Magnetic field dependence of low-frequency flux noise and spatial distribution of vortices in YBCO dc Squids

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Outline

- Motivation
- Vortex imaging - signal generation
- Results: vortex imaging & correlation with 1/*f*-noise
  - Single layer devices
  - Multilayer devices
- Conclusions

High T_c SQUIDs: noise limitations

- ✗ white (thermal) noise is low ✓
- ✗ low frequency noise can be high:

  ☛ improve for applications

Nature of low frequency noise:

- ➤ I_c-fluctuations of Josephson junctions ✓
- ➤ thermally activated motion of vortices

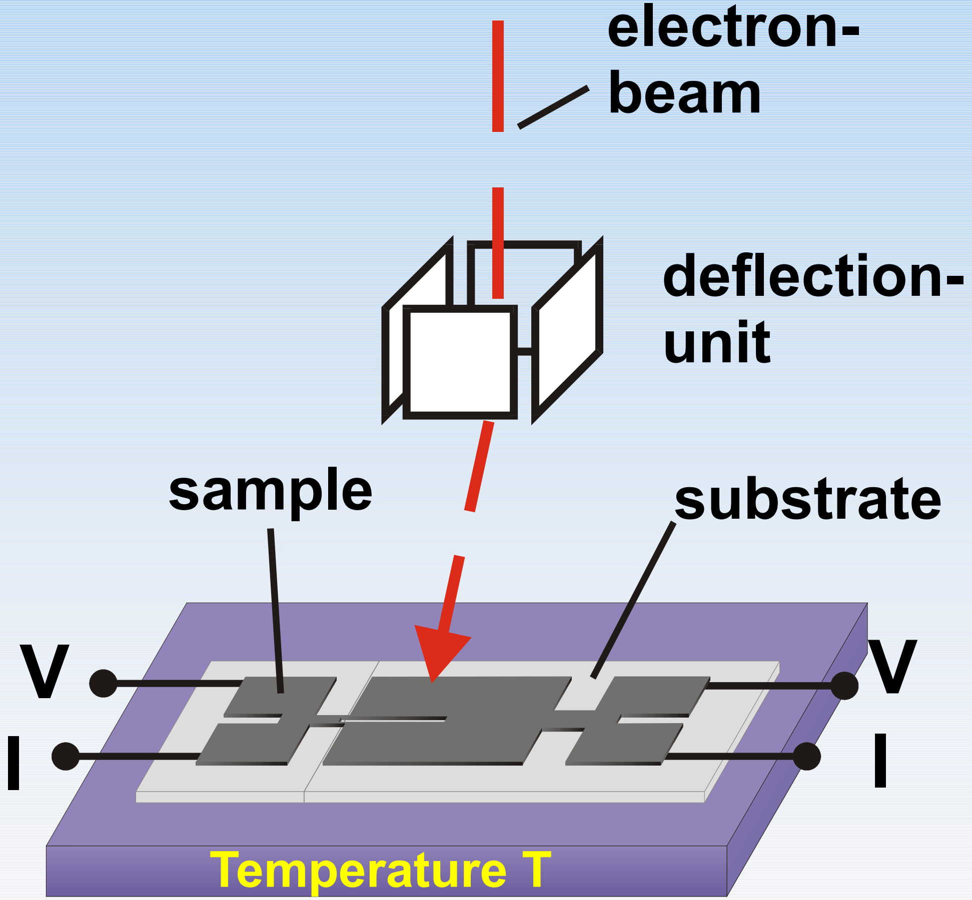
☛ **Defects !!!**

Flux noise ⇔ local property

- ✗ where do vortices go?
  - ➥ vortex imaging
- ✗ flux coupling to SQUID?
  - ➥ measure coupling strength $\delta\Phi/\delta r$
- ✗ fluctuation strength?
  - ➥ spectral density of spatial fluctuations S_r

➡ Local analysis via Low Temperature Scanning Electron Microscopy (LTSEM)

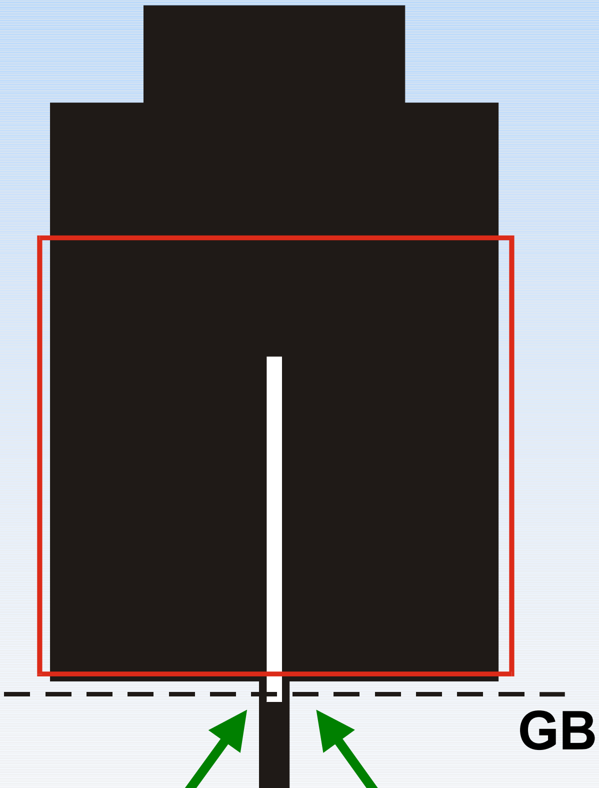
LTSEM on SQUIDs



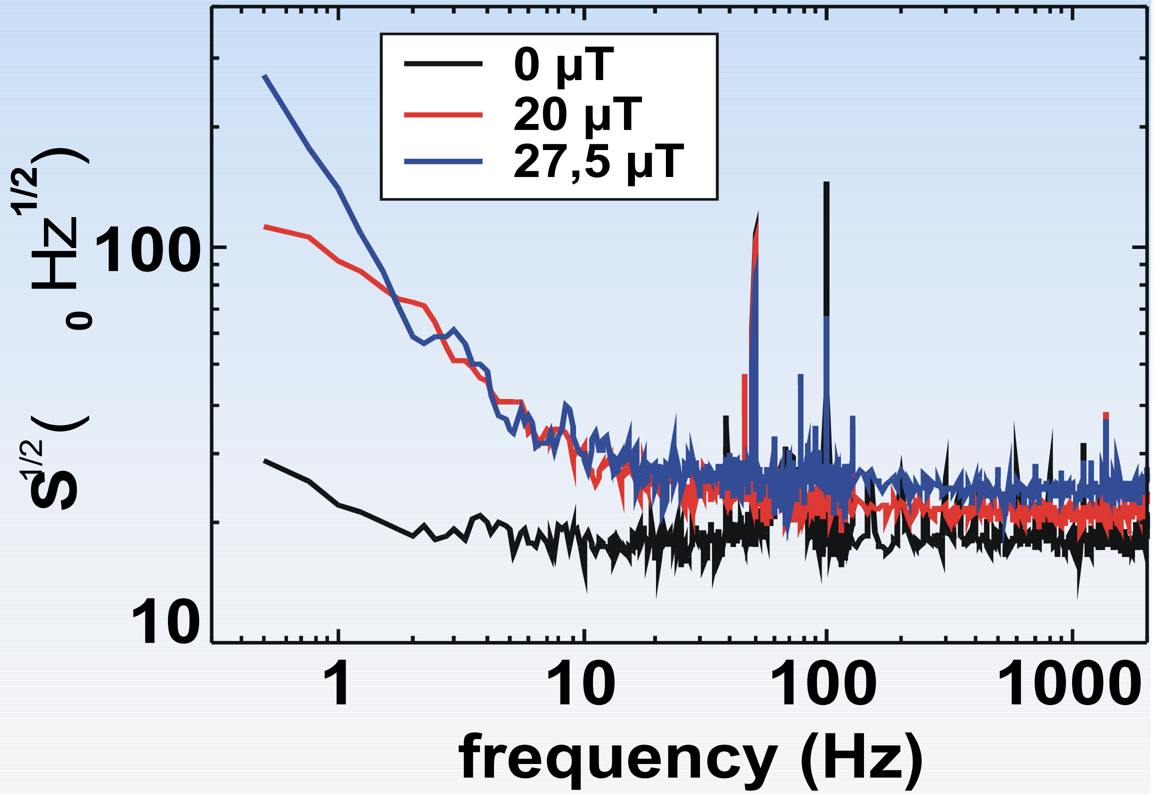
- $77\ K \leq T \leq T_c$
- $B \leq 1$ mT stabilized via YBCO cylinder
- flux locked loop provides $V \sim \Delta\Phi$
- noise measurement inside LTSEM

Samples and noise measurements

YBCO dc SQUID

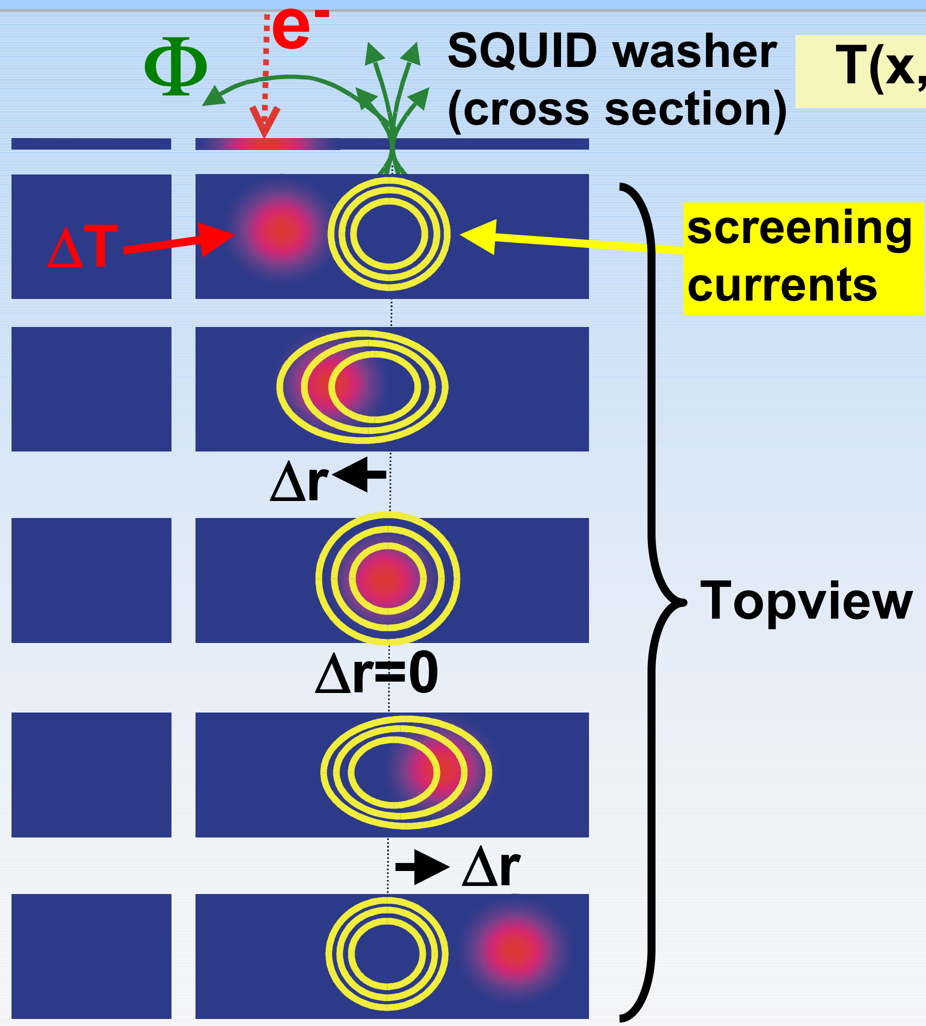


typical noise measurements

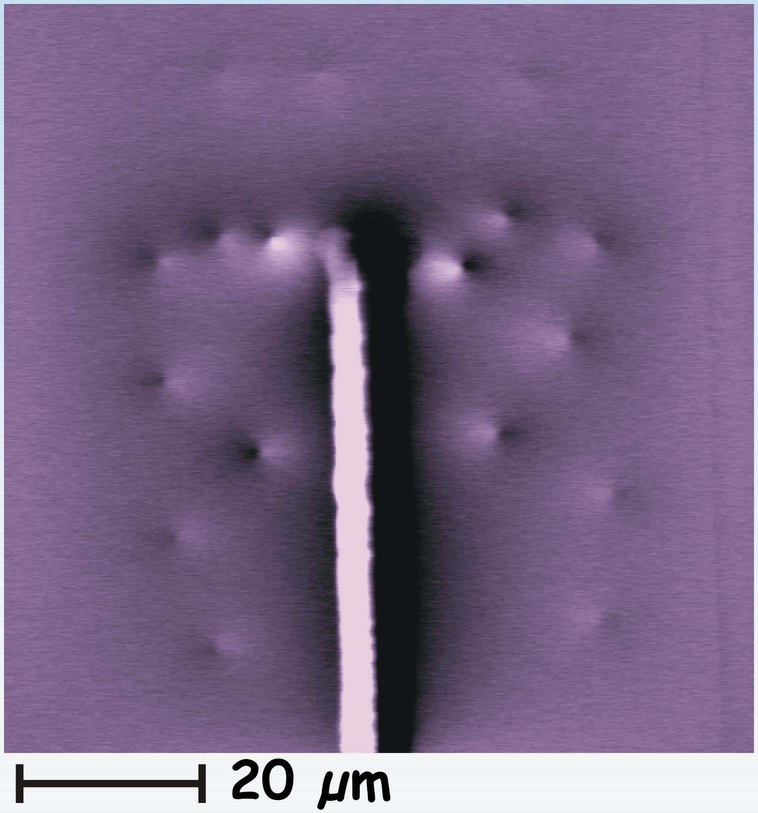


Vortex imaging

T(x,y) → (x,y) → r(x,y) → (x,y)



ΔΦ-image



Signal vs position of vortex

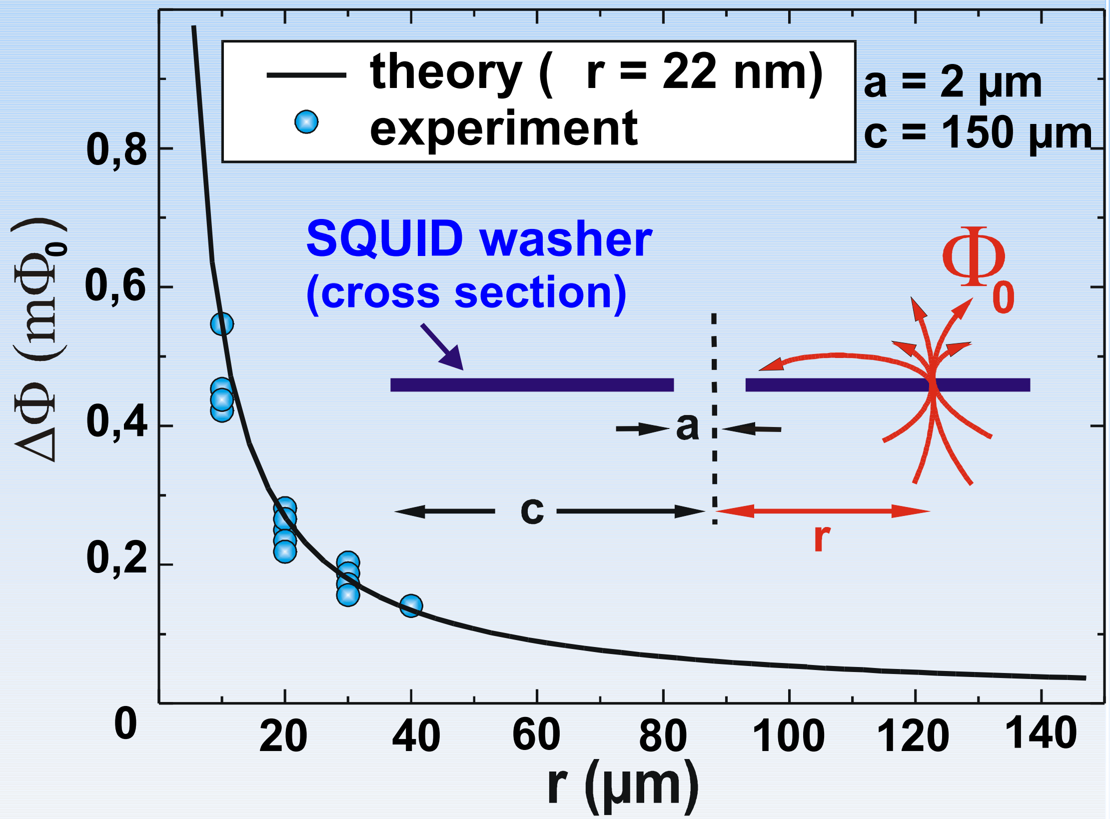
- ✗ spatial resolution: ~1 μm
- ✗ signal:

  $\Delta\Phi = (\delta\Phi/\delta r)\,\Delta r$

- ✗ noise from a vortex:

  $S_\Phi = S_r (\delta\Phi/\delta r)$

  average radial vortex hopping distance (~Å)

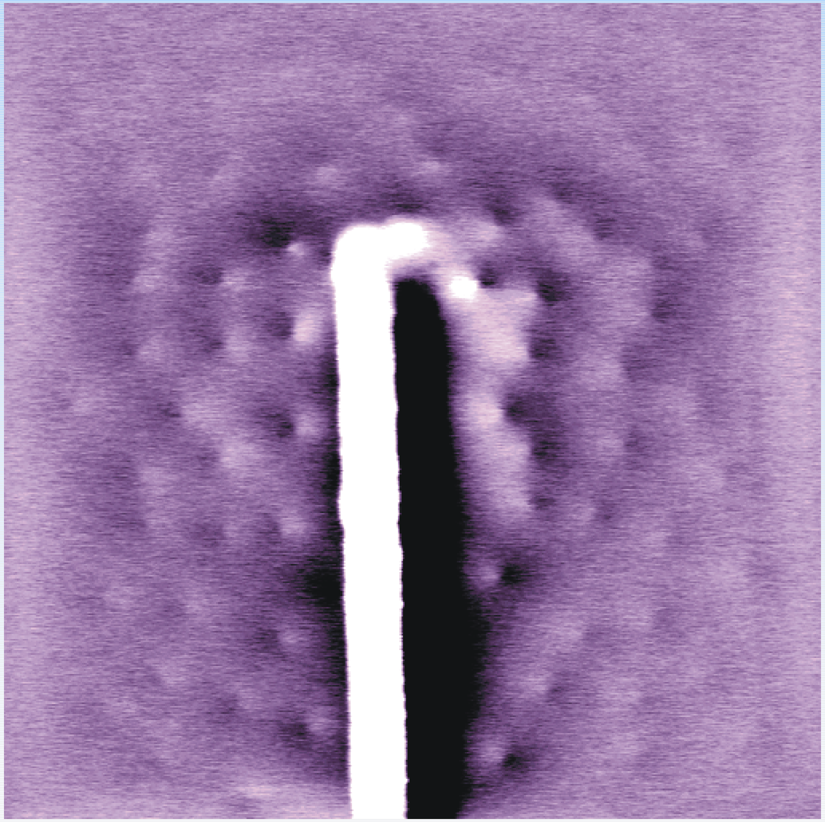


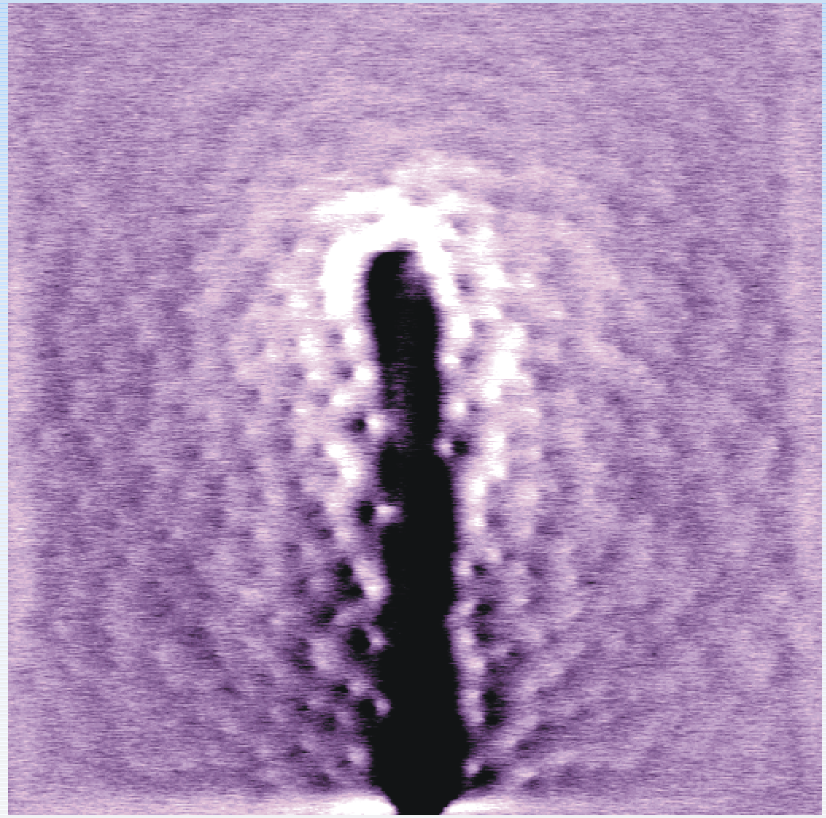
Δr: beam induced vortex displacement

r: radial distance of vortex from SQUID-hole

Vortex images

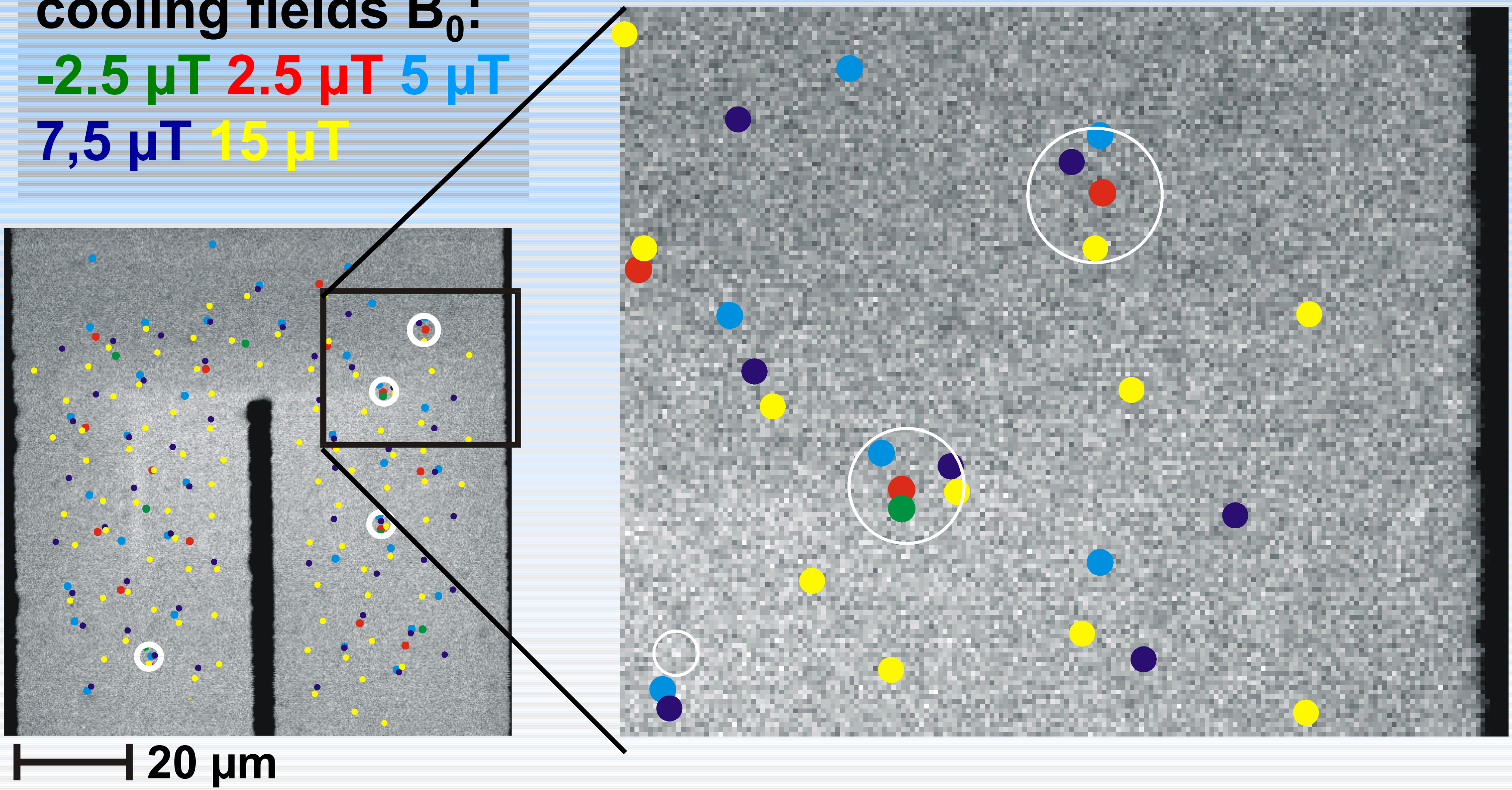
cooling field B_0= 5 µT **20 µm** **B_0= 35 µT**





Locations of vortices

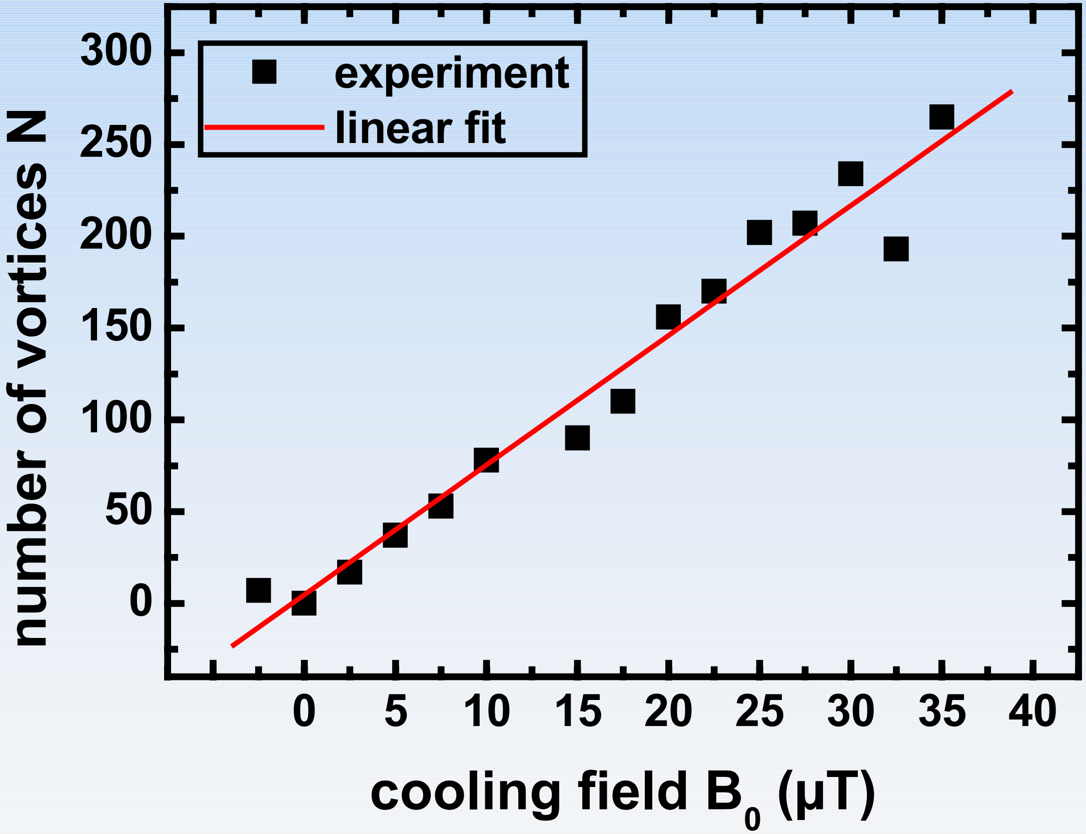
cooling fields B_0:
-2.5 µT 2.5 µT 5 µT
7,5 µT 15 µT



Number of vortices N ⇔ cooling field B_0

- **Expected:**
  number of vortices
  ~ cooling field B_0

- **Found:**
  $N \approx B_0 \cdot A/\Phi_0$
  i.e. no Meissner-screening



Low-frequency noise power @ 1Hz

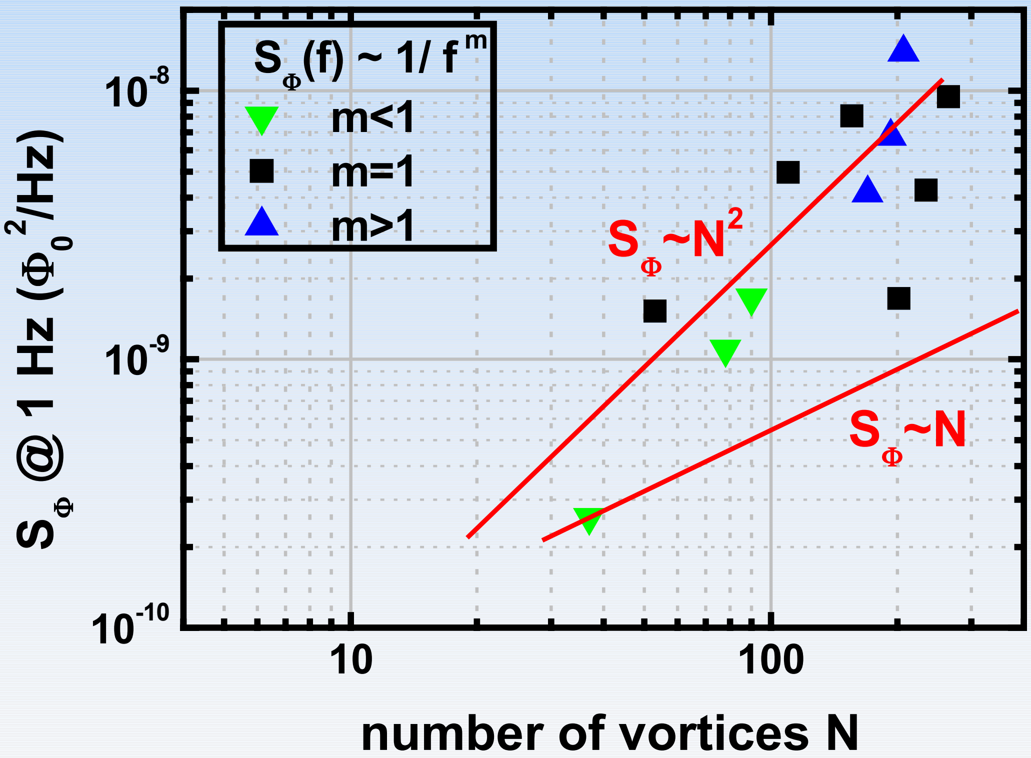
Simple model:

- ✗ vortices uncorrelated
- ✗ vortices distributed uniformely

$$S_\Phi \sim N \sim B_0$$

Result:

deviation from $S_\Phi \sim N$



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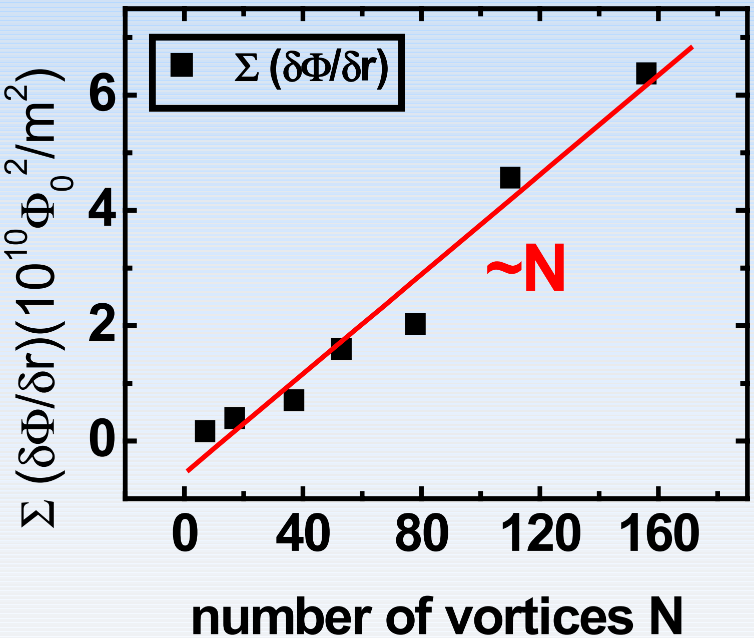
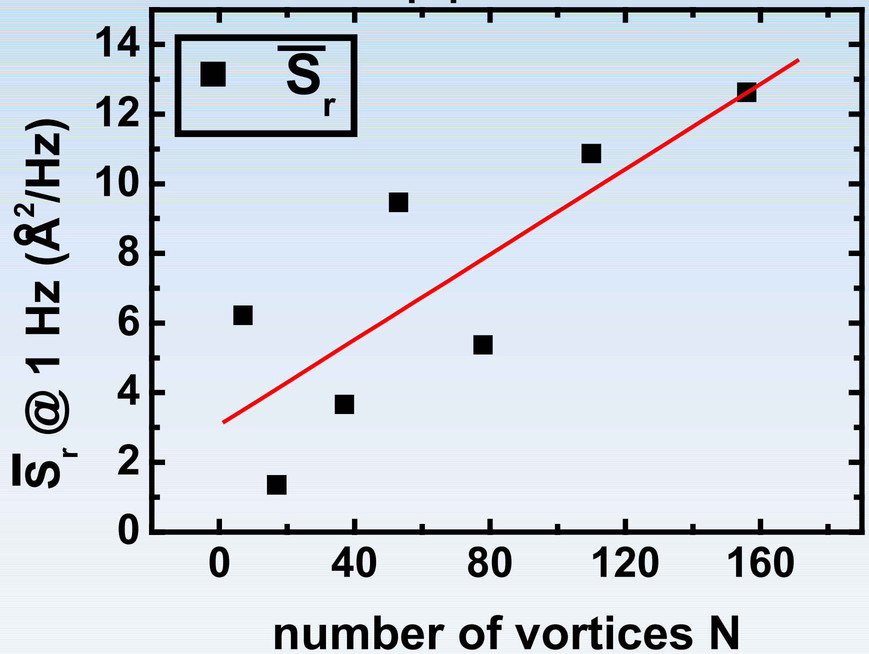
Test of the model

single vortex: $S_{\Phi i}=S_{ri}\cdot(\delta\Phi/\delta r)_i$

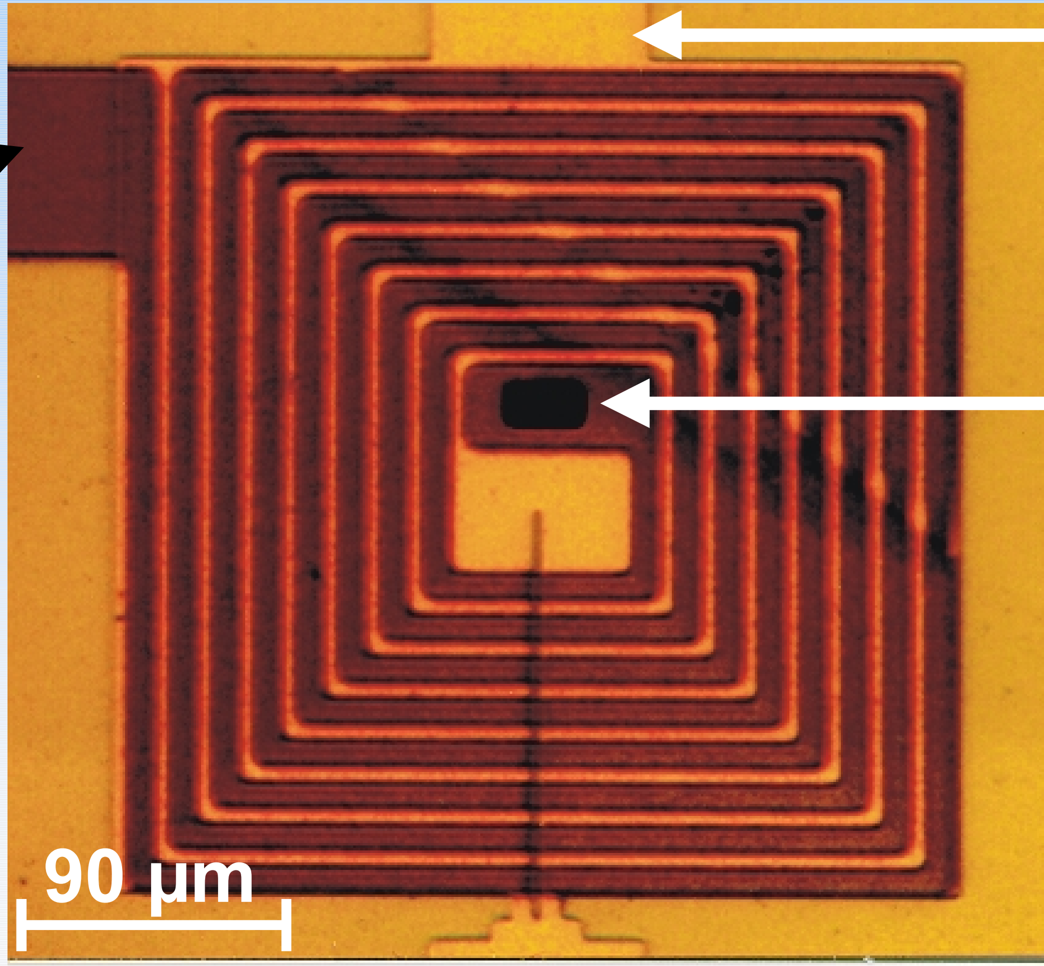
many vortices: $S_{\Phi} = \sum_{i=1}^{N}\left(S_{ri}\cdot(\delta\Phi/\delta r)_i\right) \approx \overline{S}_r\cdot\sum_{i=1}^{N}(\delta\Phi/\delta r)_i$



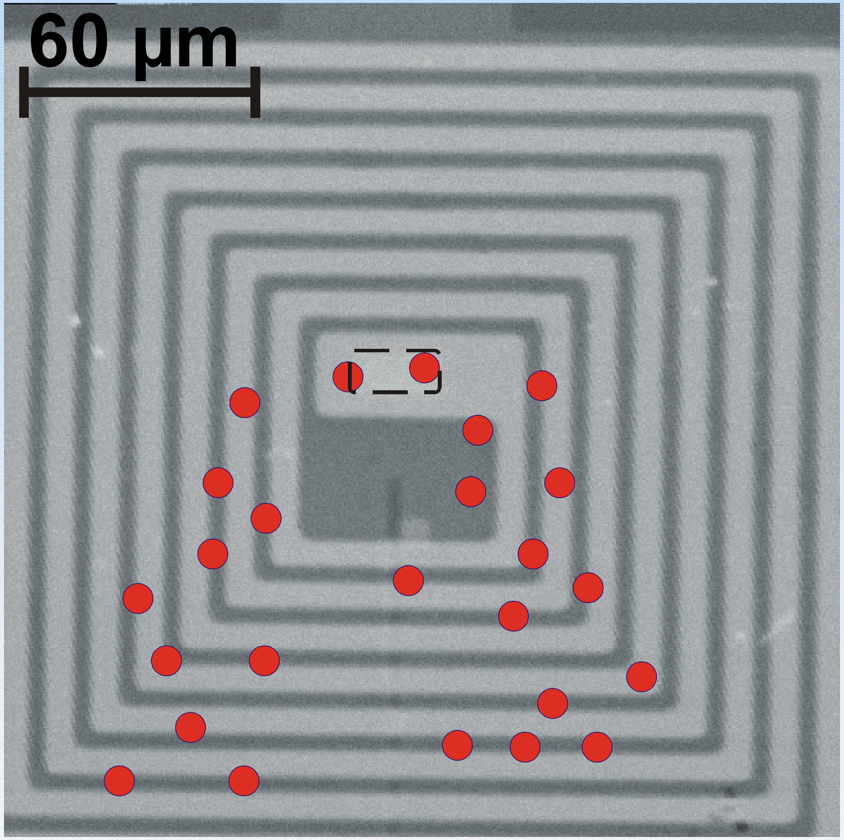


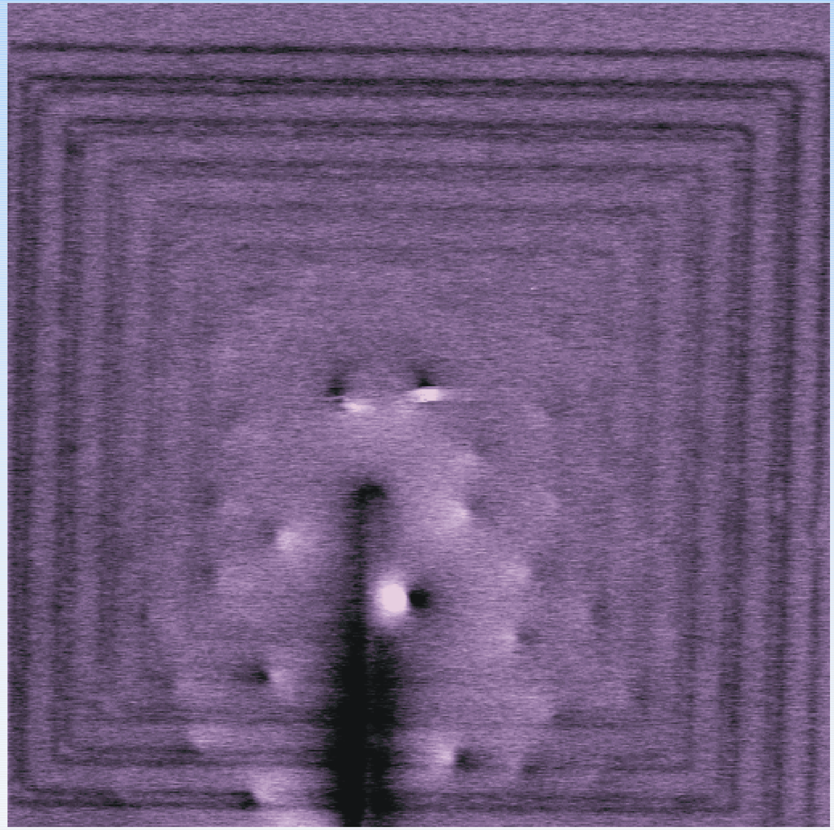
average radial hopping distance @ 1 Hz: 1-4 Å

Washer dc SQUID with input coil



SEM-image vs flux image

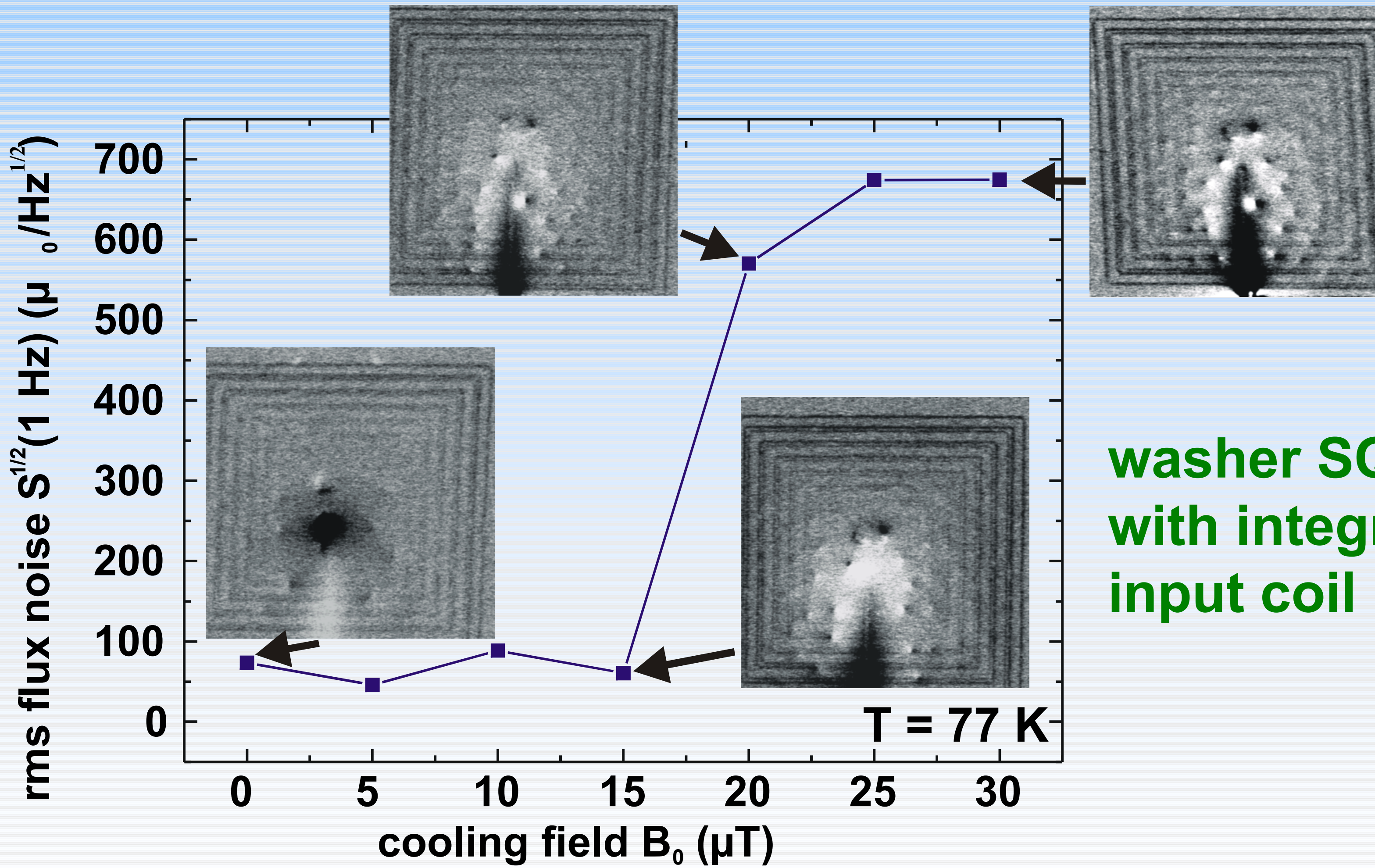




● position of vortex

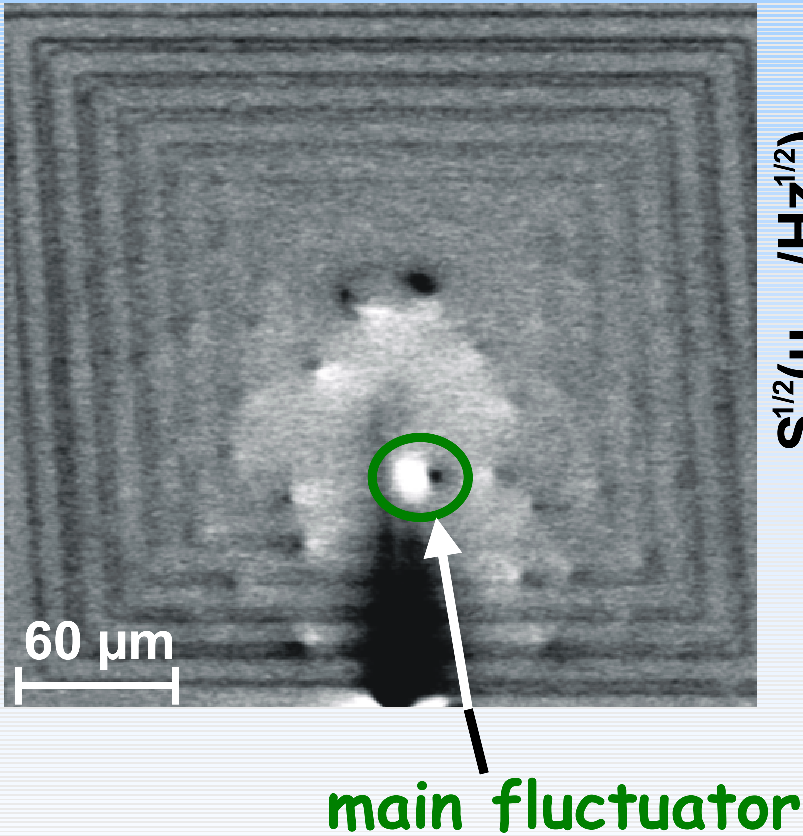
B_o= 20 µT T = 77 K

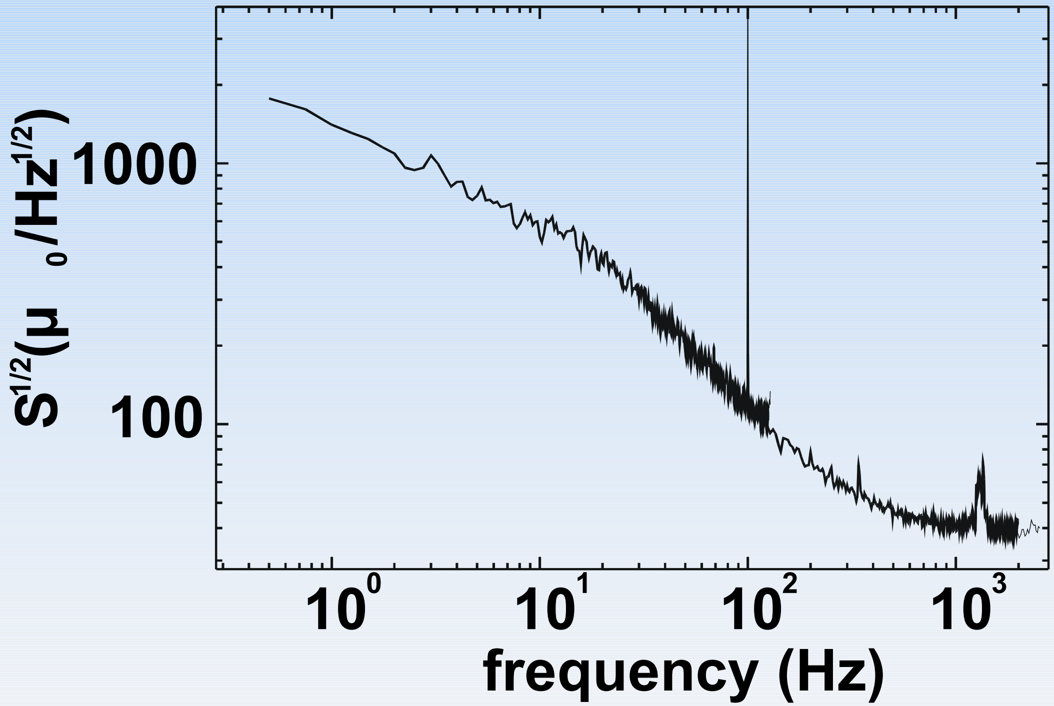
Flux noise at 1 Hz vs cooling field B_0



washer SQUID with integrated input coil

Identification of main fluctuator





Conclusions

spatially resolved analysis of high T_c SQUIDs by LTSEM

- imaging of vortices (~1µm spatial resolution)
- coupling strength ($\delta\Phi/\delta r$) of vortices
- correlation with low frequency noise
  - determination of $\bar{S}_r$
  - identification of noise sources

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