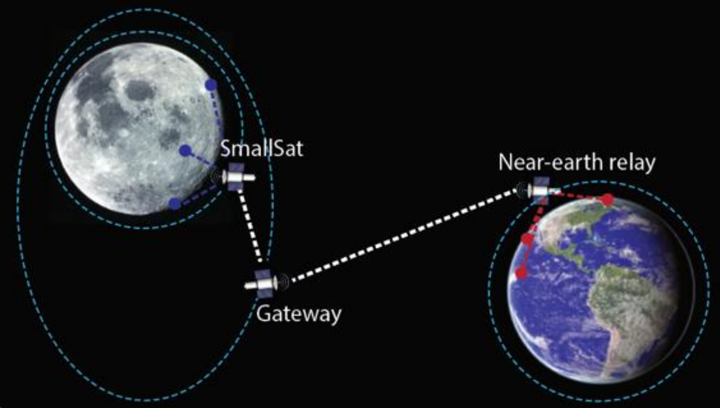
# Miniature high-performance microwave oscillators using optical frequency division

Qing-Xin Ji, Peng Liu, Kerry Vahala; Caltech
Wei Zhang, Anatoliy Savchenkov, Vladimir Iltchenko, Andrey Matsko; JPL
Joel Guo, Jonathan Peters, John Bowers; UCSB
Warren Jin, Avi Feshali, Mario Paniccia; Anello Photonics

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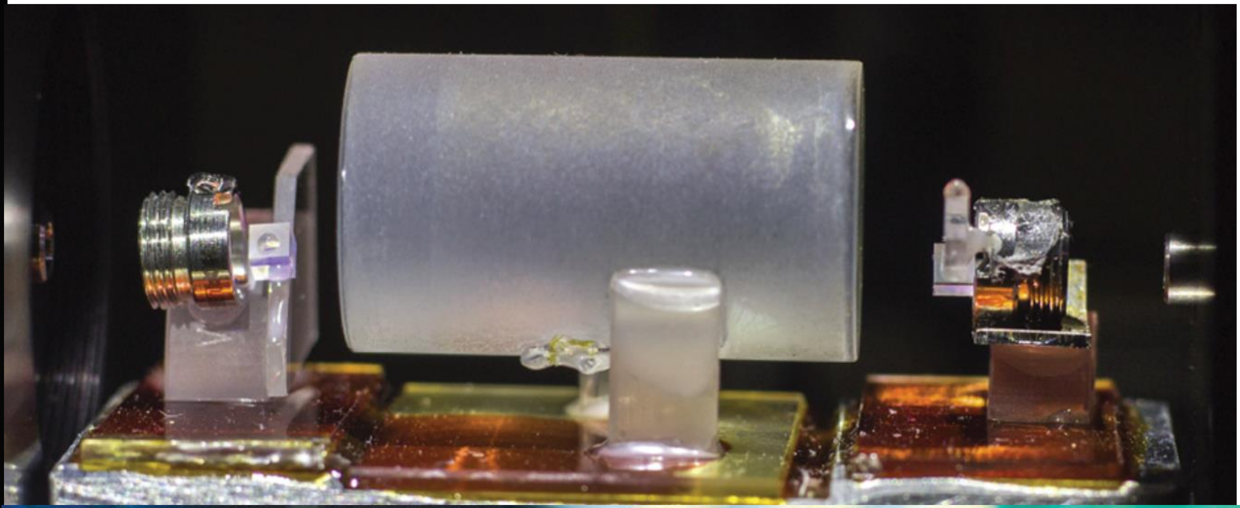
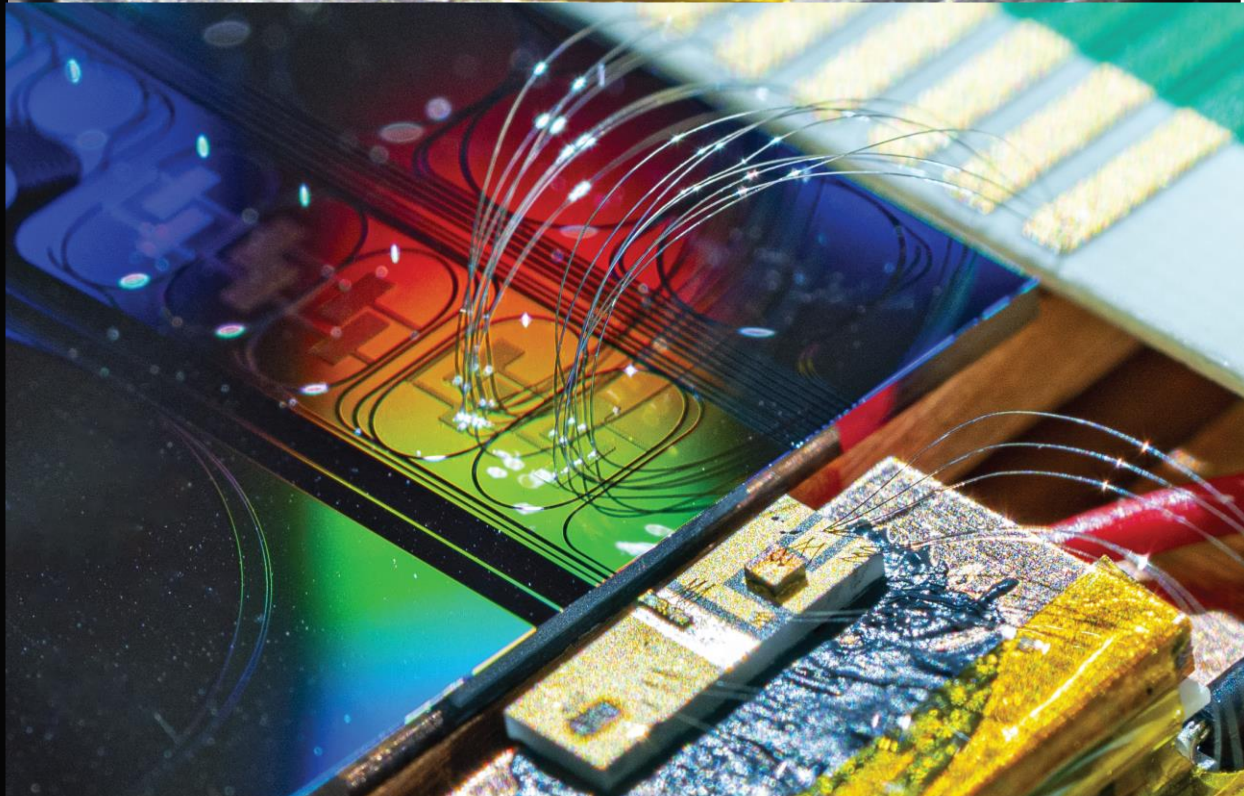
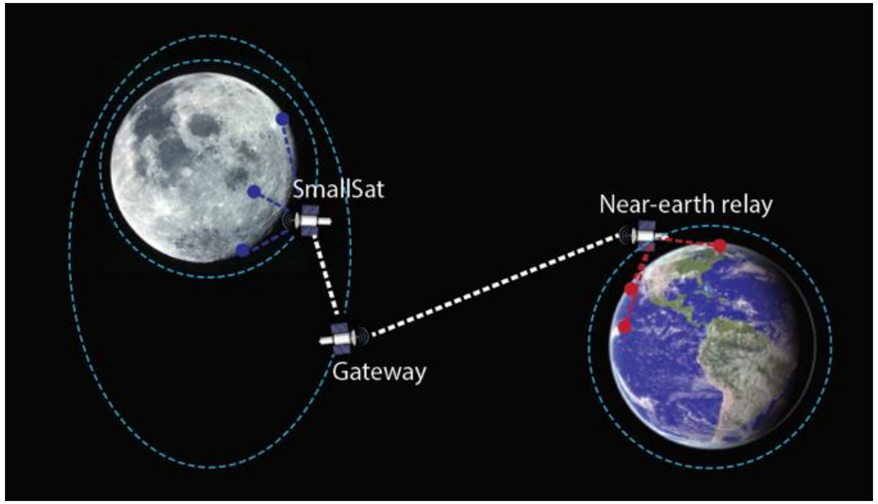


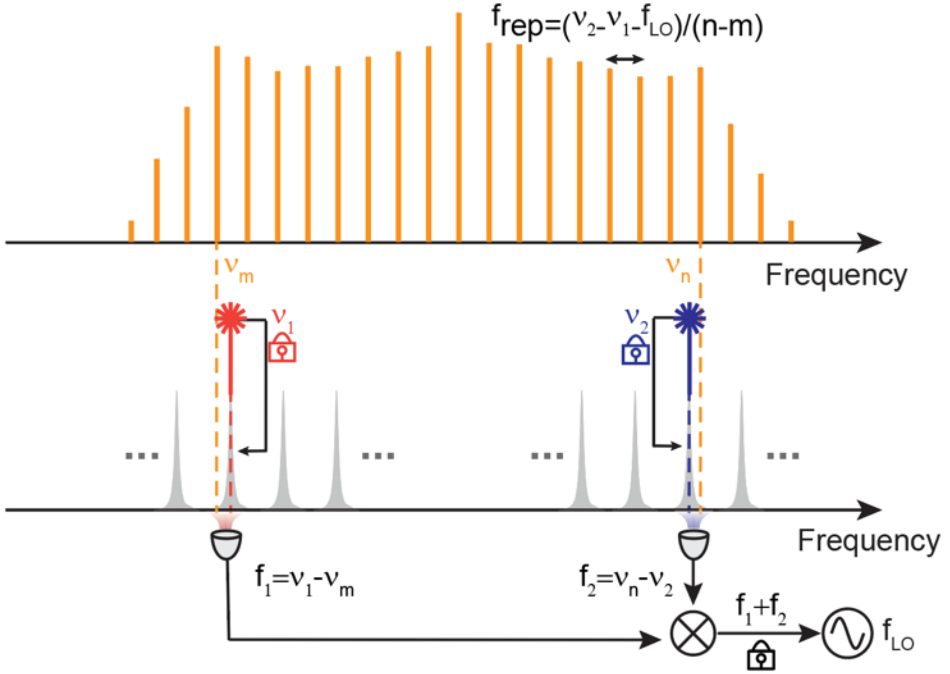


# Clock concept using on-chip 2-point OFD

**High-performance, small microwave oscillators for Lunar Network**

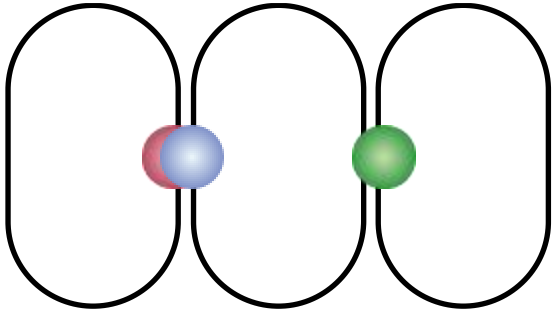


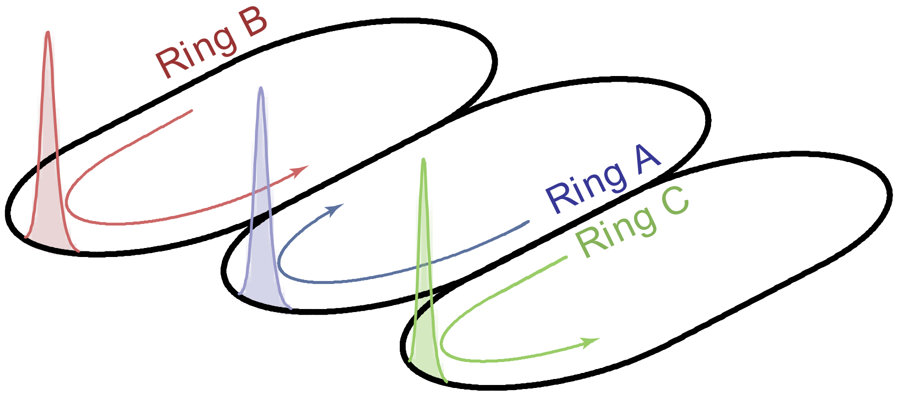

- Microwave oscillator on a small spacecraft can provide cost-effective communications, monitoring, and inspection.
- Clock based on optical frequency division (OFD) will have an order of magnitude better stability than CSAC or existing electronic microwave oscillators.

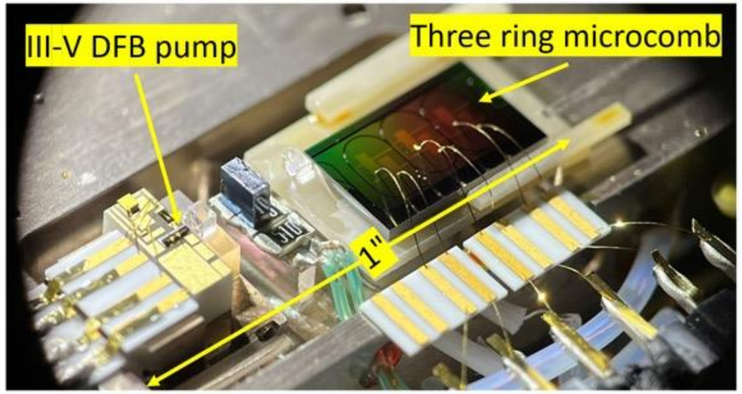


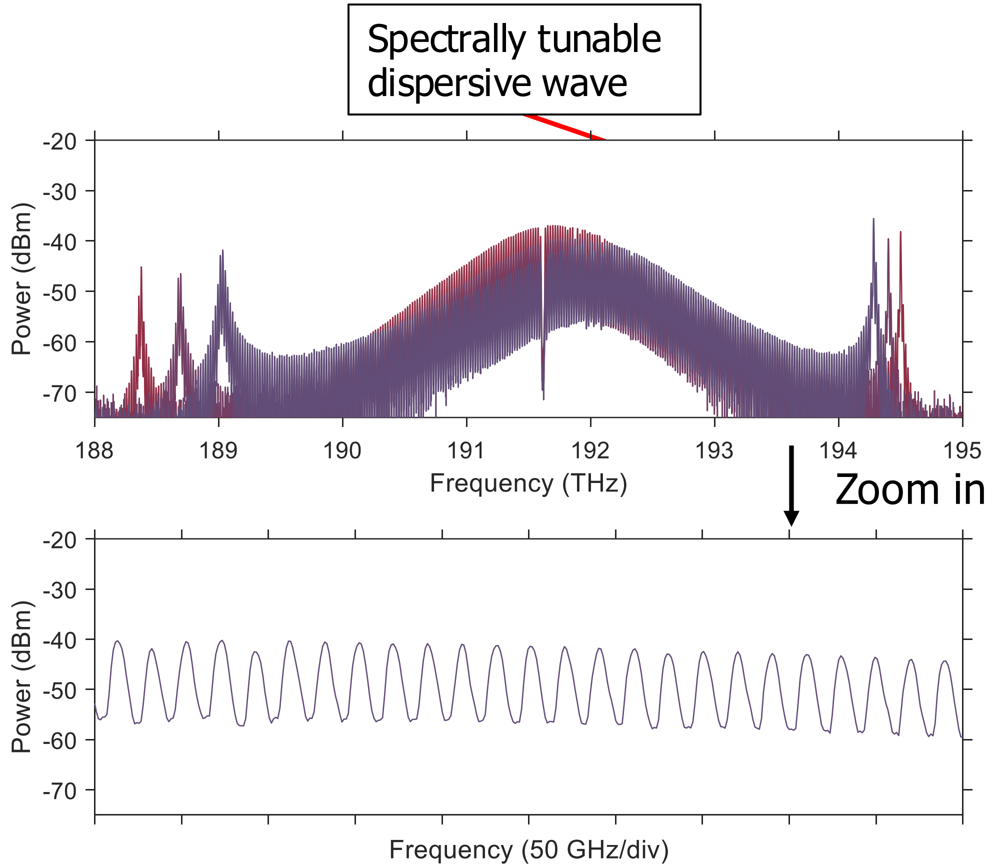

- Use an optical frequency comb (equally-spaced frequency ruler) to divide the optical frequency down to a microwave tone.
- Electrical mixing eliminates optical pump frequency.
  - $f_{rep} = \frac{v_2 - v_1 - f_{LO}}{n-m}$.
  - Phase noise is reduced by $(n-m)^2$.

# Frequency comb generation



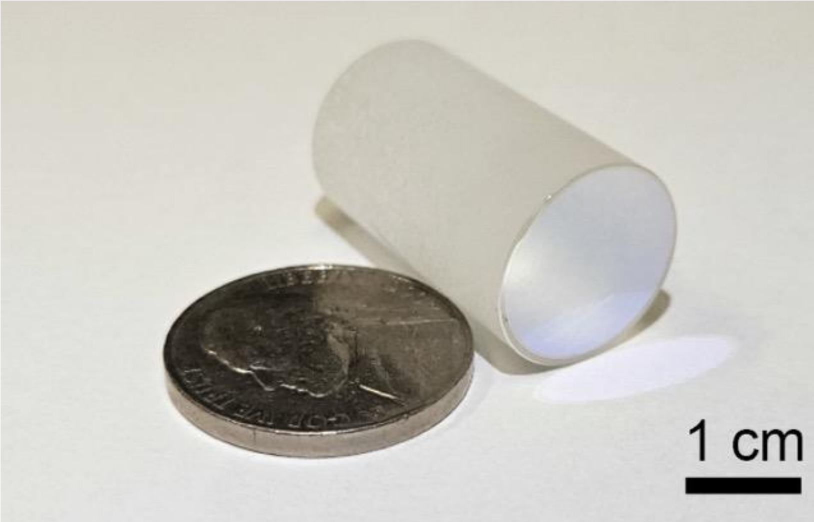



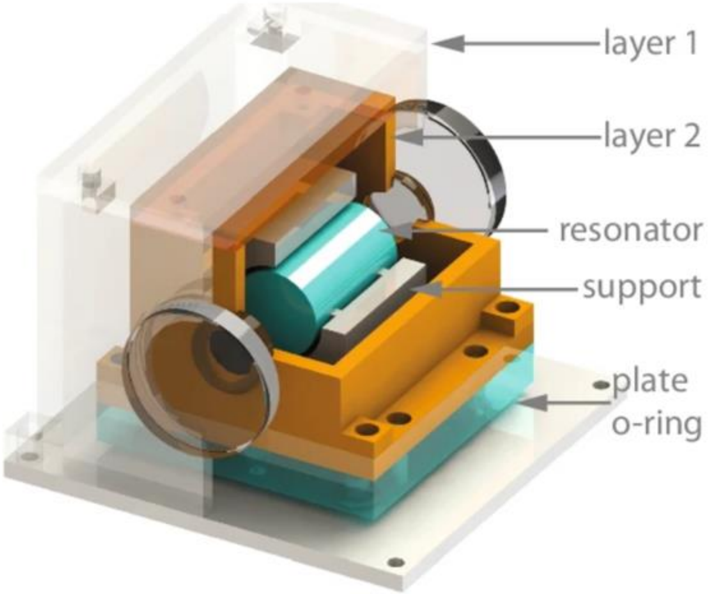



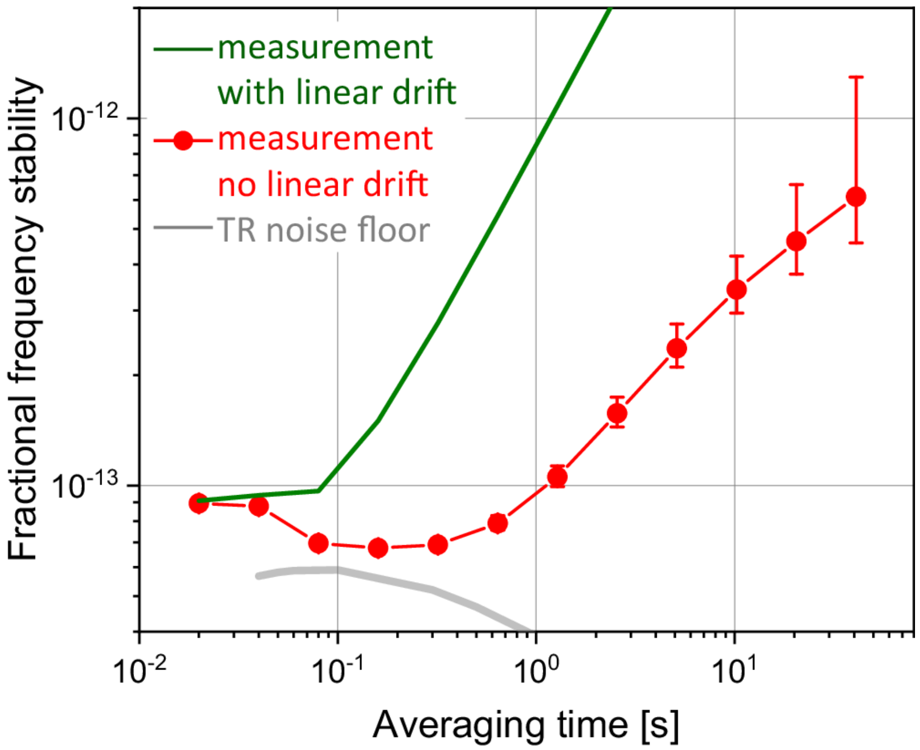

- Use spectrally tunable dispersive wave (frequency comb lines with enhance power) to improve system performance.
- Frequency comb is packaged with optical pump and tuning control.

arXiv preprint arXiv:2403.00973 (2024).

# Compact Fabry–Pérot cavity



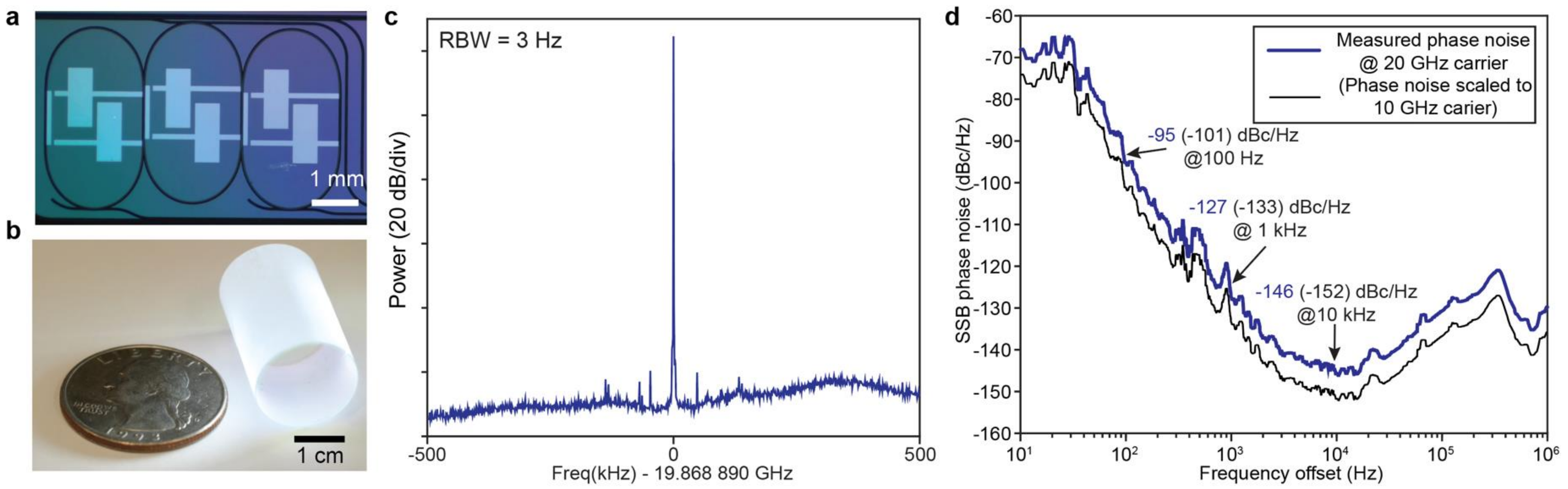




- Compact, high-finesse (200,000) Fabry–Pérot cavity serves as the optical reference (which will ultimately be upgraded to an atomic transition).
- Frequency stability better than $10^{-13}$ is demonstrated (timing error 10× better than a quartz oscillator).

*Communications Physics* 7.1 (2024): 177.

# Low-noise microwave generation




- **Panel c**: A stable 20 GHz microwave tone is generated.
- **Panel d**: Phase noise measured at a 20 GHz carrier (blue) and scaled down to a 10 GHz carrier for comparison purposes (black).
  - Phase noise as low as -152 dBc/Hz at 10 kHz frequency offset is demonstrate for a 10 GHz carrier
  - **>10 dB improvement compared with previous record in Nature 627, 534–539 (2024)**.
- **Next step**: improve SWaP and performance to make the system ideal for the Lunar Network.