小麦基因组的战争与和平

Order From Chaos

— 转座子与小麦进化

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复旦大学生命科学学院

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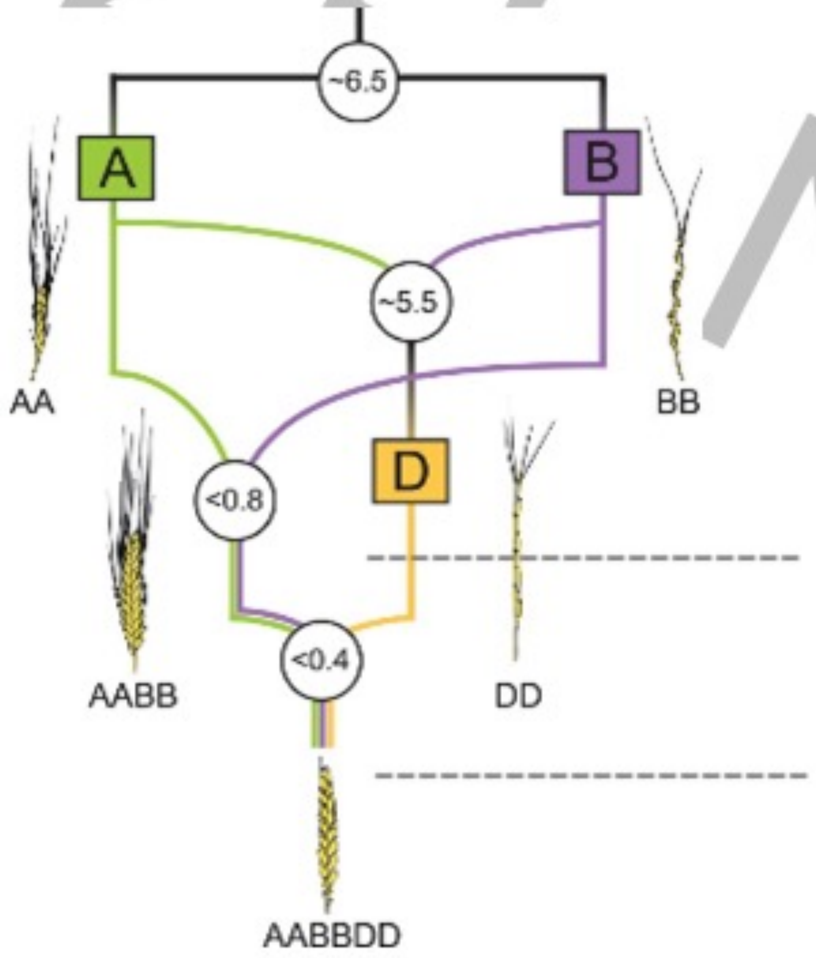
小麦进化 VS 人类进化



小麦驯化了人类 OR 人类驯化了小麦

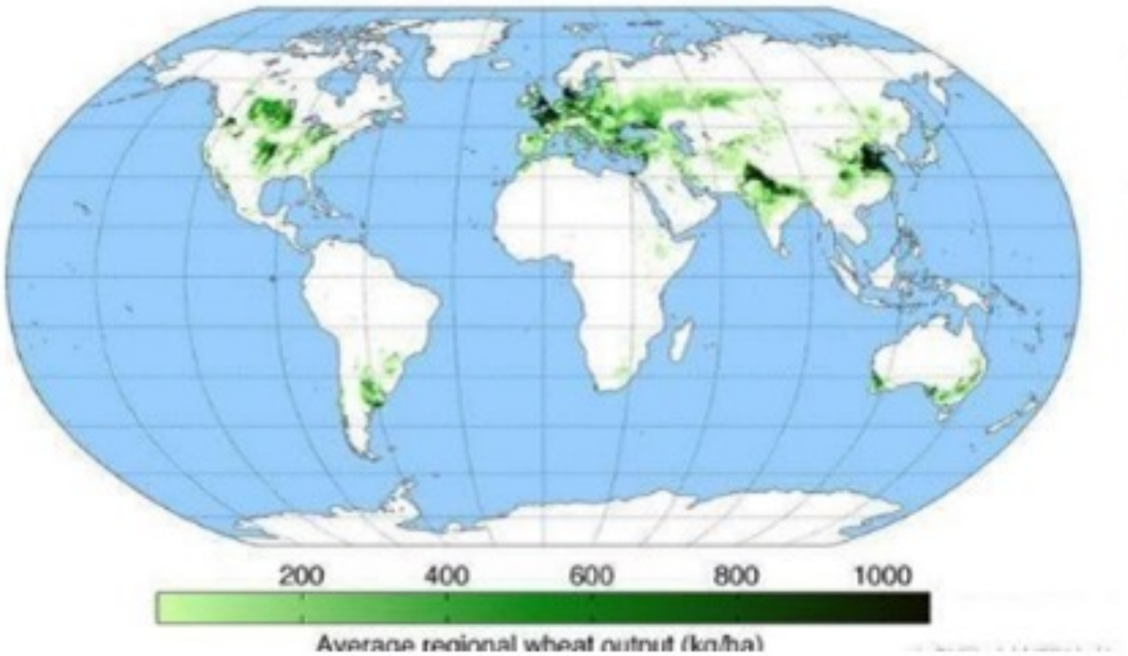
We did not domesticate wheat. It domesticated us."
—Yuval Noah Harari
Sapiens: A Brief History of Humankind (2018)

约公元20万年前
现代人起源

约公元1万年前
农业革命

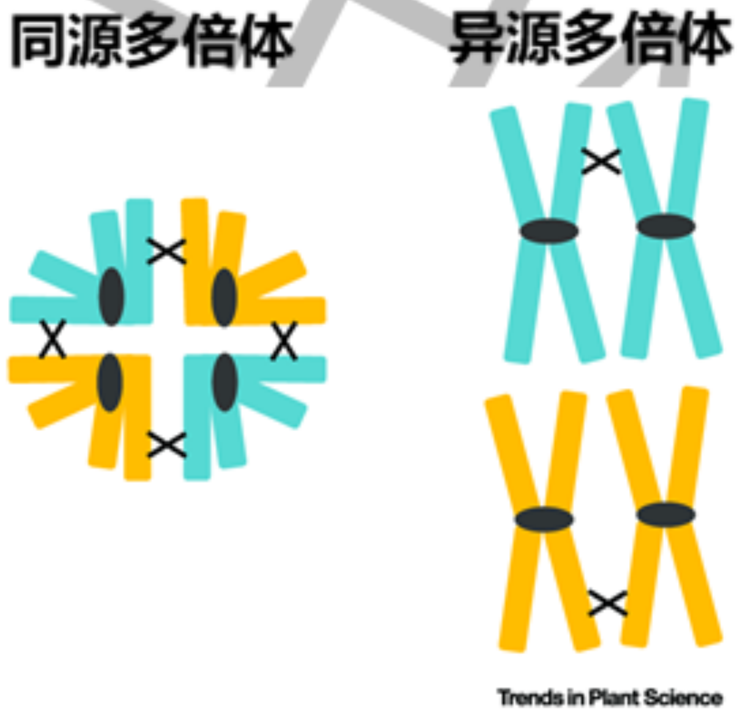
普通小麦是全球分布最广泛的谷物

多倍体普通小麦具有高度环境适应性



~4000到4500年前传入中国

同源、异源多倍体与适应性进化



推测多倍体优势的形成机制

- 加倍（同源+异源）：冗余，纯化选择压力降低，多态性提高
- 杂交（异源）：固定杂种优势

异源多倍体多态性: 个体增加 VS 群体匮乏（**多倍体瓶颈**）

转座子跳跃与杂交后新物种的形成

Barbara McClintock

The Nobel Prize in Physiology or Medicine

1983

THE SIGNIFICANCE OF RESPONSES OF THE GENOME TO CHALLENGE

Nobel lecture, 8 December, 1983

by

BARBARA McCLINTOCK

Carnegie Institution of Washington
Cold Spring Harbor Laboratory
Cold Spring Harbor, New York, U.S.A.

such initial hybrids. The commercially useful plant, *Triticale*, is an example. Wheat *(Triticum)* and rye (Secale) were crossed and the combined set of chromosomes doubled to provide reproductive stability. Nevertheless, this genome was not altogether stable. Selections continued in later generations for better perfor-

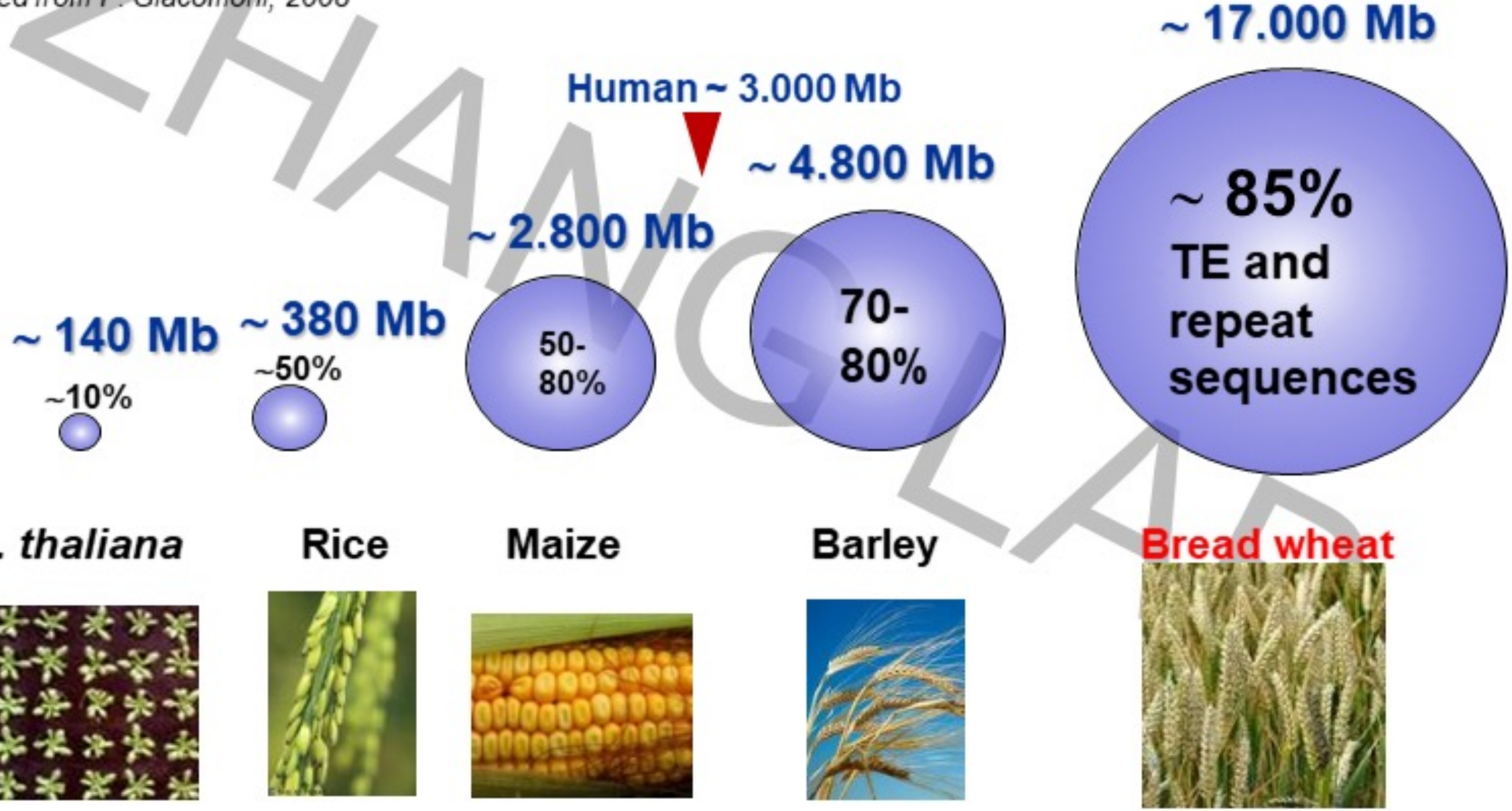
小麦族物种杂交基因组物种的稳定性与选择

degrees of freedom in considering such origins. It is difficult to resist concluding that some specific "shock" was responsible for the origins of new species in the two instances to be described below.

可能存在特殊的"shock"贡献于新物种的产生

小麦庞大的基因组与转座子的爆发

Modified from F. Giacomoni, 2008



六倍体小麦基因组中矛盾的平衡

转座子扩张：转座子VS宿主

异源多倍体：亚基因组之间

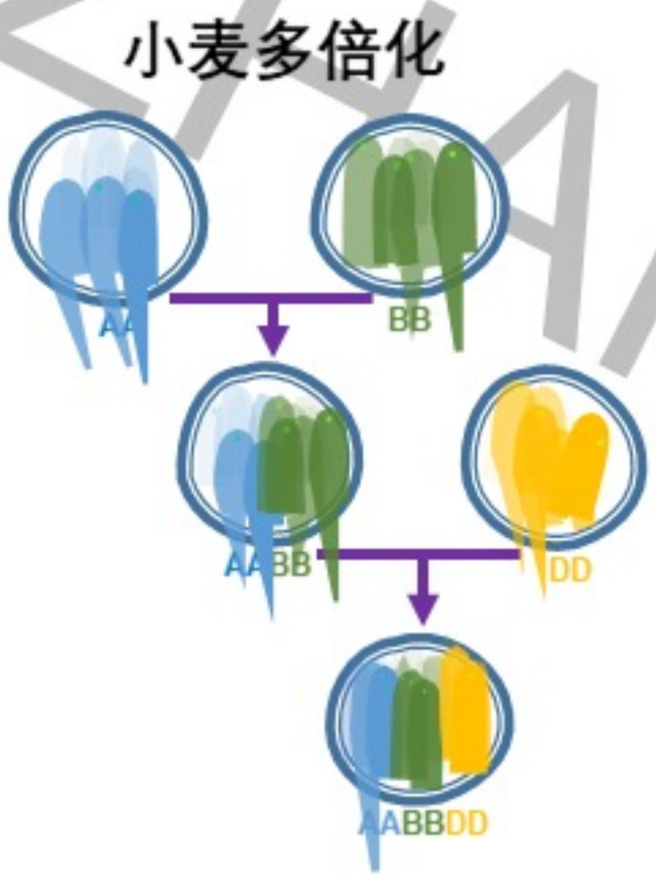
独立VS互作（染色体层面）

分化VS协同 （基因层面）

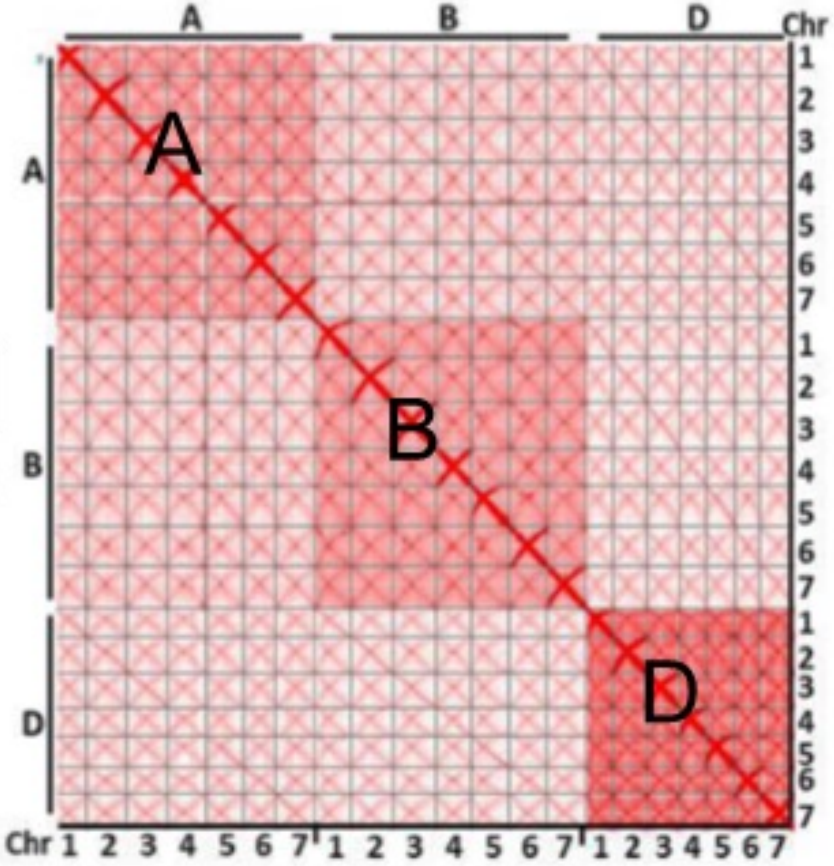
⬇

多倍体小麦的适应性进化

三套不同的亚基因组如何相对独立而稳定存在于细胞中?



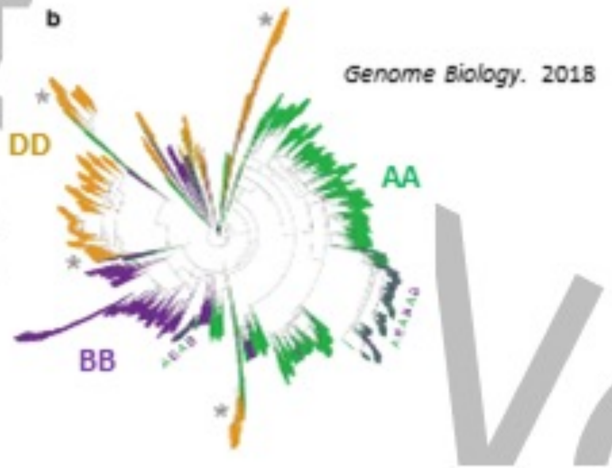
多倍化后亚基因组稳定性的维持?



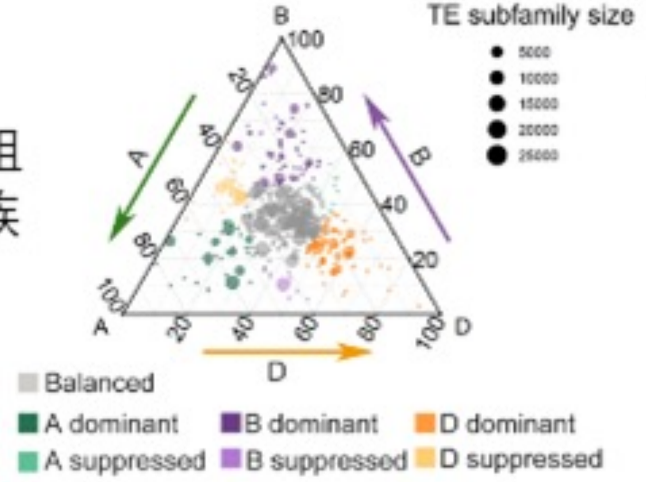
亚基因组内部染色体间具有强互作

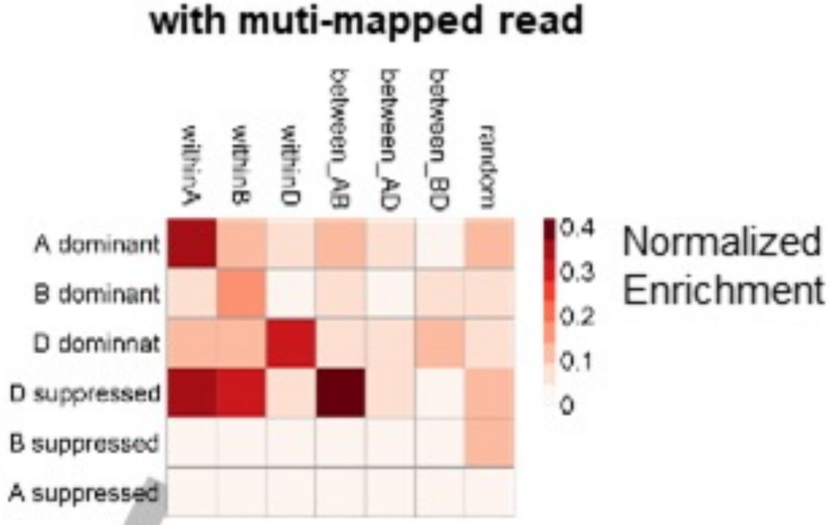
亚基因组特异性转座子富集在亚基因组内部染色体互作区

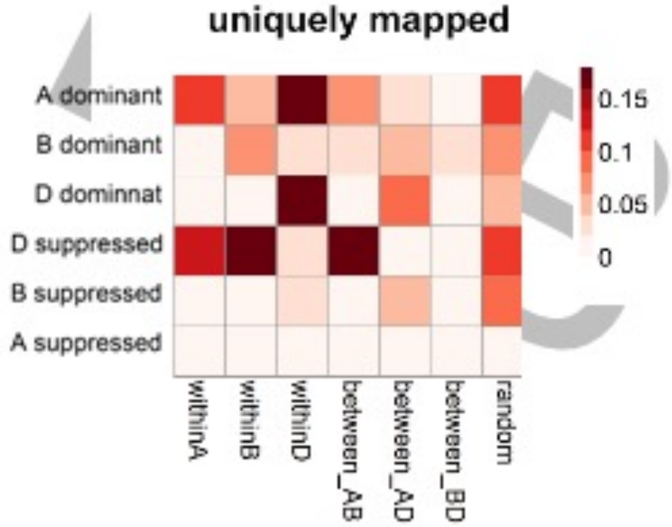
亚基因组独立
进化的TE家族



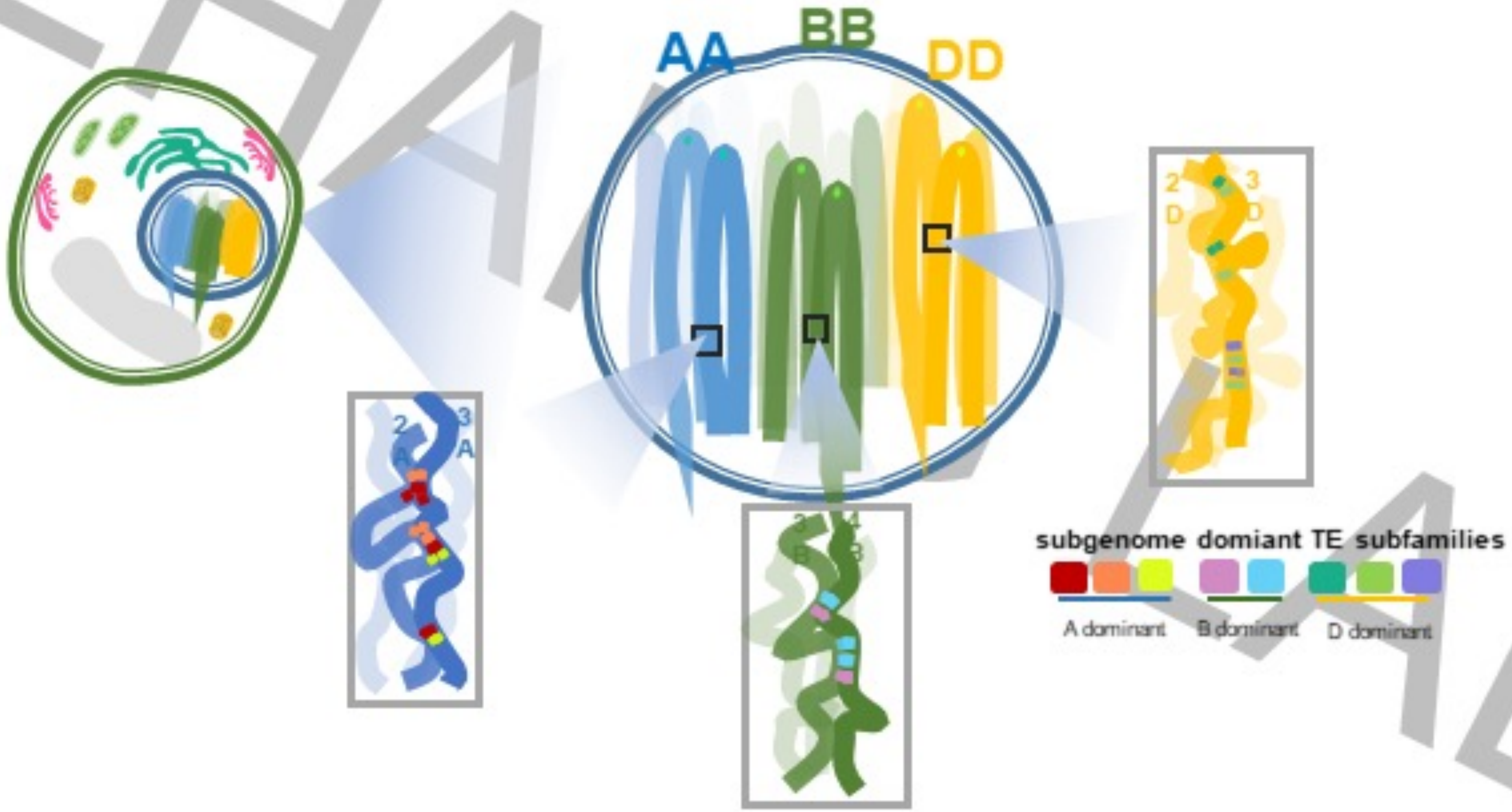
定义亚基因组
偏好性TE家族







亚基因组稳定性模型

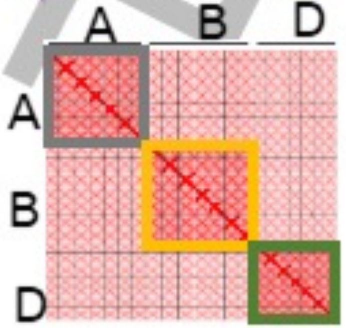


Genome Biology, 2021

小麦转座子多层面参与调控小麦基因组演化

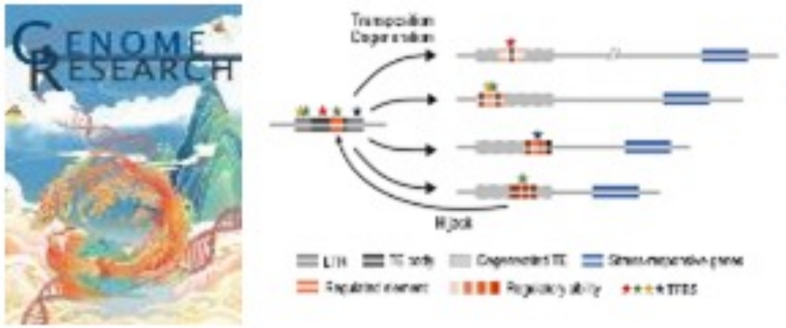
亚基因组独立VS互作

转座子 ↔ 高级结构 → 多倍体稳定性



Genome Biology, 2021

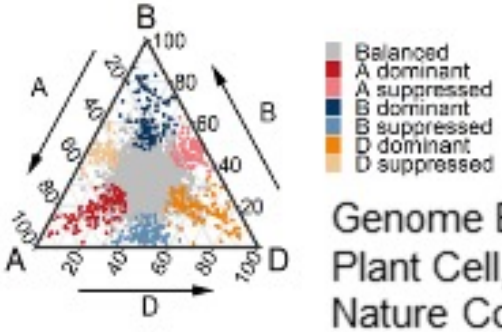
转座子VS宿主基因



Genome Research, 2021

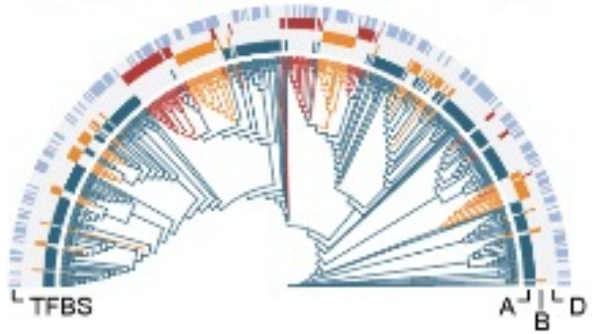
小麦转座子
与基因组
演化

亚基因组分化VS协同



Genome Biology, 2019,2022
Plant Cell, 2021
Nature Communications, 2022

转座子的演化 VS 调控的演化



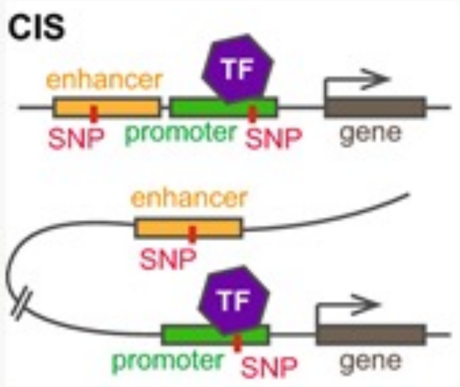
基因 VS. 基因调控

VS

顺式与反式元件

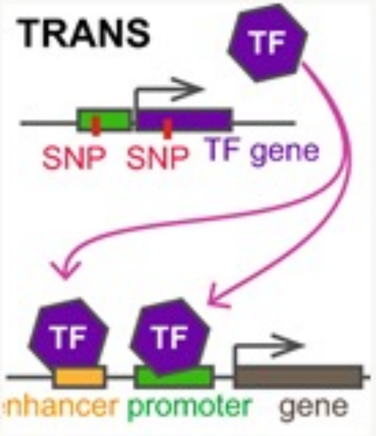
顺式元件

- 启动子
- 增强子

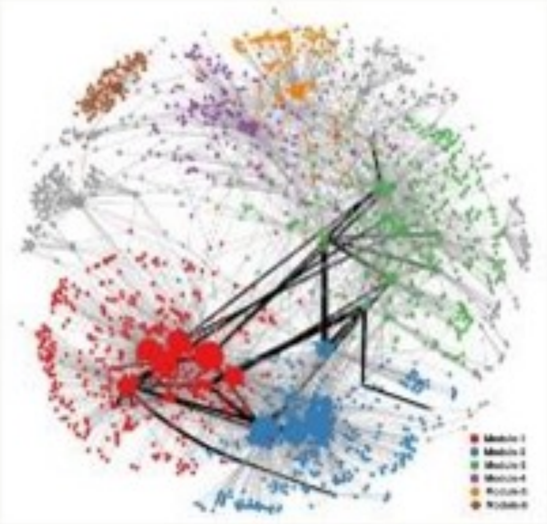


反式因子

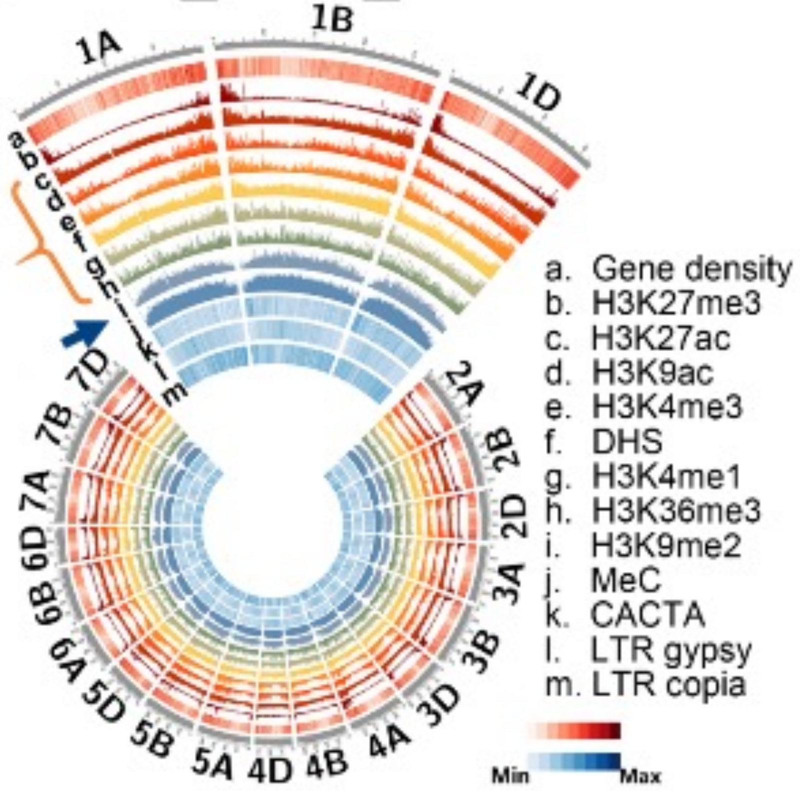
- 转录因子
- 表观因子



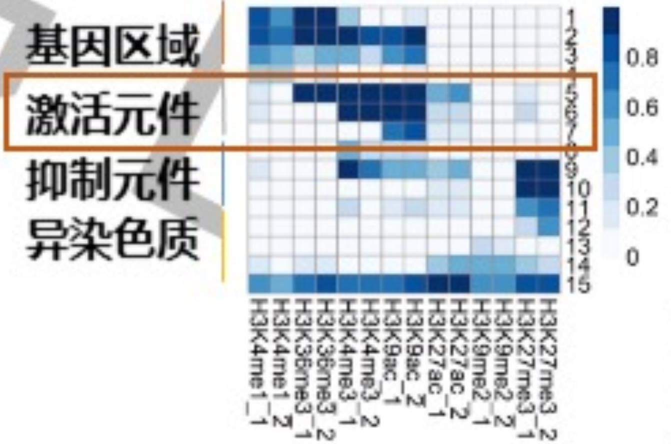
调控网络



一、顺式元件：表观组合鉴定DNA调控元件



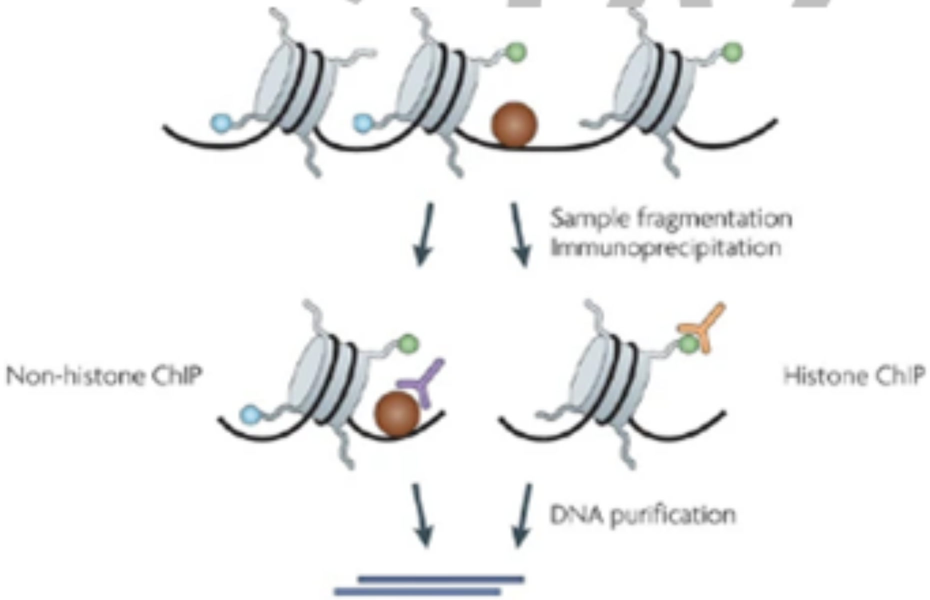
Genome Biology (2019)



23563个顺式元件

二、反式因子：转录因子全基因组刻画方案

ChIP-seq vs. DAP-seq



ChIP-seq:

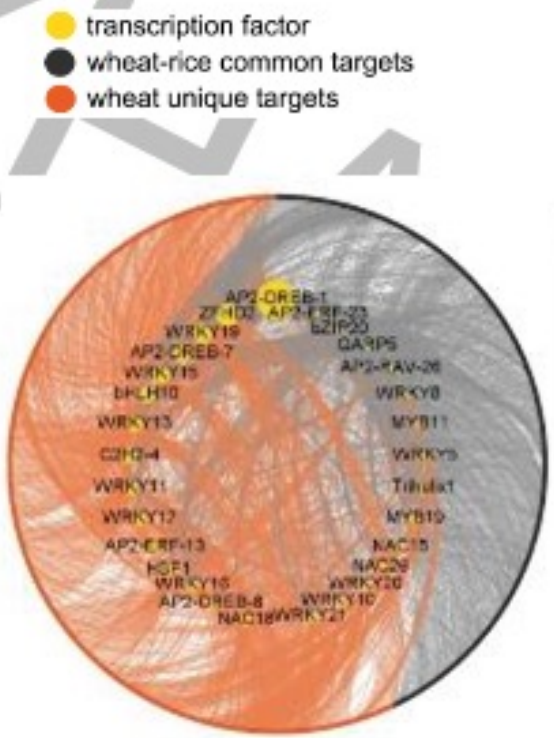
体内抗体免疫沉淀转录因子结合位置

DAP-seq:

体外表达转录因子

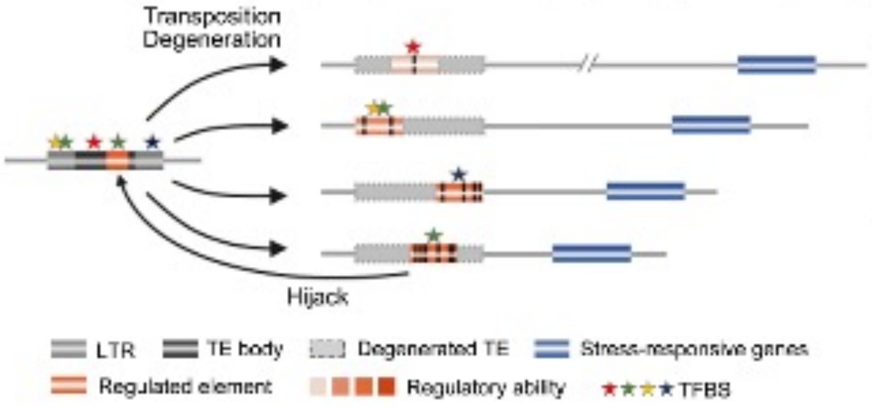
Bartlett et al. Nat Protoc 2017

转座子贡献于调控网络的扩张



2021.12

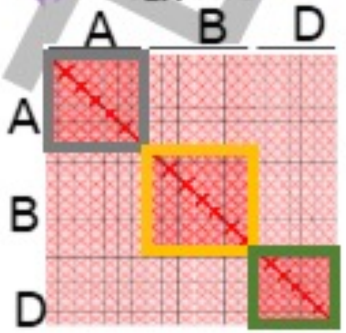
TE来源TFBS持续贡献于小麦转录调控网络的扩张



小麦转座子多层面参与调控小麦基因组演化

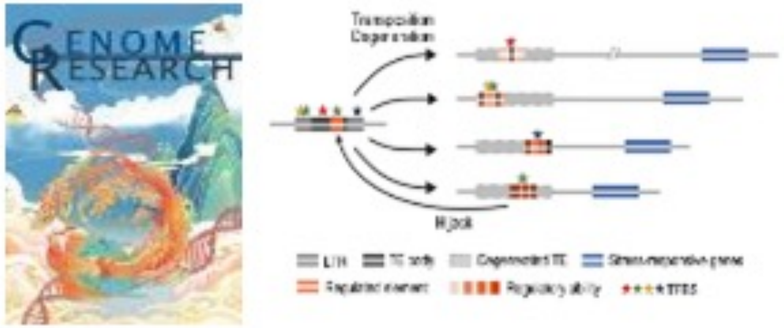
亚基因组独立VS互作

转座子 ⇔ 高级结构 ⇒ 多倍体稳定性



Genome Biology, 2021

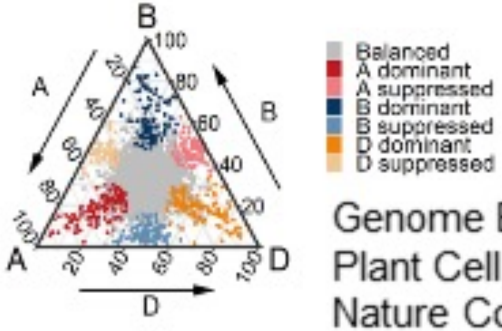
转座子VS宿主基因



Genome Research, 2021

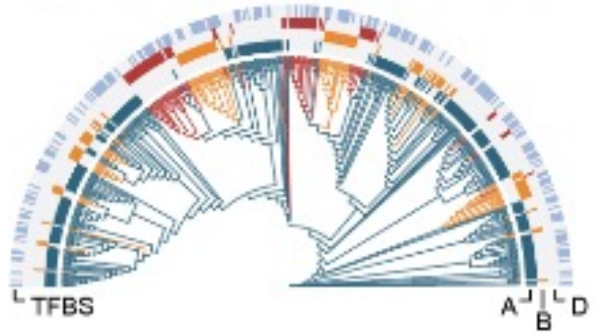
小麦转座子
与基因组
演化

亚基因组分化VS协同

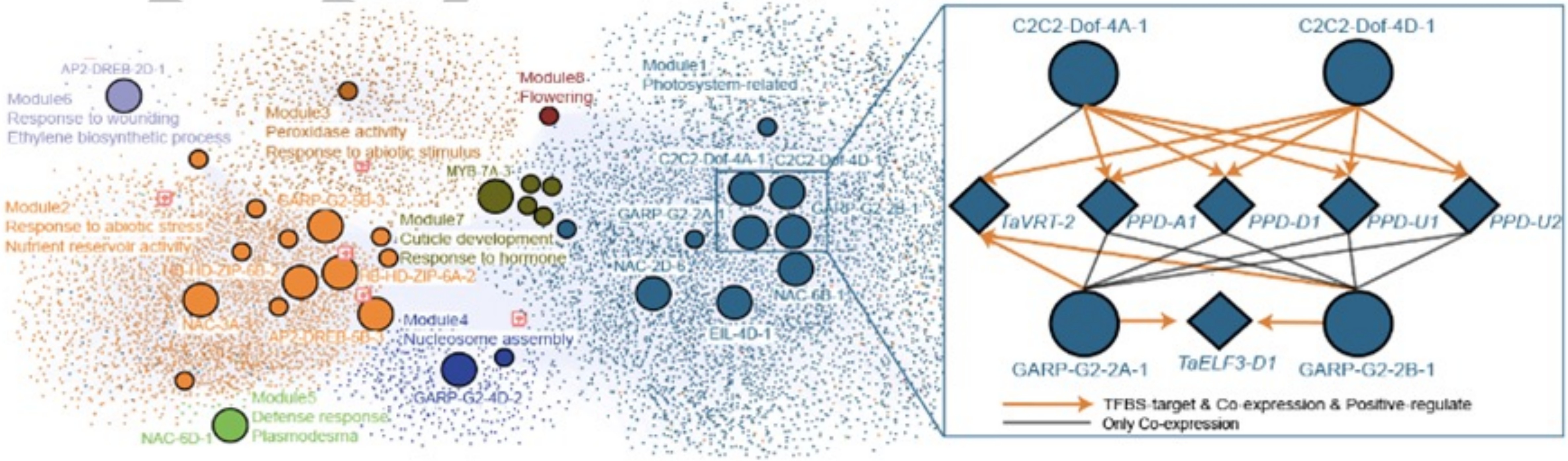


Genome Biology, 2019,2022
Plant Cell, 2021
Nature Communications, 2022

转座子的演化 VS 调控的演化

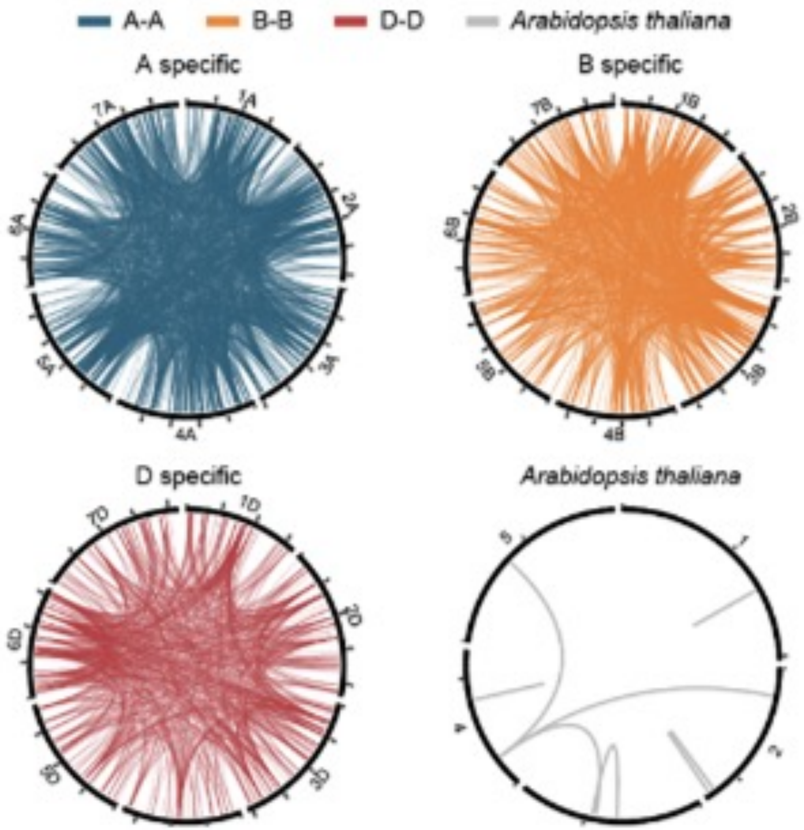


六倍体小麦转录调控网络搭建

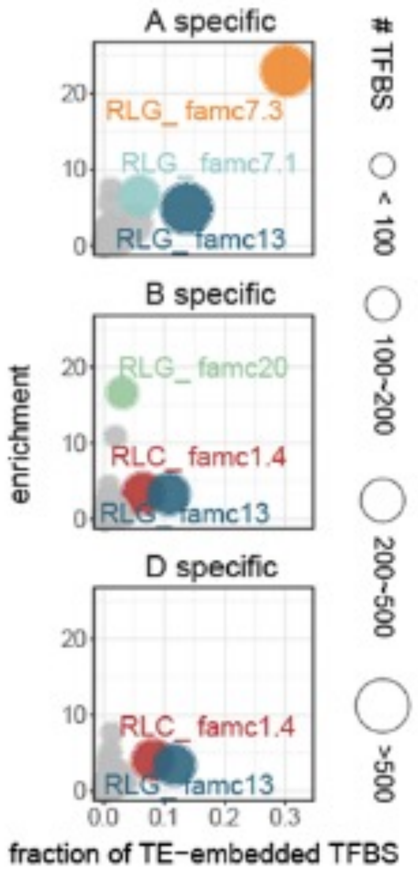


亚基因组特异TE扩张贡献亚基因组特异TFBS扩张

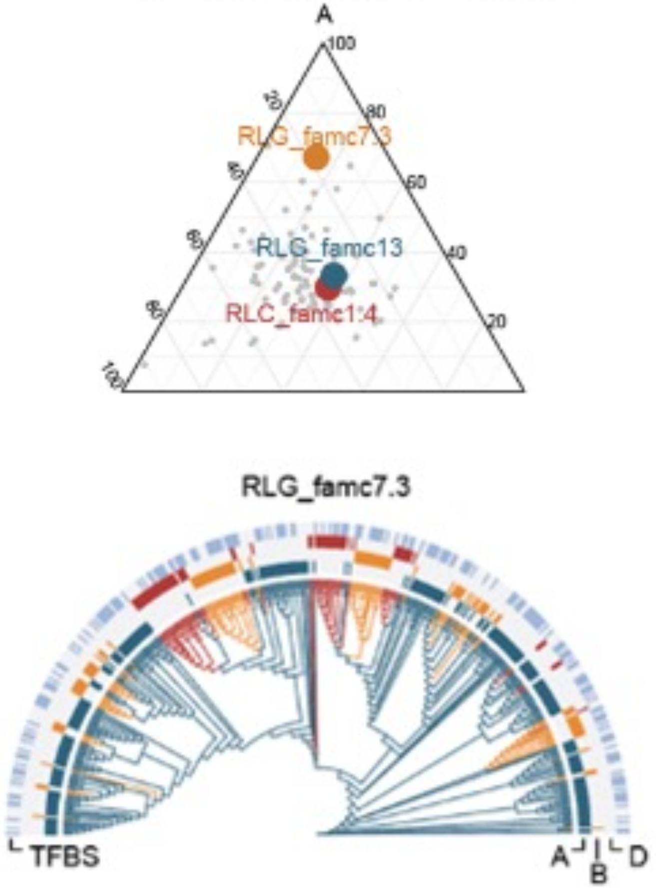
普通小麦TFBS亚基因组特异性扩张



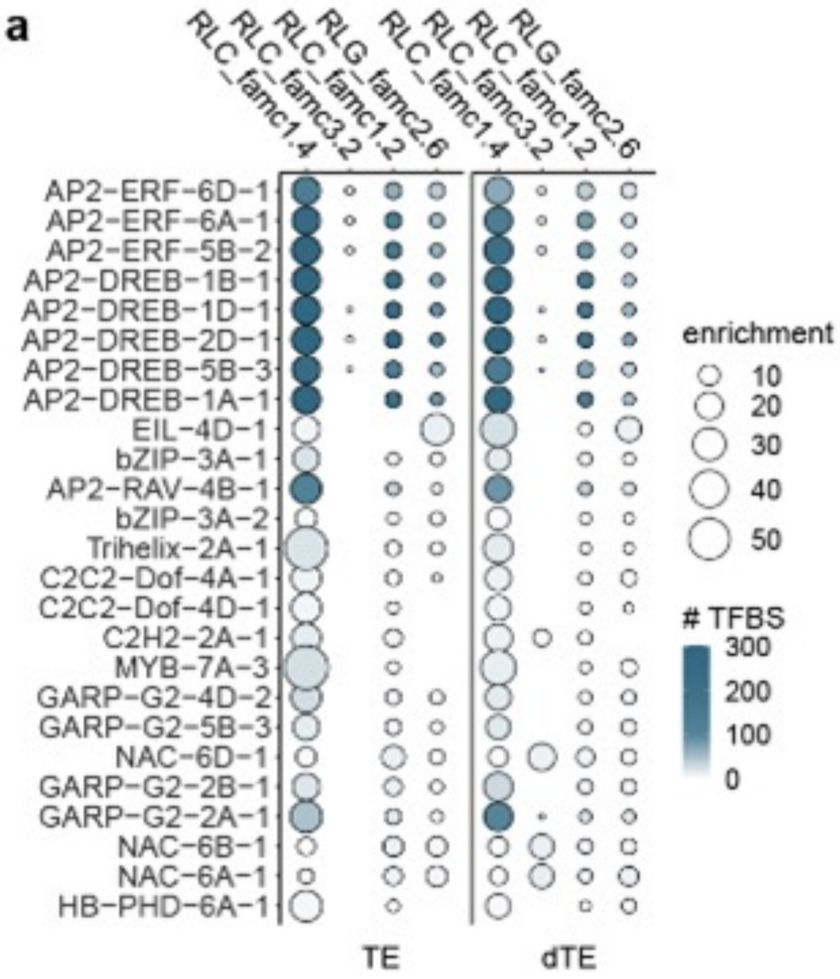
富集特定TE家族

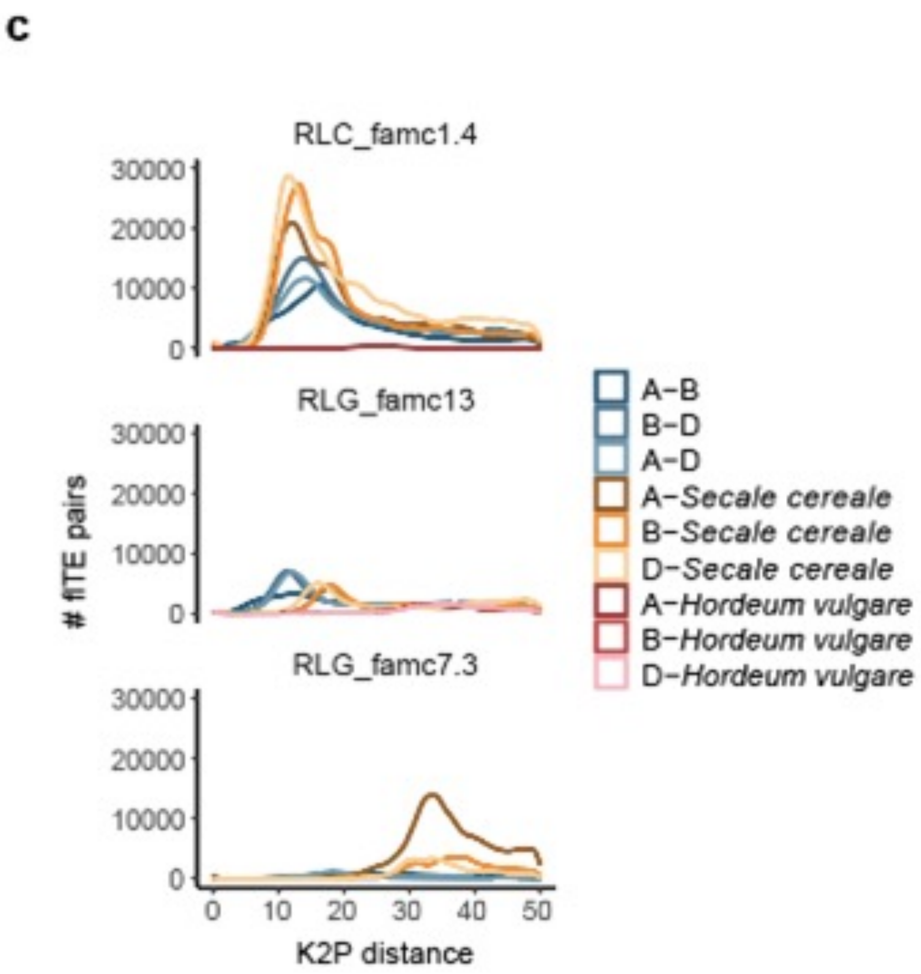


TE家族的特异性扩张

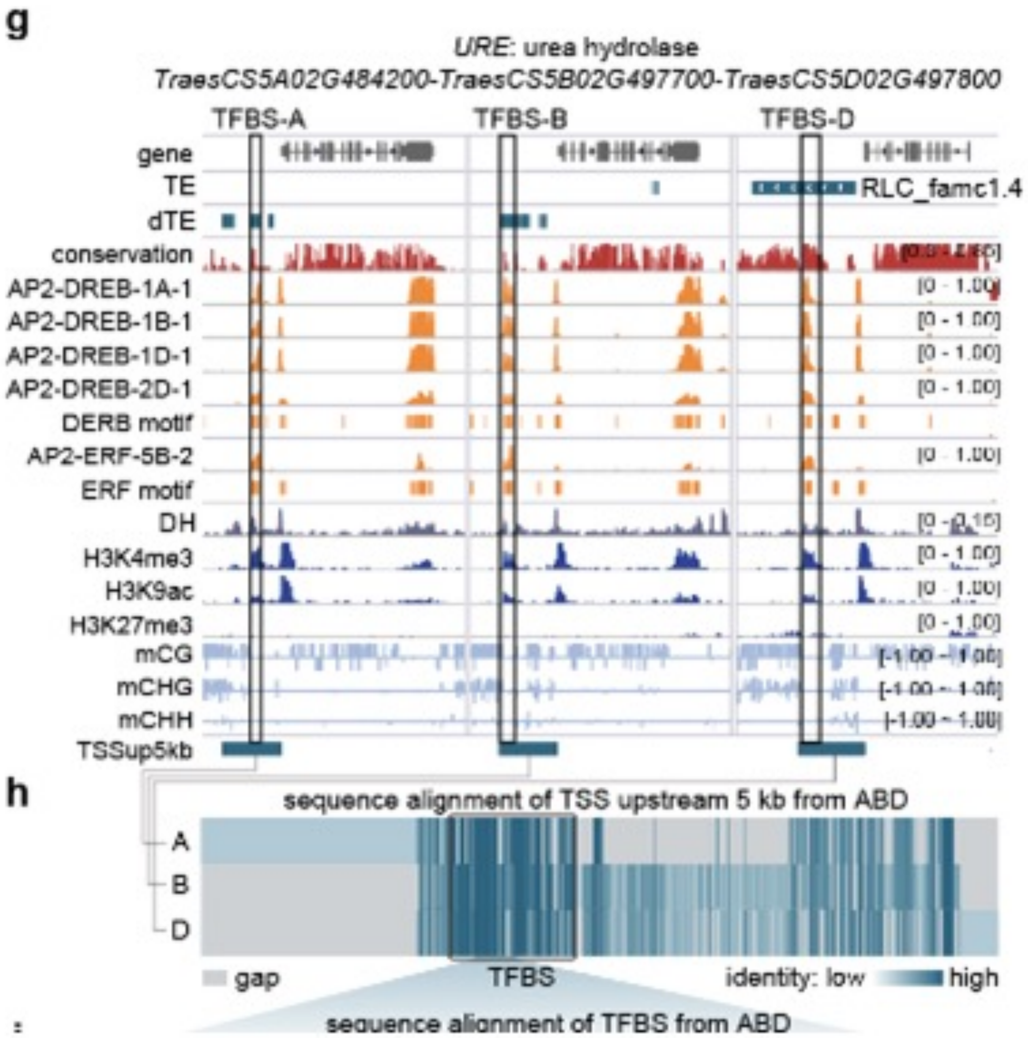


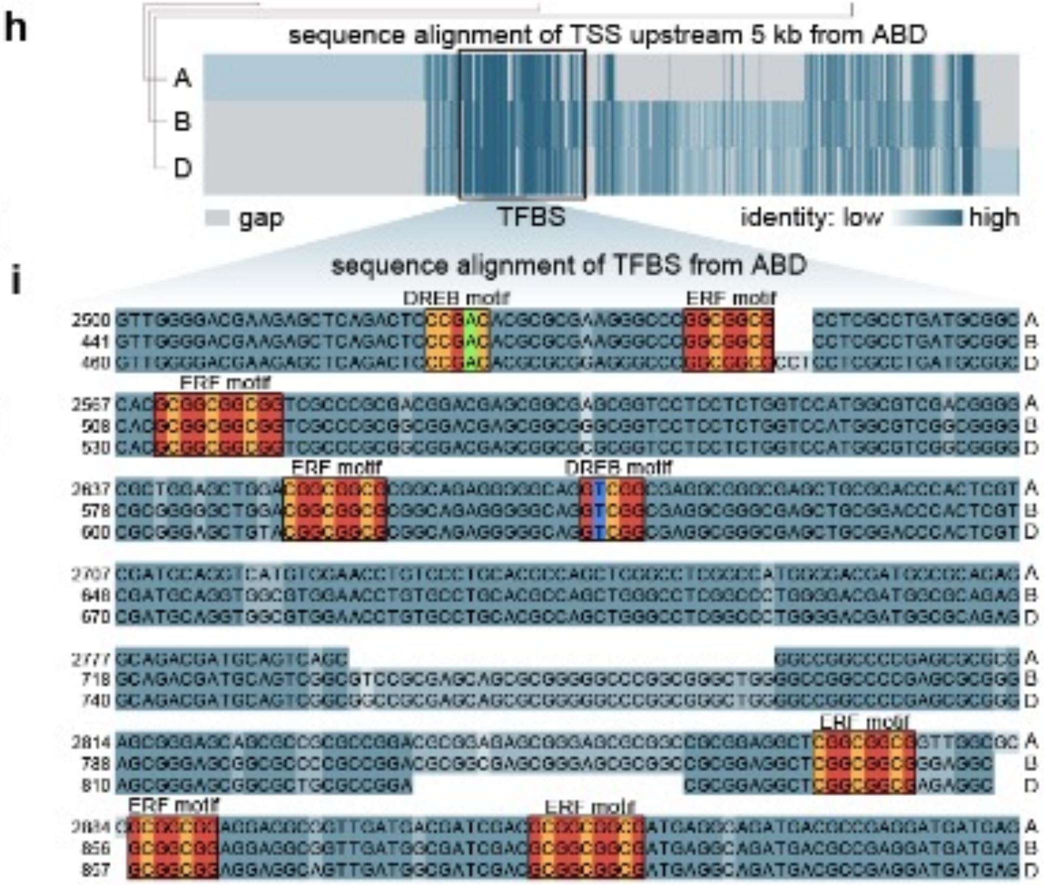
古老TE的扩张与平行选择贡献于亚基因组平衡的TFBS



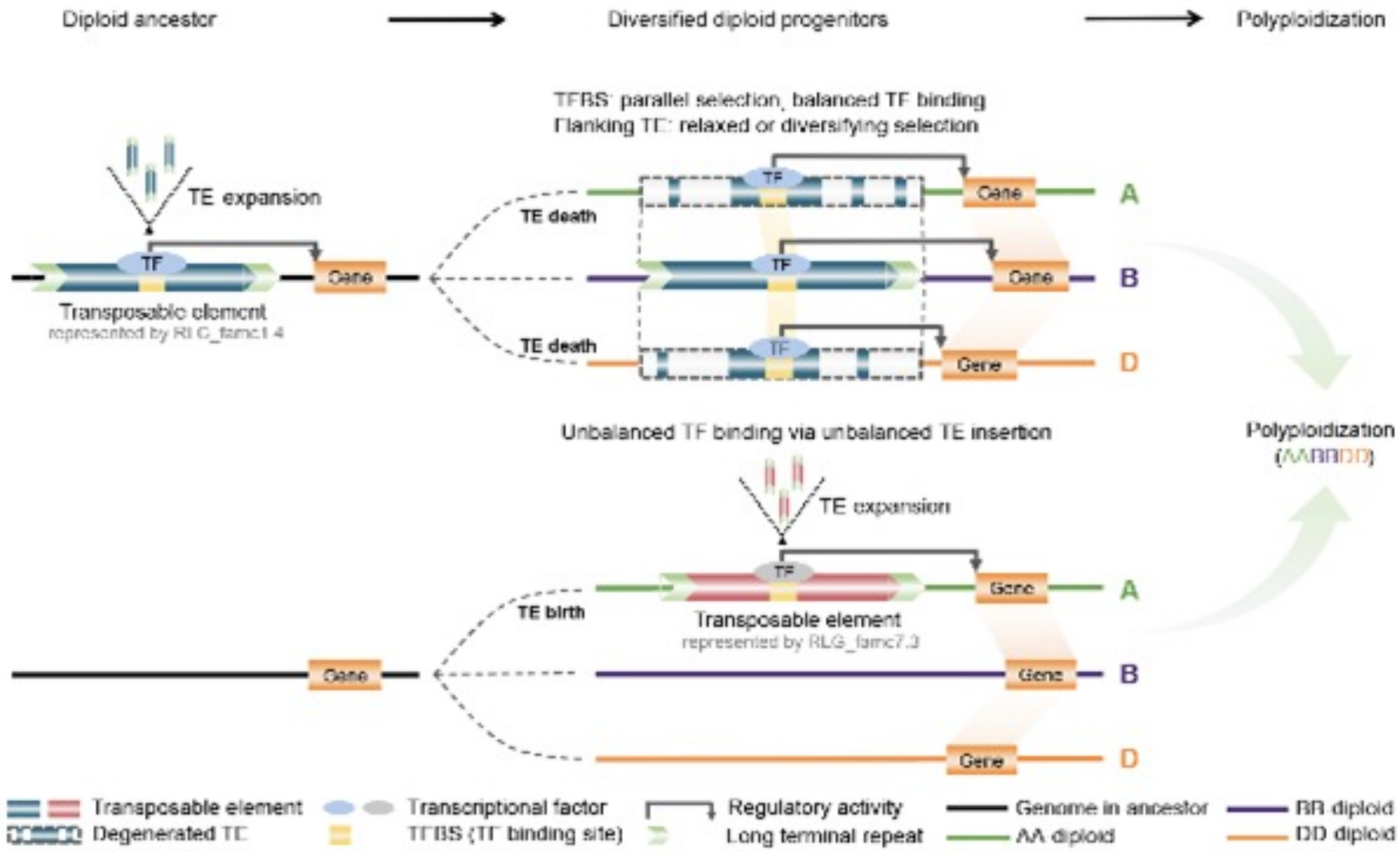


示例：平衡的TFBS，不平衡的TE降解





TE 池的多态性与多倍体调控的可塑性



Nature Communications (2022)

普通小麦不“普通”

人类驯化了小麦
小麦驯化了人类

垃圾序列不"垃圾”

基因组驯化了转座子
转座子驯化了基因组