Neurogenesis and the evolution of segmentation

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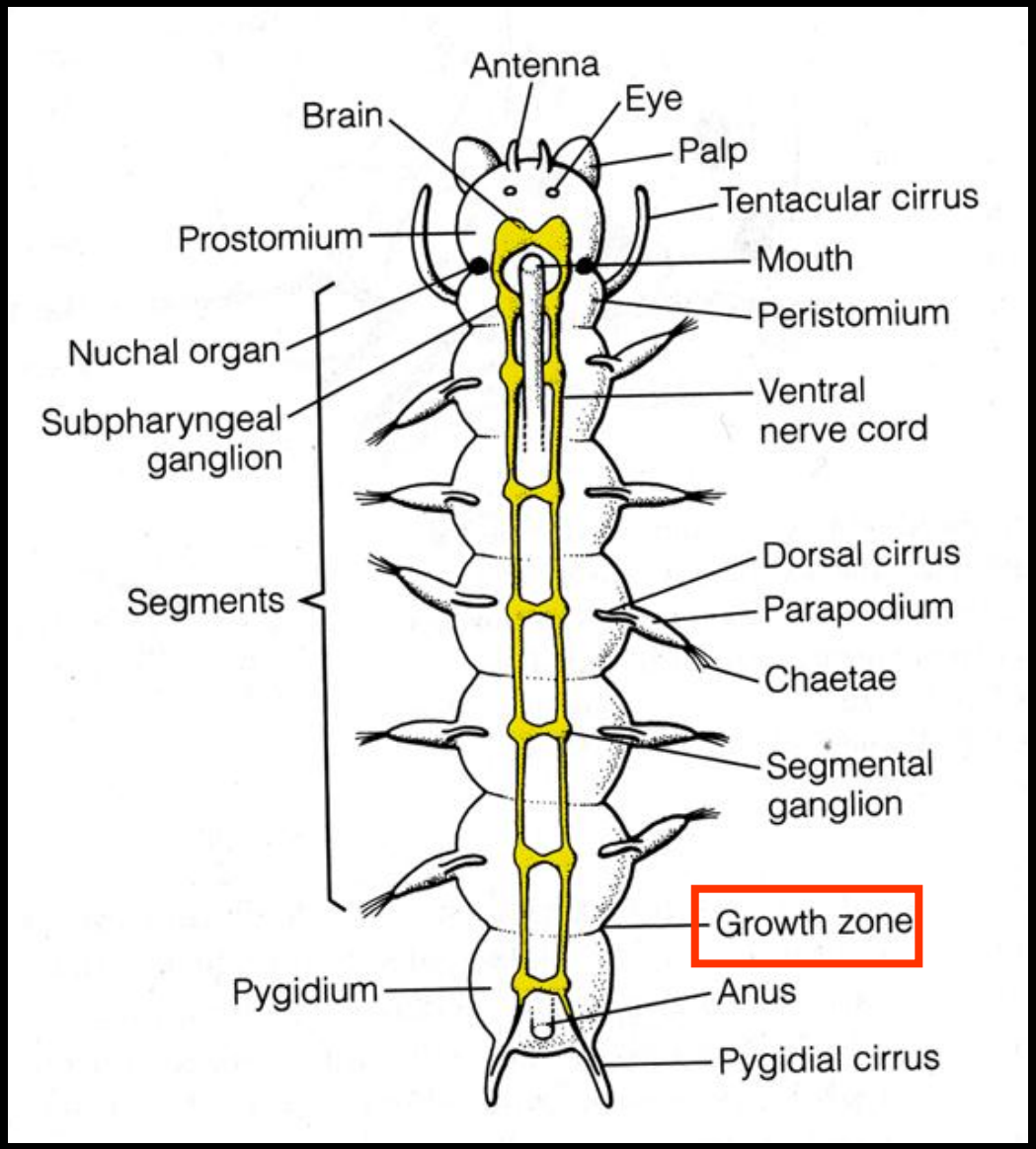
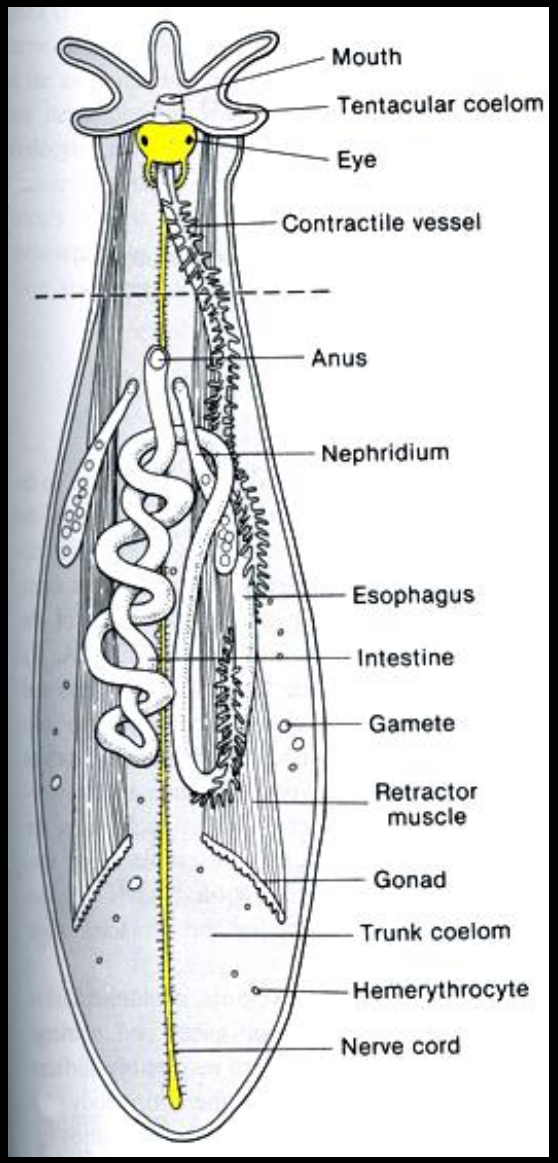
Segmented versus non-segmented bodies

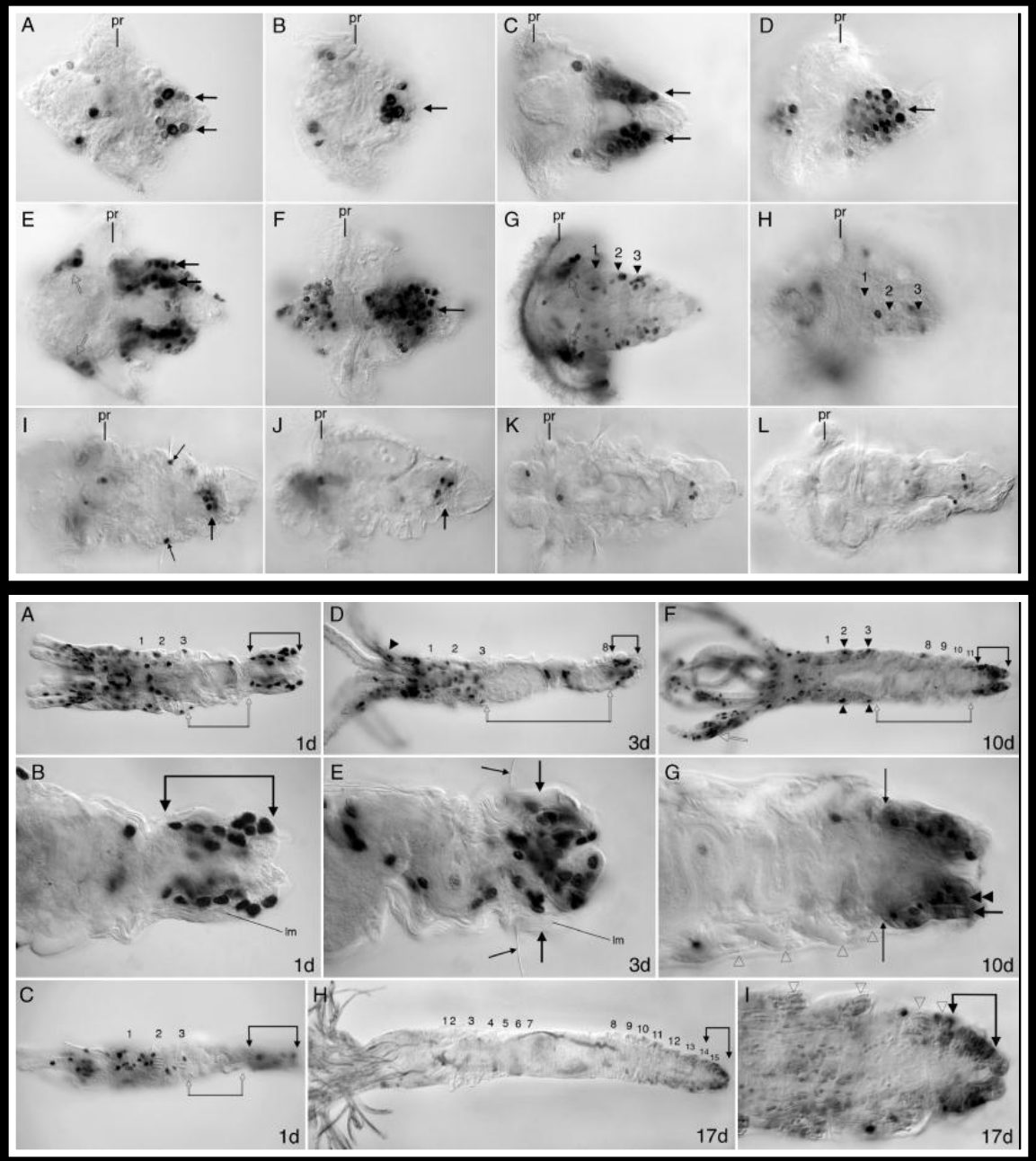




Ruppert, Fox & Barnes (2004)

Growth zone

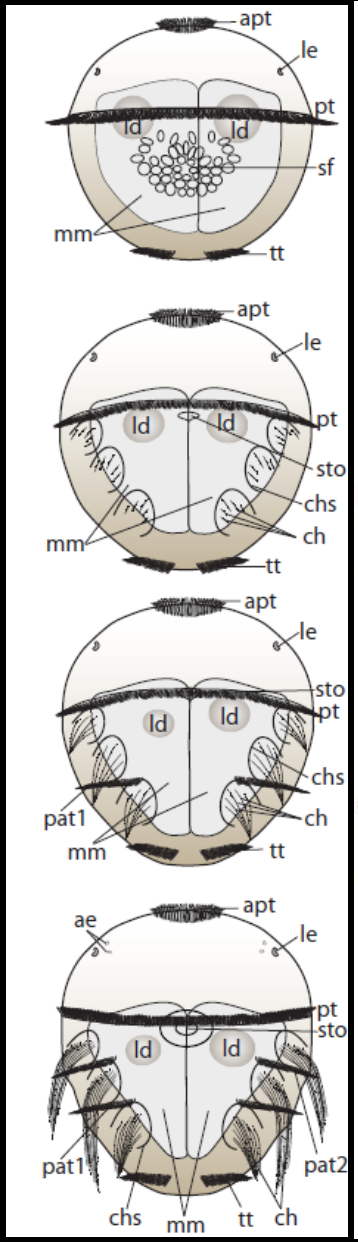
Hydroides

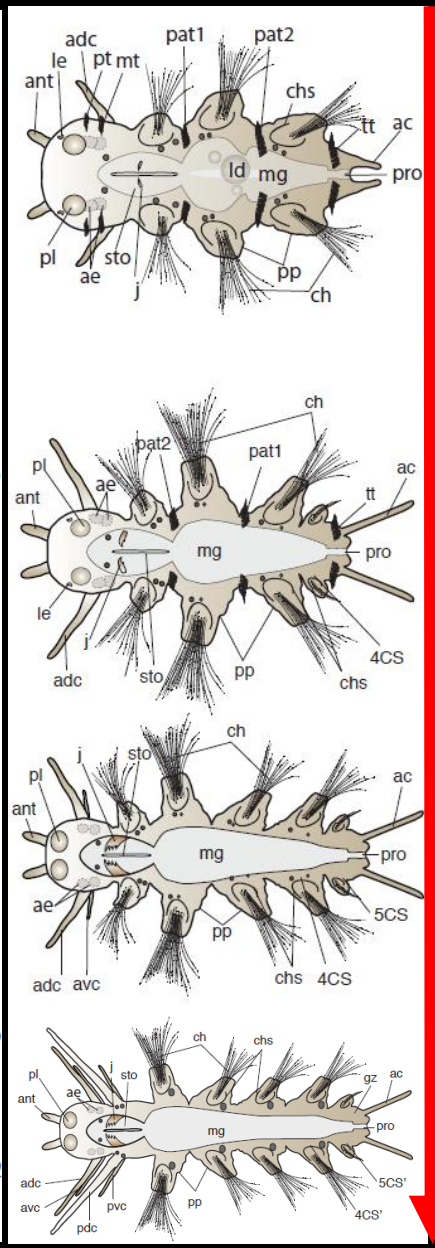


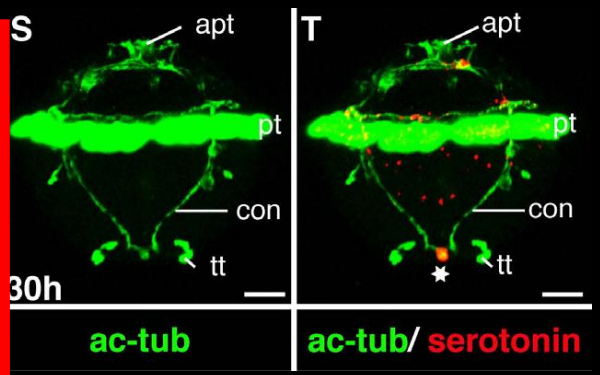
Seaver, Thamm & Hill: *Evol. Dev. (2005)*

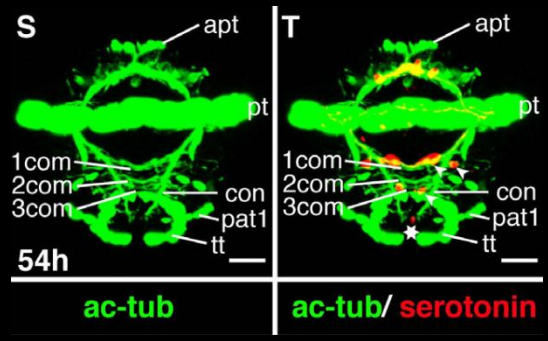
Anterior-posterior formation of structures

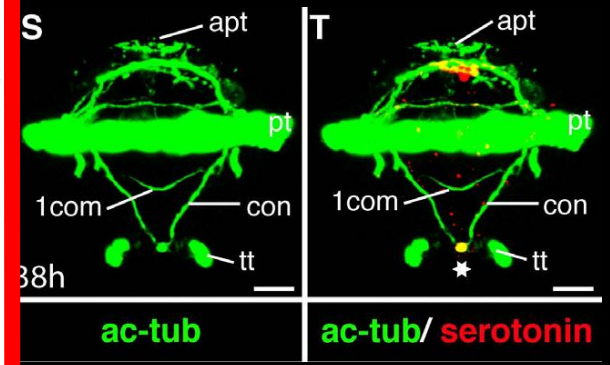
Platynereis

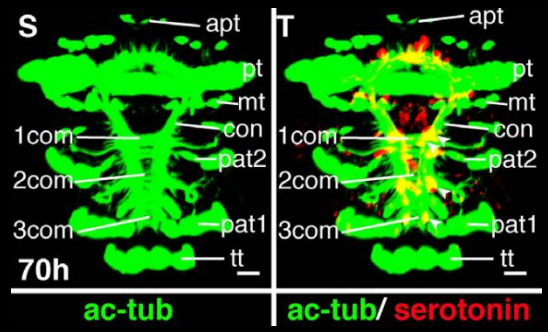


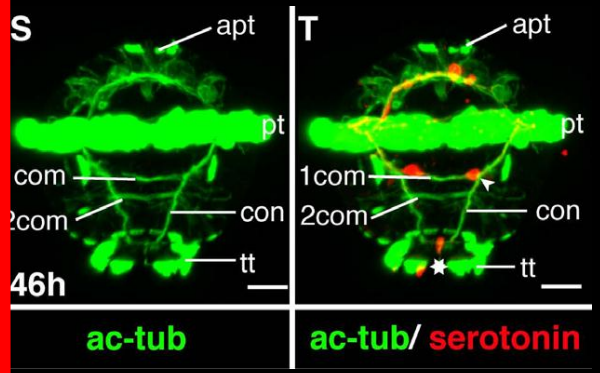


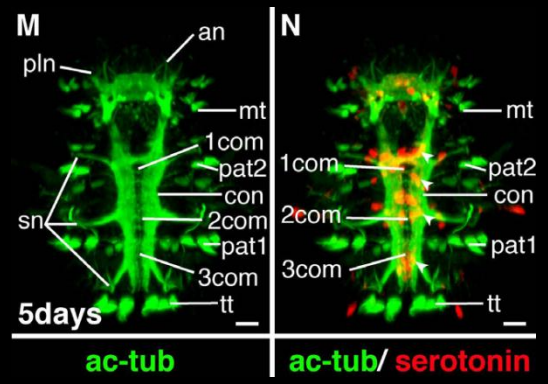








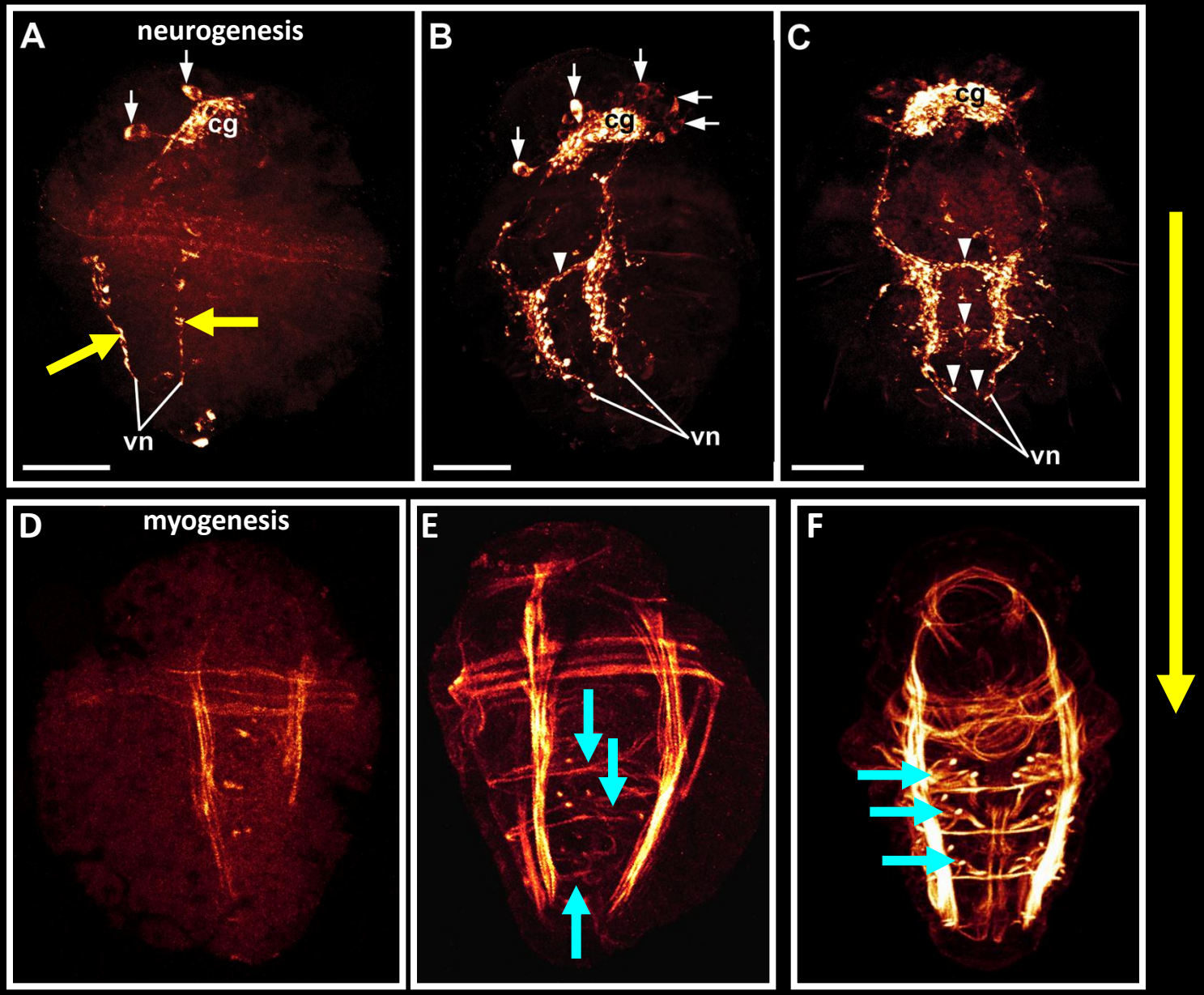




Fischer et al.: *Front. Zool. (2010)*

Anterior-posterior formation of structures

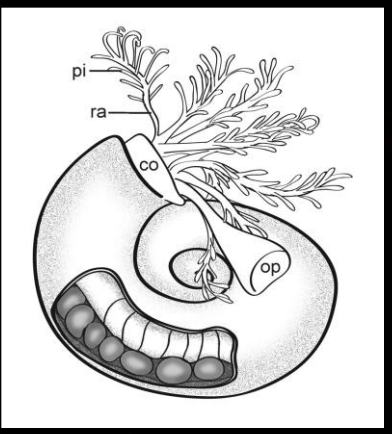
Filograna

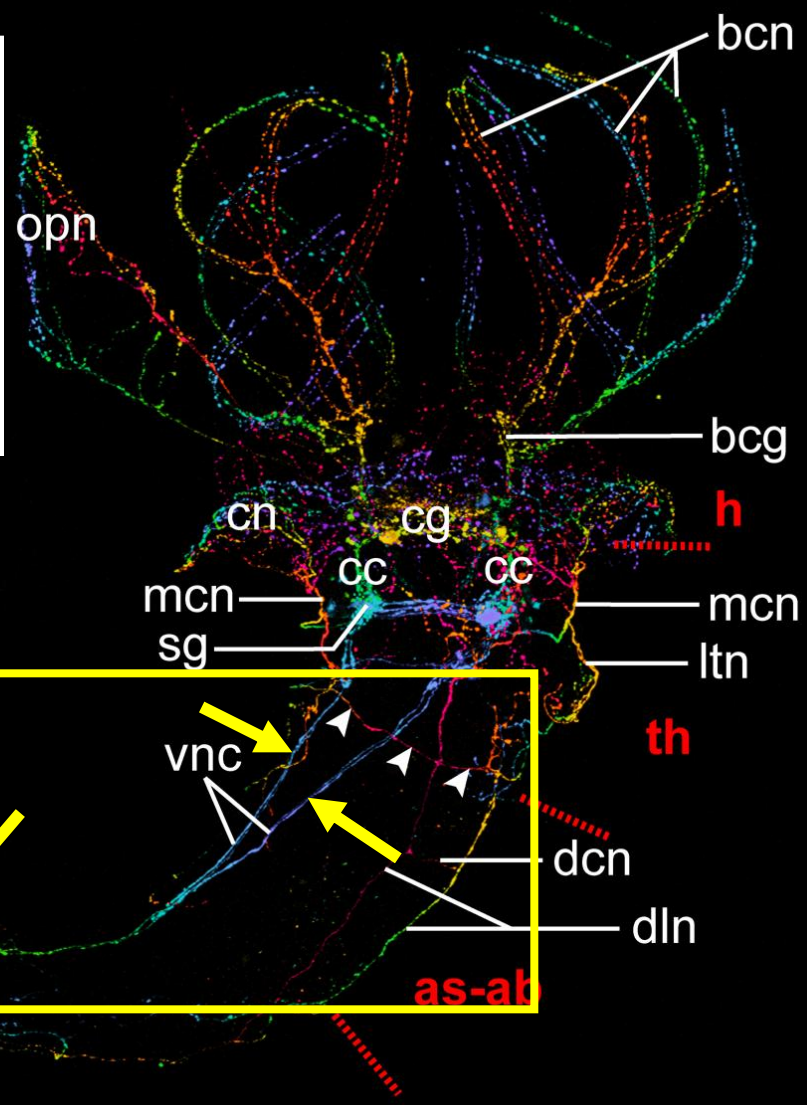


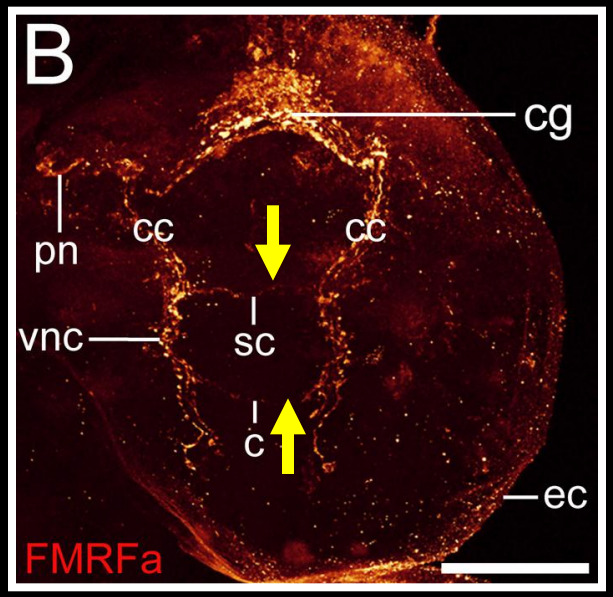
Wanninger: *Biol. Bull. (2009)*

Anterior-posterior formation of structures

Spirorbis



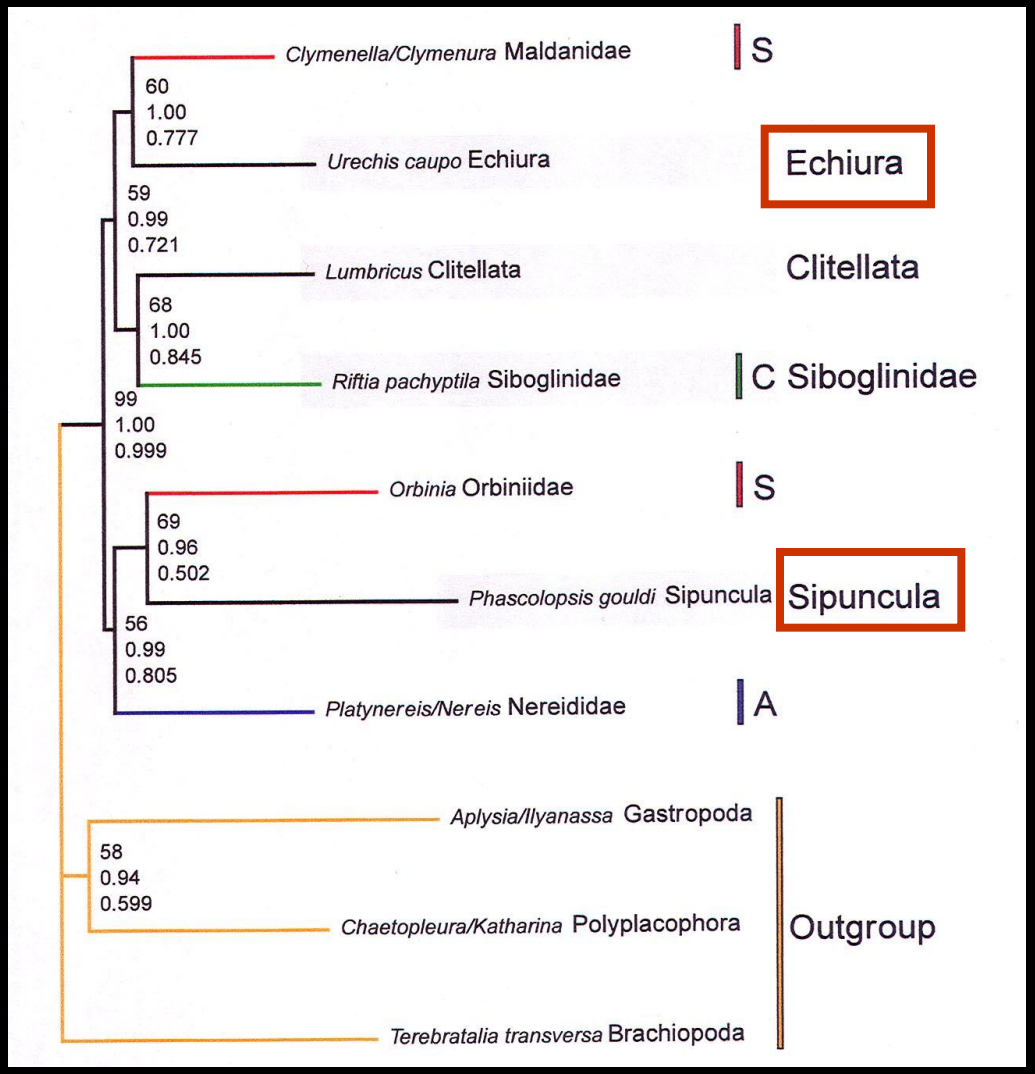


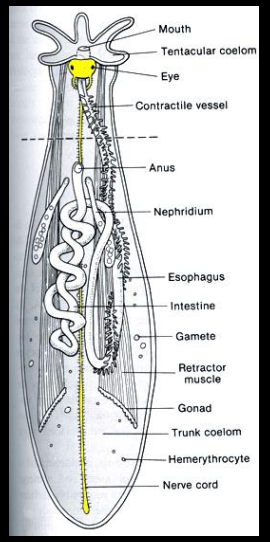


Brinkmann & Wanninger: *BMC Evol. Biol. (2009)*

”New” annelids?

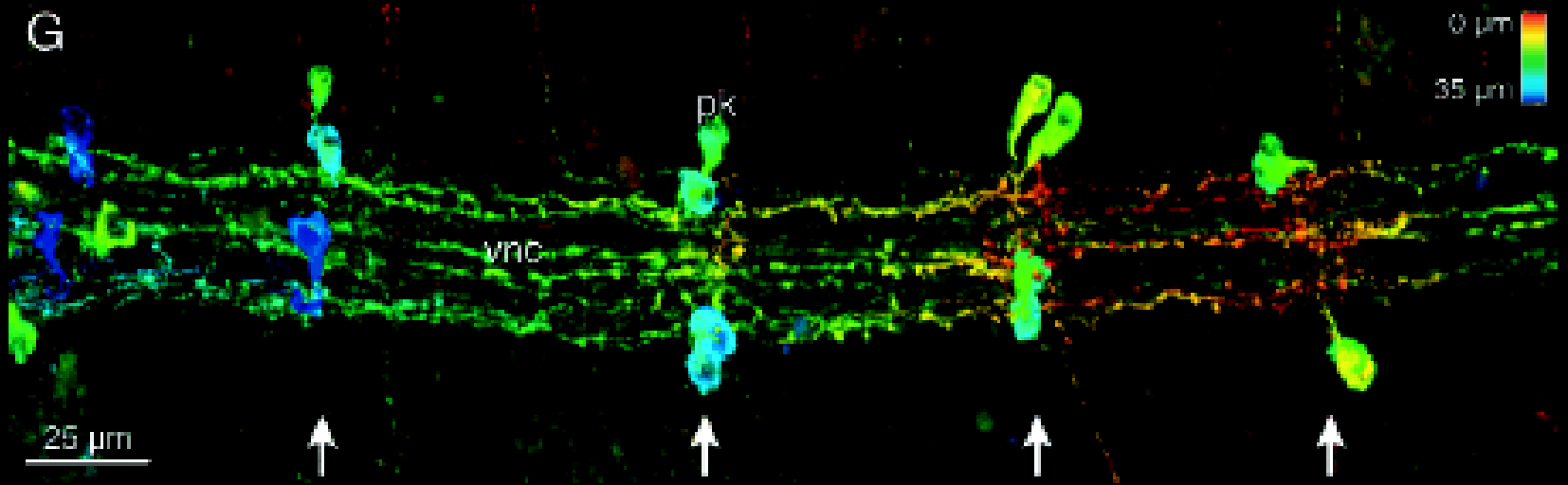
”New” annelid phylogeny





Struck et al.: *BMC Evol. Biol. (2007)*

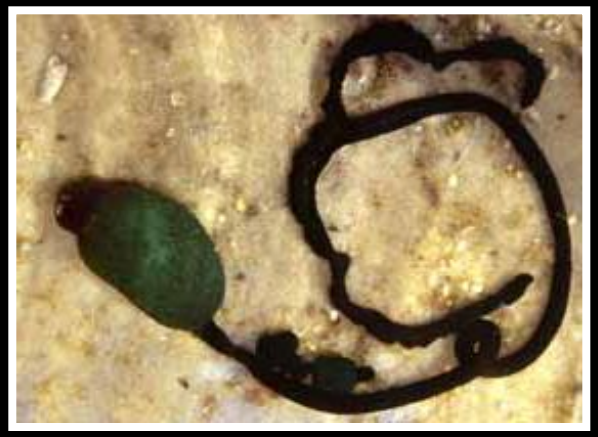
Neurogenesis in Echiura

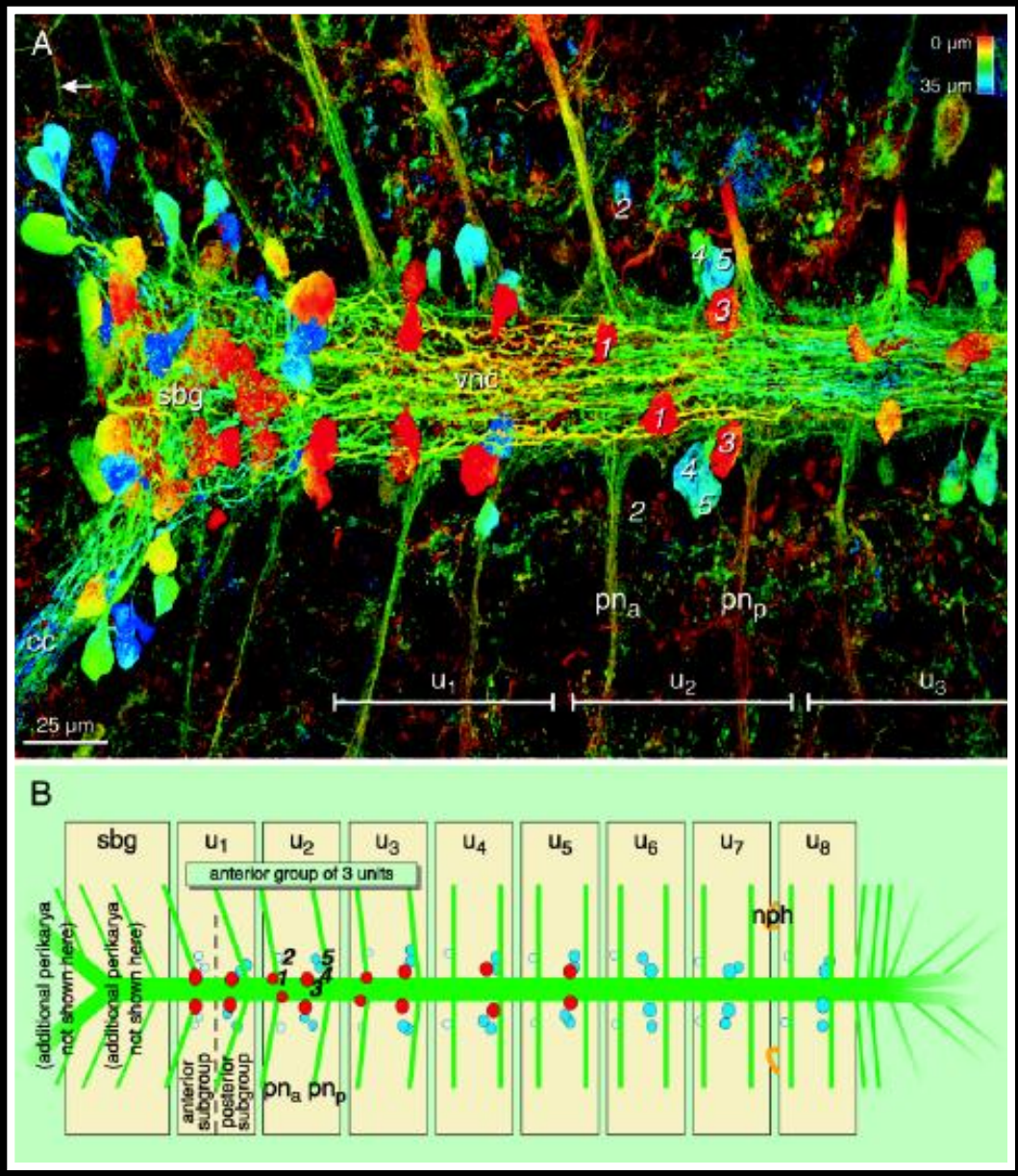


Hessling & Westheide: *J. Morphol. (2002)*

Neurogenesis in Echiura

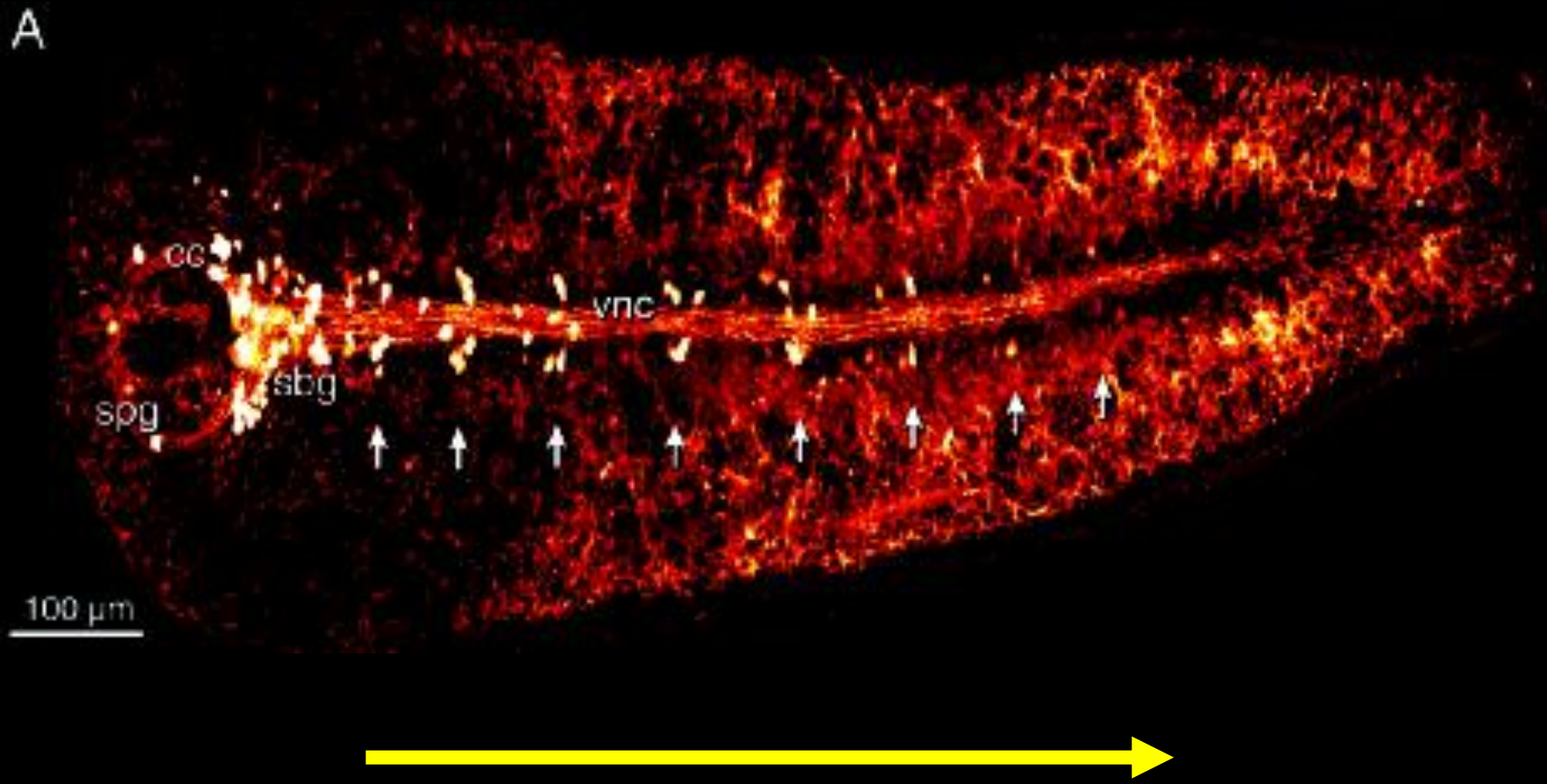
Echiura: *Bonellia*





Hessling & Westheide: *J. Morphol. (2002)*

Neurogenesis in Echiura



Hessling & Westheide: *J. Morphol. (2002)*

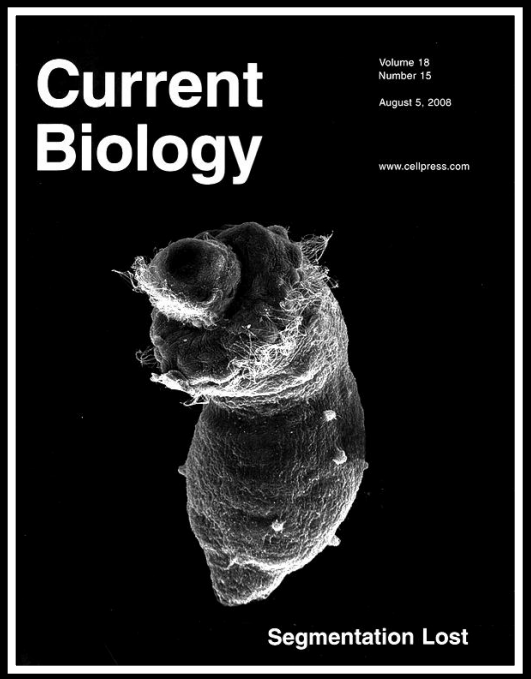
Cell proliferation in Echiura

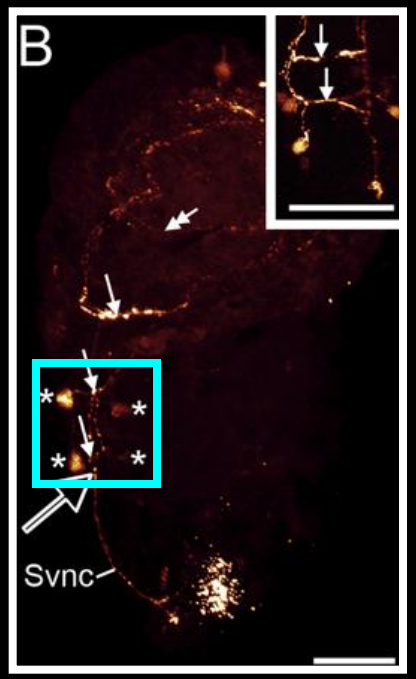
Echiura (*Bonellia*): terminal growth

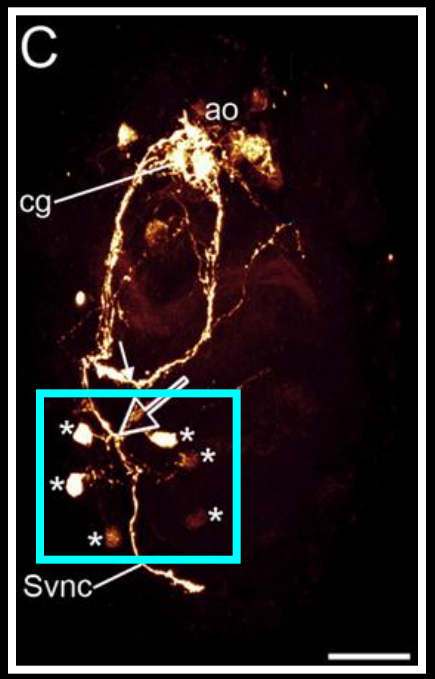
Hessling : *Hydrobiologia (2003)*

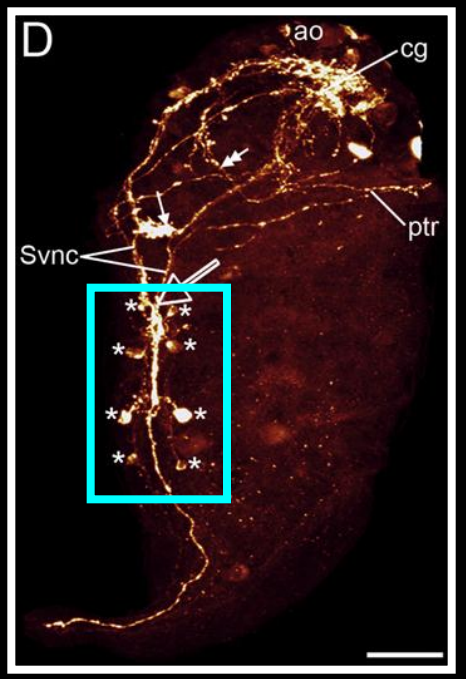
Neurogenesis in Sipuncula

Phascolosoma





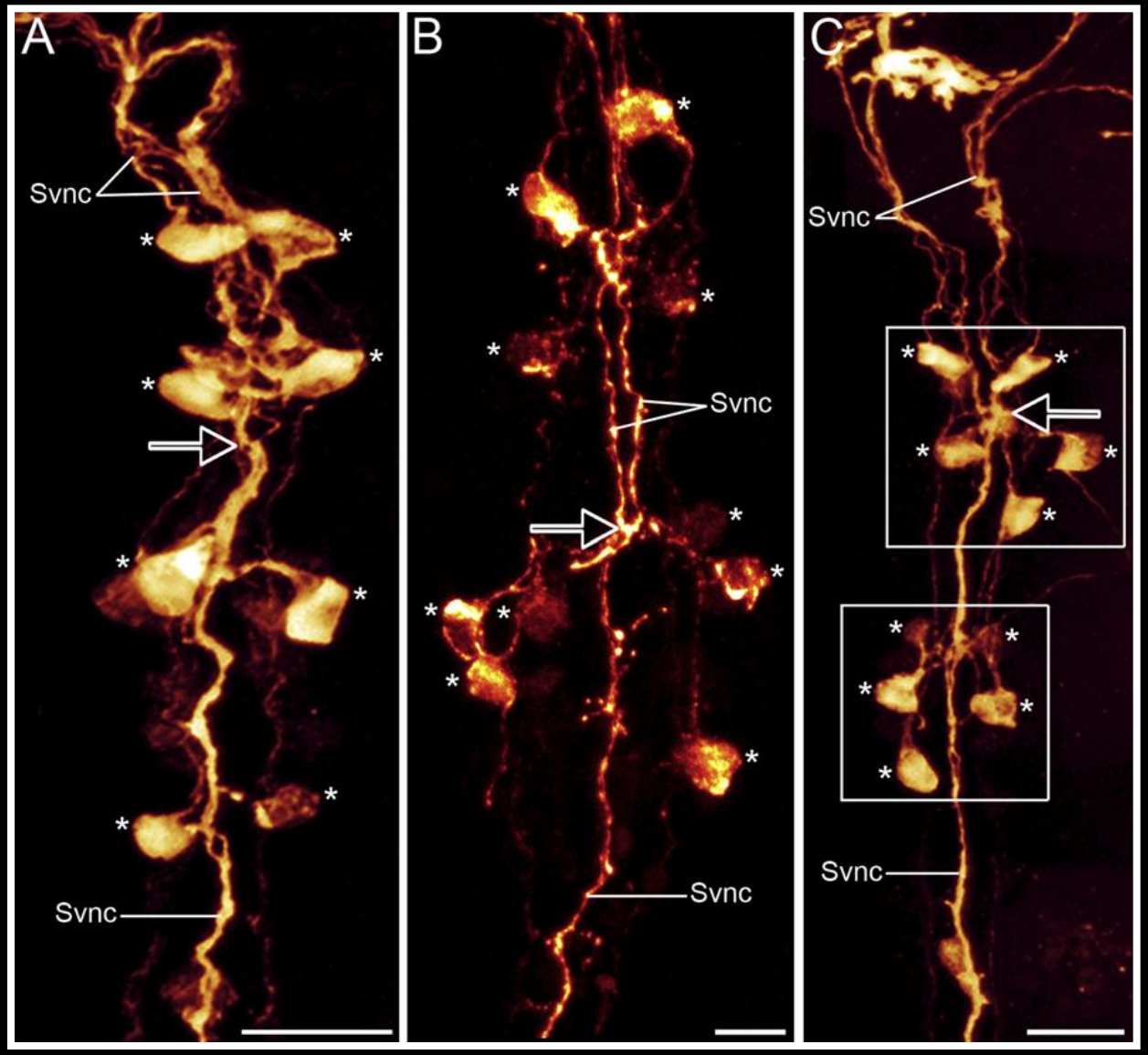




Kristof, Wollesen & Wanninger: *Curr. Biol. (2008)*

Neurogenesis in Sipuncula

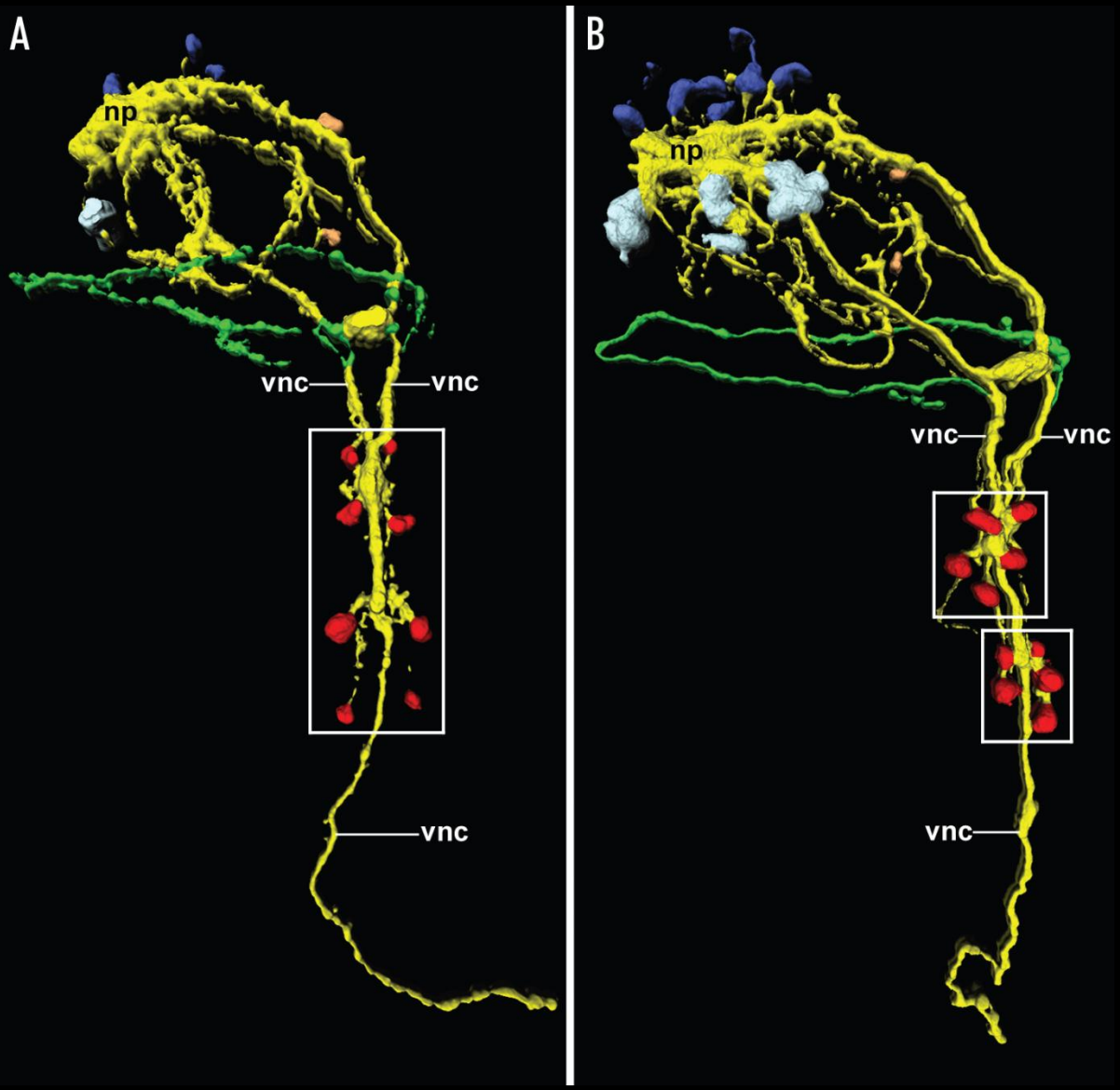
Phascolosoma



Kristof, Wollesen & Wanninger: *Curr. Biol. (2008)*

Neurogenesis in Sipuncula

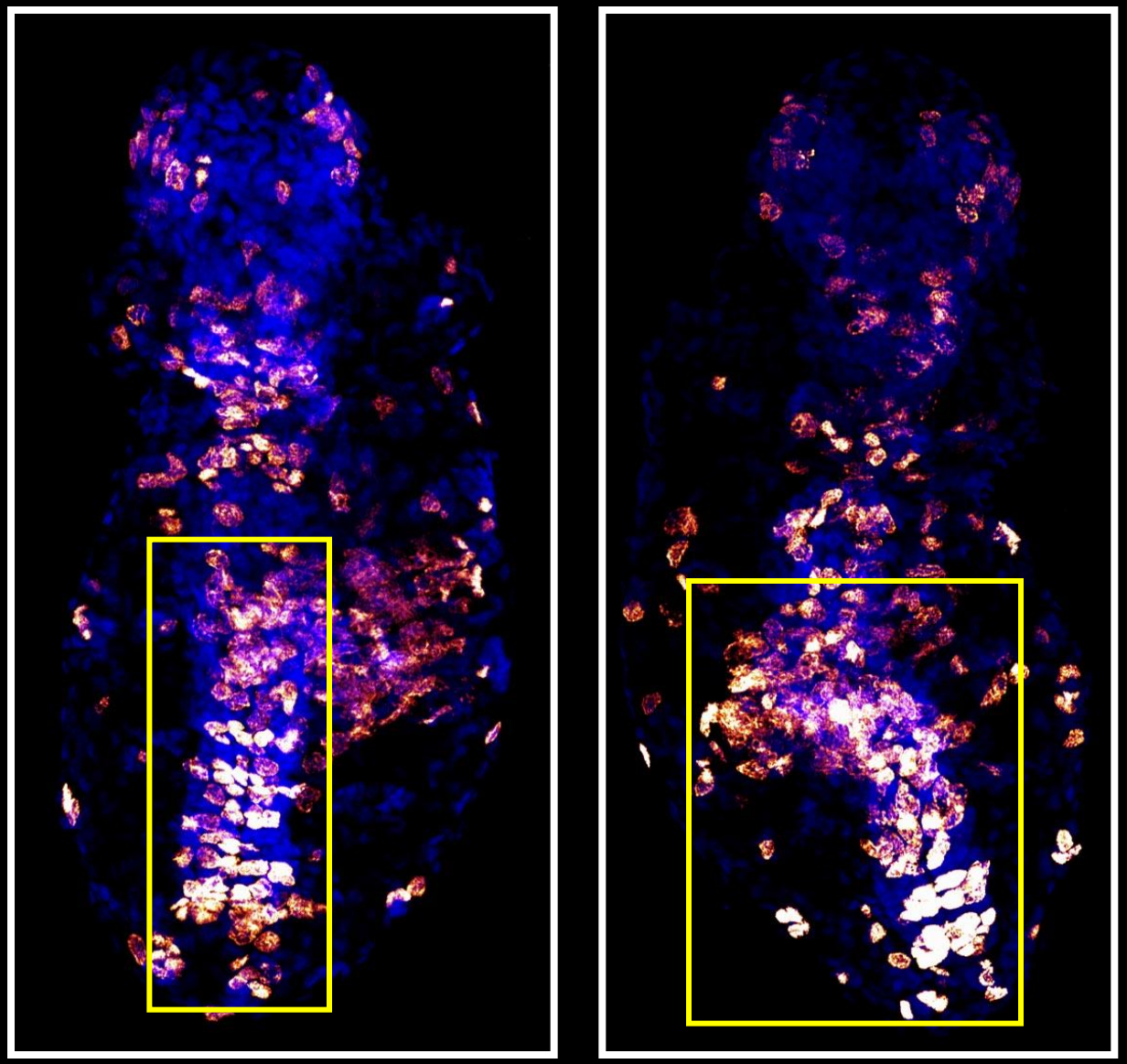
Phascolosoma



Wanninger, Kristof & Brinkmann: *Comm. Integr. Biol. (2009)*

Cell proliferation in Sipuncula

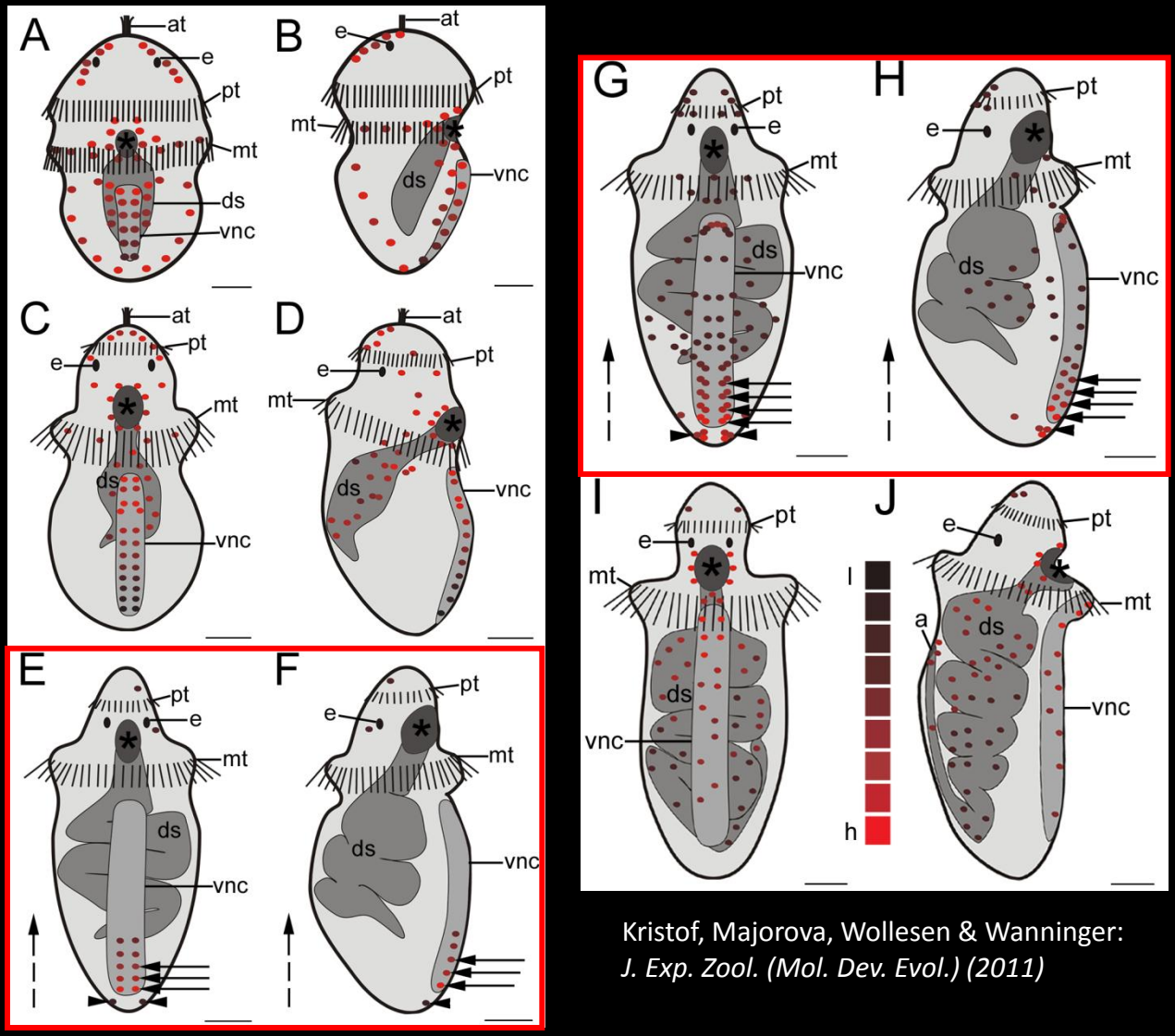
Sipuncula (*Themiste*): Terminal growth



Kristof, Majorova, Wollesen & Wanninger: *J. Exp. Zool. (Mol. Dev. Evol.) (2011)*

Cell proliferation in Sipuncula

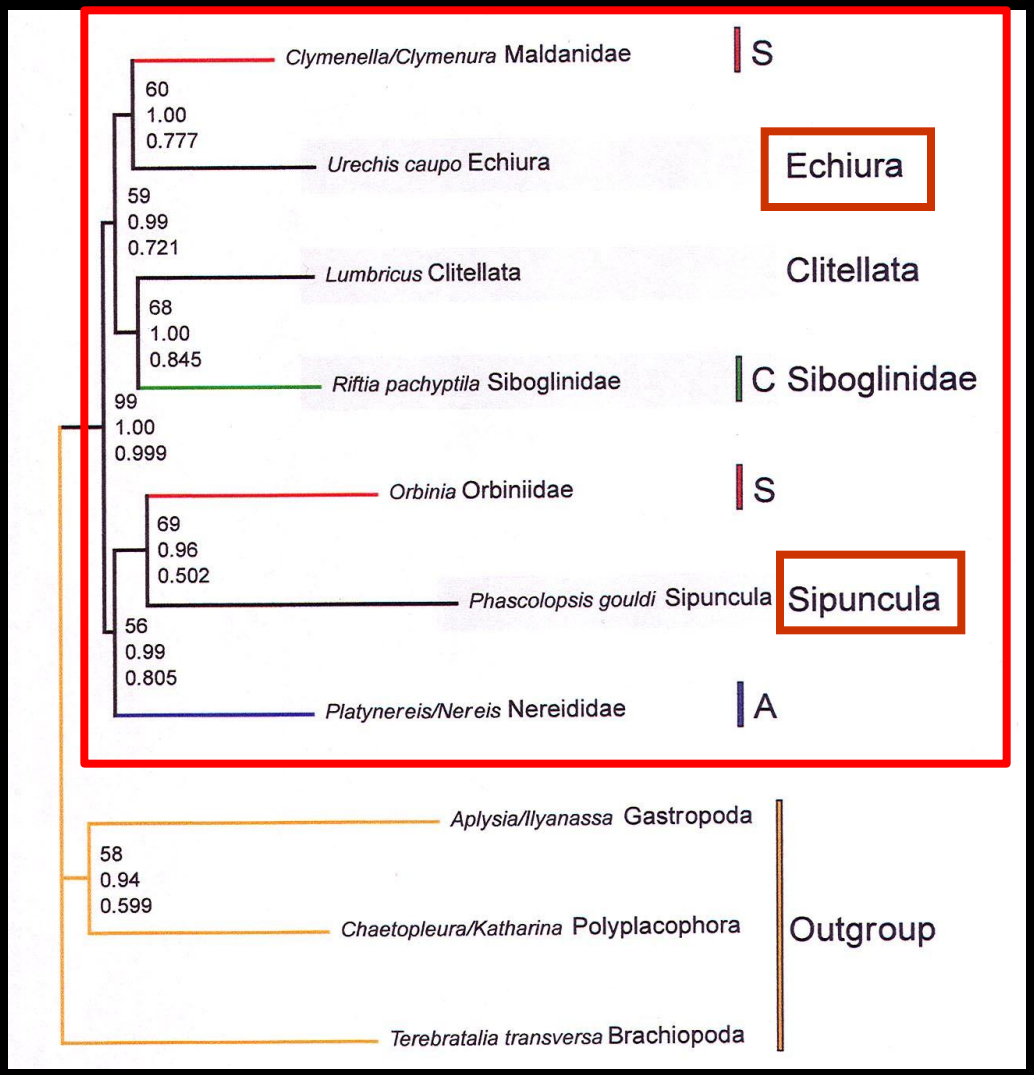
Sipuncula (*Themiste*): Terminal growth



Kristof, Majorova, Wollesen & Wanninger:
J. Exp. Zool. (Mol. Dev. Evol.) (2011)

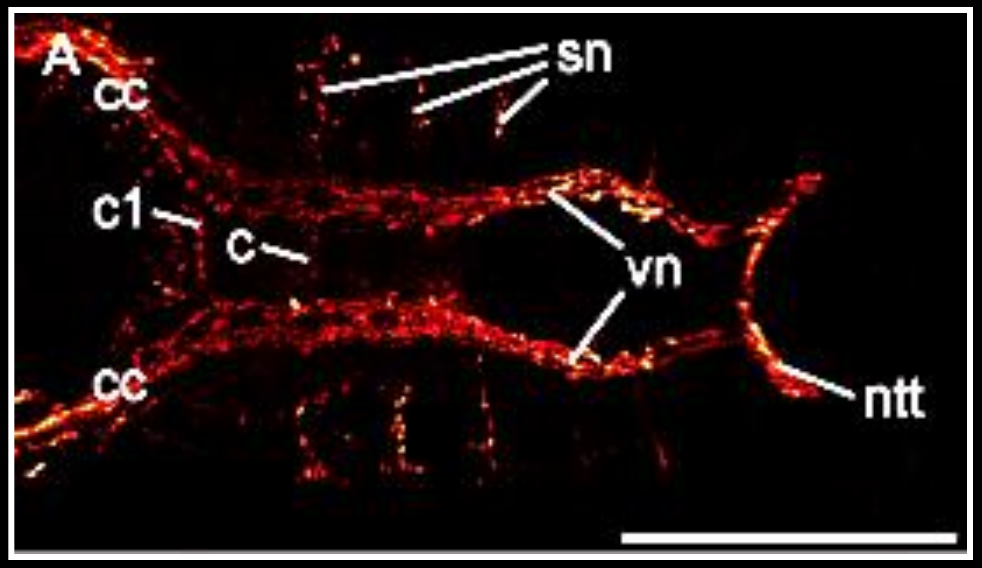
Echiurans and sipunculans are annelids?

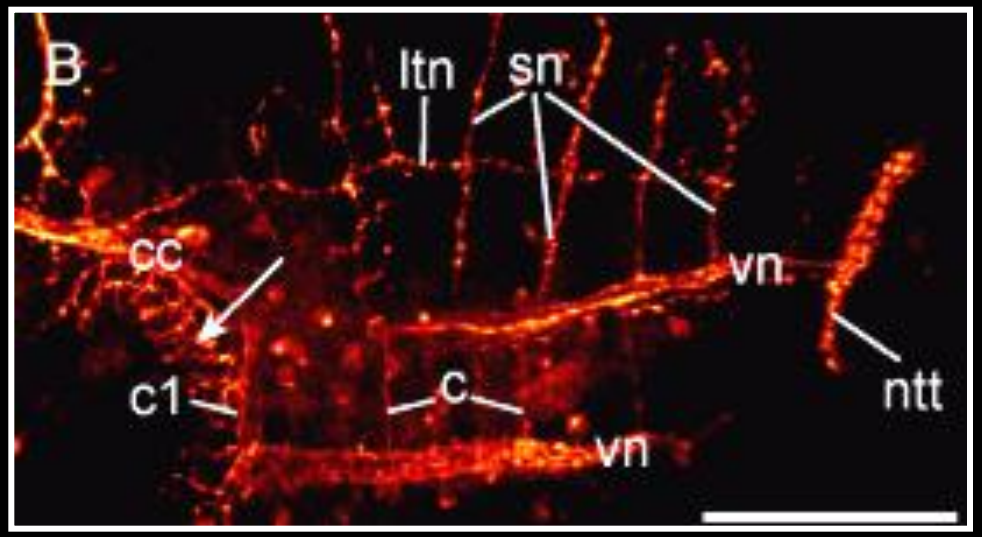
Morphogensis confirms segmental origin of sipunculans and echiurans and thus their close relationship to/inclusion within the Annelida

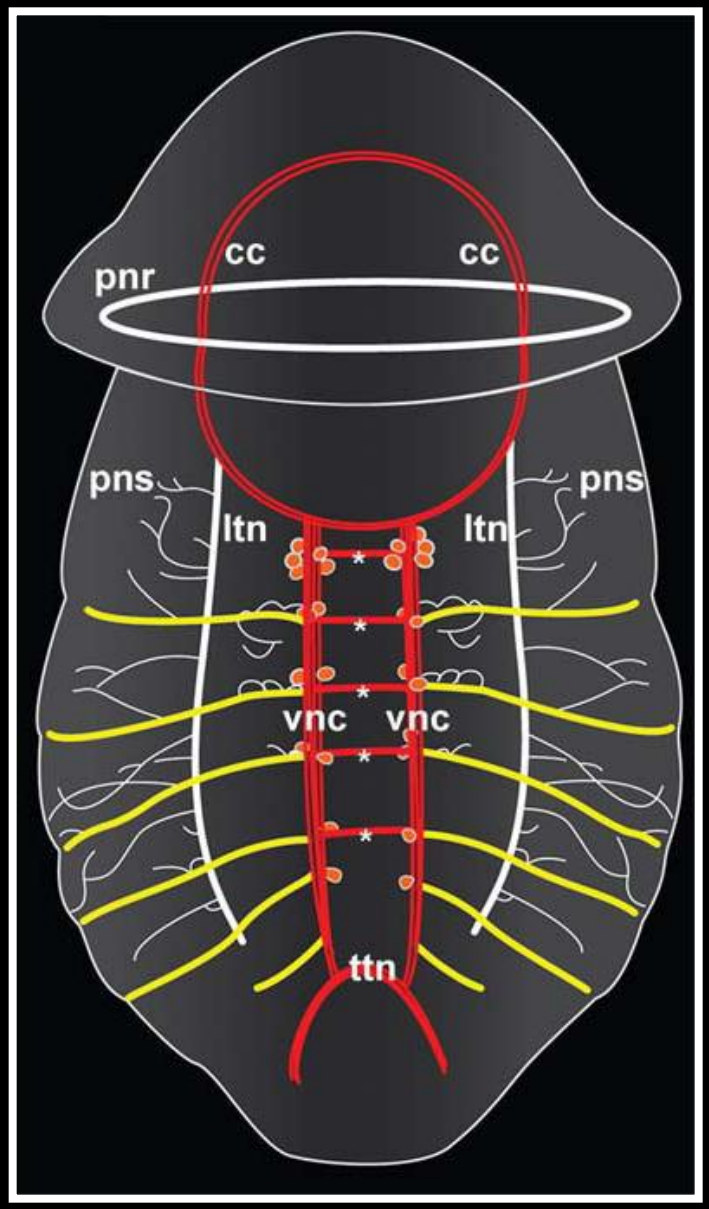


Struck et al.: *BMC Evol. Biol. (2007)*

But: plasticity in annelid neurogenesis

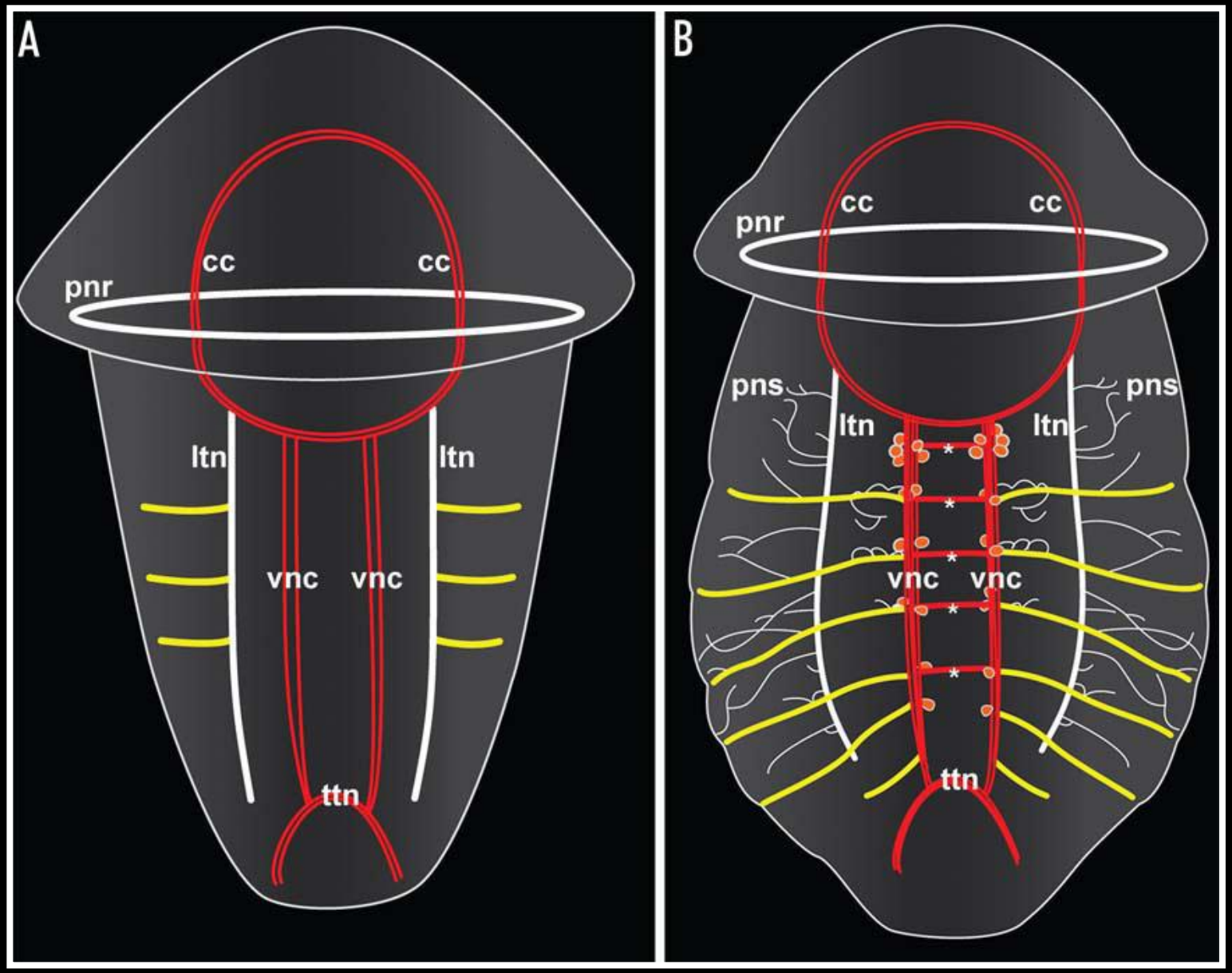






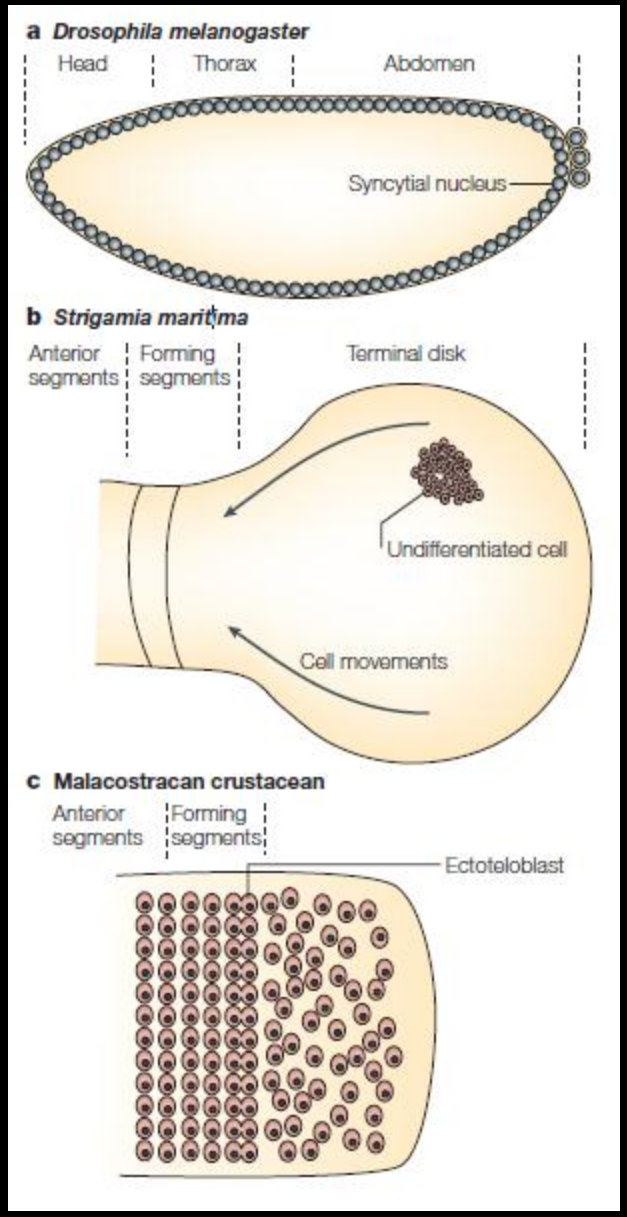
Brinkmann & Wanninger (2008)

But: plasticity in annelid neurogenesis



Brinkmann & Wanninger (2008)

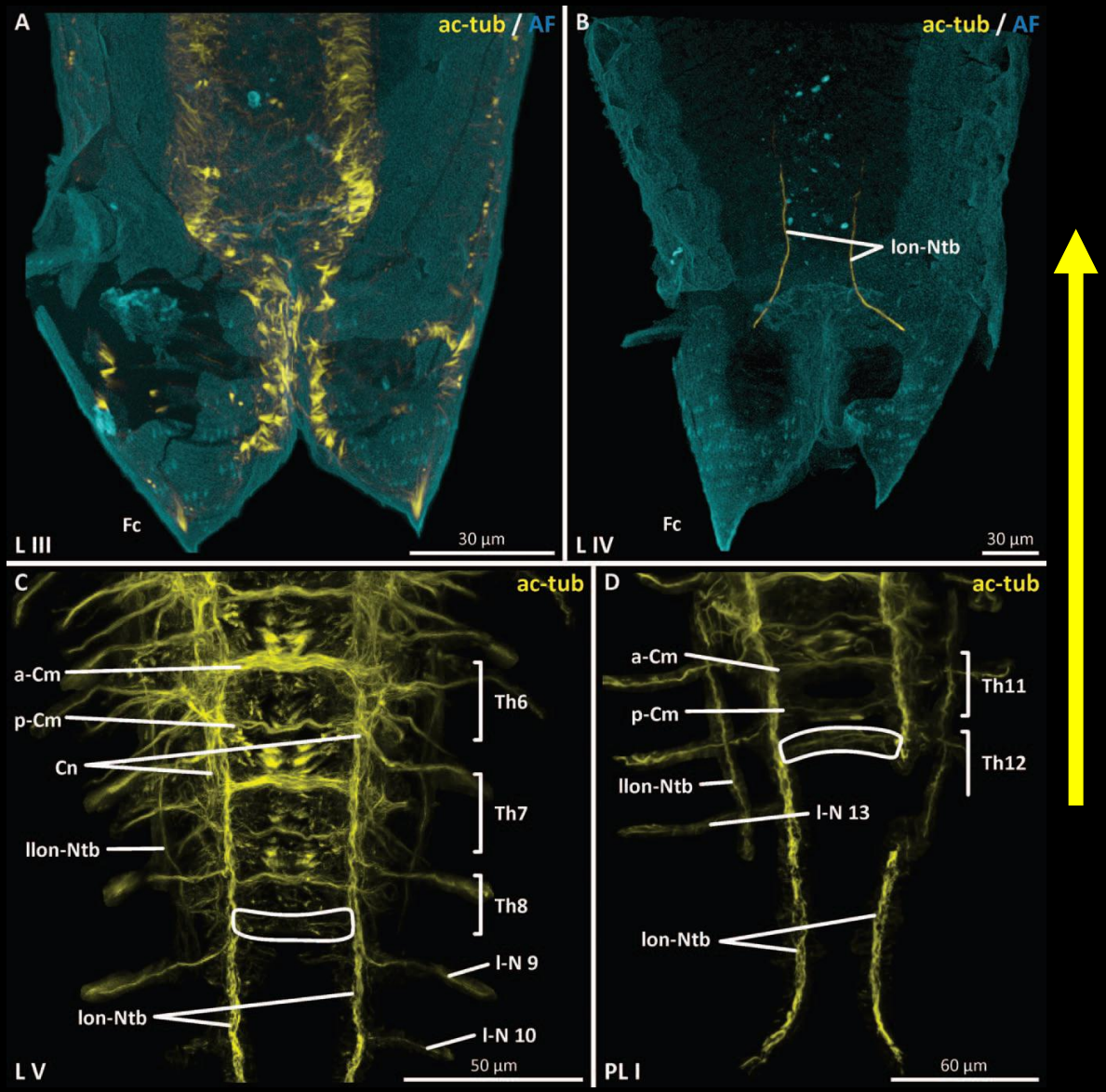
Segmentation in arthropods



Peel et al.: *Nat. Rev. Genet. (2005)*

Segmentation in arthropods

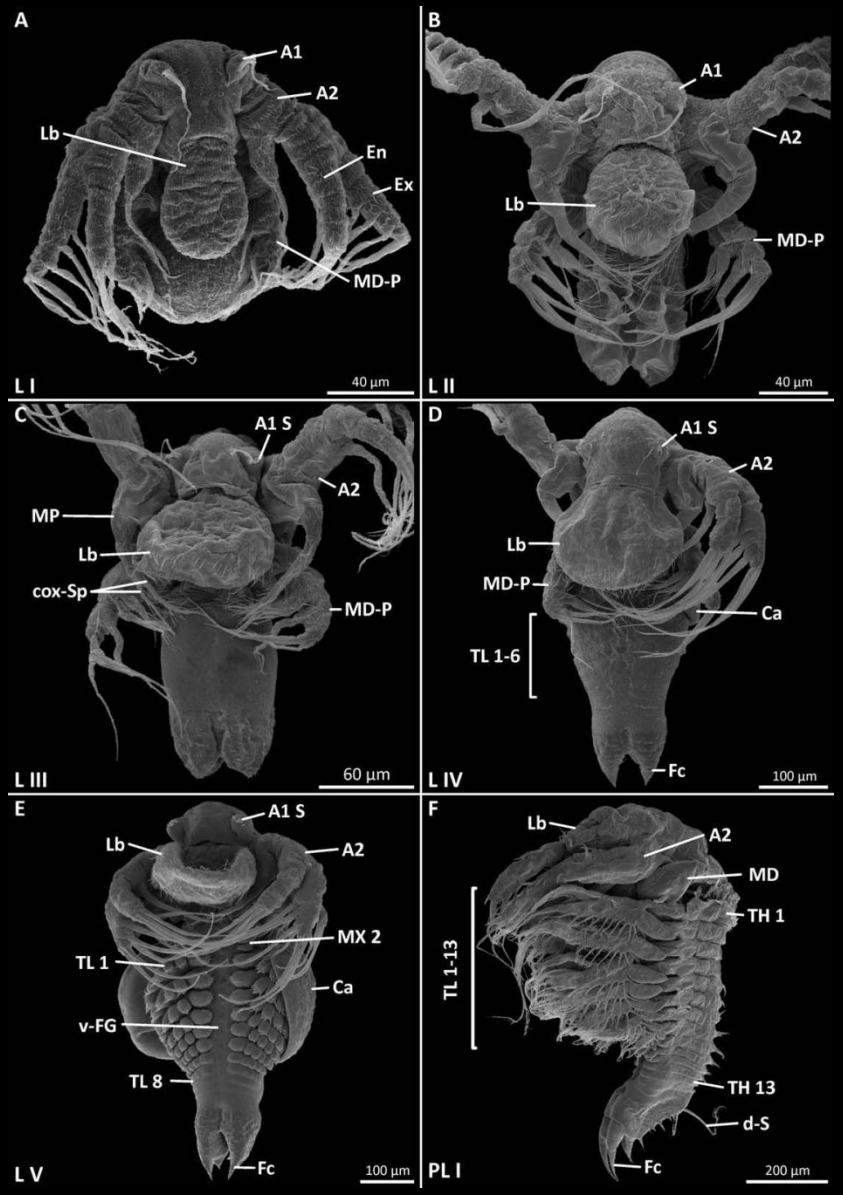
***Leptestheria* (Crustacea, Branchiopoda)**

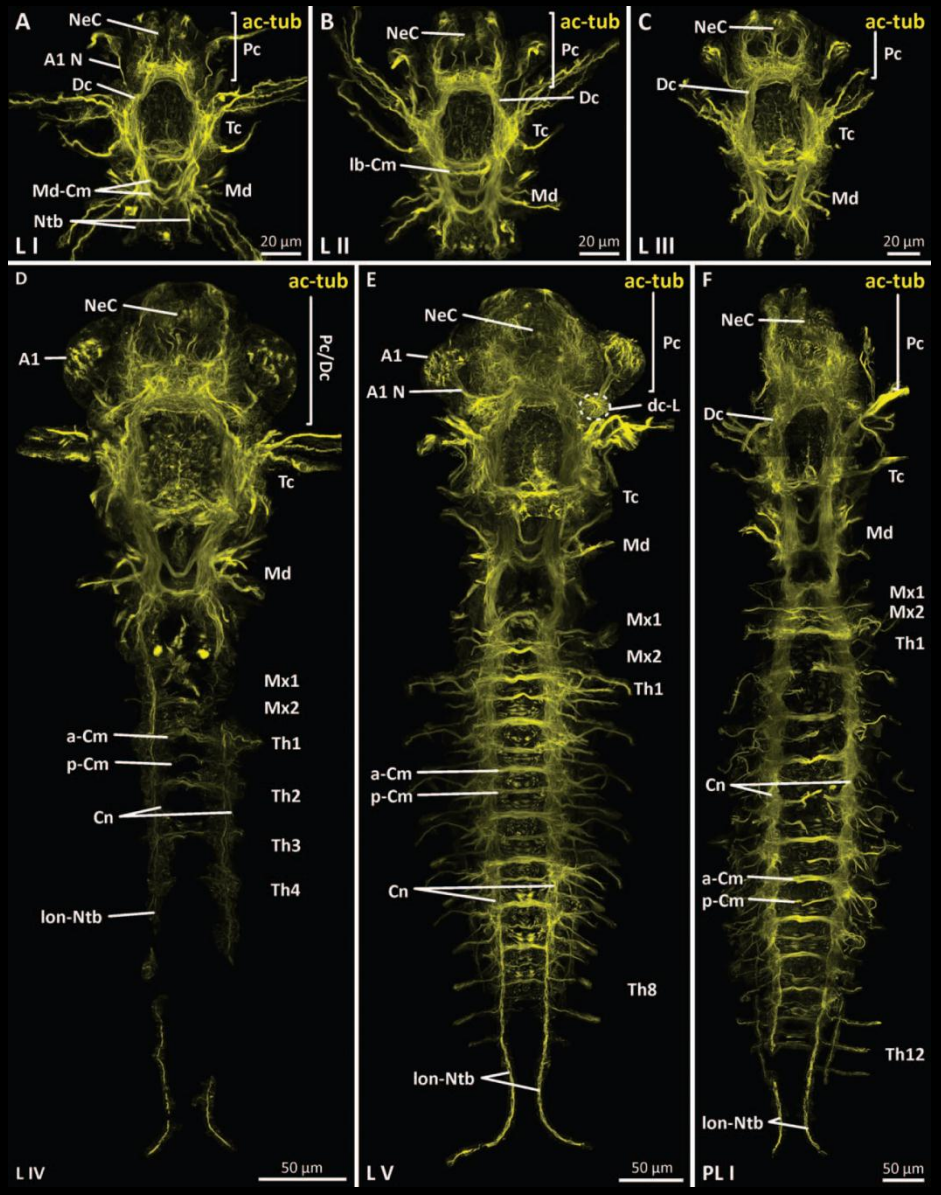


Fritsch & Richter: *J. Morphol. (2012)*

Segmentation in arthropods

Leptestheria **(Crustacea, Branchiopoda)**



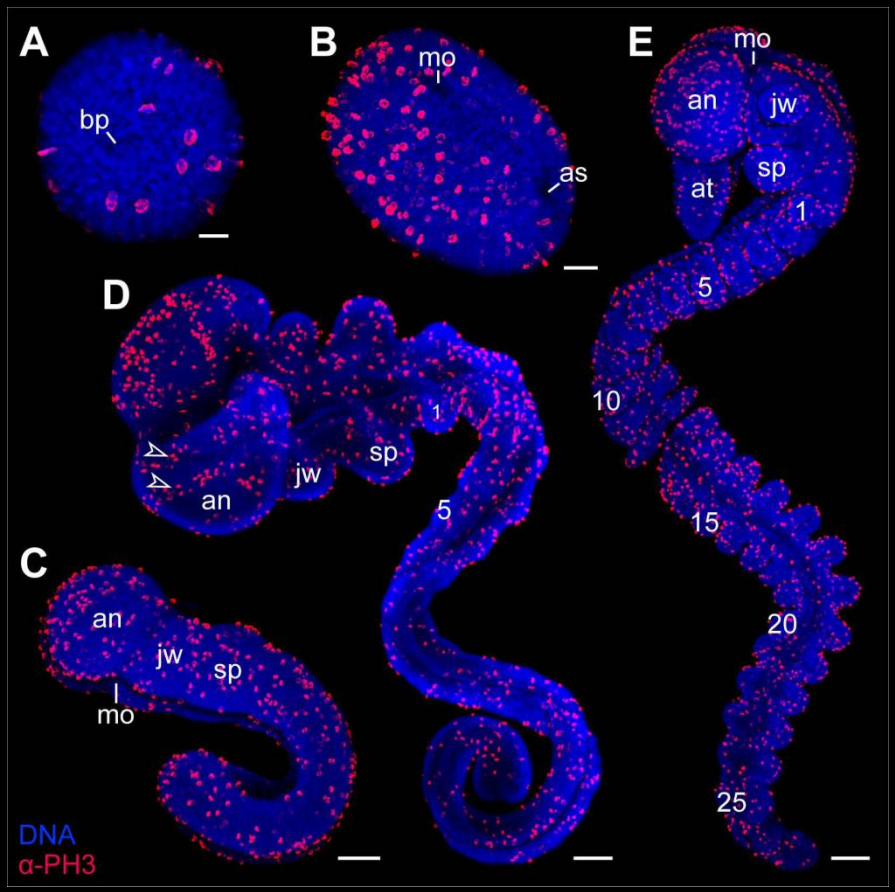


Fritsch & Richter: *J. Morphol. (2012)*

Segmentation in Onychophora

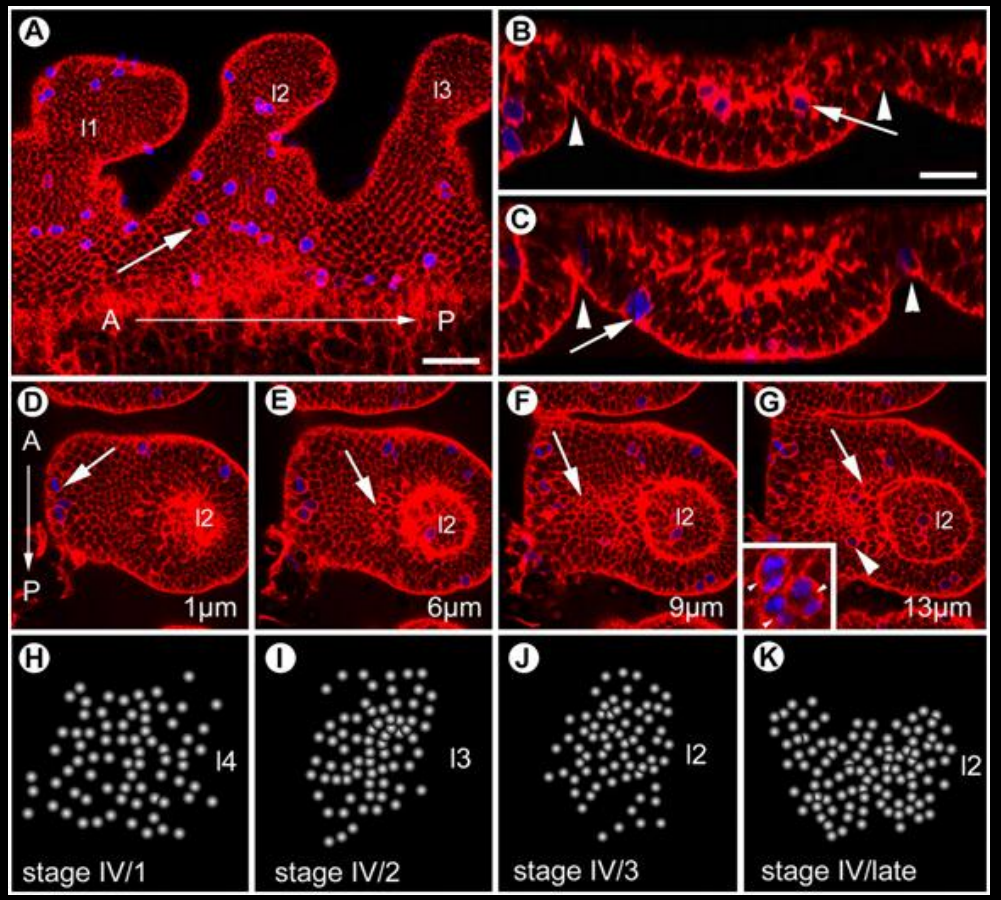
- **No posterior growth zone**
- **Neurogenesis by irregular proliferation of neural precursor cells**

Epiperipatus



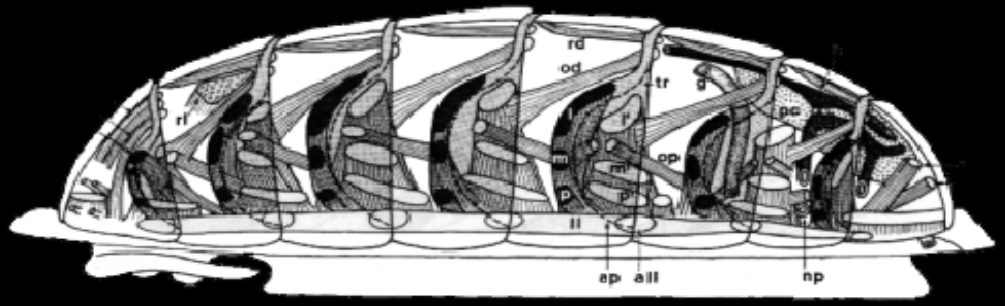
Mayer et al.: *BMC Evol. Biol. (2010)*

Euperipatoides

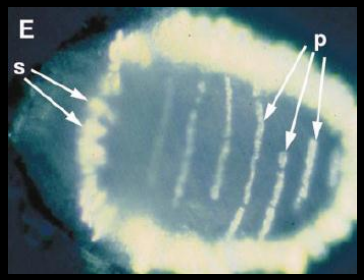


Eriksson & Stollewerk: *PNAS (2010)*

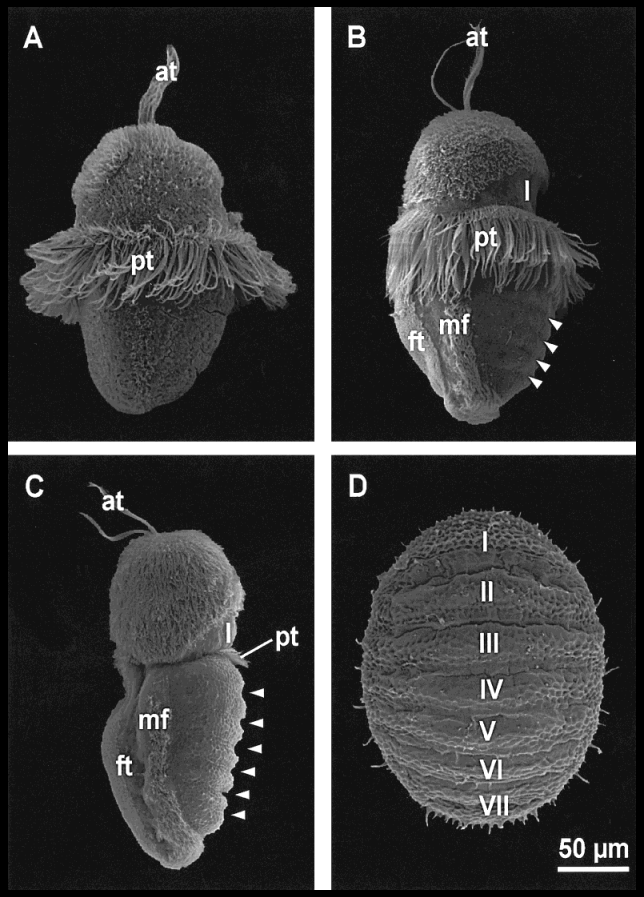
Organogenesis in basal Mollusca



Wingstrand: *Galathea Report (1985)*

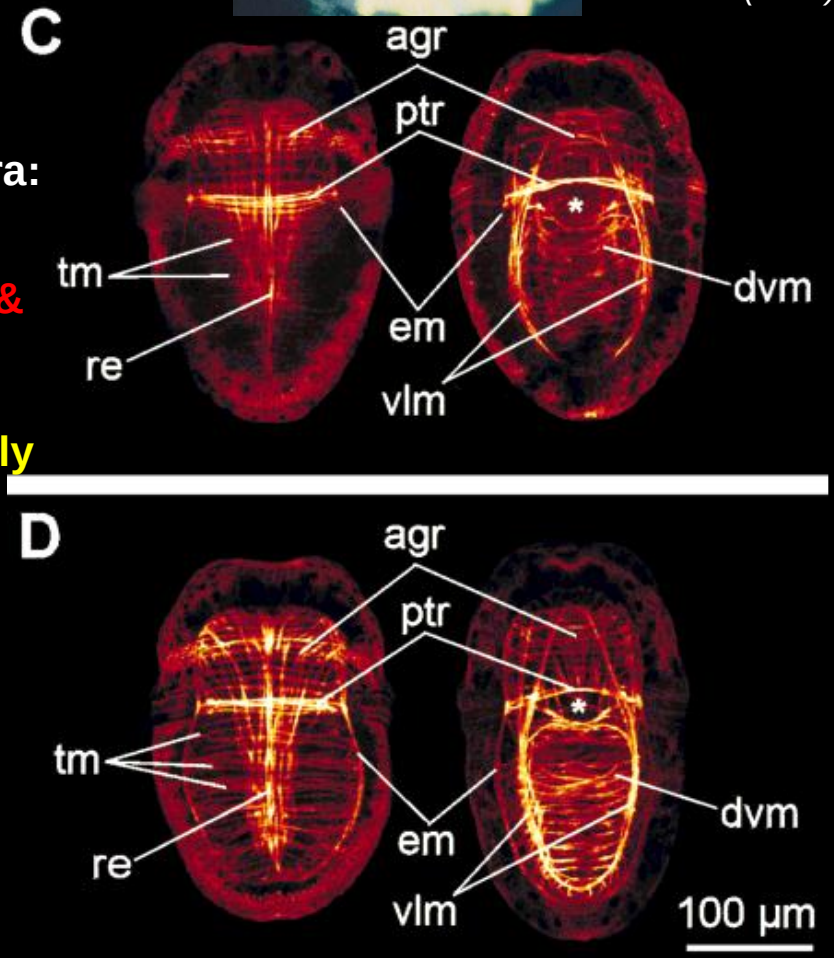


Jacobs et al.:
Evol. Dev. (2000)



Polyplacophora:

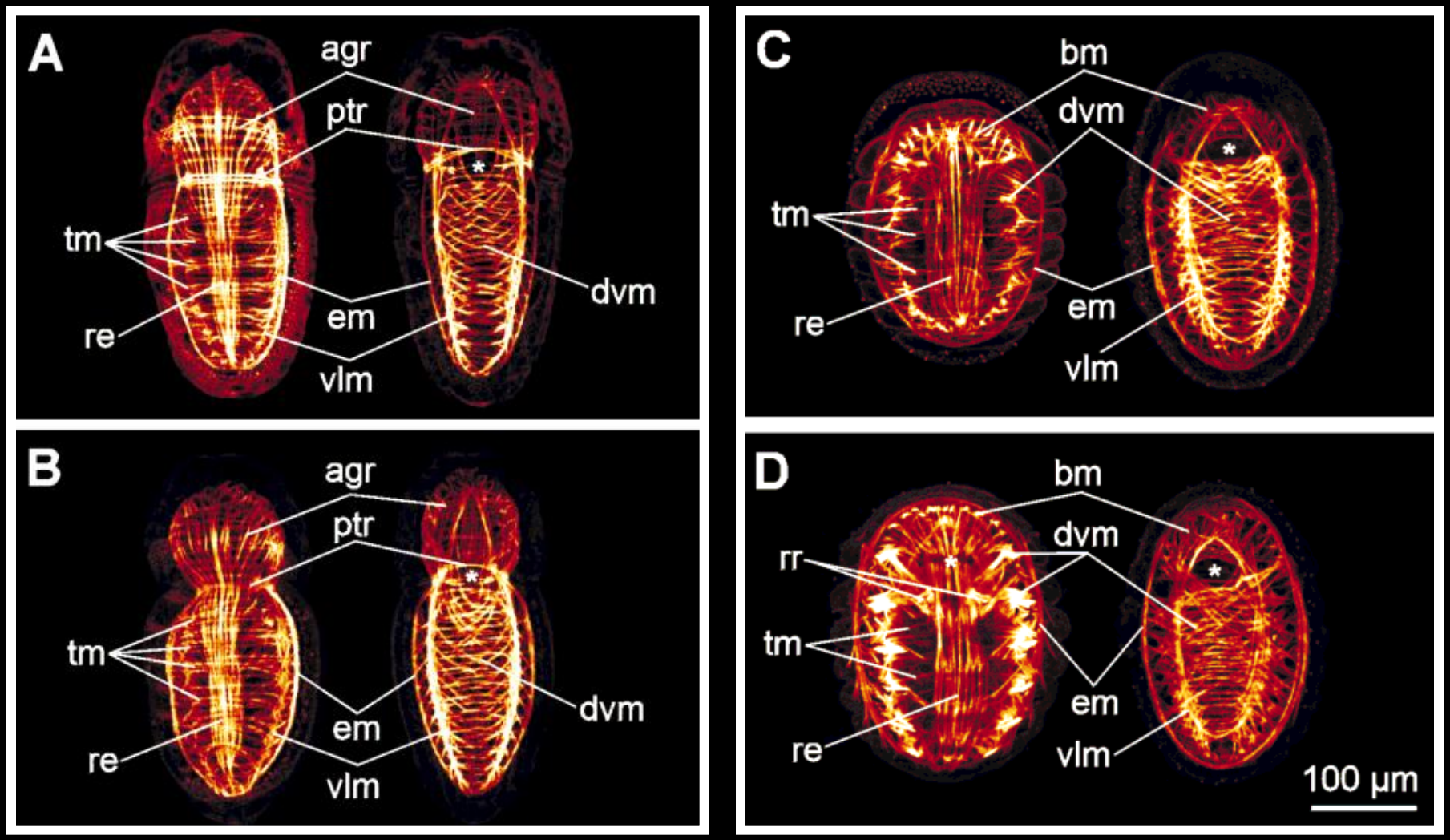
Shell plates, dorso-ventral & transversal muscles arise synchroneously



Wanninger & Haszprunar: *J. Morphol. (2002)*

Organogenesis in basal Mollusca

Polyplacophora: **formation of 8-seriality of dorso-ventral muscles after metamorphosis**

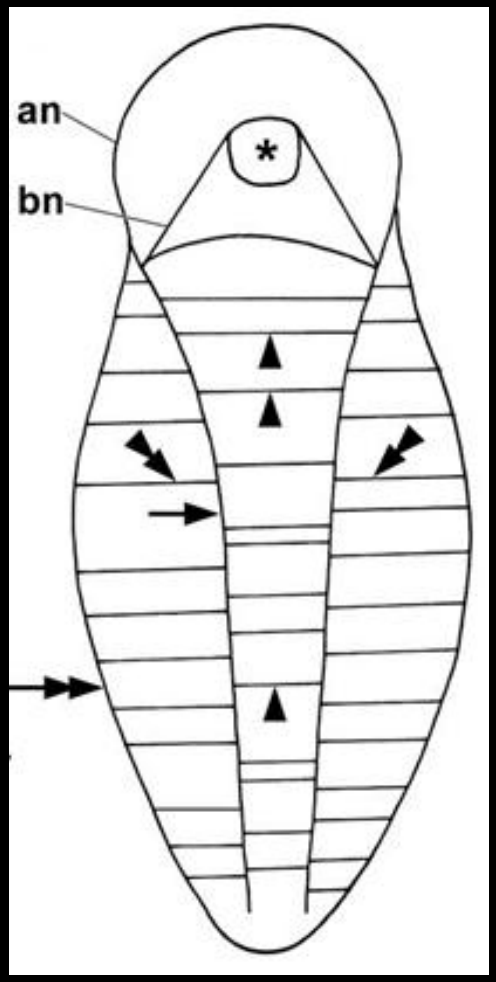


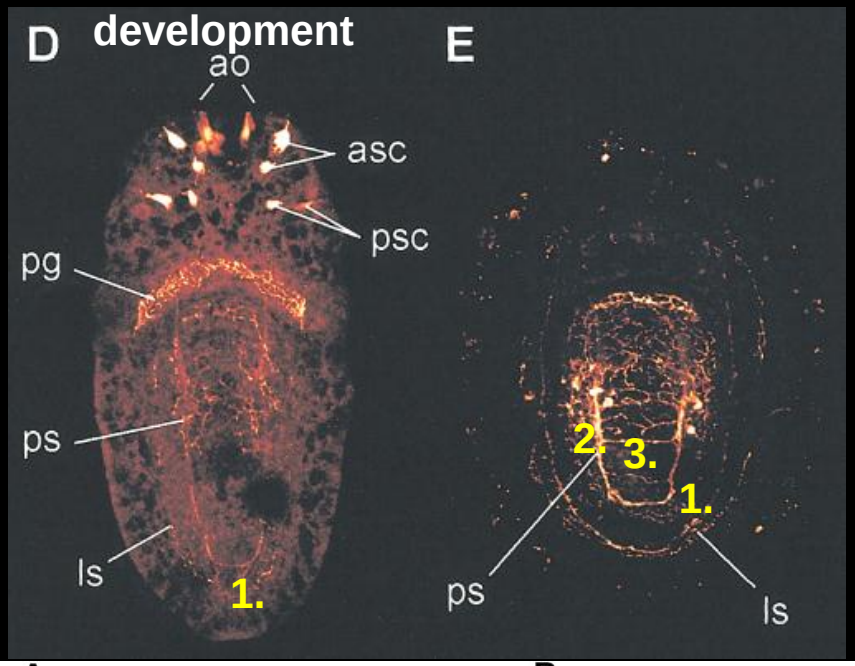
Wanninger & Haszprunar: *J. Morphol. (2002)*

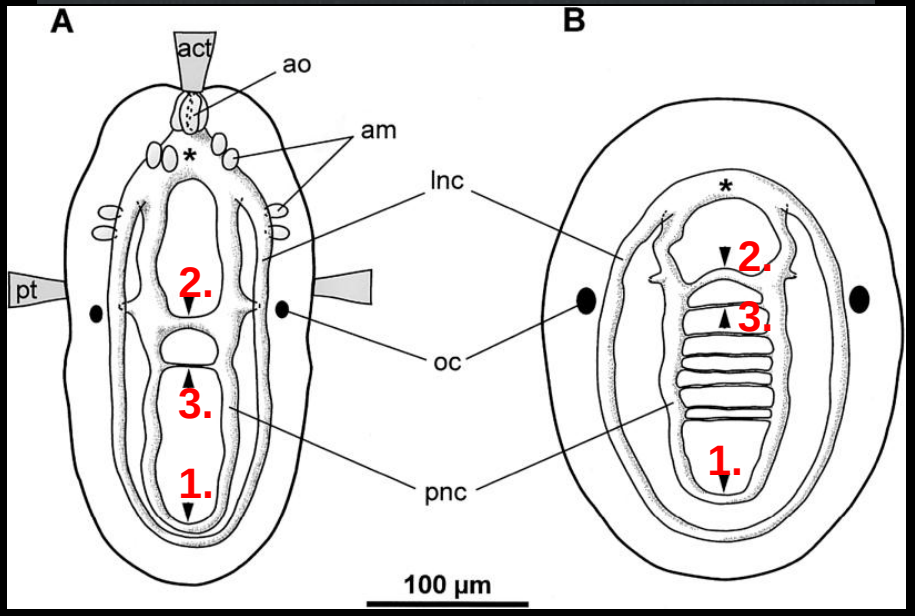
Organogenesis in basal Mollusca

Polyplacophora (*Mopalia muscosa*):
ventral commissures are not formed in anterior-posterior progression

adult: seriality of commissures



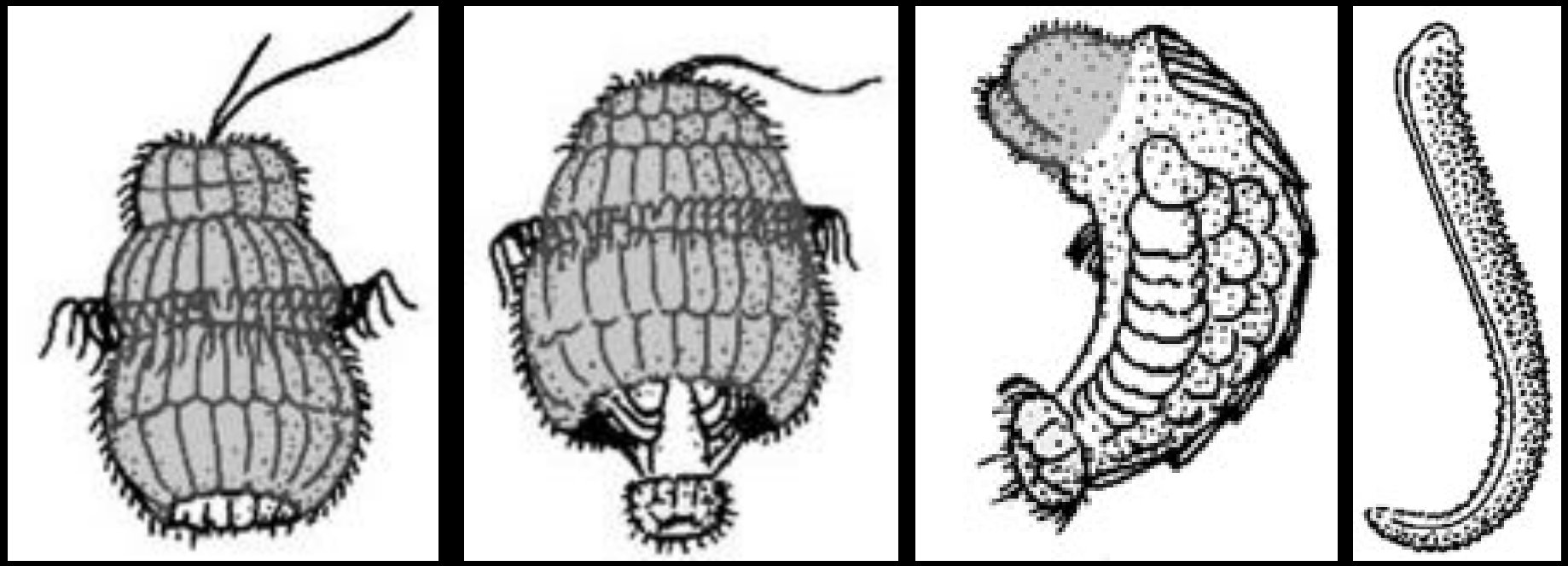




Friedrich, Wanninger, Brückner & Wanninger: *J. Morphol. (2002)*

Organogenesis in basal Mollusca

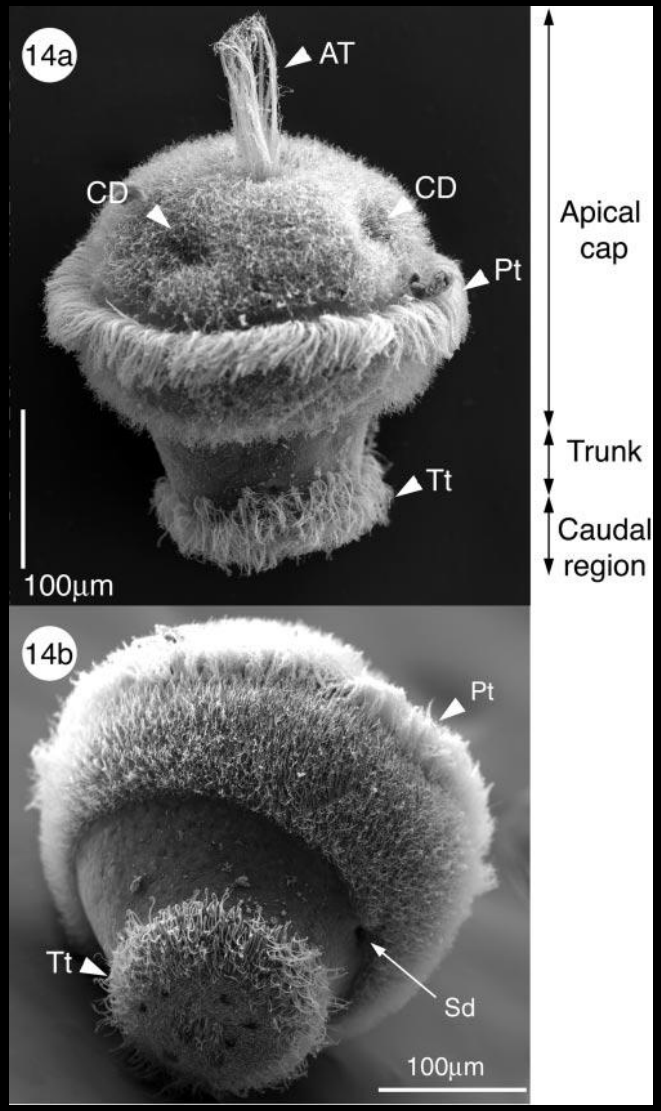
Solenogastres (Neomeniomorpha): *Nematomenia banyulensis*

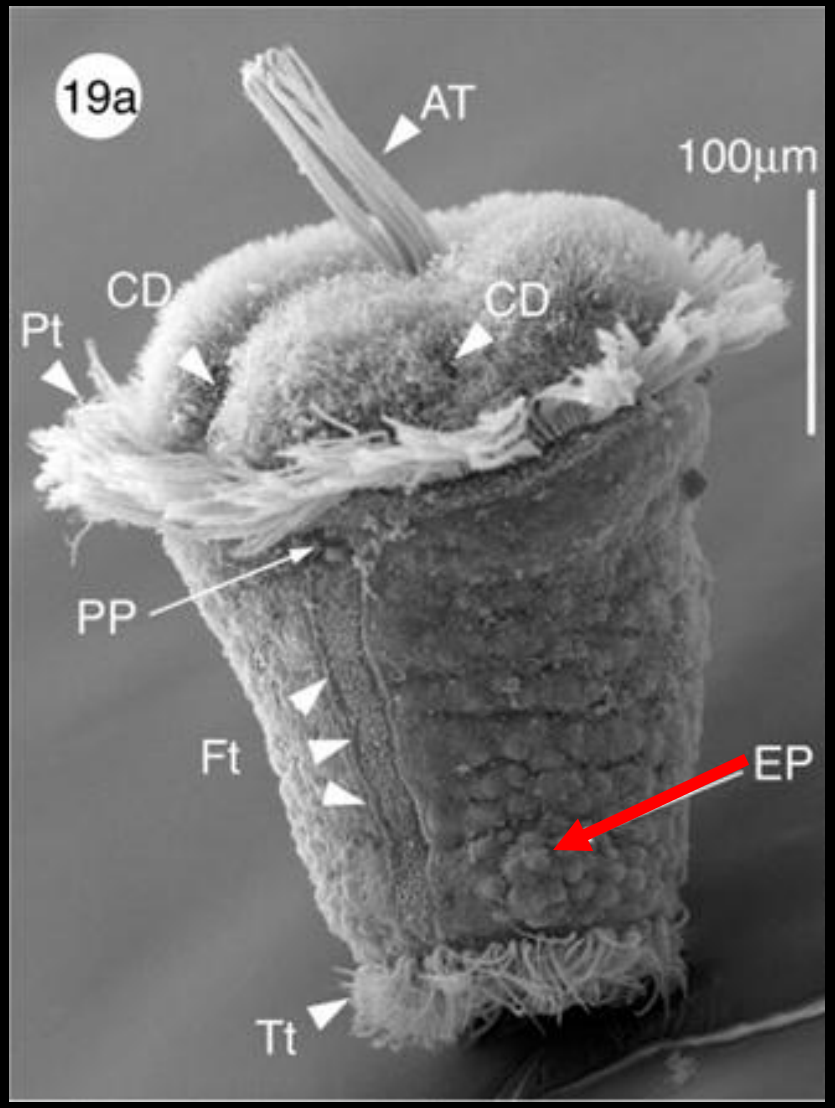


After Pruvot: *C. R. Acad. Sci. Paris. (1890)*

Organogenesis in basal Mollusca

Solenogastres (Neomeniomorpha): *Epimenia babai*: no serial arrangement of epidermal papillae

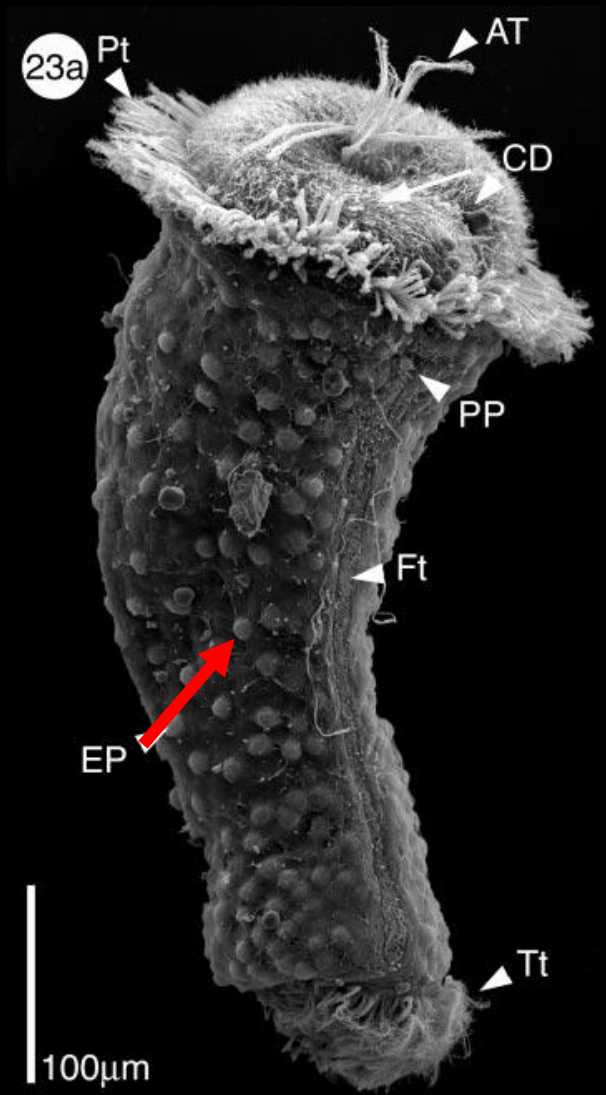


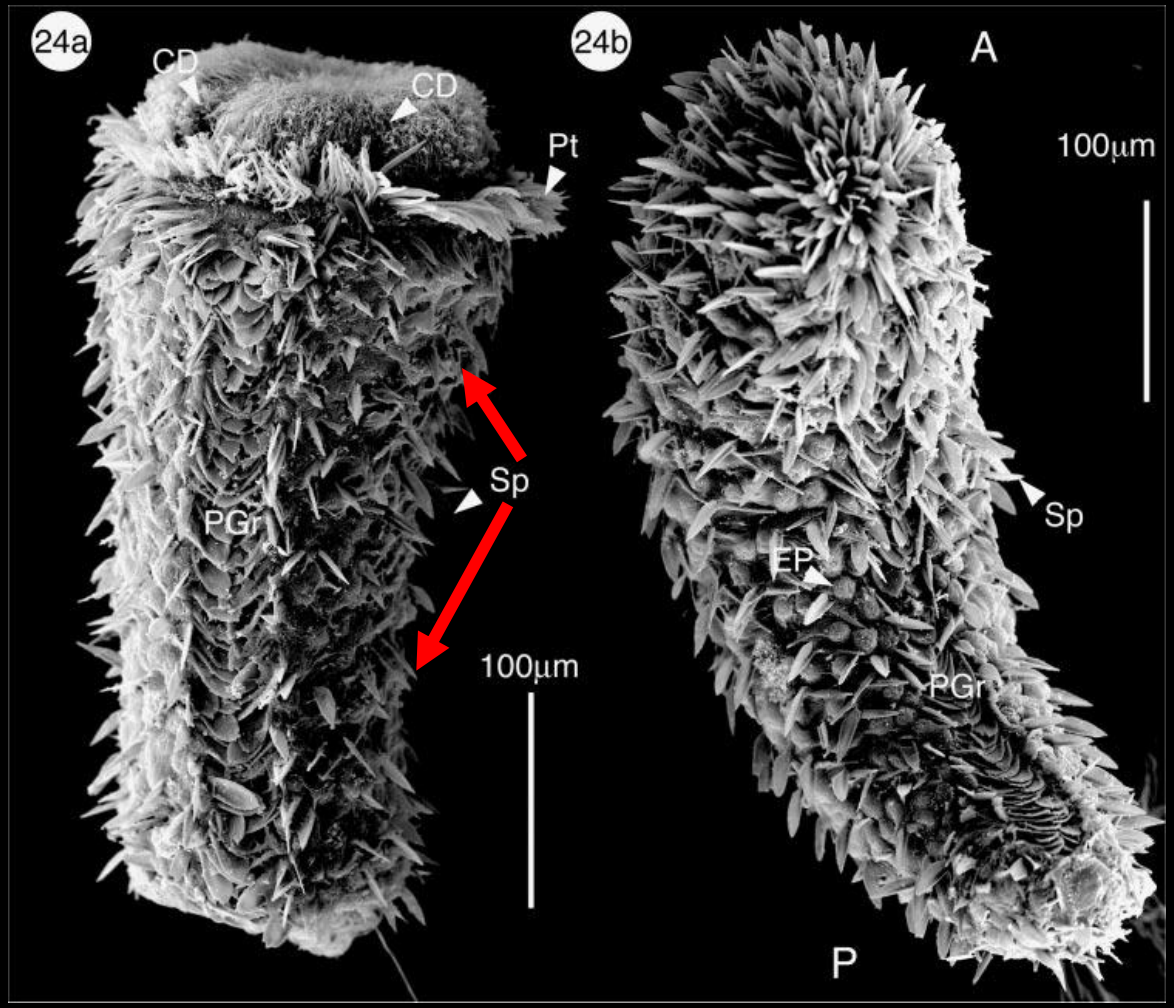


Okusu: *Biol. Bull. (2002)*

Organogenesis in basal Mollusca

Solenogastres (Neomeniomorpha): *Epimenia babai*: no serial arrangement of epidermal papillae, no anterior-posterior progression of spicule formation

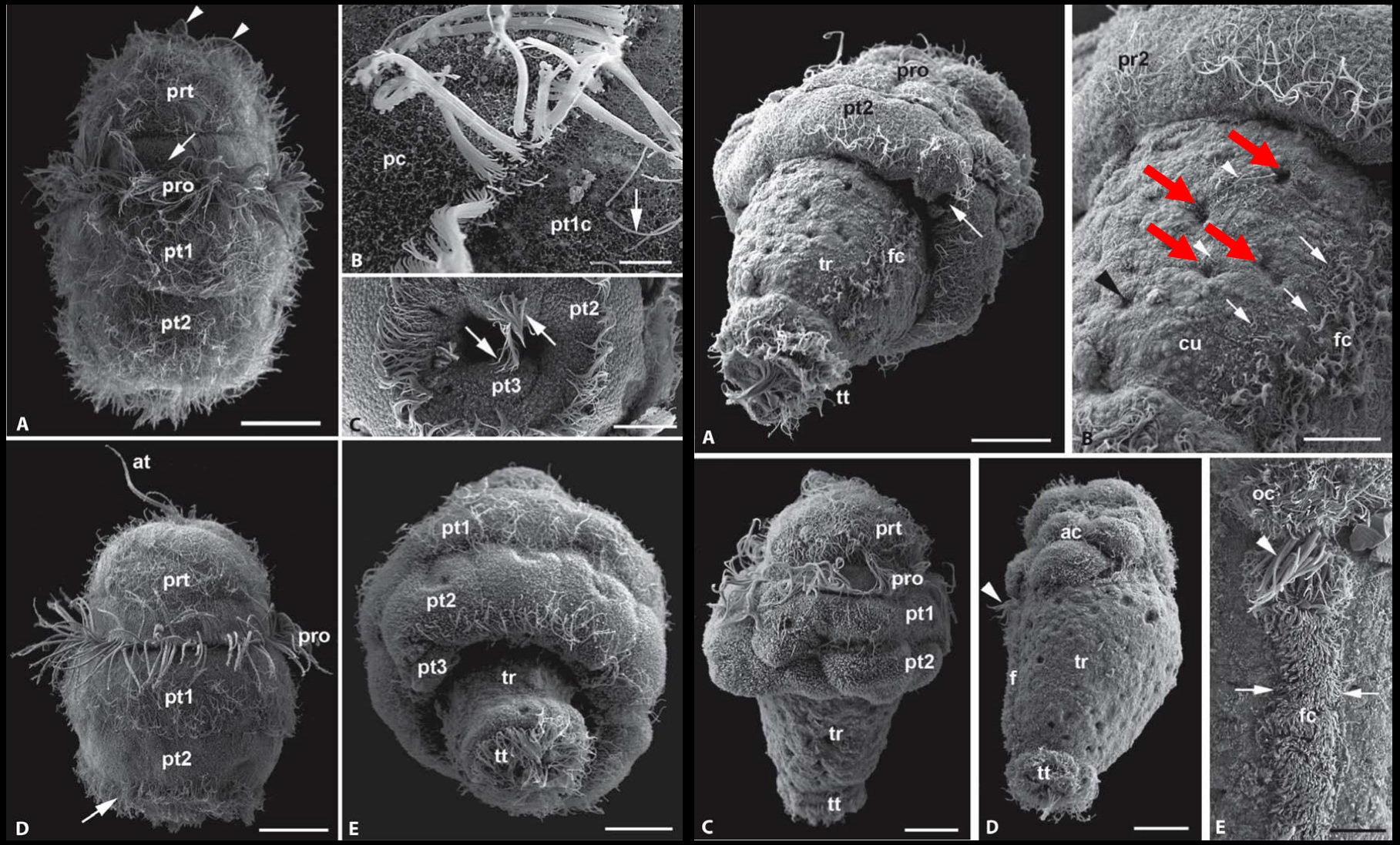




Okusu: *Biol. Bull. (2002)*

Organogenesis in basal Mollusca

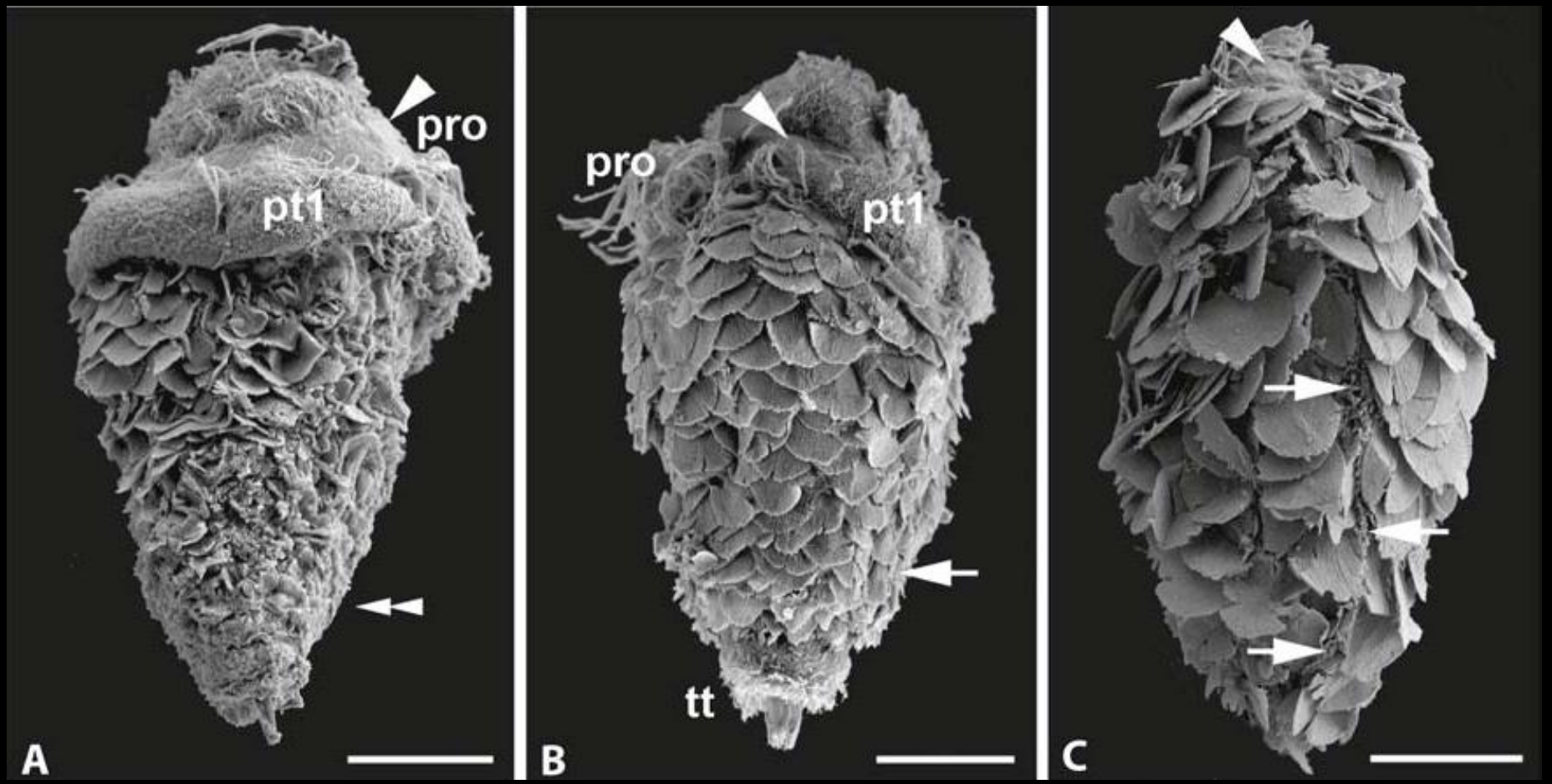
Solenogastres (Neomeniomorpha): *Wirenia argentea*: epidermal pores not serially arranged



Todt & Wanninger: *Front. Zool. (2010)*

Organogenesis in basal Mollusca

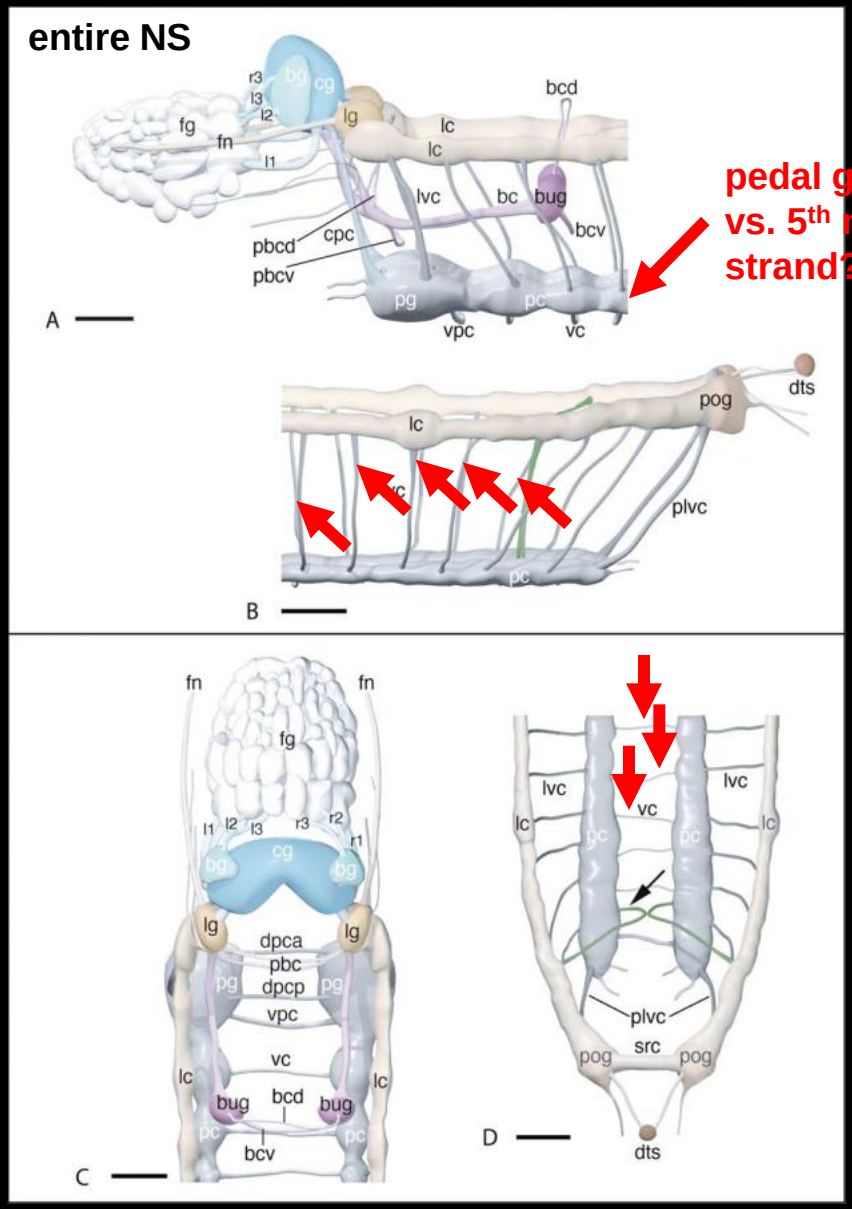
Solenogastres (Neomeniomorpha): *Wirenia argentea*: no anterior-posterior progression in spicule formation after completion of metamorphosis



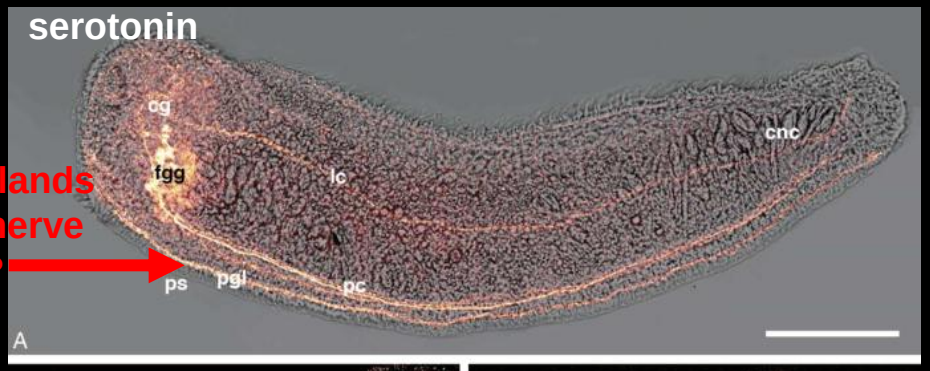
Todt & Wanninger: *Front. Zool. (2010)*

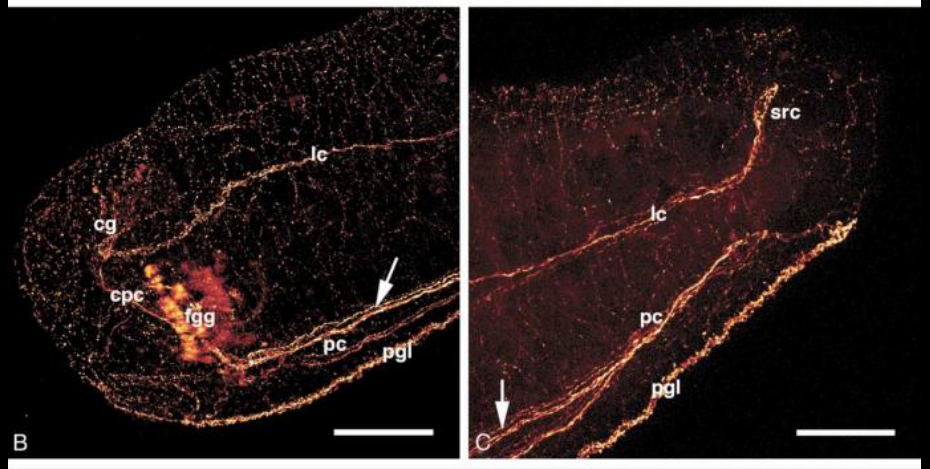
Organogenesis in basal Mollusca

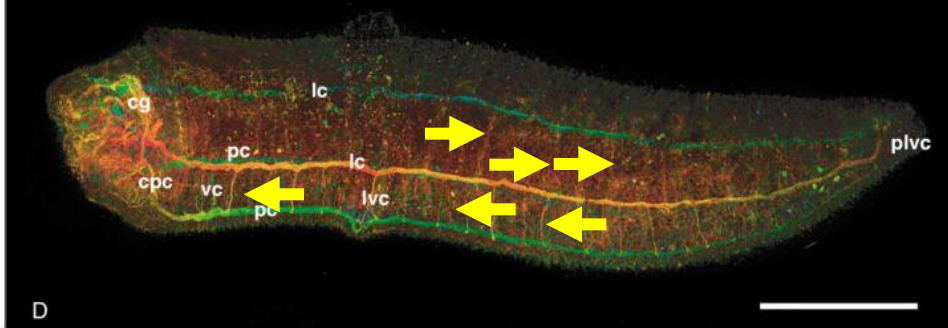
Solenogastres (*Wirenia argentea*): adult seriality of commissures



pedal glands vs. 5th nerve strand?



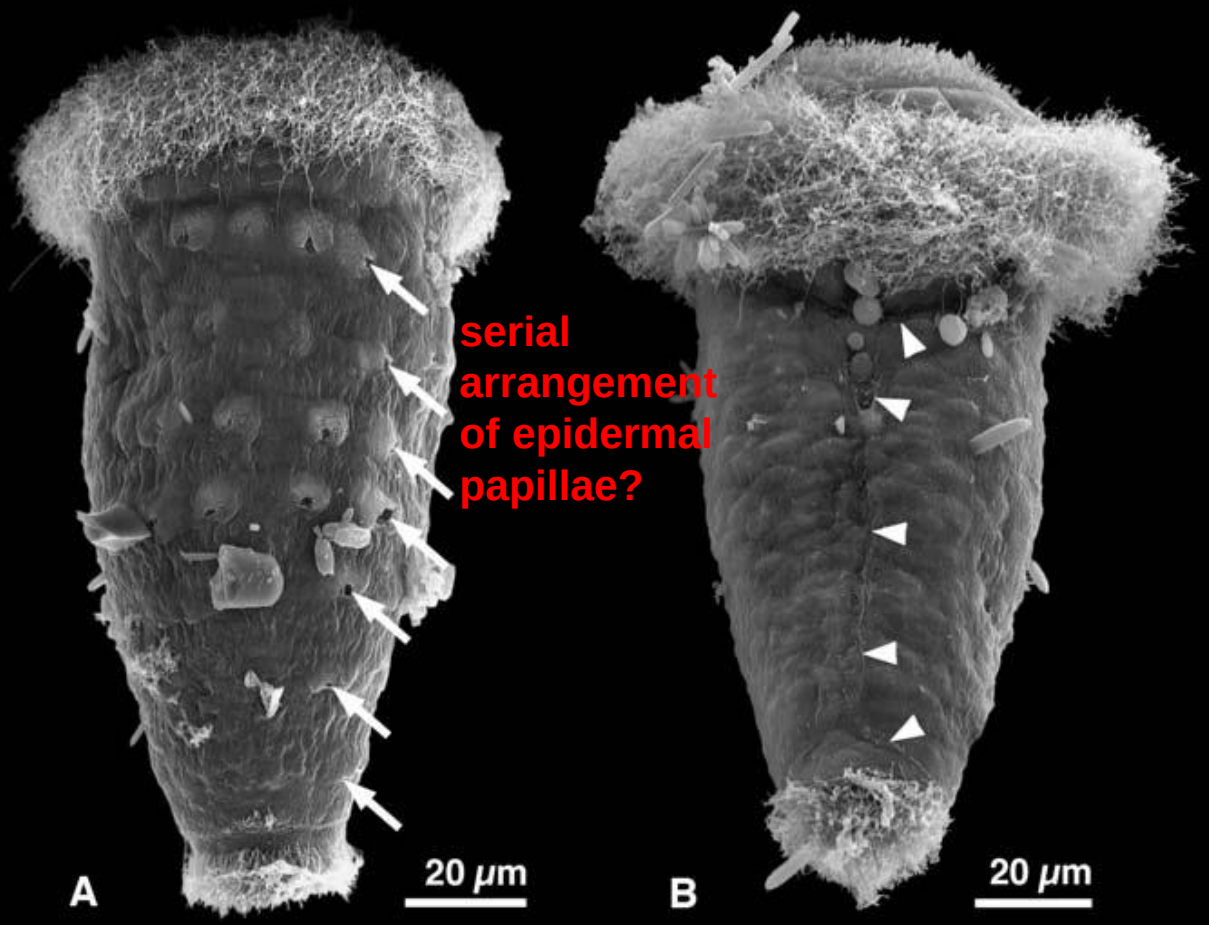




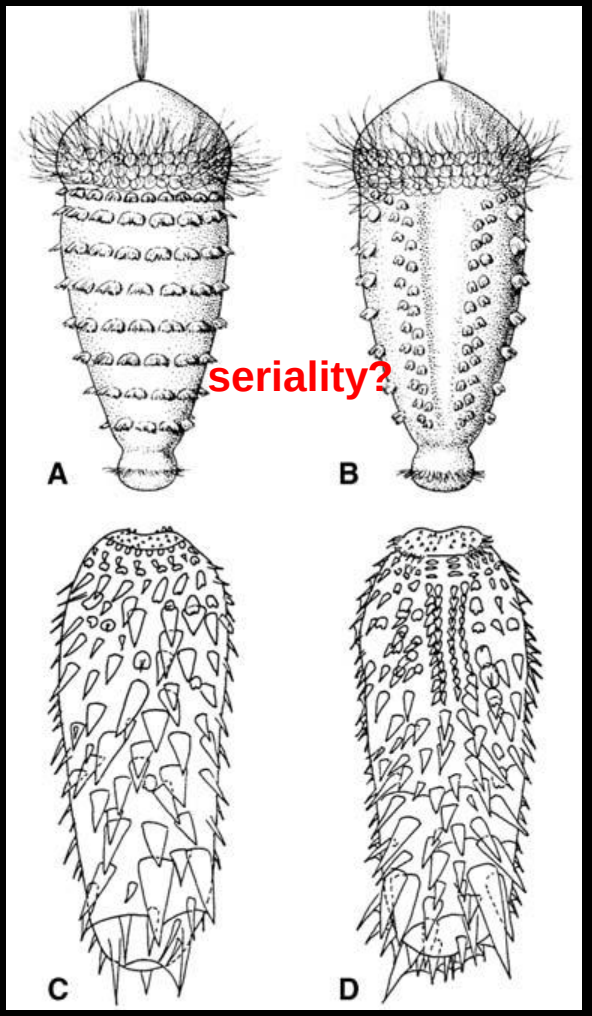
Todt, Büchinger & Wanninger: *Mar. Biol. Res. (2008)*

Organogenesis in basal Mollusca

Caudofoveata (Chaetodermomorpha): *Chaetoderma nitidulum*



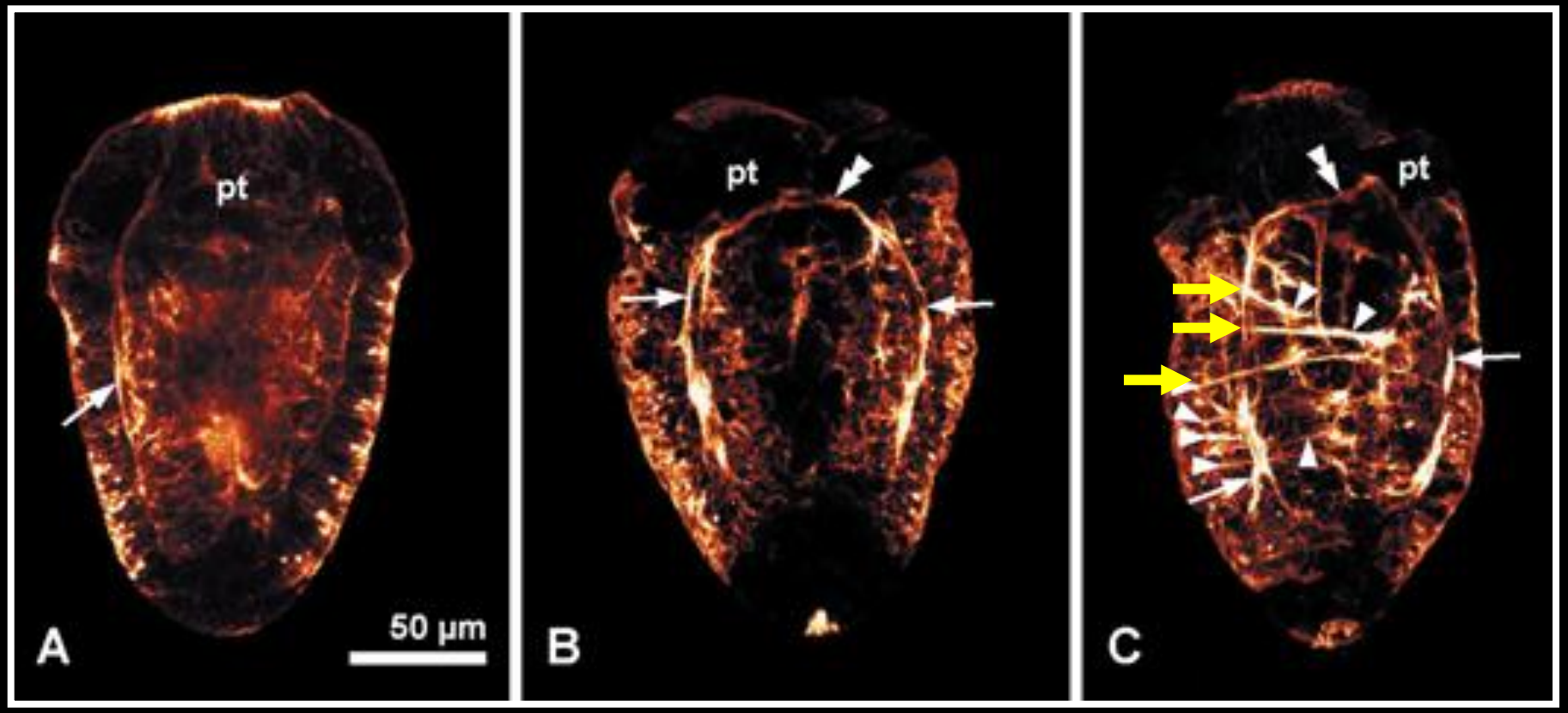
Nielsen, Haszprunar, Ruthensteiner & Wanninger: *Acta Zool. (2007)*



Organogenesis in basal Mollusca

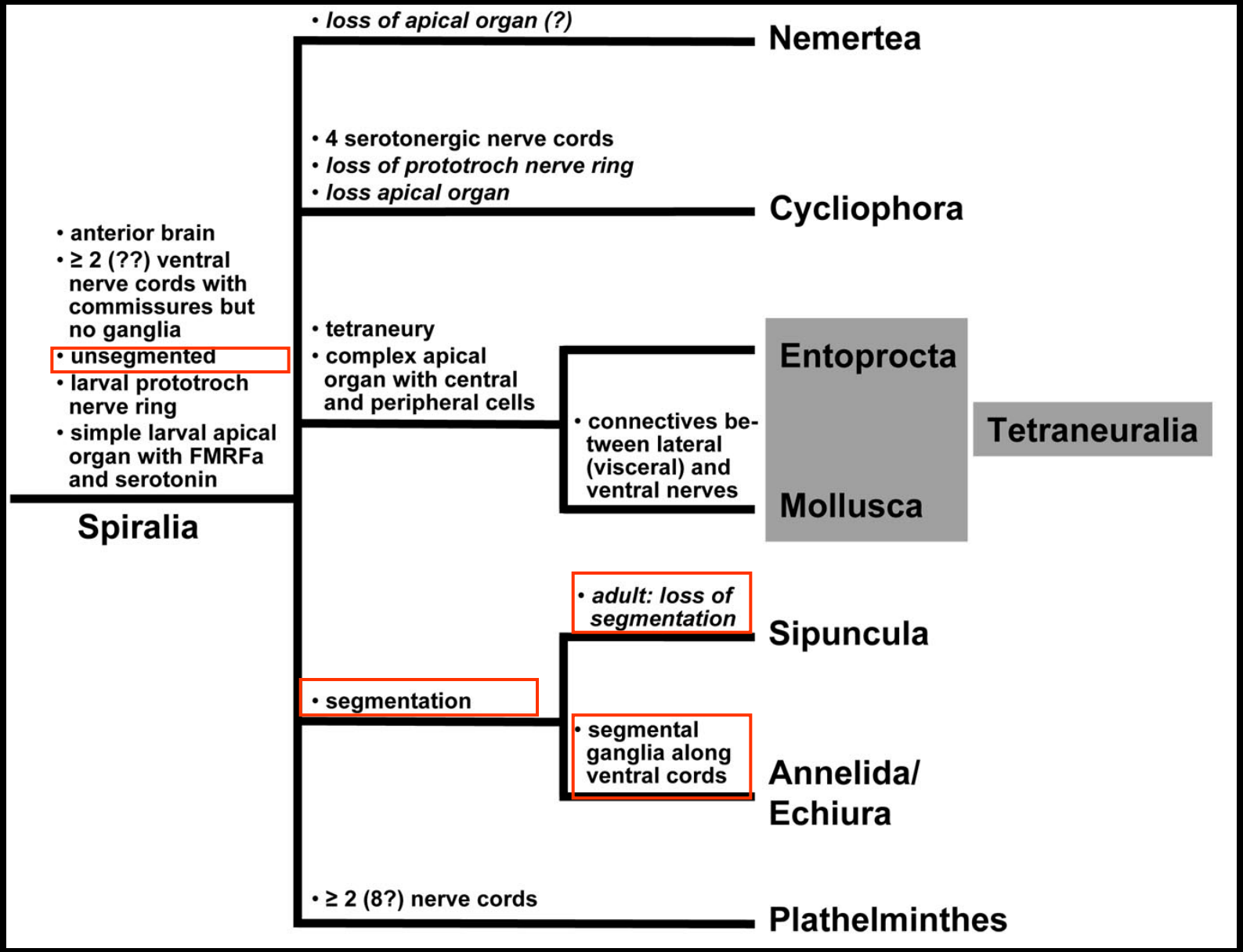
Caudofoveata (Chaetodermomorpha): *Chaetoderma nitidulum*

Myogenesis: ring muscles not formed in anterior-posterior sequence



Nielsen, Haszprunar, Ruthensteiner & Wanninger: *Acta Zool. (2007)*

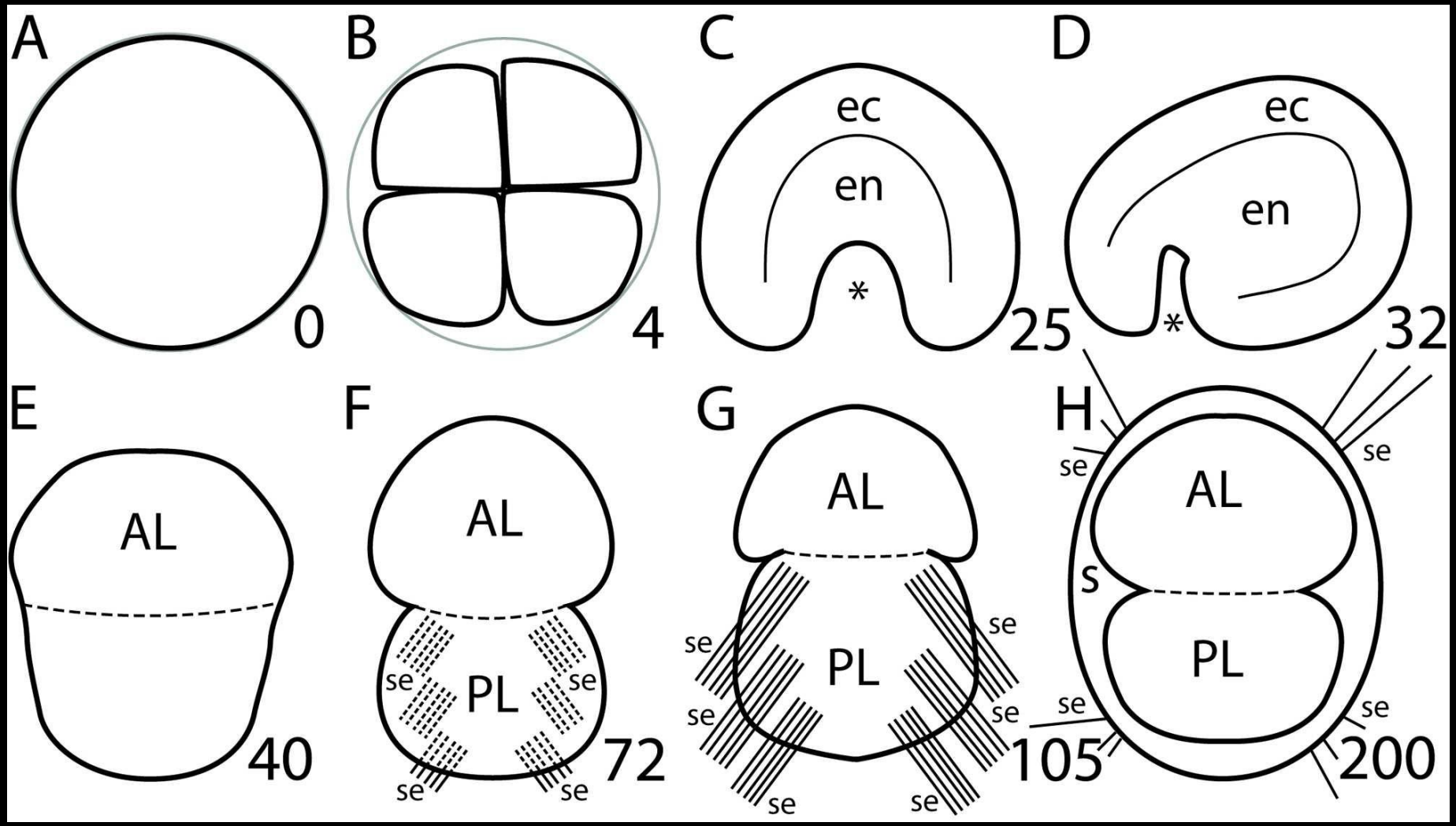
Evolution of segmentation in Lophotrochozoa



Wanninger: *Biol. Bull. (2009)*

Development in Brachiopoda

Novocrania anomala

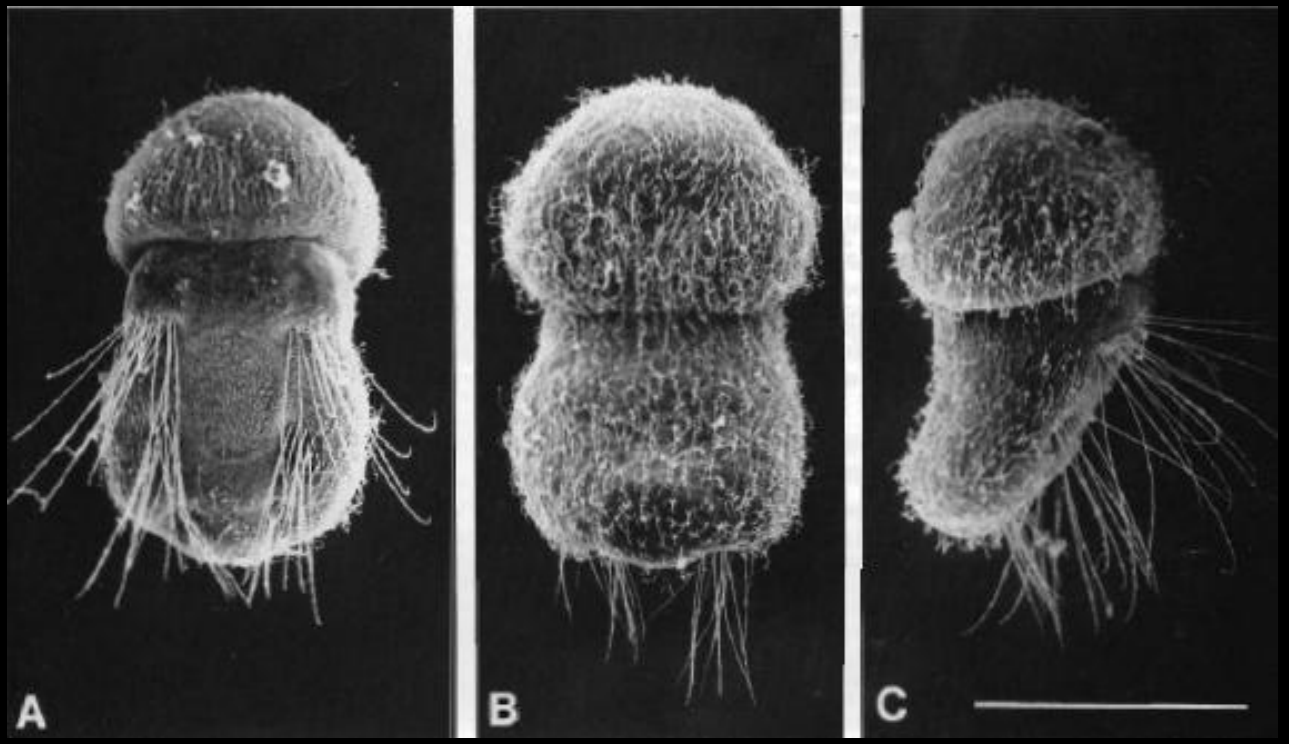


Altenburger & Wanninger: *(unpublished)*

Development in Brachiopoda

Neurogenese bei Brachiopoda

Novocrania anomala



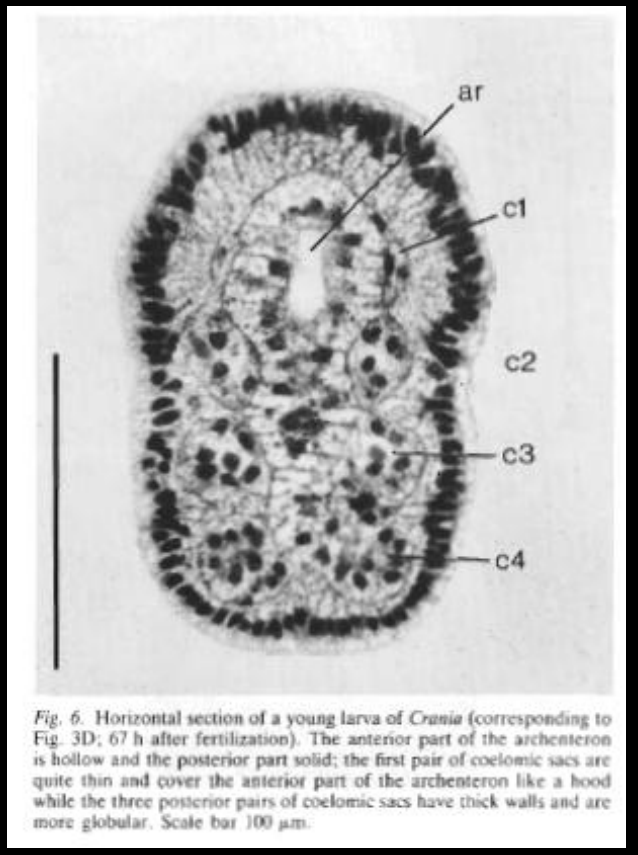
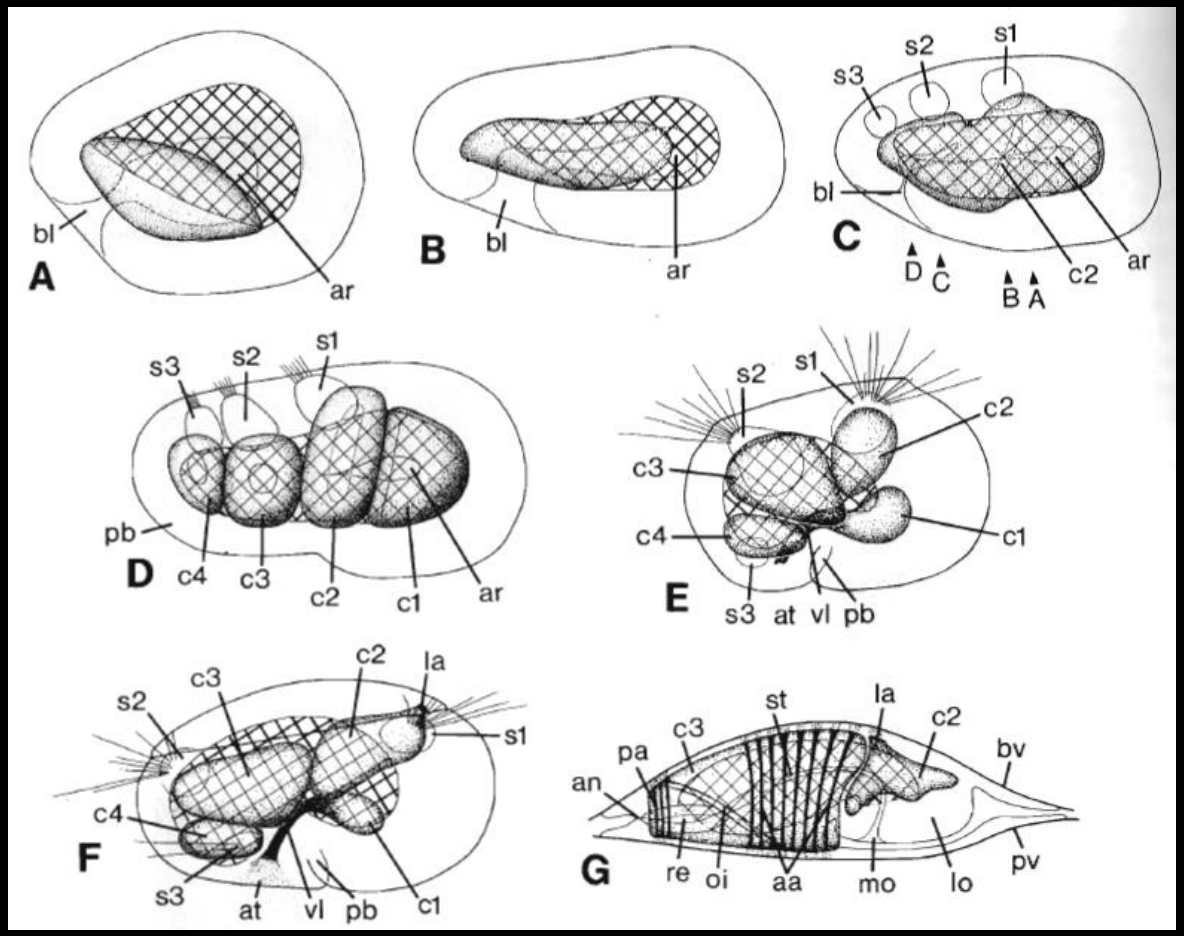


Fig. 6. Horizontal section of a young larva of *Crania* (corresponding to Fig. 3D; 67 h after fertilization). The anterior part of the archenteron is hollow and the posterior part solid; the first pair of coelomic sacs are quite thin and cover the anterior part of the archenteron like a hood while the three posterior pairs of coelomic sacs have thick walls and are more globular. Scale bar 100 μm.

Nielsen: ***Acta Zool. (1991)***

Development in Brachiopoda

Novocrania anomala



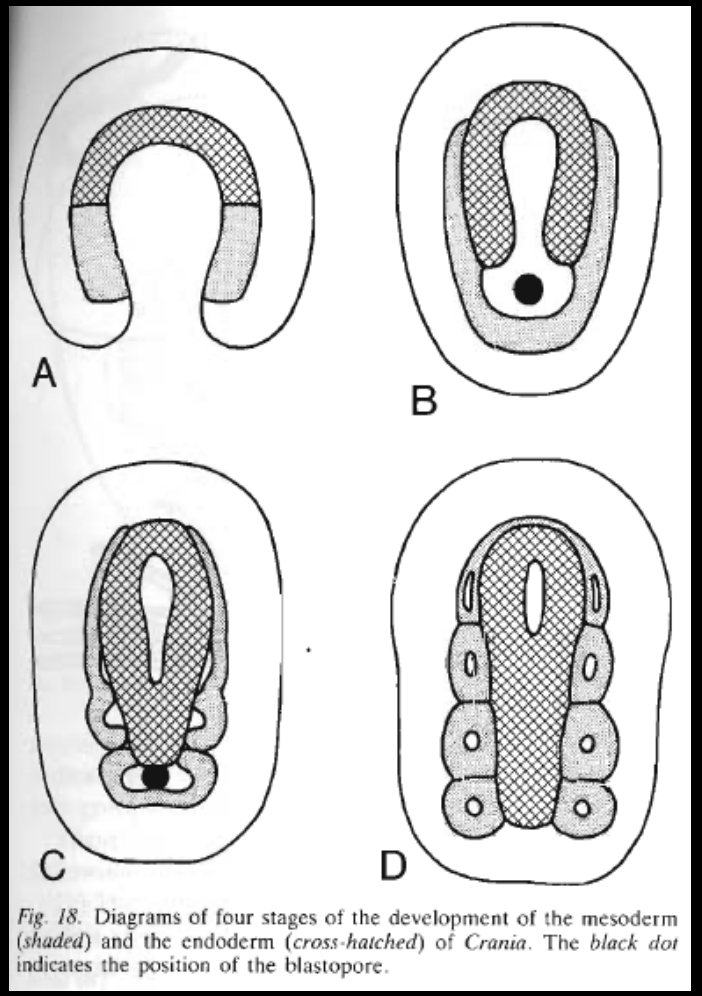
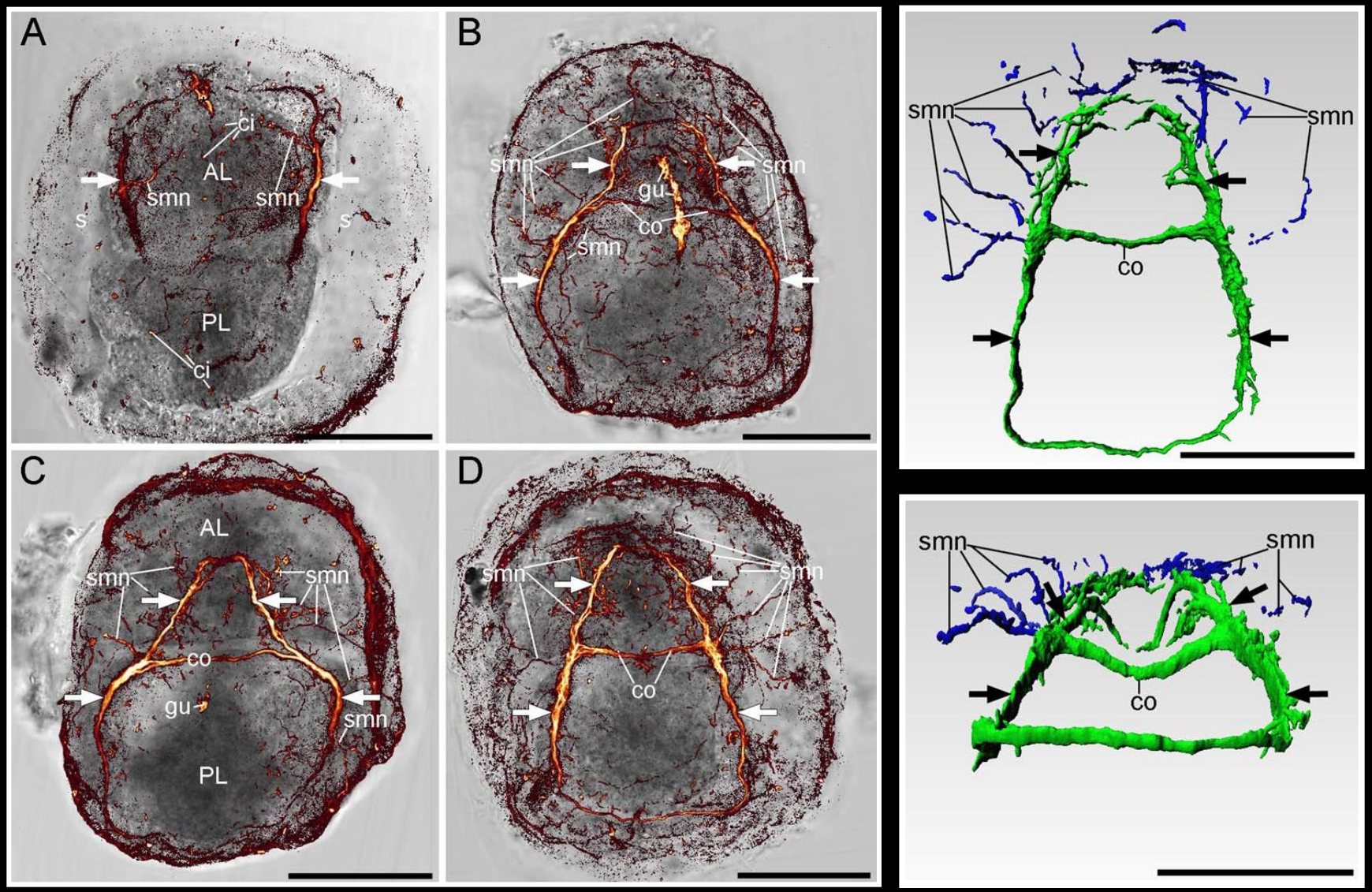


Fig. 18. Diagrams of four stages of the development of the mesoderm (*shaded*) and the endoderm (*cross-hatched*) of *Crania*. The *black dot* indicates the position of the blastopore.

Nielsen: ***Acta Zool. (1991)***

Neurogenesis in Brachiopoda

Novocrania anomala

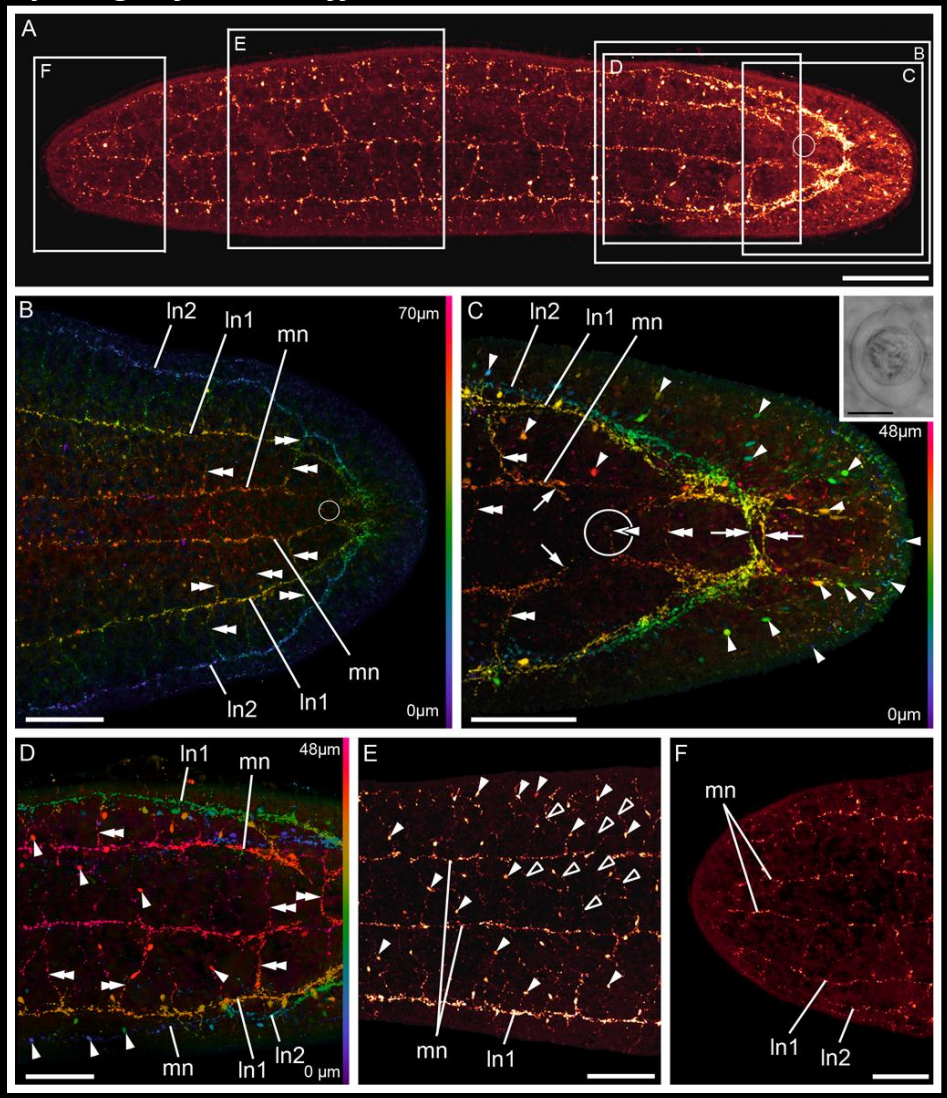


Altenburger & Wanninger: *Evol. Dev. (2010)*

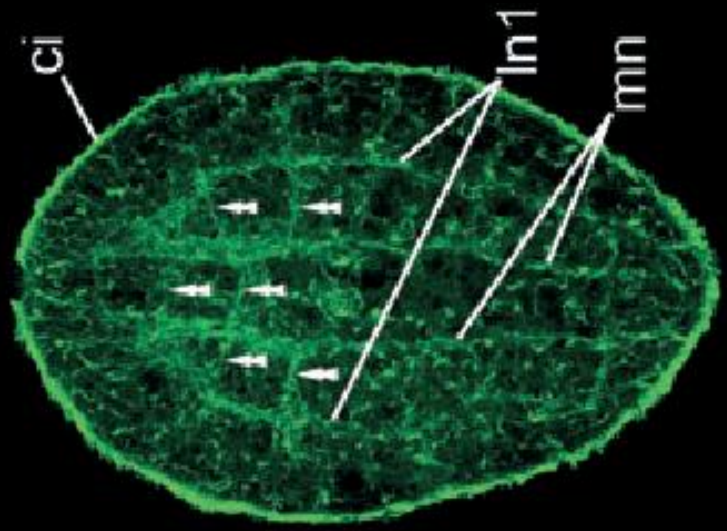
Neurogenesis in Acoela

- **Irregular arrangement of repetitive commissures between connectives**
- **Formation plexus-like**

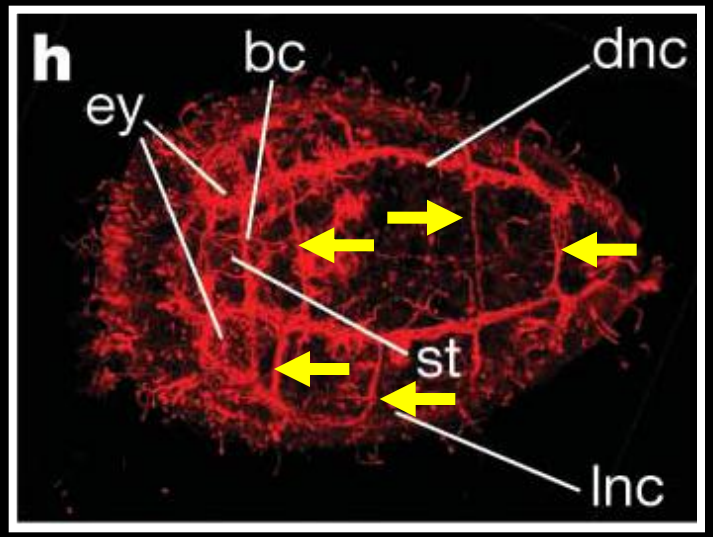
Symsagittifera roscoffensis



Semmler, Choidin, Bailly, Martinez & Wanninger: *Dev. Growth Diff. (2010)*



Convolutriloba longifissura



Hejnol & Martindale: *Nature (2008)*

Evolution of segmentation

Several times independently;

In **Lophotrochozoa: only Annelida (incl. Echiura and Sipuncula);**
First 3 (larval) segments arise simultaneously (??), all others from **posterior growth zone**, one after another (**teloblasts**)

In **Arthropoda:**
1) In *Drosophila*: simultaneously
2) In **crustaceans:** first **3 larval** (naupliar) **segments simultaneously, all others** from **posterior growth zone**, one after another (**ectoteloblasts**)
3) **others: first segments simultaneously, all others** from **posterior growth zone**, one after another (**blastodisc**)

Box 2 | **Diverse cellular mechanisms of segmentation in arthropods**

In *Drosophila melanogaster*, all segments are patterned more or less simultaneously while the blastoderm is still syncytial (panel a; also see BOX 1). By contrast, most other arthropods pattern a small number of segments at the blastoderm stage, and then add posterior segments consecutively from a growth zone. The first patterned segments include at least the three anterior segments: the antennal segment, the intercalary segment (which is the second antennal segment in crustaceans) and the mandibular segment. These three segments are sometimes referred to as the naupliar segments, and are the only ones that are present in the larval stages of many crustacean groups. In many insects, in addition to the naupliar segments, two to five other segments are formed in the blastoderm stage, including up to three thoracic segments. Little is known about the mechanism behind the formation of anterior segments. It is possible that they are generated by a mechanism that is distinct from those that function during the formation of more posterior segments.

In most arthropods posterior segments are generated in a cellular environment. In some cases these segments arise from a small population of posterior cells in the blastoderm, which proliferate later to generate the tissue from which segments are patterned (this occurs, for example, in *Artemia franciscana* and other branchiopod crustaceans, and in most 'short germ' insects). In other cases (such as in the centipede *Strigamia maritima*, panel b) a blastodisc that contains many thousands of apparently undifferentiated cells persists after the completion of anterior segmentation, and posterior segments are generated sequentially from this population by a combination of proliferation and cell rearrangement.

In MALACOSTRACAN crustaceans, cells of the germ band organize into a square array, each row of which will give rise to a single segment through a stereotyped series of polarized cell divisions (panel c). Sometimes these rows are generated by the aggregation of cells from a preformed blastodisc (for example, in *Parhyale hawaiiensis* and other AMPHIPODS). In many cases they are generated by the sequential divisions of ectoteloblasts — stem cells that lie at the posterior of the germ band.