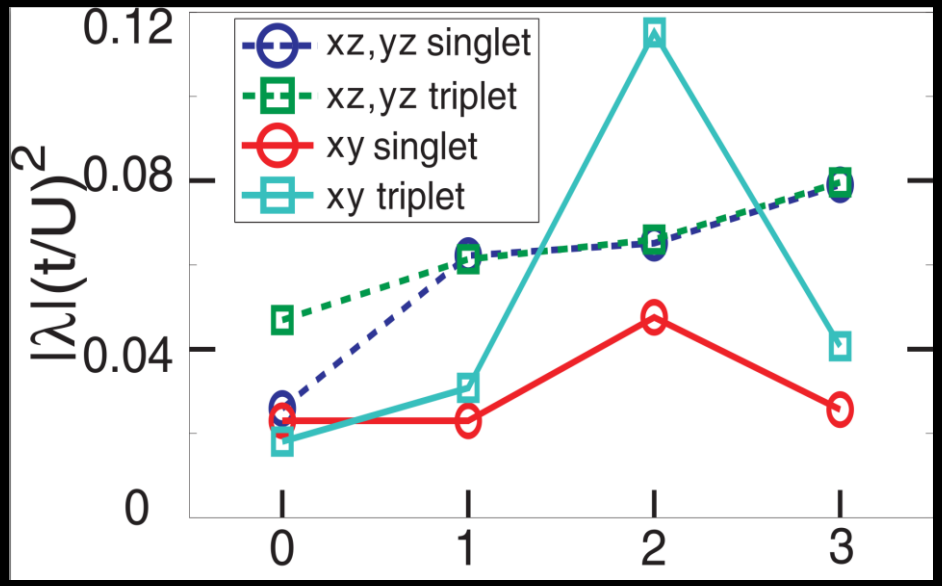
Towards Higher T_c Topological Superconductors



Eun-Ah Kim
(Cornell University)

Yi-Ting Hsu

Weejee Cho

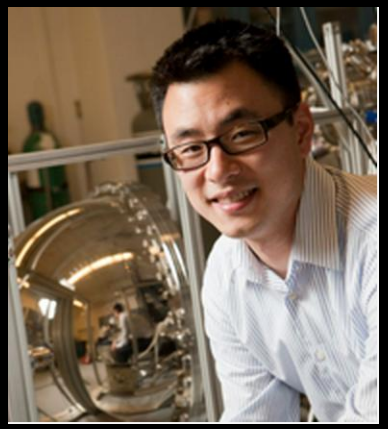
Andrew Mulder

Craig Fennie

Bulat Burganov

Carolina Adamo

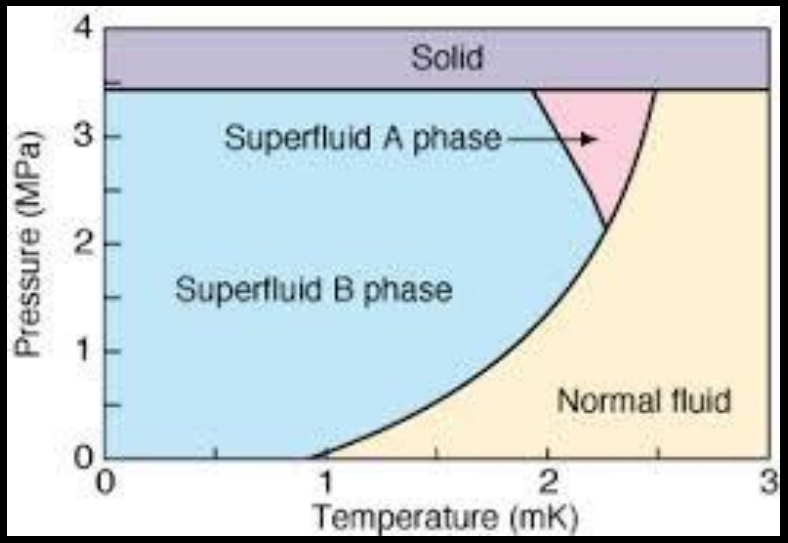
Darrell Schlom



Kyle Shen

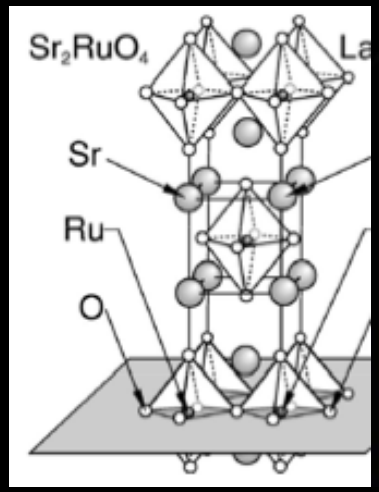
Existing Topo SC

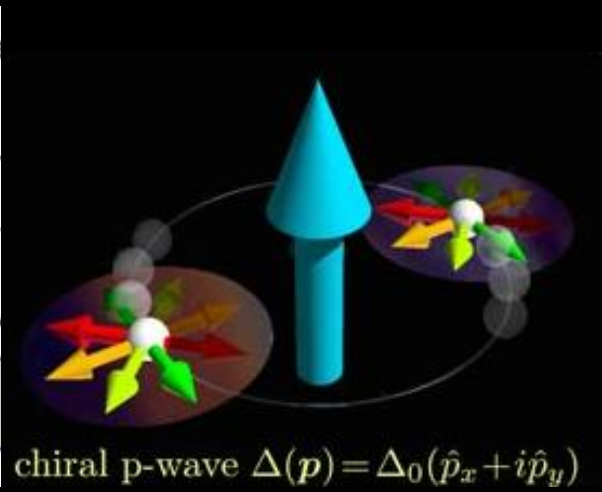
Superfluid He3



- The original (only) realization of topological superfluid

Sr_2RuO_4?

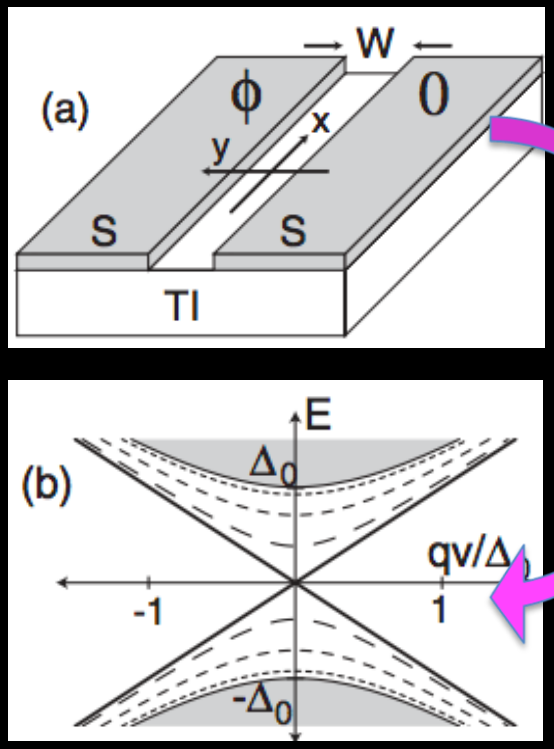




- Triplet SC with broken TRS
- Tc=1.5K
- Topological?

Approaches for Engineering New or Improved TopoSC

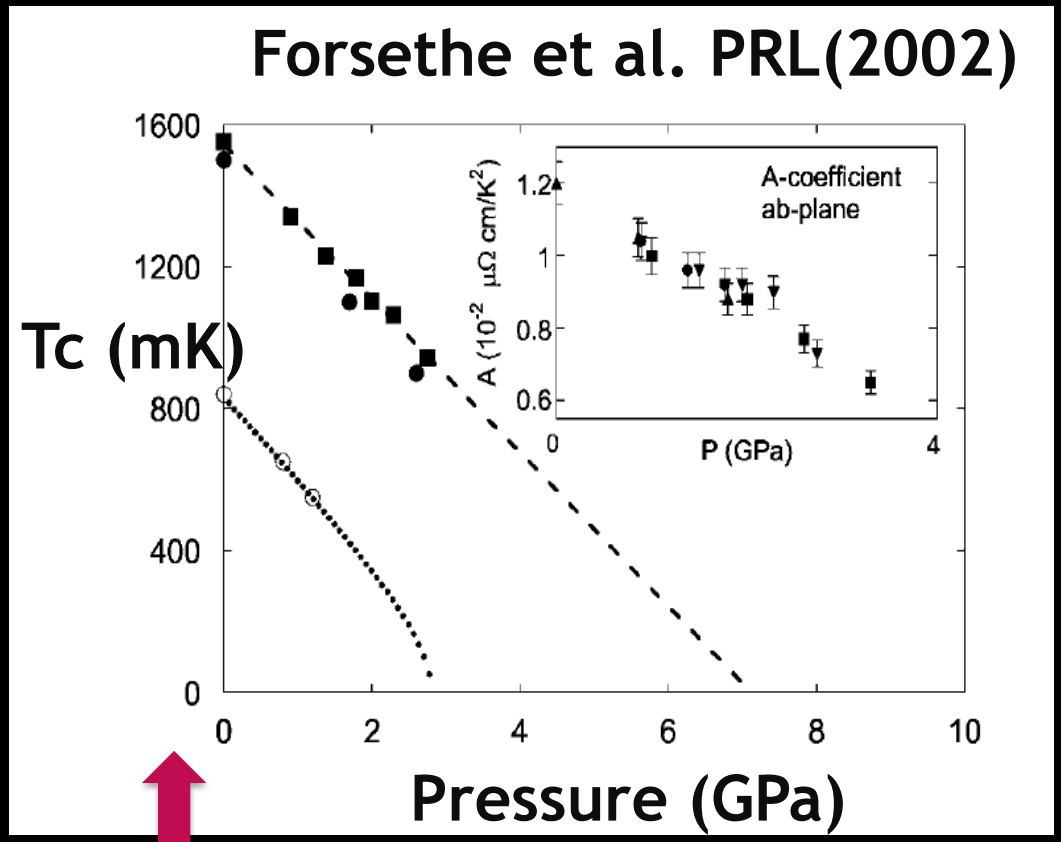
Hybrid Films of TI and s-SC



Fu&Kane PRL (2008)

- Experiments observe proximity effect
- Interfacial effect

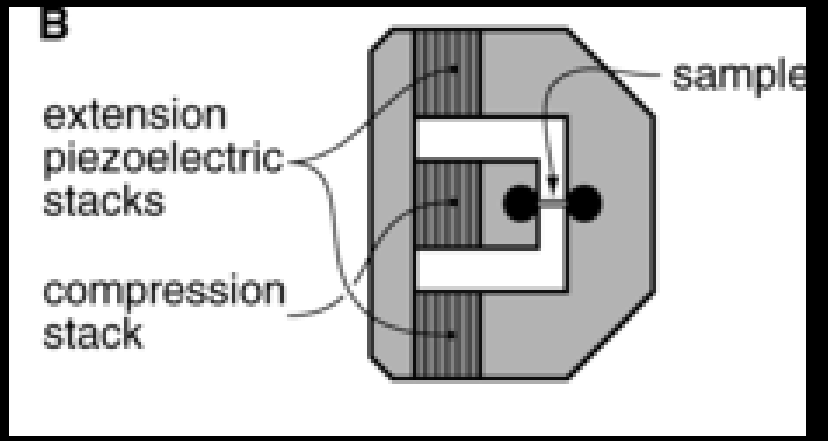
Pressurizing Bulk Sr_2RuO_4: I. Hydrostatic Pressure

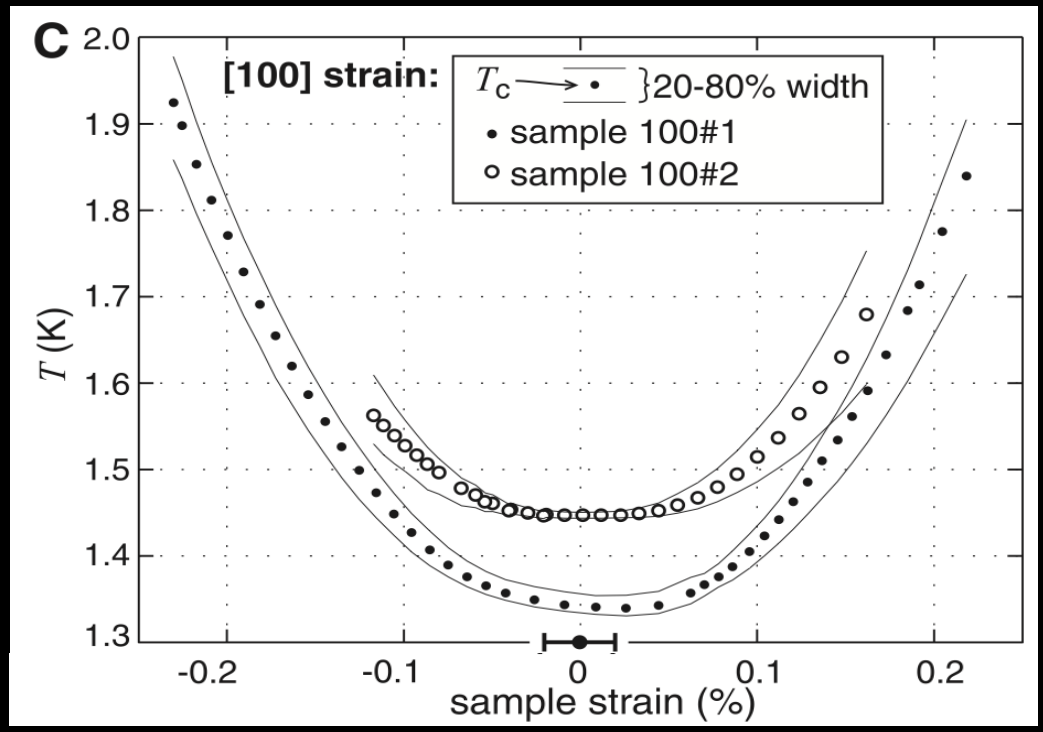


As grown Sr_2RuO_4

Decrease in T_c

Pressurizing Bulk Sr_2RuO_4: II. Uni-axial Strain



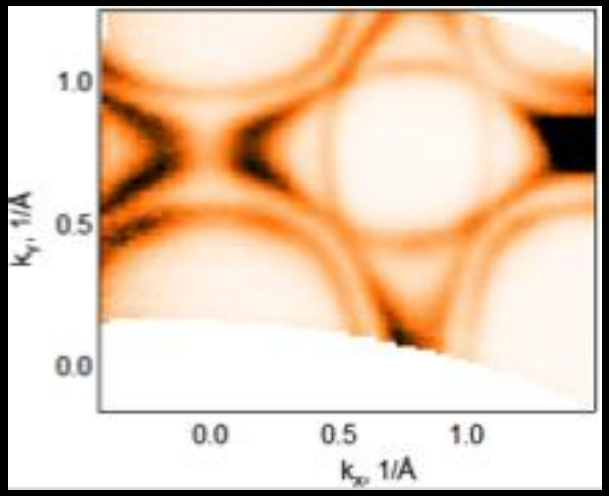


C. Hicks et al, Science 2014

Tc goes up
Not topological

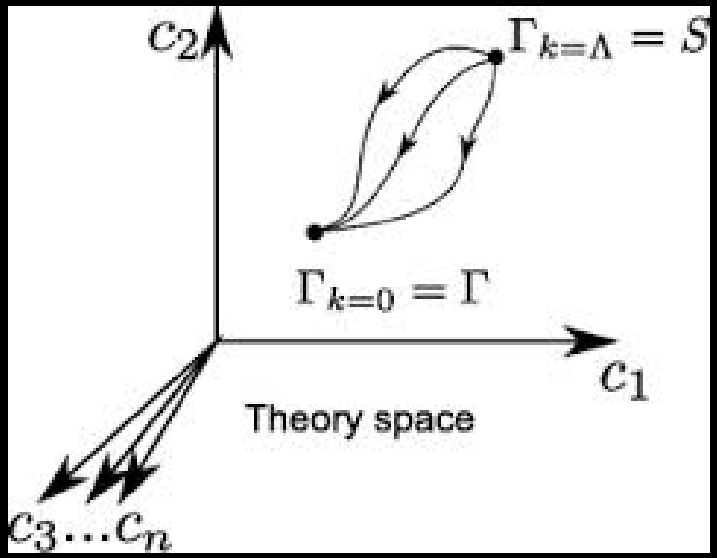
Our Approach

Strain Engineering via MBE

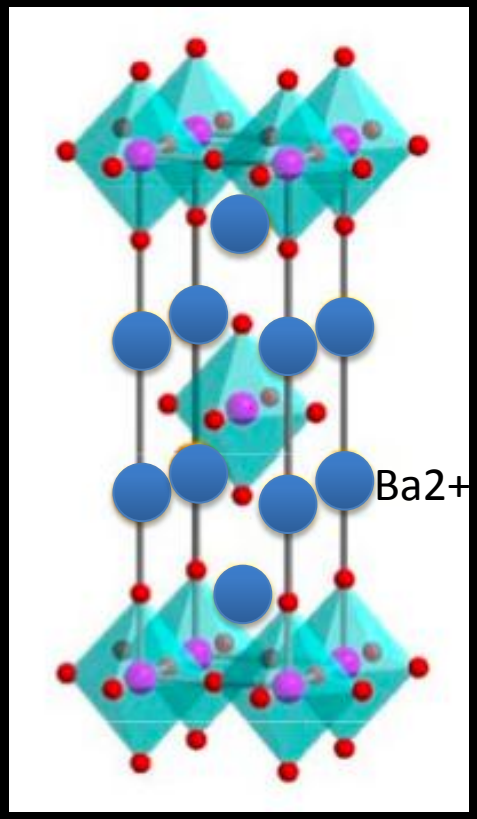


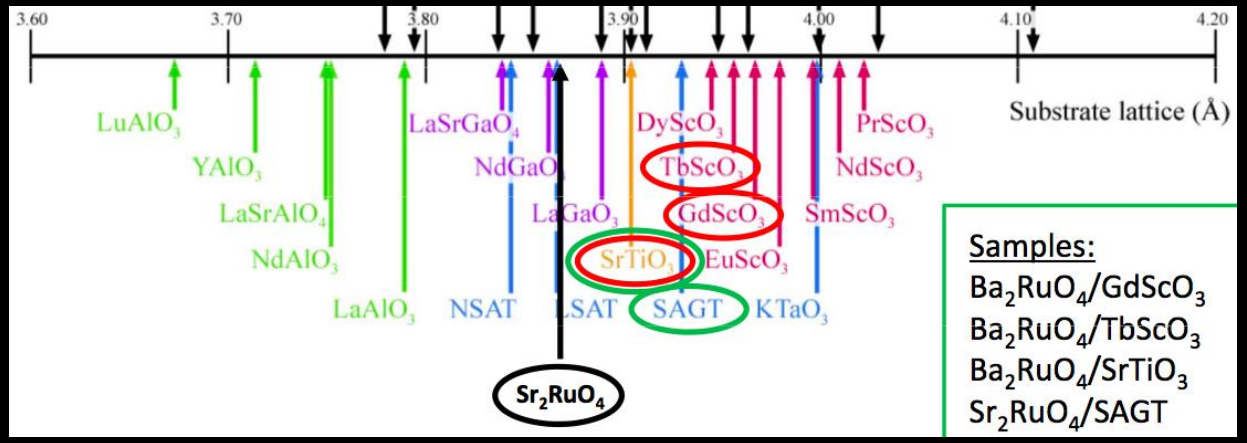
In Situ ARPES

Predictions based on RG



Phase Space for Strain Engineering in MBE





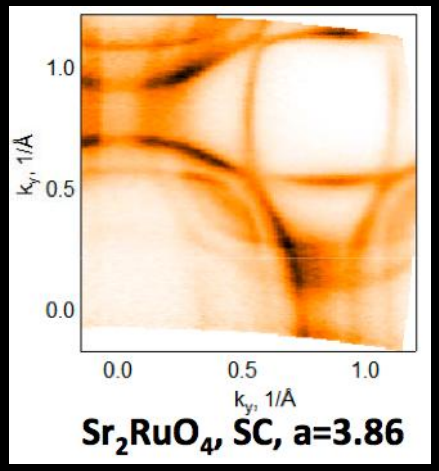
Isovalent Substitution

Film – Substrate Lattice Matching

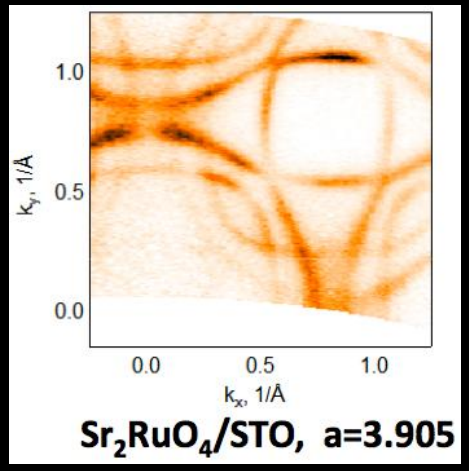
Two Step Strategy:

1. Explore the Phase Space for Films
2. Refine a Theoretically Guided Target

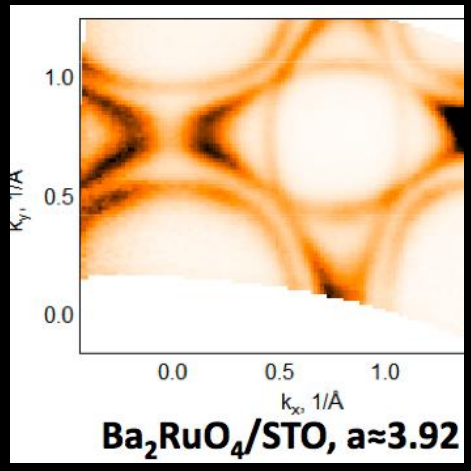
Fermi Surface Data



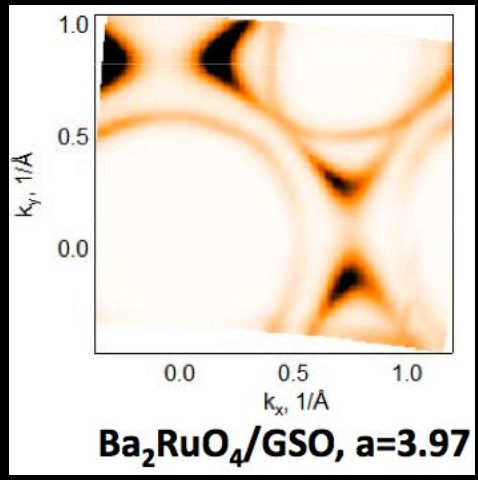
Sr_2RuO_4, SC, a=3.86



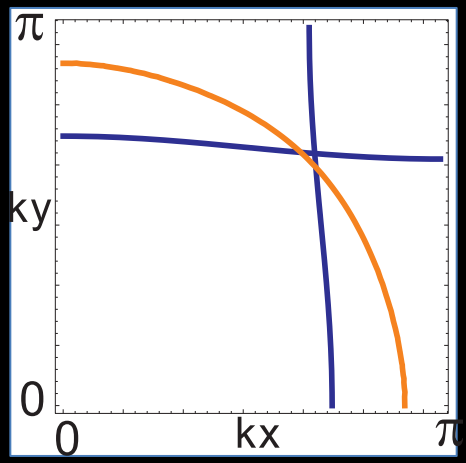
Sr_2RuO_4/STO, a=3.905

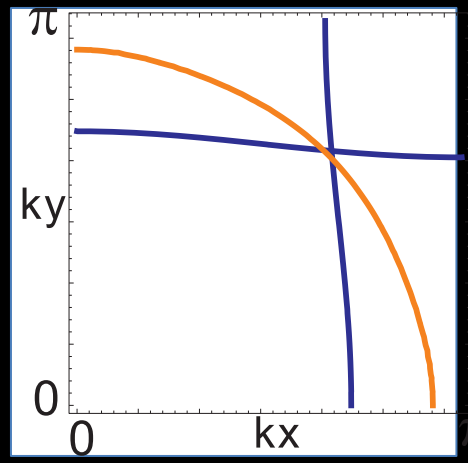


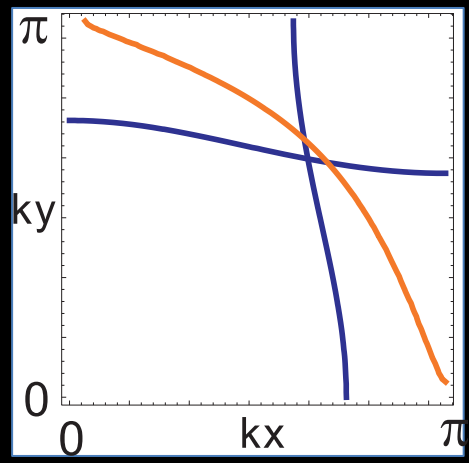
Ba_2RuO_4/STO, a≈3.92

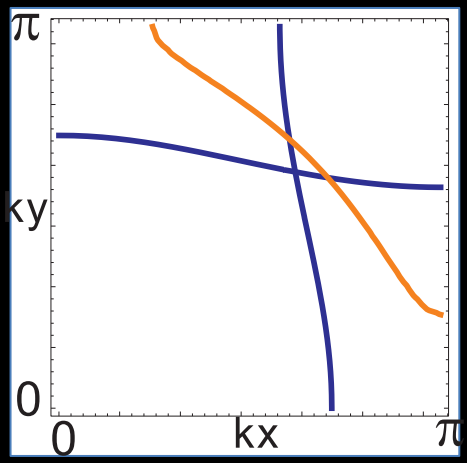


Ba_2RuO_4/GSO, a=3.97









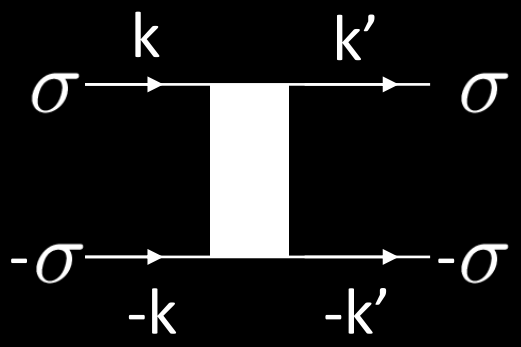
Bulat et al (2014, in preparation)

Lessons from small U/t limit
Two stage RG of the U>0 Hubbard model

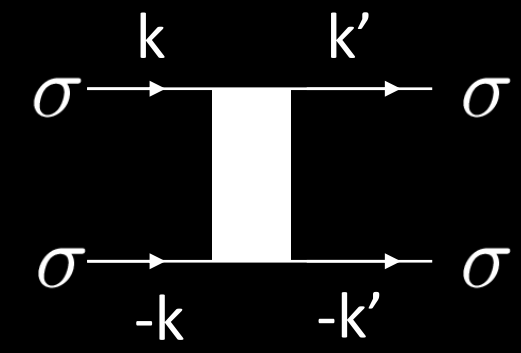
Raghu et al. PRB(2010), Raghu et al. PRL(2010)

1: Generate an effective interaction Matrix $E=\Lambda_0$

Γ_s



Γ_t



2: Eigenvalues each run independently

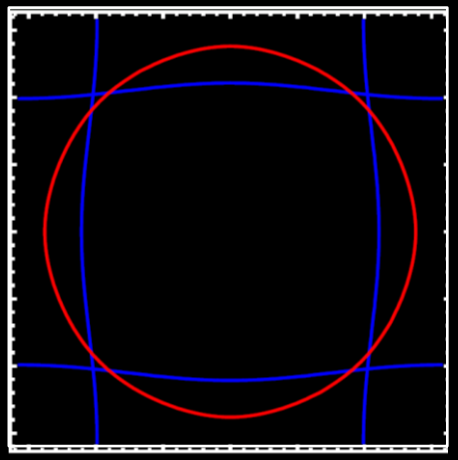
$$\frac{d\lambda^{\alpha}_{s/t,n}}{dy} = -\lambda^{\alpha}_{s/t,n}{}^{2}$$

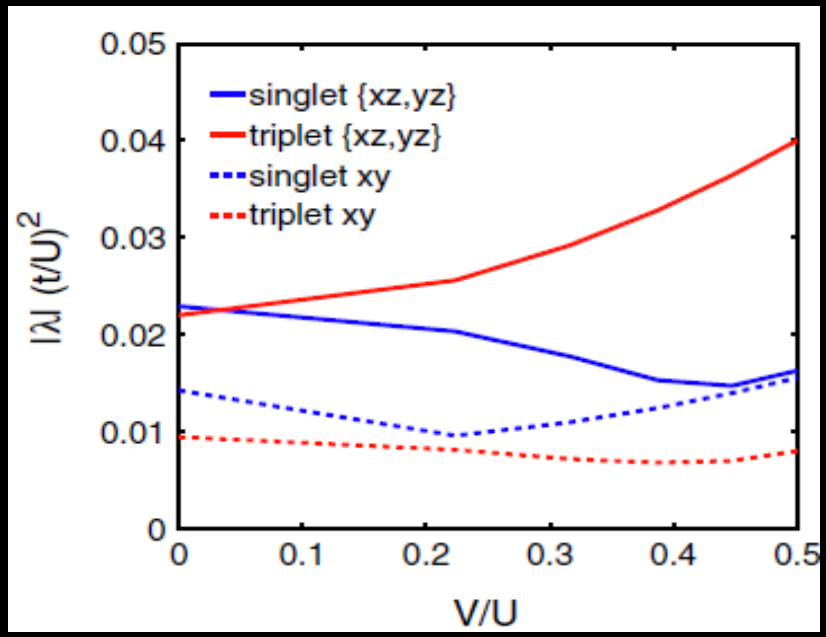
- Most negative eigenvalue at Λ_0, $\lambda^{\alpha,0}_{s/t,n}$ determines channel and T_c $T_c \sim We^{-1/|\lambda^{\alpha,0}_{s/t,0}|}$.

- Fermiology controls $\lambda^{\alpha,0}_{s/t,n}$

Two-Stage RG applied to bulk Sr_2RuO_4

Raghu et al. PRL(2010)





- $\Pi_{ph}(\vec{q} = 2k_F)$ rules
- **Triplet SC driven by 1D band at finite V**
- **Can be chiral but not topological**

Strategy for topological SC:

- Triplet 2D band driven SC with stronger pairing
- Want $\Pi_{ph}^{xy}(\vec{q}=0)$ dominating over

$$\Pi_{ph}^{xy}(\vec{q}=\vec{Q}) \quad \text{or} \quad \Pi_{ph}^{x,y}(\vec{q}=2k_F)$$

Mission: Find Goldilock's Film

Two stage RG Applied to Film Fermiology

Model

- Parametrize measured FS and LDA results

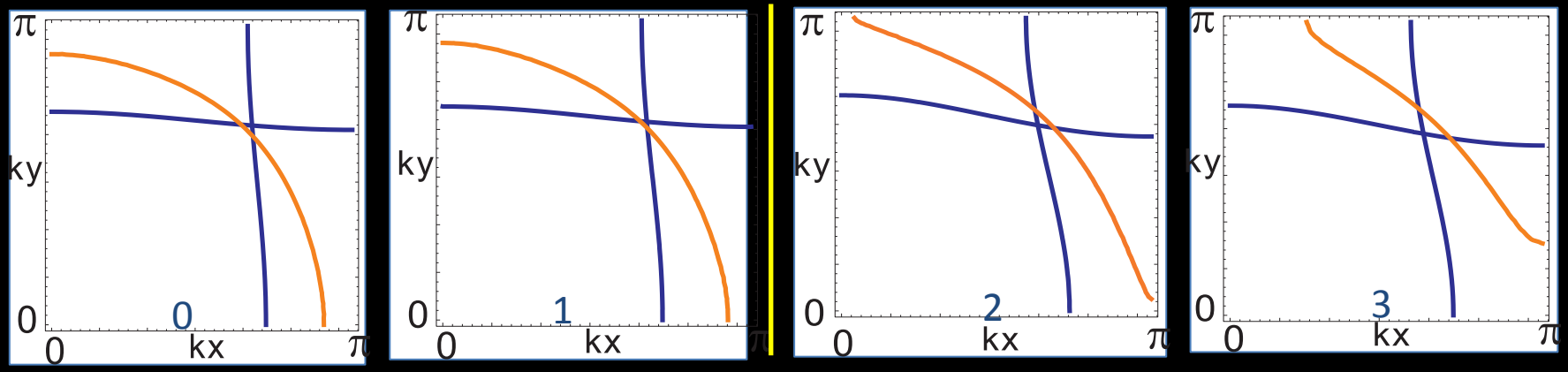
$$\epsilon^{xz(yz)}(\vec{k}) = -2t\cos k_{x(y)} - 2t^{\perp}\cos k_{y(x)} - \mu_1$$

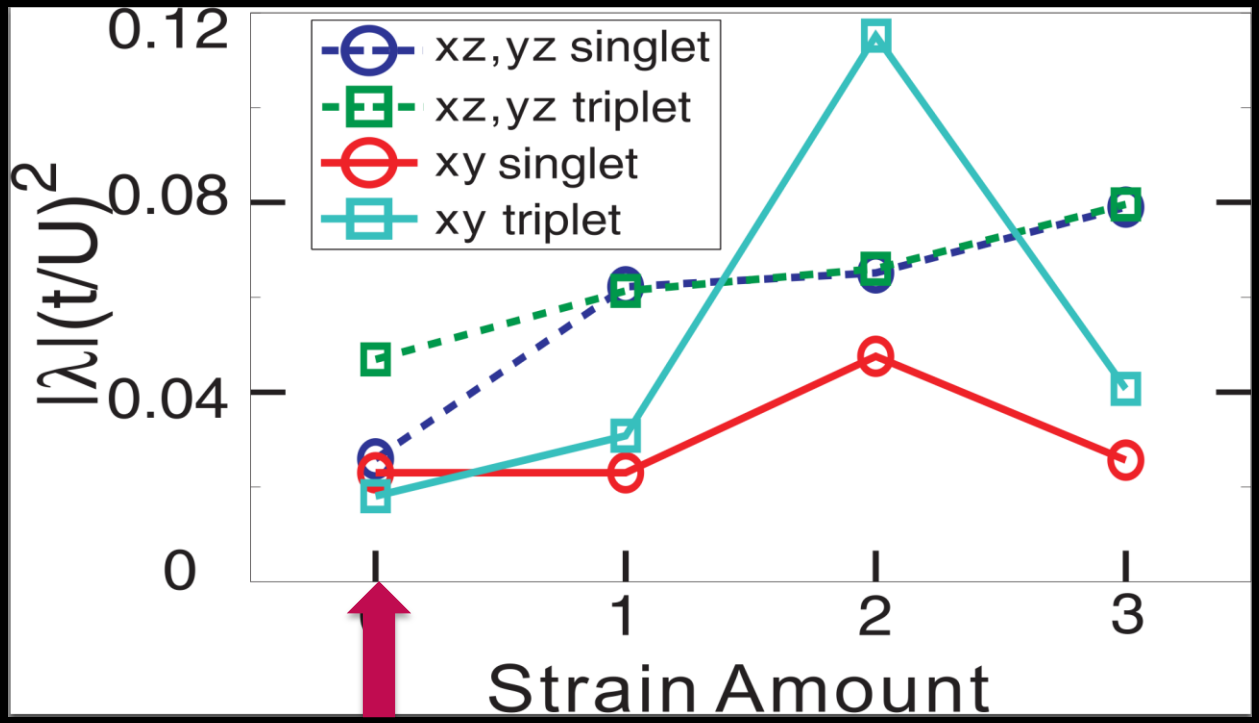
$$\epsilon^{xy}(\vec{k}) = -2t'(\cos k_x + \cos k_y) - 4t''\cos k_x \cos k_y - \mu_2,$$

- Start from Hubbard model as the UV limit

$$H = \sum_{\vec{k}\alpha\sigma} \epsilon^{\alpha}(\vec{k}) c^{\dagger}_{\vec{k}\alpha\sigma} c_{\vec{k}\alpha\sigma} + U \sum_{i\alpha} n_{i\alpha\uparrow} n_{i\alpha\downarrow}$$

SC tendencies for Strained Films

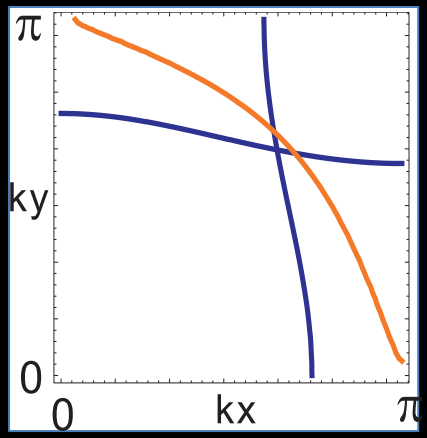




As grown Sr_2RuO_4

Y. Hsu et at, (2014, in preparation)

Goldilock's film



Ba_2RuO_4/STO

- 2D Hole-FS near van-Hove singularity
- Nesting is poor

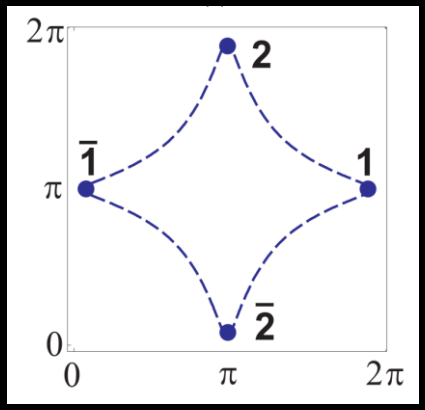
$$\Pi^{xy}_{ph}(\vec{q}=0) >> \Pi^{xy}_{ph}(\vec{q}=\vec{Q}) \text{ or } \Pi^{x,y}_{ph}(\vec{q}=2k_F)$$

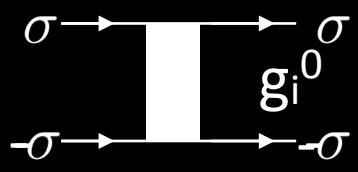
- Escapes symmetry prohibition of triplet pairing for vH point

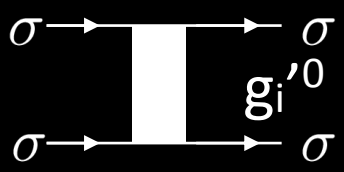
(Nankishore, Thomale, Chubukov PRB2014)

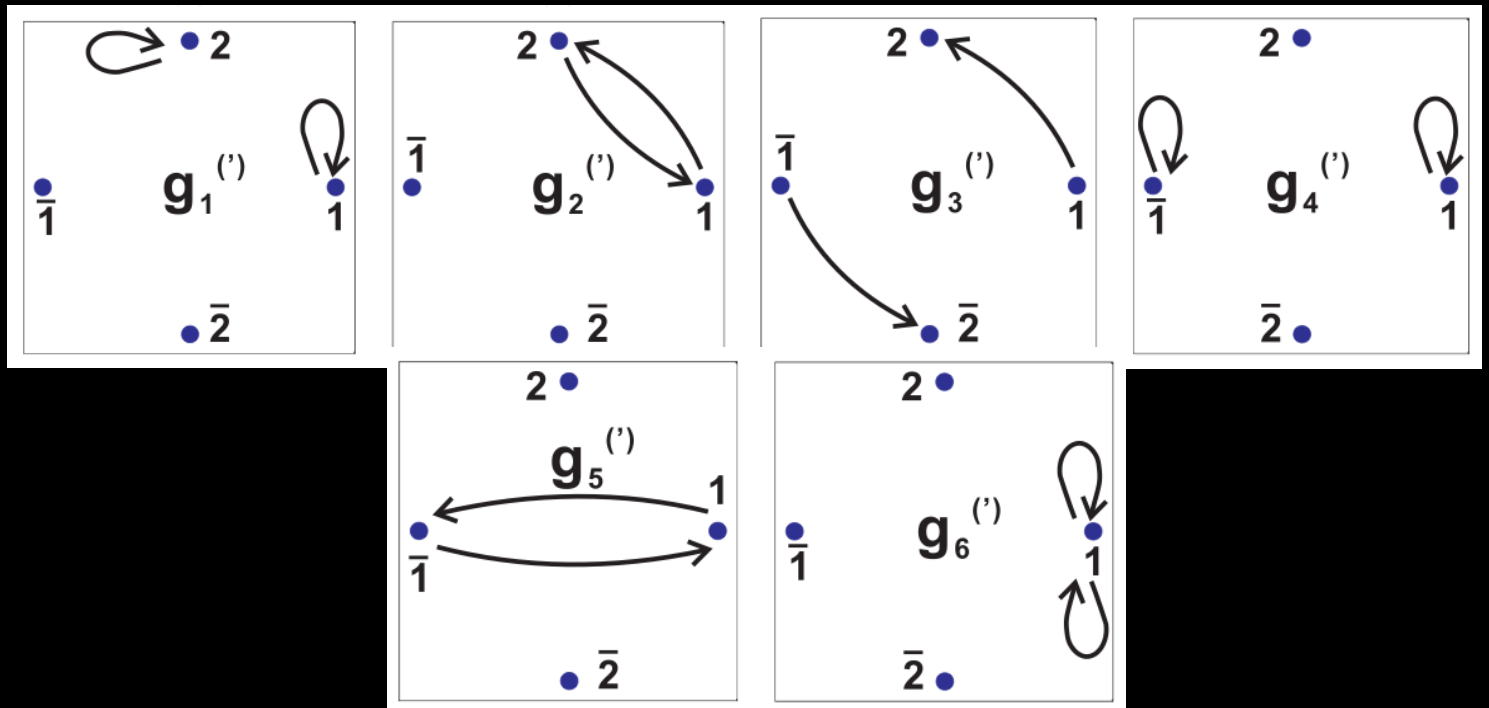
Patch Parquet RG Starting from the Effective Theory

4-Patches and Effective Interactions

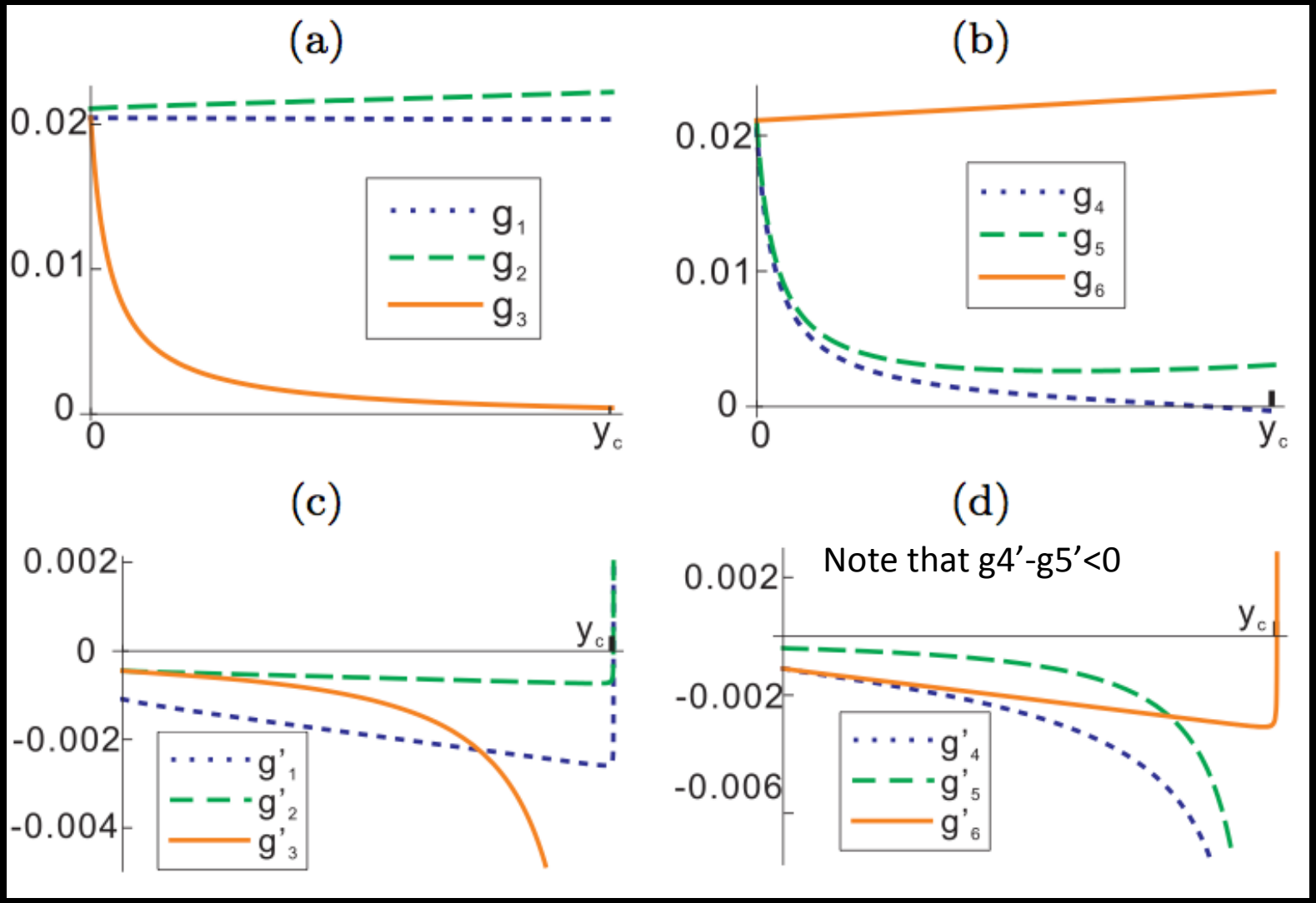




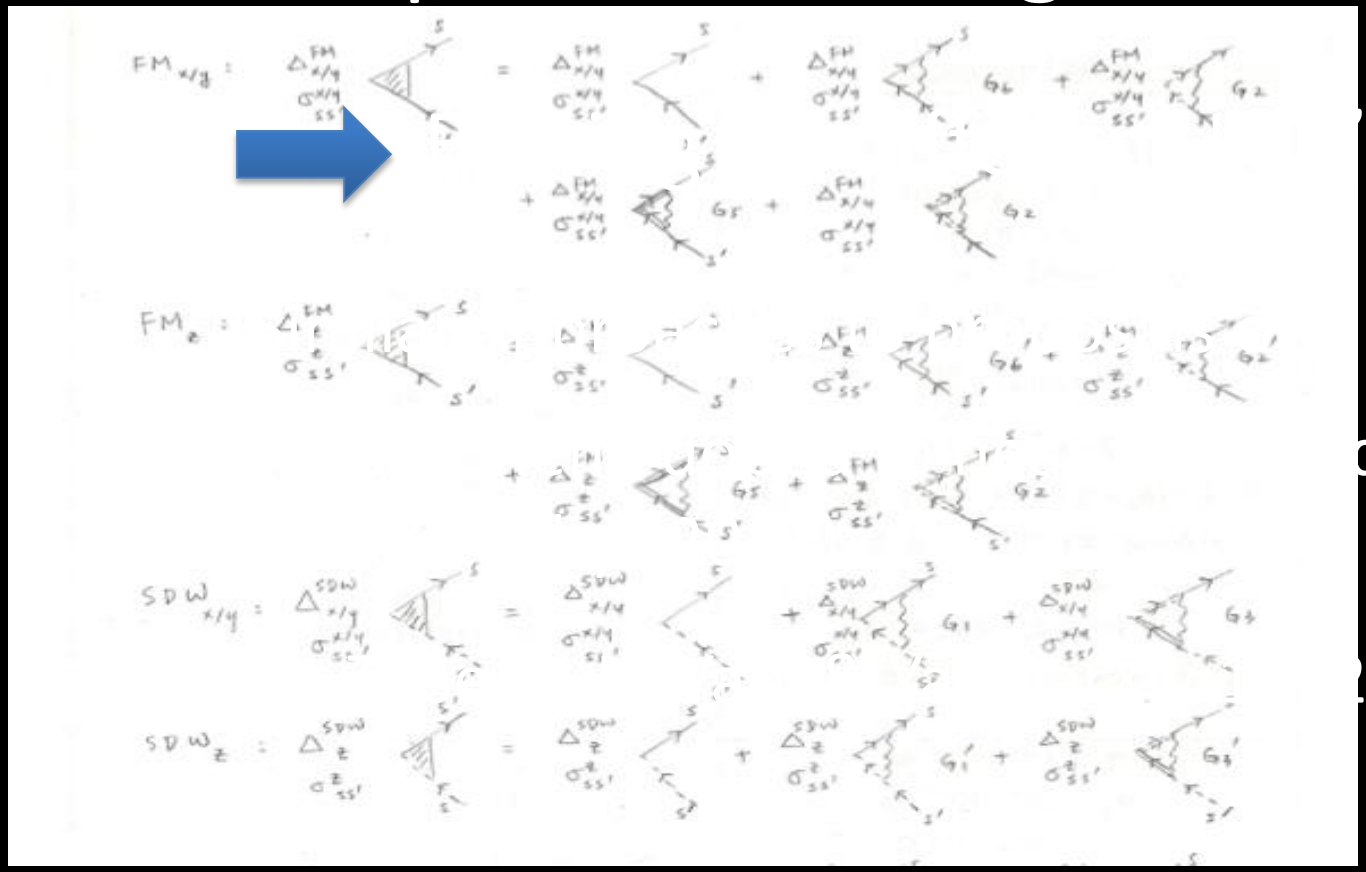




Parquet RG flow



Competition among Instabilities



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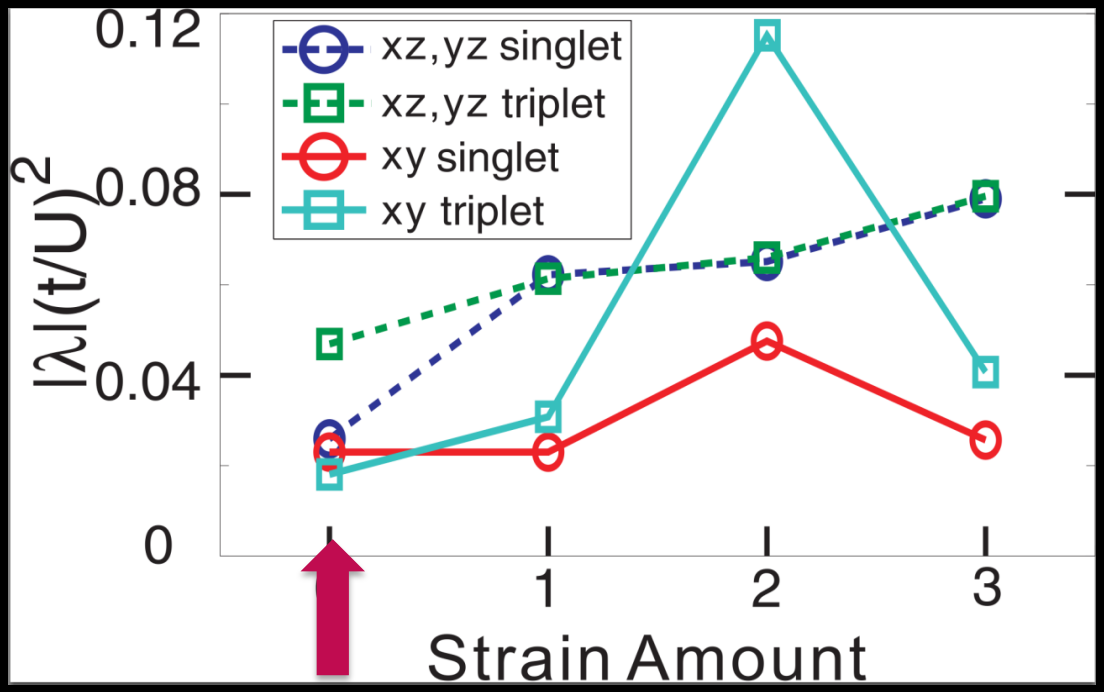
dkishore et al

.0077

Higher Tc Topo SC predicted to be dominant in Ba2RuO4/STO, with FM subdominant

Summary

- Strained Sr/Ba-RuO_4 films: engineer fermiology
- Proximity to vH with poor nesting can lead to higher Tc topological SC



As grown Sr_2RuO_4