25 W CW Raman-fiber-amplifier-based 589 nm source for laser guide star

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June 18, 2009, CJ5.1, CLEO Europe

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Background: Sodium laser guide star

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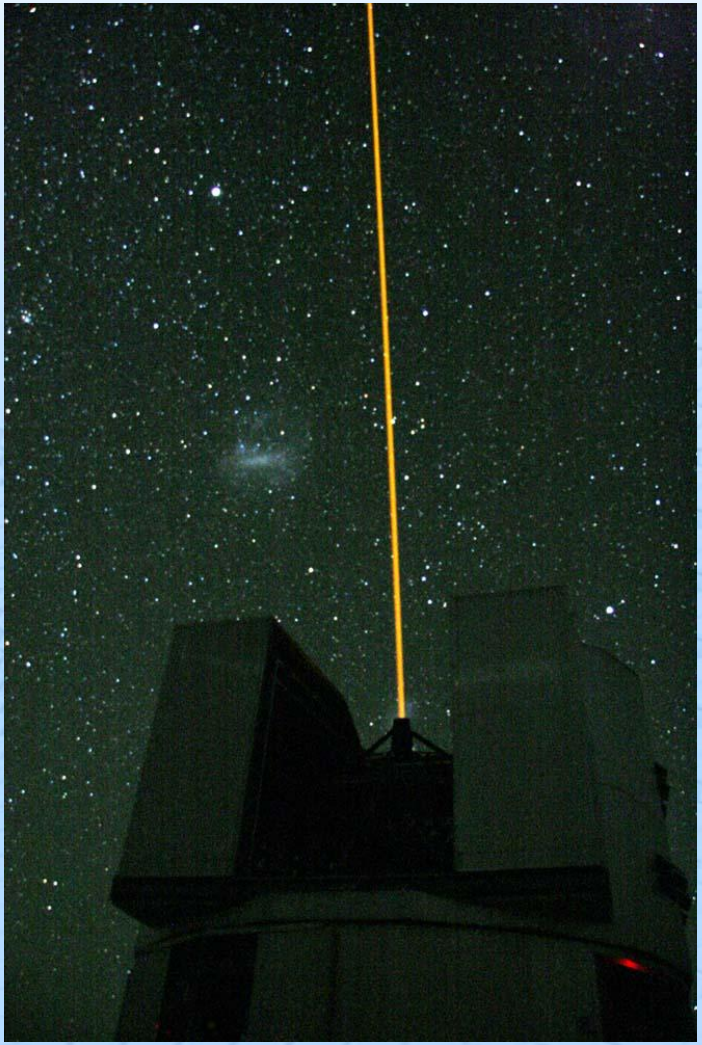
- For large astronomical telescopes, adaptive optics systems are necessary for correcting wavefront distortions by atmosphere turbulence.
- Artificial guide stars are used for improving sky coverage.
- A sodium LGS is formed by focusing a 589nm laser to the sodium layer at an altitude of 90km.
- The laser has to be
  - ✓ resonant with Sodium ion
  - ✓ narrow linewidth
  - ✓ high power
  - ✓ stable
  - ✓ excellent beam quality
  - ✓ High degree of polarization
  - ✓ reliable and turn-key operation



Candidate Laser Technologies

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- Narrow linewidth Raman fiber MOPA at 1178 nm and frequency doubling
- Sum frequency of two Nd:YAG lasers at 1064nm and 1319nm
  examples: FASORtronics LLC, Lockheed Martin Coherent Technologies
- Optically pumped semiconductor laser, or VECSEL, SDL
- Sum frequency of two fiber lasers/amplifiers at 938 nm and 1583nm (LLNL & ESO)
- Long wavelength Yb fiber laser/amplifier
- Bismuth doped fiber laser/amplifier
- Dye laser (it is the past)

Narrow linewidth Raman fiber amplifier

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- Why Raman (but not other fiber laser technologies)?
  - Long wavelength Yb fiber laser
    - Gain per length is low, suffering from amplified spontaneous emission at short wavelengths and photodarkening (there are progresses)
  - Bi-doped fiber lasers
    - Still too lossy for efficient narrow-line amplifier operation
  - Sum-frequency of a 1583 nm Er-doped fiber laser and 938 nm Nd-doped fiber laser
    - The quasi-three-level nature of 938 nm laser has limited so far its output power
  - Raman fiber amplifier
    - Gain per length is proportional to pump intensity, no physical limit
    - Well established technology from the telecomm industry
- SBS and linewidth broadening suppression in Raman fiber amplifier, an ESO proprietary technology

Experimental Setup, Optical

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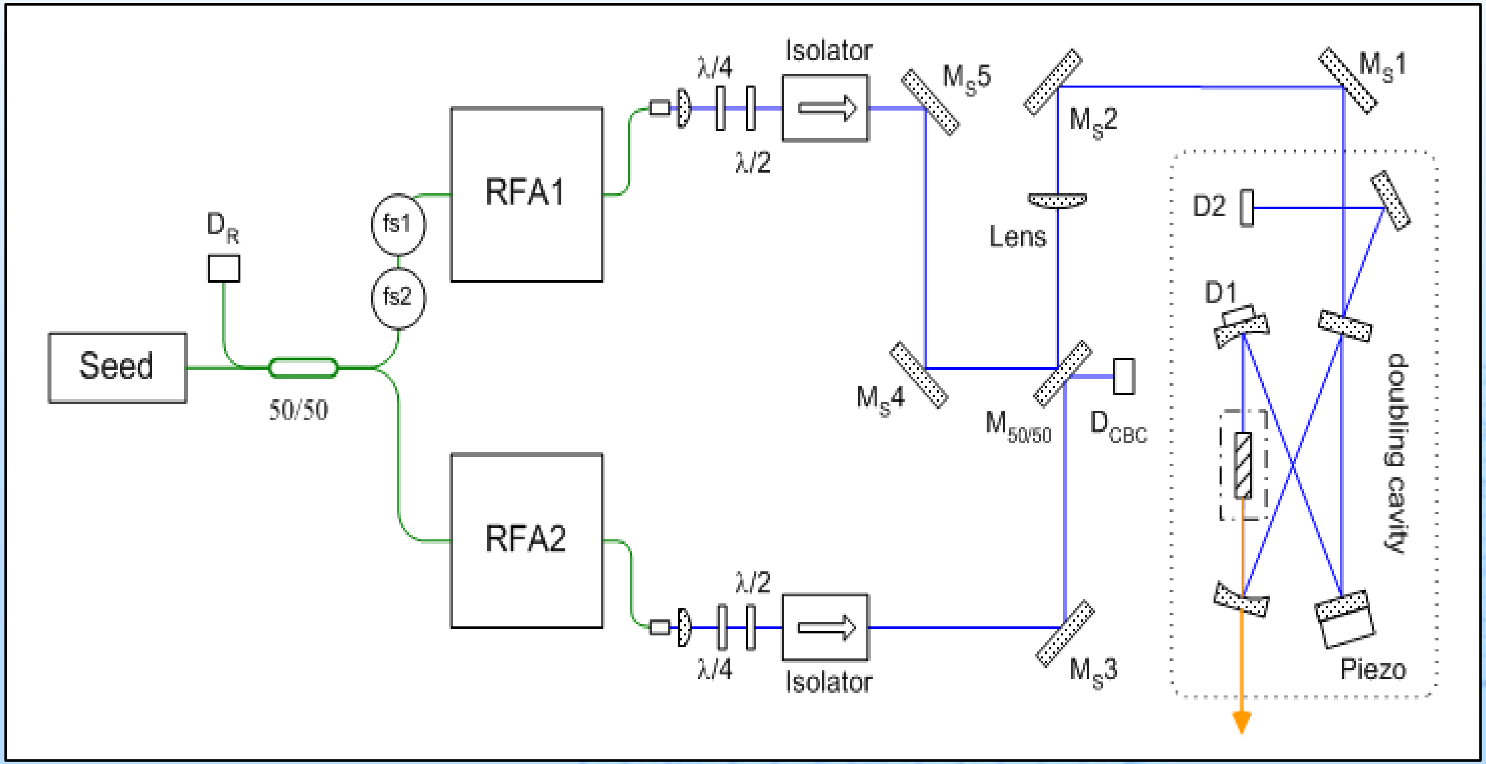

- ❑ Seed laser is split 50 by 50 with a fused fiber coupler
- ❑ Independently amplified in two Raman fiber amplifiers, non-PM fibers are used
- ❑ Polarization control with motorized λ/4 and λ/2 waveplate pair
- ❑ Recombined in free space at a 50/50 mirror
- ❑ Monitoring the dark port (D_{CBC}) and phasing one of the amplifiers with two fiber stretchers
- ❑ Frequency doubled in an external cavity with a LBO crystal

Coherent beam combination and cavity locking control system are from Toptica

Single channel results

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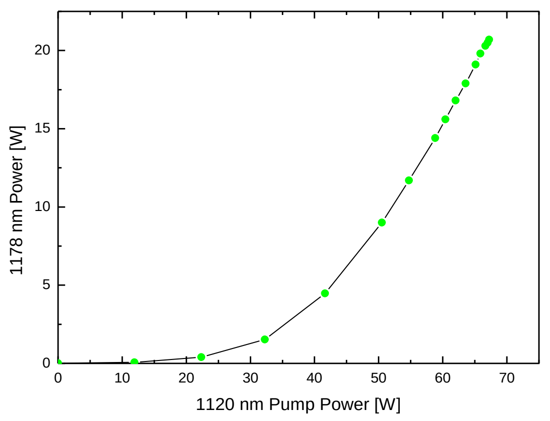
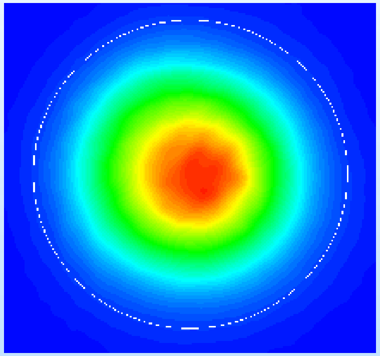
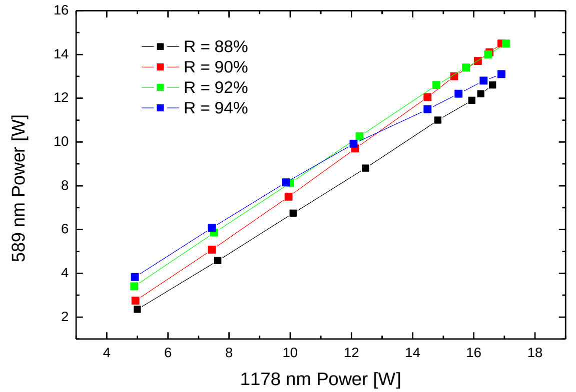


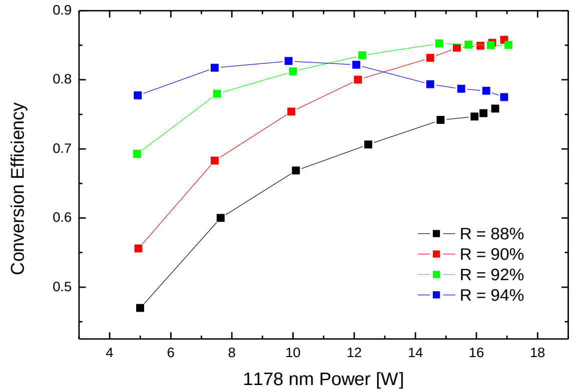
1178 nm laser power versus 1120nm power



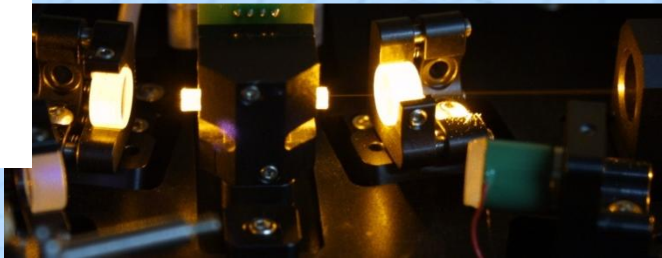
the phase-front error within the $1/e^2$ diameter < 0.018λ (11nm rms)

- ❑ 1178 nm
  20 W
  linearly polarized after λ/4 and λ/2 adjustment, PER 25dB
- ❑ 589 nm
  14 W
  diffraction limited
  86% conversion efficiency (measured after
  and before the cavity)





Y. Feng *et al*, Photonics West 2009 (postdeadline paper 7195-101)



589 nm laser power and conversion efficiency as a function 1178nm power with different in-coupling mirror

Coherent Beam Combination

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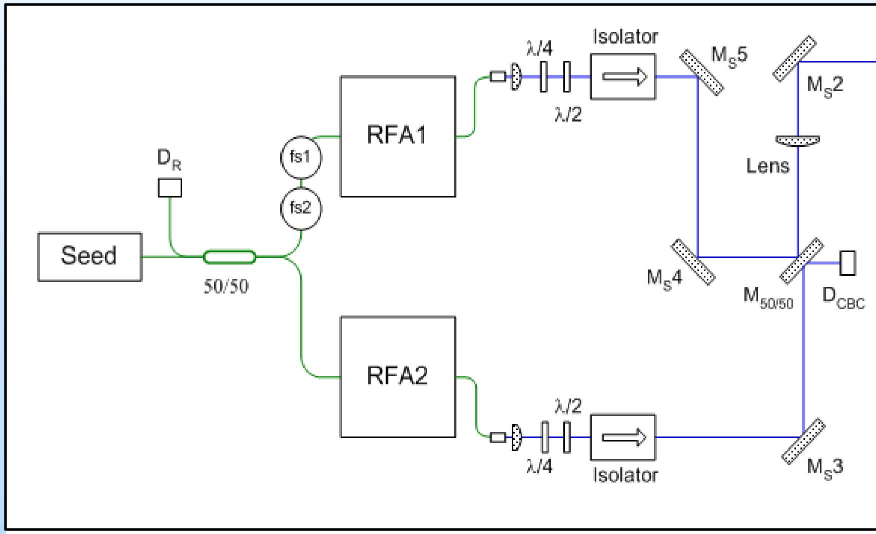
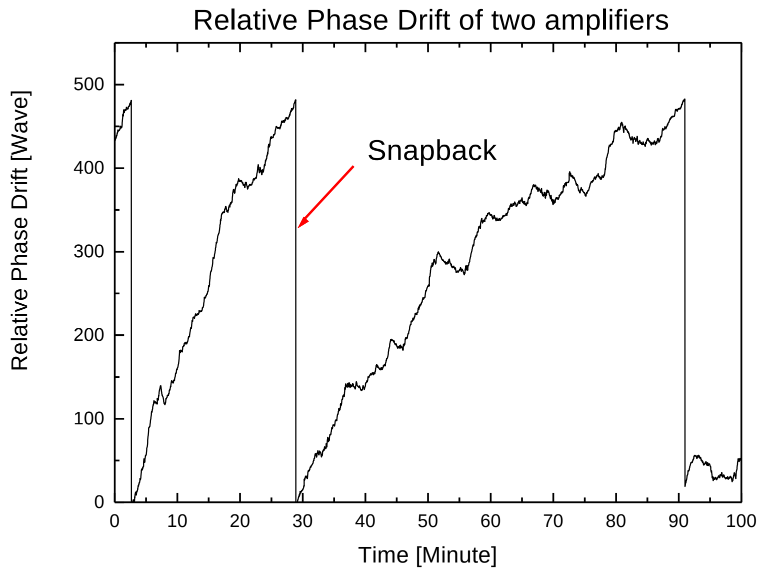
- Coherent beam combination for power scaling
- Essentially a Mach-Zehnder interferometer with amplifying arms
- free space beam combining since free space optics are used for polarization control
- Two fiber stretchers (slow and fast) for compensating phase drift.
- > 95% combining efficiency => maximum 29.5 W power before the doubling cavity





Resonantly enhanced frequency doubling

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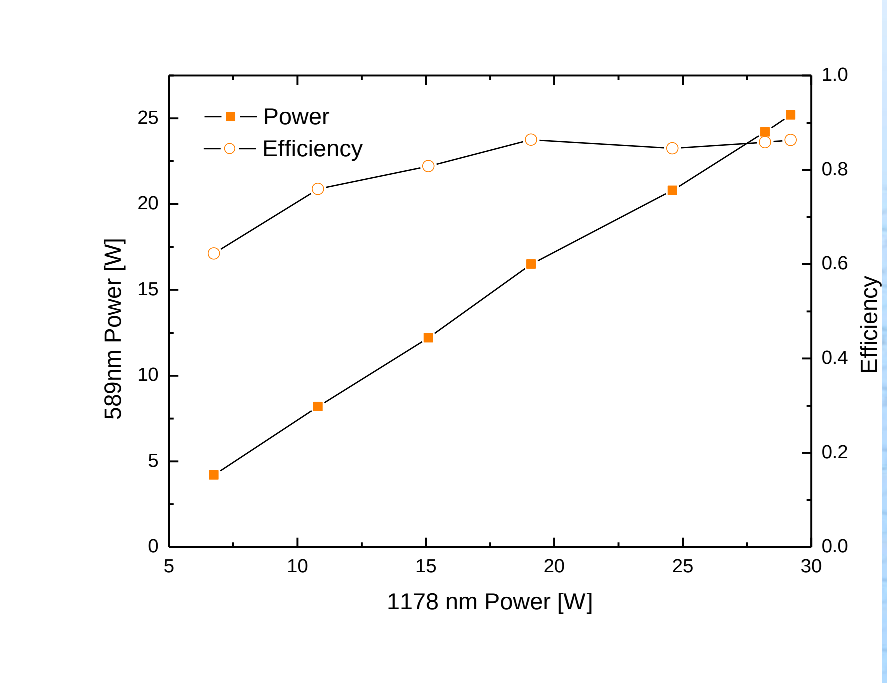
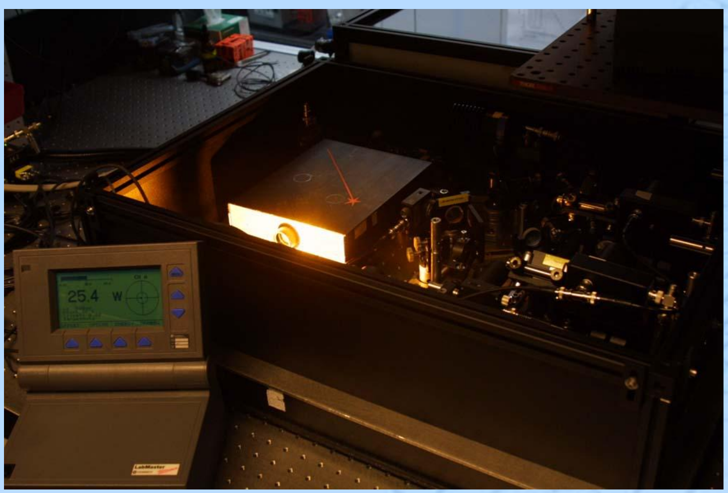
- Crystal: 30mm LBO
  Non-critically phase matched, 40°C
- Pound-Drever-Hall technique for cavity locking
- Incoupling mirror reflectivity: 90%
- 25.4 W CW 589nm laser with conversion efficiency of 86%





Spectrum

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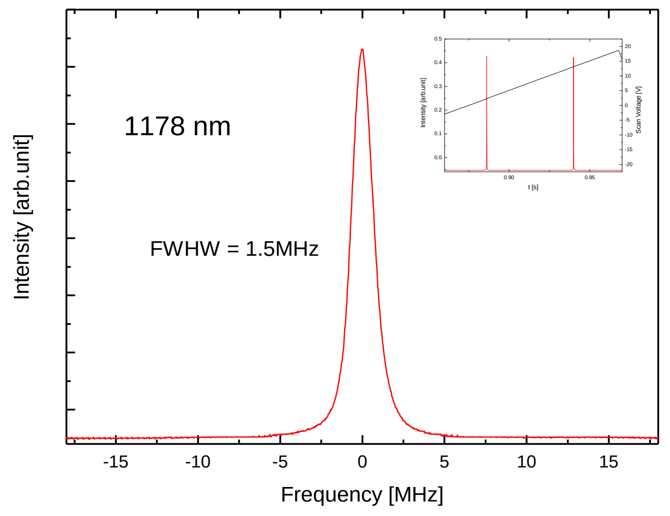

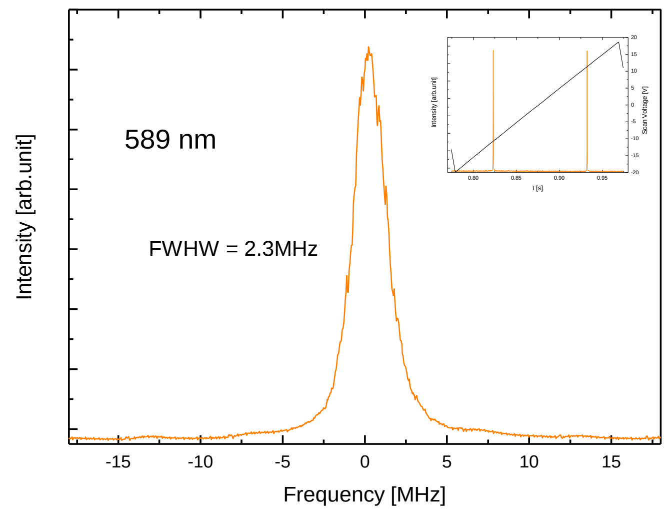

1178 nm linewidth < 1.5 MHz; 589 nm linewidth < 2.3 MHz

Device resolution limited

Seed laser: DL PRO from Toptica, typical linewidth 100 KHz

Summary and perspective

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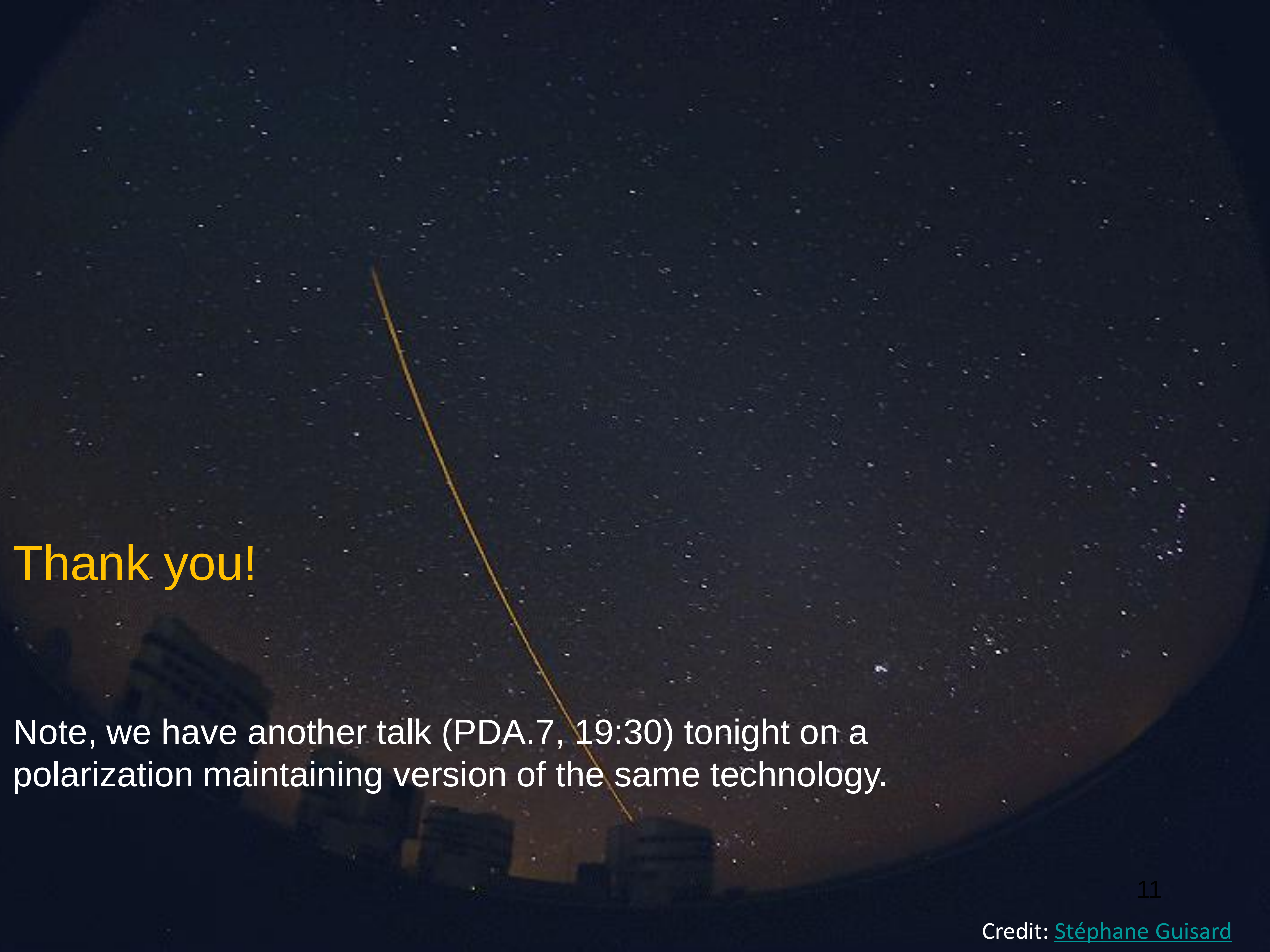
- We have demonstrated in the lab
  - Single channel narrow linewidth Raman fiber amplifier with power > 20W
  - Coherent beam combining of two Raman fiber amplifier with efficiency >95% linewidth < 1.5MHz
  - Frequency doubling in an external resonant cavity with efficiency of 86%
  - Generated 25 W continuous wave narrowband (< 2.3 MHz) 589 nm laser

- We have transferred our narrow linewidth Raman fiber amplifier technology to industry.
  - They have demonstrated similar results with a polarization maintaining and in-fiber beam combination version
  - The results will be presented tonight (PDA.7, 19:30)

- The technology can be extended to other wavelengths, since it is based on Raman fiber amplifier



Thank you!

Note, we have another talk (PDA.7, 19:30) tonight on a polarization maintaining version of the same technology.

Credit: Stéphane Guisard