



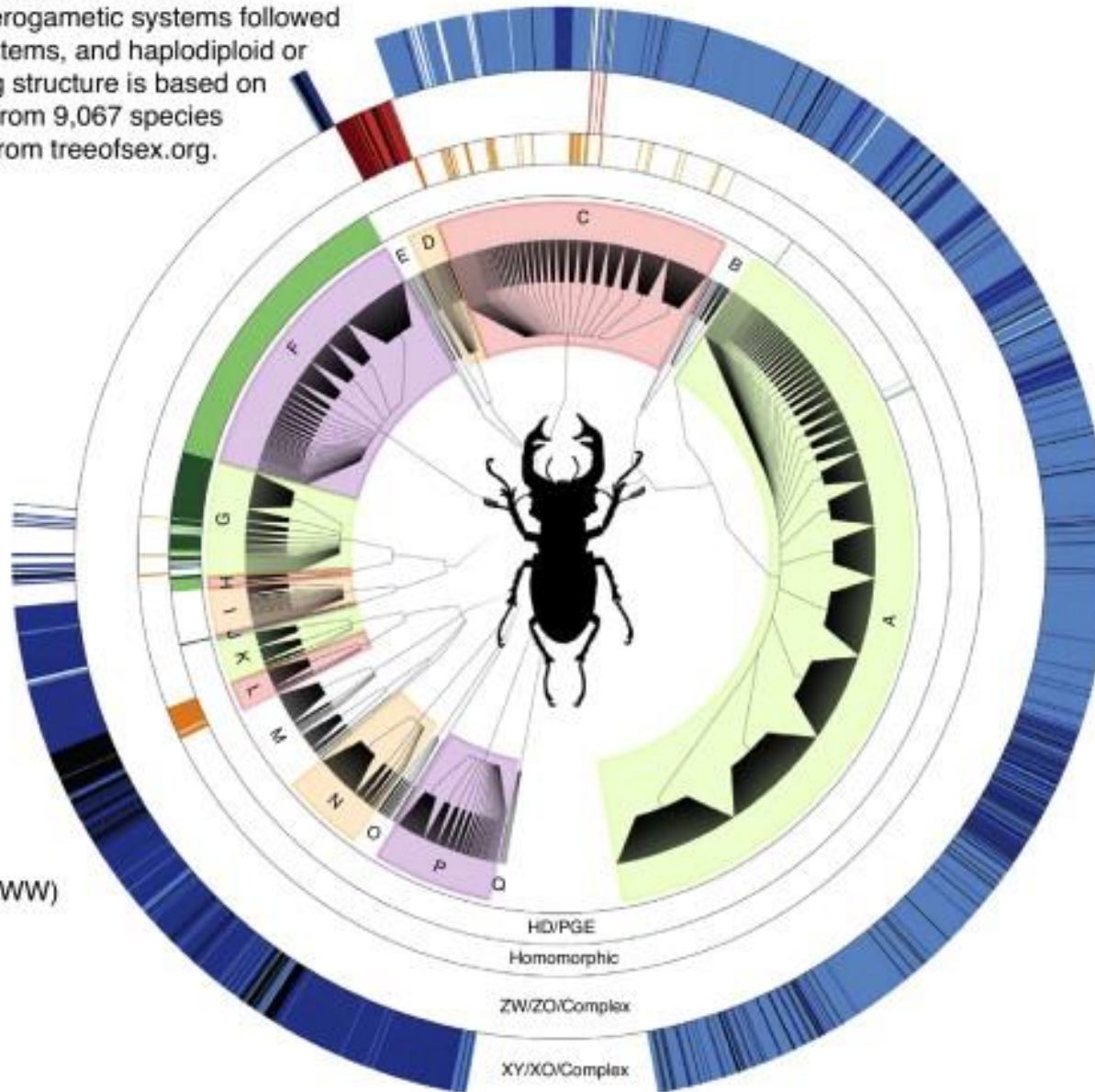
Определение пола у насекомых: История одного заблуждения

— Ты мальчик или девочка?
— Я ещё не определился.
© Д.Пучков «Две сорванные башни»

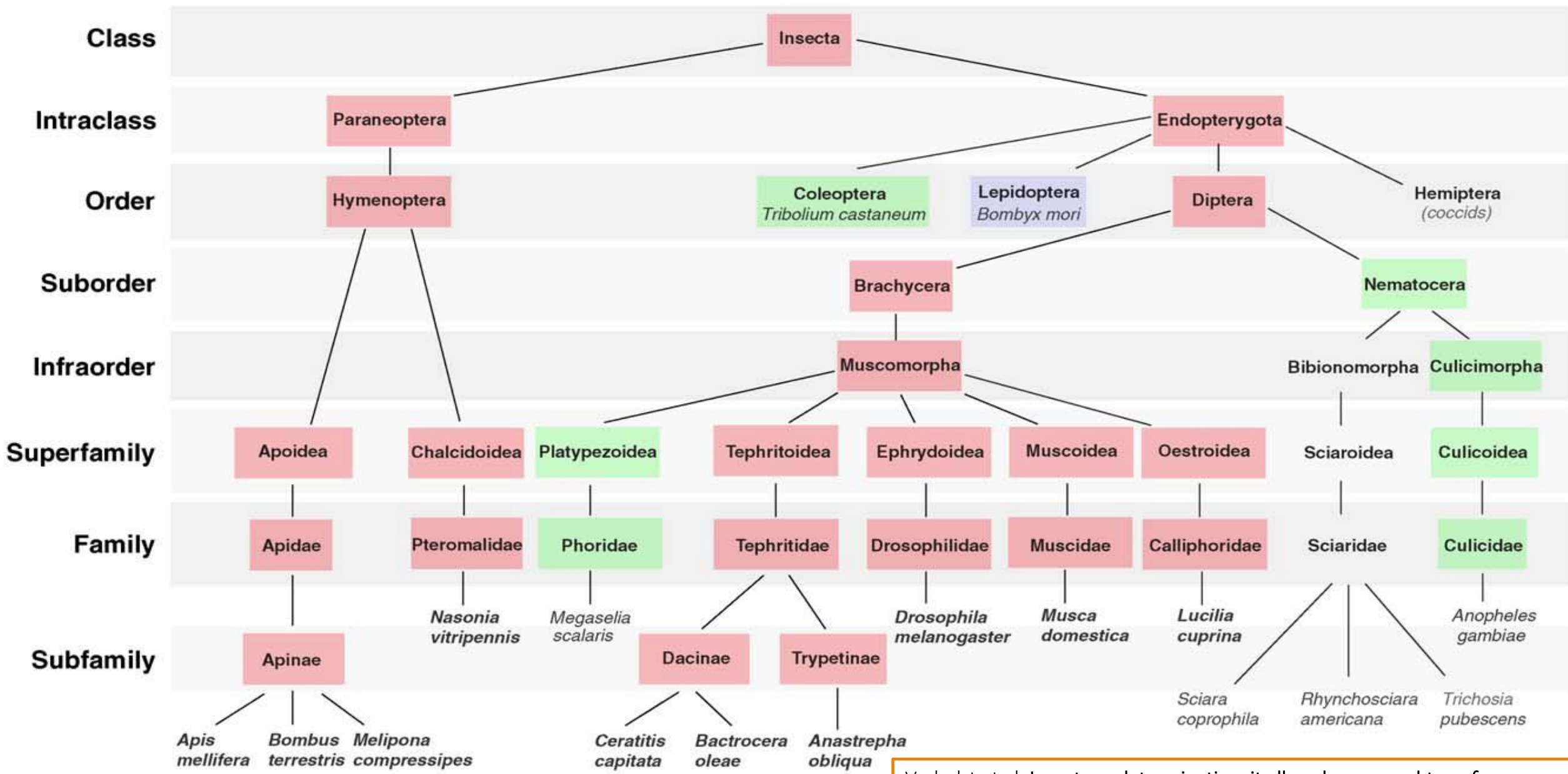
Genus level distribution of sex determination characteristics in insects. The colored bars indicate the presence of a character in a genus. The exterior ring indicates male heterogametic systems followed by female heterogametic, homomorphic systems, and haplodiploid or paternal genome elimination. The branching structure is based on taxonomy and the figure incorporates data from 9,067 species representing 2725 genera. Data available from treeofsex.org.

- | | |
|----------------|-----------------|
| A Coleoptera | J Phthiraptera |
| B Megaloptera | K Blattodea |
| Neuroptera | L Isoptera |
| Raphidioptera | M Embiidina |
| Strepsiptera | Grylloblata |
| C Diptera | Mantodea |
| D Lepidoptera | Phasmatodea |
| E Mecoptera | N Orthoptera |
| Siphonaptera | O Dermaptera |
| Trichoptera | Plecoptera |
| F Hymenoptera | Zoraptera |
| G Hemiptera | P Odonata |
| H Thysanoptera | Q Ephemeroptera |
| I Psocoptera | Zygentoma |

- XY
- XO
- ZW
- ZO
- Multiple XY; Multiple ZW (e.g. XXXY, ZWW)
- Haplodiploidy
- Paternal Genome Elimination



Blackmon H., Demuth J.P., **Genomic origin of insect sex chromosomes.** *Current Opinion in Insect Science* 2015, 7:(45-50)

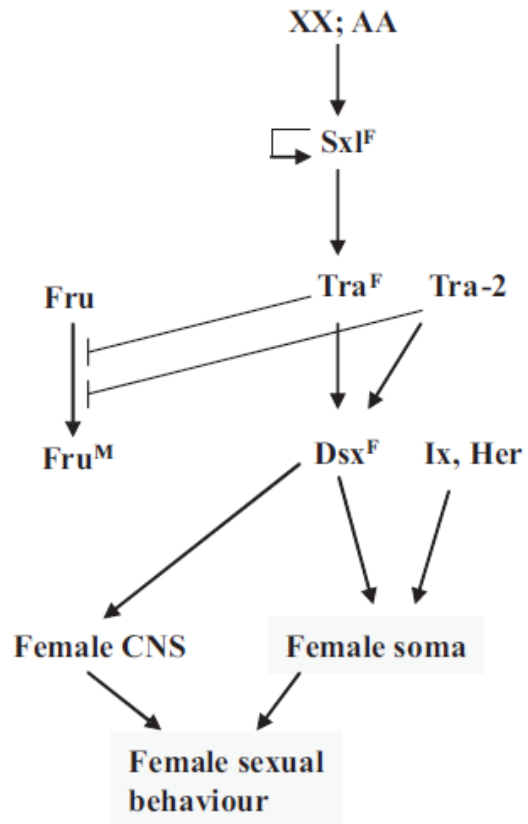


Verhulst et al. Insect sex determination: it all evolves around *transformer*.
Current Opinion in Genetics & Development 2010, 20:376–383

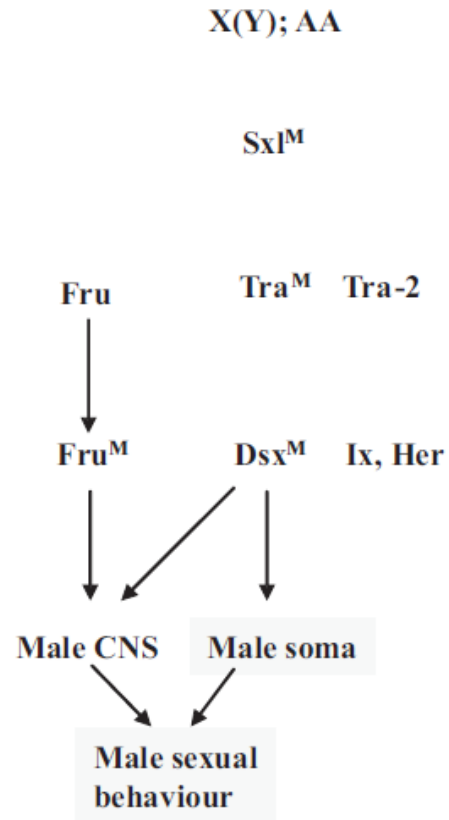
Drosophila melanogaster, Drosophilidae



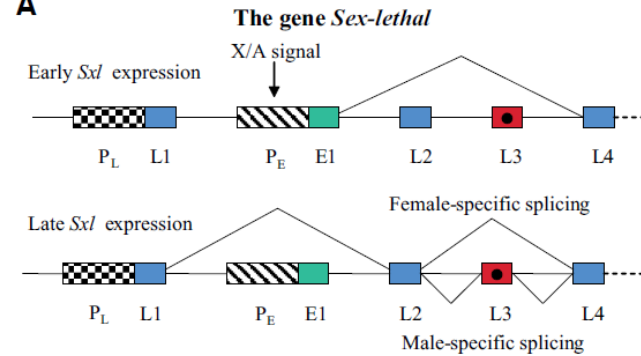
Femaleness



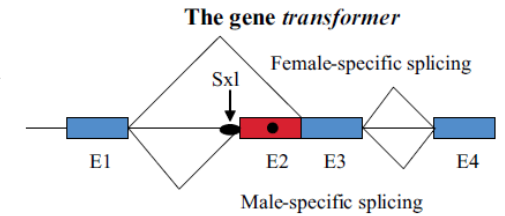
Maleness



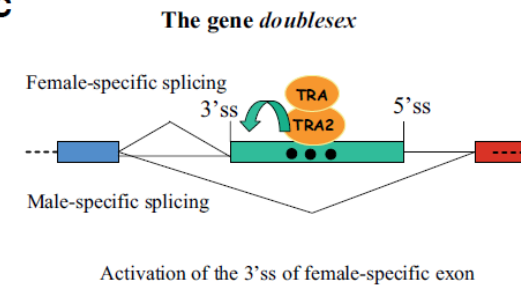
A



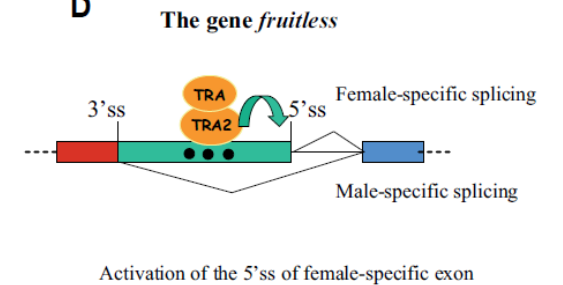
B



C



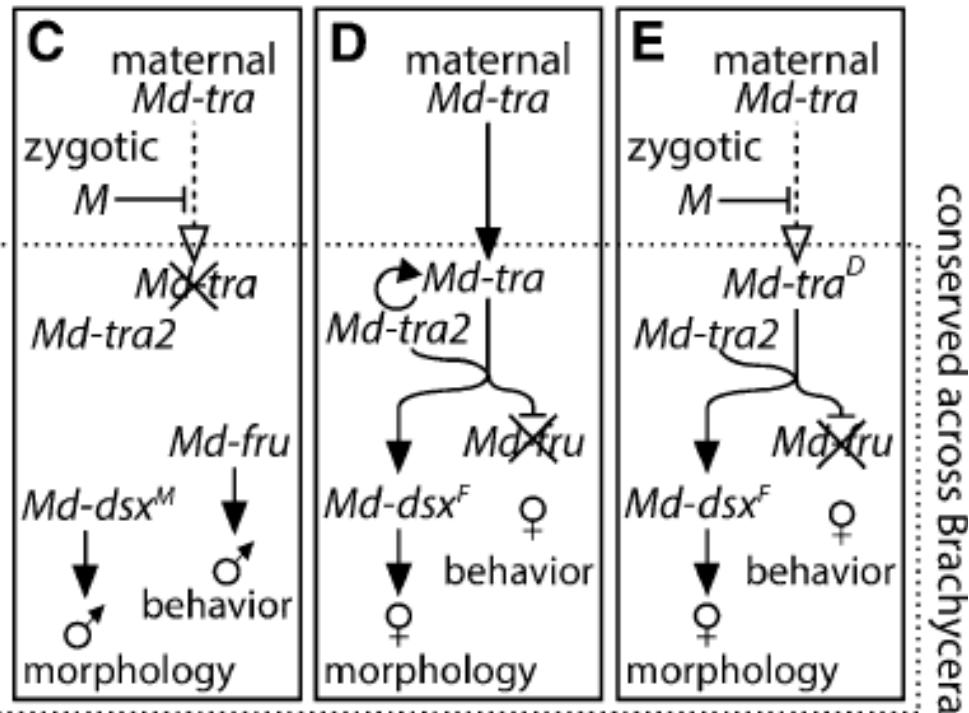
D



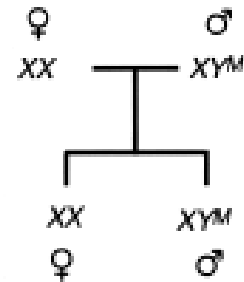
Sánchez Sex-determining mechanisms in insects Int. J. Dev. Biol. 2008 ,52: 837-856

Musca domestica, Muscidae (*Ceratitis capitata*, *Bactrocera dorsalis* Tyrphidae)

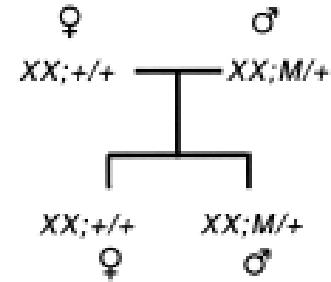
Musca domestica



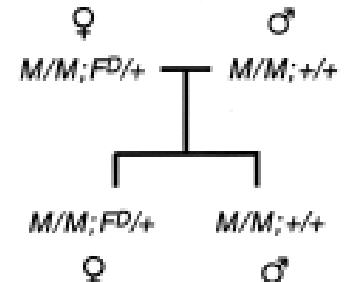
Standard: male-determining Y



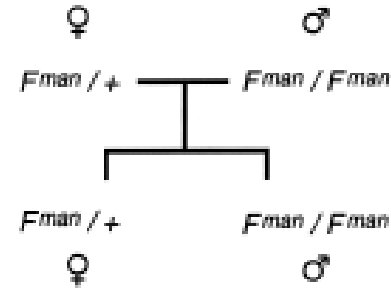
Dominant autosomal male-determiner



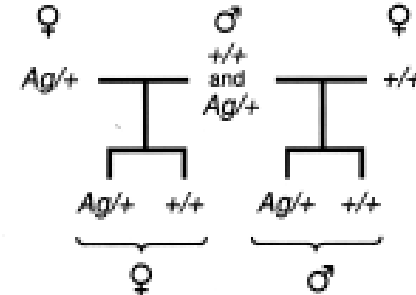
Dominant autosomal female-determiner



System without M



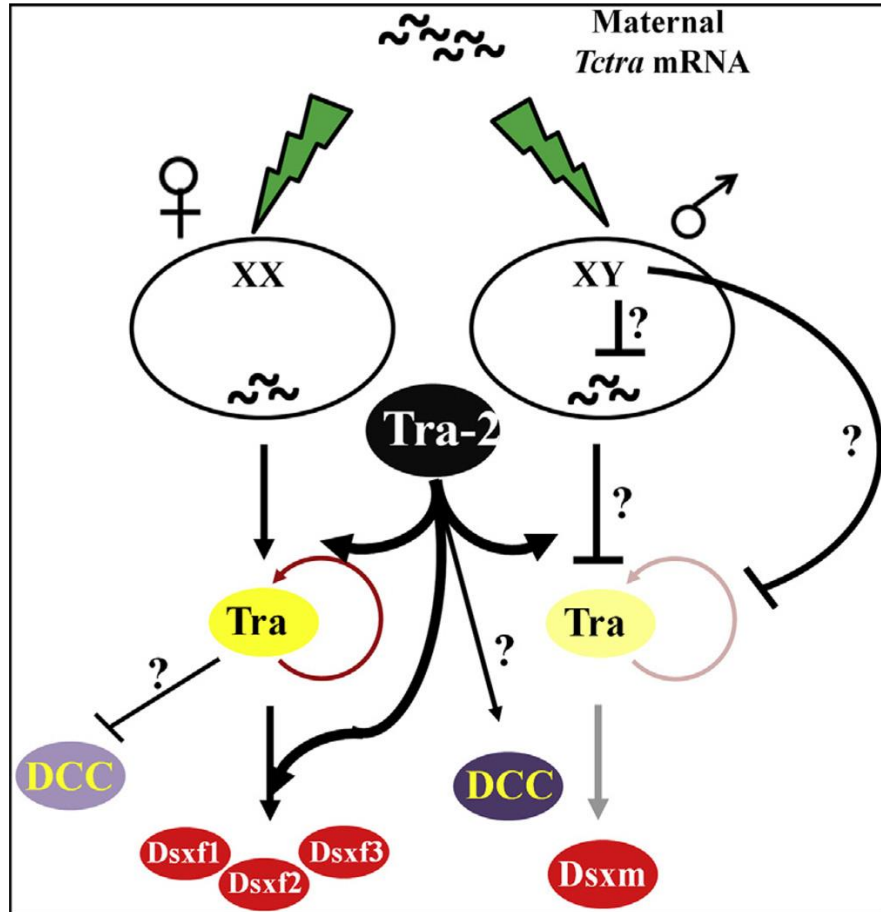
Maternal effect male determiner



Hamm et al. The Evolving Puzzle of Autosomal Versus Y-linked Male Determination in *Musca domestica*. G3 2015 5:371-384

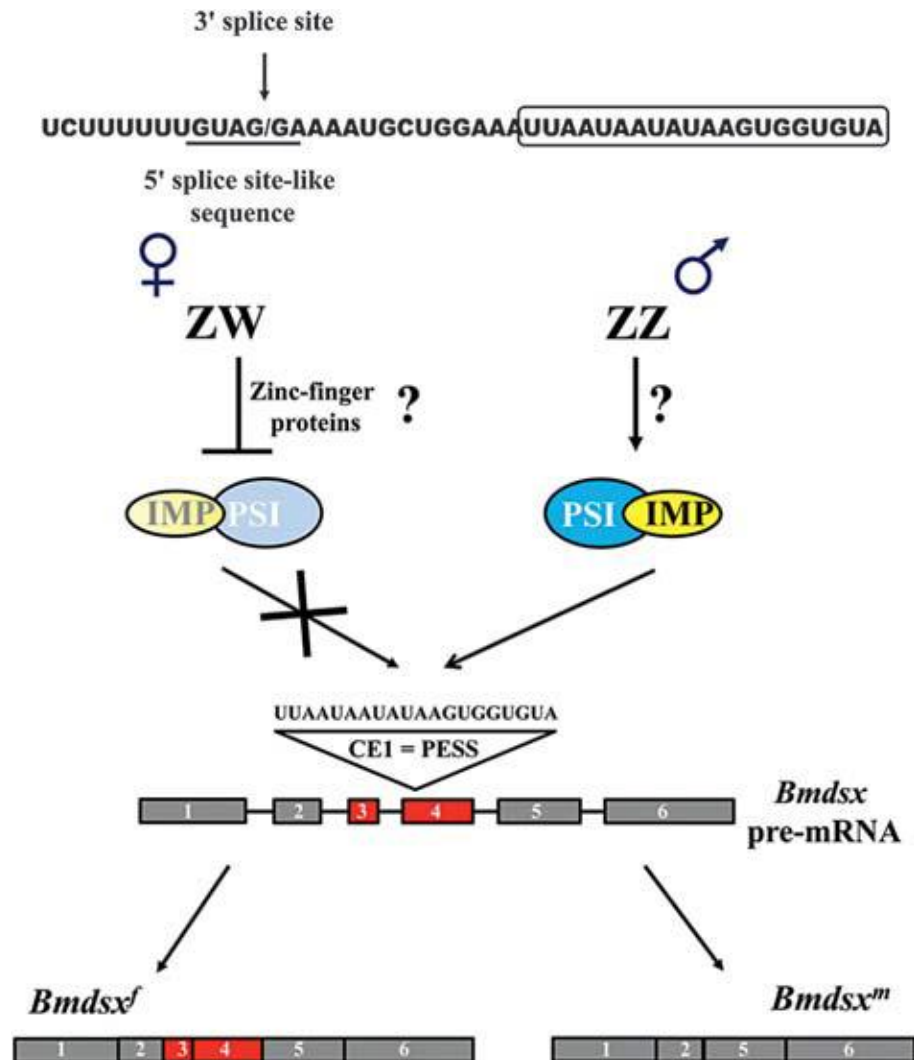
Dübendorfer A. *Musca domestica*, a window on the evolution of sex-determining mechanisms in insects, Int. J. Dev. Biol. 2002, 46: 75-79

Tribolium castaneum, Coleoptera



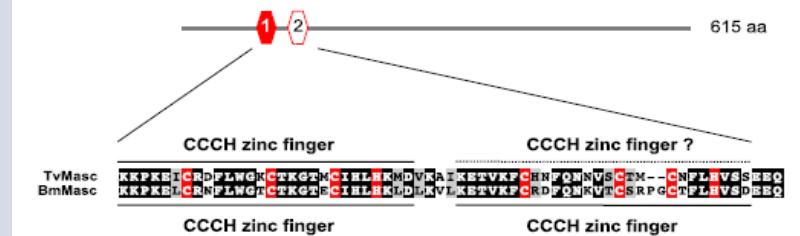
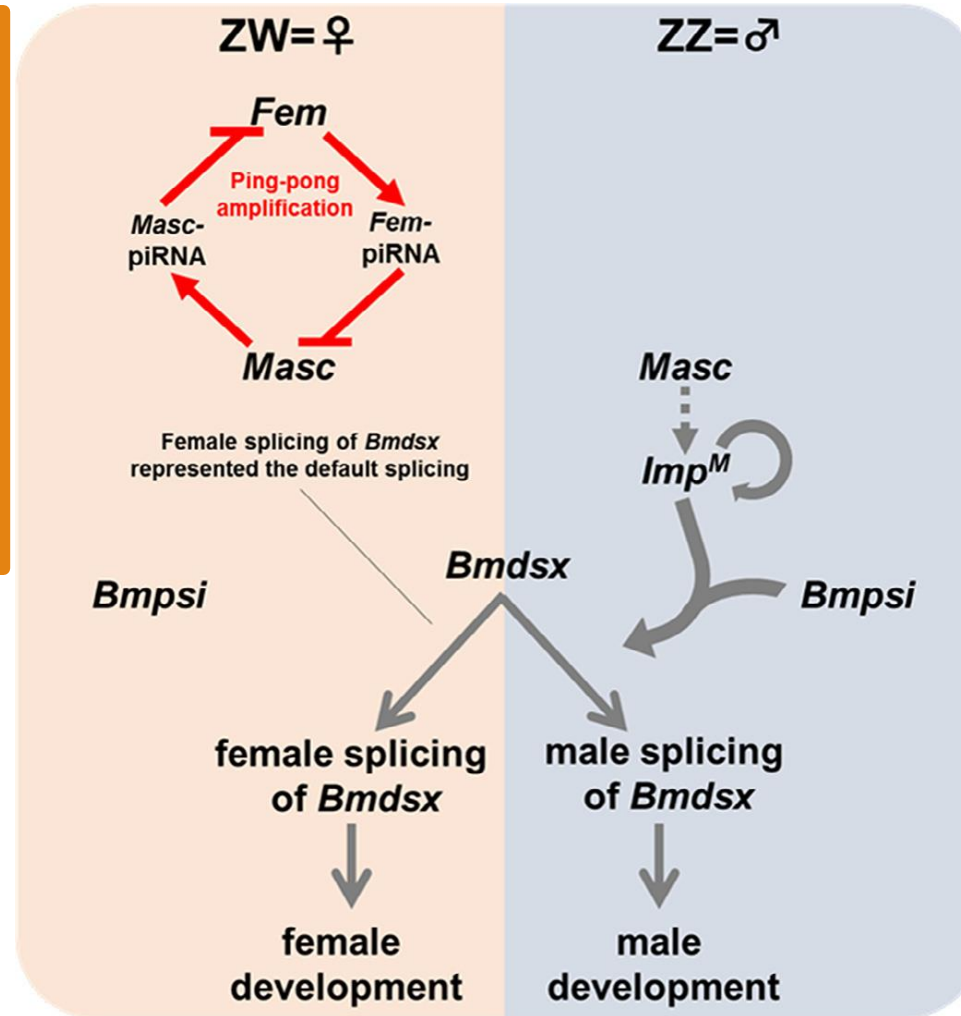
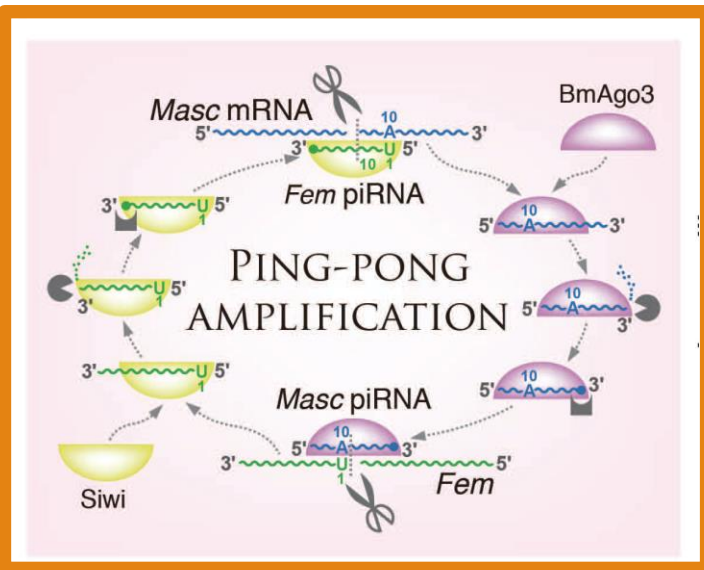
Shukla JN, Palli SR, *Tribolium castaneum*
Transformer-2 regulates sex determination
and development in both males and females
Insect Biochem Mol Biol. 2013 43(12): 1125–
1132

Bombyx mori, Lepidoptera



Nagaraju J. et al. **Lepidopteran Sex Determination: A Cascade of Surprises.** Sex Dev 2014, DOI: 10.1159/000357483

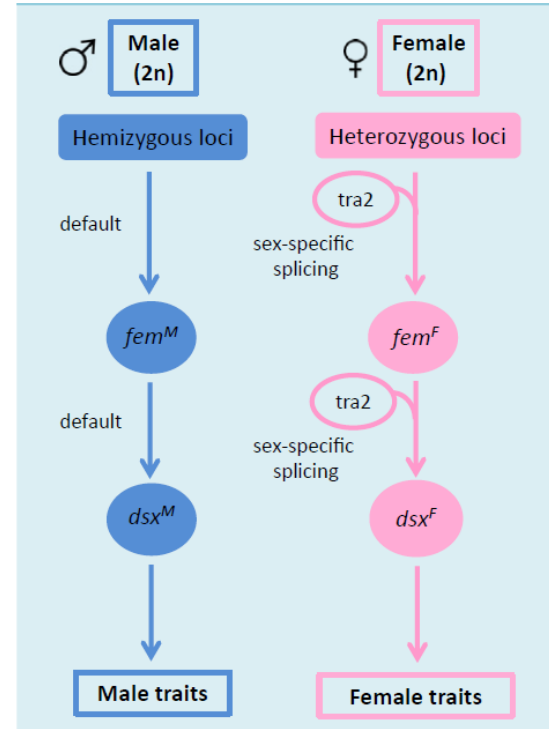
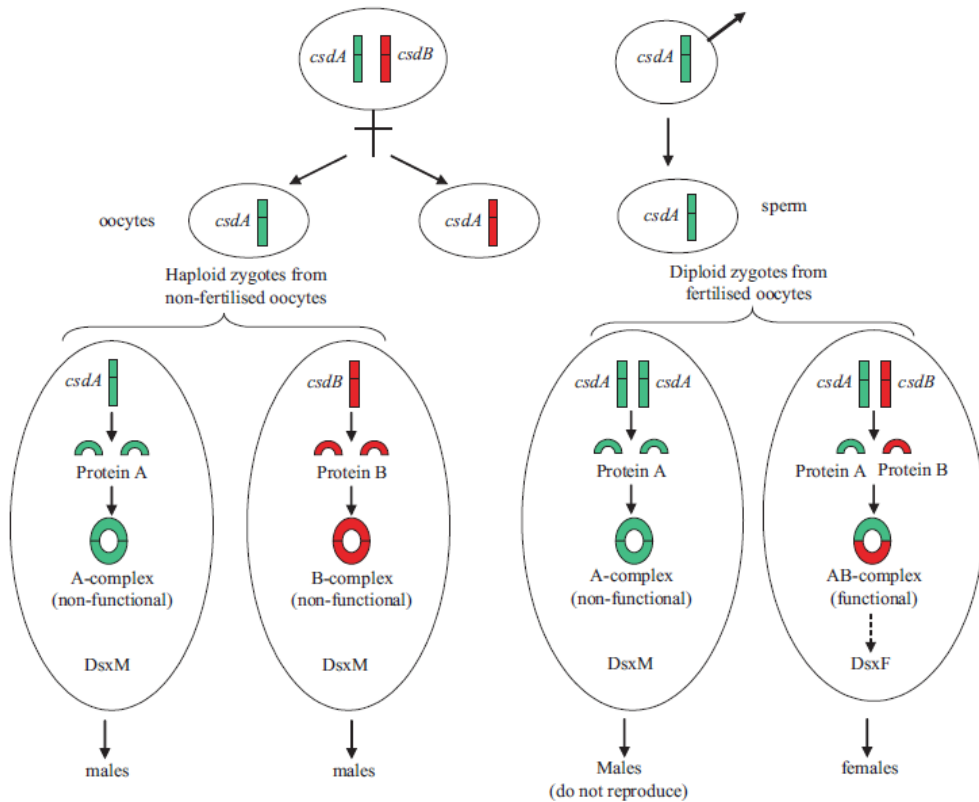
Bombyx mori, Lepidoptera



Sakai et al. Functional analysis of sex-determination genes by gene silencing with LNA–DNA gapmers in the silkworm, *Bombyx mori*. Mechanisms of Development, 2015, 137:45–52

Kiuchi et al. A single female-specific piRNA is the primary determiner of sex in the silkworm. Nature 2014, 509:633–637

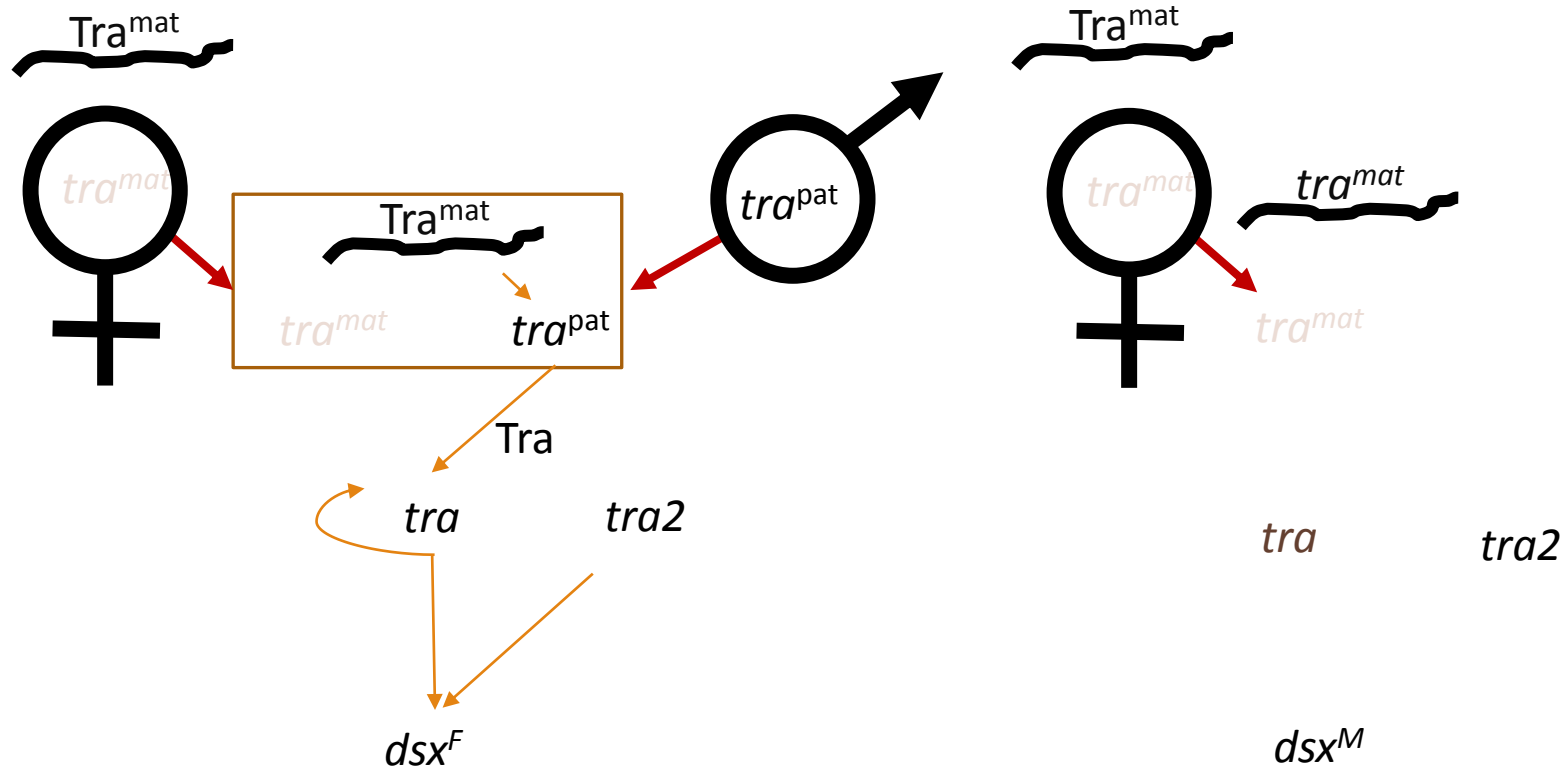
Apis mellifera, Apidae



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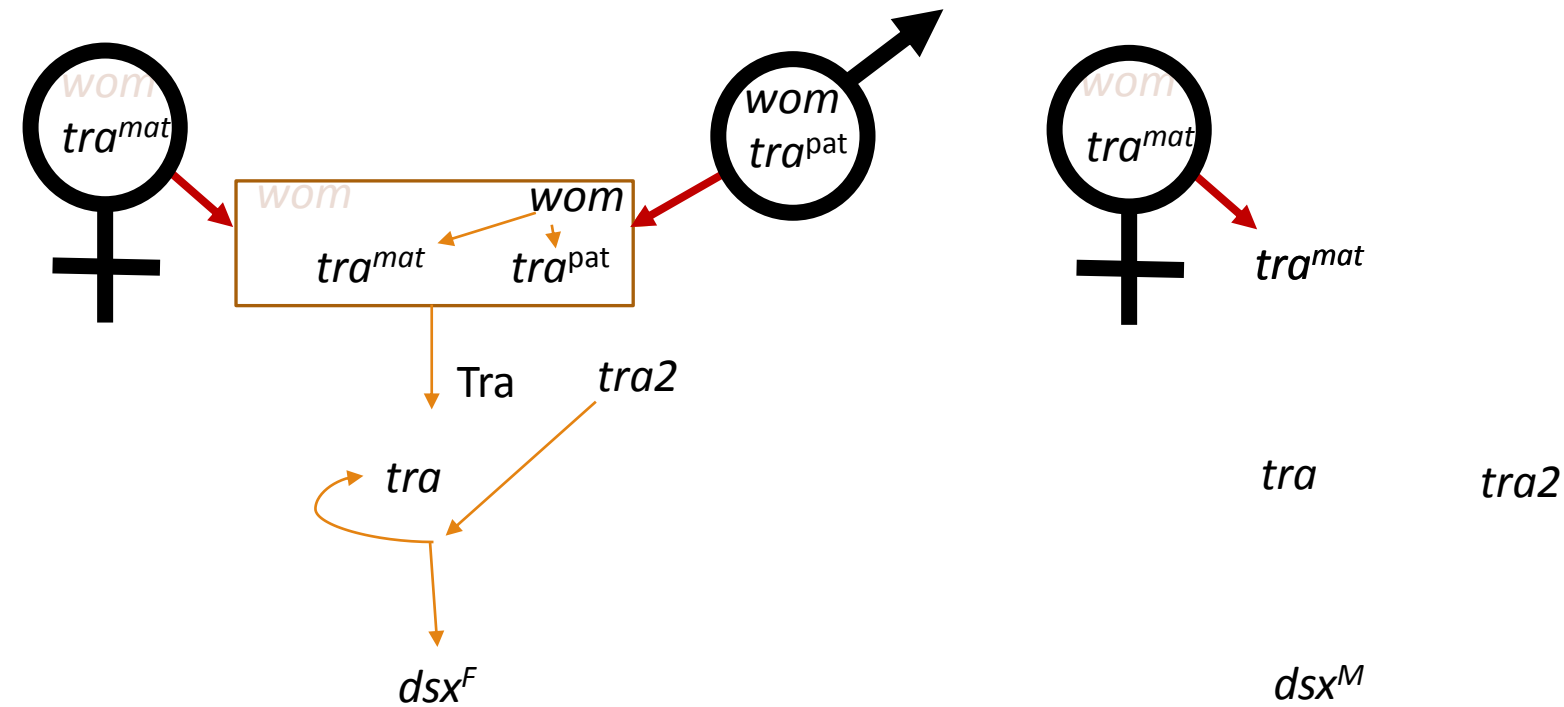
Brito DV et al. Molecular characterization of the gene feminizer in the stingless bee *Melipona interrupta* (Hymenoptera: Apidae) reveals association to sex and caste development. Insect Biochemistry and Molecular Biology 2015, 66:24-30

Nasonia vitripennis, Chalcidoidea



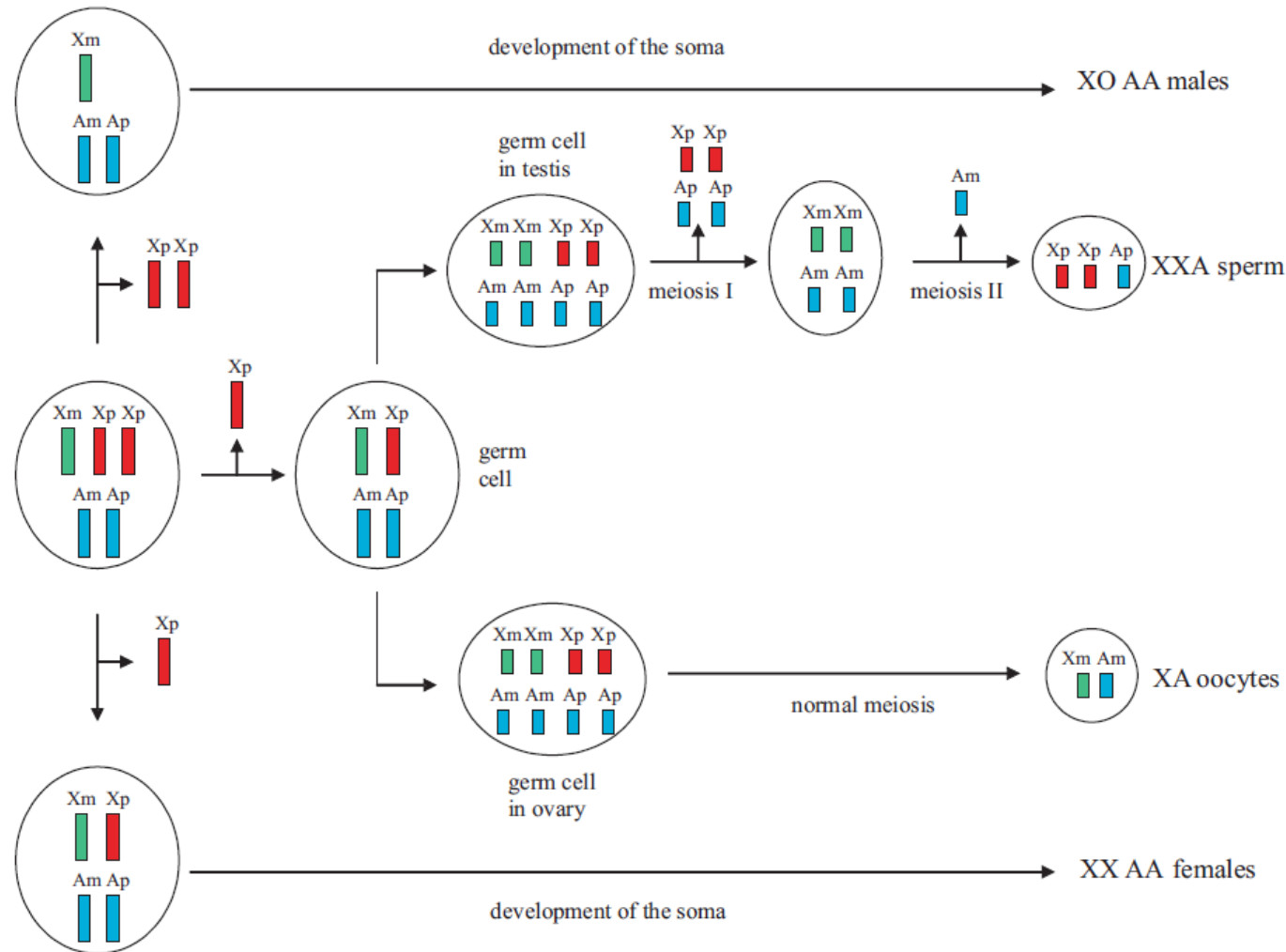
Beukeboom L., Van de Zande L., Genetics of sex determination in haplodiploid wasp *Nasonia vitripennis* (Hymenoptera: Chalcidoidea). J. Genet 2010, 89:333-339

Nasonia vitripennis, Chalcidoidea

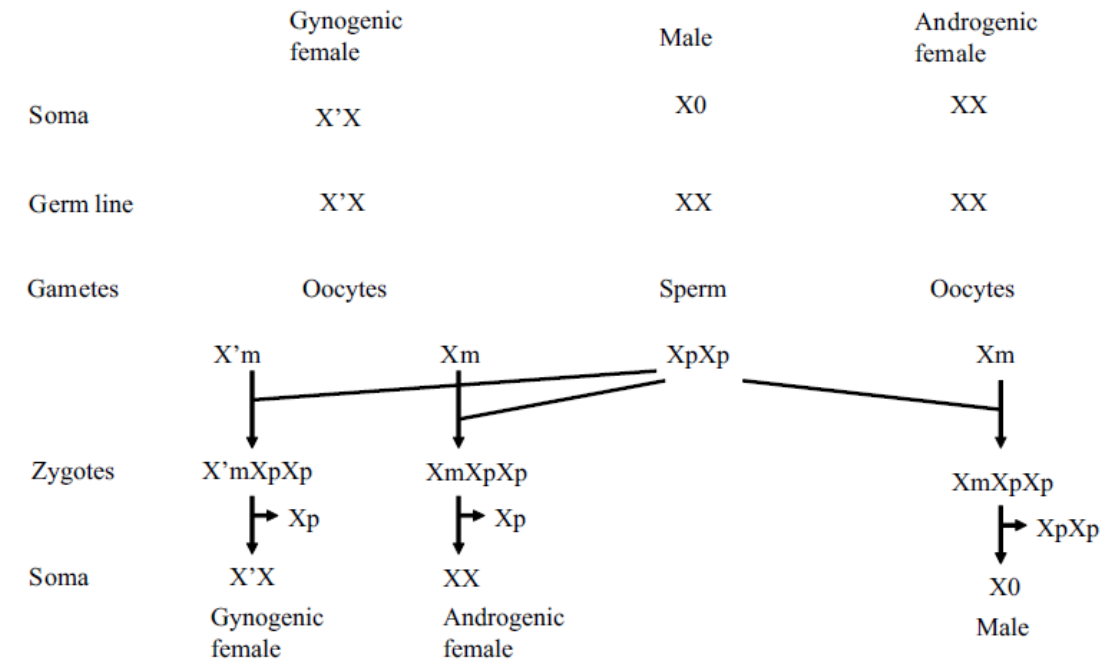


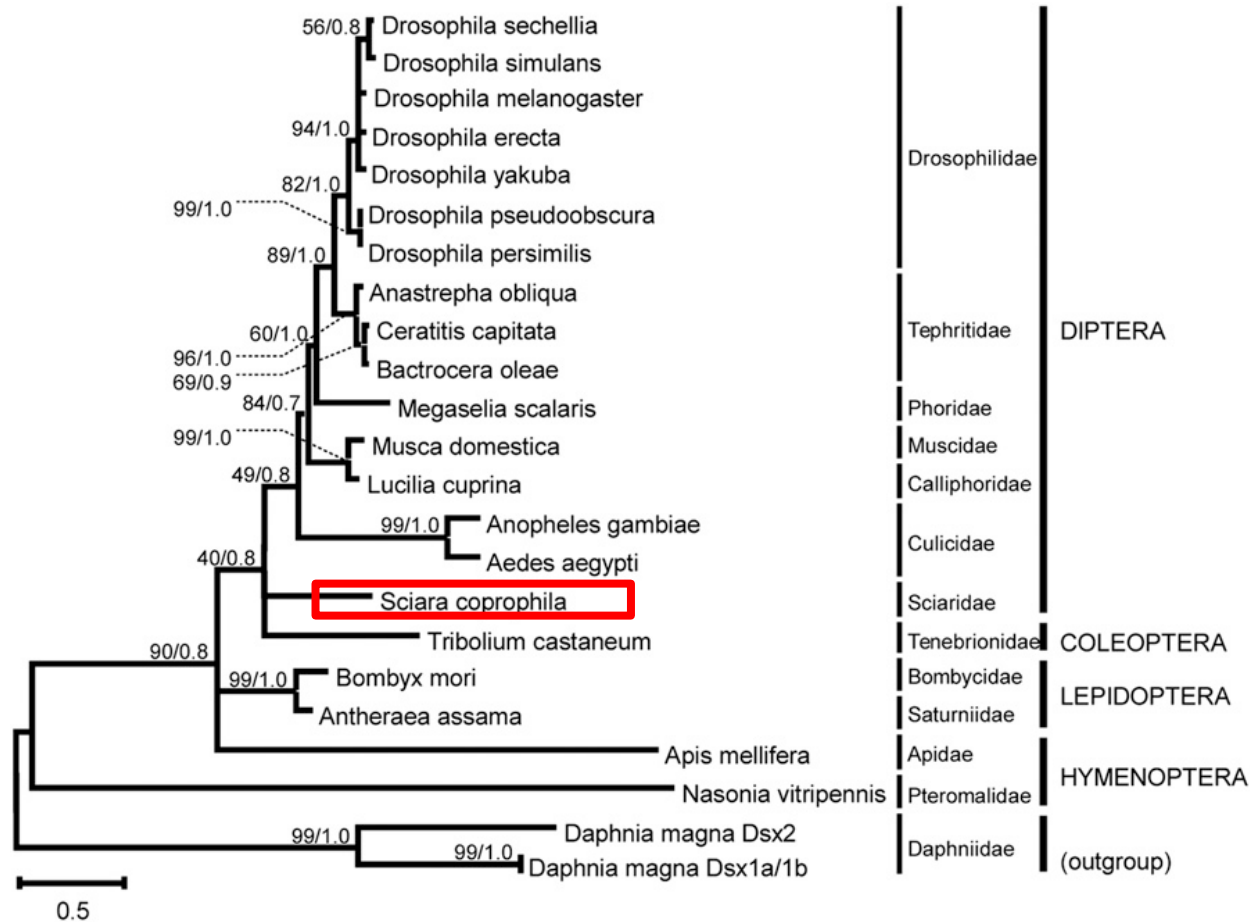
Verhulst EC, Lynch JA, Bopp D, Beukeboom LW, van de Zande L. A New Component of the *Nasonia* Sex Determining Cascade Is Maternally Silenced and Regulates Transformer Expression. PLoS ONE 2013 8(5): e63618.

Sciaridae

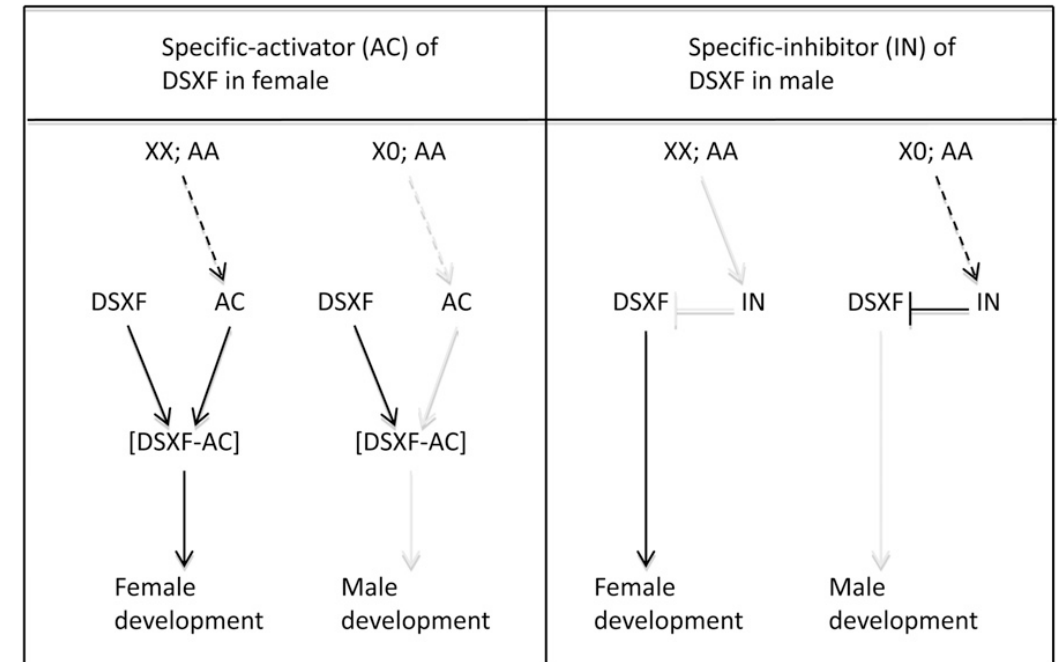
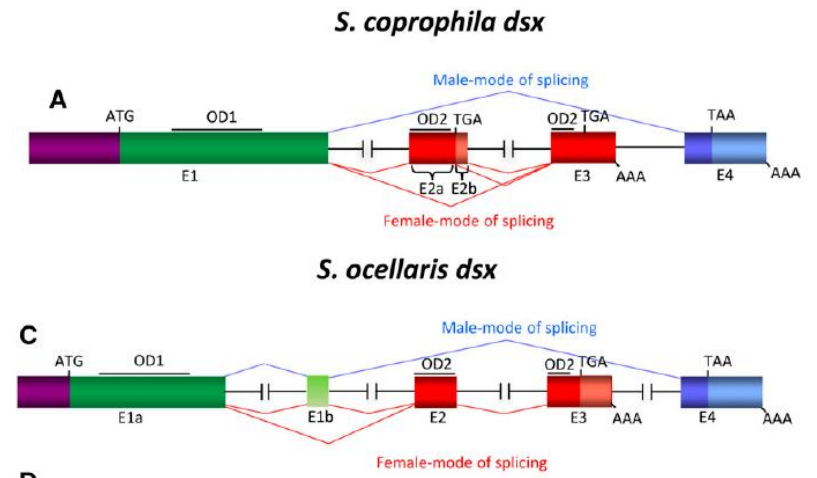


Sánchez Sex-determining mechanisms in insects Int. J. Dev. Biol. 2008 ,52: 837-856

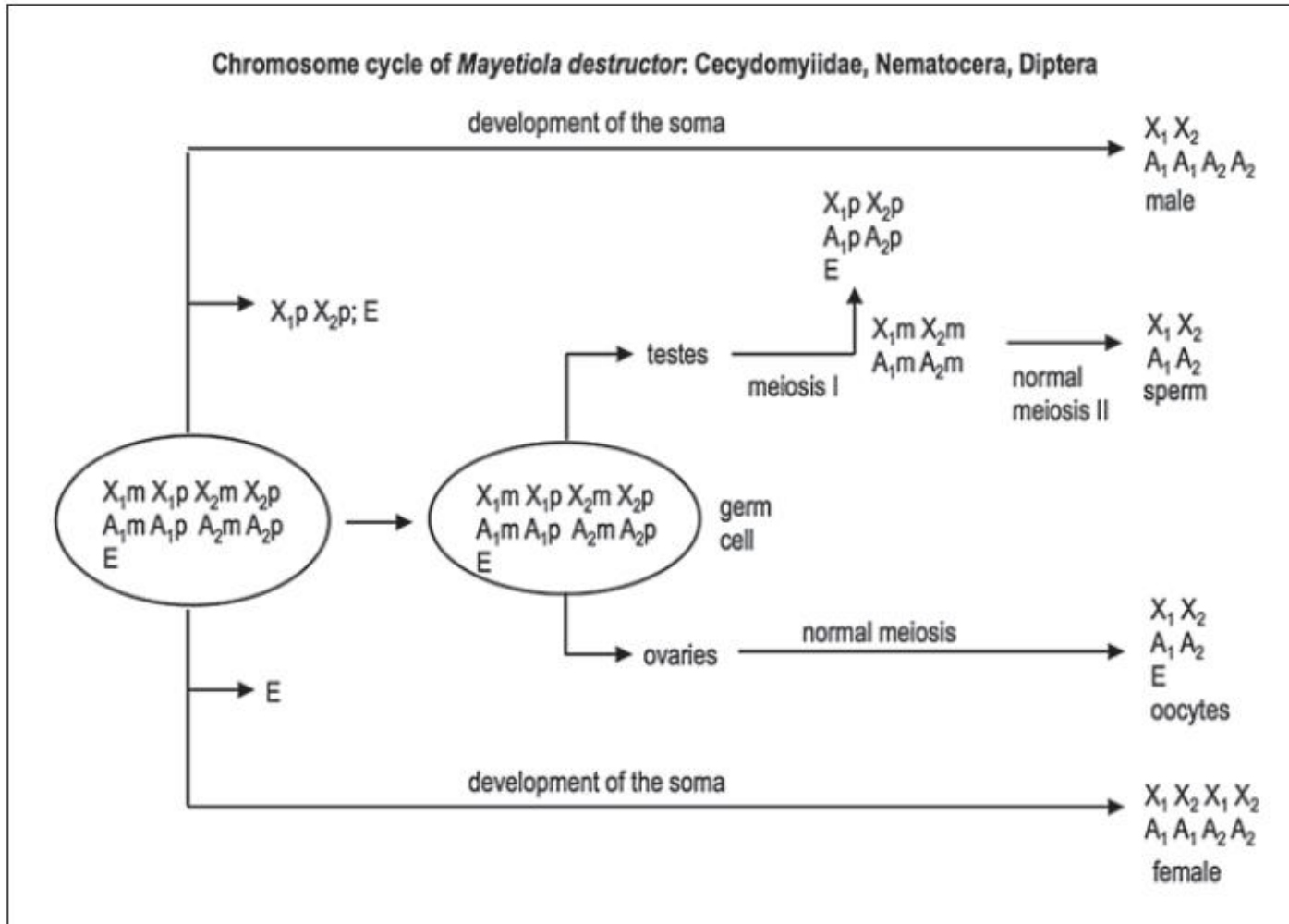




Ruiz MF et al. An Unusual Role for doublesex in Sex Determination in the Dipteran *Sciara*. Genetics, 200:1181–1199



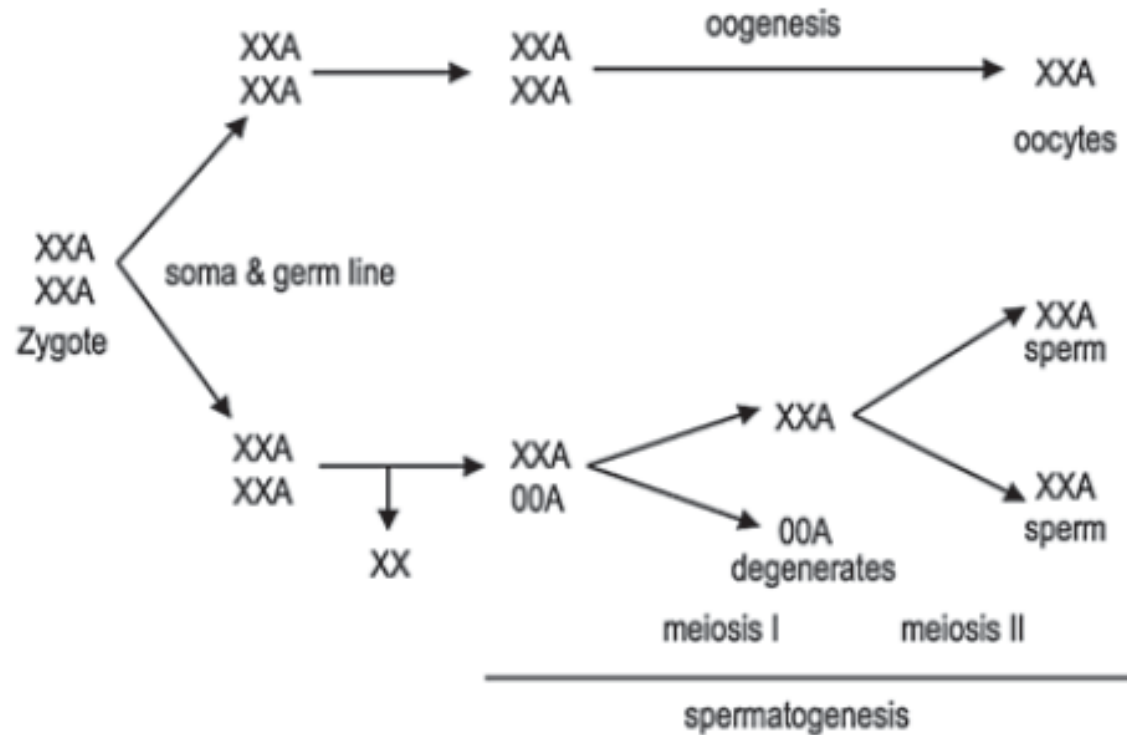
Mayetiola destructor, Cecydomyiidae



Sanchez Sex-Determining Mechanisms in Insects Based on Imprinting and Elimination of Chromosomes. Sex Dev 2014;8:83–103

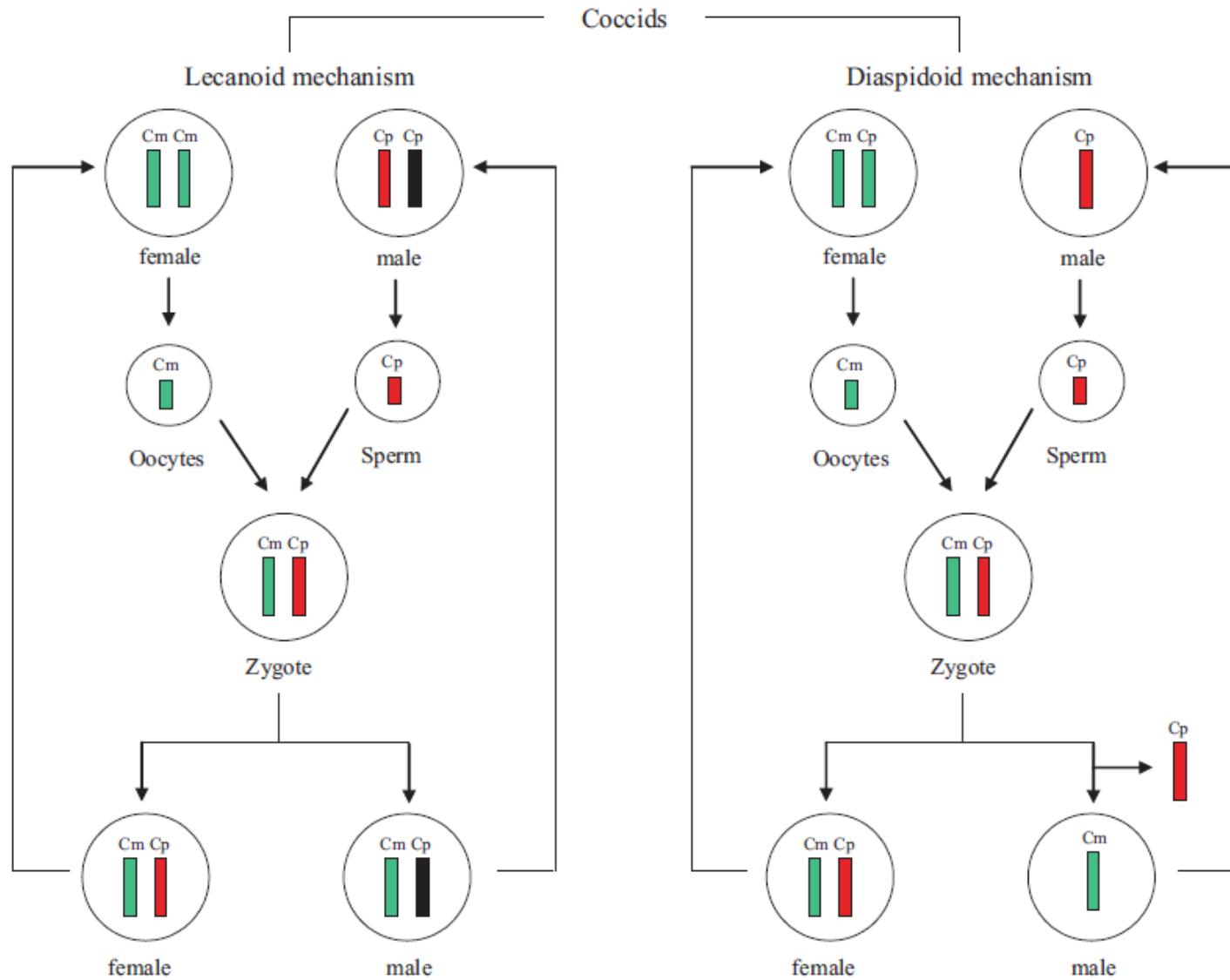
Collembola

Chromosome cycle of *Allacma fusca* and *Sminthurus viridis*: Sminthuridae, Collembola

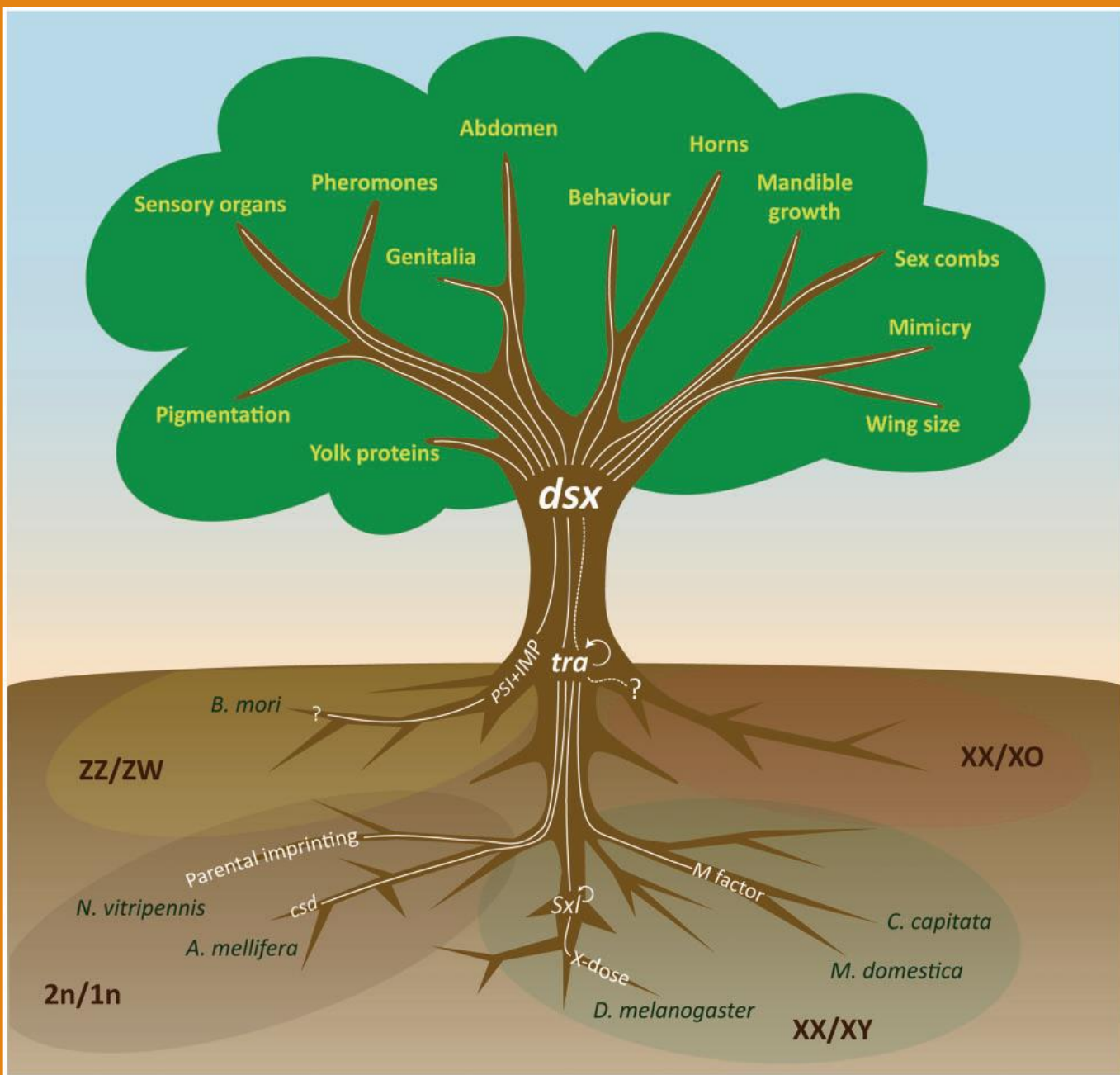


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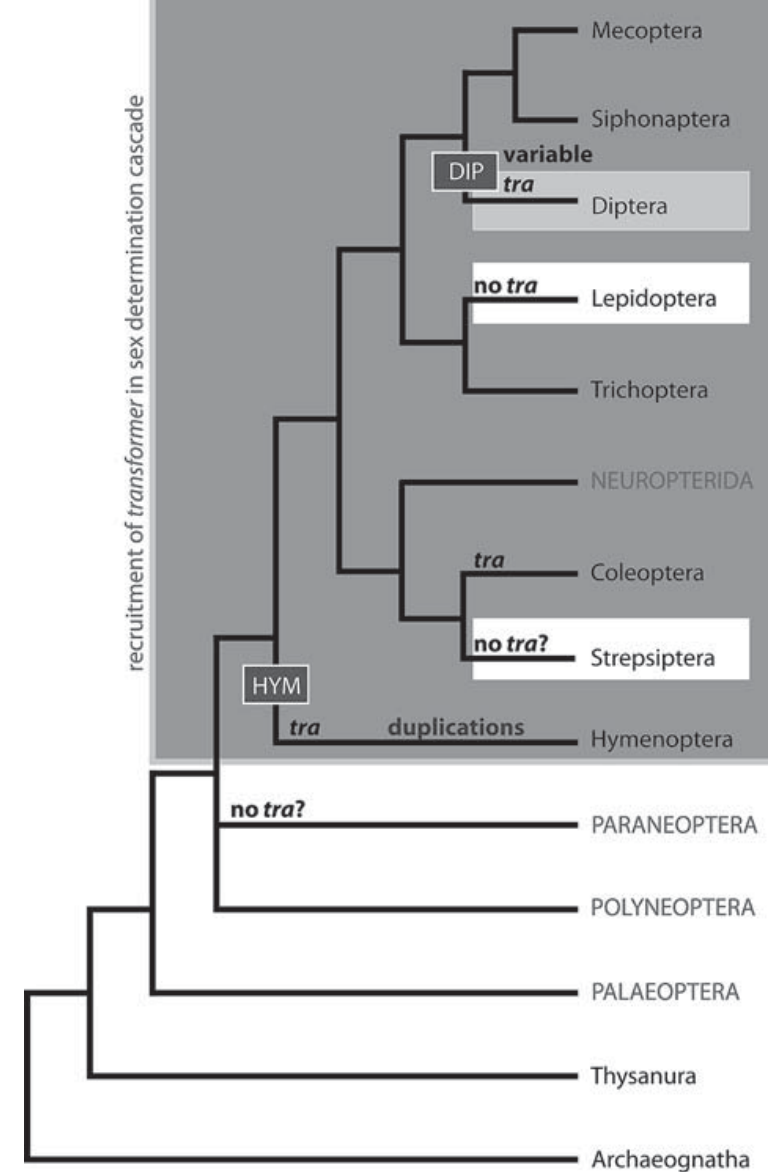
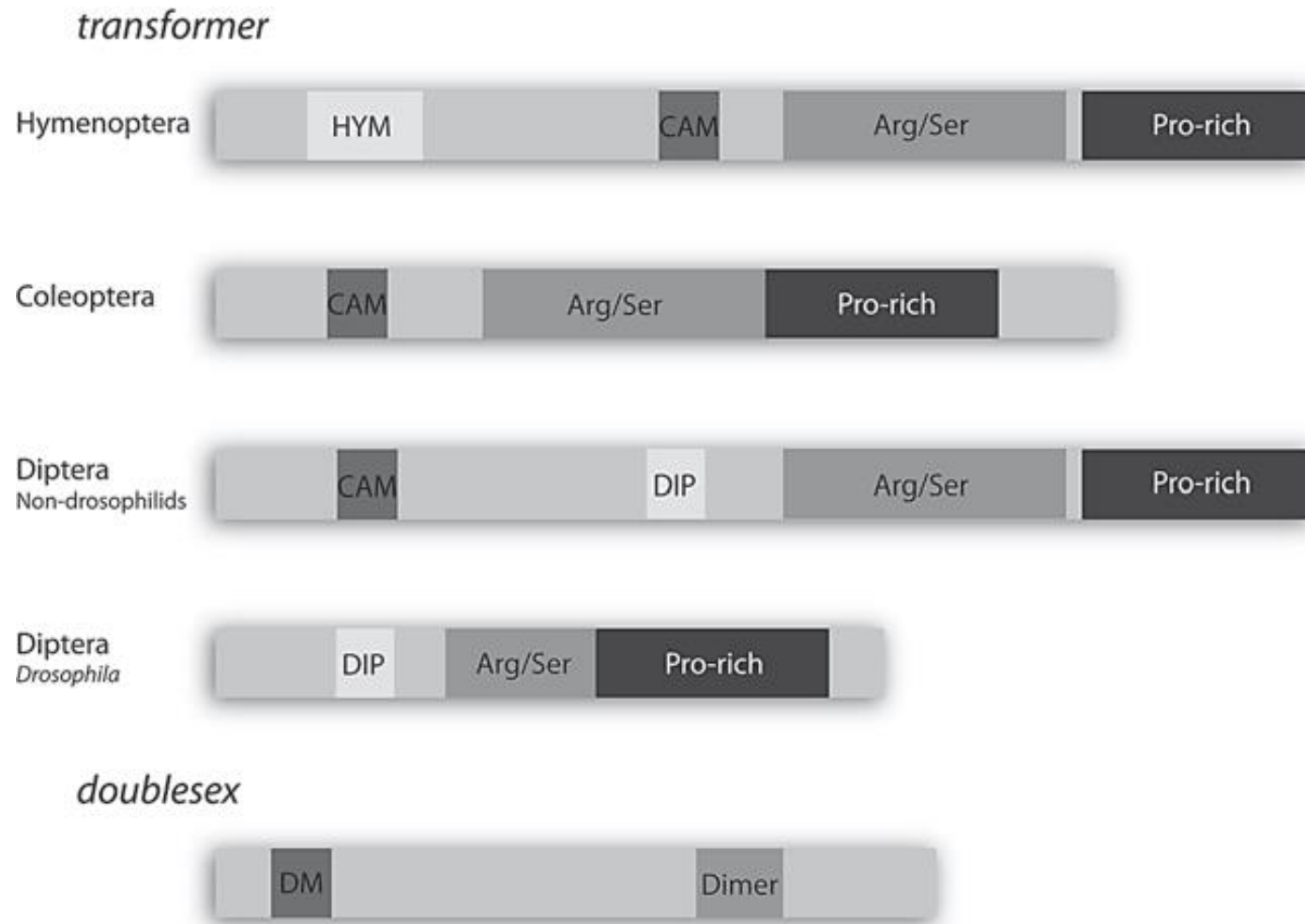
Coccida



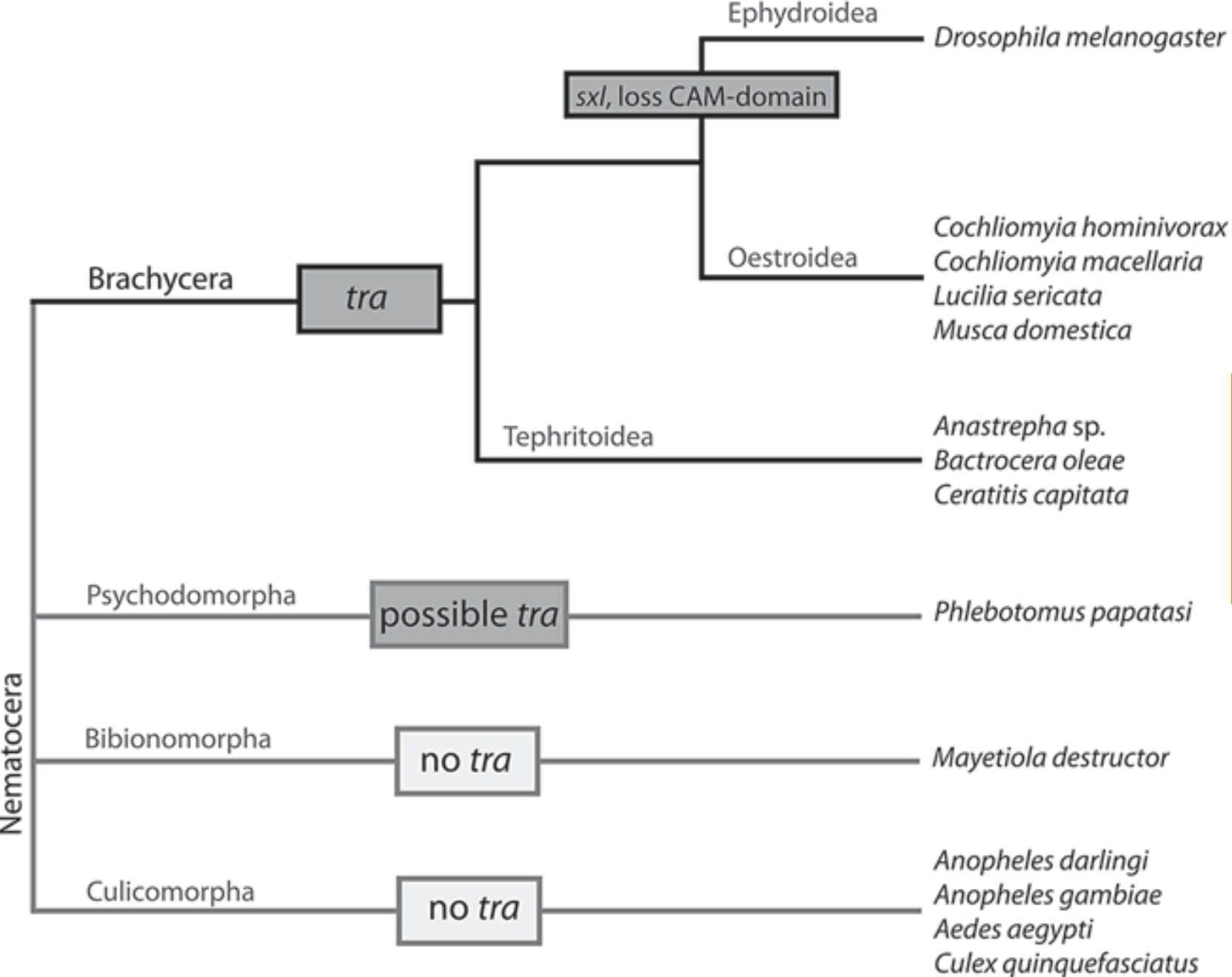
Sánchez Sex-determining mechanisms in insects Int. J. Dev. Biol. 2008 ,52: 837-856



Verhulst EC, van de Zande L, **Doublesex is the connecting element in sex determination.** Briefings in Functional Genomics, 2015, 1–11



Geuverink E., Beukeboom L.W. Phylogenetic Distribution and Evolutionary Dynamics of the Sex Determination Genes *doublesex* and *transformer* in Insects Sex Dev 2014;8:38–49



Geuverink E., Beukeboom L.W. Phylogenetic Distribution and Evolutionary Dynamics of the Sex Determination Genes *doublesex* and *transformer* in Insects Sex Dev 2014;8:38–49

- 1) В отличие от млекопитающих пол у насекомых определяется в каждой клетке в результате действия каскада генов, который запускается на ранних стадиях эмбриогенеза.
- 2) Основным механизмом определения пола это альтернативный сплайсинг, который приводит к «полоспецифичным» продуктам генов участников каскада
- 3) Основным ген-исполнитель – *dsx* – транскрипционный фактор семейства *DMRT*, действующий на множество мишеней в геноме.
- 4) Важную роль в сплайсинге транскрипта гена *dsx* играет продукт гена *tra* совместно с продуктом гена *Tra2*
- 5) В каскад легко включаются новые регулирующие элементы на более высоком уровне, например ген *S/x*.