Sparse Sampling for Fast Quasiparticle Interference (QPI) Mapping

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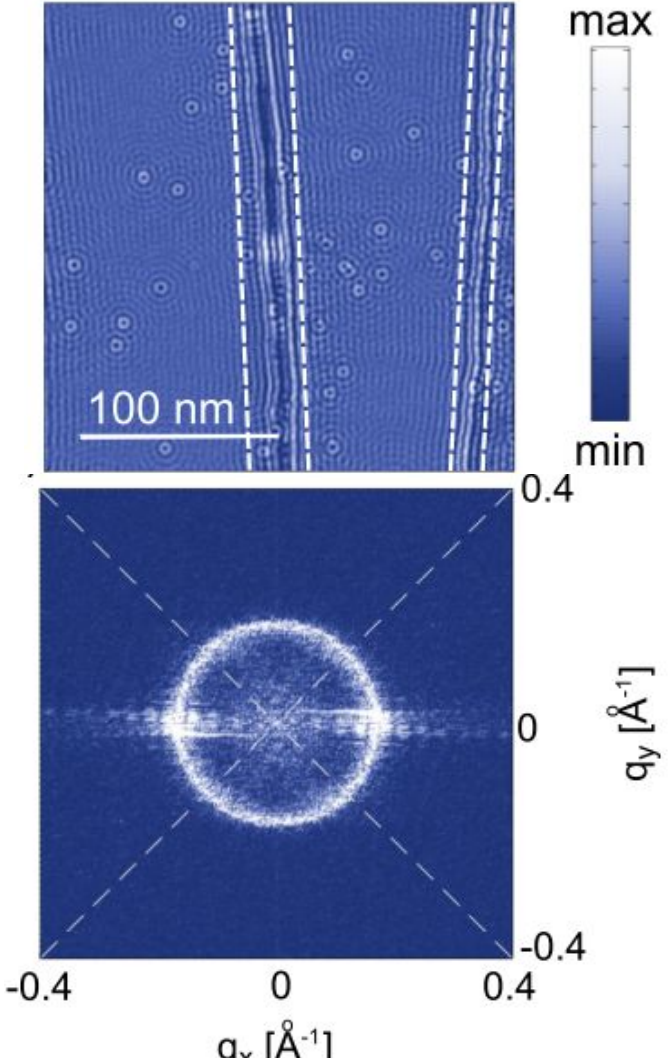
References:

- **Main paper: https://arxiv.org/ftp/arxiv/papers/1908/1908.01903.pdf**
- Topological surface states protected from backscattering by chiral spin texture: https://www.nature.com/articles/nature08308
- Imaging Quasiparticle Interference in Bi-2212:

  https://science.sciencemag.org/content/sci/297/5584/1148.full.pdf

Applications of QPI in Condensed Matter Physics

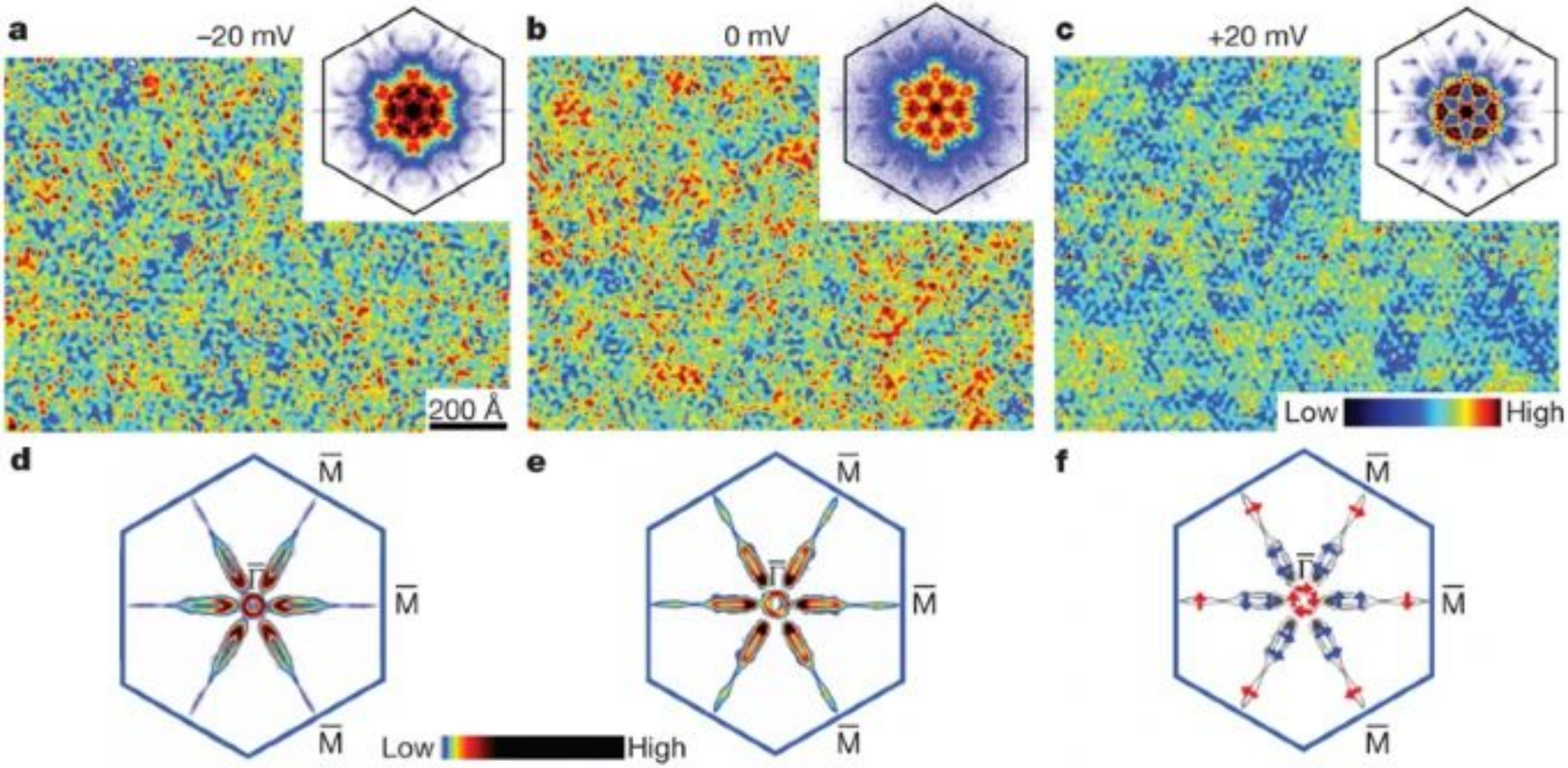
- Extracts wavevector-space information about electronic states using real space imaging (STM).
- Reveals intensities of inter- and intra-band quasiparticle scattering off of impurities.
- Sensitivity to many-body effects that modify e.g dispersion, scattering intensities.



QPI vs. ARPES

- Traditional ARPES is unable to study sample variations that are used for exploring quantum phase transitions.
  - Magnetic field dependence
  - Pressure changes
  - Gate tunability
  - Sub-microscopic samples
- QPI excels in all these areas when combined with atomic manipulation and STM.

Complementary Approaches: QPI and ARPES



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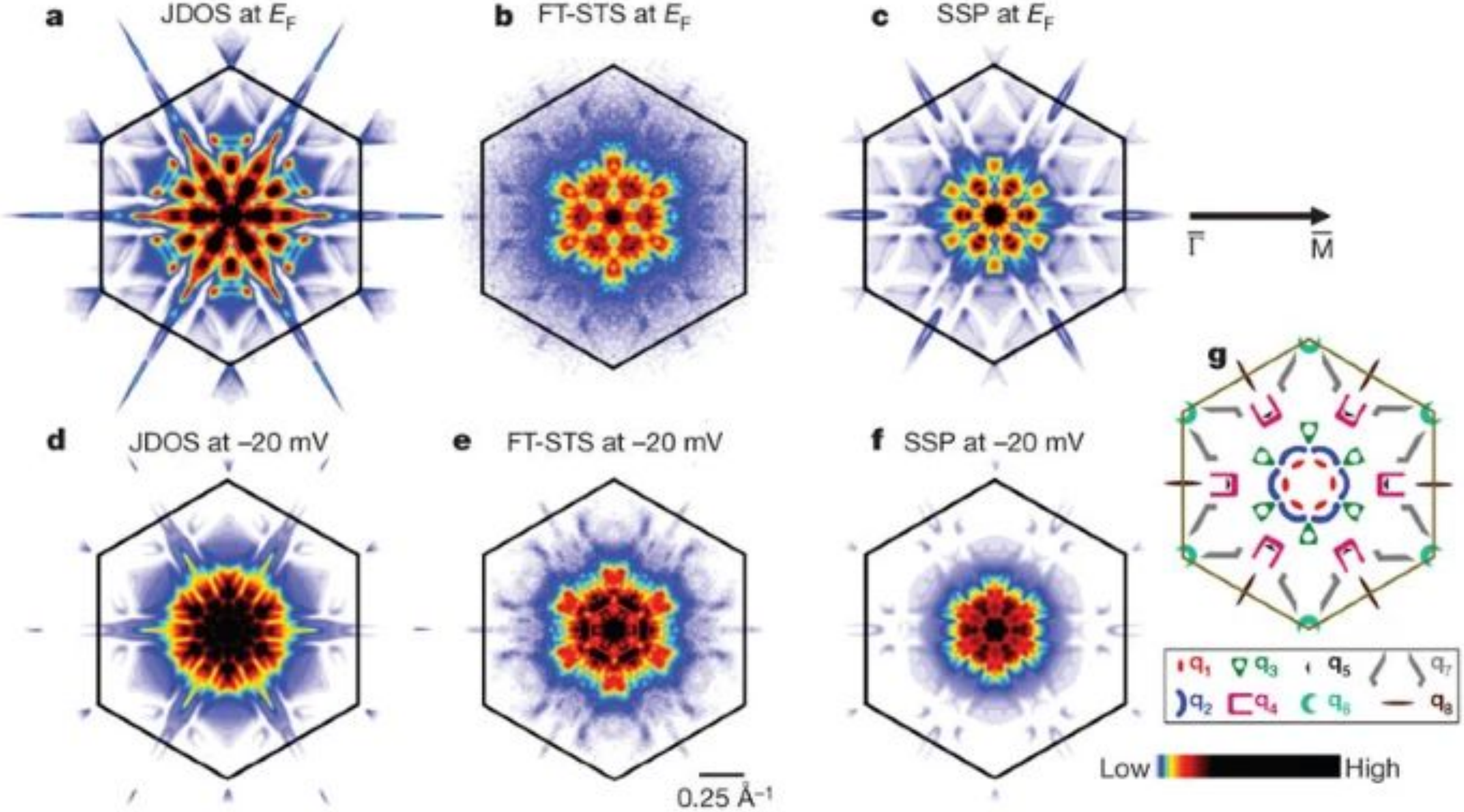
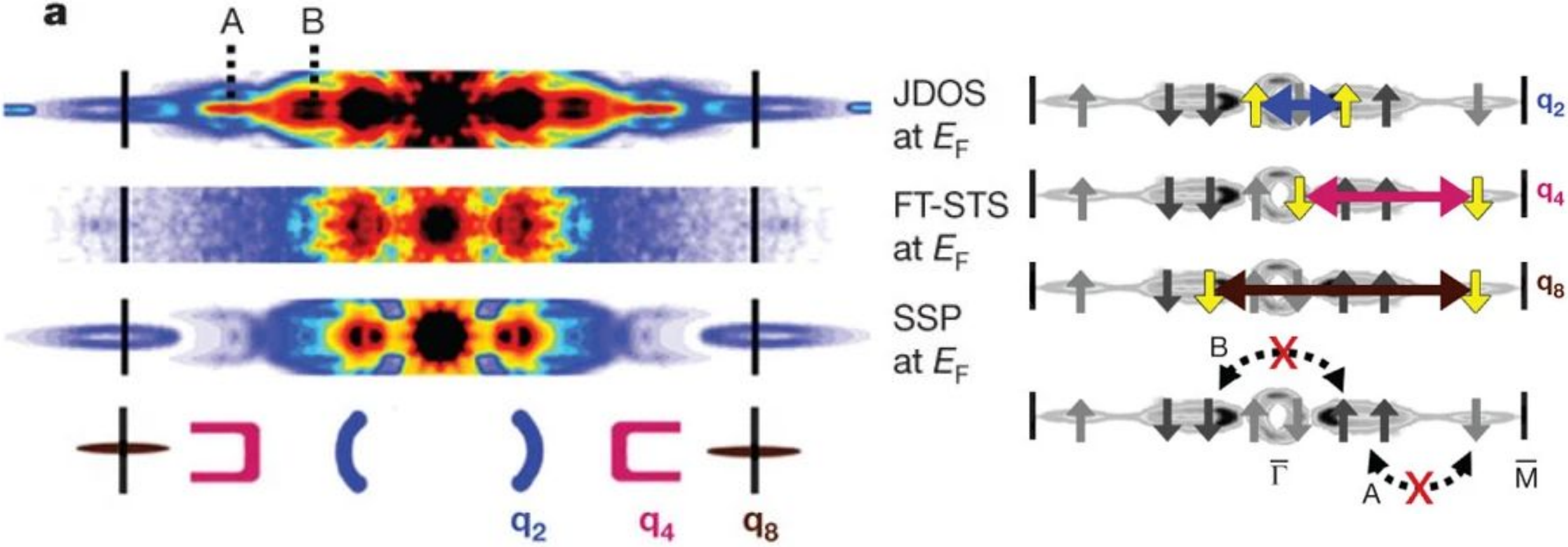


Spin-Selective Scattering Profiles

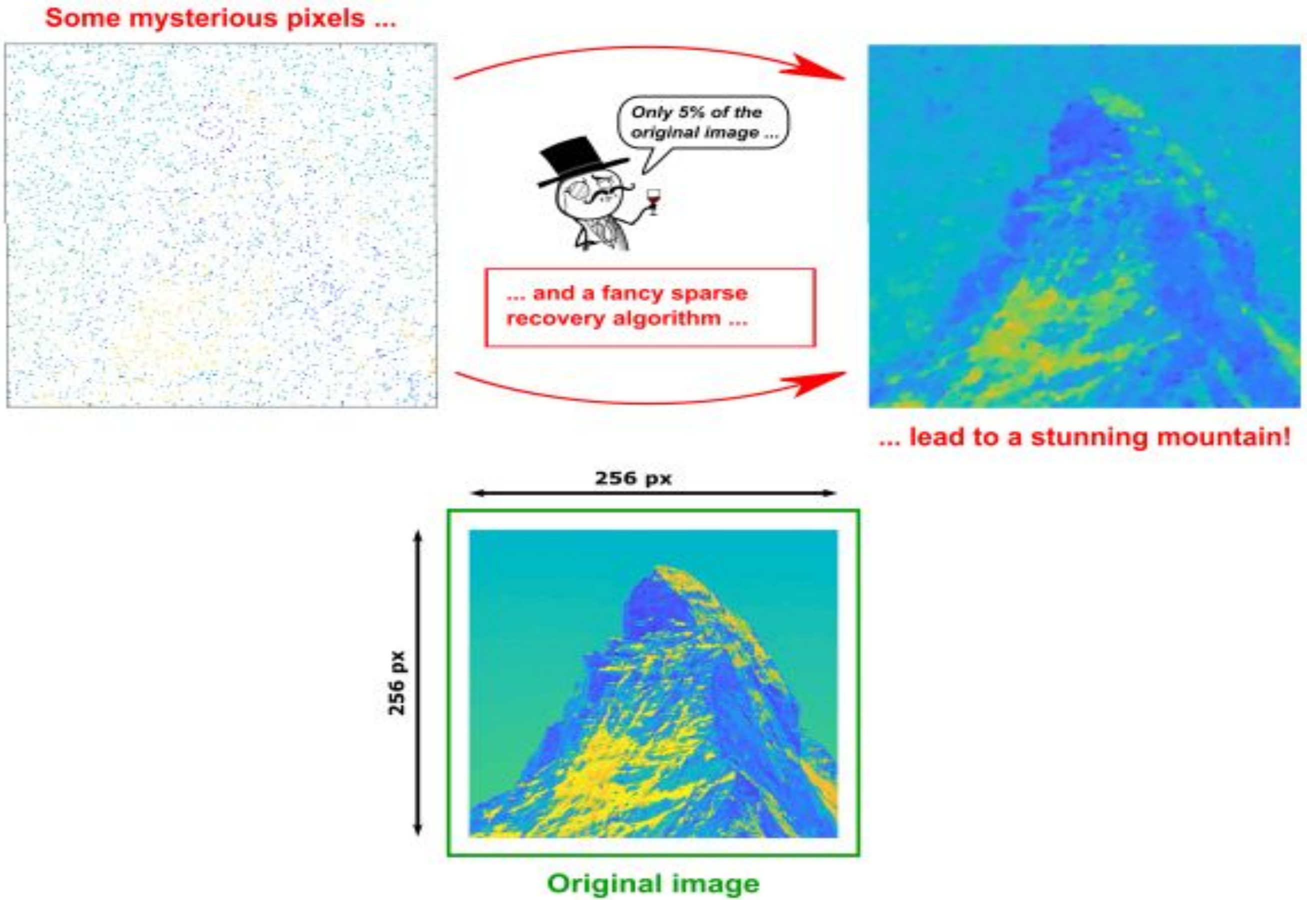


$$\mathrm{JDOS}(\mathbf{q}) = \int I(\mathbf{k}) I(\mathbf{k}+\mathbf{q}) \mathrm{d}^2\mathbf{k}$$

$$\mathrm{SSP}(\mathbf{q}) = \int I(\mathbf{k}) T(\mathbf{q},\mathbf{k}) I(\mathbf{k}+\mathbf{q}) \mathrm{d}^2\mathbf{k}$$

$$T(\mathbf{q},\mathbf{k}) = |\langle \mathbf{S}(\mathbf{k}) \mid \mathbf{S}(\mathbf{k}+\mathbf{q}) \rangle|^2$$

Sparse Algorithms for Image Reconstruction



Sparsity in Reciprocal Space Signals

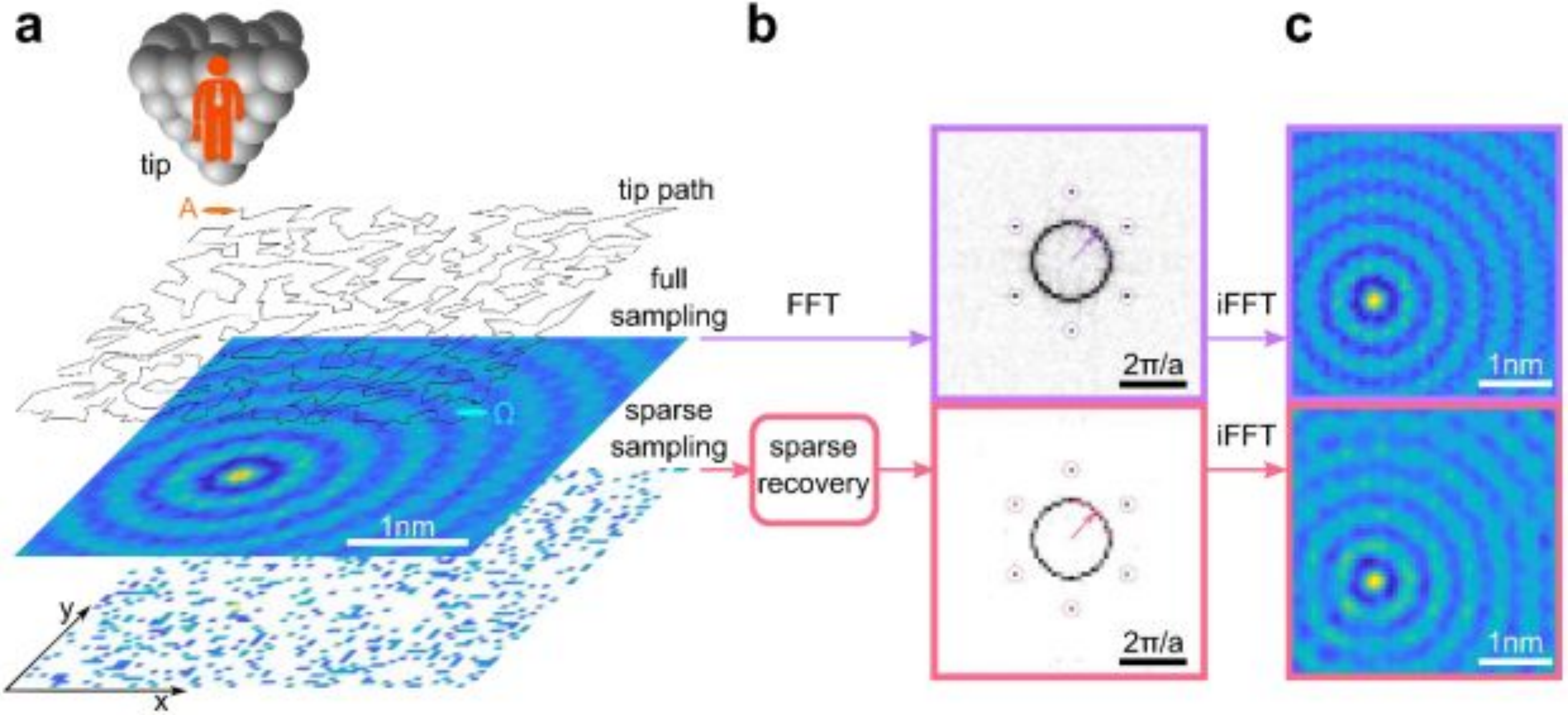


Figure 1

Random and Informed Sparse Sampling

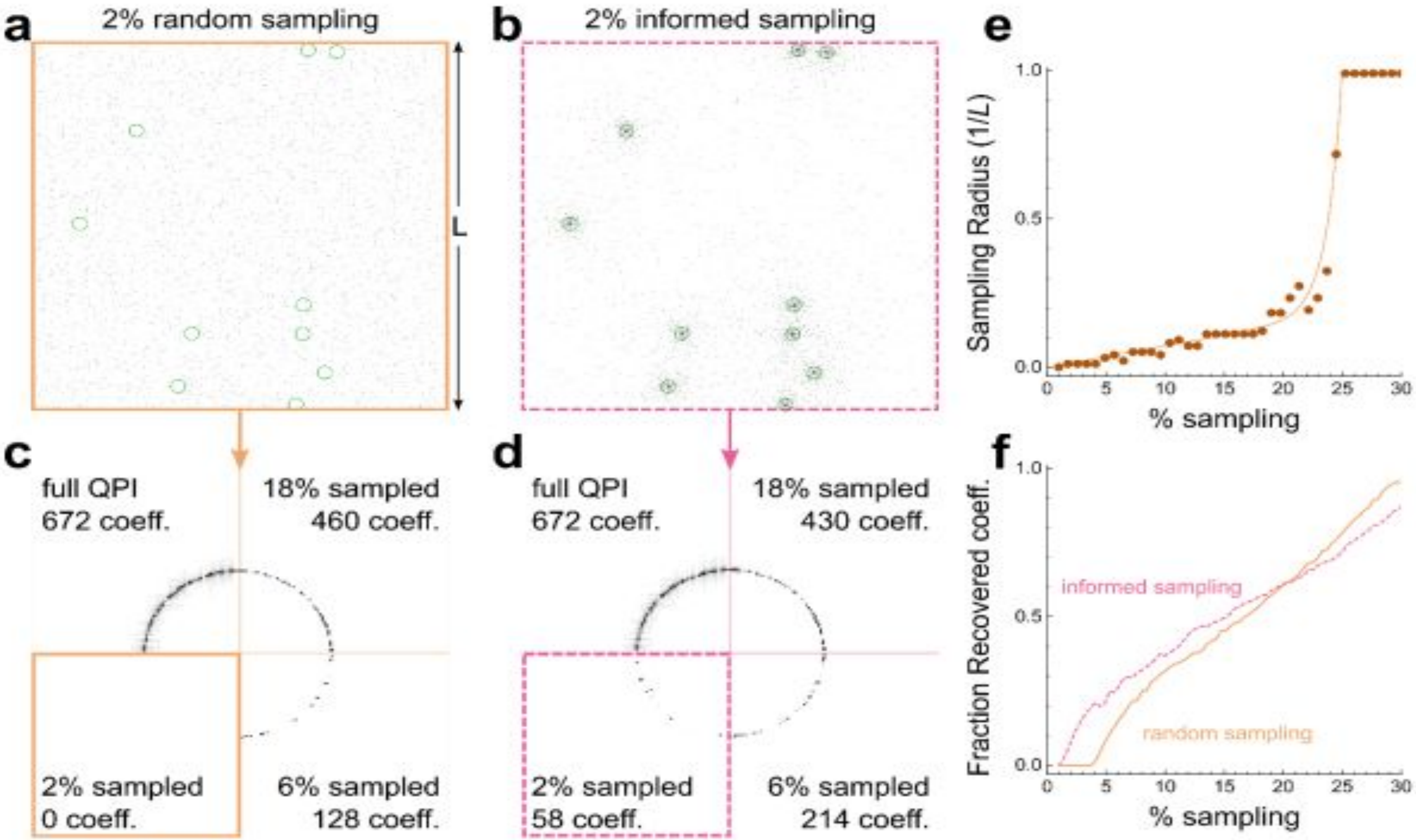
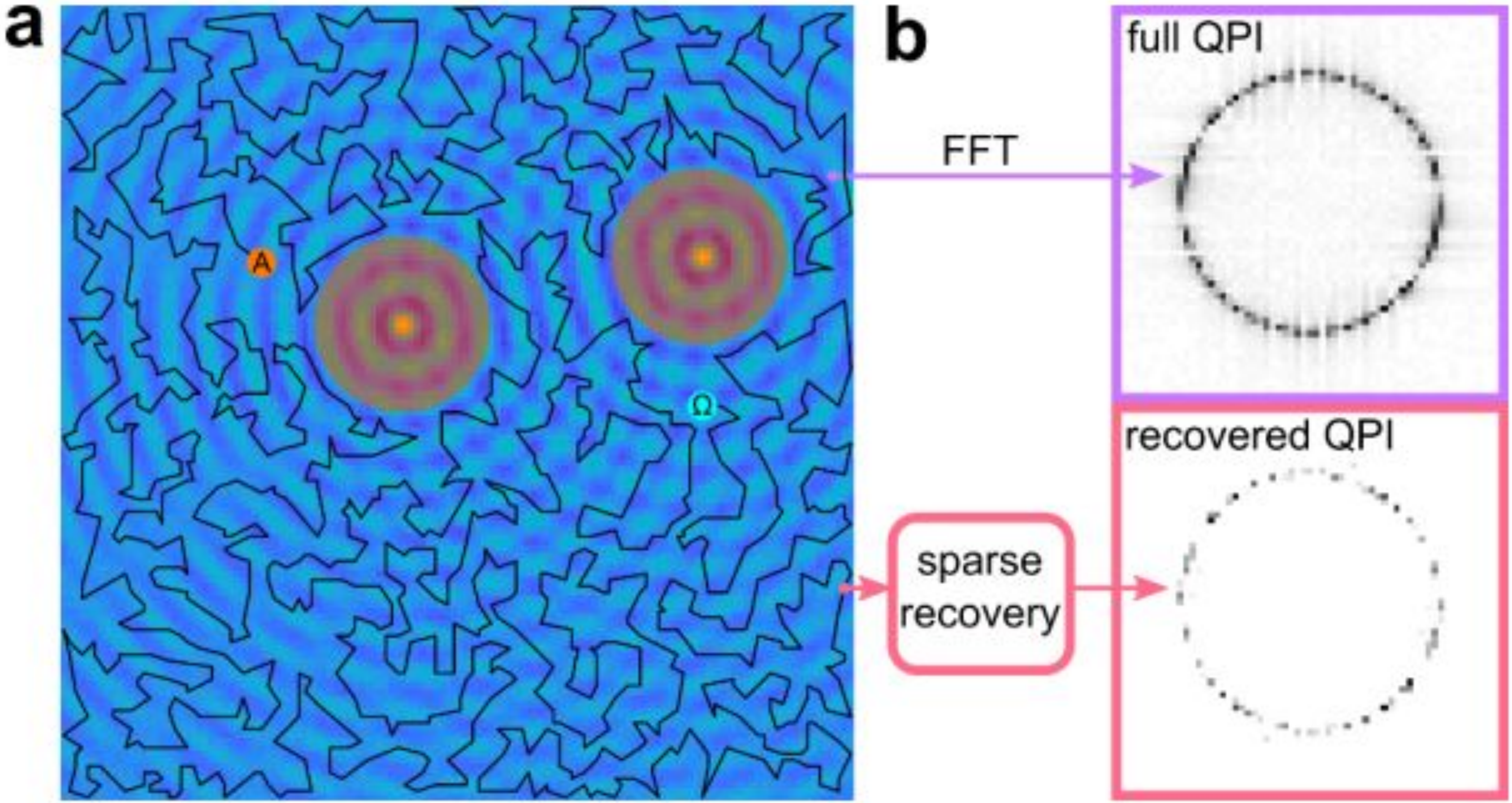
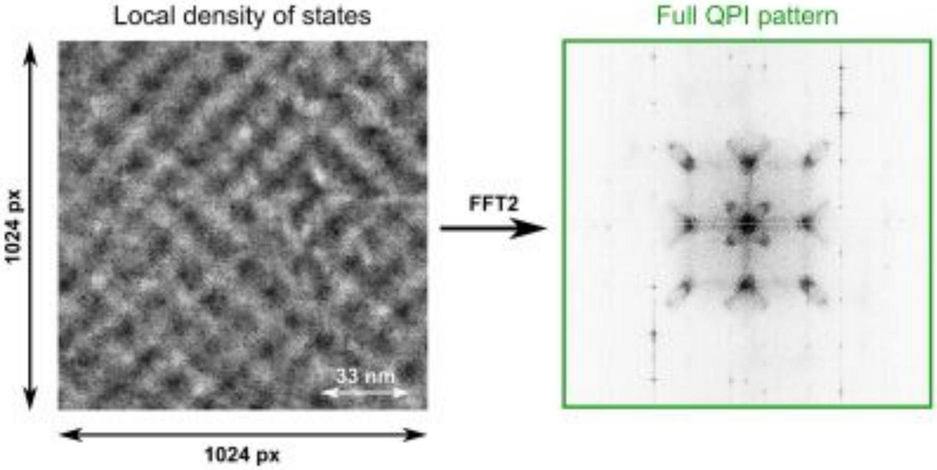


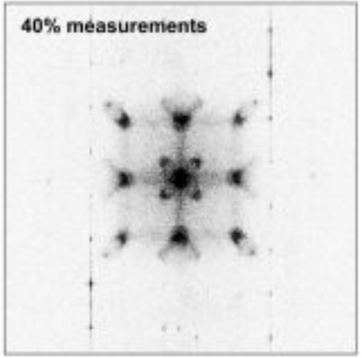
Figure 2

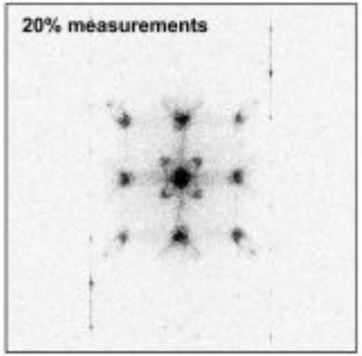
Restricting Sample Space

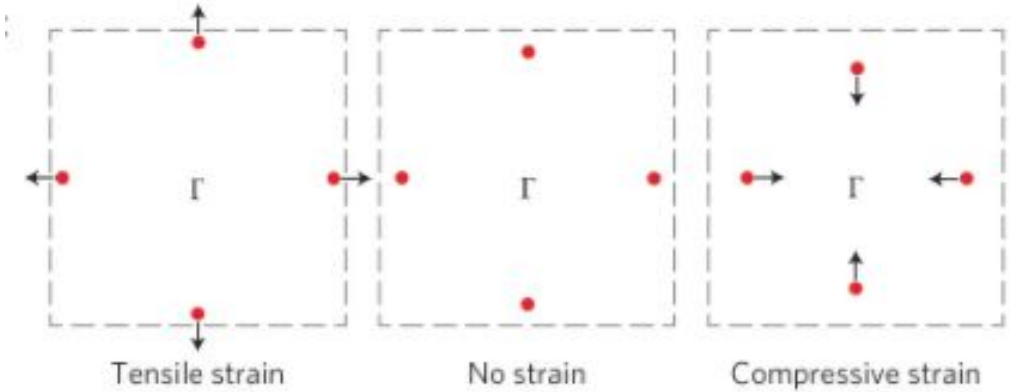


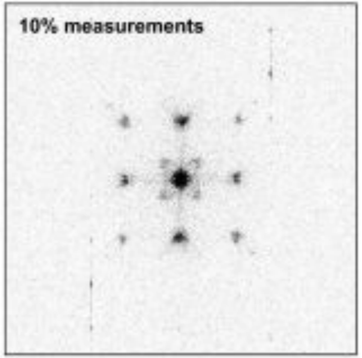
Experimental Example: Surface State of TI SnTe

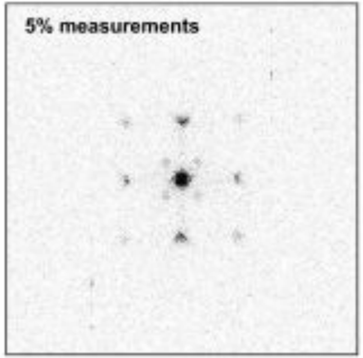












Sparse Recovery Algorithm

Compressive Sensing: sparse signal reconstruction

- **Representing a signal with $K \ll N$ sparse (non-zero) coefficients in a vector domain where N represents the total signal length**
- **Requires incoherent m measurements with $K \ll m < N$**
- **ℓ_1 minimization subject to $\|Ax - b\|_2 < \sigma$**
- **Random measurement matrix $A \in \mathbb{R}^{m \times N}$: sparse recovery for $m \geq cK\, log(N/m)$ [1]**
- **Achieves sampling rates much lower than stated in the Nyquist theorem**