Microtubules and Left/Right Asymmetry of Amphibian Embryos

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Avatar: Paleo Darwin

International Embryo Physics Course

http://slurl.com/secondlife/Owlet/147/164/119/?title=SBR%20Embryo%20Course

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The Problem of Left/Right Asymmetry

Jackson Beardy - Life and Art by Kenneth James Hughes

TABLE OF CONTENTS:

Hughes, K.J. (1979). *Jackson Beardy - Life and Art. Winnipeg, Canadian Dimension Publishers & J. Lorimer.*

Loons IV by Jackson Beardy

http://www.eastudiosjasper.com/by_artist/beardy/bigpics/nsloons_IV.html

Left Side: Meet My Right Side

- One classical experiment done by photographers was to take a front on picture of a person, split it down the middle, and make mirror images of each half. Nowadays those of us inept with darkroom chemicals can do this easily with a digital camera and an image processing program. The result: each of us has two entirely different personalities: our left side and our right side.

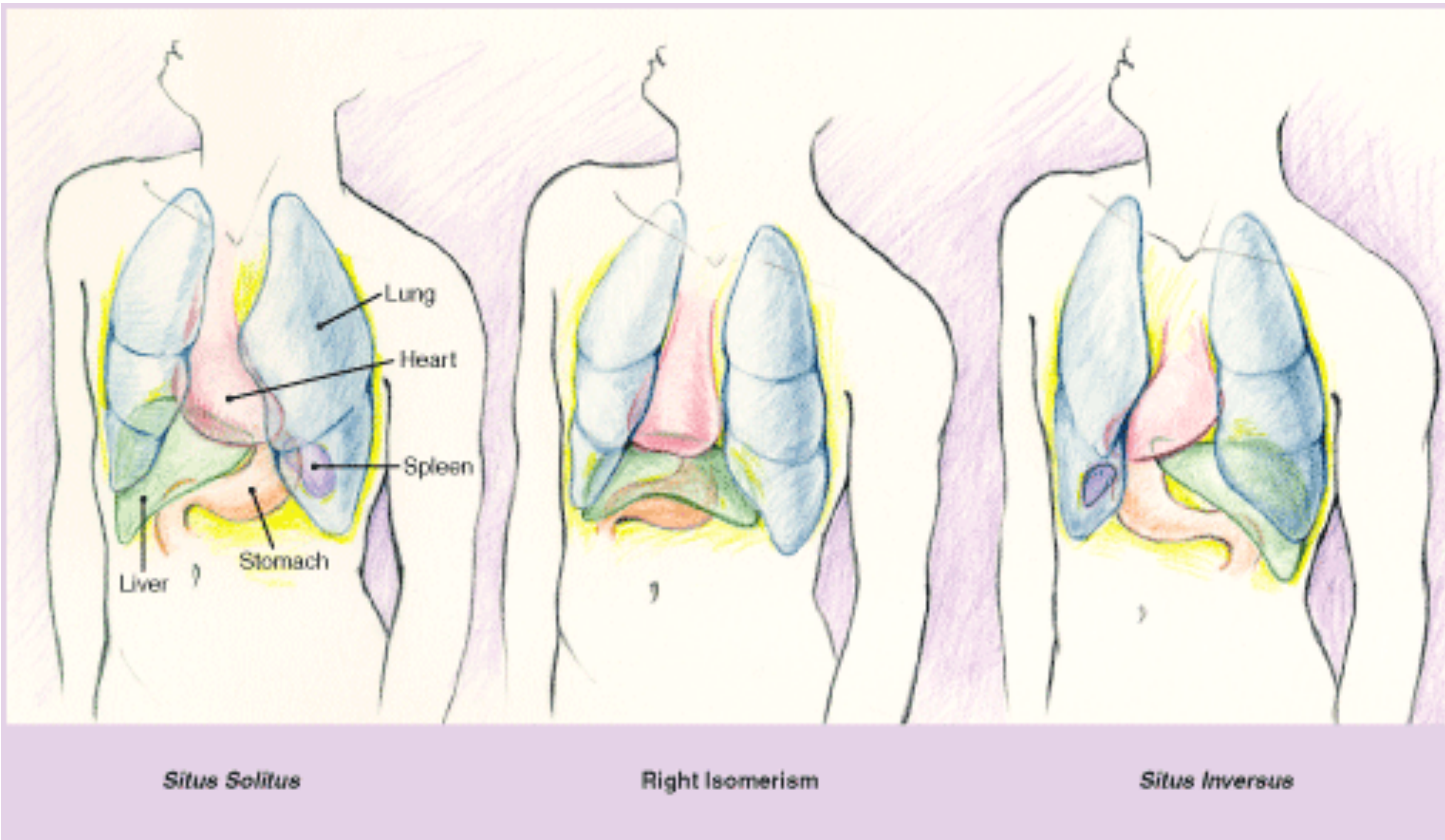
The two sides of my friend and colleague, David Hoult, with whom I've worked on:

Tomanek, B., D.I. Hoult, X. Chen & R. Gordon (2000). A probe with chest shielding for improved breast MR imaging. *Mag. Res. Med.* **43**(6), 917-920.

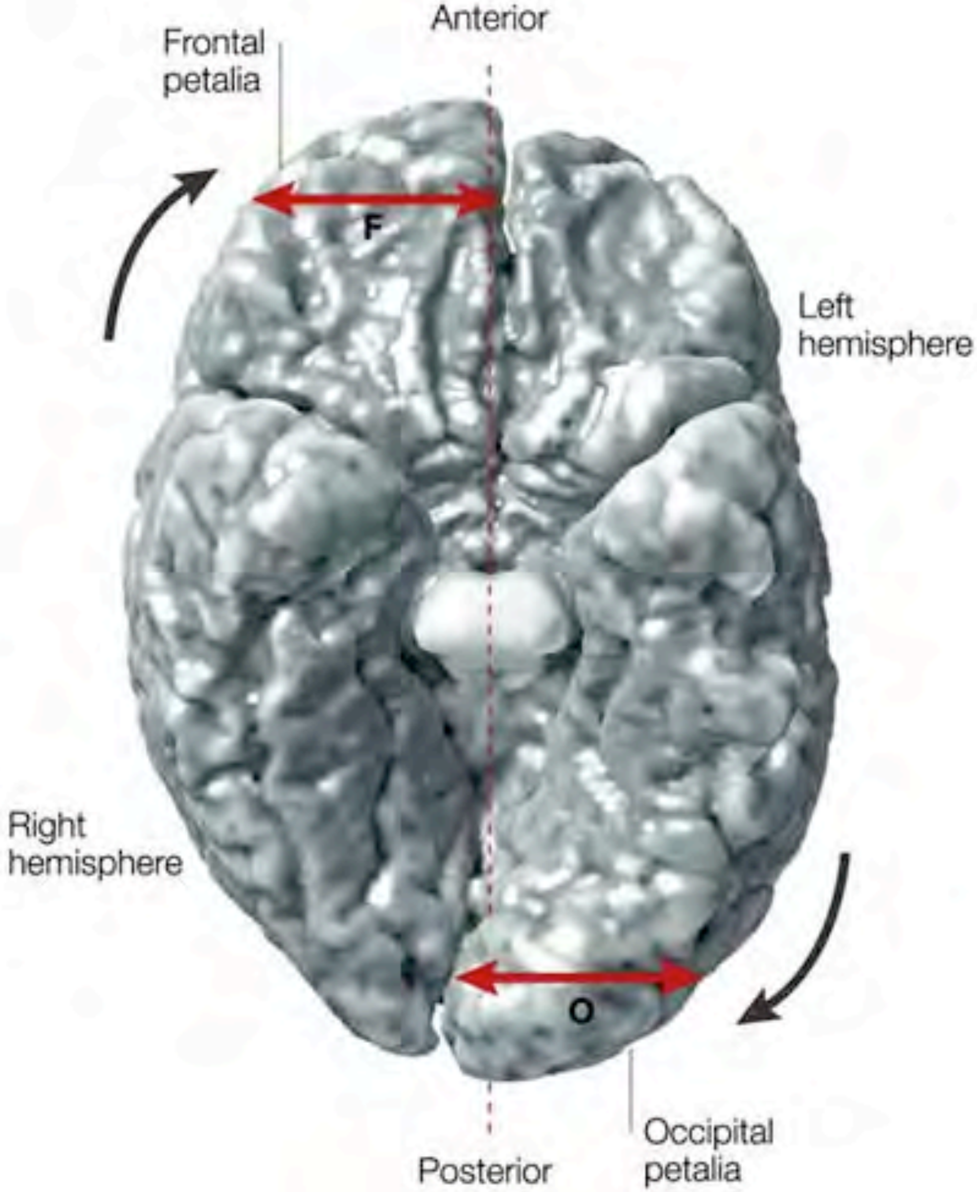
Left Side: Meet My Right Side

- The point of this exercise is that even on the outside, our left and right sides are different. Lest you think that this has an “environmental explanation”, just compare your fingerprints for corresponding fingers or your thumbs. No, we believe that the genomes in cells on our left and right sides are identical, yet anatomically we come out different left and right. This proves that genetic determinism does not work.

L/R Asymmetry of Internal Organs



R&D Systems. (2003). TGF-beta ligands in left-right development.
http://www.rndsystems.com/mini_review_detail_objectname_MR03_TGF-betaLigands.aspx



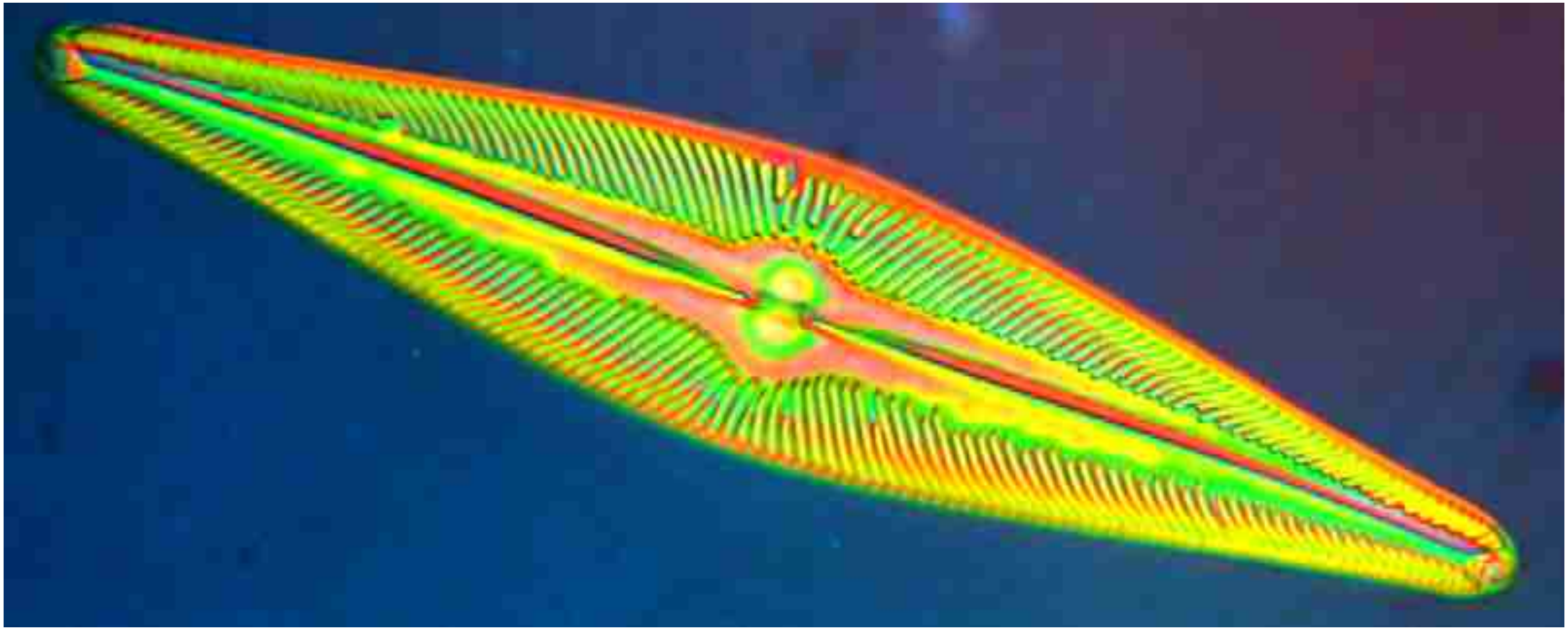
Brain L/R Asymmetry

"Noticeable protrusions of the hemispheres, anteriorly and posteriorly, are observed, as well as differences in the widths of the frontal (F) and occipital (O) lobes.... A twisting effect is also observed, known as Yakovlevian torque.... The left occipital lobe is also splayed across the midline and skews the interhemispheric fissure in a rightward direction." Rendered from a live MRI.

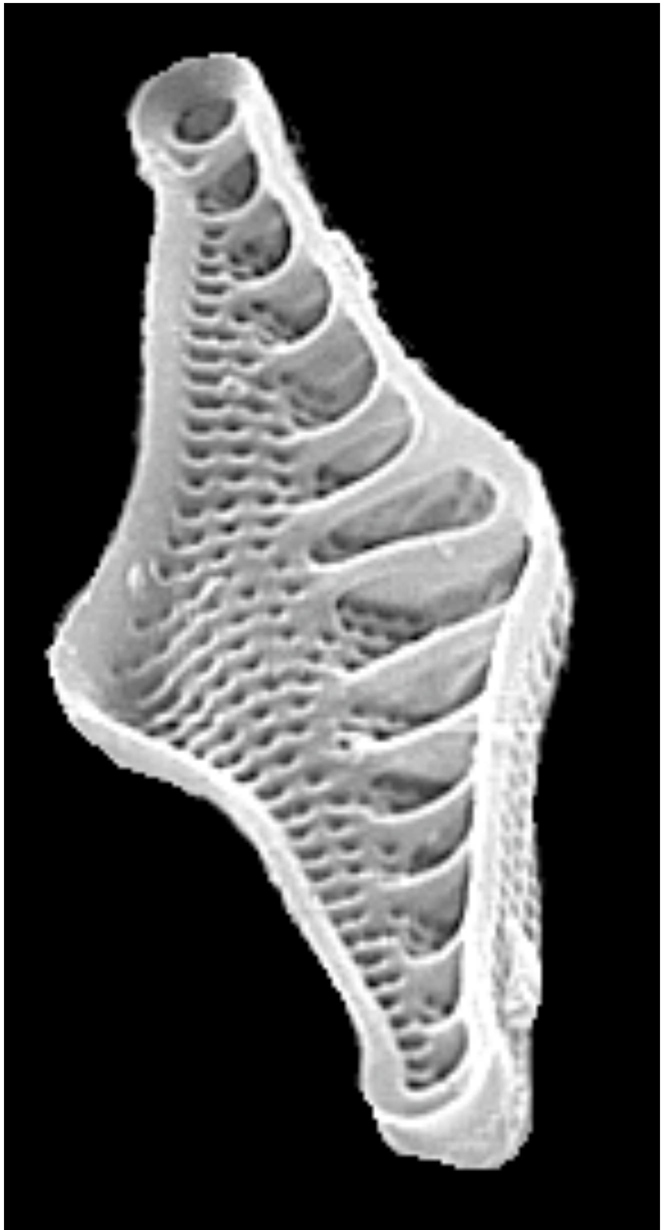
- Toga, A.W. & P.M. Thompson (2003). Mapping brain asymmetry. *Nature Reviews Neuroscience* ***4(1), 37-48.***

Examples of Left/Right Asymmetry

- Single cell microorganisms: pennate diatom *Pinnularia*
- Note L/R asymmetry of midline raphes at ends



Jamin-Lebedeff interference microscopy, Copyright retained, large TIFF file available, Stephen Nagy, M.D., http://montanadiatoms.tripod.comhttp://www.stpetes.org/physicians/physician.php?id=80

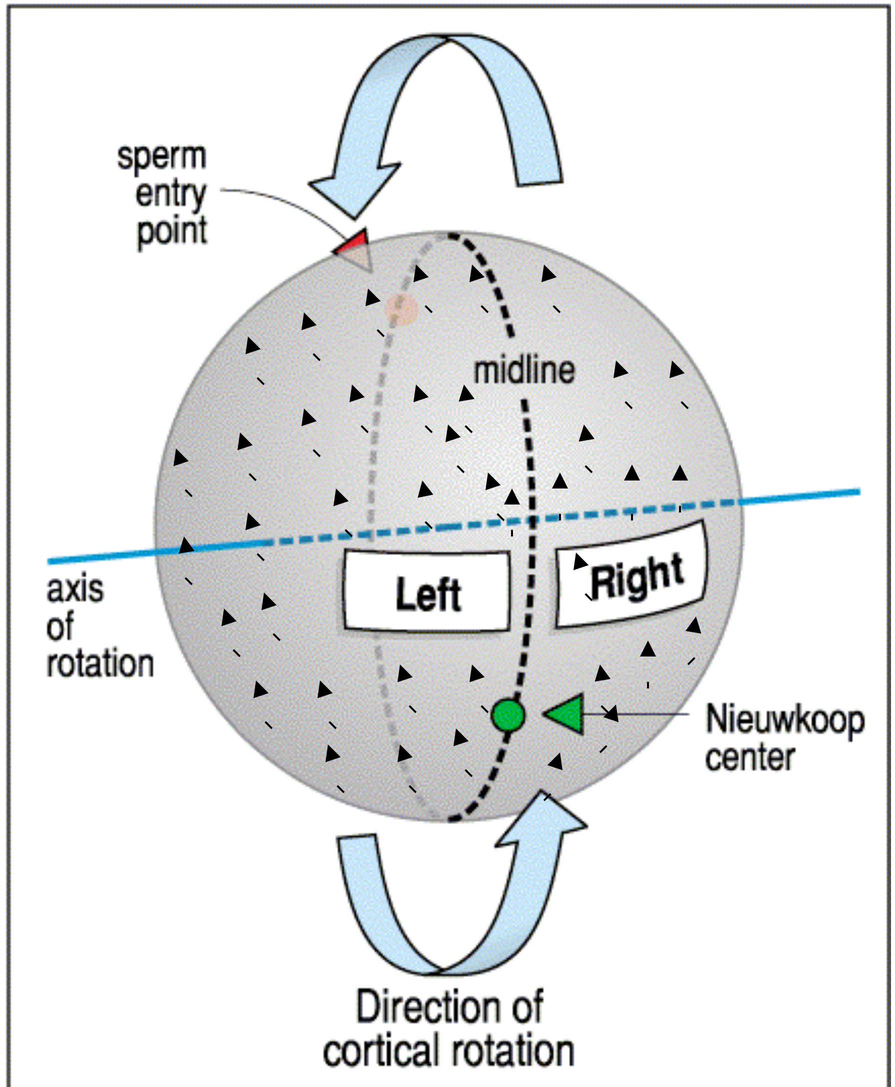


Major L/R Asymmetry

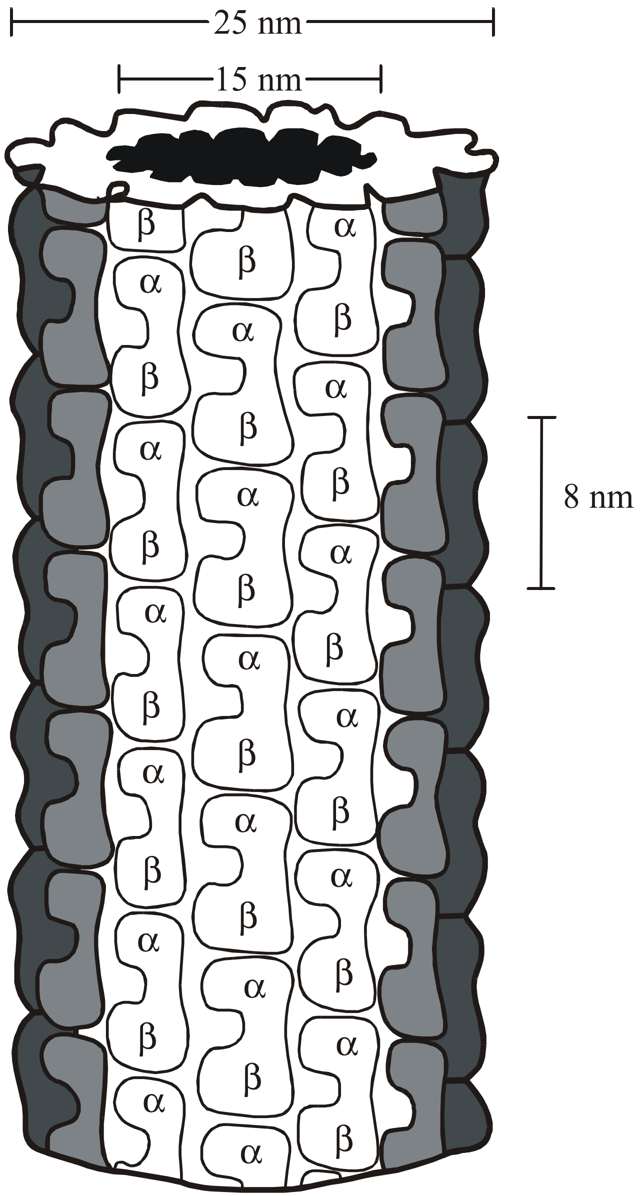
- Inner view of a pennate diatom shell (amorphous silica) showing a major L/R asymmetry:
- *Nitzschia* sp.
- SEM (scanning electron micrograph)
- http://www.bgsu.edu/departments/biology/facilities/algae/SEM/nitz1.gif
- Drum, R.W. & R. Gordon (2003). Star Trek replicators and diatom nanotechnology. *TibTech (Trends in Biotechnology)* ***21(8), 325-328.***

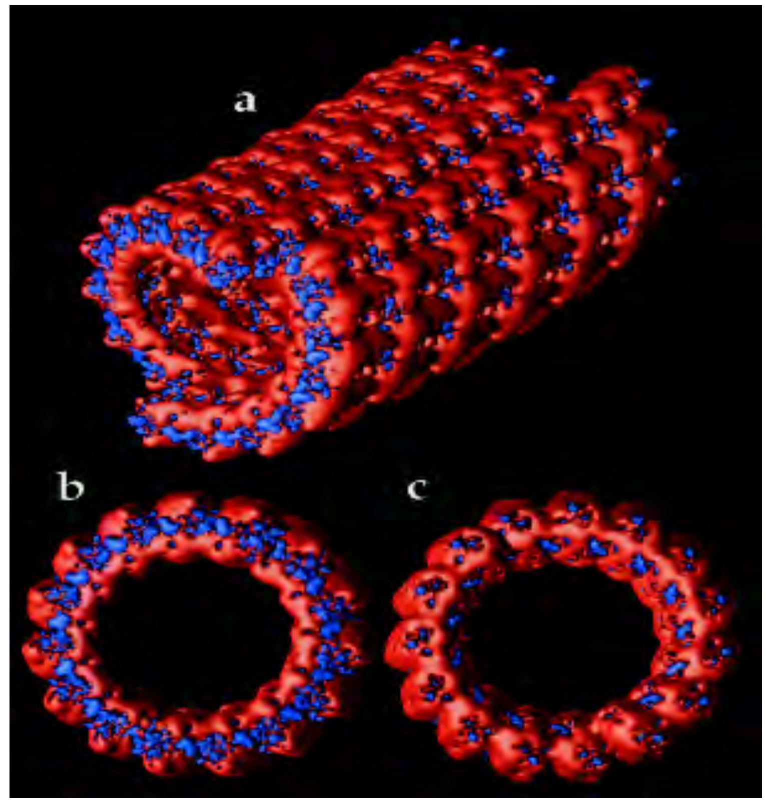
Spherical Ising model with microtubules

Sperm entry point biases direction of cortical rotation to within ±8° in anuran amphibians, such as *Xenopus laevis*, but not in polyspermic Urodele amphibians, such as the axolotl *Ambystoma mexicanum*



Microtubule Chiral Structure



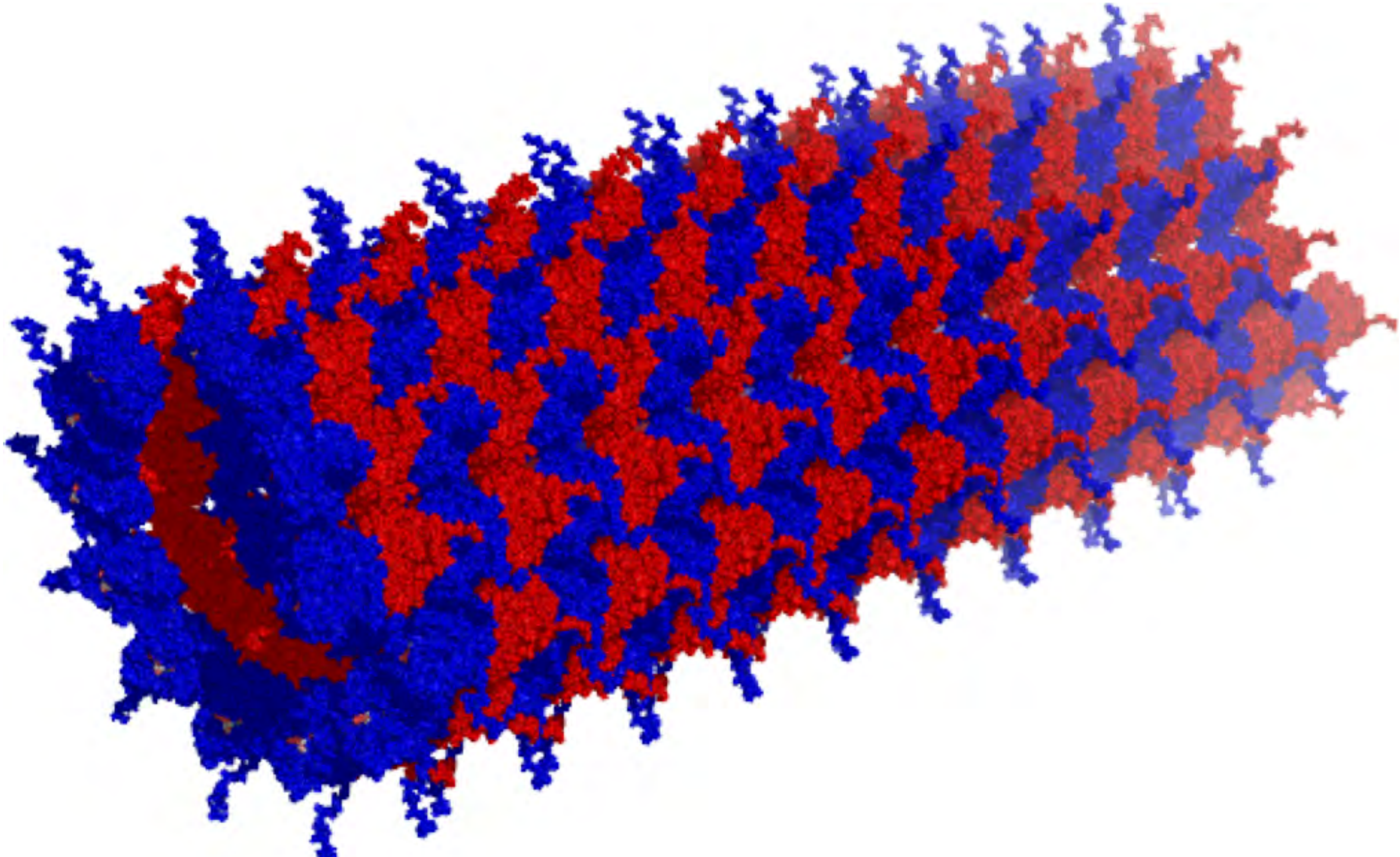


^Baker, N.A., D. Sept, S. Joseph, M.J. Holst & J.A. McCammon (2001). Electrostatics of nanosystems: application to microtubules and the ribosome. *Proc Natl Acad Sci U S A* ***98(18), 10037-10041.***

Microtubules

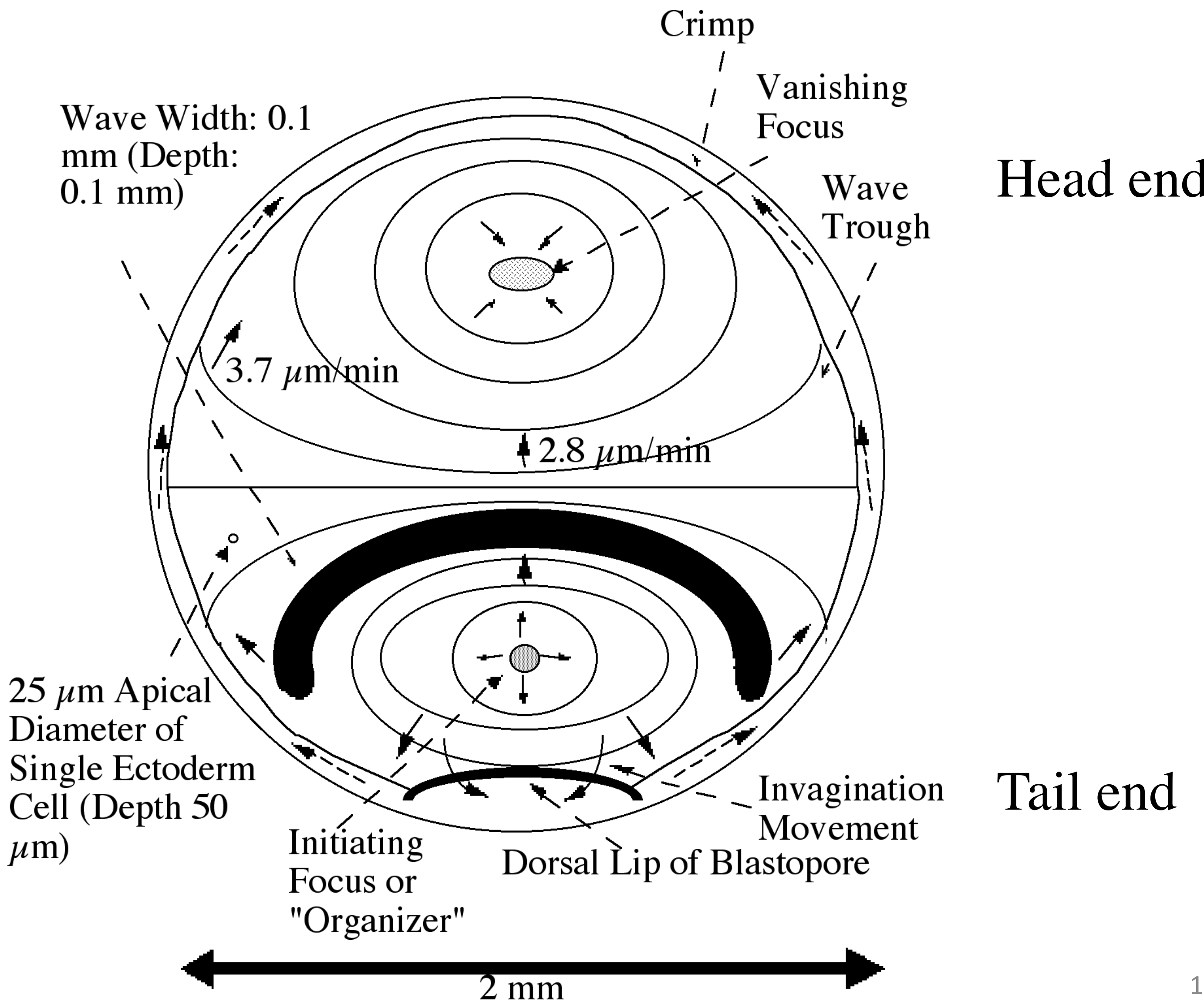
- The tubulin heterodimer is actually only a component of an extremely large protein complex known as the microtubule.
- Microtubules are composed of repeating alpha/beta tubulin dimers, which arrange themselves end to end to form a structure known as a protofilament.
- These protofilaments interact laterally to then form a tube, known as a microtubule, which has a diameter of approximately 25 nanometers.
- This reconstruction of a microtubule contains 10 alpha/beta heterodimers per protofilament and the 13 protofilaments that are found within a canonical microtubule. Just for reference, a microtubule that is found within a cell would actually be many orders of magnitude longer than the one depicted here.
- Above by Jack Tuszynski

Microtubule Reconstruction



A Peculiar Trajectory: Why the Wave doesn't Turn the Whole Ectoderm into Brain

Does the invagination movement generate a strain field that restricts the wave to one hemisphere?



Gordon, R., N.K. Björklund & P.D. Nieuwkoop (1994). Dialogue on embryonic induction and differentiation waves. *Int. Rev. Cytol.* 150, 373-420.

Back to Cortical Rotation

- Microtubules consist of a-tubulin and b-tubulin dimers stacked in a helical array that has a polarity and is chiral
- Therefore a microtubule is not its own mirror image
- Let us assume that the apical orientation of the microtubules oriented during cortical rotation is retained during cytokinesis
- Given two cells that are in mirror image positions during early gastrulation, they are therefore *not* mirror images of one

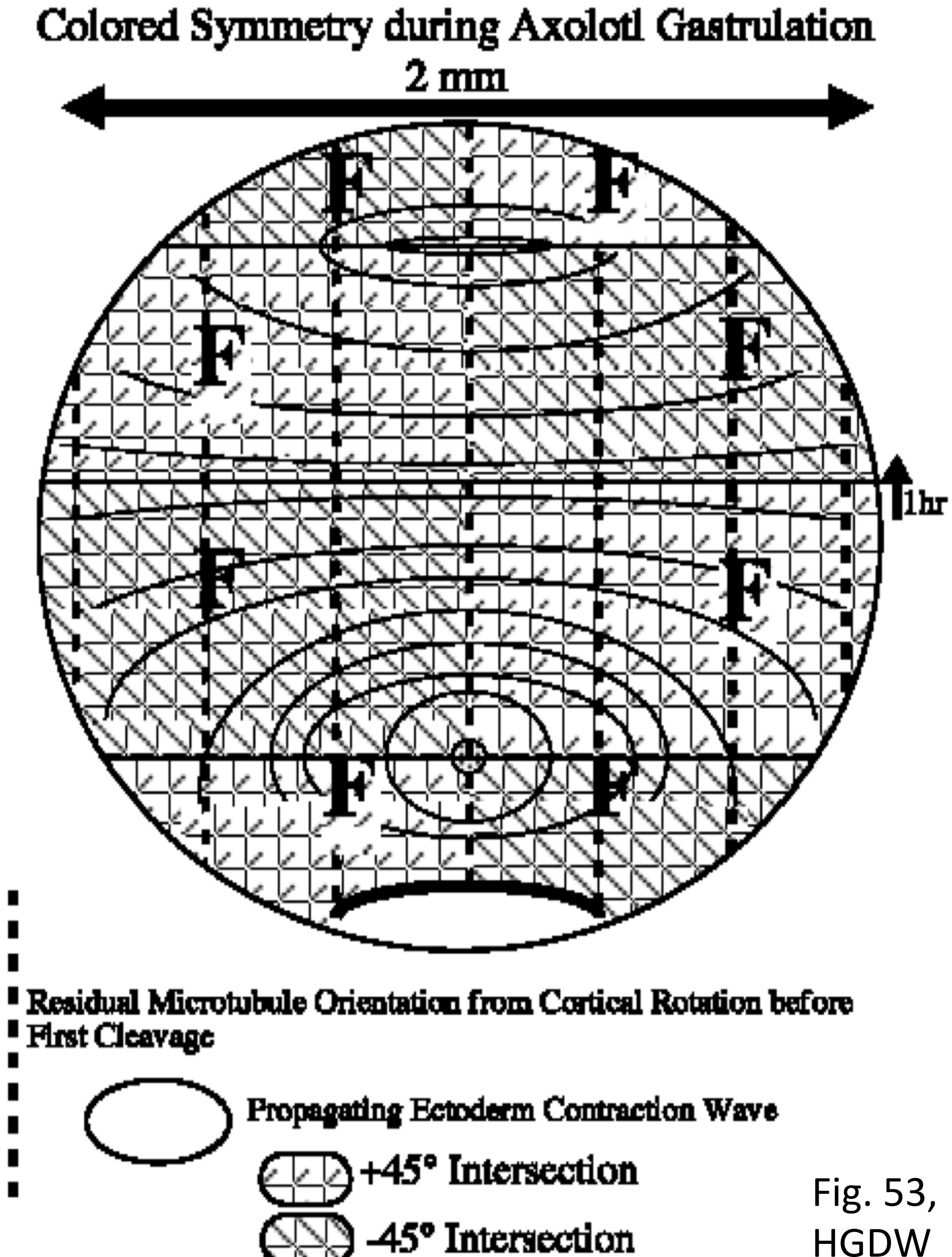
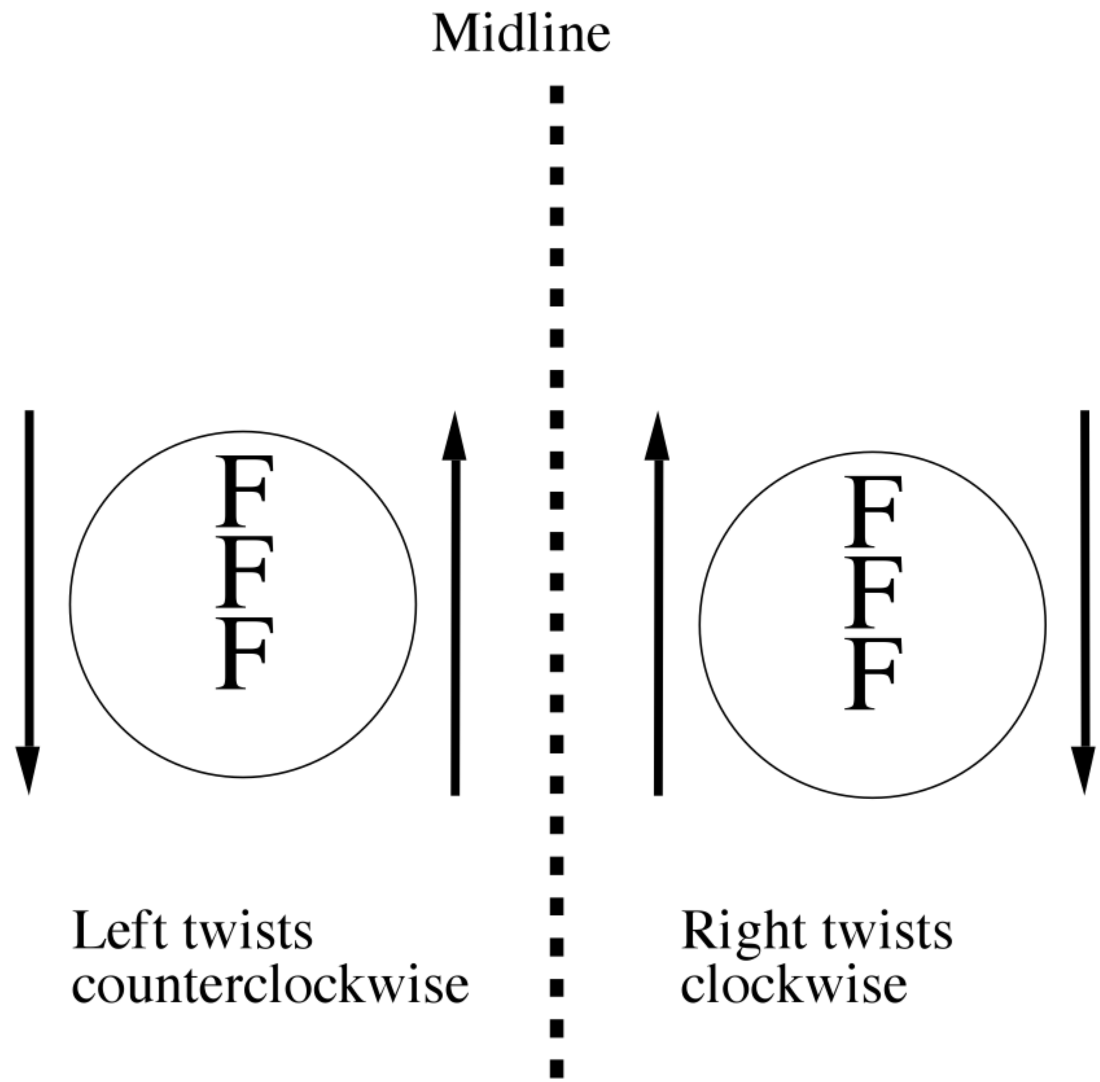


Fig. 53, HGDW

The ectoderm contraction wave is shown, along with parallel, aligned rows of microtubules (FF), whose orientation is presumed to be preserved from the initial cortical rotation. The Fs indicate the handedness of the microtubules. The diagonal shading blocks off regions in which the angle between the microtubules and the advancing wave front is closest to +45° or -45° from the midsagittal plane. Since bilaterally placed regions have opposite shading, this is a case of colored symmetry.

Mechanical Model for Left/Right Asymmetry

- Involution movement during early gastrulation generates a nonuniform strain state in the ectoderm
- This produces a torque on each cell
- Fig. 54 HGDW



Mechanical Model for Left/Right Asymmetry

- The torque adds to the supercoiling on one side and subtracts on the other
- A polymerizing microtubule therefore has a different degree of supercoiling from a microtubule in its mirror image position
- Dynein binds to one supercoiled state, but not the other
- Free/bound dynein -> different subsets of gene expression left/right
- Fig. 55 HGDW

Reference

- Gordon, R. (1999). The Hierarchical Genome and Differentiation Waves: Novel Unification of Development, Genetics and Evolution, Singapore & London: World Scientific & Imperial College Press. US$99, http://www.worldscibooks.com/books/lifesci/2755.html, 2 vols., 1836p.