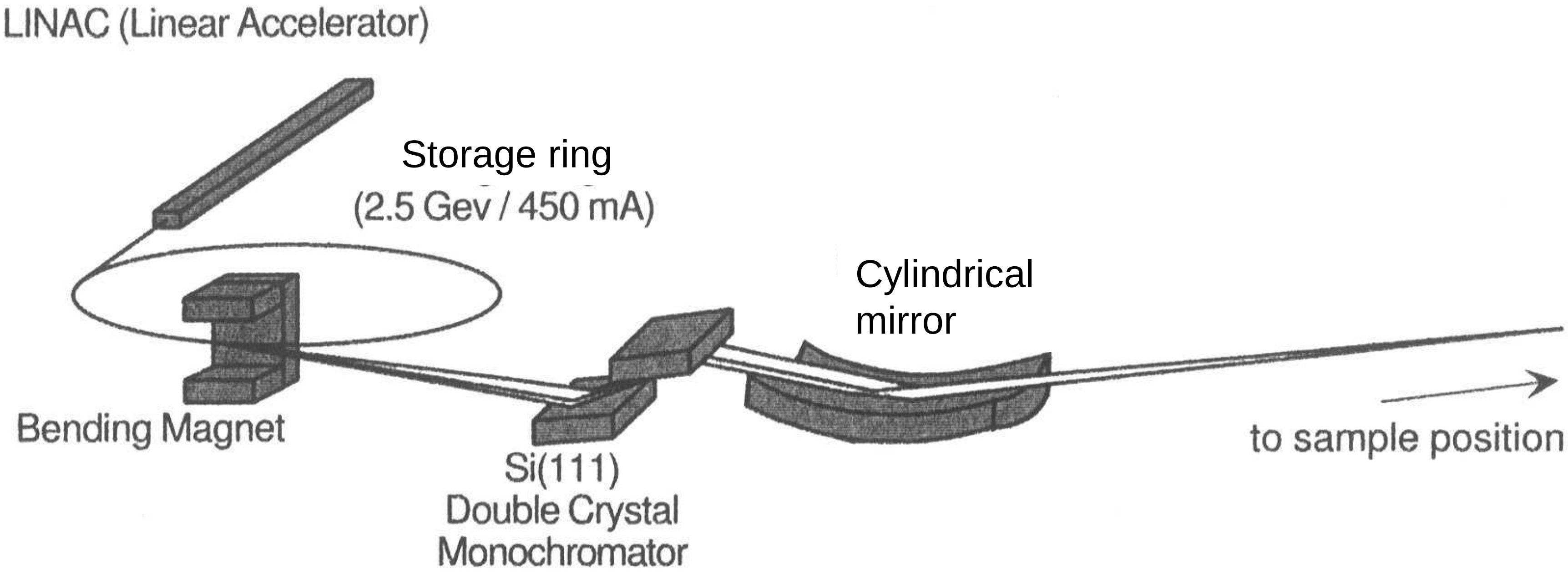
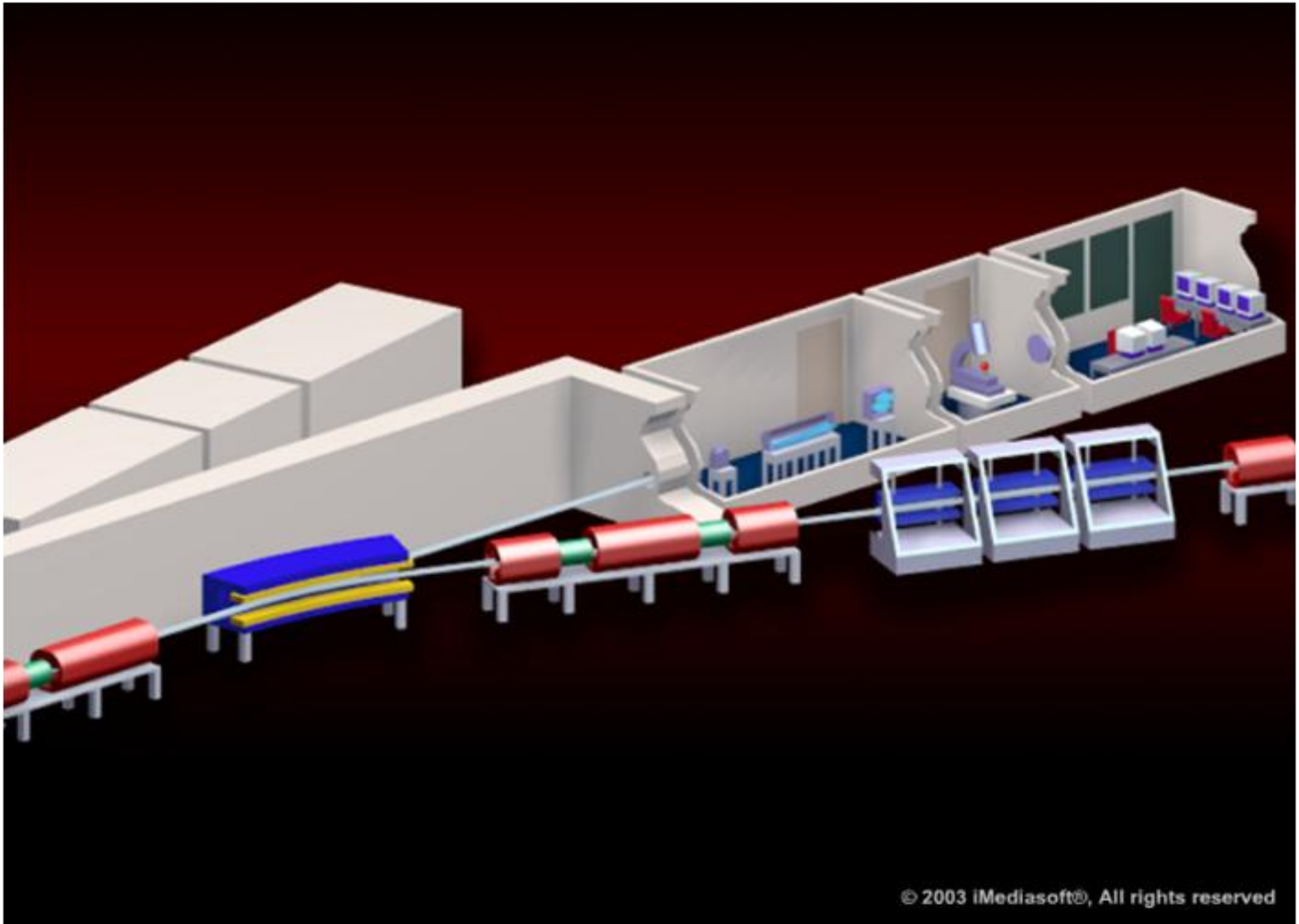
Beamline organization

This is a typical x-ray beamline.
Optics hutch contains elements for conditioning the x-ray beam



How does a beamline work?

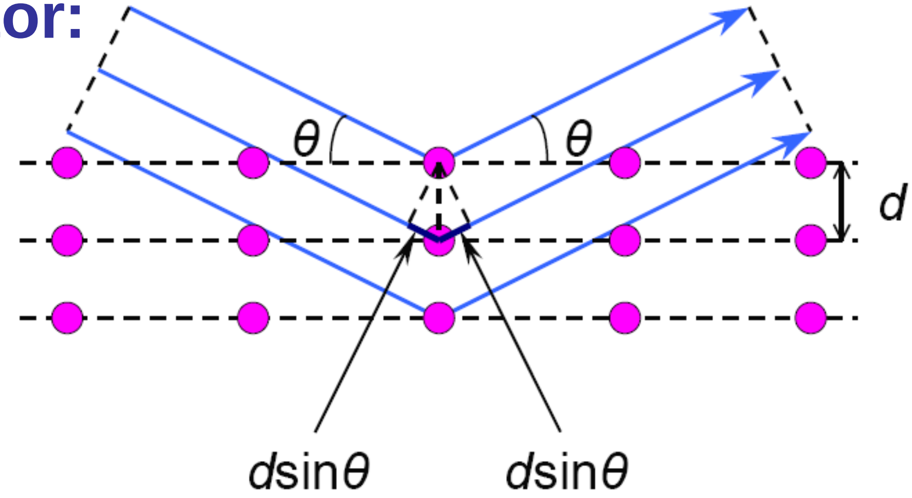


X-ray monochromator using perfect crystal

Basic principle of monochromator:

Bragg reflection from perfect single crystal

$$\boxed{2d_{hkl}\sin\theta = n\lambda}$$



Energy range of standard monochromator

Bragg Reflection

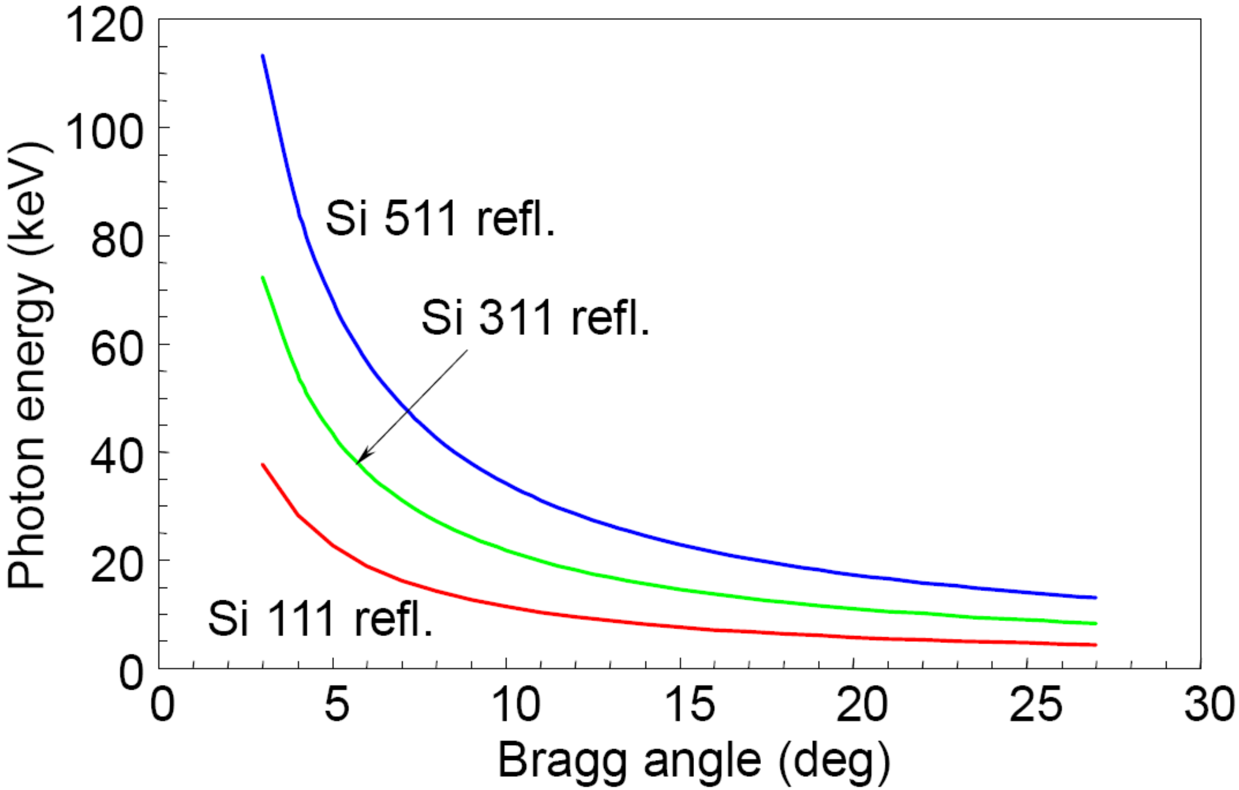
- **Si 111**
- **Si 311**
- **Si 511**
- **.....**

Bragg angles

- **3~27°**

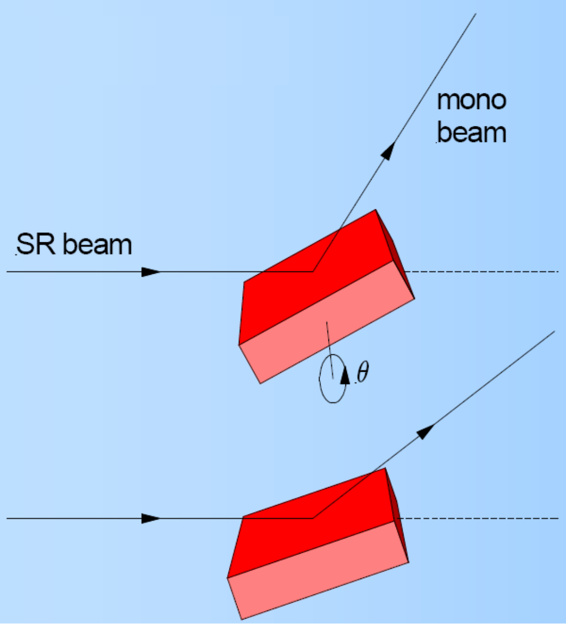
Energy range

- **4.4~110 keV**



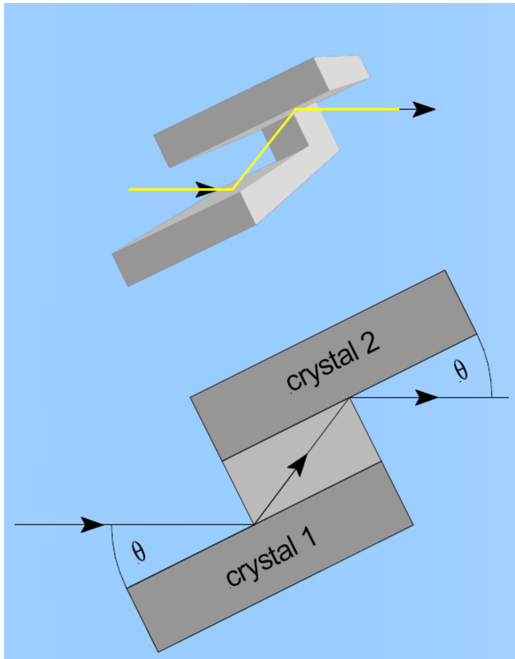
Photon energy (wavelength) can be selected by crystal, net planes, and Bragg angle.

Double crystal monochromator



Problems with single crystal monochromators

- the monochromatic beam moves when the energy is changed
- high harmonic content
- big tails



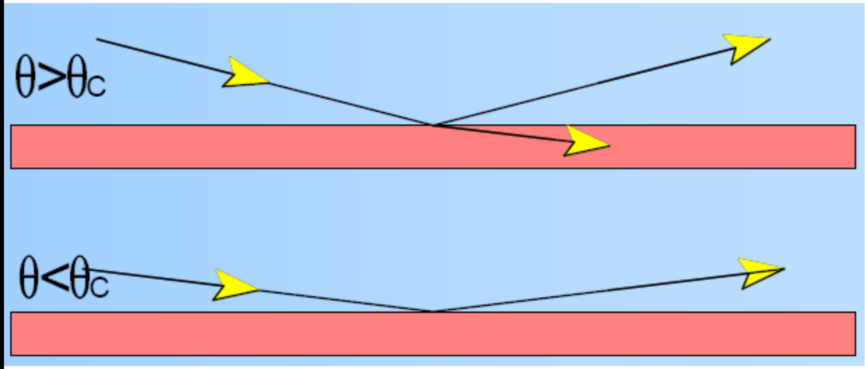
Solution: double crystal design!
Simplest design: cutting a channel for the beam in a silicon block (**channel cut monochromator**)

- **Use the same crystals and *d*-spacing for 1st and 2nd crystals**
- **Keep parallel setting**

X-ray Mirrors

reflectivity at grazing angles:

refractive index: $n = 1 - r_0\,\rho\,\lambda^2 / 2\pi - i\,\mu\lambda / 4\,\pi$

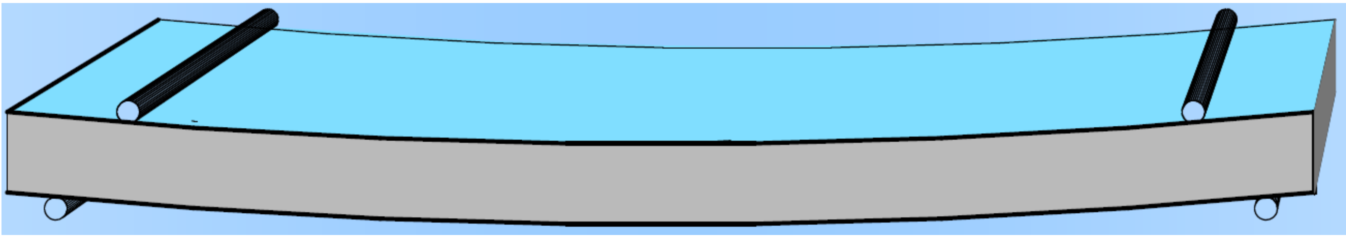


By Snell's law ($n_1 \cos(\theta_1) = n_2 \cos(\theta_2)$ with θ the grazing angle) in the absence of absorption (total reflection), we find total external reflection for angles less than $\theta_c \approx \lambda(r_0\,\rho / \pi)^{1/2}$

θ_c typically a few mrad for x-ray mirrors

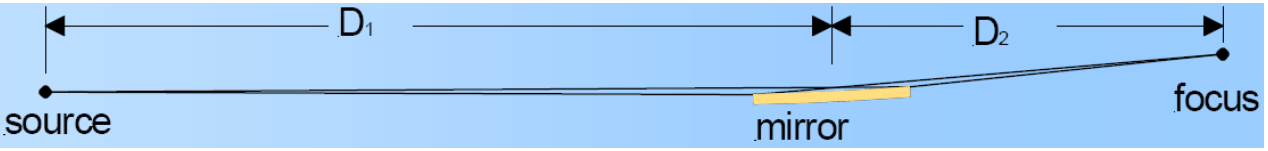
Surface roughness must be considered around critical energy (angle).

Bent mirrors (focusing and collimating)



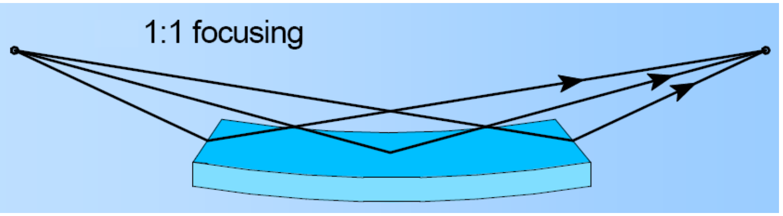
Focusing of the x-ray beam → reflecting surface must have some curvature (achieved e.g. by bending mirror, **mirror focuses in one plane only**!)

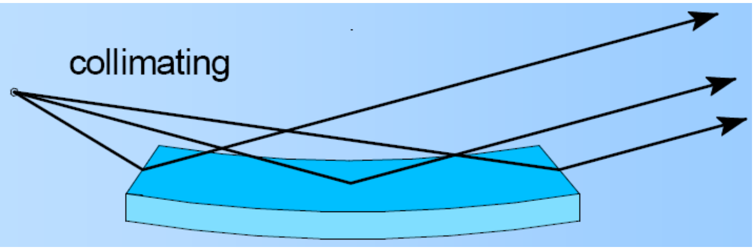
Bending radius *R* (can be ~ 10 km)



$$R = \frac{2D_1D_2}{\theta(D_1 + D_2)}$$

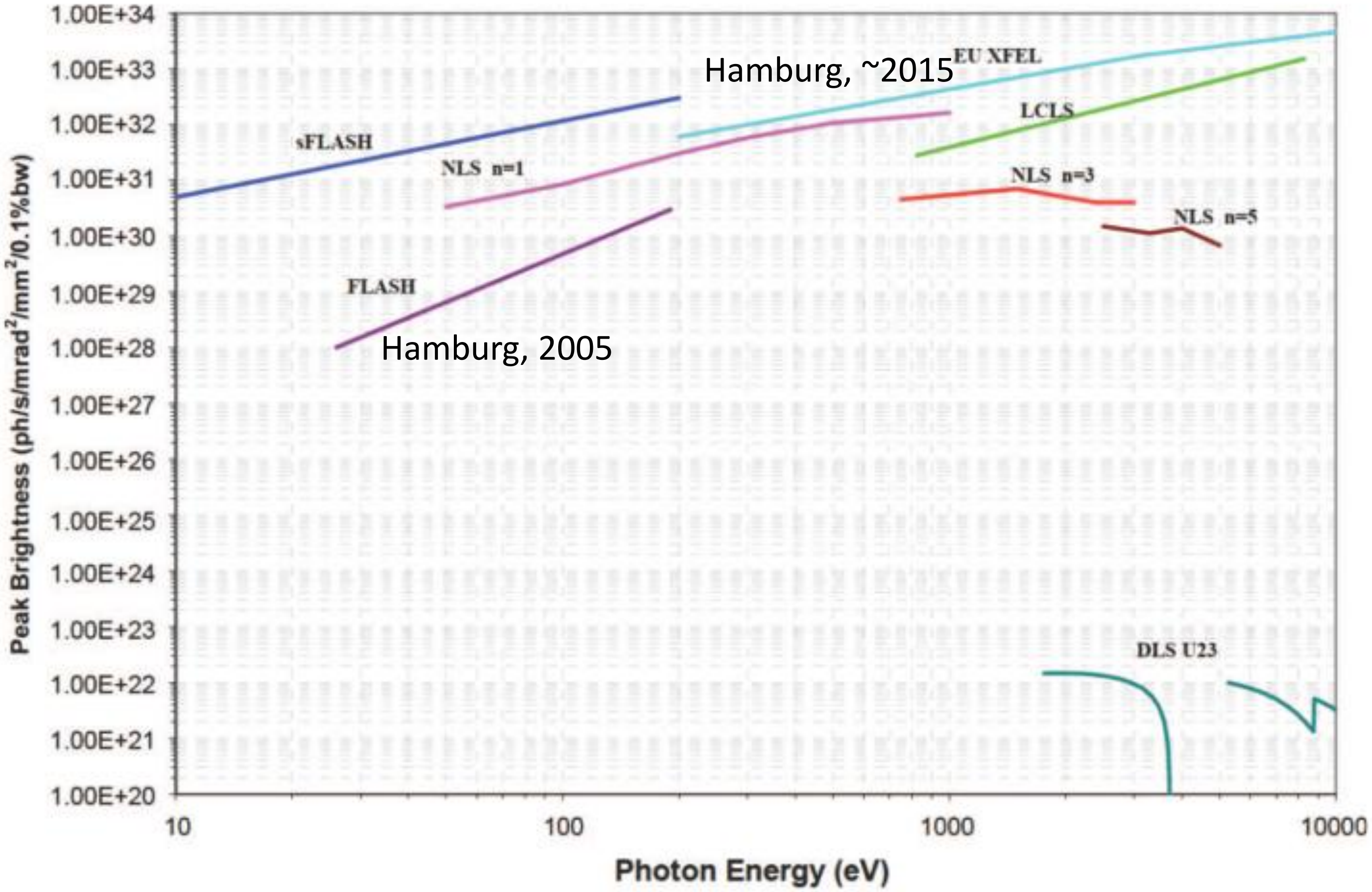
imaging the source in the vertical direction with unity magnefication (1:1 focusing)





improving energy resolution of a following monochromator by production of a parallel beam (collimating)

Free electron laser (FEL)



Hamburg, ~2015

Hamburg, 2005

Figure 1. Comparison of several recently commissioned FELs (FLASH and LCLS) and several planned FELs (sFLASH, Euro XFEL, NLS) with a state-of-the-art undulator beamline on the Diamond Light source. The standard definition of brightness is given in photons/unit time/unit solid angle/unit area/normalised bandwidth. Courtesy of STFC, New Light Source Conceptual Design Report (2010) [1].

SASE – spontaneous amplified self-emission

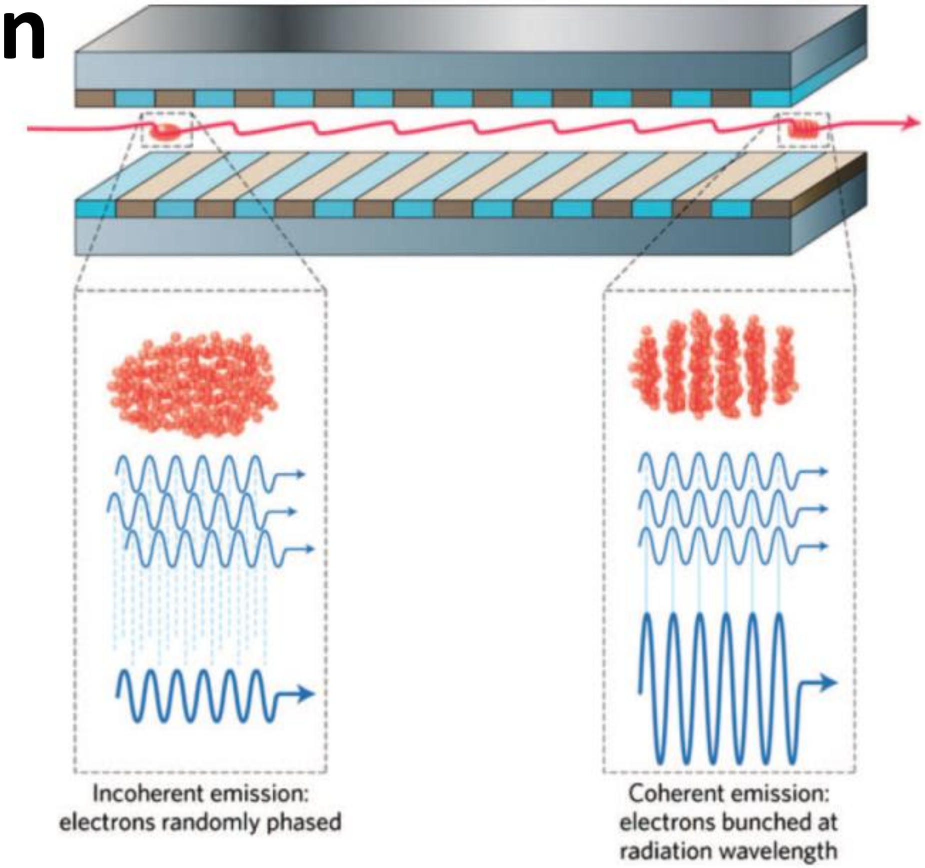
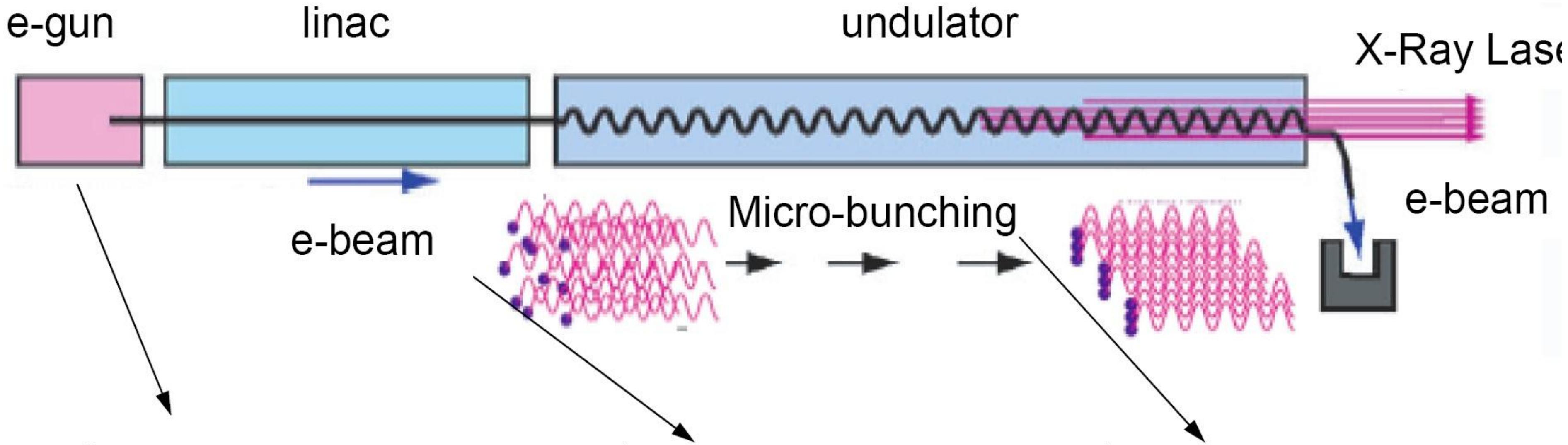


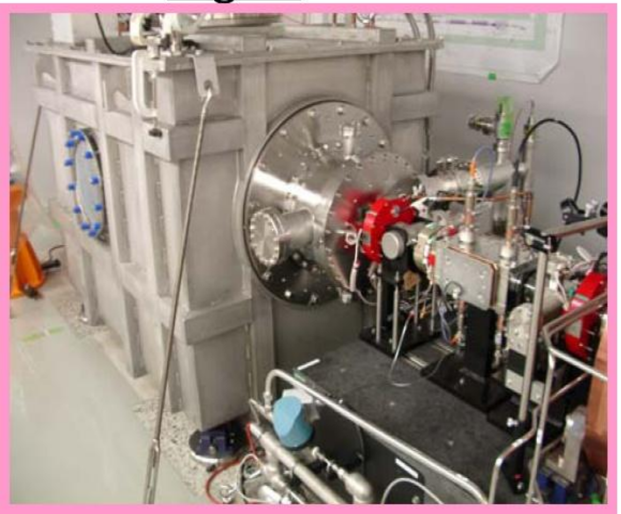
Figure 3. Schematic of SASE operation where the oscillation induced in the electron beam by the periodic magnetic field leads to radiation emission and, at the end of a sufficiently long undulator, self-organisation of the electrons gives rise to coherent X-ray emission. Reprinted by permission from Macmillan Publishers Ltd., Nature Photonics, B.W.J. McNeil and N.R. Thompson, *X-ray free electron lasers*, Nature Photonics, 4 (2010), pp. 814–821, copyright (2010).

Linac-based Free Electron Laser
Self-Amplified Spontaneous Emission (SASE)

Principle design (SPring-8, Japan):



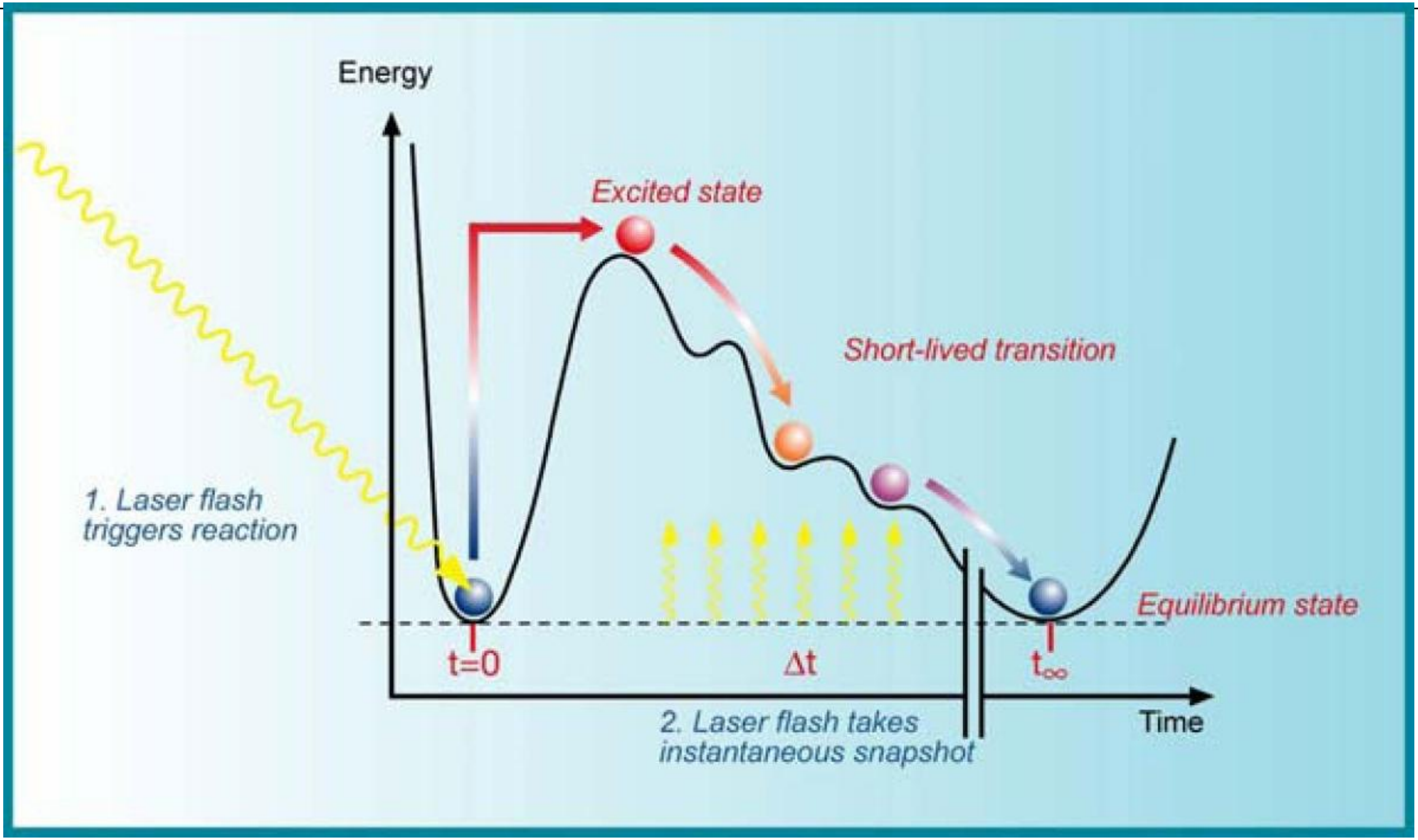
◆ **e-gun** (pulsed)



◆ **linac** (linear accelerator)

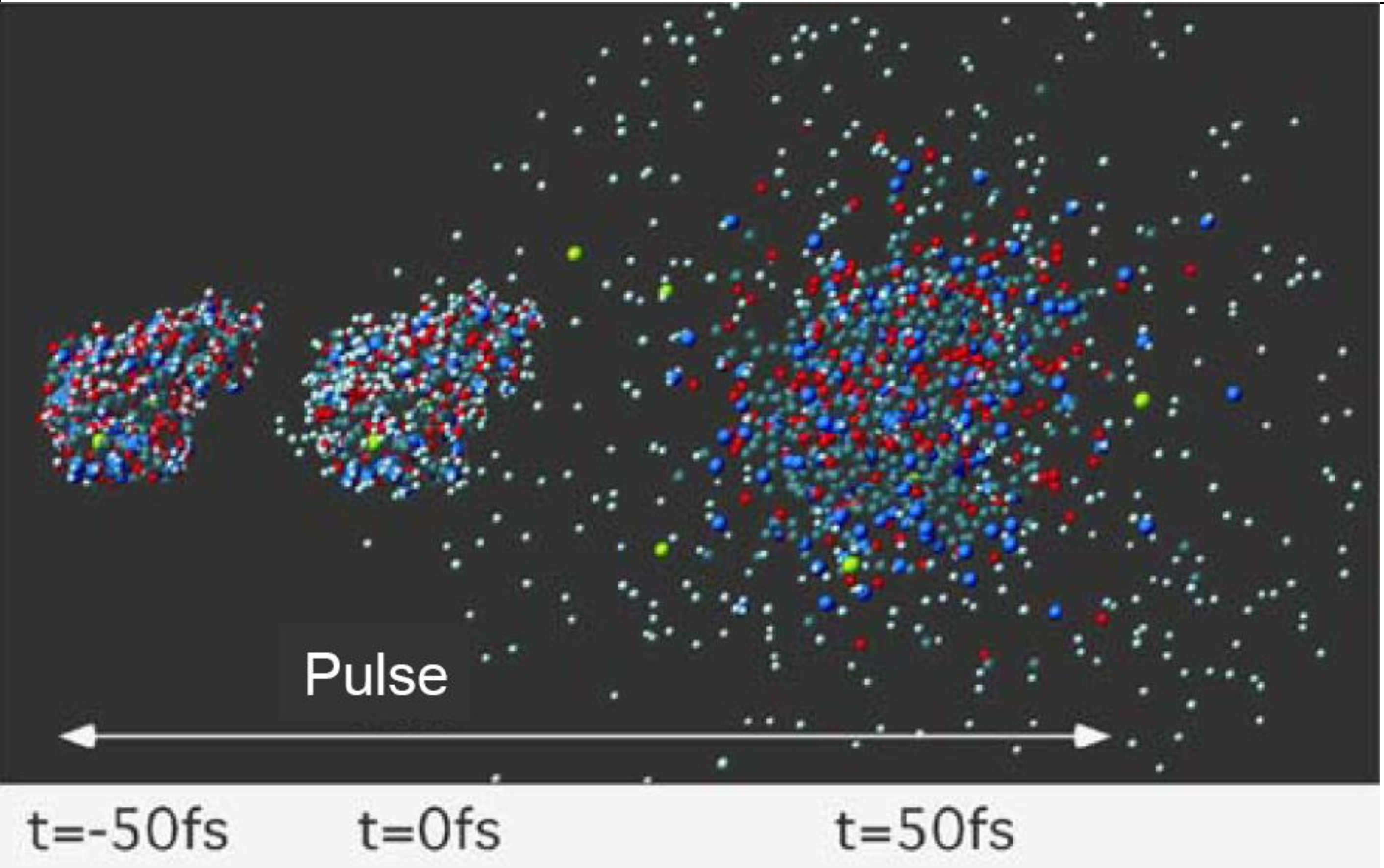
◆ **undulator**

Pump-probe experiment



Snapshots for different times after excitation (“pump-probe experiment”) ⇒ “film” of the reaction

Obstacle: Coulomb-Explosion



Example:

Lysozyme

white: Hydrogen,
grey: Carbon,
blue: Nitrogen,
red: Oxygen,
yellow: Sulfur

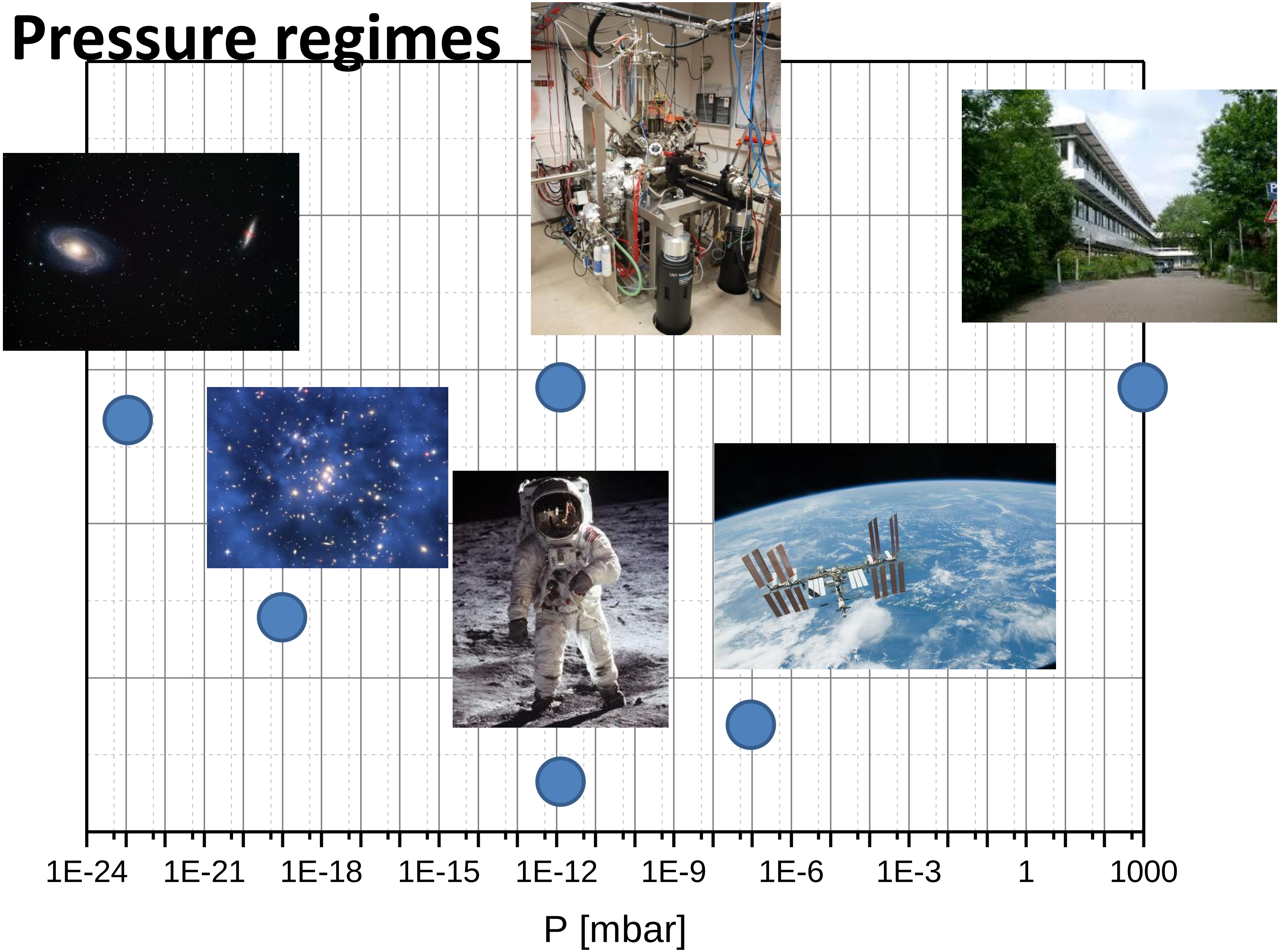
Requirement: **Pulse must be short enough and not to intense,**
to take picture before molecule disintegrates !

R. Neutze et al., Nature, August 2000

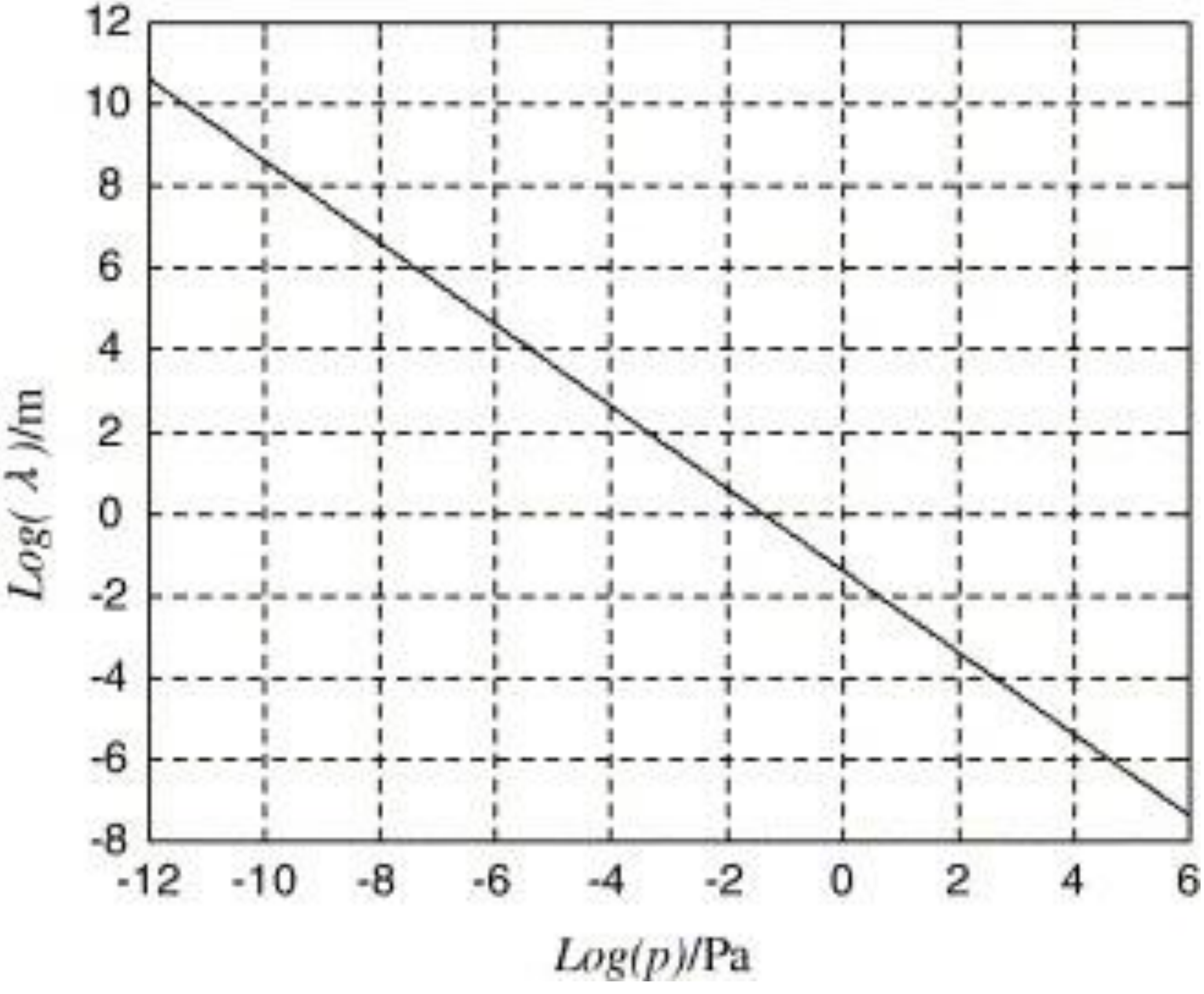
Properties of vacuum

pressure	monolayer time constant	molecular density	mean free path
p [mbar]	t (s)	n [m-3]	l [m]
1,00E+03	3E-09	2E+25	8E-09
1,00E+00	3E-06	2E+22	8E-06
1,00E-03	3E-03	2E+19	8E-03
1,00E-06	3E+00	2E+16	8E+00
1,00E-09	3E+03	2E+13	8E+03
1,00E-12	3E+06	2E+10	8E+06
1,00E-15	3E+09	2E+07	8E+09

Pressure regimes



Mean free path of electrons



Turbomolecular pump

Ion pump

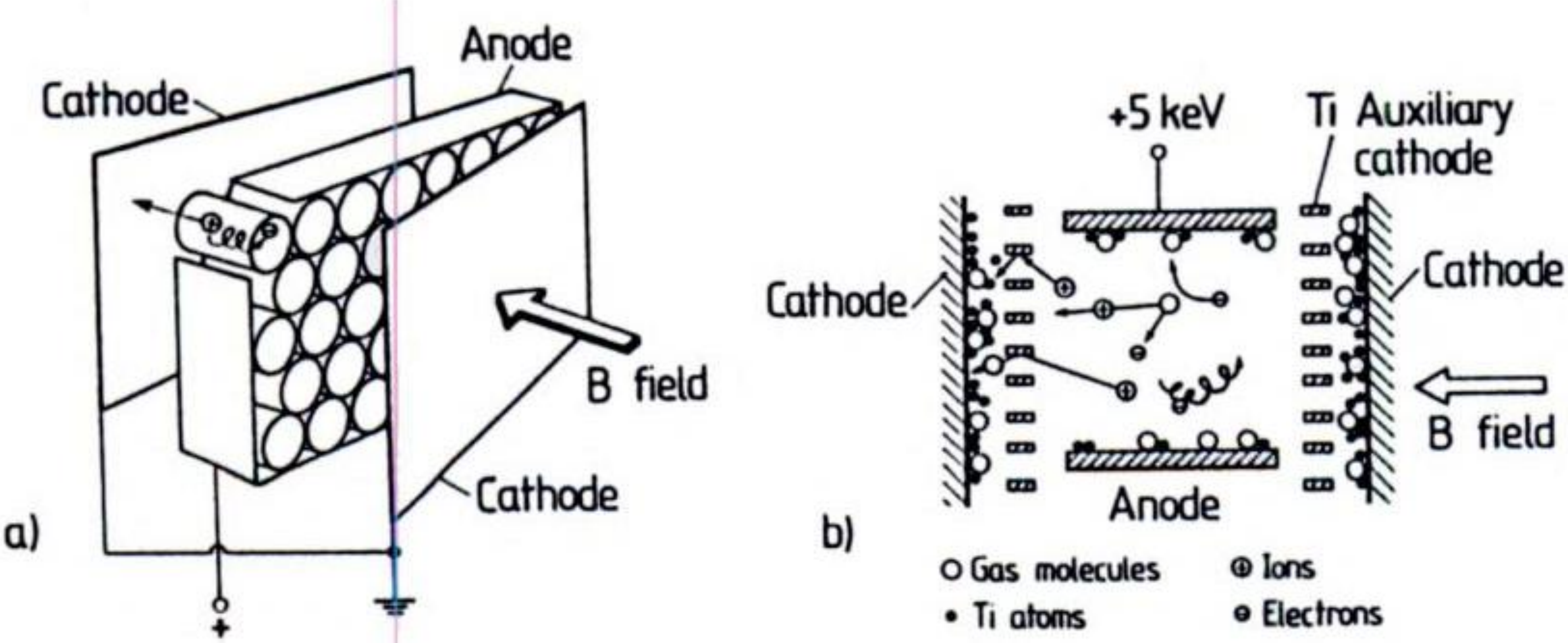
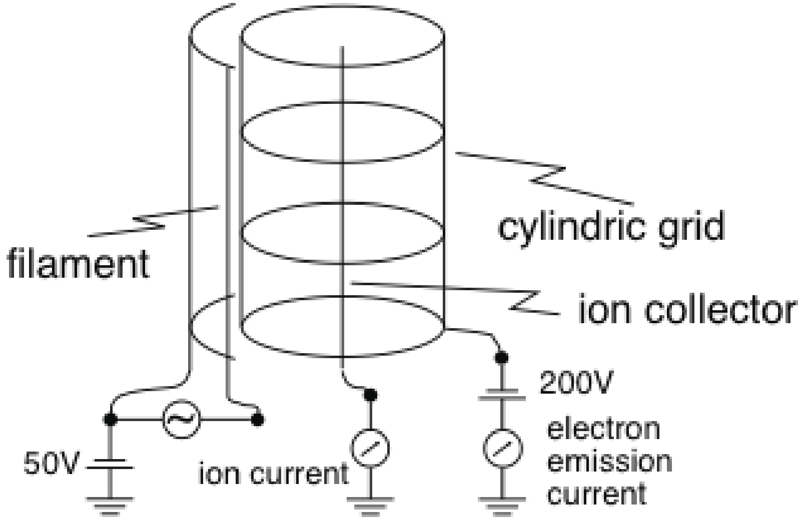


Fig. I.7a,b. Schematic view of an ion-getter pump: (**a**) The basic multicell arrangement. Each cell consists essentially of a tube-like anode. The cells are sandwiched between two common cathode plates of Ti, possibly together with auxiliary cathodes of Ti. (**b**) Detailed representation of the processes occurring within a single cell. Residual gas molecules are hit by electrons spiralling around the magnetic field B and are ionized. The ions are accelerated to the cathode and/or auxiliary cathode; they are trapped on the active cathode surface or they sputter Ti atoms from the auxiliary cathode, which in turn help to trap further residual gas ions

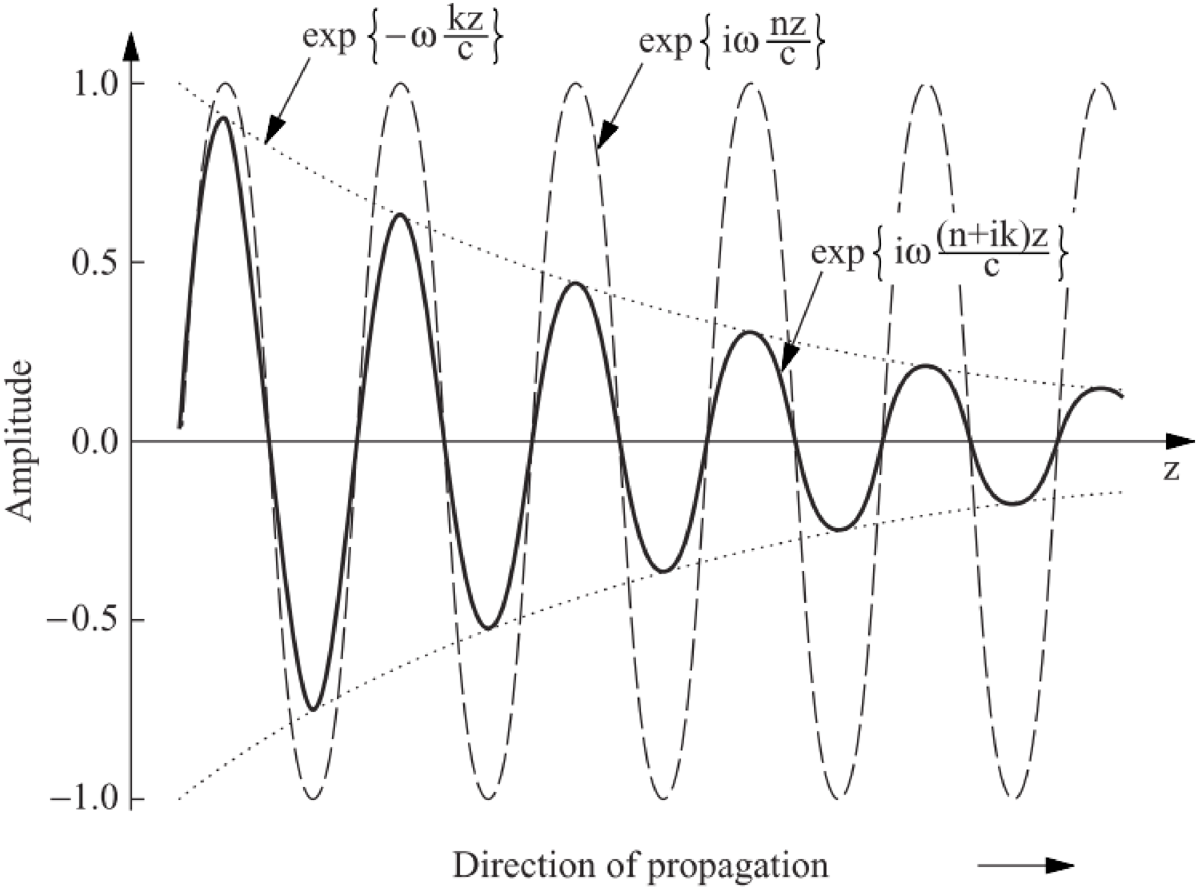
CF-flange

Ionization gauge

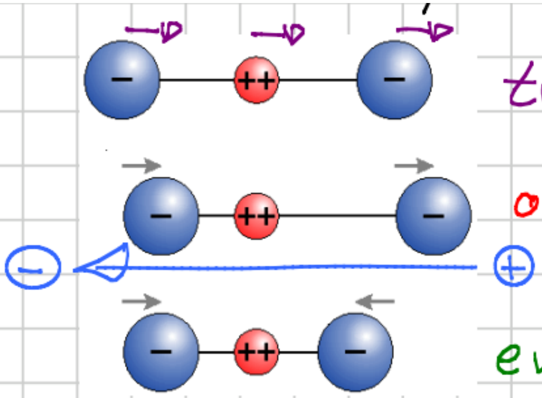


Electromagnetic wave in mater

$$\vec{E} = \vec{E}_0 e^{-\frac{k\omega}{c}\vec{n}_q\cdot\vec{r}}\; e^{i(\frac{n\omega}{c}\vec{n}_q\cdot\vec{r}-\omega t)}$$



Drude-Lorentz-model



translation

odd (→ infrared active) couples to $\vec{E} = \vec{E}_0 e^{-i\omega t}$ $(q = 0)$

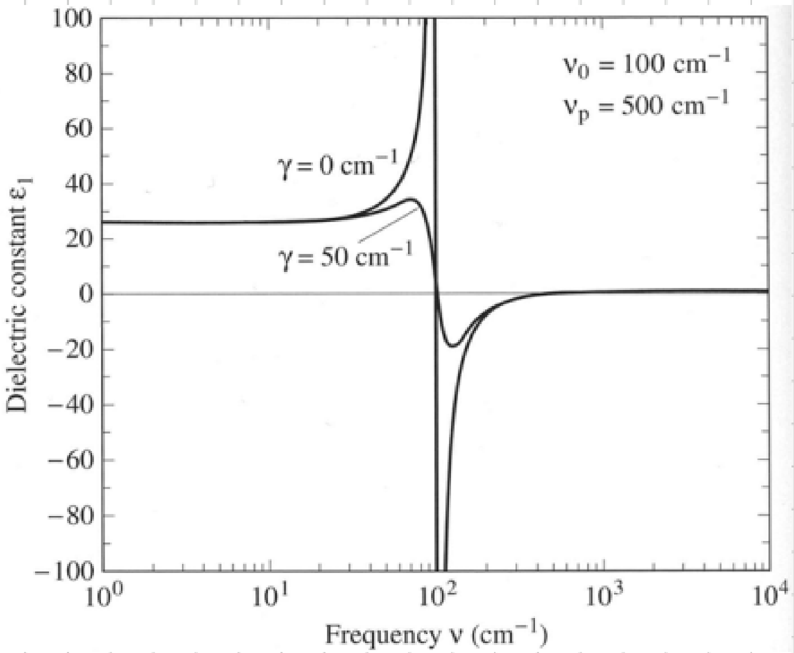
even (→ Raman)

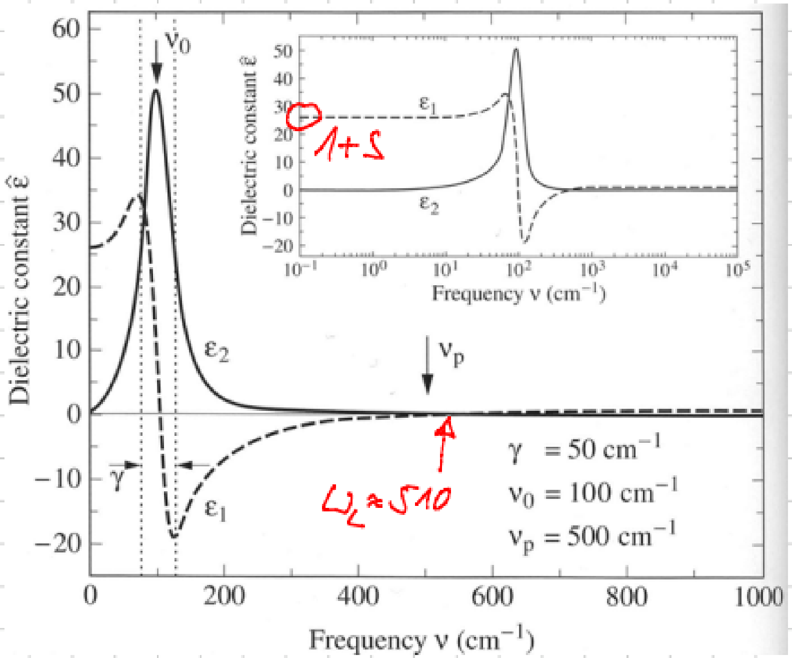
Examples for Lorentz oscillators

example

Lorentz

oscillator

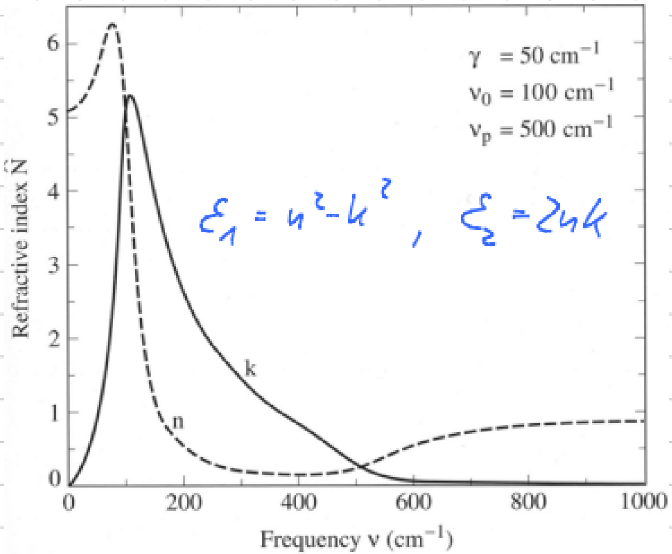




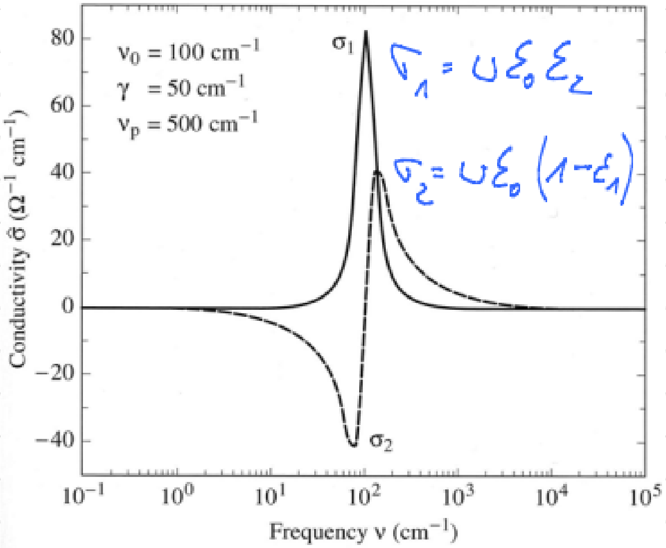
$1+S$

$\omega_L \approx 510$

(Dressel)



$\varepsilon_1 = n^2 - k^2 \,, \quad \varepsilon_2 = 2nk$



$\sigma_1 = \omega \varepsilon_0 \varepsilon_2$

$\sigma_2 = \omega \varepsilon_0 (1 - \varepsilon_1)$

$$\varepsilon = 1 + \frac{\omega_p^2}{\omega_0^2 - \omega^2 - i\gamma\omega}$$

$$\varepsilon_1(\omega_L) = 0$$

$$\varepsilon_2(\omega_0) = \frac{\omega_p^2}{\gamma\omega_0}$$

→ δ-function for $\gamma = 0$

$$S = \frac{\omega_p^2}{\omega_0^2} = \Delta\varepsilon$$