01. Introduction to the PIC simulation

02. Random number generation and its application

03. Particle weighting and normalization

04. Particle pusher

05. Poisson's equation

06. One-dimensional electrostatic PIC code

07. Numerical tips and tricks in PIC simulations

Particle-in-Cell (PIC) kinetic simulations
08. Visualization

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University of São Paulo, 2019.11.25-12.06

www.slido.com code: #B194

Grid data? Particle data?

4 field data for 512 girds: ~19KB (position, charge density, electric potential, electric field)

position and velocity data for 16384 particles: ~350 KB

FT10000 - 記事本

檔案(F) 編輯(E) 格式(O) 檢視(V) 說明(H)

```
1. -18.785973 0.09905946 -0.025676806
2. -11.101639 0.05135361 0.091071546
3. -11.673347 -0.08308364 0.18003662
4. -10.099533 -0.30871964 0.26508686
5. -2.8517303 -0.61325735 0.31567755
6. -9.3025055 -0.94007474 0.36315468
7. -4.427788 -1.3395667 0.41678944
8. 4.0066147 -1.7736536 0.41843486
9. 5.478752 -2.1764364 0.38138193
10. -11.15918 -2.5364175 0.4035709
11. 13.998161 -2.9835782 0.39248133
12. -1.8151474 -3.3213801 0.34489298
13. 3.0695267 -3.6733642 0.33999205
14. 0.80976105 -4.001364 0.32483792
15. 2.4582672 -4.32304 0.31207228
16. -8.019768 -4.625509 0.33379626
17. -2.4197235 -4.9906325 0.37457657
18. -12.882652 -5.374662 0.43435073
19. 4.919792 -5.859334 0.465456
20. 12.065071 -6.305574 0.3991084
21. 9.150169 -6.657551 0.3162365
22. 4.3674774 -6.938047 0.26343584
23. 13.9928055 -7.1844225 0.19171405
24. 11.490707 -7.321475 0.09217024
25. -8.301613 -7.368763 0.079713345
26. -10.930321 -7.4809017 0.15483451
27. 3.7501755 -7.678432 0.18288326
28. 16.054672 -7.8466682 0.10552287
29. -14.930031 -7.8894777 0.101129055
30. 5.575203 -8.048926 0.13767195
31. 4.781624 -8.164822 0.09721422
32. -0.84490204 -8.243355 0.08184004
33. -1.6359329 -8.328502 0.091528416
34. 10.967194 -8.426412 0.05507183
```

PET10000 - 記事本

檔案(F) 編輯(E) 格式(O) 檢視(V) 說明(H)

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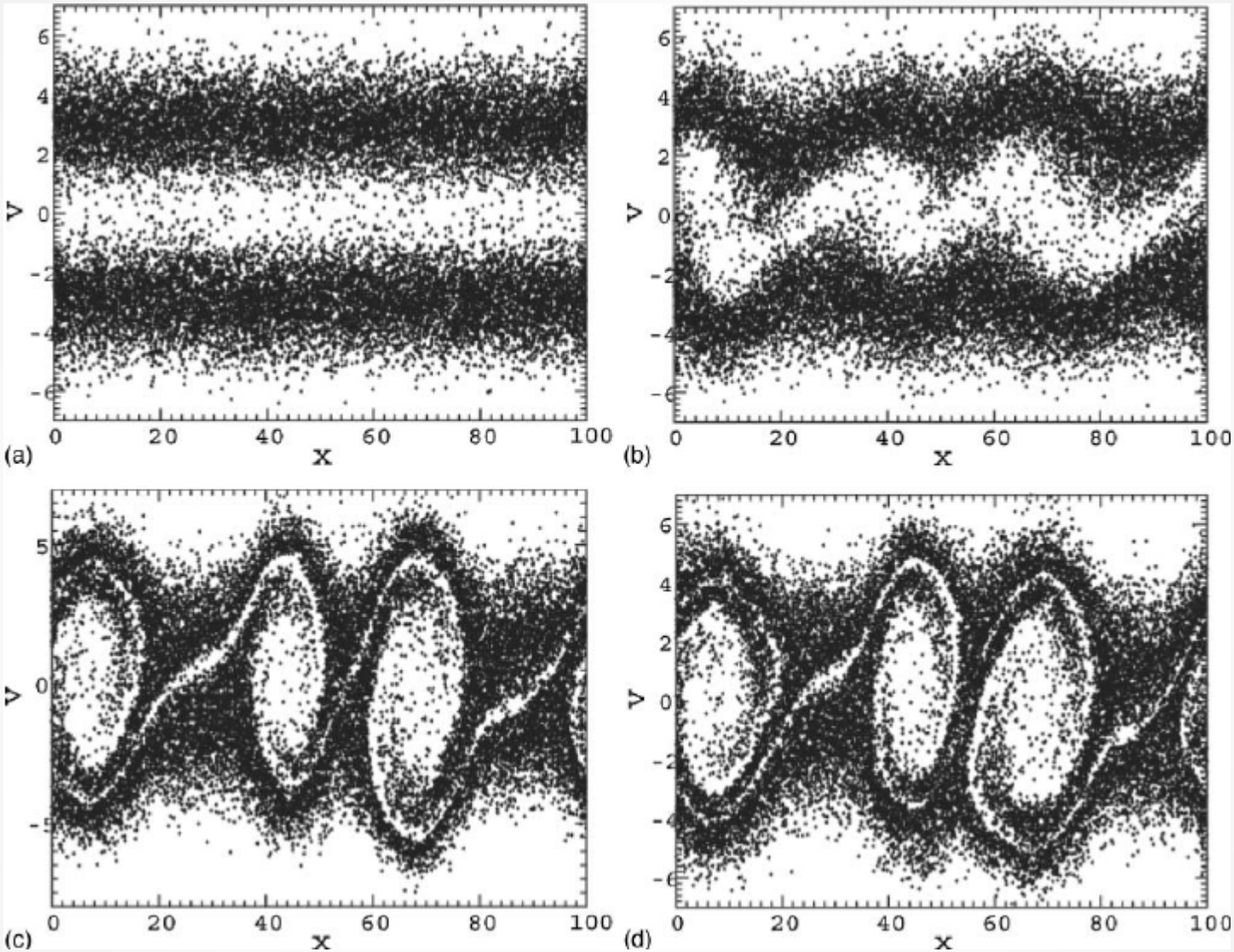
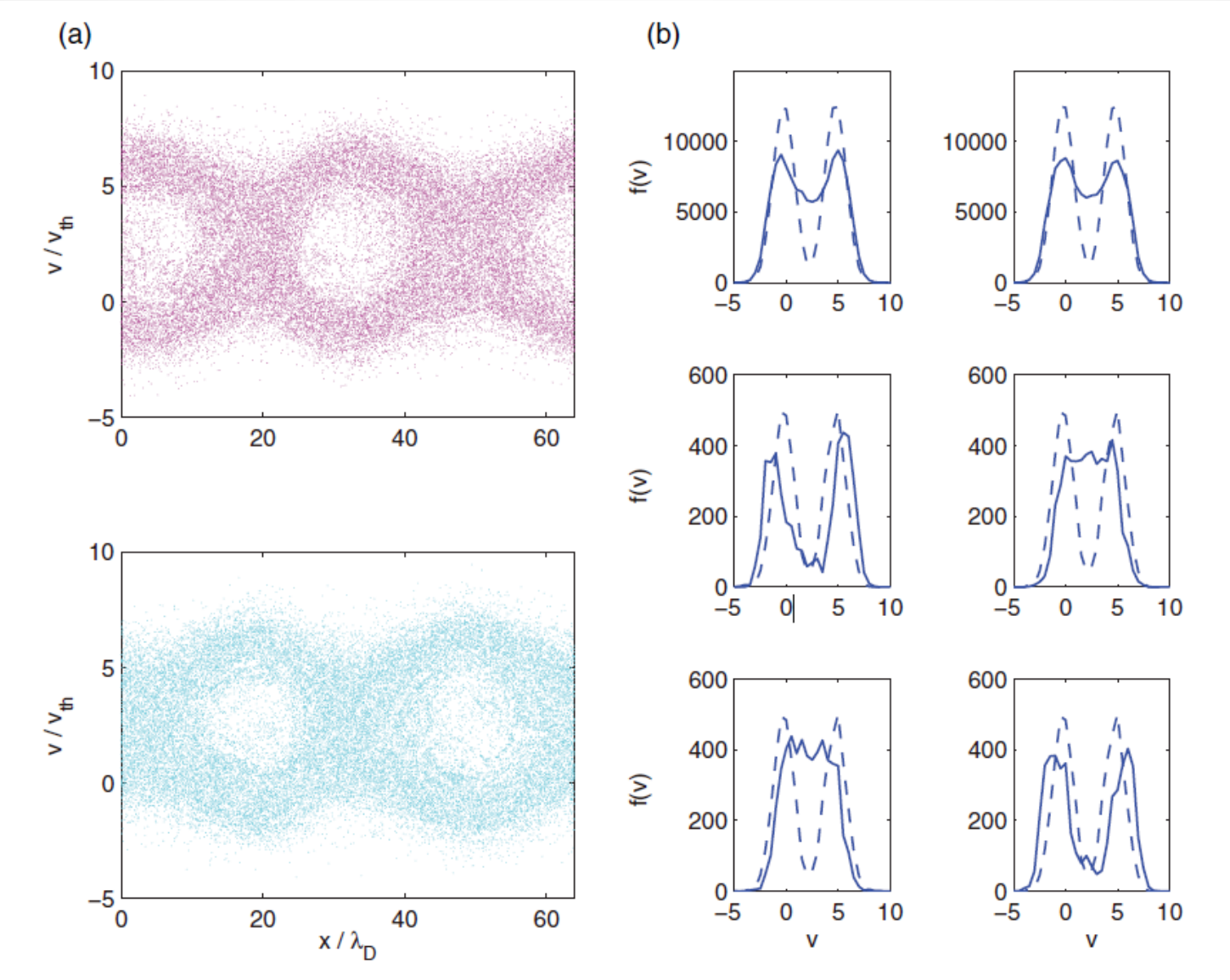
110.954926 4.8420444
82.89475 4.971293
111.9092 6.0639706
124.39214 6.331952
56.316177 6.2354894
60.567738 5.0892954
1.1126056 6.1900654
93.09318 4.5976157
69.45339 5.062493
58.1951 4.8294253
47.18144 4.539171
38.70396 5.685086
124.60518 5.756644
75.73011 3.4201784
9.727312 4.408493
54.53315 4.8272014
51.46079 4.664064
13.238763 4.134509
113.99179 5.2985806
33.21238 5.929594
108.79333 5.6589217
104.46534 6.167946
41.94589 4.593159
43.97585 5.124974
33.13078 4.784654
67.195786 3.660469
125.252914 3.7895157
66.66894 6.0047874
97.37988 3.731464
68.91275 4.9103494
87.95576 5.099932
16.745125 5.5878186
103.50659 4.3382845
27.621367 5.839361
```

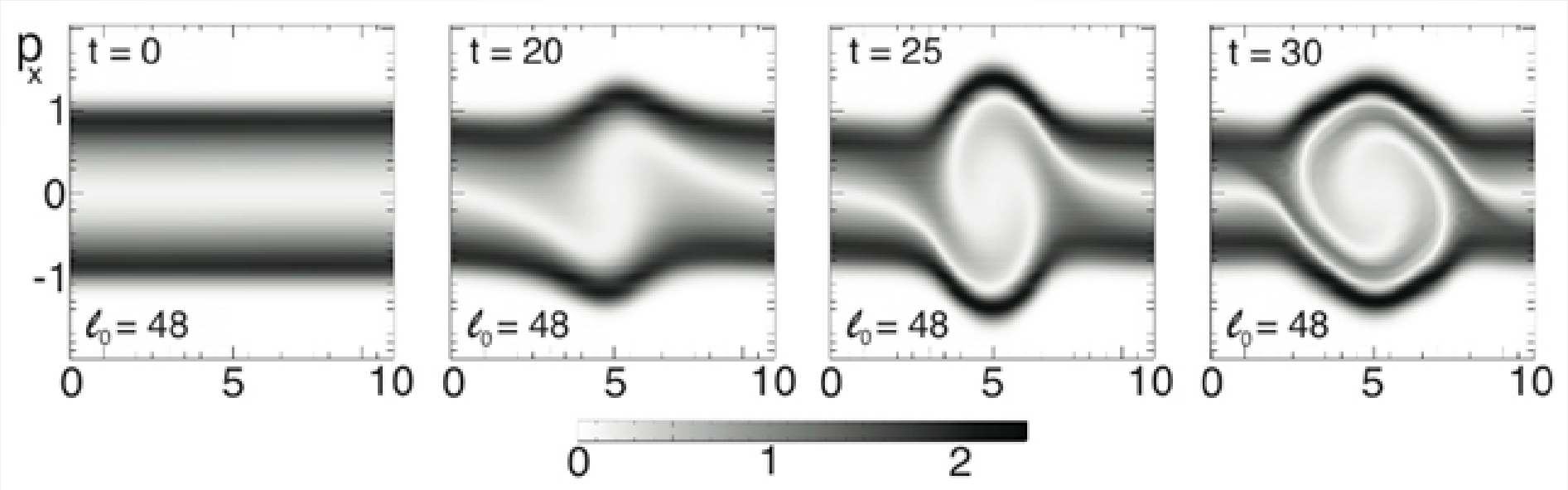
Phase space



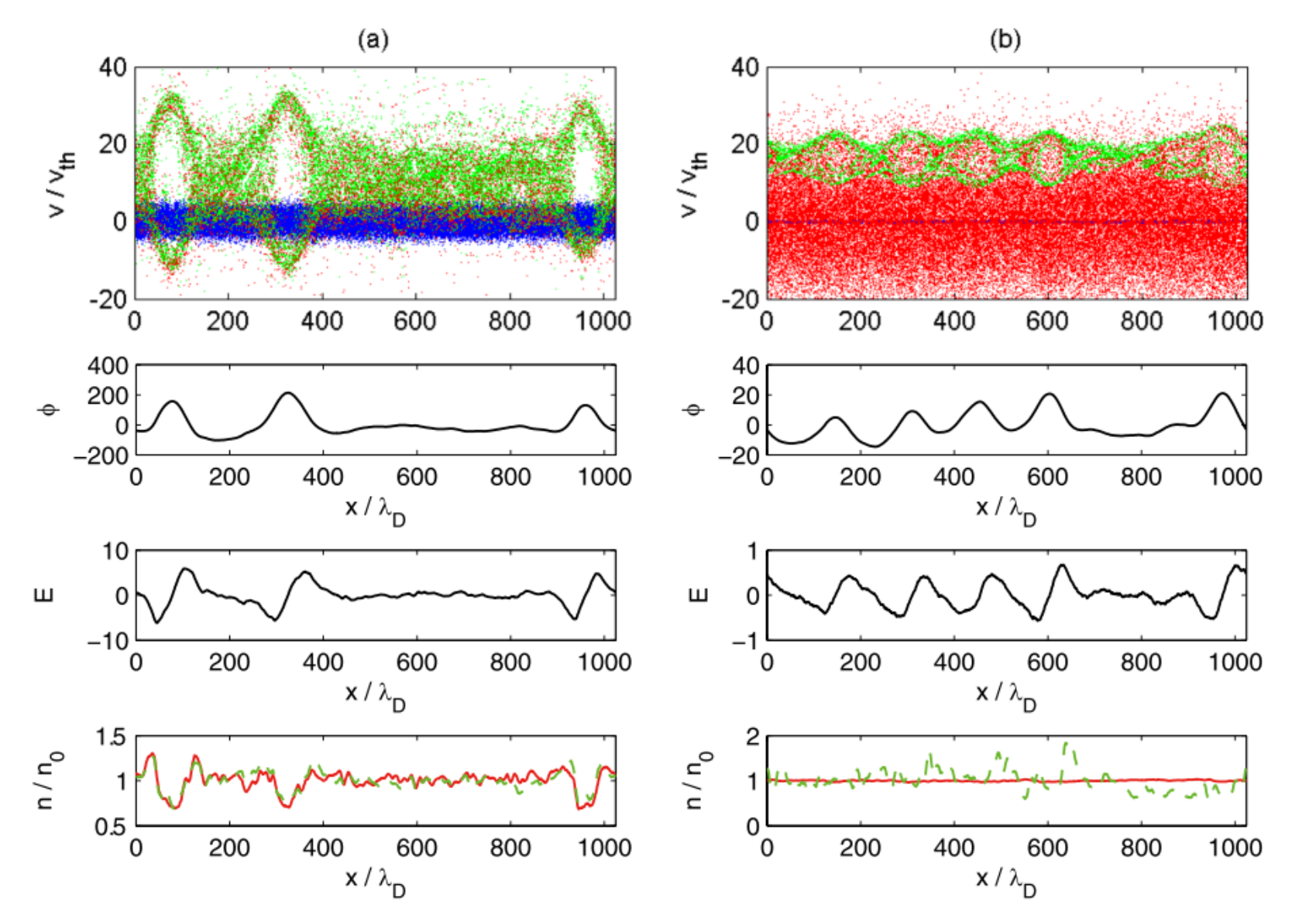
Velocity distribution (total/local)



Phase space



Field data



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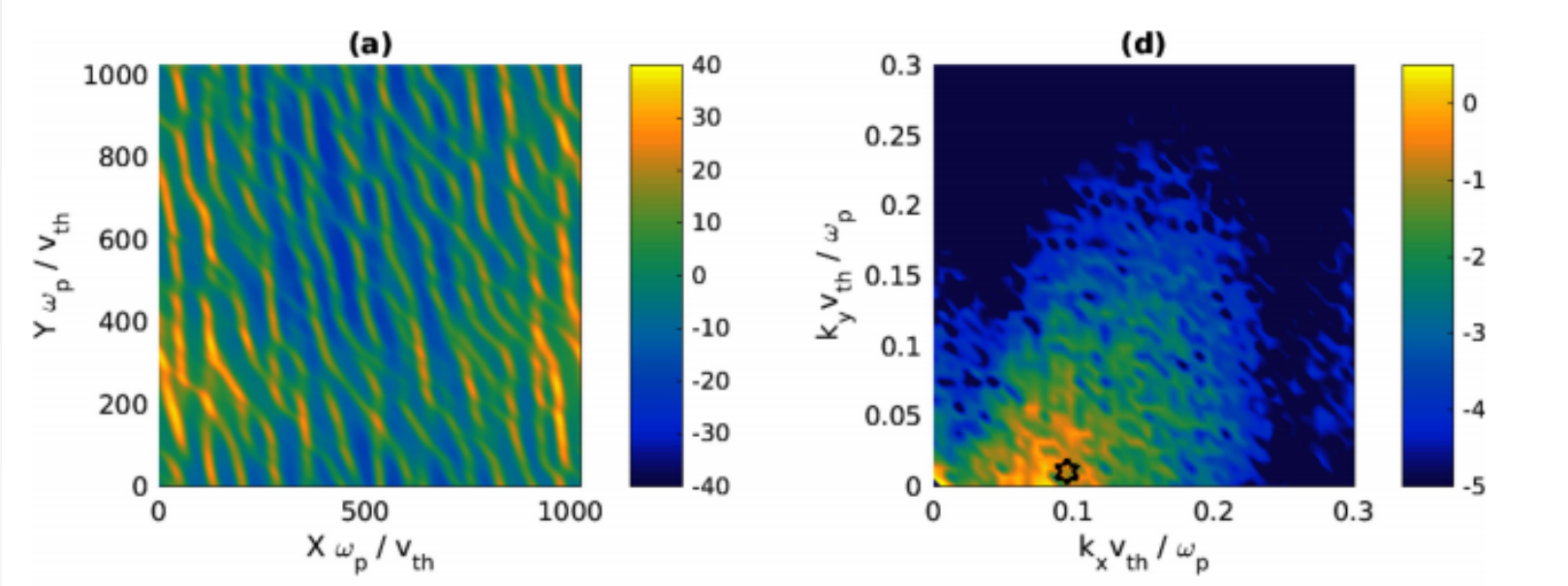
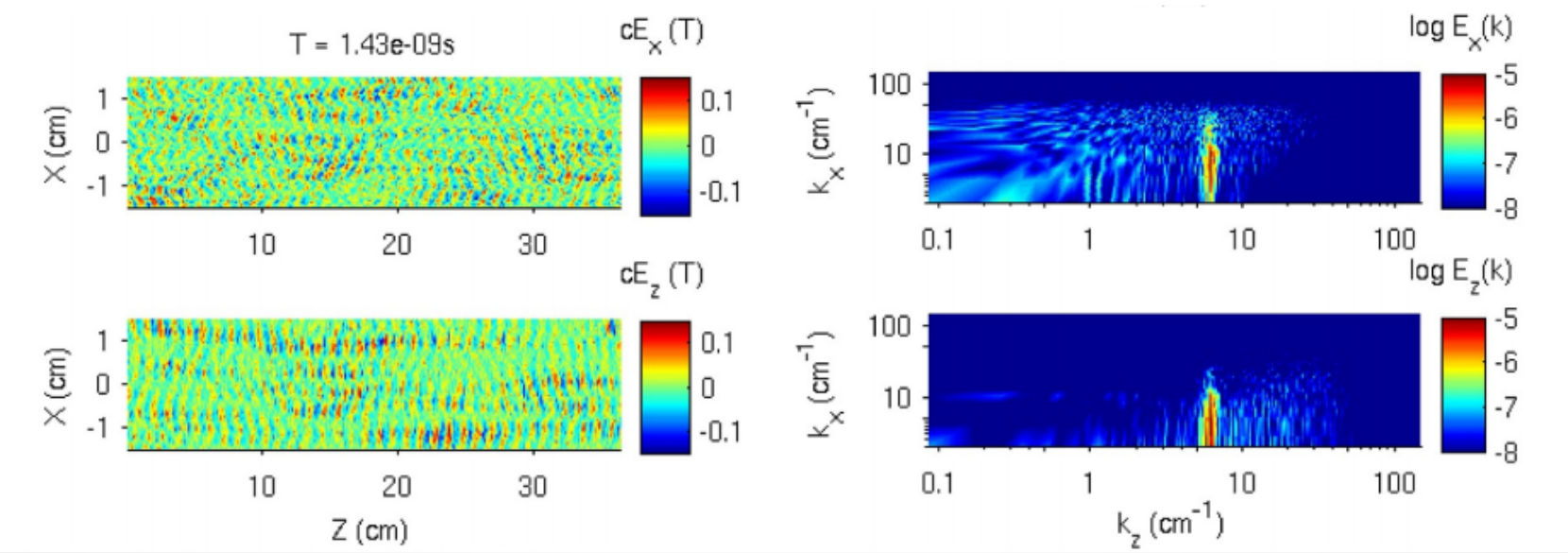
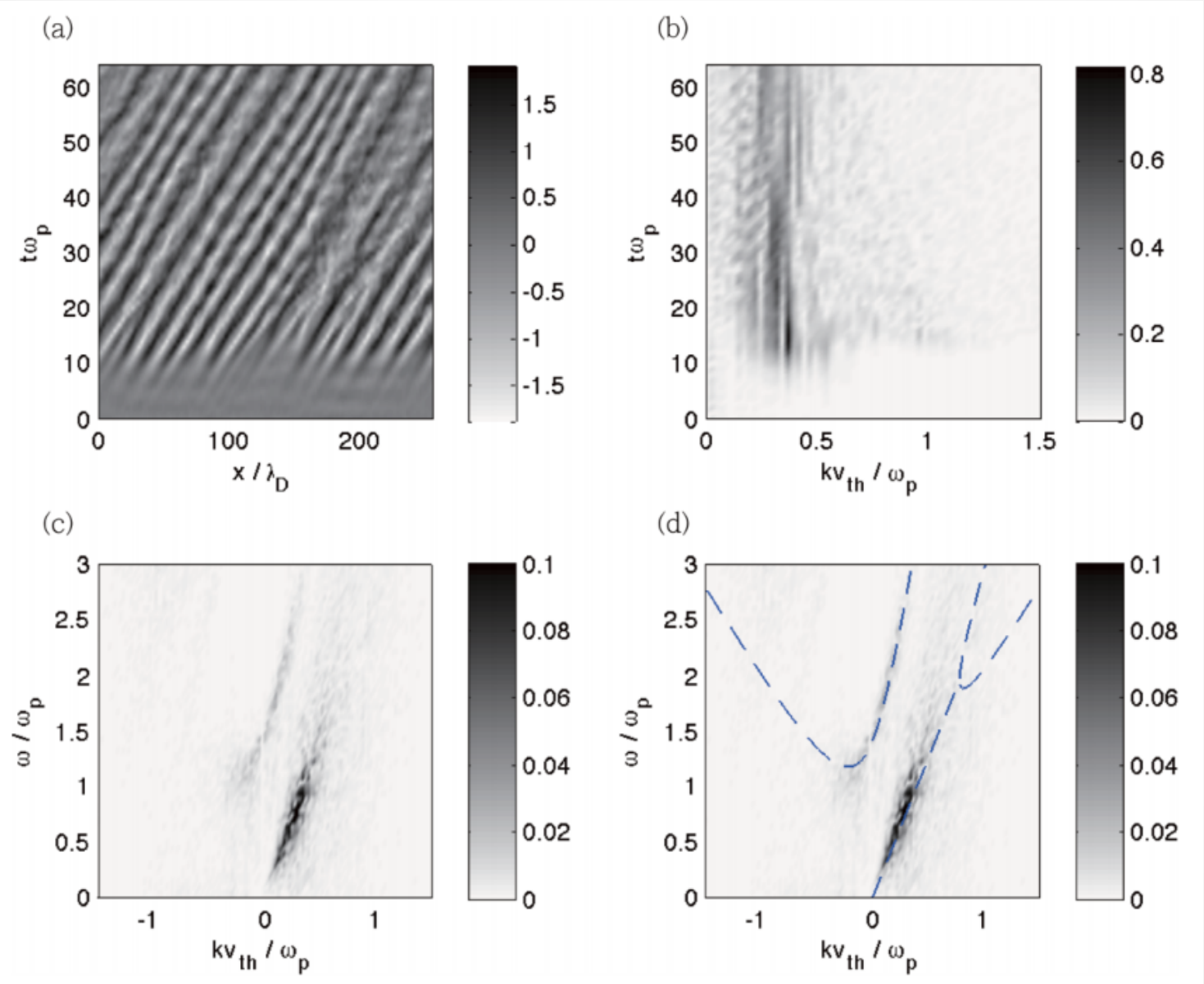
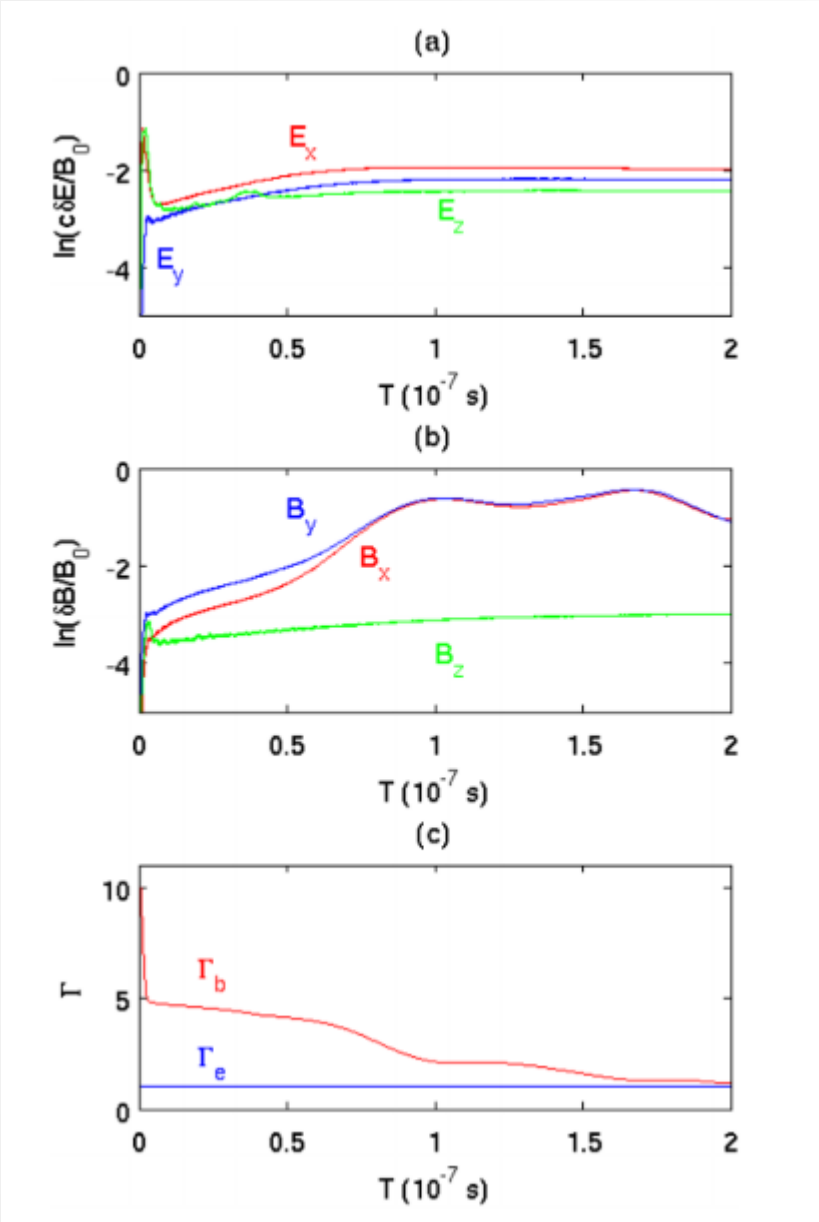

(a)
Y ωp / vth
X ωp / vth
(d)
ky vth / ωp
kx vth / ωp

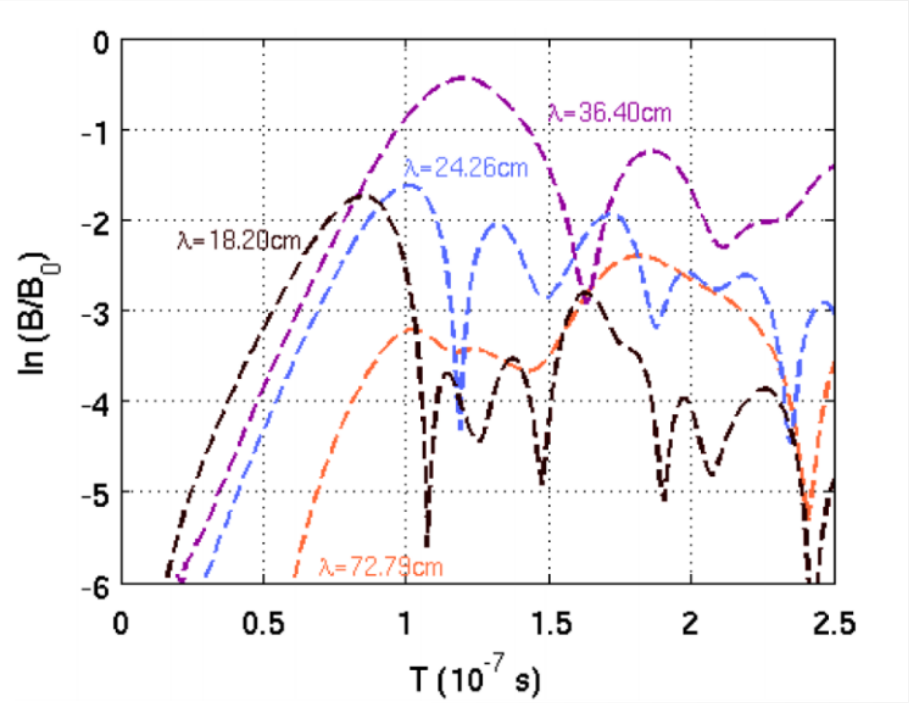

T = 1.43e-09s
cEx (T)
X (cm)
cEz (T)
Z (cm)
log Ex(k)
log Ez(k)
kx (cm-1)
kz (cm-1)

Field data



Field data


(a)
ln(cδE/B0)
Ex
Ey
Ez
T (10-7 s)
(b)
ln(δB/B0)
By
Bx
Bz
T (10-7 s)
(c)
Γ
Γb
Γe
T (10-7 s)


ln (B/B0)
λ=36.40cm
λ=24.26cm
λ=18.20cm
λ=72.79cm
T (10-7 s)

Visualization: hand on

1. Lx =128, Δx = 1, NX = 128, Δt = 0.01, NT = 25600

2. EF = 0, BF=0 field and B field on the grid.

3. Give the position and the velocity to all particles at T = 0.

Ion: m = 1836, e = 1, vdx = 0.0, vdy = vdz = 0.0, vthx = vthy = vthz = 0.1, NP = 128*128, uniform distribution
electron1: m = 1 , e = -1, vdx = 5.0, vdy = vdz = 0.0, vthx = vthy = vthz = 1.0, NP = 64*128, uniform distribution
electron2: m = 1 , e = -1, vdx = -5.0, vdy = vdz = 0.0, vthx = vthy = vthz = 1.0, NP = 64*128, uniform distribution
ε_0 = ??

Example:07_01_initial_withBug

Visualization: hand on

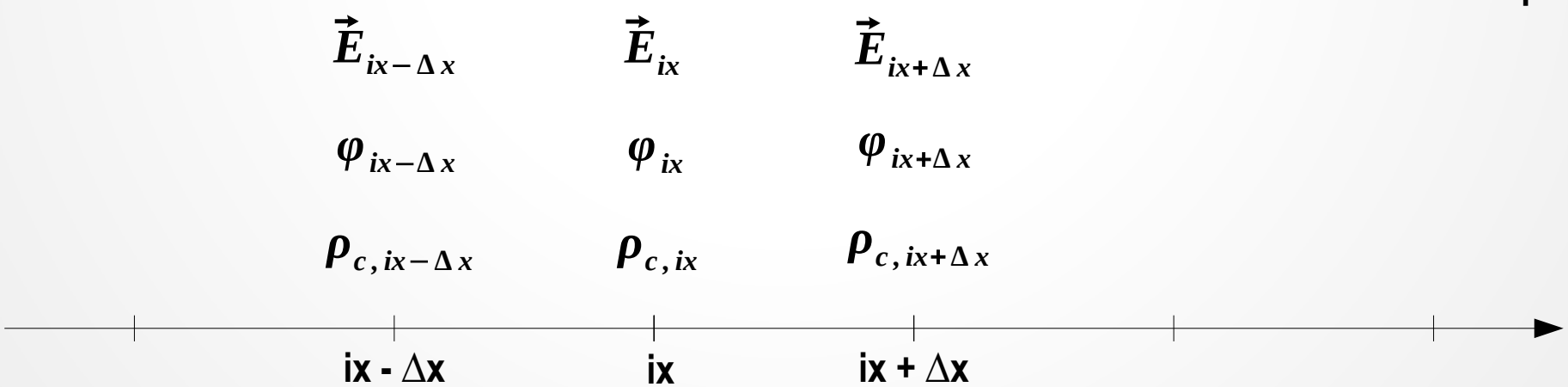
$$-\nabla^2 \varphi = \frac{\rho_c}{\varepsilon_0}$$

$$\vec{E} = -\nabla \varphi$$

$$\frac{\vec{\varphi}_{ix+\Delta x} - 2\vec{\varphi}_{ix} + \vec{\varphi}_{ix-\Delta x}}{(\Delta x)^2} = -\frac{\rho_{c,ix}}{\varepsilon_0}$$

$$\vec{E}_{ix} = \frac{-\vec{\varphi}_{ix+\Delta x} + \vec{\varphi}_{ix-\Delta x}}{2\Delta x}$$

At each time step



Visualization: hand on

$$-\nabla^2 \varphi = \frac{\rho_c}{\varepsilon_0}$$

$$\vec{\varphi}_{ix+\Delta x} - 2\vec{\varphi}_{ix} + \vec{\varphi}_{ix-\Delta x} = -(\Delta x)^2 \frac{\rho_{c,ix}}{\varepsilon_0}$$

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -2 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & -2 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -2 & 1 & 0 & 0 & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & 0 & 0 & 1 & -2 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \varphi_0 \\ \varphi_1 \\ \varphi_2 \\ \varphi_3 \\ .. \\ \varphi_{NX-1} \\ \varphi_{NX} \end{bmatrix} = \frac{-(\Delta x)^2}{\varepsilon_0} \begin{bmatrix} 0 \\ \rho_{c,1} \\ \rho_{c,2} \\ \rho_{c,3} \\ .. \\ \rho_{c,NX-1} \\ 0 \end{bmatrix}$$

$$A\varphi = w \qquad \varphi = A^{-1} w$$

inverse matrix

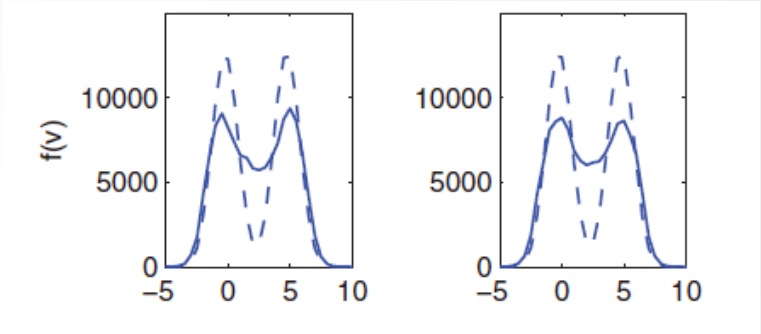
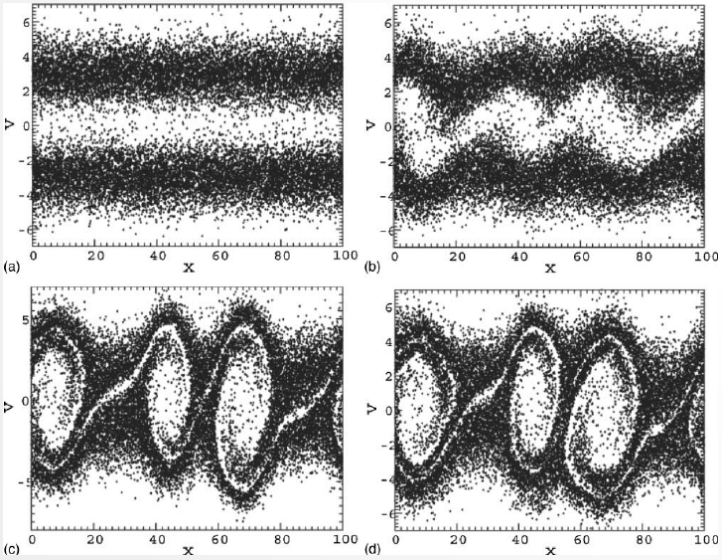
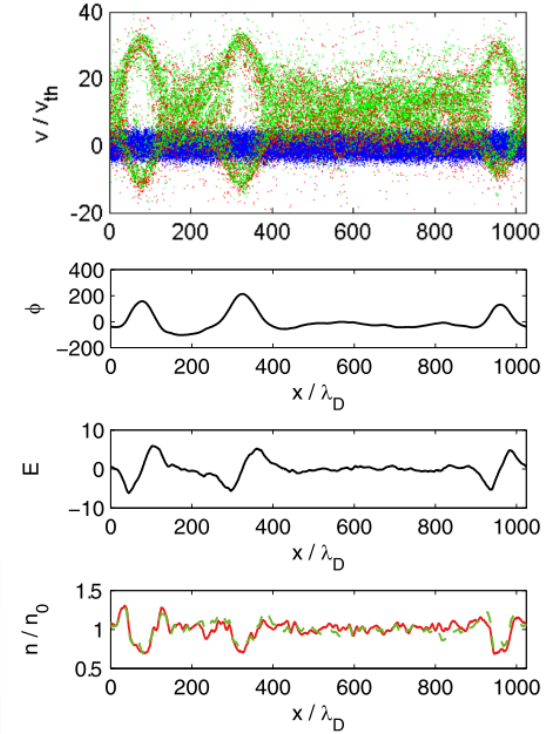
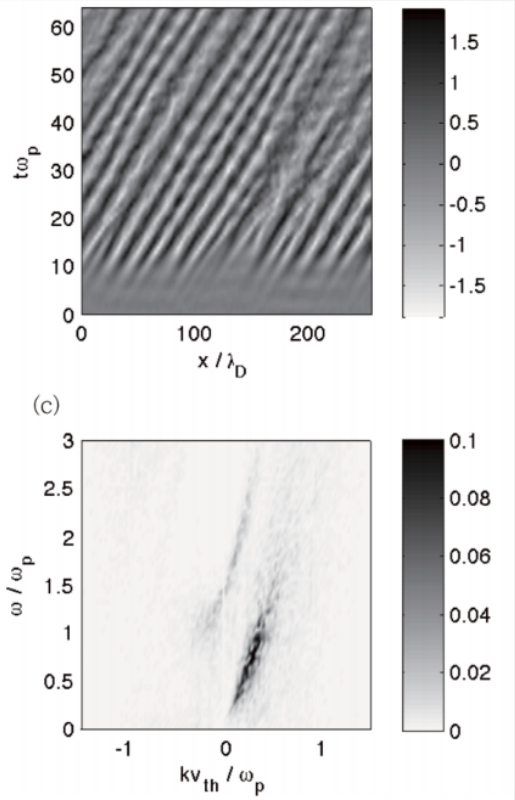
Visualization: hand on

1. Lx =128, Δx = 1, NX = 128, Δt = 0.01, NT = 25600
2. EF = 0, BF=0 field and B field on the grid.
3. Give the position and the velocity to all particles at T = 0.

   Ion: m = 1836, e = 1, vdx = 0.0, vdy = vdz = 0.0,
   vthx = vthy = vthz = 0.1, NP = 128*128, uniform distribution

   electron1: m = 1 , e = -1, vdx = 5.0, vdy = vdz = 0.0,
   vthx = vthy = vthz = 1.0, NP = 64*128, uniform distribution

   electron2: m = 1 , e = -1, vdx = -5.0, vdy = vdz = 0.0,
   vthx = vthy = vthz = 1.0, NP = 64*128, uniform distribution



Example:07_01_initial_withBug