

Nonlinear magnetic field dependence of the conductance in d-wave NIS tunnel junctions

M Fogelström^{1,3}, D. Rainer^{2,3} and J. A. Sauls³

¹Department of Microelectronics & Nanoscience (MC2)
Chalmers University of Technology
412 96 Göteborg, Sweden

²Physikalisches Institut
Universität Bayreuth
D-95441 Bayreuth, Germany

³Department of Physics & Astronomy
Northwestern University
Evanston, Illinois 60208, USA

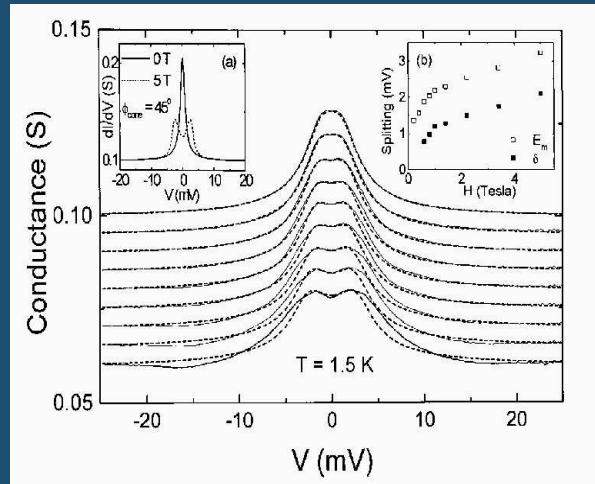
Low-bias conductance of YBCO thin films

Field-dependent split ZBCP

-ZBCP, Zero-Bias Conductance Peak, hallmark of d-wave induced Andreev bound states at zero energy

-ZBCP splits in applied field due to Doppler shift by screening currents

$$\epsilon \rightarrow \epsilon + \vec{v}_f \cdot \vec{p}_s$$

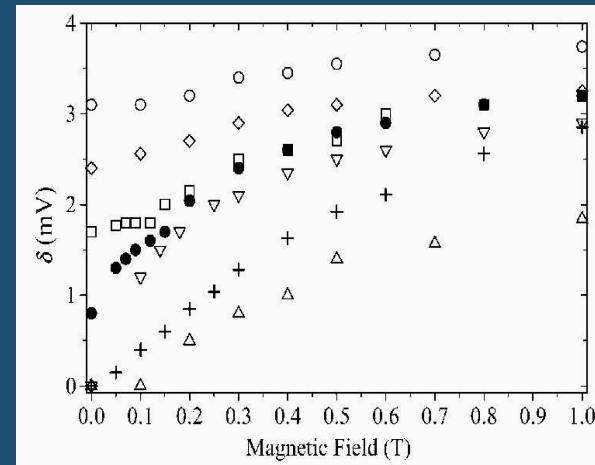


Aprili, Badica & Greene, Phys Rev Lett. 83, 4630 (1999)

Doping dependence of ZBCP-split

-Doppler shift alone \Rightarrow linear-in-field split but nonlinear-in-field split of ZBCP observed.

-doping dependence of the ZBCP-split under doped \Rightarrow suppressed splitting over doped \Rightarrow spontaneous splitting



Dagan & Deutscher, Phys Rev Lett. 87, 177004 (2001)

Nonlinear conductance and subdominant pairing channels

Having non-zero pairing interaction in other representations, Γ , than in dominant d-wave (B_{1g}) may give a mixed state \mathcal{T} -breaking state*

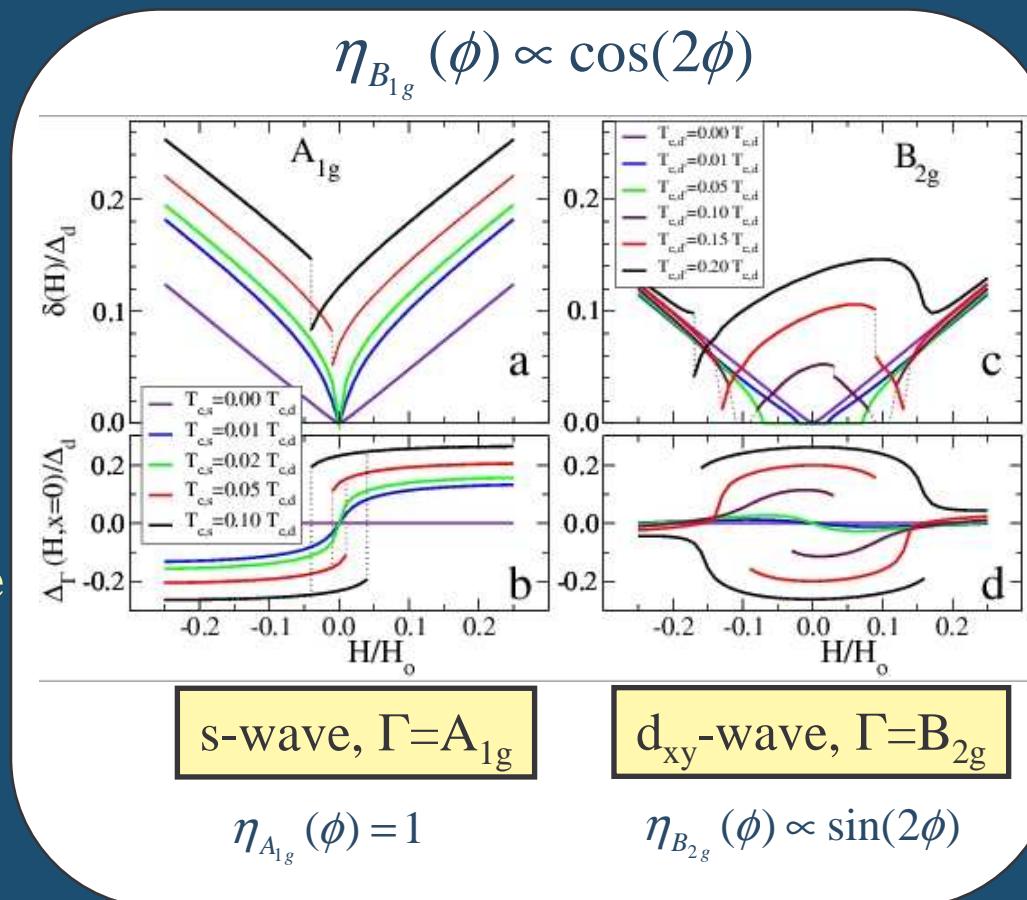
$$\Delta(\mathbf{p}_f) = \Delta_d(\mathbf{p}_f) + i\Delta_\Gamma(\mathbf{p}_f)$$

locally at the interface.

This leads to an additional shift of the Andreev bound states

$$\varepsilon_b(\mathbf{p}_f) = -\mathbf{v}_f \cdot \mathbf{p}_s - s_\Gamma \Delta_\Gamma(\mathbf{p}_f)$$

$$s_\Gamma = \text{sgn}[\Delta_d(\mathbf{p}_f)\Delta_\Gamma(\mathbf{p}_f)]$$



This modifies the low-bias conductance in a field !

*Covington, et al. PRL 79, 277 (1997), Fogelström, Rainer and Sauls PRL 79, 281 (1997)

Doping dependence ?

Pairing interaction with

-repulsive magnetic contribution:

correlation length $\xi_{\text{AF}} \sim 2 a$

incommensurate spin fluctuations $\delta_{x,y}$

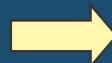
-attractive electron-phonon contribution

λ_{ep} which is weak, magnitude \sim doping

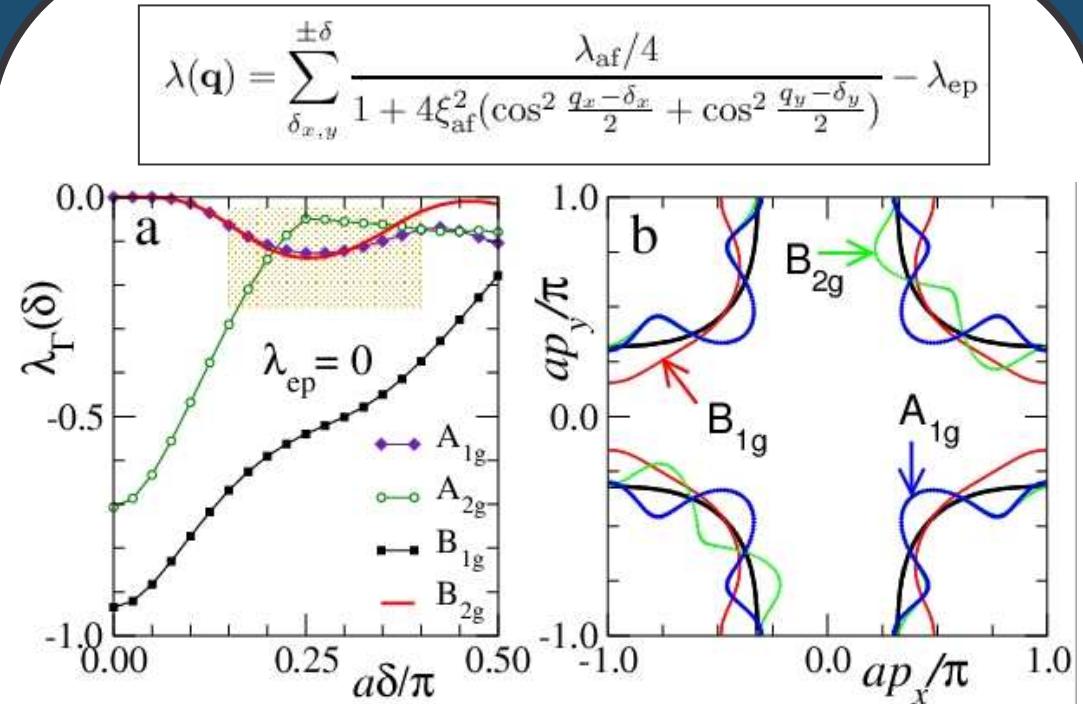
Tight-binding bandstructure

R. J. Radtdke & M. Norman,
PRB 9554 (1994)

Solve linearized gap equation for
the eigenvalues λ_{Γ} and eigen-
functions $\eta_{\Gamma}(p_F)$



- $\delta_{x,y} > 0$ finite attractive λ_{Γ} for all Γ
- highly anisotropic $\eta_{\Gamma}(p_F)$
- anisotropy of η_{A1g} may be
reduced by λ_{ep} → handle to doping



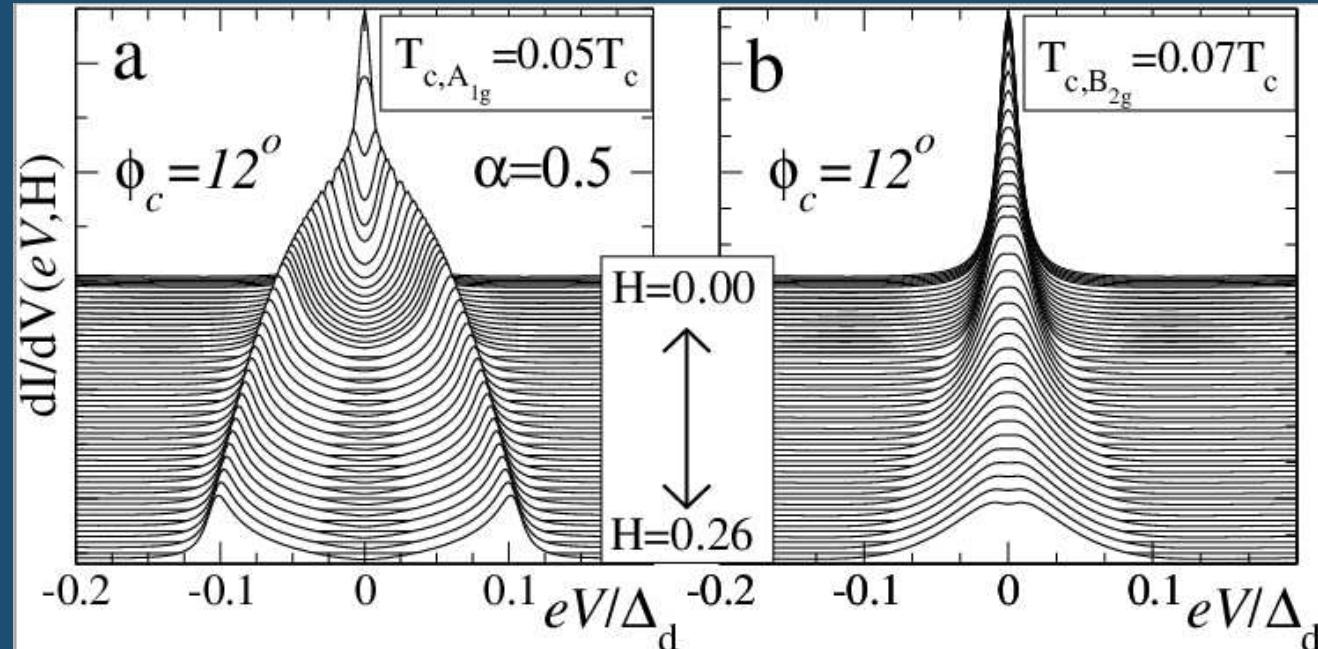
$$\Delta(\mathbf{p}_f, \mathbf{R}) = T \sum_{\epsilon_n} \int d^2 \mathbf{p}'_f \lambda(\mathbf{p}_f - \mathbf{p}'_f) \mathfrak{F}(\mathbf{p}'_f, \mathbf{R}; \epsilon_n)$$

$$\lambda(\mathbf{p}_f - \mathbf{p}'_f) = \sum_{\Gamma} \lambda_{\Gamma} \eta_{\Gamma}(\mathbf{p}_f) \eta_{\Gamma}^*(\mathbf{p}'_f) \quad \lambda_{\Gamma}, \epsilon_c \rightarrow T_c^{\Gamma}$$

Input to quasiclassical calculations of surface state and NIS-conductance...

Low-bias conductance for $\Delta(\mathbf{p}_f) = \Delta_d(\mathbf{p}_f) + i\Delta_\Gamma(\mathbf{p}_f)$

Magnetic field along the c-axis: $H_0 = (c/e)\Delta/v_f \lambda \sim 1$ Tesla for YBCO



$$\eta_{A_{1g}}(\phi)$$

$$\Gamma = A_{1g}$$

$$\eta_{A_{1g}}(\phi; \alpha) \propto [\alpha - (1-\alpha)\sin(2\phi)\sin(6\phi)]$$



subdominant pairing enhances $\delta(H)$

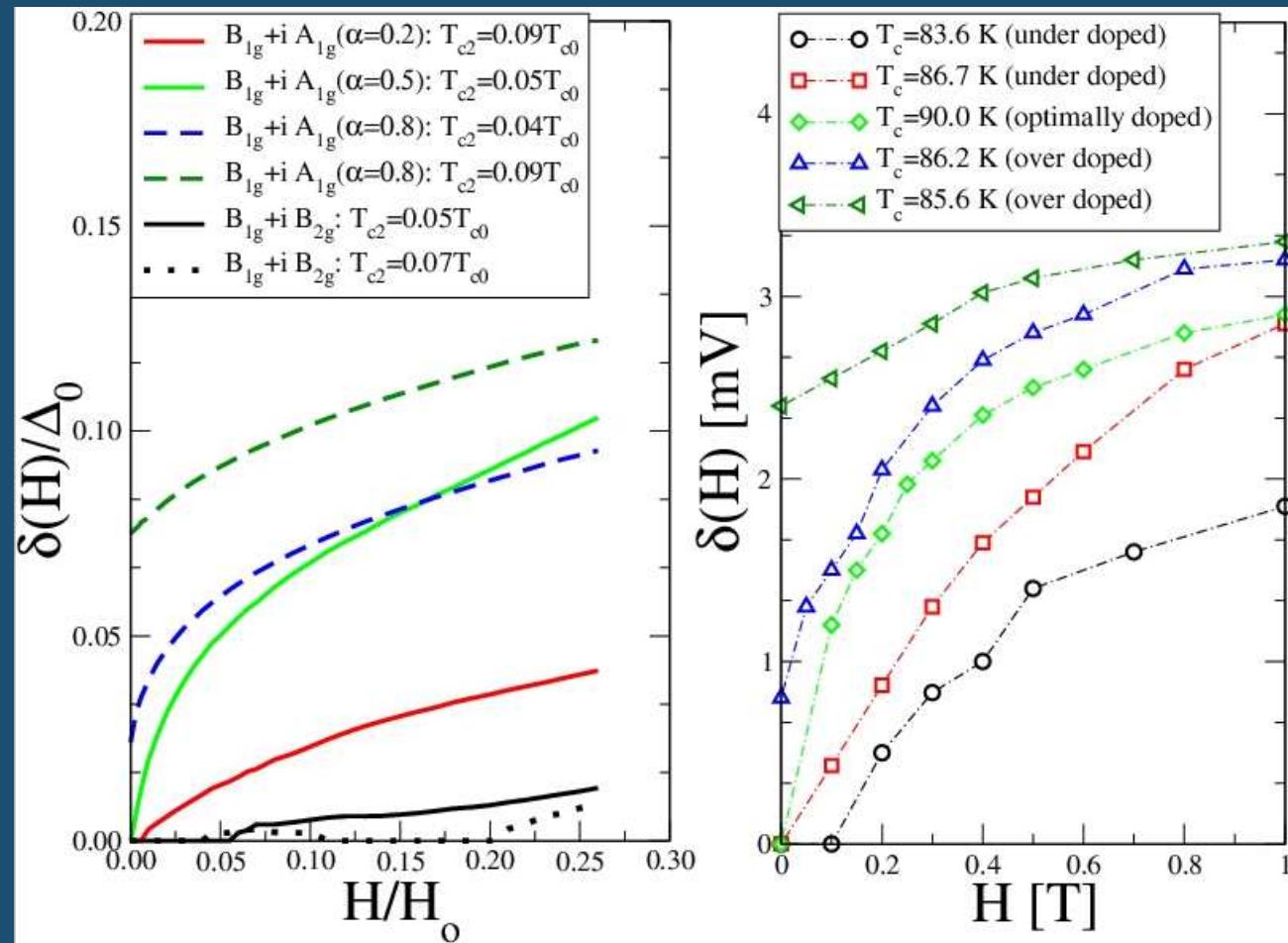
$$\Gamma = B_{2g}$$

$$\eta_{B_{2g}}(\phi) \propto |\sin(2\phi)|\sin(6\phi)$$



subdominant pairing suppresses $\delta(H)$

Low-bias conductance vs doping



Fogelström, Rainer & Sauls cond-mat/0302197

Dagan & Deutscher, Phys Rev Lett. 87, 177004 (2001)

Conclusions

- Presence of a subdominant pairing channel gives a nonlinear split of ZBCP in a magnetic field
- Nonlinearity of split is distinct for each pairing channel
- Simple model to include doping by introducing an electron-phonon part to the pairing interaction gives good agreement with experiments