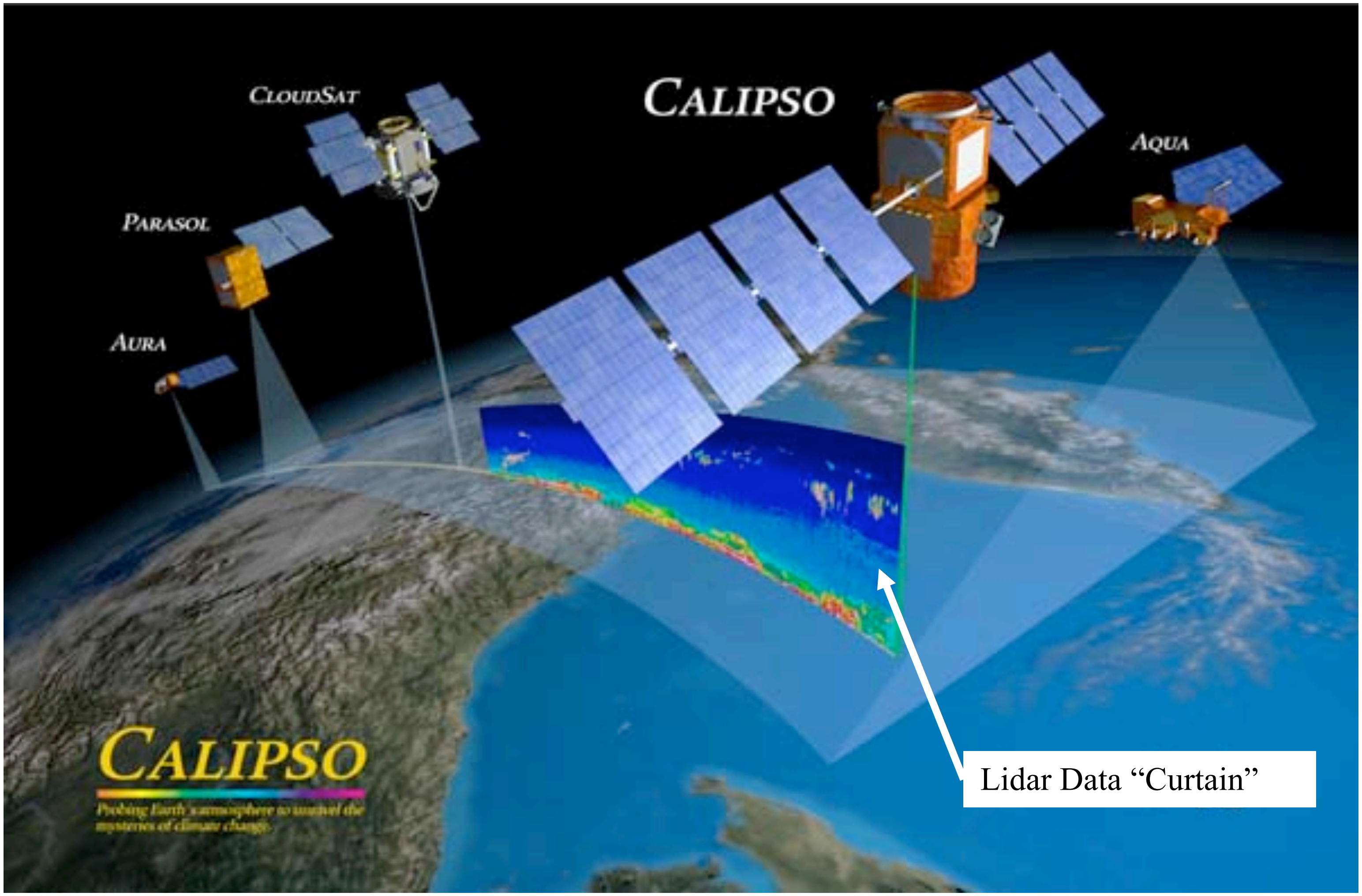
# CALIPSO On-Orbit - Lidar

**Cloud - Aerosol Lidar and Infrared Pathfinder Satellite Observations**




***Carl Weimer 11/10/08***

# Outline

- **Why CALIPSO?**
- **Some Early Science Results**
- **Selected Engineering Results**

Principal Investigator – David Winker – NASA LaRC

Co-PIs – Patrick McCormick (Hampton University) and Jacque Pelon (IPSL)

NASA - Ball Payload

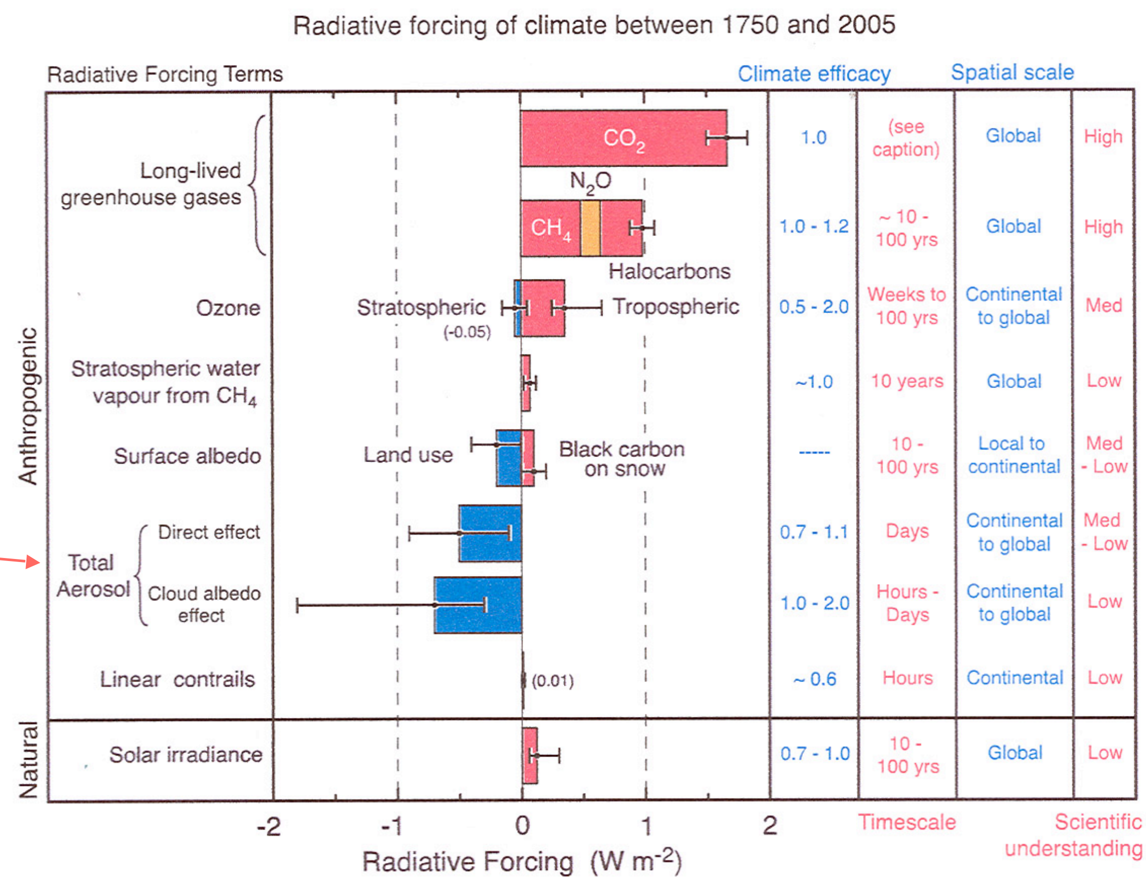
CNES – Alcatel Proteus Spacecraft

**Summary: The CALIPSO Satellite has three instruments including the CALIOP Lidar. CALIOP is a two-wavelength (532 /1064 nm) polarization-sensitive Rayleigh-Mie lidar. Launched April 29, 2006**

# Scientific Need for CALIPSO

**Scientists understanding of human impact on the Earth's Radiation Budget - Global Warming**

CALIPSO
Will Help
Address

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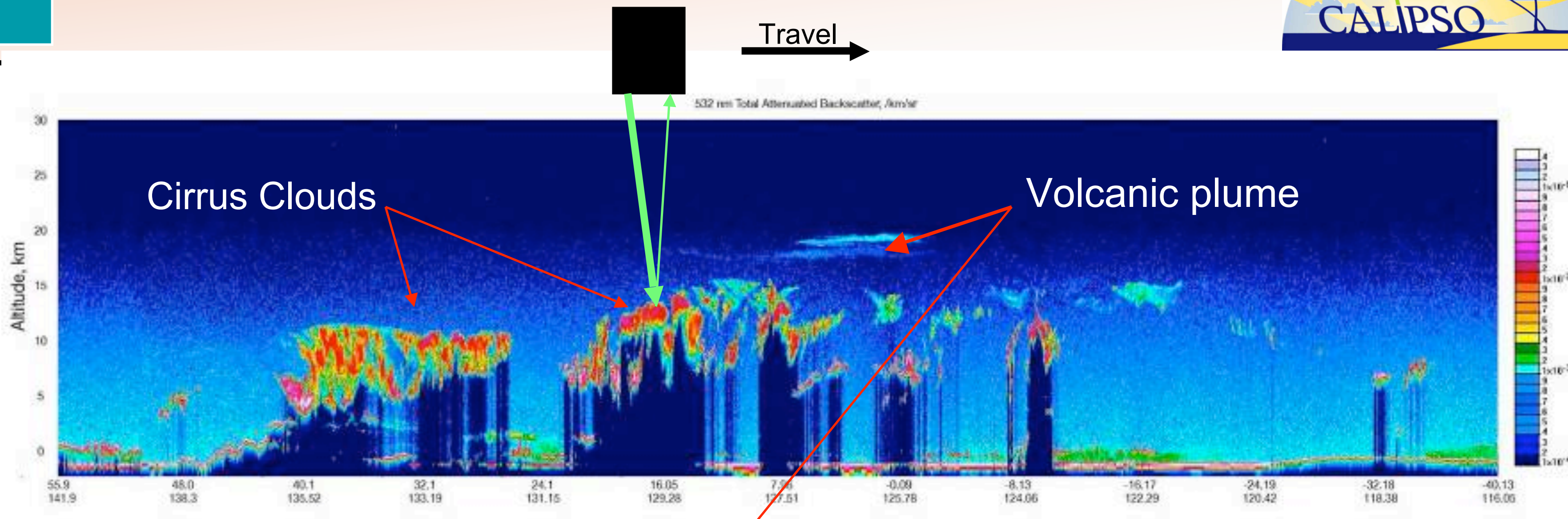
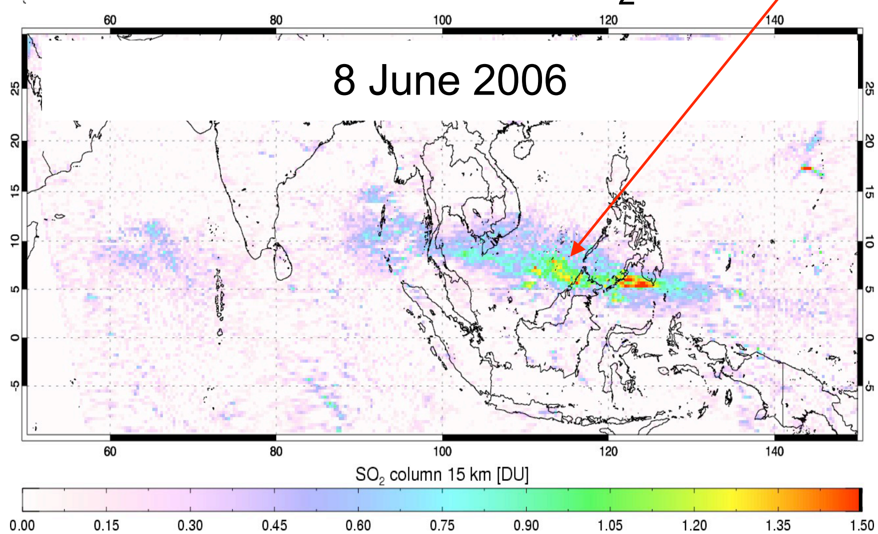
**CALIPSO offers unique contributions to help address important questions in climate change and air quality. New applications are being explored (e.g. Ocean)**

# CALIPSO Lidar First Light (from NASA LaRC)

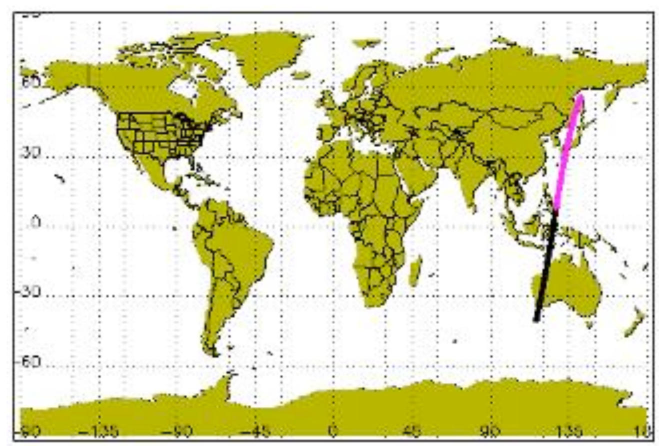



Aura/OMI Column $SO_2$



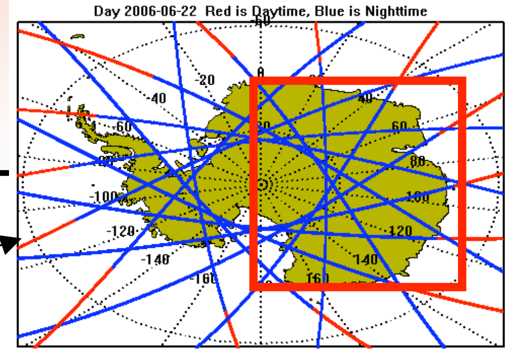

CALIPSO Orbit Track

7 June 2006



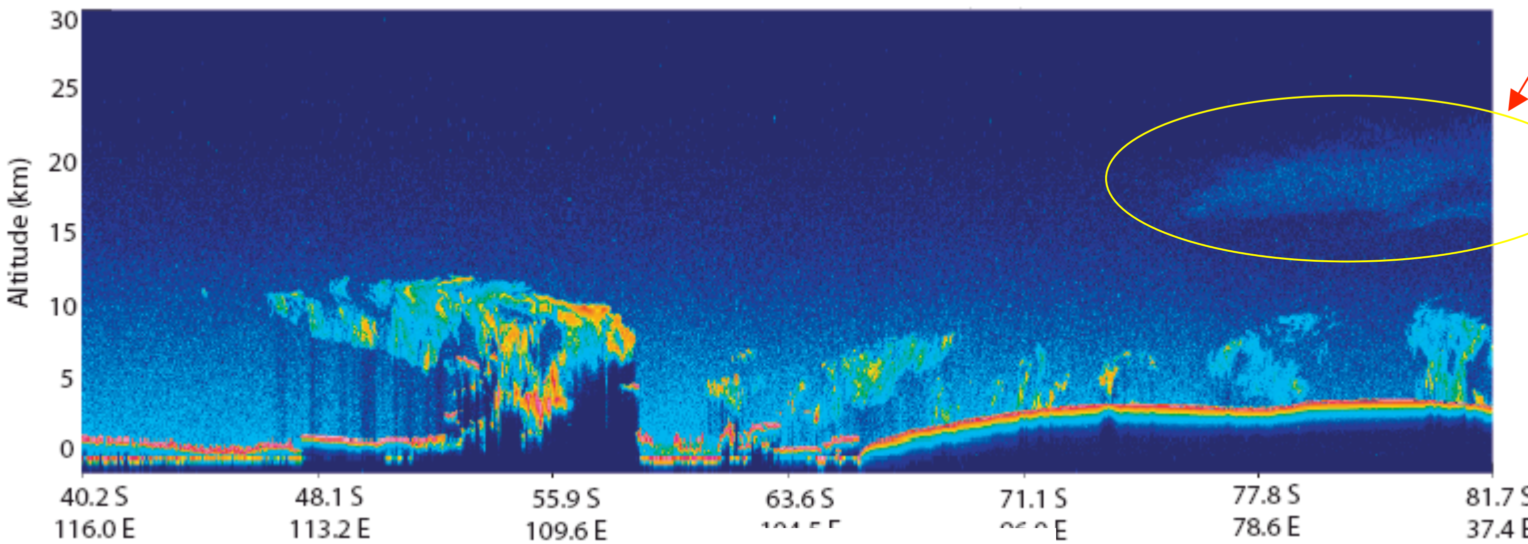
***Soufriere (Montserrat – Caribbean) erupted on May 20. Its water droplet/sulfuric acid plume was tracked by OMI and seen crossing over Indonesia by CALIPSO on June 7.***

# CALIPSO and CloudSat Data



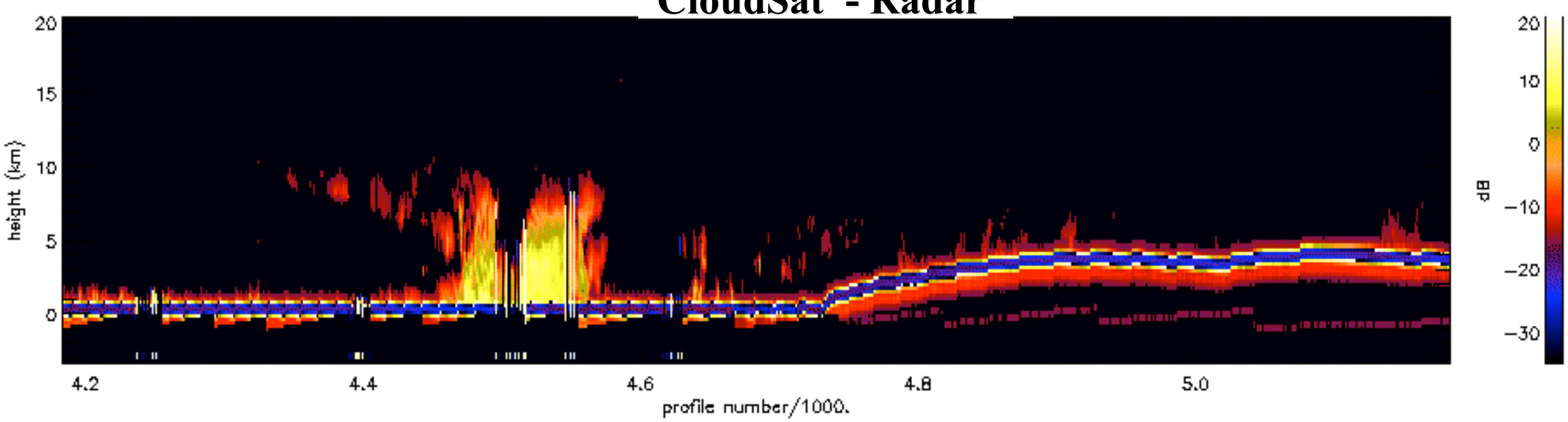

Antarctica

## CALIPSO-Lidar

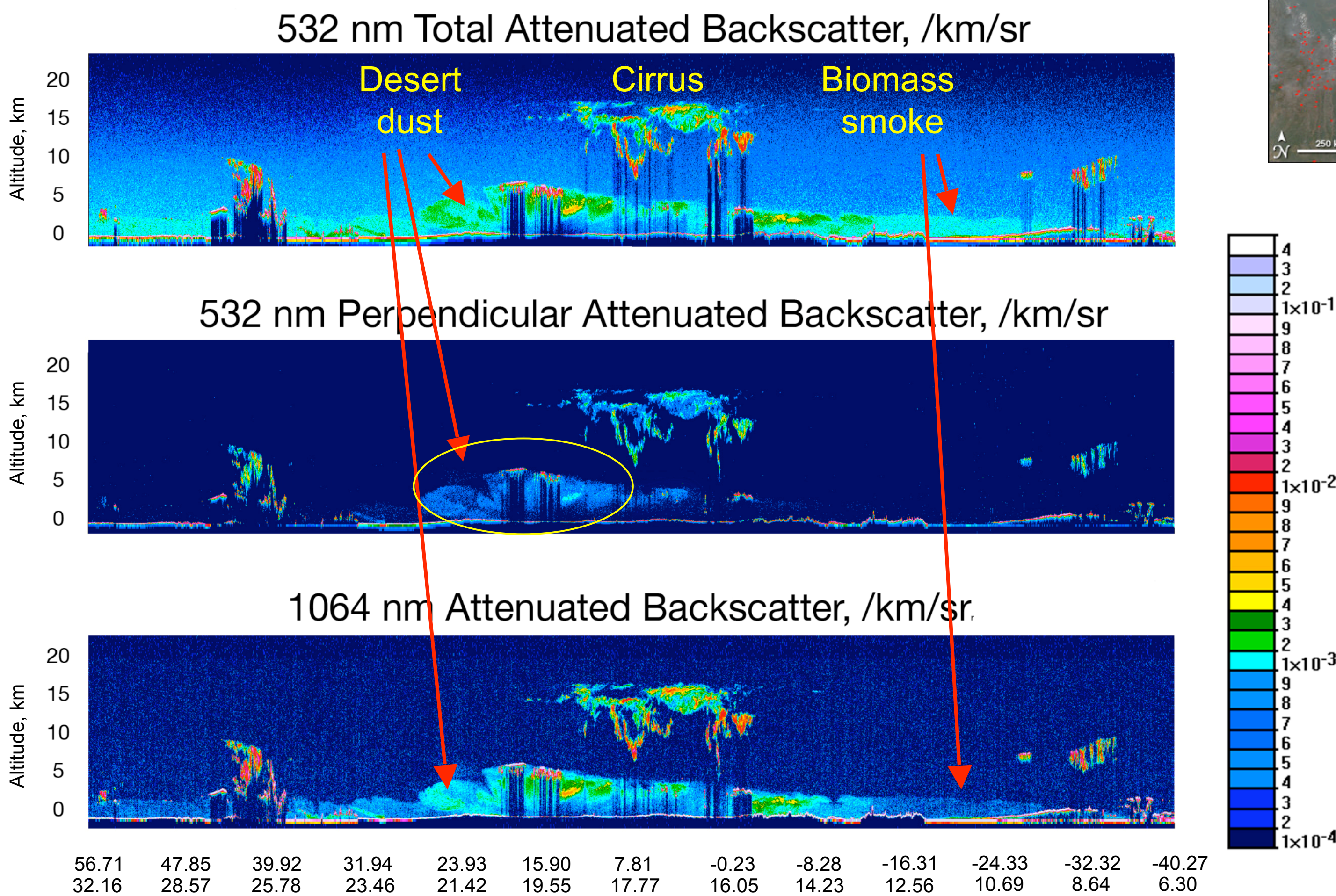


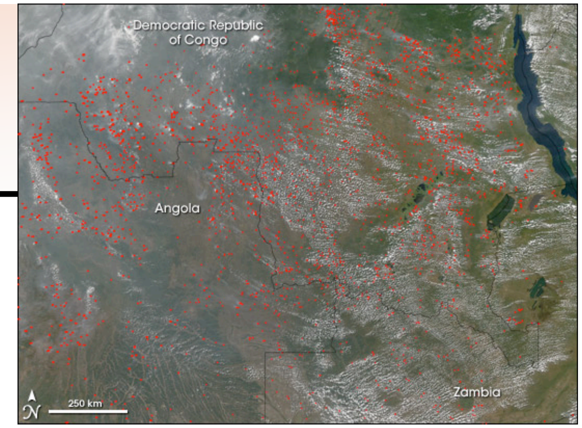

Polar Stratospheric Cloud

## CloudSat - Radar

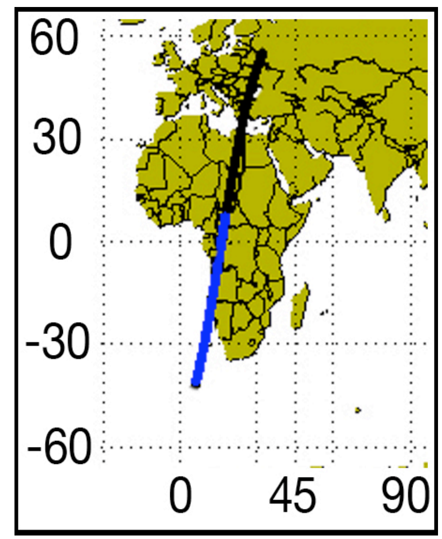


# CALIPSO Data – All Three Lidar Channels




Fire locations in southern Africa from MODIS, 6/10/06

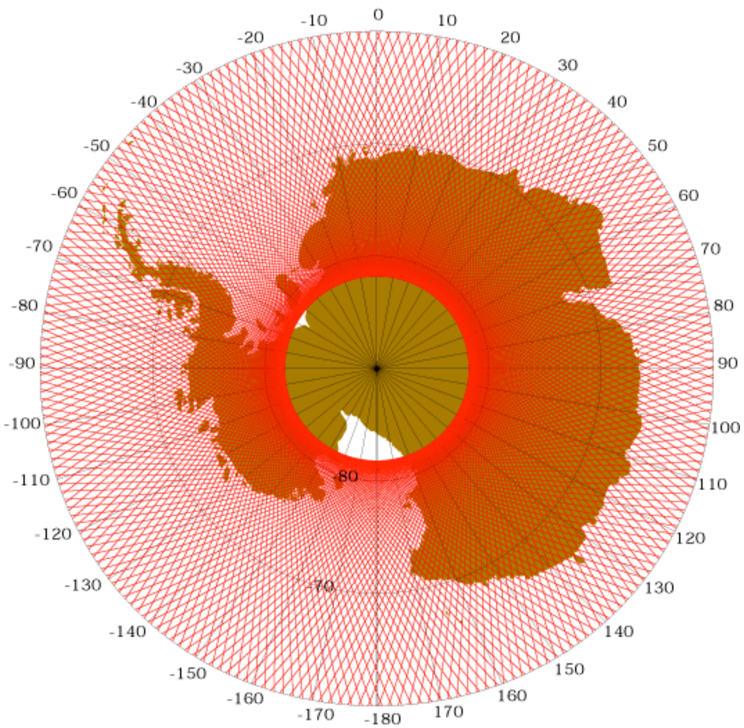


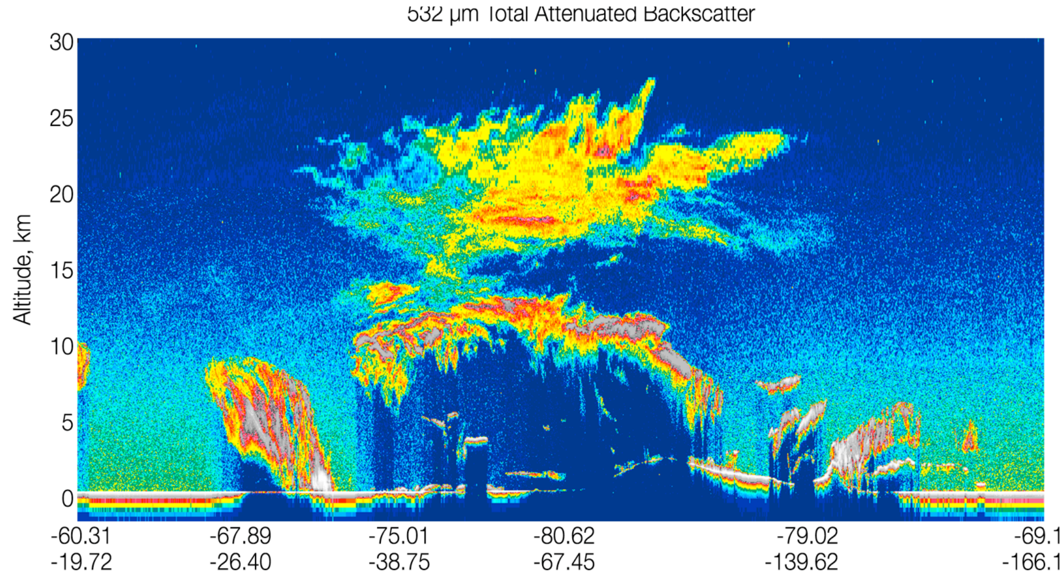

**Ratios of Channels give estimate of particle size, particle shape, and differentiate water/ice clouds**

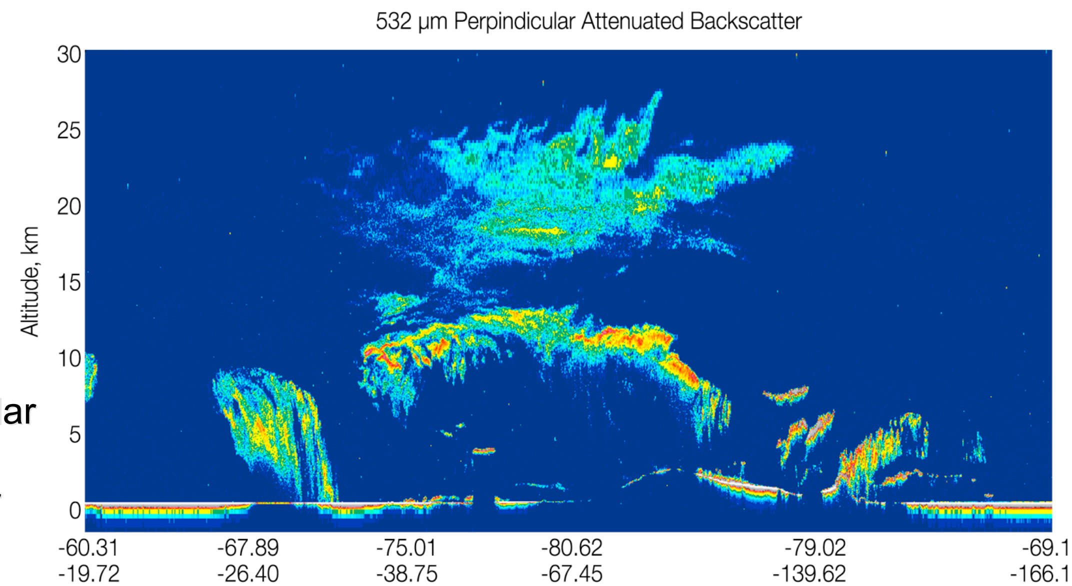
# Antarctic Polar Stratospheric Clouds

## July 24, 2006

532 nm Total Attenuated Backscatter



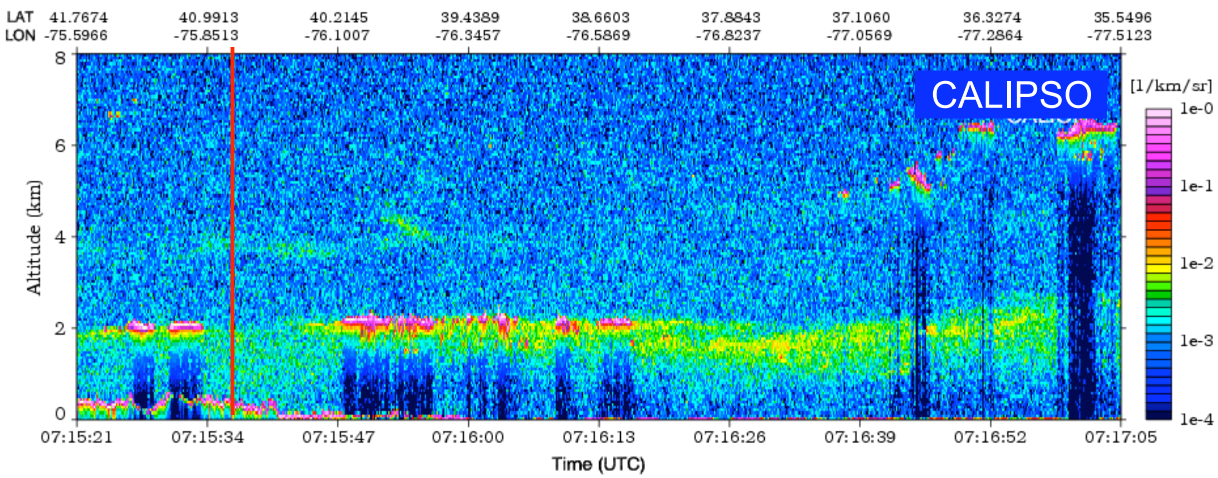

532 nm Perpendicular Attenuated Backscatter

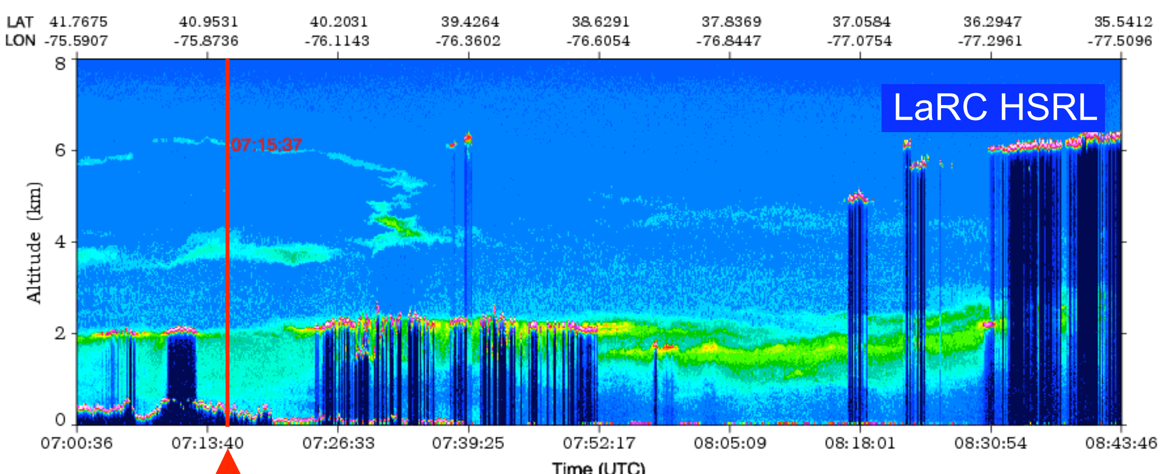
Courtesy: Dave Winker

# Validation Intercomparisons: Aerosols



## August 10, 2006

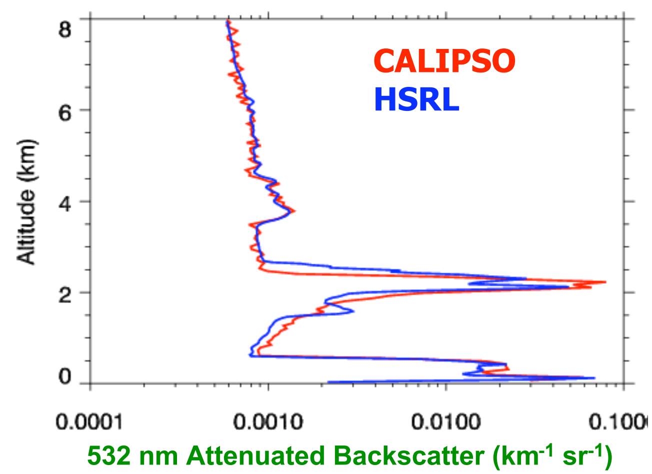


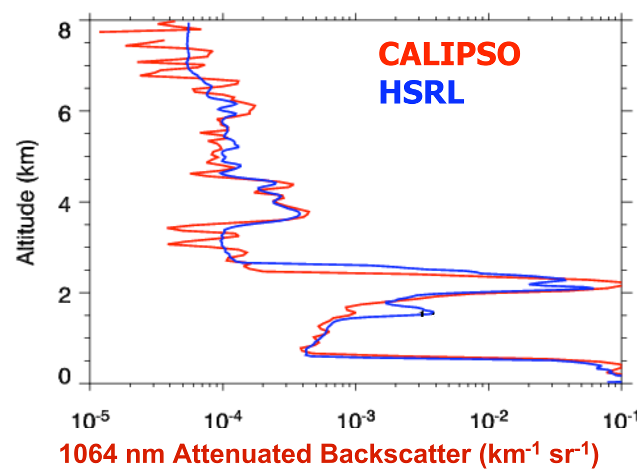




Coincidence

NASA LaRC High Spectral Resolution Lidar is being flown on Aircraft to support validating CALIPSO Data

Coincidence




Courtesy: Dave Winker

# What is different about Lidar from Space?

- Long distance from atmosphere – 400- 800 km Low Earth Orbit (LEO) –
  - Low Signal-to-Noise because of $1/R^2$ term in lidar equation
  - Looking down through atmosphere- strongest scatter from furthest distance
  - Ground/Ocean scatter sets far boundary condition
  - Satellite motion, typical LEO velocity 7000 m/s – limits averaging time, can cause doppler shift if laser has a component along-motion
    - Satellite velocity can be measured with GPS system to better than 1 m/s
  - Strong Solar background light signal – Solar spectrum reflected from clouds or ice is the most demanding
  - Attitude control critical to pointing where you want
    - Well-developed techniques
- Space Environment
  - Radiation (Galactic, Solar, Van-Allen Belts)
  - Vacuum – Outgassing and Contamination concerns
  - Microgravity – Alignments different than on Earth
  - Atomic Oxygen – Erosion and reaction
  - Micrometeroids and space junk
  - Charging of Surfaces – Corona Discharge
  - Thermal environment – Controlled through careful design using radiators and heaters

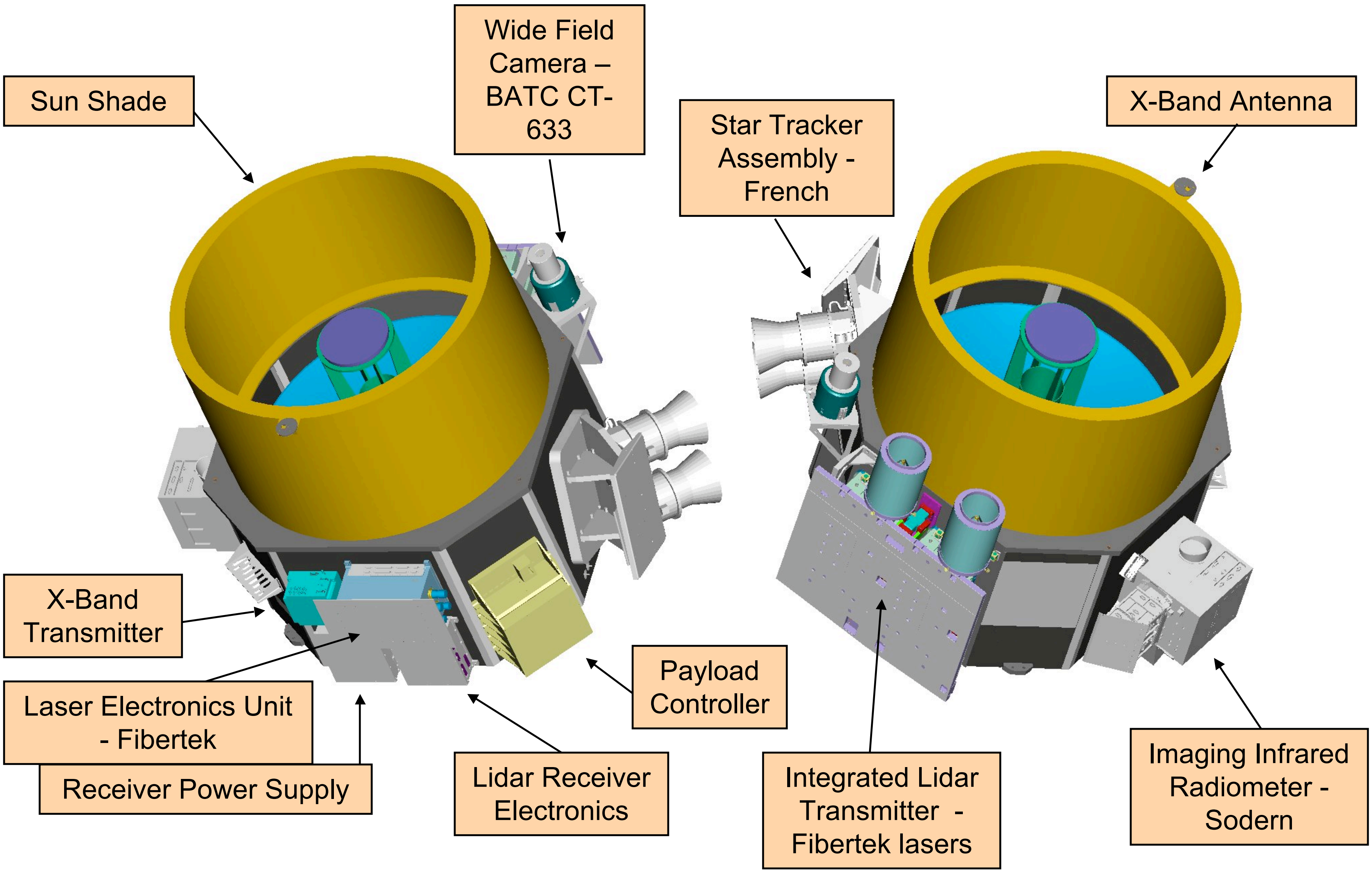
# Differences (continued)

- Launch Environment
  - Alignments and structure must withstand vibration and shock
  - Limited Weight can be lifted – Typical 100 – 500 kg range for instrument
- Limited power available – Typical 100 – 500 W available from solar arrays for instrument
- Semi-Autonomous Operation over multiple years – Daily data downlink, weekly uplinks
- Calibration Methods
  - Instrument level (e.g. depolarizers, "built-in-tests", LED illuminators)
  - Lidar System level - Scattering from "known targets" (e.g. Molecular scattering fro intensity, scene edges for geolocation, Digital Elevation Maps for ranging).
    - New work using Ocean Surface (http://www.atmos-chem-phys-discuss.net/8/2771/2008/acpd-8-2771-2008.pdf)

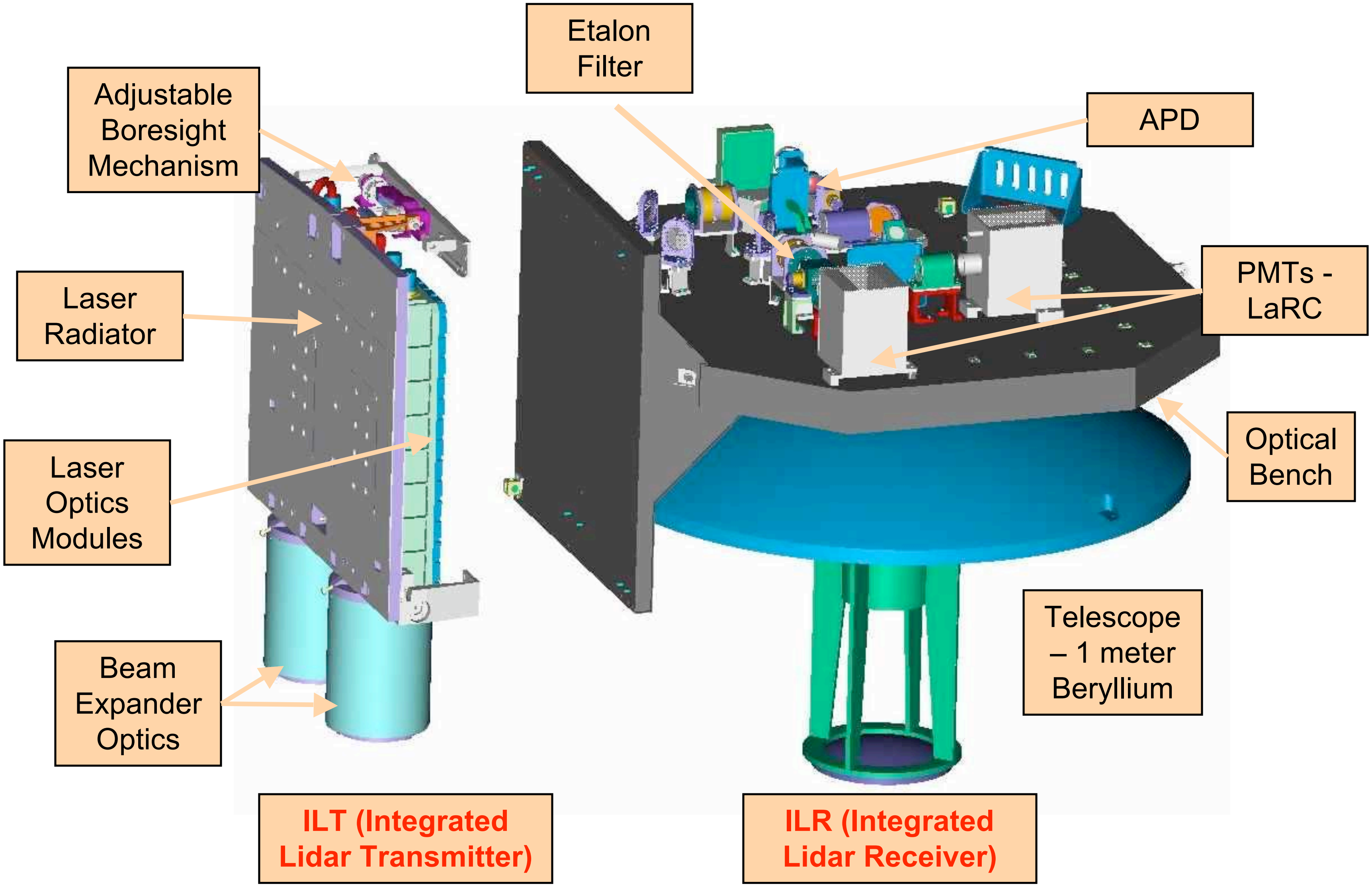
# Lidar in Space
# Building for Reliability

- High Cost of Space Missions requires that a space lidar be designed and built to achieve maximum reliability affordable within cost and schedule constraints
- Standard Aerospace Engineering practices followed, combined with unique lidar specific techniques
- High Reliability Parts Program
  - Electronic Parts are all "screened" – tested for lifetime – this limits what parts can be used
  - All classes of parts must have passed radiation testing
  - Optical parts must be able to withstand radiation, Ultra-violet, laser fluence (if appropriate), vacuum, atomic Oxygen
- Parts, Sub-assemblies, Assemblies must pass Qualification Test Program
  - Thermal-vacuum
  - Vibration
  - Acoustic
  - Shock
  - Electromagnetic Interference
  - Health/Performance tests in conjunction with each of the above

# Different Views of CALIPSO Payload



# Lidar Core – Transmitter and Receiver



# CALIPSO – Random Numbers

- **Lidar Data "Curtain"**
  - 70 meter diameter footprint
  - 330 meter steps
  - 30 meter (and up) vertical range bins
  - Extends from the ground to 40 km (130,000 ft - clean air)

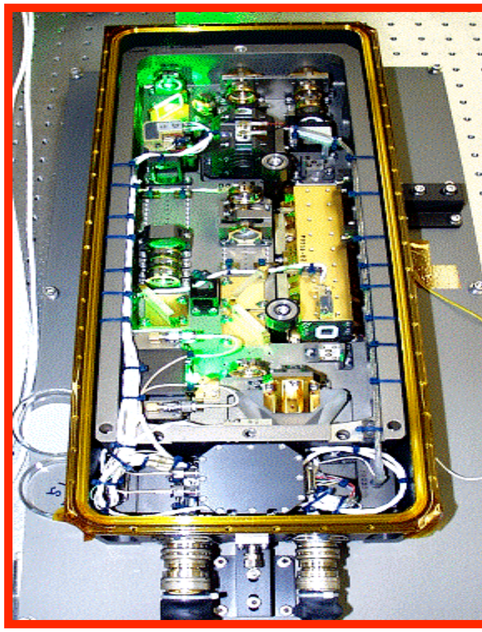
- **Lasers**
  - 4 Watt average power, 11 MWatt peak (20 nsec pulse), 20 Hz repetition
  - Each laser pulse contains $10^{18}$ photons
  - All the light is contained in very narrow wavelength bands
    - 0.035 nm at 532 nm (1 part per 15,000)
    - 0.100 nm at 1064 nm (1 part per 11,000)

- **Photomultiplier Detectors used at 532 nm are sensitive to single photons (but not photon counting)**
  - Avalanche Photodiode used for 1064 nm – less sensitive but much more rugged (also 550 V vs 2 kV)

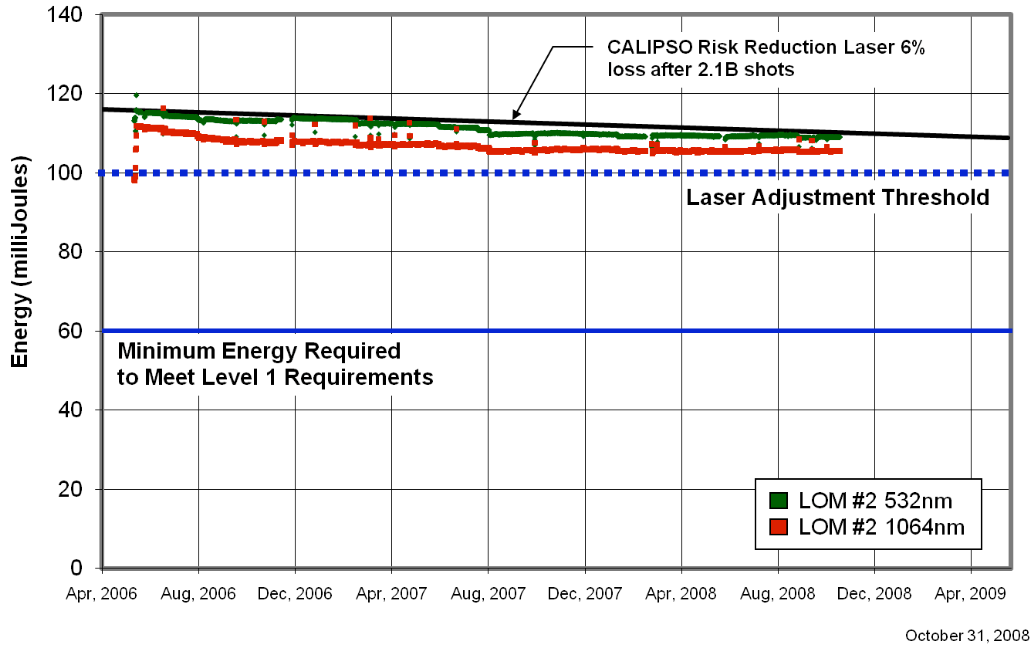
- **To date - on-orbit**
  - 3.5 TByte of science data collected
  - 1.45 Billion laser shots "fired" (1900 Mshots = full mission)
  - 2.5 years into a 3 year mission – extension is being sought

# Space Qualified Lasers

- Built by Fibertek of Herndon VA, with Ball
- Engineering Unit built that demonstrated full mission lifetime (2 billion shots).
- Laser is Nd:YAG in a zigzag slab with 192 diode bar pumps
- Utilizes a KD*P Q-switch (20 ns pulses) and a KTP frequency Doubler
- 110 mJ/pulse for each color @ 20 Hz
- Spectral linewidth (Multi-transverse mode)
- 532 nm Output polarized to > 1000:1
- Conductive Cooling – Heaters/radiators
- Ball designed Beam Expander Optics set laser divergence to approximately 100 microrad
- Weight 35 kg, uses 100 W (incl. Heaters)
- Redundant Lasers used – each designed for full mission life

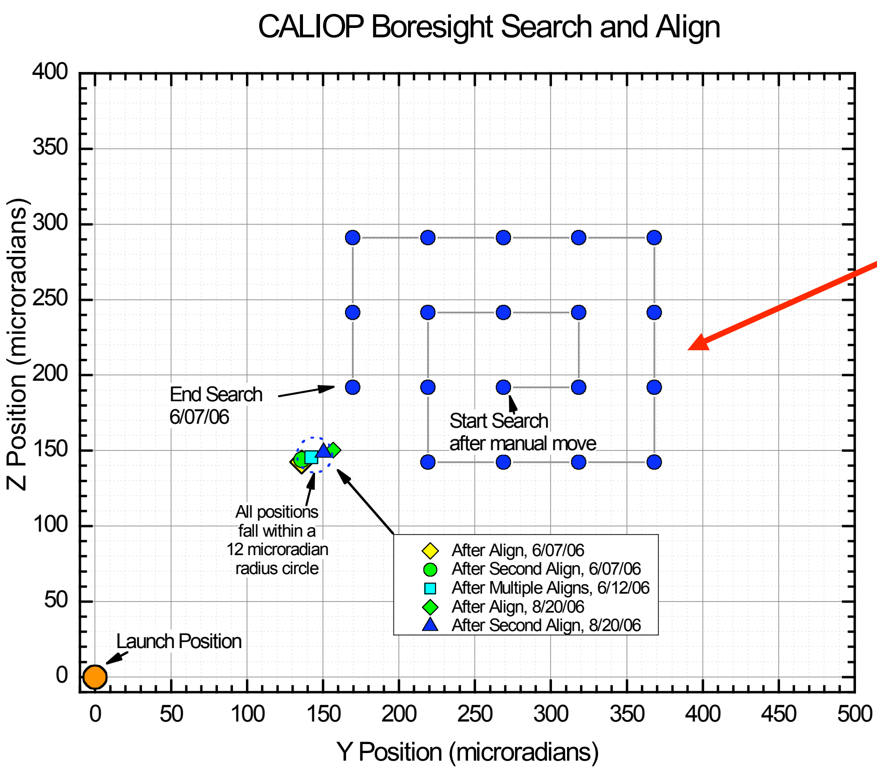


# Laser Energy – Long-term Orbit Trend



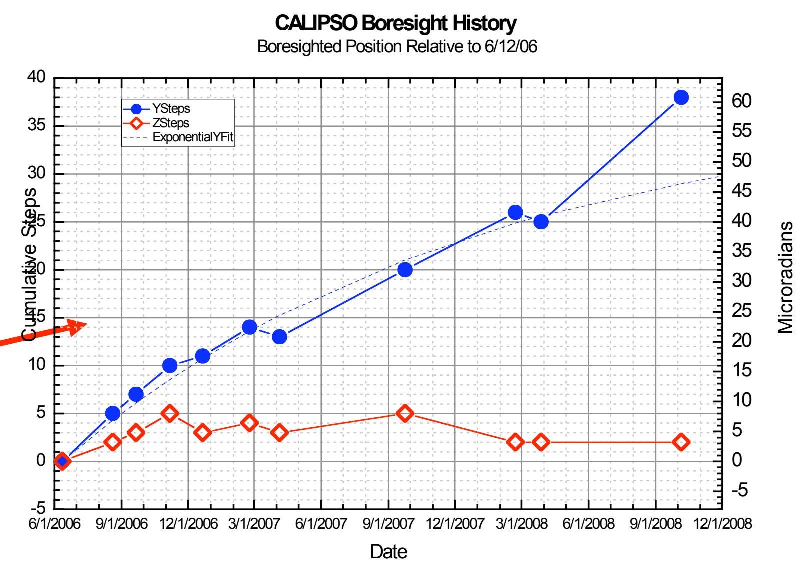

- **Trend is consistent with Risk Reduction Laser (RRL)**
  - **Slow decay is due to the diode lasers degrading – 15,200 used as "pumps"**
- **Redundant second laser hasn't been turned on, yet**
- **Laser Power is adjustable – Running at 70%, so we still have 30 % margin**
- **Laser Canister pressure decaying but looks acceptable for mission**
- **Trending of all parameters is critical to watching for health issues**

# Aligning the Laser and Receiver Pointing




- Ball mechanisms and software autonomously aligned the lidar
  - Search completed in 4 minutes
  - Align completed in 10 minutes
- Predicted align position agreed to 130 µrad with actual

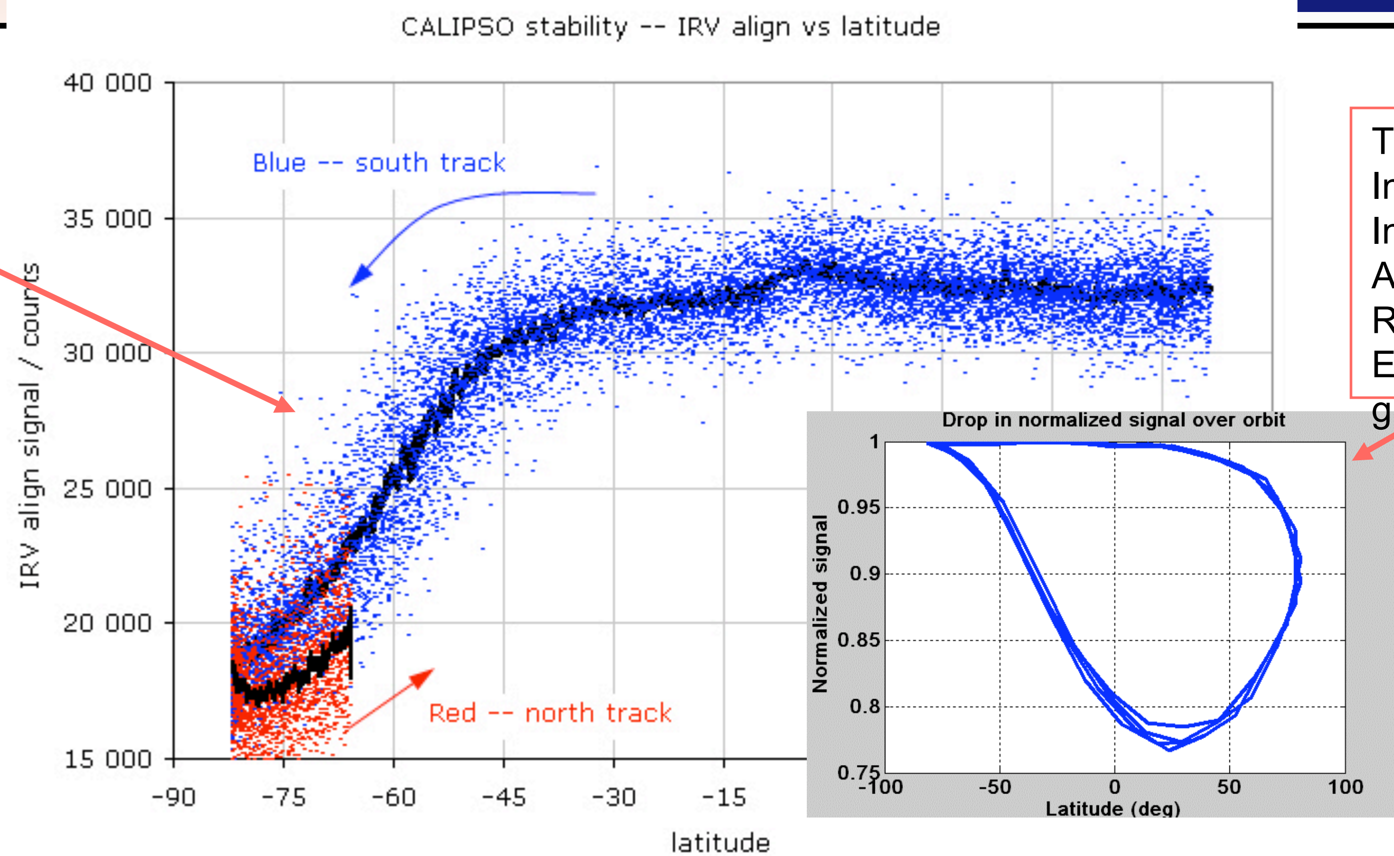
- Stability of full lidar system checked monthly
  - Relative pointing has been stable to < 50 µrad over 2 years
  - Signal stability over multiple orbits is better than 1% (night), but …………



# Study of Lidar Stability

Polar Vortex over Antarctica -

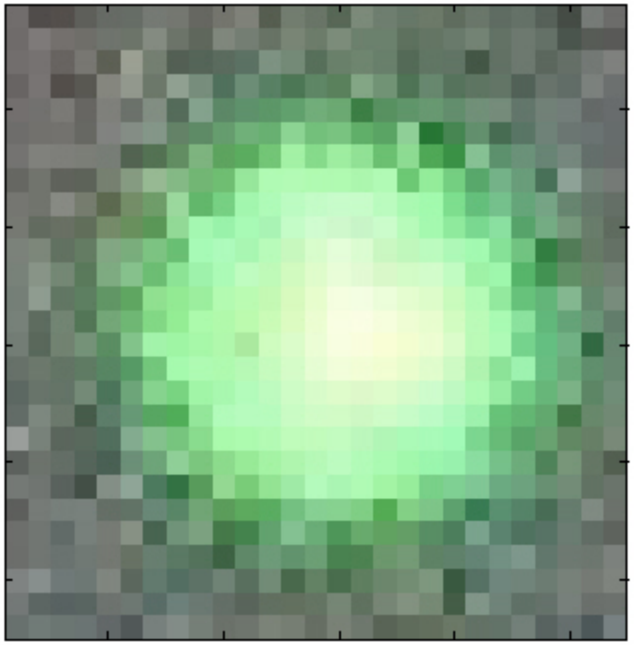
Real Science




Thermally Induced Instrument Alignment – Real Engineering

- **Rayleigh (Molecular) scattering from 27- 40 km altitude (June)**
- **Ground track starts over Northern Hemisphere and goes to Southern**
- **Lidar is temperature cycling – cooling**
- **Signal does not repeat on itself – slight alignment shift**

# CALIPSO Laser output as it passes over Nederland



Photograph by Gregg Hendry 7/14/06

More Information about CALIPSO at:

http://www-calipso.larc.nasa.gov

http://smsc.cnes.fr/CALIPSO/

http://calipsooutreach.hamptonu.edu/

http://www.n2yo.com/?s=29108

Also See:

http://giovanni.gsfc.nasa.gov

http://www.nuforc.org/webreports/055/S55212.html

# Some Lidars in Space

| | | |
|---|---|---|
| • Apollo 15 | 1971 | Ranging |
| • Clementine | 1994 | Ranging (Mapped the Moon) |
| • LITE | 1994 | Profiling (Shuttle) |
| • Balkan | 1995 | Profiling |
| • NEAR | 1996 | Ranging |
| • SLA-01 | 1996 | Ranging |
| • MOLA II | 1996 | Ranging (Mapped Mars) |
| • SLA-02 | 1997 | Ranging |
| • Icesat/GLAS | 2003 | Ranging/Profiling (Icesheets) |
| • MLA | 2004 | Ranging (Mercury) |
| • CALIPSO | 2006 | Profiling of Aerosols/Clouds |
| • Phoenix | 9/2007 | Profiling Dust (Mars) |
| • LOLA | 2009 | Ranging (Moon) |
| • ADM-Aladin | 2010 | Wind Measurements (ESA) |