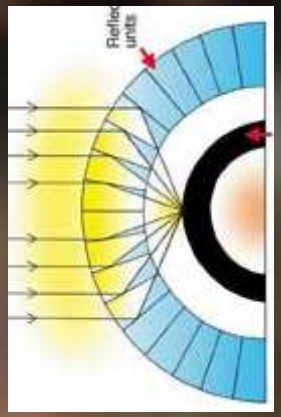
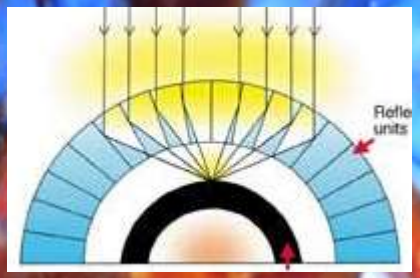
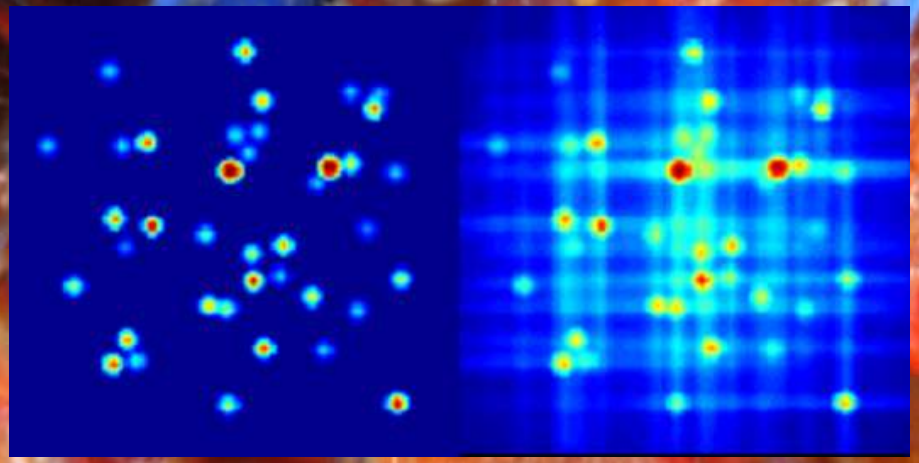
Biomimetics – learning from the nature

Refractive lobster eyes







Biomimetics (of sea animals) in General

- **Lobster Eye will go to the space soon (Czech nanosat VZLUSAT1 in 2017 and BepiColombo in 2018)**
- **But there are also other mirror based animal (mostly sea) eyes, some recent new discoveries, worth to study in detail for possible technical applications**
- **Small student project – Open Science, Czech Academy of Science recently**

Motivation

- **Understanding of very specific mirror eyes of sea animals may help to design and develop special optics for scientific applications**
- **Example: Lobster Eye optics used in wide field astronomical space X ray telescopes**
- **The knowledge of strange animal mirror eyes has potential for another scientific and technical applications**
- **This field is very little exploited**

Goals

- **To understand the way animal mirror eyes work**
- **To learn what are the advantages of these eye arrangements**
- **To find out whether these optics can be used in advanced devices e.g. in space instrumentation**

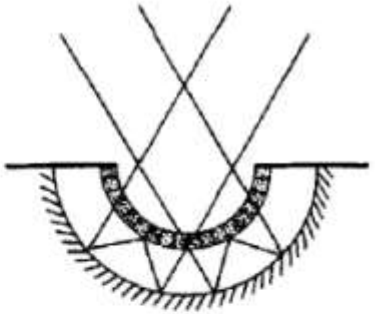
- **All above very little exploited so far**

Animal eyes

PIGMENTED PIT

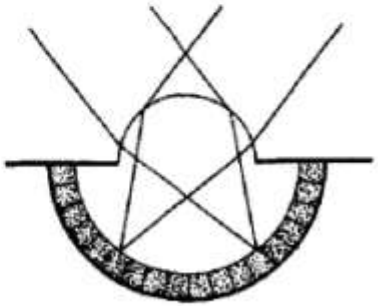
SPHERICAL LENS EYE

APPOSITION COMPOUND EYE

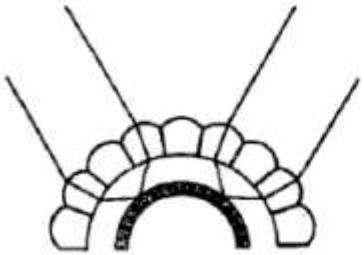


SIMPLE MIRROR EYE

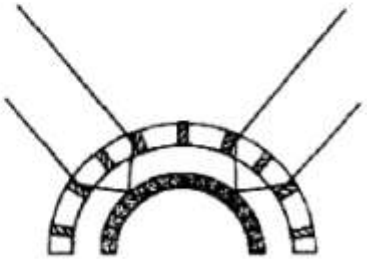
MULTIPLE PIGMENTED TUBES



CORNEAL REFRACTION



SUPERPOSITION COMPOUND EYE

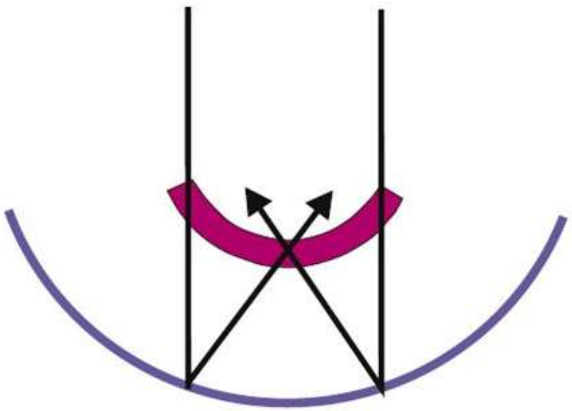


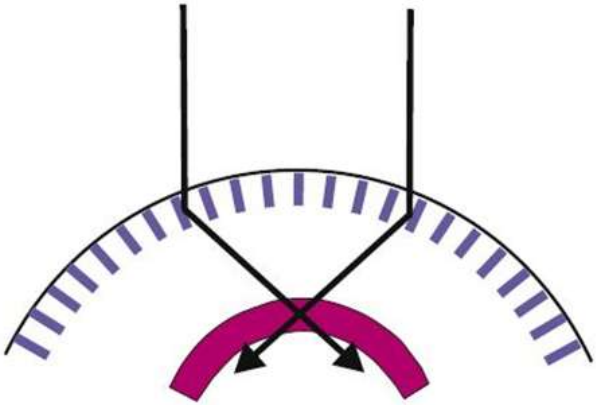
REFLECTING SUPERPOSITION COMPOUND EYE

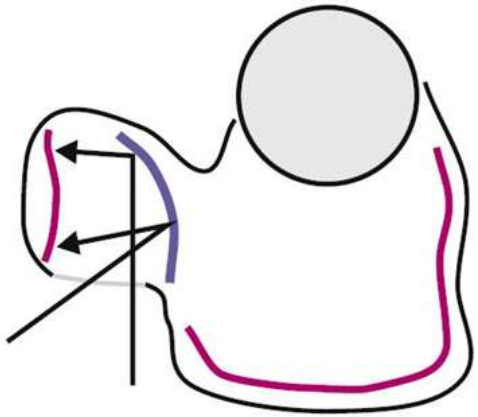
Lobster Eye

Mirror eyes

MOLLUSCS **CRUSTACEANS** **FISHES**



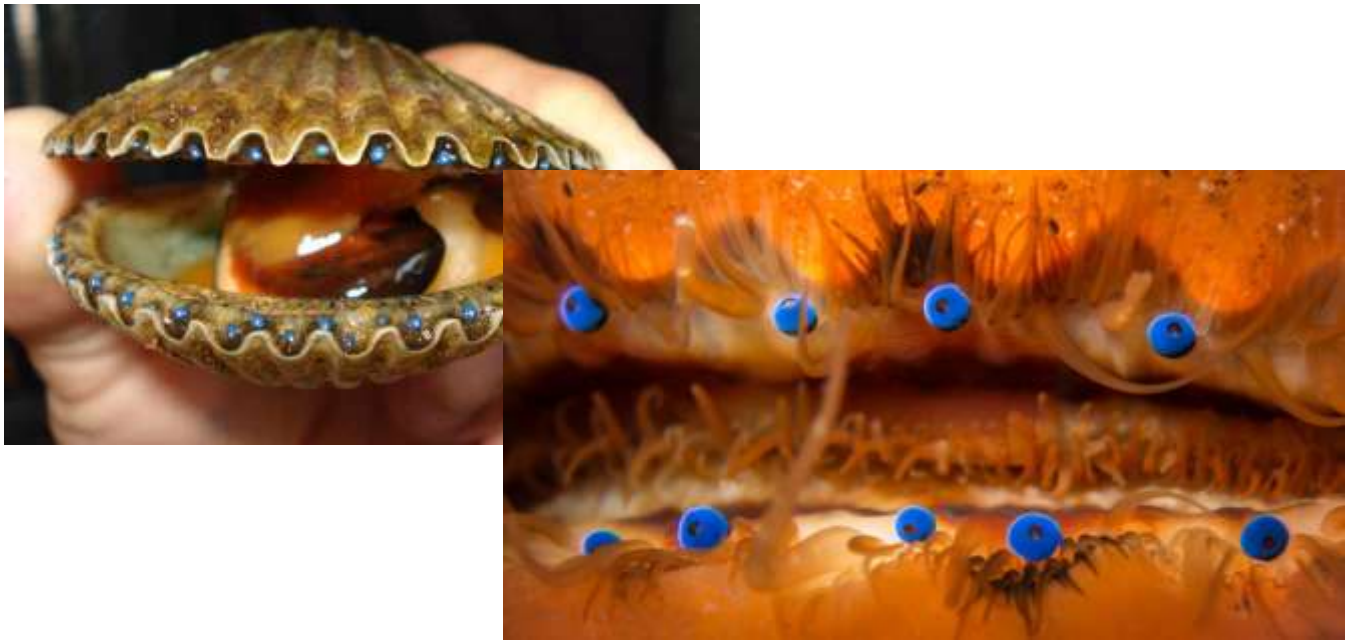




Lobster Eye

Mirror eyes of scallops (*Pecten*)

Mirror eyes of scallops (*Pecten*)



Mirror eyes of scallops (*Pecten*)

Mirror eyes of decapods (*Astacus*)

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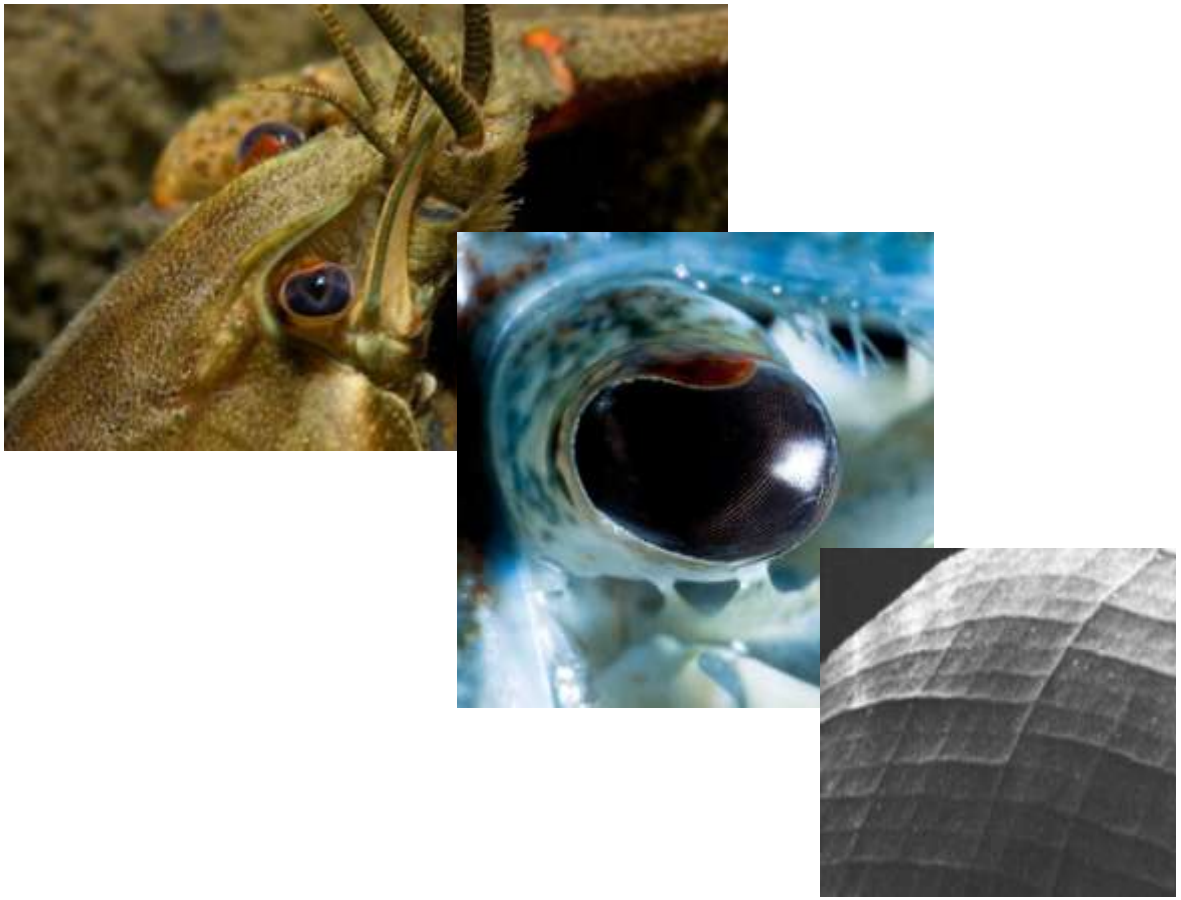
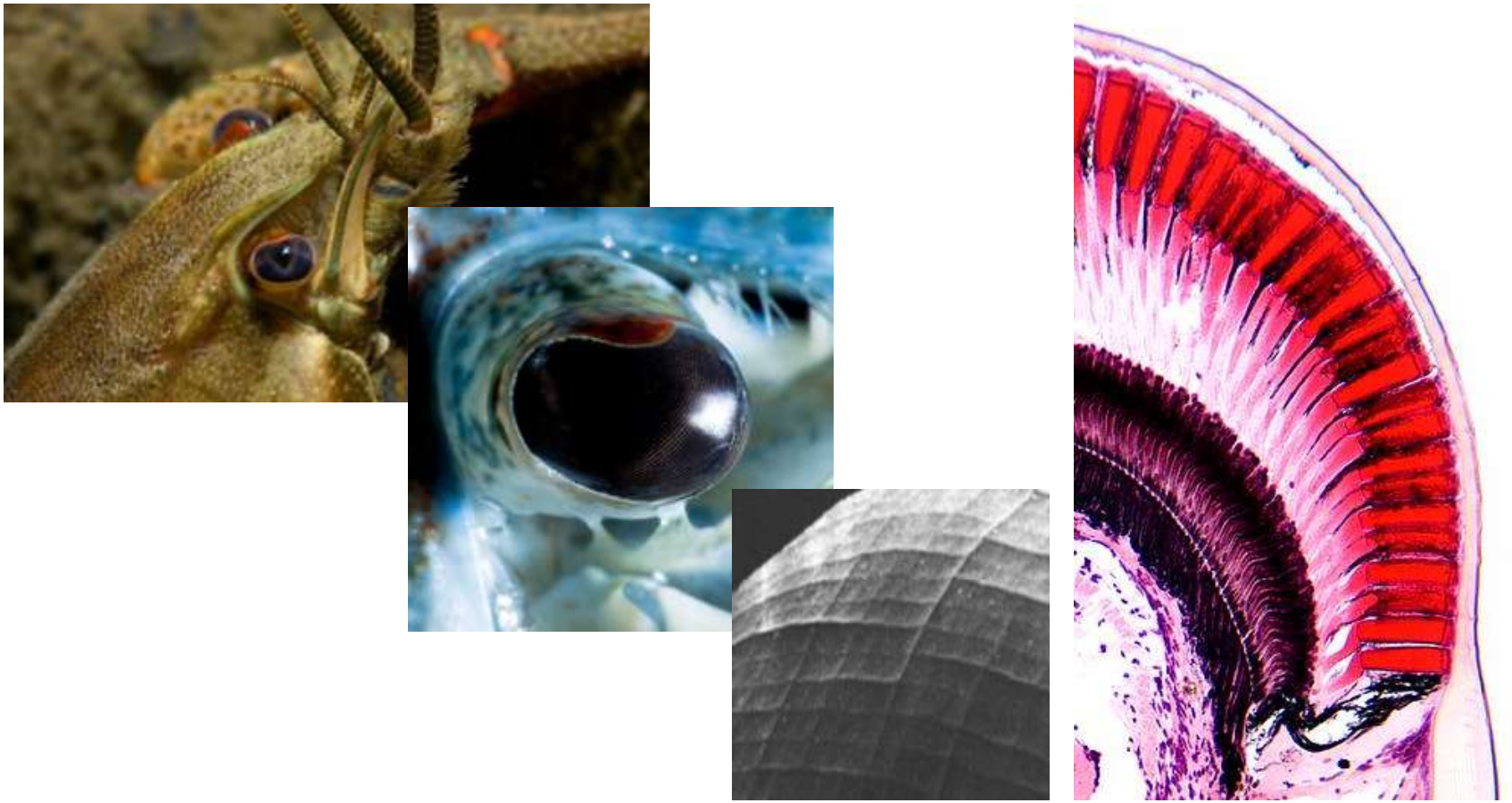
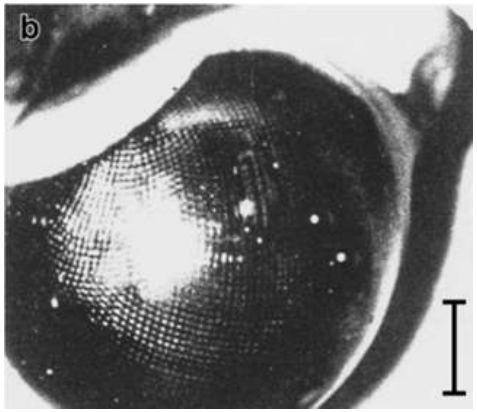


Mirror eyes of decapods (*Astacus*)

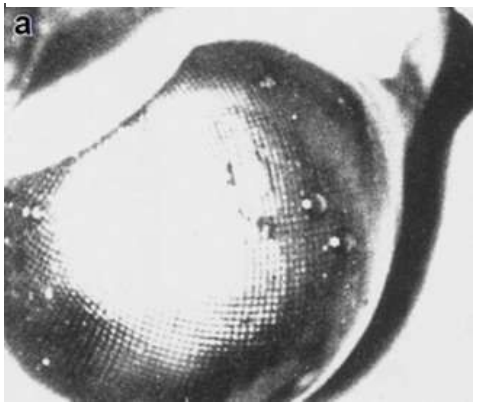


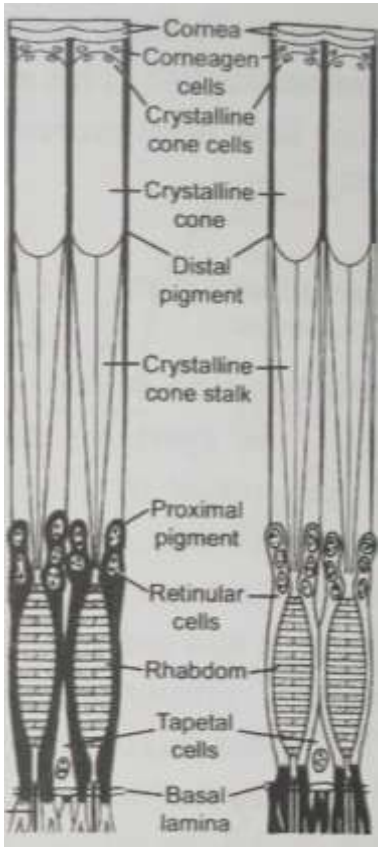
Features of decapod eyes



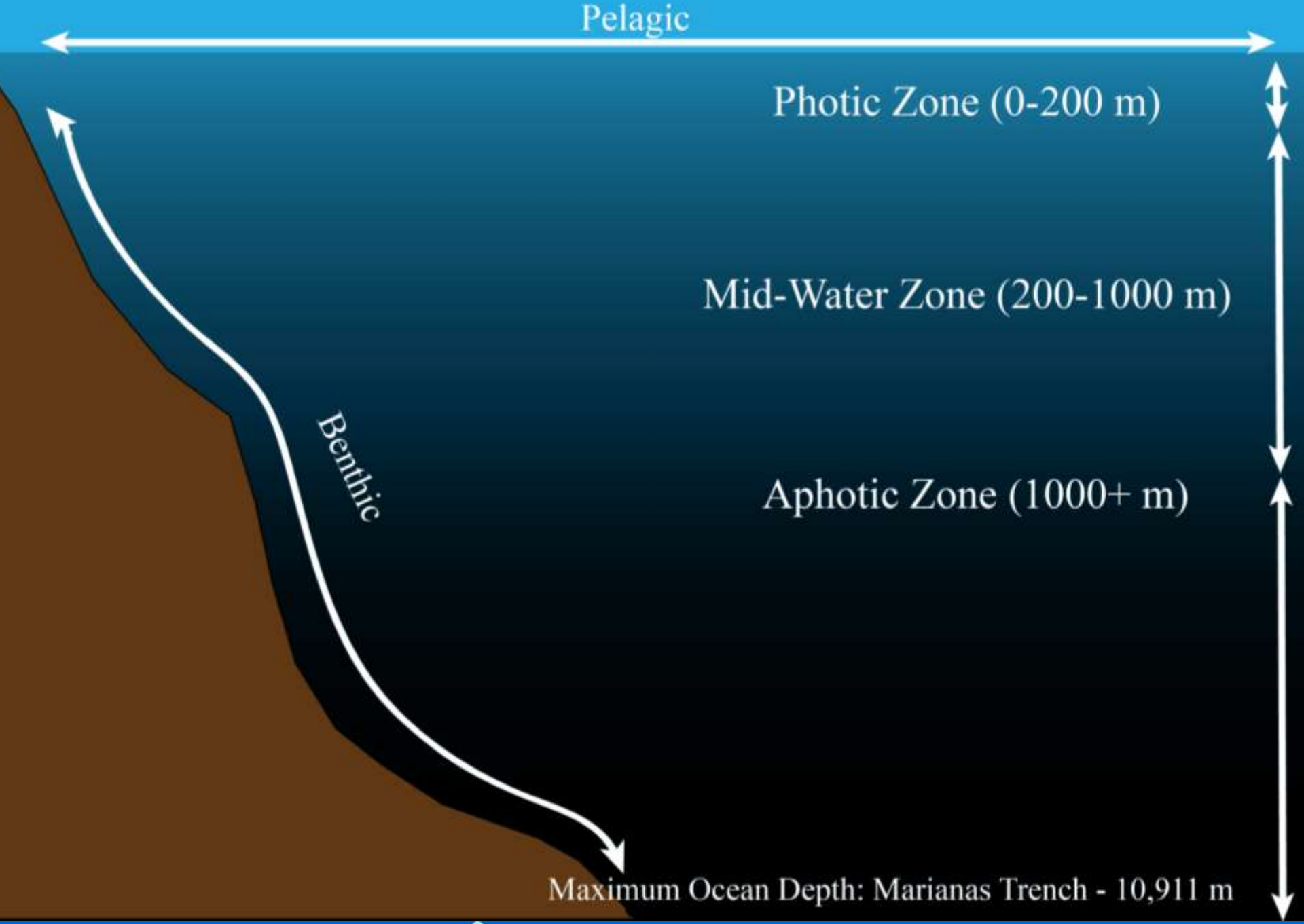
LIGHT

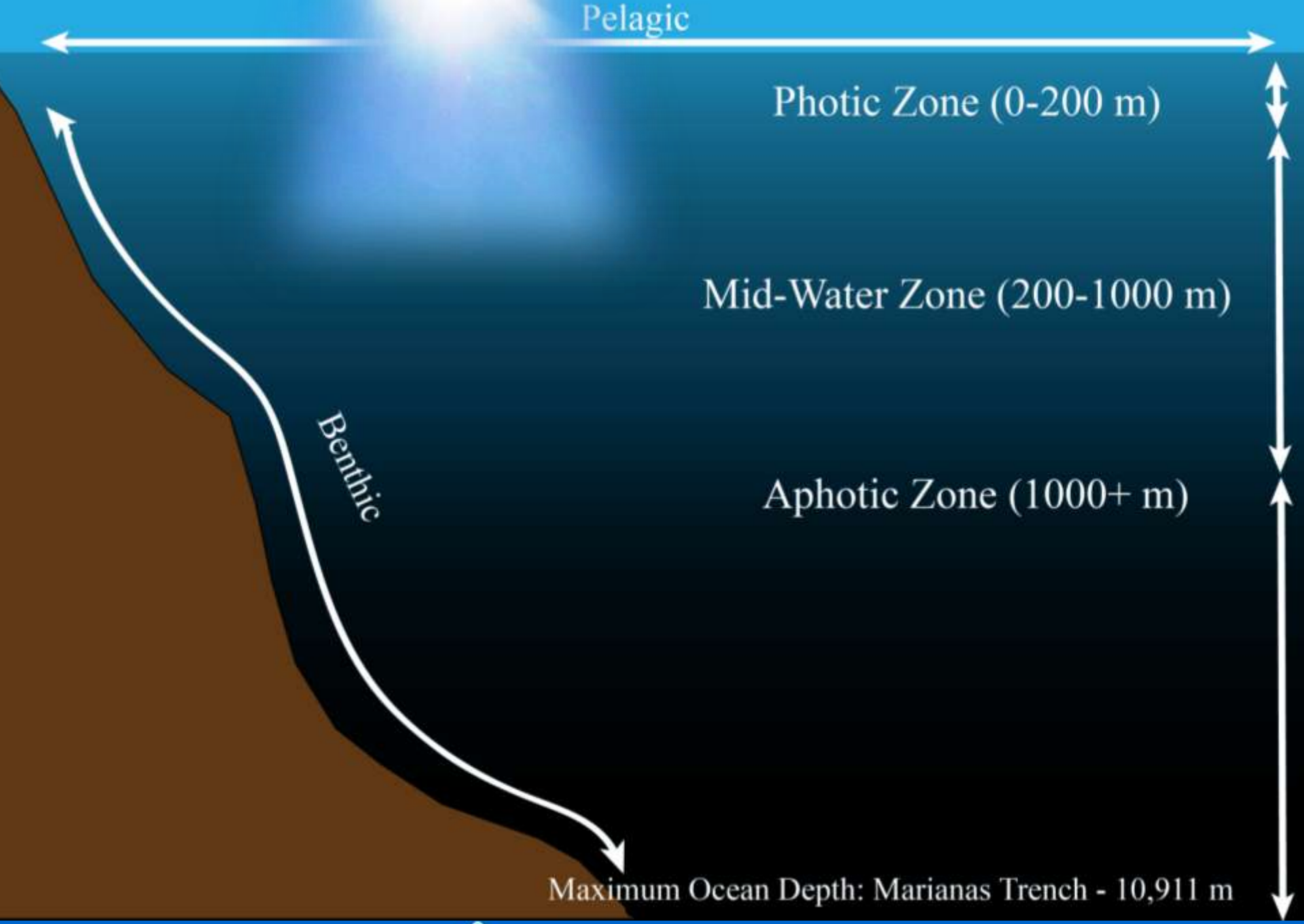
DARK





LIGHT DARK


Pelagic
Photic Zone (0-200 m)
Mid-Water Zone (200-1000 m)
Aphotic Zone (1000+ m)
Benthic
Maximum Ocean Depth: Marianas Trench - 10,911 m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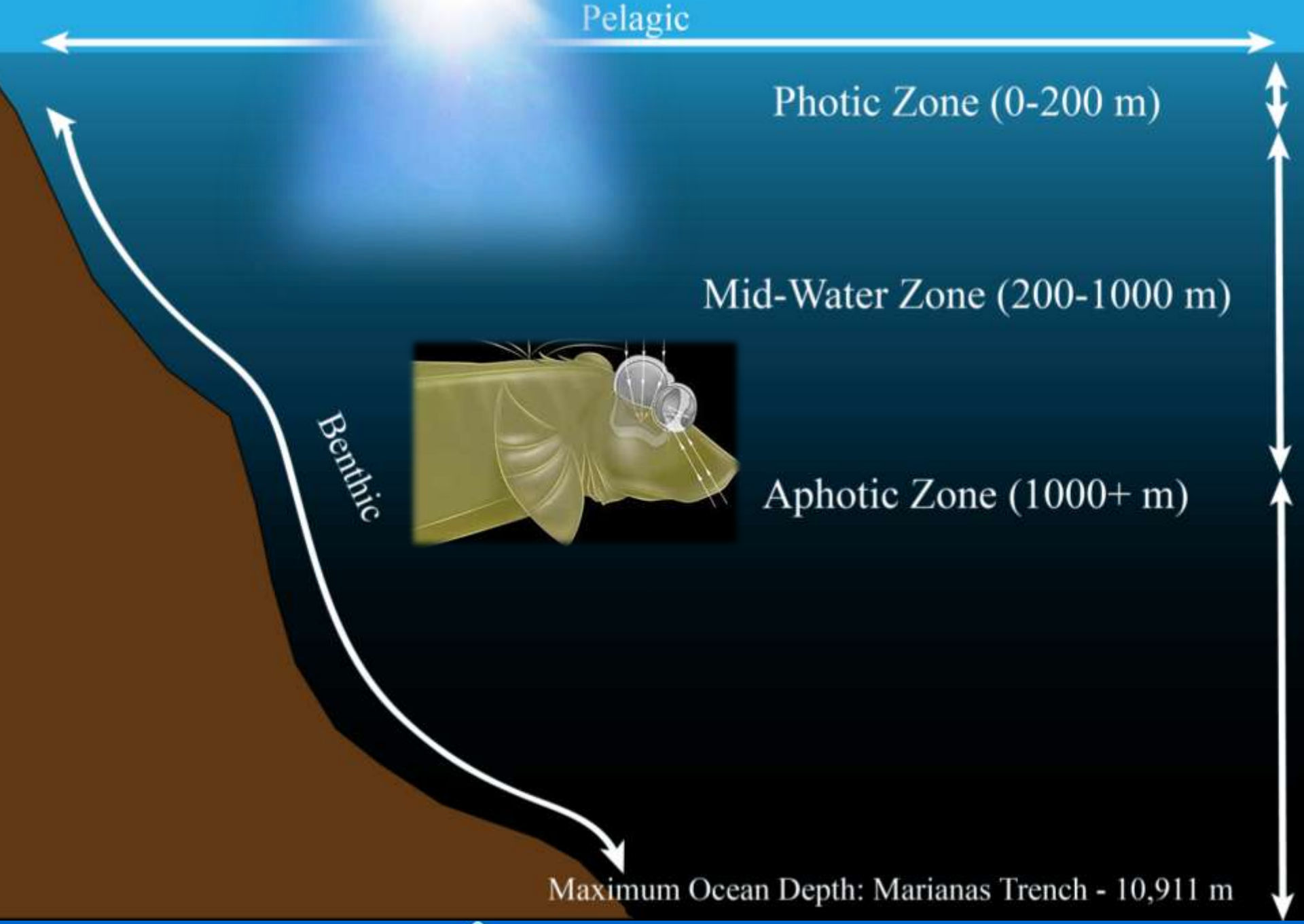
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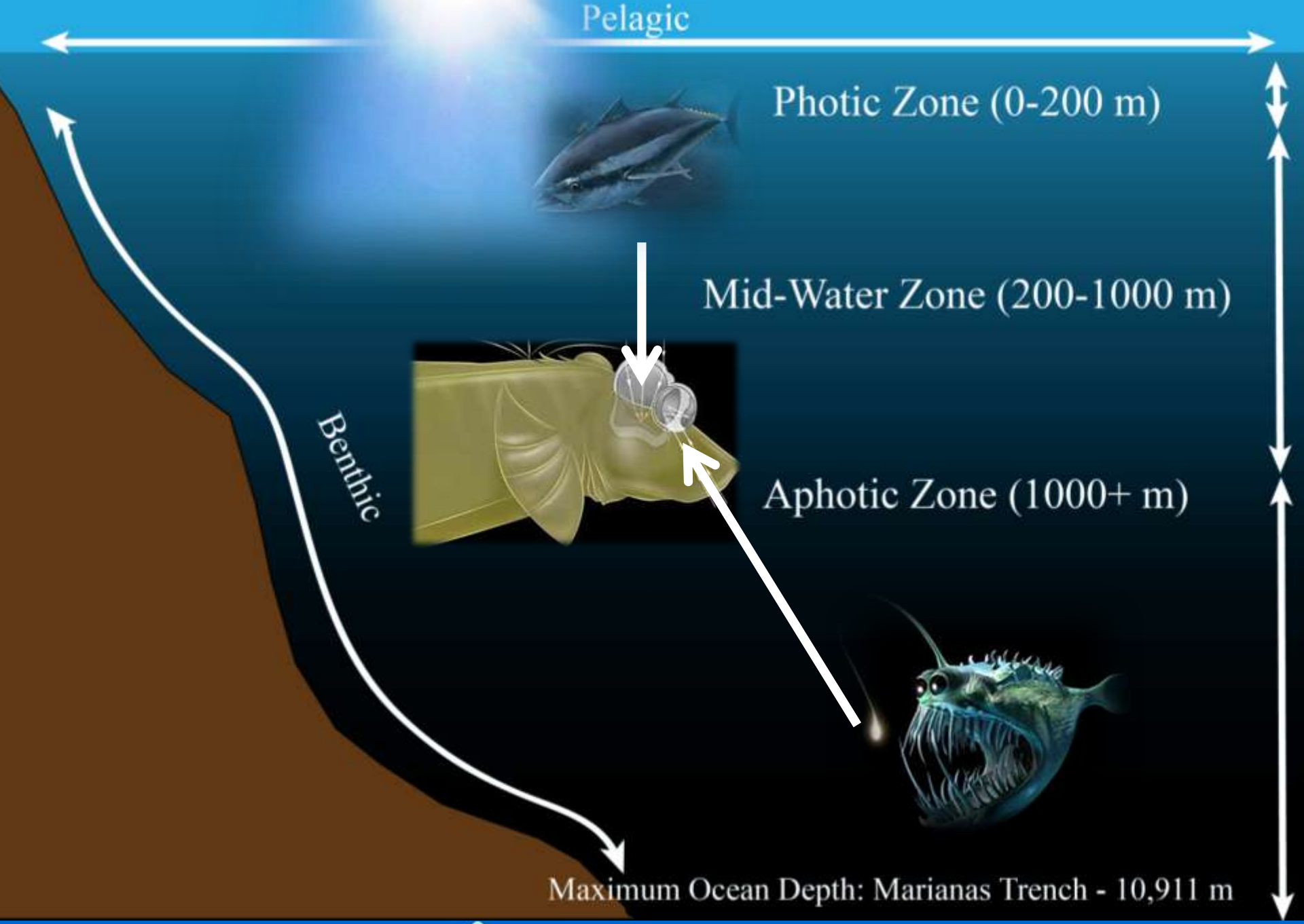
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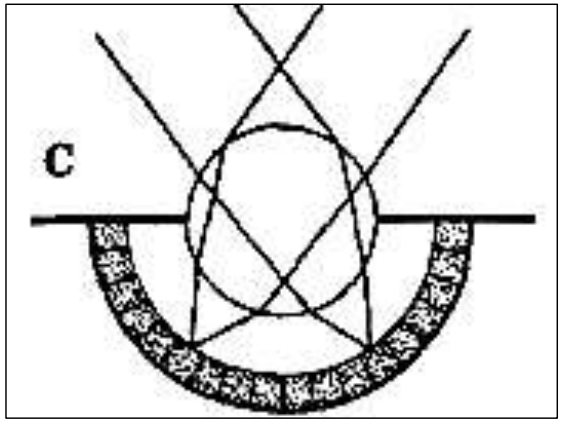
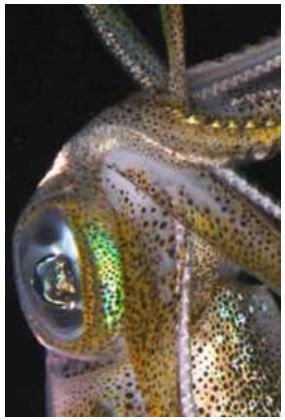
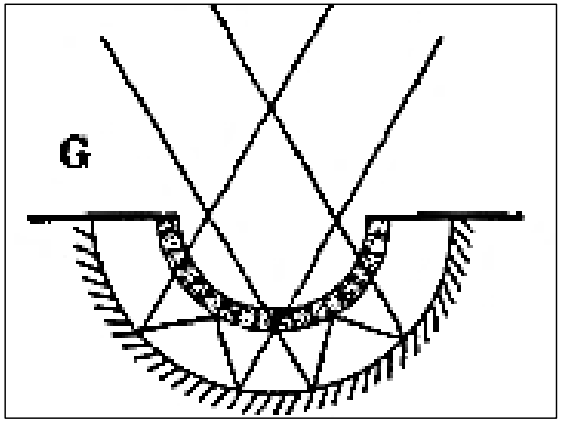
BASIC TYPES OF MARINE SPECIES EYES

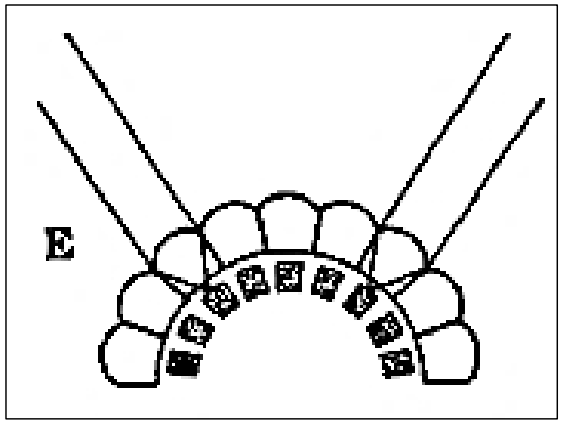




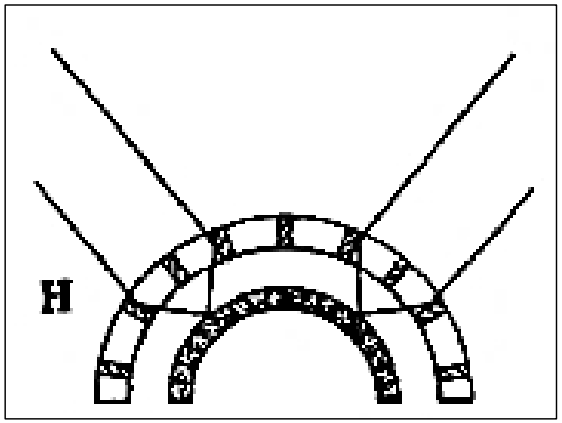
- Spherical lens eye
  e. g. fishes, cephalopod

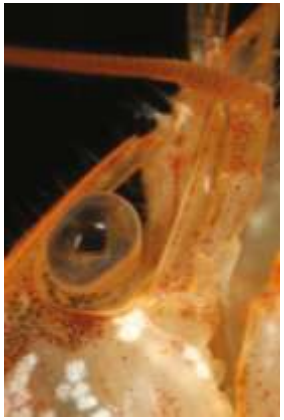


- Simple mirror eye
  e. g. *Pecten*, *Gigantocypris*



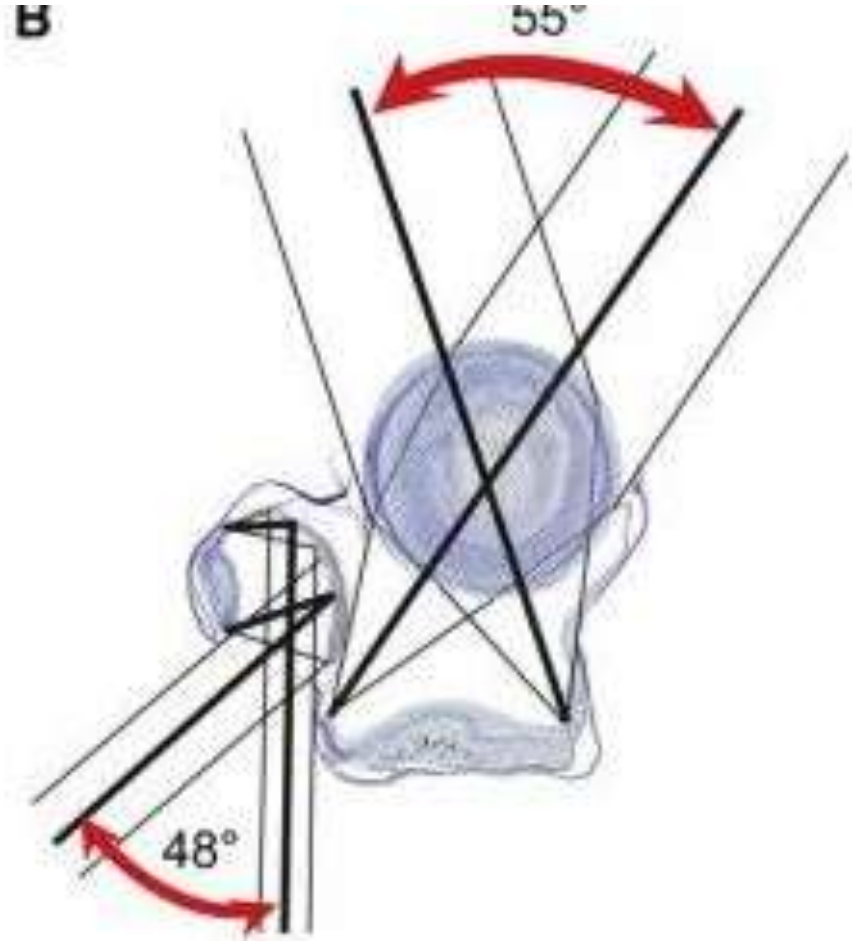
- Apposition compound eye
  e. g. shallow-water crustaceans





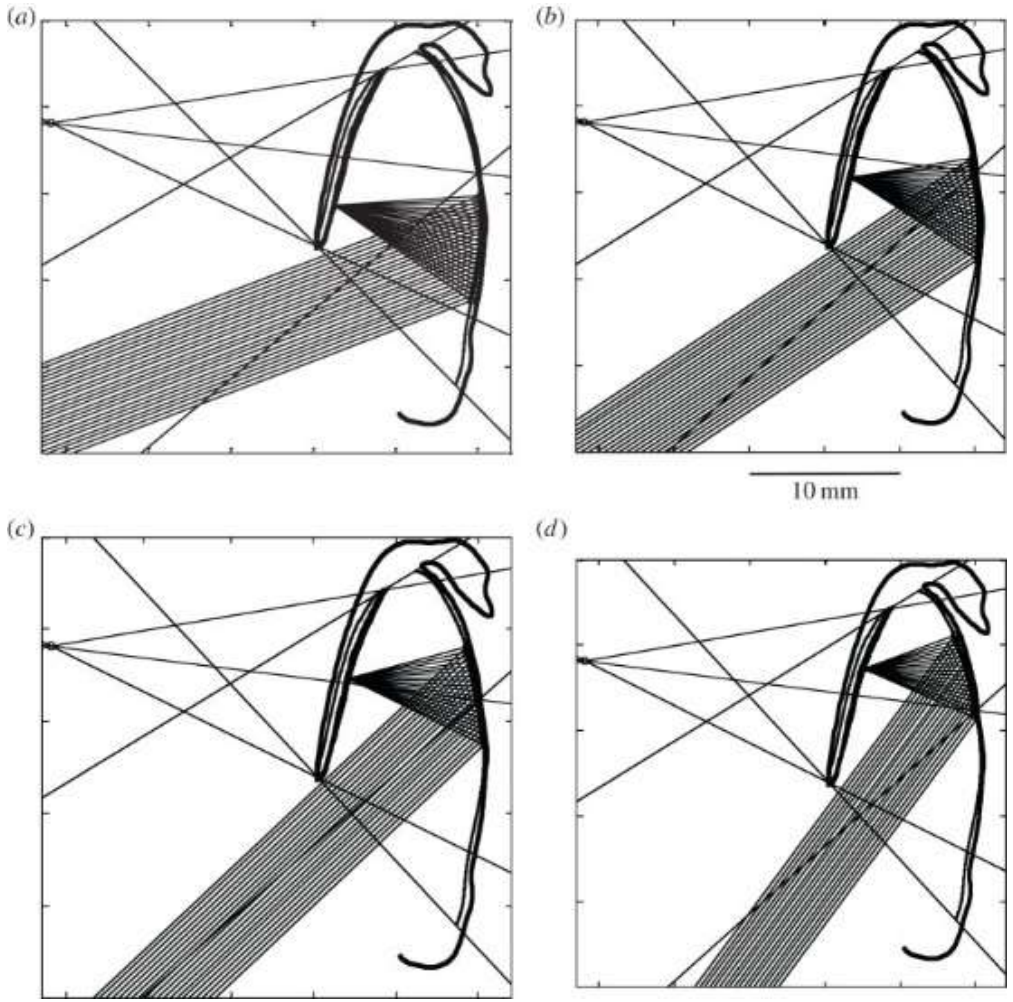
- Reflecting superposition compound eye
  e. g. shrimps, prawns

Strange eyes of deep sea fish Rhynchohyalus natalensis



- The fish has 4 eyes
- 2 with lens and
- 2 with mirror surfaces
- These mirrors are formed by large number of small mirrors perhaps in analogy to active mirror optics

Rhynchohyalus natalensis (spookfish)



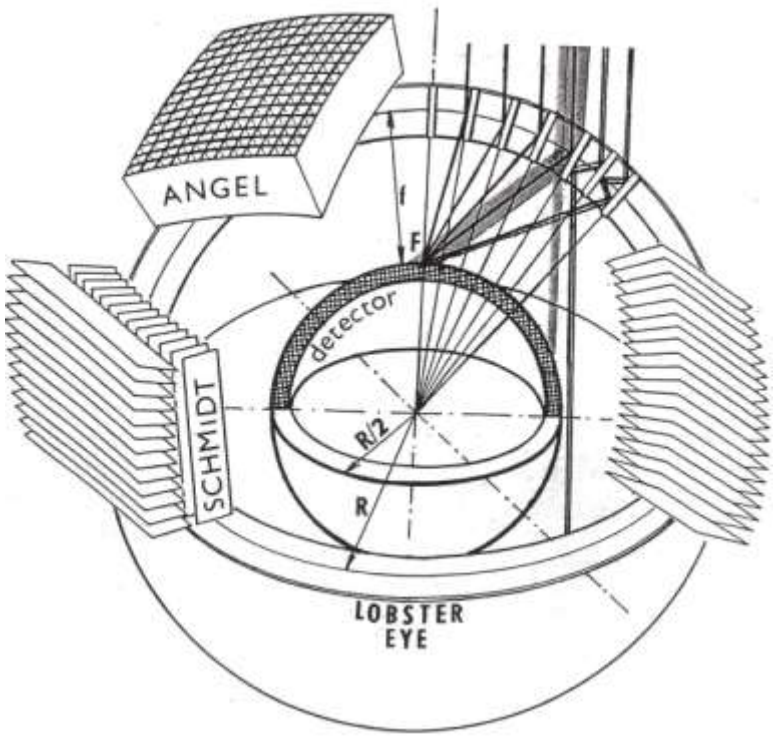
A new discovery (2014)
Mirror developed from the choroidal argentea

Crystals are oriented almost parallel to the mirror's surface

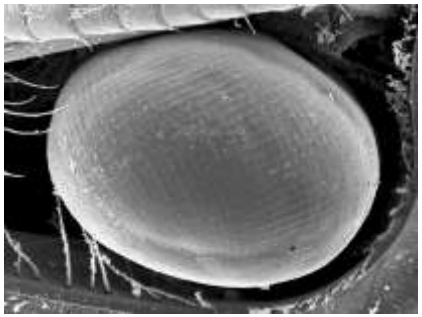
- **Optical surface formed by large number of small mirrors (guanine crystals in ML arrangement)**
- **May be multi layer active optics**

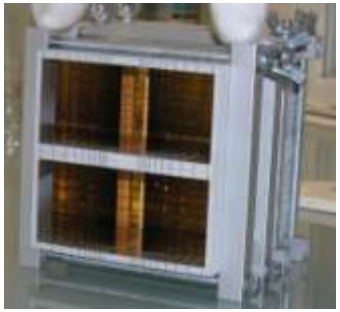
Example: Lobster Eye X-ray Optics

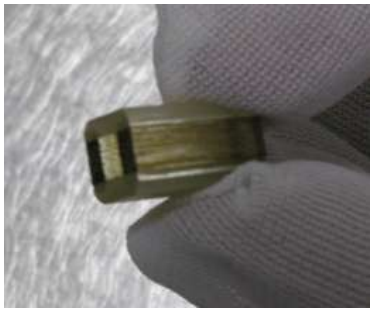
Lobster Eye optics (LE)

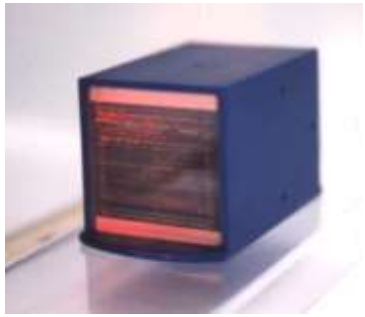


- **Analogy with lobster eyes**
- Wide FOV - FOV of 100 sq. deg. and more easily possible (classical X-ray optics only 1 deg or less)
- Designed for astronomy, but laboratory applications also possible
- Glass and / or silicon substrates for soft X-rays
- Planar & ellipsoidal mirrors
- Foils 3 × 3 mm to 300 × 300 mm
- Foil thickness from 30 μm to 1 mm



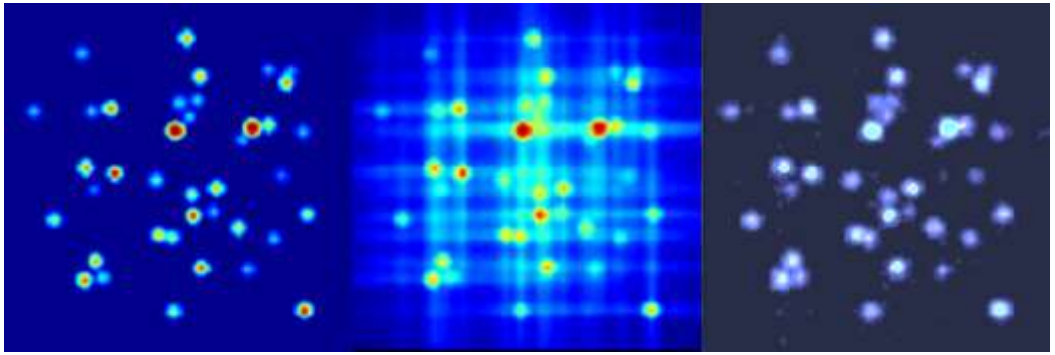






(Animal) Lobster Eyes

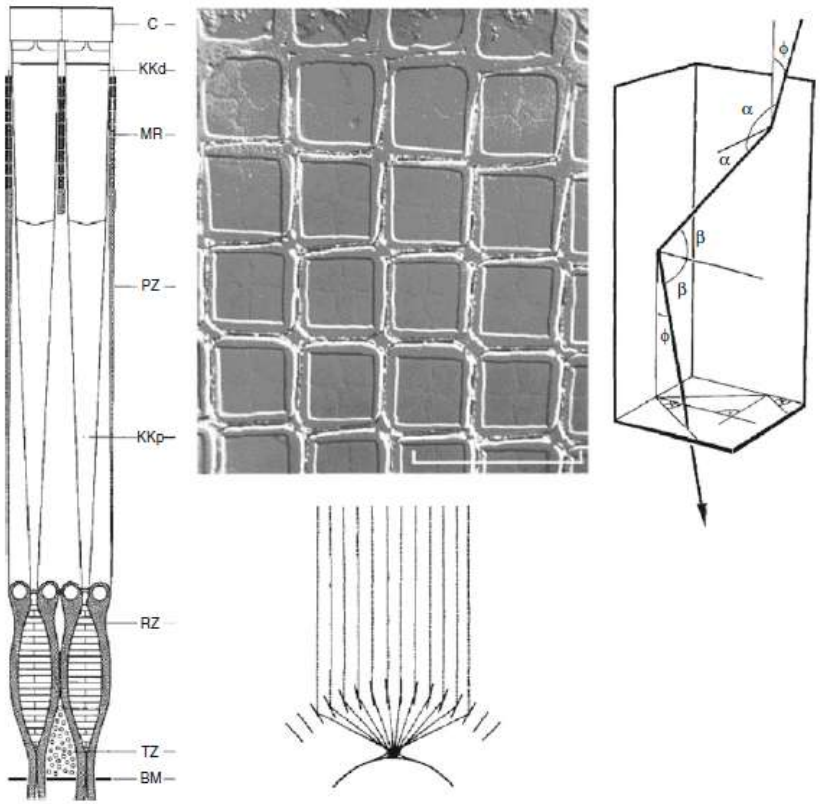
- **NOT ONLY imaging device but:**
- **Image reconstruction/deconvolution in lobster brain**



- **Adaption to light low/high**
- **Protection against light damage**
- **Recognize polarized light**

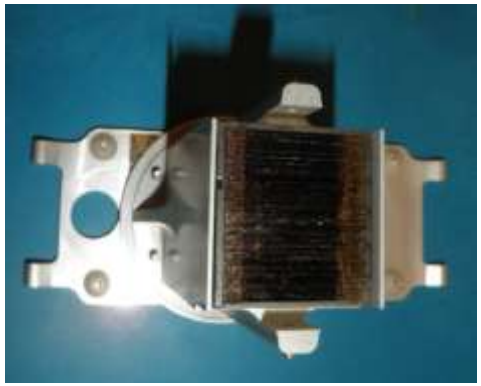
MIRROR EYES

- Multilayers of material with alternating high and low refractive indices
- Interference of light reflected from the upper and lower surfaces of each layer
- High sensitivity to light



Lobster Eye for VZLUSAT-1

- 1D Lobster Eye module with focal length 250 mm
- Composed of 182 wedges and 90 reflective double-sided gold-plated foils (thickness 150 µm)
- Input aperture: 29x19 mm, outer dimensions: 29x31x60 mm
- Active part of the foils: 19 mm in width and 60 mm in length
- Energy range 3 to 20 keV



Conclusion

- **Strange animal mirror eyes are challenging and little investigated**
- **New discoveries**
- **Possible multilayer, multimirror adjustable (active) optics in deep sea fishes**
- **Worth study**
- **Potential of applications in optics/space optics**
- **Especially in low level light applications (deep sea and space)**
- **Example Lobster Eye X ray Optics**

THANK YOU FOR ATTENTION

And see you at AXRO2017 in Prague

http://axro.cz

And SPIE Conference XUV Optics Synergy between Laboratory and Space Prague April 2017

Prague