Lecture 32. Target Lidar (1)
Laser Induced Fluorescence Lidar

- Motivations for Target Lidar
- Fluorescence from Liquids and Solids
- Remote Fluorescence Recording
- Illustrations of Fluorescence Lidar Applications
  1) Marine Monitoring
  2) Vegetation Monitoring
  3) Historical Monuments
- Summary

Motivations to Study Targets

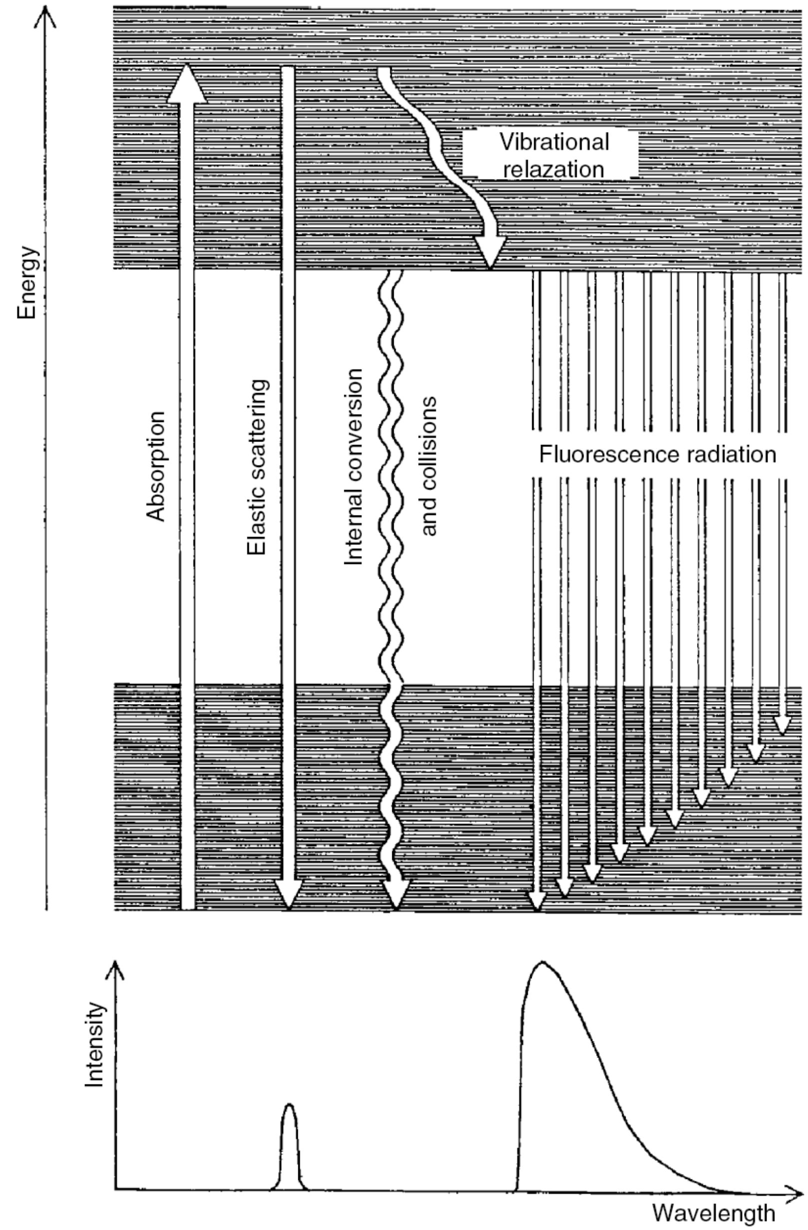
- What were discussed above are all concerned about atmospheric lidars, with the main purpose to study the atmosphere, and mainly based on the scattering processes (including elastic and inelastic scattering, and absorption and resonance fluorescence) from gas phase atoms, molecules, and aerosols.
- Besides atmosphere, our environment includes many other things, like the solid earth, cryosphere, hydrosphere, and non-gas-phase objects on the earth, in the ocean, and in the air (e.g., plants, oil, buildings) etc. Study of our environment demands good measurement technology and approach for measurements in all sorts of occasions. Therefore, lidar technology for target (anything other than gas phase objects) detection is essential and highly demanded.
- Two main categories for target lidars: (1) lidars for ranging (laser altimeter) and (2) laser induced fluorescence lidar.
- Laser altimeter - an important approach to monitor sea level, earth and cryosphere surface, military targets for precise range determination
- Fluorescence lidar - environmental study of hydrosphere, solid earth, croysphere, plants, oil films on the surface, etc.

More Target Lidar / Imaging Lidar

- Besides laser altimeter and fluorescence lidar, other target lidars include the lidars for detecting fish school (fish lidar, NOAA), for detecting vibrations (Coherent Technologies, Inc), for detecting or imaging buildings, military targets, airplanes, etc.
- They all utilize the time-of-flight between the reflected laser pulses or light from the targets and the transmitted laser pulse to determine the positions (range or 3-D spatial position) of targets.
- The scanning type of target lidars is sometimes called "ladar", meaning "laser radar". Utah State University has a group doing ladar business.
- By scanning fluorescence lidars, the mapping of ocean surface or plant distributions can be obtained.
- Airborne and spaceborne lidars, especially the laser altimeter and fluorescence lidar, have found wide application range and usefulness.
- Compact laser altimeter aboard Unmanned Aerospace Vehicle (UAV) has promise applications. Aerospace faculty James Maslanik and Brian Argrow are leading the effort of laser altimeter on UAV.

Fluorescence from Liquids and Solids

- In contrast to free atoms and molecules (gas phase), solids and liquids exhibit broad absorption and emission spectra because of the strong intermolecular interactions.
- A fixed frequency laser can be used for the excitation due to the broad absorption.
- Following the excitation, there is a very fast (ps) radiationless relaxation down to the lowest sub-level of the excited state, where the molecules remain for a typical excited-state fluorescence lifetime (some ns).
- The decay then occurs to different sub-levels of the ground state giving rise to a distribution of fluorescence light, which reflect the lower-state level distribution.
- Fixing the excitation wavelength, we can obtain fluorescence spectra. While fixing the detection channel and varying the excitation wavelength, an excitation spectrum can be recorded.



Fluorosensor for Fiber-Optic Point Monitoring

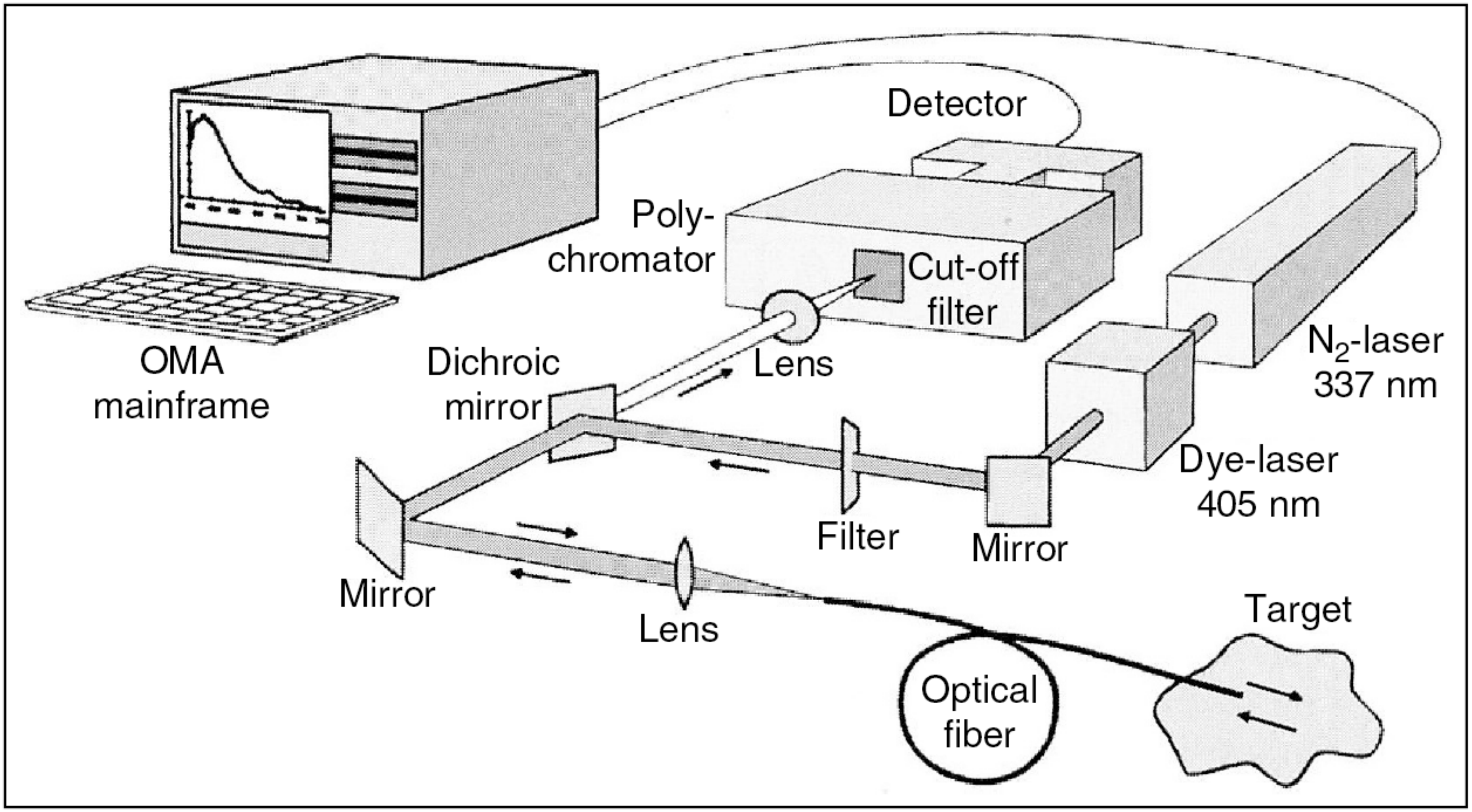
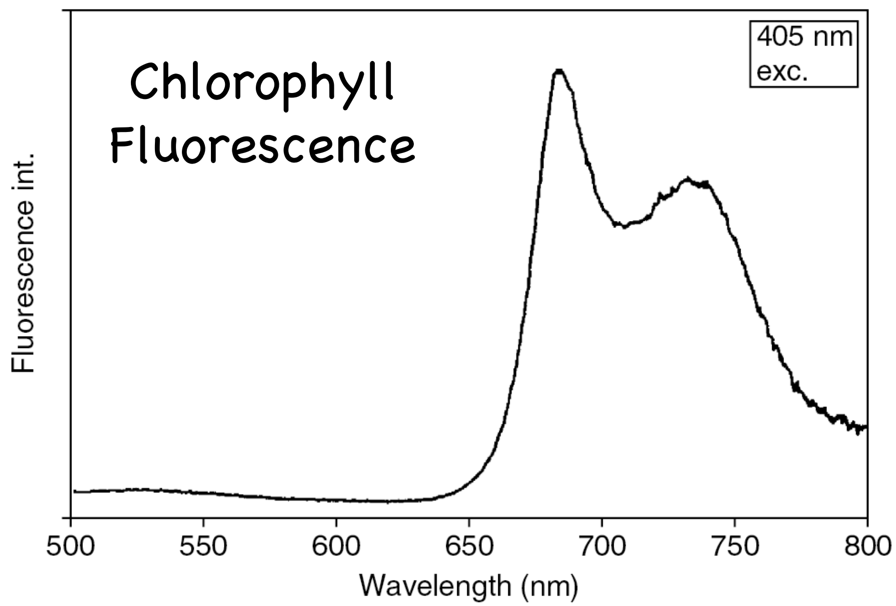


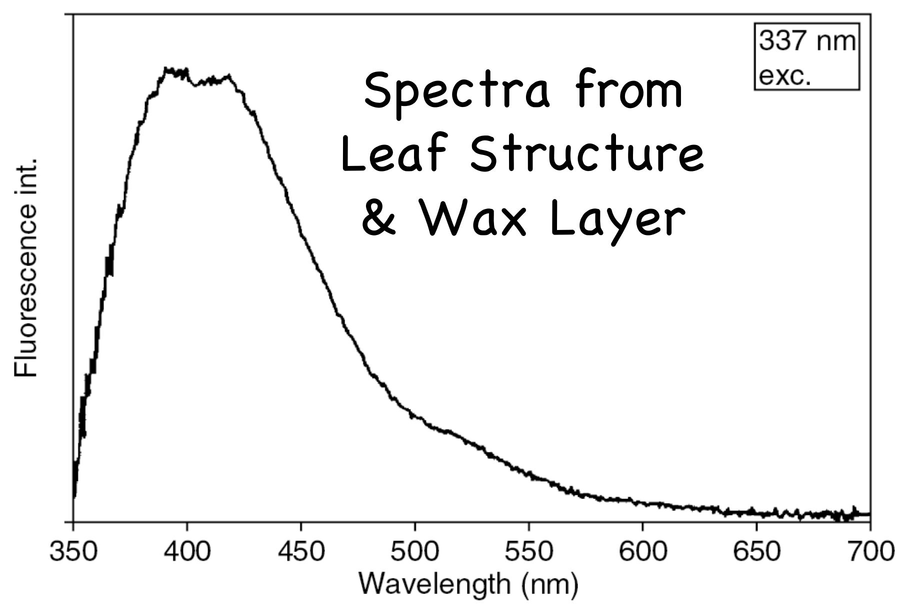
Figure 6.2 in Chapter 6 of our textbook

Fluorosensor

- Excitation: 337nm from N_2-laser, or 405 nm from dye-laser
- Fiber: transmit laser pulse and collect laser-induced-fluorescence
- Filters: Dichroic mirror reflects laser light but transmits red-shifted fluorescence; cut-off filter further reducing background
- Time-gating: only accept light during a narrow time window (100 ns) after certain delay time corresponding to the time of the arrival of the pulse - efficiently eliminate background light
- Detector: spectrometer + CCD to record full spectrum covering 350-800 nm following each laser shot
- Multiple shots can be averaged to increase the signal-to-noise ratio.
- Note: This is a setup for time-integrated fluorescence detection. Time-resolved detection of fluorescence can provide additional diagnostic information of the sample under study.
- Remote fluorescence measurements must provide means to isolate temporal delays due to excited-state lifetime from temporal delays due to larger physical distance in a 3-D target. By first monitoring the elastic range-resolved backscatter from a canopy, into which the laser beam successively penetrates, and then recording the fluorescence lidar return for some wavelengths, it is possible to separate lifetime effects from propagation effects.

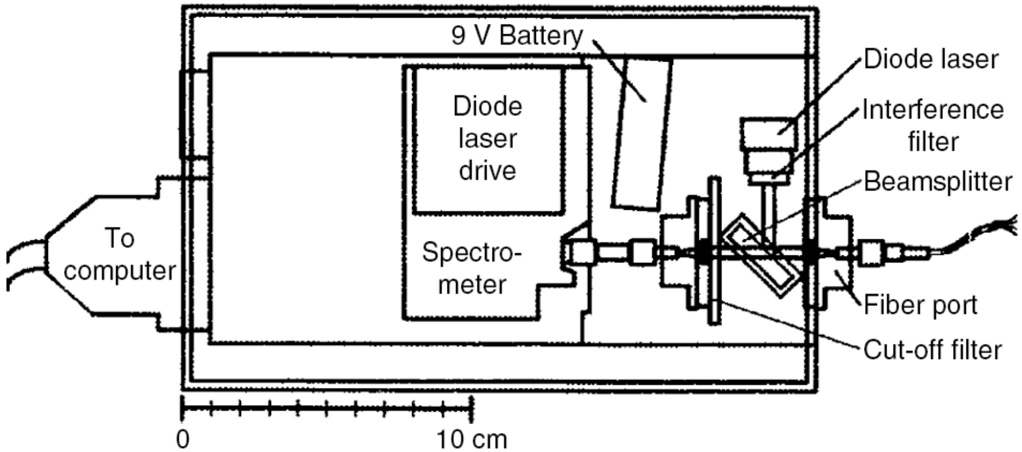
Example Spectra from Fluorosensor





- When excited by 405 nm, the chlorophyll fluorescence is clearly visible with peaks at 690 and 735 nm. This also means that chlorophyll has strong absorption at the red spectra.
- When excited by 337 nm, the fluorescence from wax layer is strong in the blue spectra, while protection layer prevents the penetration of UV light reaching chlorophyll.

Fluorosensor with Blue Diode Lasers



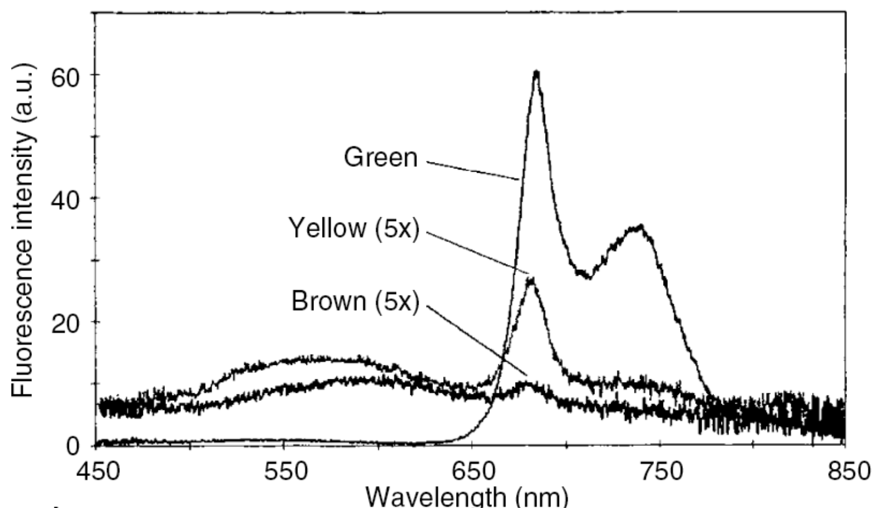
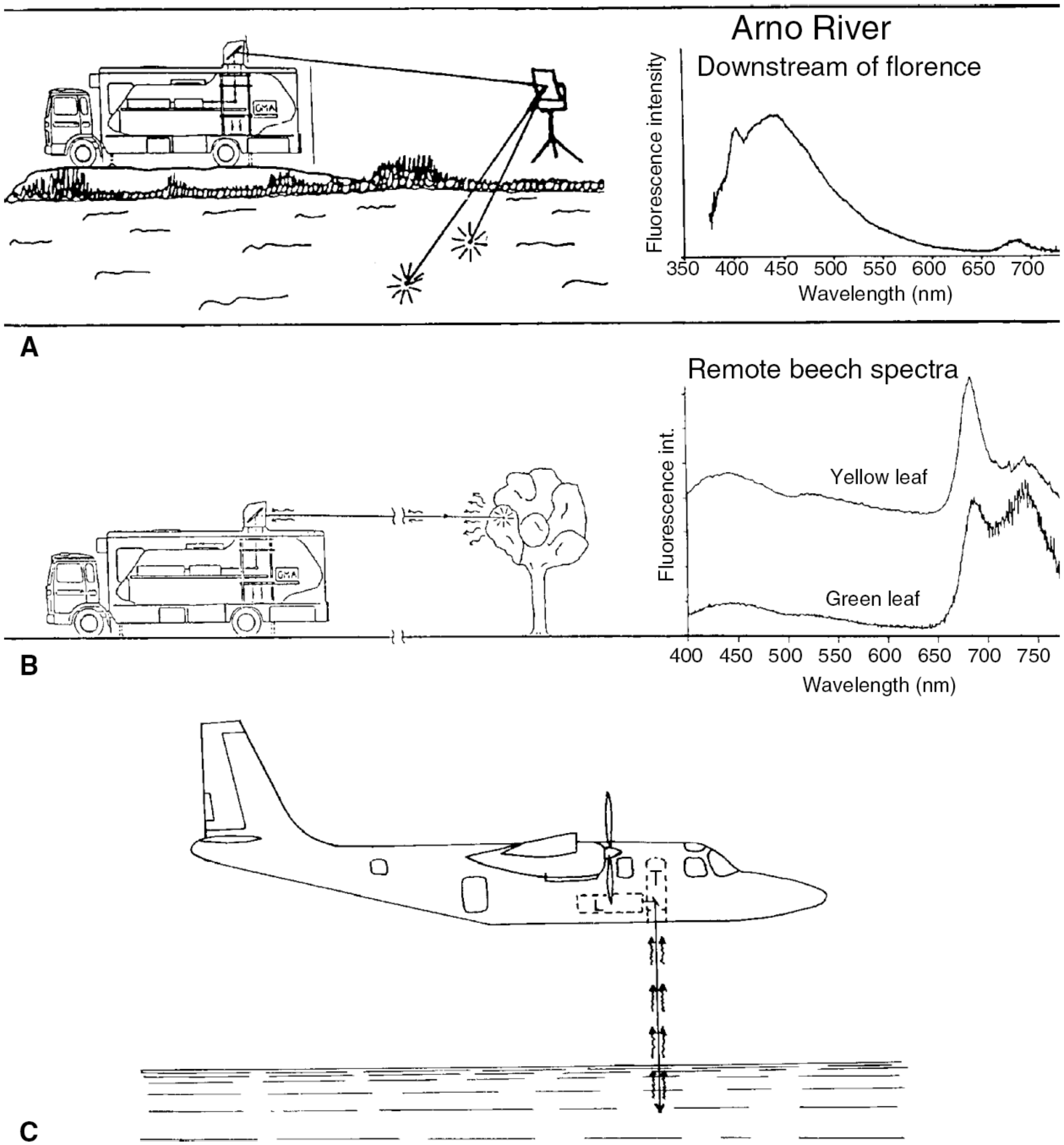


Figure 6.4 (a) Compact blue fluorosensor based on a violet diode laser. (b) Fluorescence spectra from different parts of a beech leaf, showing green, yellow, or brown color in reflectance. (From Gustafsson, U. et al., *Rev. Sci. Instrum.*, 71, 3004, 2000. With permission.)

Scenarios for Fluorescence Lidar

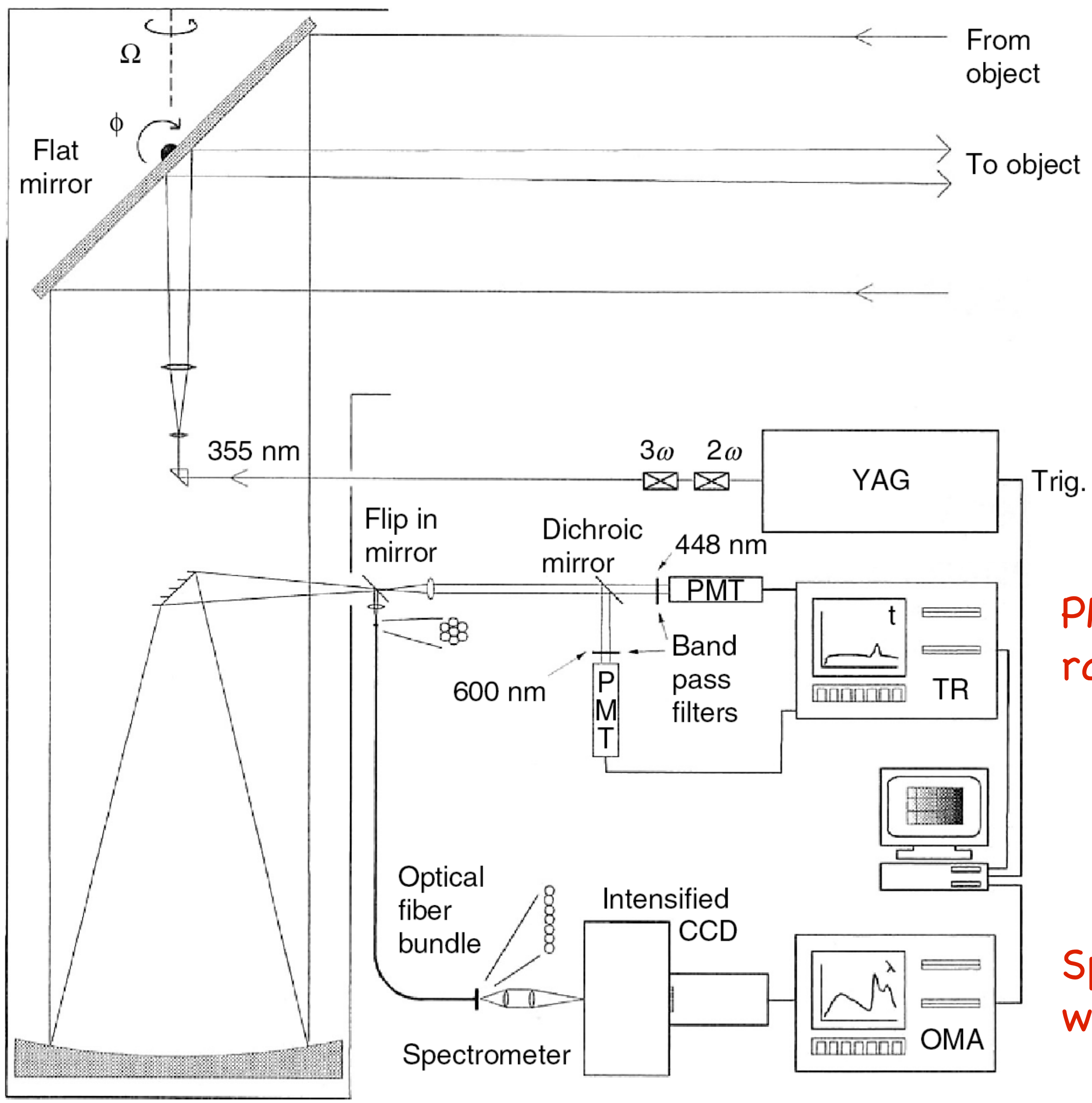


Aquatic monitoring
Via folding mirror

Vegetation
Monitoring

Airborne
Fluorescence

Fluorescence Lidar System



PMT for time-resolved, i.e., range-resolved signal

Spectrometer + CCD for wavelength-resolved signal

Scenarios for Fluorescence Imaging

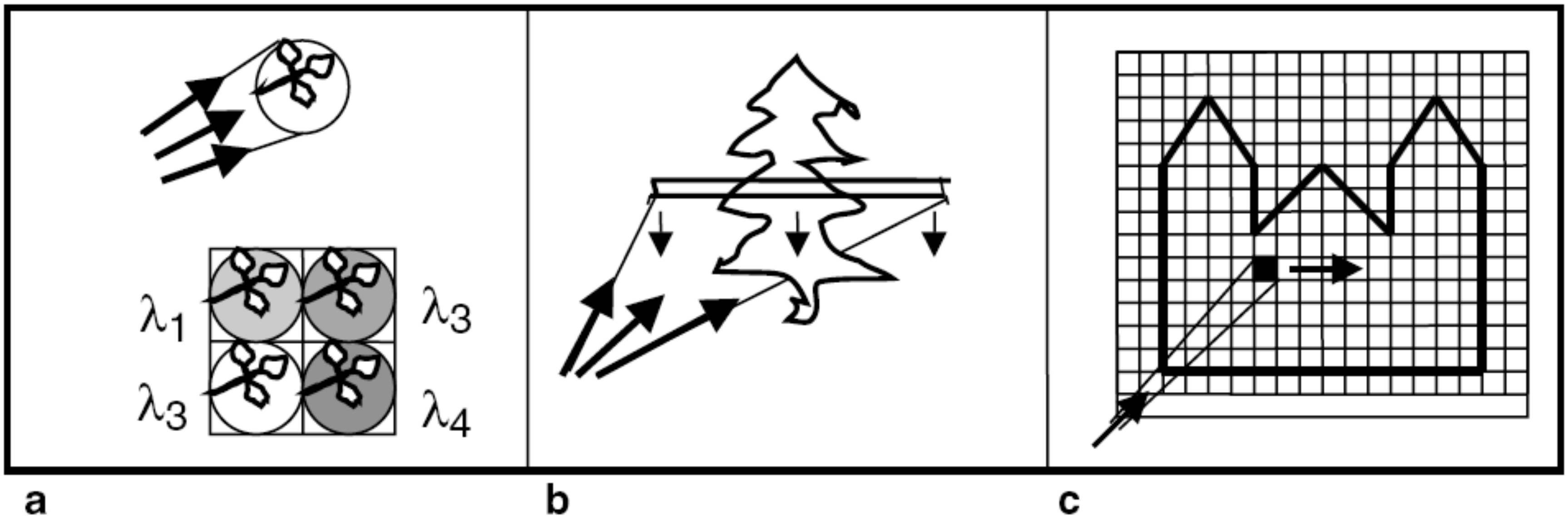
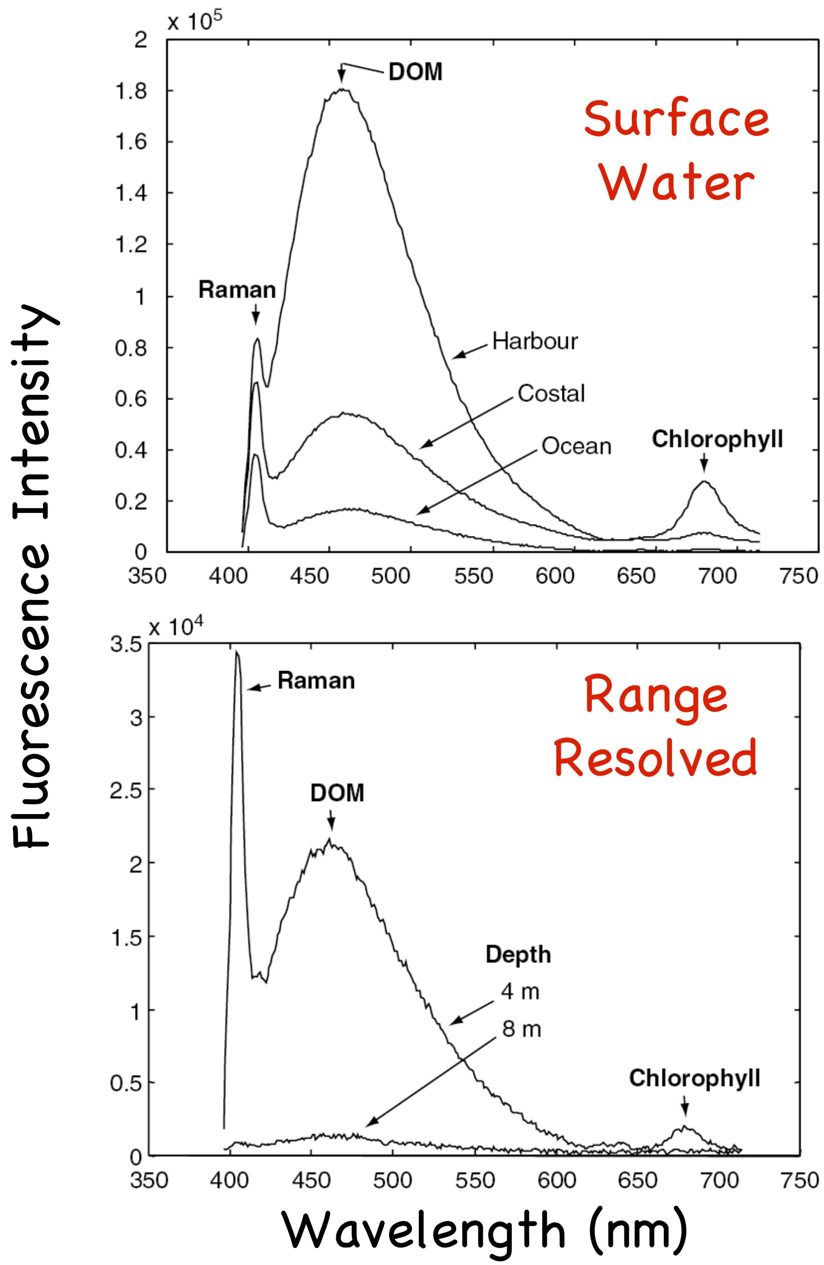


Figure 6.7 Scenarios for remote fluorescence spectroscopy and fluorescence imaging with special consideration of background: (a) simultaneous four-color imaging; (b) pushbroom imaging; and (c) scanning pointwise imaging.

Marine Monitoring



- Excitation at 355 nm
- Raman scattering from H_2O at 404 nm (Raman shift: 3400 cm^{-1}) - Because the aggregation of water molecules depends on the temperature, the analysis of the detailed shape of the Raman signal can be utilized to measure surface water temperature.
- DOM (Dissolved Organic Matter) fluorescence in the blue-green spectral region for assessment of the general level of DOM.
- By normalizing the DOM signal to the bkg-free water Raman signal, the percentage of DOM in water can be derived (a built-in reference).
- Range-resolved fluorescence data can be taken by gating the image intensifier at different delays.

Vegetation Monitoring

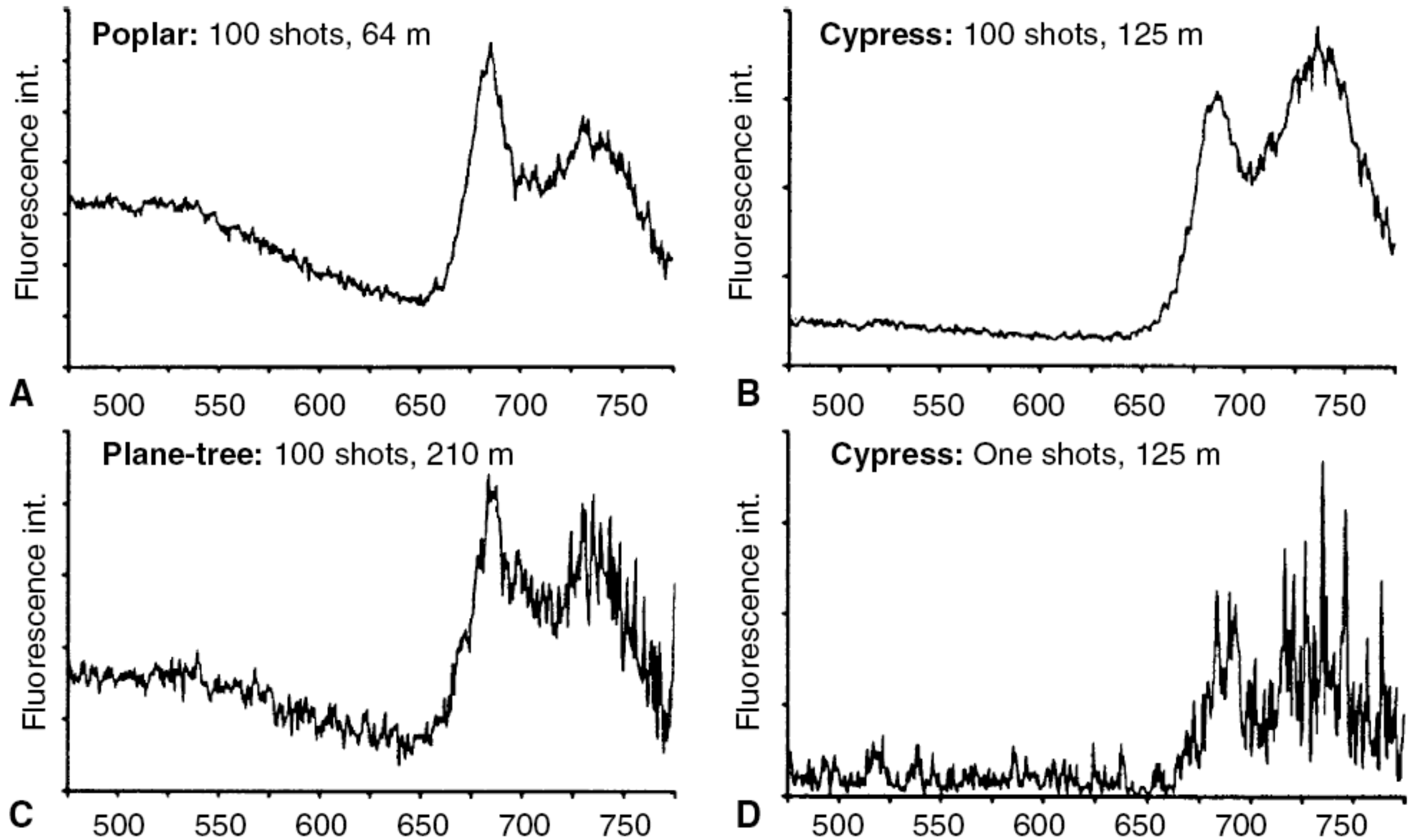


Figure 6.10 Fluorescence spectra of poplar, cypress, and plane-tree recorded at different ranges employing 100 laser shots. Spectra for cypress are shown using 100 as well as one laser shot. (From Andersson, M. et al., Proc. ISPRS Symposium on Physical Measurements and Signatures in Remote Sensing, Cal d'Isère, 1994; With permission.)

Detection of Historic Monument

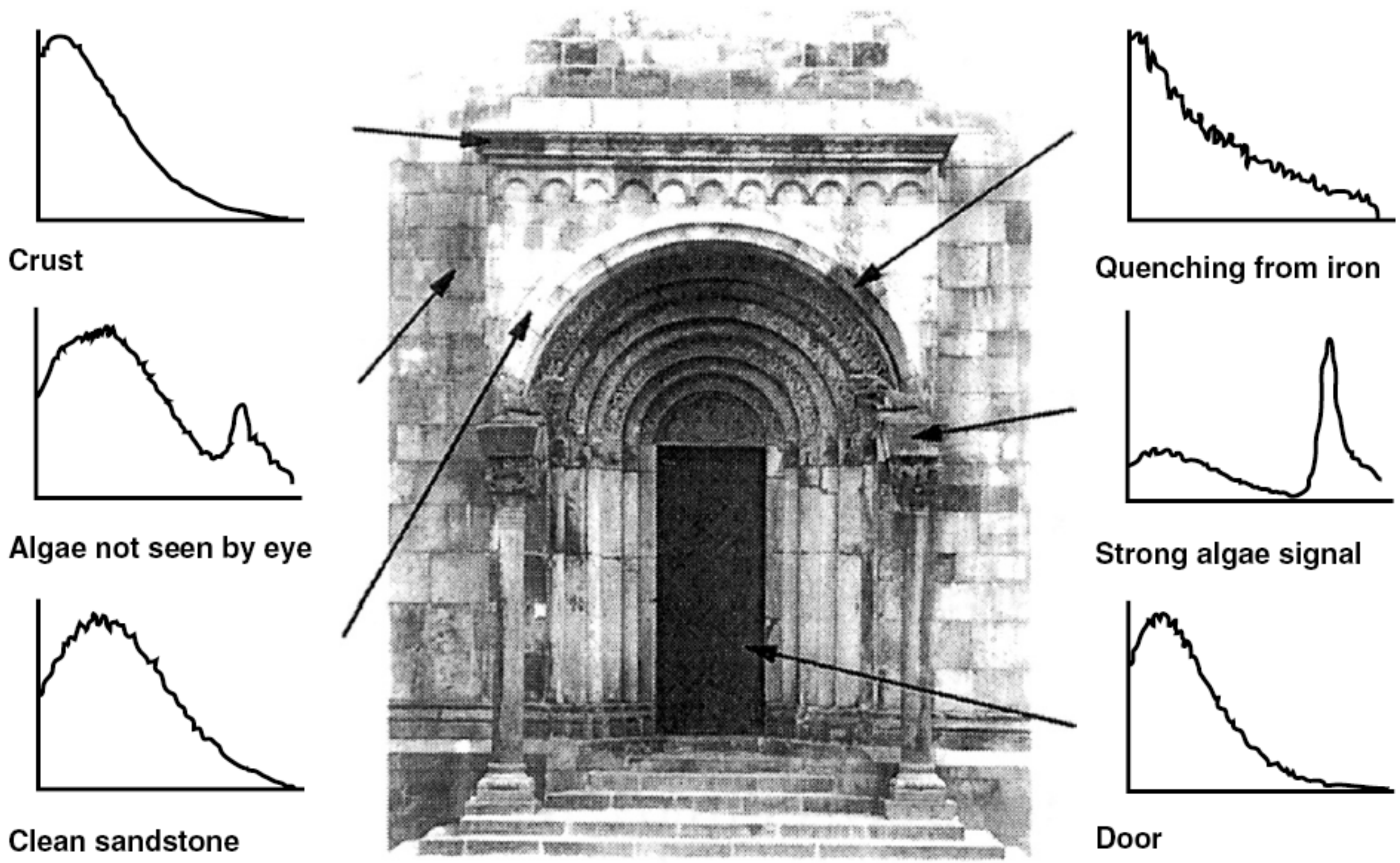


Figure 6.13 Photograph of the northern gate of the Lund Cathedral and six remotely recorded fluorescence spectra. (From Weibring, P. et al., *Appl. Opt.*, 40, 6111, 2001. With permission.)

Summary of Fluorescence Lidar

- Fluorescence spectroscopy has widely been used in many applications, such as the indoor experiments of forensic science, art inspection, and tissue diagnostics.
- Fluorescence lidar techniques make it possible to extend the application of fluorescence spectroscopy to the outdoor environment (remote sensing), where large distance and uncontrollable background light have to be dealt with.
- Liquid or solid targets may have fluorescence effects with the fluorescence wavelengths red-shifted. By monitoring the fluorescence signals (in a wide wavelength range), faint species can be identified. This is especially useful in marine and vegetation monitoring.
- By proper gating the timing, range-resolved fluorescence can be collected from different ranges. Thus, the fluorescence lidar provides specie information versus range.
- By scanning the lidar beam in combination with modern signal processing techniques, fluorescence lidar can also map the targets, revealing many features that are invisible to naked eyes.