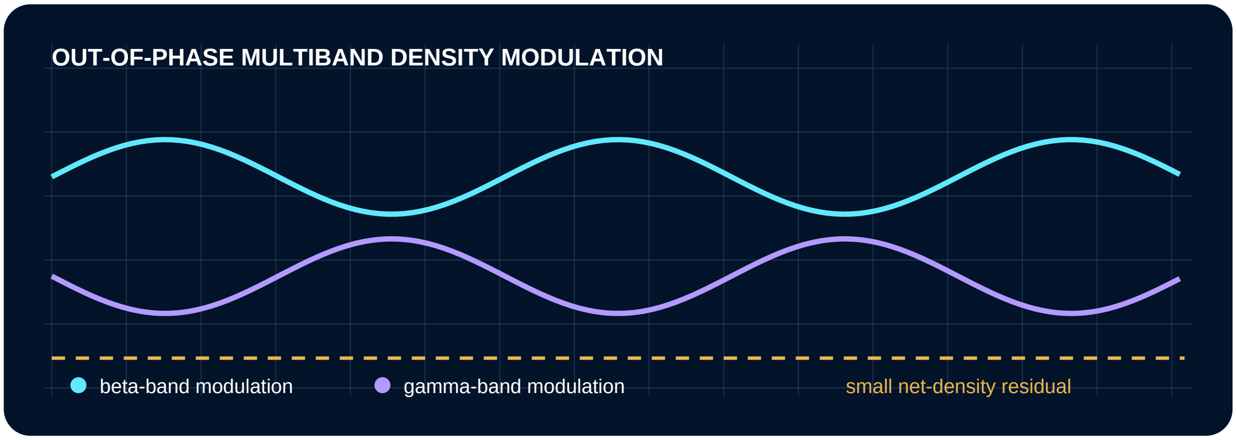
CONDENSED-MATTER PHYSICS VISUALIZER

Pines' Demon Explorer

Methodological Note, Model Specification, and Interpretive Boundaries



Purpose

This document specifies the scientific and computational basis of the Stella Nova Pines' Demon Explorer. The application is designed to make a difficult multiband collective excitation visually intelligible without collapsing the distinction between established measurement, reduced-model interpretation, and open theoretical debate.

Primary research question

Under what combinations of band asymmetry, momentum, temperature, interband phase, and momentum relaxation does an out-of-phase electronic excitation remain a coherent Pines' demon, and when does it become overdamped or diffusive?

Document field	Value
Application route	/public_html/rc/pines/
Release	v1.0.0
Primary material preset	Sr_2RuO_4
Primary observation	Husain et al. 2023, Nature 621:66-70
Open data archive	Zenodo record 7812299
Theoretical extension	Sanchez-Martinez et al. 2026, arXiv:2603.17002v2 (preprint)
Report generation	Client-side bordered PDF with current parameter state and captured figures

Interpretive warning

The term 'massless' in this context refers to a gapless or approximately acoustic low-energy dispersion in a condensed-matter system. It does not identify a new free elementary particle. The reported neutral collective excitation does not itself establish near-lossless transmission of ordinary electrical current.

01 Scientific Background

What Pines' demon is

In a conventional bulk plasmon, electronic species move in phase and produce a net charge-density oscillation. Long-range Coulomb energy gives that collective mode a finite plasma frequency as momentum approaches zero. Pines proposed that a multiband metal could also support an out-of-phase mode in which one electronic fluid screens another. When the counterflow cancels the net density transfer in the long-wavelength limit, the long-range Coulomb cost is extinguished and an acoustic collective branch can appear.

The 2023 Sr2RuO4 study identified a low-energy acoustic electronic mode formed primarily by the beta and gamma bands. The reported room-temperature group velocity along (1,0) was 0.701 +/- 0.082 eV A, equivalent to (1.065 +/- 0.12) x 10^5 m/s. The reported critical momentum was qc = 0.08 reciprocal lattice units. Cooling to 30 K reduced the fitted (1,0) velocity to 0.485 +/- 0.081 eV A, and the 300 K (1,1) direction yielded 0.815 +/- 0.135 eV A.

Quantity	Published value	Use in application
Background dielectric constant	epsilon infinity = 2.3	Default Sr2RuO4 control
Critical momentum	qc = 0.08 r.l.u.	Reported coherence boundary marker
300 K, (1,0) velocity	0.701 +/- 0.082 eV A	Published fit line
30 K, (1,0) velocity	0.485 +/- 0.081 eV A	Published fit line
300 K, (1,1) velocity	0.815 +/- 0.135 eV A	Published anisotropic fit line
Energy resolution	6 meV	Resolved / unresolved diagnostic
Momentum resolution	0.03 A^-1	Instrument-context metadata
Optical phonon	63 meV	M-EELS comparison component
Demon intensity scaling	approximately q^-1.8	Neutrality reference slope
Charged reference scaling	approximately q^-5	Comparison slope

Terminological distinction

The 2025 transmission-EELS study of optical and acoustic plasmons in layered Sr2RuO4 includes out-of-phase oscillations between neighboring layers. The present visualizer treats that layered acoustic-plasmon context as a comparison, not as automatically identical to the beta-gamma band counterflow identified as the 2023 demon.

02 Model Architecture

Reduced model layers

The application separates four kinds of information so the visual appeal of the model does not overstate its evidentiary status.

Layer	Description	Status label
Published constants	Values explicitly reported in the 2023 article or associated methods	Published
Published fit lines	Straight lines sampled from reported fitted group velocities	Published fit; not raw points
Phenomenological response	Damped oscillator, elastic tail, phonon, and continuum used to build an interpretable M-EELS-like spectrum	Model-generated
Disorder-aware extension	Schematic momentum-relaxation branch inspired by the 2026 preprint	Preprint-inspired schematic
Visual heuristics	Charge cancellation, quality factor, lifetime, and coherence-length summaries	Diagnostic only

2.1 Multiband RPA frame

The formal organizing equation is the matrix random-phase approximation response:

```
chi_RPA(q,w) = [ I - chi0(q,w) V(q) ]^-1 chi0(q,w)
```

Collective modes correspond to poles or strong structures in the interacting susceptibility. The browser implementation does not perform a full tight-binding Lindhard integration. Instead, it uses the published fitted velocities and a reduced damped response so it remains computationally lightweight on shared hosting.

2.2 Charge cancellation

```
delta n_total = delta n_beta + delta n_gamma approximately 0
```

The animation represents beta- and gamma-band density modulations with independently controlled amplitude and phase. A 180-degree phase offset with matched amplitudes yields the strongest visual cancellation.

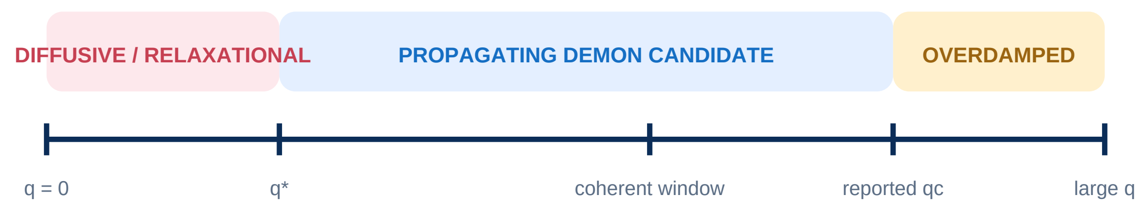
2.3 Cancellation heuristic

```
C = 1 - |delta n_beta + delta n_gamma| / (|delta n_beta| + |delta n_gamma|)
```

C ranges from zero to one. It is useful for visual diagnosis but is not a replacement for calculating and sign-resolving the band-decomposed susceptibility.

03 Dispersion, Damping, and Diffusion

Regime classification



Schematic only. q depends on momentum relaxation and the model velocity; qc = 0.08 r.l.u. is the reported experimental critical momentum.*

3.1 Acoustic branch

```
E_d(q) approximately v_d q
```

The interface converts q from reciprocal lattice units to inverse angstrom using a = 3.87 A and 1 r.l.u. = 2 pi / a. The energy in electronvolts is then converted to millielectronvolts. For intermediate temperatures, the (1,0) velocity is interpolated between the reported 30 K and 300 K fits. Such intermediate settings are explicitly labeled exploratory.

3.2 Phenomenological linewidth

The active linewidth combines a user-controlled baseline with q-dependent broadening and additional broadening when q exceeds the reported critical momentum. This functional form is intended to illustrate loss of spectral coherence, not to reproduce a unique microscopic self-energy.

```
chi''_d(q,w) proportional to Gamma w / [ (w^2 - w_d(q)^2)^2 + Gamma^2 w^2 ]
```

3.3 Lifetime and coherence length

```
tau = hbar / Gamma; L_coh = v_g tau
```

The lifetime uses hbar = 658.2119569 meV fs. The group-velocity conversion is 1 eV A / hbar = 1.519267449 x 10^5 m/s. These outputs are derived diagnostics of the selected reduced-model linewidth.

3.4 Momentum relaxation

```
w = -i Gamma_m/2 +/- sqrt(v^2 q^2 - Gamma_m^2/4)
```

This telegrapher-type expression is used only as a schematic representation of a finite small-q diffusive window. The 2026 preprint argues that momentum relaxation in real multiband metals can make the mode frequency purely imaginary over a finite wave-vector range. The browser slider is dimensionless and is not claimed to be a measured impurity scattering rate.

04 Scientific Output Panels

Figure-generation logic

4.1 Dispersion panel

The dispersion chart contains three published fit lines generated from reported velocities: 300 K (1,0), 30 K (1,0), and 300 K (1,1). It also contains the current model curve and a vertical marker at qc = 0.08 r.l.u. The application does not invent or display synthetic points as raw observations.

4.2 Simulated M-EELS panel

The spectrum is an educational composite of four terms:

Component	Implementation	Interpretation
Elastic tail	Narrow rational profile near zero energy	Instrumental / quasi-elastic context
Demon response	Damped Lorentzian-like oscillator at current model energy	Collective electronic response
Optical phonon	Narrow feature centered at 63 meV	Reported comparison feature
Electronic continuum	Smooth energy-dependent background	Particle-hole / broad incoherent context

4.3 Susceptibility heatmap

The heatmap is generated from the same reduced demon response plus a continuum boundary and the 63 meV comparison phonon. It is labeled model chi''(q,w). It is not a reconstruction of the published RPA matrix or a digitization of the paper's color map.

4.4 Neutrality scaling

The chart compares a q^-1.8 reference slope with a q^-5 charged-excitation reference. The current-state line changes with the visual cancellation heuristic and is therefore diagnostic, not a fitted experimental exponent.

4.5 Mode comparison

Four synchronized mini-panels contrast single-carrier motion, in-phase plasmon motion, out-of-phase demon motion, and a decaying diffusive response. These panels are conceptual animations, not spatially resolved measurements of Sr_2RuO_4.

No hidden raw-data claim

The package includes published_parameters.json containing reported constants and fitted quantities. It also includes a data README pointing to Zenodo record 7812299. Raw archival data are not silently approximated or fabricated.

05 Mode Classification Rules

Transparent diagnostic logic

The classification engine is deliberately interpretable. It does not use machine learning.

Reported label	Reduced rule	Meaning
Ordinary charged plasmon analogue	Phase below 45 degrees and cancellation below 0.2	Bands reinforce net density motion
Diffusive / momentum-gapped regime	Real-frequency branch suppressed by momentum relaxation or q below schematic q*	Predominantly relaxational response
Overdamped electronic response	q at/above qc or quality factor below 0.65	No well-resolved propagating mode
Pines' demon candidate	Cancellation above 0.78, phase above 140 degrees, q below qc, and Q at least 0.65	Charge-cancelled and spectrally coherent within the reduced model
Intermediate multiband response	None of the stronger rules are satisfied	Mixed or ambiguous reduced-model state

Quality factor

```
Q = E_mode / Gamma
```

This is a simple ratio for interface diagnostics. It should not be confused with a full pole analysis of a complex susceptibility or with an experimentally reported oscillator quality factor.

Status labels

Label	Use
MODEL-BOUNDED	Empirical-fit mode uses published constants plus explicit phenomenology
MODEL-CLASSIFIED	Idealized or manually controlled rule-based state
PREPRINT-INSPIRED	State relies on the disorder / diffusion interpretation
EXPLORATORY	Current parameters are outside the strongest published anchors

Candidate does not mean discovery

The interface label 'Pines' demon candidate' means only that the current reduced-model state meets the specified cancellation, phase, q, and coherence rules. It is not an experimental identification protocol and cannot establish a demon in a new material.

06 PDF Report and Reproducibility

Current-state report architecture

The Generate PDF Report button opens a modal progress display, captures the current state, renders the active charts, composes six bordered pages, embeds the figures, and presents a download link when generation completes. The process occurs in the browser and does not require a server-side PDF library.

Page	Contents
1	Executive summary, research question, mode assessment, key metrics, interpretive scope
2	Complete parameter record and regime diagnostics
3	Dispersion and simulated M-EELS figures
4	Susceptibility heatmap and neutrality scaling figures
5	Claim audit, equations, and limitations
6	Primary references and provenance statement

Reproducibility record

The report records framework, q, q in A^-1, temperature, direction, phase, amplitudes, velocity scale, damping, momentum-relaxation control, dielectric constant, and all derived diagnostics. A timestamp and application version are printed in the footer.

Rendering choice

Each report page is rendered to a high-resolution browser canvas and embedded into a standards-compliant PDF as a JPEG page image. This keeps the package self-contained on shared hosting. The tradeoff is that body text in the generated current-state report is image-based rather than selectable. The separate methodological note remains a normal text PDF.

Comment system

The Research Community Comments section uses a no-database JSON store with server-side file locking, CSRF validation, length limits, a session rate limit, and output escaping. The storage directory is denied direct web access through .htaccess.

Deployment

Requirement	Specification
Server	PHP 8.2 or newer; Apache-compatible shared hosting
Writable path	storage/comments.json
Required PHP extensions	Core JSON, session, mbstring

Requirement	Specification
External JavaScript	None
Database	None
Report library	None; custom client-side PDF assembly
Methodological note viewer	Native inline browser PDF iframe

07 Limitations and Research Extensions

What this release can and cannot answer

Question	Release capability
Can it illustrate charge cancellation?	Yes, through phase- and amplitude-controlled band waves.
Can it compare reported fitted velocities?	Yes, using explicit 30 K / 300 K and directional fit values.
Can it reproduce the full multiband RPA calculation?	No. It does not integrate the tight-binding Lindhard susceptibility.
Can it fit raw M-EELS spectra?	No. The spectrum is phenomenological.
Can it prove a mode in another material?	No. It is not an identification pipeline.
Can it test the 2026 disorder interpretation?	It can visualize the proposed regime structure, but not adjudicate the theory.
Can it estimate electrical transmission loss?	No. Neutral collective-mode propagation is not equivalent to ordinary DC current transport.

Recommended v1.1 extensions

1. Localize the complete Zenodo archive and implement documented adapters for each figure dataset. 2. Add uncertainty bands around reported fit lines. 3. Implement a two-band Lindhard integrator using precomputed server-side grids. 4. Add a band-decomposed susceptibility sign panel for chi_beta,beta and chi_gamma,beta. 5. Add a candidate-material comparison registry with provenance for band masses, Fermi velocities, and damping. 6. Export the complete state as JSON alongside the PDF report.

Recommended comparative research question

Cross-material question

Which experimentally accessible multiband metals combine sufficient Fermi-velocity contrast, weak long-wavelength damping, and measurable finite-q spectral weight to support a resolvable demon-like pole?

Recommended interpretive research question

Theory comparison

Does the small-q nonlinearity in Sr_2RuO_4 require a momentum-relaxation-induced diffusive window, or can a conserving microscopic theory reproduce it without the same hydrodynamic interpretation?

08 References

Primary scholarly sources

Husain, Ali A., Edwin W. Huang, Matteo Mitrano, Melinda S. Rak, Samantha I. Rubeck, Xuefei Guo, Hongbin Yang, et al. 2023. 'Pines' Demon Observed as a 3D Acoustic Plasmon in Sr2RuO4.' Nature 621:66-70. https://doi.org/10.1038/s41586-023-06318-8.

Pines, David. 1956. 'Collective Energy Losses in Solids.' Reviews of Modern Physics 28(3):184-198. https://doi.org/10.1103/RevModPhys.28.184.

Vig, Sean, Anshul Kogar, Matteo Mitrano, Ali A. Husain, Vivek Mishra, Melinda S. Rak, Luc Venema, et al. 2017. 'Measurement of the Dynamic Charge Response of Materials Using Low-Energy, Momentum-Resolved Electron Energy-Loss Spectroscopy (M-EELS).' SciPost Physics 3:026. https://doi.org/10.21468/SciPostPhys.3.4.026.

Schultz, J., A. Lubk, F. Jerzembeck, N. Kikugawa, M. Knupfer, D. Wolf, B. Buchner, and J. Fink. 2025. 'Optical and Acoustic Plasmons in the Layered Material Sr2RuO4.' Nature Communications 16:4287. https://doi.org/10.1038/s41467-025-58978-x.

Sanchez-Martinez, Miguel-Angel, Blaise Gouteraux, Louk Rademaker, and Felix Flicker. 2026. 'Electronic Sound and Diffusion in Disordered Multiband Metals.' arXiv:2603.17002v2. Preprint. https://doi.org/10.48550/arXiv.2603.17002.

Husain, Ali A., et al. 2022. 'Observation of Pines' Demon, a 3D Acoustic Plasmon, in Sr2RuO4.' Dataset. Zenodo record 7812299. https://doi.org/10.5281/zenodo.7812299.

Version statement

This methodological note documents Pines' Demon Explorer v1.0.0. Model behavior, fit constants, and classification thresholds should be versioned whenever changed. New evidence should be incorporated only with source-level provenance and an explicit distinction between peer-reviewed publication, preprint, dataset, and exploratory implementation.