Absorption spectroscopy of atmospheric species

Anna Serdyuchenko, IUP MolSpec group

postgraduate programme environmental physics

atmosphere, ocean, land, climate

Content

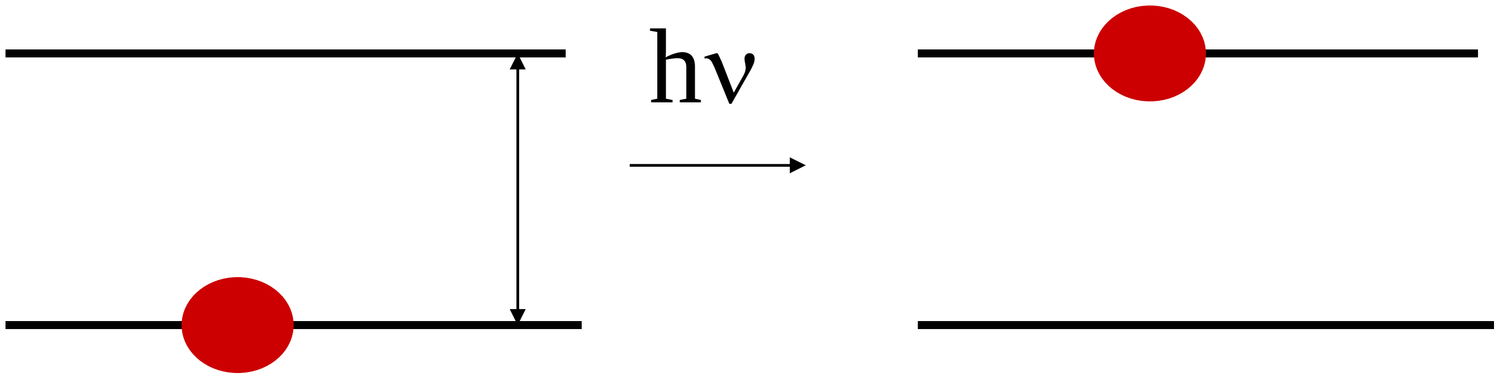
- Introduction
- Spectra origination
- Absorption experiment
- Beer-Lambert law
- Optical schemes and instruments

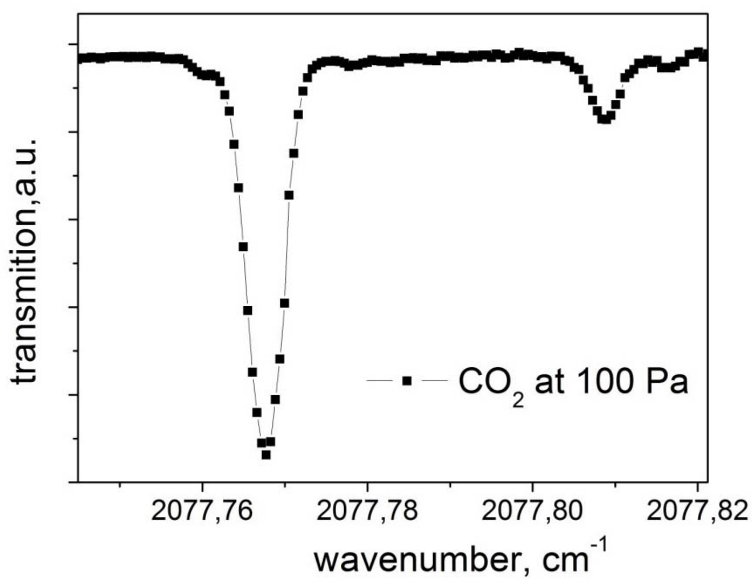
Instead of Introduction

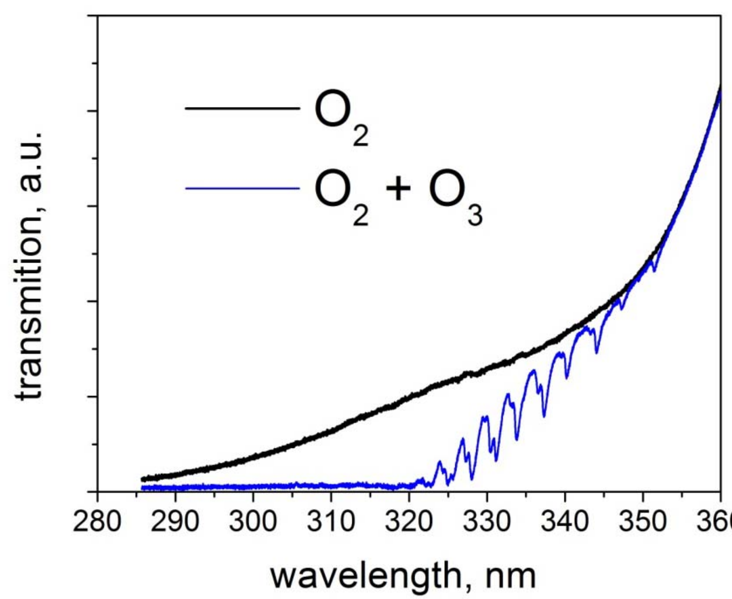
- You have 2 (two) eyes only!!!!
- You need both of them!!!

SPECTRA ORIGINATION

Absorption: spectra origination

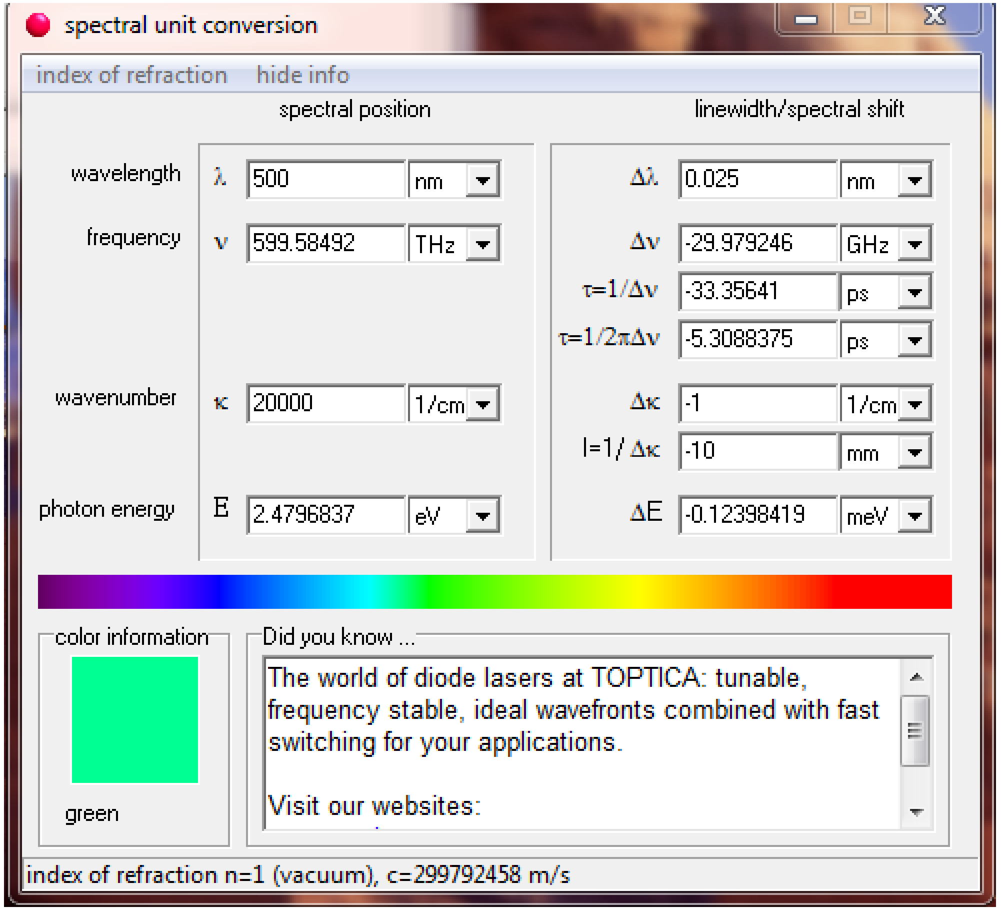






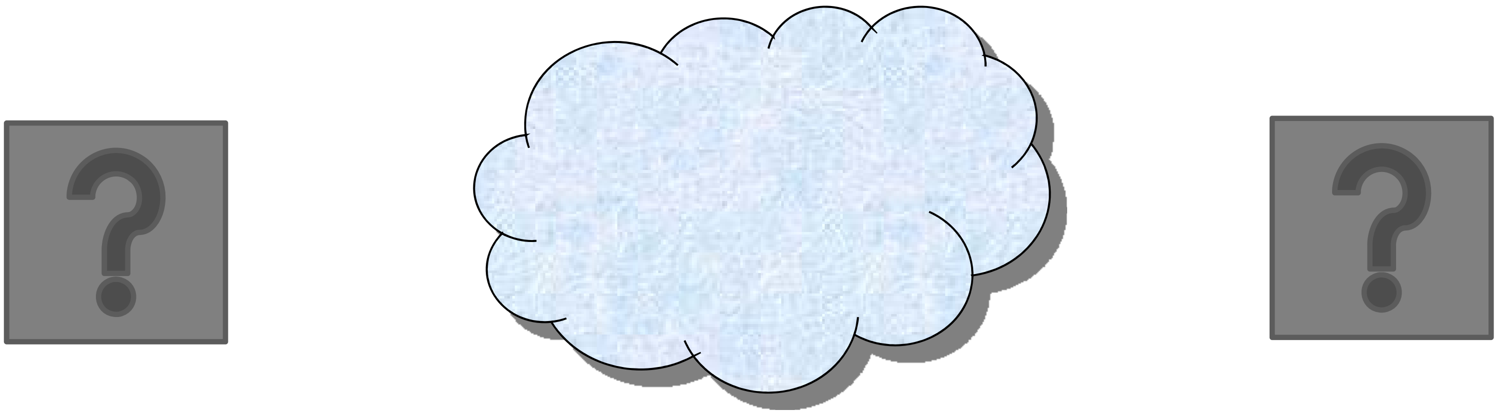
Useful conversion tool: toptica calculator

http://www.toptica.com/page/topticalc.php



ABSORPTION EXPERIMENT

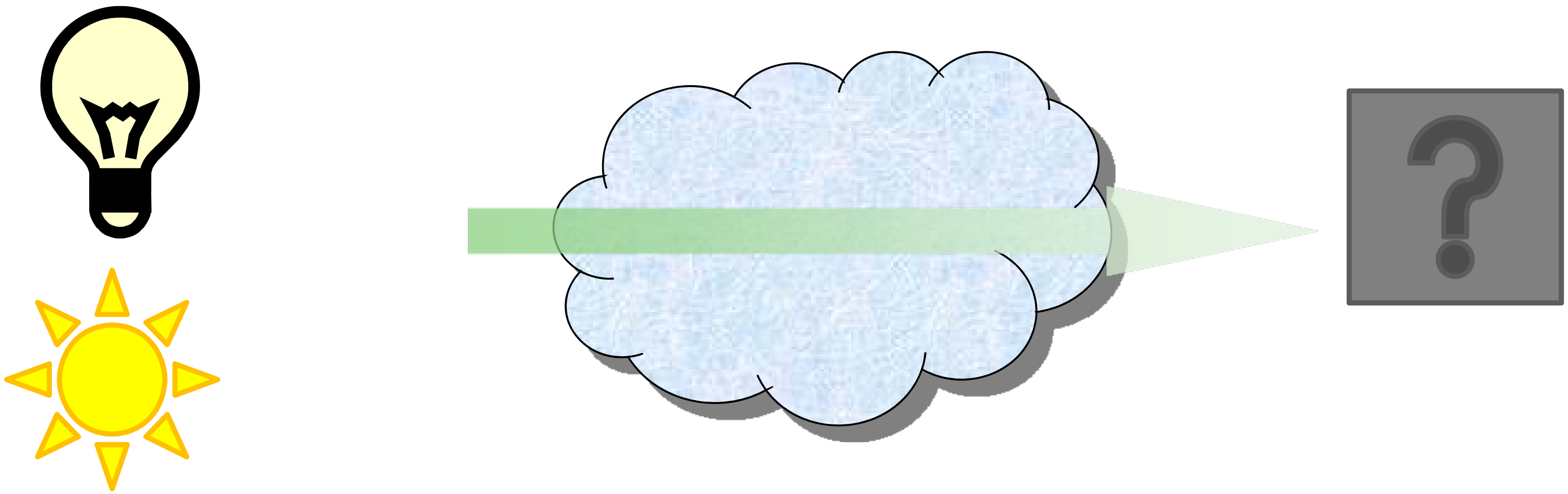
Absorption experiment: main parts?



Investigated media:

Atmosphere
Sample

Absorption experiment: main parts?



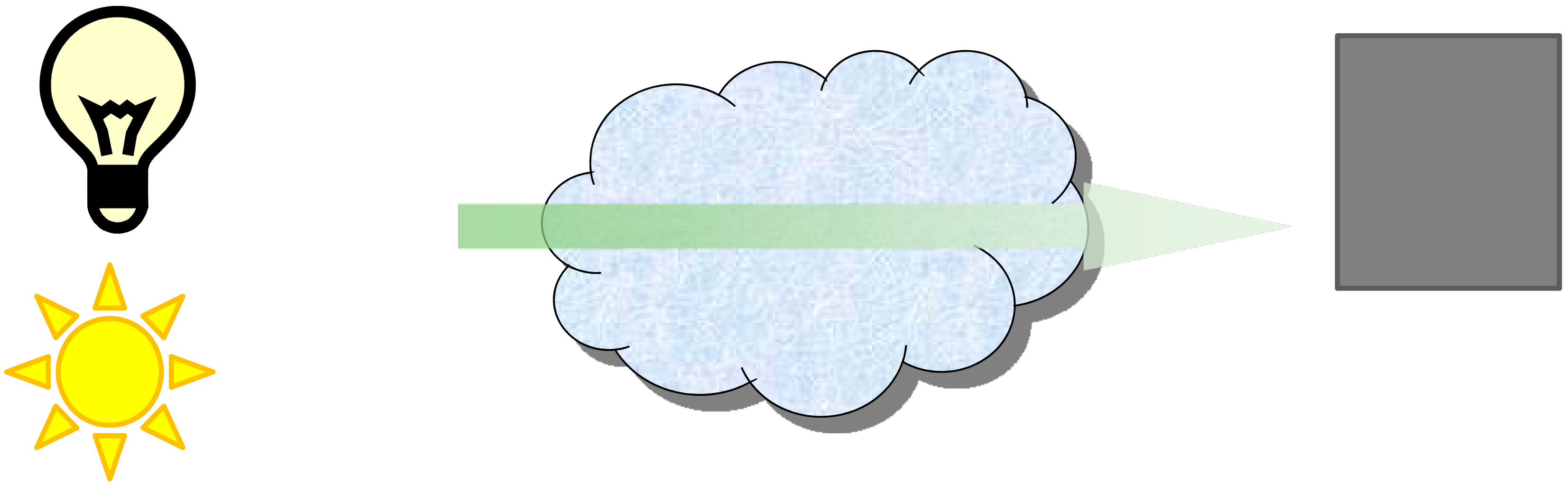
Light source:

lamp;
sun;
laser

Investigated media:

Atmosphere
Sample

Absorption experiment: main parts?



Light source:

lamp;
sun;
laser

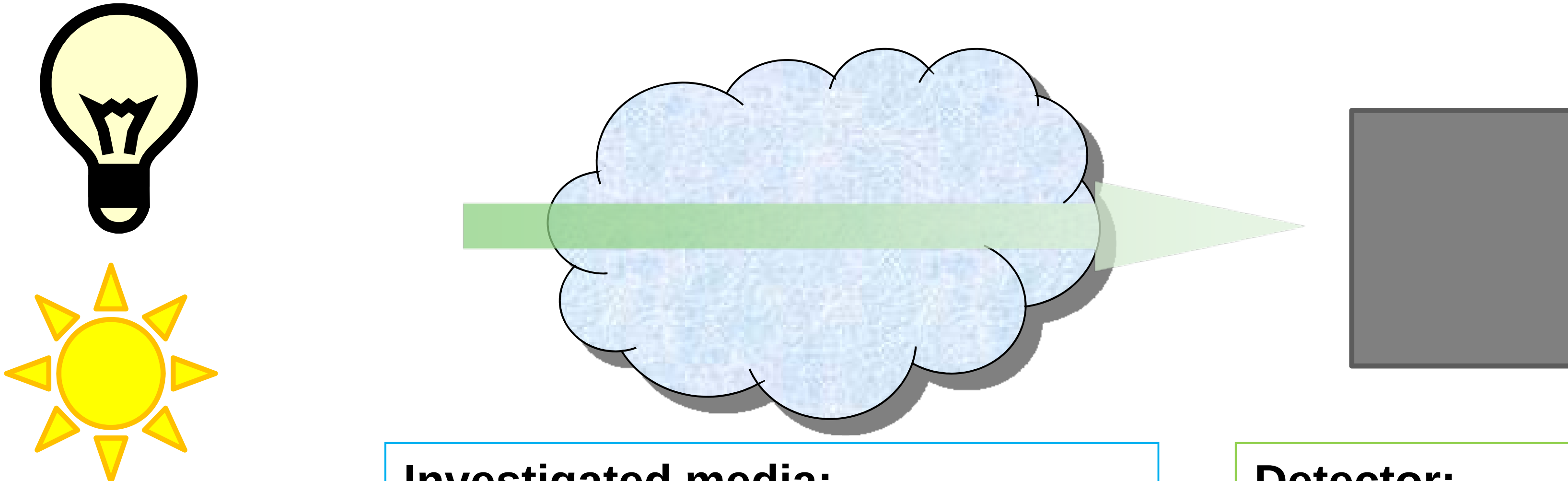
Investigated media:

Atmosphere
Sample

Detector:

Photoplate;
Semiconductor:
- -Single;
- - Array:
- - Matrix.

Absorption experiment: main parts



Light source:

Lamp;
Sun;
Laser

Investigated media:

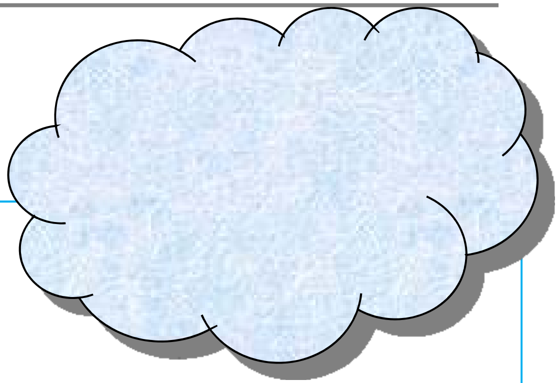
Atmosphere:
a lot of species (N_2, O_2, H_2O, CO_2 etc) at different partial pressures and temperatures scattering and absorbing at different wavelengths.

Sample: prepared mixture at known(?) pressure and temperature

Detector:

Photoplate;
Semiconductor:
- -Single;
- - Array:
- - Matrix.

Investigated media



Atmosphere:

a lot of species (N_2, O_2, H_2O, CO_2 etc) at different partial pressures and temperatures scattering and absorbing at different wavelengths.

Samples:

- In the air-born or field measurements: probe of air (contains CO, CO_2 etc) collected through the special inlets
- In the laboratory: prepared mixture at known(?) pressure and temperature
  - CH_4, CO_2 – no problem
  - CO – dangerous, safety rules
  - O_3 – dangerous , unstable

Investigated media: ozone

Ozone production in the laboratory:
co-axial cylindrical capacitor, 'silent' discharge

Ozone generator on:

$O_2 + e^- \rightarrow O + O + e^-$, $O_2 + O \rightarrow O_3$

Ozone generator off:

$O_3 + M \rightarrow O_2 + O + M$, M – surrounding molecules

$$\frac{dn_{O3}}{dt} = -k \cdot n_M \cdot n_{O3}$$

k – decay rate [cm^3/molecule/s], depends on temperature T and surrounding molecules

Why?

Investigated media: ozone

Ozone generator on

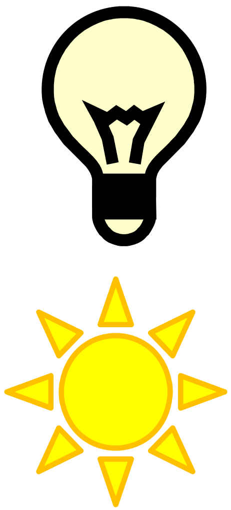
$O_2 + e^- \rightarrow O + O$
$O_2 + O \rightarrow O_3$

Ozone generator off:

$O_3 + M \rightarrow O_2 + O + M$

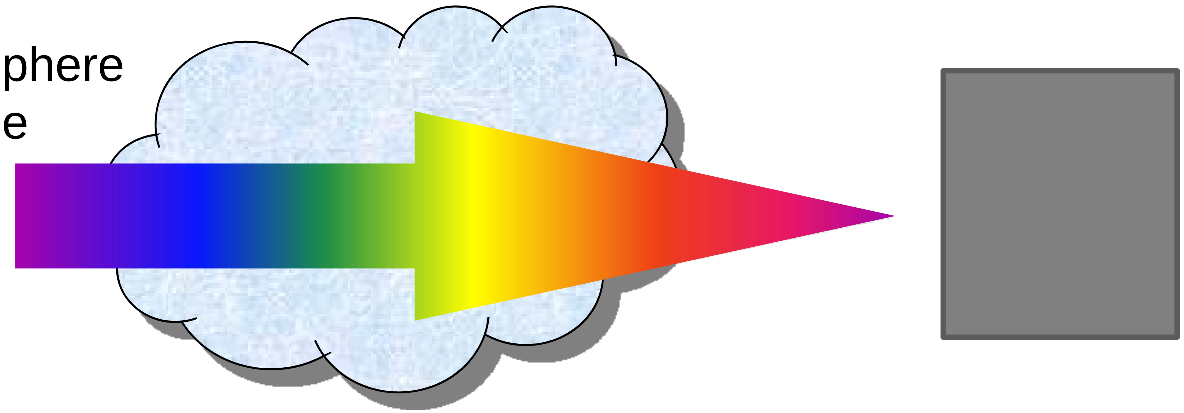
$$\frac{dn_{O3}}{dt} = -k \cdot n_M \cdot n_{O3} \qquad n_{O3}(t) = n_0 \cdot \exp\{-k_{decay}(T) \cdot n_M \cdot t\}$$

Absorption experiment: main parts



Investigated media:

Atmosphere
Sample



Light source:

Lamp;
Sun;
Laser.

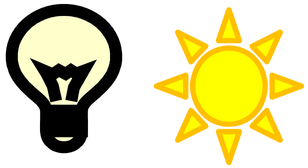
Wavelength selection:

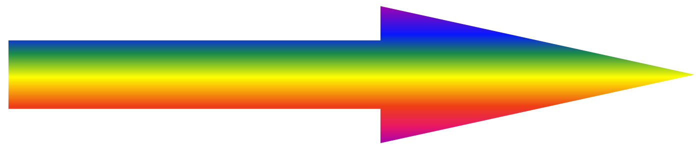
Time: FTS, tunable laser
Space: prism, grating

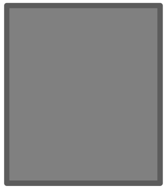
Detector:

Photoplate;
Semiconductor:
- Single;
- Array:
- Matrix.

Absorption experiment: main parts







Light source:

lamp;
sun;
laser

Important properties:

Spectrum;
Tunability;
Broad- or narrow-band.

Wavelength selection:

Time: FTS, tunable laser
Space: prism, grating

Important properties:

Resolution;
Dispersion;
Transitivity/ reflectivity

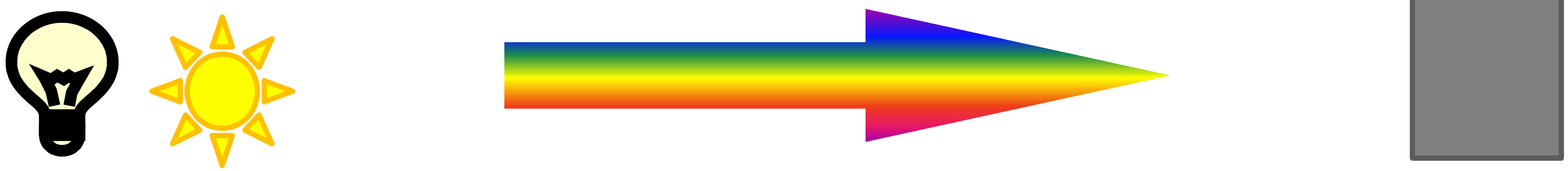
Detector:

Photoplate;
Semiconductor:
single, array, matrix

Important properties:

Sensitivity;
Response curve;
Time constant;
Dynamic range

Ideal absorption experiment



Light source:

Broad or tunable
Flat spectrum
Stable intensity

Wavelength selection:

High resolution;
High transmitivity/reflectivity.

Detector:

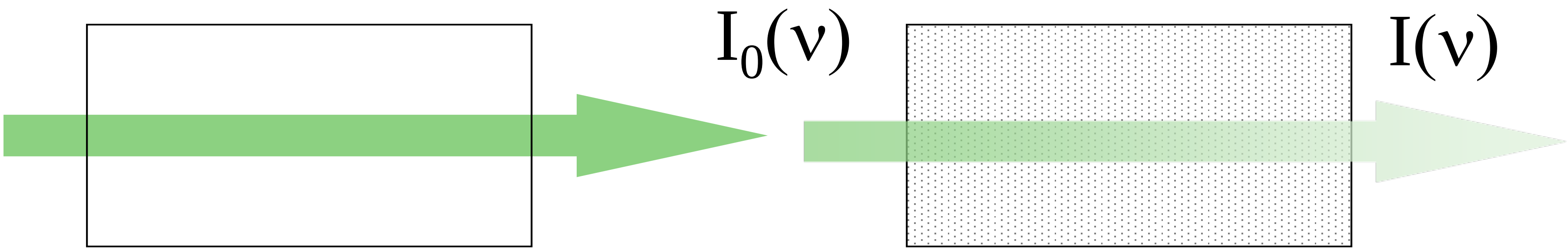
Sensitive in broad spectral range with wide dynamic range;
Fast;
Flat response curve;
Low noise

BEER-LAMBERT LAW

Beer-Lambert law

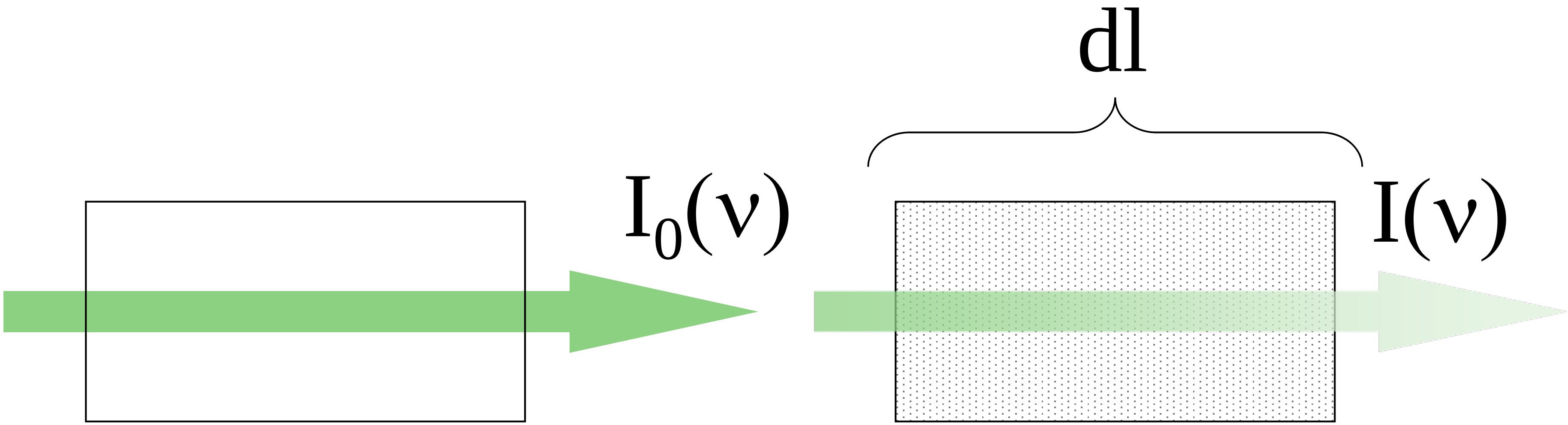
- **Beer's law = Lambert–Beer law =Beer–Lambert–Bouguer law**
- relates the ***absorption*** of light to the ***properties*** of the material

through which the light is travelling.



What else can happen?

Absorption: Beer-Lambert law



$$dI = ?$$

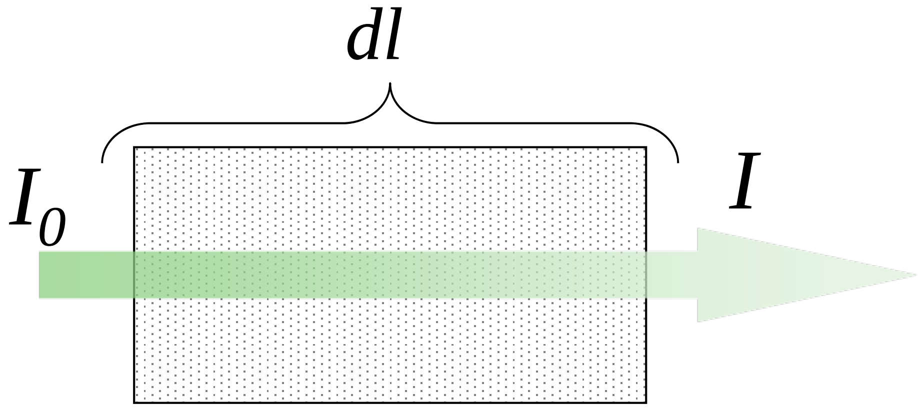
$$dI = -I \cdot n \cdot \sigma \cdot dl$$

Absorption: Beer-Lambert law

$$\frac{dI}{I} = -n \cdot \sigma \cdot dl$$

$$\int_0^L \frac{dI}{I} = -\int_0^L n \cdot \sigma \cdot dl$$

$$\ln I = -\int_0^L n \cdot \sigma \cdot dl + const$$



$$dI = -I \cdot n \cdot \sigma \cdot dl$$

$$I(\nu) = I_0(\nu)\exp\left\{-\int_0^L n(l) \cdot \sigma(\nu) \cdot dl\right\}$$

I – intensity; I_0 – initial intensity

ν – wavenumber; *n*– density of absorbing particles

L – absorbing media length; σ – absorption cross-section

Absorption: terms and units

Spatial isotropic case (n, T): $$I(\nu) = I_0(\nu)\exp\{-n \cdot \sigma(\nu) \cdot L\}$$

Optical density: $$OD = -\ln\frac{I(\nu)}{I_0(\nu)} = n \cdot \sigma(p, T, \nu) \cdot L$$

I, I_0 –	transmitted intensity with or without absorber	
ν, ν_0 *or* λ	[nm or cm^{-1}]	wavelength or wavenumber
n	**[molecules/cm^3]**	**density**
L	[cm]	absorbing media length
σ	[cm^2/molecule]	absorption cross-section

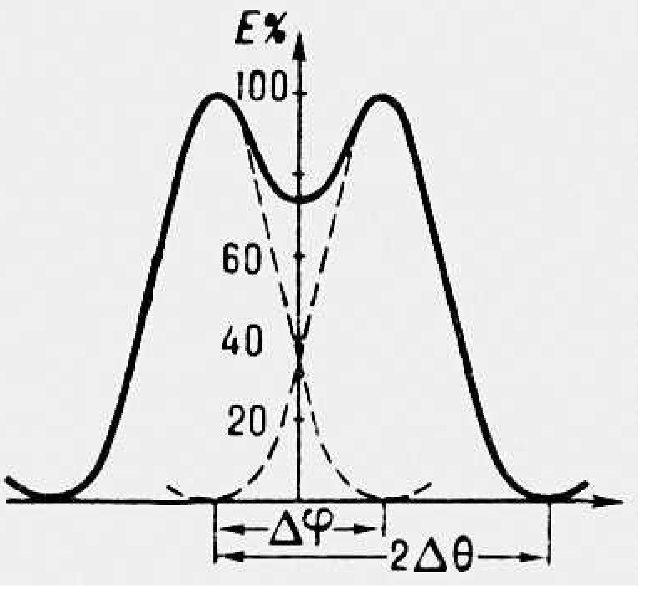
Most important conditions:

- The absorbing medium must be *homogeneously* distributed in the interaction volume and must *not scatter* the radiation;
- The incident radiation must consist of *parallel* rays, each traversing the same length in the absorbing medium;
- The incident radiation should preferably be *monochromatic*, or have at least a width that is more narrow than the absorbing transition;
- The incident flux *must not influence* the atoms or molecules:
  - the light should not cause optical saturation or optical pumping (such effects will deplete the lower level and possibly give rise to stimulated emission).

OPTICAL SCHEMES

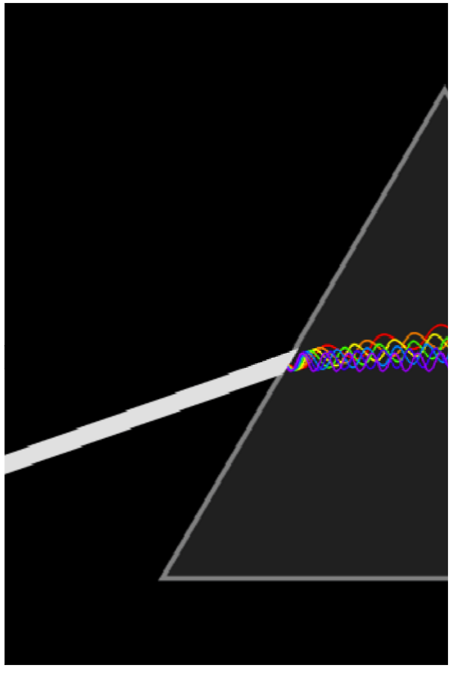
Dispersive elements

- Prism
- Diffractive grating



- Important properties:
  - Dispersion
  - Resolution
  - Response function, slit function

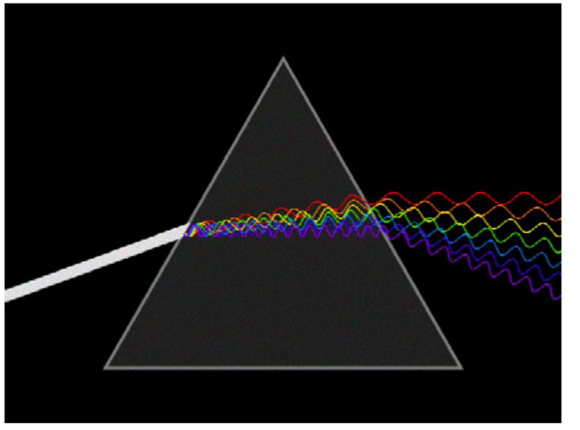
Dispersive elements: prism

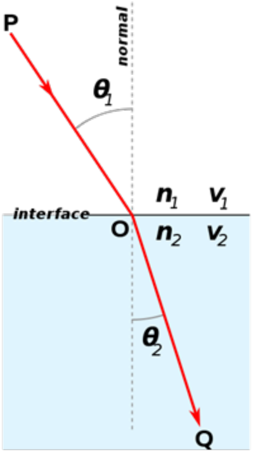


Dispersive elements: prism

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

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$





n – refraction index;

ε(λ) - material's relative permittivity;

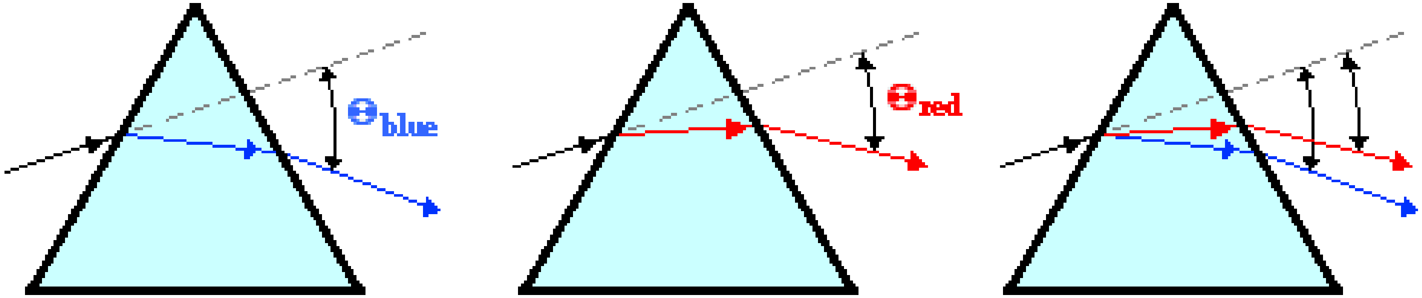
μ - relative permeability (~1 for many optical materials).

Dispersive elements: properties

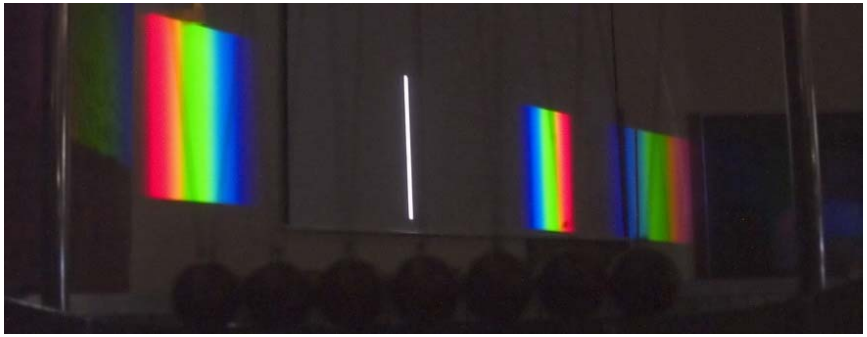
- Dispersion dθ/dλ
  - For prism angle 60º and parallel beam

$$\frac{d\theta}{d\lambda} = \frac{2}{\sqrt{4-n^2}} \frac{dn}{d\lambda}$$

- Spectral transitivity
  - Depends on material



Diffractive grating



Periodic structure

Principle of work:

1) Diffraction on every slit/stripe

2) Interference of beams created by the neighbor slits/stripes/grooves

Diffractive grating

1) Diffraction on every slit/stripe

“Maximums” condition:

$$b(\sin\varphi + \sin\psi) = q \cdot \lambda$$

Distance between maximums λ/b

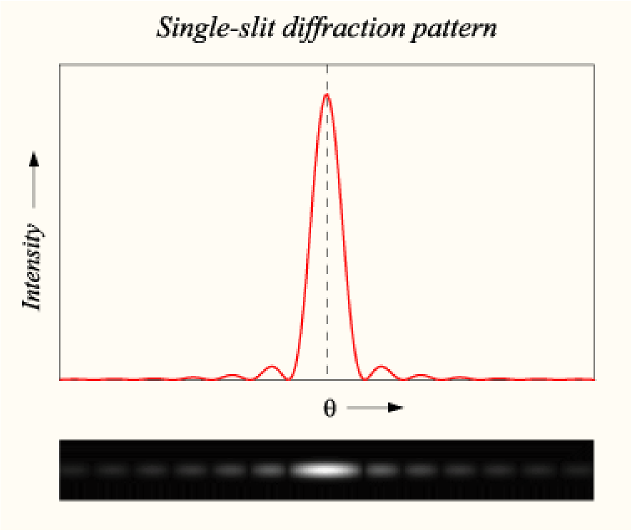
d – distance between slits/grooves

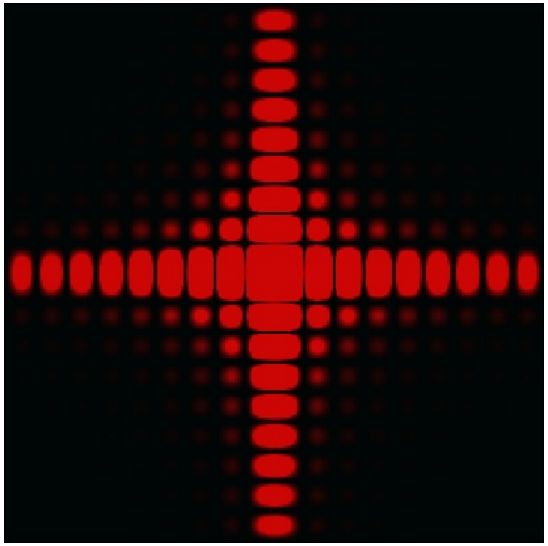
b – slit/groove width

ψ – incidence angle

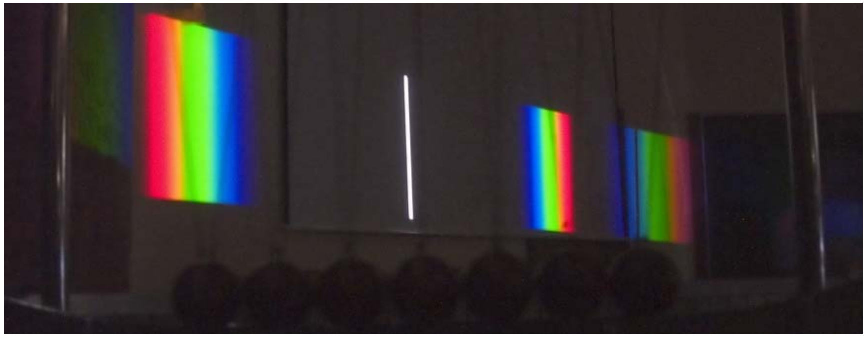
φ – diffraction angle

q – number





Diffractive grating



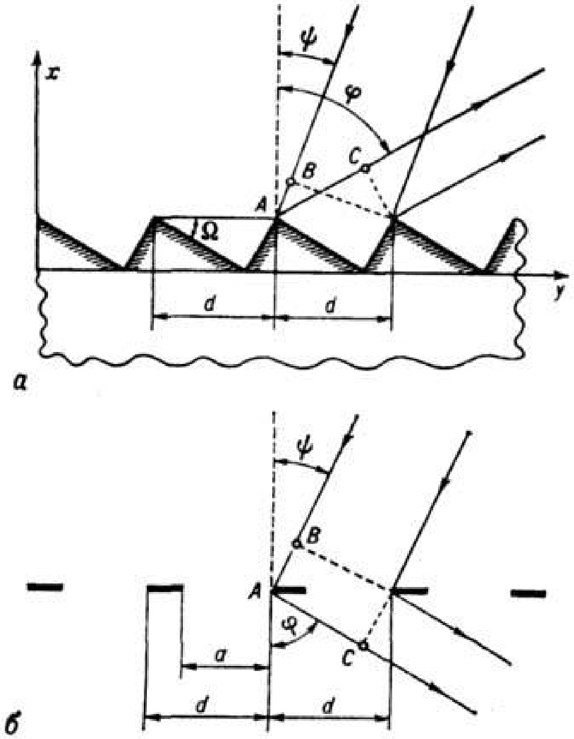
2) interference of beams reflected from the neighbor slits/stripes/grooves

"Maximums" condition:

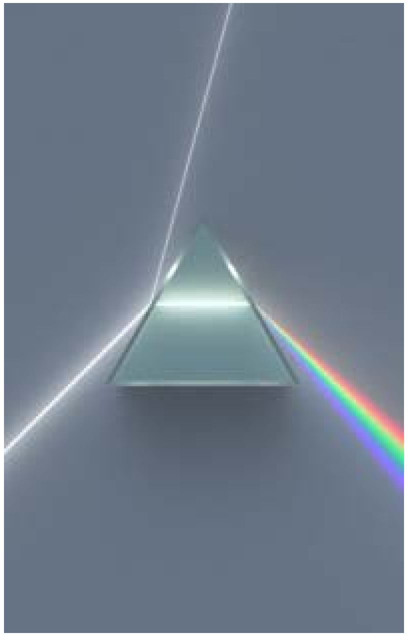
$$d\left(\sin\varphi + \sin\psi\right) = q \cdot \lambda$$

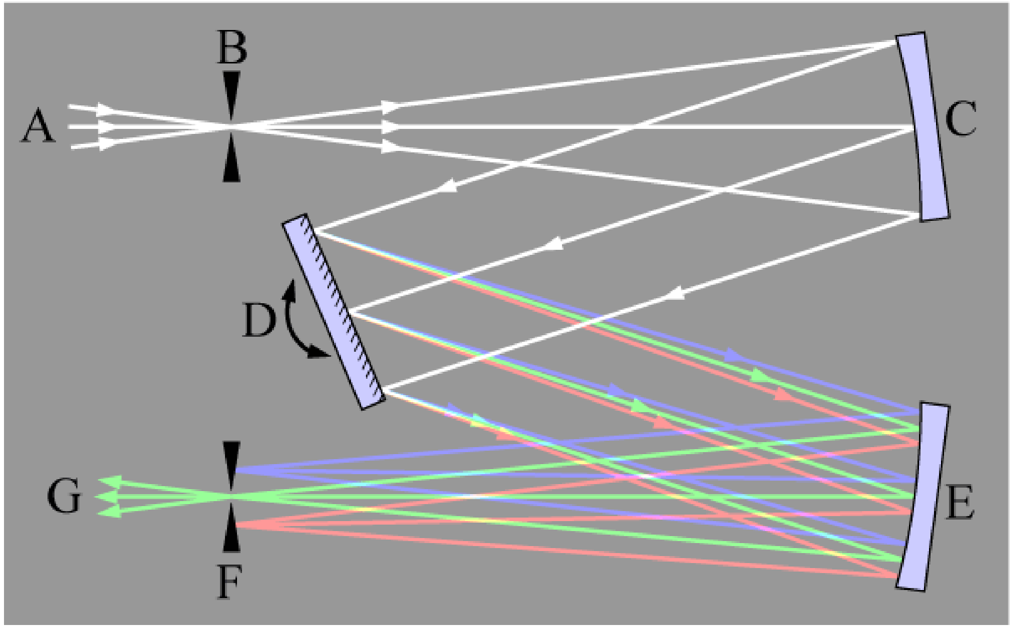
Distance between maximums λ/d

- d – distance between grooves
- b – slit/groove width
- ψ – incidence angle
- φ – diffraction angle
- q – number



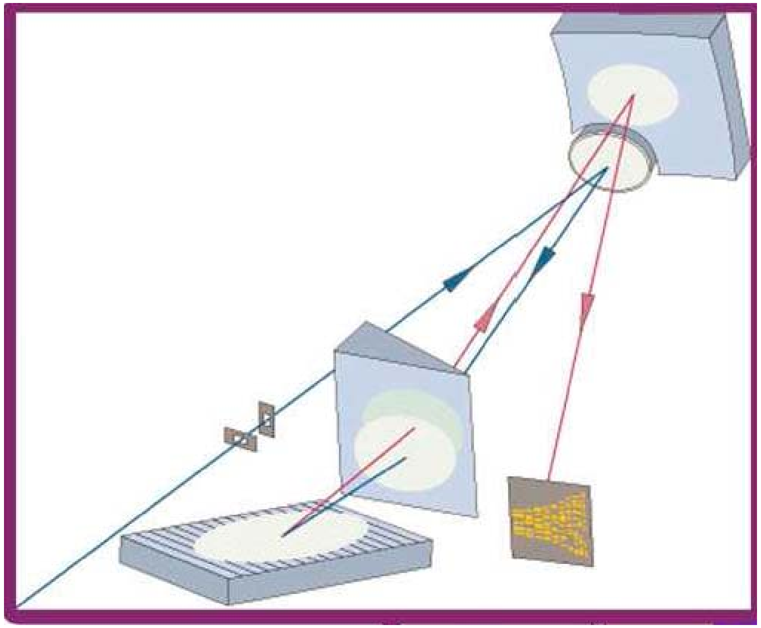
Dispersive elements: monochromator

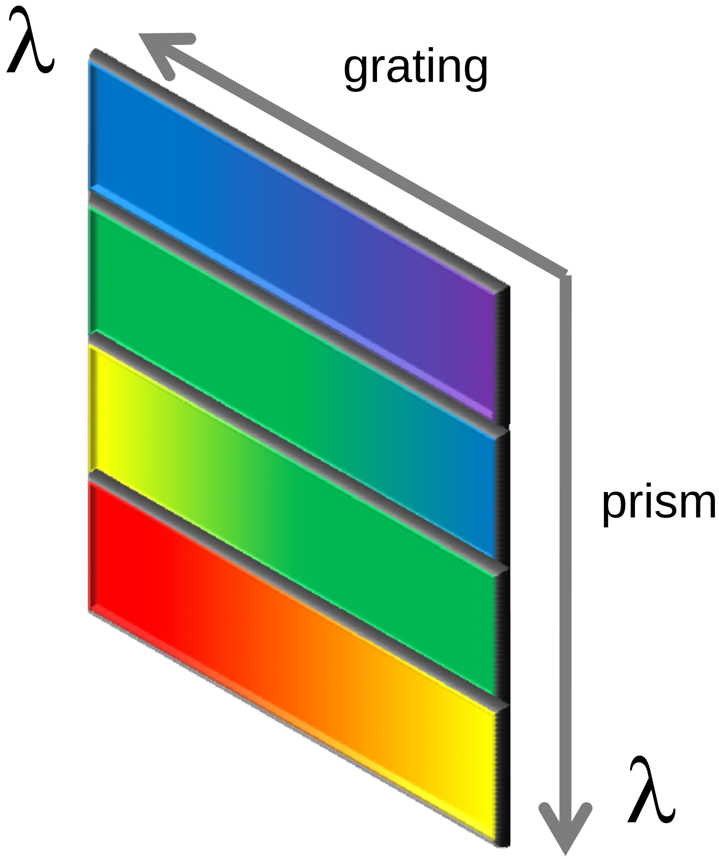




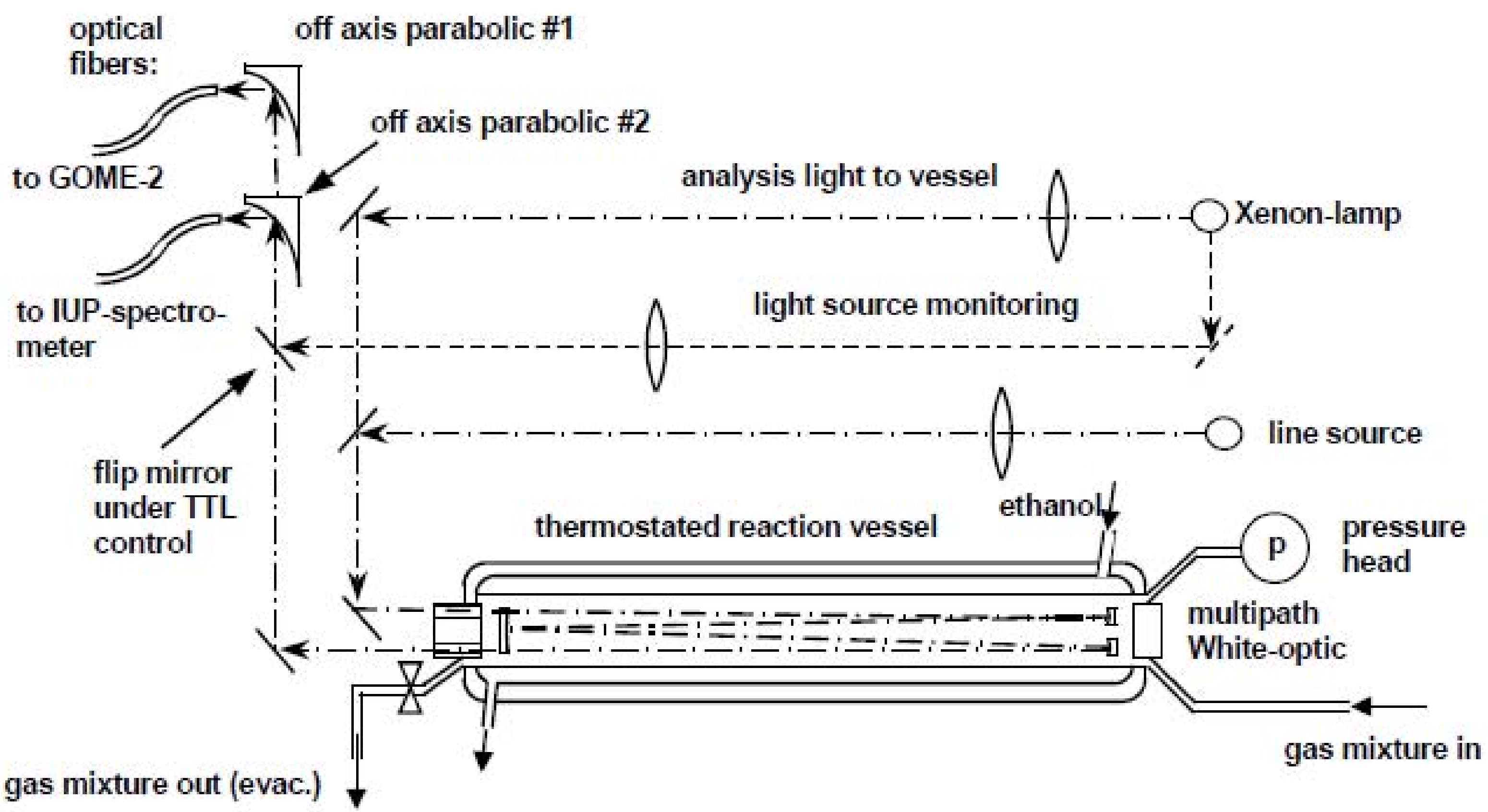
Dispersive elements: cross-dispersion

Advantages: combination of broad spectral region with high resolution

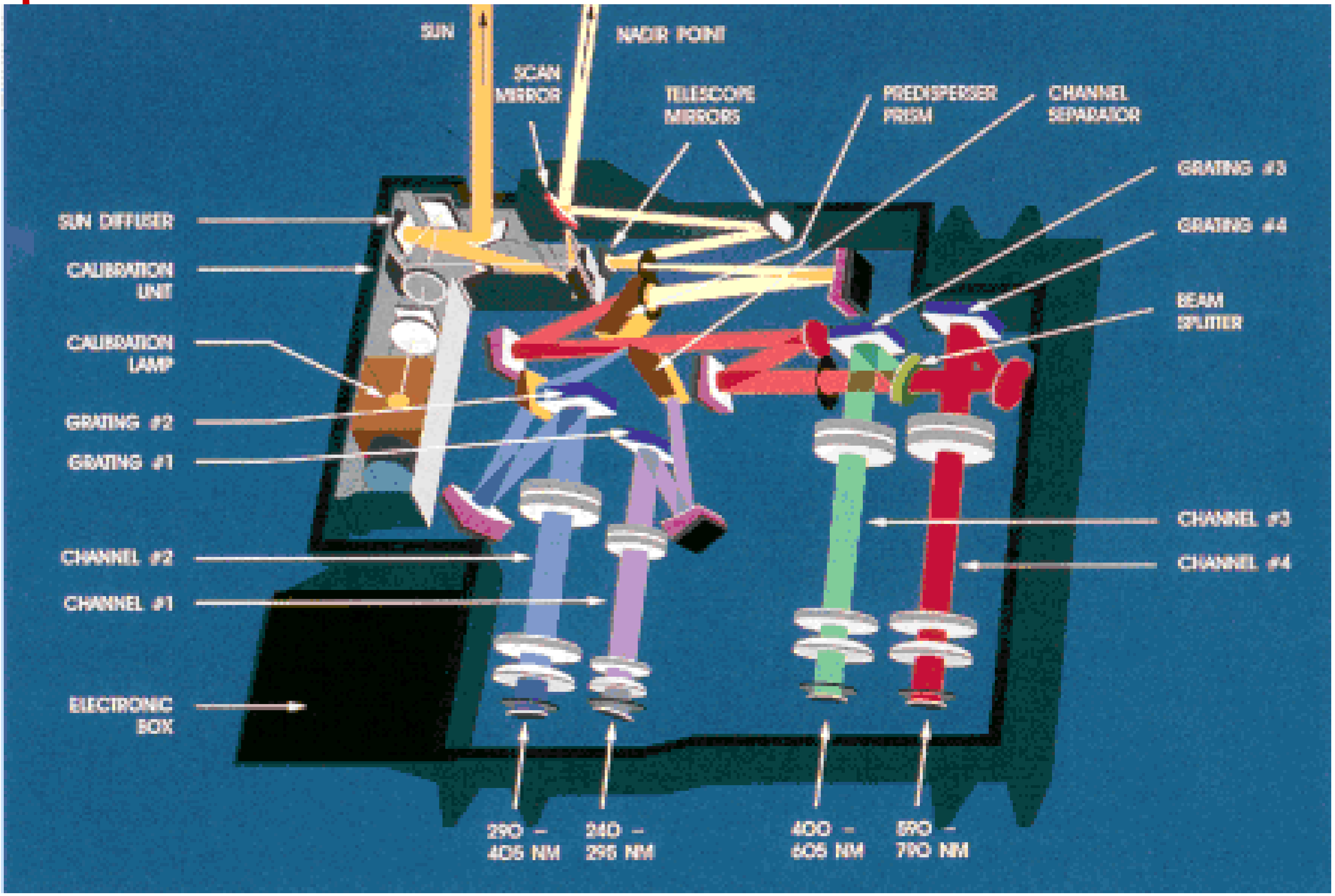




Experimental setup in the MolSpecLab

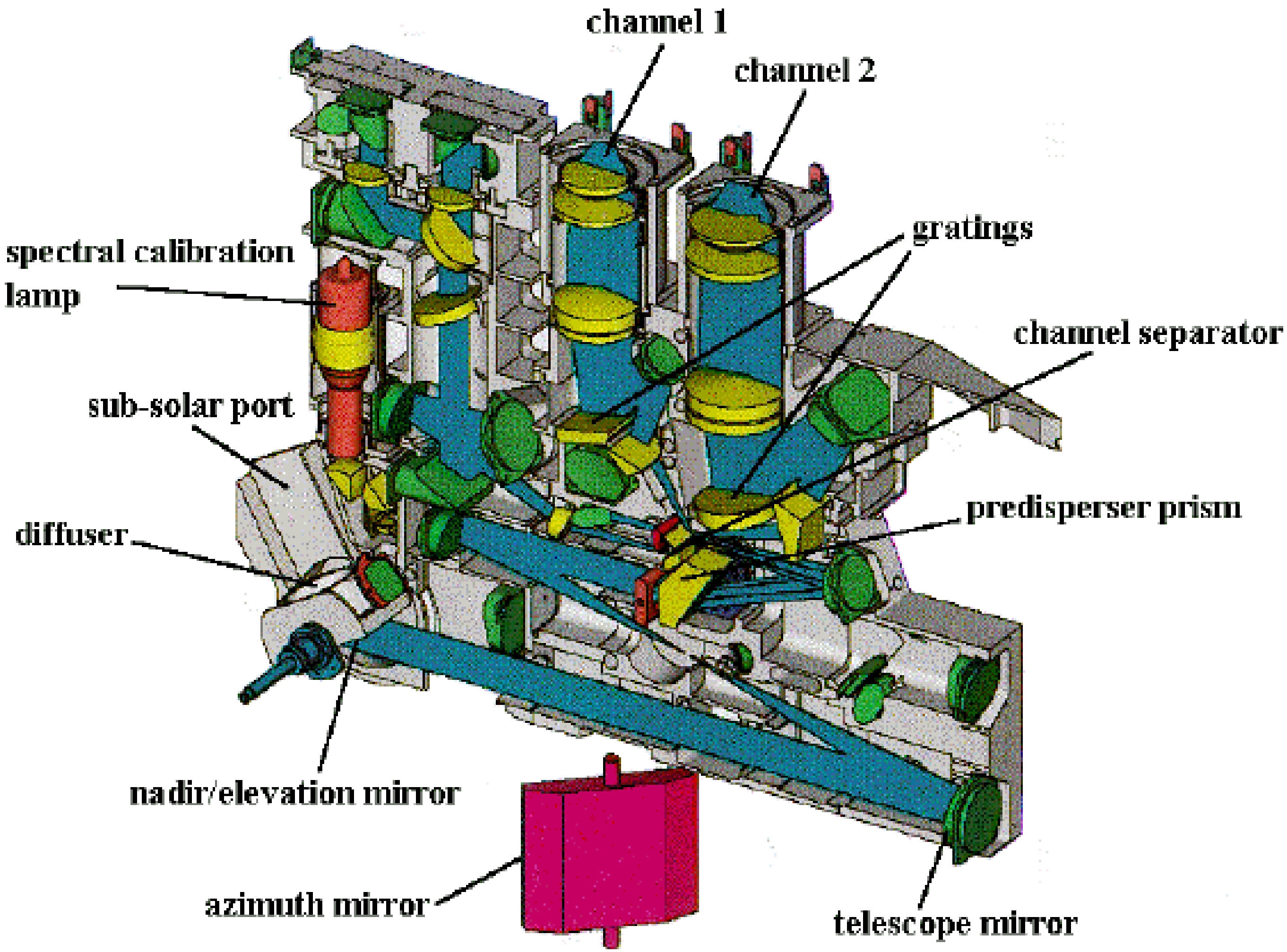


GOME: global ozone monitoring experiment



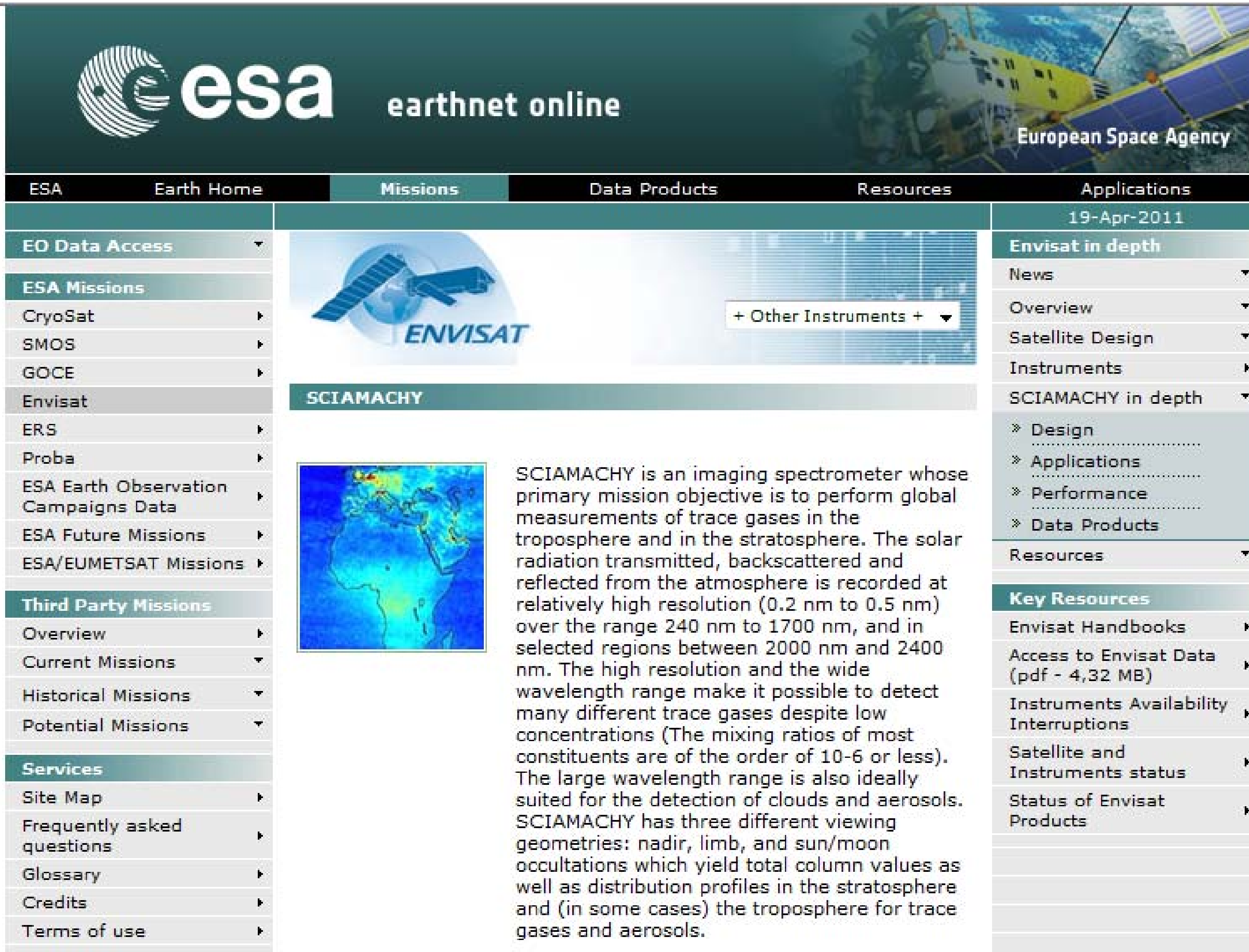
SCIAMACHY:

Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY



Satellite instruments

http://earth.esa.int/object/index.cfm?fobjectid=4004


esa earthnet online

European Space Agency

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19-Apr-2011

EO Data Access

ESA Missions
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- SMOS
- GOCE
- Envisat
- ERS
- Proba
- ESA Earth Observation Campaigns Data
- ESA Future Missions
- ESA/EUMETSAT Missions

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ENVISAT

+ Other Instruments +

SCIAMACHY

SCIAMACHY is an imaging spectrometer whose primary mission objective is to perform global measurements of trace gases in the troposphere and in the stratosphere. The solar radiation transmitted, backscattered and reflected from the atmosphere is recorded at relatively high resolution (0.2 nm to 0.5 nm) over the range 240 nm to 1700 nm, and in selected regions between 2000 nm and 2400 nm. The high resolution and the wide wavelength range make it possible to detect many different trace gases despite low concentrations (The mixing ratios of most constituents are of the order of 10-6 or less). The large wavelength range is also ideally suited for the detection of clouds and aerosols. SCIAMACHY has three different viewing geometries: nadir, limb, and sun/moon occultations which yield total column values as well as distribution profiles in the stratosphere and (in some cases) the troposphere for trace gases and aerosols.

Envisat in depth
- News
- Overview
- Satellite Design
- Instruments
- SCIAMACHY in depth
  - Design
  - Applications
  - Performance
  - Data Products
- Resources

Key Resources
- Envisat Handbooks
- Access to Envisat Data (pdf - 4,32 MB)
- Instruments Availability Interruptions
- Satellite and Instruments status
- Status of Envisat Products

Good luck!