Augmenting Reality

Axions, Anyons, Time Crystals …

Axions

Few aspects of experience are as striking as the asymmetry between past and future.

If you run a movie of everyday life backwards, it does not look like everyday life.


STOP
ODISSA

Yet time-reversal symmetry (T) was a notable property of the fundamental laws of physics for several centuries, starting with Newtonian mechanics, and continuing through general relativity and quantum electrodynamics.

Why?

As long as T symmetry appeared to be an exact, fundamental feature of physical law, it was unclear that asking “Why?” would be fruitful.

T symmetry might be rock bottom.

In 1964, James Cronin and Val Fitch discovered a subtle effect in K meson decays that slightly violates T symmetry.

⇒ T symmetry is **not** rock bottom.

It’s not even quite true - just very nearly so.

Why?

We've *almost* nailed it.

The basic, sacred* principles of modern physics - relativity + quantum mechanics + local symmetry - are very powerful.

There are exactly two possible sources of T symmetry violation, that are consistent with those principles.

One of them beautifully explains what Cronin and Fitch observed, and a lot more.

The other doesn’t happen.

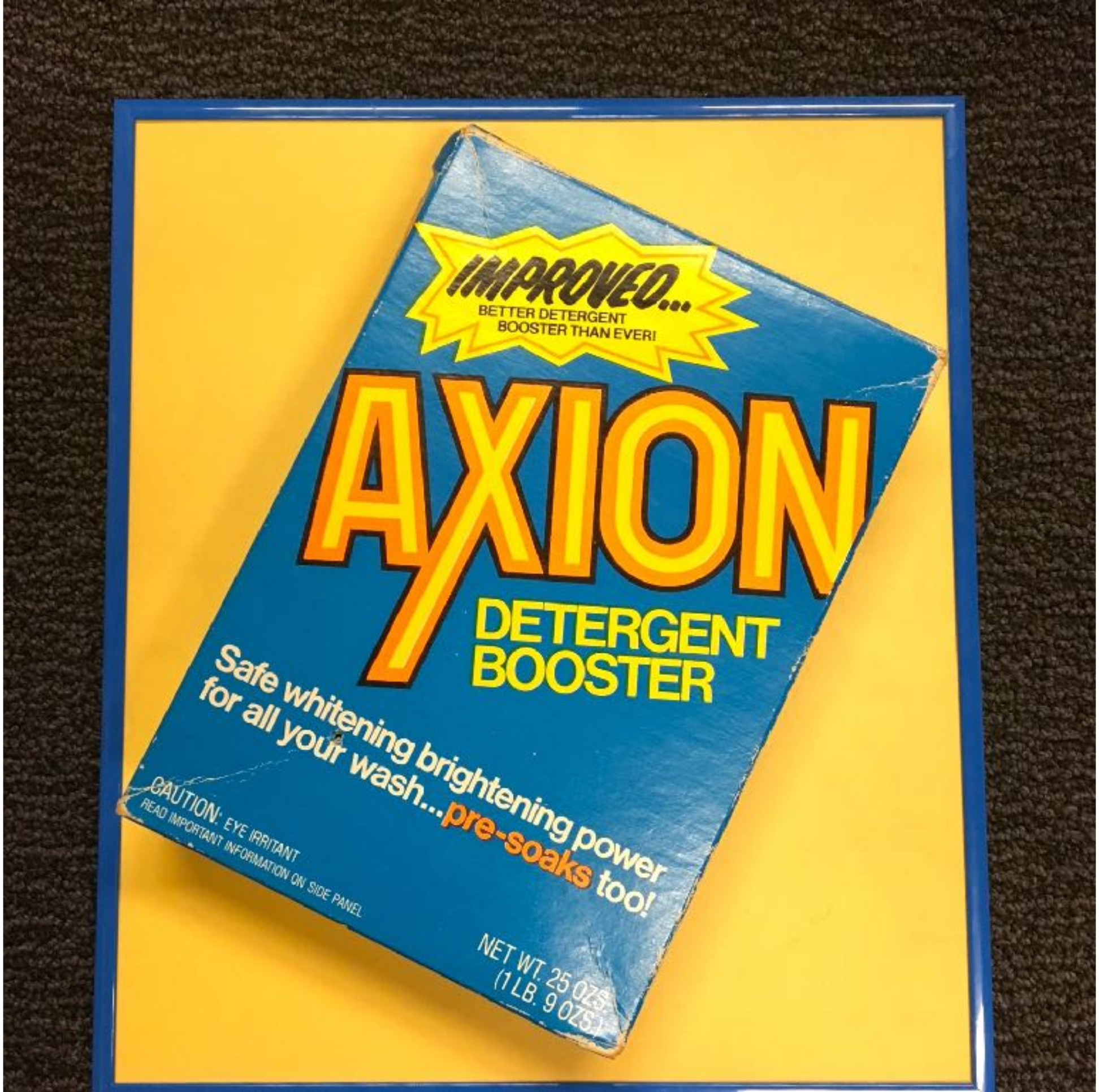
Why?

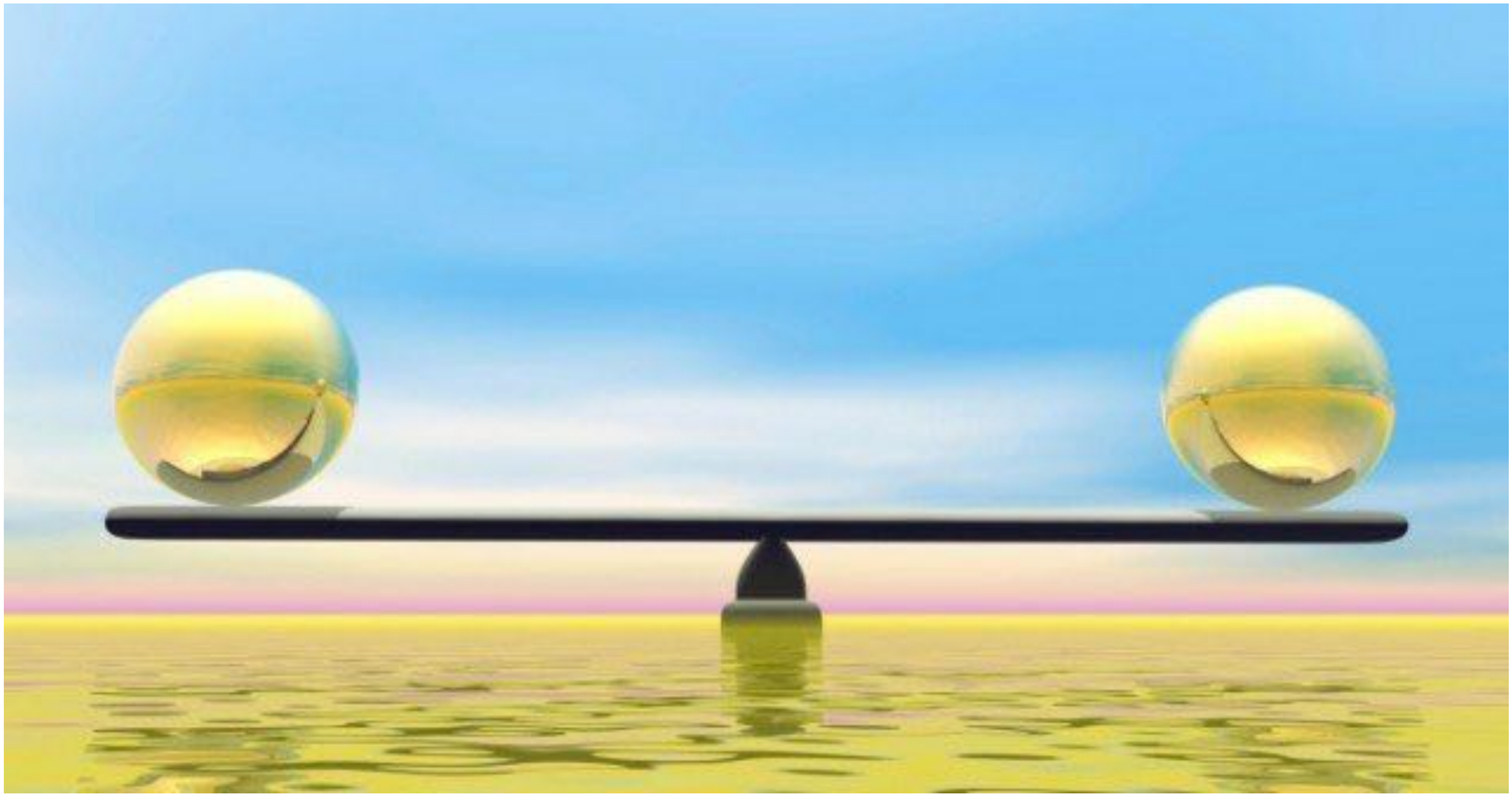
Over the past 40+ years, there have been several attempts to explain it, but only one has stood the test of time.

We promote the unwanted term to a *dynamical* entity - a “field”, which *evolves* to zero.

The new field is made of a new kind of particle.

I named it the *axion*, in homage to a laundry detergent:


IMPROVED...
BETTER DETERGENT
BOOSTER THAN EVER!
AXION
DETERGENT
BOOSTER
Safe whitening brightening power
for all your wash...pre-soaks too!
CAUTION: EYE IRRITANT
READ IMPORTANT INFORMATION ON SIDE PANEL
NET WT. 25 OZS.
(1 LB. 9 OZS.)



keeping the past and the future in balance

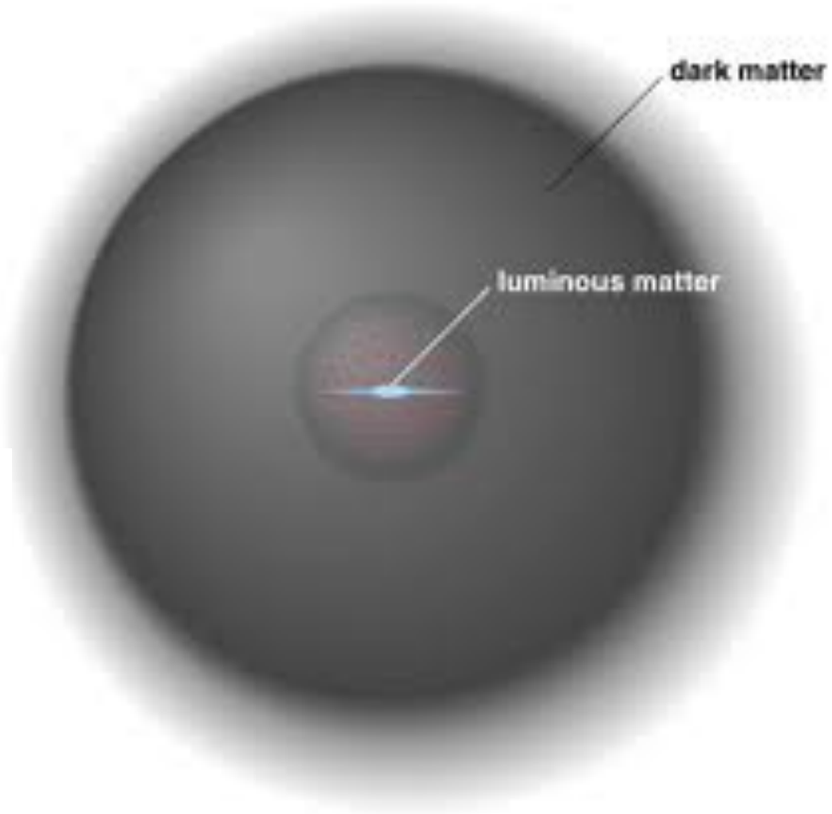
Do axions exist?

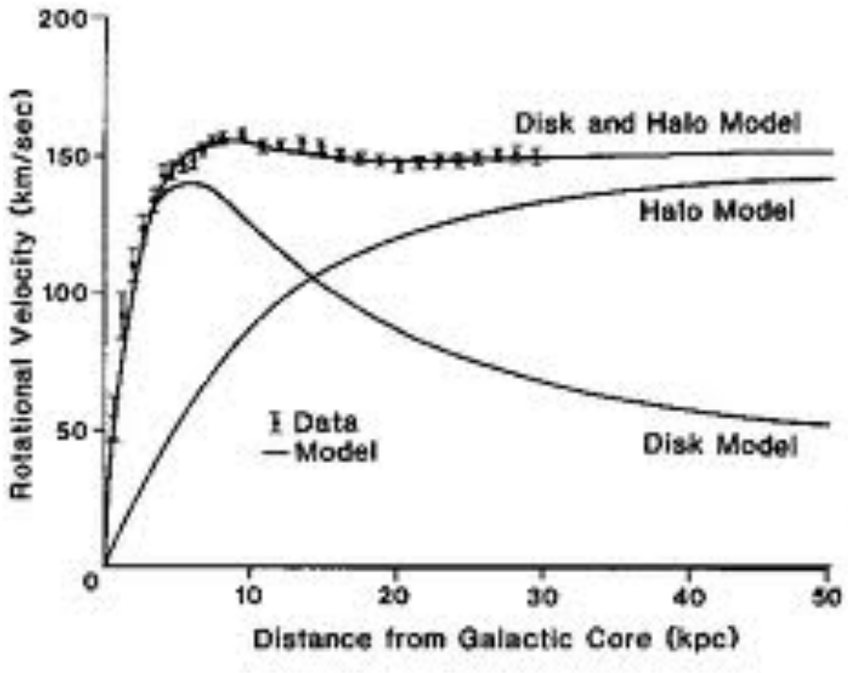
We still don’t know for sure - but in recent years the stakes have risen dramatically.

We can calculate that axions get produced in the big bang, and survive to this day.

The relic axion gas has properties consistent with the observed properties of the astronomers' "dark matter".

Dark matter halo





Dark Matter smoking gun

- Two galaxies colliding
- The regular matter (red) interacts, i.e., collides (friction) with each other
- The dark matter (blue) moves unaffected…



Bottom line:

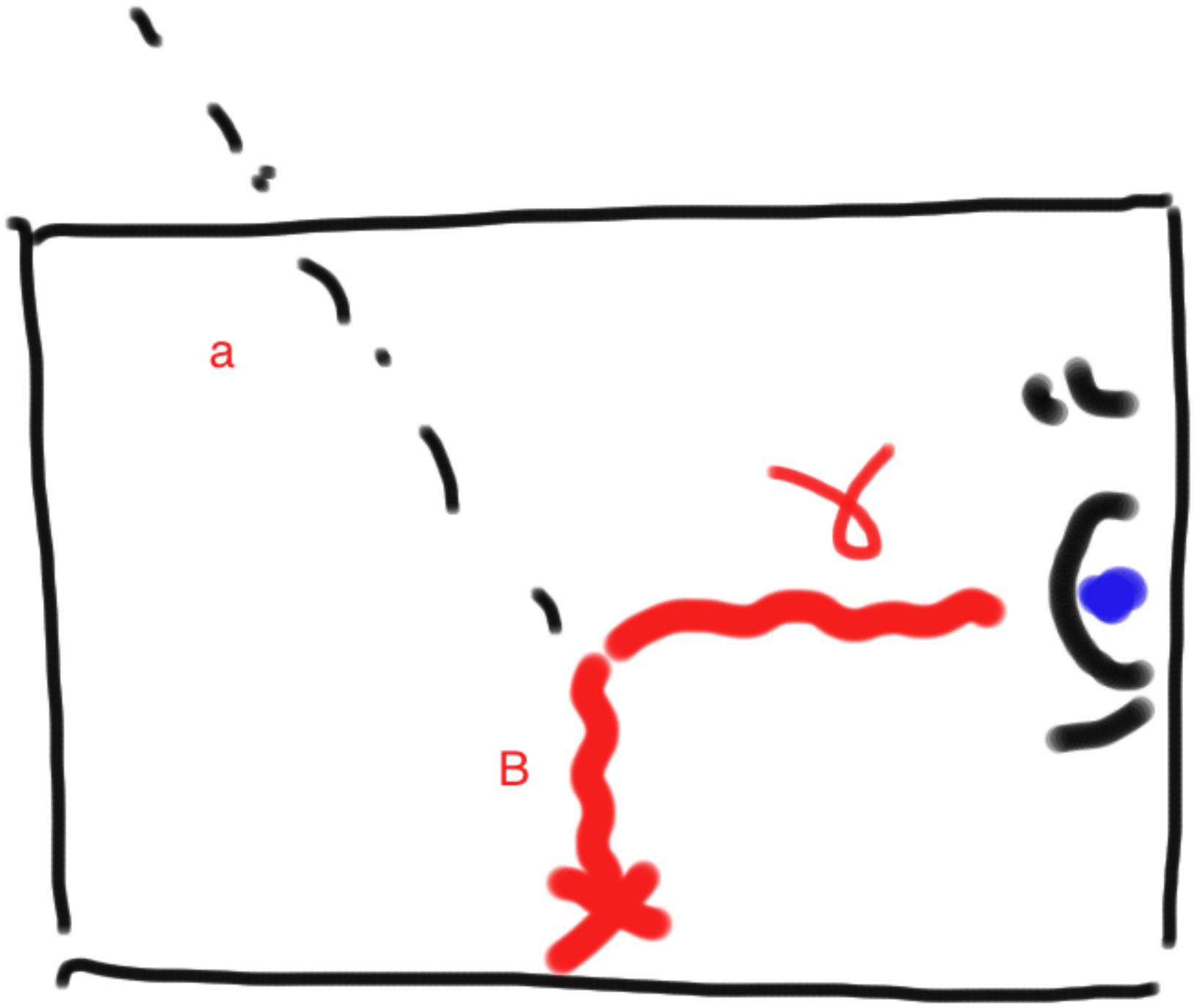
If axions exist at all, they must contribute significantly to the dark matter. Plausibly, they dominate it.


9:36 AM
70%
CP765
Axion
HP 60 / 60
Ghost / Poison
Type
0.07 kg
XS
Weight
1.42 m
Height
45849
STARDUST
23
GASTLY CANDY
POWER UP
2500
2
EVOLVE

Several clever strategies for axion detection have emerged.

It’s won’t be easy, but many determined people are at work …


KUSP
KOREA
SCIENCE PROGRAM
Center for Axion
&
Precision Physics


a
B

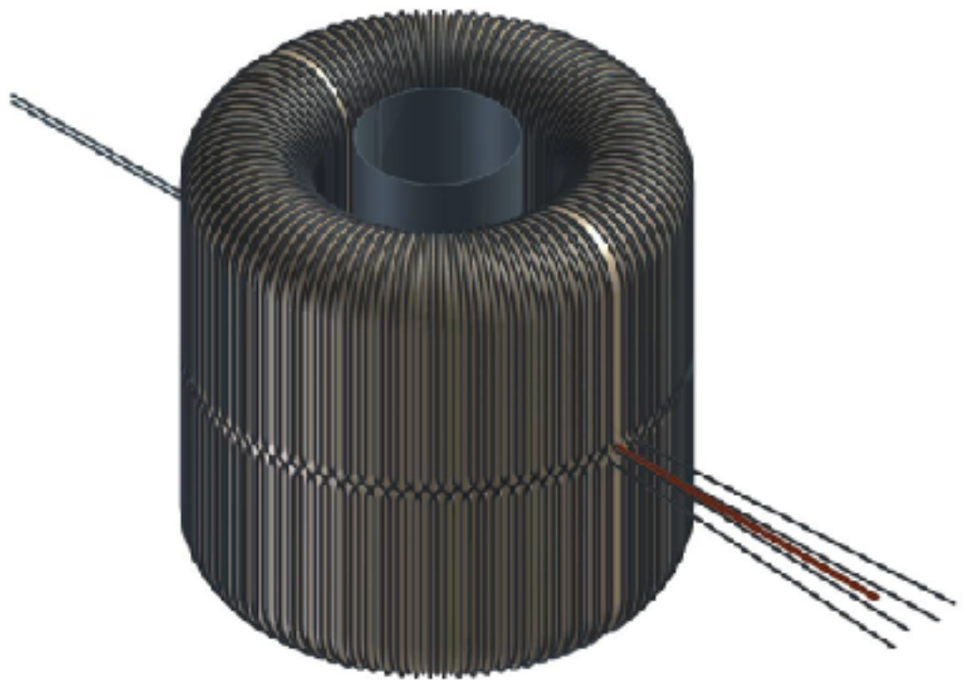
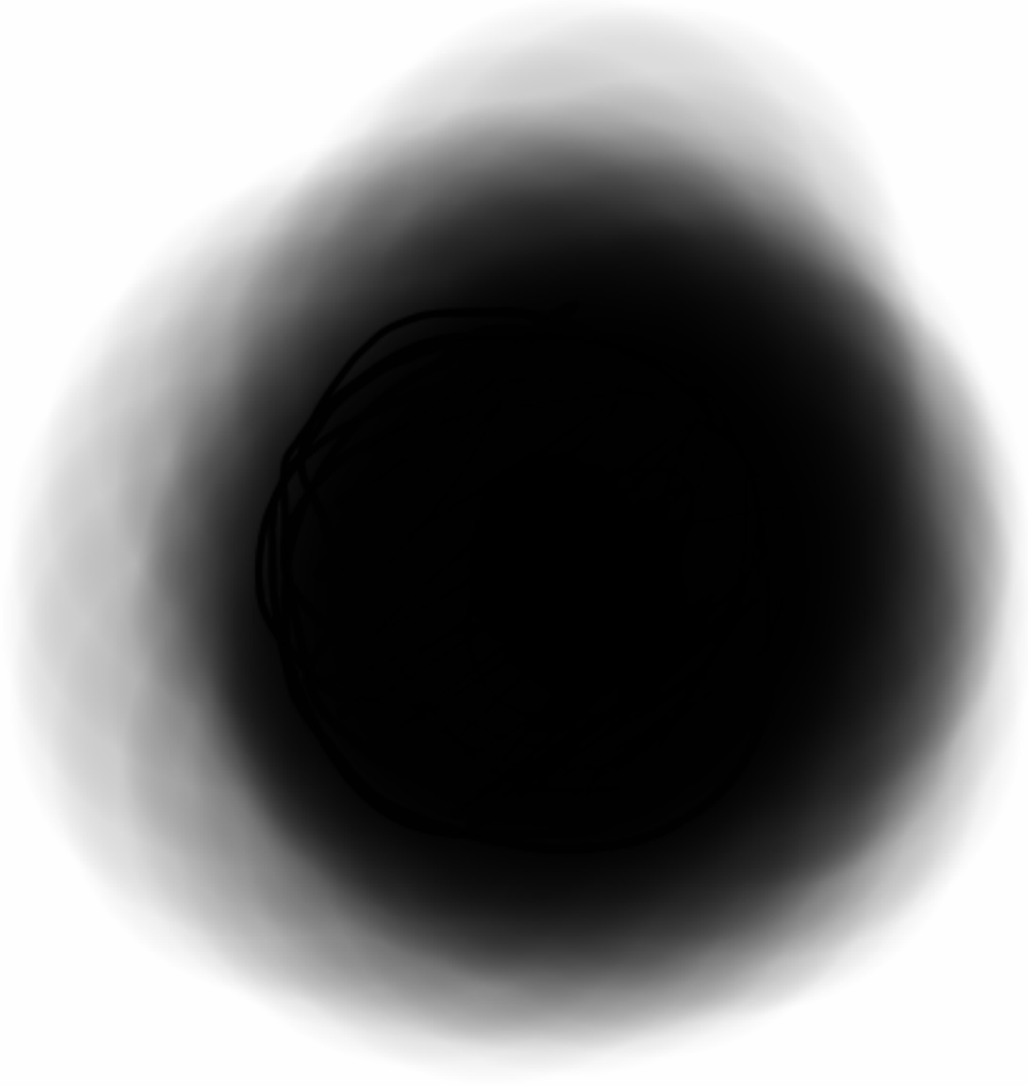


FIG. 1: A schematic of the ABRACADABRA-10cm toroidal geometry. The superconducting main coil sources a static azimuthal magnetic field. In the presence of axion DM, an effective oscillating current is induced following the magnetic field lines. The oscillating magnetic flux sourced by this effective current is picked up by a superconducting cylinder in the center of the toroid and read out through a SQUID. A test coil will wrap the inside of the torus so that an azimuthal oscillating current may be injected in order to mimic a real signal and calibrate the detector. The entire toroid and SQUID readout will be inside of a superconducting shield (not shown), inside of the dilution refrigerator.

abracadabra white paper



Anyons

Since the discovery of wave-particle duality, and its elaboration in quantum theory, we understand that the basic units of all forms of matter - including light - the same sort of thing: “wavicles”, “laves” …

or, to keep it simple, particles.

But when we consider the behavior not of single particles, but of groups of them, we find that particles divide into two great kingdoms, bosons and fermions.

Bosons are collectivists. They like to do the same thing.

(Technically, they like to occupy the same quantum state.)

Photons are bosons. A laser beam is an excellent example of their boson-ness in action.

Fermions are individualists. They hate to do the same thing.

(They refuse to occupy the same quantum state: Pauli's exclusion principle.)

Electrons are fermions. The "solidity" of matter is an excellent example of their fermion-ness in action.

In a 3-dimensional (or more) world, that's all there is.

In a 2-dimensional world - in Flatland - things get much more interesting, theoretically.

Less is more.

The reason is closely related to the theory of knots.

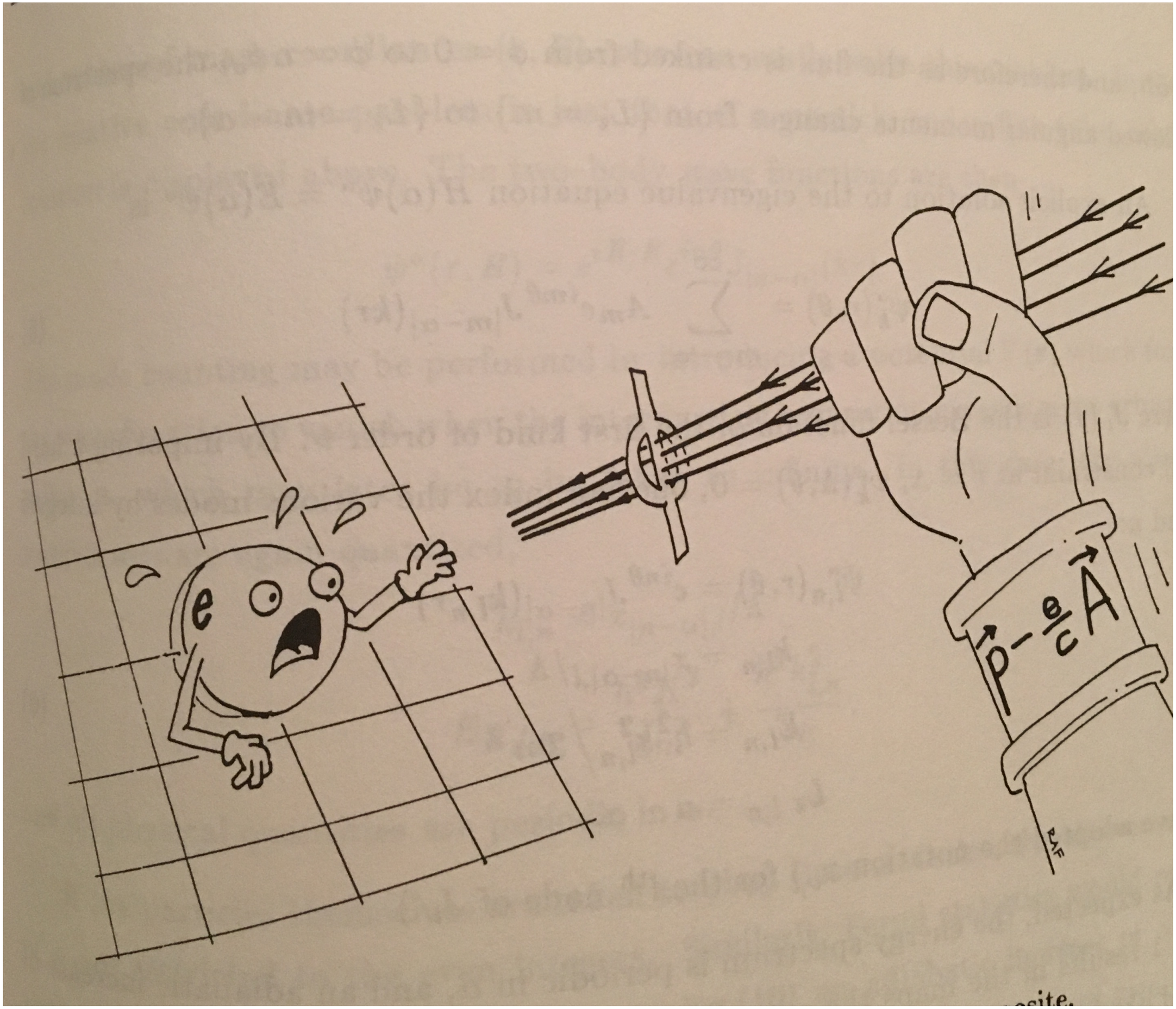
(In 4 dimensions, knots are not knotty.)

I named the new kinds of particles *anyons,* as in “anything goes”.

Experimenters can construct a wide variety of two-dimensional worlds, also known as thin layers of material.

In some of them, electrons fission into anyons.

For the electrons, this can be a shattering experience …


e
$\vec{P} - \frac{e}{c}\vec{A}$

… but their offspring, which are anyons, emerge with brilliant new powers.

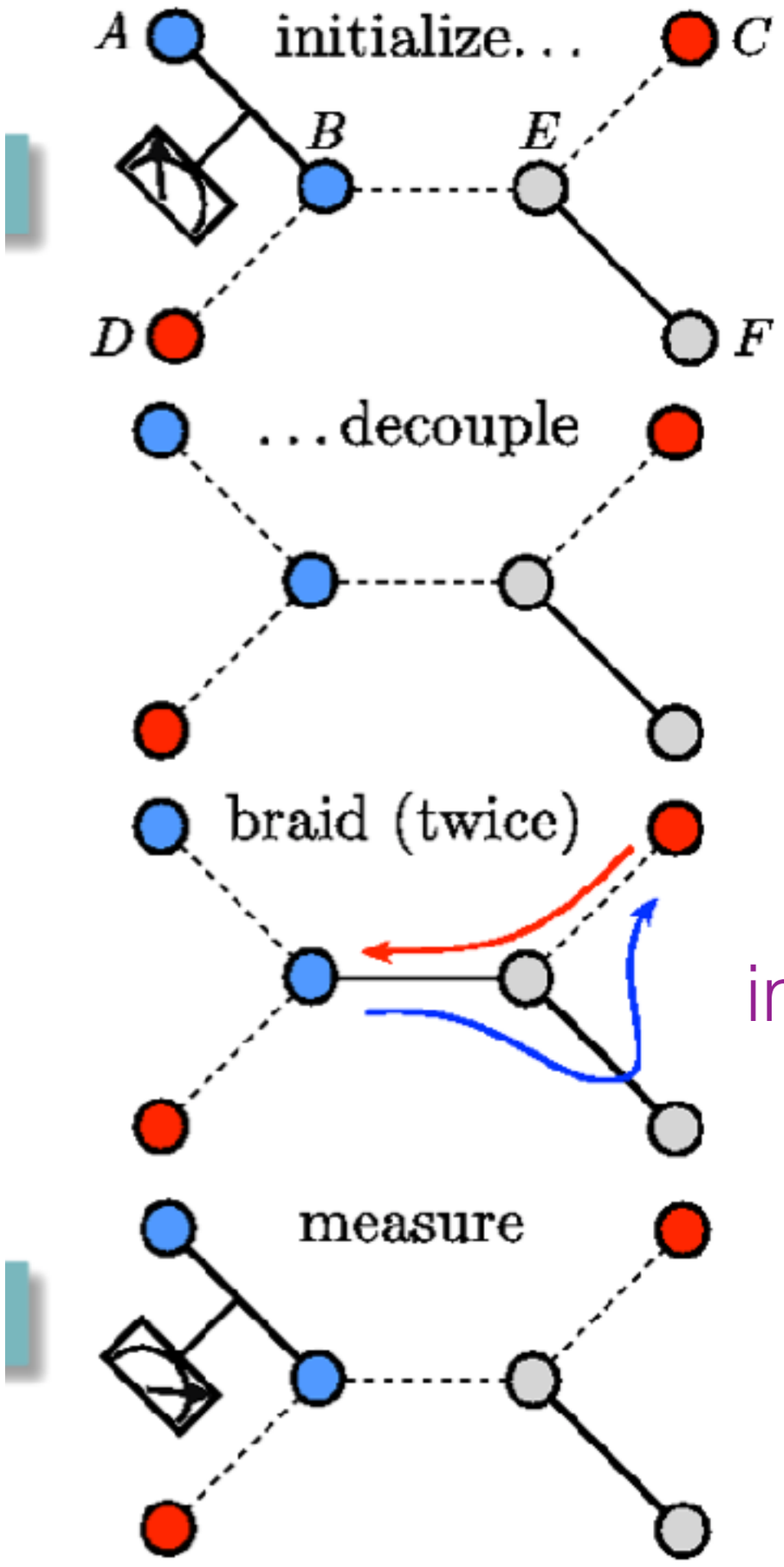
Anyons, unlike bosons or fermions, have memories.


9:35 AM
70%
CP651
Anyon
HP 67 / 67
Electric
Type
XS
43.36 kg
Weight
0.99 m
Height
45849
STARDUST
34
VOLTORB CANDY
POWER UP
1600
2
Spark
Electric
Hyper Beam
120

Some sorts of anyons support a very rich collective memory.

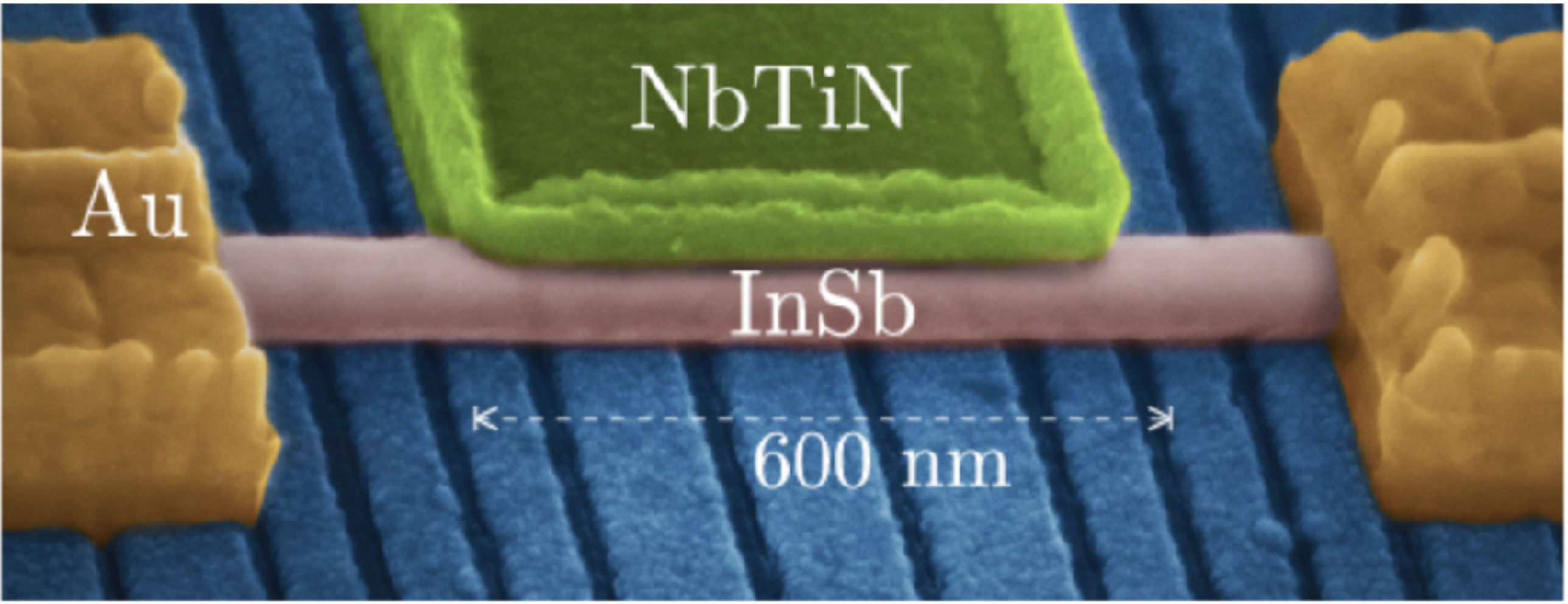
When you wind them around each other, their wave-function changes, making a record of what you've done.

This is the basis for "topological quantum computing", in which Microsoft is investing heavily.

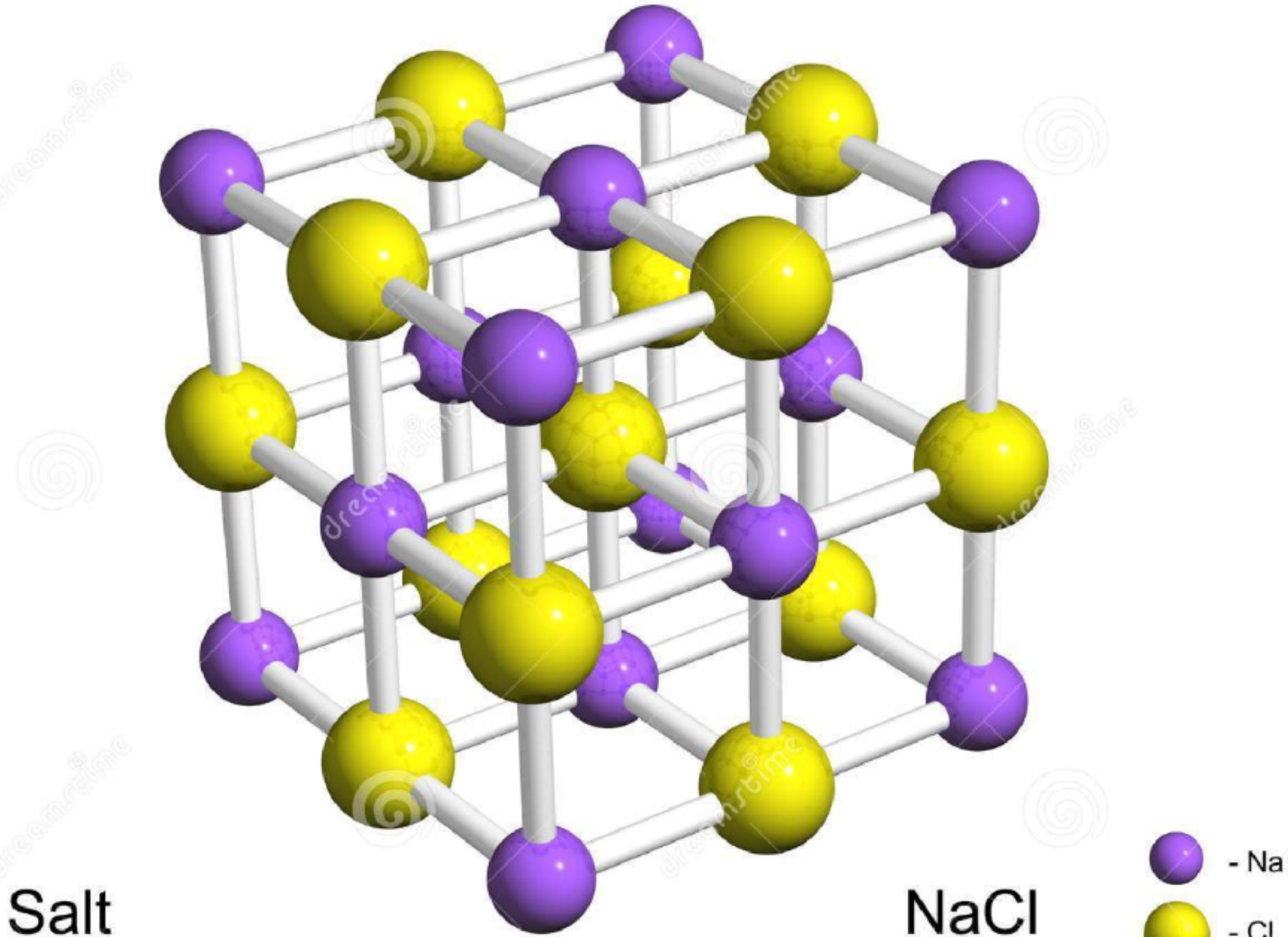


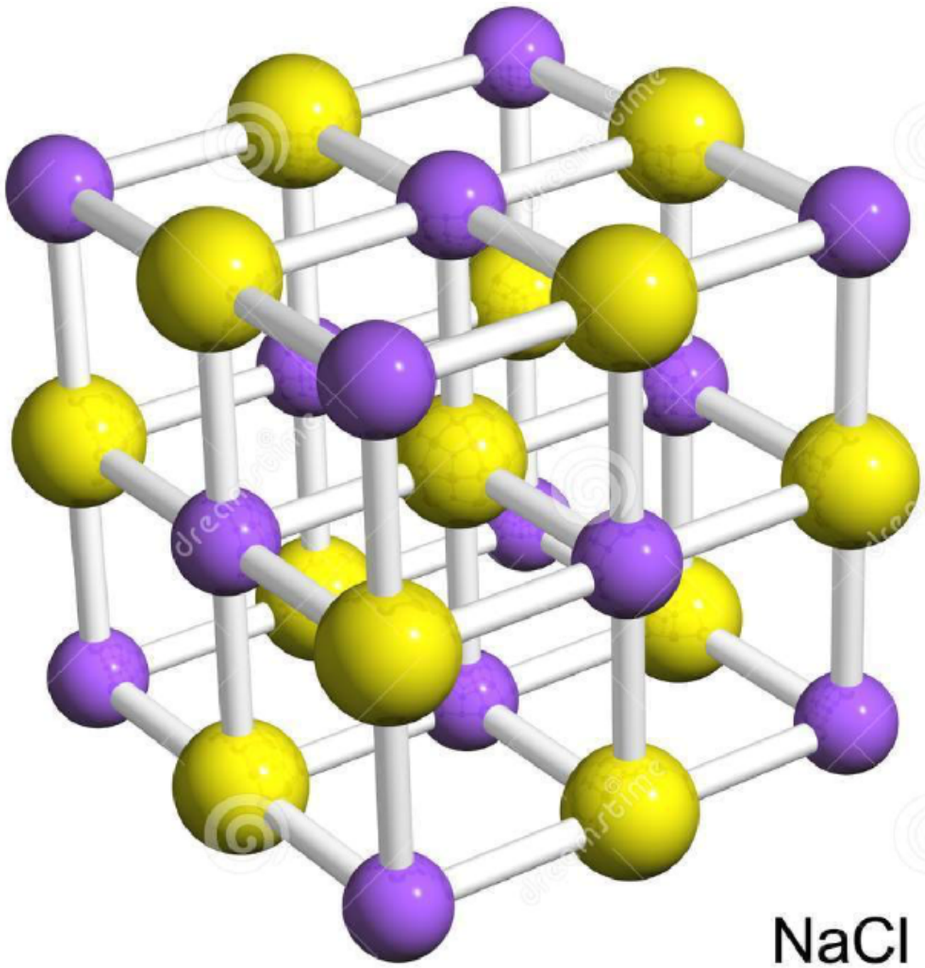
imprinting a memory

reading it out


NbTiN
Au
InSb
600 nm

Time Crystals


Salt
NaCl
- Na
- Cl

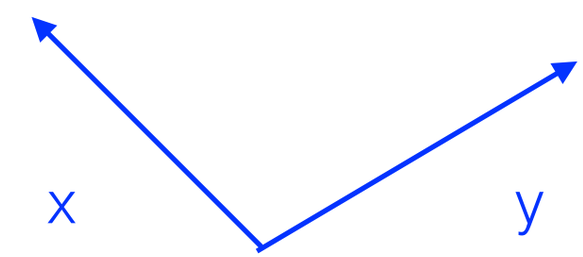


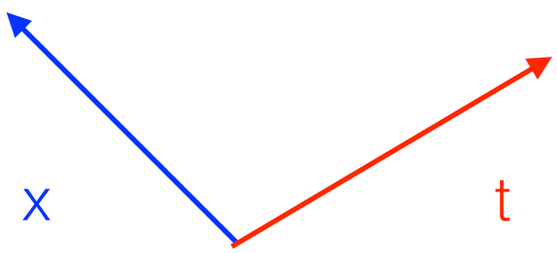
Salt

NaCl

- Na

- Cl





?

A beating heart is a sort of time crystal, but

it is complicated

it is not very precise

it requires constant feeding and maintenance

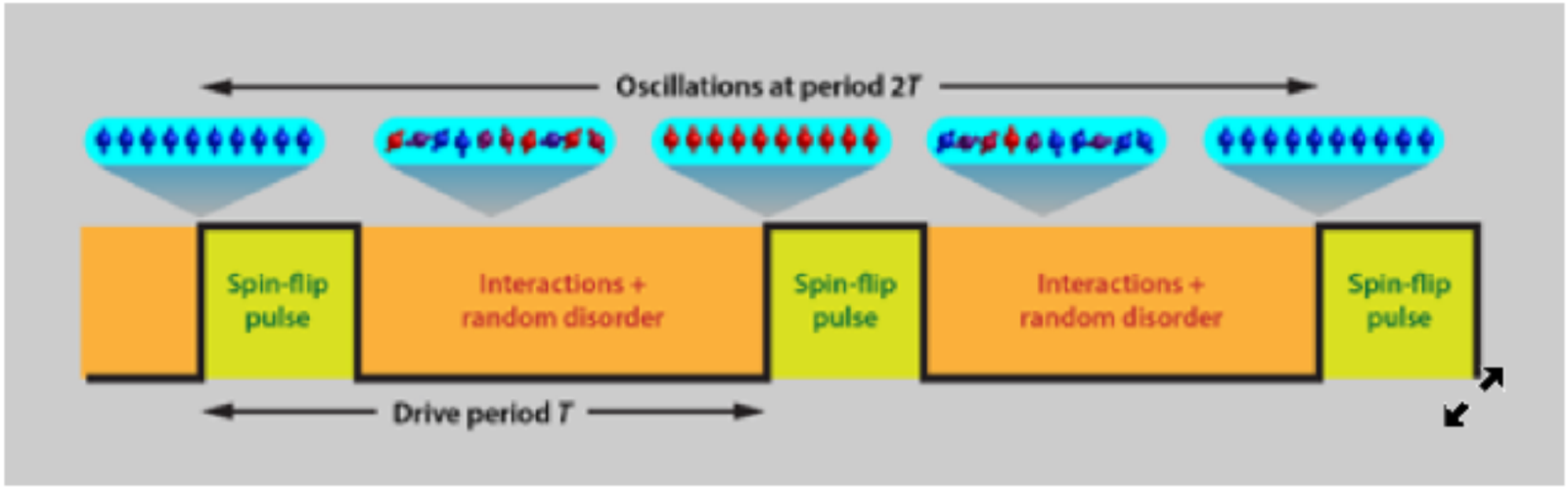
The game is to find time crystals do better in those regards: simple, precise, autonomous.

Viewpoint: How to Create a Time Crystal

Phil Richerme, Physics Department, Indiana University, Bloomington, IN 47405-7105, USA

January 18, 2017 • *Physics* 10, 5

A detailed theoretical recipe for making time crystals has been unveiled and swiftly implemented by two groups using vastly different experimental systems.



APS/**Alan Stonebraker**/Phil Richerme

Figure 1: Yao *et al.* [7] have developed a blueprint for creating a time crystal and a method for detecting it, which has been followed by two experimental groups [8, 9]. Quantum spins are subjected to imperfect spin-flip driving pulses and then allowed to int... **Show more**

