# MARLI: MARs LIdar for global wind and aerosol profiles from orbit

**James B. Abshire*, Haris Riris, Xiaoli Sun, Graham Allan, Dan Cremons**, Michael D. Smith, Scott Guzewich, Anthony Yu, Floyd Hovis***, Bruce Gentry**

NASA - Goddard Space Flight Center
Solar System Exploration & Earth Science Divisions
*- also University of Maryland College Park
**- also NPP, USRA
***- Fibertek, Herndon VA

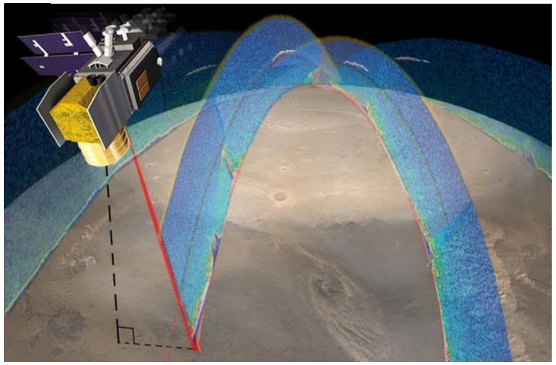
*Presentation to:*
Annual Working Group Meeting on Space-Lidar Winds
Hampton VA

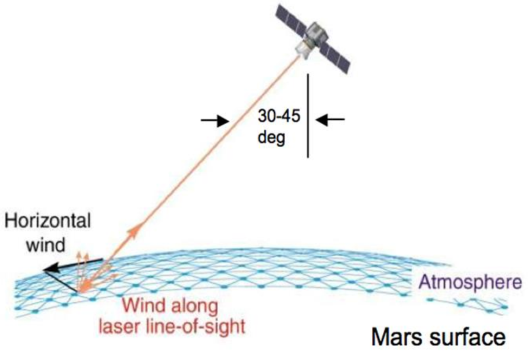
July 11, 2019

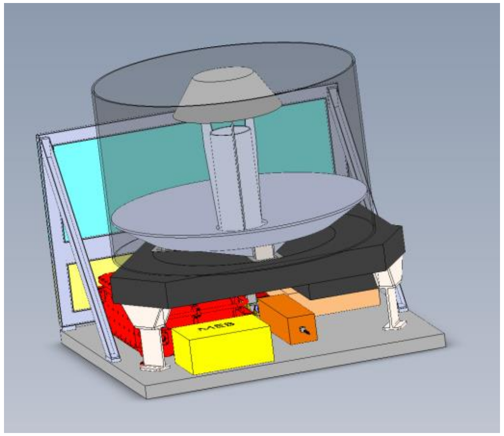
***Support: NASA's Picasso & MatISSE Programs***

# MARLI Measurement Concept

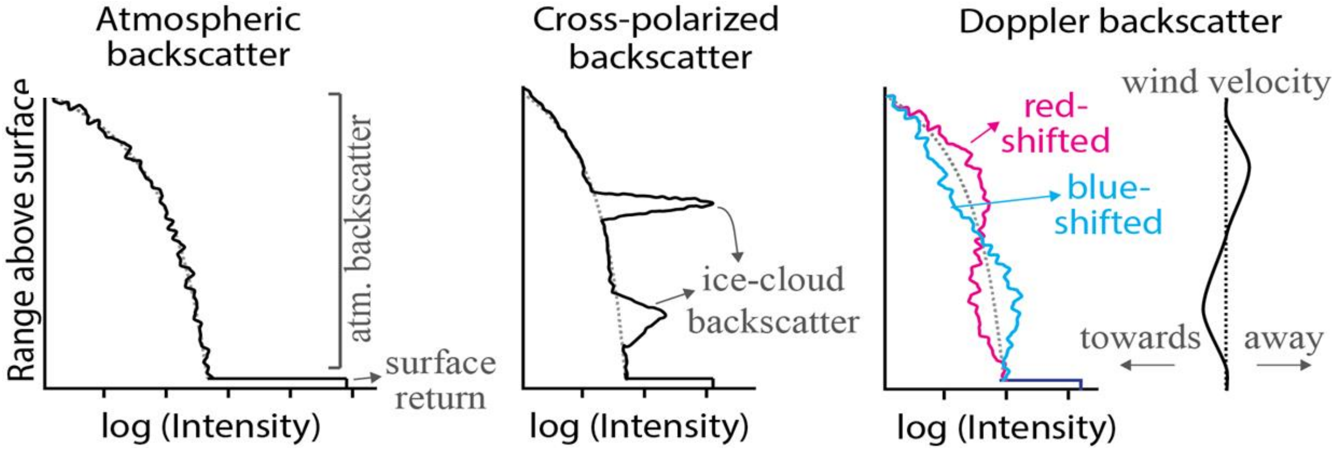
- MARLI is a direct-detection aerosol and Doppler wind lidar designed for Mars orbit
- Maps height resolved dust & winds to surface, continuously
- For Mars atmosphere, at 1064 nm, Mie-scattering dominates
  - due to dust and from low atmospheric density





## Measurement Illustration:

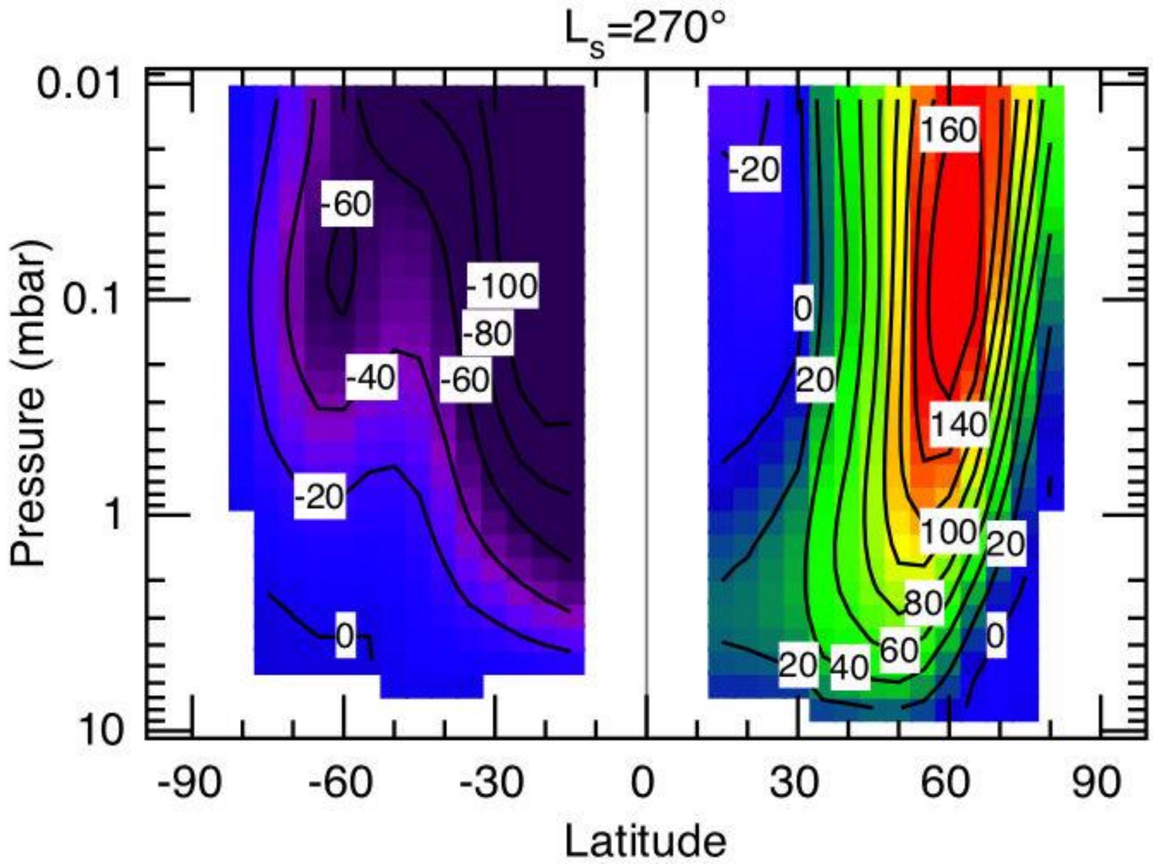


# Why Global Wind & Aerosol Profile Measurements ?

GSFC

**Global Wind profiles will provide crucial new information***

- Winds regulate transfer of gases and heat throughout the atmosphere, raise dust at surface, and are a primary player in all surface-atmosphere interactions
- Measured wind profiles provide sensitive new input for improving the current GCM models
- Winds are important for the safety and precision of spacecraft entry, descent and landing (EDL)
- Are also many needs for mapping & monitoring dust profiles



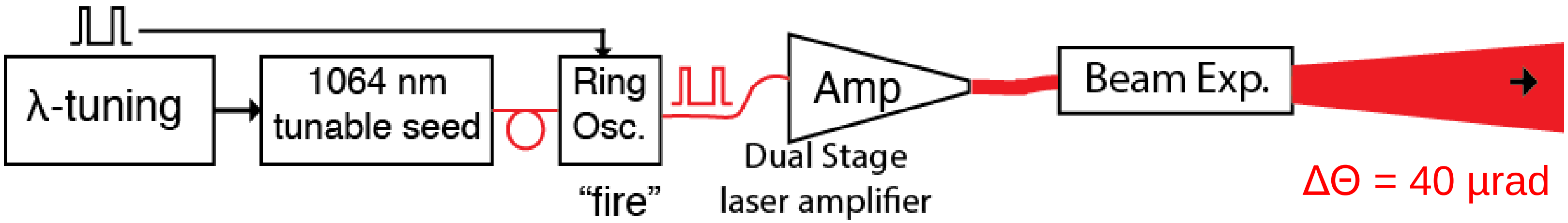

Calculated "gradient winds" (m/sec) for season Ls=270, inferred from latitude gradients of temperature. They describe, in a very broad sense, the general modeled winds from GCMs.

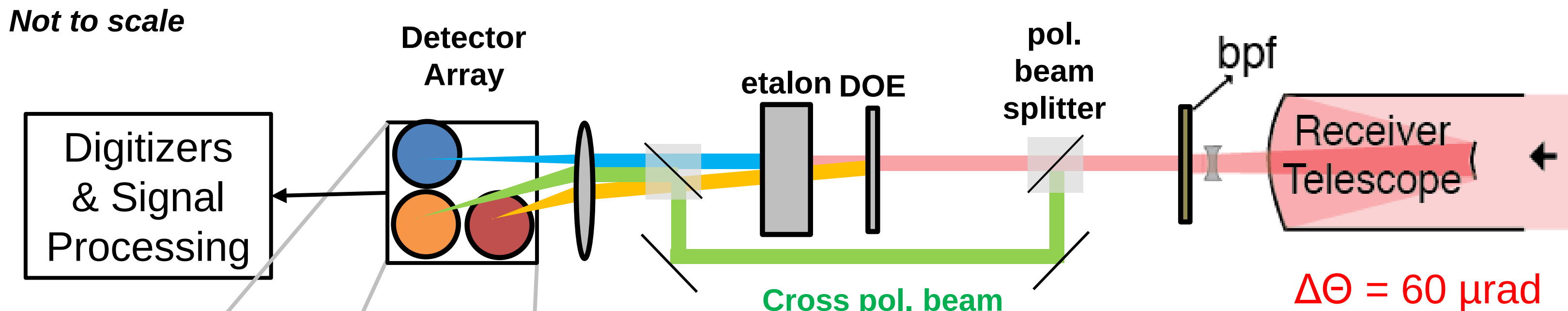
* - Summary: MEPAG NEX-SAG Report (2015), Report from the Next Orbiter Science Analysis Group

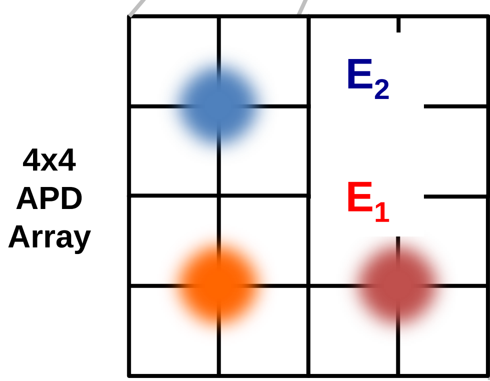
**Shortcomings: These require lots of assumptions, don't work near the equator, only give zonal (east-west) winds, don't include weather or any local phenomena, and are not very precise.**

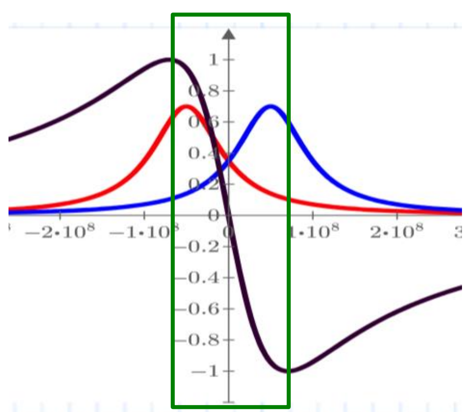
# MARLI - Lidar Approach





**Doppler Shift calculation:**

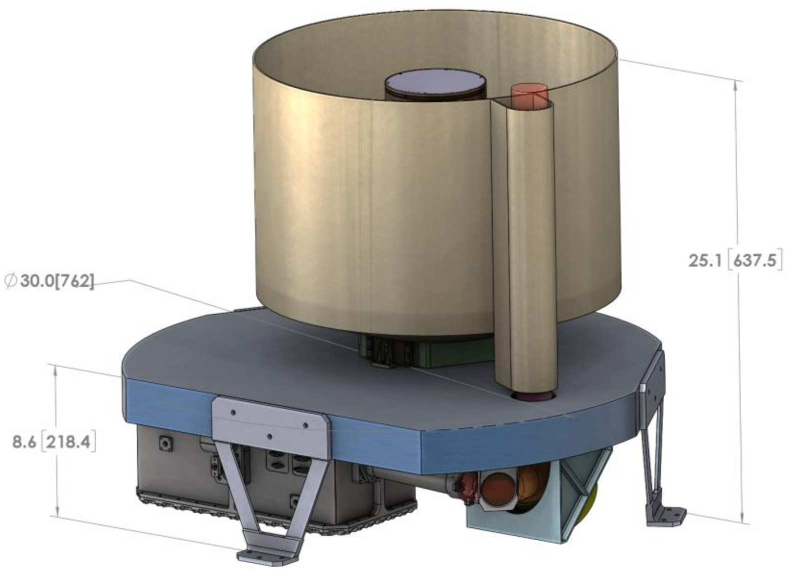
Red & Blue curves: transmission through etalon

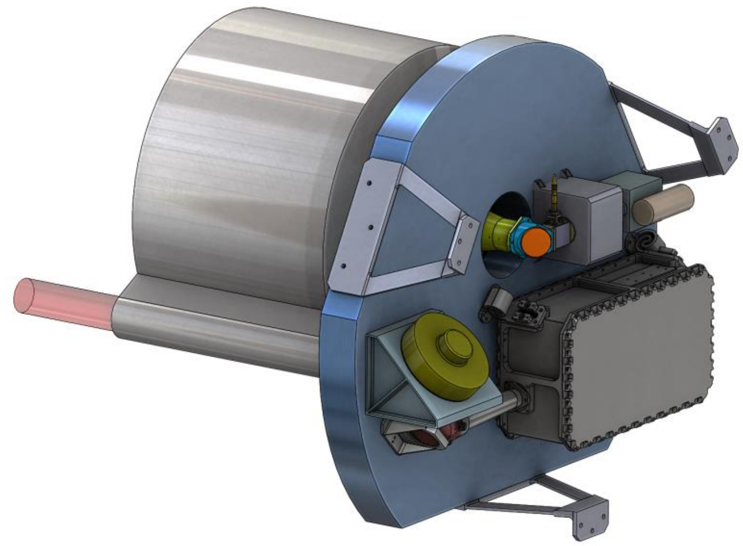
Black curve = $(E_1 - E_2)/(E_1 + E_2)$

Also called "Rdos"

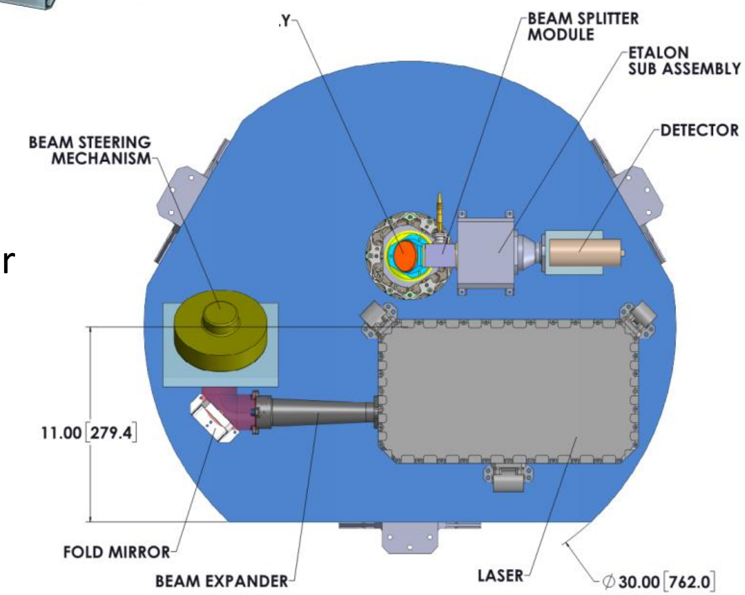
Doppler shift calculated from linear region of black curve (in green box)

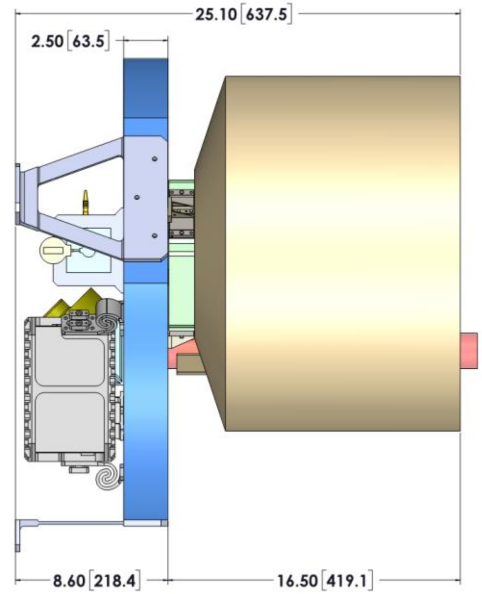
# Sept 2018 Instrument Concept - Static



- Receiver telescope mirror diameter is 50 cm
- Is also a gimballed approach that allows a slow conical scan



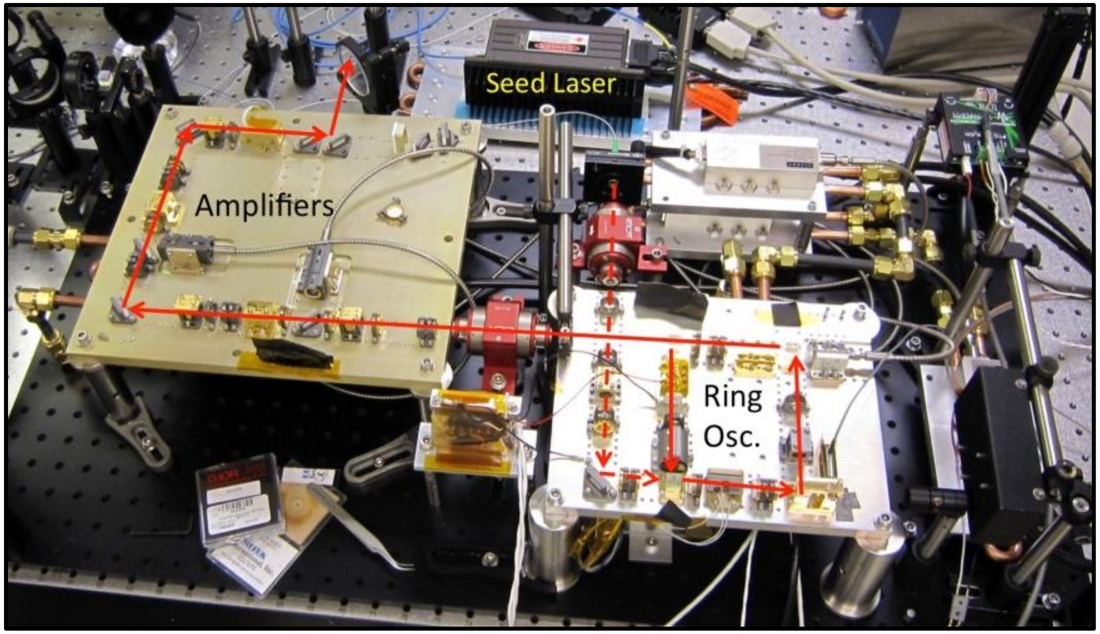
# MARLI Laser Breadboard

Fibertek
vision – innovation – leadership

**Breadboard developed for MARLI (under Picasso)**

- Based on the laser in CATS lidar, flown on ISS
- Pulsed, single-frequency diode-pumped Nd:YAG
- Seeded ring oscillator followed by amplifier
- Seed laser used to tune frequency to etalon “center”
- 25 MHz linewidth, frequency-stable to 3 MHz/hour

| Parameter | Goal | Demonstrated |
|---|---|---|
| Wavelength | 1064 nm | 1064 nm |
| Pulse Energy | 4 mJ | 3.4 mJ |
| Repetition Rate | 1 kHz | 4 kHz |
| Linewidth | < 30 MHz | 25 MHz |
| Polarization purity | 30:1 | 100:1 |
| Pulse width | > 20 ns | 28 ns |
| Beam quality | $M^2 < 2$ | 1.5 |




**Packaged laser flown in CATS lidar on ISS**

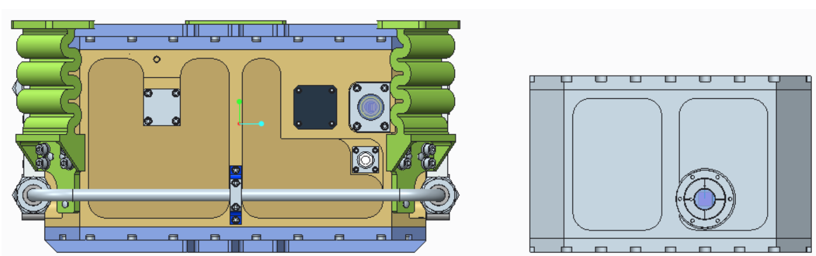
- MARLI version being developed now
- smaller, lower mass, less electrical power



More on MARLI Laser - See presentation by Hovis et al.

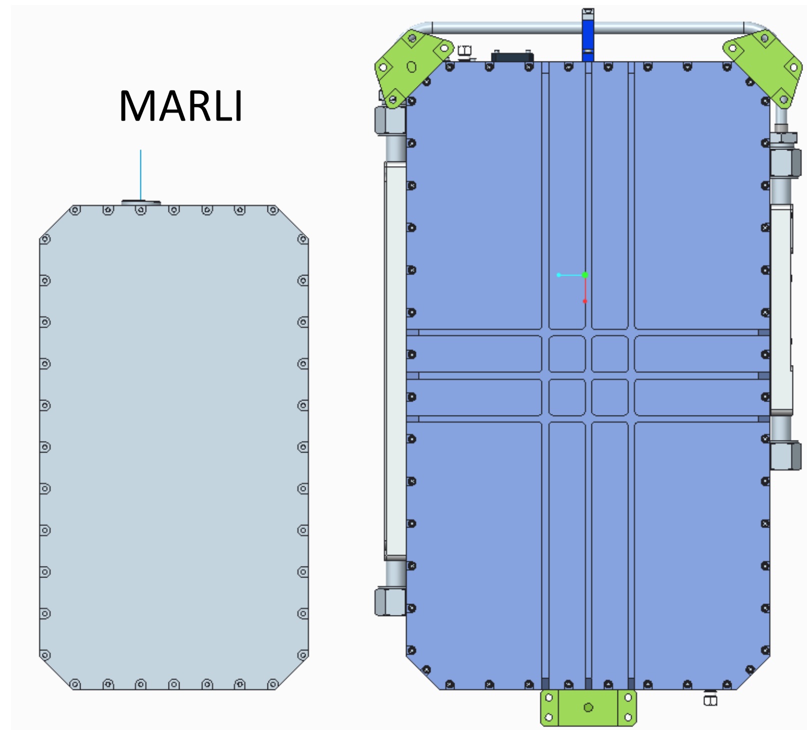
# MARLI Laser
# Size vs CATS/ISS laser

- CATS – 19”x11”x6.6” (5.9” without cover ribs)
- MARLI - 14.67”x8.12”x5.1”
  - 57% of CATS footprint
  - 44% of CATS volume



CATS MARLI

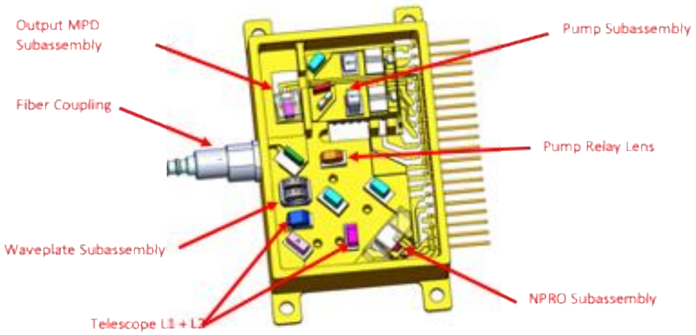
MARLI CATS

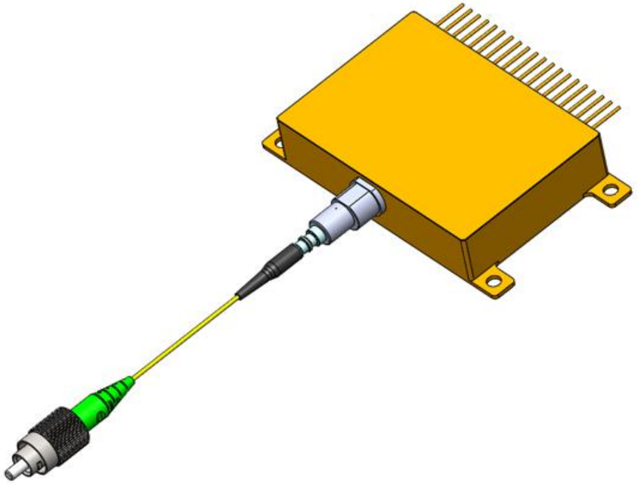


More on MARLI Laser - See presentation by Hovis et al.

# mNPRO Seed laser Option - Status and Summary (More margin in seed power & wavelength stability)

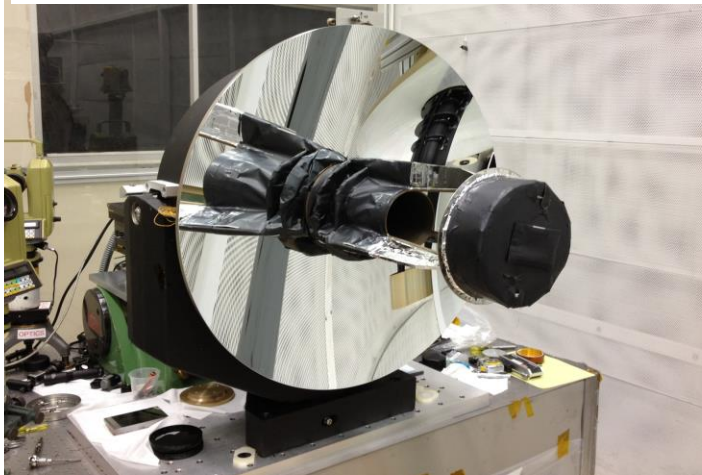
- **PDR was completed in April, 2019.**
- Issues affecting overall performance encountered while building four packages have been identified.
  - Many have been addressed.
  - Remedies were verified & form basis for current re-design
- Mechanical model has been developed in accordance with optical design and required optical alignment tolerances.
- Design allows for minimal mechanical changes to move from prototype versions where epoxy is used to hold/align optics
  - In production epoxy is eliminated in favor or welded or soldered components.
- Packages will not be sealed until assembly process is mature.
- Final package designed to be seam sealed
- Schedule:
  - All long lead items have been ordered
  - Assembly of laser to begin in mid-September 2019
  - **Delivery to MARLI: November**



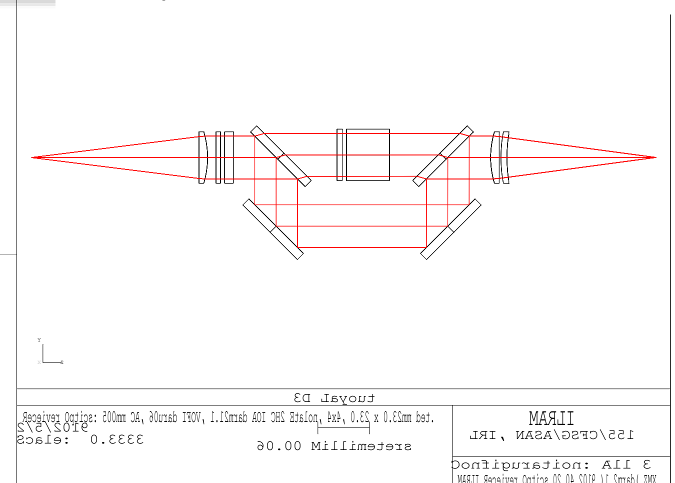



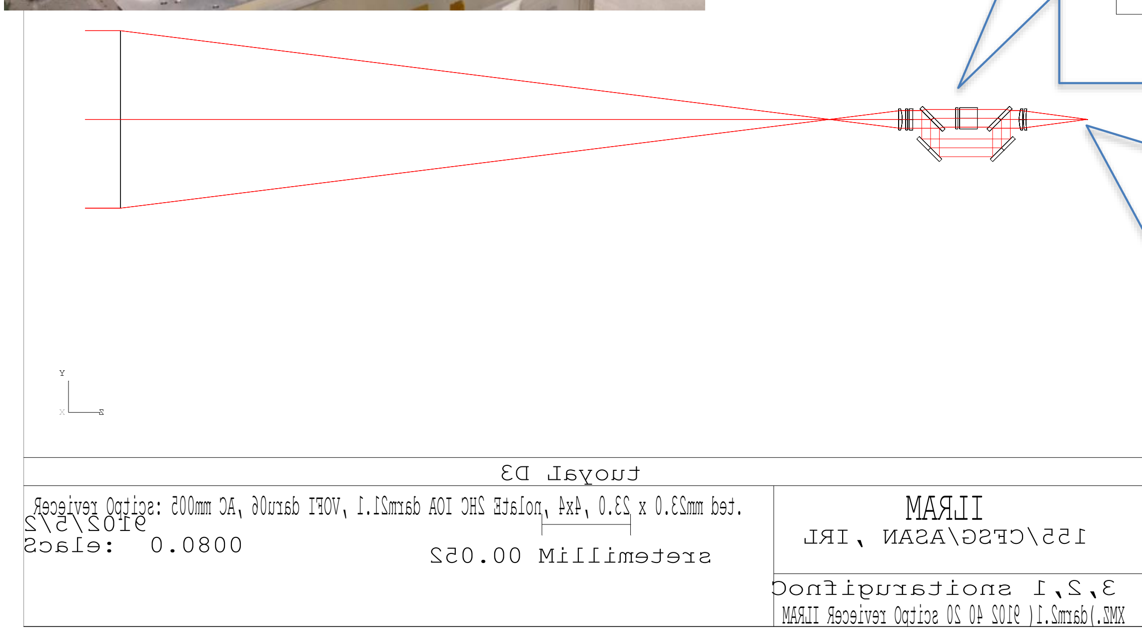
# Receiver Optics: Telescope to Detector Pixels

50 cm diameter Be receiver telescope like flown on MOLA

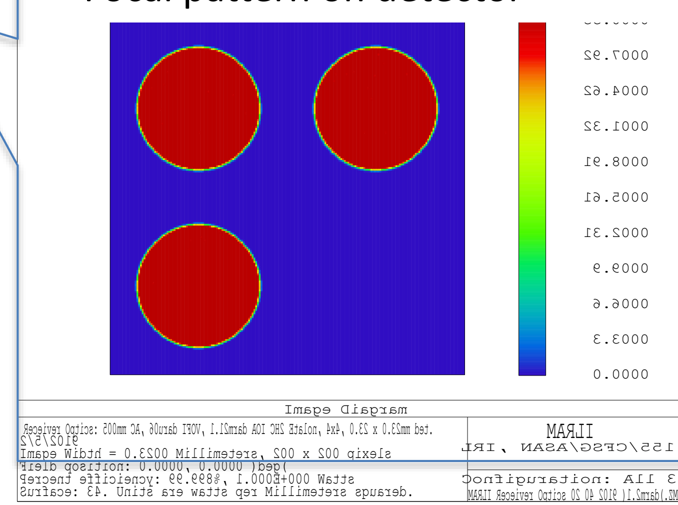


Aft optics with filter & Etalons



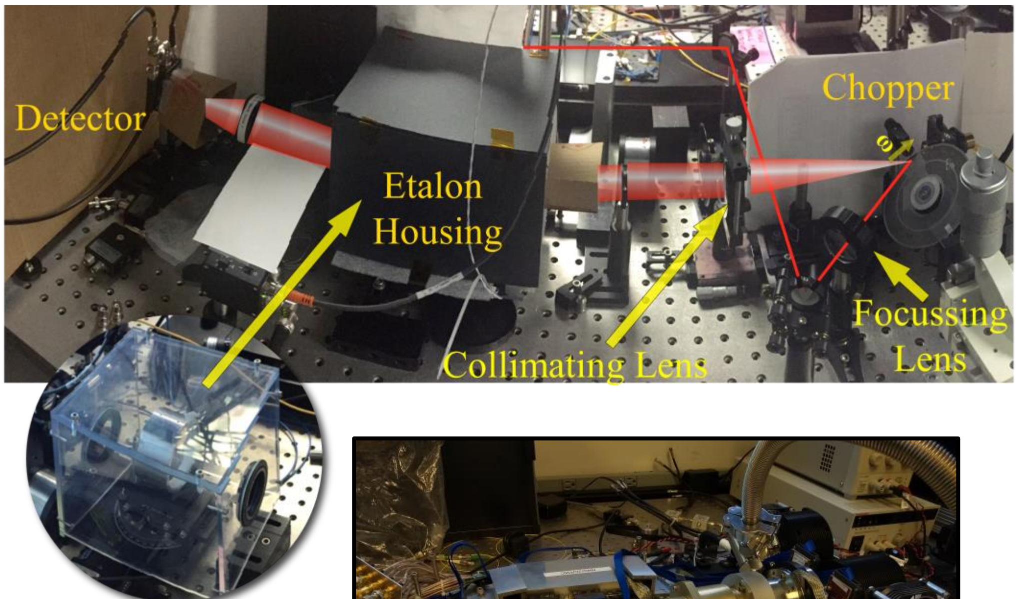


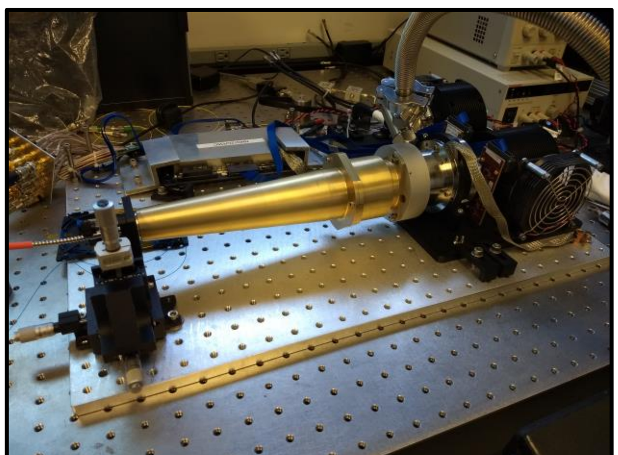
Focal pattern on detector

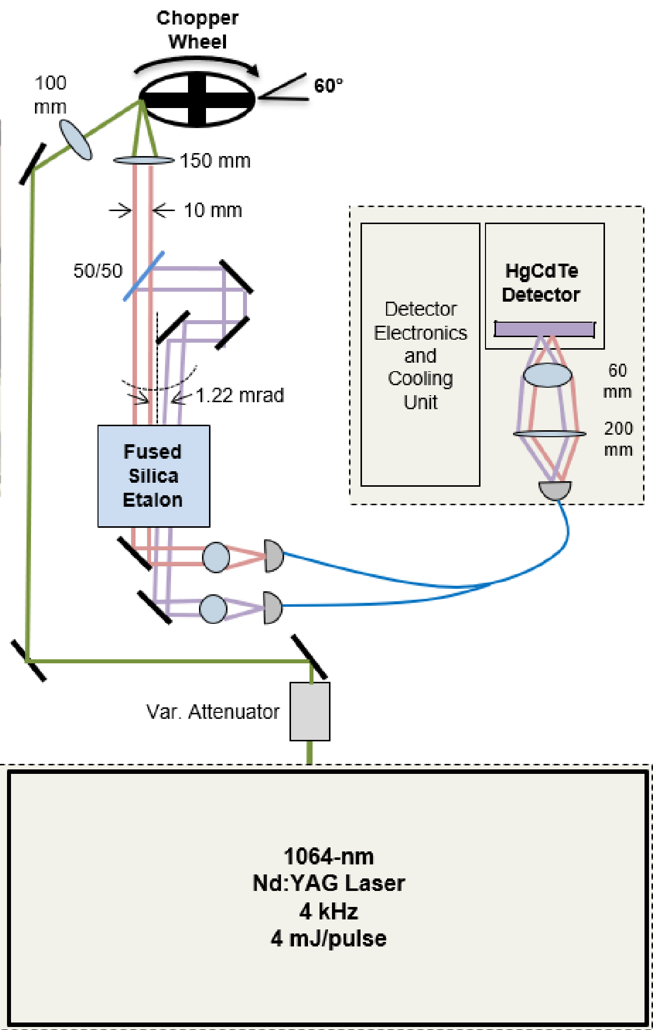


# Laser Doppler Experiments in Laboratory (Using backscatter from speed-controlled wheel)





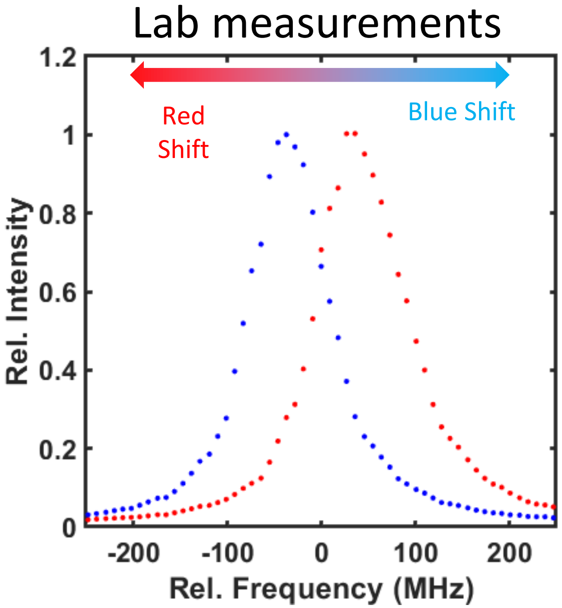



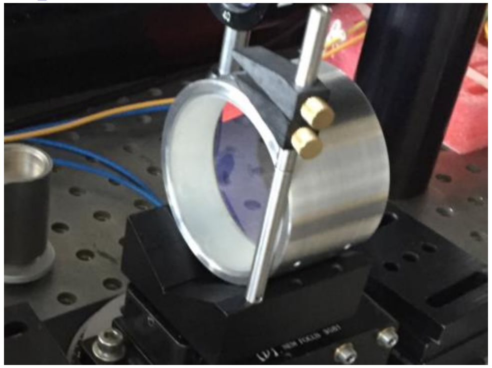



Motivation — Instrument — Laboratory — Field

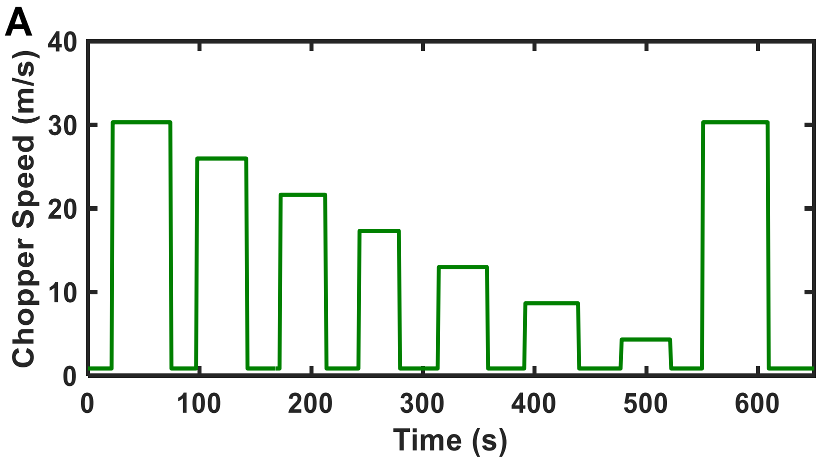
# Etalon-based Doppler Discriminator & Experiments in Laboratory

GSFC

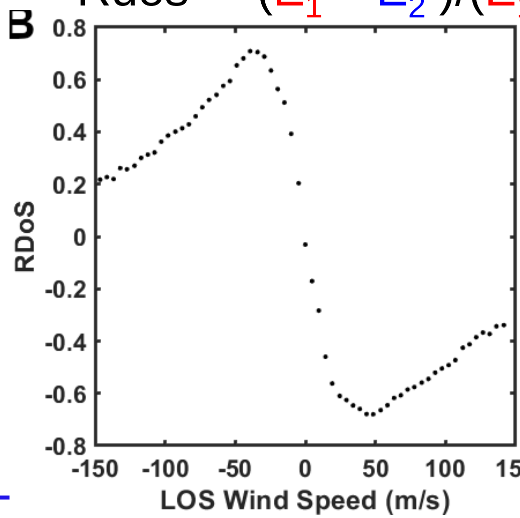


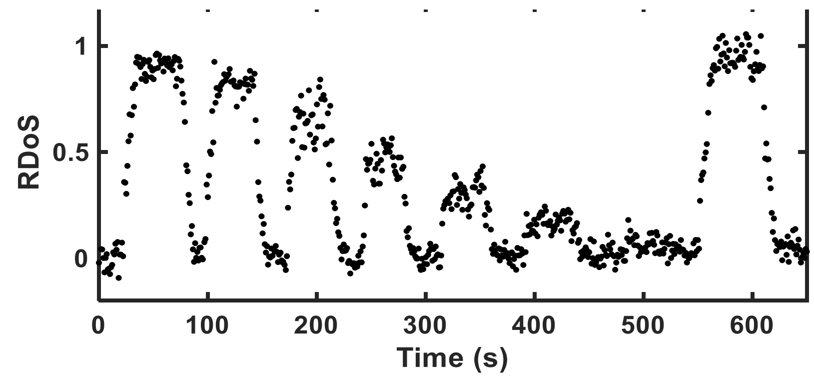



- Single solid fused-silica Fabry-Perot etalon
  - Diameter: 60 mm
  - Thickness: 40 mm
- Transmission vs frequency response also depends on incident angle
- RDoS allows solving for Doppler shift

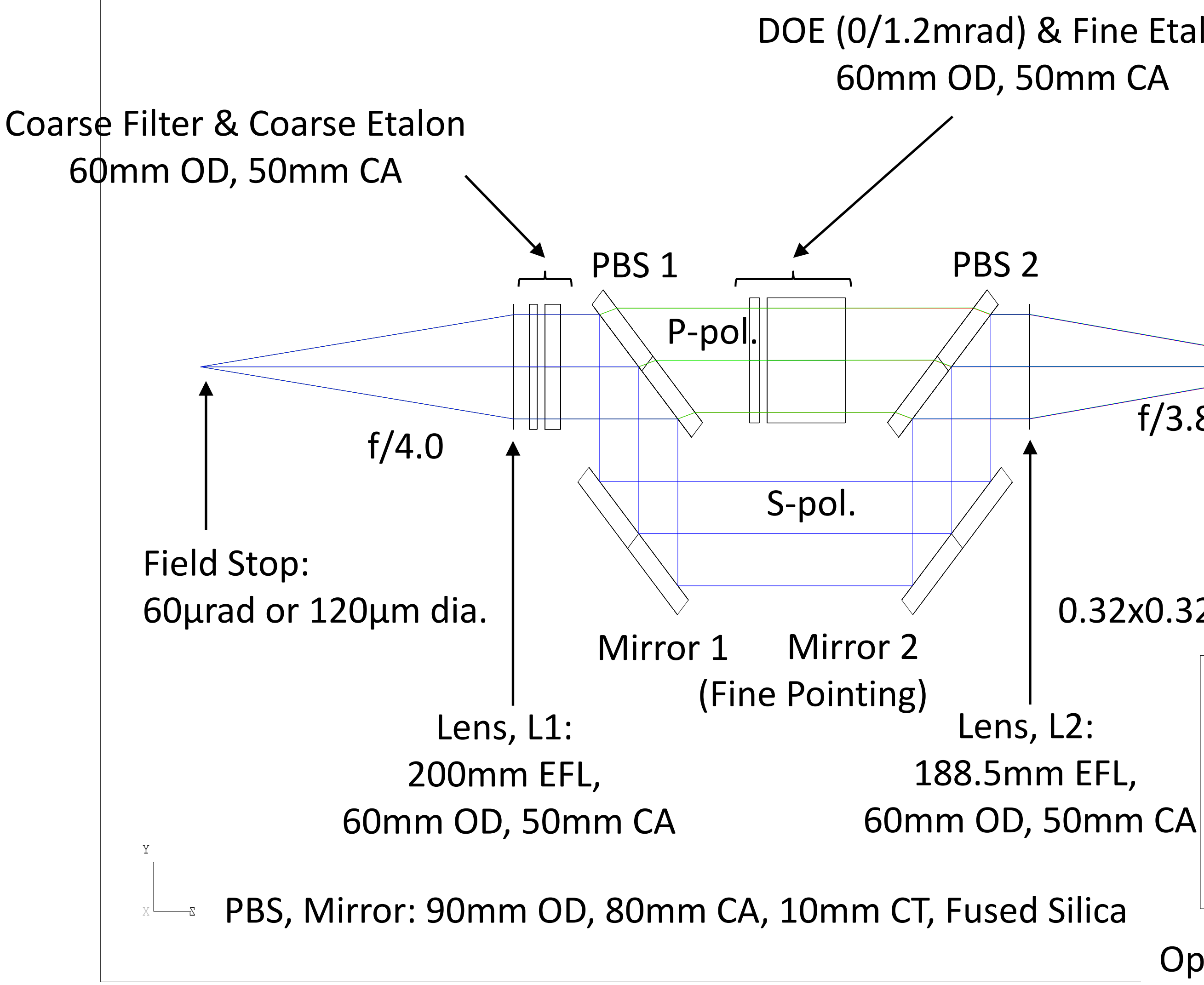


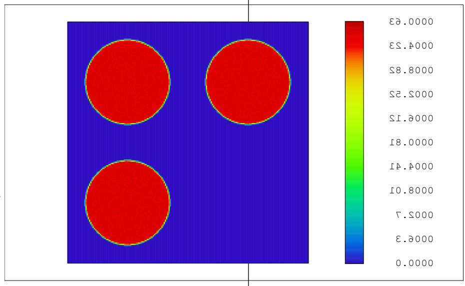

$$\text{Rdos} = (E_1 - E_2)/(E_1 + E_2)$$



# Lidar Receiver Aft Optics: Layout & Components



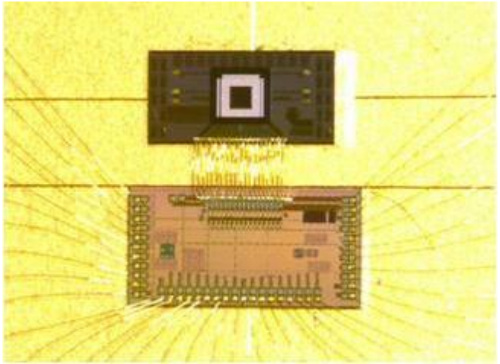
Optical pattern on detector

# MARLI HgCdTe APD Detector

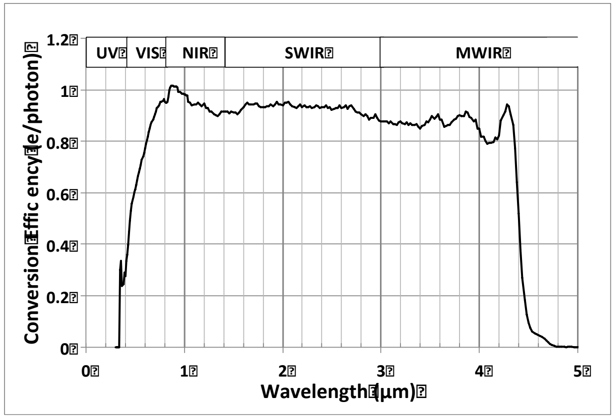
**Detector chips:**

- HgCdTe APD arrays (4x4 pixels ) were developed by Leonardo DRS for GSFC under NASA ESTO IIP program 2010-2014, & QRS program from 2014 to 2018.
- Our work showed NEP<0.5 fW/Hz$^{1/2}$ and near quantum-limited SNR at 110K.
- Linear dynamic range (with gain changes) is $10^5$
- Used in GSFC's airborne $CO_2$ and $CH_4$ Sounder IPDA lidar 2014-2017.
- Radiation damage tested with protons and gamma rays to 100 krad(Si).

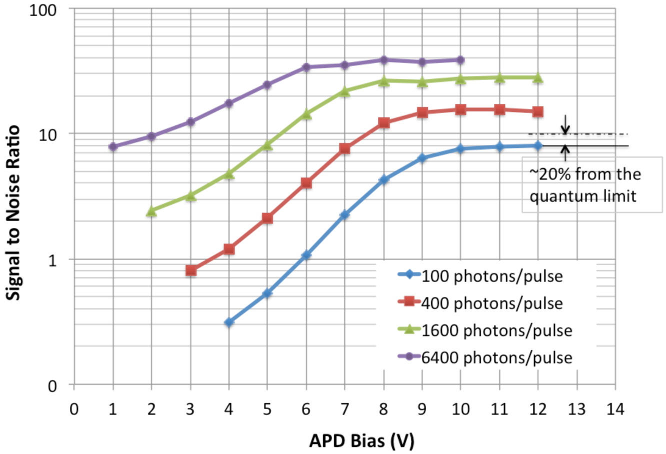
**HgCdTe APD and preamplifier side by side on ceramic carrier**



**Spectral response**



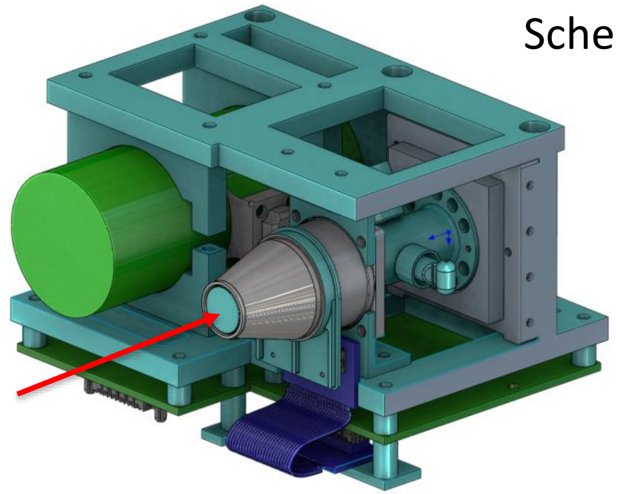

**Signal to noise ratio (SNR) vs. input**



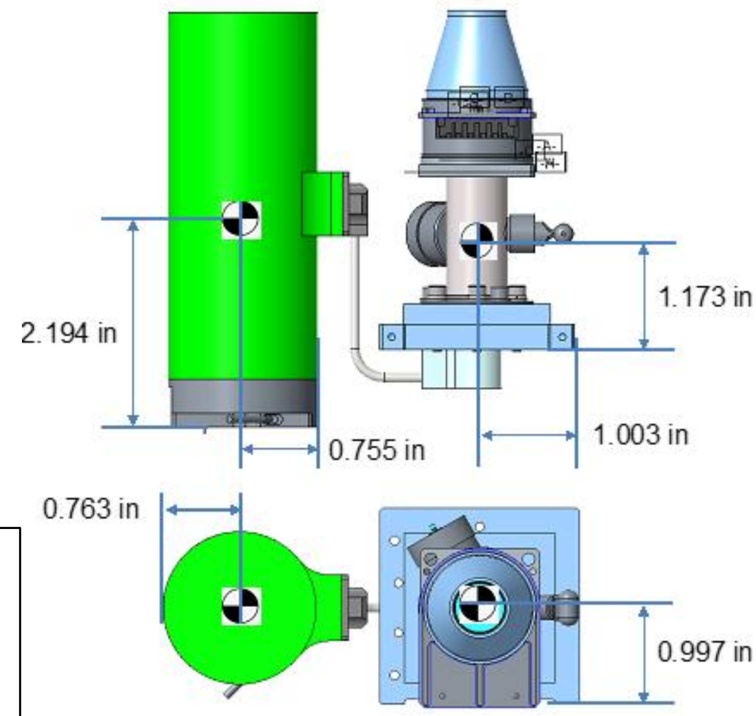
# Integrated Detector Cooler Assembly for MARLI for 4x4 pixel HgCdTe APD array

## Under development now at DRS Leonardo

Scheduled delivery: January 2020




| Component | Weight (lb) | Weight(g) |
|---|---|---|
| Compressor Assembly | .9276 | 420.8 |
| Transfer Tube Assembly | .0683 | 31.0 |
| Expander Assembly | .0166 | 7.5 |
| Vacuum Dewar Assembly | .2524 | 114.5 |
| **Total** | **1.2649** | **573.8** |




Optical Engineering 58(6), 067103 (June 2019)

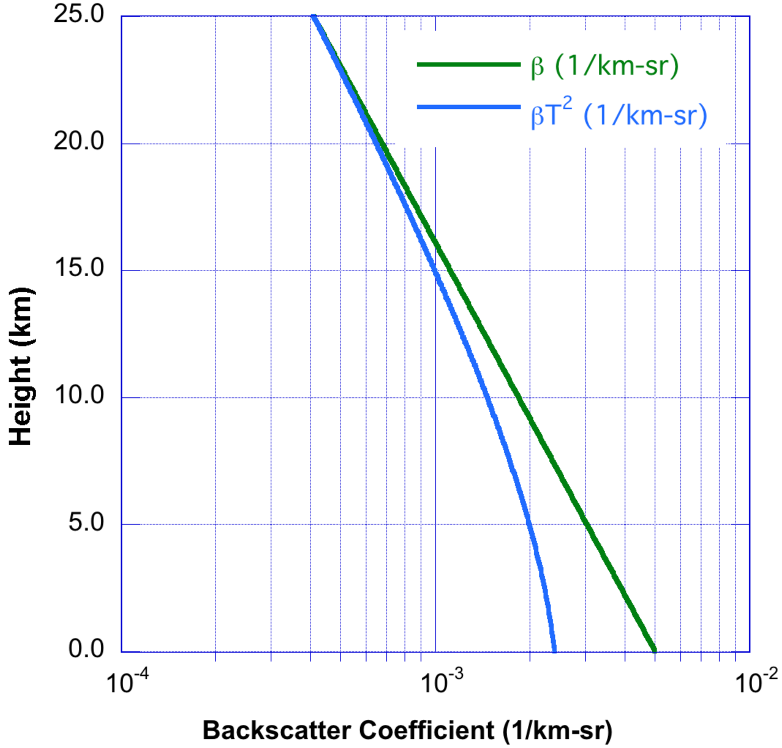
**HgCdTe avalanche photodiode array detectors with single photon sensitivity and integrated detector cooler assemblies for space lidar applications**

Xiaoli Sun,[a,*] James B. Abshire,[a] Michael A. Krainak,[a] Wei Lu,[b] Jeff D. Beck,[c] William W. Sullivan III,[c] Pradip Mitra,[c] Dick M. Rawlings,[c] Renny A. Fields,[d] David A. Hinkley,[d] and Bradley S. Hirasuna[d]

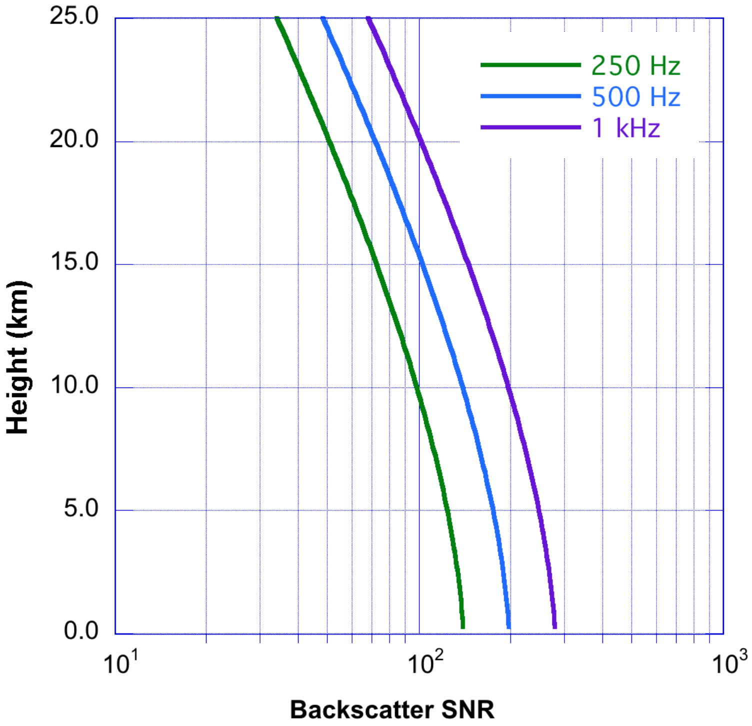
# Updated Measurement Performance: Assumptions & Estimates vs. altitude

GSFC

Updates for:
- Laser energy, pulse rate
- 50 cm telescope, detector parameters

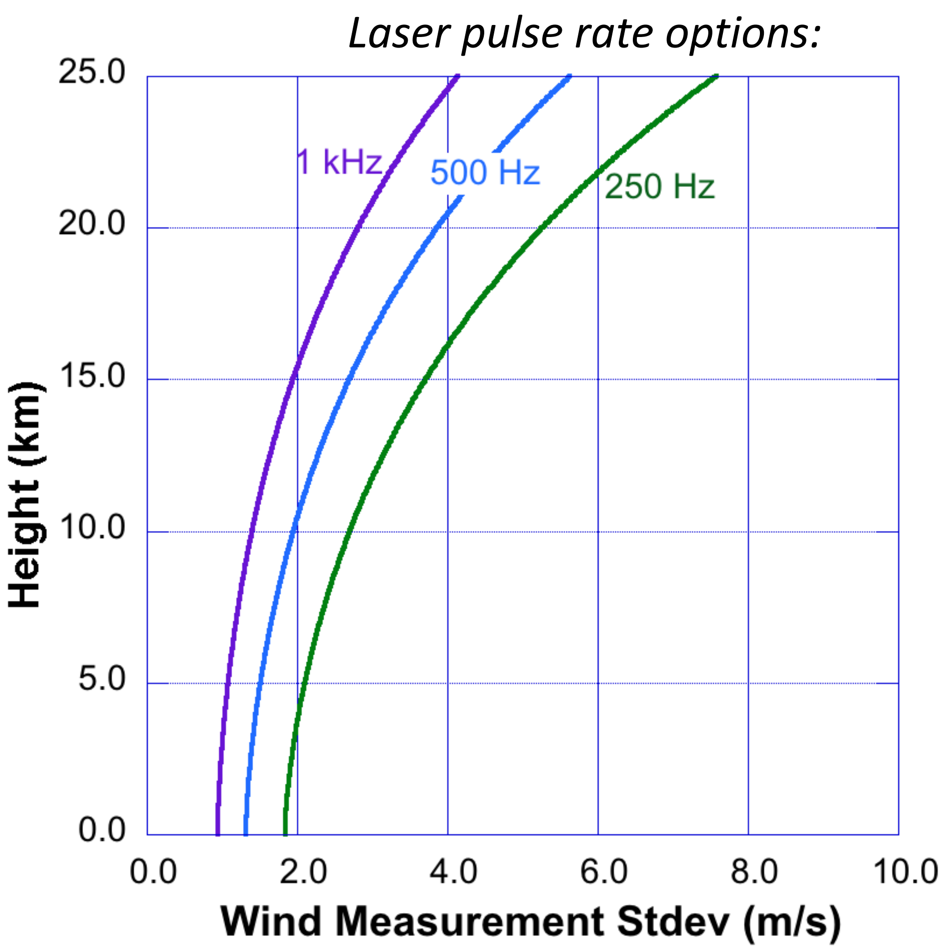



*Backscatter profile SNR for Laser pulse rate options:*




- MARLI measures backscatter profiles with ~30-m vertical resolution at 10 Hz sample rate
- Performance is calculated on averaging (on ground):
  - 2-km bin depth and 40-s (2 deg. along track)

# Calculated Wind Measurement Performance: Random error in wind speed vs. altitude




- MARLI measures backscatter profiles with ~30-m vertical resolution at 10 Hz sample rate
- Performance is calculated on averaging (to be done on Earth):
  - Assumes 2-km bin depth and 40-s (2 deg. Resolution along track)

# JPL's Mars Orbital Wind Mission - Approach Assessment
## Summarized in Fall 2018 AGU poster

GSFC

P43L-3916: An Assessment of Martian Atmospheric Wind Measurement Techniques: A Workshop Report

**Thursday, 13 December 2018** **13:40 - 18:00**

*Walter E Washington Convention Center - Hall A-C (Poster Hall)*

# An Assessment of Martian Atmospheric Wind Measurement Techniques: A Workshop Report

Leslie K. Tamppari[1], Nathaniel J. Livesey[1], James B. Abshire[2], Anthony Colapret[3], David J. Diner[1], Sabrina Feldman[1], Scott Guzewich[2], Michael Mischna[1], Michael D. Smith[2]

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA (leslie.tamppari@jpl.nasa.gov)

[2]NASA Goddard Spaceflight Center, Greenbelt, MD, [3]NASA Ames Research Center, Mountain View, CA

## 1. Introduction

A full understanding of Mars atmospheric circulation and transport is one of the primary goals of the Mars program (cited in the Mars Exploration Program Analysis Group Goals document). To address these science goals, systematic atmospheric wind measurements are needed. We held a workshop in Sept. 2018 to assess the strengths and weaknesses of various approaches to measuring Martian atmospheric winds from a Mars-orbiting vantage point. The overall goal was to strengthen the understanding and justification for various approaches, encourage cross-technique fertilization of ideas, and to enhance the likelihood that these approaches would be technically and scientifically attractive for a future Mars mission. We considered multiple factors including: (1) Expected measurement capability (precision, resolution, likely accuracy, ability to measure in darkness, horizontal resolution and coverage, vertical resolution and coverage, etc.); (2) Expected instrument envelope (mass/power/volume/data rate) and TRL; (3) Other factors (ability to steer, capability for measurements in addition to wind such as atmospheric composition); (4) Suitability to different classes of mission (CubeSat/small/medium/large, directed/competed etc.); and (5) Technique efficacy for various science questions (global circulation, topographically driven winds, atmospheric waves, etc.).

## 2. Workshop origination

This workshop was proposed to and awarded by the Jet Propulsion Laboratory (JPL) *Center Innovation Fund* internal R&D program. As a *Center Innovation Fund* award, the task was restricted to NASA centers, including JPL. With strong Mars atmospheric research and development capabilities at three centers, this workshop brought together eight scientists and instrument providers from NASA Ames Research Center, Goddard Space Flight Center, and JPL, representing four unique techniques to measure Martian atmospheric winds from an orbital vantage point. The workshop resulted in a completed matrix of the various instruments' attributes, including a pairing of instruments to science needs (Figure 1), and an assessment of key future development needs and opportunities (Box 6).

## 3a. Four techniques to measure global winds in the Martian Atmosphere

Group members presented their fundamental measurement technique to the rest of the group. Because the workshop was focused solely on wind measurements, the additional science capabilities or each technique (e.g., aerosol, trace gas, and temperature measurements) were noted, but not thoroughly discussed.

| | Lidar | Infrared limb | Submm limb | Cloud/feature tracking |
|---|---|---|---|---|
| **Fundamental measurement: What is the physical quantity being measured, from which wind information is being deduced?** | Range-resolved Doppler shift of the laser backscatter profile along the laser beam line of sight. This is based on the range resolved scatter from dust/aerosol. | 1. Doppler shift of many thermal emission lines to obtain one wind component.<br>2. Doppler width of many thermal emission lines for determining kinetic temperature. | Position (and thus Doppler shift) and shape (width, strength) of submm thermal emission lines from molecules including $H_2O$, CO isotopologues and (potentially) other species.<br>Measurements made in a limb geometry to give vertically resolved "line of sight" winds in viewing direction. | Automated pattern-matching of cloud and aerosol dust plume features in visible imagery at multiple along-track view angles.<br>Uses time lapse between views to obtain vector (along- and cross-track) winds, stereo parallax to provide height assignments. |

## 3b. Capabilities of the four techniques

The group presented the measurement resolutions and precisions for each technique along with viewing geometry and measurement cadence assumed.

| | Lidar | Infrared limb | Submm limb | Cloud/feature tracking |
|---|---|---|---|---|
| **Viewing geometry** | Options are:<br>1. Static: line of sight ~30-deg off nadir cross track.<br>2. Scanning: slow spiral scan with fixed 30-deg offset from nadir. | 20- to 25-degree-wide image of the Mars limb, centered perpendicular to the satellite velocity vector. | Limb scan, e.g., from surface to 150 km. Most likely an azimuthally steerable beam, with each limb scan performed at a fixed azimuth. | Imaging at multiple view angles (~5–7) between nadir and 60º at the instrument, forward and backward of nadir. |
| **Nominal measurement cadence** | Can return aerosol profiles at 1- to 10-Hz rate. Need averaging for useful wind measurements. Typically (for static) 10–40 s (0.5 to 2 deg along track). Assumed 3 km/s at 400-km near-polar orbit. | Measurements at all altitudes nominally every second (4.5 km along-track at limb) from a low Mars Orbit. Assume >4 km/s speed, 300-400 km altitude, at polar incline of ~78 deg. For scanning at all times of day. | Vertical scan of the limb every 75 s gives 250-km along-track spacing. Faster scans over selected altitude regions readily accomplished (reduces signal-to-noise ratio). 300-400-km orbits, any polar or inclined orbit. | Continuous pushbroom imaging at each view angle with along-track line spacing of a few hundred m (~100 ms line repeat interval). Orbit assumption 300-400 km altitude, 3 km/s. |
| **Nominal horizontal resolution/coverage** | Is a tradeoff of wind measurement error (std dev) vs averaging time. 30- to 120-km res. See the numbers above. | Along-track resolution of 4.5 km at limb. Limb measurement resolution (along-sight) of 100-200 km (TBR). | Along-track resolution of 250 km or better at limb. Limb measurement resolution (along-sight) of 100-200 km (TBR). | ~700-km swath to provide global coverage in 3 sols, with 300–400-m spatial resolution/pixel. Wind hoz res ~20 km. |
| **Expected precision** | Depends on laser pulse rate, (which can be varied) with high pulse rates needing more electr power. For 250-Hz pulse rate, 40-s averaging time (2-deg along-track resolution) and 2-km vertical resolution: 2 m/s (0–5 km altitude), ~ 3 m/s (5–12 km), 4 m/s at 16 km, 6 m/s at 22 km. | Random noise will range from sub 1 m/s to over 100% error at high altitudes. Vertical resolution will range from 2 km to 6 km. Will be 4 altitude regions (TBD) of 10 to 15 km each. Measurement will be day and night. | Precision: 10–15 m/s for ~15- to 80-km altitude, ~20 m/s for 5- to15-km altitude, no useful signal below ~5 km. Vertical resolution: 10 km at 5-km altitude, improving to ~5 km by 40 km. | ±3 m/s along-track and cross-track, with ±300-m vertical resolution for height assignments. Based on actual performance, including precision, accuracy . . . (multiple factors). |

# Summary

GSFC

- Are developing MARLI as a small direct-detection Doppler lidar for mapping wind and aerosol profiles continuously from Mars orbit
- Developed a breadboard instrument and demonstrated Doppler measurements with it in the laboratory
- Used breadboard in initial field campaign to make atmospheric measurements
  - Measurements to moving clouds agreed with cloud motion determined from ranging
- Are developing engineering models of the laser, receiver optics, & detector
- Documented progress in several conference papers

## Ongoing Work

- Will complete brassboard instrument to bring to TRL-6 during Spring 2020
- Plan to demonstrate measurement performance from the ground to optically thin wind blown cirrus clouds

# More information-1 : Conference Papers on Instrument – 2018




## International Workshop on Instrumentation for Planetary Missions

### MARLI: MARs LIdar for global wind and aerosol profiles from orbit

J. B. Abshire[1], S.D. Guzewich[1,2], M.D. Smith[1], H. Riris[1], X. Sun[1], B.M. Gentry[1], A. Yu[1], and G. R. Allan[3]

[1]NASA Goddard Space Flight Center, Greenbelt MD USA (james.b.abshire@nasa.gov), [2]CRESST/Universities Space Research Association, Columbia MD, USA [3]Sigma Space Corporation, Greenbelt, MD USA.

**Abstract**

The Mars Exploration Analysis Group's Next Orbiter Science Analysis Group (NEX-SAG) identified atmospheric wind measurements as one of 5 top compelling science objectives for a future Mars orbiter [1]. To date, only isolated lander observations of Mars winds exist.

Winds are the key variable to understand atmospheric transport and answer fundamental questions about the three primary cycles of the martian climate: $CO_2$, $H_2O$, and dust. However, the direct lack of observations and imprecise and indirect inferences from temperature observations leave many basic questions about the atmospheric circulation unanswered. In addition to addressing high priority science questions, direct wind observations from orbit would help validate 3D general circulation models (GCMs) while also providing key input to atmospheric reanalyses.

The dust and $CO_2$ cycles on Mars are partially coupled and their influences on the atmospheric circulation modify the global wind field. Dust absorbs solar infrared radiation and its variable spatial distribution forces changes in the atmospheric temperature and wind fields. Thus it is important to simultaneously measure the height-resolved wind and dust profiles. MARLI provides a unique capability to observe these variables continuously, day and night, from orbit.

Nd:YAG laser and direct detection receiver and makes measurements at 1064 nm. Its measurement types are shown in Figure 2. The MARLI development is being supported by the NASA Picasso and Matisse Programs.

**2. Lidar Description**

The laser backscatter from the Mars atmosphere is weak and is distributed in range and thus a highly sensitive lidar approach is necessary. The present MARLI approach measures the height resolved atmospheric characteristics along a single line-of-sight. The lidar uses an efficient pulsed ND:YAG laser with flight heritage, a low-mass receiver telescope and photon-sensitive detectors.

The basic design of MARLI, shown in Figure 3, utilizes a pulsed single-frequency diode-pumped Nd:YAG laser. Its output pulses are wavelength stabilized near 1064 nm. The laser emits ~50 nsec wide pulses at a 1 kHz pulse rate. Nominally, the receiver uses a ~50 cm diameter telescope and splits the returned signal into 3 paths. One path is a cross-polarized channel to allow dust/ice discrimination. The other two paths are used to illuminate an etalon at different angles then are focused onto separate detectors. These receiver elements are configured as a double-edge Doppler (optical frequency-shift) discriminator. It is also feasible to measure vector-resolved wind profiles using a dual-telescope-

## PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

### Development of a Mars lidar (MARLI) for measuring wind and aerosol profiles from orbit

Daniel R. Cremons, James Abshire, Graham Allan, Xiaoli Sun, Haris Riris, et al.

Daniel R. Cremons, James Abshire, Graham Allan, Xiaoli Sun, Haris Riris, Michael Smith, Scott Guzewich, Anthony Yu, Floyd Hovis, "Development of a Mars lidar (MARLI) for measuring wind and aerosol profiles from orbit," Proc. SPIE 10791, Lidar Technologies, Techniques, and Measurements for Atmospheric Remote Sensing XIV, 1079106 (9 October 2018); doi: 10.1117/12.2325408

SPIE.

Event: SPIE Remote Sensing, 2018, Berlin, Germany

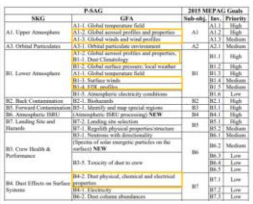

# More information - 2: Fall AGU Poster & Manuscript to CEOS

## MARLI: Mars Lidar for Global Wind Measurements from Orbit

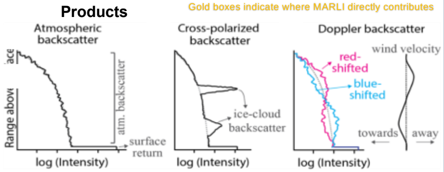
### Why Measure Wind on Mars?

- Understanding of Mars atmosphere is essential to the study of past, present, and future **habitability**.
- Winds regulate **volatile, dust, and heat transport** in the atmosphere.
- Winds play a vital role in all **atmosphere-surface interactions**.
- Winds measurements provide crucial data for safe, precise **entry, descent, and landing** (EDL).
- Optical depth, particle size, and particle velocity will help forecast current and future **dust storms**, ensuring mission **success of robotic and human exploration of Mars**.

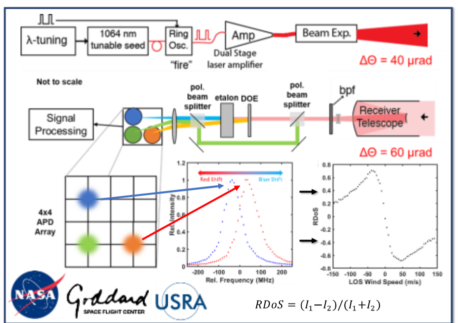

Photo Credit: NASA/JPL/MSSS


*From Mars Exploration Program Analysis Group Goals Document, 2015*
Gold boxes indicate where MARLI directly contributes

**MARLI Science Data Products**



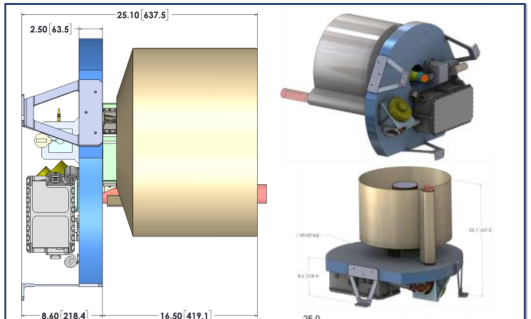

### Instrument Approach



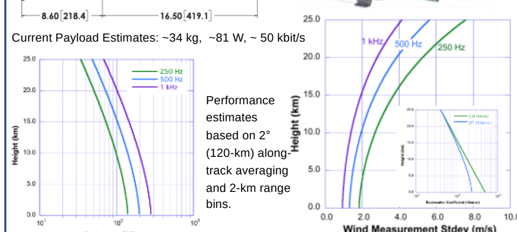

### Instrument and Mission Parameters

| Lidar Parameters | | Mission Parameters | |
|---|---|---|---|
| Transmitter wavelength | 1064 nm | Orbit altitude | 400 km |
| Laser pulses/s | 250 | Off-nadir pointing angle | 30° |
| Pulse energy | 4 mJ | One-way transmission | 0.7 |
| Pulse width | 25 ns | Diffuse surface reflectivity | 0.26 |
| Transmitter divergence | 40 μrad | Atm. backscatter coeff. at 5 km | $3 \cdot 10^{-6}$ $m^{-1}sr^{-1}$ |
| Telescope diam. | 50 cm | Spatial averaging | 2° |
| Receiver bandwidth | 100 MHz | Averaging length | 120 km |
| Receiver FOV | 60 μrad | Atmospheric range bin | 2 km |
| Detector Q.E. | 75% | Backscatter SNR (0-25 km alt.) | 150-30 |
| Detector bandwidth | 8 MHz | Wind speed std. dev (0-25 km alt.) | 1.8-7.5 m/s |

### Flight Instrument Concept

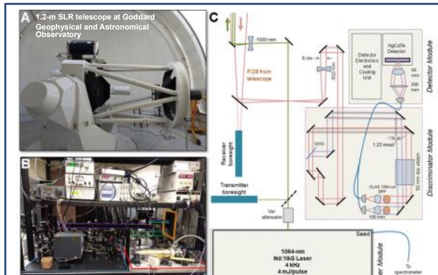



Current Payload Estimates: ~34 kg, ~81 W, ~ 50 kbit/s




Performance estimates based on 2° (120-km) along-track averaging and 2-km range bins.

### Initial Wind Measurements




For more information, see: Cremons, D. R, *et. al.*, Development of a Mars lidar (MARLI) for measuring wind and aerosol profiles from Orbit, *Proc. SPIE* **2018**, 10791, 1079106.

## Design and Field Testing of an Orbital Wind and Aerosol Lidar for Mars (MARLI)

Daniel R. Cremons[1,2], James Abshire[1,3], Xiaoli Sun[1], Graham Allan[1,4], Haris Riris[1], Michael Smith[1], Scott Guzewich[1], Anthony Yu[1], Floyd Hovis[5]

[1] NASA Goddard Space Flight Center, Greenbelt MD 20771; [2] Universities Space Research Association, Columbia MD 21046; [3] University of Maryland, [4] Sigma Space Corporation, Lanham MD 20706; [5] Fibertek Inc., Herndon VA 20171

Corresponding Author: Daniel R. Cremons

Email: daniel.cremons@nasa.gov

Phone: (1) 301-614-6722

**ABSTRACT**

Our understanding of the Mars atmosphere and the coupled atmospheric processes that drive its seasonal cycles is currently limited by a lack of observational and *in situ* data, particularly measurements that capture diurnal and seasonal variations on a global scale. Orbital measurements of height-resolved aerosol backscatter and wind profiles are a high-priority for the scientific community and would be valuable science products as part of a next-generation orbital science package. We have designed and tested a breadboard version of a direct detection lidar to provide global 4D measurements of dust, water vapor, and wind from Mars orbit. The instrument comprises a single-frequency, seeded Nd:YAG laser ring oscillator operating at 1064 nm (4 kHz repetition rate), with a 25-ns pulse duration amplified to 4 mJ pulse energy. The receiver system uses a Fabry-Perot etalon as part of a double-edge optical discrimination technique to isolate the Doppler-induced frequency shift of the aerosol-backscattered laser pulses. To detect weak aerosol backscatter profiles in the Mars atmosphere, the instrument uses a 4x4 pixel, photon-counting HgCdTe APD detector. With the MARLI lidar breadboard instrument, we were able to measure Doppler shifts continuously between 1 and 30 m/s by using a rotating chopper wheel to impart a Doppler shift to incident laser pulses in the laboratory. We then coupled the transmitter and receiver systems to a laser ranging telescope at the Goddard Geophysical and Astronomical Observatory (GGAO) to measure backscatter and Doppler wind profiles in the Earth's atmosphere from the ground. We measured a 5.3 ± 0.8 m/s wind speed from clouds in the planetary boundary layer at a range of 4 to 6 km. This measurement was confirmed with range-over-time measurements as well as compared to EMC meteorological models, which all show good agreement.

**Keywords**: Mars, lidar, wind, remote sensing

# Backup

# Congratulations to the ADM-Aeolus Team!
# First Wind Lidar in Space

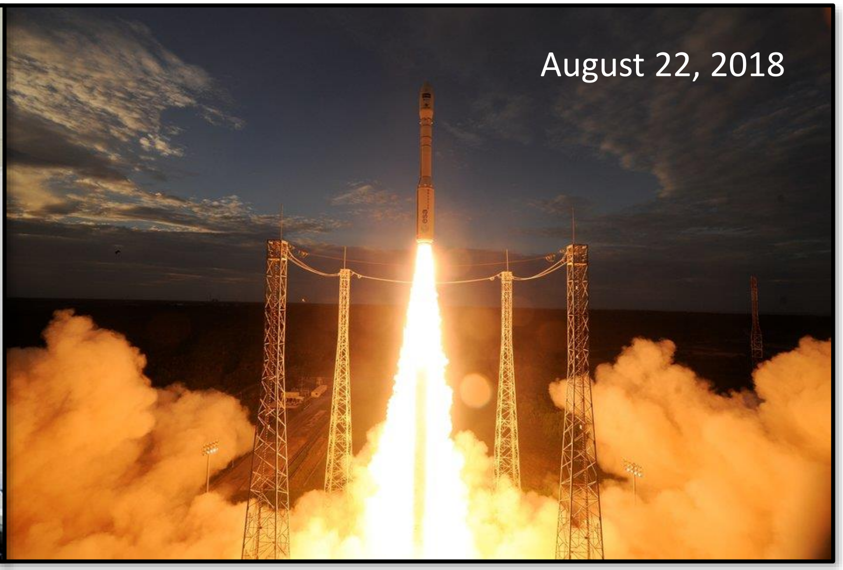




Photo credit: ESA Events

**Wind lidar for Mars atmosphere –vs- ADM-Aeolus for Earth**

- Mars measurement requirements aren't nearly as demanding
- Mie scattering (by fine, suspended aerosols) dominates
- Allows a smaller, simpler lidar working at laser fundamental (1064 nm)
- 1064 nm laser is smaller, simpler and more power efficient
- Very narrow backscatter spectrum simplifies the lidar receiver

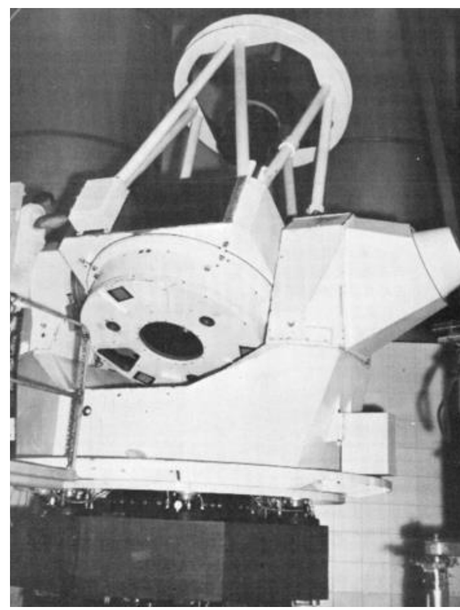
# MARLI backscatter & wind measurement experiments at Goddard's 1.2 m Telescope

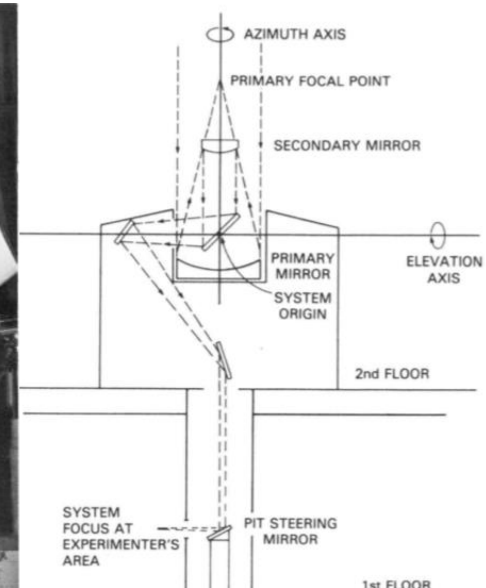
**Laser tracking telescope used in many experiments: satellite ranging, Earth-Mars & -Moon laser detection**

- 1.2 m diameter primary mirror (only partially used here)
- **32 m focal length**
- Elevation over azimuth pointing mount

**Telescope Benefits:**

- Allows lidar measurements to be made over all azimuth & elevation angles
- Site certified for eye safety and laser beams in atmosphere



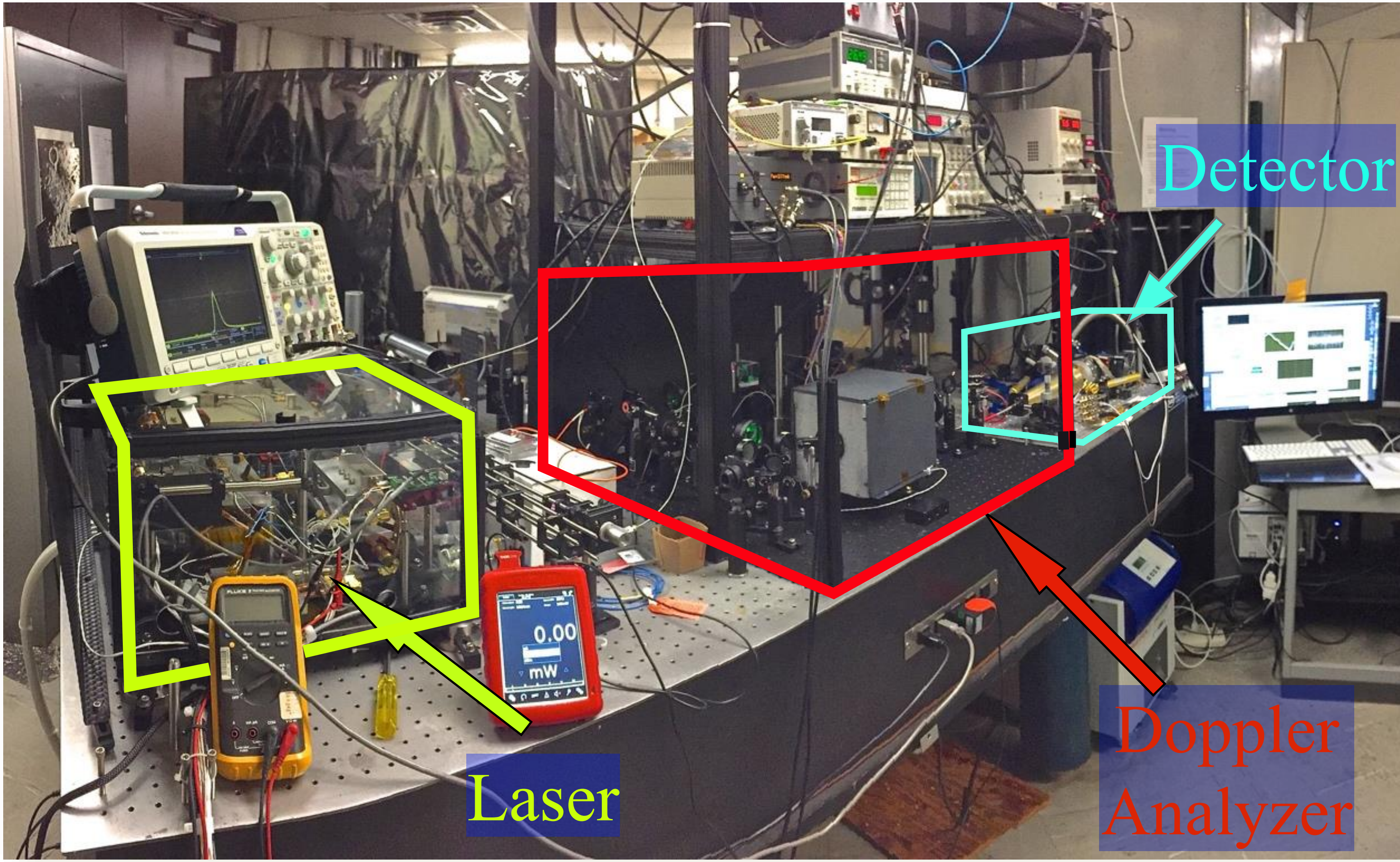



**This telescope added <u>limitations:</u>**

- Optics are challenging for experiment
- Very long focal length, scattering etc., leads to low transmissions
- Receiver share optics with transmit beam, so < 1/3 of primary mirror available

**Don't have these limits with planned 50 cm telescope**

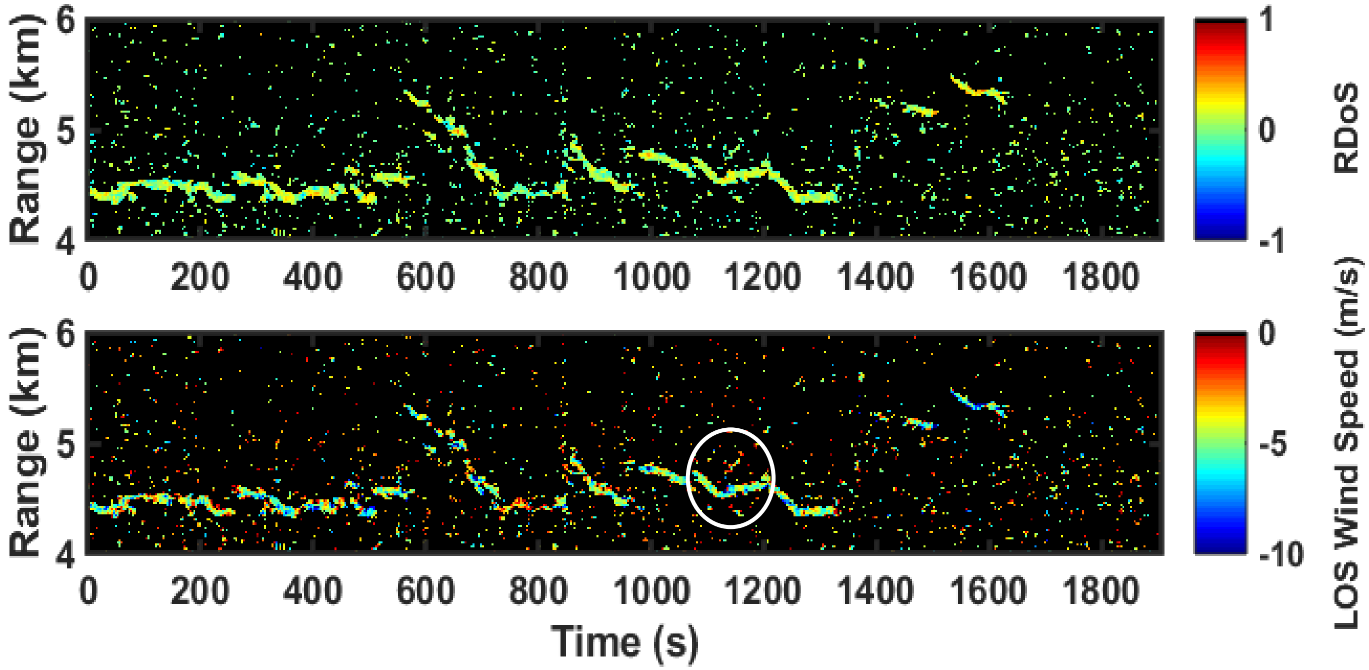
# MARLI Setup in 1.2 m telescope's Coude' room at GGAO

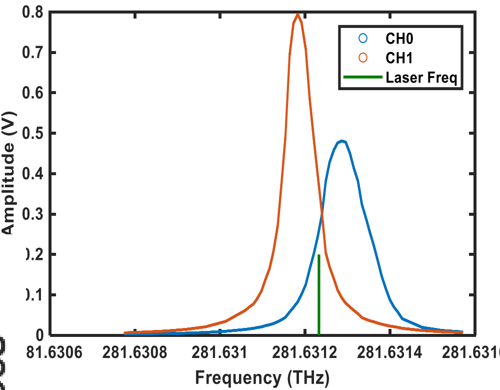


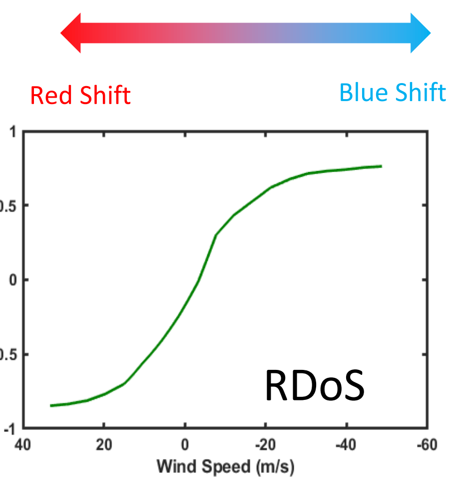
# Initial Doppler Wind calculation from lidar signals through two etalon channels

GSFC

Pulse Energy: 300 µJ, PRF: 4000 Hz Date: 07/29/18
APD Gain: 12 V, 10-s windowed average
Telescope Azimuth: 270° (W),Telescope Elevation: 25°




**Doppler Lidar Measured Wind Speed (at ~1150 sec):**
**-5.3 ± 0.8 m/s (mean over 60 s and 200 m range)**

**Velocity from changing range to approaching cloud : -5 m/sec**