

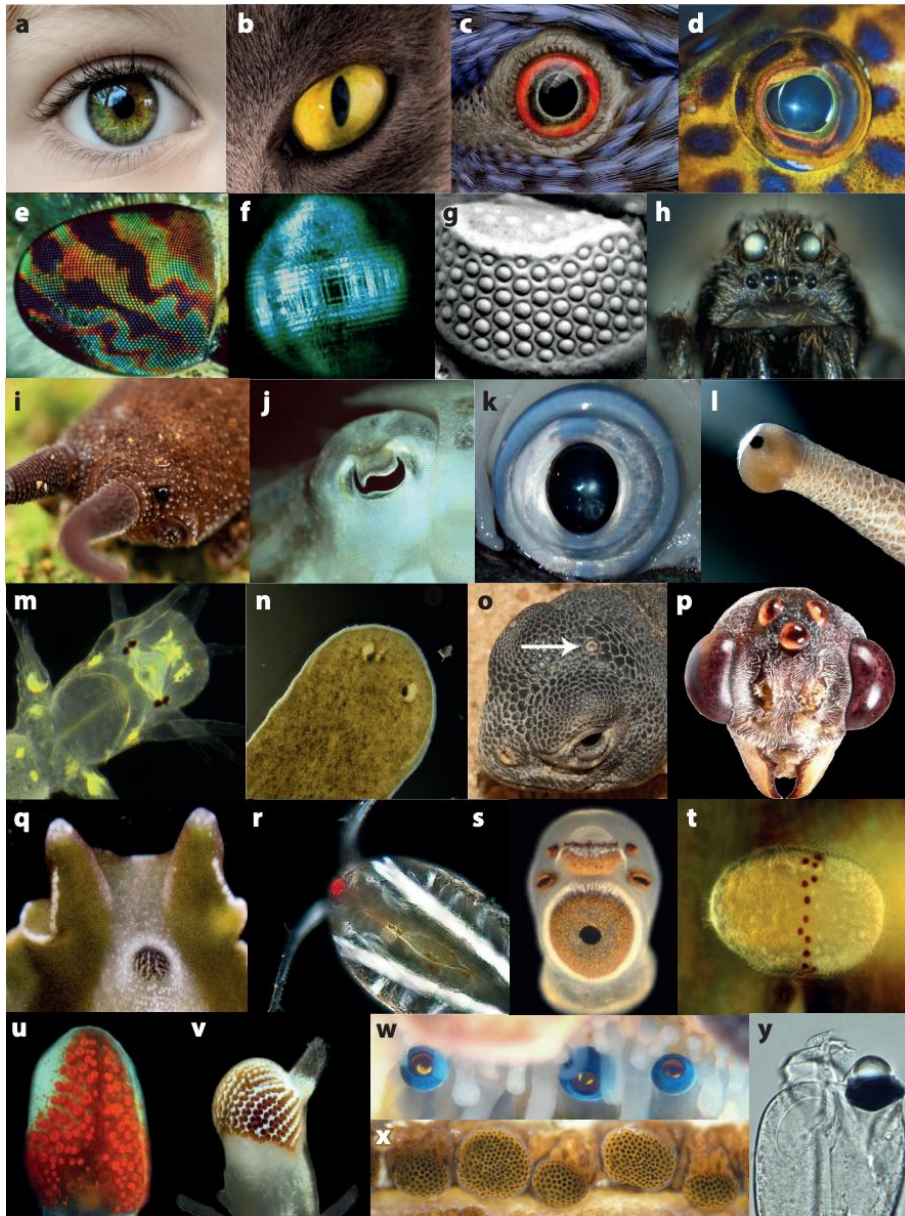
Beyond Rods and Cones:

From Rod Color Vision Hypothesis to Hybrid Photoreceptors in Deep-Sea Fishes

Xinyu Zhang

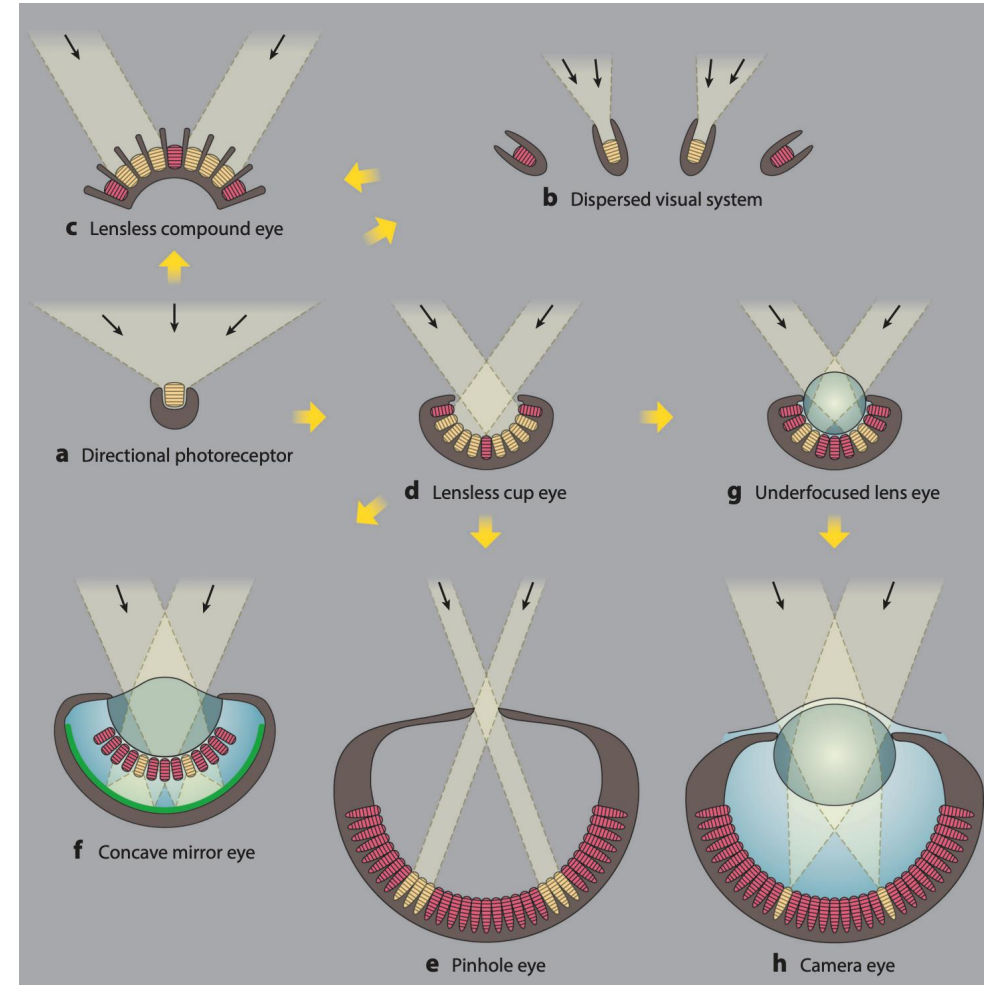
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Diversity of Animal Vision

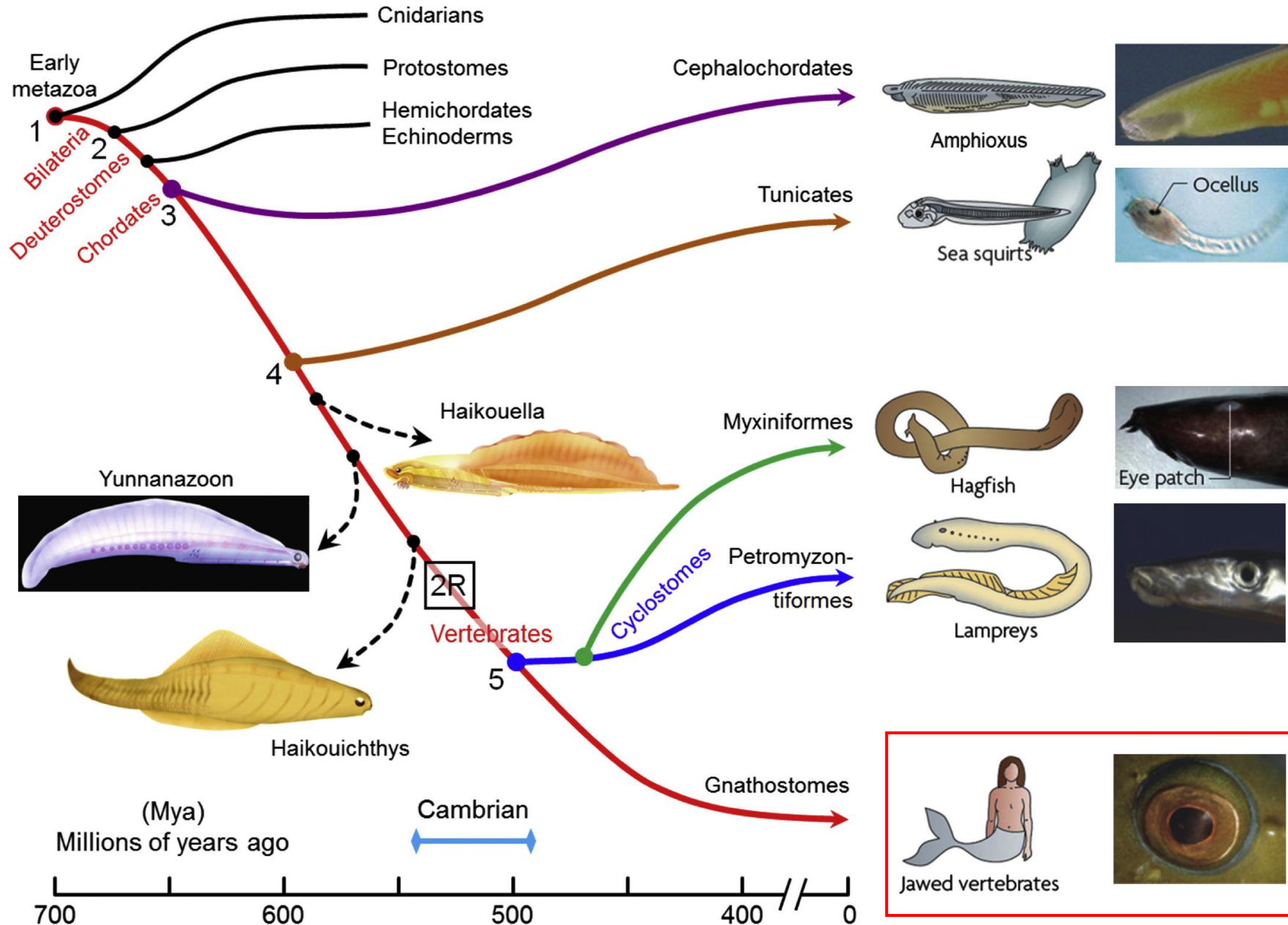


Vision evolved repeatedly

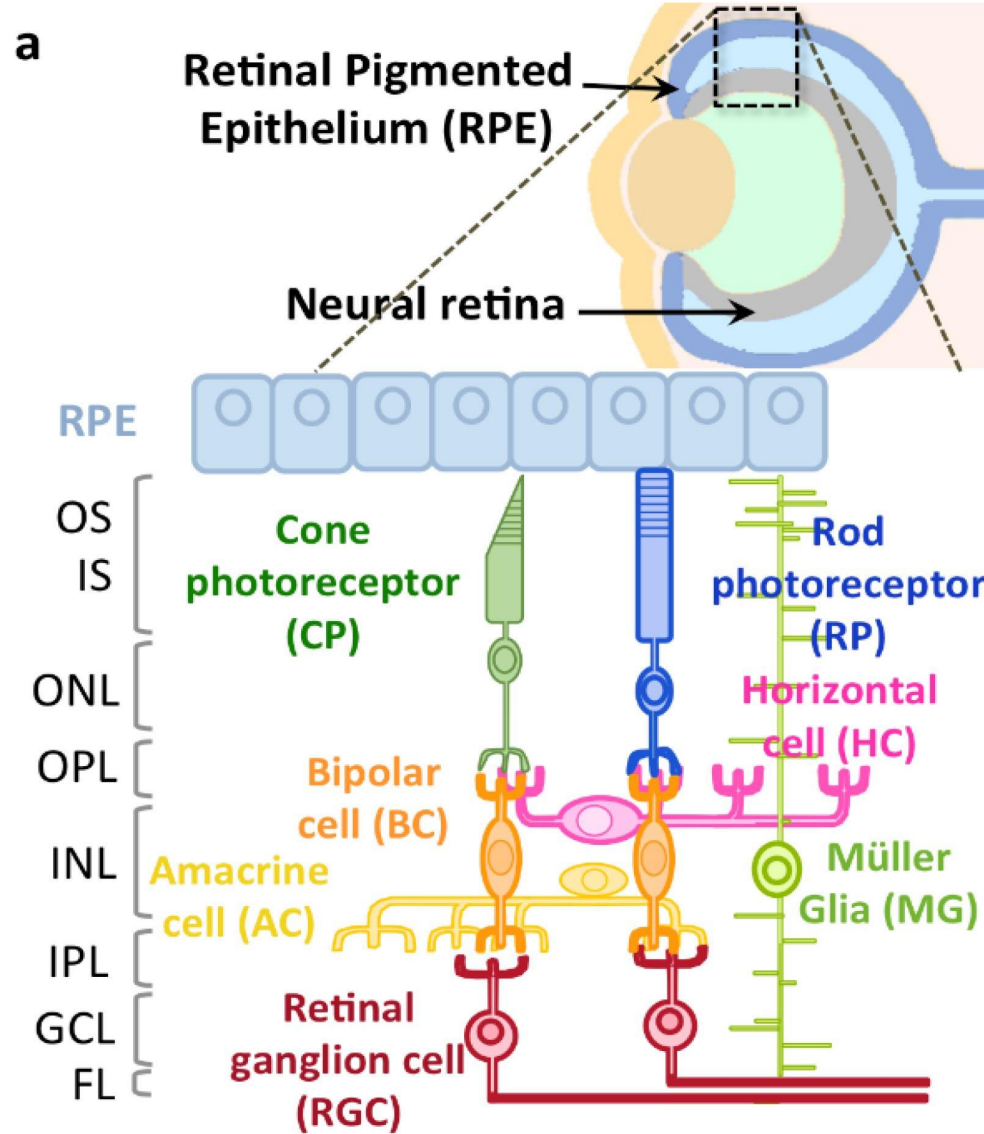
- Diverse eye morphologies
- Diverse image-forming systems
- Shared molecular foundations



Evolution of Animal Visual Systems



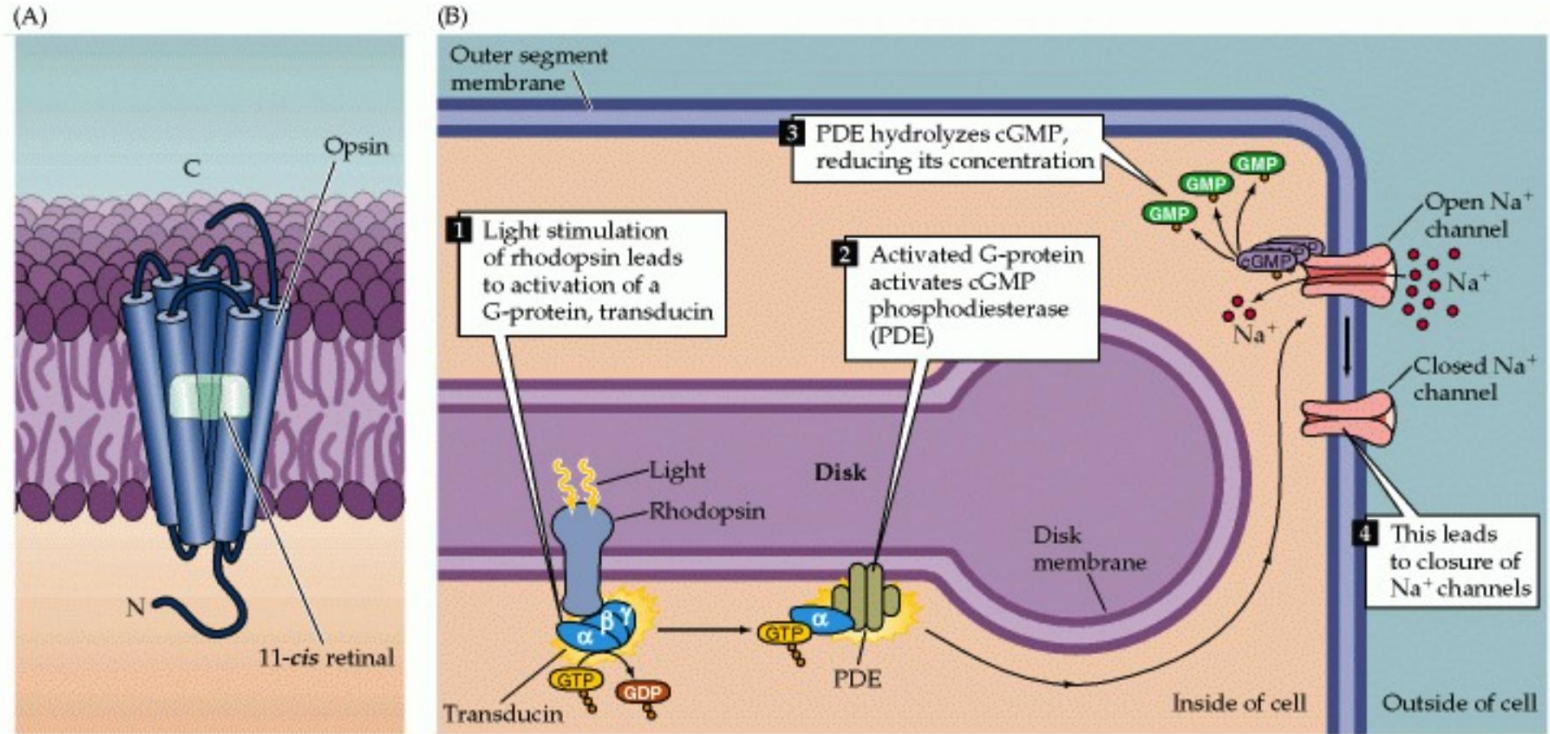
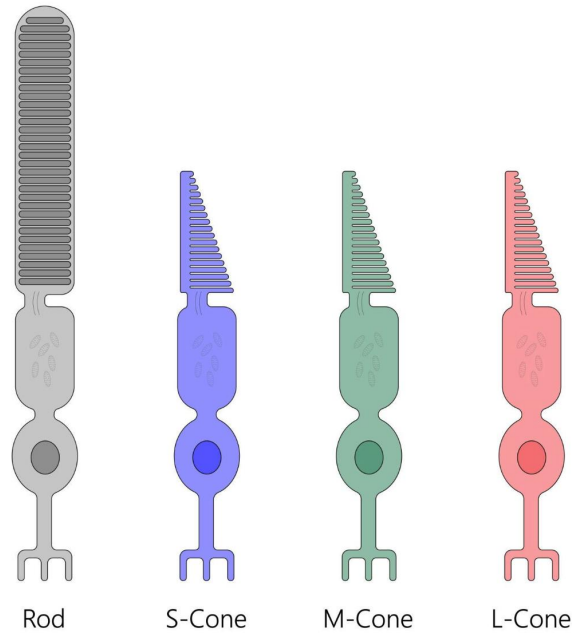
The Vertebrate Retina



Major retinal cell types

- Rods
- Cones
- Bipolar cells
- Horizontal cells
- Amacrine cells
- Retinal ganglion cells

Five Ancestral Photoreceptors



Cell type	Opsin	λ max
Rod	RH1	~500 nm
S-Cone	SWS1	~415 nm
S-Cone	SWS2	~455 nm
M-Cone	RH2	~508 nm
L-Cone	LWS	~570 nm

Multiple cone opsins → color vision

Single RH1 → brightness vision

The deep sea as an extreme visual environment

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REPORT



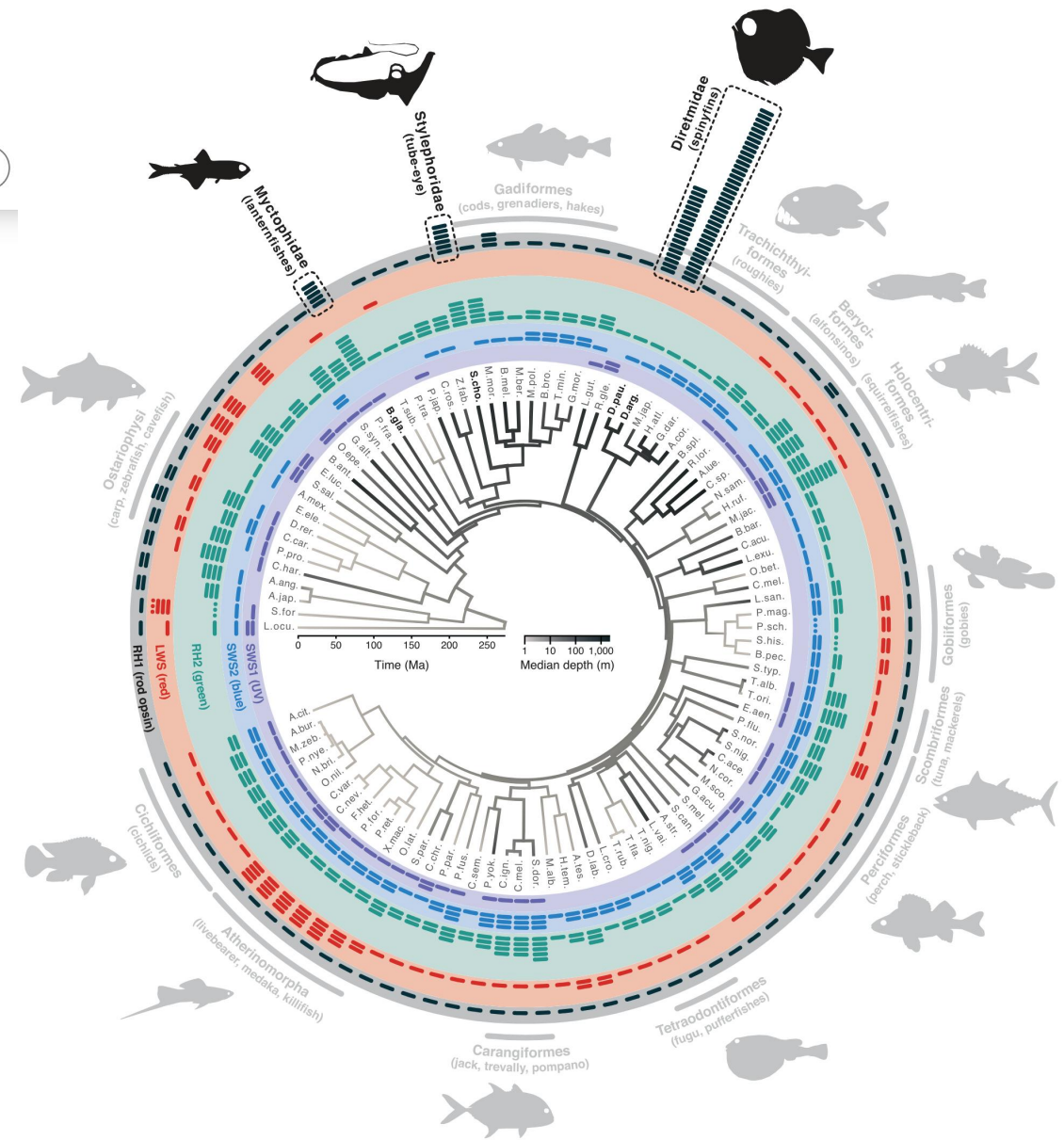
Vision using multiple distinct rod opsins in deep-sea fishes

ZUZANA MUSILOVA [ID](#), FABIO CORTESI [ID](#), MICHAEL MATSCHINER, WAYNE I. L. DAVIES, JAGDISH SURESH PATEL [ID](#), SARA M. STIEB [ID](#), FANNY DE BUSSEROLLES [ID](#), MARTIN MALMSTRÖM [ID](#), OLE K. TØRRESEN [ID](#), CELESTE J. BROWN [ID](#), JESSICA K. MOUNTFORD [ID](#), REINHOLD HANEL, DEBORAH L. STENKAMP [ID](#), KJETILL S. JAKOBSEN [ID](#), KAREN L. CARLETON [ID](#), SISSEL JENTOFT [ID](#), JUSTIN MARSHALL [ID](#), AND WALTER SALZBURGER [ID](#) [fewer](#) [Authors Info & Affiliations](#)

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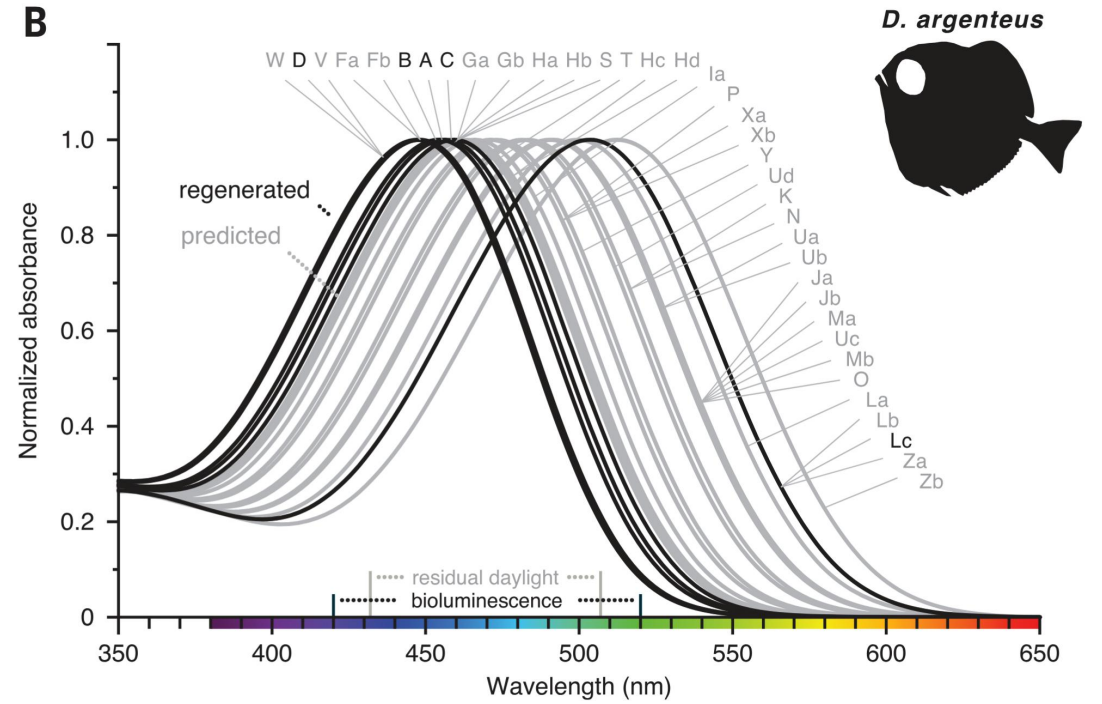
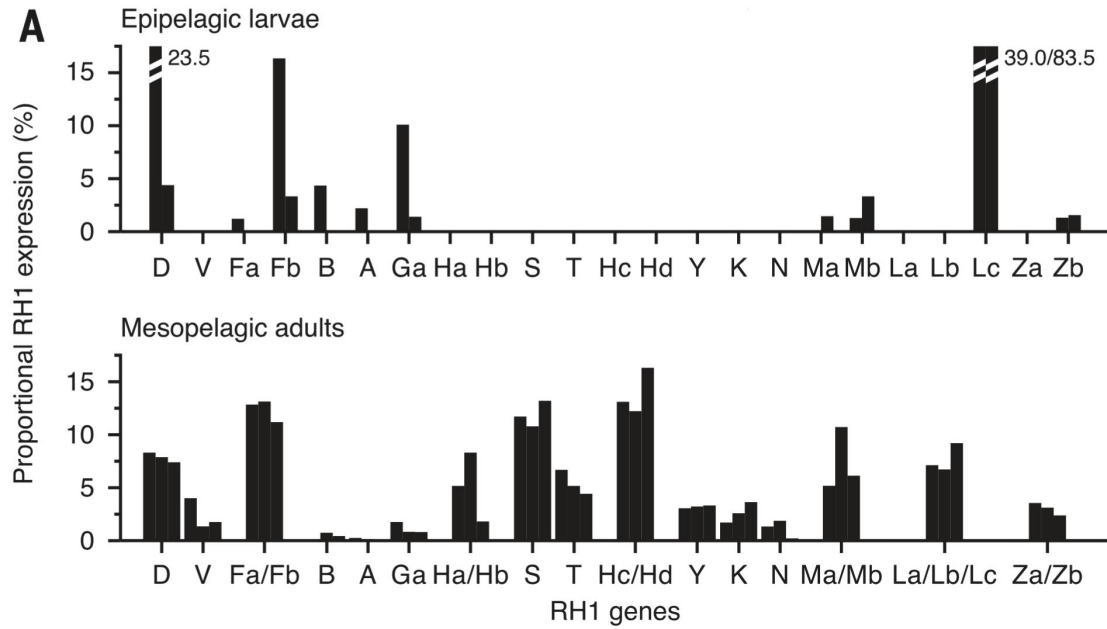


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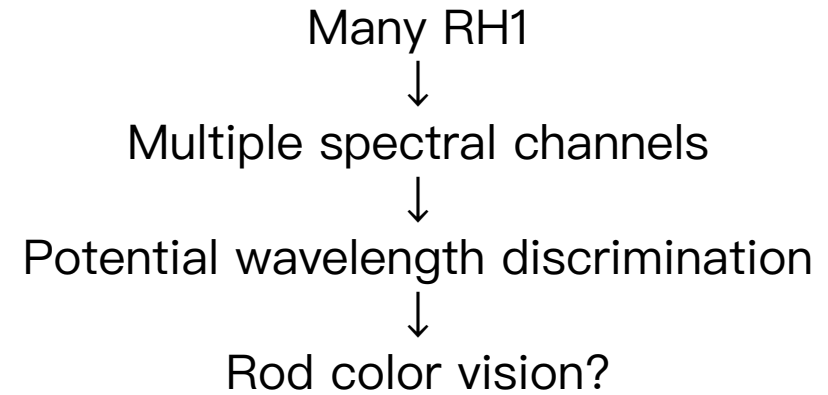
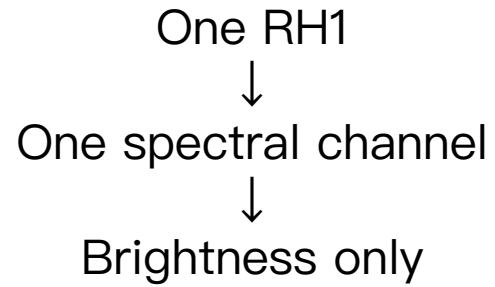
Deep-sea fishes possess unprecedented numbers of RH1 genes

Massive RH1 Expansion

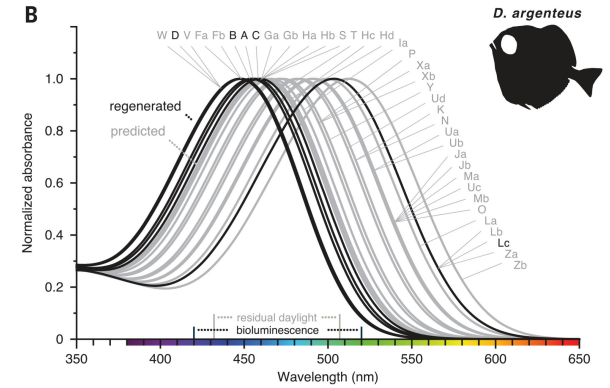
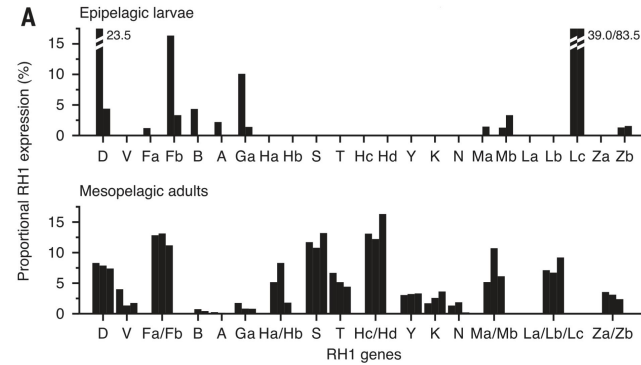
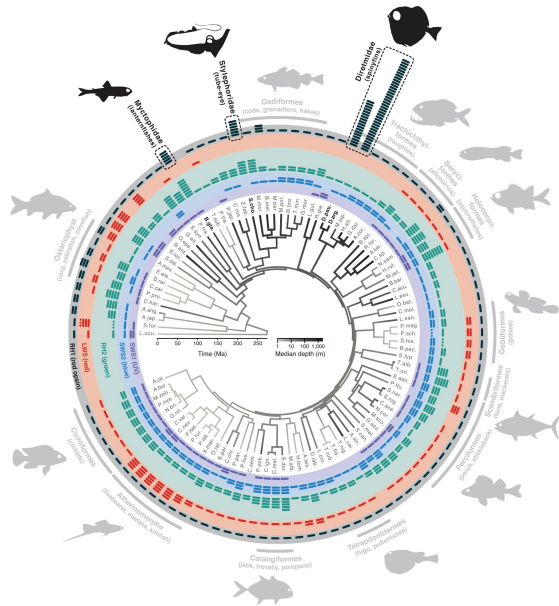


Multiple RH1 genes are expressed and spectrally distinct

The Rod Color Vision Hypothesis



An Incomplete Hypothesis



What remains unknown?

What was demonstrated?

- ☑ Multiple RH1 genes
- ☑ Retinal expression
- ☑ Spectral diversity

Functional

- Is color vision actually achieved?
- Is there opponent processing?
- Is there behavioral evidence?

Cellular

- Which cells express these RH1 variants?
- Are they canonical rods?
- How should a rod be defined?

Alternative developmental trajectories in deep-sea fishes

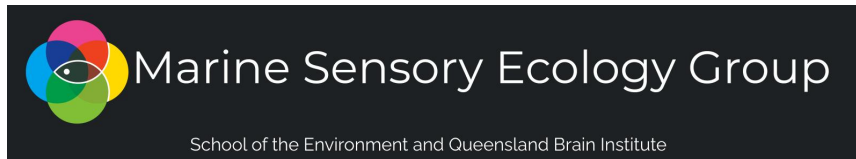


Deep-sea fish reveal an alternative developmental trajectory for vertebrate vision

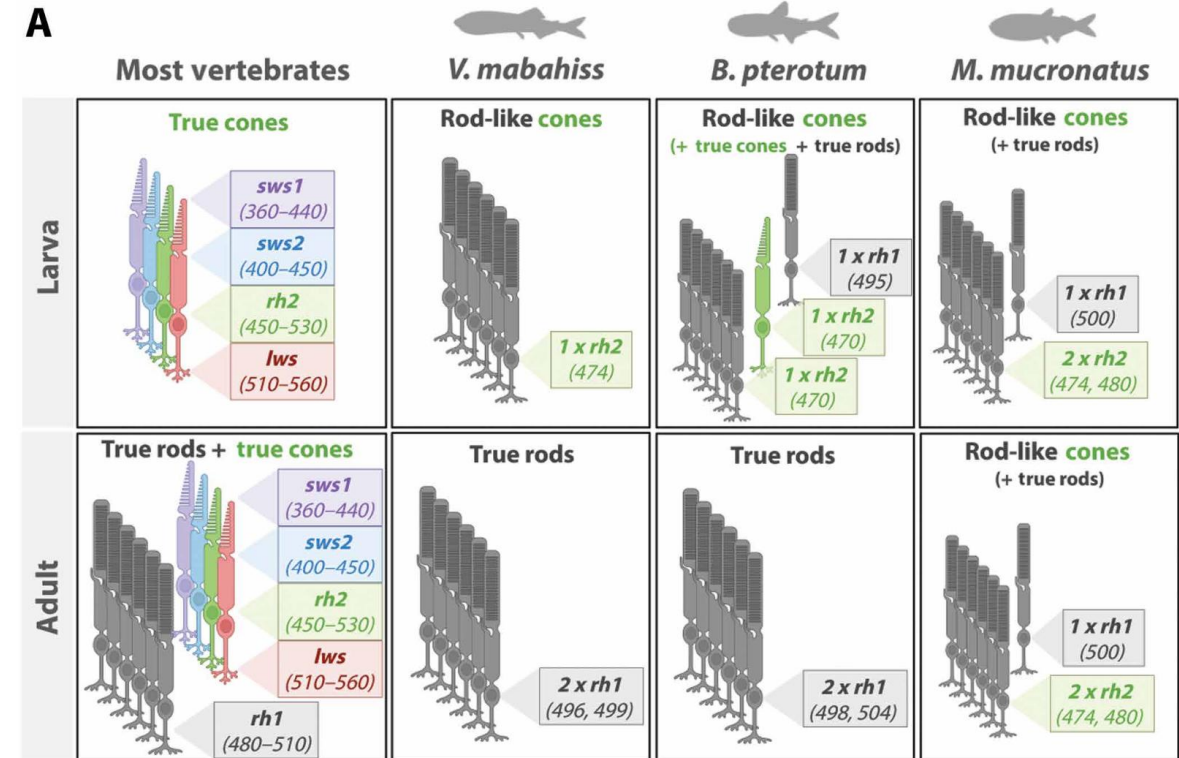
LILY G. FOGG, STAMATINA ISARI, JONATHAN E. BARNES, JAGDISH SURESH PATEL, N. MARSHALL, WALTER SALZBURGER, FANNY DE BUSSEROLLES, AND FABIO CORTESI

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Deep-sea fishes

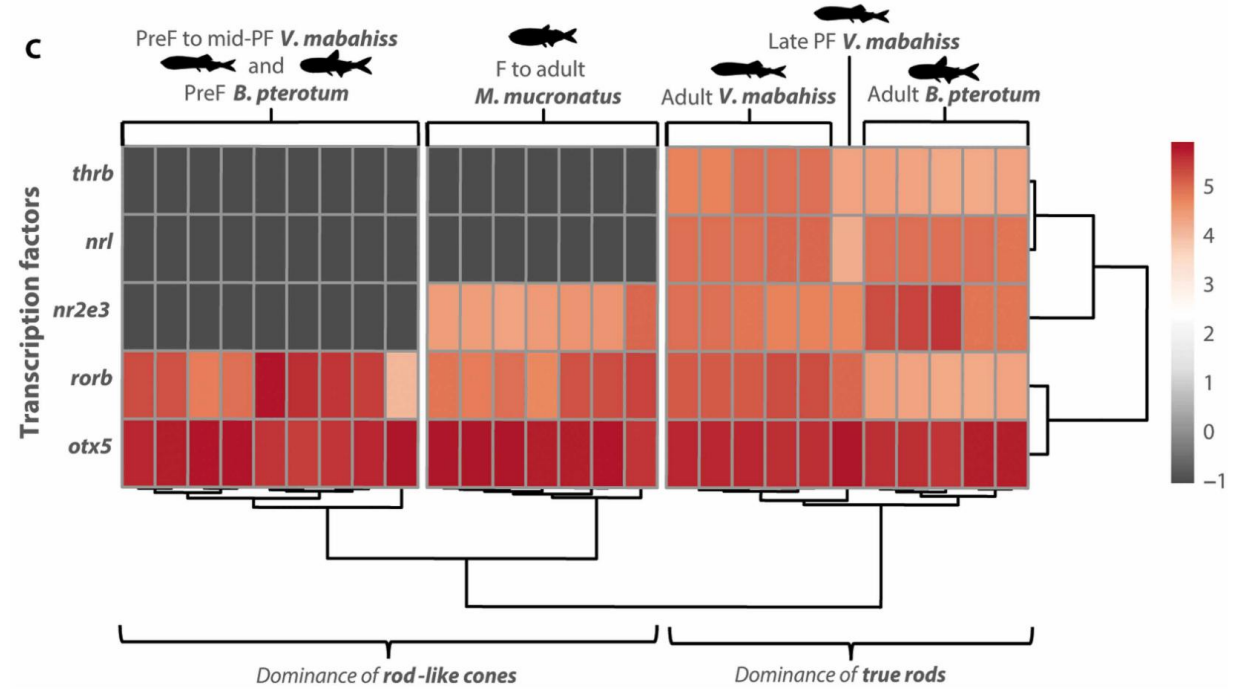
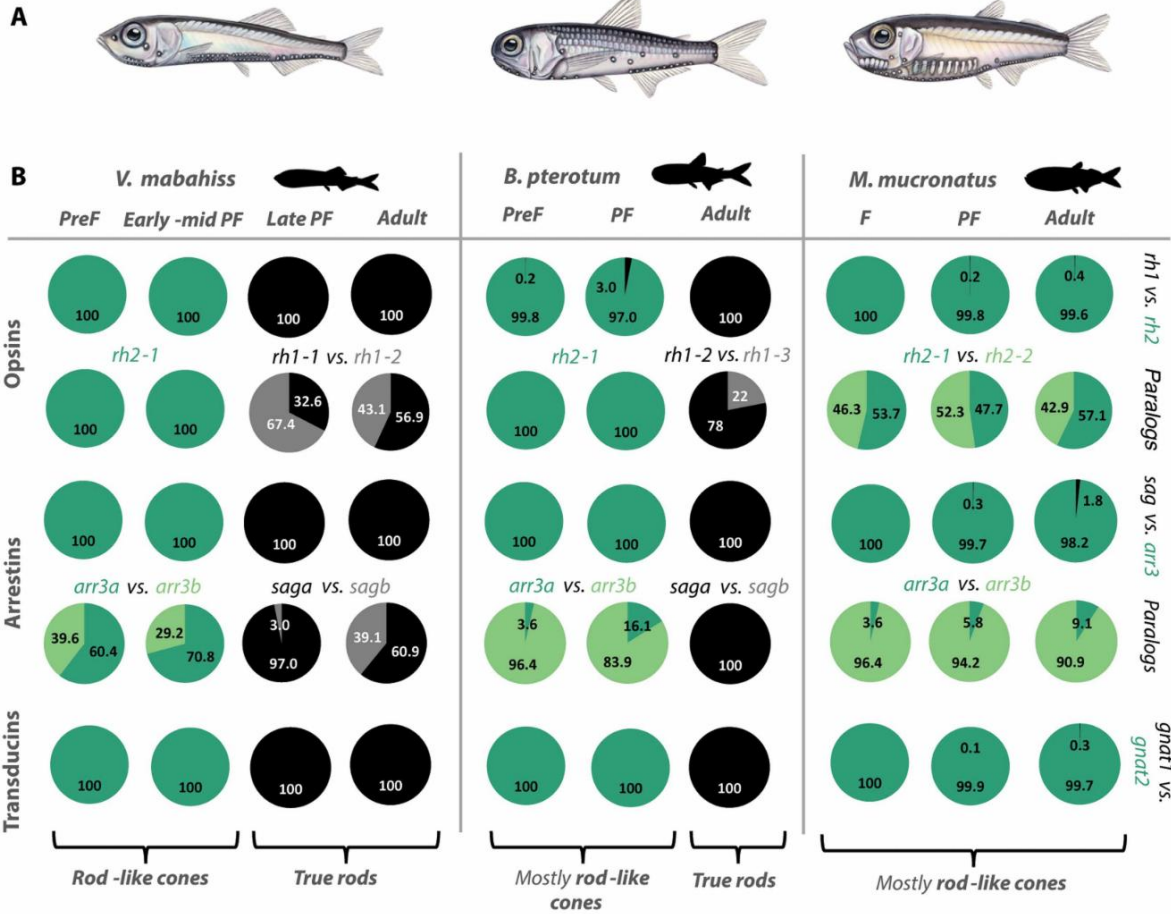
Alternative developmental trajectory



Rod-like cone retina

Evidence for Hybrid Photoreceptors

PreF, preflexion; F, flexion; PF, postflexion.



Rod morphology, cone molecular identity

Take-Home Messages

2019:
Can rods see color?
↓
2025:
What is a rod?

Traditional expectation

Deep sea
↓
Relaxed selection
↓
Opsin loss
↓
Visual degeneration

Emerging picture

Deep sea
↓
Novel selection pressures
↓
RH1 expansion
↓
Developmental remodeling
↓
New visual strategies

1. Deep-sea fishes challenge the classical rod/cone paradigm
2. Multiple RH1 genes suggest potential rod-based spectral discrimination
3. Hybrid photoreceptors reveal developmental flexibility
4. Photoreceptor identity remains an open evolutionary question

The deep sea does not simply erase vision. It may reinvent it.

Science Is Never Finished



Every answer creates new questions.