The Closing Quasiparticle Spectral Gap and its Implications for Nb_3Sn

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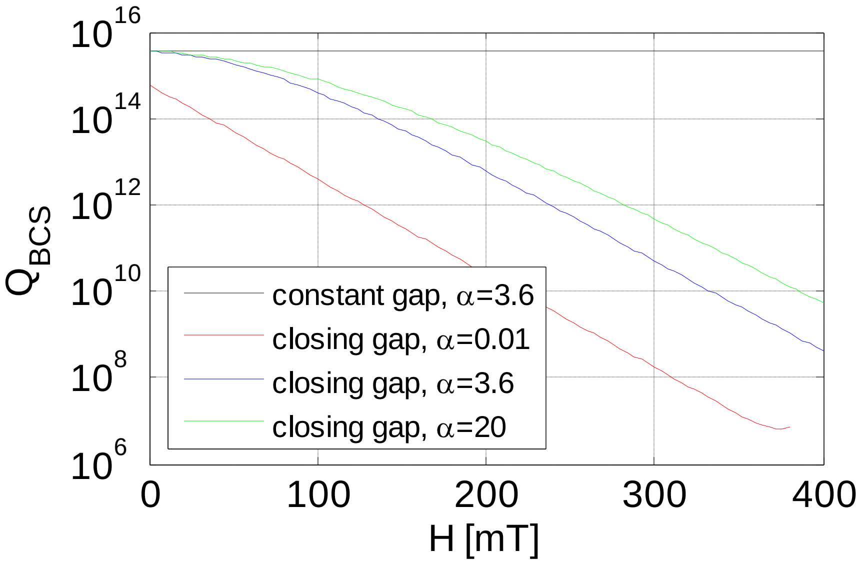

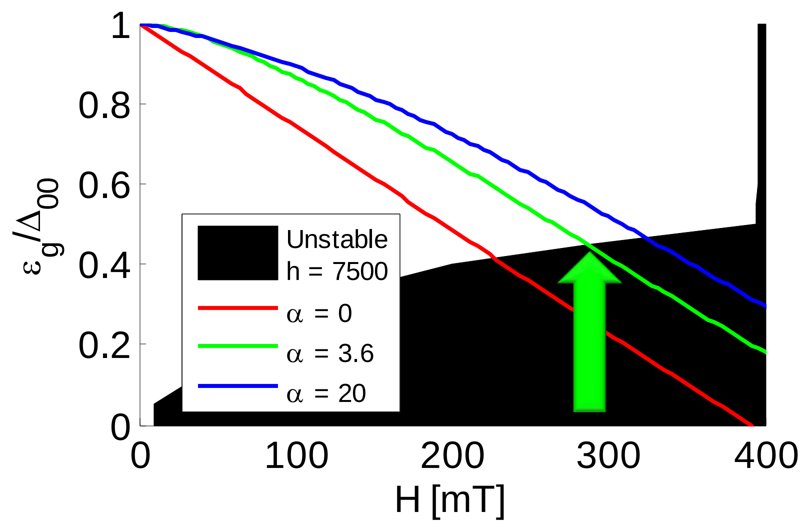

Concerns About Nb_3Sn

- ~~Predicted H_{sh} for large κ is small~~
  - Improved theory predicts very large H_{sh}
- Gap closes below H_{sh}, leading to high R_s
  - Will discuss this today
- Low ξ makes Nb_3Sn sensitive to small flaws like grain boundaries
  - Future study

	Nb	Nb_3Sn
κ	1.4	~30
$H_{sh}(0)$	200 mT	~400 mT
ξ	~60 nm	~3-6 nm

Paper by F. Lin and A. Gurevich

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Effect of impurities on the superheating field of type-II superconductors

- Solved Eilenburger's anomalous Greens functions in high-κ limit to calculate DOS
- DOS gives quasiparticle gap ε_g(H, dirt)
  - Reminder: ε_g differs from Δ (the pairing potential) as it includes the effect of current
  - Lin and Gurevich suggest that R_s α exp($-\varepsilon_g/kT$)
- Reassuring: $\varepsilon_g \rightarrow 0$ at 97% of H_{sh}, and dirt pushes gap closing above H_{sh}
- Today: Careful extraction of $R_s(H$, dirt) from Lin/Gurevich theory for Nb_3Sn

Numerical Solutions

- Reproduce calculations of quasiparticle spectrum through numerical solution of Eilenburger equations in high κ, low T limit

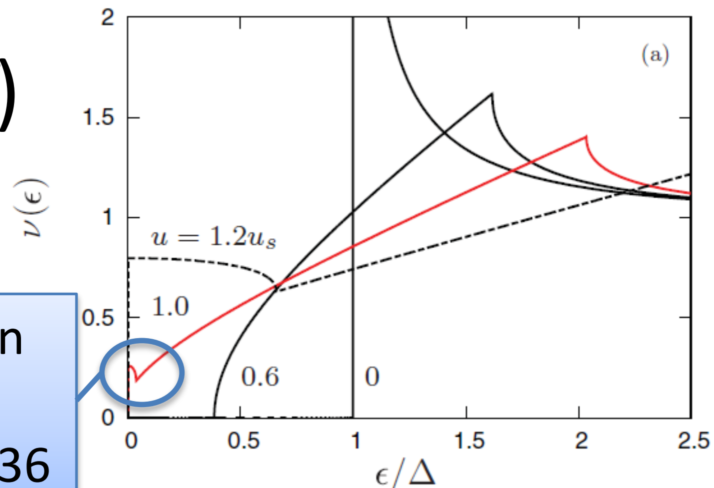
$$\left(\frac{\Delta \sin X\tau_-}{uv\tau_- - X}\right)^2 + \left(\frac{\omega_n \tau_+}{uv\tau_+ \cot X - 1}\right)^2 = \frac{1}{4}.$$

$$\ln\frac{T}{T_c} + 2\pi T \sum_{n=0}^{\infty}\left\{\frac{1}{\omega_n} - \frac{2X\tau_-}{uv\tau_- - X}\right\} = 0,$$

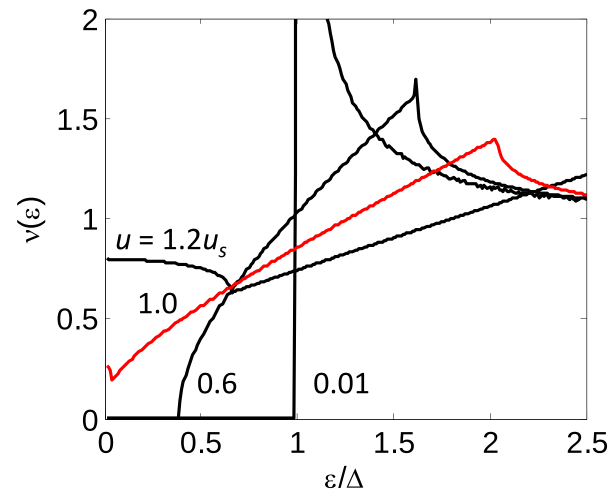
$$\nu(\epsilon) = \mathrm{Im}\frac{2uv\tau^2\epsilon}{uv\tau - \tan\chi},$$

$R_s \propto \exp(-\varepsilon_g/kT)$

Clean limit (α = 0) shown
$\varepsilon_g \rightarrow 0$ at 97% of H_{sh}
Gap stays open for α > 0.36

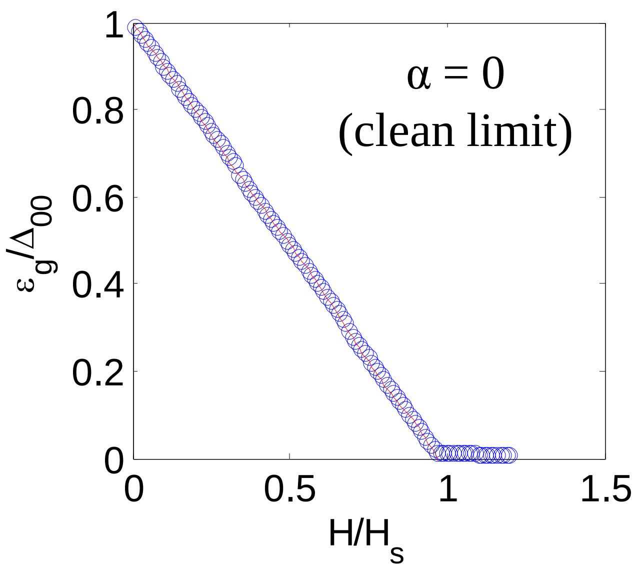


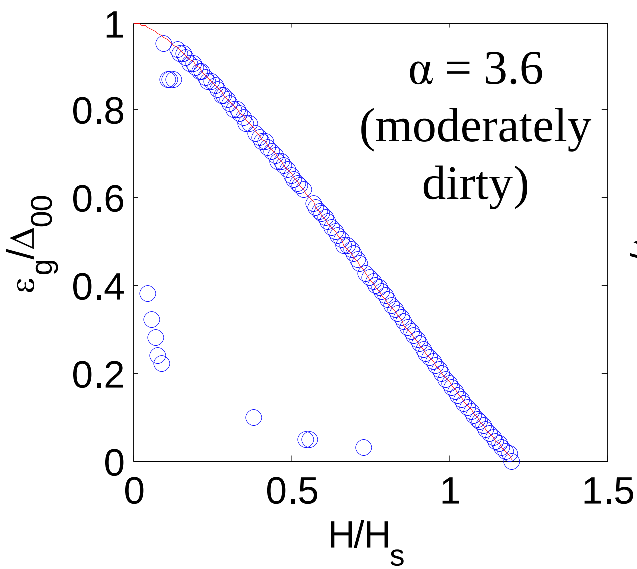
Lin and Gurevich, PRB, 2012

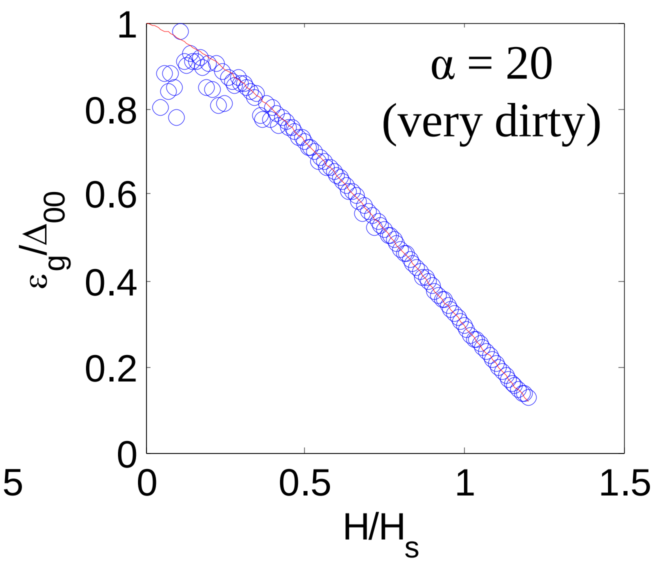


Reproduction of calculations

ε_g as a Function of Field







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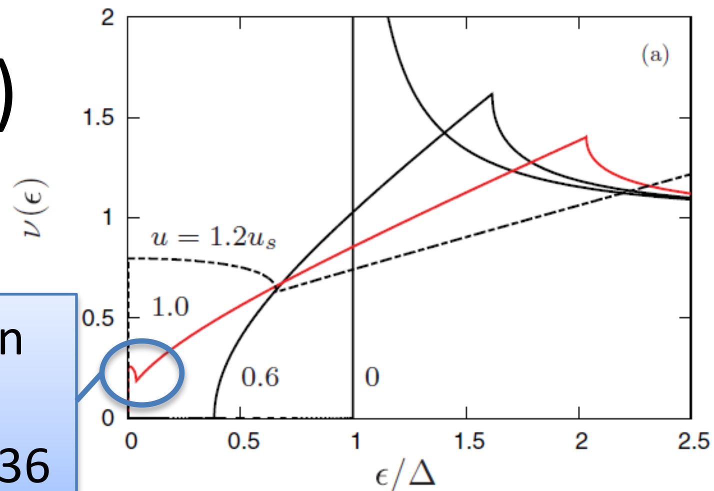

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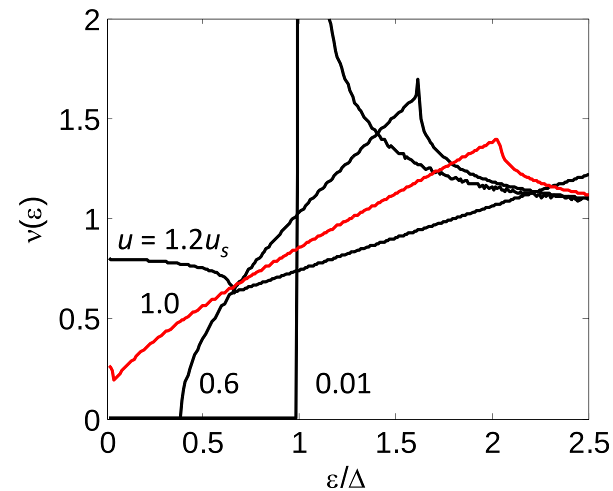
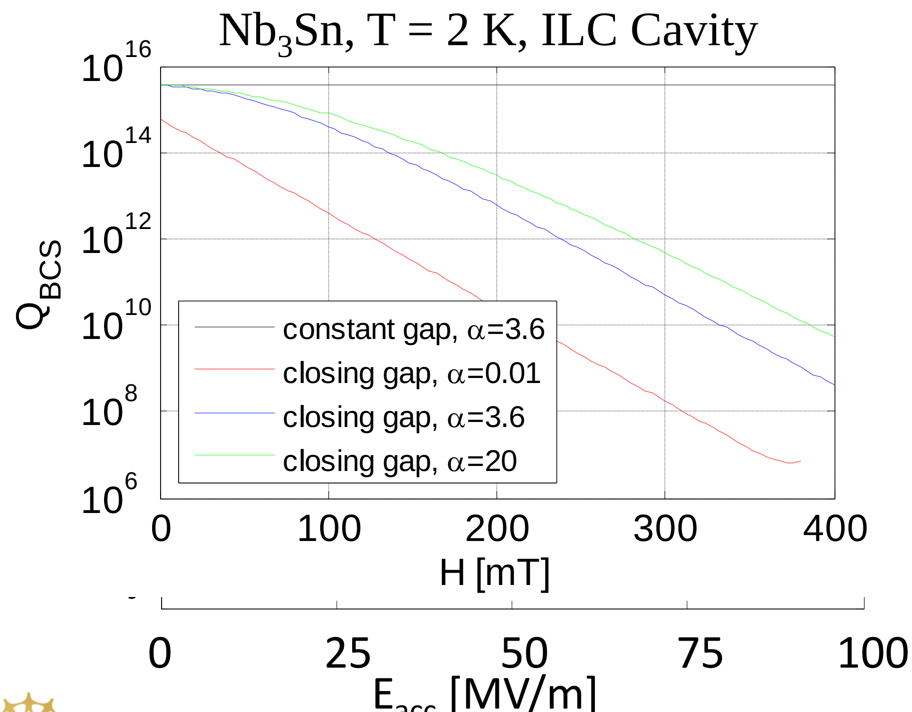
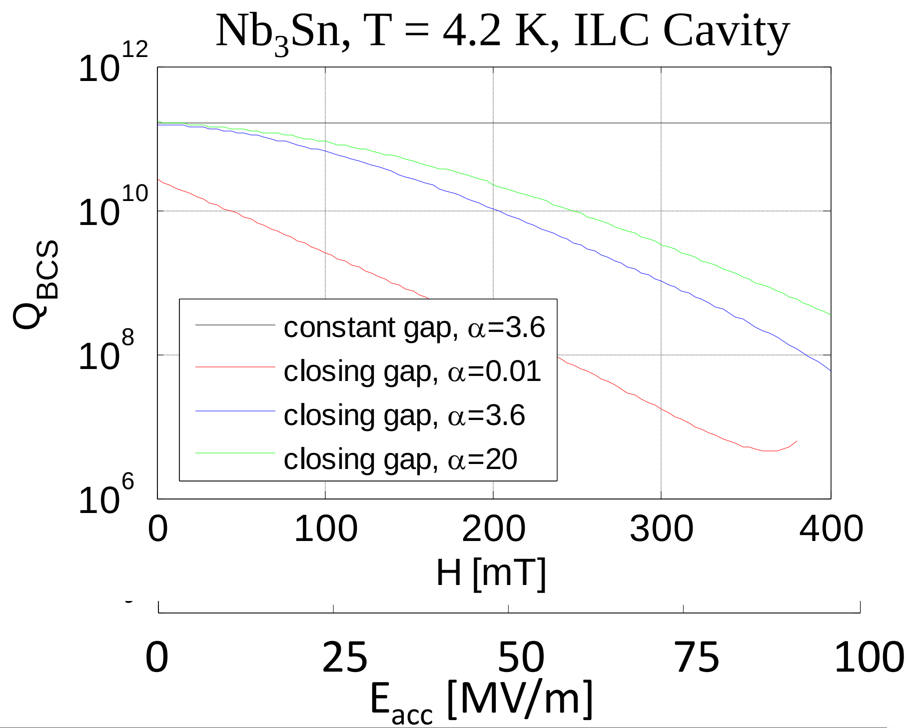


Reproduction of calculations

$Q_{BCS}(H)$ with Gap Closing

- Use SRIMP to calculate $R_s(T, \text{gap}, T_c, f, \xi, \lambda, \text{RRR})$
- Assumes ~1/2 of cavity surface is at $H_{surface,max}$ (approximation for an ILC cavity)
- Gives an overestimate of R_s

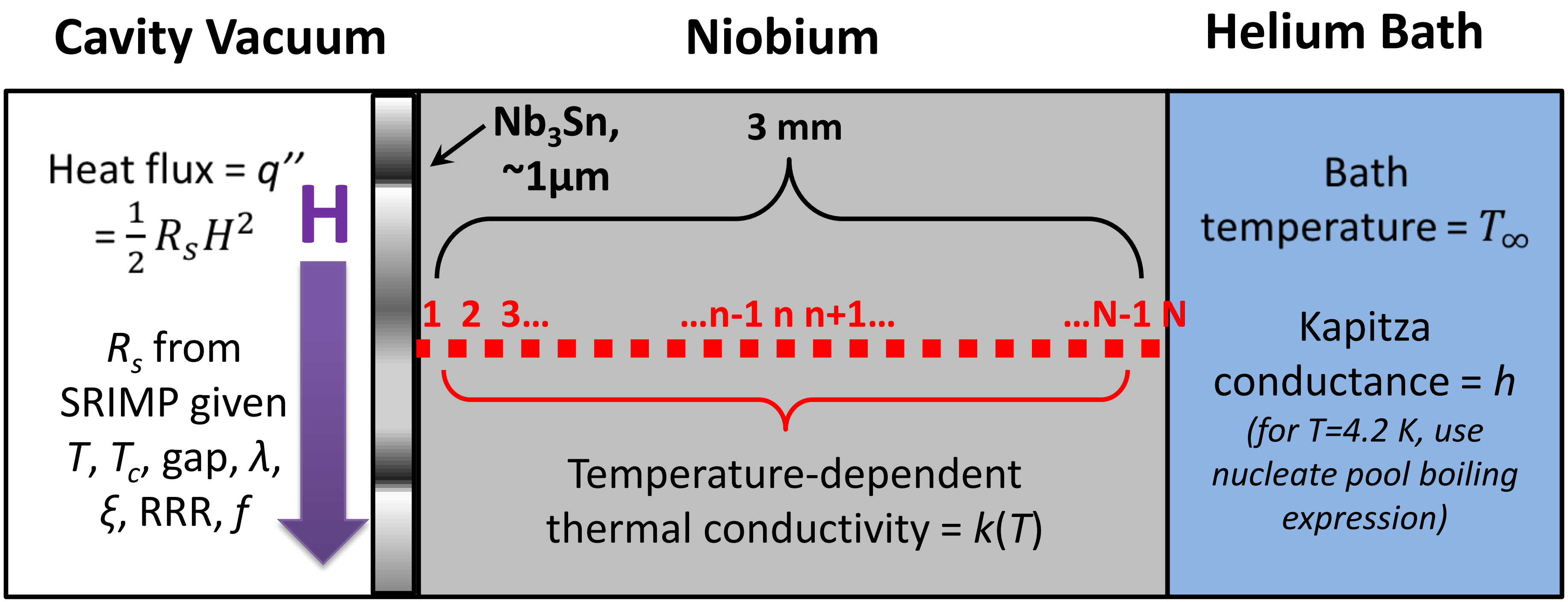




Maximum Field for Stable Operation

- Given R_s, how high in field can we get to?
- 3 mm thick Nb
- 2 K bath or 4.2 K bath
  - Cooling by Kapitza resistance or nucleate pool boiling
- Solve 1-D thermal conduction equation with temperature dependent thermal conductivity
  - Find T of inner surface
  - Find max H before thermal runaway occurs

1-D Heat Conduction Model



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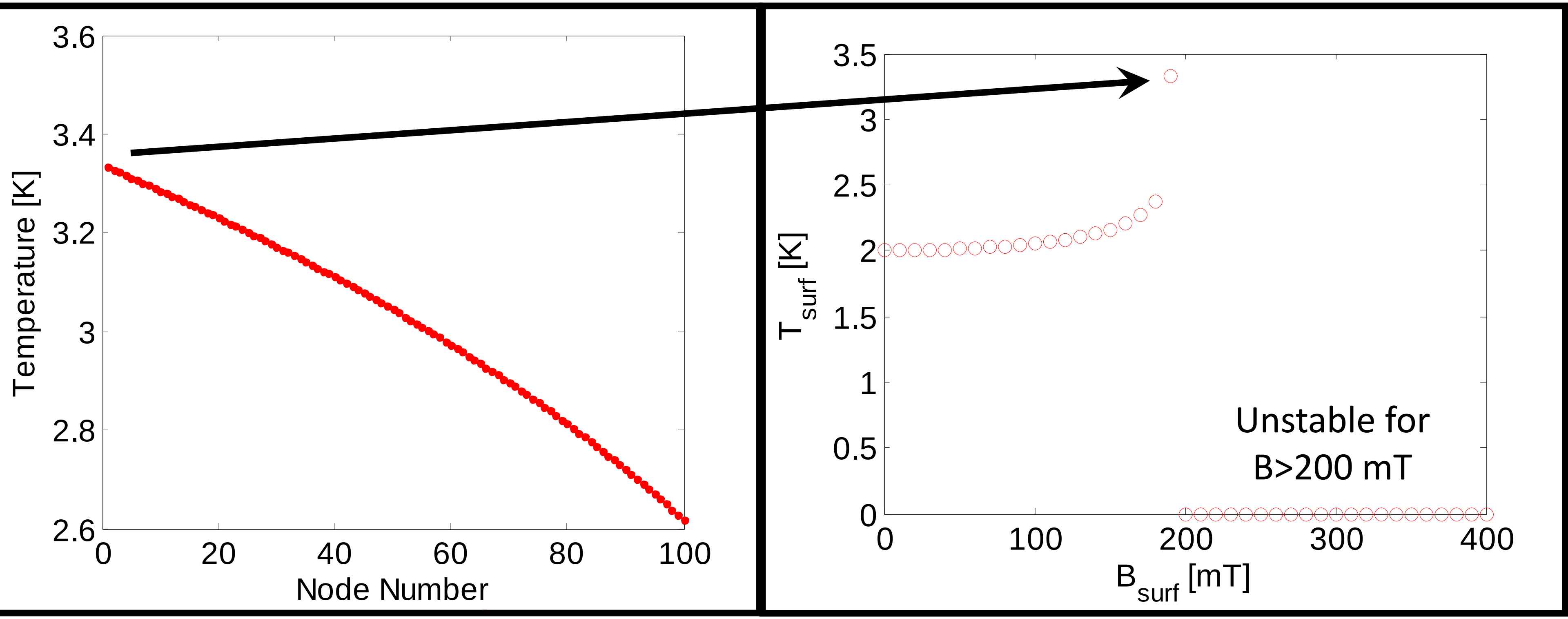
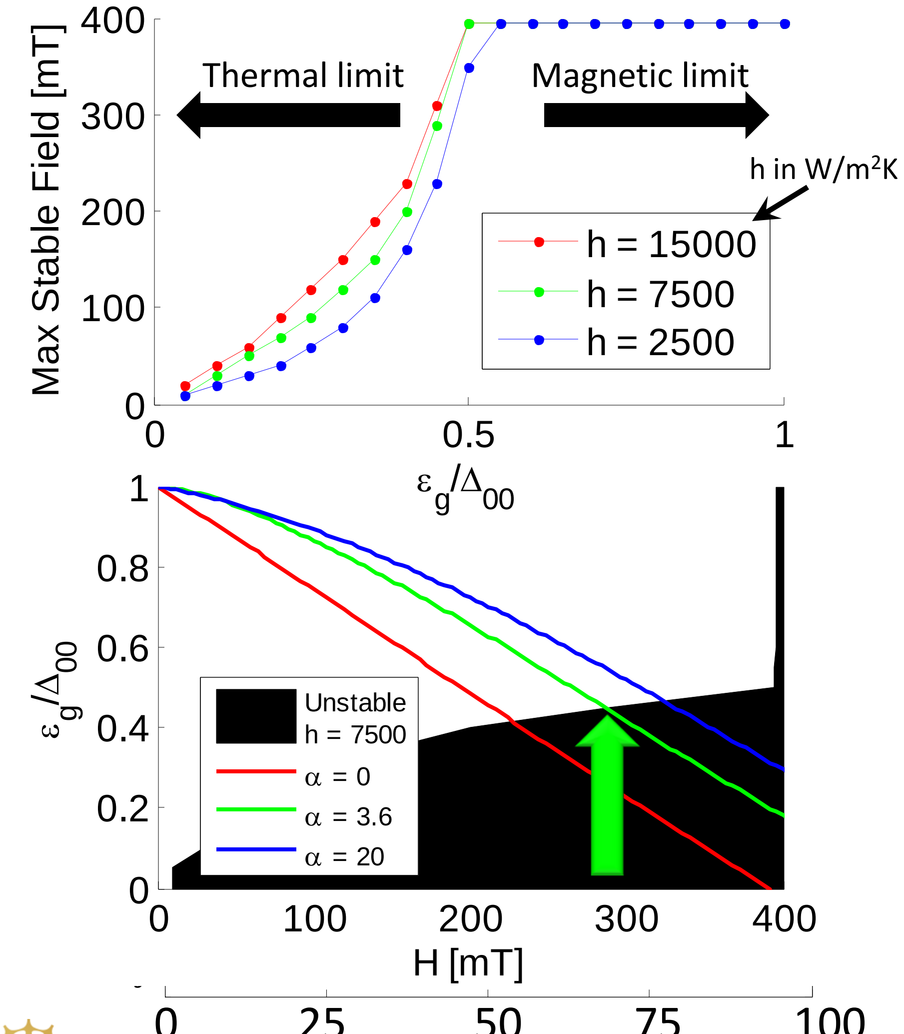


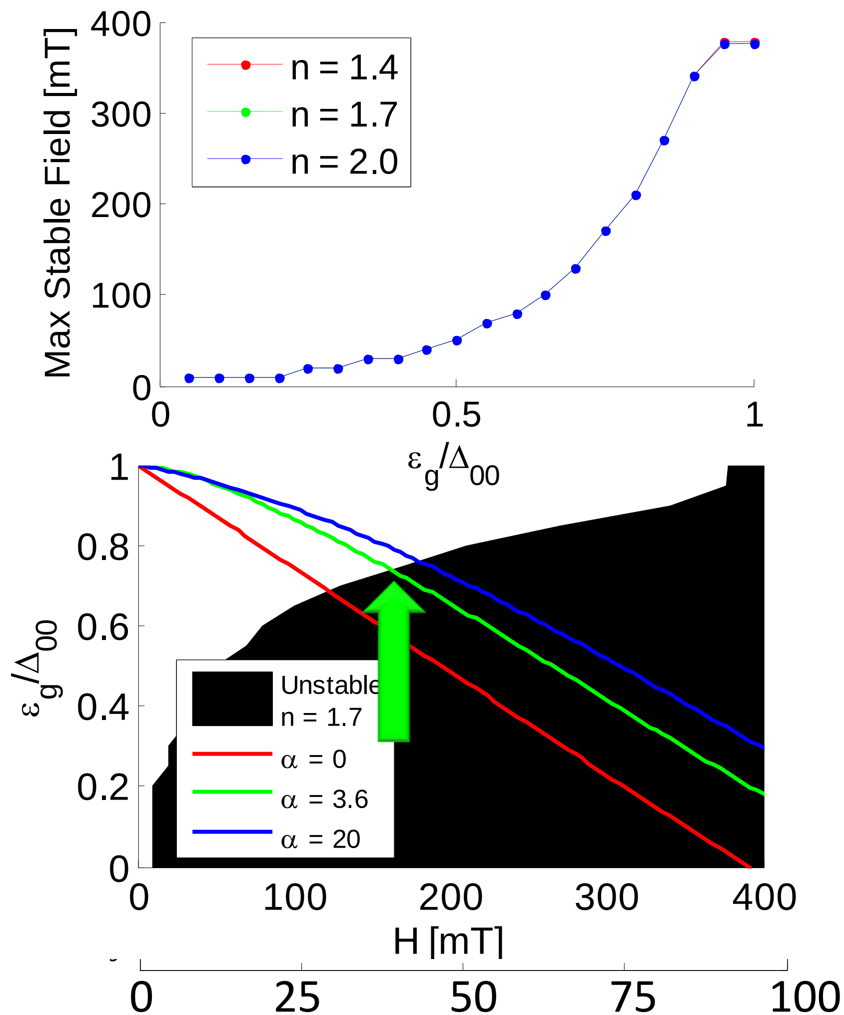
Example: T_{bath} = 2 K, gap = $0.4\Delta_{00}$, h = 7500 W/m^{2}K

$H_{max,stable}(\varepsilon_g)$ for Nb_3Sn, $H_{sh}(0)$ = 400 mT, *RRR*=0.5, *f*=1.3 GHz

T_{bath} = 2 K – Kapitza resistance regime:
$q'' = h\Delta T$, h depends on surface preparation, T_{bath}



T_{bath} = 4.2 K – Nucleate pool boiling regime:
$q'' = C\Delta T^n$, $C \sim 1$ W/cm² up to total
$q'' \sim 1$ W/cm², where vapor film forms



Conclusions

- Good range of operation for Nb_3Sn even with exponential increase in R_s with B caused by closing quasiparticle gap
- Potential for high Q performance at moderate-to-high fields not compromised by this theory
  - Predicts R_{BCS} ~ 3 nΩ at 300 mT, 1.3 GHz, 2K
- Predicts thermal instability onset at ~290 mT at 2 K, ~180 mT at 4.2 K

Acknowledgements

- Special thanks to J. Halbritter for development of the SRIMP code
- Special thanks to N. Valles for developing MATLAB SRIMP code and for help with complex numerical solvers
  - There is now a website where you can run SRIMP!
  - http://www.lns.cornell.edu/~liepe/webpage/researchsrimp.html