SQUID Microscope read-out on a Josephson junction array

Cinzia De Leo and Giacomo Rotoli[§]

Università di L'Aquila,

Dipartimento di Energetica and [§] UdR I.N.F.M.,

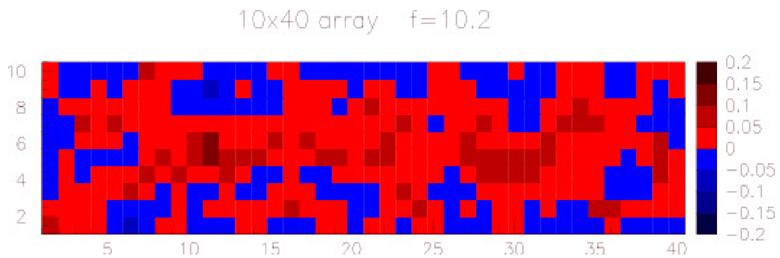
Località Monteluco I67041, L'Aquila, ITALY

ISEC'01, Osaka, June 19-22 2001
Poster # P1-B4

ISEC'01

OSAKA

JUNE 19-22 2001



Superconductivity group

Applied Physics Division

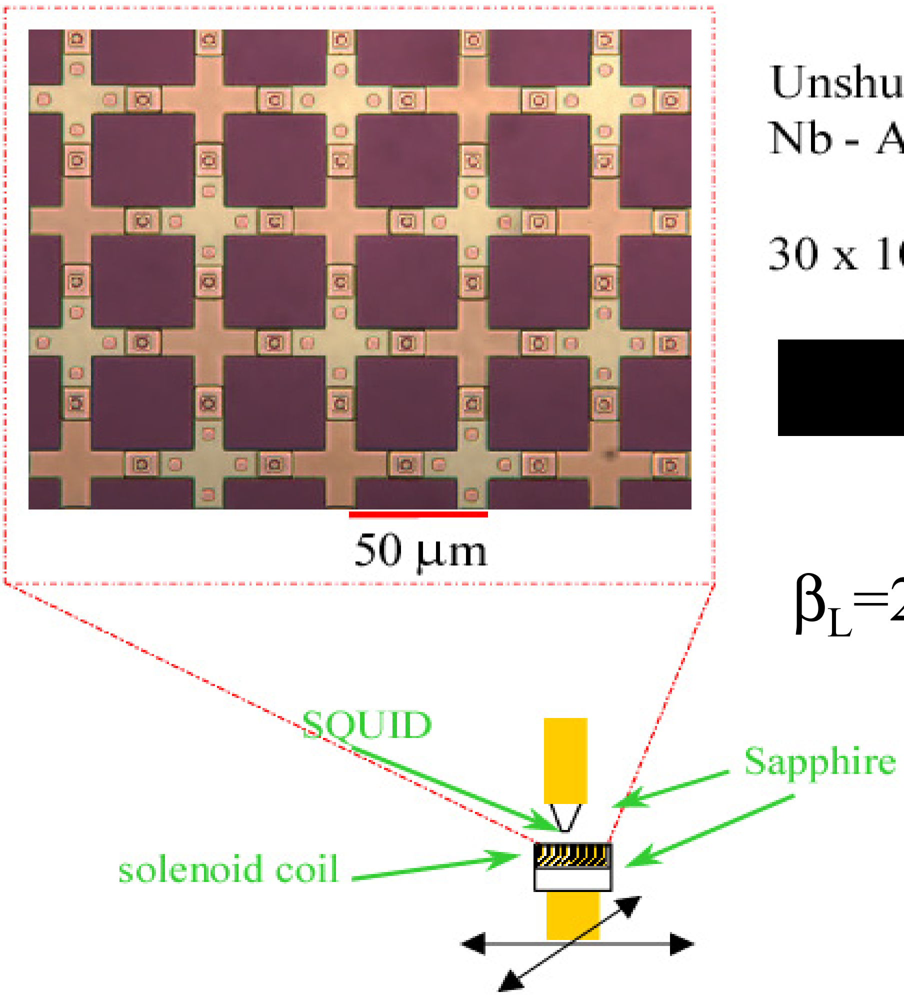
Dipartimento di Energetica

L'Aquila

Recent experiment shows paramagnetism in LTC JJA

CSR,
at College Park,
University of Maryland
A.Nielsen et al, [1]

Scanning SQUID Experiment



Unshunted Array
Nb - AlOx -Nb

30 x 100 junctions

[redacted]

$\beta_L = 2\pi L I_0/\Phi_0 = 30$

Sample is field cooled
Measured with field turned on

Arrays

Single Mesh

Both show dia and para states

1) mostly para for about f>3
2) small average magnetization apparently unrelated to β_L

1) 50% para & 50% dia with a clear dependence on frustation
2) (relatively) large magnetization evidently related to β_L

Arrays only

3) para and dia mesh coexist
4) dia meshes appears to be more dense at boundary

2D Array Equation in full mutual inductance approach:

We simulate a square array of 10x10 meshes.
The equations describing the array in vector notation read as (cf. ref.[2]):

$$\frac{\beta_L}{2\pi}\sin\vec{\varphi} + \sqrt{\frac{\beta_L}{\beta_C}}\,\dot{\vec{\varphi}} + \ddot{\vec{\varphi}} = \hat{K}\hat{L}^{-1}\vec{m}$$

$\vec{\varphi}$ is the vector containing the phases of junctions;
$\hat{K}$ is a matrix depending on the array geometry and
$\hat{L}$ is the full mutual inductance matrix of the array,
$\vec{m}$ represents the mesh magnetization and its expression is:

$$\vec{m} = \frac{\vec{\phi}_{tot}}{\Phi_0} - \frac{\vec{\phi}_{extt}}{\Phi_0} = \frac{1}{2\pi}\left(\hat{M}\vec{\varphi} + 2\pi\vec{n} - 2\pi\vec{f}\right)$$

$\vec{M}$ is an integer matrix performing (oriented) summing up the phases of each mesh; $\vec{n}$ is an integer vector and $\vec{f}$ is the normalized external flux in each mesh which modulus is the so-called frustation $f = \Phi/\Phi_0$?

Numerical Procedure

1. To simulate field cooling we integrate numerically the JJA equations starting by a given frustation *f* and increasing β_L in step until its final value 30.
2. After a proper time interval the phases are collected when the transitory effects in the dynamical terms wane out.

Details of the integration routine can be found in [3]

The prevailing response of N>5 array to field cooling procedure is found to be paramagnetic just for small values of frustation, e.g., for f>3

Far-field Construction

Once JJA Equations was solved the magnetization can be easily generated using its expression, but this vector represents magnetization of meshes on the array plane at *zero* distance from the array.

Naturally the SQUID is sampling not on the array plane but at a given distance z above it.

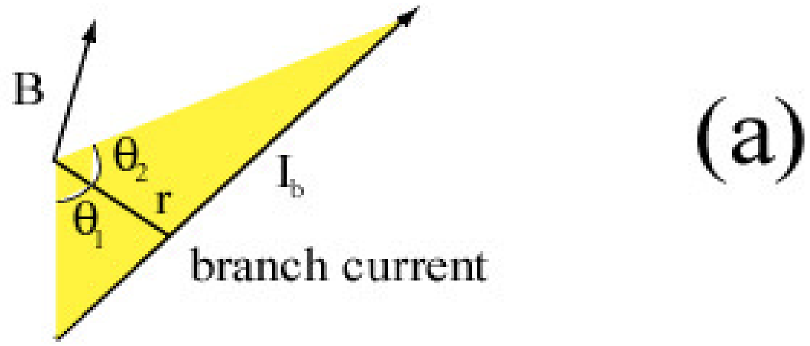
To have a faithful read-out is necessary calculate the JJA far-field. The magnetic far field of the array is made by superposition. For each branch we have [4] (cf. Fig.1a):

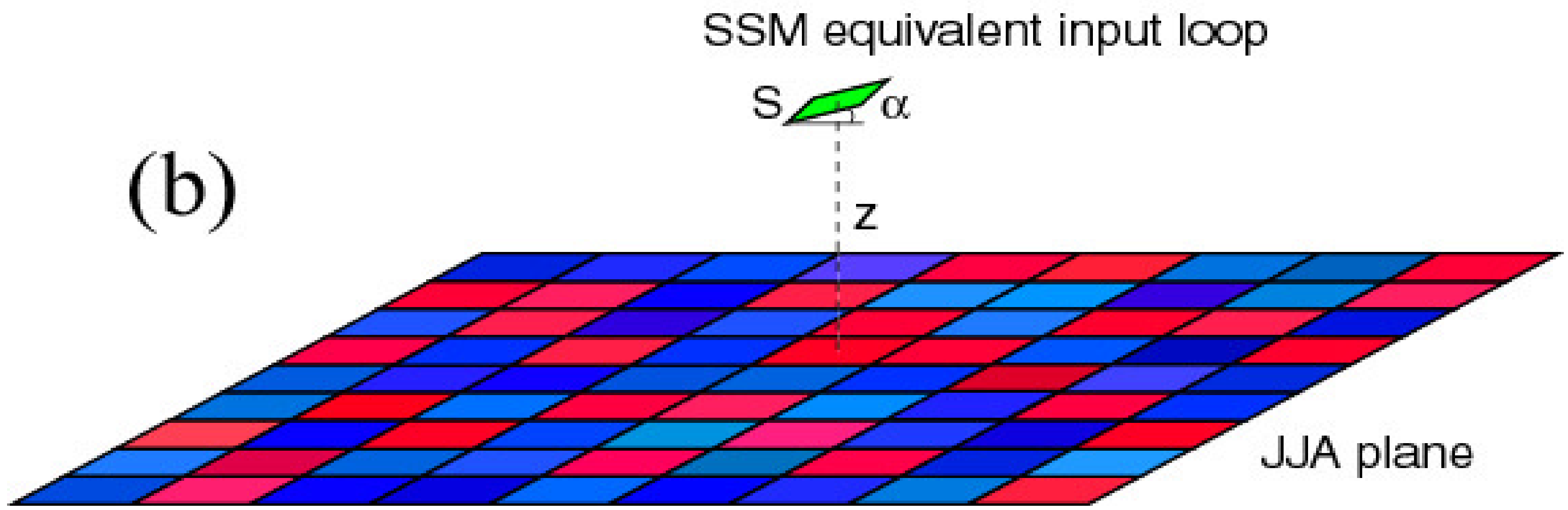
$$\vec{B} = \frac{\mu_0 I_b}{4\pi r}\left[\sin\theta_1 \pm \sin\theta_2\right]\hat{u}$$

After field is known it become possible evaluate the flux in a given loop of area S which center is placed at distance z with a tilting angle α over the array (cf. Fig.1b).

Far-field Construction (2)

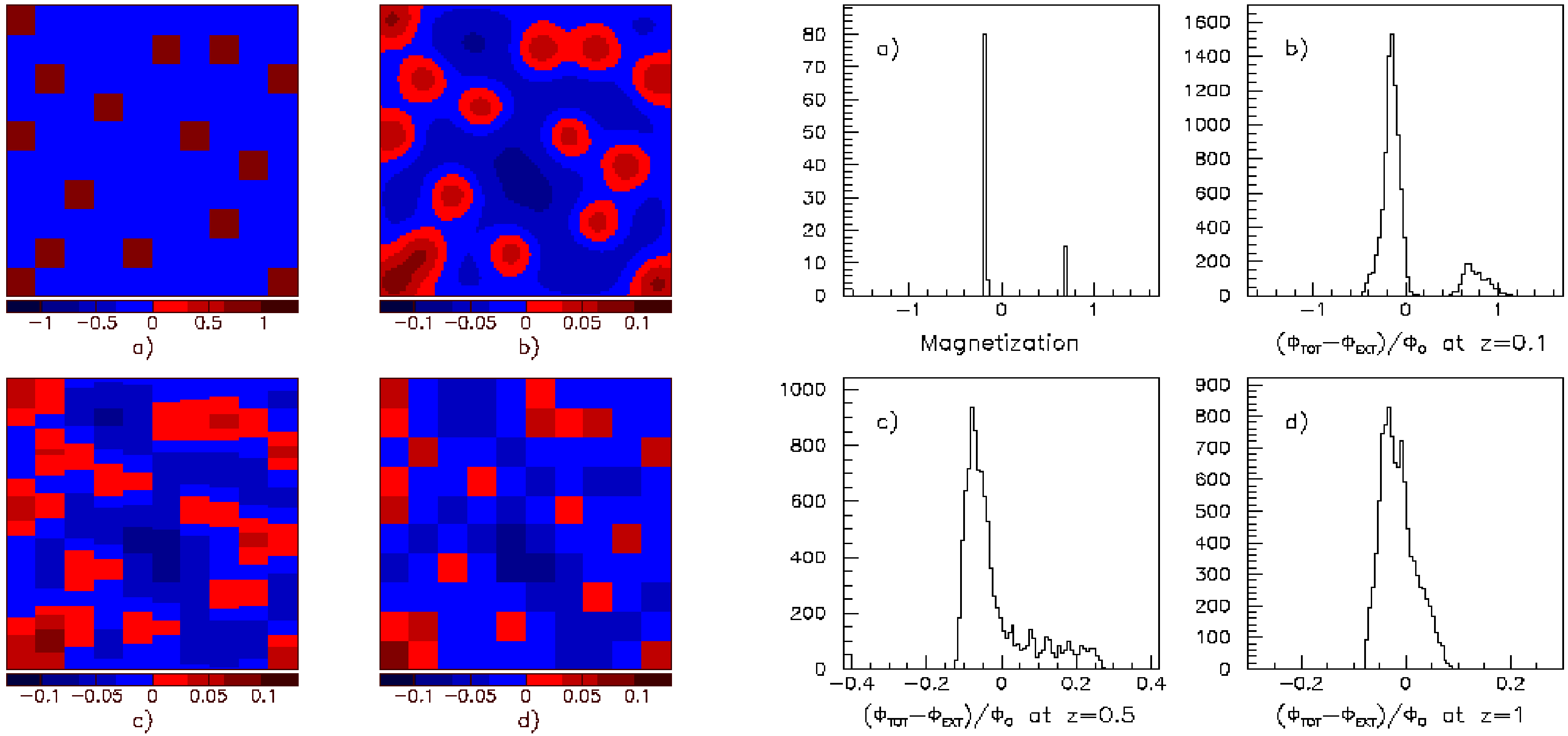
Fig.1





Simulated read-out for f=1.2

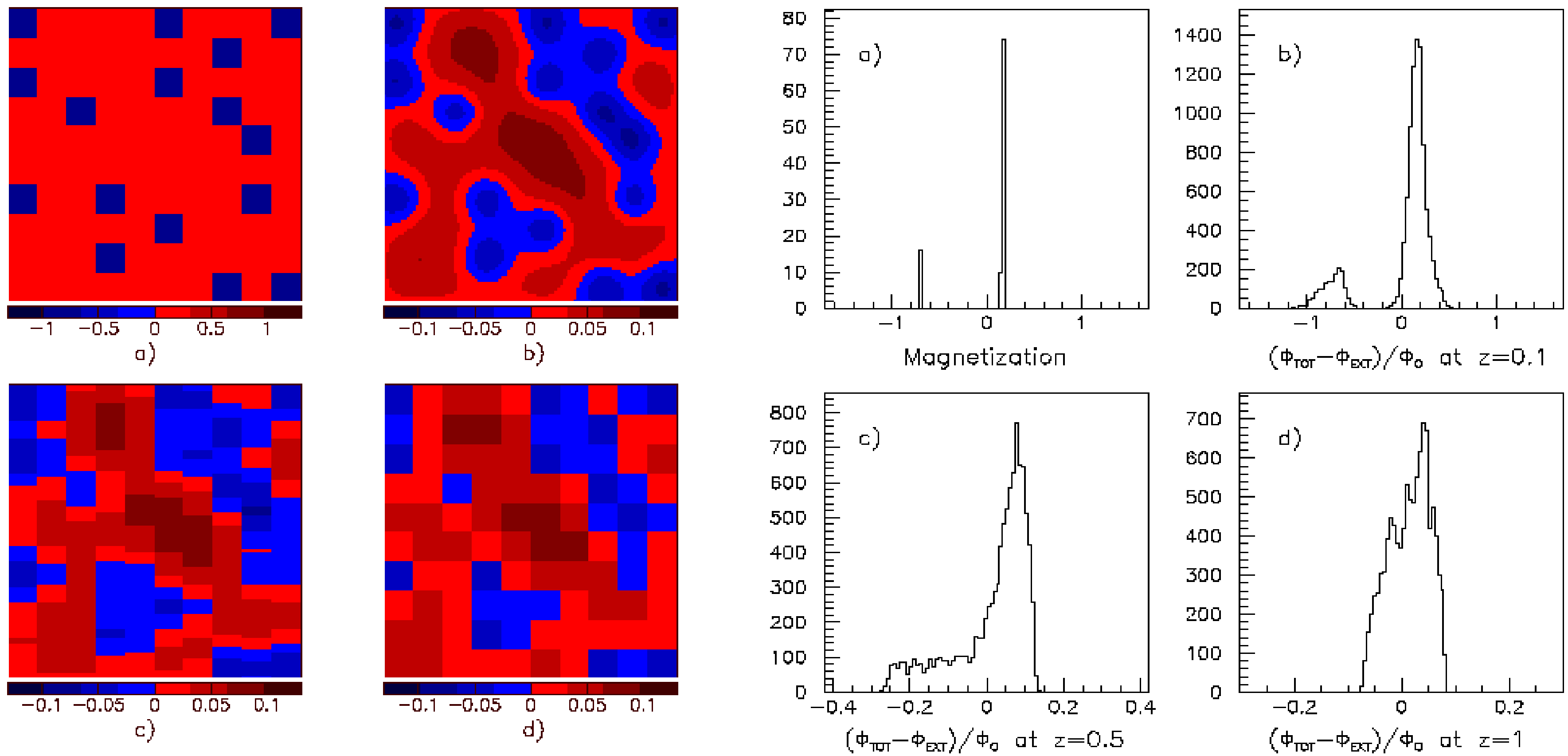
a) z=0; b) z=1, S=1/100, c) asymmetric samping; d) z=1, S=1.



Mean magnetization: $\langle m \rangle_0$=-0.0527, $\langle m \rangle_1$=-0.0148

Simulated read-out for f=4.8

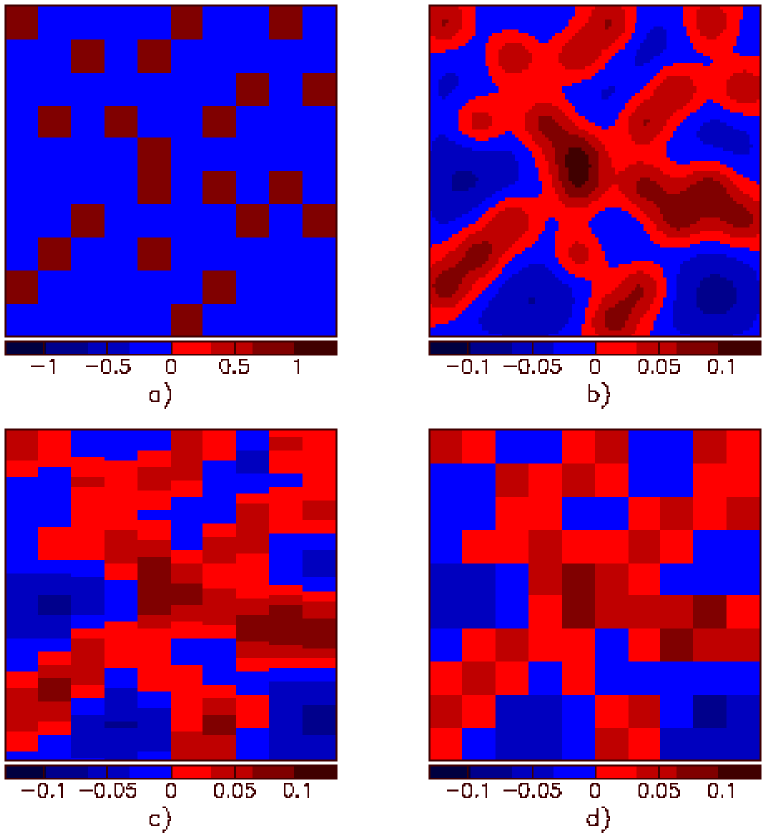
a) z=0; b) z=1, S=1/100, c) asymmetric samping; d) z=1, S=1.

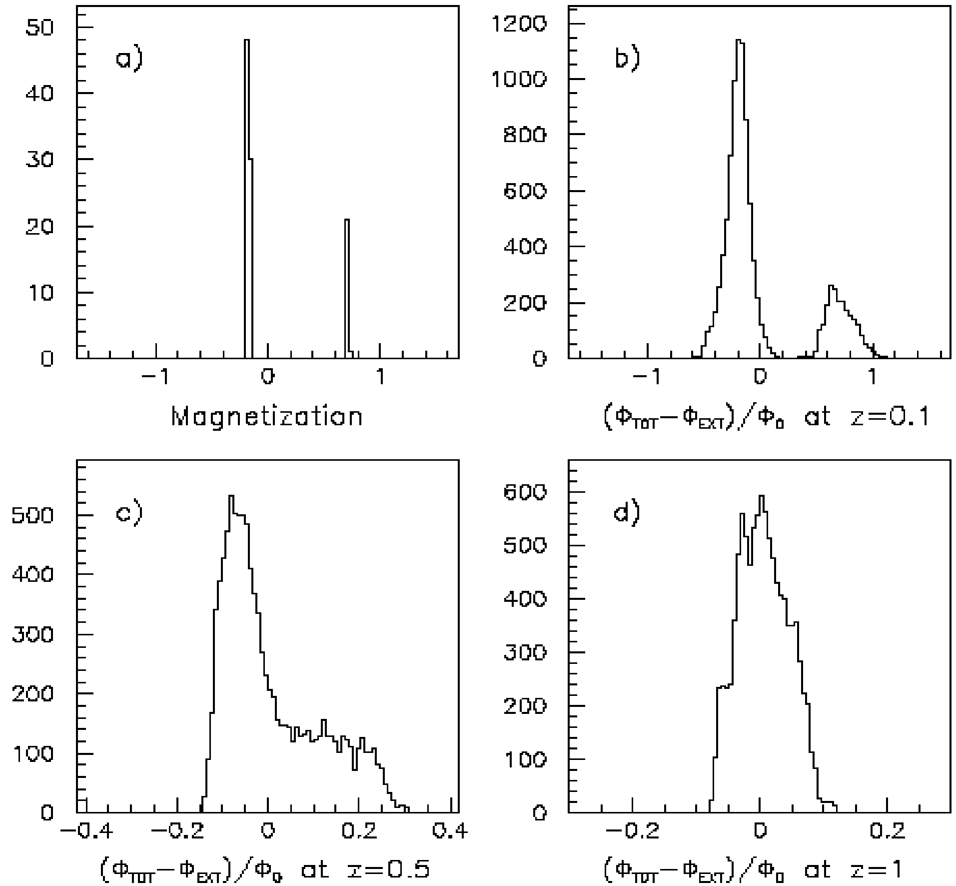


Mean magnetization: $\langle m \rangle_0 = 0.0431$, $\langle m \rangle_1 = 0.0133$

Simulated read-out f=12.2

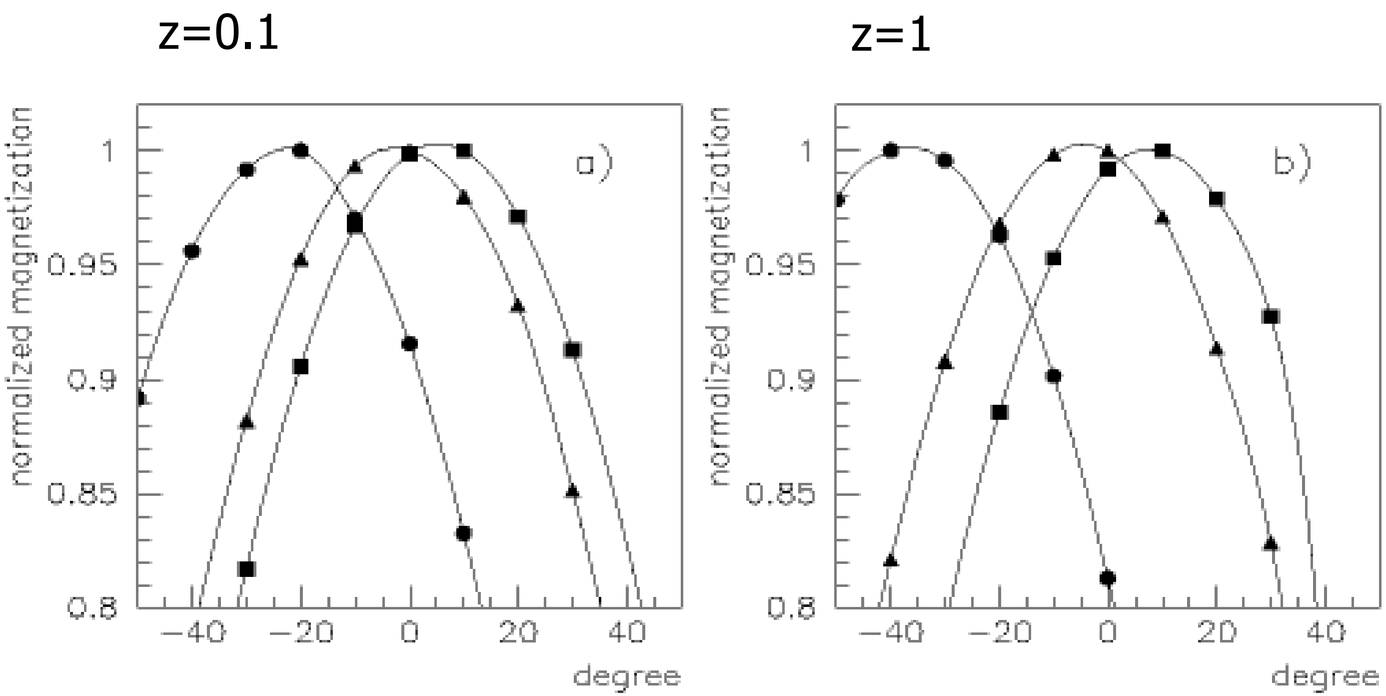
a) z=0; b) z=1, S=1/100, c) asymmetric samping; d) z=1, S=1.





Mean magnetization: $\langle m \rangle_0=0.0182$, $\langle m \rangle_1=0.0065$

Tilt angle effect



Triangles f=1.2
Squares f=4.8
Circles f=12.2

Noise Effect

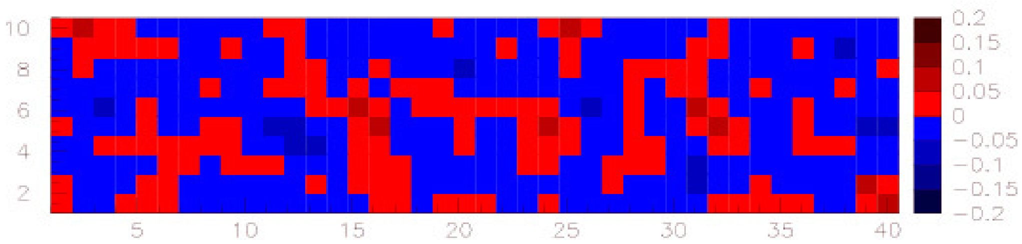
To obtain SSM simulated images comparable with experiments is necessary to make the random choice of the vector of quantum numbers $\vec{n}$.

The reason for this procedure is the following: at the beginning of the simulation Josephson energy is very small so thermal noise is dominant and can put random phase-slips in the array, these corresponds to give a random distribution of quantum numbers n over the array.

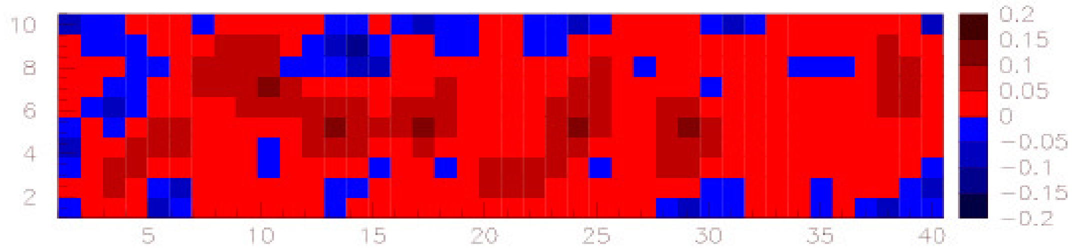
This distribution is frozen when the Josephson barriers overcomes the thermal noise. The variation of the mean magnetization for the change of distribution of quantum numbers was evaluated to be roughly of 2% at least for the number of statistical realizations we have simulated which here is of 10-12 for each frustation value. The result is the same for larger array [2]-[5], though due to long CPU times the number of realization is roughly halved.

Simulations on a 10x40 array (ref.[2], subm to PRB), here z=0,1 and S=1

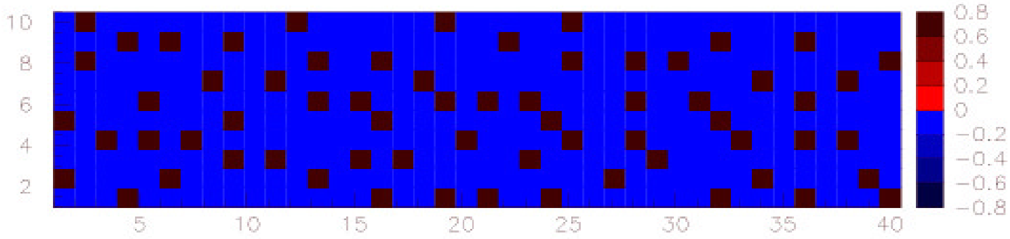
10x40 array f=1.2



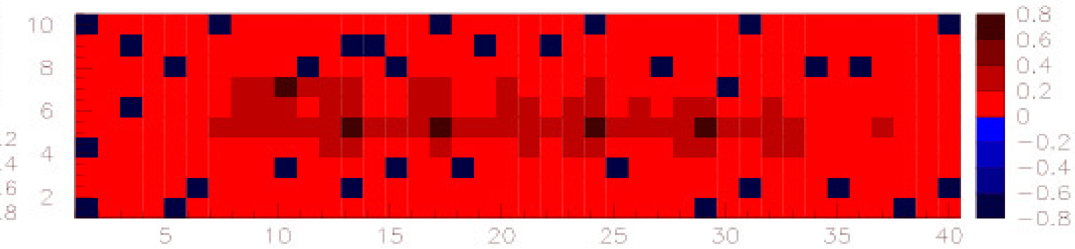
10x40 array f=4.8



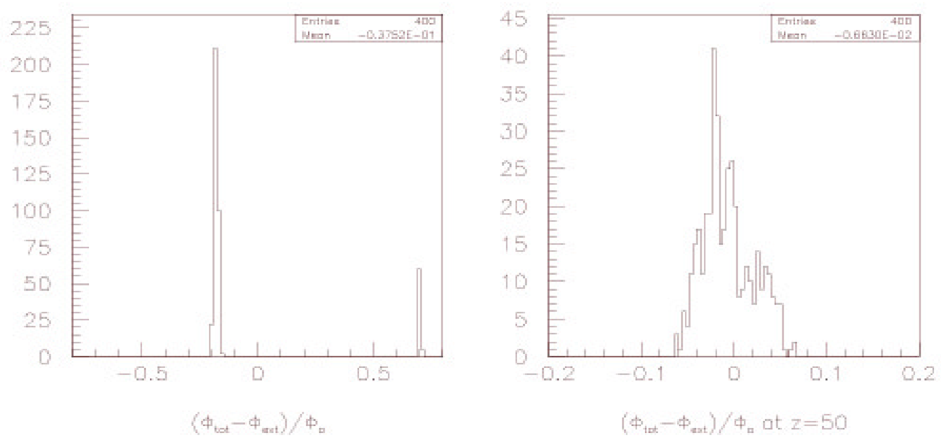
10x40 array f=1.2



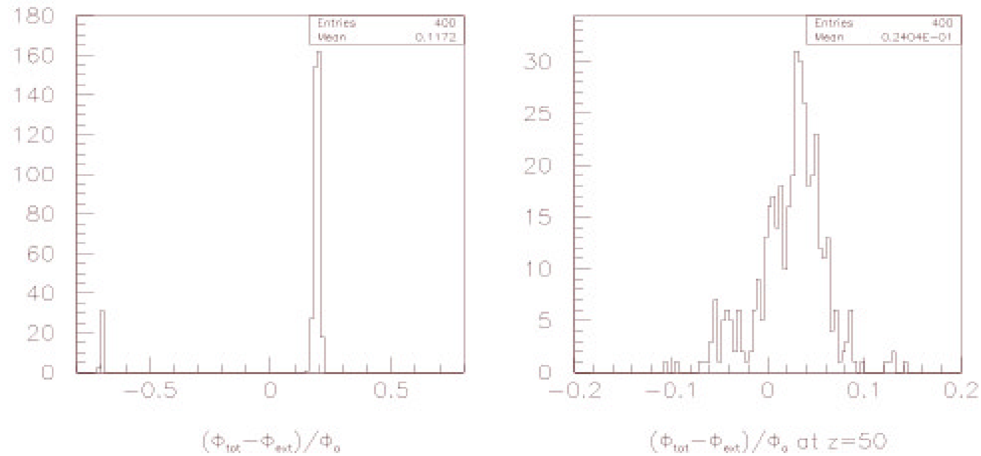
10x40 array f=4.8



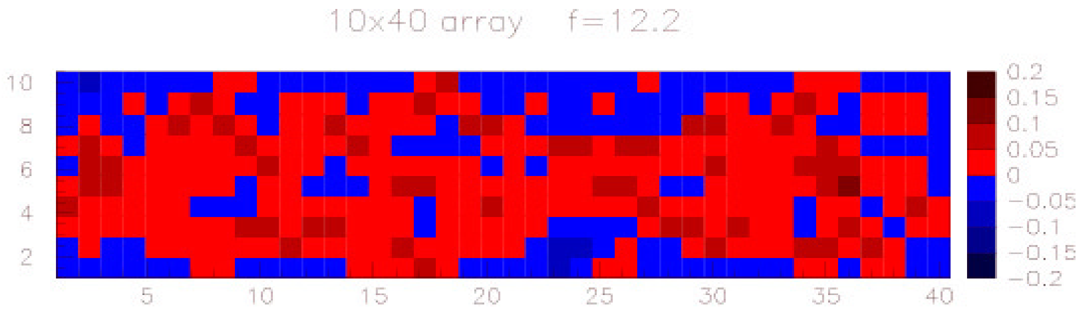
10x40 array f=1.2

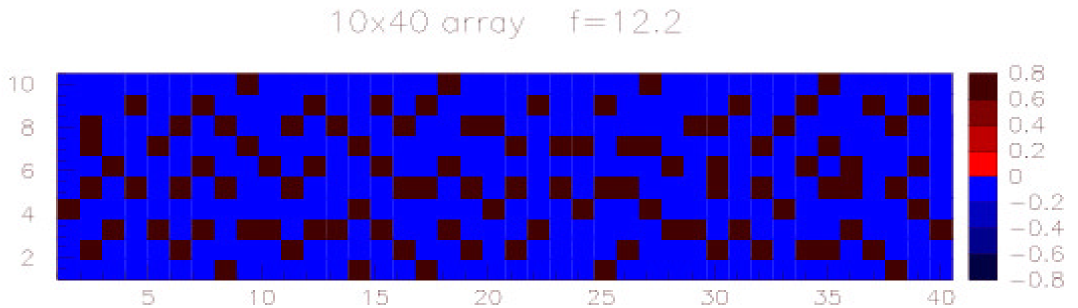


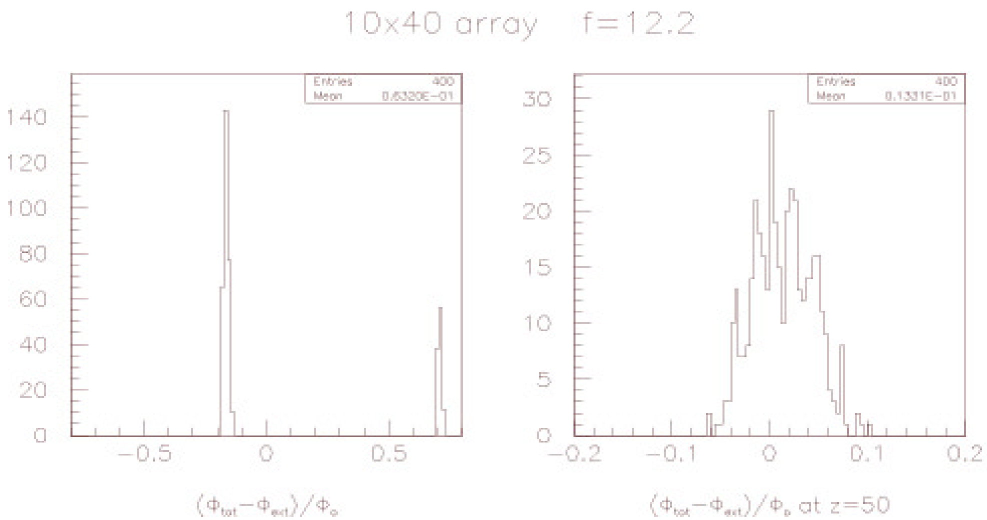
10x40 array f=4.8

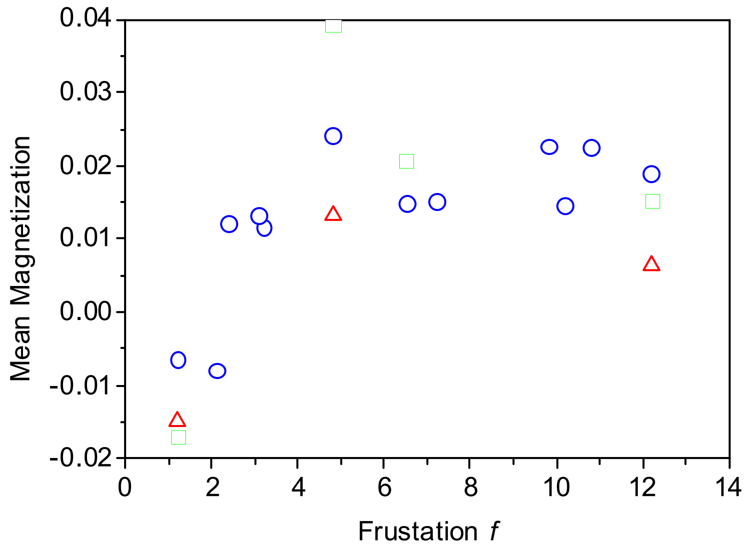


Simulations on a 10x40 array (ref.[2], subm to PRB)









Mean magnetization for the simulation in ref.[2] (circles) plus the three frustations values used here for 10x10 arrays (triangles) plus the three frustation of ref.[5].

Conclusion

We have shown by means of numerical simulations of field cooling experiments over LTC-JJA how magnetic images of the array taken by a SSM are influenced by resolution, distance and tilting of the input SQUID loop.
Beyond this a number of improvements and further studies can be suggested. Among these the study of paramagnetic response via magnetic images of more complex situation, e.g., disordered JJA or arrays containing the so-called π-junctions, is the most promising.

Acknowledgements

We thank warmly P.Barbara, A.P.Nielsen and C.J.Lobb for useful discussions and suggestions. This research was supported by Italian MURST Cofin2000 Project *Dynamics and Thermodynamics of vortex structures in supeconducting tunneling*.

References:

[1] A.P.Nielsen et al., Phys.Rev.B**62**, 14380, 2000

[2] C.De Leo et al., subm Phys.Rev.B, cond-mat/0103199

[3] G.Filatrella, A.Petraglia and G.Rotoli, Eur.J.Phys.B**12**, 23, 1999

[4] E.Durand, *Magnetostatique*, Masson, Paris 1953.

[5] C.De Leo and G.Rotoli subm to Studies of High Tc Superconductors, A.V.Narlikar and F.Araùjo-Moreiro ed.s

Contact:
e-mail: rotoli@ing.univaq.it
web: http://ing.univaq.it/energeti/research/Fisica/supgru.htm