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Label-free cell identity and dynamic functional state monitoring via surface-enhanced Raman spectroscopy and machine learning

Stanford researchers have developed a label-free platform that combines surface-enhanced Raman spectroscopy (SERS) with machine learning to enable rapid, non-destructive profiling of cell identity and functional state at single-cell resolution.

Current methods for cell characterization, such as flow cytometry, sequencing, and immunoassays, require labels, extensive sample preparation, or destructive workflows, and typically provide only static snapshots of cellular behavior. These limitations make it difficult to capture dynamic biological processes and increase cost, complexity, and time.

This technology addresses these challenges by using Raman spectroscopy to capture intrinsic biochemical signatures of cells, reflecting their molecular composition and functional state. When combined with machine learning, these signatures can be used to classify cell types, phenotypes, and dynamic states such as activation, signaling, metabolic changes, and interactions between cells. Importantly, this approach operates without labels or dyes, enabling continuous or time-resolved monitoring of live cells at single cell resolution, with plasmonic enhancement allowing rapid measurements that support high throughput workflows and real time analysis.

By enabling label free, information-rich profiling of dynamic cell states, this platform offers a practical and scalable approach for applications in research, clinical decision making, and cell therapy development and manufacturing.

Applications

- Cell therapy development and manufacturing (e.g., CAR T, stem cells)
- Monitoring cell identity, activation, and functional state
- Immune profiling for cancer, infectious, and autoimmune diseases
- Drug response and pharmacodynamic studies
- Real-time analysis of cell behavior and interactions

Advantages

- Label-free and non-destructive cell analysis
- Captures both cell identity and functional state in a single platform
- Enables real-time and longitudinal monitoring of live cells
- Faster and more cost-effective than sequencing-based approaches
- Provides information-rich, unbiased readouts beyond predefined markers

Publications

- Stiber, Ariel, et al. Dynamic, single-cell monitoring of CAR T cell identity and activation with Raman spectroscopy. *bioRxiv* (2025).

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