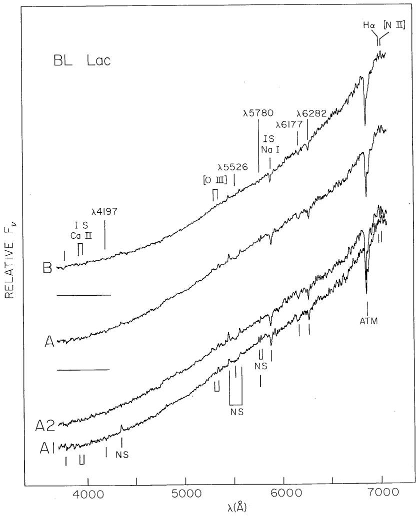
BL Lac and OVVs

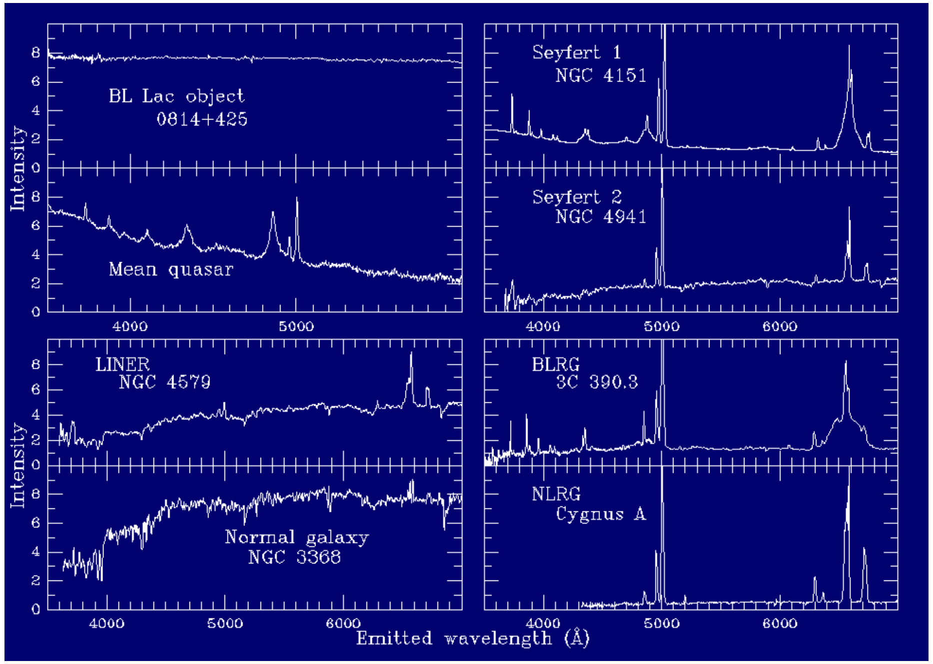


(Miller & Hawley, 1977, Fig. 1)

Most AGN show continuum variability (see later), but some show fast, large amplitude variability: blazars.

Subclasses:

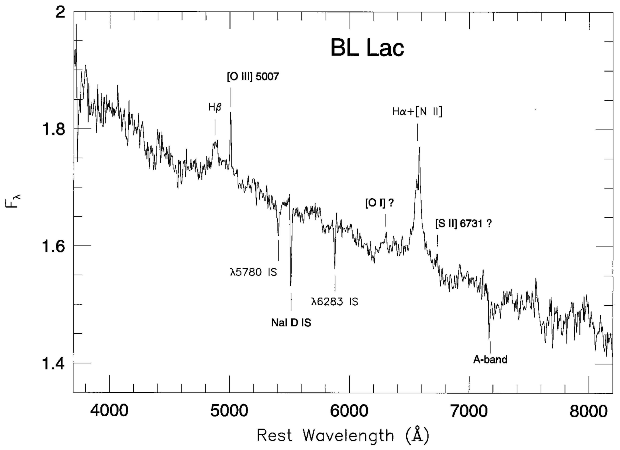
- Optically Violent Variables: OVVs: $\Delta m \gtrsim 0.1$ mag.
- BL Lac Objects: after prototype BL Lacertae (originally classified as a star, $m_{\mathrm{B}} = 14$–16 mag): virtual absence of emission lines above continuum



(W. Keel, priv. comm.)

Summary of optical spectra of different AGN types

BL Lac and OVVs

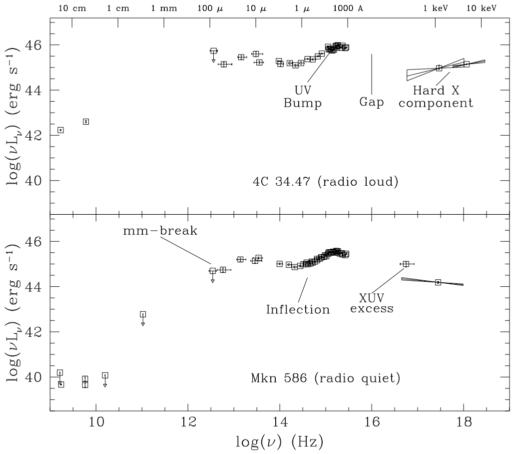


(Vermeulen et al., 1995, “When is BL Lac not a BL Lac?”, Fig. 3)

In weak phases, BL Lac shows a spectrum $F_\nu \propto \nu^{-1.7}$ (strongly polarized, synchrotron radiation) and broad emission lines $\Longrightarrow$ typical AGN continuum!

$\Longrightarrow$ There seems to be a continuum between Seyferts, QSOs, and Blazars $\Longrightarrow$ Same physics? $\Longrightarrow$ Unification.

Accretion Disks in AGN, I

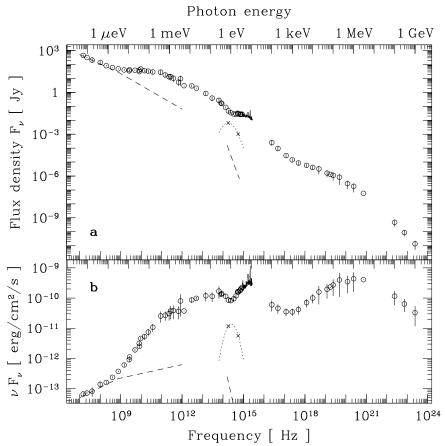


Spectral Energy Distribution of radio-loud and radio-quiet AGN (Elvis et al., 1994)

Big Blue Bump: Excess radiation in ~UV range $\Longrightarrow$ disk?

IR Bump: Excess radiation in ~IR range $\Longrightarrow$ dust? (peak T: 2000 K; dust sublimation?)

Accretion Disks in AGN, II

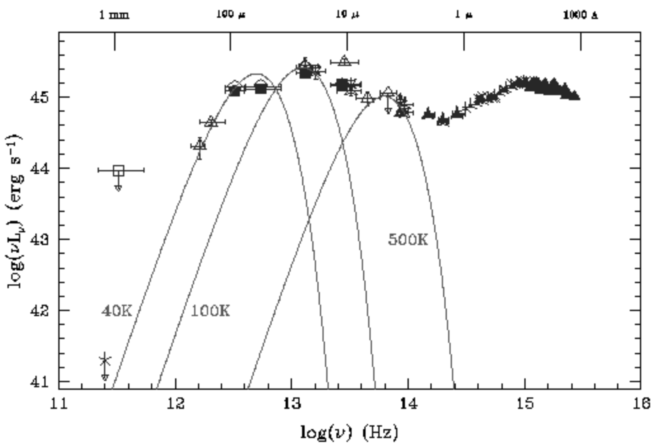


Spectral Energy Distribution of 3C273 (Türler et al., 1999)

Big Blue Bump: Excess radiation in ∼UV range $\Longrightarrow$ disk?

IR Bump: Excess radiation in ∼IR range $\Longrightarrow$ dust? (peak T: 2000 K; dust sublimation?)

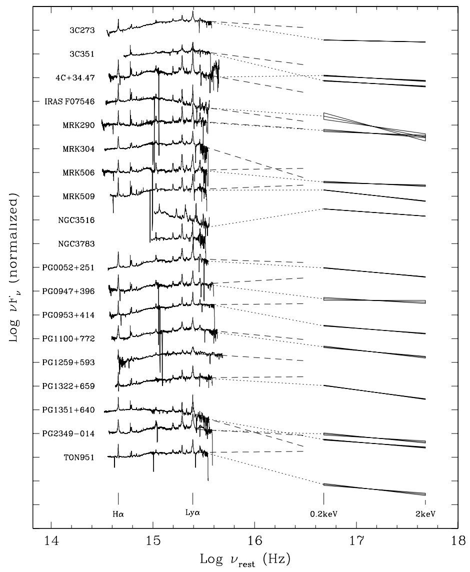
IR Bump



mm–optical SED of PG1351+640: dust has wide range of temperatures (Wilkes, 2004).

IR-Bump: too cold for disk, has substructure $\Longrightarrow$ different emission regions.

UV Bump



In *some* AGN: extrapolated UV power law smoothly matches X-ray continuum.

Remember: $f_\nu \propto \nu^{-\alpha}$

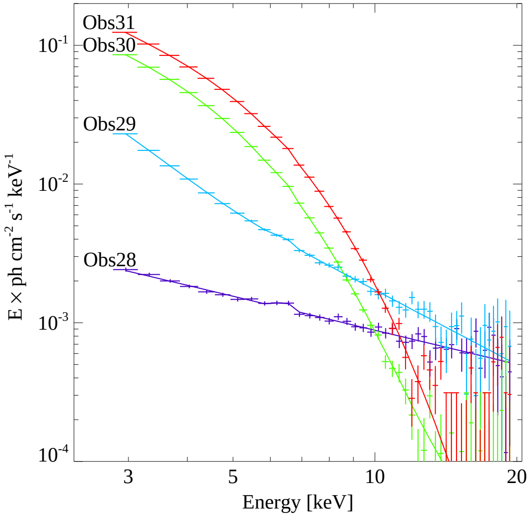
Break wavelengh between 800 and 1600 Å, in rough agreement with accretion disk models.

Theory of the break: H-Lyman edge, possibly smeared by Comptonization or relativistic effects.

However: no correlation between UV slope and BH mass as expected from accretion disk models?!?

(Shang et al., 2005)

Galactic Black Holes



LMC X-3, (Wilms et al., 2001)

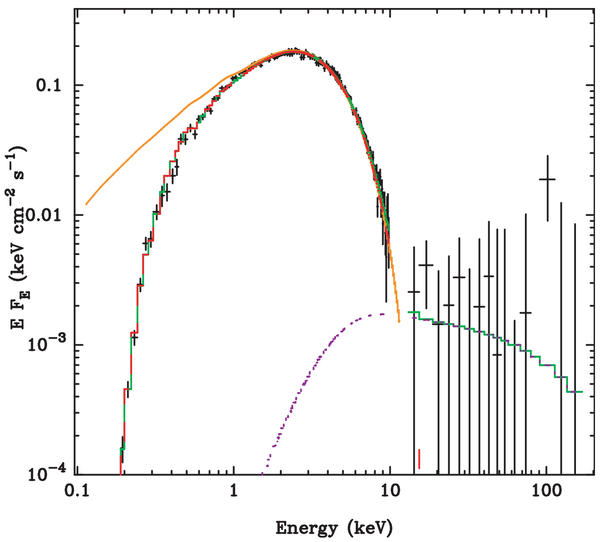
Problem with AGN: peak of disk in UV

$\Longrightarrow$ Galactic Black Holes: T is higher

Find ok agreement between accretion disk models and theory.

In general: models with just $T \propto r^{-3/4}$ and no additional (atomic) physics seem to work best?!?

Galactic Black Holes



Comparison of self-consistent accretion disk model with LMC X-3 data $\Longrightarrow$ good agreement, although values of α smaller than expected (fits find $0.01 < \alpha < 0.1$ instead of 0.1–0.8).

(Davis, Done & Blaes, 2006)

Top red line: inferred accretion disk spectrum without interstellar absorption.

4–32

Balbus, S. A., & Hawley, J. F., 1991, ApJ, 376, 214

Chandrasekhar, S., 1961, Hydrodynamic and Hydromagnetic Stability, (Oxford: Oxford Univ. Press), (reprinted 1981 by Dover, New York)

Davis, S. W., Blaes, O. M., Hubeny, I., & Turner, N. J., 2005, ApJ, 621, 372

Davis, S. W., Done, C., & Blaes, O. M., 2006, ApJ, 647, 525

Elvis, M., et al., 1994, ApJS, 95, 1

Hawley, J. F., & Krolik, J. H., 2002, ApJ, 566, 164

Shang, Z., et al., 2005, ApJ, 619, 41

Türler, M., et al., 1999, A&AS, 134, 89

Velikhov, E. P., 1959, Sov. Phys. – JETP, 9, 995

Wilkes, B., 2004, in AGN Physics with the Sloan Digital Sky Survey, ed. G. T. Richards, P. B. Hall, 37

Wilms, J., Nowak, M. A., Pottschmidt, K., Heindl, W. A., Dove, J. B., & Begelman, M. C., 2001, MNRAS, 320, 327

X-Ray Detectors

Introduction

A large amount of our understanding of AGN comes from non-optical observations.

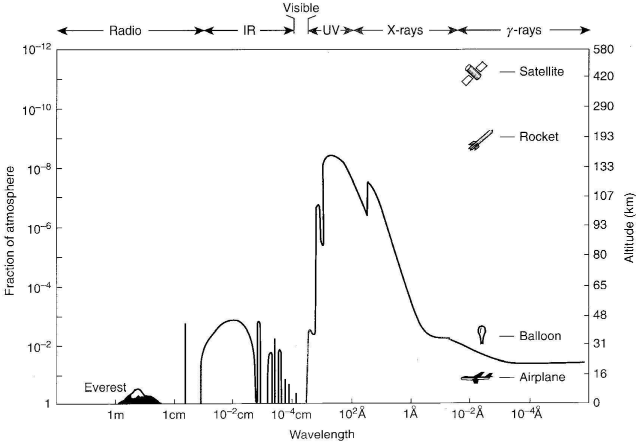
$\Longrightarrow$ we need to understand how these observations are made to be able to interpret their results.

$\Longrightarrow$ Will take a “side trip” into the world of X-ray detectors.

There are two main issues to deal with:

- X-ray Optics
- X-ray Detectors

Earth's Atmosphere



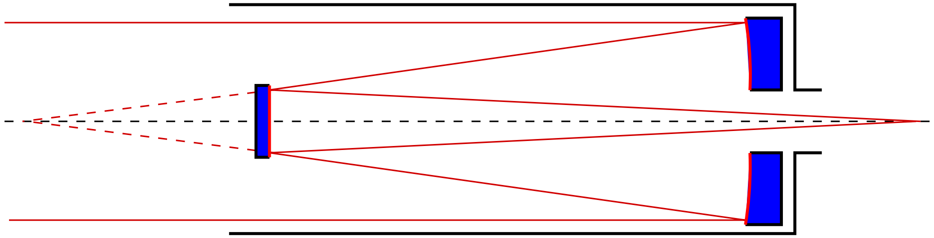
Charles & Seward, Fig. 1.12

Earth's atmosphere is opaque for all types of EM radiation except for optical light and radio.

Major contributer at high energies: photoabsorption ($\propto E^{-3}$), esp. from oxygen (edge at $\sim$500 eV).

$\Longrightarrow$ If one wants to look at the sky in other wavebands, one *has* to go to space!

Optical Imaging, I



Cassegrain telescope, after Wikipedia

Reminder: Optical telescopes are usually reflectors:

primary mirror (paraboloid) → secondary mirror (often flat) → detector

Main characteristics of a telescope:

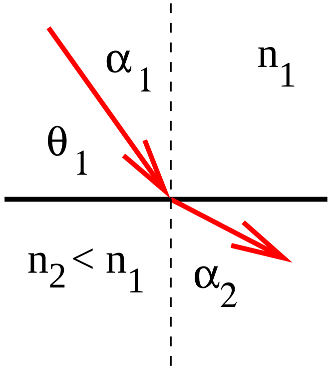
- collecting area (i.e., open area of telescope, $\sim \pi d^2/4$, where d: telescope diameter)
- for small telescopes: angular resolution,

$$\theta = 1.22\frac{\lambda}{d} \tag{5.1}$$

but in the optical: do not forget the seeing!

Optical Imaging, II

Optical telescopes are based on principle that reflection "just works" with metallic surfaces.



Snell's law of refraction:

$$\frac{\sin\alpha_1}{\sin\alpha_2} = \frac{n_2}{n_1} = n \tag{5.2}$$

where n index of refraction, and $\alpha_{1,2}$ angle wrt. surface normal. If $n \gg 1$: Total internal reflection

Total reflection occurs for $\alpha_2 = 90^\circ$, i.e. for

$$\sin\alpha_{1,\mathrm{c}} = n \quad\Longleftrightarrow\quad \cos\theta_{\mathrm{c}} = n \tag{5.3}$$

with the critical angle $\theta_{\mathrm{c}} = \pi/2 - \alpha_{1,\mathrm{c}}$.
Clearly, total reflection is only possible for $n < 1$.

Light in glass at glass/air interface: $n = 1/1.6 \Longrightarrow \theta_{\mathrm{c}} \sim 50^\circ \Longrightarrow$ principle behind optical fibers.

Optical Imaging, III

X-rays: index of refraction vacuum versus material is (Aschenbach, 1985):

$$n = 1 - N_\mathrm{A} \frac{Z}{A} \frac{r_\mathrm{e}}{2\pi} \rho \lambda^2 =: 1 - \delta \tag{5.4}$$

N_A: Avogadro's number, $r_\mathrm{e} = 2.8 \times 10^{-15}\,\mathrm{m}$, Z: atomic number, A: atomic weight ($Z/A \sim 0.5$), ρ: density, λ: wavelength (X-rays: $\lambda \sim 0.1$–$1\,\mathrm{nm}$).

Critical angle for X-ray reflection:

$$\cos\theta_\mathrm{c} = 1 - \delta \tag{5.5}$$

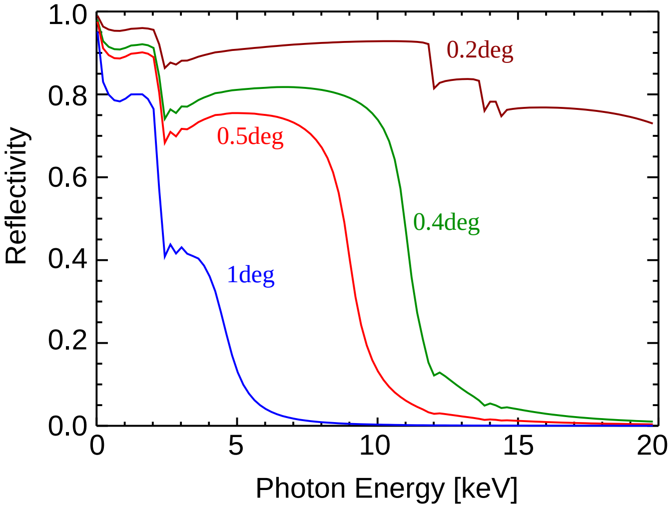
Since $\delta \ll 1$, Taylor ($\cos x \sim 1 - x^2/2$):

$$\theta_\mathrm{c} = \sqrt{2\delta} = 56' \rho^{1/2} \frac{\lambda}{1\,\mathrm{nm}} \tag{5.6}$$

So for $\lambda \sim 1\,\mathrm{nm}$: $\theta_\mathrm{c} \sim 1^\circ$.

To increase θ_c: need material with high ρ
$\Longrightarrow$ gold (*XMM-Newton*) or iridium (*Chandra*).

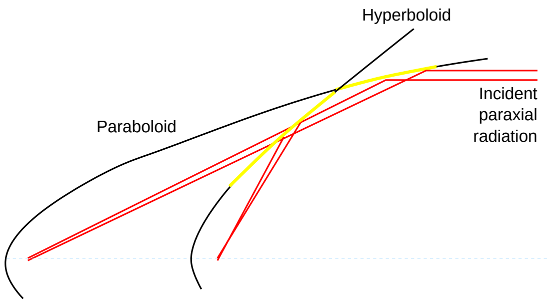
Optical Imaging, IV



X-rays: Total reflection only works in the soft X-rays and only under grazing incidence $\Longrightarrow$ grazing incidence optics.

Reflectivity for Gold

Wolter Telescopes, IV

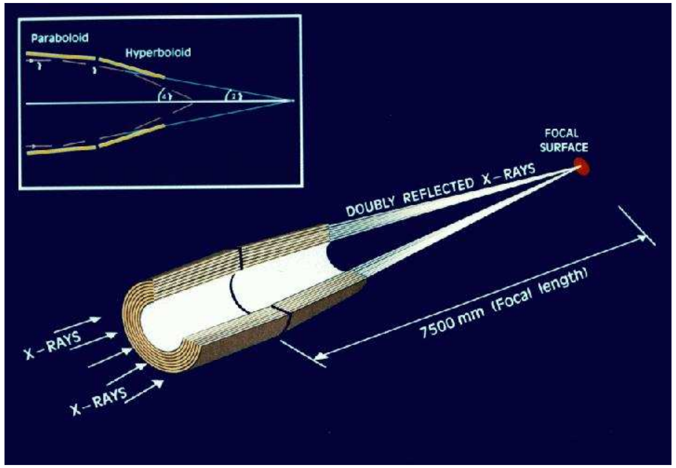


To obtain manageable focal lengths ($\sim 10\,\mathrm{m}$), do imaging with telescope using two reflections on a parabolic and a hyperboloidal mirror ("Wolter type I").

(Wolter, 1952, for X-ray microscopes, Giacconi, 1961, for UV- and X-rays).

But: small collecting area ($A \sim \pi r^2 l/f$ where f: focal length)

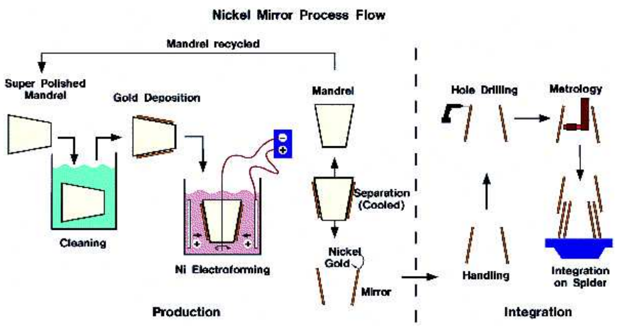
Wolter Telescopes, V



ESA/XMM

Solution to small collecting area: nested mirrors.

Mirror manufacture, I

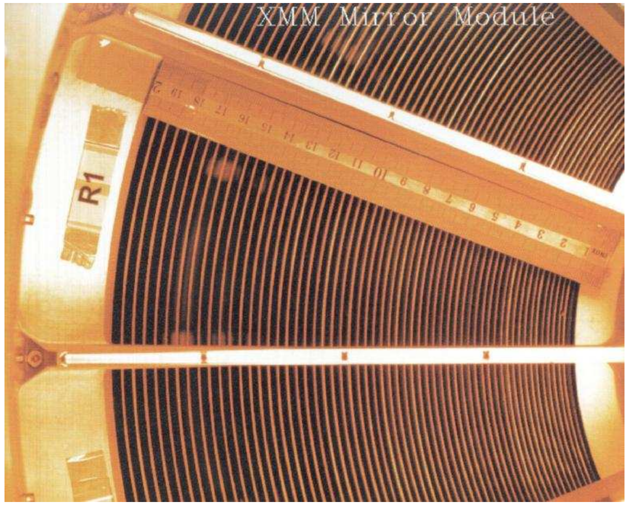


Recipe for making an X-ray mirror:

1. Produce mirror negative (“Mandrels”): Al coated with Kanigen nickel (Ni+10% phosphorus), super-polished [0.4 nm roughness]).
2. Deposit 250 nm Au onto Mandrel
3. Deposit 1 mm Ni onto mandrel (“electro-forming”, 10 μm/h)
4. Cool Mandrel with liquid N. Au sticks to Nickel
5. Verify mirror on optical bench.

Total production time of one mirror: 12 d, for XMM: 3×58 mirrors.

XMM-Newton



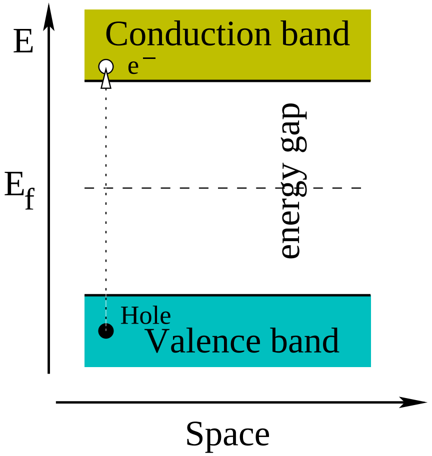
Top of the XMM mirrors:

3 mirror sets, each consisting of 58 mirrors,

- Thickness between 0.47 and 1.07 mm
- Diameter between 306 and 700 mm,
- Masses between 2.35 and 12.30 kg,
- Mirror-Height 600 mm
- Reflecting material: 250 nm Au.

photo: Kayser-Threde

Semi-Conductors



Semiconductors: separation of valence band and conduction band ~1 eV (=energy of visible light).

Absorption of photon produces

$$N \sim \frac{h\nu}{E_{\text{gap}}} \qquad (5.7)$$

electron-hole pairs.

For Si: $E_{\text{gap}} = 1.12$ eV; 3.61 pairs created per eV photon energy [takes into account collective effects in semiconductor]

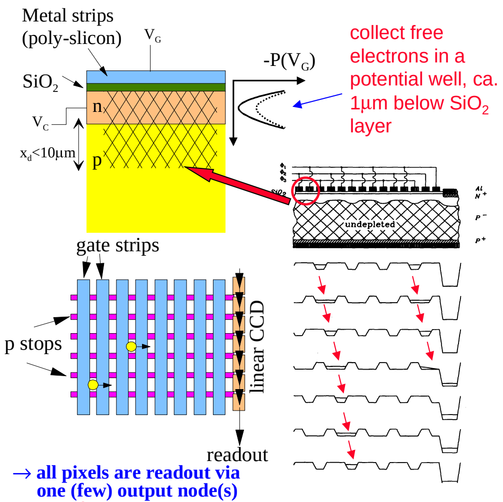
Note: band gap small $\Longrightarrow$ need cooling!

- optical light: ~1 electron-hole pair
- X-rays (keV): ~1000 electron-hole pairs

Problem: electron-hole pairs recombine immediately in a normal semiconductor $\Longrightarrow$ in practice, apply voltage to a “pn-junction” to separate electrons and pairs.

◆ Charge Coupled Devices (CCD)

MOS structure with segmented metal layer



collect free electrons in a potential well, ca. 1µm below SiO_2 layer

→ all pixels are readout via one (few) output node(s)

→ very few electronic channels but long readout time!

Charge transport by periodic change of gate voltage triplets (ϕ_1,ϕ_2,ϕ_3)