

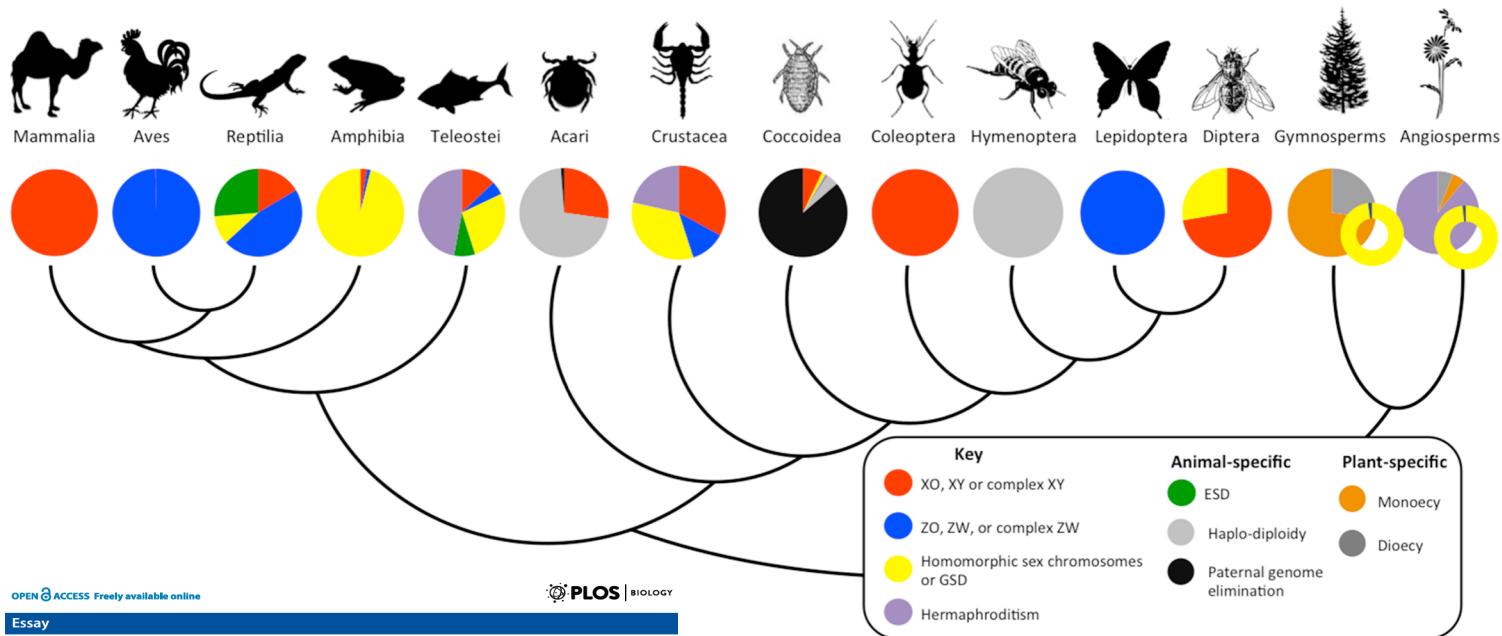
A species having sex is not the same as a species having different sexes

- The fundamental difference between male and female function is Anisogamy (Gametes differ in size)
- Male sexual function:
 - Small mobile gametes
- Female sexual function:
 - Larger less mobile gametes
 - Maternal provisions



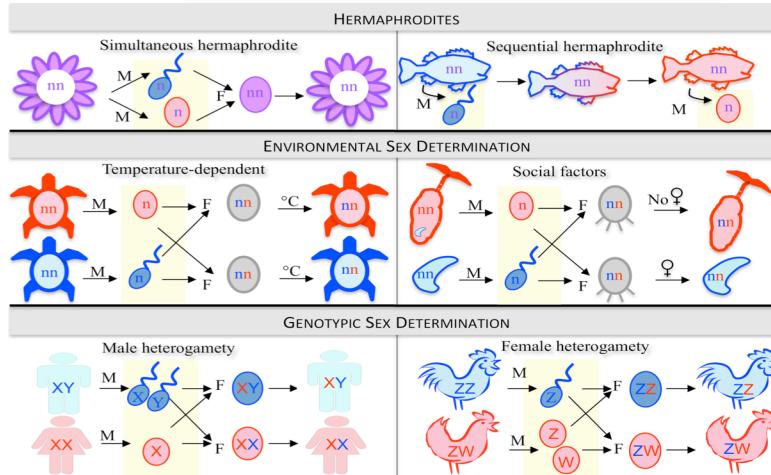
Zimmer book

Male and female functions do not necessarily mean sexes are separate individuals
But separate sexes have arisen many times
Perhaps because of:
Selection for specialization
or inbreeding avoidance.



Sex Determination: Why So Many Ways of Doing It?

Doris Bachtrog^{1*}, Judith E. Mank², Catherine L. Peichel³, Mark Kirkpatrick⁴, Sarah P. Otto⁵, Tia-Lynn Ashman⁶, Matthew W. Hahn⁷, Jun Kitano⁸, Itay Mayrose⁹, Ray Ming¹⁰, Nicolas Perrin¹¹, Laura Ross¹², Nicole Valenzuela¹³, Jana C. Vamosi¹⁴, The Tree of Sex Consortium¹

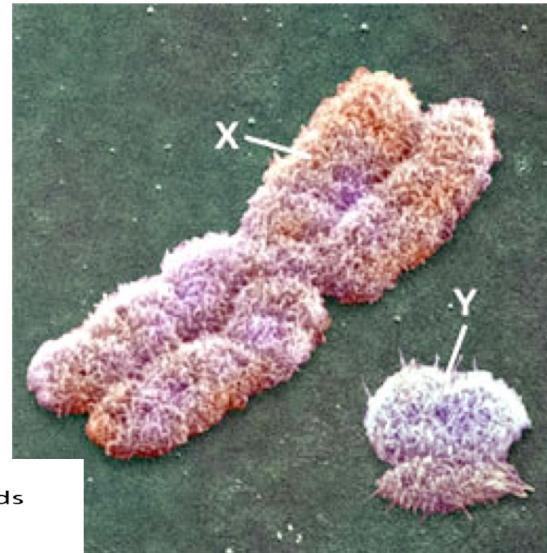
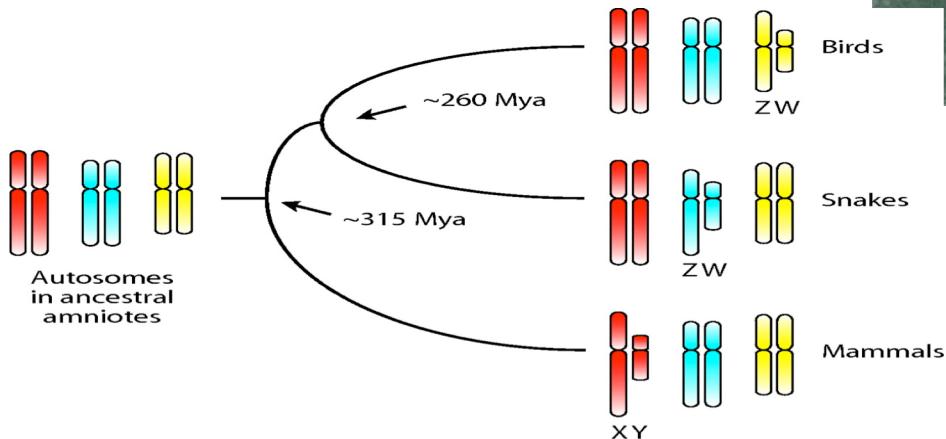


Evolution of sex chromosomes

In species with genetic sex determination
the chromosomes containing the sex determining factors
are often heteromorphic:
One is much reduced in
function and size.
And does not recombine.

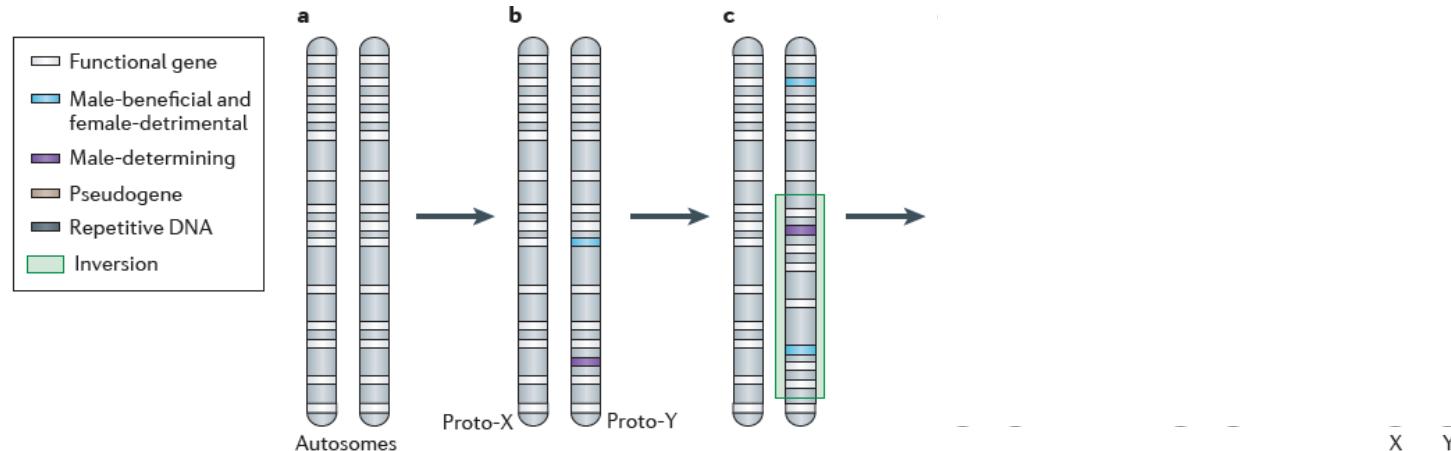
Human Y: 60 Mbp ~80 genes

Human X: 153 Mbp ~2000 genes



Heteromorphic sex chromosomes have evolved independently many times

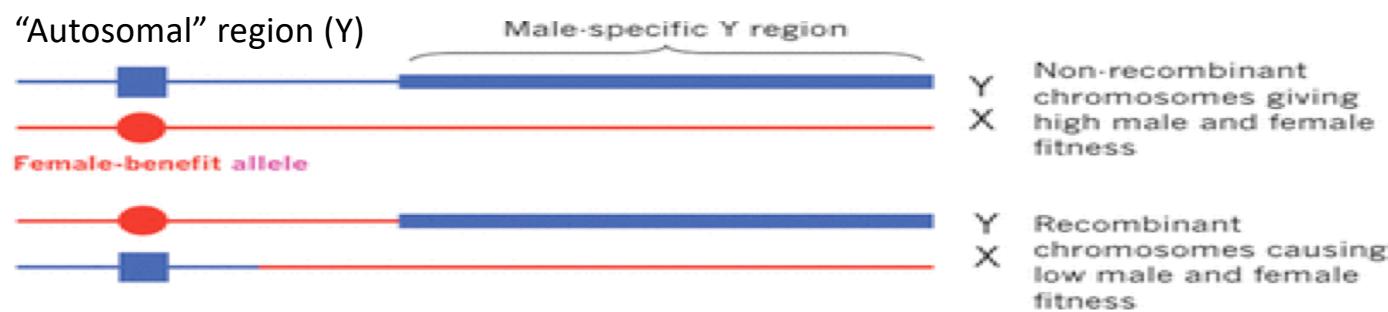
The evolution of sex chromosomes

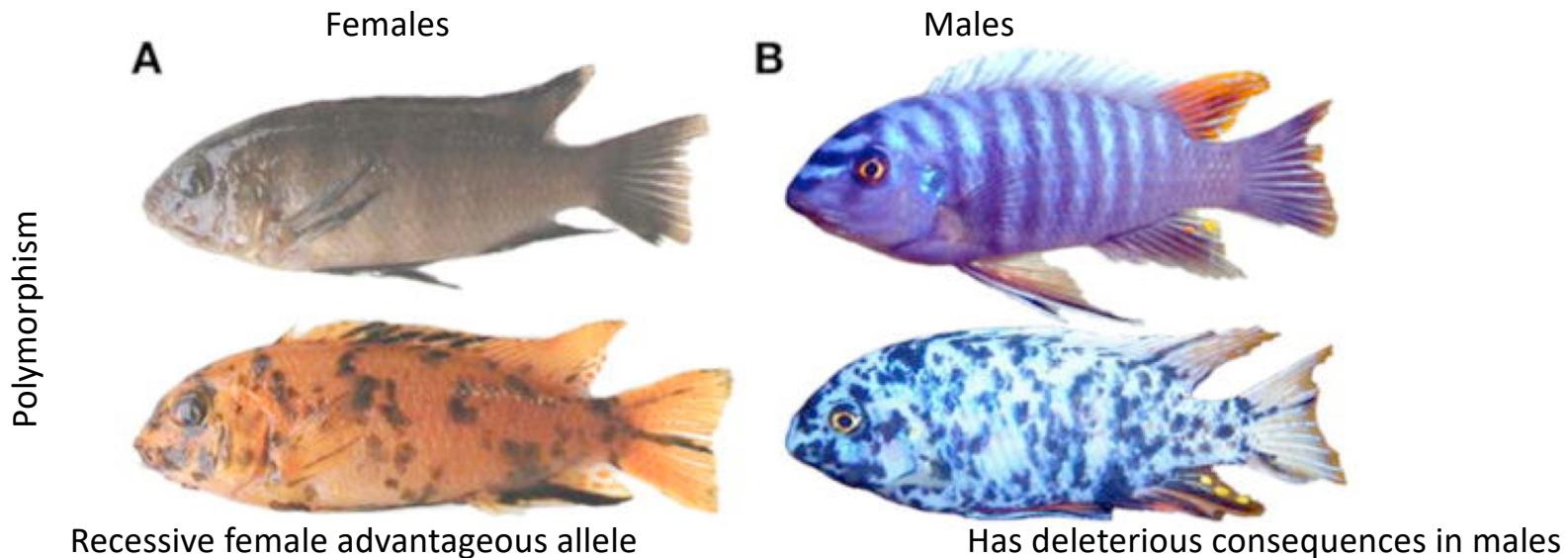


Sex determining allele arises (e.g. dominant male determining allele)

Recombination between sexually antagonistic allele and male-determining allele have lowers fitness.

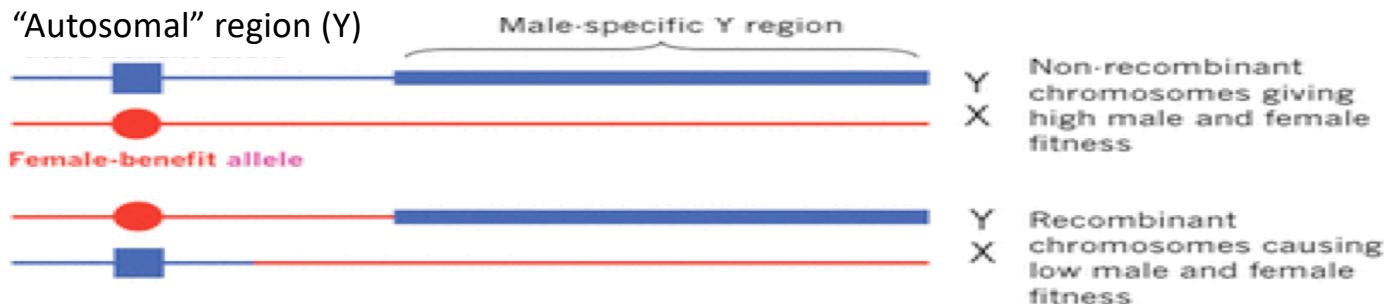
Recombination between these loci suppressed by inversion



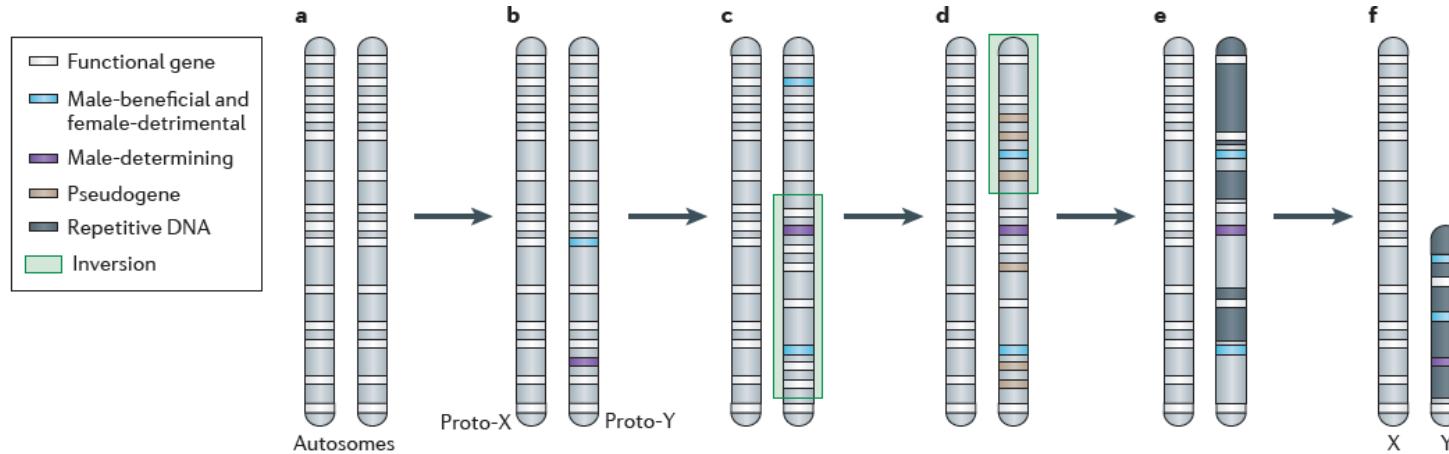


Sexual Conflict Resolved by Invasion of a Novel Sex Determiner in Lake Malawi Cichlid Fishes

Reade B. Roberts, Jennifer R. Ser, Thomas D. Kocher*



The evolution of sex chromosomes



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Recombination between sexually antagonistic allele and male-determining allele have lowers fitness.

Recombination between these loci suppressed by inversion

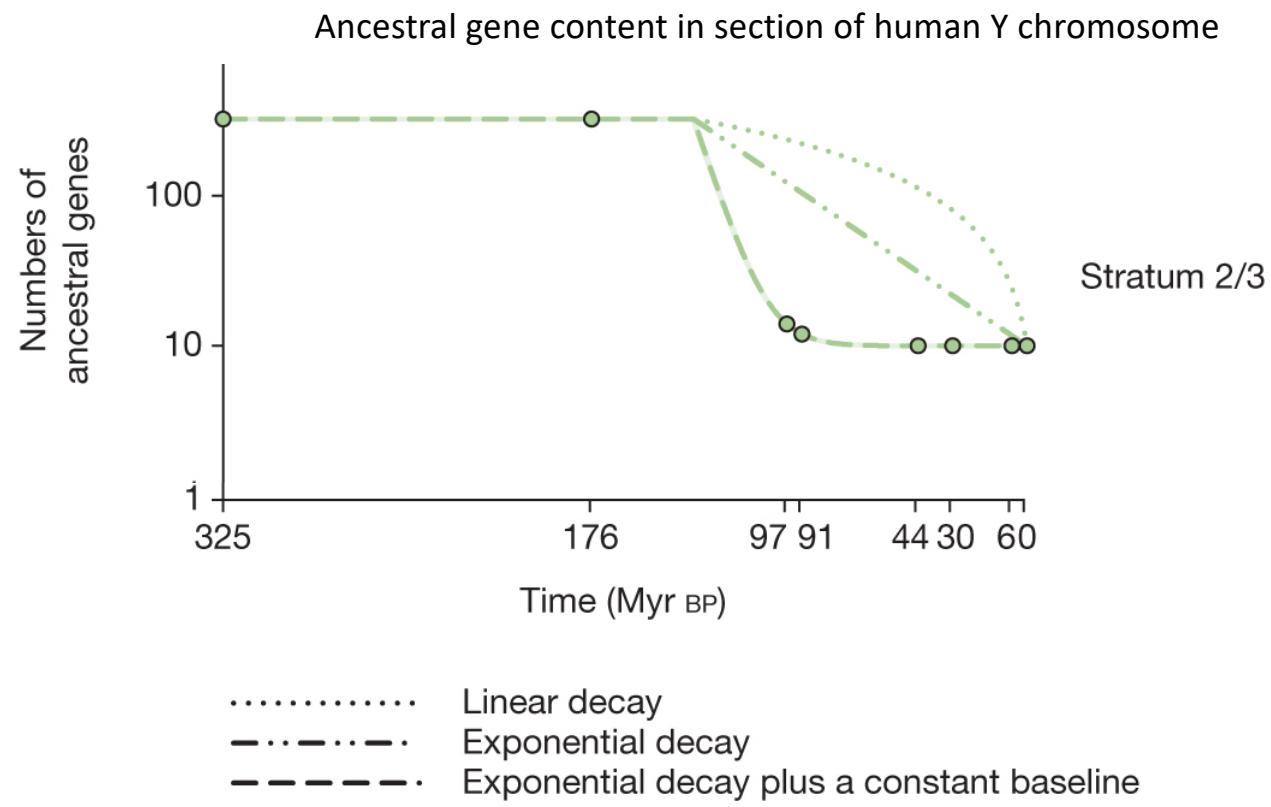
Shutting off recombination now means that this section of Proto-Y no long recombines (note that Proto-X can recombine with itself in females)

This in turn leads to degeneration of Y sex chromosome genes due to:

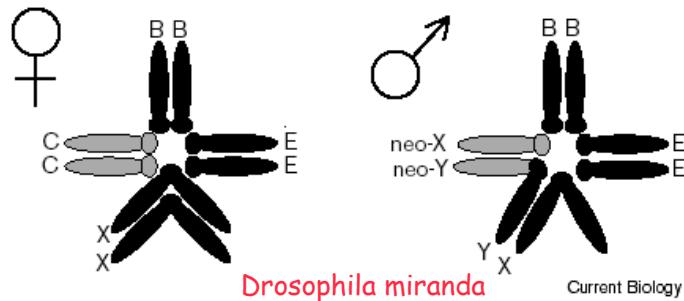
Muller's Ratchet

And the hitchhiking of deleterious alleles.

Accumulation of repeats and transposable elements.



Bellot et al 2015, Nature



A neo-Y chromosome region was formed in *Drosophila miranda* 1.25 Myrs ago and has rapidly decayed

Majority of genes (open reading frames, ORFs)

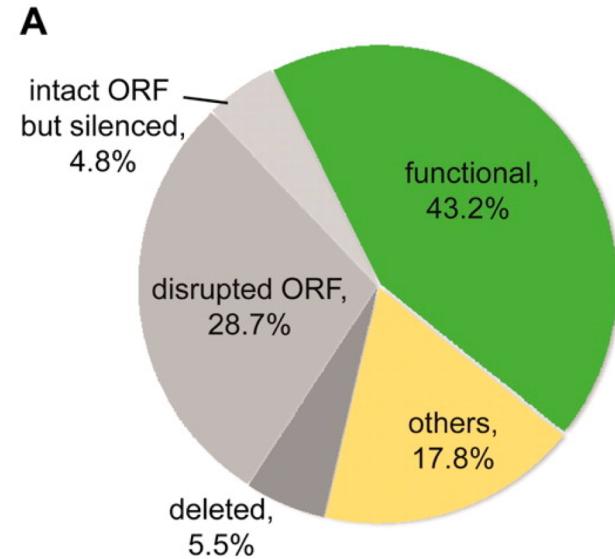
In neo-Y region have become non-functional

degeneration of Y sex chromosome genes due to:

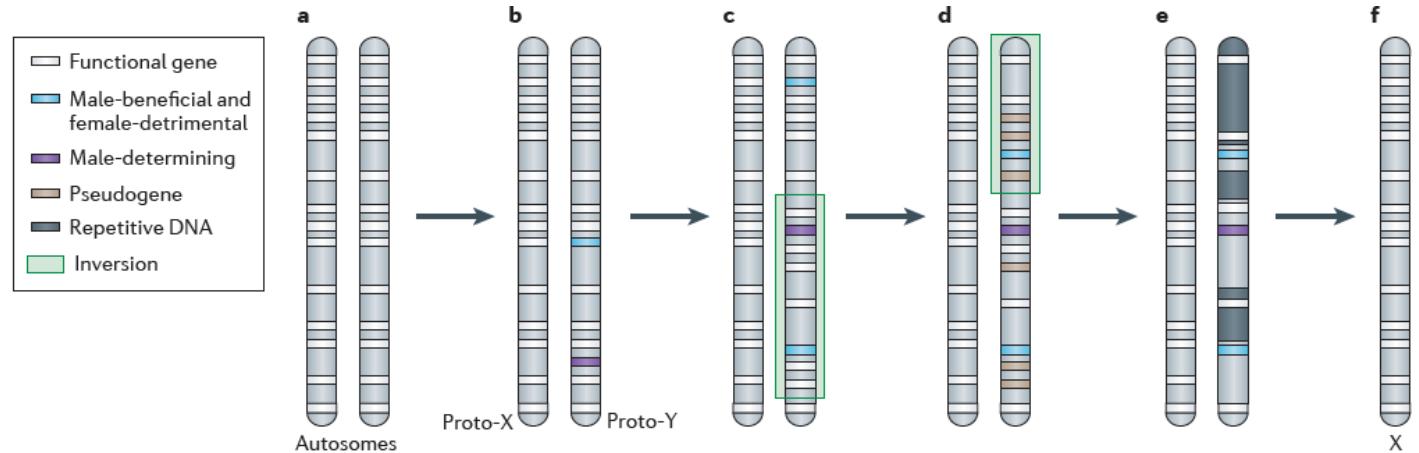
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The evolution of sex chromosomes

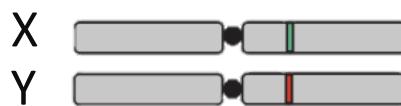


Convergent evolution and different ages of sex chromosomes

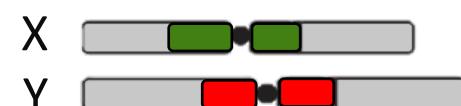
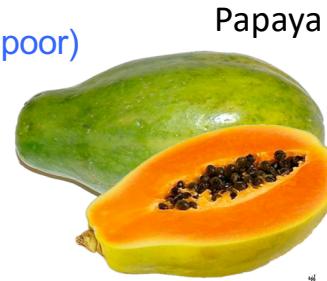


Corresponding X

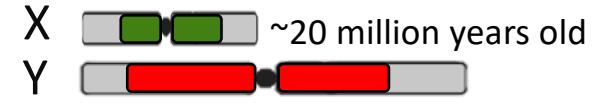
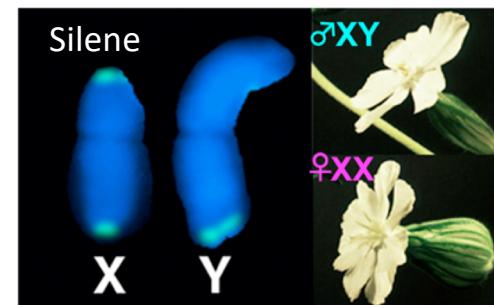
Non-recombining Y (gene poor)



~2 million years old

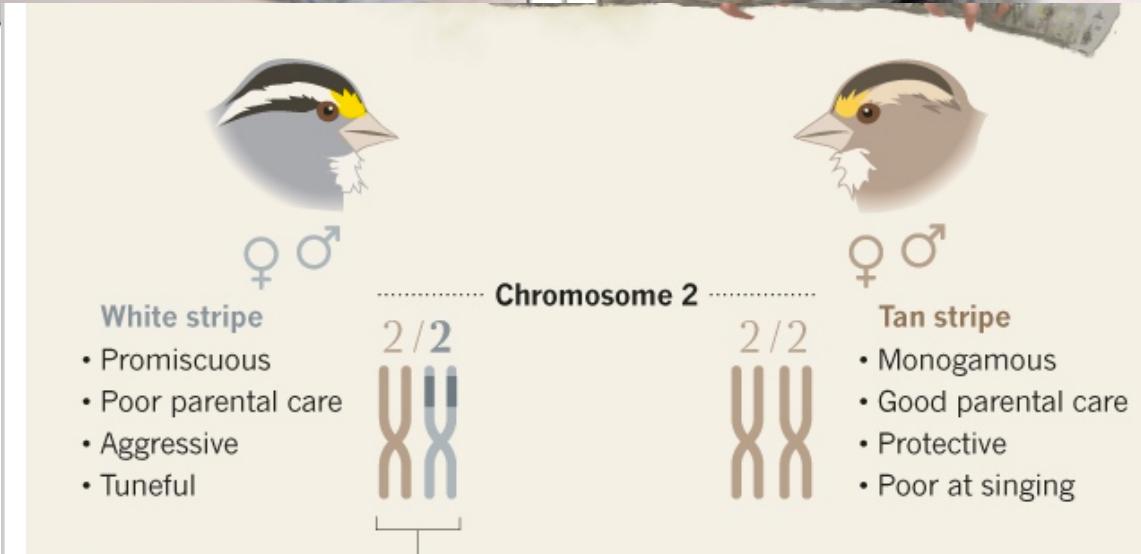


~10 million years old



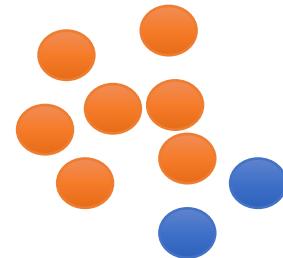
Cannabis also has old XY

2 colour morphs, 1 super gene, 4 sexes?



- The optimum sex ratio for a population would be many females fertilized by few males.

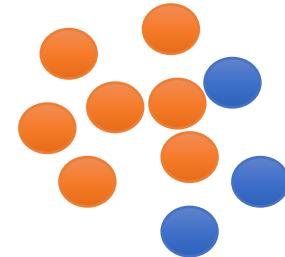
 Female
 Male



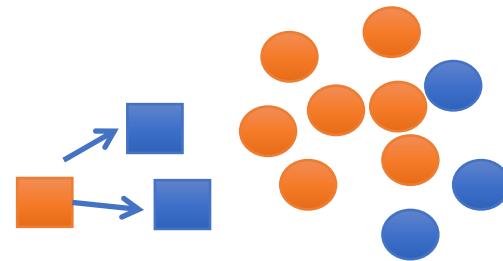
This would maximize growth rate and lower chance of extinction.

Why a 50/50 sex ratio?
Even in species where sex determination isn't genetic
we see a close to 50/50 sex ratio.

- If the current sex ratio is females biased.

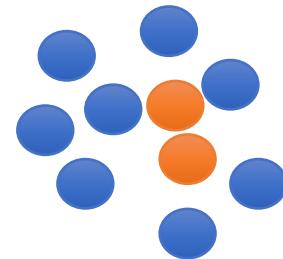


A new allele causes female carriers to produce more sons.

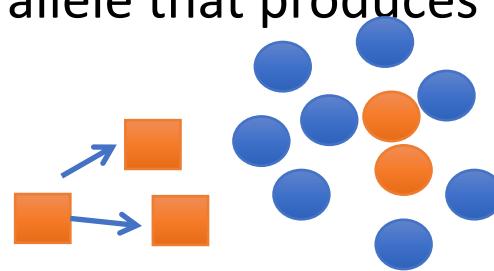


As a result individuals carrying that allele would have more grandkids. Thus this allele would initially spread.

- Similarly If the current sex ratio is male biased.



- Imagine a new allele that produces more daughters.



- The individuals carrying that allele would have more grandkids. Thus this allele would initially spread.

Why a 50/50 sex ratio?

- Alleles that move the sex ratio closer to 50/50 spread.
- If sex ratio is 50/50 then the population can not be invaded by allele that changes the sex ratio*
- This argument is an example of an evolutionary stable strategy.
 - If males and females are equally costly to produce, and the alleles are autosomal

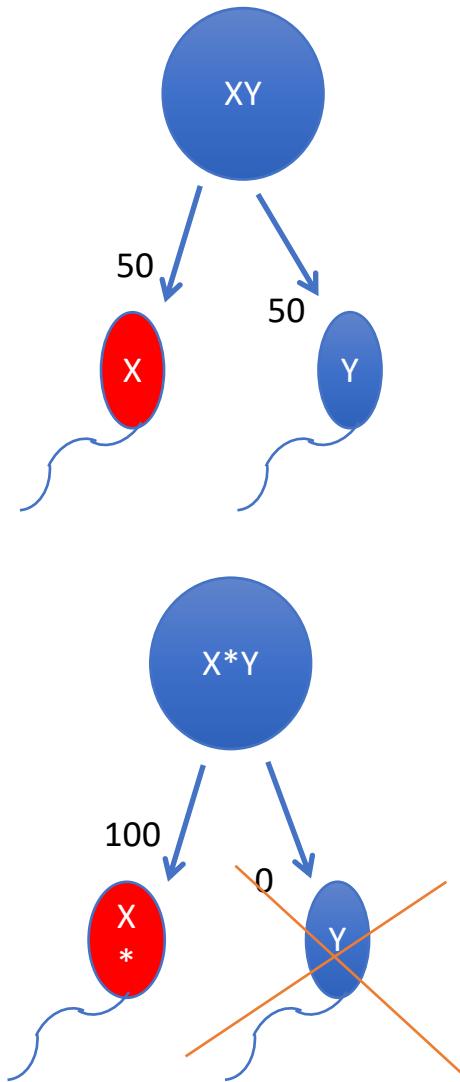
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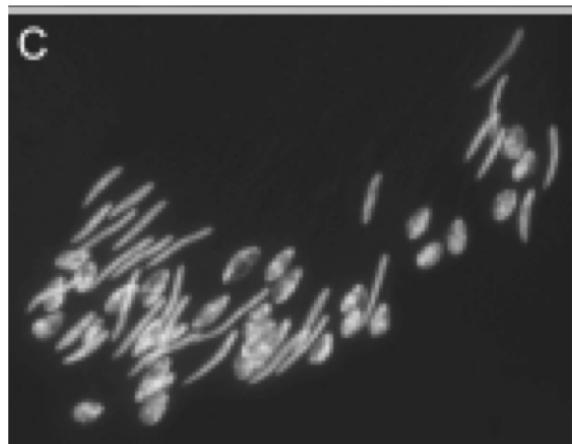
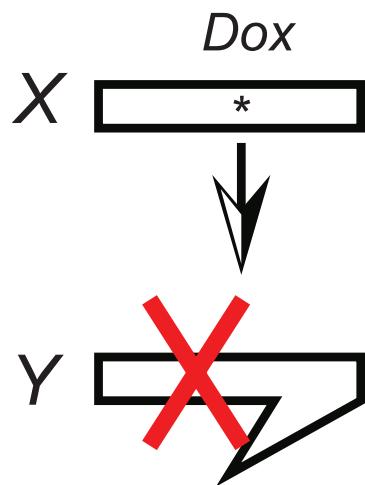
Selfish Genetic Elements: selection below the individual

Sex ratio distorters

- The X chromosome of a father is not transmitted to his male offspring.
- Therefore the X chromosome in males can benefit by evolving to damage sperm carrying the Y.



An example of a sex ratio distorter



Winters sex ratio distorter

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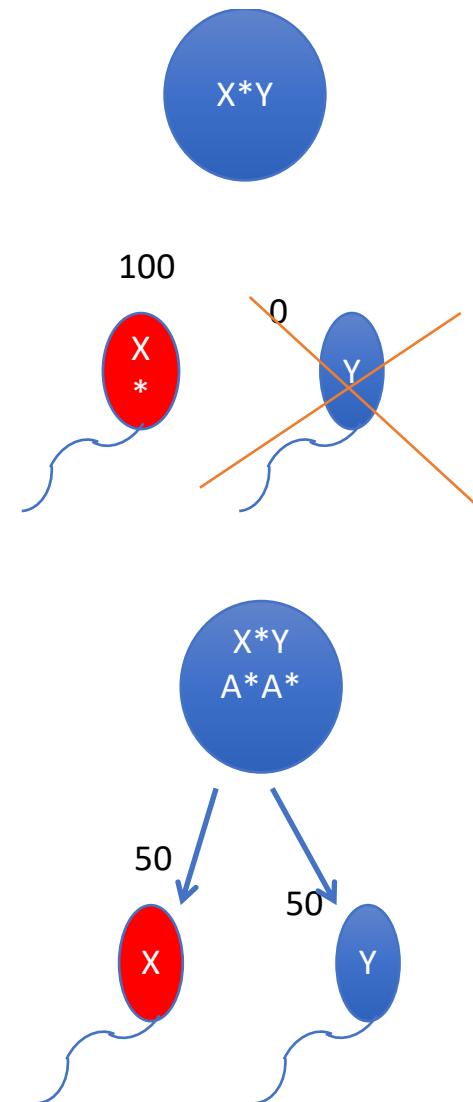
A sex-ratio Meiotic Drive System in *Drosophila simulans*. II: An X-linked Distorter

Yun Tao^{1,2*}, Luciana Araripe¹, Sarah B. Kingan¹, Yeyan Ke¹, Hailian Xiao², Daniel L. Hartl¹

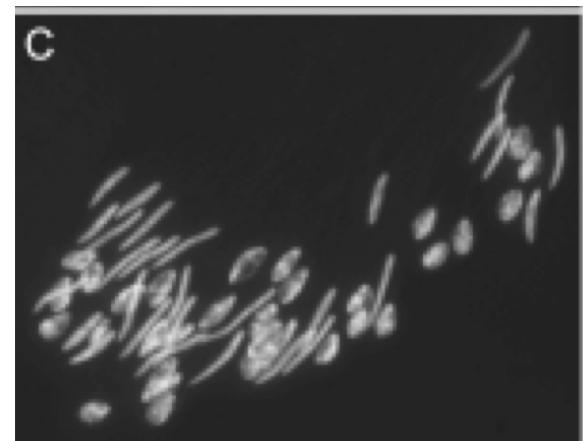
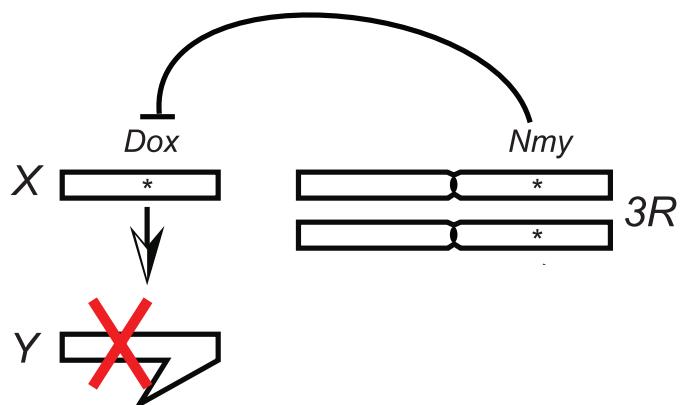
¹ Department of Organismic and Evolutionary Biology, Harvard University, Cambridge, Massachusetts, United States of America, ² Department of Biology, Emory University, Atlanta, Georgia, United States of America

Sex ratio distorters

- Subsequently suppressors of distortion can arise and spread restoring sex ratio to 50/50.
- These occur on the:
 - Other sex chromosome (e.g. Y)
 - Autosomes
- Systems of drivers and suppressors are frequently uncovered in crosses between species



An example of a sex ratio distorter



Winters sex ratio distorter

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A sex-ratio Meiotic Drive System in *Drosophila simulans*. I: An Autosomal Suppressor

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¹ Department of Organismic and Evolutionary Biology, Harvard University, Cambridge, Massachusetts, United States of America, ² Department of Biology, Emory University, Atlanta, Georgia, United States of America, ³ Department of Biology, University of Rochester, Rochester, New York, United States of America

Sequencing the Mouse Y Chromosome Reveals Convergent Gene Acquisition and Amplification on Both Sex Chromosomes

Y.Q. Shirleen Soh,^{1,2,7} Jessica Alföldi,^{1,2,7,8} Tatyana Pyntikova,¹ Laura G. Brown,^{1,3} Tina Graves,⁴ Patrick J. Minx,⁴ Robert S. Fulton,⁴ Colin Kremitzer,⁴ Natalia Koutseva,¹ Jacob L. Mueller,^{1,9} Steve Rozen,^{1,10} Jennifer F. Hughes,¹ Elaine Owens,⁵ James E. Womack,⁵ William J. Murphy,⁵ Qing Cao,⁶ Pieter de Jong,⁶ Wesley C. Warren,⁴ Richard K. Wilson,⁴ Helen Skaletsky,^{1,3} and David C. Page^{1,2,3,*}

