Sodium Beacon VECSELs and SOR Laser Overview

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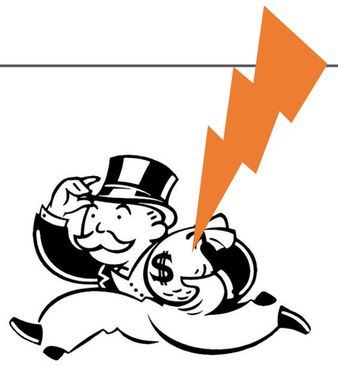
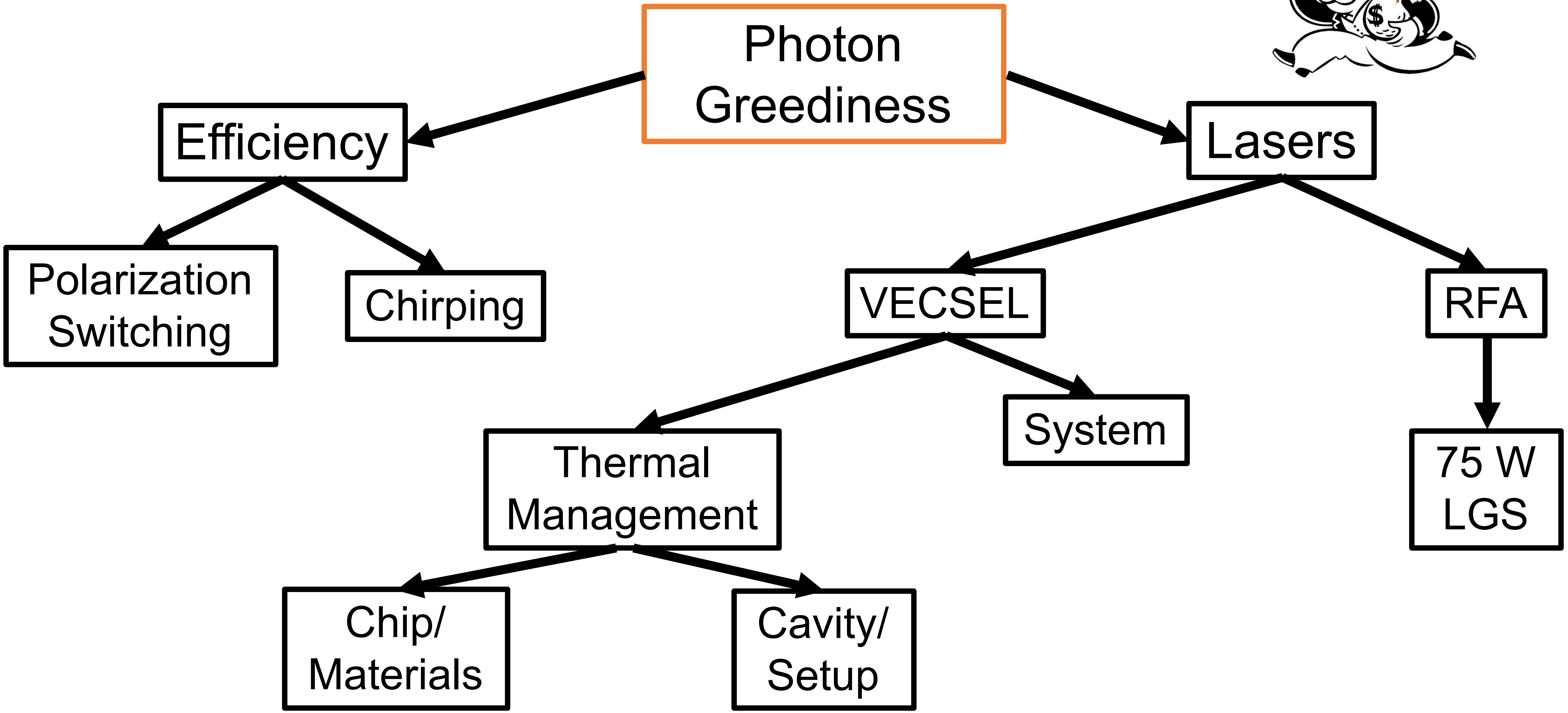
AFRL/RDSS

11 June 2019

Next Generation at SOR

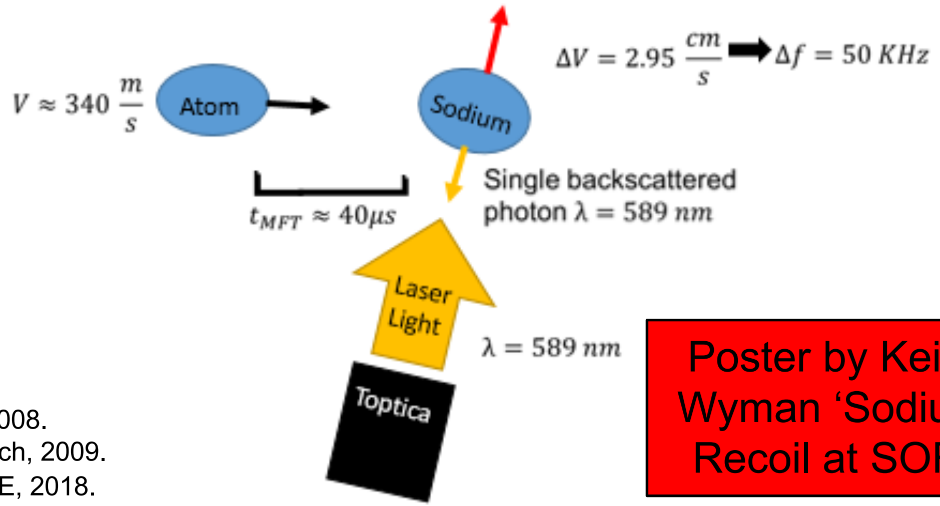




Efficiency

Chirping

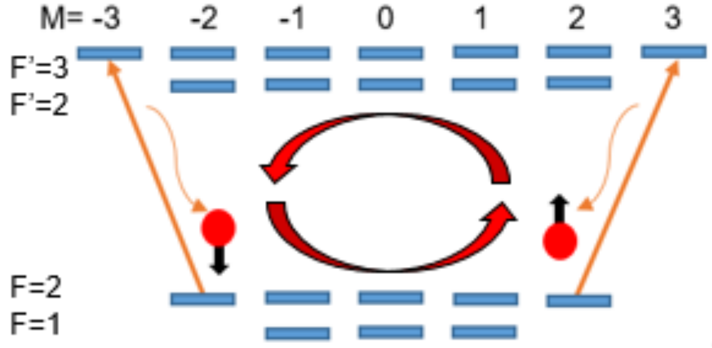
- Recoil/Radiation Pressure
- Red-shifted 50 kHz based on Doppler effect
- Stops with: Collision, spin exchange or inability of source radiation to keep up
- Rate depends on radiative lifetime and fraction of atoms in ^2P state
- Chirping over the length of a mean free time could increase photon returns



Poster by Keith Wyman 'Sodium Recoil at SOR'

Polarization Switching

- Larmor precession due to the Earth's geomagnetic field (0.48G)
- Redistributes the magnetic sub-level population
- Negates F = 2 to F = 3 transition of optical pumping if angle between the laser and the geomagnetic field is large enough
- Switch beam polarization at the Larmor frequency (~328kHz) to trap atom between two ideal repumping states



Hillman, et al, SPIE, 2008.
Kibblewhite, AMOSTech, 2009.
Wyman, K., et al, SPIE, 2018.
Hackett, Shawn, UNM Digital Repository, November 2016

Moussaoui, N., et al, Astron. Astrophys., 501, pp. 793799, 2009.
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Drummond, J., AMOS Conference Proceedings, September 2007.
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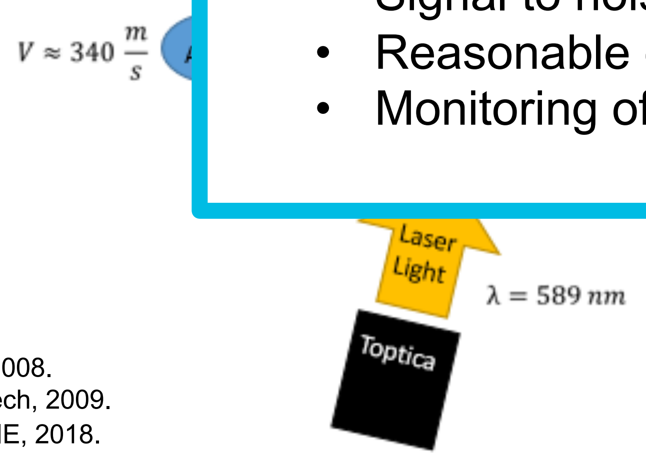

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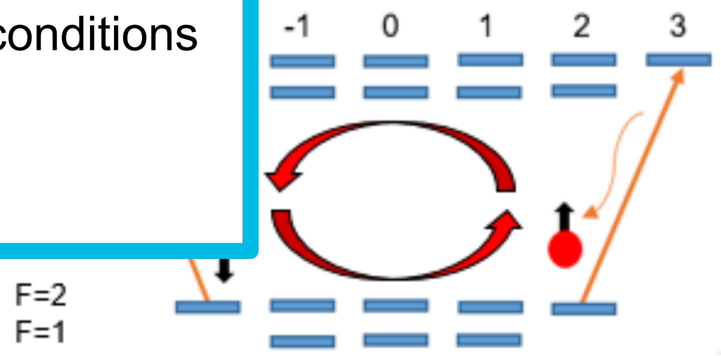

LIDAR

24-7 atmospheric monitoring

- Includes detectors, filters, data acquisition managers, optics, and pulsed 3-frequency solid state laser system
- Center wavelength 589nm
- Un-conditioned environments w/ minimal human intervention
- Signal to noise ratio greater than 5 in day and night conditions
- Reasonable cost for small observatories
- Monitoring of sodium layer height, wind, temperature

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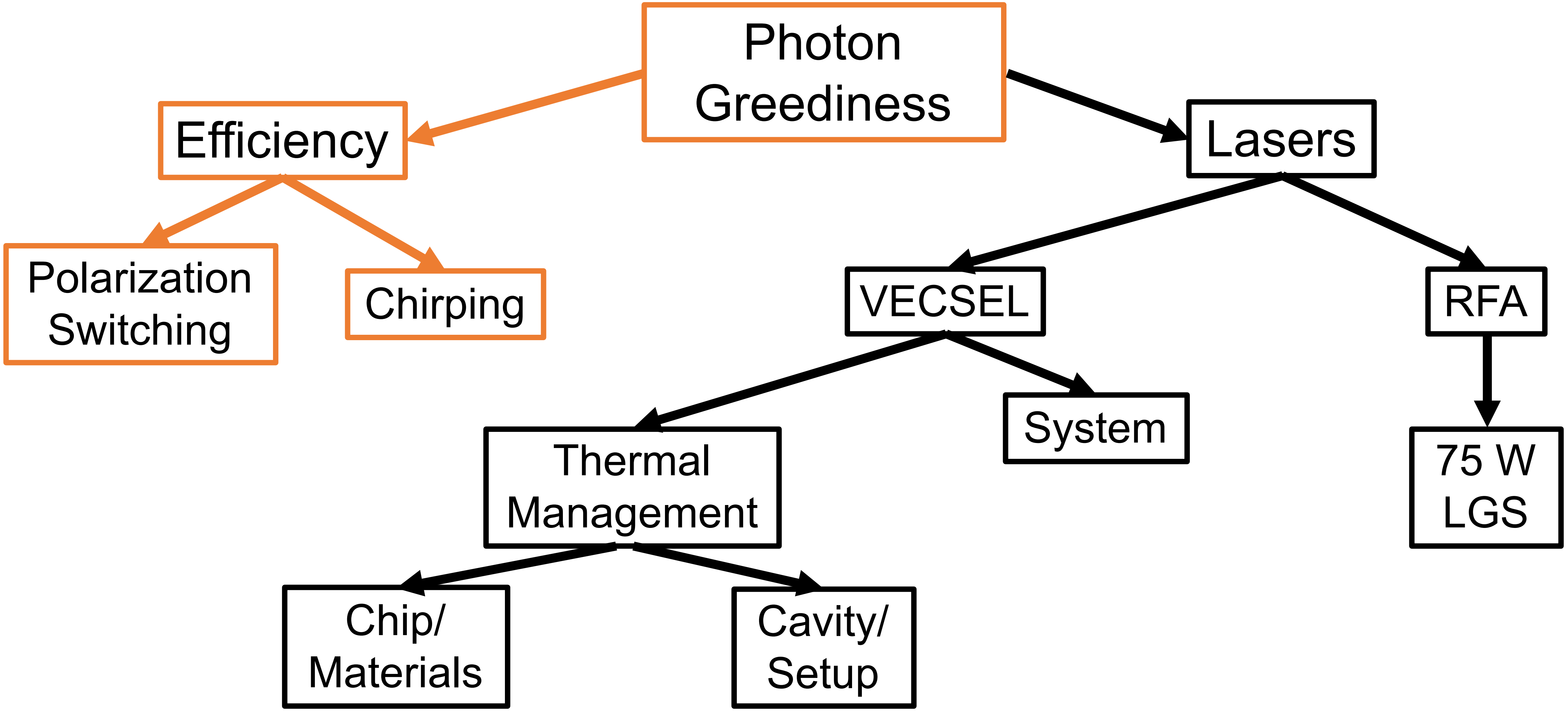
Next Generation at SOR



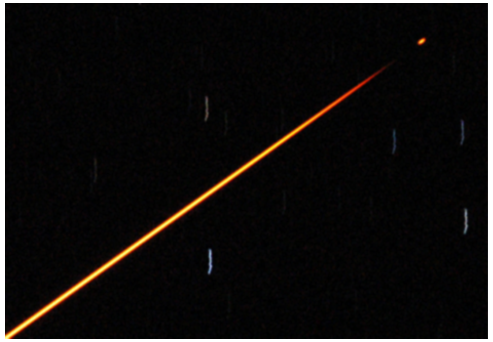
75 W Laser Beacon

Two-Phase OTA :

1. RFA risk reduction- 15 months
2. 75 W beacon prototype- 27 months

Technical goals for Phase II:

- Laser power of at least 75 W at 589.159 nm
- Re-pumper 1717.8±10 MHz away from laser line center with at least 22.5% power
- Tunable across entire D2a line
- Bandwidth 12.5 MHz FWHM or less
- Wavelength stabilized to peak of sodium line by ±10 MHz or better
- Include frequency chirping



Date closes: 21 June 2019
Located on FedBizOpps, Solicitation Number: FA9451-19-9-0001

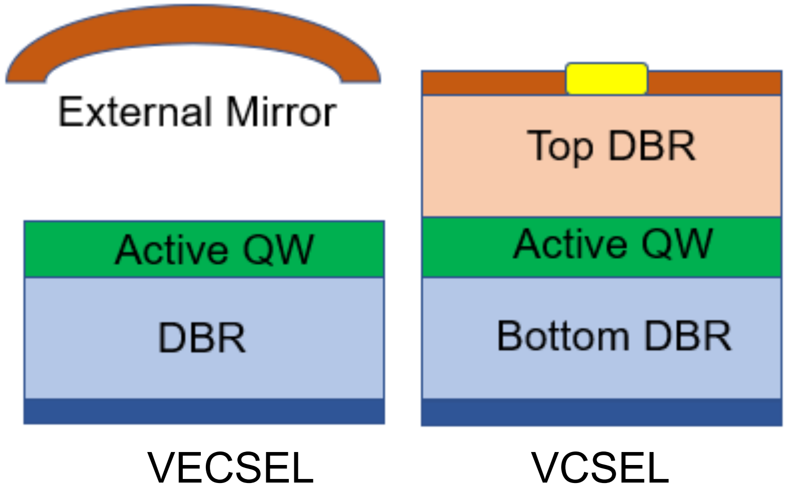
VECSEL effort overview

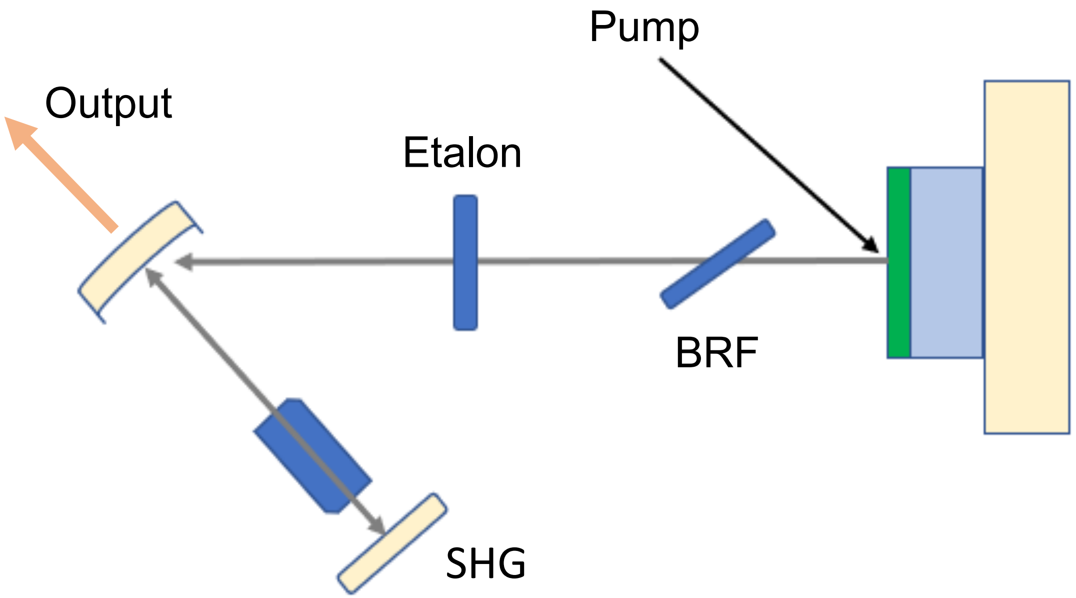
VECSEL, OPSL, SDL, etc
- different from VCSEL
- diffraction-limited beam and higher optical powers

Benefits of VECSELs
- low cost
- low complexity and compact
- reliable, little maintenance

Potential use as next-generation beacon
- beam combination, multiple beacons, or small observatories
- dedicated repumper

Difficulties with VECSELs
- difficult to get high power and single-frequency
- thermal management issues





VECSEL effort overview

STTR Overview

Current Phase II of a Small Business Technology Transfer (STTR) program to develop Vertical External-Cavity Surface-Emitting Laser (VECSEL) technology

- The STTR program helps provide financial assistance to pursue technologies in support of DoD missions
- Encourages collaboration between industry and research institution

This STTR

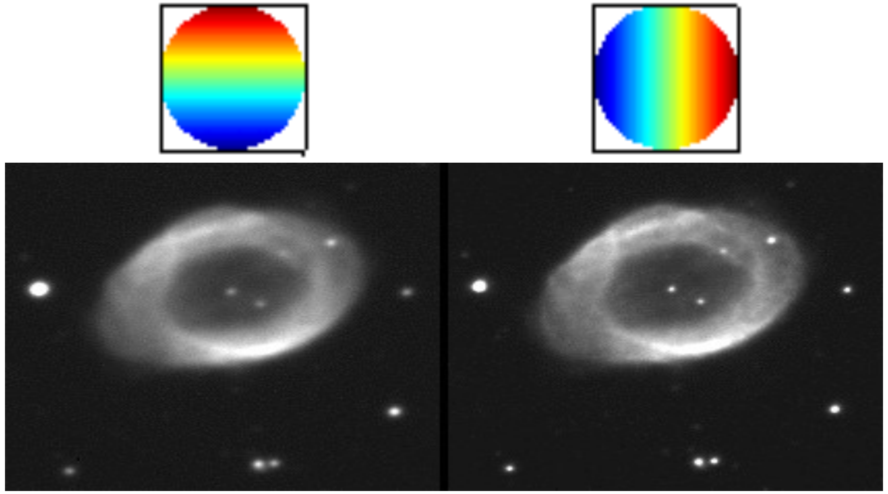
For a polychromatic VECSEL at 589nm and 1140nm

- Phase I: Develop plan for <1GHz, 6GHz tunable, >10W VECSELs at 1140 and 589nm
- Phase II: Develop lab demonstration with λ stability, system robustness, and proof of concept implementation on-sky
- Phase III: Deliver working prototype capable of attaching to telescope for use at 1140 and 589nm

5 or 6 months into the effort

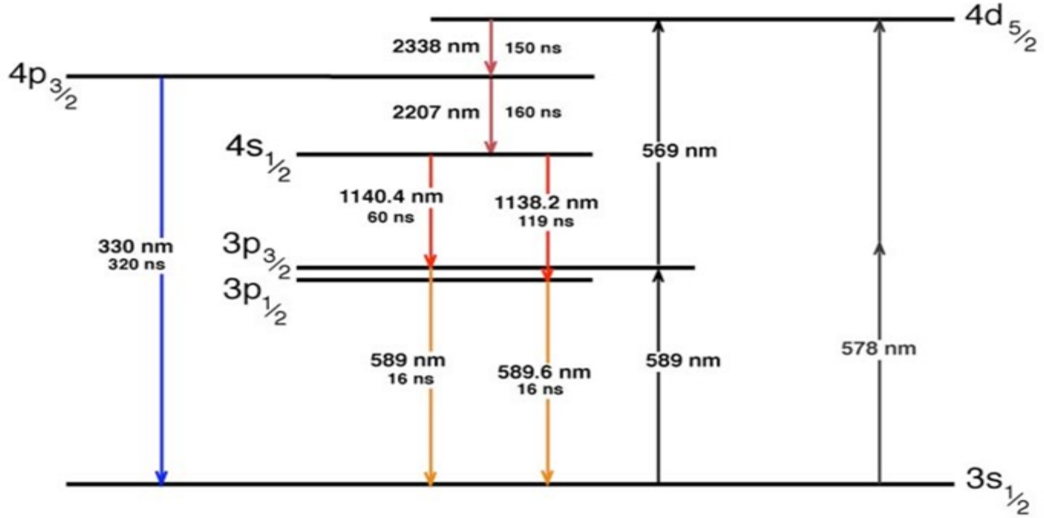
Polychromatic laser guide stars

- Tip-tilt aberration, cannot be corrected by monochromatic sources, same optical path
- Typically due to atmospheric refraction, causes image smearing for most relevant objects (planets, satellites, etc)
- Usually a separate two-axes, tip-tilt mirror looking at a NGS
- Polychromatic guide star can be used (overlapping, different optical path)
  - 1140 nm is chosen because atmospheric transmission, difference in index of refraction, source availability, limits Rayleigh
  - need >10W in both wavelengths



Imagery of the Ring Nebula taken with and without tip-tilt AO correction
S.B.I.G. Adaptive Optics System Introduction; September 1997

Pumps the sodium $3P_{3/2}$ to $4S_{1/2}$ transition



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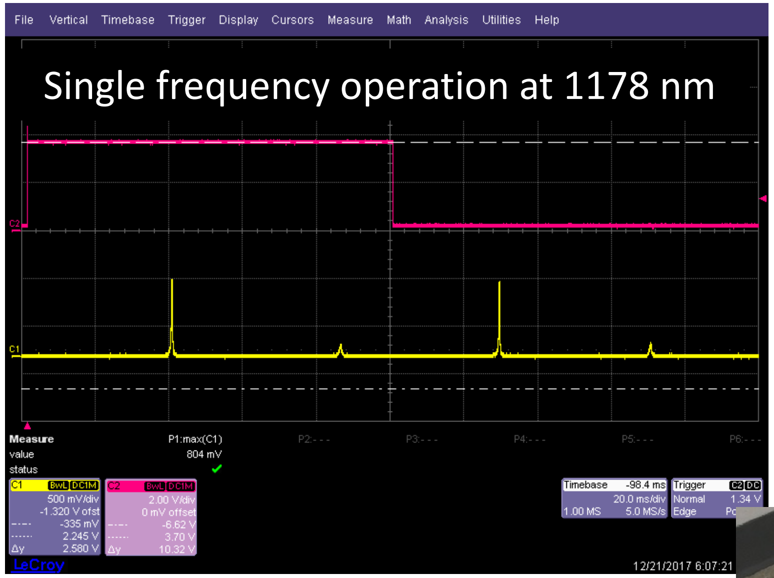
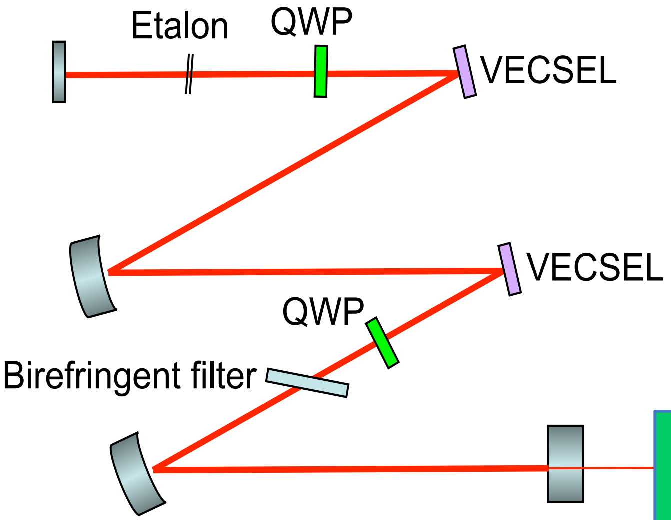
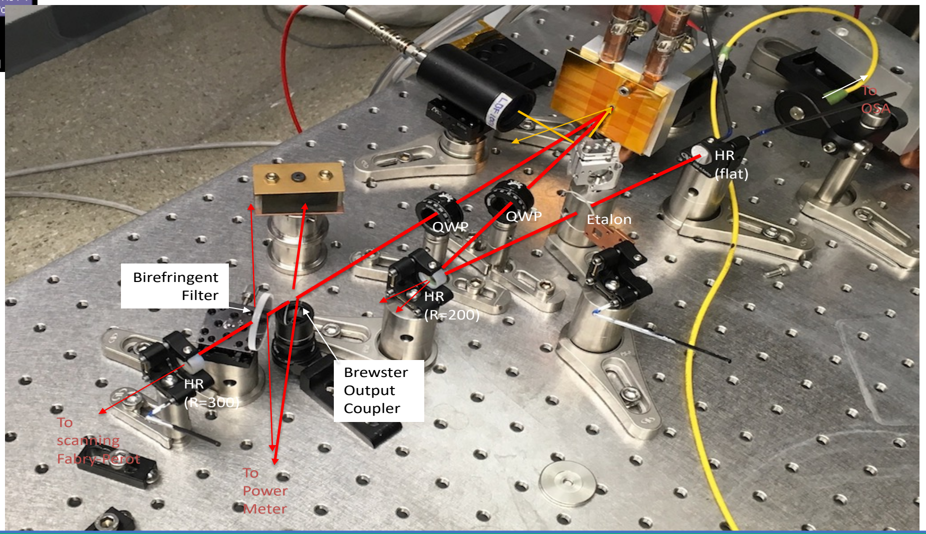
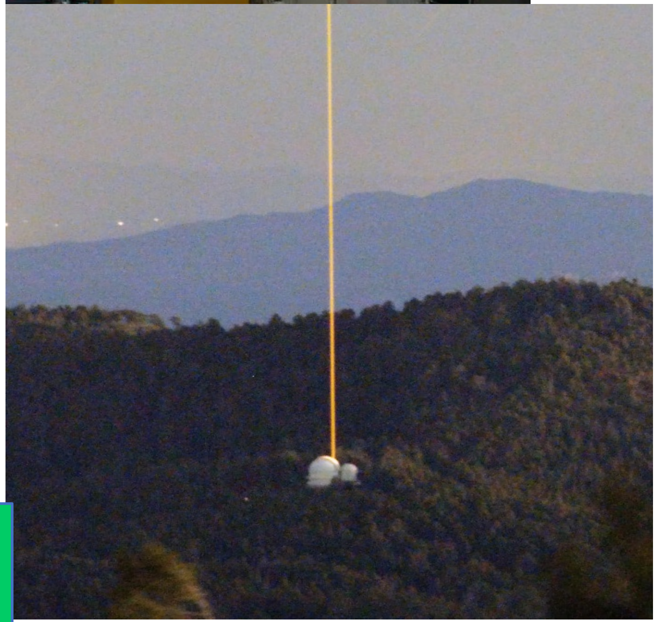
Single-frequency VECSEL



- **The HartSCI/UA approach uses a "twisted mode" cavity – orthogonal circular polarizations in forward and reverse directions.**
- **Enforces single-line frequency stability with multiple VECSEL devices in the cavity for longitudinal power scaling.**
- **Currently running at 1178 nm; will use SHG to get to 589 nm.**
- **Phase II will see a 4-VECSEL laser with SHG fielded at UA's 1.5 m Kuiper telescope.**



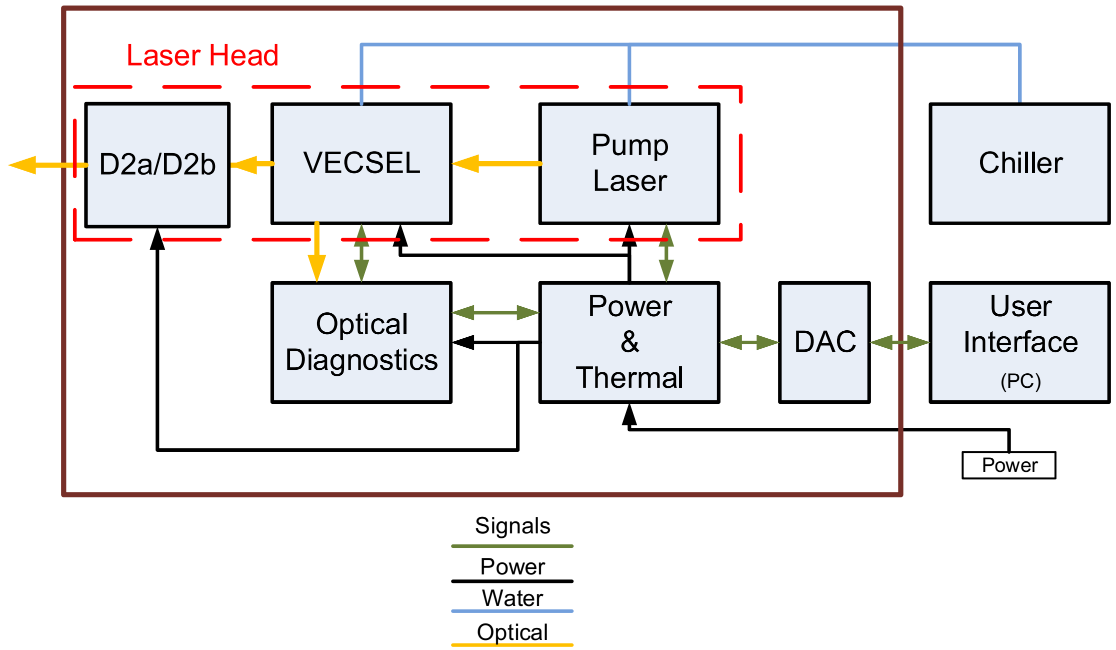




Achieved > 10 W single frequency with 2-VECSEL laser at 1178 nm

Areté's VECSEL GSL System

Guide Star Laser System



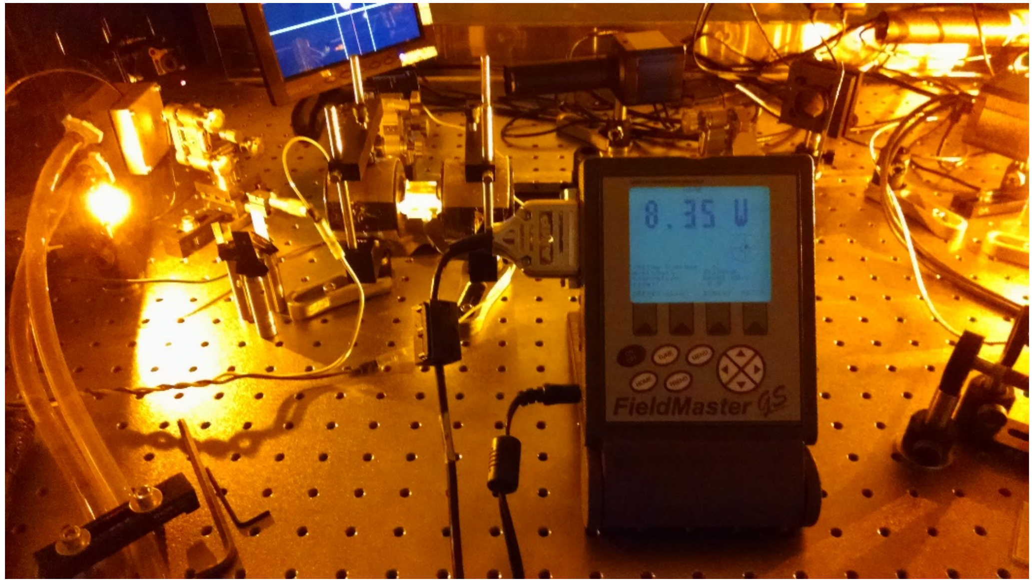
Goal: Design a system that:

- Demonstrates the viability of VECSELs for Guidestar applications
- Serves as a foundational prototype on which to build future units
    - Lowers acquisition and maintenance costs of GSLs
- Provides utility to astronomy, space situational awareness, communications, and other applications

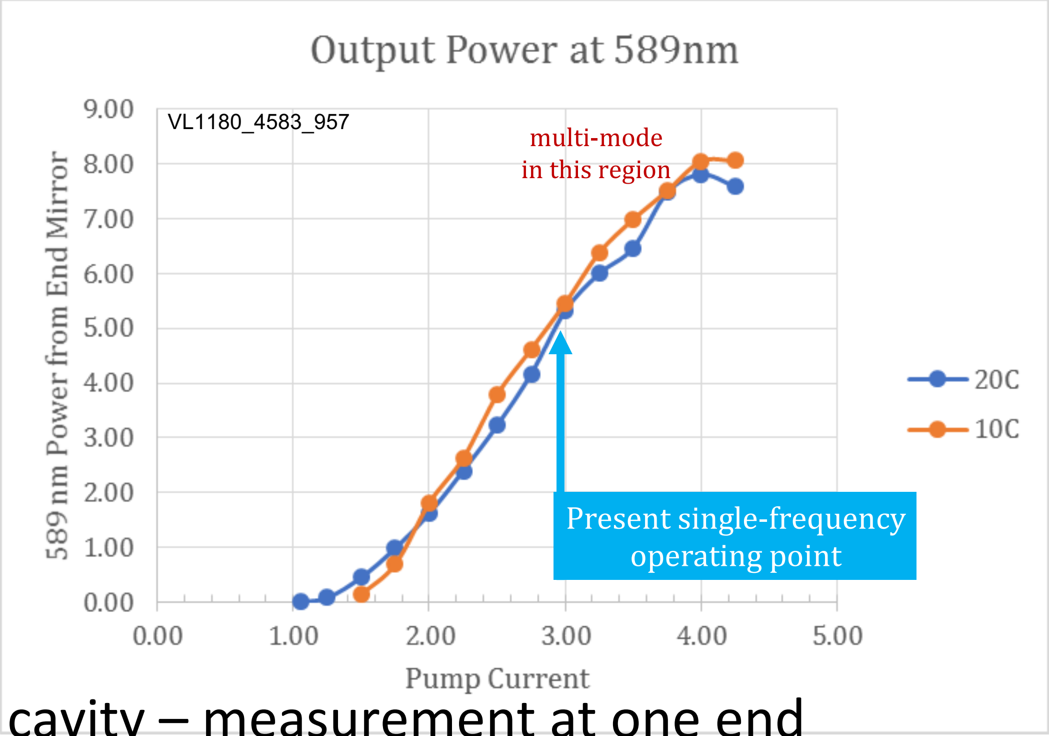
Characteristic	Values and Rationale
Primary λ and Power	8-20 W locked to Na(D_{2a}) ~589 nm
Secondary λ and Power	Tunable and lockable at D_{2b} $\Delta\lambda$= 1.7 GHz from D_{2a}
Waveform	Continuous Wave
Linewidth	5-50 MHz
Fine Tuning	~1 GHz, continuous *Scan sodium transition to enable line locking*
Gross Tuning	~5 GHz, does not need to be continuous *Allow capture of Rayleigh backscatter*
Beam Quality	$M^2 < 1.2$ *Near Diffraction Limited*
Polarization	Well defined polarization, contrast ratio >20 *Circular polarization is broadcast*
User Interface	PC Based GUI
Diagnostics	Wavelength and power
Power	110-240 V AC
Water	4-8 slpm flow of *cool* water

Laser Performance

Power from End Mirror Only

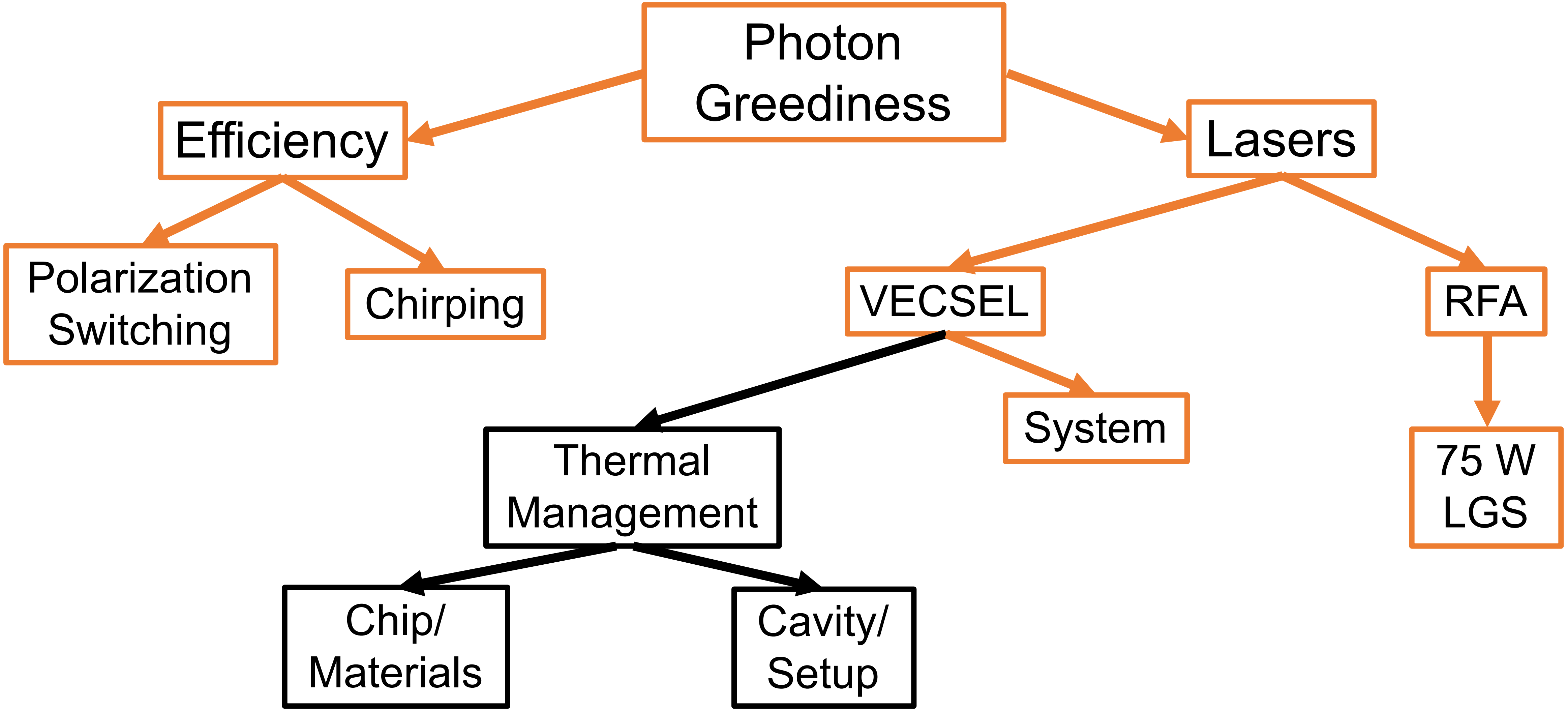


12W Multi-Mode Power at 589 nm

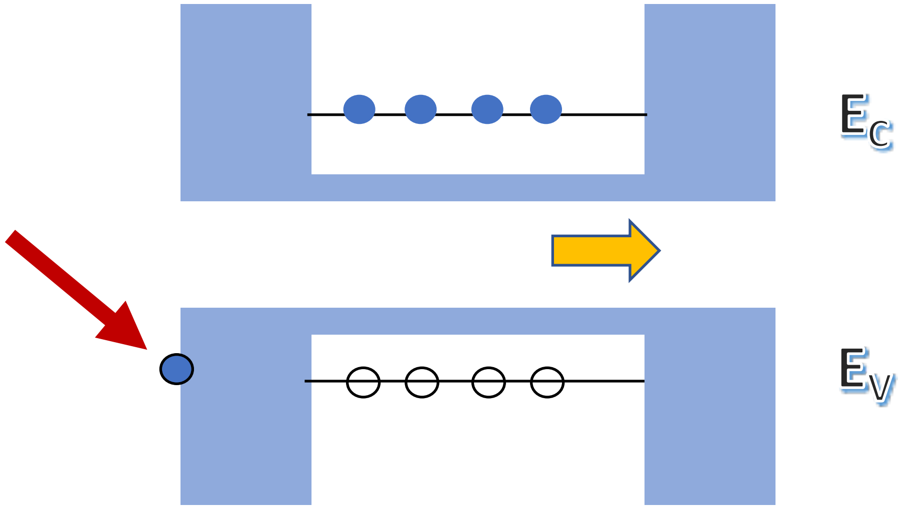


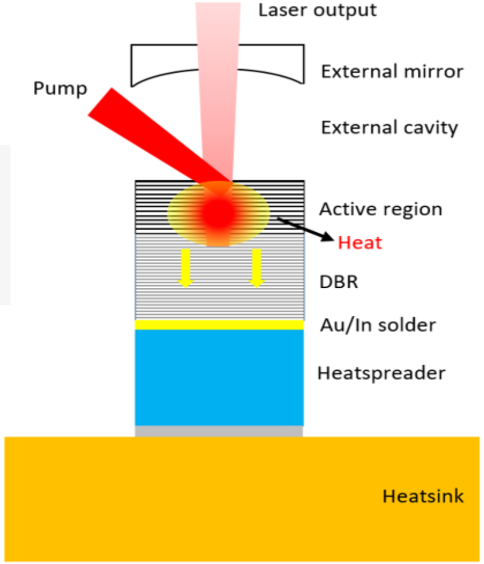
- Power emitted from two mirrors in the cavity – measurement at one end
- Higher single frequency is possible
  - Improved mode selectivity
  - Improved thermal management
  - Optimization of nonlinear crystal parameters

Next Generation at SOR



VECSEL technical overview





- Pump photons are absorbed causing generation of free electrons and holes in the quantum well barrier. Carriers diffuse to QW and recombine for photon emission.
- QW designed so discrete energy levels emit photons at wavelengths of interest
  - Bandgap energy of lasing materials
- Multiple Quantum Well (MQW)
- Amplification in gain region, usually using DBR
  - DBR-free adds additional external mirrors
  - Removes low thermal conductivity DBR
- Highly strained quantum well structures
  - Increase Indium, Increase Wavelength
  - InGaAs, large lattice constant mismatch, degradation
  - Addition of Phosphorus or Nitrogen

Fallahi, M., et at, IEEE Photonics Technol. Lett., 20, no. 20, 2008.
Kantola, E., et al, Optical Express, Vol 22. Issue 6, 6372-6380, March 2014.
Hackett, Shawn, UNM Digital Repository, November 2016

Heat

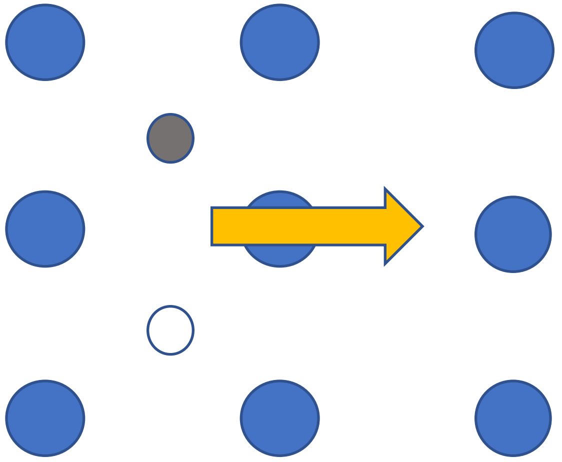
Non-radiative recombination, growth defect, quantum defect

1. Non-radiative recombination: form of recombination in which a phonon is released

2. Growth defects: issues in epitaxial growth; MOCVD or MBE

3. Quantum defect: difference in the energy per photon between pump photons and emitted laser photons

4. Inefficient heat dissipation: DBR low thermal conductivity, soldering, SiC or diamond heatspreader



DIAMOND
- Surface quality
- Expensive for optical grade

SiC
- Lower thermal conductivity

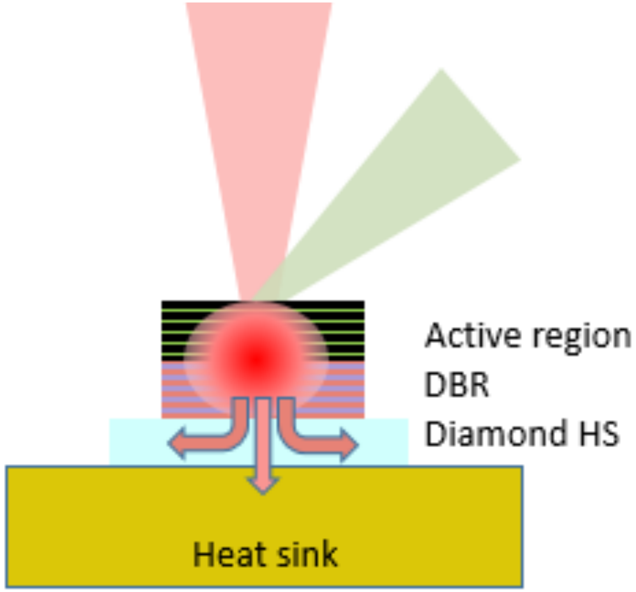
To chill or not to chill?

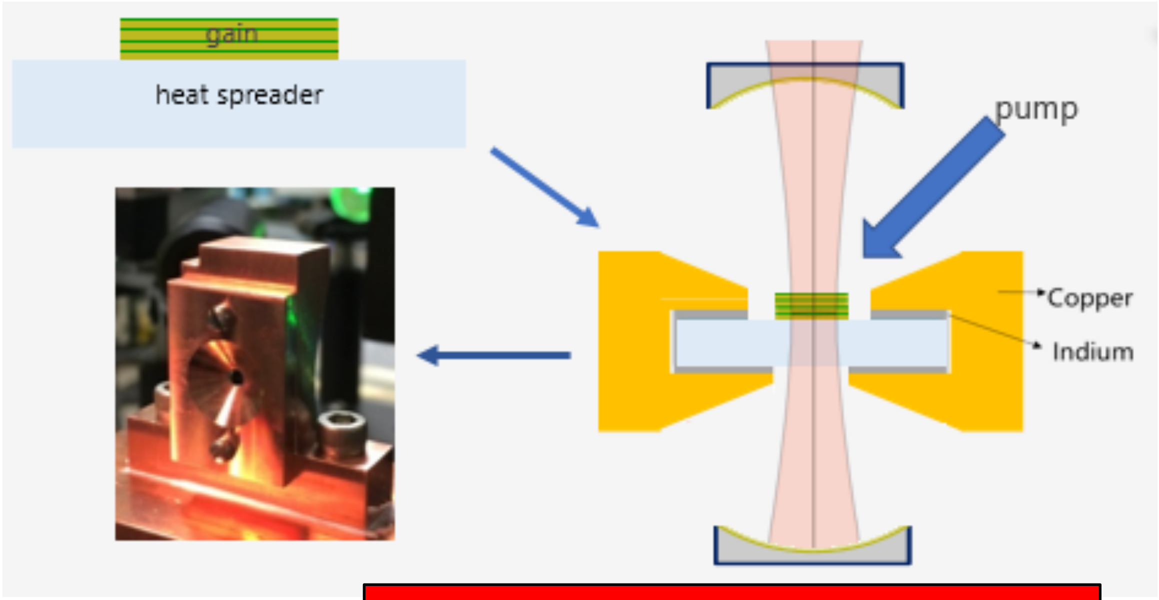
CONDENSATION

Crystalline Mirror Solutions & University of New Mexico

Elimination of the DBR in the VECSEL architecture

- Addition of a direct-bonded intracavity transparent heatspreader to MQW active region
- Comparing thermal conductivity and surface quality of diamond and SiC





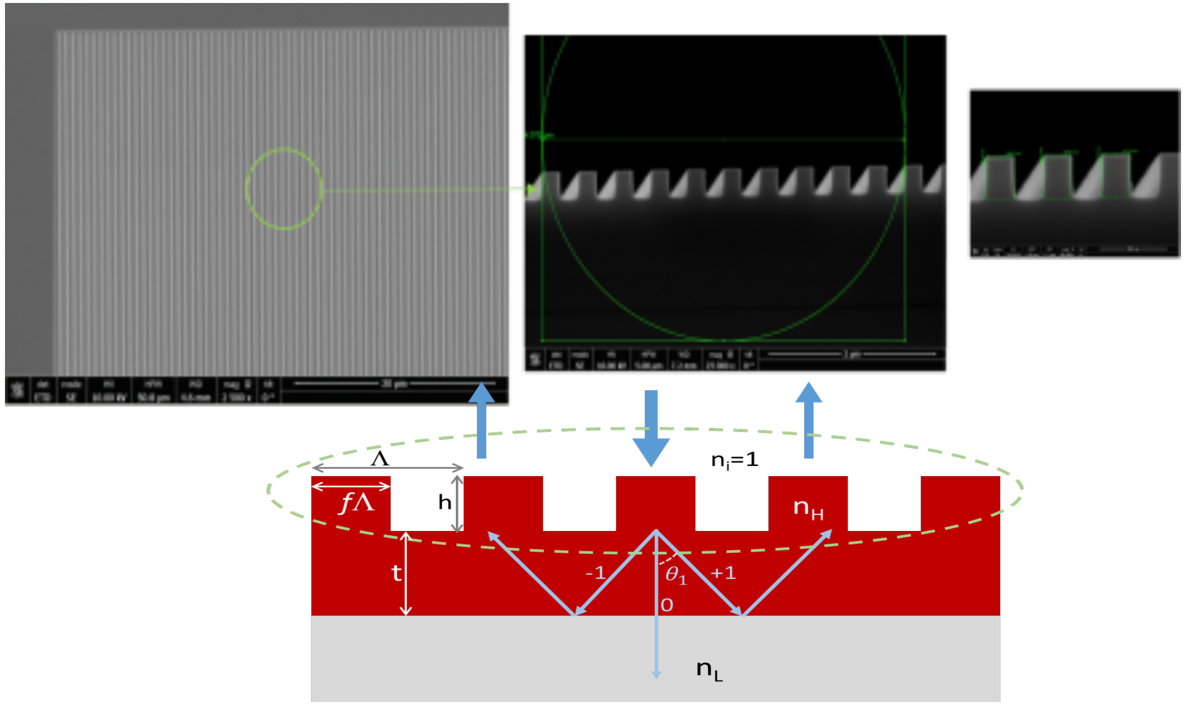
Maximum 7 W reached at 1178nm

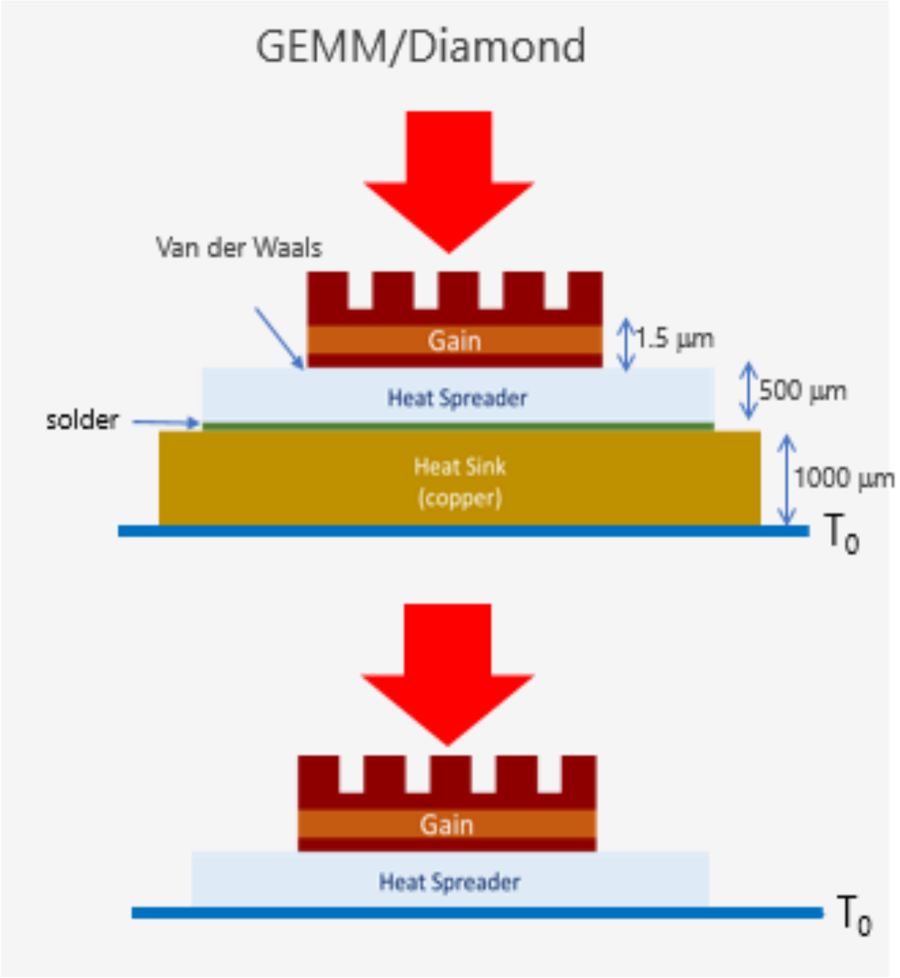
- M. Sheik-Bahae, U.S. Patent # 11/845,367 (2009)
- Z. Yang, A. R. Albrecht, J.G. Cederberg, M. Sheik-Bahae, Opt. Express, 23 (26), 33164 (2015)
- H. Kahle *et al.*, *Optica*, vol. 3, no. 12, pp. 1506–1512 (2016)
- S. Mirkhanov *et al.*, *Electron. Lett.*, vol. 53, no. 23, pp. 1537–1539, (2017)

CMS & UNM cont.

Development of a novel VECSEL architecture:
Gain-Embedded Meta Mirror technology (GEMM)

- Broadband active meta-mirror utilizes total internal reflection from a surface grating atop an underlying gain medium





- Z. Yang, D. Lidsky, M. Sheik-Bahae, “Gain-Embedded Meta Mirrors for Optically Pumped Semiconductor Disk Lasers” https://arxiv.org/pdf/1901.00472 (2018)

Big Thanks To…

- Sodium team:

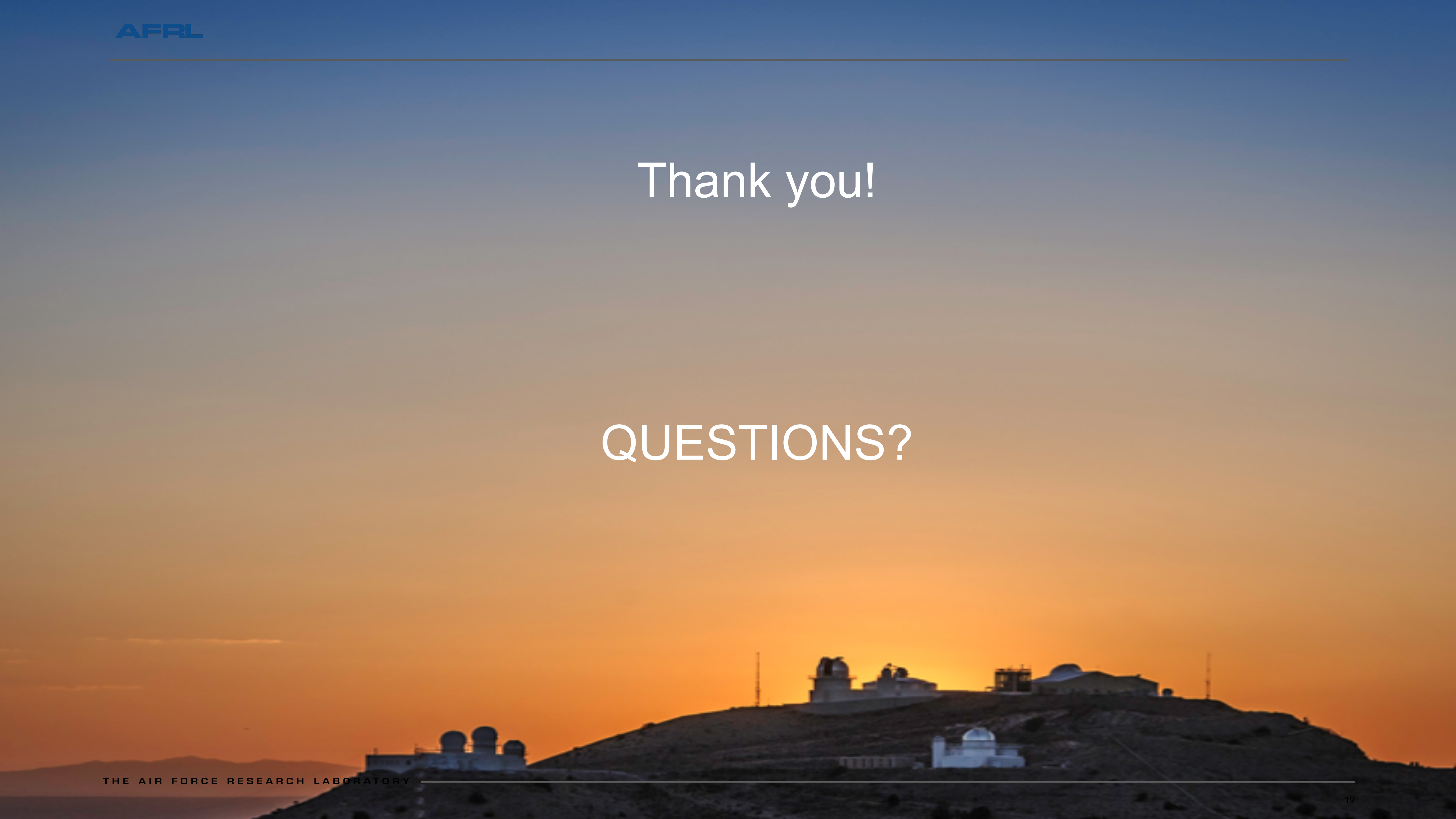
Lee Kann, Mark Eickhoff, David Ireland

- All industry/research teams:

Areté and MIT/LL

HartScientific and University of Arizona

CMS and University of New Mexico


Thank you!
QUESTIONS?