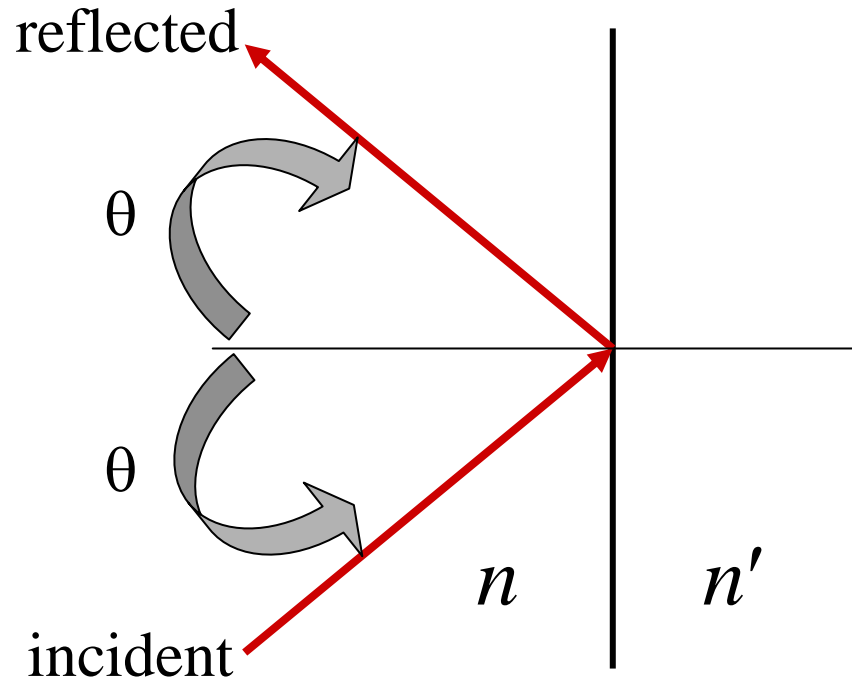# Prisms, fibers, and reflective lenses

- Total internal reflection

- Prisms

- Dispersion

- Optical fibers and other waveguides

- Reflection from paraboloidal mirrors

Total Internal Reflection (TIR)

reflected

θ

θ

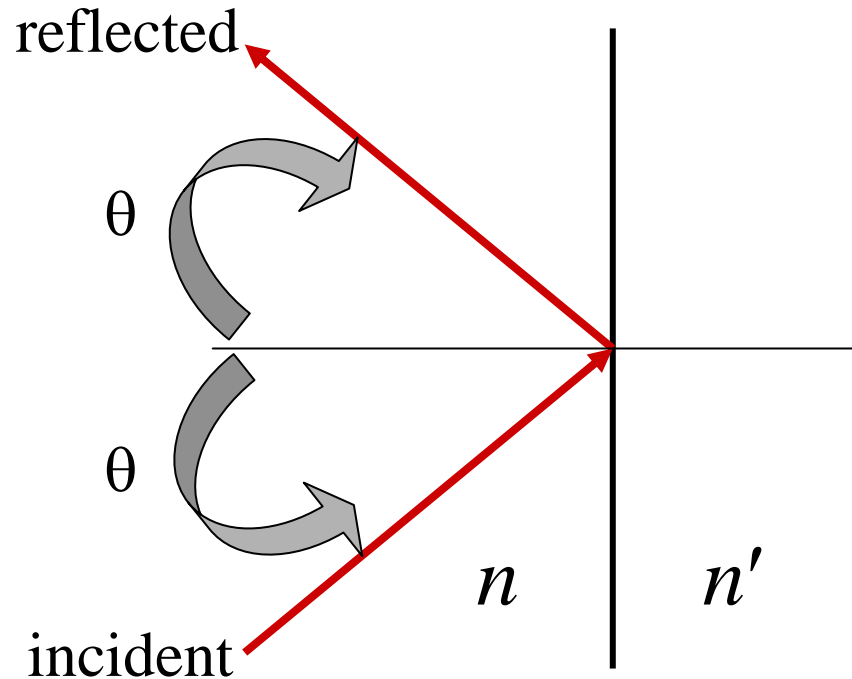n | n'

incident

E.g. interface
from glass to air

$n=1.5,\ n'=1$

$\dfrac{n}{n'}\sin\theta > 1$ if

$\theta > \theta_{\text{crit}} \quad = \sin^{-1}\dfrac{n'}{n}$

$= 41.8°$

$n\sin\theta = n'\sin\theta' \ \Rightarrow\ \sin\theta' = \dfrac{n}{n'}\sin\theta$

what if $\quad \dfrac{n}{n'}\sin\theta > 1\ \dots?$

Total Internal Reflection (TIR)

reflected

θ
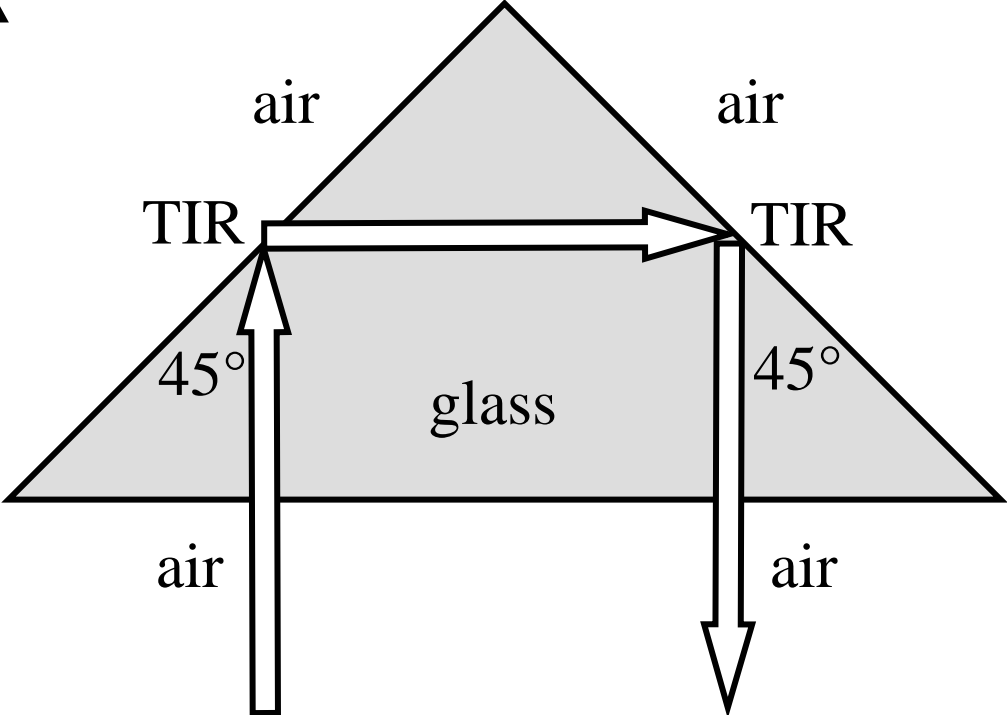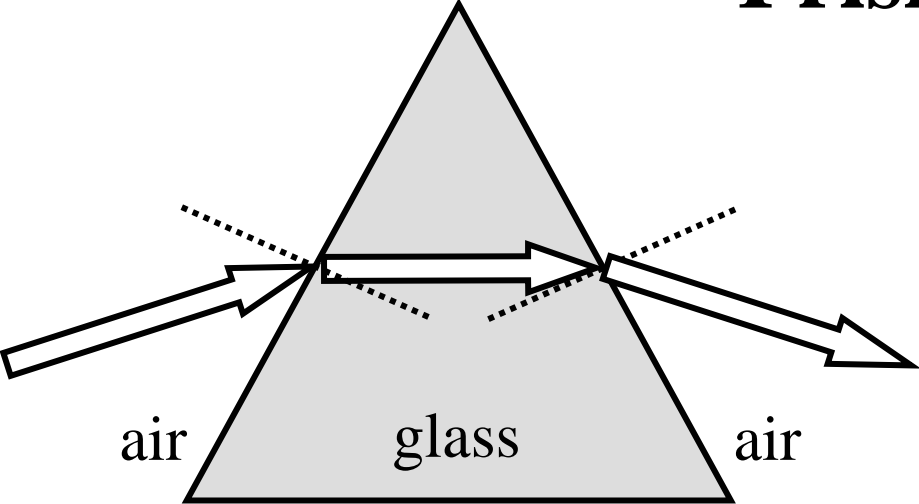
θ

incident

n | n'

no light enters the optically less dense space

(in actuality the light field in the optically dense space is **evanescent**, i.e. exponentially decaying)

θ' becomes imaginary when $\theta > \theta_{\text{crit}}$

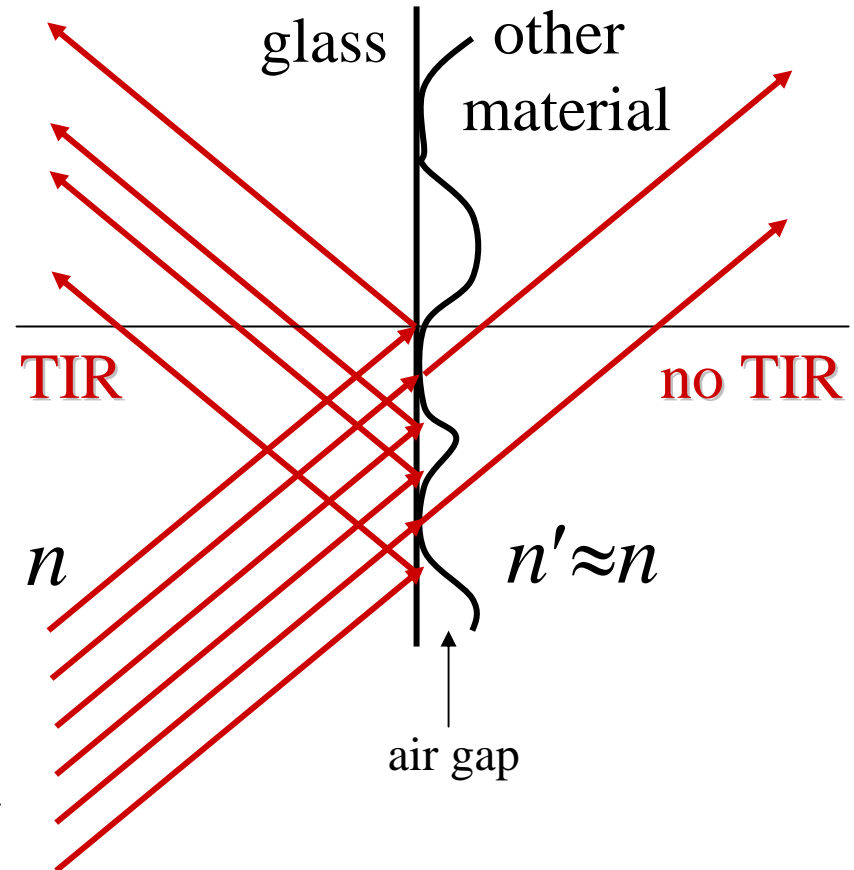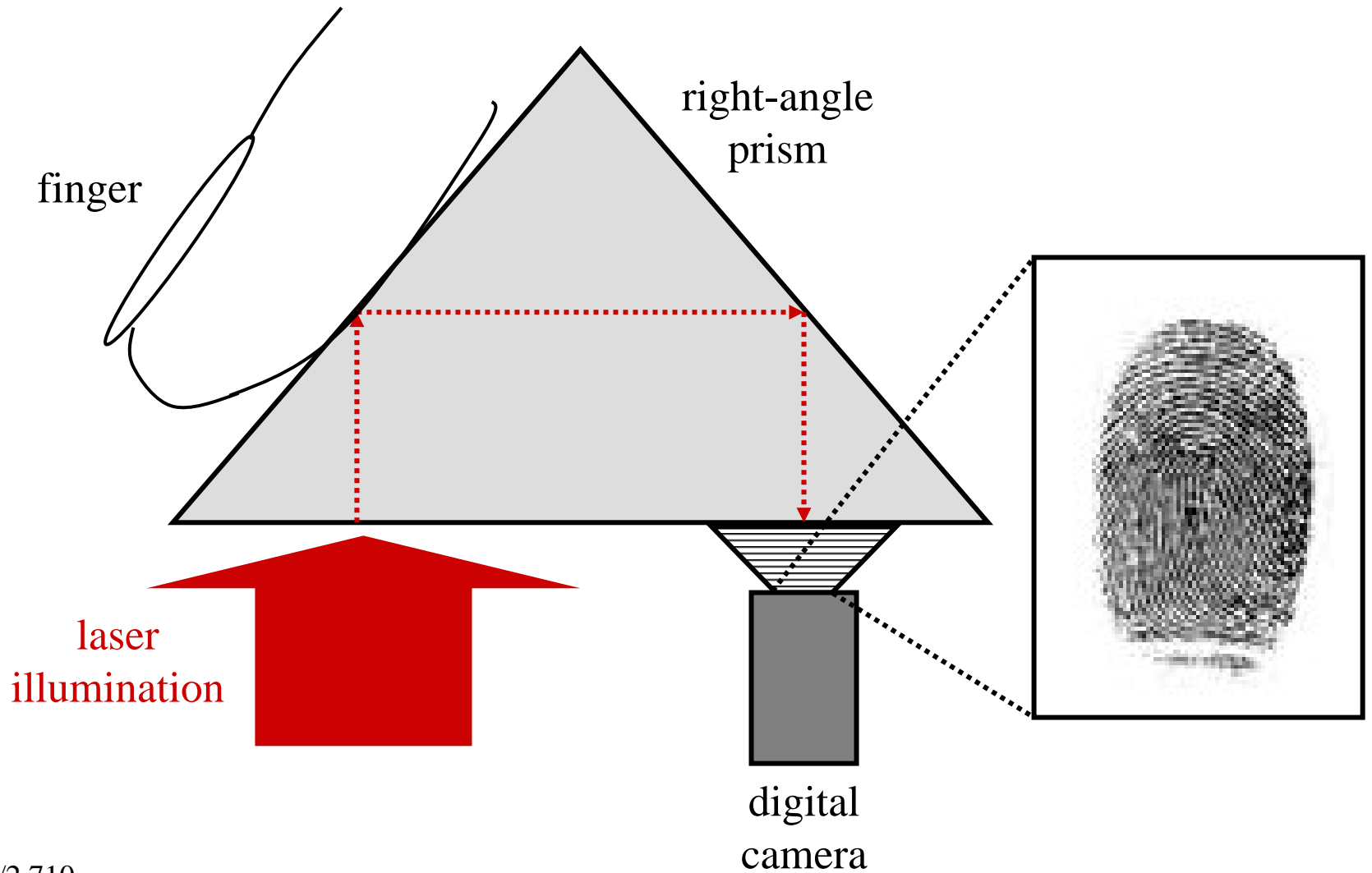$\Rightarrow$ reflected beam disappears, all energy is reflected

Prisms

air   glass   air

air   air

TIR   TIR

45°   glass   45°

air   air

Frustrated Total Internal Reflection (FTIR)

Reflected rays are missing where index-matched surfaces touch $\Rightarrow$ shadow is formed

glass

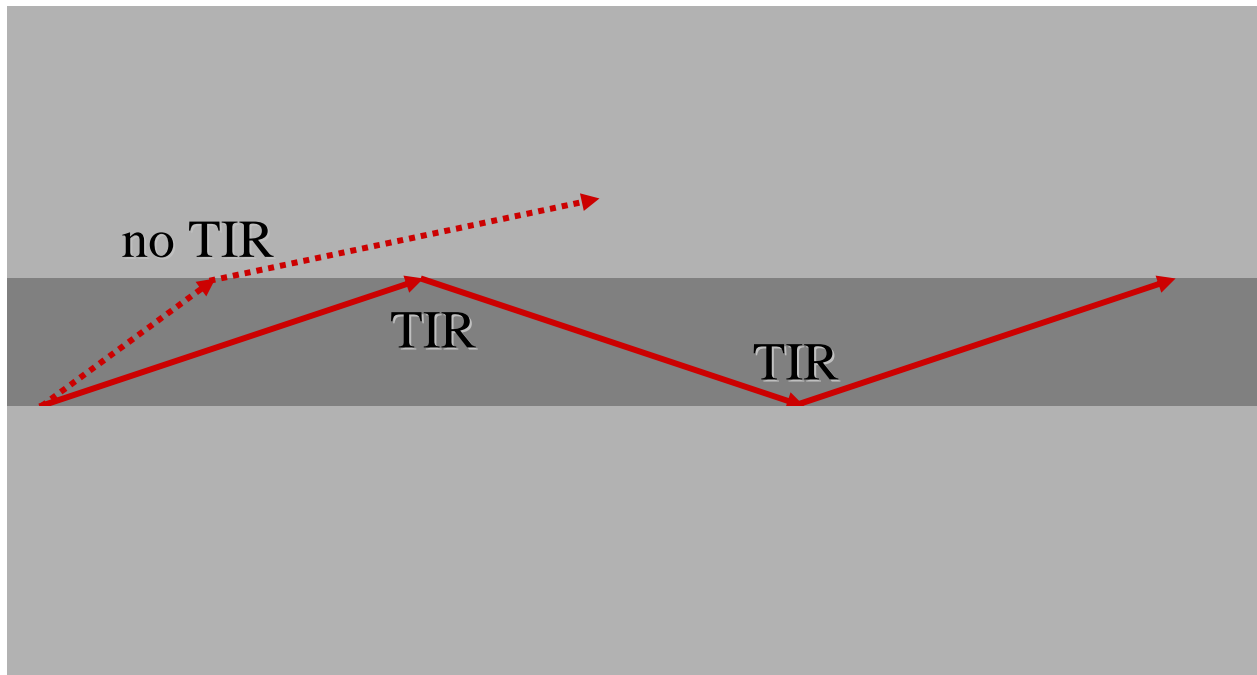other material

TIR

no TIR

n

$n'\approx n$

air gap

Angle of incidence exceeds critical angle

Fingerprint sensors

finger

right-angle
prism

laser
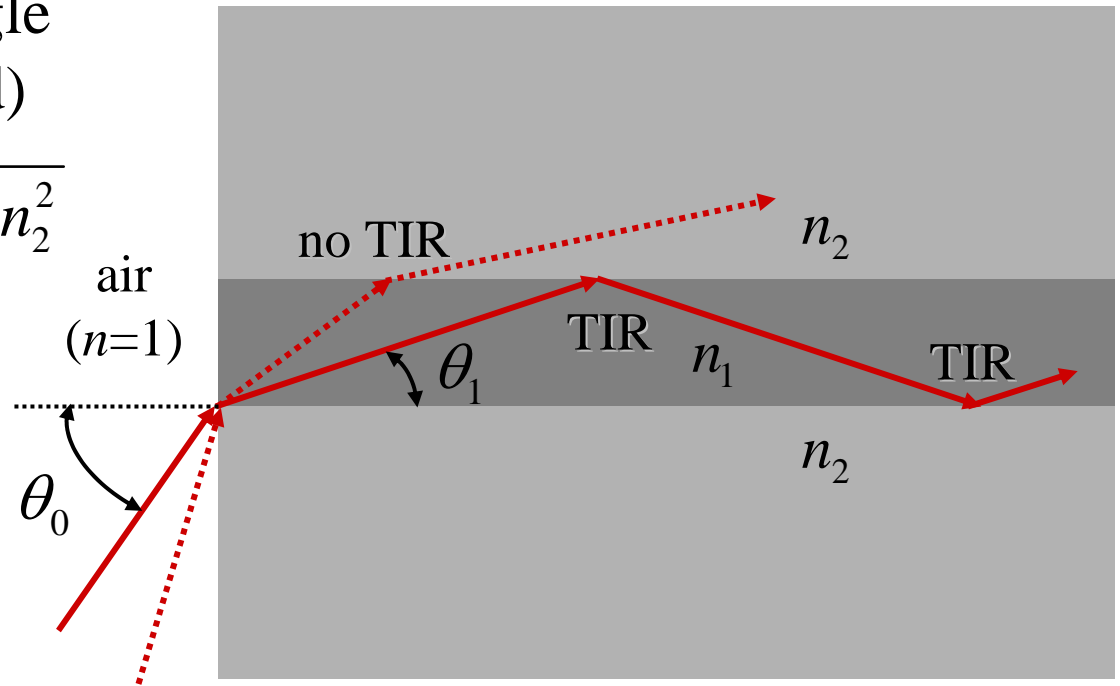illumination

digital
camera

Optical waveguides

"planar" waveguide: high-index dielectric material
sandwiched between lower-index dielectrics

Optical waveguides:
numerical aperture (NA)

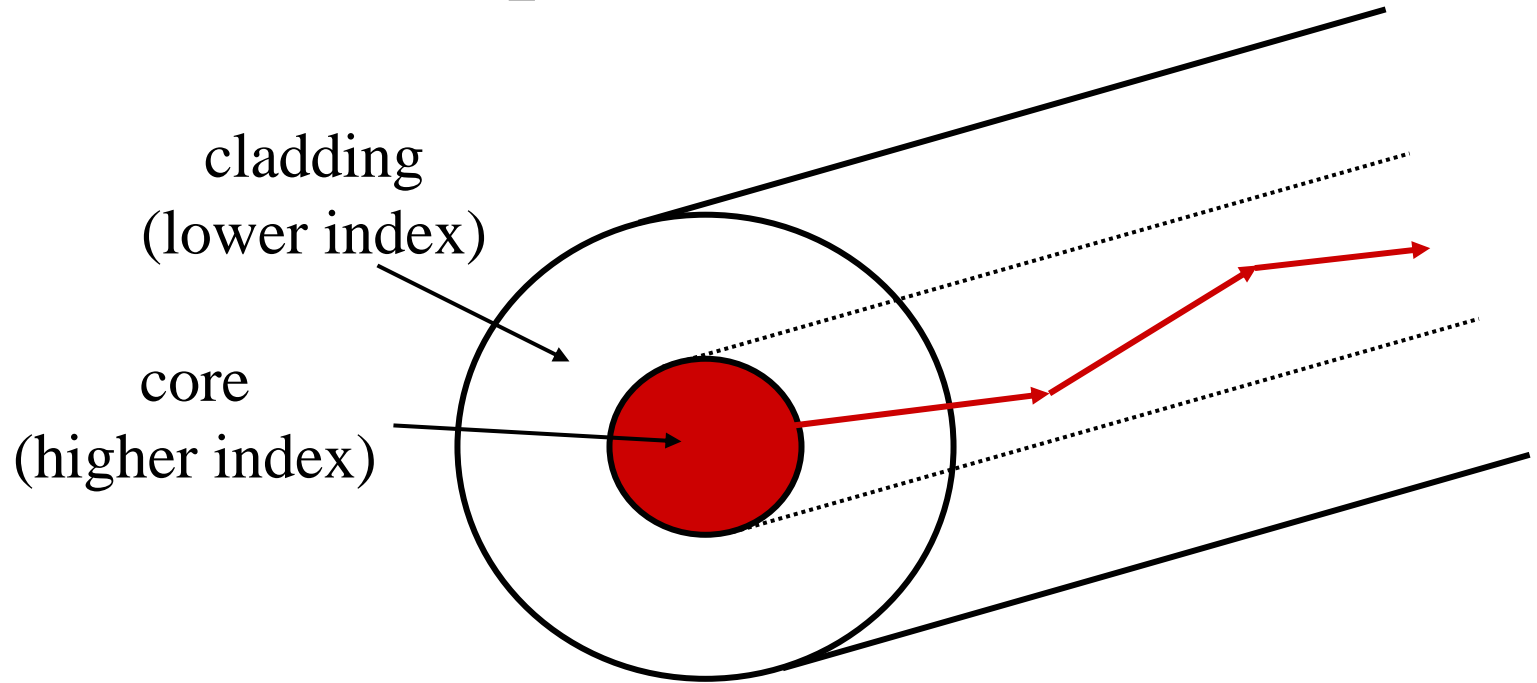NA=sin(largest angle
that is waveguided)

$$\text{NA} = \sin\theta_0 \leq \sqrt{n_1^2 - n_2^2}$$

air
($n=1$)

no TIR

n_2

TIR n_1

θ_1

TIR

n_2

θ_0

high index contrast (n_1/n_2) $\Leftrightarrow$ high NA
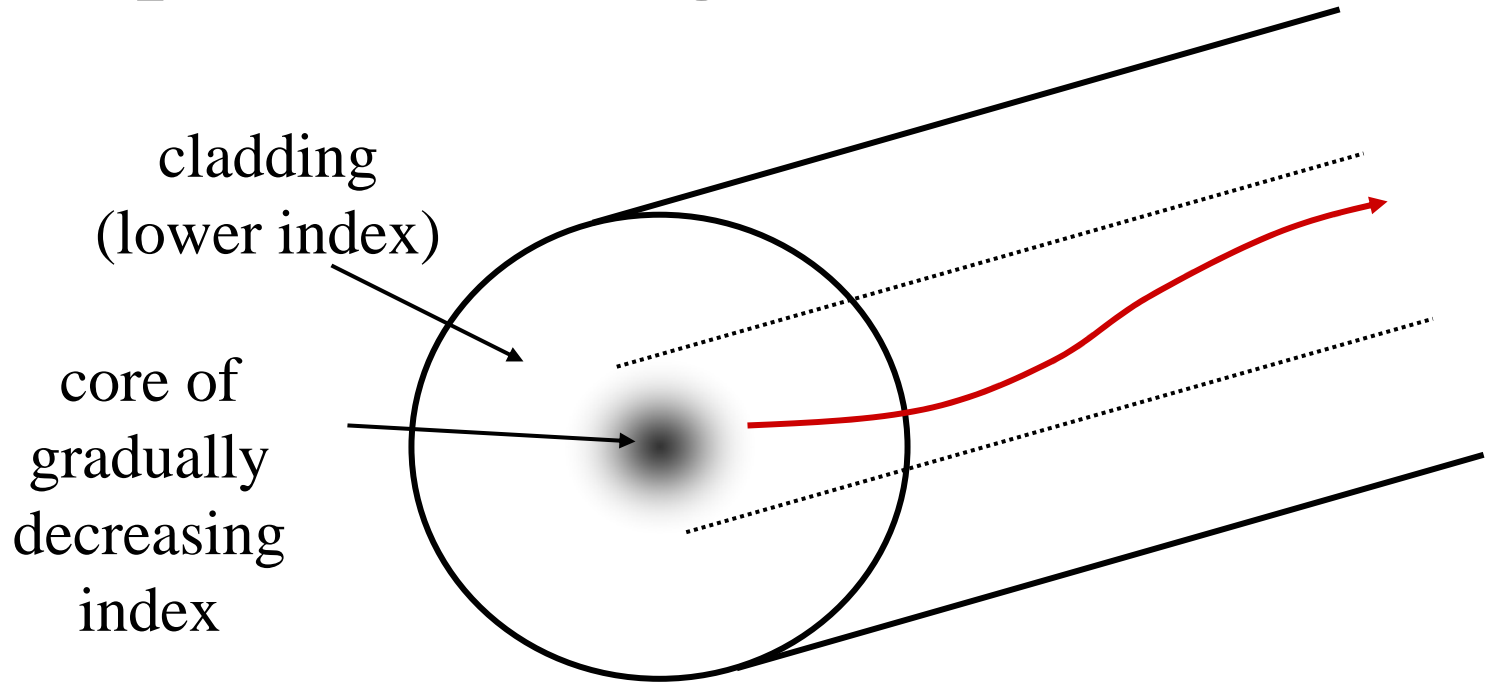
Optical fibers

cladding
(lower index)

core
(higher index)

Core diameter = 8-10μm (commercial grade)
Cladding diameter = 250μm (commercial grade)
Index contrast $\Delta n = 0.007$ (*very* low NA)
attenuation = 0.25dB/km

Optical fibers: gradient index

cladding
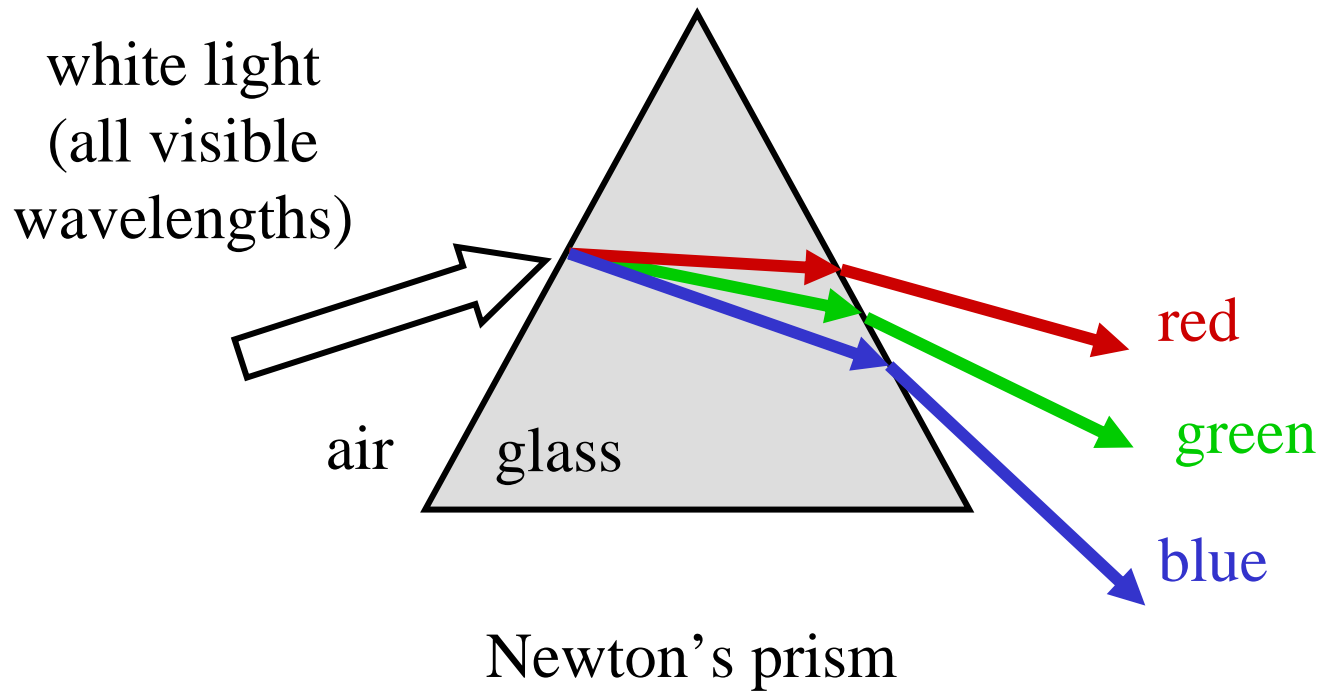(lower index)

core of
gradually
decreasing
index

optical rays "swirl" around the axis of the core!

Gradient index waveguides in nature: insect eyes (composite eyes)

Images removed due to copyright concerns

Dispersion

Refractive index n is function of the wavelength

white light
(all visible
wavelengths)

air   glass

red

green

blue

Newton's prism

Dispersion measures

Reference color lines
C (H- λ=656.3nm, red), D (Na- λ=589.2nm, yellow),
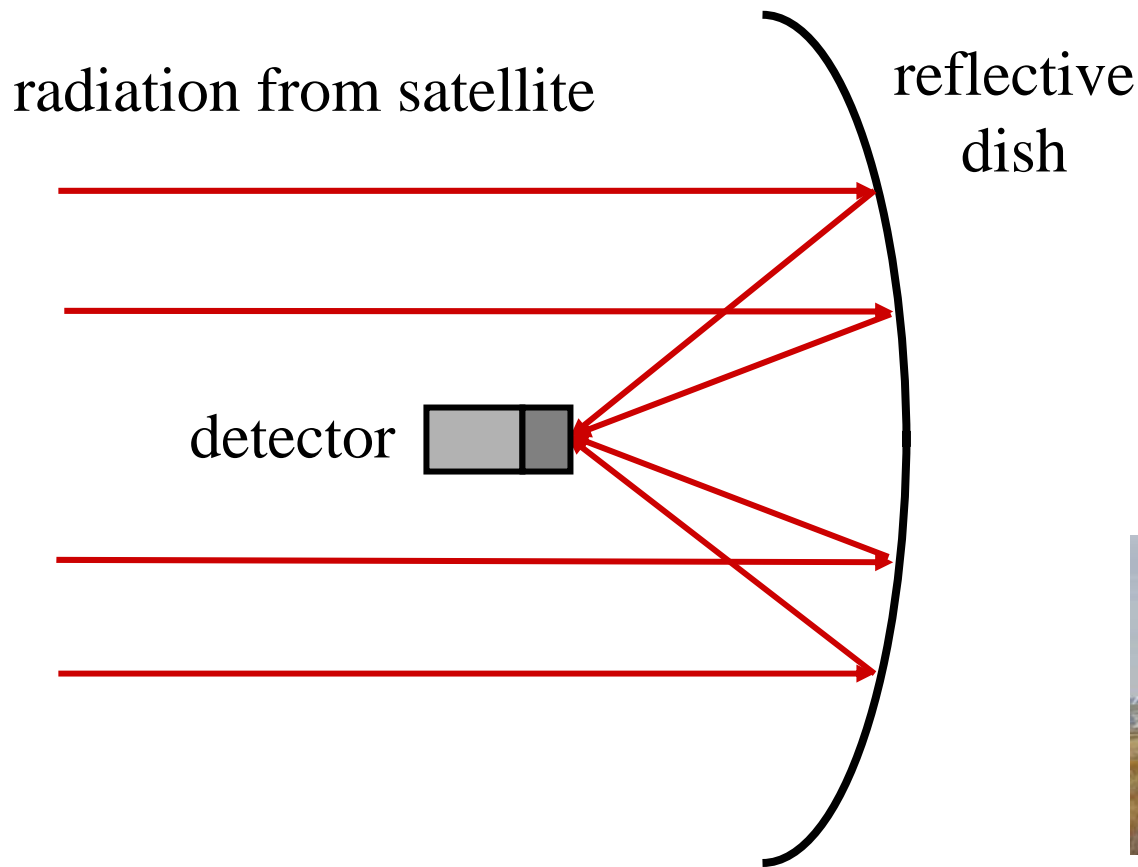F (H- λ=486.1nm, blue)

Crown glass has

$$n_F = 1.52933 \qquad n_D = 1.52300 \qquad n_C = 1.52042$$

Dispersive power $\quad V = \dfrac{n_F - n_C}{n_D - 1}$

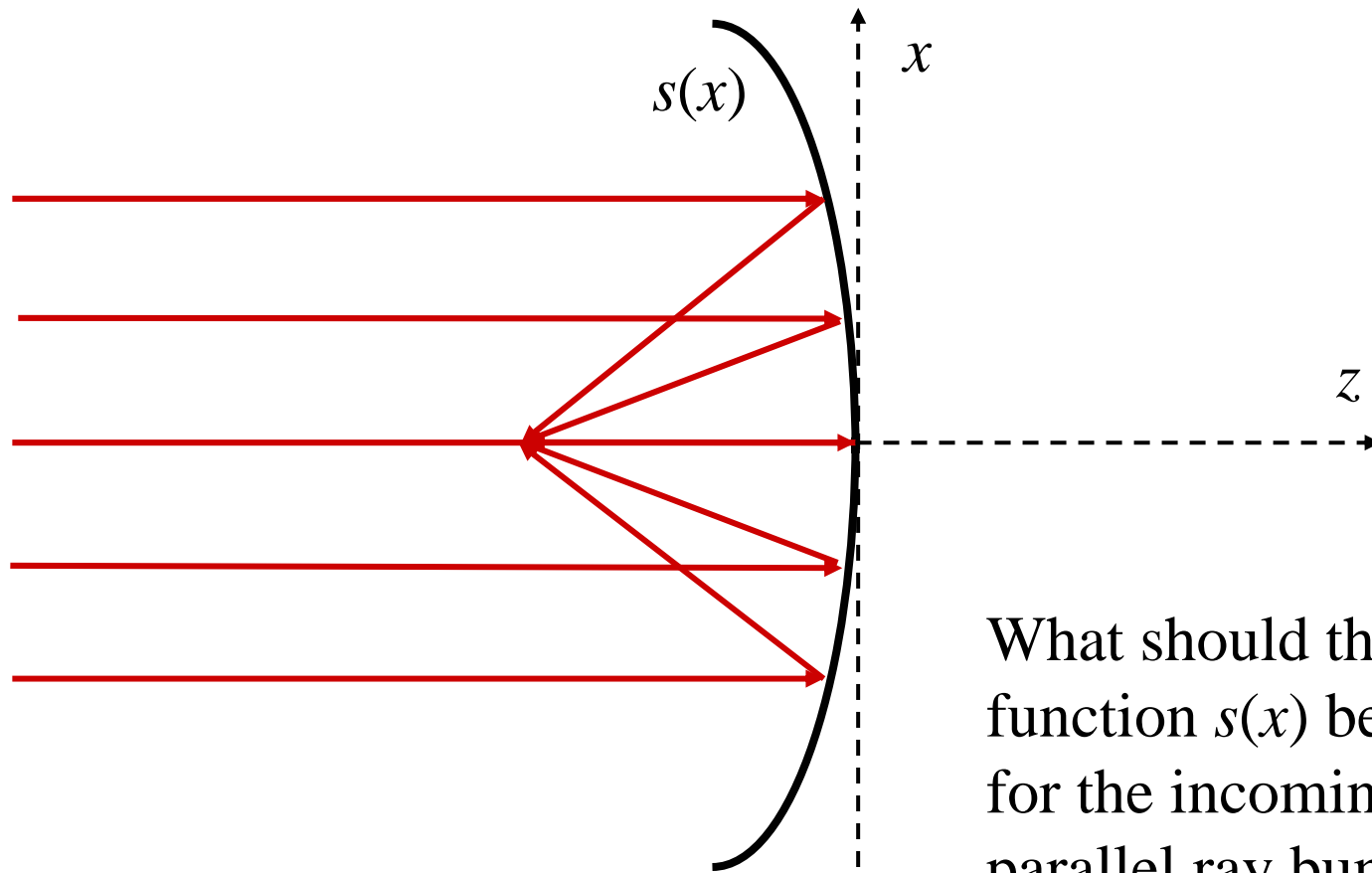Dispersive index $\quad v = \dfrac{1}{V} = \dfrac{n_D - 1}{n_F - n_C}$

Curved reflecting surfaces

(e.g. satellite dish)

radiation from satellite

reflective dish

detector

Paraboloid mirror: <u>perfect</u> focusing

(e.g. satellite dish)

$s(x)$

x

z

What should the shape function $s(x)$ be in order for the incoming parallel ray bundle to come to perfect focus?

Paraboloid mirror: <u>perfect</u> focusing

(e.g. satellite dish)

$s(x)$

x

f: focal length

z

f

$$s(x) = \frac{x^2}{4f}$$