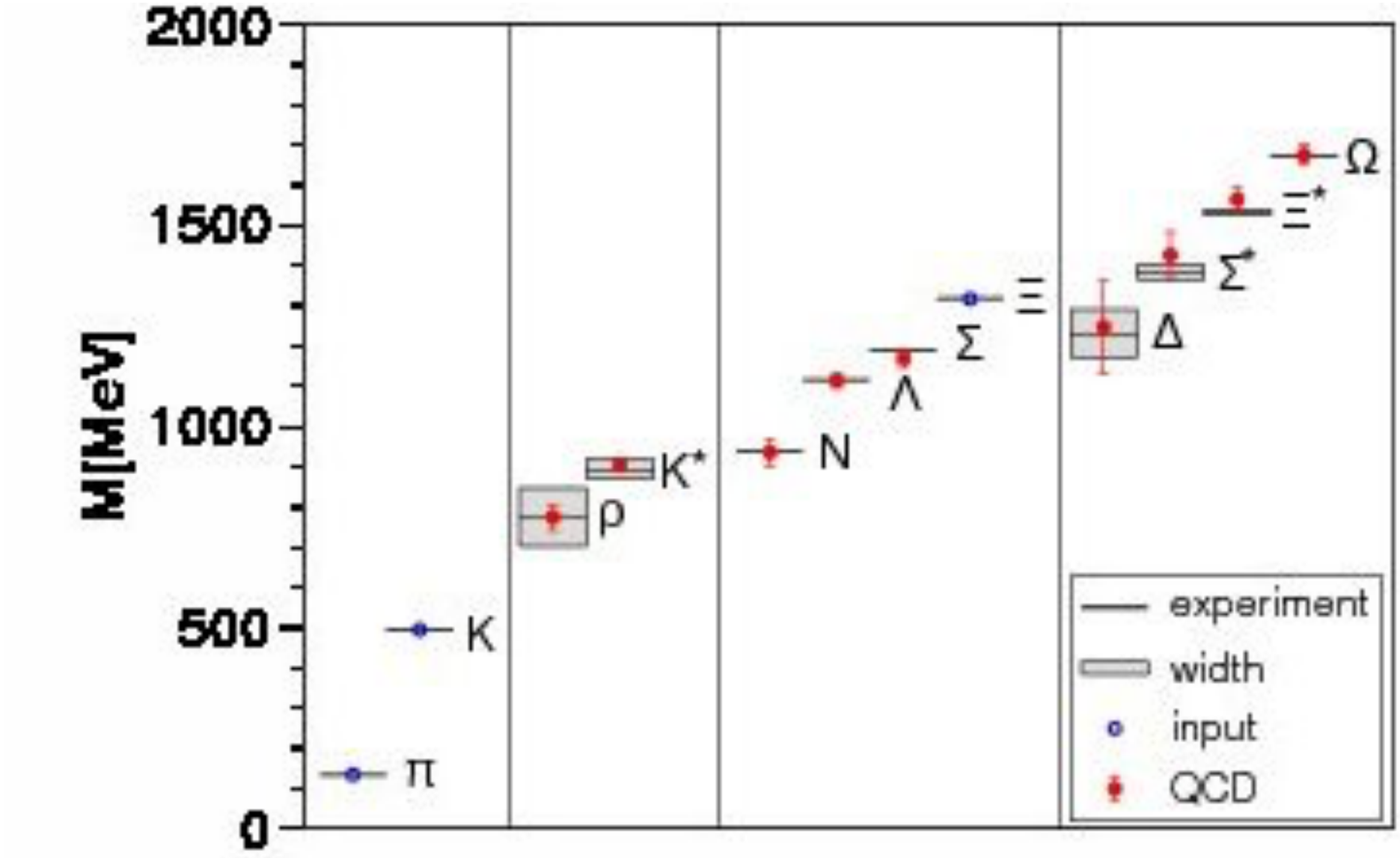
Dark Matter We Can Use

SUSY and Axions

The Standard Model: Glory and Discontents

Our current core theories are a glorious success. They provide an adequate foundation, in fundamental law, for chemistry, biology (probably), and all plausible forms of engineering.

They support long, complex calculations that connect physical reality to ideal mathematical principles. For example:


2000
1500
1000
500
0
M[MeV]
π
K
ρ
K*
N
Λ
Σ
Ξ
Δ
Σ*
Ξ*
Ω
experiment
width
input
QCD

But they are not as beautiful as they should be.

And they leave big questions, including the nature of dark matter and dark energy, unanswered.

Unification

$$\begin{pmatrix} u & u & u \\ d & d & d \end{pmatrix}^{L}_{1/6}$$

$$\begin{pmatrix} \nu \\ e \end{pmatrix}^{L}_{-1/2}$$

$$(u \quad u \quad u)^{R}_{2/3}$$

$$(d \quad d \quad d)^{R}_{-1/3}$$

$$(e)^{R}_{-1}$$

No ν^{R}

SU(3) x SU(2) x U(1)

mixed, not unified

three fundamental "forces"

(plus gravity)

six fundamental "materials"

(plus 2 repeats)

(plus Higgs sector)

One "material"

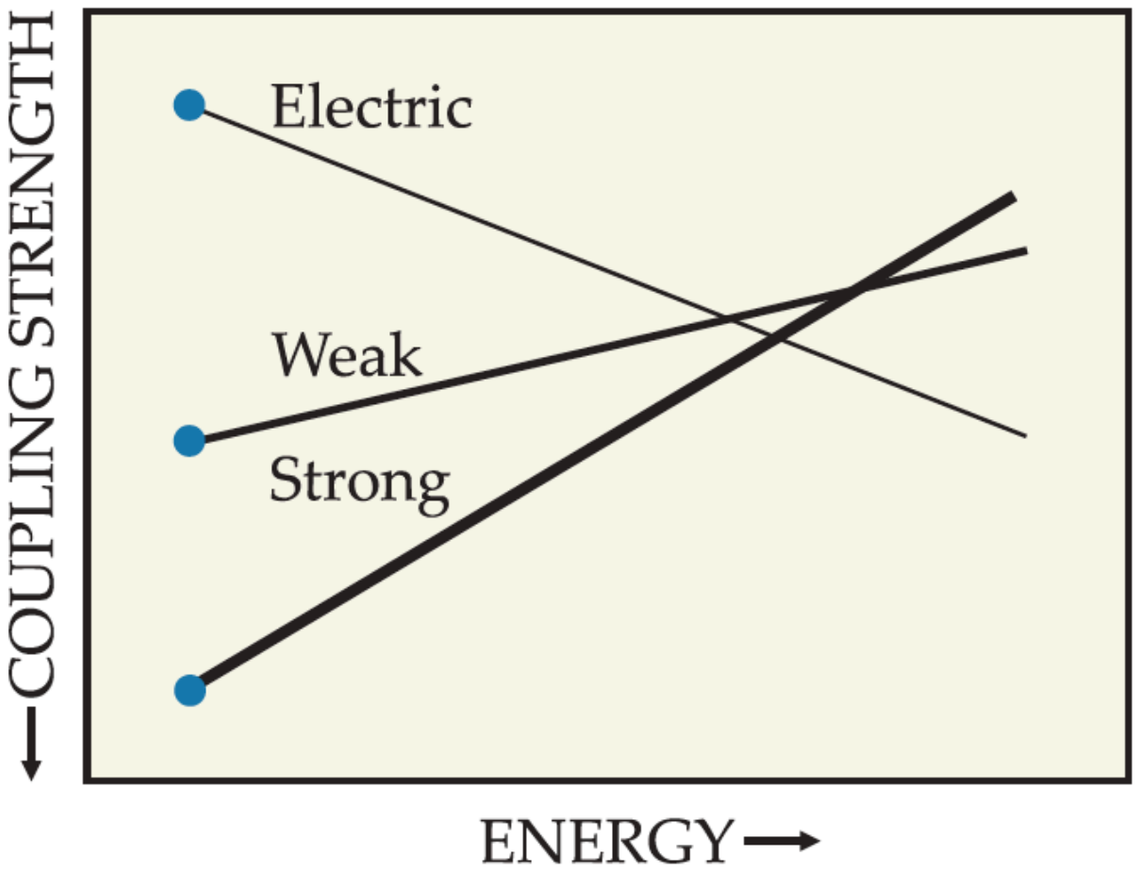
	R	W	B	G	P
u	+	-	-	+	-
u	-	+	-	+	-
u	-	-	+	+	-
d	+	-	-	-	+
d	-	+	-	-	+
d	-	-	+	-	+
u^c	-	+	+	-	-
u^c	+	-	+	-	-
u^c	+	+	-	-	-
d^c	-	+	+	+	+
d^c	+	-	+	+	+
d^c	+	+	-	+	+
ν	+	+	+	+	-
e	+	+	+	-	+
e^c	-	-	-	+	+
N	-	-	-	-	-

SO(10)

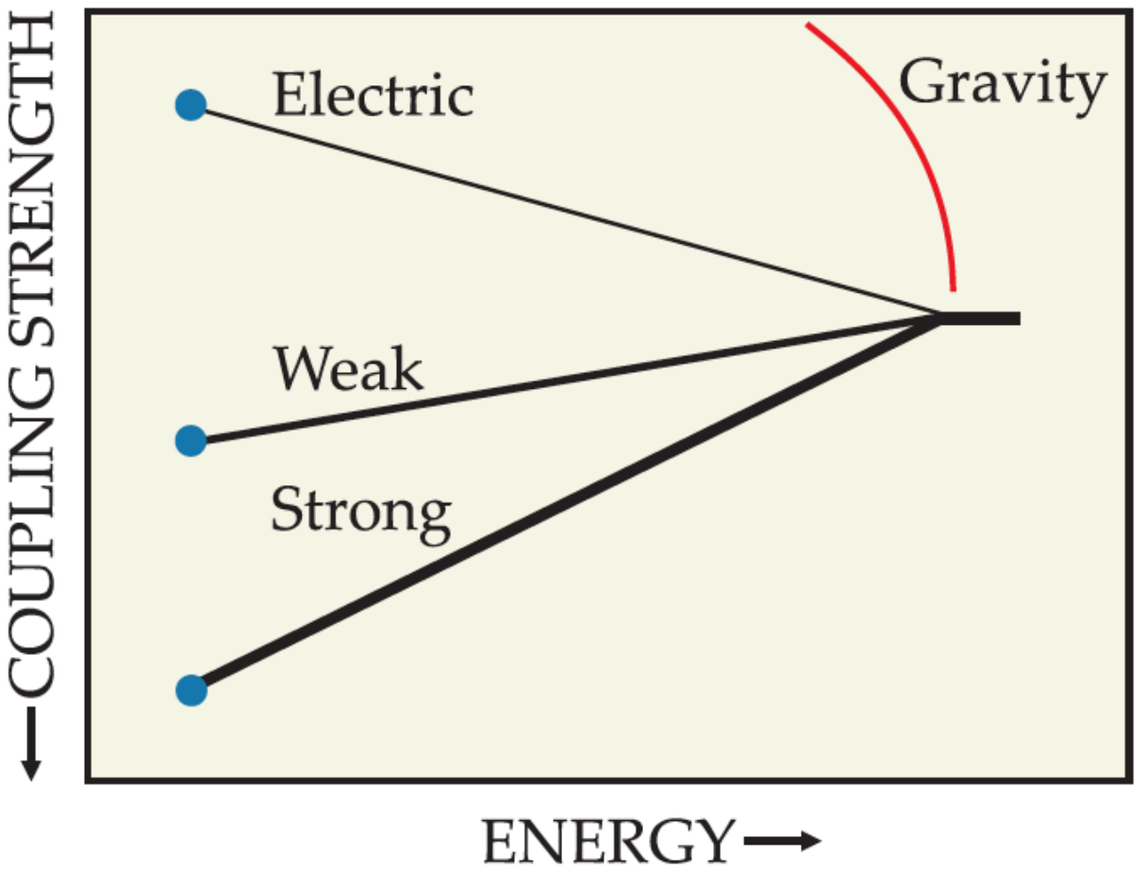
One "force"

Hypercharge Y = -1/6 (R+W+B) + 1/4 (G+P)

known particles



adding SUSY



unification of forces

All particles in the standard model have positive R-parity, where $R \equiv (-1)^{3B+L+2S}$. Their supersymmetry partners have negative R-parity.

The lightest particle with R-parity -1 will probably be very stable.

In many models, this “lightest supersymmetric particle”, or LSP, has roughly the right properties to provide the astronomical dark matter.

On the other hand, low-energy supersymmetry has a lot to answer for:

"conspiratorial" Higgs structure

possible proton decay

possible CP violation

many potential, but unrealized, LHC signals

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
ODPSSA

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.

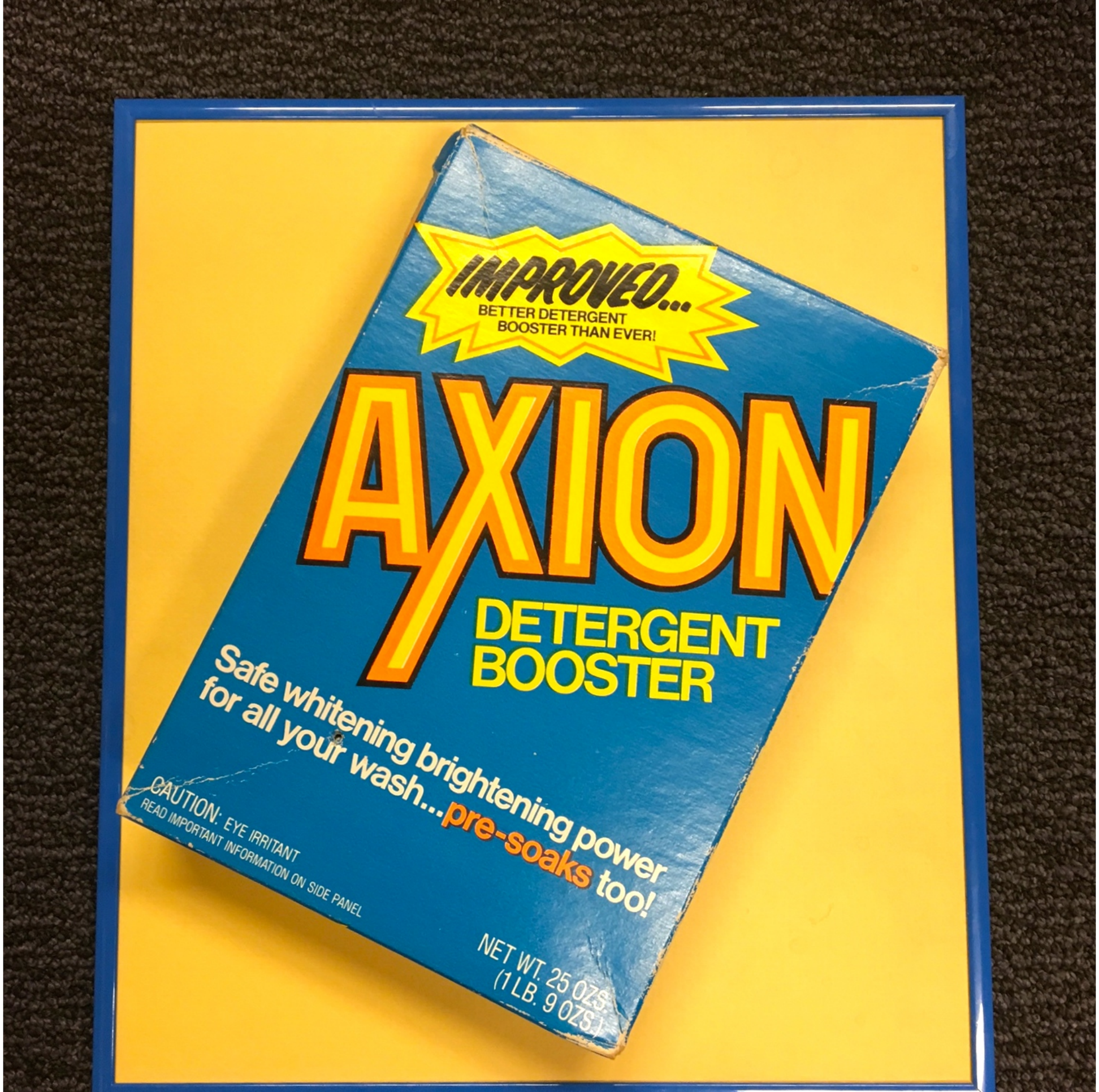
Why?

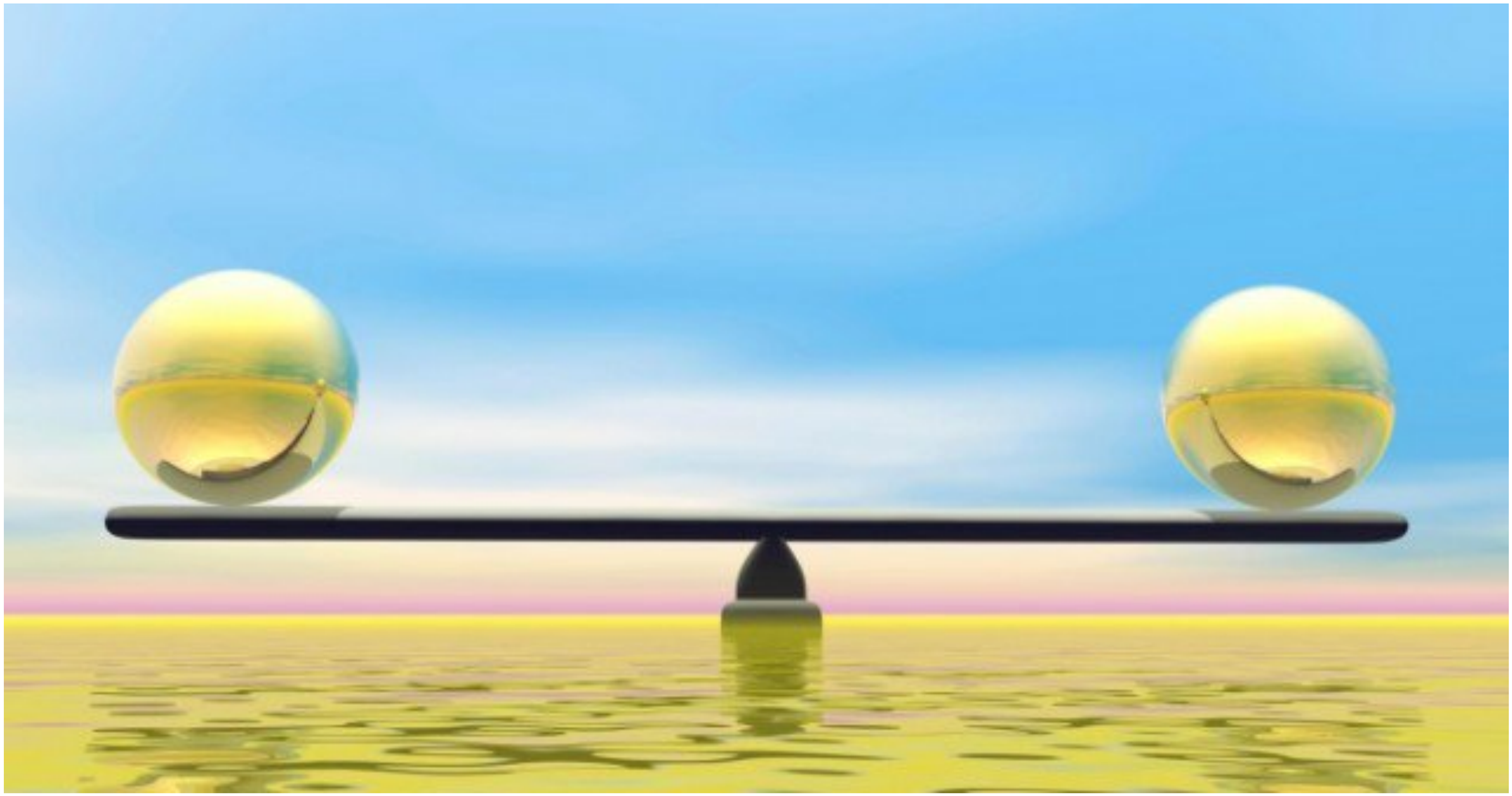
Over the past 40+ years, there have been several attempts to explain it, but only one has stood the test of time.

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".

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

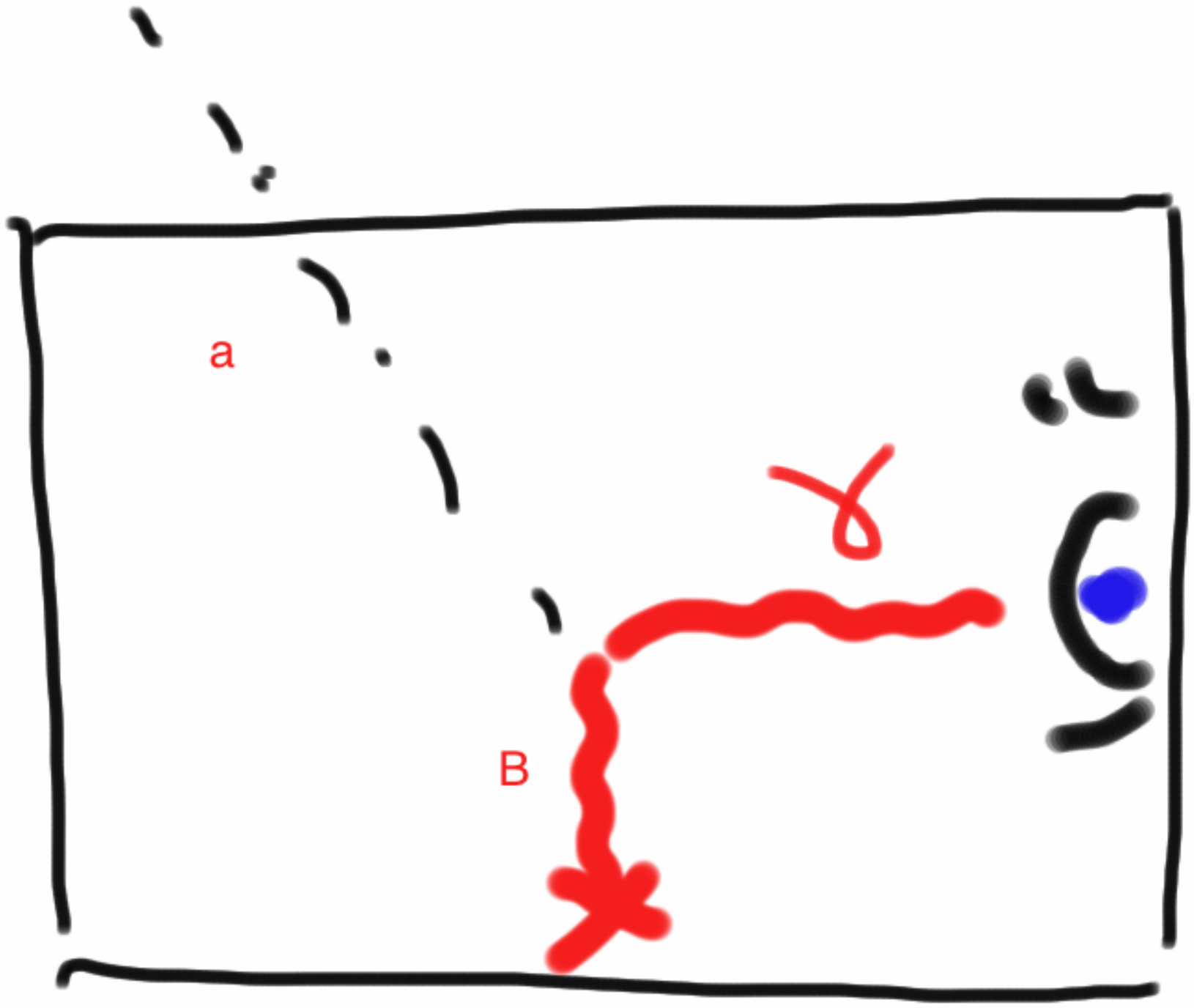
POWER UP 2500 2

EVOLVE 100

Several clever strategies for axion detection have emerged.

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


KUSP
KOREA
UNDERGRADUATE/GRADUATE/H.S.
SCIENCE PROGRAM
Center for Axion
&
Precision Physics


a
B

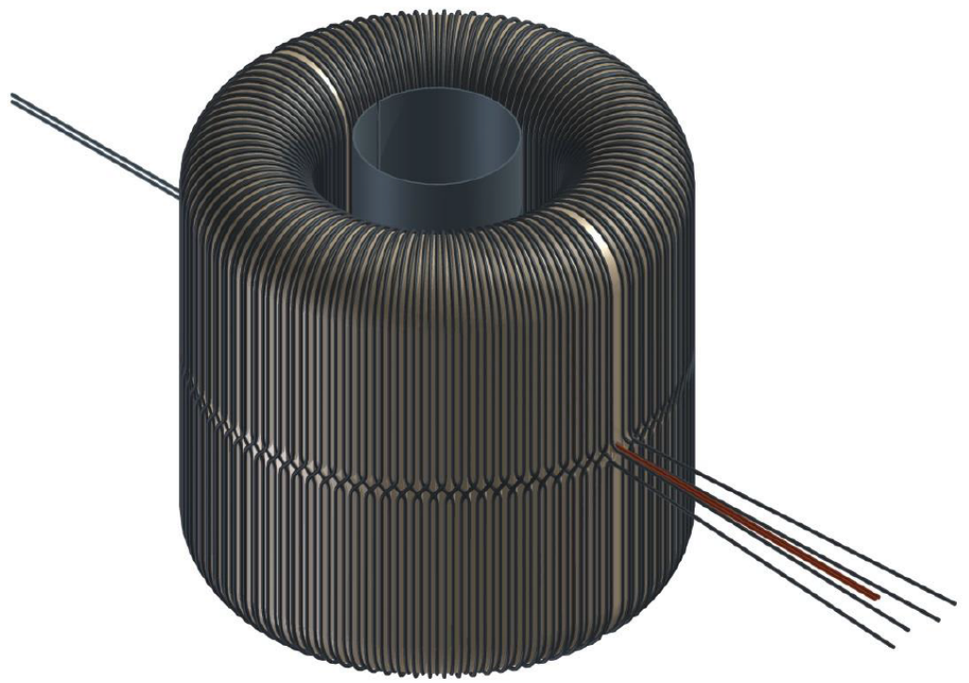
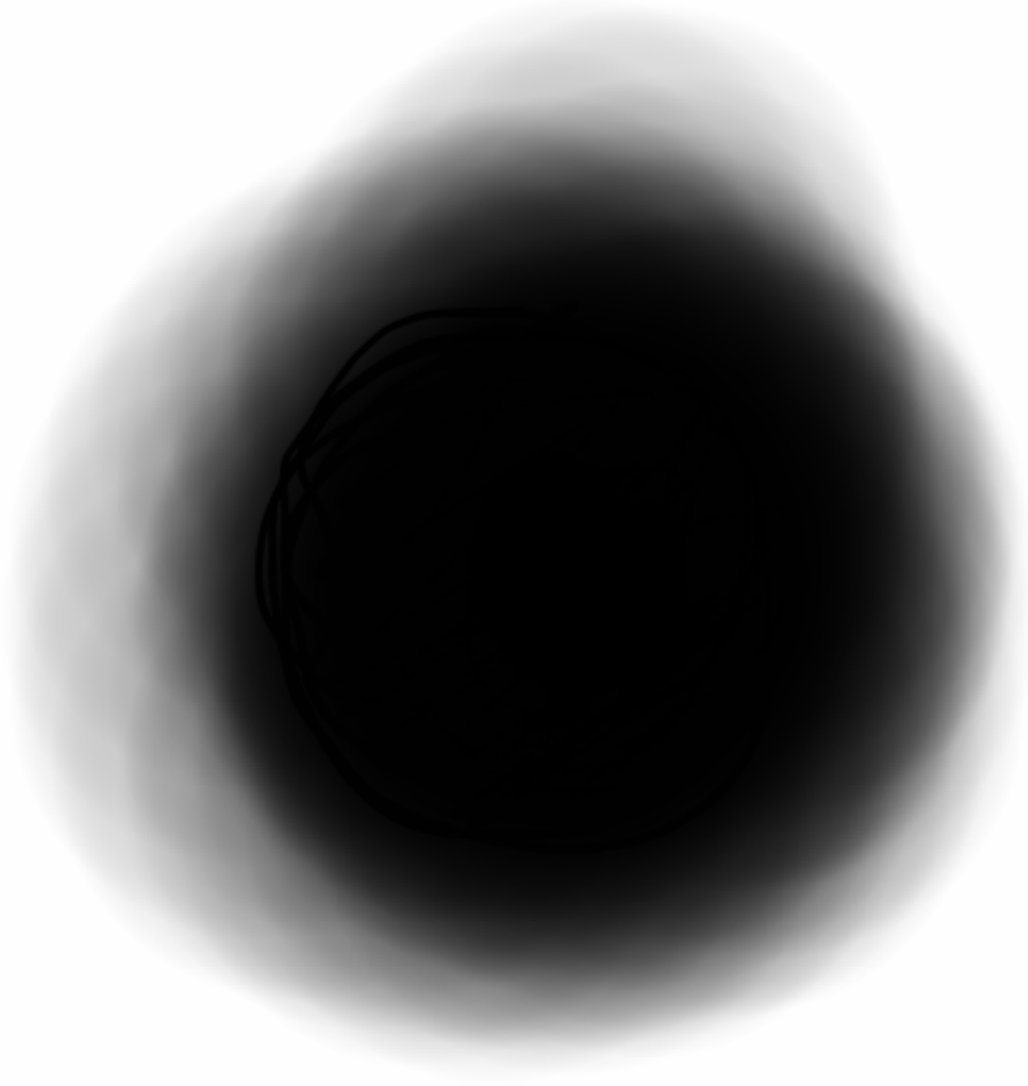


FIG. 1: A schematic of the ABRACADABRA-10cm toroidal geometry. The superconducting main coil sources a static azimuthal magnetic field. In the presence of axion DM, an effective oscillating current is induced following the magnetic field lines. The oscillating magnetic flux sourced by this effective 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.



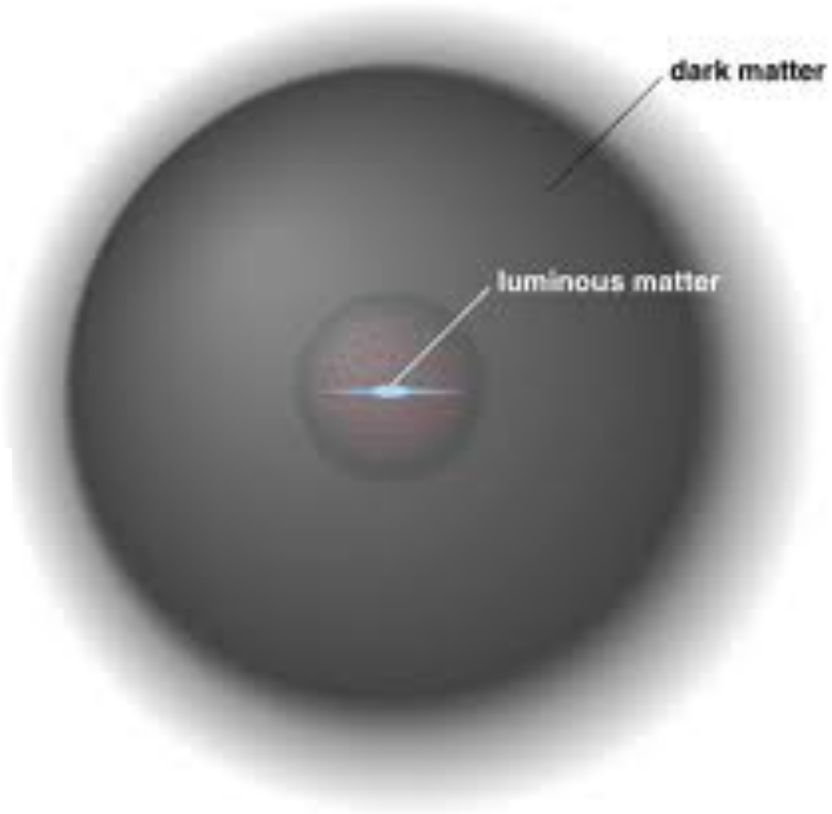
Summary

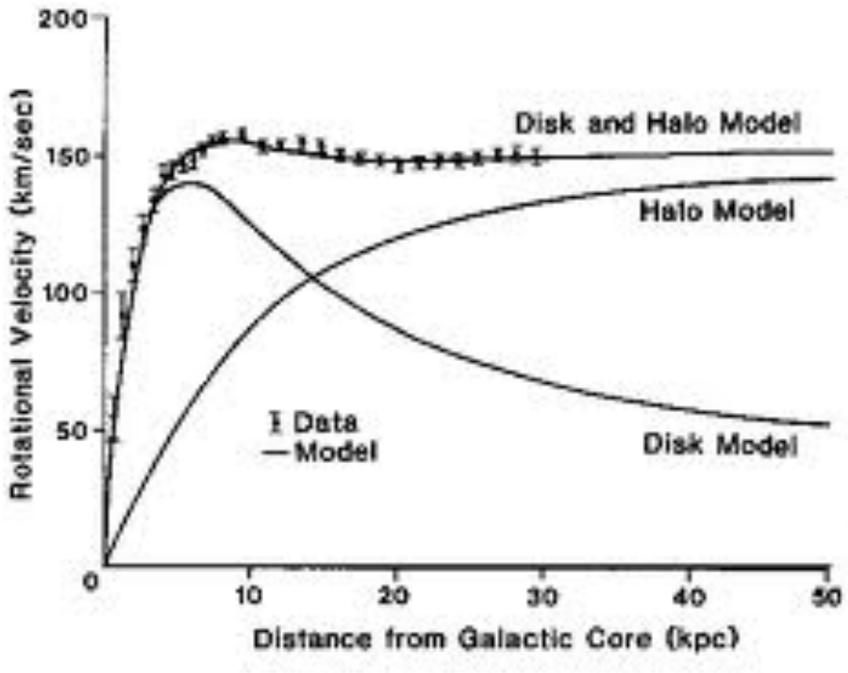
On the face of it, we have an opportunity for a great synthesis, linking fundamental physics to observational cosmology.

But …

Nature gets the last word.

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…

