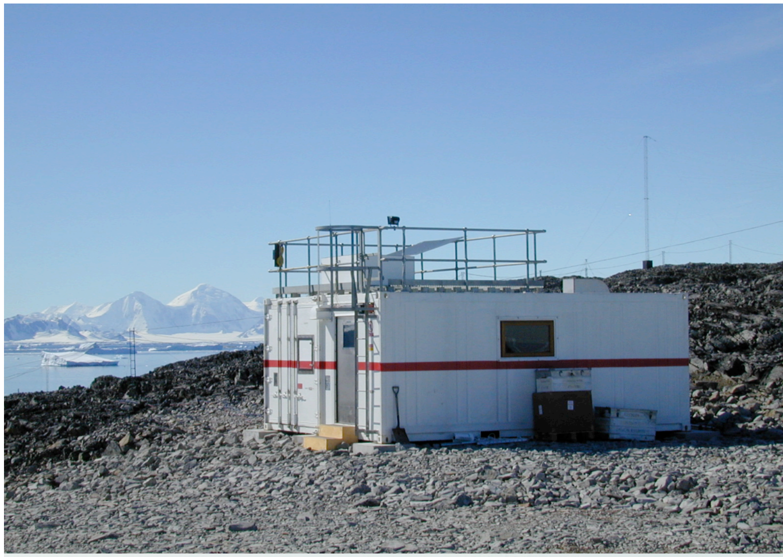
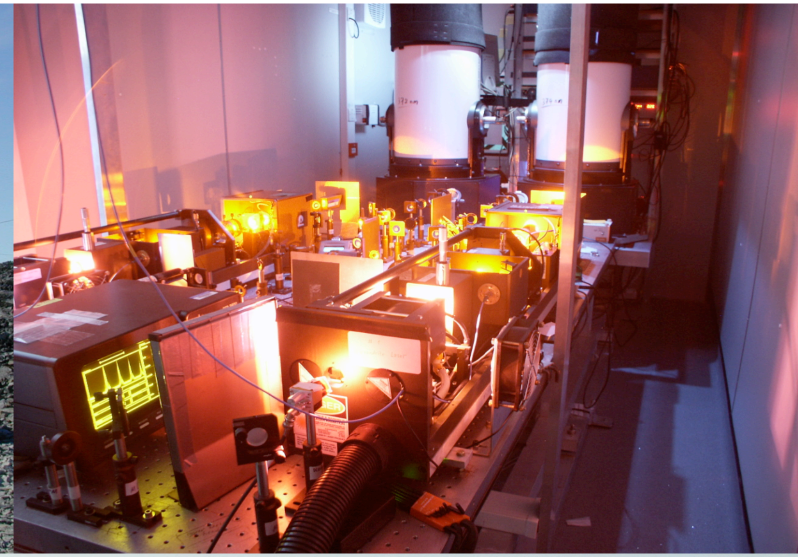
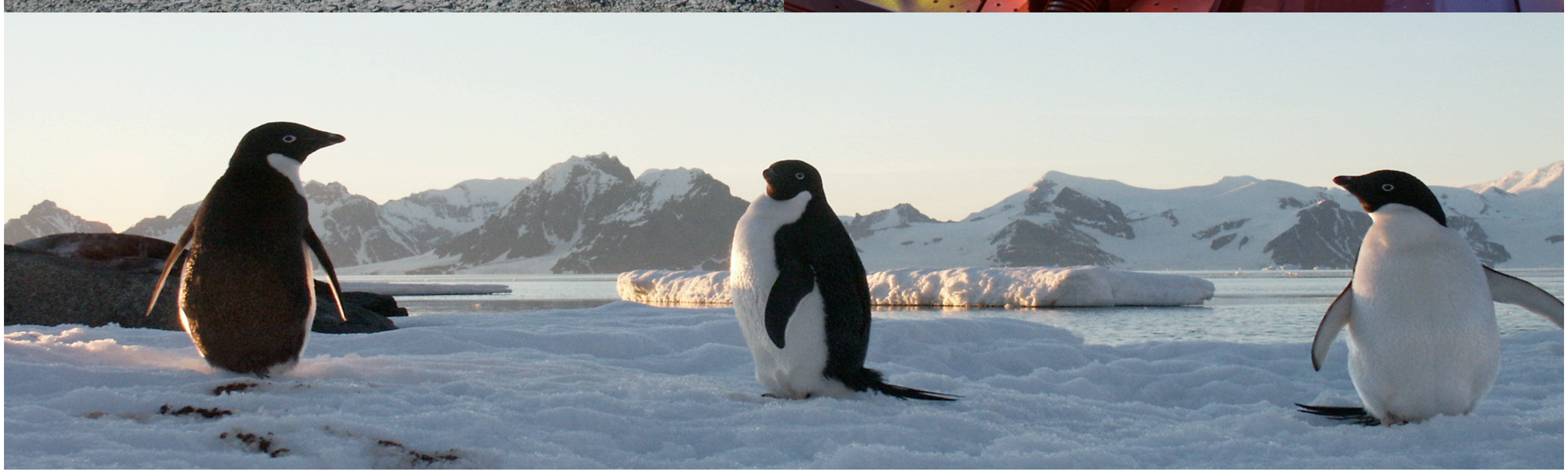
ASEN-5519 Laser Remote Sensing

Fundamentals and Applications in Science and Engineering







Lecture 1. Introduction

- Laser remote sensing is an advanced technology that is not only replacing conventional sensors in science, engineering and medicine, but also creating new methods with unique properties that could not be achieved before.
- This course will cover laser remote sensing principle, technology, and their applications in scientific research and industry engineering.
- Our goals are to provide students a comprehensive understanding of the fundamentals of laser remote sensing, and the necessary knowledge and ability to pursue research in the lidar and remote sensing field.

Concept of Remote Sensing

- Remote Sensing is the science and technology of obtaining information about an object without having the sensor in direct physical-contact with the object.

- Remote sensing is opposite to *in situ* methods that obtain information locally.

Concept of Remote Sensing

- The Nature of Remote Sensing is one kind of measurements.
- Measurements are to obtain or acquire information of an object using experimental methods.
- There must be some interaction between the object and the instruments in order to acquire the information of the object.
- The interaction can be direct (local) or remote.

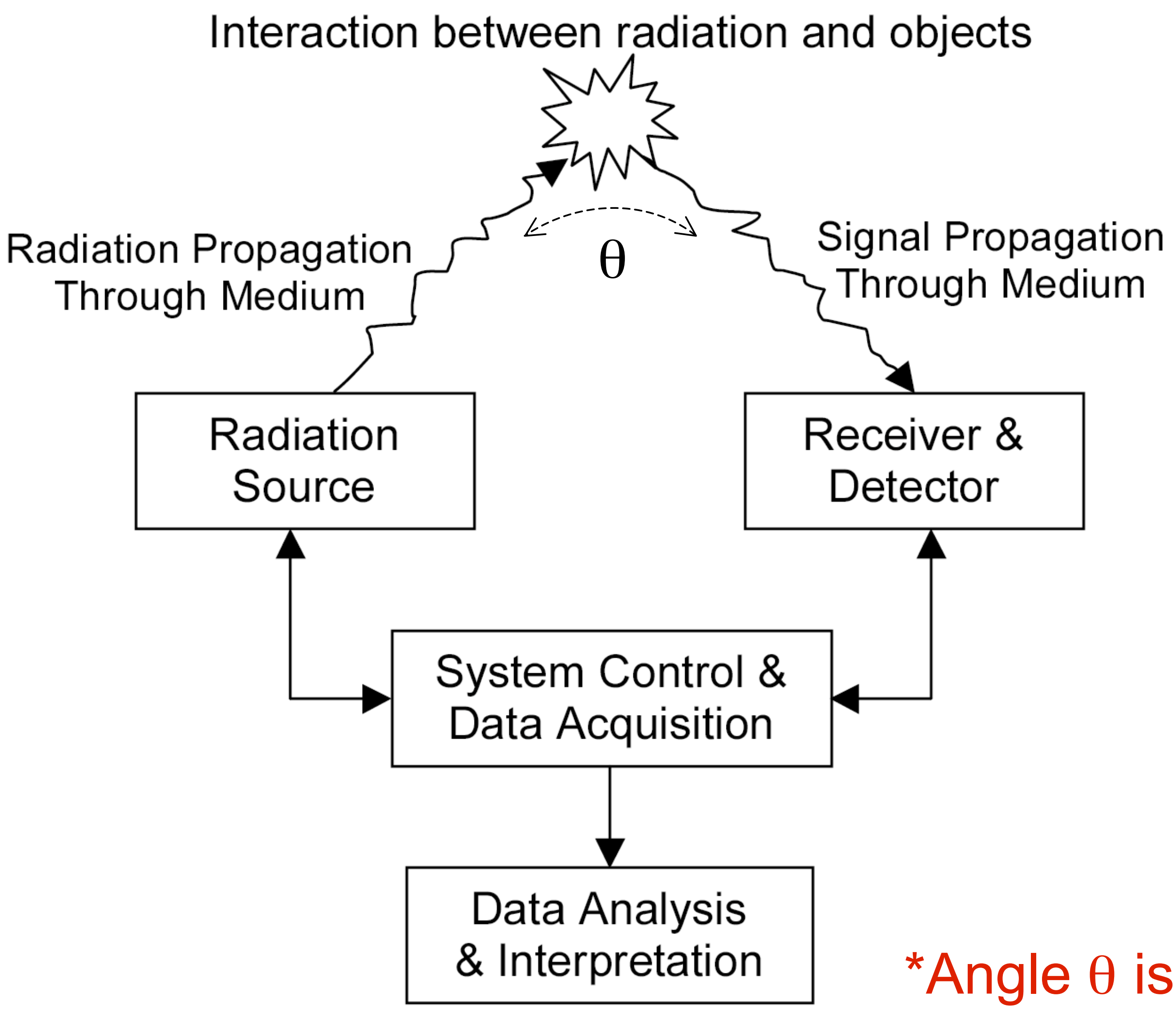
Concept of Remote Sensing

- Without direct physical contact between the sensor and the object, some remote interaction must be introduced to carry away the object information so that the information can be acquired by the sensor remotely.

- The interaction between radiation and the object is the most common interaction used in modern remote sensing.

- The radiation includes electromagnetic radiation and acoustic waves.

Concept of Remote Sensing System

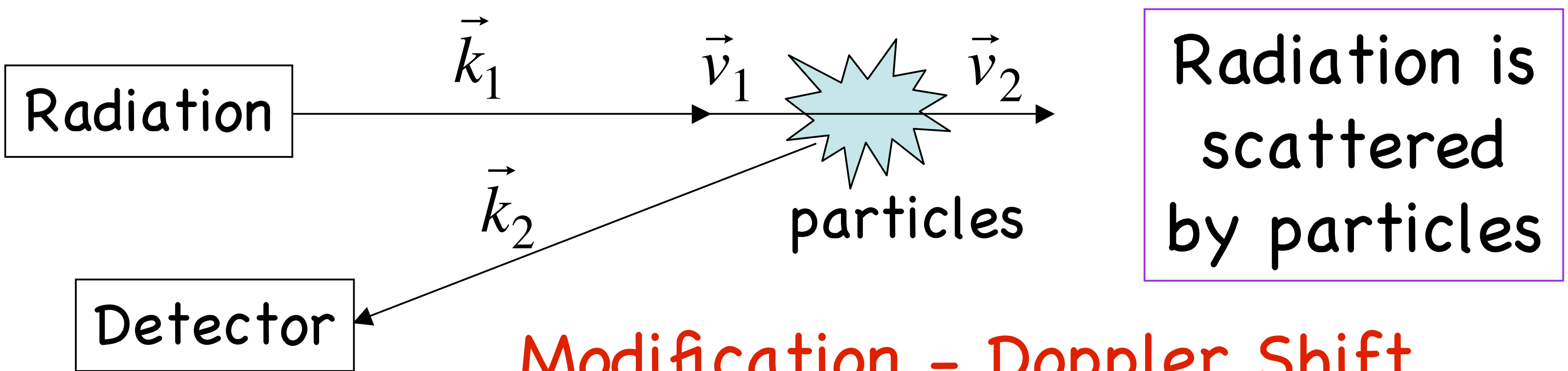


*Angle θ is arbitrary

Concept of Remote Sensing

- During the interaction, radiation properties are modified by the object, therefore, containing the information of the object. Through recording and analyzing the modifications of the radiation, the object information can be retrieved.

An example: the wind measurements



Modification – Doppler Shift

$$\Delta\omega = \omega_2 - \omega_1 = -(\vec{k}_1 \bullet \vec{v}_1 - \vec{k}_2 \bullet \vec{v}_2)$$

Concept of Remote Sensing

- Remote Sensing contains many aspects, not only the instrumentation and data acquisition, but also the data processing, analysis, and interpretation.
- It includes both technology and science, so not only an engineering course, but also with science contents.

Remote Sensing Aspects

1. Physical Science and Technology Development:

    physical interaction study,

    sensor design, development, and calibration,

    data collection/acquisition,

2. Signal Processing:

    data processing,

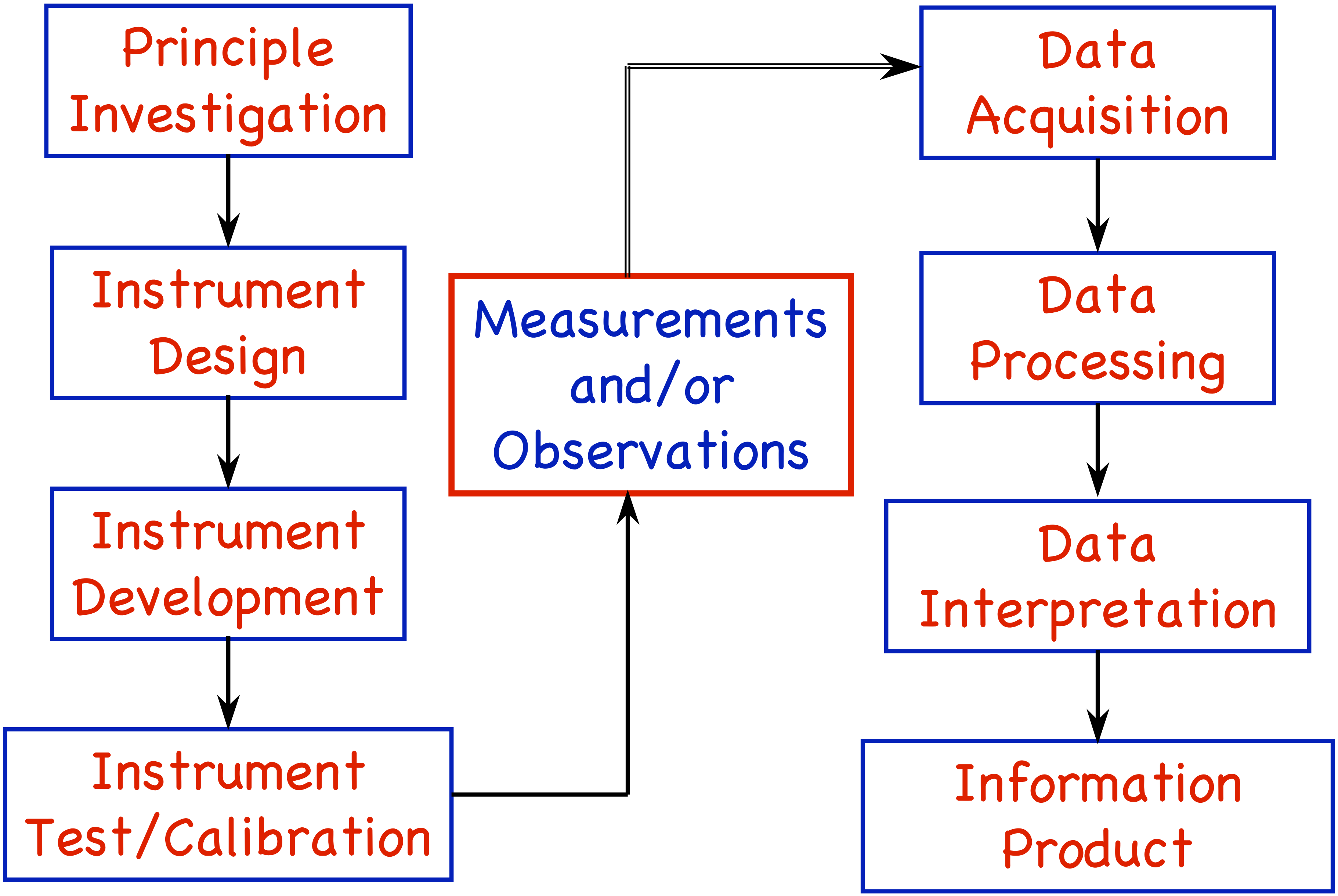
    information retrieval,

    error analysis

3. GeoScience Study:

    data analysis and interpretation.

Content of Remote Sensing



Remote Sensing Applications

- Space Science
- Atmospheric Science
- Solid-Earth Science
- Ocean Science
- Environmental Monitoring (pollution, toxic)
- Airplane detection
- Astronomy exploration
- … …

Advantages of Remote Sensing

- Reaching inaccessible/difficult regions to make reliable measurements
- Avoiding hazardous to reach regions
- Fast and inexpensive probing of large volumes
- Minimal disturbance of measured processes

Classification of Remote Sensing

- Passive Remote Sensing: no self-generated radiation is used in the sensing, but using naturally occurring radiation, such as sunlight or nightglow emission.

- Active Remote Sensing: self-generated radiation sources are used, such as laser light, radio- and micro-wave, acoustic wave.

Depending on whether a human-generated radiation source is used in the sensing process

Classification of Remote Sensing

- Optical Remote Sensing: probing and detecting in optical frequency range
- Radio Remote Sensing: probing and detecting in radio and microwave frequency
- Acoustic Remote Sensing: probing and detecting in acoustic frequency range

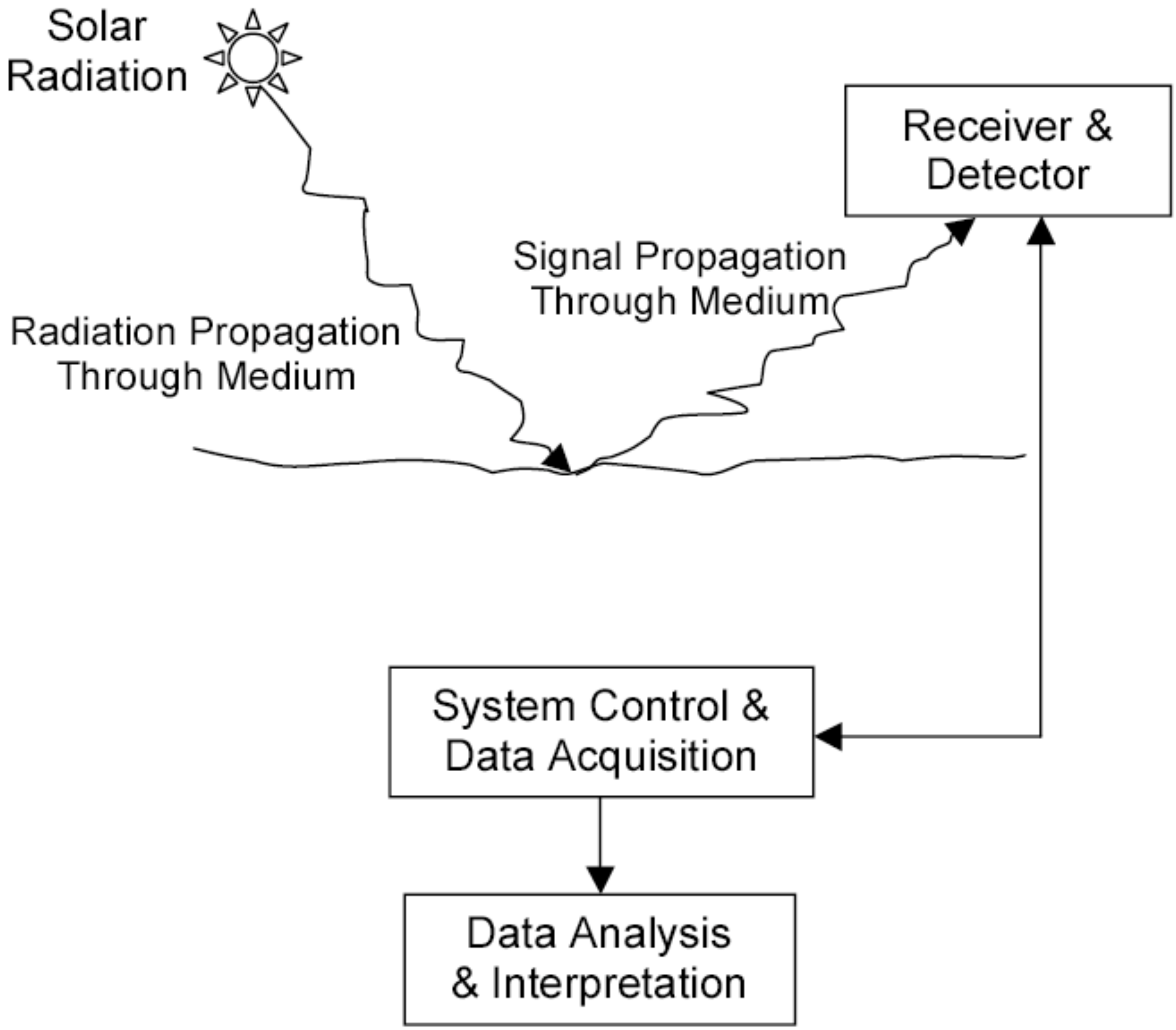
All include passive and active remote sensing

Depending on the frequency of radiation used in the probing and detection

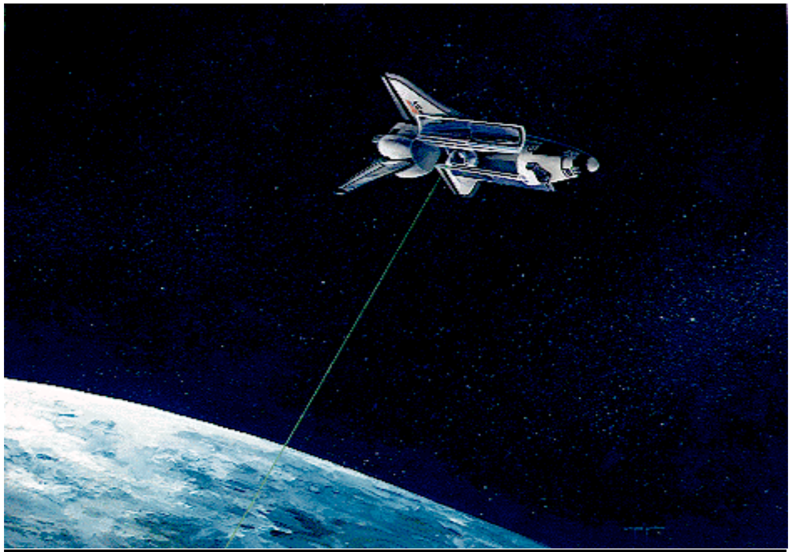
Passive Remote Sensing

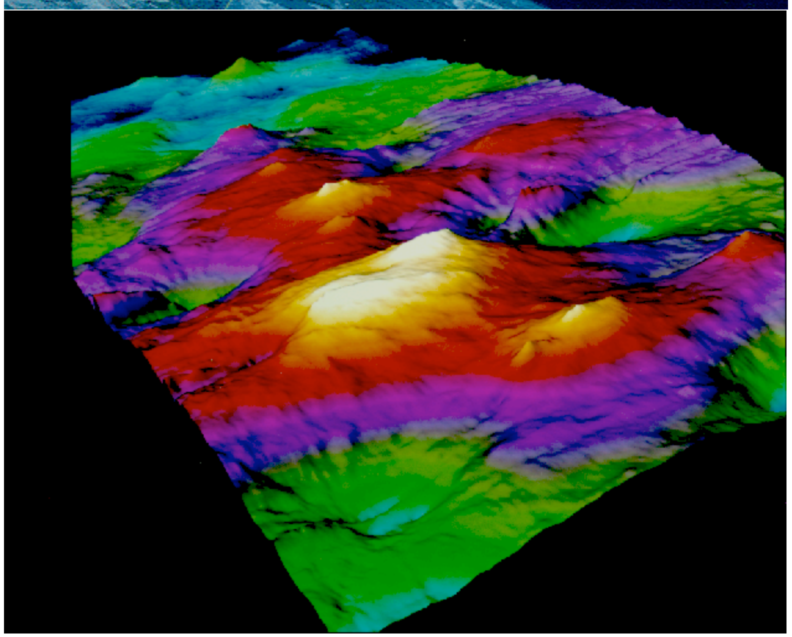
- Satellite or airborne photography
- Radiometer
- All-sky-imager
- Spectrometers
- Interferometer
- …

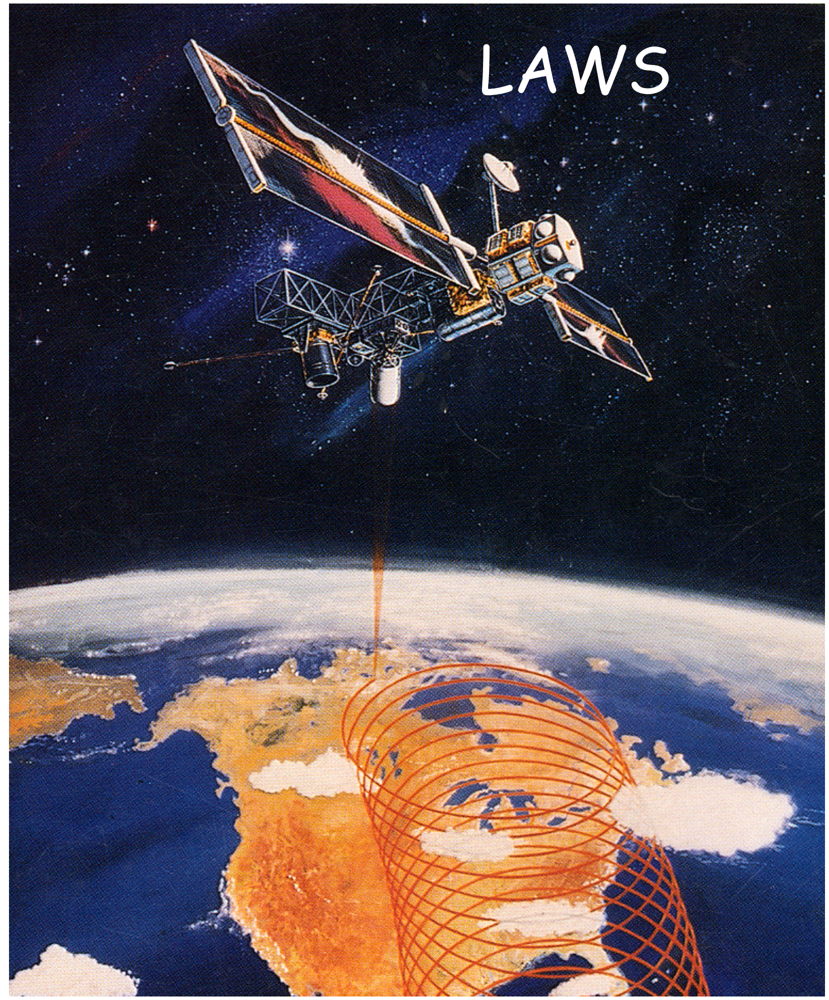
Passive Remote Sensing (Scattering)



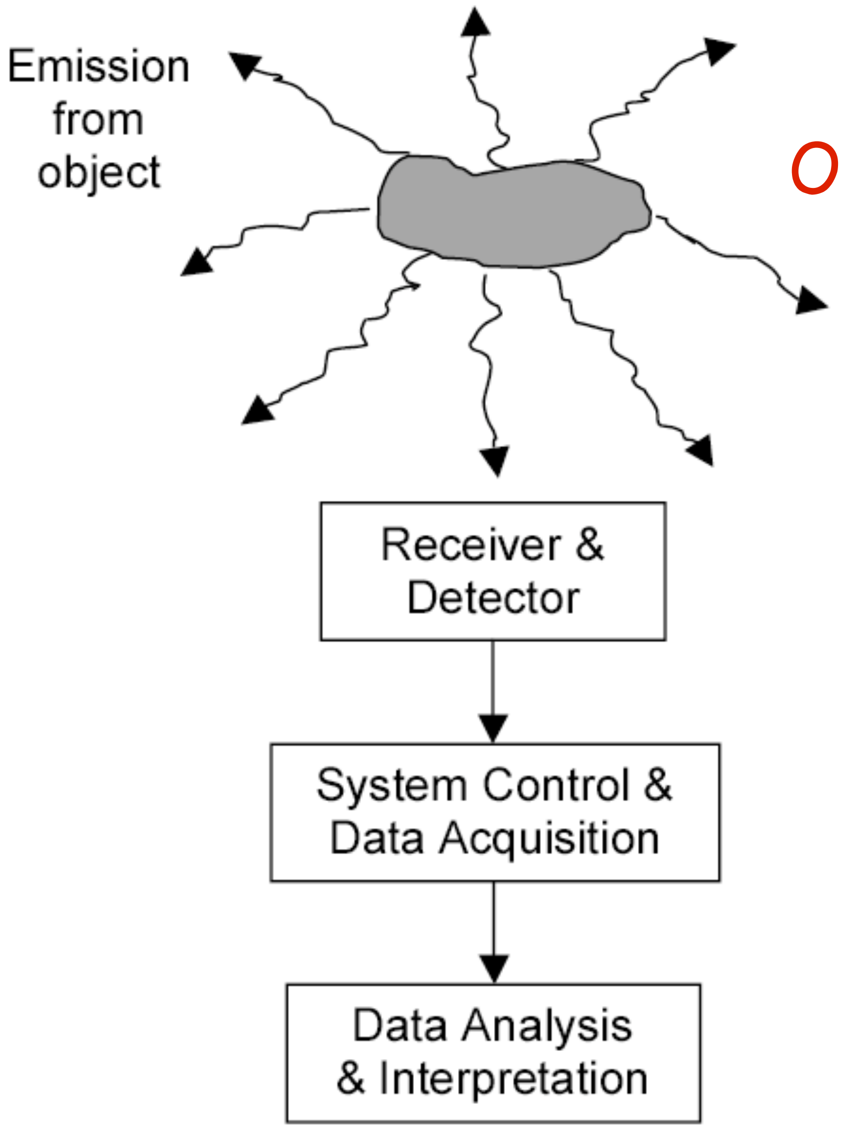
Space Imaging (Scattering)





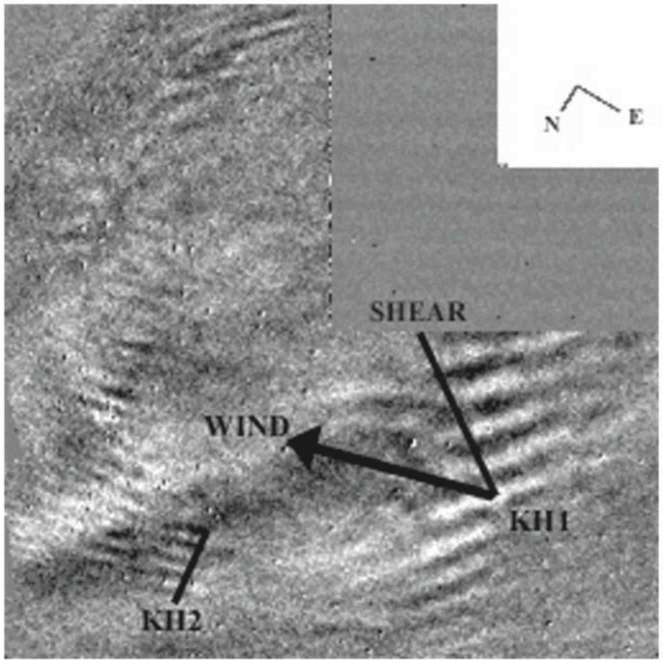


Passive Remote Sensing (Emission)



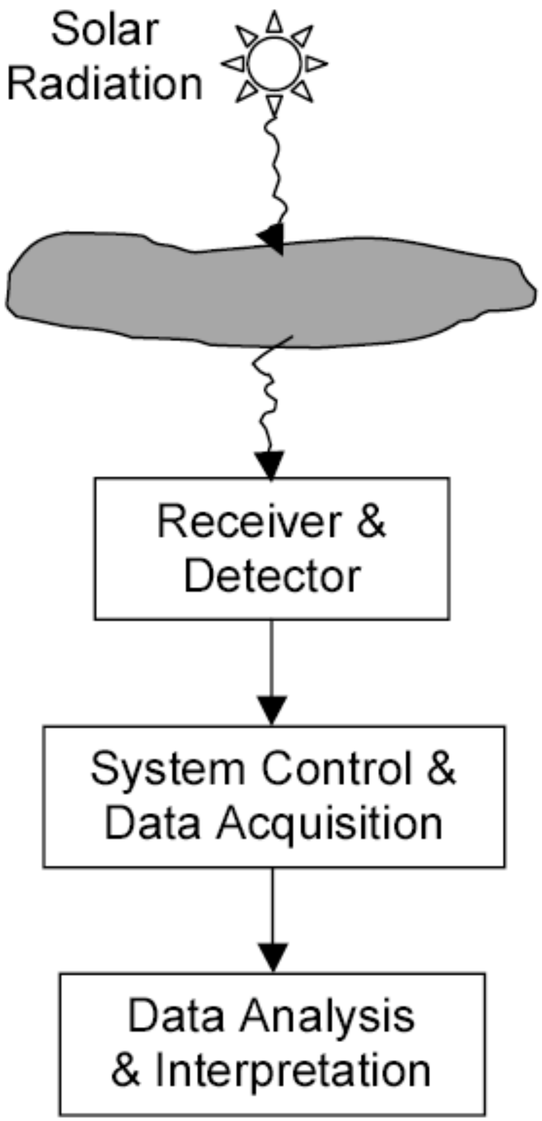
OH, Na, O

All-Sky-Camera (Emission)



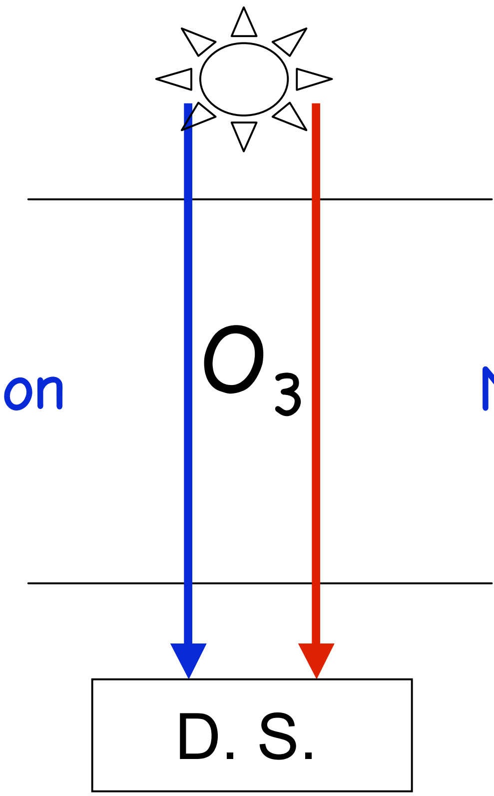
Emissions from
OH, Na, O, etc

Passive Remote Sensing (Extinction)



NOAA Dobson Spectrometer
to measure ozone
from the ground

Dobson Spectrometer (Extinction)



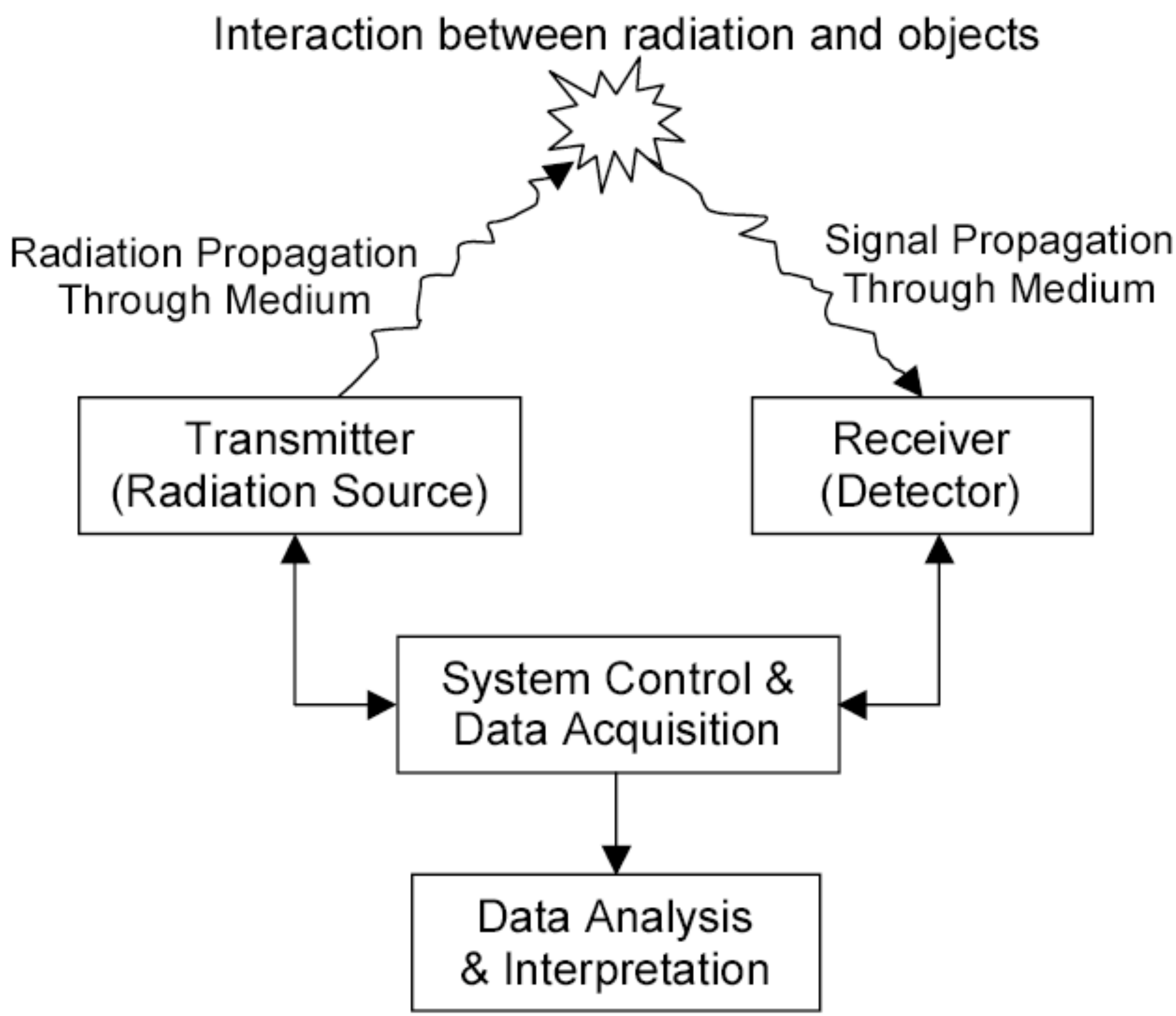
305 nm
Strong Absorption
by ozone

325 nm
No Absorption
by ozone

$$R = \frac{I_{325}}{I_{305}} \propto N_{O_3}$$

The ratio between the two light intensity is a measure of the total amount of ozone in the light path from the sun to the observing D.S.

Active Remote Sensing



SODAR (Sound Detection and Ranging)

Desert Research Institute Doppler SODAR

http://www.dri.edu/Projects/Radar/SODAR/

SODAR (Sound Detection and Ranging)

Atmospheric Research LTD SODAR at Airfield

http://www.a-research.com.au/sodar.html

Three directions are measured with the SODAR so that the 3 components (u, v, w) of wind field can be derived

SODAR

- Sound wave or acoustic wave is used in the sensing. This is real mechanical sound wave, i.e., longitudinal wave, produced by compressing the atmosphere medium. It is not electromagnetic wave at the sound frequency.

- The speed used is the speed of sound (340 m/s).

- SODAR works better in the air with more moisture, rather than the dry air. Usually, it goes up to several hundred meters.

SODAR & SONAR

- SONAR is Sound Navigation Ranging, used under water, for the ocean detection, like submarine.

- SODAR is usually referred to the sound detection and ranging in the atmosphere. We use it for general description of SODAR and SONAR.

- SONAR works better under water.

RADAR (Radiowave Detection and Ranging)

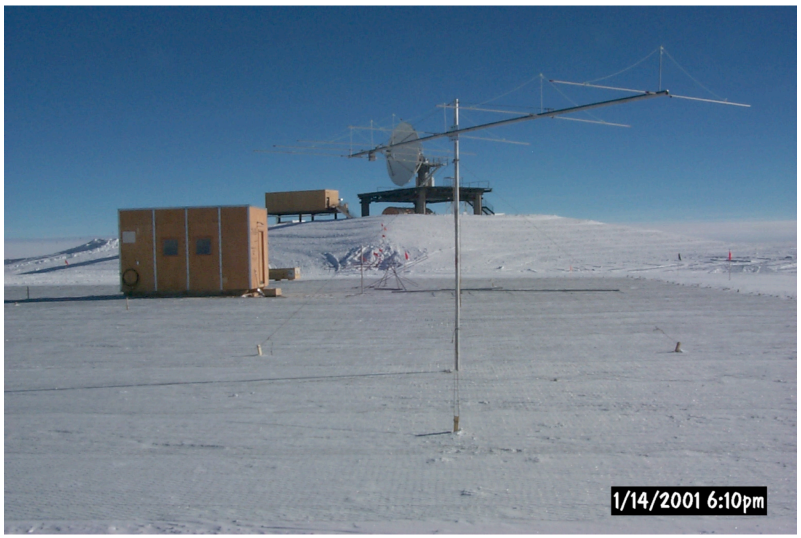
- Electromagnetic waves in the radio frequency and microwave frequency range are used in the sensing.

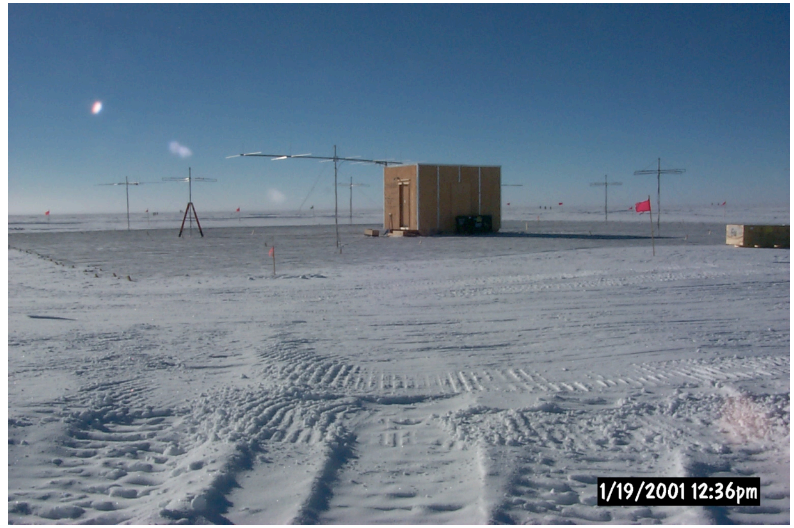
- The speed used is the light speed (3×10^8 m/s).

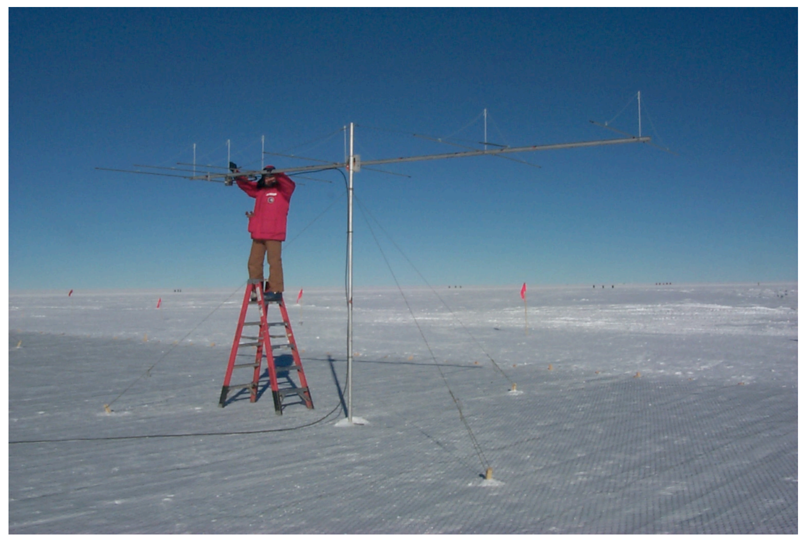
ASEN5245. Radar and Remote Sensing
Taught by Prof. Jeff Thayer

NEXRAD Weather Radar System

South Pole Meteor Scatter Radar

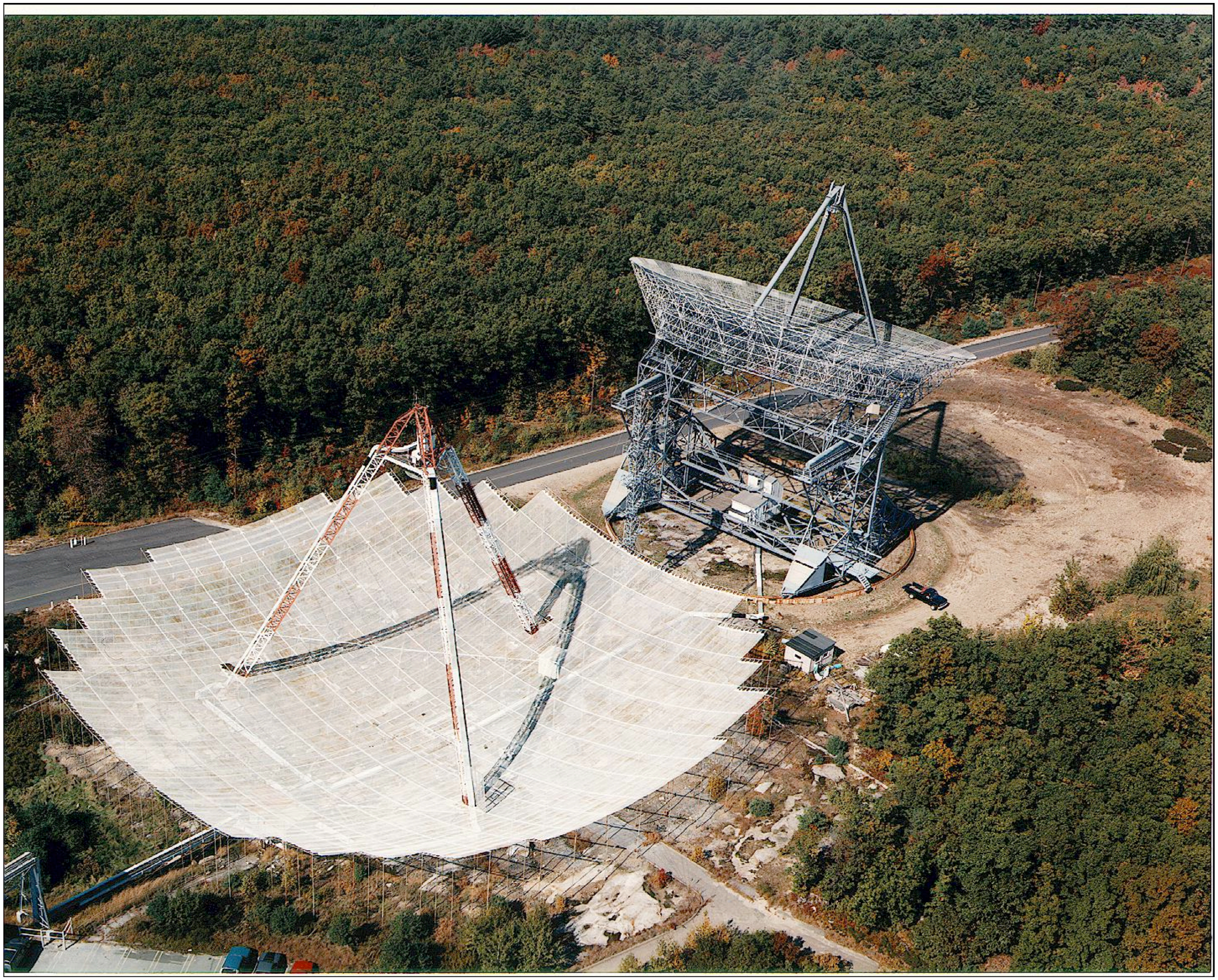






Arecibo Incoherent Scatter Radar

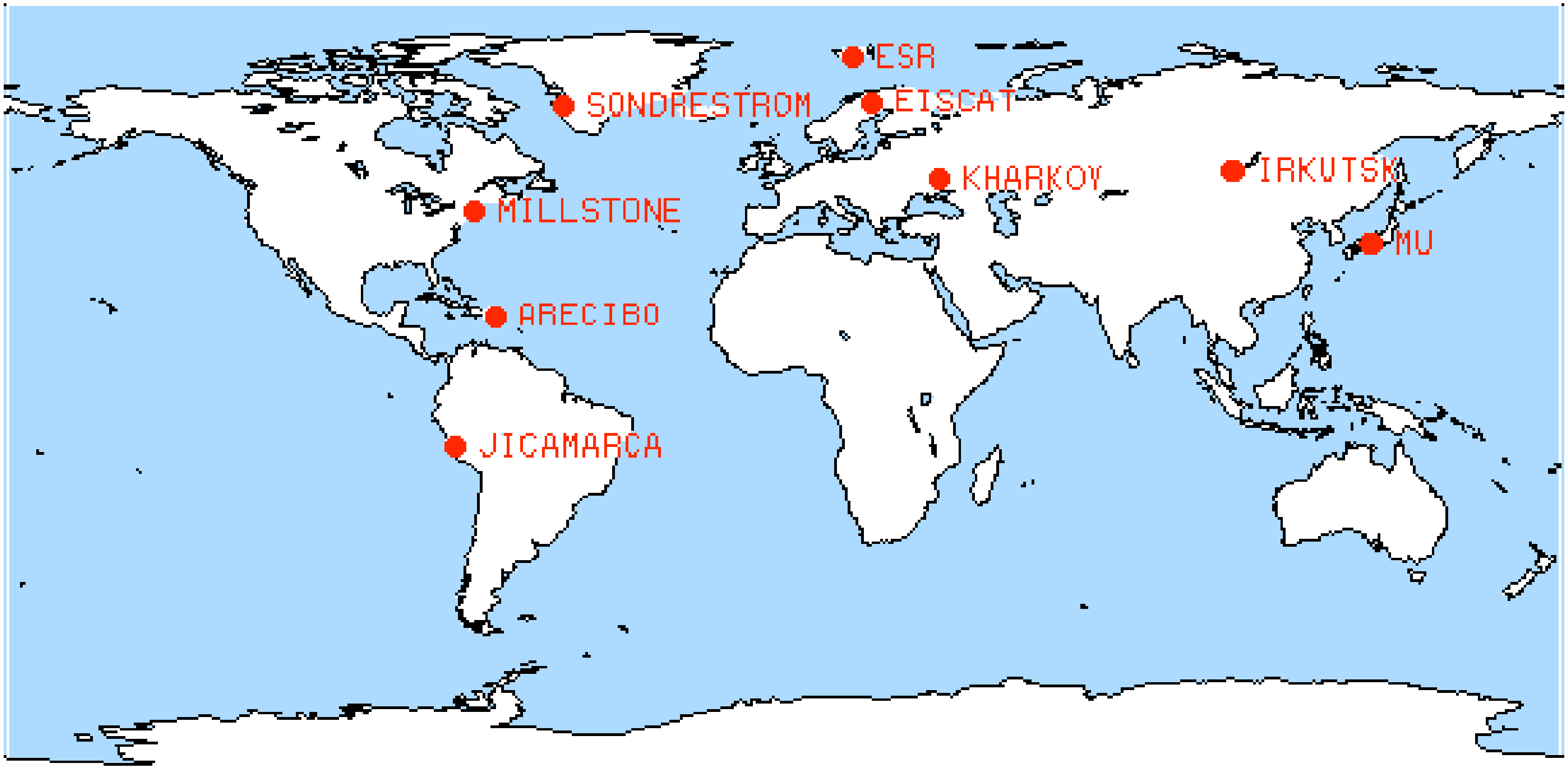
Millstone Incoherent Scatter Radar



Jicamarca Incoherent Scatter Radar

Sondrestrom Incoherent Scatter Radar

Incoherent Scatter RADAR Map



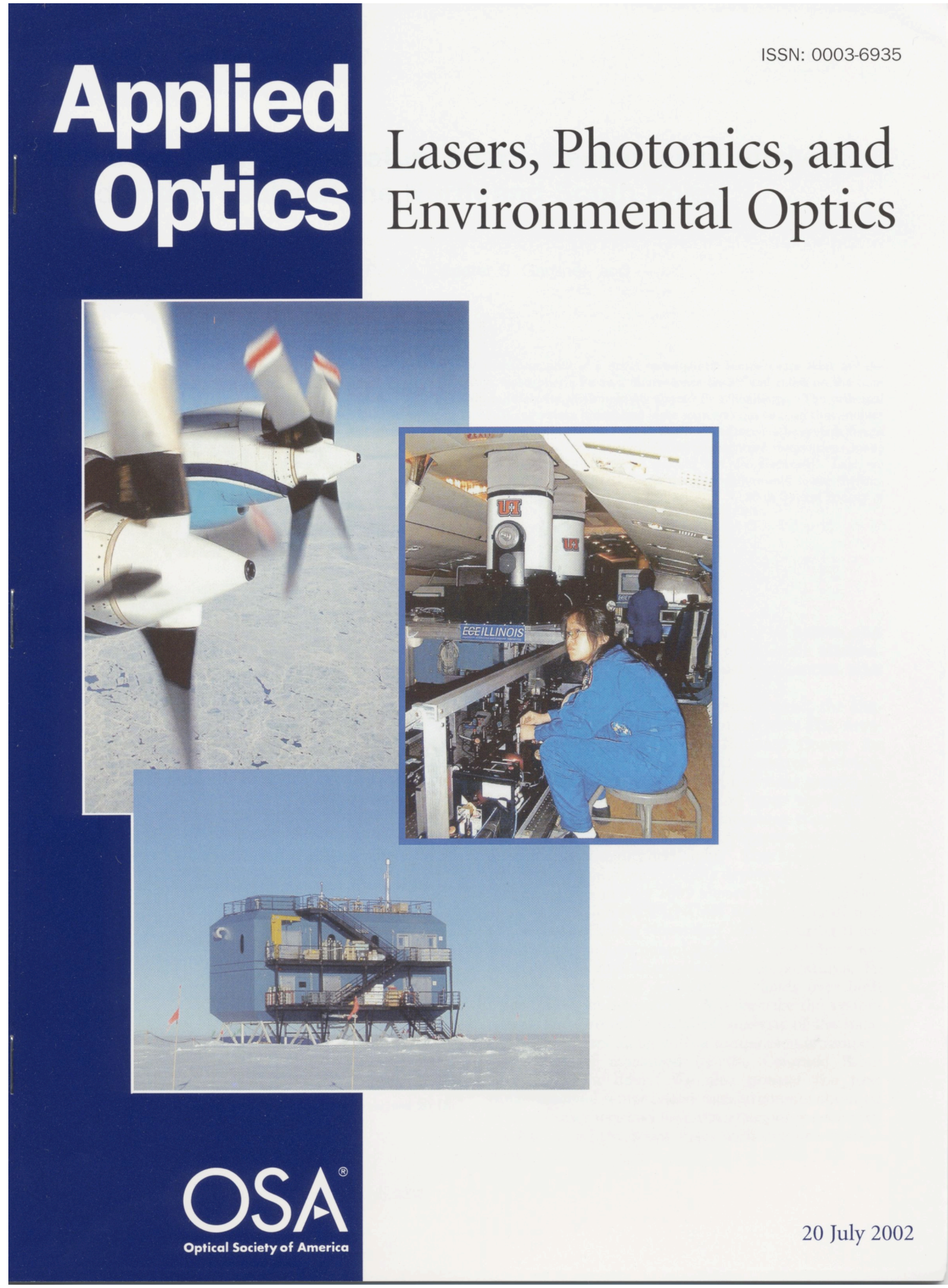
LIDAR (Light Detection and Ranging)

- Electromagnetic waves in the optical frequency range are used in the sensing.

- More commonly, we say light, especially laser light, is used in the sensing.

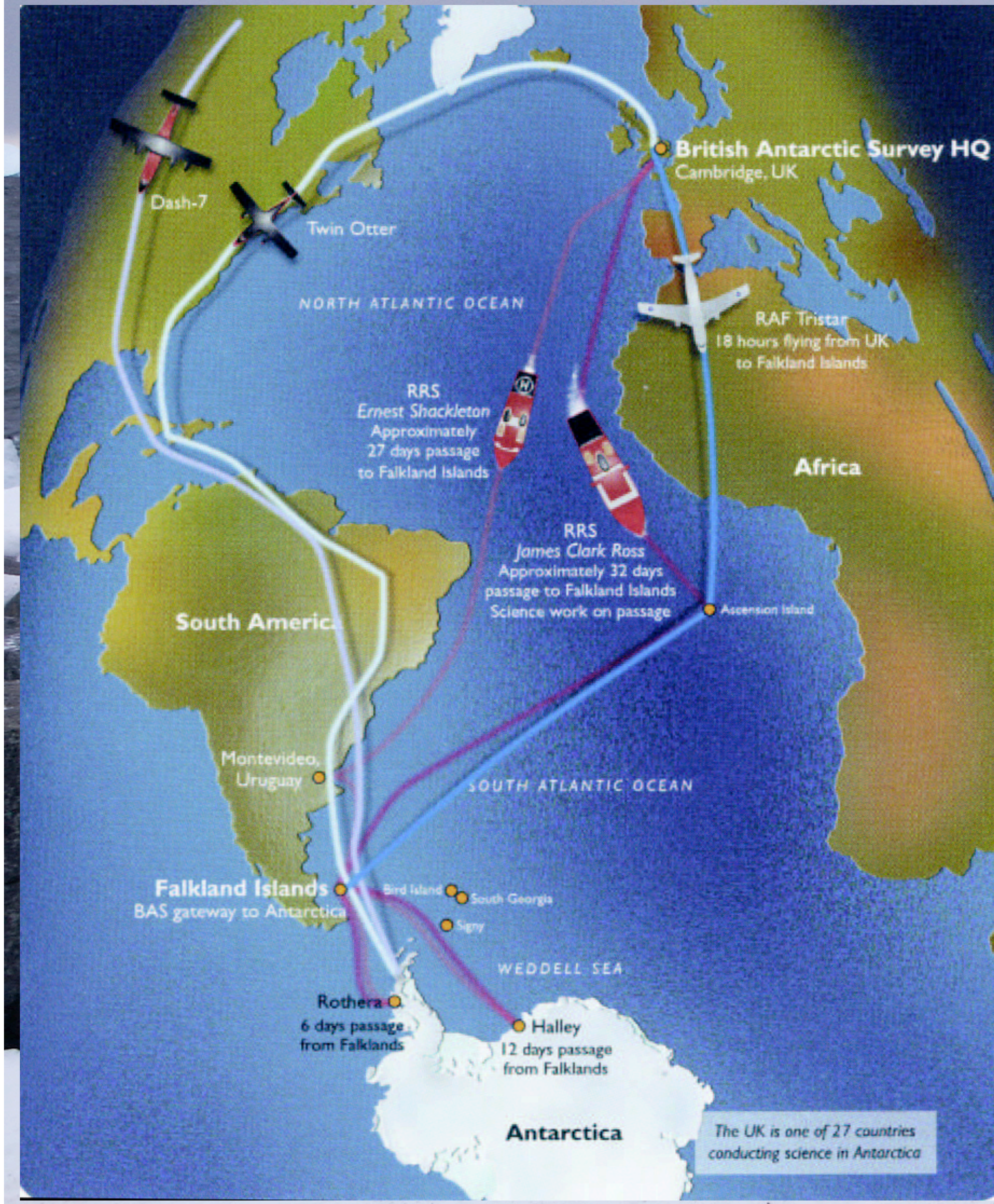
- The speed used is the light speed (3×10^8 m/s).

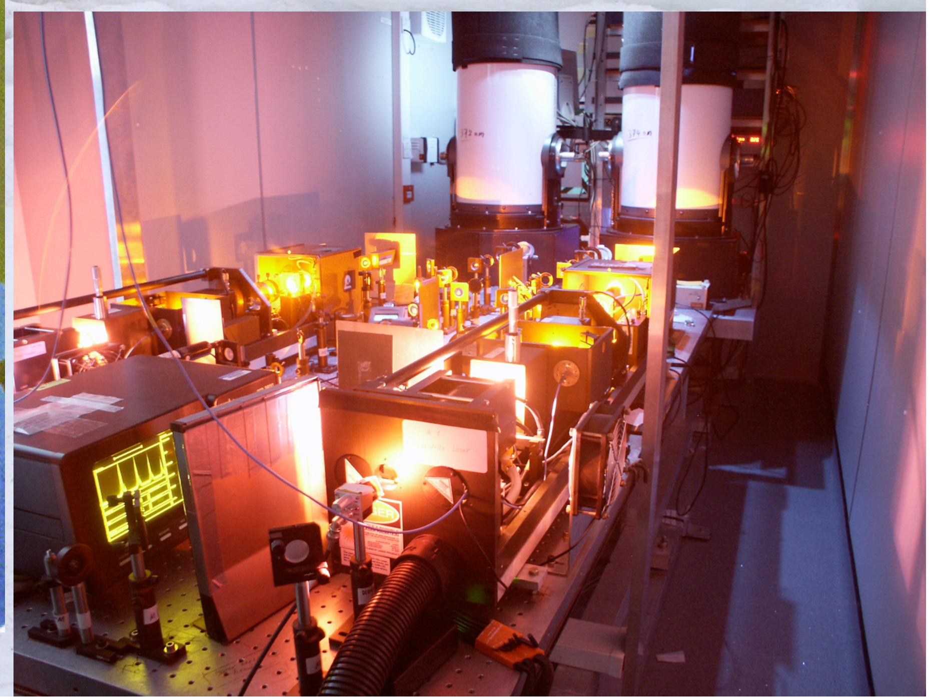
Airborne Fe Boltzmann Temperature Lidar



South Pole (90°S) Fe Boltzmann Lidar

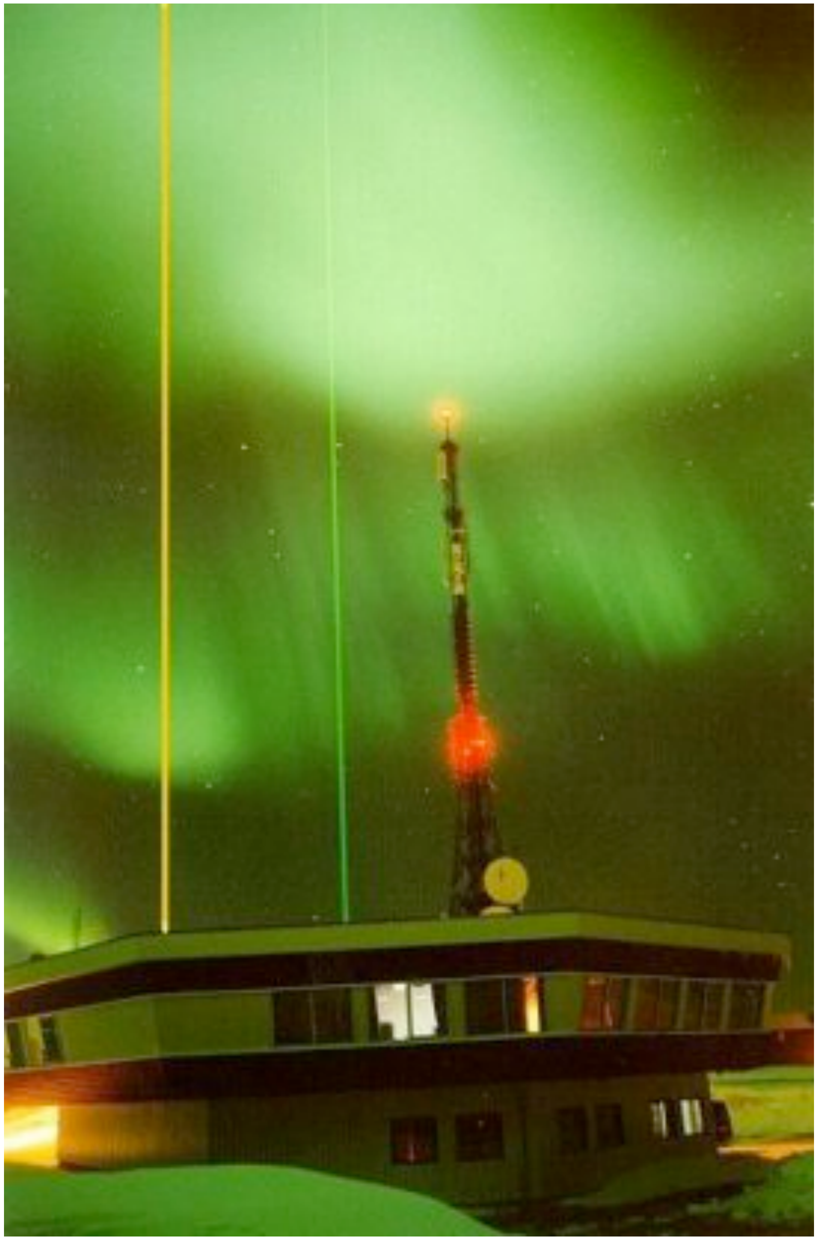
Rothera (67.5°S)
Fe Lidar



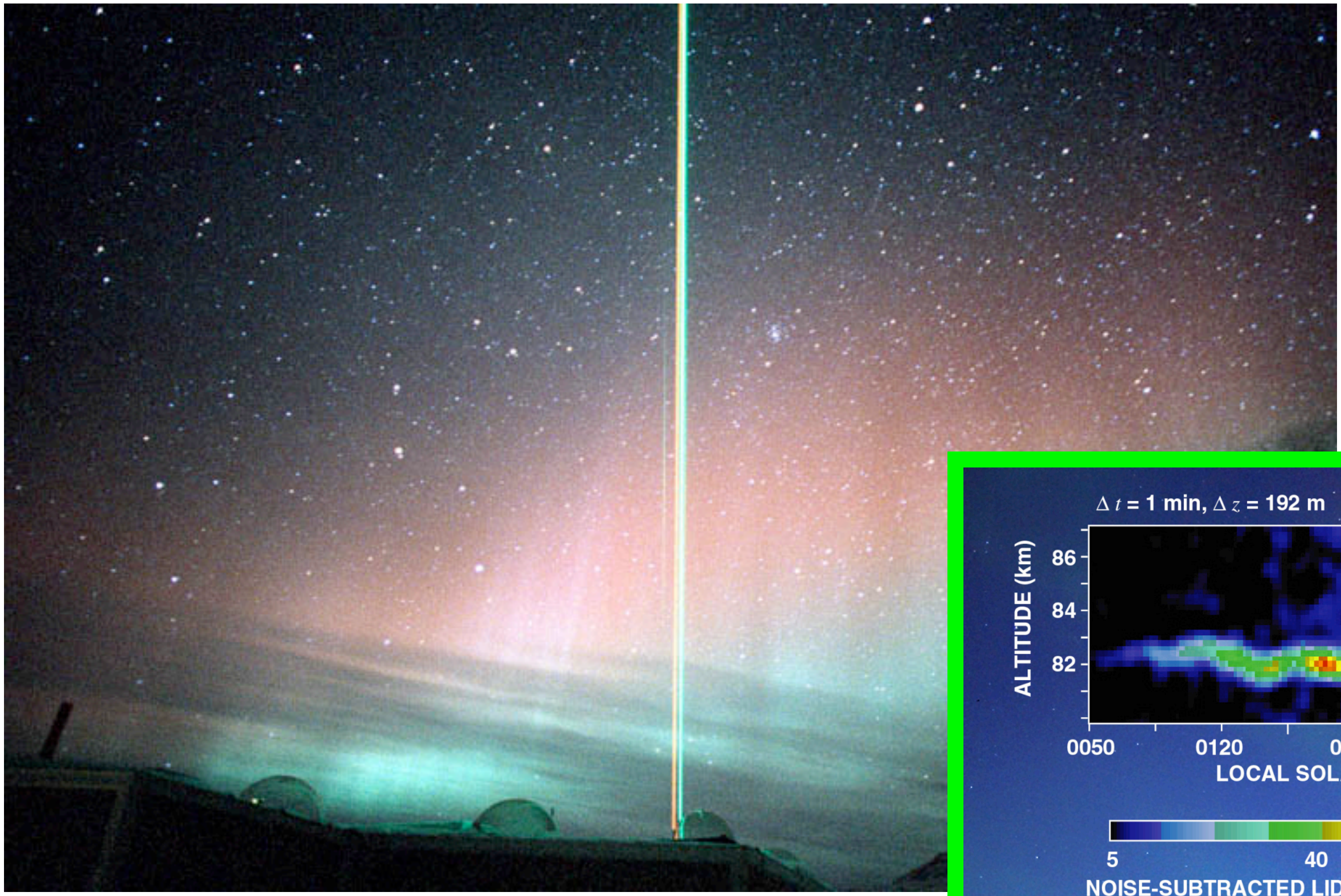


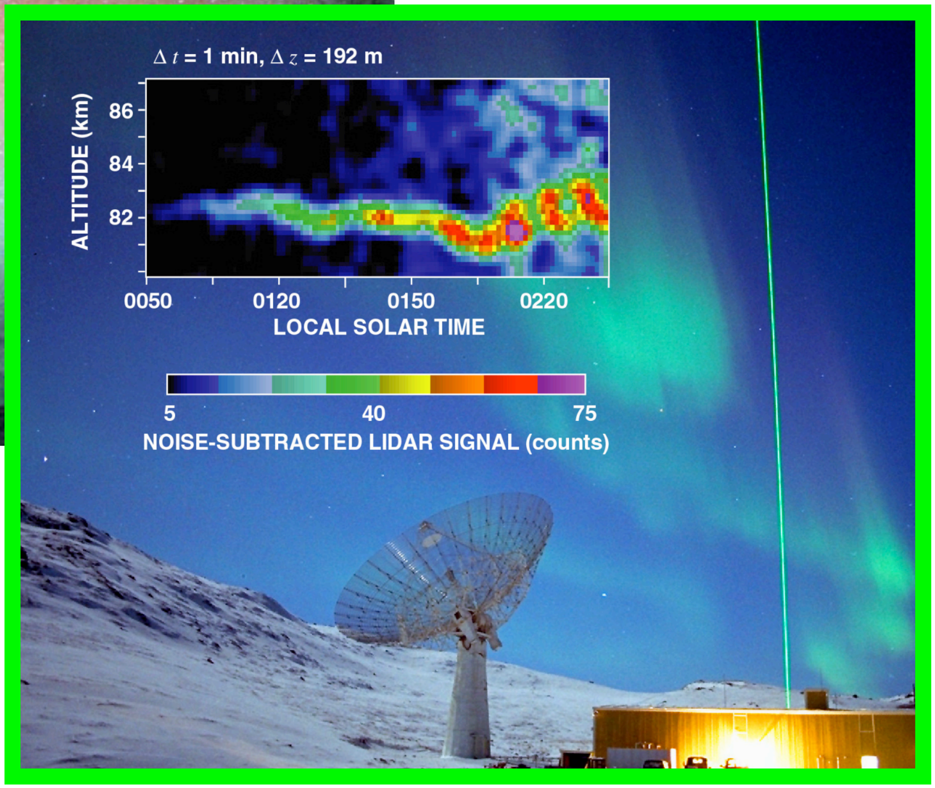
Svalbard (78°N) K Doppler Lidar

Andoya (69°N) Rayleigh & Na Lidars

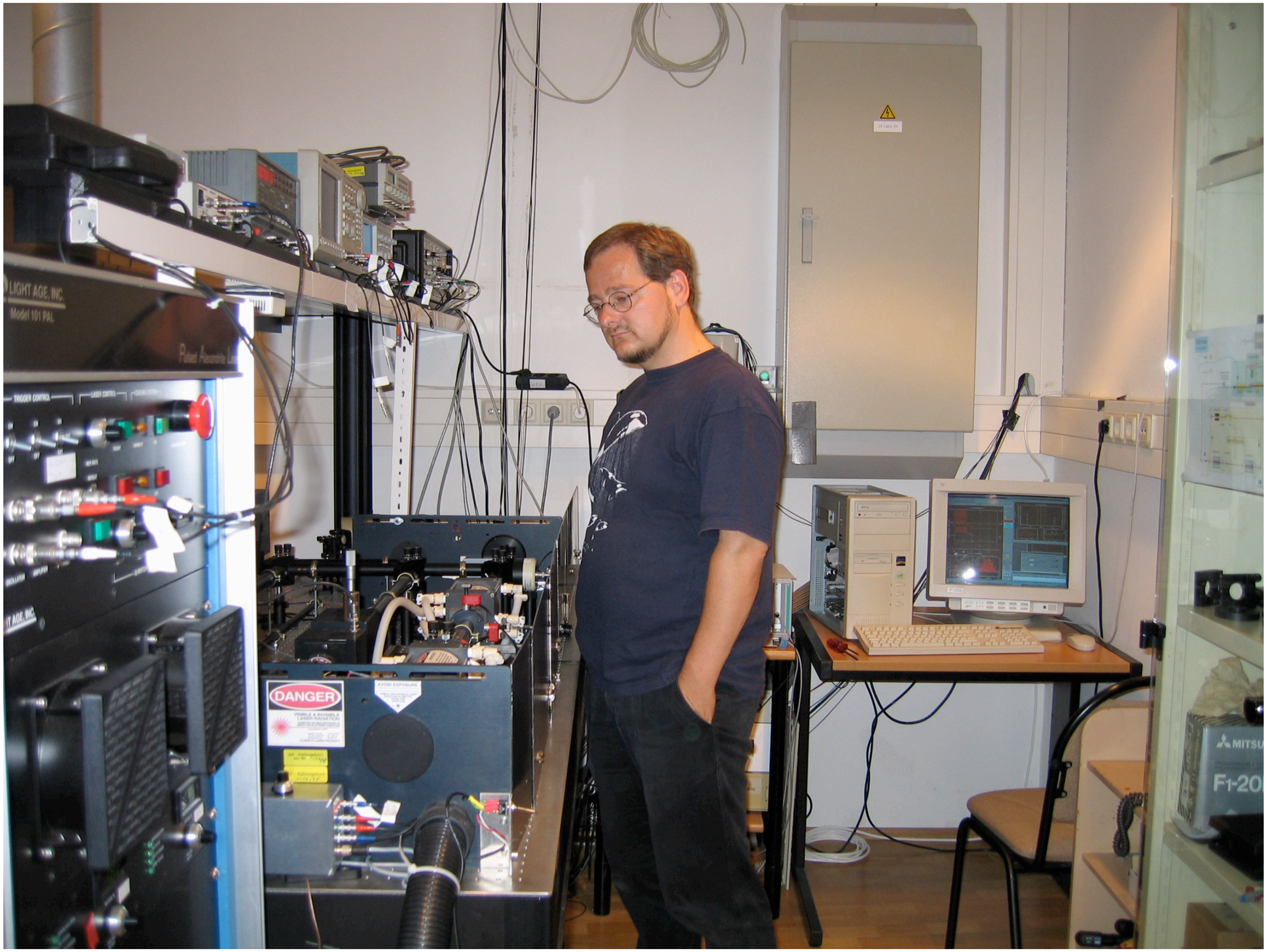


Sondrestrom (67°N) Rayleigh Lidar

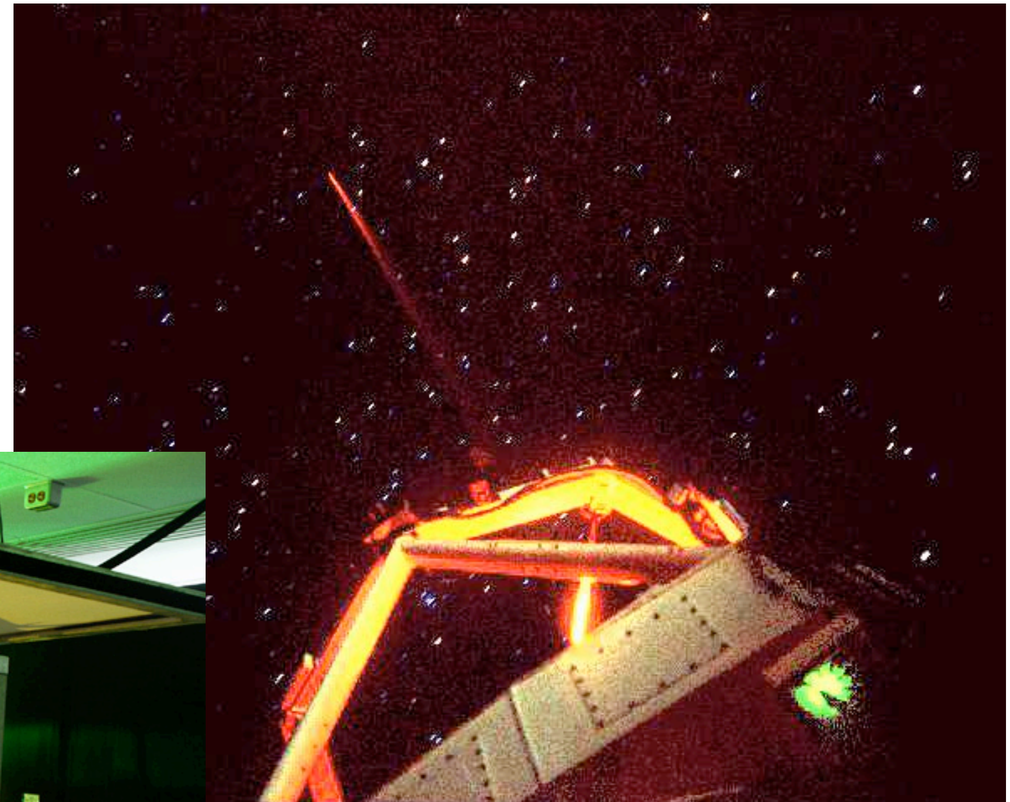


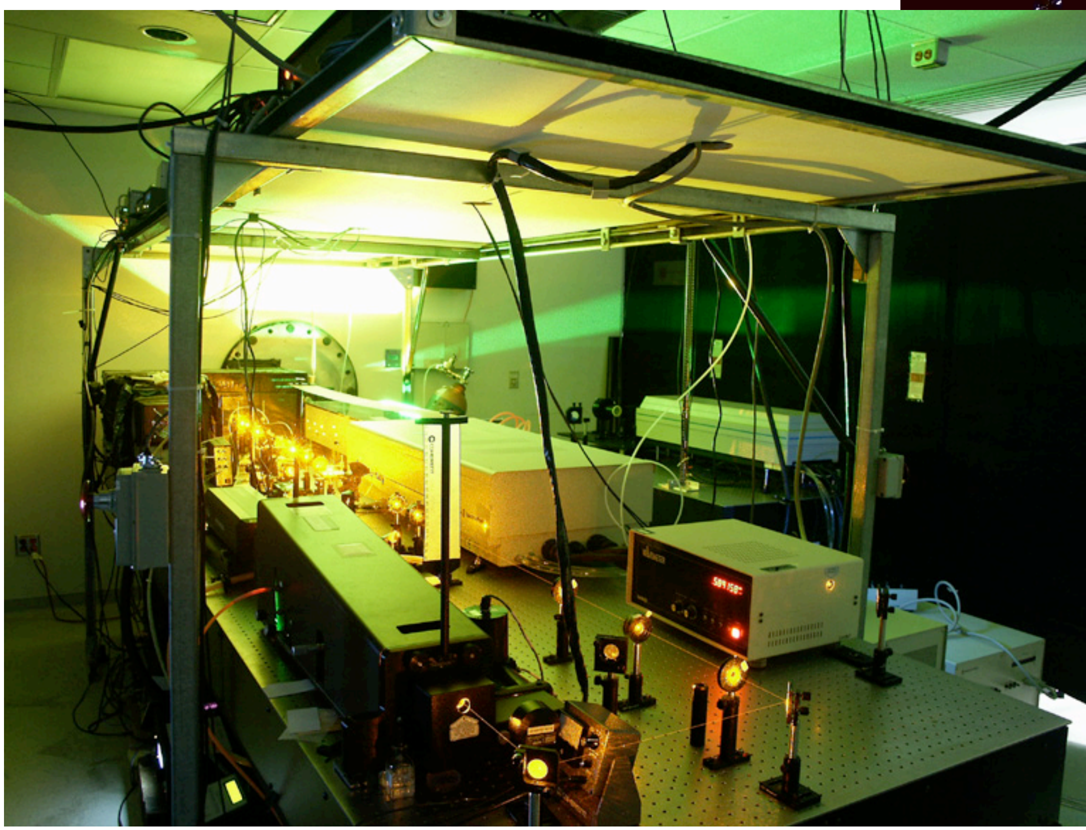


Kühlungsborn (54°N) K Doppler Lidar

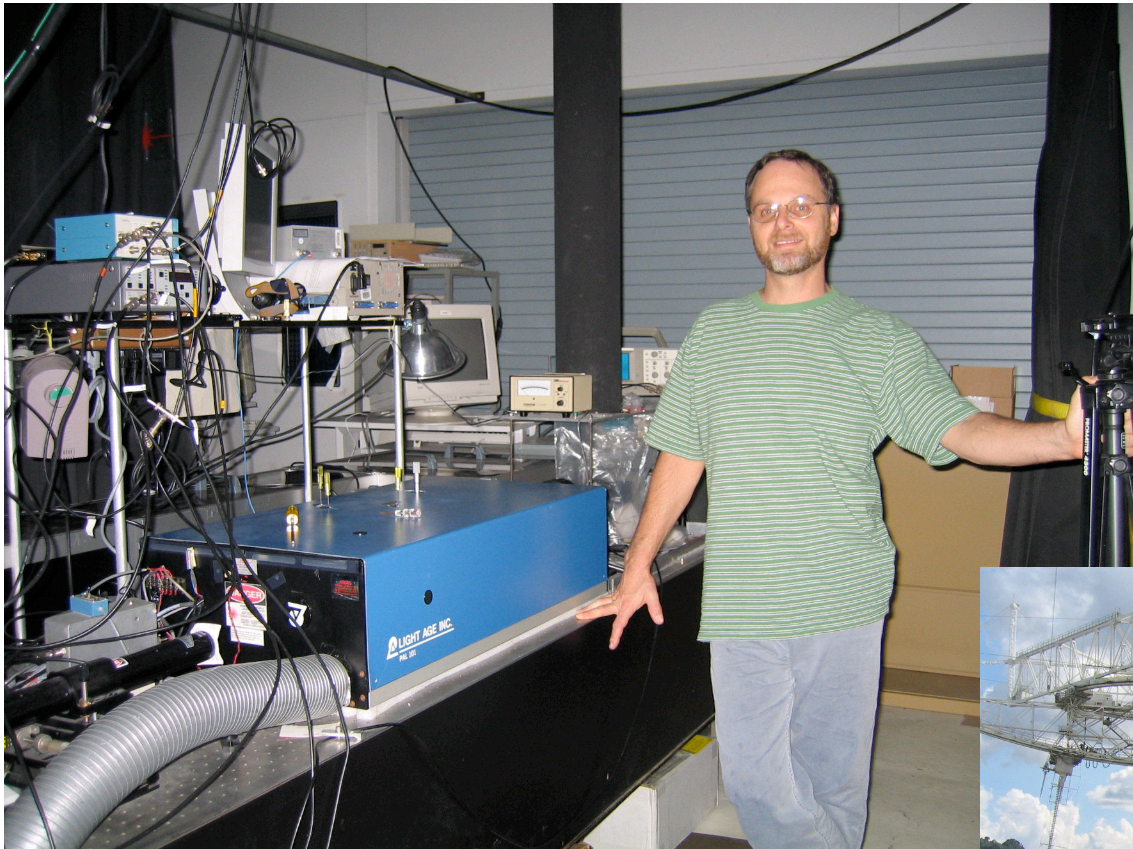


Na Wind and Temperature Lidar at SOR (35°N) & Maui (20.7°N)





Arecibo Observatory (18.4°N) K Lidar



NASA & NOAA Lidars

NASA have many lidars for airborne and spaceborne deployment.

NOAA optical remote sensing group led by Dr. Mike Hardesty, have nine lidars, from Coherent Doppler lidar, aerosol lidar, differential absorption lidar, to fish lidar. Dr. Alan Brewer will be invited to give a guest lecture on Coherent Doppler lidar.

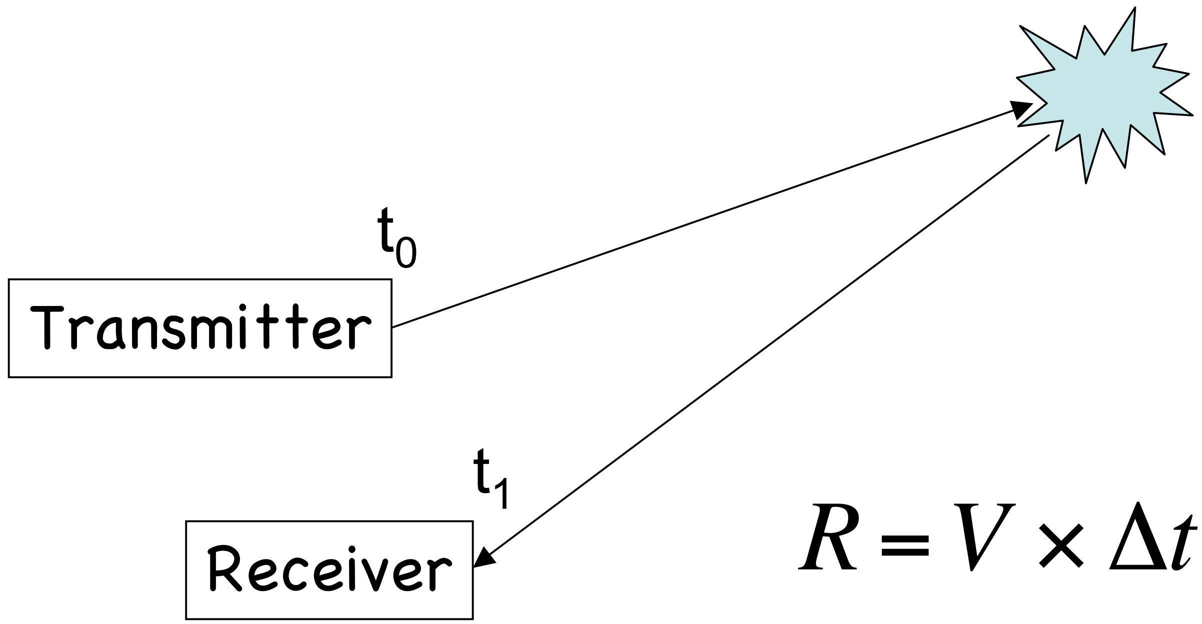
Advantages of Active Remote Sensing

- independence of natural radiation sources and time of day;
- reduced sensitivity to background light;
- high intensity of stimulating signal;
- control of stimulating signal;
- knowledge of stimulating signal;
- capable of line integral, line average, line profile, 2-D coverage, 3-D coverage, 3-D spectrum – all as a function of time
- …

Comparison of Remote Sensing

	Passive			Active	
	Scattering	Emission	Extinction	Scattering	Extinction
Optical	Aerial / Space Photography UARS satellite TIMED/SABER AIM satellite	Airglow Imager Bomem Spectrometer Fabry-Perot Interferometer	Dobson Spectrometer HALOE occultation	LIDAR	
Radio		Passive Radiometer		RADAR	GPS Radio Occultation
Sound				SODAR	

How does sodar, radar & lidar work?



$$R = V \times \Delta t / 2$$

Where $\Delta t = t_1 - t_0$, i.e., the time of flight

For radar and lidar, V = c, i.e., the light speed

For sodar, V = the sound speed

Hardware of sodar,radar & lidar

	SODAR	RADAR	LIDAR
Transmitter	Electric-acoustic converter	Electronic circuit + Antenna	Laser
Receiver	Headphone	Antenna	Optical telescope + Photon detector
Transmitted Energy	Acoustic Energy	Electromagnetic Waves	Light

Active Remote Sensing

From Biological Sonar

To SODAR, RADAR, LIDAR

SODAR: Sound Detection And Ranging

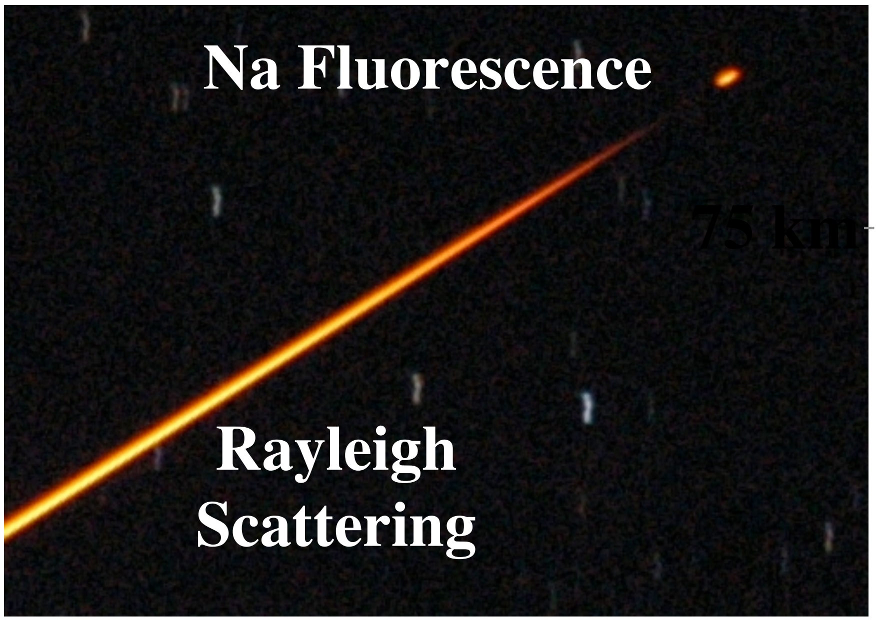
RADAR: Radiowave Detection And Ranging

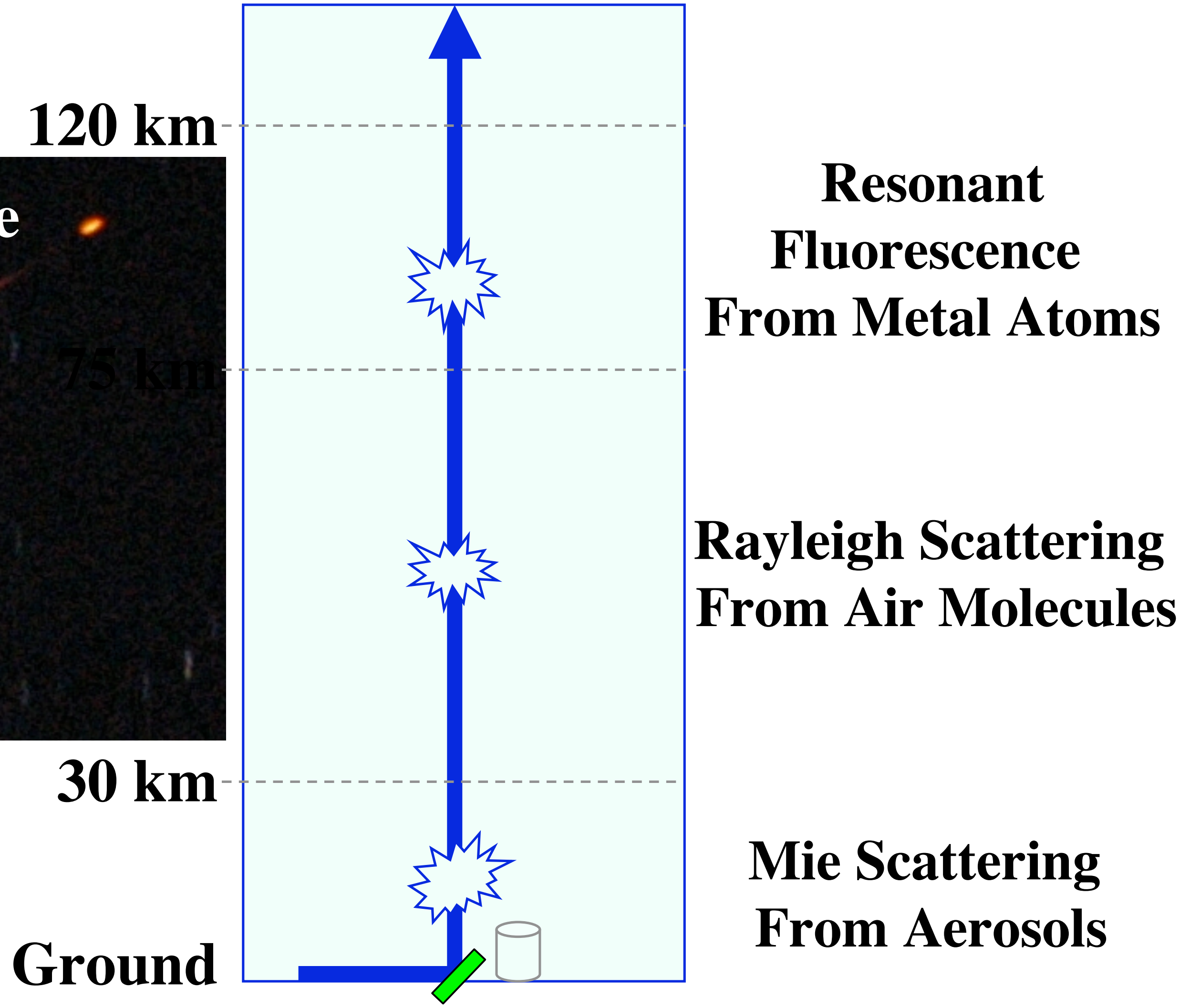
LIDAR: Light Detection And Ranging

Based on the Same Principle

Radiation is transmitted into environment, backscattered by the objects, and then detected and analyzed by receivers.

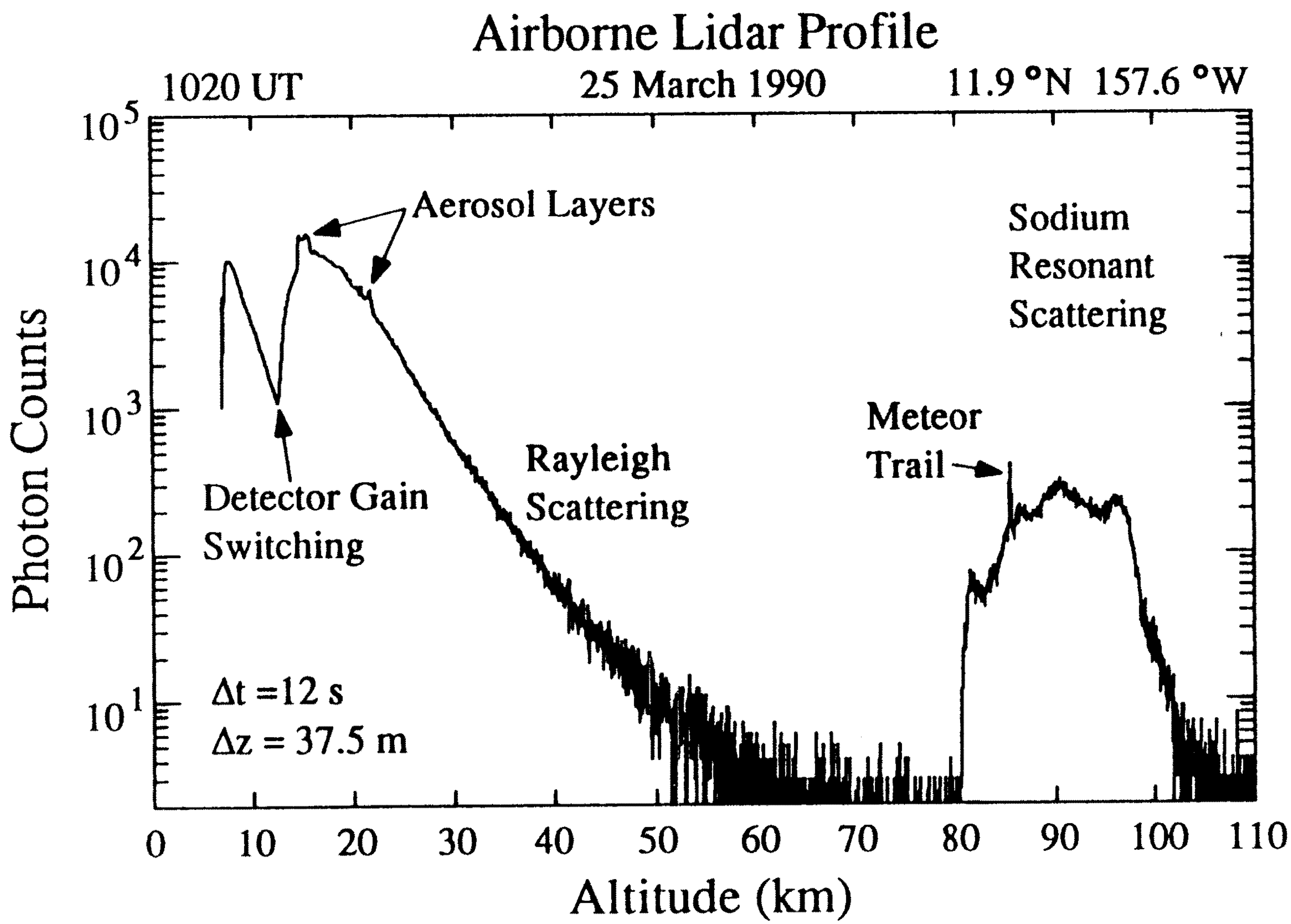
Light Detection And Ranging (LIDAR)





Range Determined From Time-of-Flight: $R = c \cdot \Delta t / 2$

Typical LIDAR Profile



Summary For Lecture 1

- Remote Sensing concept & Basics.
- Nature of remote sensing & measurements
- Classifications of remote sensing tech
- Active remote sensing
- Lidar and radar

References and additional reading

1. Physical Principles of Remote Sensing, 2nd edition, by W. G. Rees, Cambridge University Press, 2001.
2. Laser Remote Sensing, 2005, "Introduction"

Reading materials for Lecture 2

1. Laser Remote Sensing, 2005, "Introduction"
2. Laser Remote Sensing, 2005, Section 5.2.1.1 "general form of lidar equation".