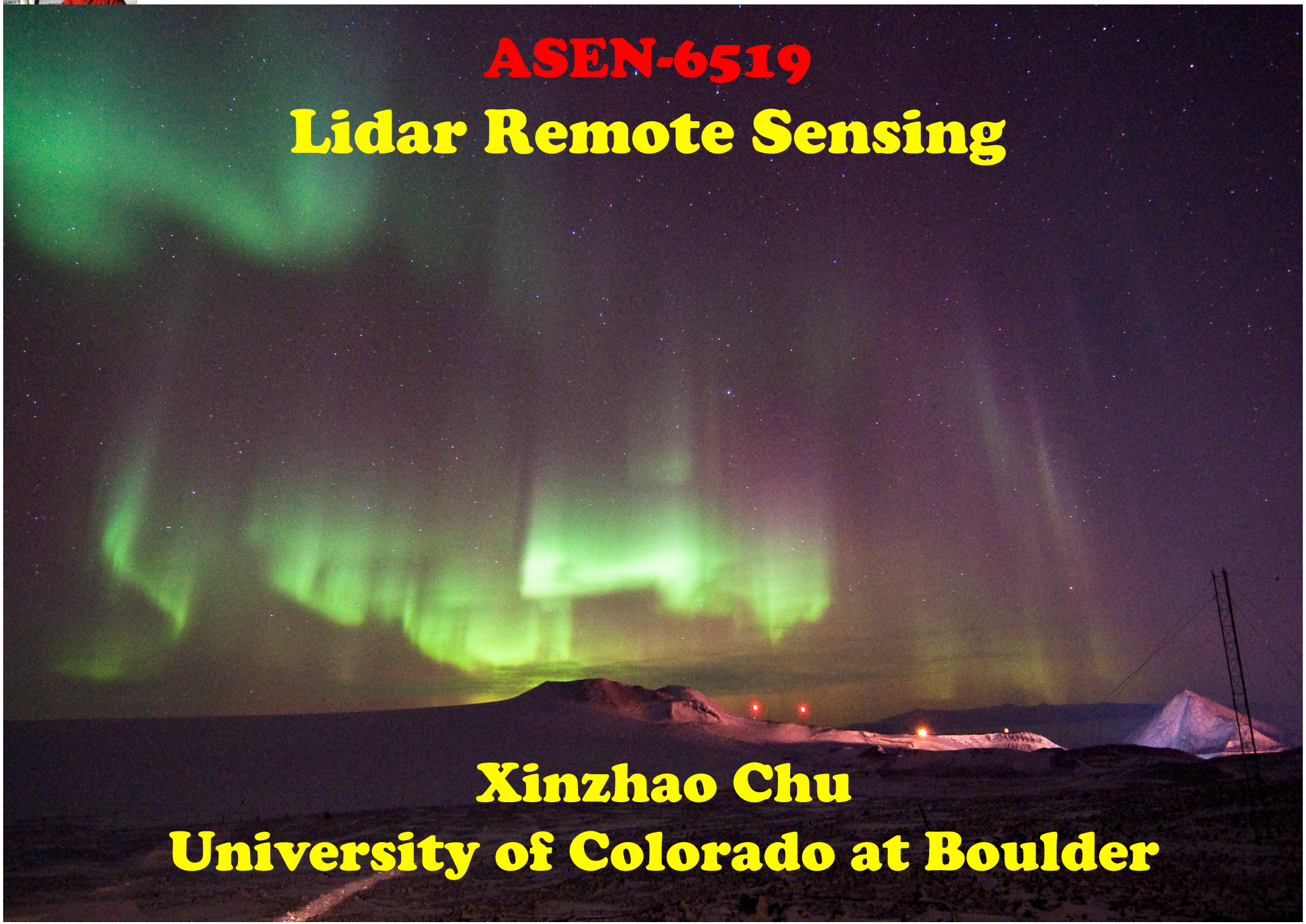
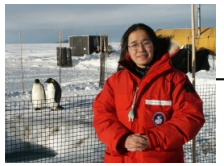


ASEN-6519
Lidar Remote Sensing

Xinzhao Chu
University of Colorado at Boulder

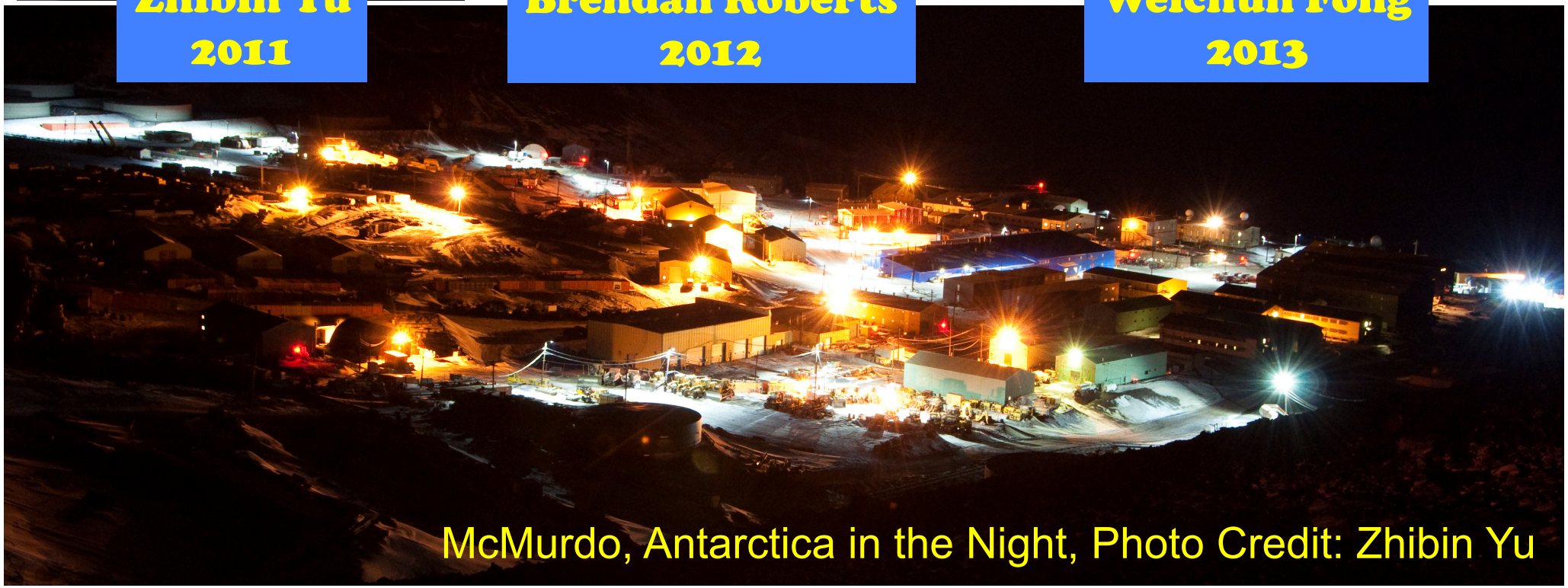


Winter-Over Students: Yu, Roberts & Fong

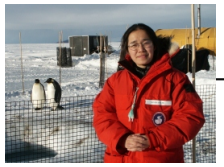
Zhibin Yu
2011

Brendan Roberts
2012

Weichun Fong
2013

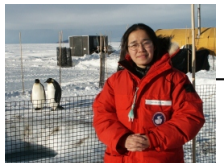


McMurdo, Antarctica in the Night, Photo Credit: Zhibin Yu

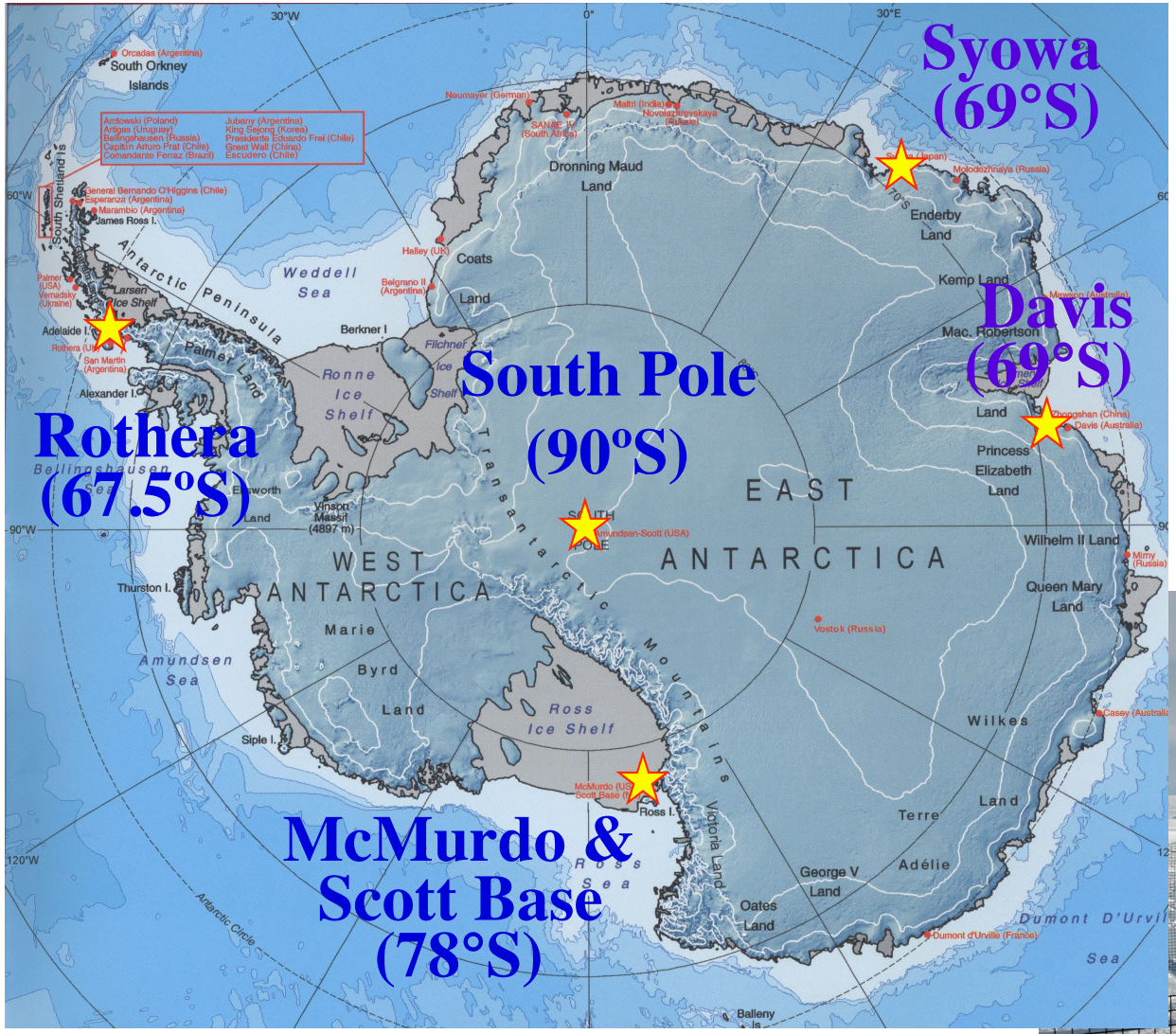


Cao Chen (2014) & Jian Zhao (2015)

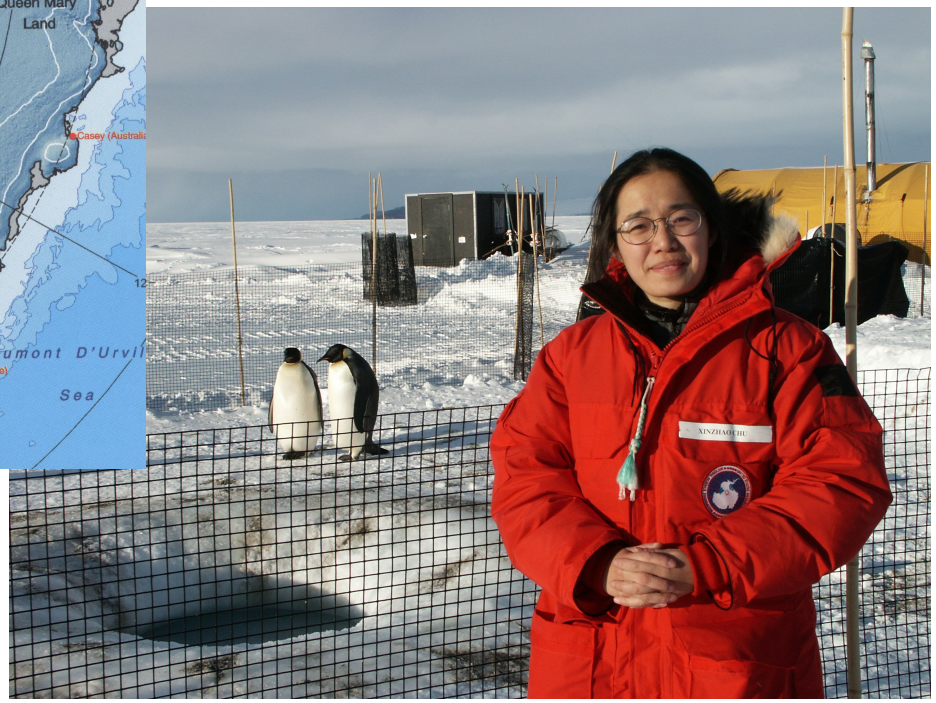
Lidar Marathon 12/29/2013 – 1/6/2014



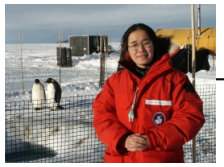
Lidar Campaign @ McMurdo



"Three Penguins"



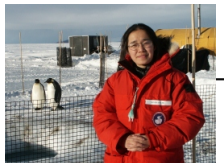
To complete an observational chain for Antarctica by filling in an important gap



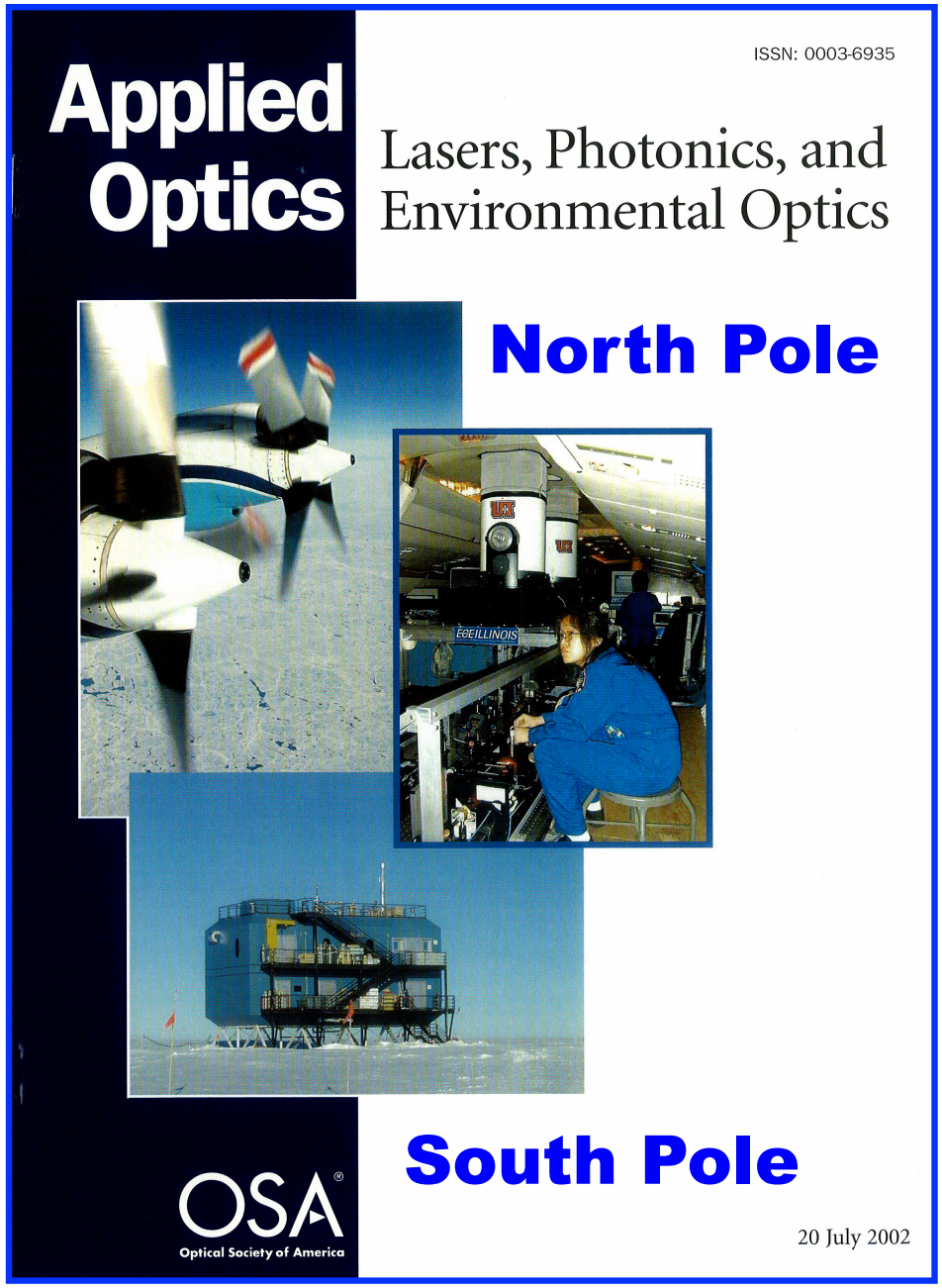
Traveling to the End of the World

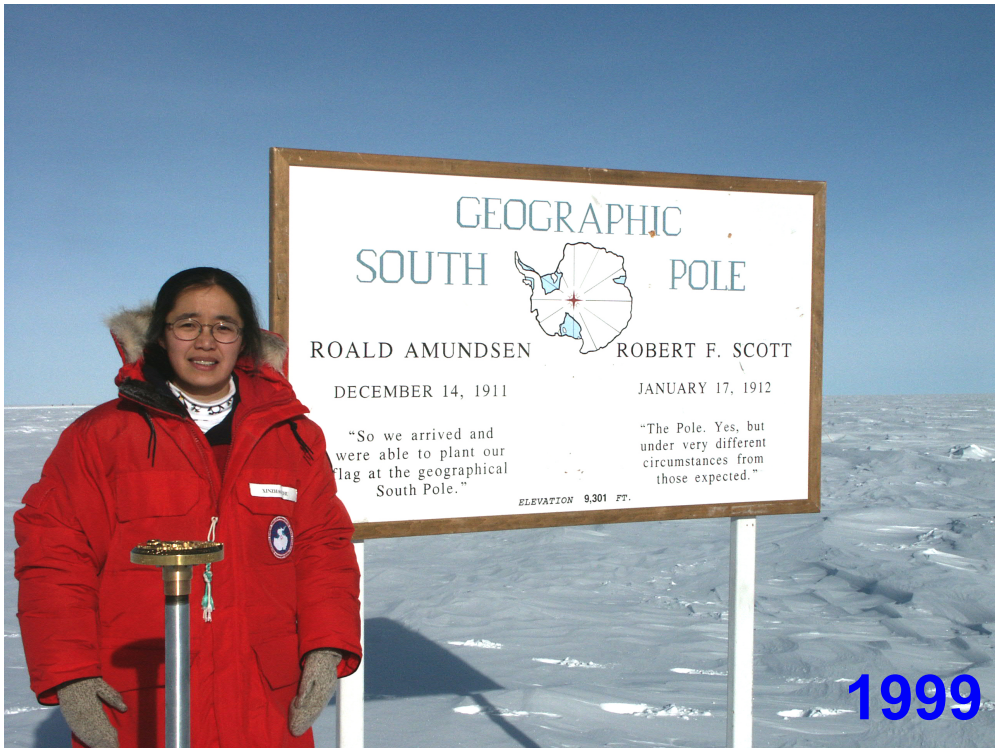
To make new discoveries in atmospheric and space sciences for advancing space weather and climate research

http://cires.colorado.edu/science/groups/chu/projects/mcmurdo.html

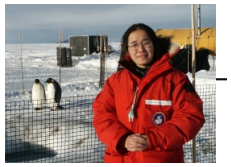


Pole-to-Pole Lidar Observations

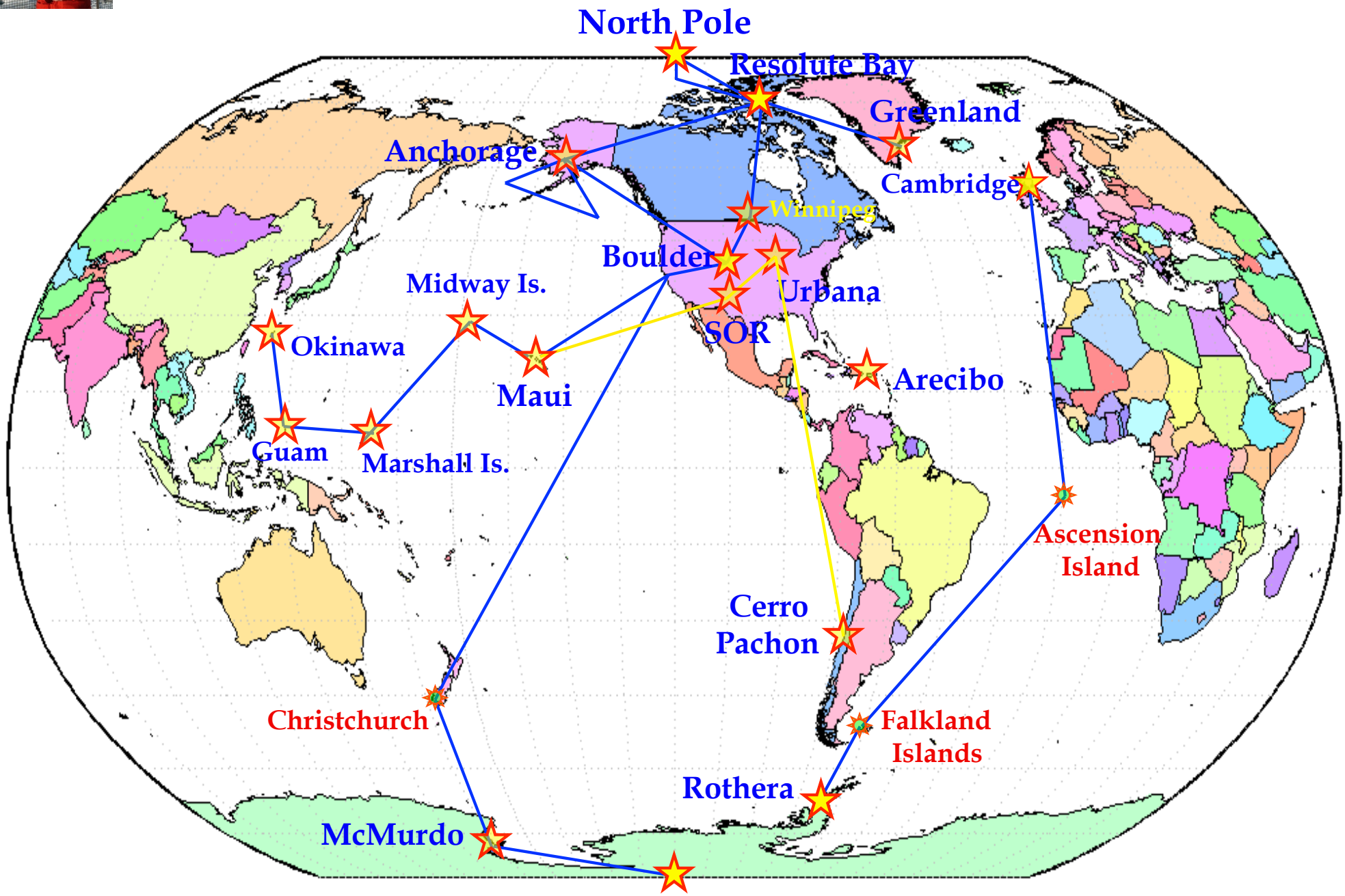


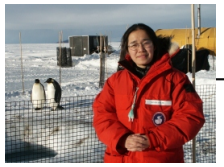



I was flying the Electra,
right above the North Pole!
ADF
NV2
OFF
TrimbleNavigation
PRESENT POSITION
IFR GPS
ADV
ENT
NAV
WPT
APT/VOR
MSG



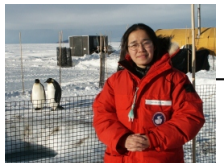
LIDAR Expeditions over the World





Lecture 01
Introduction to LIDAR Course

My goal is to provide the opportunities through this class for people to gain comprehensive understanding of lidar principles, technologies and applications, as well as quantitative analyses of lidar data, sensitivity and error. Lidar simulation and design will be further developed upon these understandings and analyses.

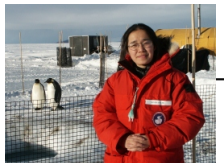


LIDAR: What and Why?

LIDAR stands for Light Detection and Ranging, commonly known as Laser Radar.

Lidar is not only replacing conventional sensors, but also creating new methods with unique properties that could not be achieved before.

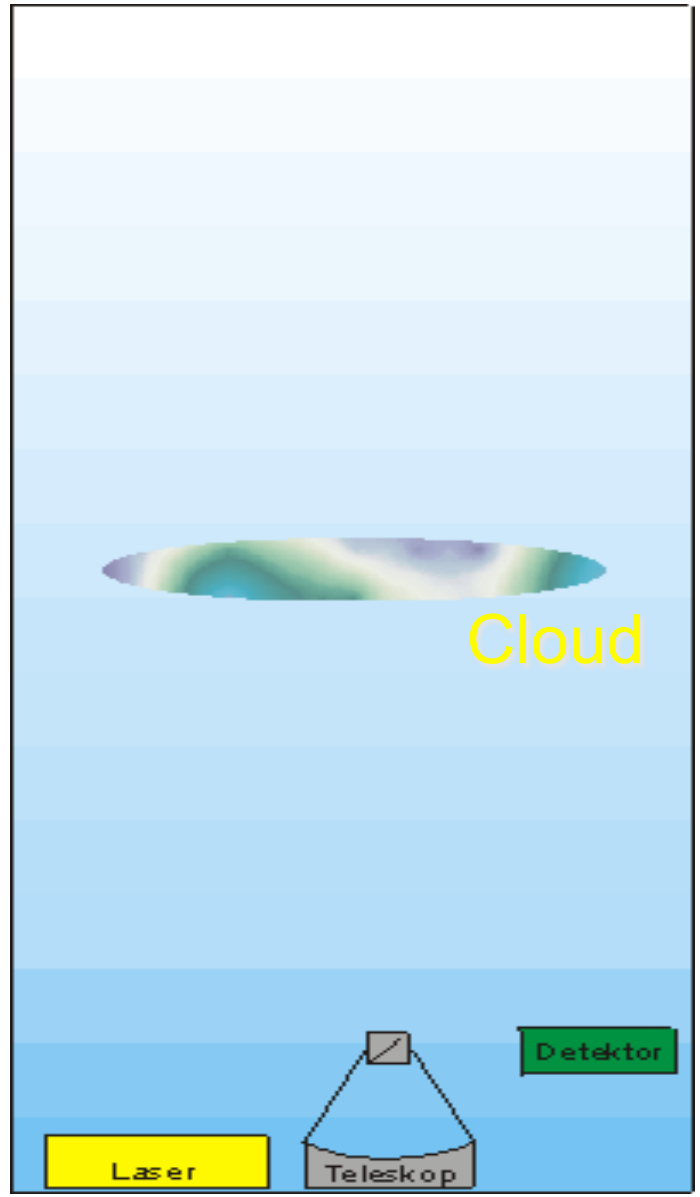
Lidar is extremely useful in atmospheric and environmental research as well as space exploration. It also has wide applications in industry, defense, and military.

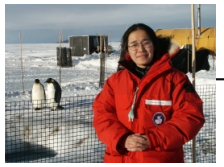


LIDAR: Light Detection And Ranging

- Send light to the atmosphere or other medium
- Record light scattered by the atmosphere/other medium/ objects as function of time
- Convert time of flight to distance (1 ms ~ 150 km)

$$R = c \cdot \Delta t / 2 \qquad (1.1)$$

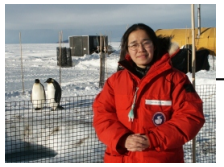




Lidar Course Objectives

1. Comprehensive and up-to-date understandings of lidar principles, technologies, and applications;
2. Approaches for lidar simulation, lidar sensitivity and error analysis, lidar data retrieval, and lidar system design to quantitatively analyze lidar system performance and measurement errors;
3. Opportunities to see and operate the real state-of-the-art lidar systems and make connections to lidar experts in the nation and world.

STAR Na Doppler lidar at Table Mountain Lidar Facility (Student Training and Atmospheric Research)



Lidar Course Contents

What is covered in this lidar class?

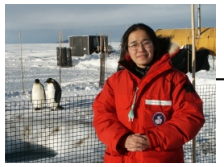
From lidar signals, we can infer information in two major categories:

1) Timing – distance of the objects
2) Properties of the scattering objects

Tracking the distance over time, movement can be derived.

-- Scattering lidars concerning both properties and timing;
-- Rangefinder lidars concerning timing in very details;
-- Some fluorescence lidars concerning species properties only.

Our lidar class will cover all these topics of lidar.



Textbook and Reading Materials

Textbook:

"Laser Remote Sensing" (2005) edited by Fujii and Fukuchi for its thoroughness on resonance lidar and wind lidar

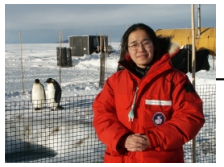
Major Reference Books:

"Lidar" (2005) edited by C. Weitkamp

"Laser Remote Sensing: Fundamentals & Applications" (1984) by Raymond Measures

Other References:

- "Selected Papers on Laser Distance Measurements" (1995), SPIE Milestone Series, Volume MS 115
- "Selected Papers on Laser Applications in Remote Sensing" (1997), SPIE Milestone Series Volume MS 141
- "Proceedings of 24th, 25th and 26th ILRC" and journal papers



Course Format

1. PPT presentation in classroom

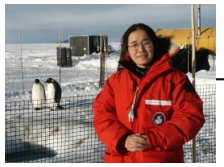
2. Lecture notes posted at the class webpage:

http://cires.colorado.edu/science/groups/chu/classes/

3. Homework Reading Reports over reading materials

4. Homework Projects of lidar simulation and data retrieval

5. Final project integrating reading, design, and simulation together, with class presentation and final written report



Grading Policy

20% Homework Reading Reports: your understanding to lidar principles, technologies, and applications

60% Homework Projects:

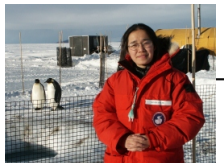
(1) Lidar simulations (e.g., range-resolved or non-range-resolved lidar photon counts, error analysis)

(2) Lidar data retrieval and error analysis (e.g., Na density, Doppler temp and wind, Boltzmann and Rayleigh temperature, coherent wind, HSRL aerosol, DIAL, or Raman lidar data)

(3) Lidar design and performance analysis

20% Final Project: Select one type of lidars and go through principle, design, simulation, error analysis, application

100-point grading system for reports and projects

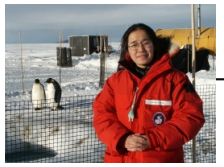


Final Projects: Design/Characterize A Lidar for Real Applications

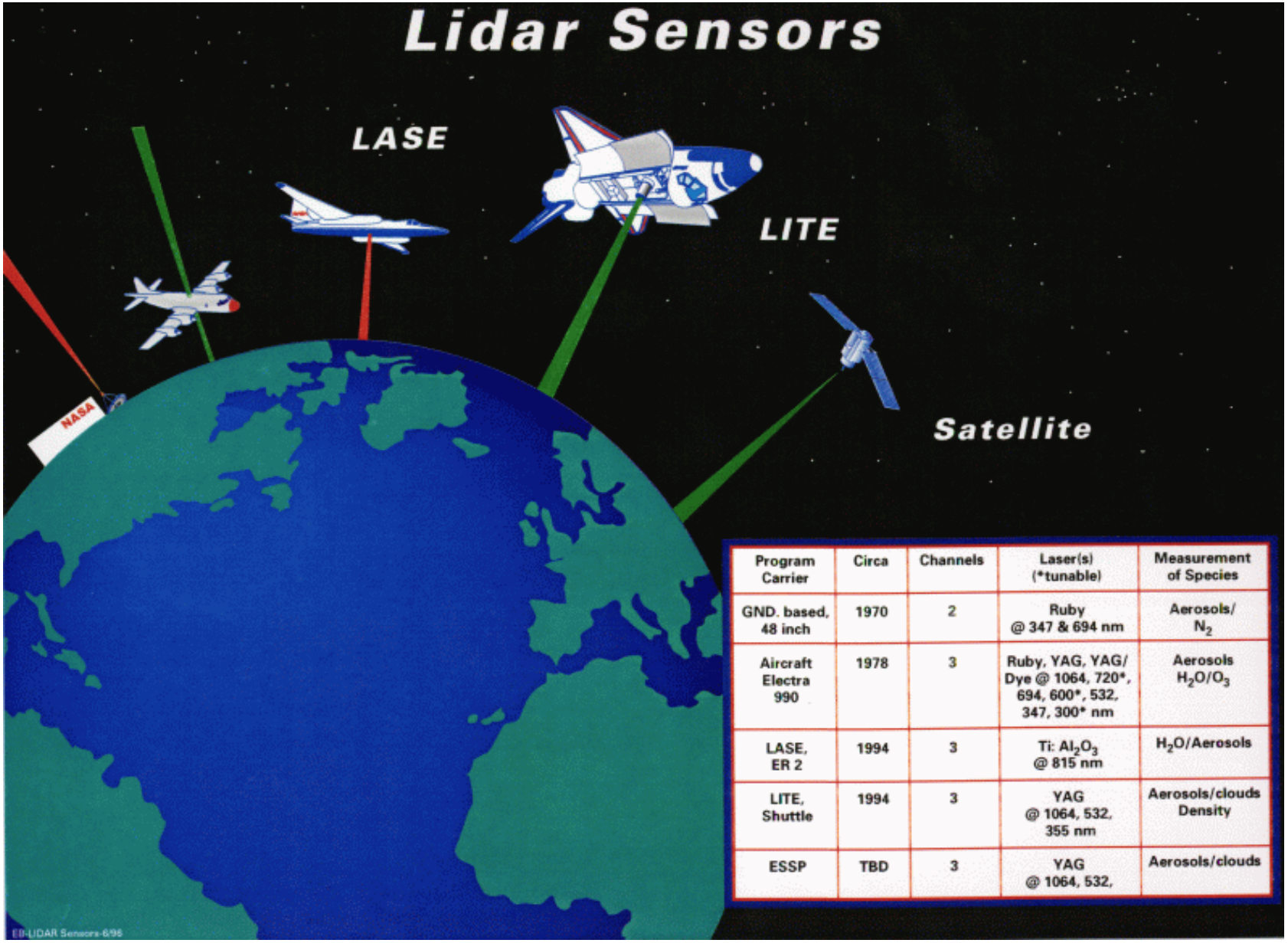
Choosing one of the lidar topics that is either closely related to your research or your interest, the final project will cover the following contents:

- Principles, history, and current status of this type of lidar
- Design or characterization of a lidar system
- Simulation of expected lidar signals
- Sensitivity or error analysis
- Comparison to real lidar signals if any
- Applications

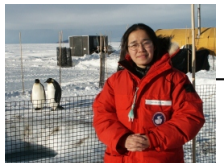
The final project will be presented to the class and a written report is required for the final grading.



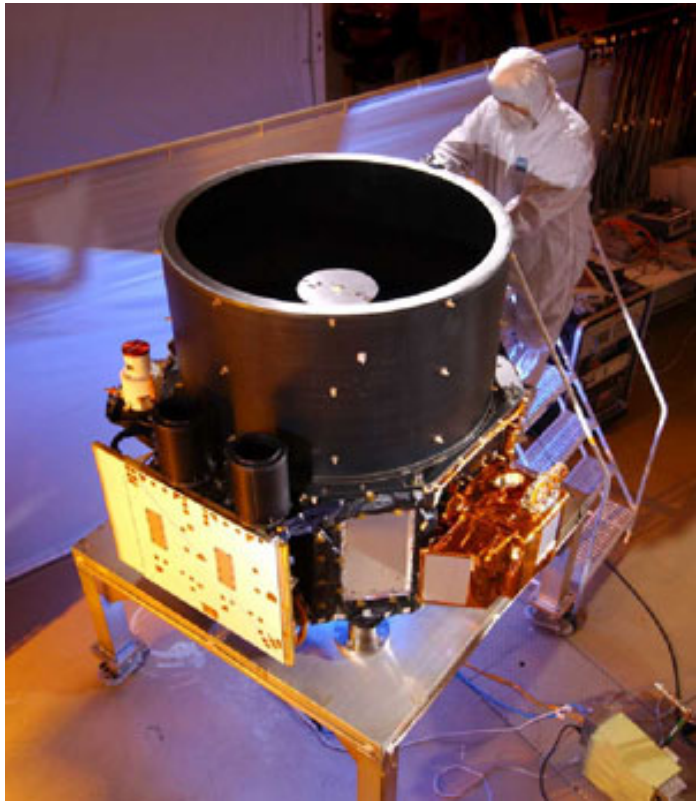
Lidar from Ground to Space

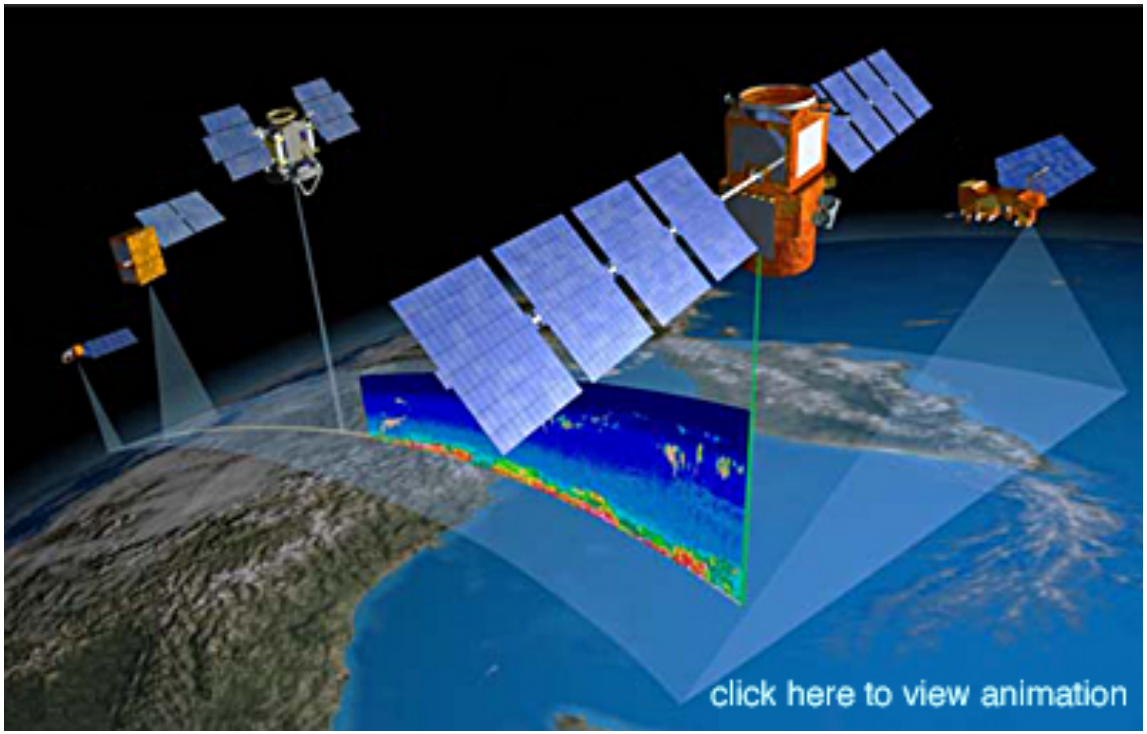


Program Carrier	Circa	Channels	Laser(s) (*tunable)	Measurement of Species
GND. based, 48 inch	1970	2	Ruby @ 347 & 694 nm	Aerosols/ N_2
Aircraft Electra 990	1978	3	Ruby, YAG, YAG/ Dye @ 1064, 720*, 694, 600*, 532, 347, 300* nm	Aerosols H_2O/O_3
LASE, ER 2	1994	3	Ti: Al_2O_3 @ 815 nm	H_2O/Aerosols
LITE, Shuttle	1994	3	YAG @ 1064, 532, 355 nm	Aerosols/clouds Density
ESSP	TBD	3	YAG @ 1064, 532,	Aerosols/clouds



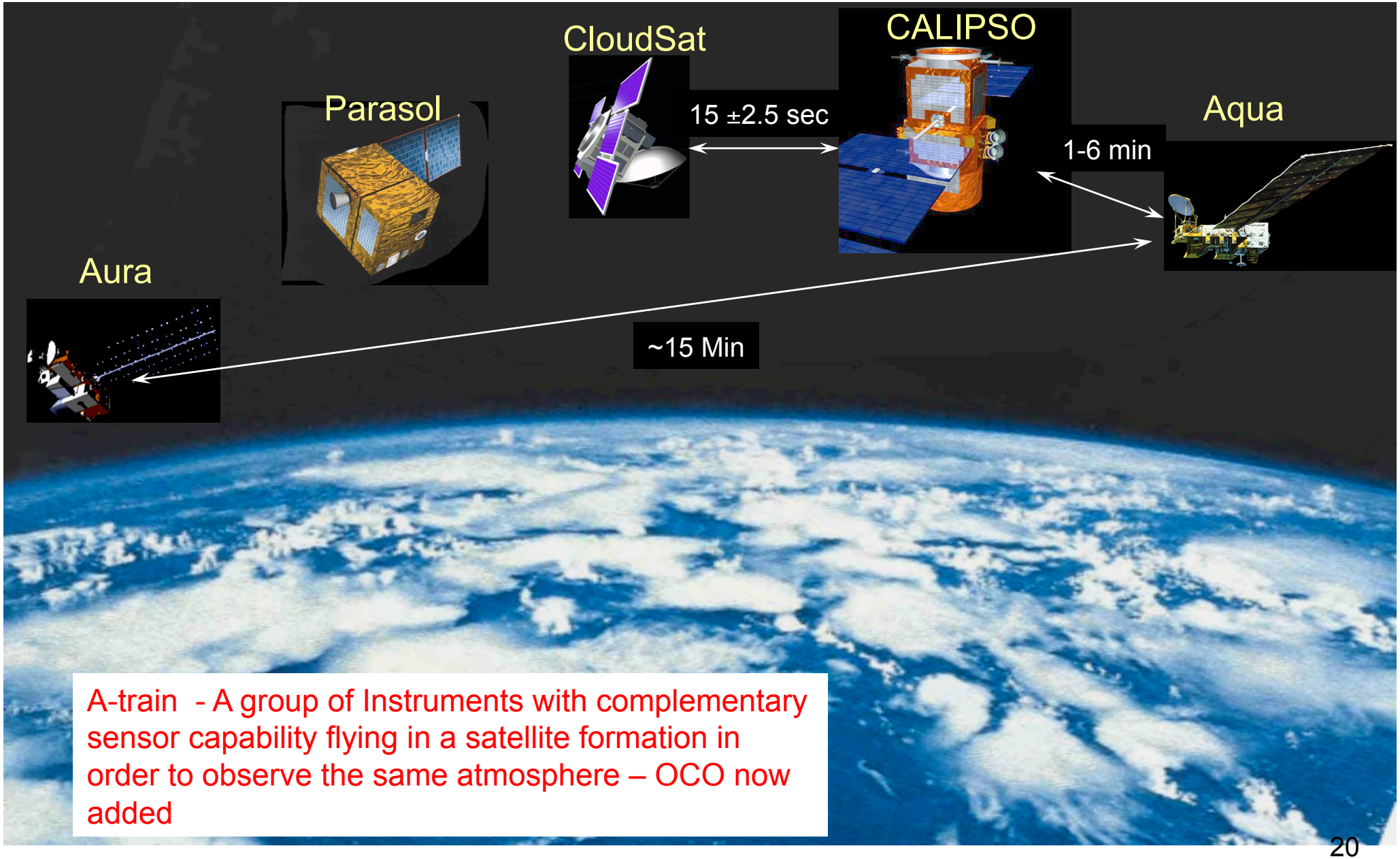
CALIPSO: Lidar on Satellite



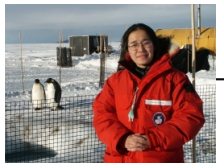


http://www-calipso.larc.nasa.gov/

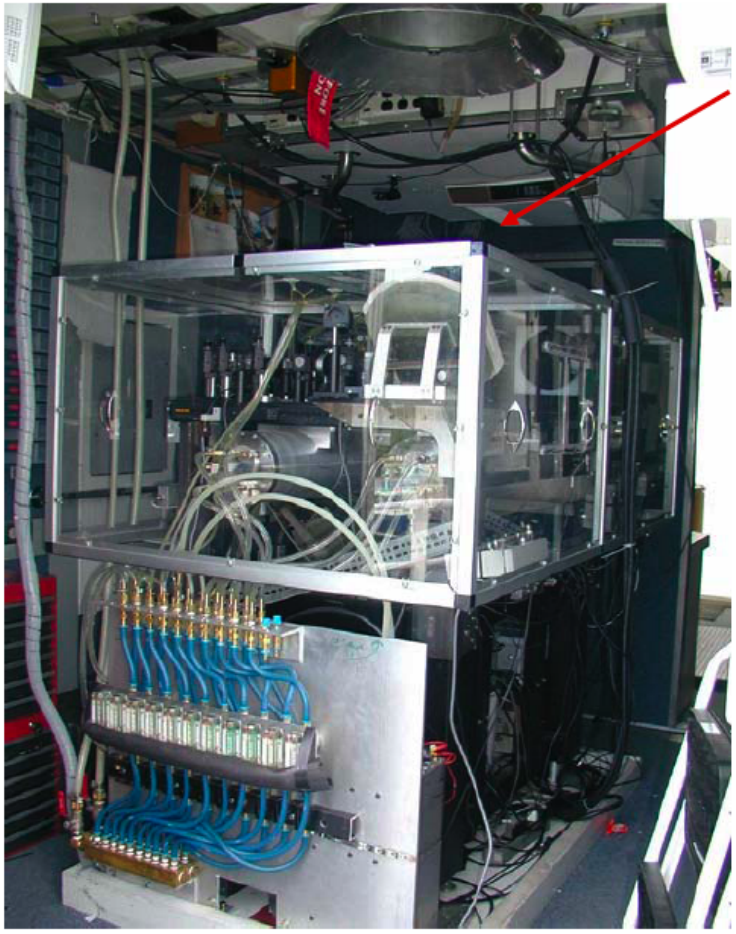
Aqua (A) Train for Multiple Observations



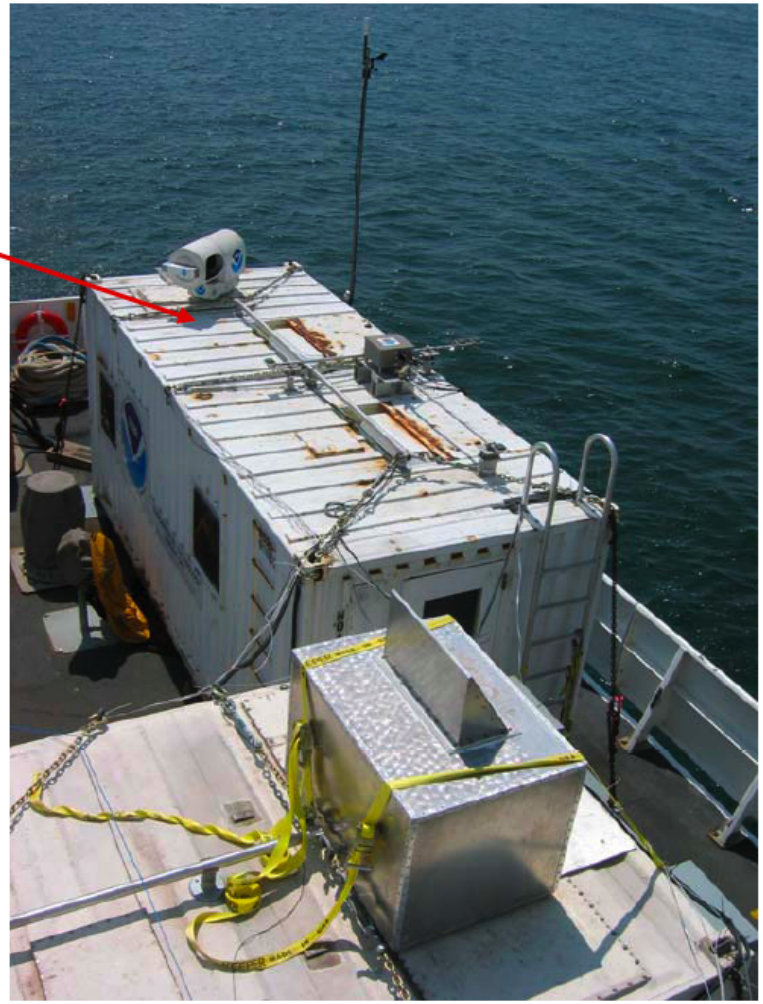
A-train - A group of Instruments with complementary sensor capability flying in a satellite formation in order to observe the same atmosphere – OCO now added



NOAA ESRL Lidars on Ocean



- Mini-MOPA
- HRDL
- OPAL
- TOPAZ
- DABUL
- Fish Lidars
- TUV
- CODI
- TEAC0
- ABAeL



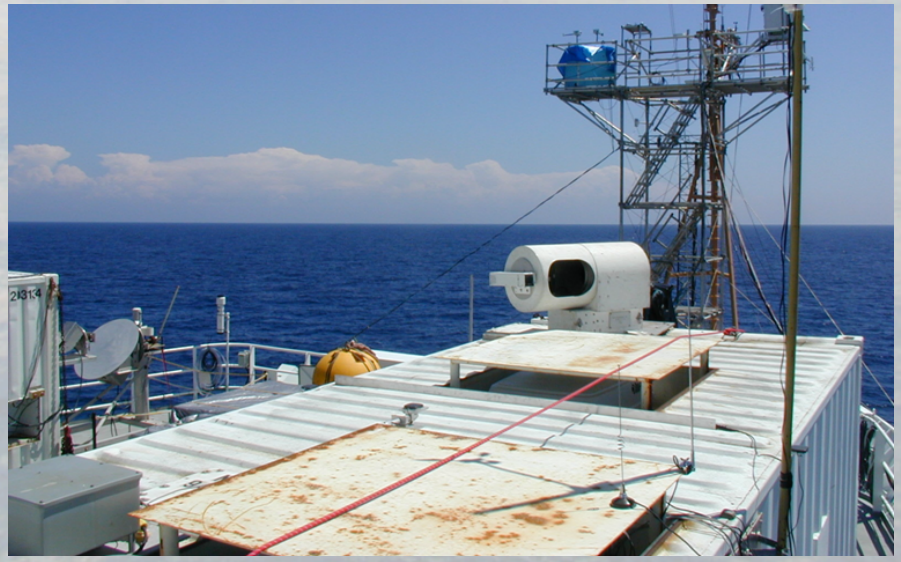
Basic Lidar measurements

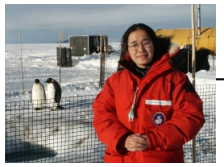
- Chemical distributions (ozone, water vapor, NH3, CO2)
- Cloud properties
- Aerosol measurements
- Low level mean winds
- Residual winds
- Turbulence, general dynamics

Instruments have been mounted on research ships for sea based operation

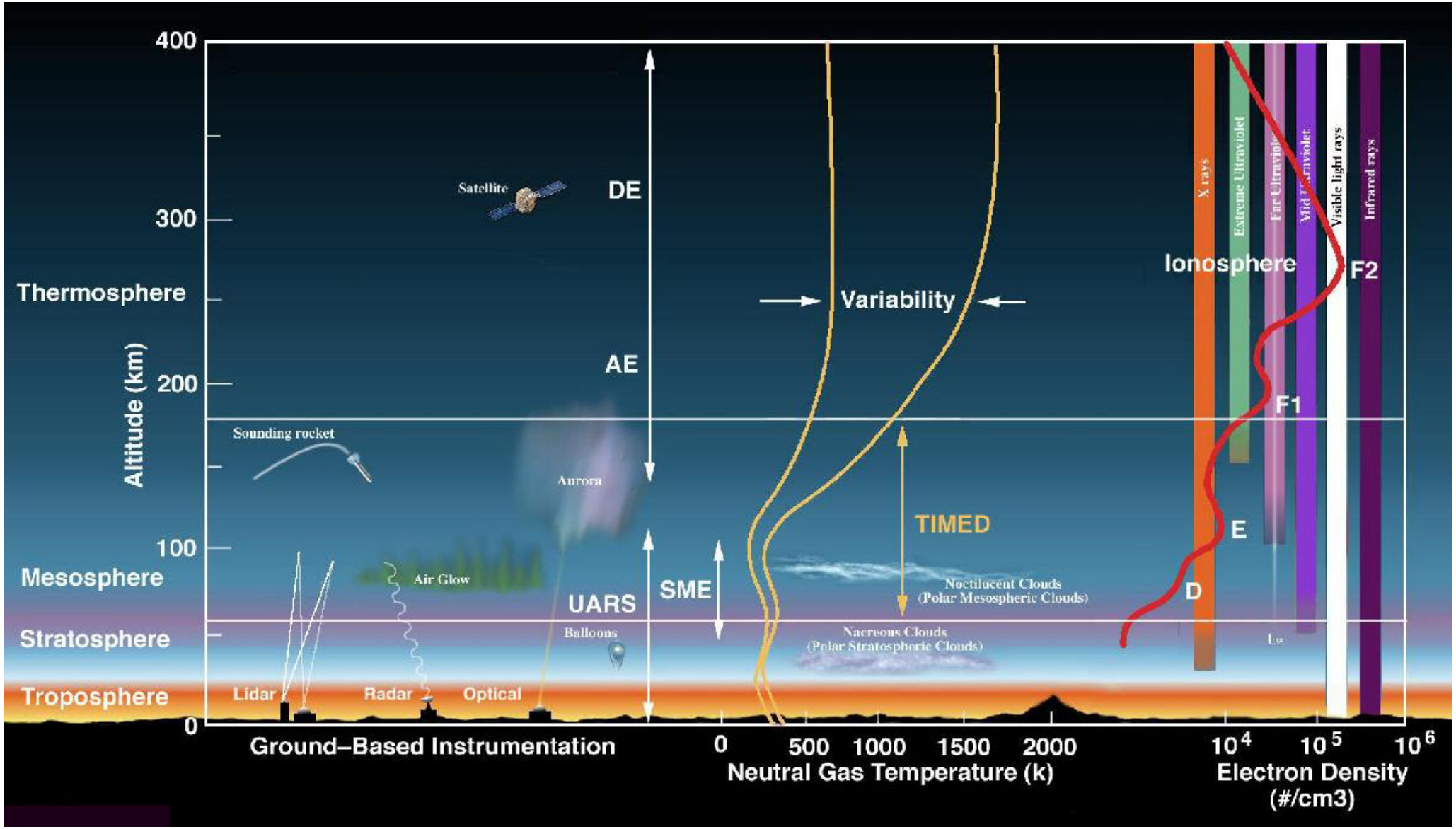
Challenges include:

- Sea salt corrosive environment
- High vibration
- Platform motion & orientation
- Low frequency accelerations – stability issues
- Big waves and leaky seatainers





Earth's Atmosphere and Space

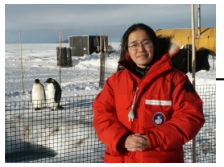


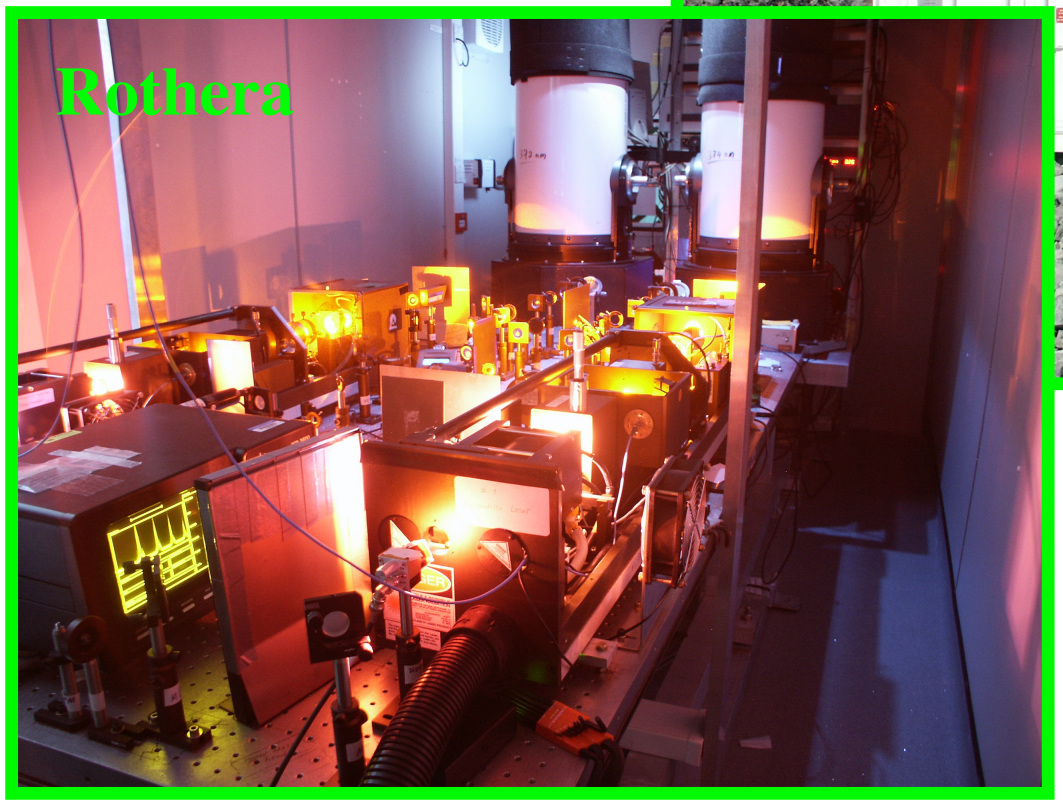
Courtesy to Stan Solomon, NCAR

NSF/NCAR Electra Aircraft

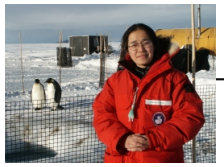
Airborne Fe Boltzmann Lidar

Groundbased Lidar at the South Pole

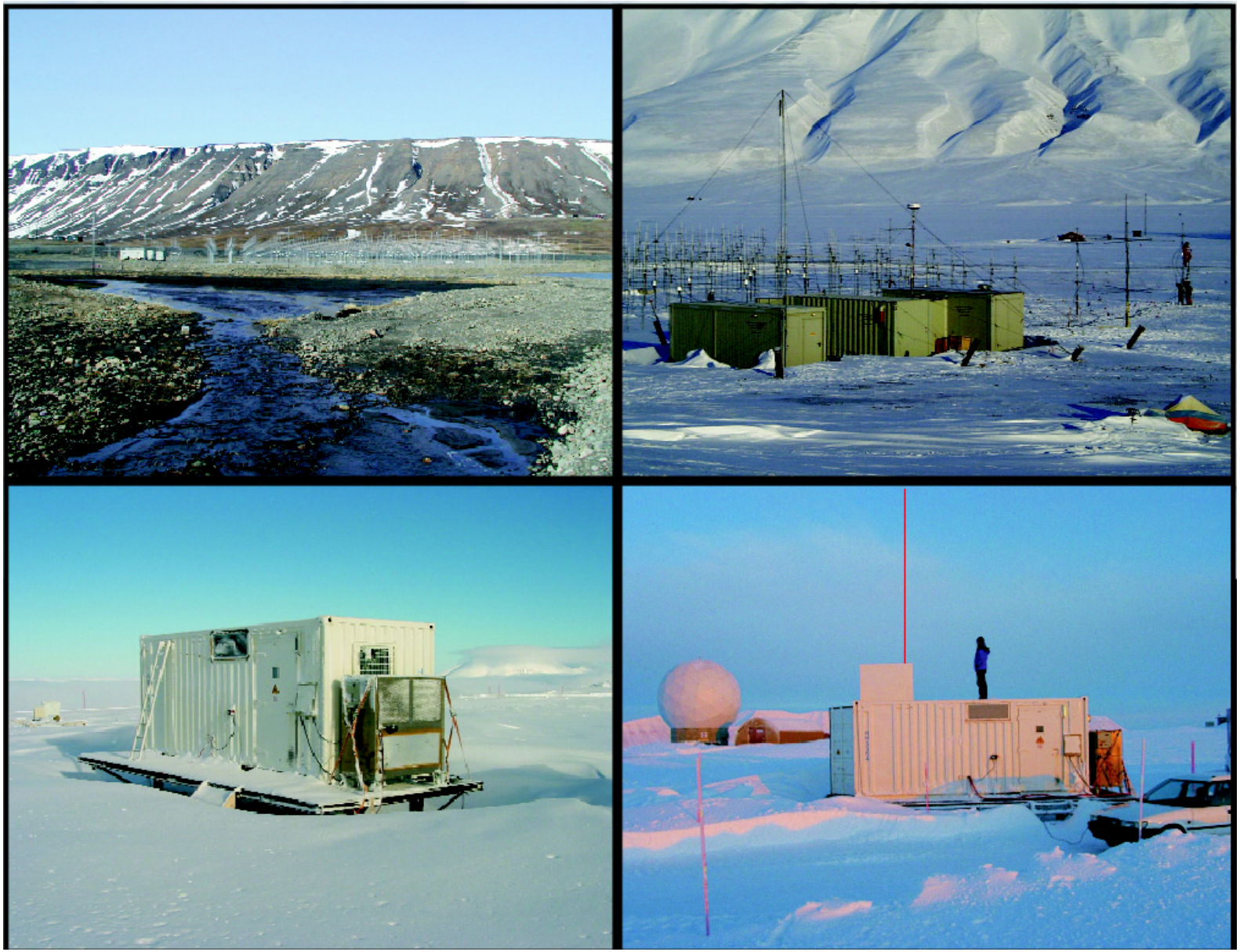


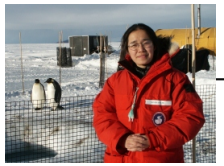


Containerized Lidar at Rothera, Antarctica

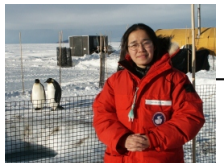


Containerized Lidar at Svalbard

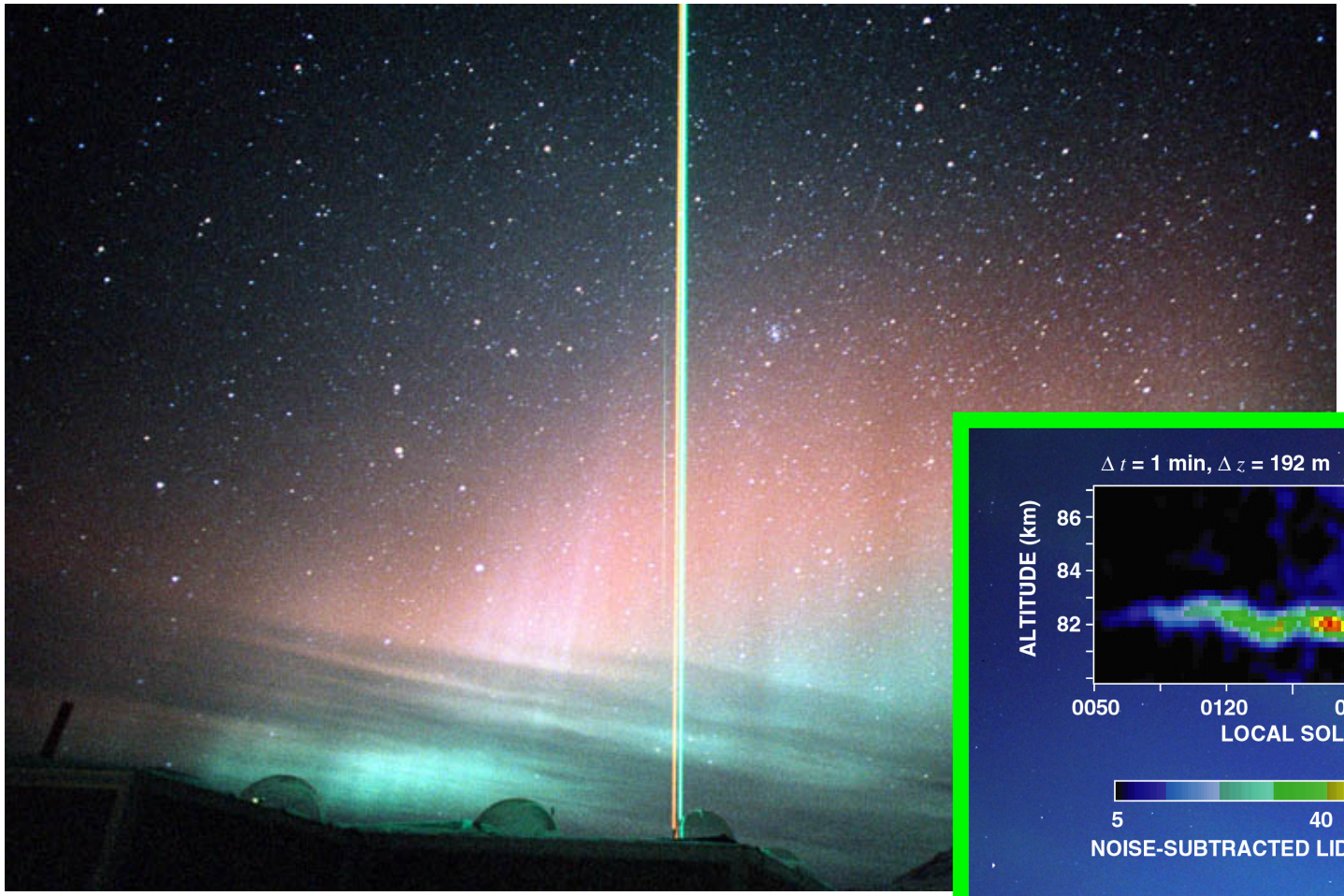


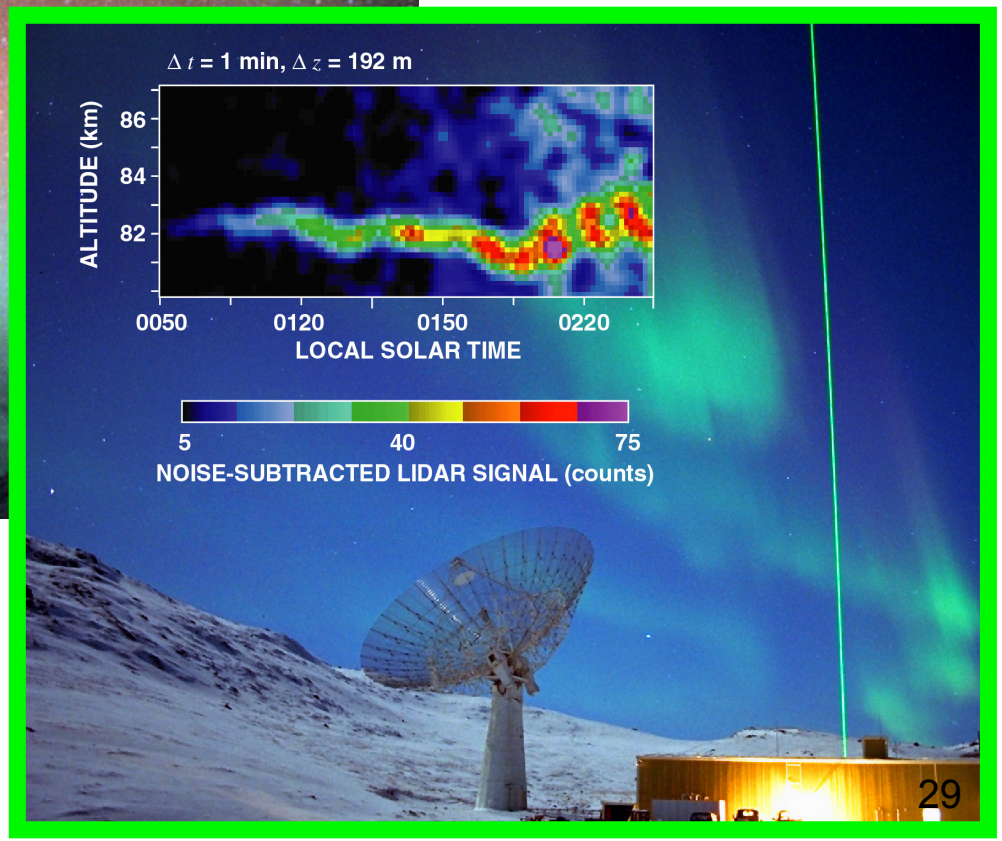


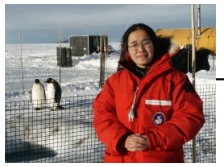
Andoya Rayleigh & Na Lidars



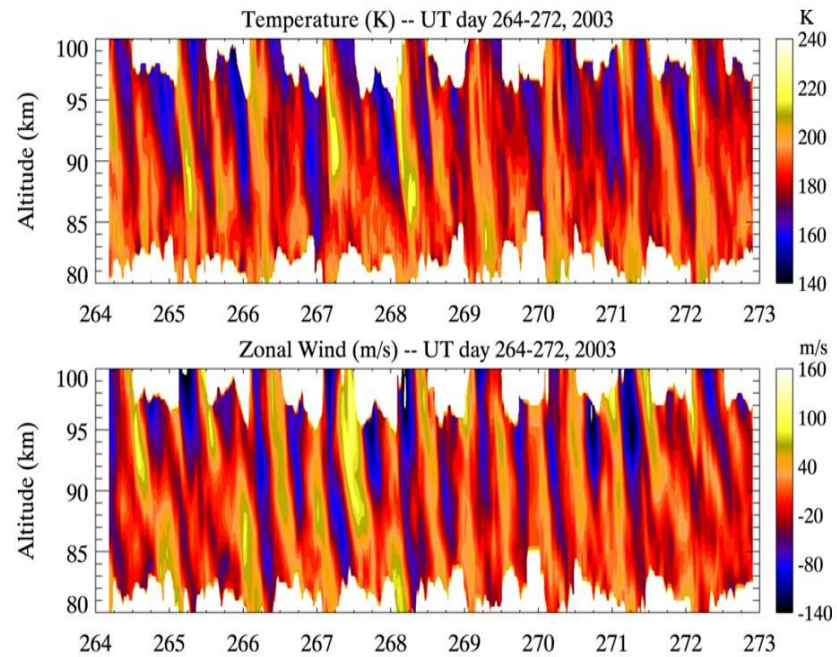
Sondrestrom Rayleigh Lidar



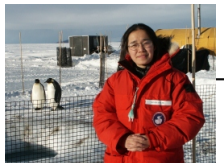




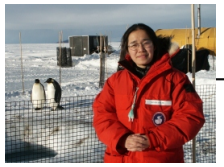
CSU/USU Na Doppler W/T Lidar



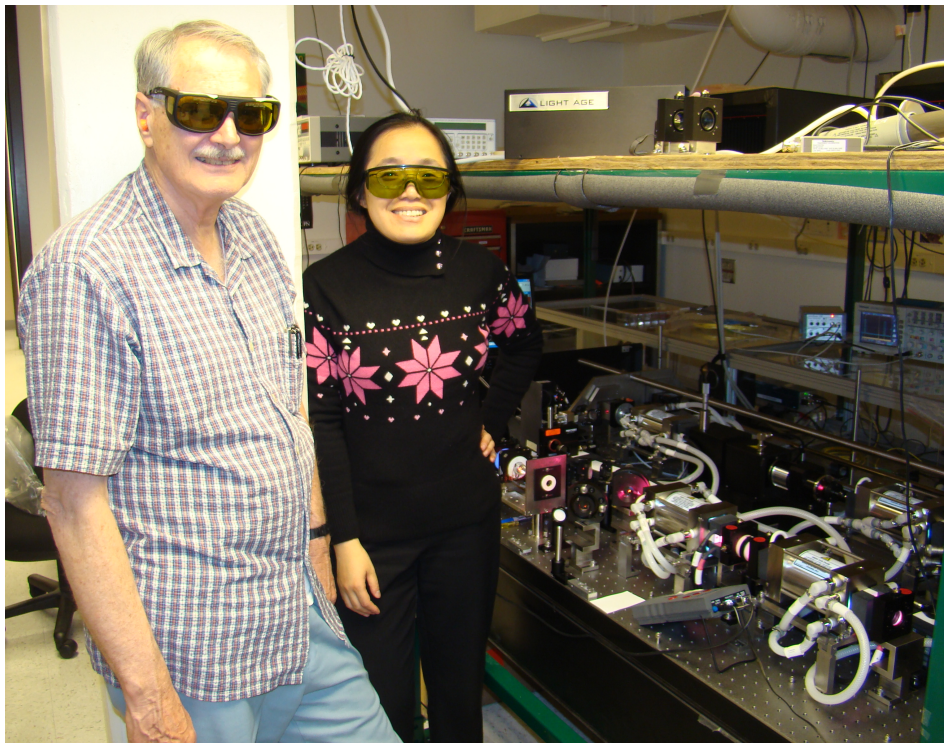
Full Diurnal Coverage and Multiple Beams for Wind and Temperature Measurements

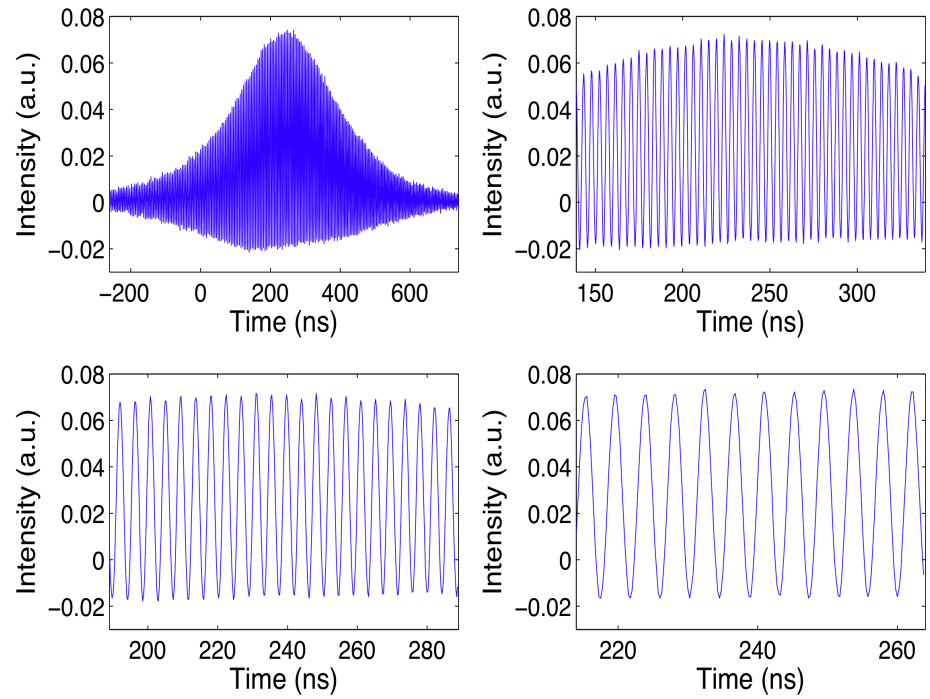


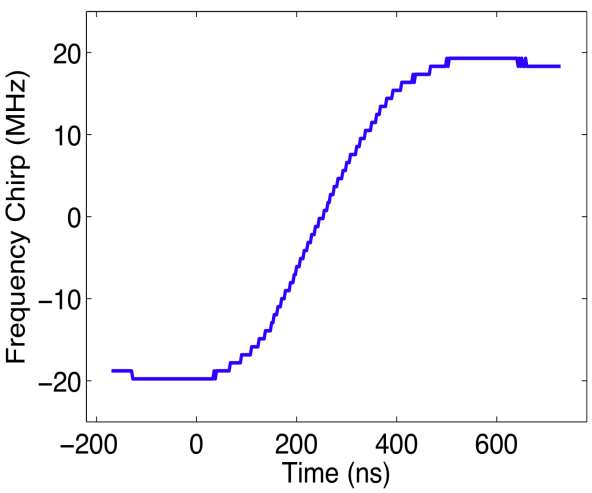
Large-Aperture Na Doppler Lidar at SOR, NM and Maui, HI

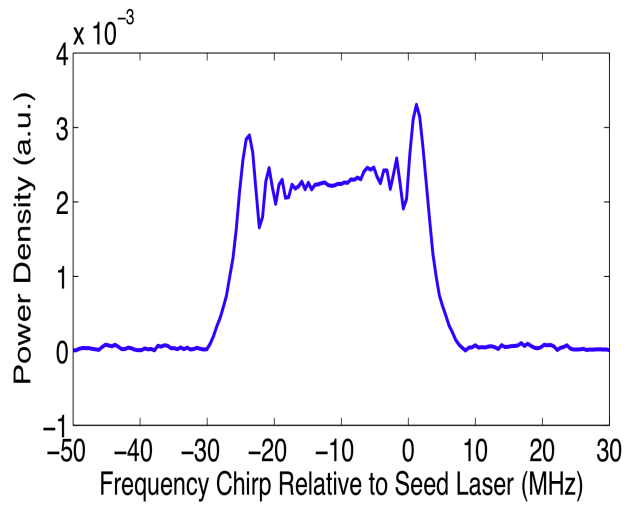


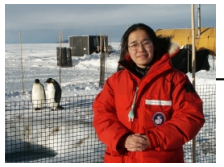
Mobile MRI Fe/Rayleigh/Mie Doppler Lidar



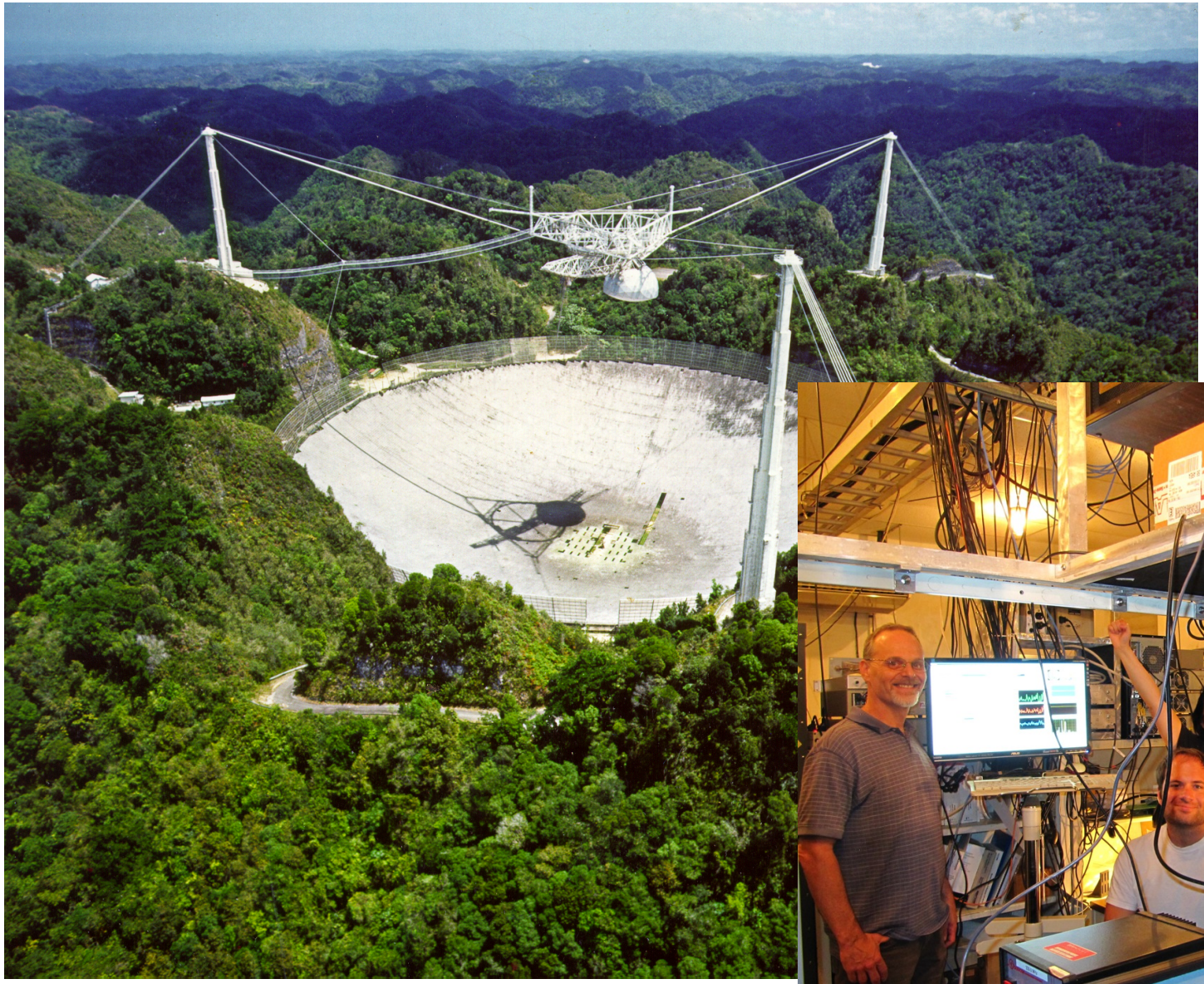


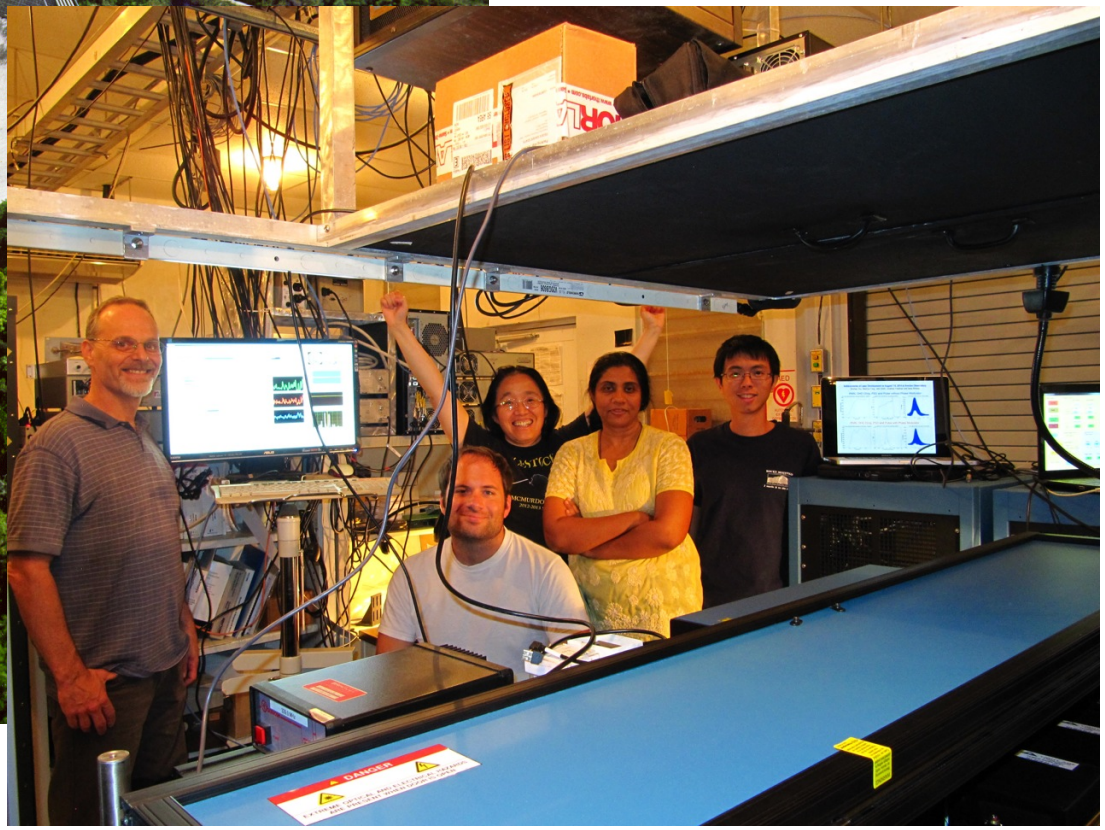


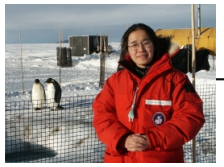




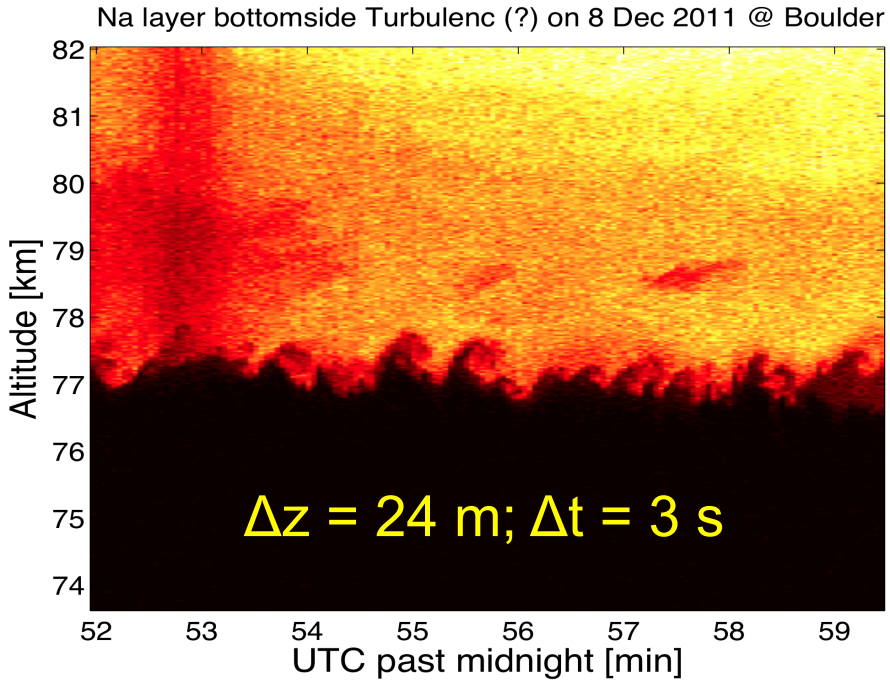
Arecibo Observatory K Doppler Lidar

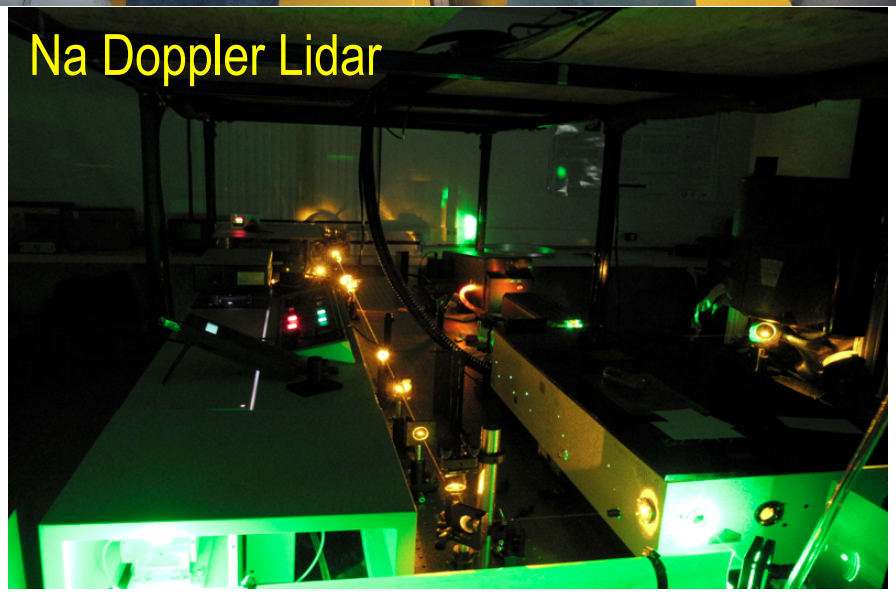


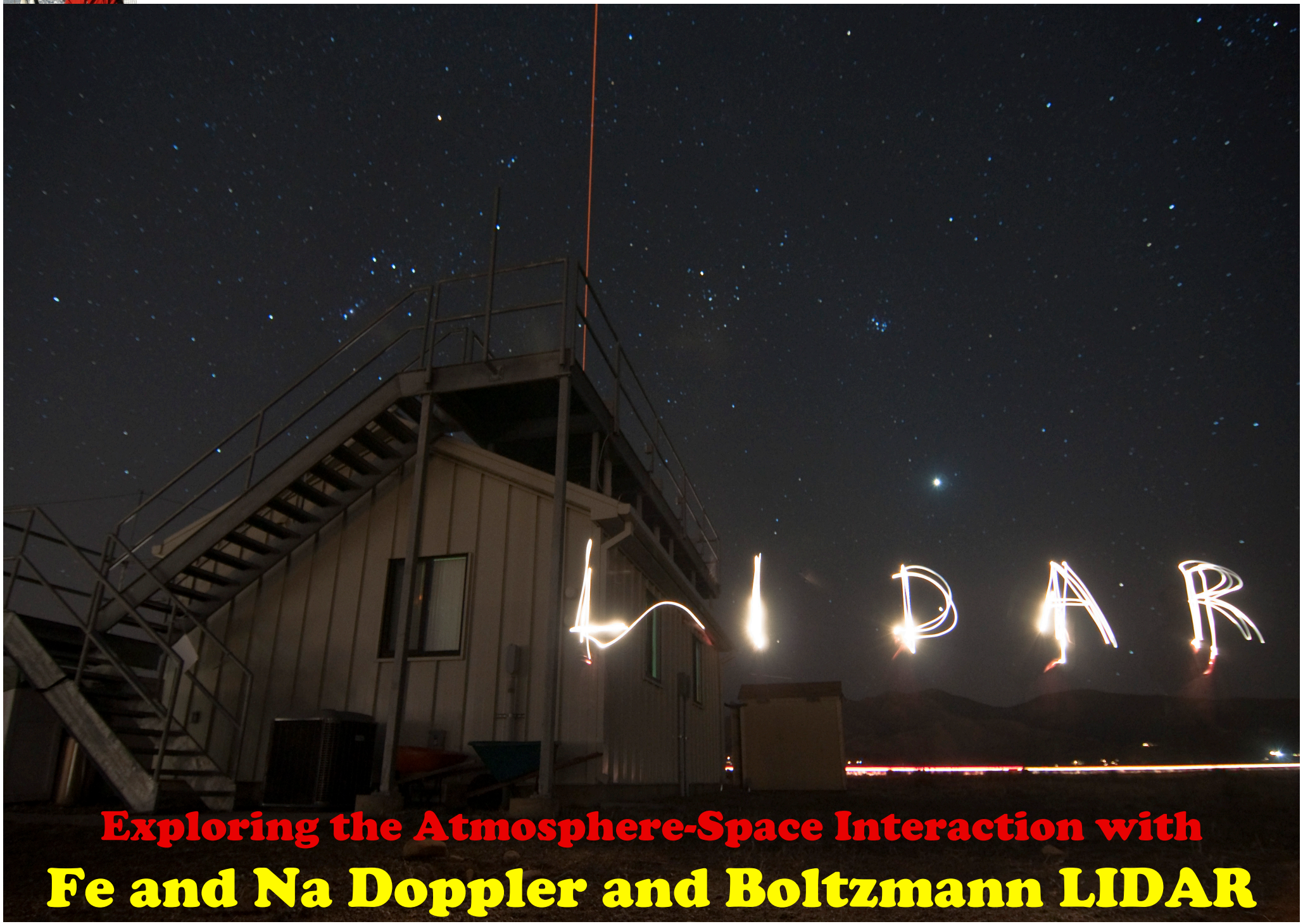




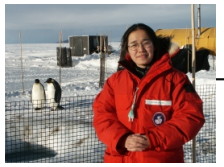
STAR Na Doppler Lidars







Exploring the Atmosphere-Space Interaction with Fe and Na Doppler and Boltzmann LIDAR



Summary

We expect an exciting adventure through the wonderful "lidar remote sensing" field …

Let us work together to make new contributions to lidar science and technology …

Reference Reading Materials

Chapter 1 of "Laser Remote Sensing" textbook

IntroRemoteSensing.pdf and IntroLidar.pdf (at website)