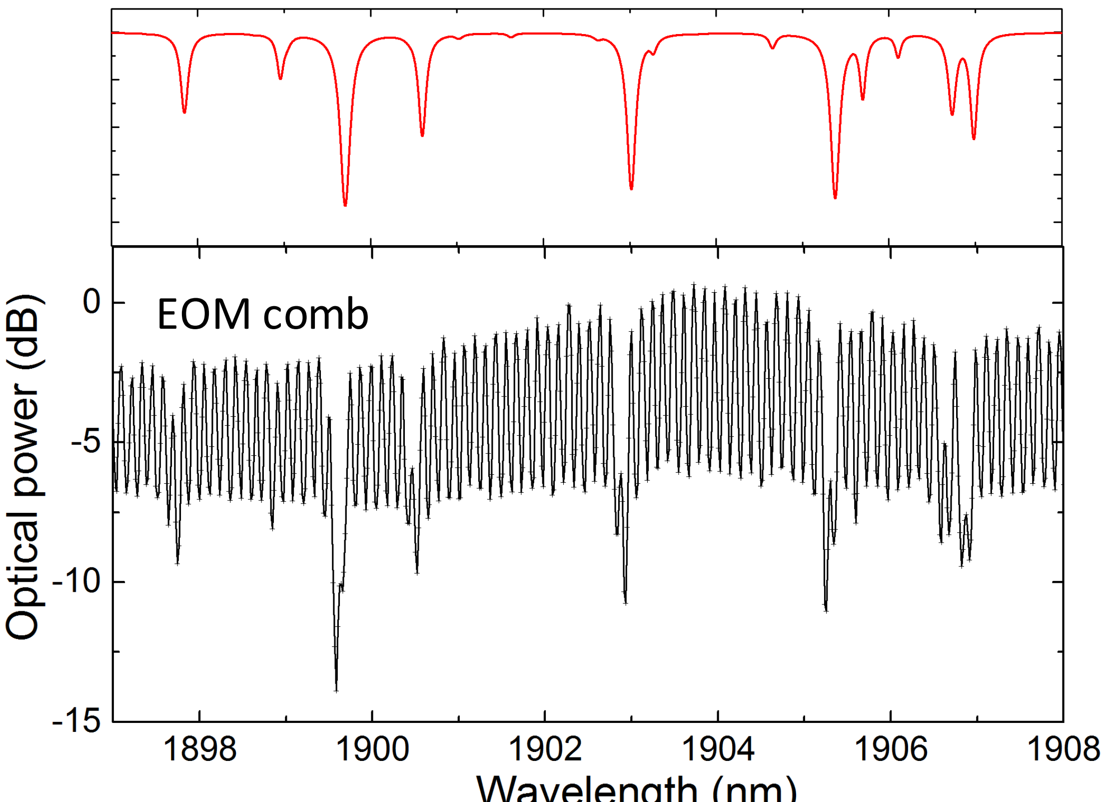
Self-referencing electro-optic frequency combs

Scott Papp & Scott Diddams

National Institute of Standards and Technology
Boulder, CO USA

NIST

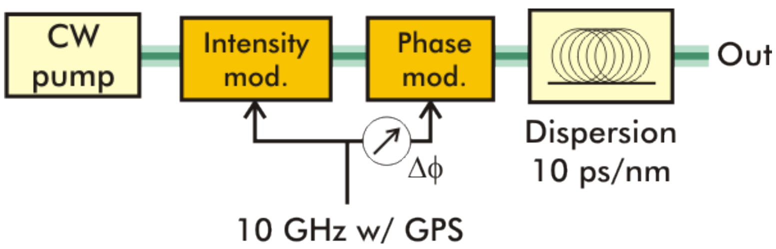


Funding: NIST,
DARPA (QuASAR, PULSE, DODOS)
AFOSR, NASA, NRC

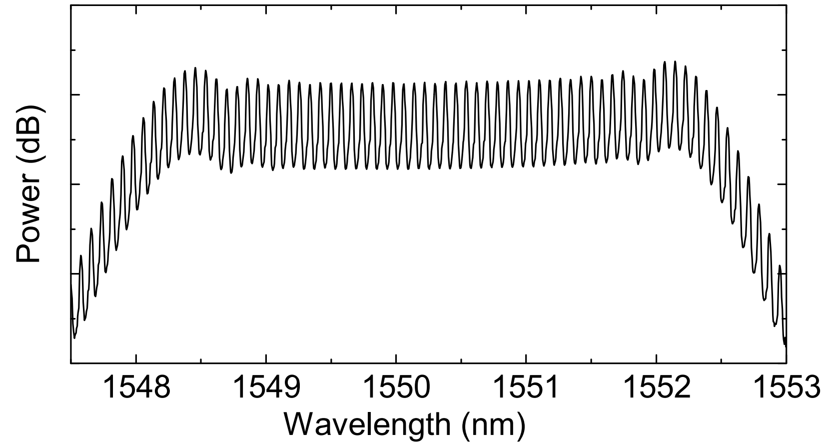
Different combs for different jobs

NIST

Electro-optic modulation combs



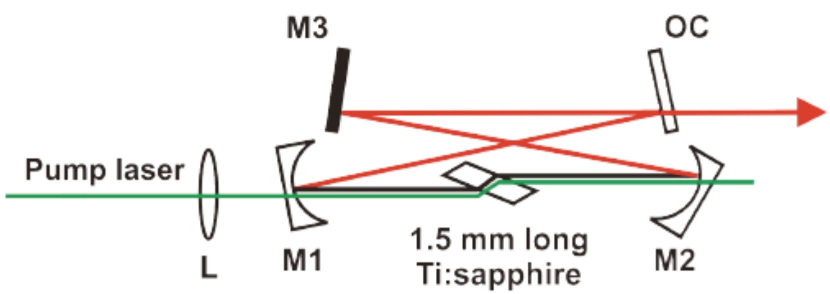
EOM combs: Purdue, JILA, Tokyo IT, UC Davis, NTT, NIST …

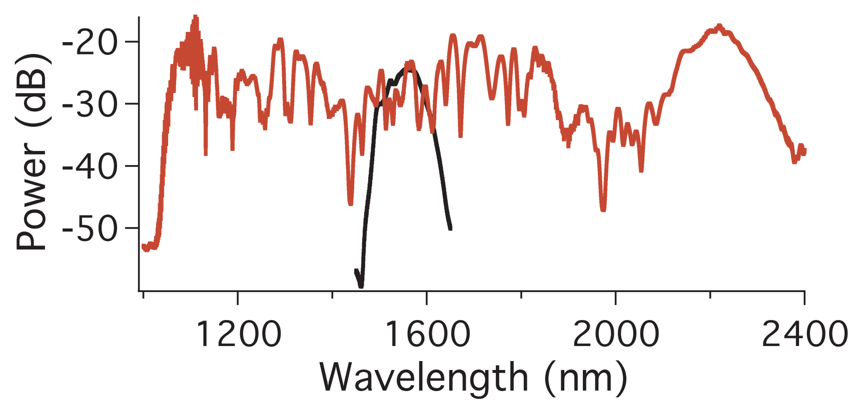


Features: Wide mode spacing, tunable, mWs per mode, COTS + scalable fabrication, retrace

Challenges: Low pulse energy, narrow BW, electro-optical noise

Modelocked laser comb



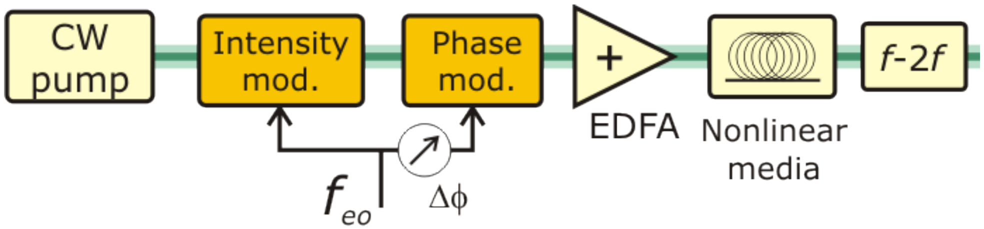


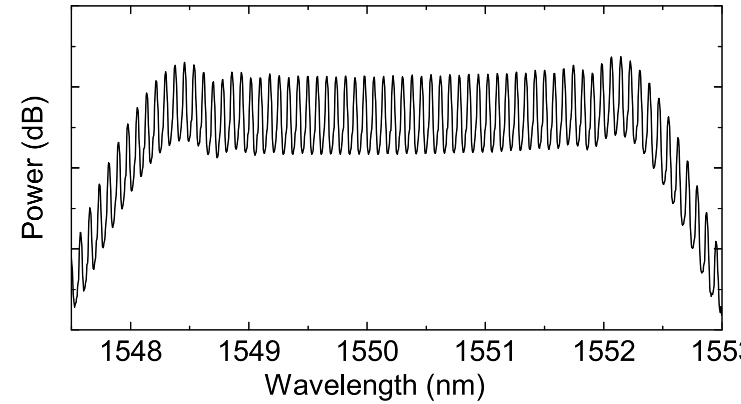
Features: Large pulse energy, wide BW, many examples self-referenced

Challenges: Narrow mode spacing, modelocking, power per line

Self-referencing EOM & Kerr combs

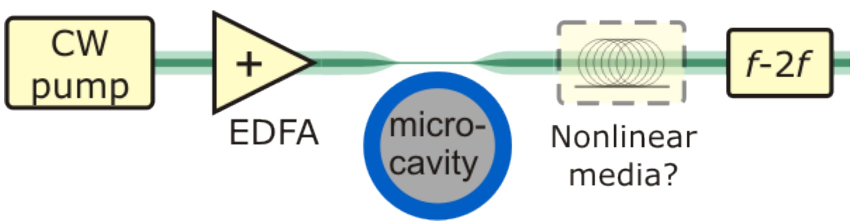
Electro-optic modulation (EOM) comb

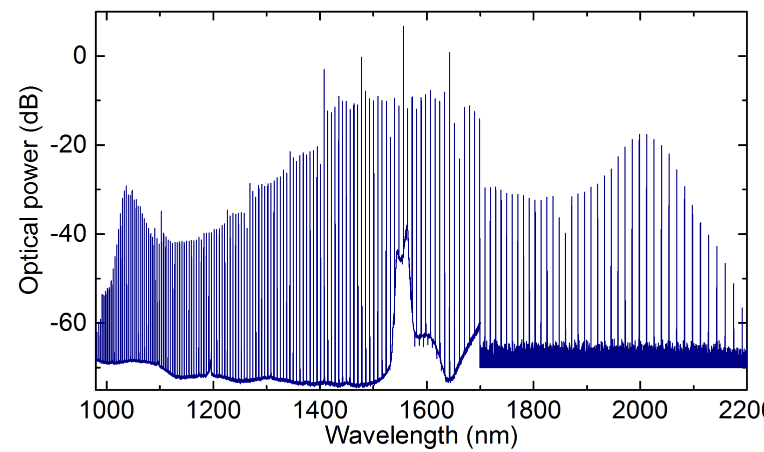




CW laser is the center of comb

Kerr microcomb



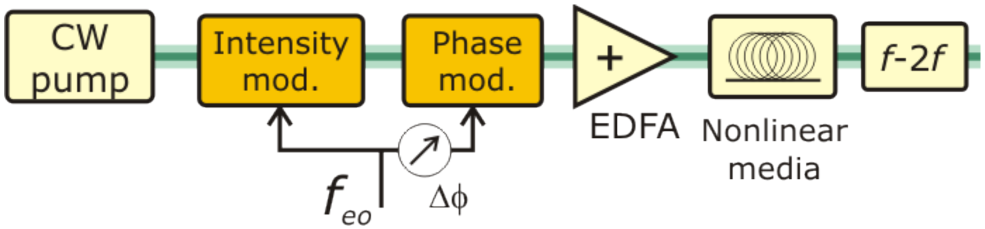


microcombs: EPFL, Caltech, OEwaves, JPL, Cornell, NIST, Purdue, Yale, Columbia, FEMTO-ST ...

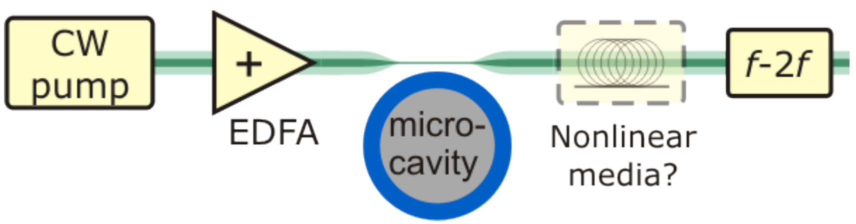
f-2f detection gives carrier-offset frequency: f_0 = CW laser – **19,340** x 10 GHz

Outline

Electro-optic modulation (EOM) comb



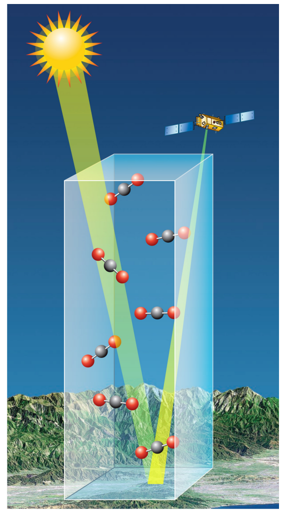
Kerr microcomb



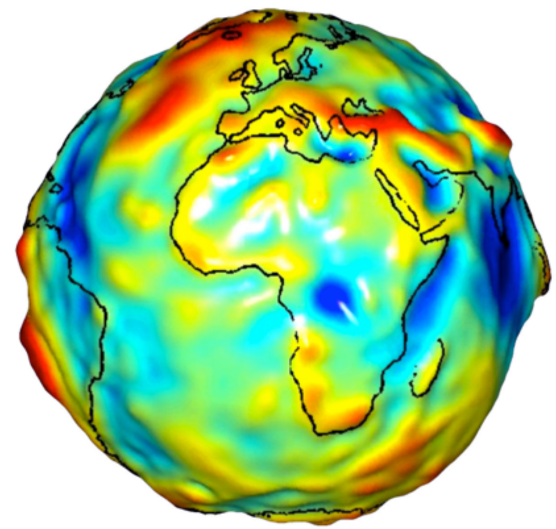
- Bit on possible applications
- EOM combs, two challenges:
  1. Spectral broadening
  2. Electro-optic noise
- EOM/microcombs in practice
- Future perspective

EOM/Kerr comb applications

Molecular identification / spectroscopy

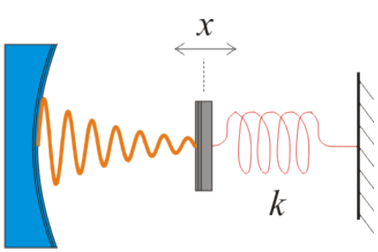


Geodesy/ranging. Grace-FO mission

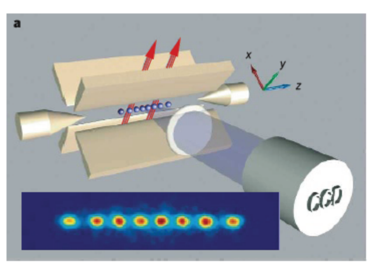


Quantum-based systems: Comb is a classical phase reference. Microcombs at quantum interface

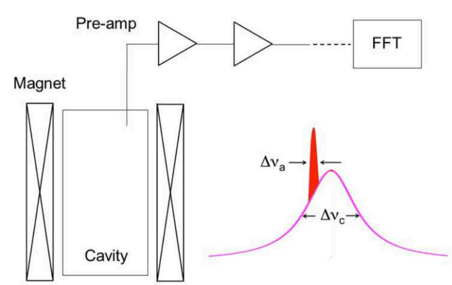
Cavity optomechanics

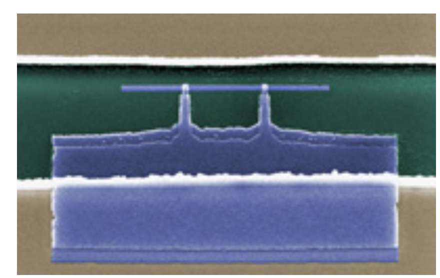


Atoms, ions

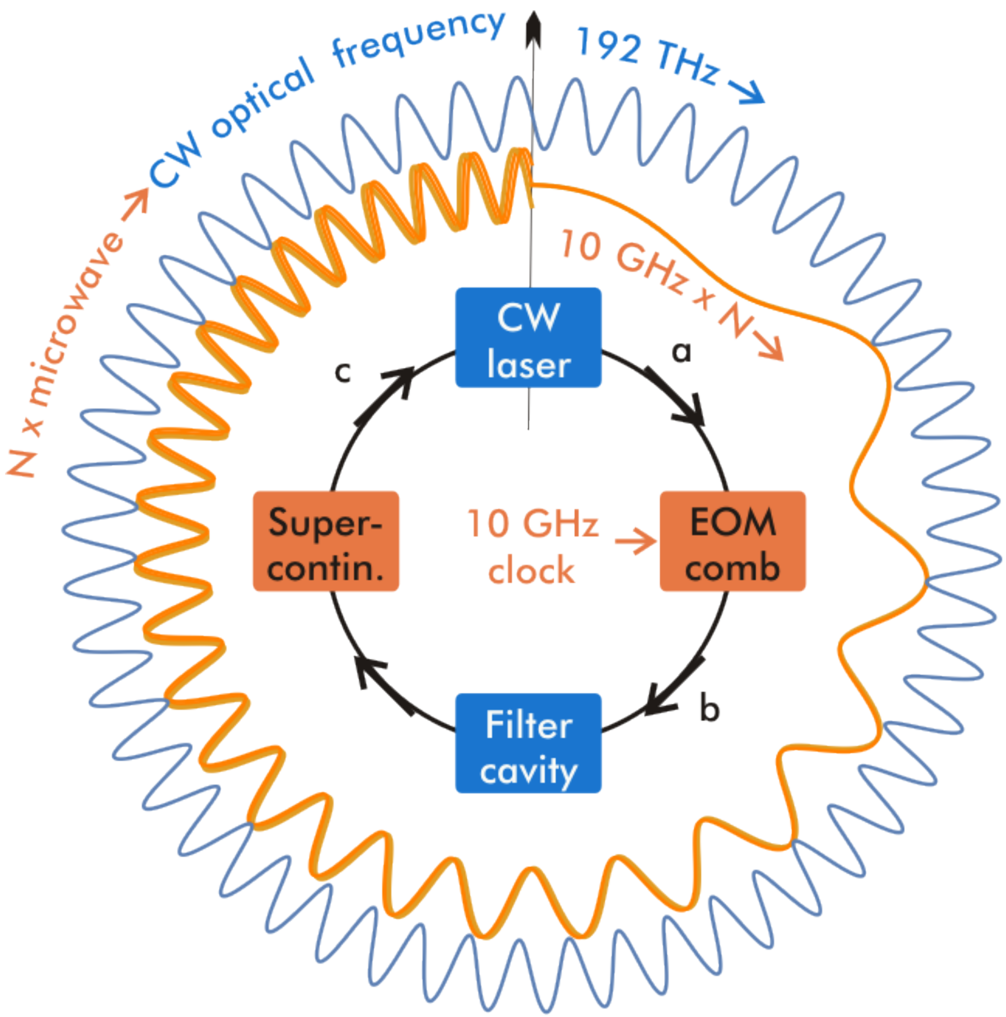


Microwave systems: ADMX dark matter





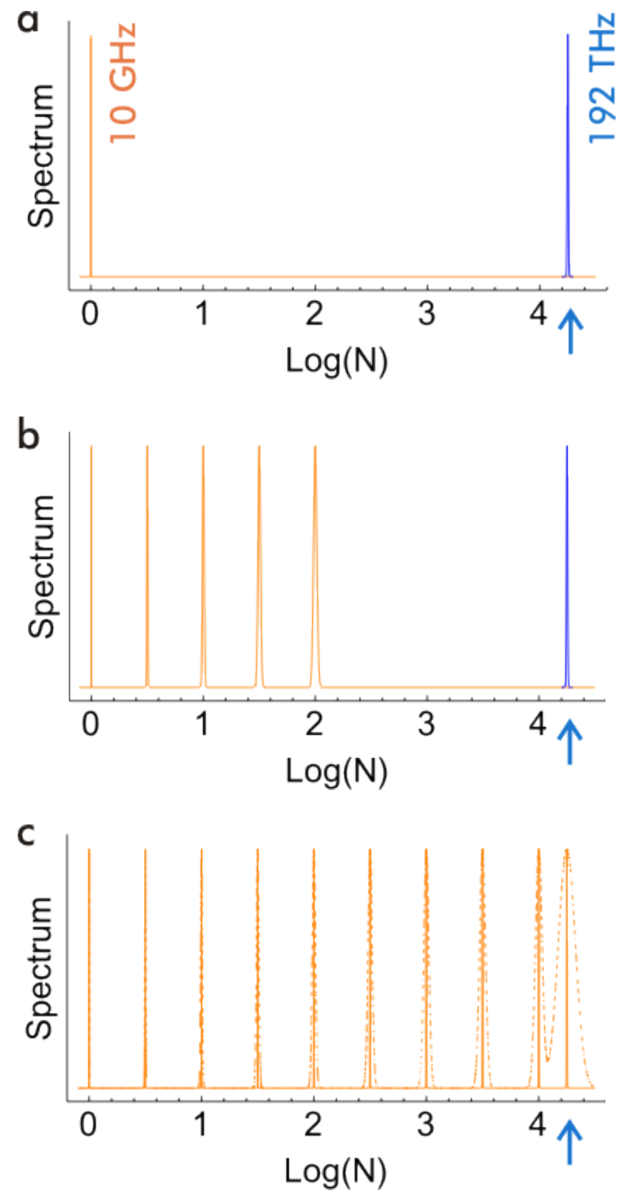
Building an EOM comb line-by-line



Laser

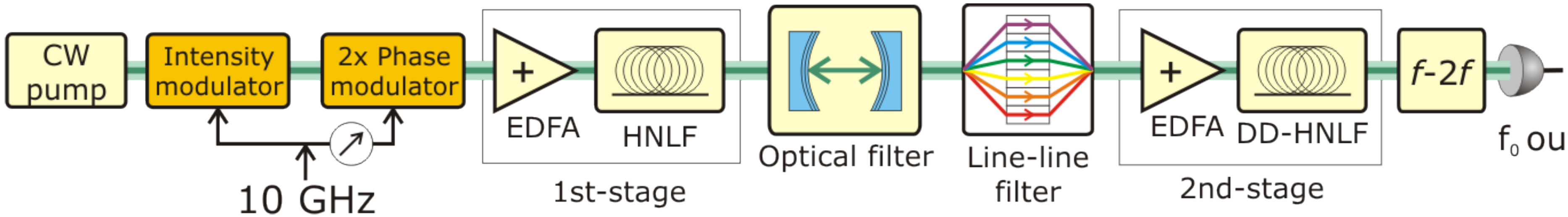
EOM comb

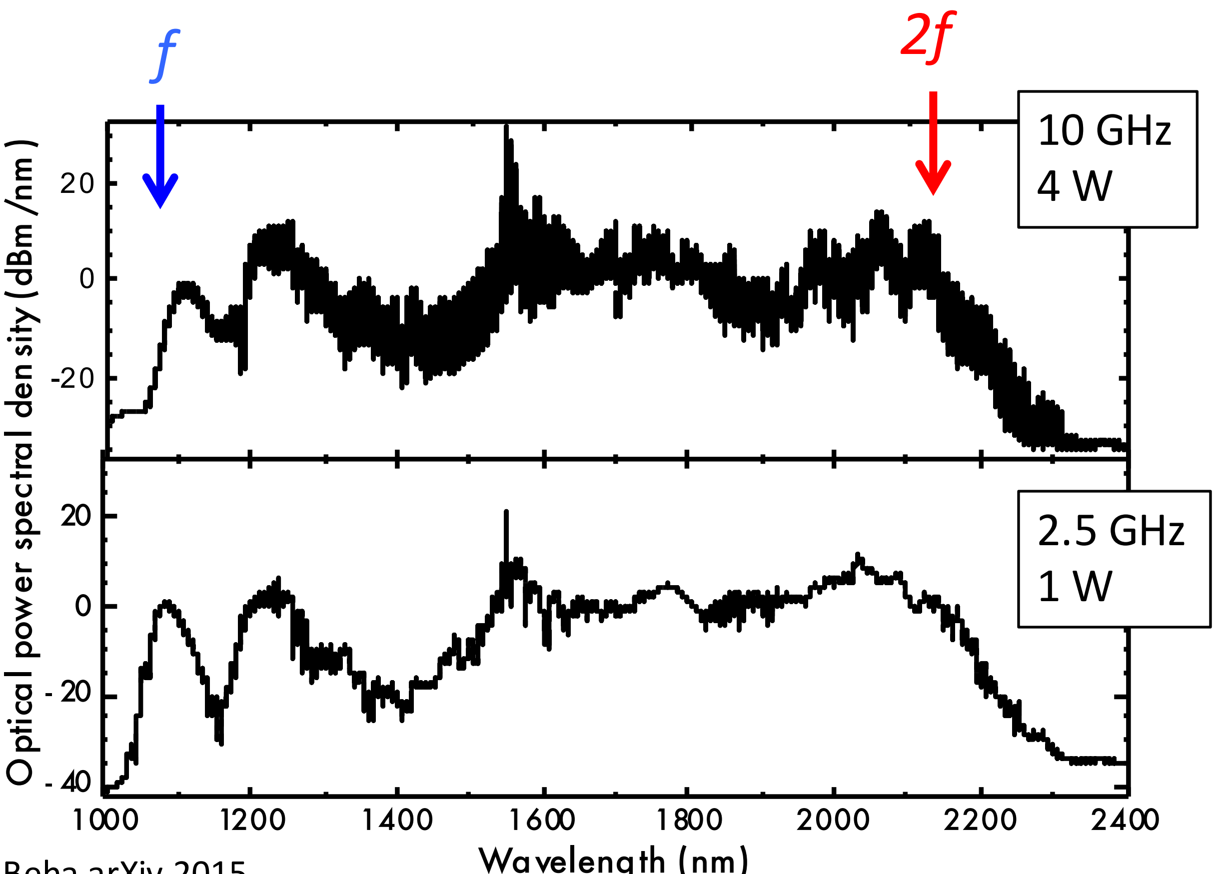
EOM super-contin.



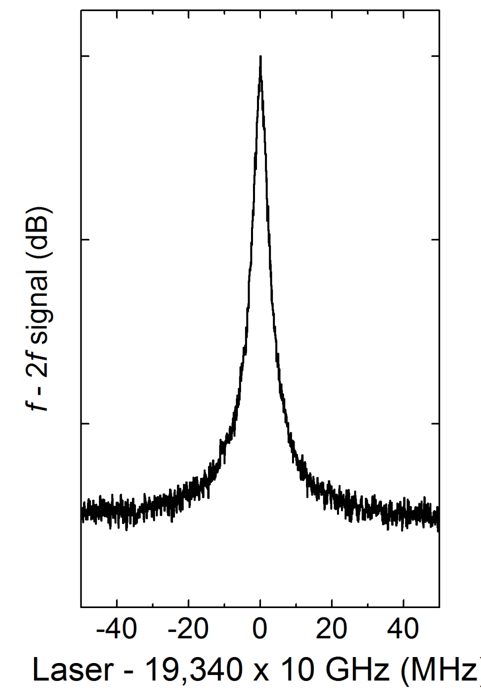
Self-referencing an EOM comb

NIST





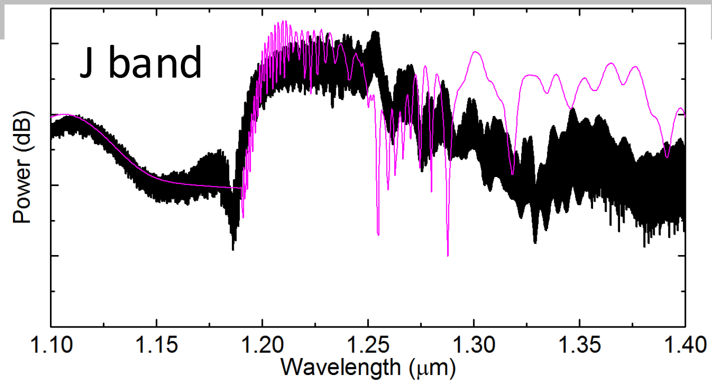
f_0 = CW laser – 19340 x 10 GHz

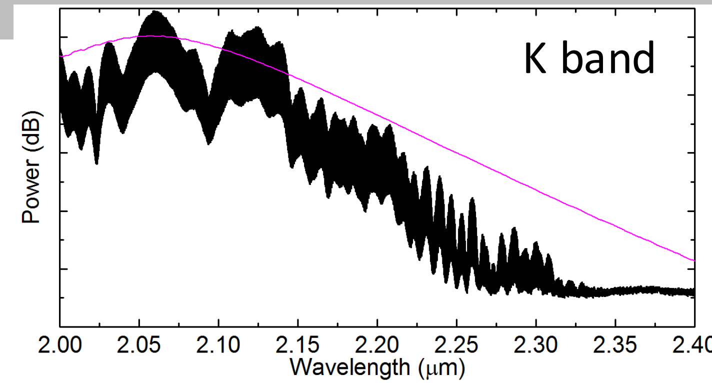


Beha arXiv 2015

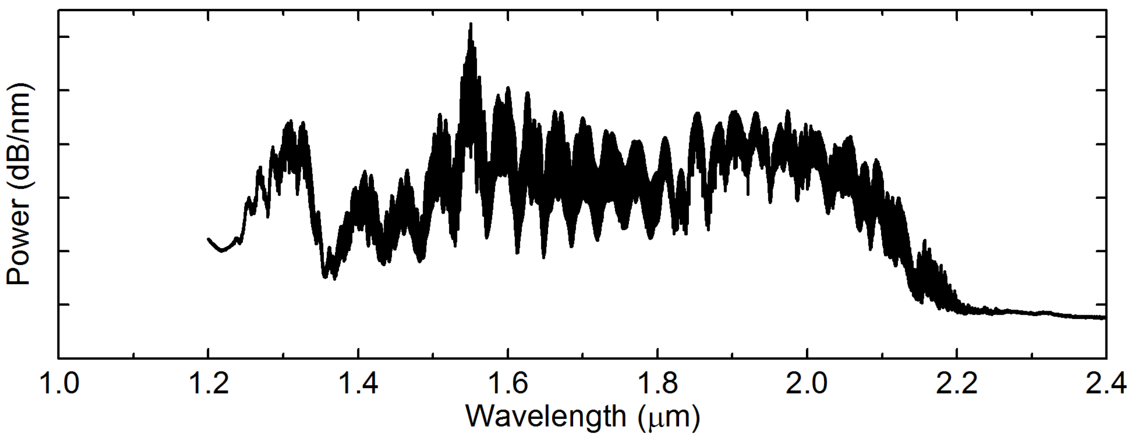
Supercontinuum at 10's of GHz

NIST

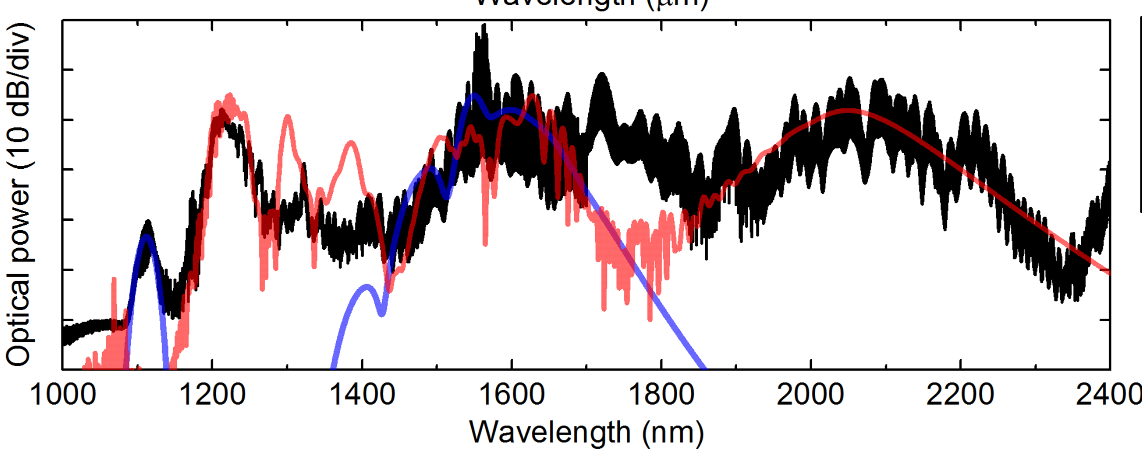




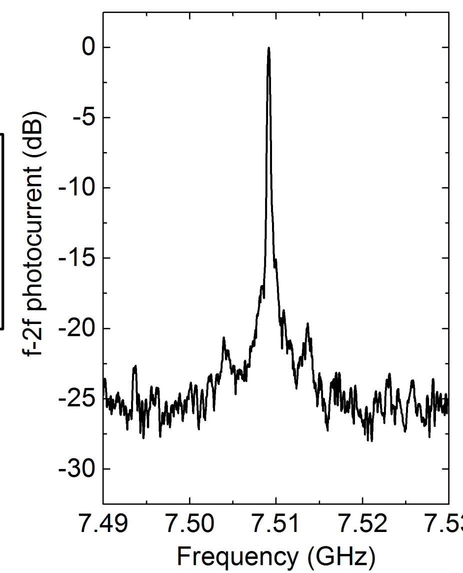
EOM comb
10 GHz
4 W



EOM comb
33 GHz
4 W

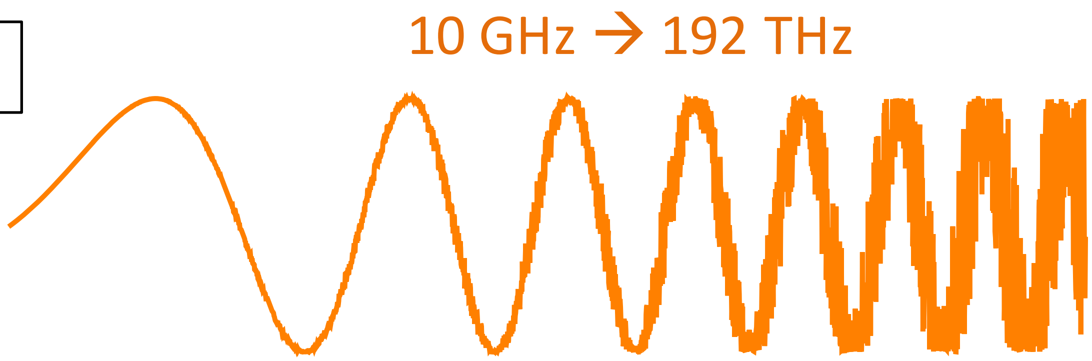


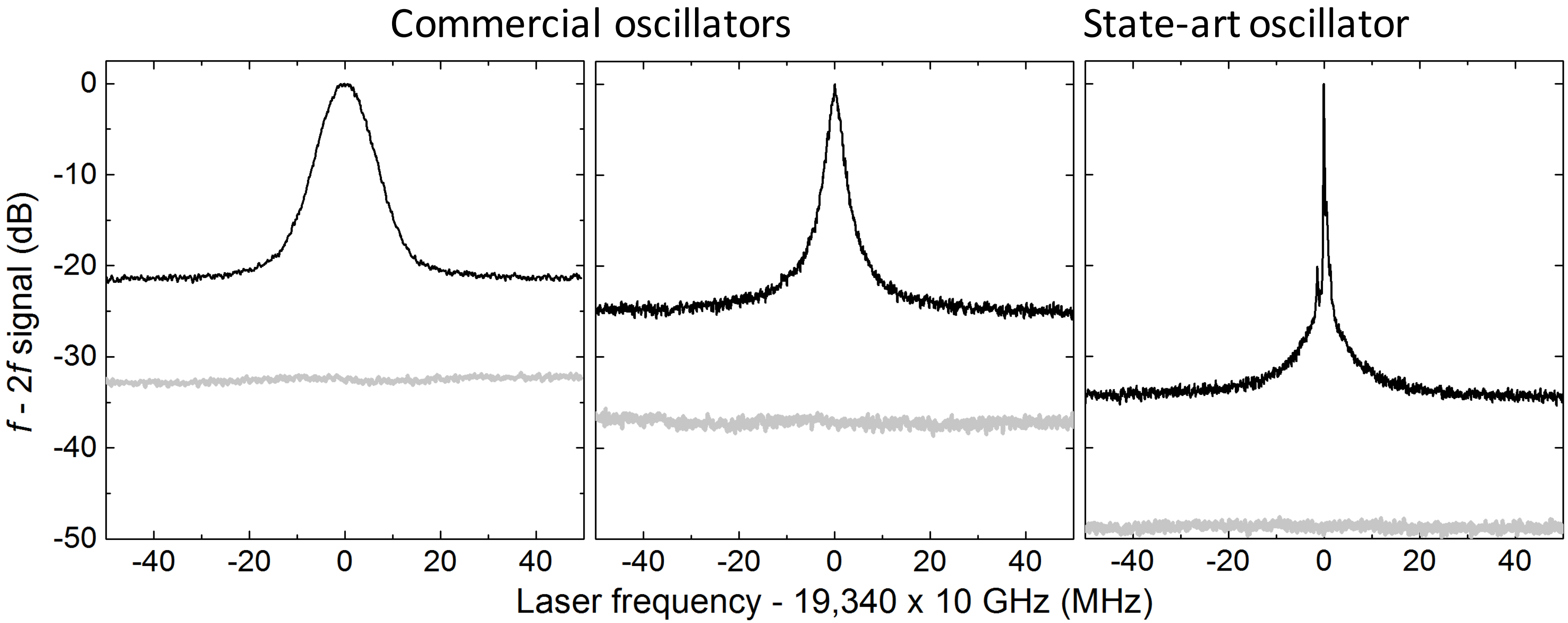
Microcomb
16.5 GHz
5 W



Electro-optic noise

f_0 = CW laser – 19340 x 10 GHz



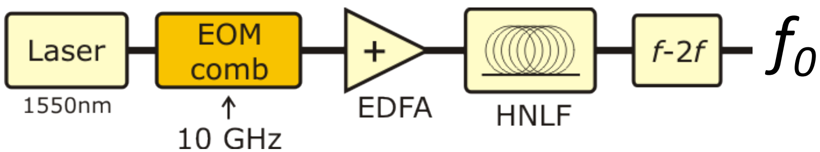


Putting EOM combs to work

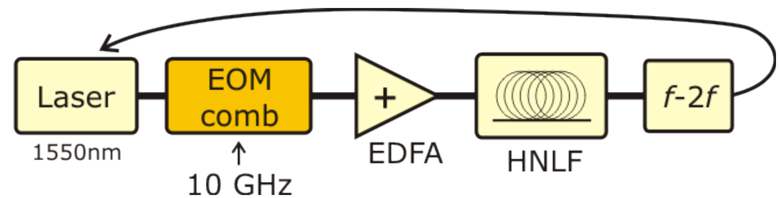
f_0 = CW laser – 19340 x 10 GHz

Beha arXiv 2015

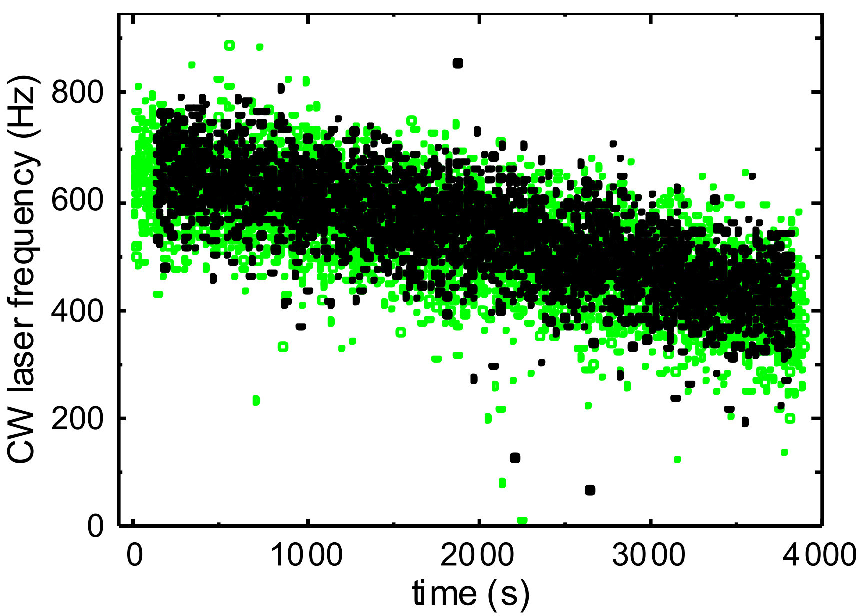
Sensing: Observe optical reference drift ~70 mHz/s

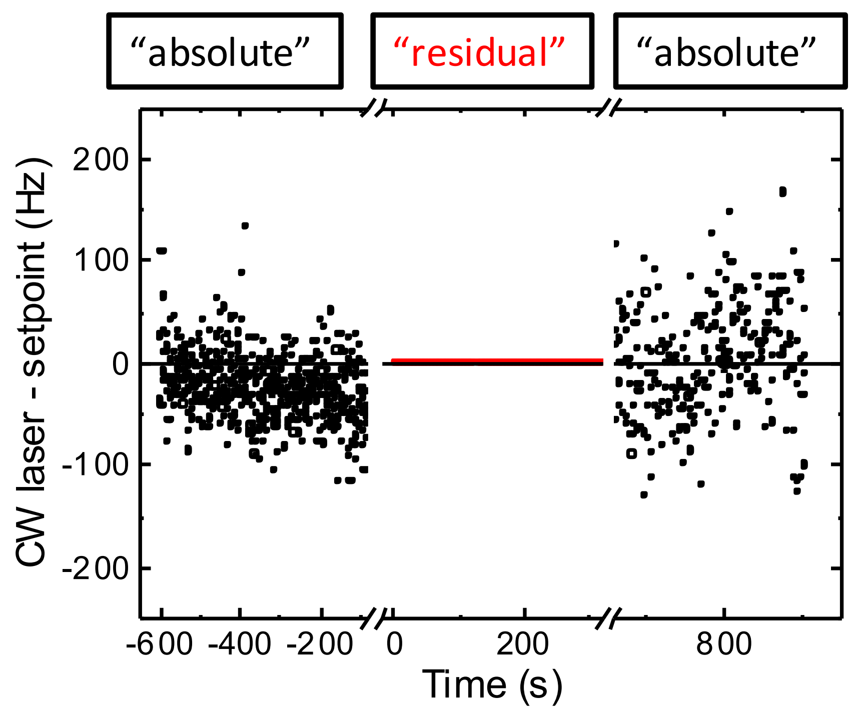


Synthesis: Locking the EOM seed laser

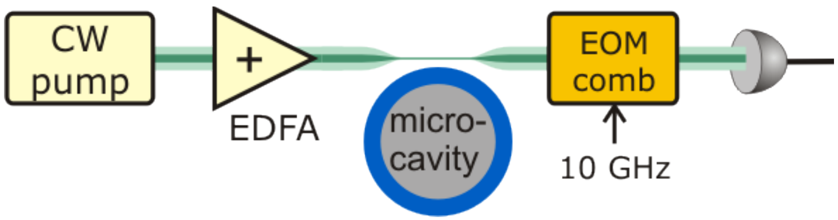


- Menlo fiber comb
- EOM comb

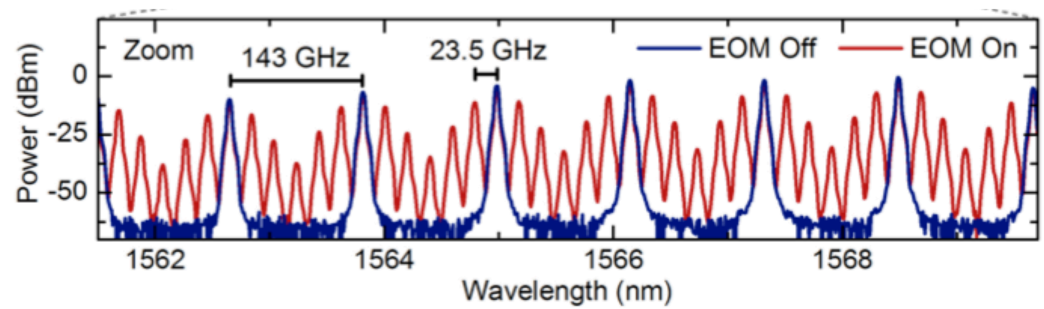




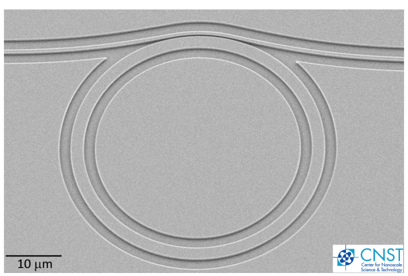
What might future systems look like?



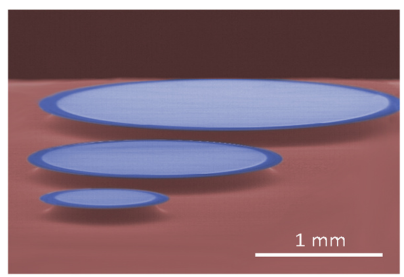
Silica resonators at 100+ GHz



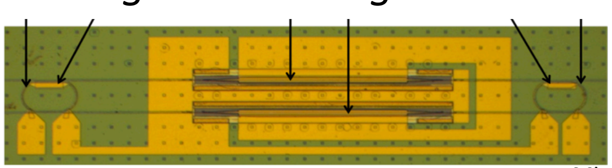
Silicon nitride comb



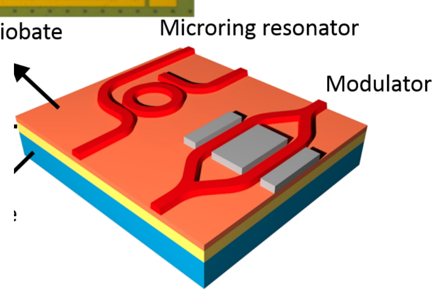
Silica comb

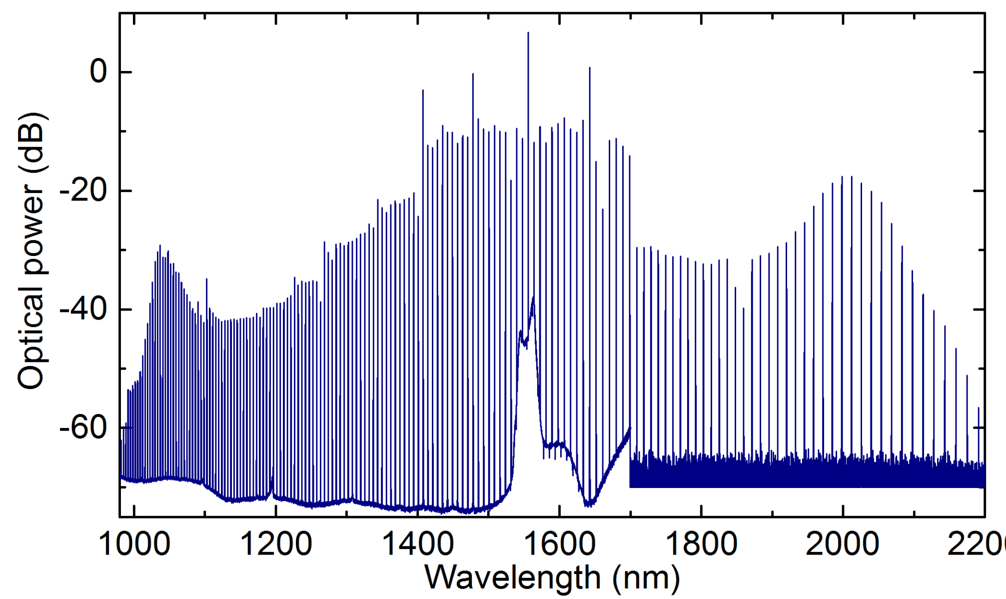


Heterogeneous integraton



Thin-film lithium-niobate on silicon

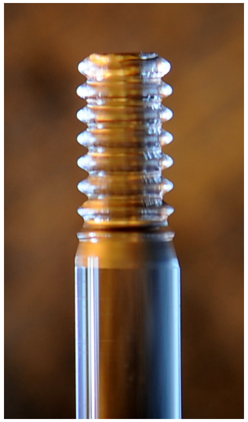


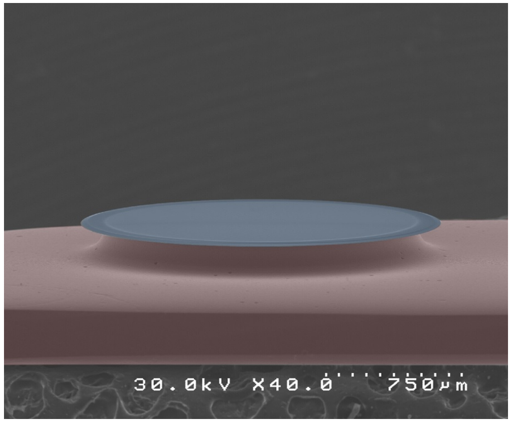


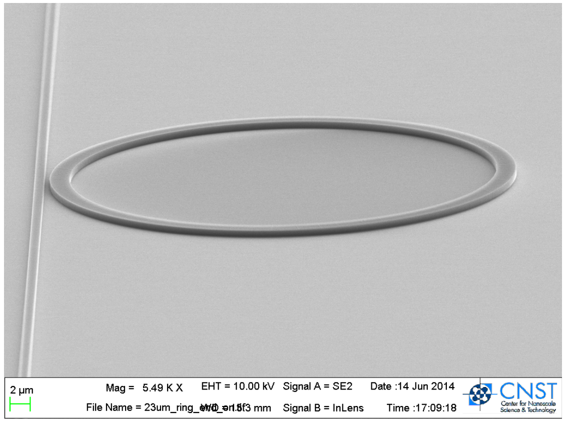
Conclusion

Chip-scale combs are an interesting new direction for experimenters.

- EOM combs are based on mature technology.
- Chip-integrated systems on the horizon.
- Basic physics of microcombs remains interesting. Will be a driver of applications in future.







Thank you!

Scott Diddams
Katja Beha
Daniel Cole
Pascal Del'Haye
Aurélien Coillet
Erin Lamb

→ EOM comb & microcomb self-referencing

William Loh
Joe Becker
Adam Green
Fred Baynes

→ <100 Hz linewidth chip-scale lasers

Travis Briles
Jordan Stone
Yi-Chen Chuang

→ High rep rate SiN combs

Collaborators
Kerry Vahala, Caltech
Kartik Srinivasan, NIST
John Bowers, UCSB