Neel and Bloch domain walls

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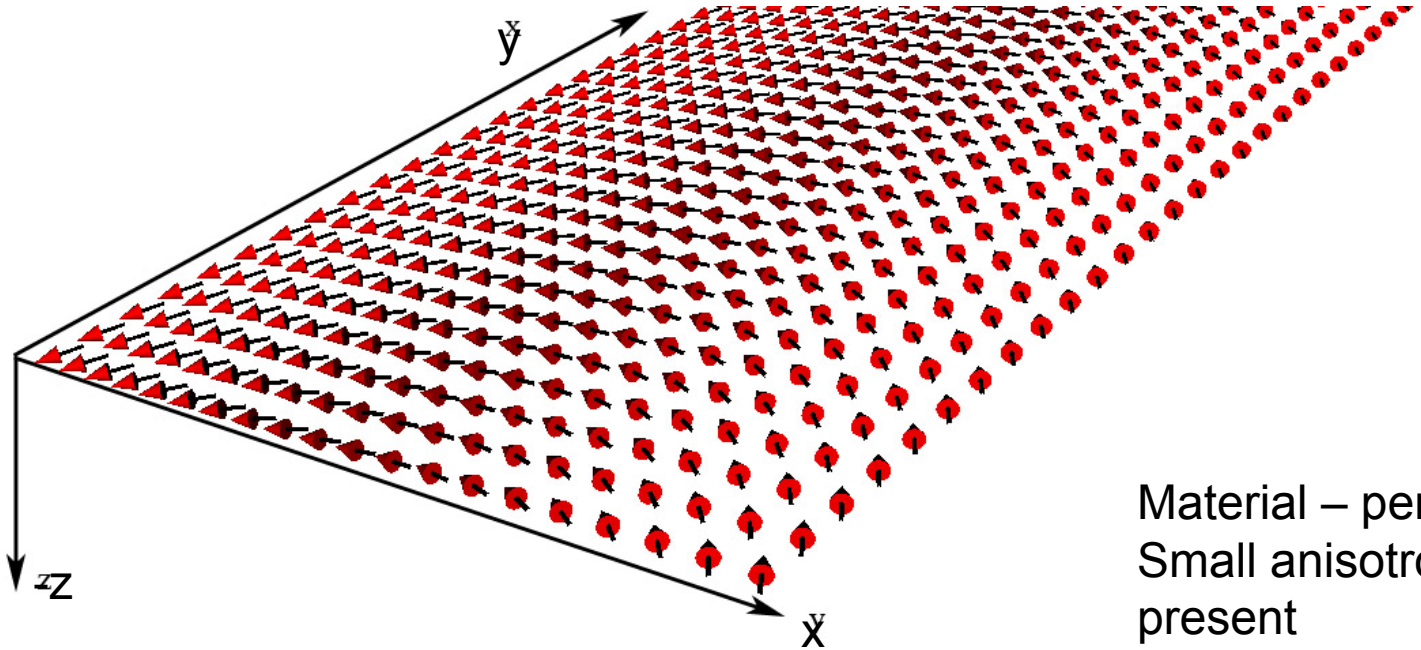
Coordinate system:

Thin along z, infinite along y.



Material – permalloy
Small anisotropy could be present
M_s=795 erg/cm

h – thickness
w - width

Analytical expressions

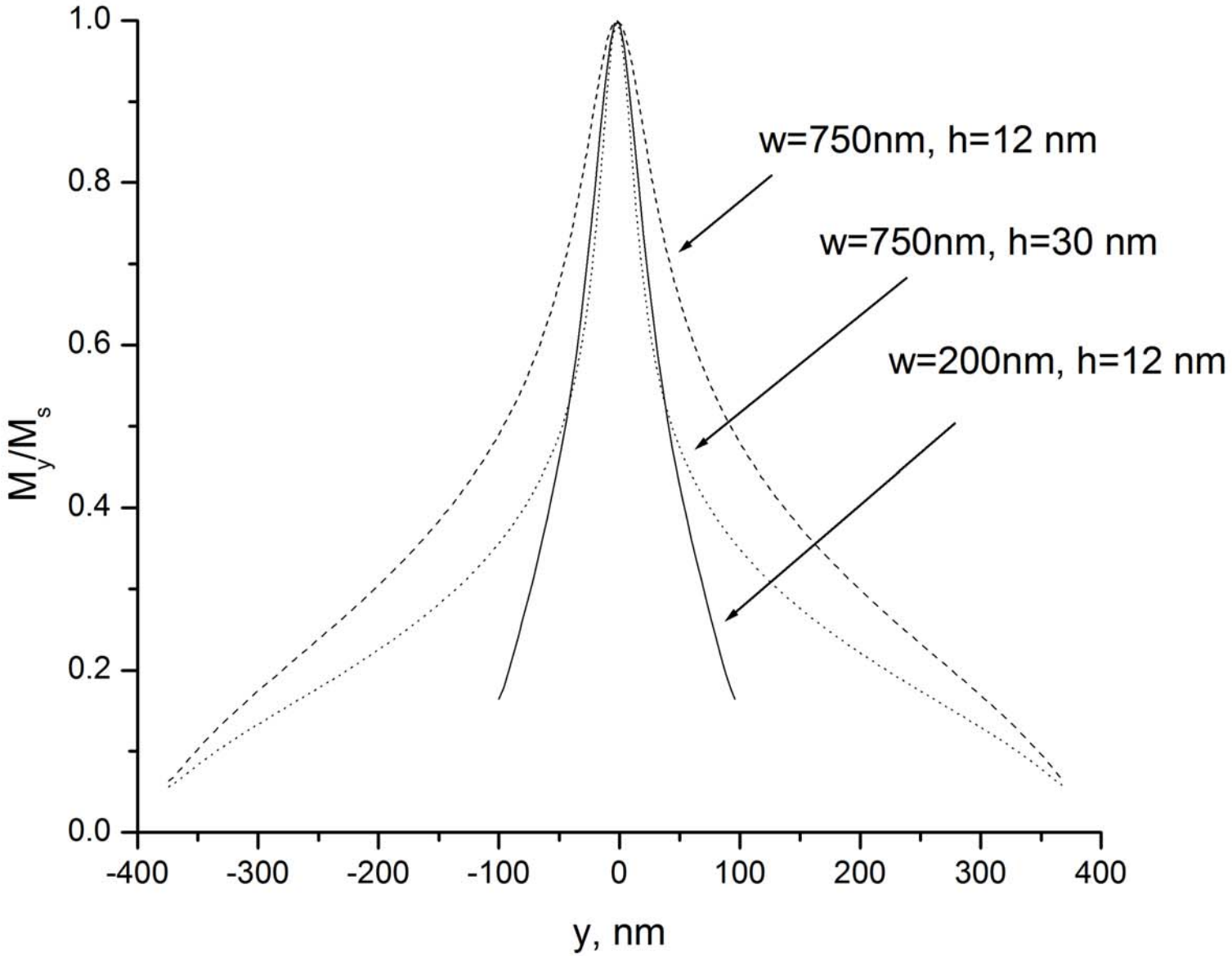
If $\frac{\mathbf{M}}{M_s} = (v, u, 0), \; u \gg v$:

$$u(x) \approx \Lambda \int_0^\infty \frac{\cos(kx)}{k + 1/\omega} dk = \Lambda \left(\cos\left(\frac{x}{\omega}\right) ci\left(\frac{x}{\omega}\right) + \sin\left(\frac{x}{\omega}\right) si\left(\frac{x}{\omega}\right) \right) \qquad \omega = \sqrt{\frac{J}{K}}$$

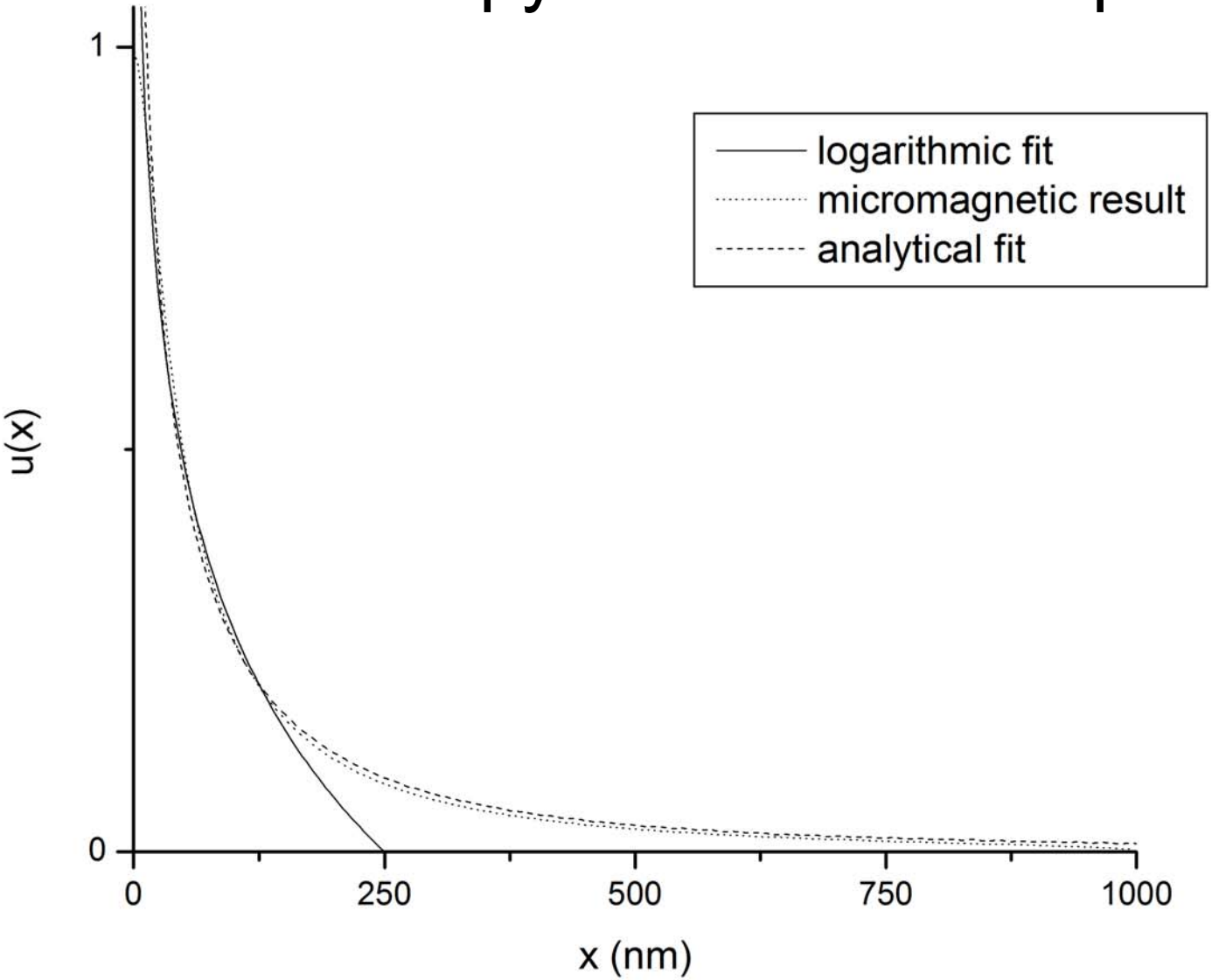
In the center:

$$u \sim \sec h\left(\sqrt{\frac{h}{w}} \frac{x}{l_{ex}}\right) \qquad l_{ex} = \sqrt{\frac{A}{2\pi M_s^2}}$$

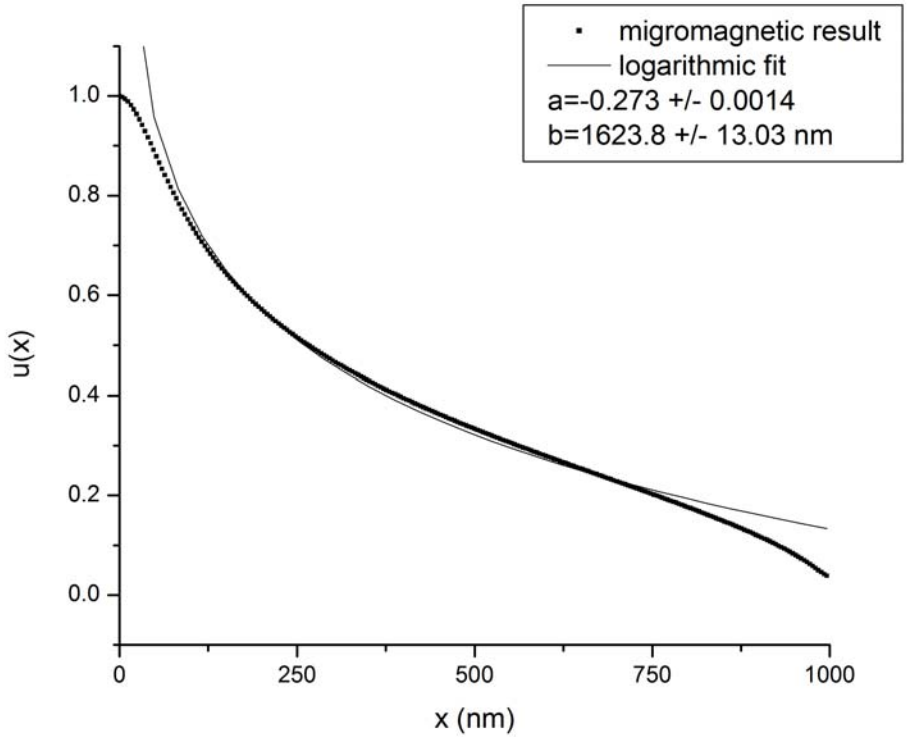
Tails

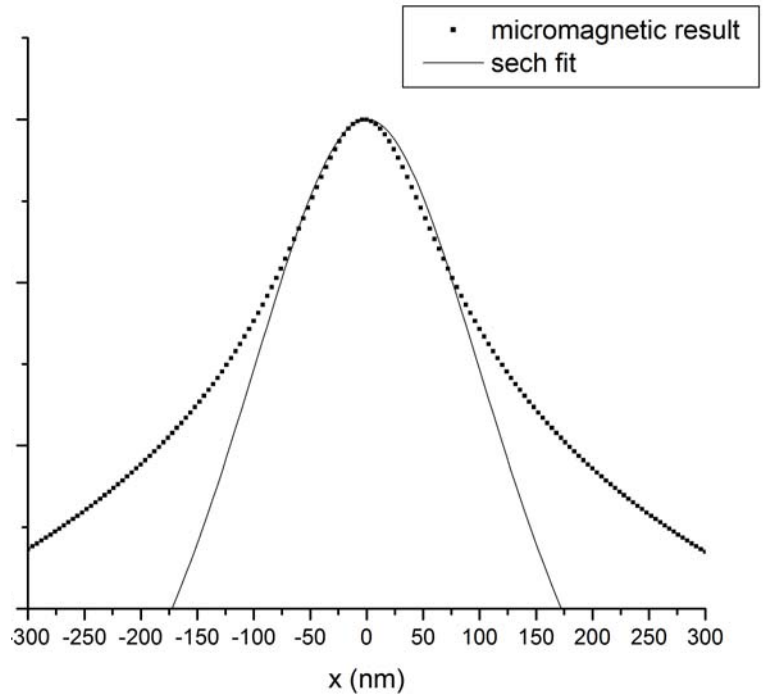

1.0
0.8
0.6
0.4
0.2
0.0
M_y/M_s
-400
-300
-200
-100
0
100
200
300
400
y, nm
w=750nm, h=12 nm
w=750nm, h=30 nm
w=200nm, h=12 nm

Anisotropy-dominated sample



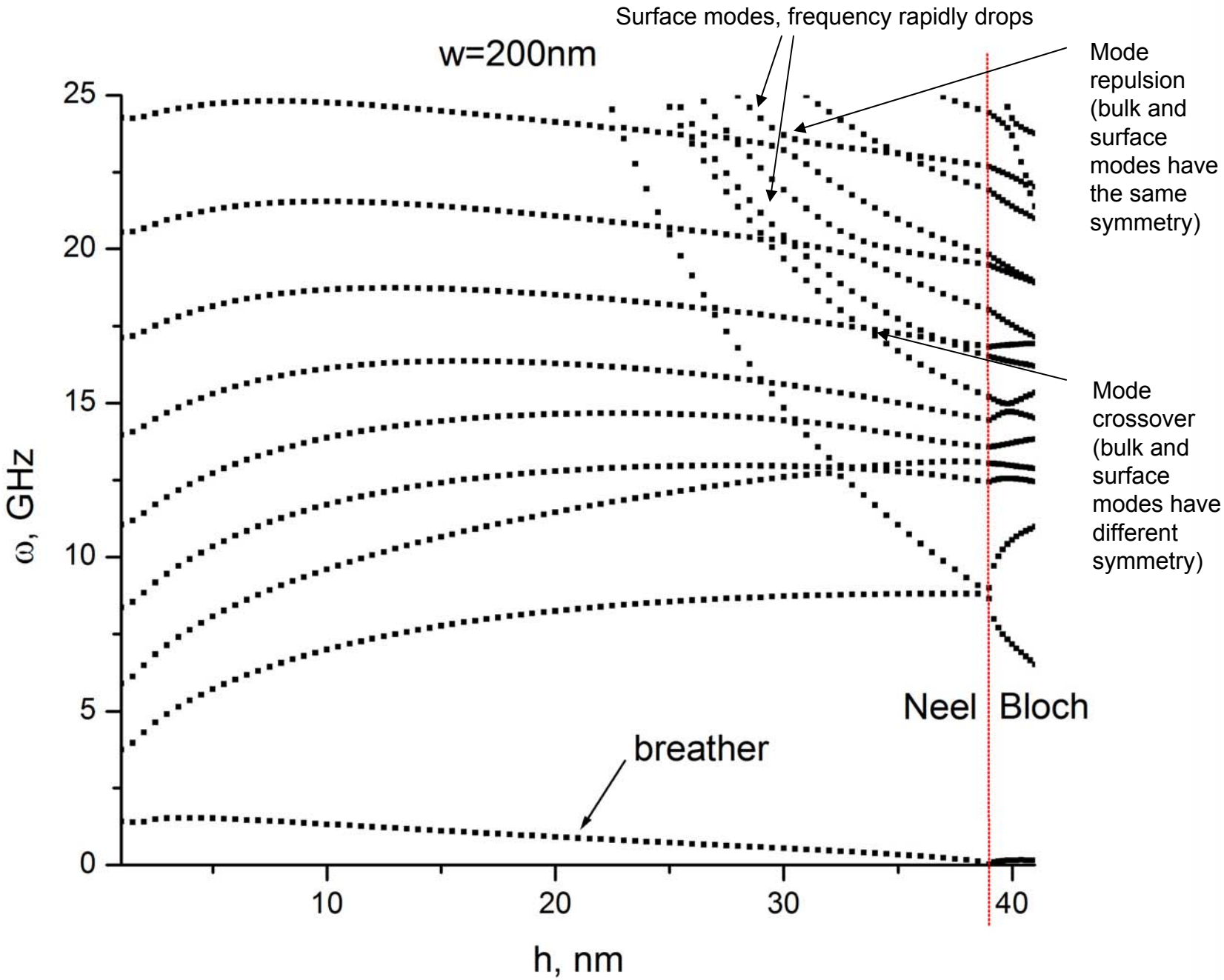
Dipole-Dipole dominated sample



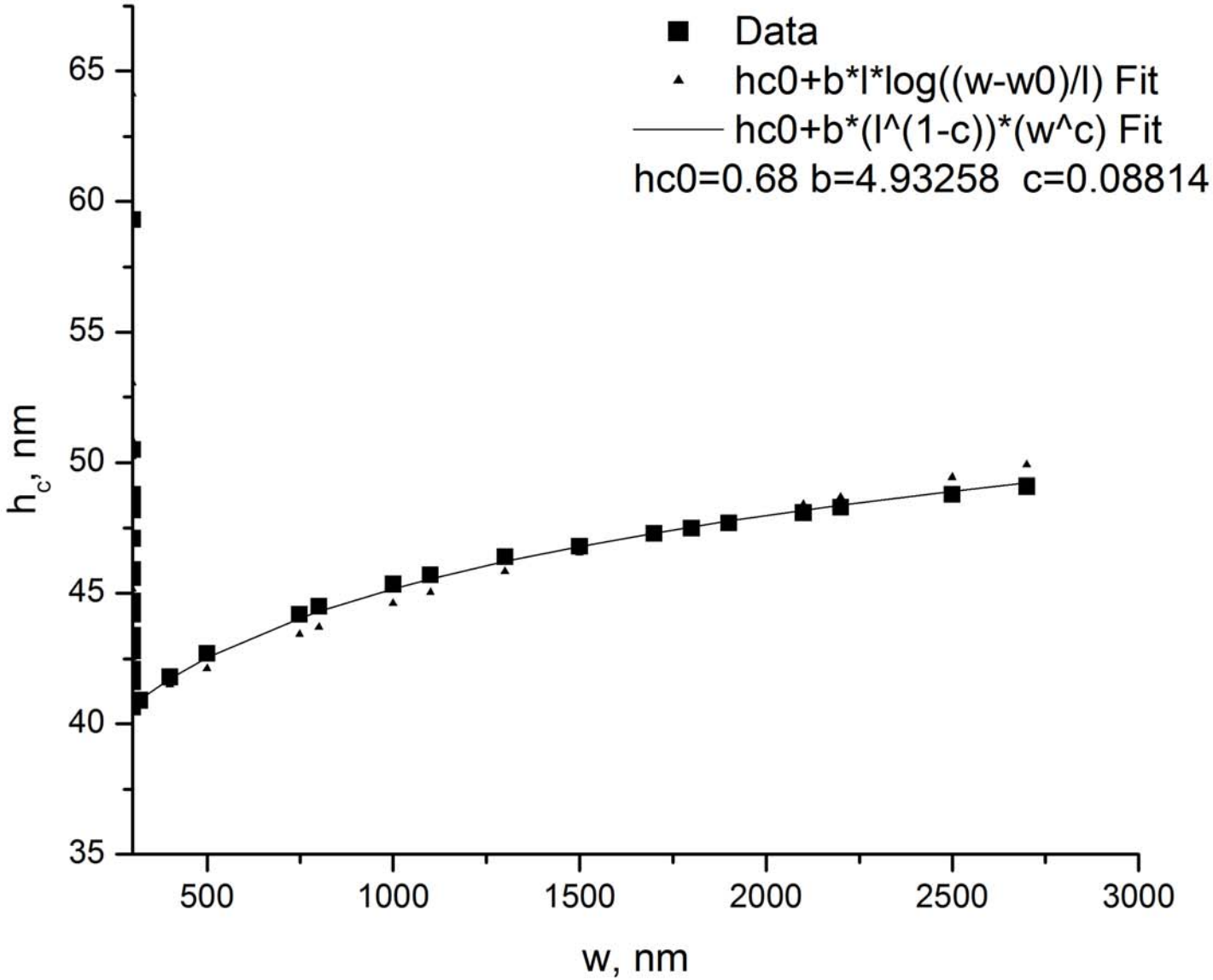


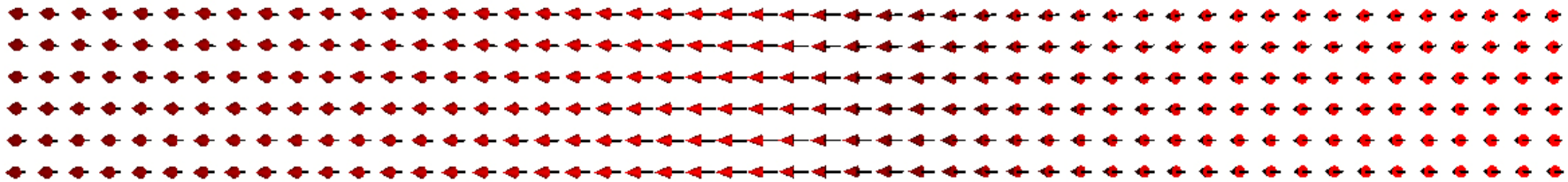
Normal Modes
Phase transitions

- Lyapunov stability analysis and normal modes from solving linearized Landau-Lifshitz equation
- RKMAG (www.rkmag.com) micromagnetics package
- Neel and Bloch regimes

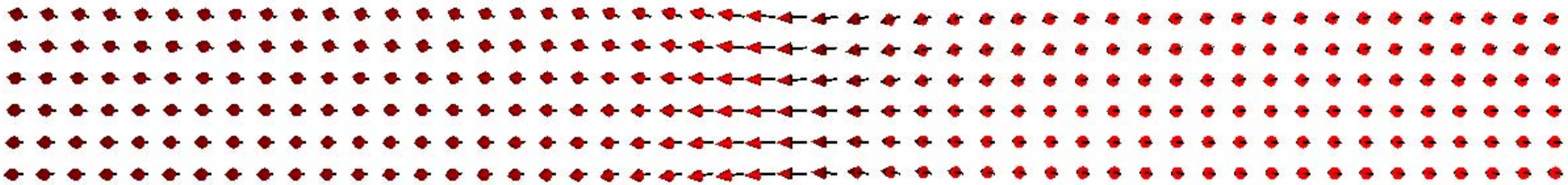

Surface modes, frequency rapidly drops
w=200nm
Mode repulsion (bulk and surface modes have the same symmetry)
Mode crossover (bulk and surface modes have different symmetry)
Neel
Bloch
breather
ω, GHz
h, nm
0
5
10
15
20
25
10
20
30
40

Critical thickness



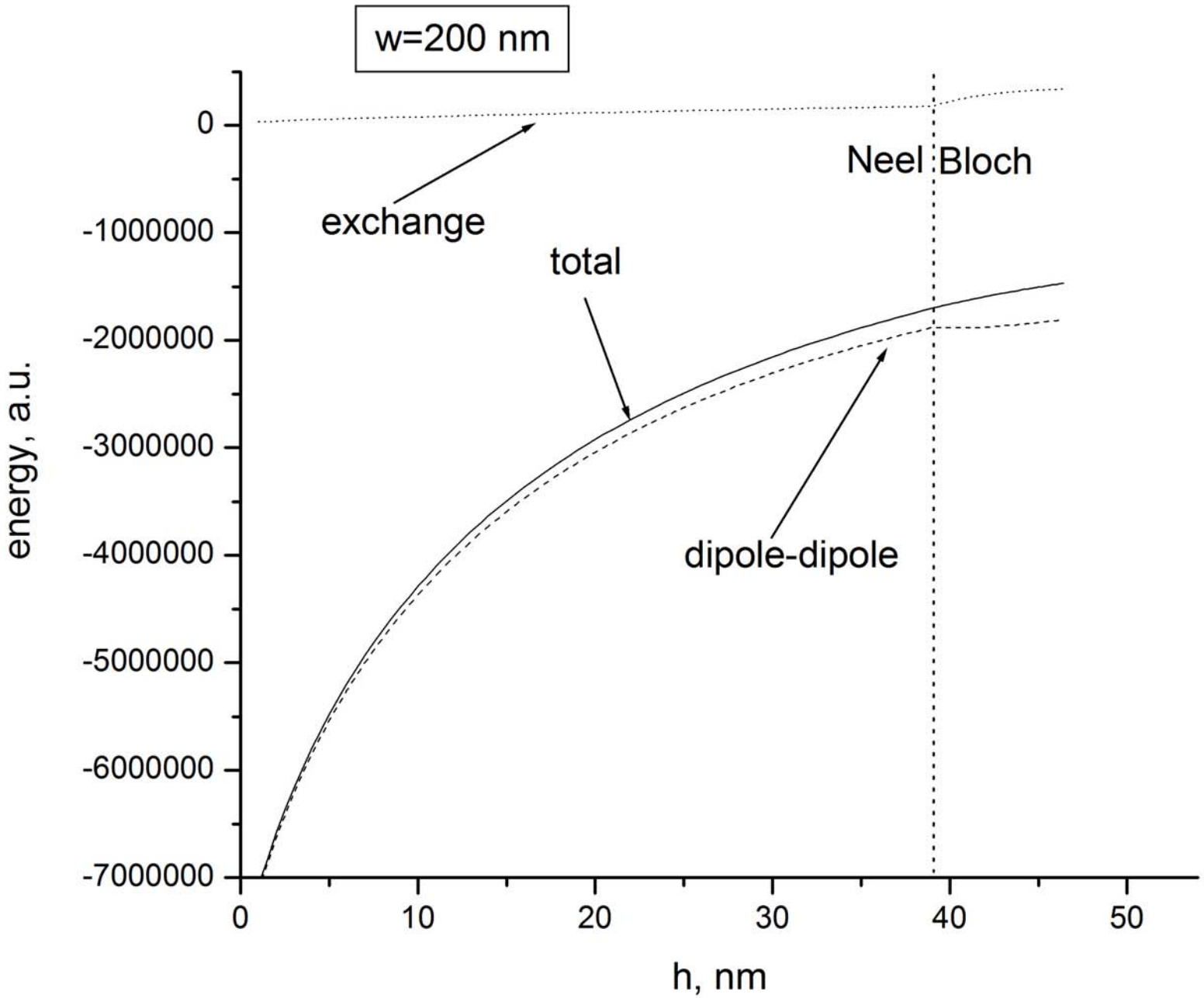


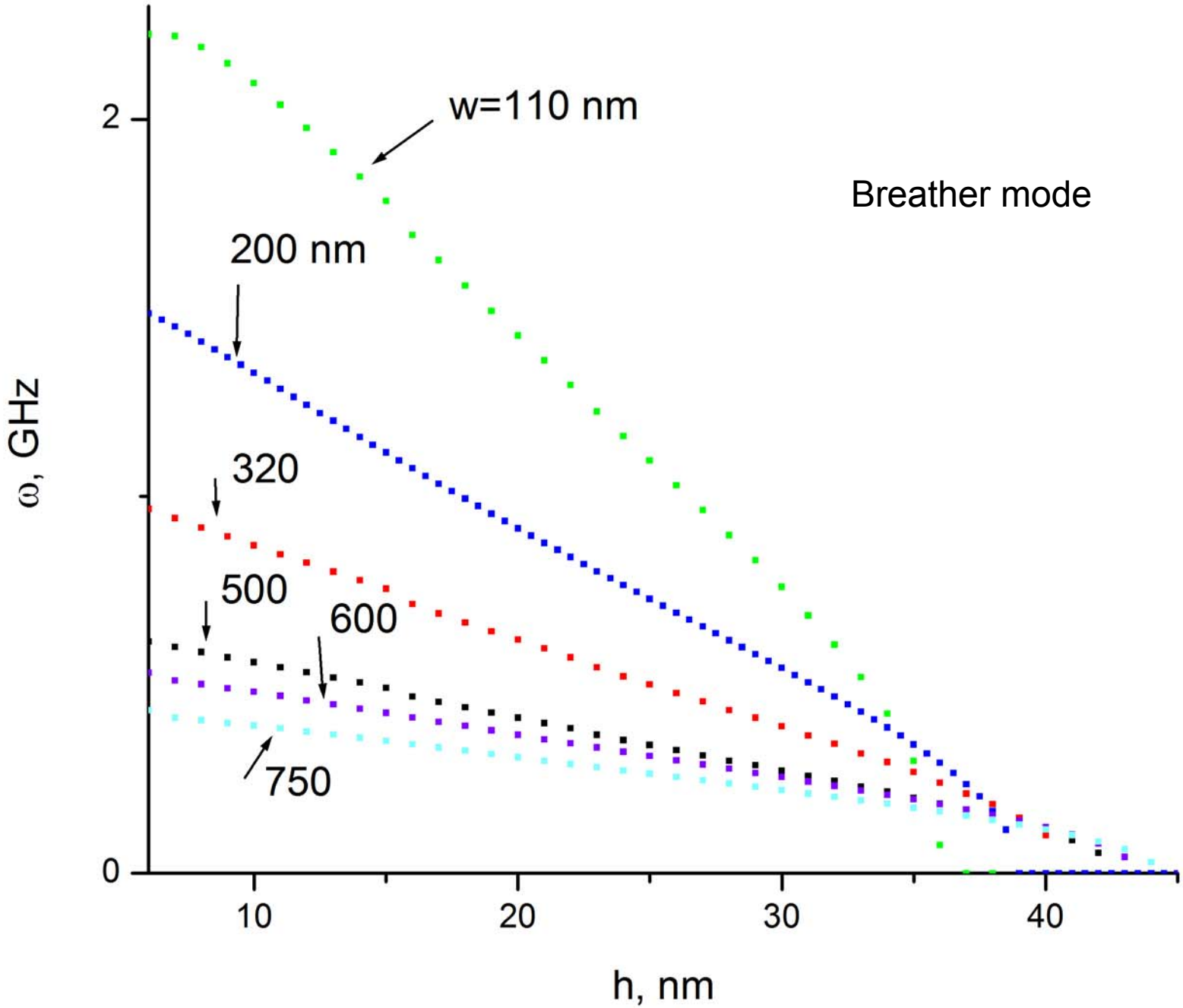
Neel wall, w=200nm, h=10nm

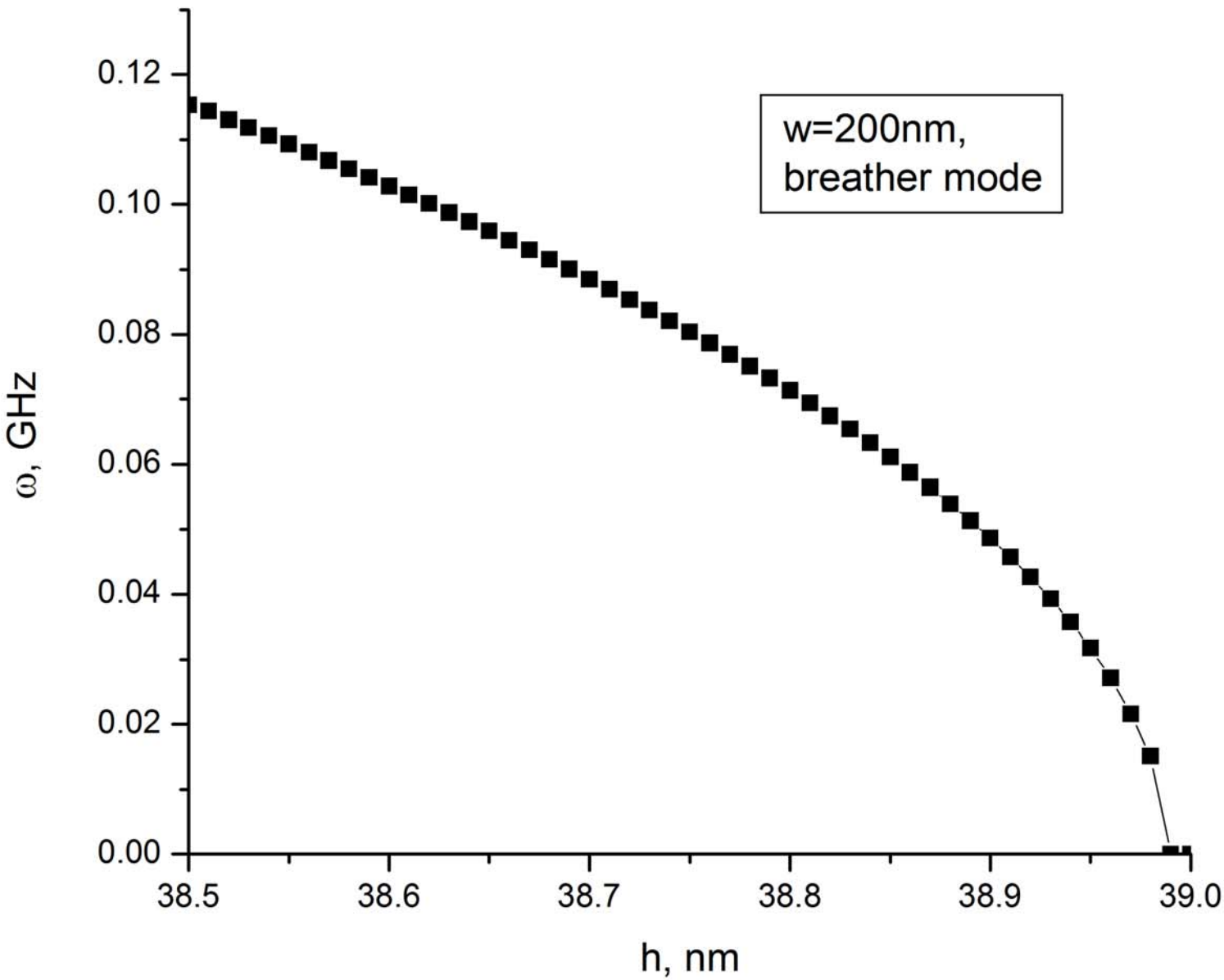


Bloch wall, w=200nm, h=39nm

Bloch wall, assymetric, w=200nm, h=43nm

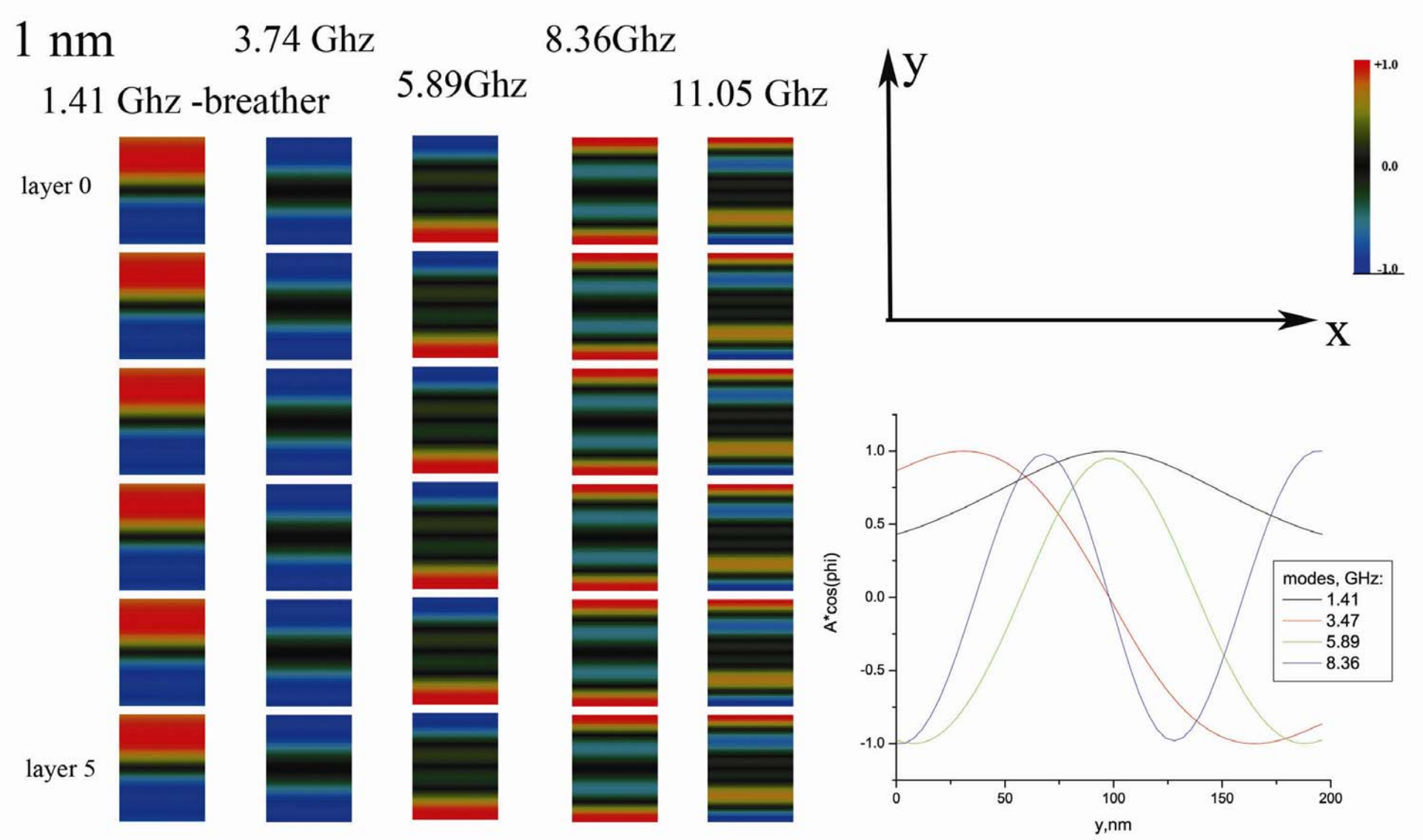

w=200 nm
0
-1000000
-2000000
-3000000
-4000000
-5000000
-6000000
-7000000
energy, a.u.
0
10
20
30
40
50
h, nm
Neel
Bloch
exchange
total
dipole-dipole


w=110 nm
Breather mode
200 nm
320
500
600
750
2
0
ω, GHz
10
20
30
40
h, nm


w=200nm,
breather mode
ω, GHz
0.12
0.10
0.08
0.06
0.04
0.02
0.00
38.5
38.6
38.7
38.8
38.9
39.0
h, nm

Neel to Bloch transtion

- Happens for large enough thickness
- Second order transition, mediated by a single mode (“breather” mode), whose frequency goes through zero.
- Total energy and at least its first derivatives are continuous while both exchange and dipole-dipole energies have a discontinuous first derivative.
- Frequencies of the modes are continuous.
- The frequency of the “breather” mode goes to zero as square root – Landau-Ginzburg theory
- The instability is extremely small and can be easily missed by conjugate gradient and other methods that do not calculate the modes, as a result wrong conclusions can be reached.


1 nm
3.74 Ghz
8.36Ghz
1.41 Ghz -breather
5.89Ghz
11.05 Ghz
layer 0
layer 5
y
x
+1.0
0.0
-1.0
A*cos(phi)
y,nm
modes, GHz:
1.41
3.47
5.89
8.36

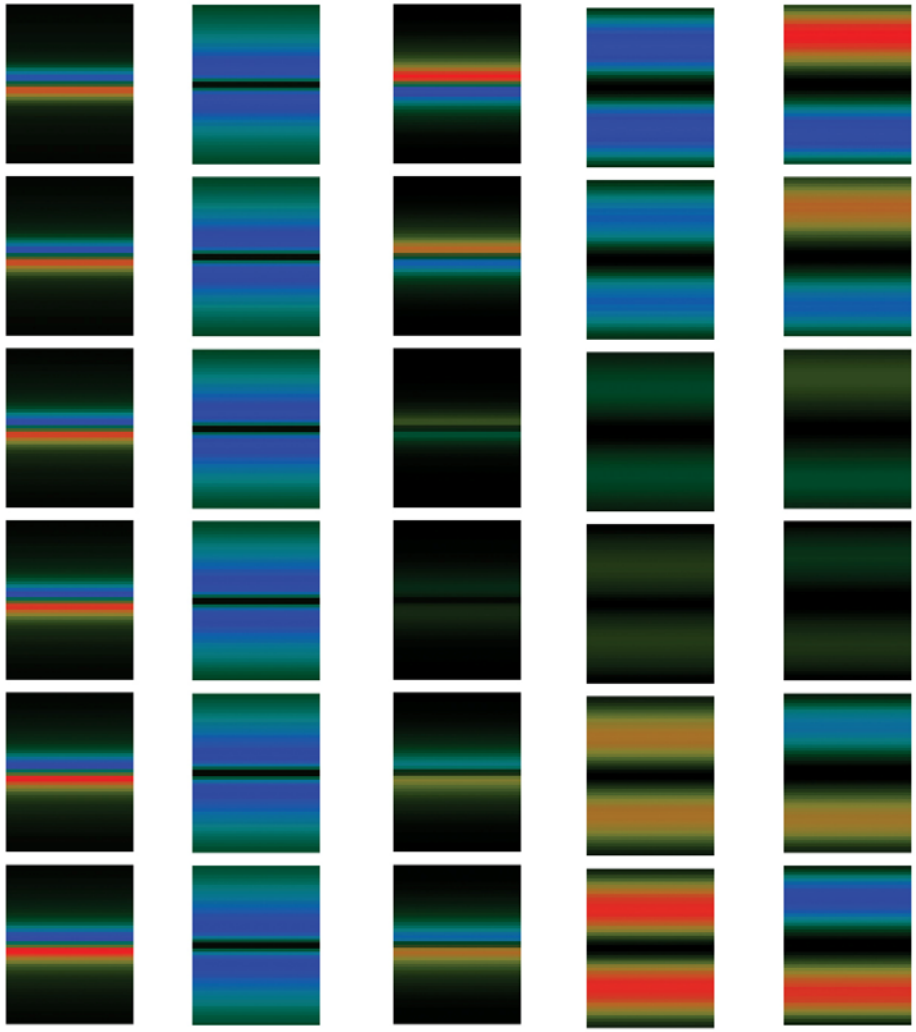
385nm

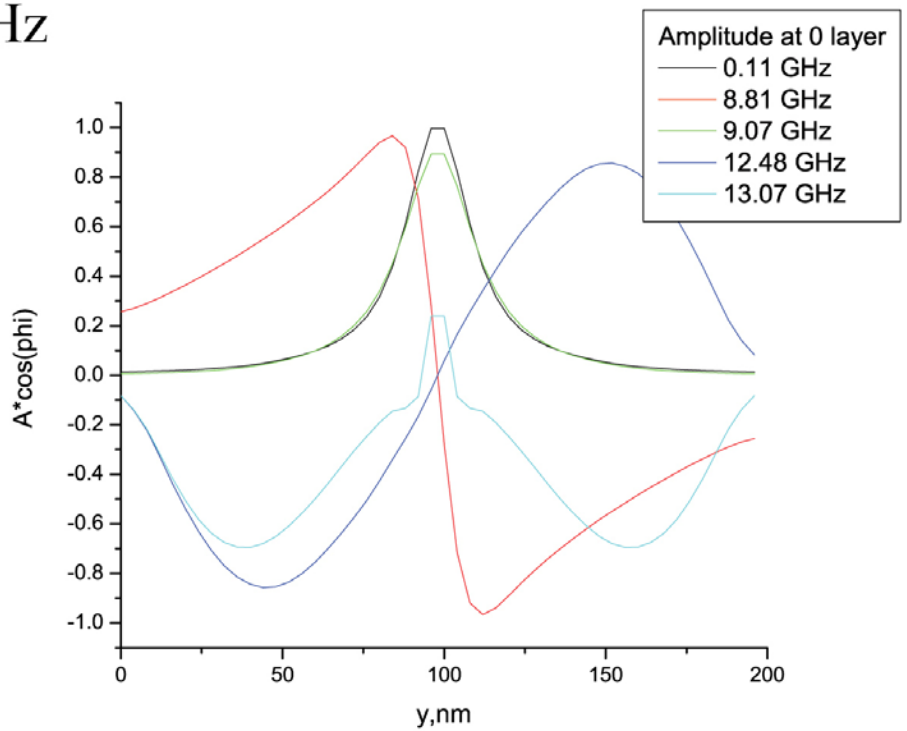
8.81 GHz

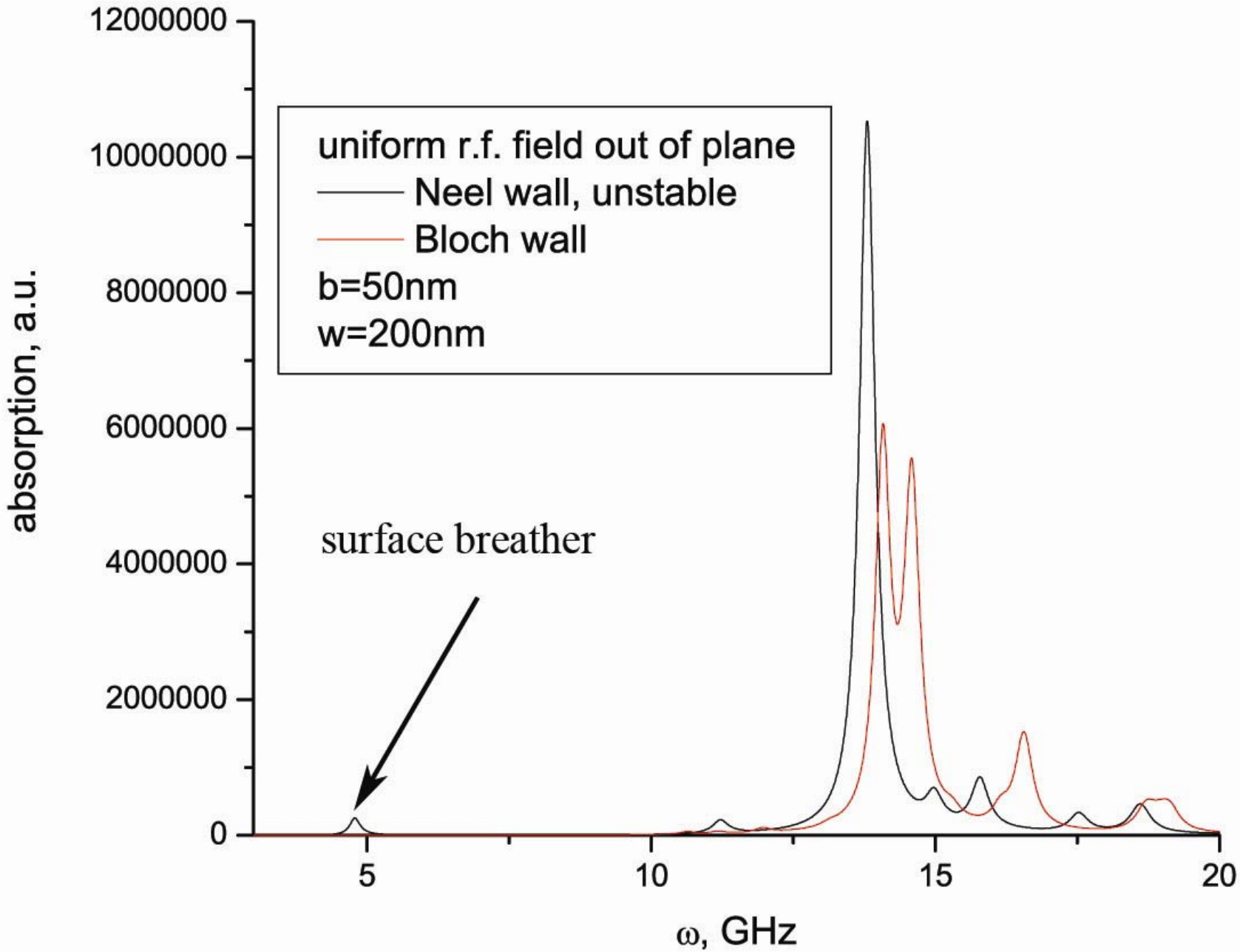
12.48 GHz

0.11 GHz -breather 9.07 GHz

13.07 GHz






uniform r.f. field out of plane
Neel wall, unstable
Bloch wall
b=50nm
w=200nm
surface breather
absorption, a.u.
ω, GHz
12000000
10000000
8000000
6000000
4000000
2000000
0
5
10
15
20