ATHENA-OAWL: Instrument Overview

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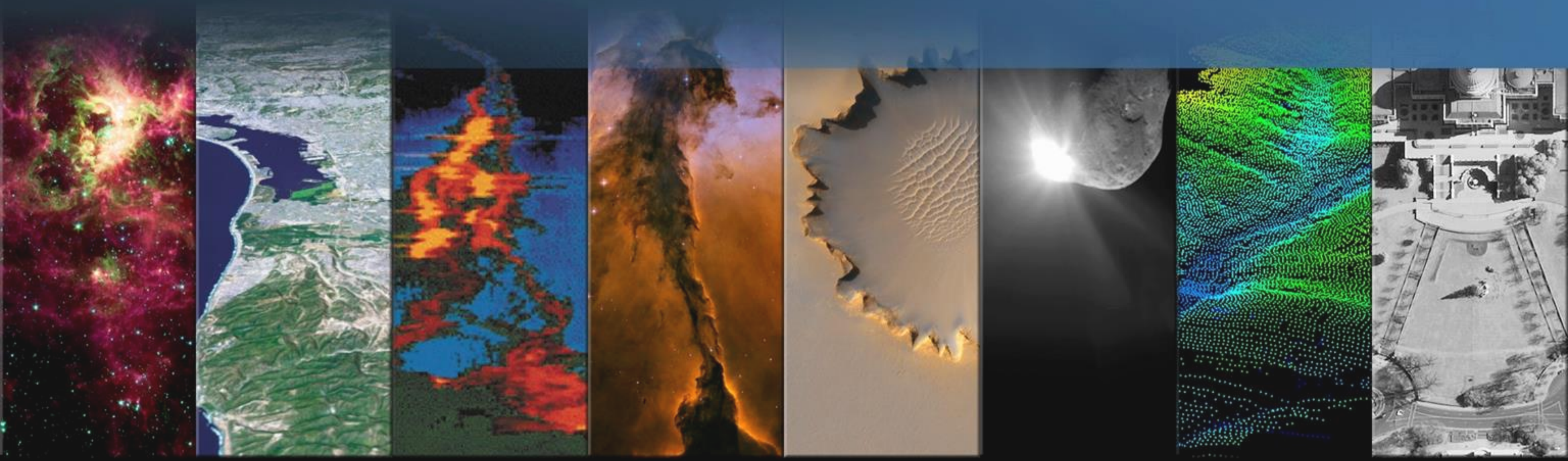

Agility to Innovate, Strength to Deliver

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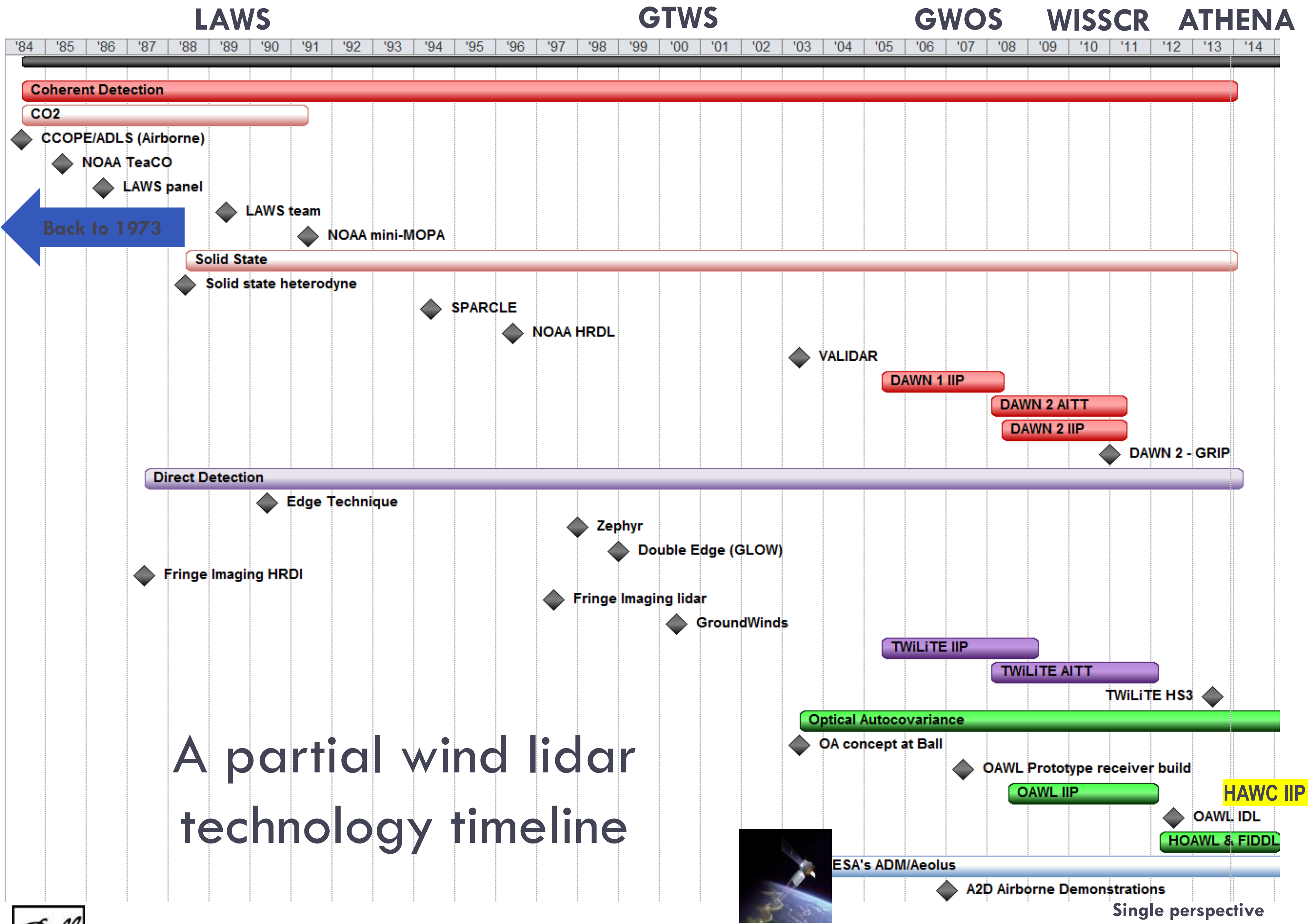
Wind Lidar for Space

A partial wind lidar technology timeline



Space-borne Doppler Wind Lidar Efforts

- >30 years of NASA investments in wind lidar technology

LAWS - 1989	deselected in 1994: cost and technological risk
GTWS – 2001	attempted NASA/NOAA data-buy: user requirements not met
GWOS – 2007	Response to NRC Decadal Survey 3D-Winds (Tier3)
WISSCR – 2011	2-λ hybrid instrument mission concept targeted at NASA's Earth Venture-Mission 1; costs exceeded EV-M cap.
ESTO – ~1999+	Multiple technology investments

- ESA's Aeolus Mission (ADM)
  - Single-perspective line-of-sight winds
  - Expected launch 2015

Status of space-based wind lidar

Advancements

- Ground and Airborne Demonstrations
- Advancements in laser technology
  - UV and near-IR
- Multiple system architecture feasibility studies (IDL)
- Model-related Advancements
  - Forecast advancements enabled by wind data
  - OSSE's demonstrating wind lidar data impact

Challenges

- 3D-Winds *hybrid* system concept: 2 lidars, 2 different lasers, 2 receivers
  - (two systems) High Risk and Cost
- Real and Perceived technical risks in:
  - Optics, Detectors, Electronics, Mechanisms, Spacecraft platform motion, and
  - Lasers
    - Power: pulse energy and frequency
    - Wavelength (optical coatings)
    - Frequency stability
- Need for more wind scientists

ATHENA-OAWL
Instrument Overview

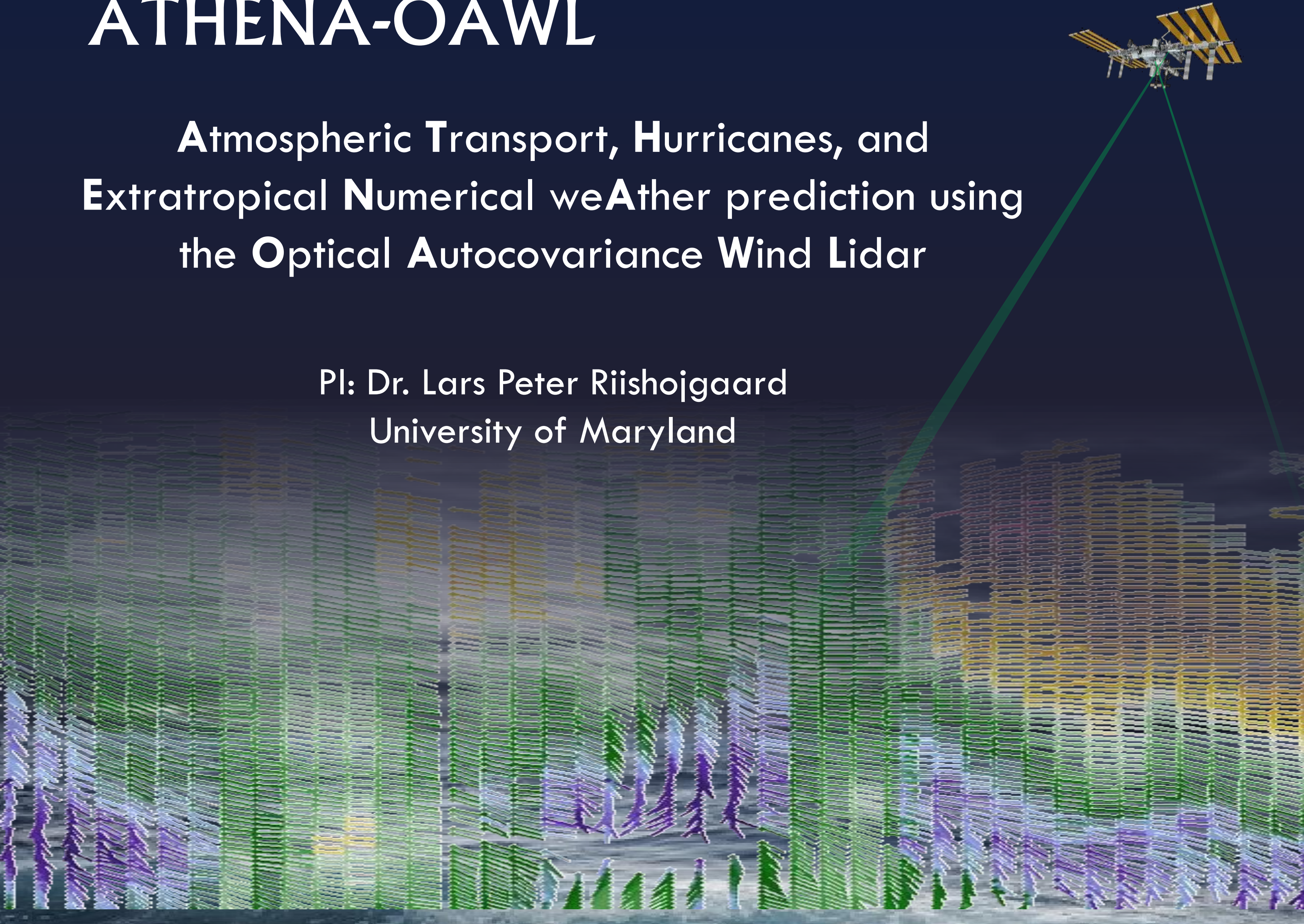
Earth Venture Instrument (EV-I)

- Earth Venture: PI-led Science Driven Missions
  - Science Demonstration – not the 3D-Winds Decadal Survey Mission
- EV-Instrument Cost bucket $94M
- PI Riishojgaard challenged Ball to fit a wind lidar in this cost cap
- Ball has a history of ESSP/Earth Venture:
  - CALIPSO/CLOUDSAT
    - Just celebrated 8 years on orbit (April 28)
    - CALIPSO at well over 4 Billion shots (< $0.35 per 5km profile)
  - TEMPO/GEMS – EVI-1
  - Multiple Earth Venture (mission & instrument) proposals

ATHENA-OAWL

Atmospheric **T**ransport, **H**urricanes, and **E**xtratropical **N**umerical we**A**ther prediction using the **O**ptical **A**utocovariance **W**ind **L**idar

PI: Dr. Lars Peter Riishojgaard
University of Maryland



ATHENA-OAWL Mission Approach

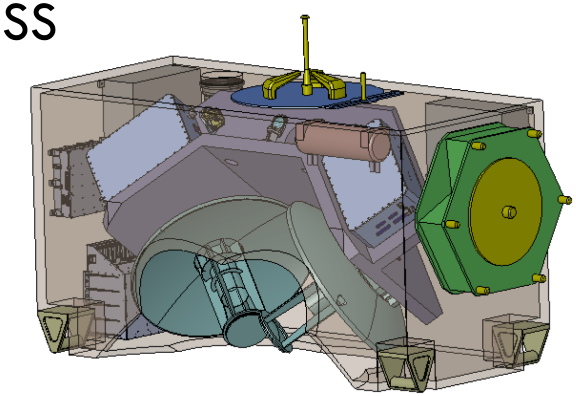
ATHENA-OAWL; path-finding science for next-generation global weather prediction and climate analysis

- Use a design-to-cost approach based on heritage systems
- Meet WMO requirements for "breakthrough" wind measurements
- Compared to the existing radiosonde network:
  - At least double the number of available wind profiles per day…
  - …but provide better spatial distribution

GSFC IDL Study: OAWL on ISS

- ESTO-funded GSFC Instrument Design Lab (IDL) run: demonstrate feasibility of the **355nm** OAWL Instrument on the ISS JEM-EF for a winds mission.

- Conclusions:
  - the baseline OAWL system design for ISS is feasible
  - Many components for OAWL are at high TRL
  - The system can fit within the volume, mass, power, and thermal budgets of a JEM-EF module on the ISS
  - >80% reliability for a 1-year requirement, 2-year goal



OAWL approach offers technical risk solutions

Optical Autocovariance Wind Lidar

- Field-widened Mach Zehnder interferometer receiver
  - Reduced telescope costs.
  - Reduced telescope risks (CALIPSO telescope)
- Flexible wavelength (see below)
- No laser frequency stability requirements
- CALIPSO-like electronics rates reduce risk and cost
- Platform motion removed in processing

355 nm OAWL (2 configurations)

- Aerosol only: high performance in lower trop.

-Or-

- An aerosol & molecular: reduced precision but have coverage from 0-20km+

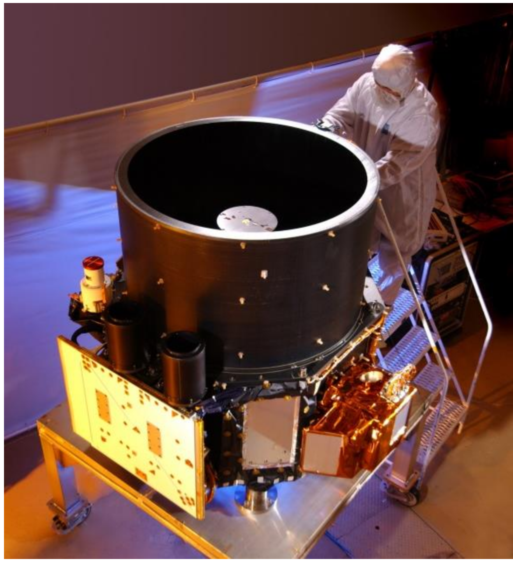
532 nm OAWL

- Aerosol-only
- Makes the most use of high TRL technologies used on CALIPSO

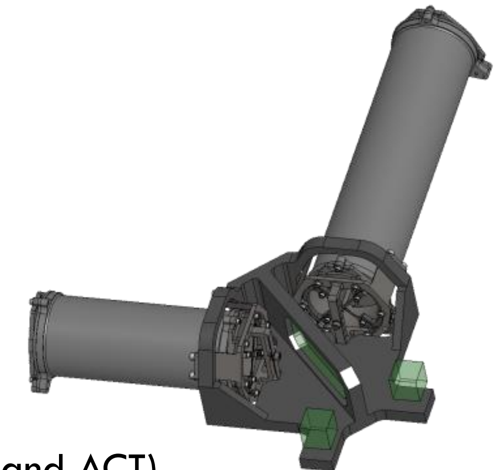
Approach to meeting EV-I Cost Cap

- Take advantage of ISS/JEM-EF enabling technologies:
  - power, mass
  - Cooling loops on JEM-EF
  - TDRSS communications

- Use existing technology - A 532 nm OAWL instrument:
  - Builds on laser development at Fibertek
  - Makes use of many CALIPSO components
    - 532nm optical components: mirrors, telescope, etalon (filter), lenses,
    - Electronics Architectures: e.g. large dynamic range PMT detectors
    - Software architecture and code reuse



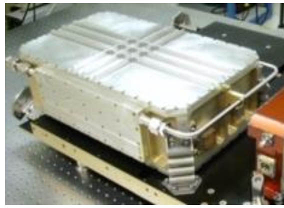
Approach to meeting EV-I Cost Cap, cont'd.



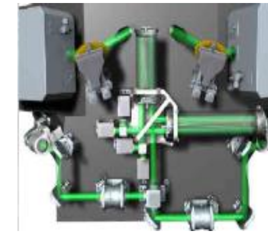
- Incorporate low-risk recent advances:
  - Internal Research and Development at Ball
    - OAWL system development at 355 and 532 nm
    - Athermal OAWL Interferometer design
    - Real-time FPGA-based wind processing
  - NASA ESTO investments
    - OAWL demonstration and validation efforts (IIP and ACT)
    - OAWL IDL and OSSE studies
    - Fibertek Lasers
- Program Management: University of Maryland
- Science Team: University, NASA, NOAA, Industry, and International communities bring diversity and agency support to the mission
- Balance science, engineering, and cost in the development of the Science Traceability Matrix

THE ATHENA-OAWL INSTRUMENT

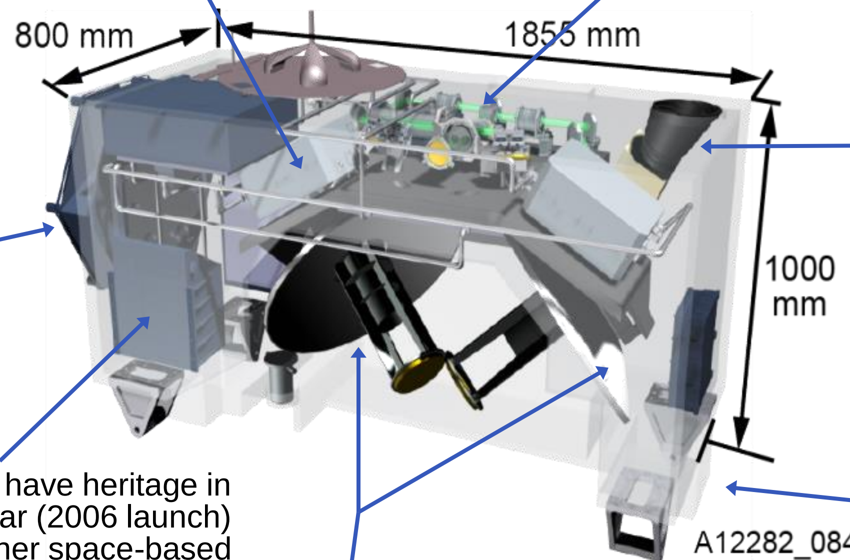
Fibertek 532 nm laser based on ESTO-funded HEUVD



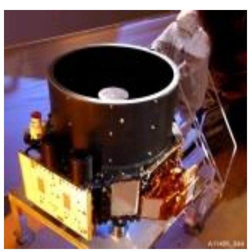
Proven OAWL interferometer system



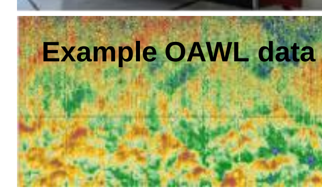
ISS enabling capabilities: TDRSS, cooling loop, etc.



TRL-9 Star tracker system for pointing knowledge

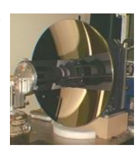


Many components have heritage in the CALIPSO lidar (2006 launch) and other space-based missions

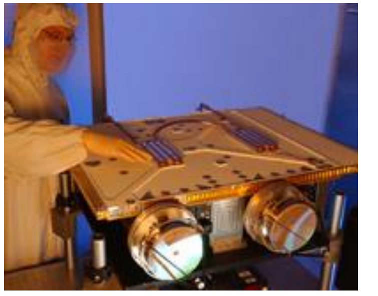


Autonomous OAWL IIP system: NASA WB-57 pallet (2011) - on par with JEM-EF mass, volume, power and cooling approach.

two light-weighted GDIT (Axsys) telescopes (CALIOP, CATS, and GLAS)



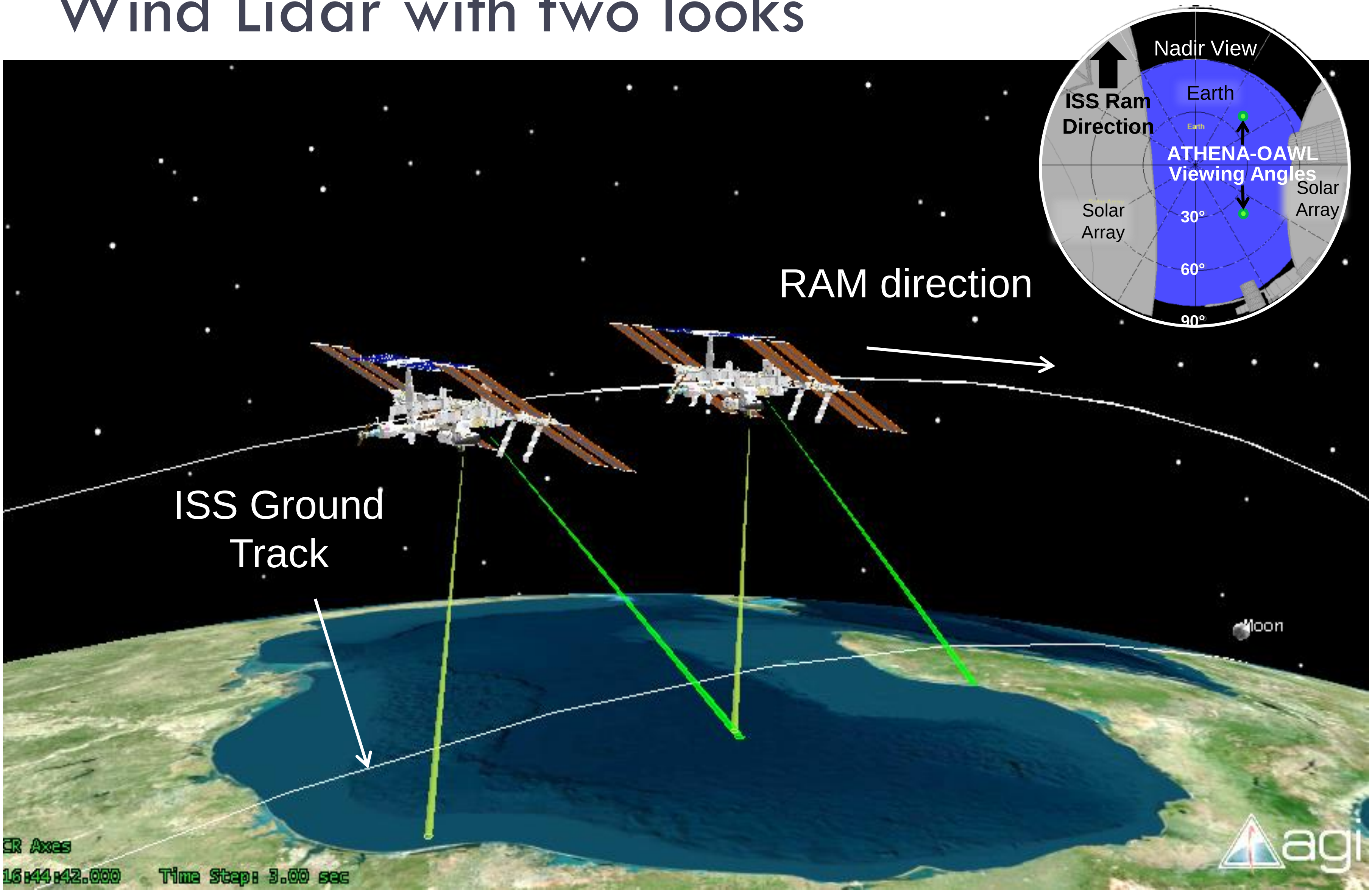
ATHENA-OAWL Laser



- 532 nm wavelength
  - Technology is ready and demonstrated through CALIPSO
    - CALIPSO: 8 years on orbit, over 4 Billion shots
    - CALIPSO: 110 mJ/20 Hz
    - ATHENA-OAWL: 160 mJ/150 Hz (~8x)
  - The same eye-safety is achieved through additional divergence
- 532 is a good trade on high aerosol backscatter cross-section vs. extinction
  - See next talk (Emmitt) on high altitude aerosol profiles at 532 nm
- Build on the ESTO-funded Fibertek HEUVD (High Efficiency UV Demonstrator)
  - The Fibertek HEUVD will also demonstrate high 532 nm power
  - Waiting for final results of the 355 nm HEUVD system before committing to proposing a space-based UV system
  - Minimal additional testing of the HEUVD to demonstrate TRL 6 for the 532 nm ATHENA-OAWL lasers

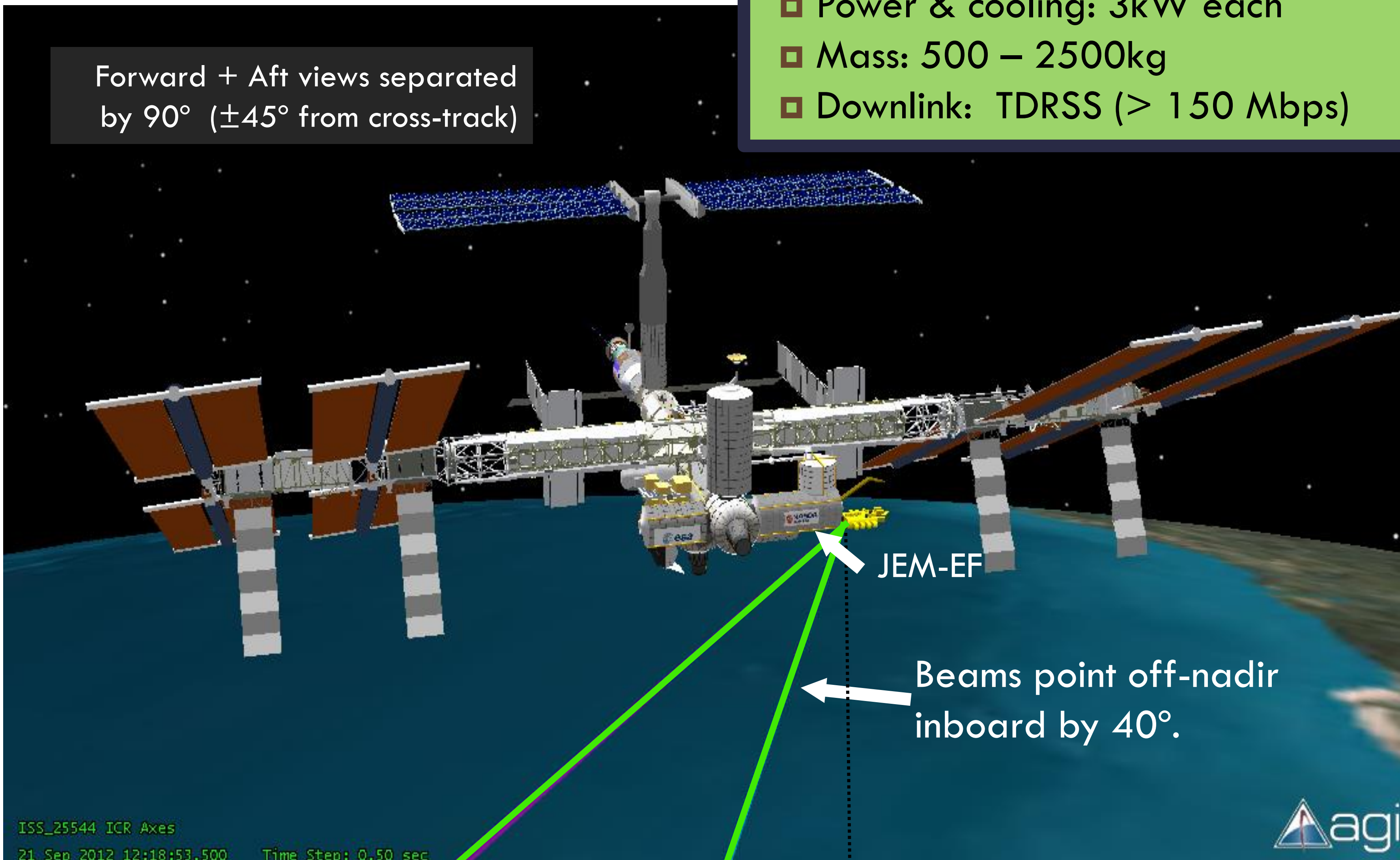
FIBERTEK, INC.

Wind Lidar with two looks



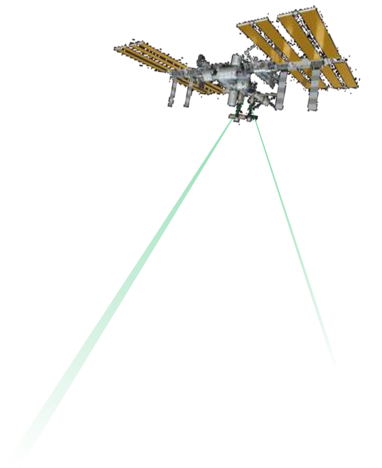
Wind Lidar on ISS JEM-EF

ISS & JEM-EF modules provide
- Volume: 1.86m x 1.00m x 0.80m
- Power & cooling: 3kW each
- Mass: 500 – 2500kg
- Downlink: TDRSS (> 150 Mbps)



Proposal effort highlights/results

- A tremendous amount of work to put this together
  - Built on Ball experience with EV proposals
  - Able to incorporate experience from TEMPO contract
- Better understanding of the ISS capabilities and resources
  - Several former JSC/ISS employees now at Ball
  - Numerous conversations with JSC/ISS program office representation
  - Unearthed lots of ISS documentation (not provided by the IDL)
- Completed system designs and architecture to greater fidelity than provided to and approved by the IDL
- Athermal interferometer design:
  - Looking for funding to build prototype which, …
  - If demo built, it could be used on HAWC-OAWL
- Completed thermal analysis and analysis of beam pointing and vibe effects on overall system accuracy and precision
- Now have aerosol profiles and OAWL performance prediction for **532 nm**
- Built a scientifically diverse science team with strong scientific goals



ATHENA-OAWL and CALIPSO

System parameters:

Instrument Parameter	CALIPSO	A-OAWL
Wavelength(s)	1064 nm and 532 nm	532 nm
Laser Energy @ 532 nm	110 mJ (per wavelength – 220 mJ total)	160 mJ of 532
Laser PRF	20 Hz	150 Hz
Telescope Diameter	1 m	0.7 m
Background Light Filtering	30 pm etalon filter and 1 nm interference filter	Same
Detector Type	PMT, QE 0.15	PMT, QE 0.18
Orbit Altitude	705 km	~400 km
Pointing Angle	0.3°-3.0° off nadir	40° off nadir
Sample gates (both 23 bit)	30 m	30 m

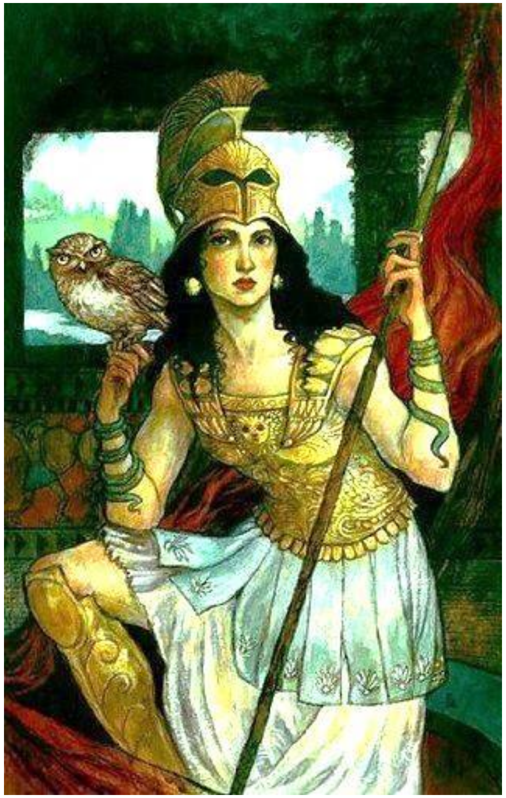
Aeolus, ATHENA (and CALIPSO): A Wind Lidar Odyssey

	ATHENA	AEOLUS
Wavelength	532 nm	355 nm
Laser	Pressurized Canister (CALIPSO heritage) 150 mJ (160Hz) of **532**, consistent with CALIPSO	Not pressurized, now with oxygen flow 110 mJ (100 Hz) of **355**
Frequency Stability	OA approach – no transmitter/receiver locking High speed sampling removes	Transmitter frequency locking: On-chip accumulation requires 4MHz (over 7s) frequency stability
Return Signal	Aerosol (HSRL)	Aerosol & Molecular (HSRL)
Orbit/Platform	~400km/ISS: Power/Mass/TDRSS comm.	408km/Free Flyer
Mission	1-2 years	3 year
Field Overlap	Field widened Mach-Zehnder → Wide FOV biaxial system OK	No field-widening → requires narrow FOV (22μrad) and strict field overlap control → coaxial design with shutter for detectors.
Telescope/looks	Two–looks, with 0.7m CALIPSO heritage telescope	Single look, 1.5m SiC telescope
Pointing	Requires Platform Knowledge	Spacecraft pointing control

ATHENA as a follow-on to Aeolus → both leading to a 3D-Winds mission

Summary

- A wind lidar in an Earth Venture is challenging, but made possible, by:
  - Building on successful system(s) including CALIPSO
  - Employing ISS enabling technologies: power, mass, coolant, & communications
  - Efficient management approach
  - Ball and ESTO investments



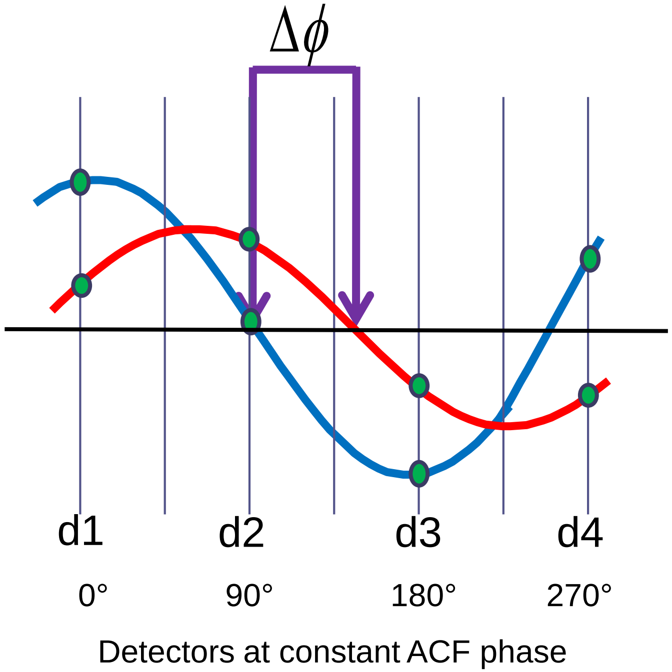
The ATHENA-OAWL Mission offers a design-to-cost approach to meeting WMO requirements for the missing wind observations.

Thank you

Extras

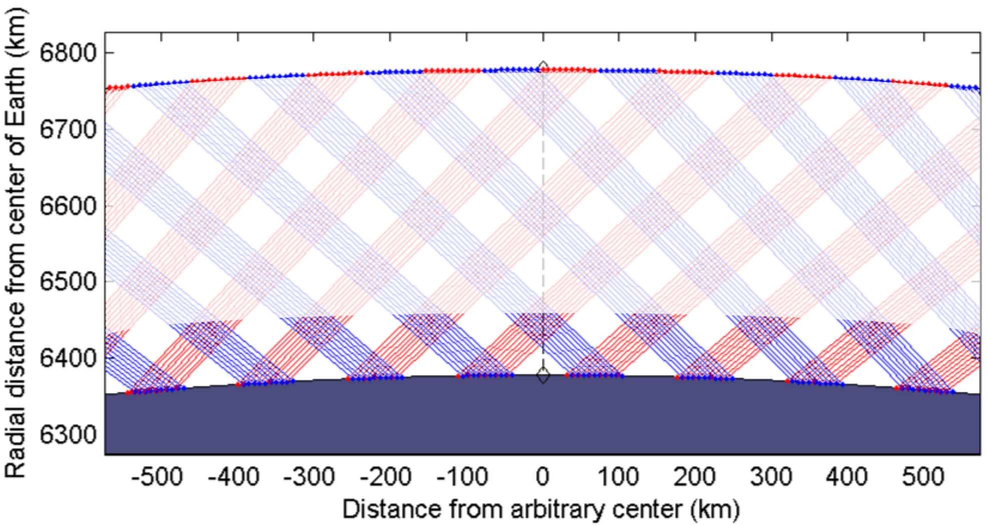
OAWL Interferometer Fringe Measurement

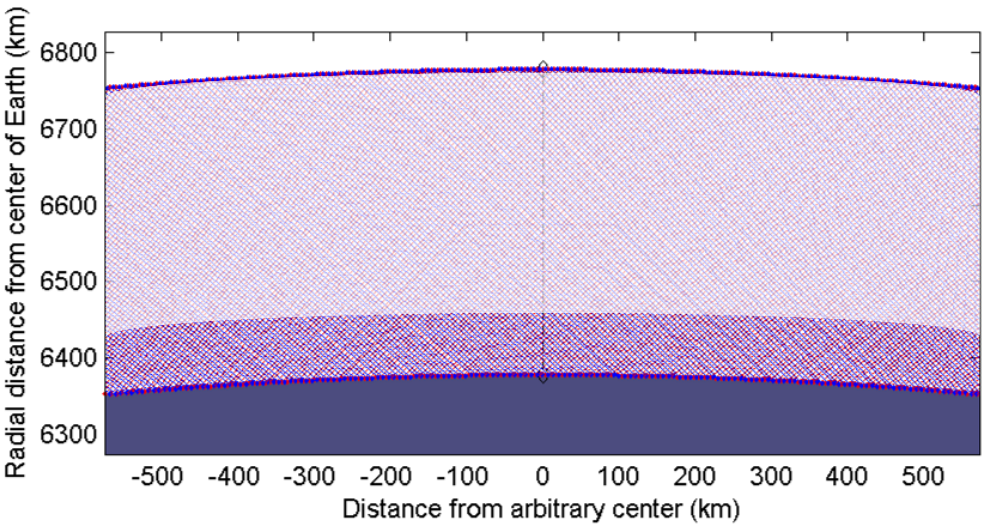
- Four channels sample the interferometer fringe phase and contrast.
  - -- Outgoing "T0" pulse
  - -- Atmospheric Return
- The relative **phase shift** correlates to the **wind-** induced Doppler shift.
- The change in **fringe contrast** corresponds to the **aerosol loading**



Lidar beam geometry from 400 km orbit

- ±45° (forward and aft) beams (40° off nadir).
- **OPTION 1**: Mechanism switches beams between forward & aft telescopes.
  - overlap is periodic
  - Predefined accumulation areas (~72 km wide)
- ✓ **OPTION 2**: two lasers, one per telescope.
  - Overlap is continuous
  - allows for variable horizontal averaging
  - No high speed mechanism required.





OAWL GSFC Instrument Design Lab Study

- Output Summaries for the more challenging 355 nm system

- **Laser**: "TRL5 can be reached quickly by simply building a final form, fit, and function unit at Fibertek. Then pursuit of TRL6 can begin with Flight Qual."
- **Electrical**: "No electrical tall poles or low TRL concerns."
- **Flight Software**: "Line Of Code estimation shows 79% code reuse for MEB. High heritage based on Ball/GSFC approach. …No technical show-stoppers"
- **Mechanical**: "It fits! Re-packaged the optics and telescopes to fit within the JEM attached payload envelope."
- **Optical**: "Beryllium telescopes have a lot of flight heritage for this spaceflight application and should be considered high TRL. 355 nm operating wavelength poses minimal risk to design due to proven Ni plating technology and HR coatings.
- **Detectors**: "PMTs have flown on many space flight missions including the Compton gamma ray telescope…Thermal cycling and radiation effects are not an issue…TRL of these PMTs is TRL-5"
- **Reliability**: "Instrument exceeds 80% Reliability at 1 year operation with lower confidence limit in excess of 70%. Degraded Science (one laser) Reliability exceeds 95% at 1 year operation."