Tutorial:
Magnetization switching of single particles and assemblies

The Stoner-Wohlfarth model

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For a more detailed description of the model:

E.C. STONER, E.P. WOHLFARTH

"A mechanism of magnetic hysteresis in heterogeneous alloys"

Philosophical Transaction Royal Society-London, 240 (1948) 599-642

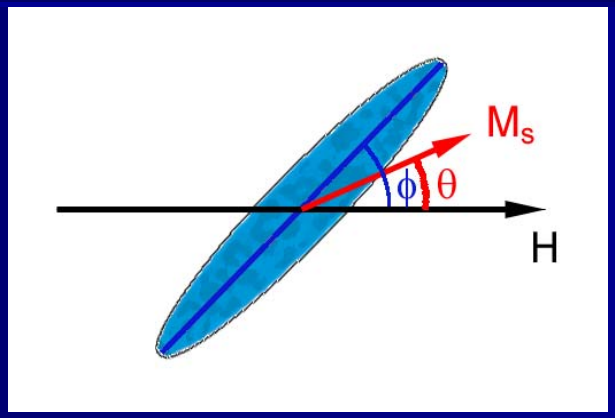
Reprinted at IEEE Trans. Mag. 27 (1991) 3475-3518

OLIVIER FRUCHART

"Simple concepts of magnetization processes - from macrospins to materials"

Lectures at this European School of Magnetism

Uniaxial anisotropy: Phenomenological model (S-W)



- Energy density:
  - Orientation of magnetization with respect to H
  - Orientation with respect to easy axis: even powers

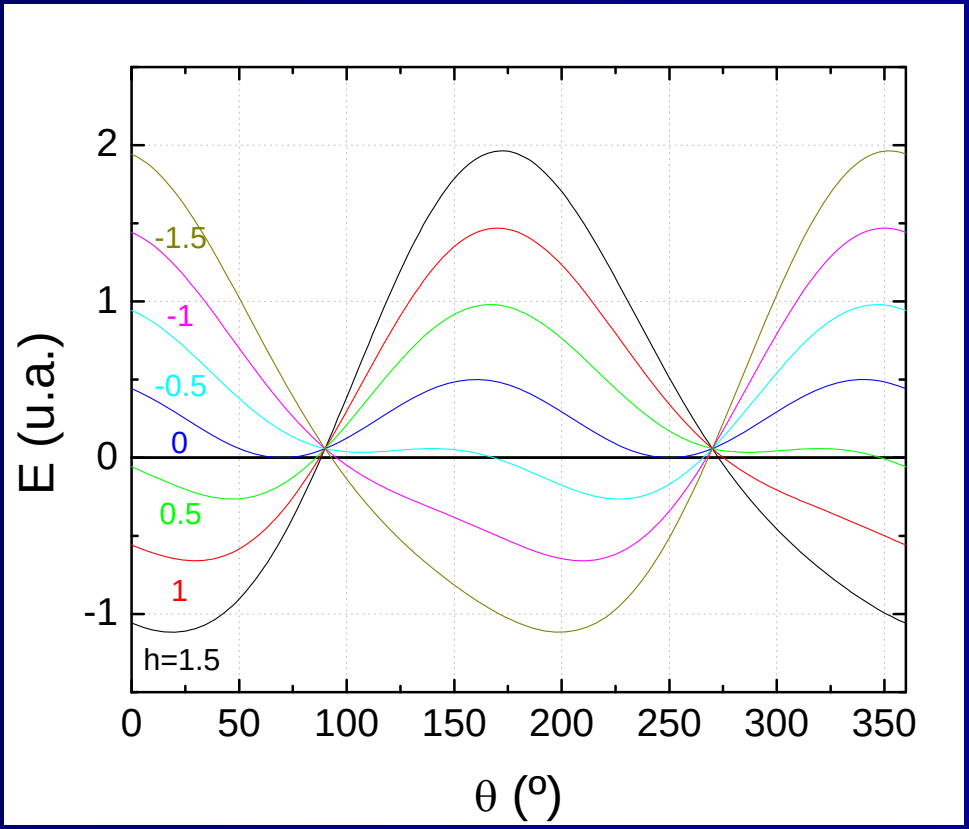
$$E = -\mu_0 \cdot H \cdot M_S \cdot \cos(\theta) + K \cdot \sin^2(\varphi - \theta)$$

$$H_K = 2K / \mu_0 M_S \qquad h = H / H_K$$

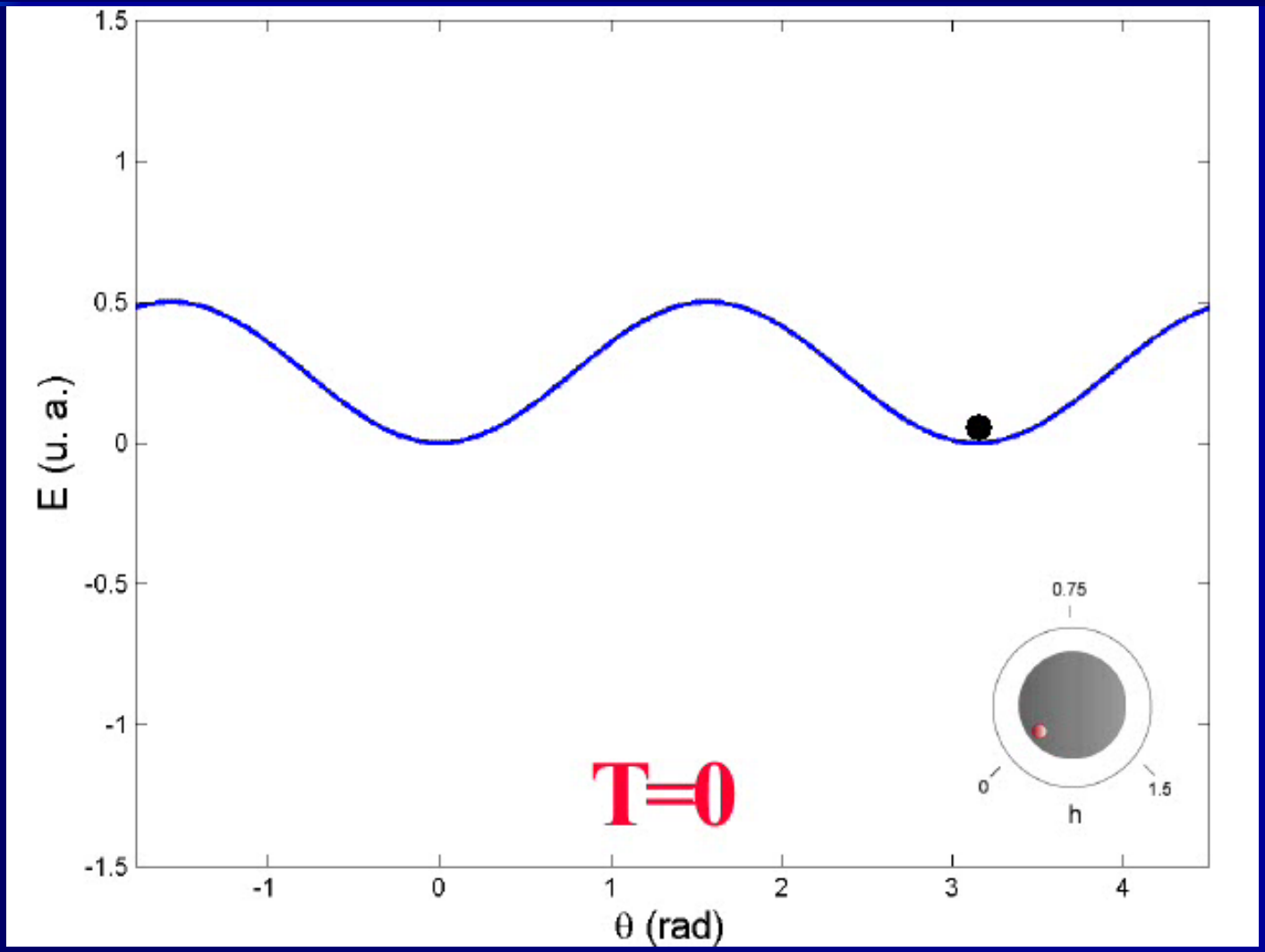
  - Disregarding proportionality factors

$$E = 1/2 \cdot \sin^2(\varphi - \theta) - h \cdot \cos(\theta)$$

- Field applied at 70º with respect to easy axis
- Energy curves



S-W model



Calculation of the magnetization curve

- Magnetization value which corresponds to the energy minimum

$$M = M_S \cos\theta$$

$$\frac{dE}{d\theta} = -\sin(\phi-\theta)\cdot\cos(\phi-\theta) + h\cdot\sin(\theta) = 0$$

$$\frac{d^2E}{d\theta^2} = \cos^2(\phi-\theta) - \sin^2(\phi-\theta) + h\cdot\cos(\theta) \geq 0$$

Avoid brute force for solving the problem

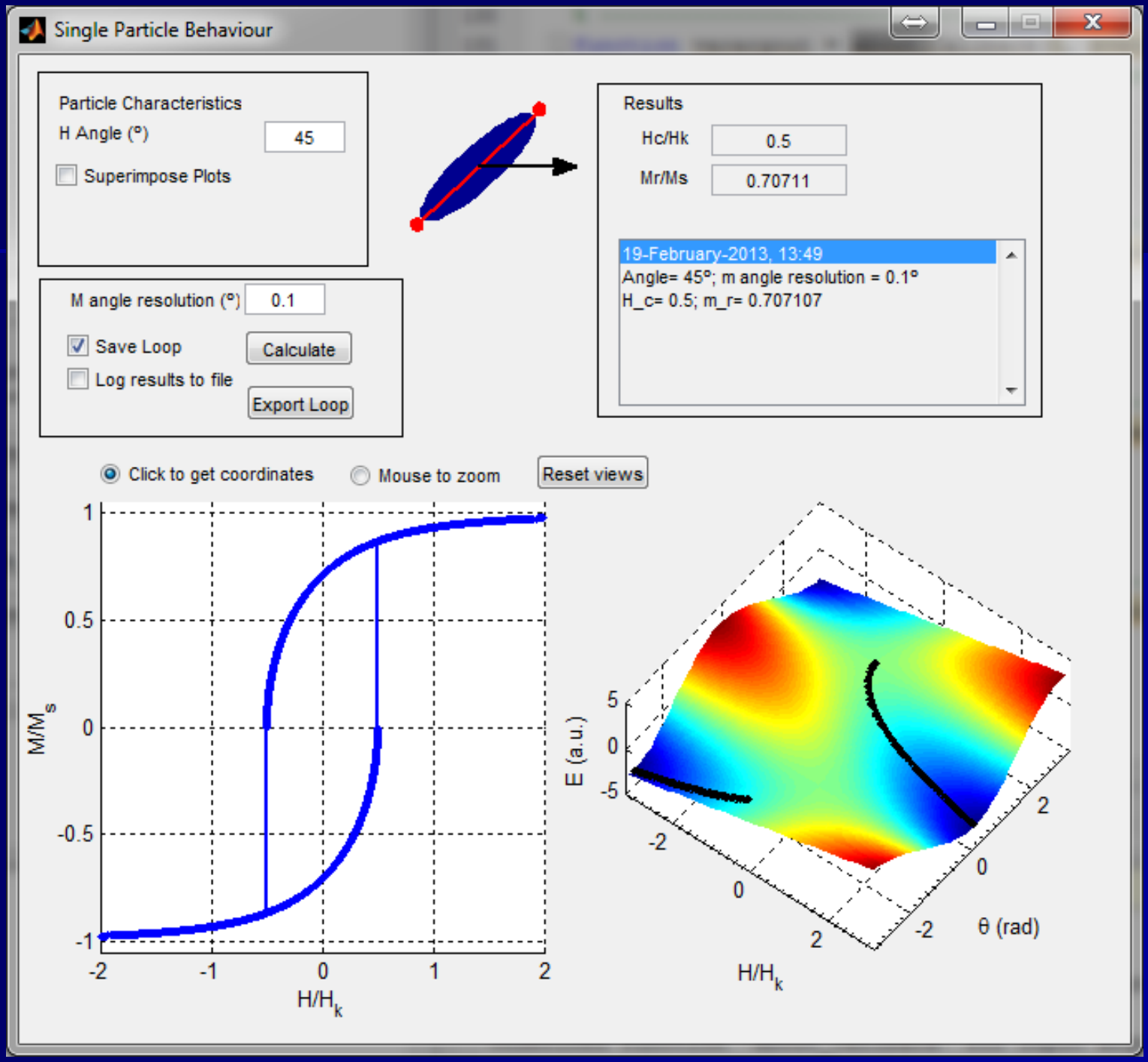
$$\frac{dE}{d\theta} = -\sin(\phi-\theta)\cdot\cos(\phi-\theta) + h\cdot\sin(\theta) = 0$$

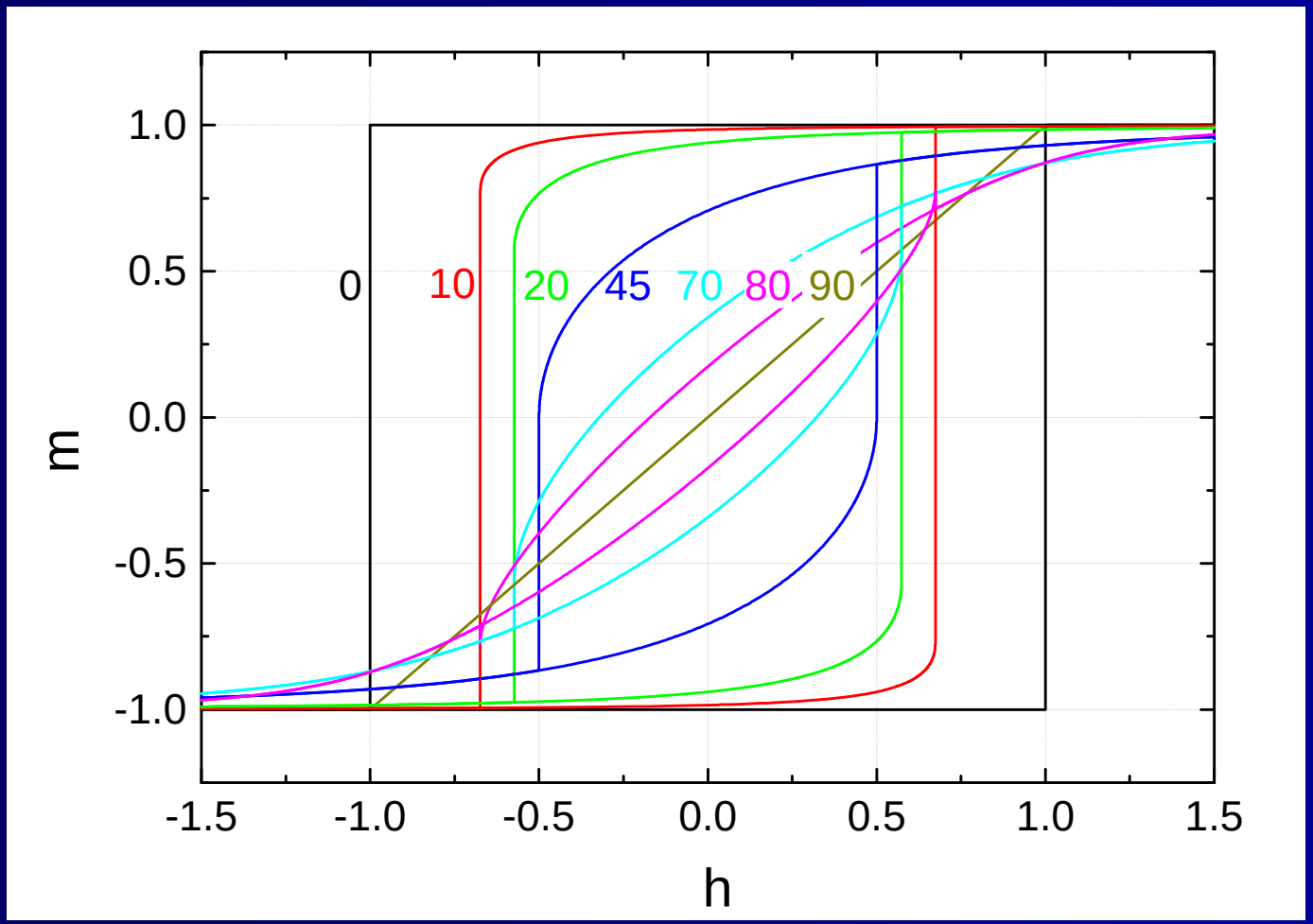
- We cannot solve analytically $\theta(h)$
- It is trivial to obtain $h(\theta)$

$$h = \frac{\sin(\phi-\theta)\cdot\cos(\phi-\theta)}{\sin(\theta)}$$

  - Check which parts of the curve are stable
    - Astroid... or any other method


Ston...
Stoner Wohlfarth Model
Single Particle
Particle Distribution
Log File
Configure
About...
Exit


Single Particle Behaviour
Particle Characteristics
H Angle (°)
45
Superimpose Plots
Results
Hc/Hk
0.5
Mr/Ms
0.70711
19-February-2013, 13:49
Angle= 45°; m angle resolution = 0.1°
H_c= 0.5; m_r= 0.707107
M angle resolution (°)
0.1
Save Loop
Calculate
Log results to file
Export Loop
Click to get coordinates
Mouse to zoom
Reset views
M/Ms
H/Hk
E (a.u.)
θ (rad)


1.0
0.5
0.0
-0.5
-1.0
m
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
h
0
10
20
45
70
80
90


Ston...
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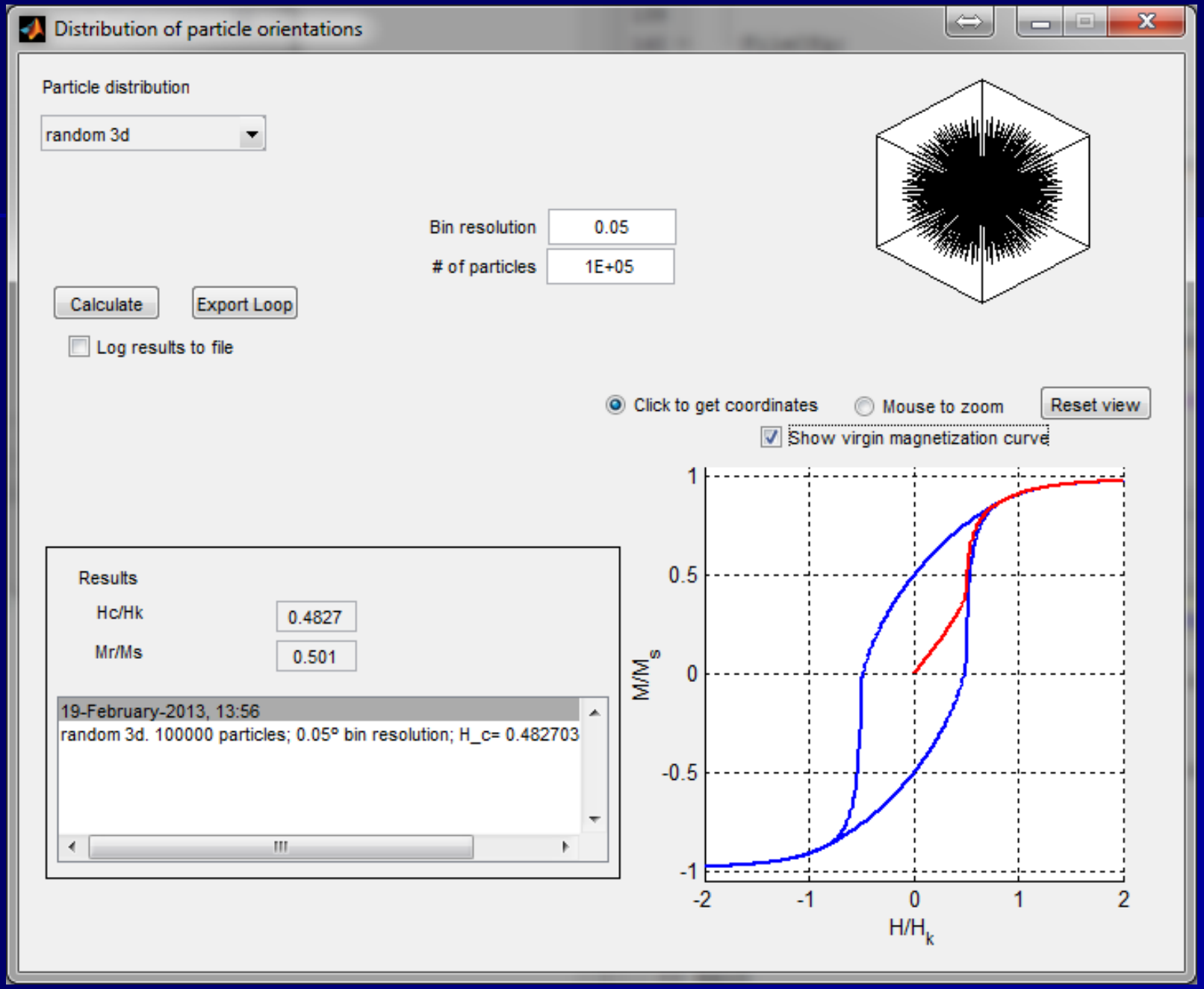
Distribution of particle orientations
Particle distribution
random 3d
Bin resolution
0.05
# of particles
1E+05
Calculate
Export Loop
Log results to file
Click to get coordinates
Mouse to zoom
Reset view
Show virgin magnetization curve
Results
Hc/Hk
0.4827
Mr/Ms
0.501
19-February-2013, 13:56
random 3d. 100000 particles; 0.05° bin resolution; H_c= 0.482703
M/M_s
H/H_k
1
0.5
0
-0.5
-1
-2
-1
0
1
2

What to do?

- Individual particles:
  - Observe the loops for different particle orientations.
  - Register the dependence of coercivity and the field of irreversible rotation on the orientation.
    - Are they related?
  - Register the angular dependence of the reduced remanence.
  - Is it possible to construct minor loops for any of these particles?

- Particle distributions:
  - Observe the influence of the number of particles on the resulting loop for a 3D random distribution
    - Which number of particles is necessary to obtain a truly uniform distribution?
  - Compare the results for 2D and 3D distributions.
  - For a distribution composed of equal number of particles with orientations 0º, 45º and 90º, calculate the magnetization curve h=2→-1.5→.75→-0.4→0