Title: Quantum Darwinism and the Fate of Jimmy Hoffa

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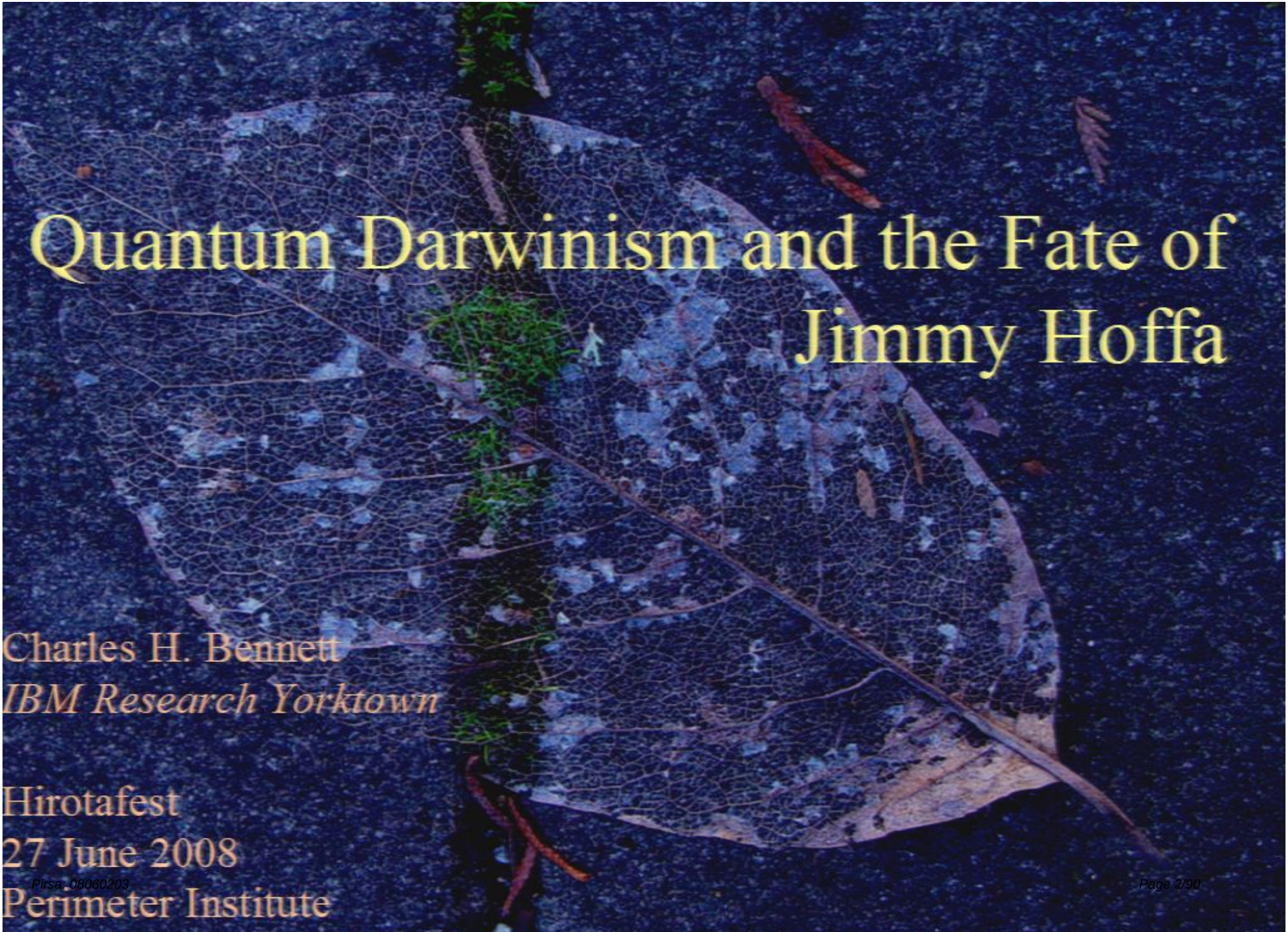
Abstract:

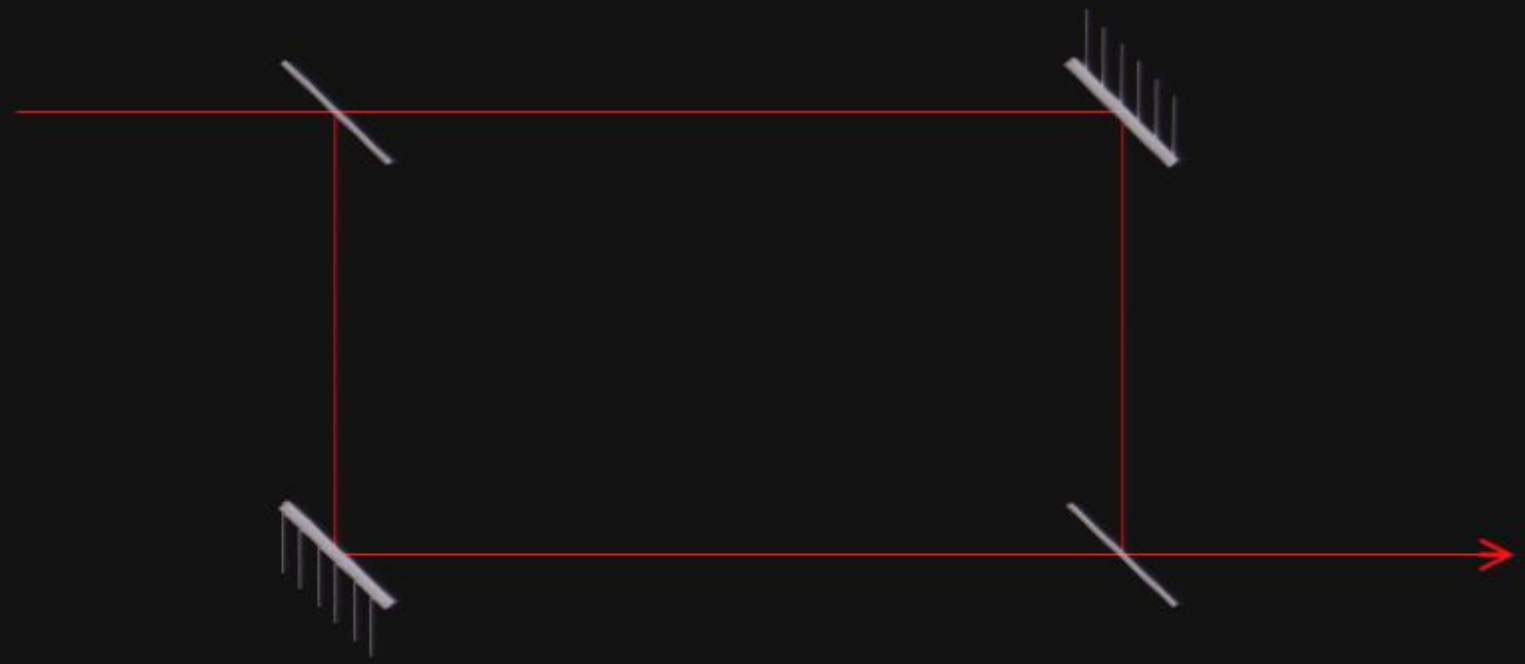


Quantum Darwinism and the Fate of Jimmy Hoffa

Charles H. Bennett
IBM Research Yorktown

Hirotafest
27 June 2008
Perimeter Institute

Quantum information is famously evanescent



If no record is made of which path a photon follows through an interferometer, or if a record is made but then unmade, the photon will have followed a superposition of both paths. After the experiment is over, even God doesn't remember.

It seems there are 3 levels of privacy.

- **Quantum:** Information like the path taken in an interferometer, that exists only temporarily, and afterward can best be thought of as never having existed.

- **Classically Private:** Information that has been amplified to the point of becoming classical, but is not widely distributed in easily recoverable form. Humans can erase it, then lie about it with impunity, although perhaps not without guilt.

- **Public:** Information that is so widely distributed that it is infeasible to conceal. Lying about it only makes you look foolish.

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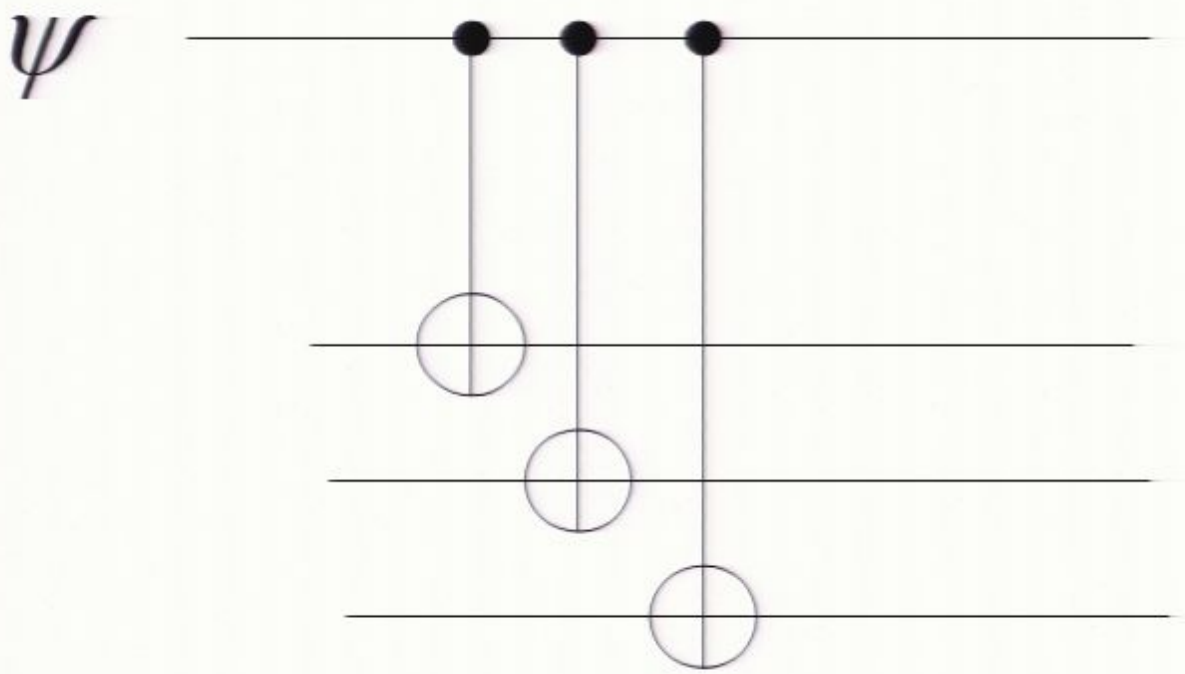

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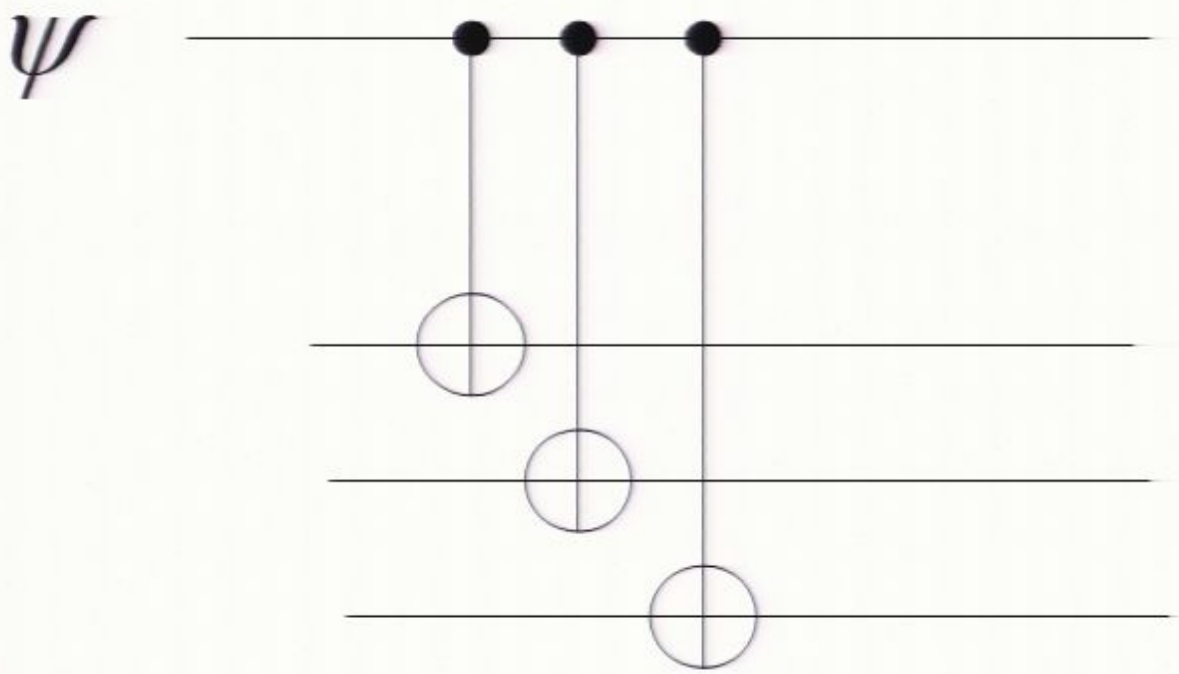

System

Environment:

Measured in 0/1 basis, it yields many redundant copies of the system's information. In other bases it does not.

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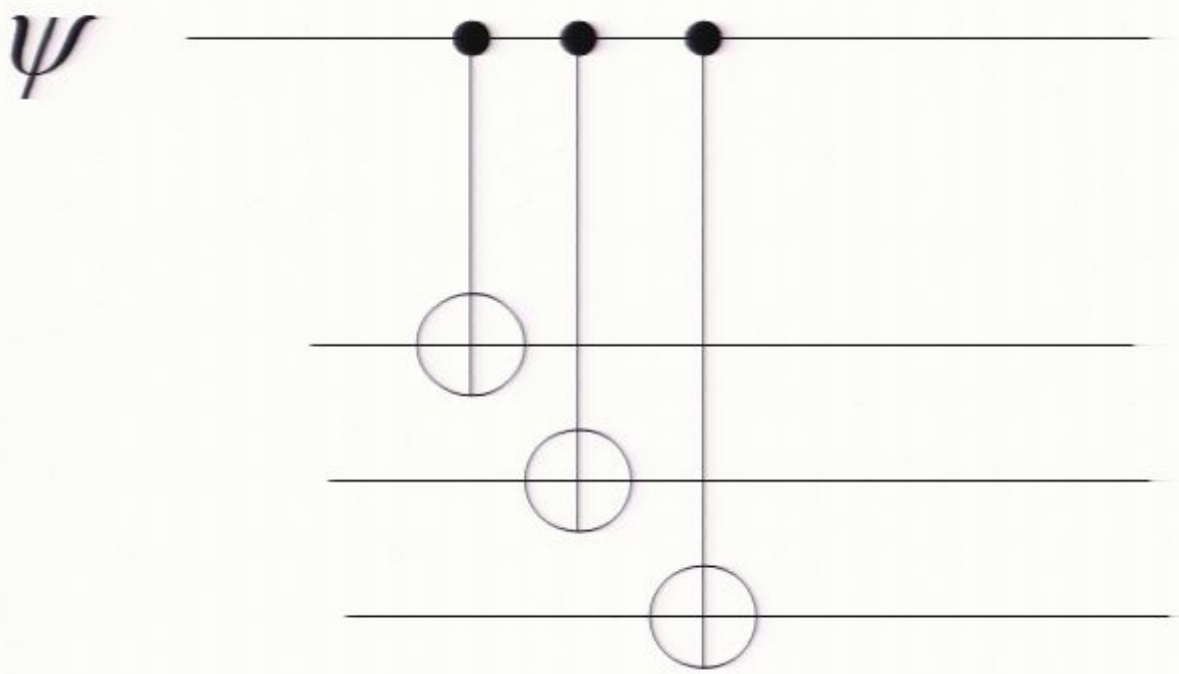


Information becomes classical by being replicated redundantly throughout the environment. "Quantum Darwinism" Blume-Kohout, Zurek quant-ph/0505031 etc.

This doesn't always happen. Seems to require a tensor factorization of environment's Hilbert space into subsystems that interact more strongly with system than with each other, departure from thermal equilibrium, perhaps other conditions on the Hamiltonian

Nowadays, it is tempting to believe that, for good or ill, once information has become public, it can never be destroyed.

The modern world appears very different in this regard from the ancient pre-Gutenberg era, when major literary works were written down, performed, and widely known, but then then lost.

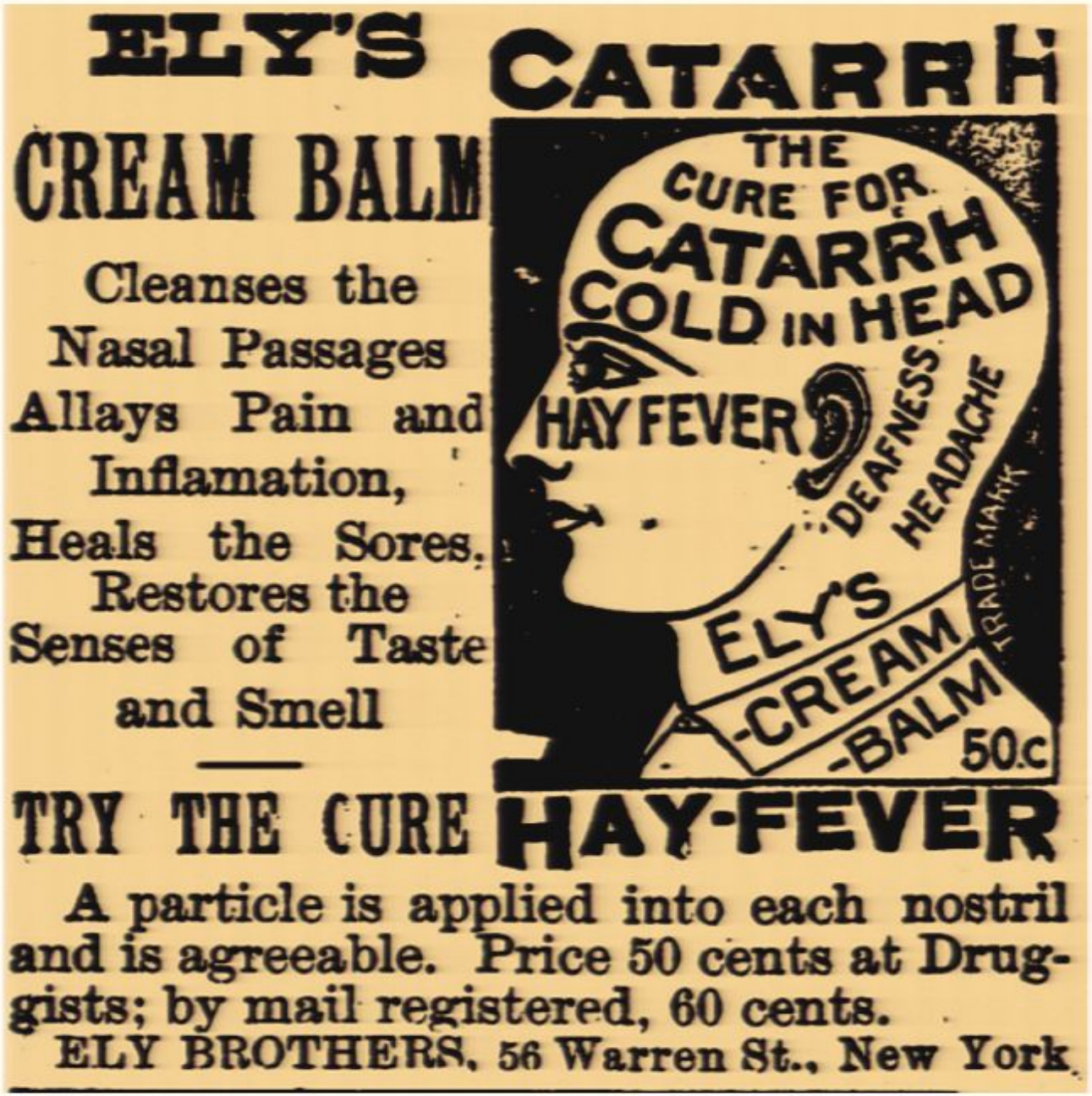
Sappho, ca 620-525 BC, by Gustav Klimmt

"Since classical times, Sappho has been a source of fascination and romantic construction. The ancients, who had nine books of her poems at their disposal, were unstinting in their admiration.... It is difficult to judge her for ourselves when so little of her work remains. What we have consists on the one hand of quotations and more general references in ancient authors, and on the other hand of torn scraps from ancient papyrus and parchment copies.... Only twenty-one contain any complete stanzas; and only three – till now – gave us poems near enough complete to appreciate as literary structures.

"A recent find enables us to raise this number to four... This text, recovered from Egyptian mummy cartonnage, is the earliest manuscript of her work so far known. It was copied early in the third century bc, not much more than 300 years after she wrote."

[Martin West, Times Literary Supplement 24 June 2005]

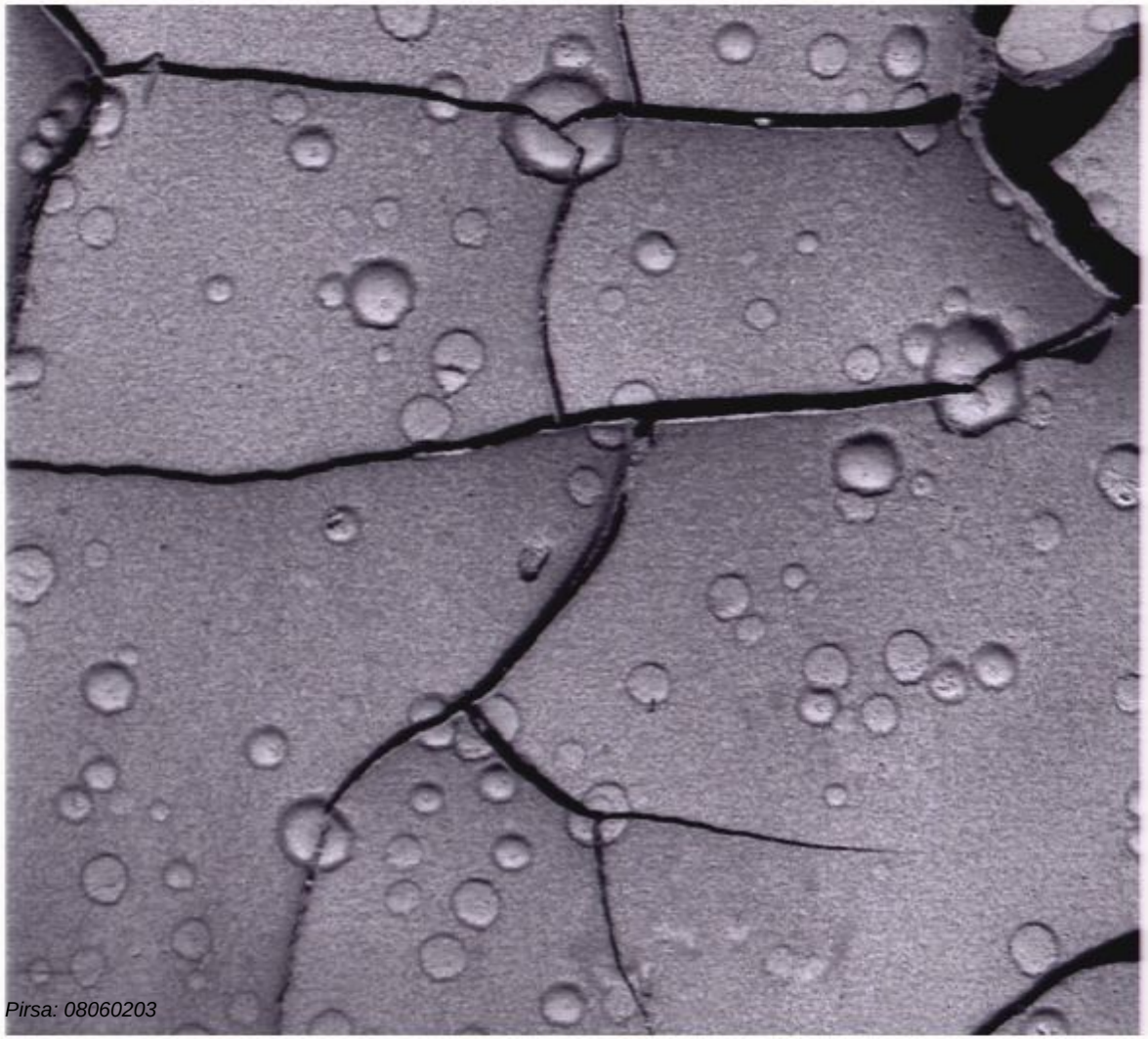
Papyrus fragments from Egyptian mummy cartonnage which, in conjunction with another fragmentary manuscript found decades earlier, allowed Sappho's latest poem to be reconstructed



Advertisement from an 1891 newspaper used as a drawer liner in a piece of antique furniture.

A modern example of accidental fossilization not so different from the repurposing of Sappho's poems as mummy cartonnage, when her poems temporarily fell out of favor .

But even in today's world, much macroscopic, publicly accessible information is lost because no person, nor any natural process, happens to record it in a durable medium.



Dried mud with cracks and raindrop craters in a river bed in Las Vegas, USA in 1965. A few days later these details were washed away by a subsequent rain.

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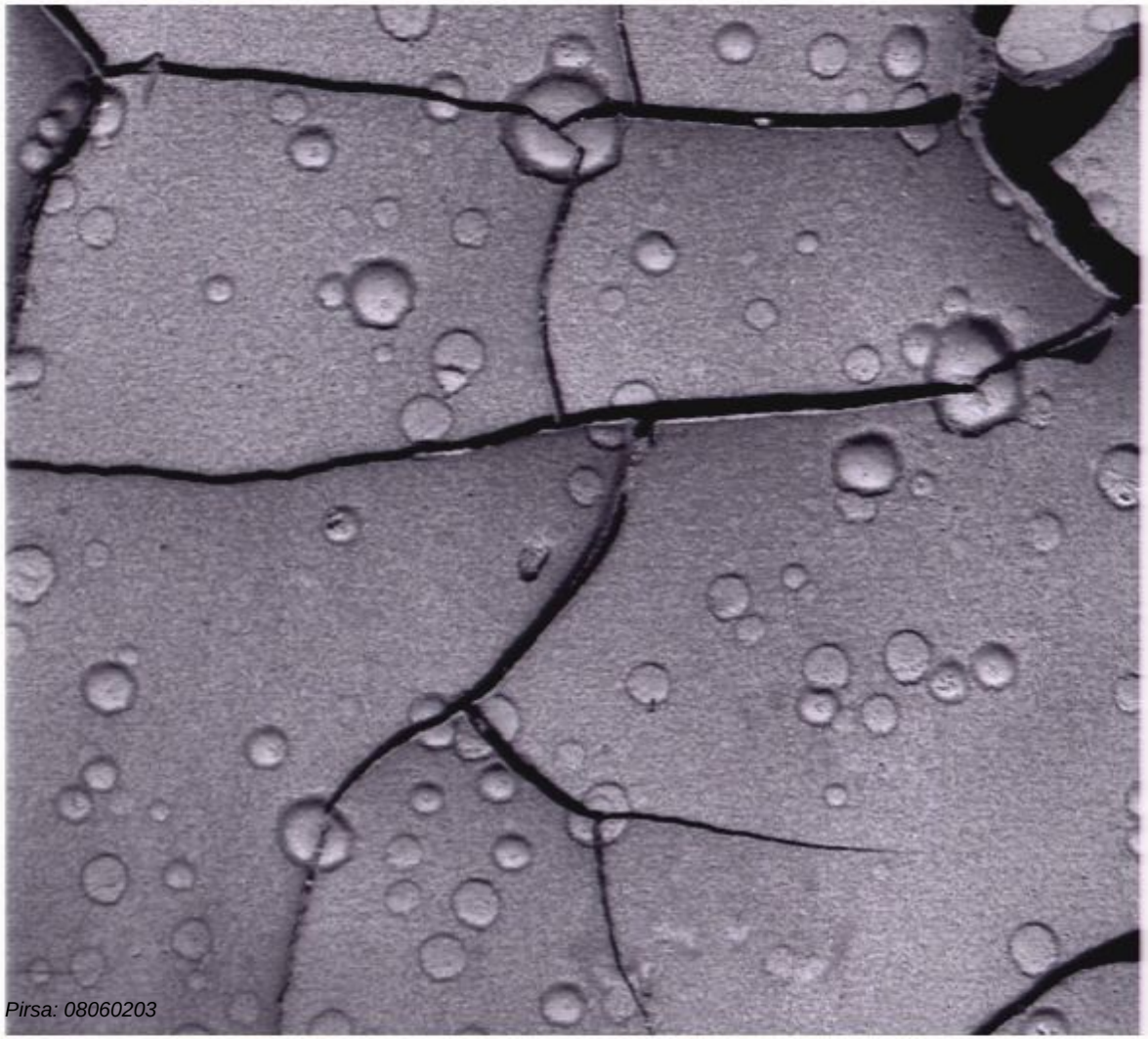

Dried mud with cracks and raindrop craters in a river bed in Las Vegas, USA in 1965. A few days later these details were washed away by a subsequent rain.

If no one had photographed them, would all record of them have been lost?

It is tempting to believe that such macroscopic information is not lost, just that it becomes so diffusely and complexly spread out as to be irrecoverable in practice while being still recoverable in principle (just as when a book is burned its contents are in principle recoverable from the exact state of the smoke, ashes, and heat it generated).

Could it be that every major past phenomenon, say Sappho's other poems, or the fate of mysteriously disappeared persons like the physicist Ettore Majorana or US labor leader Jimmy Hoffa, can be recovered from physical evidence in principle, if not in practice?

To believe otherwise is venturing dangerously close to the postmodernist view, abhorred by most scientists as arrogantly anthropocentric, that the past (or maybe even the present) has no objective reality independent of our beliefs about it, and therefore that it is pointless to inquire what "actually" happened.

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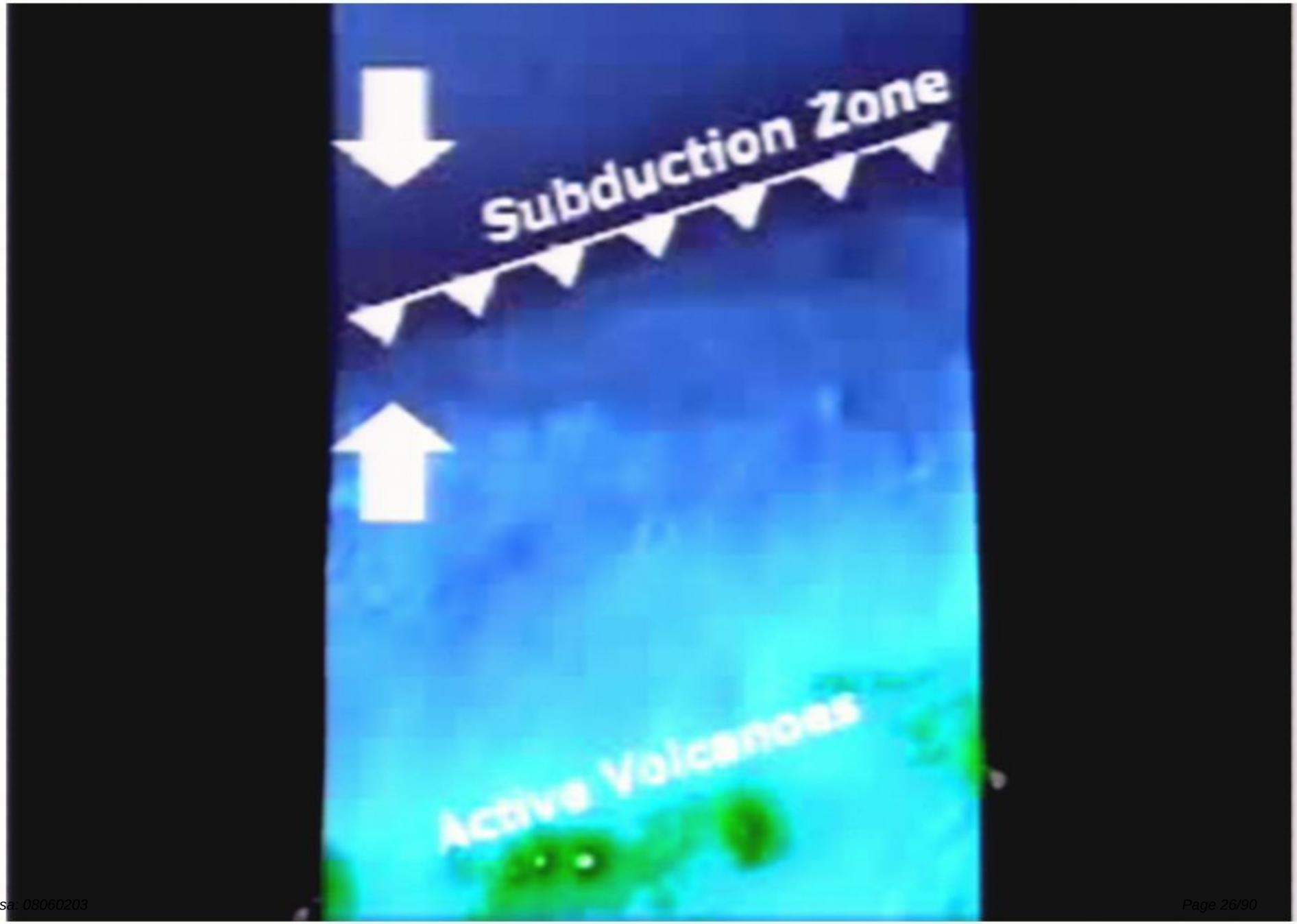
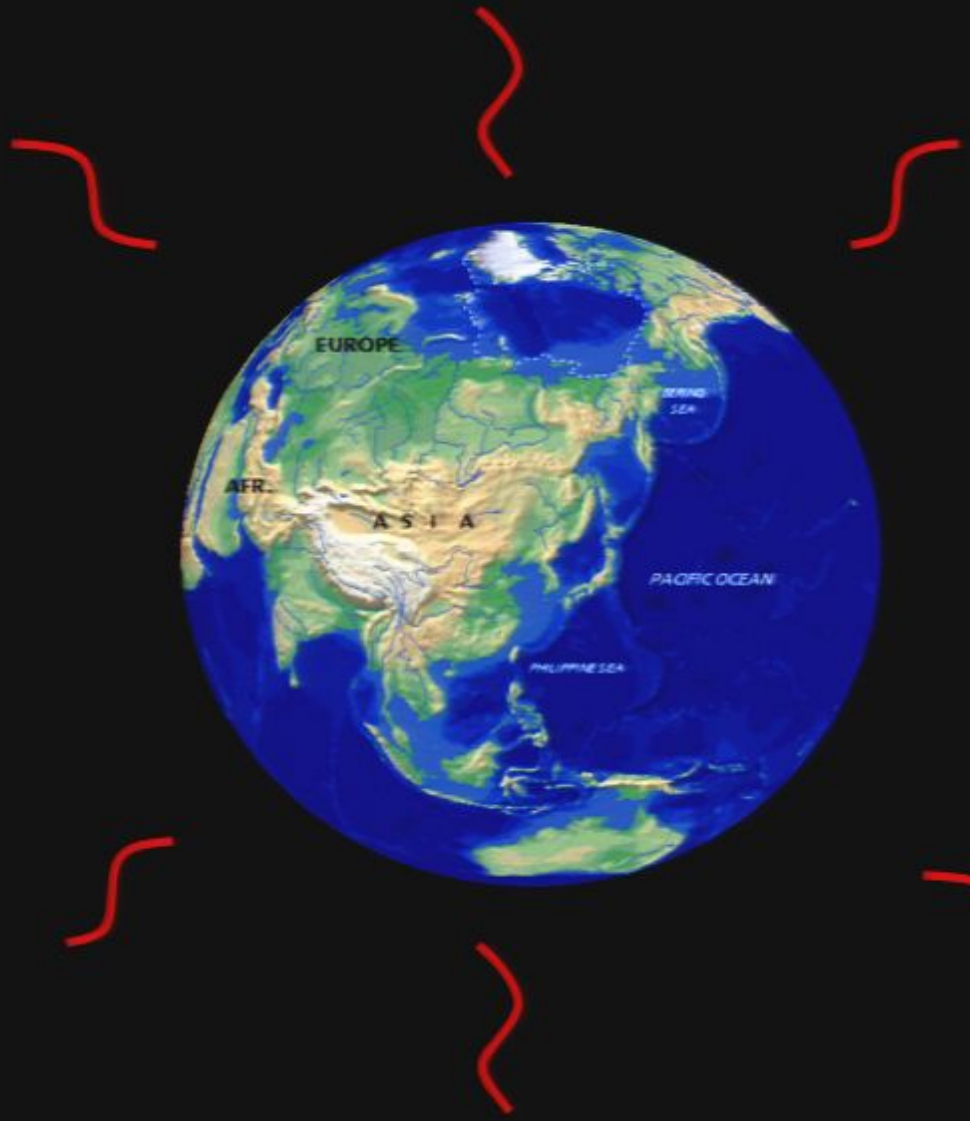
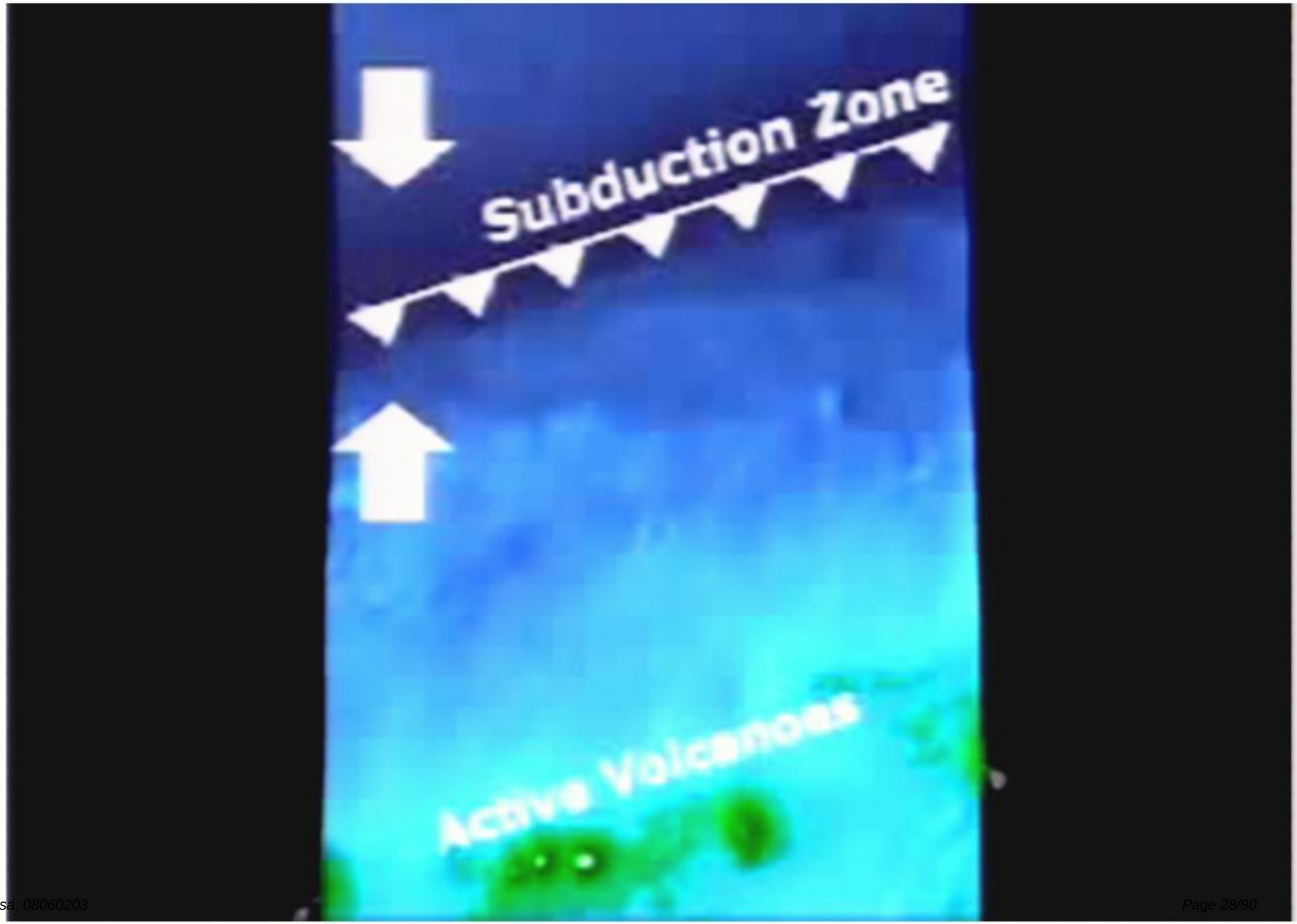

Subduction Zone
Active Volcanoes



To catch up with the thermal radiation leaving Earth, one would need to travel faster than light. So the information is still in the universe, but not recoverable by us.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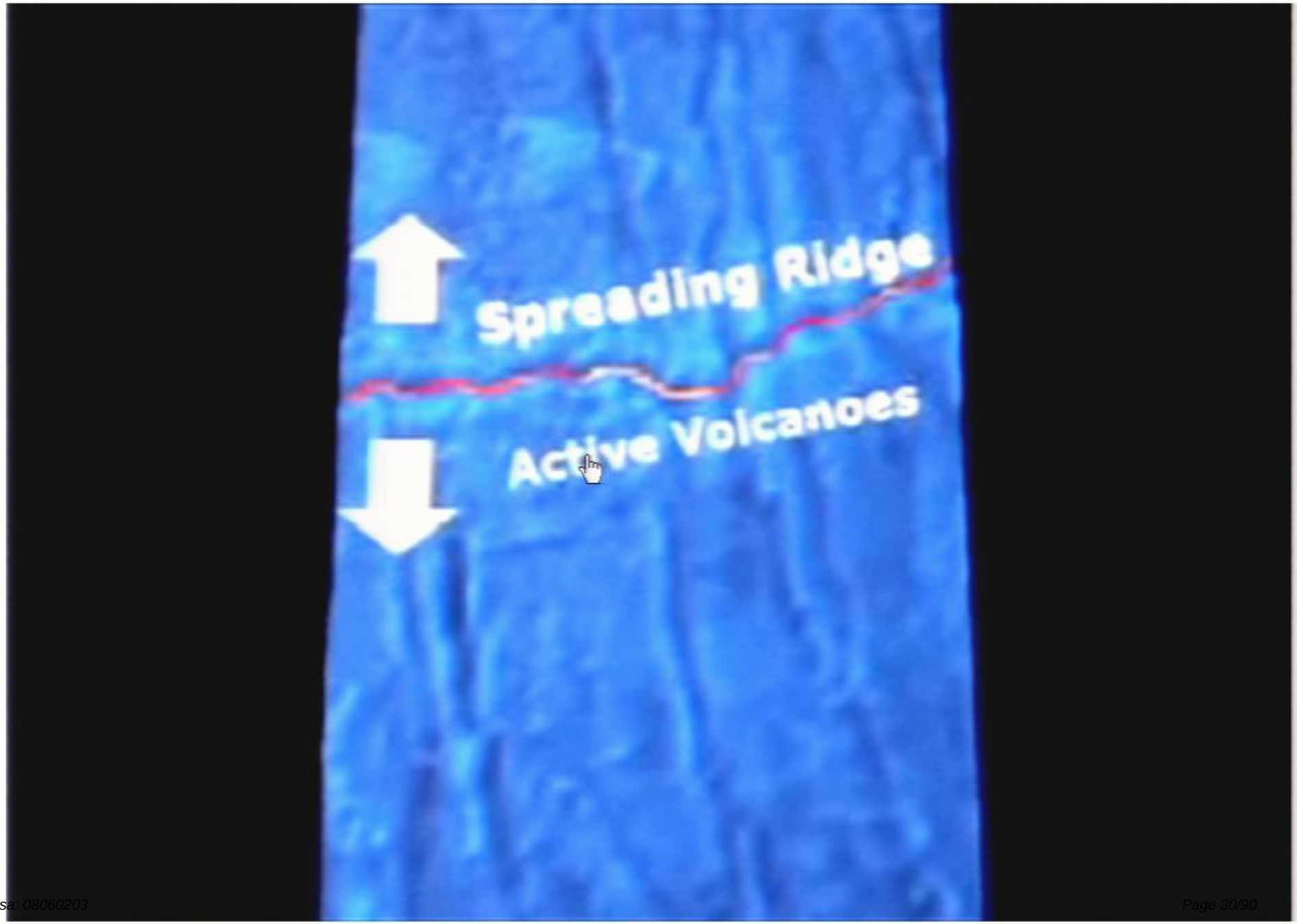
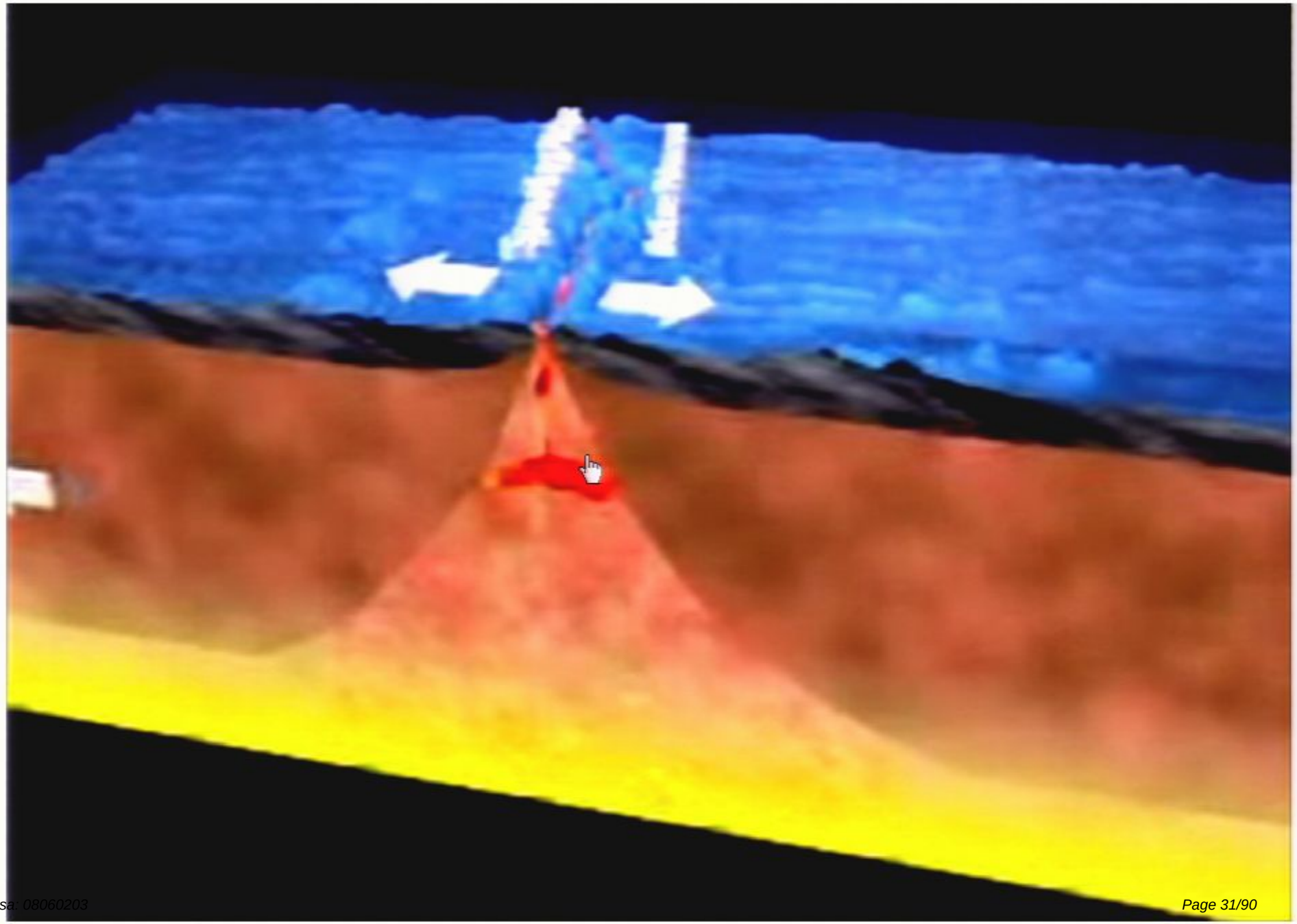
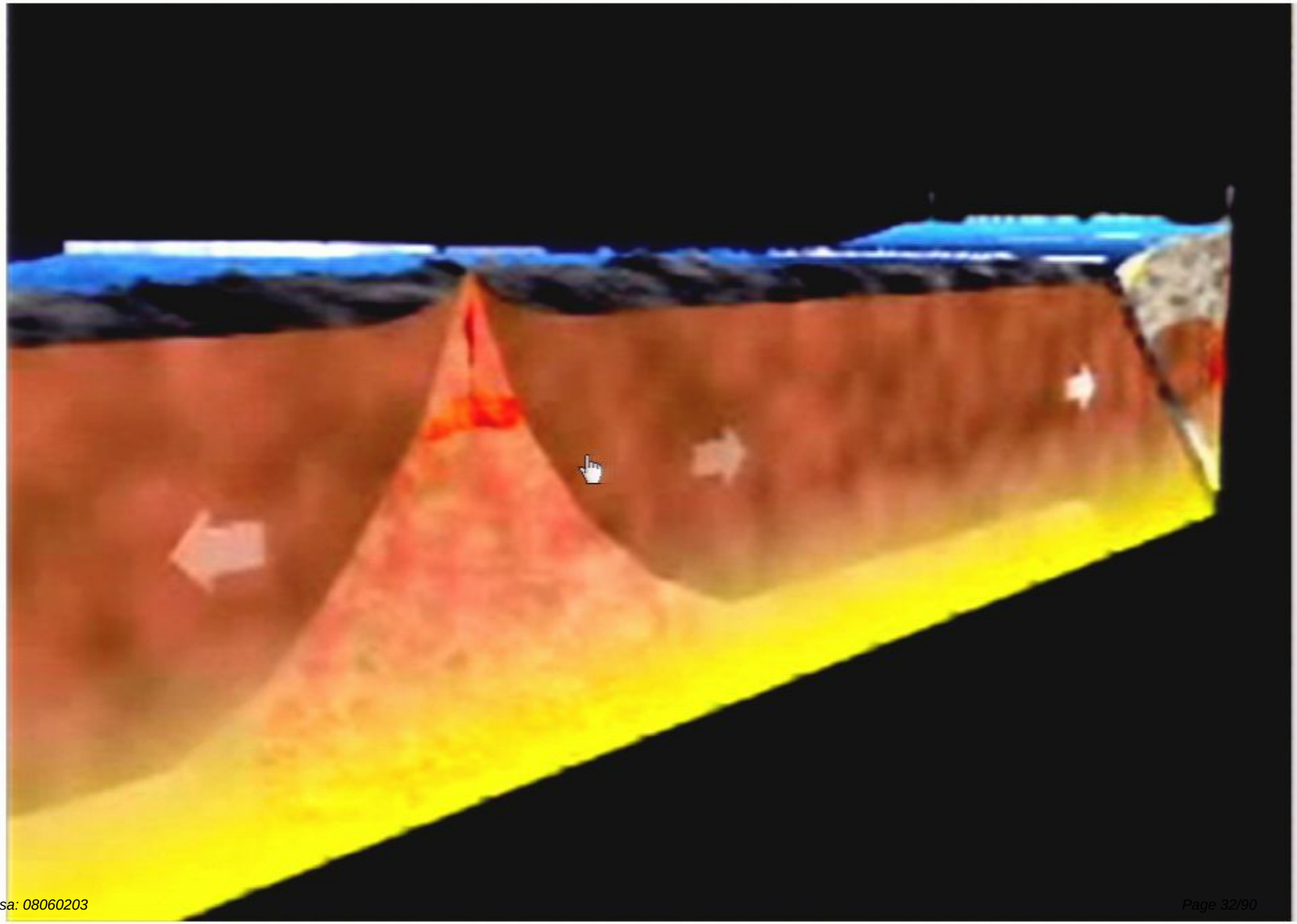
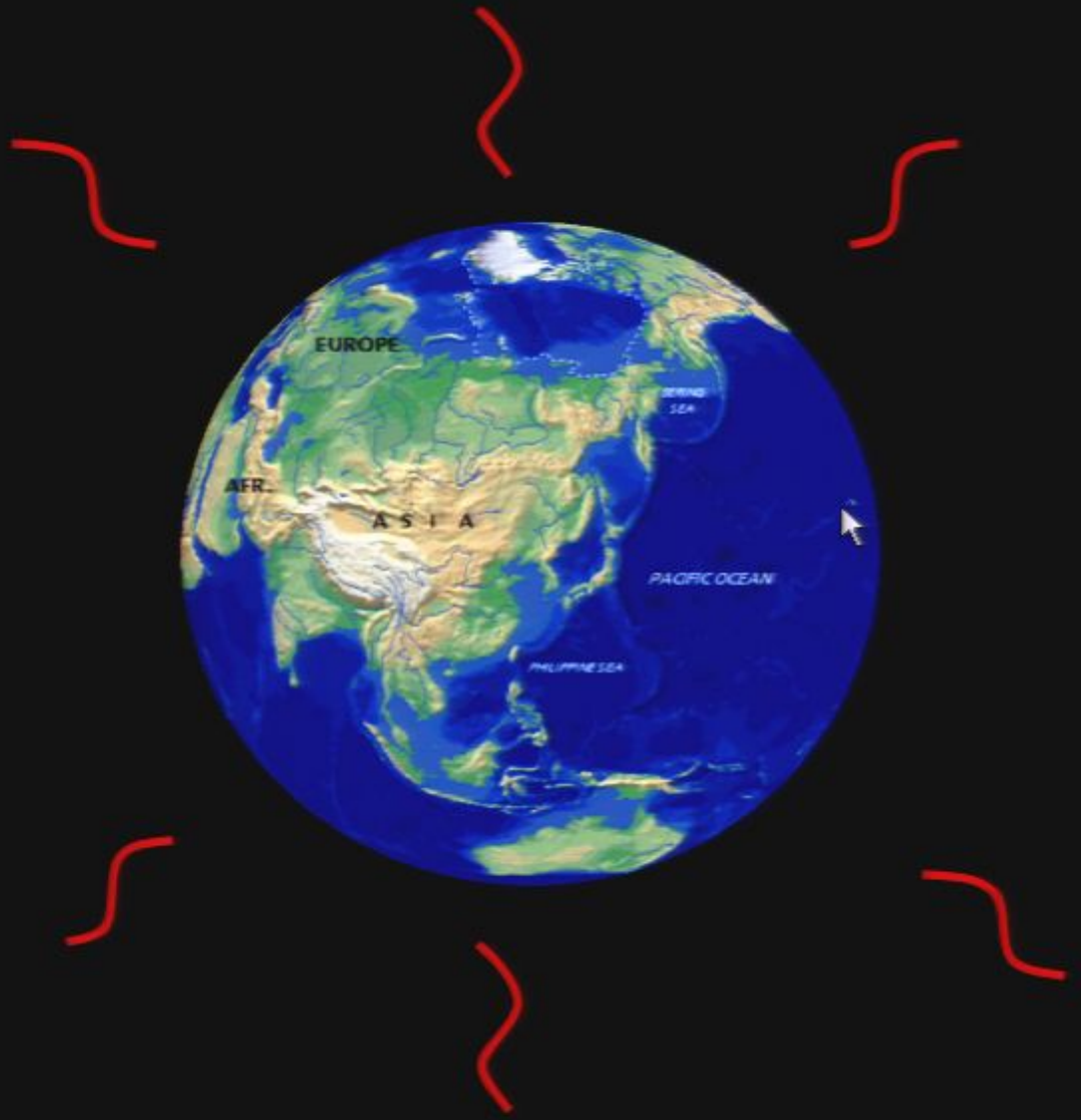

Spreading Ridge
Active Volcanoes







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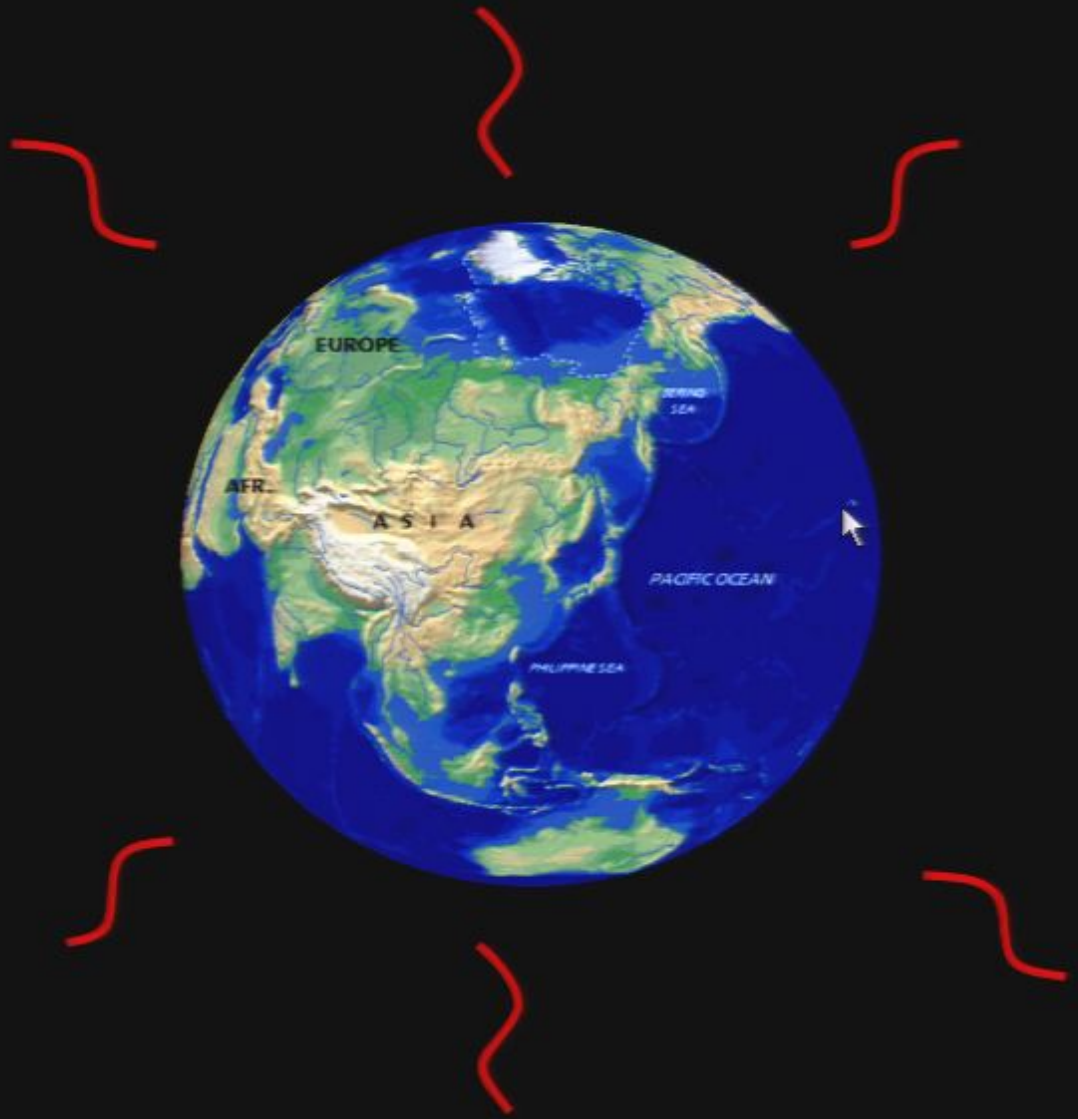

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So should we now we add a new level of privacy?

- **Quantum:** Information like the path taken in an interferometer, that exists only temporarily, and afterward can best be thought of as never having existed.

- **Classical but Escaped:** Information that has been amplified to the point of becoming classical, but has escaped from Earth in thermal radiation. Humans have no way of recovering it.

- **Classically Private:** Information that has been amplified to the point of becoming classical, and still resides on earth in a few places recoverable in principle.

- **Public and Permanent** Information that is so widely distributed that it is infeasible to erase all the copies.

Mysteries of the Past:

Still recorded on earth, though unknown to any human and inaccessible with current technology:

- Locations of gold rings, dropped in an annual ceremony into the Venice Lagoon over a period of several centuries, to symbolize Venice's marriage to the Sea.

Maybe still recorded on earth, maybe escaped: Fates of mysteriously disappeared persons such as

- Physicist Ettore Majorana disappeared 1938
- Labor leader Jimmy Hoffa disappeared 1975
- Computer Scientist Jim Gray disappeared 2007

Escaped:

- Unrecorded raindrops from past rain storms.
- Pattern of foam on my yesterday morning's cappuccino.

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- To preserve important works of literature
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Record the information in a durable digital medium, and bury many copies in geologically stable rock formations in various parts of the world, as if it were nuclear waste.

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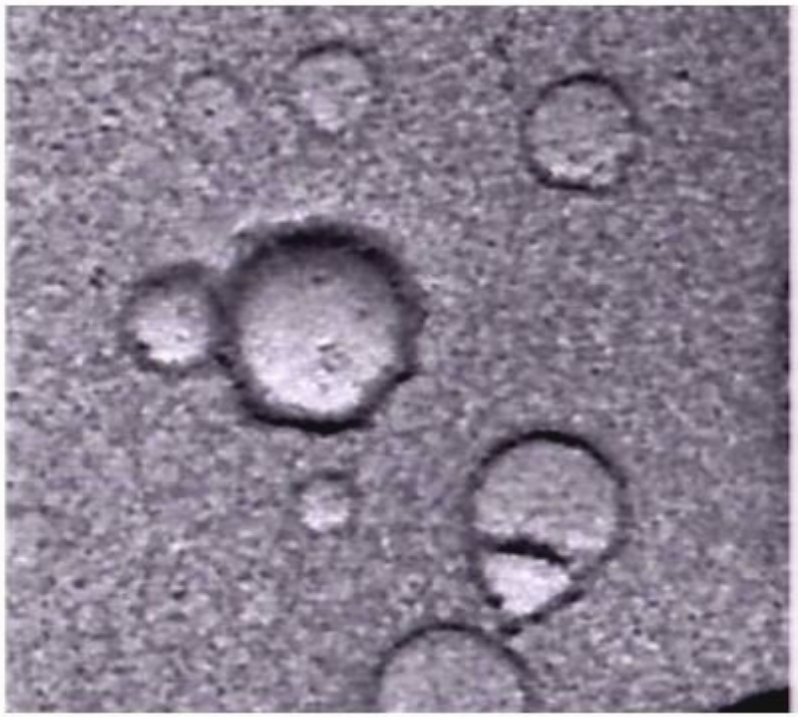
Probably not, due to randomizing effect of dynamics.

Randomizing dynamics in a representative case.



Though the raindrop originates in quantum and thermal fluctuations, it does not fall in a superposition of places. Independent observers would agree where it fell, and as long as the drop or its crater exists, reflected light will generate a torrent of replicas of the information, fulfilling the classicality criterion of quantum Darwinism. However, unless the crater is lucky enough to get fossilized, it will be washed away, and its former location will then lose any stable earthly embodiment. The torrent of optical replicas will cease, and the old optical replicas will escape into space. So the classical information of where it was remains in the universe, but not the Earth.

How to obliterate earthly evidence of Jimmy Hoffa's demise? (Former US labor leader disappeared in 1975, presumed murdered by the New York City Mafia, but body was never found. Police are still searching.)

- Cremate his body and let the smoke and heat escape

- Dissolve the ashes to make a clear liquid, with no solid fragments, then pour the liquid into the ocean

- Don't tell anyone you did it, even on your deathbed

- For good measure, have yourself cremated and your ashes dissolved to make sure physical traces of your memory are thoroughly gone.

Some further Questions

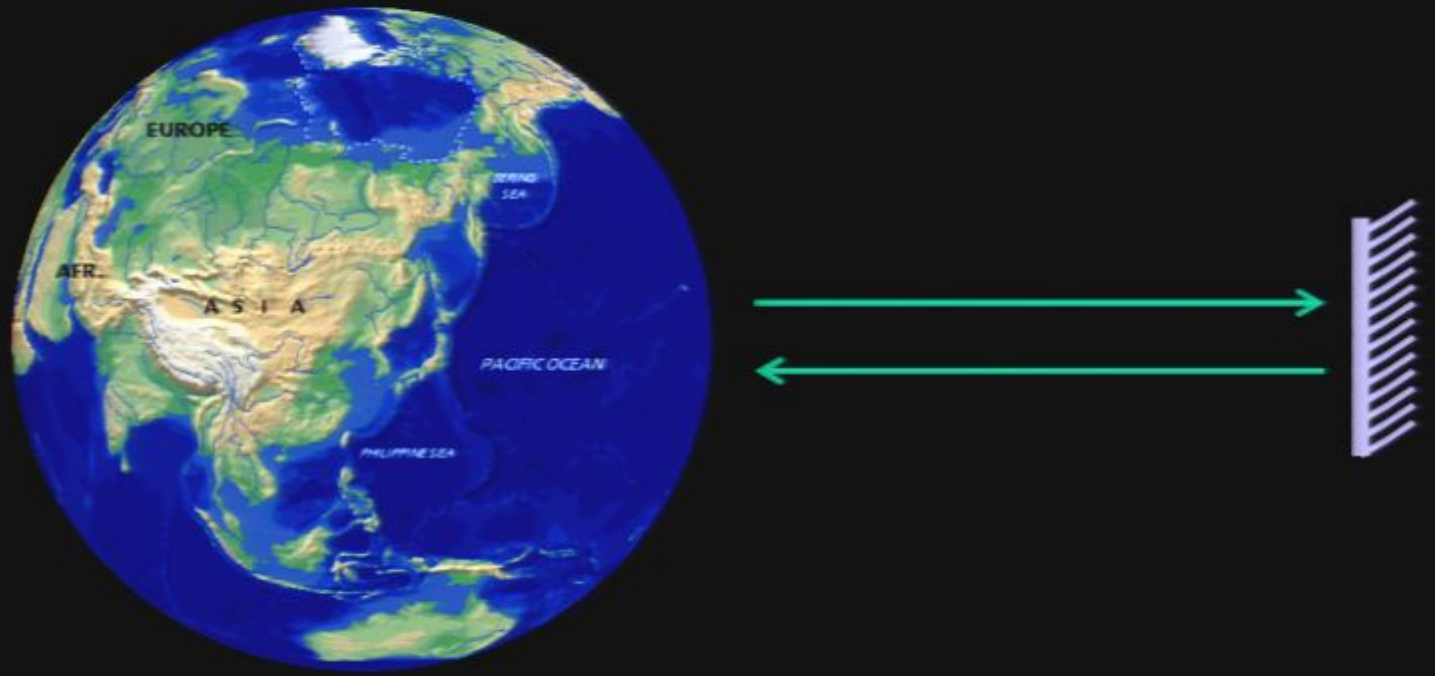
- Is it really impossible to recapture the escaped radiation?

- What is the ontological status of escaped information? Does God remember where the raindrops fell, even after all terrestrial evidence is gone?

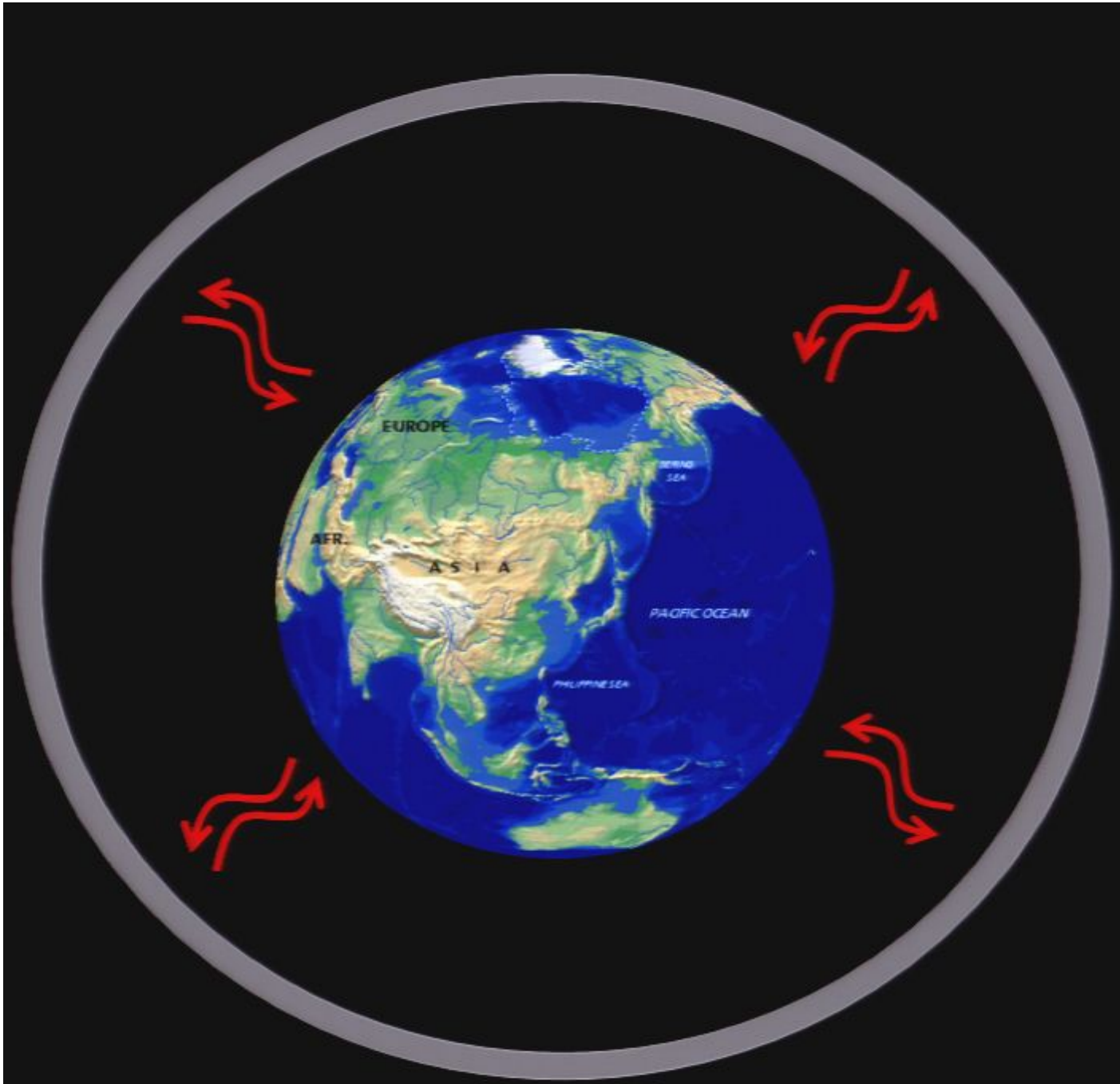
- Is random input (e.g. entropy of incoming solar radiation) necessary to make the earth forget things?

- Even after classical information is lost from "hard" geological storage, might it still be retained in the earth's far more numerous "soft" degrees of freedom such as phonons in the earth's core and mantle?

Can we arrange for escaped information to be reflected back to us later, making it again accessible?

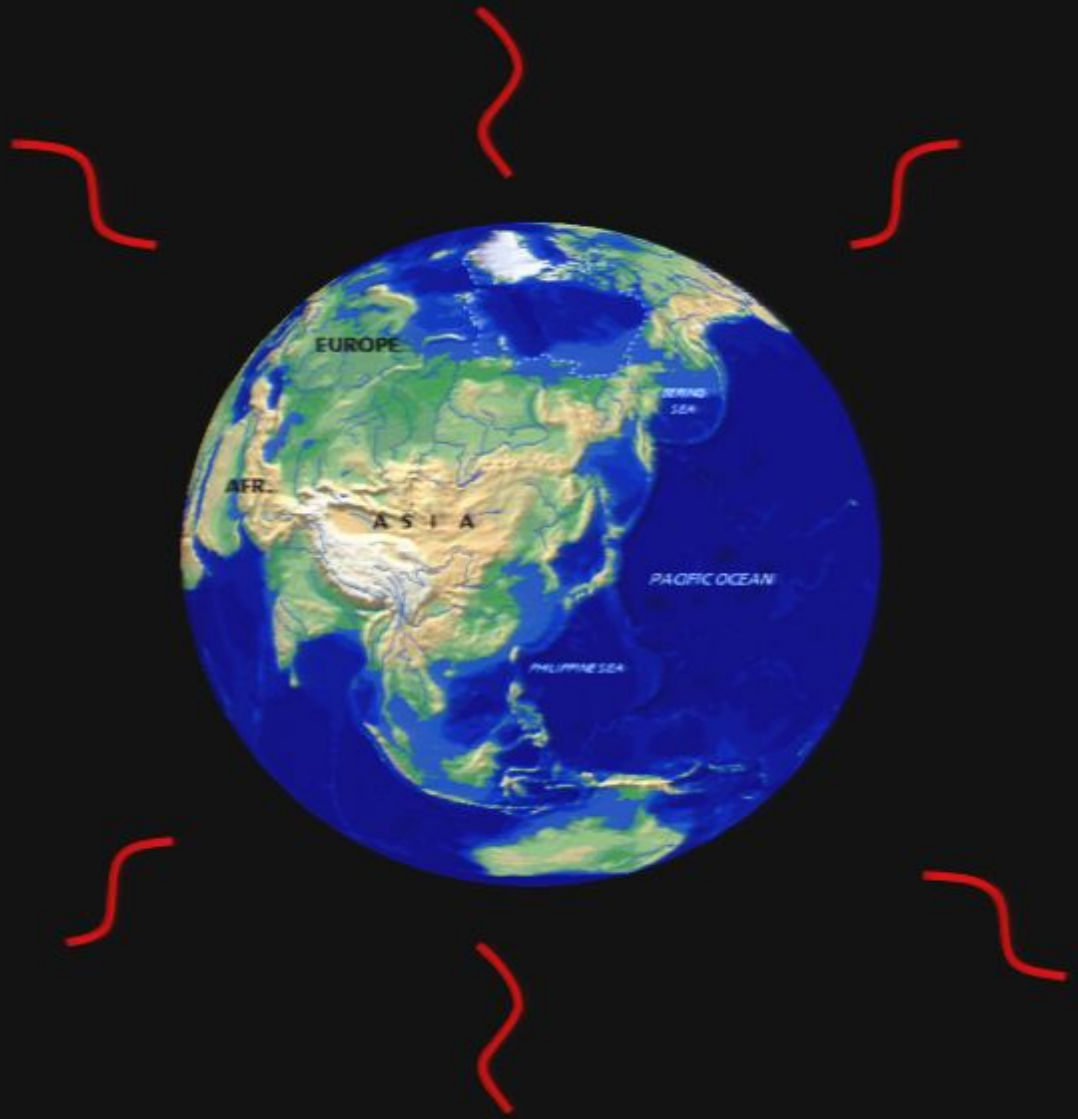


Yes. For specific items of non-thermalized outgoing radiation (e.g. optical earth views, old TV broadcasts) , this could be arranged, with advance planning, or it might happen accidentally. Such information could be called extraterrestrial fossils.



But for fully thermalized radiation we would have to catch and reflect back so much of it, to reconstruct any particular item of interest, that the earth would badly overheat.

- Can we outrun the radiation?



For example, one might hope to outrun the thermal radiation, because the refractive index of interstellar space is slightly >1.

But this hope is probably dashed by the accelerating expansion of the universe (a.k.a. cosmological constant, dark energy) which causes remote objects now visible (e.g. other galaxies) to eventually become inaccessible.

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"The past exists only insofar as it is recorded in the present." —Wheeler

The Evolving Human Viewpoint

• Before raindrop forms: Humans know it's about to rain, but they don't know where the drops will fall.

• (LLLL+RRRR) /√2 Humans agree where drop has fallen. Depending on how it affects their plans, they may or may not care, but they all agree that one of the outcomes R or L is real while the other is merely an unrealized possibility.

• (LLLLL+RRRRR) /√2 Drop has entirely evaporated. People may remember that it fell but no one remembers where. No other terrestrial memory remains about which of the possibilities, L or R, "happened" and which did not.

In the end, humans will come to accept what God knew all along, that the distinction between what happened and what might have happened is transient and illusory.

Most classical information, such as the pattern of snow flakes on the ground last winter, or rice grains on my dinner plate last night, is impermanent, eventually losing its durable embodiment and escaping from the earth in outgoing radiation.

Occasionally information is lucky enough to get fossilized by natural processes or recorded by humans in a durable medium. Such information can last billions of years.

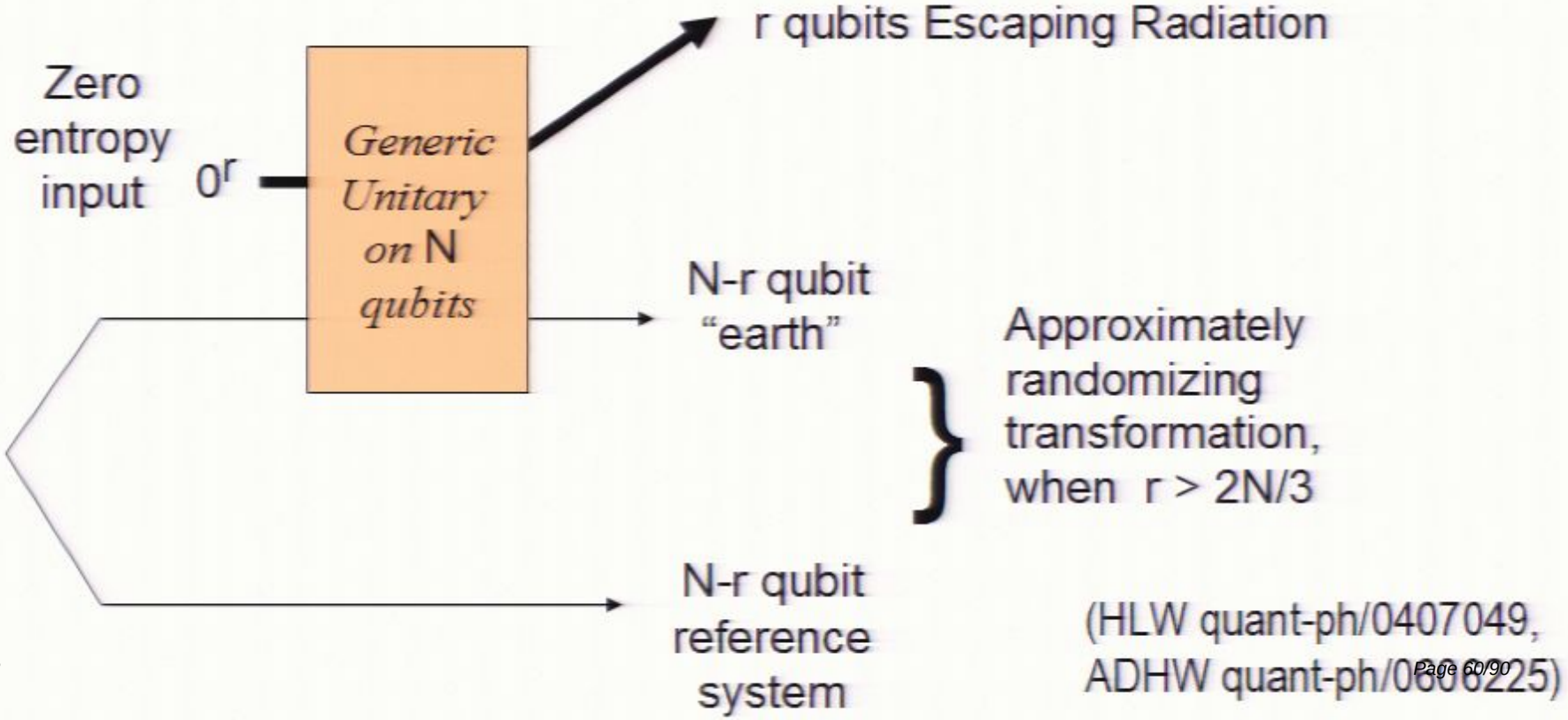
Escaped information still exists in the universe, but it is inaccessible on earth.

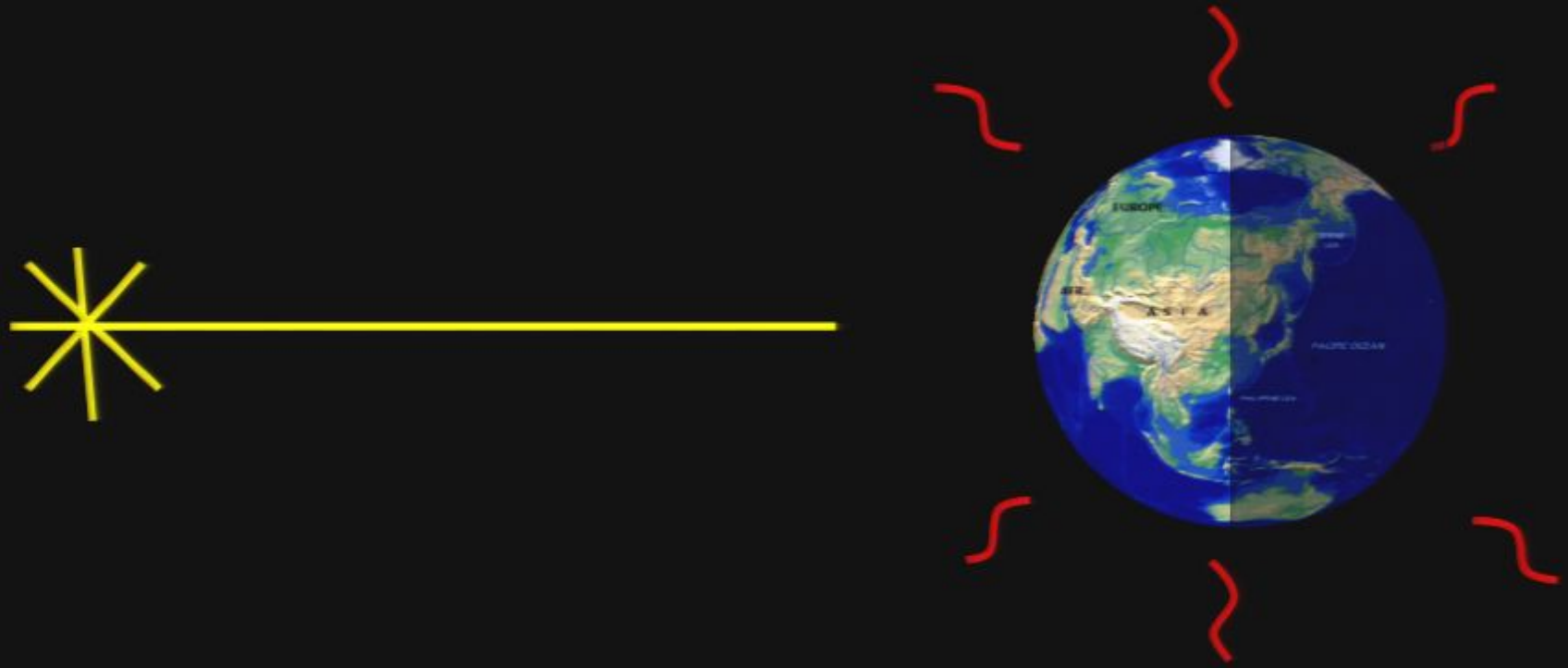
Humans have little justification for continuing to think that one alternative really happened and the others didn't.


IN 1832 ON
THIS SPOT
NOTHING
HAPPENED

• Is random input (eg radiation from the sun) necessary to achieve randomization?

Not always. Unlike a classical system, a deterministically evolving quantum system can be randomized simply by allowing enough information to escape from it.





If the earth's solar input were replaced by a laser beam of equal power, the input entropy would be zero while its apparent output entropy rate would be about the same. Thus at a steady state the output entropy rate would also be zero, because of entanglement among the output modes. The earth would be functioning as a giant down-converter. Unlike an ordinary down-converter, the correlations would be exceedingly computationally complex and unobservable in practice.

Radiation from a deterministically evolving system with zero input entropy

Discrete Classical (e.g. reversible cellular automaton):

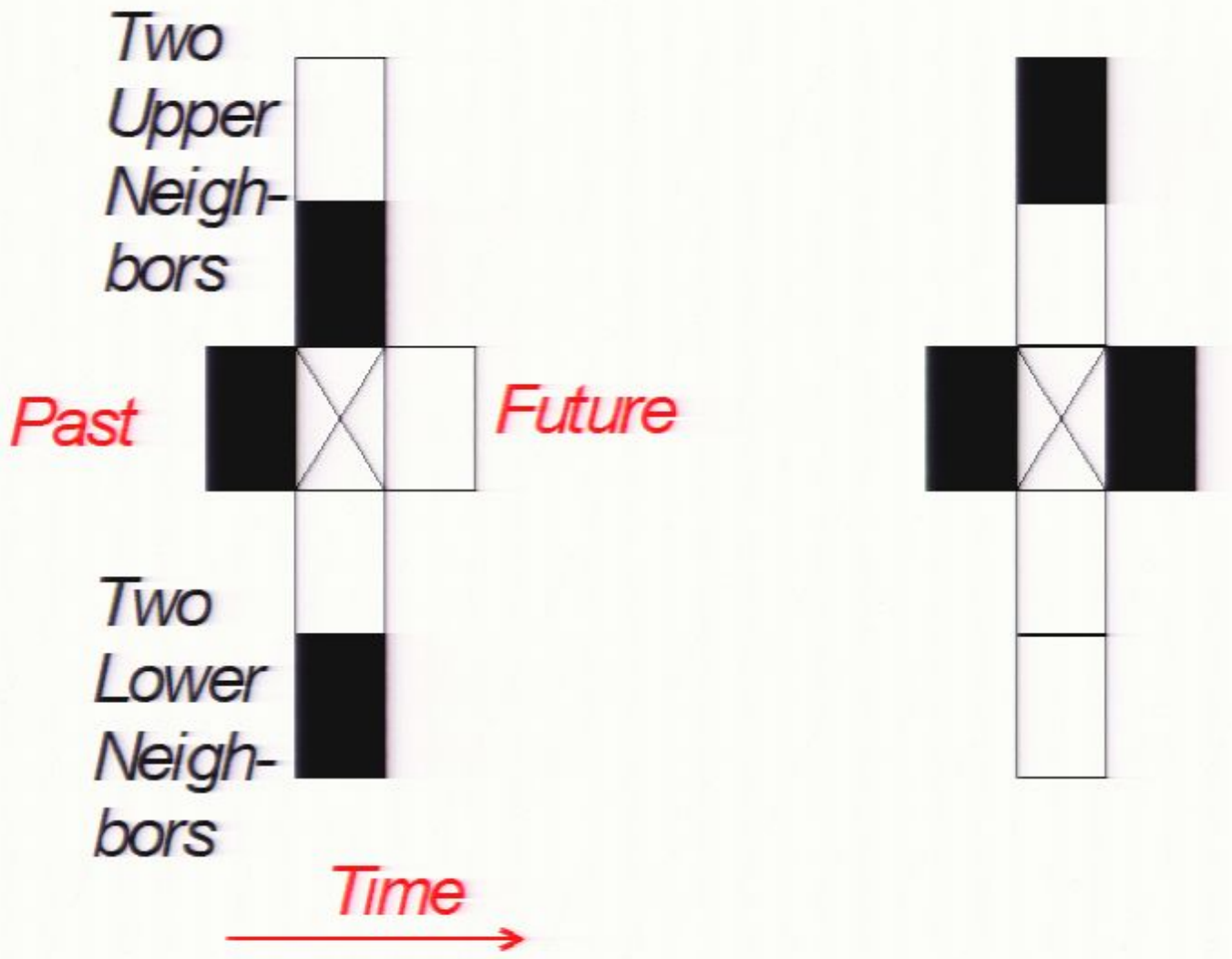
Pseudorandom radiation, pseudorandom residual system

Continuous Classical (chaotic)

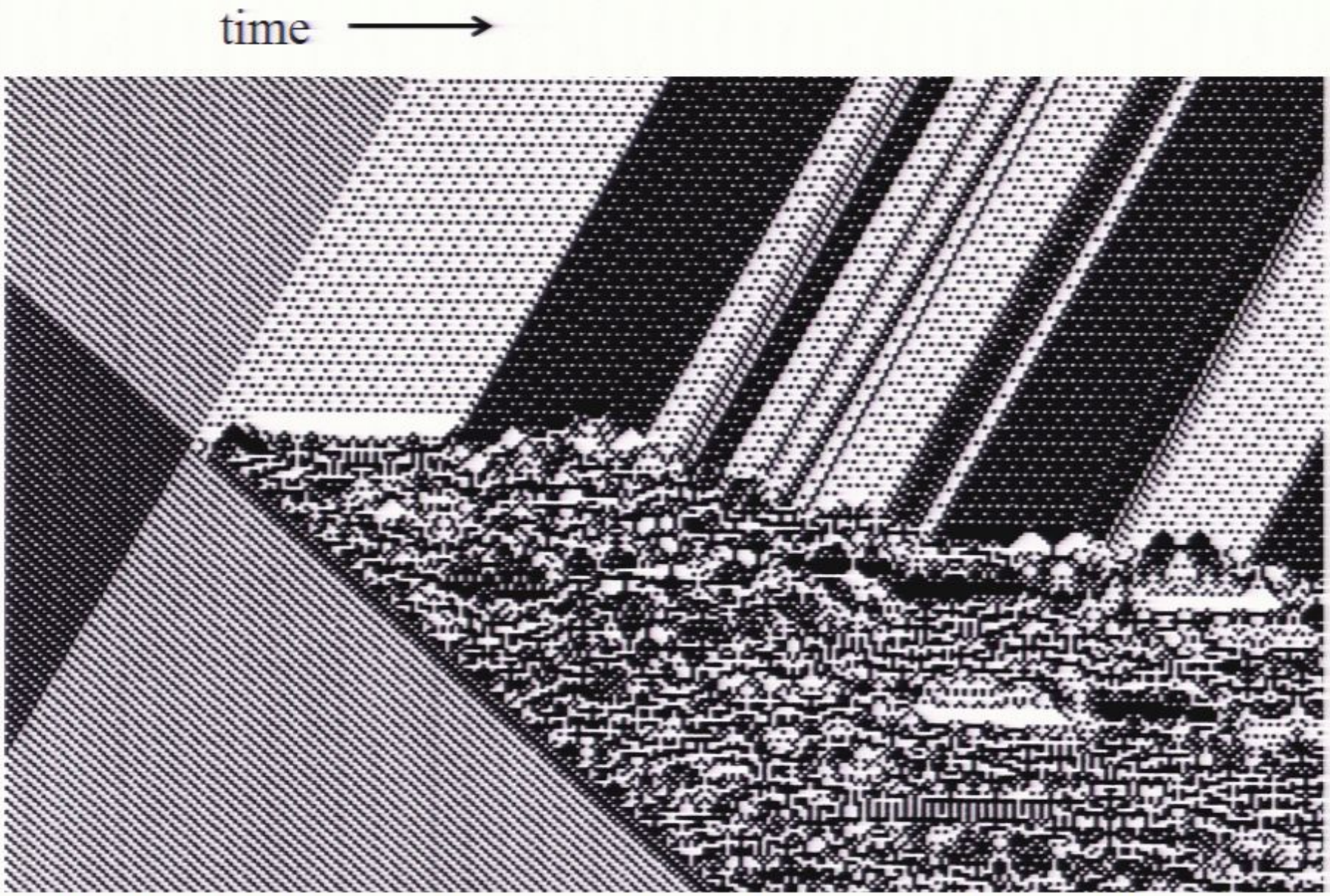
Random radiation, random residual system (both from mining the infinite-precision generic initial condition. If initial condition were special, both residual system and radiation would be pseudorandom)

Discrete Quantum:

Random residual system, random-looking radiation, entangled with itself and with residual system



Range-2, deterministic, 1-dimensional Ising rule. Future differs from past if exactly two of the four nearest upper and lower neighbors are black and two are white at the present time.

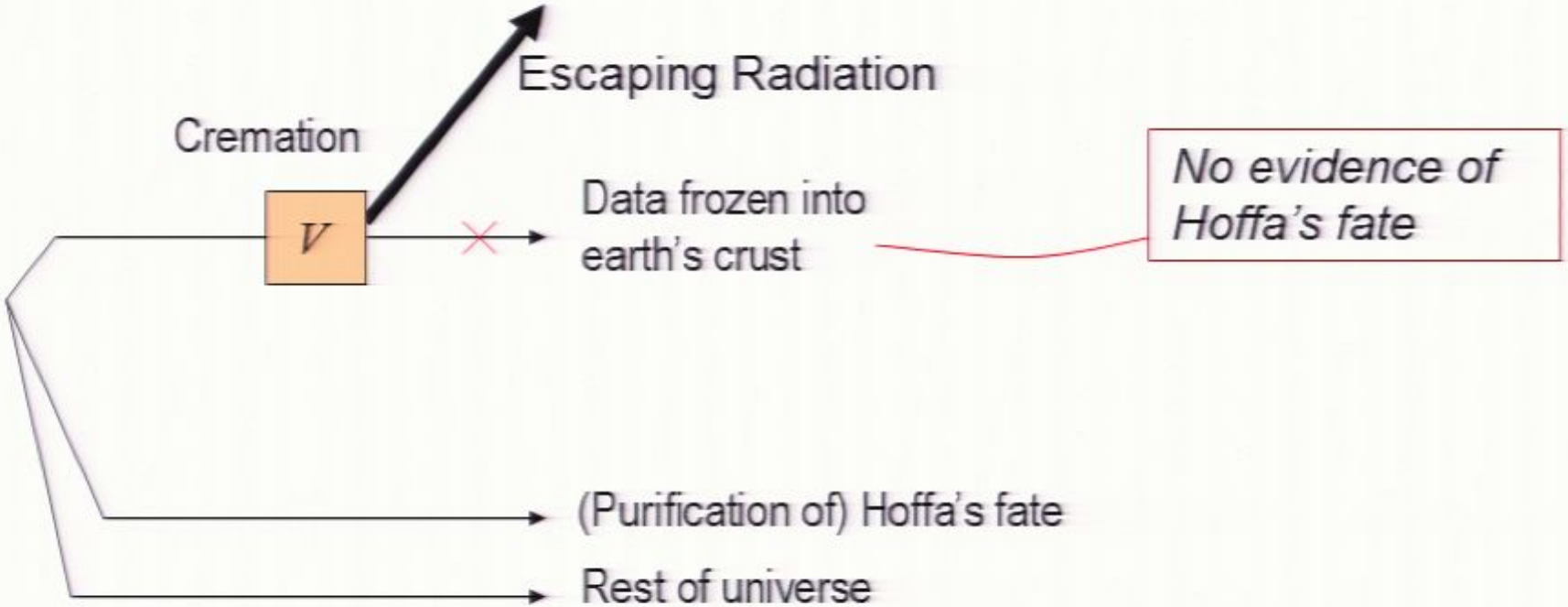


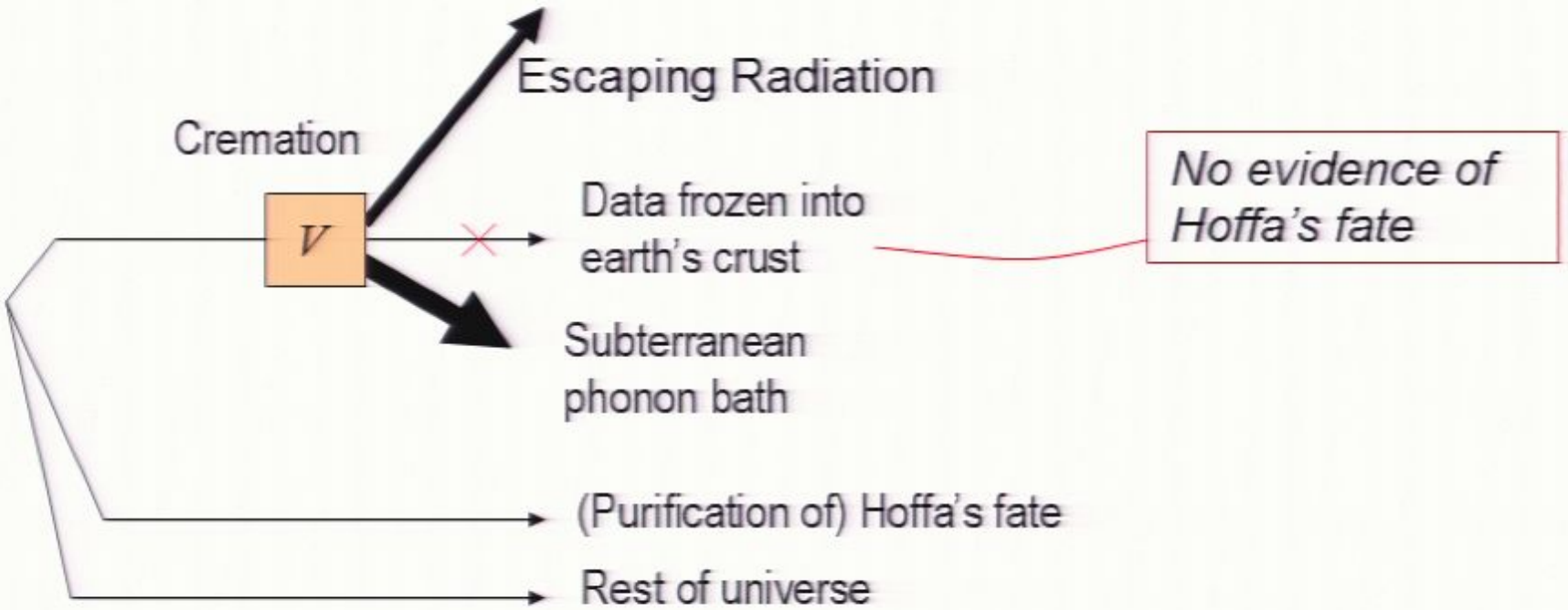
"Radiation" from a hot pseudorandom state formed by collision of two domain edges in simple initial condition in range-2 reversible deterministic 1d Ising cellular automaton

Up to now, I have considered only geologically stable "hard" degrees of freedom in the crust, and neglected the far more numerous "soft" degrees of freedom (e.g. phonons and photons) in not only the crust but the whole body of the earth. These degrees of freedom have entropy about a million times *greater* than the annual radiant entropy flux leaving the earth.

Therefore the condition $r > 2N/3$ for quantum randomization without random input is badly unfulfilled.

Could it be that, if Hoffa were cremated in a way that efficiently couples to soft degrees of freedom in the earth (deep in a mine, for example), this soft evidence will persist for about half a million years, even after the hard evidence is gone?


Escaping Radiation
Cremation
V
Data frozen into
earth's crust
No evidence of
Hoffa's fate
(Purification of) Hoffa's fate
Rest of universe


Escaping Radiation
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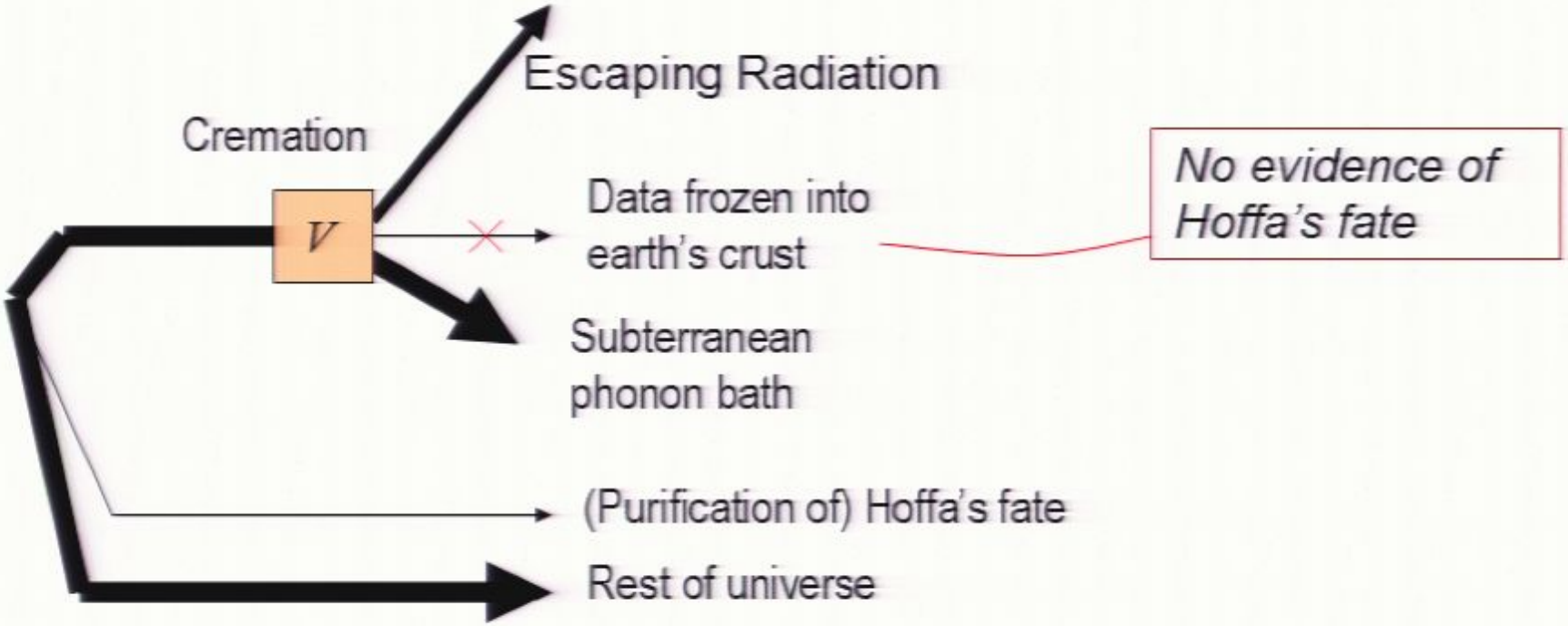
No evidence of
Hoffa's fate
Subterranean
phonon bath
(Purification of) Hoffa's fate
Rest of universe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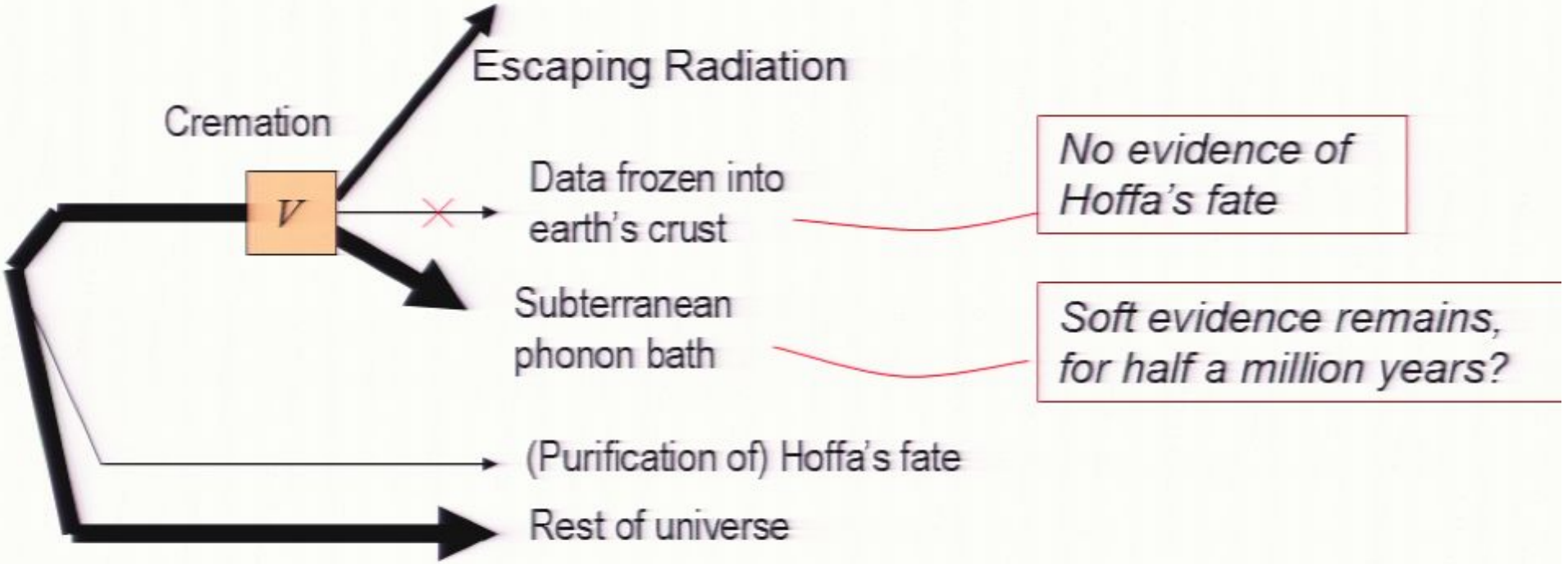
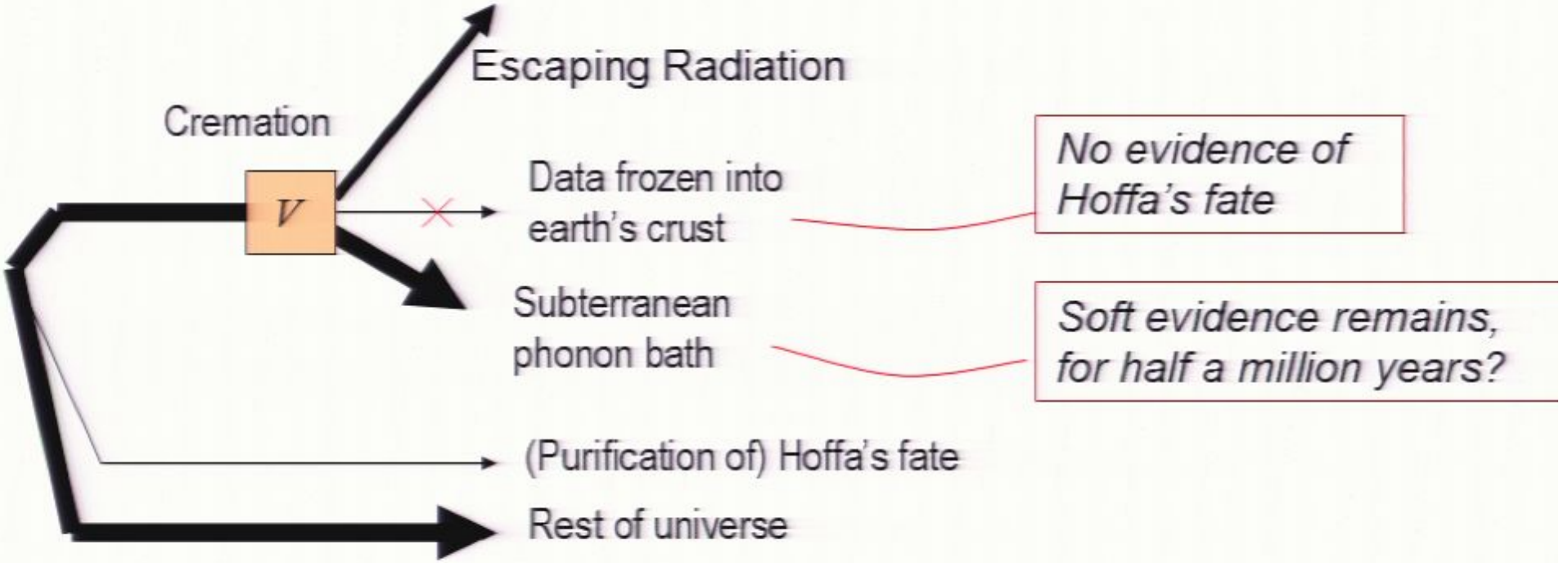
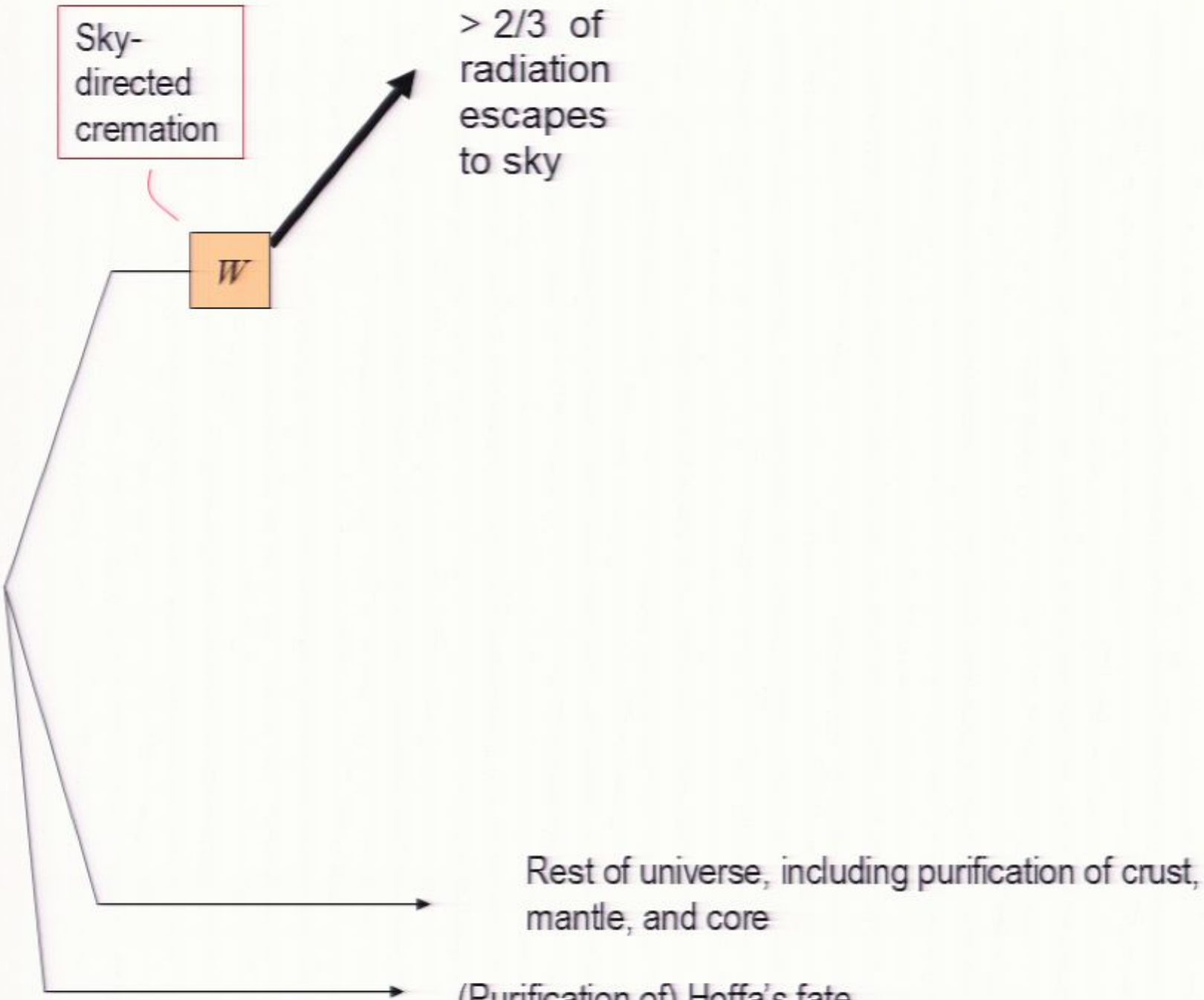
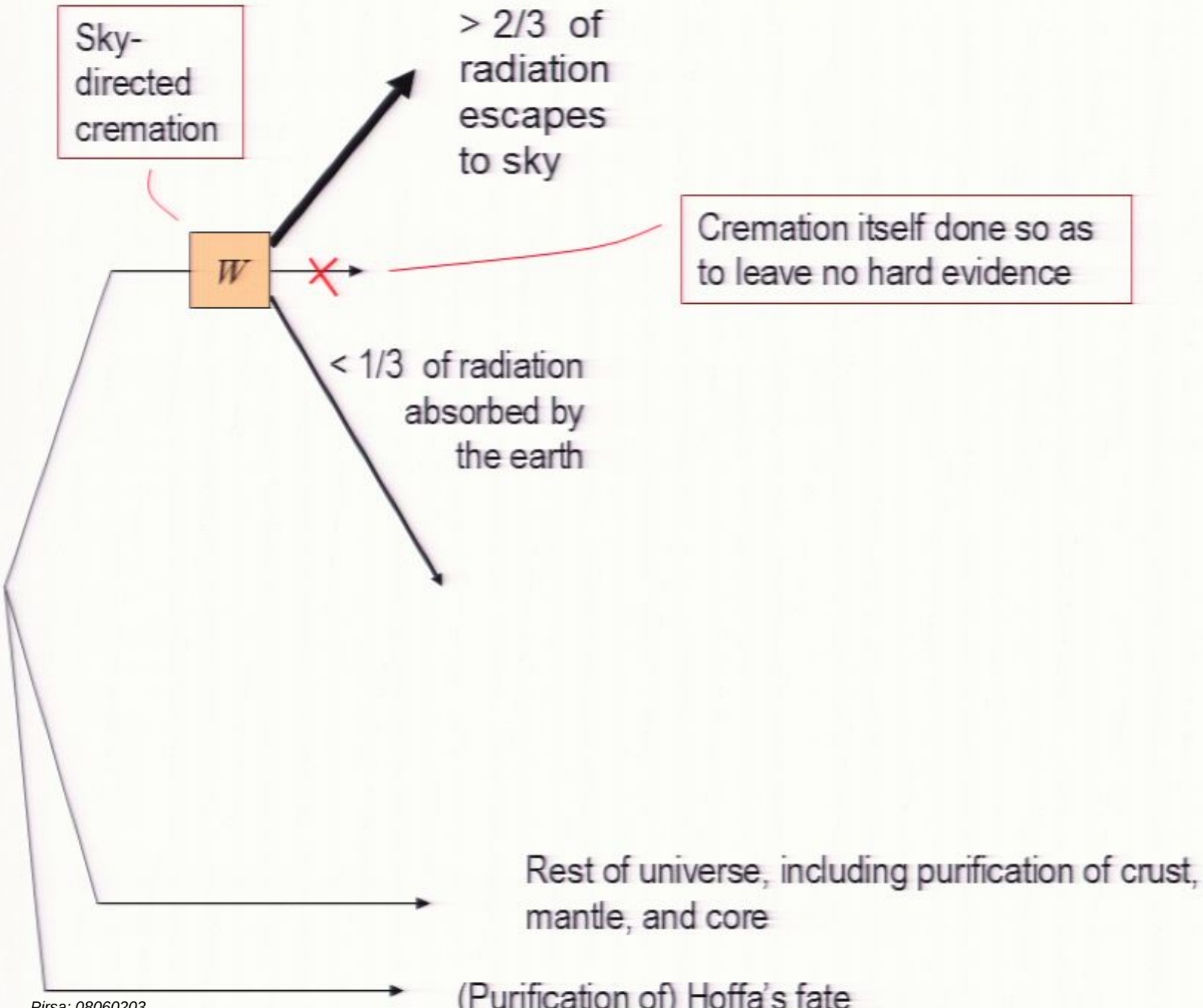
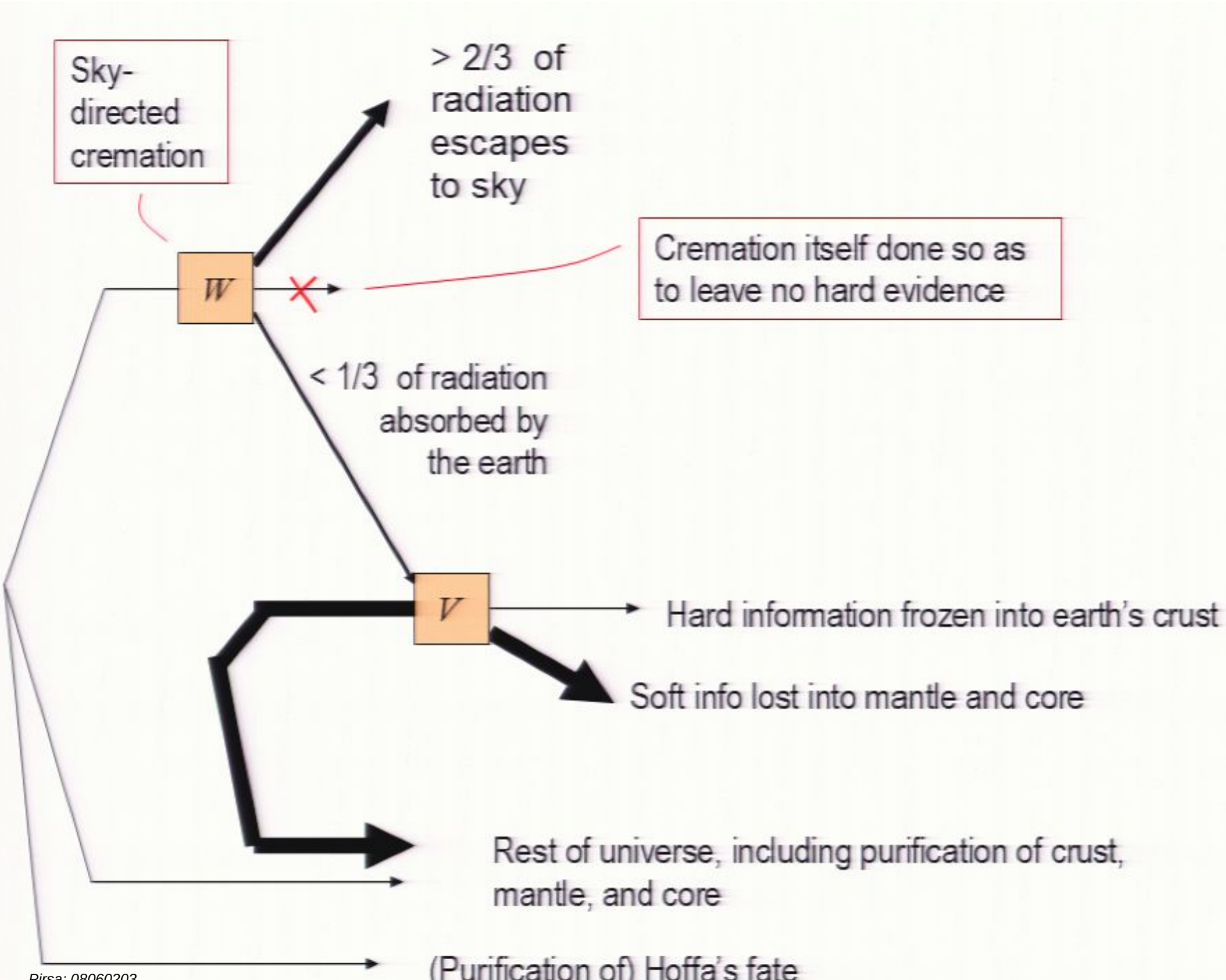

Escaping Radiation
Cremation
V
Data frozen into earth's crust
No evidence of Hoffa's fate
Subterranean phonon bath
Soft evidence remains, for half a million years?
(Purification of) Hoffa's fate
Rest of universe

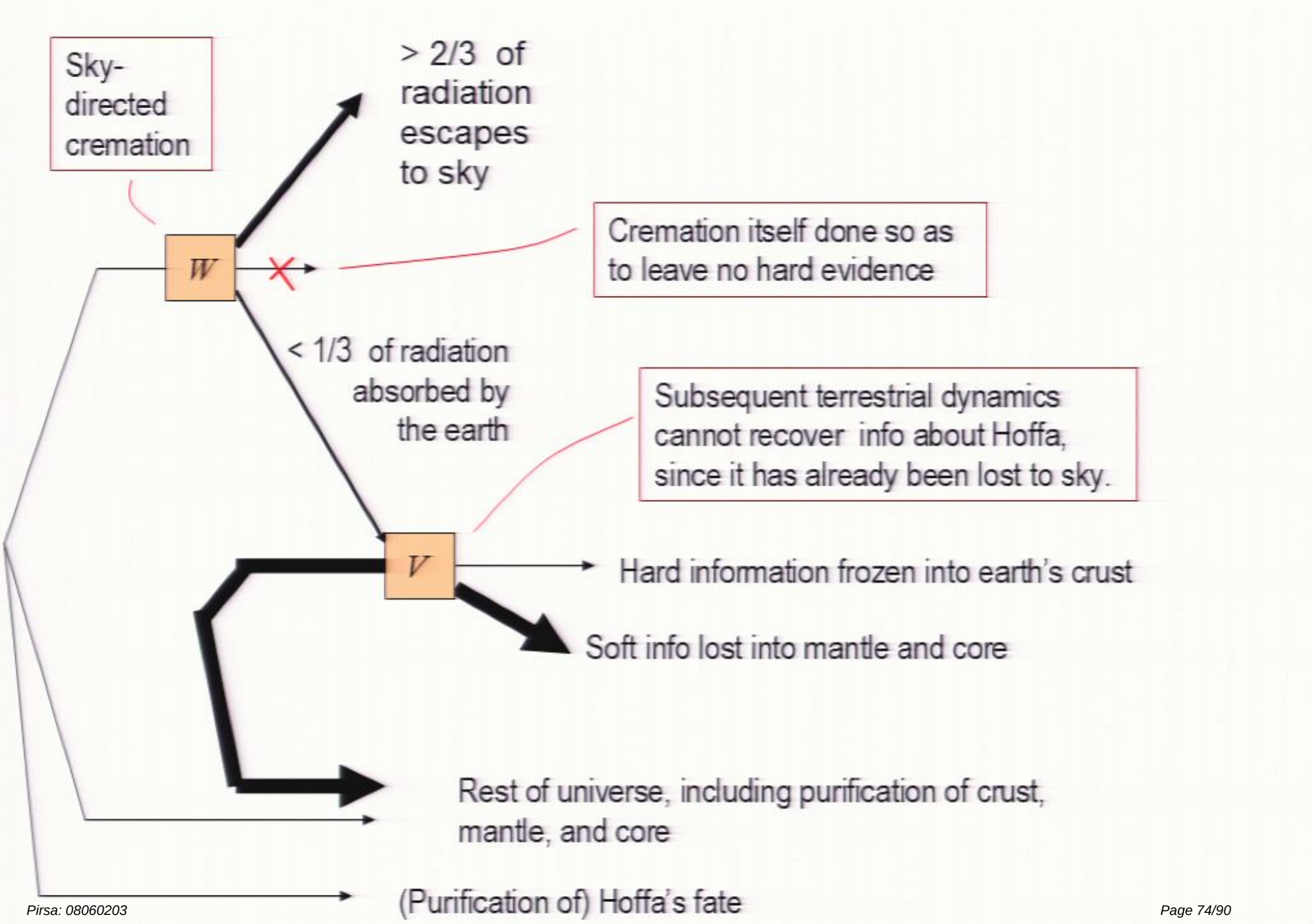


To keep the earth from storing soft evidence of Hoffa's death, cremate him outdoors in an insulated reflective pan that directs most of the radiation skyward and otherwise randomizes his state. Avoid doing it on a cloudy day.

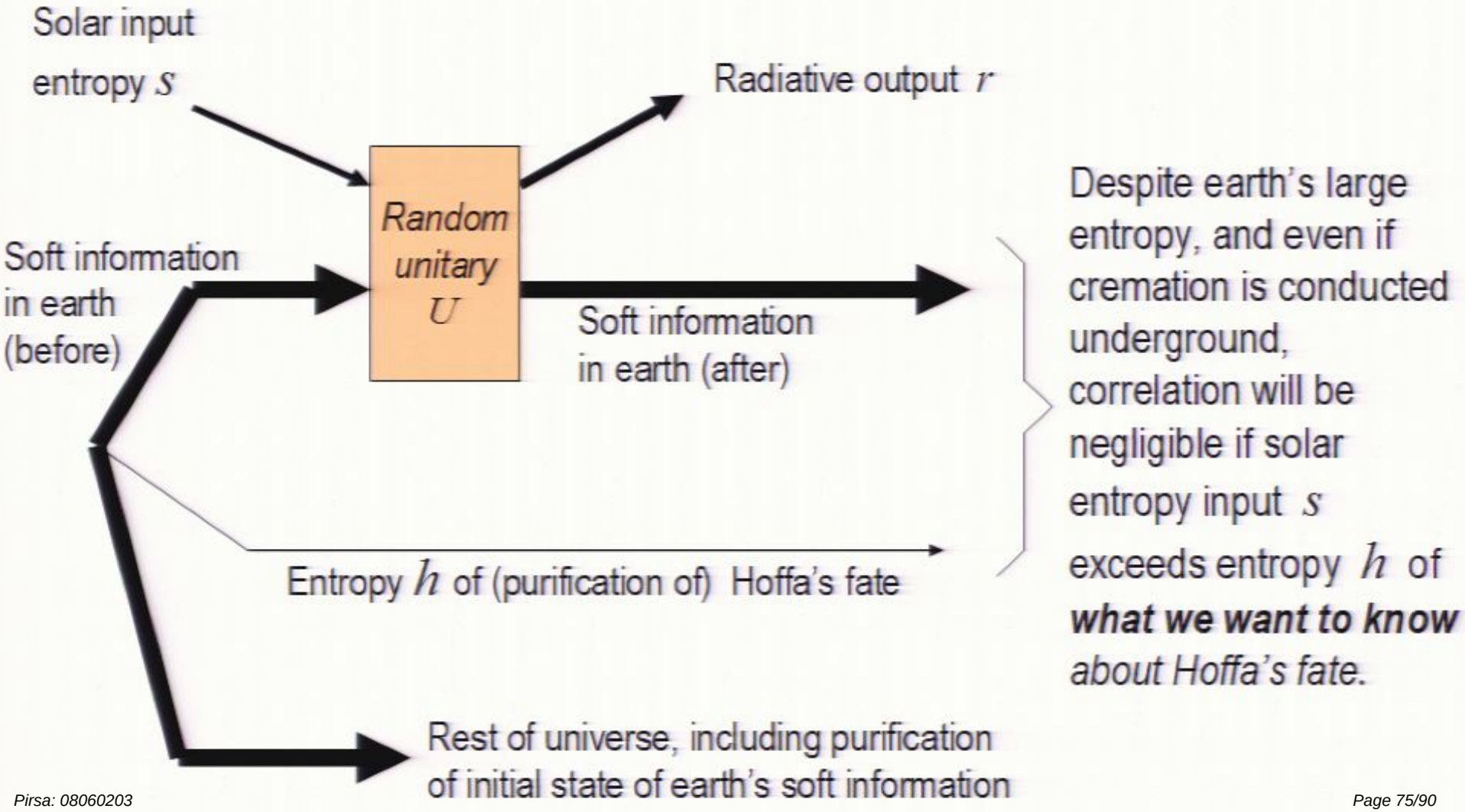

Sky-directed cremation
> 2/3 of radiation escapes to sky
W
Rest of universe, including purification of crust, mantle, and core
(Purification of) Hoffa's fate

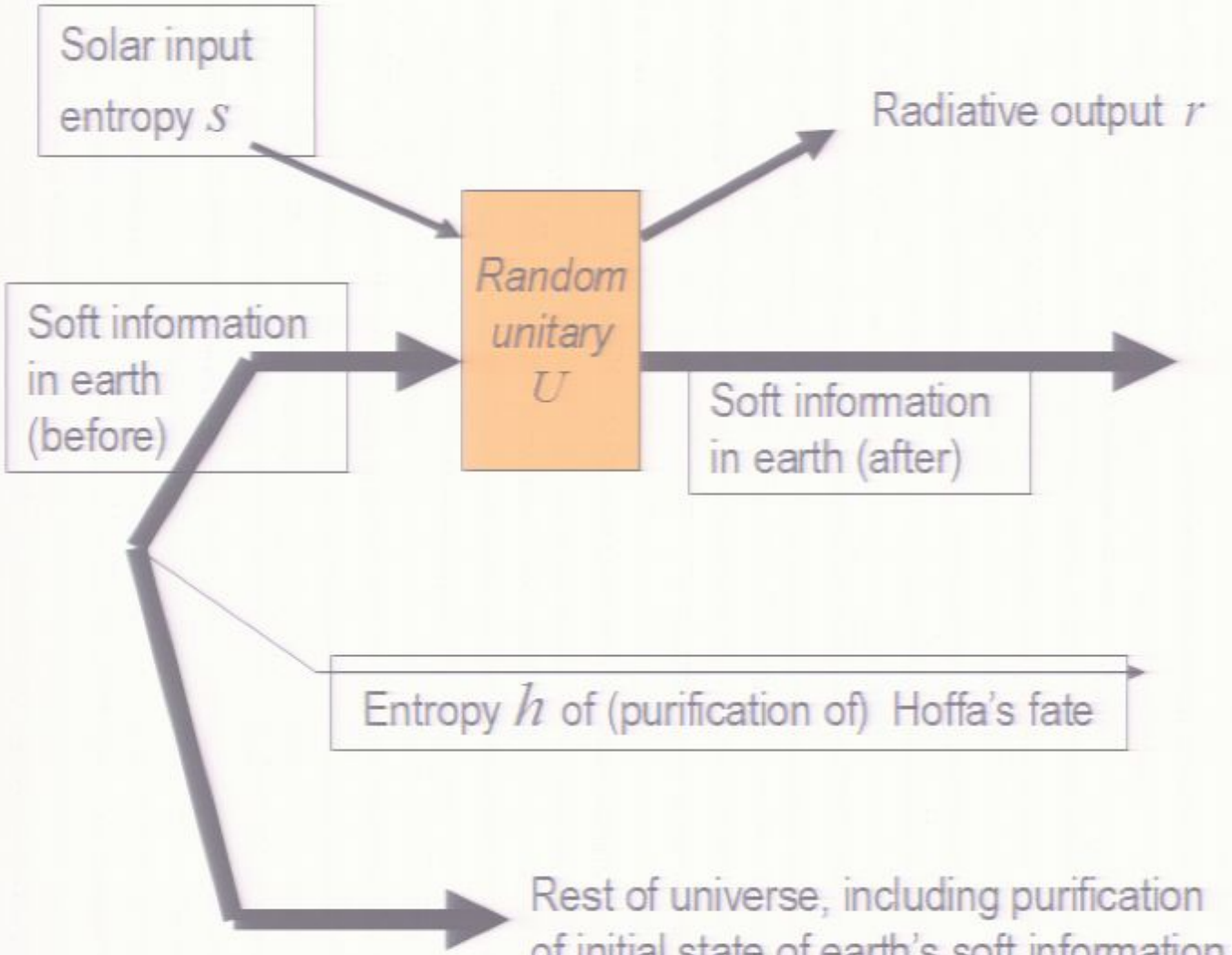

Sky-directed cremation
> 2/3 of radiation escapes to sky
Cremation itself done so as to leave no hard evidence
W
< 1/3 of radiation absorbed by the earth
Rest of universe, including purification of crust, mantle, and core
(Purification of) Hoffa's fate


Sky-directed cremation
> 2/3 of radiation escapes to sky
Cremation itself done so as to leave no hard evidence
W
< 1/3 of radiation absorbed by the earth
V
Hard information frozen into earth's crust
Soft info lost into mantle and core
Rest of universe, including purification of crust, mantle, and core
(Purification of) Hoffa's fate


Sky-directed cremation
> 2/3 of radiation escapes to sky
W
Cremation itself done so as to leave no hard evidence
< 1/3 of radiation absorbed by the earth
Subsequent terrestrial dynamics cannot recover info about Hoffa, since it has already been lost to sky.
V
Hard information frozen into earth's crust
Soft info lost into mantle and core
Rest of universe, including purification of crust, mantle, and core
(Purification of) Hoffa's fate

But such elaborate precautions are probably unnecessary, because of additional randomization from solar input radiation (the sun is not a laser).





An example of information locking.

Earth doesn't remember whether Hoffa was killed in New York or New Jersey, but does remember a useless and complicated function of that, Sappho's poems, last winter's snowfall, yesterday's cappuccino, etc.

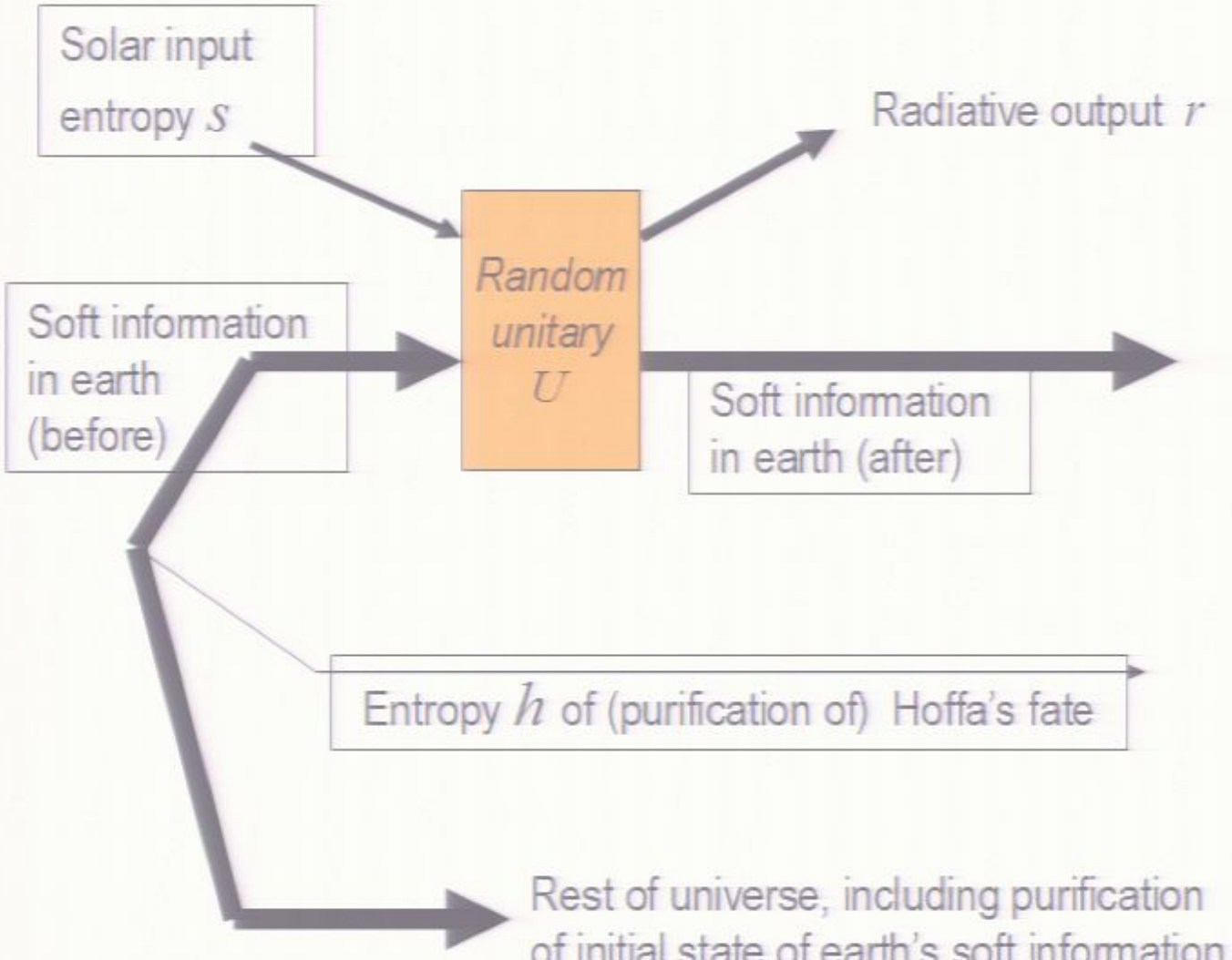
Enough about information & remembering and forgetting.

Can we find a non-anthropocentric definition of what kind of information is *worth* remembering?

How should *complexity* be defined?

How does it originate?

Why is the universe complex?



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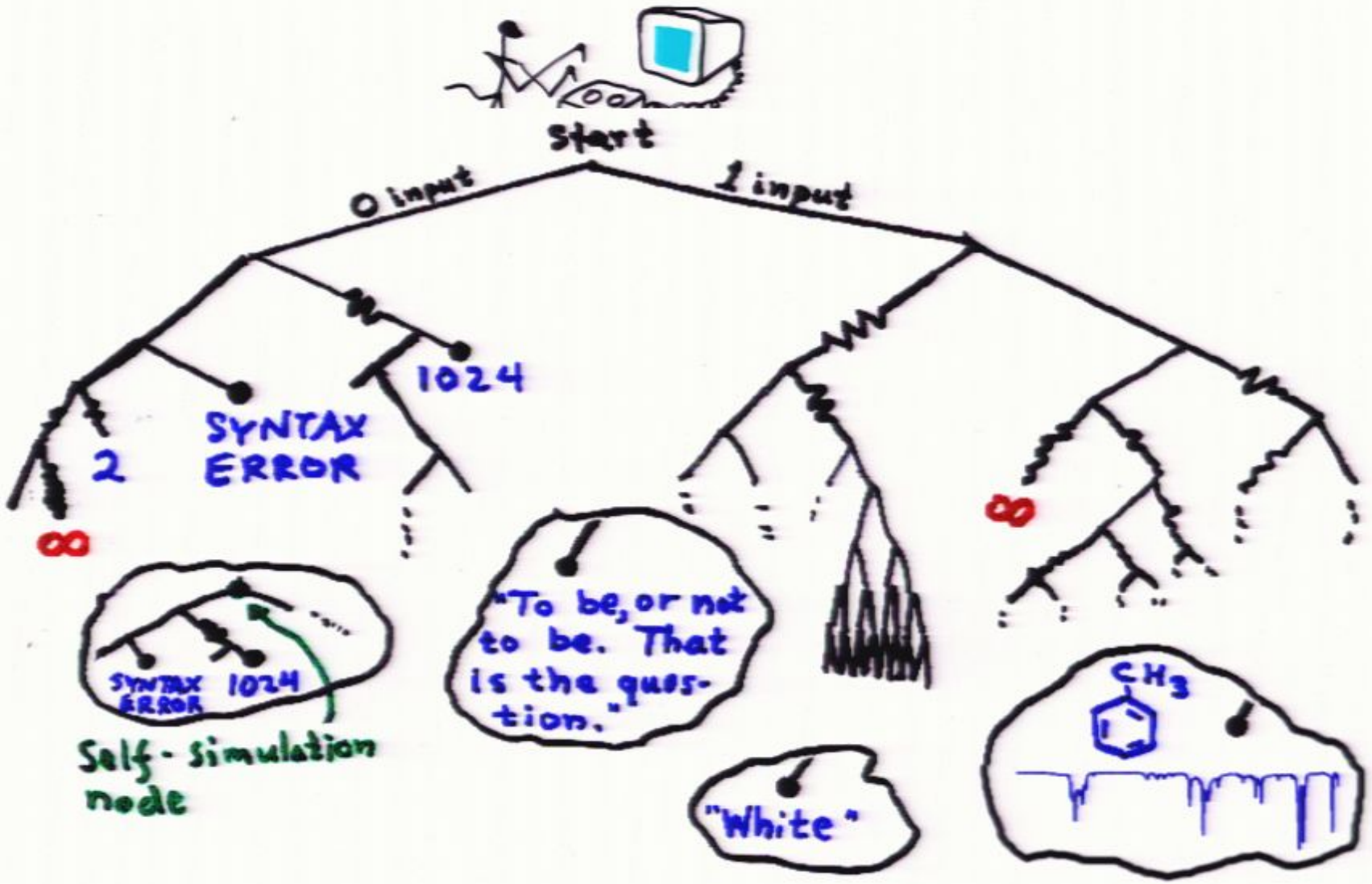
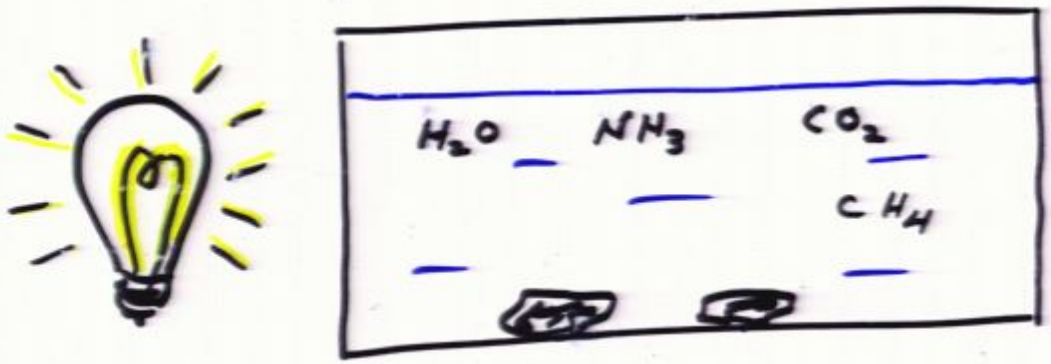
Defining complexity: use a computerized version of the old idea of a monkey at a typewriter eventually typing the works of Shakespeare. Of course a modern monkey uses a computer instead of a typewriter.

A monkey randomly typing 0s and 1s into a universal binary computer has some chance of getting it to do any computation, produce any output (Chaitin 1975)

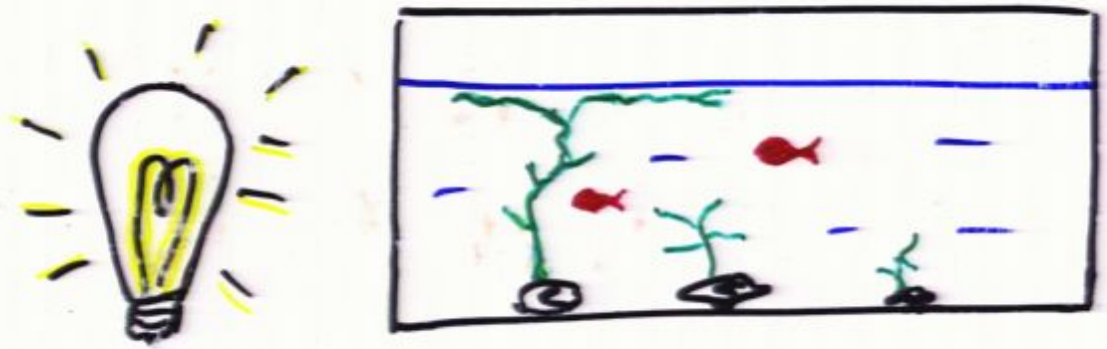


The input/output graph of this or any other universal computer is a microcosm of all cause/effect relations that can be demonstrated by deductive reasoning or numerical simulation.

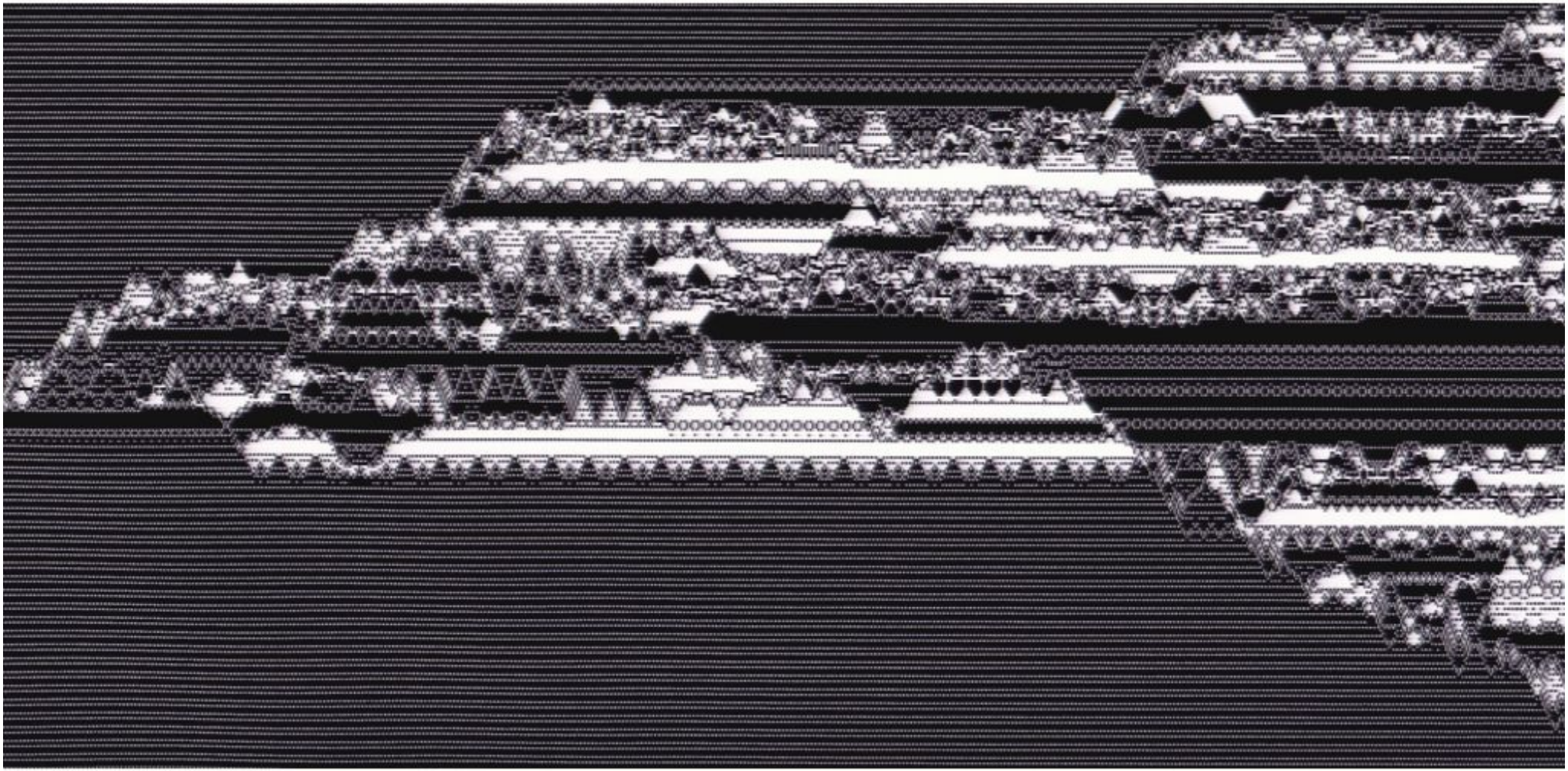
A simple cause can have a complicated effect, but not right away.



Much later

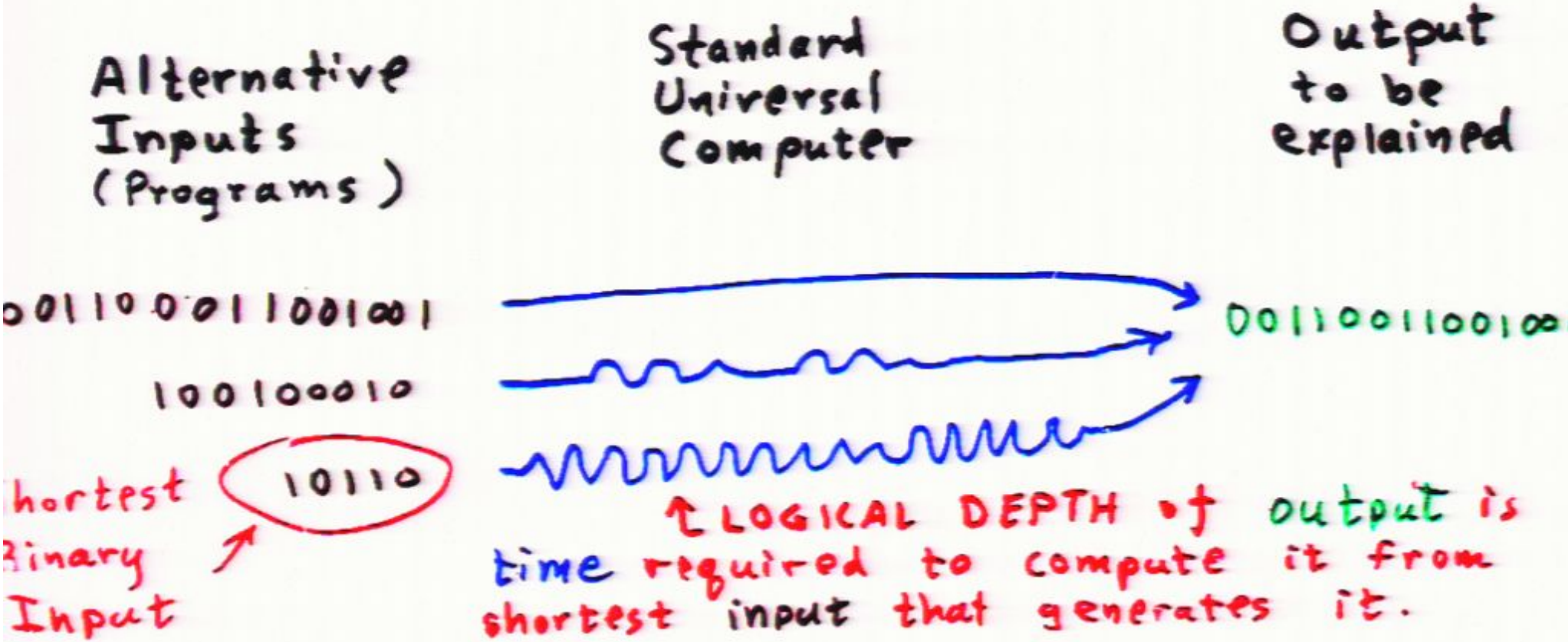


elf-organization, the spontaneous increase of complexity.
simple dynamics (the same 1 dimensional reversible cellular
utomaton) can produce a complicated effect from a simple cause.



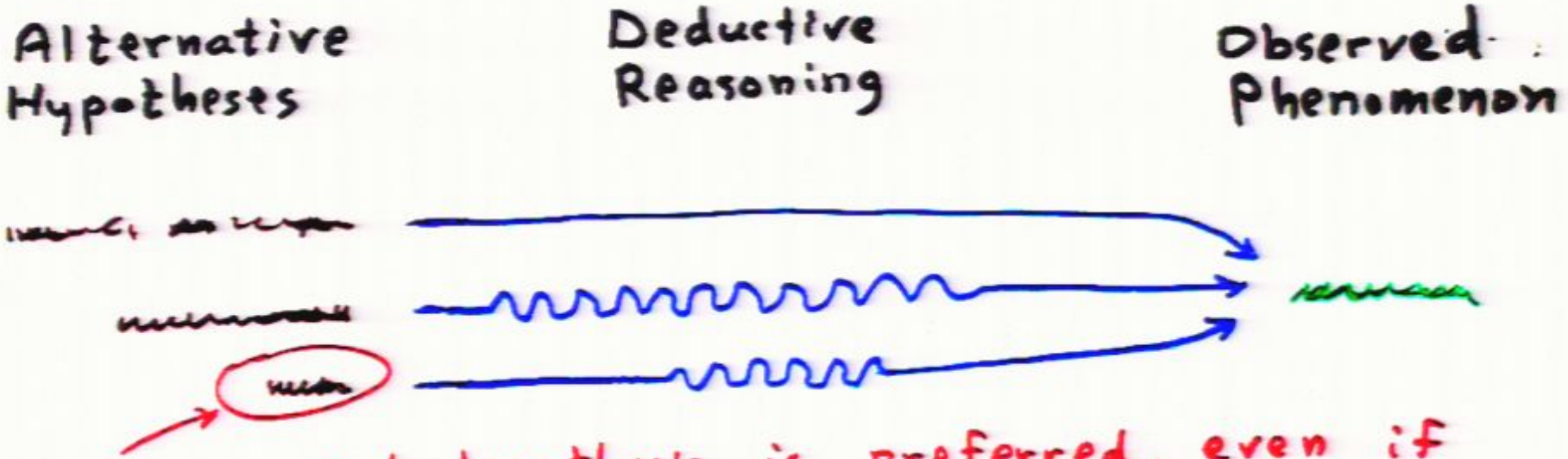
Small irregularity (green) in initial pattern produces a complex deterministic "wake" spreading out behind it.

This idea is formalized using a universal computer (a device versatile enough in principle to follow any deductive path, or derive the consequences of any physical laws):



Logically deep objects contain internal evidence of having undergone a long and complicated evolution

In the philosophy of science, the principle of Occam's Razor directs us to choose the most economical hypothesis able to explain a given body of observed phenomena.



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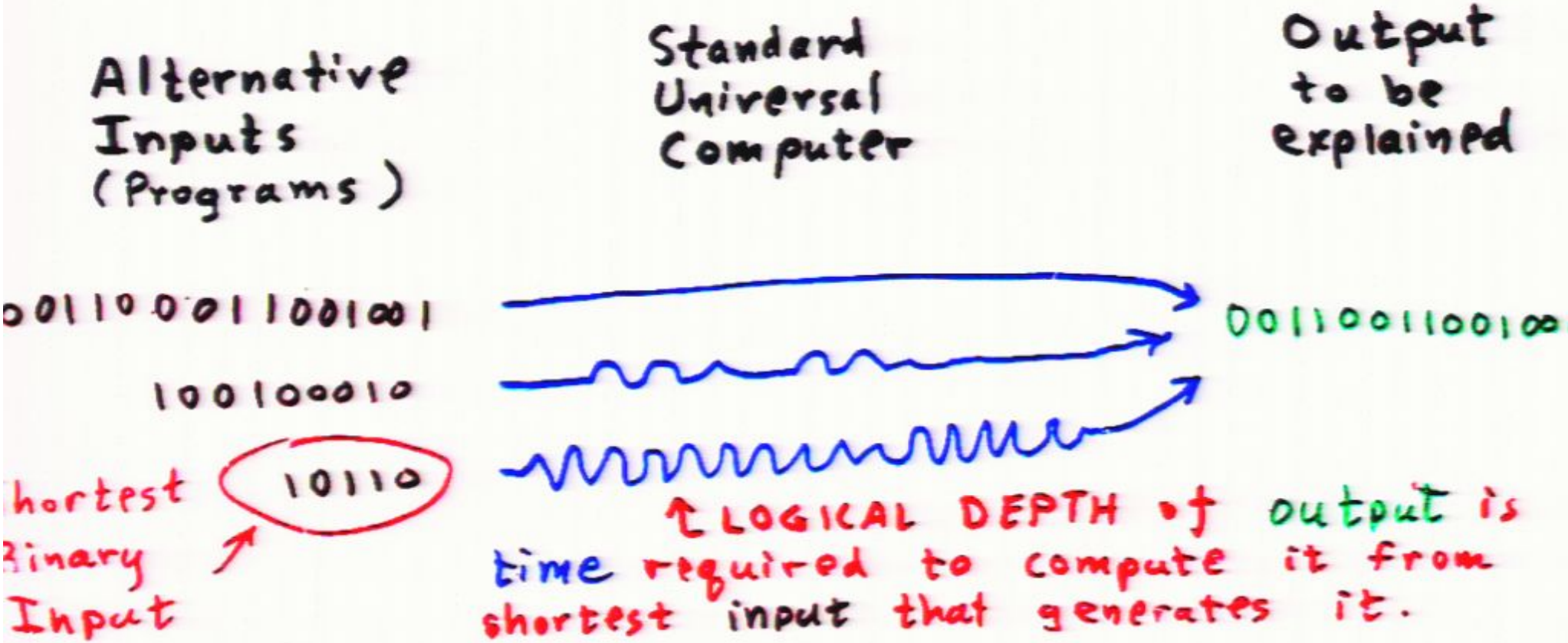


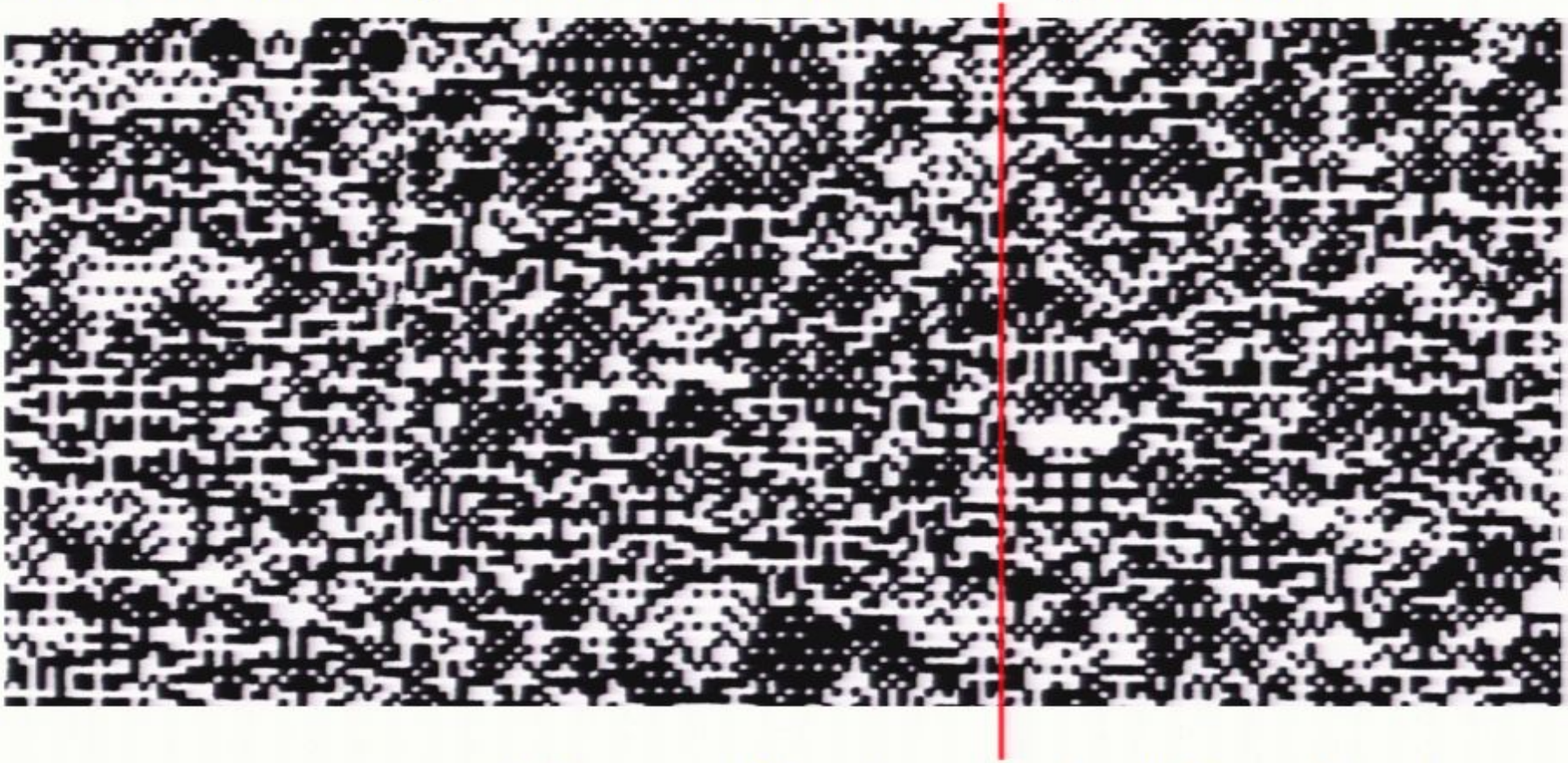
Logically deep objects contain internal evidence of having undergone a long and complicated evolution

A trivially orderly sequence like 111111… is logically shallow because it can be computed rapidly from a short description.

A typical random sequence, produced by coin tossing, is also logically shallow, because it essentially its own shortest description, and is rapidly computable from that.
Depth thus differs from Kolmogorov complexity or algorithmic information, defined as the length of the shortest description, which is high for random sequences.

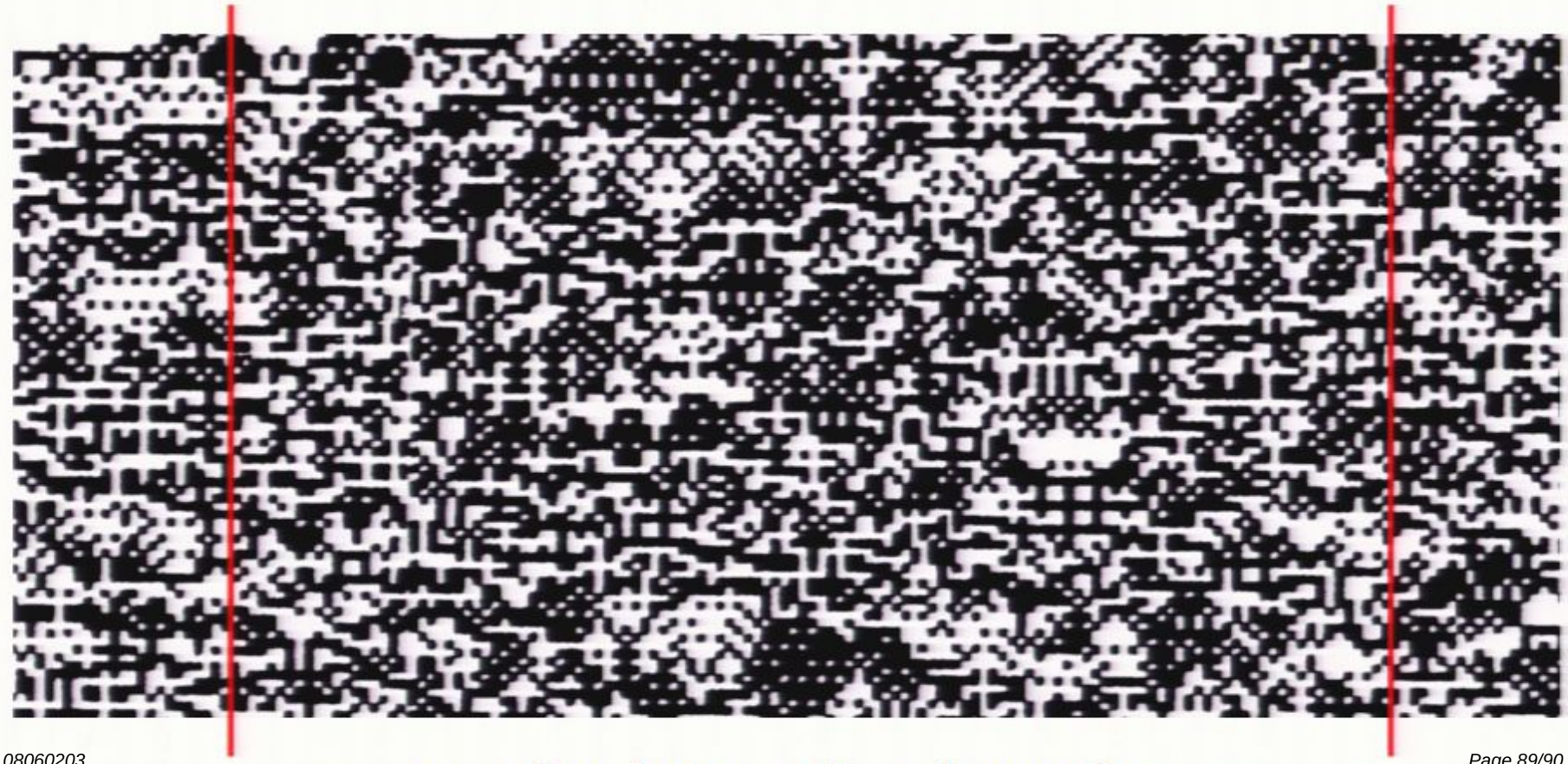
If a reversible local dynamics (e.g. the 1d system considered earlier) is allowed to run long enough in a closed system, comparable to the Poincaré recurrence time, the state becomes trivial and random.

Our world is complex because it is out of equilibrium.

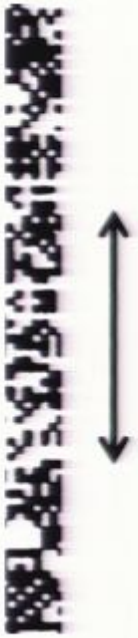


After equilibration, typical time slice is shallow, with only local correlations.

At equilibrium, complexity still persists in 2-time correlations. Two time slices of the equilibrated system contain internal evidence of the intervening dynamics, even though each slice itself is shallow. The inhabitants of this world, being confined to one time slice, can't see this complexity. (Also they'd be dead.)



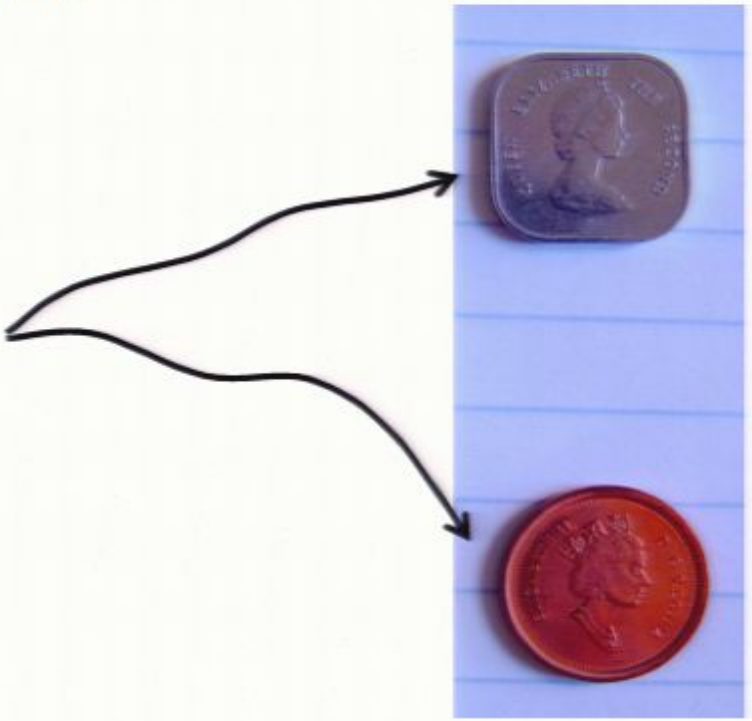
In an equilibrium world with local interactions (e.g. a thermal ensemble under a local Hamiltonian) correlations are generically local, mediated through the present.



equilibrium correlations mediated through present only

By contrast, in a non-equilibrium world, local dynamics can generically give rise to long range correlations, mediated not through the present but through a V-shaped path in space-time representing a common history.

time ⟶



Grenada 1999

Canada 2002