

THE CAMPBELL-STATON GROUP



PRINCETON UNIVERSITY

Evolution in the Age of Us: Mechanisms of adaptation to a human-modified world

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Princeton University

Evolution in the Anthropocene

Nuclear Disaster



Pollution



Urbanization



Human-Wildlife Conflict





Border Politics



Climate Adaptation

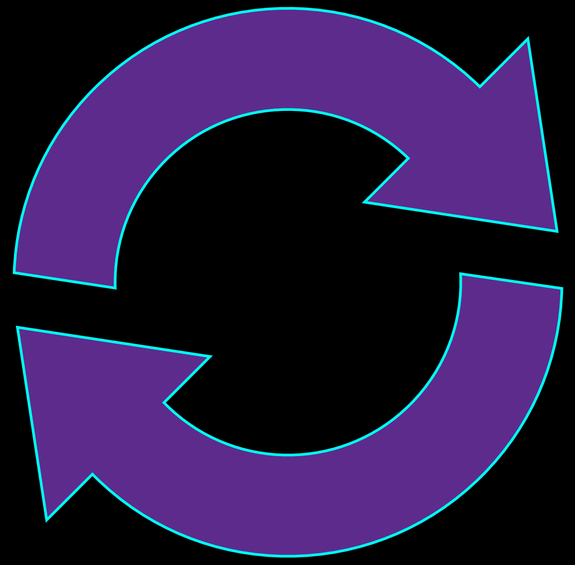




Extreme Weather Events

REVEALS THE LASTING
BIOLOGICAL IMPACTS OF

Evolution



Anthropogenic Change

PROVIDES UNIQUE
INSIGHTS ABOUT THE
PROCESS OF

FEATURED PROJECTS

Evolution in the Anthropocene

PART I

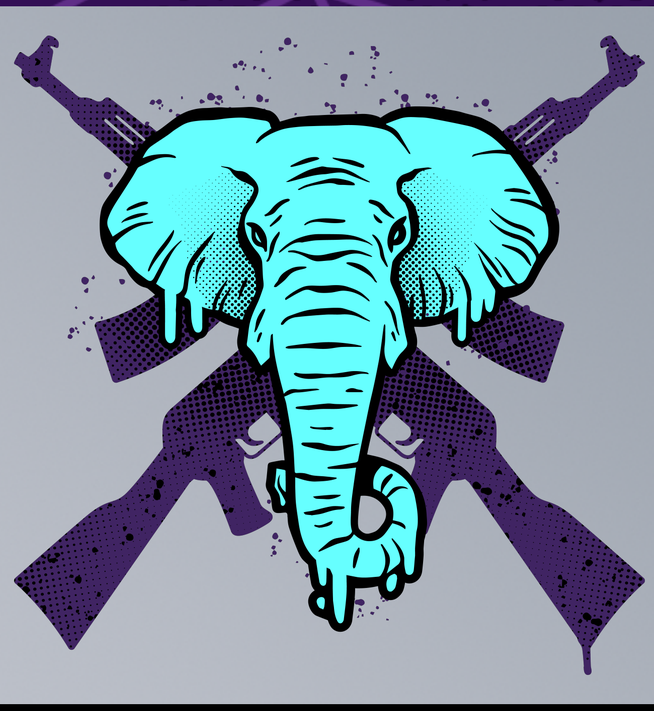
THERMAL STRESS AND ADAPTATION OF COMPLEX TRAITS



URBANIZATION

PART II

ECOLOGICAL IMPACTS OF HUMAN-MEDIATED SELECTION



HUMAN-WILDLIFE CONFLICT

PART III

HUMAN-MEDIATED SELECTION AND EVOLUTIONARY MEDICINE



CONTAMINATION/ POLLUTION

URBANIZATION

THERMAL STRESS AND ADAPTATION OF COMPLEX TRAITS

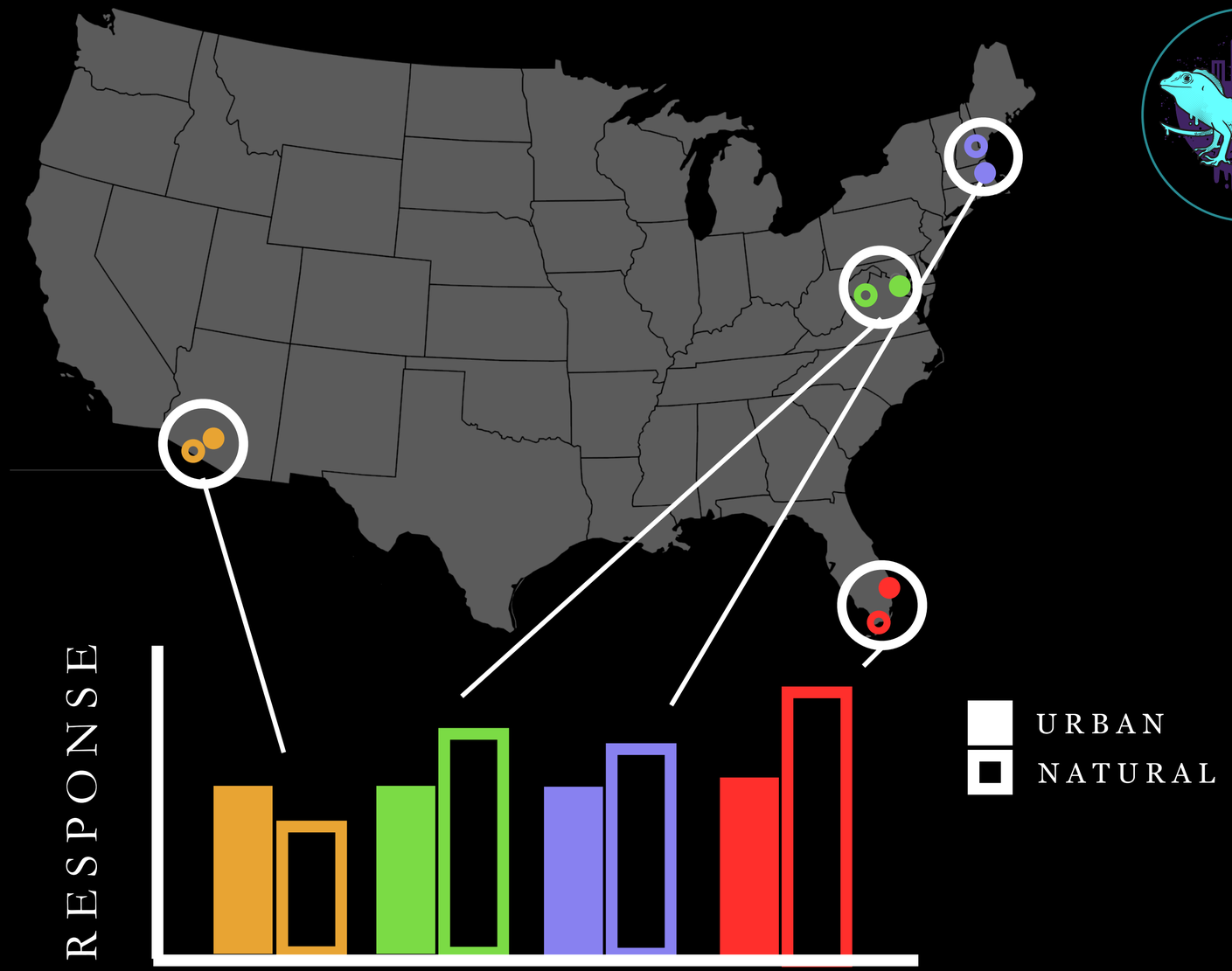




Ecological Homogenization of Urban Environments

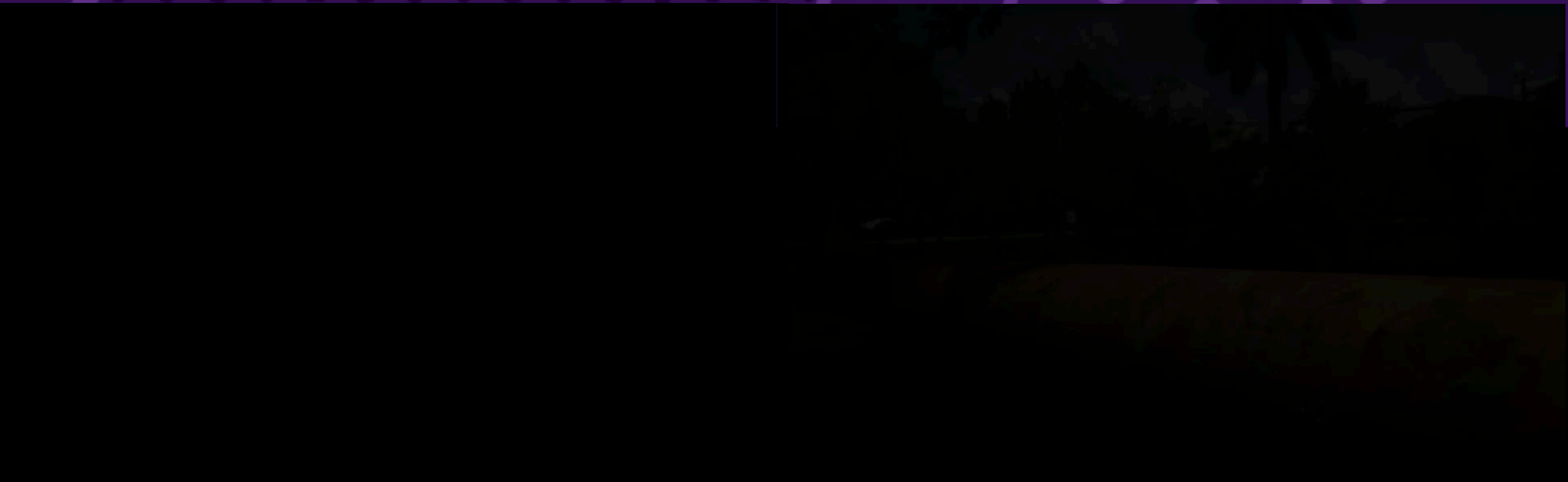
Gould Revisited:

DO POPULATIONS THAT COLONIZE HUMAN-MODIFIED ENVIRONMENTS FIND SIMILAR EVOLUTIONARY PATHS TO ADAPTATION?



Modified from Groffman et al. 2005, *Front. Ecol. Envir.*

Urbanization: Global Environmental Homogenization

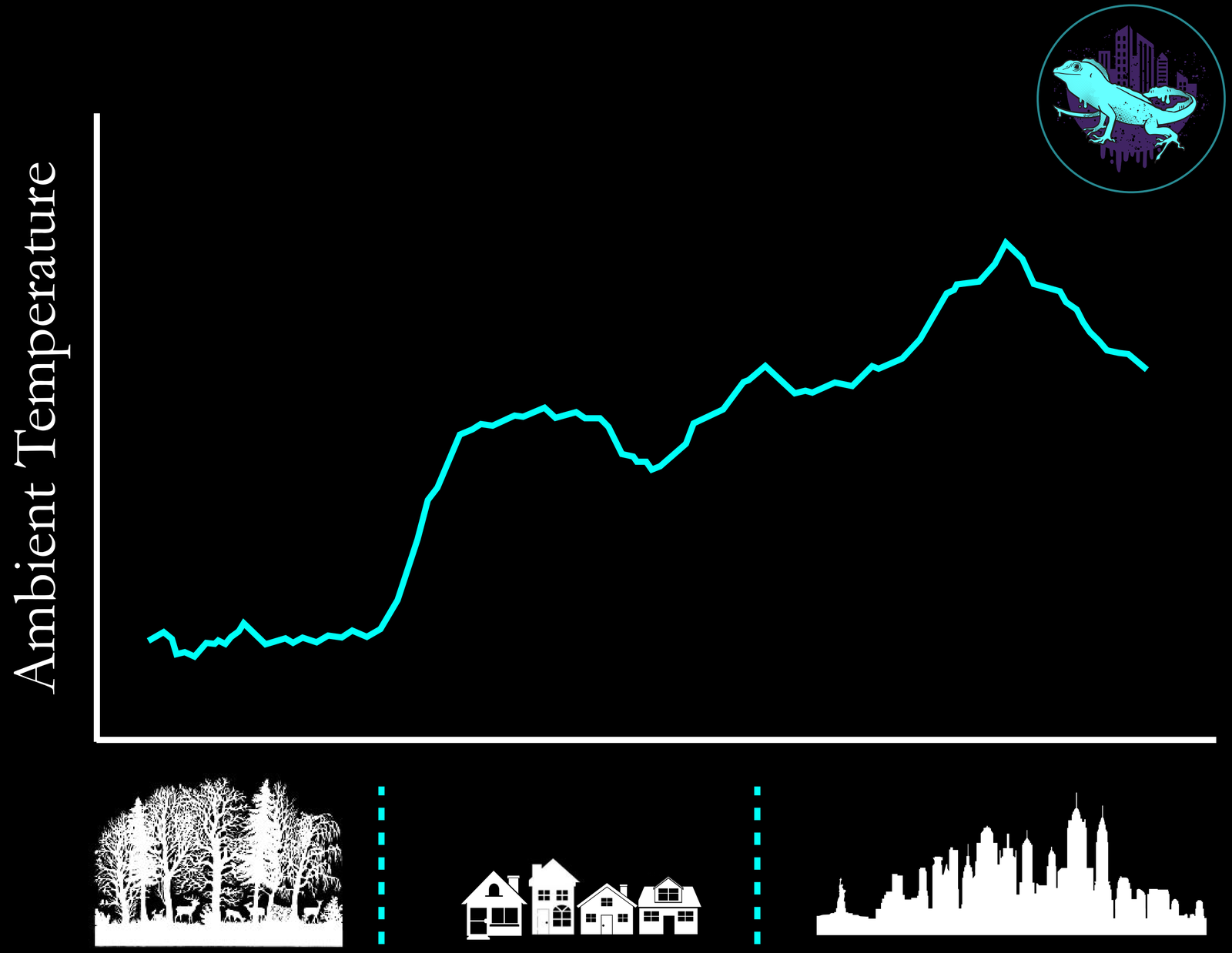


FOREST

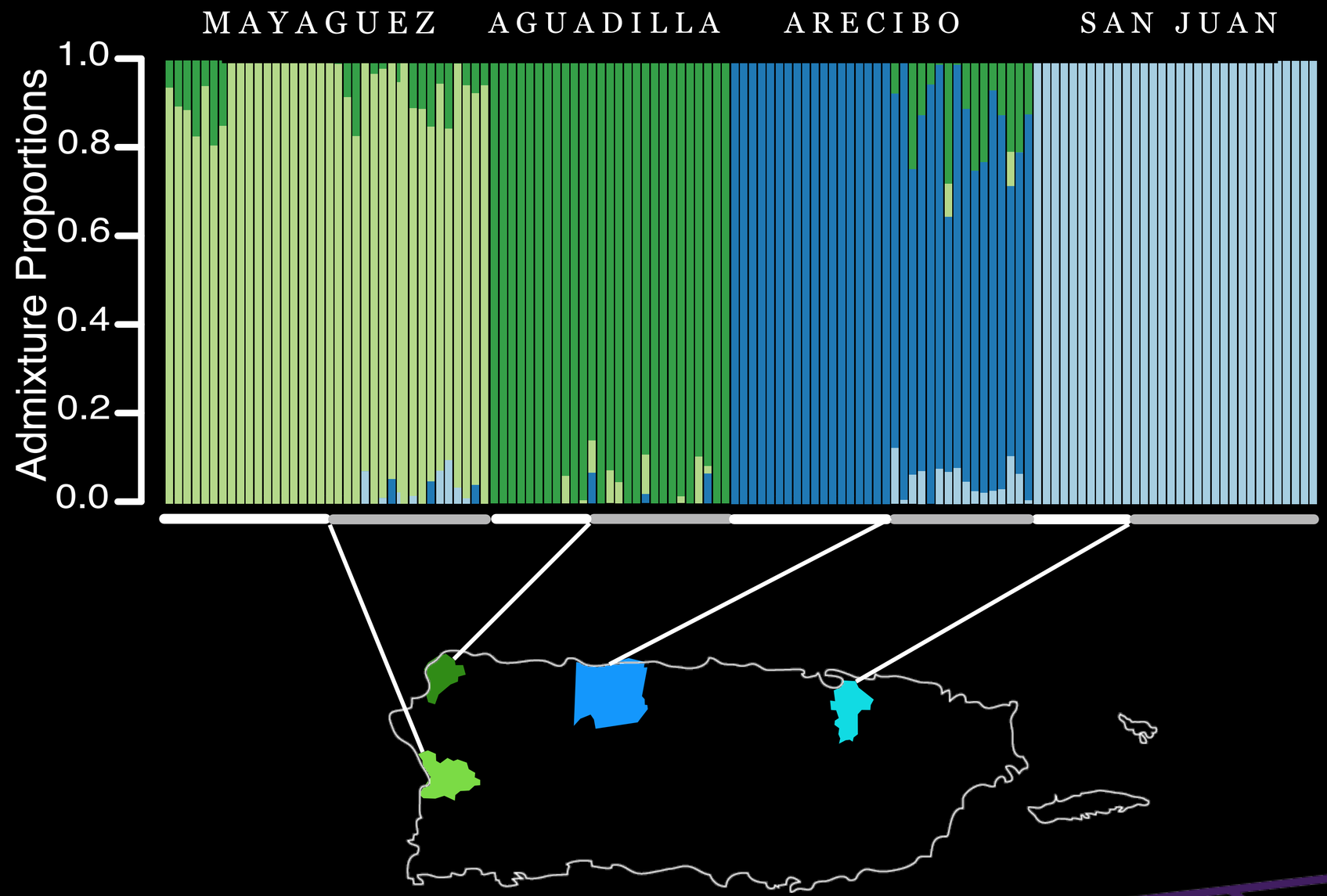
URBAN

Urban Heat Island Effect

IMPERVIOUS SURFACES IN DENSE URBAN AREAS CREATE LOCALLY ELEVATED TEMPERATURES



Modified from Oke 1978, *Atmos. Environ.*



PARALLELISM

Genetic structure across municipalities

Provides a framework for testing the repeatability of urban adaptation

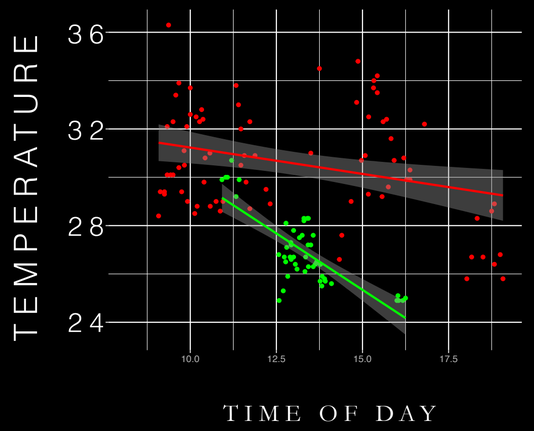
MAJOR FINDINGS

Divergence thermal profiles across habitats

Lizards in urban environments endure higher temperatures than their forest counterparts throughout the day

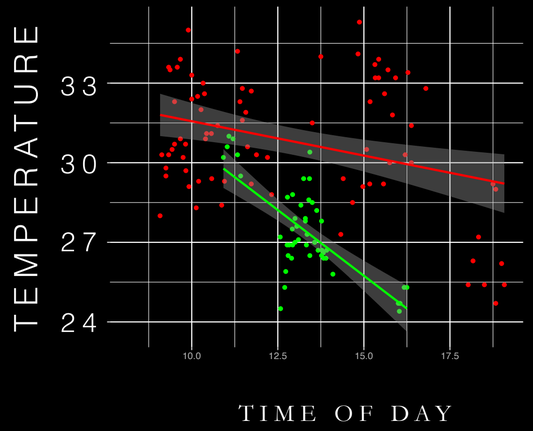
OPERATIVE TEMPERATURE

3.806 +/- 0.363



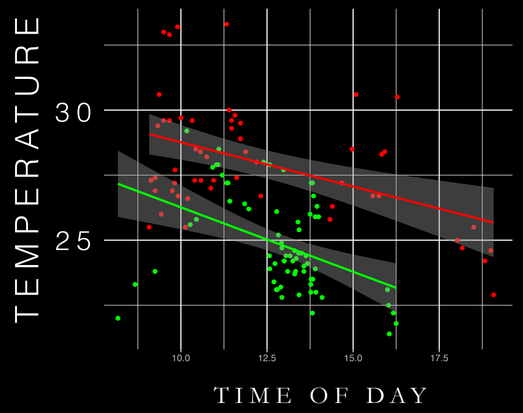
PERCH TEMPERATURE

2.974+/- 0.372



BODY TEMPERATURE

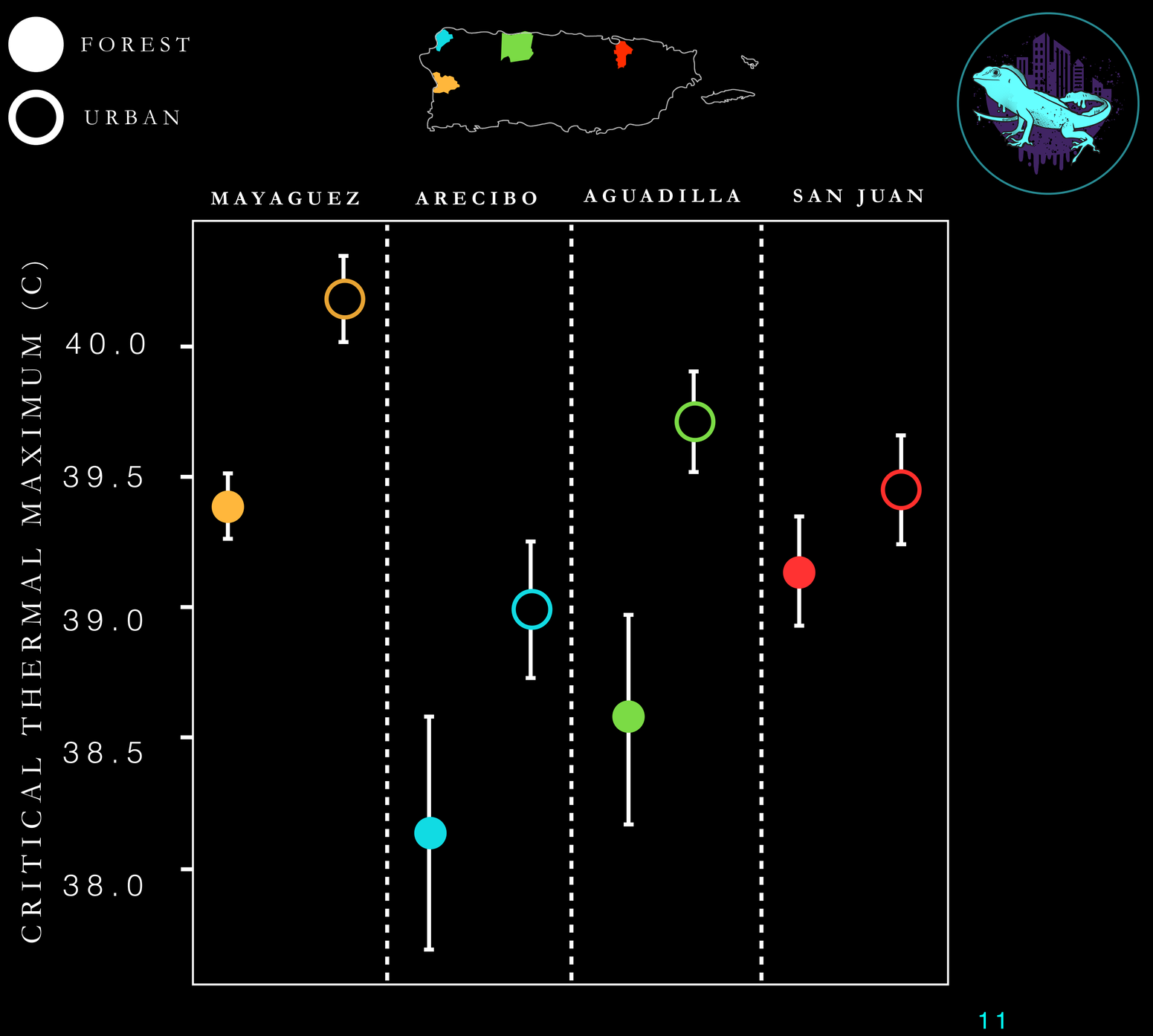
3.449 +/- 0.397



CAMPBELL-STATON ET AL. 2020, *NAT. ECO. EVO.*

Temperature - dependent functional divergence between habitats

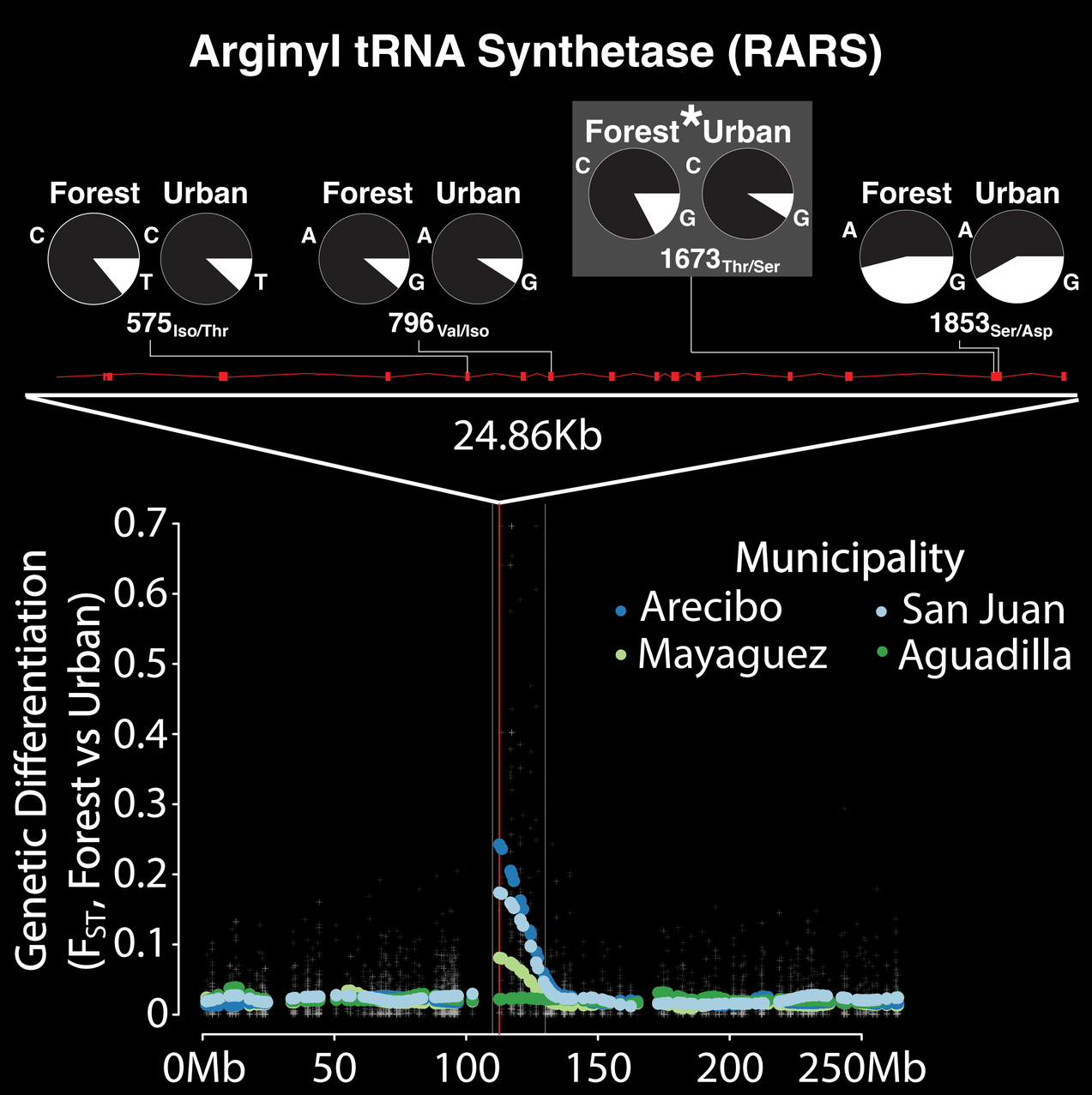
PARALLEL INCREASES IN HEAT TOLERANCE ACROSS MULTIPLE CITY COLONIZATIONS



CAMPBELL-STATON ET AL. 2020, *NAT. ECO. EVO.*

Parallel signatures of selection at a single locus

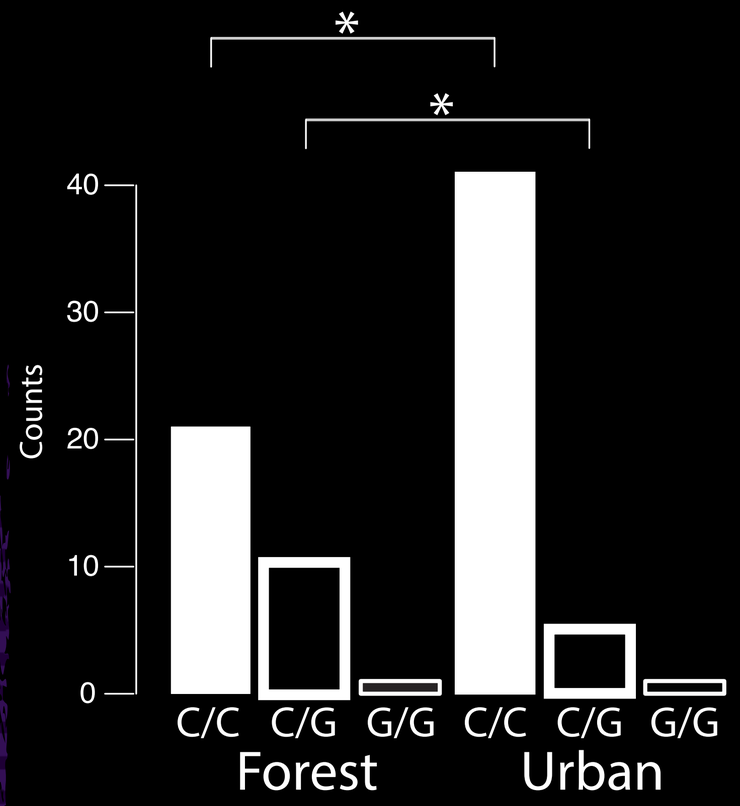
A SINGLE NON SYNONYMOUS POLYMORPHISM WITHIN THE RARS LOCUS SEGREGATES AT DIFFERENT FREQUENCIES IN URBAN AND FOREST HABITATS

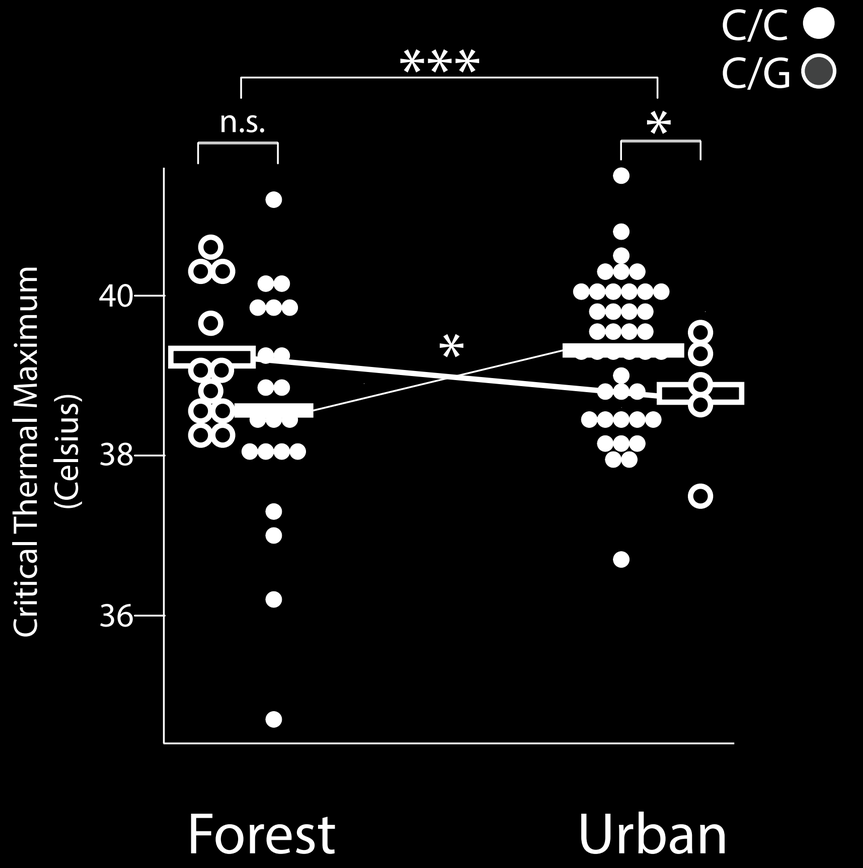


CAMPBELL-STATON ET AL. 2020, *NAT. ECO. EVO.*

Parallel signatures of selection at a single locus

GENOTYPE AT THE NON SYNONYMOUS POSITION IS ASSOCIATED WITH DIFFERENCES IN HEAT TOLERANCE WITHIN URBAN HABITATS





CAMPBELL-STATON ET AL. 2020, *NAT. ECO. EVO.*

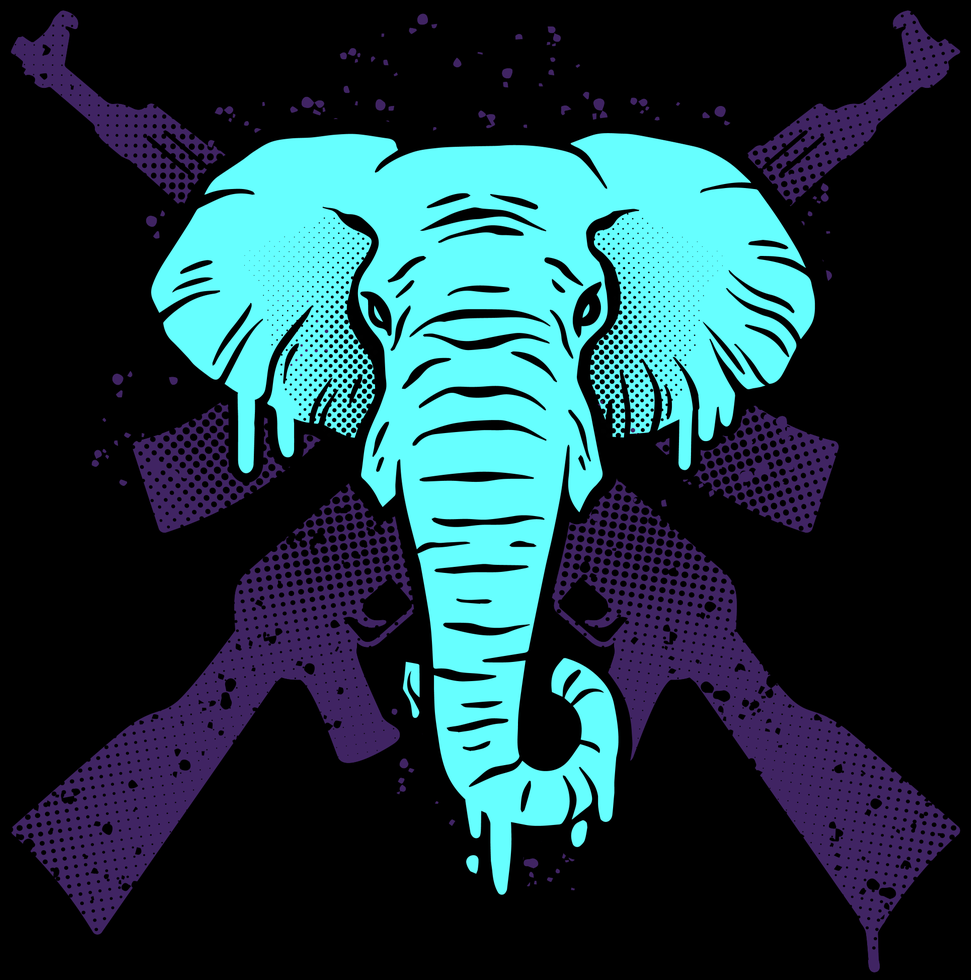


Take Home Points:

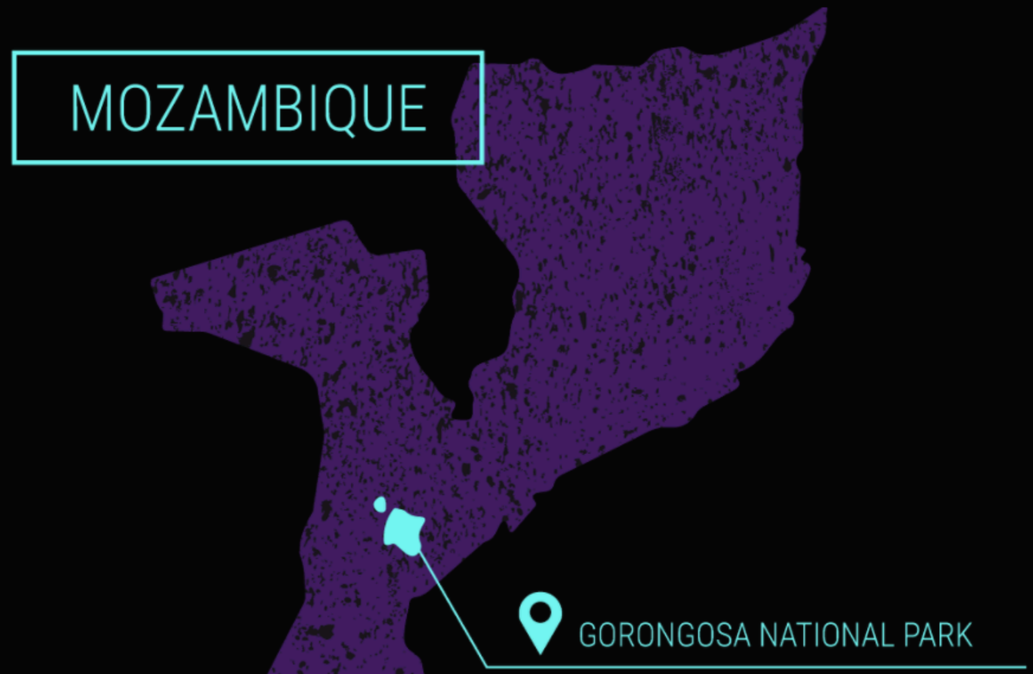
- Human-built environments can present extreme selection pressures that require rapid adaptation of complex traits in wildlife
- Even with complex traits, these evolutionary changes can be highly repeatable (i.e. predictable)

HUMAN-ANIMAL CONFLICT

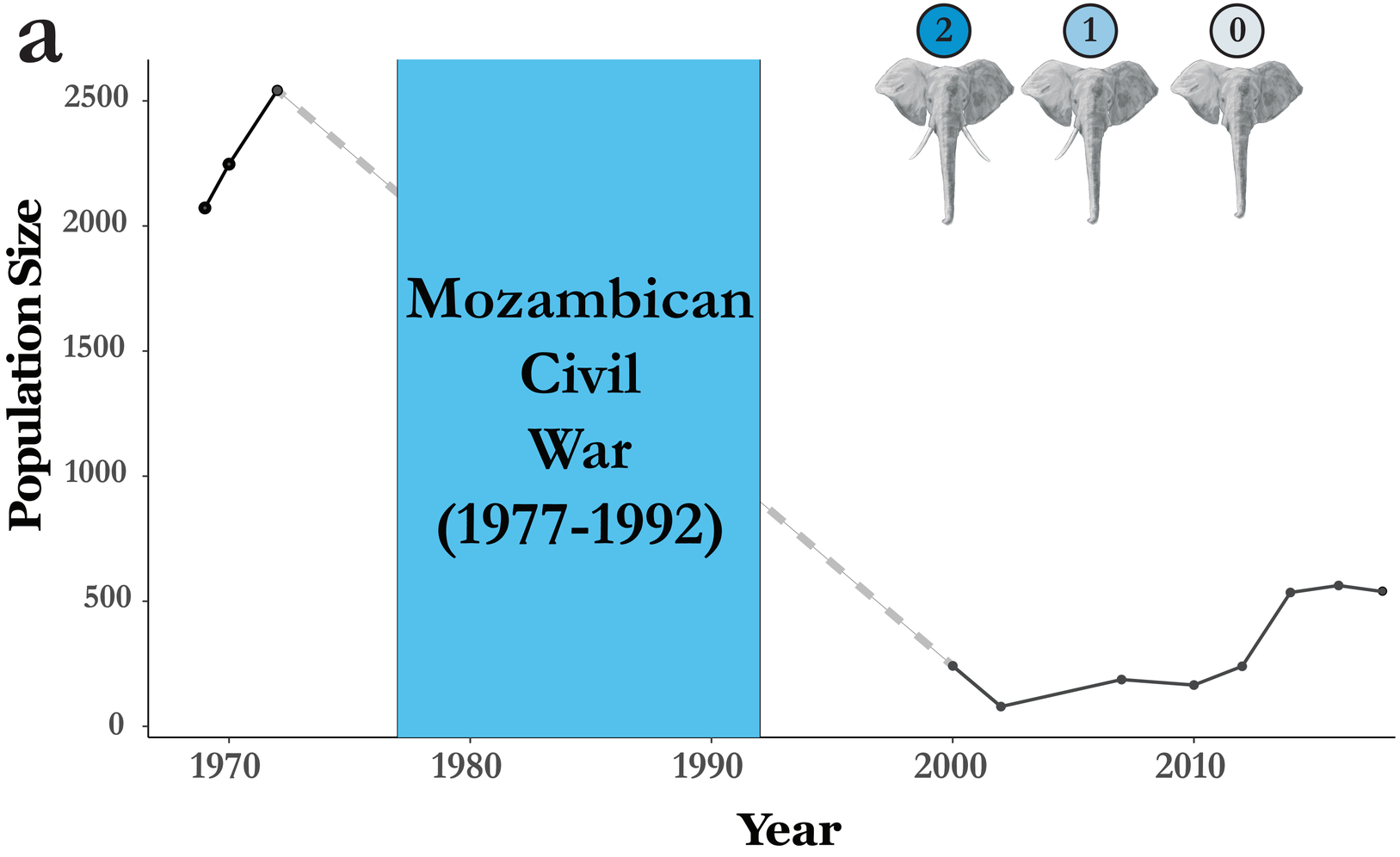
ECOLOGICAL IMPACTS OF ANTHROPOGENIC SELECTION



Campbell-Staton et al. 2021, *Science*



SIGNIFICANT CHANGES IN POPULATION SIZE AND FREQUENCY OF TUSKLESSNESS ASSOCIATED WITH 15 YEARS OF CIVIL WAR

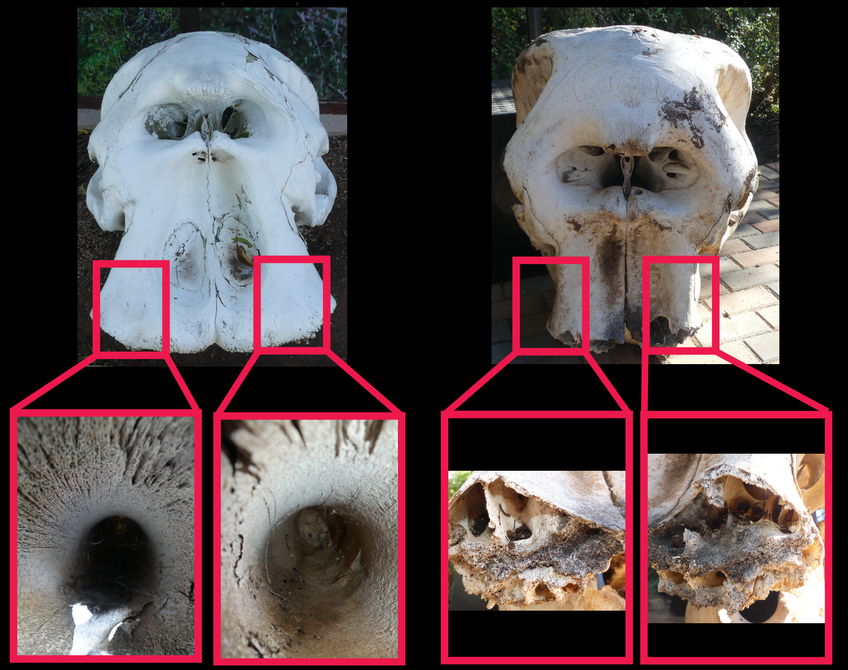


Campbell-Staton et al. 2021, *Science*

Tusklessness in the African elephant

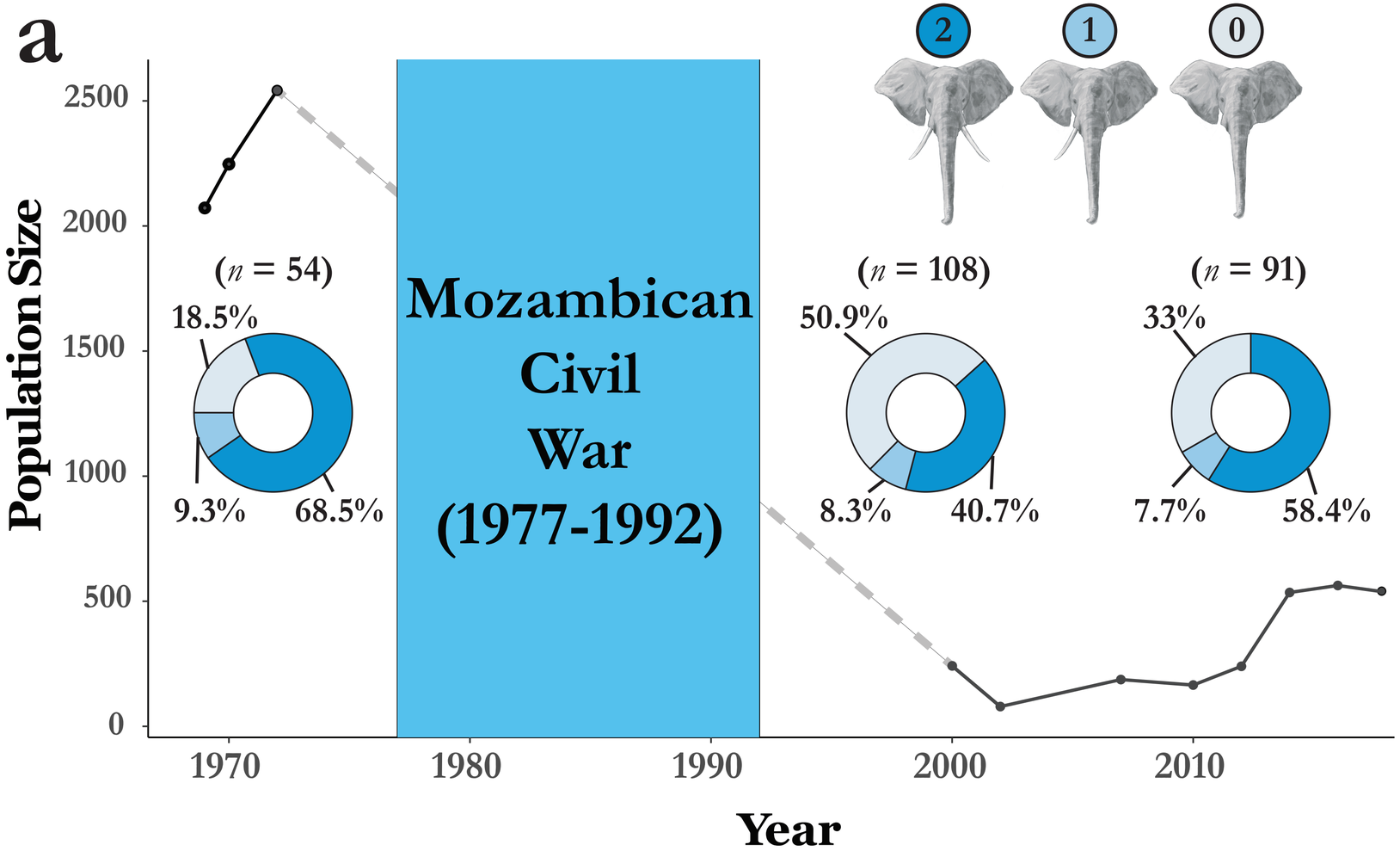
A low frequency (2-10%) female-specific trait





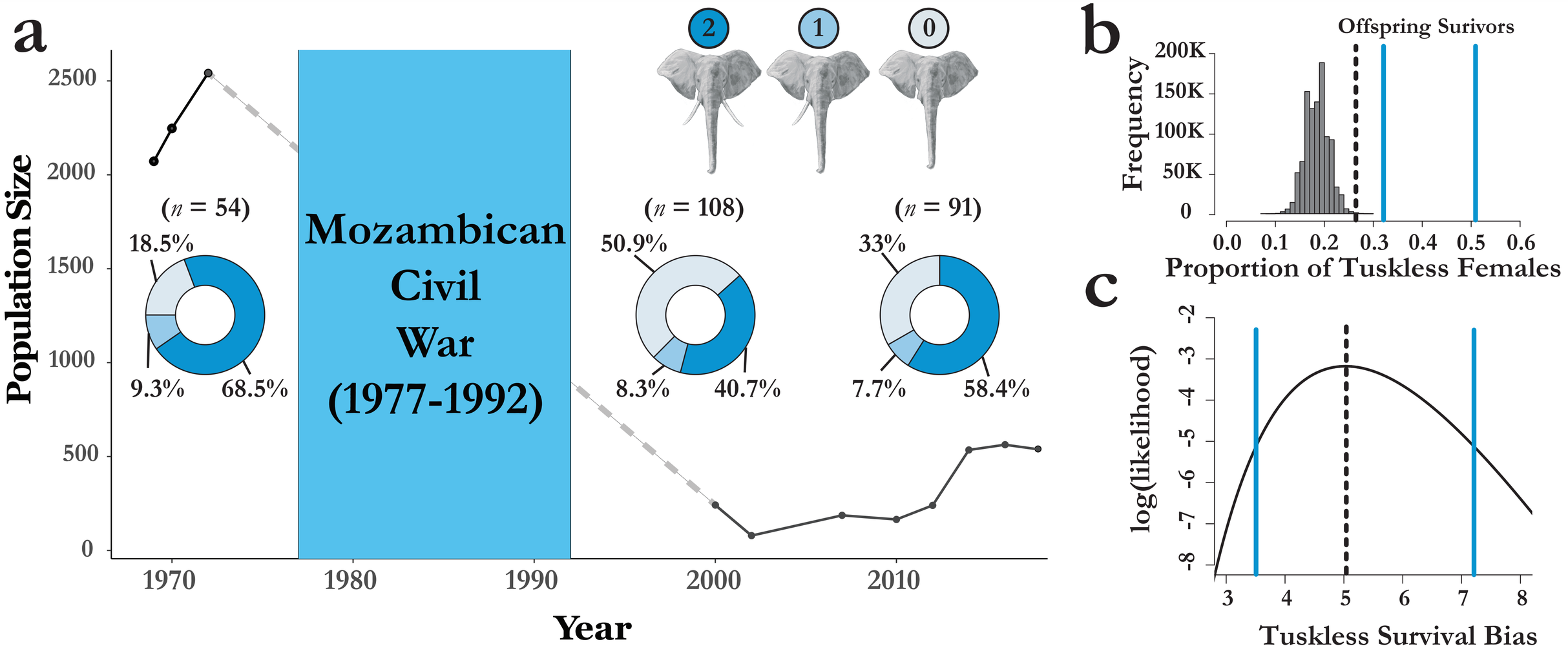
Campbell-Staton et al. 2021, *Science*

SIGNIFICANT CHANGES IN POPULATION SIZE AND FREQUENCY OF TUSKLESSNESS ASSOCIATED WITH 15 YEARS OF CIVIL WAR



Campbell-Staton et al. 2021, *Science*

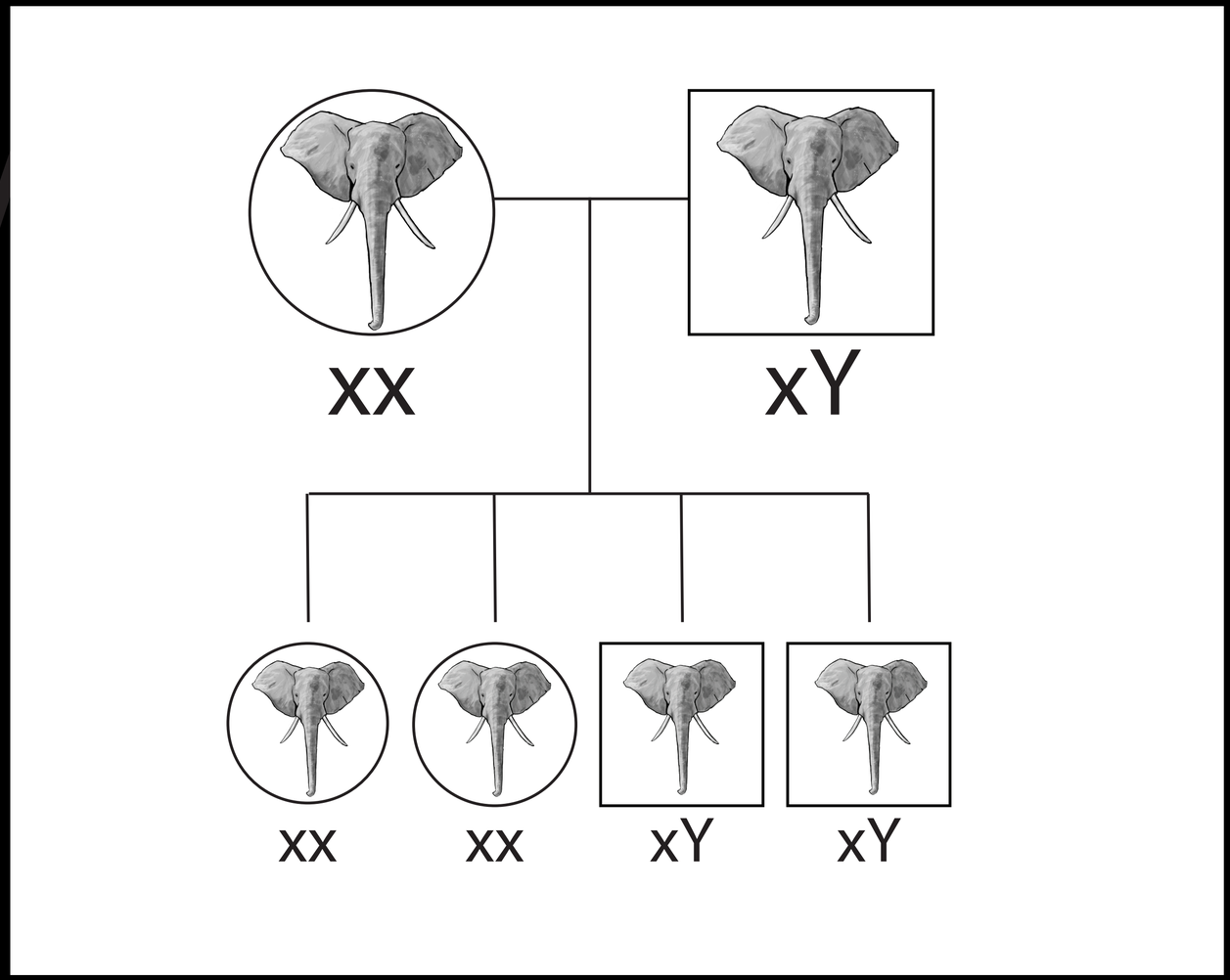
TUSKLESS SURVIVAL 5.13 TIMES GREATER THAT TUSKED COUNTERPARTS DURING 15 YEAR PERIOD OF WAR (95% CI: 3.98 - 6.6)



Campbell-Staton et al. 2021, *Science*

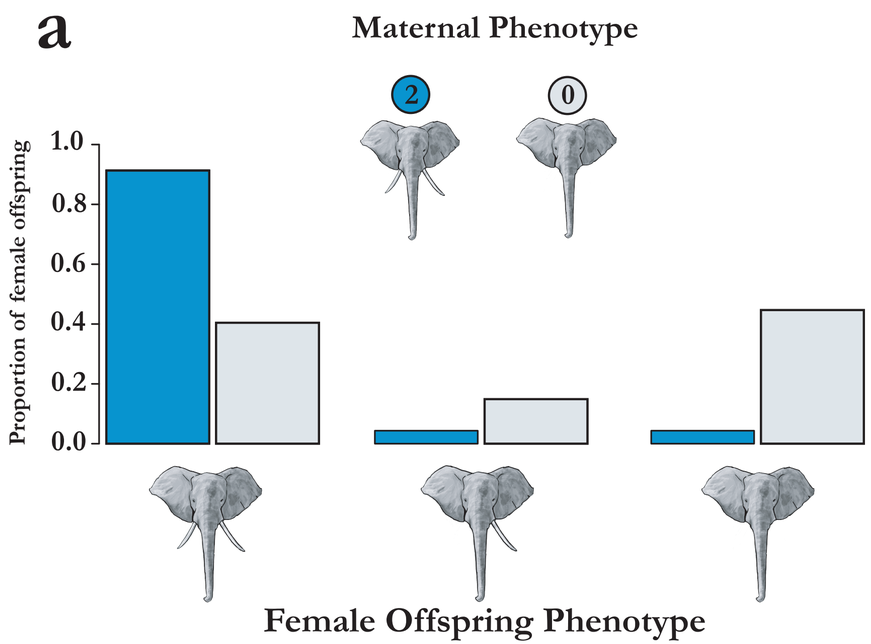
Evidence for tusk loss as an X-linked dominant trait with male lethality

Prediction 1: Two- tusked mothers have exclusively two-tusked daughters



Campbell-Staton et al. 2021, *Science*

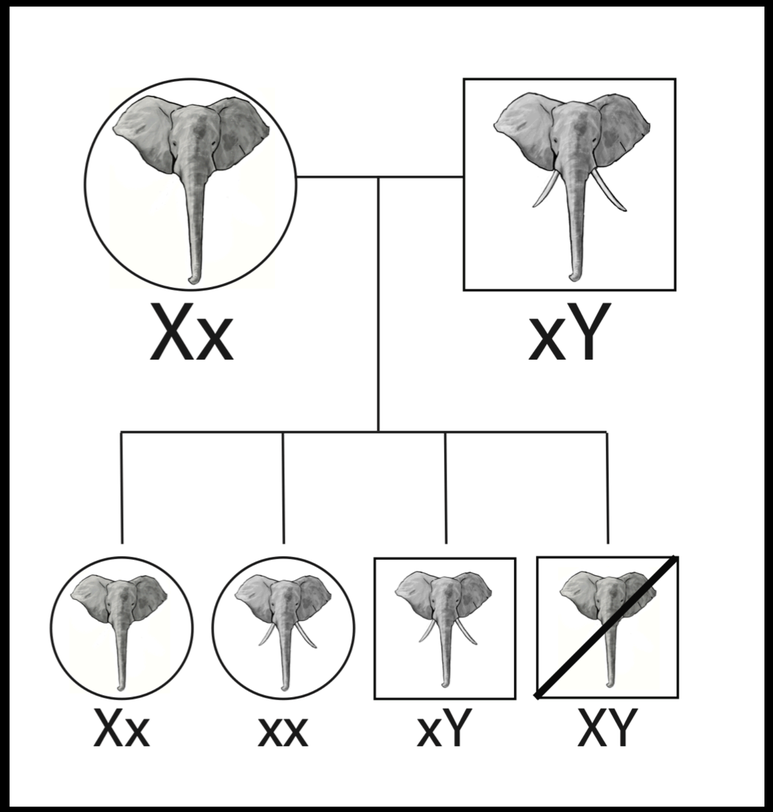
TWO-TUSKED MOTHERS DISPLAY SIGNIFICANT SKEW TOWARDS TWO-TUSKED DAUGHTERS



Campbell-Staton et al. 2021, *Science*

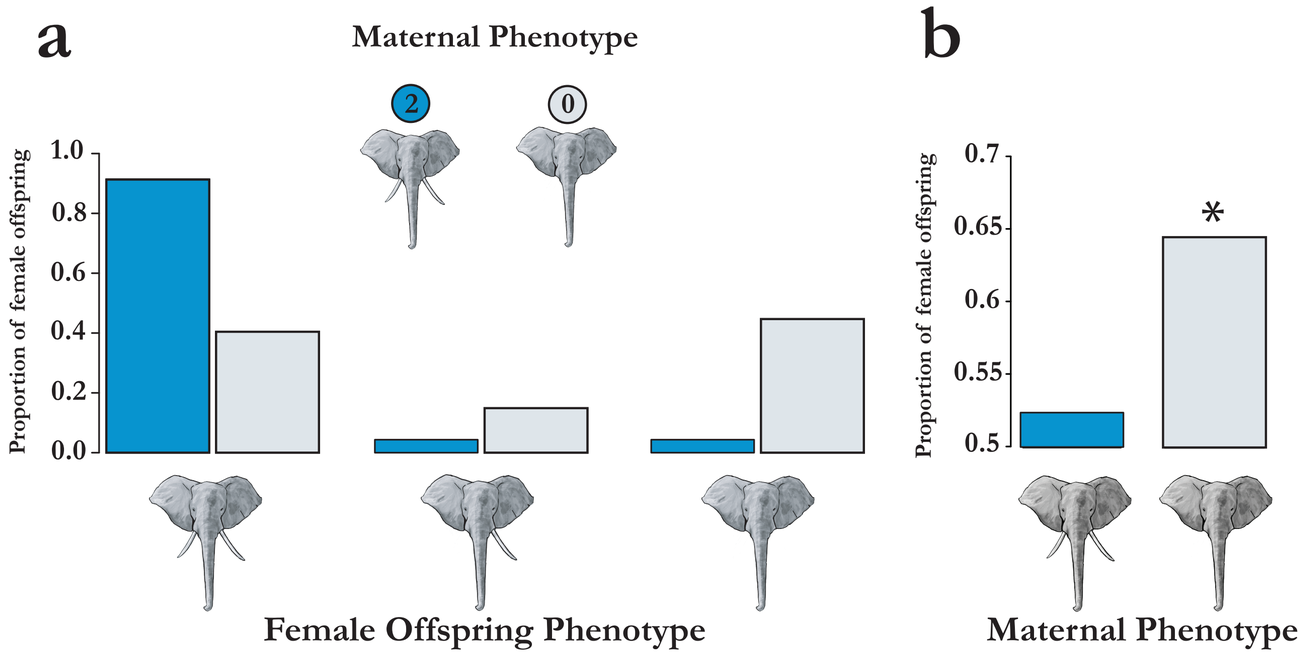
Evidence for tusk loss as an X-linked dominant trait with male lethality

Prediction 2: Tuskless mothers show a significant female offspring bias (66.67%)



Campbell-Staton et al. 2021, *Science*

TUSKLESS MOTHERS DISPLAY SIGNIFICANT FEMALE OFFSPRING BIAS

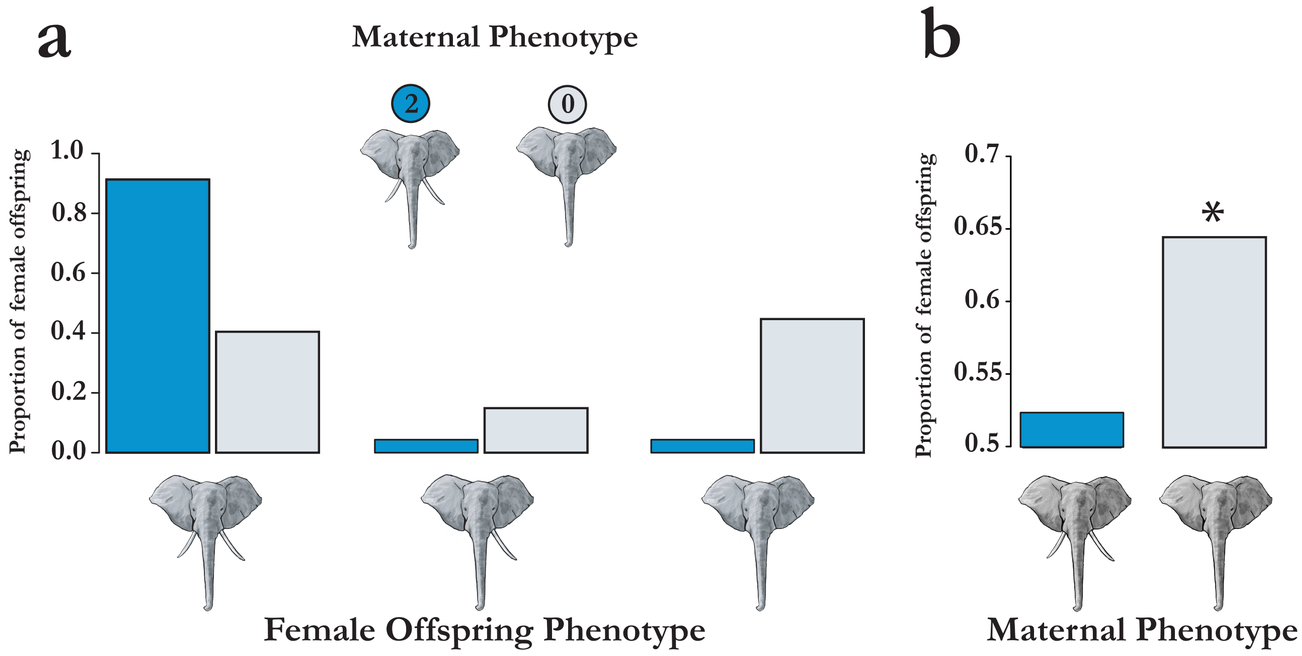


Campbell-Staton et al. 2021, *Science*

SINGLE LOCUS MODEL EXPLAINS 87.15% OF ALL TUSK INHERITANCE PATTERNS IN GORONGOSA

FEMALE SEX-BIAS AMONG OFFSPRING MEET 98.9% OF MODEL EXPECTATIONS

RESULTS CONSISTENT WITH SINGLE SEX-LINKED LOCUS OF LARGE EFFECT WITH ONE OR MORE MODIFIER LOCI OF SMALLER EFFECT



Campbell-Staton et al. 2021, *Science*

METHODS

Genetic sampling of African elephants

Blood samples taken from sedated female elephants in Gorongosa National Park, Mozambique

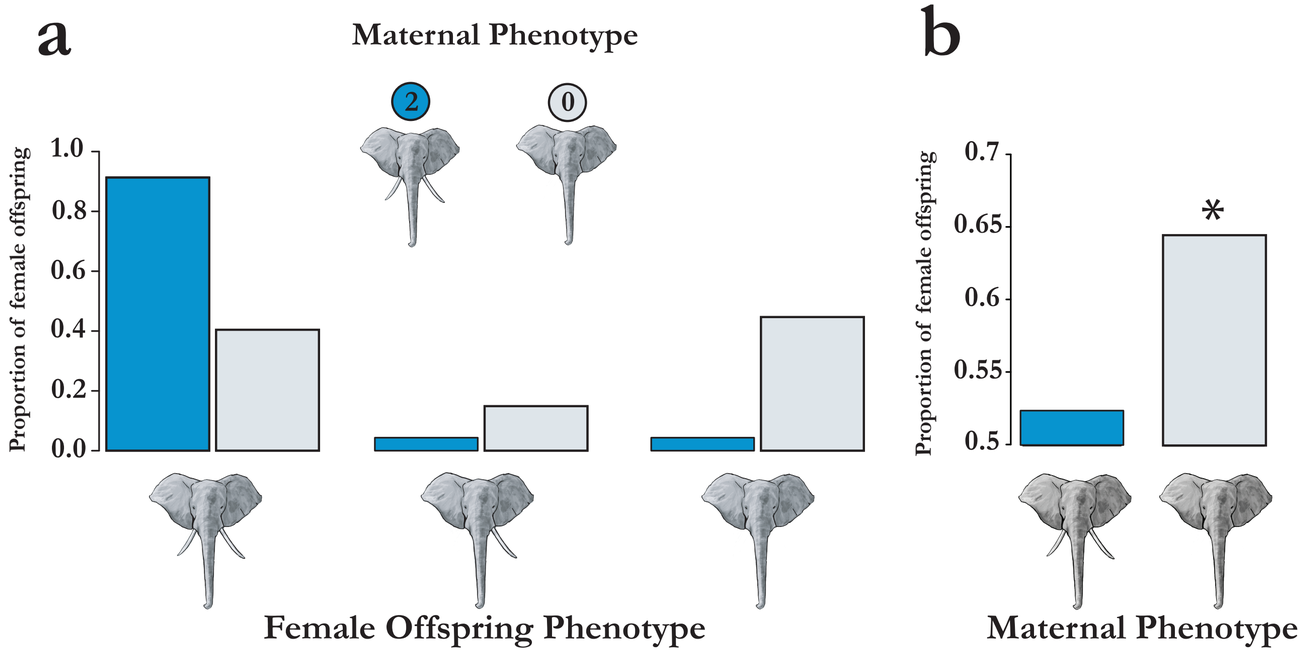


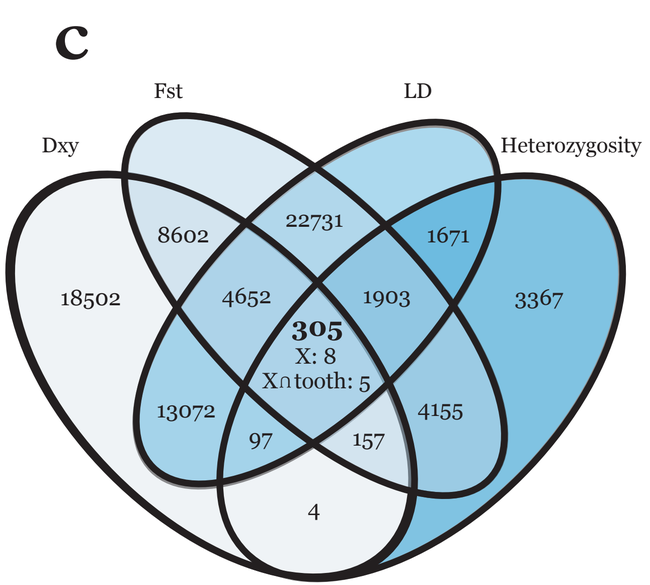
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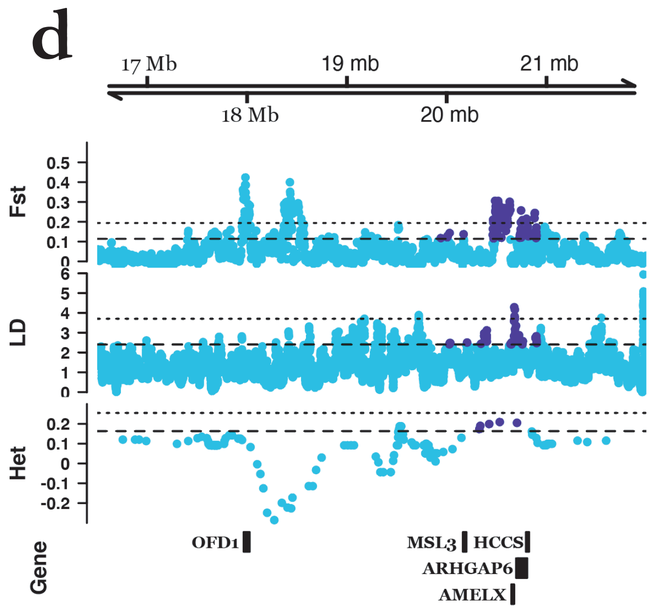
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Campbell-Staton et al. 2021, *Science*

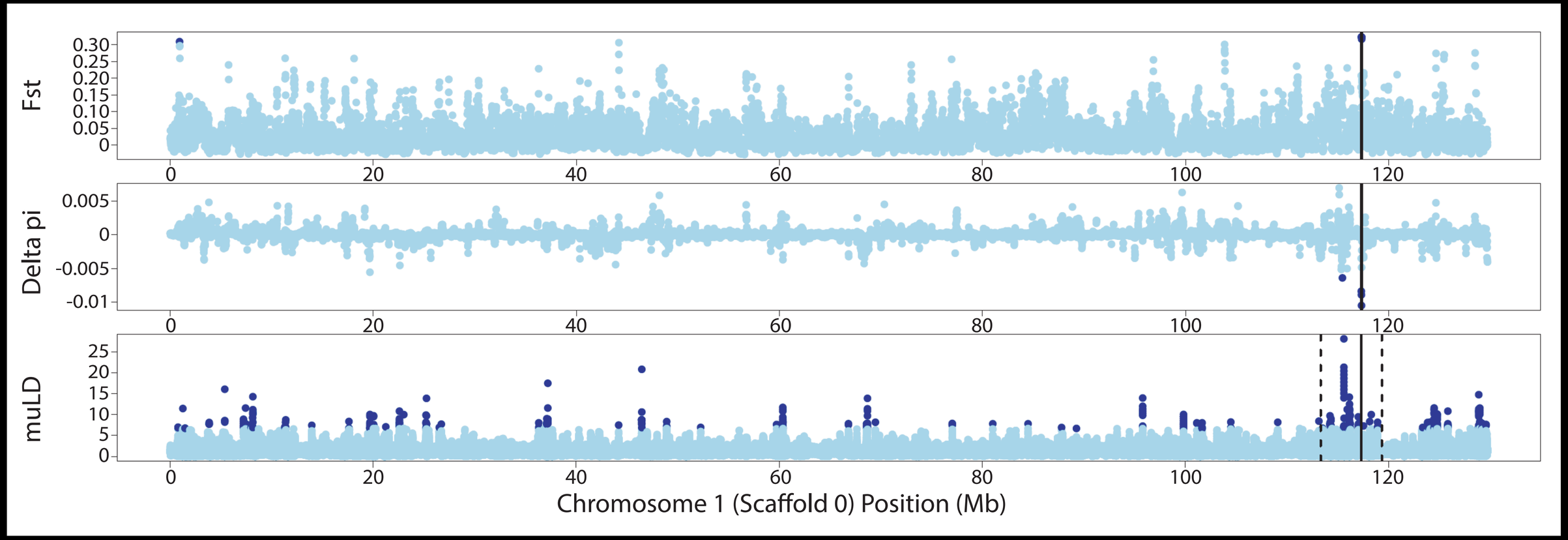






GENOME-WIDE SCANS IDENTIFY SECOND CANDIDATE LOCUS FOR TUSKLESSNESS IN GORONGOSA

MEP1A



Campbell-Staton et al. 2021, *Science*

Known Functional Effects of Candidate Loci on Mammalian Tooth Development

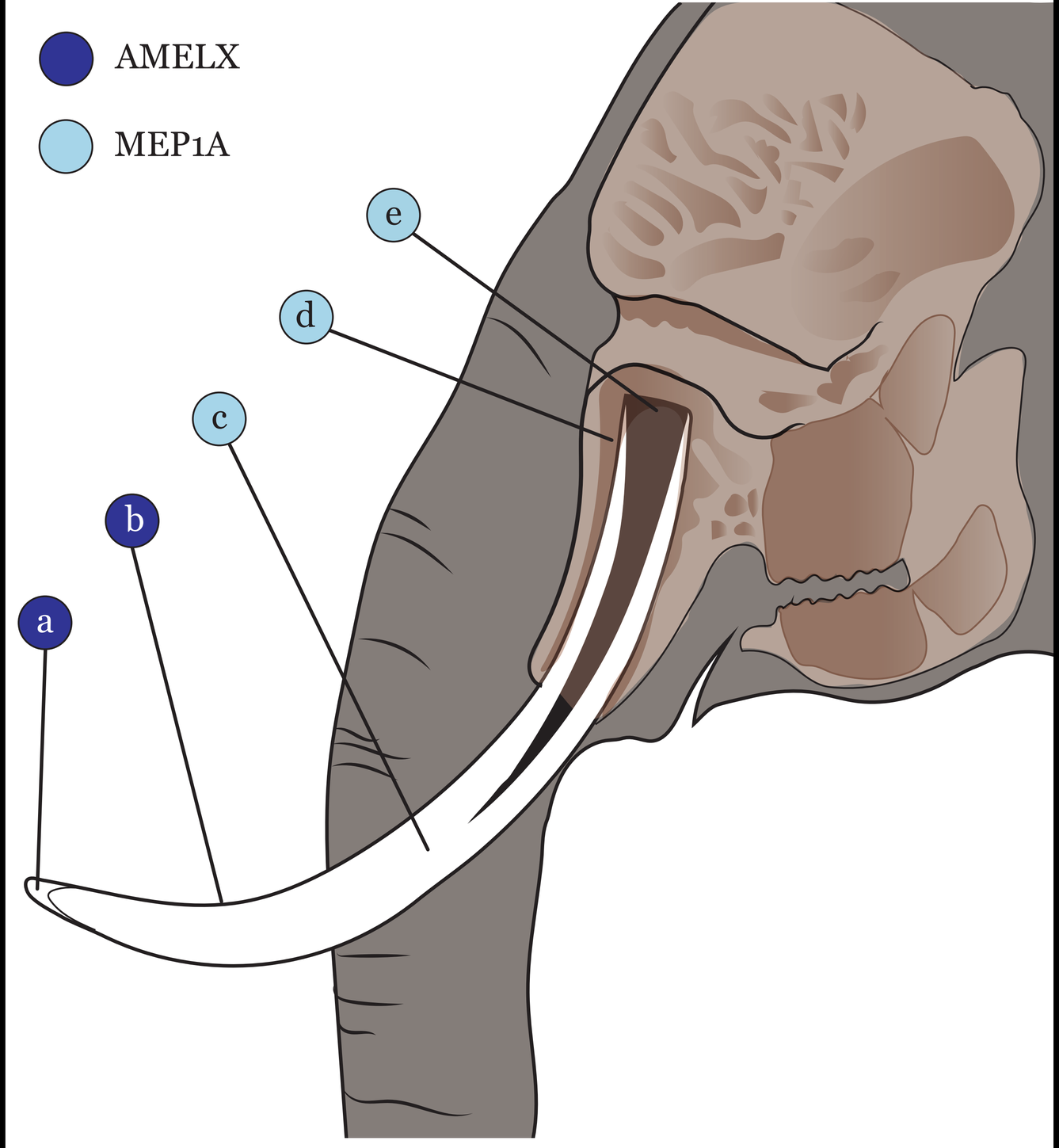
a) Enamel

b) Cementum

c) Dentin (Ivory)

d) Periodontium

e) Root

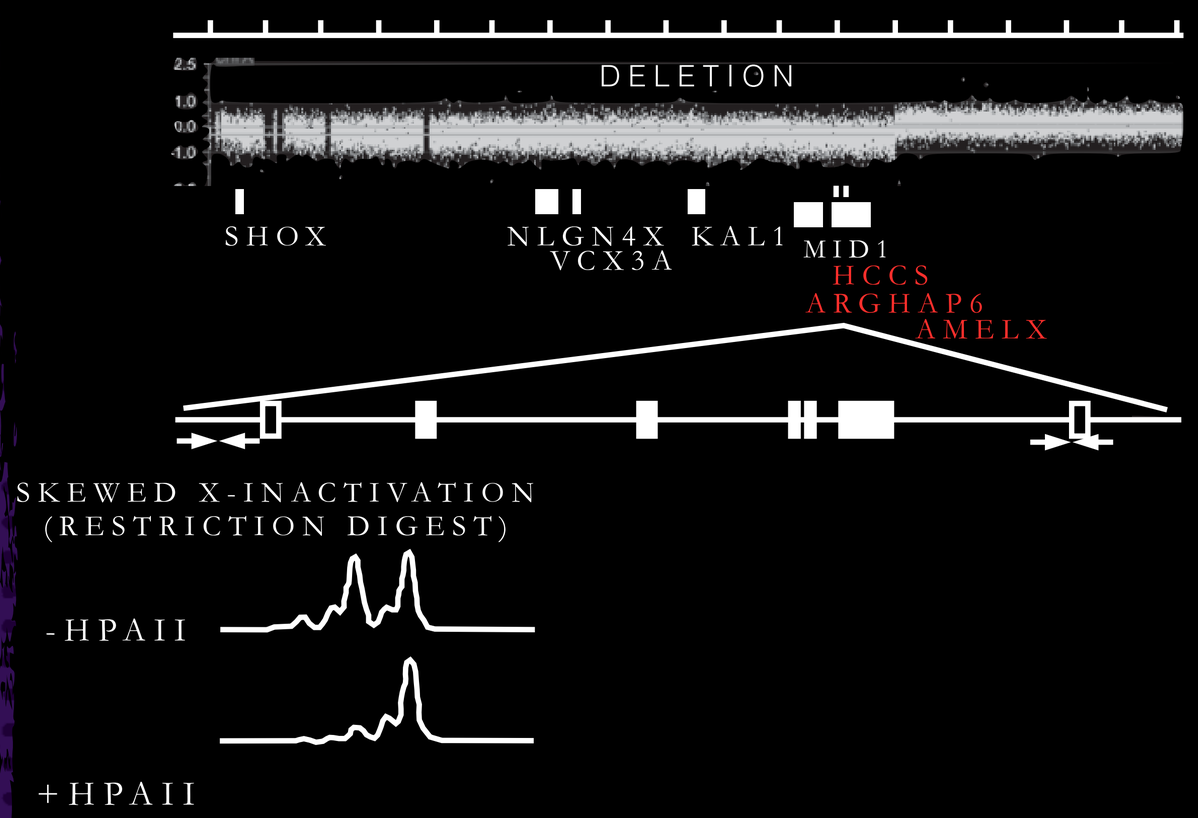


Campbell-Staton et al. 2021,
Science

Candidate locus is associated with ameliogenesis imperfecta in humans

A RARE AND SPORADIC X-LINKED CONDITION IN HUMANS THAT IS USUALLY LETHAL IN MALES

AMELIOGENESIS IMPERFECTA



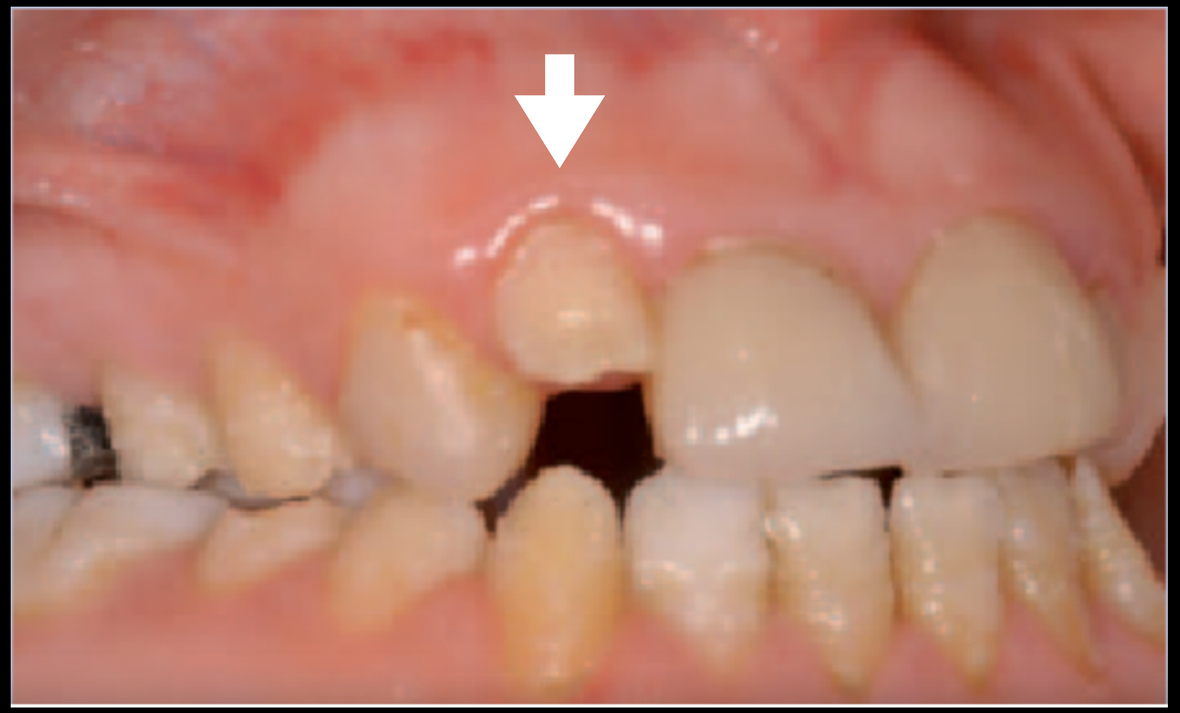
MALIK ET AL. 2012, *BRIT. DENT. J.*

Candidate locus is associated with ameliogenesis imperfecta in humans

A RARE AND SPORADIC X-LINKED CONDITION IN HUMANS THAT IS USUALLY LETHAL IN MALES

"AT THE FIRST DENTAL EXAMINATION BY AHB AT 12 YEARS OF AGE, THE PERMANENT UPPER LEFT LATERAL INCISOR WAS ABSENT AND THE PERMANENT UPPER RIGHT LATERAL INCISOR WAS MICRODONT" (HOBSON ET AL. 2009)

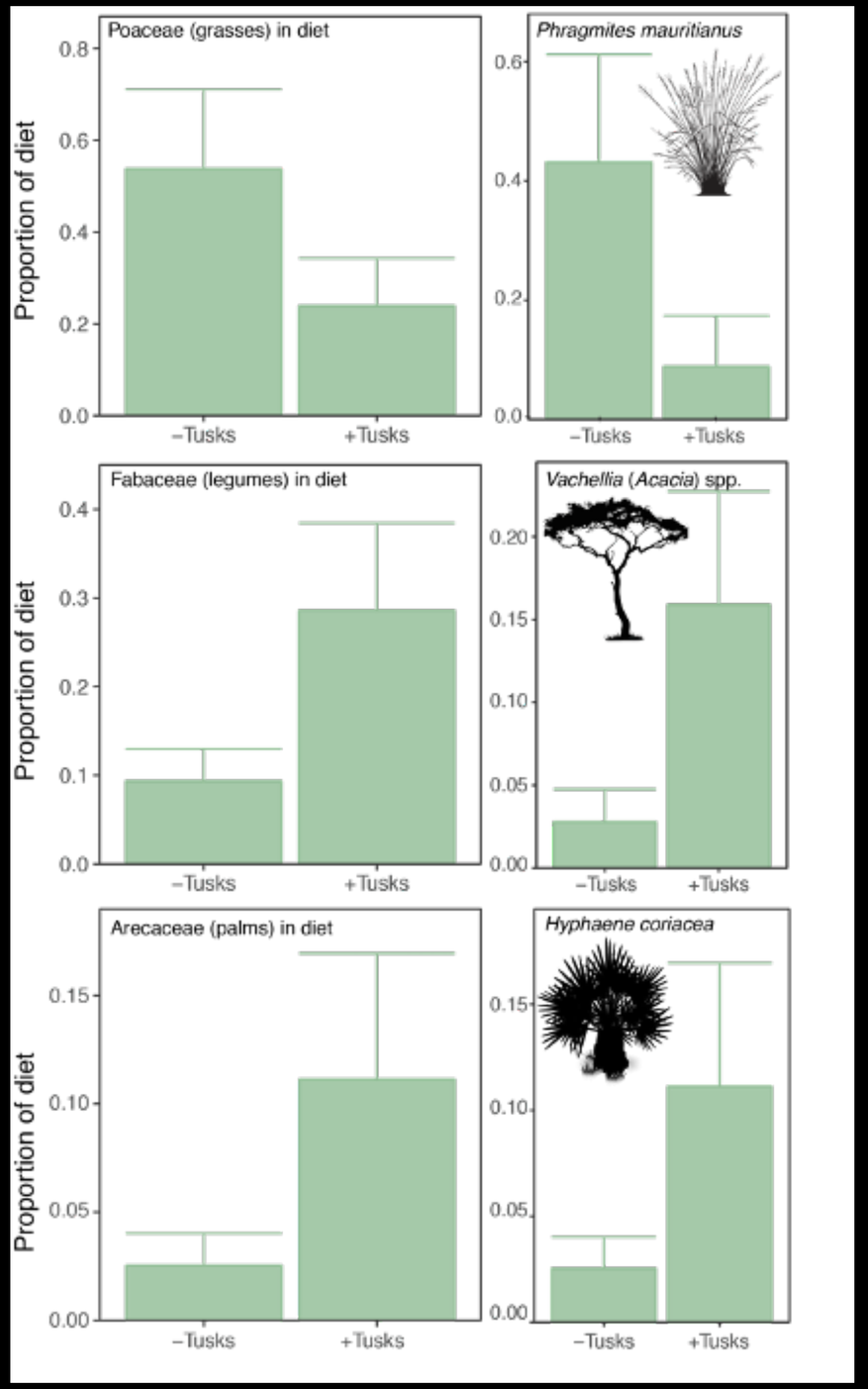
MICRODONT UPPER



MALIK ET AL. 2012, *BRIT. DENT. J.*

Behavioral and Ecological Consequences of Selection Against Key Innovation in Keystone Species

DOWNSTREAM IMPACTS OF HUMAN-MEDIATED SELECTION ON ECOSYSTEM HEALTH



Dietary shifts associated with tusk morphology

Tuskless individuals consume less woody vegetation and more grasses

Data: Pringle Lab, Princeton University

FUTURE DIRECTIONS: HIERARCHICAL MULTIGENERATIONAL IMPACTS OF ANTHROPOGENIC SELECTION

HABITAT MODIFICATION



NUTRIENT DISTRIBUTION



NICHE CREATION AND RESOURCE AVAILABILITY





SPECIES DIVERSITY AND ABUNDANCE





ECOSYSTEM HEALTH AND SUSTAINABILITY





Take Home Points:

- Human action can have rapid evolutionary impacts on long-lived species, via demographic and adaptive evolutionary change
- Selection targeting one or a few genes in a single species may have cascading impacts for broader regional biodiversity that impact ecosystem quality

RADIATION-INDUCED SELECTION

IMPLICATIONS FOR EVOLUTIONARY MEDICINE





Principles of Evolutionary Medicine



DR. AUGUST KROGH (1874 - 1949)

Krogh's Principle

"for some large number of [medical] problems there will be some animal of choice, or a few such animals, on which it can be most conveniently studied."

Estimated number of new global cancer cases

2040

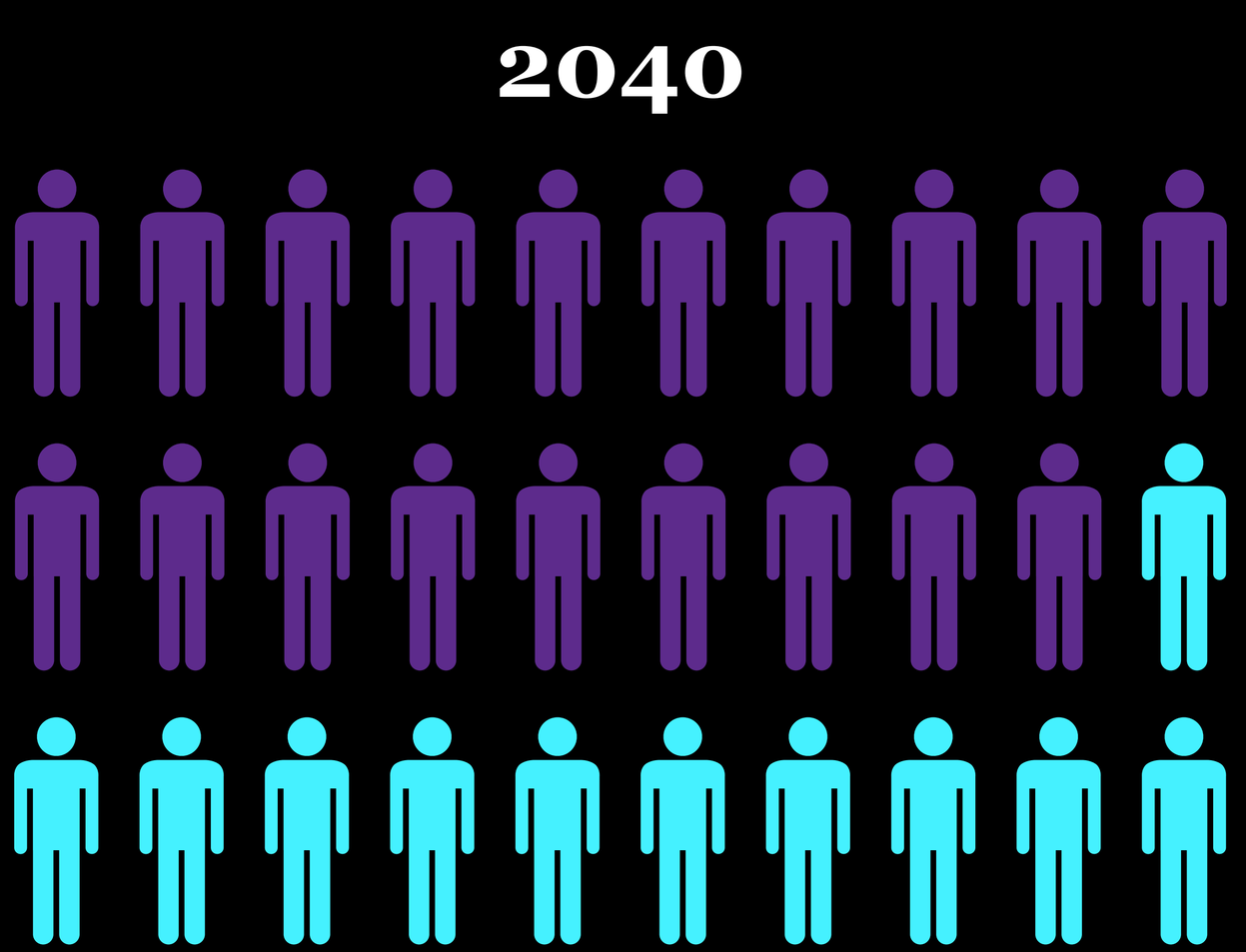


= 1 Million

19.3 Million

World Health Organization
International Agency for Research on Cancer

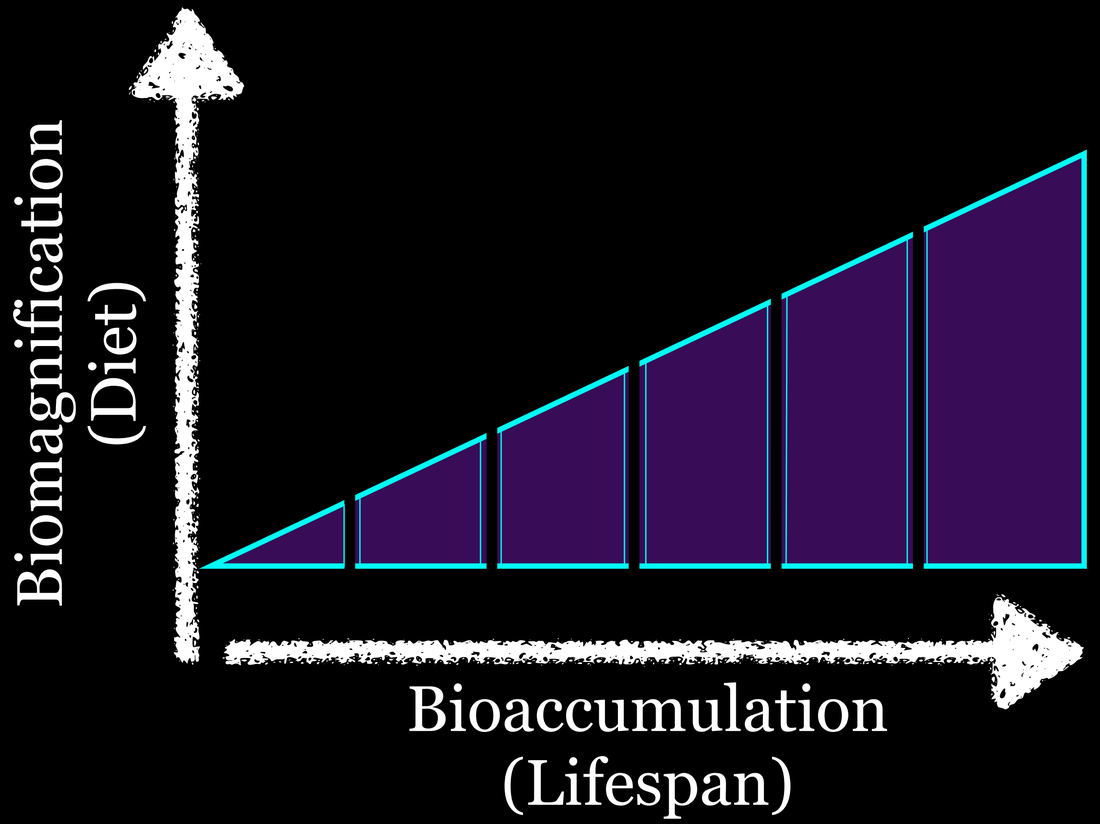
Estimated number of new global cancer cases



World Health Organization
International Agency for Research on Cancer

Chernobyl wolf population:
~7 generations of chronic low-dose radiation exposure

Chronic Radiation Exposure

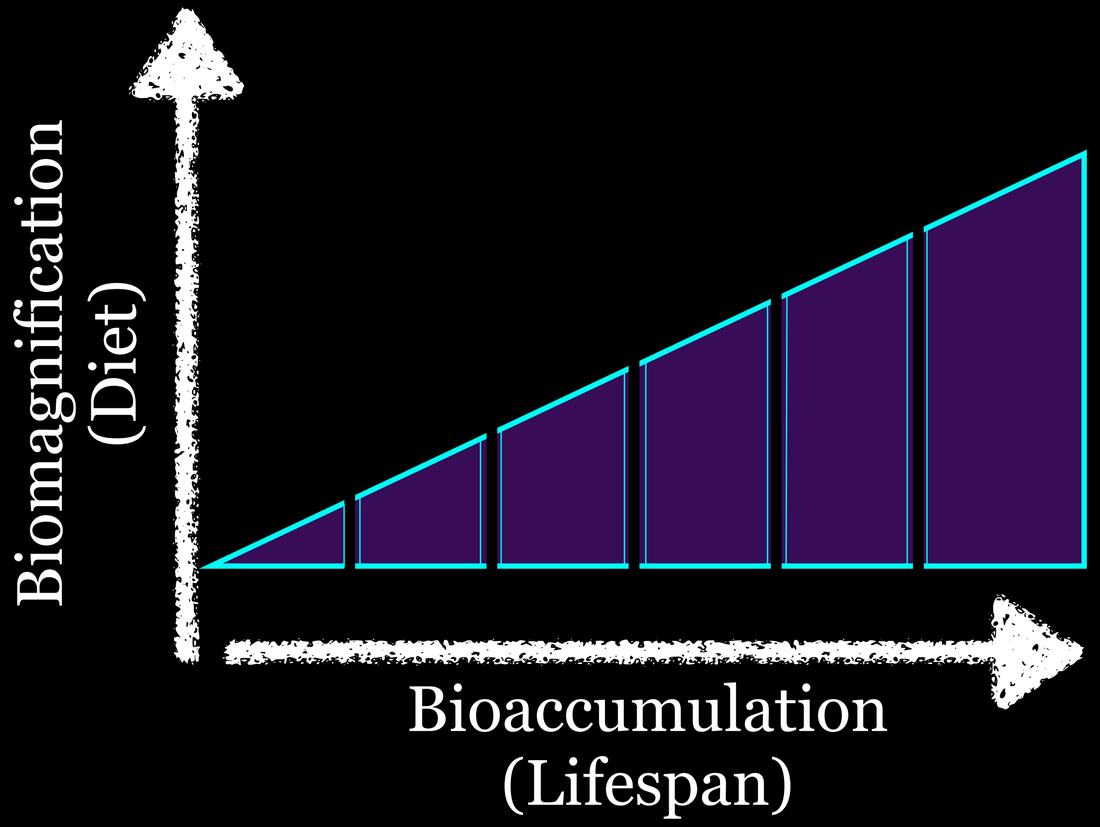


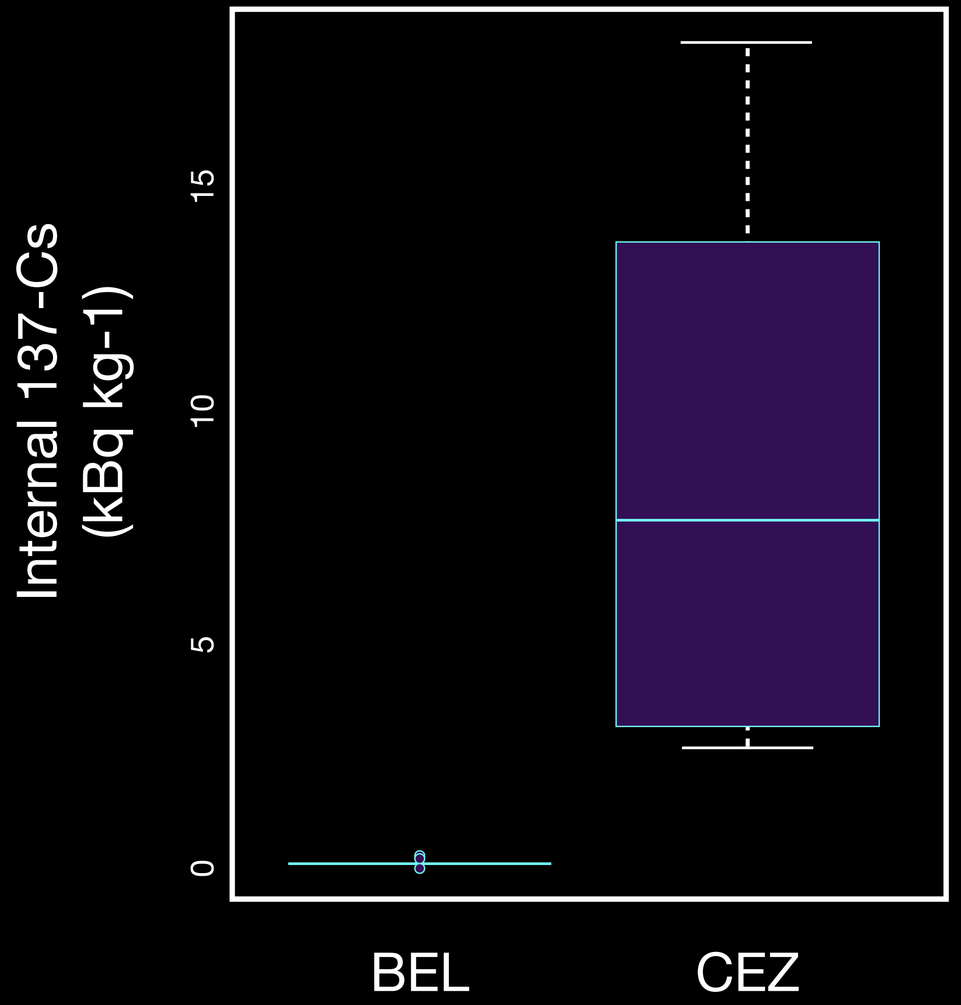


Grey Wolf (Canis lupus)

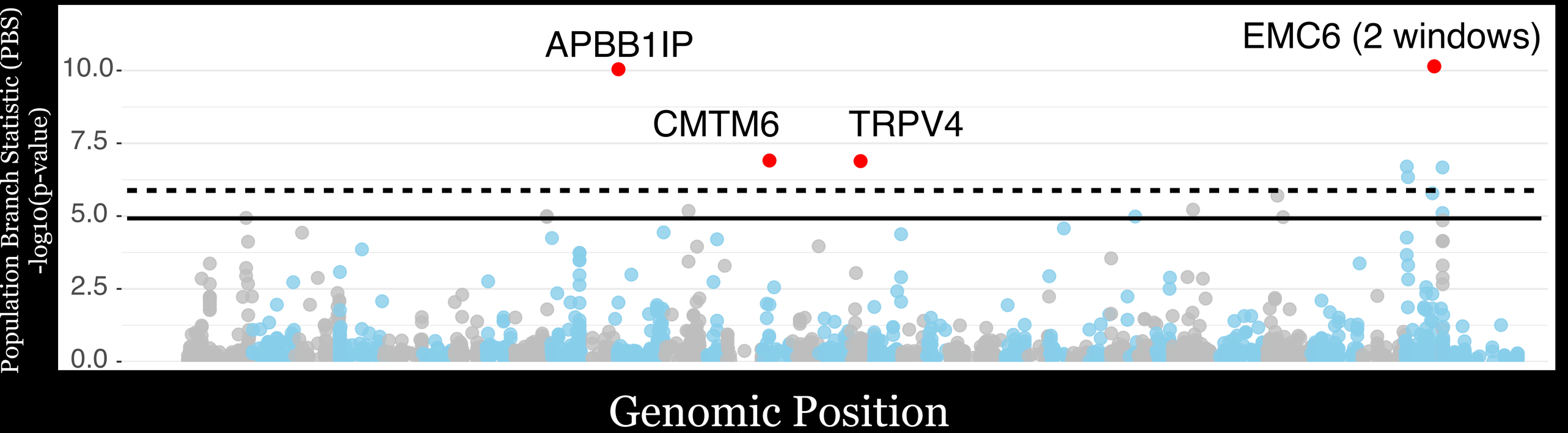
Chernobyl wolf population:
~7 generations of chronic low-dose radiation exposure

Chronic Radiation Exposure



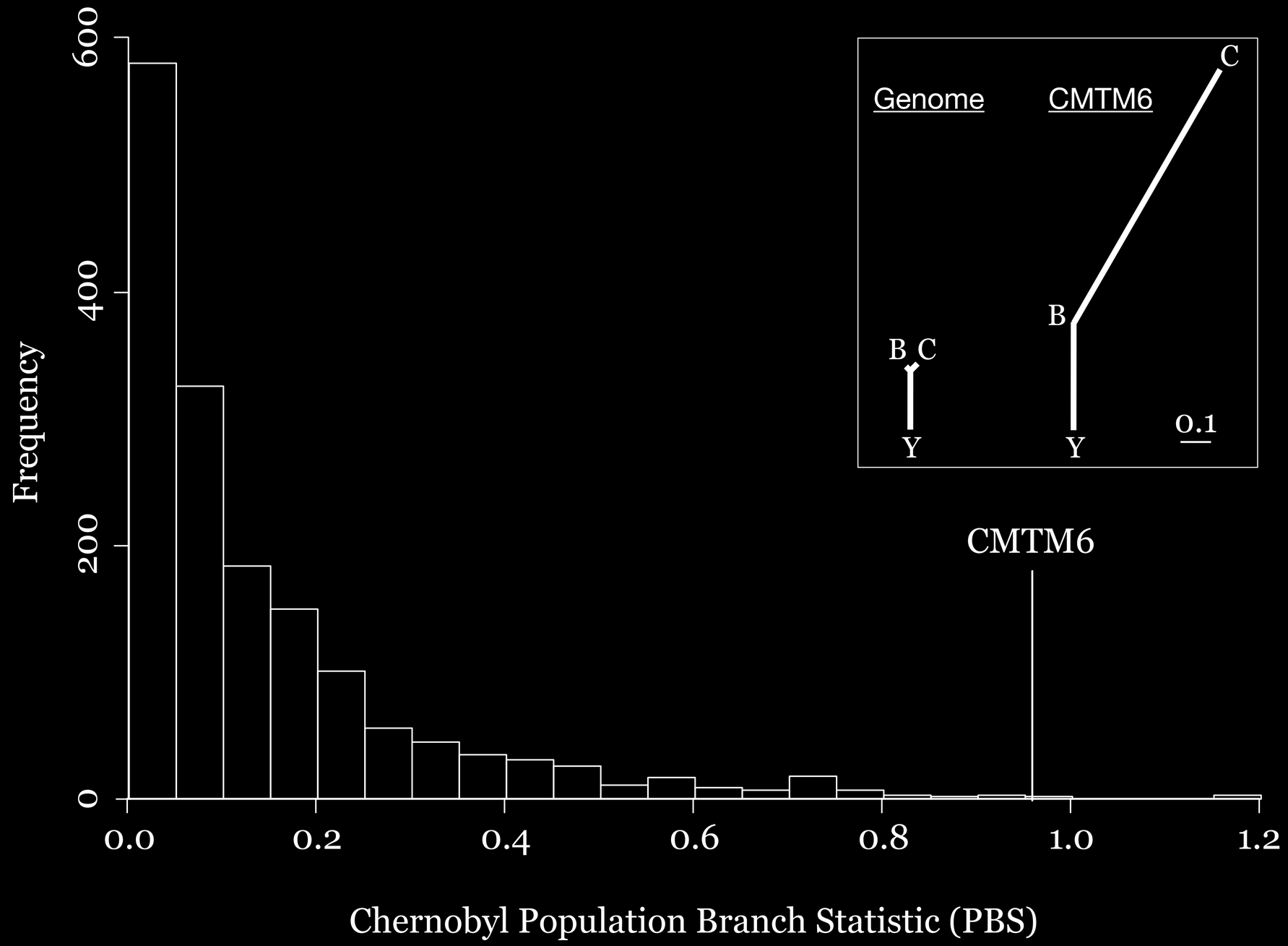


Lineage-specific genetic divergence within the CEZ

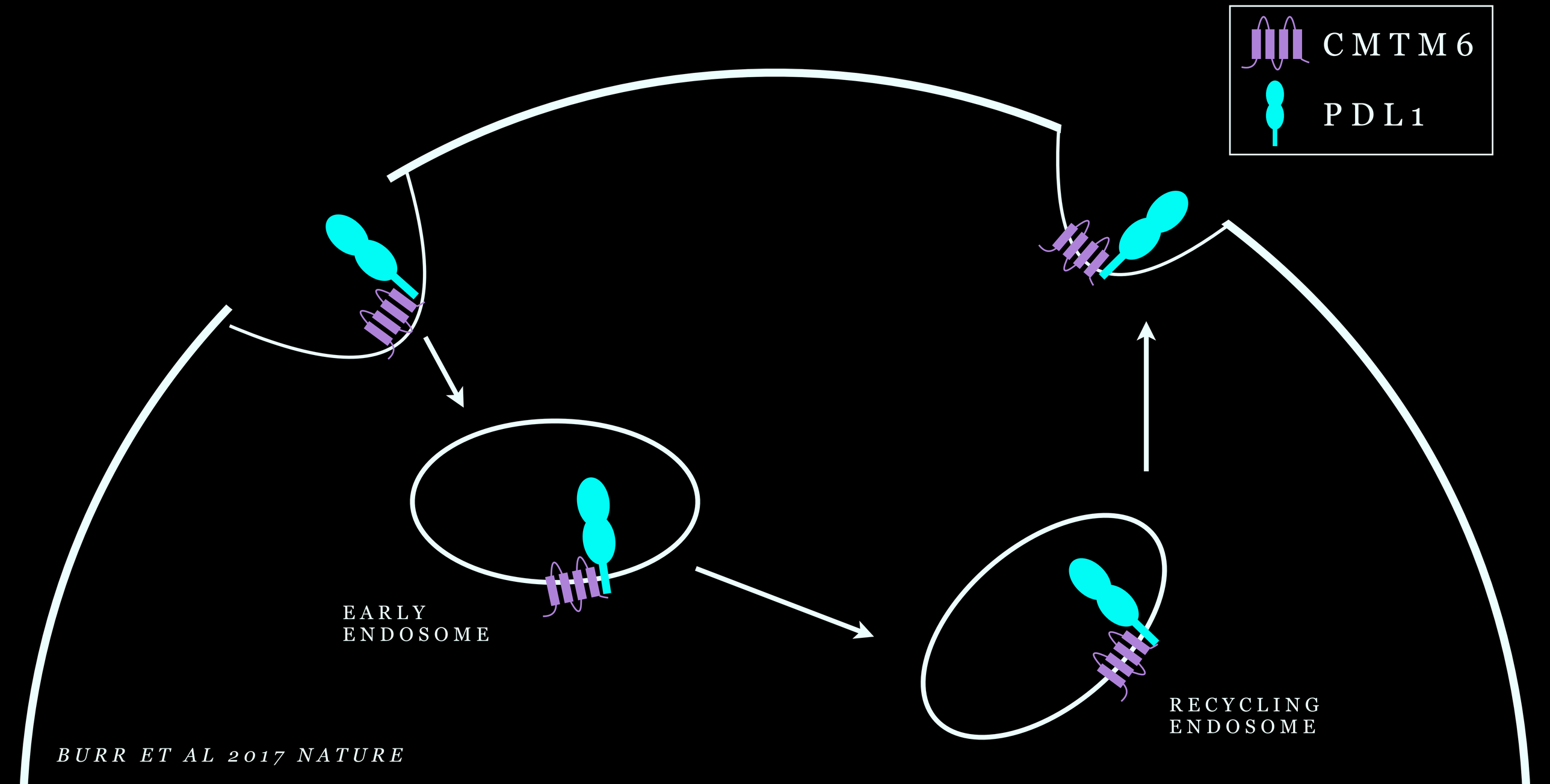


Extreme genetic divergence among cancer-related loci

CMTM6 - anti-tumor immunity
EMC6 - tumor proliferation
TRPV4 - invasion/migration
APBB1IP - prognostic marker

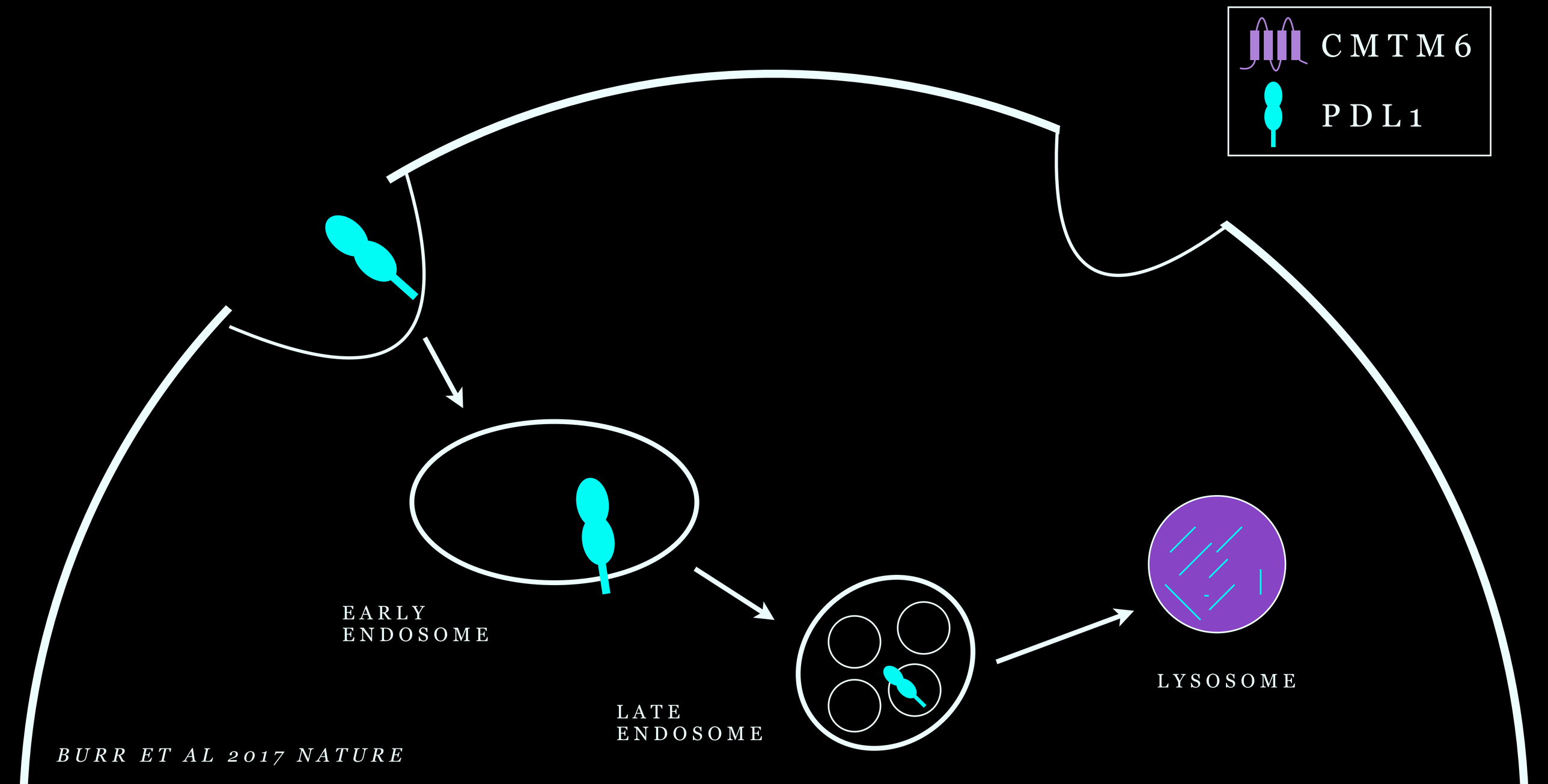

Frequency
600
400
200
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Chernobyl Population Branch Statistic (PBS)
CMTM6
Genome
CMTM6
B C
Y
B
C
Y
0.1

CMTM6 POSITIVELY REGULATES PDL1 BY PROMOTING ENDOSOMAL RECYCLING OF THE SURFACE PROTEIN



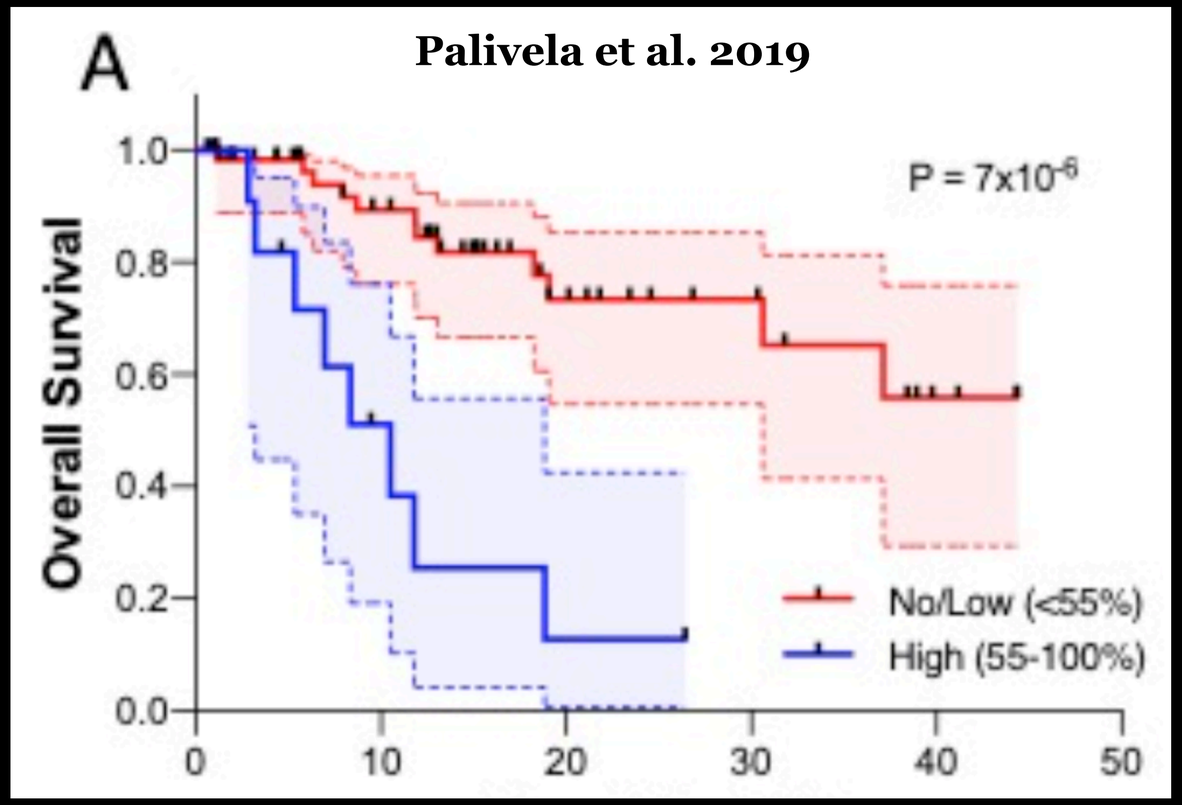
BURR ET AL 2017 NATURE

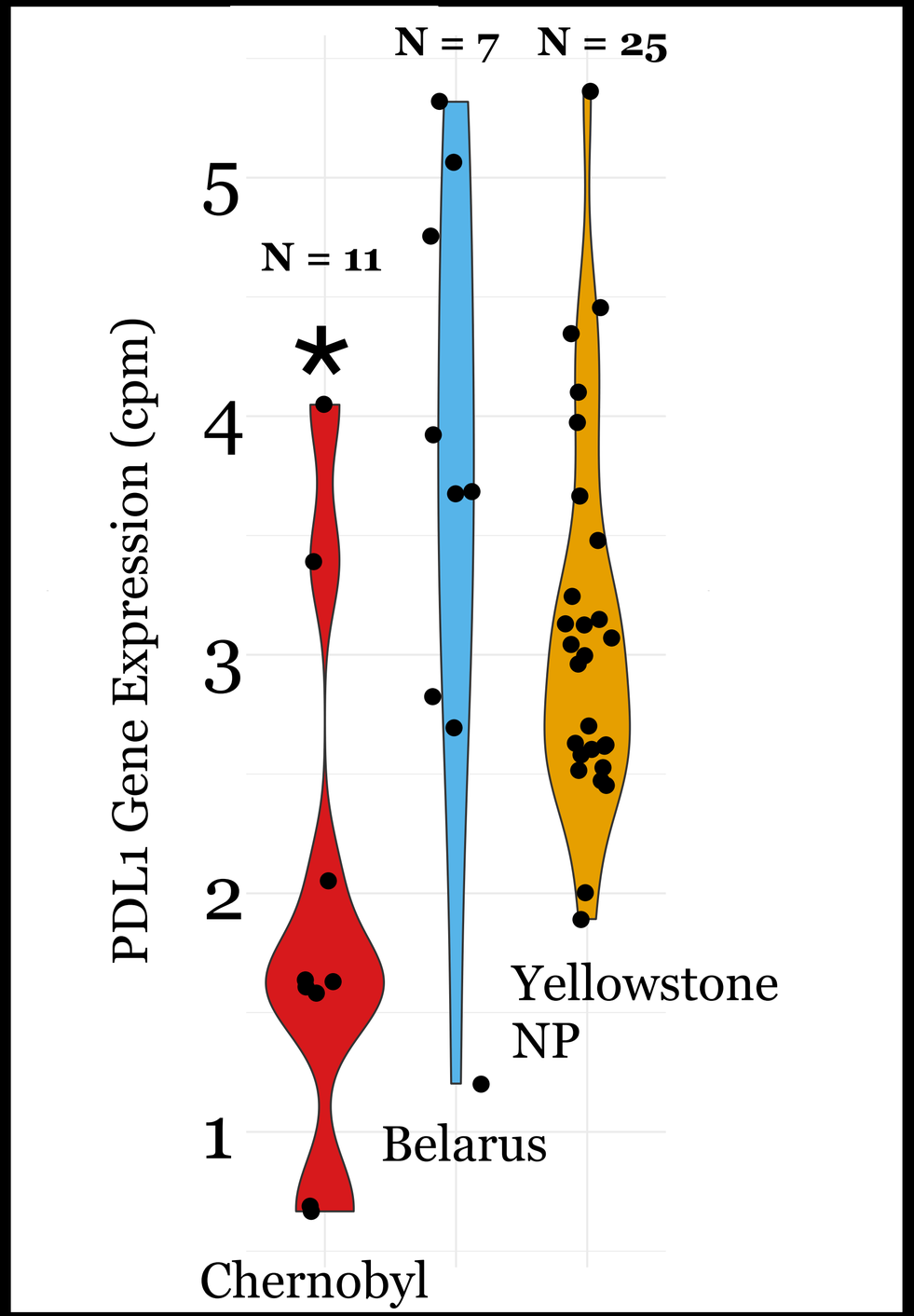
CMTM6 KO RESULTS IN LYSOSOMAL DEGRADATION OF PDL1 AND INCREASED IMMUNE RECOGNITION



BURR ET AL 2017 NATURE

PDL1 Expression Correlates with Cancer Survival Outcomes





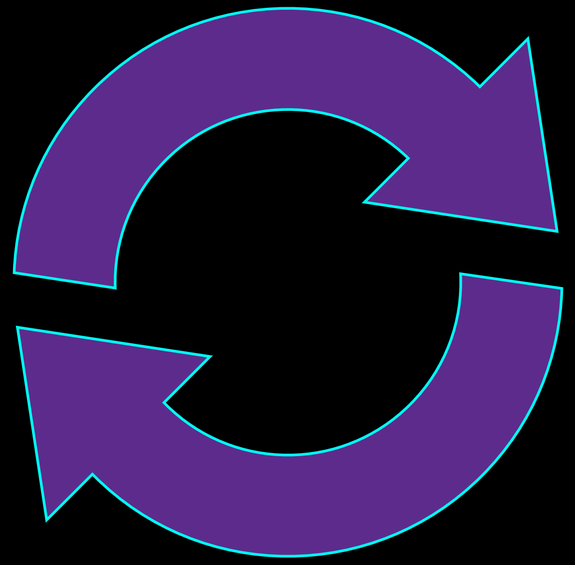


Take Home Points:

- Wildlife exposed to anthropogenic pressures are sentinels for environmental quality and potential physiological threats
- Adaptive response to anthropogenic stressors may reveal biological solutions for human health in a modern world

REVEALS THE LASTING
BIOLOGICAL IMPACTS OF

Evolution



Anthropogenic Change

PROVIDES UNIQUE
INSIGHTS ABOUT THE
PROCESS OF

MAJOR TAKEAWAYS

Evolution in the Anthropocene



A powerful tool for understanding adaptive innovation of complex traits and the repeatability of evolution



Unique insights into the ecological consequences of human-driven evolution



Means for identifying candidate genes associated with human disease states

Coming in 2023…

HUMAN FOOTPRINT

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Exploring the global impact of Earth's most ingenious, destructive, and adaptable species: **us**.

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Evolution in the Anthropocene

Nuclear Disaster



Pollution



Urbanization



Human-Wildlife Conflict





Border Politics



Climate Adaptation





Extreme Weather Events

Thank you



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