A 1-gram wireless microscope for mesoscopic neural observation during fully unconstrianed behavior

Lekang Yuan[5], Anran Li[4], Mingrui Wang[2], Weihao Zhao[3], Yuanlong Zhang[1]

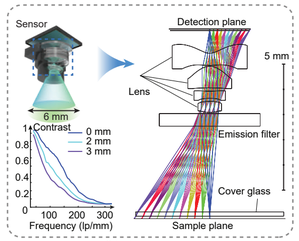
1 Life Sci., Tsinghua Univ., Beijing, China; 2 Tsinghua Shenzhen Intl. Grad. Sch., Tsinghua Univ., Shenzhen, China; 3 Dept. of ENT, Chinese PLA Gen. Hosp., Beijing, China;
4 Sch. of Information Sci. and Technol., Fudan Univ., Shanghai, China; 5 Princeton Univ., Princeton, NJ, USA;

Introduction

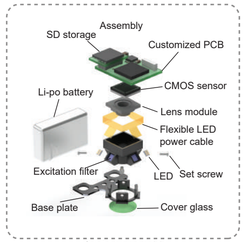
A key challenge in systems neuroscience is to understand how distributed cortical circuits coordinate natural behavior in freely moving animals. Two fundamental bottlenecks prevent progress toward this goal: **1. Optical scaling**: Expanding the field of view while preserving single-neuron resolution (⩽5 μm) requires increasingly complex optics that are difficult to miniaturize, causing head-mounted devices to fall short of tabletop mesoscopes. **2. Tethering:** Cabled connections for data and power delivery on head-mounted devices continue to constrain studies of complex, natural behaviors, especially in social or group settings. Existing wireless platforms operate at drastically reduced throughput (~30× lower than wired systems), suffer from signal interference or blind operation, and often exceed ~3 g in weight, limiting truly free movement. **In this work, we introduce Airscope, a fully wireless miniaturized mesoscope that achieves 4 μm lateral resolution across a 6 mm field of view at 10 Hz, while weighing only 1 gram. Airscope enables cable-free calcium imaging of over 8,000 neurons, representing a twenty-fold improvement over previous wireless systems. Combined with a zero-shot behavioral analyzer, it allows cortical imaging under previously inaccessible conditions, including room-scale enriched arenas, swimming assays, and multi-organ or multi-animal recordings.**

Methods

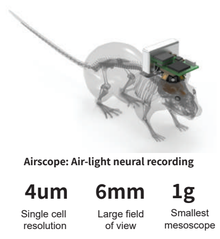
Airscope: a 1-gram wireless mesoscope



0.1g Asperical lens

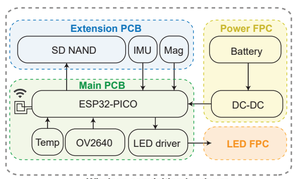


System assmebly

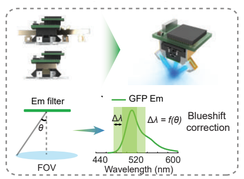


Airscope: Air-light neural recording

4um	6mm	1g
Single cell resolution	Large field of view	Smallest mesoscope



Wireless acquisition hardware



Illumination design

Fully wireless

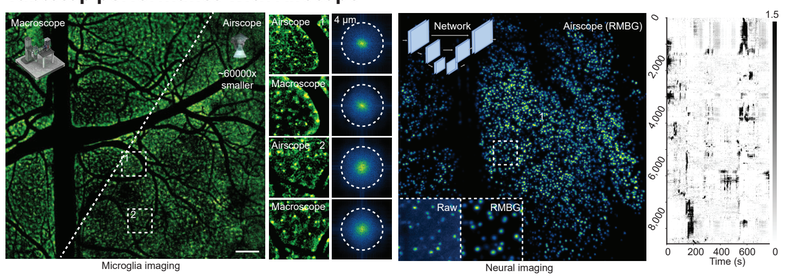
Wireless streaming	Wireless logging	Wireless control

Up to 8000

Wirelessly recorded neurons in freely moving mice

20x advance

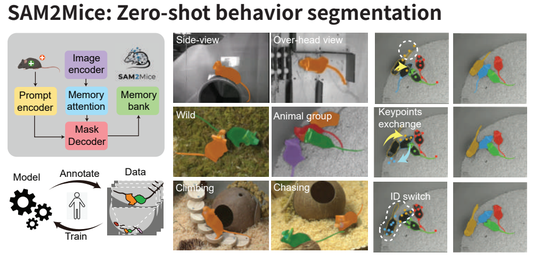
Tabletop performance with Airscope



Microglia imaging

Neural imaging

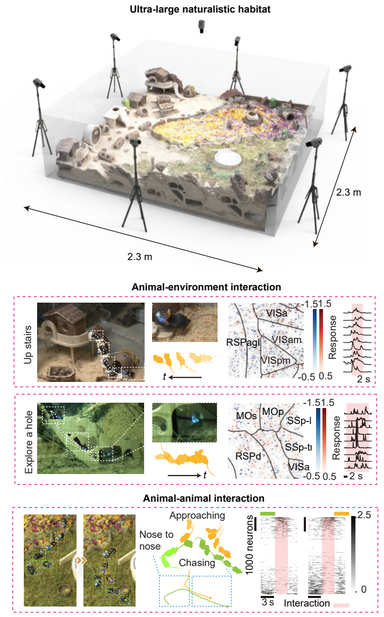
SAM2Mice: Zero-shot behavior segmentation

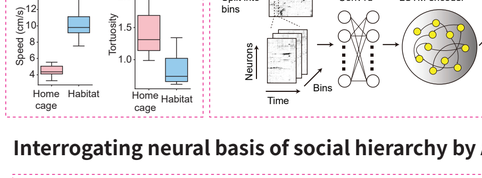


Results

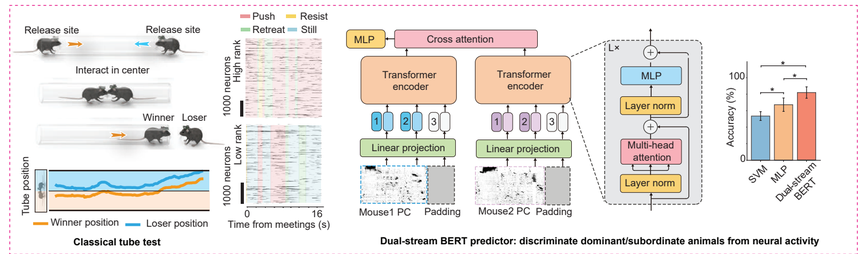
Airscope imaging of freely moving animals in 5m² naturalistic arena



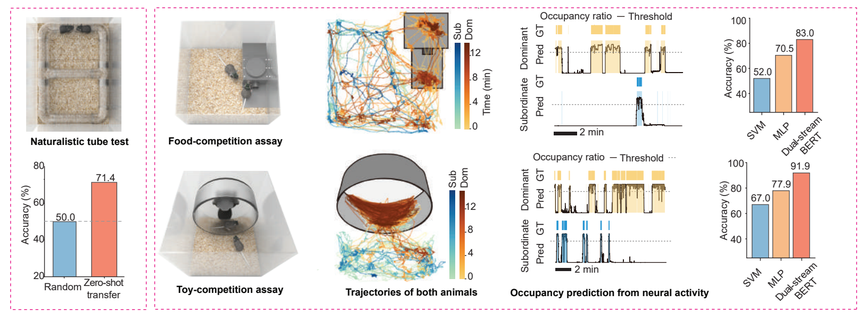




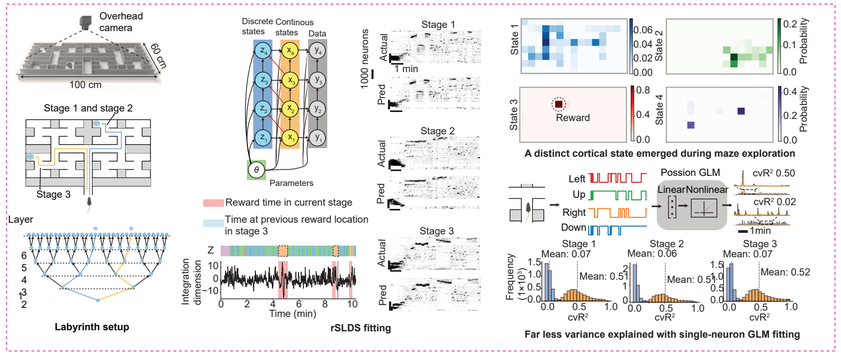
Interrogating neural basis of social hierarchy by Airscope



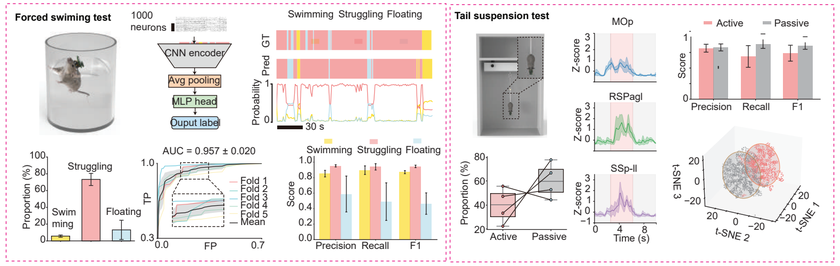
Do these rank-specific neural signatures persist in more naturalistic competitive settings?



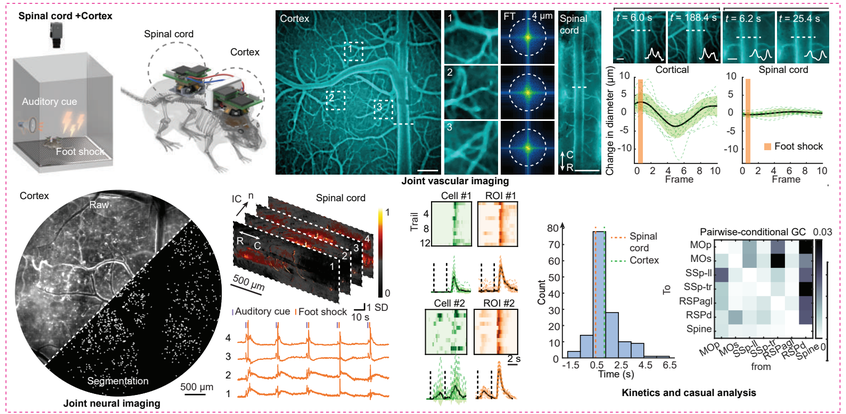
Airscope unveiled cortical basis of animals' natural exploration in a labyinth

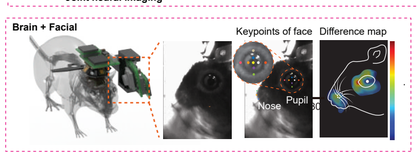


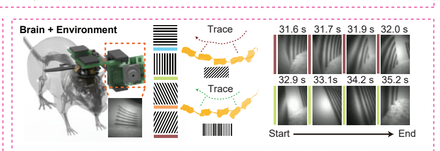
Airscope investigates cortical dynamics during FST and TST



Simultaneous multimodal imaging using dual Airscopes







Conclusions

We introduced Airscope, a 1-gram fully wireless miniaturized mesoscope that enables benchtop-grade recording of over 8,000 neurons in freely moving animals. Using Airscope, we performed an initial exploration of untethered brain–behavior dynamics. These results demonstrate that Airscope seamlessly integrates large-scale, cellular-resolution imaging with natural, unconstrained behavior, establishing a foundational platform for naturalistic systems neuroscience.

Interested in using Airscope in your research? We're excited to collaborate!
Please contact: ly7150@princeton.edu; yuanlongzhang94@gmail.com