

The origin of animal eggs and the
'embryonic hourglass':
a new (joint) interpretation

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Embryo Physics Course

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November 10, 2010

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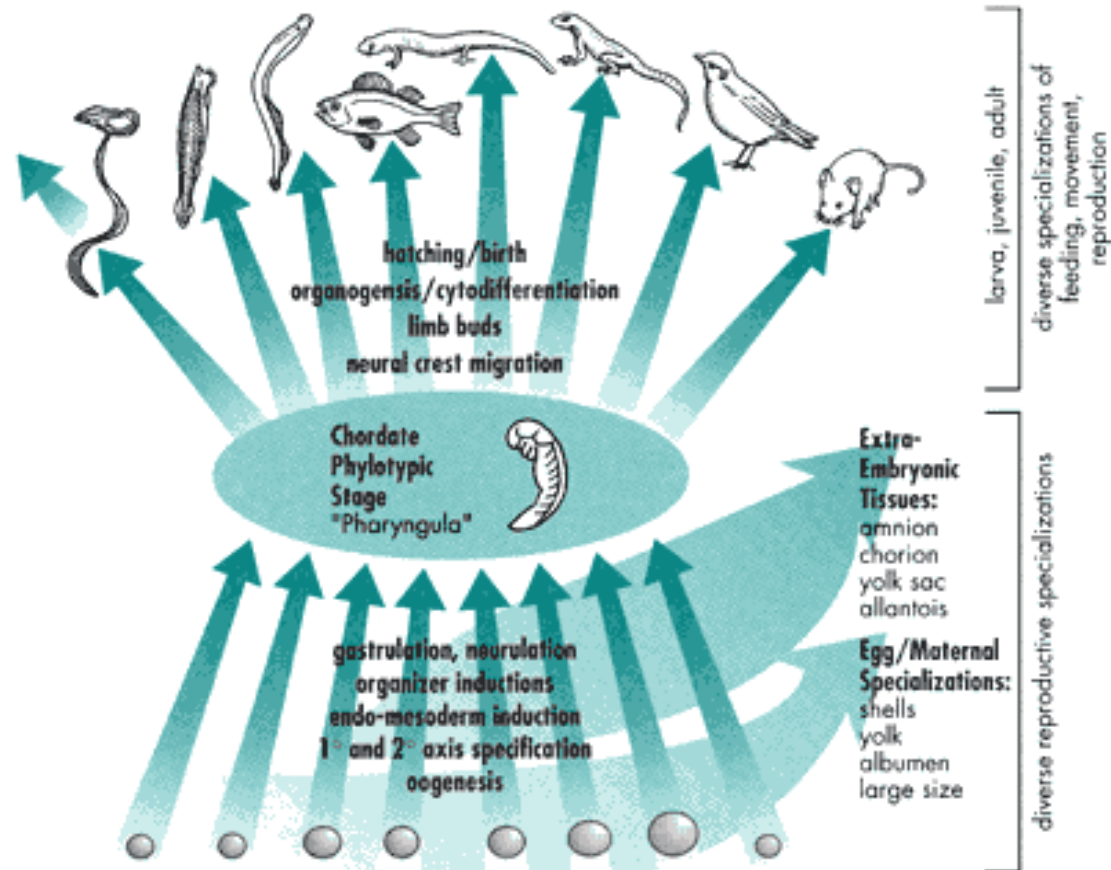
The origin of animal eggs and the 'embryonic hourglass': a new (joint) interpretation

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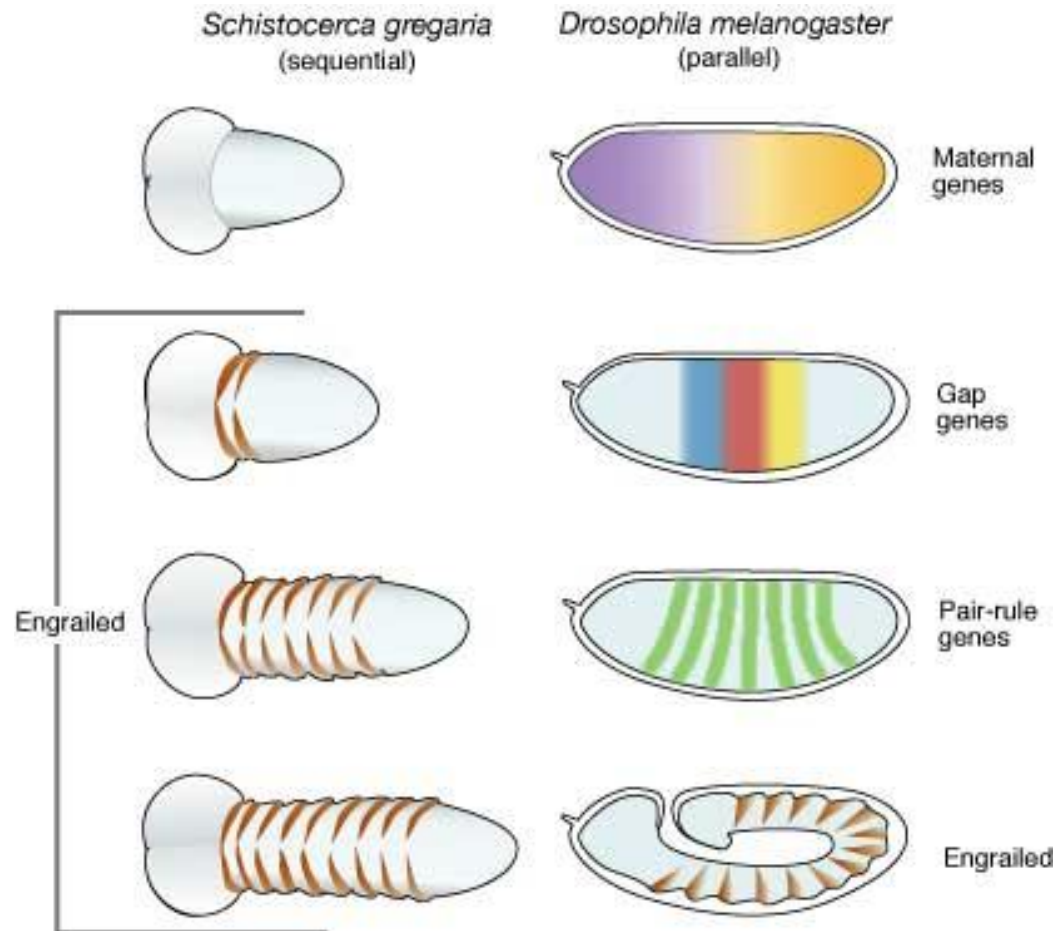
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The “embryonic hourglass”

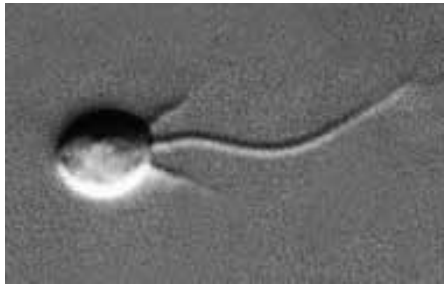


Different routes to insect segmentation

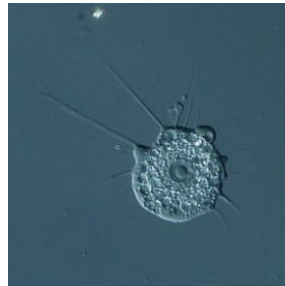


From Forgacs & Newman, *Biological Physics of the Developing Embryo*; 2005. Based on (left) Patel et al., *Nature*; 1994 and (right) Ingham, *Nature*; 1988.

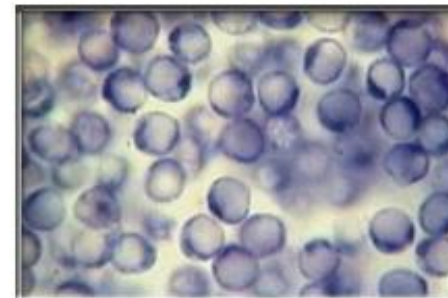
The phylum Choanozoa is a unicellular sister clade of the Metazoa



Monosiga brevicollis



Nuclearia



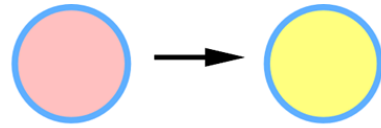
Mesomycetozoea

One or more of the choanozoans (and thus the unicellular ancestor of the Metazoa) contain genes specifying cadherins, C-type lectins, Notch and Hedgehog, members of the metazoan developmental-genetic toolkit.

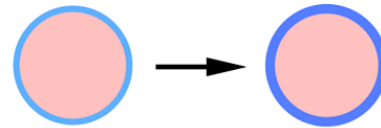
King *et al.*, *Nature* 451:783; 2008

Shalchian-Tabrizi *et al.*, *PLoS ONE* 3:e2098; 2008

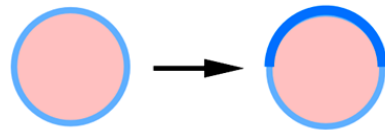
Some single-cell functionalities



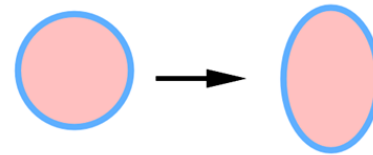
cell type switching



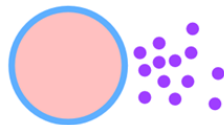
cell surface variation



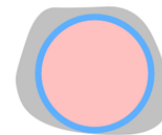
cell surface polarization



cell shape polarization



secretion and release

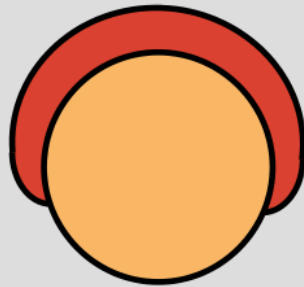


secretion and binding

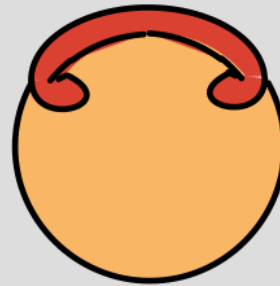


biochemical oscillation

The main types of gastrulation



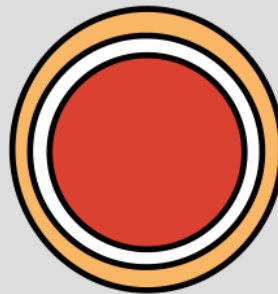
epiboly



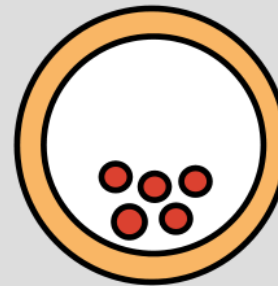
involution



invagination

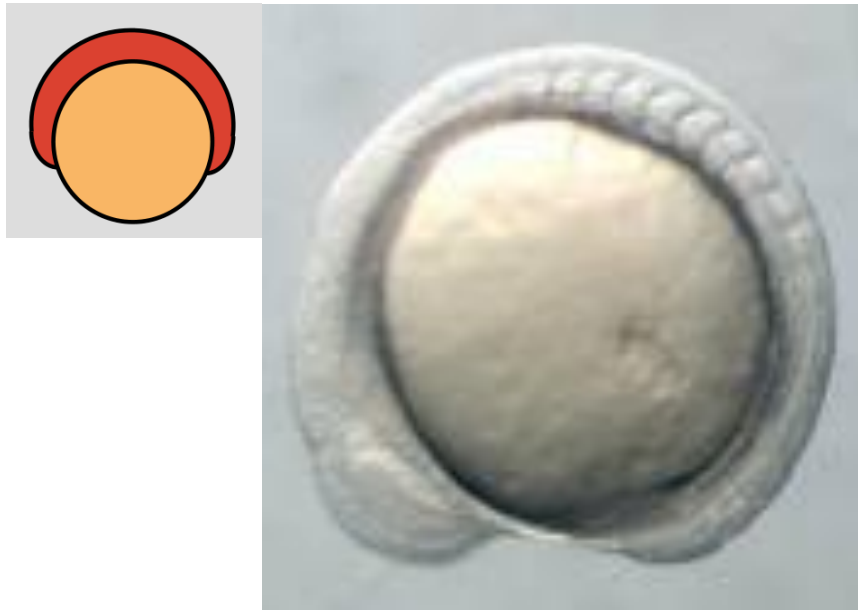


delamination



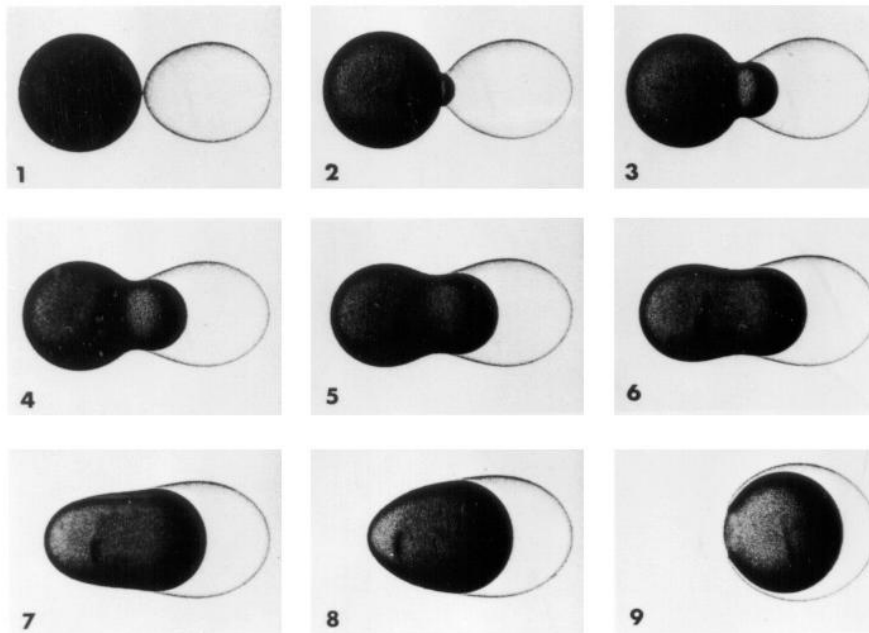
ingression

Gastrulation can involve engulfment-like tissue rearrangement (e.g., zebrafish)

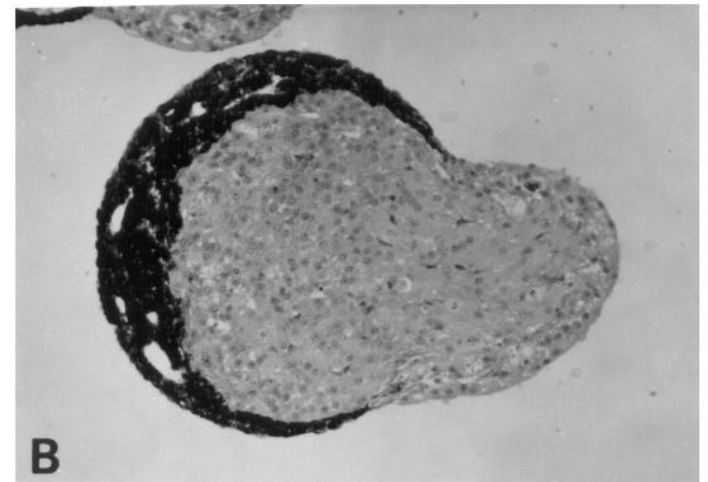


AG Gajewski; University of Cologne

Phase separation and engulfment behavior in liquids and tissues



Torza and Mason *Science* 163: 813; 1969



Armstrong, *Crit Rev Biochem Mol Biol* 24:119; 1989

Differential adhesion of cell subpopulations leads to cell sorting and tissue engulfment

SORTING-OUT



Coalescence



Equilibrium

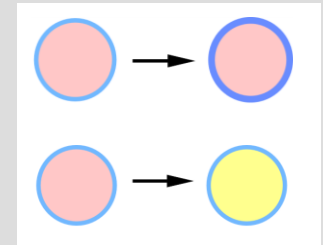
FRAGMENT FUSION



Spreading



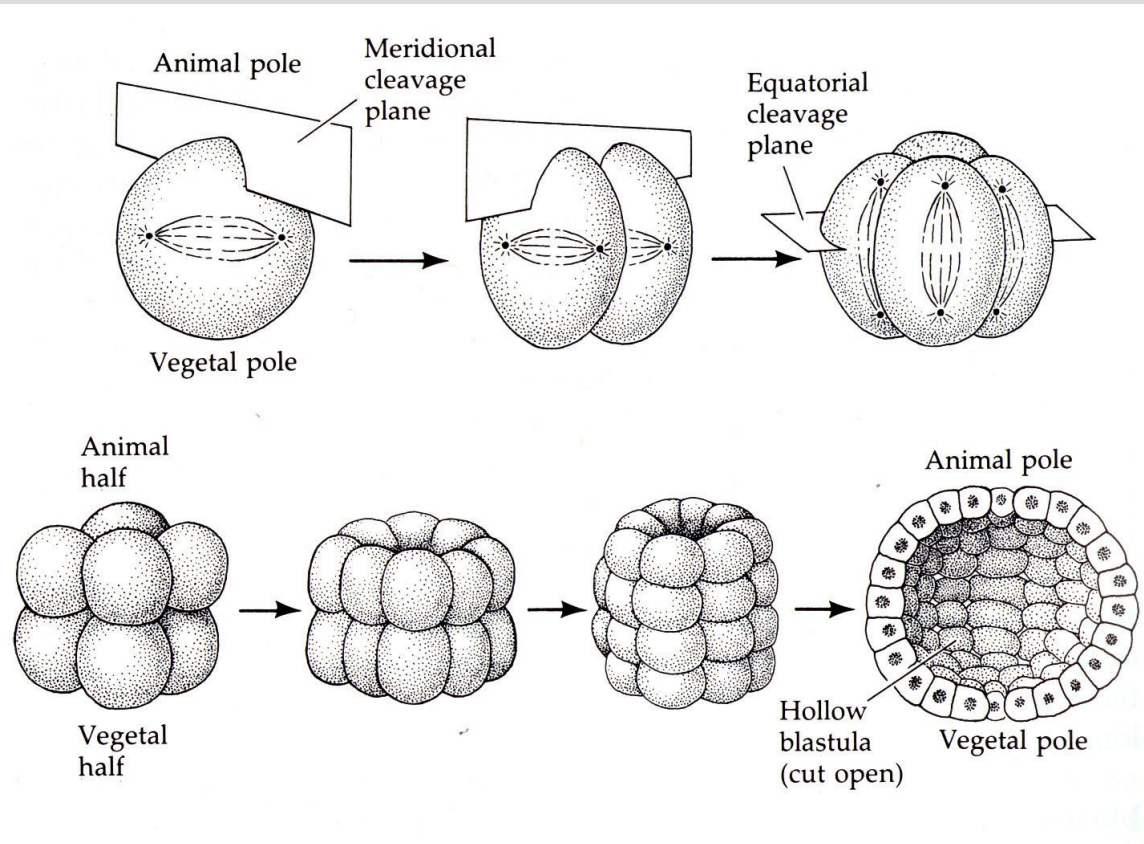
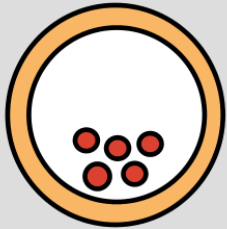
Equilibrium



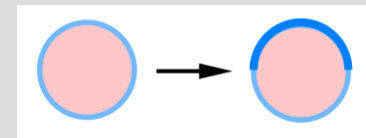
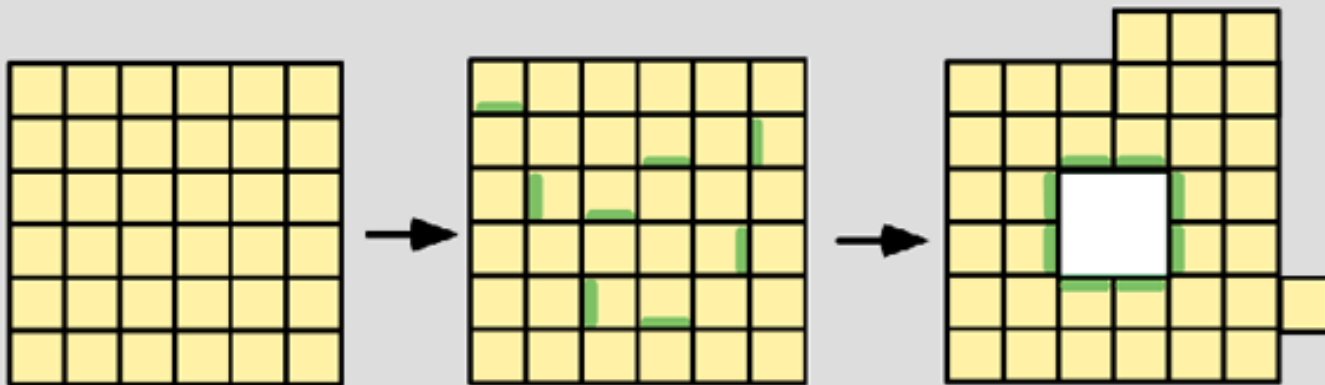
Toolkit
molecules:
cadherins;
lectins; Notch

Based on Steinberg, 1978
See Krieg et al., Nat Cell Biol; 2008

Gastrulation often involves lumen formation (e.g., sea urchins)



Lumens can automatically arise in clusters of cells that are individually apico-basally polarized



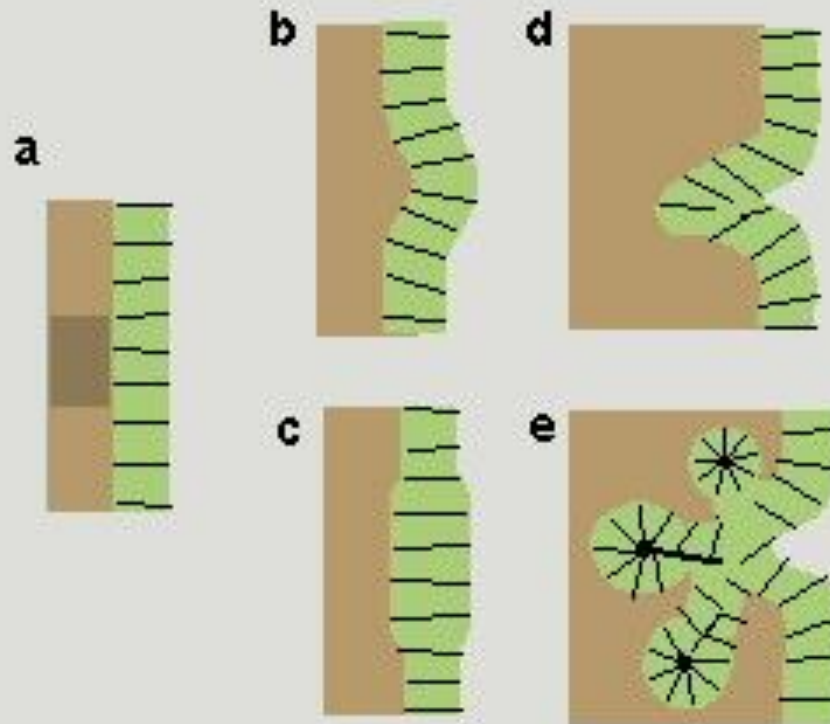
Toolkit
molecules:
Wnt pathway

Gastrulation can involve buckling-like movements of tissue sheets (e.g., *Drosophila*)



Leptin, *In* Keller et al, eds.,
Gastrulation, Plenum; 1991

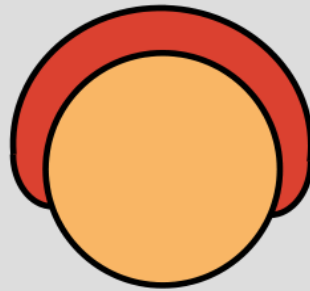
Epithelial morphogenesis by position-dependent modulation of stiffness and viscoelasticity (e.g., buckling)



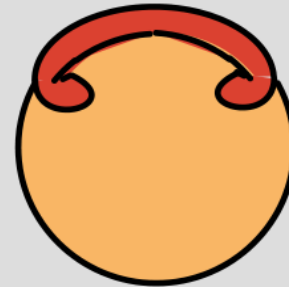
Toolkit
molecules:
collagen and
other ECM
molecules

Theory in: Gierer, *Q. Rev. Biophys.*; 1977;
Mittenthal and Mazo, *J. Theor. Biol.*; 1983

Plausible physical bases of origination of gastrulation: differential adhesion (phase separation and engulfment), \pm cell polarity, \pm epithelial folding



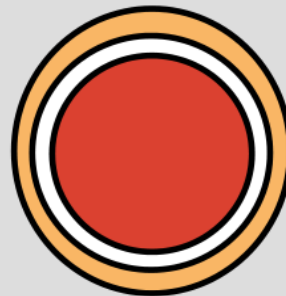
epiboly



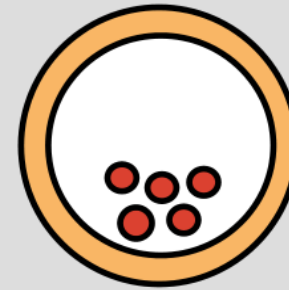
involution



invagination

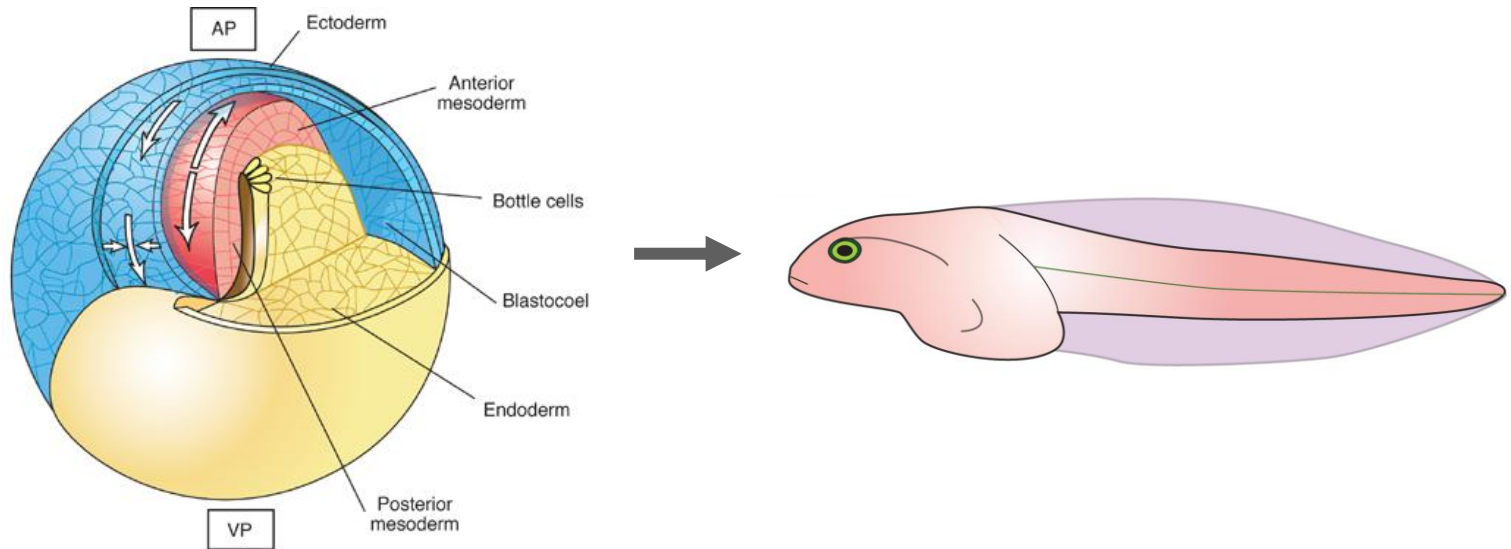


delamination



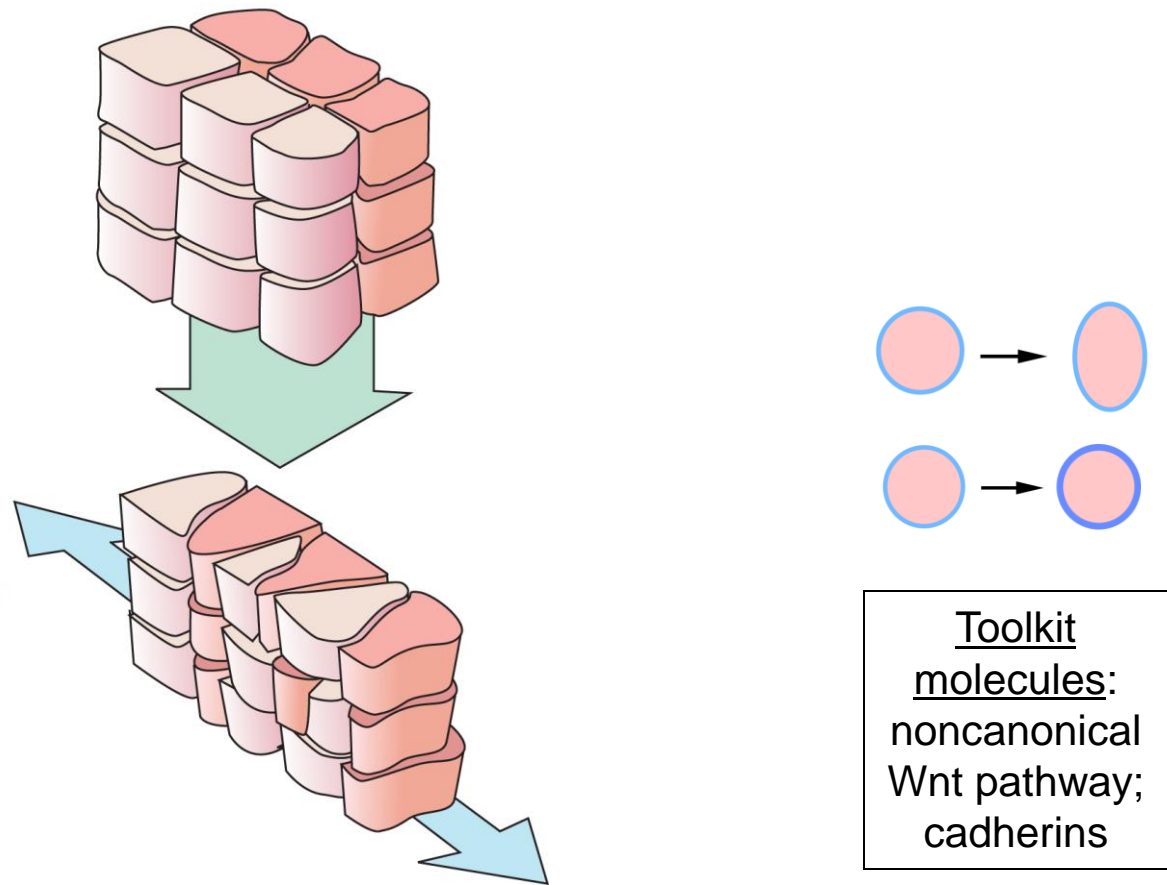
ingression

Embryos typically undergo elongation
(e.g., gastrulation, germ band extension)



Forgacs & Newman, *Biological Physics of the Developing Embryo*; 2005
(after Keller et al., 2000)

Tissue narrowing and elongation can arise from intercalation of (planar) polarized cells



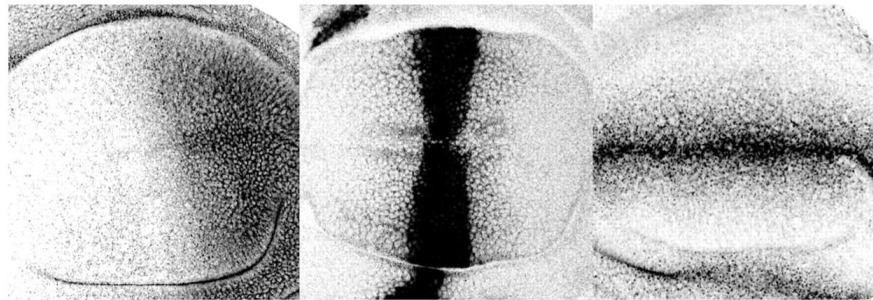
Forgacs & Newman, *Biological Physics of the Developing Embryo*; 2005 (After Keller et al.)

Morphogen gradients

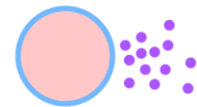
Hedgehog (~Shh)

Dpp (~BMP)

Wg (~Wnt)



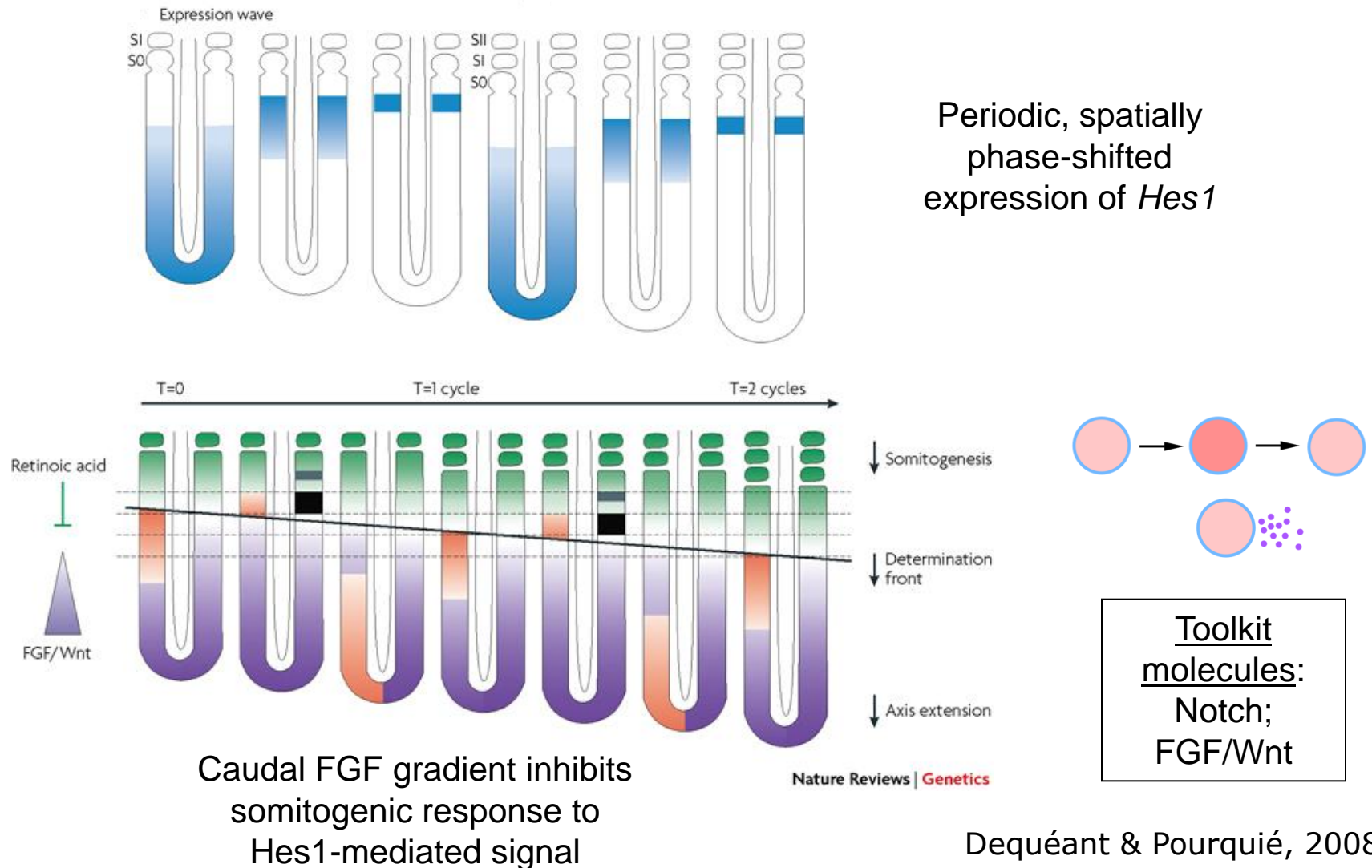
Drosophila imaginal disks

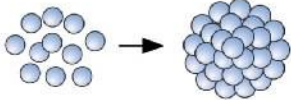
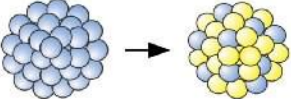
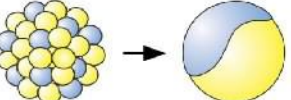
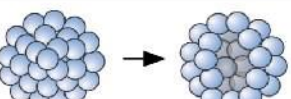
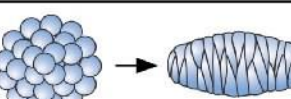
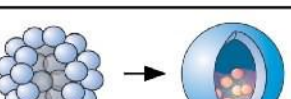
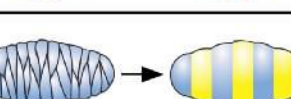
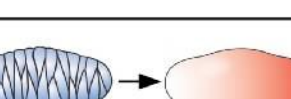
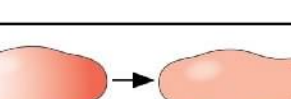


Tabata and Takei; *Development*, 2004

Toolkit
molecules:
Hh; FGF; Wnt;
BMP/TGF β

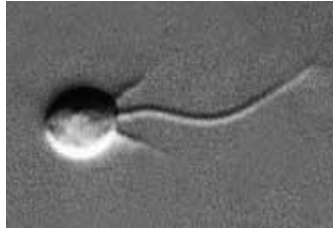
Somitogenesis results from synchronized biochemical oscillation interacting with a molecular gradient



DPM	molecules	physics	evo-devo role	effect
ADH	cadherins	adhesion	multicellularity	
LAT	Notch	lateral inhibition	coexistence of alternative cell states	
DAD	cadherins	differential adhesion	phase separation; tissue multilayering	
POL _a	Wnt	cell surface anisotropy	topological change; interior cavities	
POL _p	Wnt	cell shape anisotropy	tissue elongation	
ECM	chitin; collagen	stiffness; dispersal	tissue solidification; elasticity; EMT	
OSC	Wnt + Notch	synchrony of oscillation	morphogenetic fields; segmentation	
MOR	TGF- β /BMP; FGF; Hh	diffusion	pattern formation	
TUR	MOR + Wnt + Notch	dissipative structure	segmentation; periodic patterning	

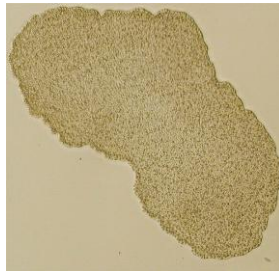
Presence of DPM-associated toolkit genes in choanozoans and metazoans

Choanozoa:
(unicellular sister
clade of Metazoa)



ADH; DAD: cadherins; C-type lectins
LAT: Notch (only some species)
MOR: Hh
ECM: collagen

All of above, plus
POL: Wnt
no Notch



Placozoa Porifera
("basal"
metazoans)



All of above, plus
MOR: TGF- β
POL: Wnt

Cnidaria:
(eumetazoans)



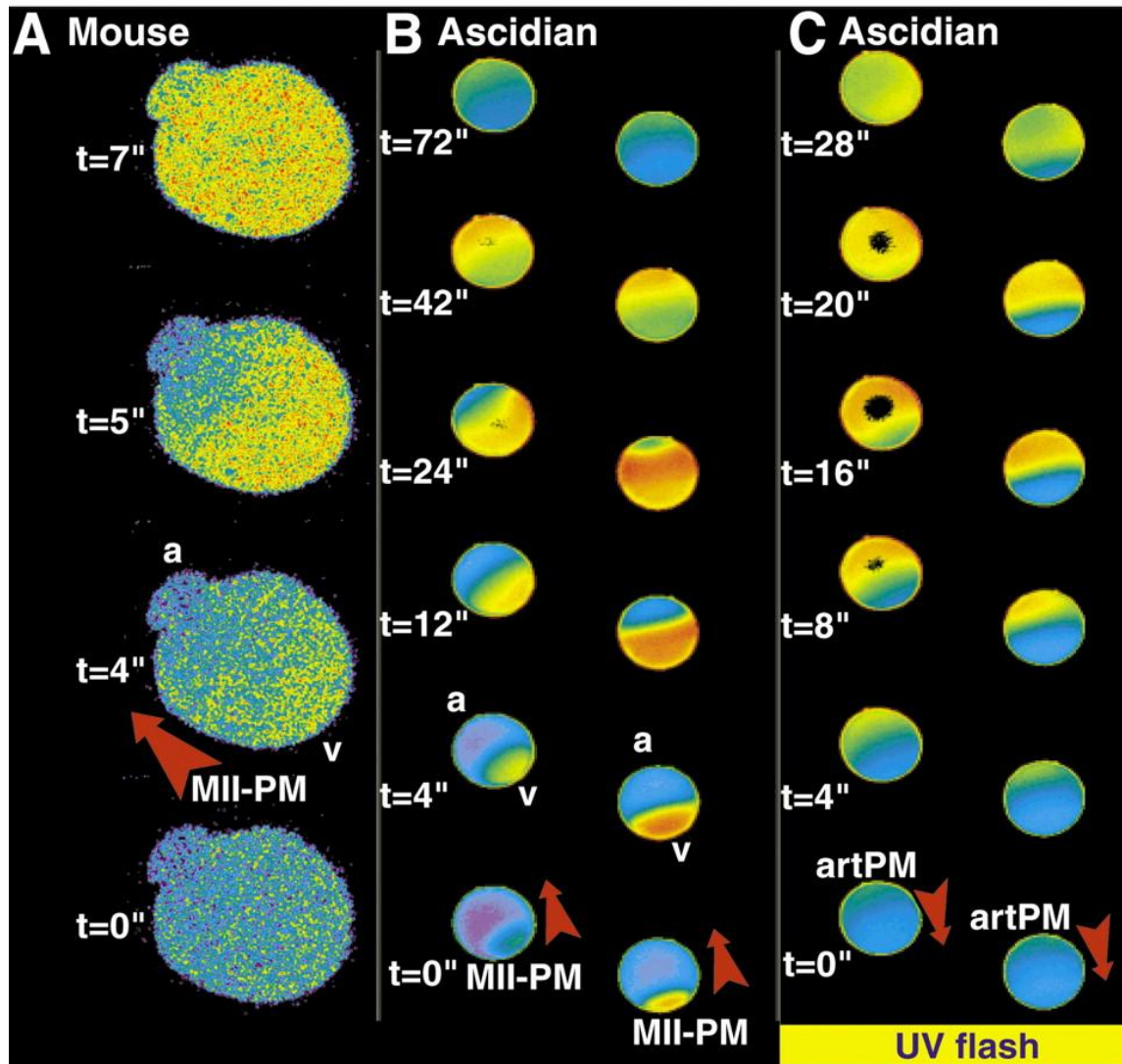
All of the above, plus
MOR: FGFs

Different combinations
of non-collagenous
ECM and matricellular
proteins

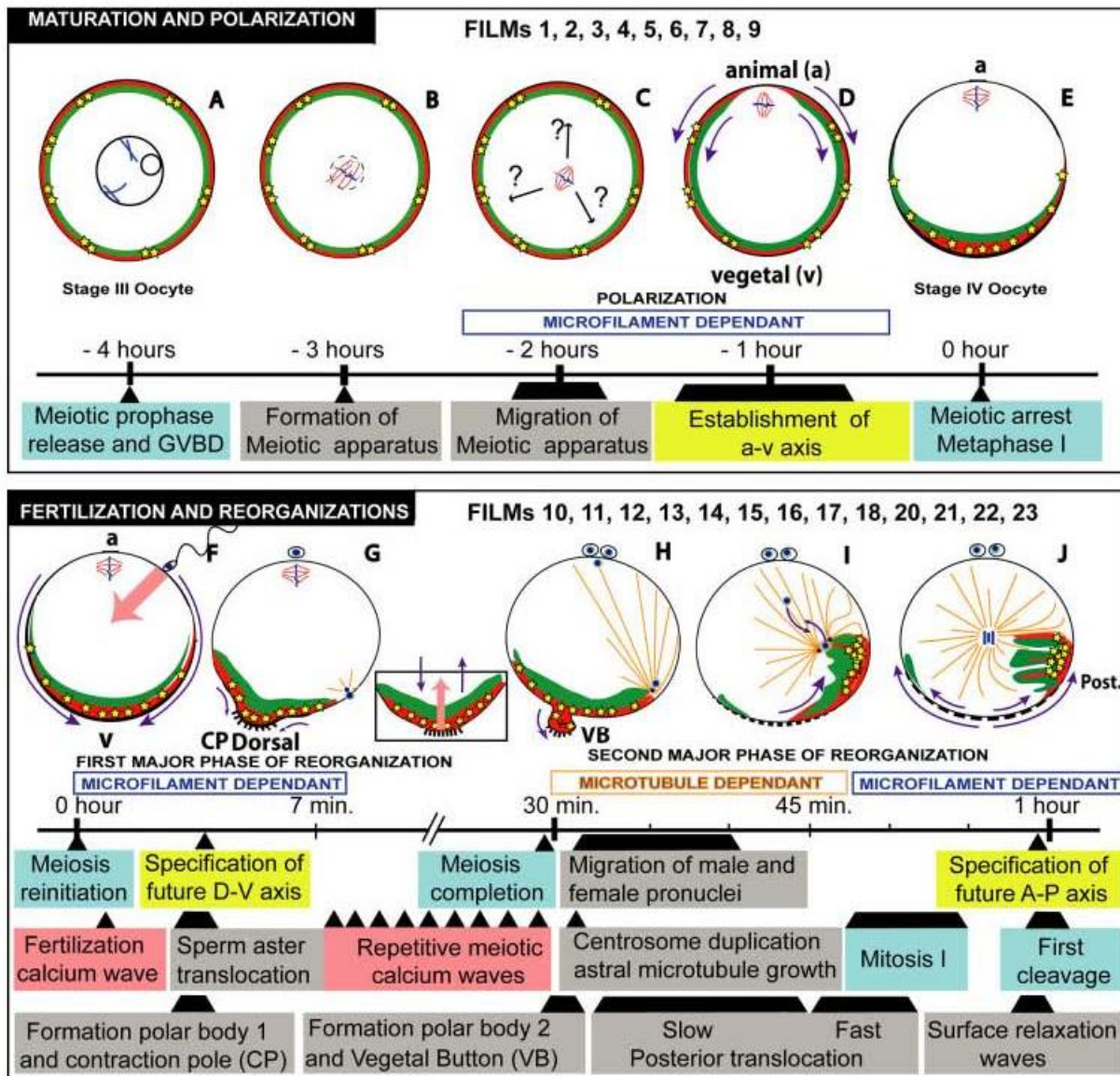
Arthropods; chordates:
(Bilateria)



All of the above

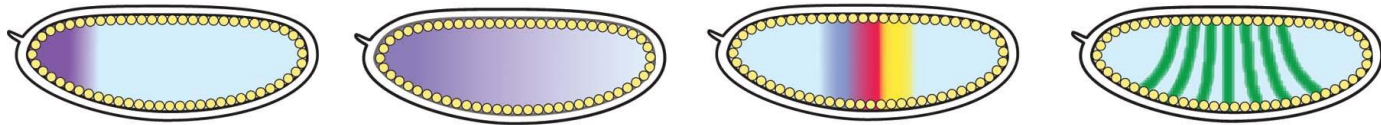


From Dumollard et al. *J. Cell Sci.*; 2002

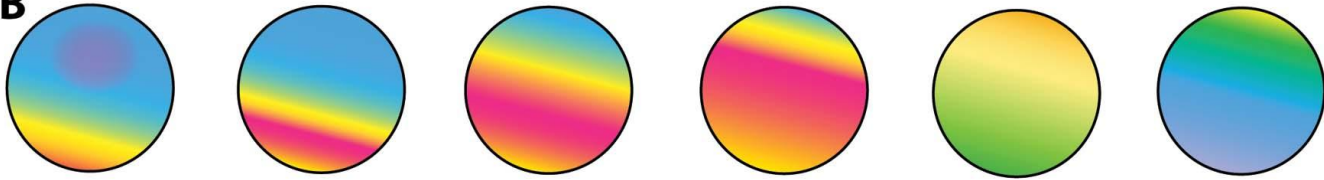


Examples of Egg-Patterning Processes (EPPs)

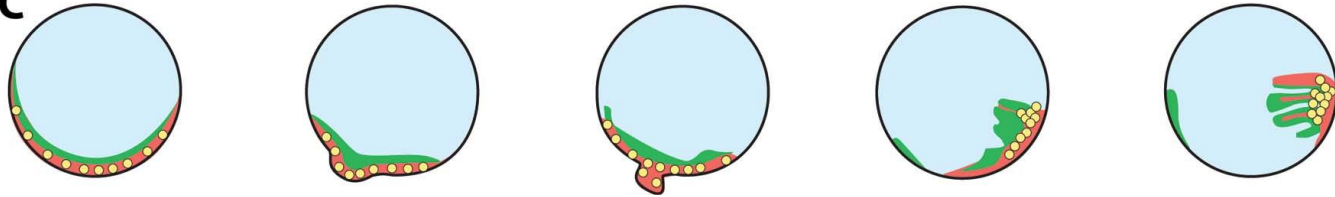
A



B



C



Two models for the embryonic hourglass

