Decadal Survey Tier 2 Mission Study
Summative Progress Report

ACE Lidar

16 November 2010

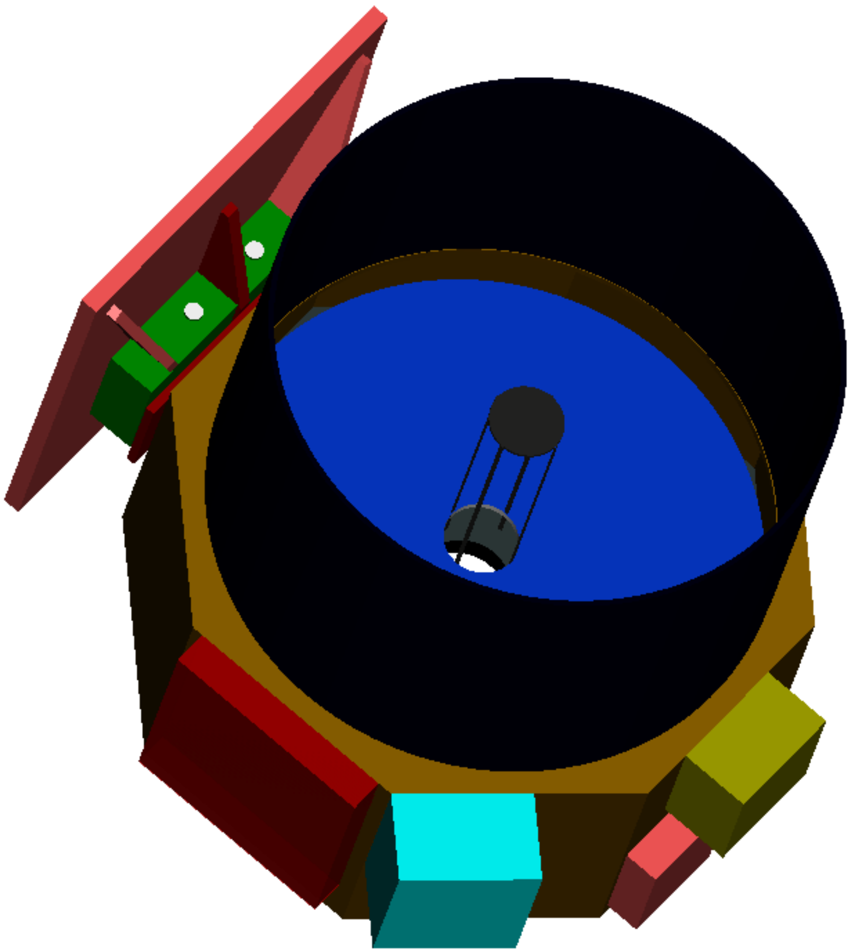
Lidar Addresses "A", "C", and "E" of ACE

- Aerosol
  - Vertically resolved optical, macrophysical, and microphysical properties
  - Vertically resolved aerosol type and amount
  - Column AOD: complex scenes and no cloud 3-D effects
- Cloud
  - Top and base heights
  - Phase
  - Extinction and optical depth
- Ocean Ecosystems
  - Aerosol correction for Ocean Color Radiometer
  - Aerosol measurements for ocean-aerosol science
  - Goal: Subsurface backscatter and extinction → NPP
  - Goal: Surface mean square slope → CO_2 air-sea exchange

Driving Requirements

- Aerosol requirements drive lidar design
  - Cloud measurements require fewer channels but impact dynamic range
  - Ocean surface/subsurface measurements maintained as *goals* rather than requirements to avoid impacting aerosol/cloud requirements or driving cost
- Driving requirements are for vertically-resolved aerosol macrophysics and microphysics:
  - Aerosol size
  - Index of refraction
  - Single scatter albedo/absorption
  - Concentration
- Baseline to meet requirements is $3\beta+2\alpha+2\delta$ lidar

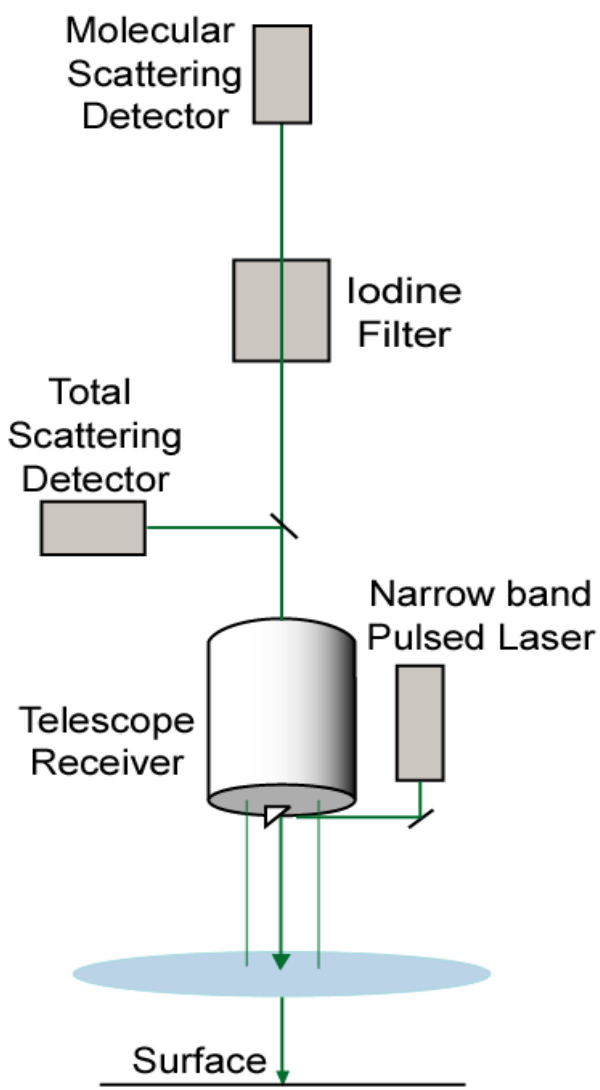
ACE Baseline Concept: *3β+2α+2δ* High Spectral Resolution Lidar (HSRL)



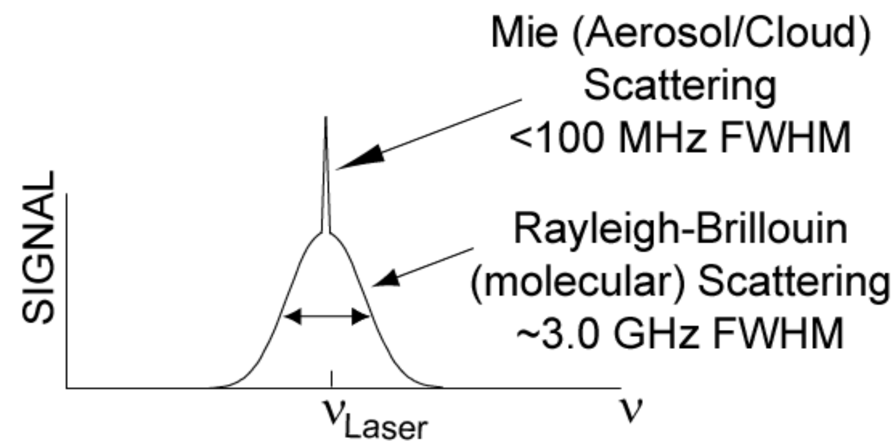
One of many possible realizations:
Transmitter: 25 W average power
Telescope: 1.5-m diameter

- Measurements
  - Backscatter at 355, 532, 1064 nm **(3β)**
  - Extinction 355 and 532 nm **(2α)**
  - Depolarization at 2 wavelengths **(2δ)**
  - Goal: ocean surface/subsurface at 532 nm (backscatter and Brillouin scatter)
- Products
  - Lidar-only retrieval of aerosol optical and microphysical properties, cloud optical properties, and aerosol/cloud vertical distribution
  - Lidar + polarimeter retrievals of aerosol optical and microphysical parameters
  - Lidar + radar cloud retrievals
  - Lidar-only retrievals of ocean surface mean square slope (air-sea gas exchange estimates)
  - Lidar-only retrievals of ocean subsurface beam attenuation coefficient

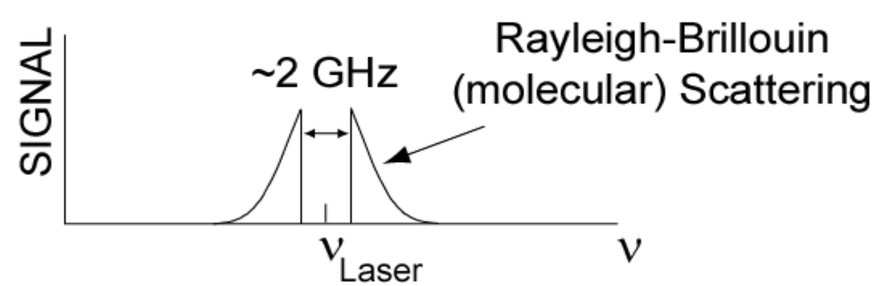
High Spectral Resolution Lidar (HSRL) Technique (Iodine Vapor Filter Implementation)



Atmospheric Scattering



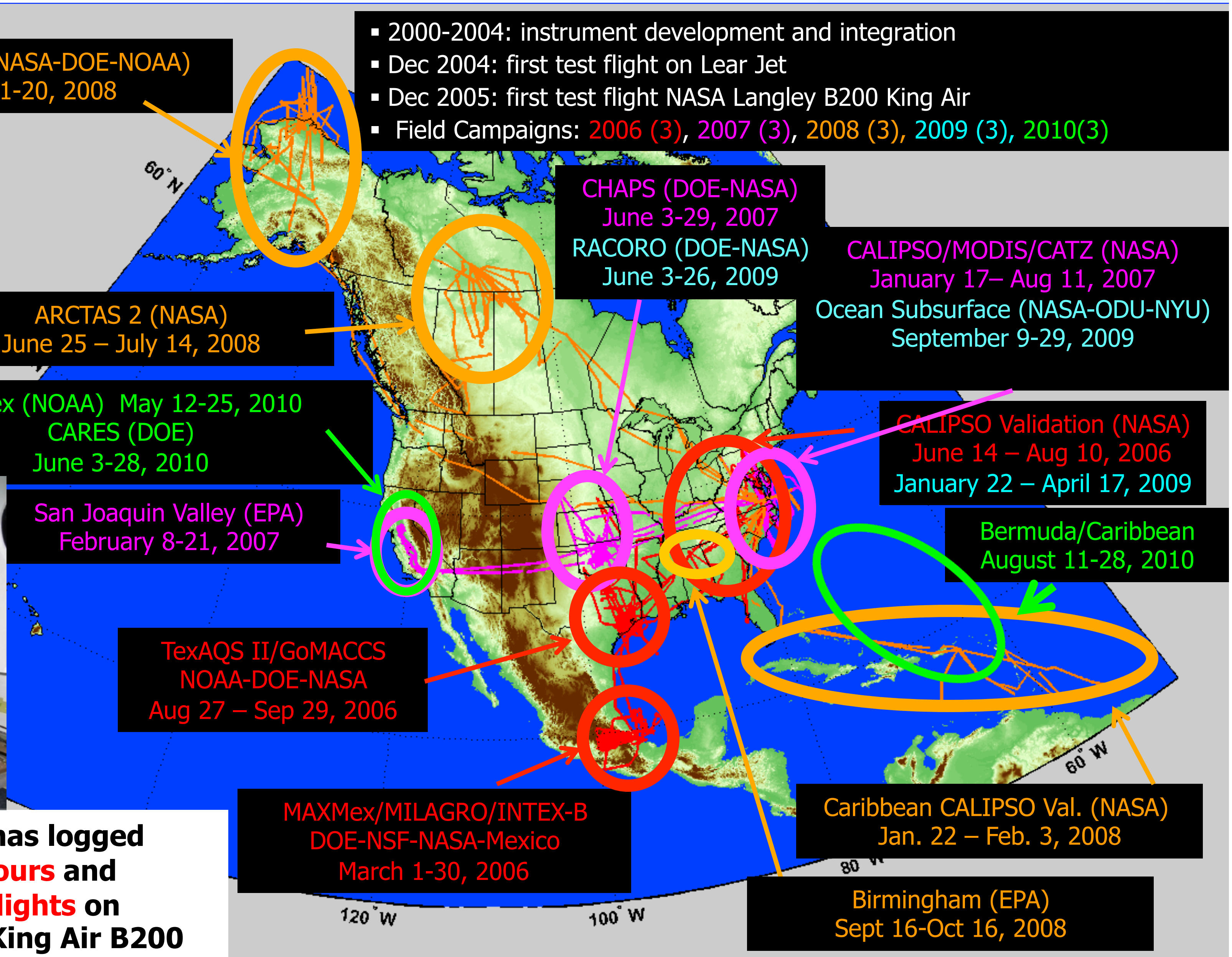
Effect of Iodine Vapor Notch Filter




ACE lidar architecture could be based on an evolution of CALIOP on CALIPSO …
CALIOP:
Backscatter: 532 and 1064 nm
Polarization Sensitive: 532 nm

… and the NASA Airborne 2β+1α+2δ HSRL

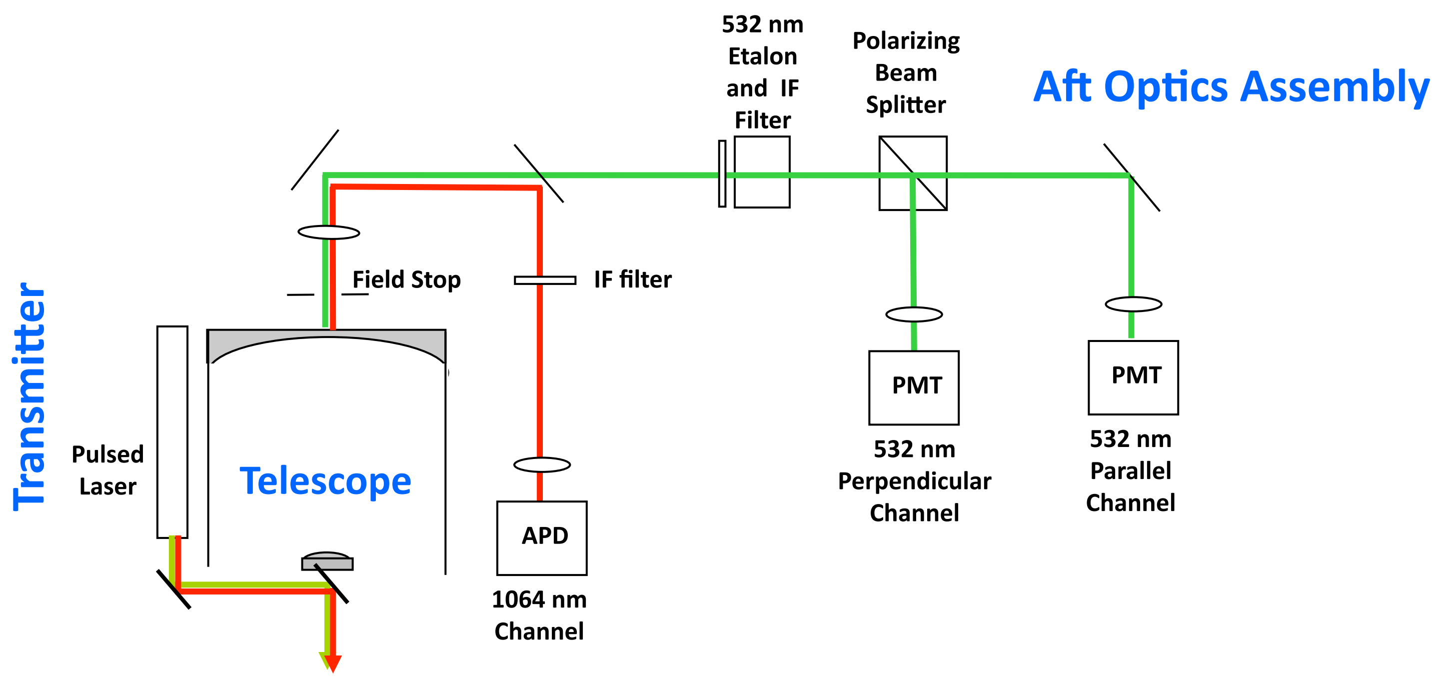
- 2000-2004: instrument development and integration
- Dec 2004: first test flight on Lear Jet
- Dec 2005: first test flight NASA Langley B200 King Air
- Field Campaigns: 2006 (3), 2007 (3), 2008 (3), 2009 (3), 2010(3)



Airborne HSRL has logged 1024 flight hours and 331 science flights on NASA Langley King Air B200

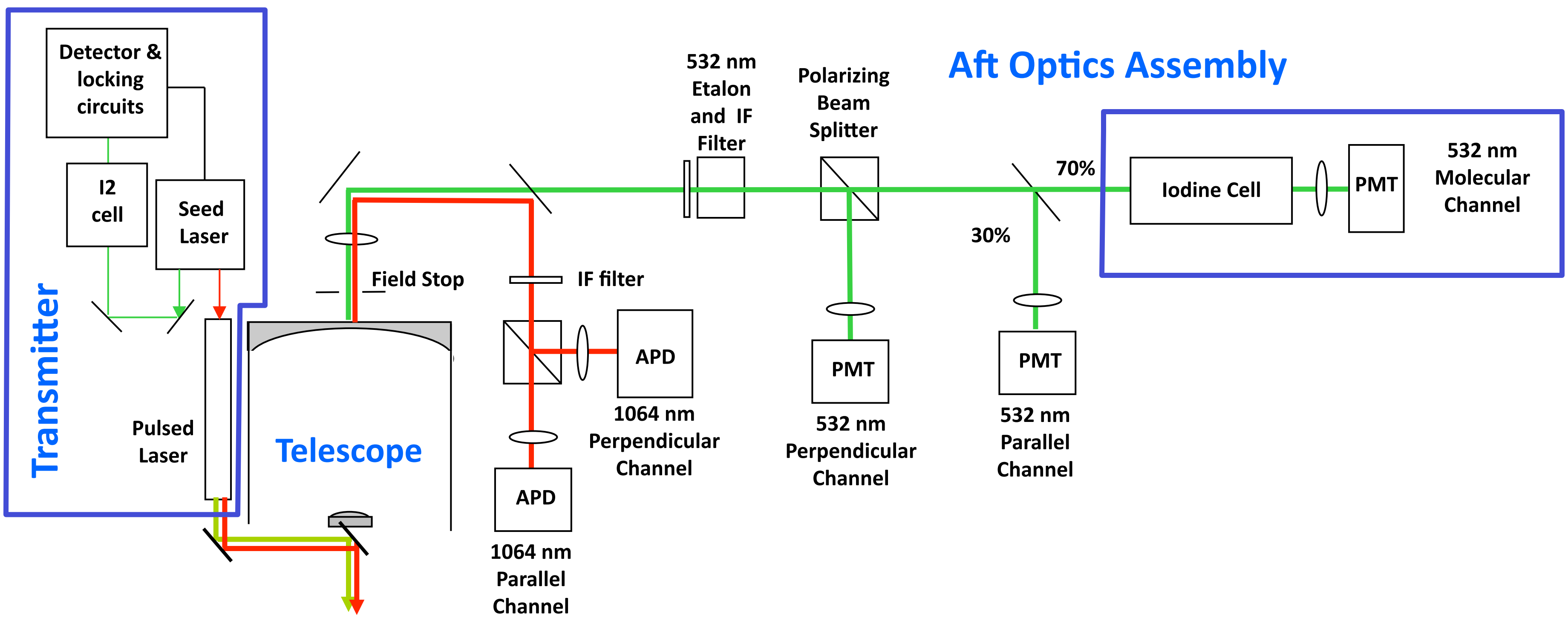
CALIOP on CALIPSO: *2β+1δ*

- Robust design
- 4.5 years near flawless operations!



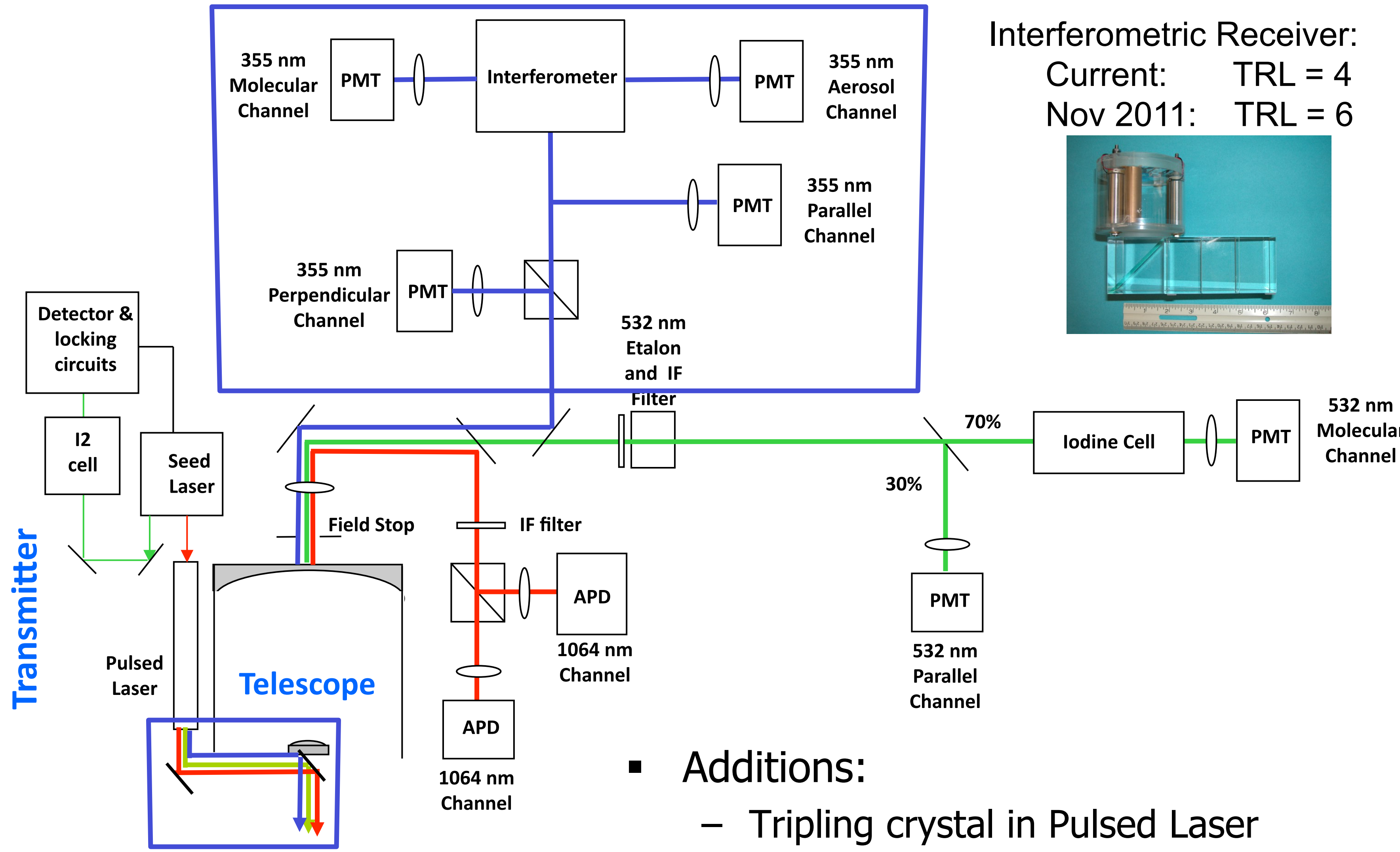
Existing Airborne HSRL: *2β+1α+2δ*

- Additions:
  - SLM laser with seed laser and frequency locking to an iodine absorption line
  - Iodine cell and extra detector in receiver
- As flown on B200 for 5 years (>300 flights)



3β+2α+2δ HSRL (one possible realization)

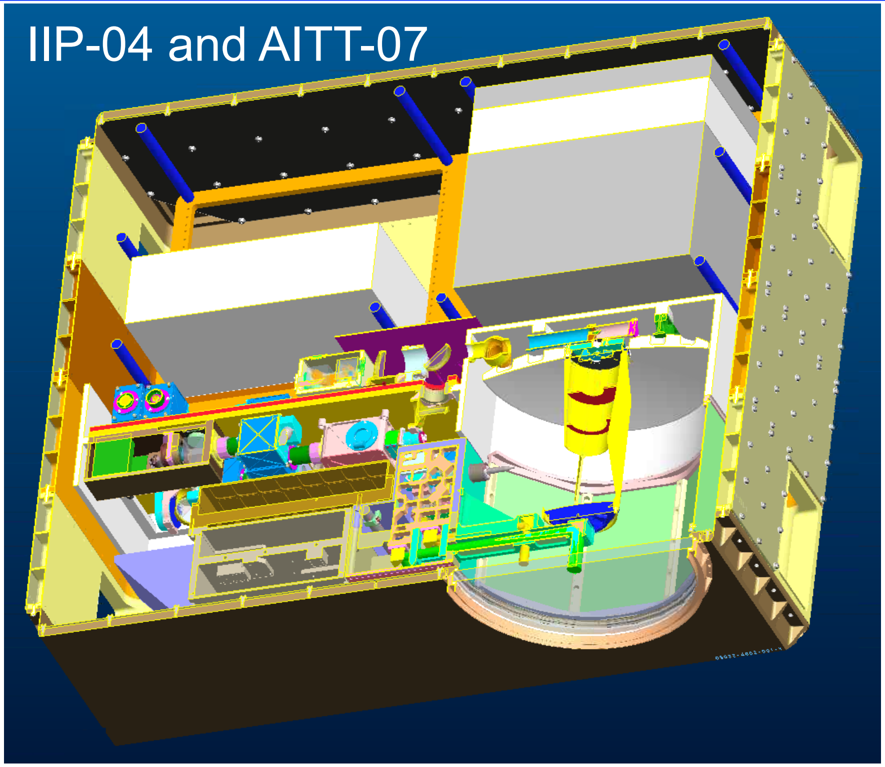
Interferometric Receiver:
Current: TRL = 4
Nov 2011: TRL = 6



Pulsed Laser: TRL= 6

- Additions:
  - Tripling crystal in Pulsed Laser
  - Interferometric HSRL receiver at 355 nm
- Prototype being built for ER-2

ACE Lidar Simulator Being Developed for ER-2



- Developing a $3\beta+2\alpha+3\delta$ HSRL and ACE aerosol algorithms
- Plan to fly on SEAC4RS (2012) and other field missions:
  - Demonstrate technology
  - Validate $3\beta+2\alpha+2\delta$ lidar-only aerosol retrievals
  - Investigate combined lidar+polarimeter retrievals of aerosols and clouds
  - Investigate combined lidar+radar retrievals of clouds

Risks

Risk	Recommended Mitigation
Laser Lifetime • Unknown whether coatings/crystals suffer long-term degradation at UV	Initiate laser lifetime testing project similar to CALIPSO Risk Reduction Laser. Determine if laser damage is a problem; if so, identify mechanism and develop solutions. 18-month program; recommend starting immediately.
Interferometric Receiver • Increased optical and calibration complexities compared to extensively demonstrated vapor filter technique	Several promising approaches being developed by Ball, Michigan Aerospace, GSFC, and LaRC: ground-based measurements have been demonstrated. Assess candidate approaches ground and airborne demonstrations.
Detectors • Detectors of desired performance at 532 and 355 nm require space qualification	Invest in space qualification of candidate detectors and down-select.
Retrievals • $3\beta+2\alpha+2\delta$ aerosol microphysical are slow and not autonomous • Retrievals for nonspherical particles demonstrated but less mature • Validation of retrievals has been limited	Continue ongoing investments toward: • Making retrievals more accurate, robust, and autonomous • Generating more accurate error estimates • Enhancing with alternate approaches (Principal Component Analysis, lidar+polarimeter, etc.) Validate retrievals from airborne prototype lidar with coincident in situ and remote sensing measurements

Technology Investments

Award Type	Topic	Institution
IIP-04	Multiwavelength HSRL and Ozone DIAL	LaRC
IIP-07	Optical Autocovariance Wind Lidar	Ball
ACT-08	CATS detector development	GSFC
ATI-10	High QE EMCCD detector assessment	LaRC
AITT-09	CATS aircraft integration	GSFC
AITT-07	Transition of multiwavelength HSRL to ER-2	LaRC
AITT-09	Co-flight of enhanced HSRL and RSP on P3	LaRC
SBIR	Injection-seeded pulsed laser development	Fibertek
SBIR	Seed laser technologies	AdVR
SBIR	FPI-based HSRL receiver	Michigan Aerospace

Other proposals pending under IIP.   Future proposals anticipated to ACT, IIP, AIST, etc.

Summary

- *3β+2α+2δ* HSRL required to meet mission objectives
- Instrument could be based on evolution of
  - CALIOP on CALIPSO
  - HSRL-1 on B200 aircraft
- Other instrument approaches exist and may prove superior; will be further assessed through ongoing ESTO projects, pre-phase A, and phase A studies.
  - Fabry-Perot interferometer approach (GSFC and Michigan Aerospace)
  - Optical autocovariance approach (Ball Aerospace)
- Risk
  - No showstoppers
  - Recommendations
    - Starting laser lifetime study immediately (ala CALIPSO Risk Reduction Laser)
    - Continuing ongoing work on prototype technologies
    - Continuing ongoing work on *3β+2α+2δ* retrievals: automation, augmentation, and validation against other measurements