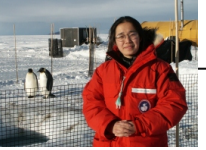


Lecture 28. Wind Lidar (7) Edge-Filter-Based DDL & Daytime Filters for Lidar

- Multi-Frequency Edge-Filter DDL

-- Na-DEMOF-based DDL

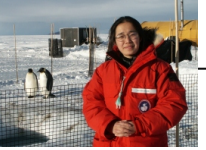
- Edge-Filter DDL combined with Rayleigh and Raman

-- I_2 Filter-based DDL

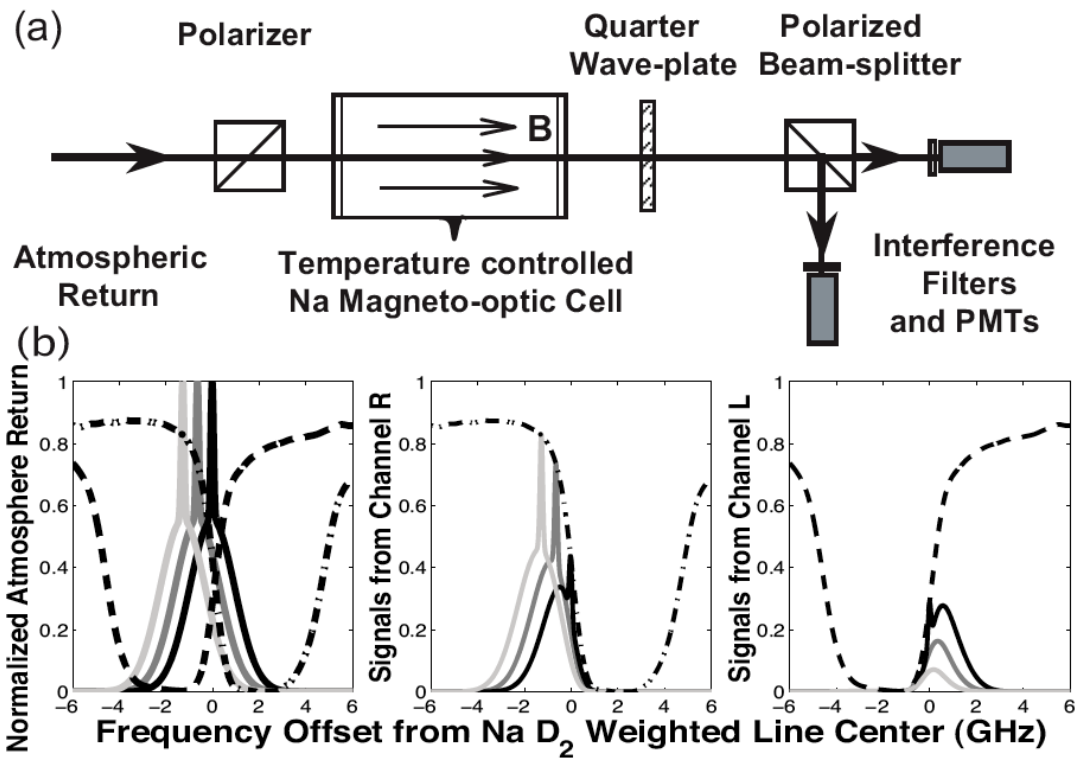
- Daytime Filters for Lidar

-- Faraday filters vs. Fabry-Perot etalons

- Summary



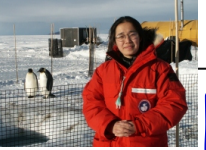
Multiple-Frequency Na/K Double-Edge Magneto-Optic Filter DDL



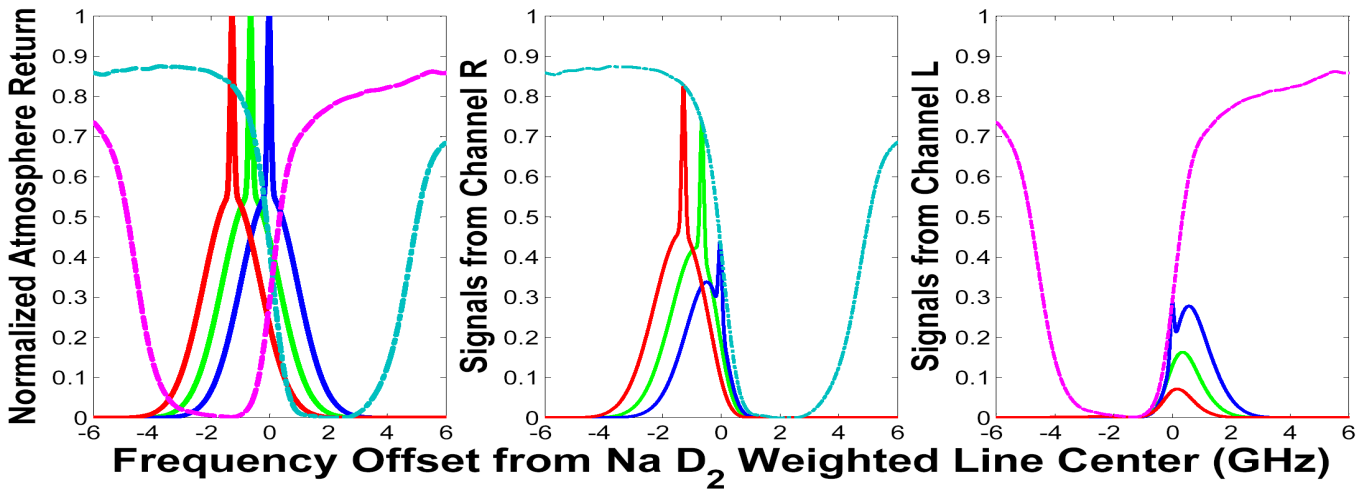
Na Double-Edge Magneto-Optic Filter (Na-DEMOF)

- With a 3-freq Na or K Doppler lidar, it is possible to measure wind, temperature, and aerosol simultaneously with a Na-DEMOF or K-DEMOF.

[Huang, Chu, Williams, et al., Optics Letters, 34, pp.199, 2009]



DEMOF with a 3-freq Na Doppler Lidar

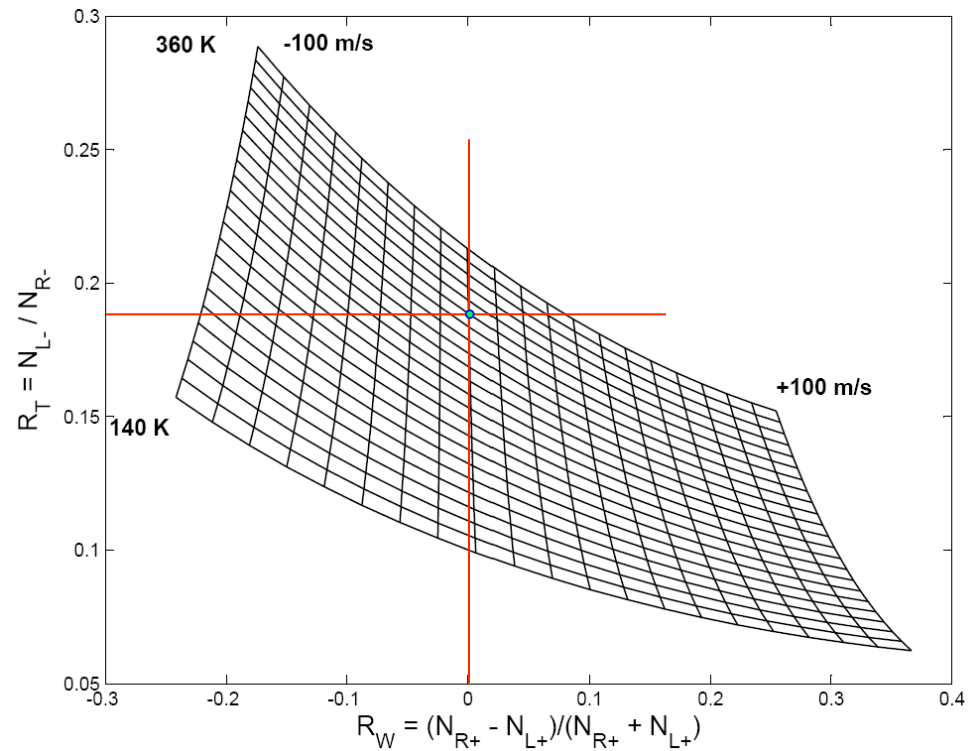


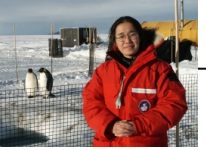
Calibration curves for ratio technique with Na-DEMOF

$$R_W(V_{LOS},T,R_b) = \frac{N_{R+} - N_{L+}}{N_{R+} + N_{L+}}$$

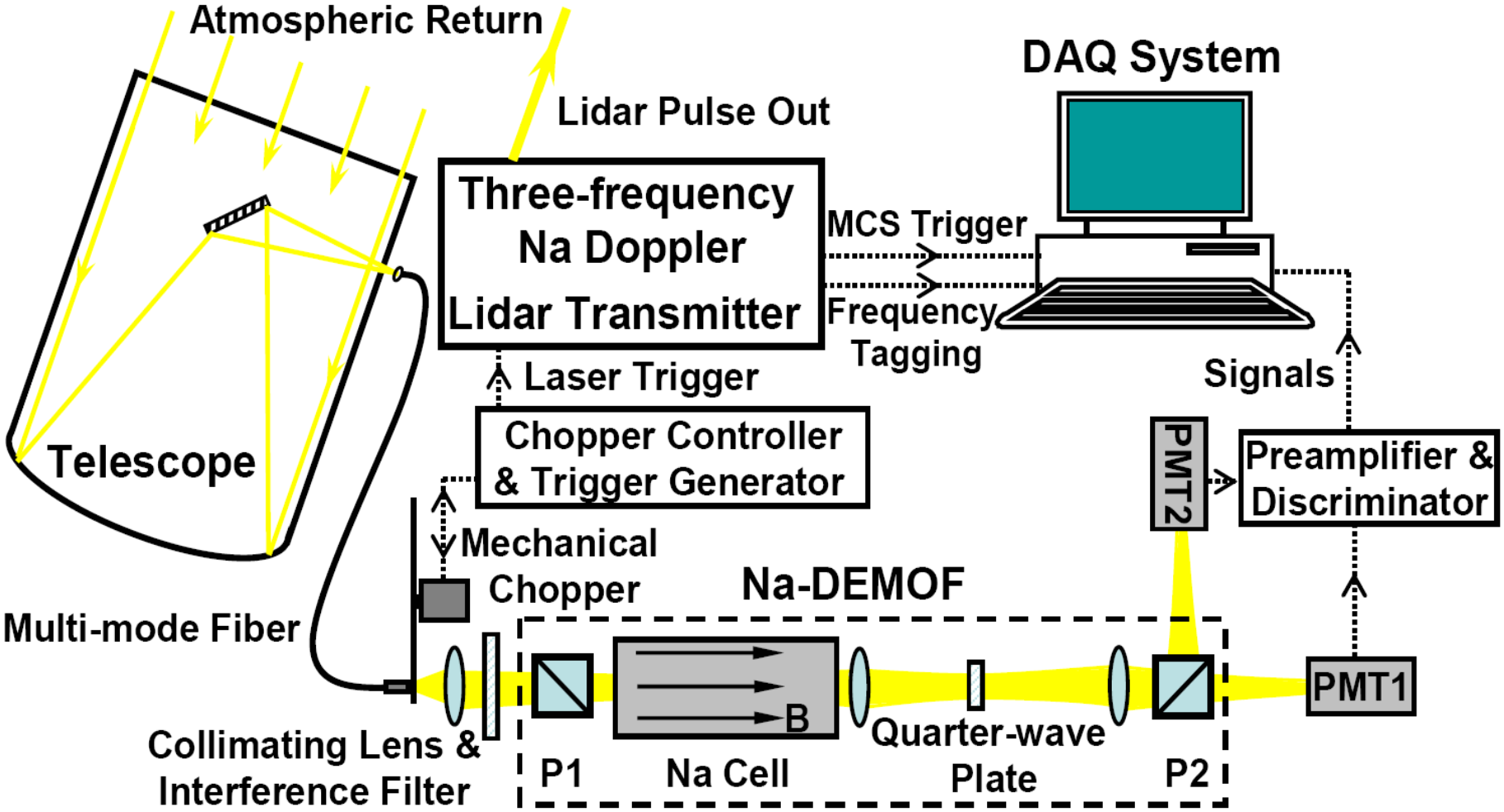
$$R_T(V_{LOS},T,R_b) = \frac{N_{L-}}{N_{R-}}$$

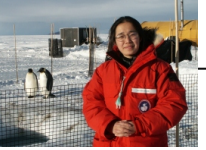
- Temperature and wind are determined simultaneously from two ratios.



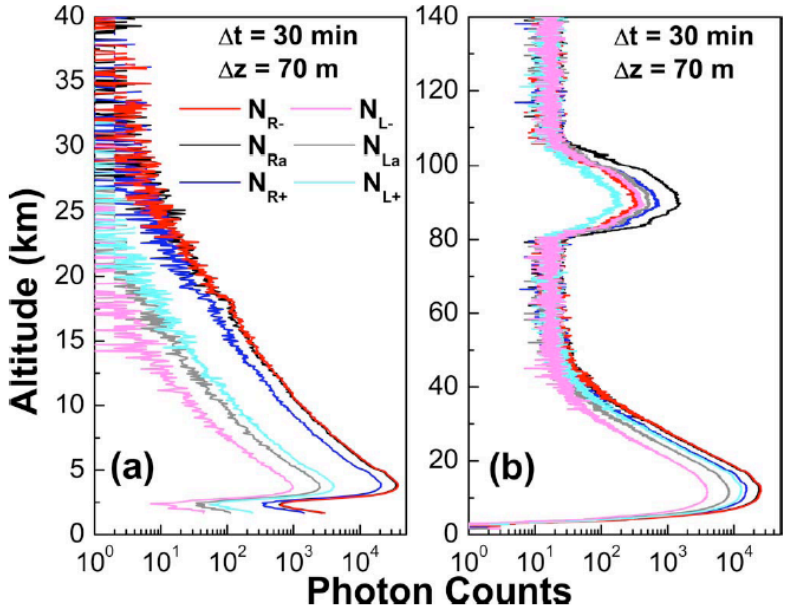


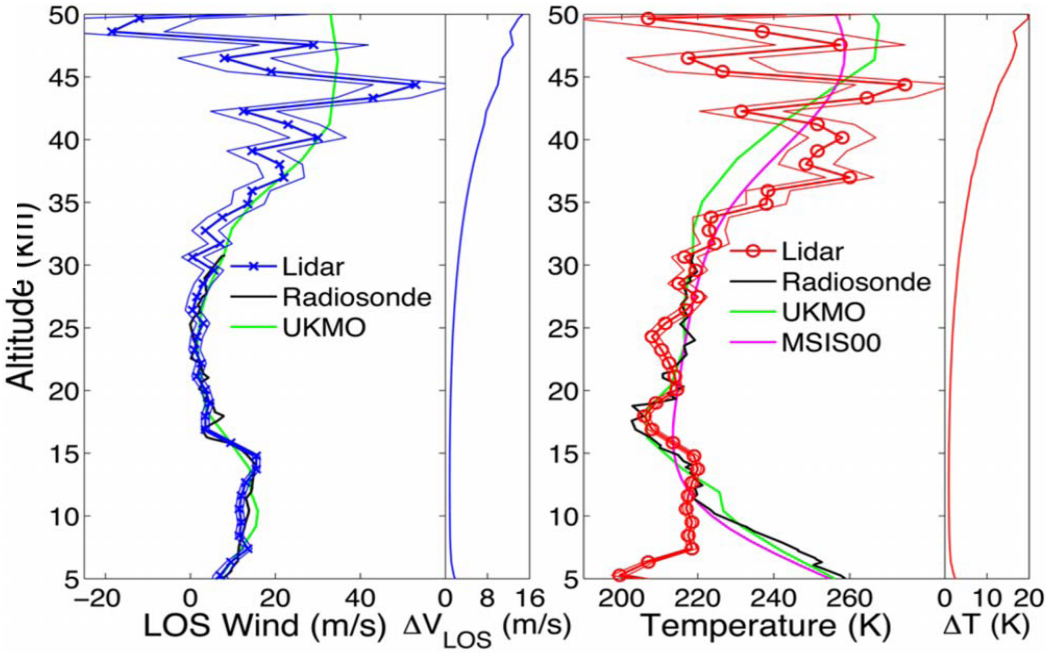
Field Demonstration of Simultaneous Wind and Temperature Measurements (10-45 km) with Na-DEMOF and 3-Frequency Na Lidar



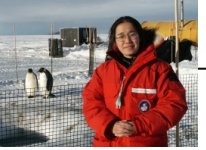


Field Demonstration of Simultaneous Wind and Temperature Measurements (10-45 km) with Na-DEMOF and 3-Frequency Na Lidar

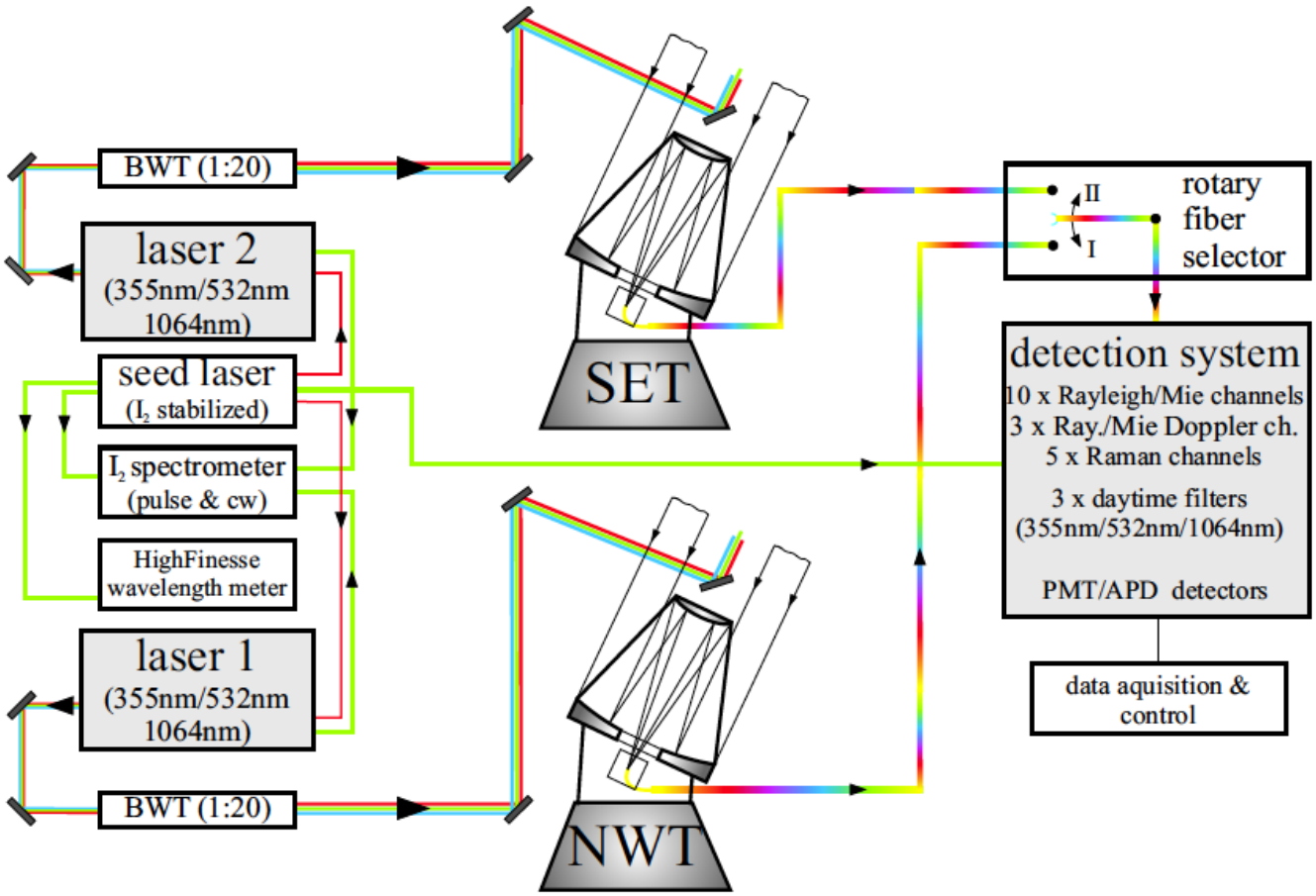




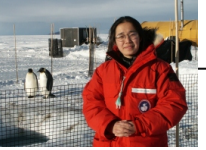
[Huang, Chu, et al., Optics Letters, 34, pp. 1552, 2009]



Doppler Rayleigh Iodine Spectrometer-Based Doppler Rayleigh/Mie/Raman Lidar to Profile Wind and Temperature up to 80 km



[Baumgarten, Atmos. Meas. Tech., 3, 1509-1518, 2010]



Doppler Rayleigh Iodine Spectrometer-Based Doppler Rayleigh/Mie/Raman Lidar to Profile Wind and Temperature up to 80 km

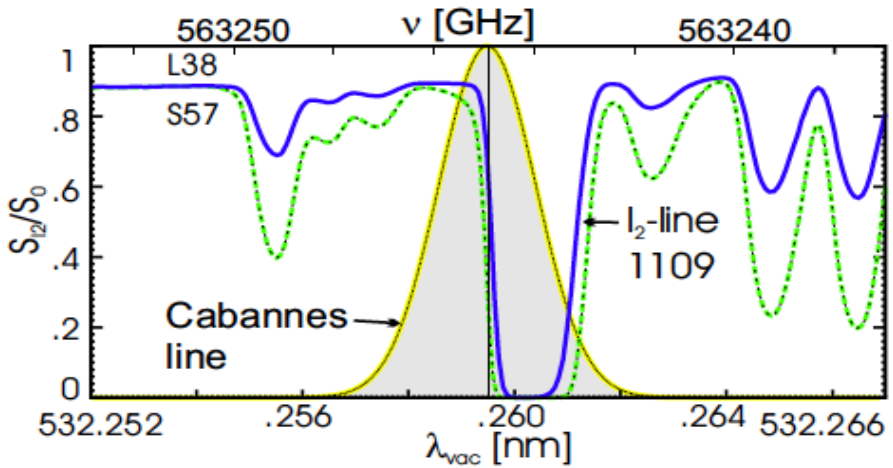
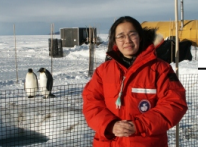


Fig. 2. Measured transmission spectrum of iodine for two cells of different length at different temperatures: 38 °C (blue L38: 15 cm long), 57 °C (green S57: 10 cm long). For reference, the Doppler broadened Cabannes line for 230 K is shown. The wavelength of the seed laser is indicated by a dotted vertical line.

Currently the data retrieval is for molecular scattering (Rayleigh) only, but since rotational and vibrational Raman as well as multiple wavelength aerosol scatterings are also detected, in principle aerosol and temperature information can be derived, so can be used to derive Doppler wind more precisely in the aerosol-loaded regions.

[Baumgarten, Atmos. Meas. Tech., 3, 1509-1518, 2010]



Doppler Rayleigh Iodine Spectrometer-Based Doppler Rayleigh/Mie/Raman Lidar to Profile Wind and Temperature up to 80 km

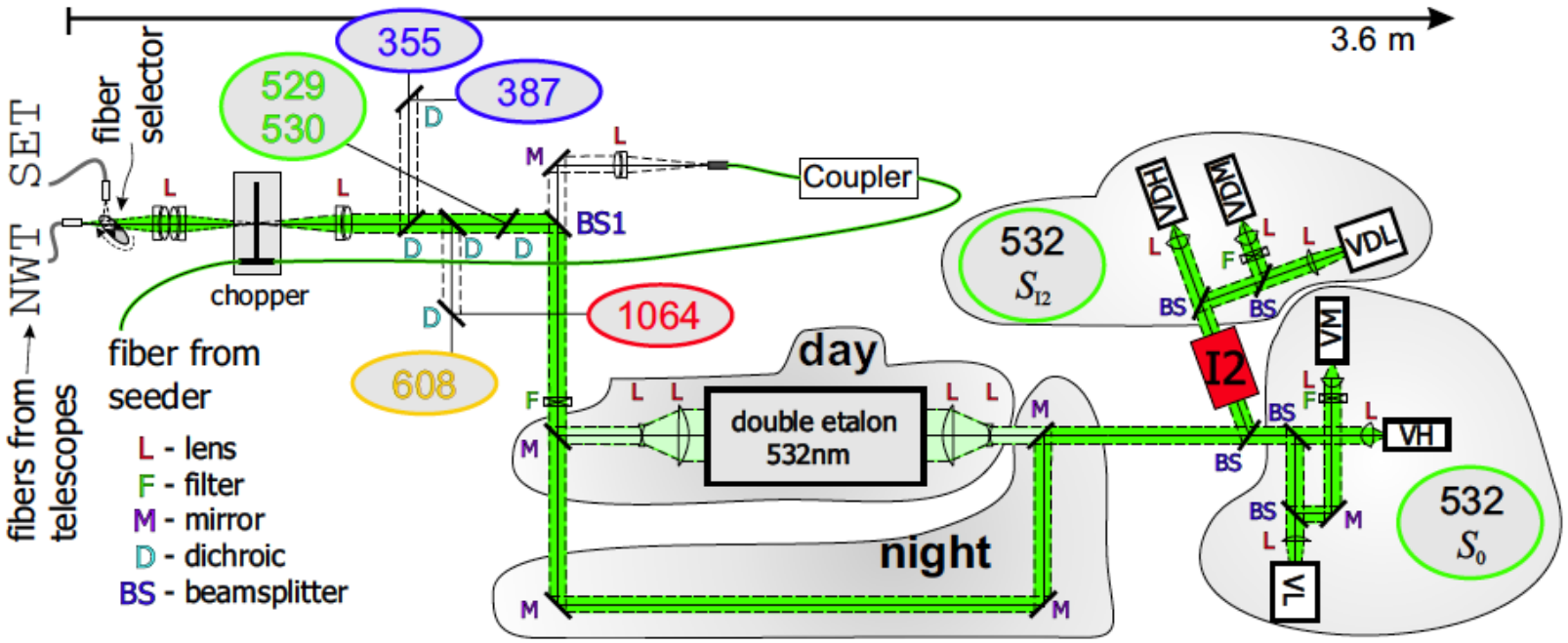
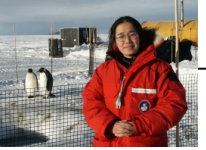


Fig. 4. Polychromatic detection system of the ALOMAR RMR lidar with emphasis on 532 nm channels. Light from the telescopes (NWT or SET) is split by wavelength and intensity. Light for the DoRIS system is detected by the channel groups 532-S_0 and 532-S_{I_2}. The system can be operated during day using a double etalon system (bandpass ~4 pm).

[Baumgarten, Atmos. Meas. Tech., 3, 1509–1518, 2010]



Doppler Rayleigh Iodine Spectrometer-Based Doppler Rayleigh/Mie/Raman Lidar to Profile Wind and Temperature up to 80 km

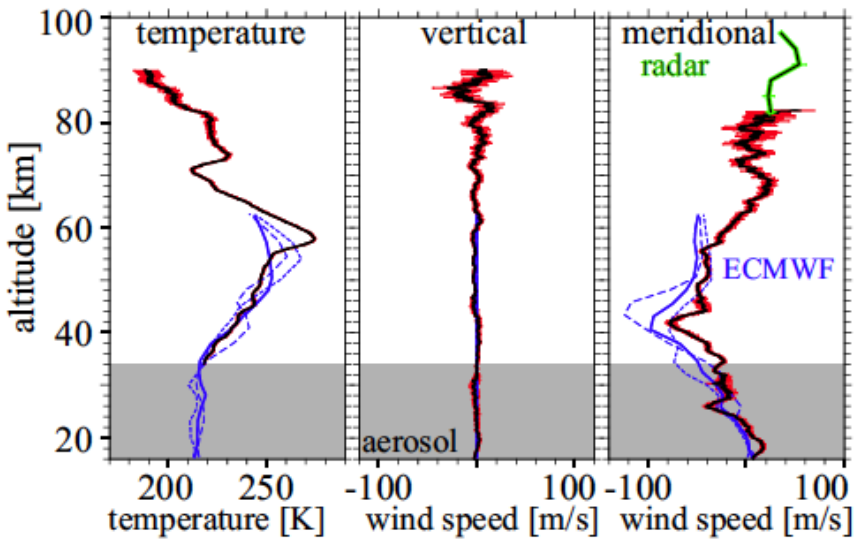


Fig. 9. Temperature, vertical and meridional wind on 17 January 2009 between 17:00 and 19:00 UT. ECMWF data from 18:00 UT (solid) and 12:00, 24:00 UT (dashed) are shown. Simultaneous observations by the collocated Meteor radar are shown. The gray area indicates altitudes with aerosol contribution as measured by the lidar.

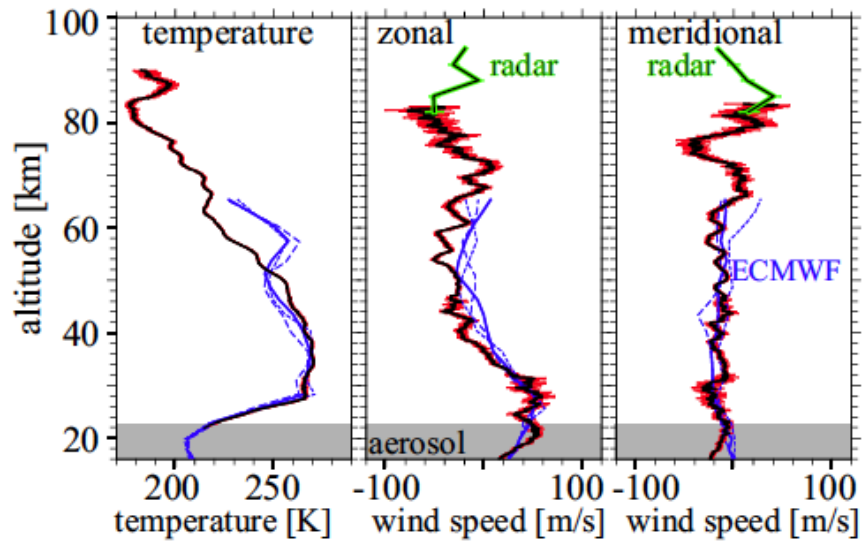
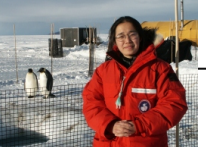


Fig. 10. Temperature and horizontal wind on 23 January 2009 between 17:00 and 19:00 UT. More details in Fig. 9.

Temperatures are derived from the integration technique combining Rayleigh and VR Raman scatterings.

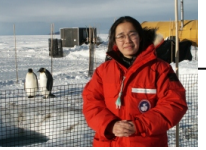
$\Delta t = 2$ h, $\Delta V_{LOS} = 0.6$ m/s @ 49 km, 10 m/s @ 80 km
$P_L = 14$ W @ 532 nm, $D_{telescope} = 1.8$ m

[Baumgarten, Atmos. Meas. Tech., 3, 1509-1518, 2010]



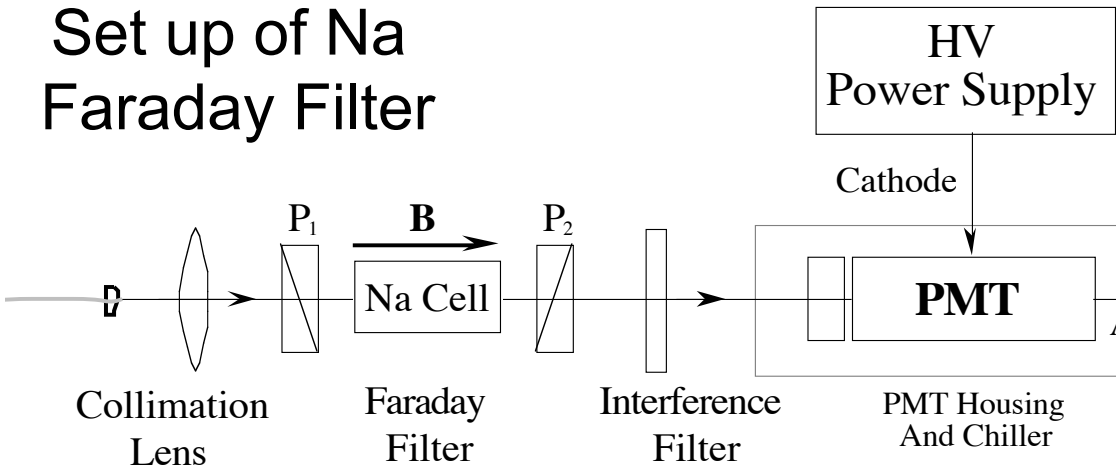
Considerations for DDL

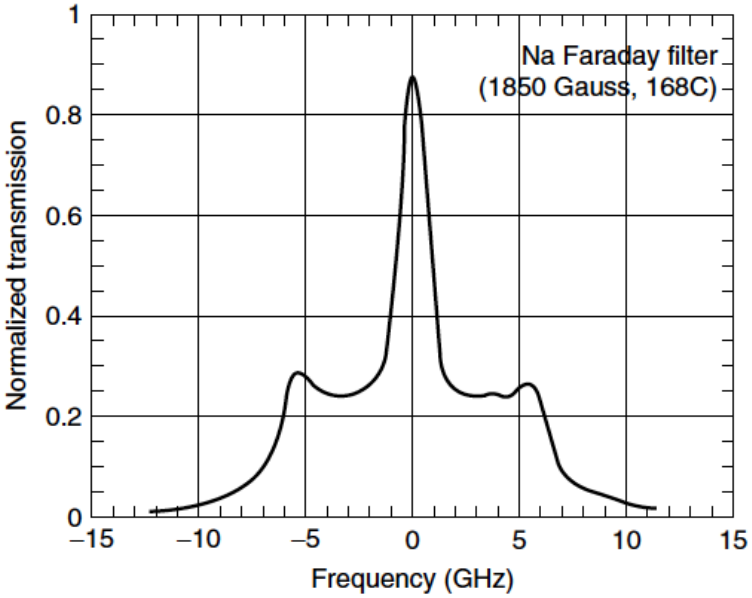
- Multiple-frequency edge-filter-based DDL provides a new idea of measuring wind and temperature simultaneously with DDL.
- The combination of Rayleigh Doppler wind with Rayleigh integration temperature provides another idea of measuring wind and temperature simultaneous with DDL.
- Adding Raman channels (both vibrational-rotational and pure-rotational) and independent aerosol channels will help to retrieval aerosol information (β and α), so enabling the wind retrieval in the aerosol-loaded regions.
- Comparing to Na or K-DEMOF, the advantage of iodine filter is the availability of high-power laser at 532 nm. By integrating our multiple-frequency idea formed from Na-DEMOF investigation to the iodine-filter lidar, it may be even more powerful.
- Nevertheless, all edge-filter DDLs suffer significant signal loss. This is because the peak of the return signals is cut or attenuated in order to have sufficiently high sensitivity to wind. That's why people look into other possibilities to do DDL.



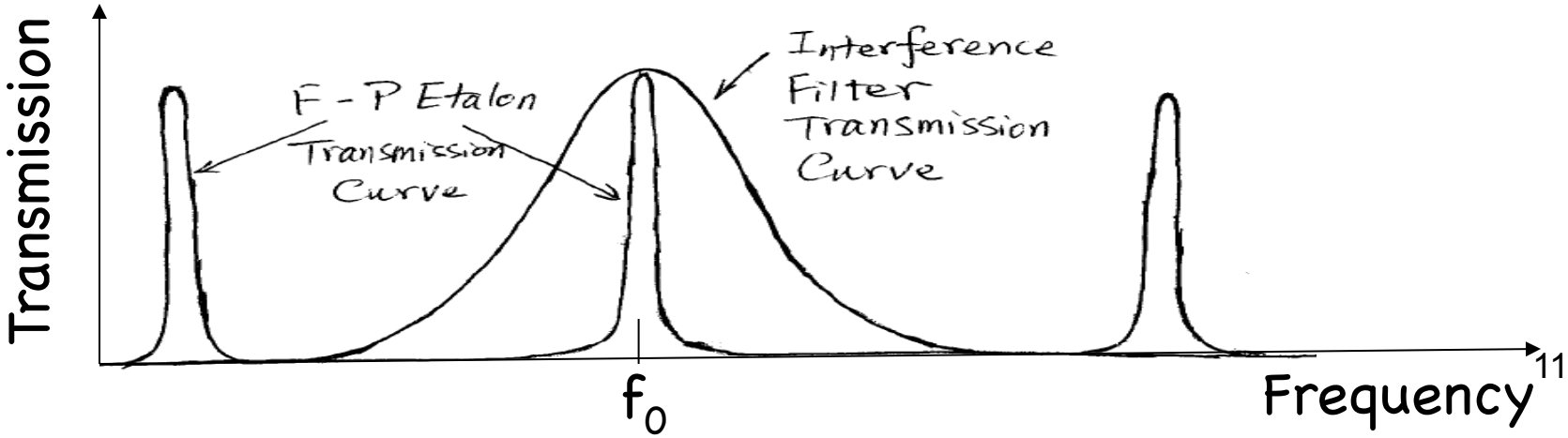
Narrowband Daytime Filter: Faraday Filter vs. Fabry-Perot Etalon

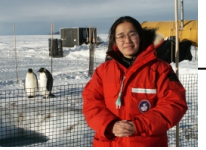
Set up of Na Faraday Filter





See textbook Chapter 5





Wave Plate: Optic Axis Parallel to Plate Surfaces

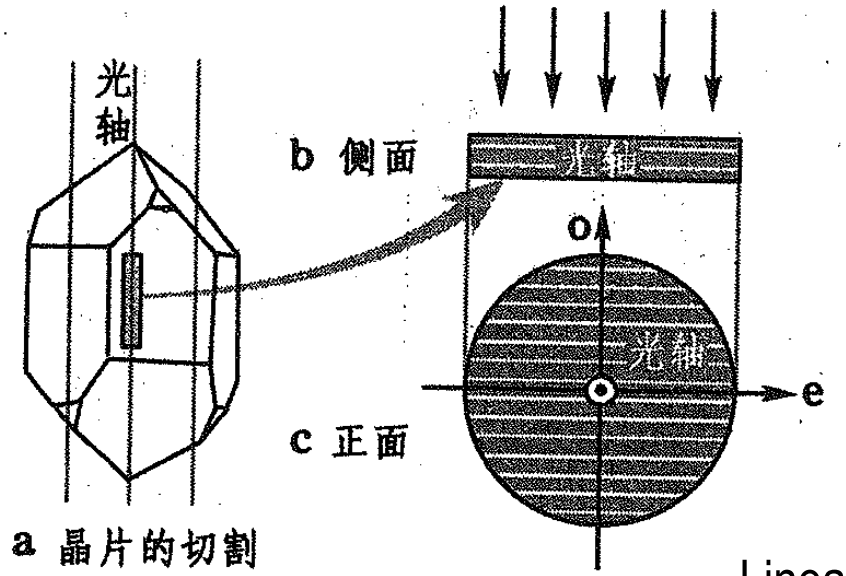


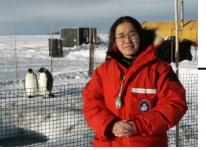
图 6－48 波晶片

Waveplates have the optic axis of uniaxial crystals parallel to the plate surfaces.

Therefore, the normal incident light has its propagation direction (wave vector K) perpendicular to the optic axis.

Linear polarization perpendicular to optic axis is o-light.
Linear polarization parallel to optic axis is e-light.

Waveplates cause polarization retardation (output polarization state depending on relationship between incident light's polarization direction and waveplate optic axis) via introducing phase retardation (different phase velocities) between o-pol and e-pol linear polarization light.



Optical Activity: Optic Axis Perpendicular to Plate Surfaces

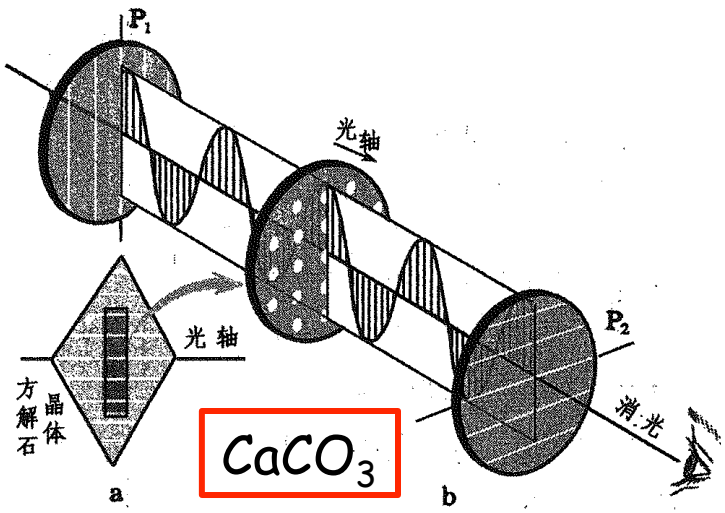


图 6 – 68 冰洲石无旋光效应

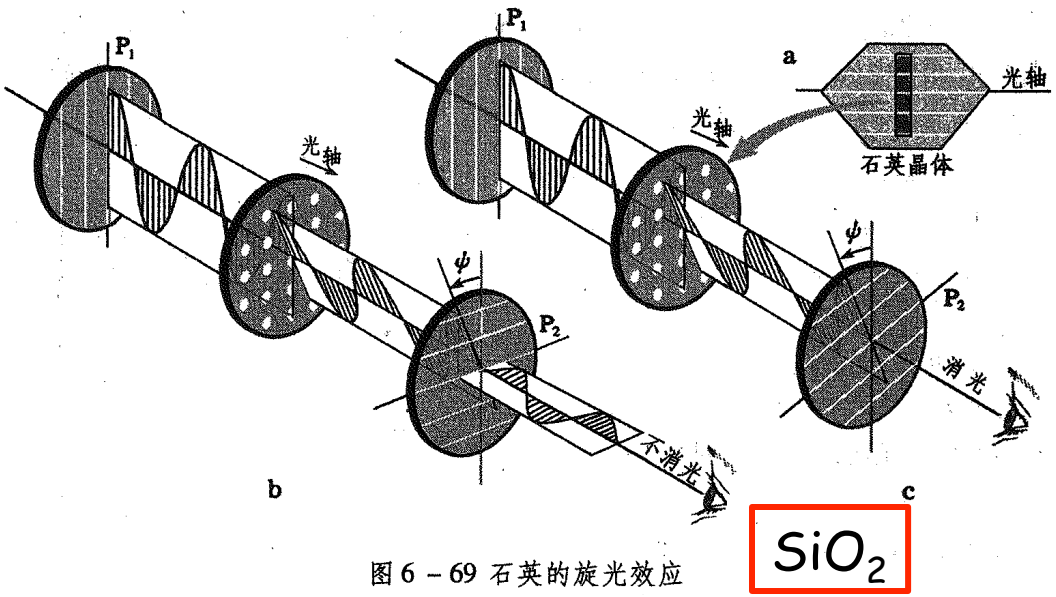
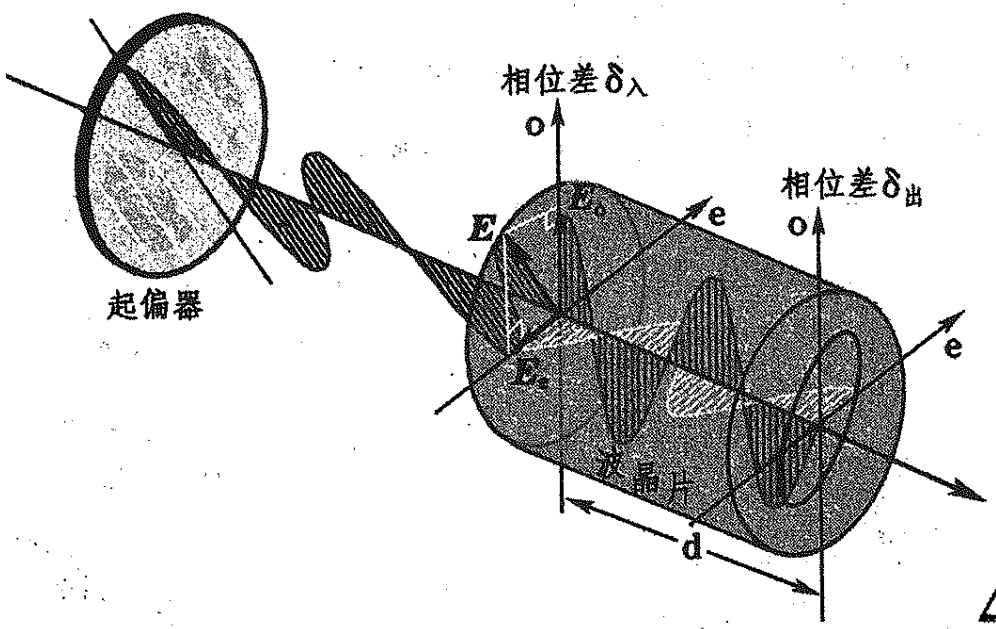


图 6 – 69 石英的旋光效应

Optical activity crystals (polarization rotation) have the optic axis of uniaxial crystals perpendicular to the plate surfaces. Therefore, the normal incident light (wave vector K) propagates along the optic axis.

Polarization rotators rotate the linear polarization via optical activity -- introducing phase delay between left and right circular polarizations. The output polarization is linear polarization if incident light is linearly polarized.

Explanation of Wave Plate Retardation



$$\varphi_o = \frac{2\pi}{\lambda} n_o d, \quad (\text{o 光})$$

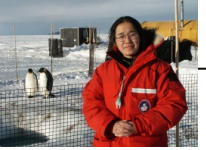
$$\varphi_e = \frac{2\pi}{\lambda} n_e d, \quad (\text{e 光})$$

$$\Delta = \varphi_o - \varphi_e = \frac{2\pi}{\lambda}(n_o - n_e)d.$$

When a linearly polarized light incidents perpendicular to the optic axis, the linear polarization can be decomposed to the superposition (synthesis) of o-light and e-light, both linearly polarized. (The e-light polarization parallel to optic axis.)

The o-light and e-light experience different refraction indexes, so phase retardation will be introduced.

The recombination of two linear polarizations result in new polarization depending on the phase retardation.



Explanation of Optical Activity

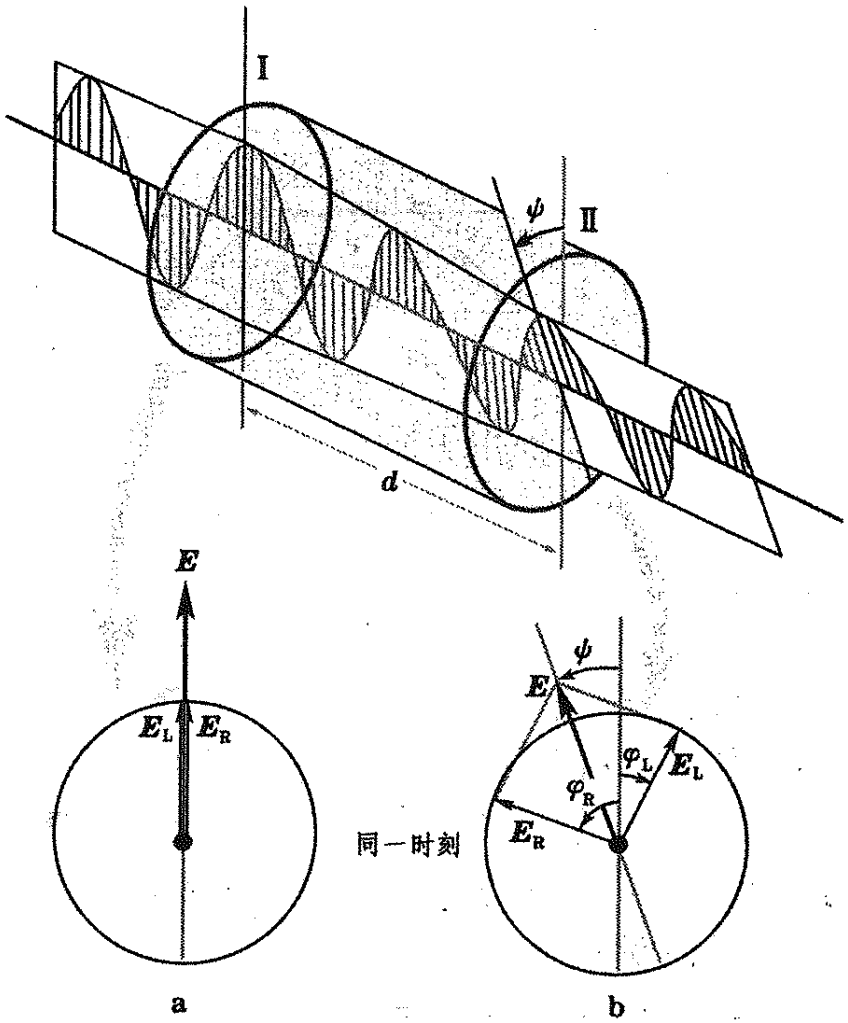


图 6－72 旋光性的解释

When light propagates along the optic axis, it can be decomposed to the superposition (synthesis) of a left and a right circularly polarized light.

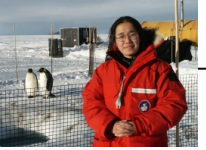
If two circular polarizations experience different refraction indexes, extra phase shift will be introduced.

Consequently, two circular polarizations recombine to form a linear polarization with its orientation rotated.

$$\varphi_L = \frac{2\pi}{\lambda} n_L d,$$

$$\varphi_R = \frac{2\pi}{\lambda} n_R d,$$

$$\psi = \frac{1}{2}(\varphi_R - \varphi_L) = \frac{\pi}{\lambda}(n_R - n_L) d.$$



Optical Activity vs. Waveplate Retardation

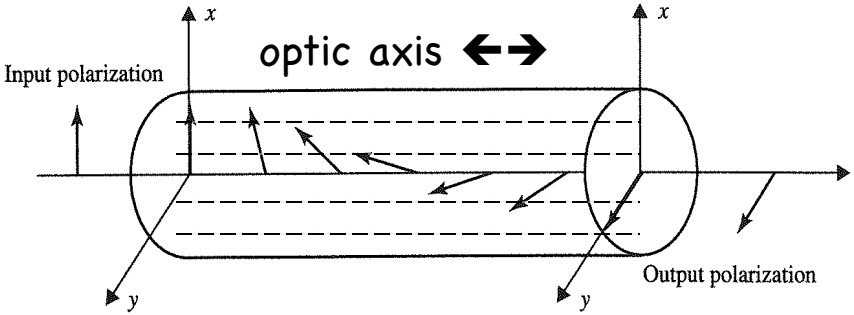
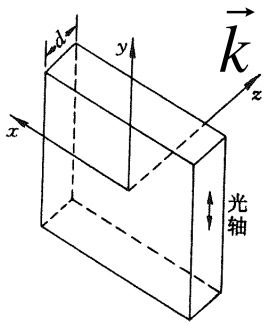
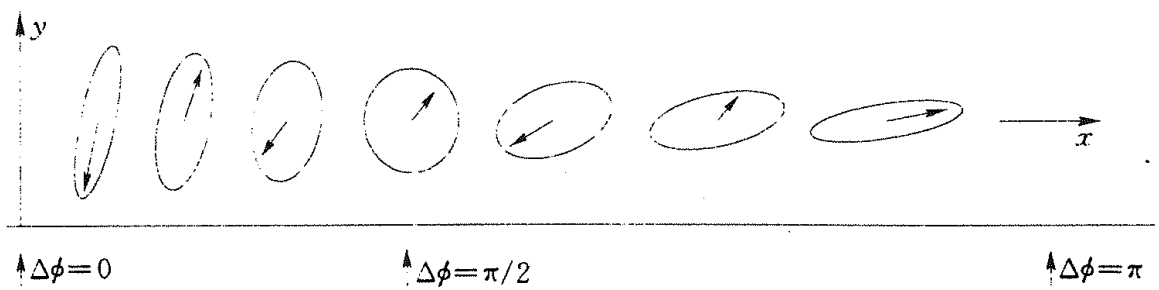


Figure 1.14 Rotation of the plane of polarization by an optically active medium.

Optical activity: linearly polarized light propagates along the optic axis with the linear polarization rotating along the way.
-- "Circular polarization birefringence"

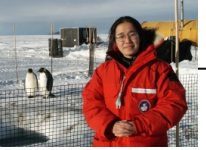




Wave plate z = 0 z(π/2) z(π)

Waveplate retardation: linearly polarized light propagates perpendicular to the optic axis and the polarization changes its state along the way.

The decomposition of linearly polarized light is based on the orthogonal eigenstates of a crystal. For example, optical activity has L and R circular polarizations as its eigen-vibrations, while wave plate has o and e linear polarization as its eigne-vibrations.



Faraday Rotator: Magnetic-Field-Induced Optical Activity

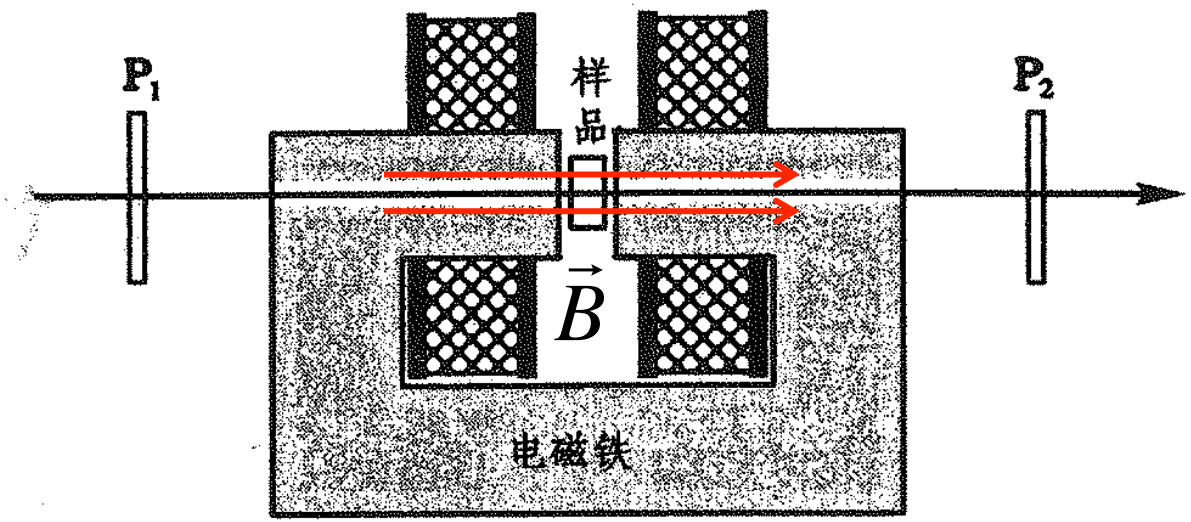
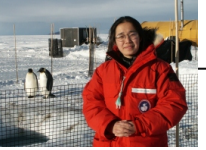


图 6 – 79 磁致旋光

Magneto-Optic (MO) crystal: Field-induced optical activity or magnetically induced optical activity (polarization rotation)

Light must propagate along the optic axis which is defined by the external magnetic field.



Faraday Rotator: Magnetic-Field-Induced Optical Activity

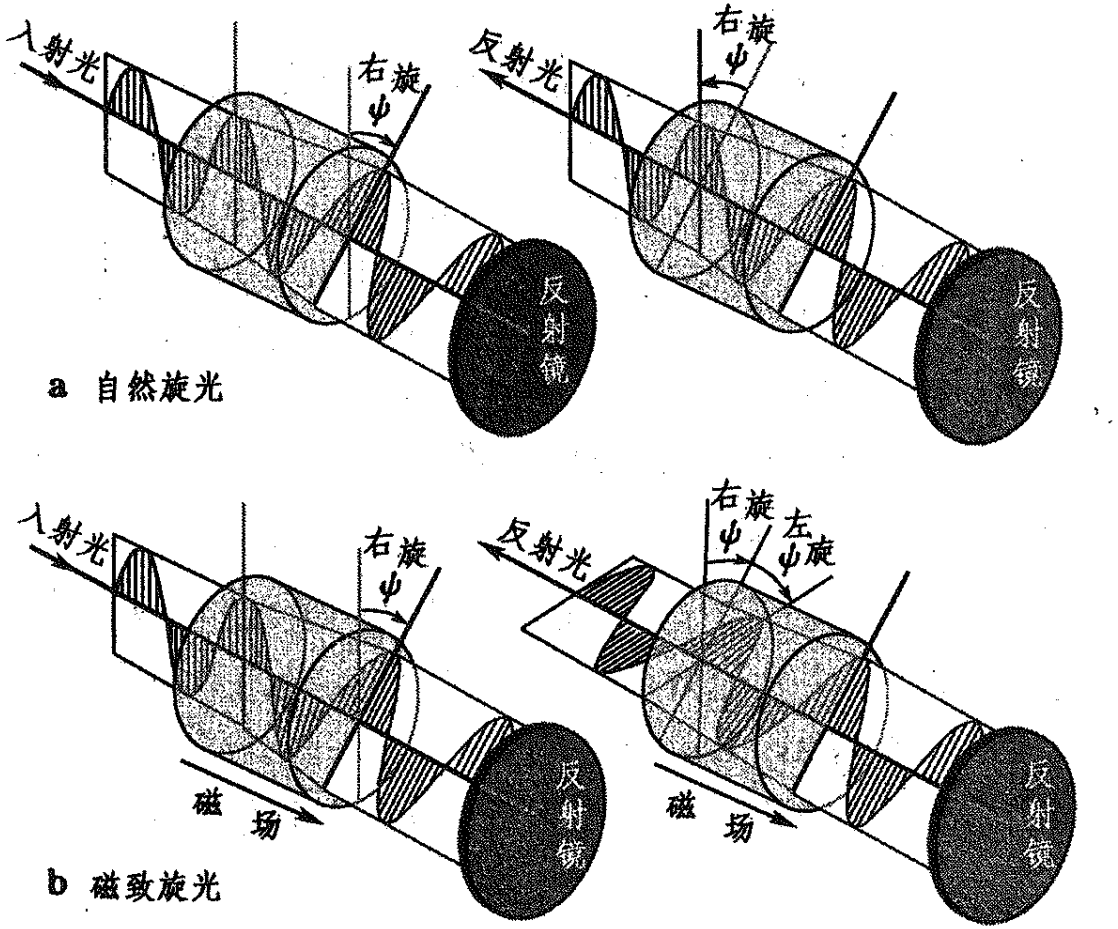
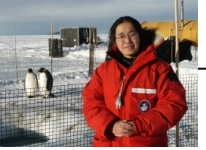


图 6 – 80 自然旋光与磁致旋光的比较

Naturally occurring optical activity

Faraday (B-field-induced) optical activity



Light Velocity vs. Refraction Index

The light speed in vacuum c is given by

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

ε_0 – dielectric constant in vacuum (the permittivity of a vacuum)

μ_0 – permeability in vacuum

The phase velocity of EM wave in medium v is given by

$$v = \frac{1}{\sqrt{\varepsilon_0 \varepsilon \mu_0 \mu}} = \frac{c}{n}$$

ε – relative dielectric constant

μ – relative permeability

The refraction index of the medium is given by

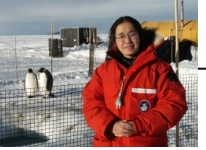
$$n = \sqrt{\varepsilon \mu}$$

Except for ferromagnetic materials, $\mu \approx 1$ is true for most materials, so

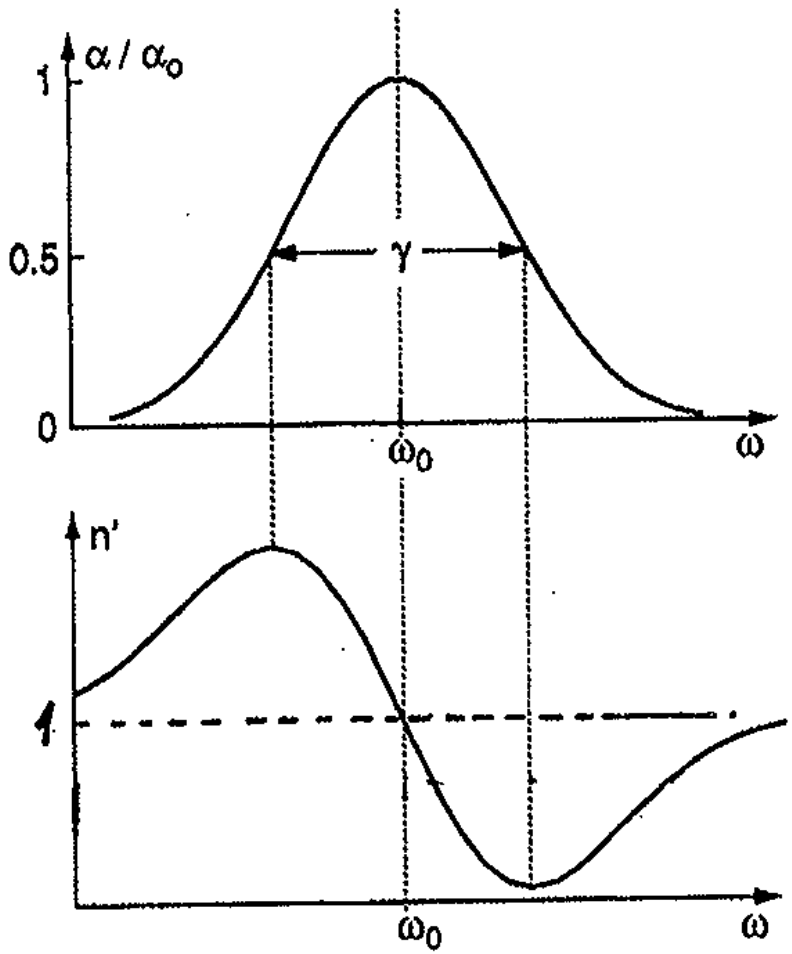
$$n = \sqrt{\varepsilon \mu} \approx \sqrt{\varepsilon} = \sqrt{1 + \chi}$$

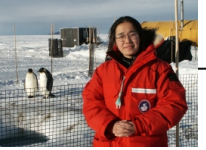
X – macroscopic electric susceptibility of the medium

$\varepsilon_m = \varepsilon_0 \varepsilon$ – the dielectric constant (permittivity) of the medium

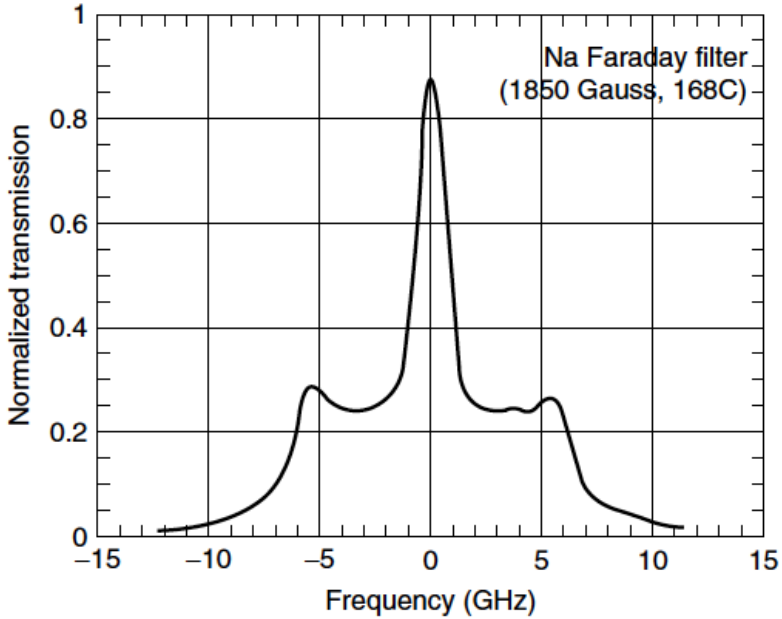


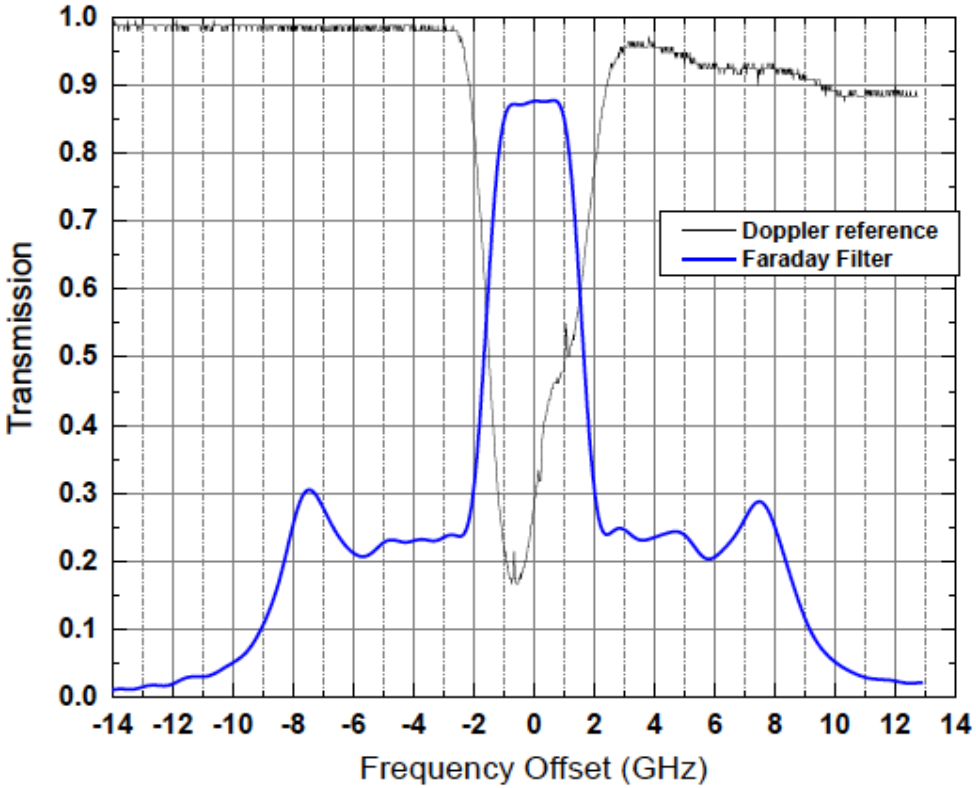
Resonance Absorption vs. Dispersion

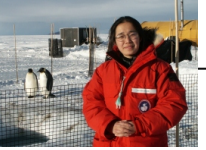




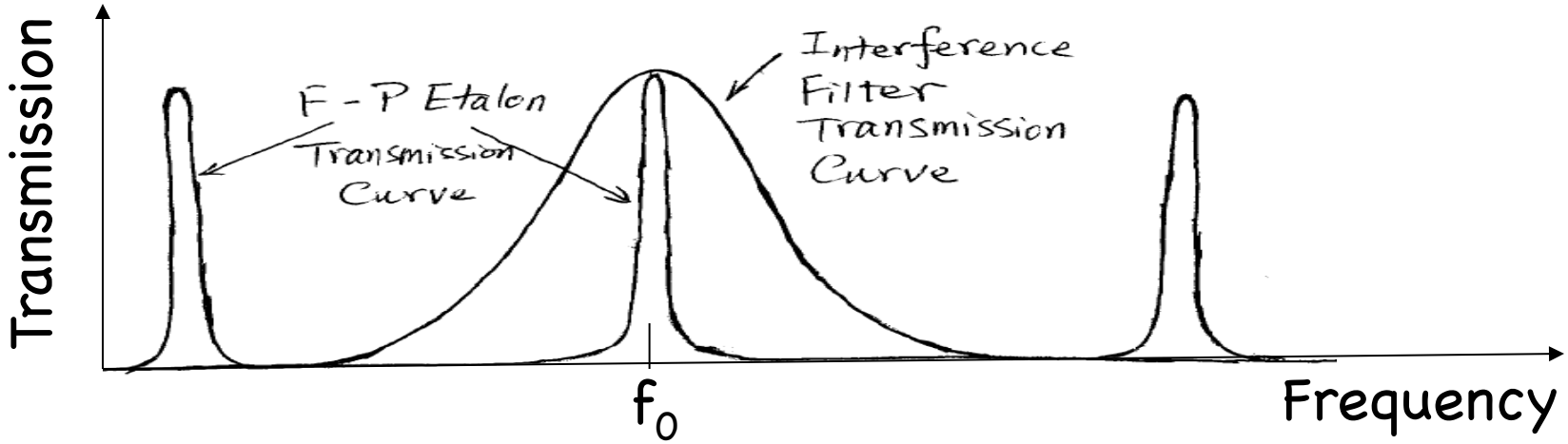
Narrowband Daytime Filter: Faraday Filter

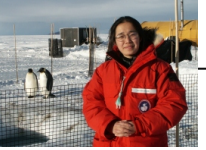




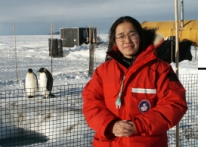


Narrowband Daytime Filter: Single Fabry-Perot Etalons





Narrowband Daytime Filter: Double Fabry-Perot Etalons



Summary

- Direct detection Doppler lidar uses atomic/molecular absorption lines, the edge filters, or fringe-imaging techniques to discriminate or analyze the of the return lidar signals (Doppler shifted and/or broadened). Potentially, DDL can measure both wind and temperature if sufficient spectral information is provided or inquired.
- For non-resonance DDL, a major issue is how to improve the signal level or collection efficiency. New developments based on various interferometers are under the way.
- For atmospheric science study, especially for waves coupling from lower to upper atmosphere, DDLs have very high potentials for the future, especially the combination of resonance DDL in MLT region with non-resonance DDL in the troposphere, stratosphere and lower mesosphere, we may be able to profile the wind and temperature from ground all the way up to 170 km. This will be a breakthrough for atmospheric science community.

Please read our textbook Chapter 7 for direct-detection Doppler lidar and for coherent-detection Doppler lidar.
Please read our textbook Chapter 5 for resonance DDL.