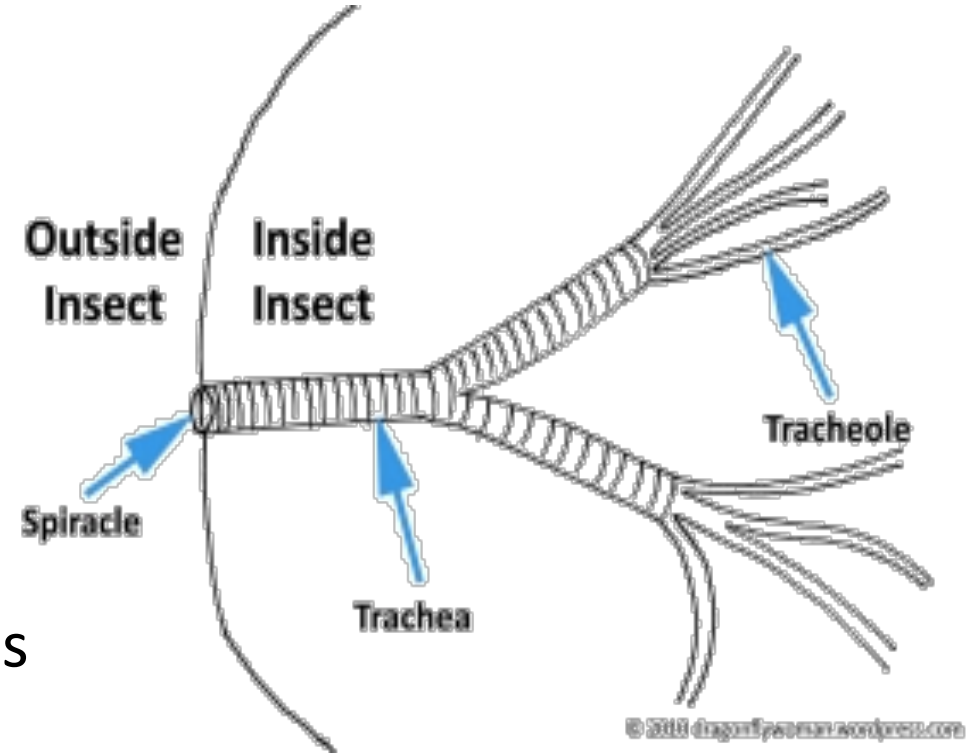
New Insights into Insect Physiology

Discussion 3

17 March 2017

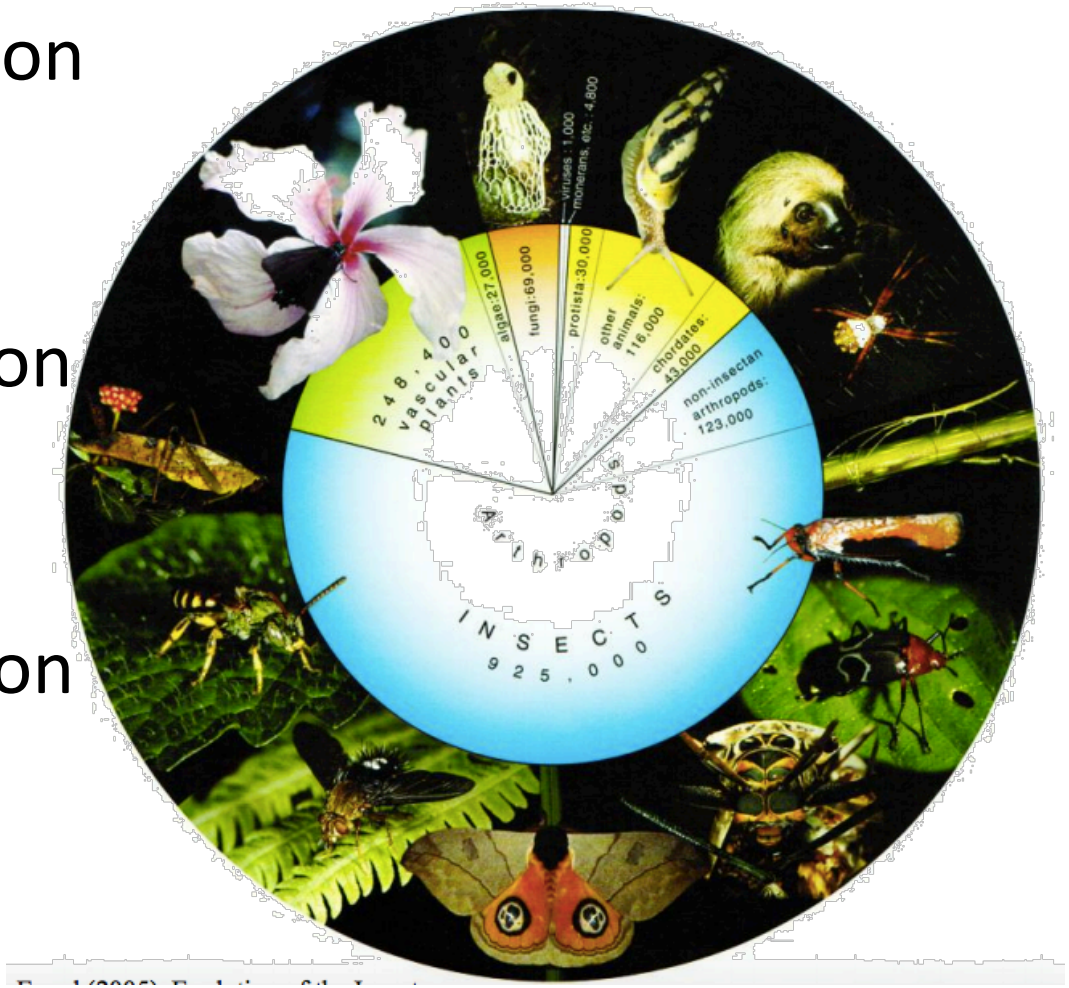
Insect Respiratory System

- Tracheal System
- Spiracles
  - Valve-like openings through which air enters
- Trachea
  - Series of air-filled tubes
- Tracheoles
  - Delivers O_2 directly to muscles



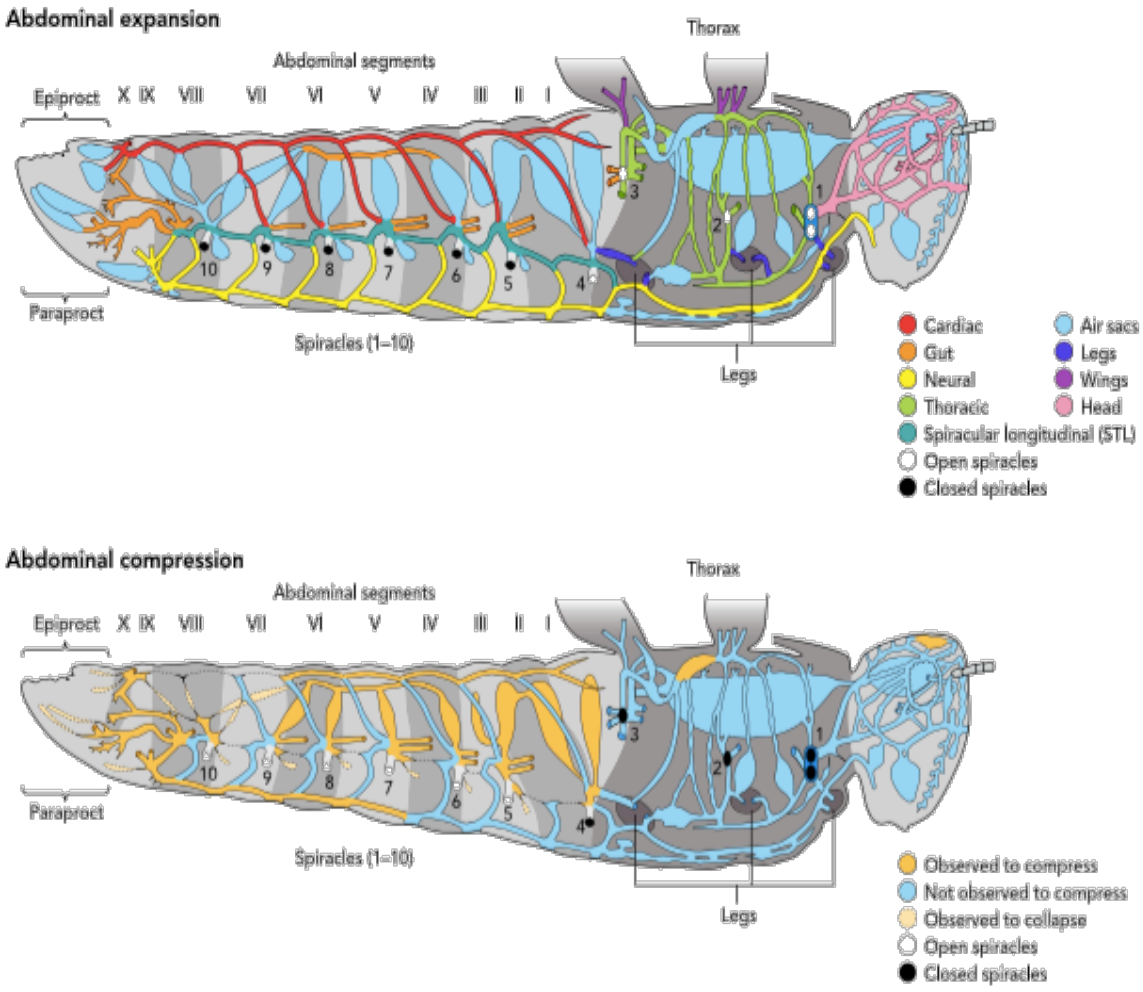
Insect Respiratory System

- O_2 delivery by diffusion alone? Right?
- Insects are the most common organisms on the planet BUT…
- Something more complex than diffusion
- Convective gas transport



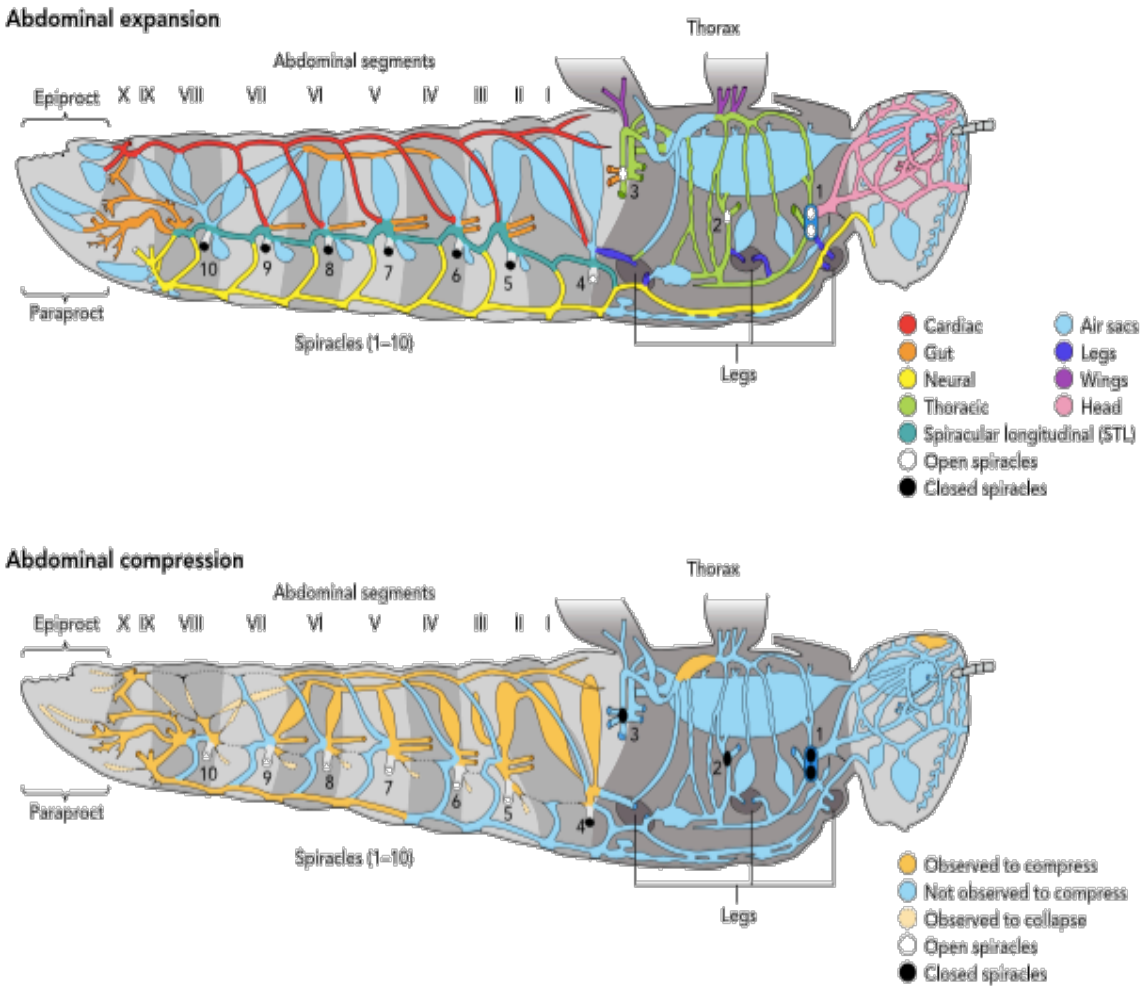
Locust Tracheal System

- 10 pairs of spiracles
  - 2 thoracic
  - 8 abdominal



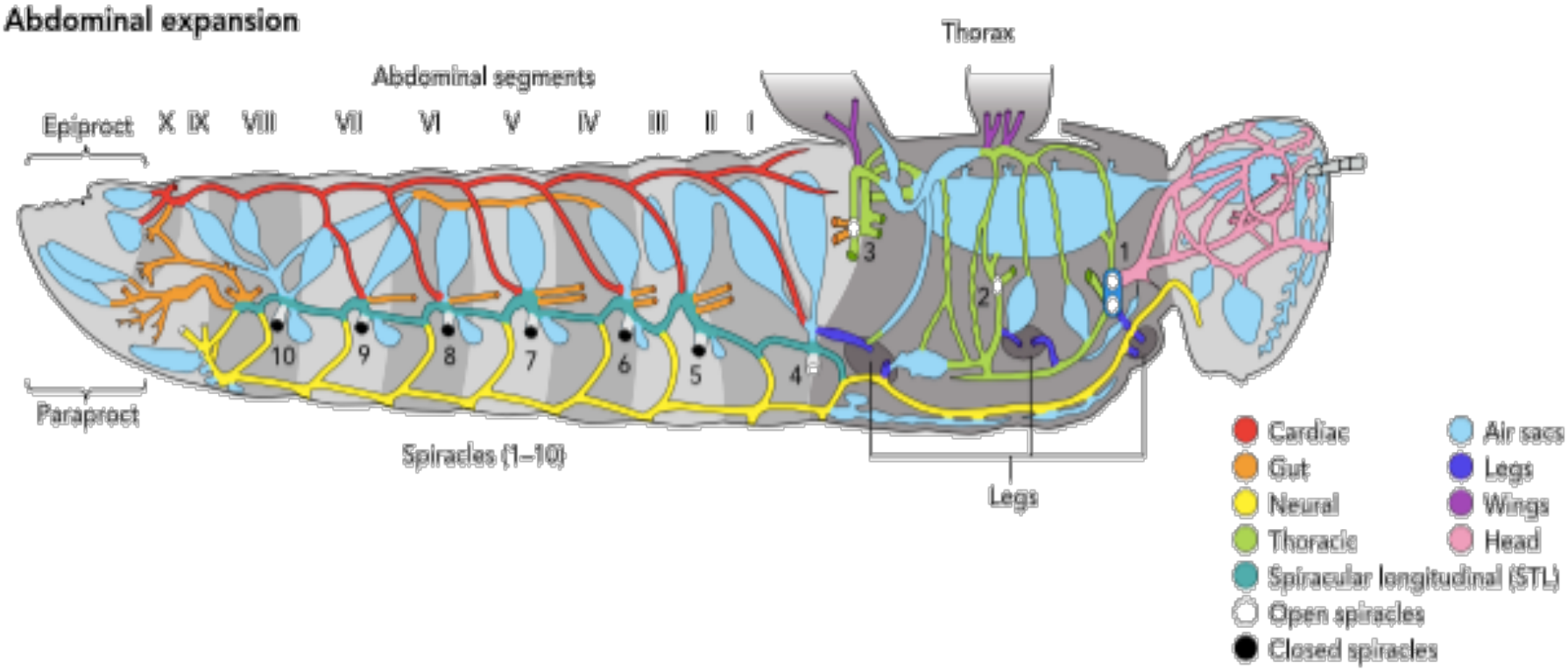
Locust Tracheal System

- Supported by taenidia
- **What are those?**
  - Prevent tracheal tubes from collapsing under reduced pressure
- Air sacs also involved



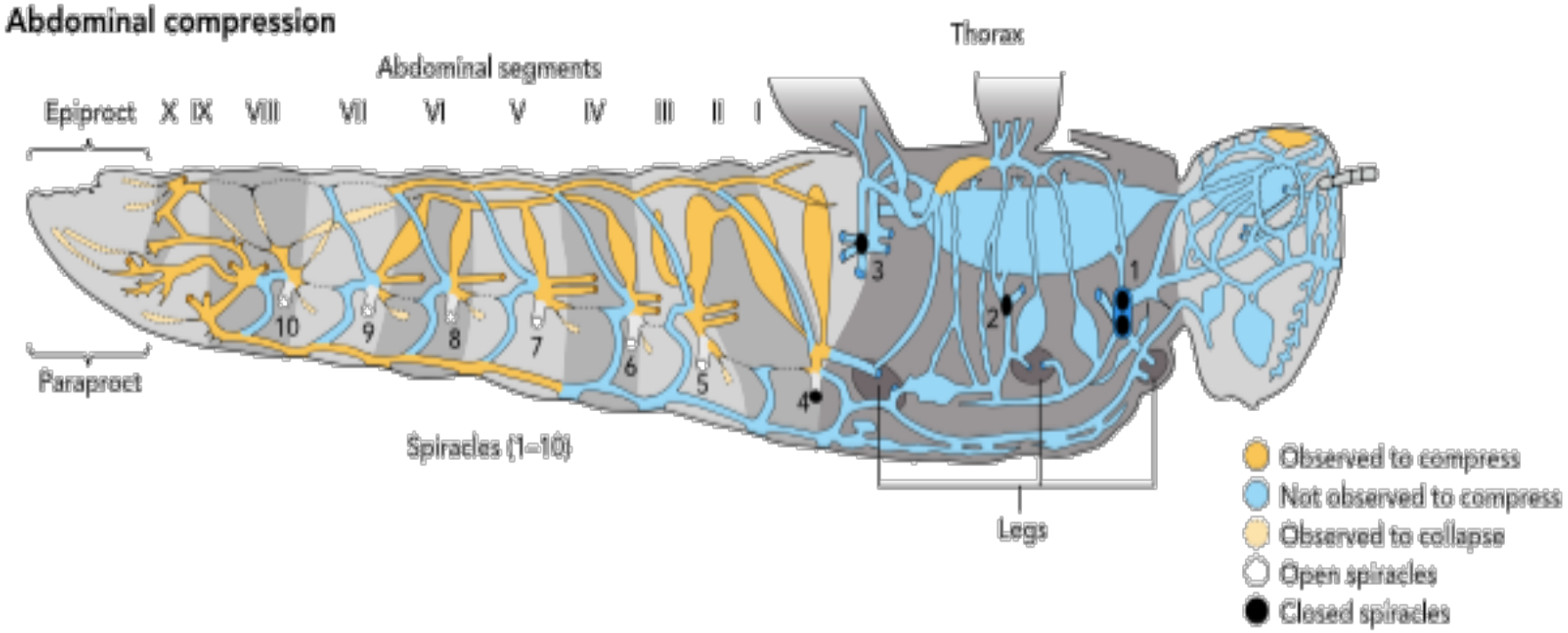
Spiracle Timing

- Inspiration
  - First 4 pairs open



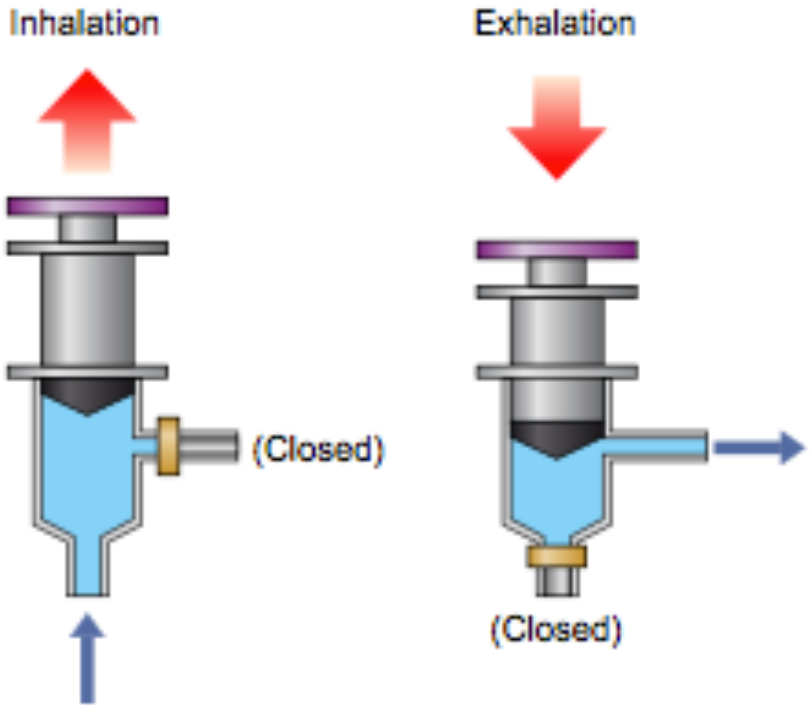
Spiracle Timing

- Expiration
  - Posterior 6 pairs open
- Some variation



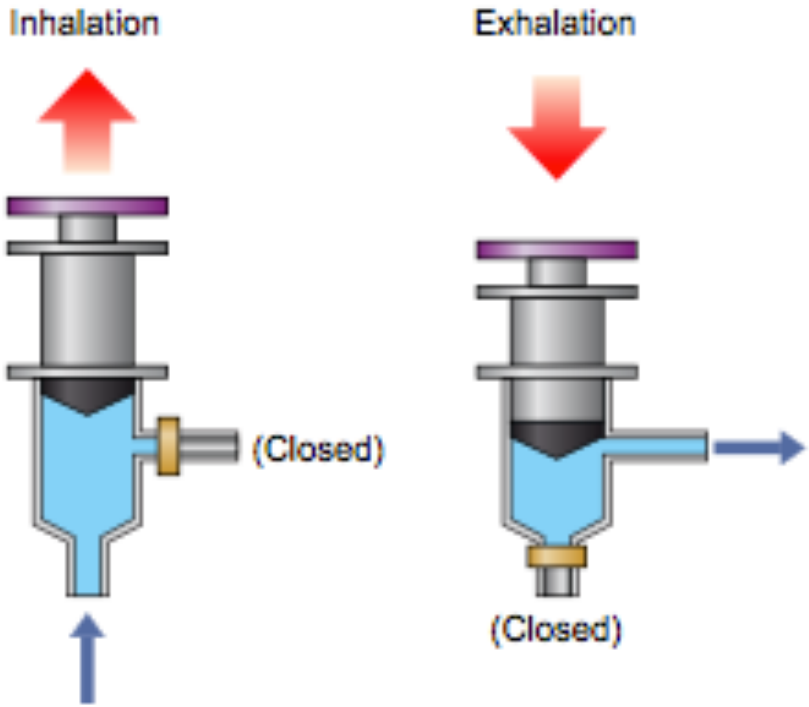
“Syringe Model”

- Simplest model
- **What is this describing?**
  - Decrease in abdominal volume
  - Increase hemolymph pressure
  - Compression of air sacs



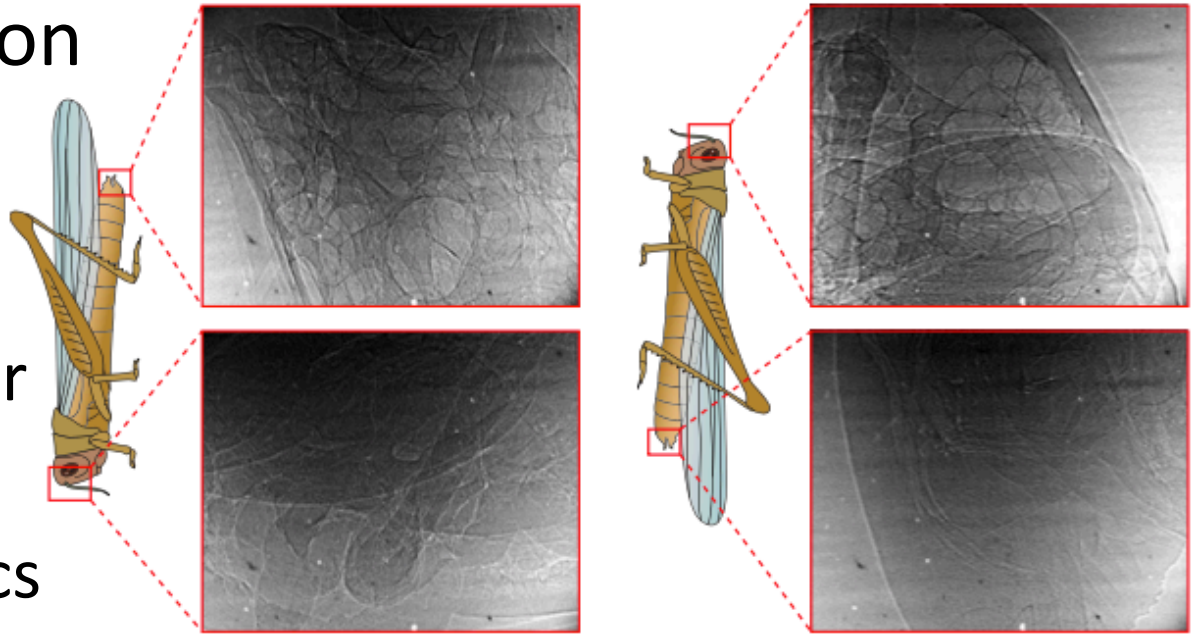
“Syringe Model”

- X-ray observations tell a different story
  - Tracheal volume changes primarily linked to the abdomen during abdominal pumping



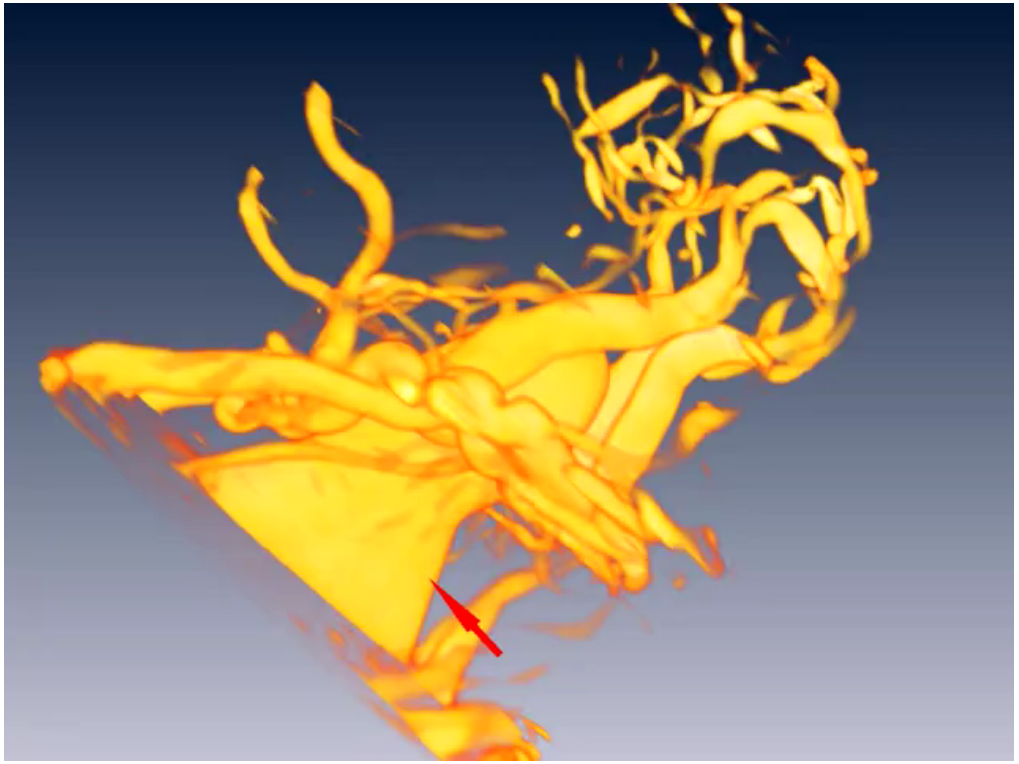
Anesthetized with Ketamine

- Normally, air sacs are not dependent upon orientation
- **What happened?**
  - Left: Abdominal air sacs expand
  - Right: Head air sacs expand



Air Sacs

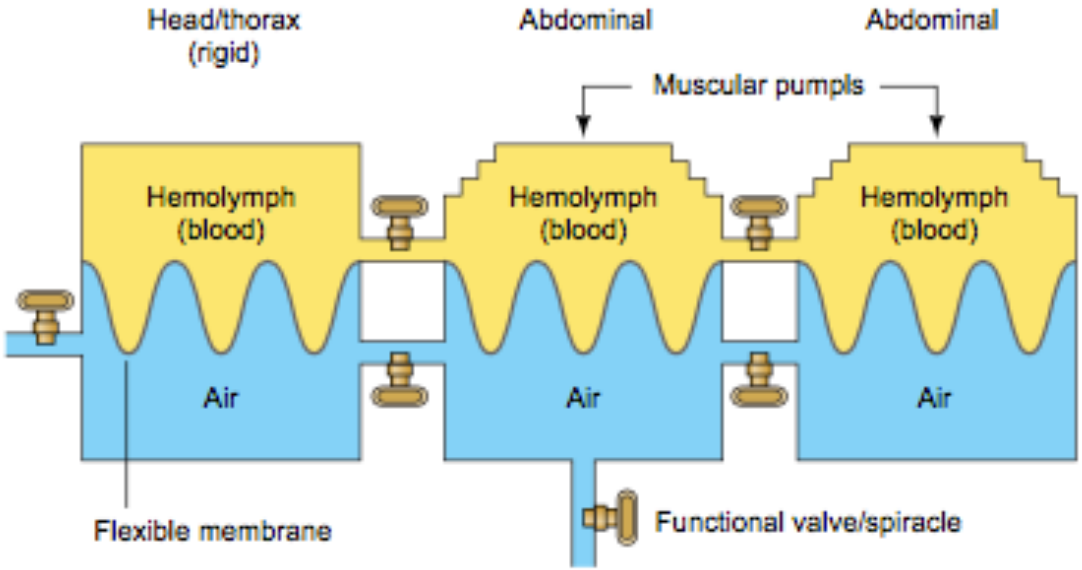
- Dynamic x-ray phase contrast microtomography
  - Bell cricket, *Meloimorpha japonica*
  - First time to directly observe 3D evolution of the air sac
  - 4D x-ray imaging
  - Observes dynamic evolution



http://www.nature.com/articles/srep32380#supplementary-information

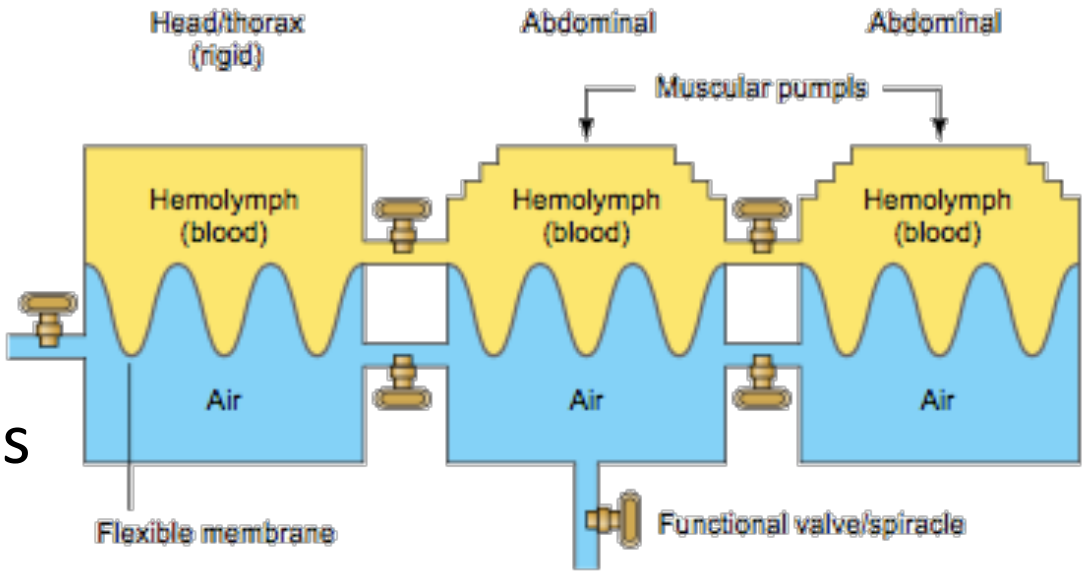
“Segmental Multi-Fluid Model”

- Functional valving between body segments
  - Allows independent pressures and air sac function in adjacent abdominal segments
  - Tracheal connections between segments remain open, allowing air flow between segments



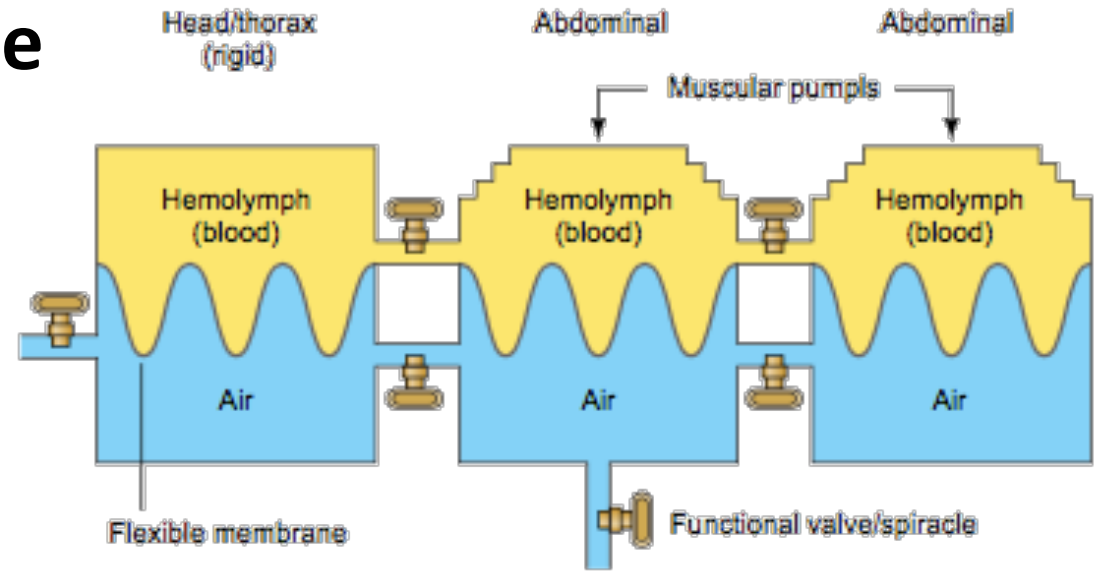
Functional Valving Between Body Segments

- How they work
  - Contractions of intersegmental muscles
  - Positional changes in the gut
- **How might this be advantageous?**



Functional Valving Between Body Segments

- **How might this be advantageous?**
  - Increased specialization
  - Defense
  - Controls where most oxygen is delivered

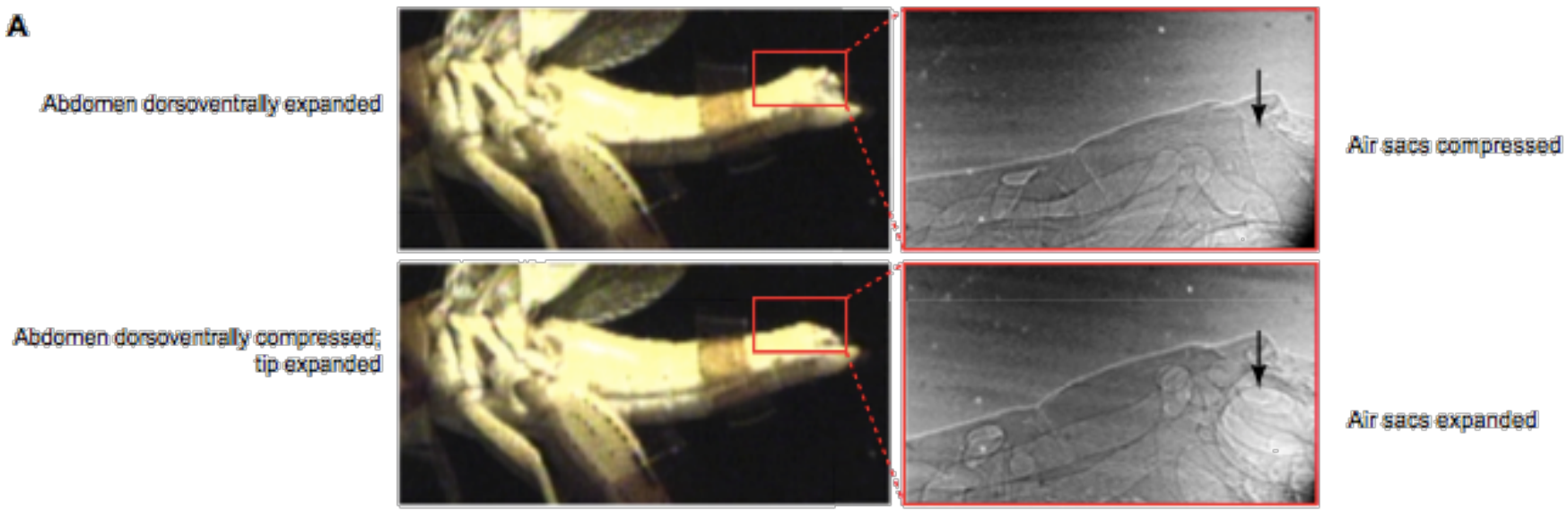


What about air flow?

- Forward spiracles close
  - Trachea compress to force air out of air sacs
  - Creates a negative pressure in the thorax
  - Posterior spiracles open
  - Air rushes posteriorly to leg and wing muscles
  - Close rear spiracles creating an anterior negative pressure

What about air flow?

- Sometimes, as the abdomen compresses, the abdomen lengthens (and vice versa)
  - Driven (at least partially) by airflow to the posterior region of the abdomen
  - **Why would they do this?**

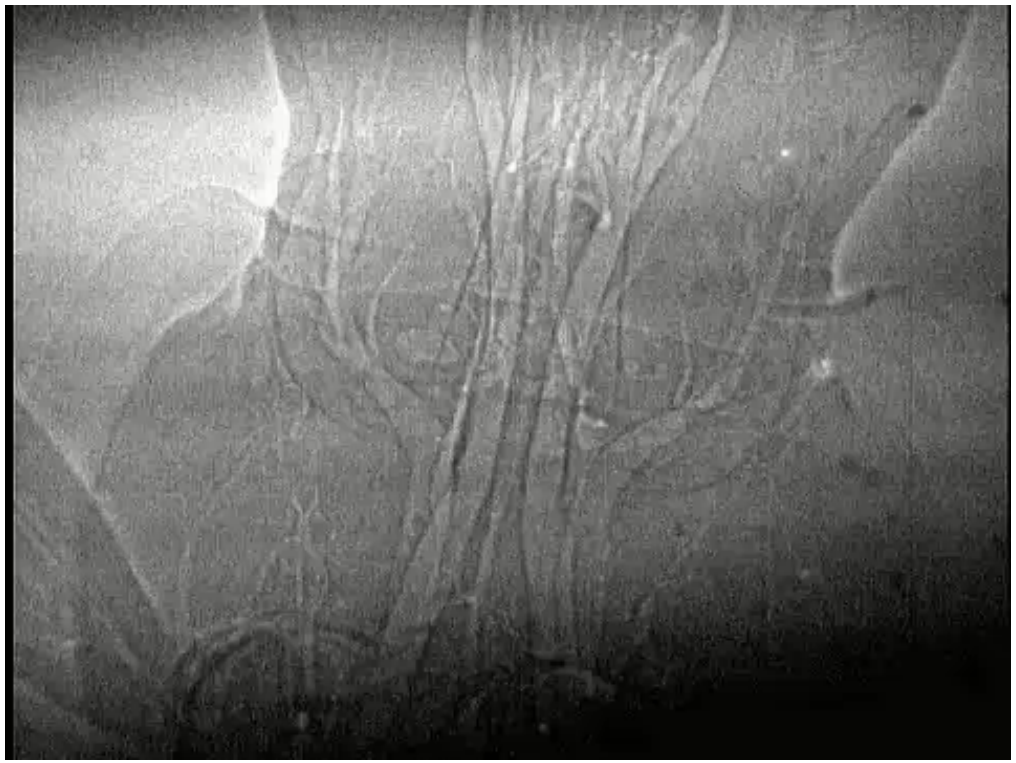


Active Respiration at Rest

- During times of stress
  - High temperatures
  - Hypoxic conditions
  - Spiracles open in a cyclical pattern to release excess CO_2

Woah, cool!

- Scientists were wrong for a long time
- Synchotron X-Ray Imaging



http://science.sciencemag.org/content/suppl/2003/01/27/299.5606.558.DC1

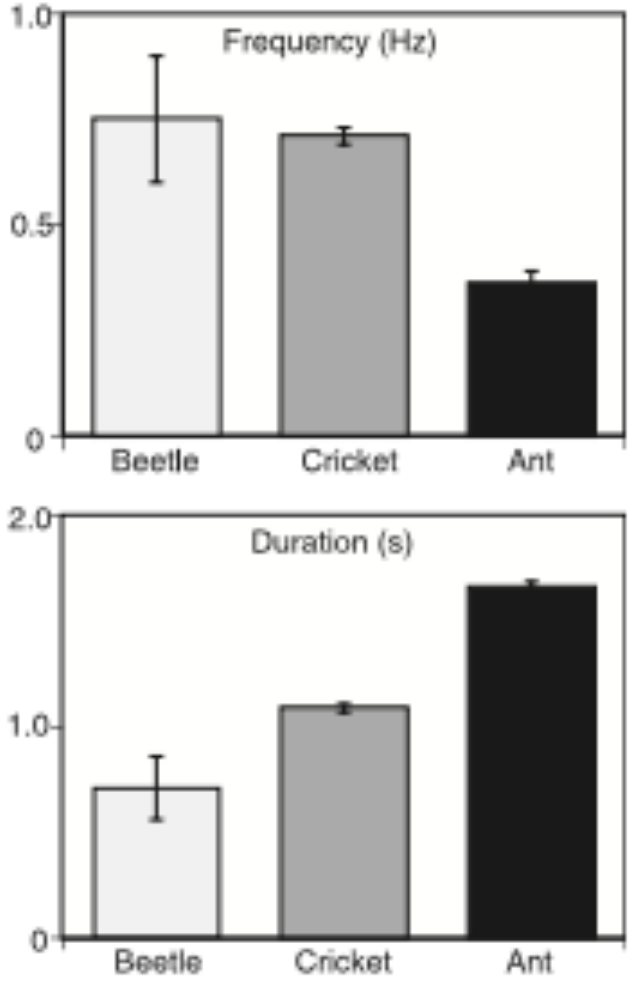
Synchotron X-Ray Imaging

- At rest
  - Inflated

- When compressed
  - Compressed
  - Cross-section looks like an ellipse

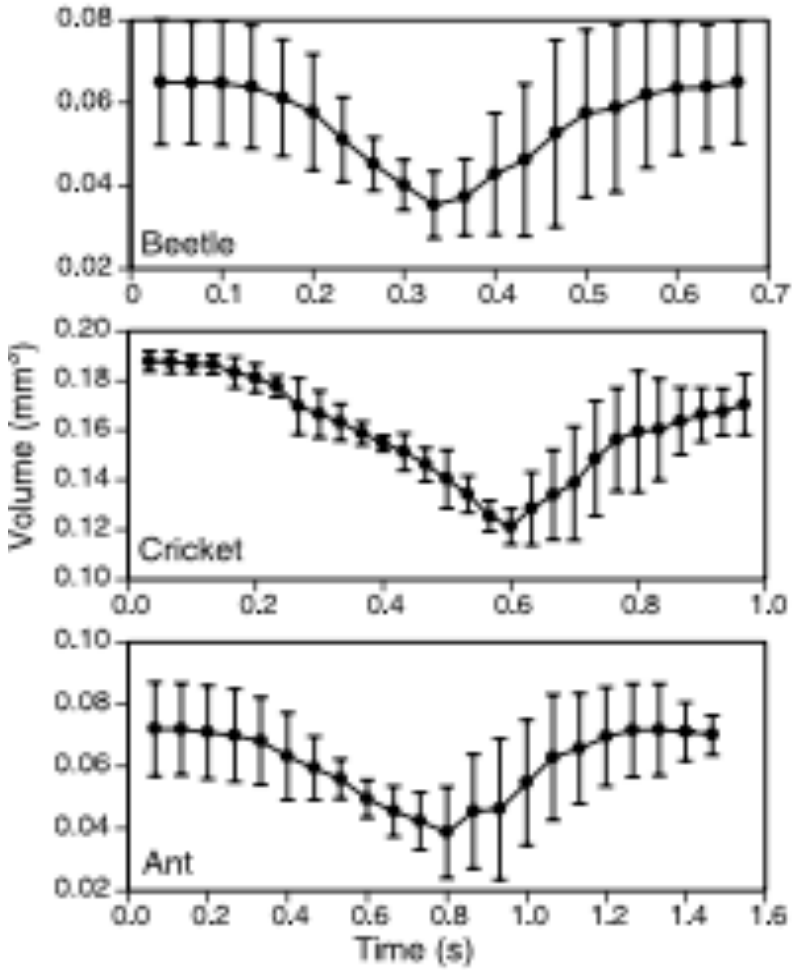
Synchotron X-Ray Imaging

- Frequency ranged from 0.4 Hz to 0.7 Hz in beetles
- Compression duration 0.7 to 1.6 s
- Indicates interspecific variability



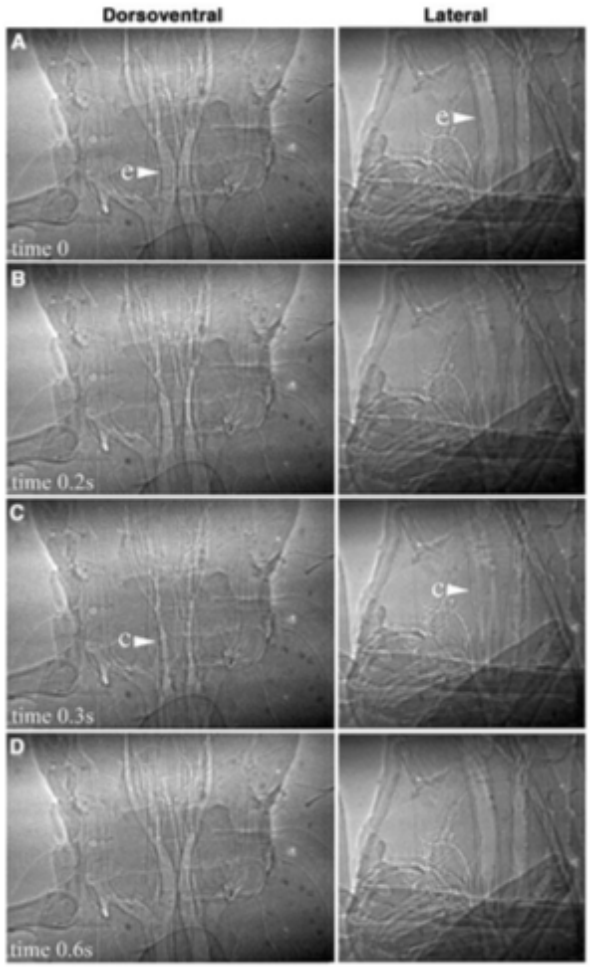
Synchotron X-Ray Imaging

- Almost 50% change in volume in tracheae of anterior thorax and basal head
- Compare to humans
  - 10% at rest
  - Up to 75% during exercise



Synchotron X-Ray Imaging

- Shooting x-ray beams onto live insects
- Remained alive for up to 10 minutes of exposure
- **How might this have altered their findings?**



The Future of Science

- Technological advances allow new discoveries to be made
- Can we ever really prove anything?

THE END

Harrison, Jon F., et al. "How locusts breathe." *Physiology* 28.1 (2013): 18-27.

Hetz, Stefan K., and Timothy J. Bradley. "Insects breathe discontinuously to avoid oxygen toxicity." Nature 433.7025 (2005): 516-519.

Westneat, Mark W., et al. "Tracheal respiration in insects visualized with synchrotron X-ray imaging." *Science* 299.5606 (2003): 558-560.

Xu, L. et al. Anisotropic shrinkage of insect air sacs revealed in vivo by X-ray microtomography. Sci. Rep. 6, 32380; doi: 10.1038/srep32380 (2016).