

# Cellular components of CNS

- Neurons

- Glial cells:

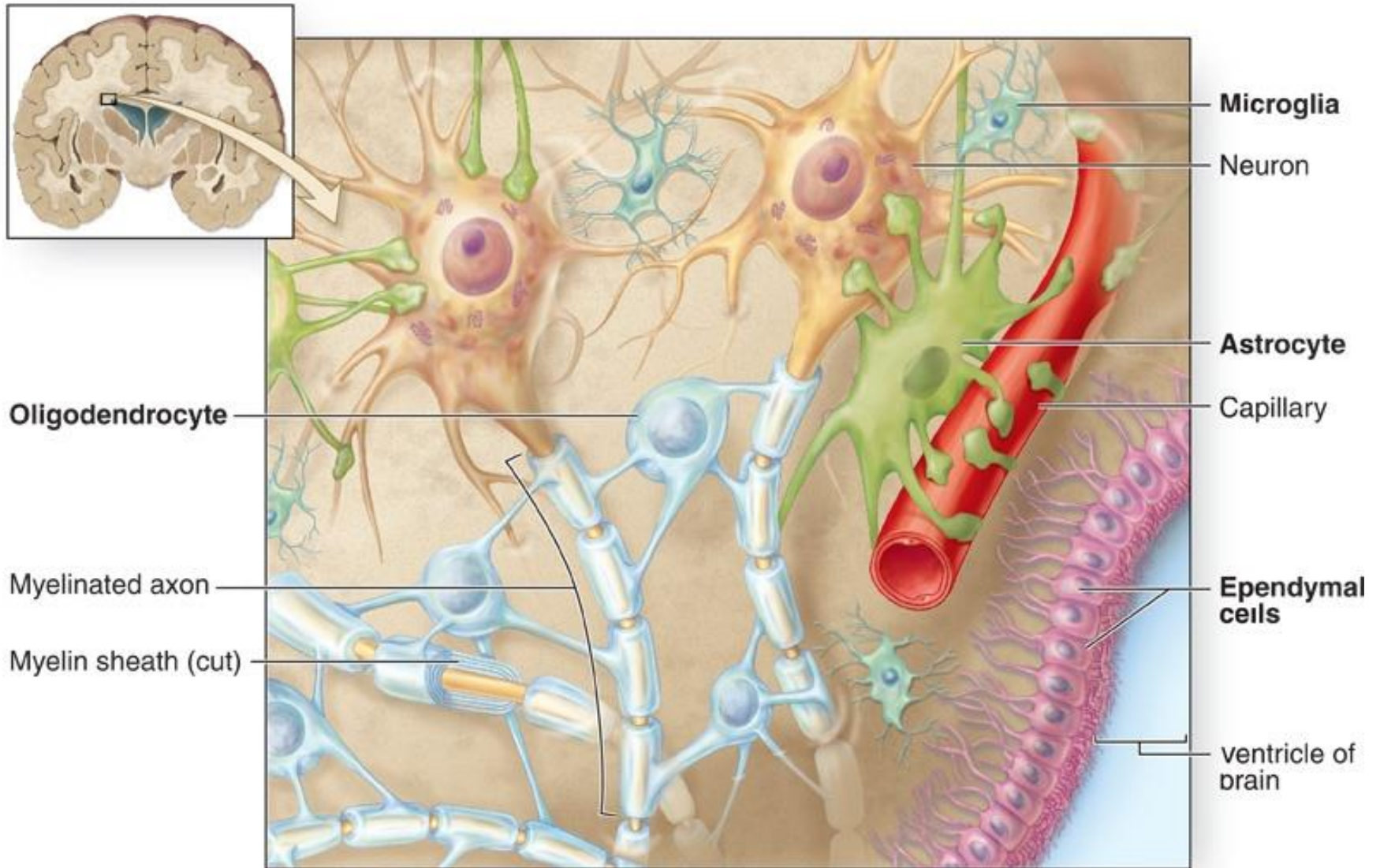
**Astrocytes (including radial glia),  
oligodendrocytes, microglia, ependymal cells**

- Epithelial cells of choroid plexus

- Endothelial cells of CNS capillaries

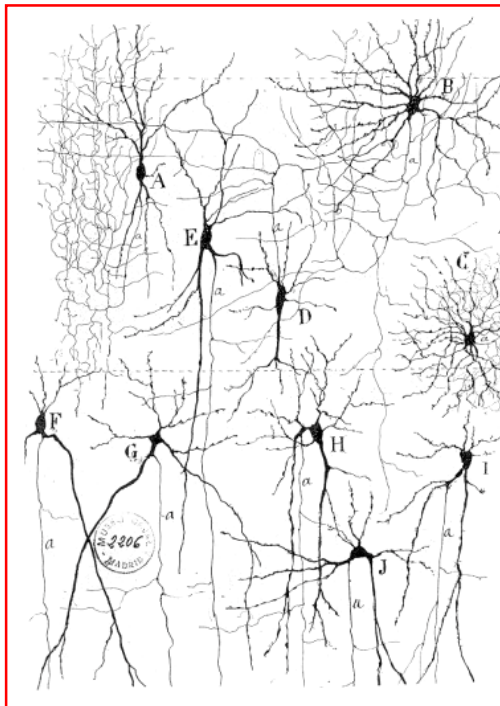
# Cellular components of CNS

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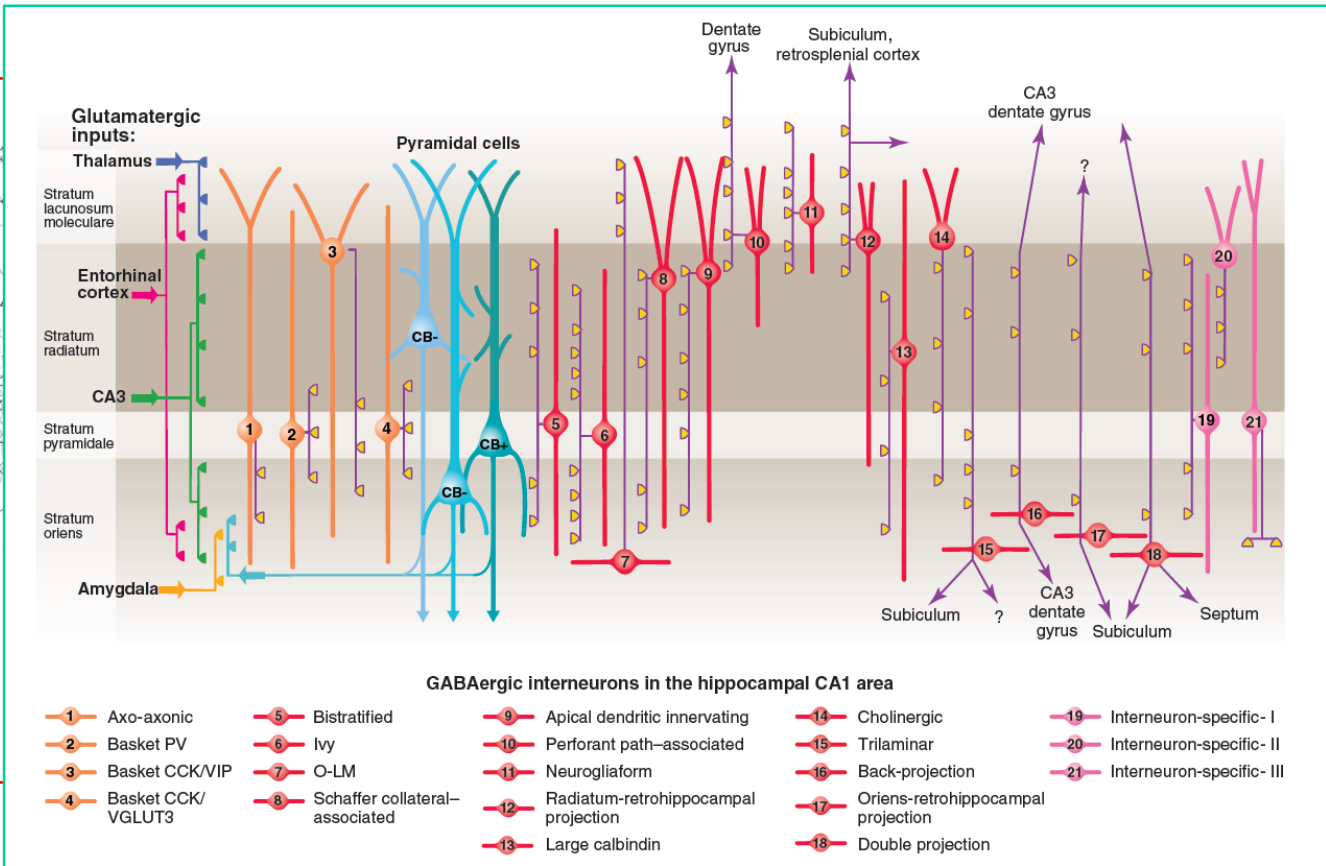


# The neuron is the basic functional unit of the nervous system

Neurons come in many different shapes and functions.....



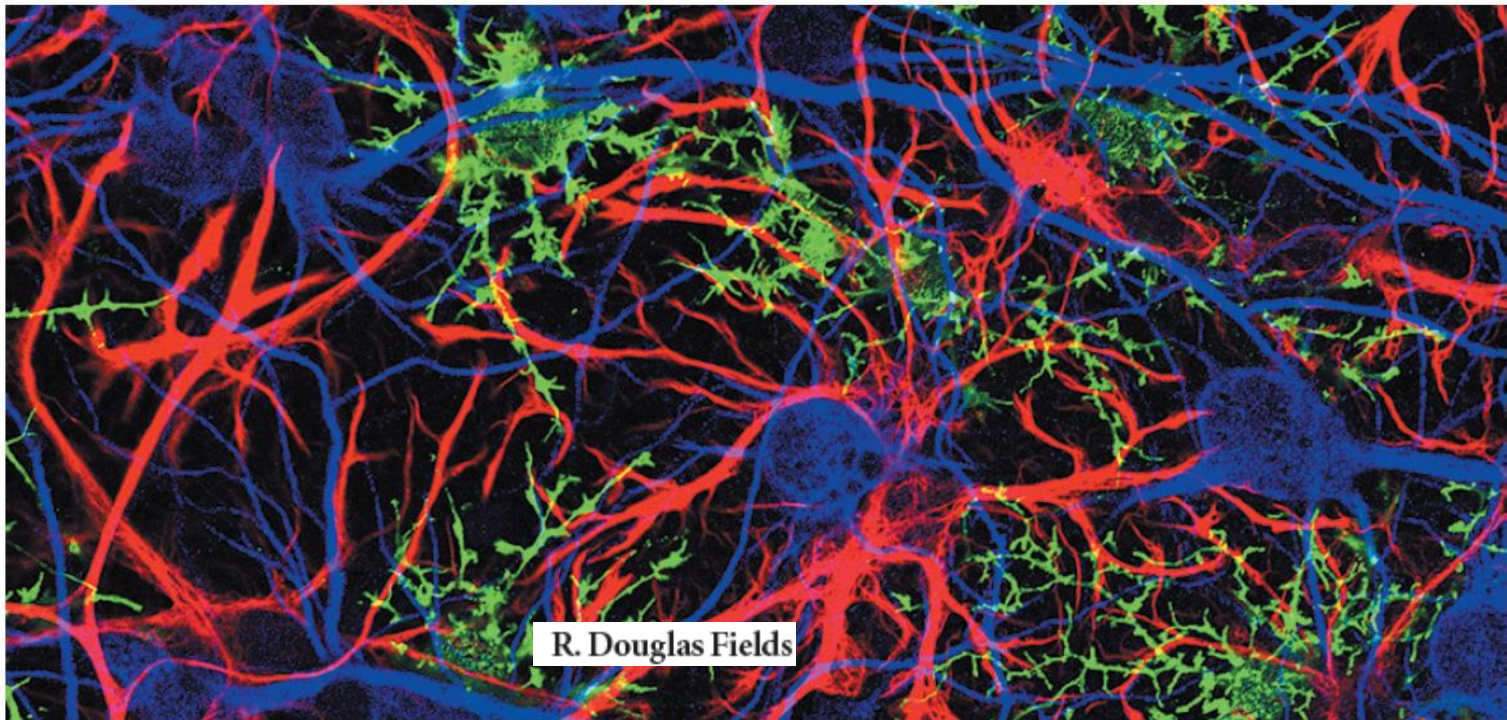
(Cajal, 1905)



Thomas Klausberger<sup>1,2\*</sup> and Peter Somogyi<sup>1\*</sup>  
 SCIENCE VOL 321 4 JULY 2008

...yet, our understanding of one half of the brain (the part comprised of **astrocytes, oligodendrocytes and microglia**) lags a century behind our knowledge of neurons.

# GLIA



Astrocytes (red) and immature oligodendrocytes (green), types of glial cell, intertwine with neurons (blue) from the brain's hippocampus.

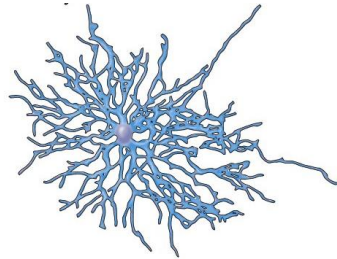
## Neurons vs. glia

- The defining characteristic of a **neuron** is... its ability to transmit rapid electrical signals in the form of action potentials.
- All other neural cells that lack this property are broadly called **glia**.
  - Traditionally, glia have been viewed as passive cells that help to maintain the function of neurons.

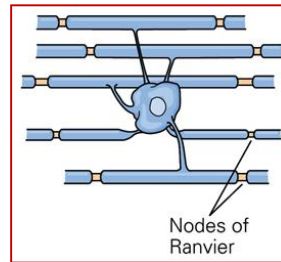
# CLASSIFICATION OF GLIAL CELLS

## MACROGLIA

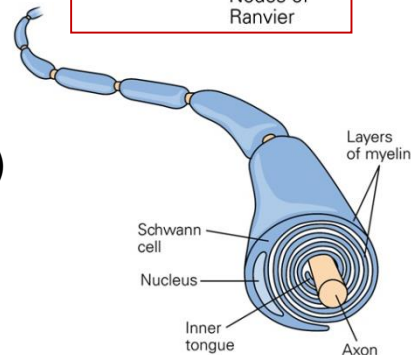
- Astrocytes (SNC)



- Oligodendrocytes (SNC)

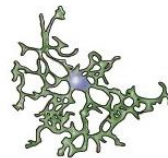


- Schwann cells (SNP)



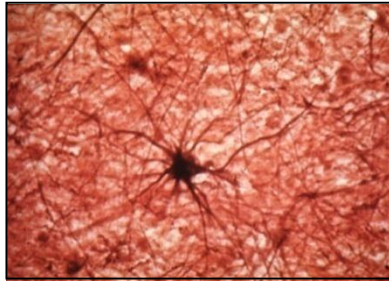
*ectodermal  
origin*

## MICROGLIA

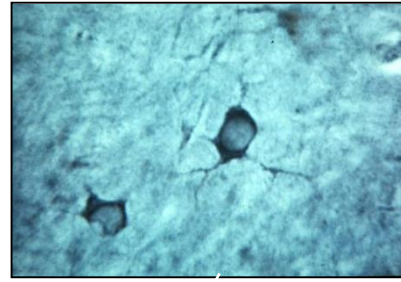


*mesodermal  
origin*

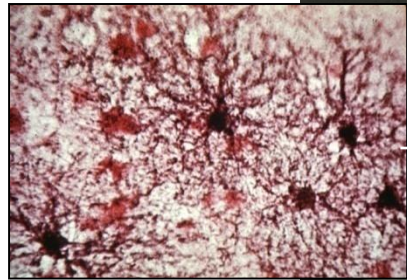
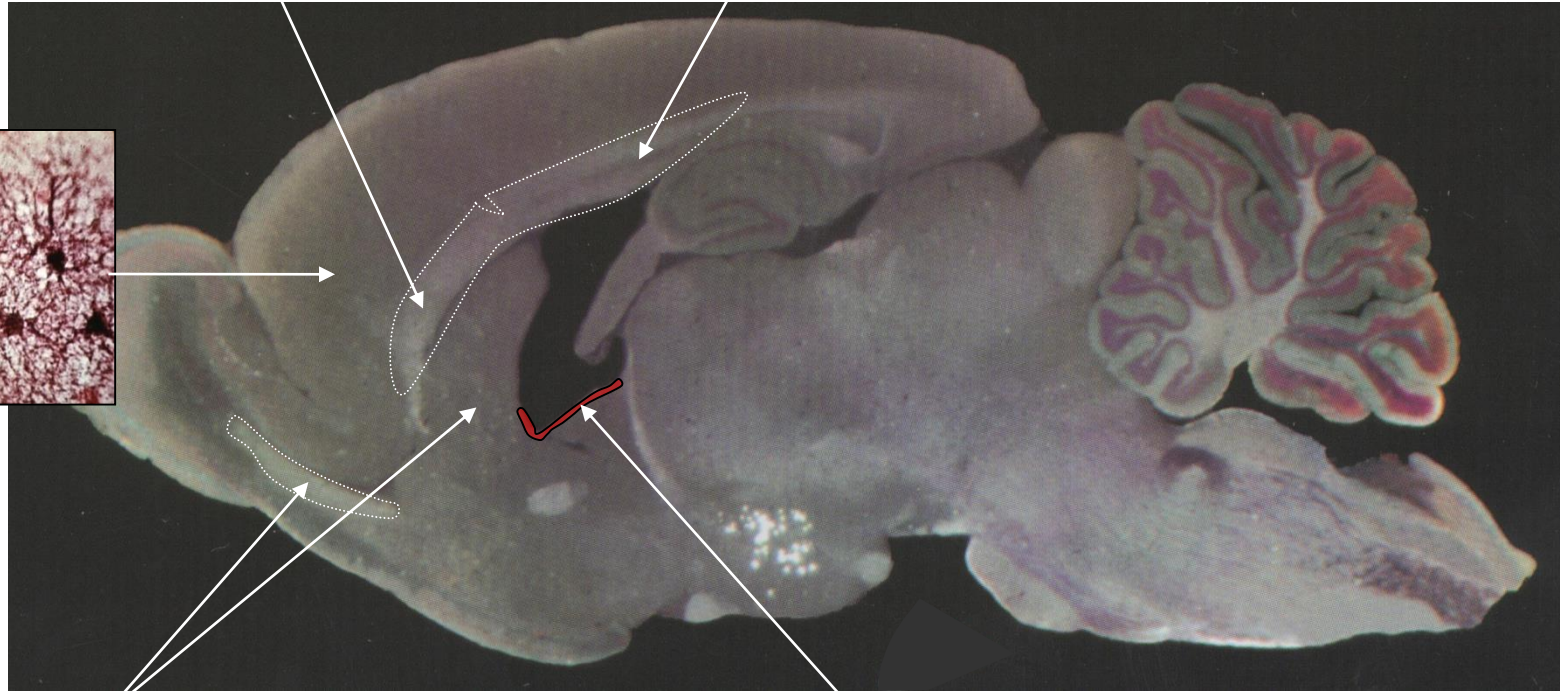
**Fibrous astrocytes**



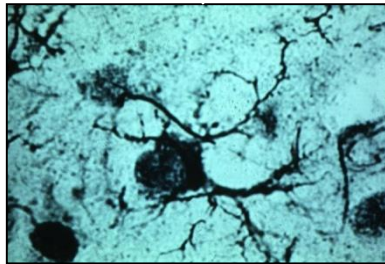
**Oligodendrocytes**



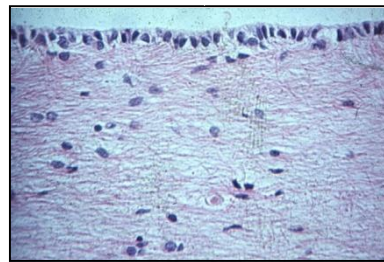
**Glial cell  
distribution *in  
vivo* in the CNS**



**Protoplasmic  
astrocytes**

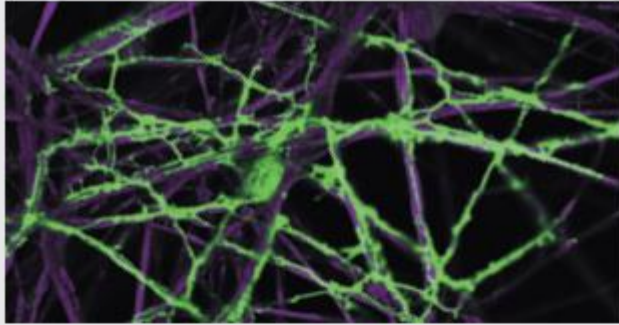


**Microglial cells**



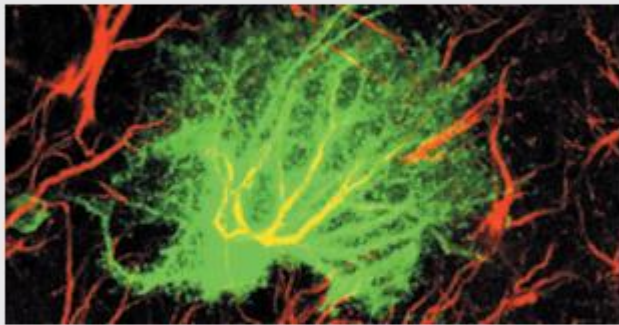
**Ependymal cells**

# ROLES OF GLIAL CELLS



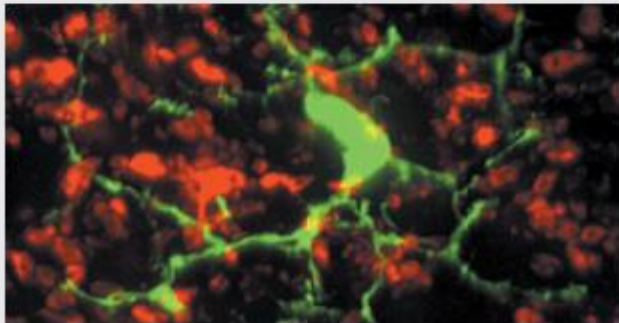
## Oligodendrocytes (green)

- Form myelin electrical insulation, increasing conduction velocity by at least 50 times.
- Provide vital metabolic support for axons (purple).
- Involved in multiple sclerosis, amyotrophic lateral sclerosis and the inhibition of repair after spinal-cord injury.



## Astrocytes (red and green)

- Ensheath synapses, regulate neuronal excitability and synaptic transmission.
- Respond to injury by secreting extracellular matrix proteins.
- Implicated in neurogenesis, cell migration, and many neurological and psychiatric disorders.



## Microglia (green)

- Highly motile and responsive to nervous-system injury and infection.
- Monitor electrical activity in neurons and prune synaptic connections (red).
- Involved in almost all nervous-system diseases and in certain psychiatric conditions.



## Brief history of glia

Glia have a long history: they were first noted in 1824 and first named in 1856.

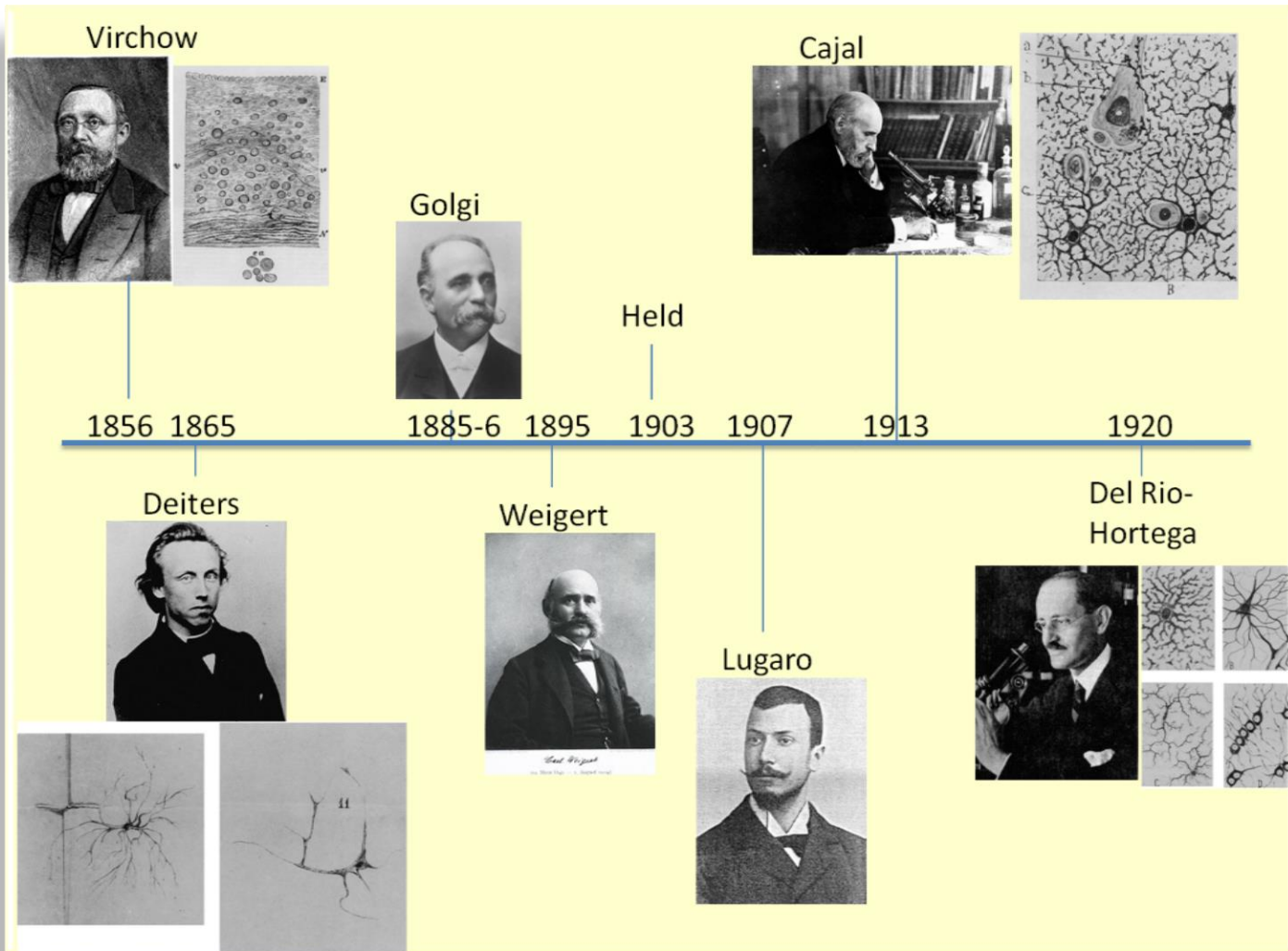
While never as studied as neurons, the early neuroscientists studied and debated glia's classification, morphology, and roles.

Very recently, more and more glial roles have been recognized and glia are being considered more active players in the nervous system than ever before.

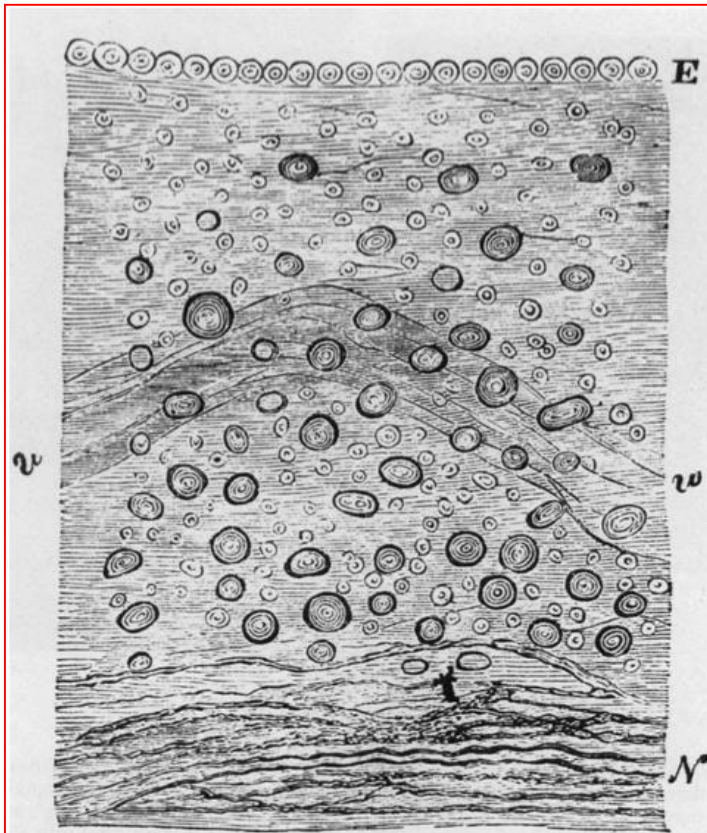
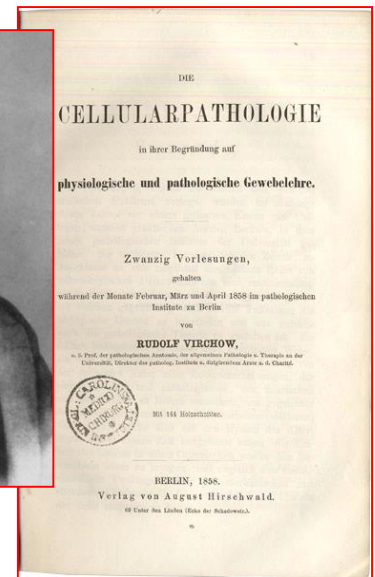
Many of the functions now recognized, however, were proposed by the earliest neuroscientists, such as glia's ability to secrete chemicals (Nageotte), their association with blood vessels (Golgi), their morphological plasticity (Cajal), their ability to electrically insulate (Cajal), their role in neurotransmitter uptake and termination (Lugaro), and role in pathology (Virchow).

# Brief history of glia

<https://wiki.brown.edu/confluence/display/BN0193S04/History+of+Glia>



# Virchow (1821-1902)

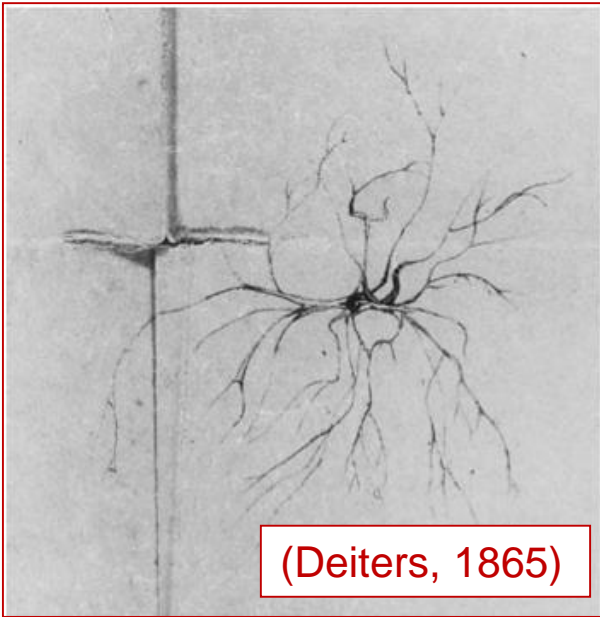


- **Virchow** has been generally credited with the discovery of CNS glia (1856, 1858).
- Was actually arguing that there is a connective substance in the brain, *nervenkitt*, or neuroglia.

(Virchow, 1858)

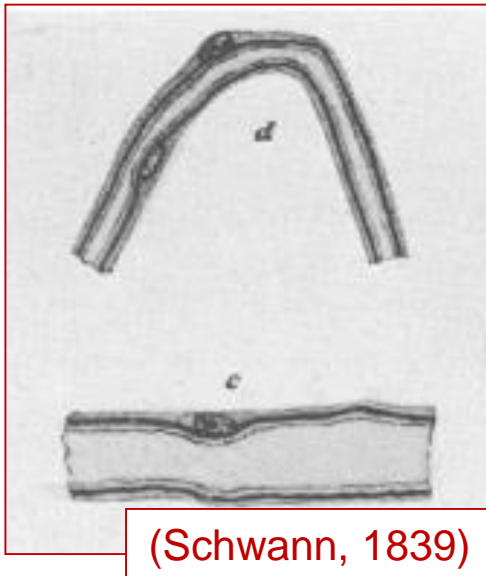


E, ependymal epithelium; v-w, blood vessel in "connective tissue"; N, nerve fibers; ca, copora amylacea--perhaps a staining artifact



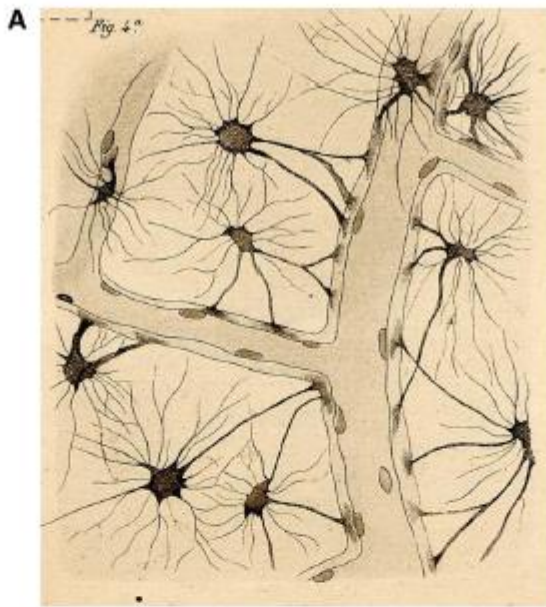
(Deiters, 1865)

**Deiters** (1865) first identified non-neuronal cells in the CNS as cells that lack axons.



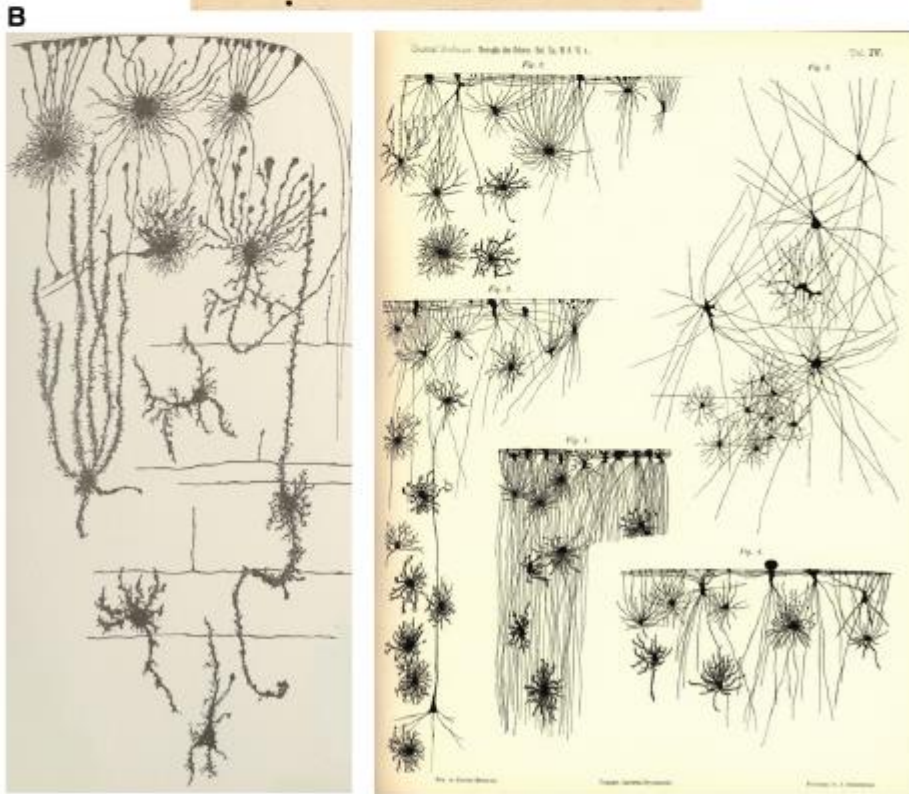
(Schwann, 1839)

**Schwann** (1839) realized that the “white substance of nervous fibers” was associated with individual cells and identified Schwann cells in the PNS.



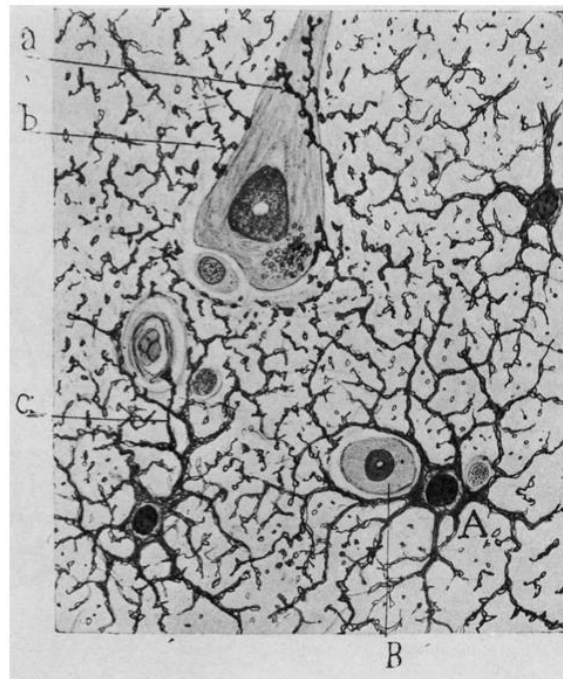
**Astroglial cells stained by the silver-chromate technique.**

**A:** Protoplasmic astroglial cells in the grey matter stained and drawn by Camillo Golgi; the astrocytes form numerous contacts (the endfeet) with brain capillaries (Golgi, 1883).



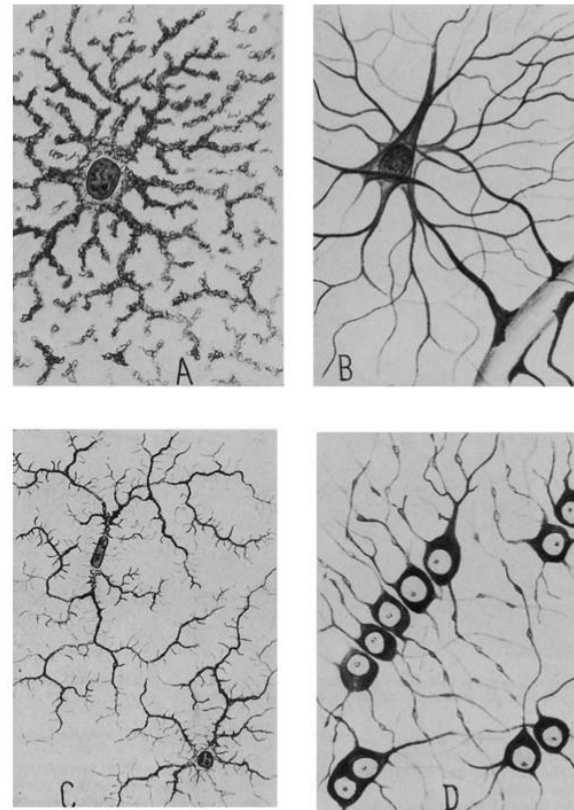
**B. Morphological heterogeneity of human astrocytes.** The astrocytes in the brain slices of human fetuses were stained by silver-chromate technique (Retzius, 1894).

By 1920, major classes of CNS glia had been identified.

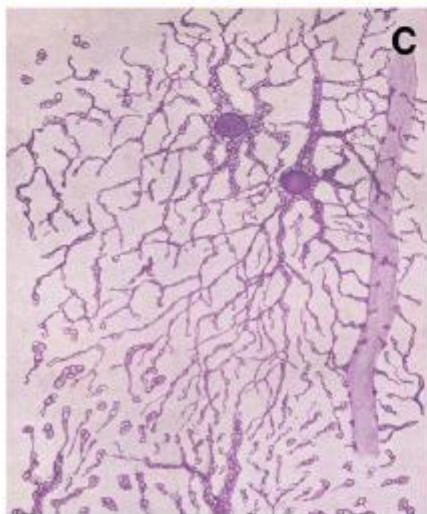
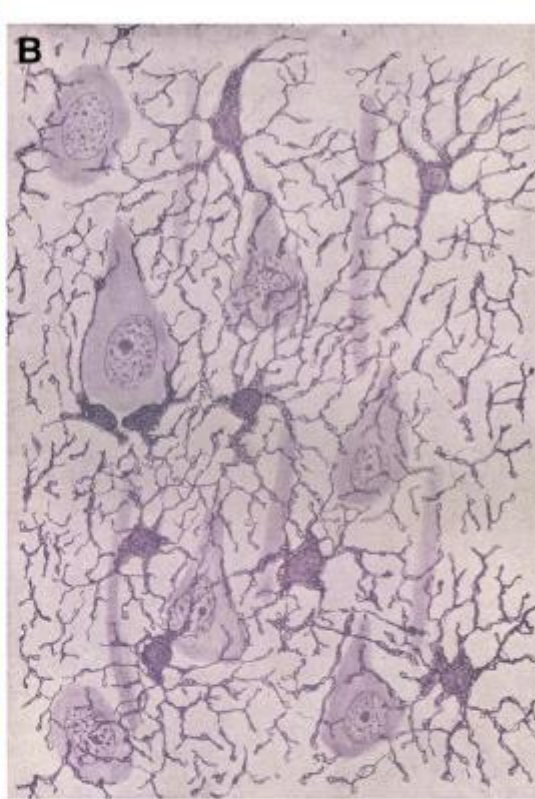
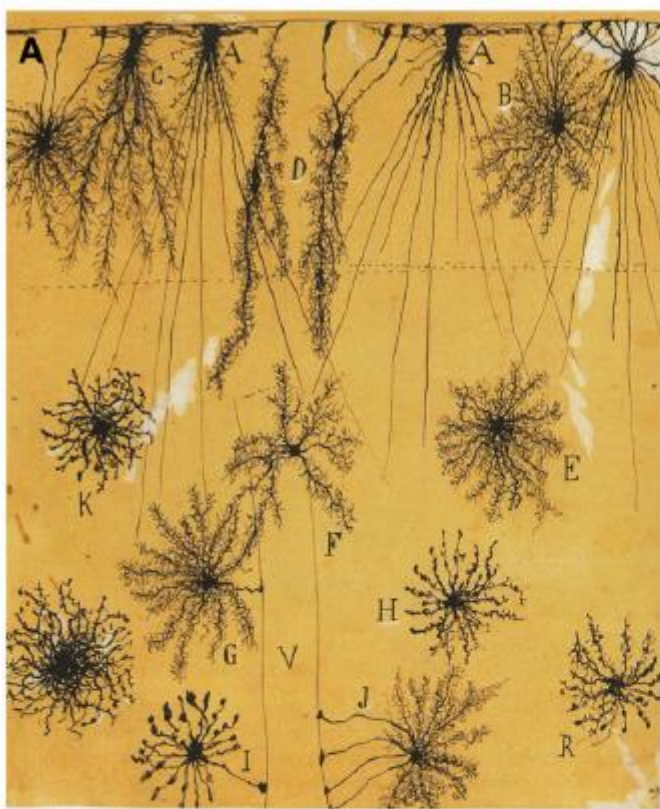


(Cajal, 1913)

(Del Rio-Hortega, 1920)



Del Rio-Hortega's four types of glia. A: Gray matter protoplasmic neuroglia. B: White matter fibrous neuroglia. C: Microglia. D: White matter interfascicular glia (oligodendrocytes) (Somjen 1988, Fig. 4)

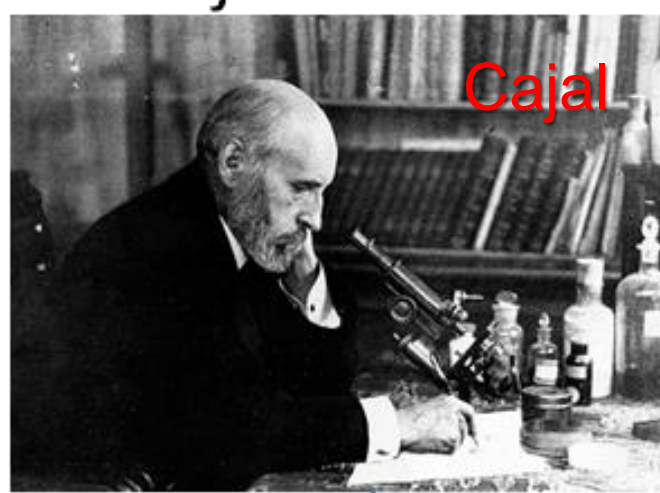


## Glial cells by the eyes of Santiago Ramón y Cajal and Pío del Río-Hortega.

**A:** Cajal's drawing of Golgi impregnated glia showing human cortical neuroglial cells of the plexiform layer (A–D), cells of the second and third layers (E–H and K, R) and perivascular glia (I, J).

**B, C:** Astrocytes in the stratum lucidum of the human **CA1 area of the hippocampus** with particular emphasis on the anatomy of **perivascular astrocytes** in the CA1 stratum radiatum.

**D, E:** Drawings of **Pío del Río-Hortega** showing the different morphological types of **microglial cells** in the rabbit Ammon's horn and cortical perivascular neuroglia.



## Early functions of glia: a strong debate

**Virchow** named glia after what he thought was their main role – structural support –.

**Golgi** argued that glia served a nutritive role for neurons.

**Santiago Ramon y Cajal**, because he believed dendrites were involved in signaling and not just nutrients in neurons, disagreed with Golgi's hypothesis. Cajal also disagreed with Virchow's and Weigert's theory that glia simply filled the spaces in between neurons or left by dead neurons. Cajal believed instead that glia's main role was to provide insulation to protect neurons from incorrect electrical signaling. Cajal also proposed that *glia could have a role in sleep by extending "their processes into synapses, reducing their activity...when astrocytic processes retract, neurons would contact one another and thus become active again"*

**Marinesco** recognized in 1896 glia's role in the phagocytosis of neurons. **Nageotte** suggested in 1910 that glia were part of the endocrine system and could secrete substances into the blood stream. **Lugaro**, in 1907, suggested many roles glial cells, including guiding neuronal migration in development and maintaining and detoxifying the interstitial fluid. He even predicted a glial role in the synapse, suggesting that glia could terminate synaptic action by chemically altering or taking up neurotransmitters



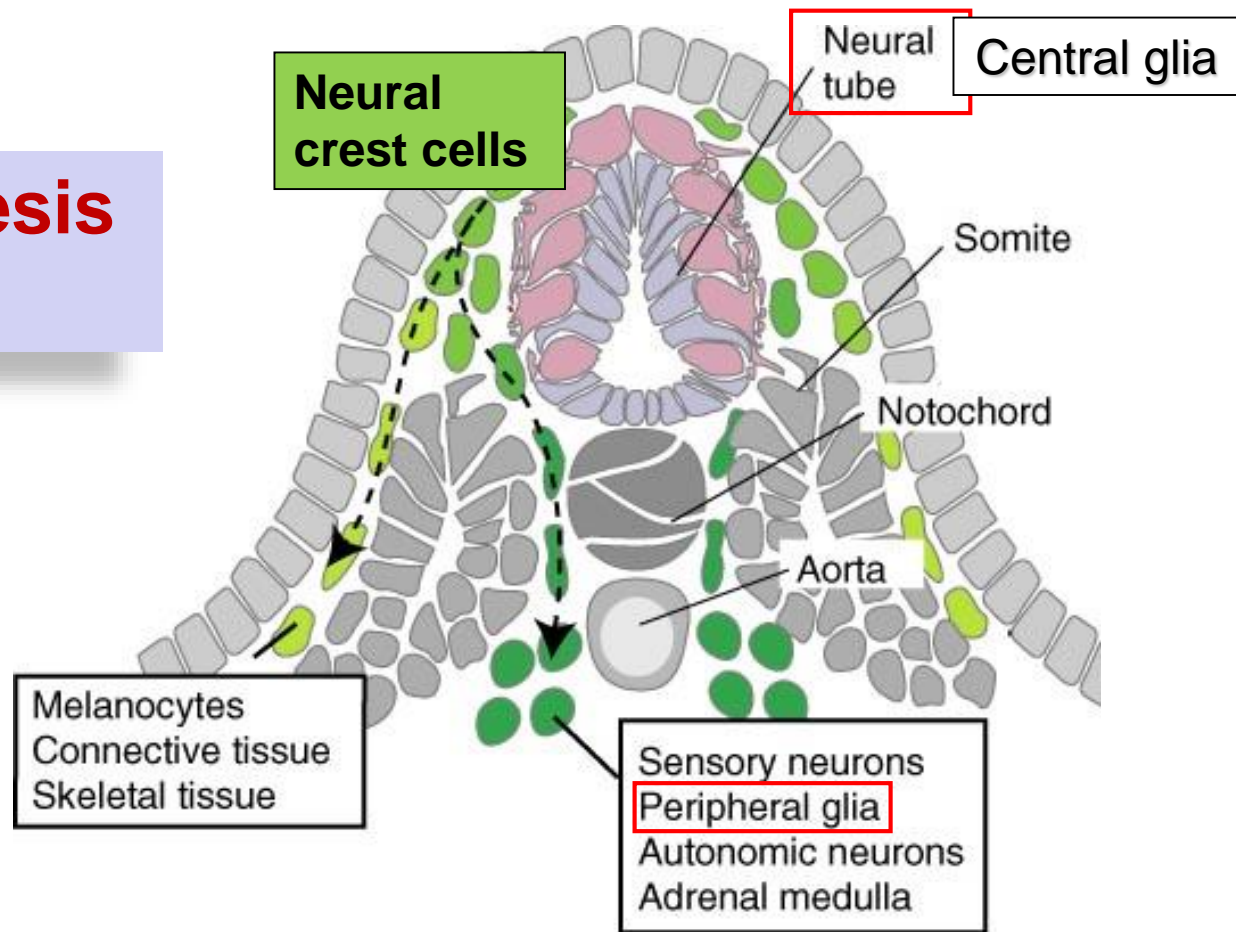
# The recent past.....

With the invention of the **electron microscopy**, investigations into the ultrastructure of astrocytes were undertaken by several scientists.

In terms of **chemical markers**, Eng et al. and Bignami et al. identified the **glial fibrillary acidic protein**, GFAP (1971 and 1972, respectively). This protein was found to be associated with astrocyte intermediate filaments, and though it is found not in all astrocytes, it has been particularly important in identifying astrocytes.

Additionally, Moore identified the **S-100 protein**, Sommer et al. identified the **C1 antigen** in Bergmann glia and retinal Muller cells, and Lagenaur et al. found the **M1 antigen** in protoplasmic and fibrous astrocytes, all of which help identify glia in immunocytochemistry today

## (Macro)gliogenesis in Vertebrates



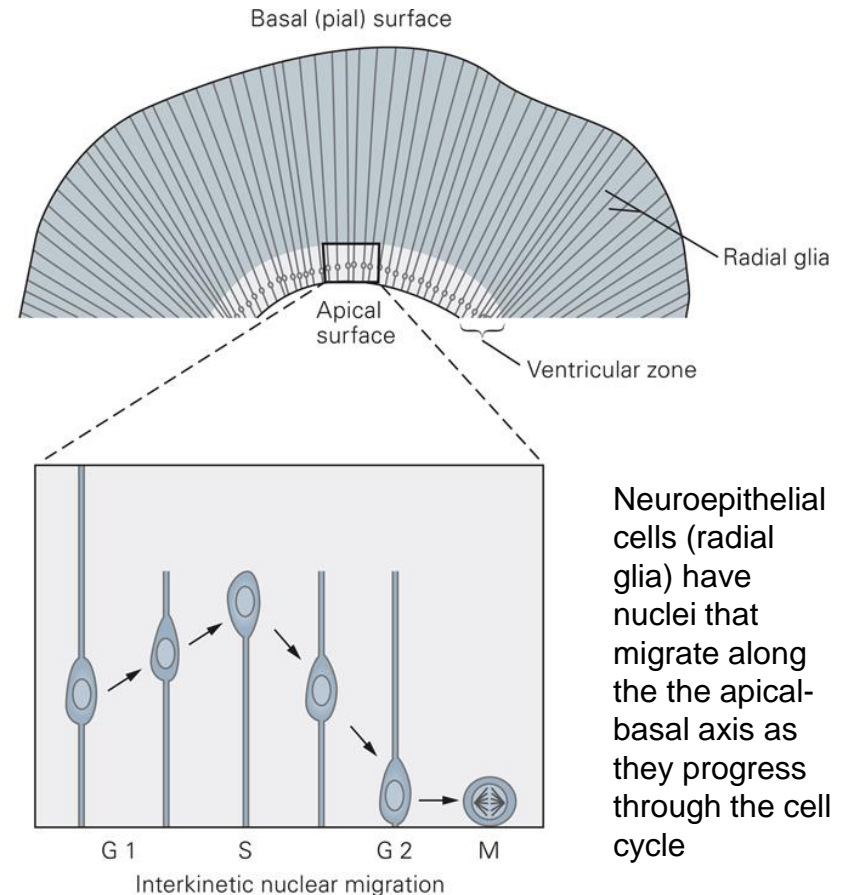
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**FIGURE 11** Neural crest lineages. Schematic cross section of vertebrate embryo in which migrating neural crest cells (green) are indicated. These cells follow two different pathways: a dorsal one (light green), giving rise to melanocytes, connective tissue, and skeletal tissue, and a ventral one, giving rise to sensory and autonomic ganglia, as well as adrenal medulla.

# Development of macroglia in the CNS

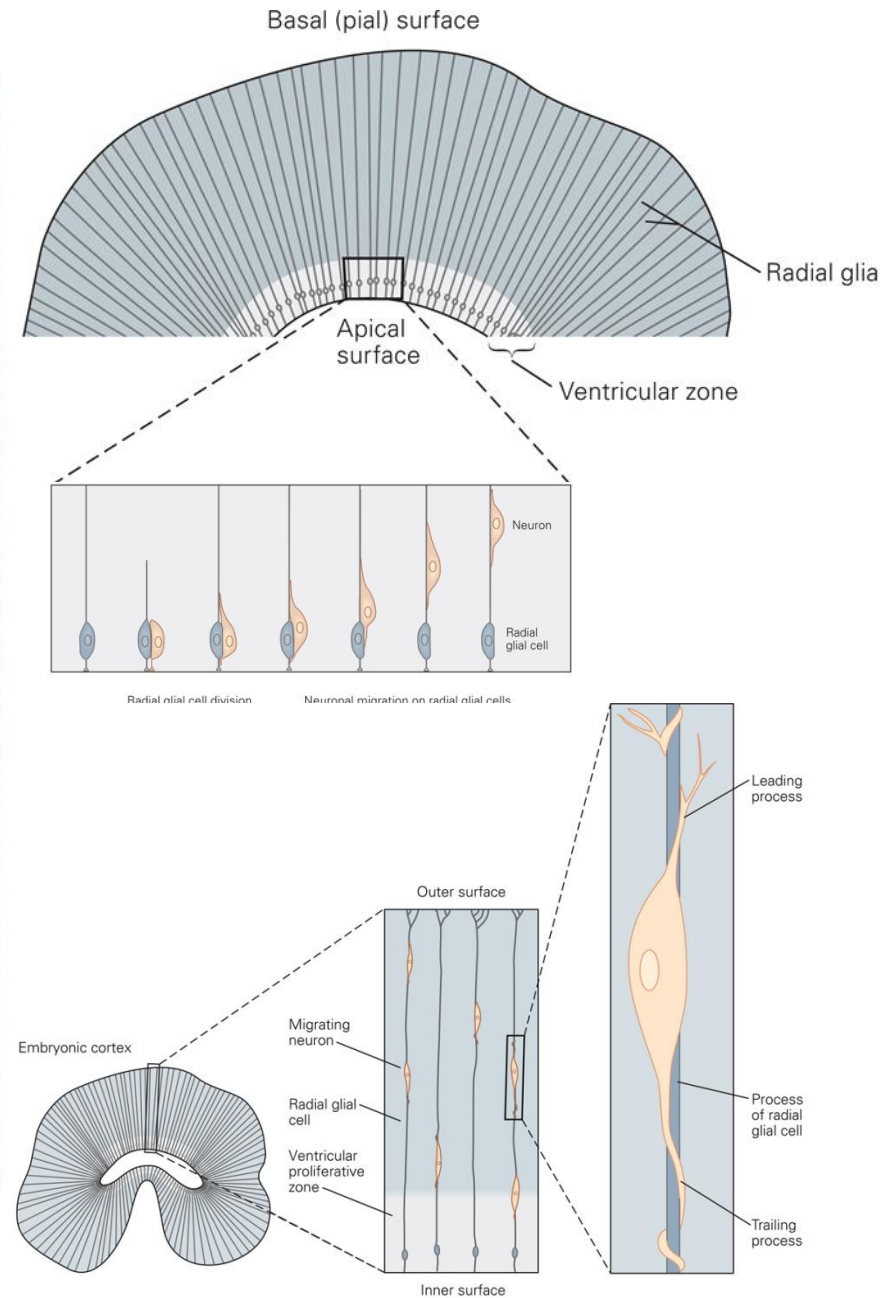
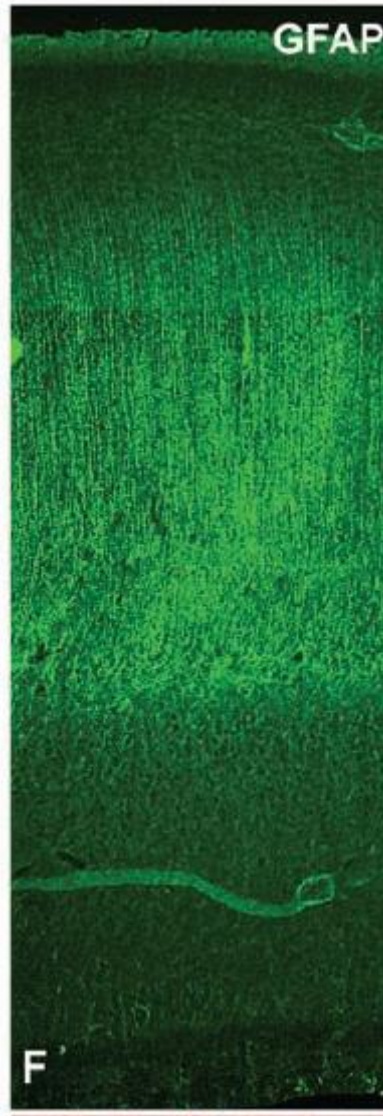
All neurons and glia (except microglia) in the developing CNS develop from precursor cells derived from the neuroectoderm.

- **neuroepithelial cells** line ventricles and spinal canal
- the earliest morphologically distinguishable cell type to appear within the neuroepithelium are **radial glial cells**



## Developmental origin

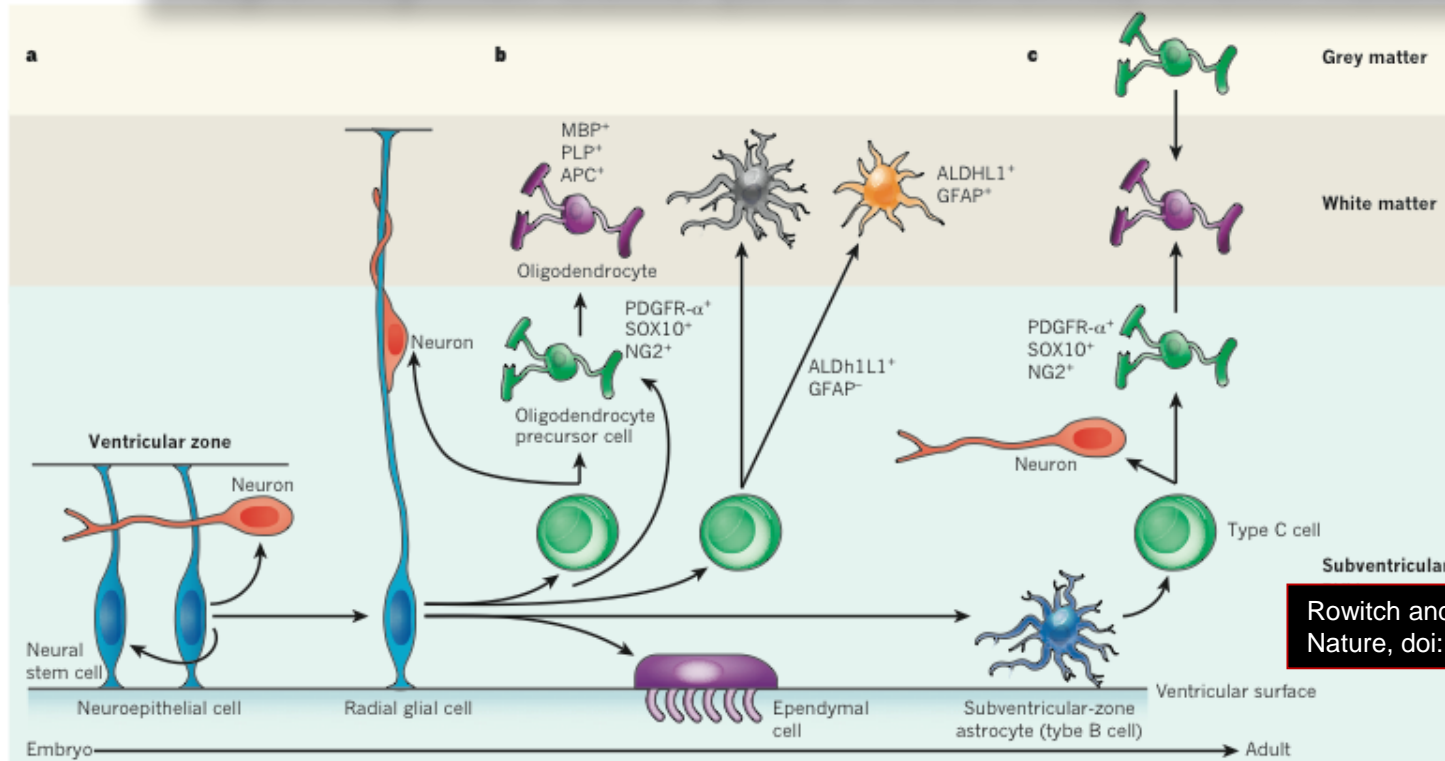
During development of the cerebral cortex, **radial glia** generates neuronal and glial progenitors and guides their migration to the appropriate position



**Figure 53-5** Neurons migrate along radial glial cells. After their generation from radial glial cells, newly generated neurons in the embryonic cerebral cortex extend a leading process that

wraps around the shaft of the radial glial cell, thus using the radial glial cells as scaffolds during their migration from the ventricular zone to the pial surface of cortex.

# Development of astrocytes, oligodendrocytes, ependymal cells (and neurons) from radial glia

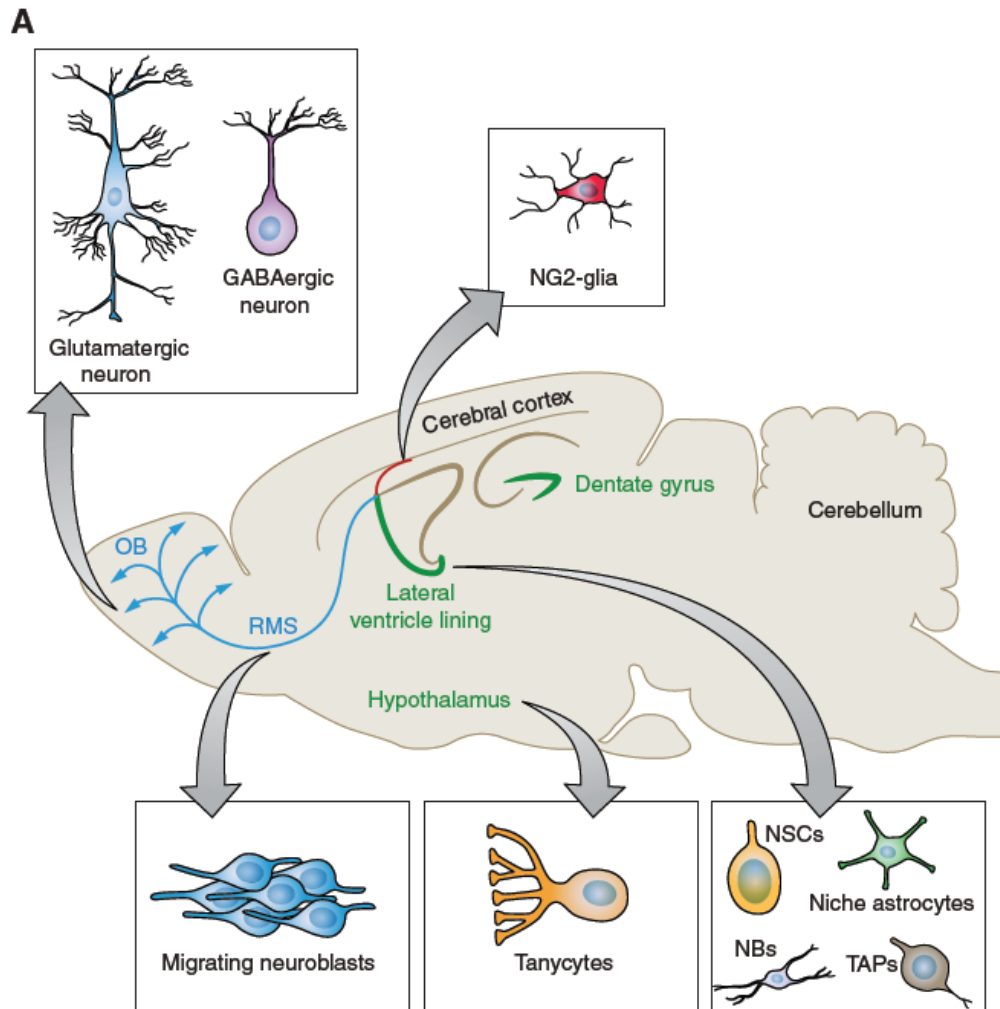


Rowitch and Kriegstein, 2010  
Nature, doi:10.1038/nature09611

**Figure 1 | Patterns of gliogenesis in embryonic and adult progenitor zones.** The progression from the embryo to the adult is shown from left to right (a to c). Black arrows indicate self-renewal or differentiation from one cell type to another. Markers of macroglia and their precursors are listed. **a**, Self-renewing neuroepithelial cells line the ventricles throughout the neuraxis at the stages of neural tube closure. These cells may generate some neurons. Neuroepithelial cells are transformed into radial glial cells as neurogenesis begins. **b**, Radial glia produce intermediate progenitor cells and oligodendrocyte precursor cells (OPCs), which in turn produce neurons and oligodendrocytes, respectively. Radial glia can also become astrocytes, as well as producing intermediate progenitors that expand in number before producing astrocytes. Protoplasmic astrocytes and fibrous

astrocytes might arise from common or independent progenitors. Radial glia also produce ependymal cells. **c**, In adults, oligodendrocytes are produced by two independent pathways: type B cells in the cortical subventricular zone produce transit-amplifying cells (known as type C cells), which in turn produce OPCs as well as neurons. The OPCs subsequently generate oligodendrocytes, and OPCs that are already resident in the grey matter also produce oligodendrocytes. ALDH1L1, aldehyde dehydrogenase 1 family, member L1; APC, adenomatous polyposis coli; GFAP, glial fibrillary acidic protein; MBP, myelin basic protein; PDGFR- $\alpha$ , platelet-derived growth-factor receptor- $\alpha$ ; PLP, proteolipid protein 1. All green cells are intermediate progenitors, with type C cells being a subset of these, and all blue cells are neural stem cells (even though each blue cell is a different type).

In the **adult mammalian brain** most radial glia disappears and neurogenesis persists only in **few niches**, those where **radial glia-like cells** (= neural stem cells) are still present

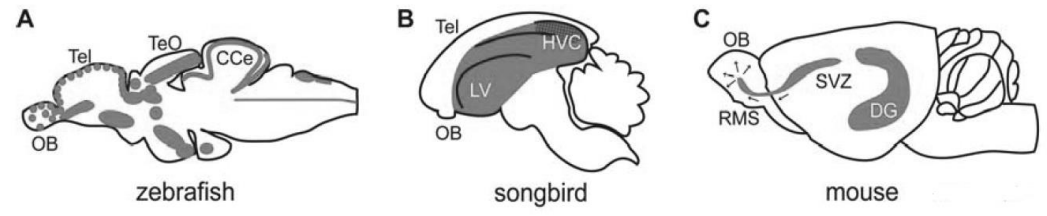


**FIGURE 3.** Glial cells as stem and progenitor cells in the healthy adult brain. **A:** endogenous neurogenesis still persists in the adult mammalian brain in few niches like the subependymal zone in the lateral wall of the lateral ventricle, the subgranular zone in the dentate gyrus, and the hypothalamus. Radial glial cells at the subependymal zone of the lateral ventricle divide and generate fast proliferating transit-amplifying progenitors [TAPs] and neuroblasts [NBs] that proliferate while they migrate through the rostral migratory stream [RMS] to their final destination, the olfactory bulb [OB], where they can differentiate to different neuronal types.

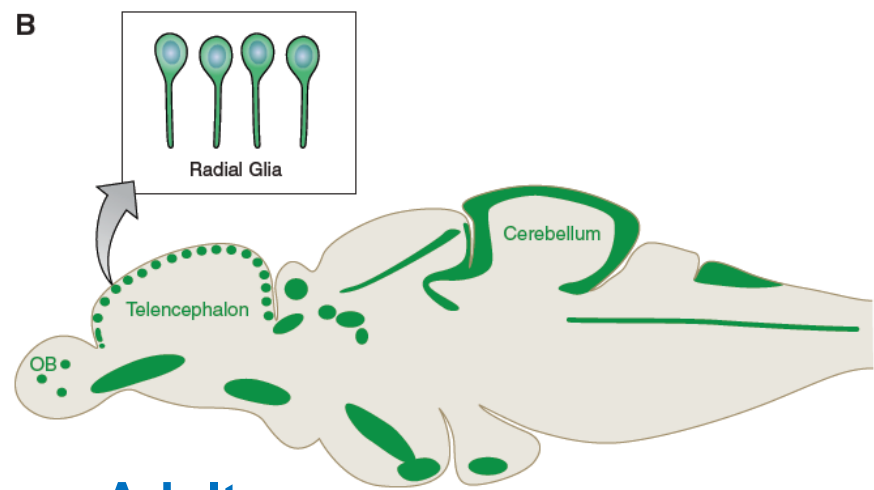
**Leda Dimou and Magdalena Götz**

*Physiol Rev* 94: 709–737, 2014  
doi:10.1152/physrev.00036.2013

In many non-mammalian vertebrates (**fish, amphibians and reptiles**) radial glial cells remain abundantly present in a widespread manner in the adult CNS



Pomatto et al., 2013



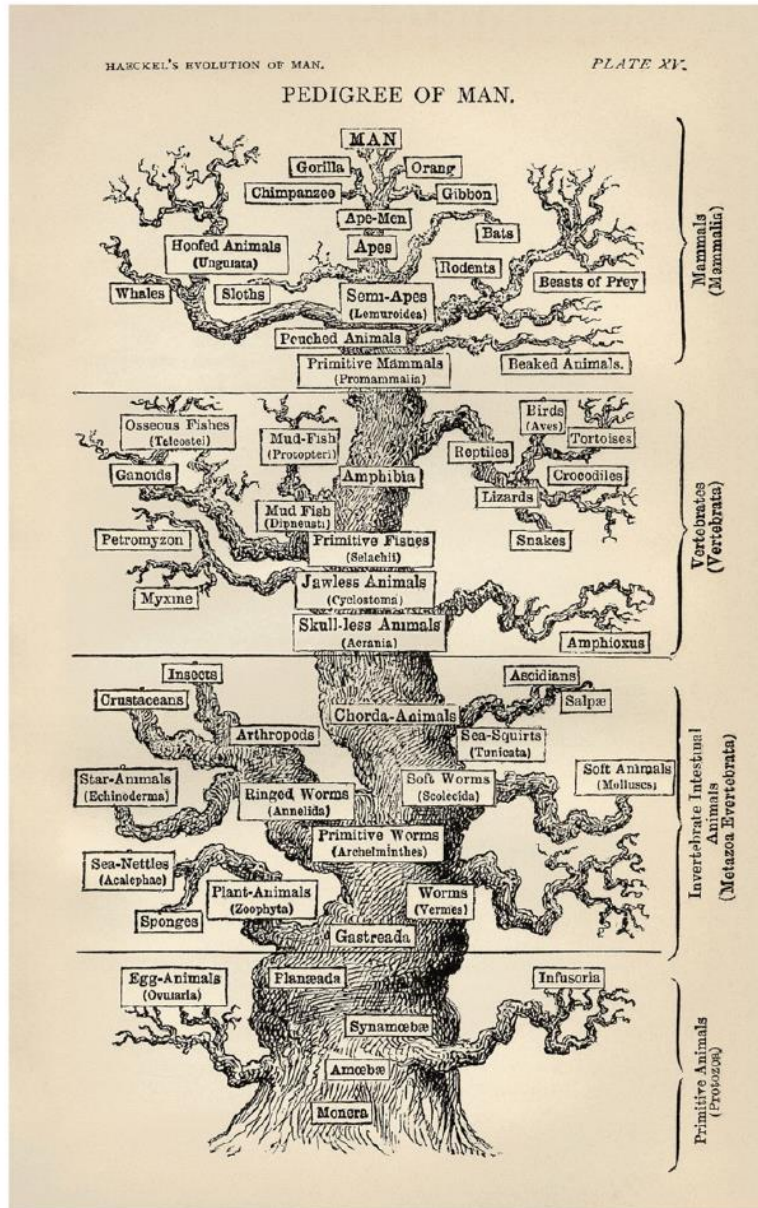
**Adult zebrafish**

*B:* radial glia cells in the adult zebrafish are more widespread than in mammals and are located along the ventricle. The zebrafish telencephalon is everted, with the ventricle lying between and above the two telencephalic hemispheres. Proliferating cells (green, based on data summary in Ref. 89) are located in distinct regions along the entire anterior-posterior axis.

**Leda Dimou and Magdalena Götz**

*Physiol Rev* 94: 709–737, 2014  
doi:10.1152/physrev.00036.2013

# Evolutionary aspects of glia



"Glial explosion" in the brains of hominides

Proto-myelinating cells appear and myelin sheath is formed around axons

Astrocytes make the primordial blood-brain barrier  
Immune cells enter the neural ganglia and form the ancestral microglia

Appearance of glia

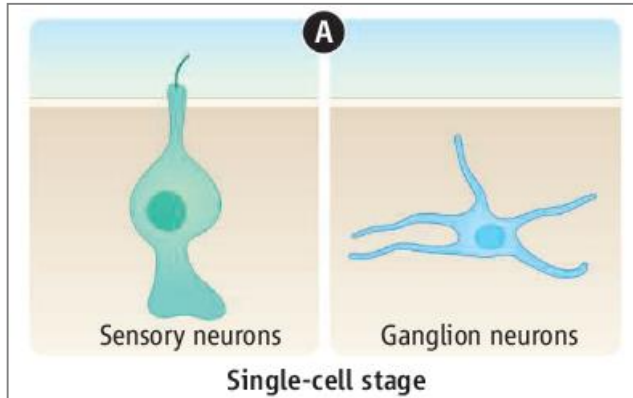
Verkhatsky et al., 2011  
Brain Res Reviews  
doi:10.1016/j.brainresrev.2010.05.002

Fig. 4 – Evolution of the neuroglia; the tree of life is taken from Haeckel (1879).

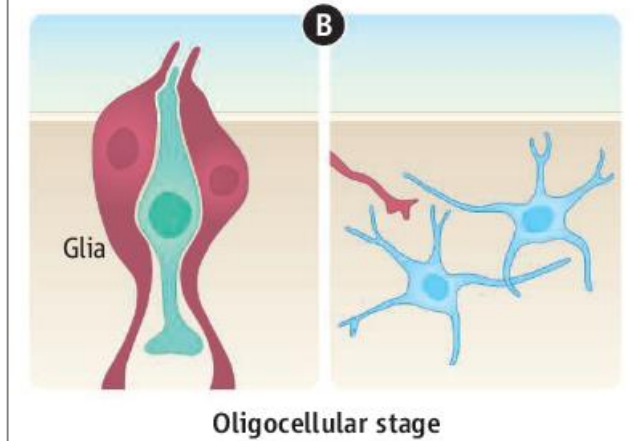


# Evolution of the **glia-to-neuron index**

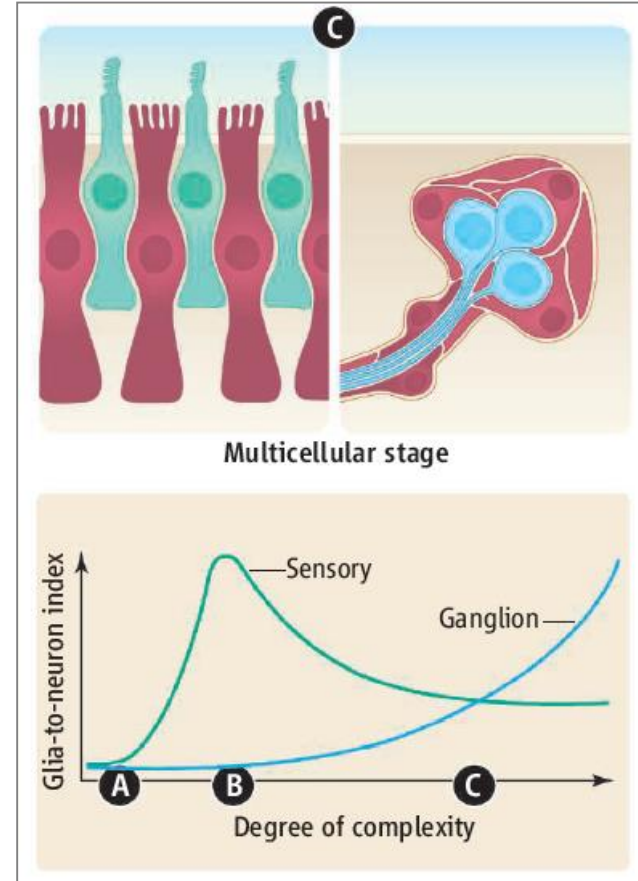
Nerve net  
(most  
Cnidarians)



Primitive  
sensory  
organs &  
ganglions  
(*C. elegans*)



Sophisticated  
sensory  
organs &  
nervous  
centers  
(brains)



**Glia, by complexity.** A schematic survey of the differentiation stages of sensory (green) and ganglion (blue) neurons and glial cells (red). The numerical relation between glial and neuronal cells (glia-to-neuron index) is shown over the three stages of increasing nervous system complexity.