Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

"EINSTEIN" Project Meeting

Foundation for Research and Technology, Heraklion, Crete, Greece

Andrey S. Vasenko

National Research University Higher School of Economics

Competitive 0- and π-states in S/F multilayers: multimode approach

Collaboration

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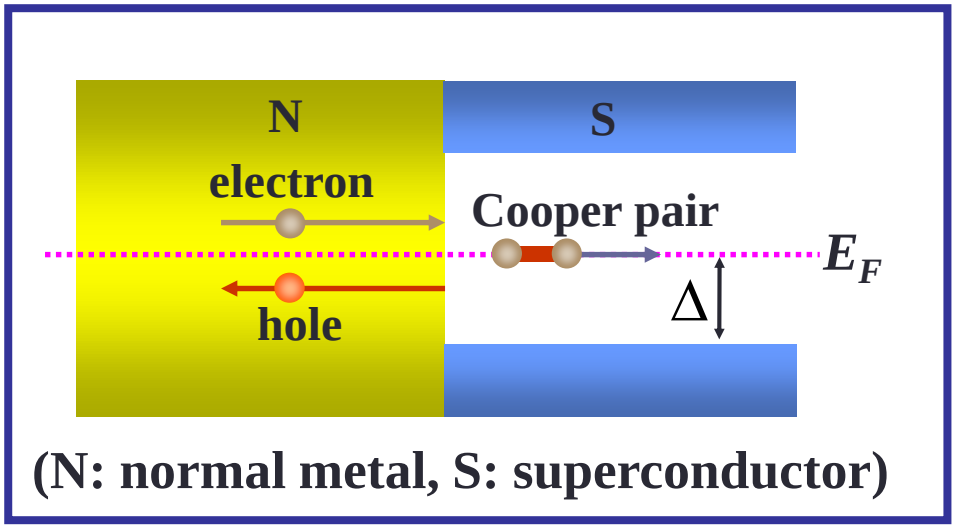
Netherlands

Vyacheslav M. Silkin,
DIPC, Spain

S/N proximity effect: Andreev reflection

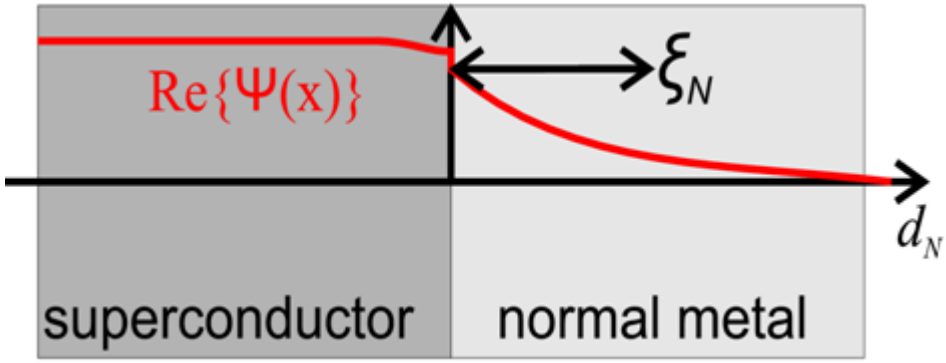
classical (A.F. Andreev, Spain, 2008)

quantum [Andreev, Sov. Phys. JETP, **19**, 1228, (1964)]

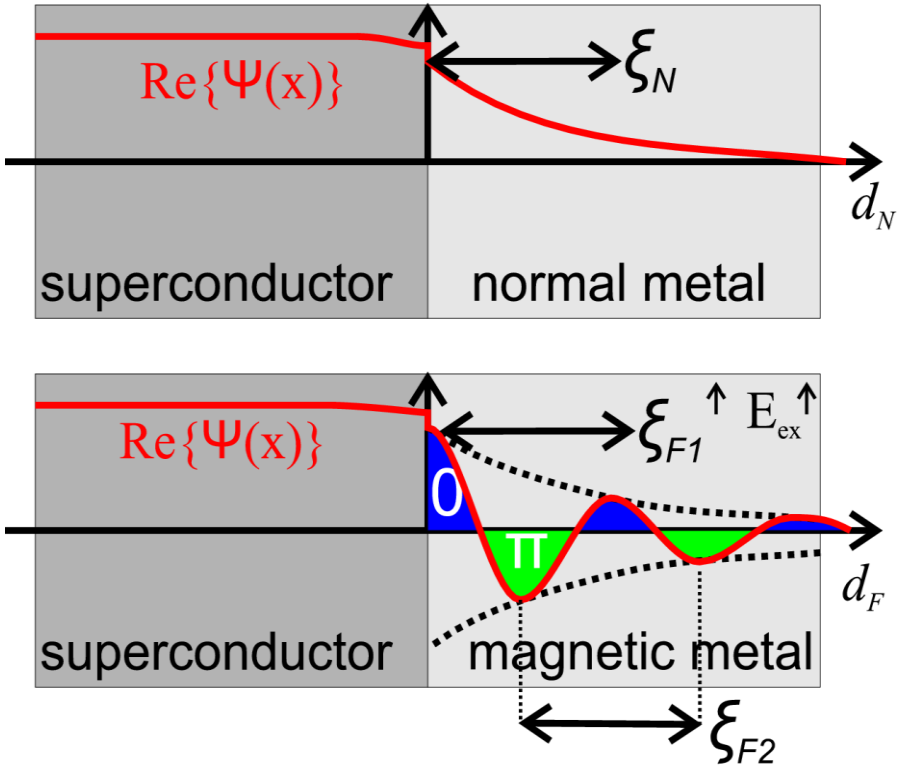


S/N proximity effect

$$\Psi = \Psi_0 e^{-d_N/\xi_N}$$



Proximity effect in S/F bilayer



S/N bilayer

$$\Psi = \Psi_0 e^{-d_N/\xi_N}$$

S/F bilayer

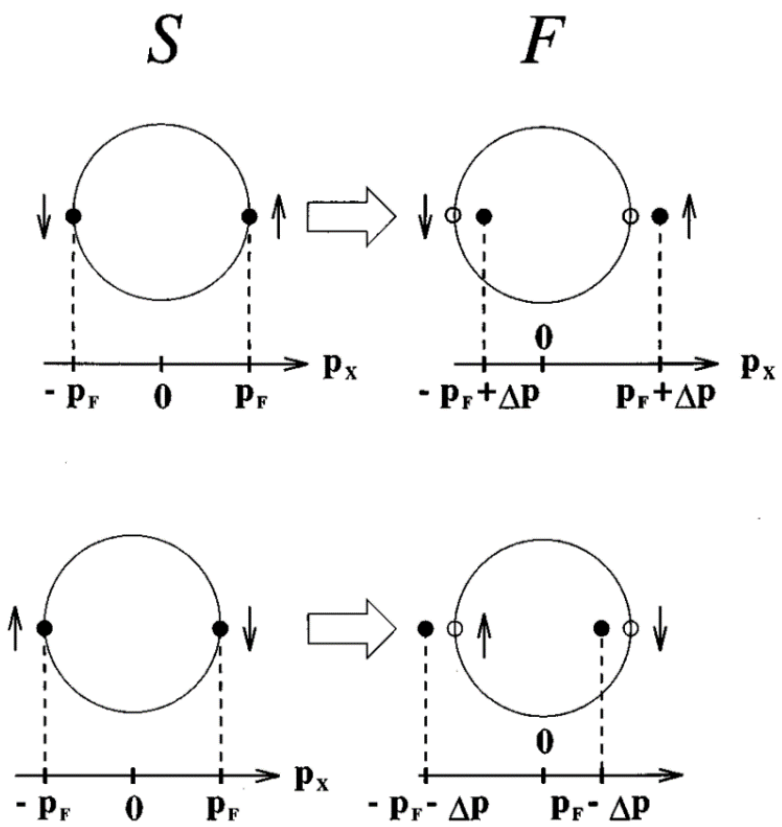
$$\Psi = \Psi_0 e^{-d_F/\xi_{F1}} \cos\left(\frac{d_F}{\xi_{F2}}\right)$$

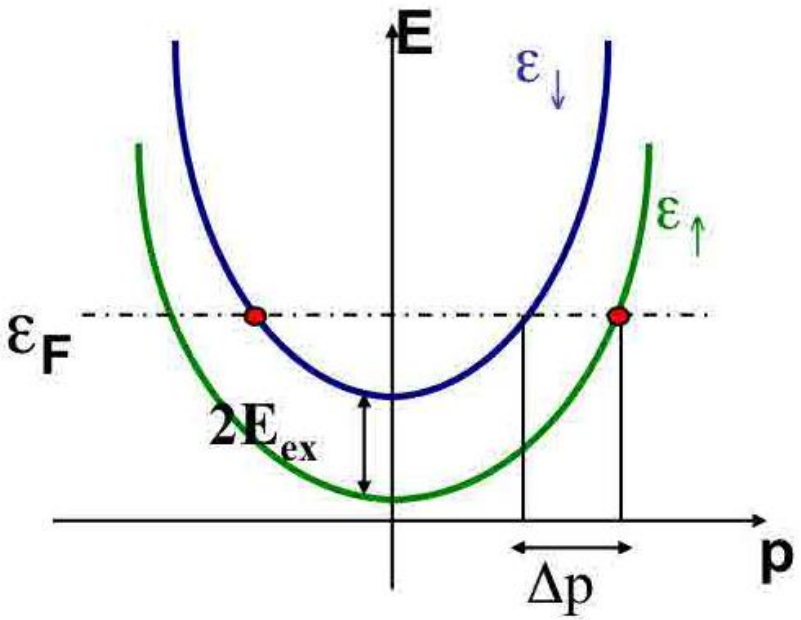
$$\xi_f = \sqrt{\mathcal{D}_f / E_{ex}}$$

Buzdin & Kupriyanov, JETP **53**, 321 (1991);

Demler *et al.*, PRB **55**, 15174 (1997)

Proximity effect in S/F bilayer

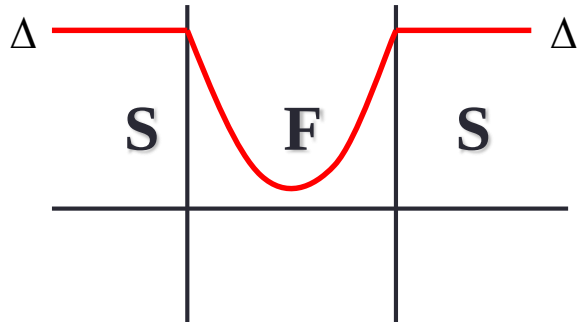




$$|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle$$

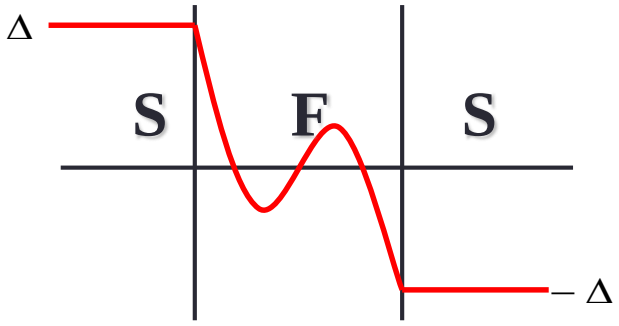
$$e^{ix\Delta p}|\uparrow\downarrow\rangle - e^{-ix\Delta p}|\downarrow\uparrow\rangle$$

S/F/S Josephson junction



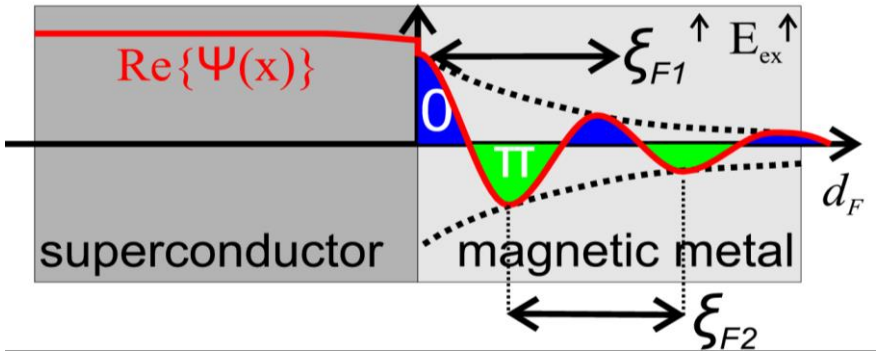
0 phase

$$I_s(\phi) = I_c \sin(\phi)$$



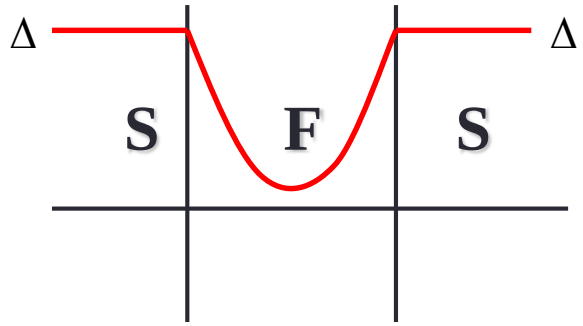
π phase

$$I_s(\phi) = I_c \sin(\phi + \pi) = -I_c \sin(\phi)$$

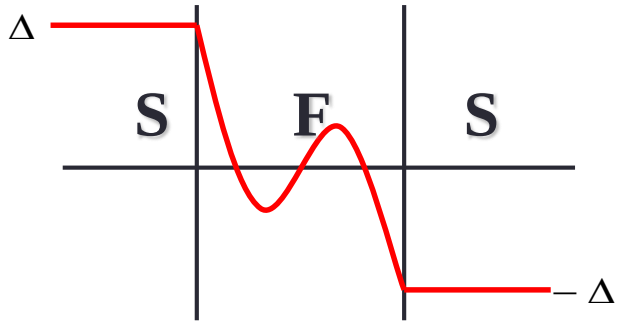


Ryazanov *et al.*, PRL **86**, 2427 (2001);
Oboznov *et al.*, PRL **96**, 197003 (2006)

S/F/S Josephson junction



0 phase



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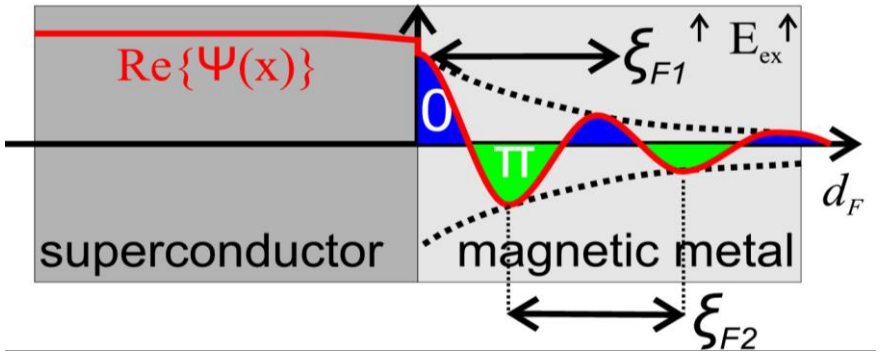
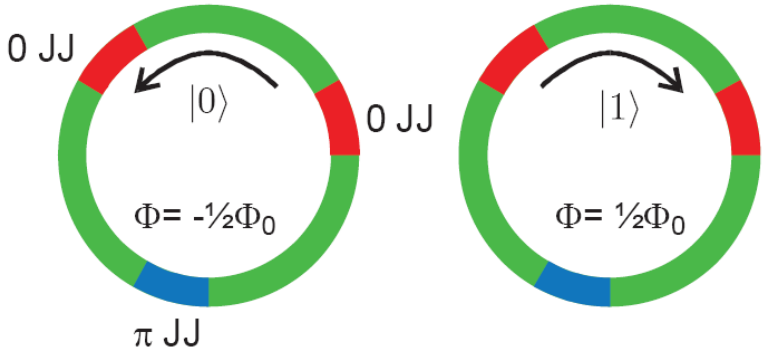




Critical temperature oscillations in Nb/Gd/Nb

Theory

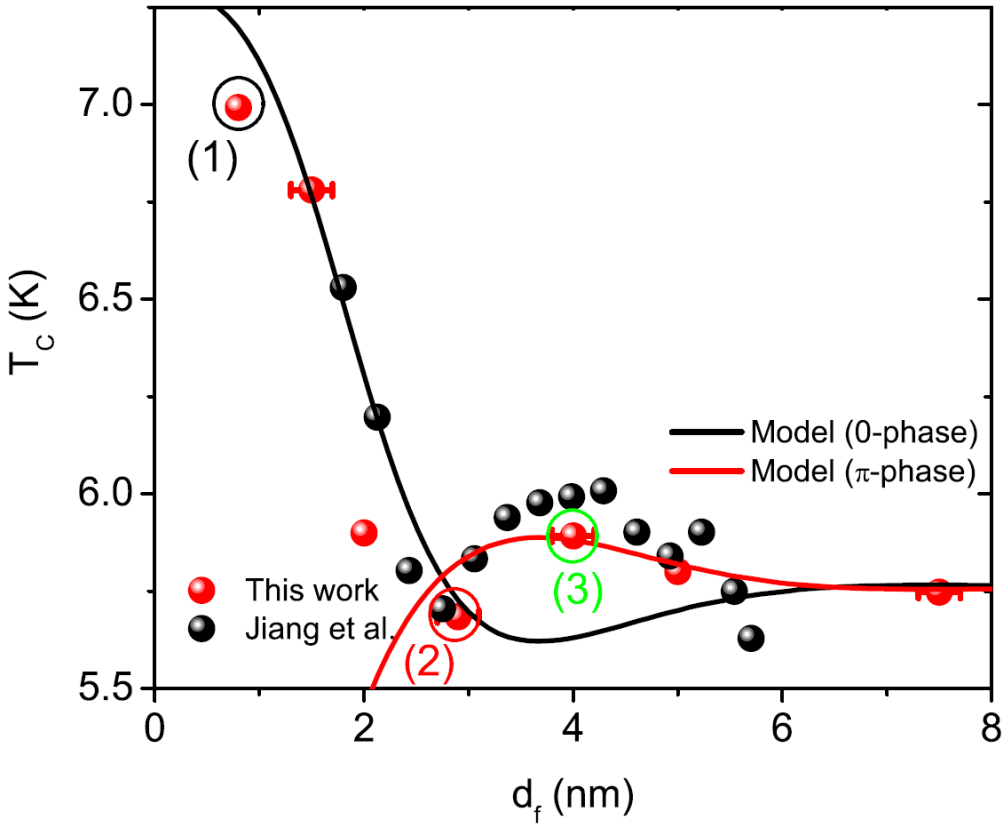
Buzdin, Kupriyanov, JETP Lett. **52**, 487 (1990);

Buzdin, Kupriyanov, Vujicic, Physica **185-189C**, 2025 (1991)

Experiment

Jiang *et al.*, PRL **74**, 314 (1995);

Khaydukov, Vasenko *et al.*, PRB **97**, 144511 (2018)



Critical temperature oscillations in Nb/Gd/Nb

Theory

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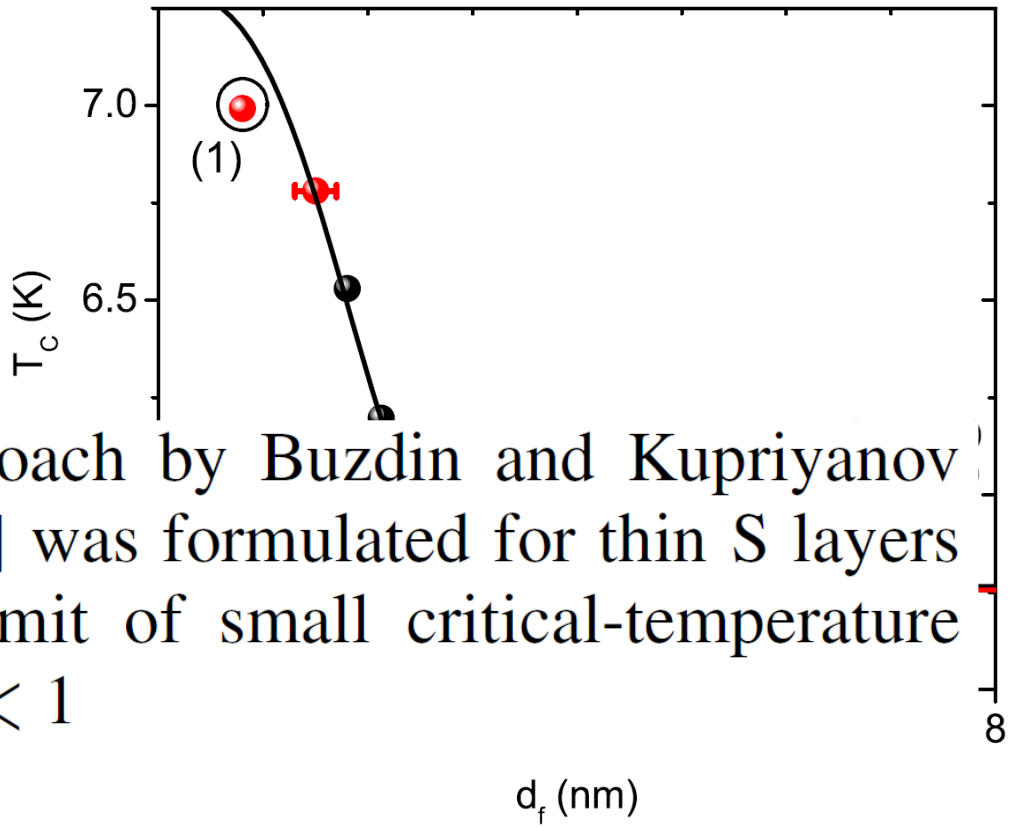
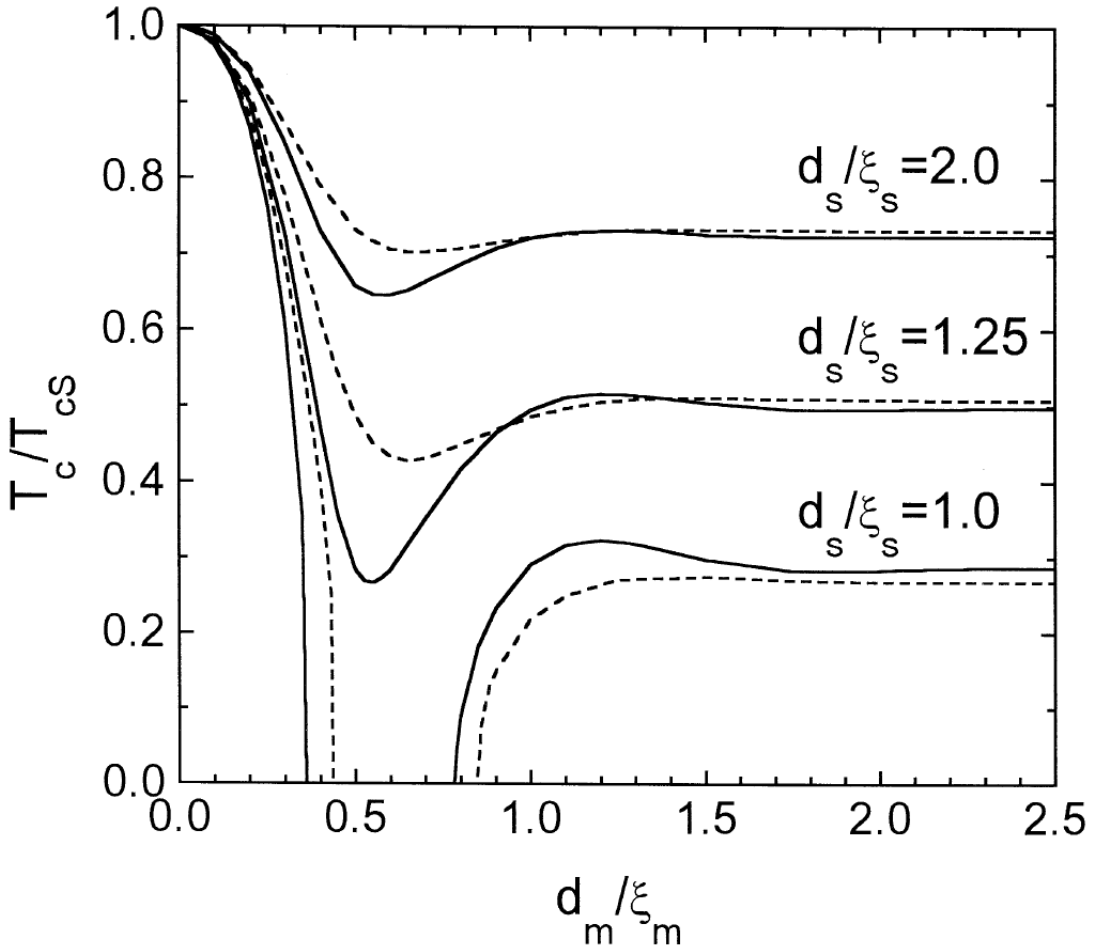


A previous approach by Buzdin and Kupriyanov [63] and Buzdin *et al.* [11] was formulated for thin S layers ($d_s/\xi_s \ll 1$) and in the limit of small critical-temperature variations $(T_{cs} - T_c)/T_{cs} \ll 1$

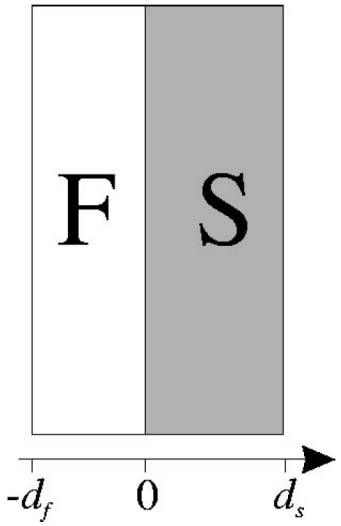
Critical temperatute in S/F bilayers

Khusainov, Proshin, PRB **56**, R14283(R) (1997): single-mode



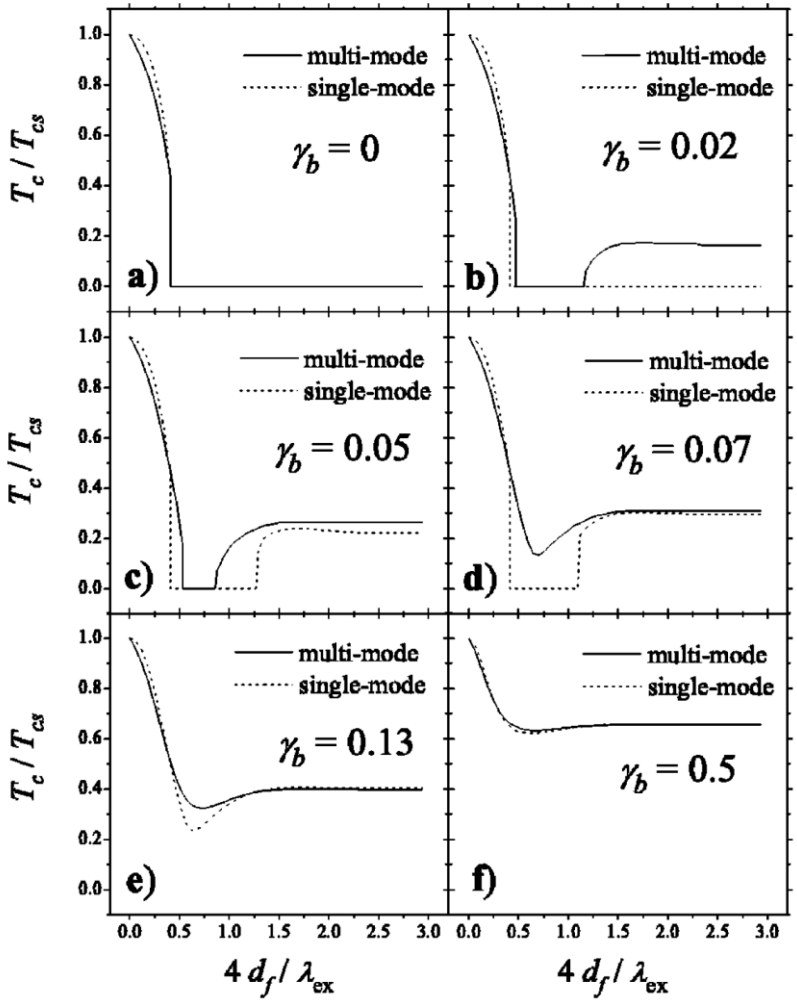
Critical temperatute in S/F bilayers

Fominov, Chtchelkatchev, Golubov, PRB **66**, 014507 (2002): multimode



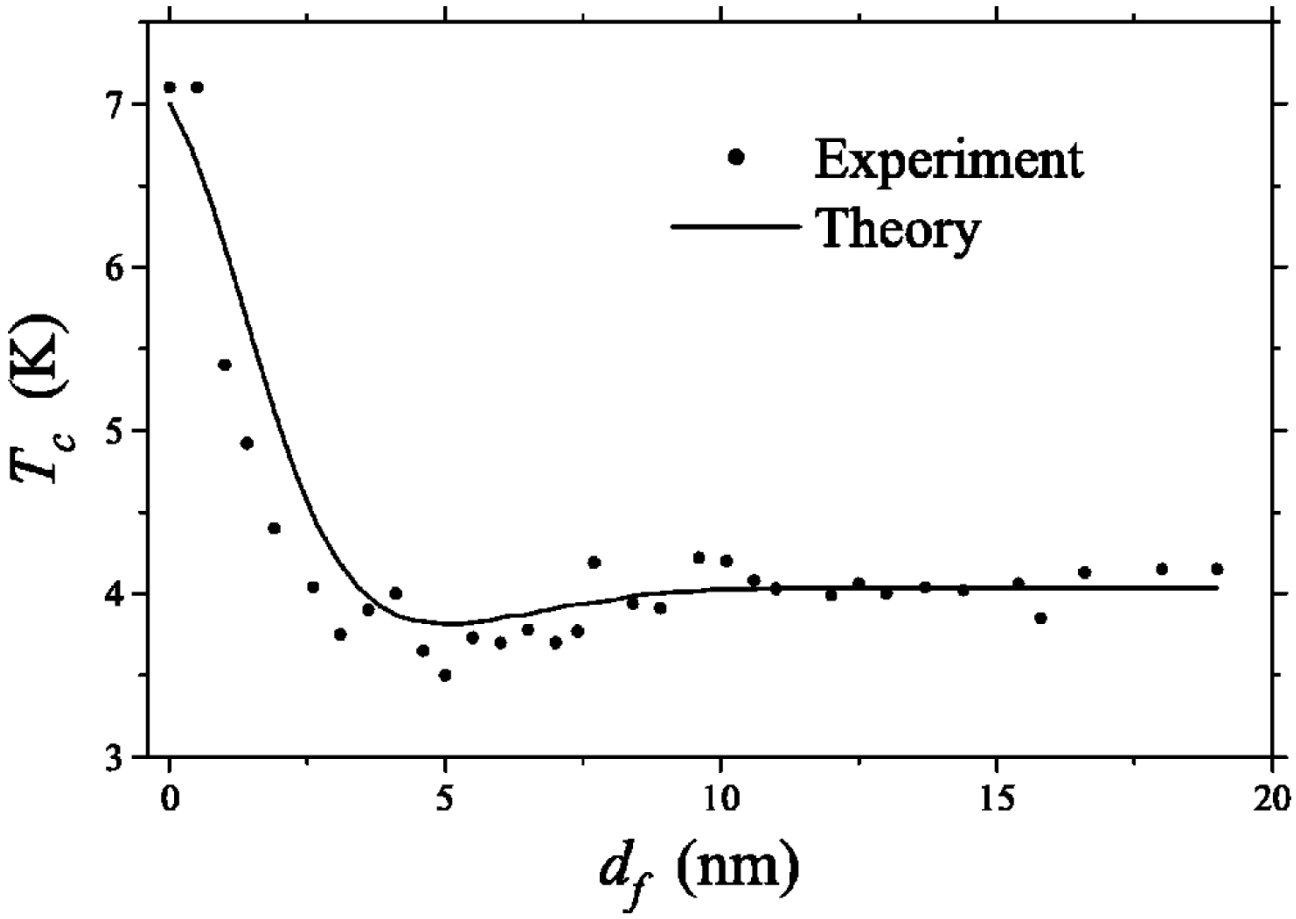
$$\gamma_b = \frac{R_b \mathcal{A}}{\rho_f \xi_f}$$

$$\sqrt{E_{ex}/\pi T_{cs}} \gg 1/\gamma_b$$

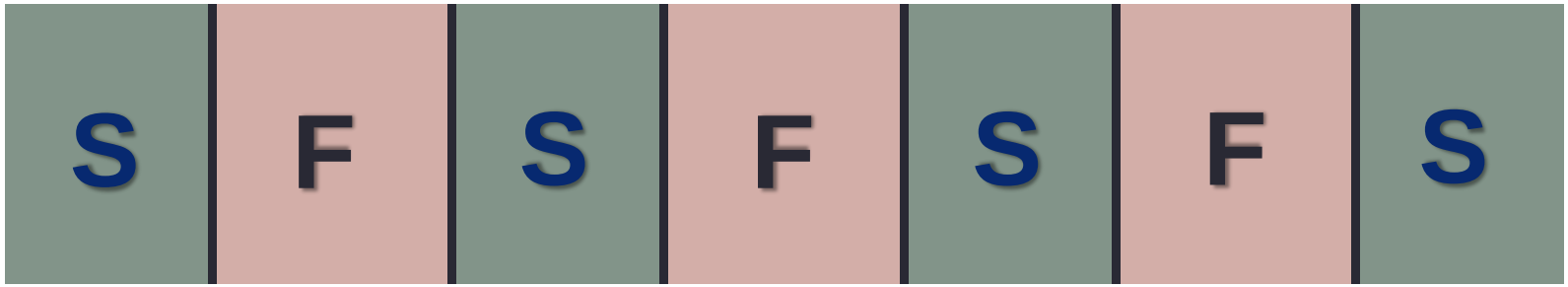


Critical temperatute in S/F bilayers

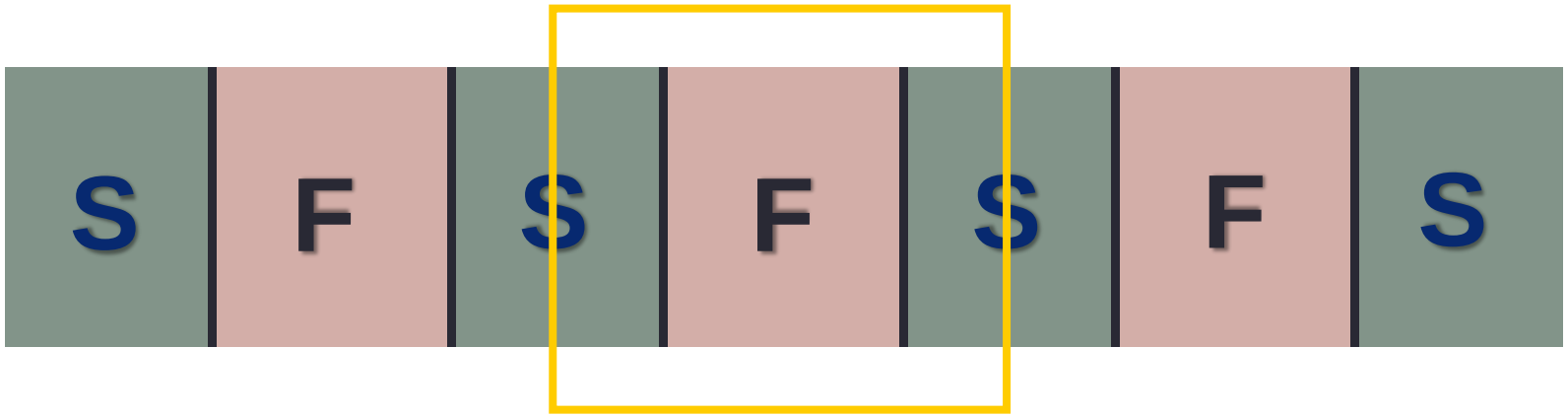
Ryazanov *et al.*, JETP Lett. **77**, 39-43 (2003)

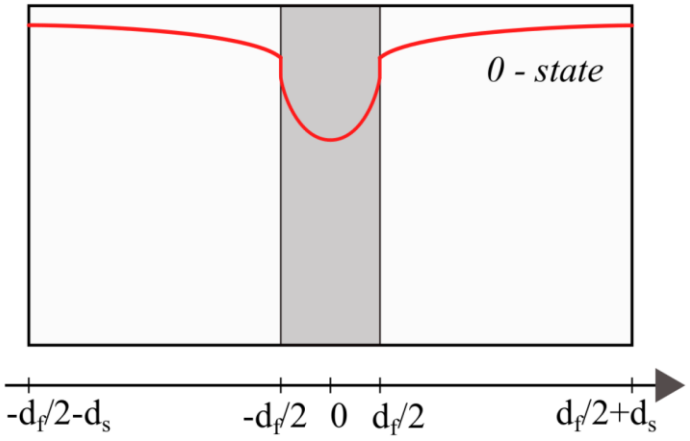


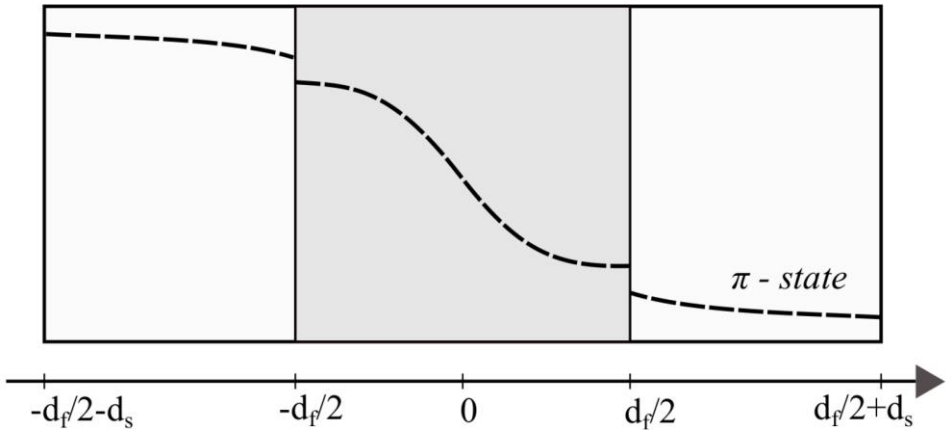
S/F multilayers: S/F/S as a single unit



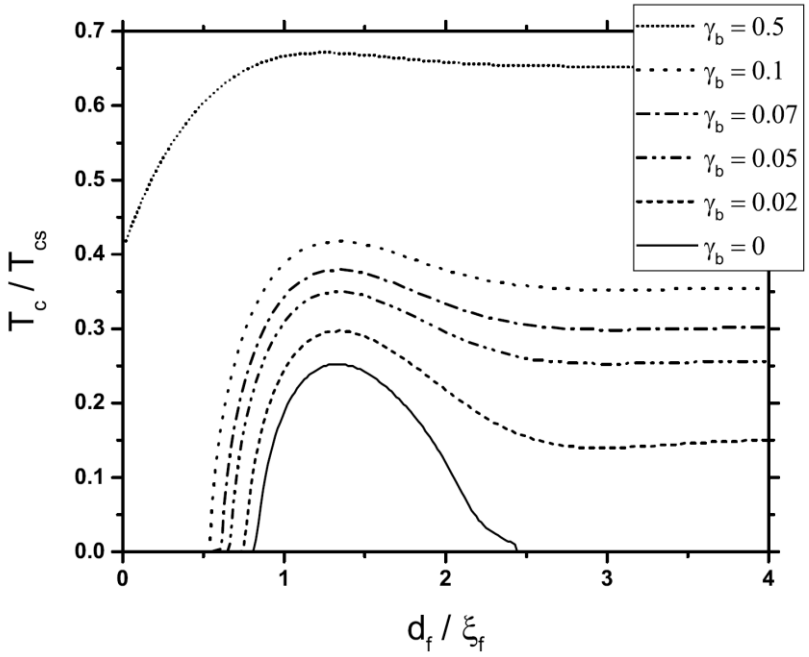
S/F multilayers: S/F/S as a single unit





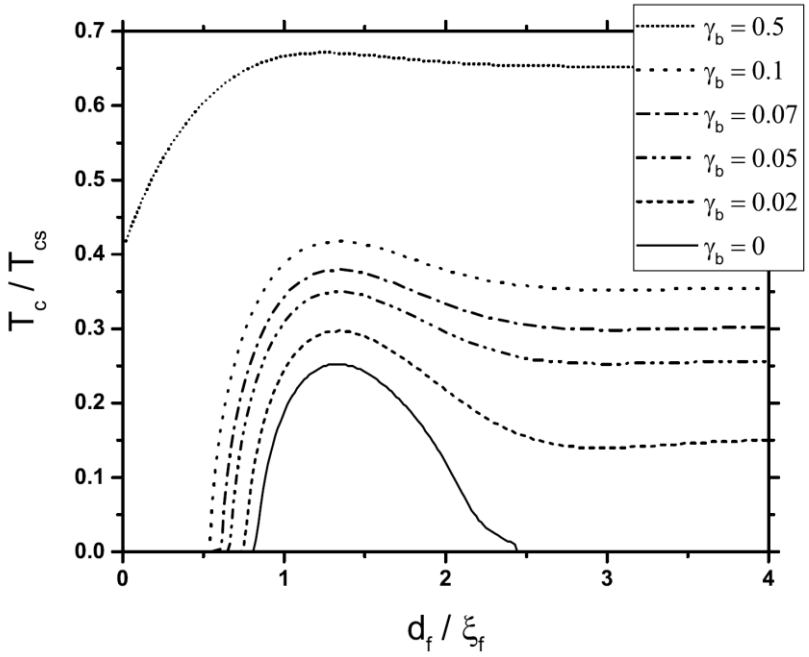


Critical temperature in S/F/S: π state

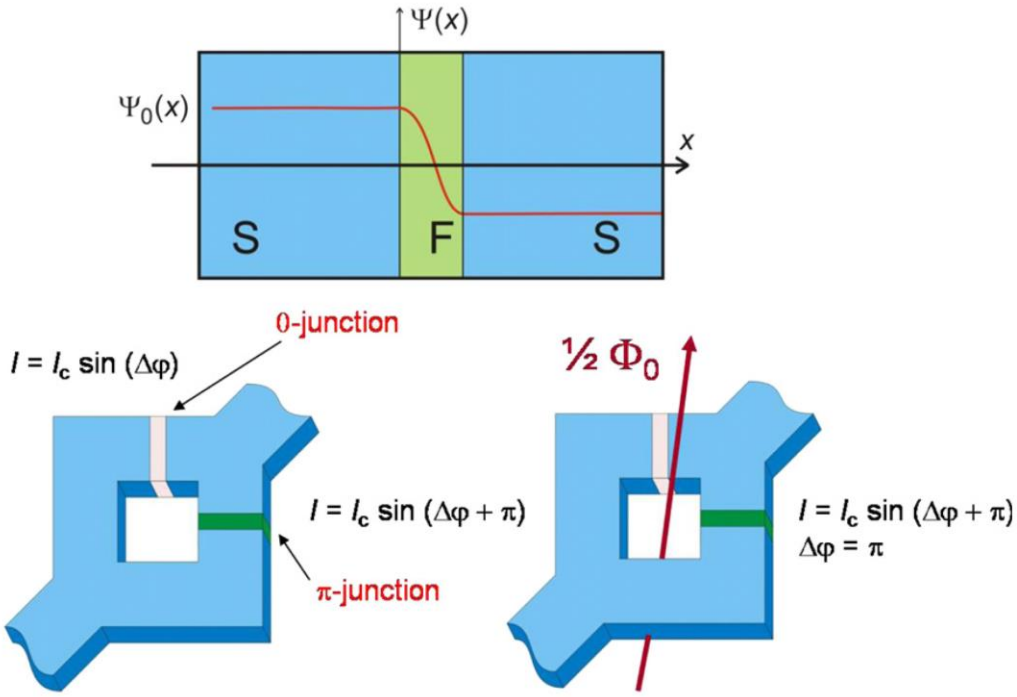


Karabassov et al., submitted to PRB (2018)

Critical temperature in S/F/S: π state

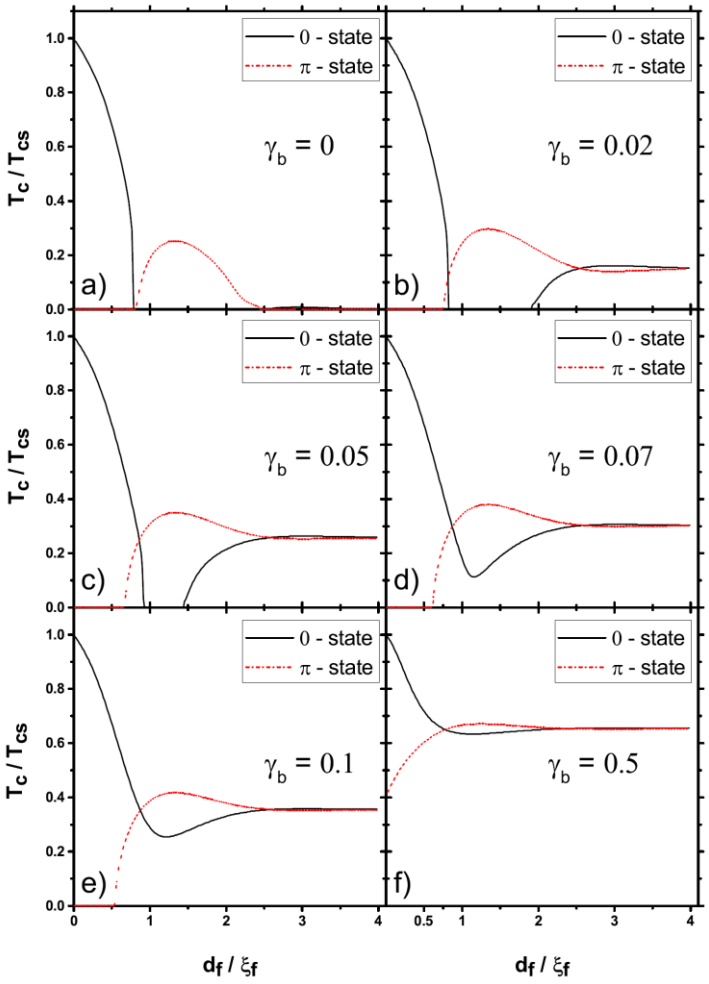


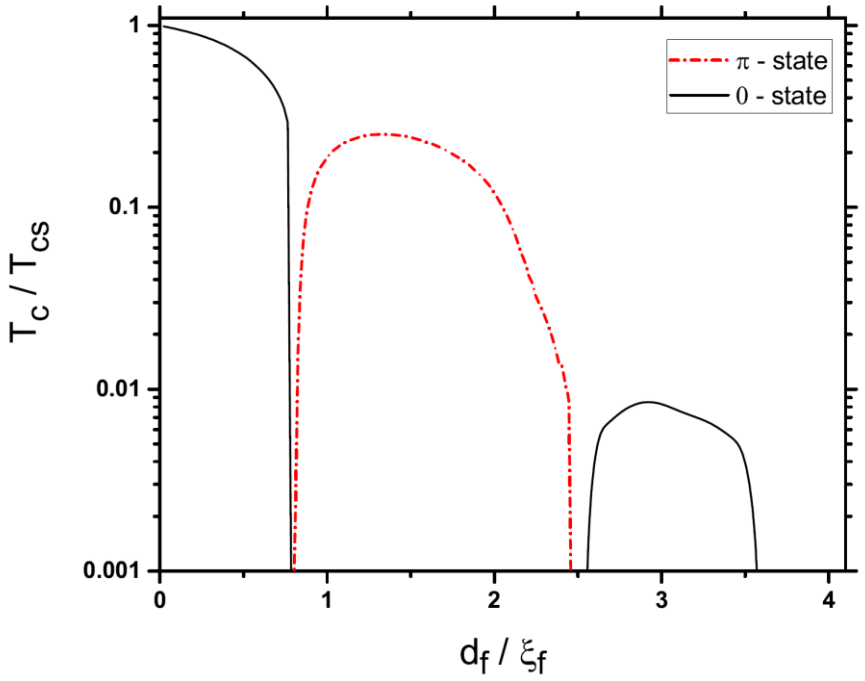
Karabassov et al., submitted to PRB (2018)



Hilgenkamp, Supercond. Sci. Technol. **21**, 034011 (2008)

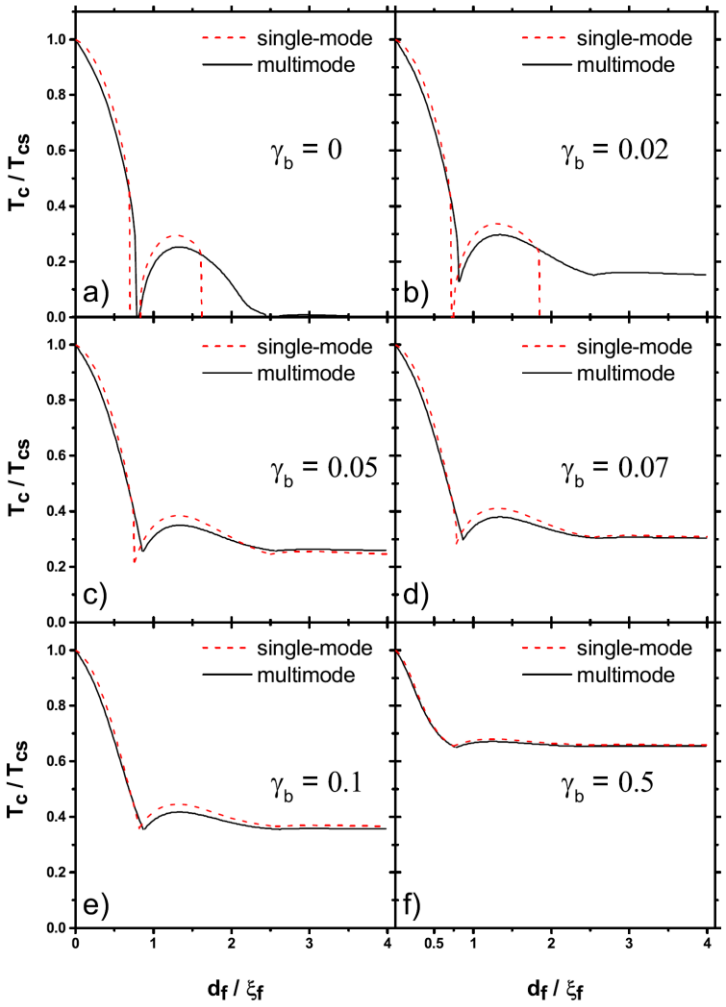
Critical temperature in S/F/S: 0-π transitions





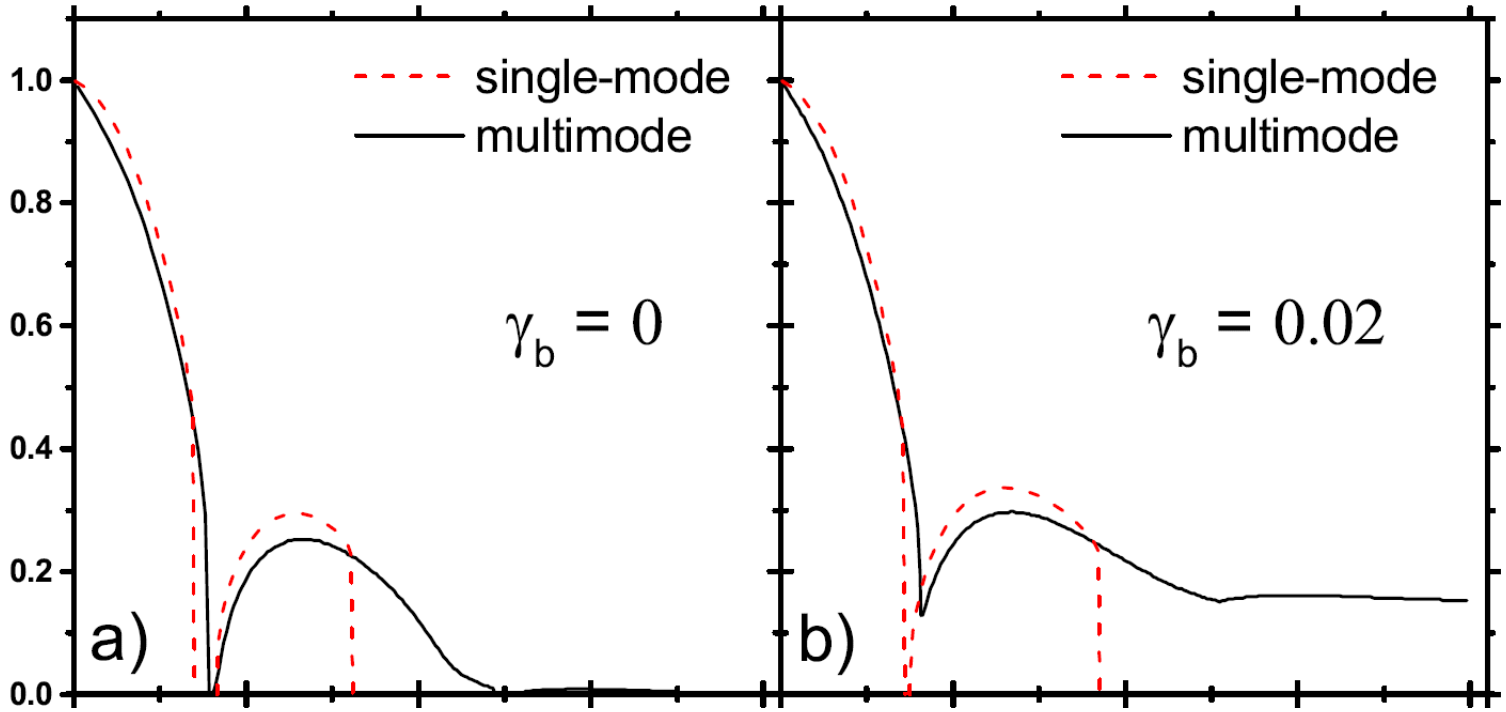
Karabassov et al., submitted to PRB (2018)

Single-mode vs. multimode method



Karabassov et al., submitted to PRB (2018)

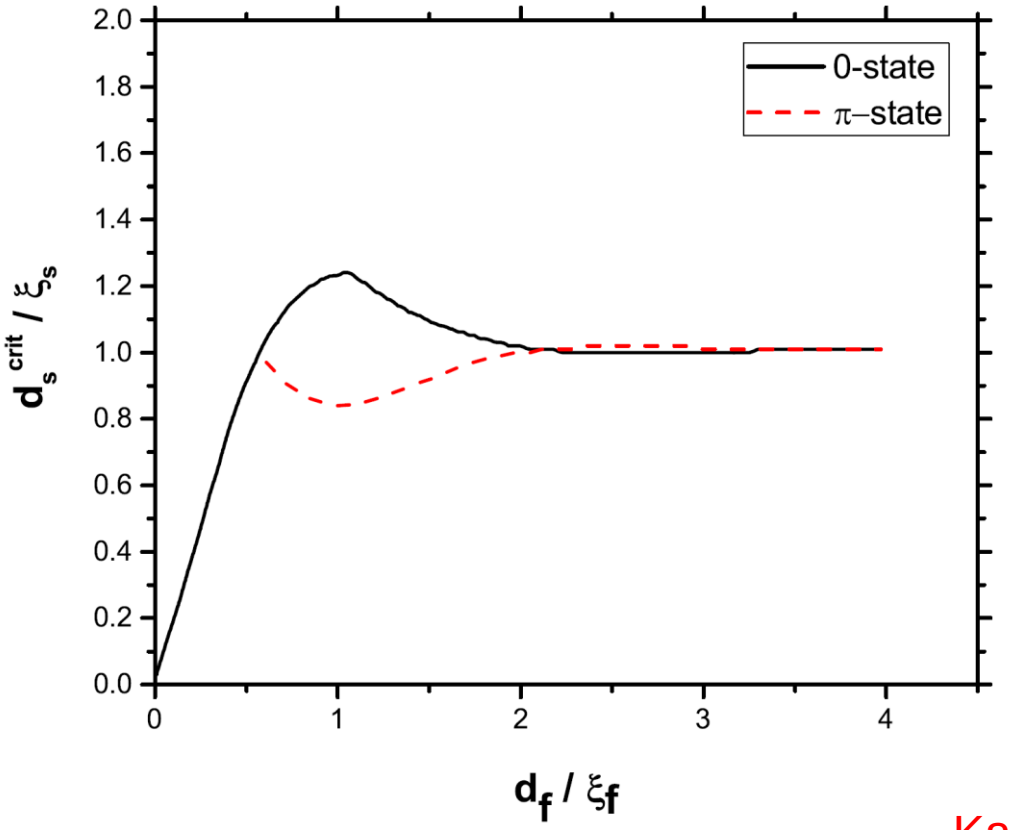
Single-mode vs. multimode method



$$\sqrt{E_{ex}/\pi T_{cs}} \gg 1/\gamma_b$$

Karabassov et al., submitted to PRB (2018)

Critical thickness of superconductor



Karabassov et al., submitted to PRB (2018)

Summary

- We have investigated the critical temperature oscillations in S/F/S trilayers;
- We have studied the 0-π transitions in S/F/S trilayers;
- We have compared single-mode and multimode methods.

Thank you!