Grid computing simulation of superconducting vortex lattice in superconducting magnetic nanostructures

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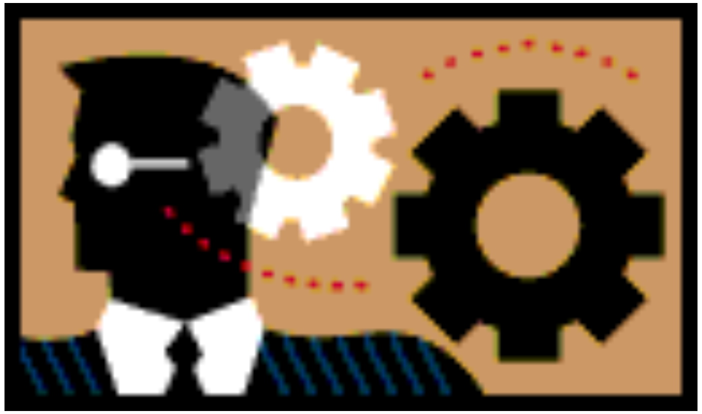
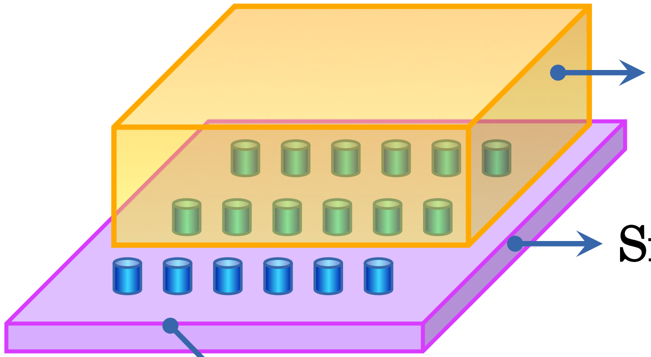
Outline

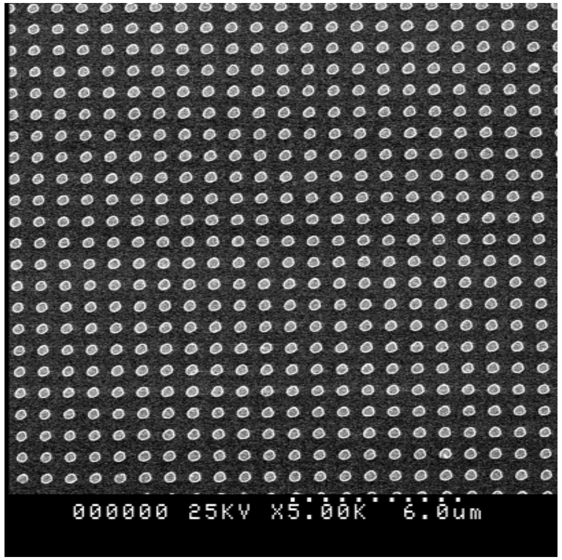
- Introduction
- The DiVoS code and its Physics
- Implementation
  - Complete DiVoS
  - Optimised DiVoS
  - Division of the problem
  - Architecture of the proposed solution
- Results
  - Testbed
  - Performance
- Conclusions



- **Superconducting (SC) Vortices Lattices (VL) are modified if nanodefects are embedded in SC samples**
  - Engineering applications
  - SC amorphous Mo_3Si (a-Mo_3Si) and Nb films on arrays of Ni nanodots

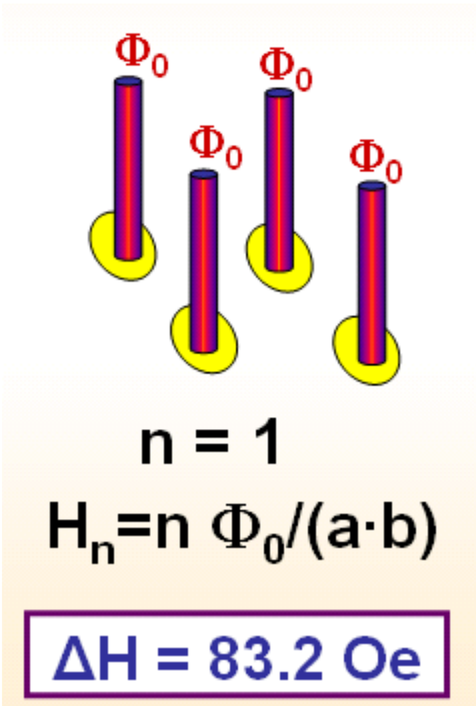


- Several effects reported
  - Induction by arrays made with different materials
  - Different diameters of the pinning centres
  - Arrays with different symmetries
  - Softening the strength of the intrinsic random pinning potentials



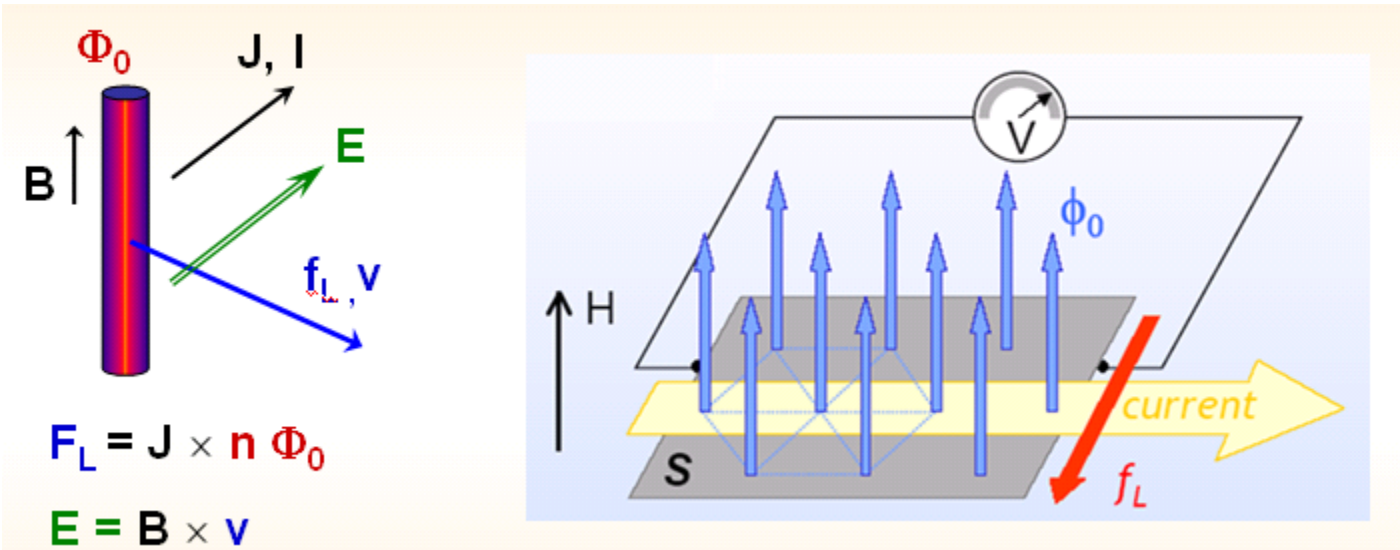
Lithography by electron beam

- Experimental VL
  - 400 x 600 nm^2 and 400 x 400 nm^2
  - The simplest case has Matching Field (MF) equal to 1

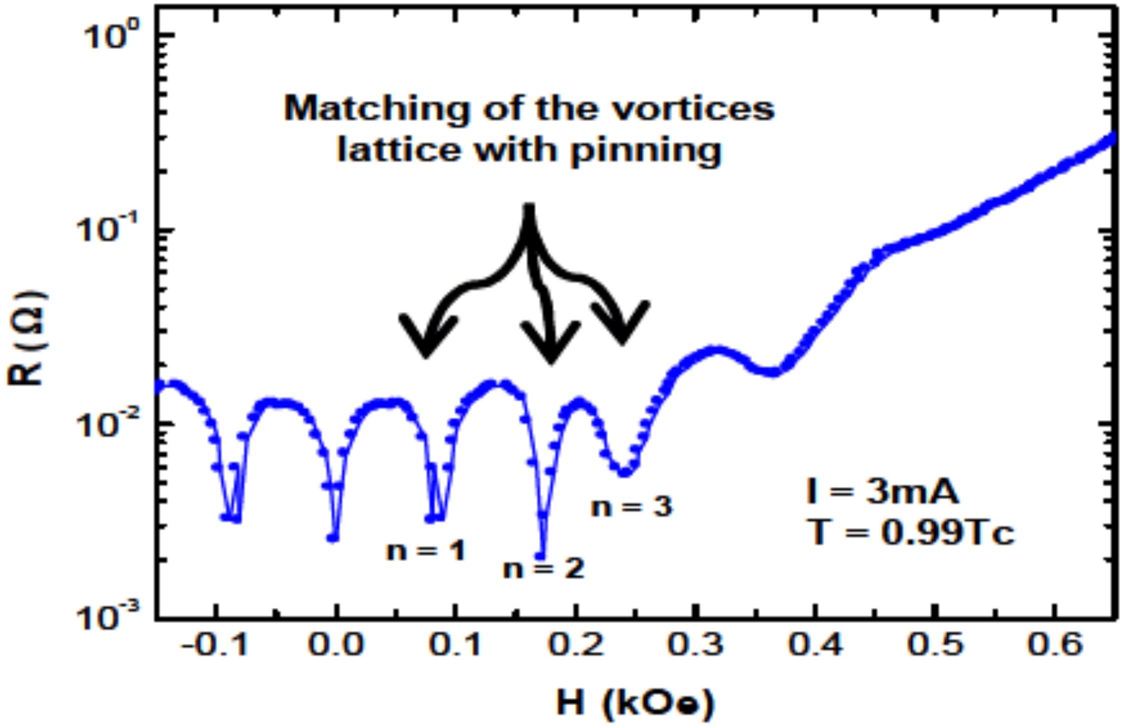


Array minima at these magnetic fields

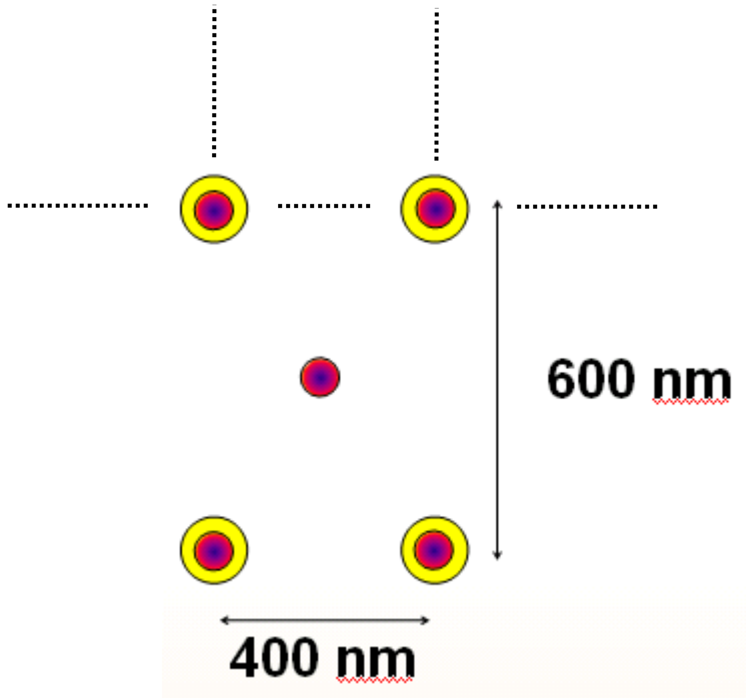
- Appliance of magnetic fields perpendicularly
- VL accommodates to the nanostructured arrays
- Vortices are moved because of Lorentz Force
- An Electric Field is then originated due to the velocity of the lattice



- Magnetoresistance of superconducting thin films with periodic arrays of pinning centres show minima when the vortex lattice matches the unit cell of the array

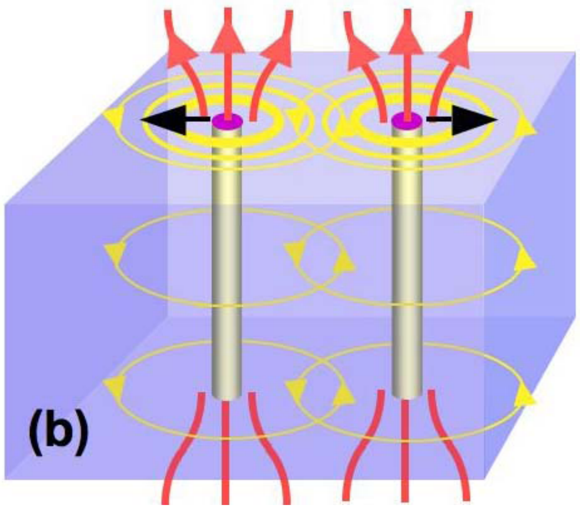


- **Dinámica de Vórtices Superconductores (DiVoS) code**
  - Fortran95
  - Study the VL dynamics in a Type-II SC
  - Simulates the observed phenomena by increasing the MF
    - The number of vortices depending on their position
      - *Vertex counts for 1/4*
      - *Edge counts for 1/2*
      - *Inner counts for 1*



- Dinámica de Vórtices Superconductores (DiVoS) code
  - Vortex-Vortex interaction

$$U_{ij}(\mathbf{r}_{ij}) = \frac{\phi_0^2}{8\pi^2\lambda^3} K_0\left(\frac{\mathbf{r}_{ij}}{\lambda}\right)$$



- **Dinámica de Vórtices Superconductores (DiVoS) code**
  - Retrieves the lowest Energy configuration
  - Any MF configuration will have *MF* solutions
    - Running from *MF - 1* to *2 · (MF - 1)*
  - The space of solutions is

$$C_{(a\times b),V_p} = \frac{(a\times b)!}{V_p!((a\times b)-V_p)!}$$

Matching Field	Number of solutions
2	$2.380 \cdot 10^{5}$
3	$2.832 \cdot 10^{10}$
4	$2.247 \cdot 10^{15}$
5	$1.337 \cdot 10^{20}$
6	$6.364 \cdot 10^{24}$
7	$2.524 \cdot 10^{29}$

400 x 600 lattice

- **Dinámica de Vórtices Superconductores (DiVoS) code**
  - Two versions
    - Complete → All possible combinations are calculated
    - Optimized → Heuristics are used
      - Symmetry → Σr_{ij} is constant
      - Minimum Distance between vortices equal to a/V_p

- **Division of the problem**
  - The evaluation of each solution is independent from the rest
  - Any vortex can be placed on a *(X,Y)* position in an *axb* lattice
  - S_p independent partitions with s_p subtasks
  - The different positions satisfy:

$$((X \cdot a + Y) \bmod S_p) = s_p$$

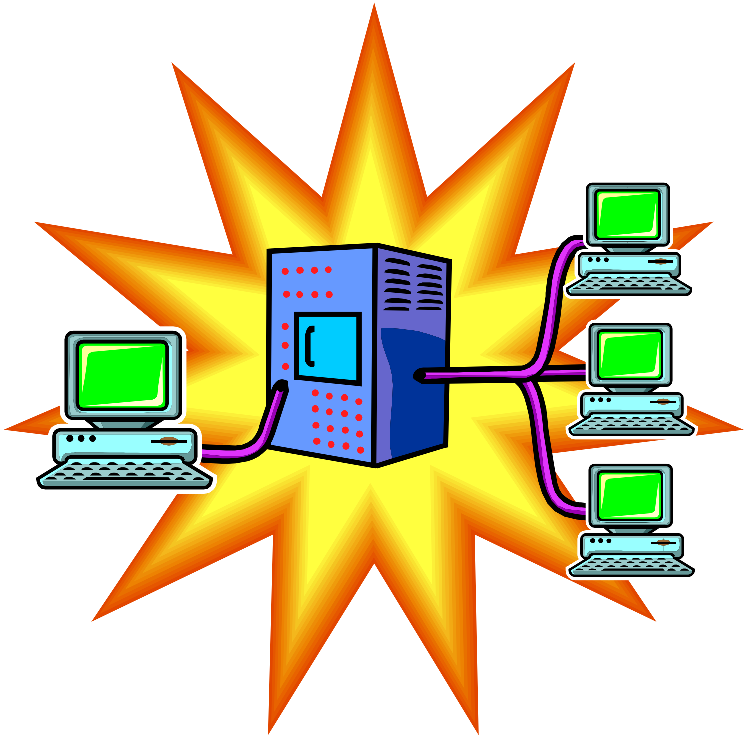
running the *a* dimension

- **Architecture**
  - Static compilation of 32 bits-X86 enabled version
  - Bessel function by NAG Library[1]
  - Submission of jobs by GridWay[2]
    - Phyton script for analysing partial results

[1] `http://www.nag.co.uk/numeric/FL/FLdocumentation.asp`

[2] E. Huedo *et al.* Software-Practice & Experience **34**, 631 (2004)

- **Testbed**
  - Local cluster
    - Euler
  - Grid
    - EGEE Infrastructure

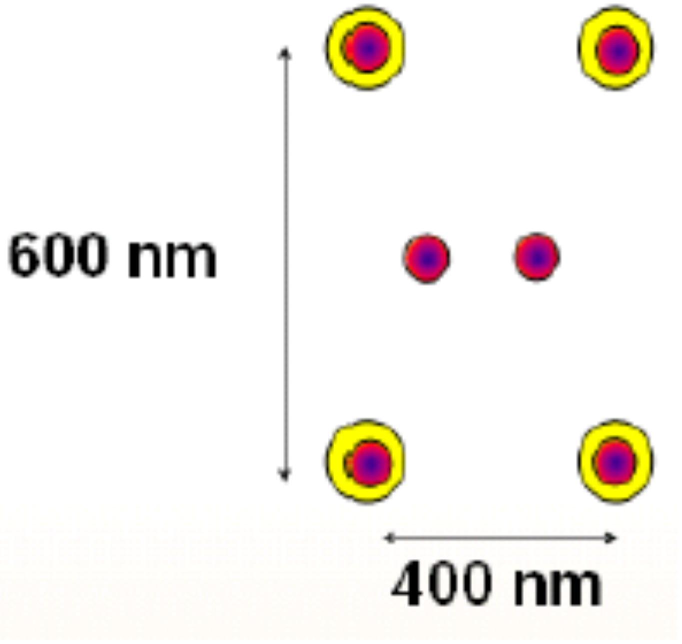


- **Euler characteristics**
  - 144 blades with 2 Xeon 5450 quad-core 3.0 GHz
  - 2 GB RAM/core
  - Double Infiniband 4X DDR
  - R_{peak} = 13.82 Tflops ; R_{max} = 10.98 Tflops
  - Queue policy
    - 104 free slots
    - Serial jobs < 70%

Name of the queue	Walltime [h]
pruebas	00 : 10 : 00
expres	02 : 30 : 00
normal	100 : 00 : 00
eterna	240 : 00 : 00

- **EGEE Infrastructure**
  - 29 sites
  - 16371 CPU
    - Free < 6010
    - Limitation of number of jobs per user
  - 90 < Number of slots < 110

- A physical result as an example…
  - MF = 3
    - Two inner vortices
    - Four vertex vortices
  - 400 x 600 nm^2
  - $U_{ij}(r_{ij}) = 5.83 \cdot 10^{-28}\ T^2m^2$

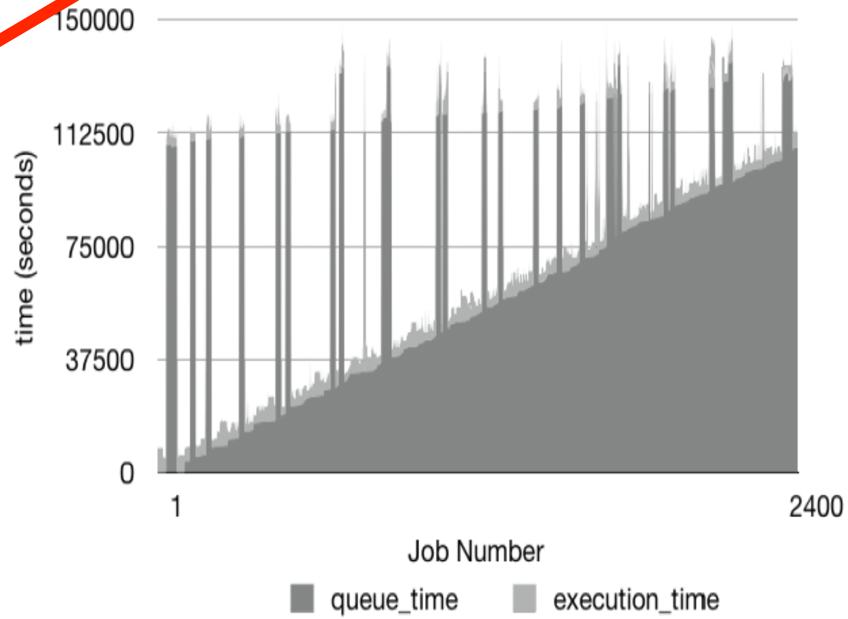


- **Comparison**

	Version	Slots	Acc. Hours	Speedup
Euler	Optimized	104	1601	86
Grid	Optimized	[90,110]	2998	22

The speedup is calculated from a hypothetical serial version

Ratio of 1.875

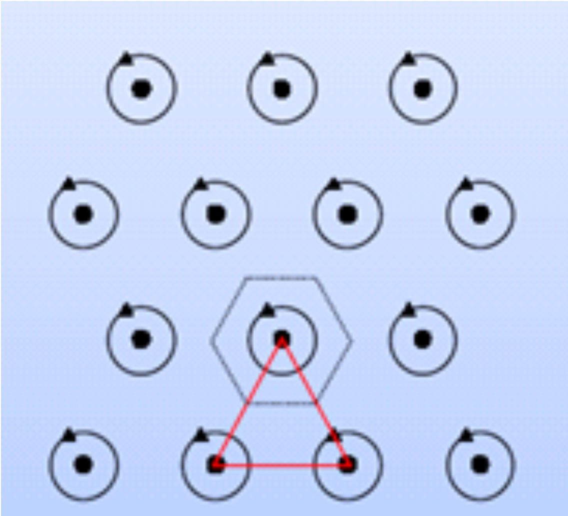


- **Heuristics**
  - Not all of them are useful
  - "Sum of distances" evaluation on a 60 x 40 lattice and Euler

MF	V_p	S_{Com}/S_{Opt}	Speedup
2	5	1.7	1.0
3	6	13.1	1.3
4	7	25108.2	7.8

  - Calculation of U_{ij} from intermediate previous positions
    - Number of candidates is reduced in a 90%...
    - …but execution time increases in a factor of 4 !!

- Conclusions
  - First approach for obtaining vortex lattice dynamics
    - Local clusters and Grid
- Improvements
  - Faster migration of Grid jobs (10')
  - New heuristics (SC & Solid State Physics)
  - New lattice geometries
    - Abrikosov
    - Surrounding lattices
  - New interactions
    - Vortex-pinning
    - Temperature



THANK YOU