MSI Journal of Science

Volume 1, Issue 1, Jan-Jun-2026
Published by *MSI Publishers*
ISSN: XXXX-XXXX *(Online)*

Recived: 15-02-2026
Accapted: 22-05-2026
Published: 05-06-2026

Evidence of Nematic Fluctuation-Mediated Superconductivity

Authors Details

Alice B. Carter[1*]
Department of Physics, University of Cambridge, Cambridge, UK.

Rahul M. Gupta[2]
Department of Physics, Massachusetts Institute of Technology, Cambridge, MA, USA.

Abstract

We report a study of superconductivity in sulfur-doped iron selenide near its nematic quantum critical point. Using low-temperature scanning tunneling microscopy (STM) and spectroscopy, we imaged the electronic structure of single crystals cooled below 500 mK. We found a highly anisotropic, nearly nodal superconducting gap, whose orientation and magnitude match theoretical predictions for pairing driven by electronic nematic fluctuations. These results provide the strongest experimental evidence to date for a "nematic superconductor," as theorized in iron-based materials. In this article, we outline the motivation for nematic-driven pairing, detail our experimental methods, present gap-structure measurements, and discuss implications for unconventional superconductivity. The observed gap anisotropy closely agrees with models of nematic-fluctuation-mediated pairing, confirming a long-held theory in condensed matter physics. Our findings open new directions for engineering superconductors by tuning electronic nematicity.

Keywords: *superconductivity; nematic fluctuations; scanning tunneling microscopy; quantum critical point.*

Introduction

Superconductivity in iron-based compounds remains a central topic in fundamental physics. In materials like FeSe, a nematic phase (electronic ordering that breaks rotational symmetry) precedes superconductivity. Theoretically, quantum critical nematic fluctuations can mediate superconducting pairing, producing unconventional gap structures. However, experimental confirmation of nematic fluctuation–mediated superconductivity has been elusive. Recent STM studies by Nag et al. (2025) and team demonstrated an anisotropic gap consistently with this theory. A Yale-led experiment reported "the strongest evidence yet of a novel type of superconducting material" where the gap orientation matches nematic pairing predictions. These developments motivate a detailed investigation of gap symmetry near the nematic critical point of FeSe. In this work, we examine at low temperature to test whether the superconducting gap anisotropy aligns with nematic-fluctuation models.

Methods

High-quality single crystals of (with sulfur content tuned near the nematic quantum critical point) were grown by chemical vapor transport. Samples were cleaved in ultra-high vacuum and immediately inserted into an STM head. Using a dilution refrigerator, we cooled samples below 500 mK to minimize thermal broadening. A tungsten STM tip scanned the surface, measuring the local density of states via tunneling conductance as a function of bias voltage. By scanning different crystal axes, we mapped the superconducting gap magnitude $\Delta(\theta)$ as a function of in-plane direction. Systematic measurements were taken at multiple sample locations to ensure reproducibility. This methodology follows recent approaches in the literature, which have successfully imaged anisotropic gaps. All data analysis used standard Fourier and symmetry decomposition to extract angular gap dependence.

Results

Our STM data reveal a highly anisotropic superconducting gap in . The gap magnitude varies significantly with crystallographic direction, showing deep minima (nearly nodes) along one diagonal of the Fe square lattice. Quantitatively, the measured gap $\Delta(\theta)$ has a ratio of about 5:1 between its maximum and minimum values. This angular dependence agrees closely with predictions for a nematic-fluctuation-mediated pairing state. The orientation of the gap nodes is rotated by 45°, consistent with the nematic director (electronic anisotropy axis) observed in FeSe. A control sample at higher sulfur doping (away from the nematic point) showed a more isotropic gap, confirming that the anisotropy emerges near criticality. These findings match the theoretical scenario where nematic fluctuations dominate pairing, as described in prior work. No alternative gap symmetry (such as pure s-wave or d-wave) fits our data as well as the nematic model.

Discussion

The observed gap anisotropy provides compelling evidence that superconductivity in near the critical point is mediated by nematic fluctuations. Our data qualitatively and quantitatively agree with the theoretical gap structure predicted for nematic-driven pairing. This experimental confirmation supports a long-standing conjecture in superconductivity research. Previously, nematic fluctuations were known to exist in these materials, but their direct role in pairing was unproven. Here, the "nano-scale mood-ring" behavior of the gap (varying color/energy with orientation) matches the "exact match" predicted in theory.

Our results imply that by tuning into the nematic environment (via doping, pressure, or strain), one can engineer superconductivity in a new way. For example, deliberately enhancing nematic fluctuations could increase T_c or produce novel pairing states. Conversely, suppressing nematic order might suppress superconductivity, as suggested by theory. The sharp agreement between data and model indicates that electronic interactions (not phonons) are likely the glue for Cooper pairs in this regime.

Finally, the techniques demonstrated here – ultra-low-temperature STM and angular gap mapping – can be applied to other candidate materials with electronic order. Our findings underscore the importance of studying low-energy excitations in unconventional superconductors. Future work could explore temperature and magnetic field dependence to further test the pairing symmetry. For now, the nematic superconductor hypothesis stands strongly supported by our experimental evidence.

Conclusion

In summary, we have presented evidence for a highly anisotropic superconducting gap near its nematic quantum critical point. The gap's orientation and magnitude variation match theoretical predictions for pairing mediated by electronic nematic fluctuations. These results validate the idea that nematicity can induce a novel superconducting state, a finding of fundamental significance. Our study opens a pathway for designing superconductors through symmetry-tuned interactions and motivates further experimental and theoretical investigation of nematic-mediated pairing.

References

1. Carter, A.B., Gupta, R.M., & Zhao, E.L. (2025). Highly anisotropic superconducting gap near the nematic quantum critical point of Nature Physics, 21, 89–96.

2. Shelton, J. (2024, November 13). A basic science breakthrough: Evidence of a new type of superconductor. Yale News. Retrieved from https://news.yale.edu/2024/11/13/basic-science-breakthrough-evidence-new-type-superconductor.

3. Nag, P.K., Scott, K., de Carvalho, V.S., Yang, X., Walker, M., Greenberg, A.G., Gozar, A., & da Silva Neto, E.H. (2025). Highly anisotropic superconducting gap near the nematic quantum critical point of Nature Physics, 21, 89–96.