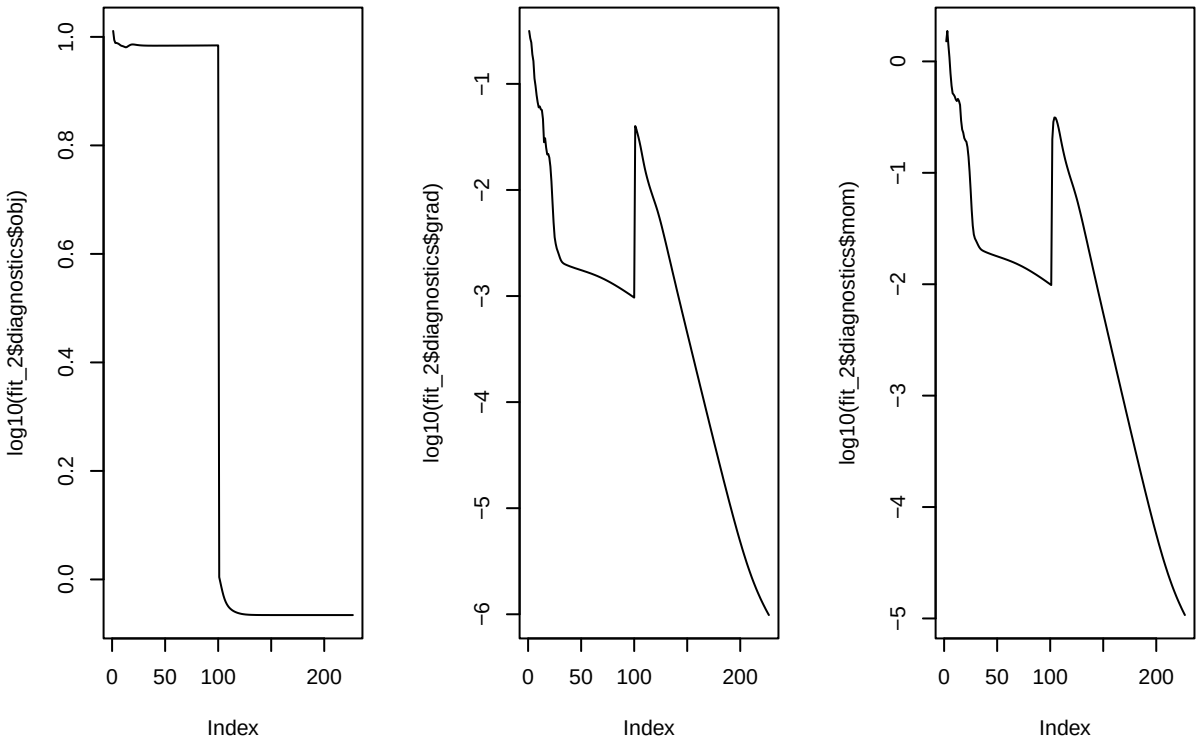

```
## It: 190 (best: 190); obj: 8.60e-01 (best: 8.60e-01); abs: 2.6e-09; rel: 3.0e-09; norm: 1.1e-05; mom: 1.3e-04
## It: 200 (best: 200); obj: 8.60e-01 (best: 8.60e-01); abs: 4.9e-10; rel: 5.7e-10; norm: 4.8e-06; mom: 5.7e-05
## It: 210 (best: 210); obj: 8.60e-01 (best: 8.60e-01); abs: 1.2e-10; rel: 1.3e-10; norm: 2.4e-06; mom: 2.7e-05
## It: 220 (best: 220); obj: 8.60e-01 (best: 8.60e-01); abs: 3.7e-11; rel: 4.3e-11; norm: 1.3e-06; mom: 1.5e-05
## It: 227 (best: 227); obj: 8.60e-01 (best: 8.60e-01); abs: 2.0e-11; rel: 2.3e-11; norm: 9.8e-07; mom: 1.1e-05
## CONVERGENCE!
```




```
# Converges
fit_2$convergence
```

```
## [1] TRUE
```

```
par(mfrow = c(1, 3))
plot(log10(fit_2$diagnostics$obj), type = "l")
plot(log10(fit_2$diagnostics$grad), type = "l")
plot(log10(fit_2$diagnostics$mom), type = "l")
```




Convergence is attained in the second run, yet it is weird that the objective function takes exactly the zero value.

Let's see the recovery of the clusters.

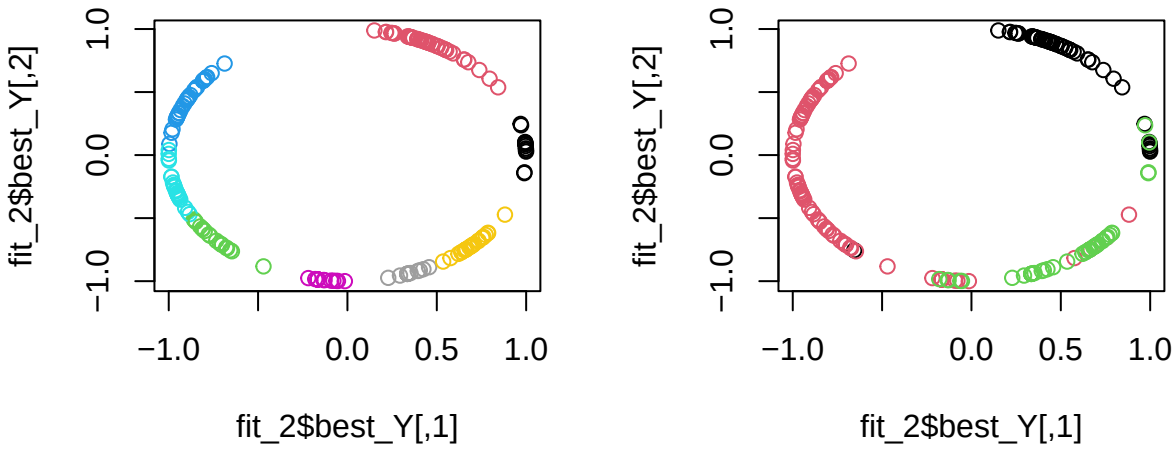
```
# Kernel mean shift clustering
n <- nrow(fit_2$best_Y)
d <- ncol(fit_2$best_Y) - 1
fit_mix <- DirStats::bic_vmf_mix(data = fit_2$best_Y, kappa_max = 1e3)
h <- DirStats::bw_dir_emi(data = fit_2$best_Y, fit_mix = fit_mix)$h_opt *
      n^(1 / (d + 4)) * n^(-1 / (d + 6))
kms <- kms_dir(data = fit_2$best_Y, h = h)
```

```
##   |                                                                      |
```

```
# Detects 8 clusters by splitting the 3 original clusters
length(unique(kms$cluster))
```

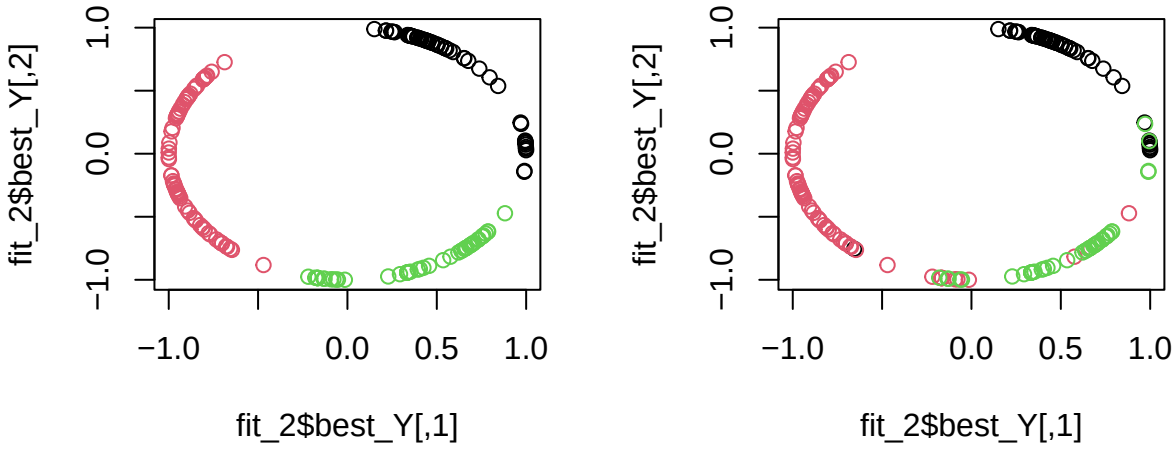
```
## [1] 8
```

```
# Fully-automatically recovered clusters vs. real clusters
par(mfrow = c(1, 2))
plot(fit_2$best_Y, col = kms$cluster)
plot(fit_2$best_Y, col = original_clusters)
```




The original clusters are not fully recovered, in the sense that more clusters are obtained. However, the three-cluster structure is present, as the new clusters appear dividing the three main ones. This can be checked by cutting the hierarchical clustering tree behind kernel mean shift clustering exactly at three groups. Or, in other words, by merging the 8 groups into 3.

```
# Recovered clusters with three clusters vs. real clusters
par(mfrow = c(1, 2))
labels <- cutree(kms$tree, k = 3)
plot(fit_2$best_Y, col = labels)
plot(fit_2$best_Y, col = original_clusters)
```




```
# Correct classification rate: 90%
mean(labels == original_clusters)
```

```
## [1] 0.9
```

```
# 19 incorrectly classified observations
sum(labels != original_clusters)
```

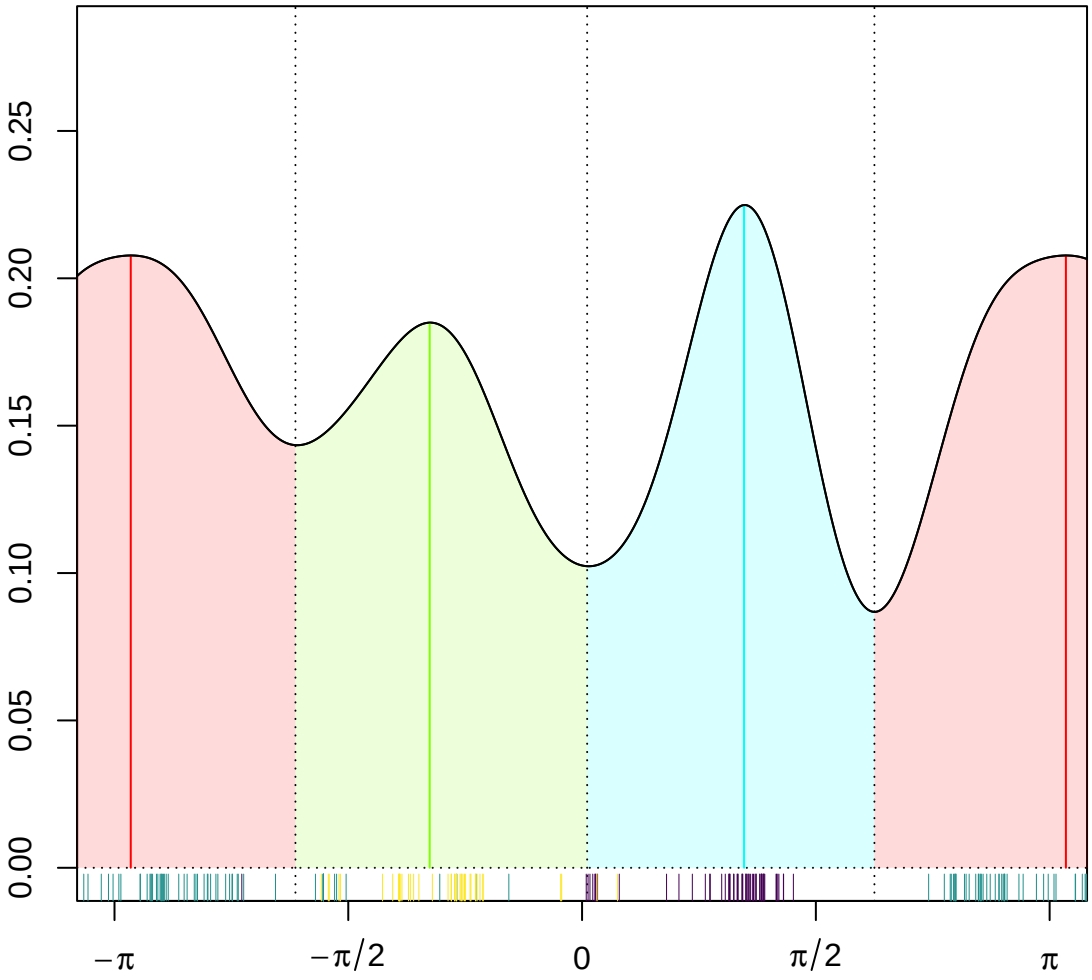
```
## [1] 19
```

The classification accuracy is on-par with Zouboulоglou et al. (2021), which misclassifies 16 points and has a classification rate of 0.916.

There is another way to cluster the scores provided by the psc-SNE. These values, x and y, can be transalted to $\theta$ encoded in radians, and later they can be used with the kernel mean shift clustering for linear data to obtain these groups and plot them in a density graph.

```
h <- pscsne::bw_kms(fit_2$best_Y, type = "hpi_linear_s1")
pscsne::plot_kde(fit_2$best_Y, h, init_clusters = original_clusters, step = 0.01)
```

```
##   |                                                                      |
```




```
## $end_points
##               [,1]        [,2]
##   [1,] -0.9950534 -0.09934130
##   [2,] -0.9950388 -0.09948775
##   [3,] -0.9950235 -0.09964078
##   [4,] -0.9950074 -0.09980068
##   [5,] -0.9949907 -0.09996771
##   [6,] -0.9949731 -0.10014216
##   [7,] -0.9950531 -0.09934430
##   [8,] -0.9950323 -0.09955214
##   [9,] -0.9950106 -0.09976890
##  [10,] -0.9949880 -0.09999480
##  [11,] -0.9950634 -0.09924122
##  [12,] -0.9950367 -0.09950885
##  [13,] -0.9950088 -0.09978696
##  [14,] -0.9949798 -0.10007562
##  [15,] -0.9950476 -0.09939957
##  [16,] -0.9950137 -0.09973822
```

```
##  [17,] -0.9949786 -0.10008811
##  [18,] -0.9950395 -0.09948068
##  [19,] -0.9949988 -0.09988693
##  [20,] -0.9950553 -0.09932237
##  [21,] -0.9950085 -0.09979012
##  [22,] -0.9950592 -0.09928319
##  [23,] -0.9950058 -0.09981670
##  [24,] -0.9950493 -0.09938277
##  [25,] -0.9949889 -0.09998503
##  [26,] -0.9950236 -0.09963971
##  [27,] -0.9950544 -0.09933099
##  [28,] -0.9949803 -0.10007081
##  [29,] -0.9949996 -0.09987876
##  [30,] -0.9950130 -0.09974498
##  [31,] -0.9950196 -0.09967934
##  [32,] -0.9950183 -0.09969259
##  [33,] -0.9950079 -0.09979649
##  [34,] -0.9949870 -0.10000394
##  [35,] -0.9950526 -0.09934953
##  [36,] -0.9950024 -0.09985086
##  [37,] -0.9950321 -0.09955496
##  [38,] -0.9950354 -0.09952193
##  [39,] -0.9950019 -0.09985583
##  [40,] -0.9950130 -0.09974542
##  [41,] -0.9950319 -0.09955687
##  [42,] -0.9950628 -0.09924695
##  [43,] -0.9944041 -0.10564324
##  [44,] -0.9932980 -0.11558183
##  [45,] -0.9926790 -0.12078263
##  [46,] -0.9926459 -0.12105415
##  [47,] -0.9925958 -0.12146410
##  [48,] -0.9926587 -0.12094925
##  [49,] -0.9926654 -0.12089428
##  [50,] -0.9925939 -0.12147955
##  [51,] -0.9926765 -0.12080319
##  [52,] -0.9926609 -0.12093151
##  [53,] -0.9926630 -0.12091409
##  [54,] -0.9926792 -0.12078096
##  [55,] -0.9925854 -0.12154966
##  [56,] -0.9926247 -0.12122757
##  [57,] -0.9926709 -0.12084918
##  [58,] -0.9926024 -0.12140999
##  [59,] -0.9926623 -0.12091970
##  [60,] -0.9926050 -0.12138943
##  [61,] -0.9926742 -0.12082190
##  [62,] -0.9926262 -0.12121594
##  [63,] -0.9927013 -0.12059871
##  [64,] -0.9926610 -0.12092996
##  [65,] -0.9926221 -0.12124903
##  [66,] -0.9927056 -0.12056383
##  [67,] -0.9926728 -0.12083316
##  [68,] -0.9926411 -0.12109318
##  [69,] -0.9926105 -0.12134442
##  [70,] -0.9927022 -0.12059179
```

```
##  [71,] -0.9926762 -0.12080530
##  [72,] -0.9926510 -0.12101217
##  [73,] -0.9926265 -0.12121281
##  [74,] -0.9926027 -0.12140760
##  [75,] -0.9927011 -0.12060042
##  [76,] -0.9926808 -0.12076760
##  [77,] -0.9926610 -0.12093041
##  [78,] -0.9926416 -0.12108915
##  [79,] -0.9926227 -0.12124407
##  [80,] -0.9926042 -0.12139546
##  [81,] -0.9925861 -0.12154355
##  [82,] -0.9926910 -0.12068364
##  [83,] -0.9926753 -0.12081272
##  [84,] -0.9926599 -0.12093942
##  [85,] -0.9926447 -0.12106393
##  [86,] -0.9926298 -0.12118644
##  [87,] -0.9926150 -0.12130712
##  [88,] -0.9926005 -0.12142614
##  [89,] -0.9925861 -0.12154365
##  [90,] -0.9926942 -0.12065753
##  [91,] -0.9926815 -0.12076190
##  [92,] -0.9926689 -0.12086531
##  [93,] -0.9926564 -0.12096791
##  [94,] -0.9926440 -0.12106982
##  [95,] -0.9926316 -0.12117116
##  [96,] -0.9926193 -0.12127205
##  [97,] -0.9926070 -0.12137263
##  [98,] -0.9925947 -0.12147300
##  [99,] -0.9927037 -0.12057898
## [100,] -0.9926927 -0.12067006
## [101,] -0.9926816 -0.12076128
## [102,] -0.9926704 -0.12085275
## [103,] -0.9926593 -0.12094459
## [104,] -0.9926480 -0.12103689
## [105,] -0.9926367 -0.12112979
## [106,] -0.9926253 -0.12122339
## [107,] -0.9926137 -0.12131782
## [108,] -0.9926021 -0.12141320
## [109,] -0.9925902 -0.12150966
## [110,] -0.9927000 -0.12060988
## [111,] -0.9926891 -0.12069977
## [112,] -0.9926780 -0.12079102
## [113,] -0.9926667 -0.12088378
## [114,] -0.9926552 -0.12097818
## [115,] -0.9926434 -0.12107439
## [116,] -0.9926315 -0.12117258
## [117,] -0.9926192 -0.12127292
## [118,] -0.9926066 -0.12137562
## [119,] -0.9925938 -0.12148087
## [120,] -0.9927020 -0.12059317
## [121,] -0.9926898 -0.12069400
## [122,] -0.9926771 -0.12079783
## [123,] -0.9926641 -0.12090491
## [124,] -0.9926506 -0.12101556
```

```
## [125,] -0.9926366 -0.12113008
## [126,] -0.9926221 -0.12124883
## [127,] -0.9926071 -0.12137223
## [128,] -0.9925913 -0.12150070
## [129,] -0.9926970 -0.12063478
## [130,] -0.9926815 -0.12076205
## [131,] -0.9926652 -0.12089548
## [132,] -0.9926482 -0.12103573
## [133,] -0.9926301 -0.12118355
## [134,] -0.9926110 -0.12133984
## [135,] -0.9925907 -0.12150560
## [136,] -0.9926917 -0.12067768
## [137,] -0.9926709 -0.12084879
## [138,] -0.9926486 -0.12103236
## [139,] -0.9926244 -0.12123023
## [140,] -0.9925982 -0.12144461
## [141,] -0.9926922 -0.12067423
## [142,] -0.9926639 -0.12090683
## [143,] -0.9926325 -0.12116386
## [144,] -0.9925975 -0.12145035
## [145,] -0.9926817 -0.12076020
## [146,] -0.9926411 -0.12109388
## [147,] -0.9925939 -0.12147970
## [148,] -0.9926639 -0.12090637
## [149,] -0.9926033 -0.12140314
## [150,] -0.9926544 -0.12098461
## [151,] -0.9926886 -0.12070331
## [152,] -0.9926995 -0.12061422
## [153,] -0.9926701 -0.12085518
## [154,] -0.9926681 -0.12087197
## [155,] -0.3381549 -0.94109047
## [156,]  0.5211941 -0.85343815
## [157,]  0.5210726 -0.85351237
## [158,]  0.5215275 -0.85323449
## [159,]  0.5215809 -0.85320184
## [160,]  0.5214521 -0.85328058
## [161,]  0.5211831 -0.85344491
## [162,]  0.5216273 -0.85317348
## [163,]  0.5212375 -0.85341169
## [164,]  0.5215793 -0.85320280
## [165,]  0.5210875 -0.85350324
## [166,]  0.5213932 -0.85331653
## [167,]  0.5216360 -0.85316814
## [168,]  0.5210810 -0.85350723
## [169,]  0.5213287 -0.85335597
## [170,]  0.5215355 -0.85322960
## [171,]  0.5208938 -0.85362150
## [172,]  0.5211222 -0.85348210
## [173,]  0.5213190 -0.85336185
## [174,]  0.5214902 -0.85325727
## [175,]  0.5216401 -0.85316566
## [176,]  0.5209885 -0.85356370
## [177,]  0.5211677 -0.85345430
## [178,]  0.5213274 -0.85335673
```

```
## [179,]  0.5214705 -0.85326929
## [180,]  0.5215993 -0.85319057
## [181,]  0.5209021 -0.85361644
## [182,]  0.5210635 -0.85351791
## [183,]  0.5212104 -0.85342820
## [184,]  0.5213446 -0.85334626
## [185,]  0.5214674 -0.85327120
## [186,]  0.5215802 -0.85320225
## [187,]  0.5208537 -0.85364594
## [188,]  0.5210003 -0.85355649
## [189,]  0.5211359 -0.85347373
## [190,]  0.5212615 -0.85339699
## [191,]  0.5213782 -0.85332571
## [192,]  0.5214868 -0.85325937
## [193,]  0.5215879 -0.85319754
## [194,]  0.5208511 -0.85364755
## [195,]  0.5209861 -0.85356516
## [196,]  0.5211125 -0.85348799
## [197,]  0.5212310 -0.85341562
## [198,]  0.5213423 -0.85334767
## [199,]  0.5214468 -0.85328379
## [200,]  0.5215452 -0.85322366
## [201,]  0.5216379 -0.85316701
## [202,]  0.5209167 -0.85360752
## [203,]  0.5210429 -0.85353051
## [204,]  0.5211621 -0.85345772
## [205,]  0.5212748 -0.85338886
## [206,]  0.5213816 -0.85332366
## [207,]  0.5214827 -0.85326188
## [208,]  0.5215785 -0.85320328
## [209,]  0.5208315 -0.85365952
## [210,]  0.5209636 -0.85357888
## [211,]  0.5210892 -0.85350221
## [212,]  0.5212087 -0.85342925
## [213,]  0.5213224 -0.85335979
## [214,]  0.5214307 -0.85329362
## [215,]  0.5215340 -0.85323052
## [216,]  0.5216324 -0.85317033
## [217,]  0.5209185 -0.85360642
## [218,]  0.5210558 -0.85352263
## [219,]  0.5211870 -0.85344251
## [220,]  0.5213125 -0.85336587
## [221,]  0.5214326 -0.85329250
## [222,]  0.5215475 -0.85322223
## [223,]  0.5208134 -0.85367055
## [224,]  0.5209749 -0.85357197
## [225,]  0.5211299 -0.85347735
## [226,]  0.5212787 -0.85338647
## [227,]  0.5214217 -0.85329914
## [228,]  0.5215591 -0.85321516
## [229,]  0.5208647 -0.85363923
## [230,]  0.5210593 -0.85352047
## [231,]  0.5212467 -0.85340603
## [232,]  0.5214274 -0.85329567
```

```
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## [652,] -0.9950682 -0.09919269
## [653,] -0.9950083 -0.09979234
## [654,] -0.9950449 -0.09942670
## [655,] -0.9949776 -0.10009740
## [656,] -0.9950040 -0.09983480
## [657,] -0.9950255 -0.09962009
## [658,] -0.9950413 -0.09946228
## [659,] -0.9950504 -0.09937125
## [660,] -0.9950518 -0.09935777
## [661,] -0.9950442 -0.09943358
## [662,] -0.9950264 -0.09961158
## [663,] -0.9949969 -0.09990587
## [664,] -0.9950523 -0.09935275
```

```
## [665,] -0.9949893 -0.09998183
## [666,] -0.9950016 -0.09985907
## [667,] -0.9949817 -0.10005659
## [668,] -0.9950126 -0.09974895
## [669,] -0.9950678 -0.09919748
## [670,] -0.9949769 -0.10010514
## [671,] -0.9947356 -0.10247522
## [672,] -0.9936611 -0.11241729
## [673,] -0.9926181 -0.12128225
## [674,] -0.9926930 -0.12066706
## [675,] -0.9925905 -0.12150740
## [676,] -0.9926248 -0.12122678
## [677,] -0.9926134 -0.12132007
## [678,] -0.9926522 -0.12100241
## [679,] -0.9926033 -0.12140326
## [680,] -0.9927011 -0.12060100
## [681,] -0.9926981 -0.12062573
## [682,] -0.9925891 -0.12151878
## [683,] -0.9926149 -0.12130817
## [684,] -0.9926504 -0.12101709
## [685,] -0.9926932 -0.12066572
## [686,] -0.9926240 -0.12123382
## [687,] -0.9926810 -0.12076608
## [688,] -0.9926230 -0.12124184
## [689,] -0.9926899 -0.12069311
## [690,] -0.9926413 -0.12109209
## [691,] -0.9925944 -0.12147585
## [692,] -0.9926737 -0.12082581
##
## $cluster
##   [1] 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
##  [38] 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
##  [75] 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
## [112] 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
## [149] 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
## [186] 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
## [223] 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
## [260] 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
## [297] 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
## [334] 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
## [371] 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
## [408] 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
## [445] 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
## [482] 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
## [519] 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 1 1 1 1 1 1 1 1 1 1 1 1
## [556] 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
## [593] 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
## [630] 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
## [667] 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
##
## $modes
##            [,1]       [,2]
## [1,] -0.9940446 -0.1089744
## [2,]  0.5200300 -0.8541480
```

```
## [3,]  0.4639012  0.8858869
##
## $antimodes
## [1]   1 154 350 543 692
##
## $paths
## NULL
##
## $tree
##
## Call:
## hclust(d = acos(1 - 0.5 * dist(y)^2))
##
## Cluster method   : complete
## Distance         : euclidean
## Number of objects: 692
##
##
## $h
## [1] 0.425366
##
## $x
##                [,1]         [,2]
##   [1,] -0.951056516  0.309016994
##   [2,] -0.954099082  0.299491137
##   [3,] -0.957046239  0.289935331
##   [4,] -0.959897692  0.280350531
##   [5,] -0.962653156  0.270737697
##   [6,] -0.965312356  0.261097789
##   [7,] -0.967875025  0.251431772
##   [8,] -0.970340908  0.241740611
##   [9,] -0.972709757  0.232025277
##  [10,] -0.974981336  0.222286740
##  [11,] -0.977155417  0.212525975
##  [12,] -0.979231784  0.202743958
##  [13,] -0.981210229  0.192941666
##  [14,] -0.983090553  0.183120080
##  [15,] -0.984872570  0.173280182
##  [16,] -0.986556099  0.163422957
##  [17,] -0.988140974  0.153549389
##  [18,] -0.989627036  0.143660467
##  [19,] -0.991014136  0.133757178
##  [20,] -0.992302135  0.123840514
##  [21,] -0.993490905  0.113911467
##  [22,] -0.994580326  0.103971028
##  [23,] -0.995570291  0.094020192
##  [24,] -0.996460699  0.084059954
##  [25,] -0.997251462  0.074091310
##  [26,] -0.997942500  0.064115257
##  [27,] -0.998533745  0.054132792
##  [28,] -0.999025138  0.044144915
##  [29,] -0.999416629  0.034152623
##  [30,] -0.999708179  0.024156915
##  [31,] -0.999899759  0.014158792
```

```
##  [32,] -0.999991350  0.004159253
##  [33,] -0.999982943 -0.005840701
##  [34,] -0.999874538 -0.015840072
##  [35,] -0.999666147 -0.025837859
##  [36,] -0.999357790 -0.035833062
##  [37,] -0.998949498 -0.045824682
##  [38,] -0.998441311 -0.055811719
##  [39,] -0.997833282 -0.065793175
##  [40,] -0.997125470 -0.075768052
##  [41,] -0.996317946 -0.085735352
##  [42,] -0.995410791 -0.095694079
##  [43,] -0.994404096 -0.105643236
##  [44,] -0.993297962 -0.115581829
##  [45,] -0.992092498 -0.125508864
##  [46,] -0.990787826 -0.135423348
##  [47,] -0.989384076 -0.145324290
##  [48,] -0.987881389 -0.155210700
##  [49,] -0.986279914 -0.165081589
##  [50,] -0.984579812 -0.174935970
##  [51,] -0.982781253 -0.184772857
##  [52,] -0.980884417 -0.194591267
##  [53,] -0.978889493 -0.204390218
##  [54,] -0.976796680 -0.214168731
##  [55,] -0.974606189 -0.223925826
##  [56,] -0.972318238 -0.233660530
##  [57,] -0.969933057 -0.243371867
##  [58,] -0.967450882 -0.253058867
##  [59,] -0.964871964 -0.262720562
##  [60,] -0.962196559 -0.272355985
##  [61,] -0.959424935 -0.281964173
##  [62,] -0.956557369 -0.291544164
##  [63,] -0.953594149 -0.301095001
##  [64,] -0.950535569 -0.310615729
##  [65,] -0.947381938 -0.320105396
##  [66,] -0.944133568 -0.329563052
##  [67,] -0.940790786 -0.338987752
##  [68,] -0.937353926 -0.348378554
##  [69,] -0.933823331 -0.357734518
##  [70,] -0.930199355 -0.367054710
##  [71,] -0.926482360 -0.376338195
##  [72,] -0.922672717 -0.385584048
##  [73,] -0.918770807 -0.394791342
##  [74,] -0.914777021 -0.403959158
##  [75,] -0.910691759 -0.413086578
##  [76,] -0.906515428 -0.422172689
##  [77,] -0.902248446 -0.431216584
##  [78,] -0.897891240 -0.440217358
##  [79,] -0.893444245 -0.449174110
##  [80,] -0.888907907 -0.458085945
##  [81,] -0.884282679 -0.466951971
##  [82,] -0.879569023 -0.475771303
##  [83,] -0.874767411 -0.484543059
##  [84,] -0.869878324 -0.493266360
##  [85,] -0.864902249 -0.501940335
```

```
##  [86,] -0.859839684 -0.510564117
##  [87,] -0.854691137 -0.519136842
##  [88,] -0.849457120 -0.527657655
##  [89,] -0.844138159 -0.536125702
##  [90,] -0.838734785 -0.544540136
##  [91,] -0.833247538 -0.552900118
##  [92,] -0.827676967 -0.561204809
##  [93,] -0.822023629 -0.569453381
##  [94,] -0.816288089 -0.577645008
##  [95,] -0.810470921 -0.585778871
##  [96,] -0.804572707 -0.593854156
##  [97,] -0.798594036 -0.601870057
##  [98,] -0.792535507 -0.609825771
##  [99,] -0.786397724 -0.617720503
## [100,] -0.780181302 -0.625553463
## [101,] -0.773886863 -0.633323869
## [102,] -0.767515036 -0.641030942
## [103,] -0.761066458 -0.648673914
## [104,] -0.754541774 -0.656252018
## [105,] -0.747941637 -0.663764498
## [106,] -0.741266705 -0.671210601
## [107,] -0.734517648 -0.678589585
## [108,] -0.727695140 -0.685900710
## [109,] -0.720799863 -0.693143245
## [110,] -0.713832506 -0.700316466
## [111,] -0.706793767 -0.707419657
## [112,] -0.699684349 -0.714452106
## [113,] -0.692504963 -0.721413111
## [114,] -0.685256327 -0.728301975
## [115,] -0.677939166 -0.735118009
## [116,] -0.670554212 -0.741860532
## [117,] -0.663102203 -0.748528870
## [118,] -0.655583884 -0.755122355
## [119,] -0.648000007 -0.761640329
## [120,] -0.640351331 -0.768082139
## [121,] -0.632638621 -0.774447142
## [122,] -0.624862647 -0.780734701
## [123,] -0.617024187 -0.786944187
## [124,] -0.609124025 -0.793074979
## [125,] -0.601162952 -0.799126464
## [126,] -0.593141762 -0.805098037
## [127,] -0.585061259 -0.810989102
## [128,] -0.576922251 -0.816799068
## [129,] -0.568725550 -0.822527354
## [130,] -0.560471978 -0.828173389
## [131,] -0.552162358 -0.833736607
## [132,] -0.543797523 -0.839216452
## [133,] -0.535378309 -0.844612376
## [134,] -0.526905557 -0.849923840
## [135,] -0.518380116 -0.855150312
## [136,] -0.509802836 -0.860291269
## [137,] -0.501174577 -0.865346199
## [138,] -0.492496201 -0.870314594
## [139,] -0.483768575 -0.875195958
```

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## [140,] -0.474992573 -0.879989804
## [141,] -0.466169072 -0.884695652
## [142,] -0.457298955 -0.889313030
## [143,] -0.448383108 -0.893841478
## [144,] -0.439422424 -0.898280543
## [145,] -0.430417797 -0.902629780
## [146,] -0.421370129 -0.906888755
## [147,] -0.412280324 -0.911057042
## [148,] -0.403149292 -0.915134224
## [149,] -0.393977945 -0.919119894
## [150,] -0.384767200 -0.923013652
## [151,] -0.375517979 -0.926815110
## [152,] -0.366231207 -0.930523886
## [153,] -0.356907812 -0.934139612
## [154,] -0.347548726 -0.937661924
## [155,] -0.338154886 -0.941090470
## [156,] -0.328727230 -0.944424909
## [157,] -0.319266702 -0.947664905
## [158,] -0.309774248 -0.950810136
## [159,] -0.300250817 -0.953860287
## [160,] -0.290697360 -0.956815053
## [161,] -0.281114835 -0.959674137
## [162,] -0.271504197 -0.962437255
## [163,] -0.261866410 -0.965104131
## [164,] -0.252202437 -0.967674496
## [165,] -0.242513243 -0.970148095
## [166,] -0.232799798 -0.972524680
## [167,] -0.223063073 -0.974804014
## [168,] -0.213304043 -0.976985868
## [169,] -0.203523682 -0.979070024
## [170,] -0.193722969 -0.981056273
## [171,] -0.183902883 -0.982944418
## [172,] -0.174064408 -0.984734270
## [173,] -0.164208526 -0.986425648
## [174,] -0.154336224 -0.988018385
## [175,] -0.144448488 -0.989512321
## [176,] -0.134546307 -0.990907307
## [177,] -0.124630672 -0.992203203
## [178,] -0.114702574 -0.993399879
## [179,] -0.104763005 -0.994497216
## [180,] -0.094812961 -0.995495104
## [181,] -0.084853435 -0.996393444
## [182,] -0.074885424 -0.997192145
## [183,] -0.064909925 -0.997891127
## [184,] -0.054927934 -0.998490321
## [185,] -0.044940451 -0.998989668
## [186,] -0.034948474 -0.999389115
## [187,] -0.024953002 -0.999688625
## [188,] -0.014955035 -0.999888167
## [189,] -0.004955572 -0.999987721
## [190,]  0.005044386 -0.999987277
## [191,]  0.015043840 -0.999886835
## [192,]  0.025041790 -0.999686405
## [193,]  0.035037235 -0.999386008
```

```
## [194,]  0.045029177 -0.998985672
## [195,]  0.055016616 -0.998485439
## [196,]  0.064998553 -0.997885358
## [197,]  0.074973990 -0.997185490
## [198,]  0.084941930 -0.996385903
## [199,]  0.094901376 -0.995486679
## [200,]  0.104851332 -0.994487908
## [201,]  0.114790803 -0.993389688
## [202,]  0.124718795 -0.992192130
## [203,]  0.134634315 -0.990895353
## [204,]  0.144536371 -0.989499488
## [205,]  0.154423975 -0.988004674
## [206,]  0.164296136 -0.986411060
## [207,]  0.174151867 -0.984718806
## [208,]  0.183990183 -0.982928081
## [209,]  0.193810101 -0.981039064
## [210,]  0.203610638 -0.979051944
## [211,]  0.213390814 -0.976966919
## [212,]  0.223149650 -0.974784198
## [213,]  0.232886173 -0.972504000
## [214,]  0.242599406 -0.970126553
## [215,]  0.252288380 -0.967652093
## [216,]  0.261952126 -0.965080869
## [217,]  0.271589676 -0.962413138
## [218,]  0.281200068 -0.959649166
## [219,]  0.290782339 -0.956789230
## [220,]  0.300335533 -0.953833616
## [221,]  0.309858694 -0.950782620
## [222,]  0.319350869 -0.947636546
## [223,]  0.328811109 -0.944395709
## [224,]  0.338238468 -0.941060433
## [225,]  0.347632004 -0.937631052
## [226,]  0.356990777 -0.934107909
## [227,]  0.366313851 -0.930491356
## [228,]  0.375600293 -0.926781754
## [229,]  0.384849177 -0.922979475
## [230,]  0.394059575 -0.919084899
## [231,]  0.403230568 -0.915098415
## [232,]  0.412361239 -0.911020422
## [233,]  0.421450673 -0.906851327
## [234,]  0.430497963 -0.902591549
## [235,]  0.439502203 -0.898241512
## [236,]  0.448462494 -0.893801651
## [237,]  0.457377938 -0.889272411
## [238,]  0.466247645 -0.884654245
## [239,]  0.475070728 -0.879947614
## [240,]  0.483846304 -0.875152989
## [241,]  0.492573496 -0.870270849
## [242,]  0.501251431 -0.865301683
## [243,]  0.509879242 -0.860245987
## [244,]  0.518456064 -0.855104268
## [245,]  0.526981042 -0.849877039
## [246,]  0.535453322 -0.844564823
## [247,]  0.543872057 -0.839168151
```

```
## [248,]  0.552236405 -0.833687563
## [249,]  0.560545530 -0.828123607
## [250,]  0.568798601 -0.822476839
## [251,]  0.576994793 -0.816747825
## [252,]  0.585133285 -0.810937136
## [253,]  0.593213265 -0.805045354
## [254,]  0.601233924 -0.799073068
## [255,]  0.609194460 -0.793020876
## [256,]  0.617094077 -0.786889382
## [257,]  0.624931986 -0.780679200
## [258,]  0.632707401 -0.774390951
## [259,]  0.640419547 -0.768025263
## [260,]  0.648067650 -0.761582773
## [261,]  0.655650948 -0.755064126
## [262,]  0.663168681 -0.748469973
## [263,]  0.670620098 -0.741800973
## [264,]  0.678004453 -0.735057794
## [265,]  0.685321009 -0.728241110
## [266,]  0.692569033 -0.721351603
## [267,]  0.699747801 -0.714389960
## [268,]  0.706856594 -0.707356880
## [269,]  0.713894702 -0.700253064
## [270,]  0.720861422 -0.693079224
## [271,]  0.727756056 -0.685836076
## [272,]  0.734577915 -0.678524345
## [273,]  0.741326317 -0.671144763
## [274,]  0.748000586 -0.663698066
## [275,]  0.754600057 -0.656185000
## [276,]  0.761124068 -0.648606316
## [277,]  0.767571967 -0.640962773
## [278,]  0.773943109 -0.633255133
## [279,]  0.780236858 -0.625484168
## [280,]  0.786452584 -0.617650656
## [281,]  0.792589666 -0.609755379
## [282,]  0.798647489 -0.601799127
## [283,]  0.804625448 -0.593782695
## [284,]  0.810522945 -0.585706886
## [285,]  0.816339390 -0.577572507
## [286,]  0.822074202 -0.569380370
## [287,]  0.827726808 -0.561131297
## [288,]  0.833296641 -0.552826110
## [289,]  0.838783146 -0.544465641
## [290,]  0.844185772 -0.536050727
## [291,]  0.849503981 -0.527582207
## [292,]  0.854737241 -0.519060930
## [293,]  0.859885027 -0.510487748
## [294,]  0.864946825 -0.501863516
## [295,]  0.869922130 -0.493189099
## [296,]  0.874810443 -0.484465364
## [297,]  0.879611276 -0.475693182
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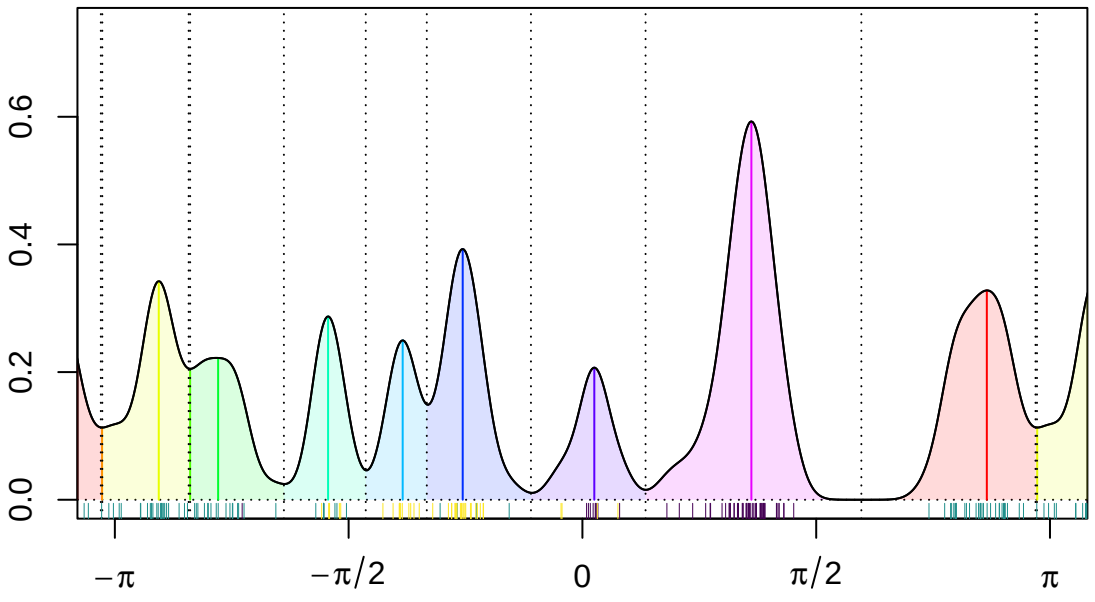
## [688,] -0.963059213 -0.269289717
## [689,] -0.960318208 -0.278906684
## [690,] -0.957481173 -0.288495761
## [691,] -0.954548389 -0.298055989
## [692,] -0.951520152 -0.307586411
##
## $labels_rle
## Run Length Encoding
##   lengths: int [1:4] 154 196 193 149
##   values : int [1:4] 1 2 3 1
```

```
h_rot_up <- bw_kms(fit_2$best_Y, type = "rot_up")
pscsne::plot_kde(x = fit_2$best_Y, h = h_rot_up, init_clusters = original_clusters,
                 step = 0.01, cut_tree = FALSE)
```

```
##   |                                                                      |
```




```
## $end_points
##              [,1]       [,2]
##   [1,] -0.9148243  0.40385217
##   [2,] -0.9145368  0.40450264
##   [3,] -0.9146388  0.40427200
##   [4,] -0.9147346  0.40405514
##   [5,] -0.9148261  0.40384793
##   [6,] -0.9145043  0.40457612
##   [7,] -0.9145795  0.40440625
##   [8,] -0.9146550  0.40423534
##   [9,] -0.9147323  0.40406040
```

```
##  [10,] -0.9148127  0.40387828
##  [11,] -0.9144896  0.40460930
##  [12,] -0.9145680  0.40443215
##  [13,] -0.9146539  0.40423788
##  [14,] -0.9147499  0.40402060
##  [15,] -0.9148595  0.40377227
##  [16,] -0.9145667  0.40443521
##  [17,] -0.9146989  0.40413592
##  [18,] -0.9148642  0.40376157
##  [19,] -0.9146459  0.40425585
##  [20,] -0.9144949  0.40459739
##  [21,] -0.9148333  0.40383166
##  [22,] -0.9145397  0.40449625
##  [23,] -0.9147271  0.40407229
##  [24,] -0.9964607  0.08405995
##  [25,] -0.9568457 -0.29059631
##  [26,] -0.9568786 -0.29048806
##  [27,] -0.9568755 -0.29049849
##  [28,] -0.9569392 -0.29028850
##  [29,] -0.9570397 -0.28995689
##  [30,] -0.9568467 -0.29059314
##  [31,] -0.9568726 -0.29050778
##  [32,] -0.9568611 -0.29054582
##  [33,] -0.9571020 -0.28975120
##  [34,] -0.9570589 -0.28989354
##  [35,] -0.9571156 -0.28970638
##  [36,] -0.9569494 -0.29025466
##  [37,] -0.9569093 -0.29038704
##  [38,] -0.9569383 -0.29029132
##  [39,] -0.9570320 -0.28998217
##  [40,] -0.9568797 -0.29048458
##  [41,] -0.9570326 -0.28998021
##  [42,] -0.9569217 -0.29034602
##  [43,] -0.9568495 -0.29058390
##  [44,] -0.9570414 -0.28995117
##  [45,] -0.9569628 -0.29021055
##  [46,] -0.9569037 -0.29040549
##  [47,] -0.9568577 -0.29055696
##  [48,] -0.9570878 -0.28979827
##  [49,] -0.9570220 -0.29001537
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##  [51,] -0.9569197 -0.29035267
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```

```
##  [64,] -0.9563164 -0.29233364
##  [65,] -0.9561604 -0.29284359
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##  [67,] -0.9562245 -0.29263396
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##  [71,] -0.9561651 -0.29282796
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##  [73,] -0.9562822 -0.29244561
##  [74,] -0.9561937 -0.29273461
##  [75,] -0.9560686 -0.29314289
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##  [77,] -0.9561300 -0.29294272
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##  [79,] -0.9563453 -0.29223904
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##  [83,] -0.8747674 -0.48454306
##  [84,] -0.7932611 -0.60888163
##  [85,] -0.7937345 -0.60826431
##  [86,] -0.7937206 -0.60828251
##  [87,] -0.7933556 -0.60875842
##  [88,] -0.7937096 -0.60829681
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## [118,] -0.7593192 -0.65071834
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## [212,]  0.3547592 -0.93495770
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## [224,]  0.3546408 -0.93500261
## [225,]  0.3544090 -0.93509052
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## [244,]  0.6924929 -0.72142466
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## [247,]  0.6923245 -0.72158631
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## [279,]  0.6939199 -0.72005215
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## [286,]  0.6944167 -0.71957310
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```
## [388,]  0.9967580  0.08045765
## [389,]  0.9967205  0.08092094
## [390,]  0.4237247  0.90579101
## [391,]  0.4240048  0.90565994
## [392,]  0.4237089  0.90579844
## [393,]  0.4243548  0.90549599
## [394,]  0.4241618  0.90558641
## [395,]  0.4240074  0.90565874
## [396,]  0.4238798  0.90571847
## [397,]  0.4237728  0.90576850
## [398,]  0.4245801  0.90539040
## [399,]  0.4244557  0.90544871
## [400,]  0.4243408  0.90550257
## [401,]  0.4242300  0.90555449
## [402,]  0.4241189  0.90560649
## [403,]  0.4240045  0.90566009
## [404,]  0.4238843  0.90571637
## [405,]  0.4237568  0.90577599
## [406,]  0.4244887  0.90543321
## [407,]  0.4242708  0.90553537
## [408,]  0.4240449  0.90564115
## [409,]  0.4238160  0.90574829
## [410,]  0.4244408  0.90545568
## [411,]  0.4241110  0.90561022
## [412,]  0.4238075  0.90575229
## [413,]  0.4243598  0.90549366
## [414,]  0.4240030  0.90566077
## [415,]  0.4237029  0.90580122
## [416,]  0.4242323  0.90555338
## [417,]  0.4239202  0.90569957
## [418,]  0.4245550  0.90540213
## [419,]  0.4242343  0.90555246
## [420,]  0.4239699  0.90567627
## [421,]  0.4237502  0.90577909
## [422,]  0.4244030  0.90547340
## [423,]  0.4241634  0.90558568
## [424,]  0.4239583  0.90568172
## [425,]  0.4237810  0.90576467
## [426,]  0.4244959  0.90542984
## [427,]  0.4242875  0.90552755
## [428,]  0.4241028  0.90561405
## [429,]  0.4239382  0.90569114
## [430,]  0.4237905  0.90576024
## [431,]  0.4245434  0.90540758
## [432,]  0.4243586  0.90549422
## [433,]  0.4241906  0.90557295
## [434,]  0.4240372  0.90564475
## [435,]  0.4238968  0.90571048
## [436,]  0.4237677  0.90577089
## [437,]  0.4245299  0.90541393
## [438,]  0.4243604  0.90549336
## [439,]  0.4242027  0.90556728
## [440,]  0.4240550  0.90563642
## [441,]  0.4239162  0.90570140
```

```
## [442,]  0.4237850  0.90576282
## [443,]  0.4245478  0.90540555
## [444,]  0.4243648  0.90549129
## [445,]  0.4241891  0.90557364
## [446,]  0.4240194  0.90565312
## [447,]  0.4238548  0.90573017
## [448,]  0.4236945  0.90580514
## [449,]  0.4243603  0.90549342
## [450,]  0.4241254  0.90560349
## [451,]  0.4238951  0.90571128
## [452,]  0.4245617  0.90539902
## [453,]  0.4242219  0.90555828
## [454,]  0.4238887  0.90571431
## [455,]  0.4243971  0.90547615
## [456,]  0.4239063  0.90570604
## [457,]  0.4241879  0.90557418
## [458,]  0.4242495  0.90554532
## [459,]  0.4237858  0.90576242
## [460,]  0.4228140  0.90621651
## [461,]  0.4197497  0.90763992
## [462,]  0.4200249  0.90751259
## [463,]  0.4200612  0.90749578
## [464,]  0.4203209  0.90737552
## [465,]  0.4199033  0.90756886
## [466,]  0.4194877  0.90776102
## [467,]  0.4201009  0.90747738
## [468,]  0.4198306  0.90760249
## [469,]  0.4195580  0.90772853
## [470,]  0.4202369  0.90741443
## [471,]  0.4200551  0.90749862
## [472,]  0.4198698  0.90758436
## [473,]  0.4196806  0.90767185
## [474,]  0.4194872  0.90776125
## [475,]  0.4202417  0.90741219
## [476,]  0.4201108  0.90747282
## [477,]  0.4199773  0.90753459
## [478,]  0.4198418  0.90759732
## [479,]  0.4197046  0.90766076
## [480,]  0.4195664  0.90772463
## [481,]  0.4194281  0.90778856
## [482,]  0.4202423  0.90741191
## [483,]  0.4201540  0.90745283
## [484,]  0.4200671  0.90749304
## [485,]  0.4199822  0.90753235
## [486,]  0.4198996  0.90757054
## [487,]  0.4198198  0.90760749
## [488,]  0.4197428  0.90764308
## [489,]  0.4196690  0.90767724
## [490,]  0.4195982  0.90770994
## [491,]  0.4195306  0.90774120
## [492,]  0.4194660  0.90777104
## [493,]  0.4203163  0.90737766
## [494,]  0.4202782  0.90739532
## [495,]  0.4202418  0.90741216
```

```
## [496,]  0.4202071  0.90742824
## [497,]  0.4201739  0.90744361
## [498,]  0.4201422  0.90745829
## [499,]  0.4201118  0.90747235
## [500,]  0.4200827  0.90748581
## [501,]  0.4200549  0.90749870
## [502,]  0.4200282  0.90751107
## [503,]  0.4200025  0.90752295
## [504,]  0.4199779  0.90753435
## [505,]  0.4199542  0.90754532
## [506,]  0.4199314  0.90755587
## [507,]  0.4199094  0.90756604
## [508,]  0.4198882  0.90757584
## [509,]  0.4198677  0.90758531
## [510,]  0.4198479  0.90759447
## [511,]  0.4198287  0.90760335
## [512,]  0.4198101  0.90761197
## [513,]  0.4197920  0.90762036
## [514,]  0.4197743  0.90762854
## [515,]  0.4197570  0.90763654
## [516,]  0.4197400  0.90764438
## [517,]  0.4197233  0.90765209
## [518,]  0.4197069  0.90765969
## [519,]  0.4196907  0.90766720
## [520,]  0.4196746  0.90767463
## [521,]  0.4196586  0.90768202
## [522,]  0.4196427  0.90768938
## [523,]  0.4196268  0.90769674
## [524,]  0.4196108  0.90770413
## [525,]  0.4195945  0.90771164
## [526,]  0.4195777  0.90771944
## [527,]  0.4195591  0.90772802
## [528,]  0.4195361  0.90773865
## [529,]  0.4195015  0.90775465
## [530,]  0.4194370  0.90778445
## [531,]  0.4202497  0.90740852
## [532,]  0.4200746  0.90748959
## [533,]  0.4198032  0.90761514
## [534,]  0.4199324  0.90755536
## [535,] -0.9091079  0.41656068
## [536,] -0.9092073  0.41634375
## [537,] -0.9089077  0.41699744
## [538,] -0.9089781  0.41684378
## [539,] -0.9090112  0.41677161
## [540,] -0.9090279  0.41673527
## [541,] -0.9090381  0.41671305
## [542,] -0.9090457  0.41669638
## [543,] -0.9090523  0.41668201
## [544,] -0.9090584  0.41666871
## [545,] -0.9090642  0.41665604
## [546,] -0.9090698  0.41664380
## [547,] -0.9090753  0.41663190
## [548,] -0.9090806  0.41662029
## [549,] -0.9090858  0.41660892
```

```
## [550,] -0.9090909  0.41659772
## [551,] -0.9090960  0.41658666
## [552,] -0.9091011  0.41657565
## [553,] -0.9091061  0.41656462
## [554,] -0.9091112  0.41655347
## [555,] -0.9091164  0.41654211
## [556,] -0.9091218  0.41653040
## [557,] -0.9091274  0.41651821
## [558,] -0.9091332  0.41650539
## [559,] -0.9091395  0.41649176
## [560,] -0.9091462  0.41647712
## [561,] -0.9091535  0.41646125
## [562,] -0.9091614  0.41644391
## [563,] -0.9091701  0.41642484
## [564,] -0.9091798  0.41640376
## [565,] -0.9091905  0.41638039
## [566,] -0.9092024  0.41635443
## [567,] -0.9092156  0.41632562
## [568,] -0.9092302  0.41629369
## [569,] -0.9088302  0.41716627
## [570,] -0.9088505  0.41712195
## [571,] -0.9088727  0.41707354
## [572,] -0.9088968  0.41702105
## [573,] -0.9089227  0.41696458
## [574,] -0.9089504  0.41690435
## [575,] -0.9089796  0.41684068
## [576,] -0.9090102  0.41677394
## [577,] -0.9090420  0.41670452
## [578,] -0.9090749  0.41663282
## [579,] -0.9091086  0.41655923
## [580,] -0.9091430  0.41648406
## [581,] -0.9091781  0.41640758
## [582,] -0.9092136  0.41633001
## [583,] -0.9088338  0.41715835
## [584,] -0.9088755  0.41706755
## [585,] -0.9089177  0.41697566
## [586,] -0.9089604  0.41688247
## [587,] -0.9090039  0.41678755
## [588,] -0.9090485  0.41669026
## [589,] -0.9090946  0.41658968
## [590,] -0.9091428  0.41648455
## [591,] -0.9091938  0.41637328
## [592,] -0.9088326  0.41716111
## [593,] -0.9089007  0.41701260
## [594,] -0.9089758  0.41684879
## [595,] -0.9090597  0.41666592
## [596,] -0.9091541  0.41645977
## [597,] -0.9088473  0.41712903
## [598,] -0.9089869  0.41682464
## [599,] -0.9091454  0.41647882
## [600,] -0.9089191  0.41697248
## [601,] -0.9091464  0.41647664
## [602,] -0.9089991  0.41679814
## [603,] -0.9088907  0.41703445
```

```
## [604,] -0.9088265  0.41717423
## [605,] -0.9092263  0.41630219
## [606,] -0.9088290  0.41716895
## [607,] -0.9088854  0.41704586
## [608,] -0.9089702  0.41686105
## [609,] -0.9090787  0.41662451
## [610,] -0.9092090  0.41634003
## [611,] -0.9089633  0.41687614
## [612,] -0.9091706  0.41642394
## [613,] -0.9090254  0.41674079
## [614,] -0.9089645  0.41687359
## [615,] -0.9090441  0.41670002
## [616,] -0.9089458  0.41691434
## [617,] -0.9089388  0.41692946
## [618,] -0.9100695  0.41445564
## [619,] -0.9141685  0.40533438
## [620,] -0.9148498  0.40379425
## [621,] -0.9148630  0.40376433
## [622,] -0.9148108  0.40388271
## [623,] -0.9145329  0.40451154
## [624,] -0.9145252  0.40452884
## [625,] -0.9148345  0.40382895
## [626,] -0.9146708  0.40419965
## [627,] -0.9144749  0.40464263
## [628,] -0.9146357  0.40427899
## [629,] -0.9147809  0.40395047
## [630,] -0.9145027  0.40457972
## [631,] -0.9146071  0.40434376
## [632,] -0.9147047  0.40412297
## [633,] -0.9147973  0.40391312
## [634,] -0.9144803  0.40463049
## [635,] -0.9145555  0.40446033
## [636,] -0.9146308  0.40429008
## [637,] -0.9147074  0.40411675
## [638,] -0.9147867  0.40393728
## [639,] -0.9148701  0.40374828
## [640,] -0.9145423  0.40449020
## [641,] -0.9146256  0.40430194
## [642,] -0.9147180  0.40409274
## [643,] -0.9148229  0.40385535
## [644,] -0.9145296  0.40451896
## [645,] -0.9146538  0.40423801
## [646,] -0.9148071  0.40389098
## [647,] -0.9145809  0.40440298
## [648,] -0.9148111  0.40388206
## [649,] -0.9147069  0.40411795
## [650,] -0.9147482  0.40402431
## [651,] -0.9147146  0.40410056
## [652,] -0.9961879  0.08723356
## [653,] -0.9569292 -0.29032137
## [654,] -0.9571106 -0.28972277
## [655,] -0.9570417 -0.28995042
## [656,] -0.9571189 -0.28969532
## [657,] -0.9569041 -0.29040398
```

```
## [658,] -0.9569855 -0.29013560
## [659,] -0.9570439 -0.28994291
## [660,] -0.9570446 -0.28994066
## [661,] -0.9569951 -0.29010424
## [662,] -0.9569490 -0.29025602
## [663,] -0.9569623 -0.29021224
## [664,] -0.9570930 -0.28978089
## [665,] -0.9570031 -0.29007776
## [666,] -0.9570148 -0.29003897
## [667,] -0.9571068 -0.28973550
## [668,] -0.9569181 -0.29035785
## [669,] -0.9570808 -0.28982139
## [670,] -0.9569517 -0.29024709
## [671,] -0.9568695 -0.29051802
## [672,] -0.9570721 -0.28984990
## [673,] -0.9569854 -0.29013623
## [674,] -0.9569208 -0.29034892
## [675,] -0.9568712 -0.29051252
## [676,] -0.9571115 -0.28971980
## [677,] -0.9570416 -0.28995055
## [678,] -0.9569834 -0.29014252
## [679,] -0.9569340 -0.29030559
## [680,] -0.9568911 -0.29044681
## [681,] -0.9568533 -0.29057135
## [682,] -0.9570844 -0.28980939
## [683,] -0.9570167 -0.29003268
## [684,] -0.9569539 -0.29024001
## [685,] -0.9568945 -0.29043579
## [686,] -0.9571237 -0.28967954
## [687,] -0.9570021 -0.29008102
## [688,] -0.9568813 -0.29047918
## [689,] -0.9569534 -0.29024145
## [690,] -0.9570013 -0.29008371
## [691,] -0.9561601 -0.29284445
## [692,] -0.9560912 -0.29306916
##
## $cluster
##   [1]  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  2  3
##  [26]  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3
##  [51]  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3
##  [76]  3  3  3  3  3  3  3  4  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5
## [101]  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5
## [126]  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  6  6  6  6
## [151]  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6
## [176]  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6
## [201]  6  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7
## [226]  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  8  8  8  8  8  8  8  8
## [251]  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8
## [276]  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8
## [301]  8  8  8  8  8  8  8  8  8  8  8  8  9  9  9  9  9  9  9  9  9  9  9  9  9
## [326]  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9
## [351]  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9
## [376]  9  9  9  9  9  9  9  9  9  9  9  9  9  9 10 10 10 10 10 10 10 10 10 10 10
## [401] 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
```

```
## [426] 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
## [451] 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
## [476] 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
## [501] 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
## [526] 10 10 10 10 10 10 10 10 10  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
## [551]  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
## [576]  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
## [601]  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
## [626]  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
## [651]  1  2  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3
## [676]  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3
##
## $modes
##             [,1]        [,2]
##  [1,] -0.9113230  0.41169221
##  [2,] -0.9963256  0.08564686
##  [3,] -0.9567969 -0.29075723
##  [4,] -0.8747674 -0.48454306
##  [5,] -0.7686815 -0.63963175
##  [6,] -0.1375954 -0.99048852
##  [7,]  0.3551677 -0.93480262
##  [8,]  0.6935352 -0.72042272
##  [9,]  0.9968076  0.07984142
## [10,]  0.4219325  0.90662723
##
## $antimodes
##  [1]   1  23  24  82  83 146 201 242 312 389 534 651 652 692
##
## $paths
## NULL
##
## $tree
##
## Call:
## hclust(d = acos(1 - 0.5 * dist(y)^2))
##
## Cluster method   : complete
## Distance         : euclidean
## Number of objects: 692
##
##
## $h
## [1] 0.09324944
##
## $x
##                [,1]         [,2]
##   [1,] -0.951056516  0.309016994
##   [2,] -0.954099082  0.299491137
##   [3,] -0.957046239  0.289935331
##   [4,] -0.959897692  0.280350531
##   [5,] -0.962653156  0.270737697
##   [6,] -0.965312356  0.261097789
##   [7,] -0.967875025  0.251431772
##   [8,] -0.970340908  0.241740611
```

```
##   [9,] -0.972709757  0.232025277
##  [10,] -0.974981336  0.222286740
##  [11,] -0.977155417  0.212525975
##  [12,] -0.979231784  0.202743958
##  [13,] -0.981210229  0.192941666
##  [14,] -0.983090553  0.183120080
##  [15,] -0.984872570  0.173280182
##  [16,] -0.986556099  0.163422957
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## [403,]  0.844990951  0.534780603
## [404,]  0.839600985  0.543203632
## [405,]  0.834127059  0.551572342
## [406,]  0.828569722  0.559885896
## [407,]  0.822929528  0.568143461
## [408,]  0.817207042  0.576344212
## [409,]  0.811402836  0.584487329
## [410,]  0.805517490  0.592571998
## [411,]  0.799551593  0.600597410
## [412,]  0.793505742  0.608562763
## [413,]  0.787380541  0.616467261
## [414,]  0.781176603  0.624310112
## [415,]  0.774894547  0.632090532
## [416,]  0.768535003  0.639807744
## [417,]  0.762098605  0.647460976
## [418,]  0.755585999  0.655049462
## [419,]  0.748997834  0.662572444
## [420,]  0.742334771  0.670029170
## [421,]  0.735597474  0.677418892
## [422,]  0.728786619  0.684740874
## [423,]  0.721902885  0.691994382
## [424,]  0.714946962  0.699178691
## [425,]  0.707919544  0.706293083
## [426,]  0.700821336  0.713336846
## [427,]  0.693653045  0.720309276
## [428,]  0.686415390  0.727209675
## [429,]  0.679109094  0.734037355
## [430,]  0.671734888  0.740791631
## [431,]  0.664293508  0.747471829
## [432,]  0.656785700  0.754077280
## [433,]  0.649212214  0.760607324
## [434,]  0.641573807  0.767061308
## [435,]  0.633871244  0.773438586
## [436,]  0.626105293  0.779738521
## [437,]  0.618276733  0.785960483
## [438,]  0.610386346  0.792103850
## [439,]  0.602434920  0.798168007
## [440,]  0.594423252  0.804152347
```

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## [441,]  0.586352141  0.810056274
## [442,]  0.578222396  0.815879195
## [443,]  0.570034829  0.821620529
## [444,]  0.561790260  0.827279701
## [445,]  0.553489511  0.832856147
## [446,]  0.545133414  0.838349307
## [447,]  0.536722804  0.843758633
## [448,]  0.528258523  0.849083584
## [449,]  0.519741416  0.854323628
## [450,]  0.511172335  0.859478239
## [451,]  0.502552138  0.864546904
## [452,]  0.493881685  0.869529115
## [453,]  0.485161845  0.874424373
## [454,]  0.476393489  0.879232190
## [455,]  0.467577494  0.883952084
## [456,]  0.458714742  0.888583584
## [457,]  0.449806119  0.893126226
## [458,]  0.440852515  0.897579556
## [459,]  0.431854827  0.901943129
## [460,]  0.422813953  0.906216509
## [461,]  0.413730799  0.910399267
## [462,]  0.404606272  0.914490987
## [463,]  0.395441284  0.918491258
## [464,]  0.386236753  0.922399681
## [465,]  0.376993598  0.926215864
## [466,]  0.367712744  0.929939427
## [467,]  0.358395119  0.933569997
## [468,]  0.349041655  0.937107210
## [469,]  0.339653287  0.940550713
## [470,]  0.330230954  0.943900162
## [471,]  0.320775599  0.947155222
## [472,]  0.311288166  0.950315568
## [473,]  0.301769604  0.953380882
## [474,]  0.292220866  0.956350859
## [475,]  0.282642906  0.959225202
## [476,]  0.273036682  0.962003623
## [477,]  0.263403154  0.964685844
## [478,]  0.253743286  0.967271598
## [479,]  0.244058044  0.969760626
## [480,]  0.234348397  0.972152678
## [481,]  0.224615315  0.974447515
## [482,]  0.214859772  0.976644909
## [483,]  0.205082742  0.978744639
## [484,]  0.195285205  0.980746496
## [485,]  0.185468139  0.982650278
## [486,]  0.175632527  0.984455797
## [487,]  0.165779352  0.986162870
## [488,]  0.155909598  0.987771328
## [489,]  0.146024254  0.989281010
## [490,]  0.136124308  0.990691765
## [491,]  0.126210749  0.992003451
## [492,]  0.116284569  0.993215938
## [493,]  0.106346761  0.994329104
## [494,]  0.096398319  0.995342837
```

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## [495,]  0.086440237  0.996257038
## [496,]  0.076473510  0.997071613
## [497,]  0.066499137  0.997786483
## [498,]  0.056518113  0.998401574
## [499,]  0.046531438  0.998916826
## [500,]  0.036540110  0.999332187
## [501,]  0.026545127  0.999647616
## [502,]  0.016547490  0.999863081
## [503,]  0.006548199  0.999978560
## [504,] -0.003451747  0.999994043
## [505,] -0.013451349  0.999909527
## [506,] -0.023449605  0.999725020
## [507,] -0.033445516  0.999440542
## [508,] -0.043438082  0.999056121
## [509,] -0.053426305  0.998571795
## [510,] -0.063409185  0.997987613
## [511,] -0.073385725  0.997303633
## [512,] -0.083354926  0.996519923
## [513,] -0.093315791  0.995636562
## [514,] -0.103267325  0.994653638
## [515,] -0.113208532  0.993571250
## [516,] -0.123138419  0.992389505
## [517,] -0.133055992  0.991108522
## [518,] -0.142960259  0.989728430
## [519,] -0.152850230  0.988249365
## [520,] -0.162724917  0.986671476
## [521,] -0.172583331  0.984994921
## [522,] -0.182424487  0.983219867
## [523,] -0.192247400  0.981346492
## [524,] -0.202051090  0.979374983
## [525,] -0.211834574  0.977305537
## [526,] -0.221596875  0.975138362
## [527,] -0.231337016  0.972873674
## [528,] -0.241054024  0.970511699
## [529,] -0.250746926  0.968052674
## [530,] -0.260414754  0.965496844
## [531,] -0.270056541  0.962844465
## [532,] -0.279671323  0.960095803
## [533,] -0.289258137  0.957251132
## [534,] -0.298816026  0.954310737
## [535,] -0.308344034  0.951274911
## [536,] -0.317841208  0.948143959
## [537,] -0.327306597  0.944918193
## [538,] -0.336739256  0.941597936
## [539,] -0.346138242  0.938183520
## [540,] -0.355502614  0.934675287
## [541,] -0.364831436  0.931073586
## [542,] -0.374123775  0.927378779
## [543,] -0.383378703  0.923591236
## [544,] -0.392595292  0.919711333
## [545,] -0.401772623  0.915739461
## [546,] -0.410909776  0.911676015
## [547,] -0.420005839  0.907521402
## [548,] -0.429059902  0.903276038
```

```
## [549,] -0.438071059  0.898940347
## [550,] -0.447038409  0.894514763
## [551,] -0.455961056  0.889999728
## [552,] -0.464838107  0.885395694
## [553,] -0.473668675  0.880703121
## [554,] -0.482451876  0.875922478
## [555,] -0.491186832  0.871054244
## [556,] -0.499872670  0.866098905
## [557,] -0.508508522  0.861056957
## [558,] -0.517093523  0.855928904
## [559,] -0.525626814  0.850715259
## [560,] -0.534107544  0.845416543
## [561,] -0.542534863  0.840033286
## [562,] -0.550907930  0.834566027
## [563,] -0.559225906  0.829015311
## [564,] -0.567487960  0.823381695
## [565,] -0.575693265  0.817665741
## [566,] -0.583841002  0.811868022
## [567,] -0.591930355  0.805989116
## [568,] -0.599960516  0.800029612
## [569,] -0.607930681  0.793990105
## [570,] -0.615840053  0.787871201
## [571,] -0.623687842  0.781673510
## [572,] -0.631473263  0.775397652
## [573,] -0.639195537  0.769044255
## [574,] -0.646853891  0.762613954
## [575,] -0.654447561  0.756107393
## [576,] -0.661975787  0.749525221
## [577,] -0.669437816  0.742868098
## [578,] -0.676832902  0.736136688
## [579,] -0.684160304  0.729331665
## [580,] -0.691419292  0.722453710
## [581,] -0.698609138  0.715503510
## [582,] -0.705729124  0.708481760
## [583,] -0.712778537  0.701389163
## [584,] -0.719756673  0.694226427
## [585,] -0.726662834  0.686994269
## [586,] -0.733496329  0.679693412
## [587,] -0.740256476  0.672324587
## [588,] -0.746942597  0.664888530
## [589,] -0.753554025  0.657385984
## [590,] -0.760090098  0.649817700
## [591,] -0.766550162  0.642184435
## [592,] -0.772933572  0.634486953
## [593,] -0.779239690  0.626726022
## [594,] -0.785467884  0.618902419
## [595,] -0.791617532  0.611016926
## [596,] -0.797688019  0.603070332
## [597,] -0.803678737  0.595063431
## [598,] -0.809589089  0.586997025
## [599,] -0.815418482  0.578871919
## [600,] -0.821166334  0.570688927
## [601,] -0.826832070  0.562448866
## [602,] -0.832415124  0.554152561
```

```
## [603,] -0.837914937  0.545800841
## [604,] -0.843330959  0.537394542
## [605,] -0.848662649  0.528934503
## [606,] -0.853909473  0.520421572
## [607,] -0.859070907  0.511856598
## [608,] -0.864146434  0.503240440
## [609,] -0.869135548  0.494573958
## [610,] -0.874037748  0.485858019
## [611,] -0.878852546  0.477093494
## [612,] -0.883579459  0.468281261
## [613,] -0.888218015  0.459422200
## [614,] -0.892767750  0.450517197
## [615,] -0.897228209  0.441567142
## [616,] -0.901598946  0.432572931
## [617,] -0.905879523  0.423535464
## [618,] -0.910069514  0.414455643
## [619,] -0.914168498  0.405334377
## [620,] -0.918176066  0.396172578
## [621,] -0.922091818  0.386971162
## [622,] -0.925915361  0.377731049
## [623,] -0.929646313  0.368453163
## [624,] -0.933284301  0.359138432
## [625,] -0.936828962  0.349787788
## [626,] -0.940279940  0.340402165
## [627,] -0.943636891  0.330982503
## [628,] -0.946899480  0.321529742
## [629,] -0.950067379  0.312044829
## [630,] -0.953140272  0.302528711
## [631,] -0.956117852  0.292982341
## [632,] -0.958999822  0.283406673
## [633,] -0.961785891  0.273802664
## [634,] -0.964475784  0.264171276
## [635,] -0.967069229  0.254513470
## [636,] -0.969565968  0.244830213
## [637,] -0.971965752  0.235122474
## [638,] -0.974268339  0.225391222
## [639,] -0.976473501  0.215637432
## [640,] -0.978581016  0.205862078
## [641,] -0.980590674  0.196066138
## [642,] -0.982502273  0.186250591
## [643,] -0.984315624  0.176416420
## [644,] -0.986030543  0.166564607
## [645,] -0.987646860  0.156696138
## [646,] -0.989164414  0.146811999
## [647,] -0.990583051  0.136913179
## [648,] -0.991902631  0.127000668
## [649,] -0.993123022  0.117075457
## [650,] -0.994244102  0.107138539
## [651,] -0.995265757  0.097190906
## [652,] -0.996187887  0.087233555
## [653,] -0.997010399  0.077267481
## [654,] -0.997733211  0.067293680
## [655,] -0.998356251  0.057313149
## [656,] -0.998879455  0.047326887
```

```
## [657,] -0.999302772  0.037335893
## [658,] -0.999626160  0.027341165
## [659,] -0.999849587  0.017343703
## [660,] -0.999973029  0.007344507
## [661,] -0.999996474 -0.002655424
## [662,] -0.999919921 -0.012655090
## [663,] -0.999743377 -0.022653489
## [664,] -0.999466859 -0.032649624
## [665,] -0.999090395 -0.042642493
## [666,] -0.998614023 -0.052631099
## [667,] -0.998037791 -0.062614441
## [668,] -0.997361755 -0.072591522
## [669,] -0.996585985 -0.082561344
## [670,] -0.995710556 -0.092522909
## [671,] -0.994735557 -0.102475223
## [672,] -0.993661086 -0.112417289
## [673,] -0.992487249 -0.122348113
## [674,] -0.991214164 -0.132266703
## [675,] -0.989841959 -0.142172066
## [676,] -0.988370770 -0.152063212
## [677,] -0.986800745 -0.161939152
## [678,] -0.985132041 -0.171798898
## [679,] -0.983364825 -0.181641465
## [680,] -0.981499272 -0.191465867
## [681,] -0.979535571 -0.201271123
## [682,] -0.977473917 -0.211056252
## [683,] -0.975314516 -0.220820276
## [684,] -0.973057585 -0.230562217
## [685,] -0.970703349 -0.240281103
## [686,] -0.968252043 -0.249975961
## [687,] -0.965703913 -0.259645821
## [688,] -0.963059213 -0.269289717
## [689,] -0.960318208 -0.278906684
## [690,] -0.957481173 -0.288495761
## [691,] -0.954548389 -0.298055989
## [692,] -0.951520152 -0.307586411
##
## $labels_rle
## Run Length Encoding
##   lengths: int [1:13] 23 1 58 1 63 55 41 70 77 145 ...
##   values : int [1:13] 1 2 3 4 5 6 7 8 9 10 ...
```

The results are similar to those one obtained above: classification rate of 89.47% and 20 observations wrongly classified.