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Electronic Devices, Invited talk, ISS 2017, Tokyo, Japan

Superconducting devices based on coherent operation of Josephson junction arrays above 77K

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Collaborators

Loughborough University

Experimental: PhD/postdoc, Daniel John
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Master students: Matthew Kemp, Jeffrey Brown, Richard Pollett

Theory: PhD Jonathan Cox,
Prof. Sergey Savelev

Nottingham University: Christopher Mellor

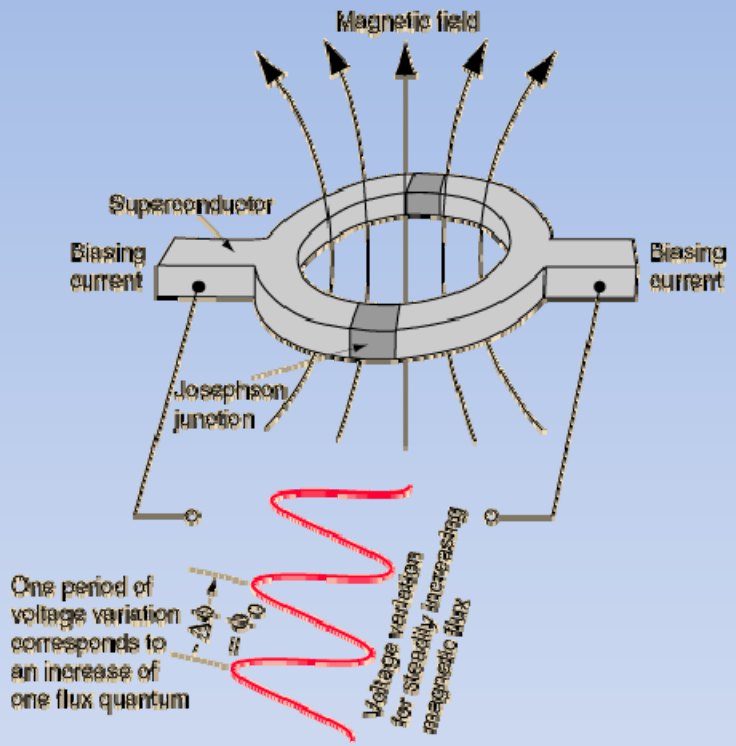
Outline

- SQUID-arrays @ 77 K better than single-SQUID @ 4.2 K
- First flux-flow microwave generators @ 77K
- Josephson vortex-flow transistors with record amplification @ 77K
- reversible flux-flow ratchets

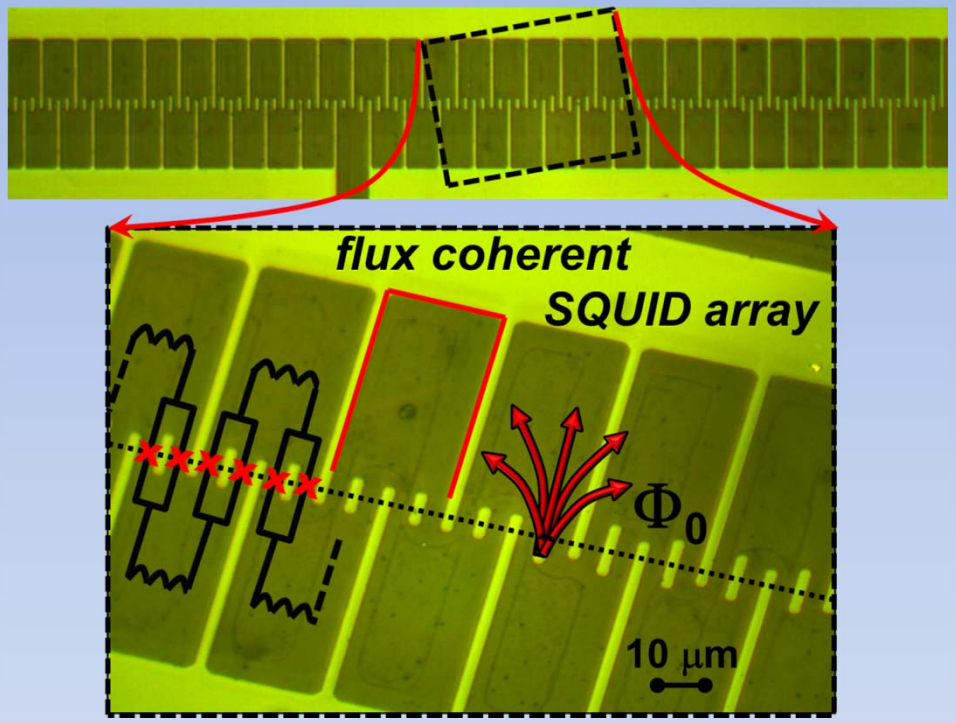
SQUID-arrays @ 77 K better than single-SQUID @ 4.2 K

SQUID arrays

SQUID



N SQUID array



B. Chesca, American Institute of Physics, press release October 2015:
https://publishing.aip.org/publishing/journal-highlights/hot-new-development-ultracold-magnetic-sensors

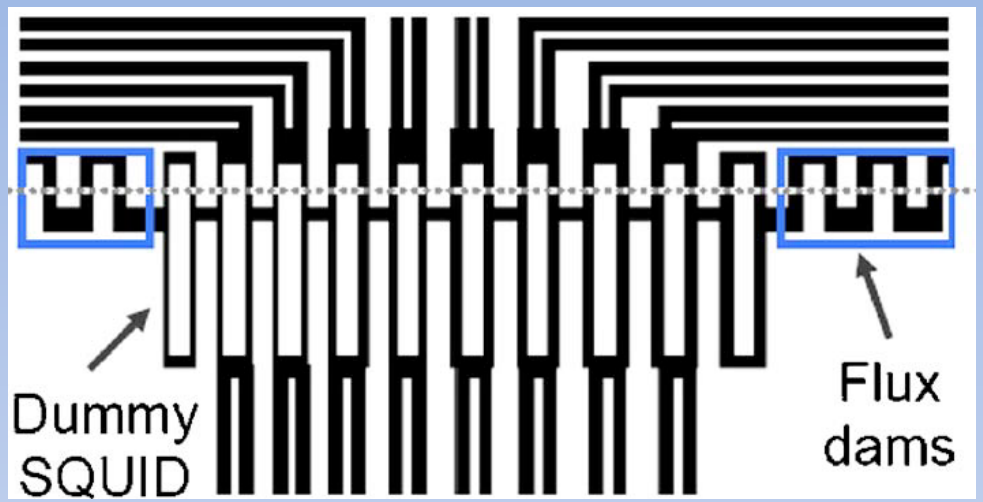
$$\text{Noise}_{\text{Array}} = N^{1/2}\,\text{Noise}_{\text{SQUID}}$$

$$V_{\text{Array}} = N\,V_{\text{SQUID}}$$

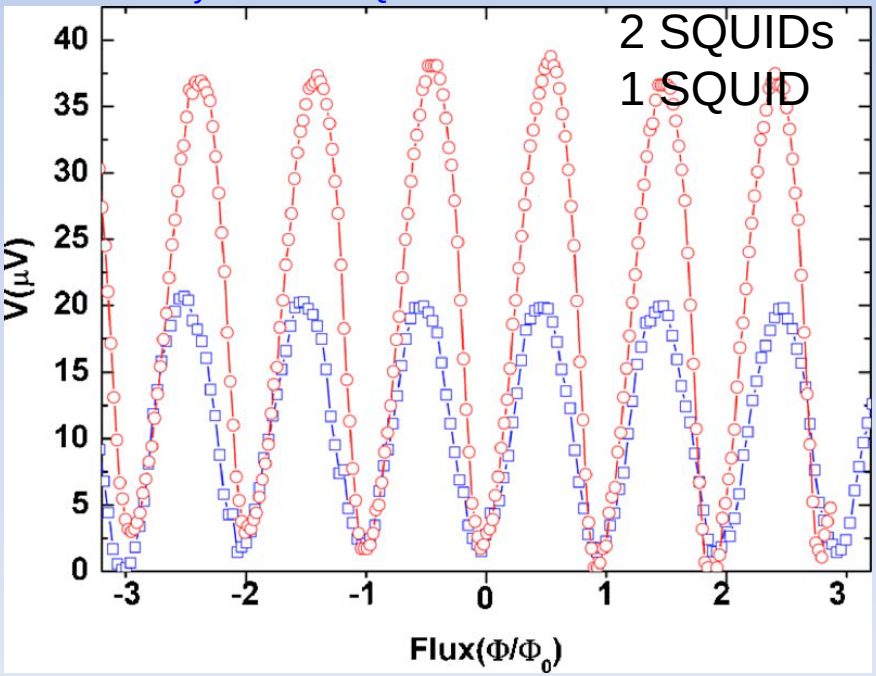
$$\Rightarrow \left[\frac{\text{Noise}}{V}\right]_{\text{Array}} = \frac{1}{N^{1/2}}\left[\frac{\text{Noise}}{V}\right]_{\text{SQUID}}$$

flux coherent & non-interacting SQUID array

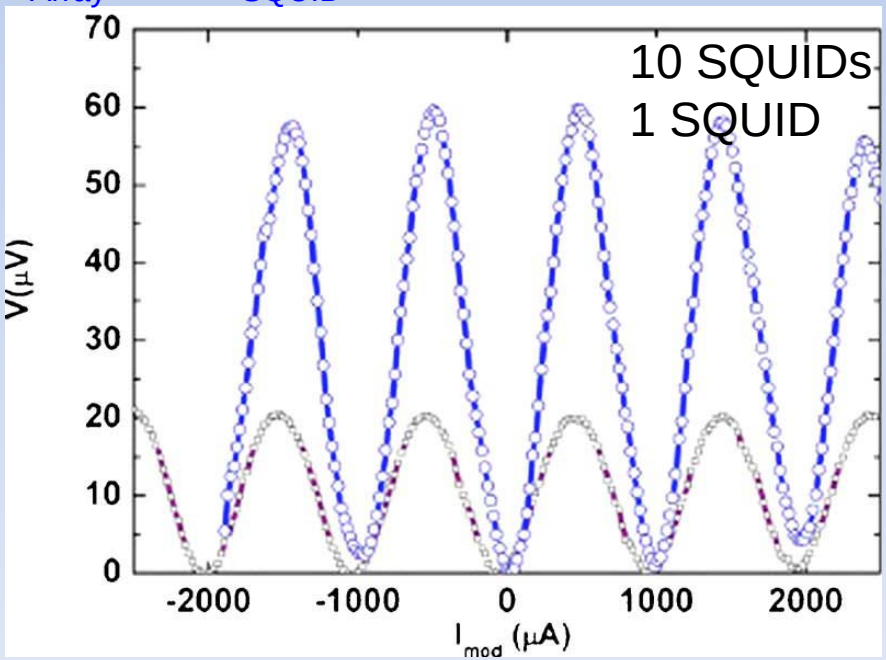
$V_{Array} = N V_{SQUID,}$ small arrays (N=10)



$V_{Array} = N V_{SQUID}$ true for 2 SQUIDs

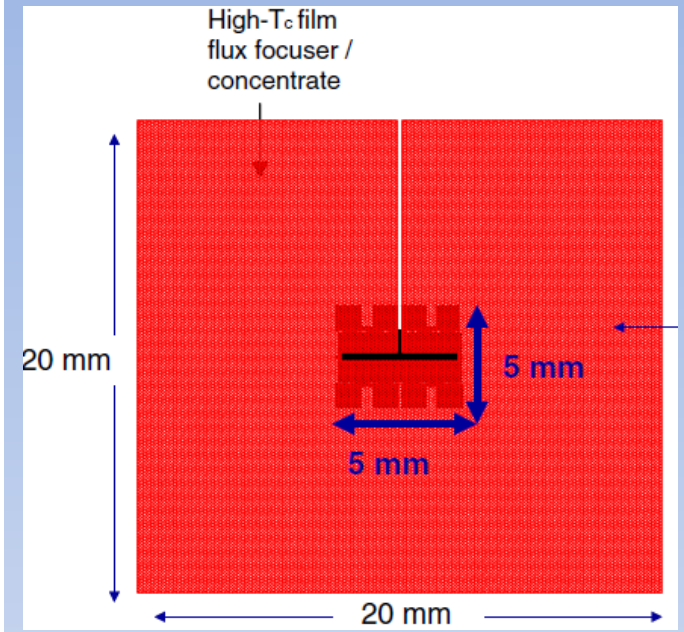


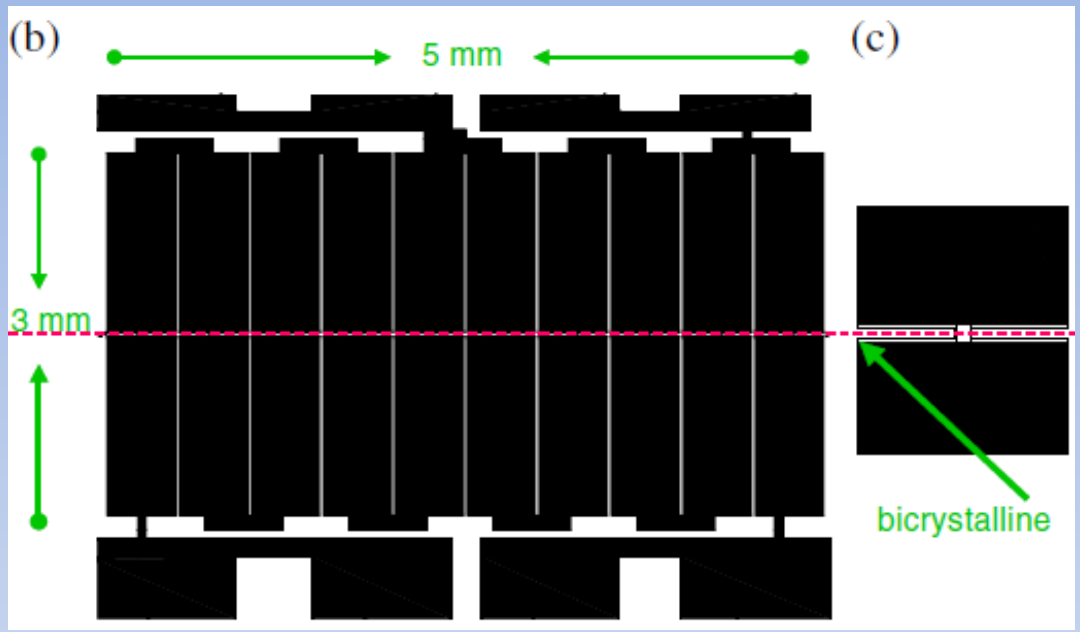
$V_{Array} = N V_{SQUID}$ **NOT** true for 10 SQUIDs!

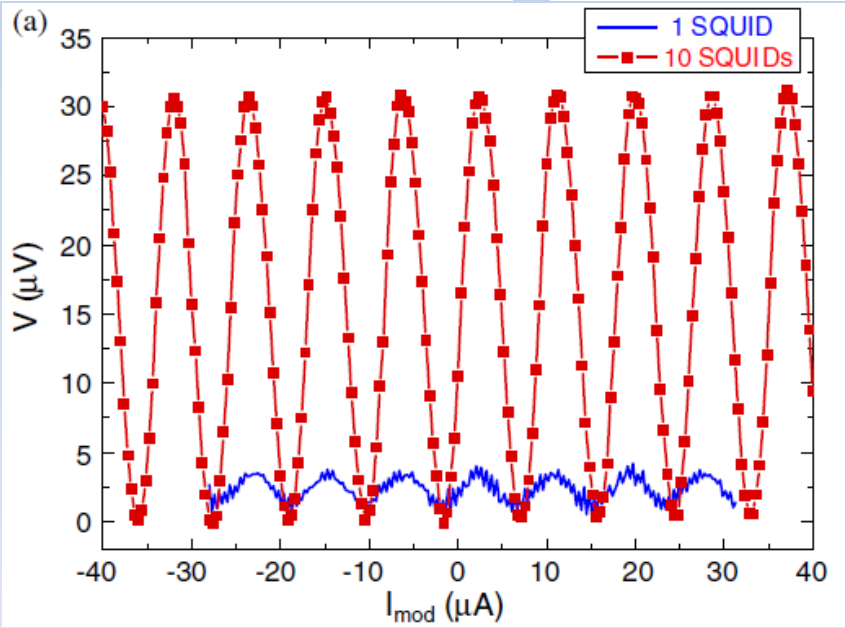


Chiu-Hsien Wu et al, J. Appl. Phys. **100**, 064510 (2006);

$V_{Array} = N\, V_{SQUID}$, small arrays (N=10)



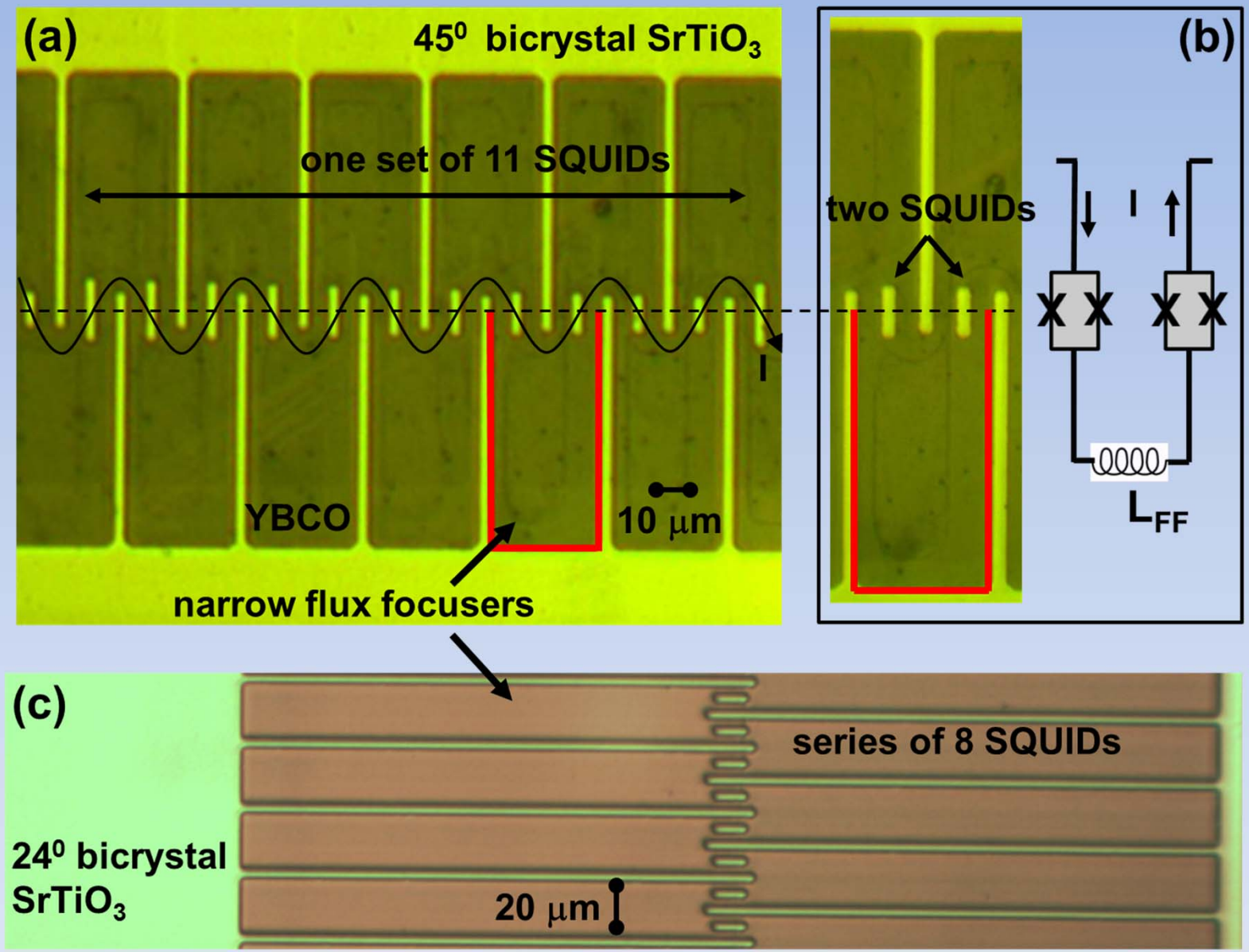




$V_{Array} = N\, V_{SQUID}$ true for 10 SQUIDs
but SQUIDs are too large;
this design is not suitable for large N!

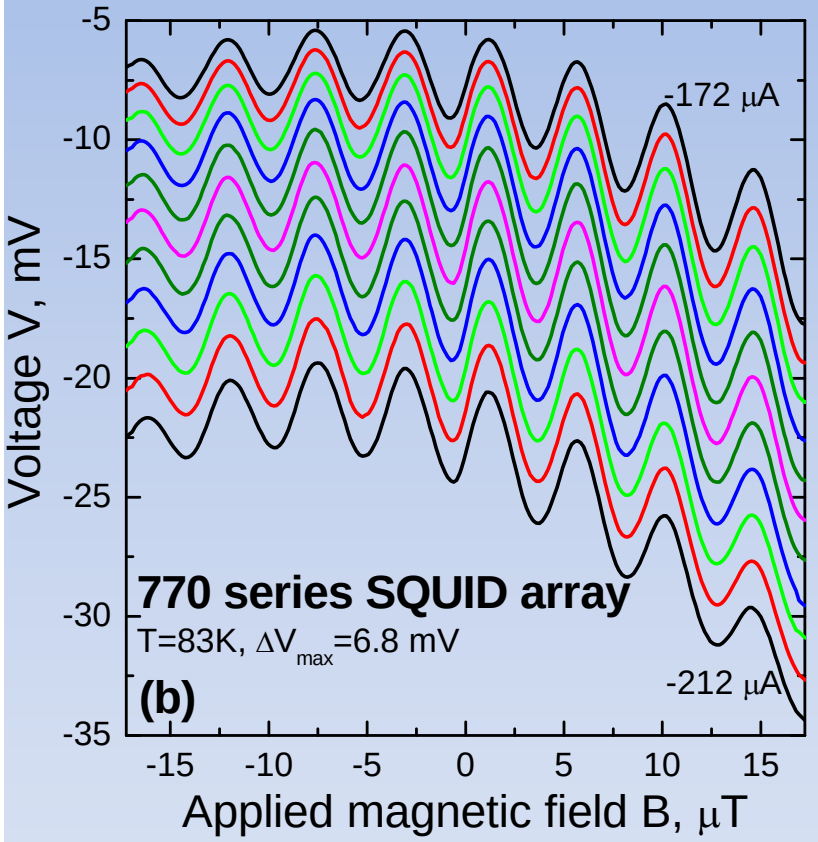
C. H. Wu et al, Supercond. Sci. Technol. **19,** S246 (2006)

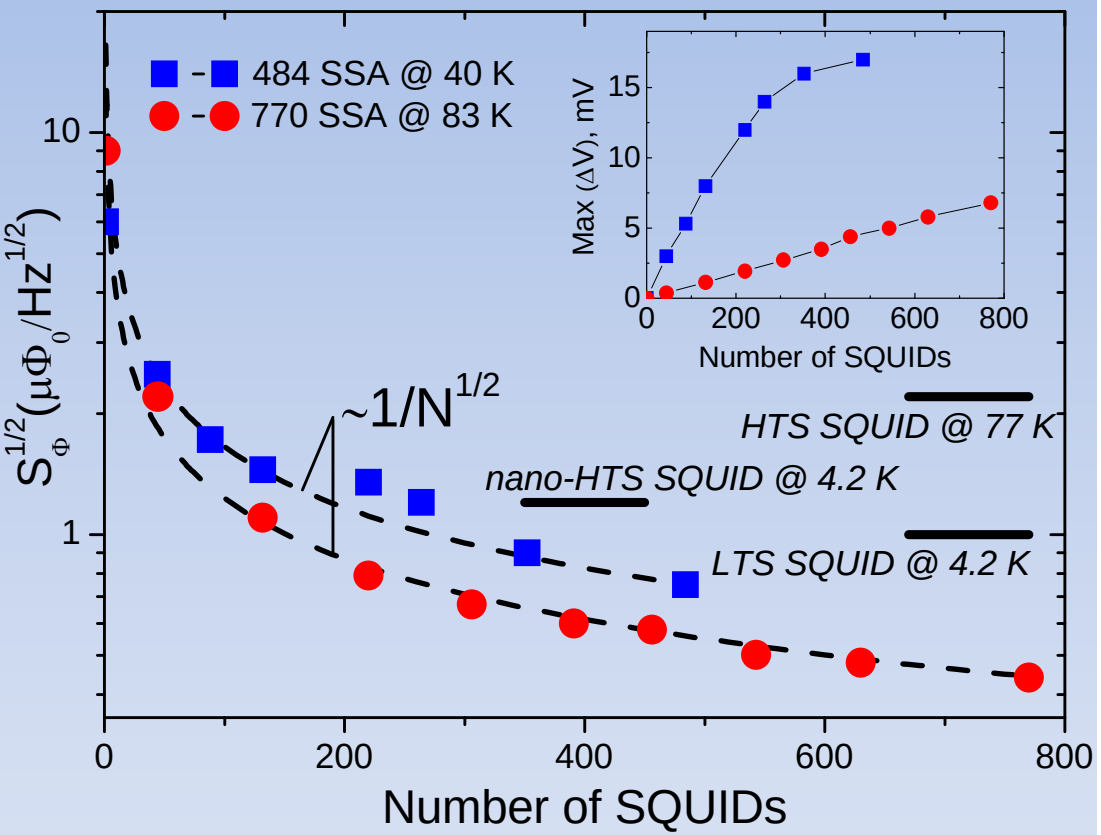
Large SQUID arrays (N=484, 770)



B. Chesca, D. John, C. Mellor, *Appl. Phys. Lett.* **107**, 162602 (2015)
International Patent, PCT: B. Chesca, D. John, WO2017006079 A1(2017)

SQUID arrays @ 77K better than SQUIDs @ 4.2 K





B. Chesca, D. John, C. Mellor, *Appl. Phys. Lett.* **107**, 162602 (2015);
D. Castelvecchi and B. Chesca, *Nature*, Research Highlights 526, 613 (2015).

First flux-flow microwave generators @ 77K

10x10 JJ array as tunable microwave generators @ 4.2K

53-230 GHz

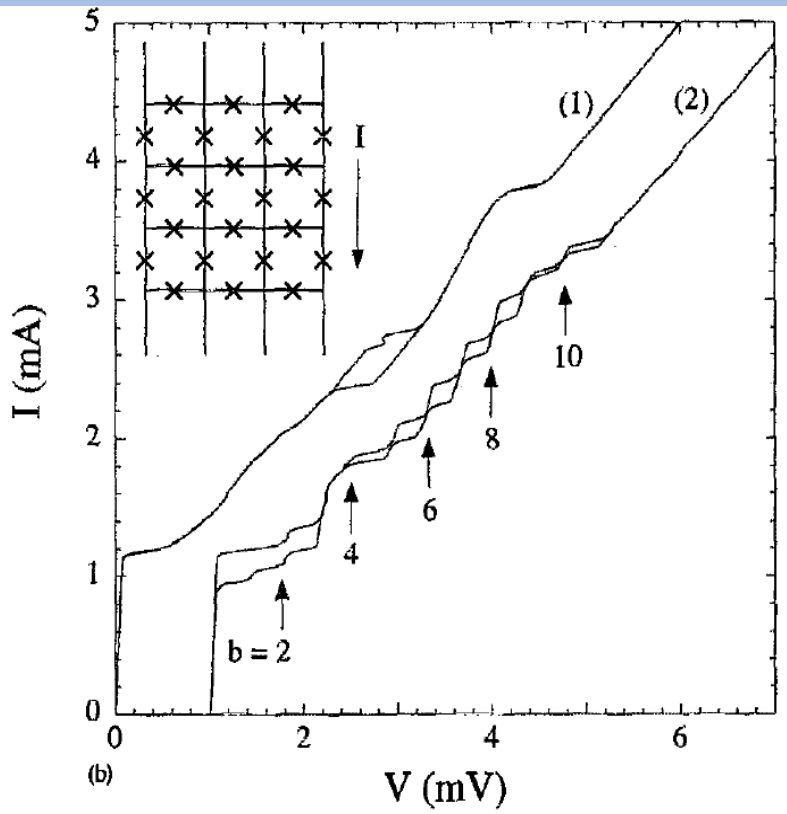


FIG. 1. (a) Photograph of a 10×10 array (left) coupled to a fin-line antenna (right), and (b) *I-V* curve of a 10×10 array without (1), and with (2) the antenna. The latter is displaced by 1 mV. Some of the resonance bands *b* are indicated with arrows.

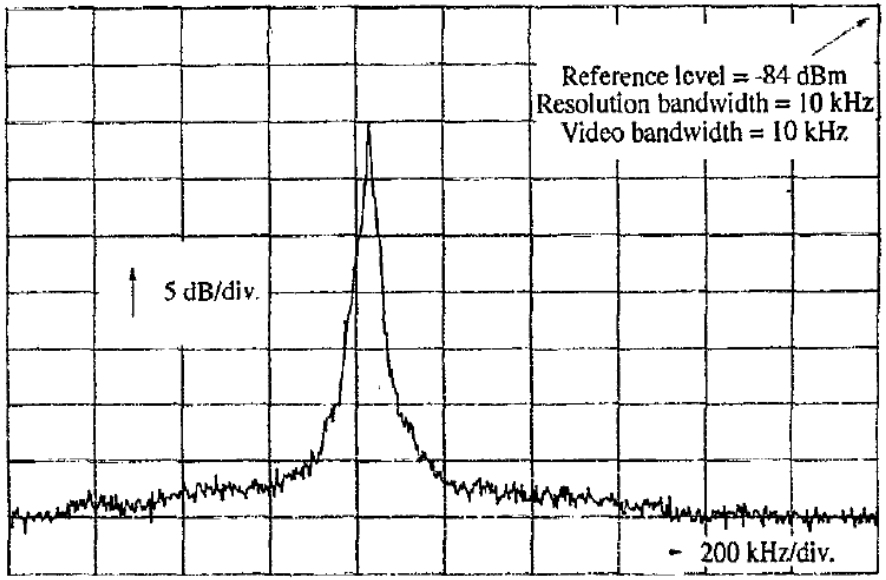


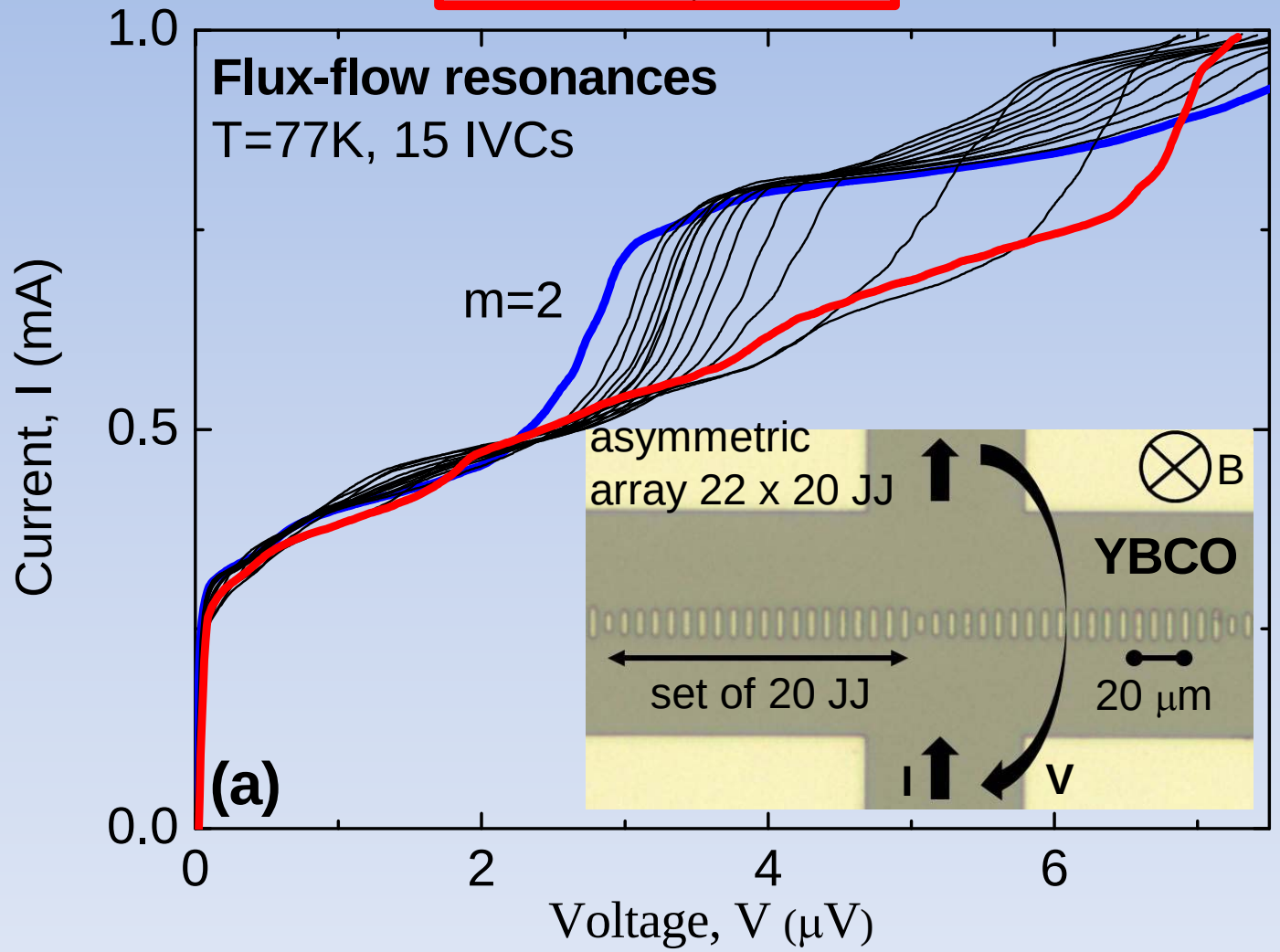
FIG. 2. Emission peak after 100 video averages at 88.844 GHz showing a ~13 kHz linewidth.

P. A. A. Booi, and S. P. Benz, *Appl. Phys. Lett.* **64**, 2163 (1994)

Flux-flow resonances in asymmetric 440 JJ arrays

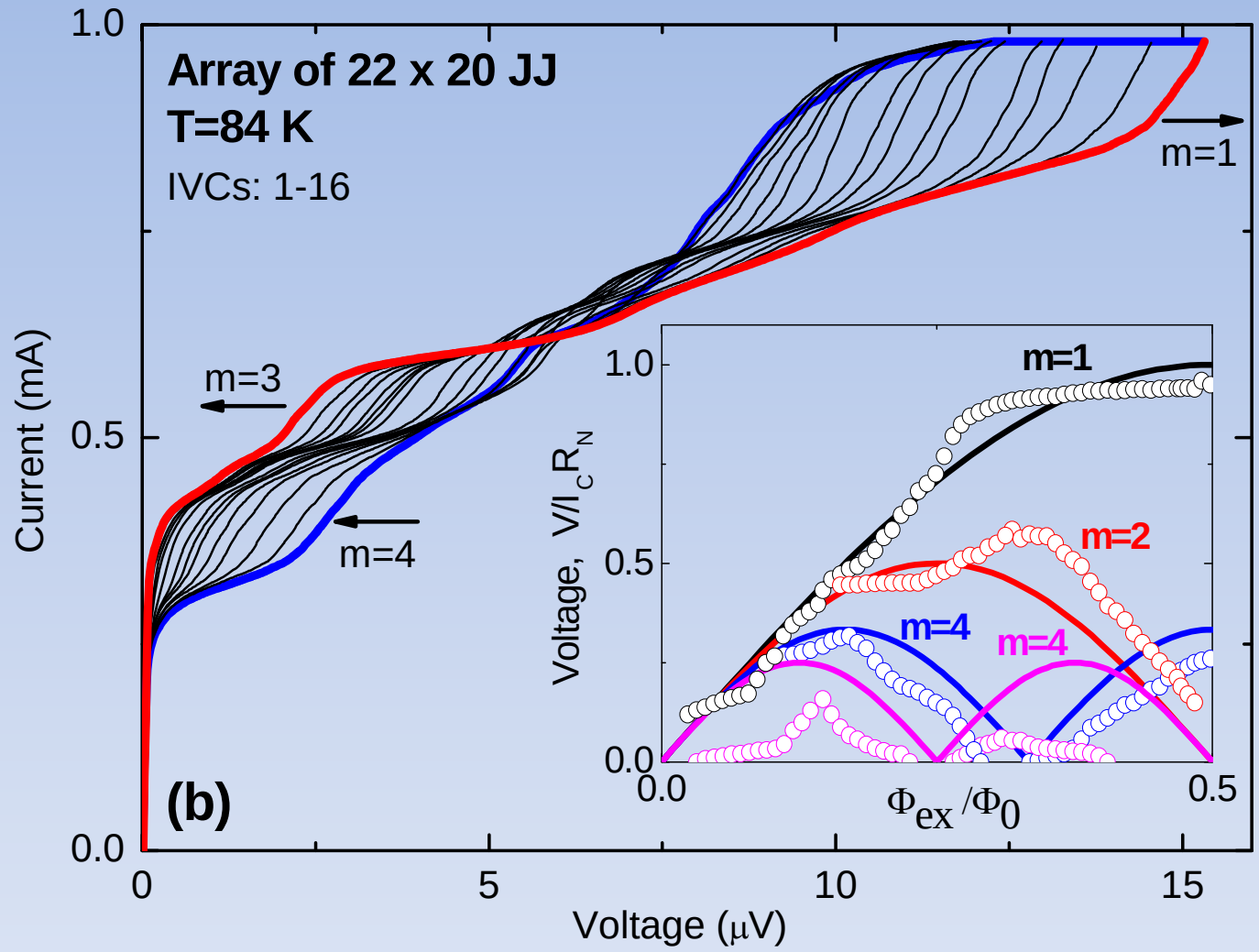
B-field tunable power of about 0.1 μW within the range (1.5-25) GHz @ 77K

$$P=0.5(I\times I_{step}/I_c)^2 R_N/N$$



B. Chesca, D. John, C. Mellor, *Supercond. Sci. Technol.* **27**, 085015 (2014)

Flux-flow resonances in asymmetric 440 JJ arrays

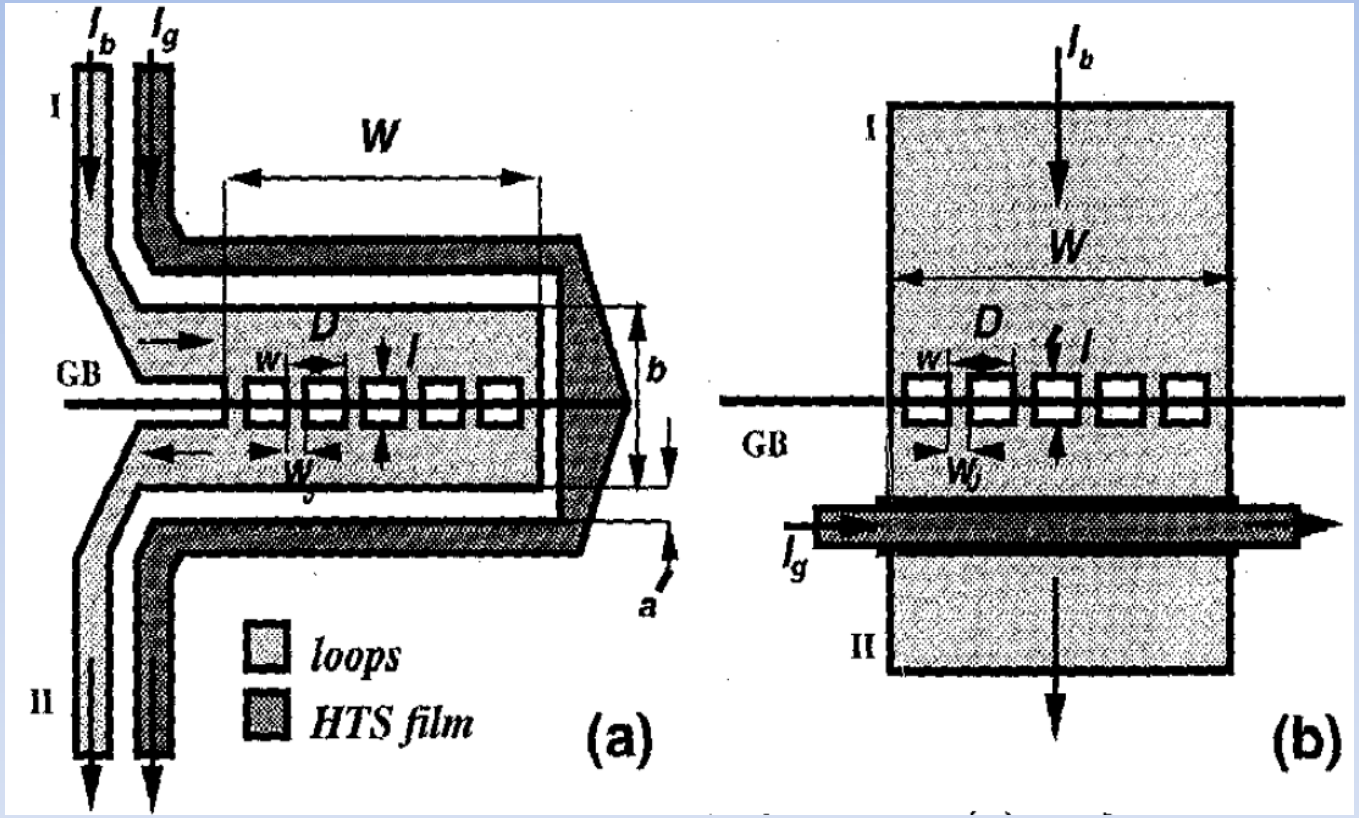


B. Chesca, D. John, C. Mellor, *Supercond. Sci. Technol.* **27**, 085015 (2014)

Josephson vortex-flow transistors (JVFT) with record amplification @ 77K

Previous JVFT designs: asymmetrical bias current

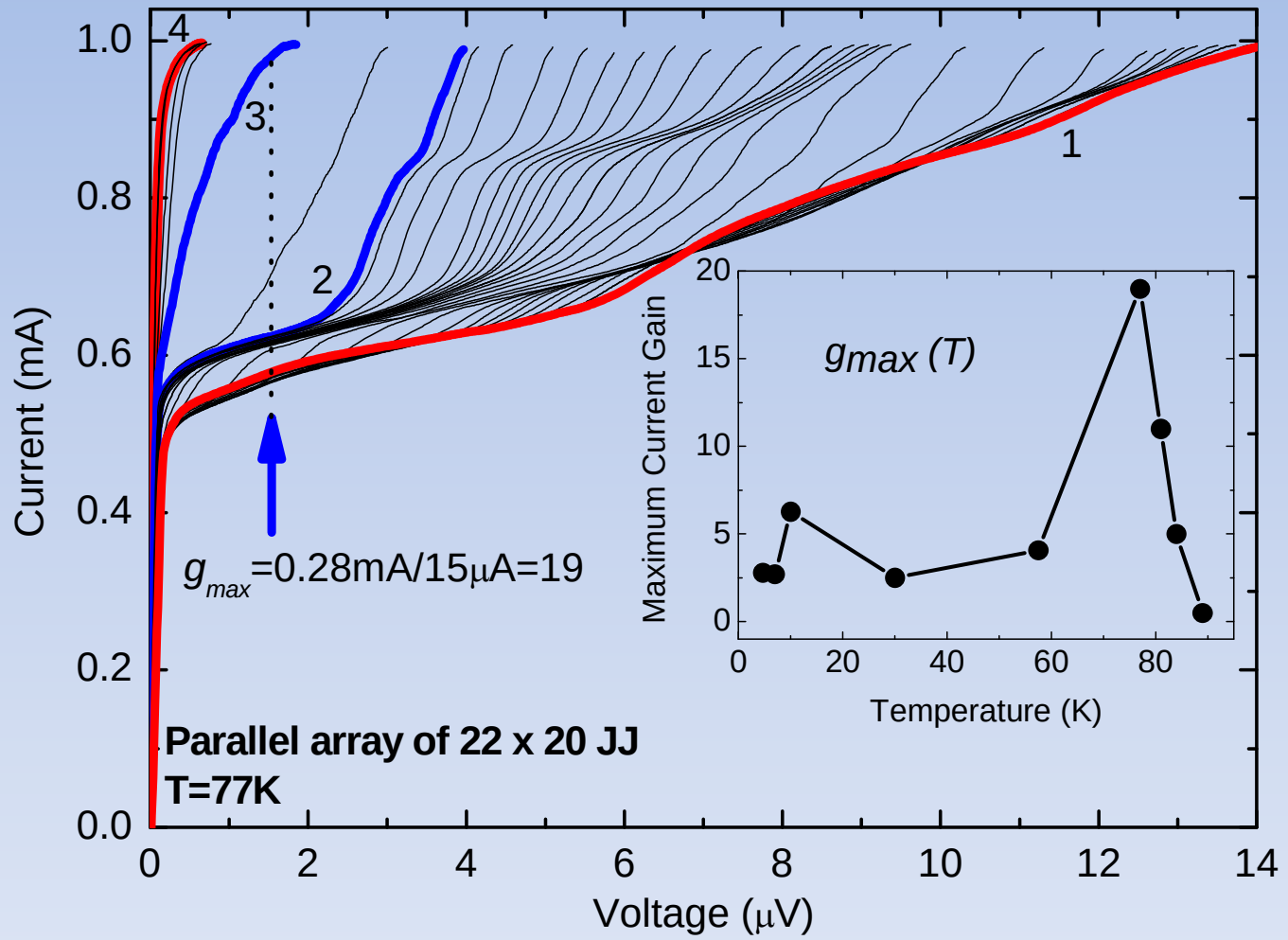
Small symmetrical arrays (6JJ), maximum current amplification @ 77K: 3.5



R. Gross, et.al, *Appl. Supercond.* **3**, 443 (1995)

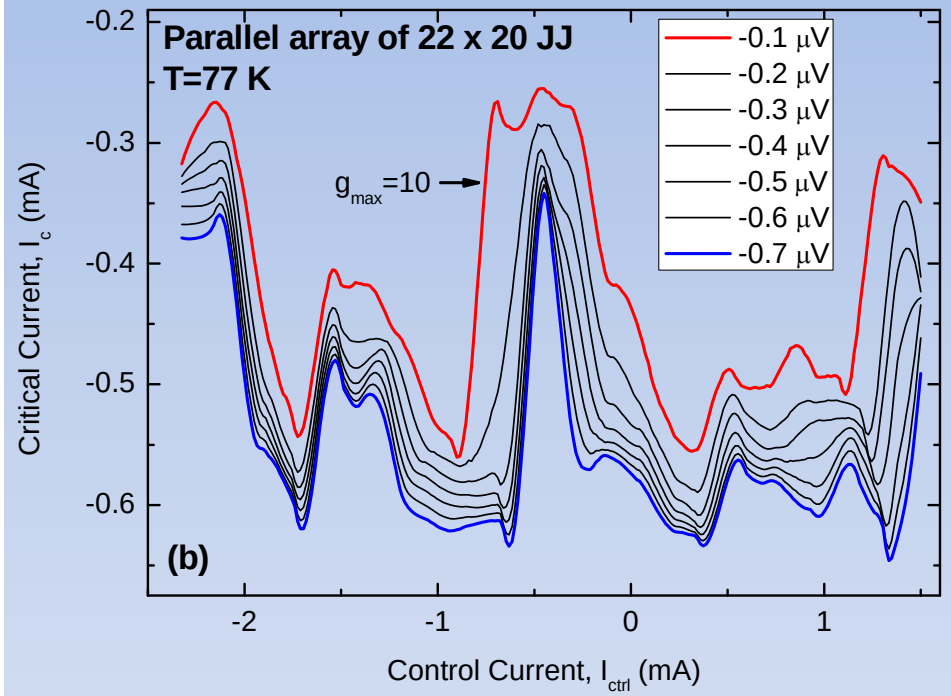
Anomalous flux-flow in large asymmetric arrays

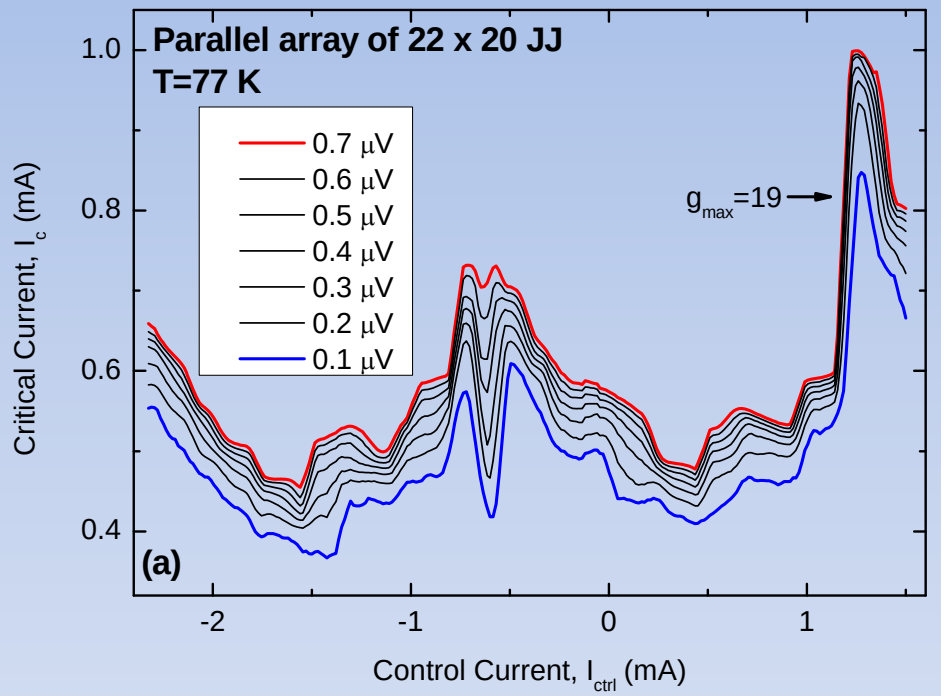
Large asymmetrical arrays (440 JJ) maximum current amplification @ 77K: 19



B. Chesca, D. John, C. Mellor, *Appl. Phys. Lett.* **103**, 092601 (2013)

Current amplification in large asymmetric arrays



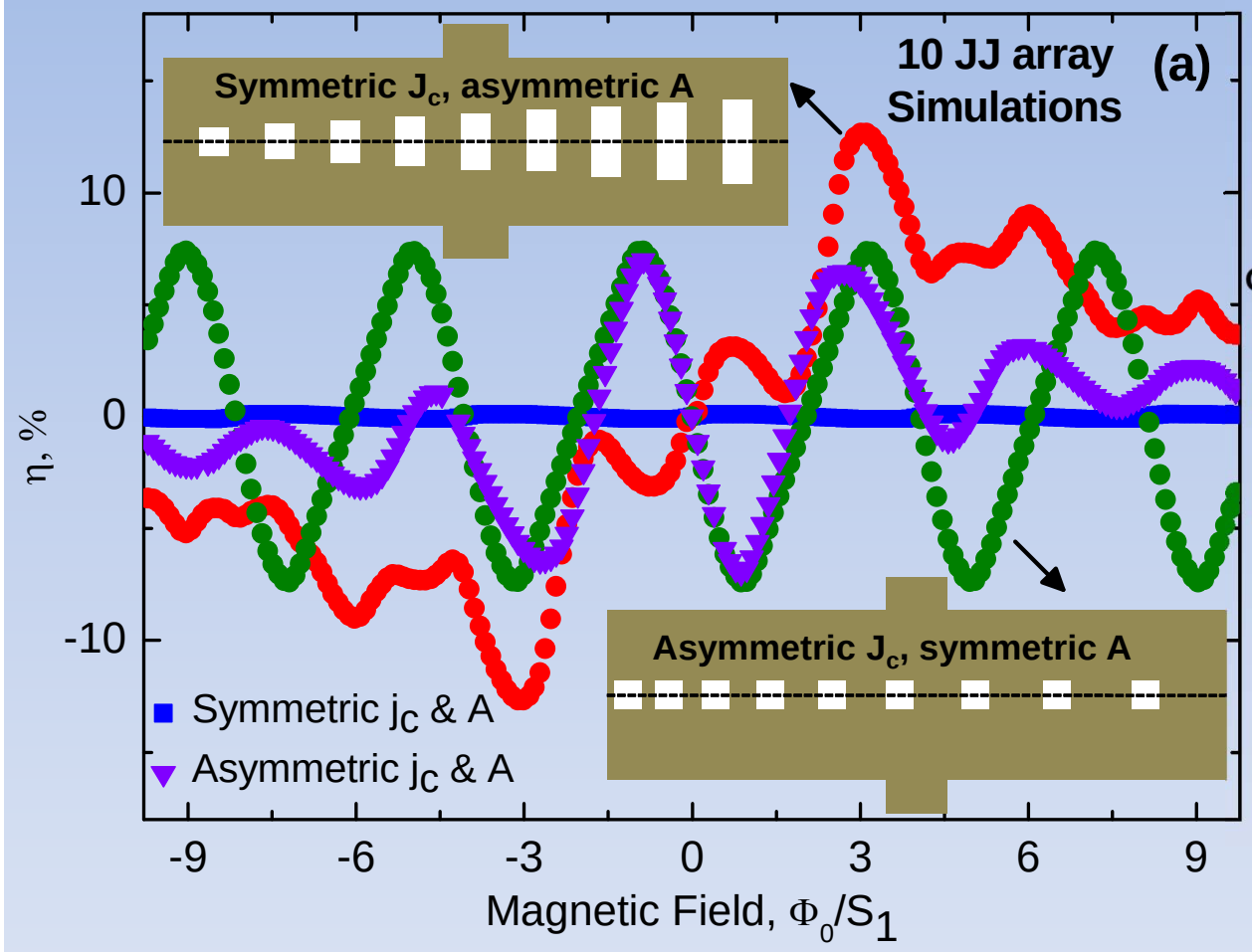


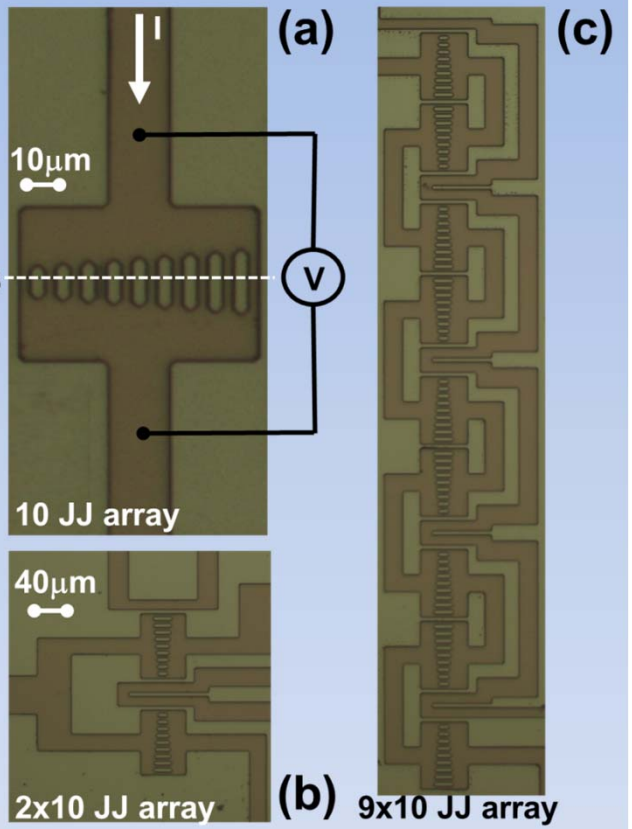
B. Chesca, D. John, C. Mellor, *Appl. Phys. Lett.* **103**, 092601 (2013)

Reversible flux-flow ratchets

Which ratchet?

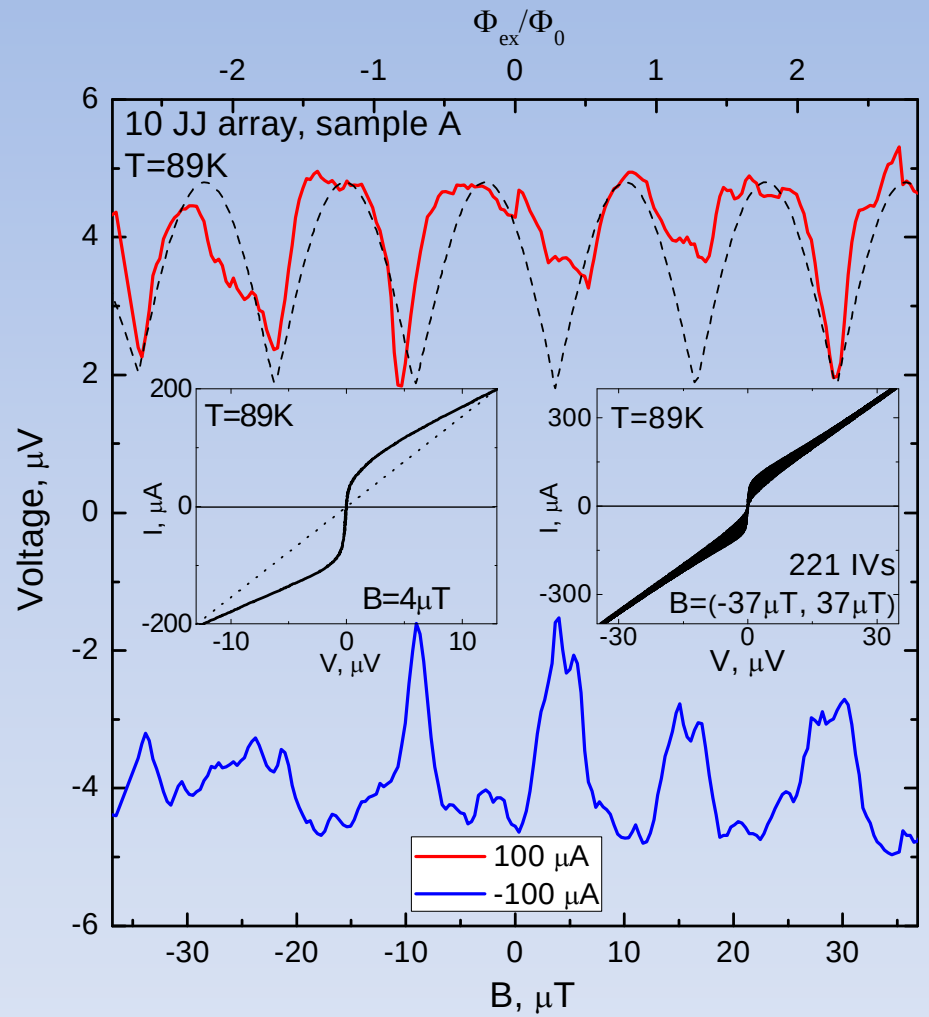
$$\eta = \left|\frac{V(I)+V(-I)}{V(I)-V(-I)}\right| \times 100\%$$

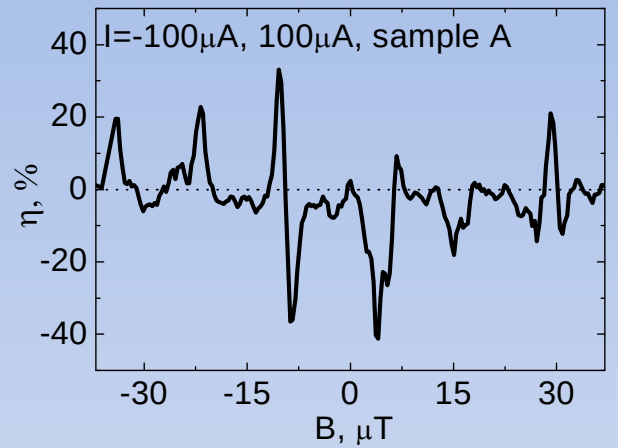


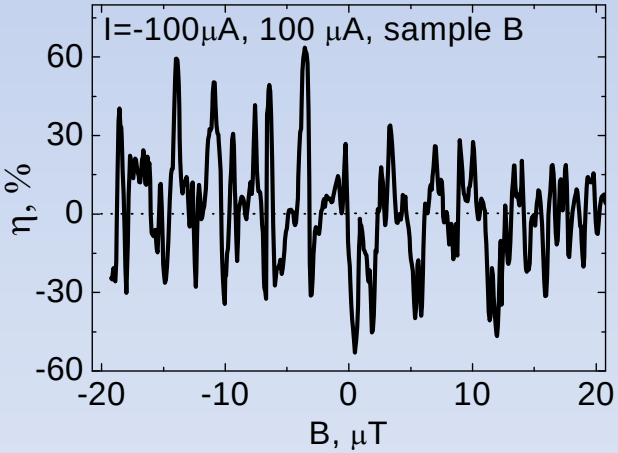


B. Chesca, D. John, R. Pollett, M. Gaifullin, J. Cox, C. Mellor, S. Savelev, *Appl. Phys. Lett.* 111, 062602 (2017).

Reversible flux-flow ratchets







B. Chesca, D. John, R. Pollett, M. Gaifullin, J. Cox, C. Mellor, S. Savelev, *Appl. Phys. Lett.* 111, 062602 (2017).

Conclusions

- **Remarkable performances shown by very large arrays-based devices @ 77K**
  - **series arrays: magnetometers**
  - **asymmetric parallel arrays: flux-flow microwave generators**
    transistors
    reversible ratchets

- **Great potential**
  - **to replace single-JJ or single-SQUID based devices @ 4.2K**
  - **performance can be further improved by optimization**