Visual System

Eye with Retina

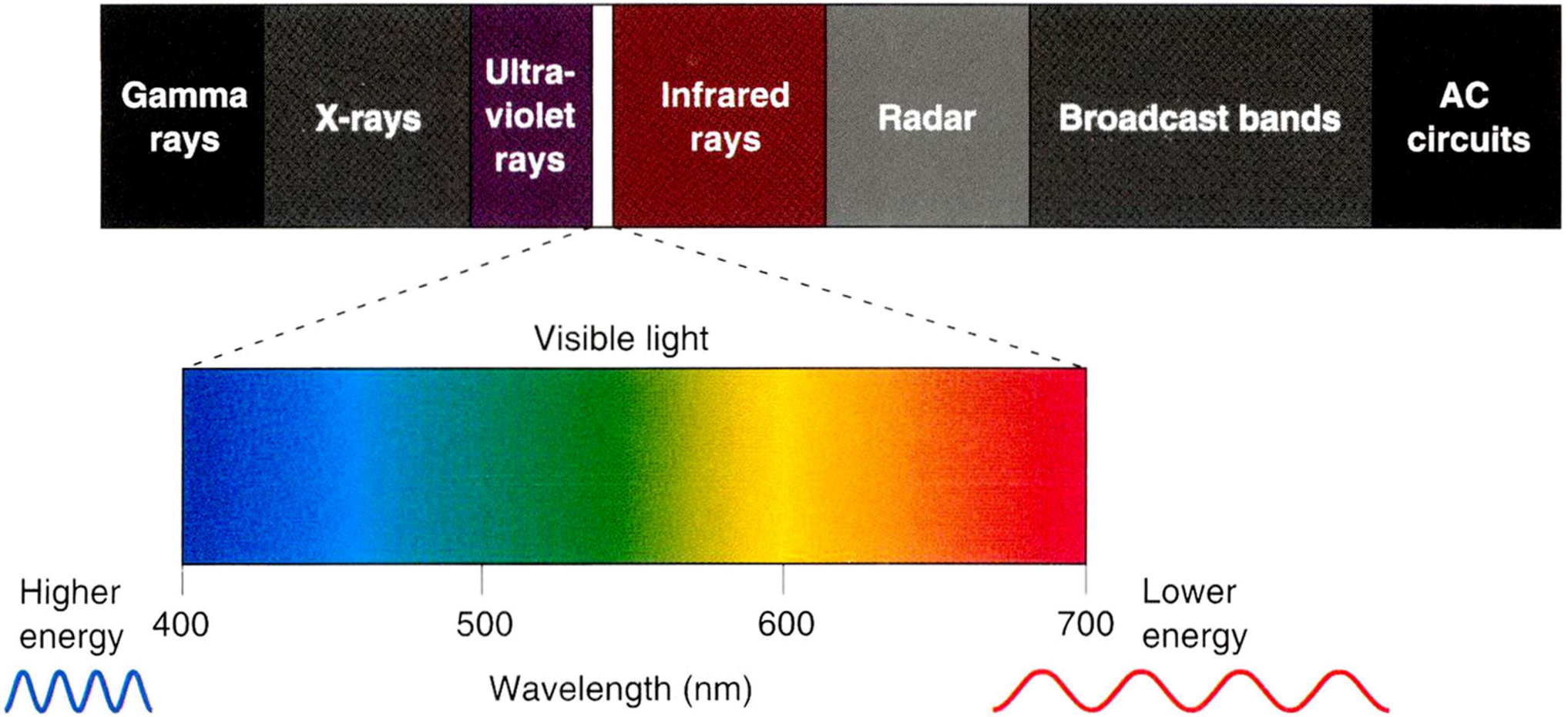
Retinofugal Projection
(Optic Nerve, Optic Chiasm, Optic Tract)

Lateral Geniculate Nucleus

Striate Cortex

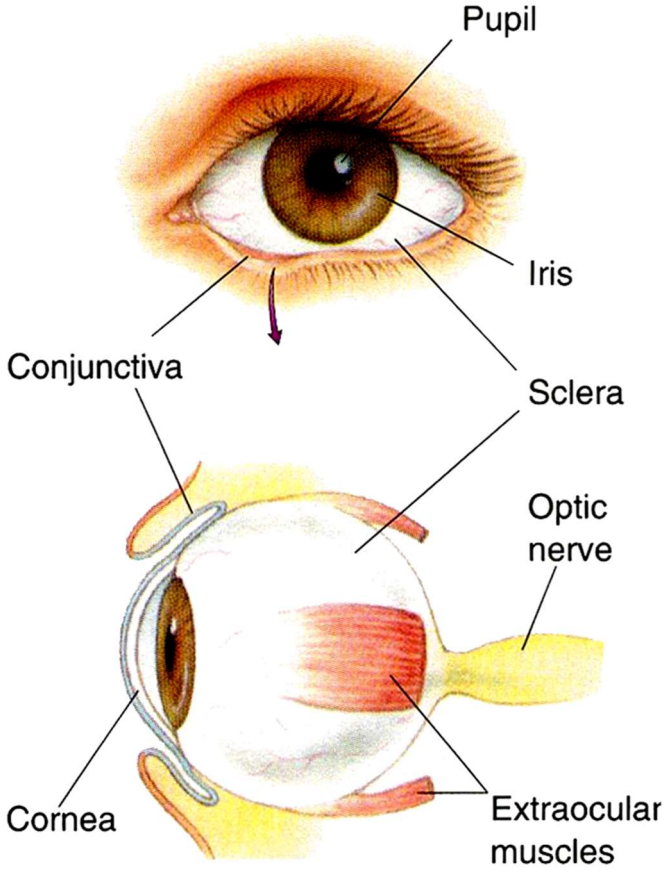
Extrastriate Cortex
(Dorsal Stream, Ventral Stream)

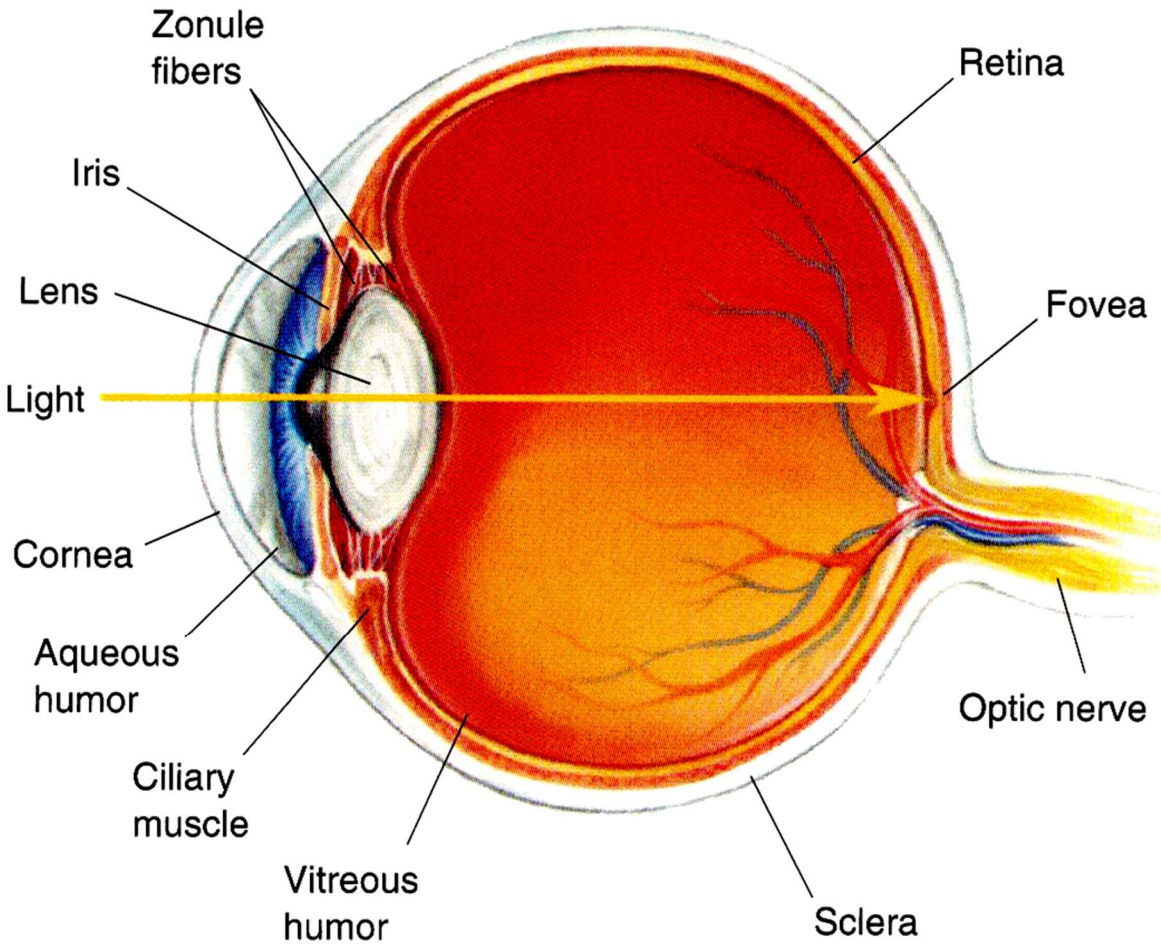
Electromagnetic Spectrum



Only Electromagnetic Radiation with Wavelengths of 400 – 700 nm is Visible to the Naked Human Eye

The Eye





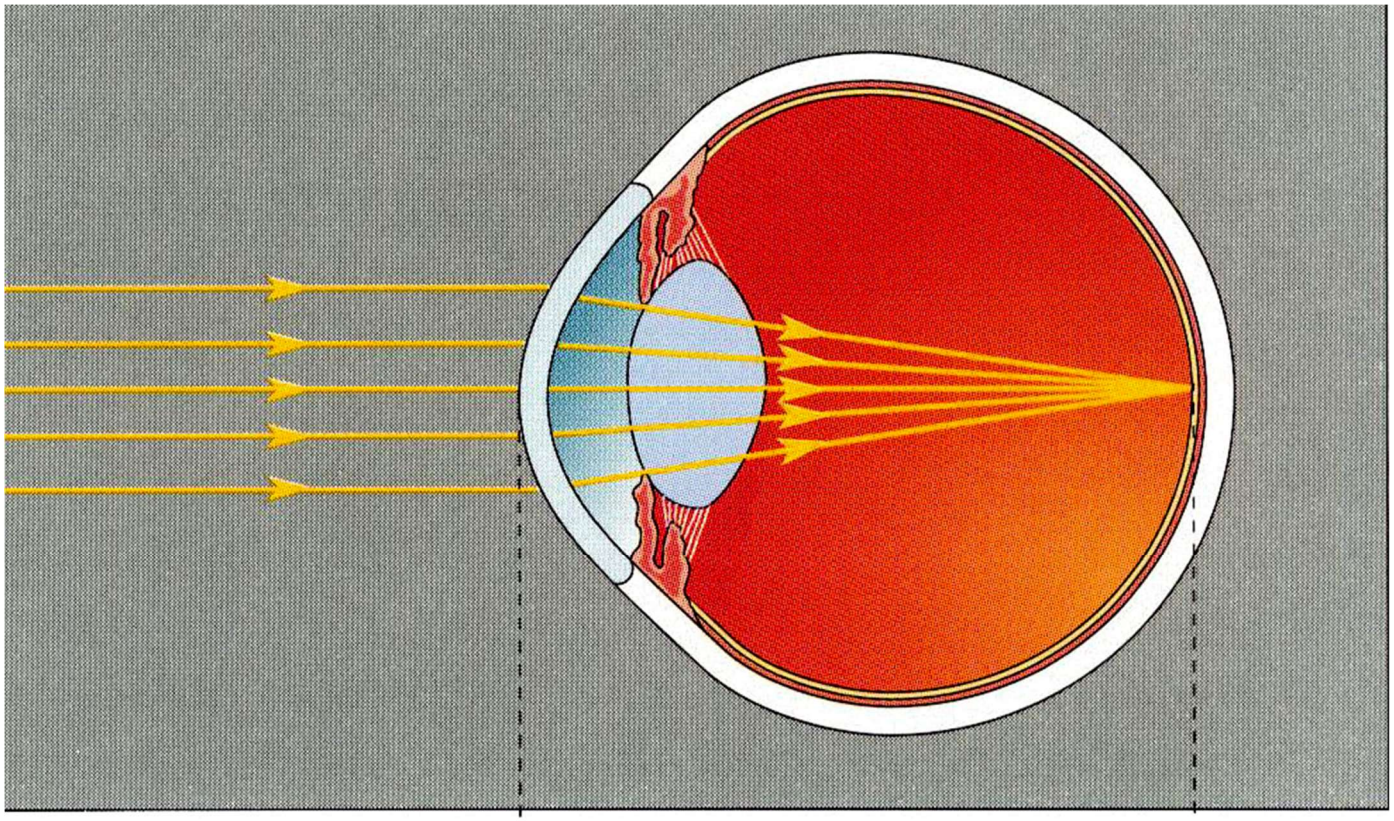
<u>3 Layers</u>:

- **<u>Outer Layer</u>: Sclera ("White of the Eye") – Cornea (Refracts Incoming Light)**
- **<u>Middle Layer</u>: Choroidea (Contains Blood Vessels) – Ciliary Body (Where the Lens is Suspended) – Iris (Provides the Eye's Color; Surrounds Pupil)**
- **<u>Inner Layer</u>: Retina (Contains Photoreceptors)**

<u>3 Cavities</u>:

- **<u>Anterior Cavity</u>: In Front of the Lens (Contains Fluid)**
- **<u>Middle Cavity</u>: Behind the Lens (Contains Fluid)**
- **<u>Posterior Cavity</u>: Vitreous Body**

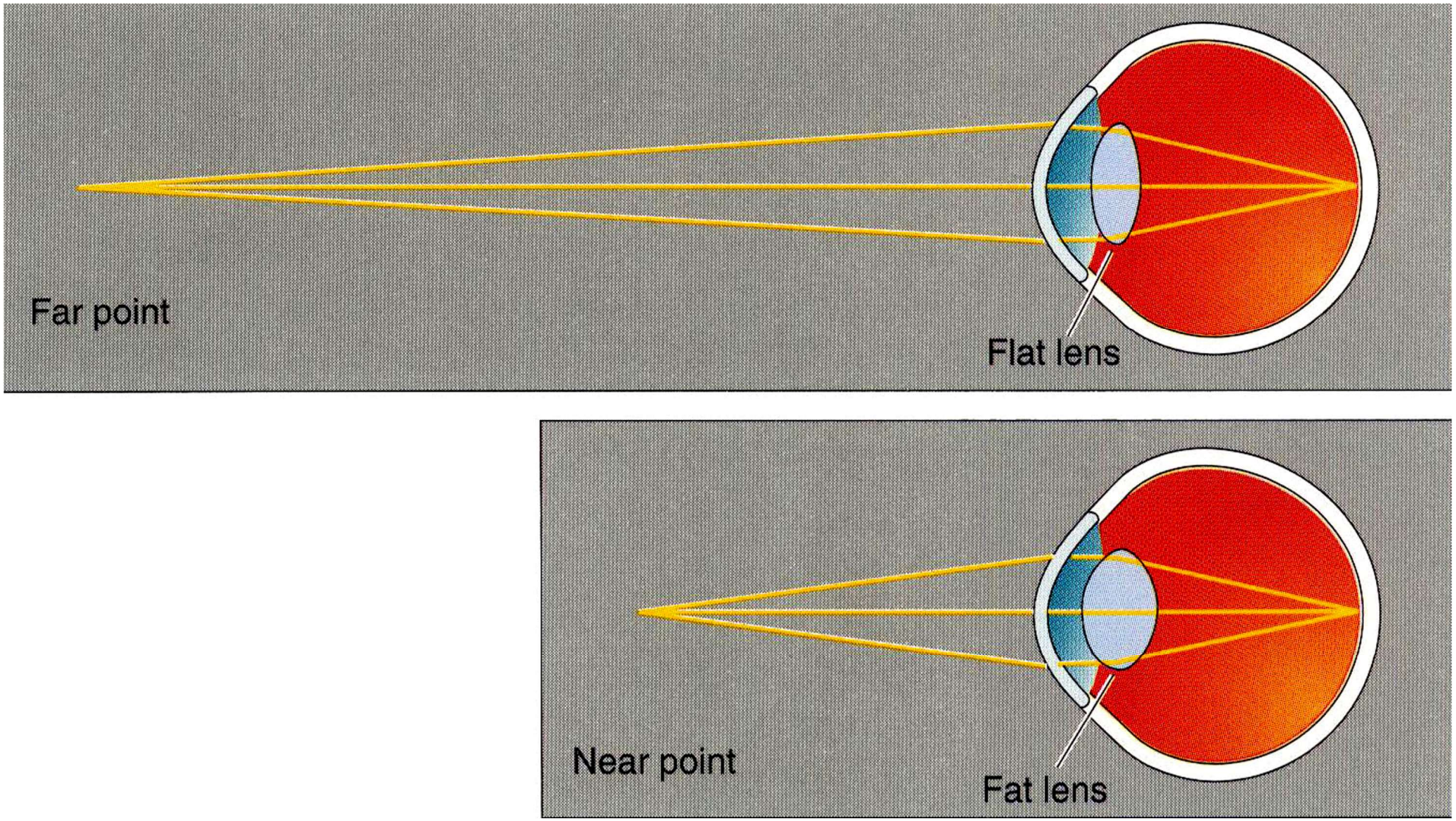
Refraction by the Cornea and the Lens



$$\text{Refractive power (diopters)} = \frac{1}{\text{focal distance (m)}}$$

Light Must be Focused on the Retina at the Back of the Eye

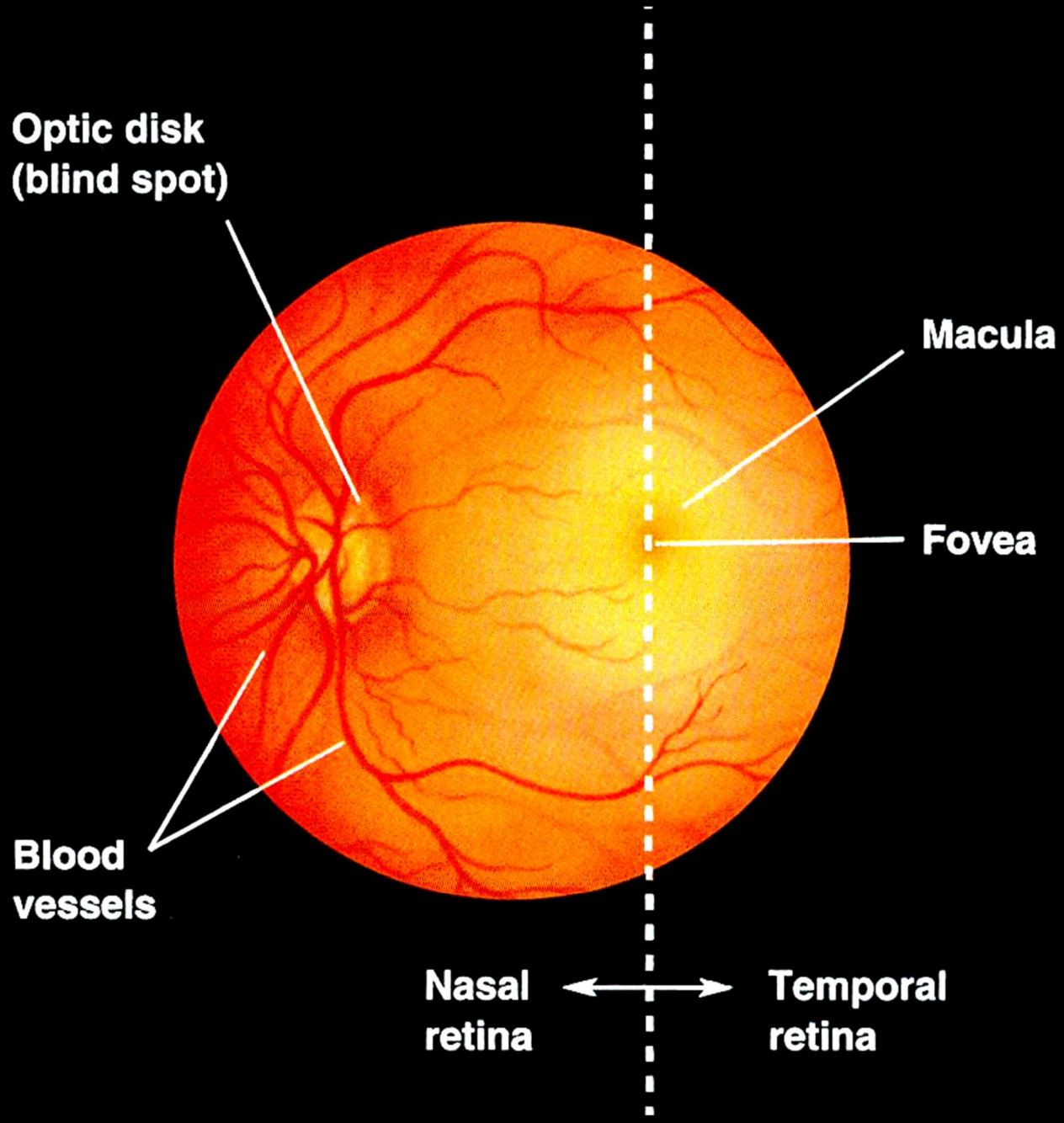
Accommodation by the Lens



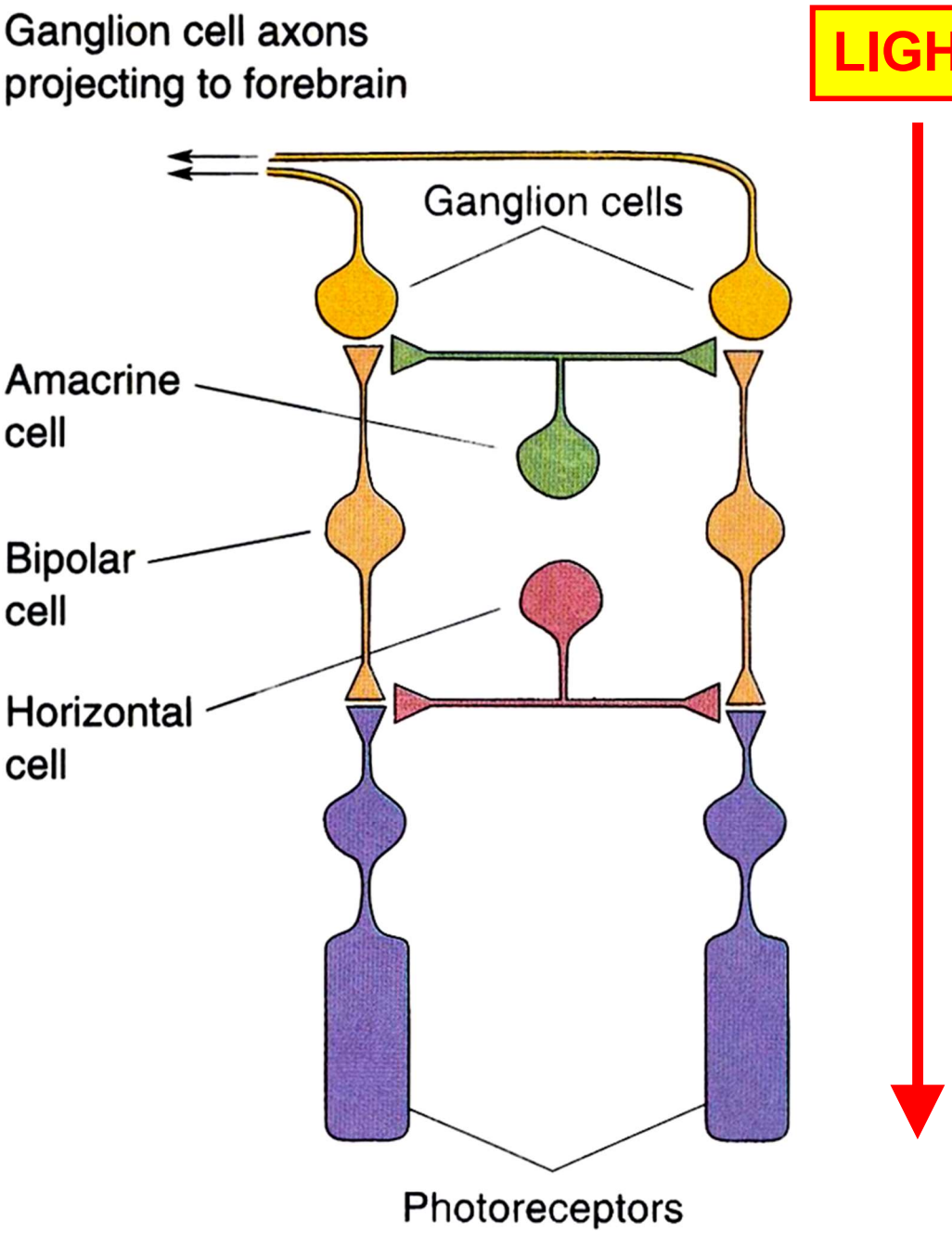
Far Objects: Little Refraction (Flat Lens)

Near Objects: Greater Refraction (More Spherical Lens)

Retina, Viewed Through an Ophthalmoscope



Basic System of Retinal Information Processing



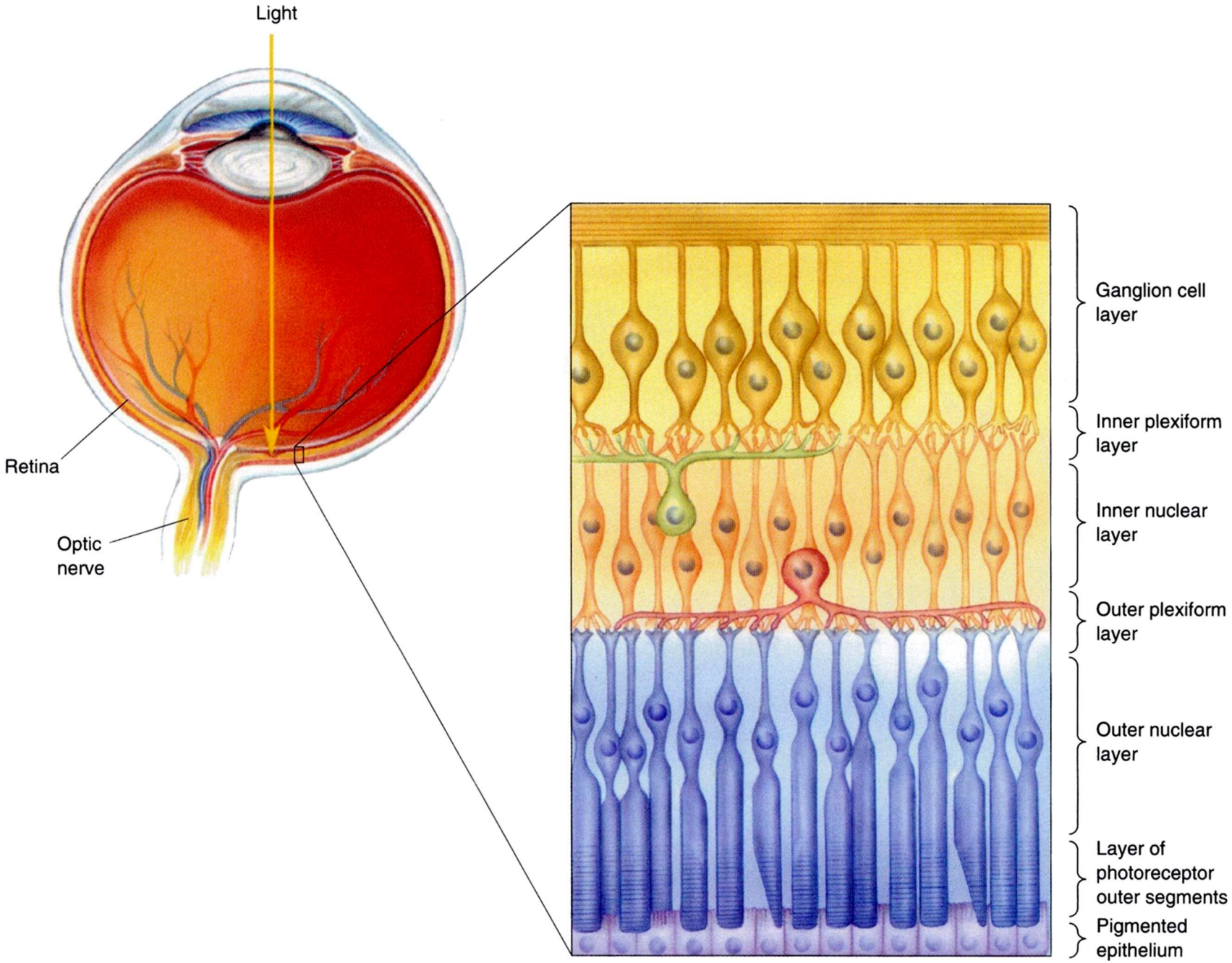
LIGHT

Third Neuron:
Ganglion Cells

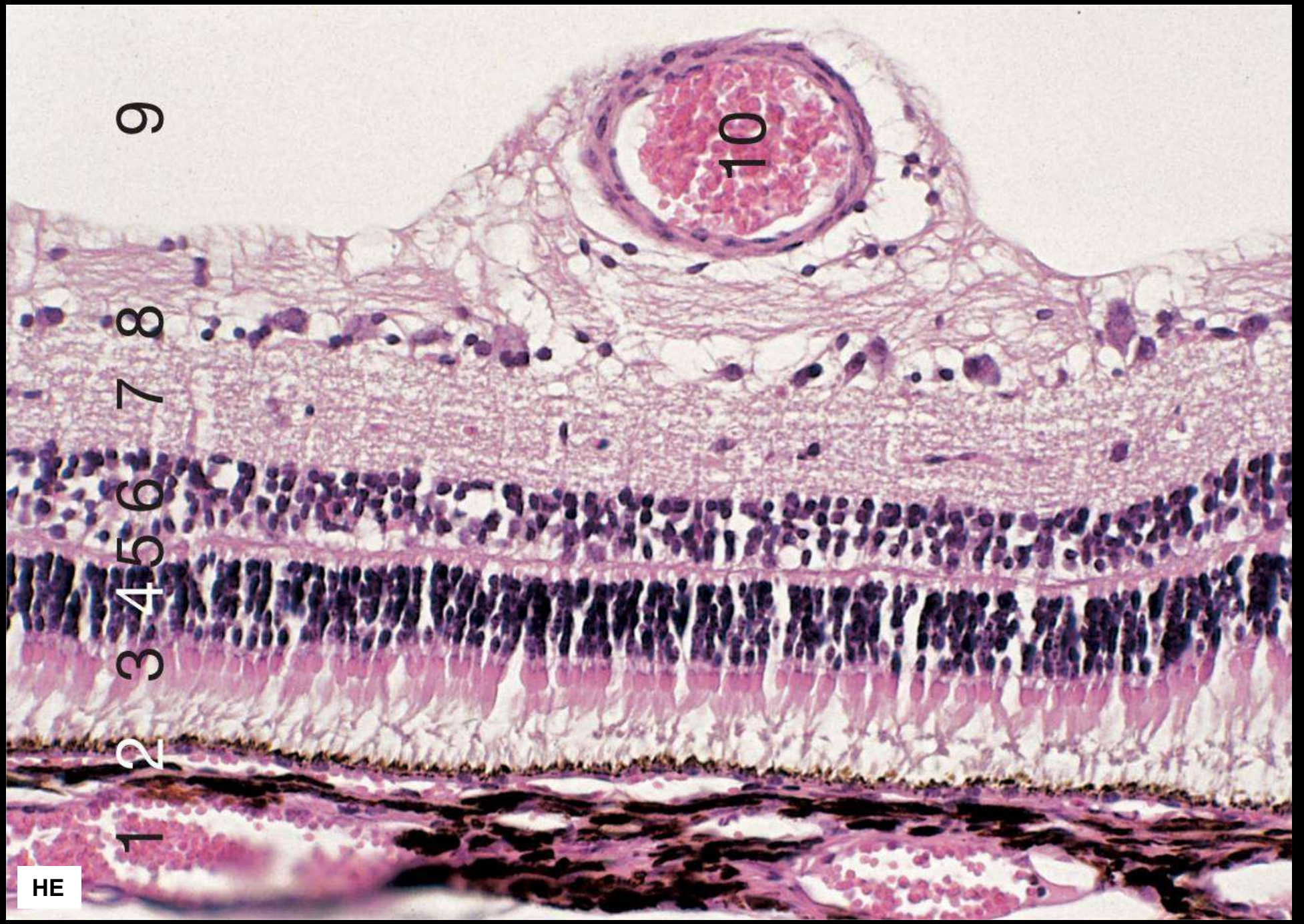
Second Neuron:
Bipolar Cells

First Neuron:
Photoreceptors (Rods, Cones)

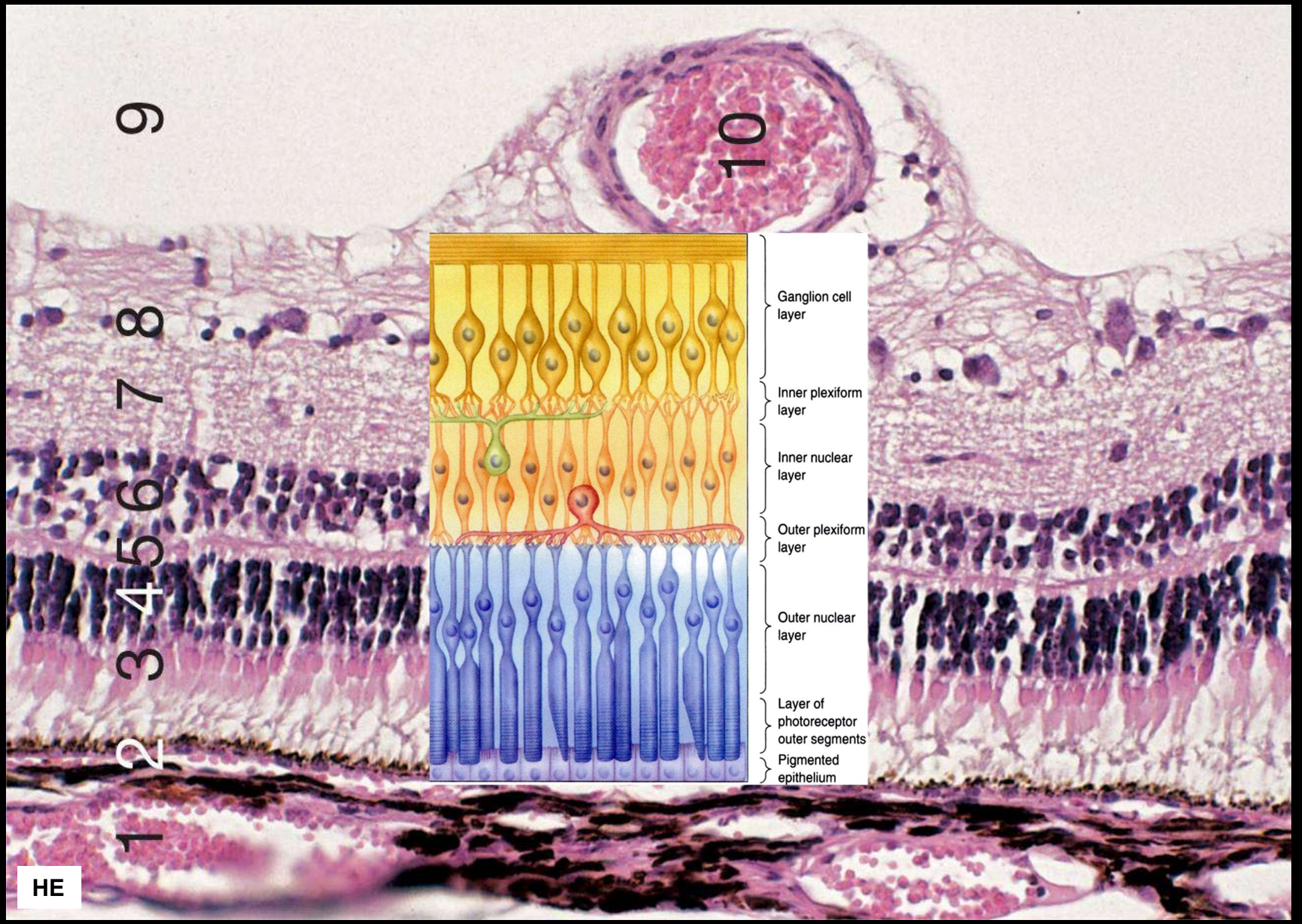
Laminar Organization of the Retina



Histology of the Retina



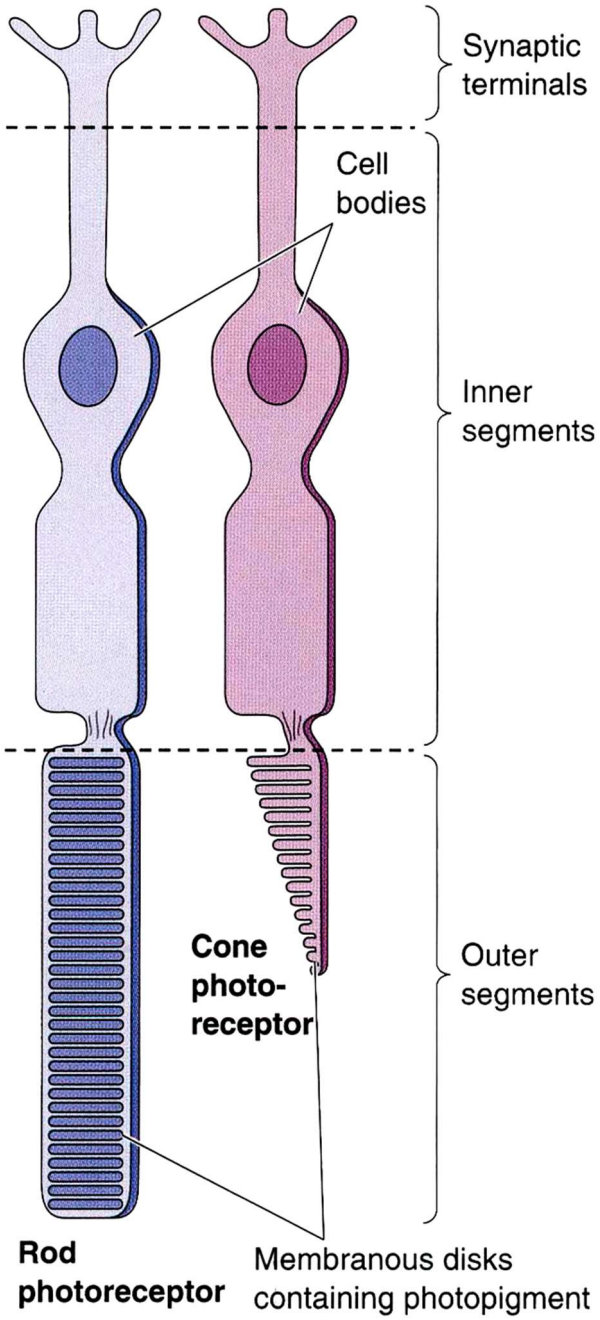
Histology of the Retina



Rods and Cones

<u>Rod Photoreceptor</u>:

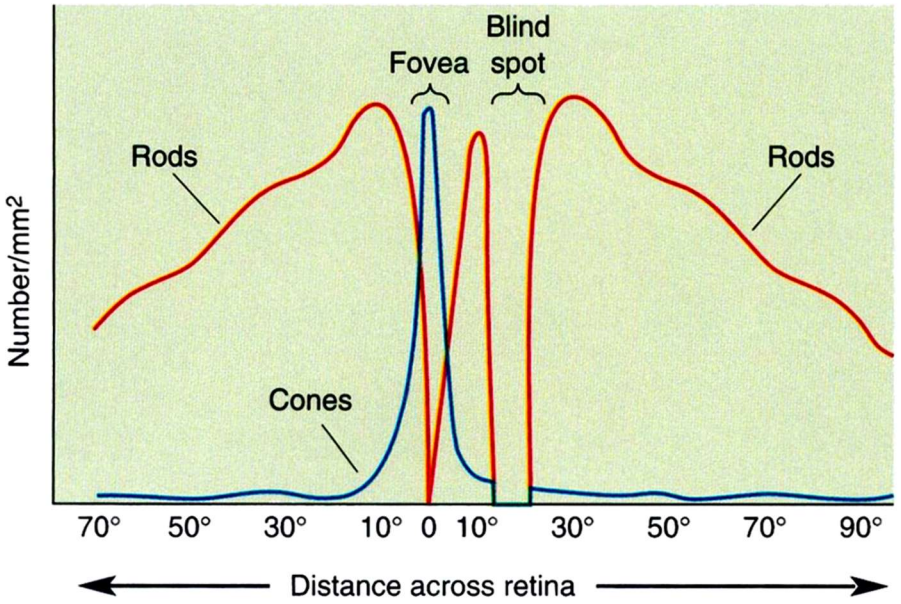
- **Long, Cylindrical Outer Segment**
- **~ 120 Million Rods per Eye**
- **Vision in Low Light (Scotopic Vision)**
- **Only Black and White**



<u>Cone Photoreceptor</u>:

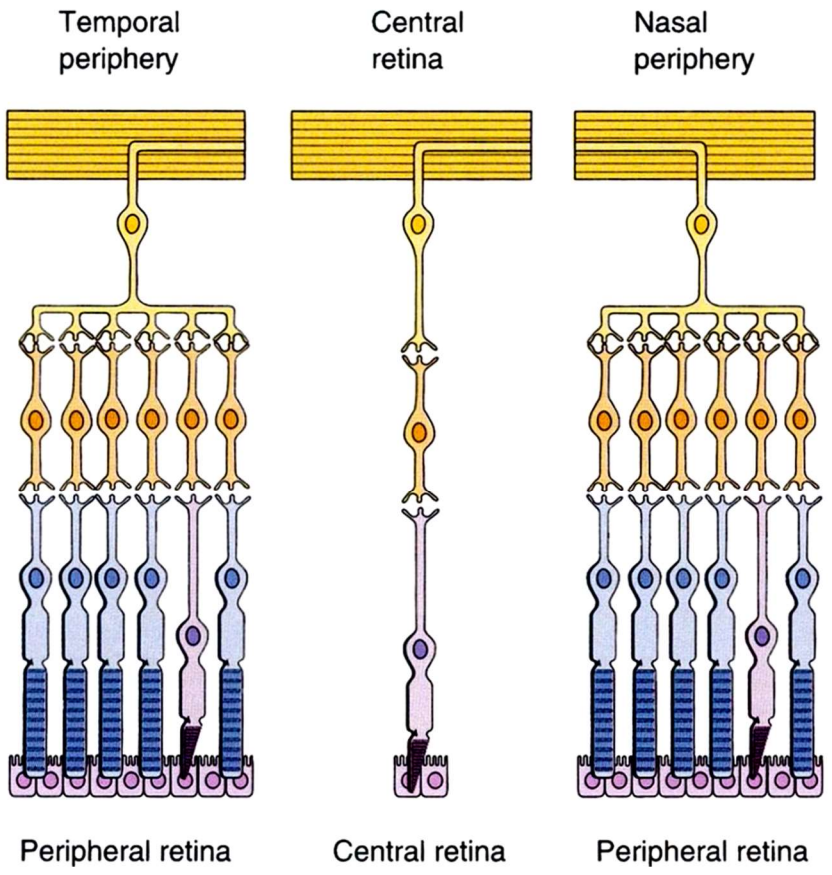
- **Shorter, Tapering Outer Segment**
- **~ 5 Million Cones per Eye**
- **Vision in Daylight (Photopic Vision)**
- **Color**

Regional Differences in Retinal Structure



Central Retina (Fovea):

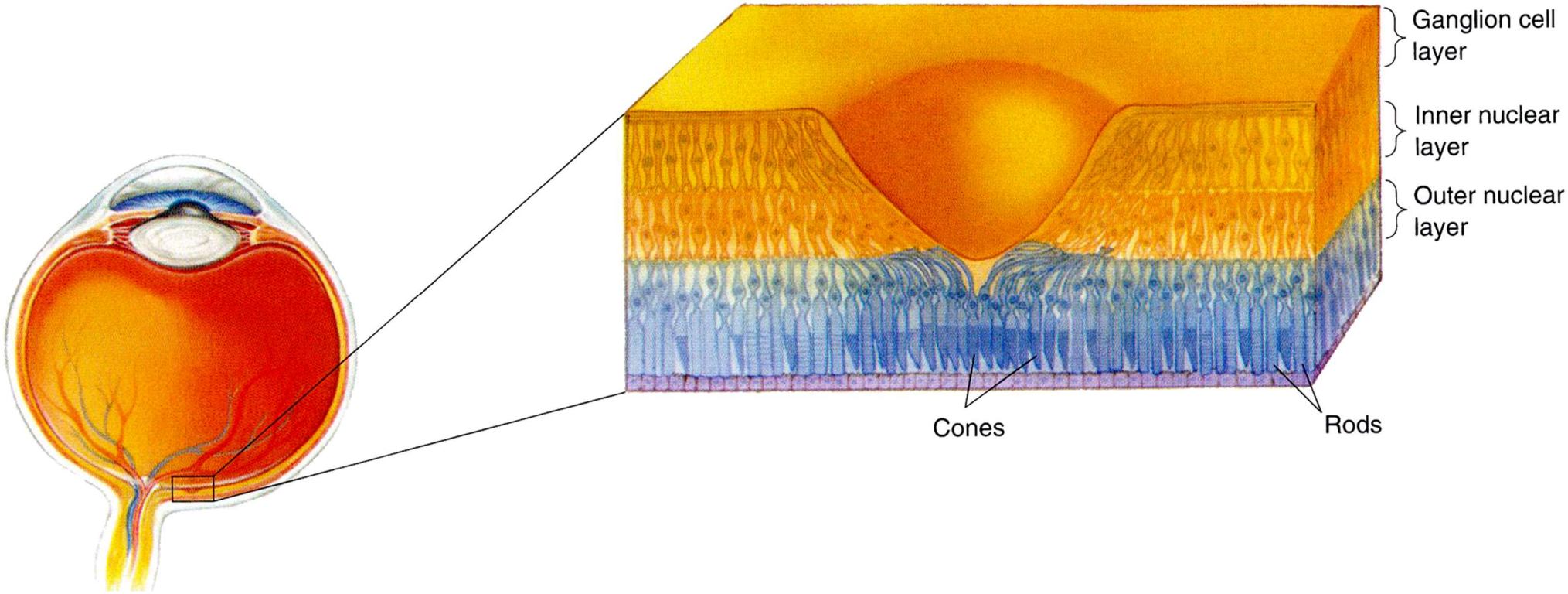
- Only Cones
- One-to-One Signal Transduction
- High Spatial Resolution



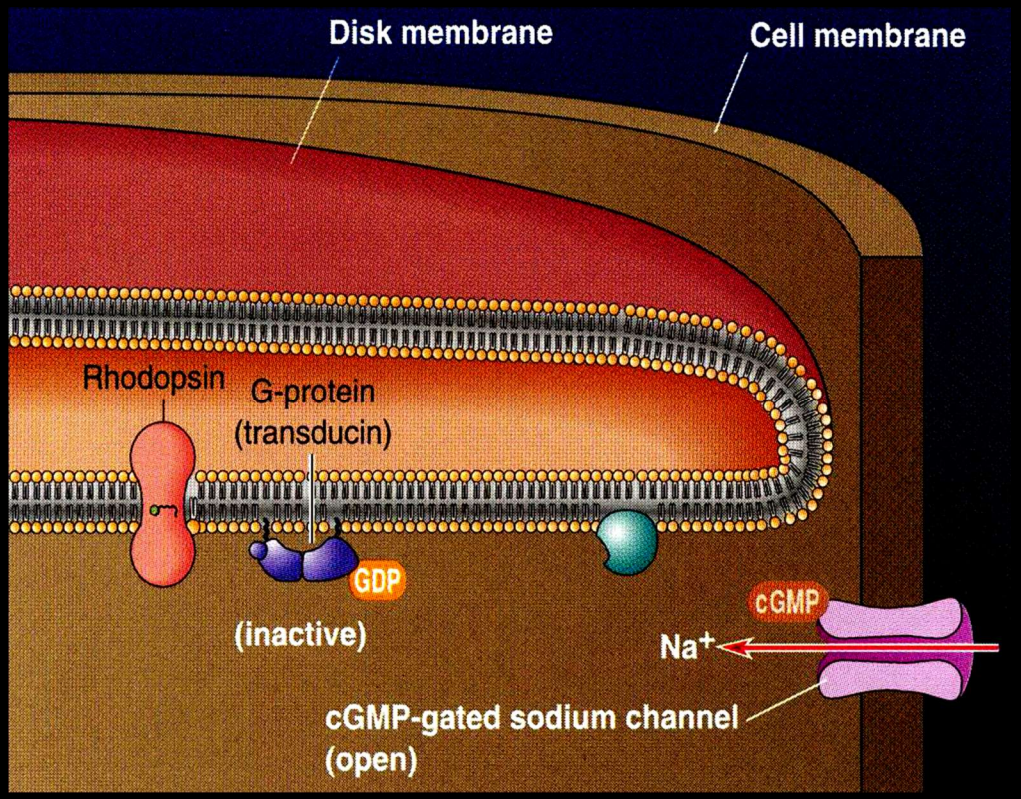
Peripheral Retina:

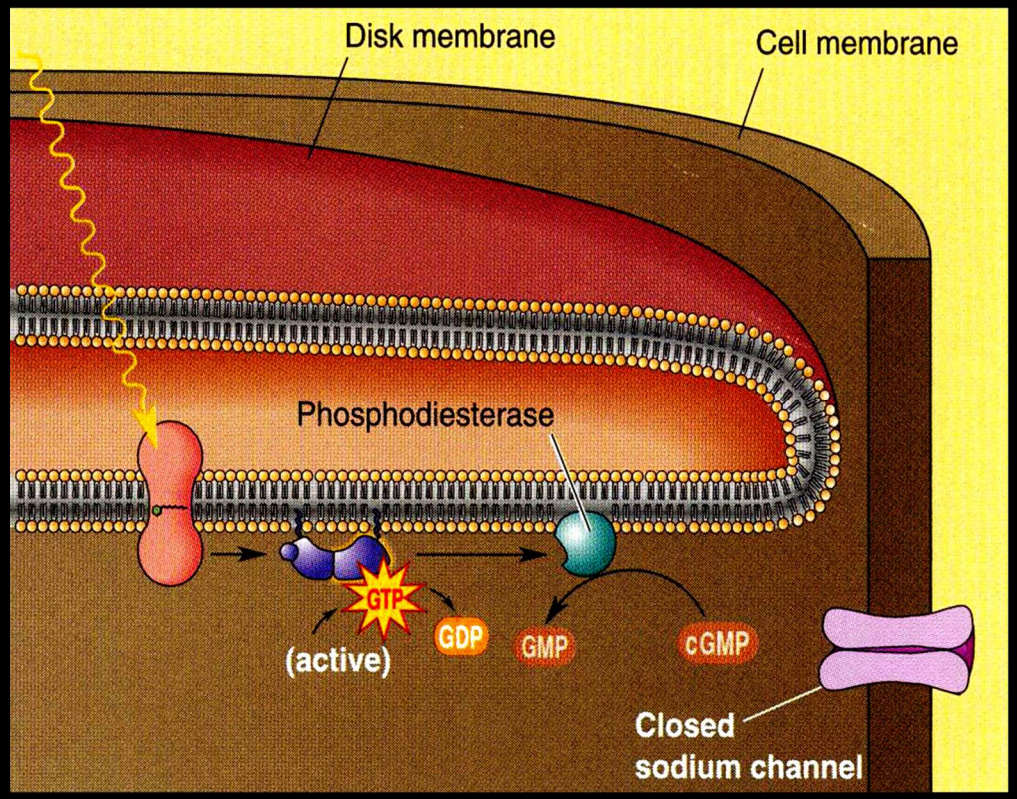
- Rods and Cones
- Convergent Signal Transduction
- Low Spatial Resolution

The Fovea
(Perhaps the Most Valuable Area of Your Body)



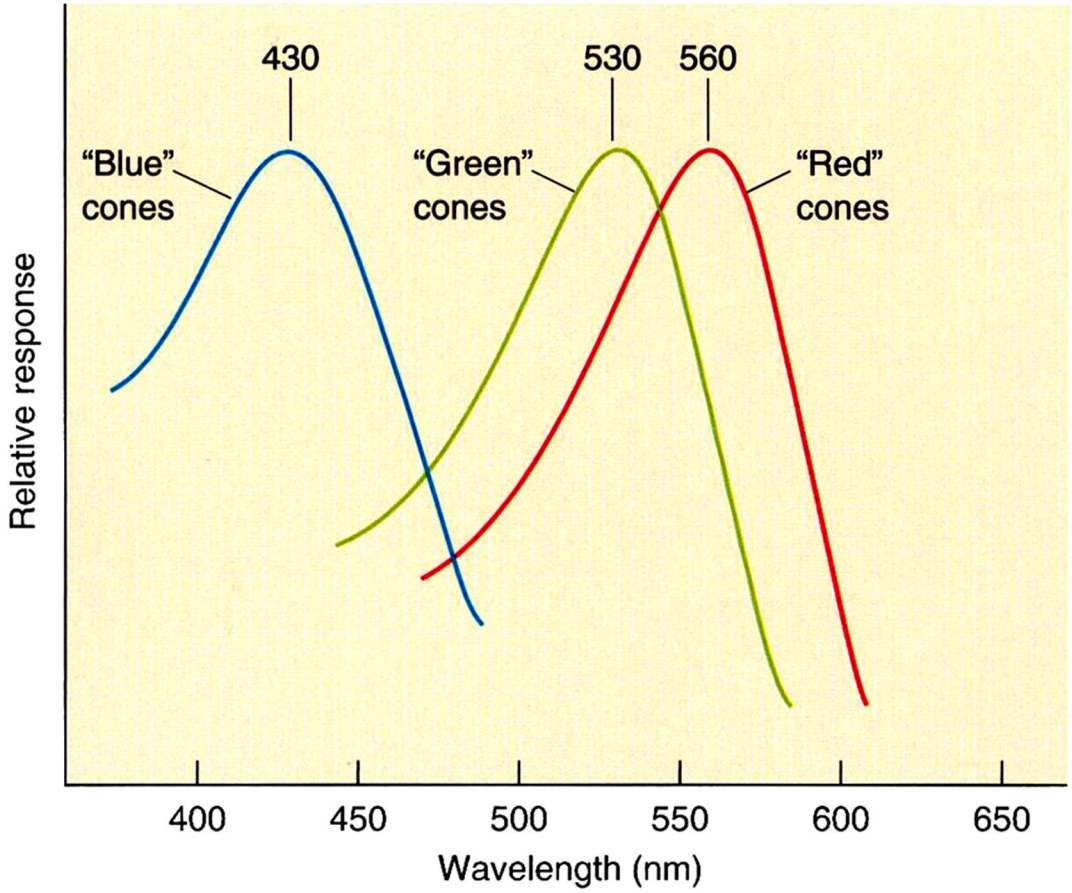
Phototransduction



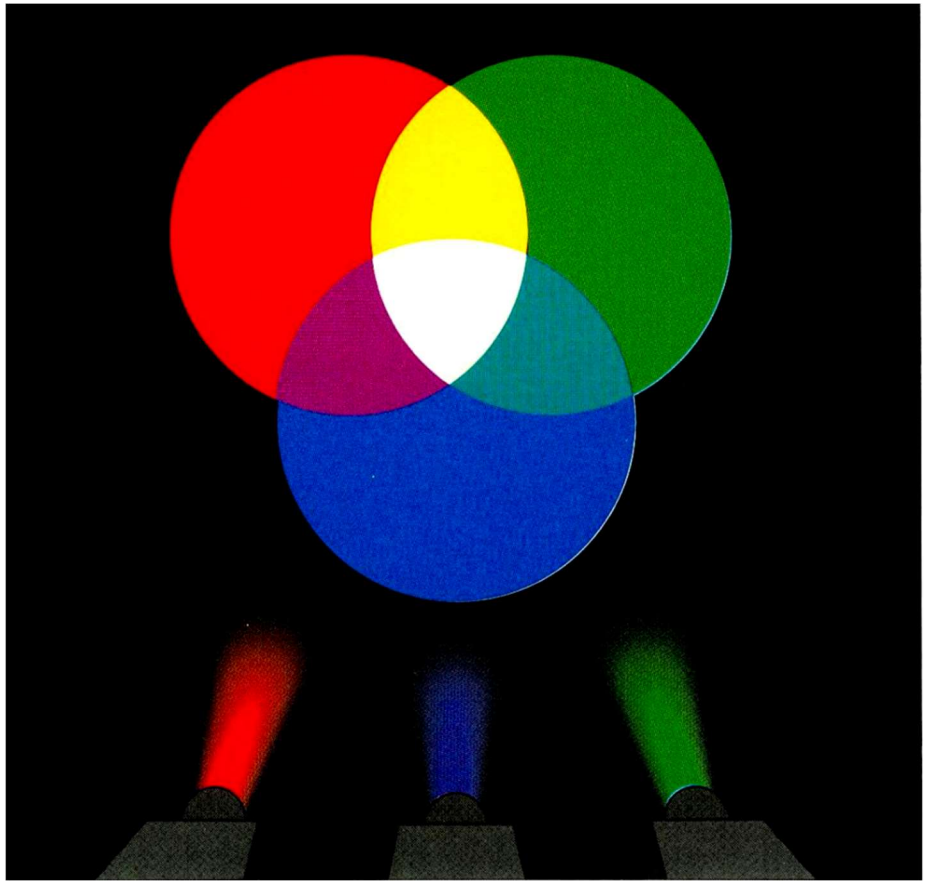


Photoreceptors Hyperpolarize in Response to Light !

Color Vision in Cones
(Young-Helmholtz Trichromacy Theory)

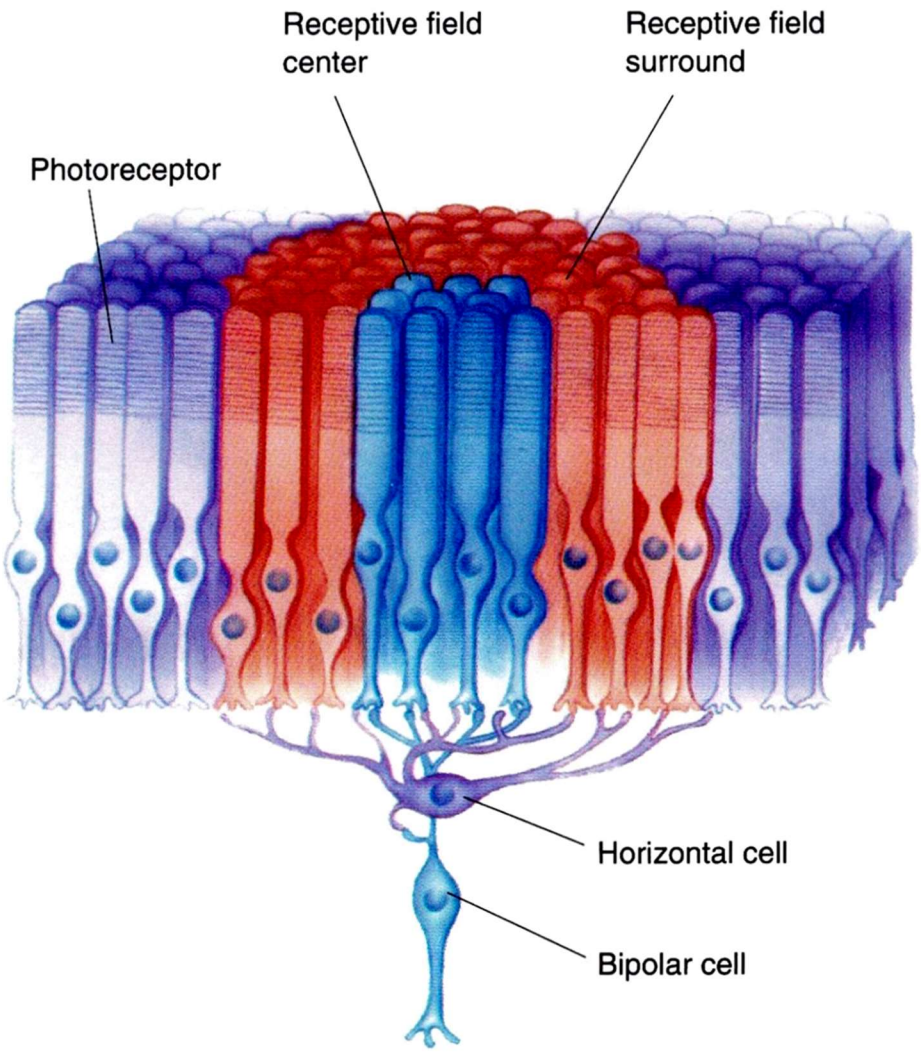


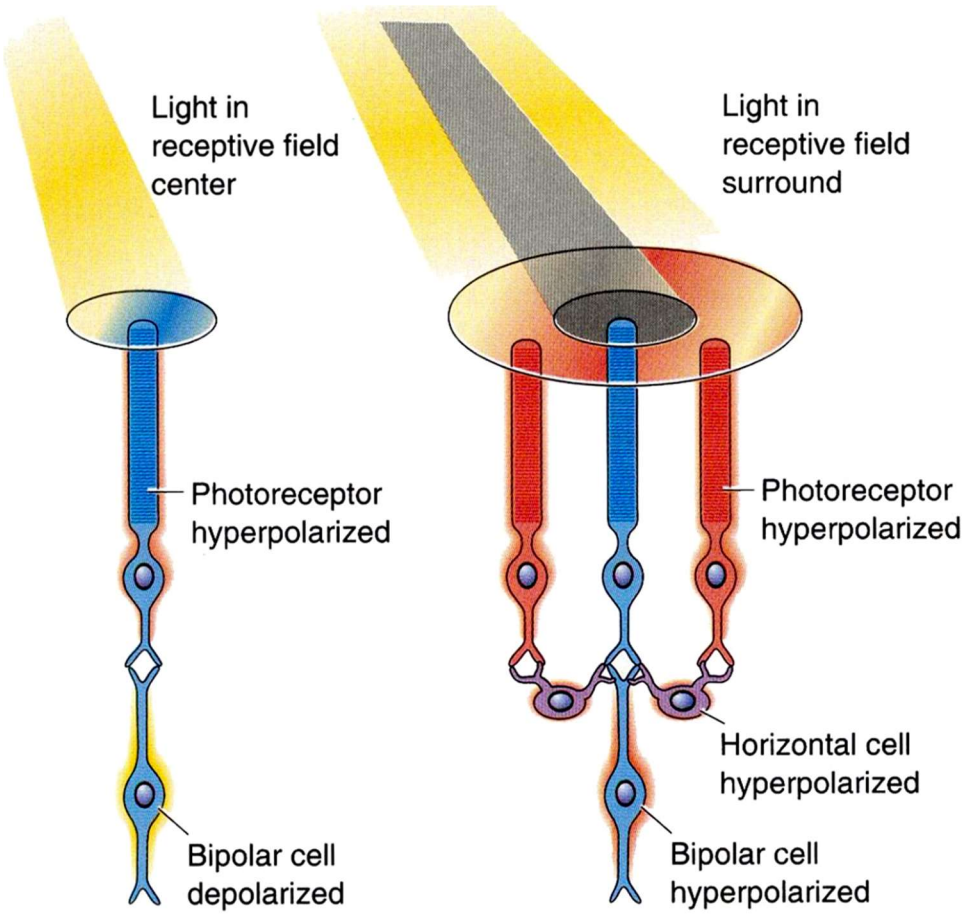
Spectral Sensitivity of the Three Types of Cone Pigments



Color Mixing (Equal Amounts of Blue, Green, and Red → White)

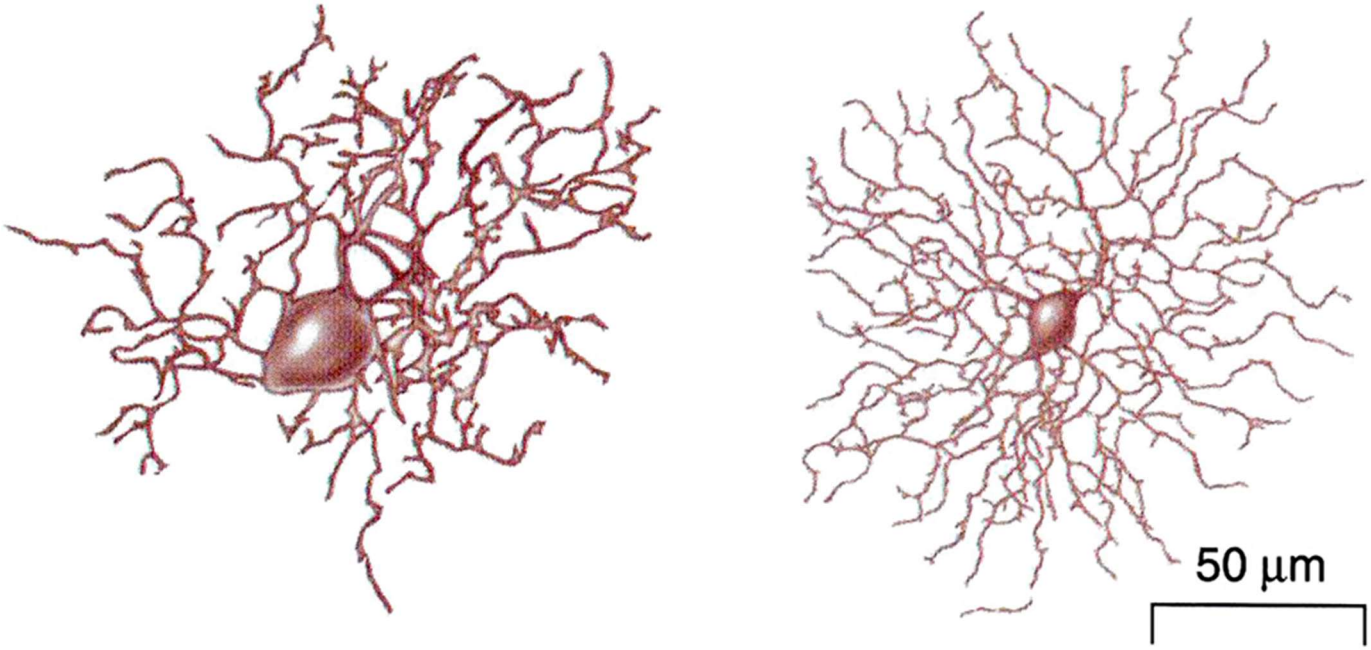
Bipolar Cells (Second Neuron)





Antagonistic Center-Surround Receptive Fields

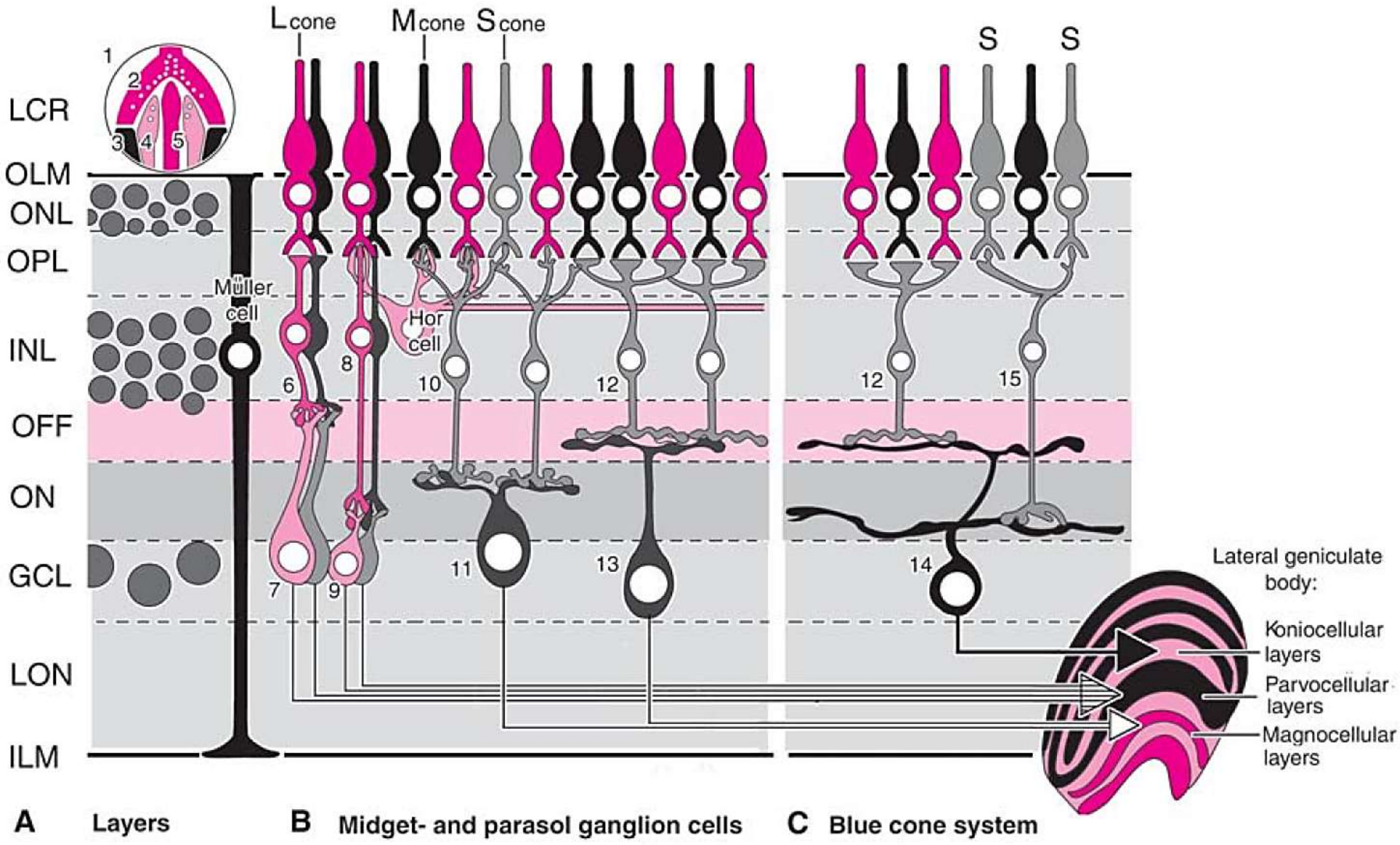
Ganglion Cells (Third Neuron)



<u>Three Types of Ganglion Cells</u>:

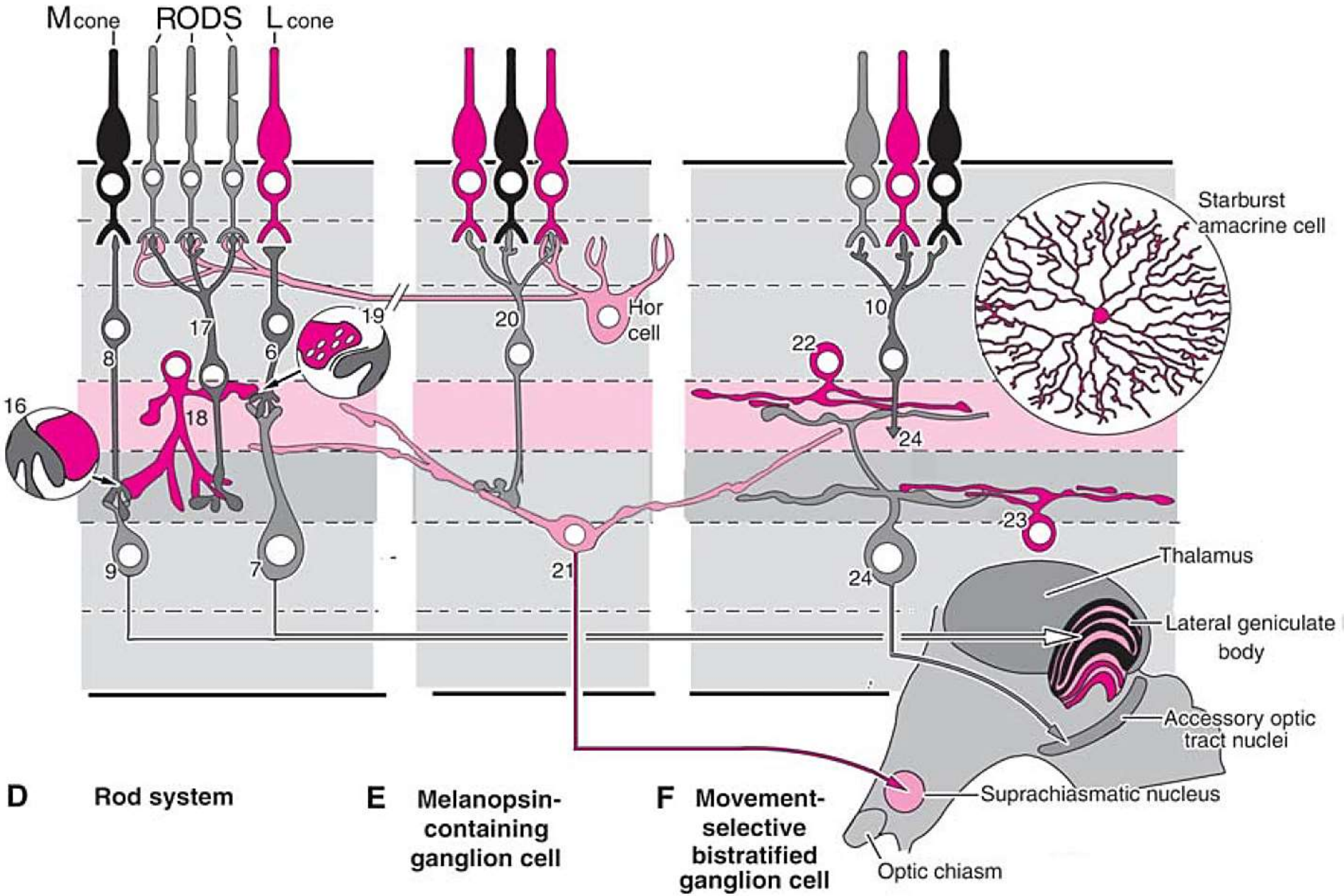
- **<u>M Cells</u> (Top Right)**
  Magnocellular (Large) Neurons (~ 5%); Detection of Movement
- **<u>P Cells</u> (Top Left)**
  Parvocellular (Small) Neurons (~ 90%); Detection of Shape and Texture
- **<u>Non M-Non P Cells</u>**
  Heterogeneous Population (~ 5%)

Ganglion Cells (Third Neuron)



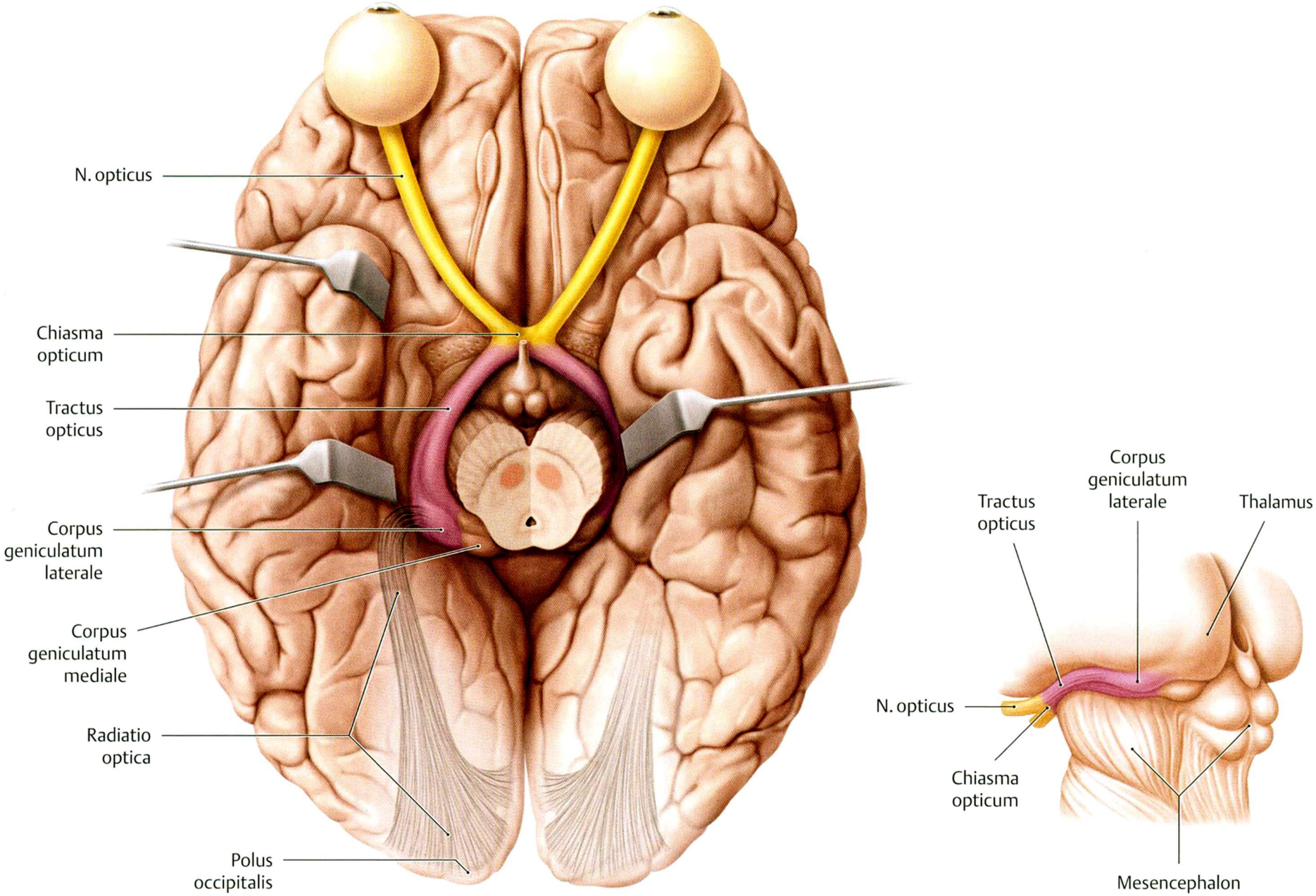
Nieuwenhuys et al.
The Human Central Nervous System Springer 2008

Ganglion Cells (Third Neuron)



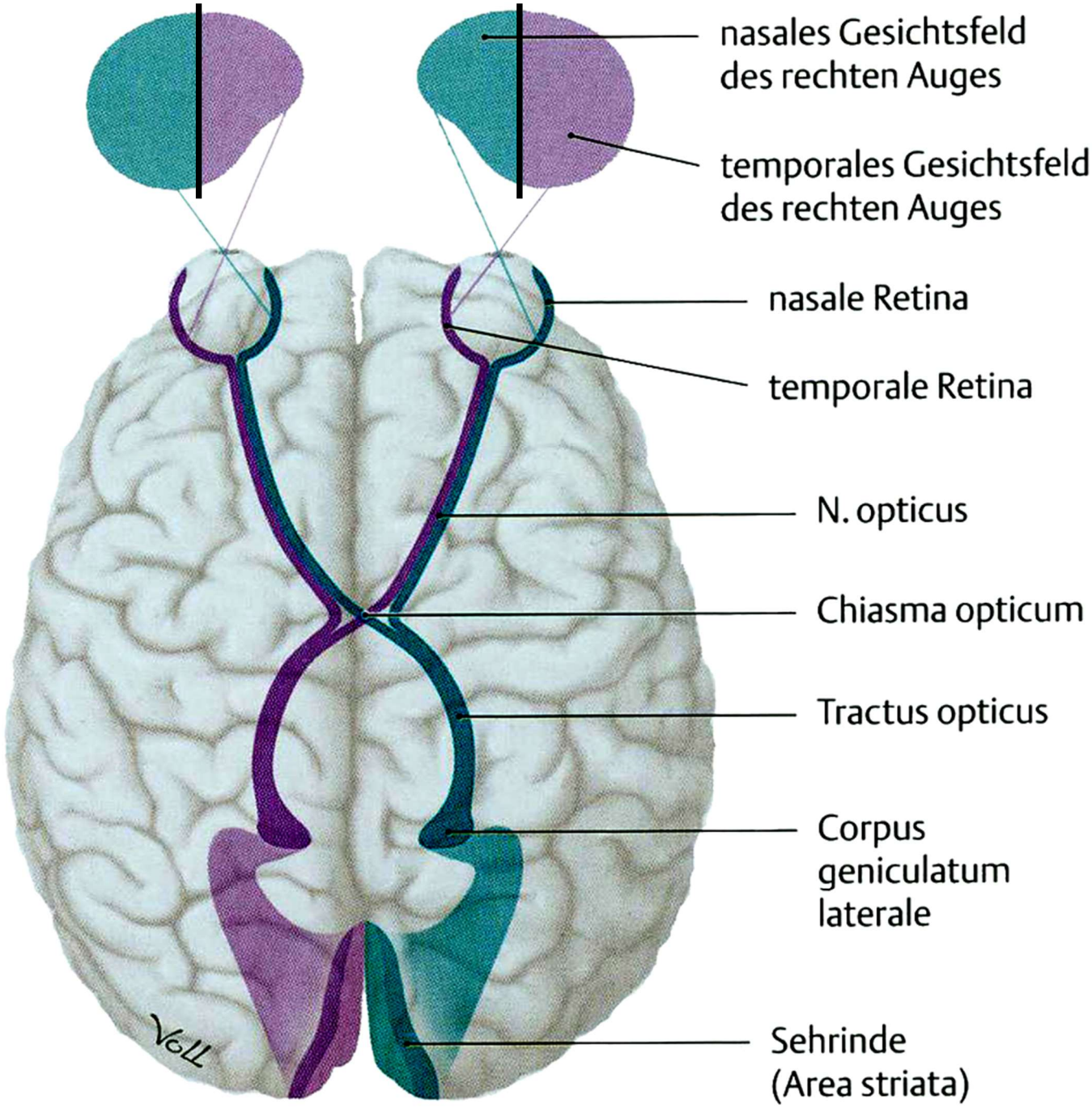
Nieuwenhuys et al.
The Human Central Nervous System Springer 2008

Retinofugal Projection

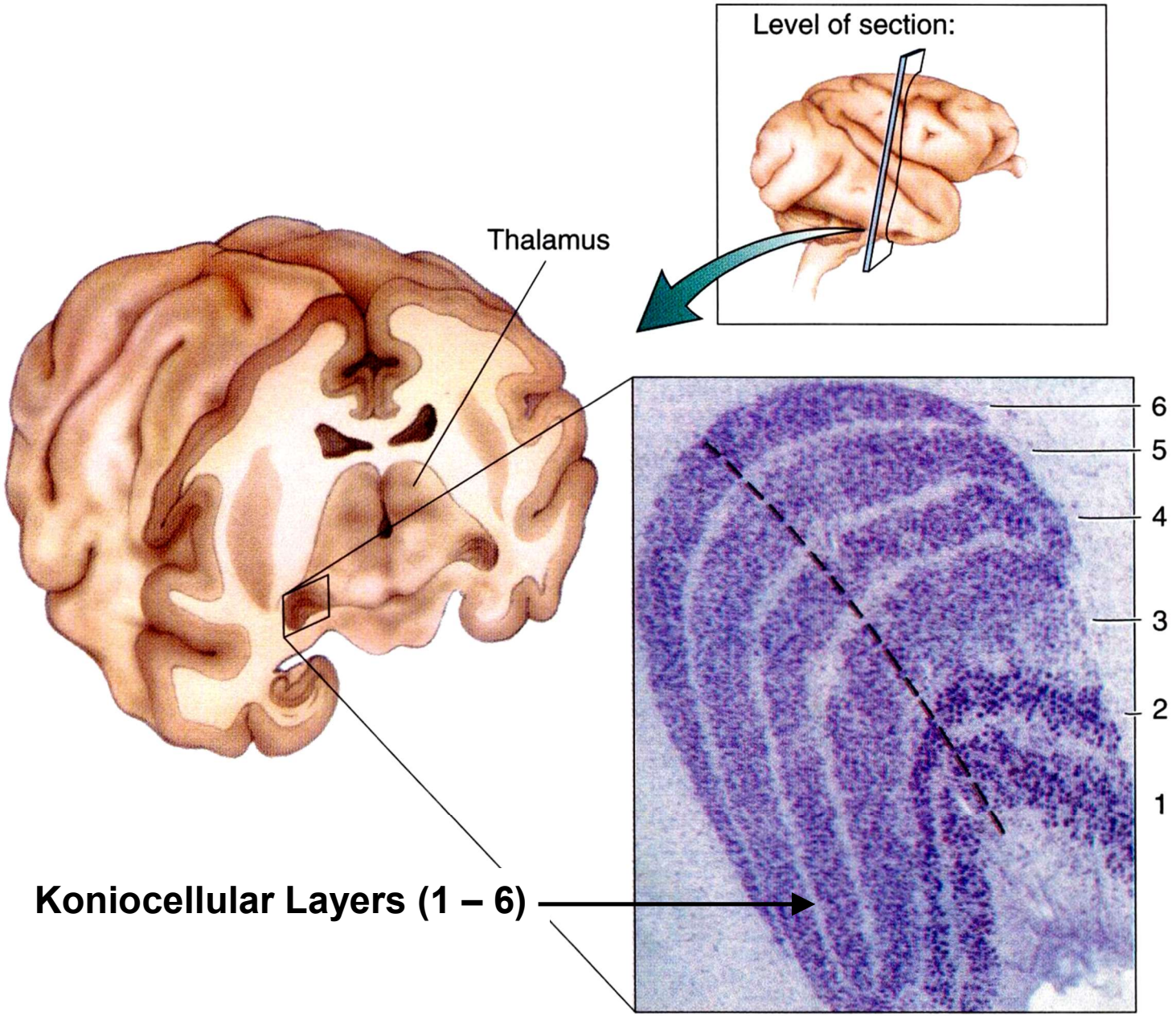


Optic Nerve – Optic Chiasm – Optic Tract – Lateral Geniculate Nucleus – Optic Radiation

Retinofugal Projection



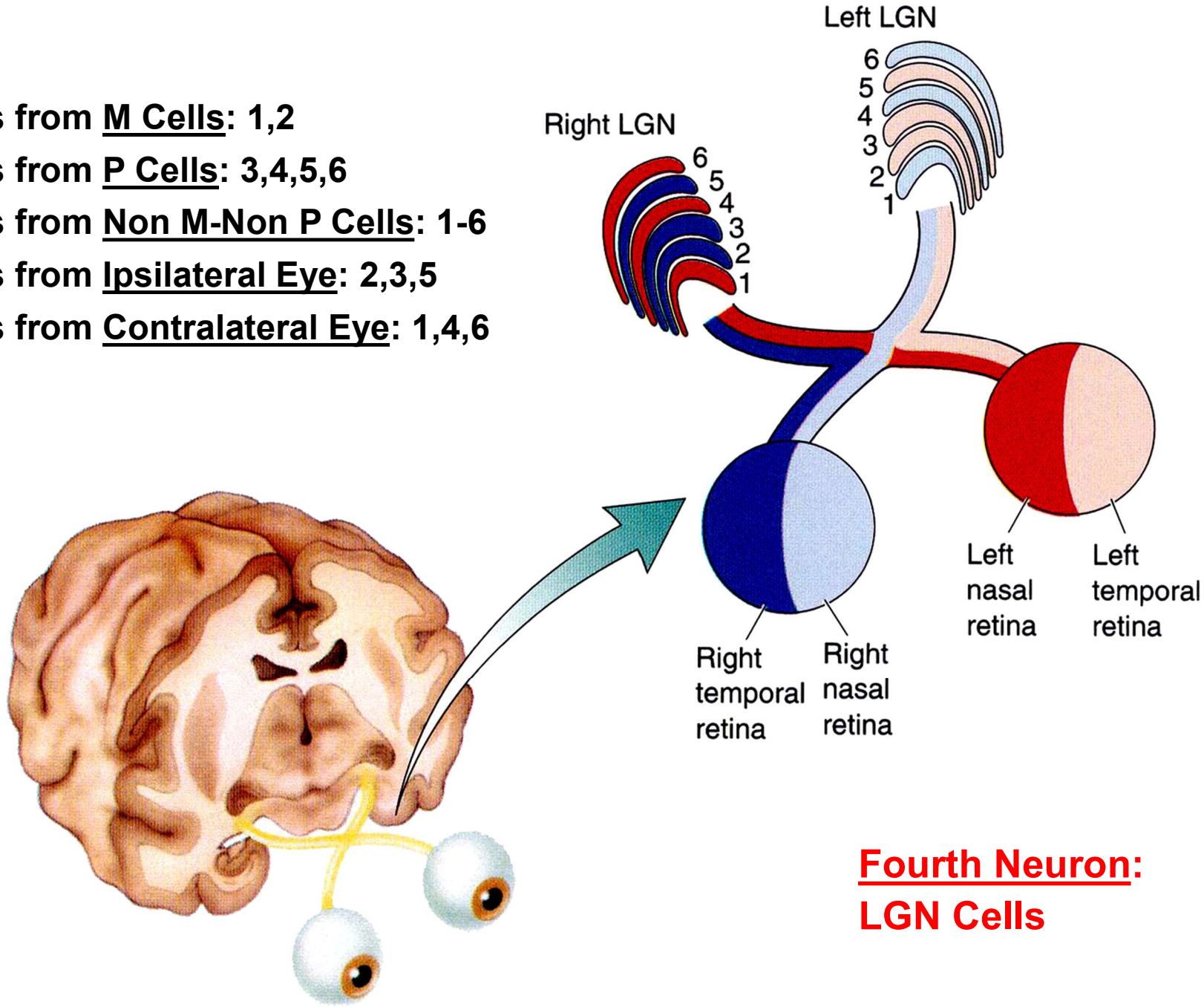
Lateral Geniculate Nucleus (LGN)



<u>6 Layers</u>: Magnocellular Layers (1 – 2) and Parvocellular Layers (3 – 6)

Lateral Geniculate Nucleus (LGN)

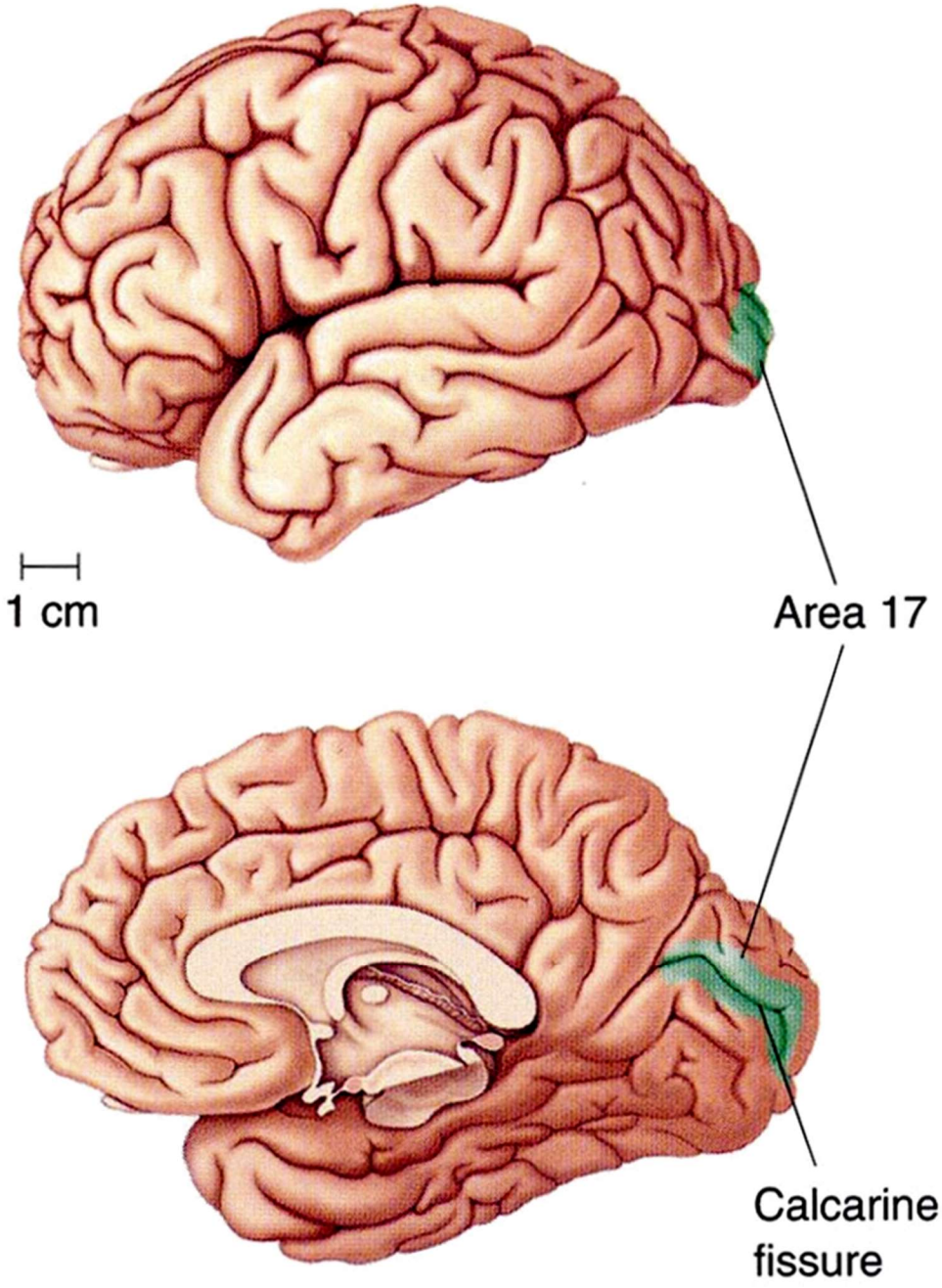
- **Axons from M Cells: 1,2**
- **Axons from P Cells: 3,4,5,6**
- **Axons from Non M-Non P Cells: 1-6**
- **Axons from Ipsilateral Eye: 2,3,5**
- **Axons from Contralateral Eye: 1,4,6**



Fourth Neuron:
LGN Cells

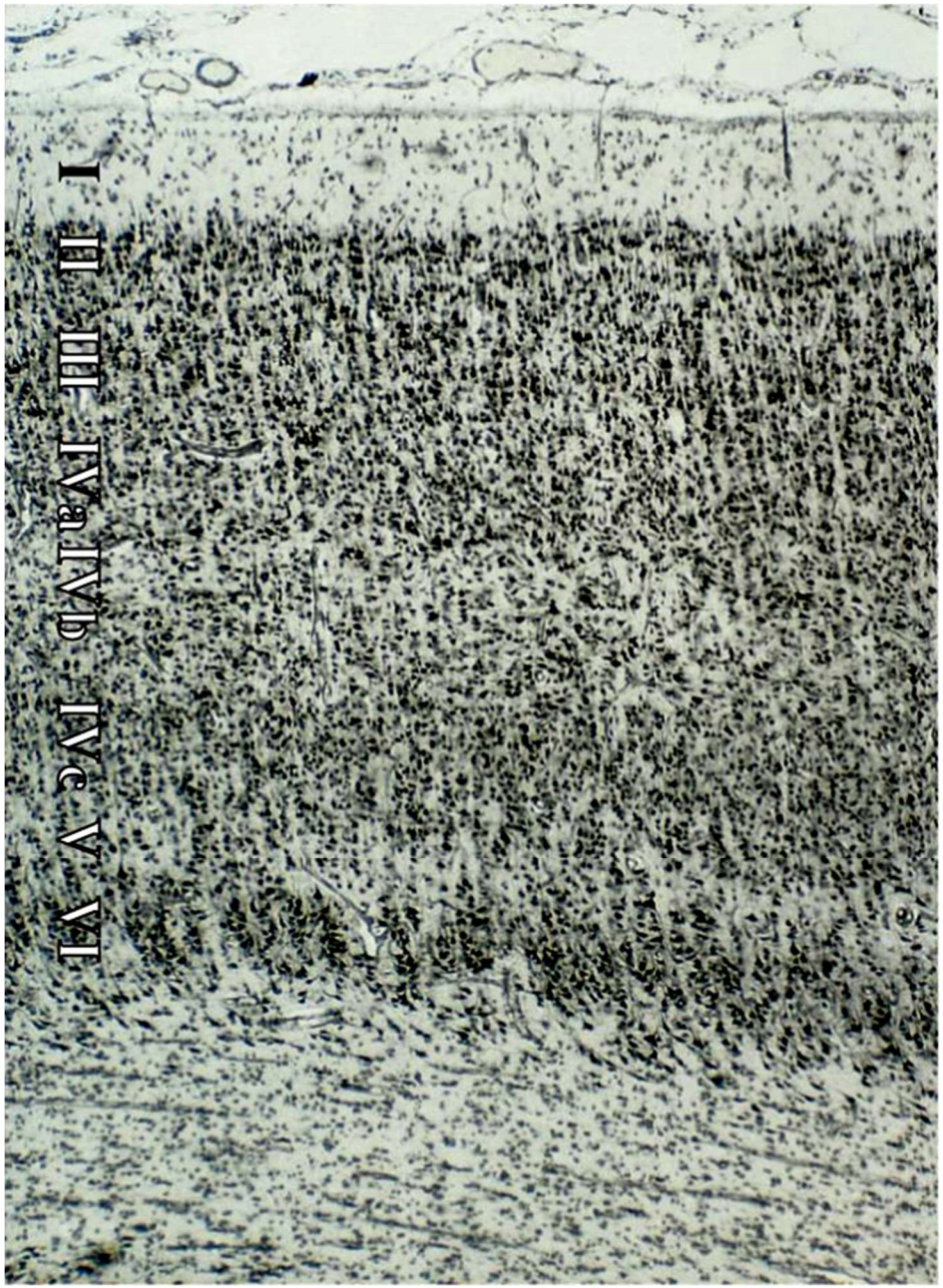
Optic Radiation

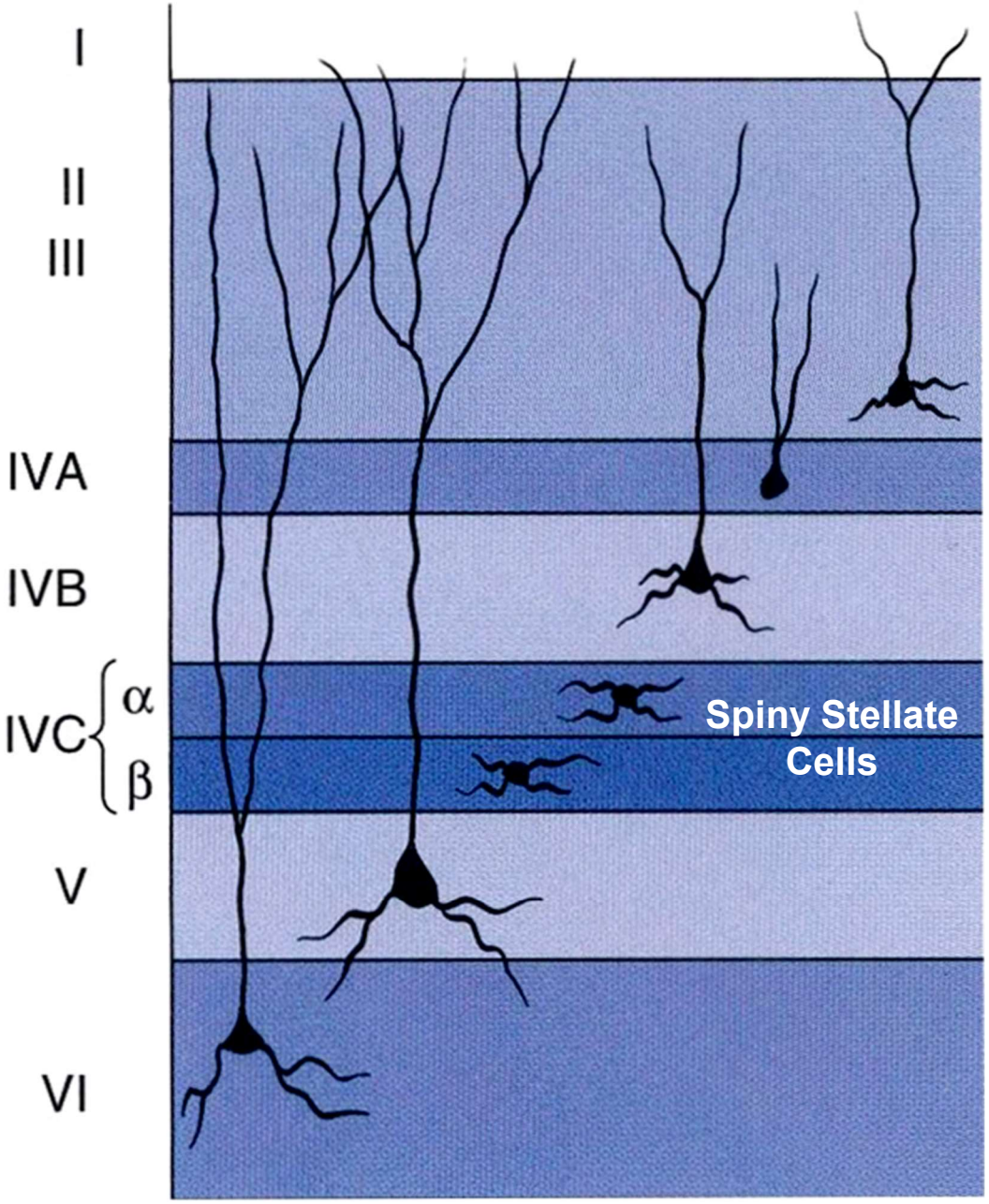
Primary Visual Cortex = V1 = Striate Cortex = Area 17



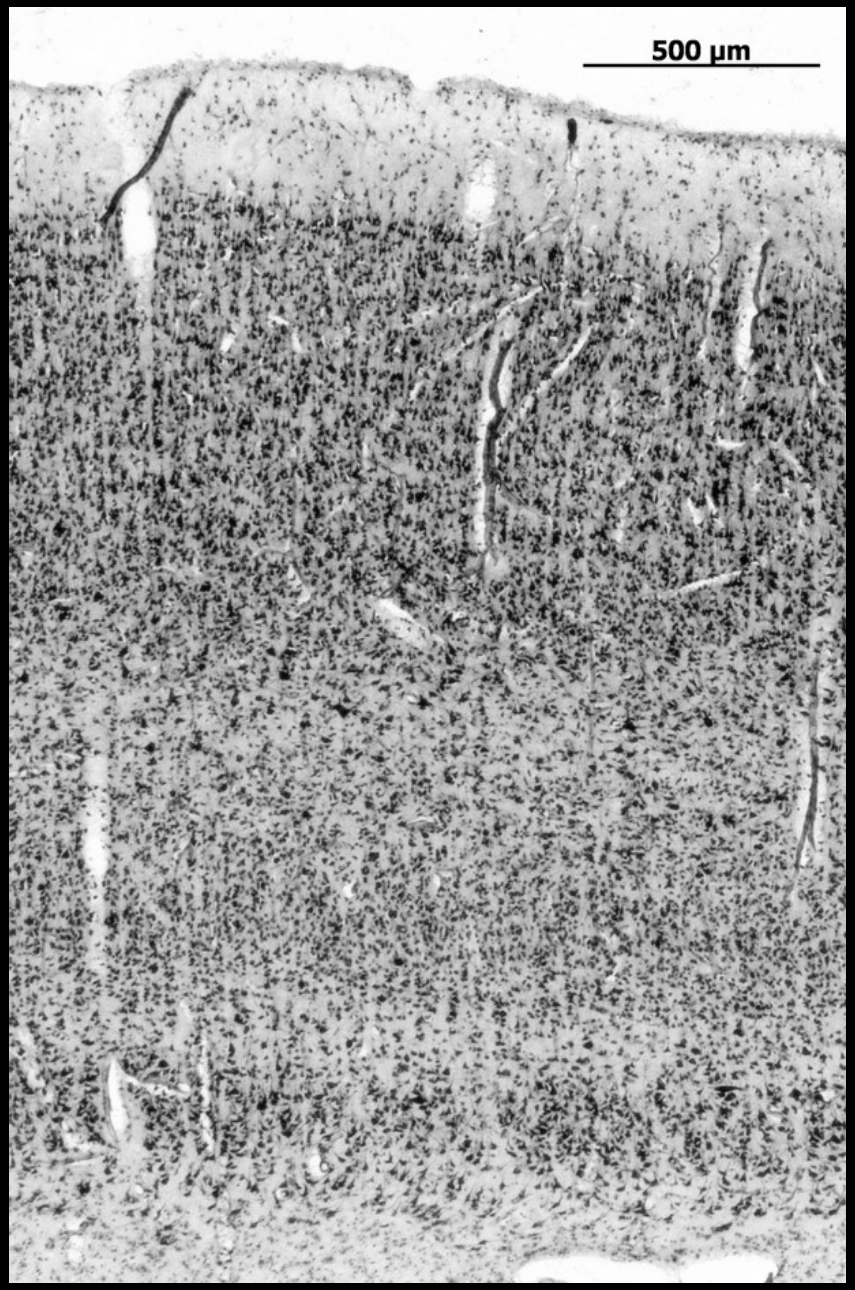
Fifth Neuron:
V1 Cells

V1: Cytoarchitecture

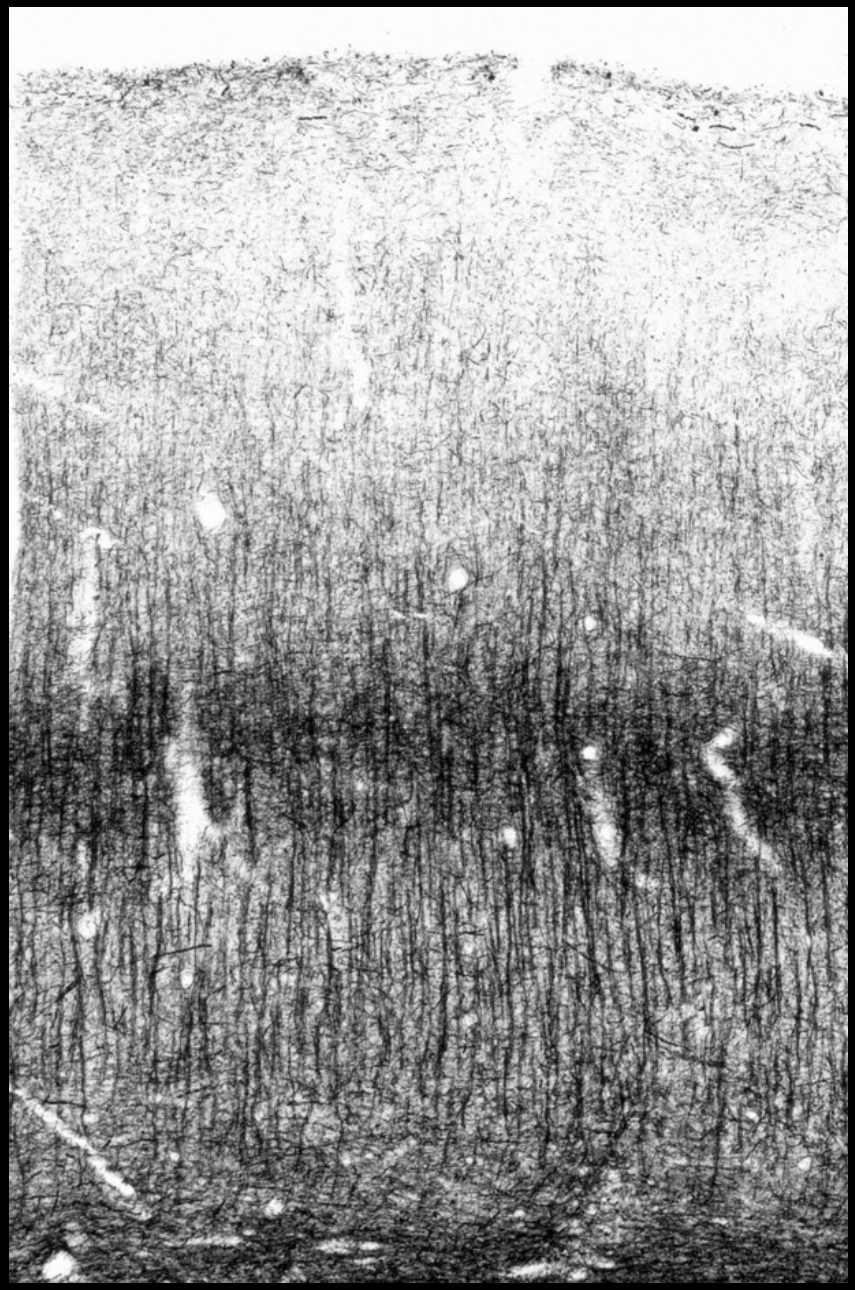




V1: Cytoarchitecture and Myeloarchitecture

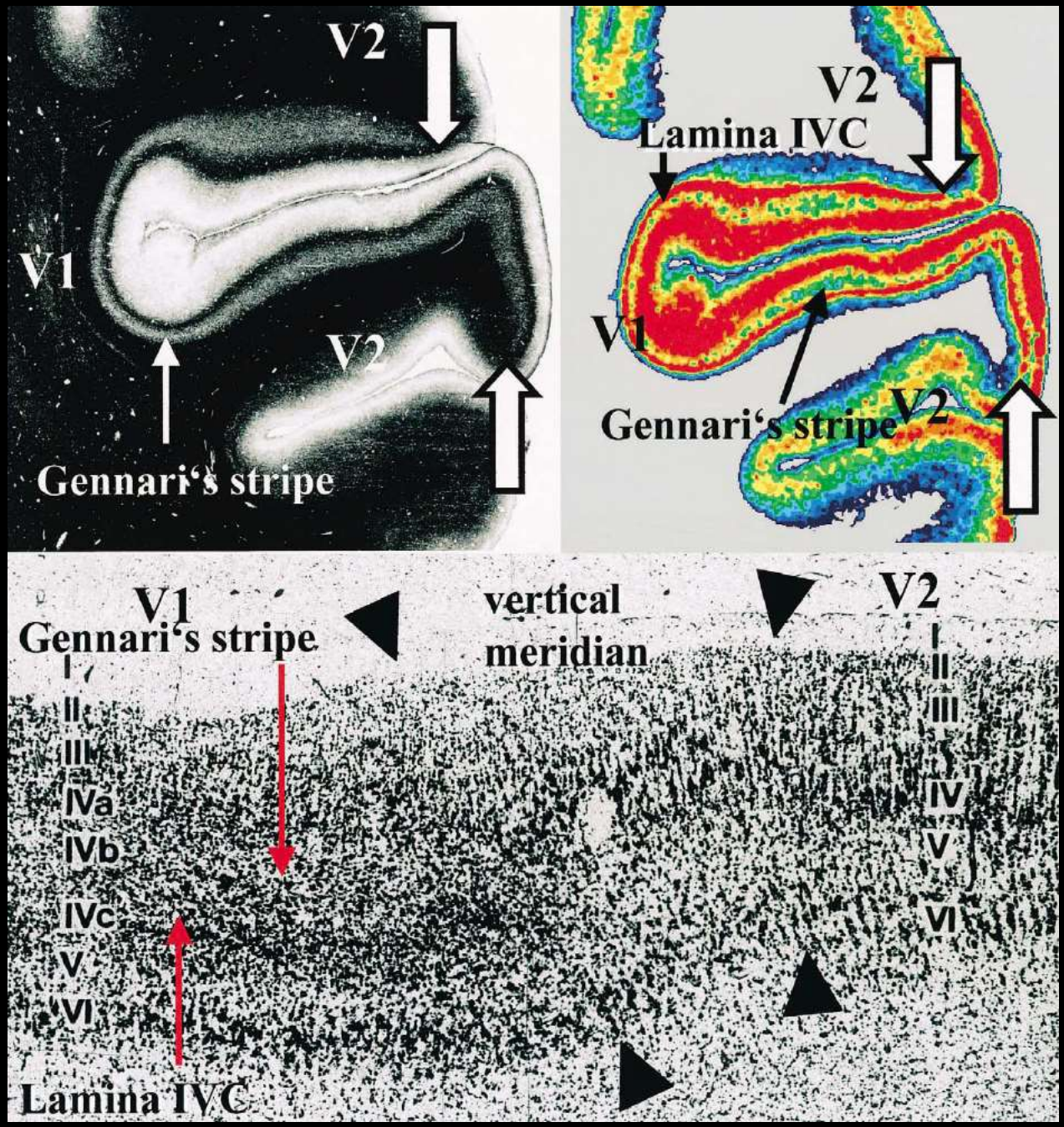


Cell Body Stain (Merker)



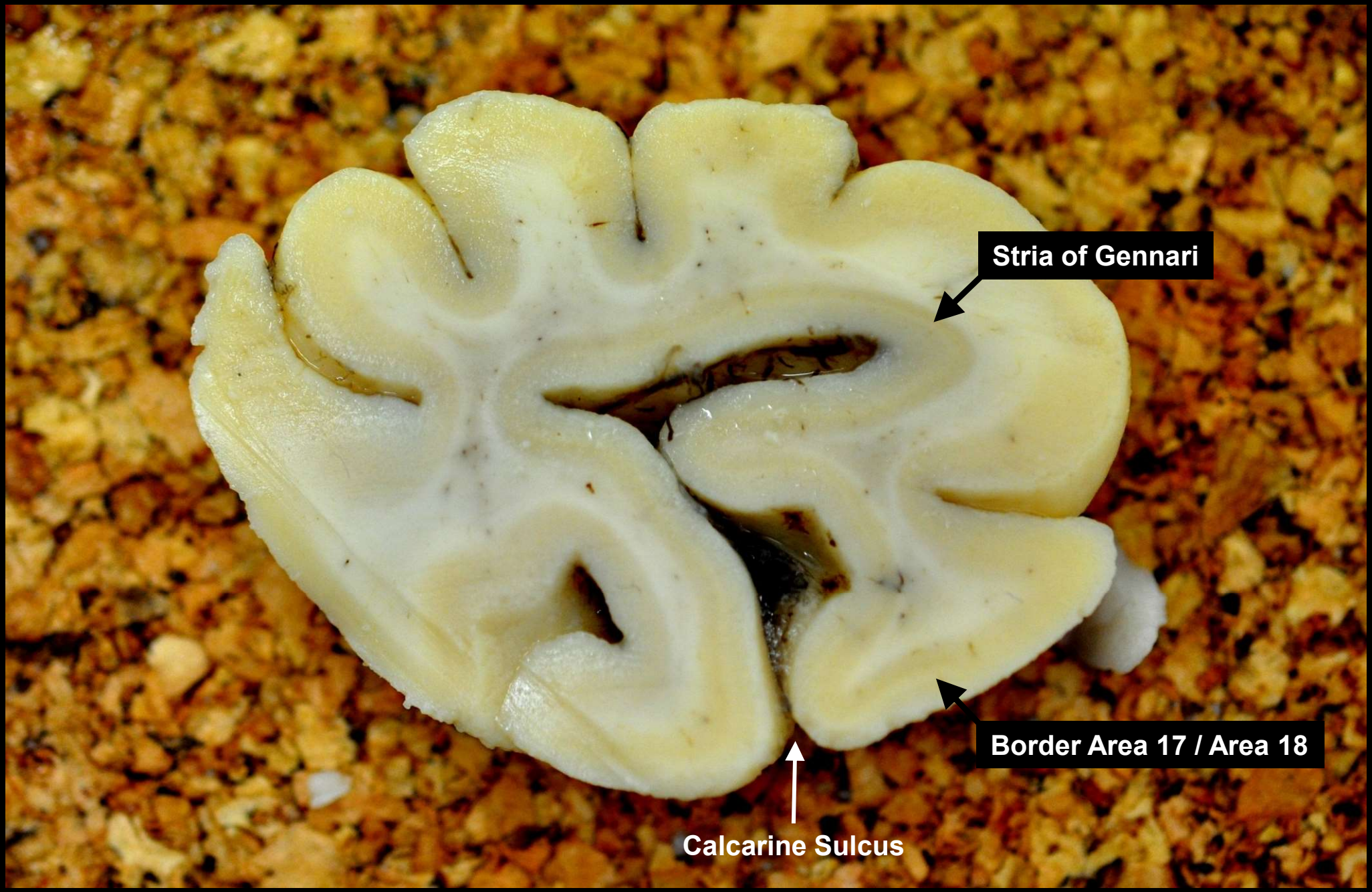
Myelin Stain (Gallyas)

V1: Cytoarchitecture and Myeloarchitecture

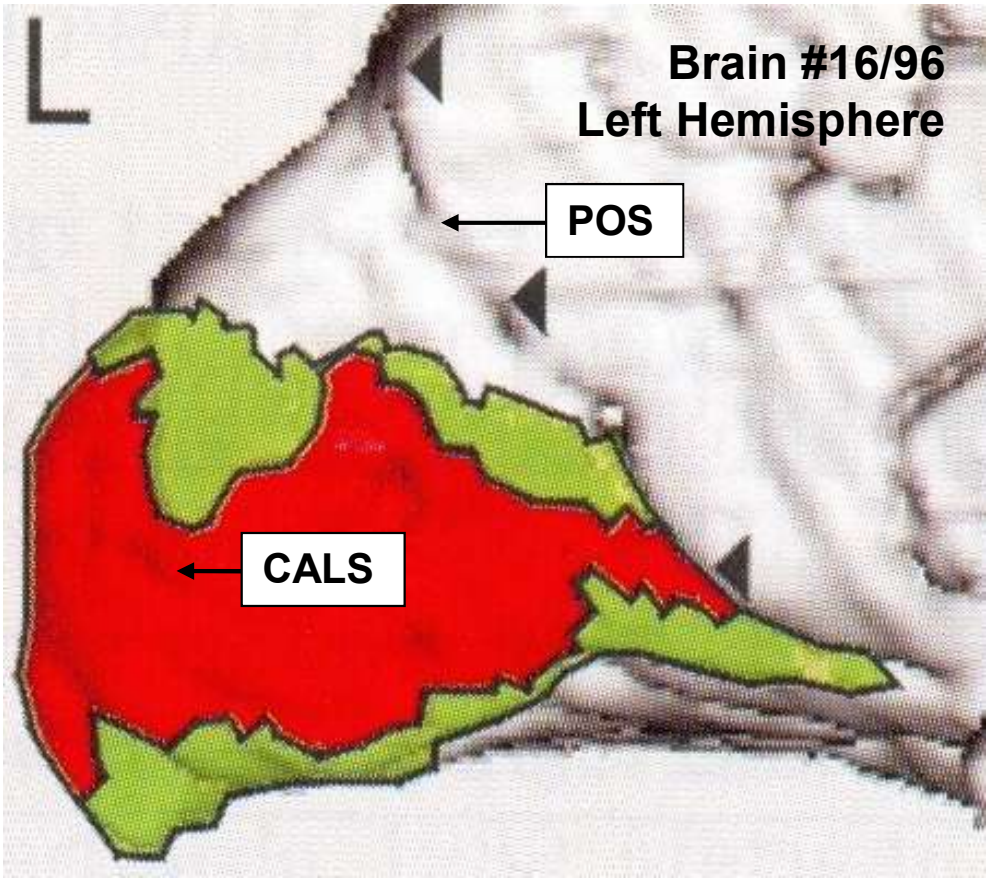


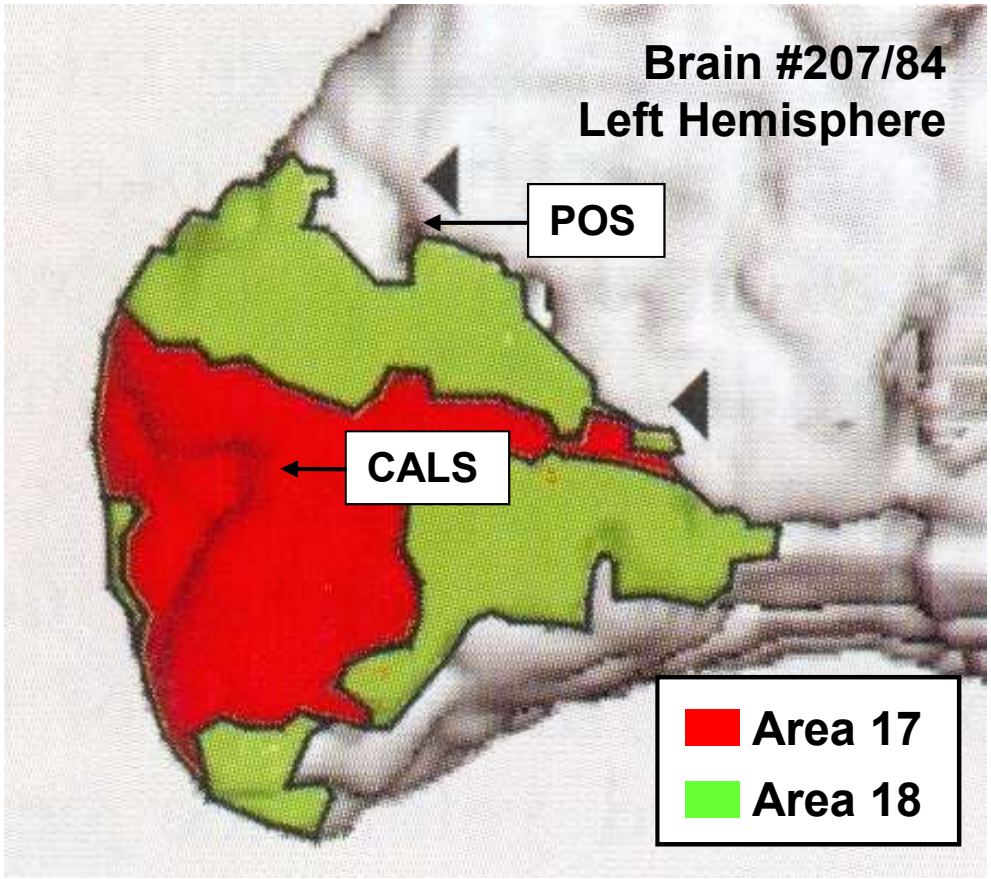
Zilles et al.
European
Neuropsychopharmacology
2002

V1: Stria of Gennari



V1 and V2: Interindividual Variability

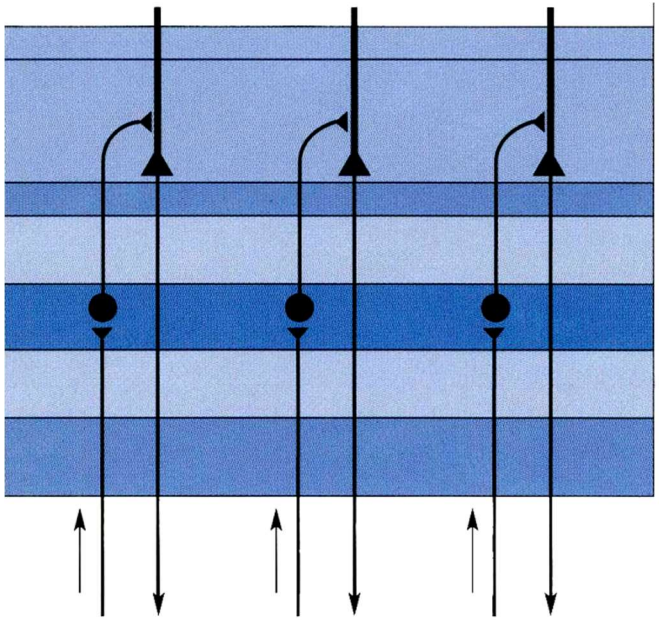


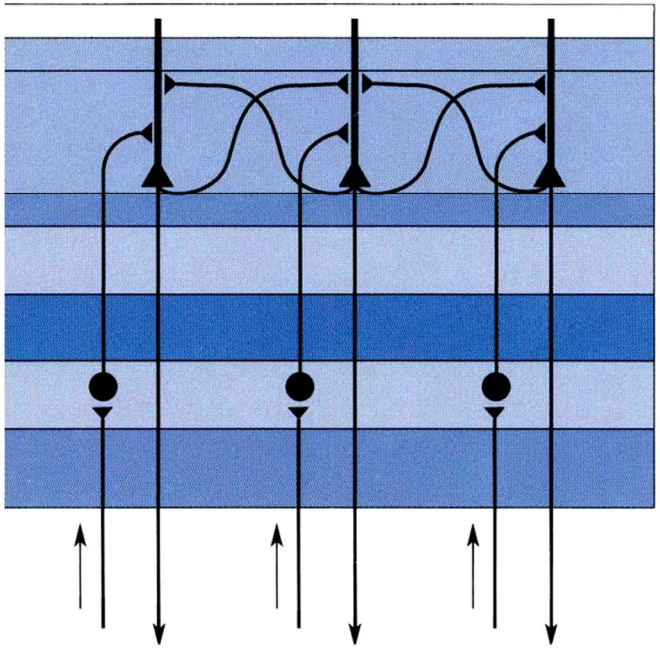


CALS: Calcarine Sulcus
POS: Parieto-Occipital Sulcus

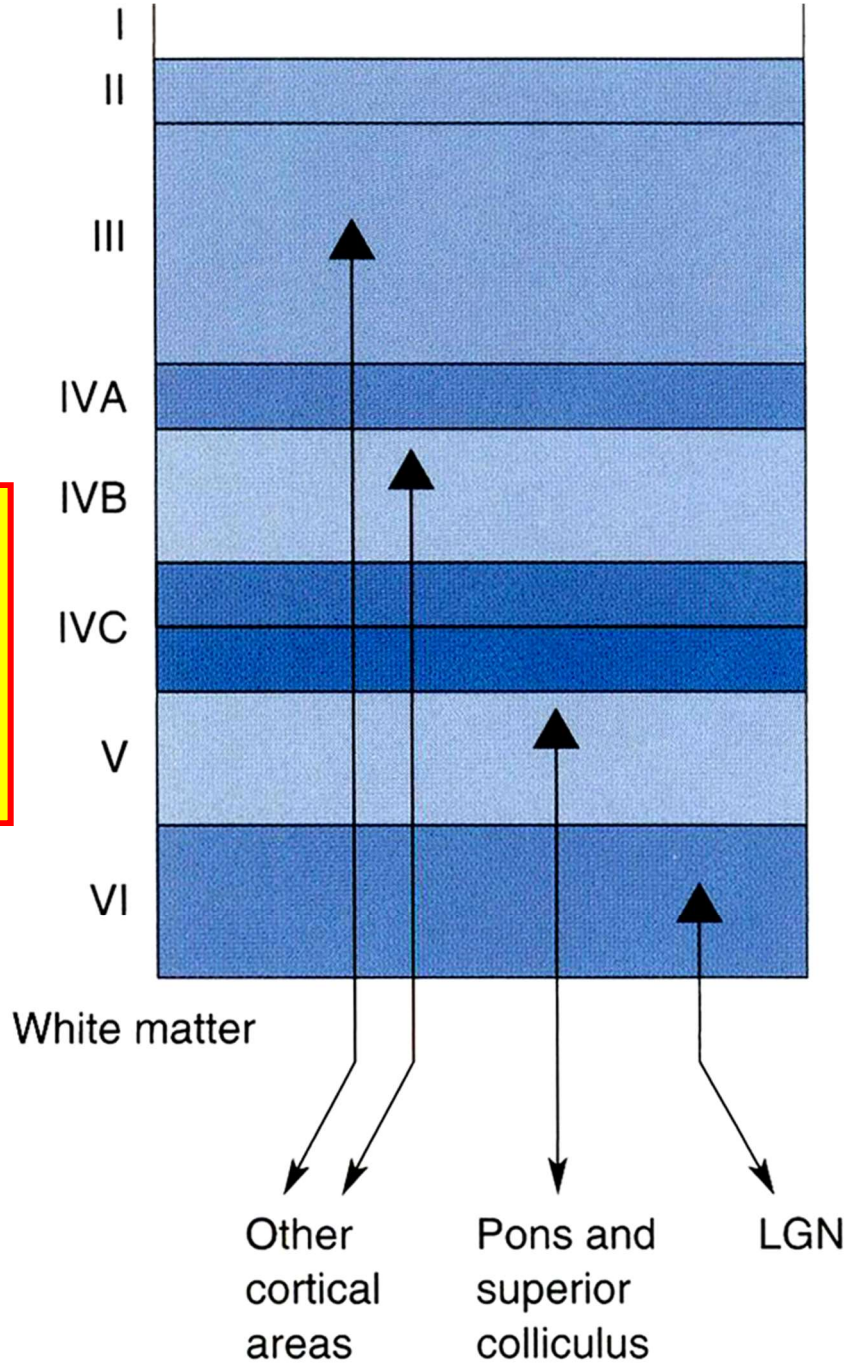
Amunts et al.
NeuroImage 2000

V1: Connectivity



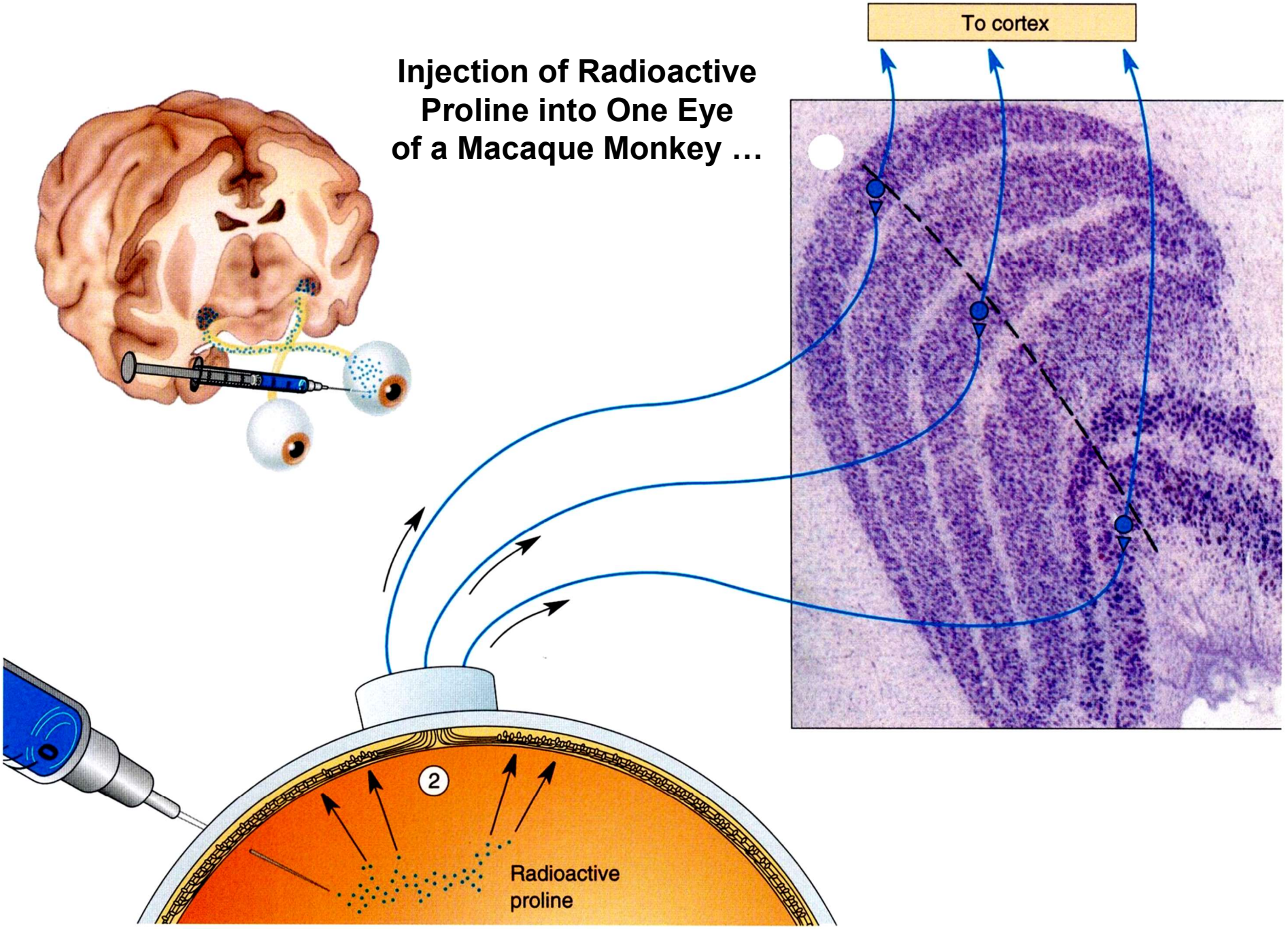


LGN Neurons
↓
Spiny Stellate Cells in Layer IVC

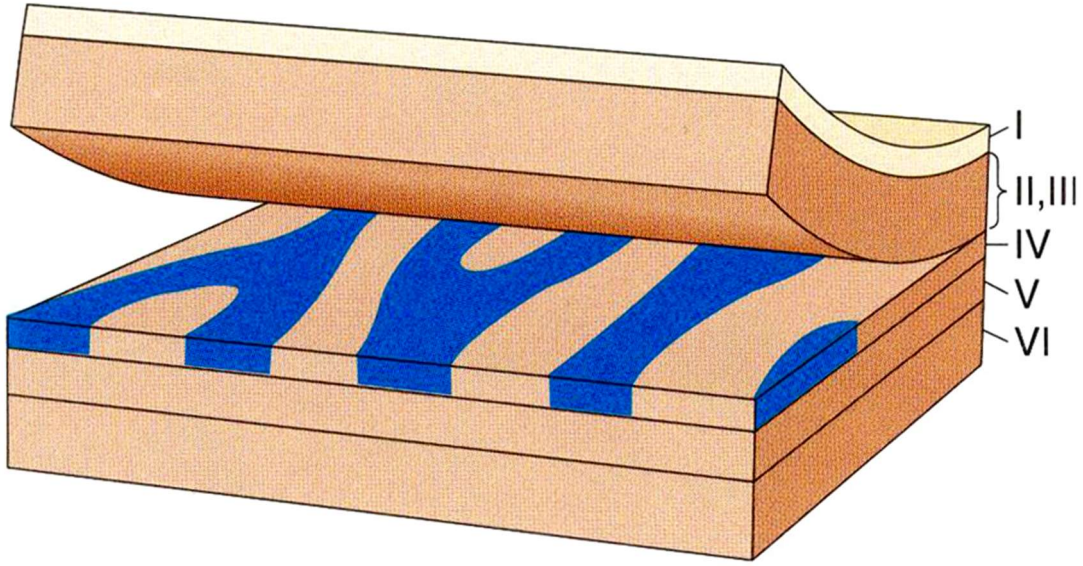


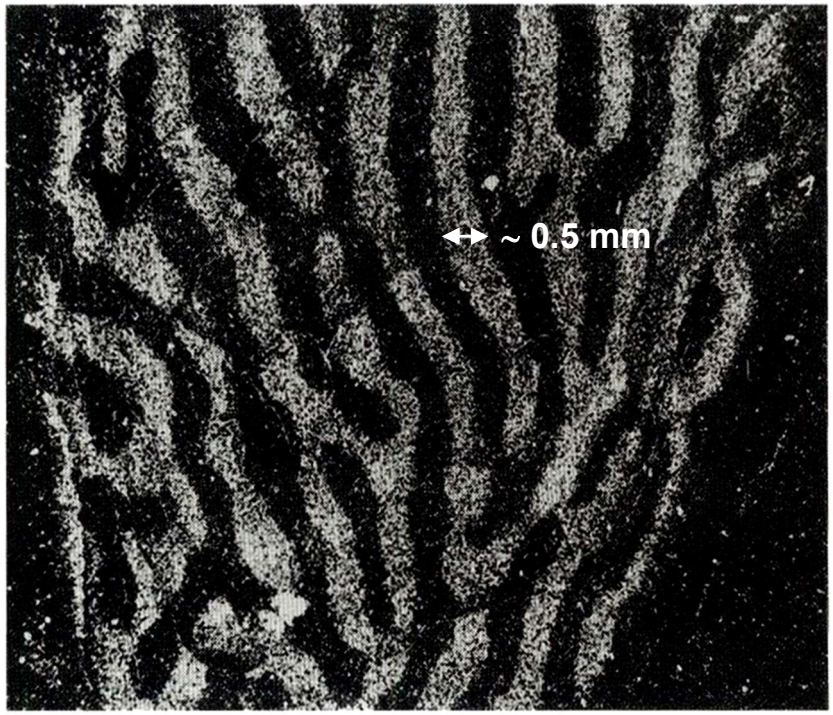
V1: Ocular Dominance Columns

Injection of Radioactive Proline into One Eye of a Macaque Monkey …



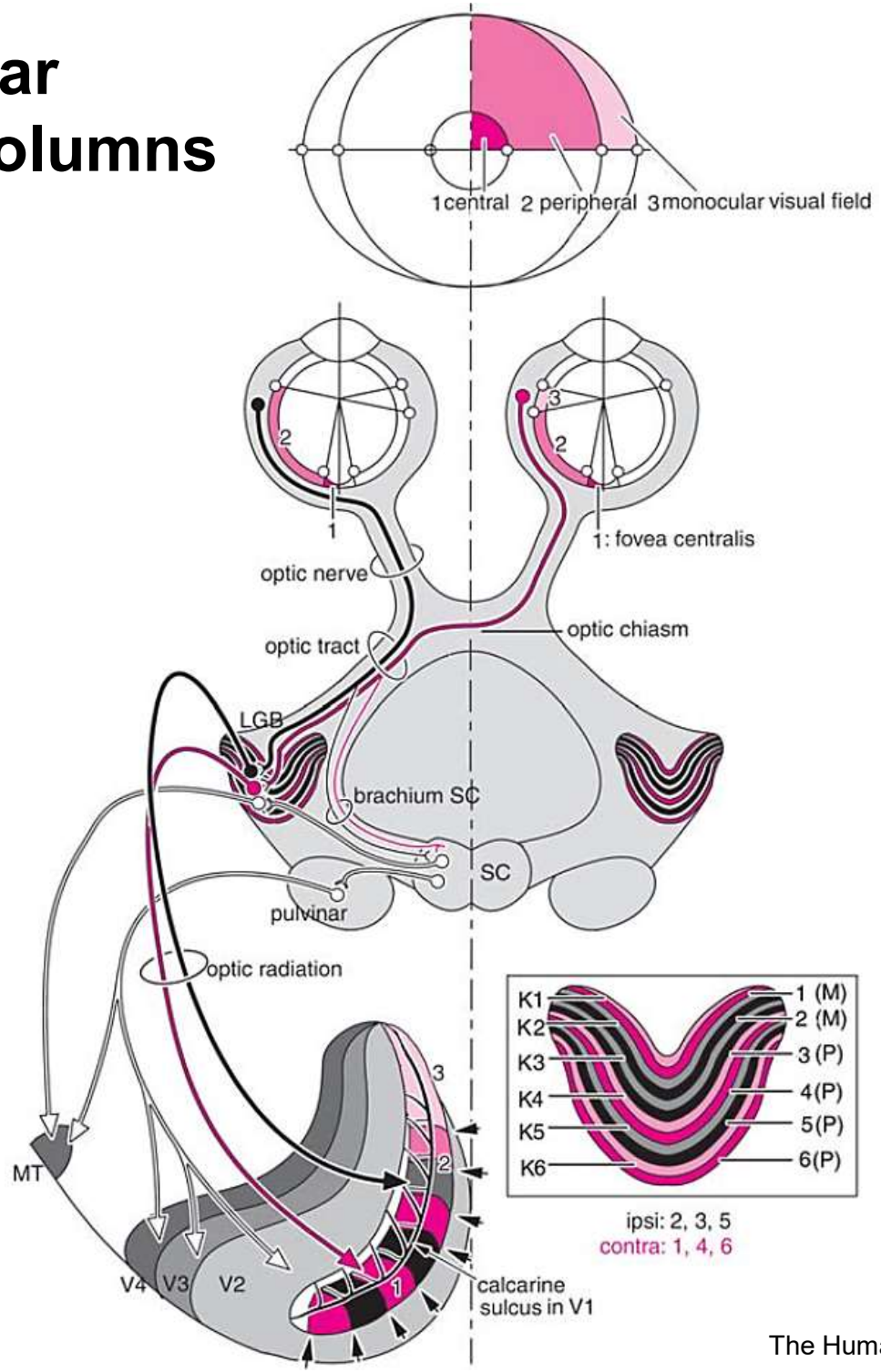
V1: Ocular Dominance Columns





… and Determination of the Location of Radioactivity in Layer IVC with Autoradiography.

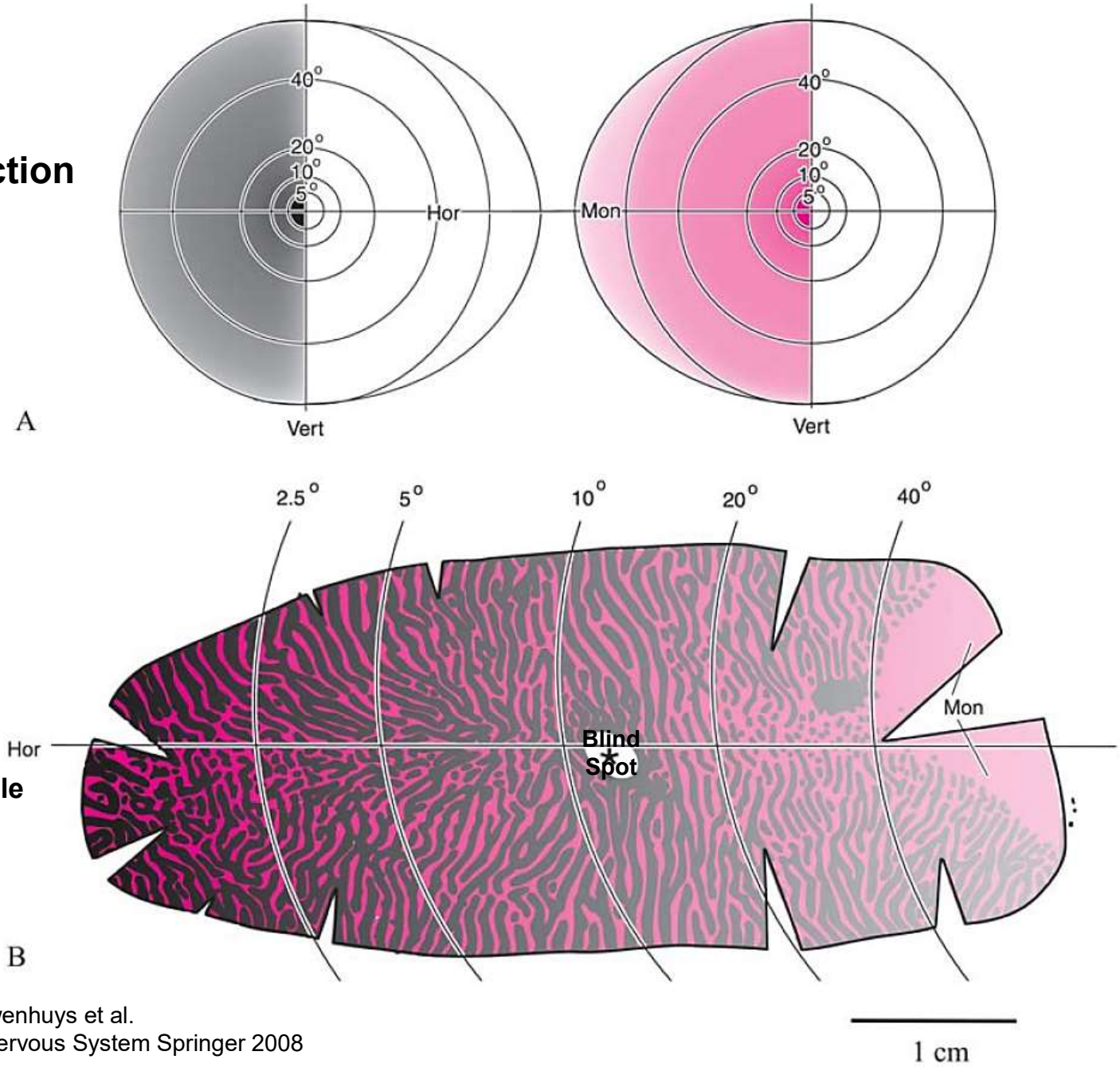
V1: Ocular Dominance Columns



Nieuwenhuys et al.
The Human Central Nervous System Springer 2008

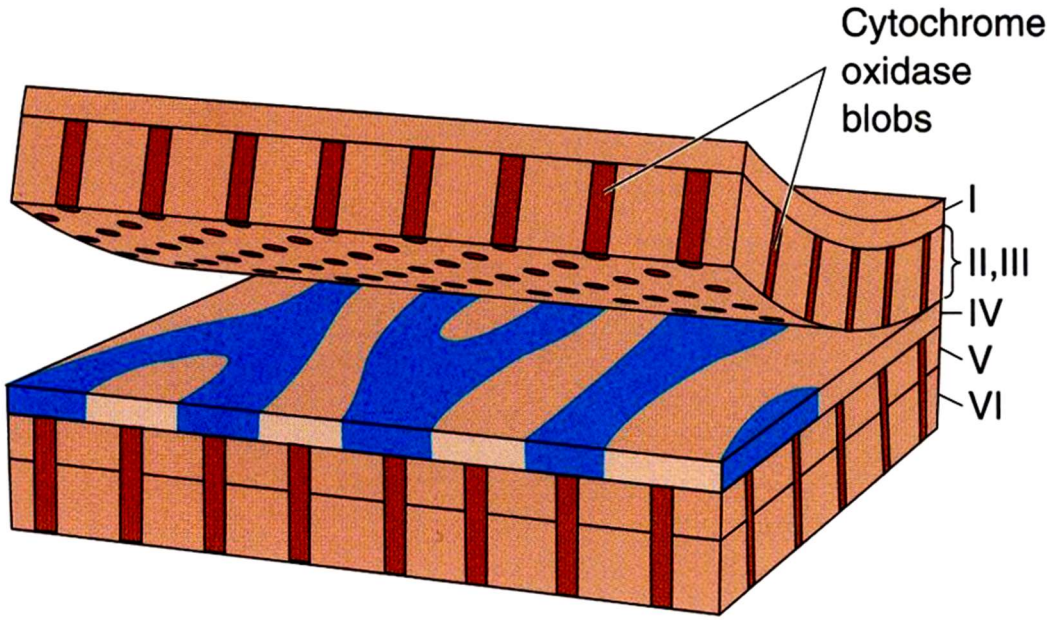
V1: Ocular Dominance Columns

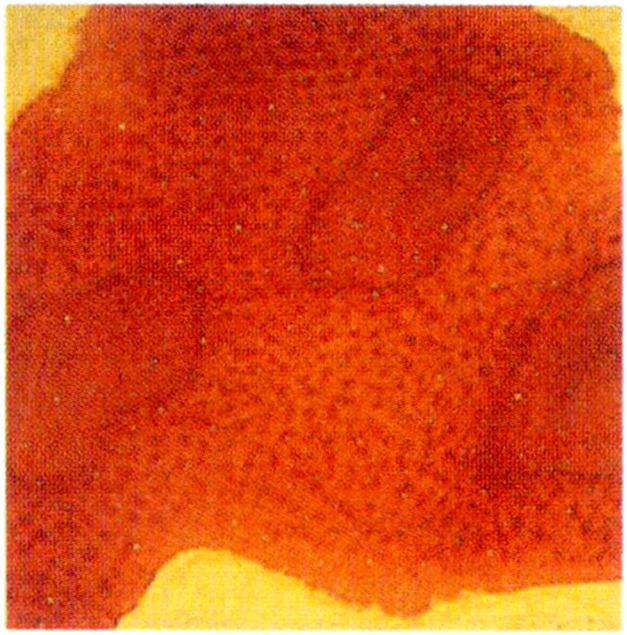
- **Macaque**
- **Left V1**
- **Computer Reconstruction**



Nieuwenhuys et al.
The Human Central Nervous System Springer 2008

V1: Cytochrome Oxidase Blobs

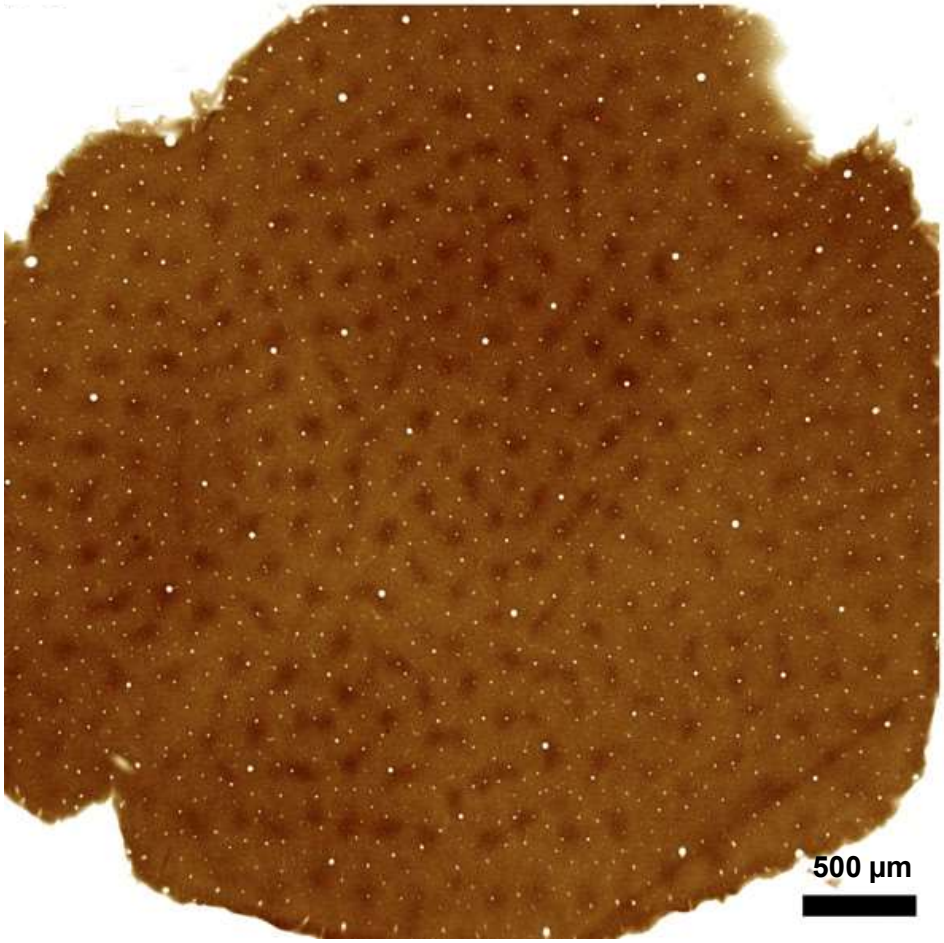


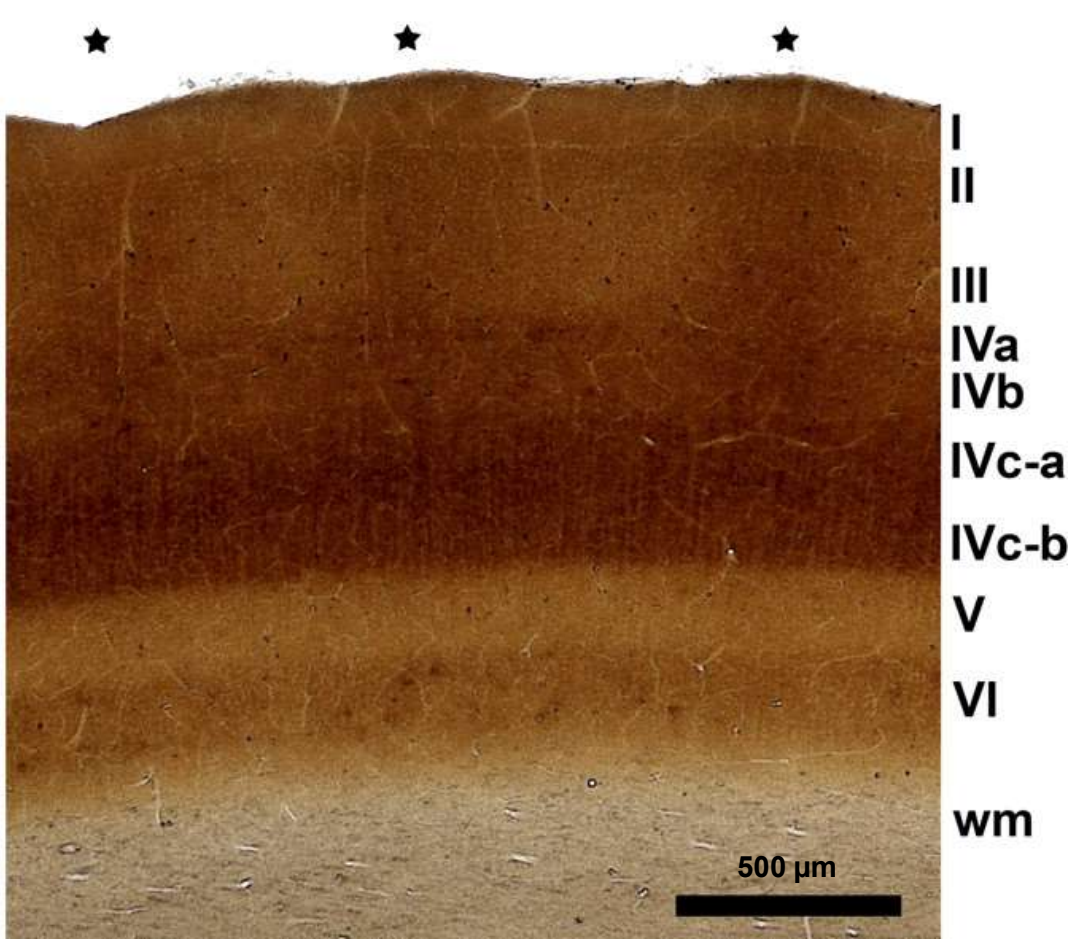


Histochemical Stain for
<u>Cytochrome Oxidase</u> (CO)
(Mitochondrial Enyzme
Used for Cell Metabolism)
↓
Columnar Pattern
in Layers II, III, V, and VI:
<u>Blobs</u> (CO-Rich)
<u>Interblobs</u> (CO-Poor)

V1: Cytochrome Oxidase Blobs

- **Squirrel and Macaque Monkey**
- **Cytochrome Oxidase Histochemistry**



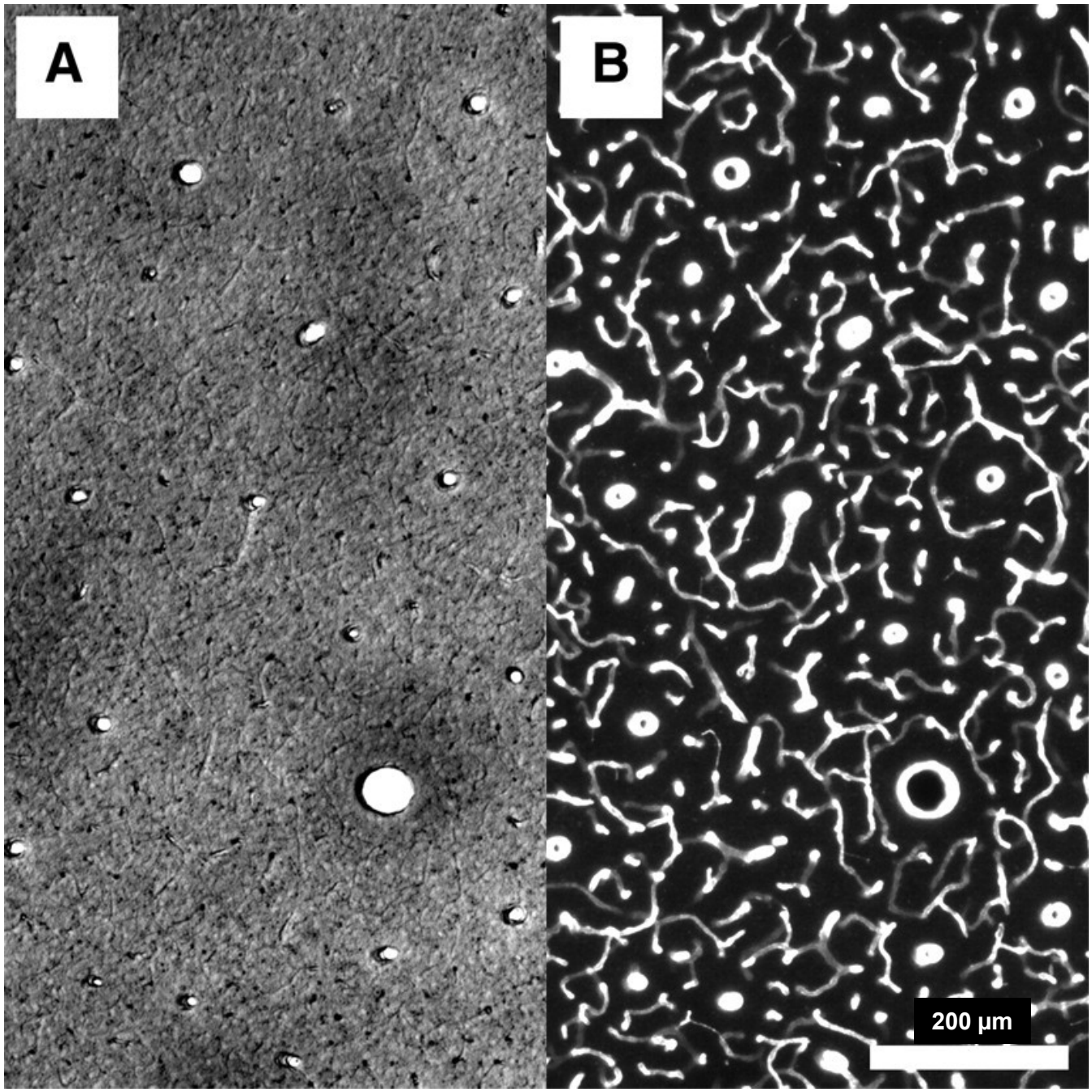


Keller et al.
Journal of Neuroscience 2011

V1: Cytochrome Oxidase Blobs

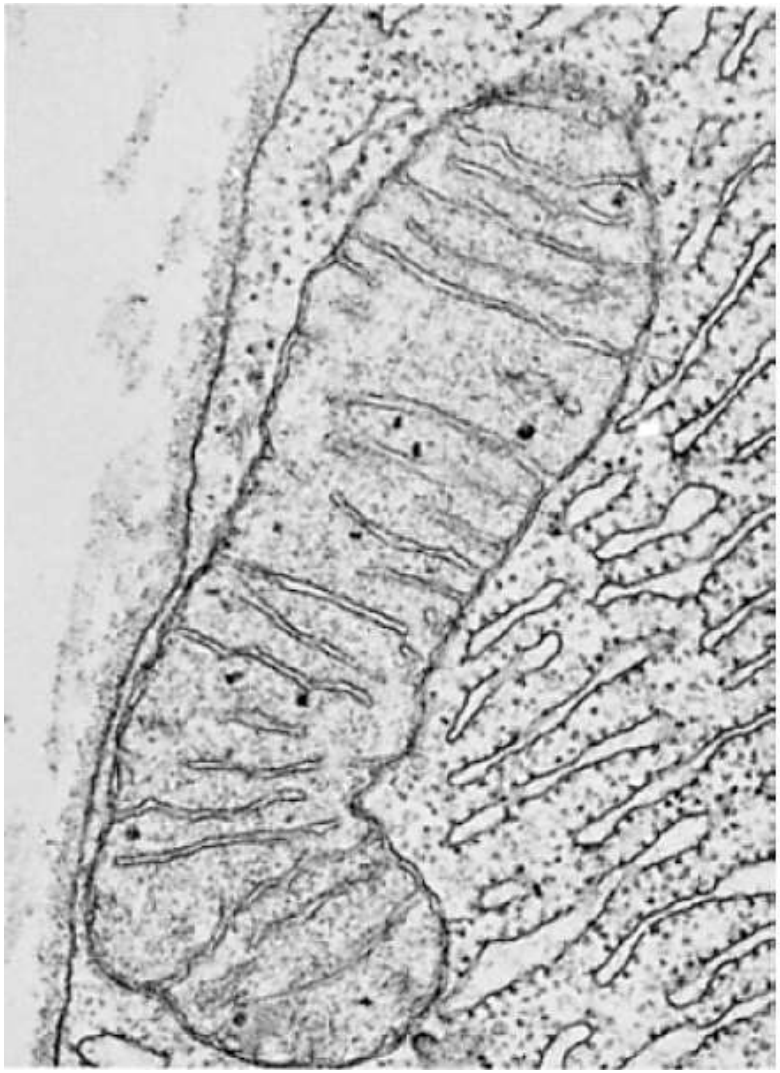
- Squirrel Monkey
- Double Staining:
  - Cytochrome Oxidase Histochemistry (A) &
  - Collagen Type IV Immunofluorescence (B)

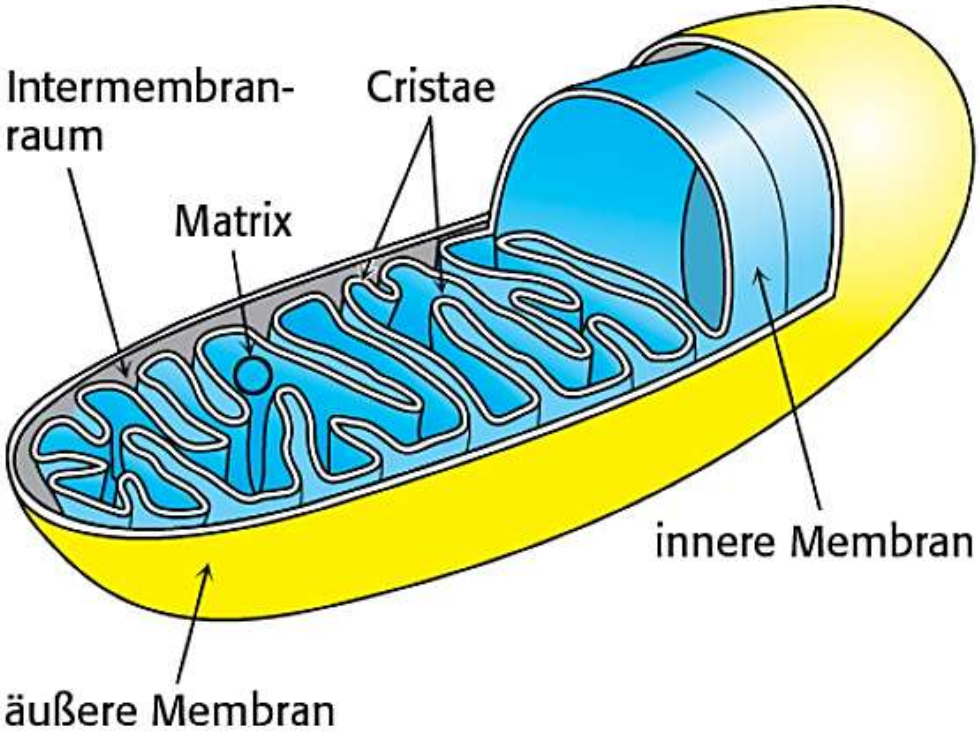
Vascular Density in Blobs ~ 4.5% Higher than in Interblob Regions



Keller et al.
Journal of Neuroscience 2011

Mitochondrion: Ultrastructure

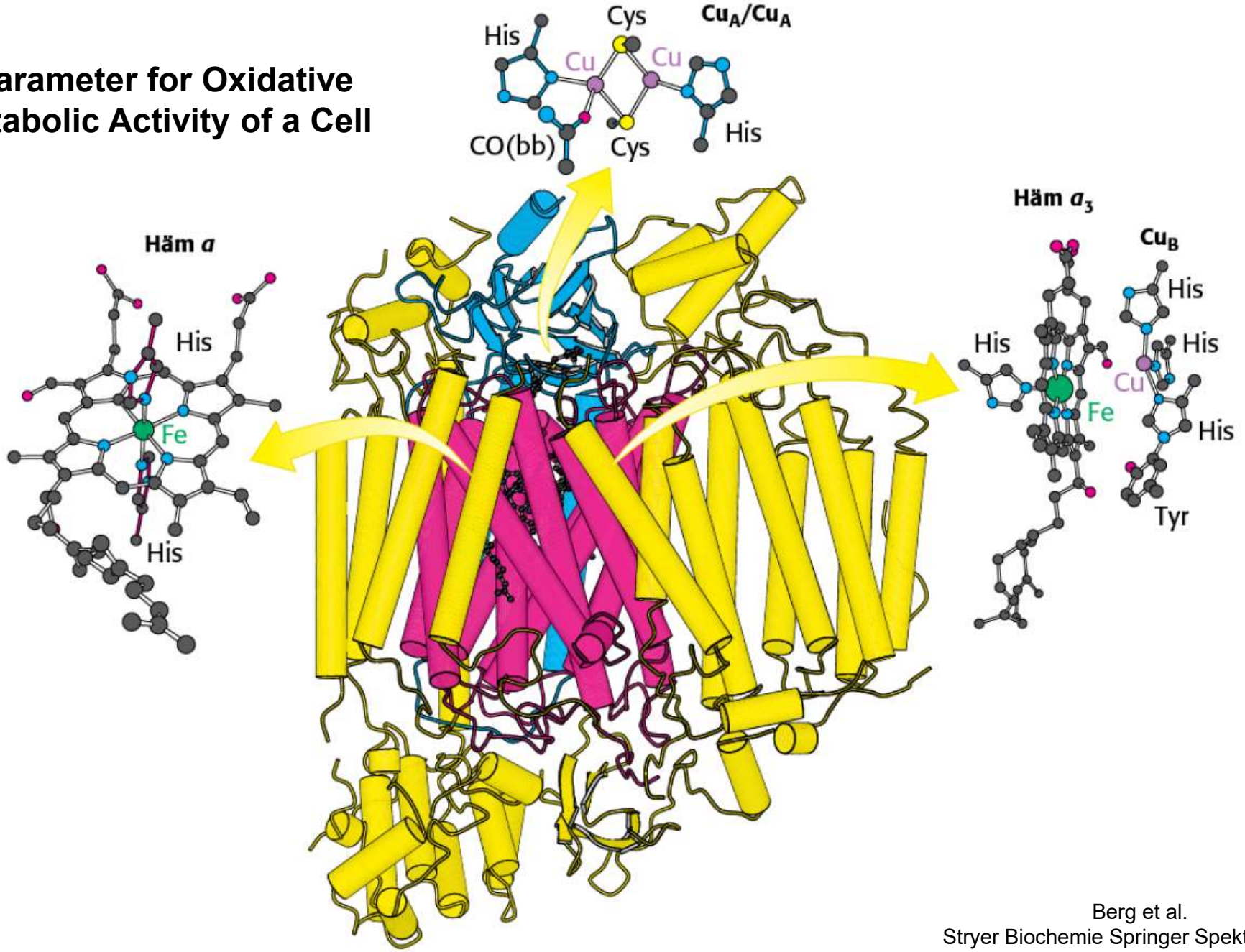




Berg et al.
Stryer Biochemie Springer Spektrum 2013

Cytochrome-C-Oxidase

Parameter for Oxidative Metabolic Activity of a Cell



Berg et al.
Stryer Biochemie Springer Spektrum 2013

Cytochrome-C-Oxidase Histochemistry

Anleitung A18.14

Cytochrom-C-Oxidase

Herstellen des Inkubationsmediums:

1. 10–15 mg p-Aminodiphenylamin (die freie Base, nicht das Hydrochlorid) und
2. 10–15 mg 1-Hydroxy-2-naphthylsäure oder Naphthol-AS-LG in 0,5 ml Dimethylformamid oder 100 % Ethanol lösen.
3. Dazu 50 ml 0,05 M Phosphat(Sörensen)- oder Tris-HCl-Puffer pH 7,2–7,4 mischen (Puffertabelle im Anhang). Alles gut mischen und filtrieren.

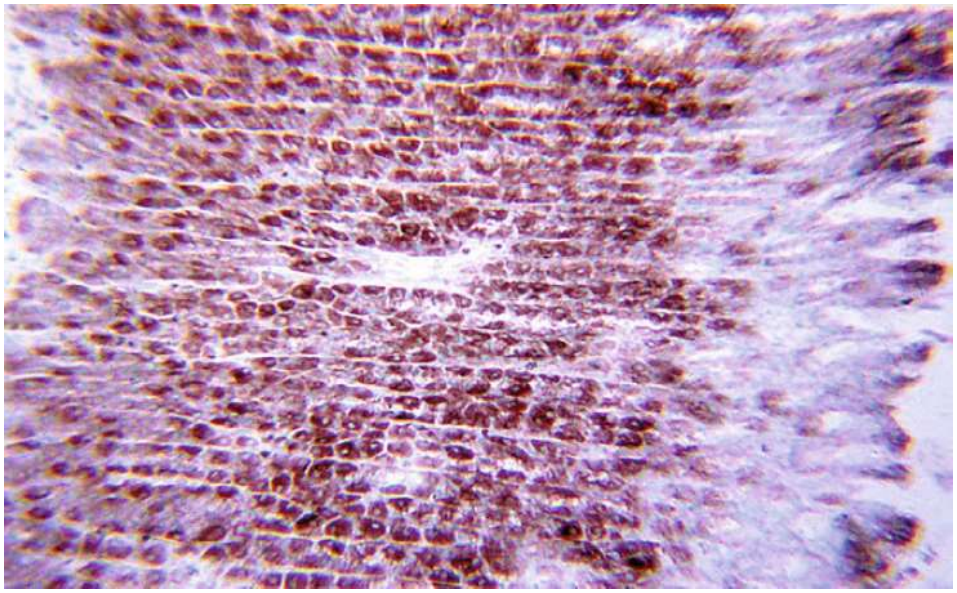
Hemmstoffe: Kaliumcyanid (0,0065–0,065 %) und Natriumacid (0,0065 %).

Methode:

1. Man inkubiert im Inkubationsmedium ausschließlich unfixierte native Gefrierschnitte bei 37 °C für 30–120 min.
2. Nach der Inkubation kommen die Präparate für 1 h direkt in 1 % Kobaltnitrat (oder Kobaltacetat) in 5 % Formalinlösung, um das Reaktionsprodukt zu stabilisieren.
3. Anschließend wird in Aqua d. gewaschen
4. In Glyceringelatine einschließen.

Ergebnis:

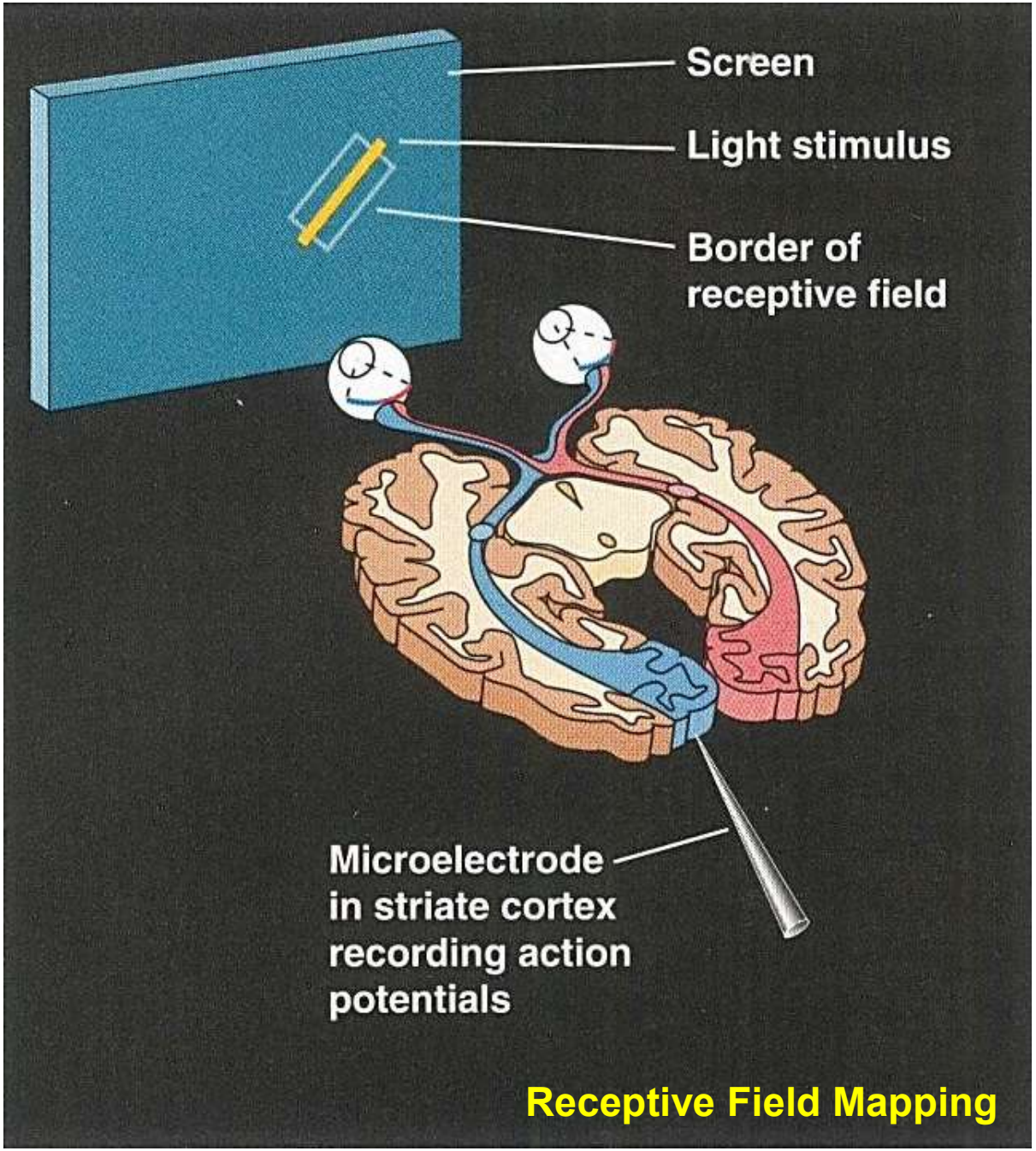
Positive Strukturen färben sich blaubraun bis schwarzbraun.

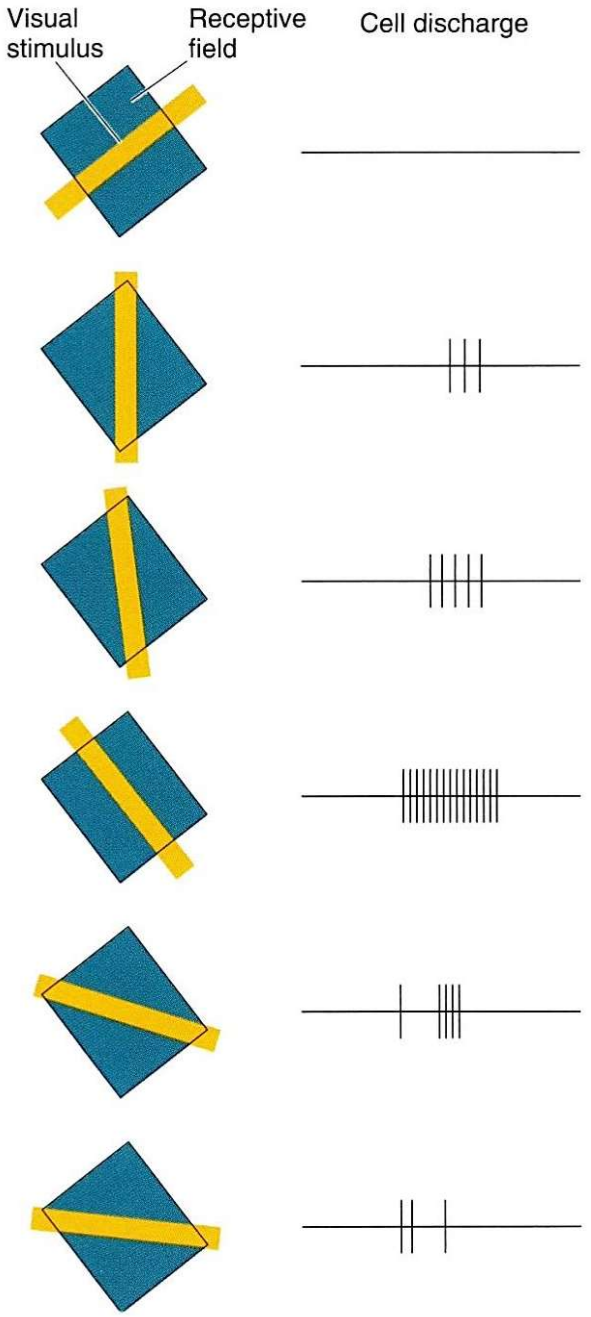


Rat Gastric Mucosa Glands

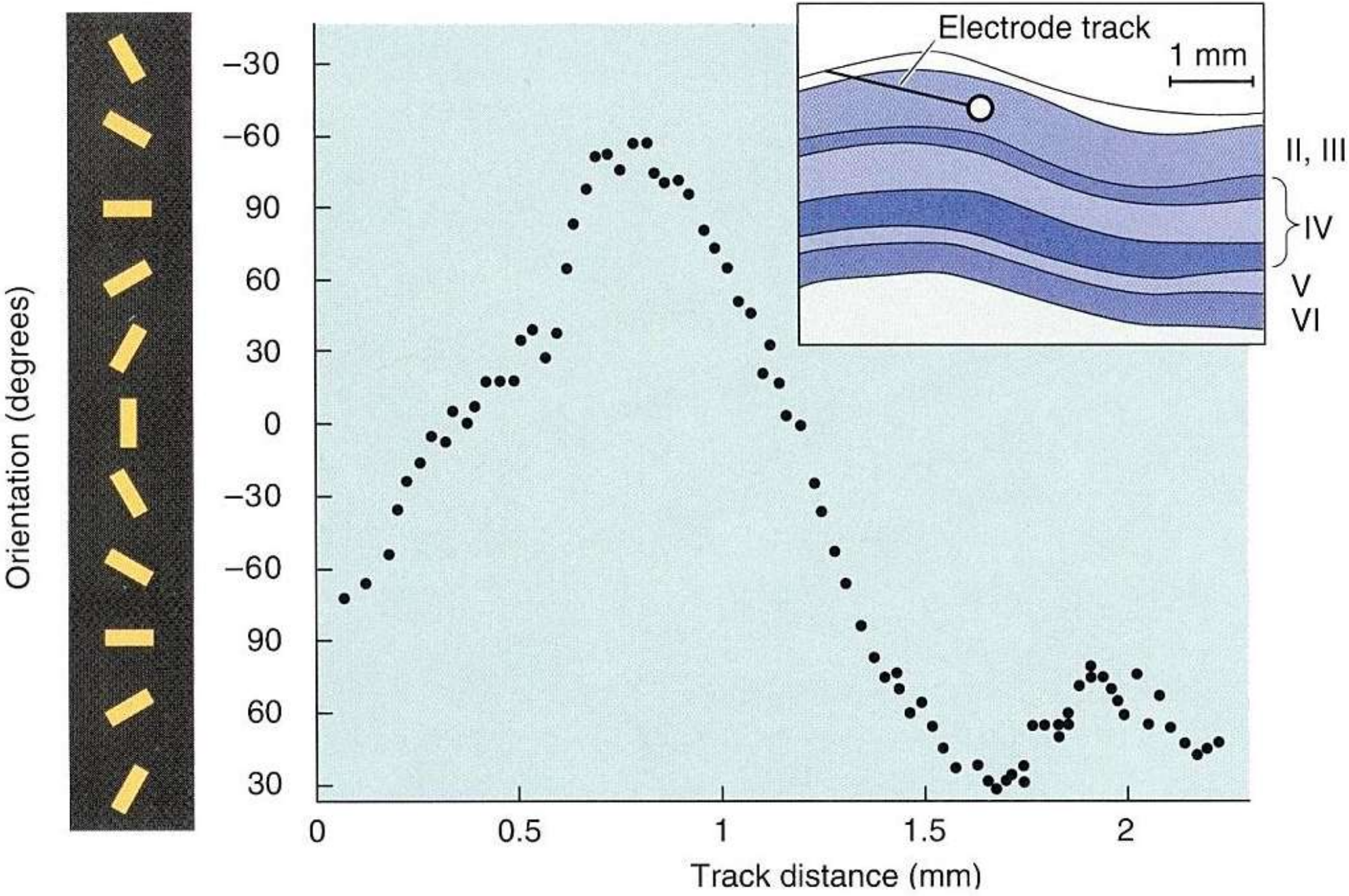
Mulisch et al.
Romeis Mikroskopische Technik
Springer Spektrum 2015

V1: Orientation Columns



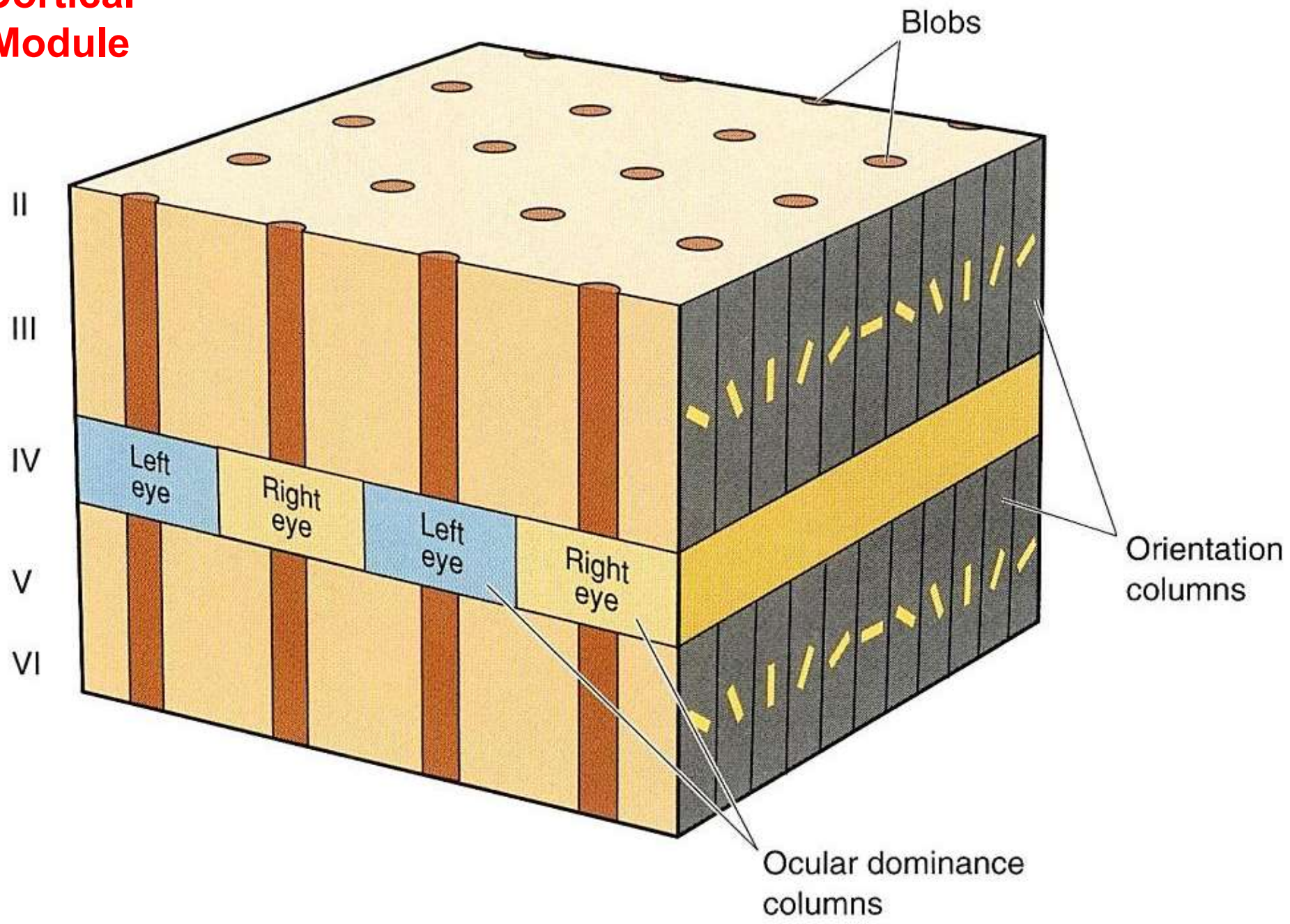


V1: Orientation Columns

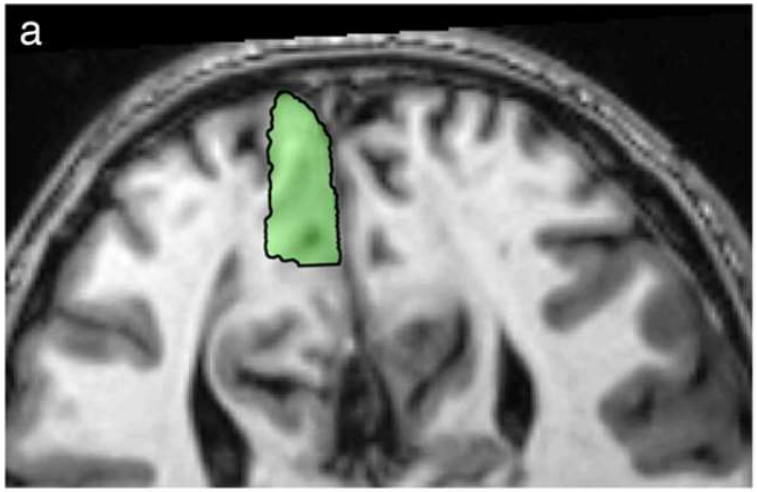


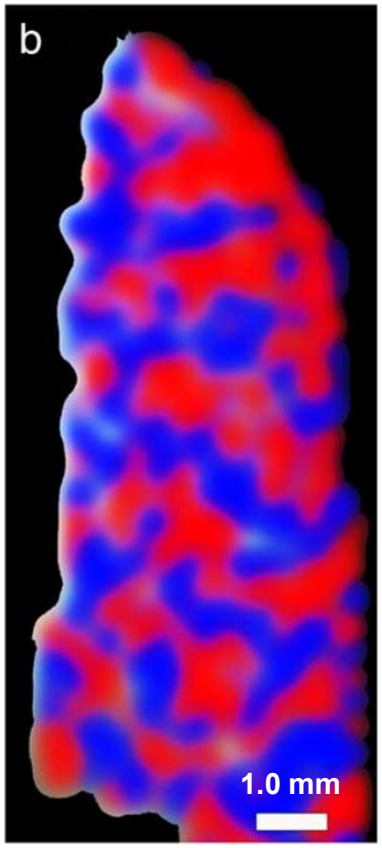
V1: Orientation Columns

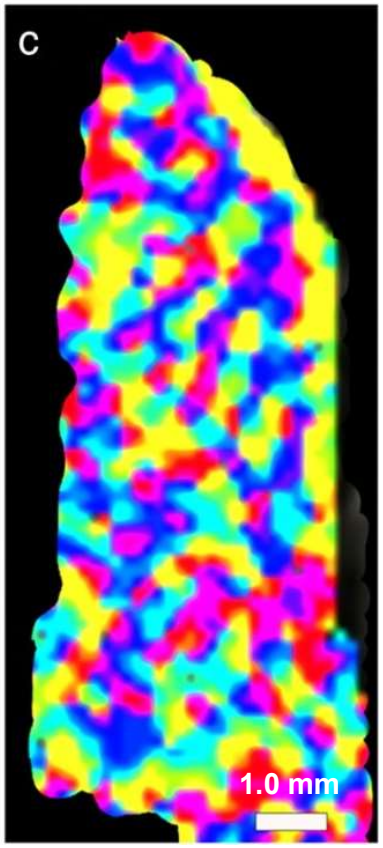
V1 Cortical Module

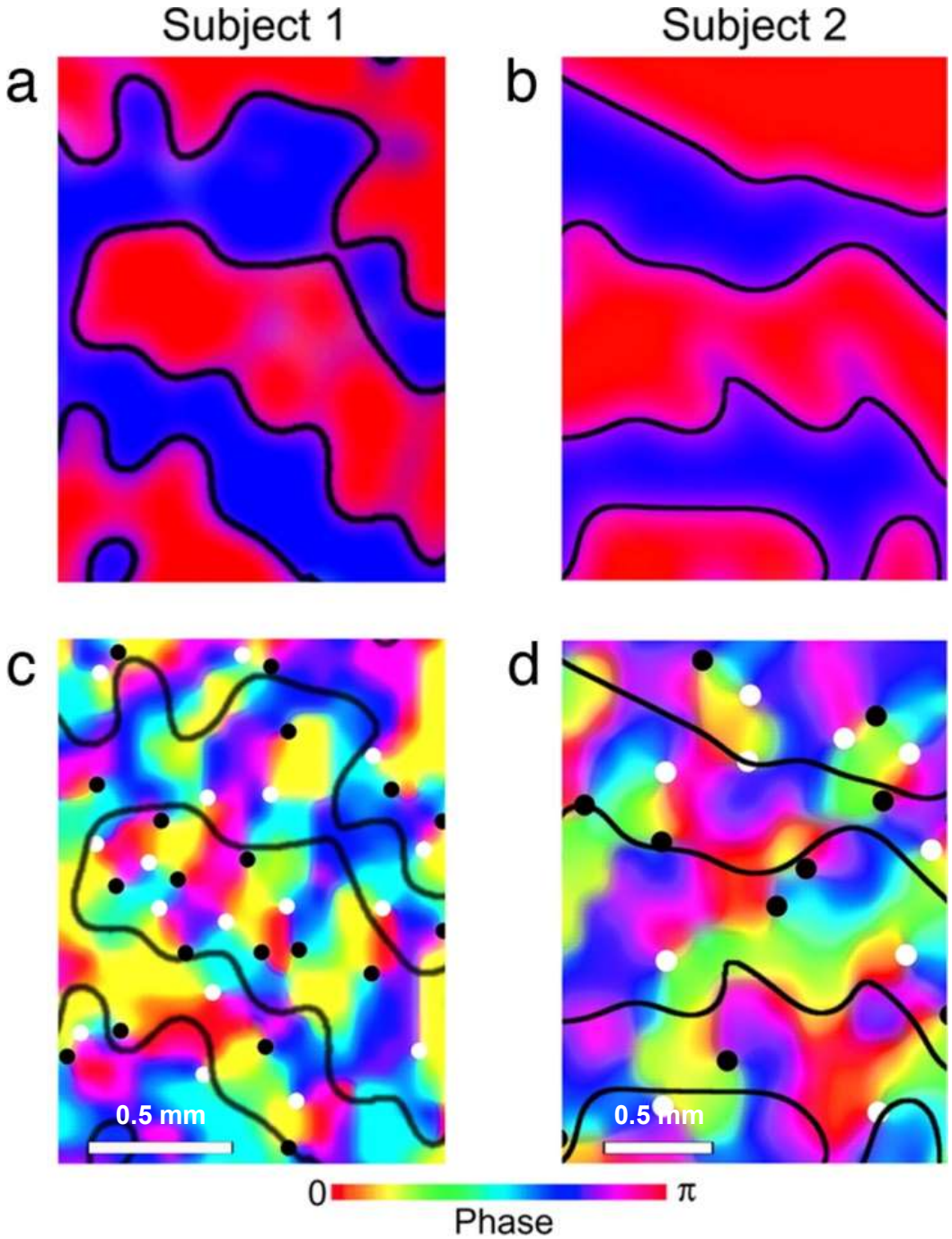


V1: Ocular Dominance and Orientation Columns



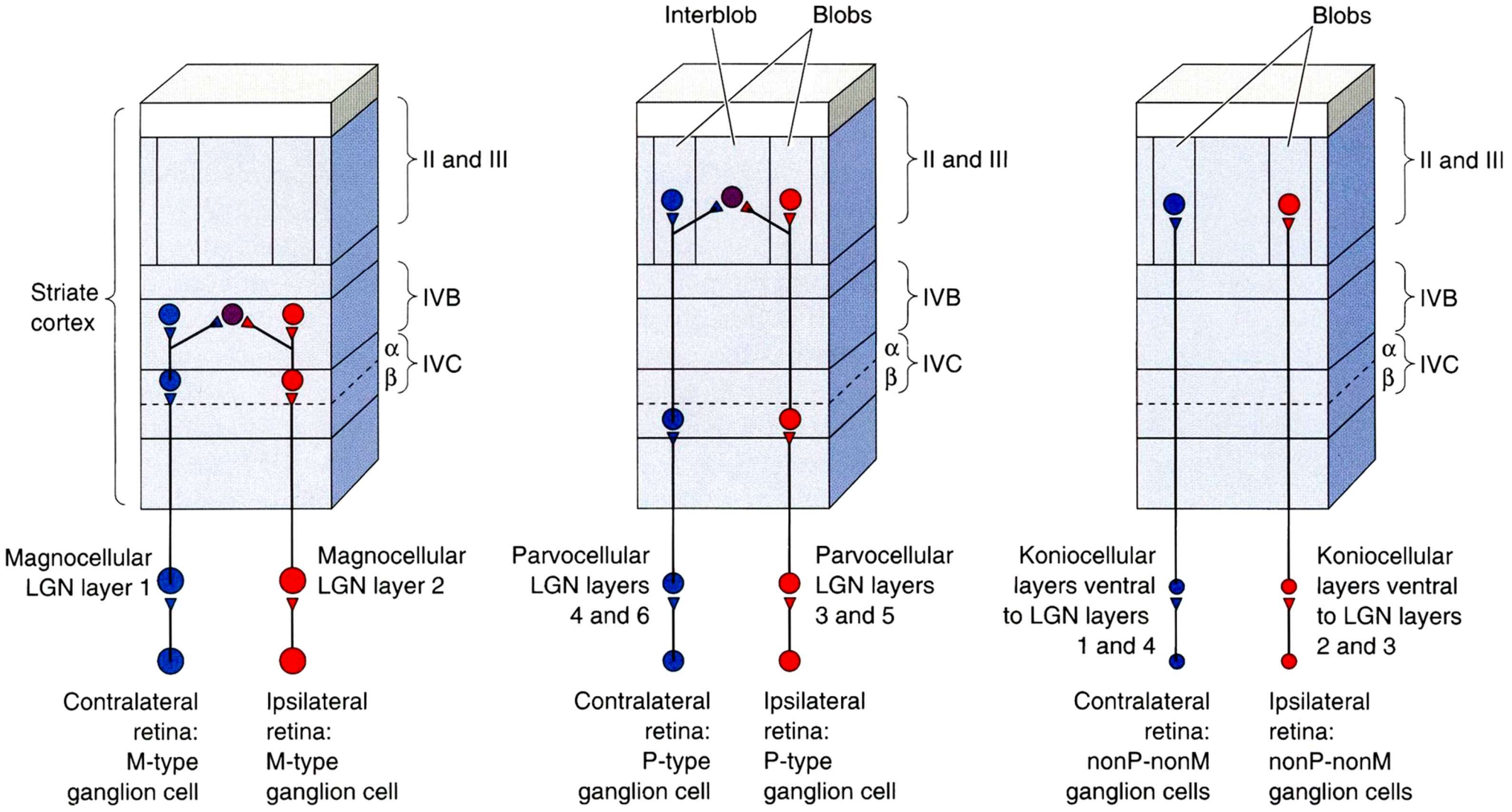






Yacoub et al. Proceedings of the National Academy of Sciences of the United States of America 2008

V1: Putting Things Together

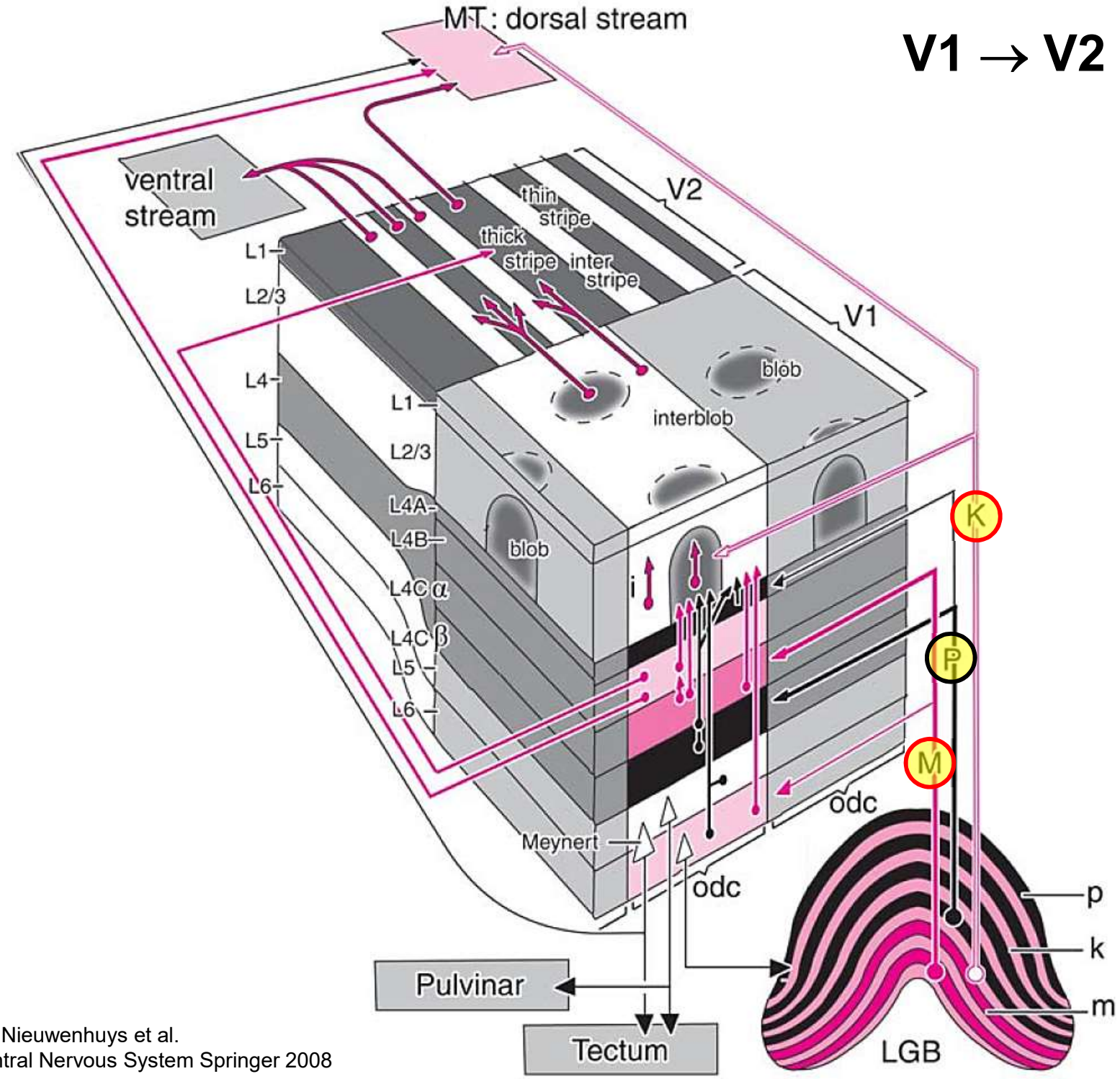


Magnocellular (M) Pathway
Object Motion

Parvocellular (P) Pathway
Object Form

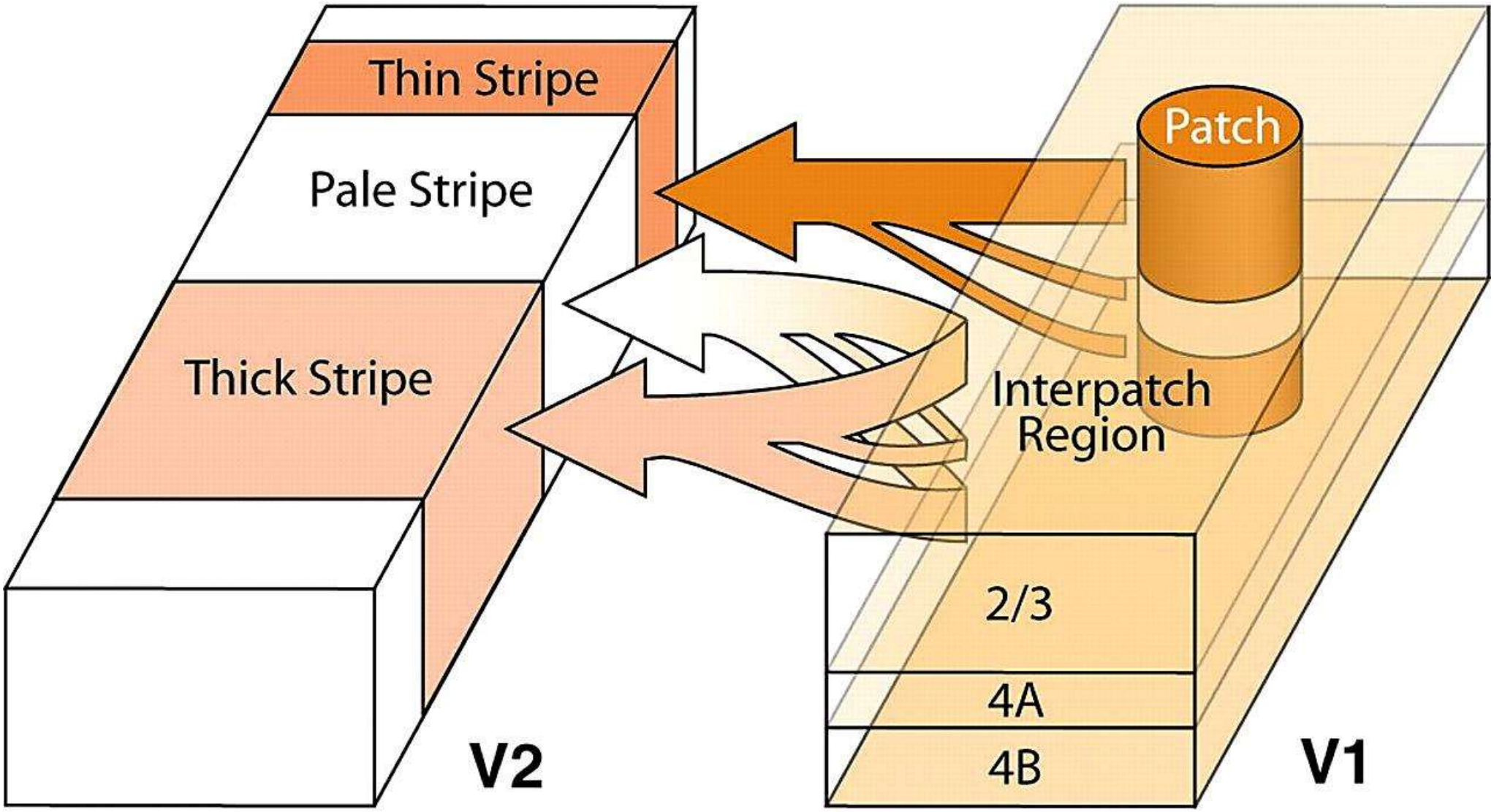
Non M-Non P (K) Pathway
Object Color

V1 → V2



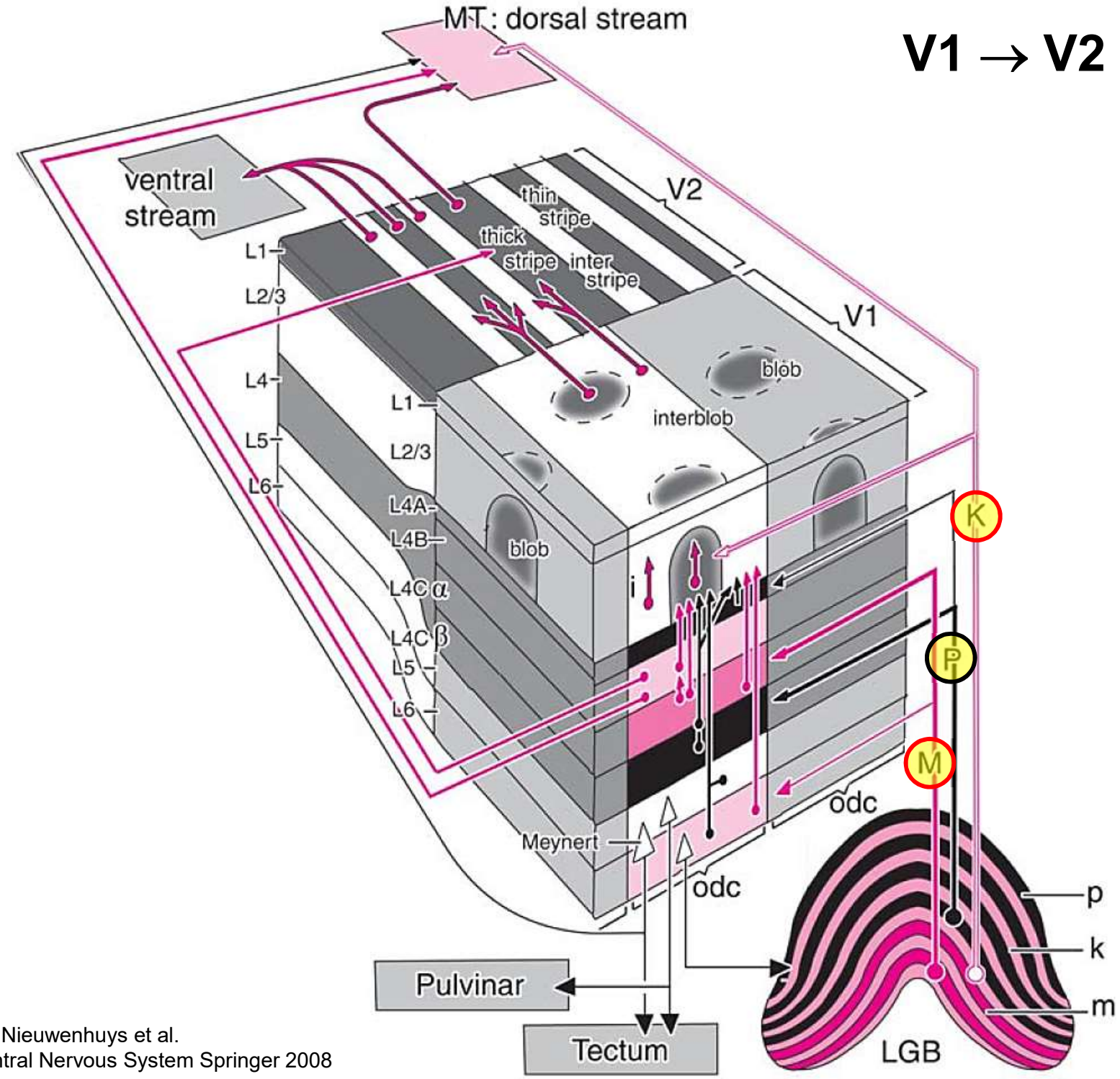
Nieuwenhuys et al.
The Human Central Nervous System Springer 2008

V1 → V2



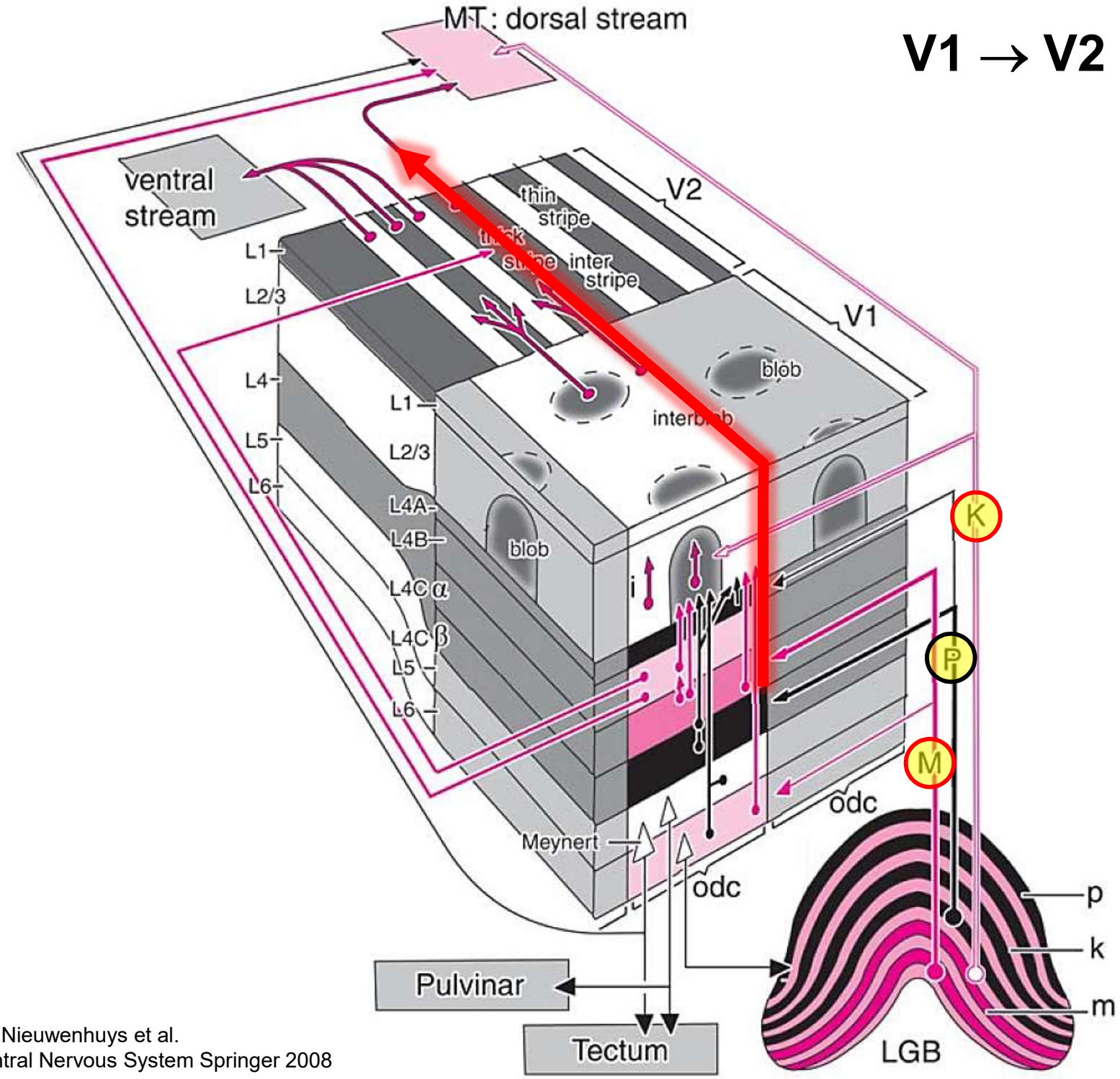
Sincich et al.
Science 2002

V1 → V2



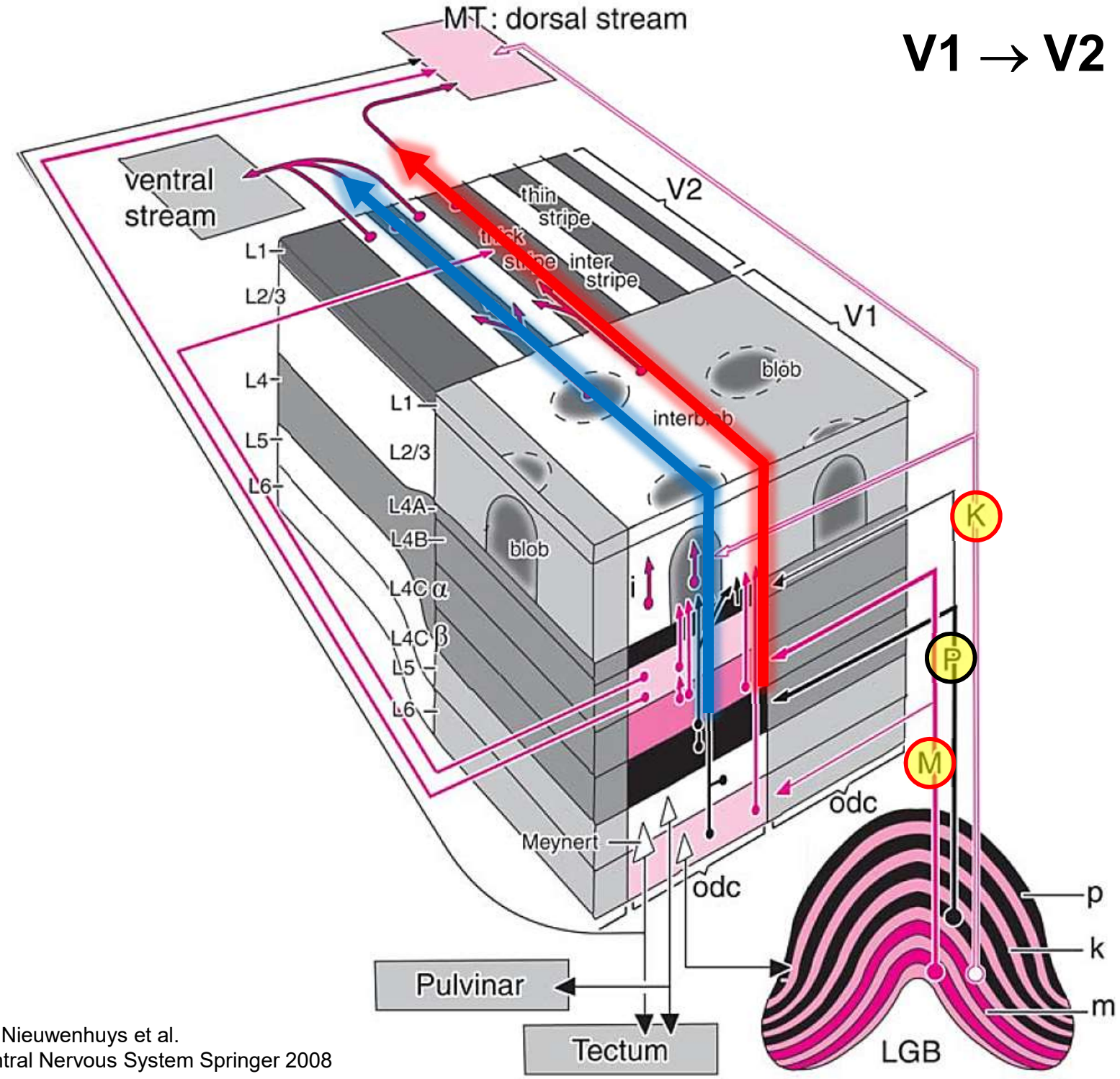
Nieuwenhuys et al.
The Human Central Nervous System Springer 2008

V1 → V2



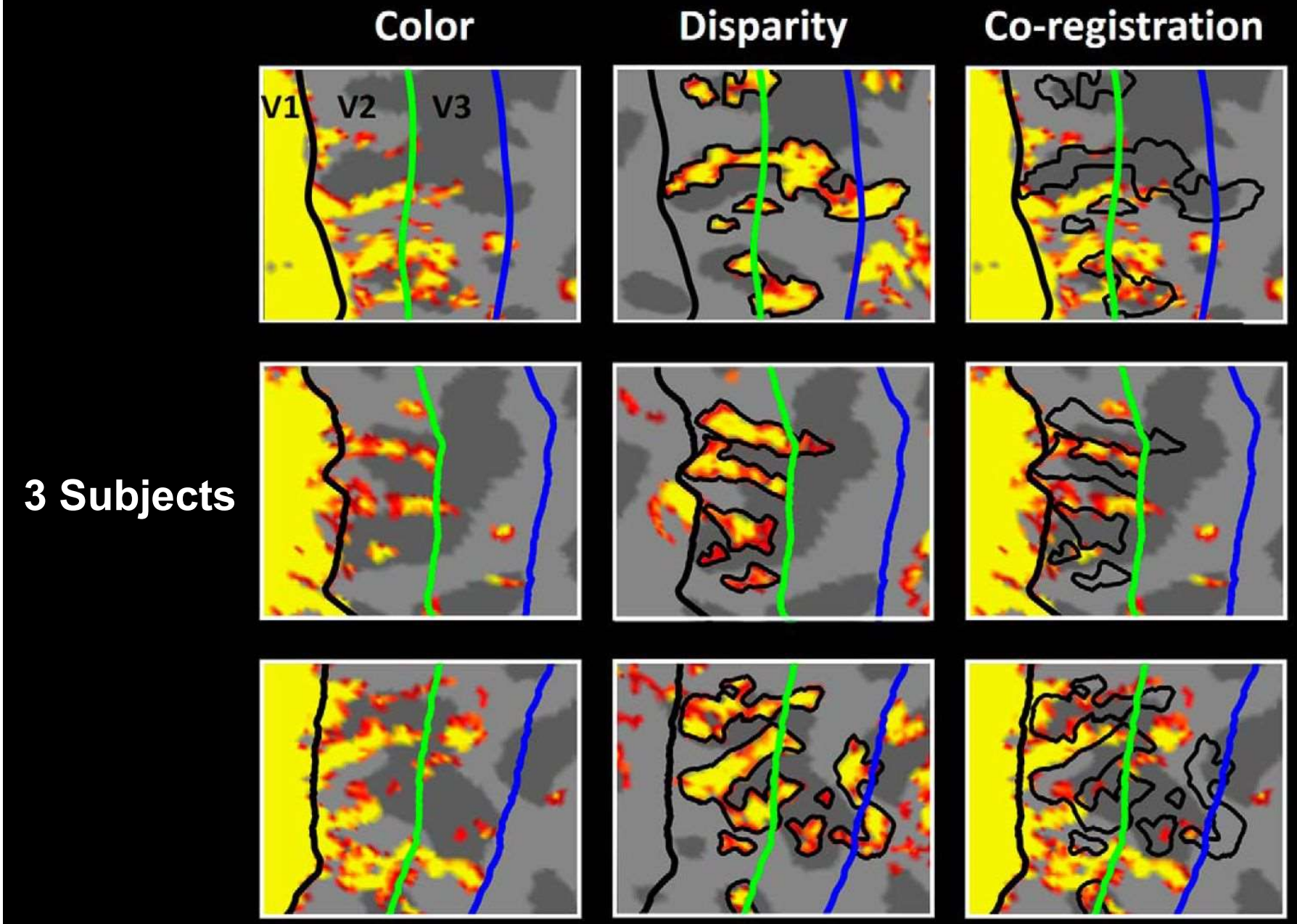
Nieuwenhuys et al.
The Human Central Nervous System Springer 2008

V1 → V2



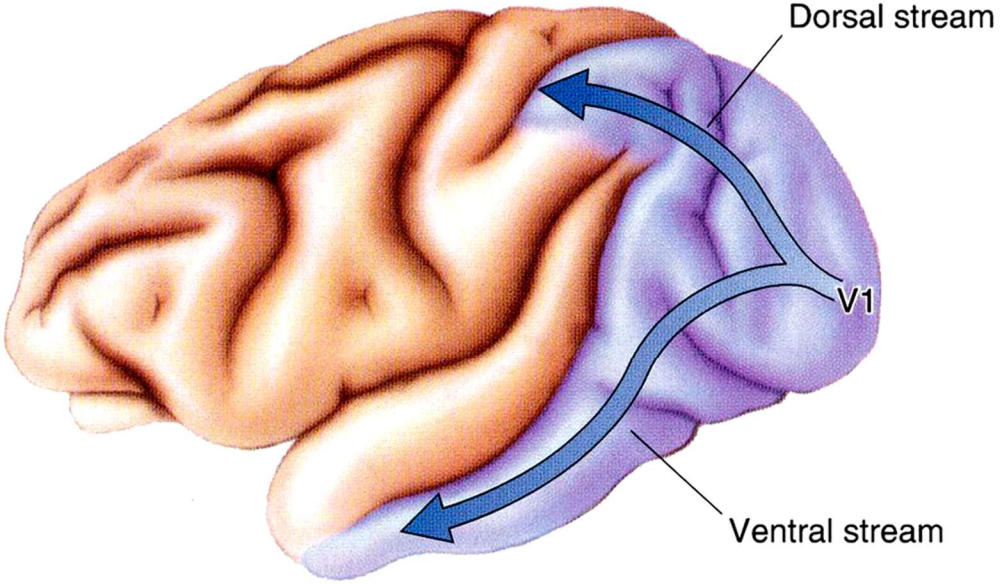
Nieuwenhuys et al.
The Human Central Nervous System Springer 2008

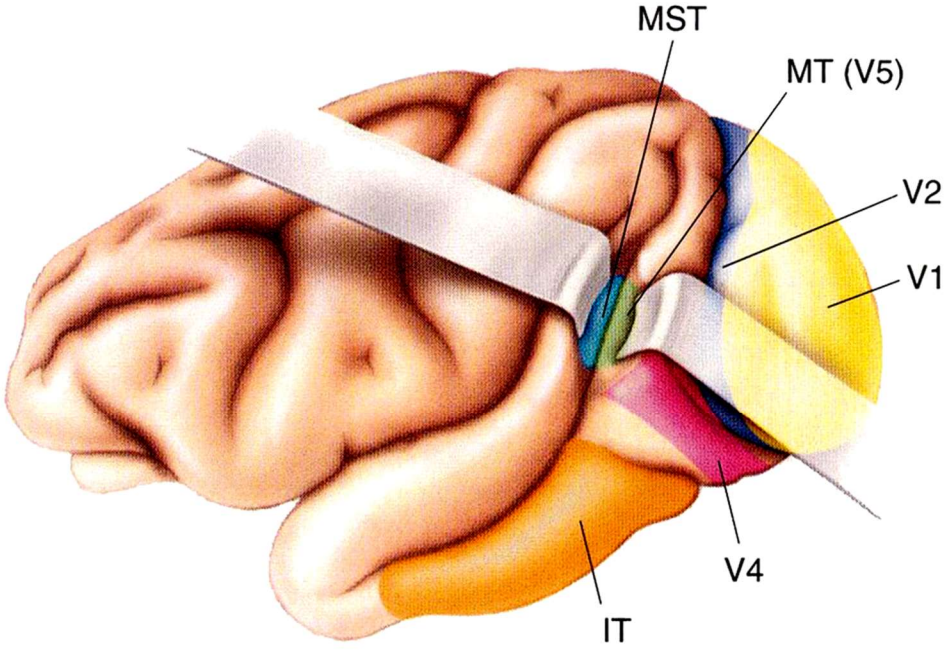
Color- and Disparity-Selective Columns in V2 and V3

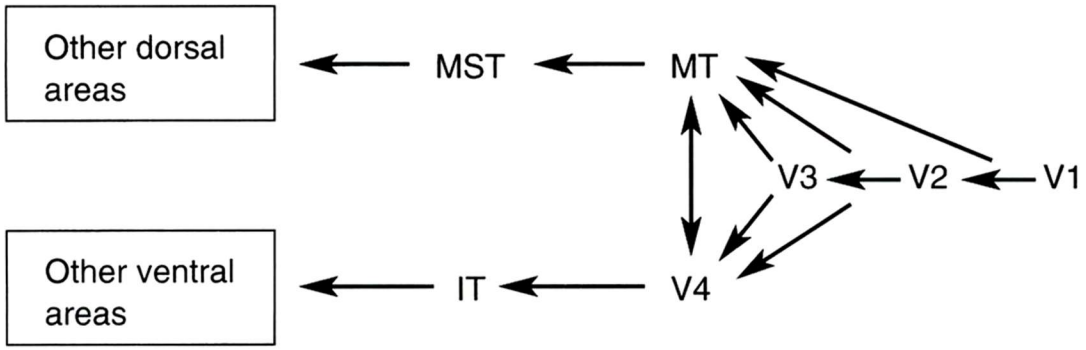


Nasr et al.
Journal of
Neuroscience
2016

Extrastriate Cortex (Macaque Monkey)

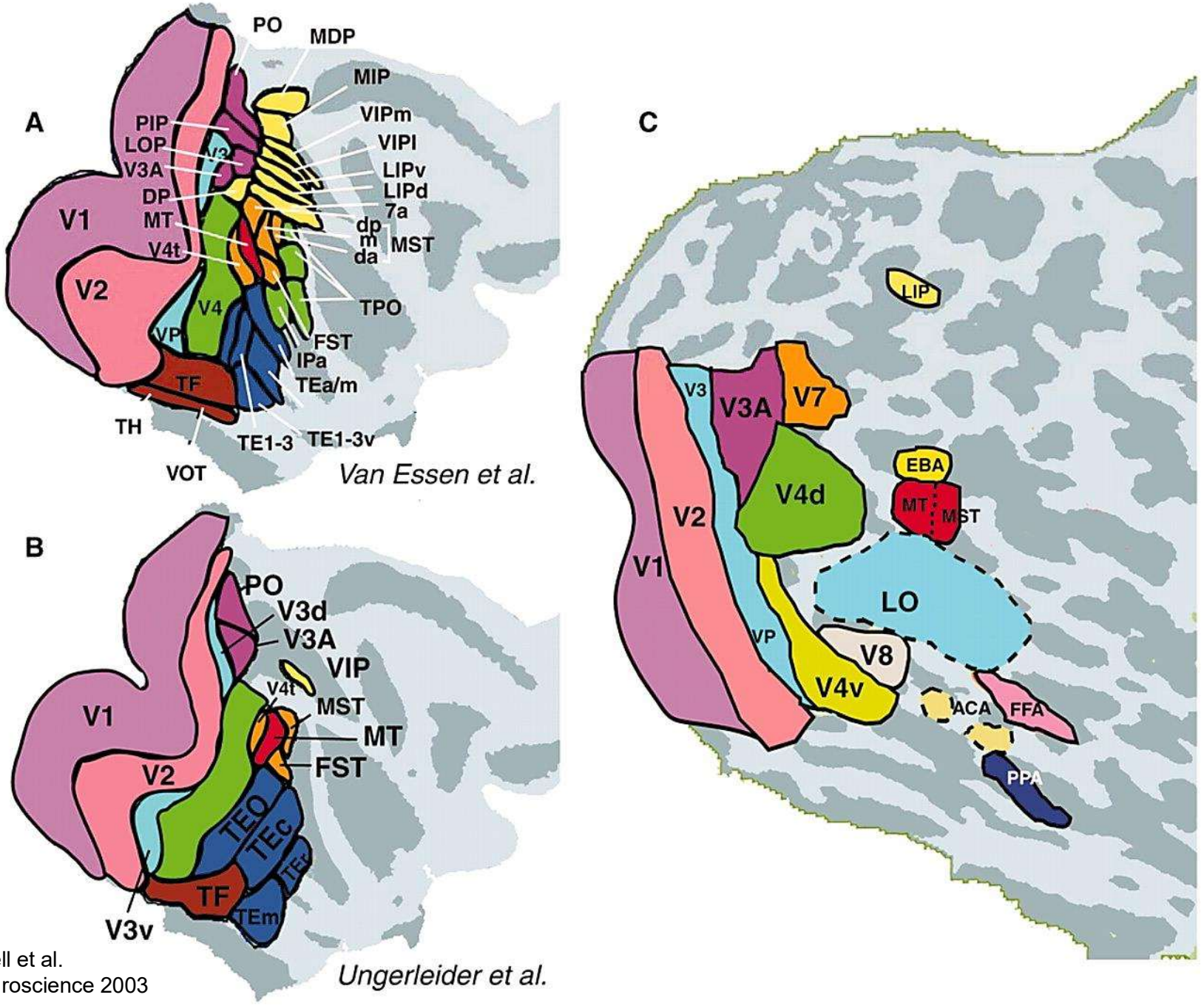






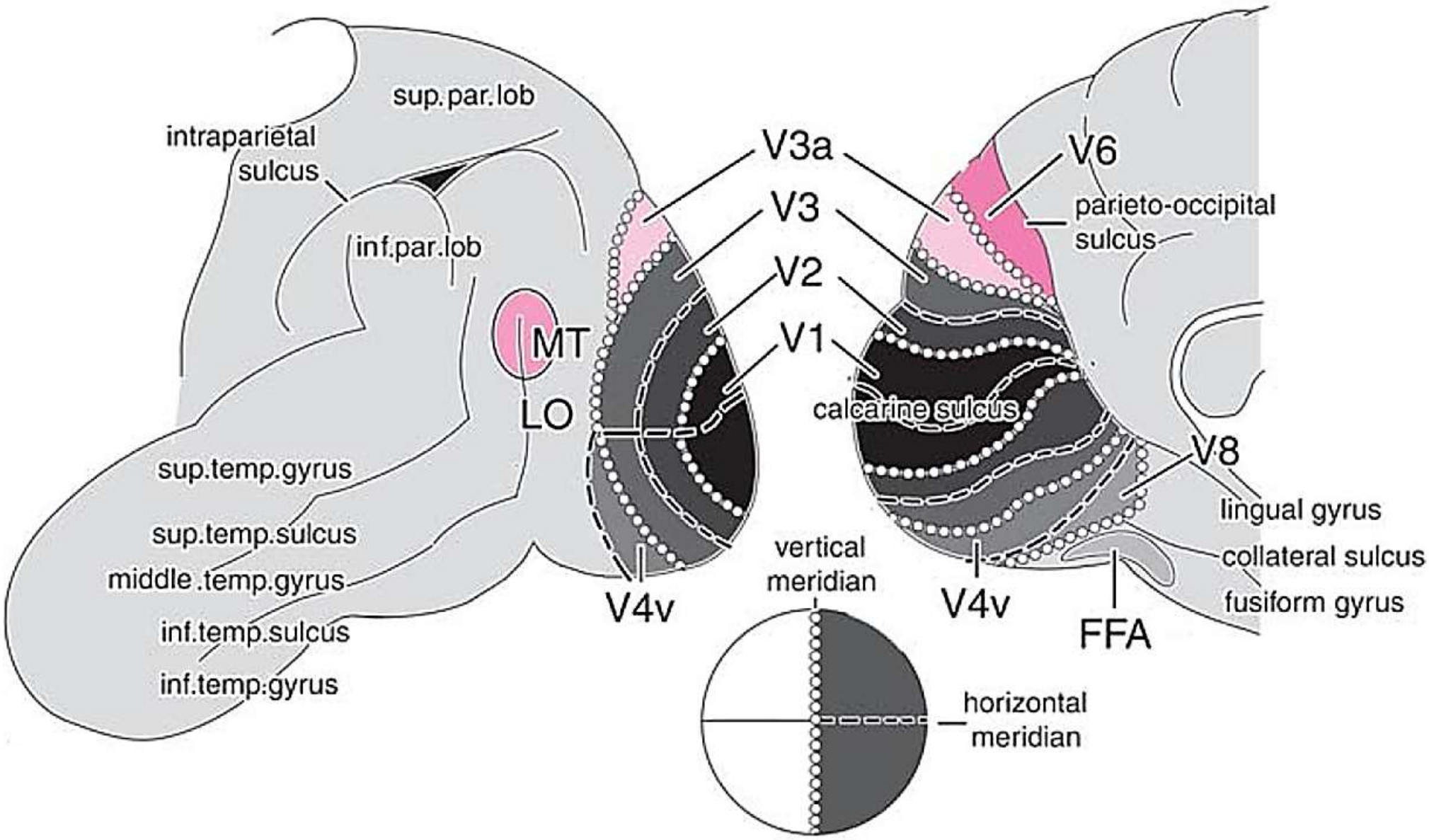
- **<u>Dorsal Stream</u> (→ Parietal Cortex): Perception of Position and Movement of Objects in Space ("Where")**
- **<u>Ventral Stream</u> (→ Temporal Cortex): Perception of Intrinsic Object Properties (e.g., Color, Shape, Size) ("What")**

Extrastriate Cortex (Macaque Monkey – Homo)



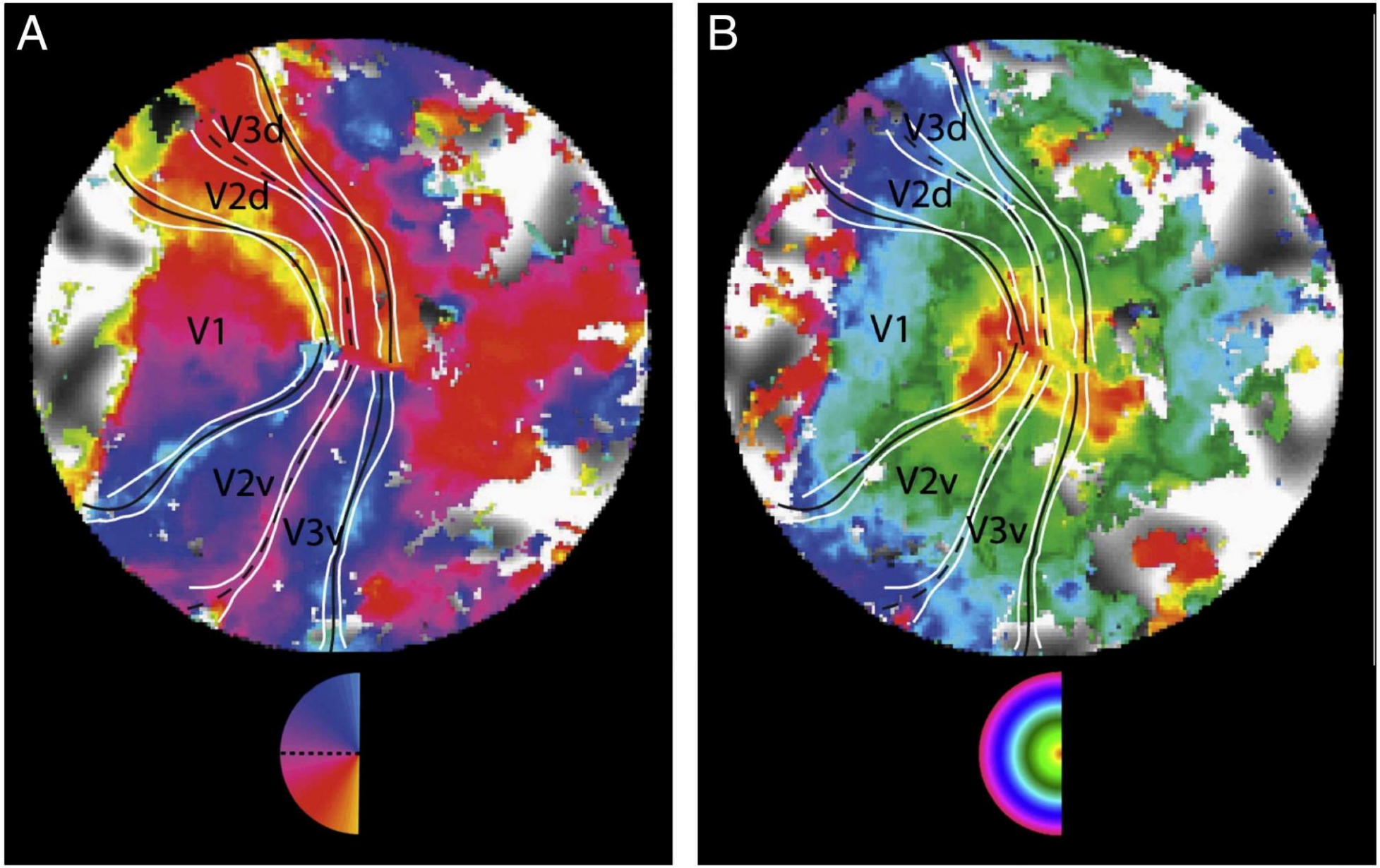
Tootell et al.
Journal of Neuroscience 2003

Extrastriate Cortex (Homo)



Nieuwenhuys et al.
The Human Central Nervous System Springer 2008

Retinotopic Mapping

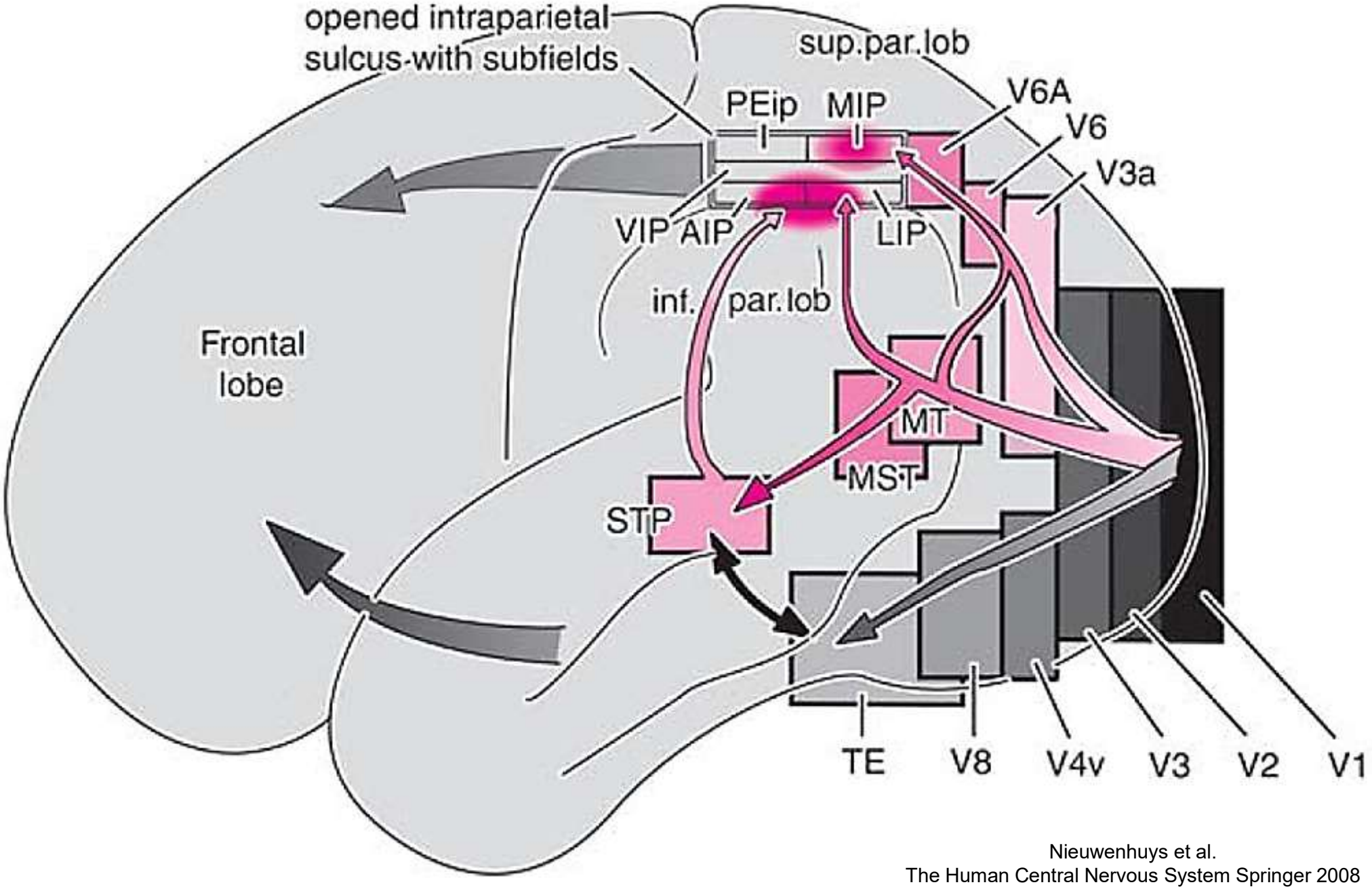


Polar Angle

Eccentricity

Buckner et al.
NeuroImage 2014

Extrastriate Cortex (Homo)



Nieuwenhuys et al.
The Human Central Nervous System Springer 2008