The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization
IAEA International Atomic Energy Agency

2018-11

Winter College on Optics in Environmental Science

2 - 18 February 2009

Fundamentals of Optical Spectroscopy I

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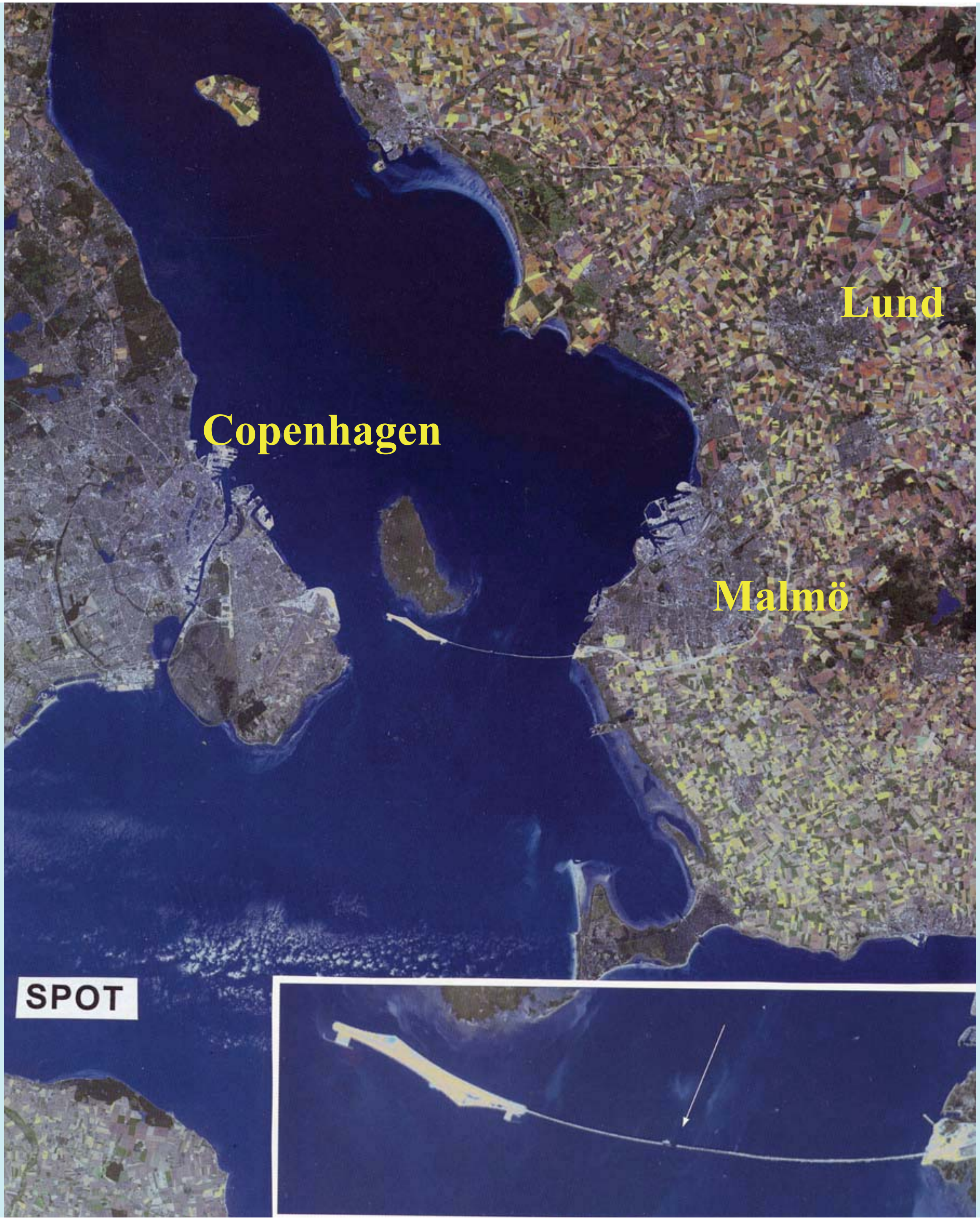
Lund Institute of Technology
Sweden

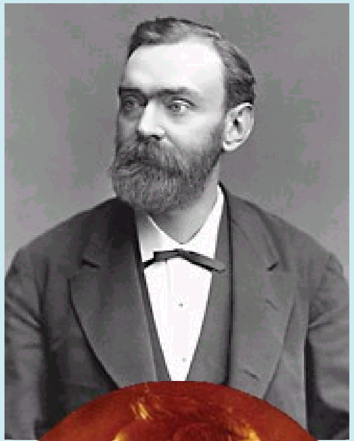
ICTP Winter School on Optics in Environmental Science 2009

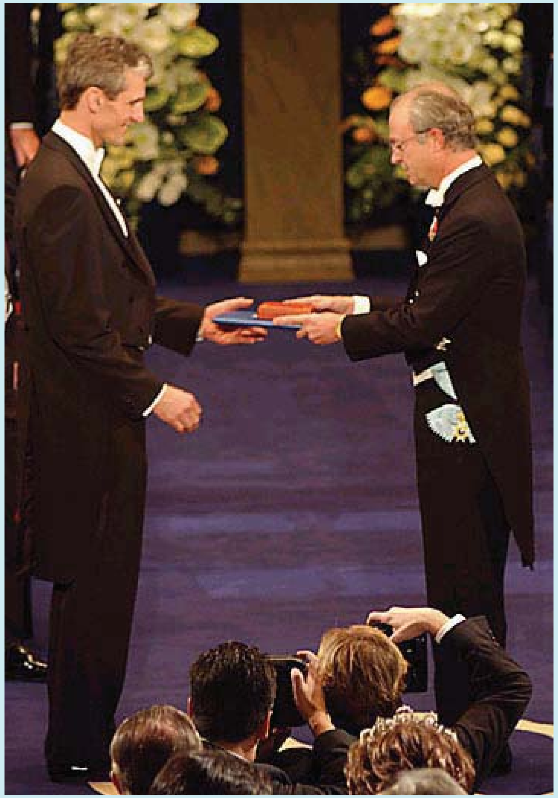
Fundamentals of Optical Spectroscopy
Part 1

Sune Svanberg
Lund Laser Centre, Lund University
Sweden


Lund
Copenhagen
Malmö
SPOT

Spectroscopy and Laser-Related Nobel Prizes



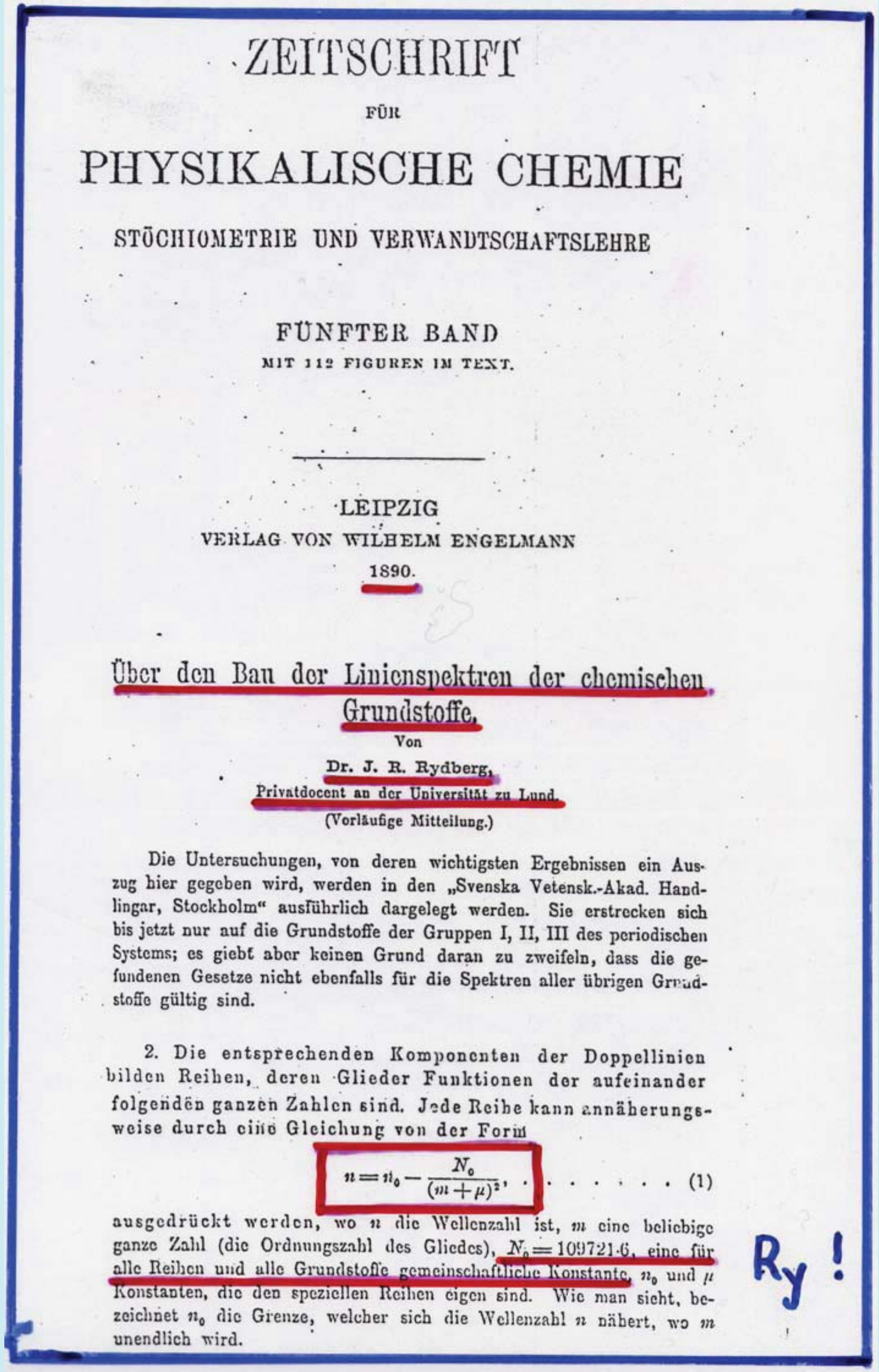


2001

Physics Ceremony

"…. On behalf of the Royal Swedish Academy of Sciences, I wish to congratulate you on your great accomplishments. now ask you to step forward to receive your Nobel Prizes from the hands of His Majesty the King".

J. Rydberg Memorial
1854-2004



ZEITSCHRIFT

FÜR

PHYSIKALISCHE CHEMIE

STÖCHIOMETRIE UND VERWANDTSCHAFTSLEHRE

FÜNFTER BAND

MIT 112 FIGUREN IM TEXT.

LEIPZIG
VERLAG VON WILHELM ENGELMANN
1890.

Über den Bau der Linienspektren der chemischen Grundstoffe.

Von

Dr. J. R. Rydberg,
Privatdocent an der Universität zu Lund.

(Vorläufige Mitteilung.)

Die Untersuchungen, von deren wichtigsten Ergebnissen ein Auszug hier gegeben wird, werden in den „Svenska Vetensk.-Akad. Handlingar, Stockholm" ausführlich dargelegt werden. Sie erstrecken sich bis jetzt nur auf die Grundstoffe der Gruppen I, II, III des periodischen Systems; es giebt aber keinen Grund daran zu zweifeln, dass die gefundenen Gesetze nicht ebenfalls für die Spektren aller übrigen Grundstoffe gültig sind.

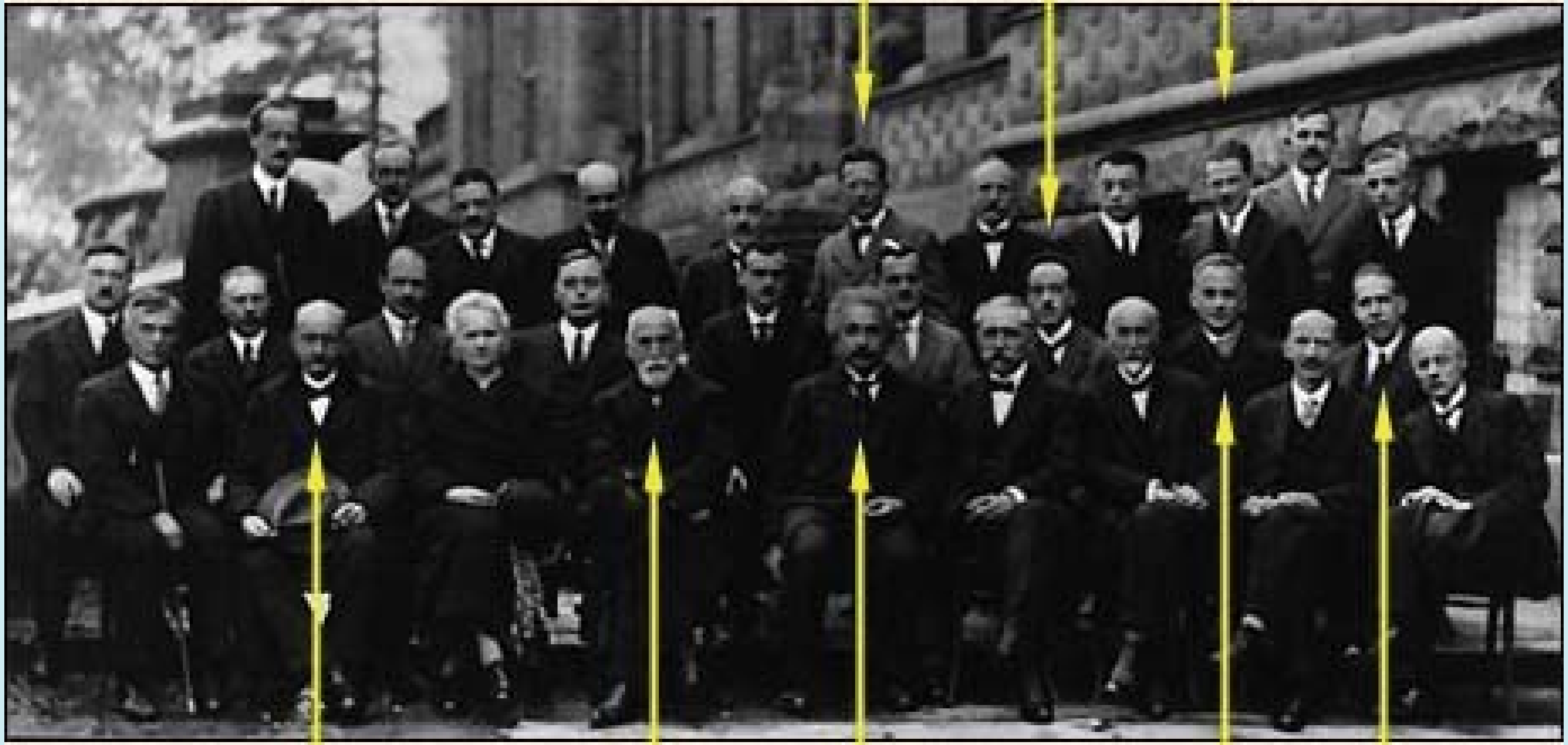
2. Die entsprechenden Komponenten der Doppellinien bilden Reihen, deren Glieder Funktionen der aufeinander folgenden ganzen Zahlen sind. Jede Reihe kann annäherungsweise durch eine Gleichung von der Form

$$n = n_0 - \frac{N_0}{(m+\mu)^2}, \qquad (1)$$

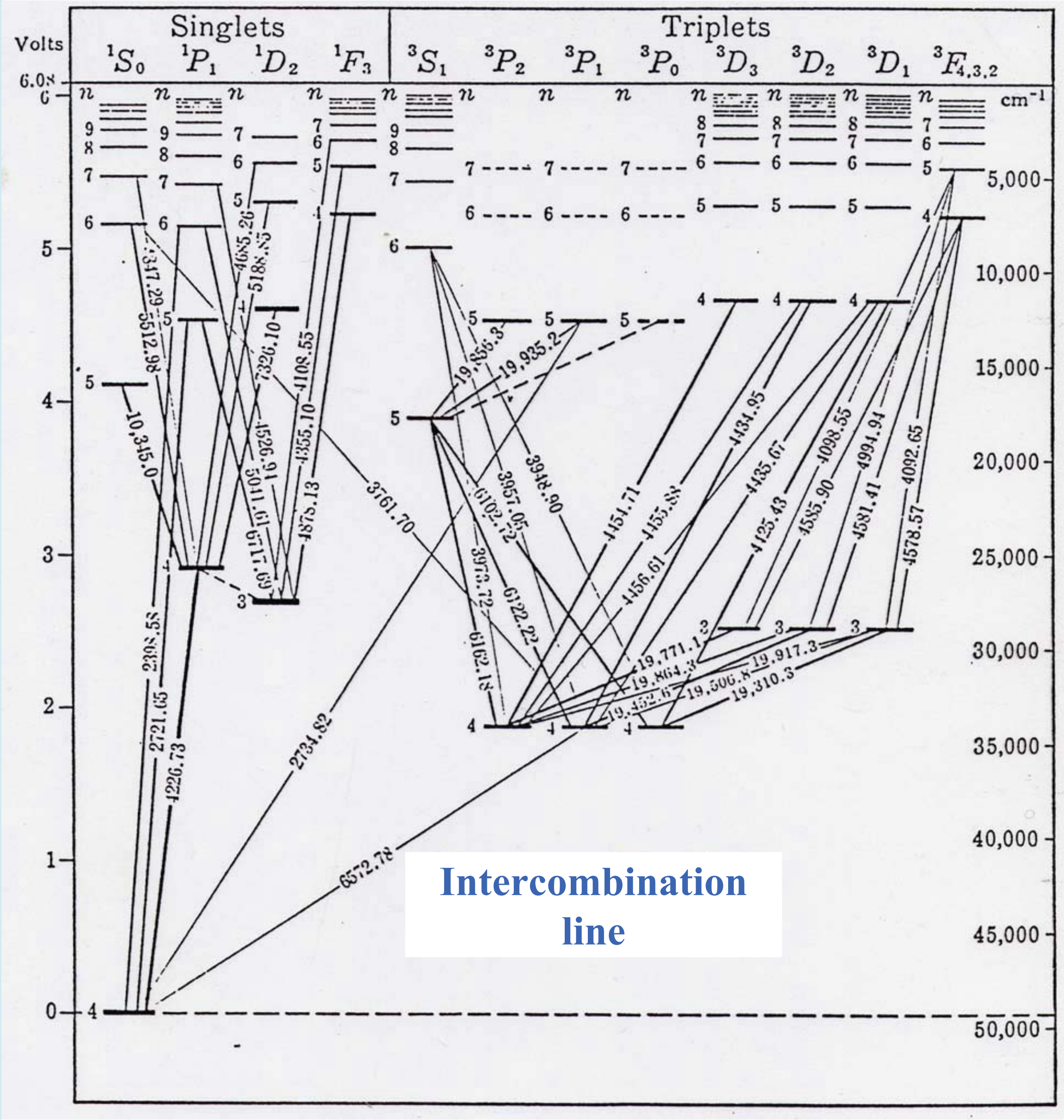
ausgedrückt werden, wo n die Wellenzahl ist, m eine beliebige ganze Zahl (die Ordnungszahl des Gliedes), $N_0 = 109721{\cdot}6$, eine für alle Reihen und alle Grundstoffe gemeinschaftliche Konstante, n_0 und μ Konstanten, die den speziellen Reihen eigen sind. Wie man sieht, bezeichnet n_0 die Grenze, welcher sich die Wellenzahl n nähert, wo m unendlich wird.

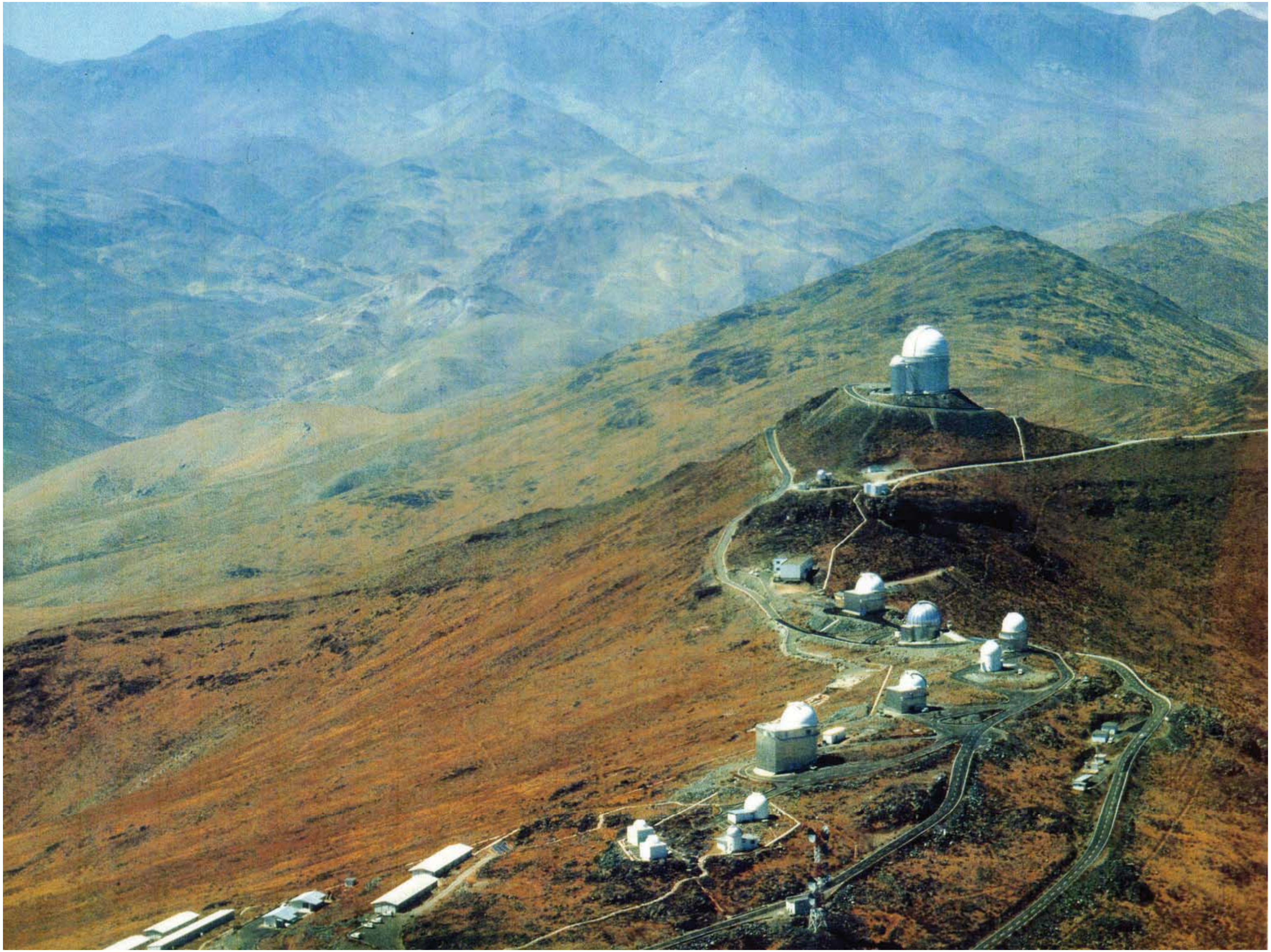
Ry !

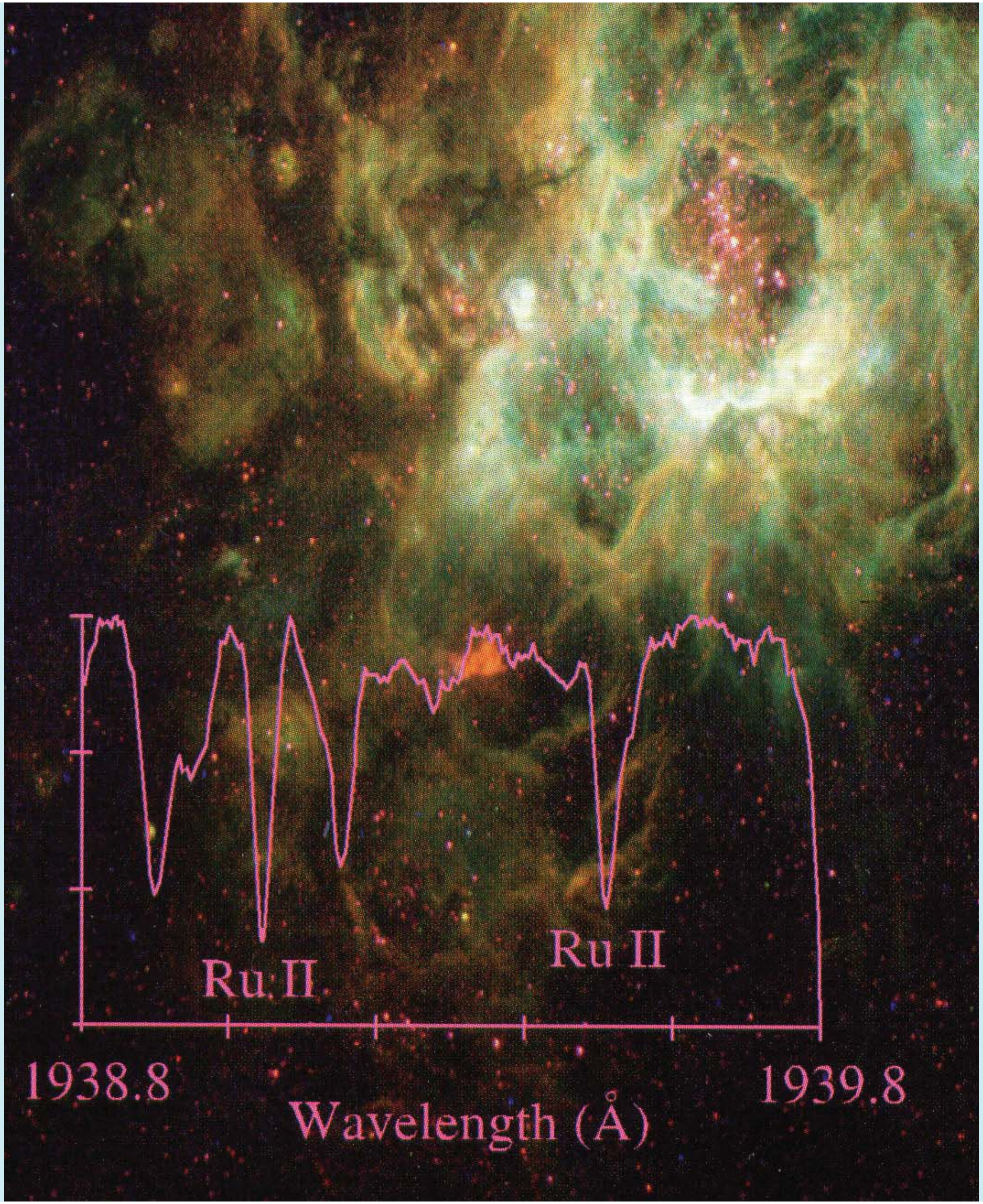
The Solvay Congress of 1927



Calcium

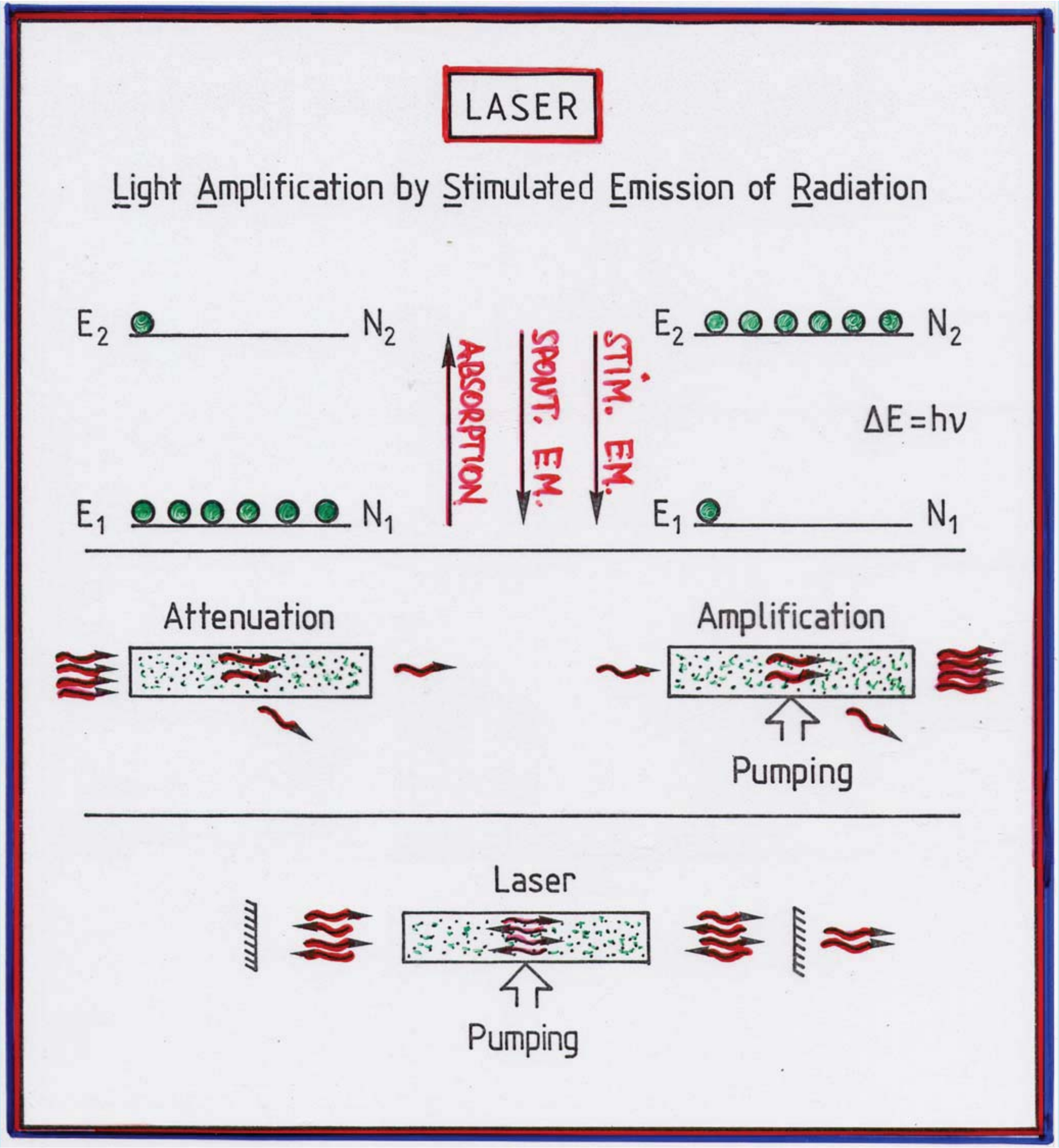

Singlets
Triplets
Volts
$^1S_0$ $^1P_1$ $^1D_2$ $^1F_3$
$^3S_1$ $^3P_2$ $^3P_1$ $^3P_0$ $^3D_3$ $^3D_2$ $^3D_1$ $^3F_{4,3,2}$
cm^{-1}
6.08
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000
6572.78
4226.73
2734.82
Intercombination line

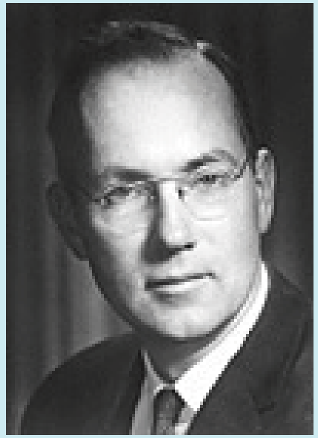


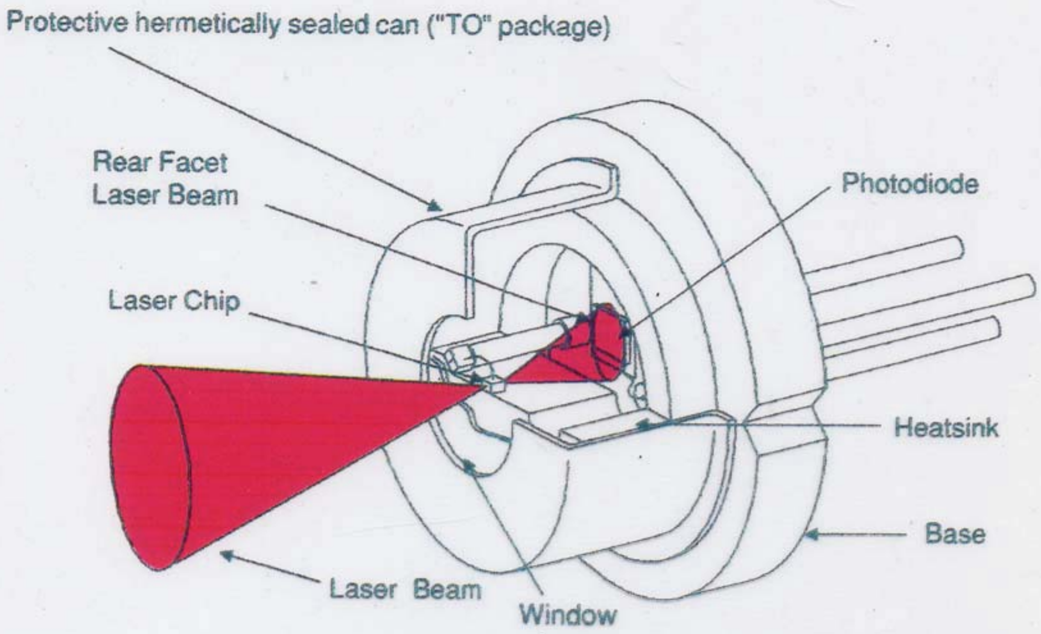


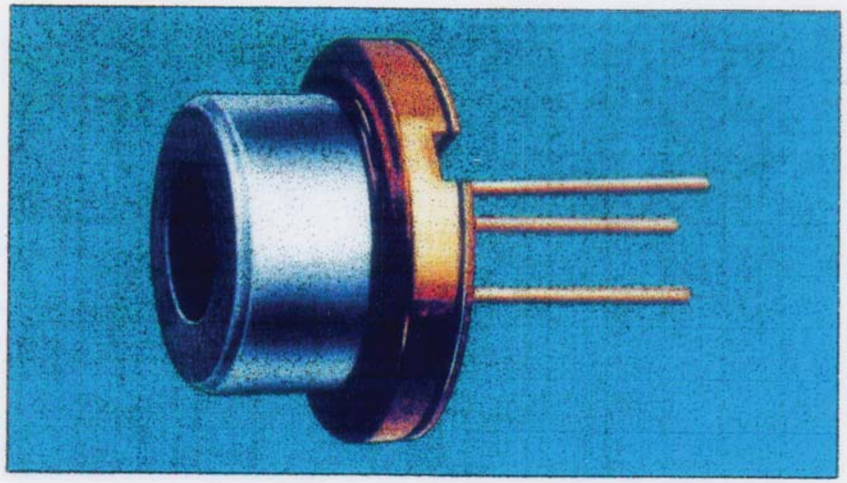
Ru II
Ru II
1938.8
1939.8
Wavelength (Å)

Stimulated emission (Einstein 1917)

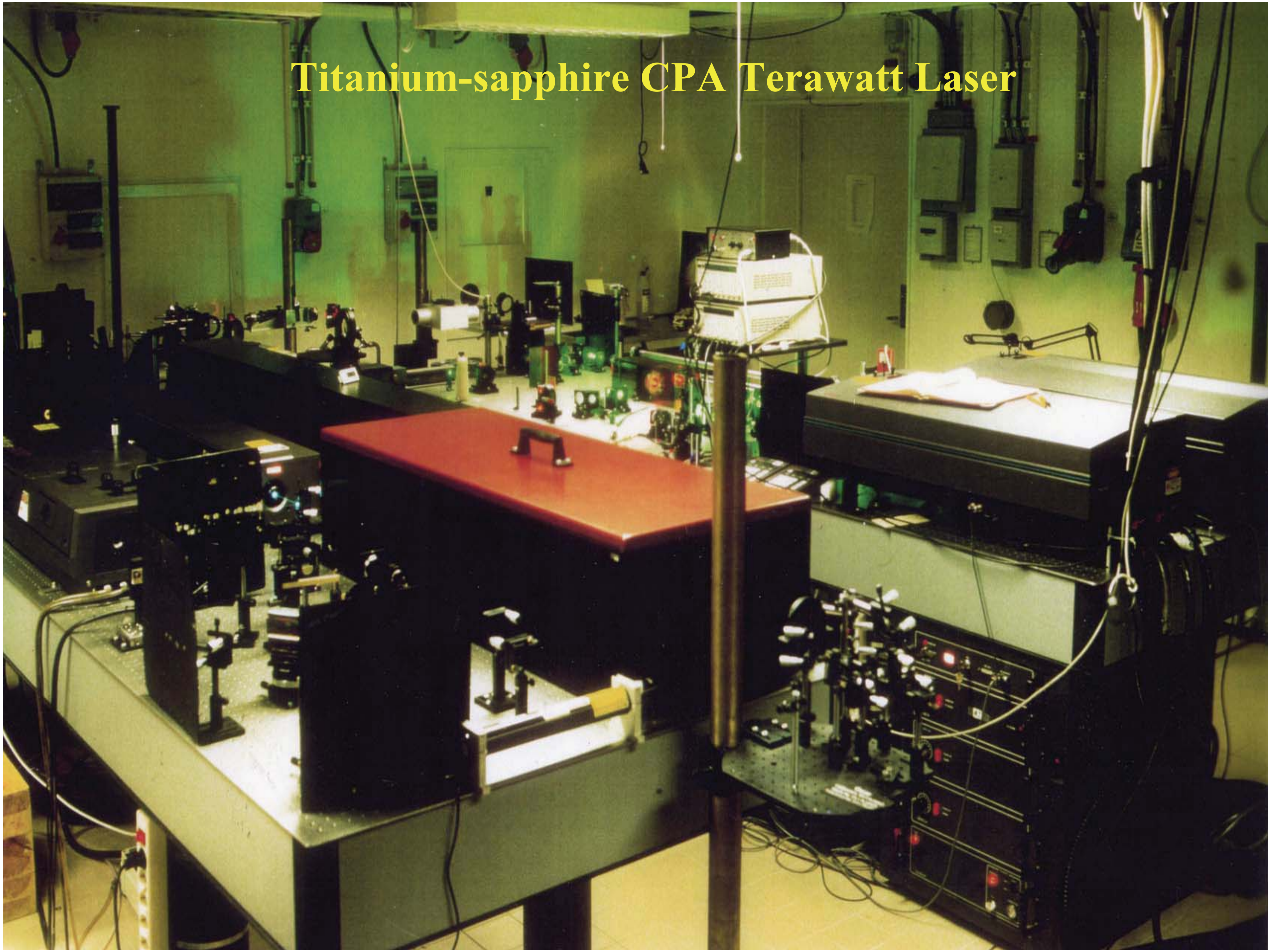




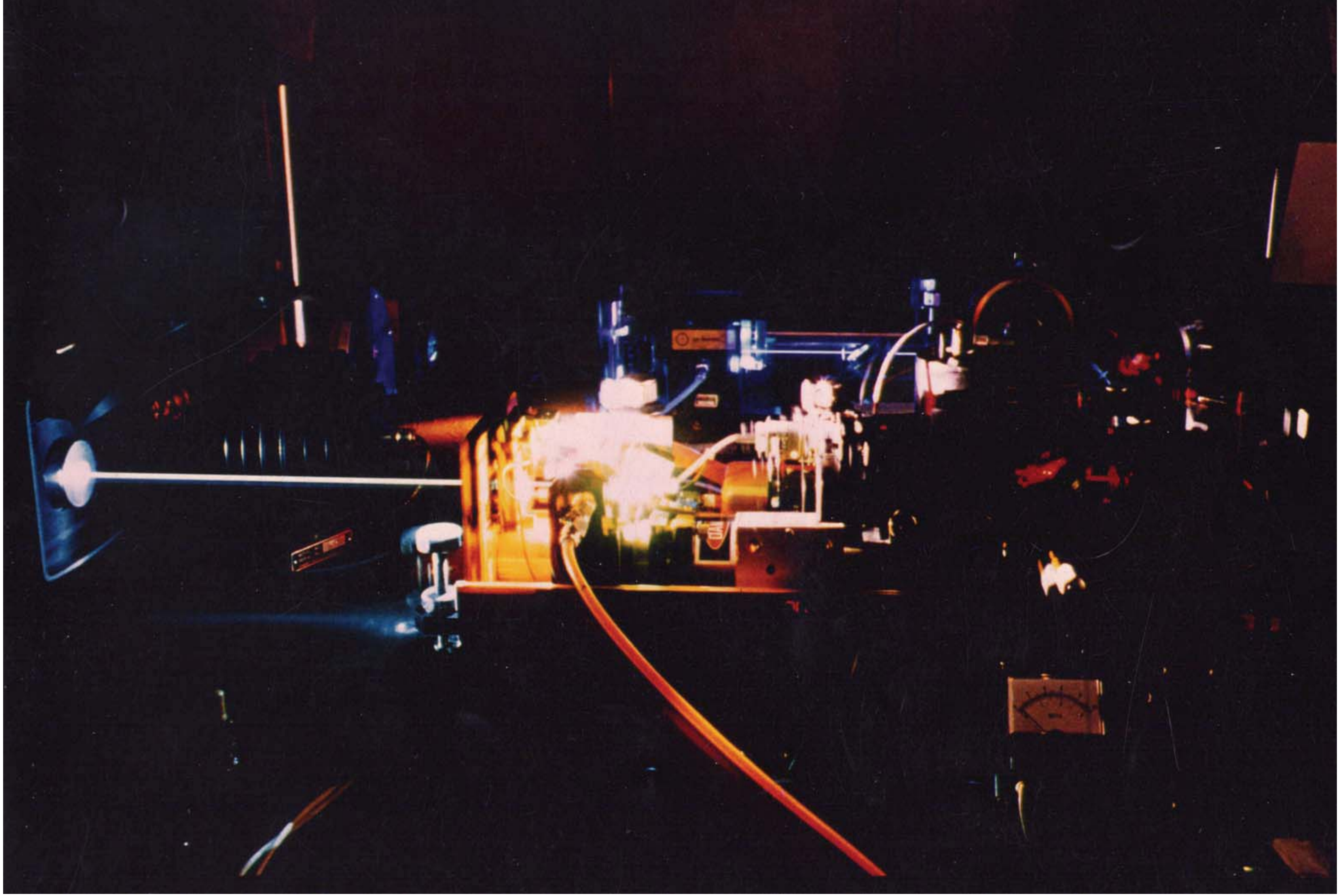




A typical compact disc style laser diode.

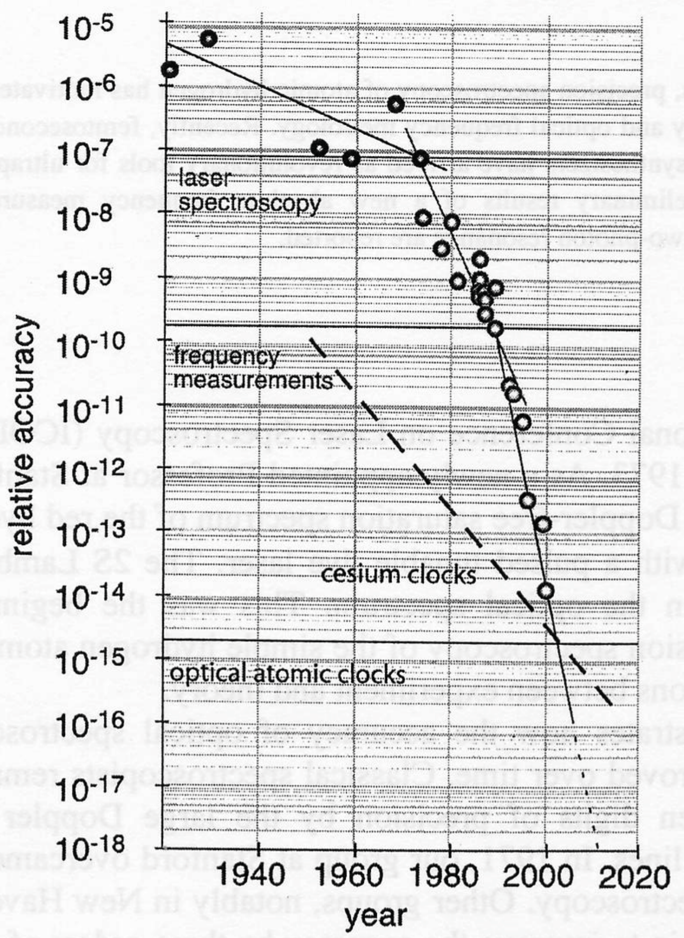

Titanium-sapphire CPA Terawatt Laser

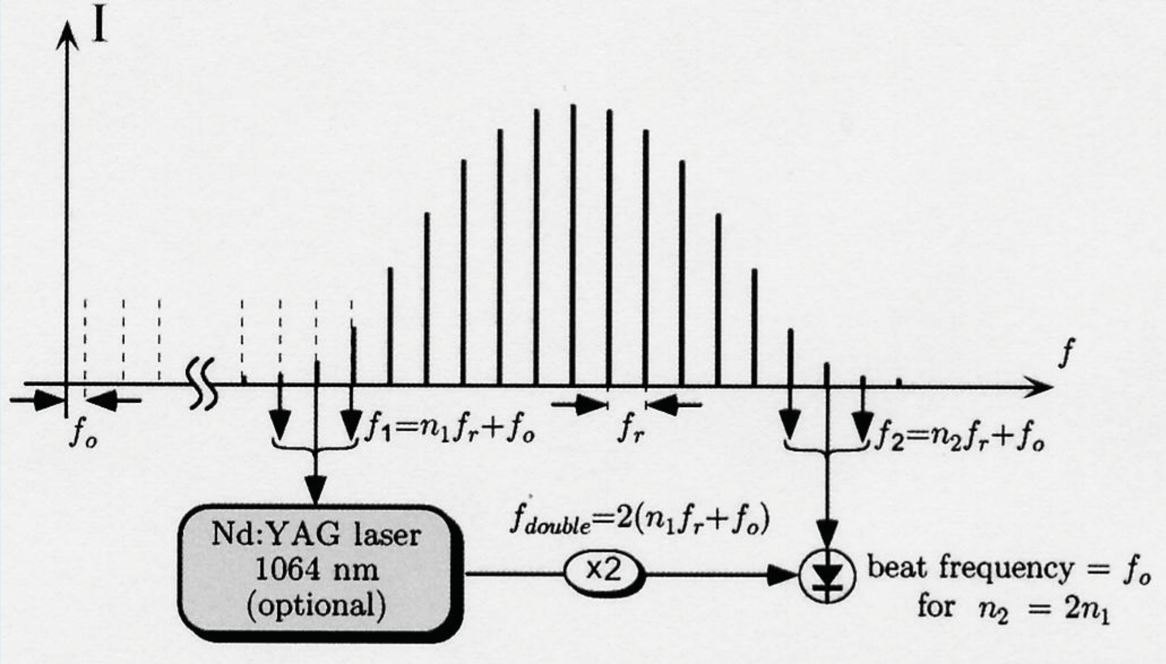
Dye lasers pumped by Ar-ion lasers



Precision spectroscopy with lasers

Optical clocks
Frequency comb technique



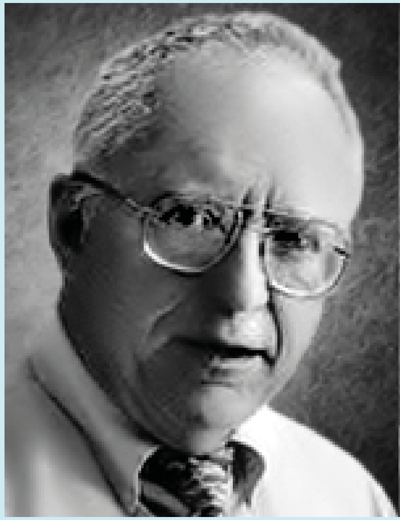


Rydberg constant: f(m,e,h,c)

Fine structure constant: f(e,h,c)

Anti-hydrogen ↔ Hydrogen

Glauber

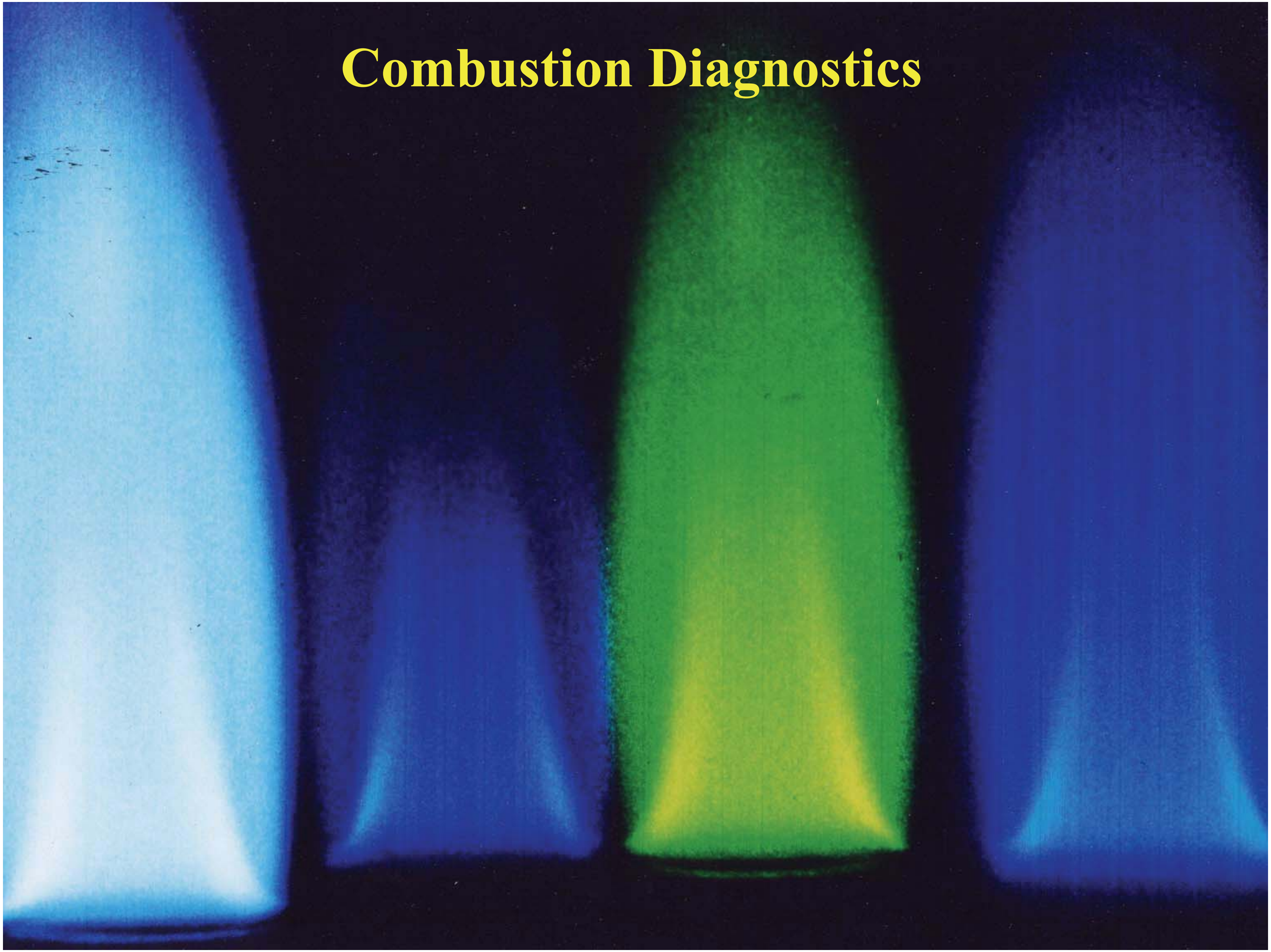


Hall

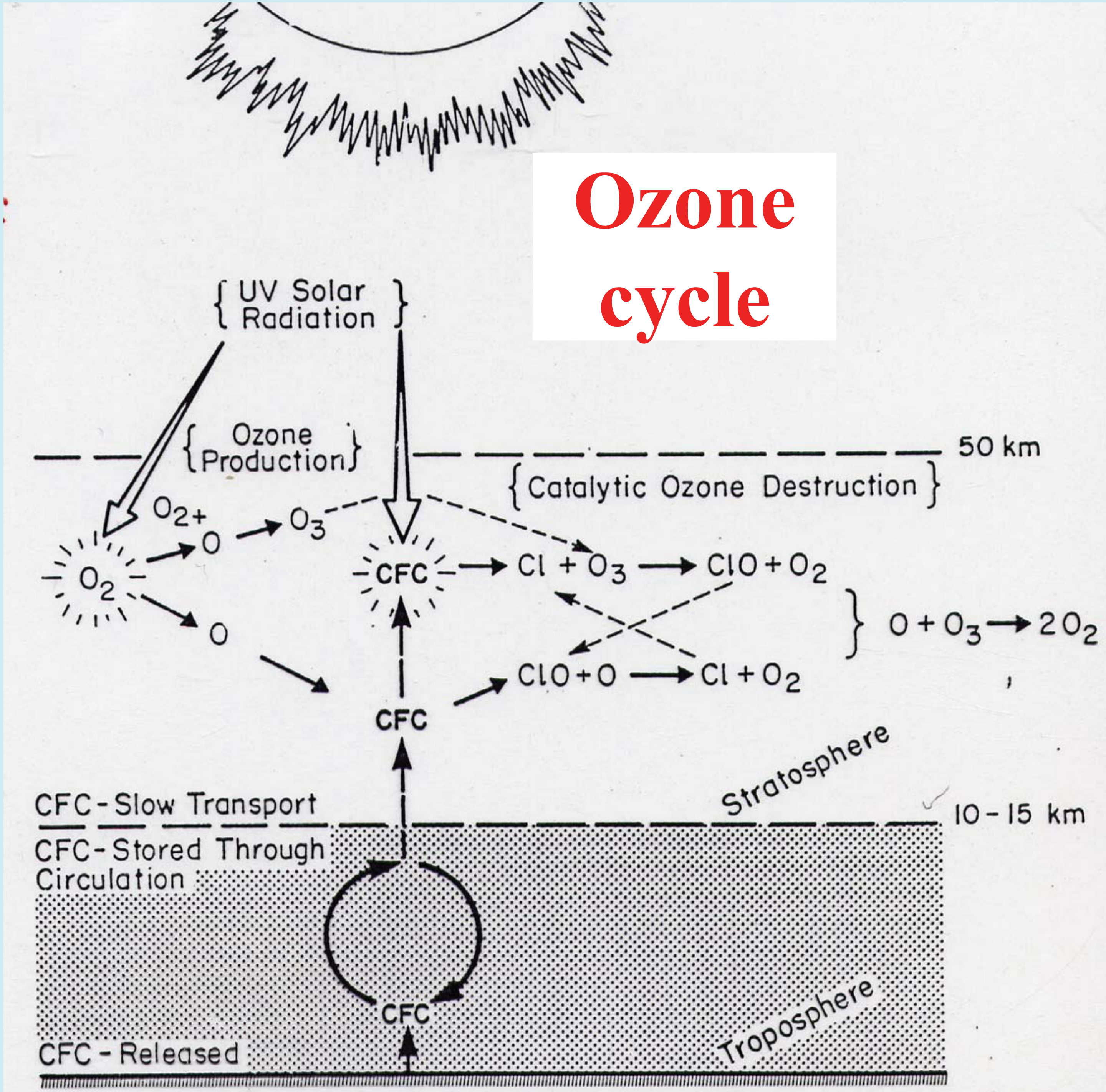
Hänsch

Nobel Prize in Physics 2005

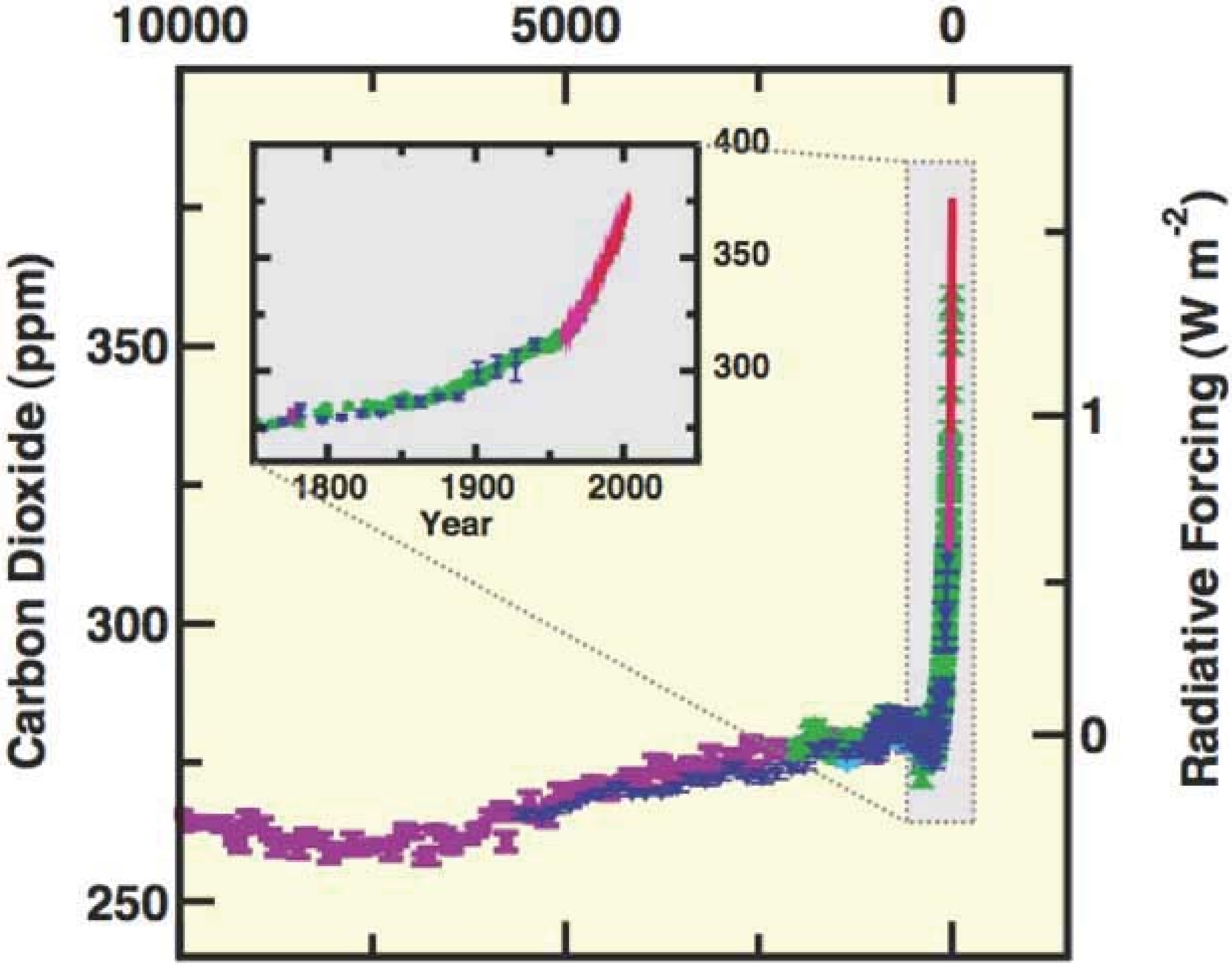
Combustion Diagnostics



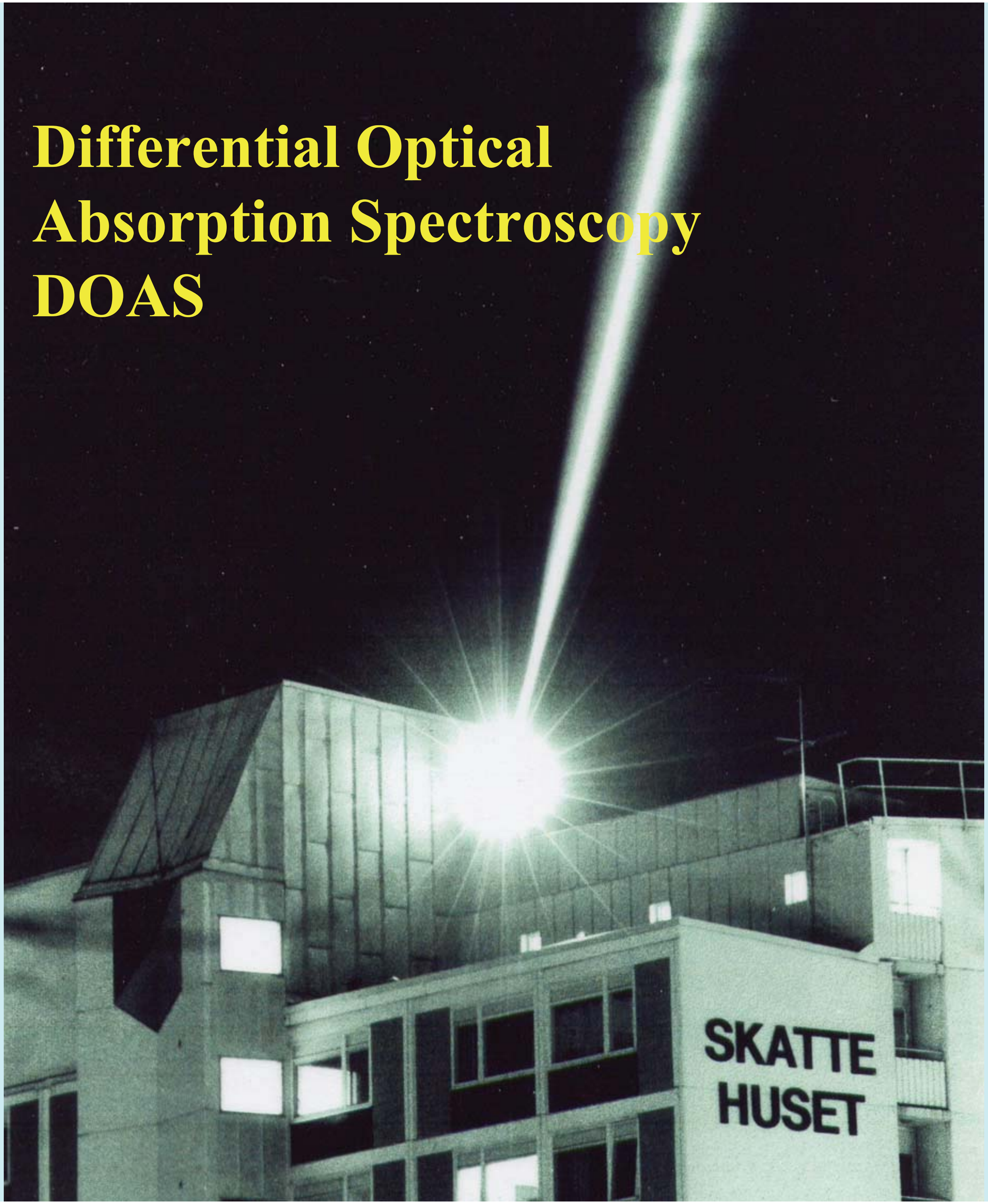
Ozone cycle


UV Solar Radiation
Ozone Production
50 km
Catalytic Ozone Destruction
O2+
O
O3
O2
O
CFC
Cl + O3
ClO + O2
ClO+O
Cl + O2
O + O3 → 2O2
CFC
CFC - Slow Transport
Stratosphere
10 - 15 km
CFC - Stored Through Circulation
CFC
CFC - Released
Troposphere

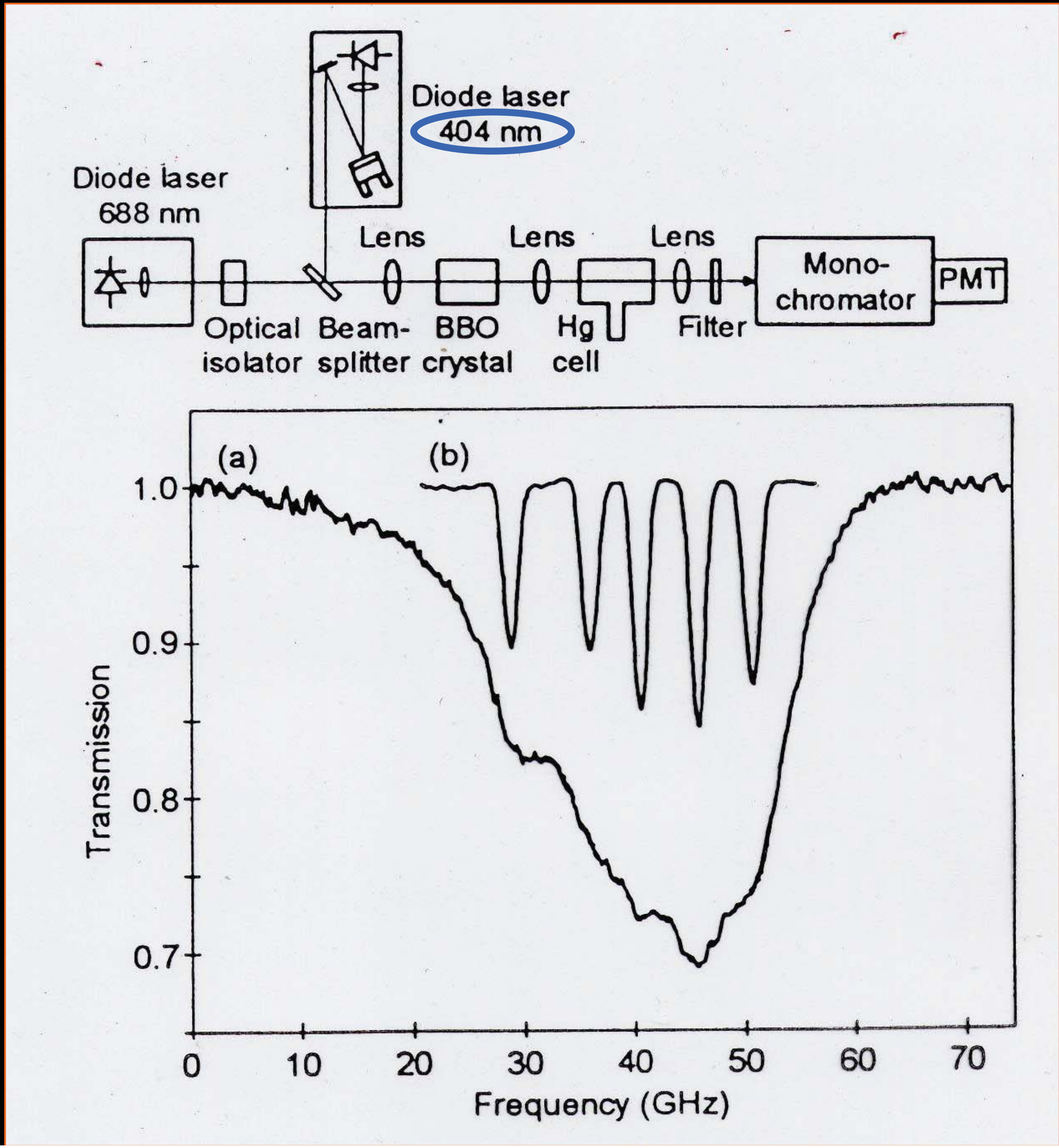
Atmospheric carbon dioxide development



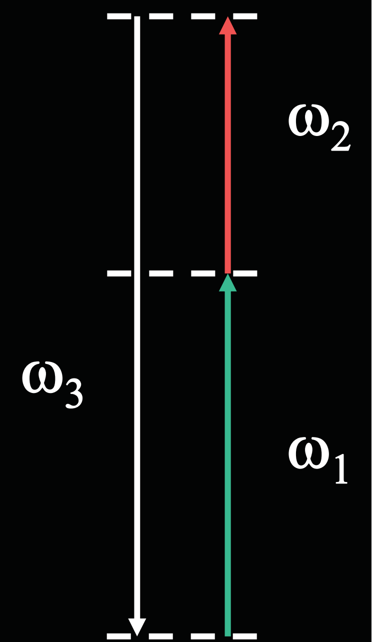
Differential Optical Absorption Spectroscopy DOAS



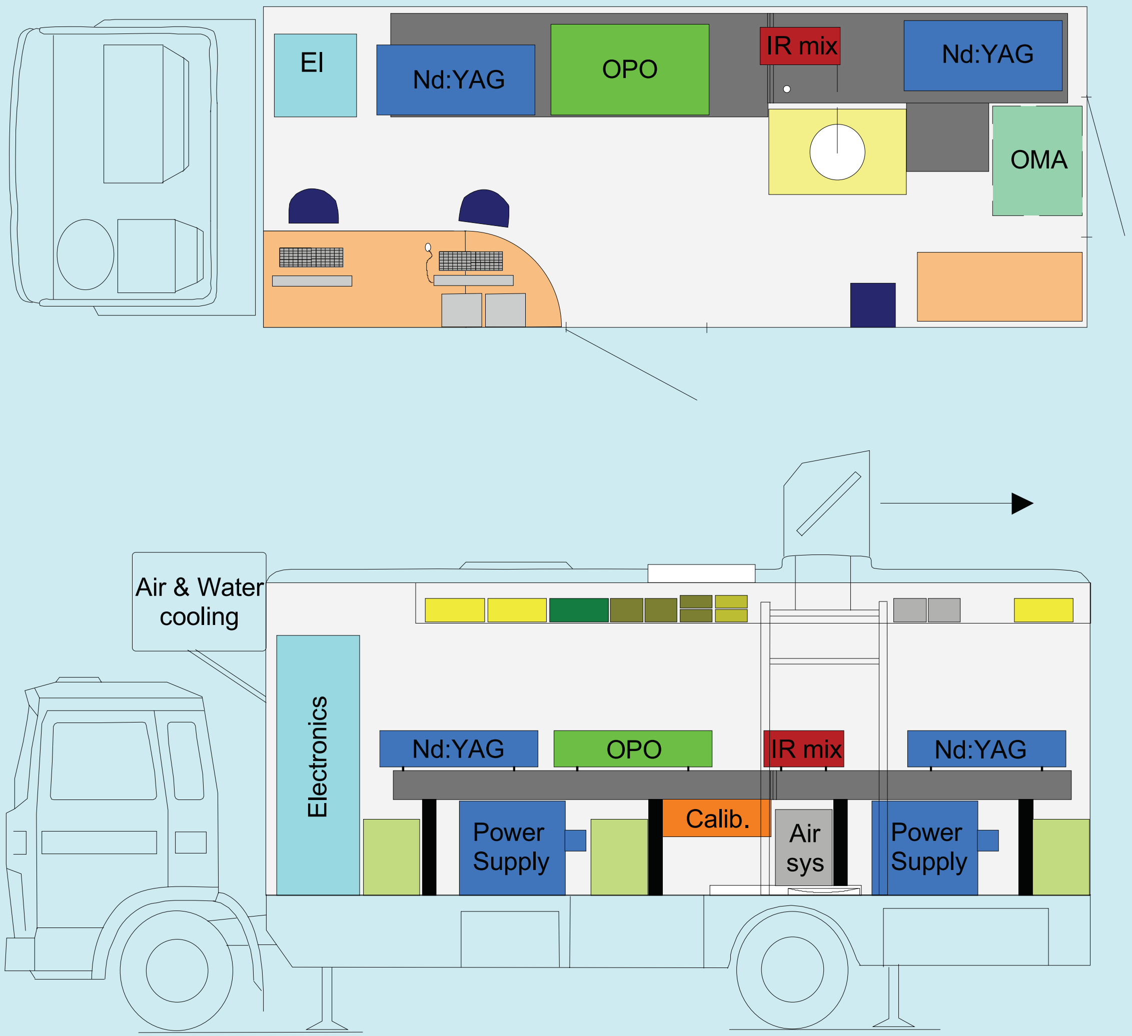
Sum-frequency generation to 254 nm: Hg



$$\omega_3 = \omega_1 + \omega_2$$

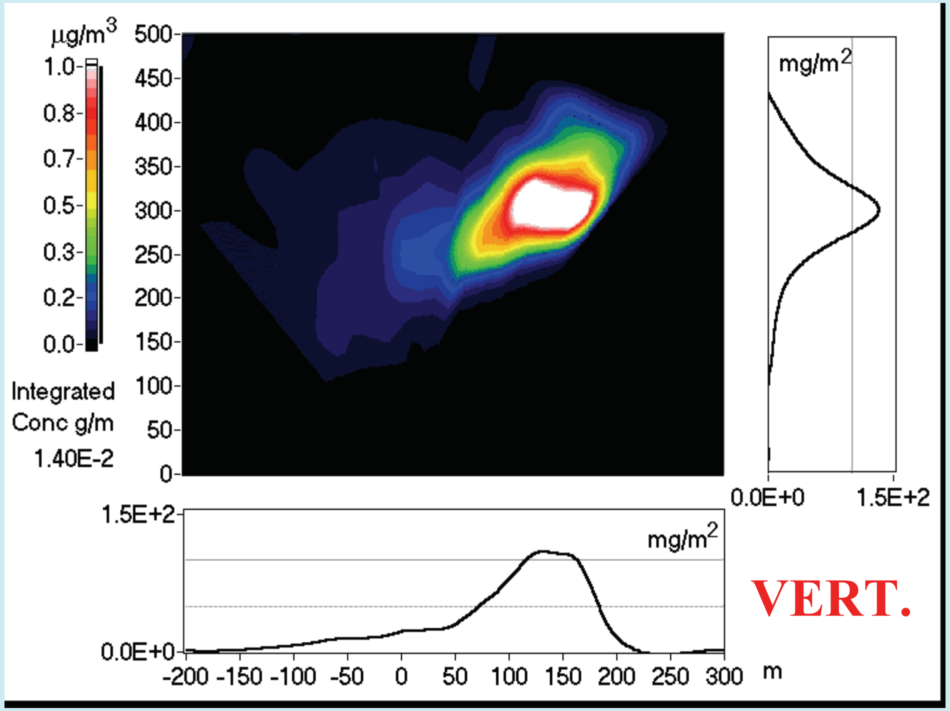


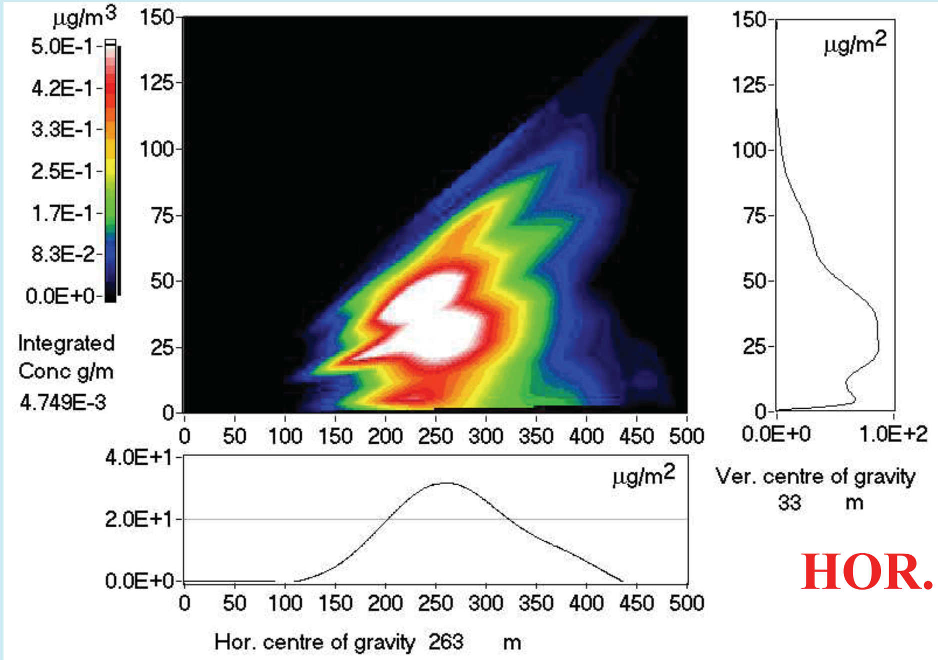
Lund mobile Lidar system



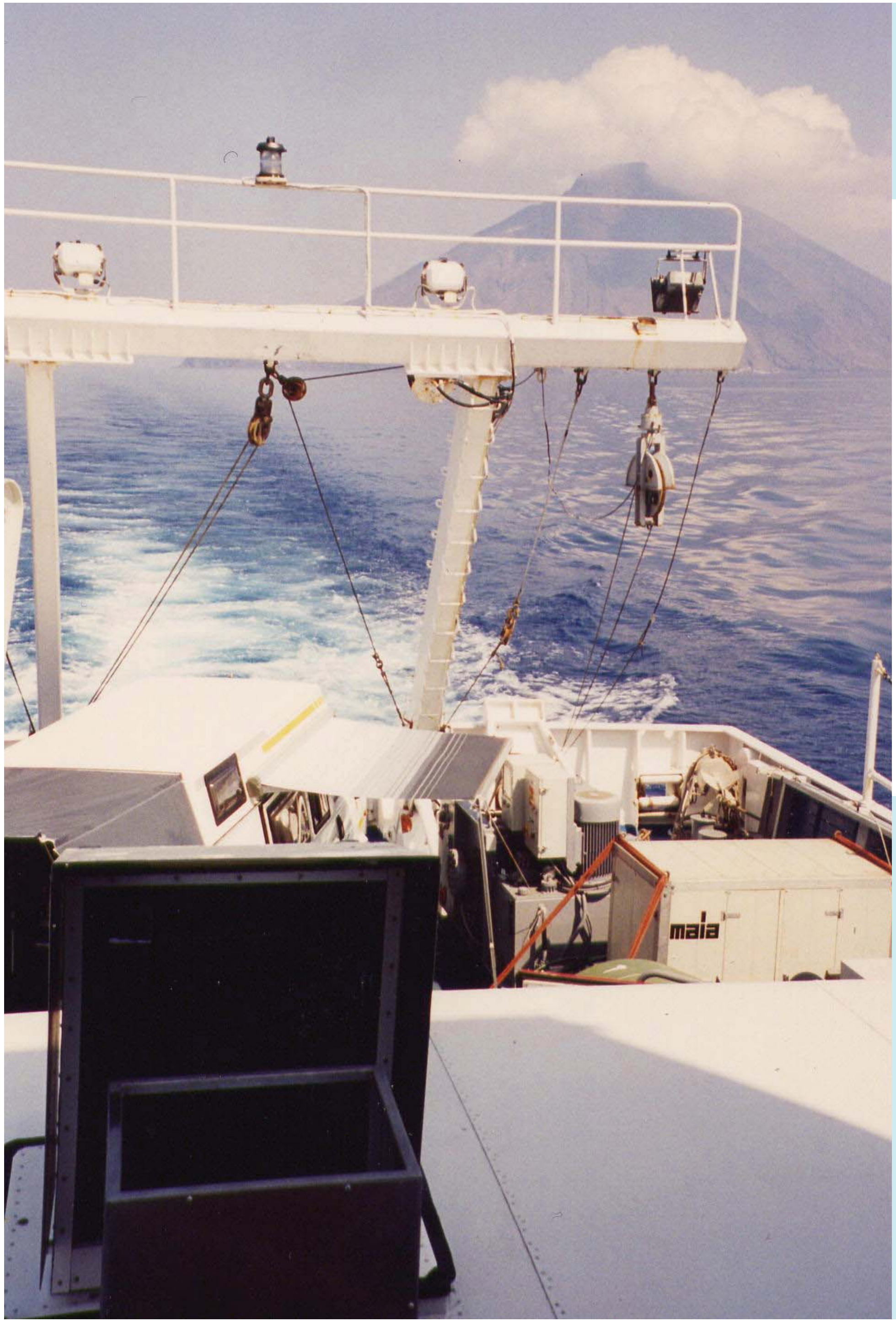
Atomic Mercury Lidar Mapping and Flux Measurement

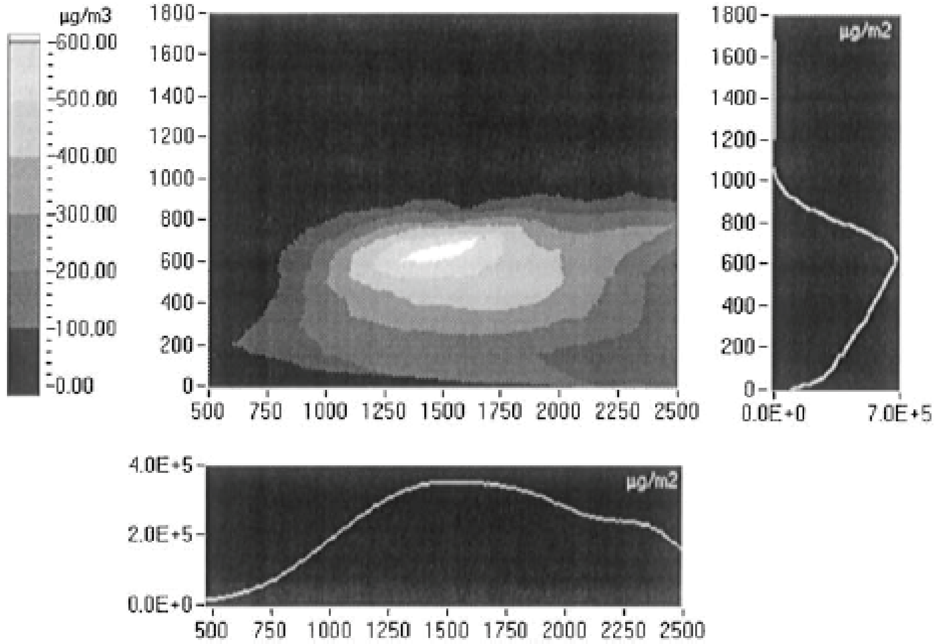
Rosignano Solvay, Italy

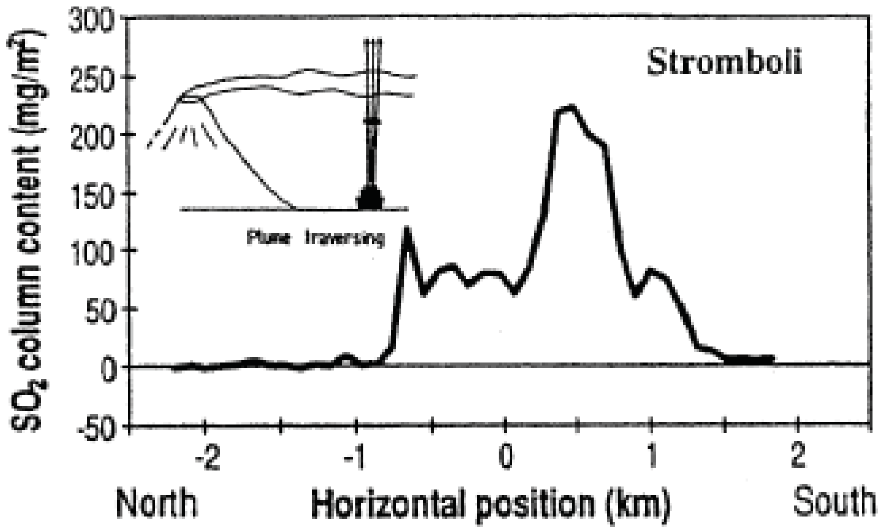




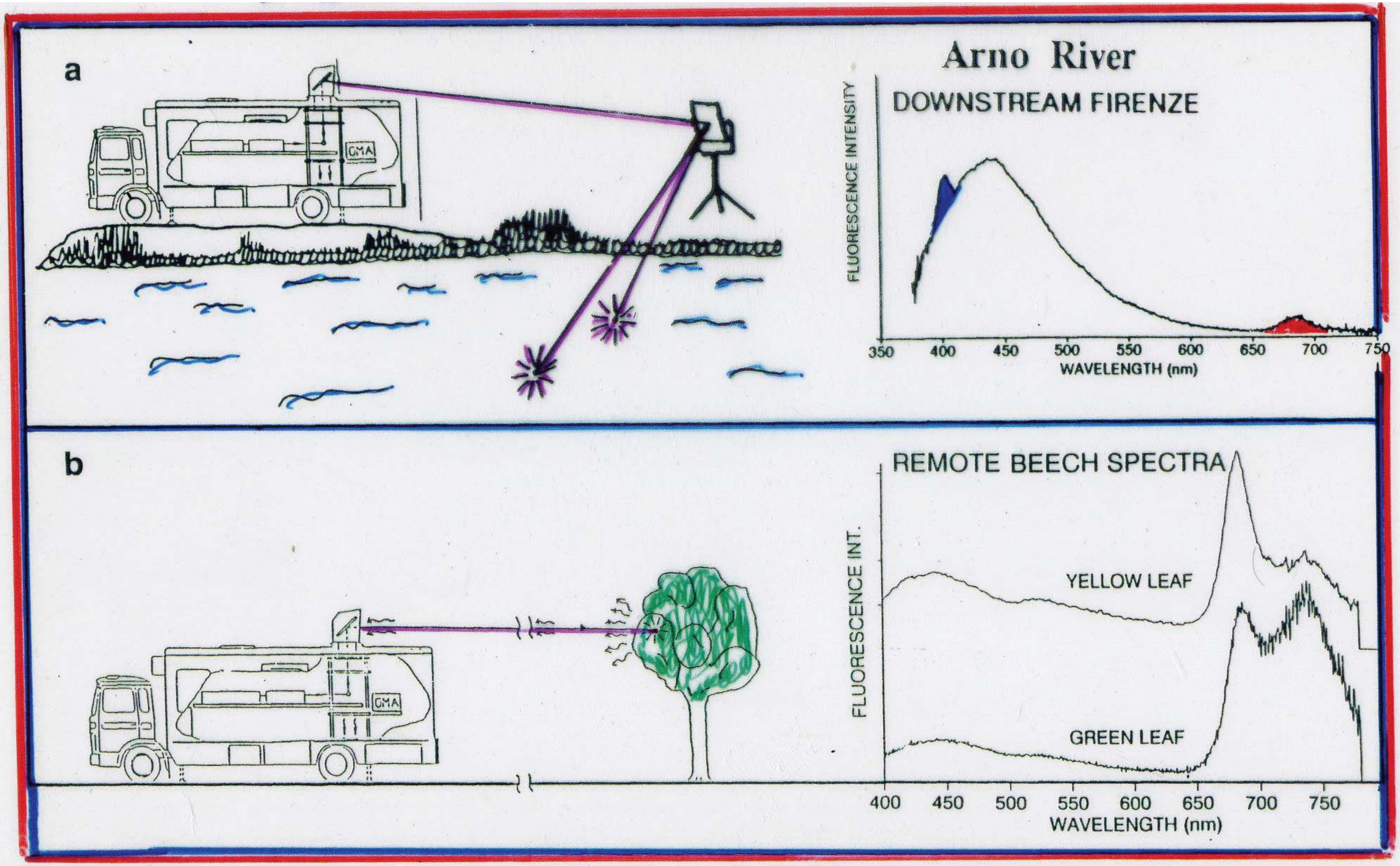
Lidar monitoring of SO_2 at Stromboli

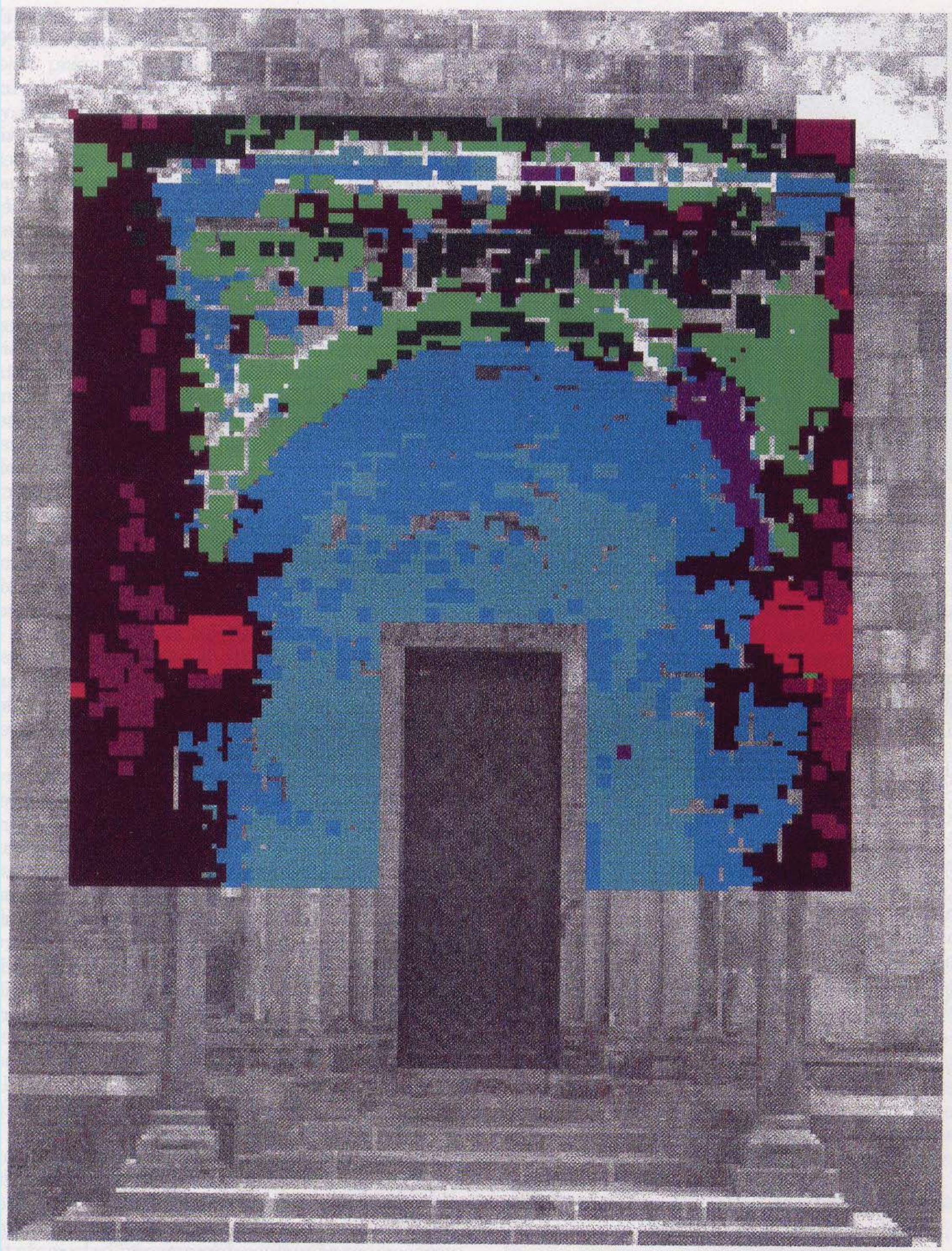






LIDAR REMOTE FLUORESCENCE MONITORING

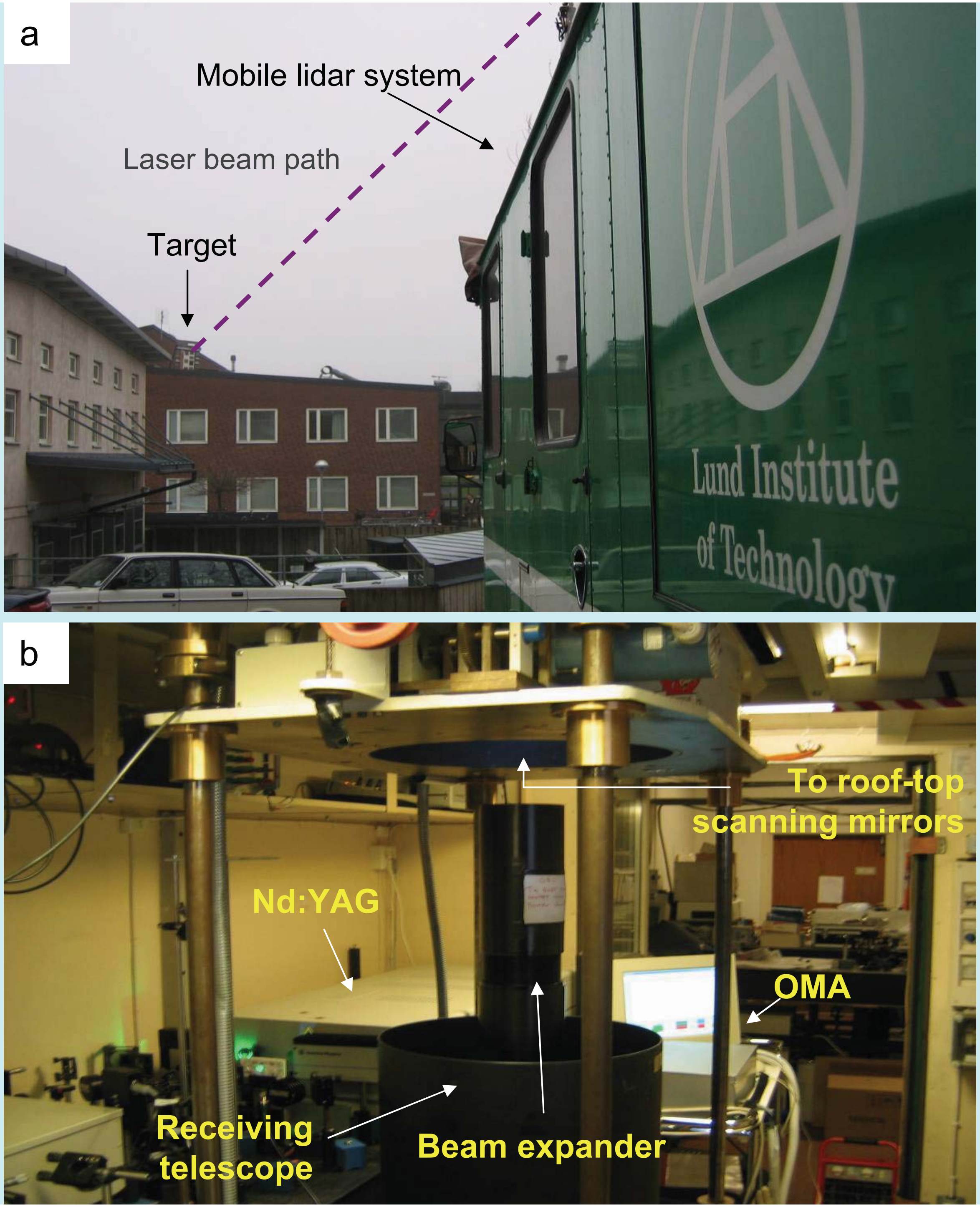




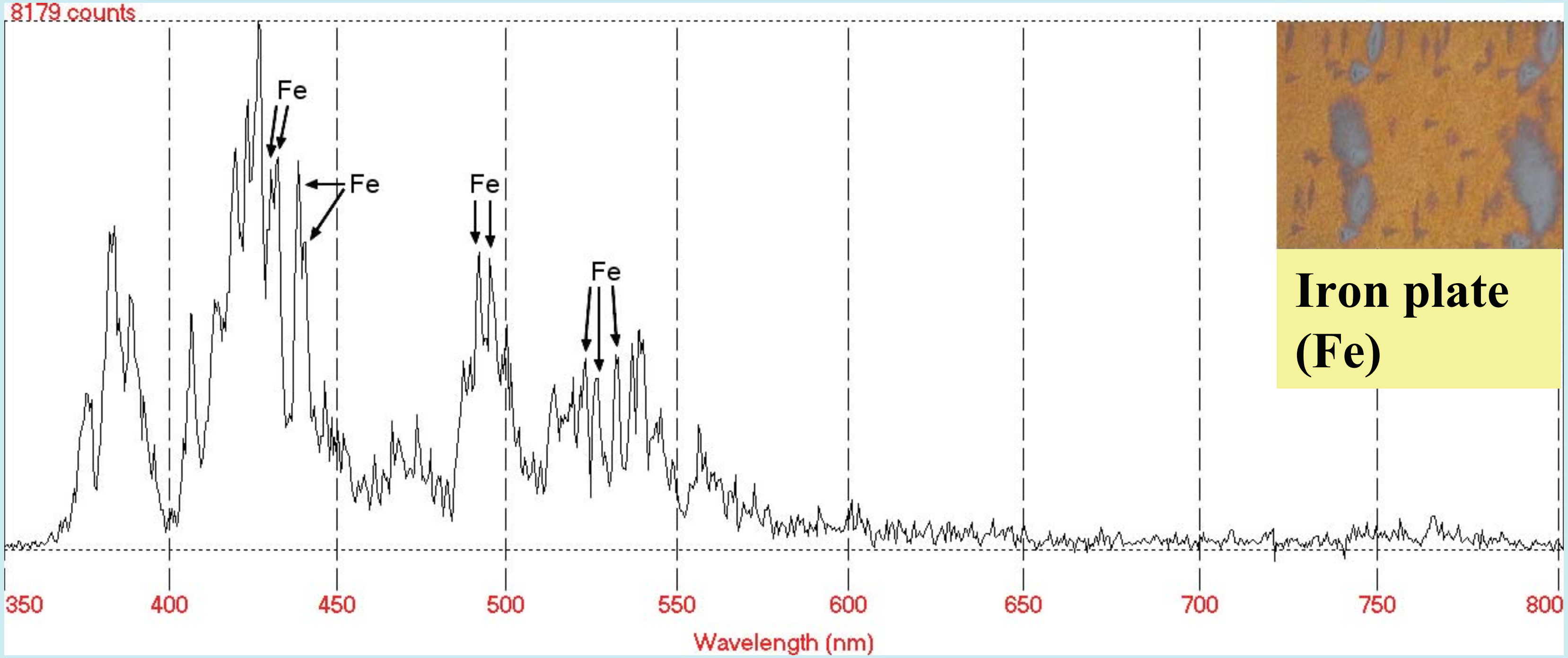
Multi-variate spectral analysis classifies areas

REMOTE

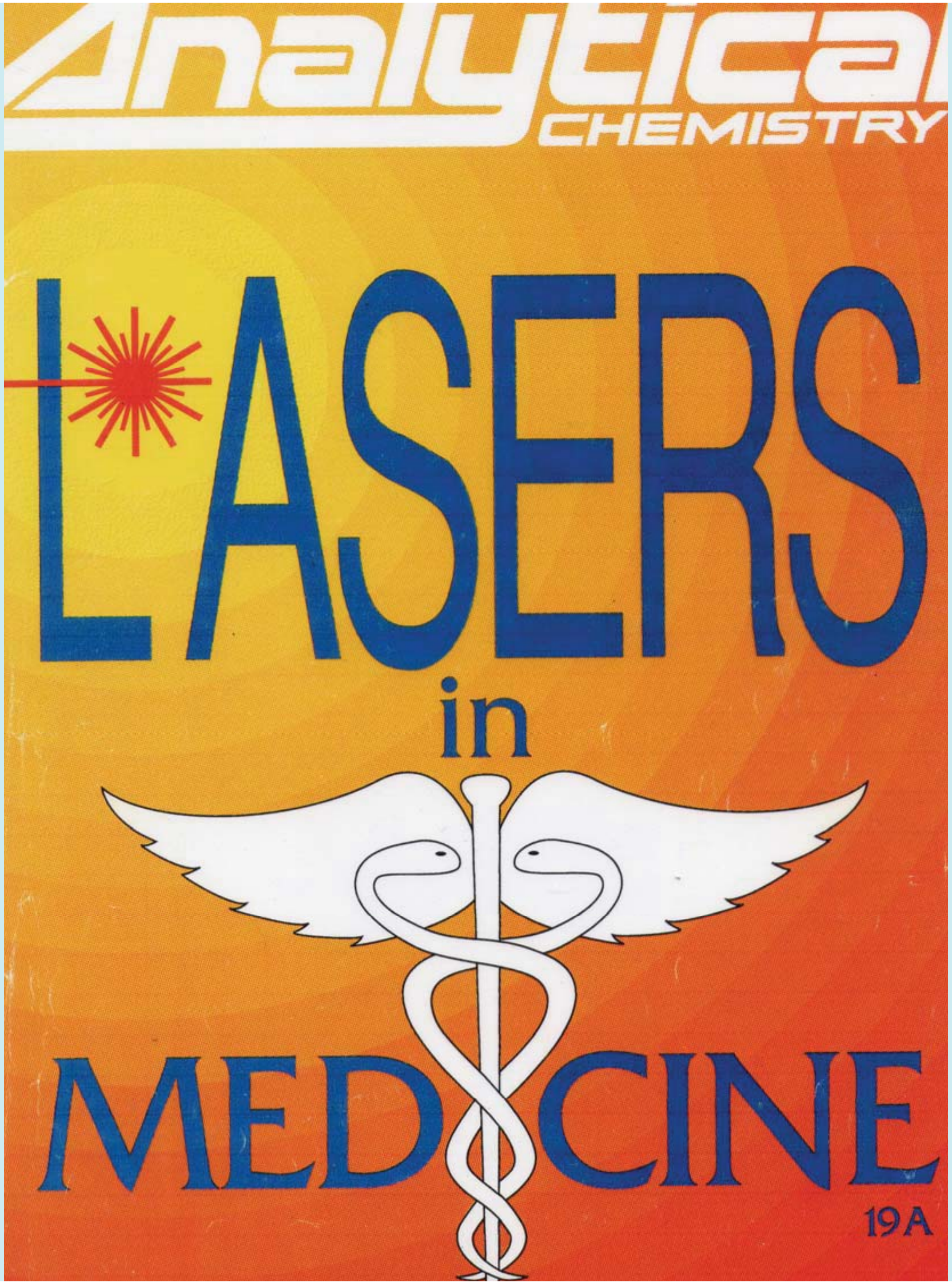
LIBS


a
Mobile lidar system
Laser beam path
Target
Lund Institute
of Technology
b
To roof-top
scanning mirrors
Nd:YAG
OMA
Receiving
telescope
Beam expander

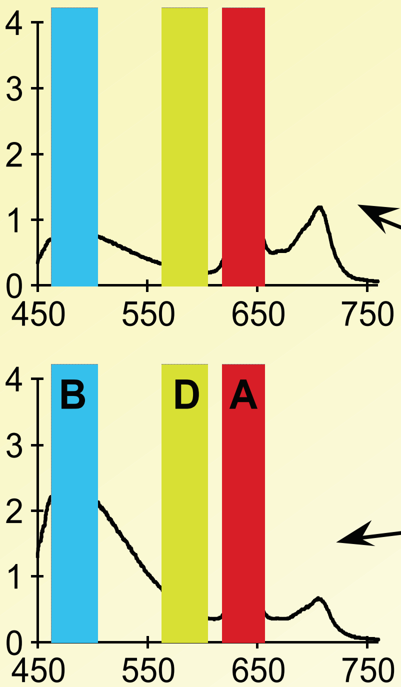
Remote Laser-Induced Break-Down Spectroscopy (LIBS)

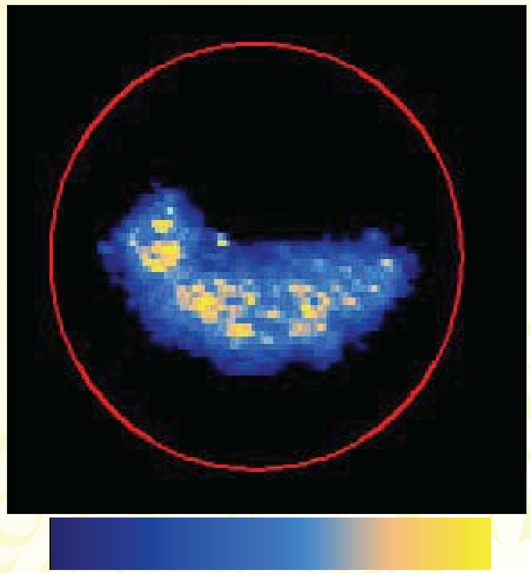


Emission spectrum detected in plasma after-glow 150 mJ/pulse


Analytical
CHEMISTRY
LASERS
in
MEDICINE
19A

Multicolour Fluorescence Imaging





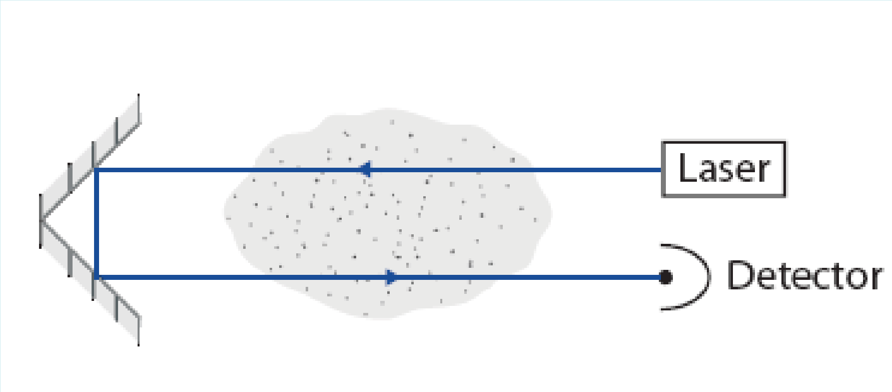
$$F_c = \frac{A - k_1 D}{k_2 B}$$

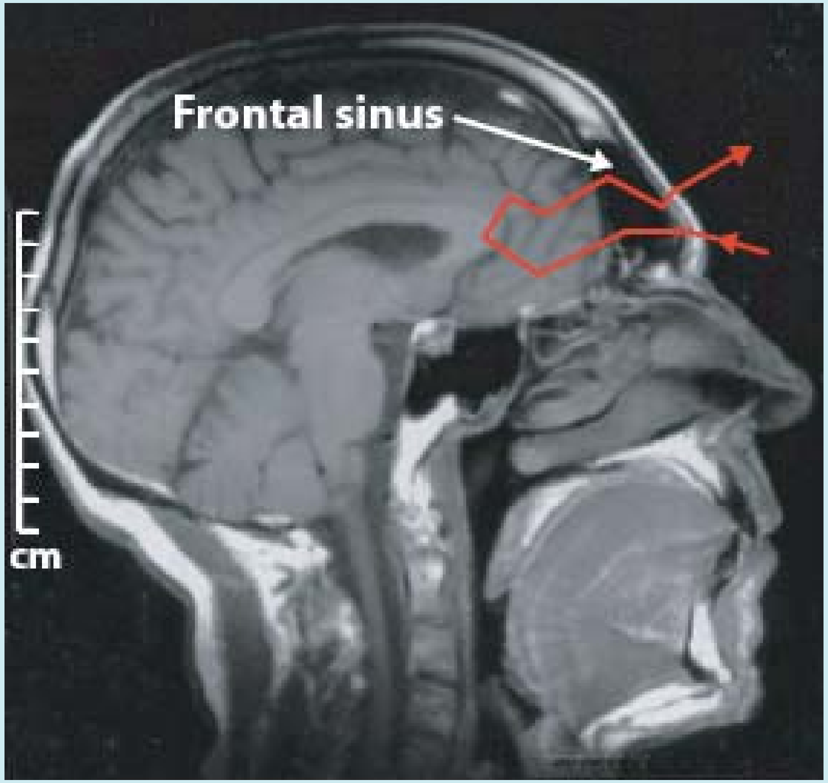
$$\frac{\text{Red} - \text{Yellow}}{\text{Blue}}$$

Andersson-Engels *et al.* LSM (2000)

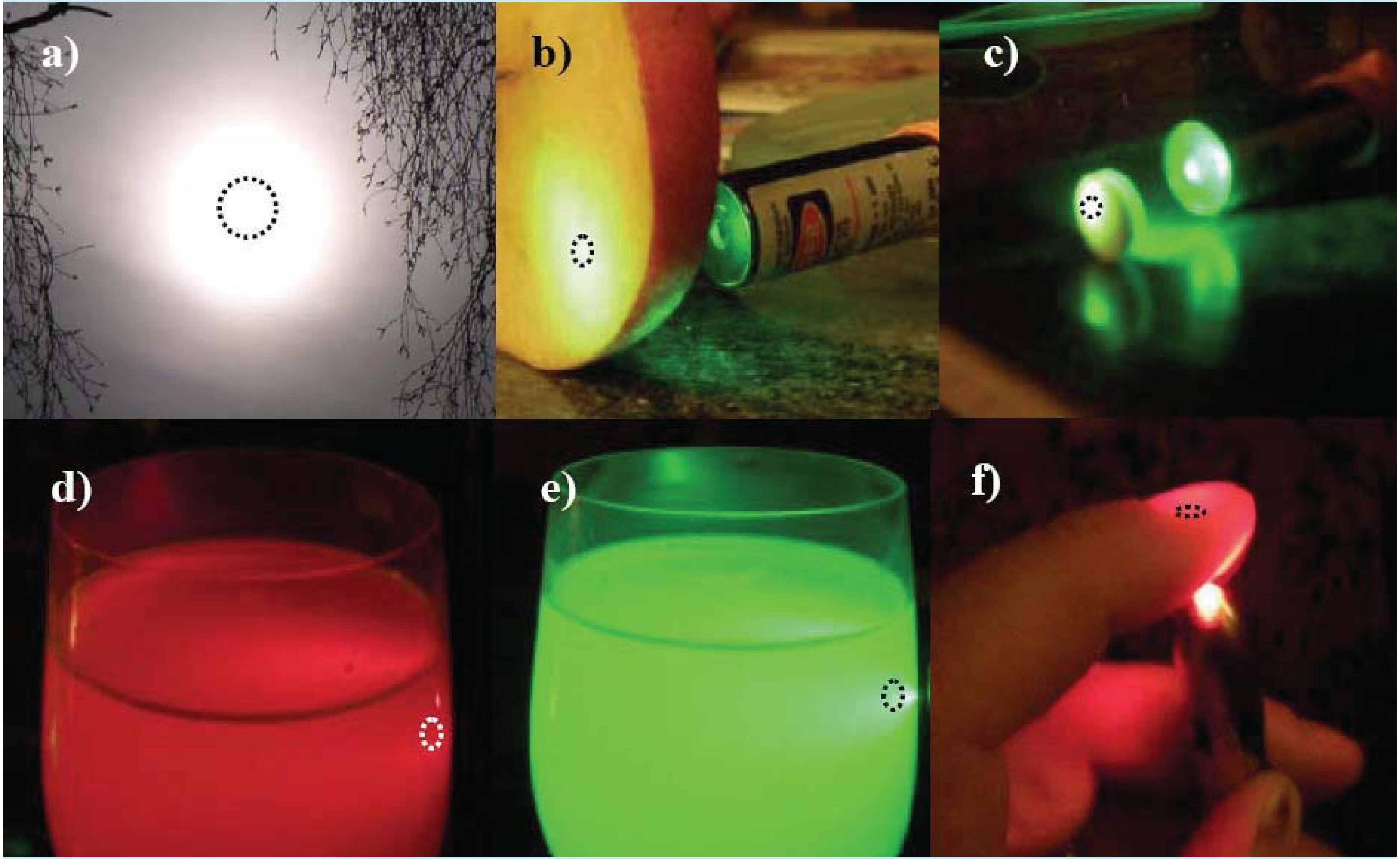
Environment

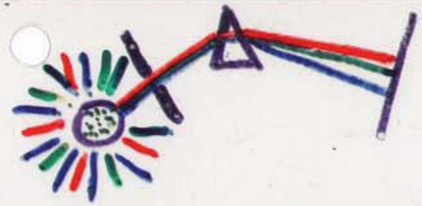
Medicine



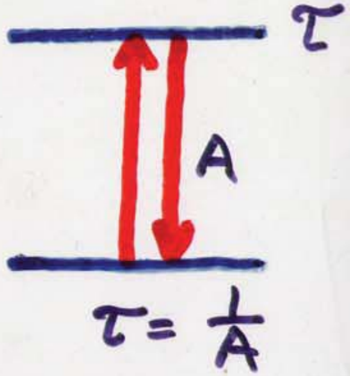


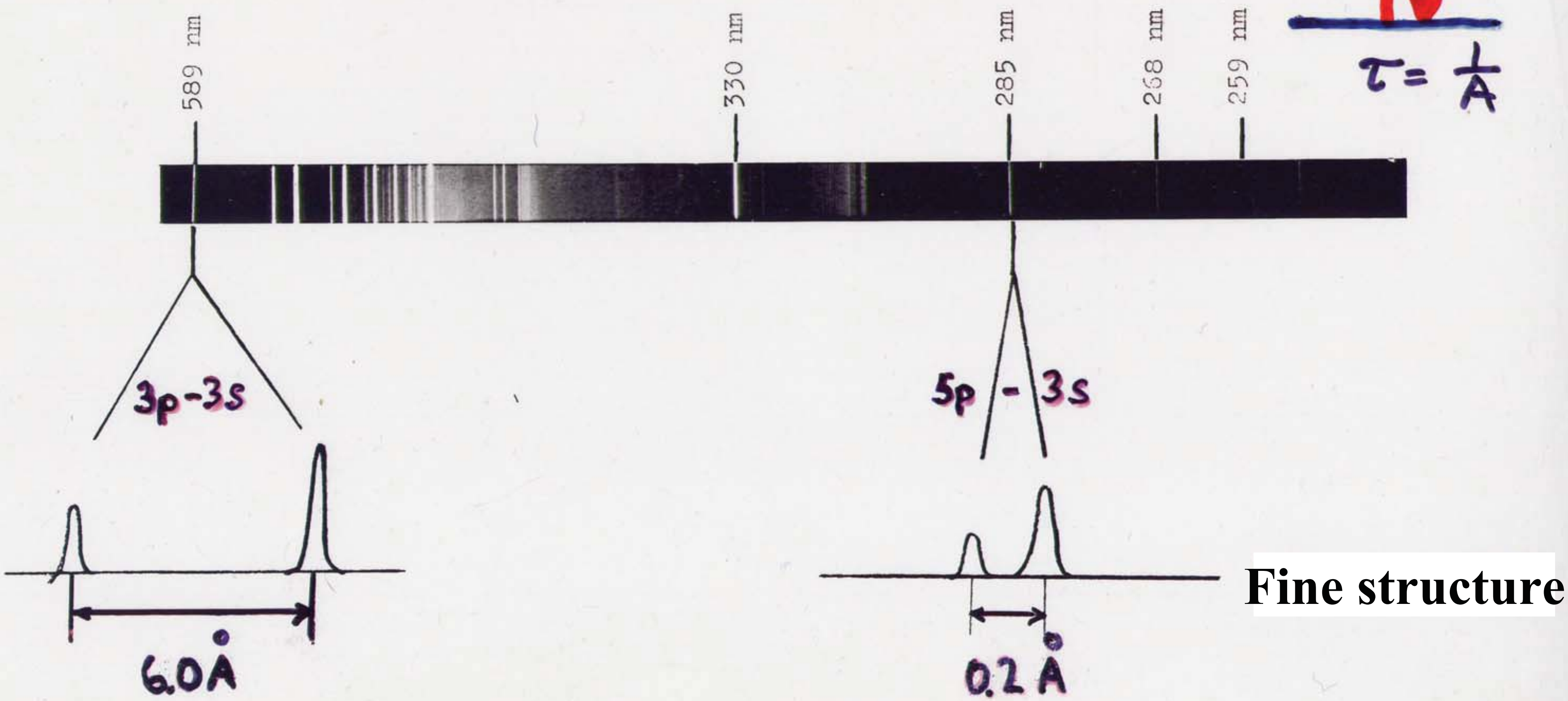
Light propagation in scattering media





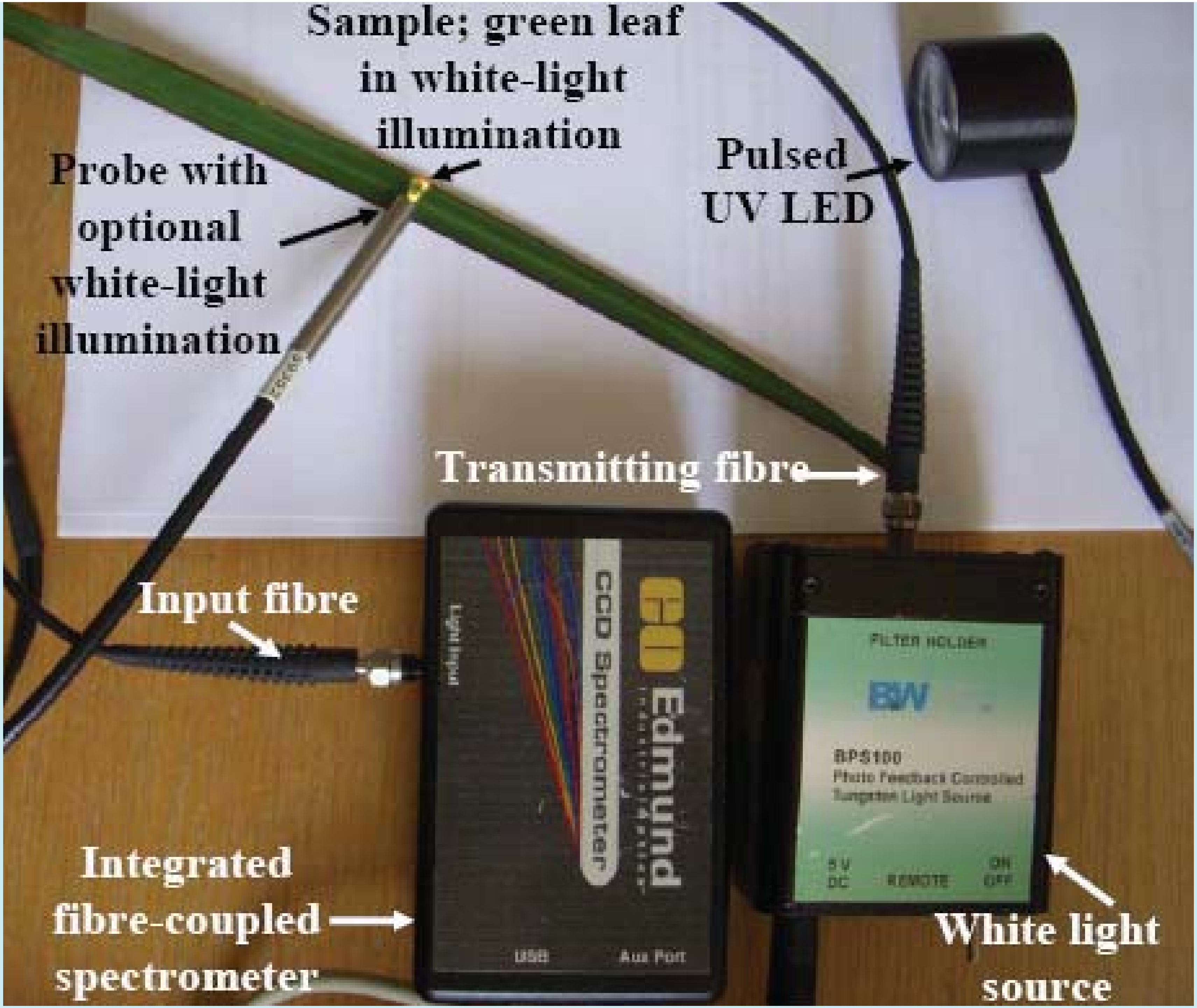
Spectrum of neutral sodium

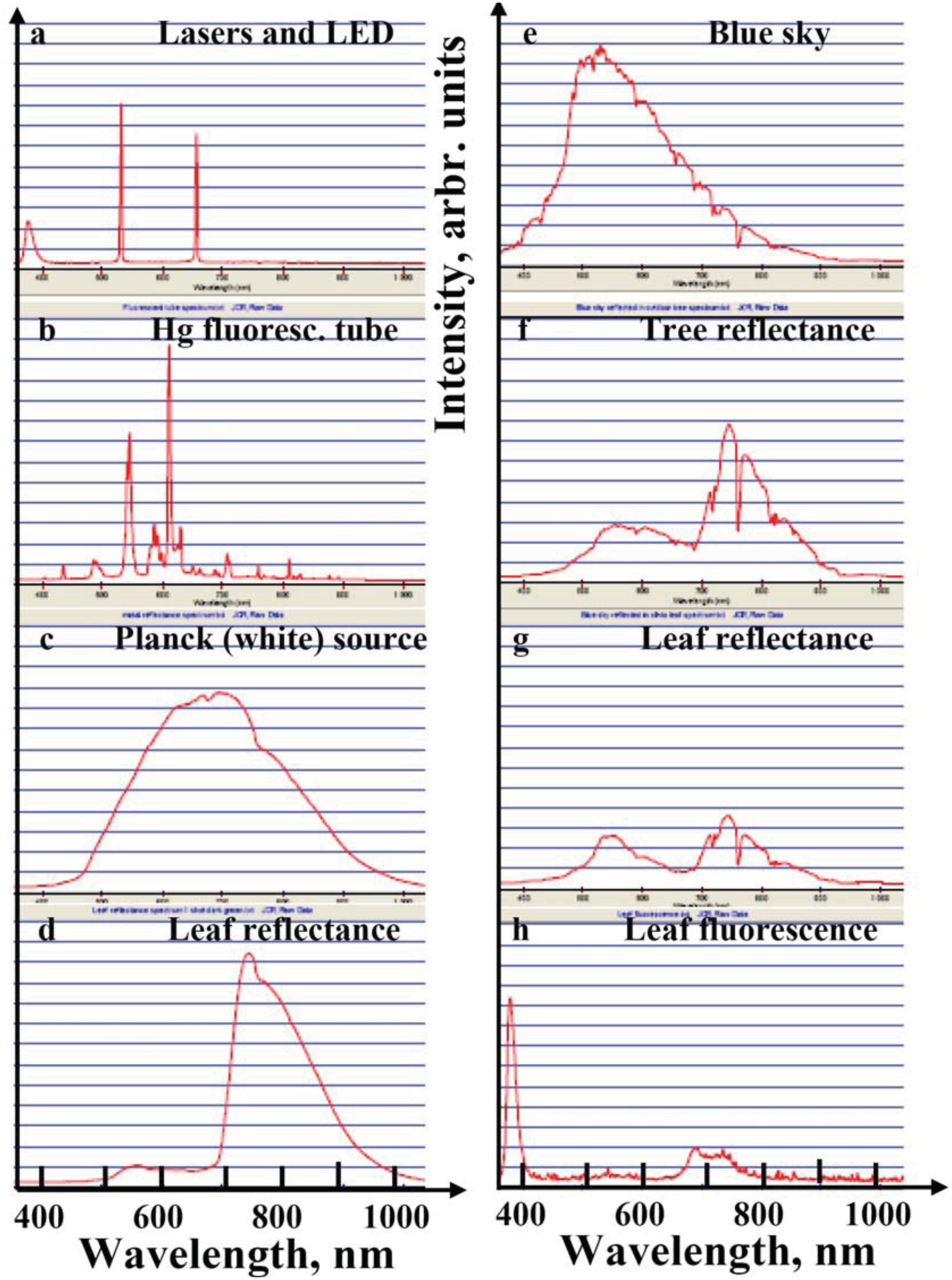




Old Spectroscope

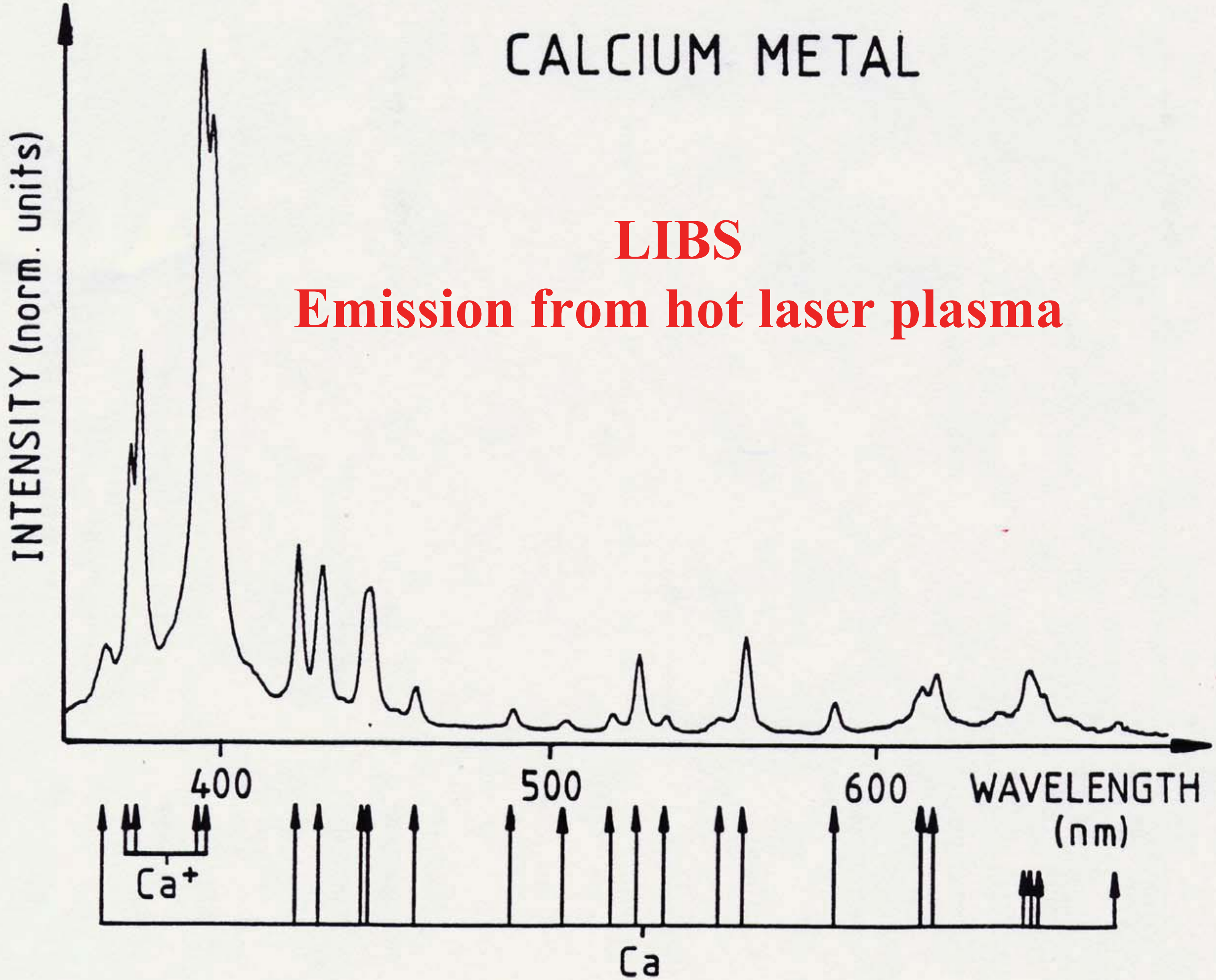
Modern Spectrometer


Sample; green leaf in white-light illumination
Probe with optional white-light illumination
Pulsed UV LED
Transmitting fibre
Input fibre
Light Input
CCD Spectrometer
Edmund
USB
Aux Port
FILTER HOLDER
BPS100
Photo Feedback Controlled Tungsten Light Source
5 V DC
REMOTE
ON OFF
Integrated fibre-coupled spectrometer
White light source

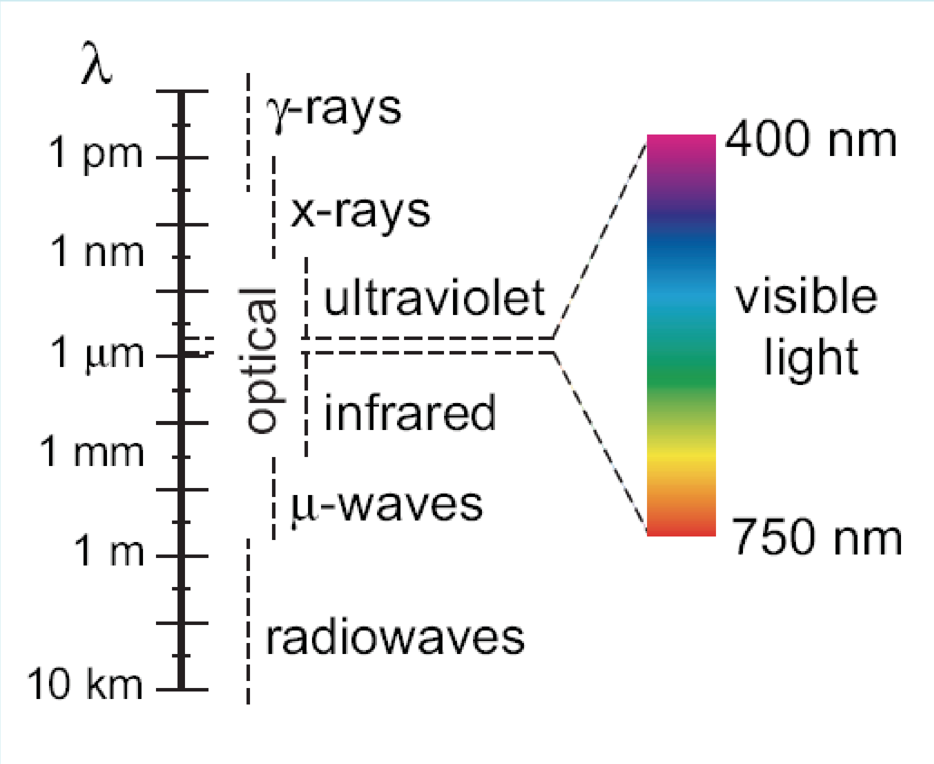


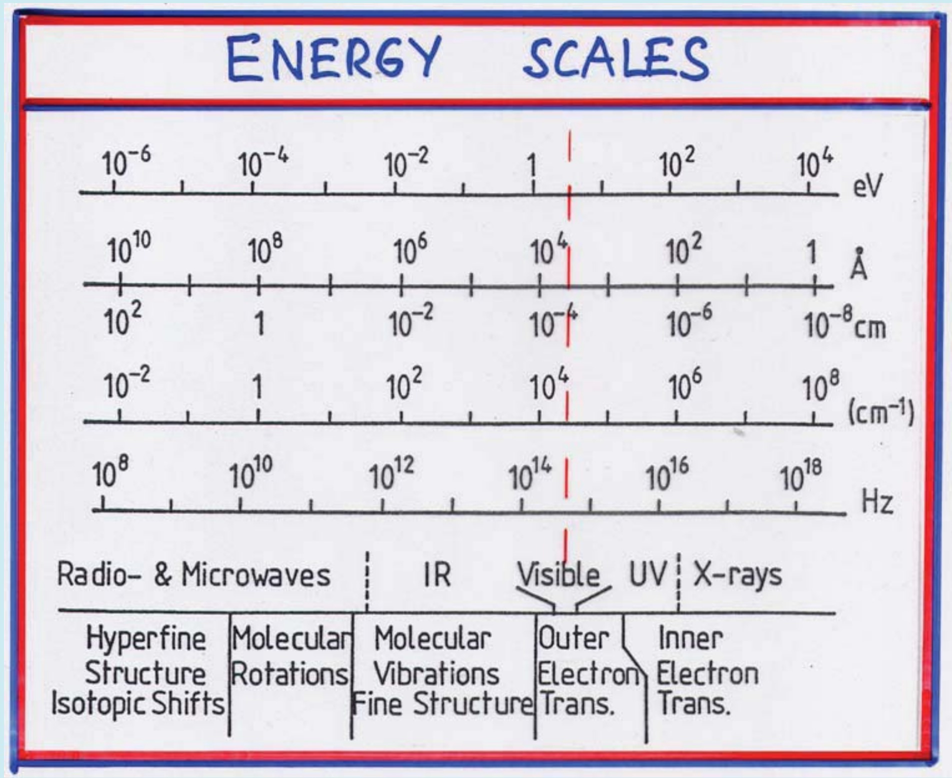
Intensity, arbr. units
a Lasers and LED
b Hg fluoresc. tube
c Planck (white) source
d Leaf reflectance
e Blue sky
f Tree reflectance
g Leaf reflectance
h Leaf fluorescence
400 600 800 1000
Wavelength, nm
400 600 800 1000
Wavelength, nm

LIBS
Emission from hot laser plasma



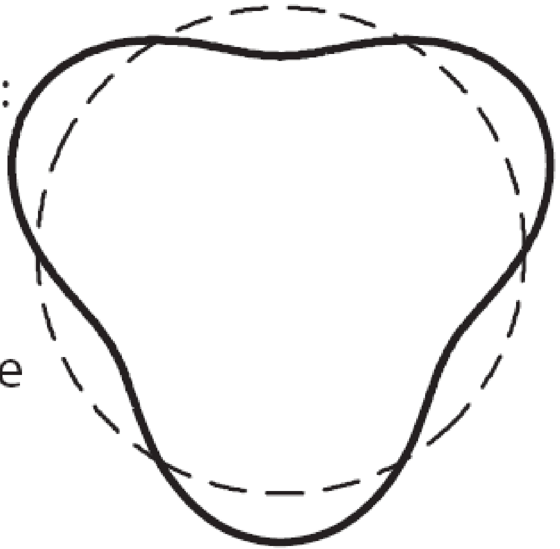
ENERGY SCALES



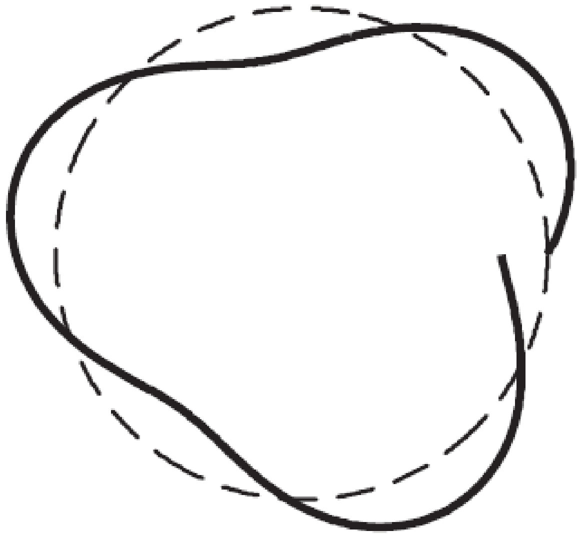


The origin on quantized states in view of constructive interference

Possible orbit:
The electron forms a circular standing wave



Impossible orbit:
The electron interferes destructively with itself

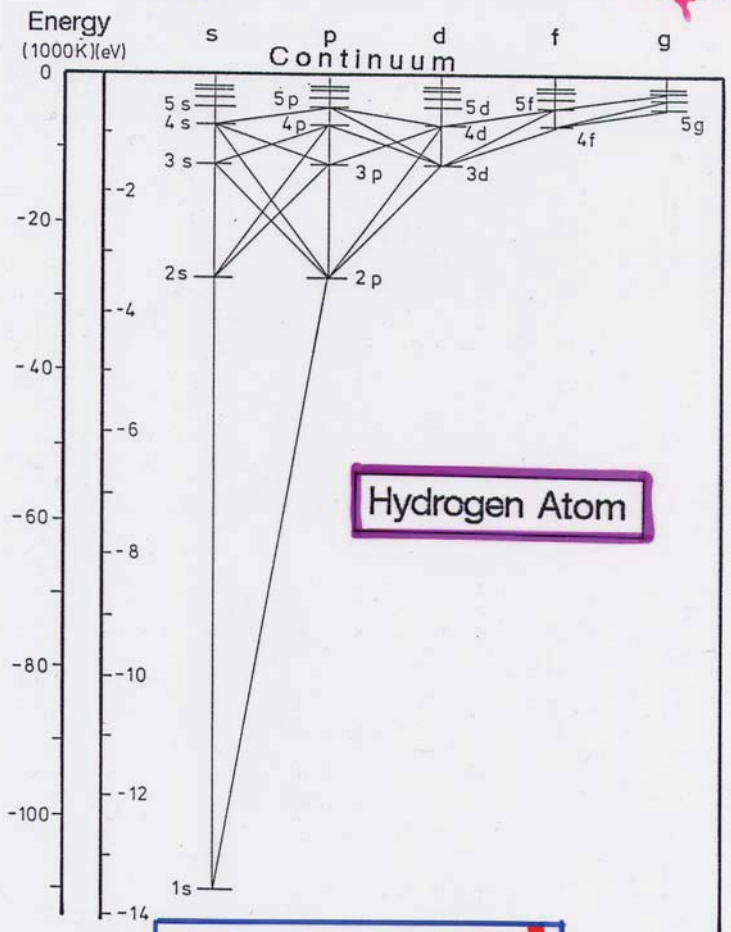


Grönlund

One-electron systems

$$V(r) = -\frac{Ze^2}{4\pi\varepsilon_0 r}$$

$$\left[-\frac{\hbar^2}{2m}\Delta + V(r)\right]\psi = E\psi$$ Schrödinger Equation



$$E_n = -hcR_y \frac{Z^2}{n^2}$$ $n = 1, 2, 3$

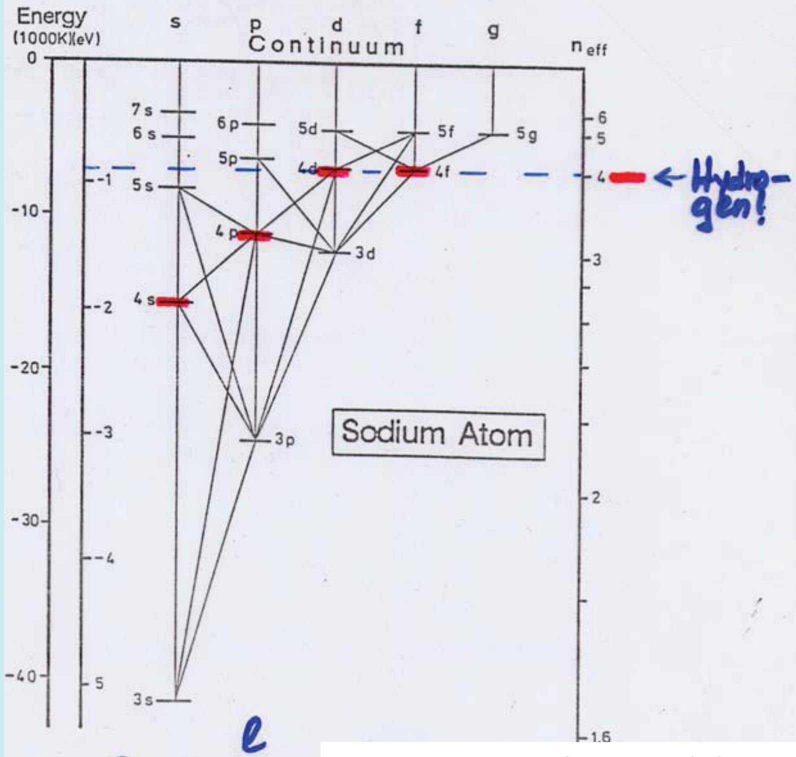
$$R_y = \frac{me^4}{4\pi(4\pi\varepsilon_0)^2 c\hbar^3}$$ l degeneracy

ALKALI ATOMS

$$E = -hcR_y \frac{1}{n_{eff}^2}$$

$$n_{eff} = n - d$$

effective n   quantum defect



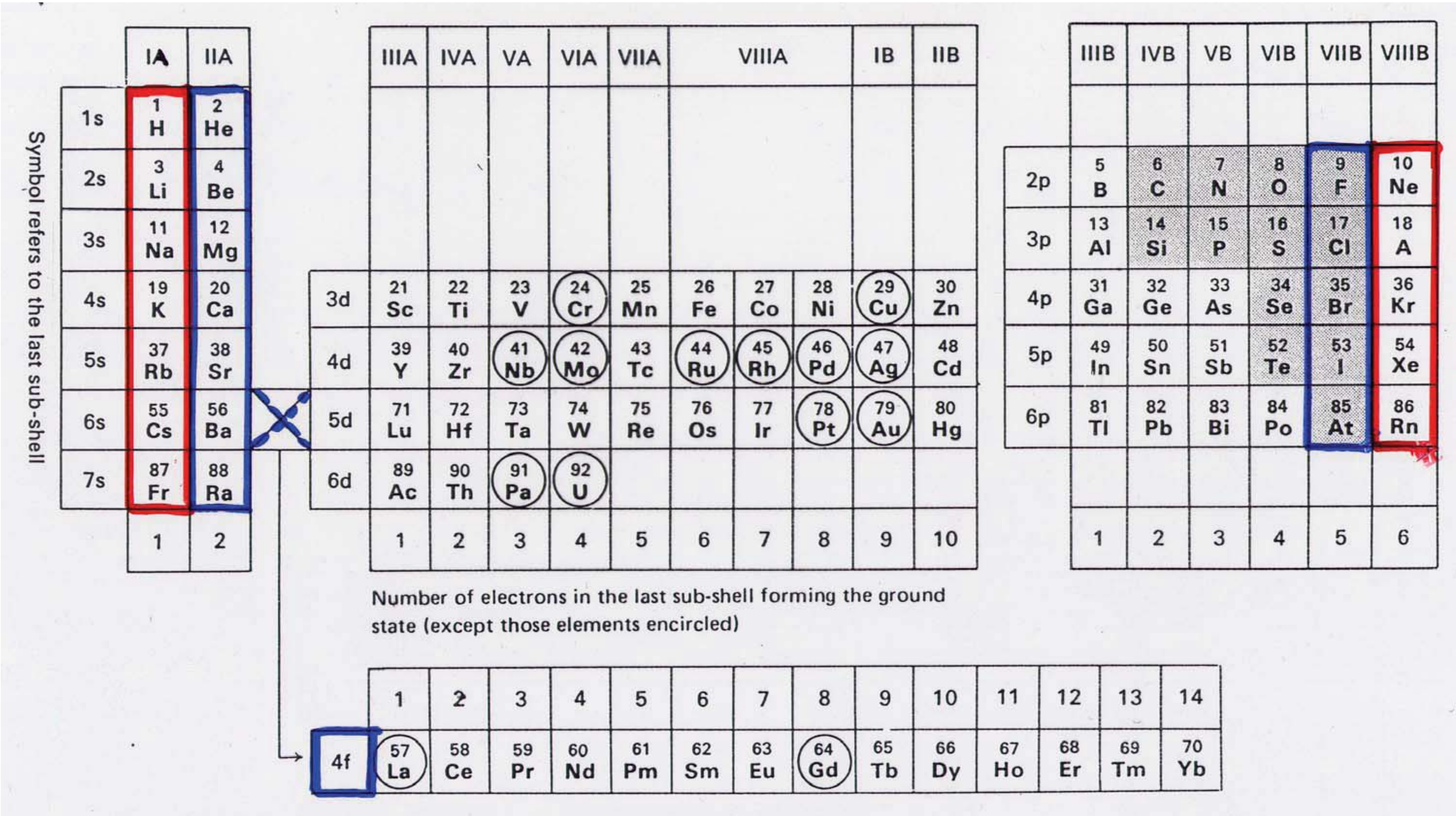
	l	
s	0	Penetrating orbit
p	1	
d	2	Non-penetrating orbit
f	3	

Build-up principle
Pauli principle - Shell structure

Atomic number Z	Element		Shells: K n=1 s	L n=2 s	L n=2 p	M n=3 s	M n=3 p	M n=3 d	N n=4 s	N n=4 p	N n=4 d	O n=5 s	O n=5 p	LS configuration of the ground state	First ionisation potential [eV]	
1	Hydrogen	H	1											$^2S_{1/2}$	13.60	
2	Helium	He	2											$^1S_0$	24.58	
3	Lithium	Li	2	1										$^2S_{1/2}$	5.39	
4	Beryllium	Be	2	2										$^1S_0$	9.32	
5	Boron	B	2	2	1									$^2P_{1/2}$	8.30	
6	Carbon	C	2	2	2									$^3P_0$	11.26	
7	Nitrogen	N	2	2	3									$^4S_{3/2}$	14.54	
8	Oxygen	O	2	2	4									$^3P_2$	13.61	
9	Fluorine	F	2	2	5									$^2P_{3/2}$	17.42	
10	Neon	Ne	2	2	6									$^1S_0$	21.56	
11	Sodium	Na	2	2	6	1								$^2S_{1/2}$	5.14	
12	Magnesium	Mg	2	2	6	2								$^1S_0$	7.64	
13	Aluminium	Al	2	2	6	2	1							$^2P_{1/2}$	5.98	
14	Silicon	Si	2	2	6	2	2							$^3P_0$	8.15	
15	Phosphorous	P	2	2	6	2	3							$^4S_{3/2}$	10.55	
16	Sulphur	S	2	2	6	2	4							$^3P_2$	10.36	
17	Chlorine	Cl	2	2	6	2	5							$^2P_{3/2}$	13.01	
18	Argon	A	2	2	6	2	6							$^1S_0$	15.76	
19	Potassium	K	2	2	6	2	6		1					$^2S_{1/2}$	4.34	
20	Calcium	Ca	2	2	6	2	6		2					$^1S_0$	6.11	
21	Scandium	Sc	2	2	6	2	6	1	2					$^2D_{3/2}$	6.56	Transition elements
22	Titanium	Ti	2	2	6	2	6	2	2					$^3F_2$	6.83	
23	Vanadium	V	2	2	6	2	6	3	2					$^4F_{3/2}$	6.74	
24	Chromium	Cr	2	2	6	2	6	5	1					$^7S_3$	6.76	
25	Manganese	Mn	2	2	6	2	6	5	2					$^6S_{5/2}$	7.43	
26	Iron	Fe	2	2	6	2	6	6	2					$^5D_4$	7.90	
27	Cobalt	Co	2	2	6	2	6	7	2					$^4F_{9/2}$	7.86	
28	Nickel	Ni	2	2	6	2	6	8	2					$^3F_4$	7.63	
29	Copper	Cu	2	2	6	2	6	10	1					$^2S_{1/2}$	7.72	
30	Zinc	Zn	2	2	6	2	6	10	2					$^1S_0$	9.39	
31	Gallium	Ga	2	2	6	2	6	10	2	1				$^2P_{1/2}$	6.00	
32	Germanium	Ge	2	2	6	2	6	10	2	2				$^3P_0$	7.88	
33	Arsenic	As	2	2	6	2	6	10	2	3				$^4S_{3/2}$	9.81	
34	Selenium	Se	2	2	6	2	6	10	2	4				$^3P_2$	9.75	
35	Bromine	Br	2	2	6	2	6	10	2	5				$^2P_{3/2}$	11.84	
36	Krypton	Kr	2	2	6	2	6	10	2	6				$^1S_0$	14.00	
37	Rubidium	Rb	2	2	6	2	6	10	2	6		1		$^2S_{1/2}$	4.18	
38	Strontium	Sr	2	2	6	2	6	10	2	6		2		$^1S_0$	5.69	
39	Yttrium	Y	2	2	6	2	6	10	2	6	1	2		$^2D_{3/2}$	6.38	Transition elements
40	Zirconium	Zr	2	2	6	2	6	10	2	6	2	2		$^3F_2$	6.84	
41	Niobium	Nb	2	2	6	2	6	10	2	6	4	1		$^6D_{1/2}$	6.88	
42	Molybdénum	Mo	2	2	6	2	6	10	2	6	5	1		$^7S_3$	7.13	
43	Technetium	Tc	2	2	6	2	6	10	2	6	6	1		$^6D_{9/2}$	7.23	
44	Ruthenium	Ru	2	2	6	2	6	10	2	6	7	1		$^5F_5$	7.37	
45	Rhodium	Rh	2	2	6	2	6	10	2	6	8	1		$^4F_{9/2}$	7.46	
46	Palladium	Pd	2	2	6	2	6	10	2	6	10			$^1S_0$	8.33	
47	Silver	Ag	2	2	6	2	6	10	2	6	10	1		$^2S_{1/2}$	7.57	
48	Cadmium	Cd	2	2	6	2	6	10	2	6	10	2		$^1S_0$	8.99	
49	Indium	In	2	2	6	2	6	10	2	6	10	2	1	$^2P_{1/2}$	5.79	
50	Tin	Sn	2	2	6	2	6	10	2	6	10	2	2	$^3P_0$	7.33	
51	Antimony	Sb	2	2	6	2	6	10	2	6	10	2	3	$^4S_{3/2}$	8.64	
52	Tellurium	Te	2	2	6	2	6	10	2	6	10	2	4	$^3P_2$	9.01	
53	Iodine	J	2	2	6	2	6	10	2	6	10	2	5	$^2P_{3/2}$	10.44	
54	Xenon	Xe	2	2	6	2	6	10	2	6	10	2	6	$^1S_0$	12.13	

Periodic table of the atoms

PERIODIC SYSTEM



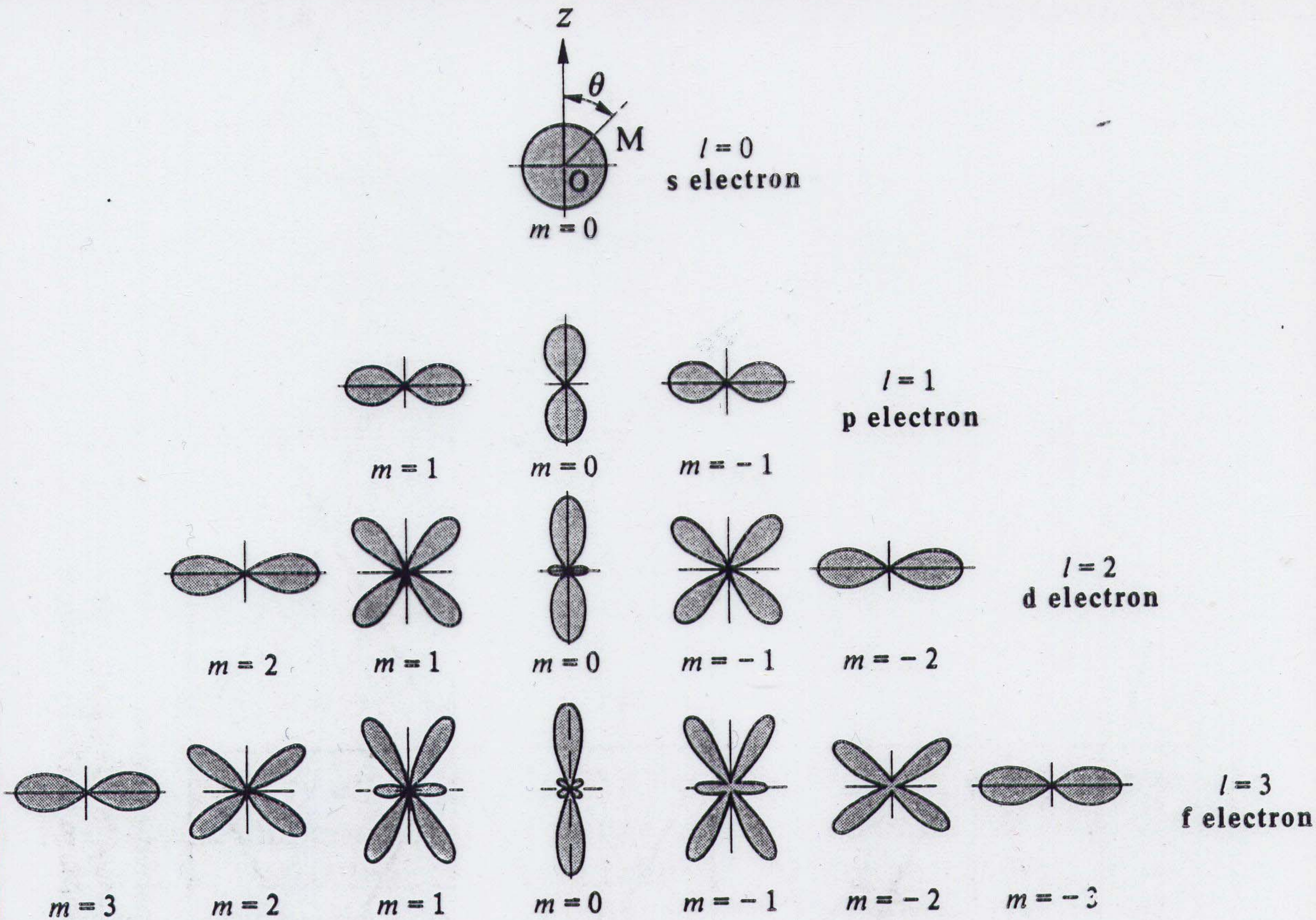
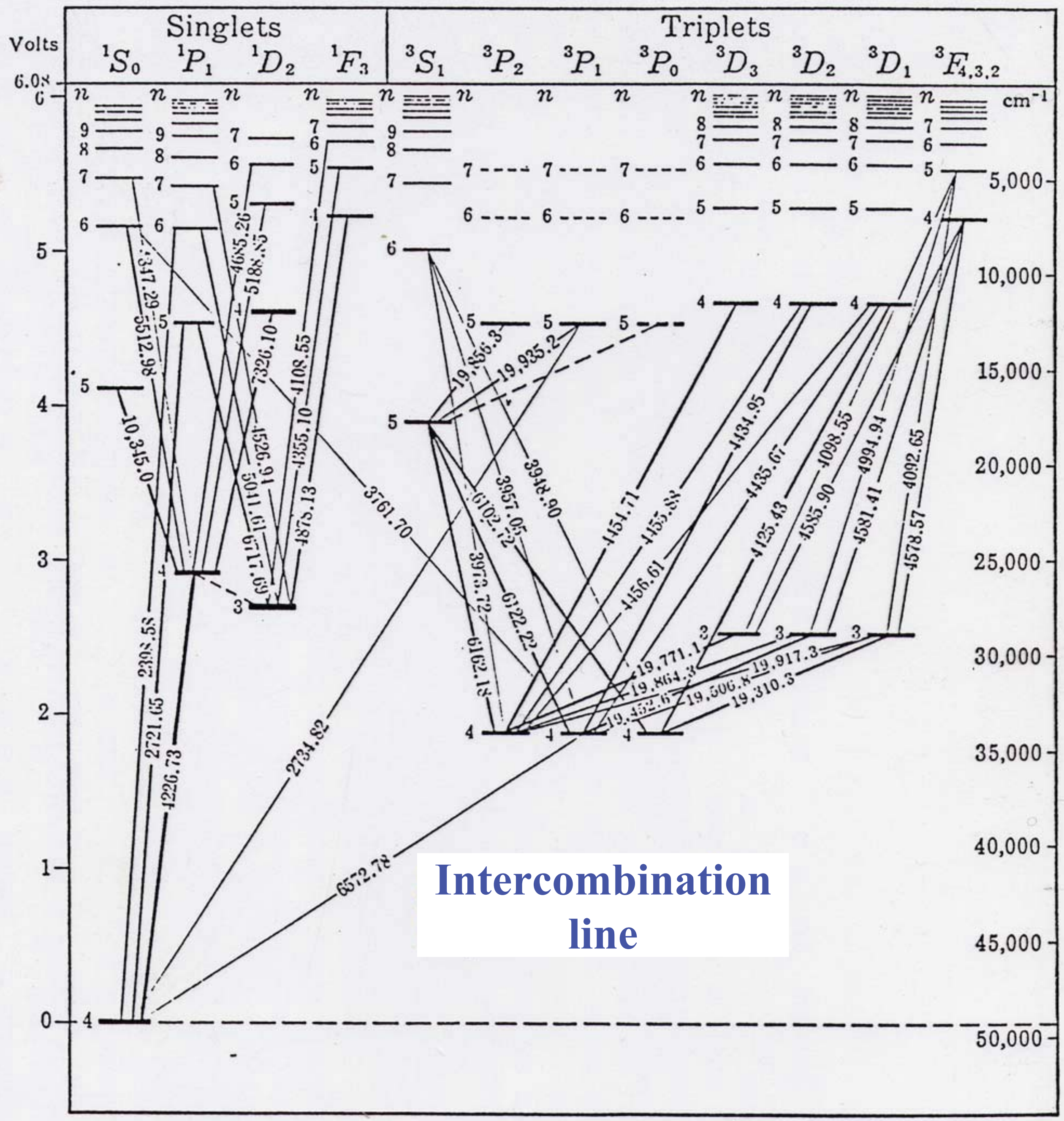


Figure 1.4 The angular probability density $D(\theta)$ in polar co-ordinates

CALCIUM



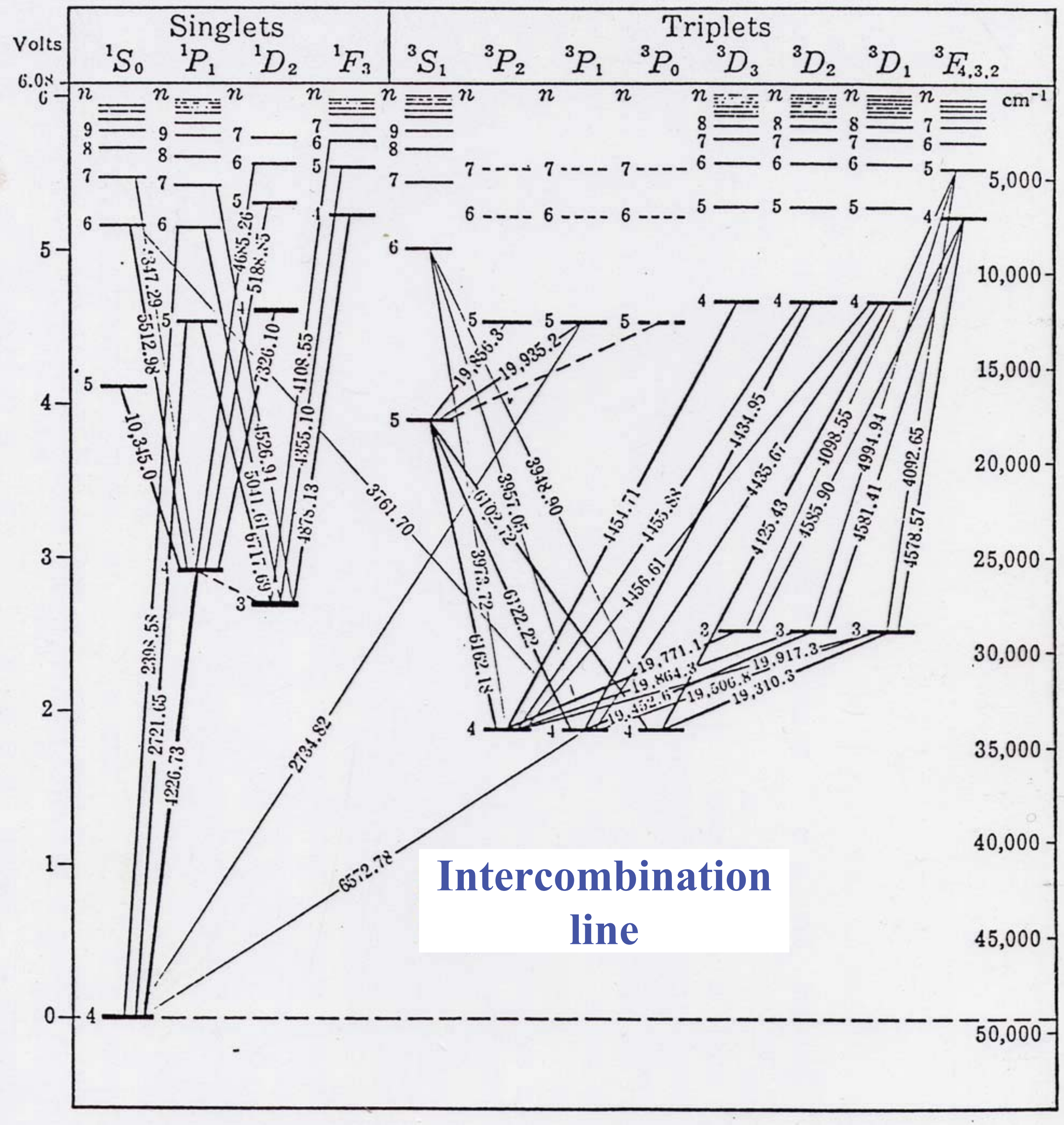
Intercombination line

ICTP Winter School on Optics in Environmental Science 2009

Fundamentals of Optical Spectroscopy Part 2

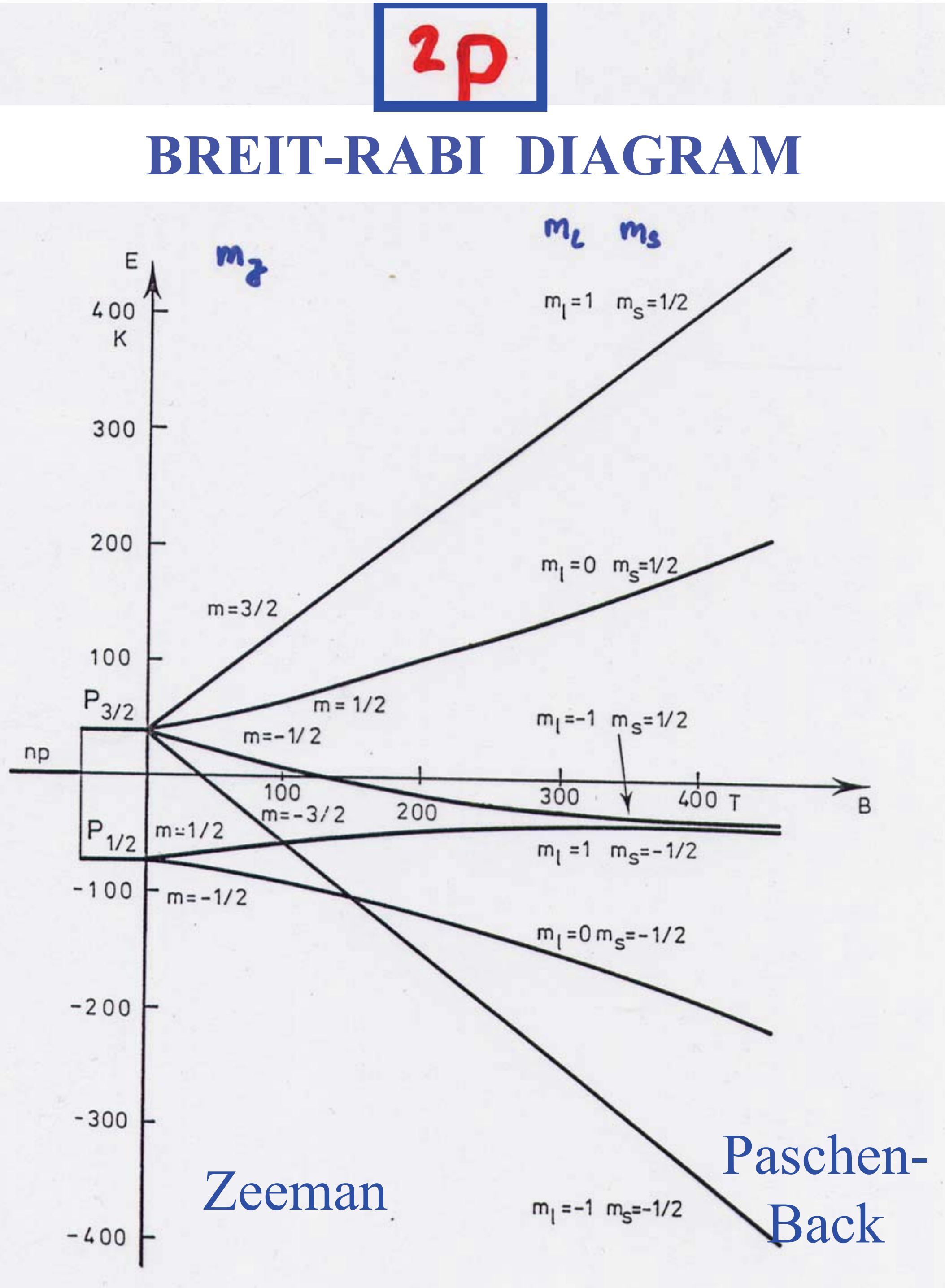
Sune Svanberg
Lund Laser Centre, Lund University
Sweden

CALCIUM



Intercombination line

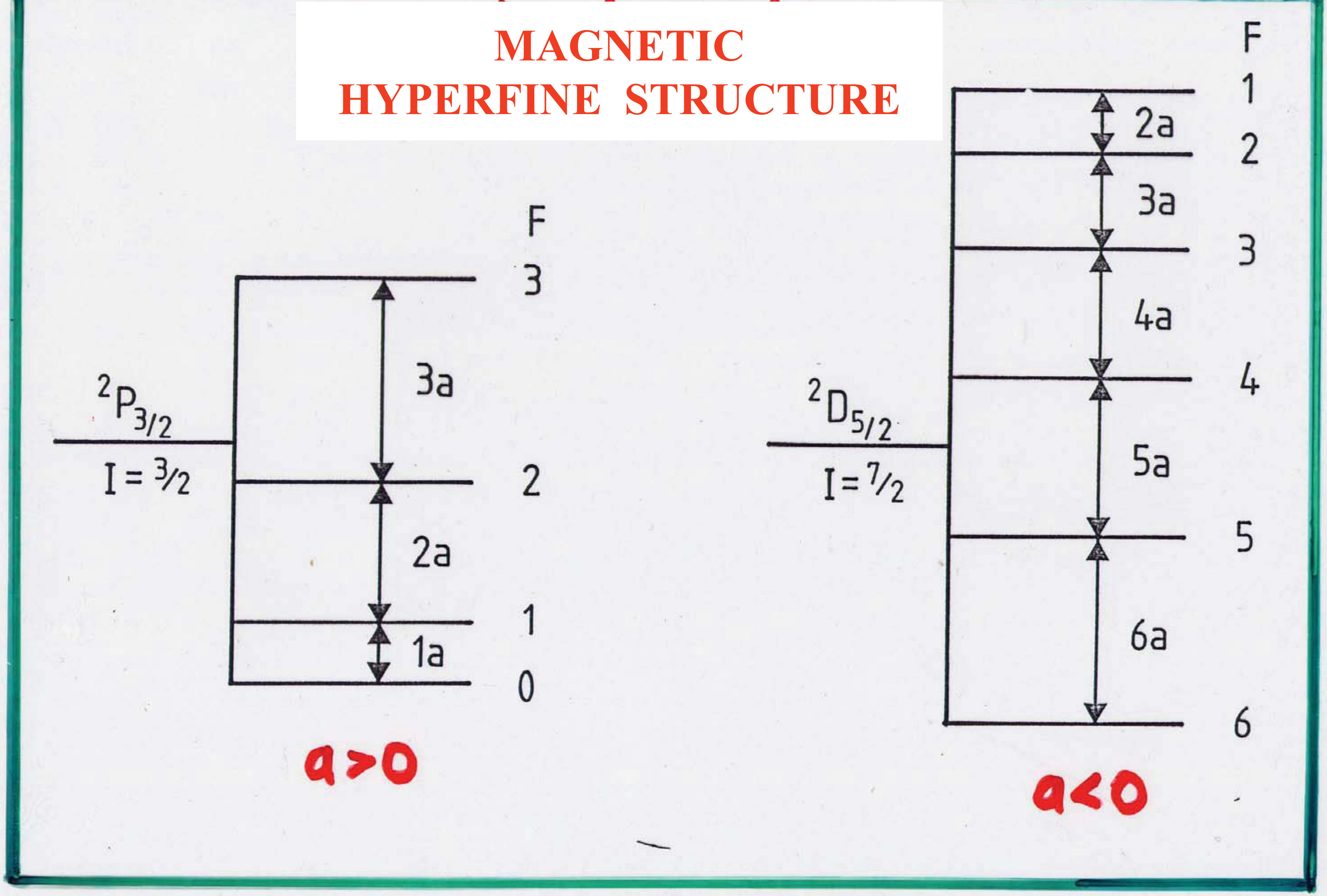
BREIT-RABI DIAGRAM



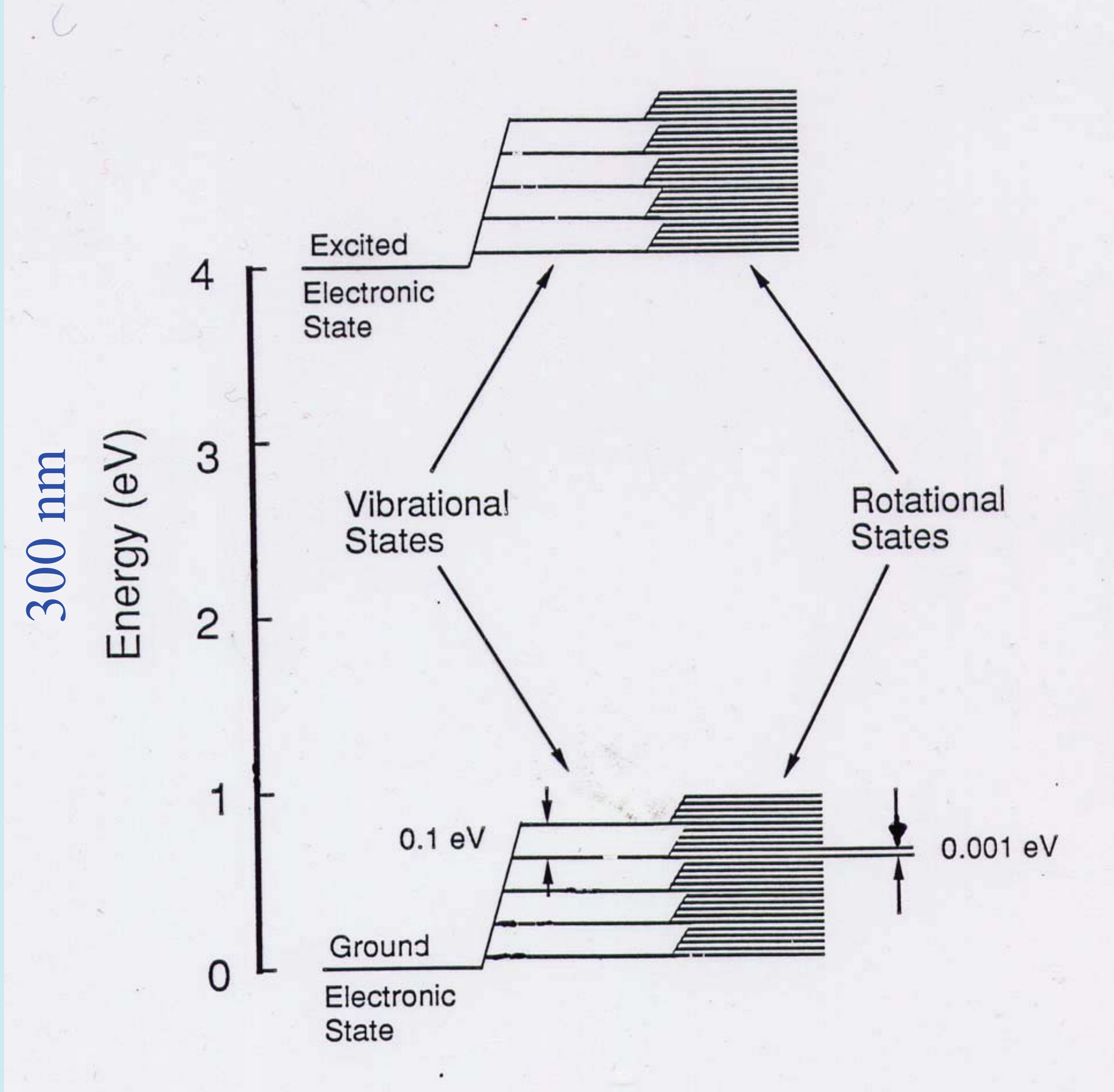
Fine structure

Magnetic field influence

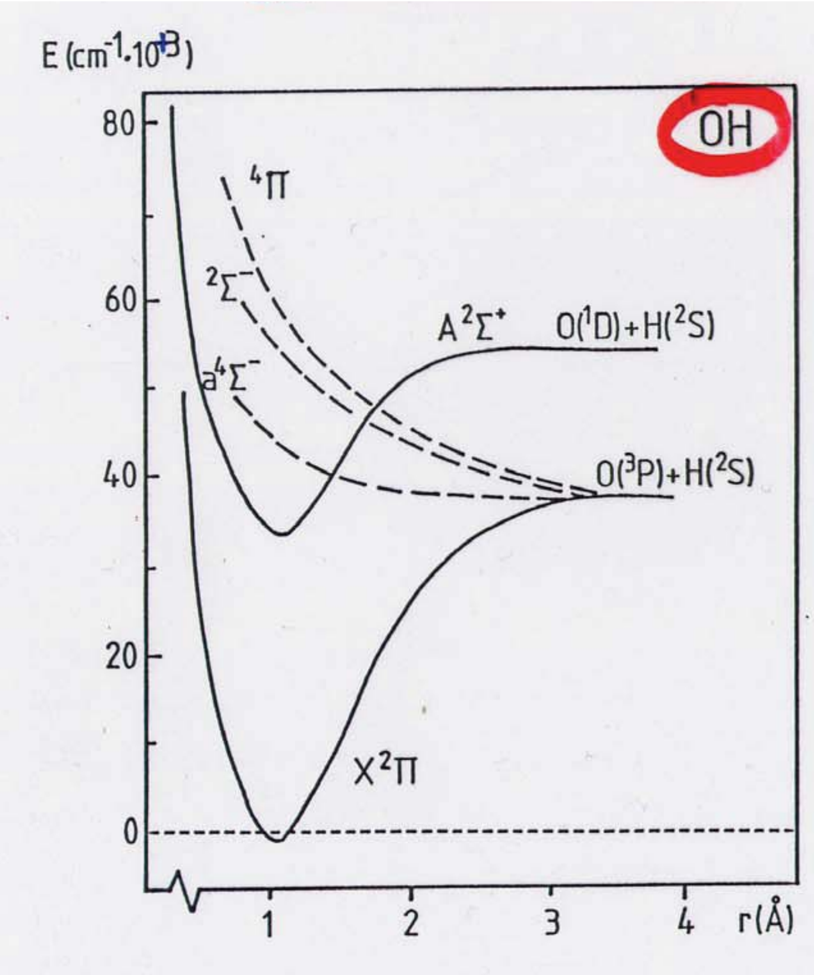
MAGNETIC HYPERFINE STRUCTURE



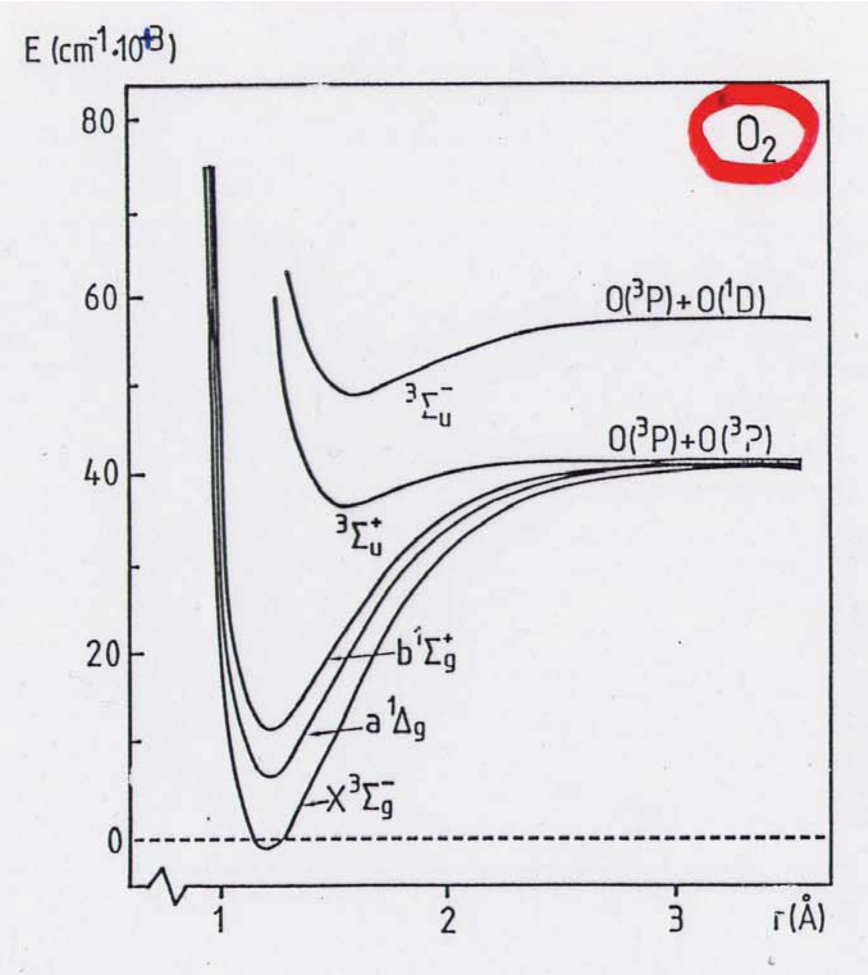
Molecular Structure



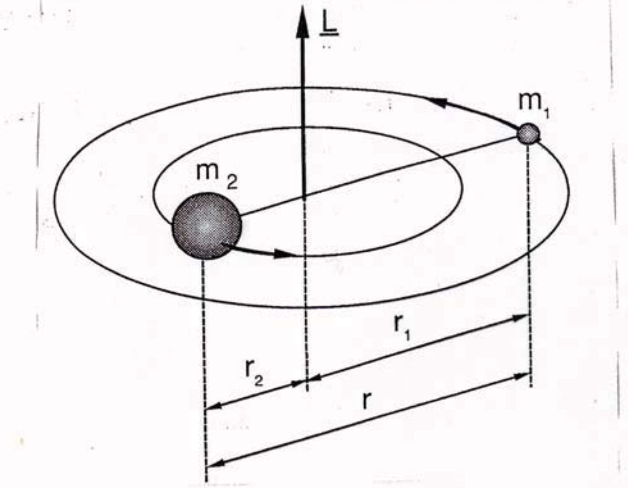
HETERONUCLEAR



HOMONUCLEAR



Rotational motion



$$r = r_1 + r_2.$$
$$m_1 r_1 = m_2 r_2,$$
$$I = m_1 r_1^2 + m_2 r_2^2.$$

We then obtain

$$I = \frac{m_1 m_2}{m_1 + m_2}(r_1 + r_2)^2 = \mu r^2$$

Reduced mass!

$$\left.\begin{array}{l} \boldsymbol{L} = I\omega/\hbar \\ E = I\omega^2/2 \end{array}\right\} \Rightarrow E = \frac{\boldsymbol{L}^2\hbar^2}{2I}$$

where ω is the angular frequency vector.

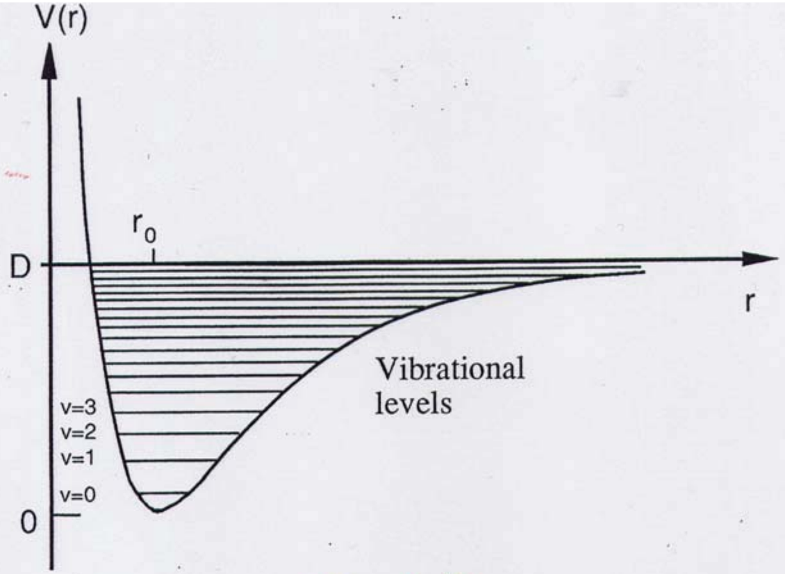
by

$$|\boldsymbol{L}| = \sqrt{J(J+1)},\ J = 0,\ 1,\ 2,\ \ldots$$

$$E_J = J(J+1)\hbar^2/2I = BJ(J+1).$$

Rot. energy

Vibrational motion



Dissociation energy

$$V(r) = D\left(1 - e^{-\alpha(r-r_0)}\right)^2$$ Morse Potential

$$V(r) = D\alpha^2(r-r_0)^2 + \dots$$

$F = -\frac{dV}{dr}$

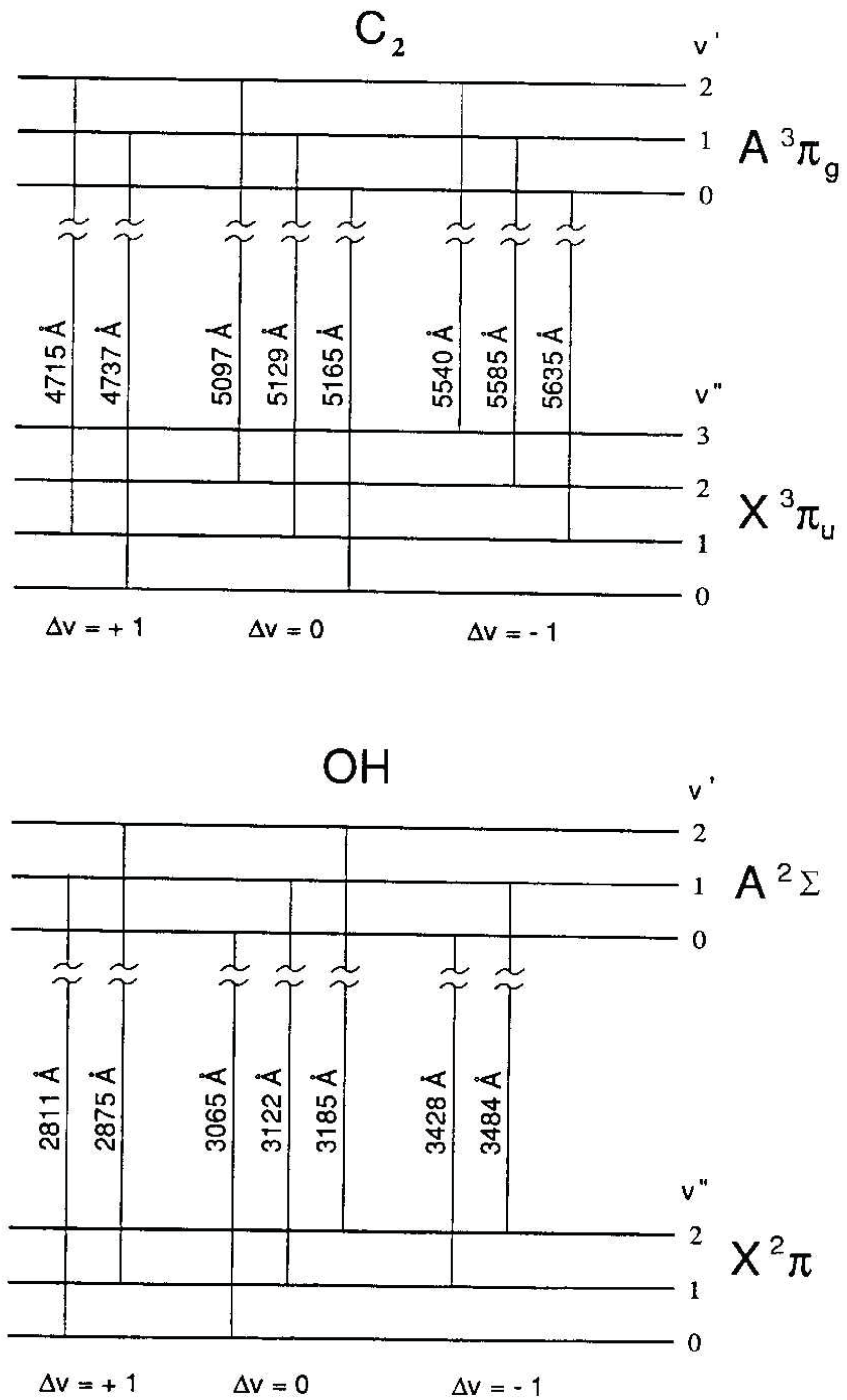
$$\nu_c = \frac{1}{2\pi}\sqrt{\frac{k}{\mu}}$$

Force constant (k)

Reduced mass (μ)

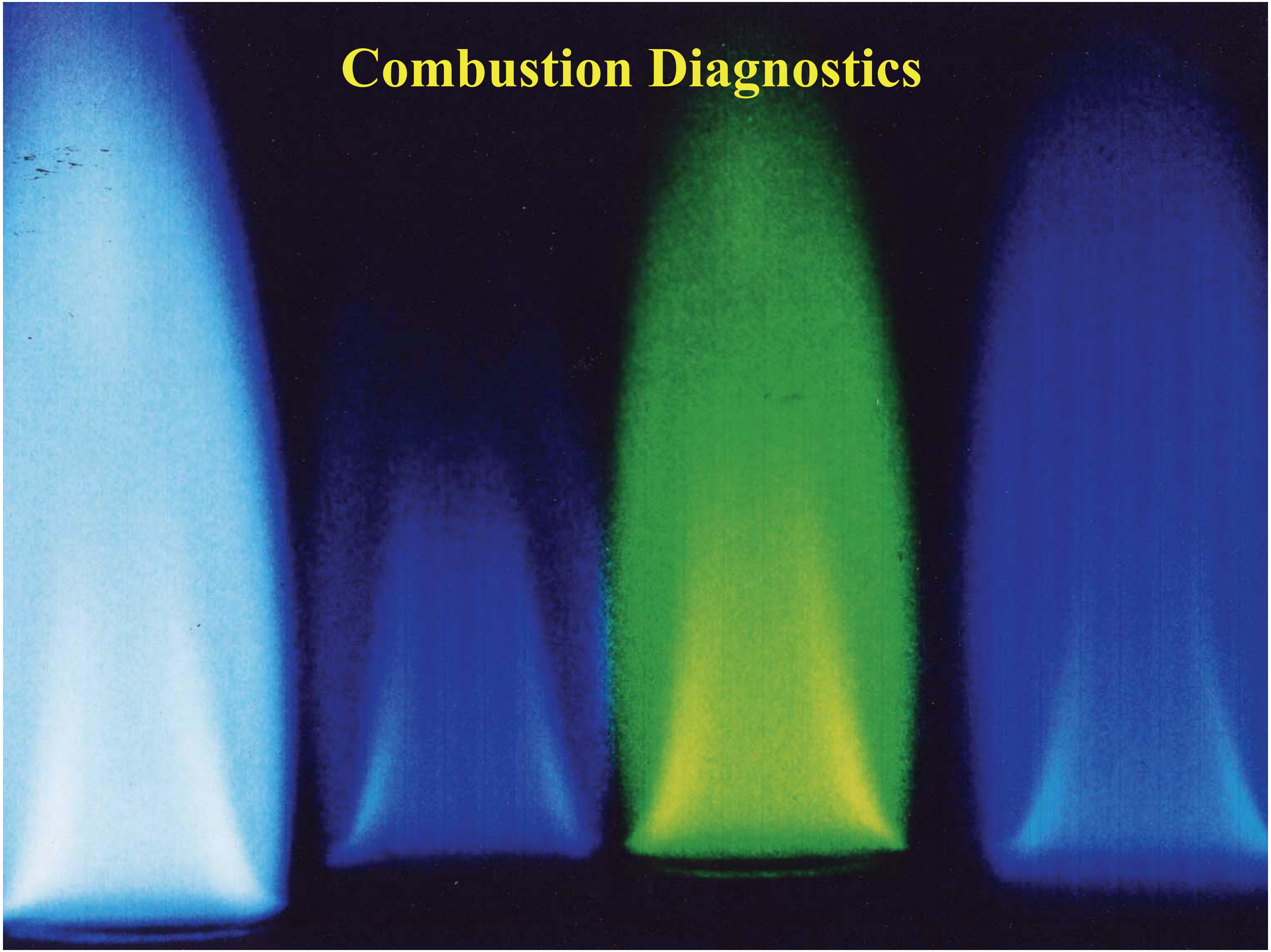
$F = -k(r-r_0)$. Thus $k = 2D\alpha^2$

$$E_v = (v + 1/2)h\nu_c, \quad v = 0, 1, 2, \dots$$

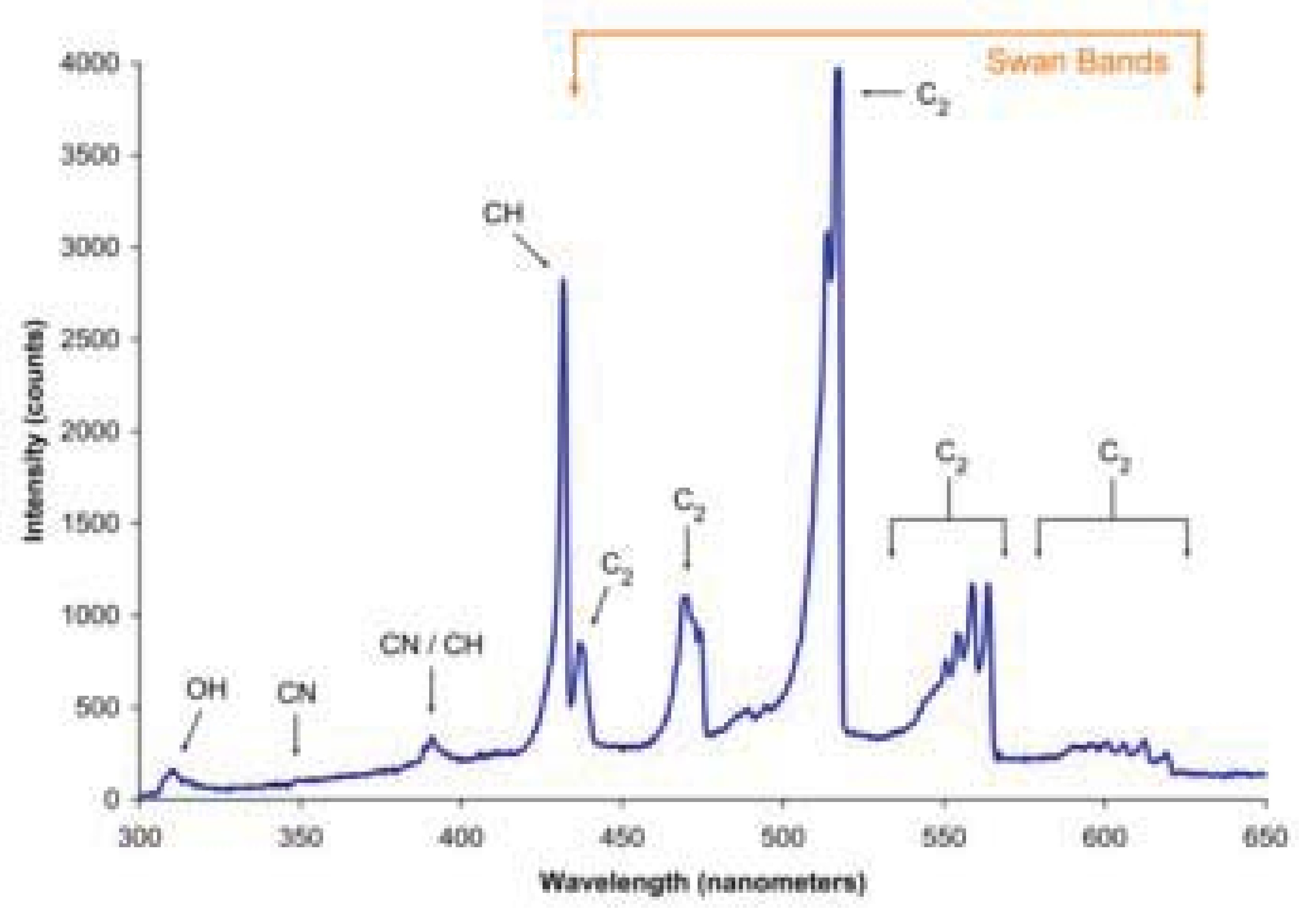


Vibrational transitions

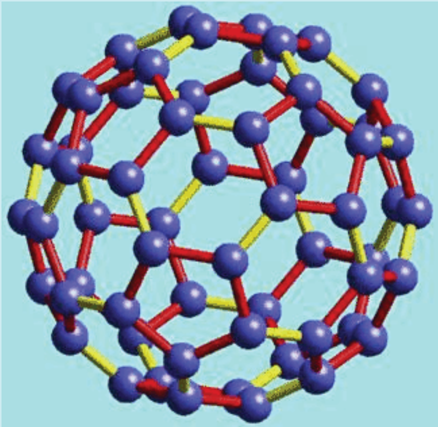
Combustion Diagnostics



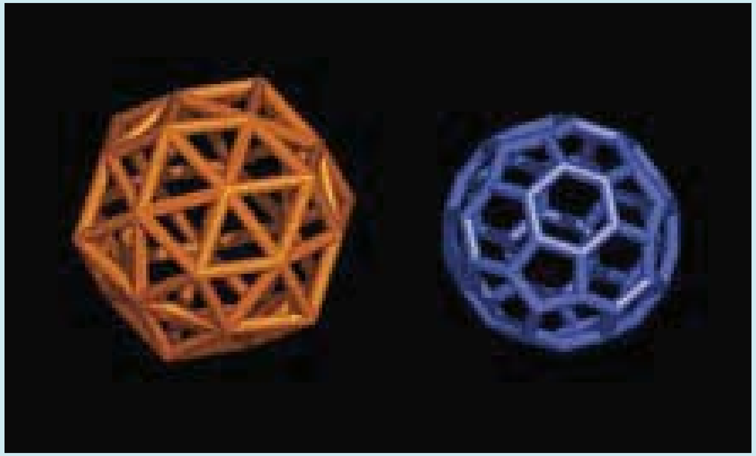
Flame spectrum

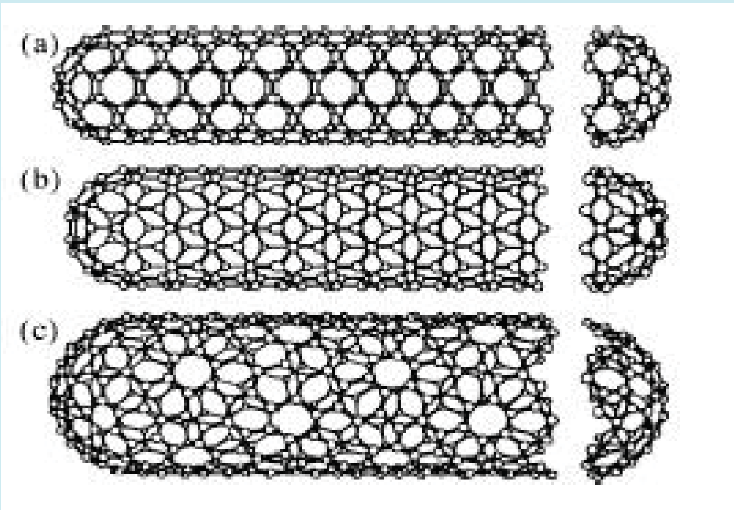


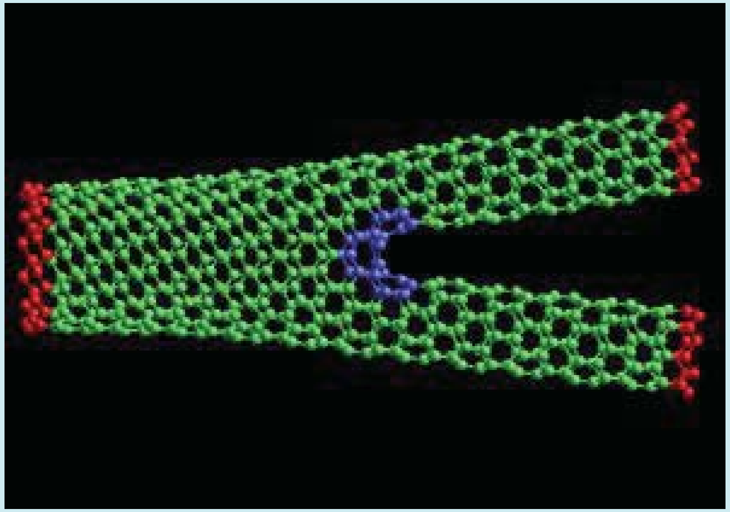
Nano balls and nano tubes



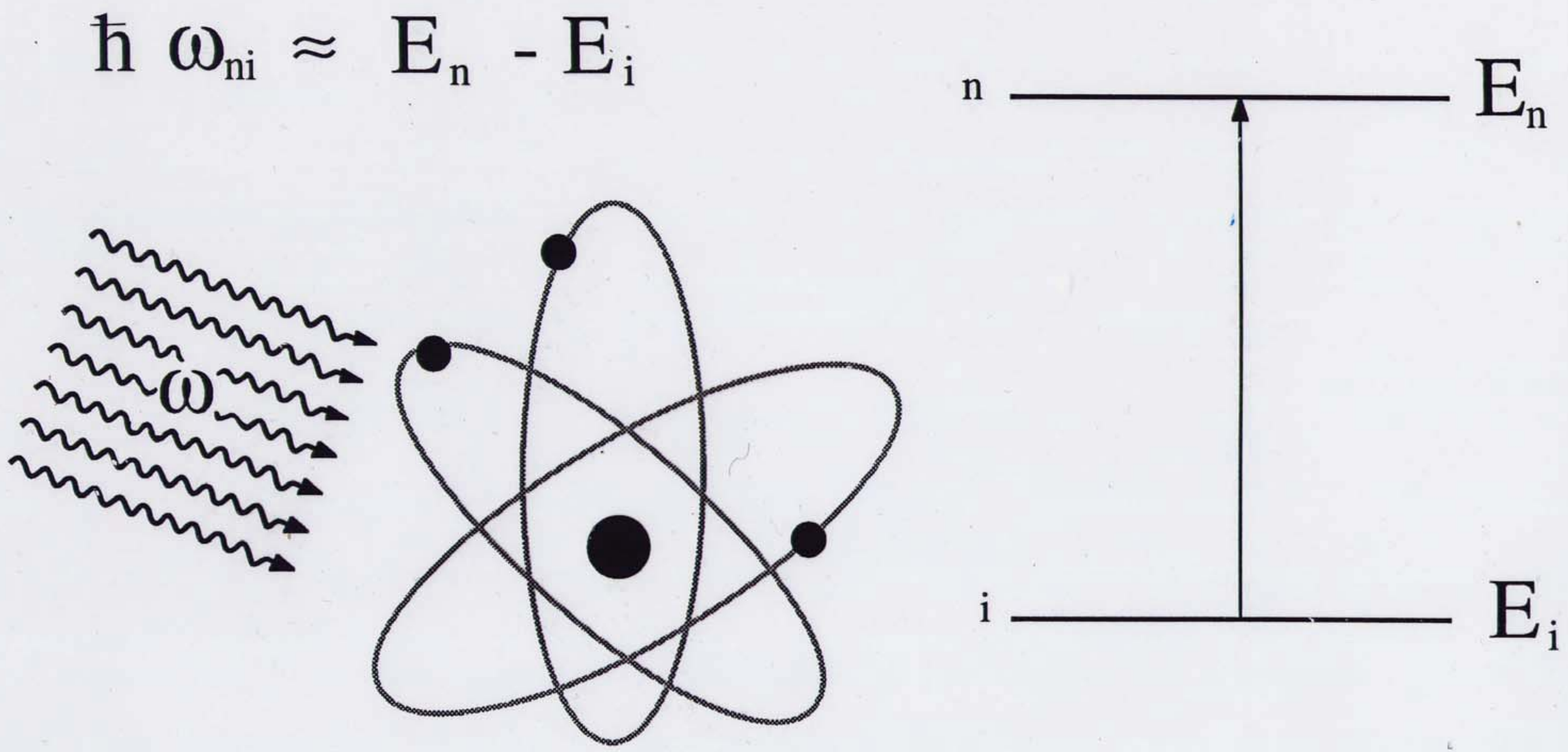
Curl, Kroto, Smalley 1996



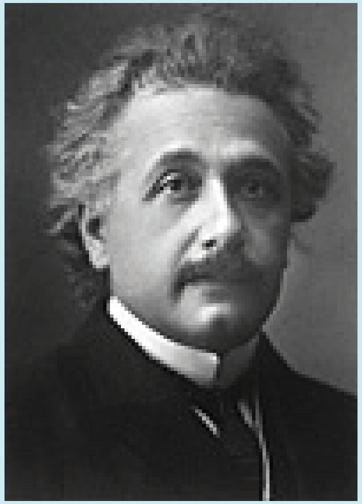


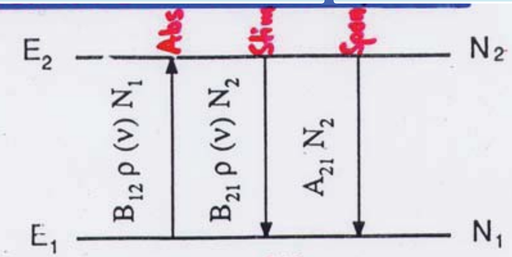


Dipole radiation



Radiative processes





Thermodynamic equilibrium:

$$\frac{dN_1}{dt} = -\frac{dN_2}{dt} = -B_{12}\rho(\nu)N_1 + B_{21}\rho(\nu)N_2 + A_{21}N_2 \qquad (4.21)$$

where $\rho(\nu)$ is the energy density of the radiation field per frequency interval, and $\nu = (E_2 - E_1)/h$. At equilibrium we have

$$\frac{dN_1}{dt} = \frac{dN_2}{dt} = 0 \qquad (4.22)$$

yielding

$$\rho(\nu) = \frac{A_{21}}{B_{12}(N_1/N_2) - B_{21}} . \qquad (4.23)$$

We now assume the system to be in thermodynamic equilibrium with the radiation field. The distribution of the atoms is governed by Boltzmann's law

$$\frac{N_1}{N_2} = \exp\left(\frac{h\nu}{kT}\right), \qquad (4.24)$$

Boltzmann

$$\rho(\nu) = \frac{A_{21}}{B_{12}(\exp\frac{h\nu}{kT}) - B_{21}} .$$

$$\rho(\nu) = \frac{16\pi^2\hbar\nu^3}{c^3}\frac{1}{\exp(h\nu/kT) - 1} \qquad (4.25)$$

Planck

we obtain the following relations between the three coefficients

$$B_{12} = B_{21}$$

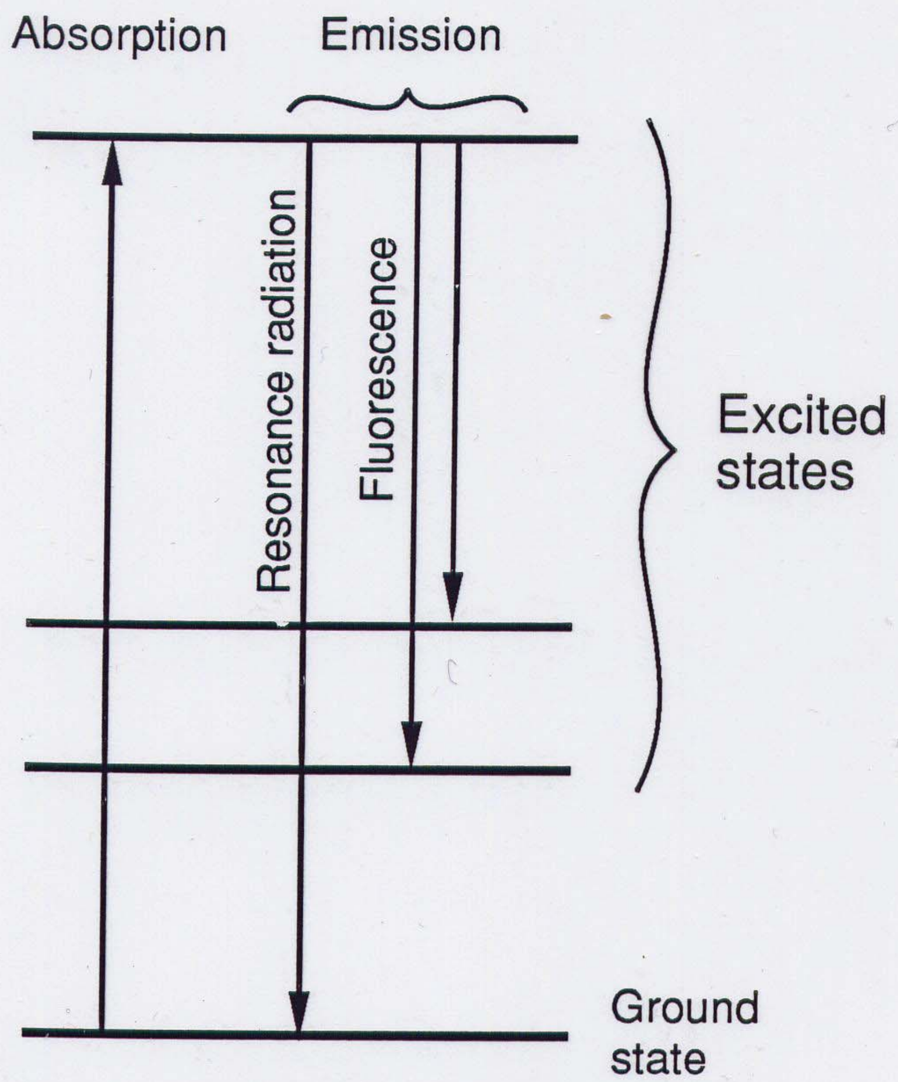
Indep. of $\rho(\nu)$!

$$\frac{A_{21}}{B_{21}} = \frac{16\pi^2\hbar\nu^3}{c^3}$$

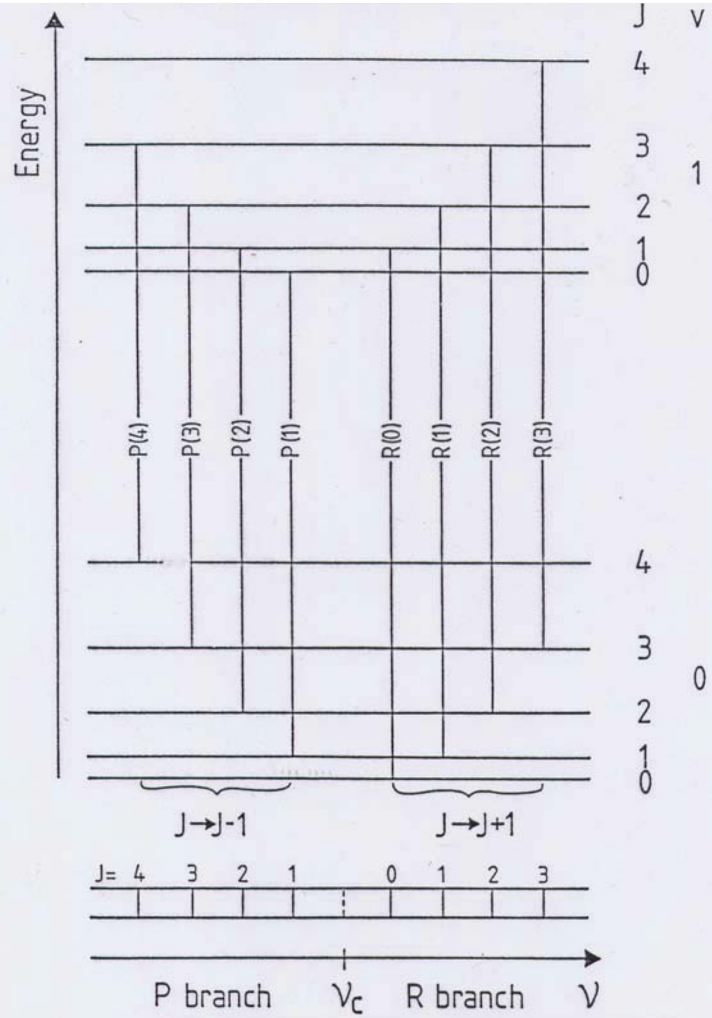
$A_{21} \sim B_{21}\nu^3$

$$A_{ik} = \frac{32\pi^3}{3}\frac{\nu^3}{4\pi\epsilon_0\hbar c^3}|\langle i|er|k\rangle|^2$$

Definitions



Vibrational-Rotational Spectra



$$E = (v + 1/2)h\nu_c + B'J(J+1)$$

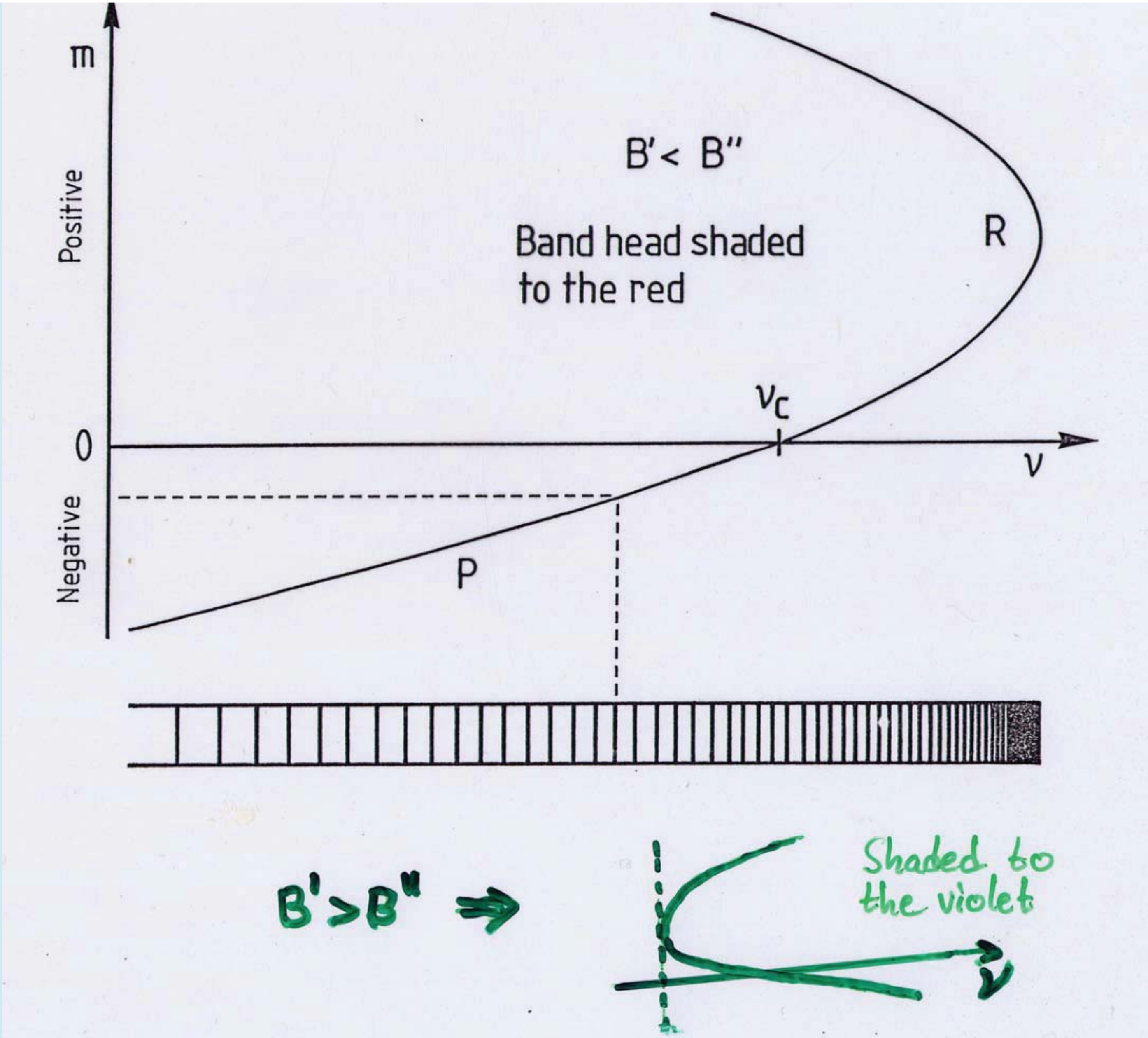
Selection rules: $\Delta v = \pm 1$, $\Delta J = \pm 1$

4.1

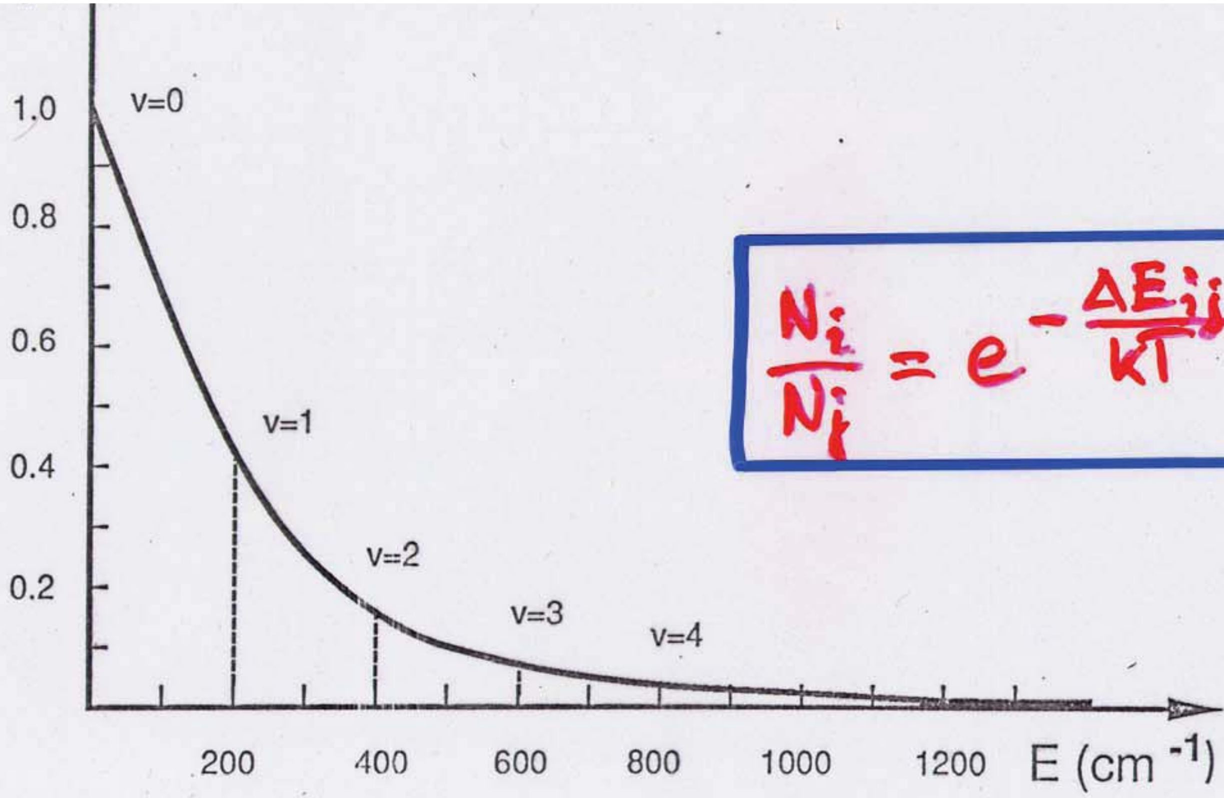
$\Delta E = h\nu_c + 2B'(J+1)$ $J \to J+1$; $J = 0,1\ldots$ R

$\Delta E = h\nu_c - 2B'J$ $J \to J-1$; $J = 1,2\ldots$ P

Fortrat parabola



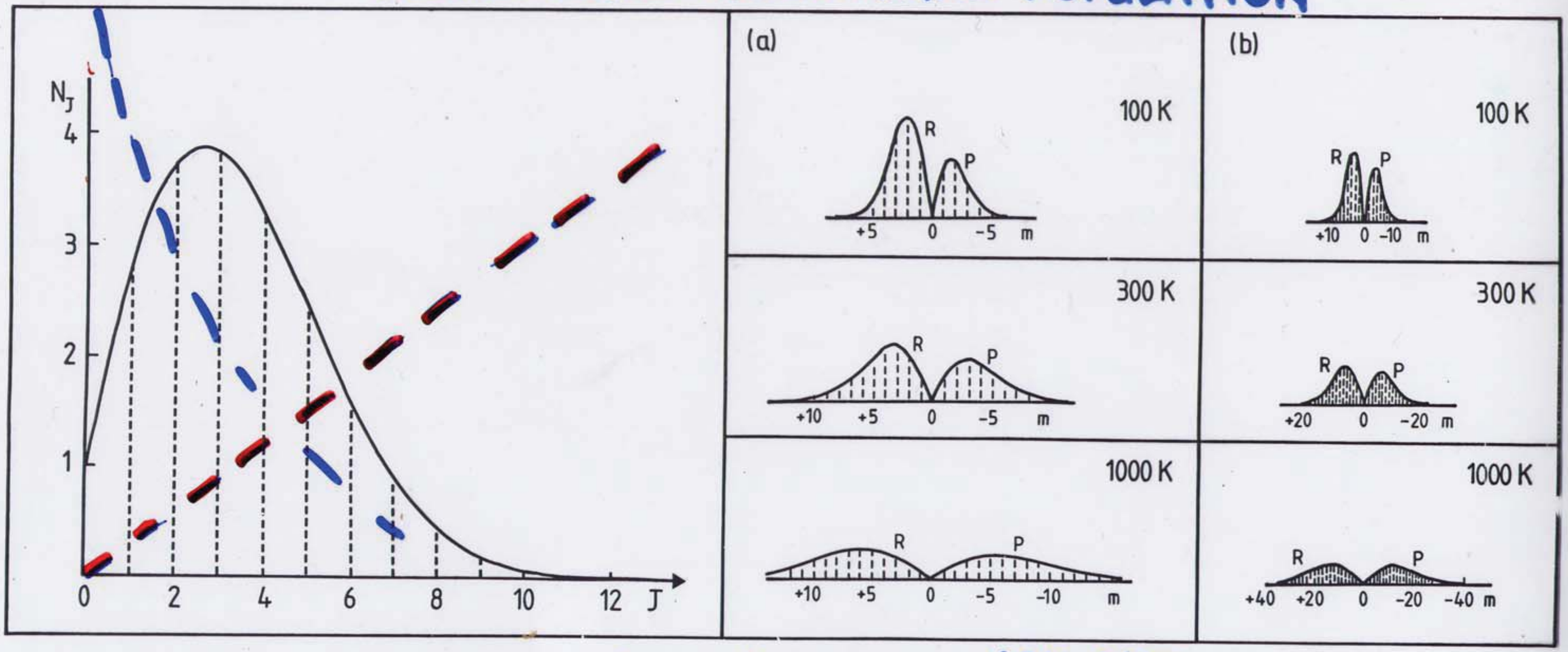
Vibrational thermal population
Iodine molecule



$$\frac{N_i}{N_j} = e^{-\frac{\Delta E_{ij}}{kT}}$$

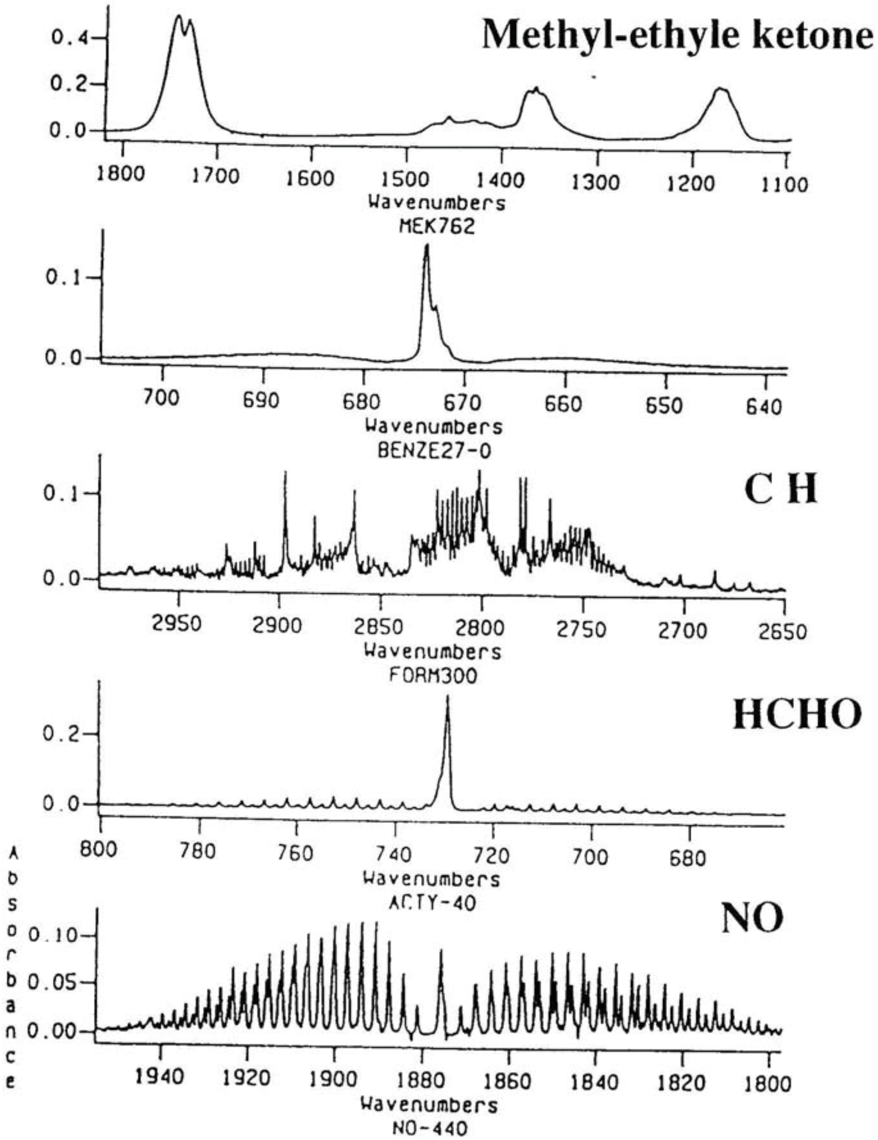
$$kT_{300} = \frac{1}{40}\ eV$$

VIBRATIONAL-ROTATIONAL POPULATION

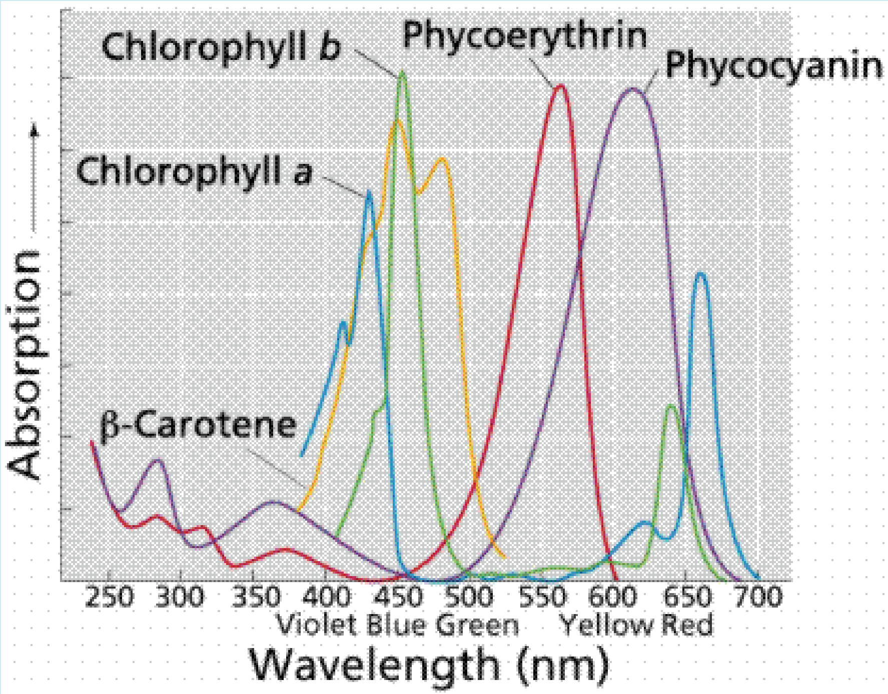


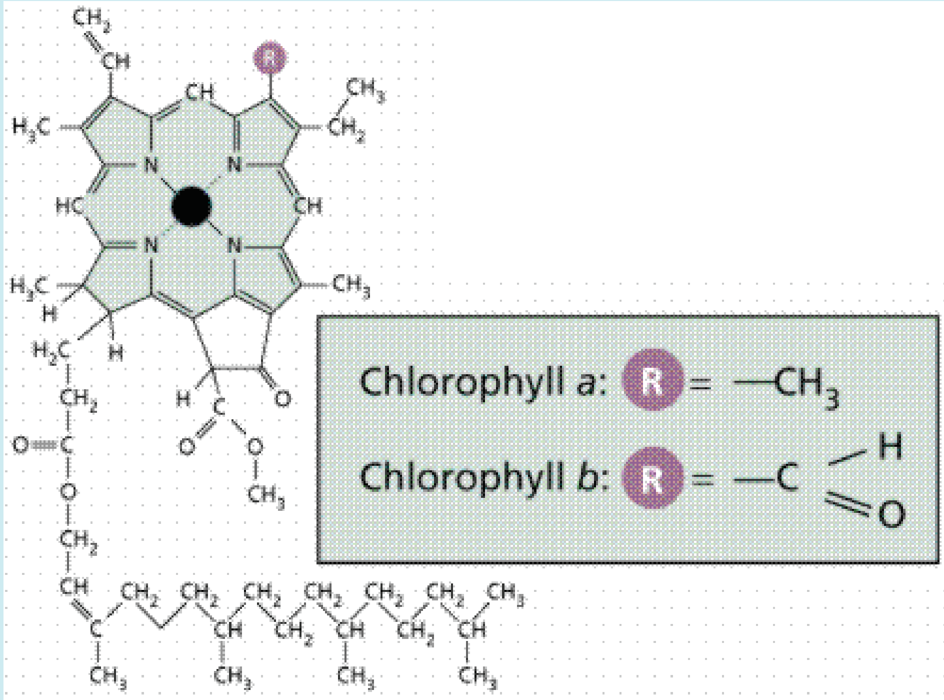
$$N_J = (2J+1)e^{-BJ(J+1)/kT}$$

Examples of absorption spectra

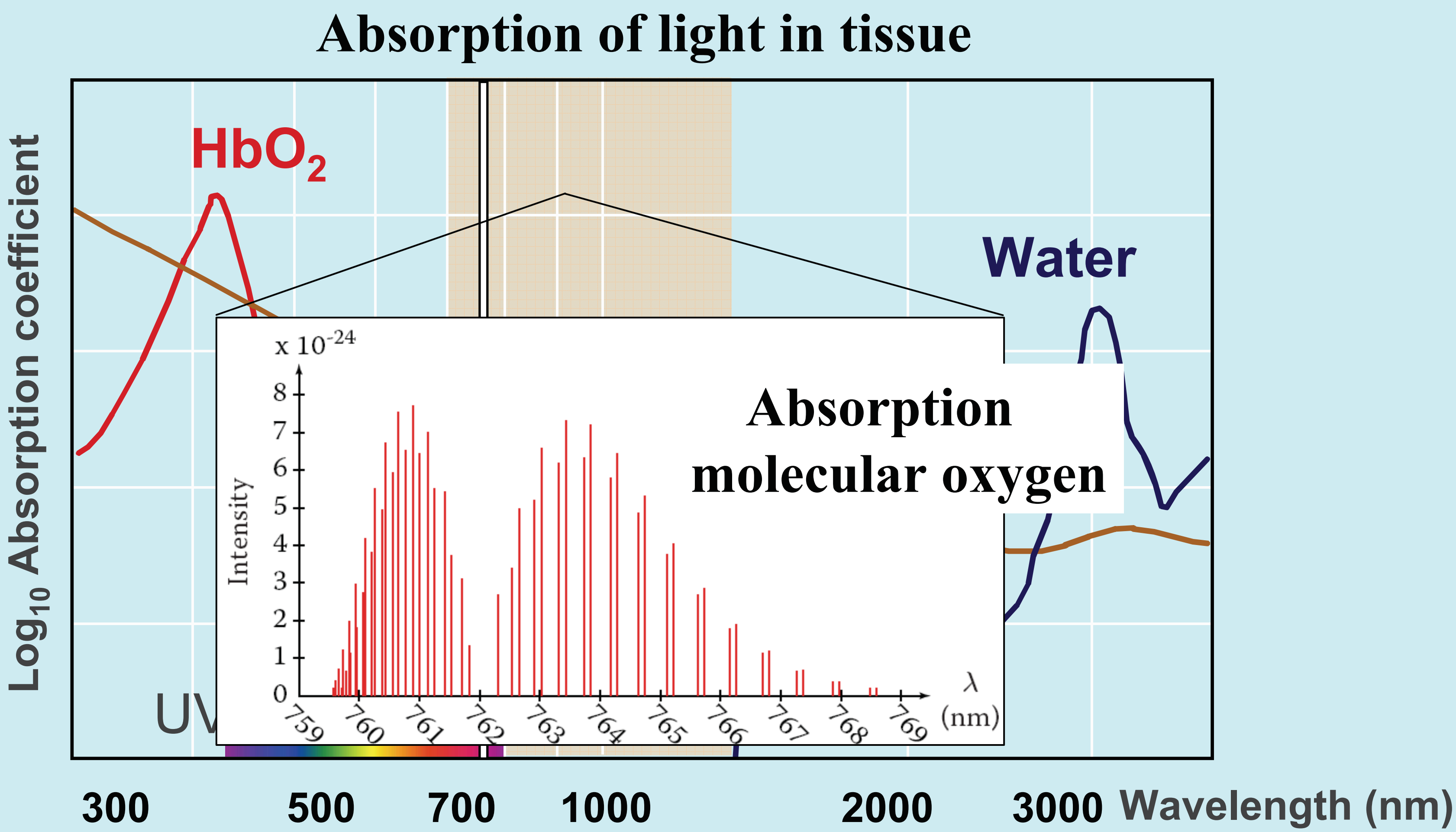


Photosynthetic pigments

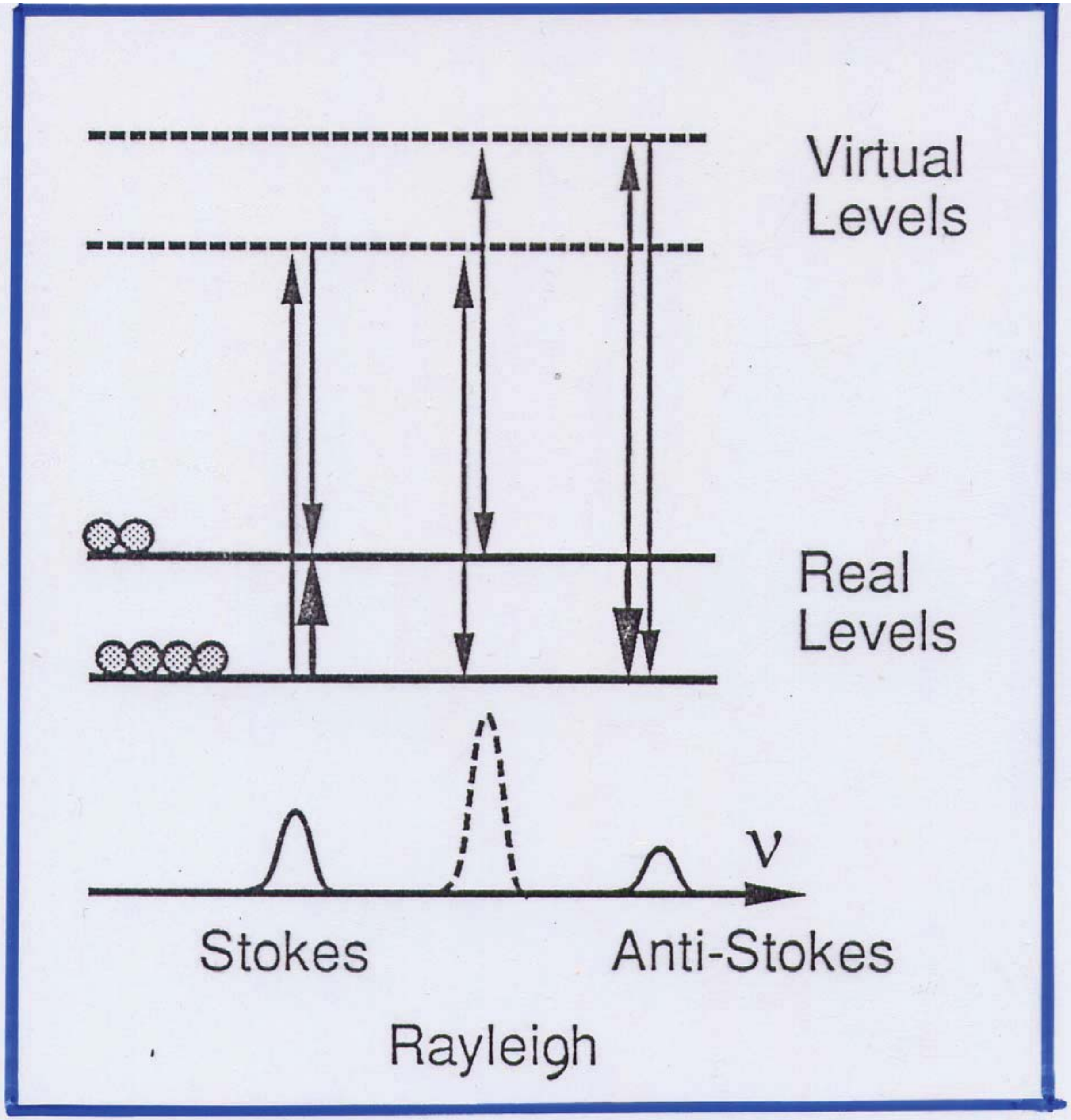




Tissue Absorption



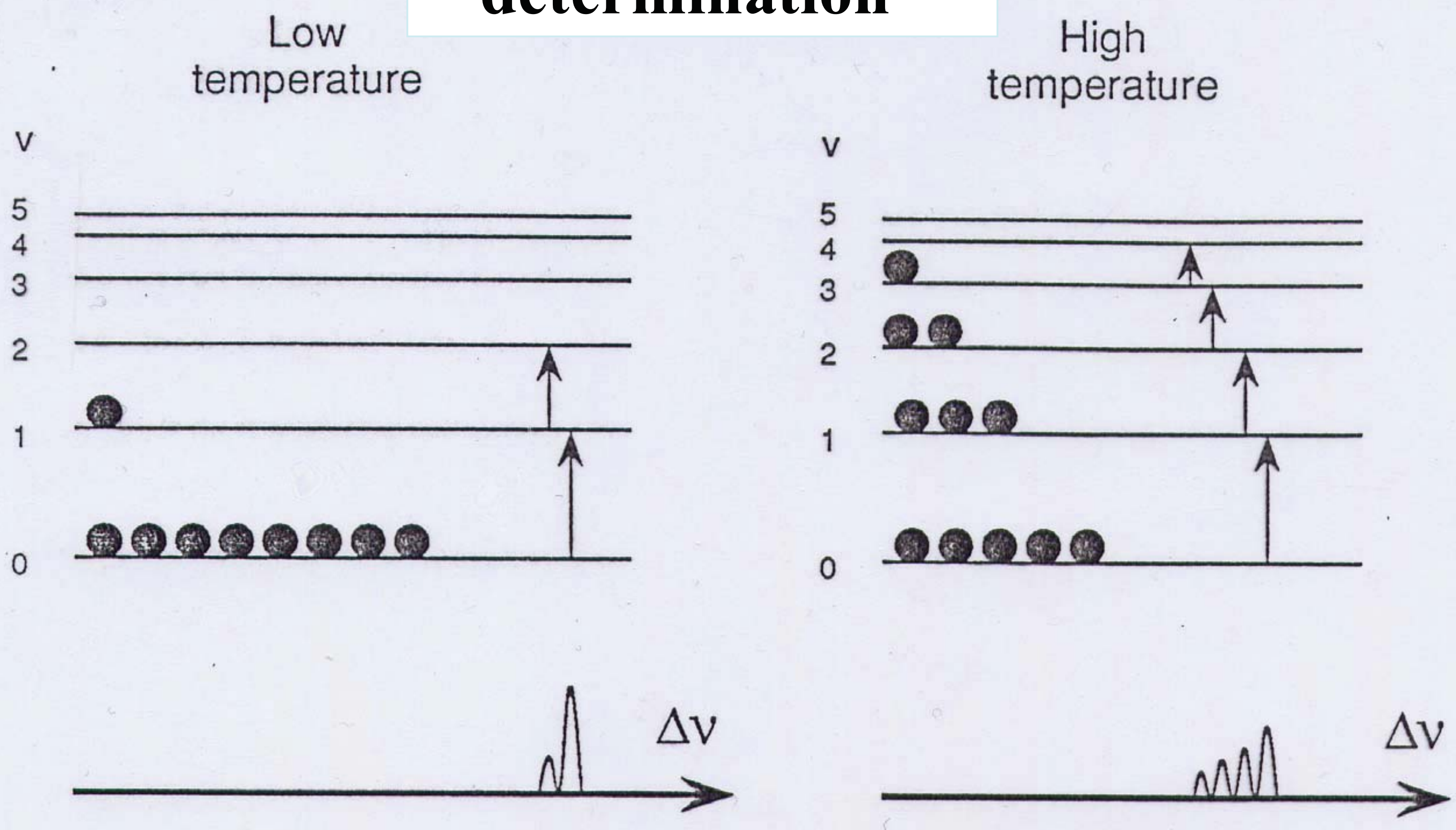
Raman Scattering

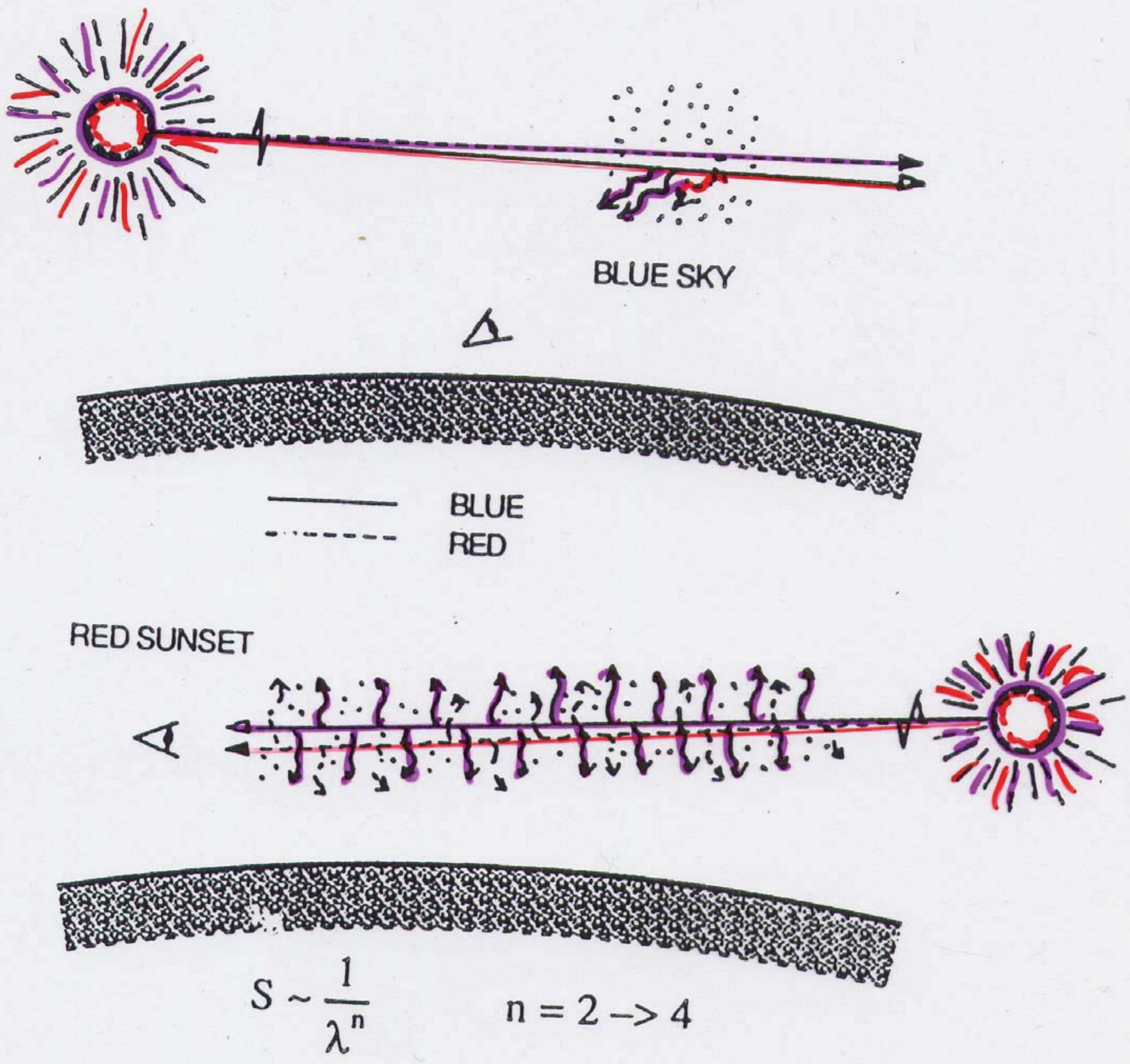


Vibrational Raman

$\Delta v = +/-1$

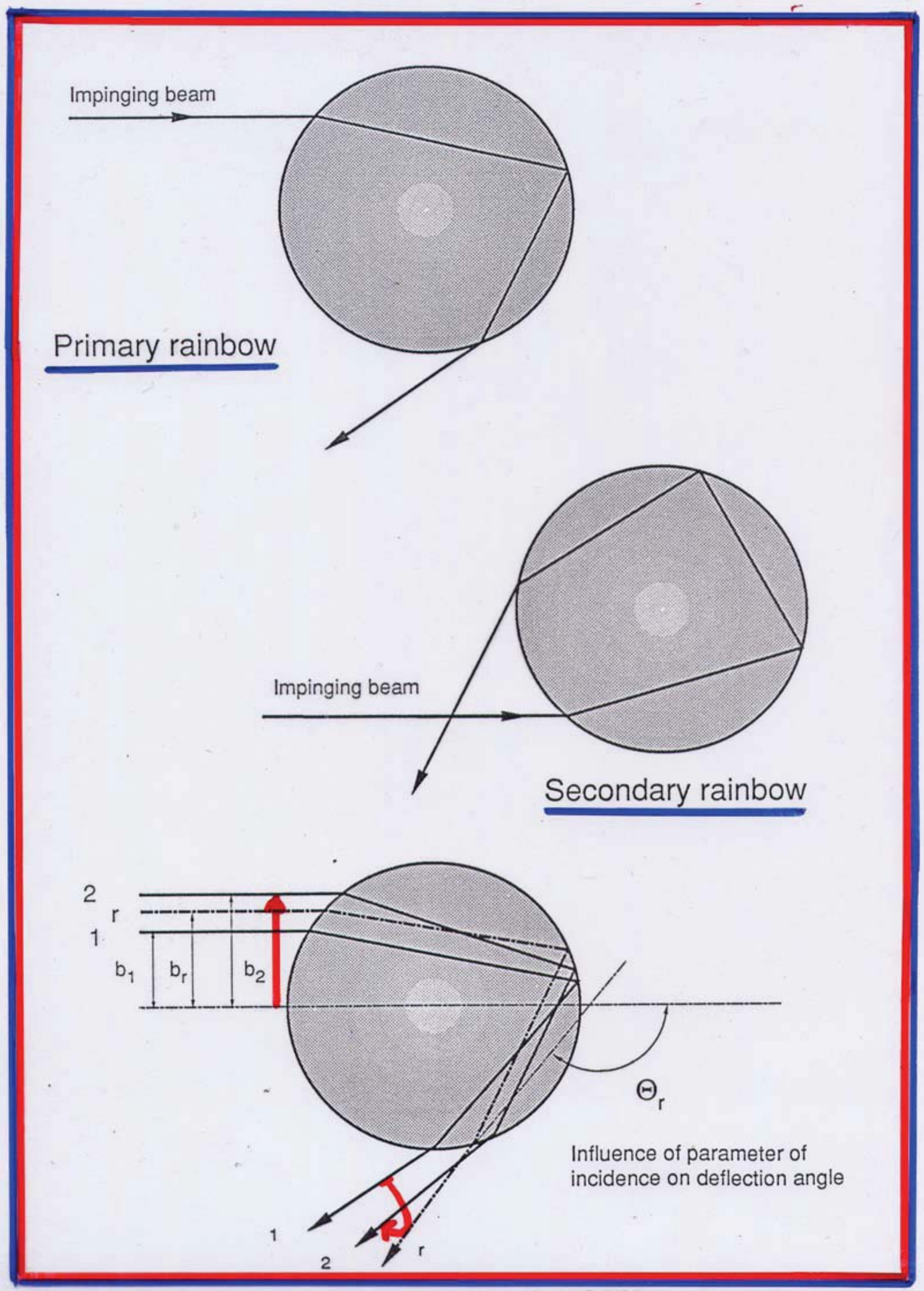
Temperature determination



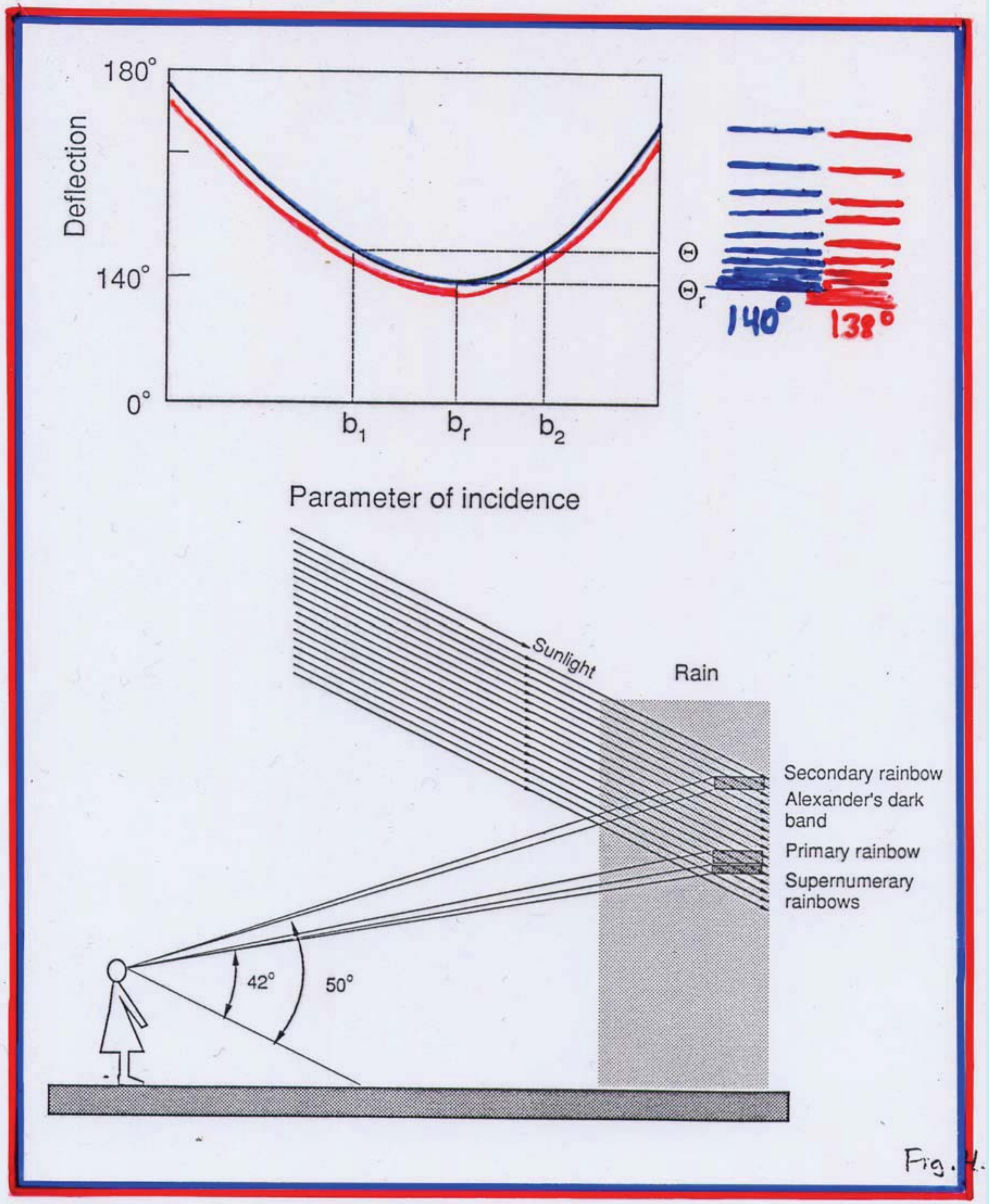


Atmospheric Scattering:

Blue sky
Red sunsets



Explanation of the rainbow


180°
Deflection
140°
0°
Θ
Θr
140°
138°
b1
br
b2
Parameter of incidence
Sunlight
Rain
Secondary rainbow
Alexander's dark band
Primary rainbow
Supernumerary rainbows
42°
50°
Fig. 4.

The rainbow(s)

Optical Spectroscopy

Light sources

Spectrometers

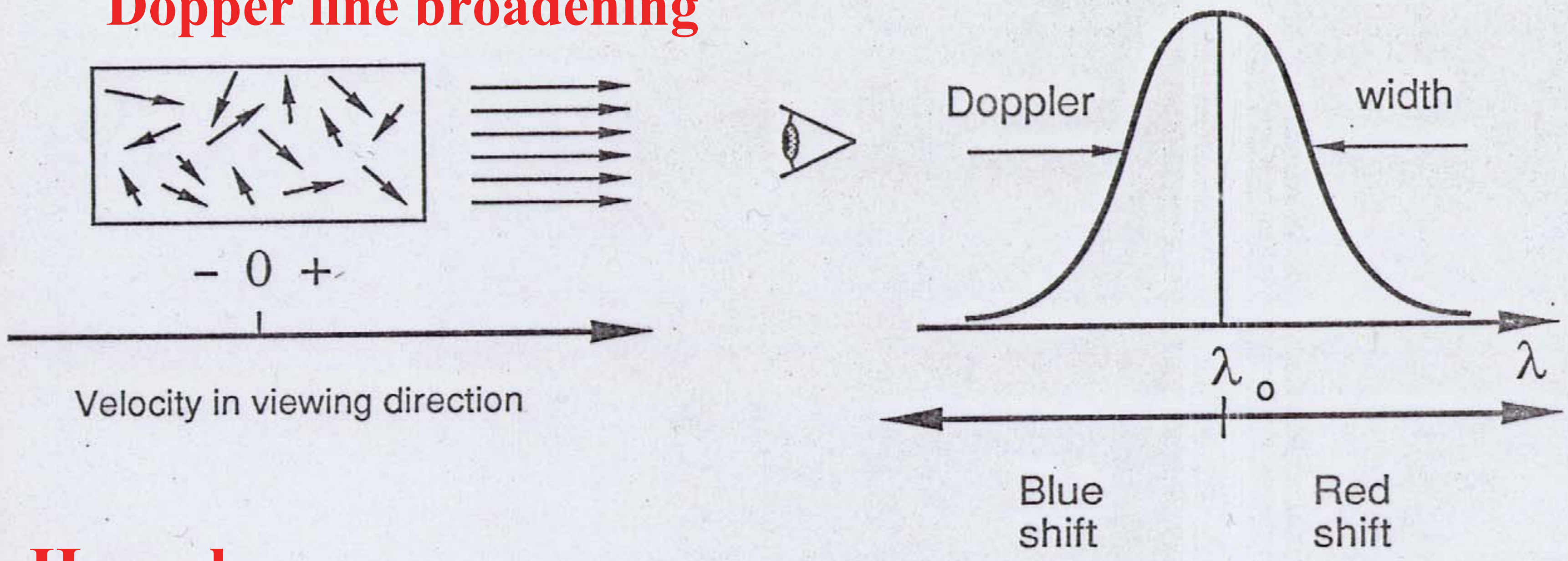
Detectors

Optical components

Transmission media

Applications

Dopper line broadening



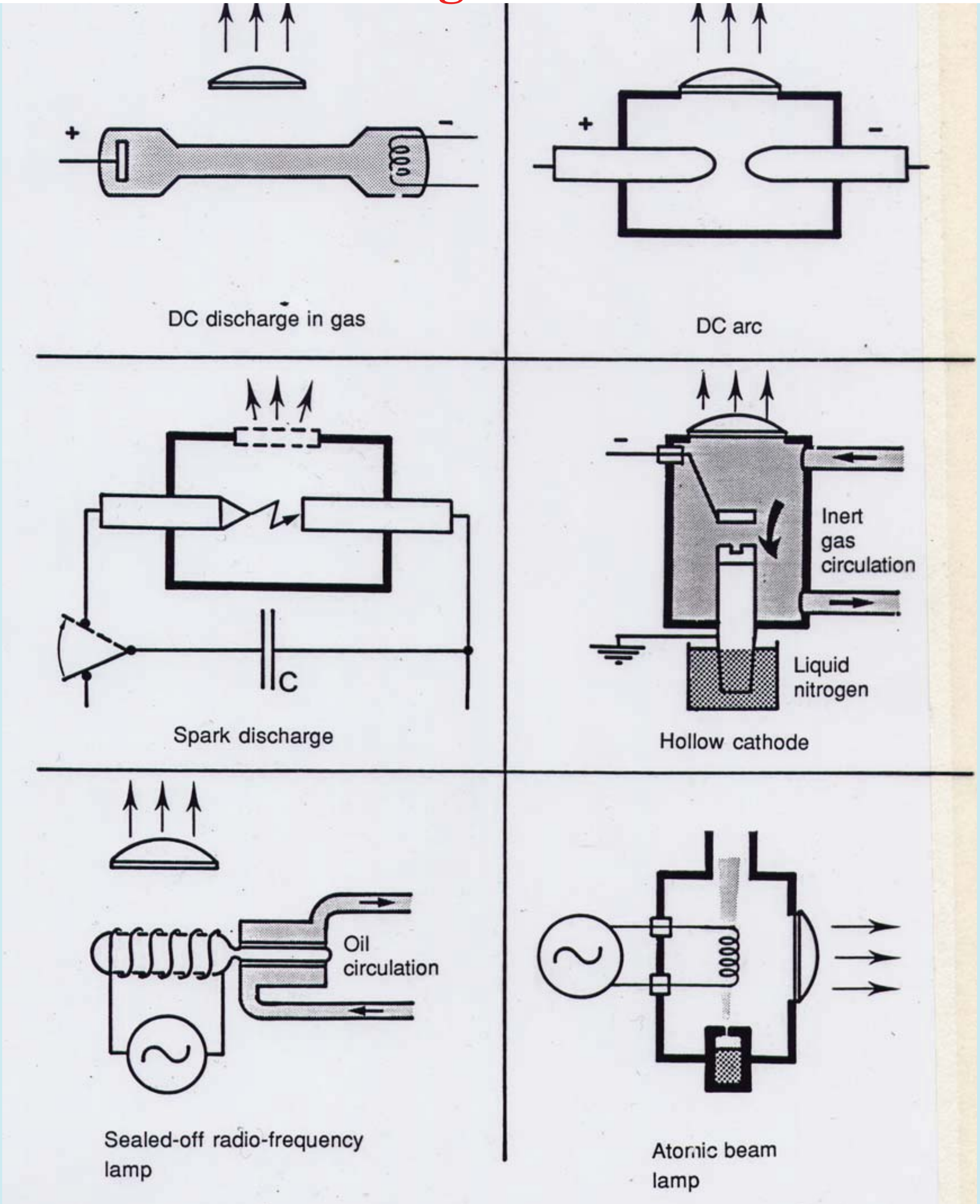
How sharp can the lines be?

$$\frac{\Delta\nu}{\nu} = \frac{v}{c} \approx \frac{3\cdot10^{2}}{3\cdot10^{8}} = 10^{-6}$$

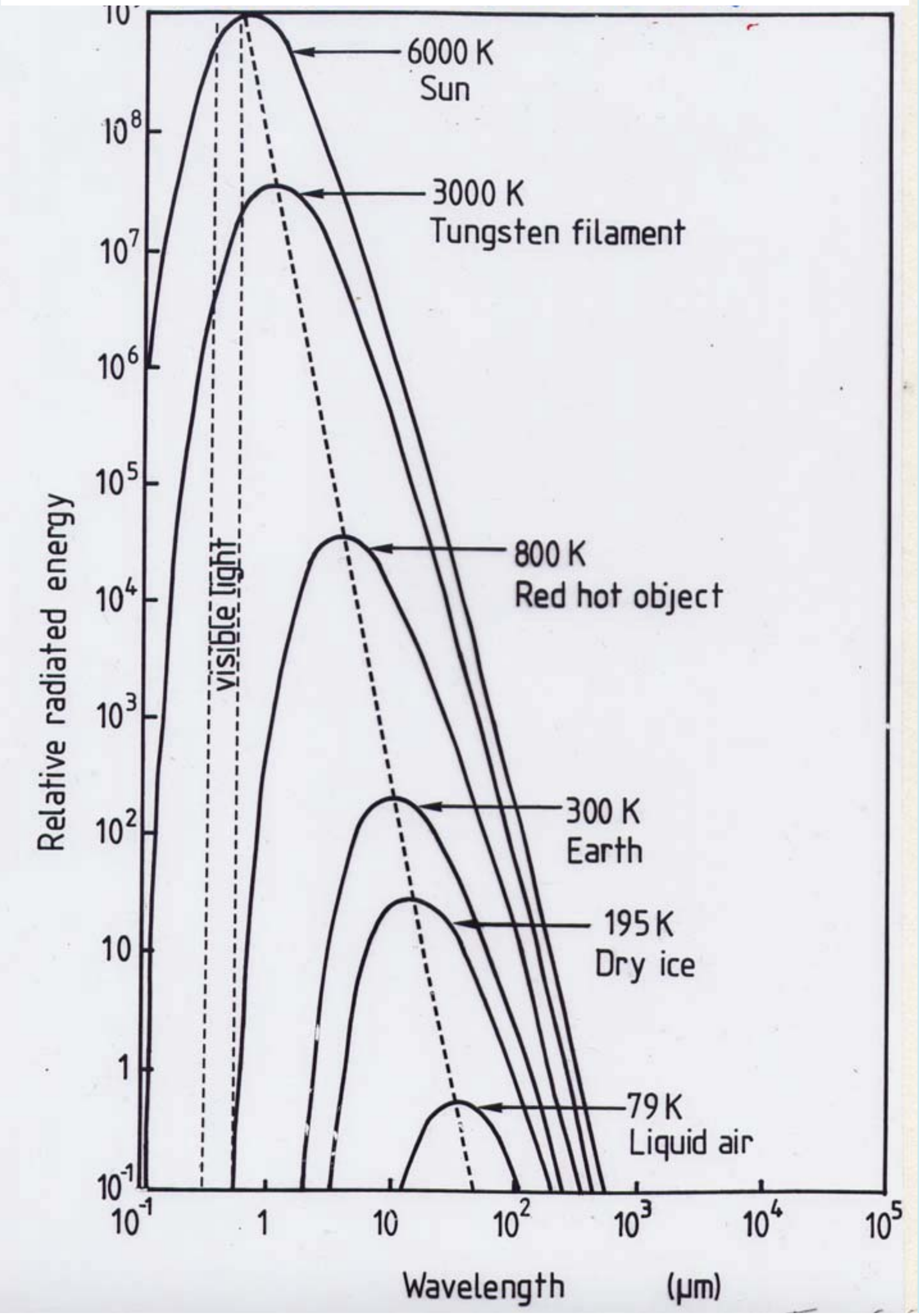
$\nu = 10^{15}$ Hz (visible light) $\rightarrow \Delta\nu = 10^{9}$ Hz

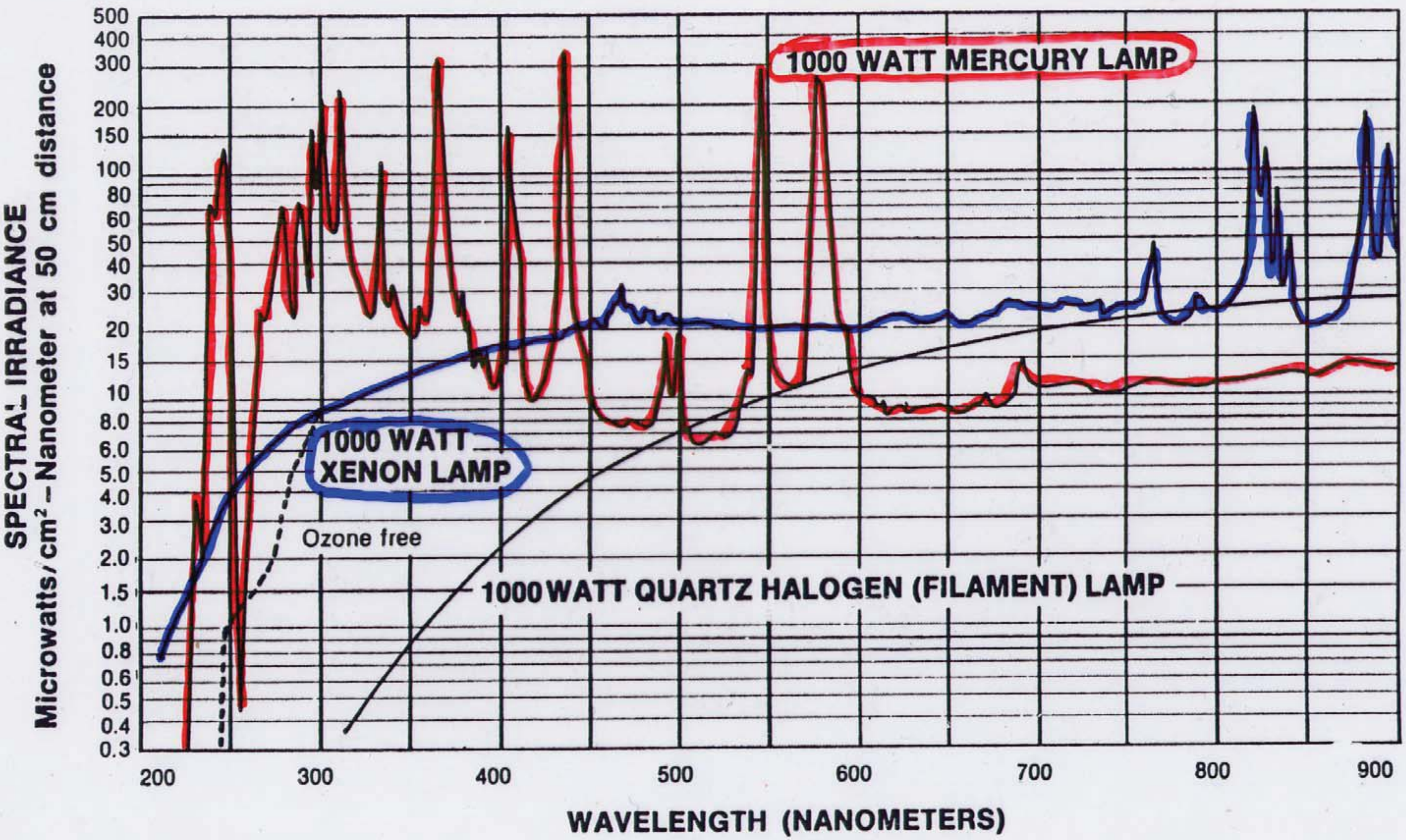
10^{9} Hz $\rightarrow$ 0,001 nm (visible)

Line Light Sources



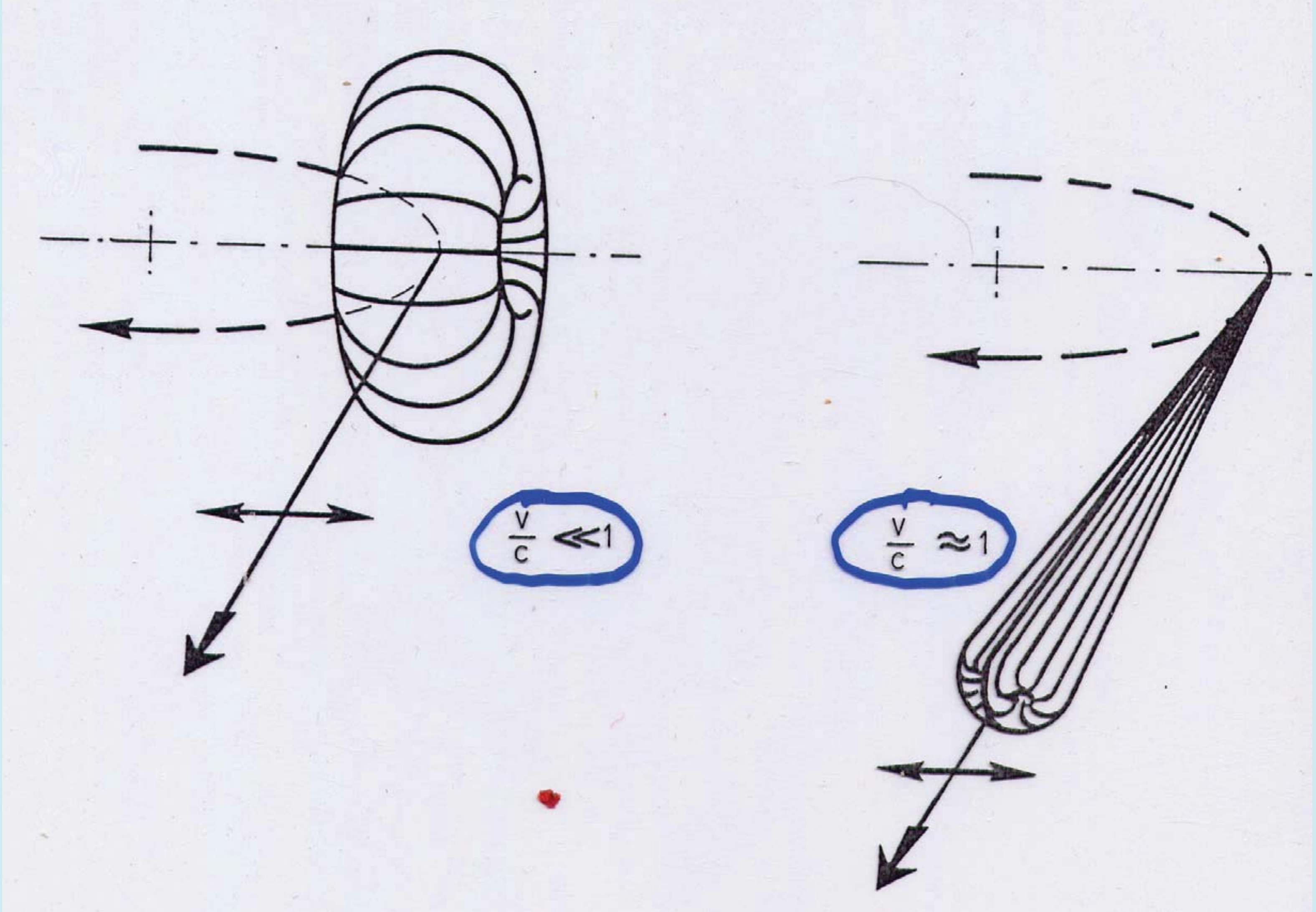
Planck radiator





1000 WATT MERCURY LAMP
1000 WATT XENON LAMP
Ozone free
1000 WATT QUARTZ HALOGEN (FILAMENT) LAMP
SPECTRAL IRRADIANCE
Microwatts/cm² – Nanometer at 50 cm distance
500
400
300
200
150
100
80
60
50
40
30
20
15
10
8.0
6.0
5.0
4.0
3.0
2.0
1.5
1.0
0.8
0.6
0.5
0.4
0.3
200
300
400
500
600
700
800
900
WAVELENGTH (NANOMETERS)

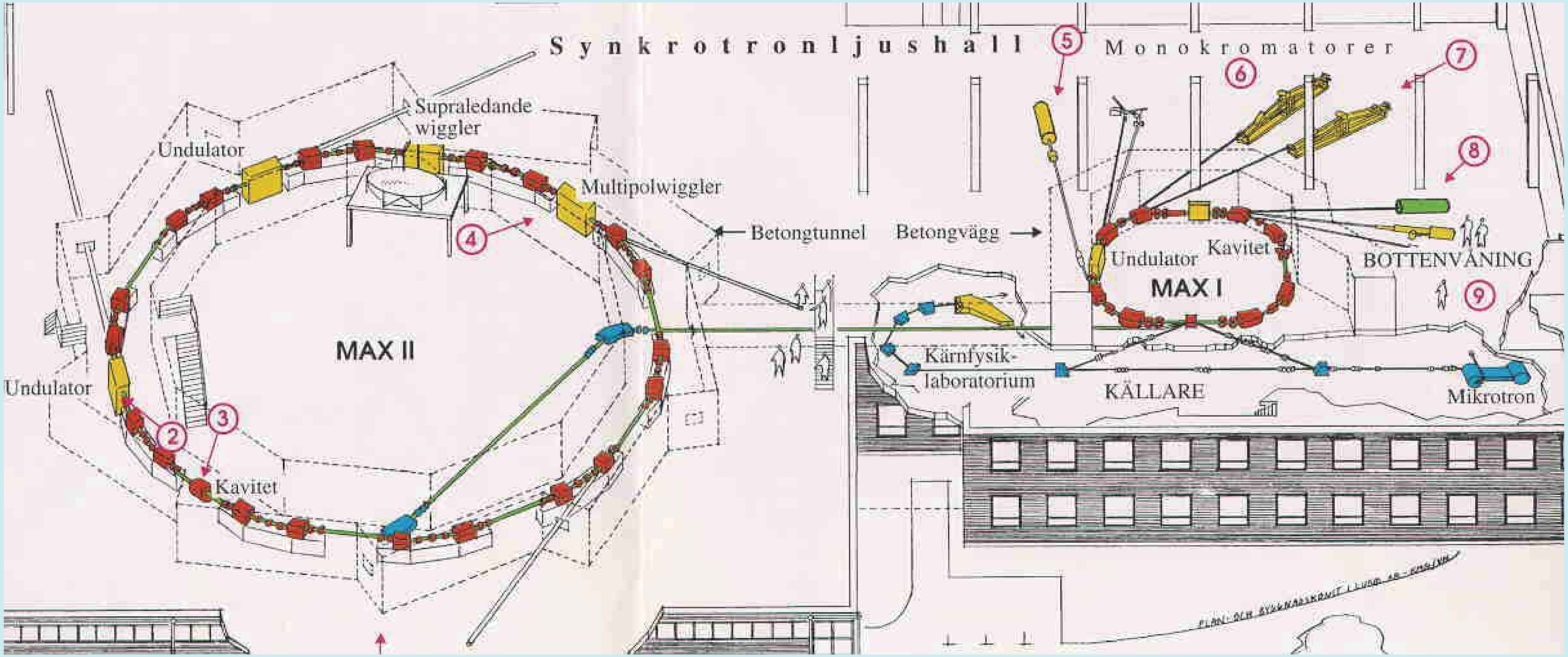
Synchrotron radiation



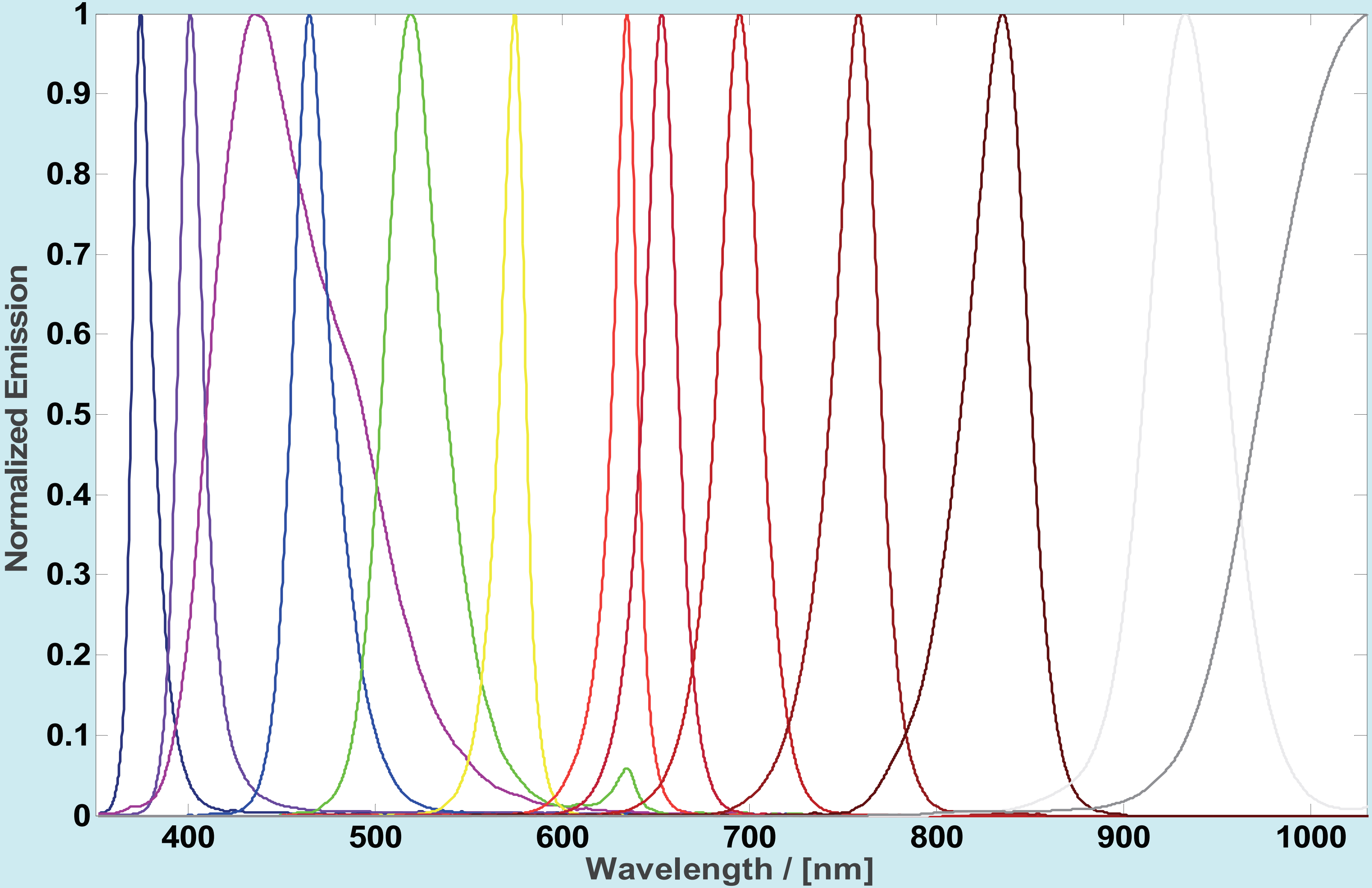
MAX-lab

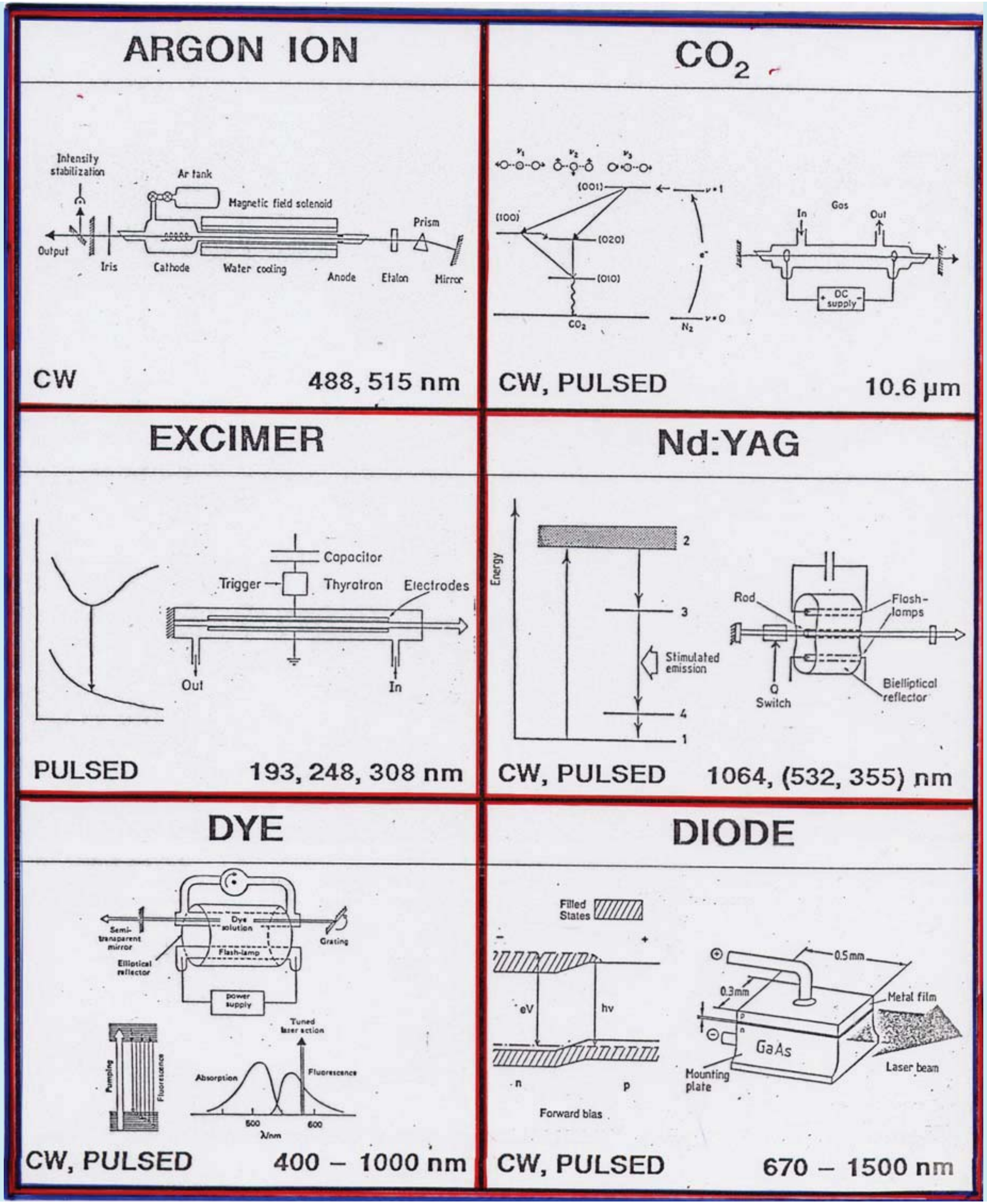
MAX-I 500 MeV MAX-II 1.5 GeV

30 m diameter



Light-emitting diodes (LEDs)




ARGON ION
Intensity stabilization
Ar tank
Magnetic field solenoid
Prism
Output
Iris
Cathode
Water cooling
Anode
Etalon
Mirror
CW
488, 515 nm
CO2
(001)
(100)
(020)
(010)
CO2
N2
Gas
In
Out
DC supply
CW, PULSED
10.6 μm
EXCIMER
Capacitor
Trigger
Thyratron
Electrodes
Out
In
PULSED
193, 248, 308 nm
Nd:YAG
Energy
2
3
Stimulated emission
4
1
Rod
Flash-lamps
Q Switch
Bielliptical reflector
CW, PULSED
1064, (532, 355) nm
DYE
Semi-transparent mirror
Dye solution
Flash-lamp
Grating
Elliptical reflector
power supply
Pumping
Fluorescence
Tuned laser action
Absorption
Fluorescence
500
600
λ/nm
CW, PULSED
400 – 1000 nm
DIODE
Filled States
eV
hv
n
p
Forward bias
0.5 mm
0.3 mm
Metal film
GaAs
Mounting plate
Laser beam
CW, PULSED
670 – 1500 nm

LASERS

ICTP Winter School on Optics
in Environmental Science
2009

Fundamentals of Optical Spectroscopy
Part 3

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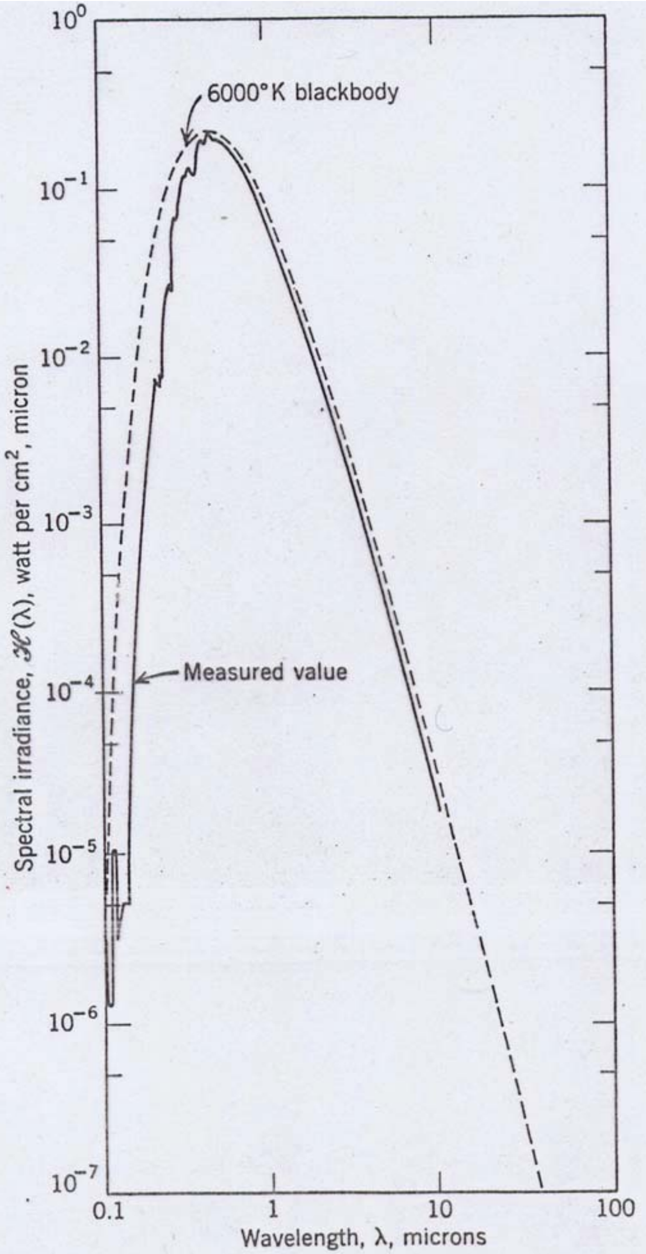
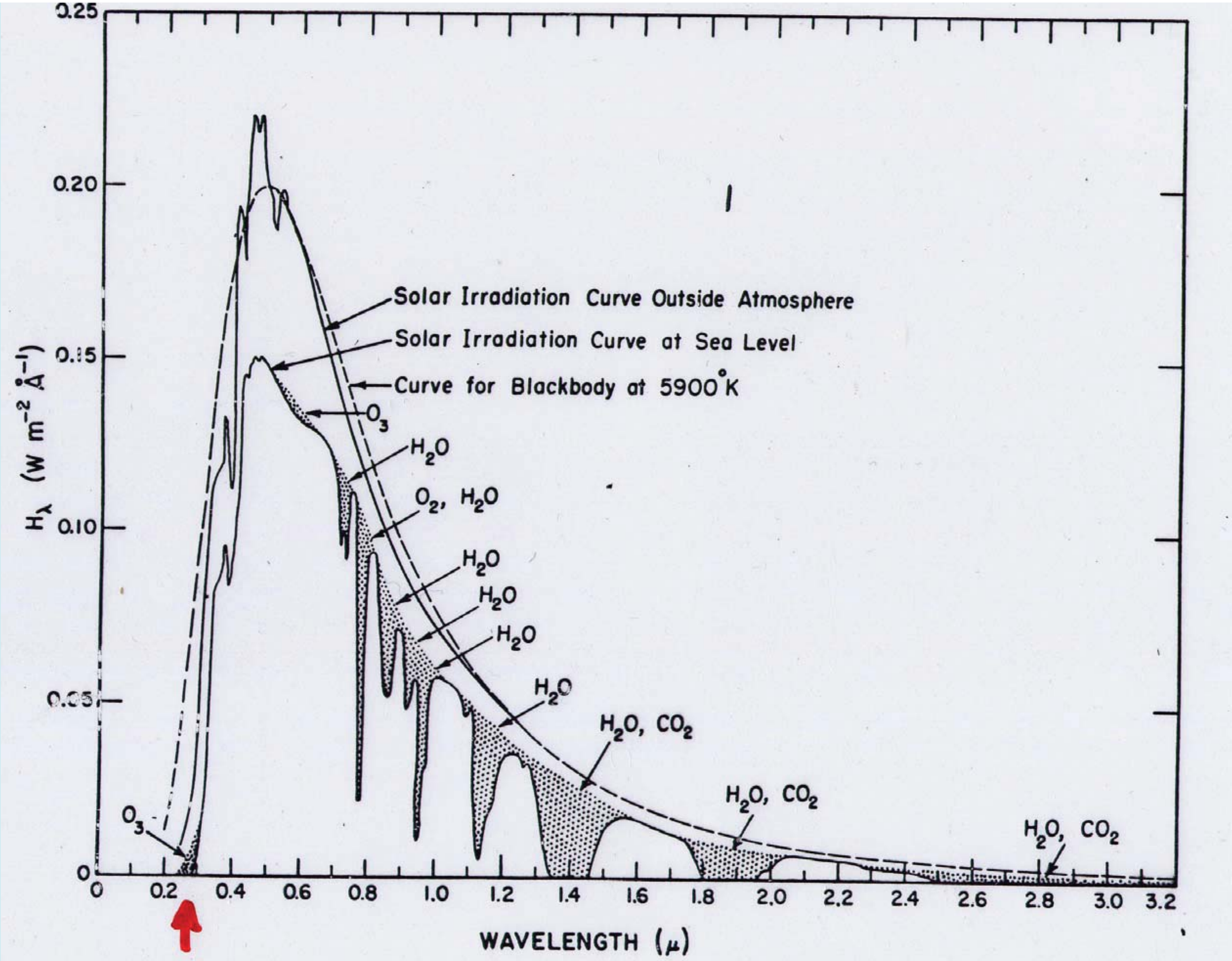
Sweden

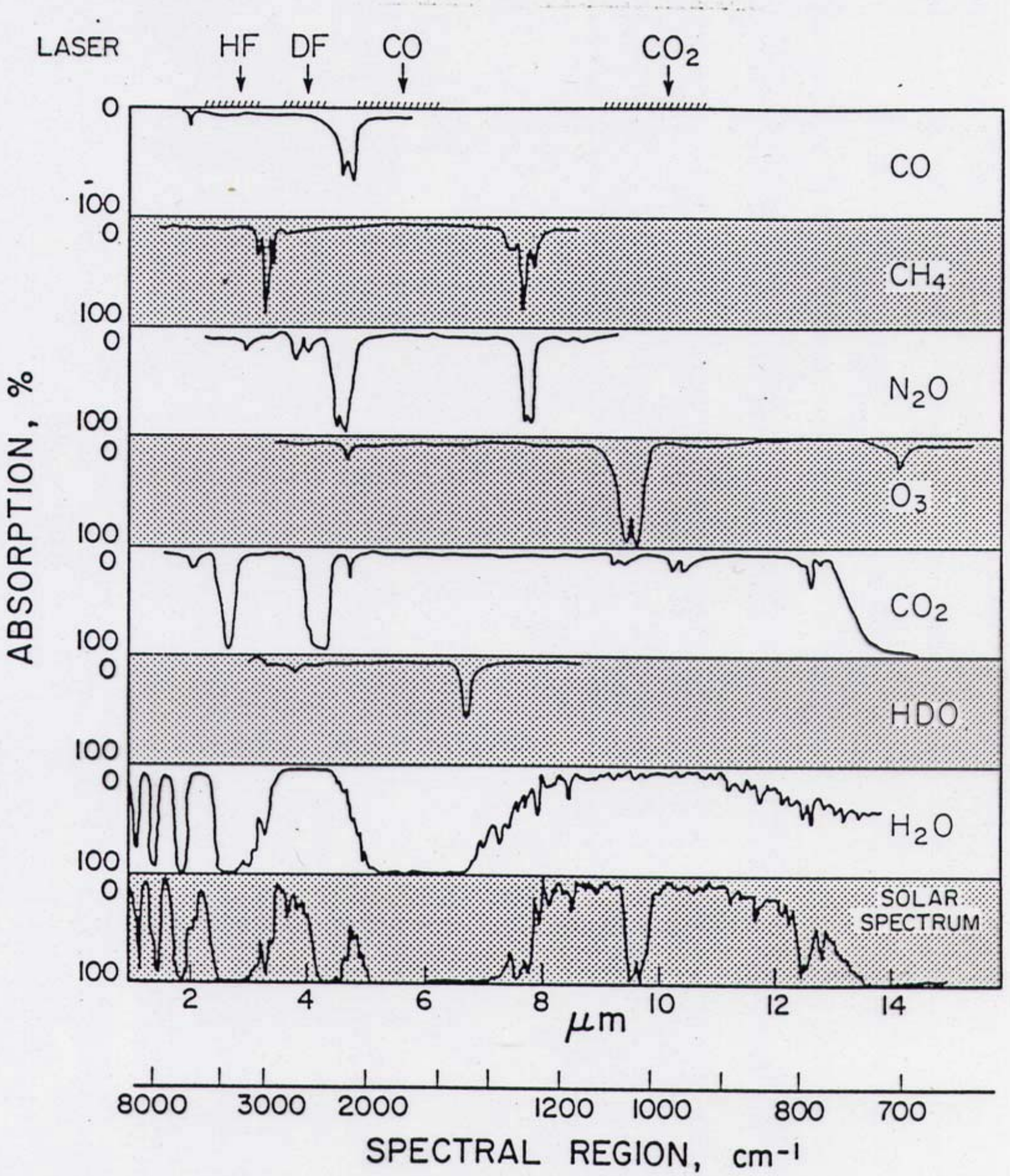
Spectral distribution of sunlight



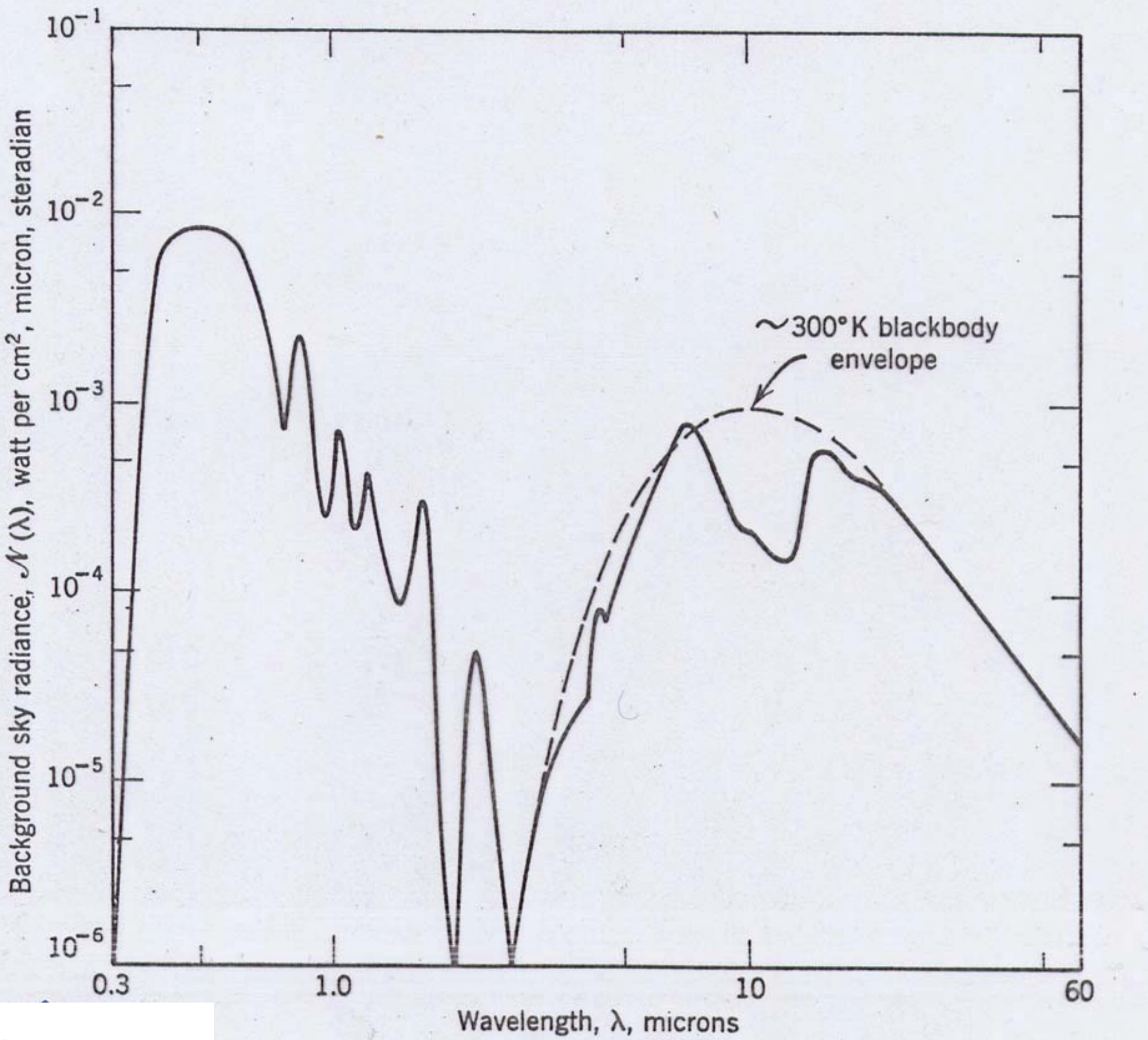
Sun spectrum



Atmospheric vertical absorption and its origin

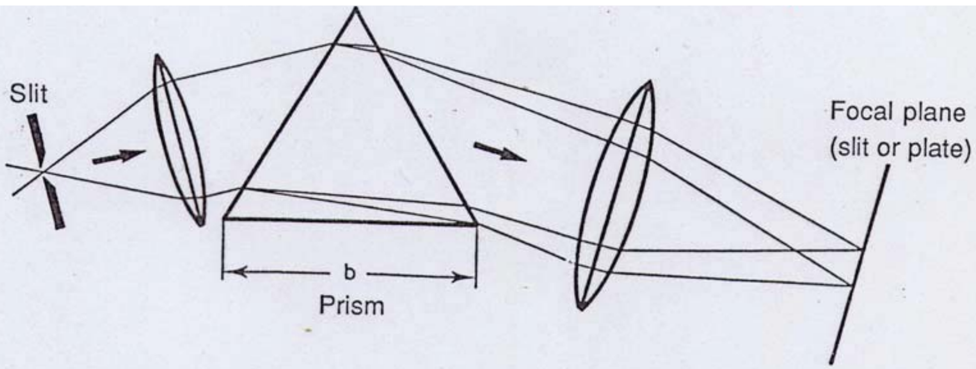


Spectral distribution of the blue sky

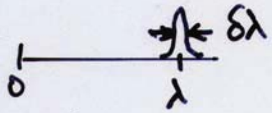


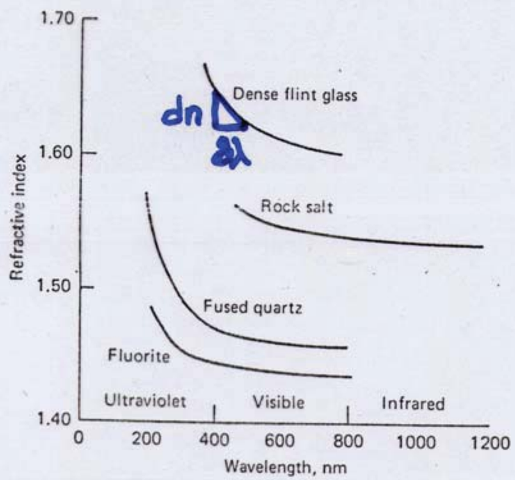
Ozone absorption

Prism spectrometer

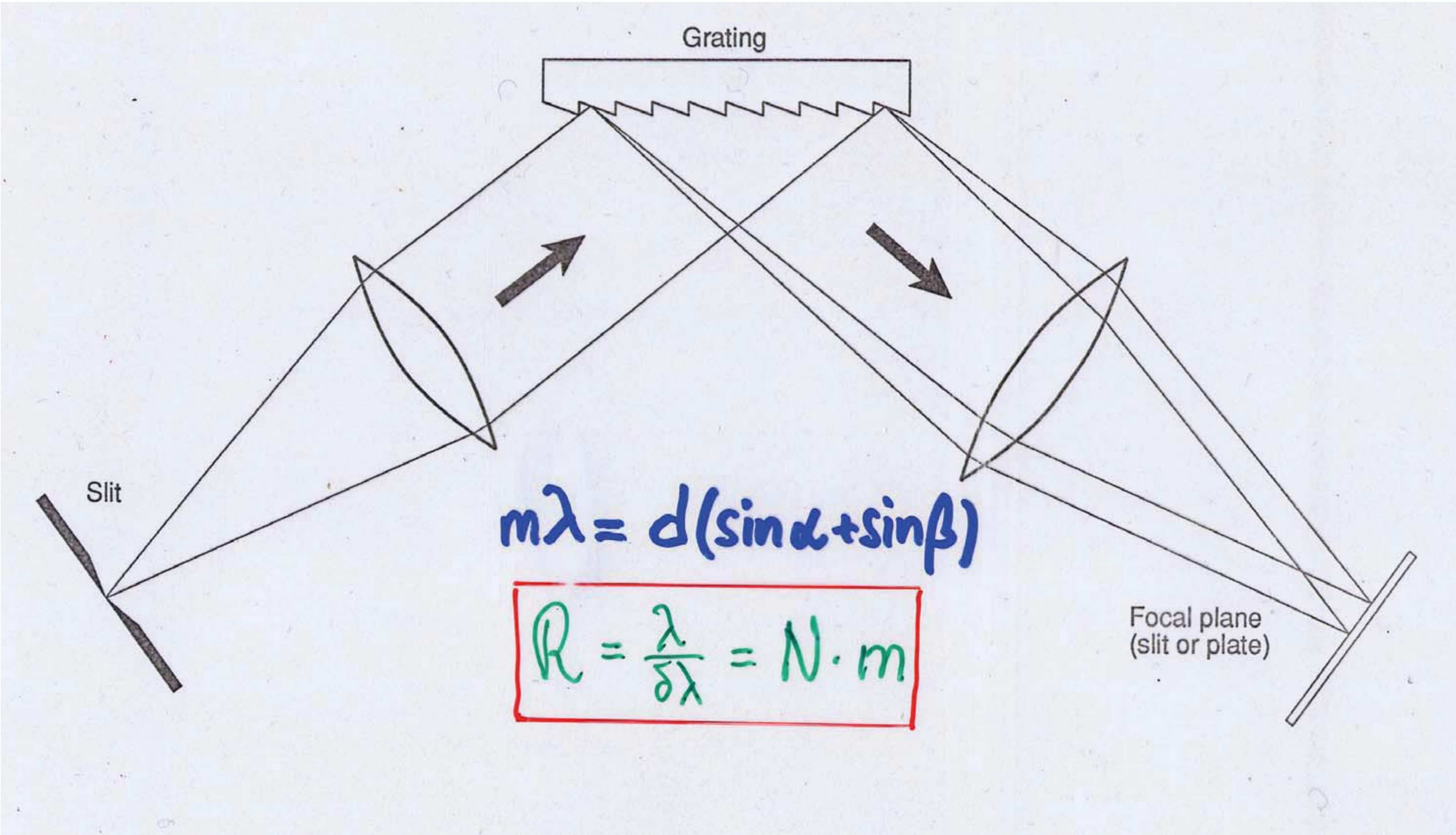


$$R = \frac{\lambda}{\delta\lambda} = b\,\frac{dn}{d\lambda}$$

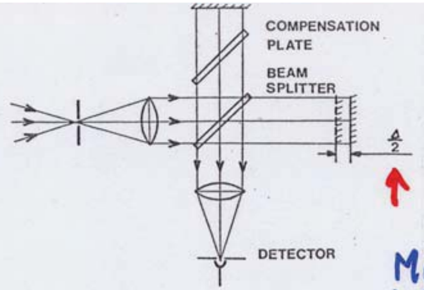




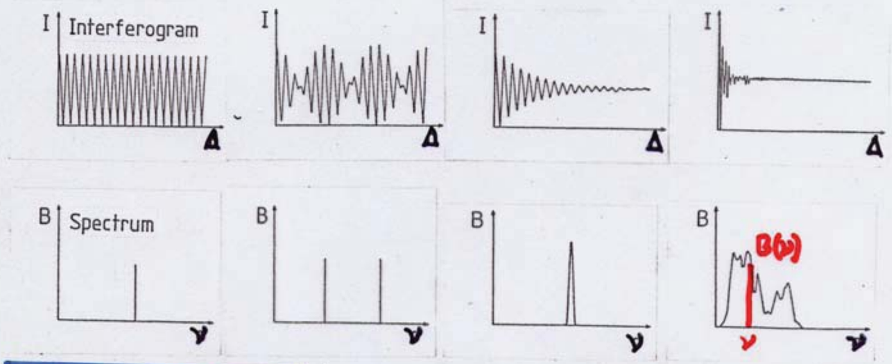
Grating spectrometer



Fourier transform spectrometer



Michelson interferometer



$$I(\Delta) = I_0 \cos^2 \frac{\varphi}{2}$$

$$\varphi = \frac{\Delta}{\lambda} 2\pi = \frac{\Delta}{c} 2\pi\nu$$

for single frequency. Superposition princ. →

$$I(\Delta) = \int_0^\infty B(\nu) \cos^2\left(\frac{\Delta}{c}\pi\nu\right) d\nu = \frac{1}{2}\int_0^\infty B(\nu)\left[1+\cos\left(\frac{\Delta}{c}2\pi\nu\right)\right] d\nu$$

$$J(\Delta) = \frac{1}{2}\int_0^\infty B(\nu) \cos\left\{\frac{\Delta}{c} 2\pi\nu\right\} d\nu$$

Interferogram

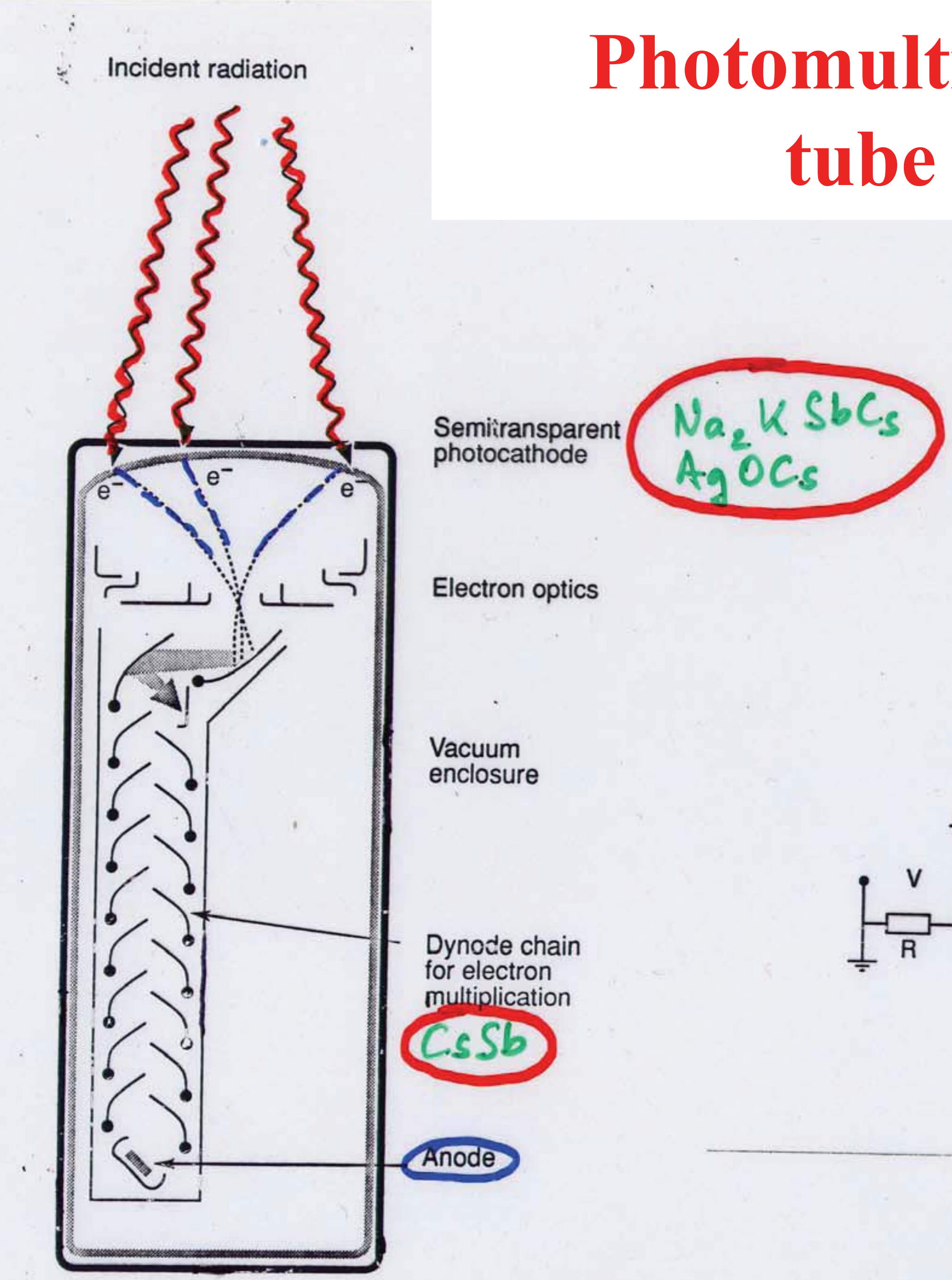
$$B(\nu) \propto \int_0^\infty J(\Delta) \cos\left\{\frac{\Delta}{c} 2\pi\nu\right\} d\Delta$$

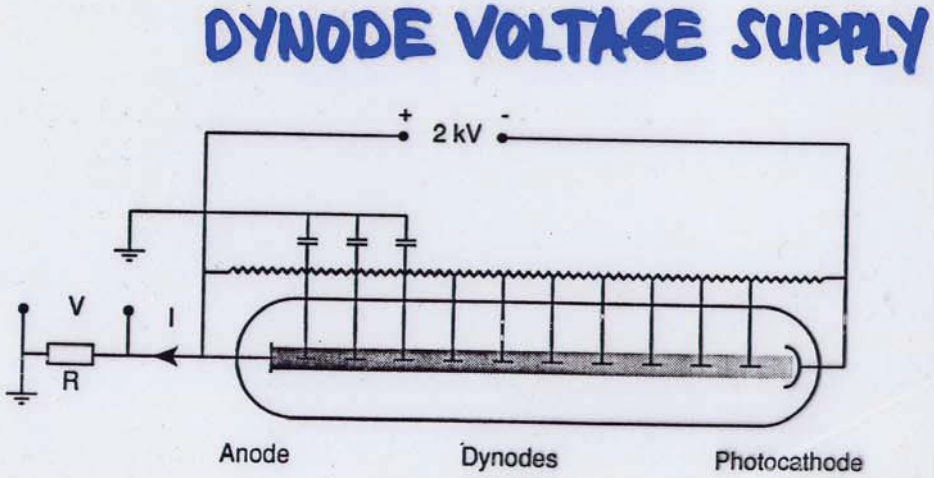
Spectrum

APODIZATION

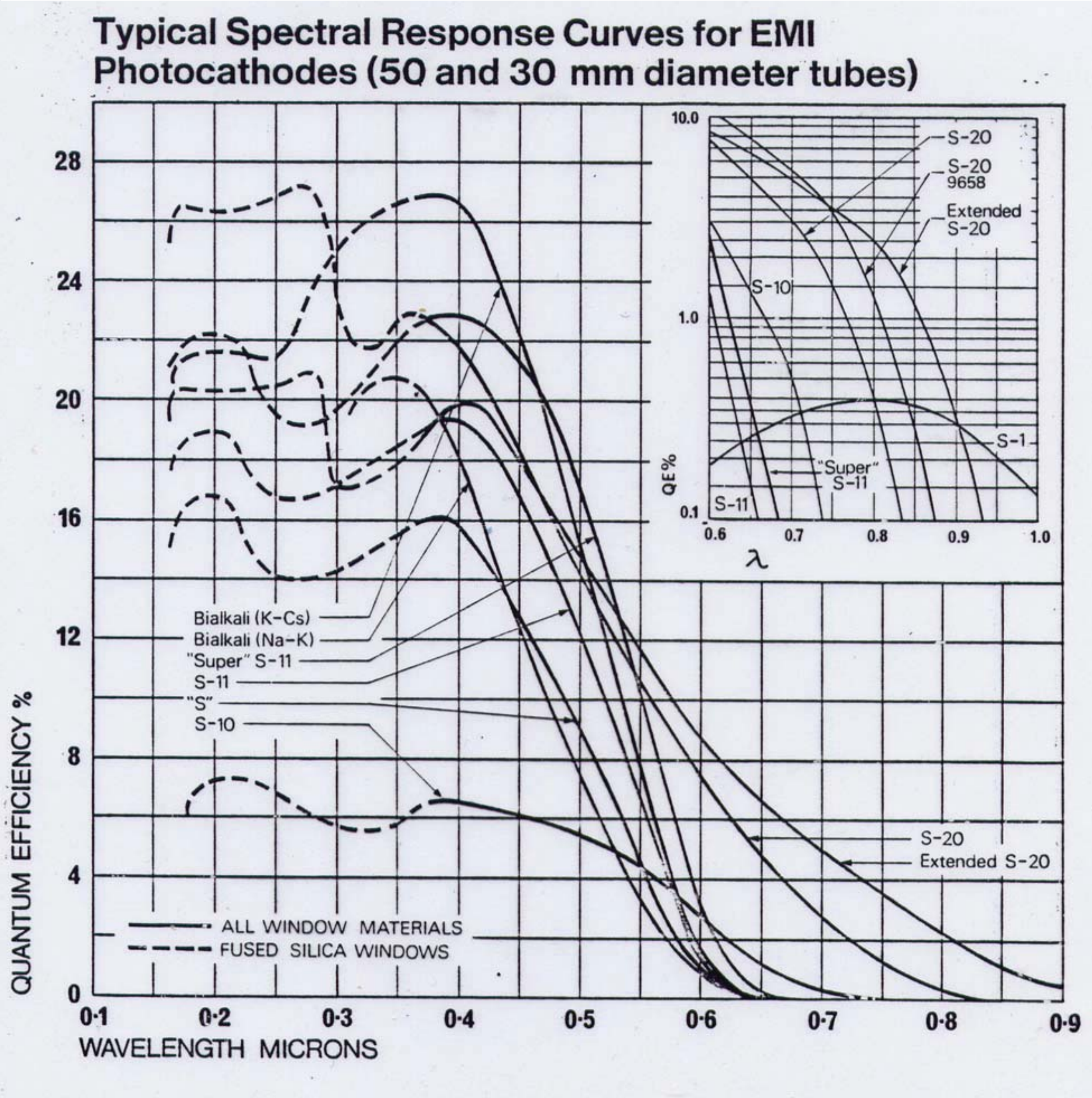
Felgett, Jaquinot } advantage

Photomultiplier tube



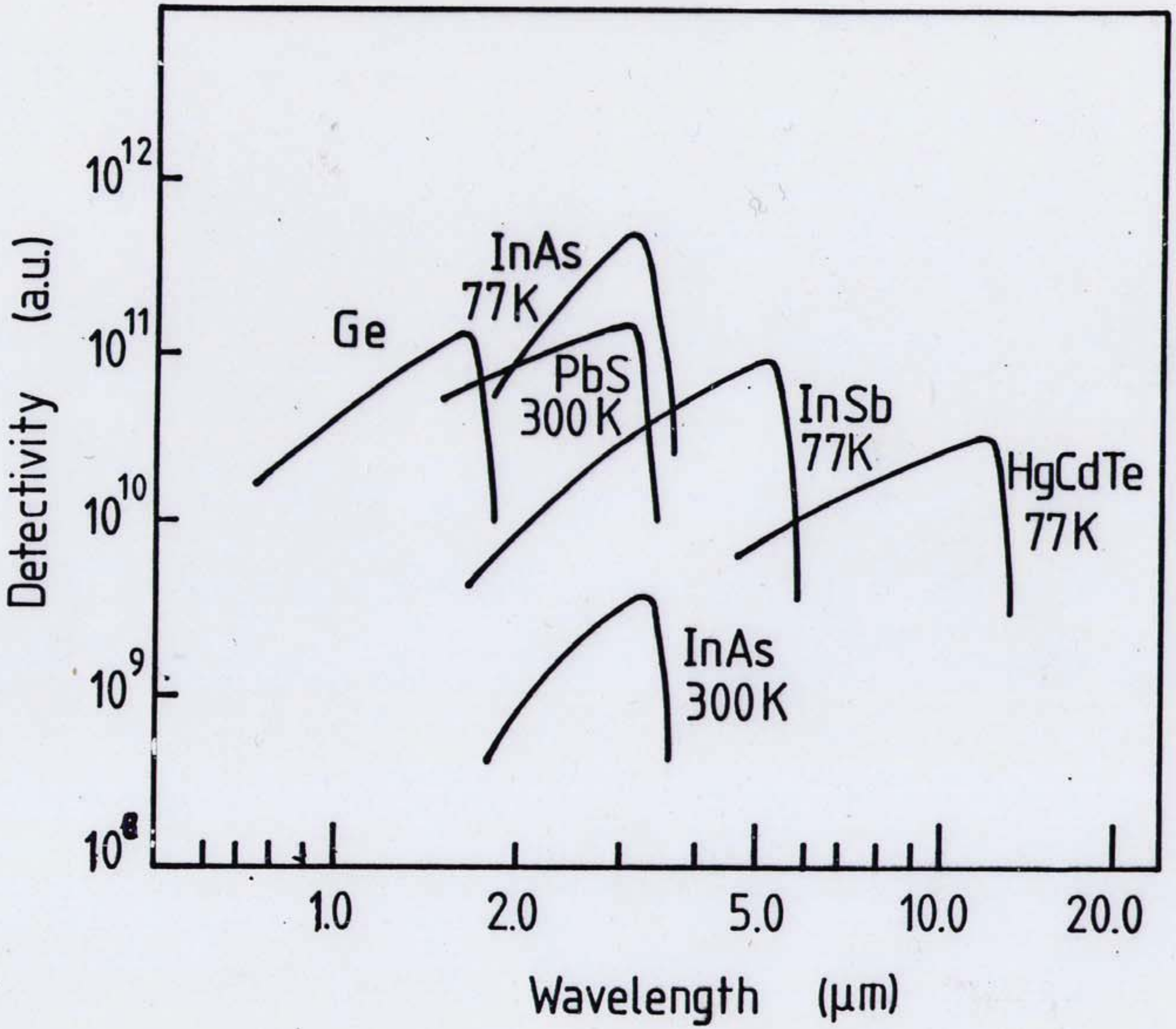


Spectral response

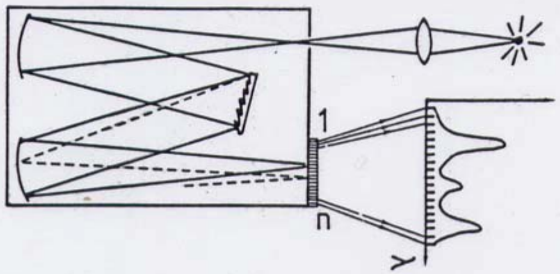


Infrared detectors

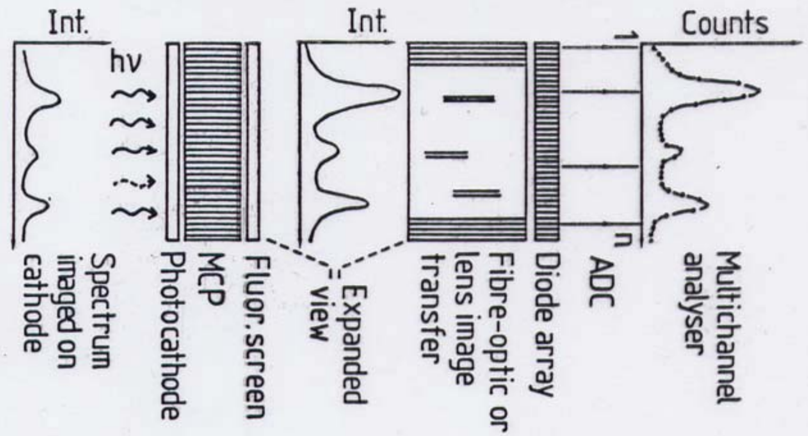
- Thermcouple
- Bolometer (ΔR)
- Pyroelectric (ΔE)
- Photoconducting
  - PbS
  - InAs
  - InSb
  - HgCdTe



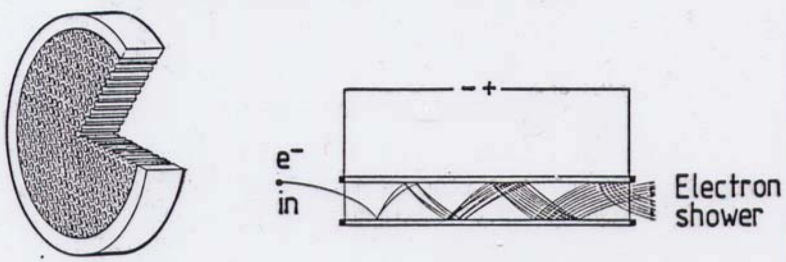
OPTICAL MULTICHANNEL ANALYSER



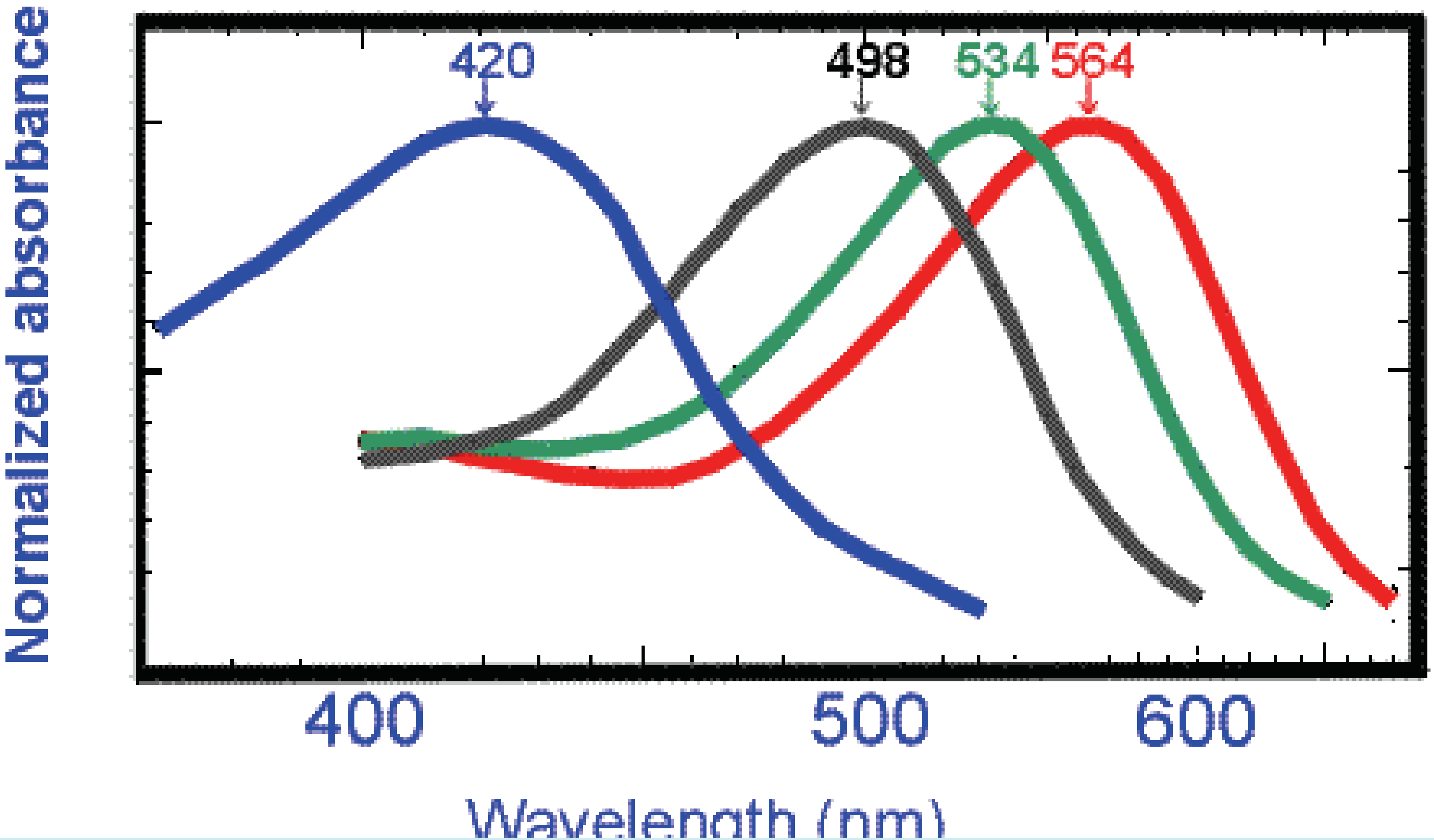
INTENSIFIED ARRAY DETECTOR



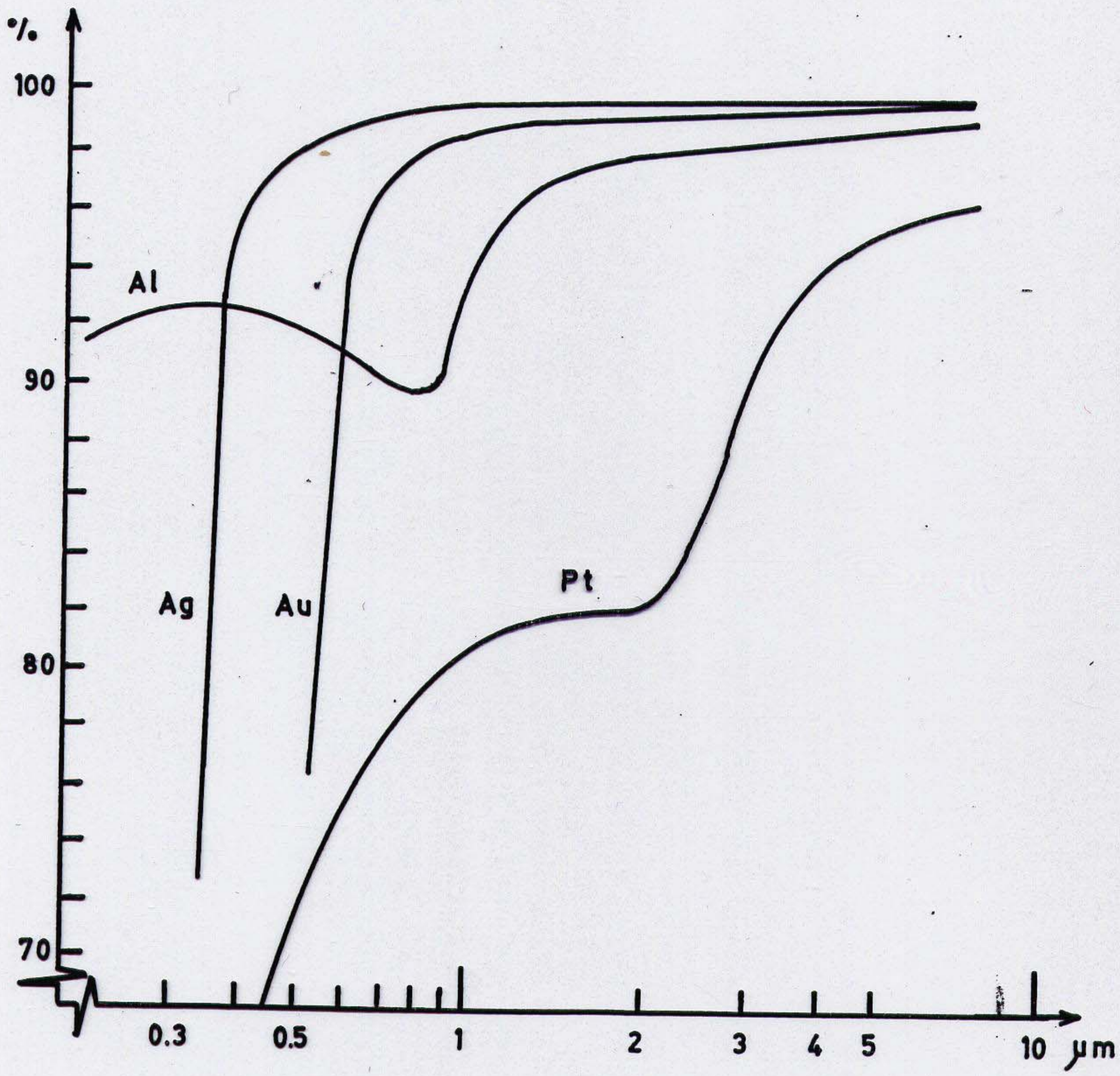
MICROCHANNEL PLATE (MCP)



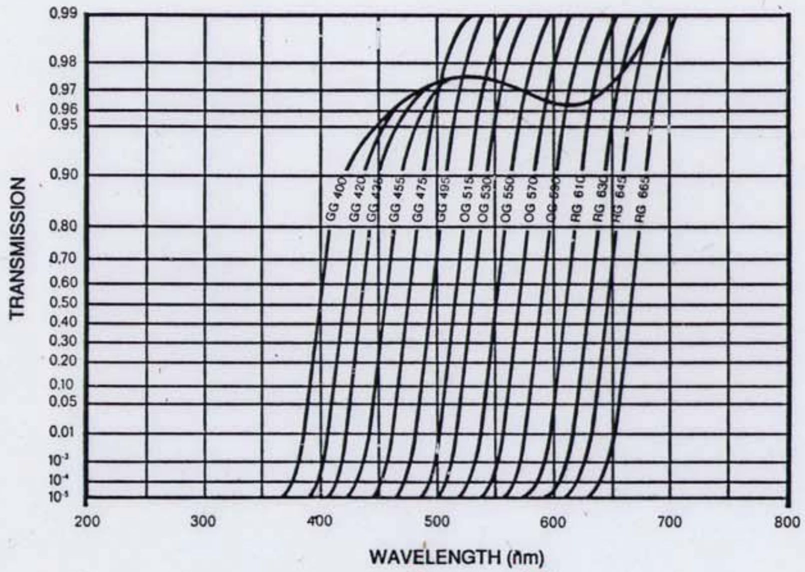
Human vision color sensitivity

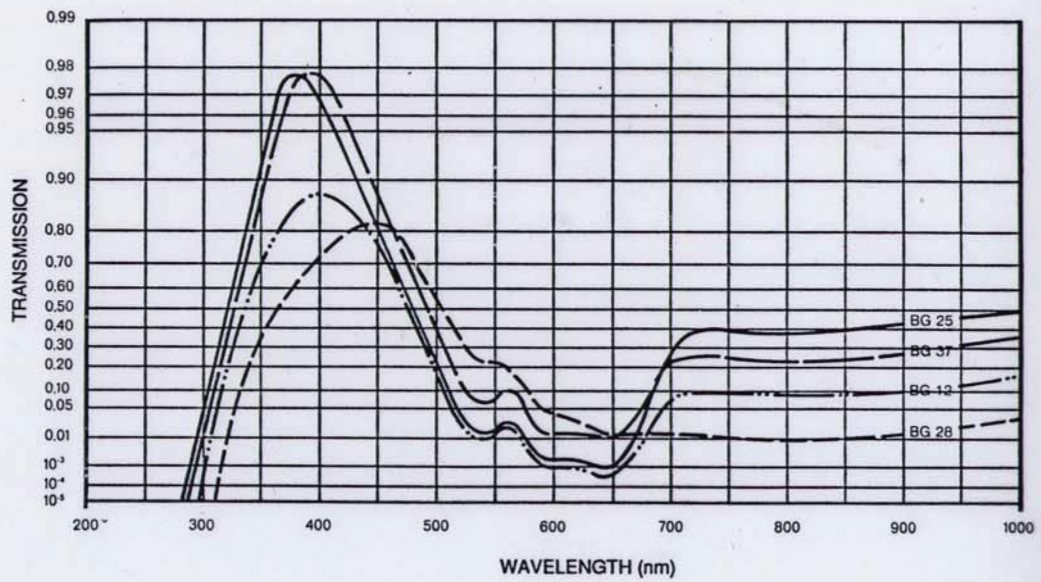


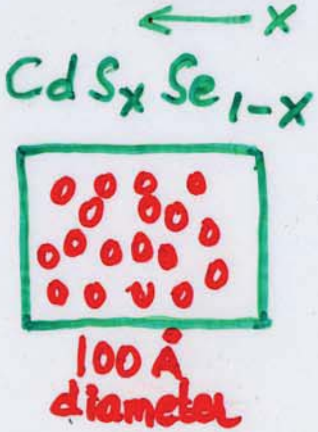
Metal mirrors



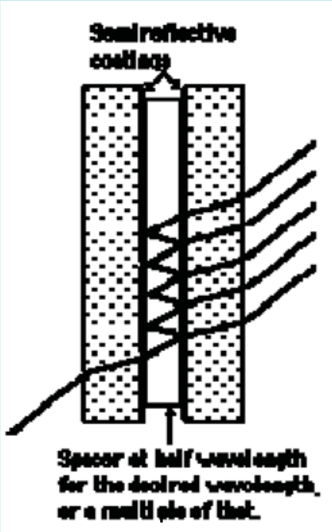
Coloured glass filter

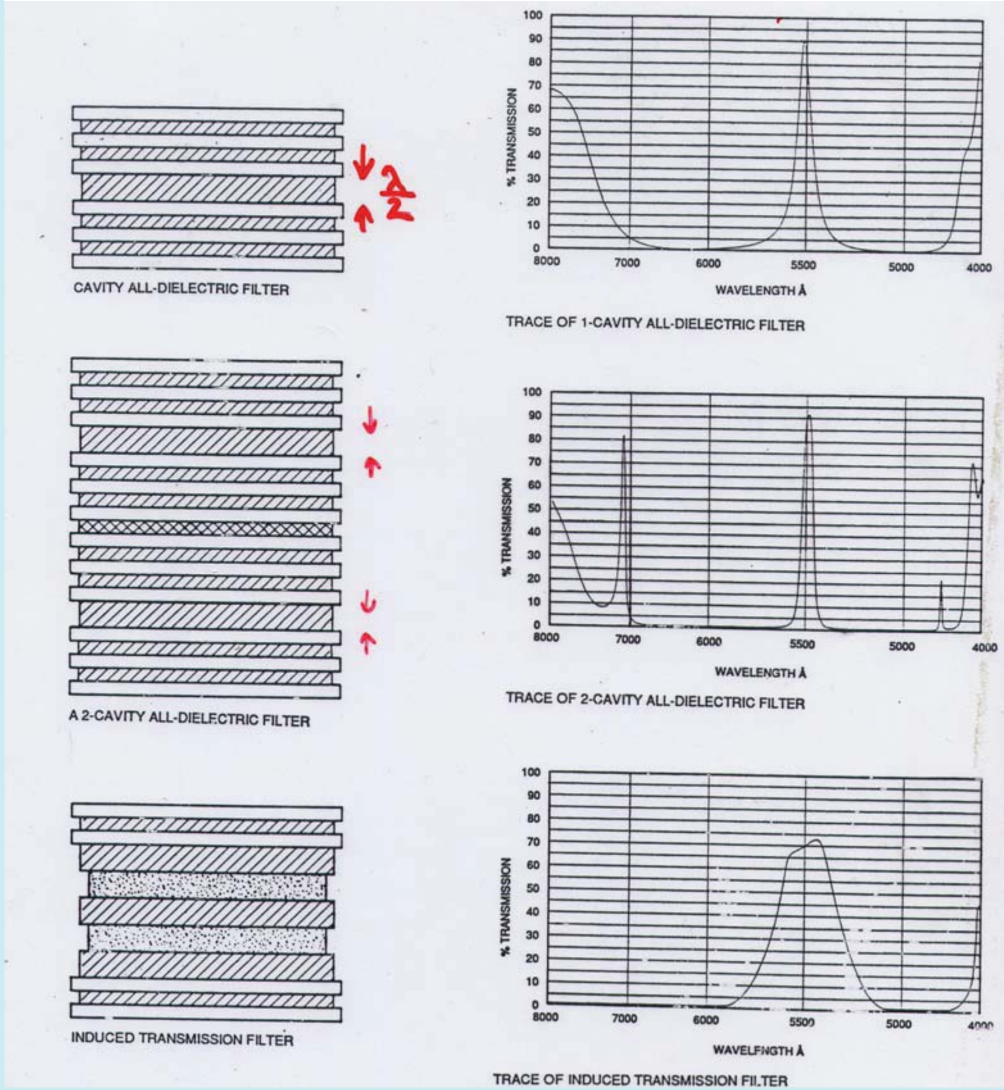




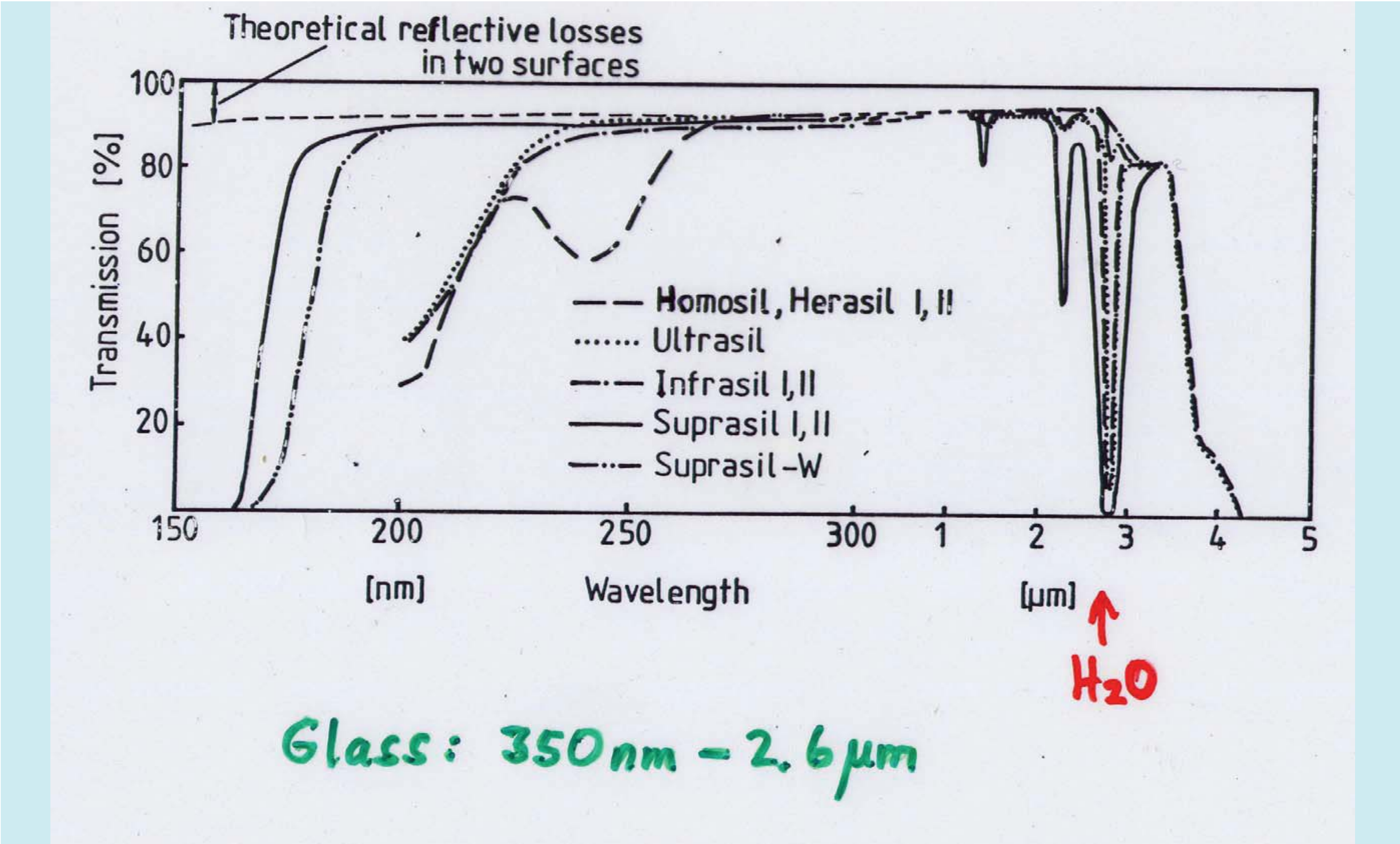


Interference filter

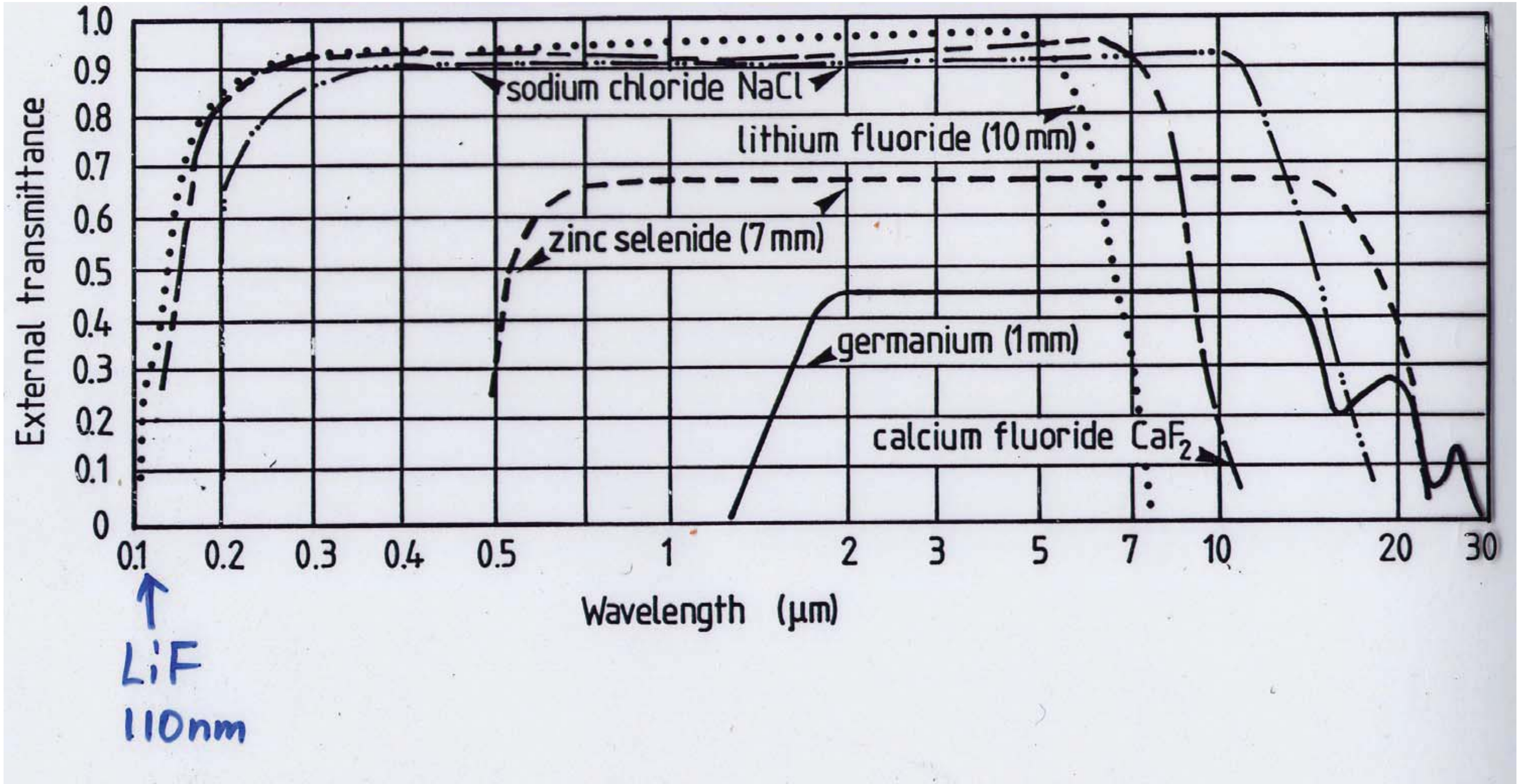




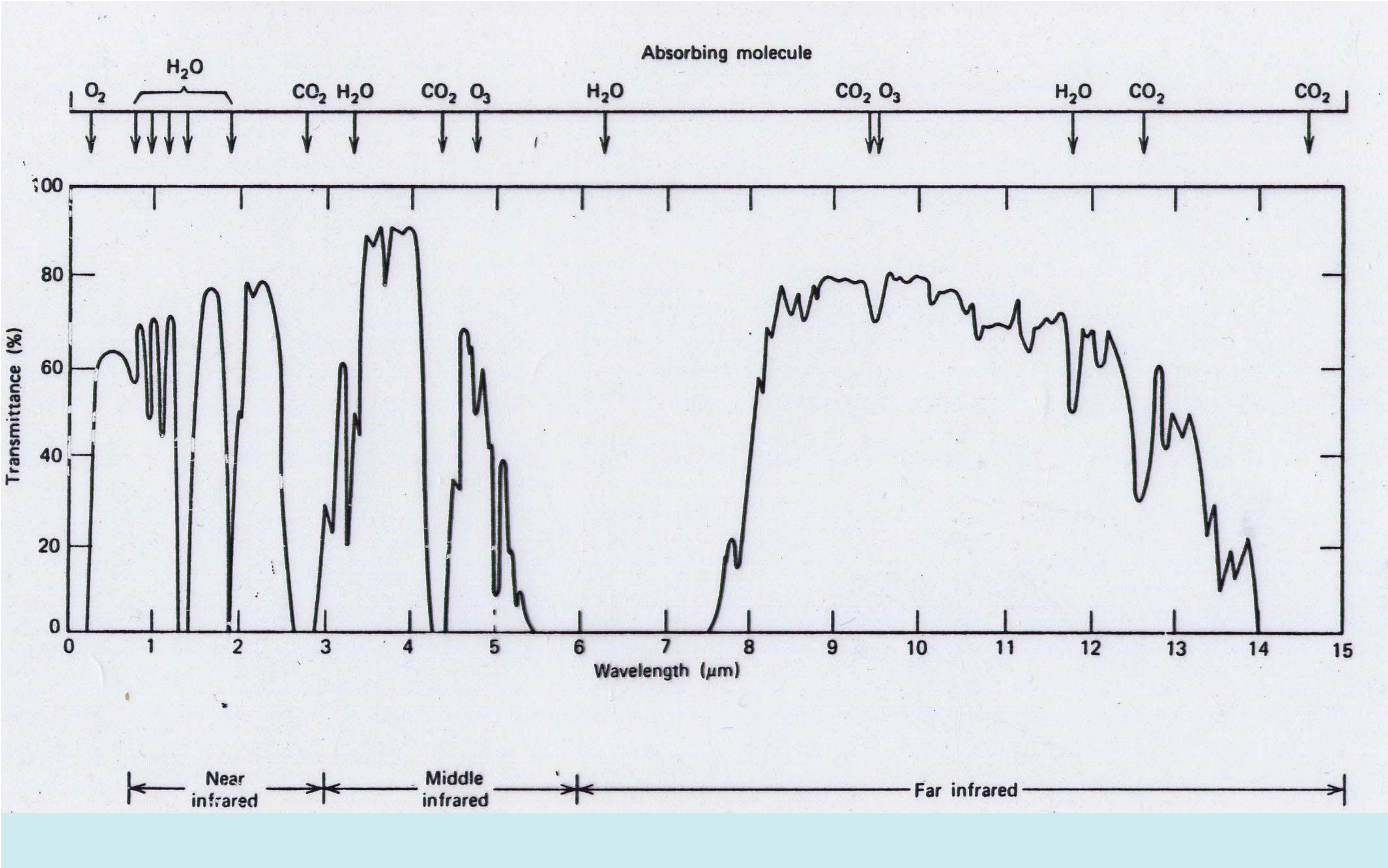
Quartz transmission



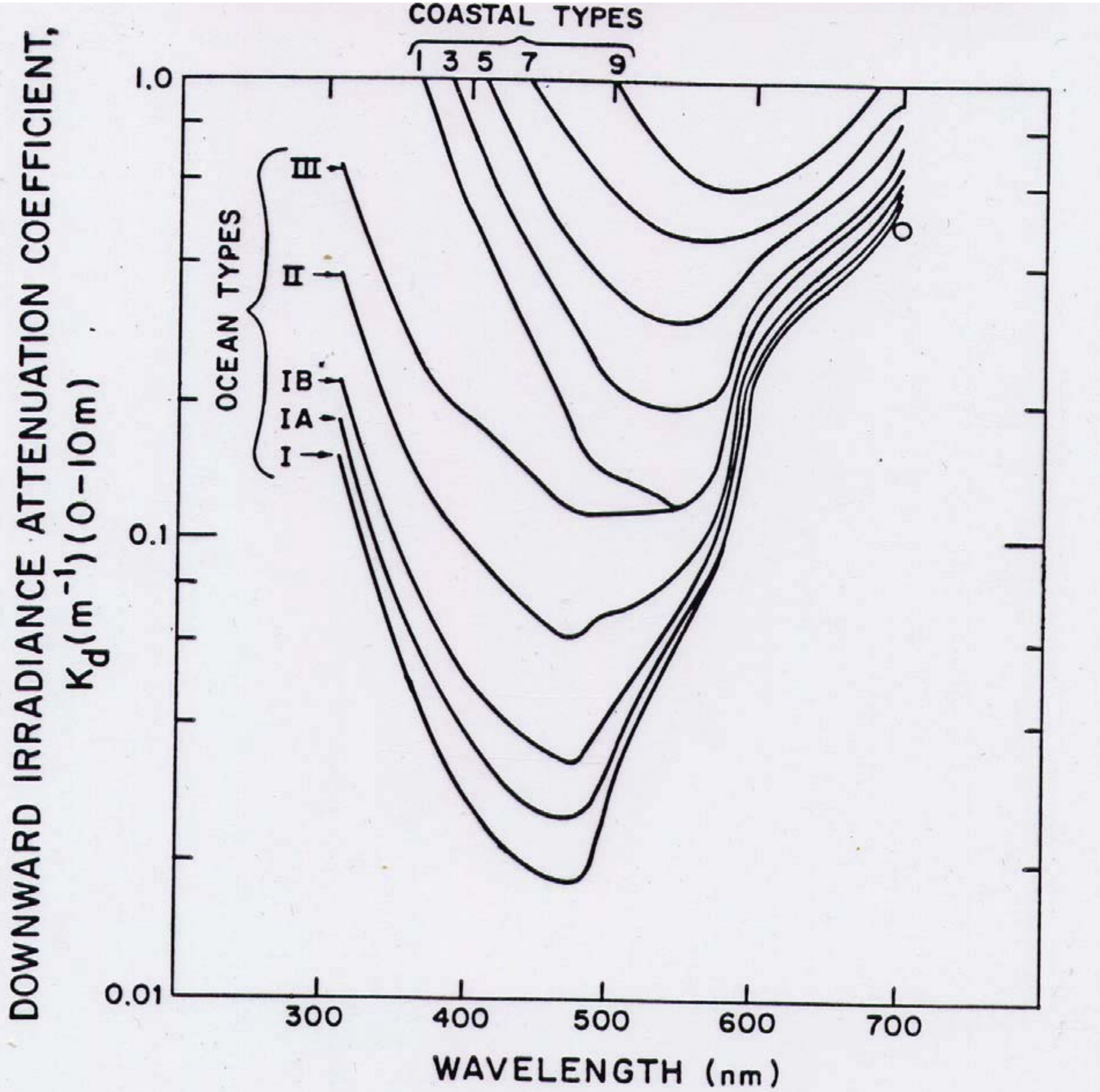
Optical material transmission



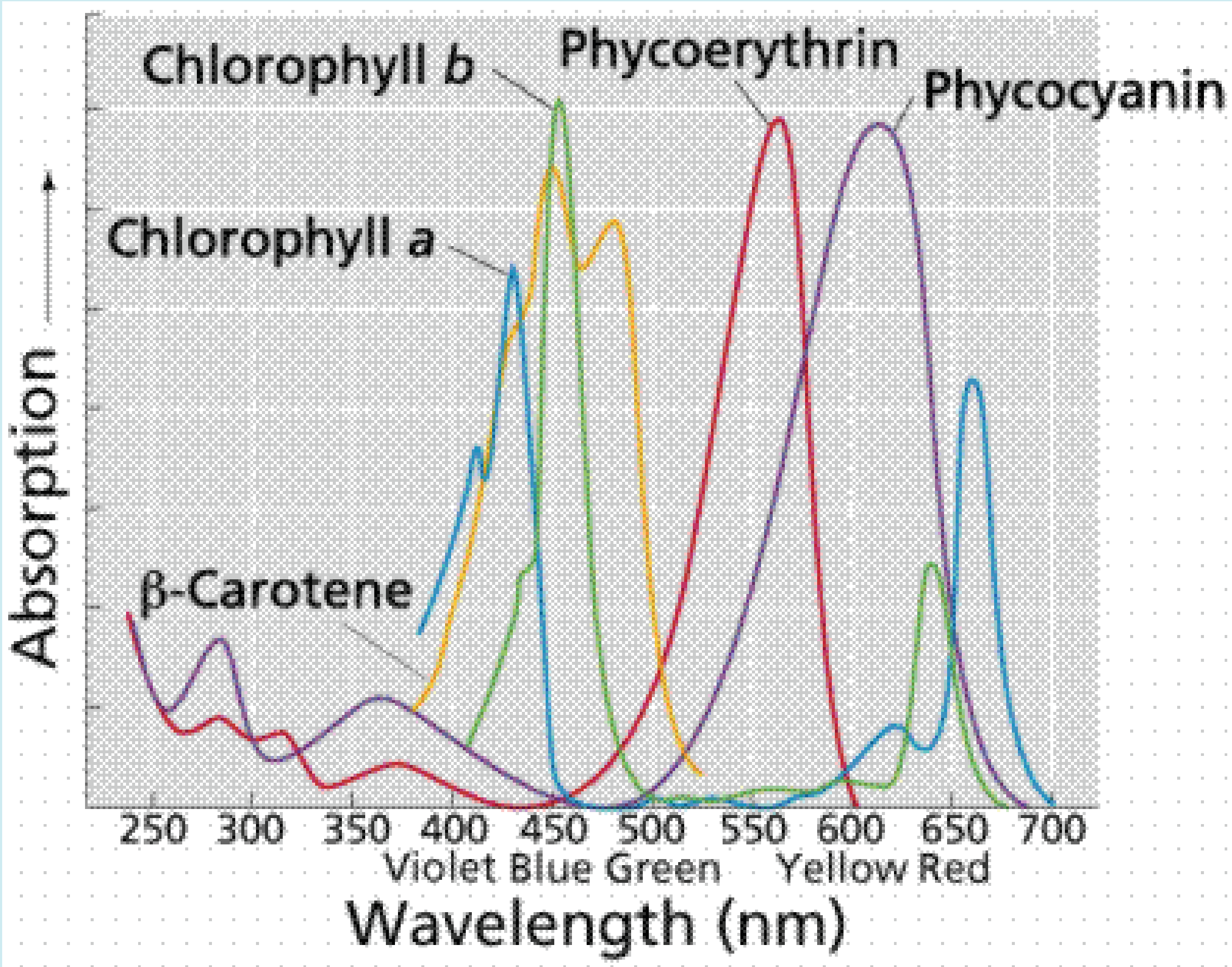
Atmospheric horizontal transmission



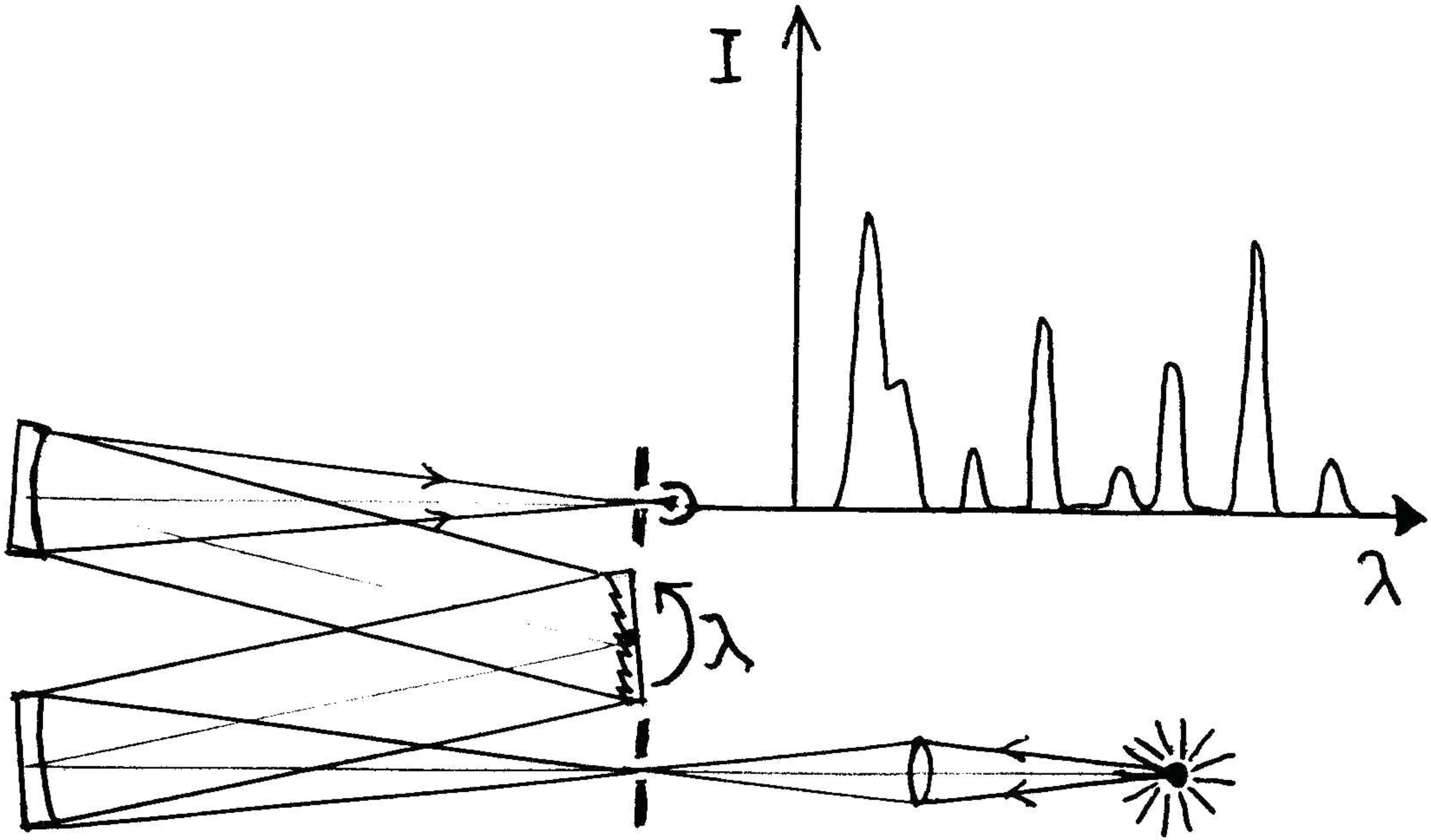
Water absorption



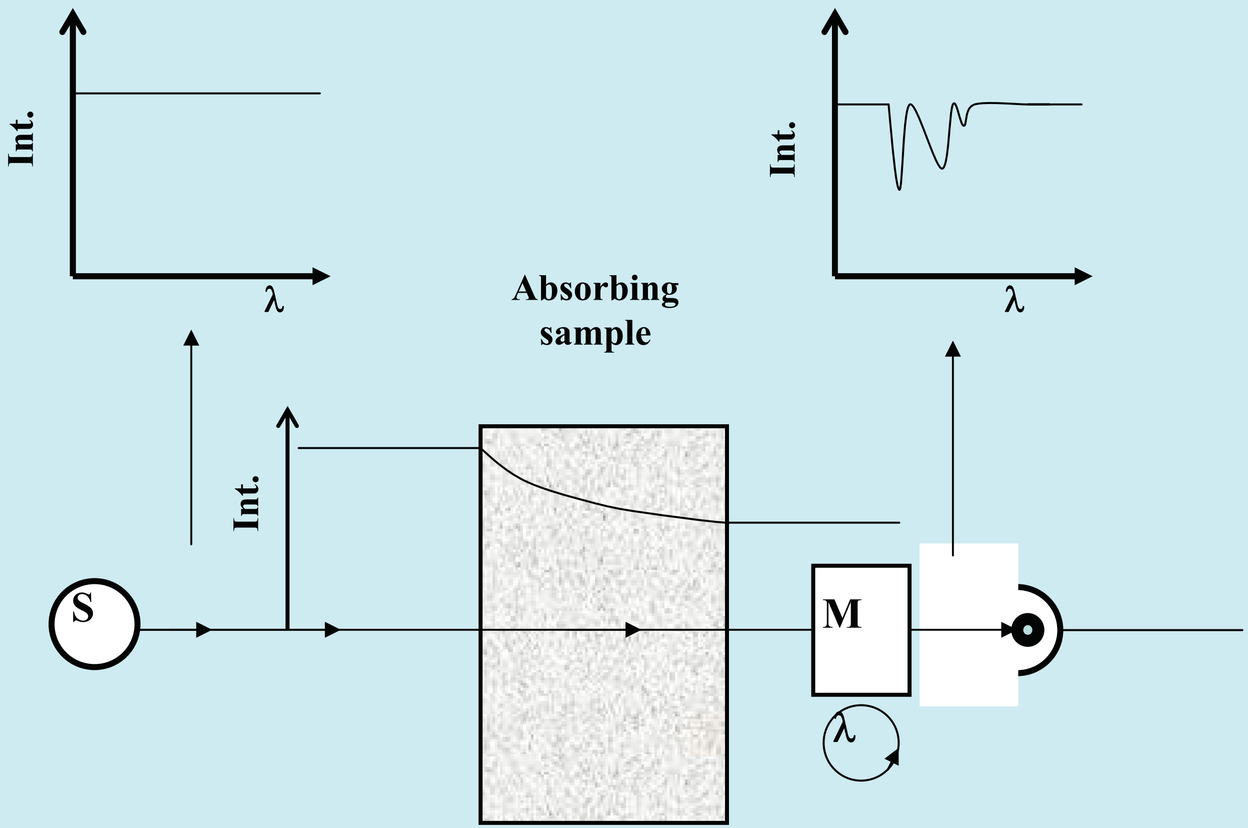
Photosynthetic pigments

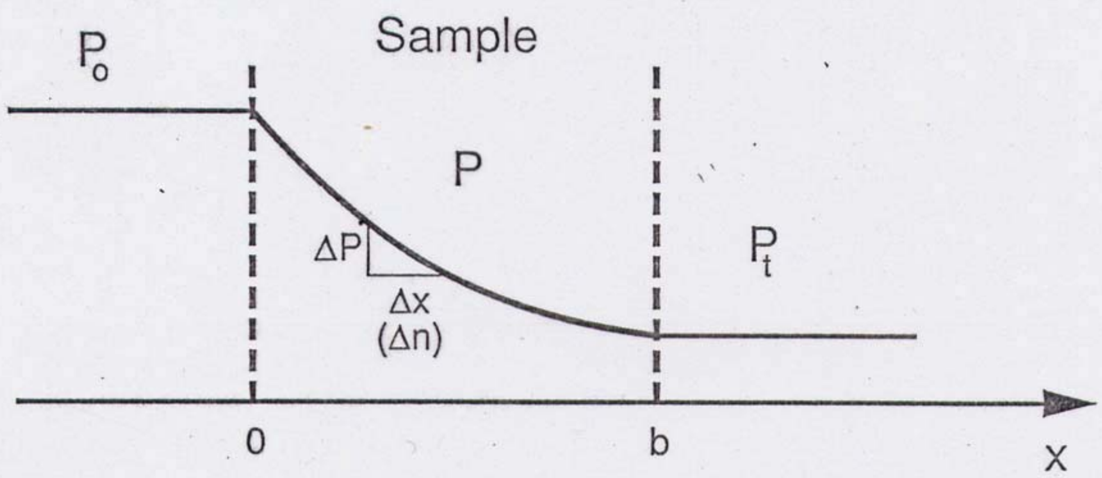


Emission spectroscopy



Absorption spectroscopy





The Beer-Lambert law

Allows concentration measurements

$$\ln \frac{P_0}{P_t} = k_1 \cdot b \cdot c$$

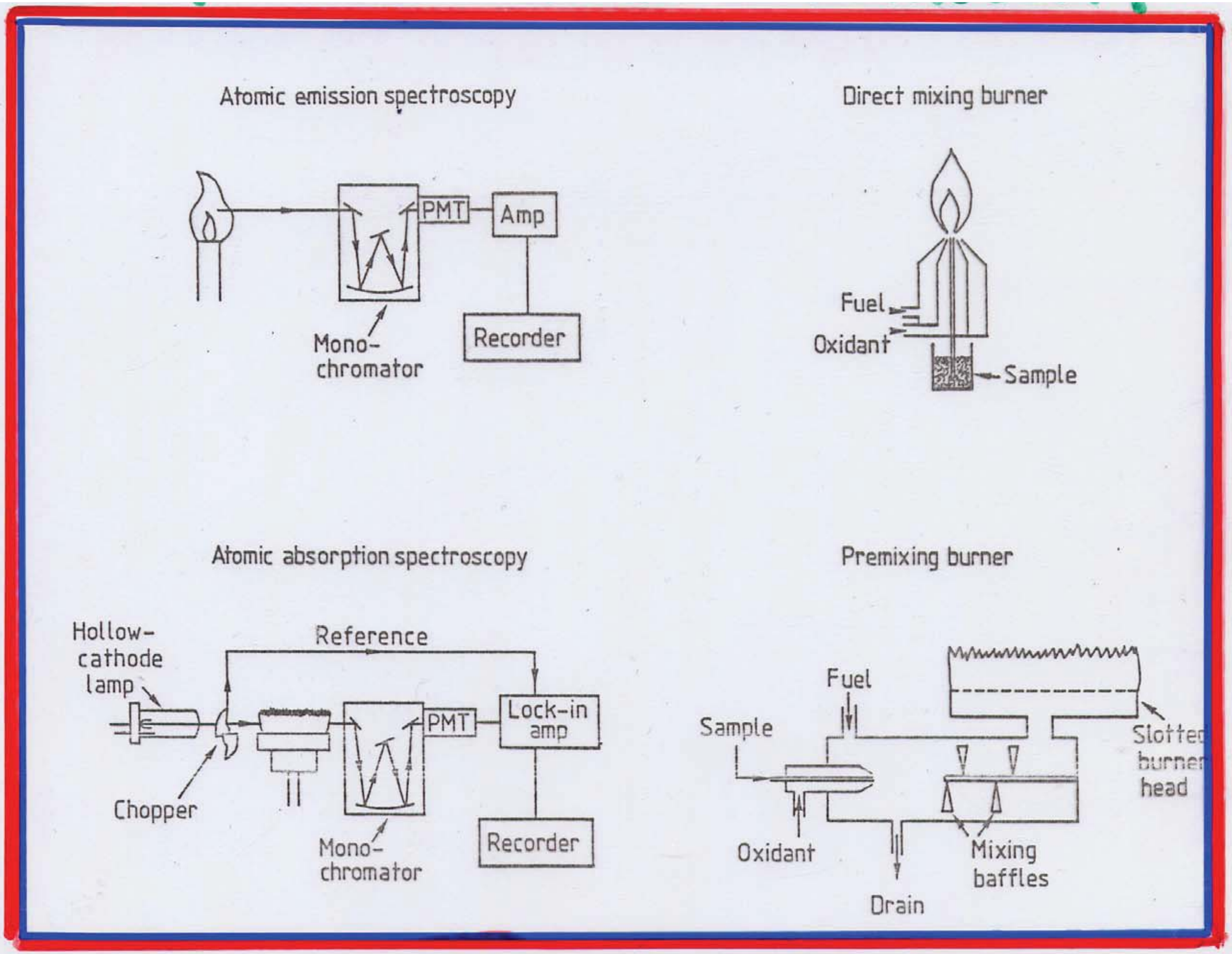
$$A = \log_{10} \frac{P_0}{P_t} = 0.434 \ln \frac{P_0}{P_t}$$

$$\boxed{A \propto c}$$

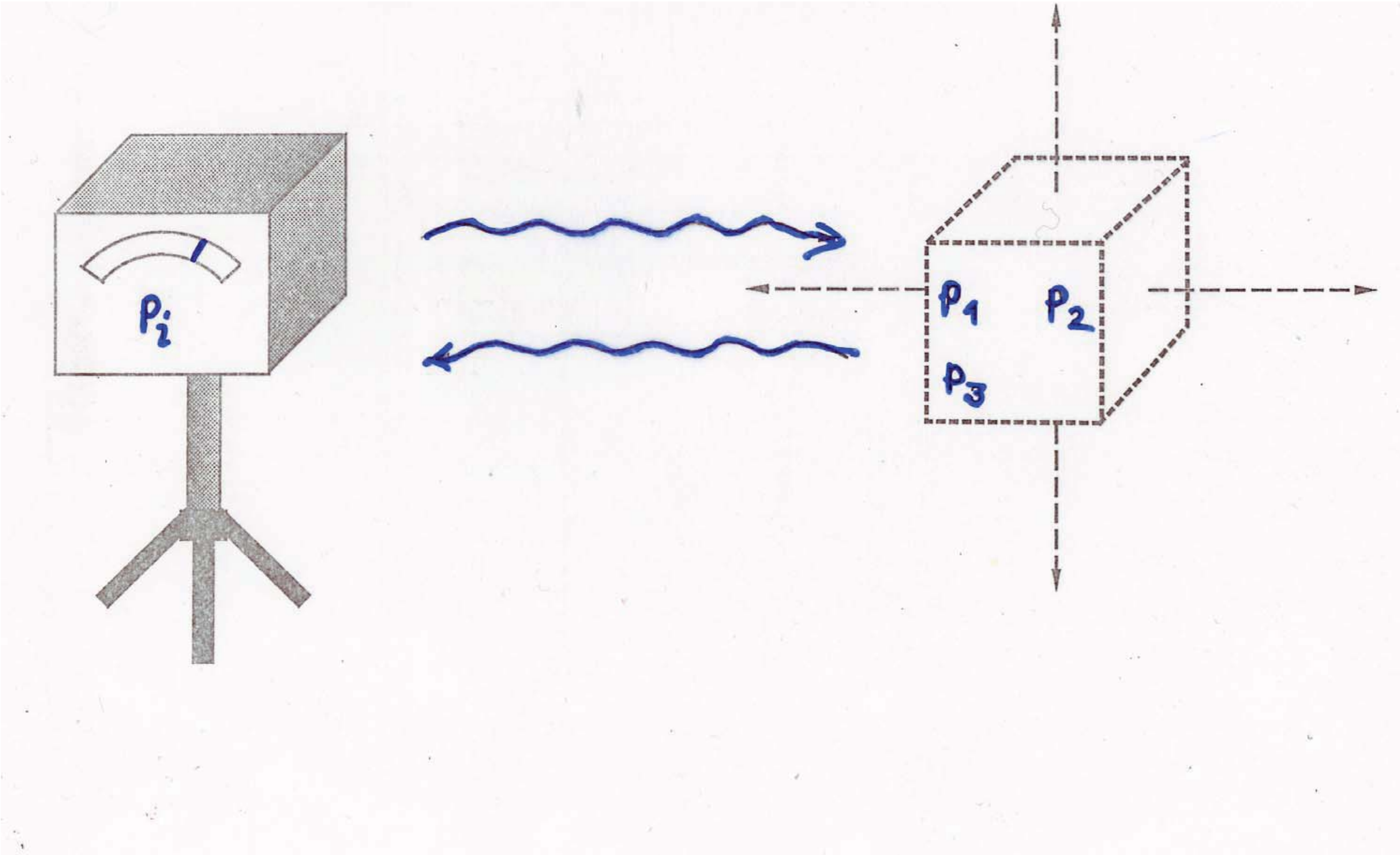
$$T = \frac{P_t}{P_0}$$

Concentration is proportional to absorbance

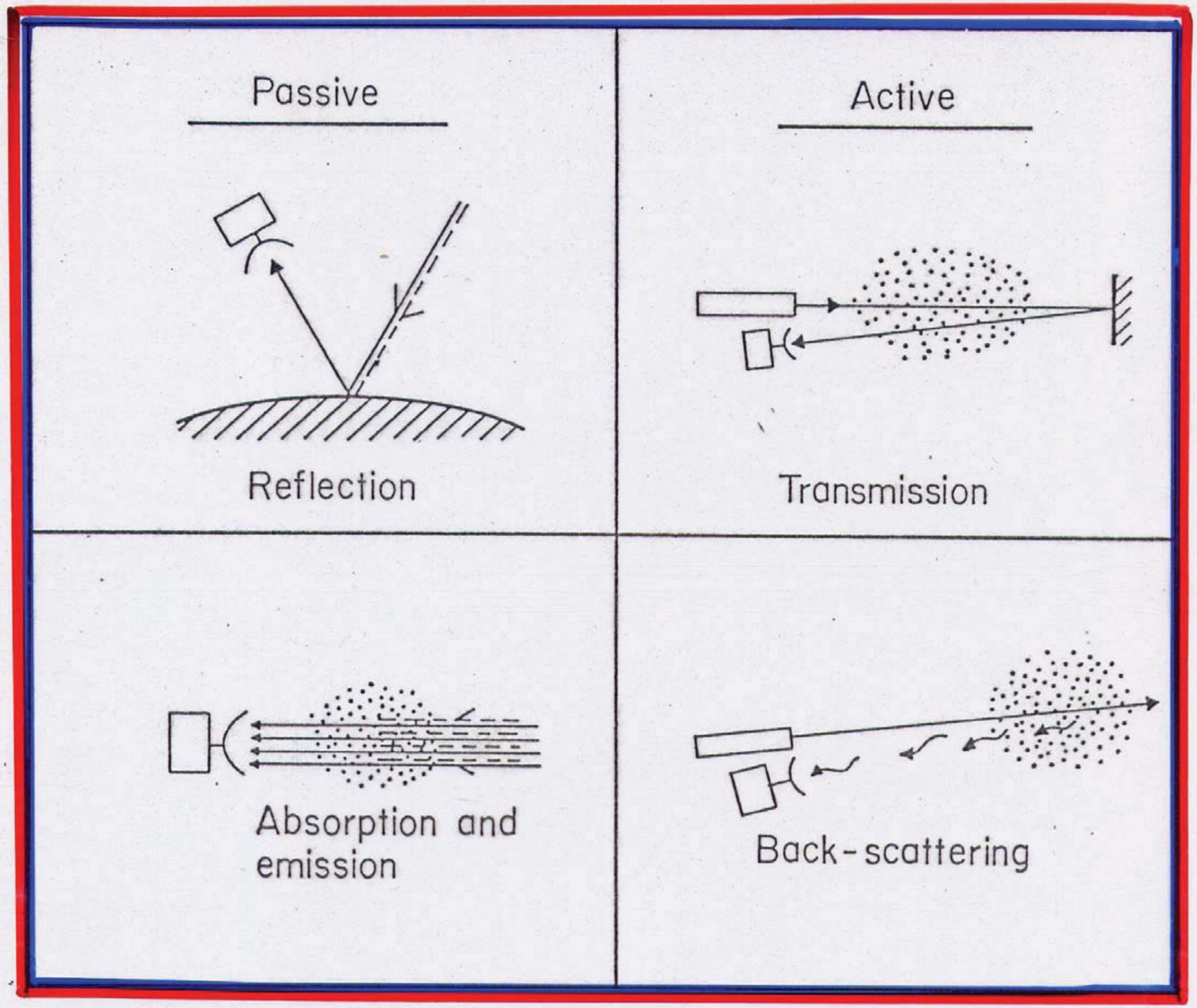
Analytical flame spectroscopy

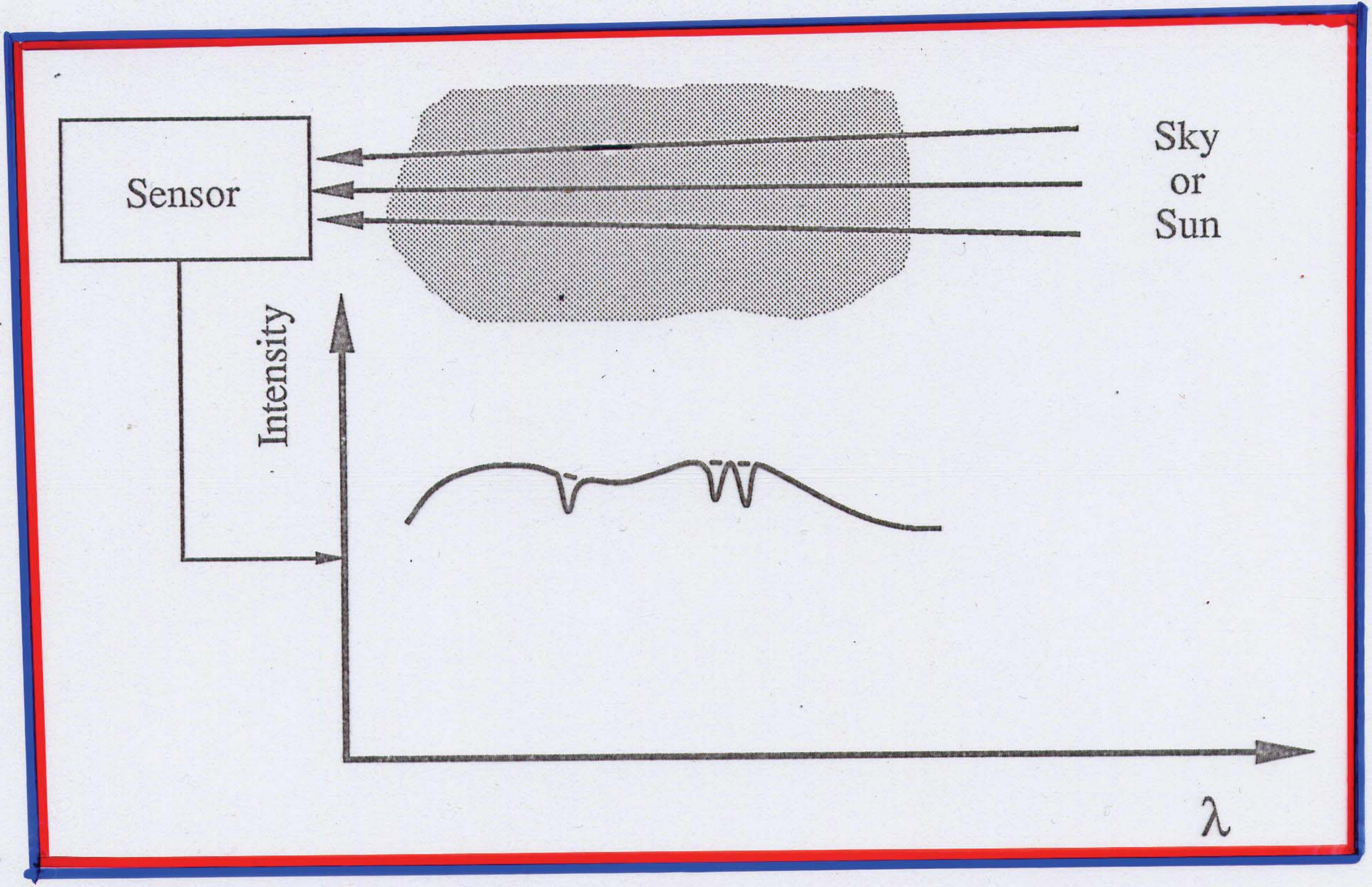


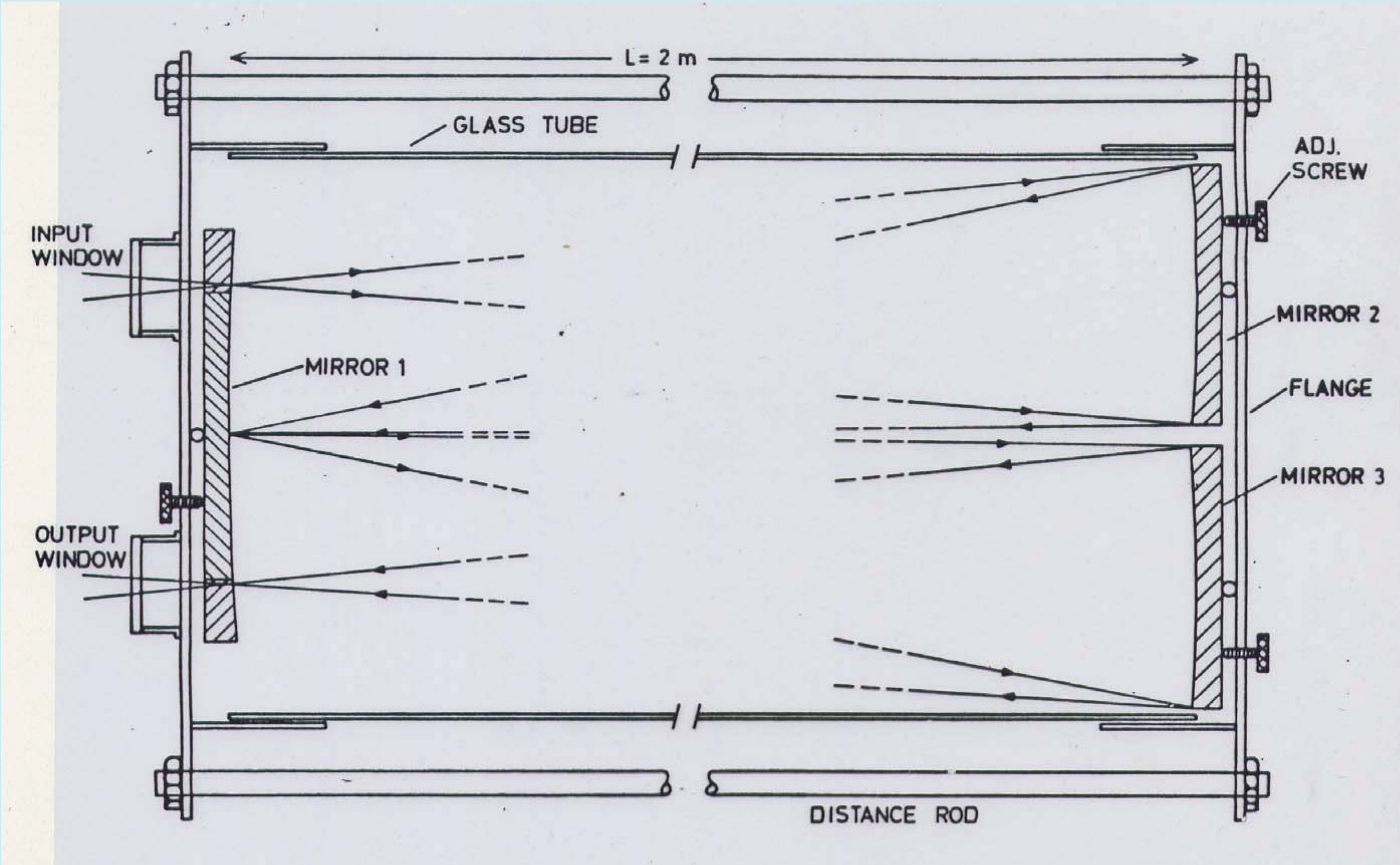
Remote sensing



Remote Sensing

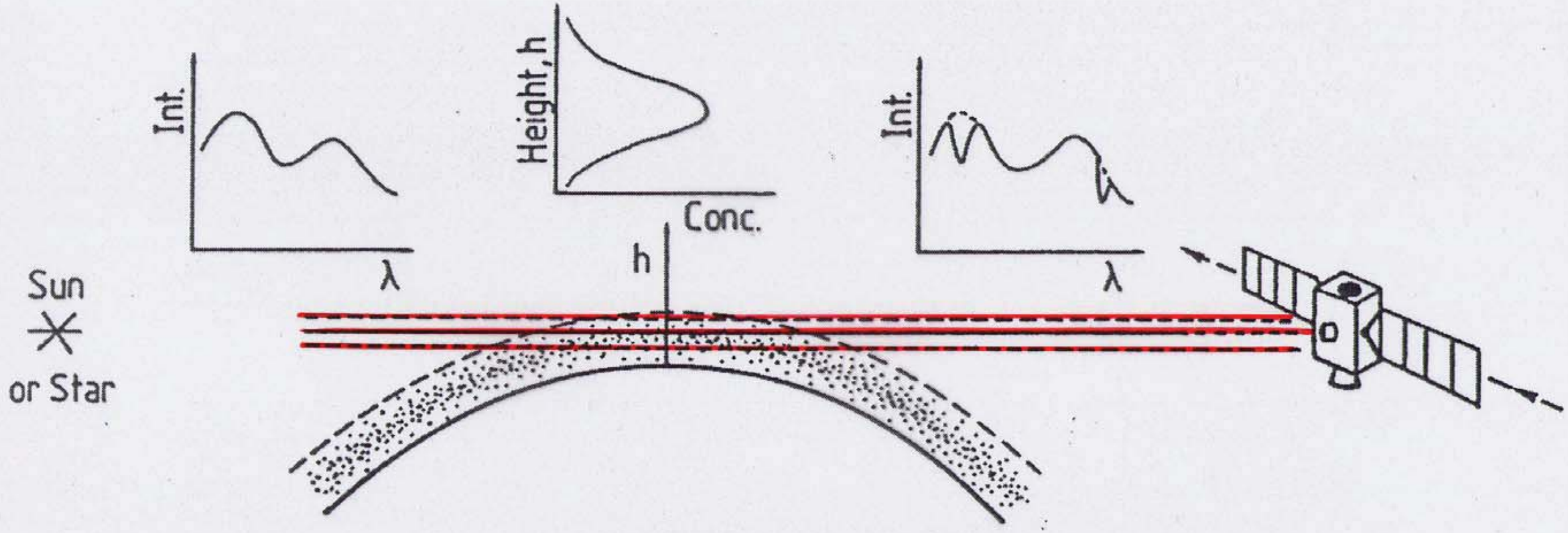



Sensor
Sky
or
Sun
Intensity
λ

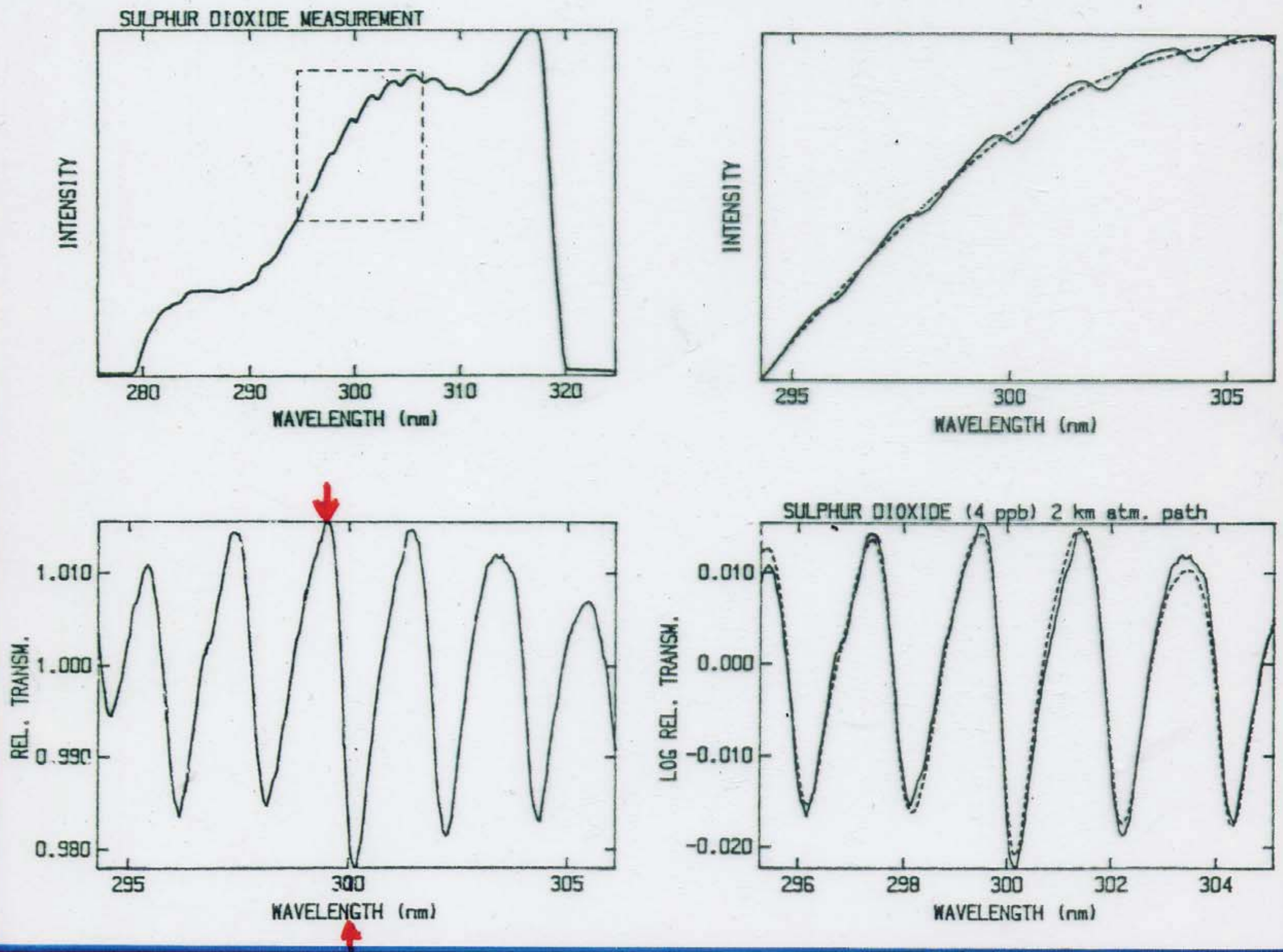


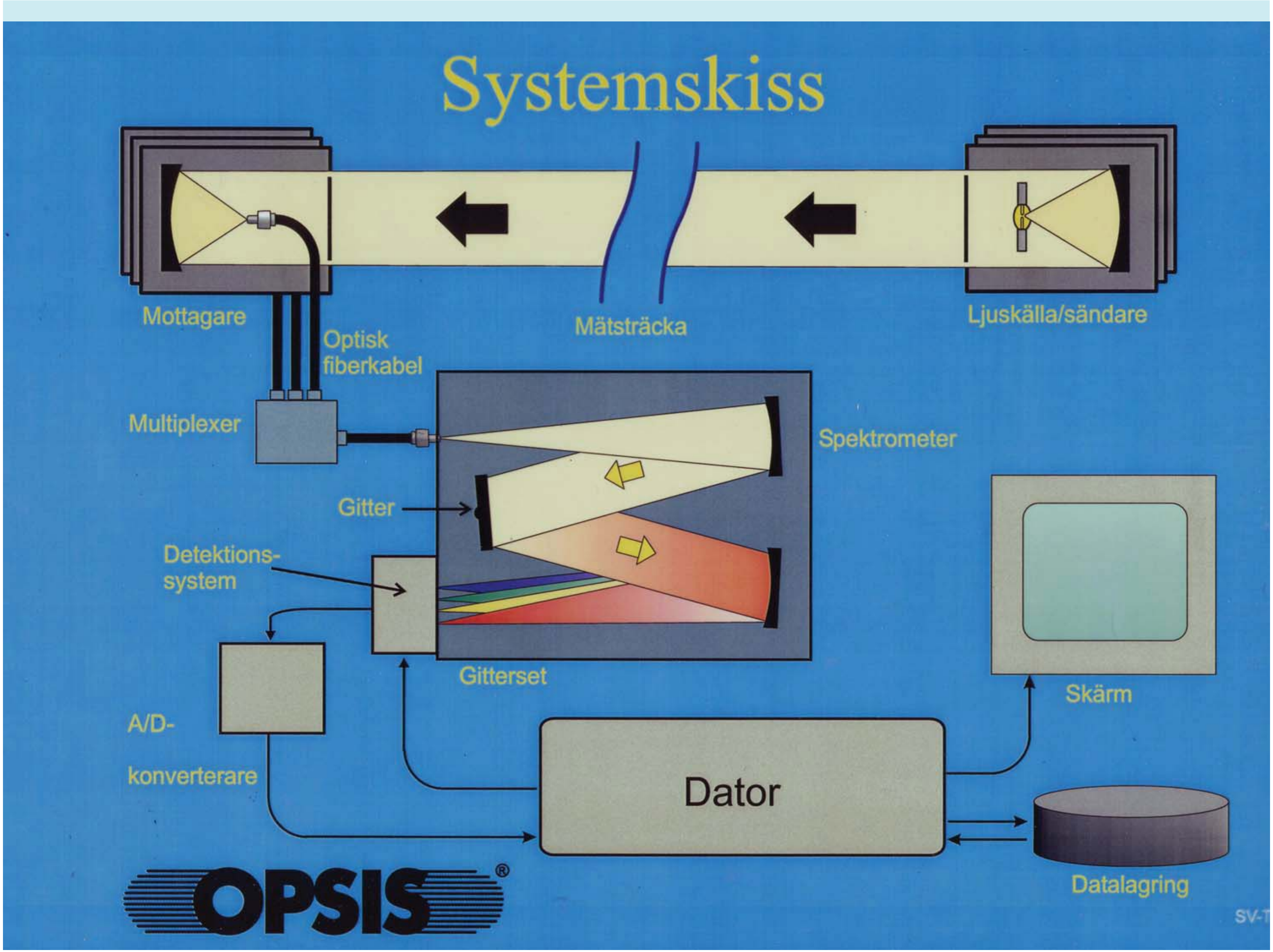
White cell – Long-path absorption in a controlled way

Limb absorption

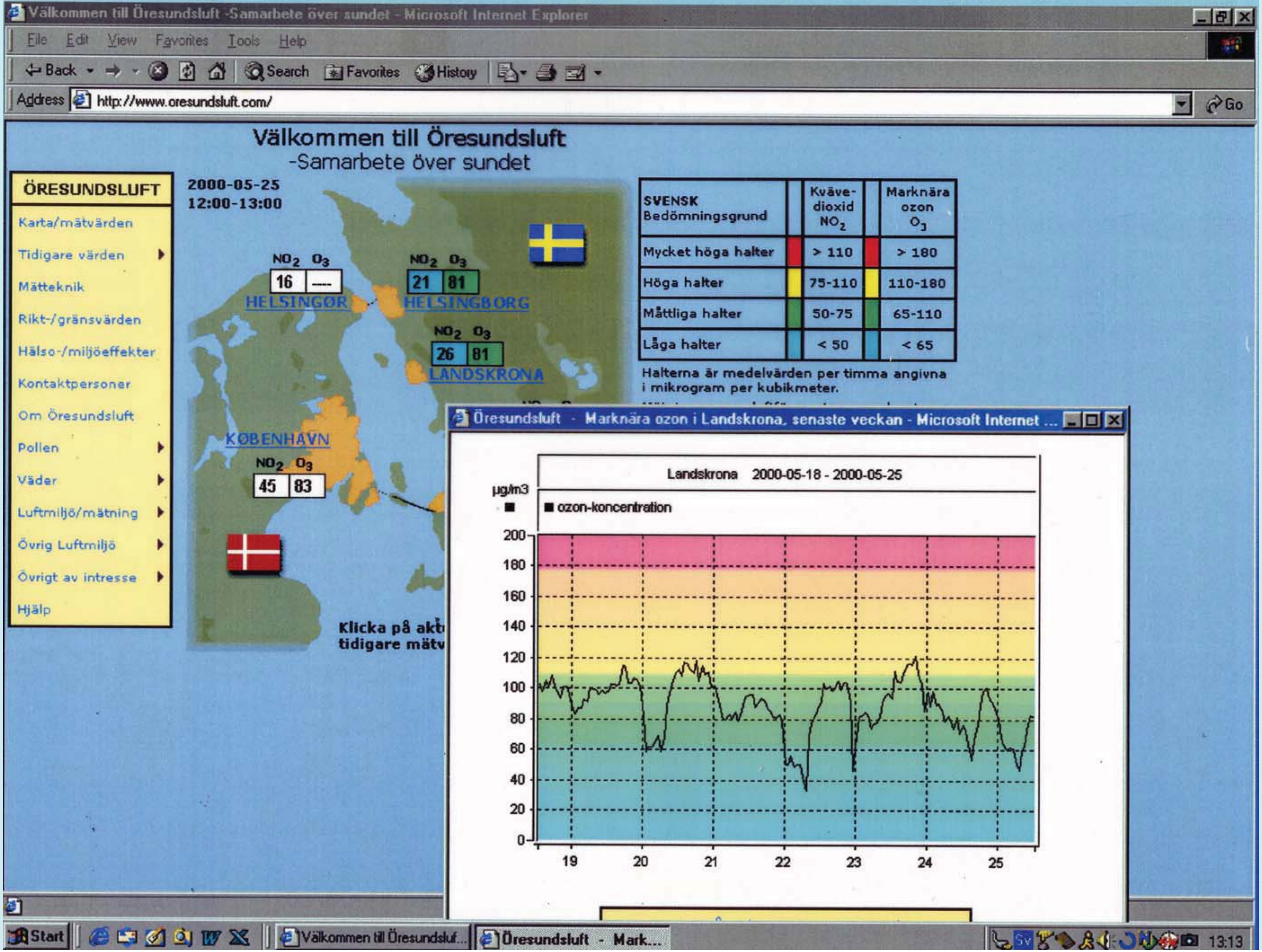


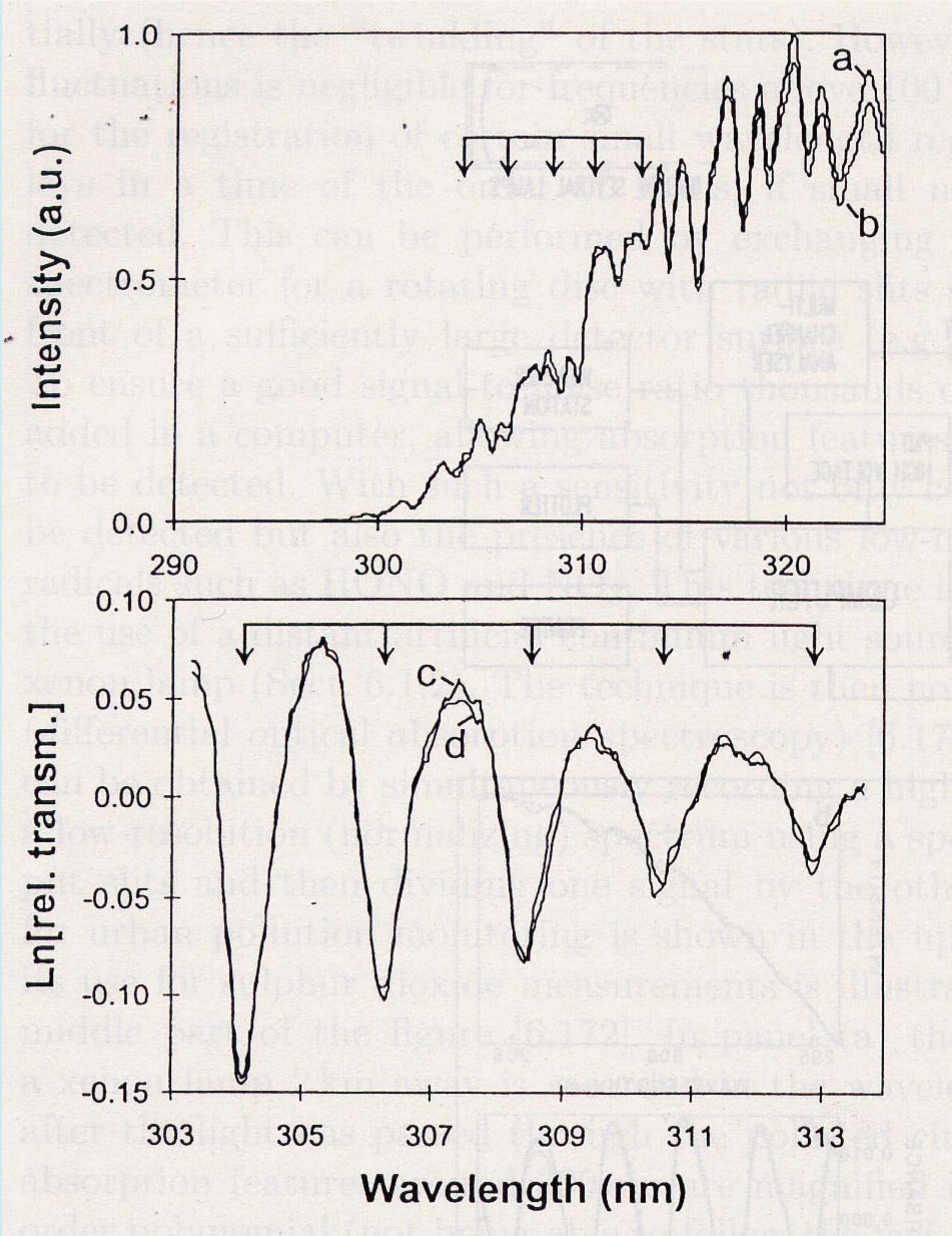
SO_2 DOAS MEASUREMENT




Systemskiss
Mottagare
Optisk fiberkabel
Mätsträcka
Ljuskälla/sändare
Multiplexer
Spektrometer
Gitter
Detektions-system
Gitterset
A/D-
konverterare
Skärm
Dator
Datalagring
OPSIS

Using Internet for public information of Air Quality

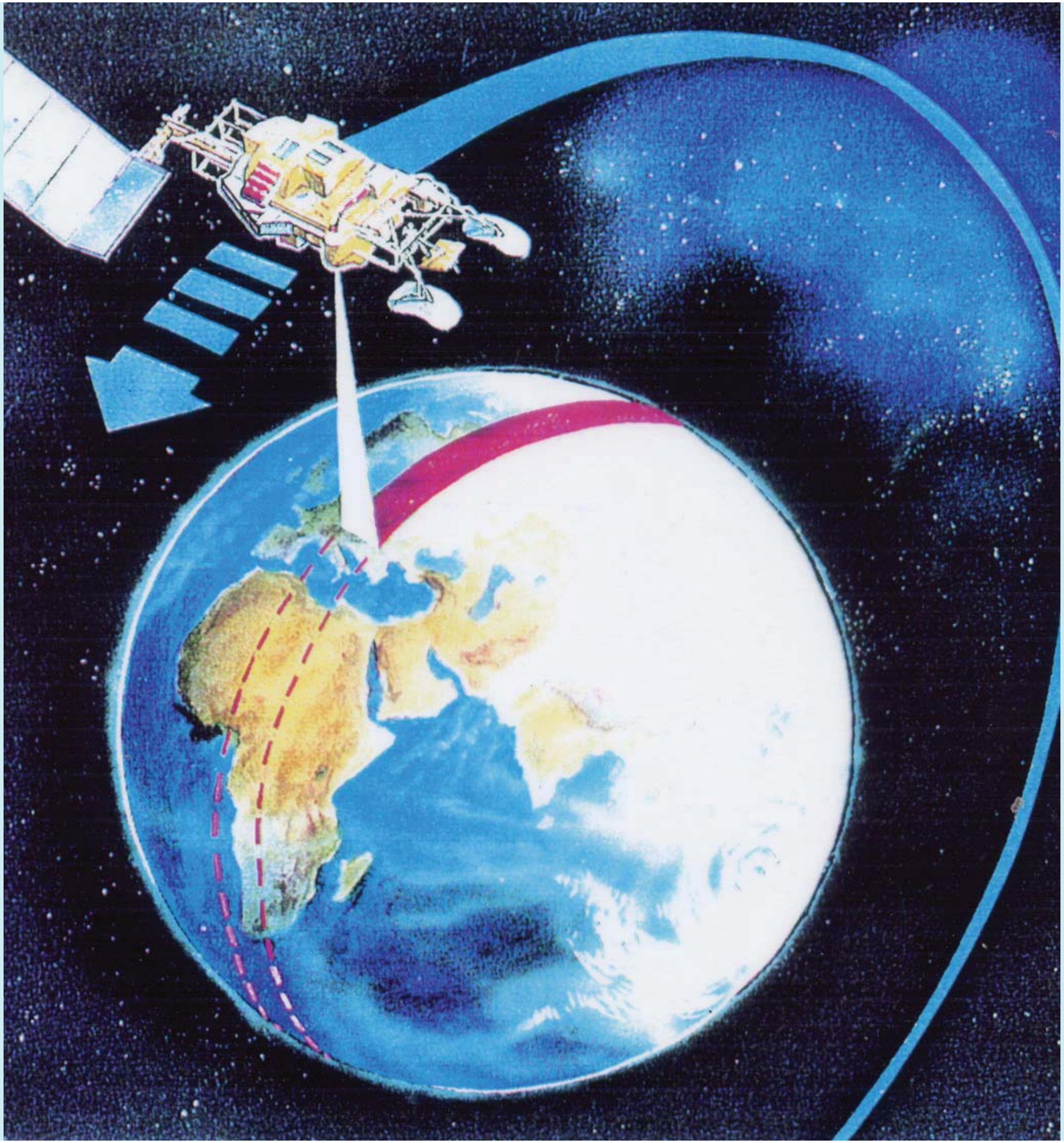




Volcanic plume
Sulfur dioxide
Measurement
Mt. Etna

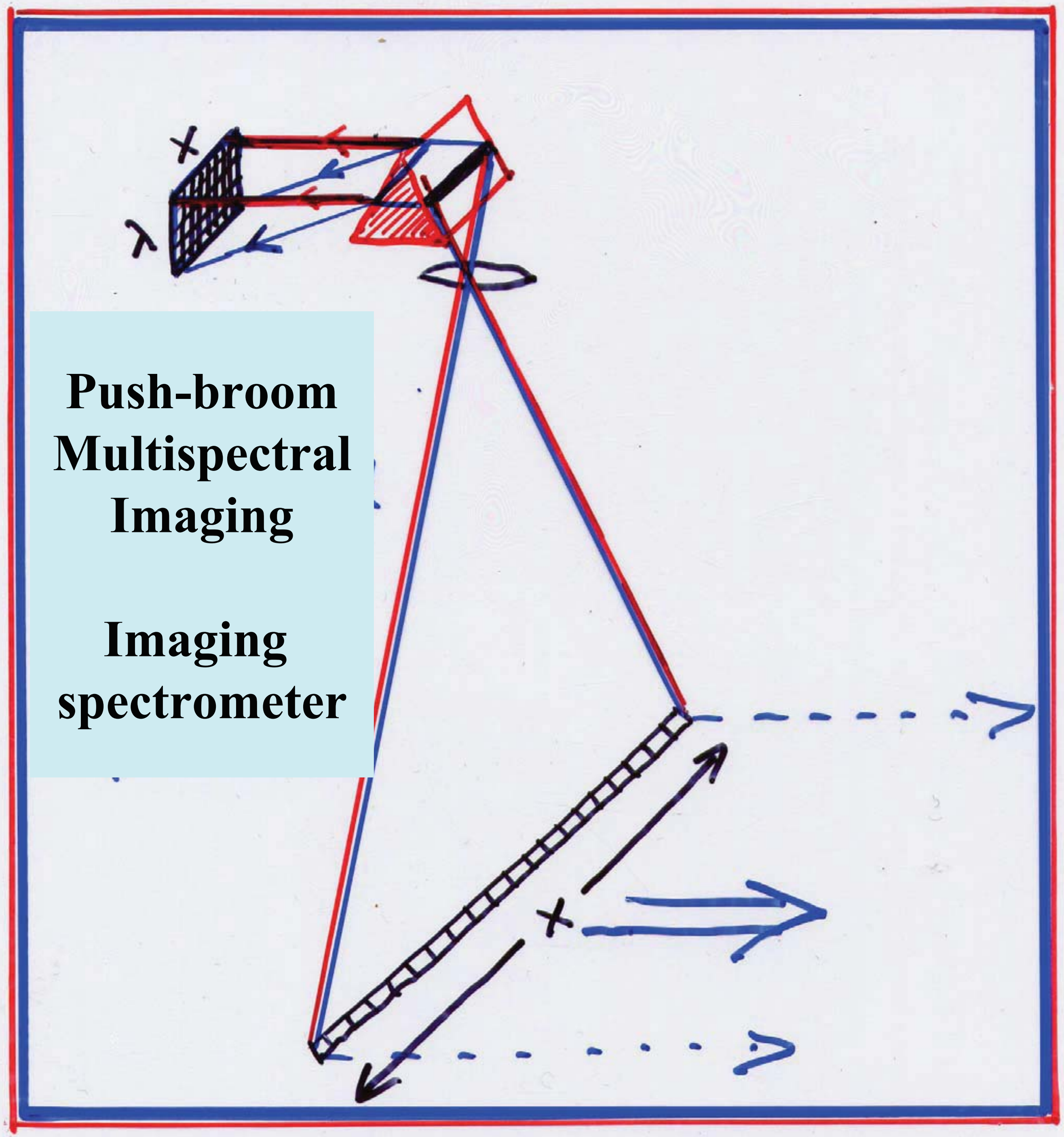
Satellite
Remote
Sensing

Earth
resource
satellites



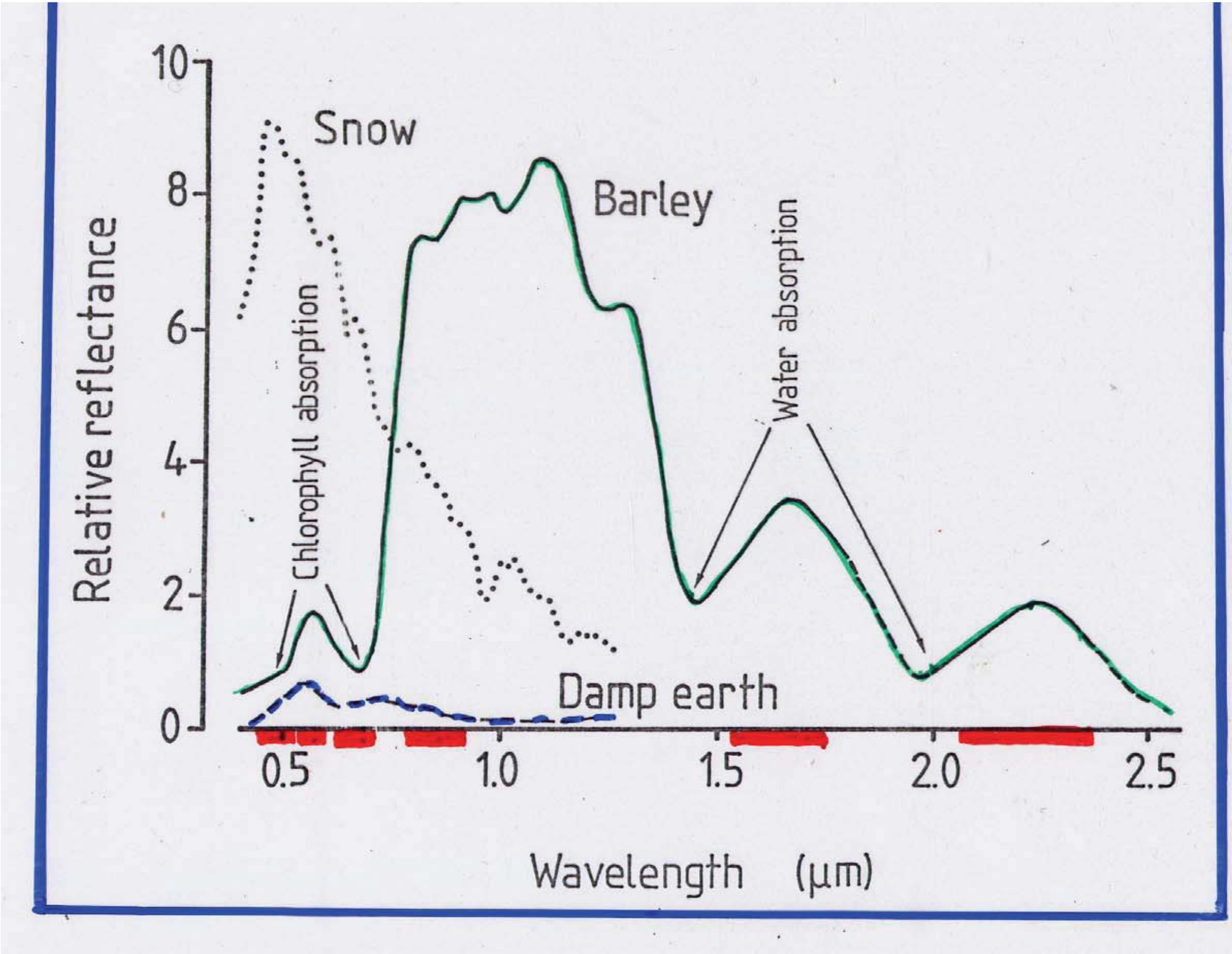
Push-broom Multispectral Imaging

Imaging spectrometer

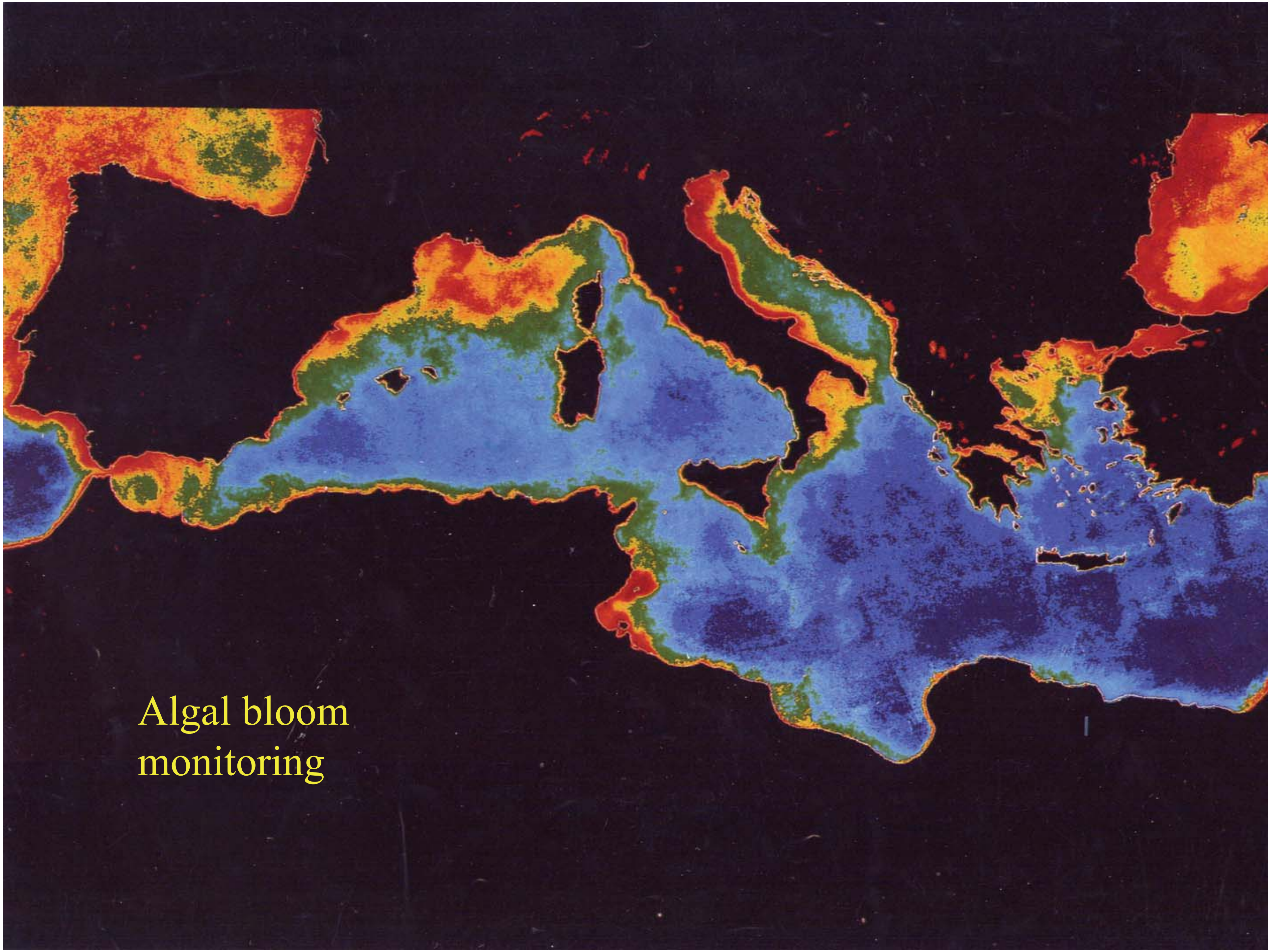



ENVISAT

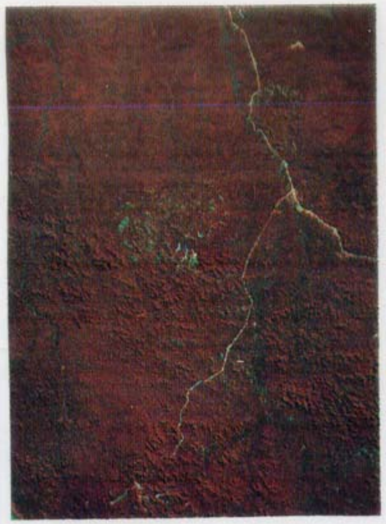
Reflectance spectra



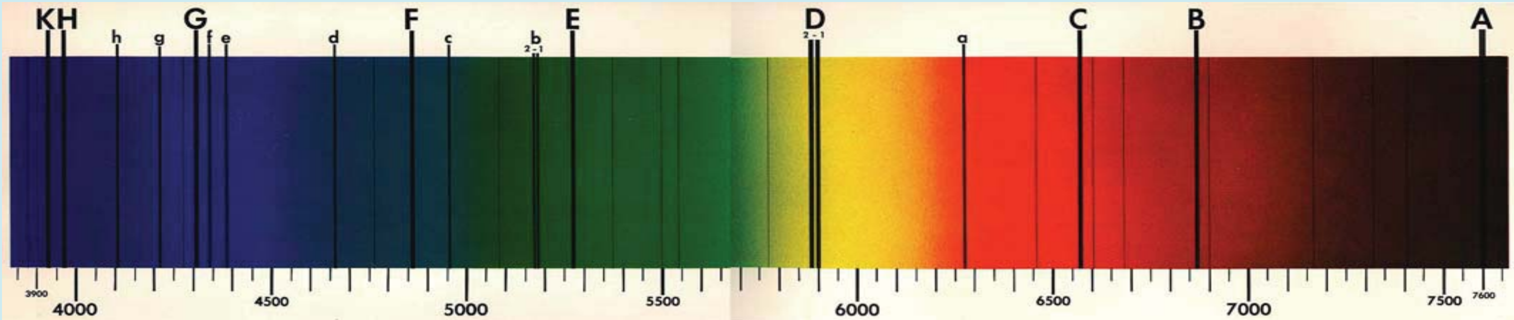
TM
Bands

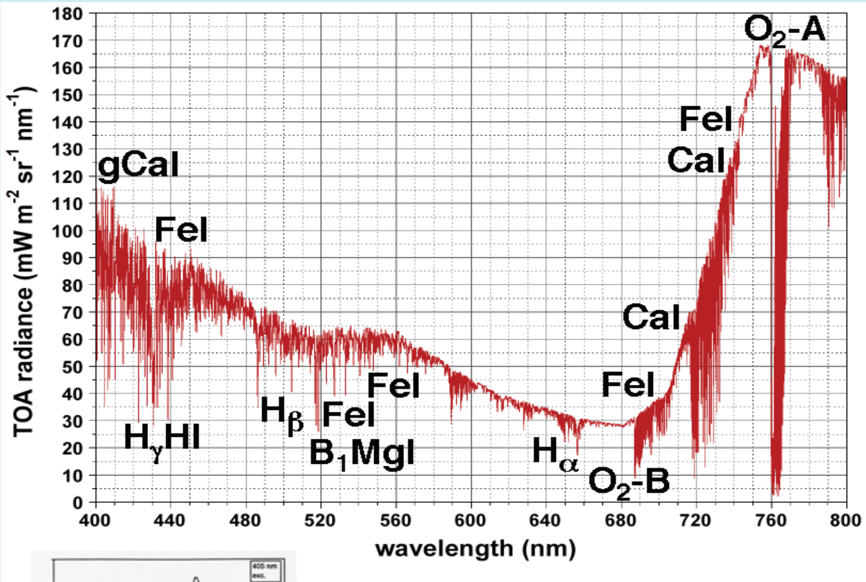

Algal bloom
monitoring

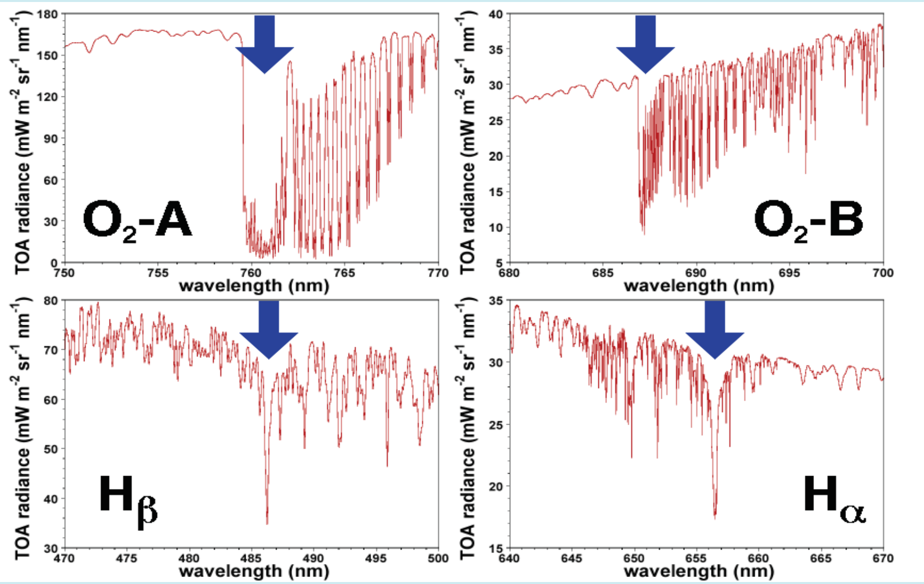

Markanvändningsklasser:
Vattendrag
Åkermark
Tallskog
Kalhyggen
Öppen mark
Granskog
Öppna myrar
Lövskog
Torvproduktion
Blandskog
Skogskärr
Plantskog
Myrmark

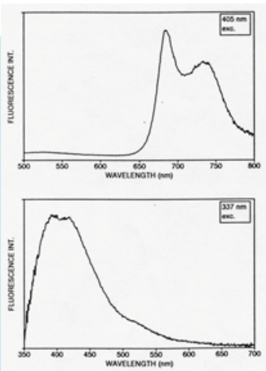


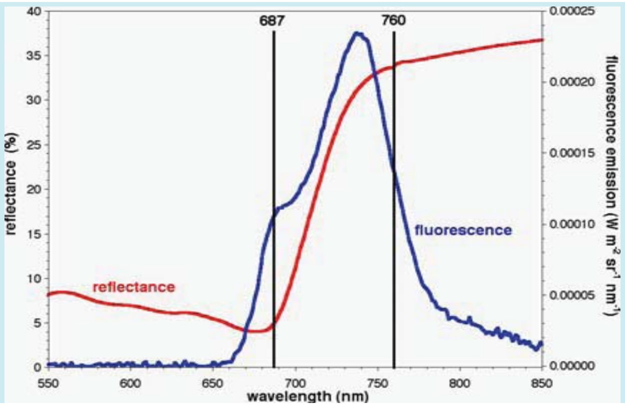
FLEX Fraunhofer Discrimination Vegetation Fluorescence Satellite

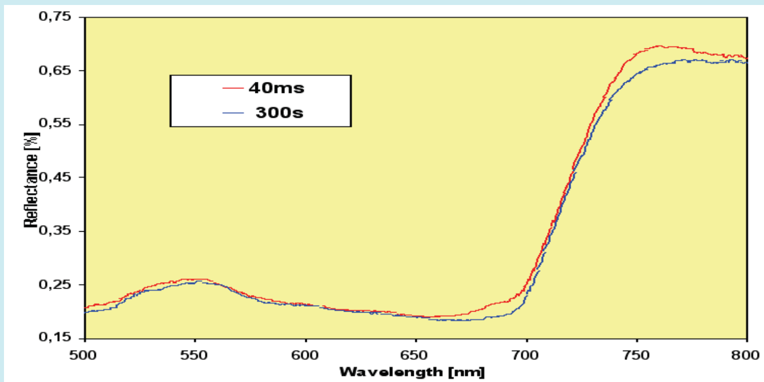






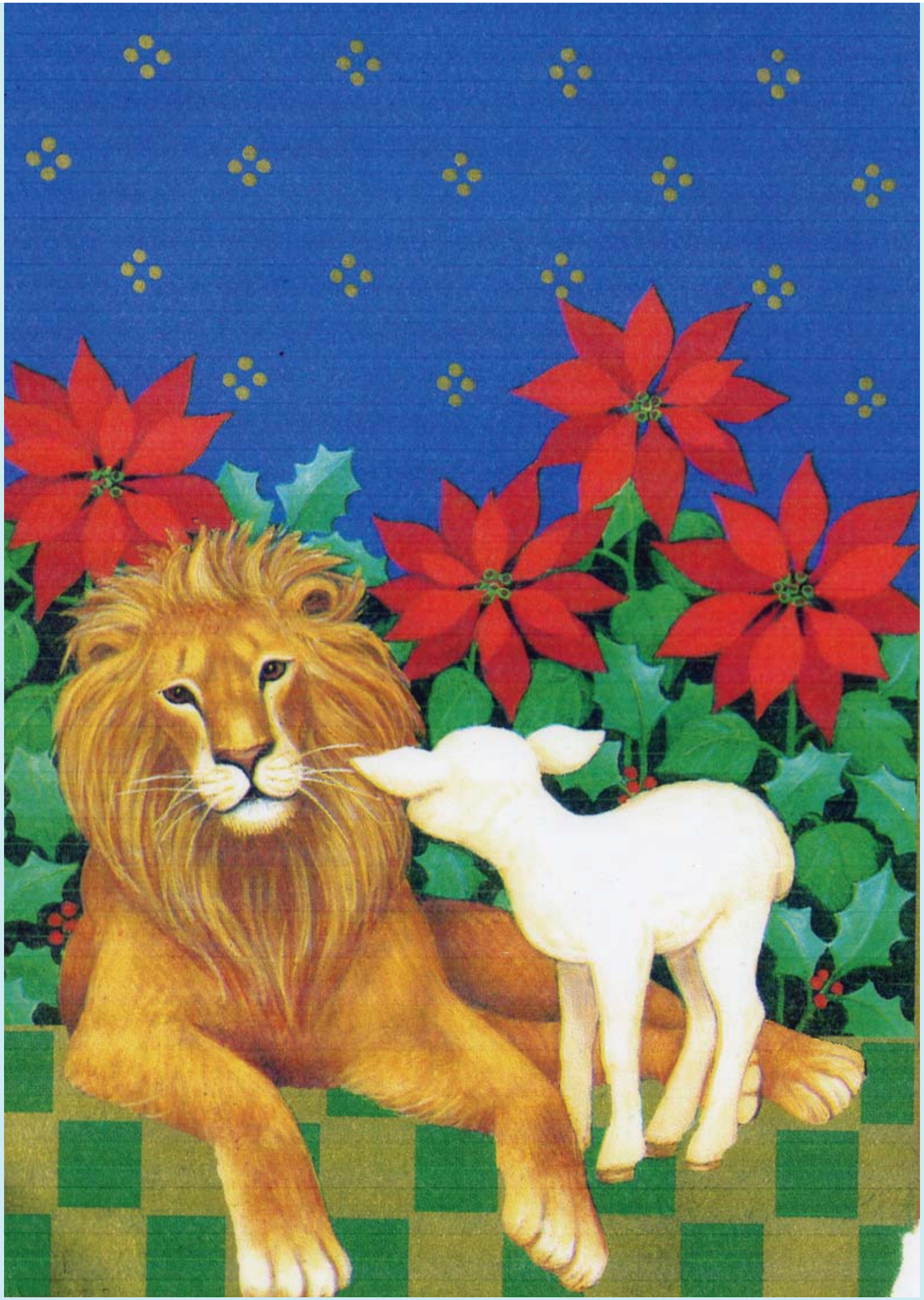






ESA FLEX Team


Earth and Moon Photographed from Mars
(NASA/JPL/MSSS



Science
and
Technology
can
Help
create
a
Better
World!

But Friendship and
Love is even more
important!


Thank you for your attention!

Literature, S. Svanberg lectures:

S. Svanberg, *Atomic and Molecular Spectroscopy*
– *Basic Aspects and Practical Applications*, 4th ed. (Springer, 2004)
S. Svanberg, *Multispectral Imaging*
– *From Astronomy to Microscopy*
- *From Radiowaves to Gamma rays* (Springer, to appear 2009)
S. Svanberg, Laser based diagnostics
- from cultural heritage to human health,
Appl. Phys. B **92**, 351 (2008)
S. Svanberg, Fluorescence Spectroscopy and Imaging of Lidar Targets,
Chapter 7 in T. Fujii and T. Fukuchi (Eds)
Laser Remote Sensing (CRC Press, Boca Raton 2005) pp 433-467
S. Svanberg, LIDAR, Invited book chapter for F. Träger, Ed.,
Springer Handbook of Lasers and Optics
(Springer, Heidelberg 2007), pp 1031-1052