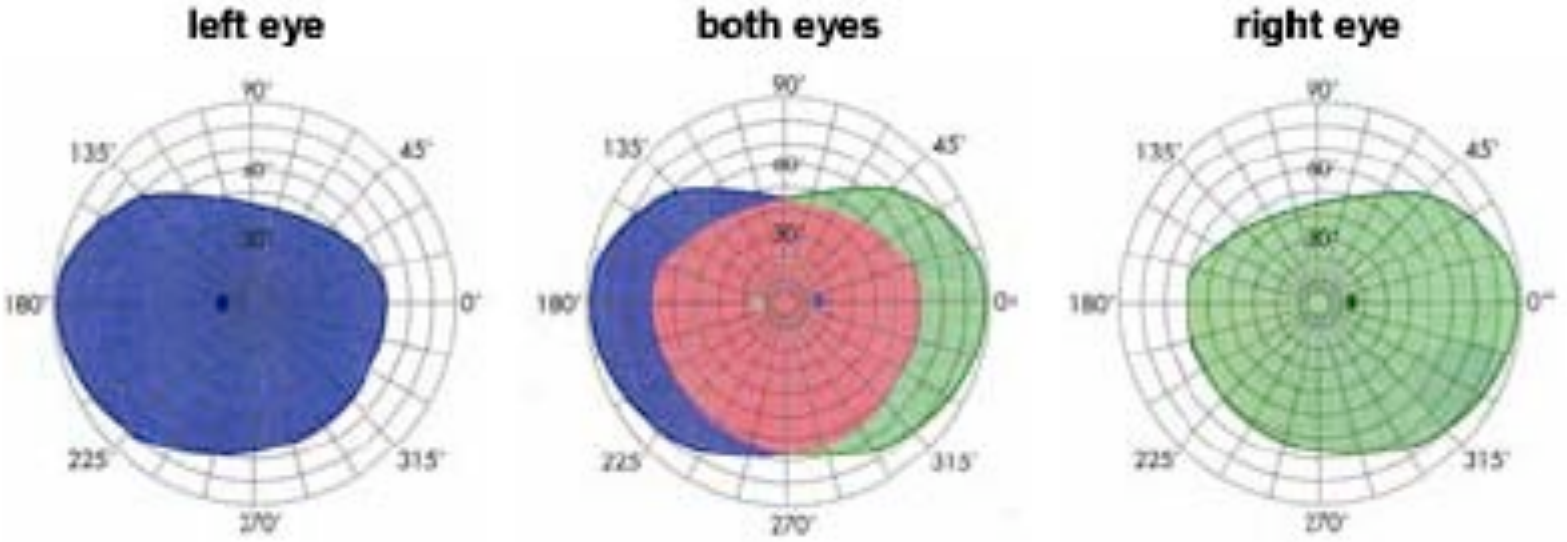
*BCS 504*

*Sensory systems*

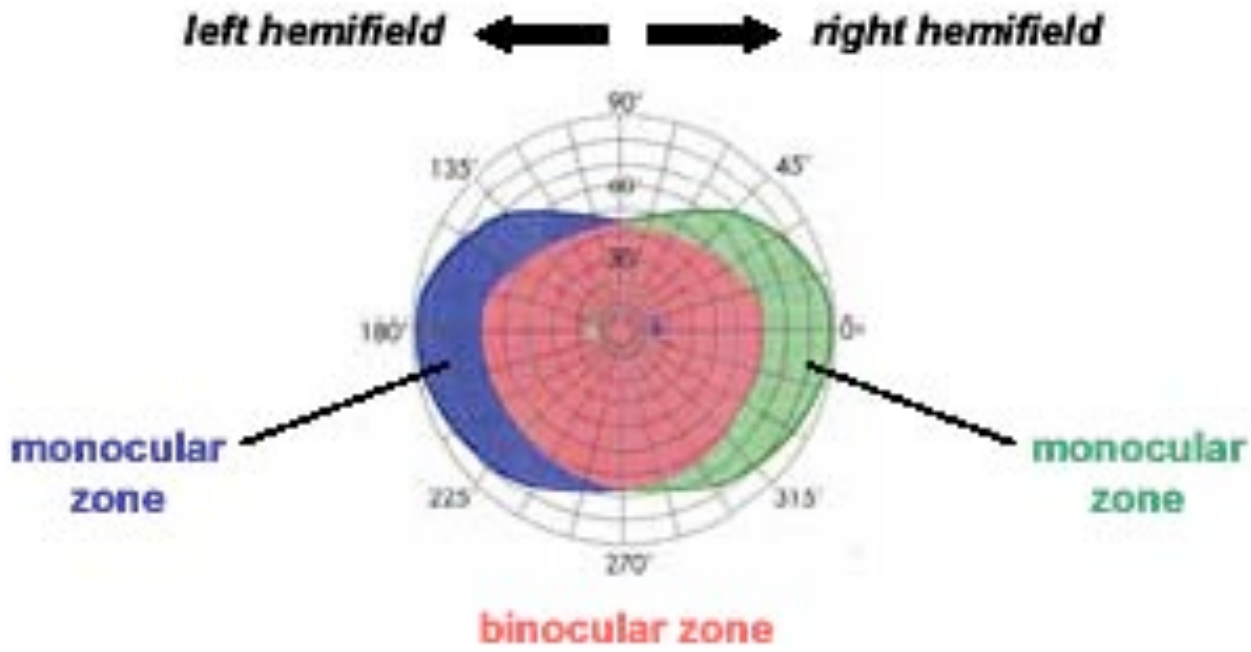
# *Subcortical pathways*

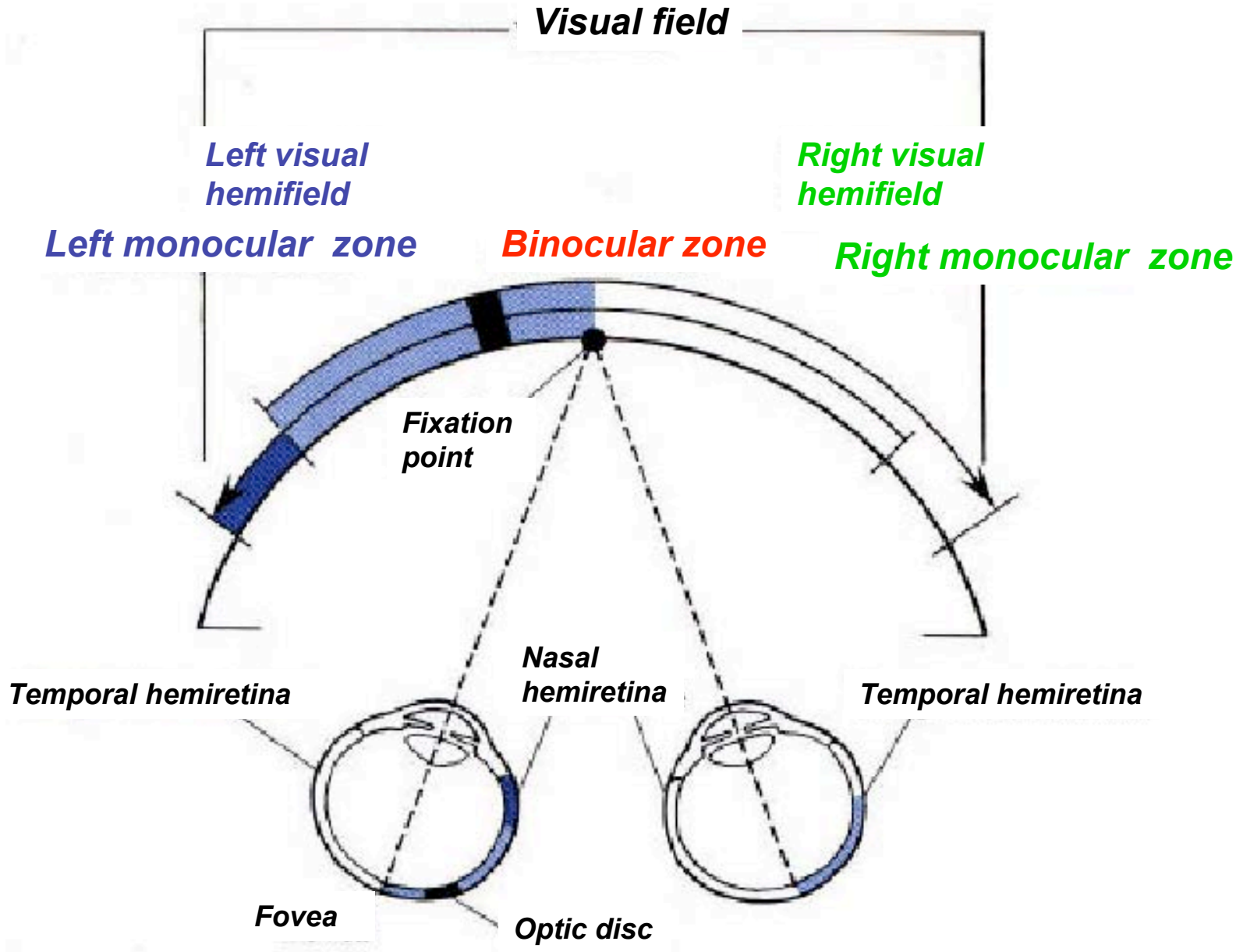
*William Merigan*

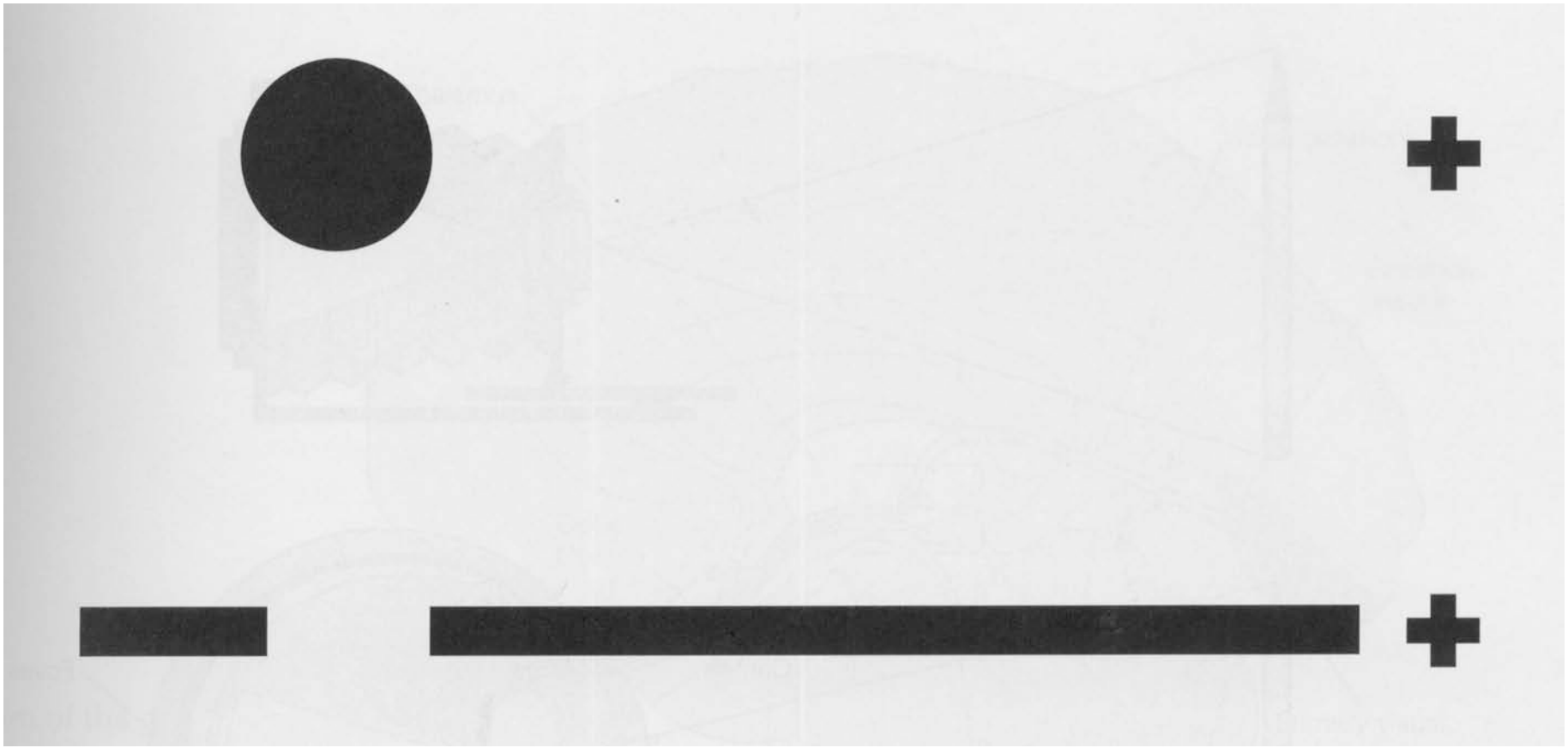
# *Representation of the visual field*



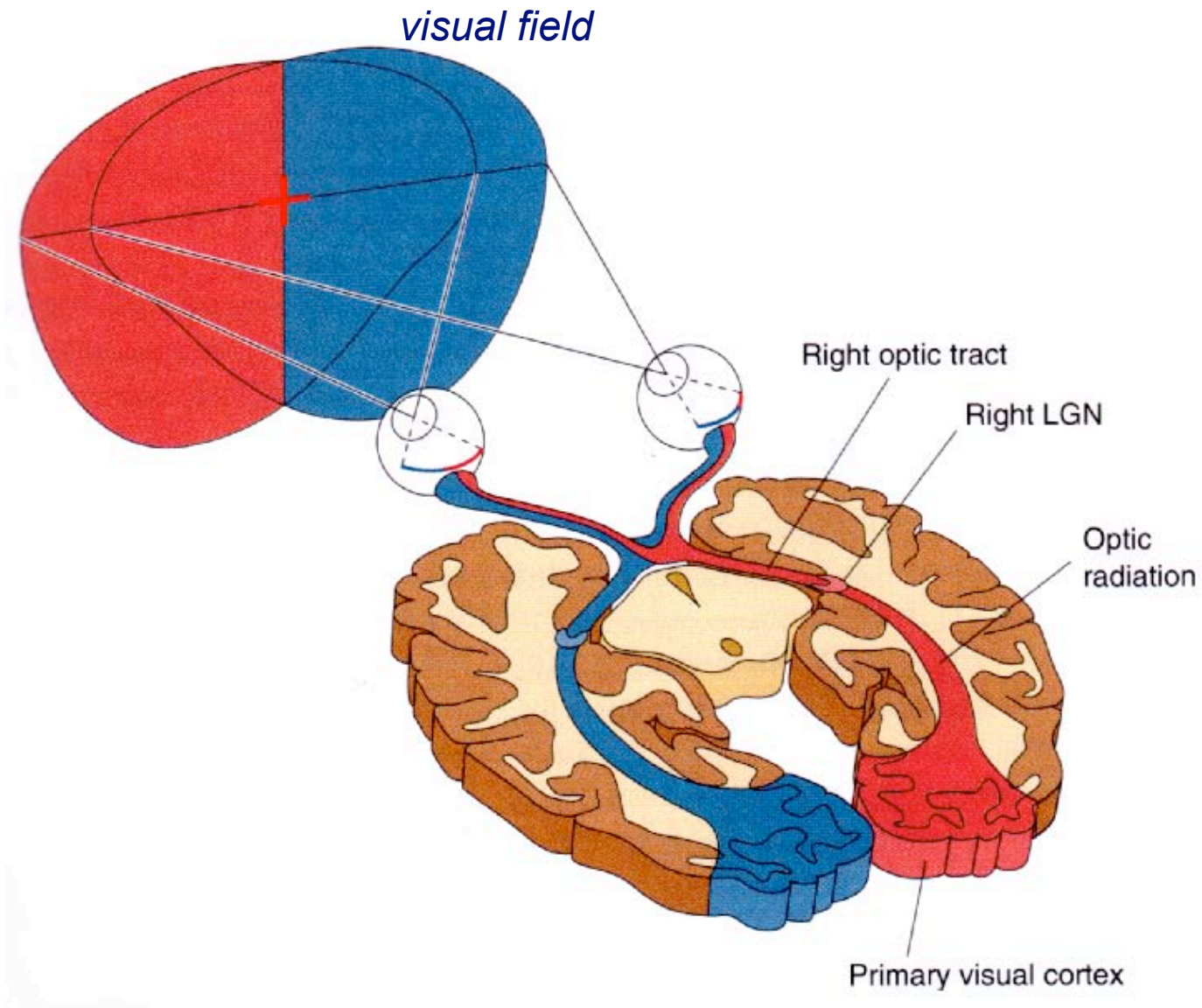
# *Representation of the visual field*



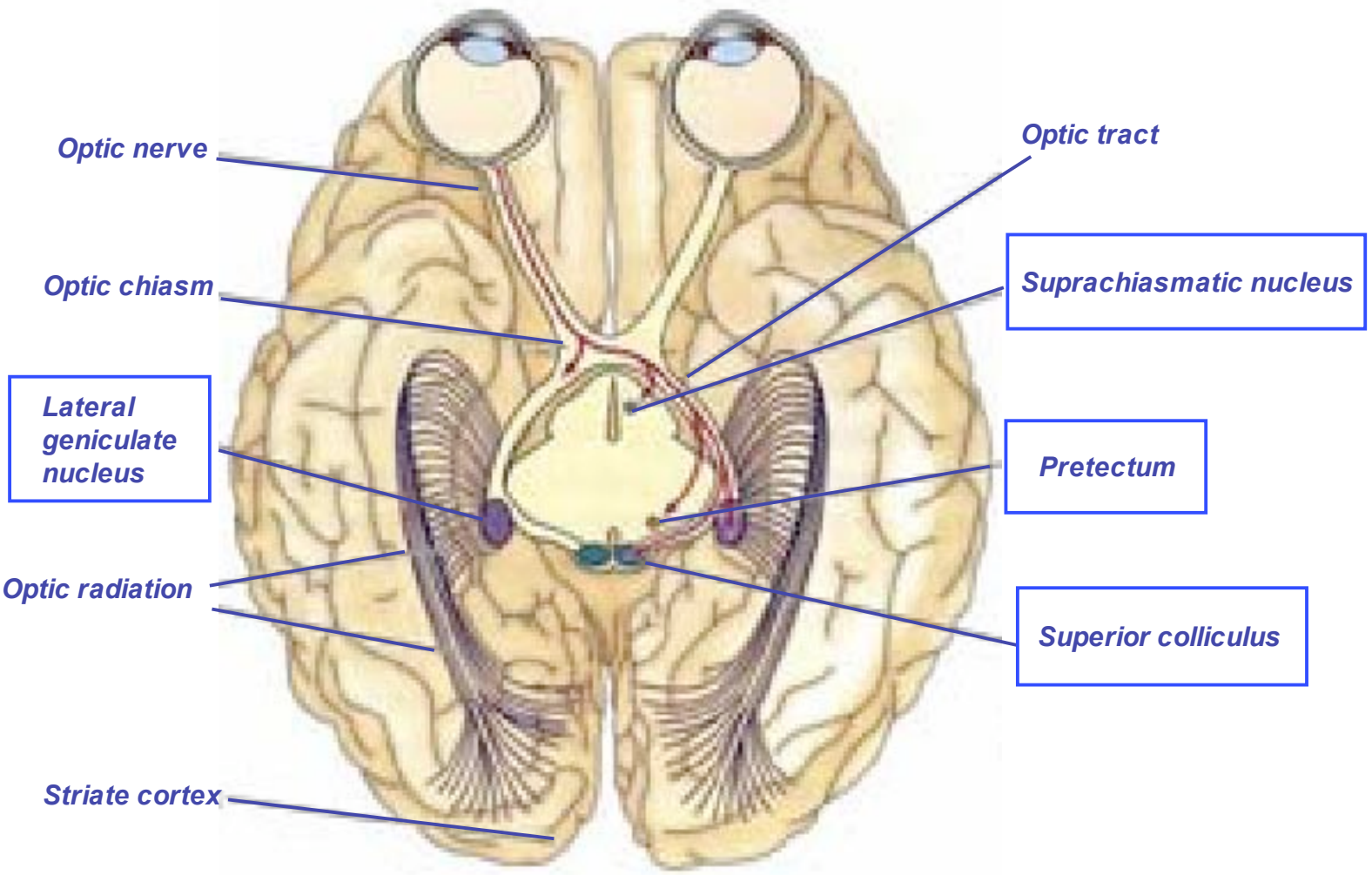

Visual field
Left visual hemifield
Right visual hemifield
Left monocular zone
Binocular zone
Right monocular zone
Fixation point
Nasal hemiretina
Temporal hemiretina
Temporal hemiretina
Fovea
Optic disc



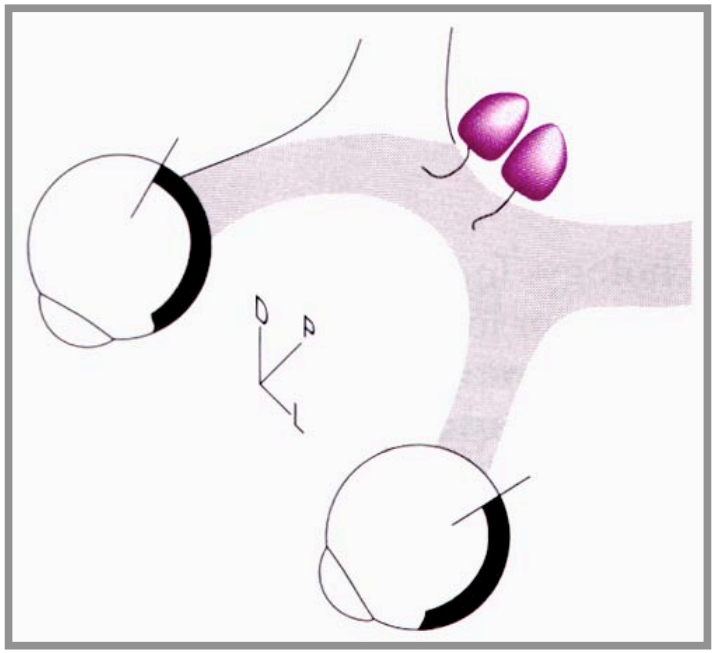
# *Representation of the Visual Field in the Brain*

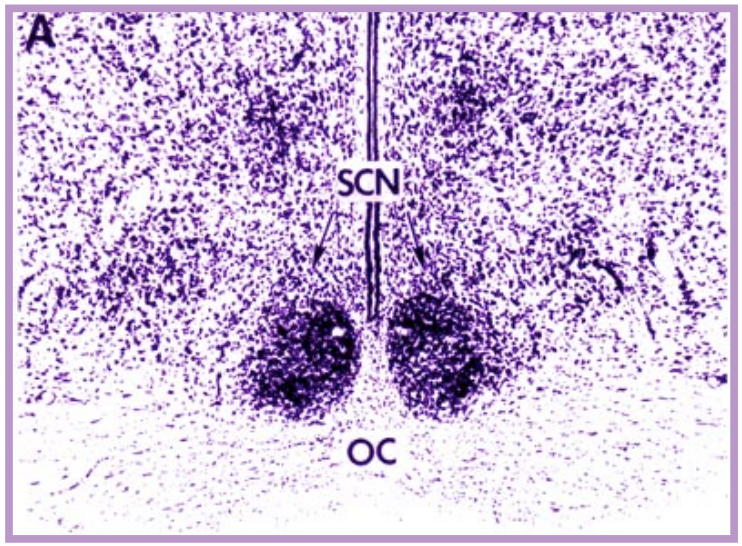


# Central Retinal Projections



# *Suprachiasmatic Nucleus (SCN)*






SCN Divisions: core & shell

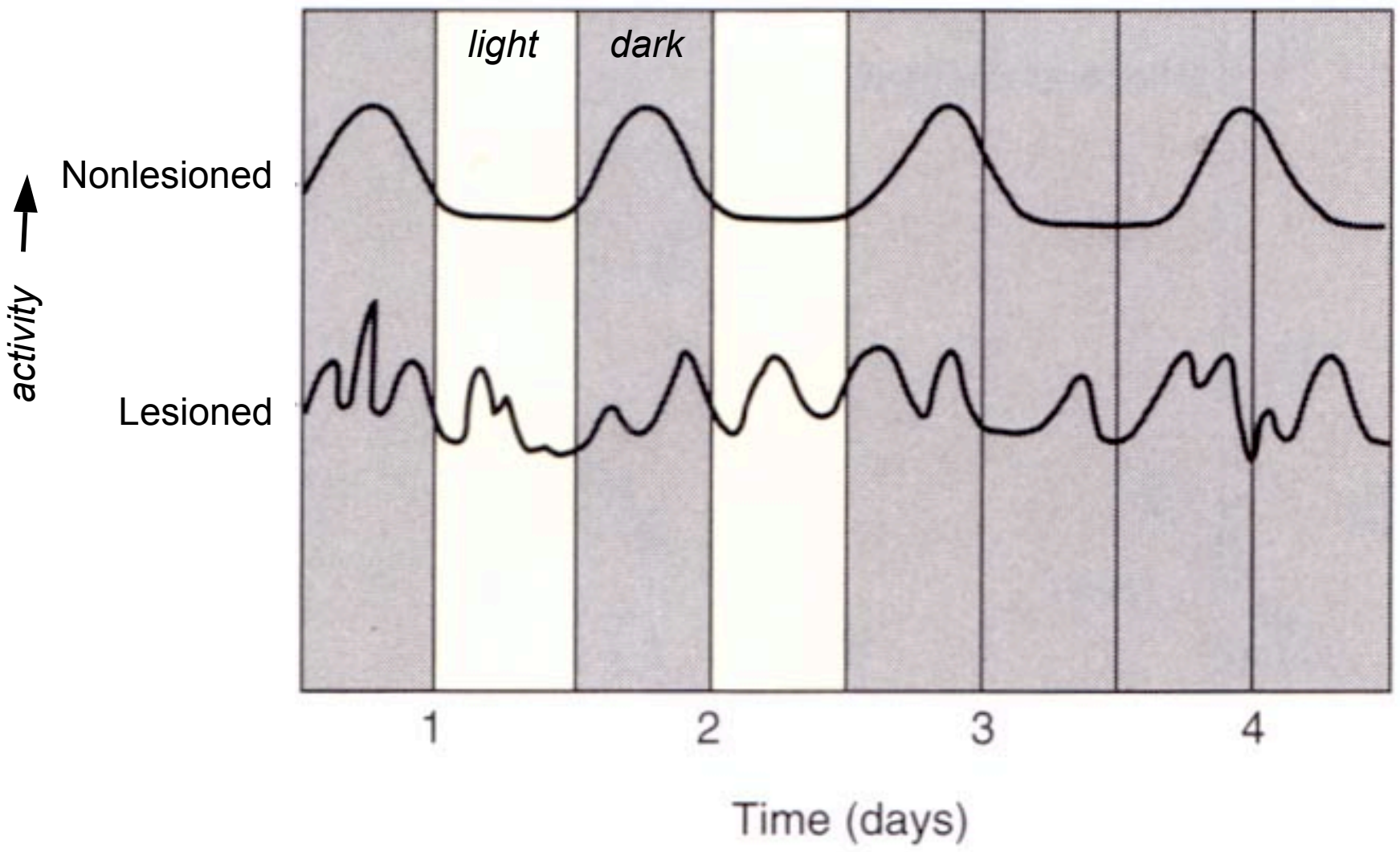
# *Suprachiasmatic Nucleus (SCN)*

*Core*
*bilateral inputs from retina, LGNv, midbrain raphe,*
*Inputs from ganglion cells containing photopigment (melanopsin)*
*neurons contain vasoactive intestinal poypeptide (VIP)*

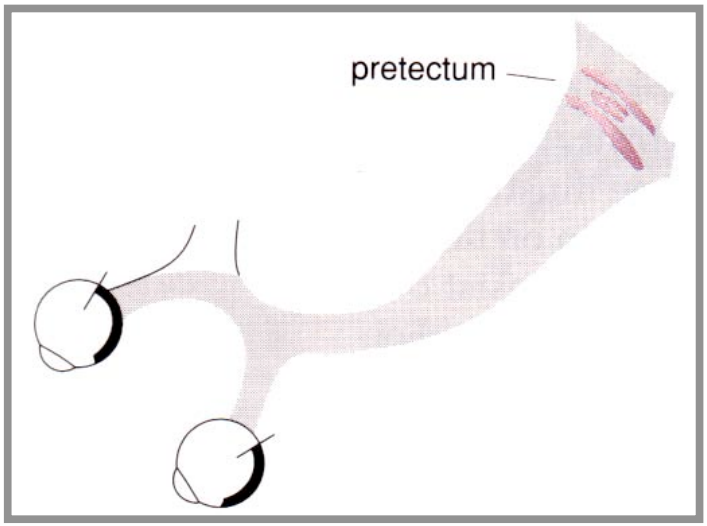
*Shell*
*inputs from brain stem, hypothalamus, basal forebrain, limbic*
*neurons contain vasopressin (AVP) and GABA*

*Function*
*Individual neurons: circadian oscillators (maintain rhythmic firing rate in culture)*
*Coupled to form a pacemaker*
*Lesions abolish sleep/wake cycle and other hormonal & behavioral rhythms*
*Serves as a primary biological clock*

# *Lesions of suprachiasmatic nucleus abolish light/dark cycles of activity in a rat*



# *Pretectum*




Nucleus of the Optic Tract (NOT)

## *Inputs*

*Bilateral retinal projections*
*Visual cortex (e.g. V1, MT,MST)*

## *Outputs*

*Edinger-Westphal nucleus*
*LGN*

## *Neuronal properties*

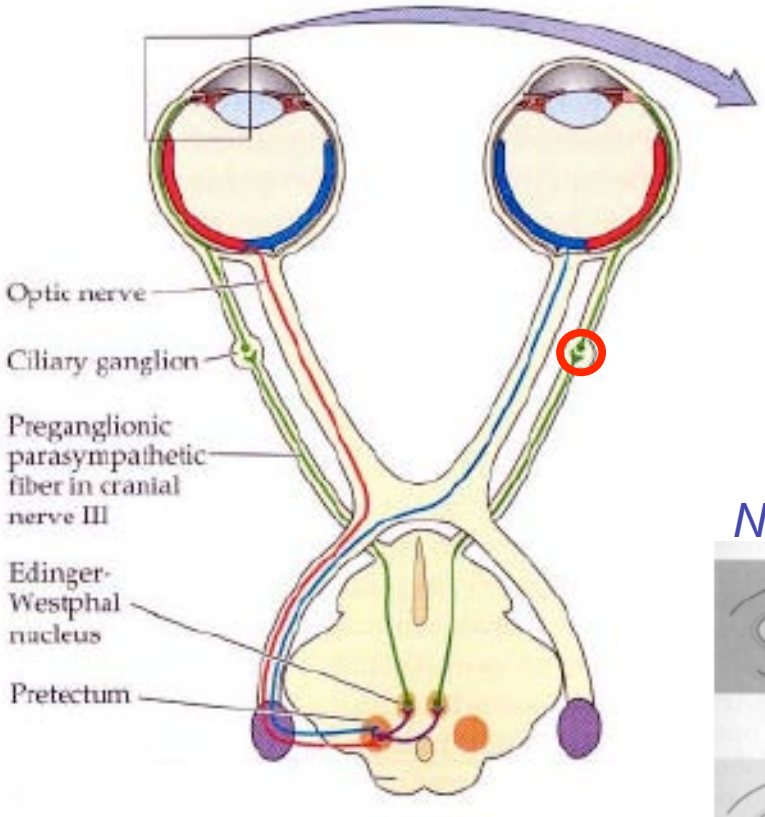
*Respond to fast motion*
*Binocular*

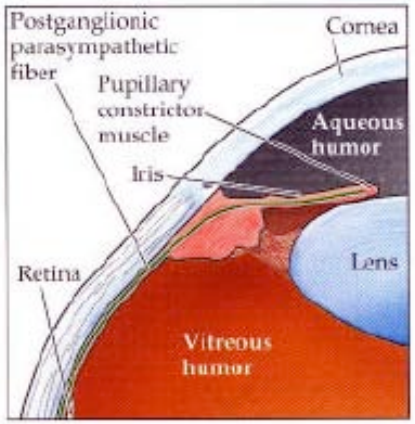
## *Function*

*Stabilize retinal image*
*Pupillary control*
*Role in fixation and optokinetic nystagmus (OKN)*

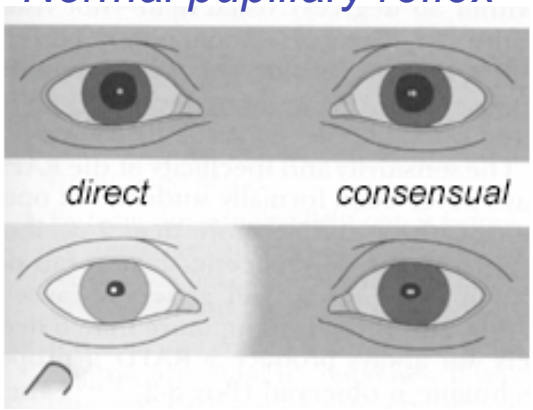
# *Pretectum plays an important role in the pupillary reflex*

*Pretectum controls the action of the pupillary constrictor muscle via its projection to both Edinger-Westphal nuclei.*




*Normal pupillary reflex*




*Left Efferent Pupil Defect*

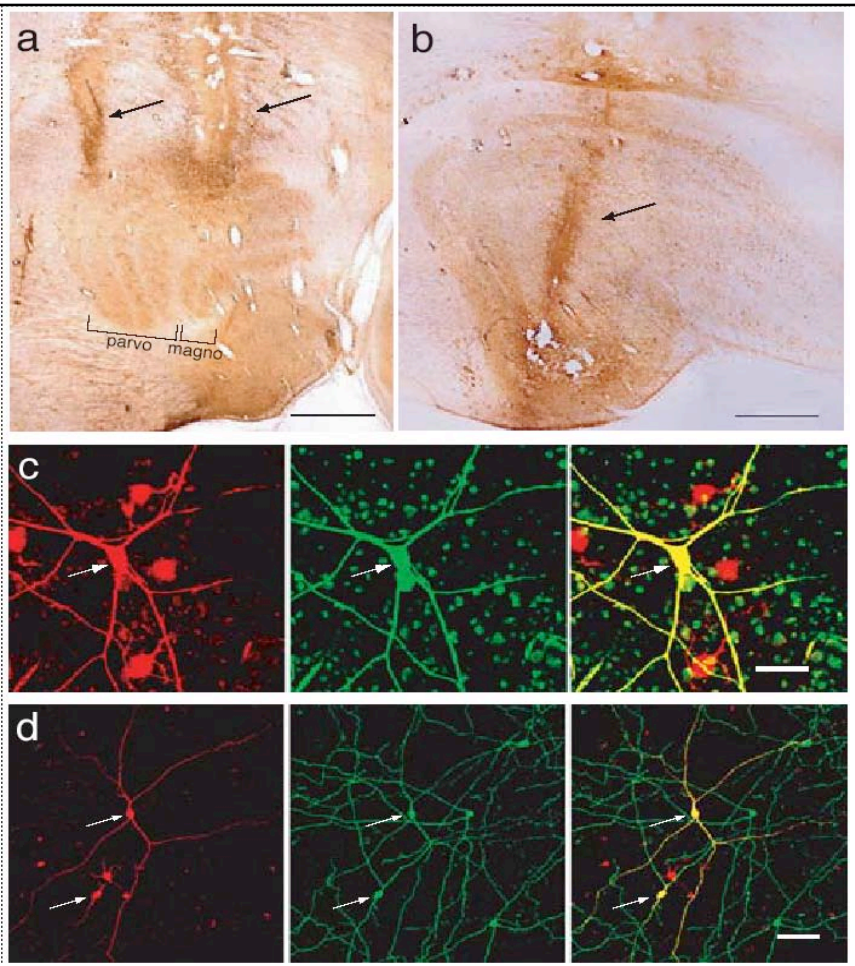



Figure 2 Retrograde labeling from LGN and pretectum colocalize with melanopsin immunostain. a-b. Coronal sections through LGN showing HRPstained tracks made by tracer injections (arrows). Injections in *a* are restricted to the parvocellular layers; track in *b* extends to the magnocellular layers. Scale bars = 2 mm. c. Confocal images of retrograde rhodamine label (red) from LGN injection (arrow, left) and melanopsin immunostaining (AlexaFluor, green; arrow, middle). Colocalization of labels appears yellow (arrow, right). Scale bar = 50 $\mu$m. d. Cells retrogradely labeled with rhodamine from injections in pretectum (arrows, left) and labeled for melanopsin immunoreactivity (arrows, middle). Colocalization appears yellow (arrows, right). Scale bar = 100 $\mu$m. e. Photoreceptive ganglion cell (arrow; scale bar = 50 $\mu$m) identified by autofluorescent granules in cell body (inset) and targeted for intracellular recording and HRP-staining in the unlabeled, in vitro retina. Tracing of the entire dendritic tree is shown on the right (arrow indicates axon; scale bar = 200 $\mu$m).

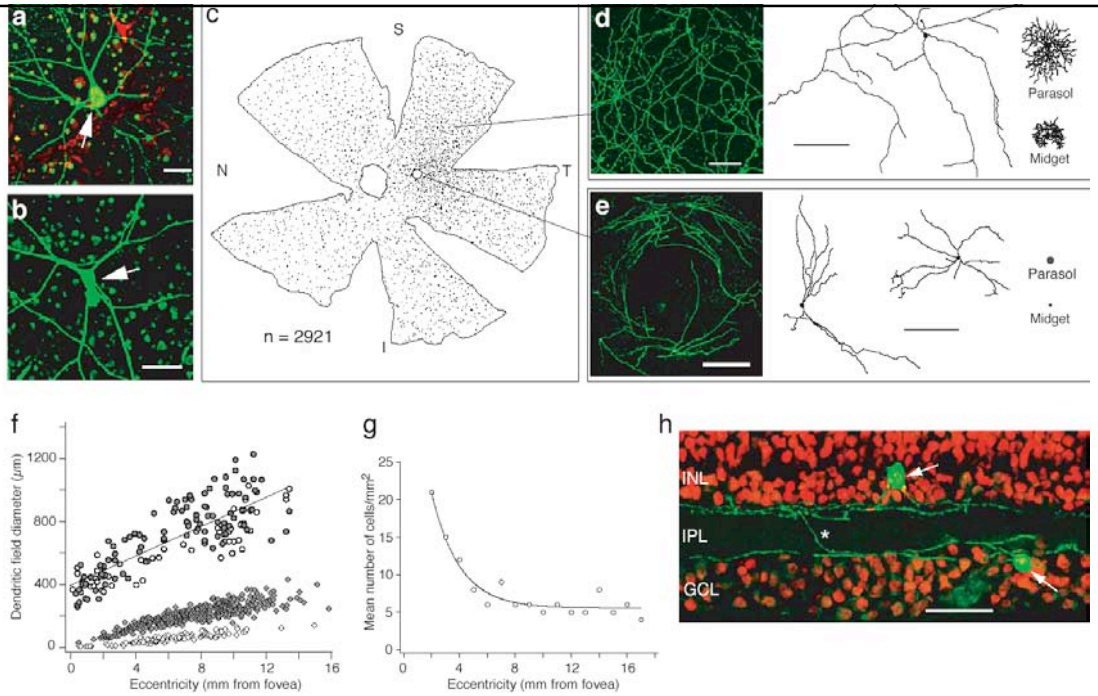
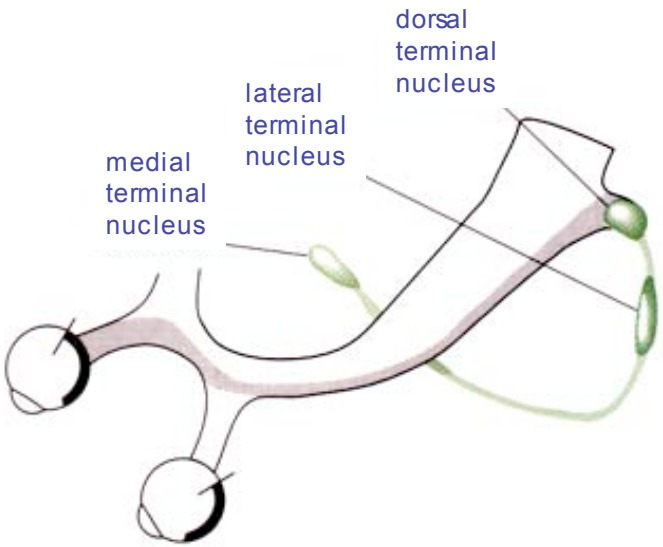



Figure 1. Morphology of melanopsin-immunoreactive ganglion cells. a. Human melanopsin immunoreactive cell (arrow); propidium iodide red counterstain. Scale bar = 50 $\mu$m. b. Macaque melanopsin immunoreactive cell (arrow). Scale bar = 50 $\mu$m.. c. Macaque retina tracing; dots represent melanopsin immunoreactive cells. T, N, S, and I, are temporal, nasal, superior and inferior retina respectively. d. Immunoreactive cells in peripheral retina (left; scale bar = 100 $\mu$m). Tracing of a peripheral HRP-stained giant cell (right; scale bar = 200 $\mu$m). Peripheral parasol and midget cells (far right) are shown for comparison. e. Immunoreactive cells encircling the fovea (left; scale bar = 200 $\mu$m). Tracings of two HRP-stained giant cells ~1-1.5 mm from the fovea (right: scale bar = 200 $\mu$m). Circles (far right) indicate size of foveal parasol and midget cells. f. Dendritic field size of melanopsin cells versus eccentricity (inner cells, filled circles; n = 93)(outer cells, open circles; n = 63). Parasol (filled diamonds; n = 333) and midget cells (open diamonds; n = 93) are shown for comparison. g. Mean cell density of immunoreactive cells versus eccentricity (total = 614 cells in 78 1-mm2 samples). h. Dendritic arbors (green) of melanopsin immunoreactive cells (arrows) from stacked confocal images of 5 consecutive vertical sections (25 $\mu$m thick). Outer stratifying cell's soma is displaced to the INL. GCL, IPL, and INL are ganglion cell layer, inner plexiform layer, and inner nuclear layer, respectively. Scale bar = 50 $\mu$m.

# Accessory Optic System (AOS)




## Inputs

*from contralateral retina (slow conducting fibers)*
*topographic projections from cortex*

## Outputs

*AOS --> Inferior olive -->cerebellum*

## Neuronal properties

*Neurons are selective to direction of slow motion*

## Function

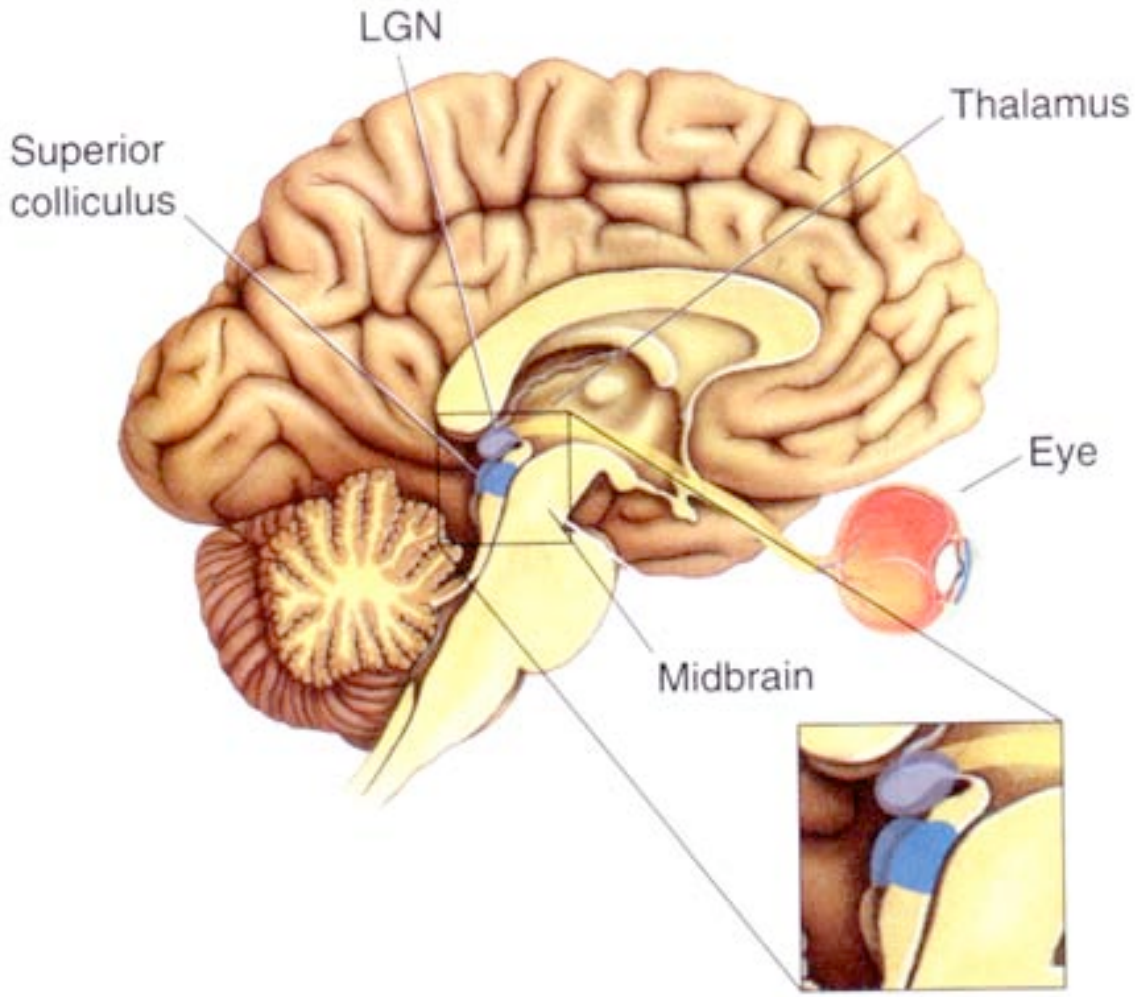
*Stabilize image on the retina*

*Involved in optokinetic nystagmus (reflex stabilizing retinal image)*

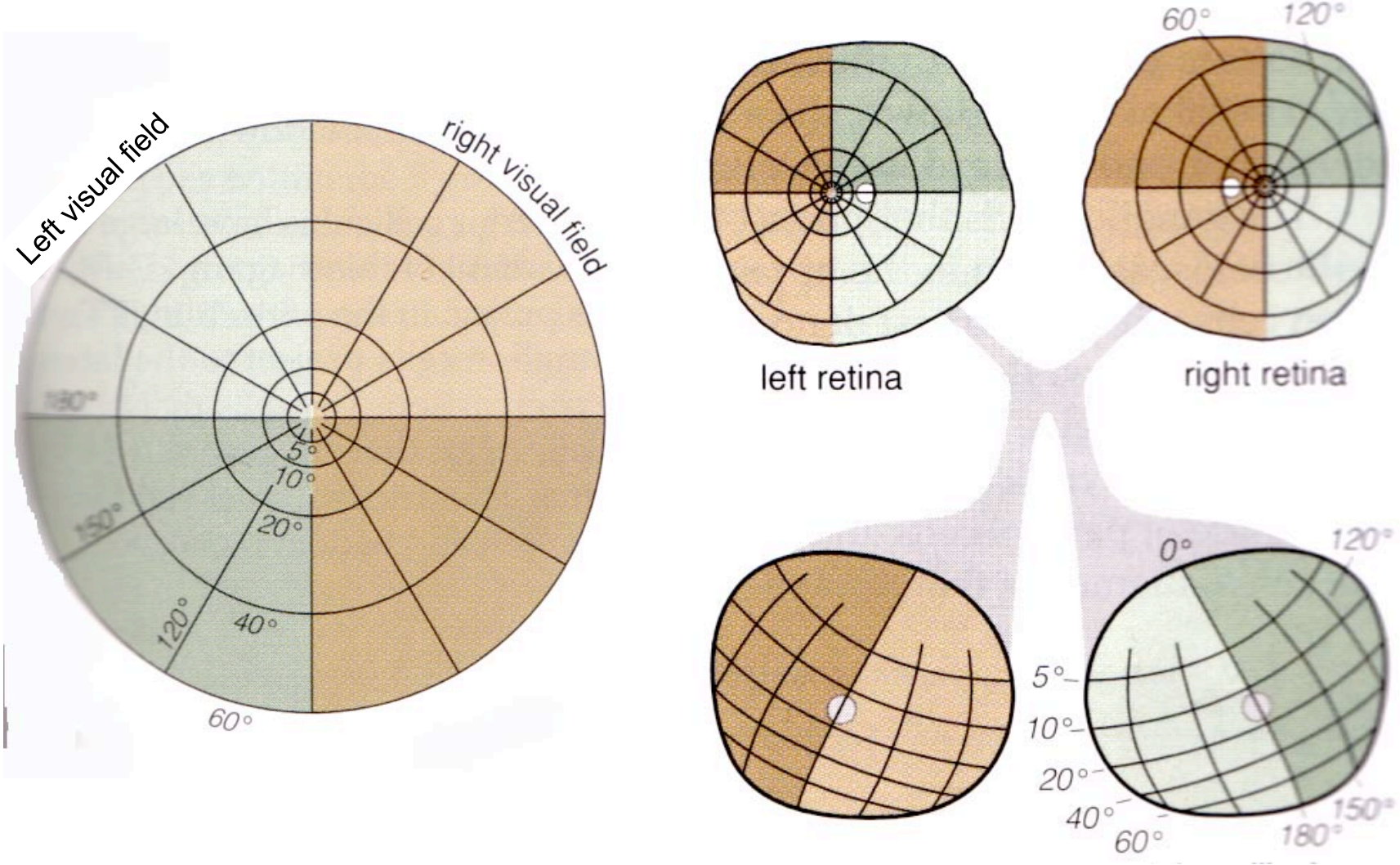
*Neurons detect retinal slip; these signals activate eye muscles to cancel retinal slip*

*AOS works with vestibular system to detect self-motion and stabilize eye & head in space*

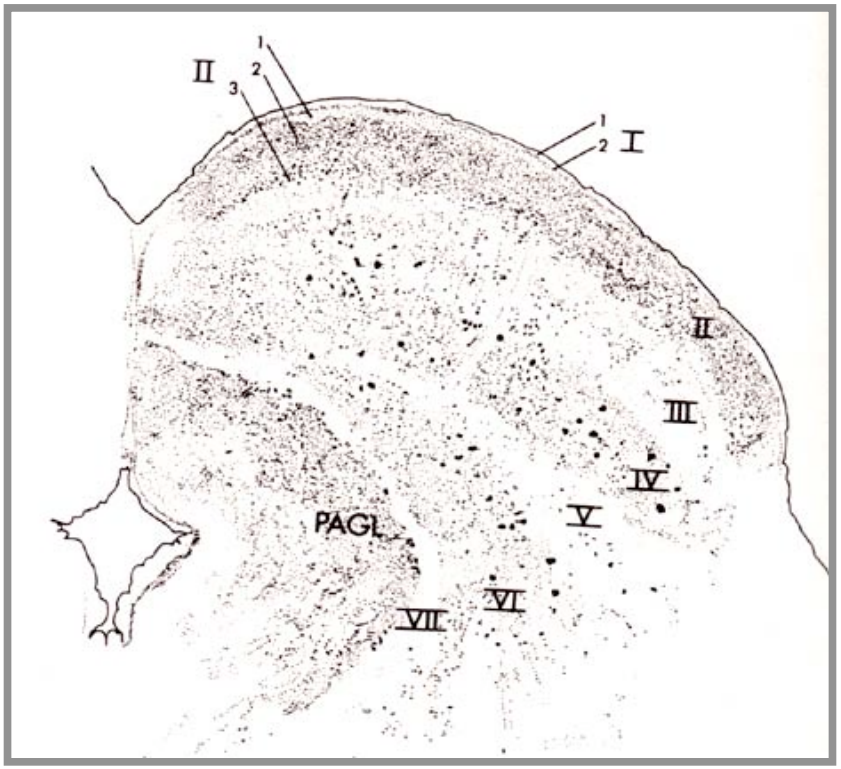
# *Superior Colliculus*



# *Representation of Visual Space in Superior Colliculus*



# Superior Colliculus




## 7 layers

*I,II,V,VII fibers*
*II,IV,VI cell bodies*

## Functional segregation

*Superficial layers*

*Deep layers*

# Superior Colliculus

## Superficial layers (I,II,III)

- ***inputs from retina***
  *10% of ganglion cells (few M, some γ)*
- ***inputs from cortex***
  ipsilateral, foveal, topographic from layer 5
  FEF (frontal eye fields)
  extrastriate
- ***Retinotopic map***
  Central $10^{o}$ occupied 30% of surface
  Contralateral visual field in primates (contra/ipsi retina)
- ***Visually responsive neurons***
  *Center/surround organization; not selective for stimulus shape*
  *Binocular*
  *Slowly conducting*
- ***Behavioral modulation of visual responses***
  enhancement before saccade into receptive field
- ***Function***
  initiation of eye movements
  involved in directing spatial attention

# Superior Colliculus

## Deep layers (V,VI)

- ***Inputs from all sensory systems***
- ***Outputs to brain stem (related to motor control. E.g. eye movements)***
- ***Locations in SC represents space around the animal***

  *Multisensory responses*

  *(e.g. acoustic, tactile, visual originating from the same region of space)*

  *Enhanced response to multisensory stimulation from the same region of space*

- ***Movement fields***

  *Neurons active before eye movements (saccades) of specific amplitude and direction*

  *(e.g 20$^{o}$ from any orbital position)*

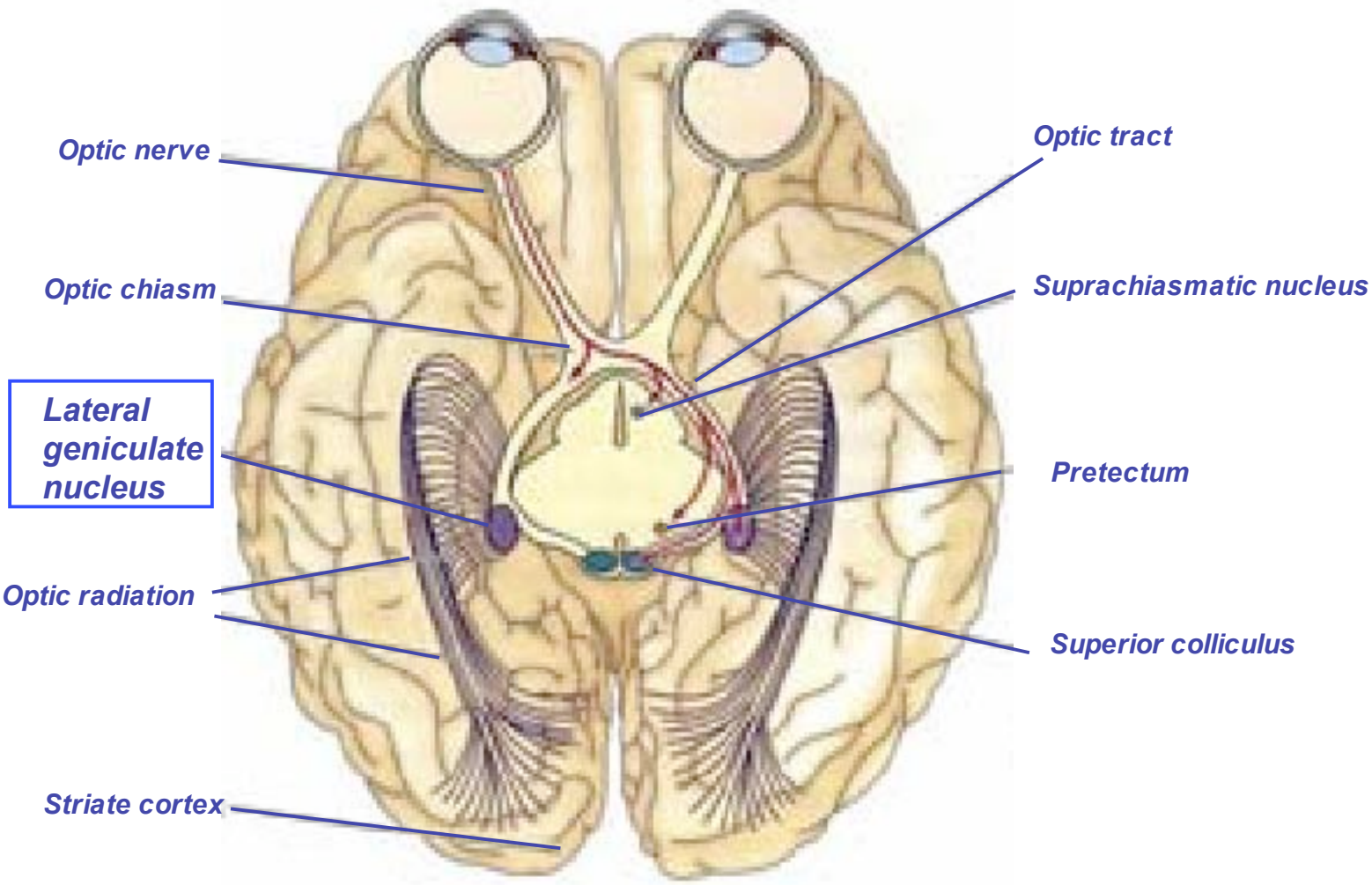
  *topographic map of movement fields across SC*

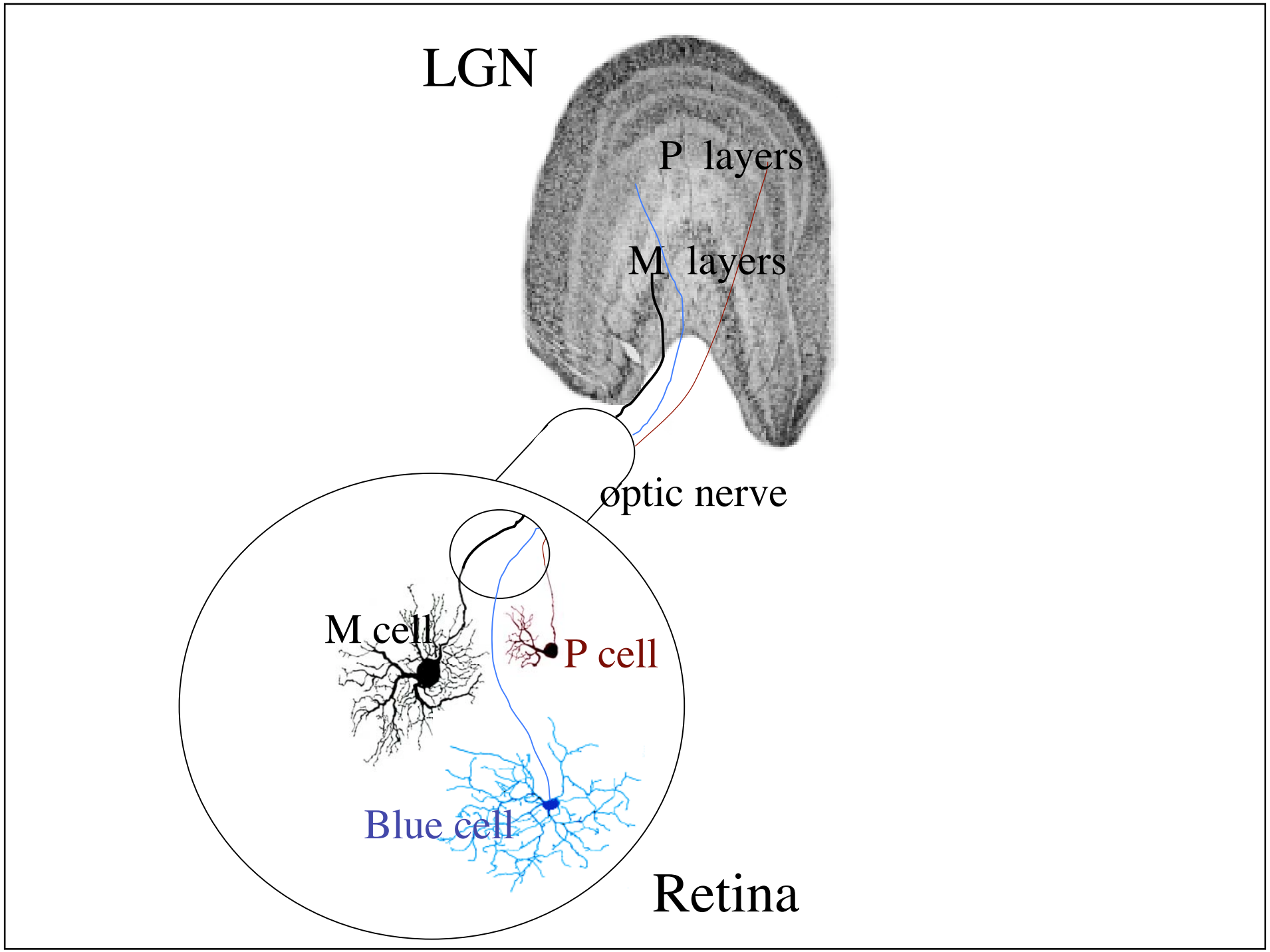
- ***Function***

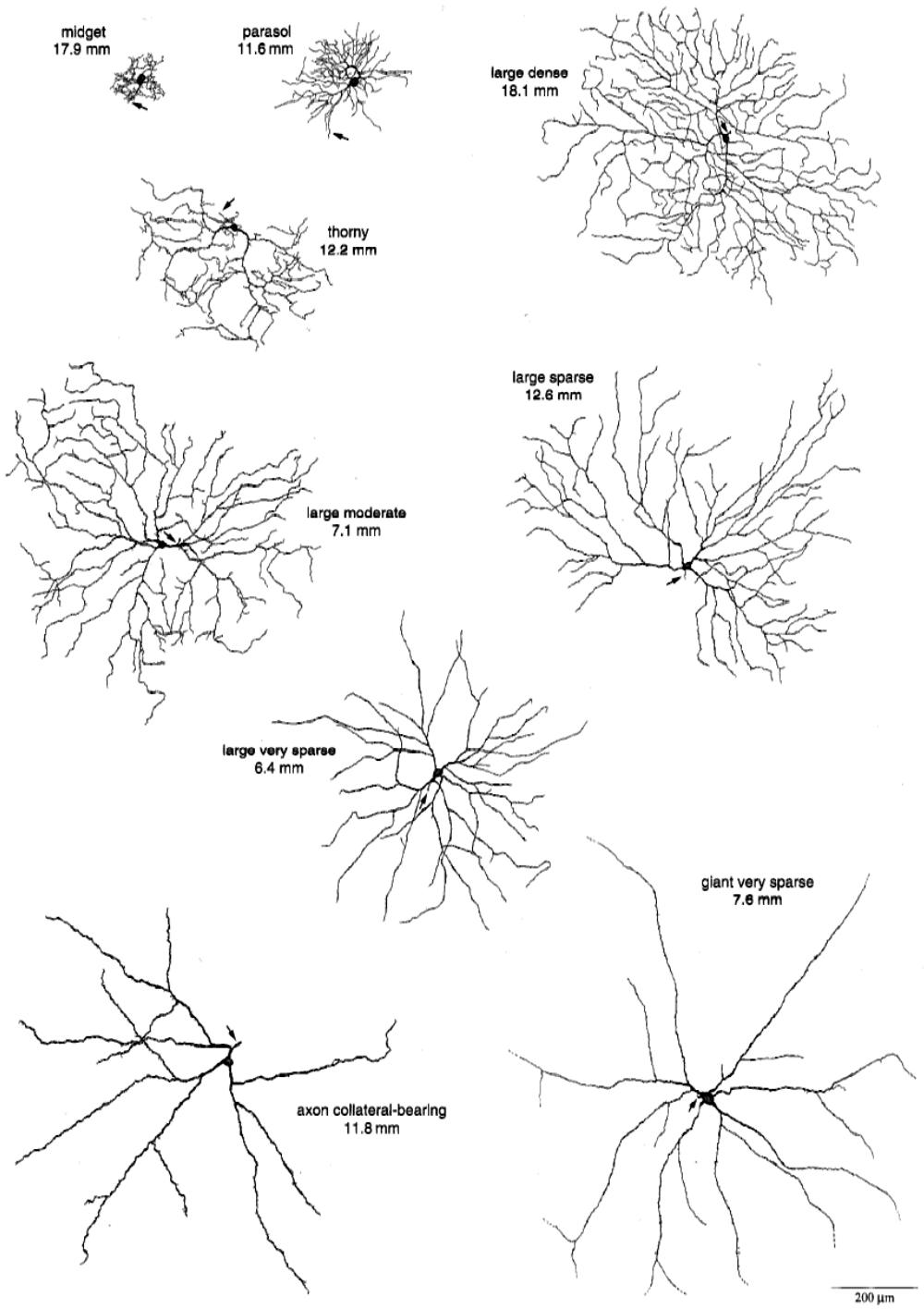
  *visual orienting reflexes*

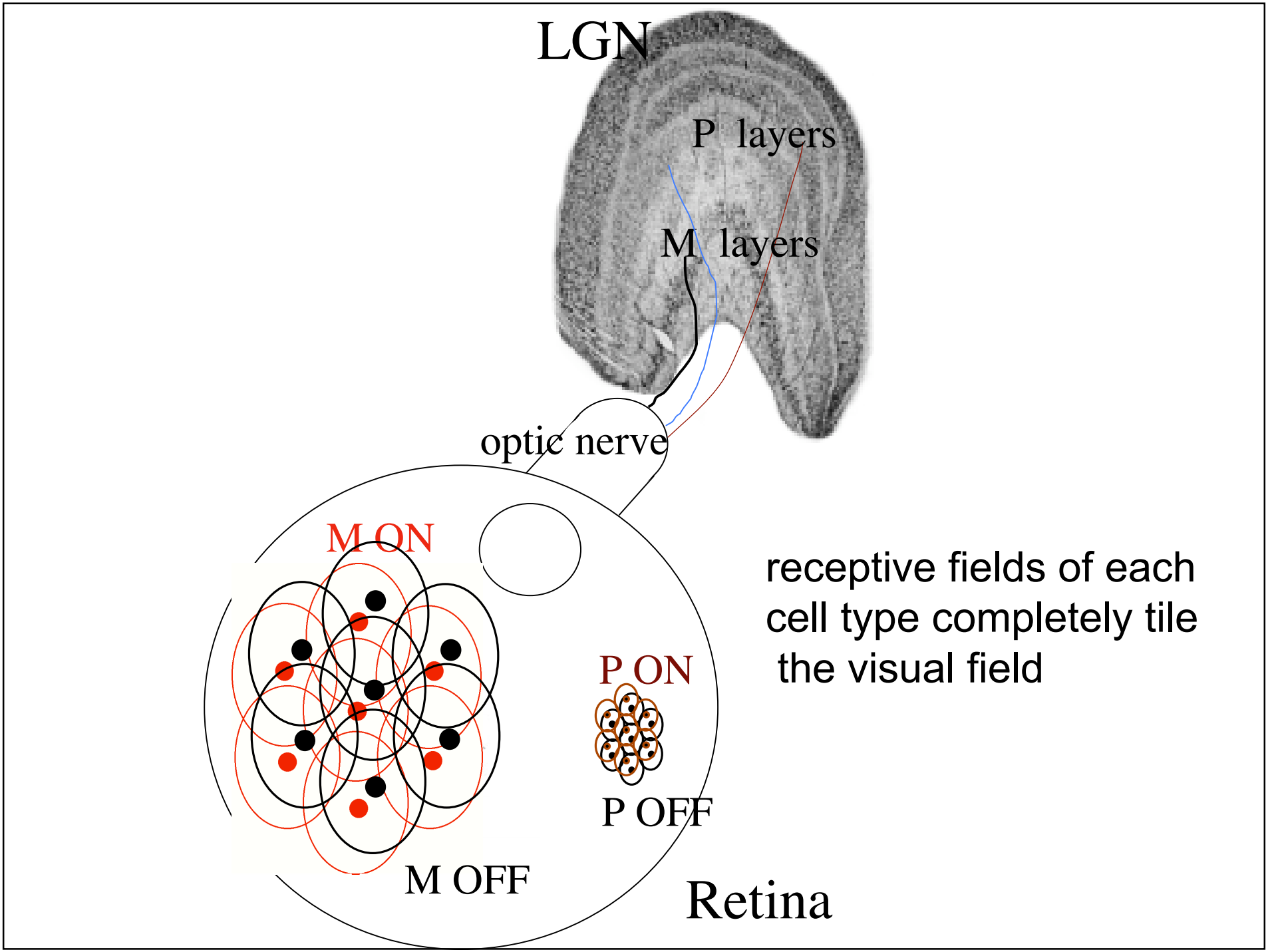
  *multisensory integration in goal oriented behaviors*

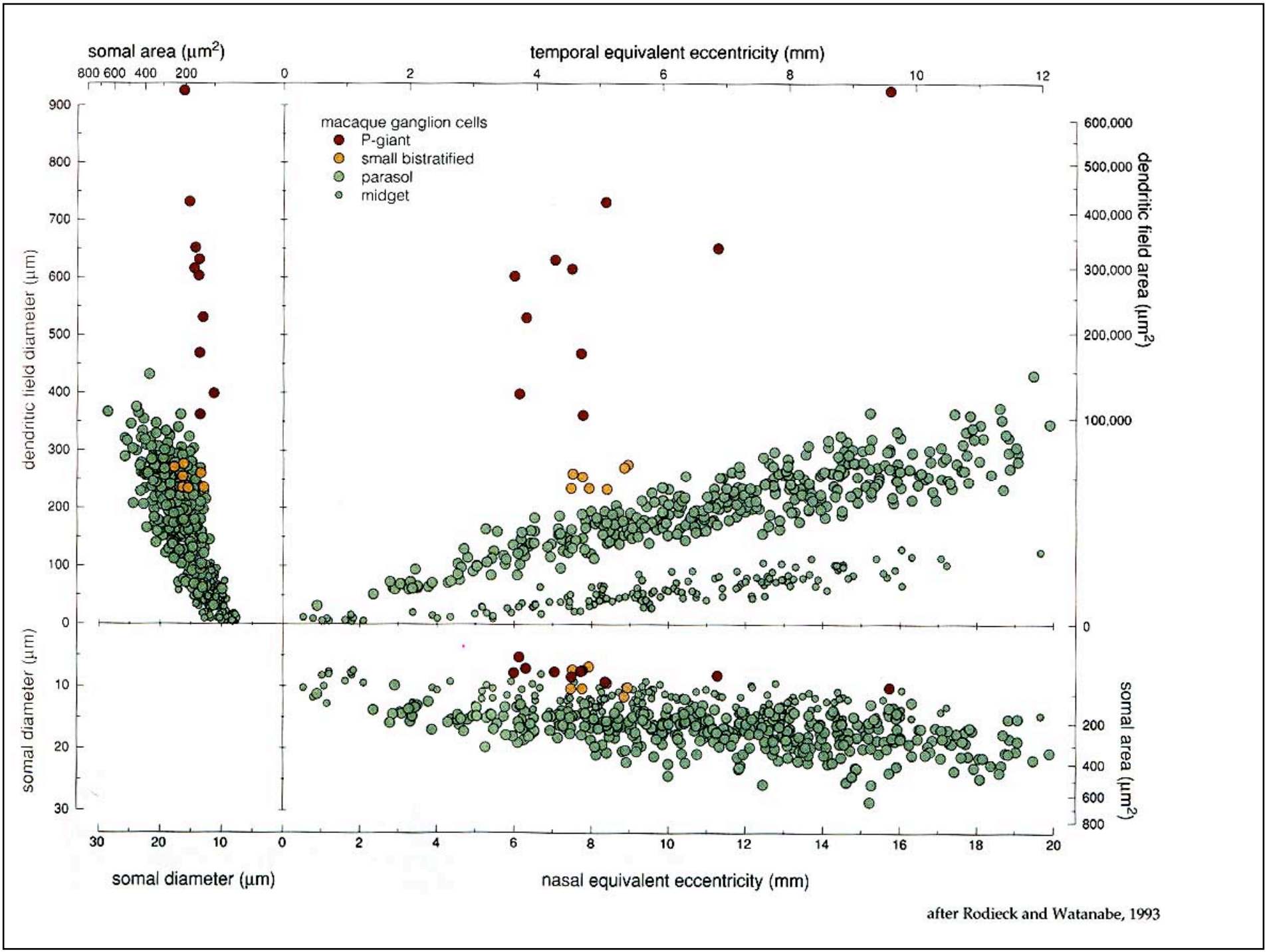
# Central Retinal Projections




LGN
P layers
M layers
optic nerve
M cell
P cell
Blue cell
Retina


midget
17.9 mm
parasol
11.6 mm
large dense
18.1 mm
thorny
12.2 mm
large sparse
12.6 mm
large moderate
7.1 mm
large very sparse
6.4 mm
giant very sparse
7.6 mm
axon collateral-bearing
11.8 mm
200 µm


LGN
P layers
M layers
optic nerve
M ON
P ON
P OFF
M OFF
Retina
receptive fields of each cell type completely tile the visual field




after Rodieck and Watanabe, 1993

# Properties of the 3 most numerous retinal-LGN cells

| | P-cells | M-cells | Blue - cells |
|---|---|---|---|
| **number** | *80%* | *10%* | *6%* |
| **Soma size** | *medium* | *large* | *small* |
| **RF size** | *small* | *large* | *large* |
| **conduction velocity** | *slow* | *fast* | *very slow* |
| **color** | *red-green* | *no* | *bue-yellow* |

# *Organization and properties of LGN*

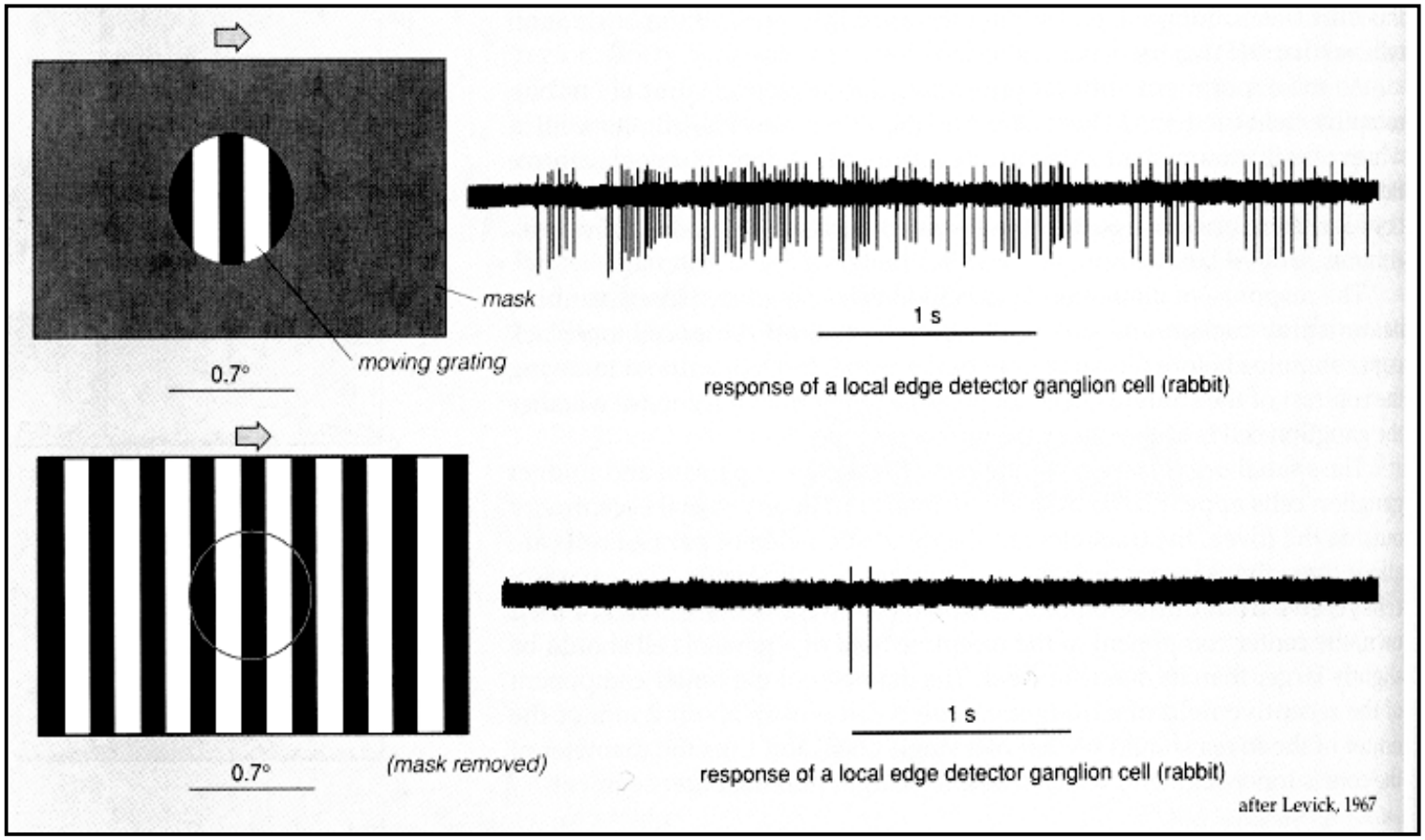
***Receptive field properties***

*Parvocellular neurons*
*red-green color, high spatial resolution, low contrast sensitivity, low temporal resolution*

*Magnocellular neurons*
*high contrast sensitivity, high flicker rates (speeds), low spatial resolution*

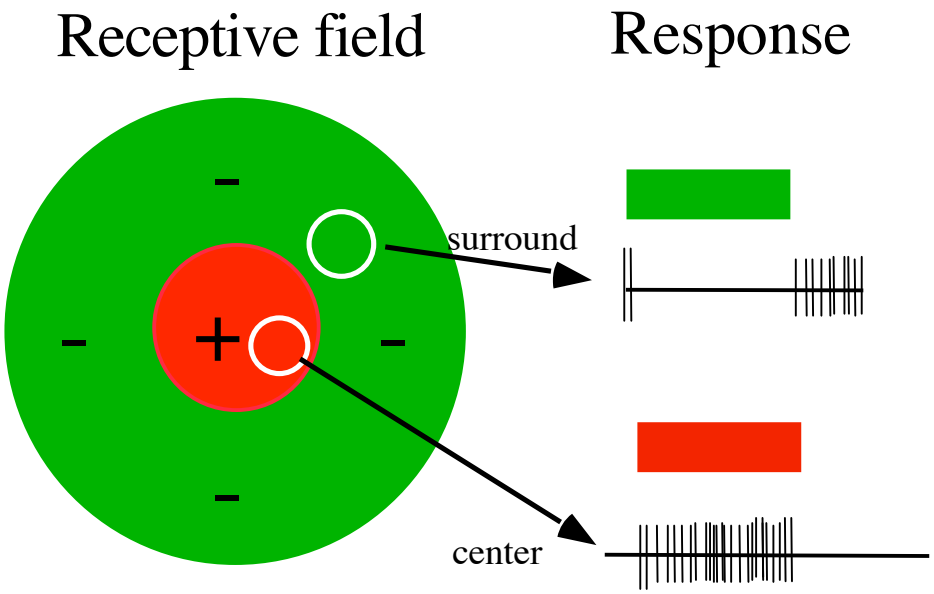
*Blue neurons*
*yellow-blue color, low spatial resolution, low contrast sensitivity, low temporal resolution*

# *Inhibitory Surrounds of Receptive Fields in the retina and LGN*



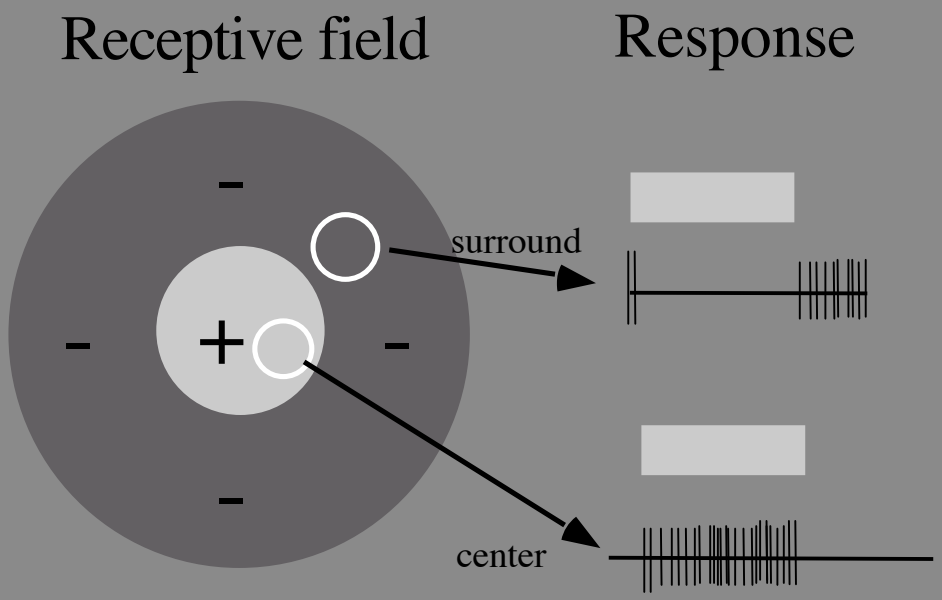
# *Red-green P-cells in the LGN*

are both spatially and chromatically opponent



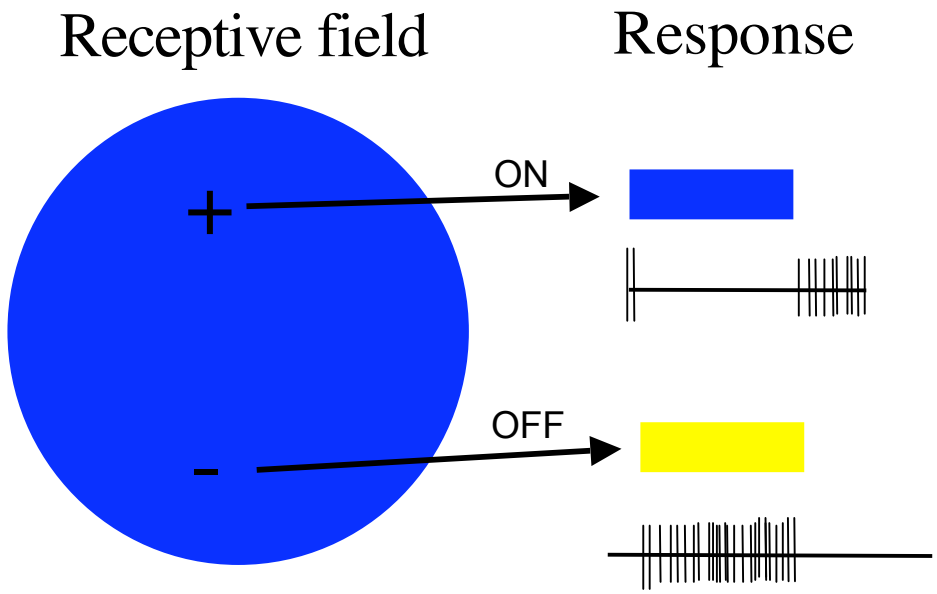
# *M-cells in the LGN*

are spatially, but not chromatically, opponent

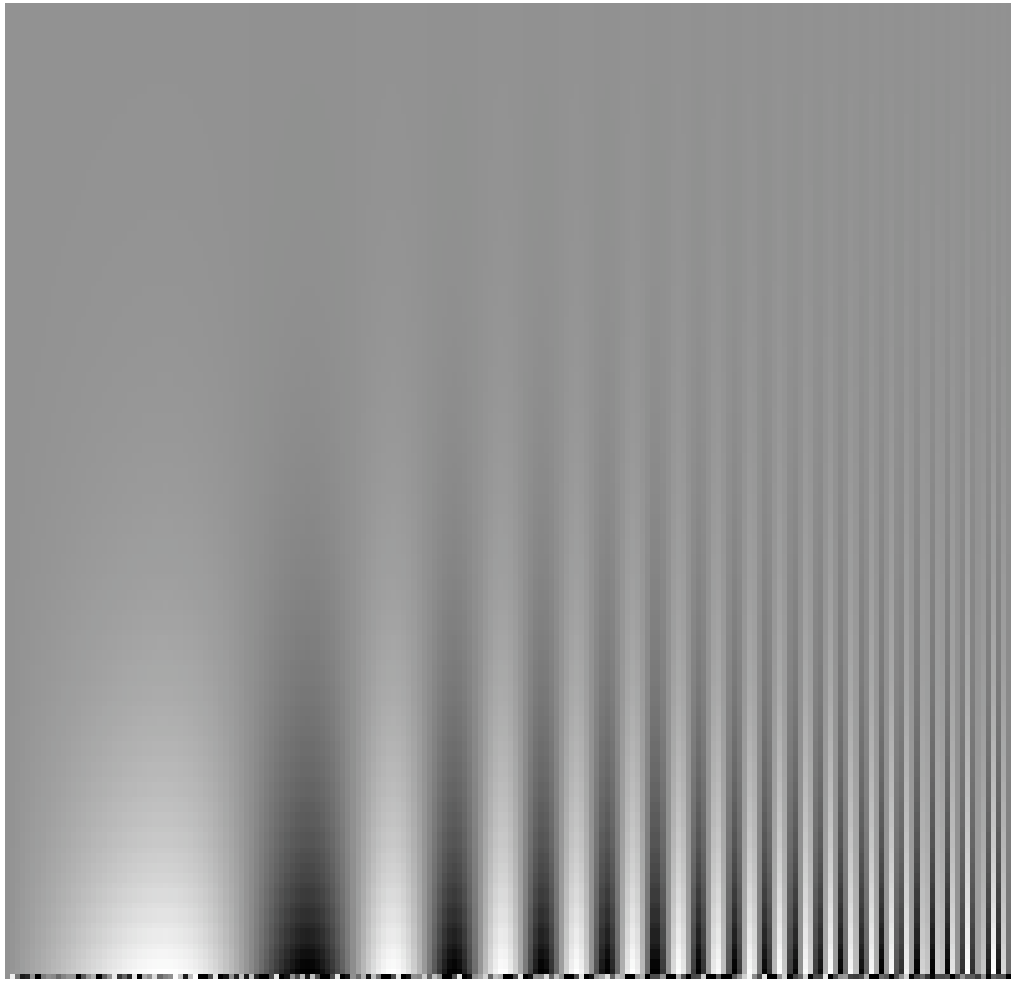


# *Blue ON-yellow OFF cell in the LGN*

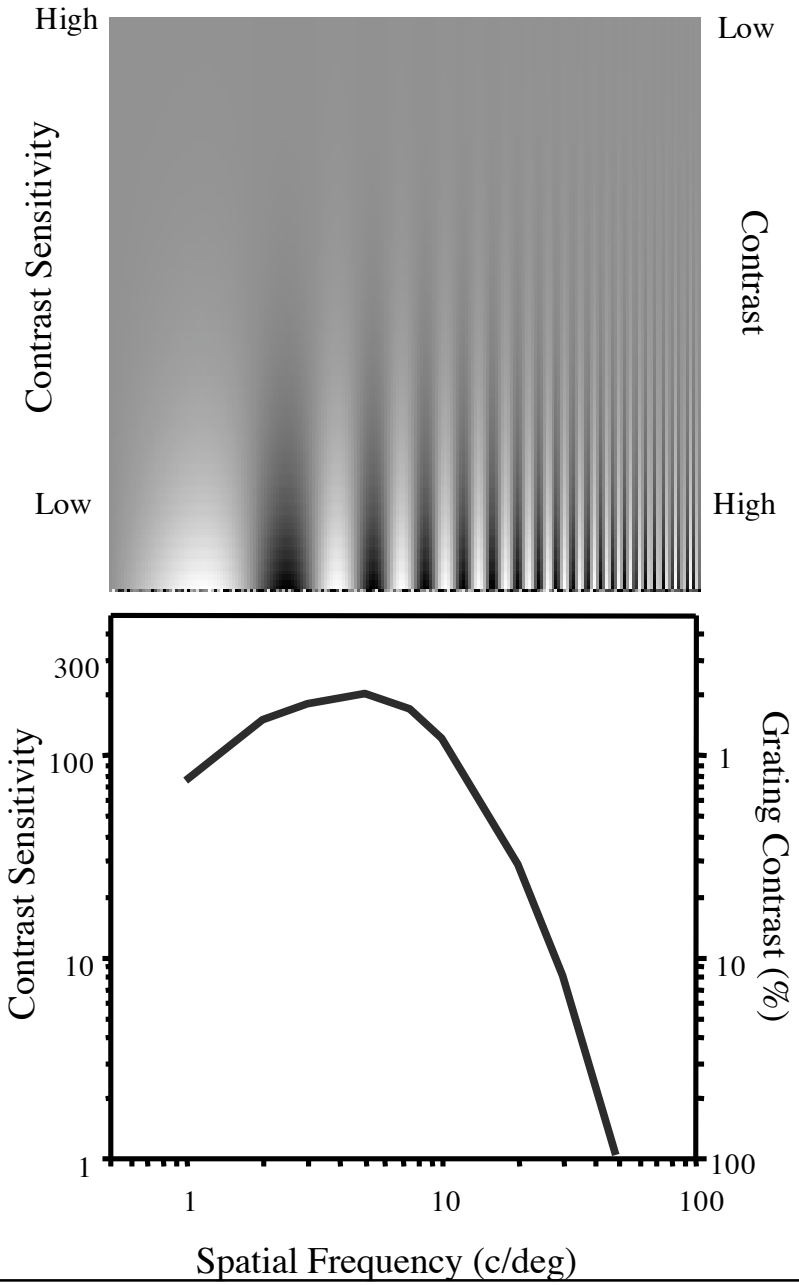
are chromatically but not spatially opponent



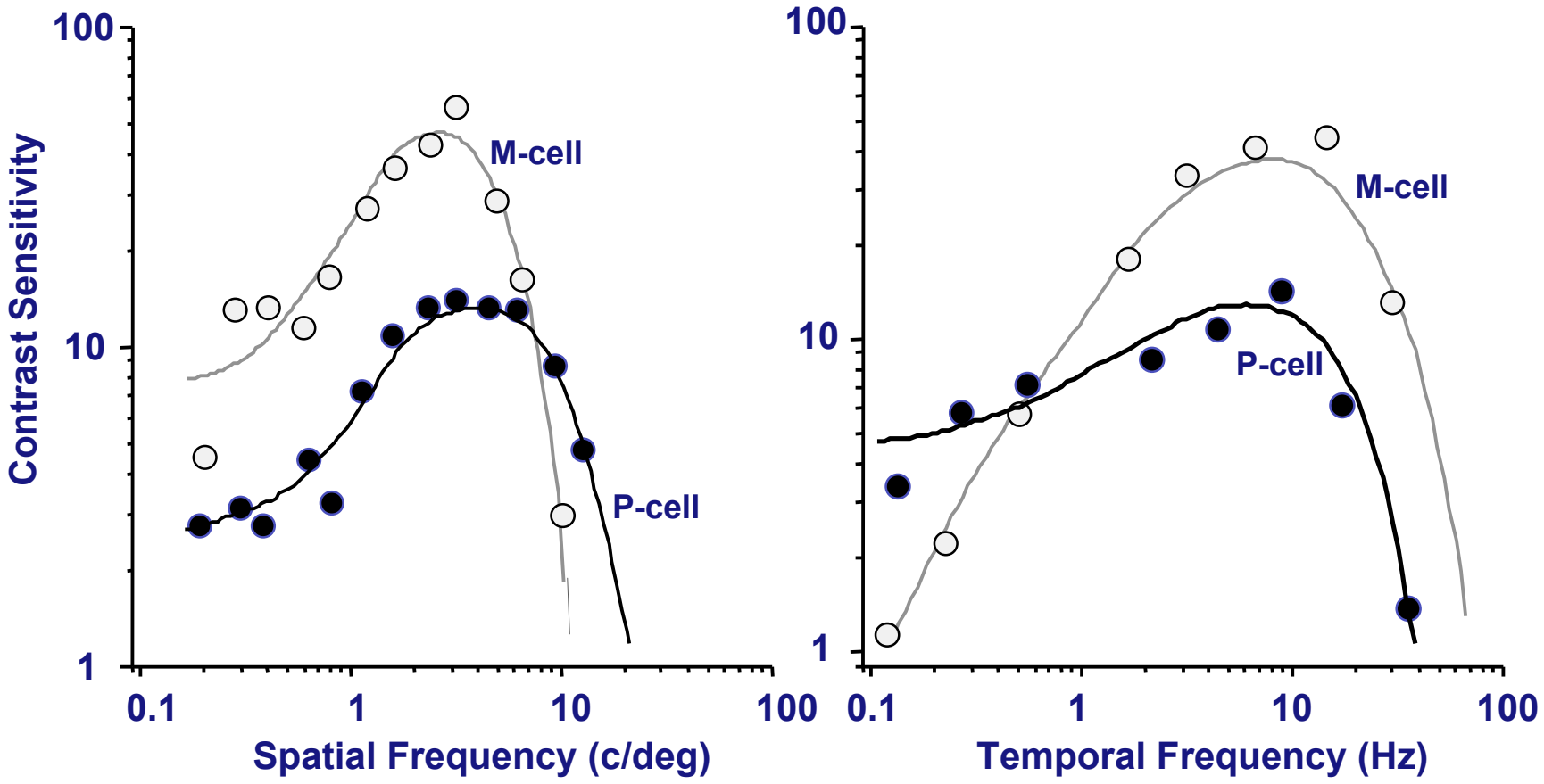
# Spatial contrast sensitivity



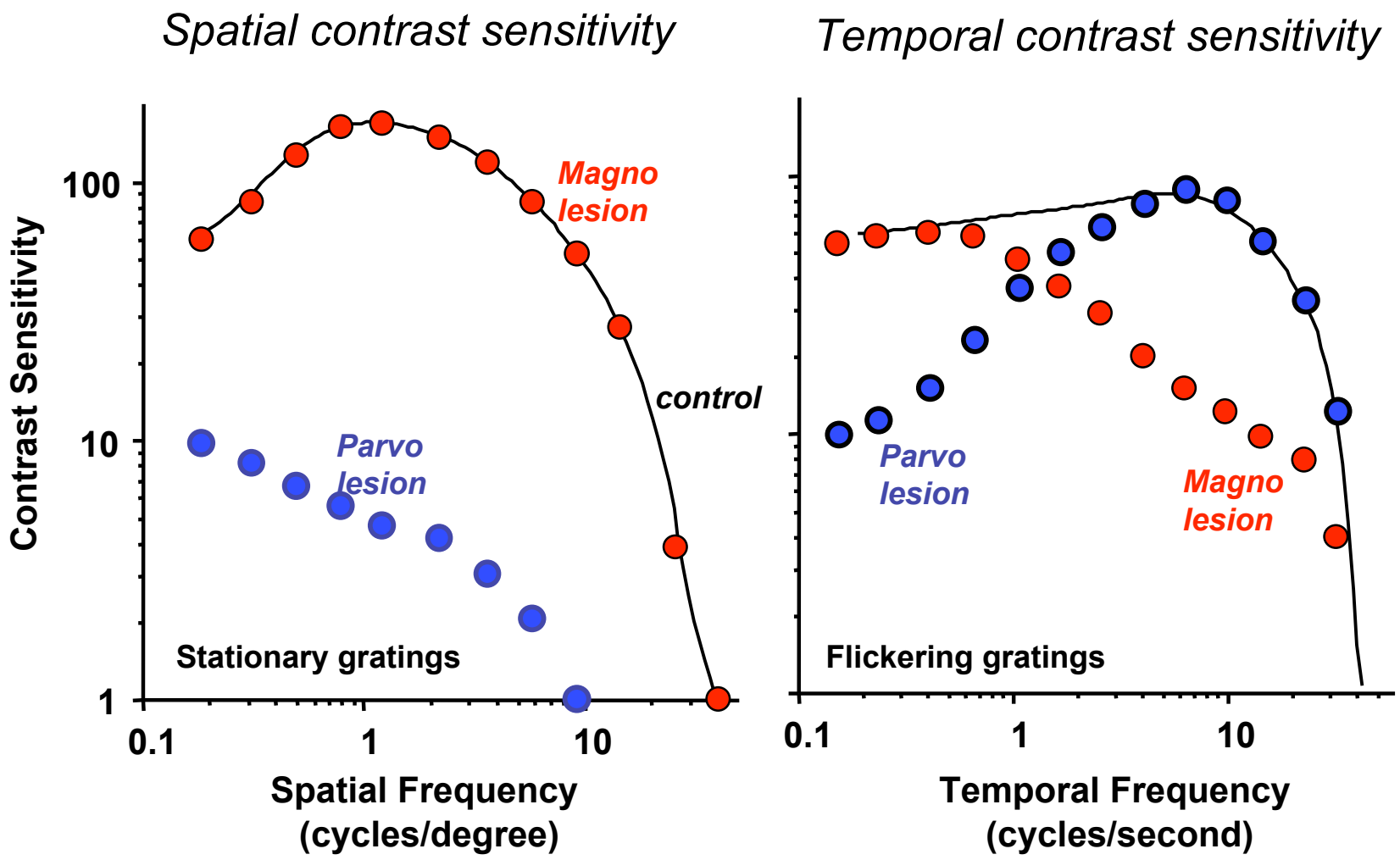
# Contrast Sensitivity Function



# *Spatiotemporal Properties of P and M-cells in the LGN*



# *Effects of P and M lesions in the LGN*



# Effects of LGN Lesions in Primates

## P- lesion

*loss of acuity*

*loss of color vision*

*loss of sensitivity to fine, slowly moving or flickering patterns*

## M - lesion

*intact acuity*

*intact color vision*

*loss of sensitivity to coarse, fast moving or flickering patterns*