Scientific Investigation: Method and Practice

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Two Major Components of Science

- Content: what is the subject matter?
  - Generalizations which the scientific community may recognize as valid.

- Method: how to do it?
  - Experiments, observations, data analyses, reasoning, etc.

Four Bold Claims of Scientific Investigation

- Rationality
  - I hold belief X for reason R with level of confidence C, where inquiry into X is within the domain of competence of method M that accesses the relevant aspects of reality.
  - e.g. “I believe what my physics teacher teaches is correct because I like him/her” versus “I believe what my physics teacher teaches is correct most of the time because the contents are coming from the most current edition of a physics textbook. I have read the book and compared it with my notes….”

Four Bold Claims of Scientific Investigation

- Objectivity
  - Knowledge on an object, not a subject or knower; e.g. Dr. Lam is the speaker of this talk (whether you like this talk or not will not change the identity of the speaker)
  - Verifiable; e.g. you have never heard the sound of tree falling in a forest, did it really happen? You can set a sound recorder etc.

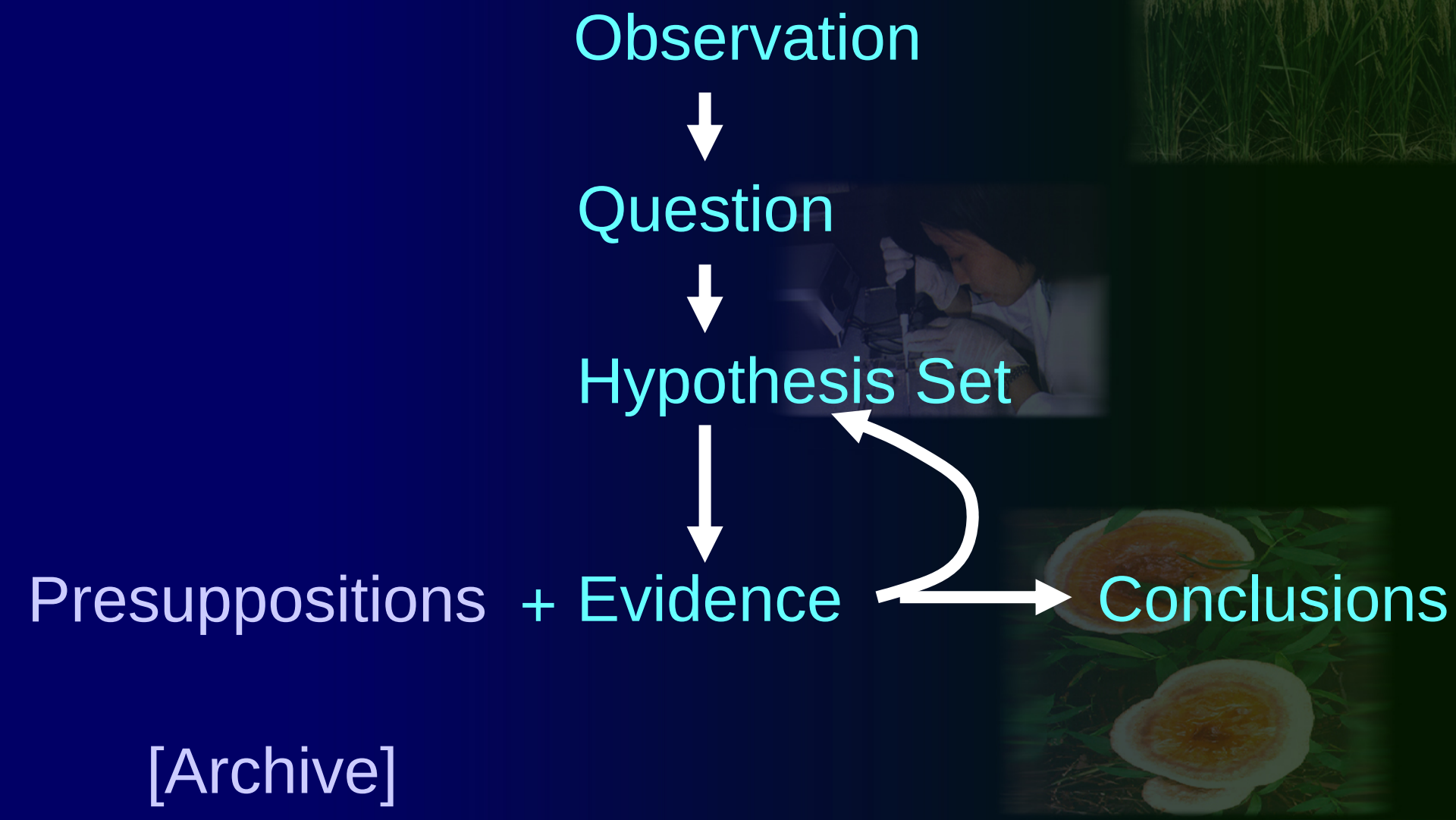
Four Bold Claims of Scientific Investigation

- Realism
  - The correspondence of human thoughts with an external and independent reality, including physical objects
  - The scientific method provides rational access to physical reality, generating much objective knowledge
  - Does not come in degrees, either yes or no

Four Bold Claims of Scientific Investigation

- Truth
  - The property of a statement corresponds with reality
  - Truth claims may be expressed with various levels of confidence
  - The price of holding onto the truth; e.g.
    - The story of Heliocentric Model Nicolaus Copernicus, Giordano Bruno, and Galileo Galilei
    - The story of agricultural centers and Nikolai I. Vavilov
    - The story of jumping genes and Barbara McClintock

Major Steps in a Scientific Investigation



- Presuppositions
  - Science requires several common-sense presuppositions, including that the physical world exists and that our sense perceptions are generally reliable; e.g. if you are not sure if you are real or you are just a dreaming butterfly, no science research can be done
- Archive
  - Irrelevant knowledge

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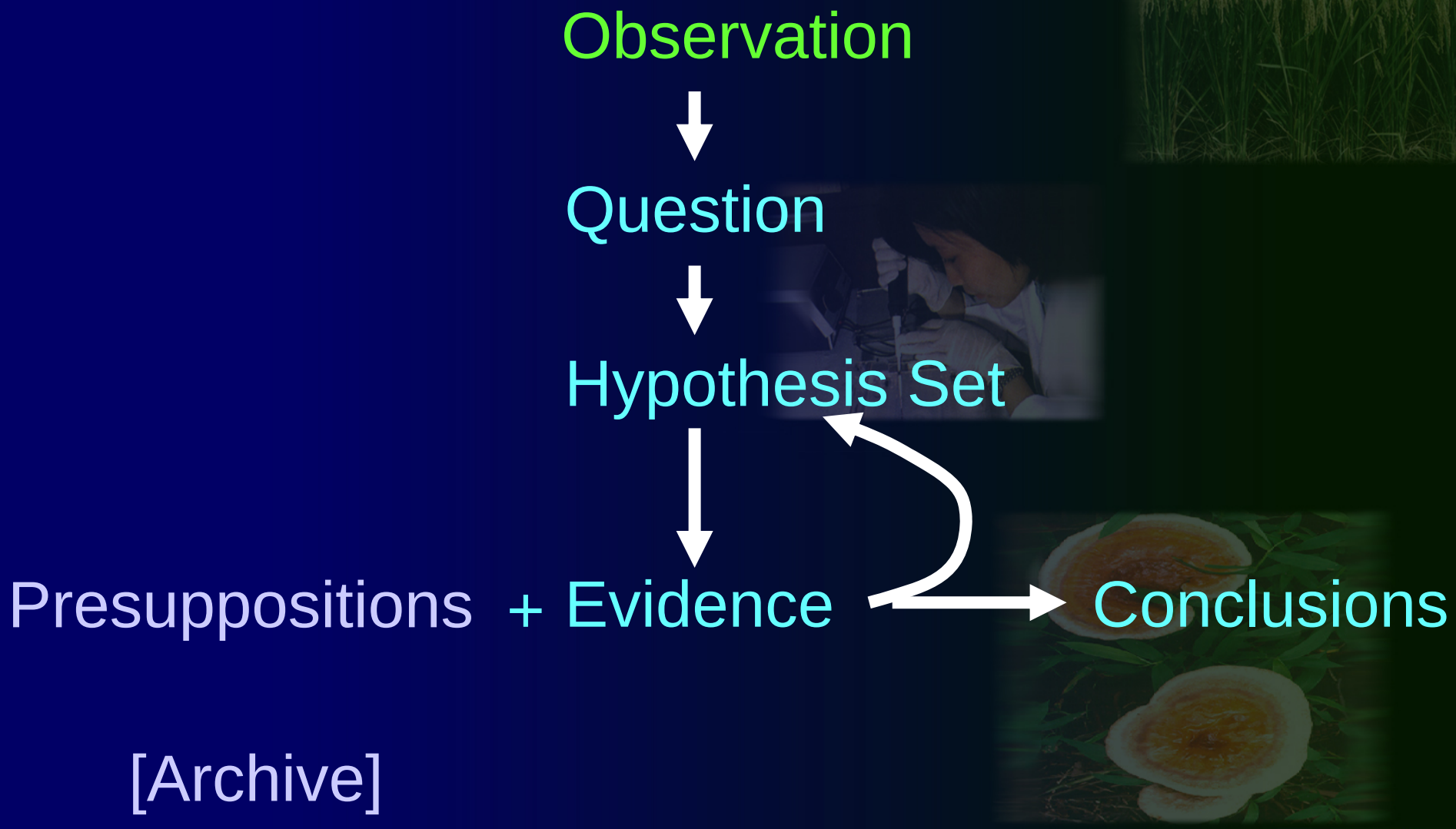

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Making Important Observations is the Essential First Step

- Sensitivity
  - E.g. the story of penicillin and Alexander Fleming
- Comprehensiveness

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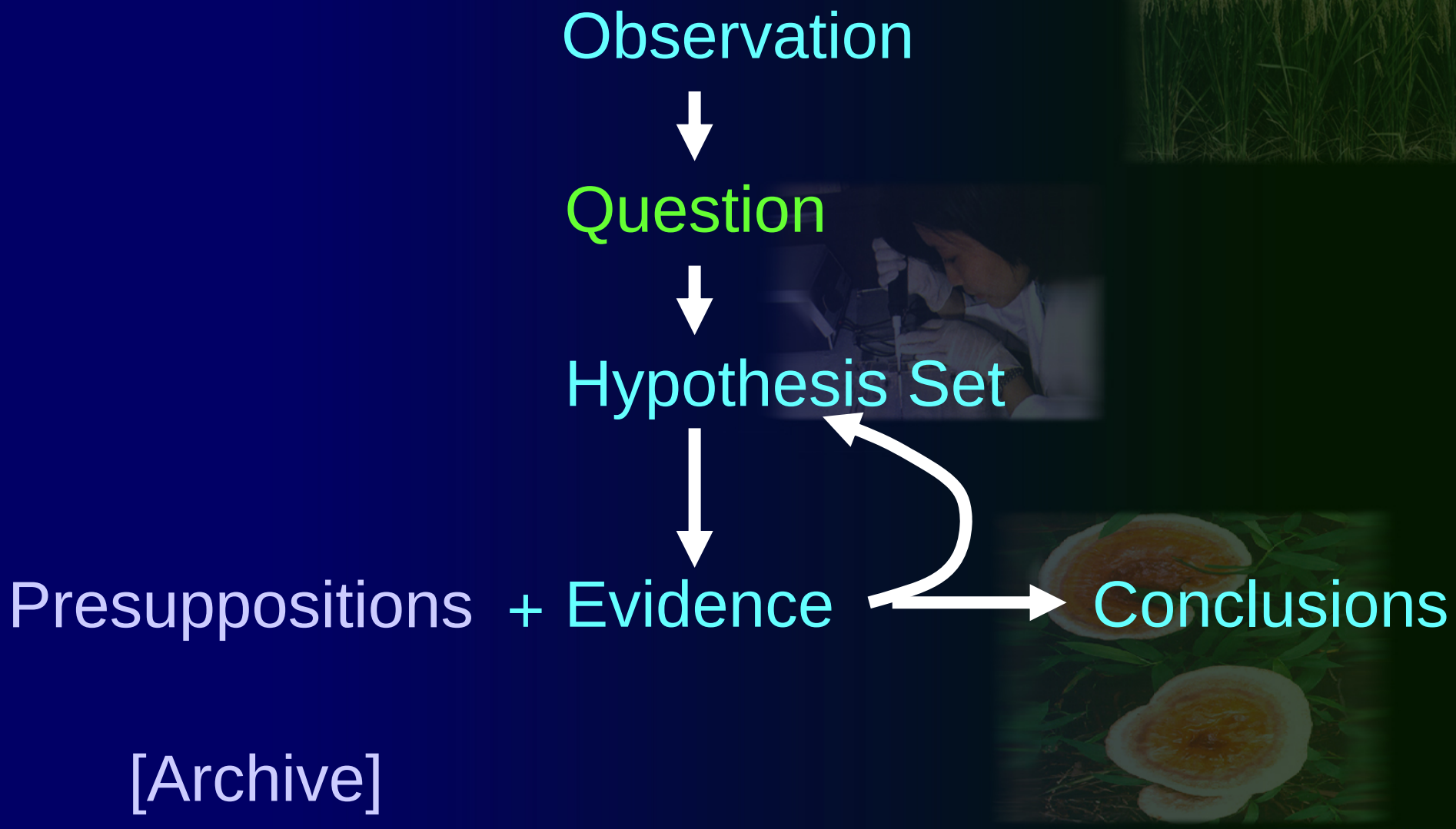

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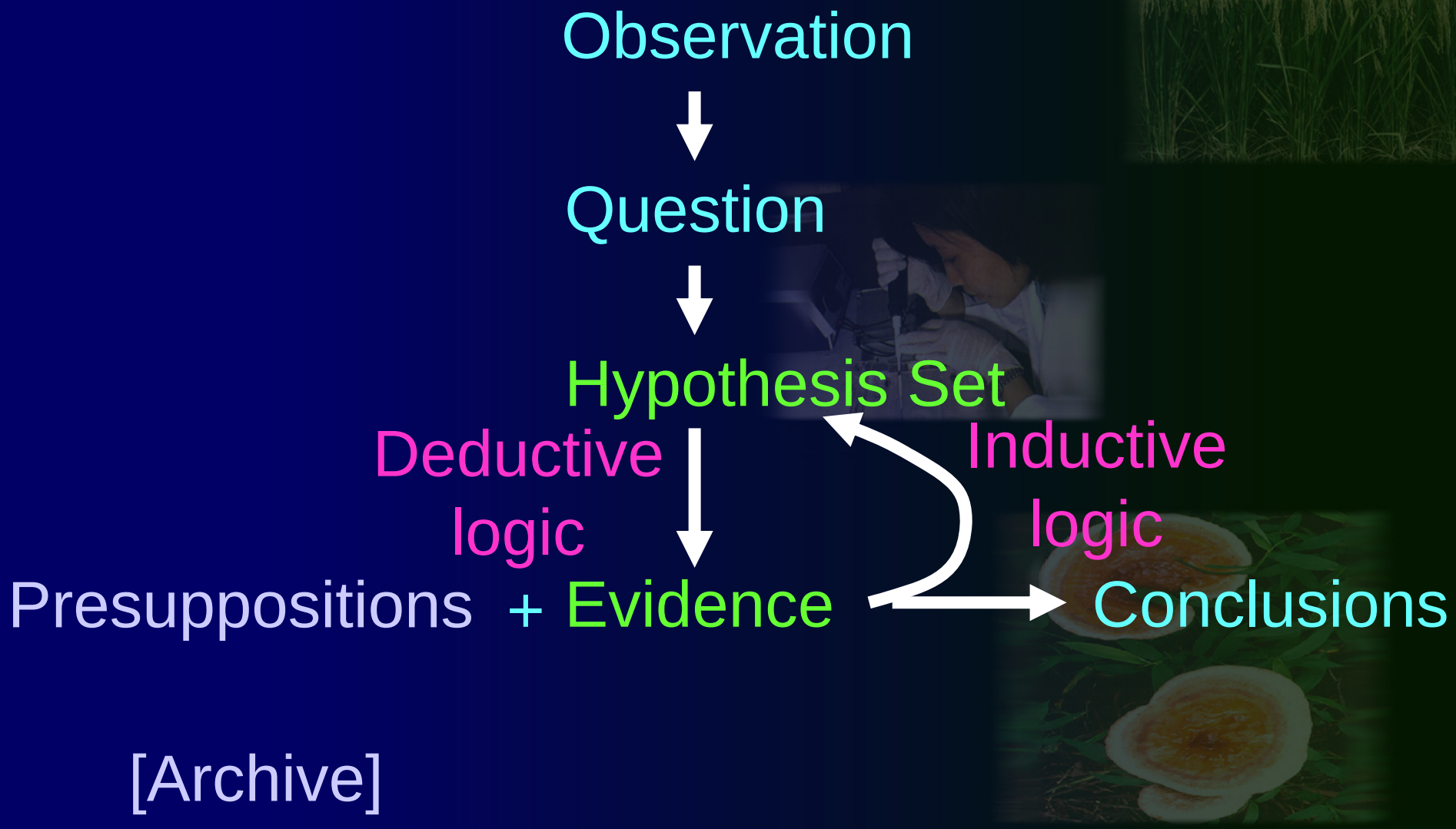
What Kind of Questions to Ask?

- Investigation of unknown (basic science)
  - Delineating concepts related to life and nature; e.g. what are the different life forms, how life functions, and how lives interacting with each other and the environment
  - Inventing new methodology to allow better observation of the world; e.g. invention of PCR
- Applying known knowledge to modify/preserve natural environment or enhance human life (applied science)
  - Scientific concept
    - E.g. Using penicillin as a medicine to kill bacteria
  - Methodology
    - E.g. applying DNA fingerprinting techniques in forensic sciences, etc.

Applying Logic in Making and Testing Hypothesis



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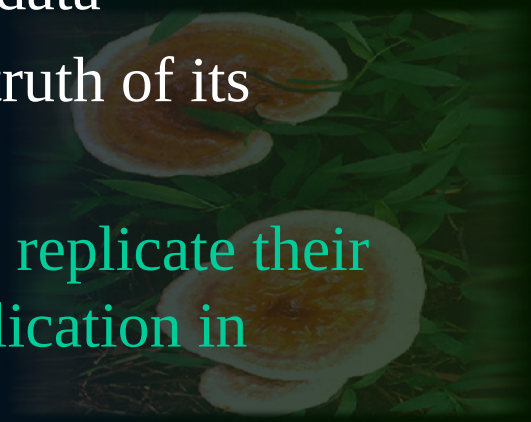
- Inductive Logic
  - From actual data to get an inferred model
  - Strong if its premises support the truth of its conclusions to a considerable degree, and is weak otherwise
  - E.g. for 100 living bacteria observed, they all are capable of doubling its DNA content during cell division; conclusion: in all bacteria, they have a mechanism to replicate DNA
- Deductive Logic
  - From a given model to predict expected data
  - The truth of its premises guarantees the truth of its conclusions, and is invalid otherwise
  - E.g. since our model that all bacteria can replicate their DNA, we should expect to see DNA replication in bacteria #101, #102, and etc.



Some Common Logical Fallacies

- Fallacies of Composition and Division
  - Na and Cl_2 are poisonous; Conclusion: NaCl is poisonous
  - Many horses are not white, a white horse is white; Conclusion: a white horse is not a horse
- False Dilemmas
  - My opponent's theory is wrong; conclusion: my theory is right
- Circular Reasoning
  - I won't be worry because I am always right
- Fallacies of will

The Prediction Power of a Hypothesis Determines Its Validity

- E.g. there were 2 hypotheses explaining why the neck of giraffe is long
  - Darwinism: mutations naturally occurred in giraffe populations; when the environment changes (less leaves close to the ground), the mutants survive better and dominate today's giraffe populations
  - Prediction: mainly two kinds of giraffe fossils, long neck and short neck
  - Lamarck: when there were less leaves close to the ground, giraffe needed to exercise their neck and gained more muscles; this acquired ability passes onto subsequent generations
  - Prediction: giraffe fossils should exhibit a graduation change of neck length

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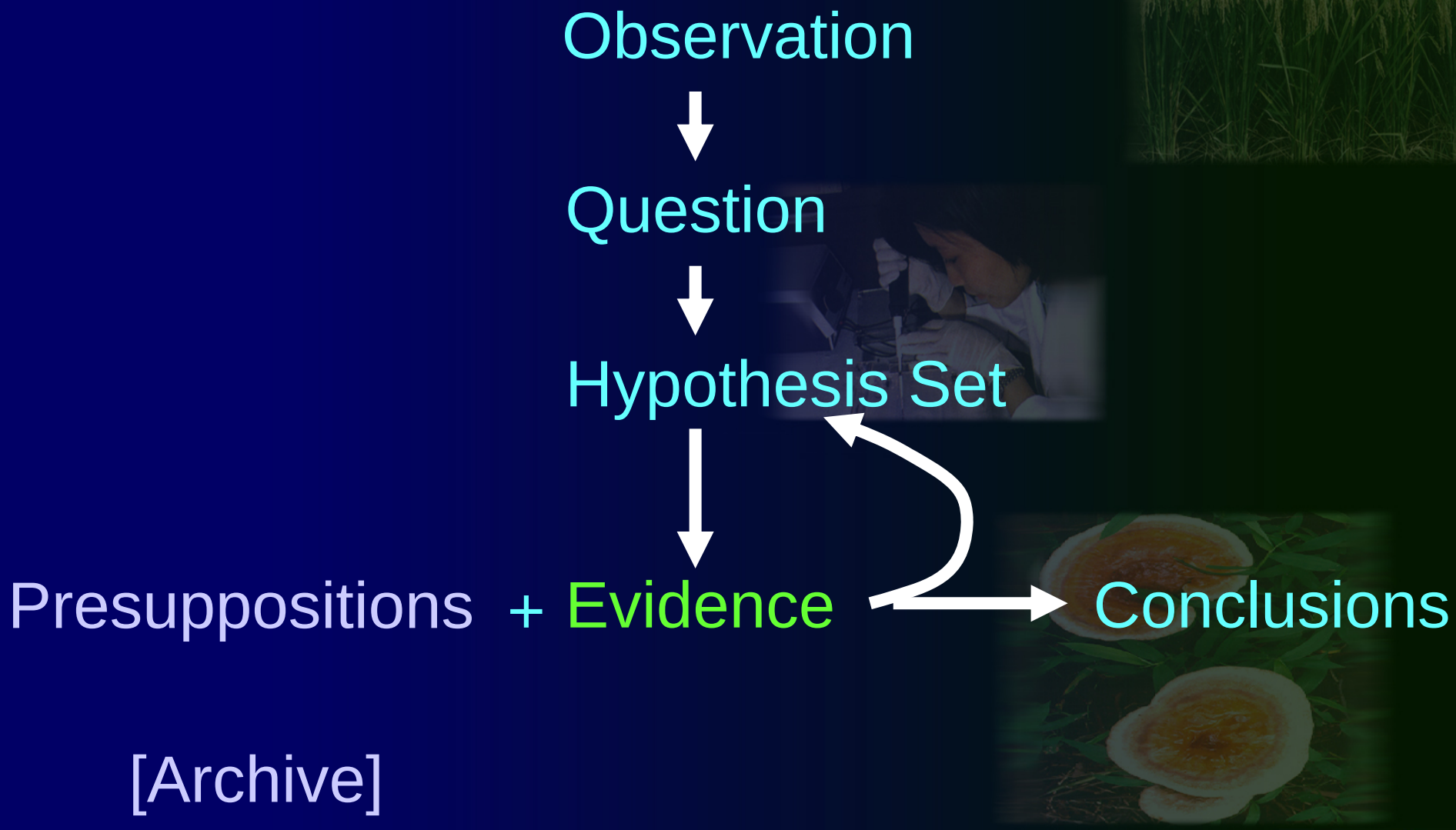

How to Collect True Evidences (Carefully Designed Experiments and Accurately Recorded Observations)

- Proper instrumentation; e.g. I. Newton decomposes light by using a prism
- Careful experimental design: controls or baseline (i.e. reference points)
- Accuracy of data; e.g. the story of phlogiston, oxygen and Antoine Laurent Lavoisier
- How to handle quantitative data (errors occur by chance): statistics; e.g. if your hypothesis is that “man is taller than woman”, it may not be always true (but can you generalize?)

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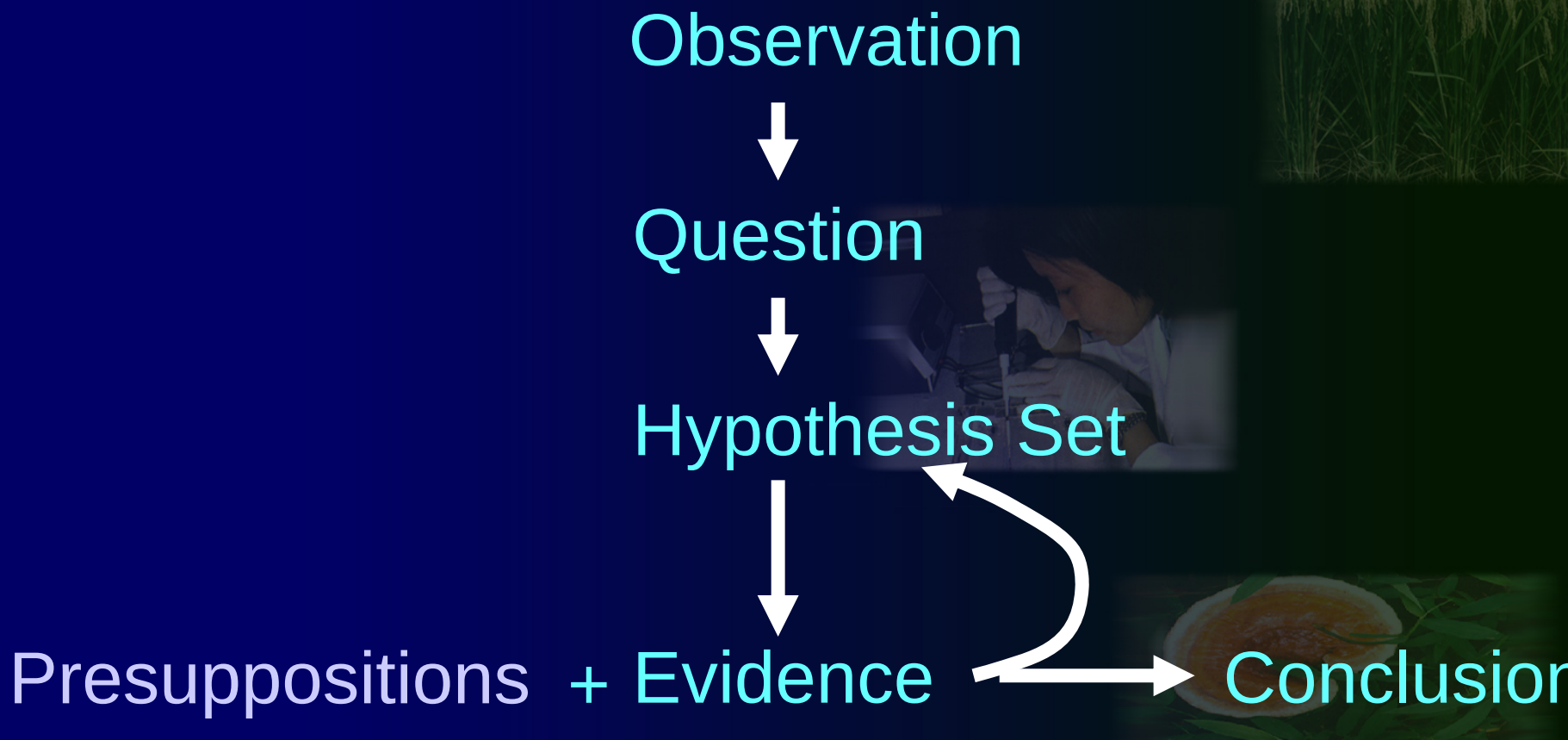

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Remark: data-driven research in post-genomic era

References

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- “Scientific Method in Practice” by H.G. Gauch, Jr.