Robust and Broadband Electro-Optic Astrocombs in the Near Infrared and Visible

NIST National Institute of Standards and Technology U.S. Department of Commerce

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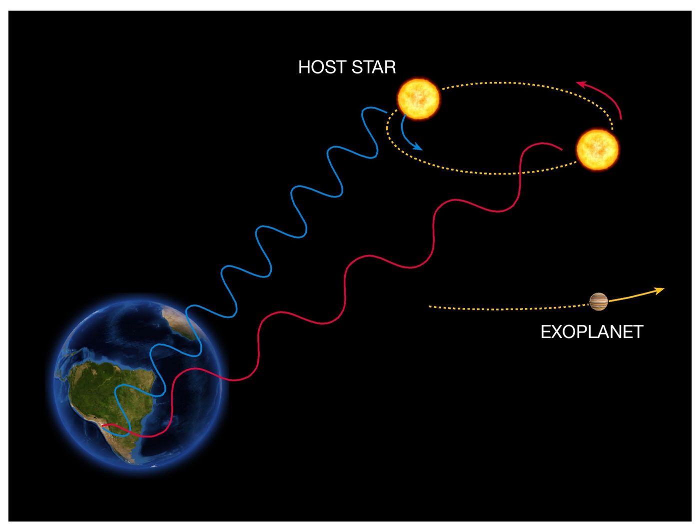
Motivation



Laser frequency combs are an ideal and necessary calibration source for detecting earth-like planets using the radial velocity (RV) method.

Desired Properties:

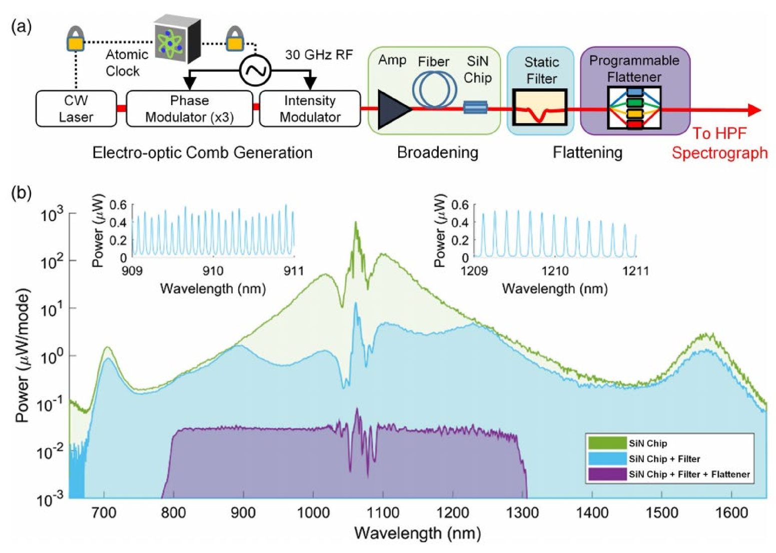
- long-term frequency stability
- mode spacing of 10 – 30 GHz
- large bandwidth > 500 nm
- uniform & stable intensity distribution
- robust and turnkey.

Outstanding Challenges:

- More simple and integrated comb
- Broadband coverage in the visible

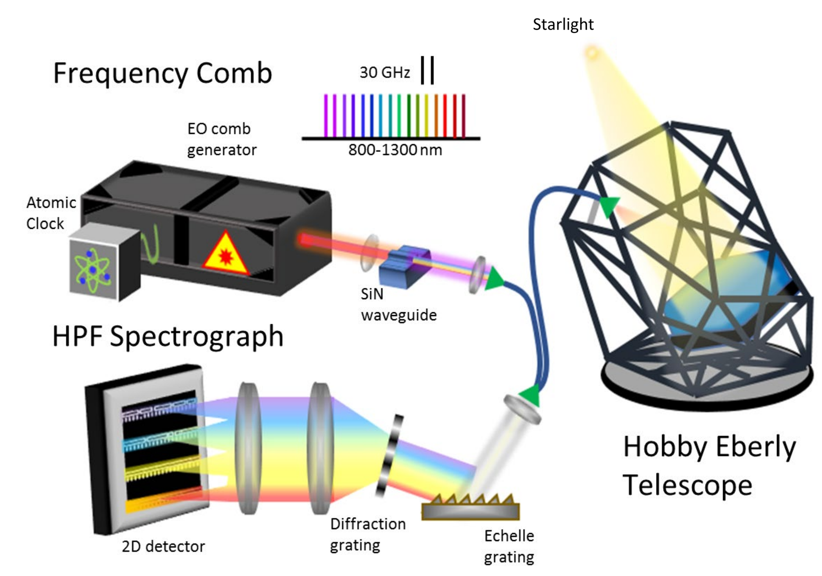
Ongoing work with a 30 GHz Astrocomb and the Habitable-zone Planet Finder

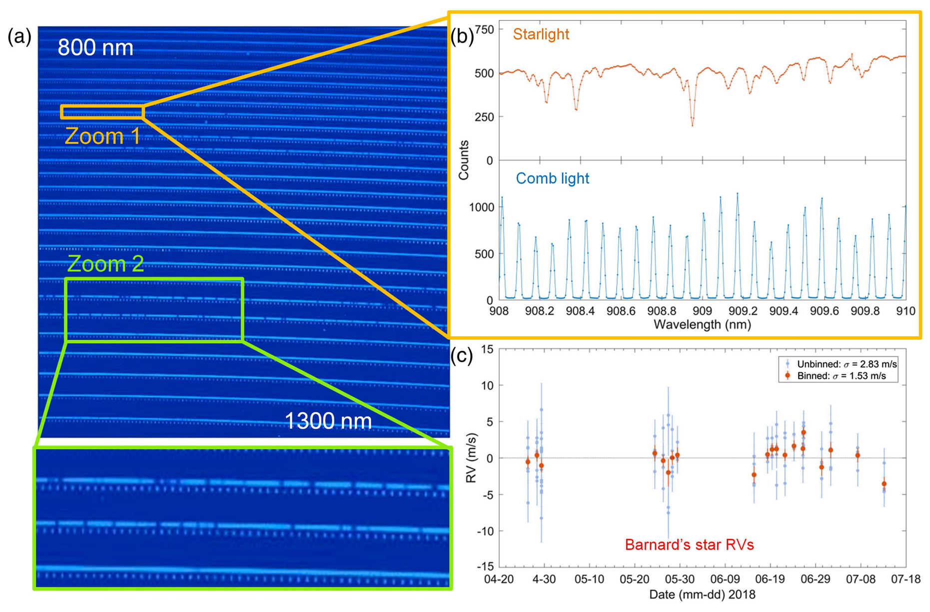
Supercontinuum spans 700-1600 nm



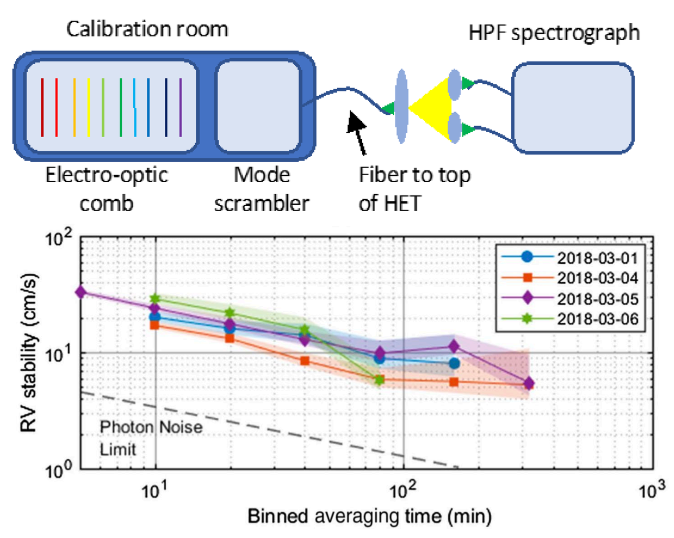
On-sky RV precision of 1.5 m/s achieved

Metcalf et al. 2019





Calibration precision < 10 cm/s



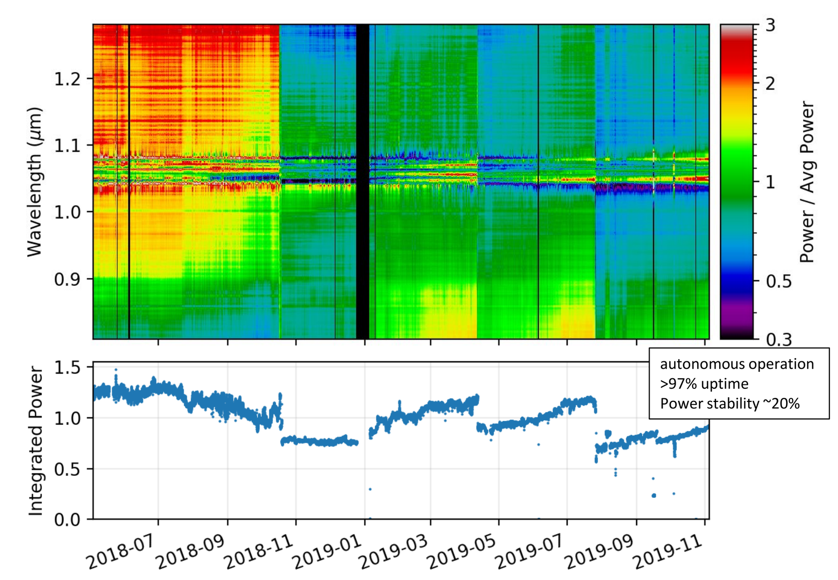
Goals:

- Characterize planets around M dwarfs
- Find targets for follow-up with JWST

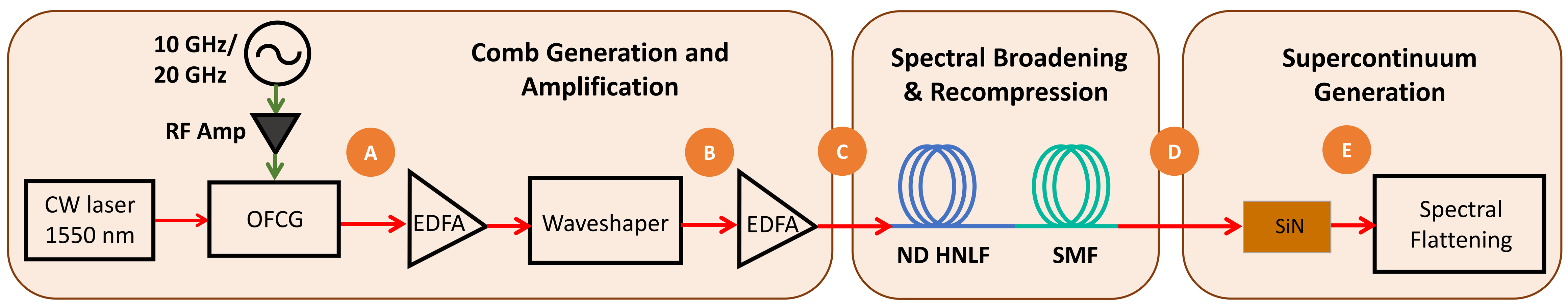
Achievements after 2+ years continuous operation:

- Sub-Neptune sized G 9-40b (Stefansson et al. 2020)
- Warm super-Neptune TOI-1728b (Kanodia et al. 2020)
- Mini-Neptune and Venus-zone planet orbiting M2-dwarf TOI-1266 (Stefansson et al. 2020)
- Reported He I 10830 Å absorption line in the exosphere of warm Neptune around GJ 3470 (Ninan et al. 2020)

Long-term reliability

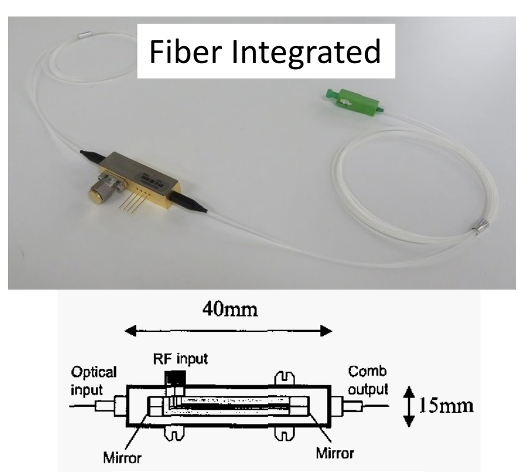


Electro-Optic Comb Generation with a Modulator in a Cavity



A Kourogi-type Electro-Optic Comb

- Simple, robust & integrated EO comb generator
- 10x lower microwave power requirement as compared to cascaded EOM approach
- Built-in cavity suppression of microwave thermal phase noise



Kourogi et al. 2005

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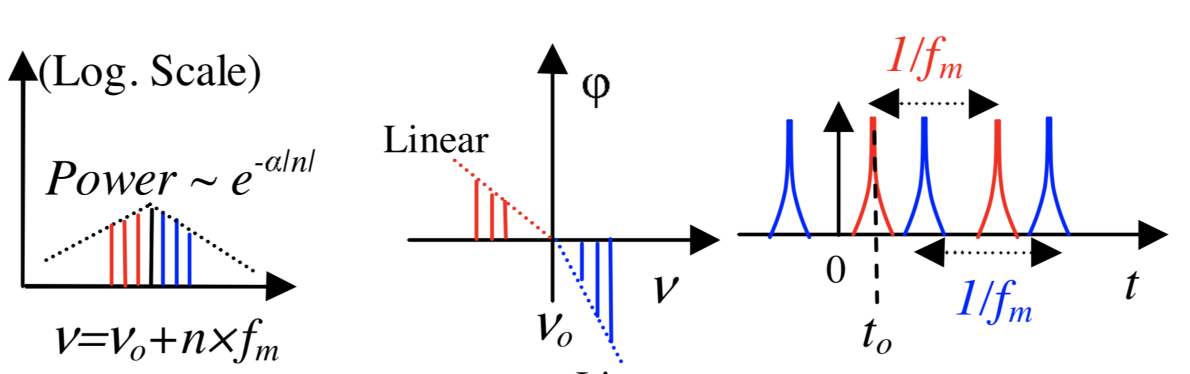
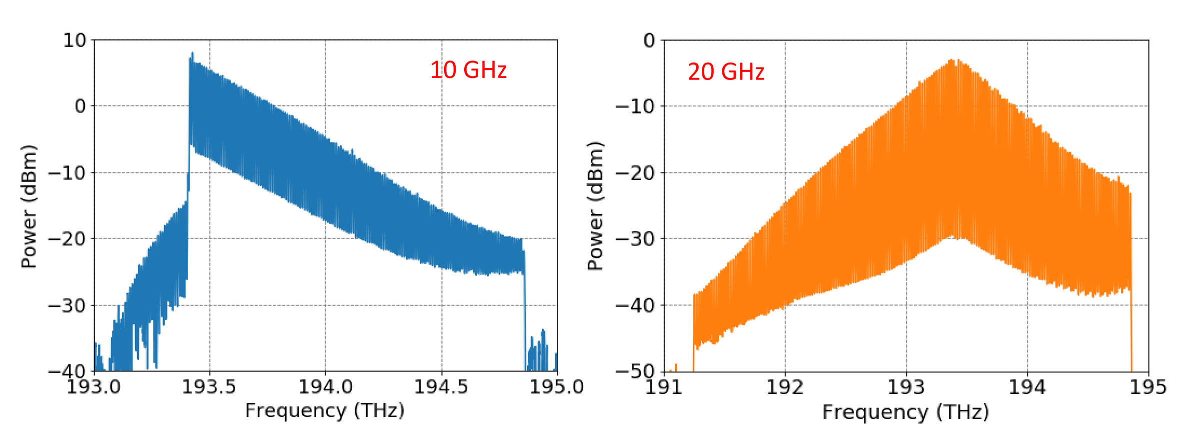
- $LiNbO_3$ waveguide phase modulator inside Fabry Perot (FP) cavity.
- Modulation frequency = n × free spectral range (FSR = 2.5 GHz)
- Two interleaved pulse trains which appear as a single pulse train with repetition rate that is twice the modulation frequency
- Large bandwidths ~ several THz as compared to the cascade of modulators



Xiao et al. (2008)

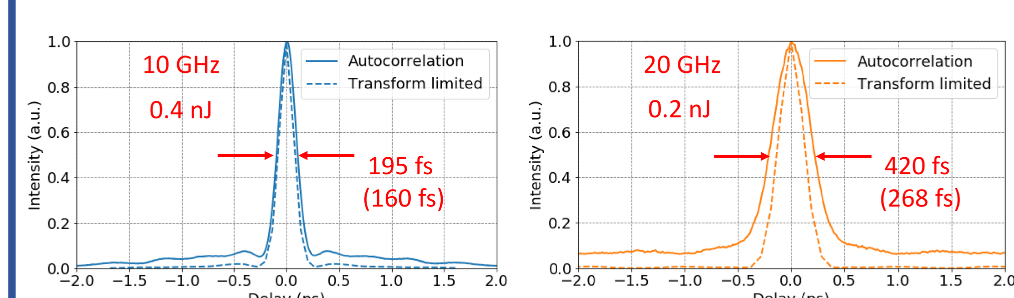
B Shaping the Spectrum

- Apply amplitude and/or phase mask using waveshaper to get pulse train with $f_r = f_m$
  - Linear phase delay applied to 20 GHz comb
  - Attenuate one half the spectrum for 10 GHz comb
- Higher order dispersion compensation



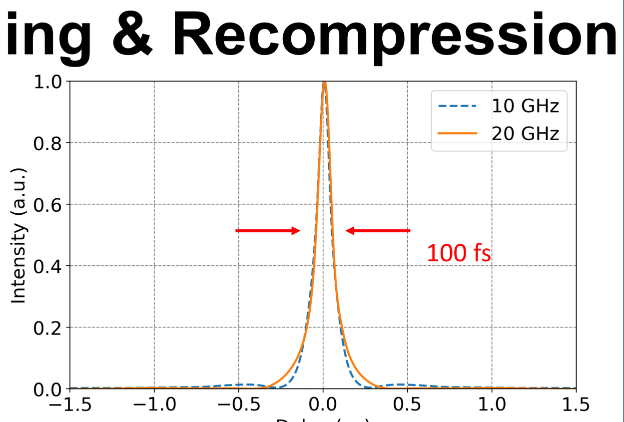
C Optical Amplification

- Amplified to 4 W



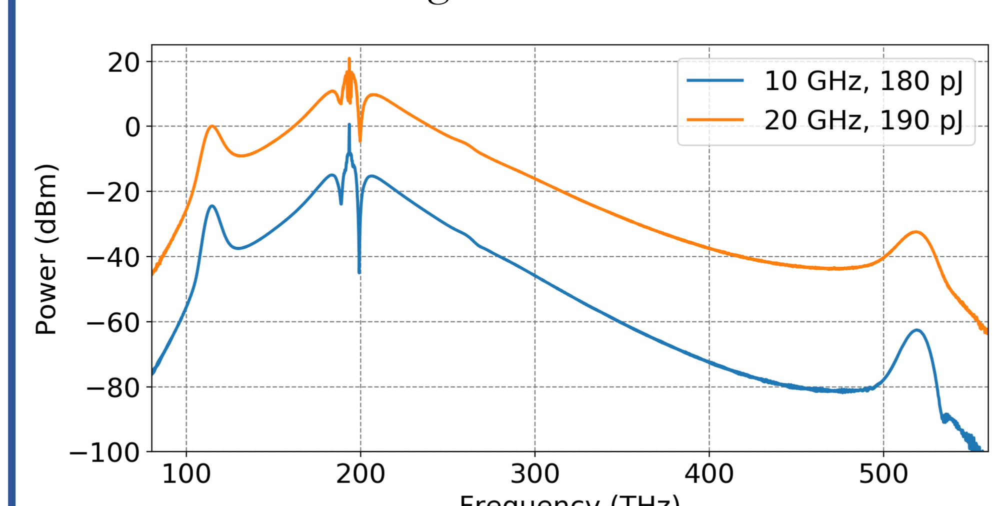
D Spectral Broadening & Recompression

- PyNLO simulations
- Normal dispersion (ND) HNLF
- Single-mode fiber (SMF)



E Supercontinuum Generation

- PyNLO simulations
- SiN waveguide : 800 nm × 1400 nm



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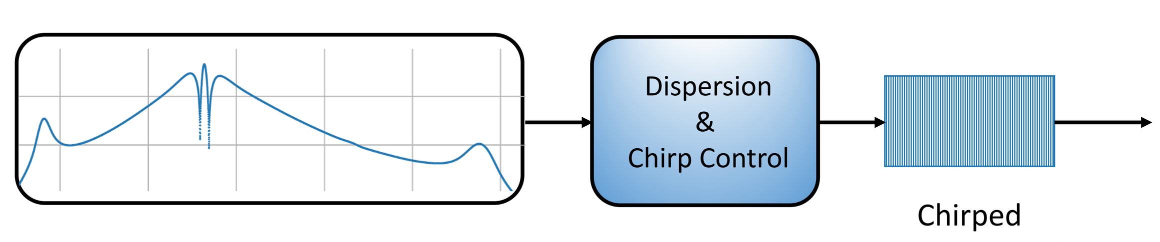
Broadband Sum-Frequency Conversion from NIR to Visible

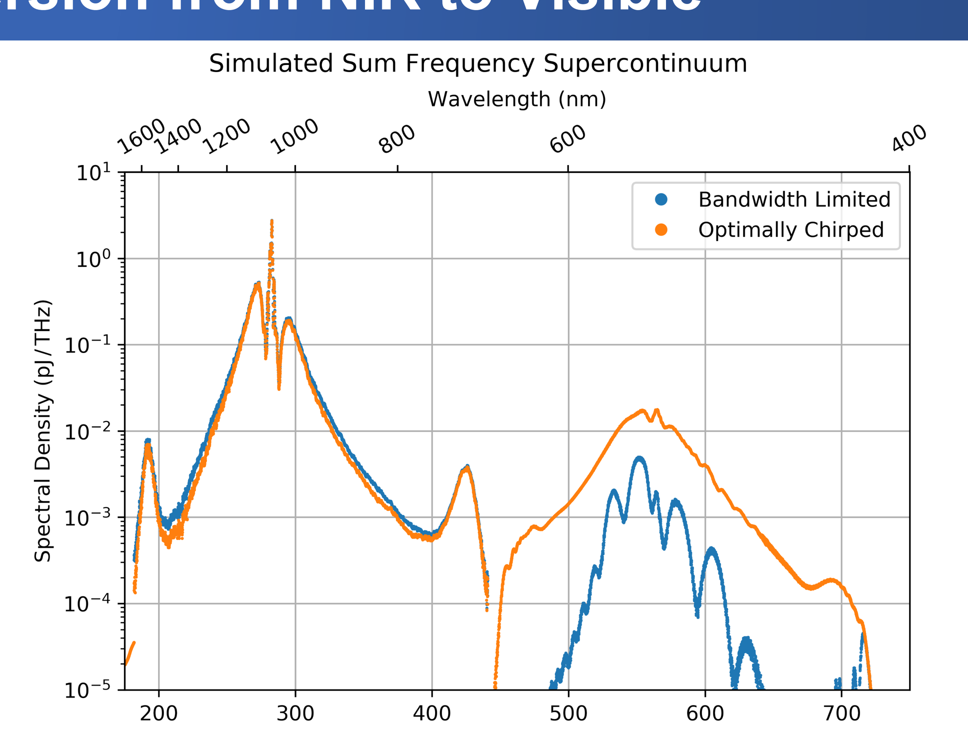
Astrocombs in the Visible

- Search for Earth-Sun analogs (e.g. with NEID)
- Study $LiNbO_3$ waveguides as alternative to silica fibers

Chirp-assisted Sum Frequency Generation (SFG)

- Optimal chirping yields efficient SFG between 1 µm and other supercontinuum wavelengths





Thanks to all the group members and HPF collaboration team.