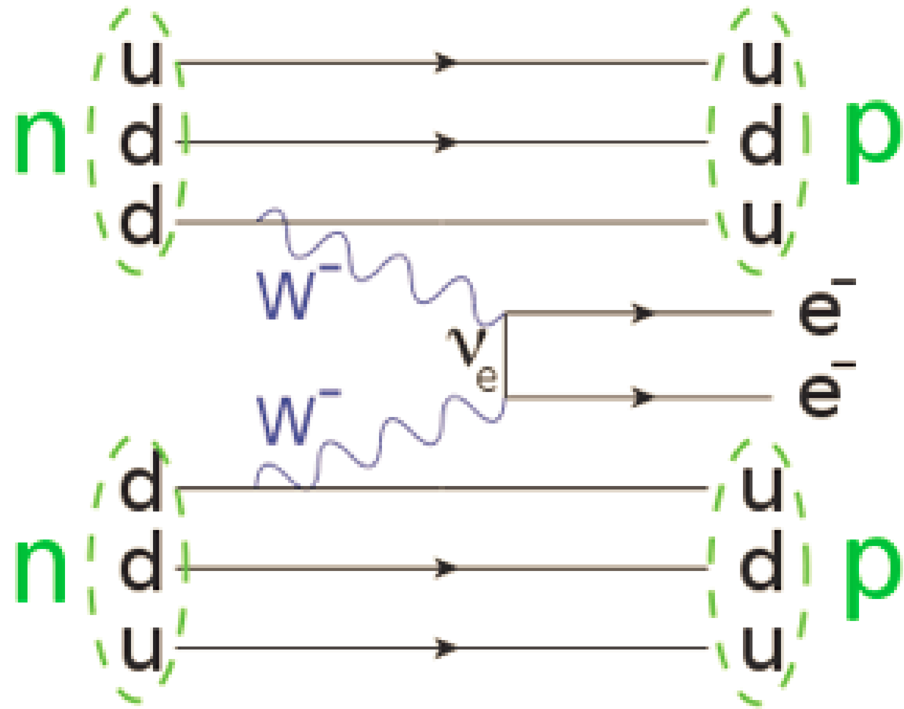
Storytelling and Communication: How to turn double β-decay into a story



Misconception about ‘Story’

- It’s for the public; it’s for kids.
- It’s not scientific because it is not accurate.

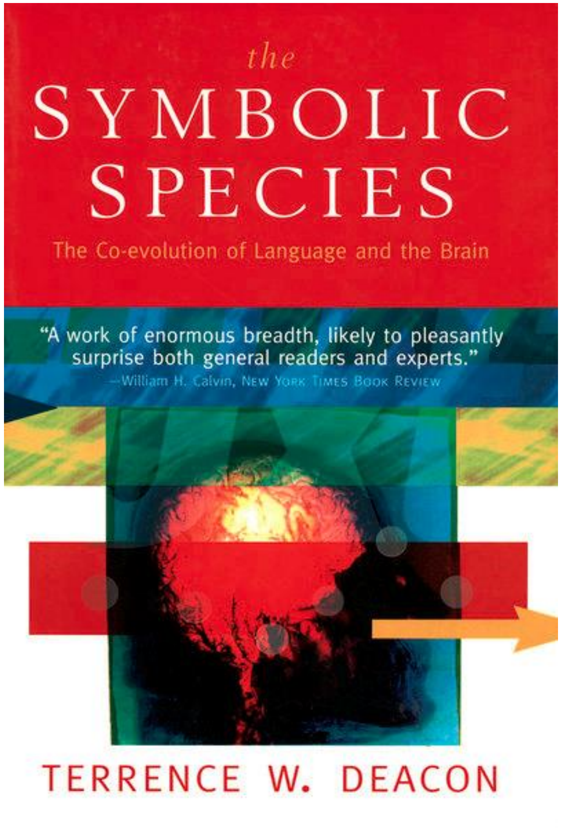
Once upon a time a radioactive monster gave birth to a pair of twins: a girl named neutrino matter and a boy named neutrino antimatter…

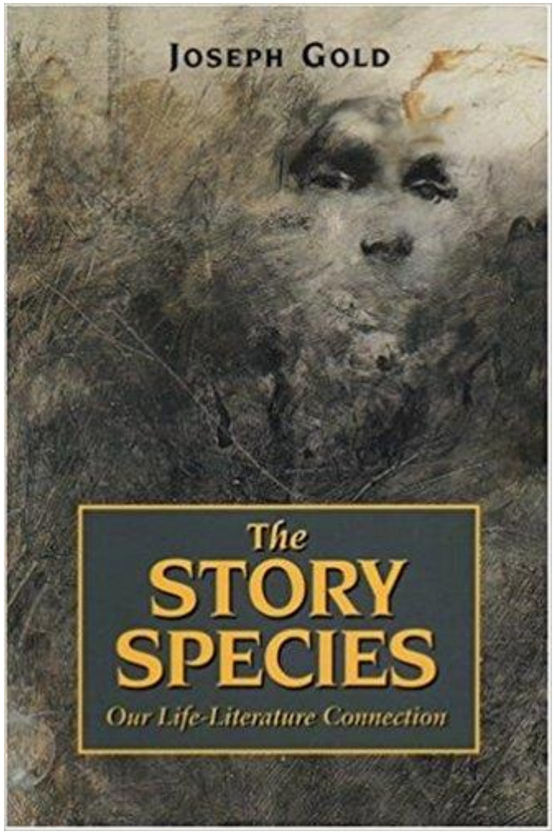
$$(A, Z) \rightarrow (A, Z + 2) + 2e^- + 2\overline{\nu}_e$$

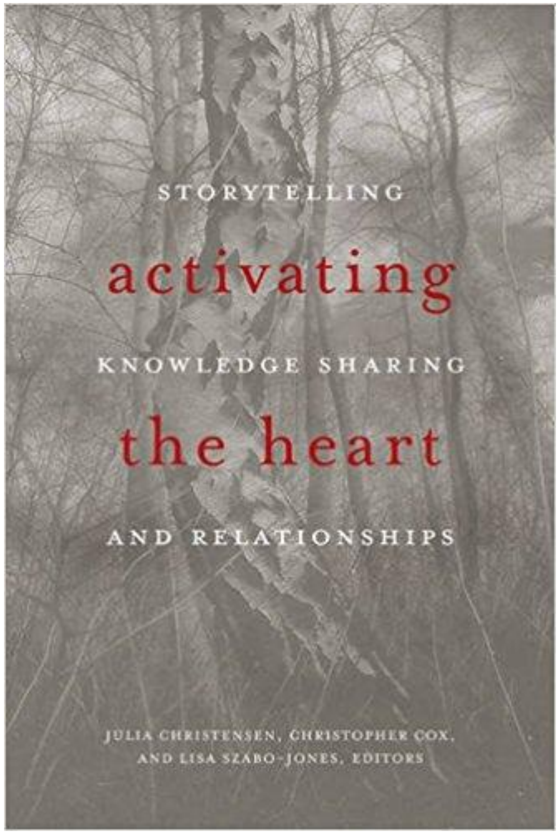
And they kill each other…

$$(A, Z) \rightarrow (A, Z + 2) + 2e^-$$

Storytelling is a human behaviour; the human species uses stories to pack and unpack complex relations, feelings, and wisdom at the same time.







Complex Systems and ‘Story’

To map complex patterns, he insists, scientists need to rely on ‘story’: with this realization, he makes his famous definition of story as ‘**a little knot or complex of that species of connectedness which we call <u>relevance</u>**’.

Bateson, Gregory. *Mind and Nature: A Necessary Unity*, Cresskill: Hampton Press, 1979, reprinted 2002, p. 12.

Carroll, Sean. *The Big Picture: On Origins of Life, Meaning, and the Universe Itself.* New York: Dutton, 2016.

Our best approach to describe the universe is not a single, unified story but an **interconnected** series of models appropriate at different levels. Each **model** has a domain in which it is applicable, and the ideas that appear as essential parts of each **story** have every right to be thought of as ‘real’. Our task is to assemble an **interlocking** set of descriptions, based on some fundamental ideas, that fit together to form a stable planet of belief. (p.4)

Key Ideas about ‘Story’

- Relevance
- Interconnectedness

What makes a story work?

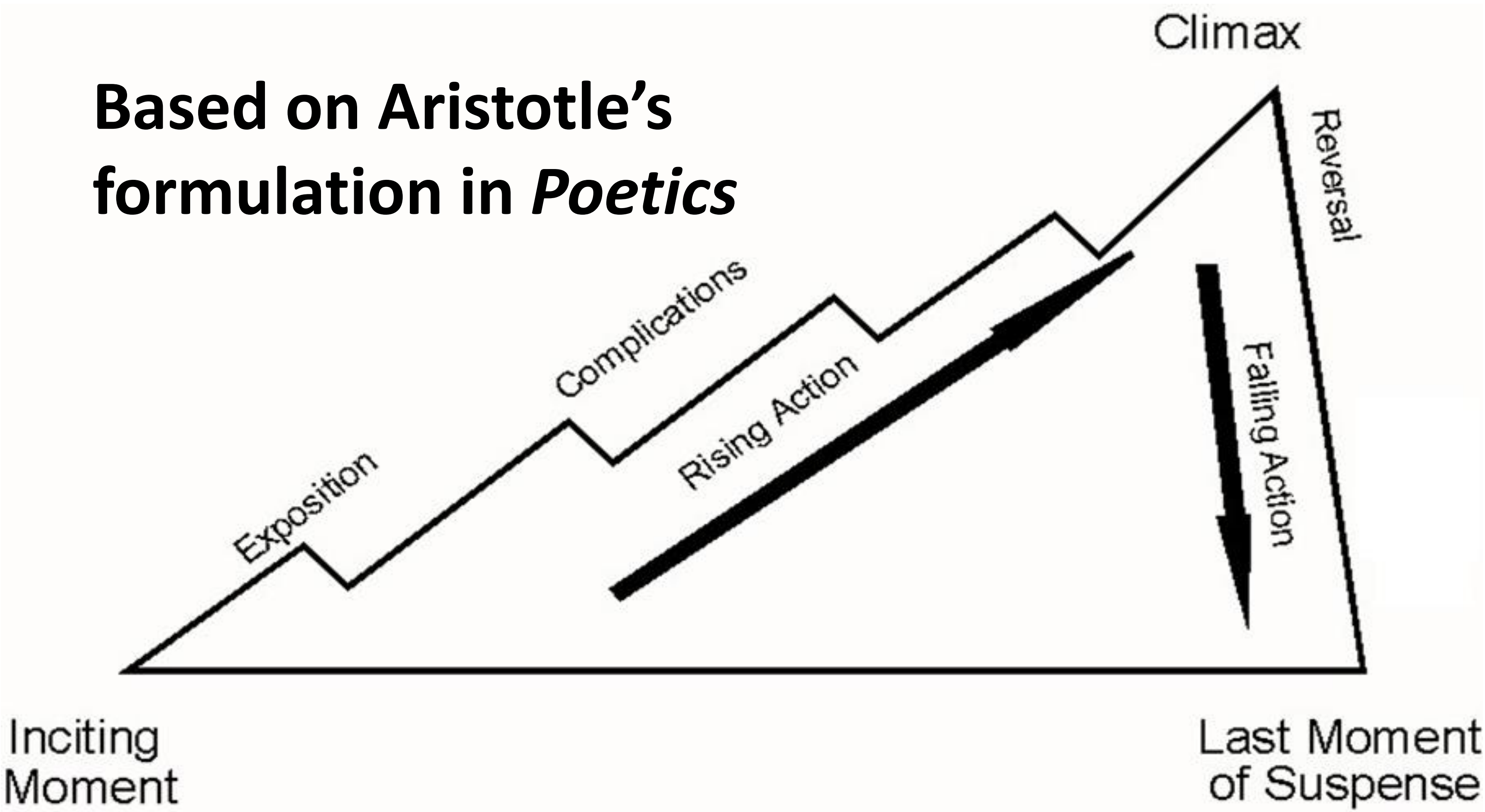
(1) Suspense: show relevance to (or raise interest in) the big picture but do not solve the mystery until the end (or, in some cases, not at all).

(2) Prioritize interconnectedness over chronological order: a good story starts in the middle (because 'logic is a poor model of cause and effect' Bateson, p. 54).

(3) Narrative progression and coherence: allow the natural progression of ideas to demonstrate how every element fits.

Complex Classical Narrative Structure

Based on Aristotle's formulation in *Poetics*



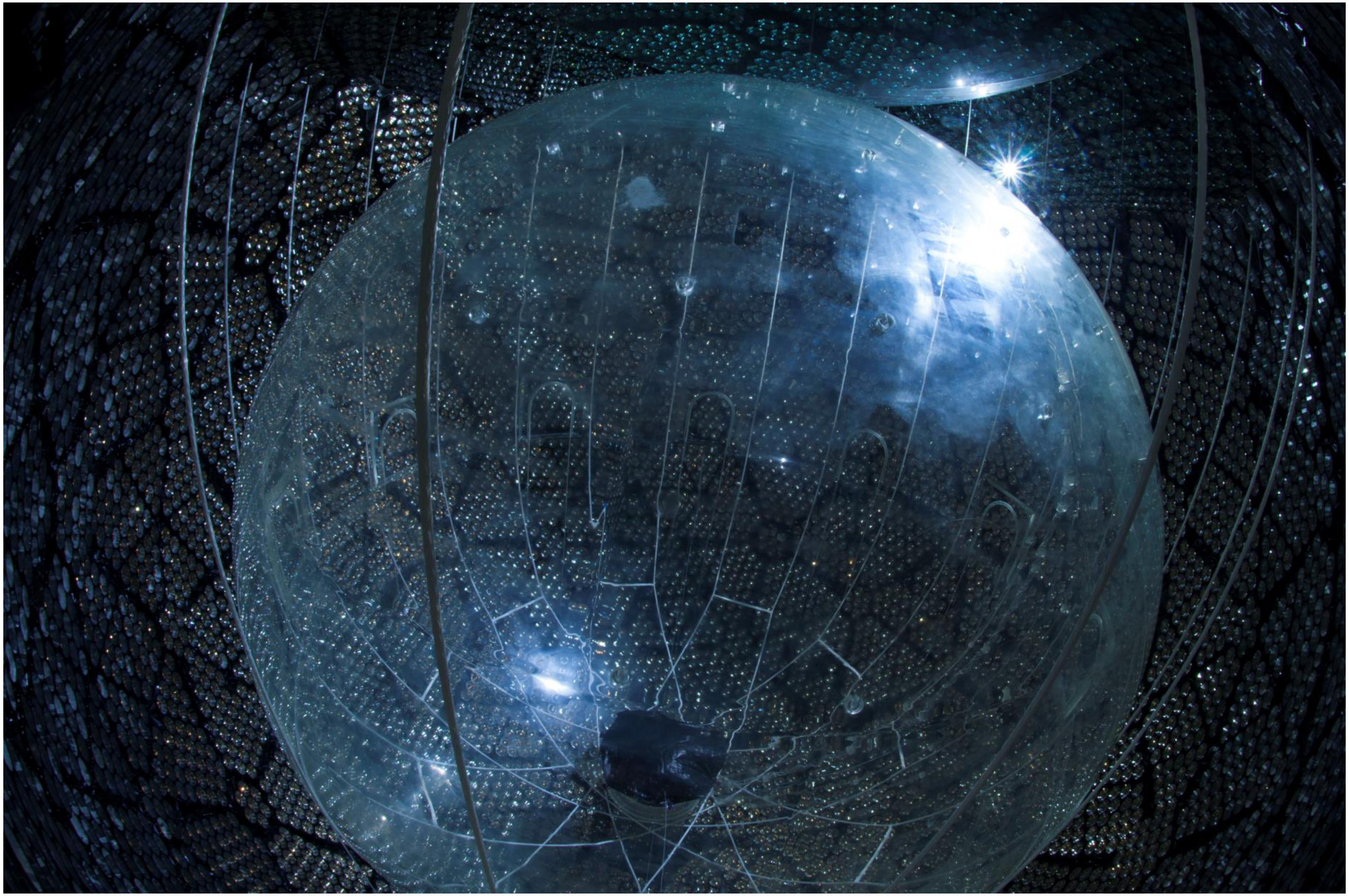
Introduction of a conflict, an interest, or a question

Resolution of the conflict, the interest, or the question

What Can We Learn from Aristotle’s Classical Narrative Formula?

- Science projects almost always have an easily defined suspense (or motive): i.e. the objective of the experiment or the problem that the theory tries to resolve.
- The problem is that there is often no ‘resolution’ because the experiment is on-going or the theory only raises new questions. In other words, there is no closure in good science.

An example



One of the most important open questions in neutrino physics is the question of whether neutrinos are Majorana or Dirac particles. For Dirac particles, which include most familiar kind, particles are distinct from anti-particles. For Majorana particles, on the other hand, particles and anti-particles are identical except for their helicities. Many theorists believe that neutrinos should be Majorana particles, as the theory of Majorana masses admits a mechanism that naturally explains the smallness of the neutrino mass.

Experimentally, the most interesting aspect of a Majorana mass is that a Majorana particle can act as it own anti-particle. This is because helicity can appear reversed in a frame of reference that "overtakes" the particle (so that the particle seems to move 'backwards' in that frame). Since Majorana particles and anti-particles are differentiated only by their helicities, switching the helicity in this way allows a particle in one frame of reference to be an anti-particle in another.

Attempts to detect the (possible) Majorana nature of neutrinos focus around the double beta decay process:

$$(A, Z) \rightarrow (A, Z + 2) + 2e^- + 2\bar{\nu}_e$$

If neutrinos are Majorana particles, the anti-neutrino emitted by one of the neutrons can be absorbed as a neutrino by the other. The resulting process, in which no neutrinos are emitted, is neutrinoless double beta decay:

$$(A, Z) \rightarrow (A, Z + 2) + 2e^-$$

If neutrinoless double beta decay were observed, it would not only prove that neutrinos are Majorana particles, but it would also provide a measurement of the neutrino mass, since the rate of neutrinoless double beta decay is related to the square of the neutrino mass. Therefore, the results of neutrinoless double beta decay searches are usually given in terms of limits on the possible Majorana mass of the neutrino (i.e. the limit on the mass of the neutrino provided that it is a Majorana-type particle).

[Current text on SNO+ website]

If the amount of matter and antimatter soon after the Big Bang were the same, the matter and antimatter would have annihilated each other, leaving a universe of radiation without substance. How did matter prevail to form our universe? How did we come into existence?

We can use SNO+'s multipurpose detector to find out the characteristics of the neutrinos emitted in a double β-decay, and by doing so, we may explain how our universe forms more matter than antimatter.

Although most of the particles formed during the Big Bang were annihilated by their antiparticles, there was a small percentage of matter that stayed behind due to the violation of CP-symmetry (or charge conjugation parity symmetry), which tipped the matter-antimatter balance in favour of our existence.

There are various ways by which CP violation can take place, but none of the currently observable sources of CP violation can account for all matter-antimatter asymmetry required to form the universe.

An important piece of evidence to solve the puzzle lies in the question of whether neutrinos are Majorana particles. A Majorana particle is a particle that is its own antiparticle (in contrast to a Dirac particle, where the particle is not its own antiparticle). Electrons are Dirac, and their antiparticles are positrons. However, some experiments have already indicated that neutrinos may be Majorana. They are able to flip back and forth as matter and antimatter. If so, we will verify more ways by which CP violation can occur. Unfortunately, since neutrinos are extremely small, we cannot measure them directly to examine the details.

The study of the double β-decay of tellurium (^{130}Te) provides a way to look into the details. In a double β-decay, two neutrinos are emitted. If the neutrinos are Dirac, the detector will only measure a broad spectrum of electron energies induced by two neutrinos. However, if the neutrinos are Majorana, the detector will display an additional reading that seems "neutrinoless," or more accurately, a narrow spectrum of mono-energetic electrons. The narrow spectrum is the result of the emission of electrons without the neutrinos.

The study of double β-decay can bring us closer to solving the mystery of the universe's existence. As a bonus, the information can also help us to determine the mass of the neutrino more accurately.

Introduction (making the experimental question relevant to the big picture)

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Development (explain the problem from the top)

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Temporary resolution leads to new question

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New Development (and new question)

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Climax

The study of the double β-decay of tellurium (^{130}Te) provides a way to look into the details. In a double β-decay, two neutrinos are emitted. If the neutrinos are Dirac, the detector will only capture a broad spectrum of electron energies induced by two neutrinos. However, if the neutrinos are Majorana, the detector will, in addition, display a reading that seems "neutrinoless," or more accurately, a narrow spectrum of mono-energetic electrons. The variety is the result of the detector reacting to the changing states of neutrinos between matter and antimatter.

A Temporary Denouement

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