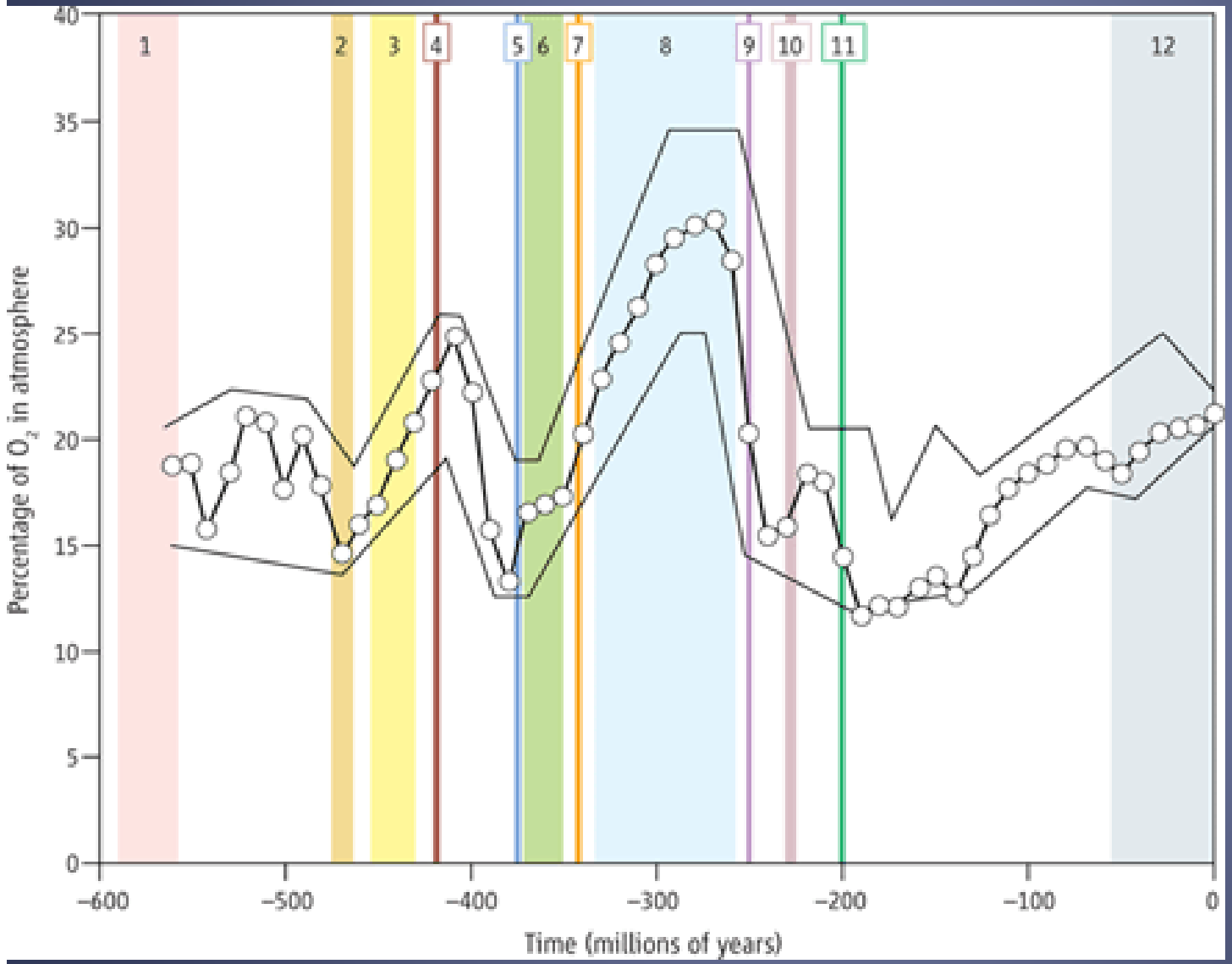

Future Challenges in Earth Sciences
John VandenBrooks
PhD ‘07

Oxygen and Evolution



1. Evolution of major phyla
2. Evolution of novel aquatic respiratory structures
3. Ordovician community diversification
4. Initial conquest of land by animals
5. Devonian Extinction
6. Romer's Gap
7. Second conquest of land
8. Arthropod gigantism/ Reptiliomorph size increase
9. Permian-Triassic extinction
10. Evolution of dinosaur air-sacs
11. Triassic-Jurassic extinction
12. Increase in mammalian body size

Berner, RA., VandenBrooks, JM, Ward, PD. 2007. Oxygen and Evolution *Science* Vol. 316. no. 5824, pp. 557 - 558.

Insect Gigantism

Lifesize reconstruction of Arthropleura. Known from the Upper Carboniferous, these huge invertebrates reached 2 meters (6 and a half feet) in length and 48 cm (19 inches) in width.
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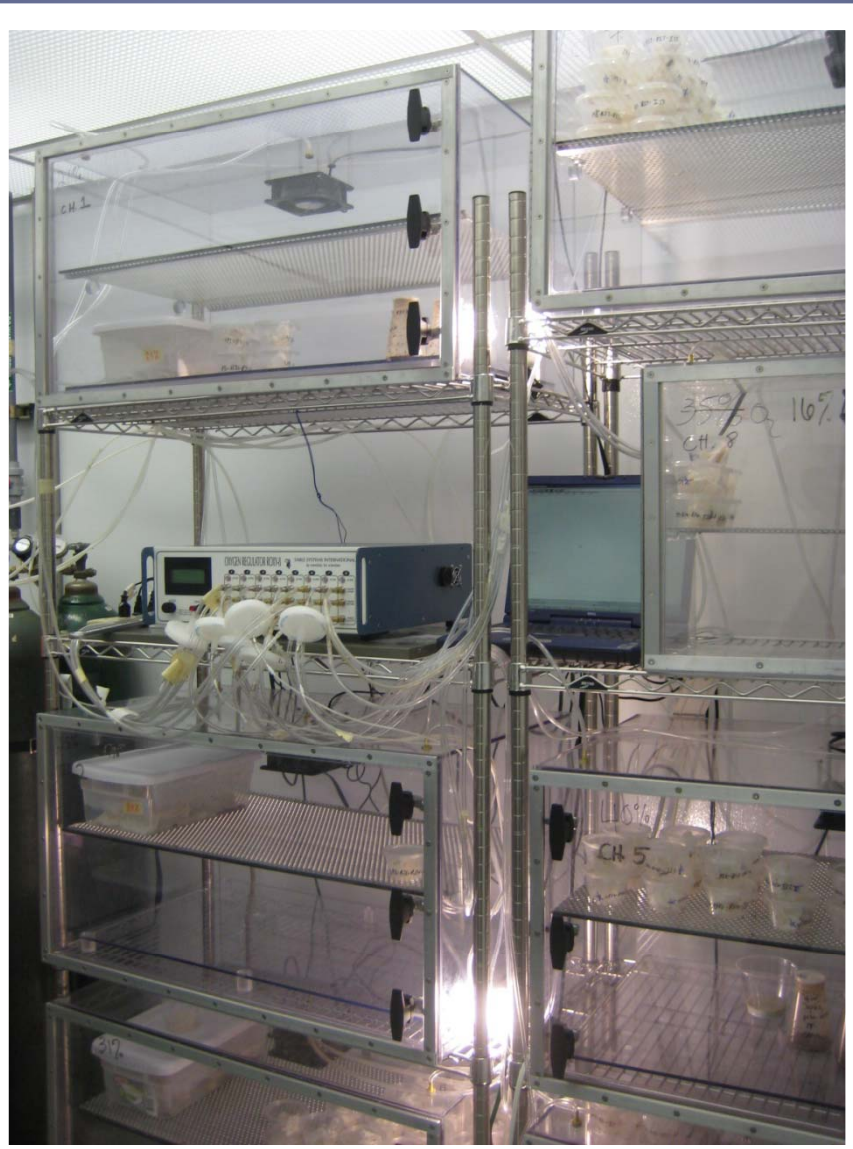
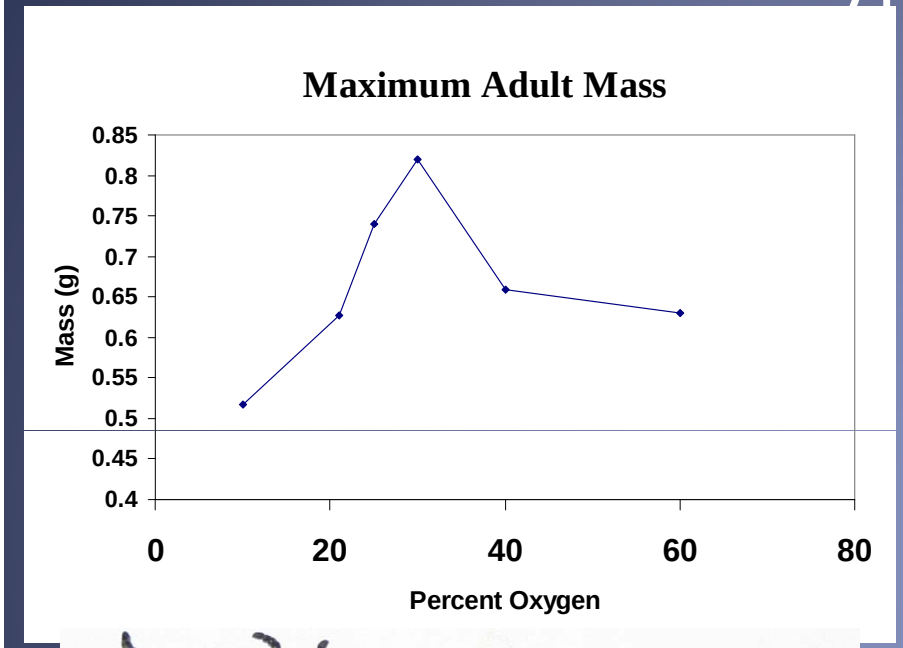
McAlester, 1970

"Perhaps the most relevant evidence would be long-term experiments on the effects of abnormally high or low oxygen partial pressures on the living representatives of the many groups which exist today"

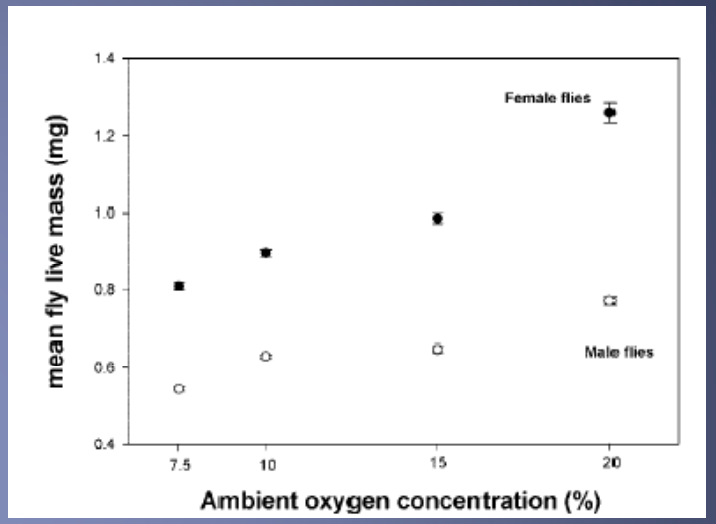
Rearing Studies



Linear response to hypoxia; biphasic response to hyperoxia



RESULTS

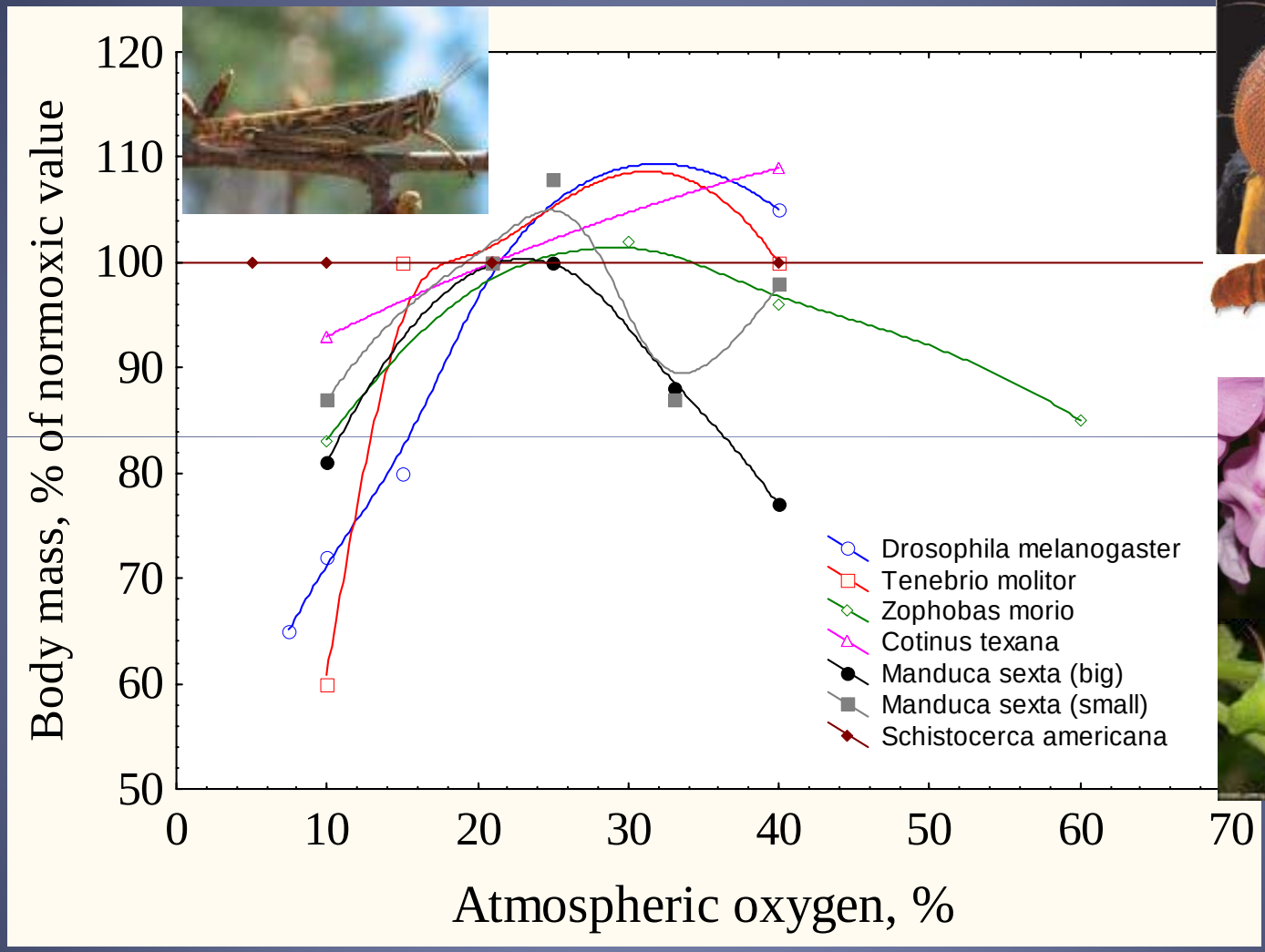


Zophobas morio

10% **21%** **30%**

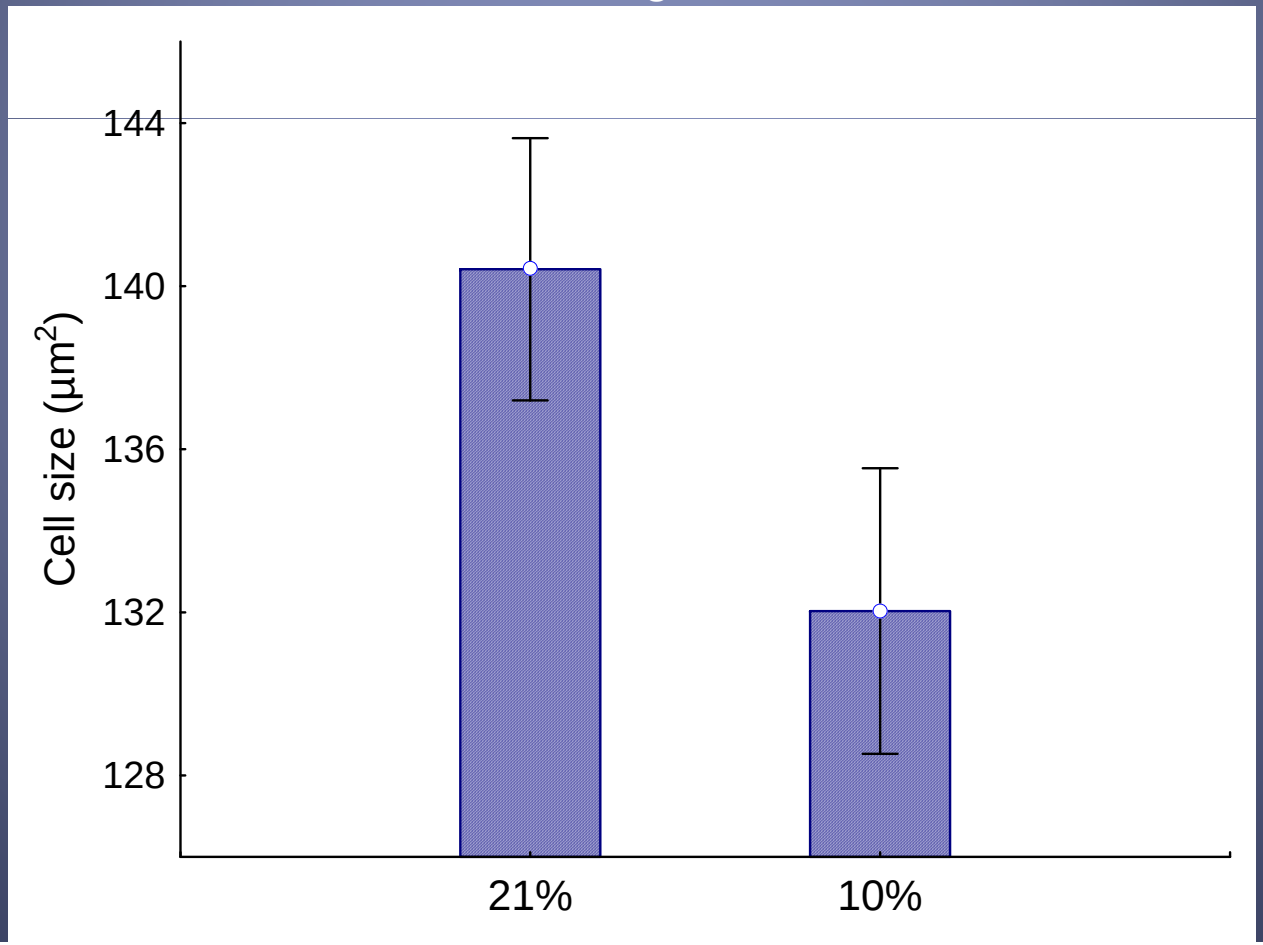
Drosophila melanogaster: Peck and Maddrell. 2005. JEZ 303A:968

Summary of single-generation rearing studies



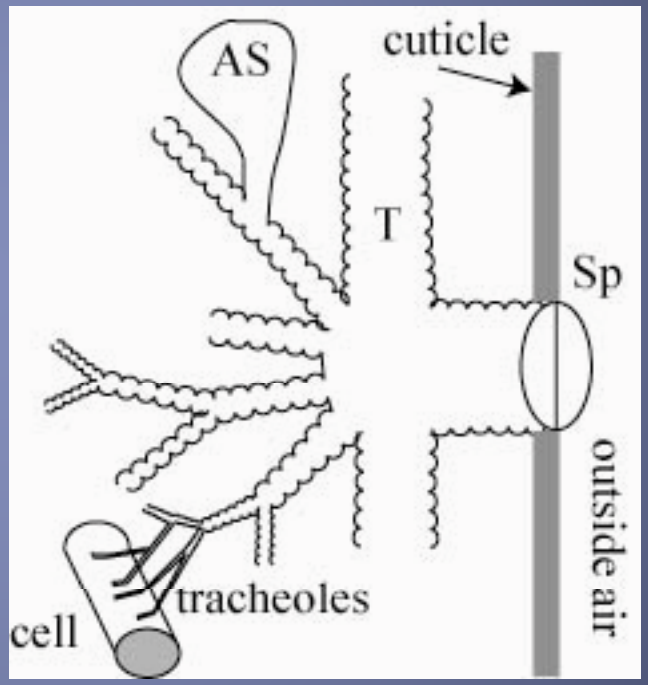
- Grasshoppers showed no effect, all other species were similar
- Hyperoxic responses usually biphasic
- Hypoxia generally has a stronger effect than hyperoxia

Proximal Cause for Hypoxic Mechanism

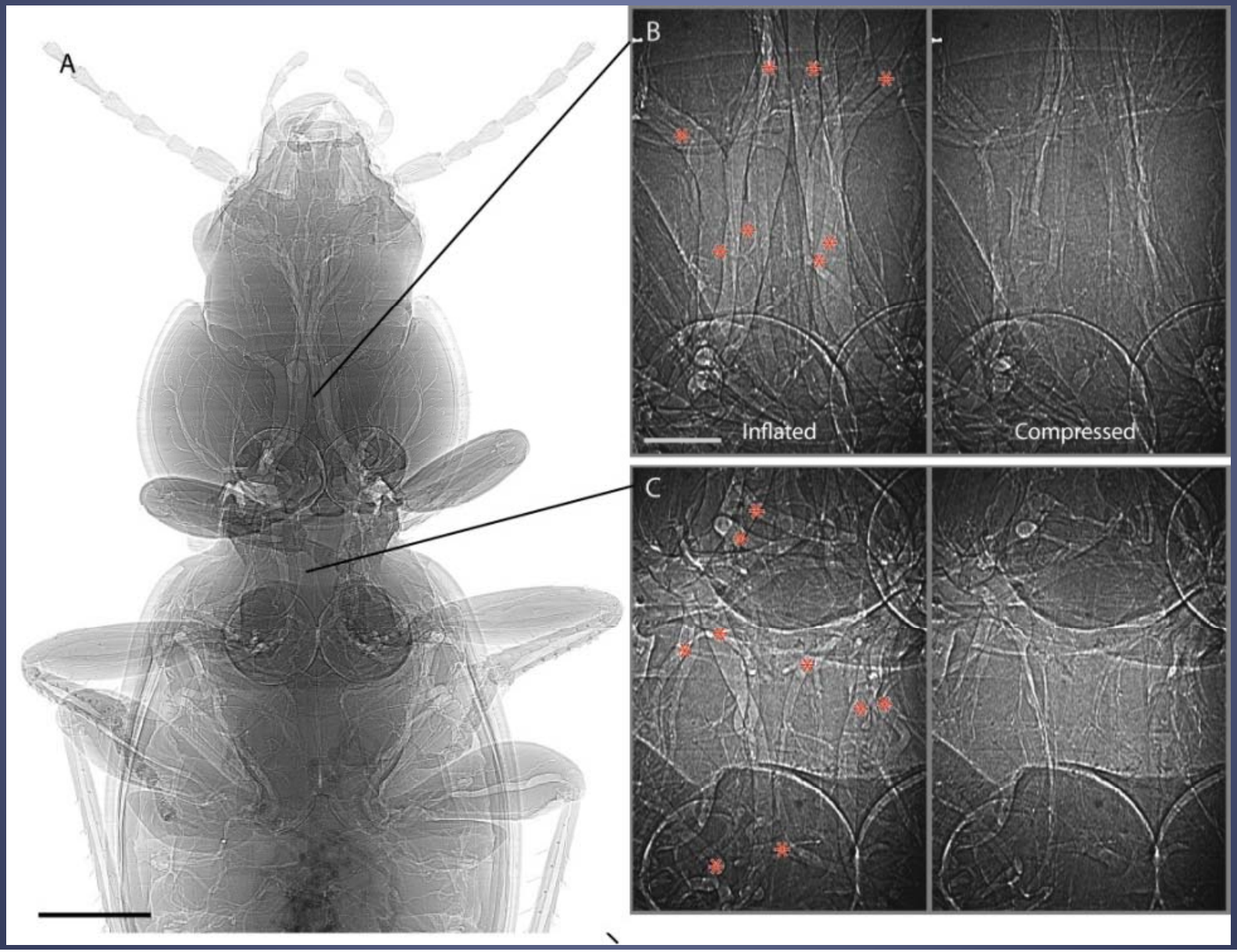


General Anatomy of Tracheal System

- Spiracle
- Trachea
- Air Sac
- Tracheoles



X-ray Synchrotron Imaging



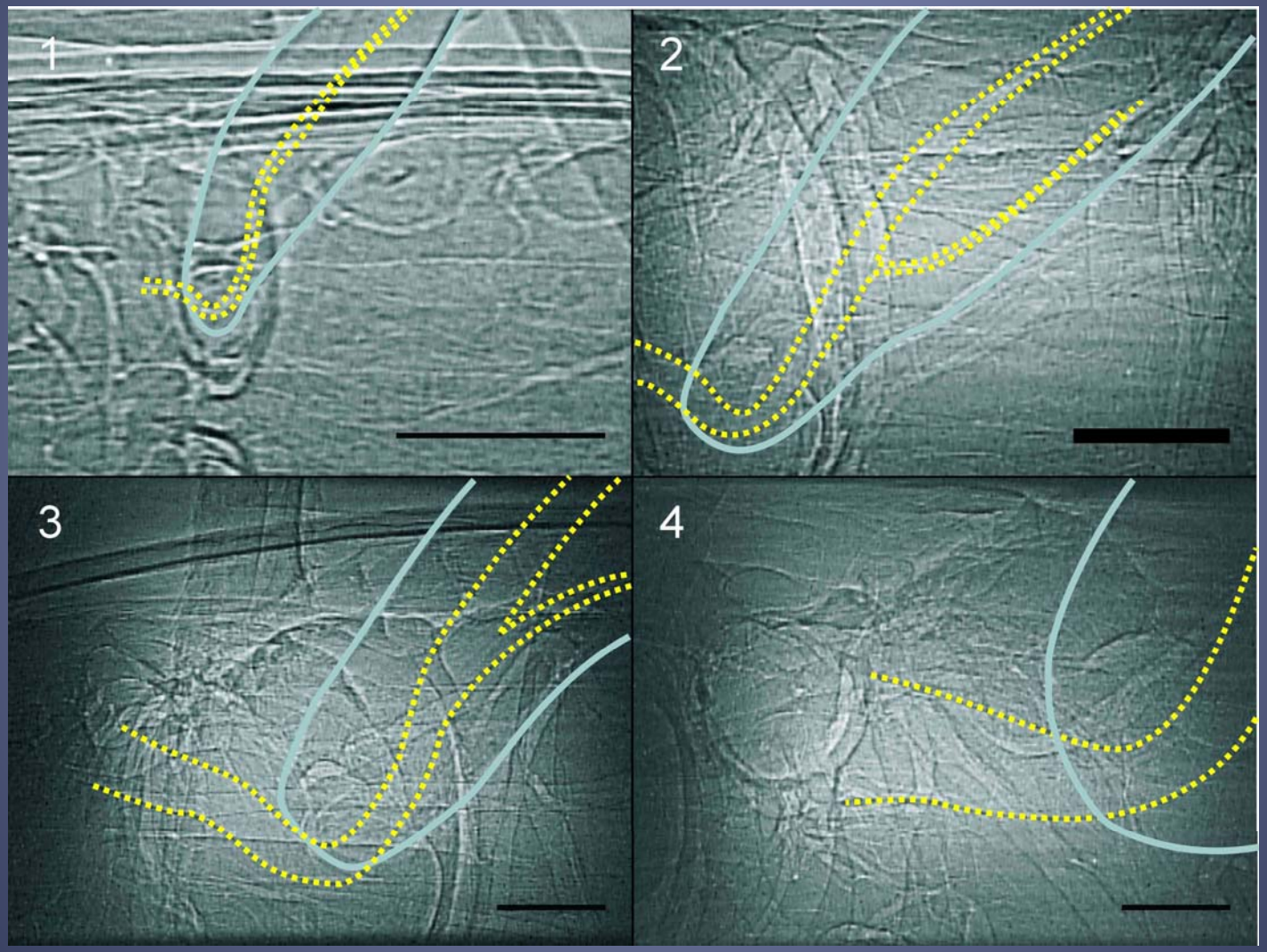
Tracheal System Limitation Hypothesis

- Possession of a blind-ended tracheal respiratory system leads to increasing challenges for gas exchange as insects get larger.
- To compensate, they increase their mass-specific investment in the tracheal system (hypermetry), and utilize more convection.
- Eventually, tracheal hypermetry leads to spatial constraints that limit insect size.
- When atmospheric oxygen is higher, tracheae are smaller, and insects can attain larger sizes before reaching limits set by spatial constraints.

Tracheae occupy an increasing % of body as beetles increase in size, especially in limbs

2 mg

132 mg



688 mg

1350 mg

Tracheal volume increases with mass$^{1.3}$

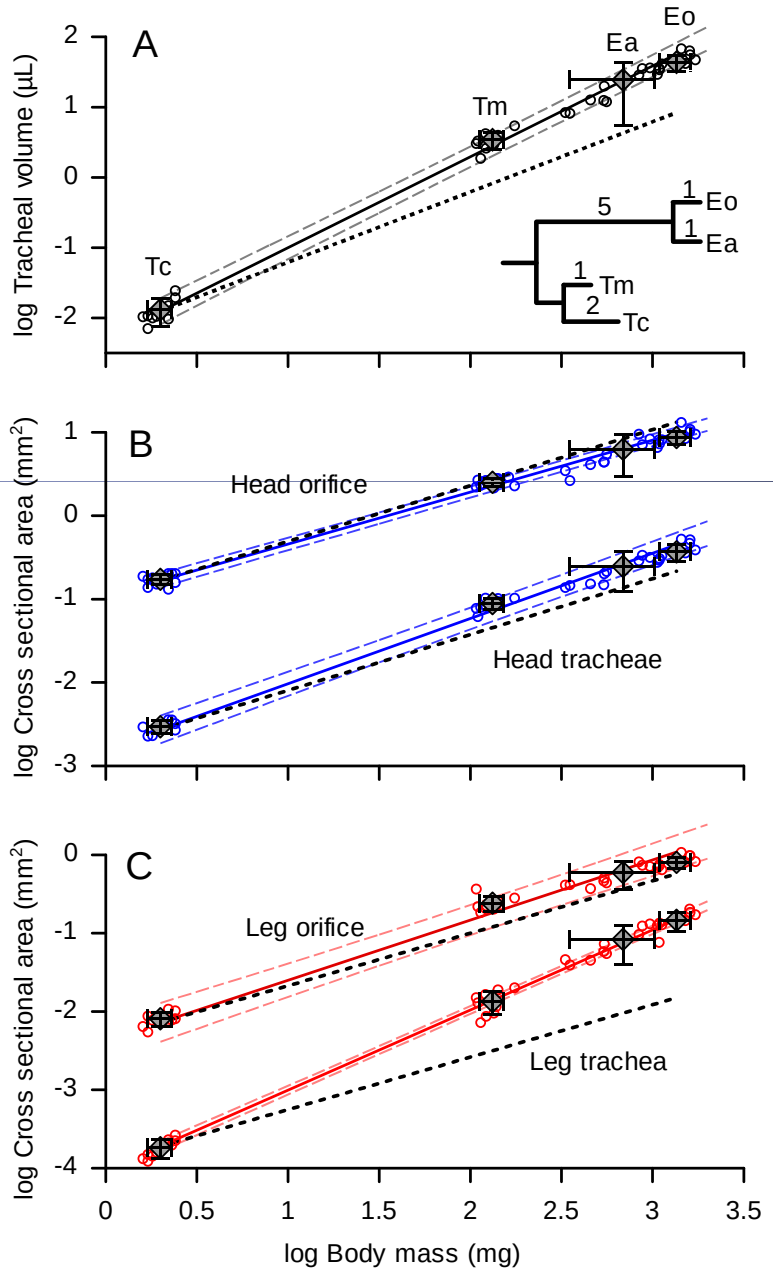
Significantly > 1, P = 0.04, phylogenetic correction

Leg orifice area scales with mass$^{0.77}$

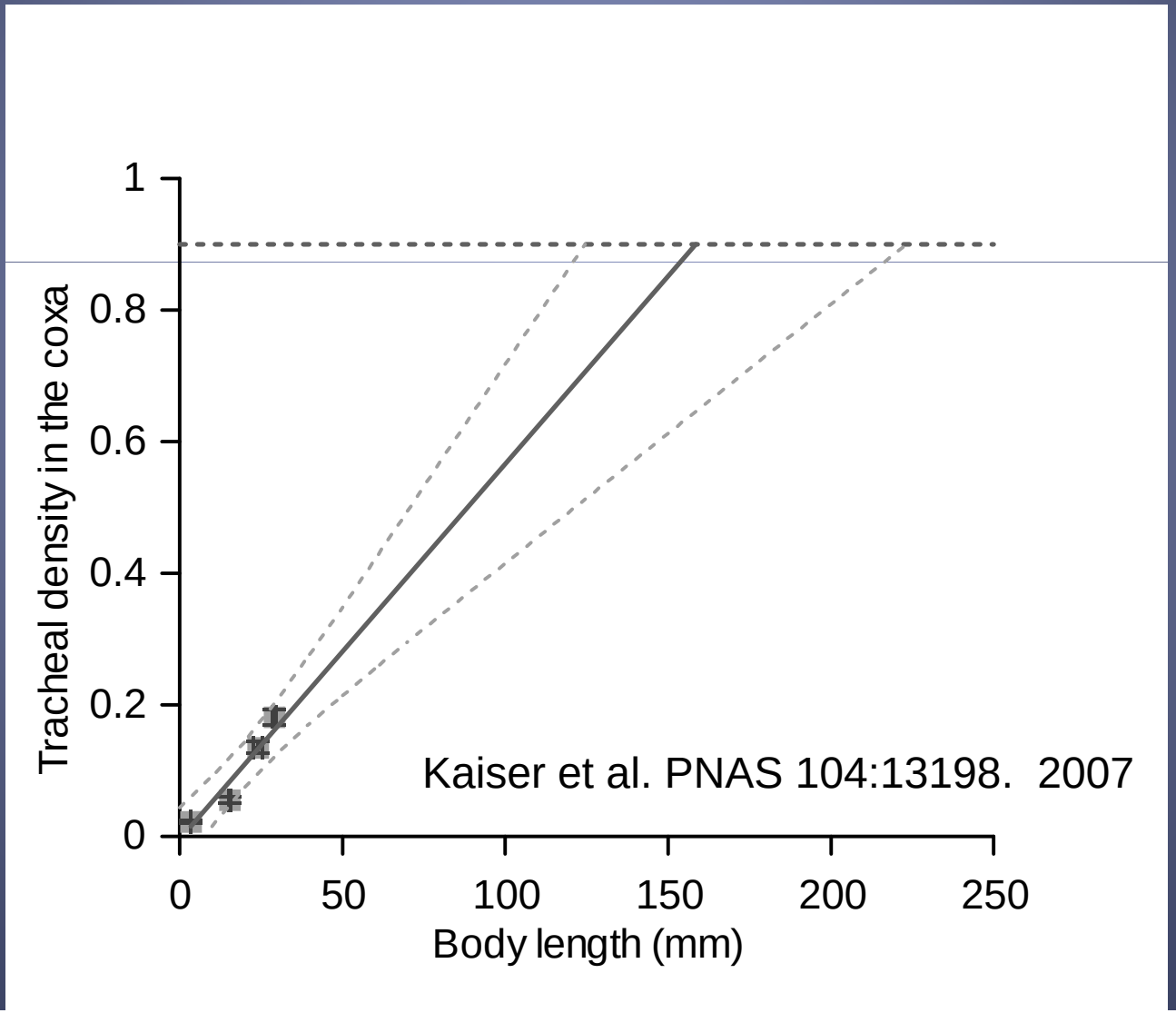
Leg tracheae scales with mass$^{1.02}$

Significantly > 0.67

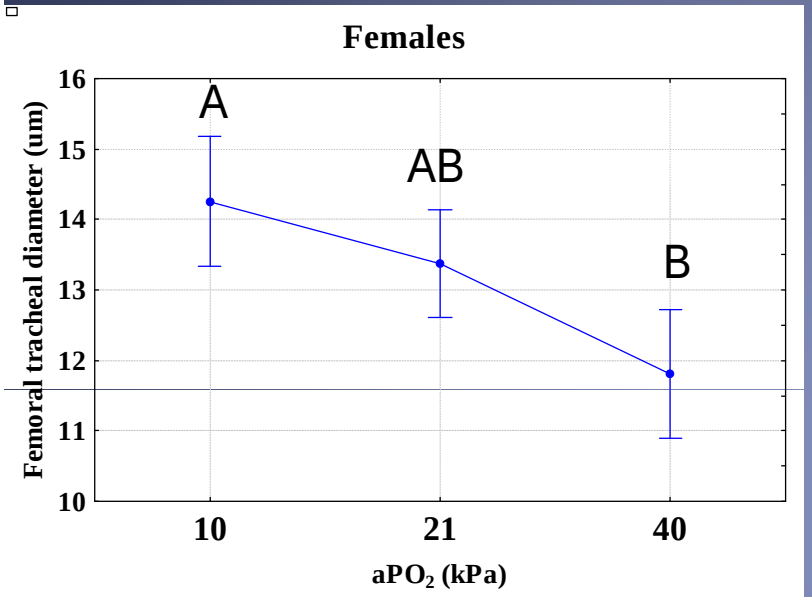
P = 0.004 with phylogenetic correction

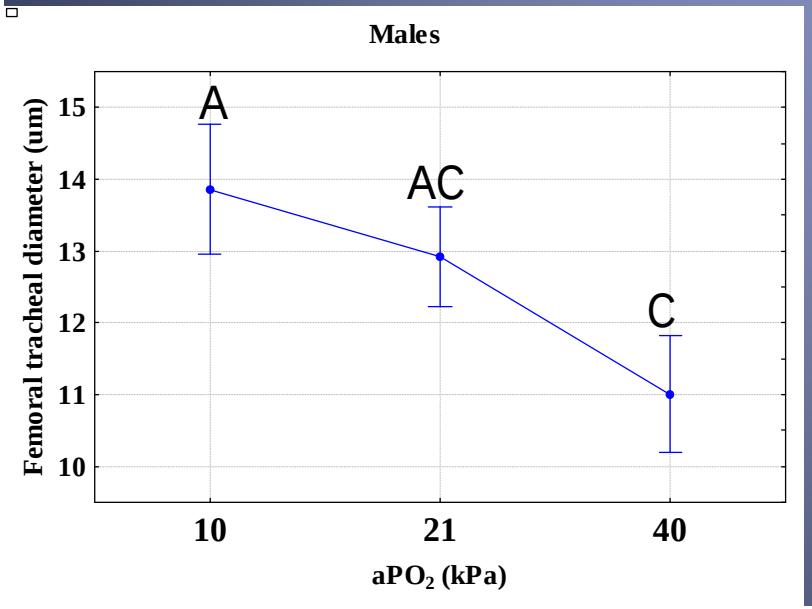


Extrapolation of these results suggests that hyper-investment in the tracheal system within the leg can limit beetle size due to spatial constraints



Second Half of the Story – Tracheal Width Correlates with Rearing Oxygen





ANCOVAs
(Femur length as size co-variate)

$F_{(2, 26)} = 6.2009$, $p = 0.00628$

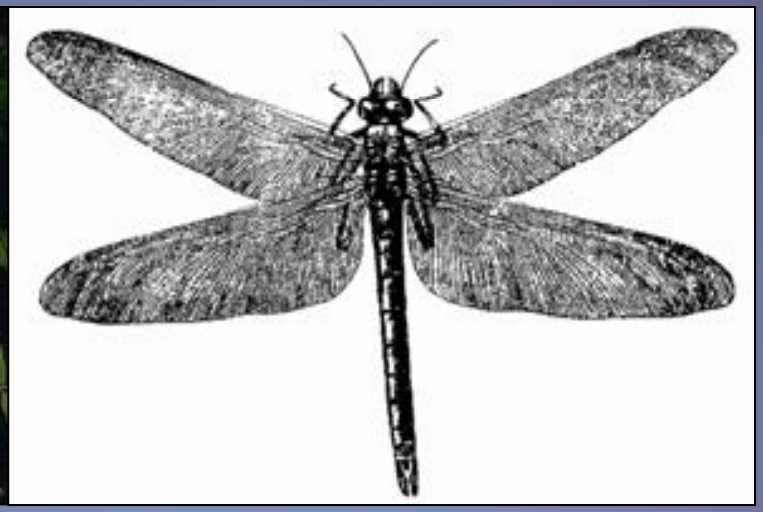
$F_{(2, 25)} = 11.343$, $p = 0.00031$

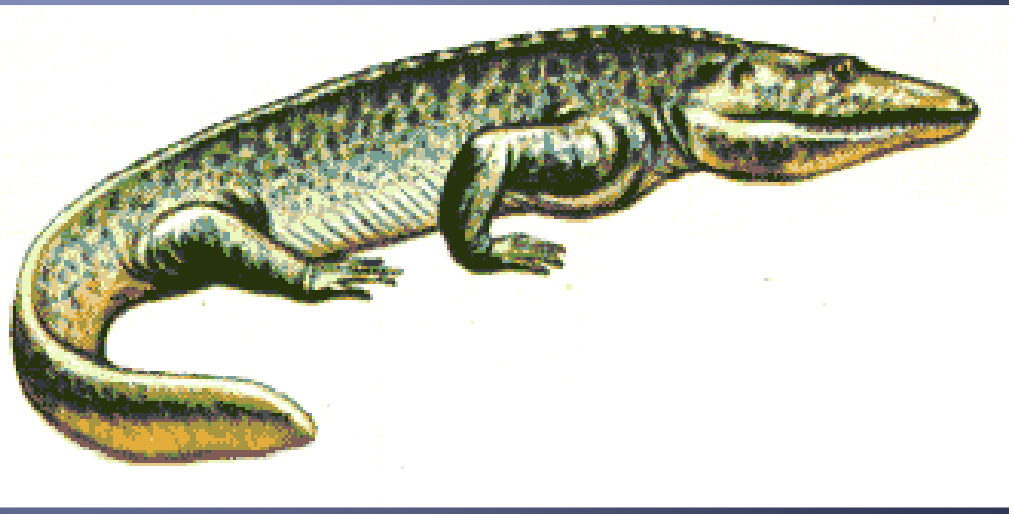
($p < 0.0001$ and $r^2 > 0.4$ in all cases)

We have also imaged tracheae in the beetle, *Zophobas morio* and preliminary analysis points to the same trend

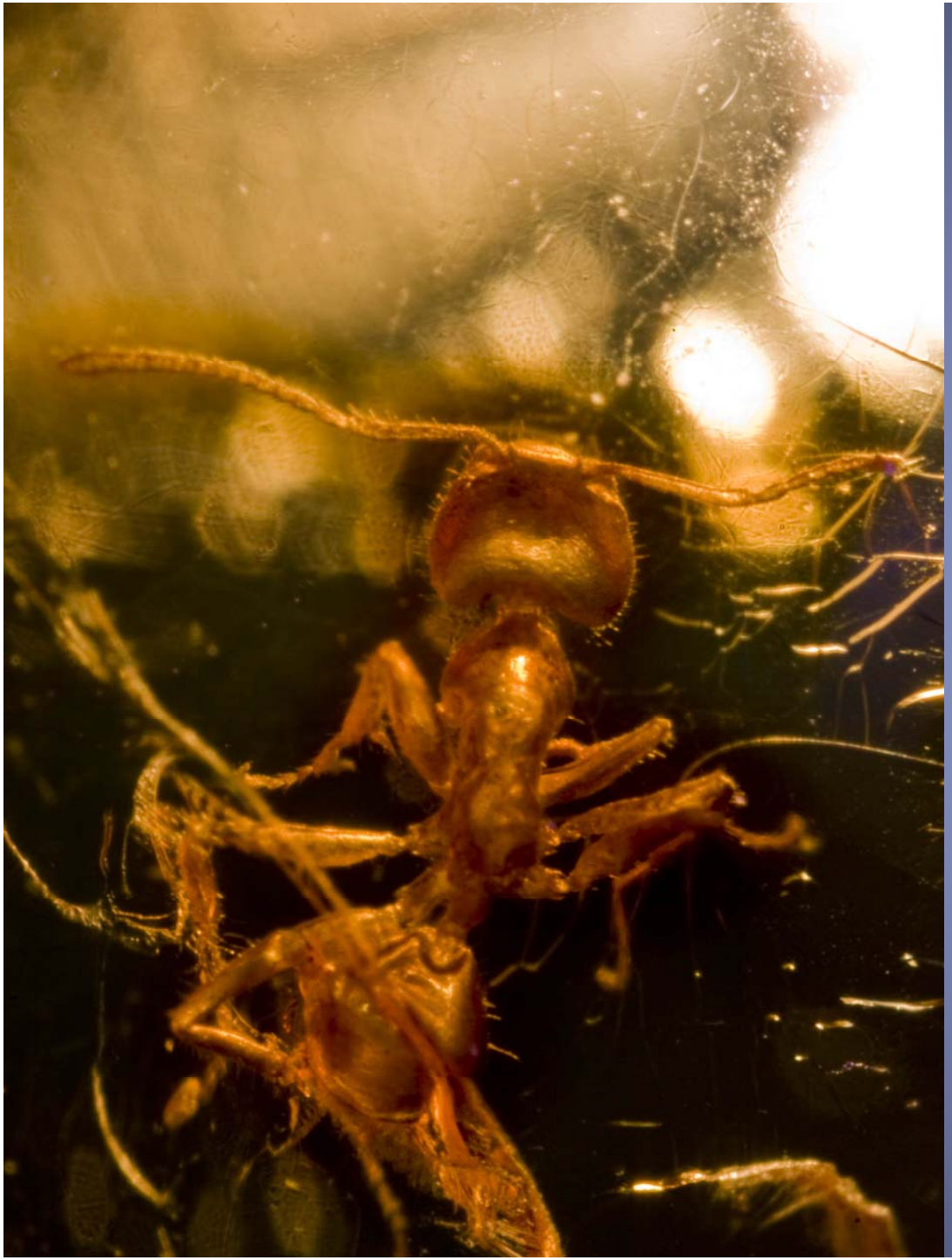
This lends support to a tracheal control mechanism of insect gigantism in the high oxygen times of the Permo-Carboniferous

Paleontological Work

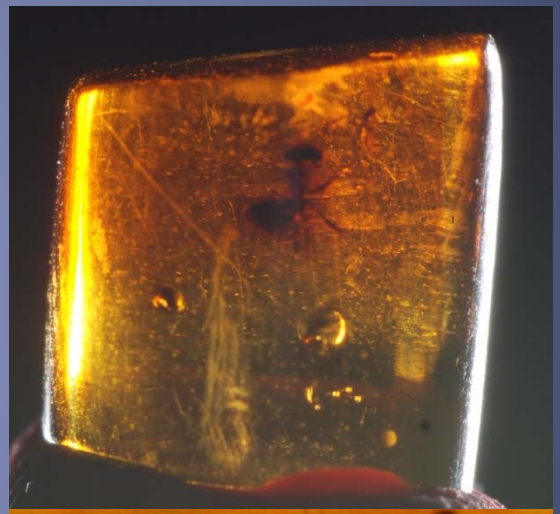




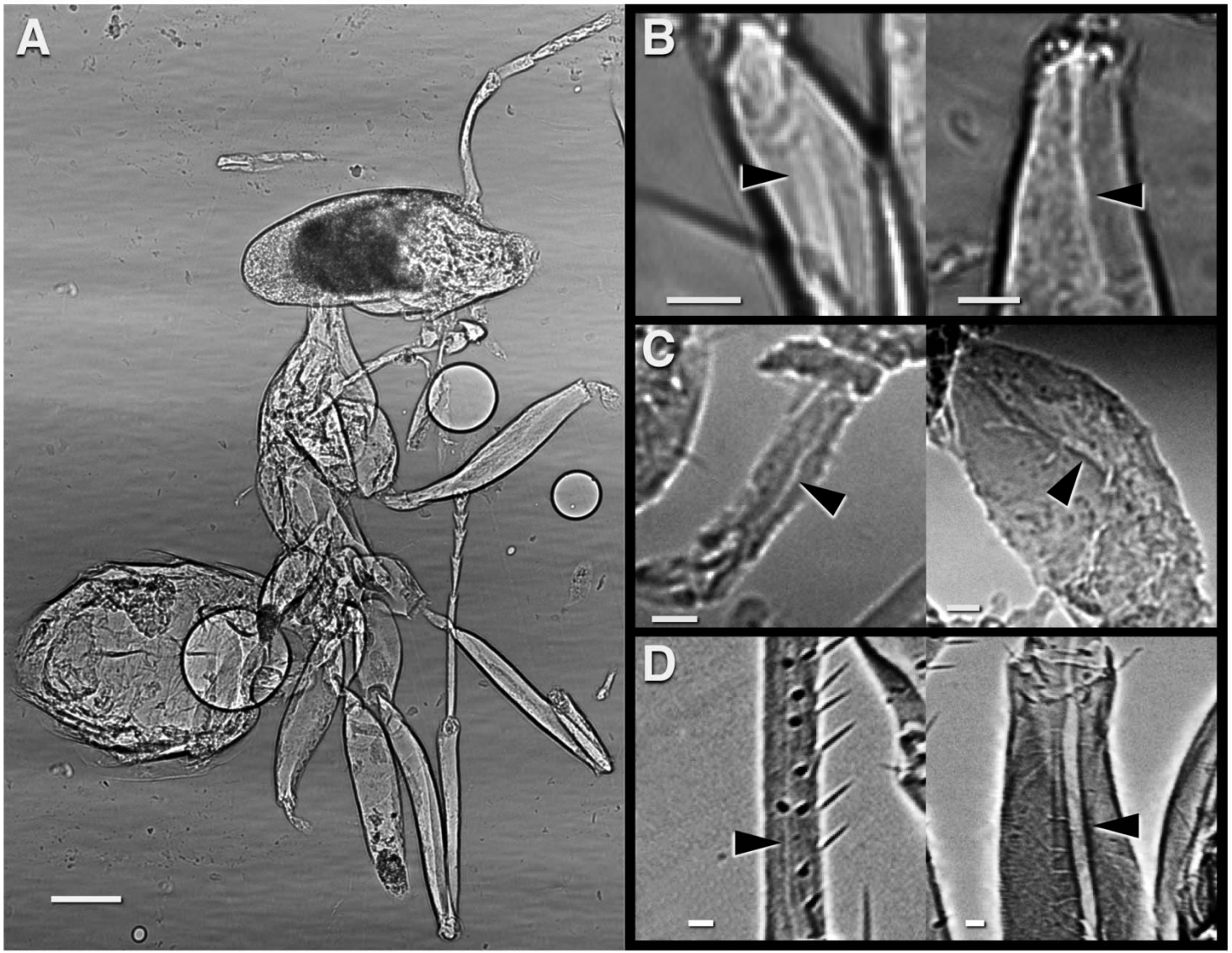
Adapted from: www.geocities.com/arturcarbonifero/carbpenvida.html

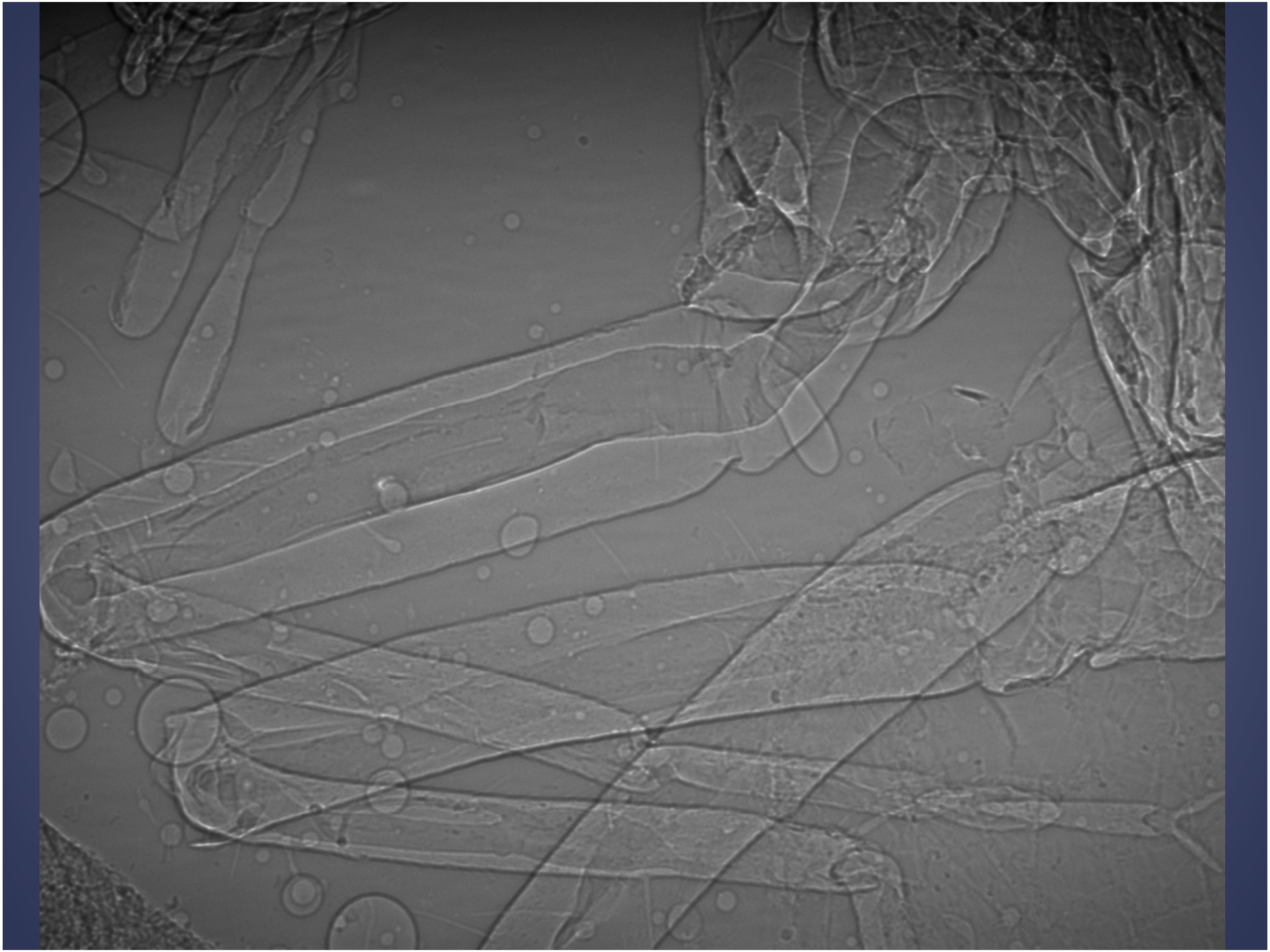


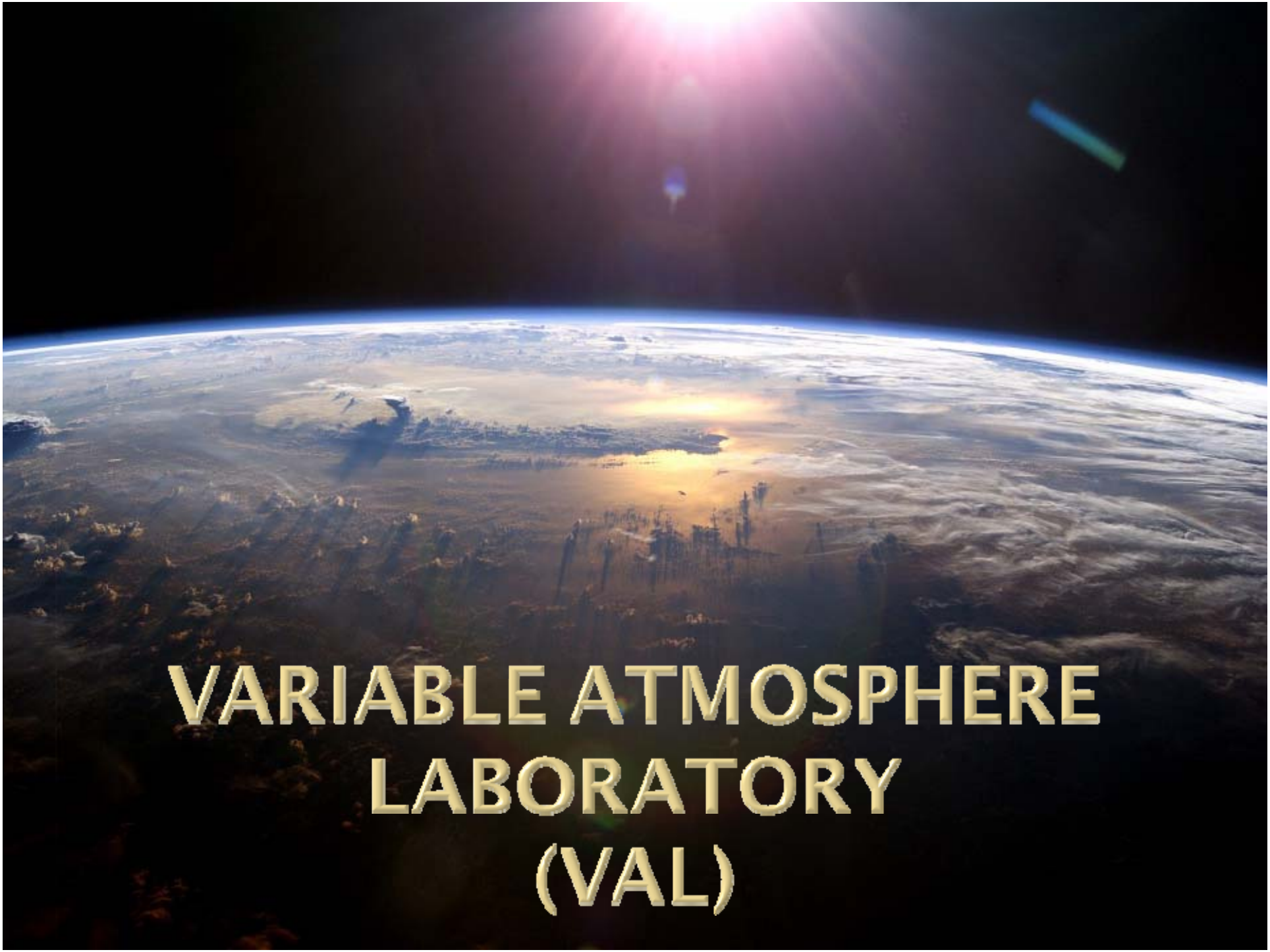
Fossil Amber



Fossil Trachea






VARIABLE ATMOSPHERE
LABORATORY
(VAL)

Some atmospheric components with major current and Phanerozoic variation

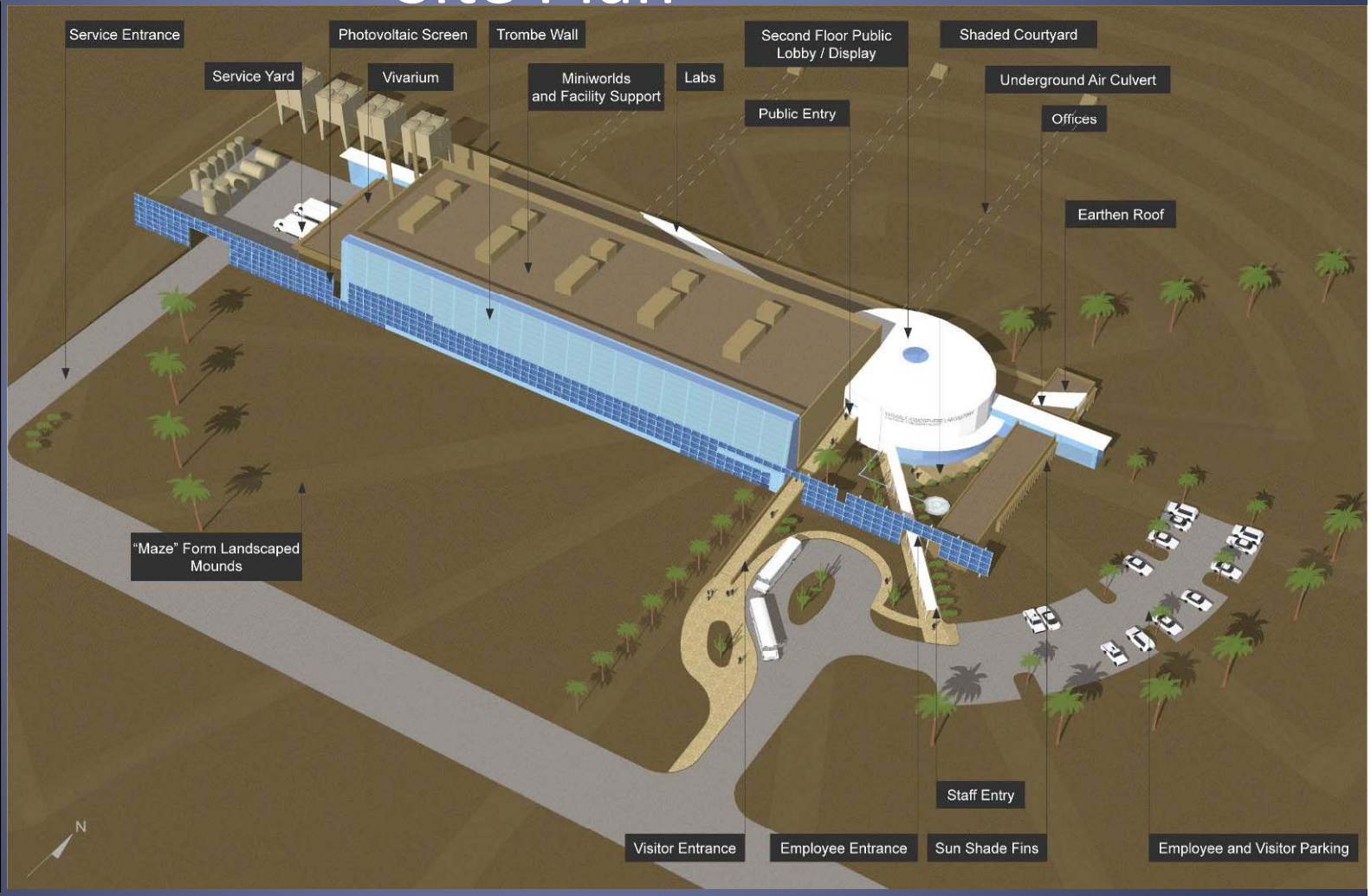
Gas	1750 levels	2005	Last 400,000 years	Phaner-ozoic
O_2	21 kPa	21 kPa	21 kPa	12-31 kPa
CO_2	280 ppm	380 ppm	180-280 ppm	180-5600 ppm
CH_4	700 ppb	1745 ppb	350-700 ppb	100-10,000 ppb
N_2O	270 ppb	319 ppb	220-280 ppb	
SO_x	1	3 (relative)		
Tropospheric O_3	1	1.5 (relative)		

VARIABLE ATMOSPHERE LABORATORY (VAL)

We propose the creation of a large scale Variable Atmosphere Laboratory (VAL) that will provide multiple, controlled spaces (henceforth referred to as “miniworlds”), within which careful experimental analysis of the interactions among atmospheric and environmental variables and organisms, materials, and ecosystems would be possible.

Conceptual Vision

Site Plan

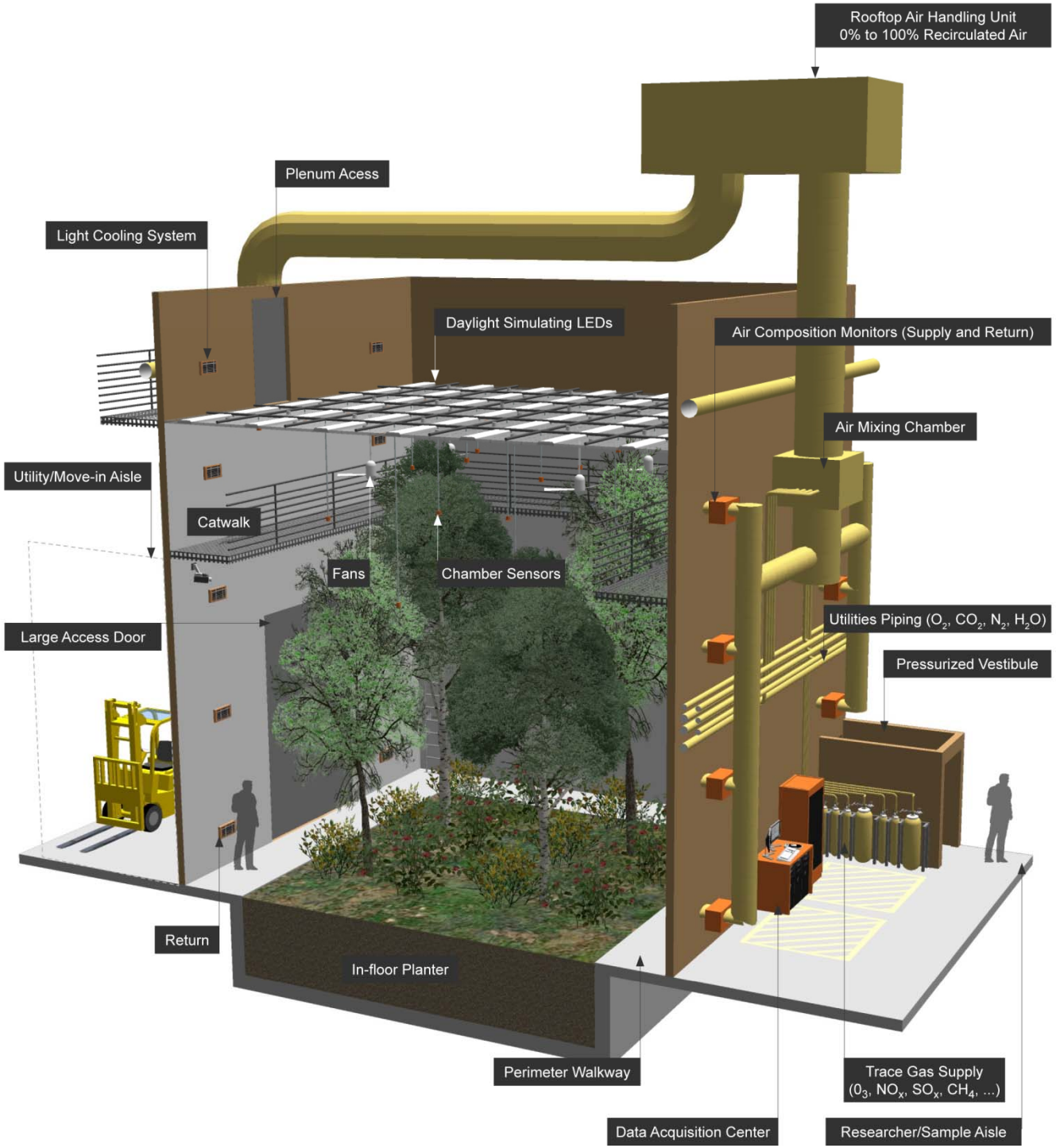


Five Major Areas of Research

- Ecological Processes and Agriculture
- Physiological and Biological Processes
- Paleontology and Biogeochemical Processes
- Astrobiology and Space Exploration
- Environmental Air Quality and Human Health

Advantages of VAL

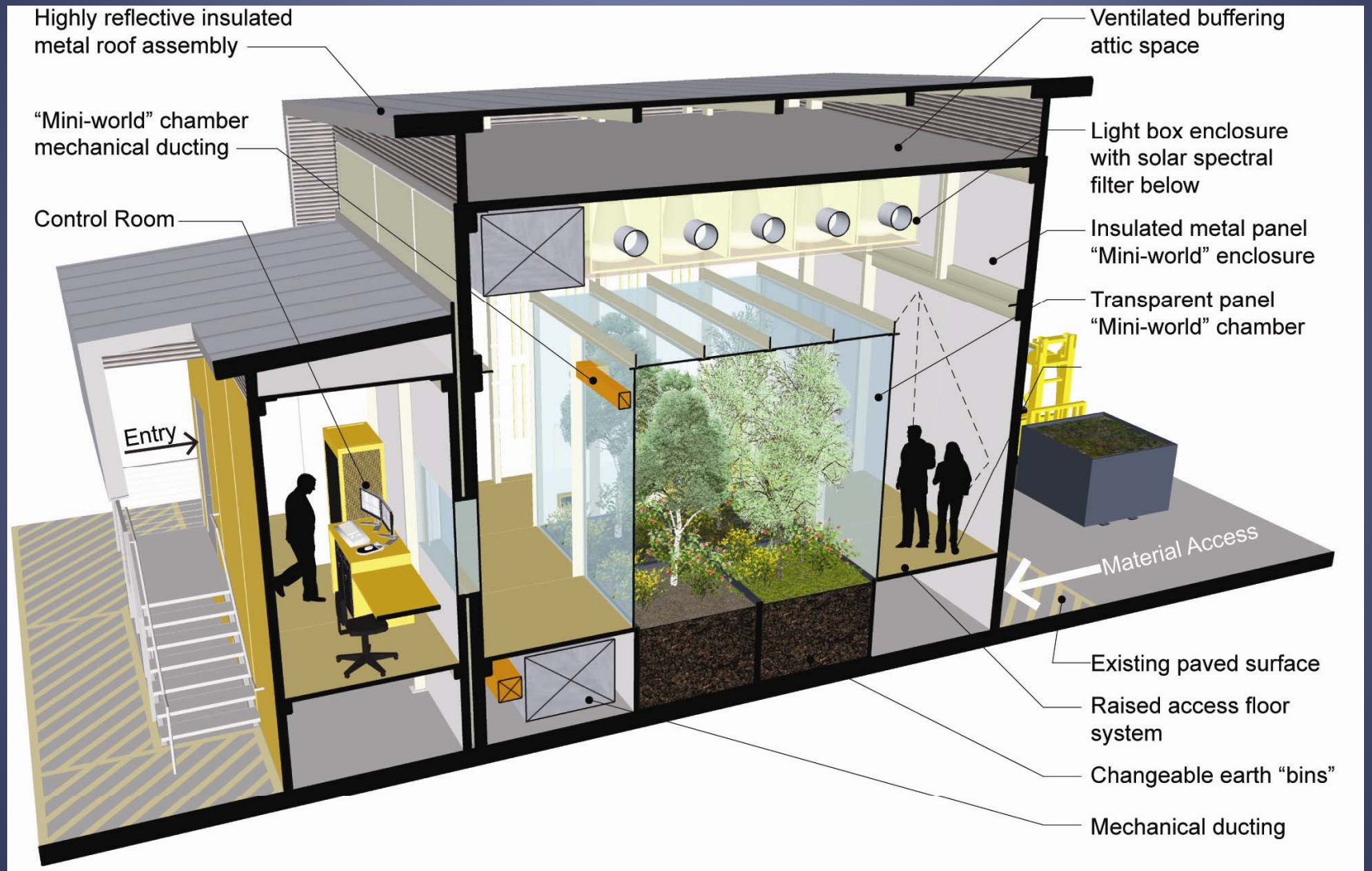
- REPLICATION: Allows experimental manipulation of replicated environments for efficient scientific experimental designs
- INTERACTION: Comprehensive interactive complex control of multiple major environmental variables including trace gas control moving beyond simply carbon dioxide and temperature control
- FLEXIBILITY: Wide array of control and the basic design flexibility allows application to broad range of disciplines to study past, current, and future climate change
- SCALE: Allows for large scale experimental designs on both short and long time scales
- MONITORING: Ability to monitor flow into and out of the miniworlds as well as the changes occurring within them



Large Miniworld Design Features

- Atmospheric Gases
- Trace Gas Control
- Sunlight, Temp, Humidity
- Circulation System
- Sensors/Monitoring
- Access/Utility
- Data Acquisition

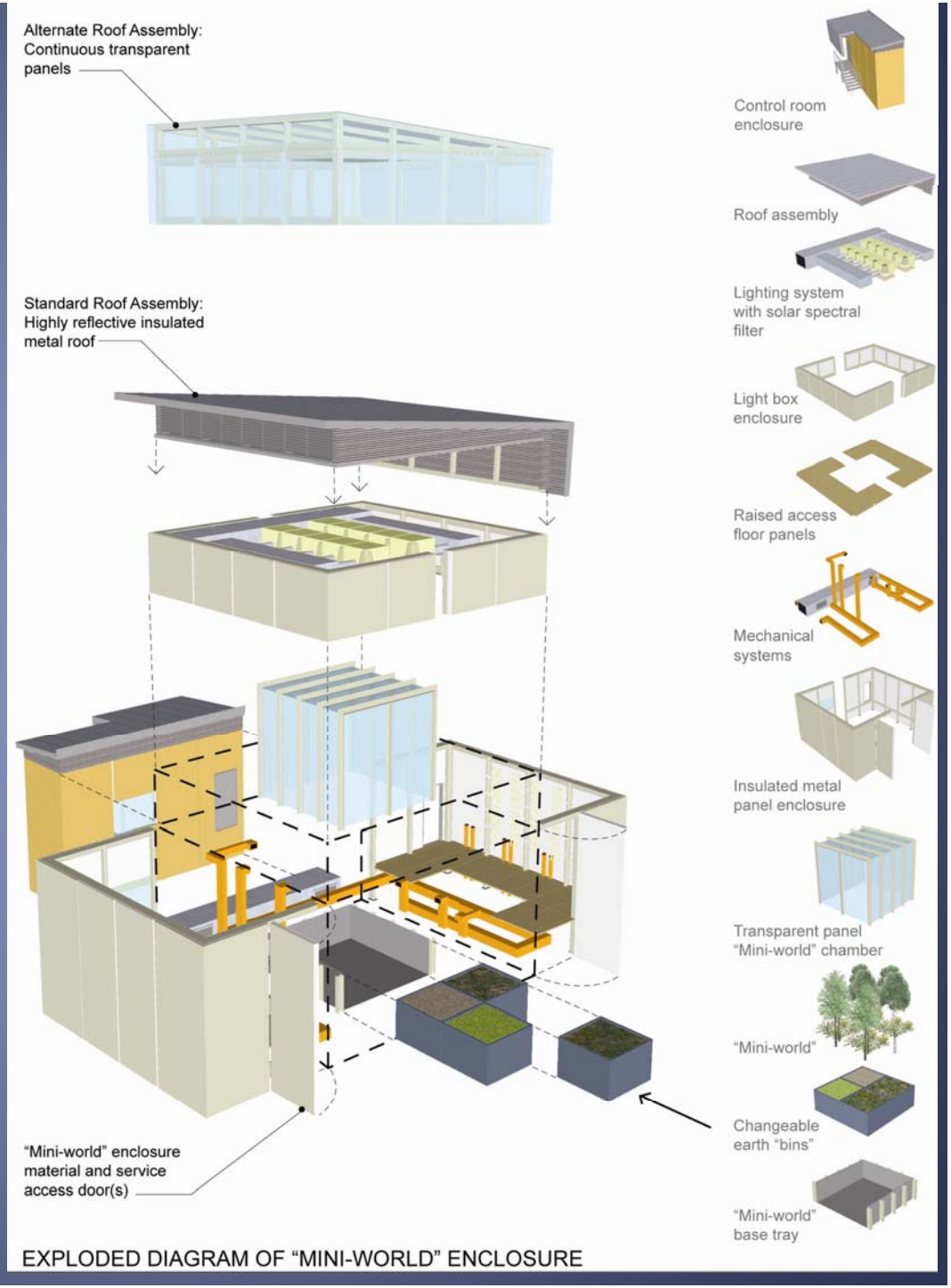
ASU NSF MRI-R2 proposal



INTERIOR PERSPECTIVE @ "MINI-WORLD" CHAMBER

Components
Kit of Parts

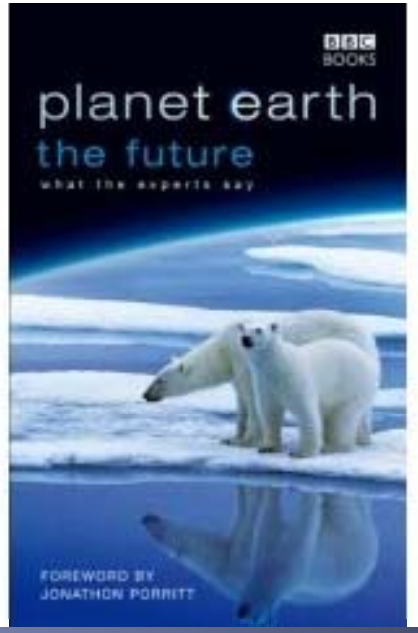
- Kit assembly concept allows for choices such as alternate roofing
- Reflective roofs
- Reflective light boxes improve lighting homogeneity
- Floor panels permit access to soil and mechanical systems
- Communities inside transparent chambers



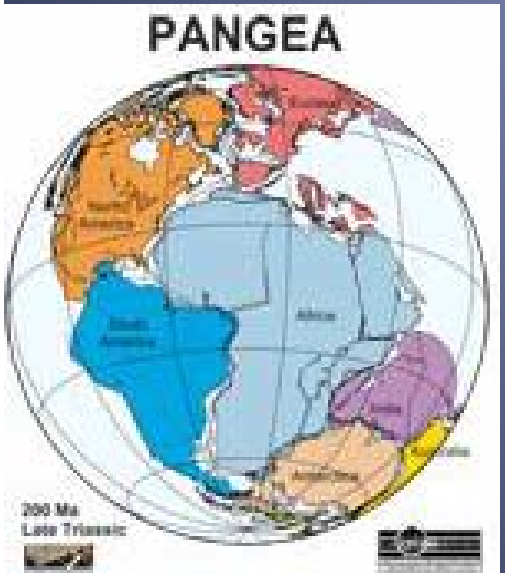
EXPLODED DIAGRAM OF "MINI-WORLD" ENCLOSURE

VAL for Research and Education

Plan for Actualization of VAL



- ✓ 1. Develop initial proposal and ideas
- ✓ 2. Identify engineering/private partner: preliminary design and cost estimates (IDC Architects/CH2M Hill: $80M)
- ✓ 3. Workshop I (ASU): Scientific goals and design needs
- ✓ 4. Workshop Report Produced (in review, Global Change Biology)



✓5. MRI-R2 proposal submitted for six miniworlds

✓6. Workshop II (Washington D.C.): Science and Funding Strategies

7. Funding for further miniworld and technology development projects

8. Funding for construction and operations (DOE, NSF, NASA, NIH, EPA, Private Donors)

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