Evolution of visual system

Origin of life

VZNIK ŽIVOTA – NEJVĚTŠÍ TAJEMSTVÍ VESMÍRU

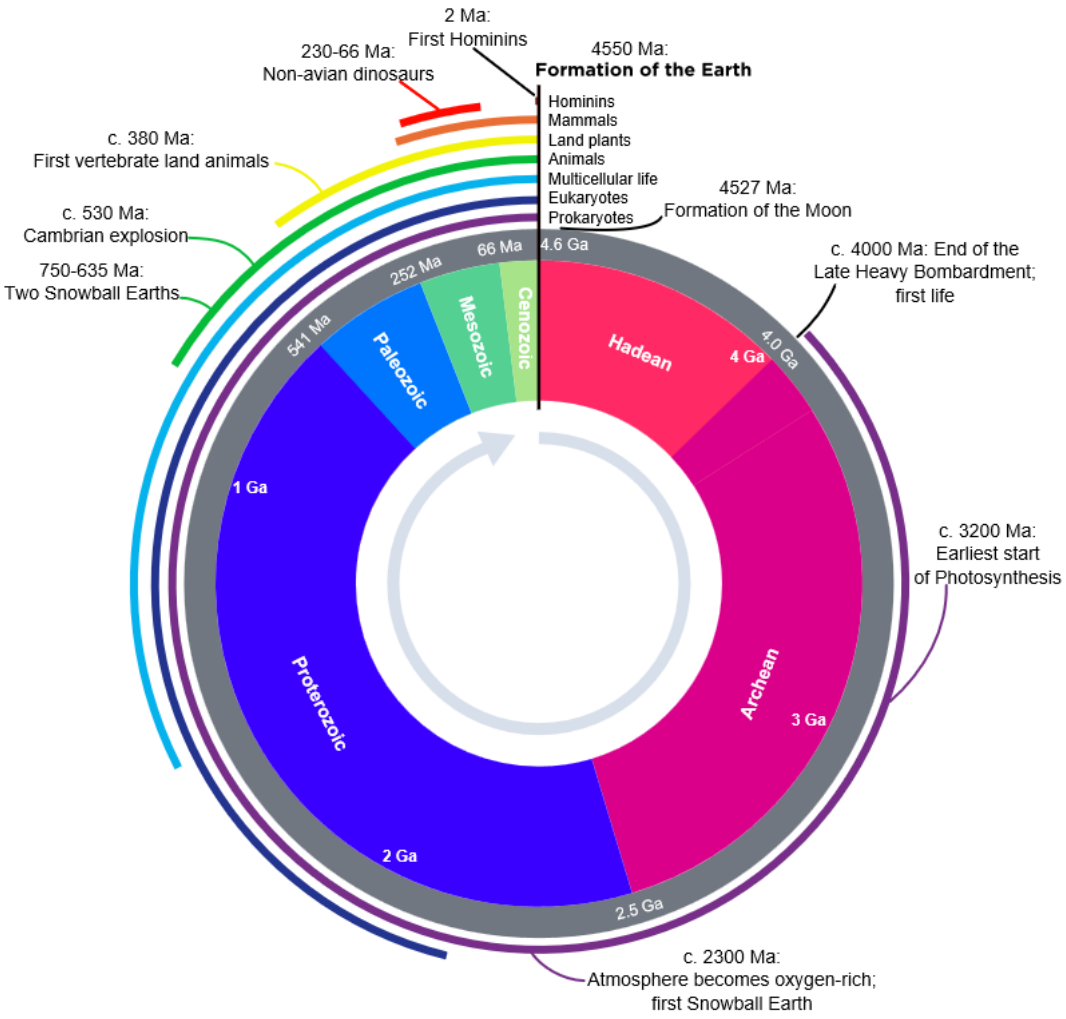
https://www.youtube.com/watch?v=c4PH_13ZPsQ

How did life begin? Abiogenesis. Origin of life from nonliving matter.

https://www.youtube.com/watch?v=nNK3u8uVG7o

https://en.wikipedia.org/wiki/History_of_Earth

Earth

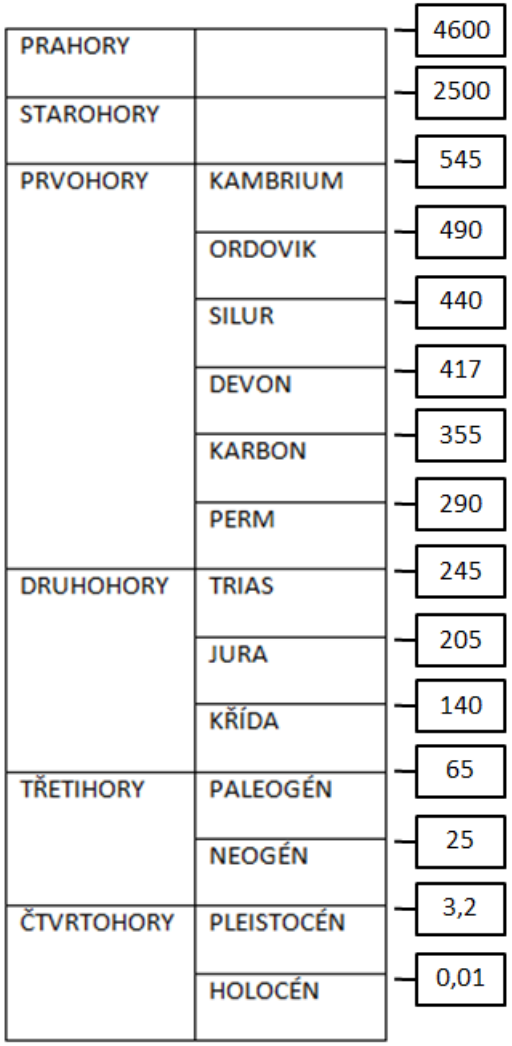


PRAHORY		4600
STAROHORY		2500
PRVOHORY	KAMBRIUM	545
	ORDOVIK	490
	SILUR	440
	DEVON	417
	KARBON	355
	PERM	290
DRUHOHORY	TRIAS	245
	JURA	205
	KŘÍDA	140
TŘETIHORY	PALEOGÉN	65
	NEOGÉN	25
ČTVRTOHORY	PLEISTOCÉN	3,2
	HOLOCÉN	0,01

Autor: WoudloperDerivative work: Hardwigg – File:Geologic_clock.jpg, Volné dílo, https://commons.wikimedia.org/w/index.php?curid=11926892

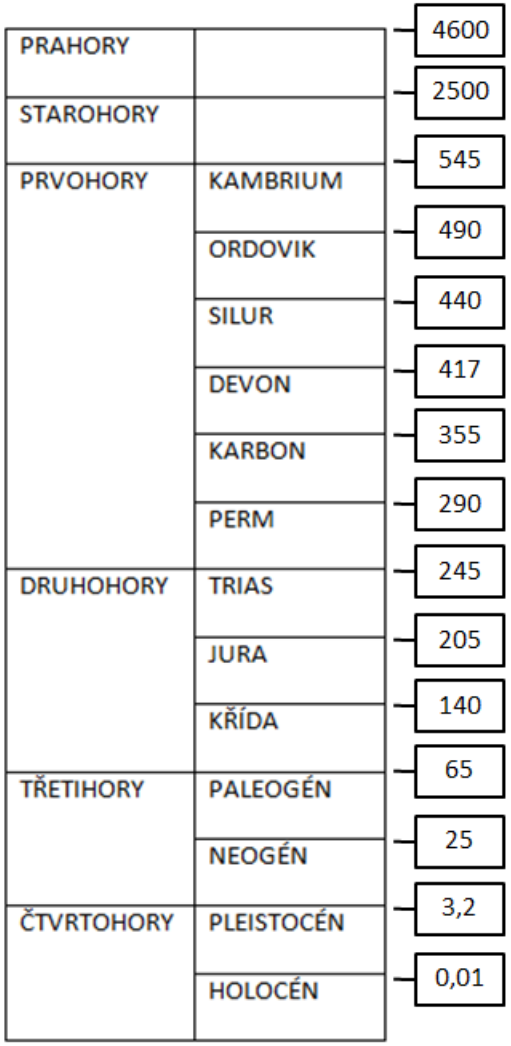
Earth

Hadean Eon	4.6–4 Gyears
Archean Eon	4,000 to 2,500 Myears
Proterozoic Eon	2,500 to 541 Myears
Phanerozoic Eon	
Paleozoic Era	542 to 251 Myears
Cambrian Period	541 Myears
Ordovician period	485 Myears
Silurian Period	443 Myears
Devonian Period	419 to 359 Myears
Carboniferous Period	358 to 298 Myears
Permian Period	298 to 252 Myears

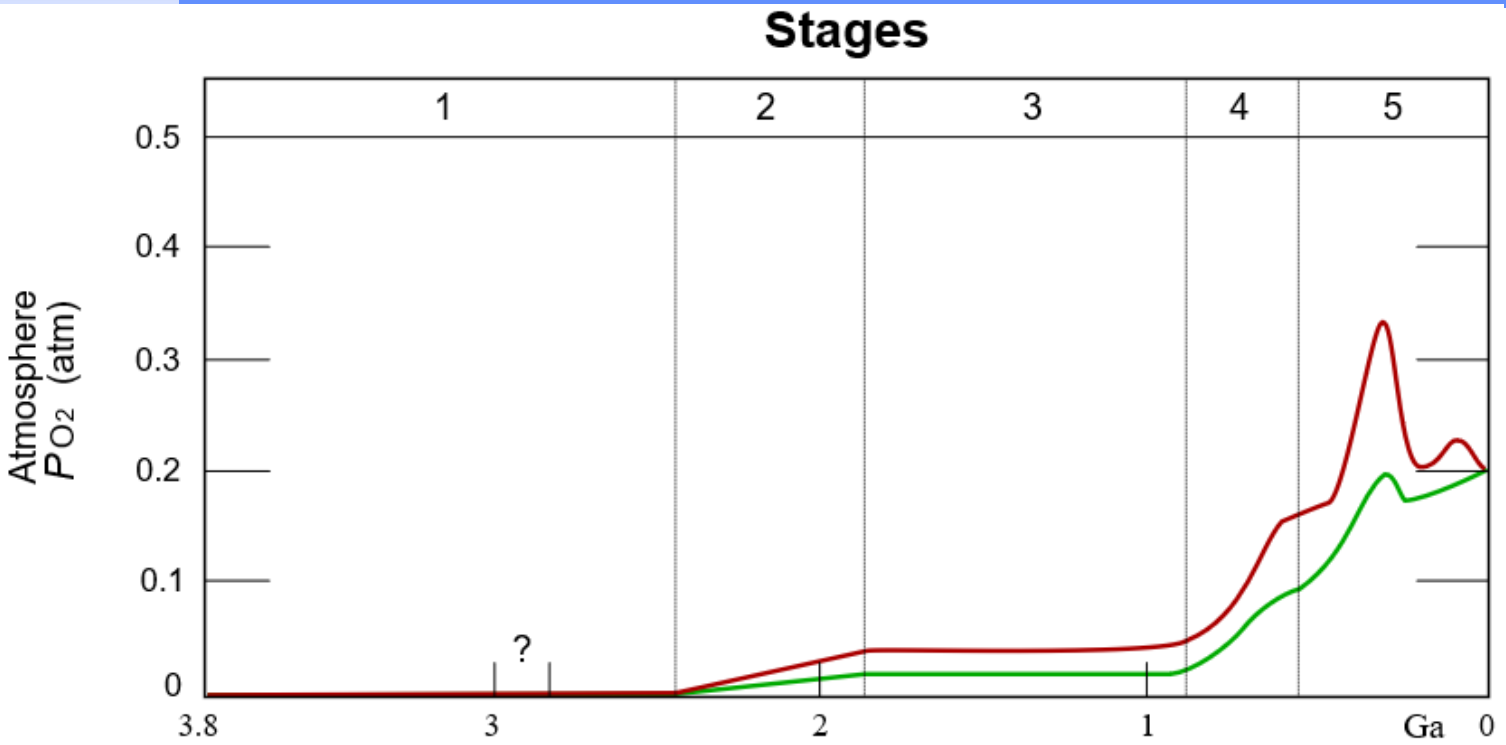


Earth

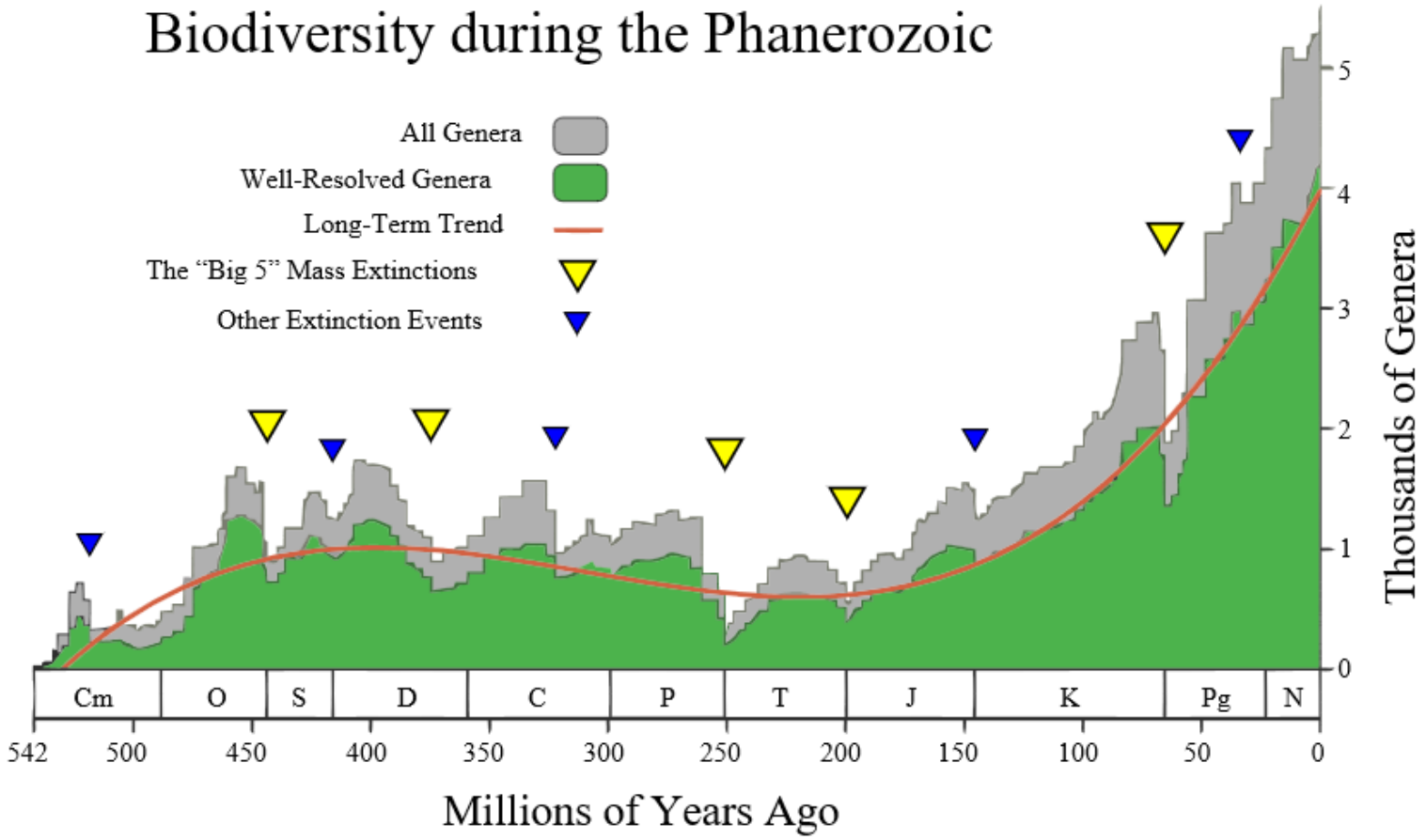
Mesozoic Era	252 to 66 Myears
Triassic Period	252 to 201 Myears
Jurassic Period	201 to 145 Myears
Cretaceous Period	145 to 66 Myears
Cenozoic Era	66 Myears
Paleogene Period	66 to 23 Myears
Eocene Epoch	56 to 33 Myears
Oligocene Epoch	34 to 23 Myears
Miocene Epoch	23 to 5 Myears
Pliocene Epoch	5 to 2.5 Myears
Pleistocene Epoch	2.5 Myears to 11,7 kyears
Holocene Epoch	11.7 kyears to present



First signs ……



O2 build-up in the Earth's atmosphere. Red and green lines represent the range of the estimates while time is measured in billions of years ago (Ga).
Stage 1 (3.85–2.45 Ga): Practically no O2 in the atmosphere.
Stage 2 (2.45–1.85 Ga): O2 produced, but absorbed in oceans and seabed rock.
Stage 3 (1.85–0.85 Ga): O2 starts to gas out of the oceans, but is absorbed by land surfaces and formation of ozone layer.
Stages 4 and 5 (0.85 Ga–present): O2 sinks filled, the gas accumulates.

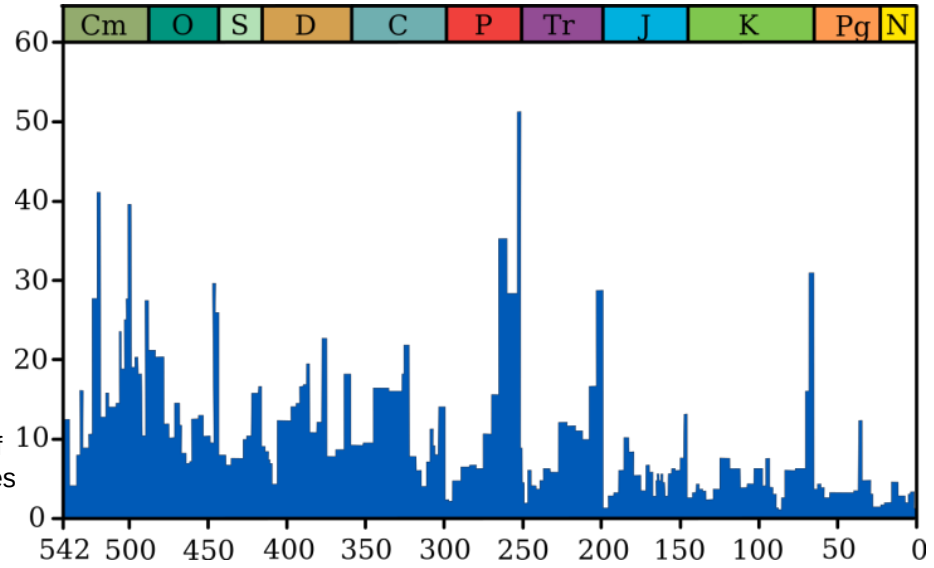


540 mil. years – Cambrian explosion

Milestones

Extinctions – in total 99,9% species
silur 440-450 Myears
devon - 60-375 Myears
perm-trias - 251 Myears, Siberia traps
trias-jura - 205 Myears
cretaceous period - 65.5 Myears, asteroid

Snow ball
2100 to 2400 Myears
650 Myears

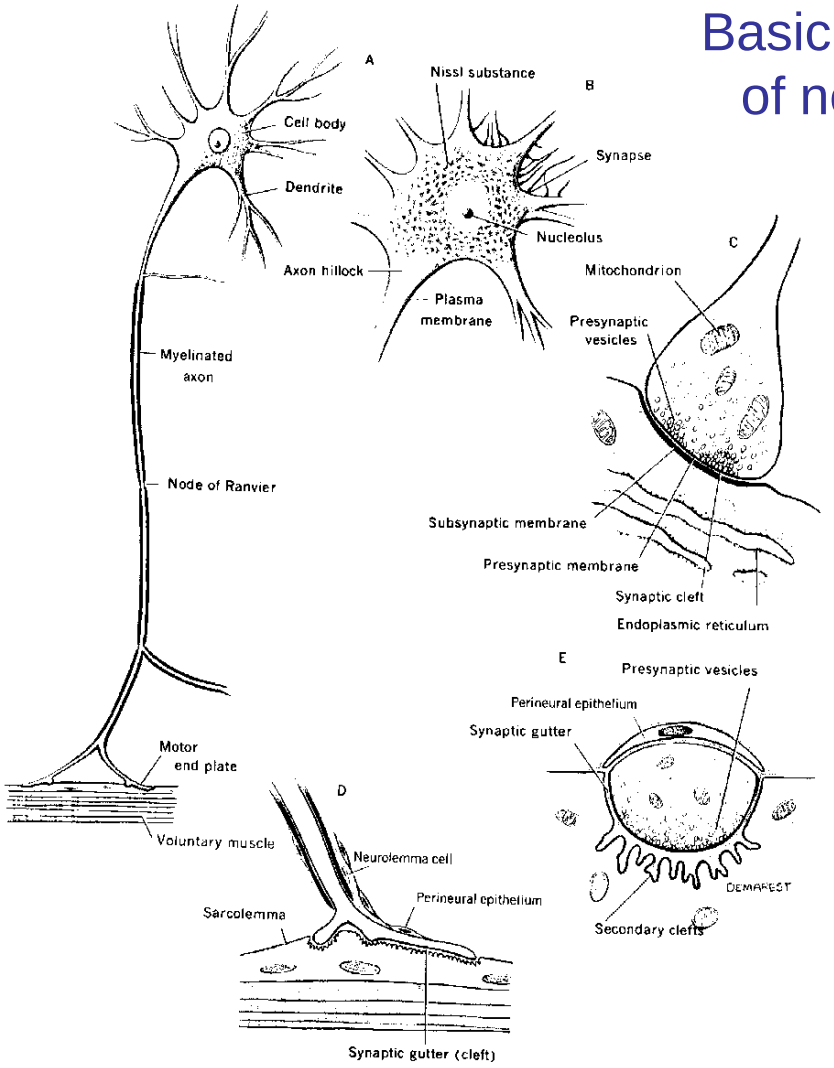


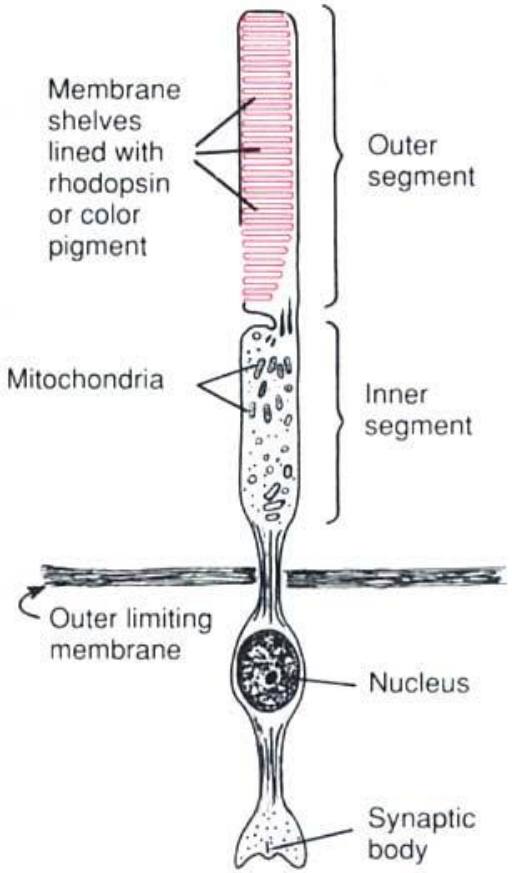
https://en.wikipedia.org/wiki/Extinction

The blue graph shows the apparent percentage (not the absolute number) of marine animal genera becoming extinct during any given time interval. It does not represent all marine species, just those that are readily fossilized. The labels of the traditional "Big Five" extinction events and the more recently recognised End-Capitanian extinction event are clickable hyperlinks; see Extinction event for more details. (source and image info)

Neuron - basics

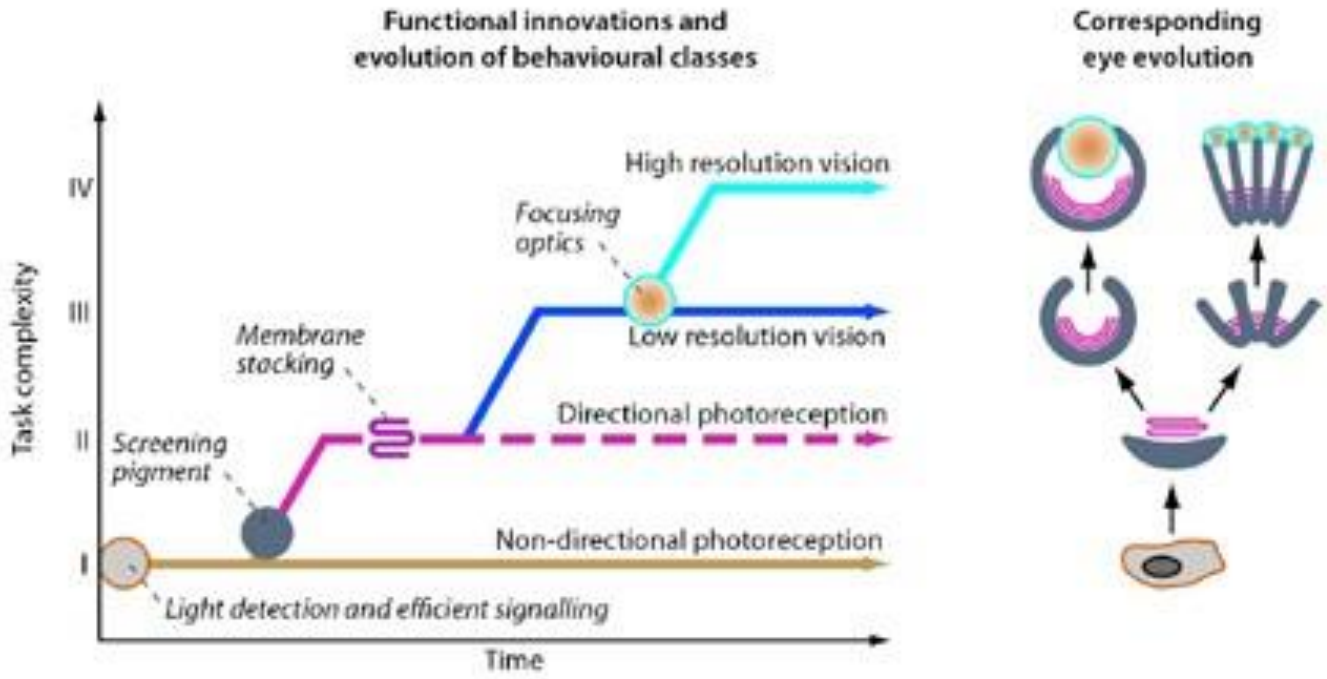
Basic elements of neural net





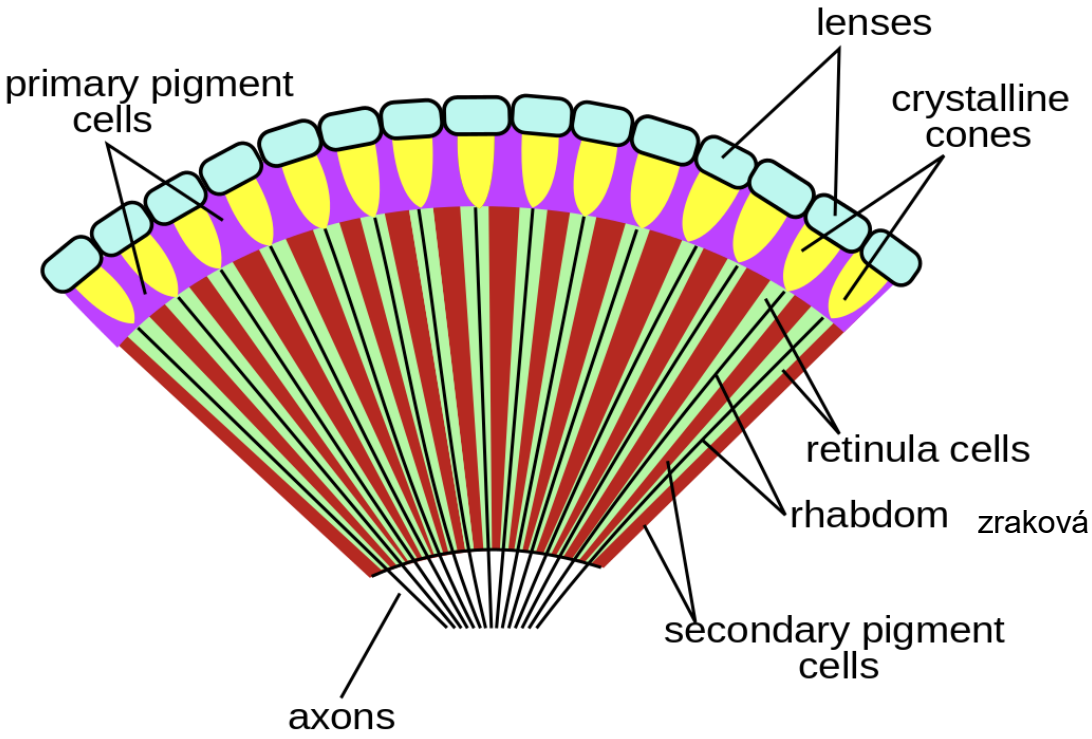
By Kosigrim at English Wikipedia - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=33725653

Key innovations that guided eye evolution



https://www.biology.lu.se/research/research-groups/lund-vision-group/research-projects/the-evolution-of-vision

Compound eye of insect



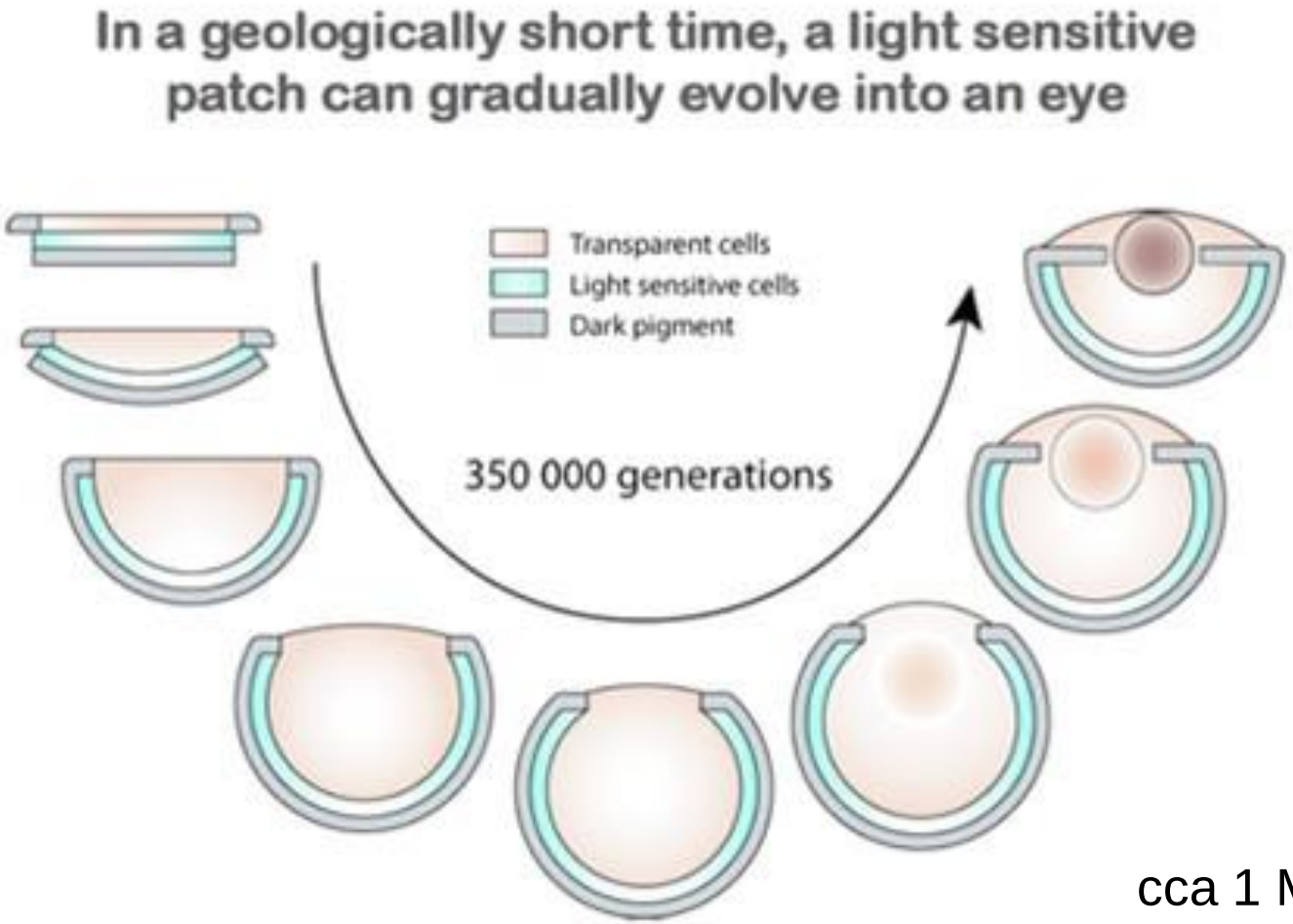
Compound eye of insect

lens and then often a second lens proximal to the first lens

ommatidium (pl. ommatidia Gr. ‘little eyes.’)

Multiple ommatidia - gene duplication
leading to as many as 30 000 individual units - dragonfly

Eye evolution

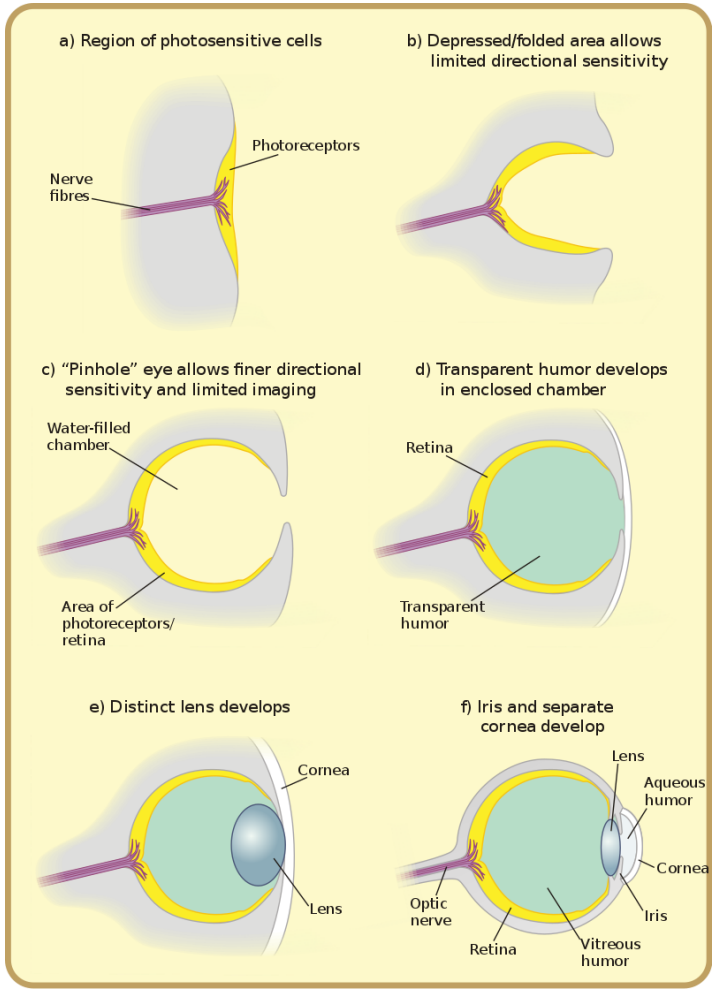


cca 1 Myears

Dan-Eric Nilsson, Susanne Pelger

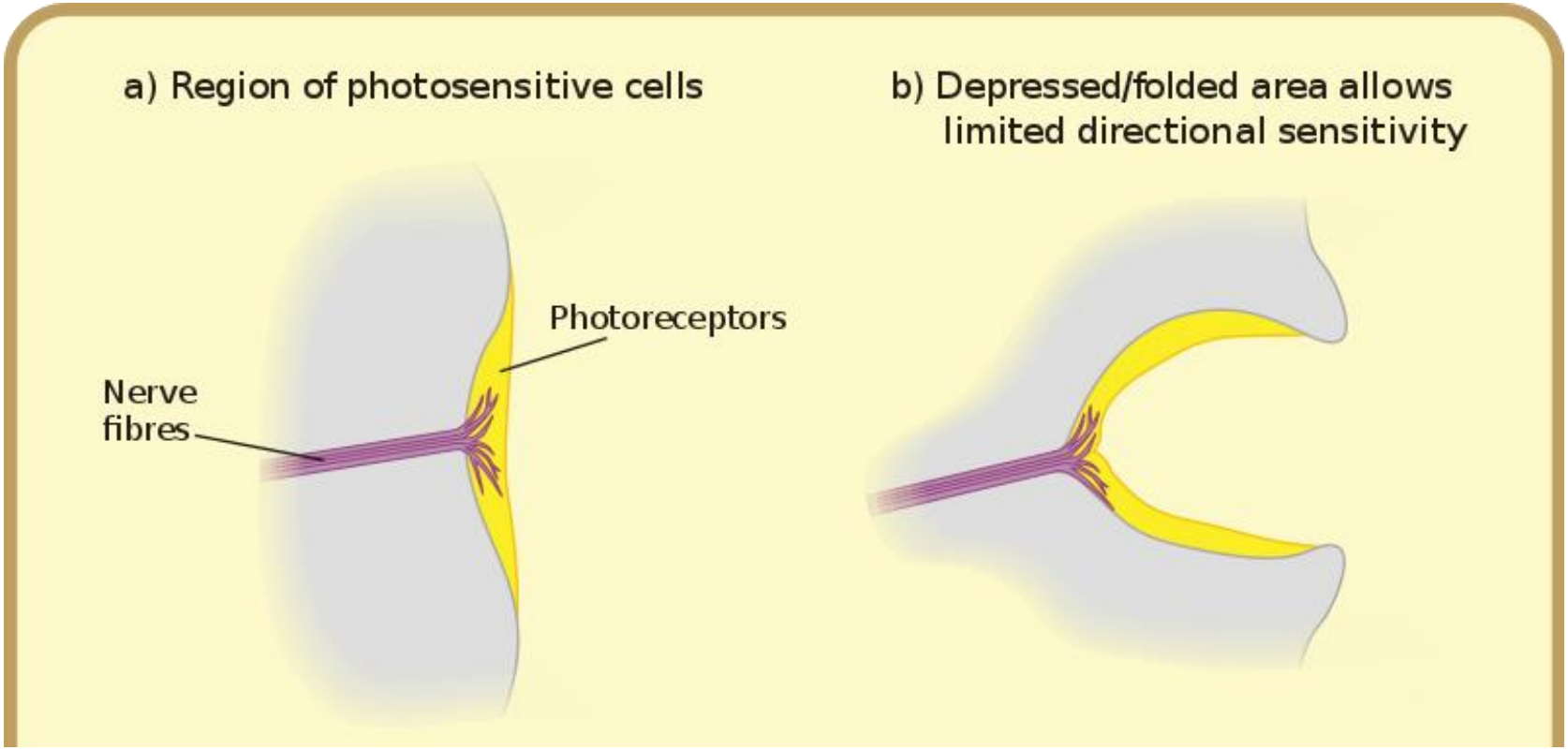
https://www.biology.lu.se/research/research-groups/lund-vision-group/research-projects/the-evolution-of-vision

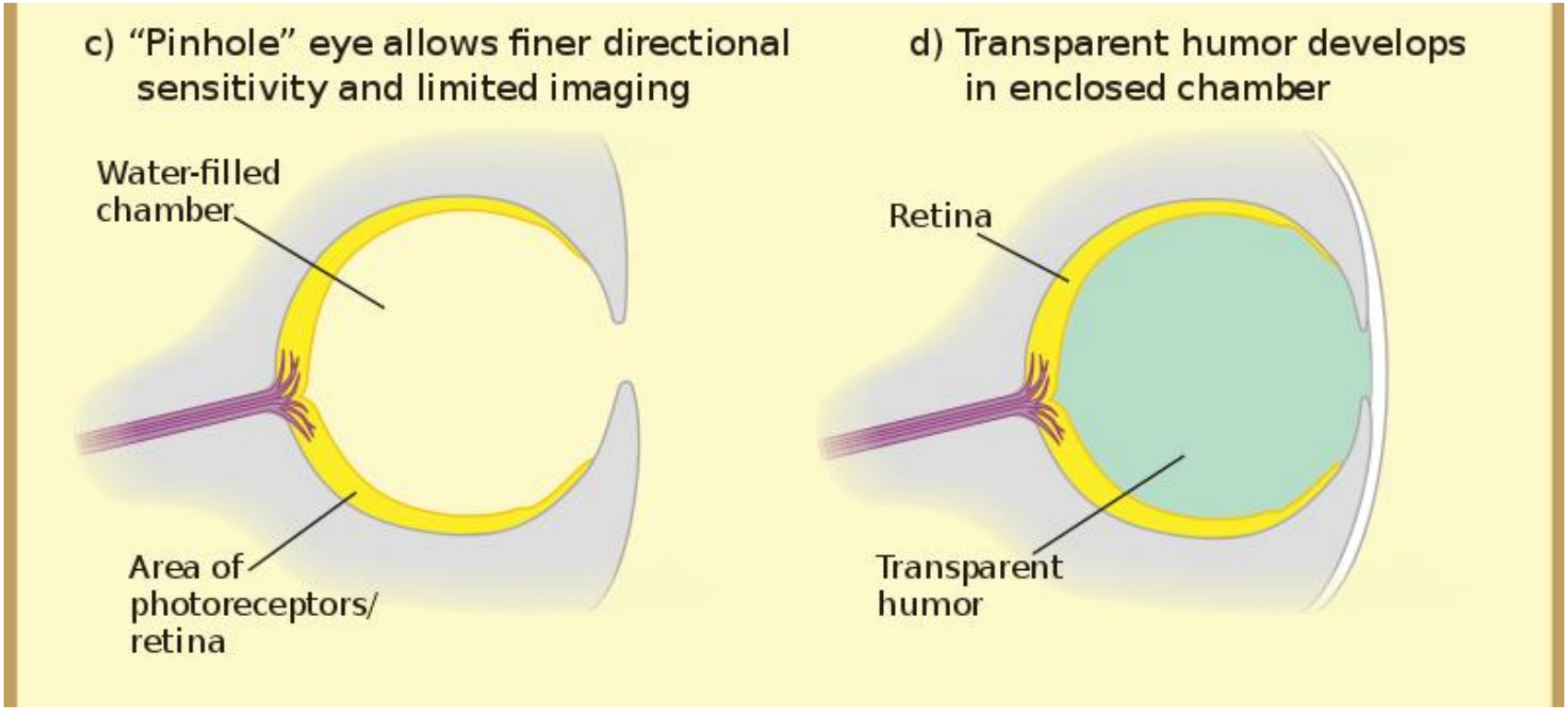
Eye evolution



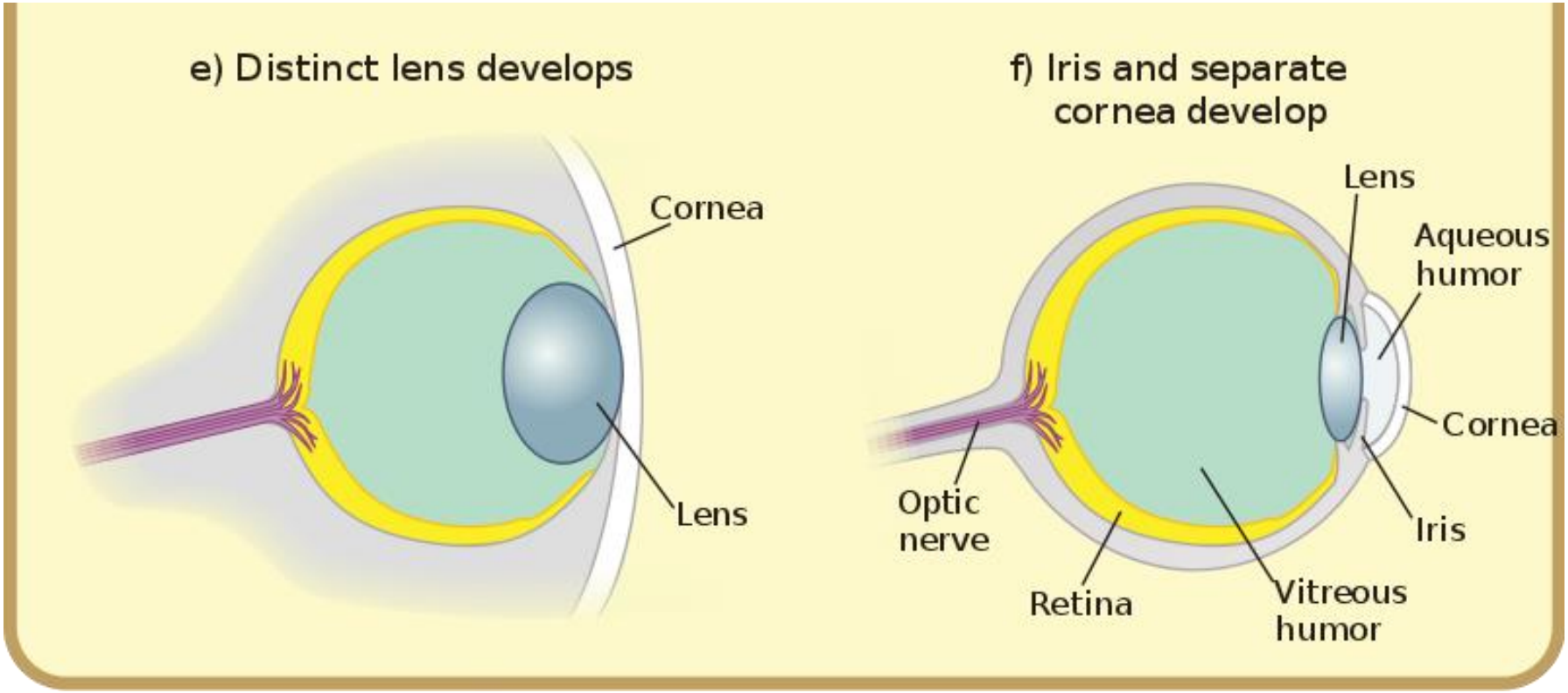
By Matticus78 at the English language Wikipedia, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=2748615

Eye evolution

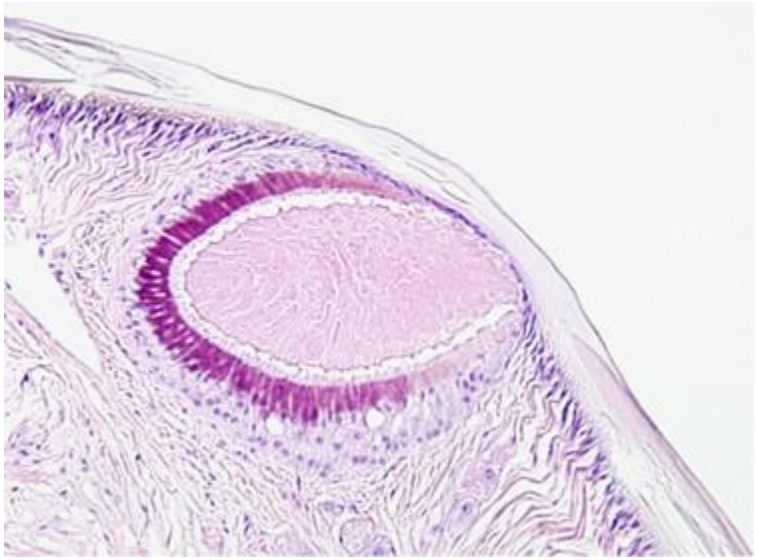



c) "Pinhole" eye allows finer directional sensitivity and limited imaging
Water-filled chamber
Area of photoreceptors/ retina
d) Transparent humor develops in enclosed chamber
Retina
Transparent humor

Eye evolution



No lens eye



From: The evolution of eyes: major steps. The Keeler lecture 2017: centenary of Keeler Ltd

Nereis virens—King sandworm: eyecup, no lens.

By Alexander Semenov - originally posted to Flickr as The Worm, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=8770570

Eye evolution

Camera obscura (dírková komora) – loděnka hlubinná Nautilus pompilius

first lens – trilobite – 540 Myears ago

544 Myears - no eye

Evolution of eye - cca 4 Myears (comparison: evolution of dog – order of 10 kyears)

Sea squirt (Sumka) - Ciona intestinalis, larva – lensless eyes, brain,

after that body - soft, translucent column-like structure, resembling a mass of intestines

Algae (Řasa) Volvox globator – rotation towards Sun, rhodopsin

Protozoans (Prvoci) dinoflagellates – minieyes with retina, lens and cornea inside cell

https://www.nature.com/articles/eye2017226

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3632888/

Eye evolution

Lens evolution
trilobite – calcite, optical axis – protein base
Guanin – DNA nucleobase, crystalizes
Human lenses – proteins – crystallines, most of them are enzymes

https://en.wikipedia.org/wiki/Crystallin

Rhodopsin
Rods - opsin (protein) + retinal (7times folded molecule, photon absorption – molecule straightening)
Cones - spectral calibration – opsin – from 350 to 625 nm
HVS – 433, 535 and 564 nm
Vision in general – tetrachromatic (incl. UV 360 nm)

https://en.wikipedia.org/wiki/Rhodopsin

Eye evolution another estimate

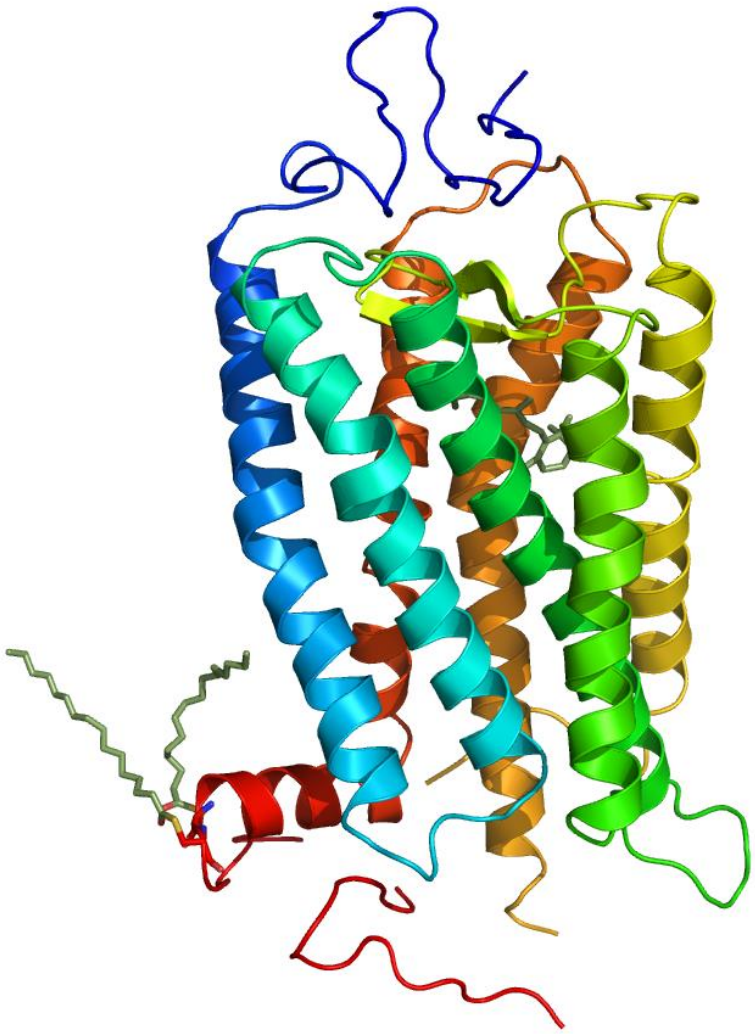
opsin (or the predecessor of the opsins) covalently bonded with retinal,

Perhaps after 35 000 generations, an organism discovered that developing a concave cup instead of a spot

As Nilsson and Pelger[12] suggested, from an eyespot to an eyecup to a fully formed camera-style eye could take as few as 364 000 generations,

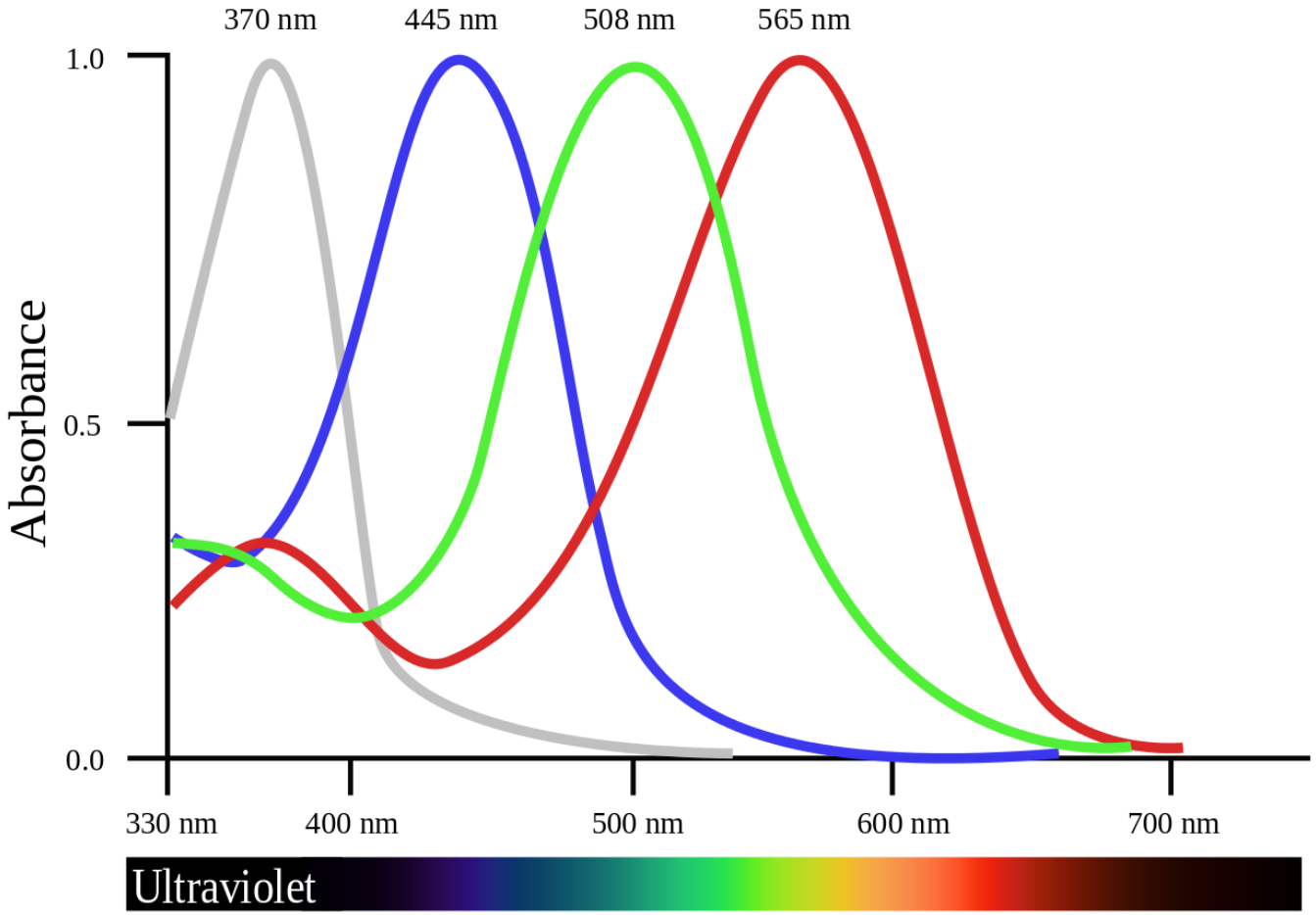
the production of such an eye in perhaps as short a period as half a million years

Rhodopsin



S. Jähnichen – Own work
3D structure model of bovine rhodopsin. Derived from the 2.6 Å crystal stucture of rhodopsin (1L9H) with covalently linked retinal and palmityl residues (grey). Structural informations were obtained from pdb.org and rendered using PyMol 0.99. Blue: TMI. Lightblue: TMII. Cyan: TMIII. Green: TMIV. Yellow: TMV. Organge: TMVI. Red-orange: TMVII. Red: Hx8.

Tetrachromatic vision

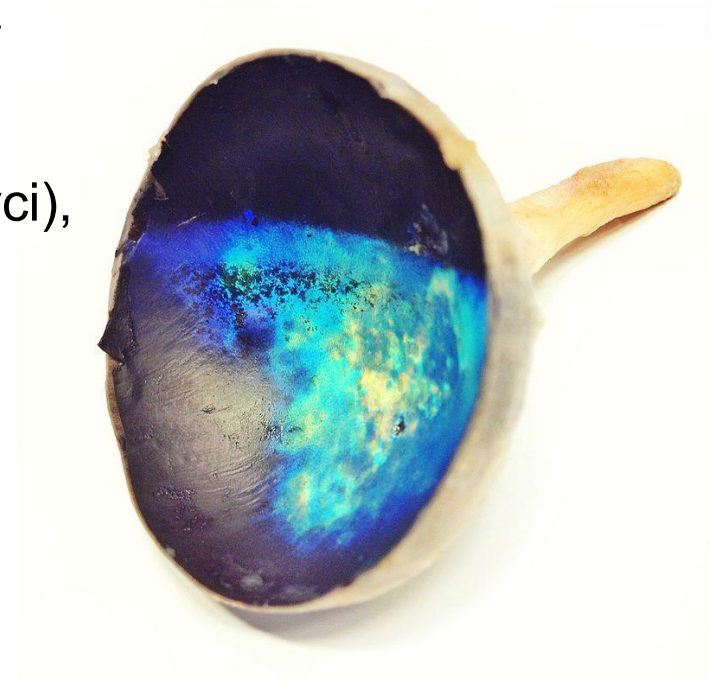


By L. Shyamal - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=6308626

tapetum lucidum

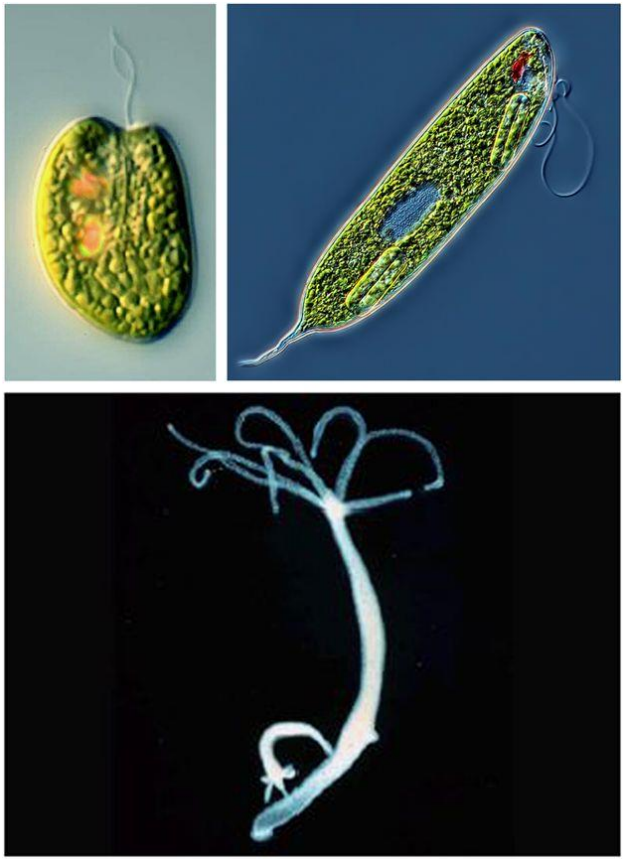
The ***tapetum lucidum*** "bright tapestry; coverlet"

layer of tissue in the eye of many vertebrates (obratlovci)
immediately behind the retina – retroreflector
reflects visible light back through the retina
slightly blurring the image
superior night vision of some animals
nocturnal, especially carnivores (masožravci),
deep sea animals.



By Andrewmeyerson - Own work, CC BY-SA 4.0,
https://commons.wikimedia.org/w/index.php?curid=51285561

Examples

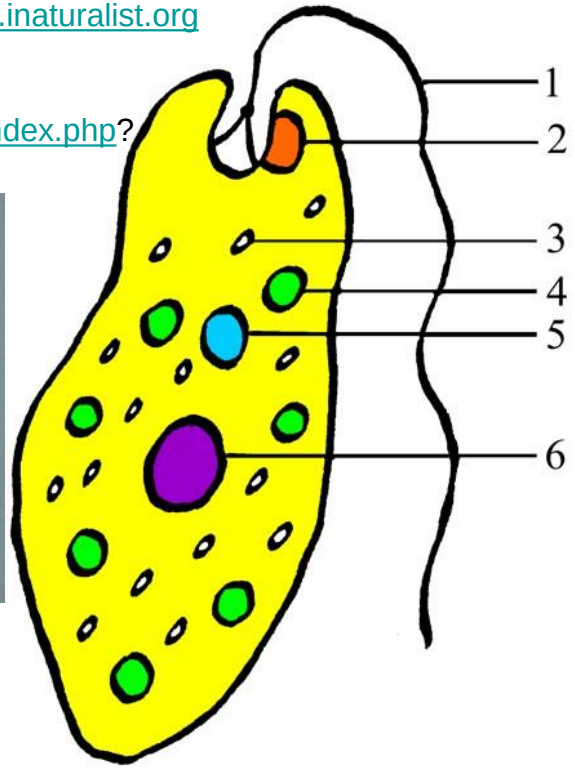


Top left Chlamydomonas rheinhartii.
Top right Euglea gracilis.
Bottom Hydra vulgaris.

https://www.nature.com/articles/eye2015220

By David J. Patterson - https://www.inaturalist.org/observations/32924345, CC BY 4.0, https://commons.wikimedia.org/w/index.php?curid=82332947

Krásnoočko

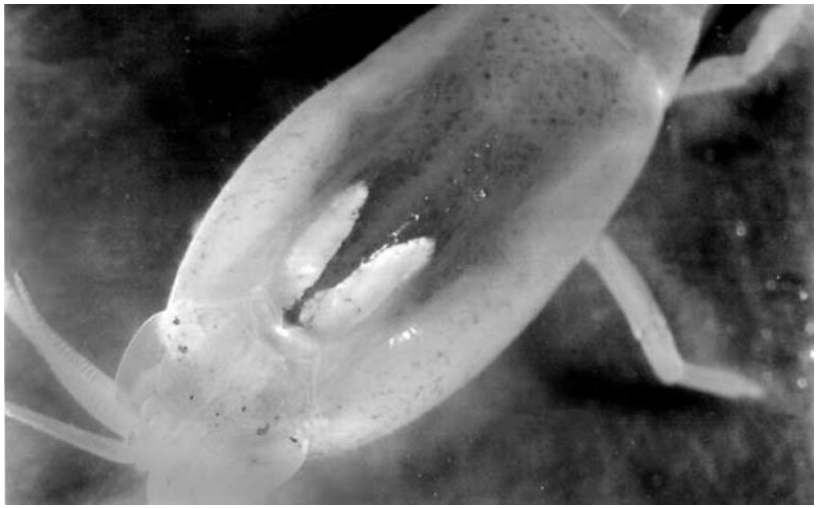


The *stigma* (2) of the euglena hides a light-sensitive spot.

1. Scourge (bičík), 2. eye-blotch (skvrna), 3. starch (škrob) - granules, 4. Chloroplaste, 5. Vakuole, 6. cell nucleus

By Ra'ike (see also: de:Benutzer:Ra'ike) - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=721814

Rimicaris exoculata – bezoká kreveta



two folds on back
rhodopsin, max. sensitivity 500 nm
larvae – standard eyes, they live close to surface, after that descend and eyes disappear
naked retina much more sensitive

Nick Lane

Trilobite eye

fossil record - first known eye was in a trilobite, *Olenellus fowleri*.
it is the first known eye because of the calcite composition of its ommatidia

This ancient arthropod probably lived between 600 and 550 Myears before the Cambrian explosion and possessed fully formed eyes with multiple individual ommatidi

Erbenochile erbenii;

By Moussa Direct Ltd. - Moussa Direct Ltd. image archive, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=4437498

https://www.youtube.com/watch?v=-JMyWerdguQ

The Evolution of Vision - Professor William Ayliffe

Trilobite eye

Trilobite eyes - compound, each lens elongated prism
number of lenses - one to thousands of lenses in a single eye
In compound eyes - lenses typically arranged hexagonally

Lenses of eyes - calcite (calcium carbonate, $CaCO_3$)
crystallographically oriented (optical axis)

change of focus - calcite formed an internal doublet structure
superb depth of field and minimal spherical aberration
living species with similar lenses - brittle star Ophiocoma wendtii
In other trilobites - gradient-index lens
(refractive index of the lens changing toward the center)

https://en.wikipedia.org/wiki/Trilobite

Trilobite eye

Holochroal eyes

great number (over 15,000) of small (30–100 μm) lenses.
lenses were hexagonally close packed, touching each other
with a single corneal membrane covering all lenses.

Schizochroal eyes

typically fewer (around 700), larger lenses, each lens had a cornea,
adjacent lenses - separated by thick interlensar cuticle, known as sclera.
appear quite suddenly in the early Ordovician
presumably derived from a holochroal ancestor
field of view, eye placement
- more defensive "early warning" system than aiding in the hunt for food

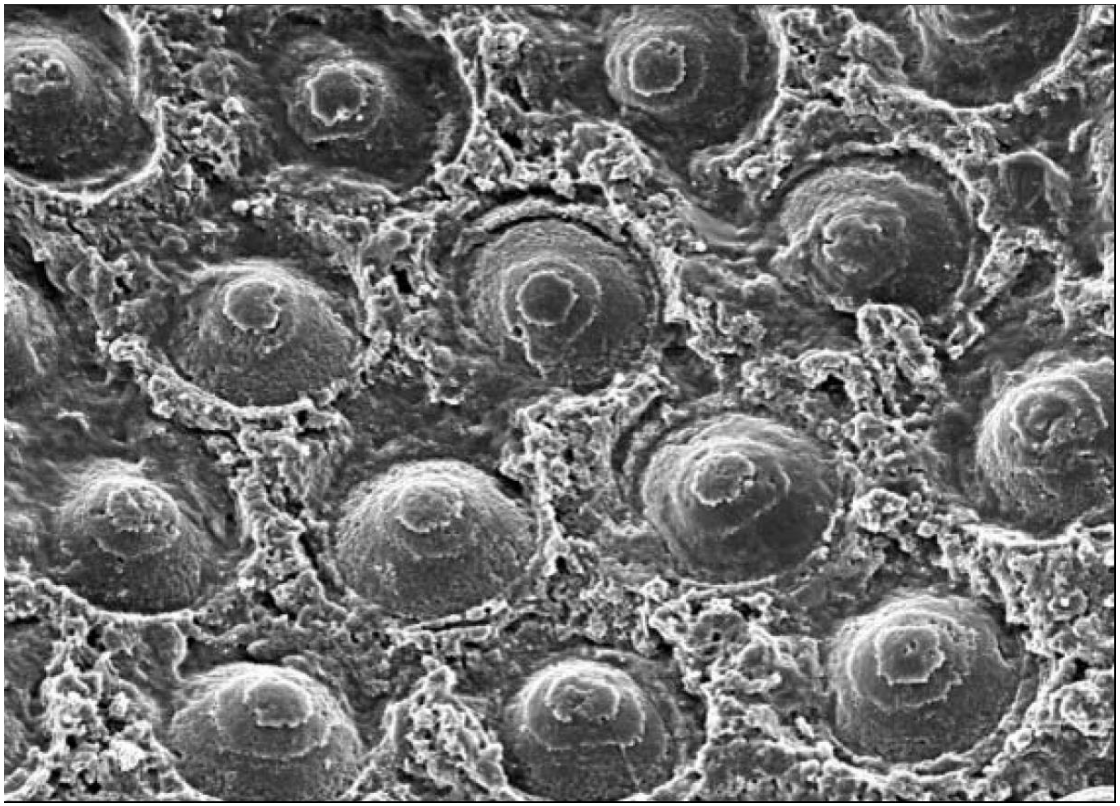
https://en.wikipedia.org/wiki/Trilobite

Trilobite eye

By Dwergenpaartje - Own work, CC BY-SA 3.0,
https://commons.wikimedia.org/w/index.php?curid=16986793

Trilobite eye

Trilobite crystal eyes - Dalmanitina socialis

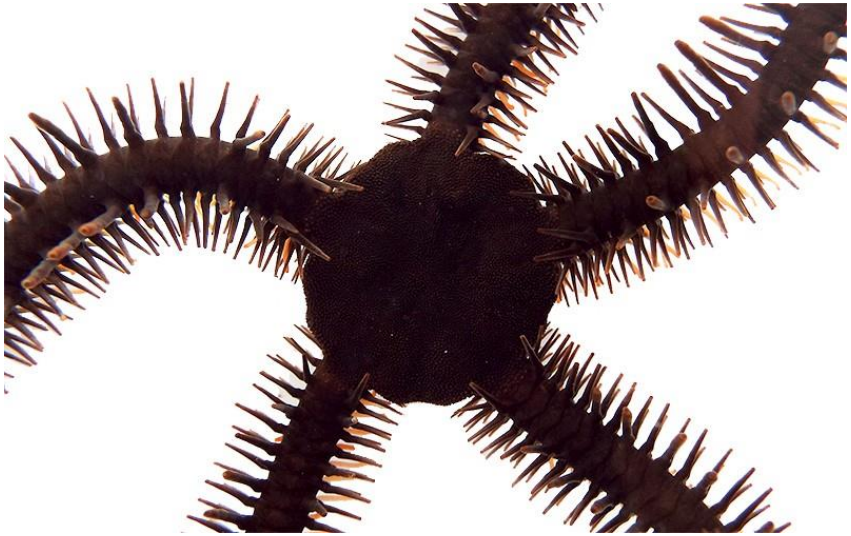


https://en.wikipedia.org/wiki/Arthropod_eye

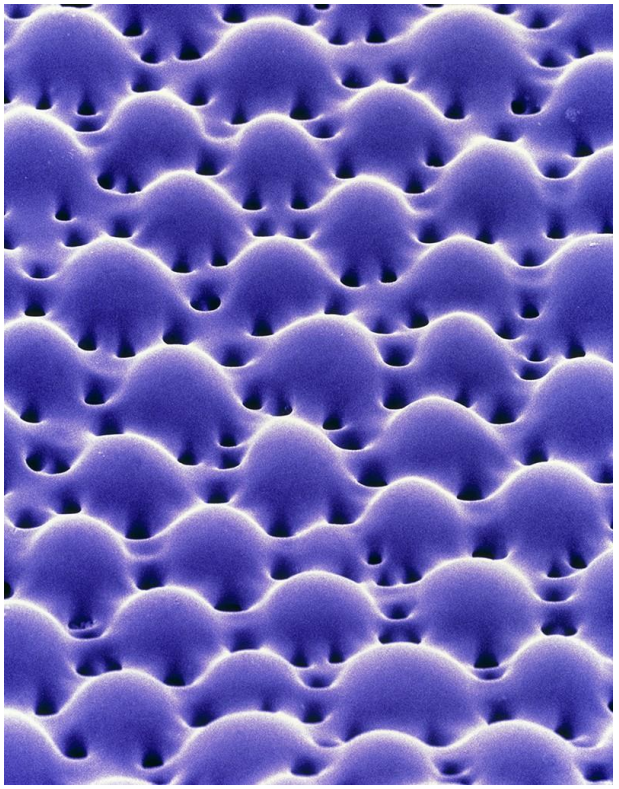
Brittlestar

Brittlestar (Hadice) Ophiocoma wendtii

oči na ramenech



The brittlestar *Ophiocoma wendtii* joins a list of animals that can 'see' without using eyes.Credit: Lauren Sumner-Rooney



Nature NEWS , 24 JANUARY 2018,
How brittlestars ‘see’ without eyes
The starfish relatives use light-sensitive cells throughout their bodies to sense their surroundings.
Giorgia Guglielmi

A coloured SEM of crystal structures in *Ophiocoma wendtii* that researchers thought acted like lenses.Credit: Lucent Technologies Bell Labs/SPL

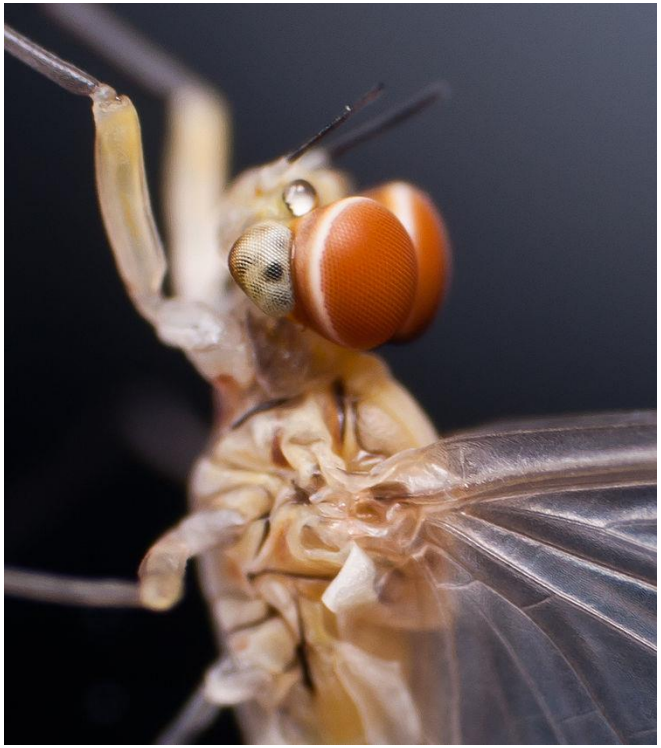
Insect

Many insects, such as the female *Tabanus lineola*, shown here, have **dichoptic** compound eyes

By Thomas Shahan - originally posted to Flickr as Female Striped Horse Fly (Tabanus lineola), CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=11751143

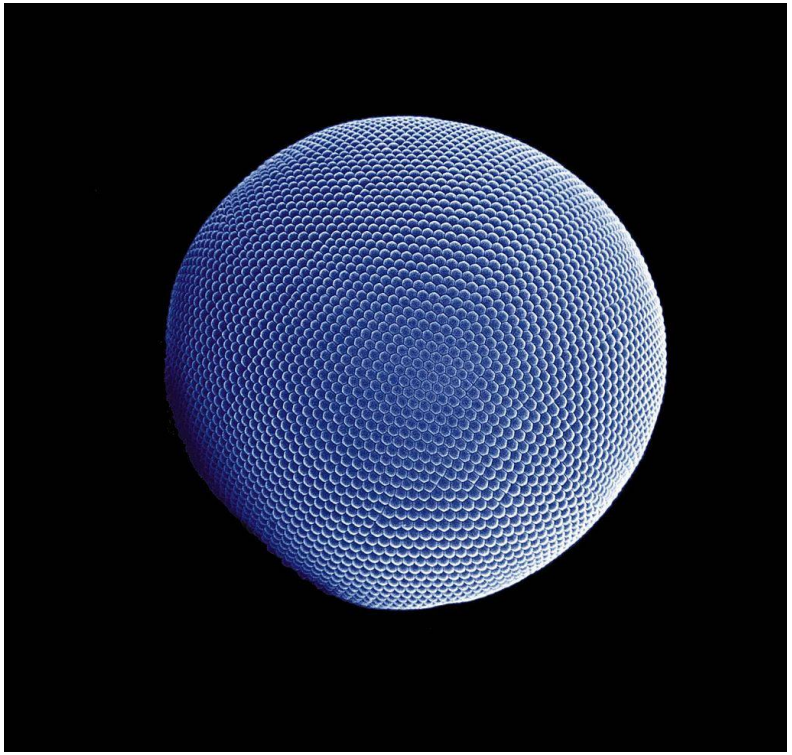
The male *Tabanus lineola* has **holoptic** compound eyes, with the dorsal ommatidia larger than the ventral ommatidia

By Thomas Shahan - Male Striped Horse Fly (Tabanus lineola)Uploaded by ComputerHotline, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=8854454



In some male mayflies (jepice) the eyes are split into separate organs for distinct visual functions

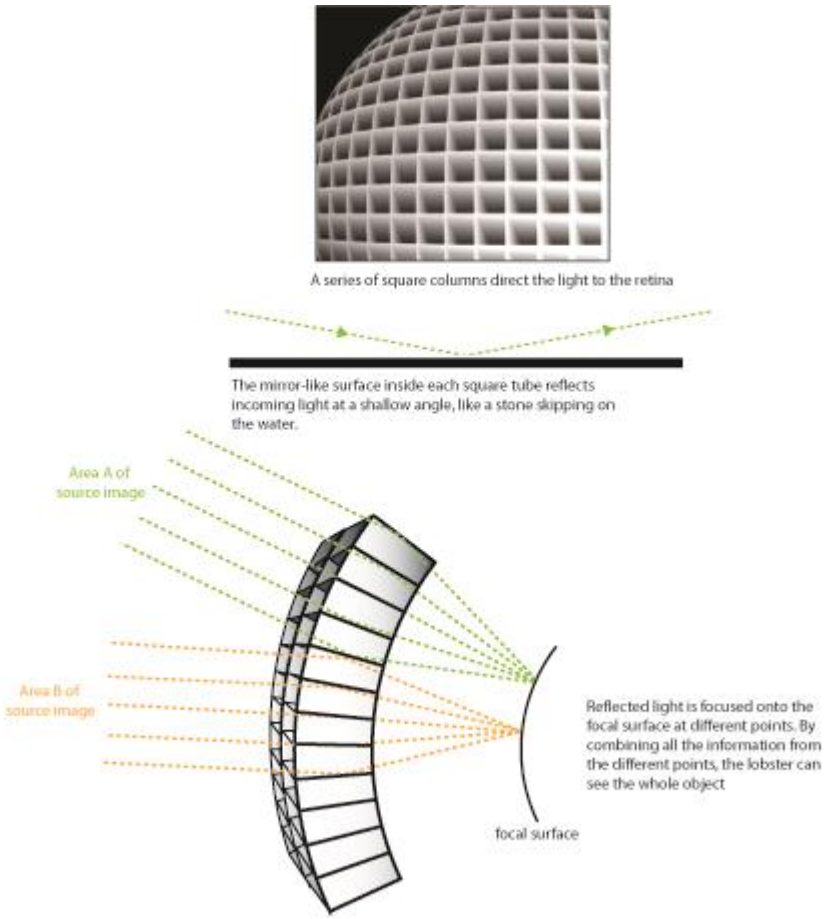
By Yasunori Koide - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=16028455



Compound eye of Antarctic krill as imaged by an electron microscope

CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=209612

Lobster eye



Lobster eye illustration. Artist: Emily Harrington. Copyright: All rights reserved.

Application of Biomimetics Principles in Space Optics

K. Remišová, R. Hudec, L. Pína, A. Inneman, V. Maršíková, D. Doubravová, V. Daniel

Astronomical Institute, Academy of Sciences of the Czech Republic, Ondřejov, Czech Republic

Charles University, Prague, Czech Republic

Czech Technical University, Prague, Czech Republic

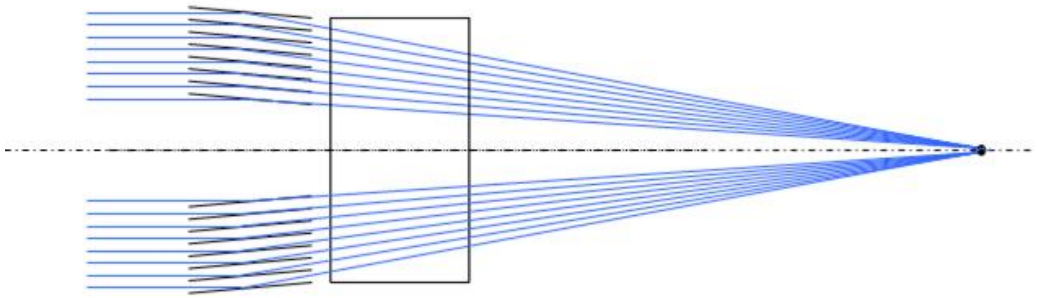
Rigaku Innovative Technologies Europe, Prague, Czech Republic

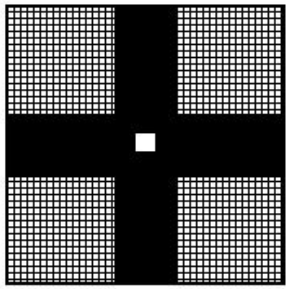
Aerospace Research and Test Establishment, Prague, Czech Republic

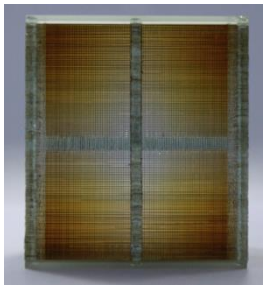
LE system – Schmidt geometry

1D vs. 2D system

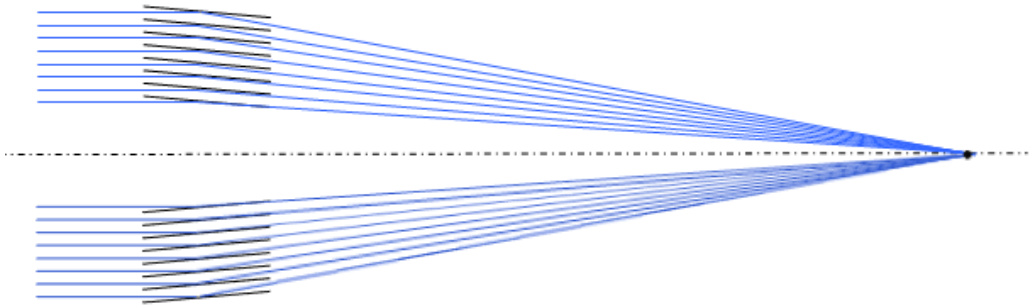
2D optics – composed of two 1D sub-modules, 2 reflections, energy range optical to 10 keV

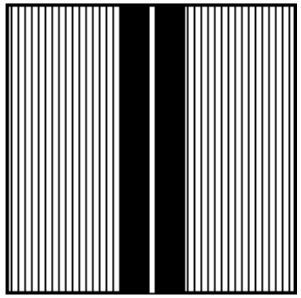






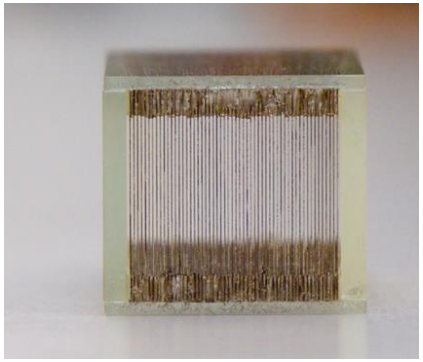
1D optics - 1 reflection, energy range optical to 30 keV

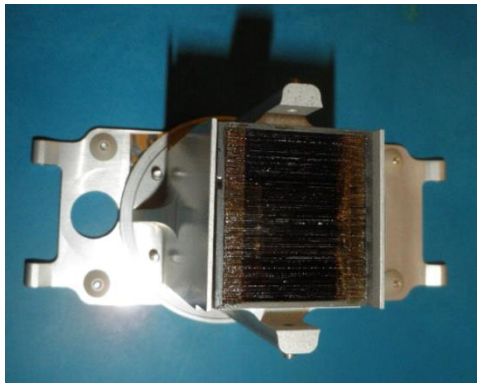




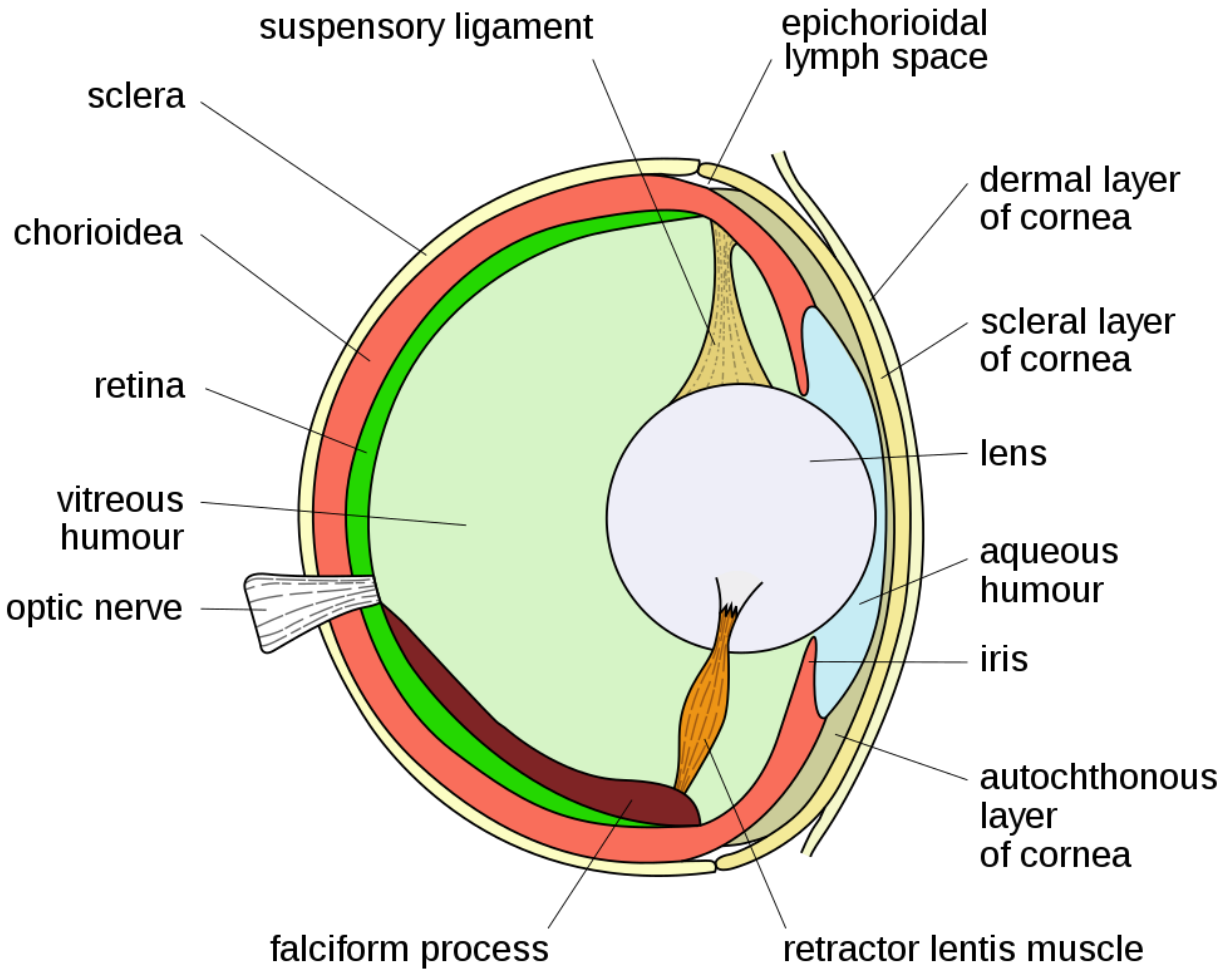
Lobster Eye for VZLUSAT-1

- 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

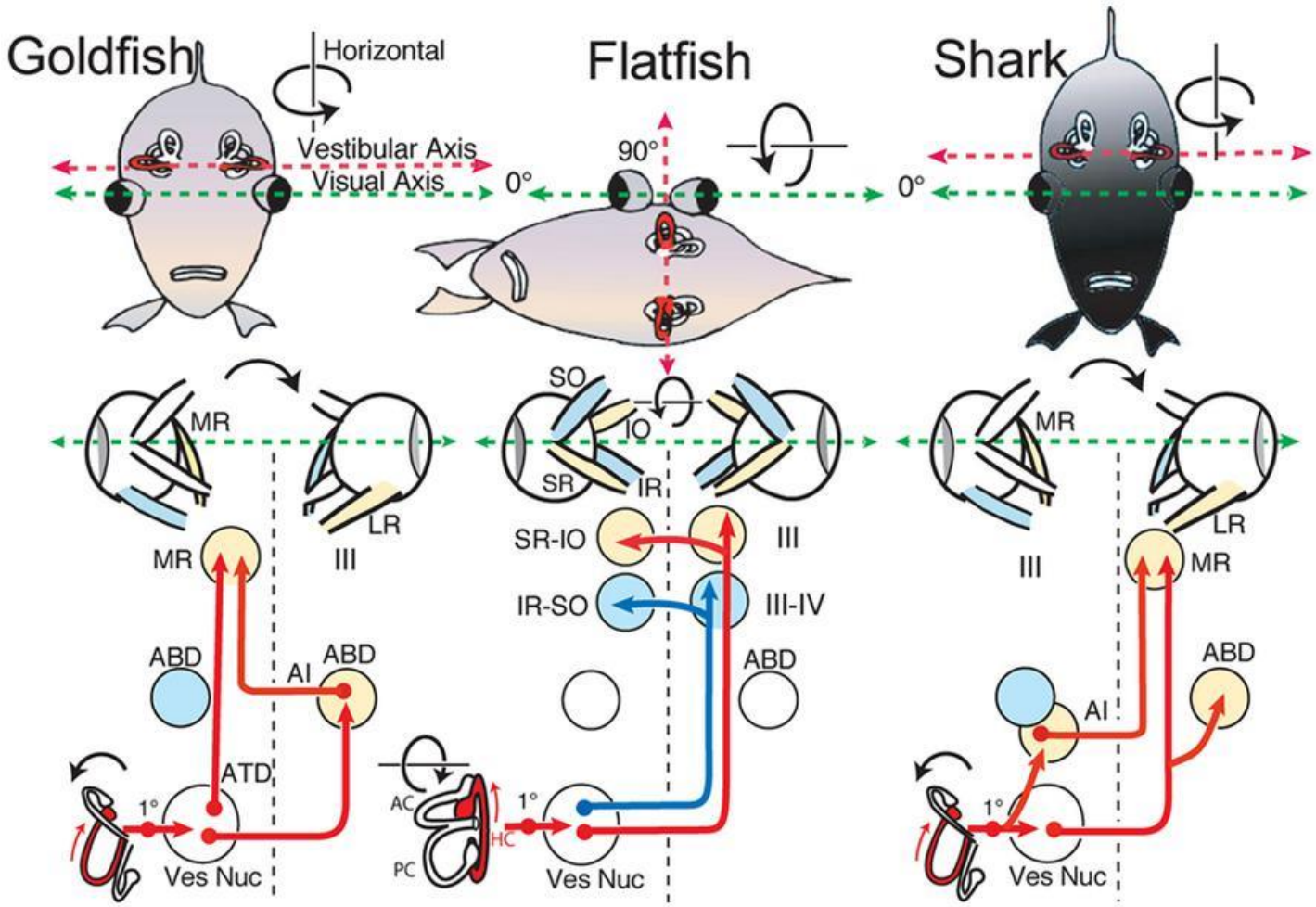




Fish



Fish



By Hans Straka and Robert Baker - [1], CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=37076540

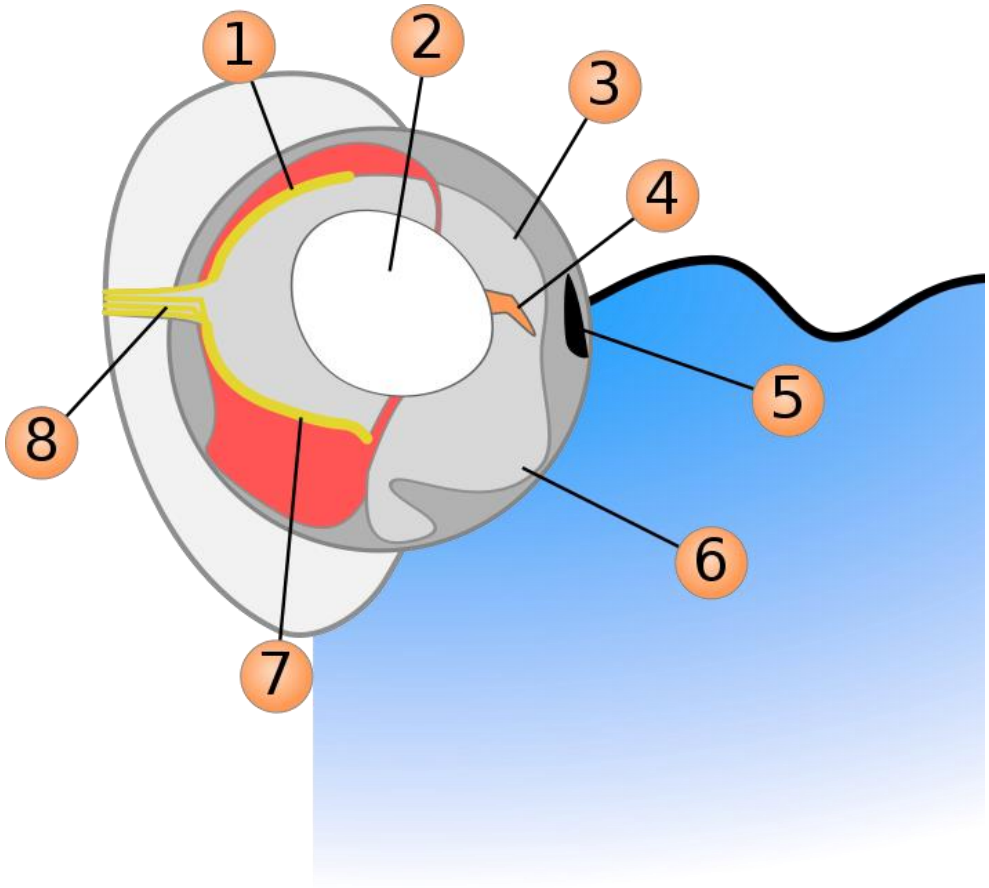
Fish

By http://www.tiermotive.de/tieralbum/4images/details.php?image_id=4929&mode=search, CC BY-SA 1.0, https://commons.wikimedia.org/w/index.php?curid=357986

Fish

Eye of a four-eyed fish

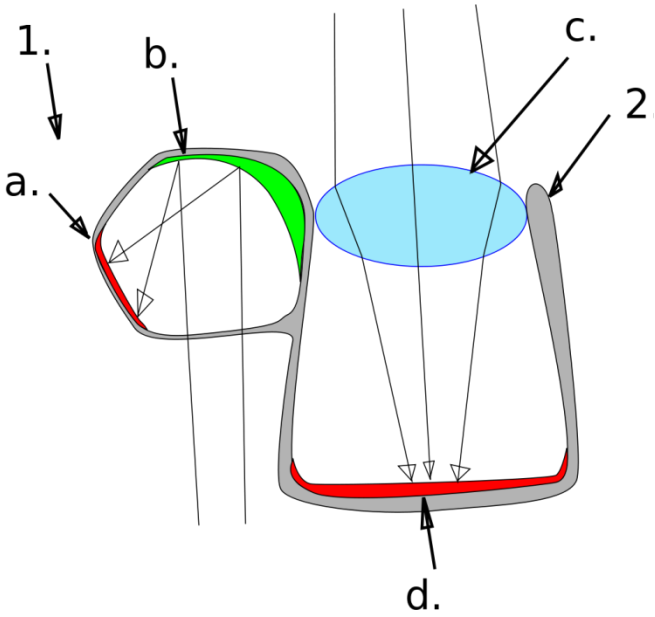
1) Underwater retina
2) Lens
3) Air pupil
4) Tissue band
5) Iris
6) Underwater pupil
7) Air retina
8) Optic nerve



Mirror eye

Dolichopteryx longipes
Brownsnout spookfish
(Strašík)

is the only vertebrate known to use a mirror in its eye.
The Barrel shaped eye
the main eye (2) which conventionally uses a lens (c) to focus light from above on the retina (d)
the secondary eye (1) uses a reflective crystal (b) to focus light from below on the secondary retina (a).



Fish

Histology of the eye of a Bluefin tuna (*Thunnus thynnus*).
equatorial diameter is ~60 mm
anterior–posterior diameter measures ~40 mm
flat eye with a large round lens
'choroidal gland' behind the macula, which is actually a plexus of blood vessels for nutrition and to provide warmth for the contents of the eye.
Histologic section by Richard Dubielzig DVM

Toad (žába)

Green_eye_of_Bufo_viridis

By Matt Reinbold - Flickr: Green, CC BY-SA 2.0,
https://commons.wikimedia.org/w/index.php?curid=20675678

Chameleon

negative
(nearsighted or concave) lens

positive
(farsighted or convex) cornea

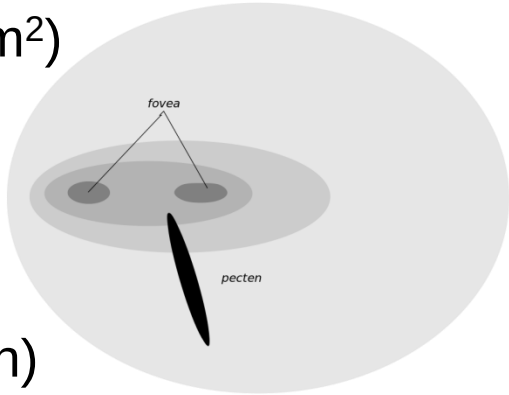
independent large motions

independent monocular focus

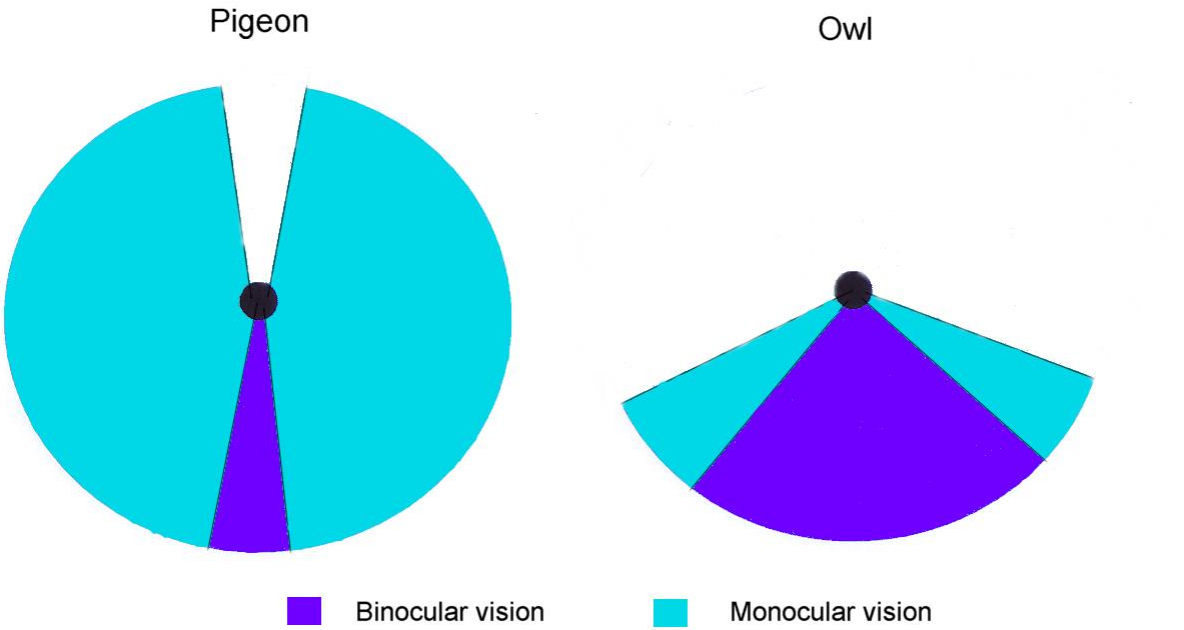
By Hans Bernhard (Schnobby) - Own work, CC BY-SA 3.0,
https://commons.wikimedia.org/w/index.php?curid=8791485

Eagle

retina - higher Nyquist limit than human
fovea - one million cells per mm^2 (humans 200,000 per mm^2)
second fovea and three eyelids (two of which are visible)
better and sharper vision
flexible head - almost 270 degrees
in flight - rabbit two miles away
diving at speeds of 125–200 miles per hour (201–322 km/h)
each eyeball moves separately
eyes - located in front of head, face forward,looking slightly askew
top eyelid - larger than bottom one
additional inner eyelid - nictitating membrane, acts a sweeping wiper
iris - pale yellow color
pecten - helps to nourish the retina, facilitates the fluids to flow through the vitreous body, absorbs light to minimize any reflections, helps perceive motion, creates a protective shade from the sun, and senses magnetic fields

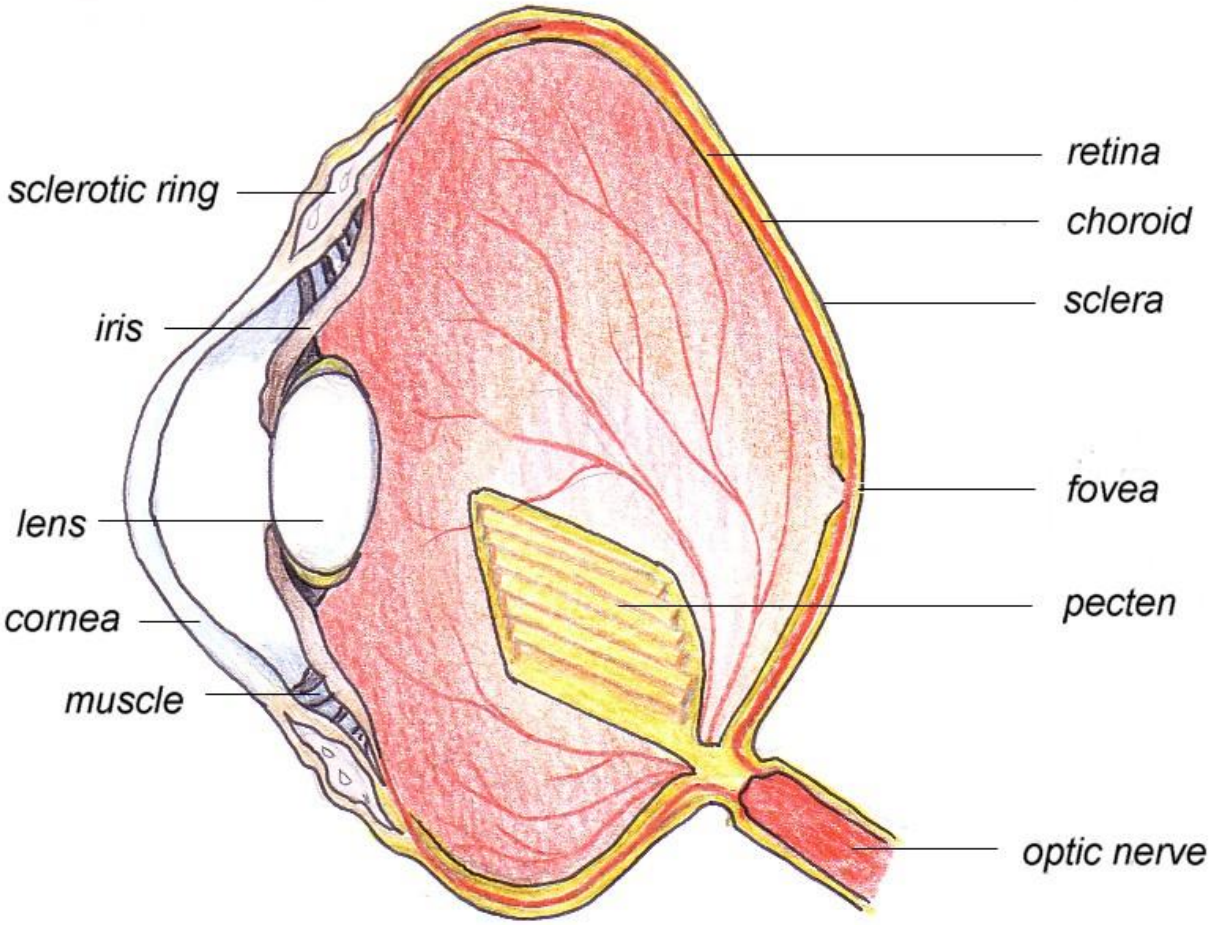


Birds



By Jimfbleak at English Wikipedia - Transferred from en.wikipedia to Commons by Jimfbleak., Public Domain, https://commons.wikimedia.org/w/index.php?curid=4464047

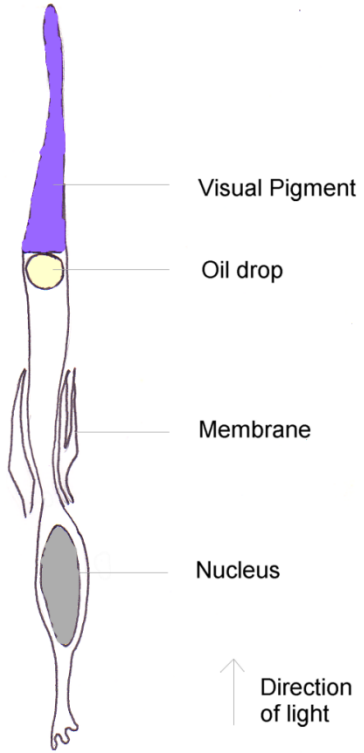
Birds



By Jimfbleak at English Wikipedia, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=4497634

Birds/reptiles

Each cone - coloured oil droplet;
Droplets - high concentrations of carotenoids,
Filters – modification of absorption spectra of the pigments, reduce the response overlap between pigments and increases the number of colours
Six types of cone oil droplets have been identified;
five of these have carotenoid mixtures
sixth type has no pigments.
UV-sensitive, possess the 'clear' or 'transparent' type of oil droplets
retinal oil droplets vary considerably among species,
dependent on the ecological niche utilised (hunter, fisher, herbivore)
oil droplets respond to natural selection faster than the cone's visual pigments

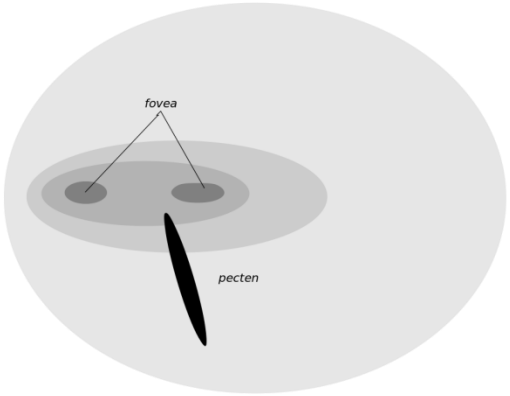


Even within the range of wavelengths that are visible to humans birds can detect colour differences that humans do not register.
This finer discrimination, together with the ability to see ultraviolet light, means that many species show sexual dichromatism that is visible to birds but not humans

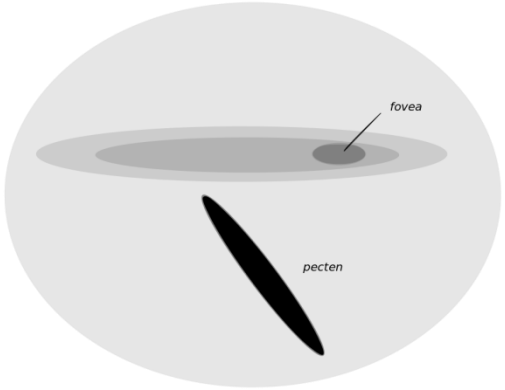
https://en.wikipedia.org/wiki/Bird_vision

By Jimfbleak - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=4454798

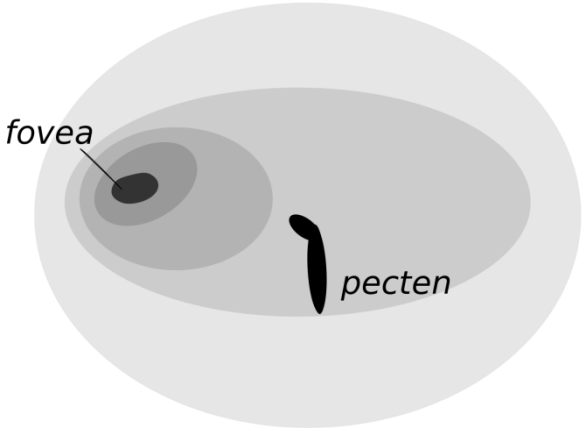
Birds



Owl
sova



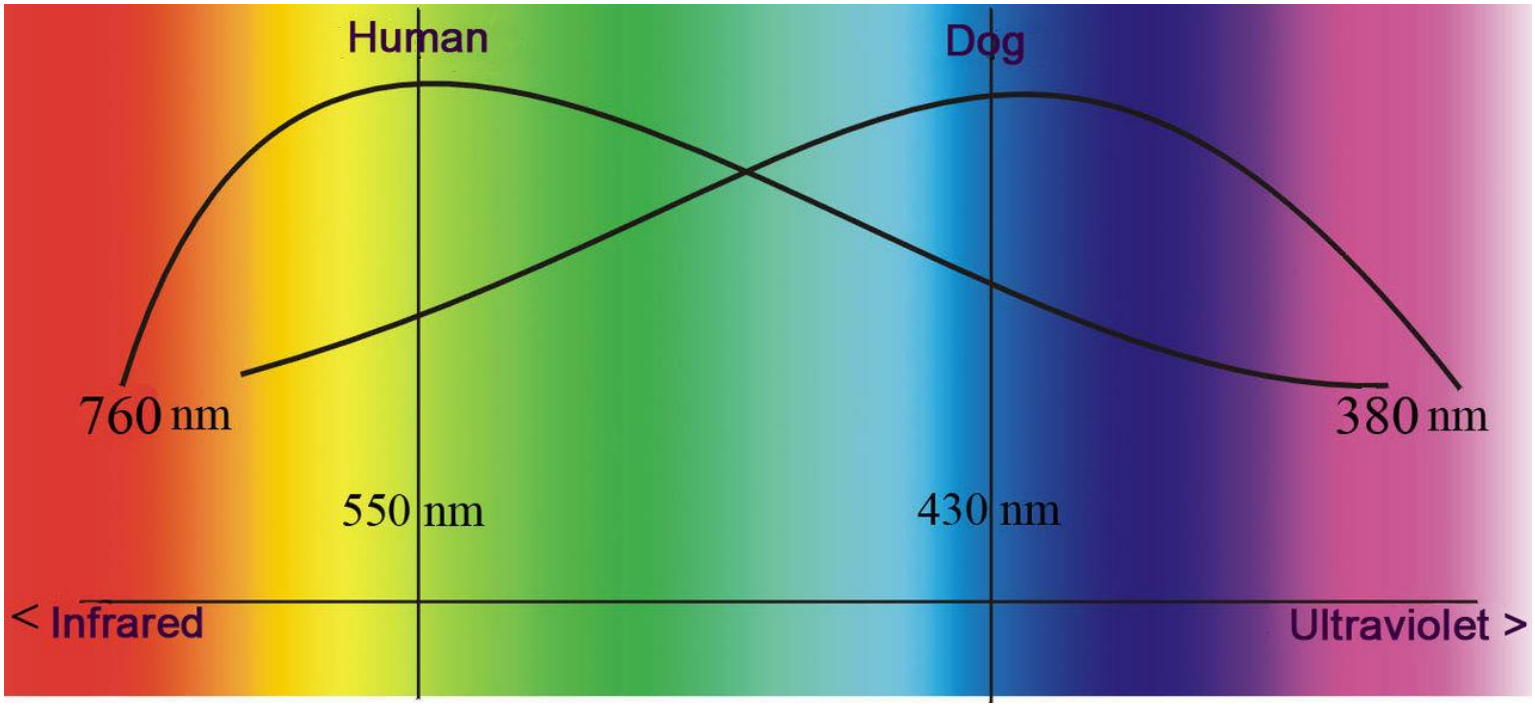
Eagle
orel



Manx shearwater
Buřňák severní

By Jimfbleak - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=4435985

Dog



very large pupils
high density of rods in the fovea,
increased flicker rate
tapetum lucidum

By Steffen Heinz (caronna) - Own work, CC BY-SA 2.5, https://commons.wikimedia.org/w/index.php?curid=1437788

Cat

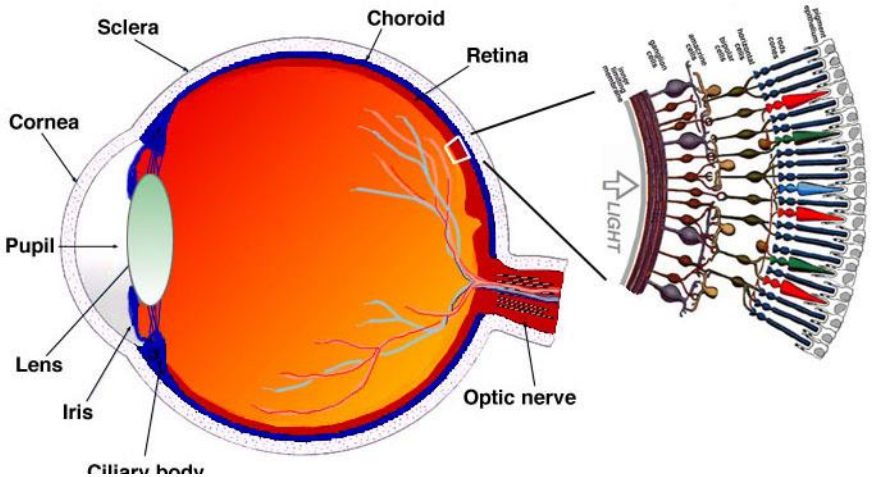
By Zakabog - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=10707385

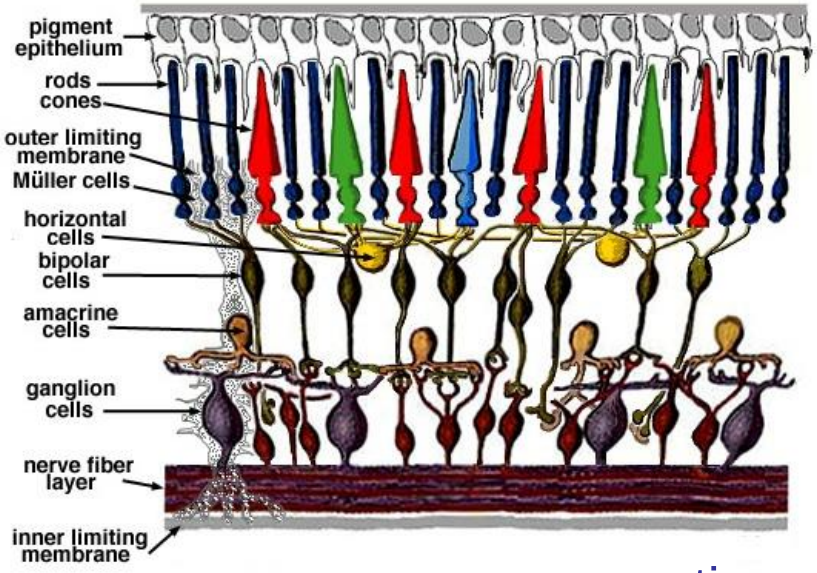
By Sepple - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=1156893

tapetum lucidum

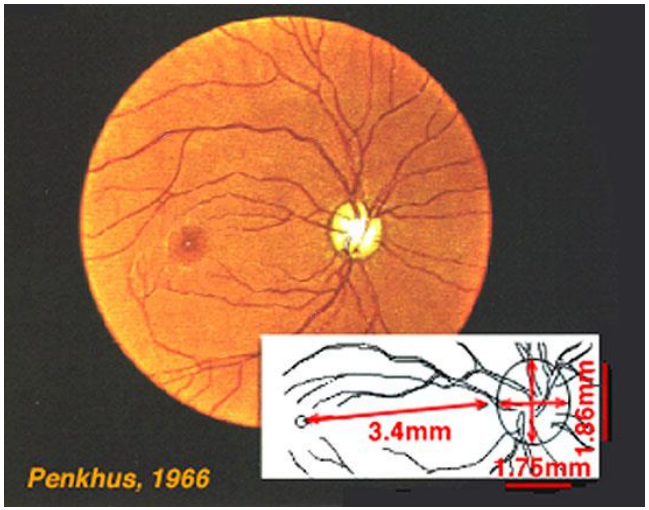
third eyelid - nictitating membrane

Humans



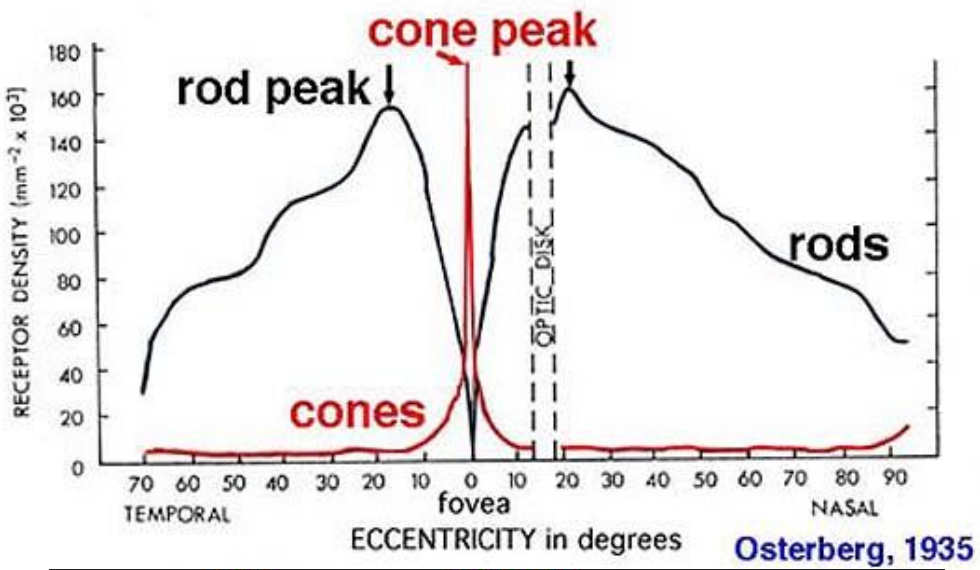


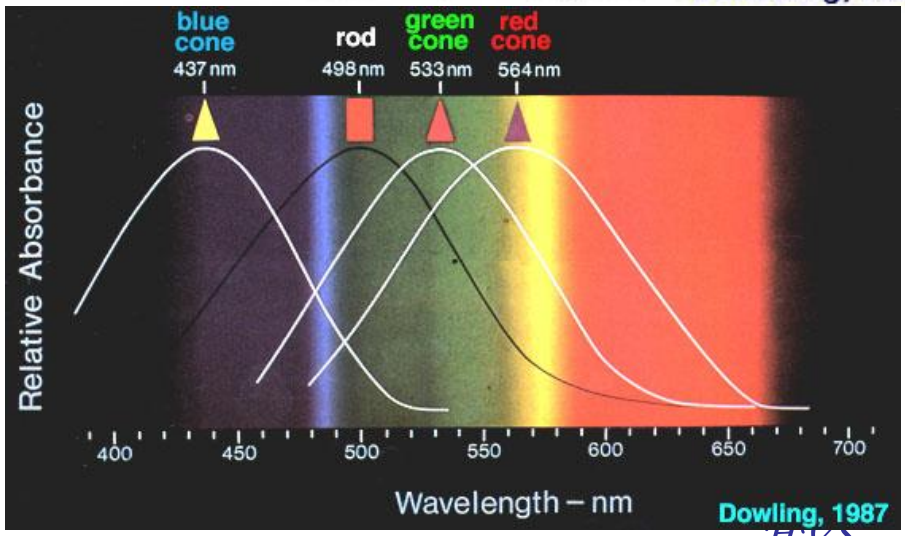
retina



Webvision: webvision.med.utah.edu)

Humans





Distribution density

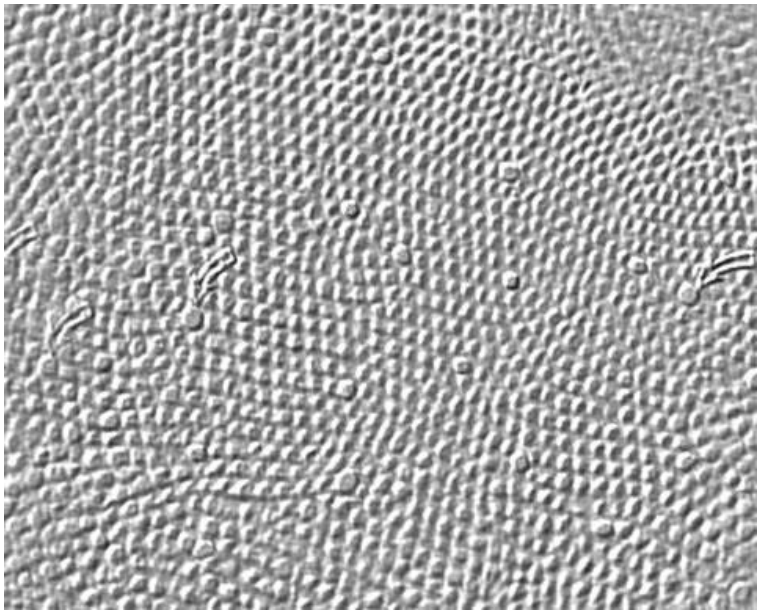
L,M – 2,5 μm / 60c/deg

S – 50 μm / 3c/deg

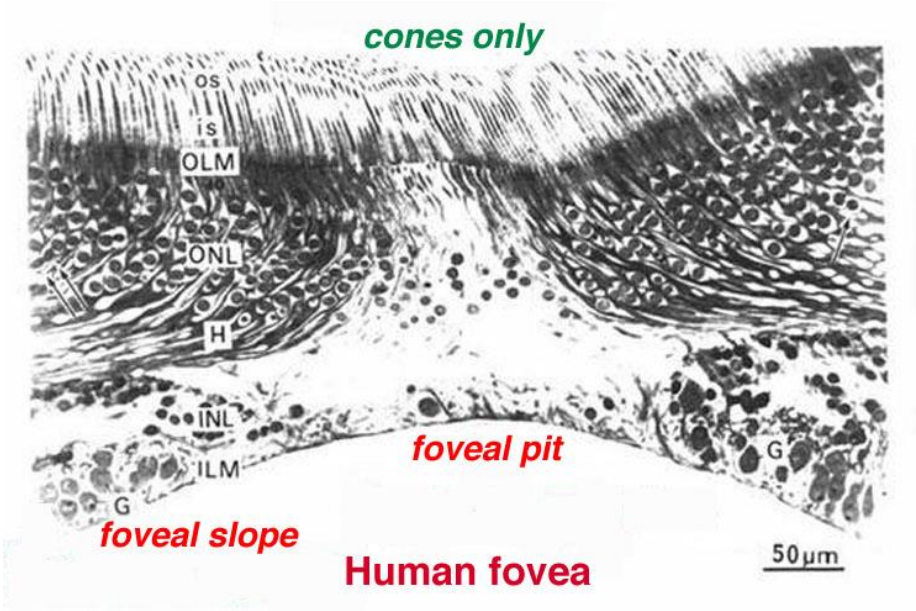
R G B – Y RG BYe

Spectral sensitivity

Humans

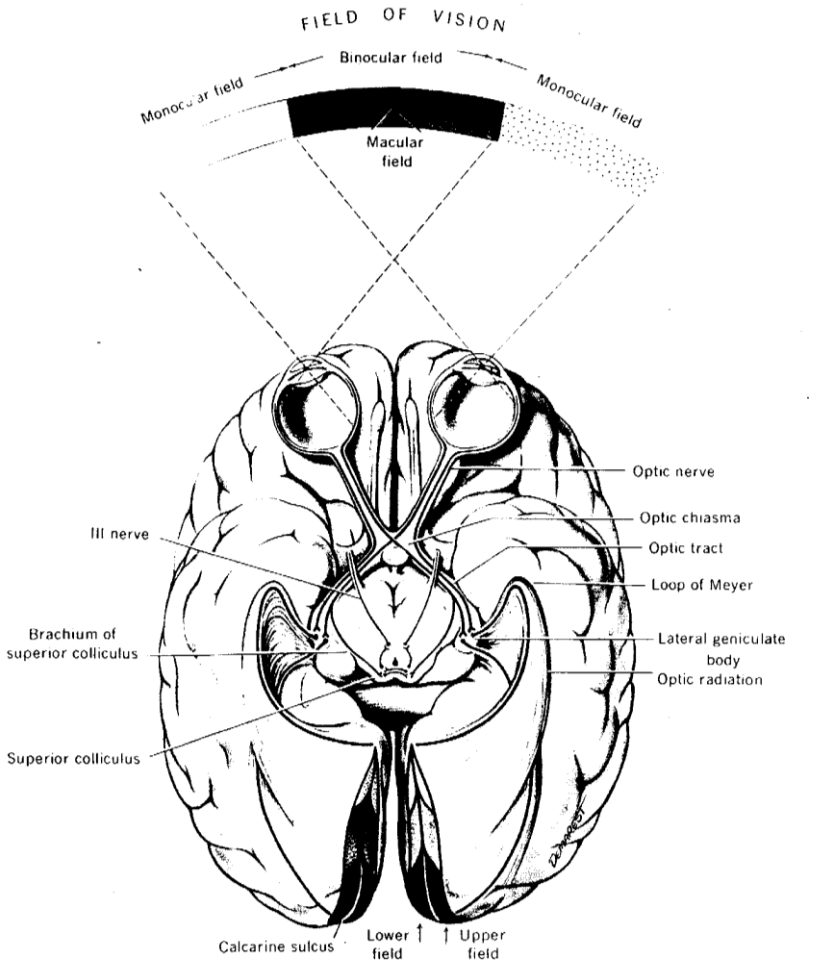


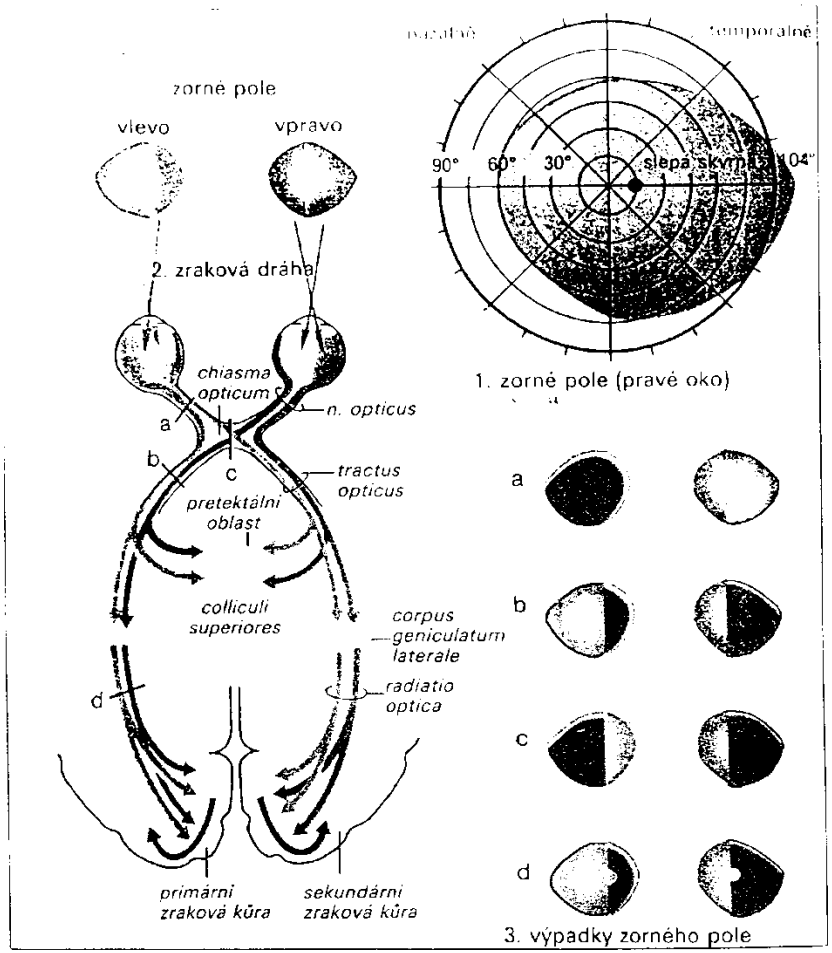
Retina structure



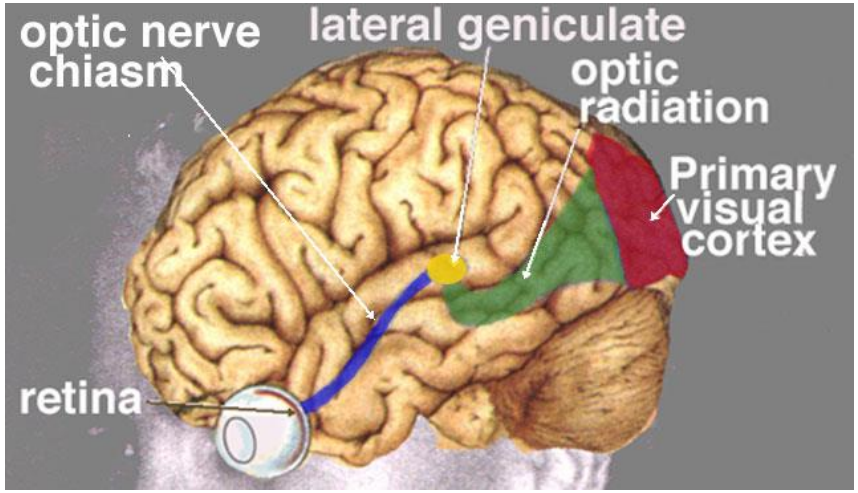
Cut - fovea

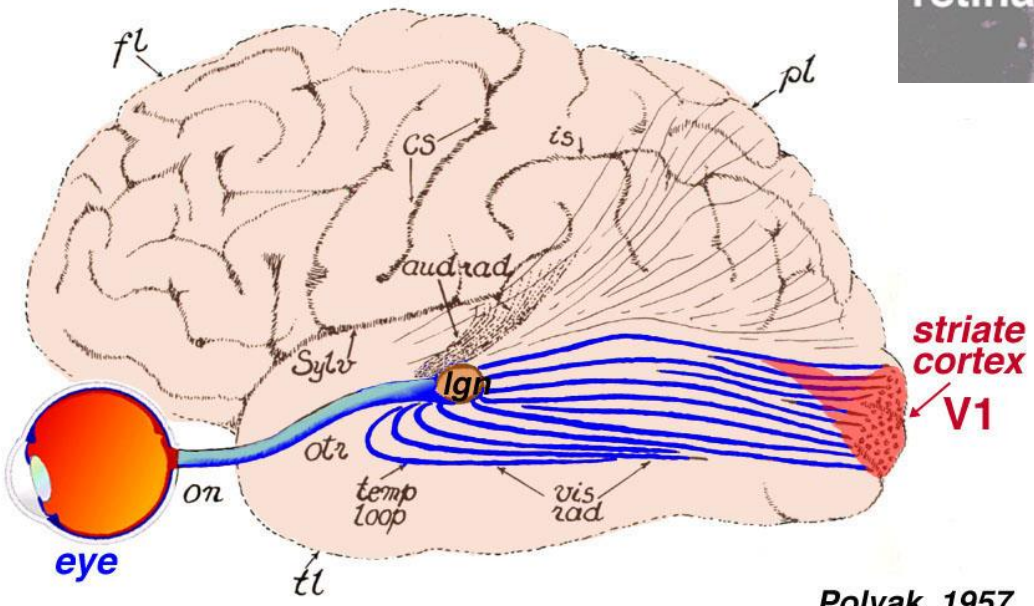
Humans


FIELD OF VISION
Binocular field
Monocular field
Monocular field
Macular field
Optic nerve
Optic chiasma
Optic tract
Loop of Meyer
Lateral geniculate body
Optic radiation
III nerve
Brachium of superior colliculus
Superior colliculus
Calcarine sulcus
Lower field
Upper field


zorné pole
vlevo
vpravo
2. zraková dráha
chiasma opticum
n. opticus
a
b
c
tractus opticus
pretektální oblast
colliculi superiores
corpus geniculatum laterale
radiatio optica
d
primární zraková kůra
sekundární zraková kůra
90°
60°
30°
slepá skvrna
104°
1. zorné pole (pravé oko)
a
b
c
d
3. výpadky zorného pole

Humans

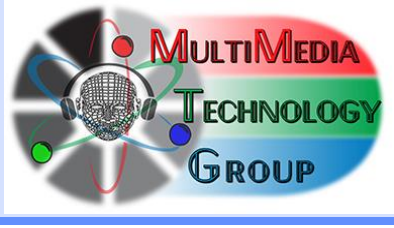




Polyak, 1957

References

- https://cs.wikipedia.org/wiki/
- https://en.wikipedia.org/wiki/
- https://www.wikiskripta.eu/w/Home
- Nick Lane, Vývoj života: Deset velkých vynálezů evoluce, Kap.7: Zrak pp 207 – 244, ISBN 978-80-7473-009-2, Kniha Zlín
- Nick Lane, Life Ascending: The ten great inventions of Evolution, ISBN-10:0393338665, Norton 2009


MULTIMEDIA
TECHNOLOGY
GROUP