

BEYOND THE STANDARD MODEL

LEC 3A: PIONS!

LEC 3B: AXIONS!

LEC 3C: WIMPS!

Flip Tanedo

UC Riverside Particle Theory



31 JULY 2019



PHYSICS &
ASTRONOMY



PI · SNOLAB · TRIUMF

TRISEP

References

Just a Taste: Lectures on Flavor Physics

Grossman & F.T. arXiv: 1711.03624

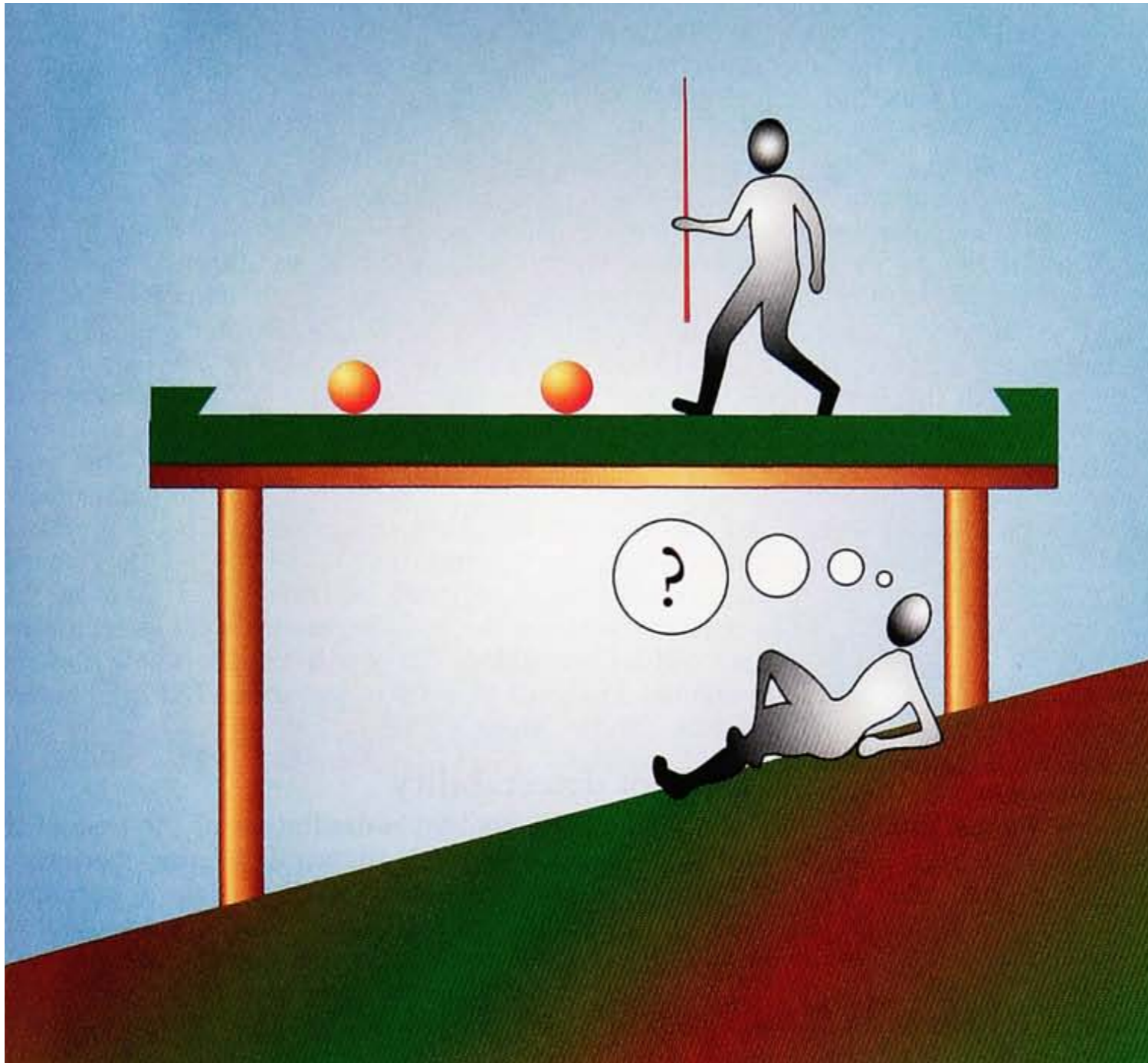
Javier Redondo's lectures on axions
e.g. ("3 hours with axions")

Cahn, "The eighteen arbitrary parameters of the
standard model in your everyday life"
RMP **68** 951 (1996)

Axion Analogy



The Pool-Table Analogy with Axion Physics (Sikivie)

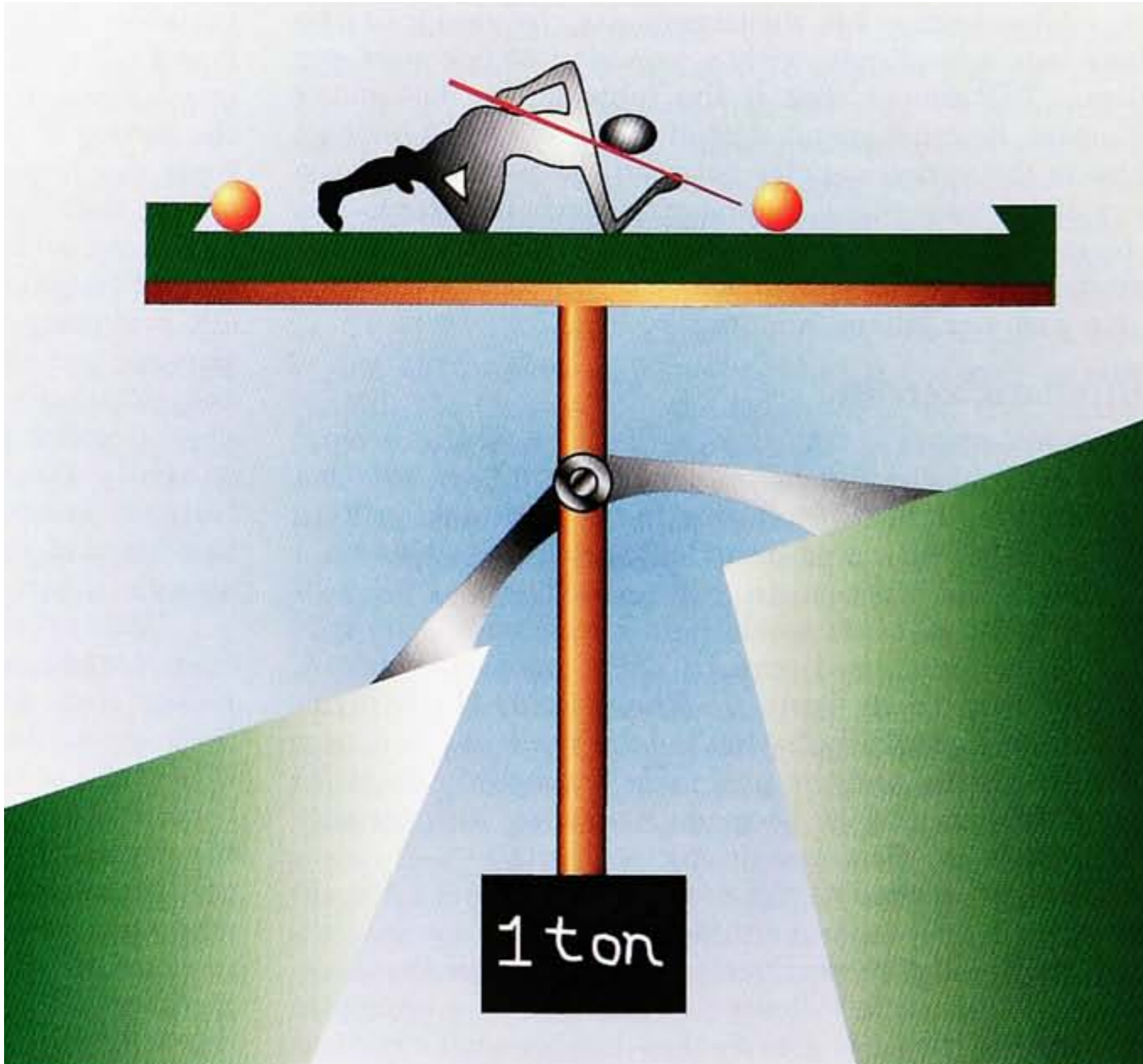


Physics Today 49, 12, 22 (1996); doi: 10.1063/1.881573

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$$1/f_a$$

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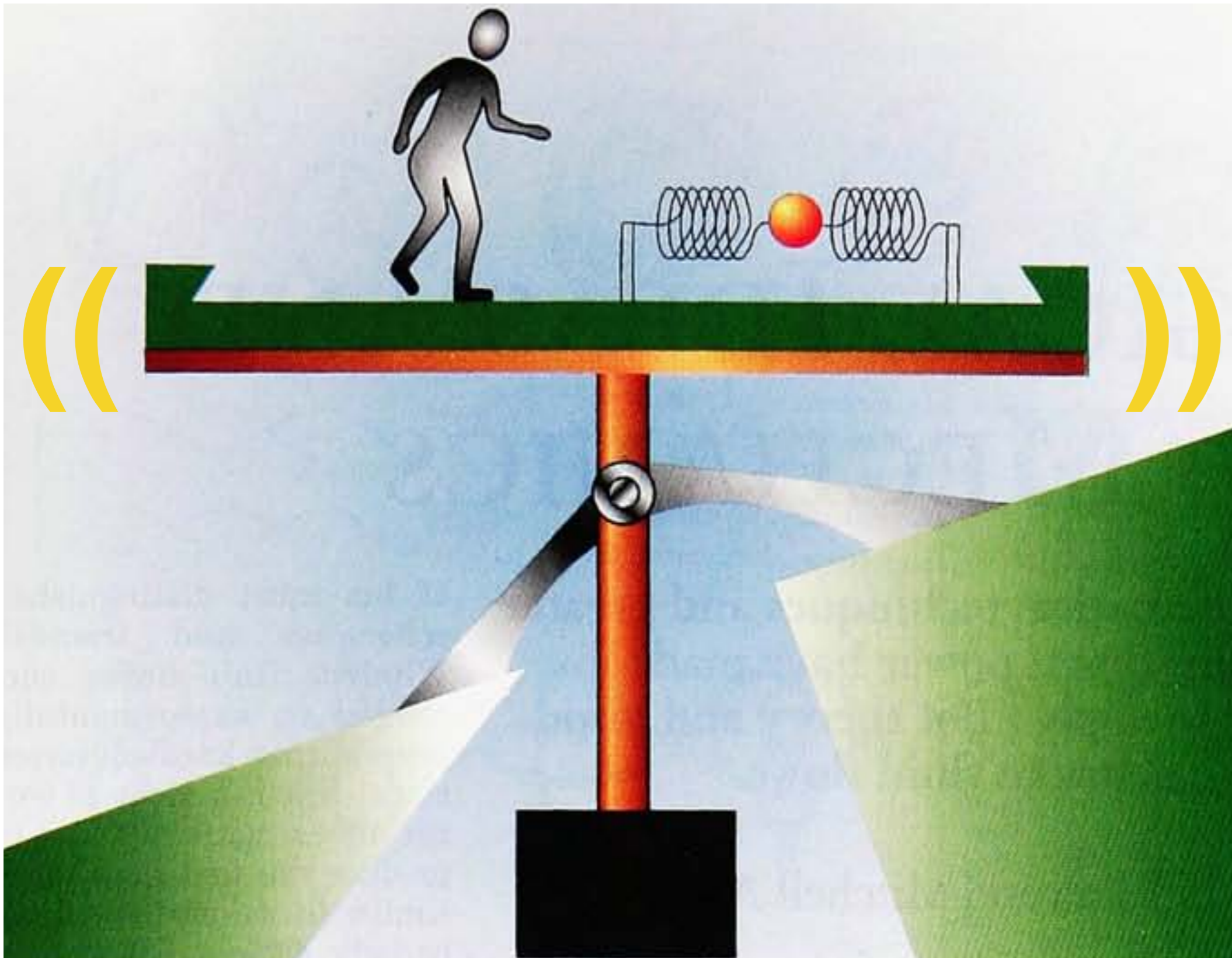
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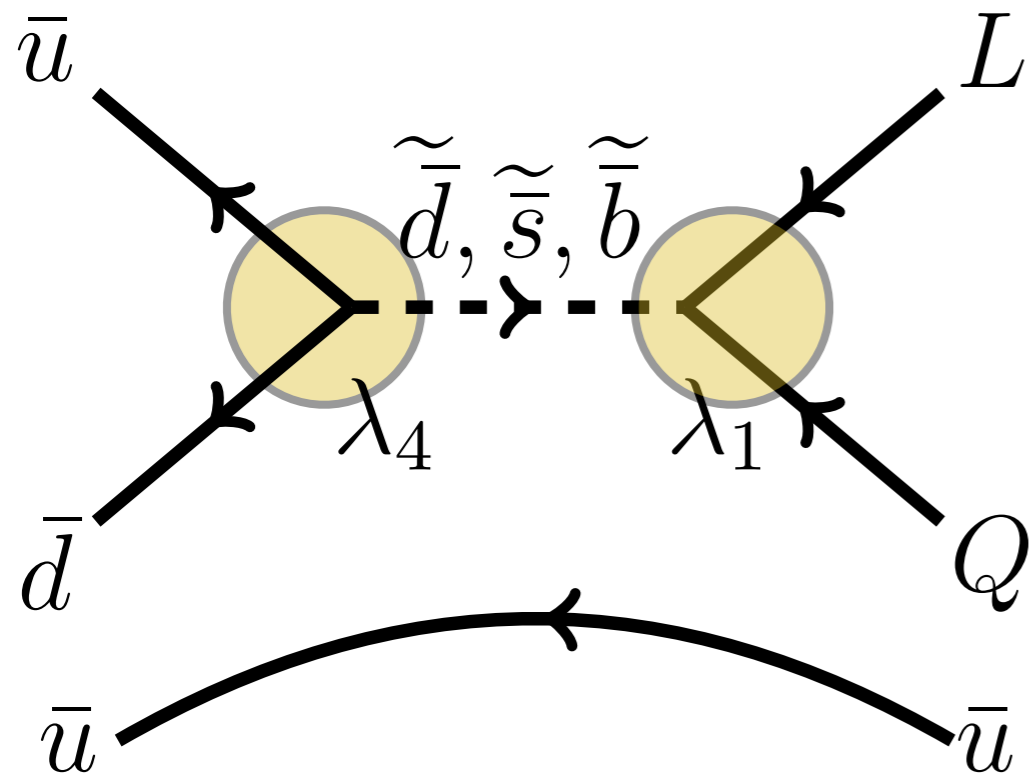
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WIMPs



Preventing Proton Decay: R-parity



$$P_R = (-)^{3(B-L)+2s}$$

$$P_R[\text{ordinary matter}] = +$$

$$P_R[\text{superpartner}] = -$$

Added bonus:
lightest superpartner is stable.

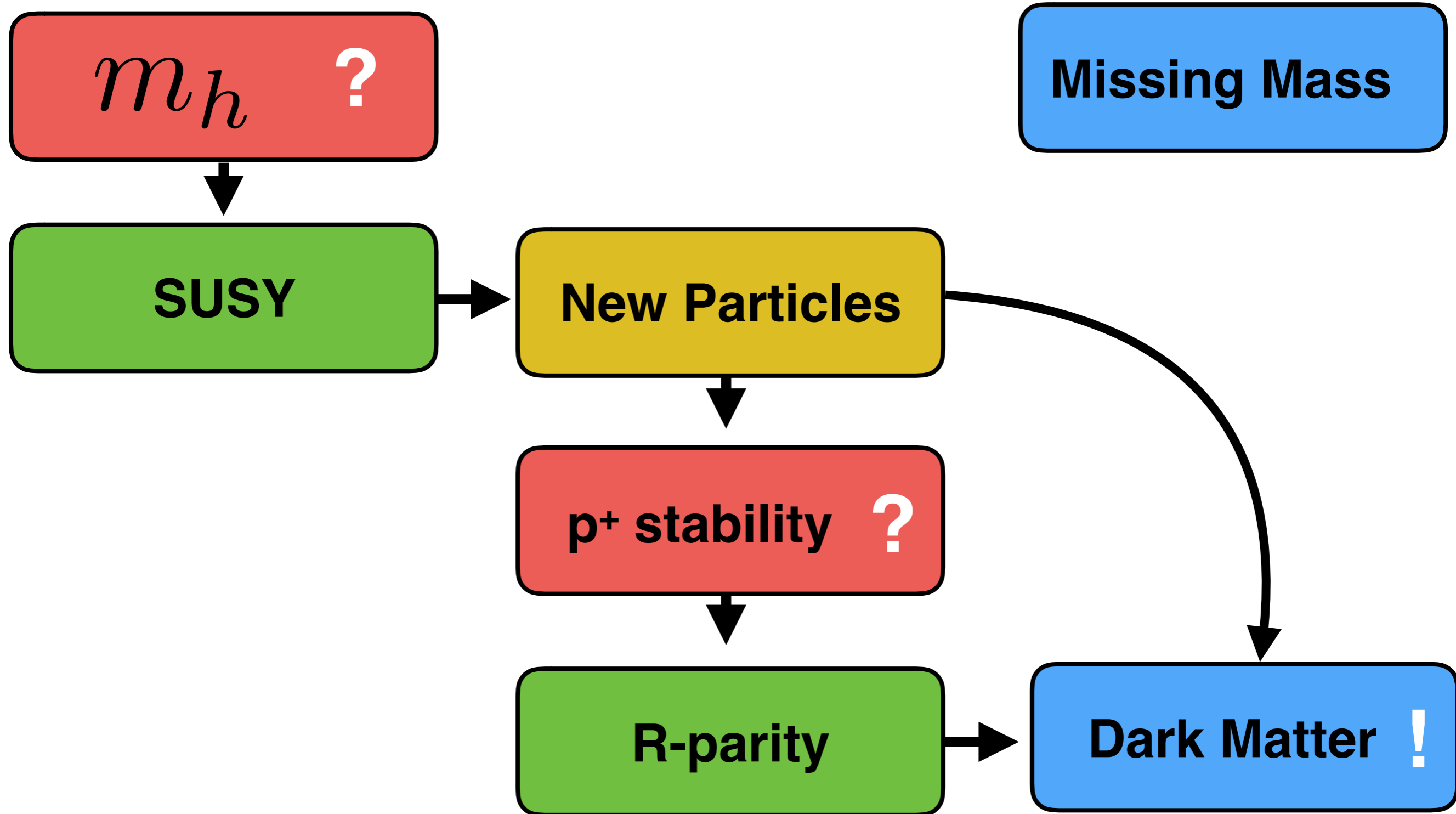


Known Unknowns

m_h ?

Missing Mass

The story so far: SUSY



Weakly-Interacting Massive Particle

m_h ?

Missing Mass

Weak scale mass ~ 100 GeV

Weak scale interaction strength G_F

No additional parameters (roughly)

Dark Matter !

One thing that we do know: density

Missing Mass

How much DARK MATTER is in my COFFEE? @FlipTa

THE MOTION OF NEARBY STARS LETS US INFER THE DARK MATTER DENSITY IN OUR GALACTIC NEIGHBORHOOD:

$$\rho_{DM}^{local} = (0.39 \pm 0.03) \cdot (1.2 \pm 0.2) \cdot (1 \pm \delta_{triax}) \frac{GeV}{cm^3} \approx \frac{1}{2} \frac{GeV}{cm^3}$$

FROM pdg.lbl.gov (PROPERTY OF DARK MATTER)

IF DARK MATTER HAS MASS M_x , THEN THE NUMBER DENSITY OF DARK MATTER IS:

$$\begin{aligned} n_{DM} &= \rho_{DM} / M_x \\ &= \frac{\rho_{DM}}{50 GeV} \cdot \left(\frac{50 GeV}{M_x} \right) \\ &\approx \left[\frac{0.01}{cm^3} \right] \cdot \left(\frac{50 GeV}{M_x} \right) \end{aligned}$$

50 GeV \approx MASS OF TITANIUM ATOM

WRITE

$$\frac{1}{M_x} = \frac{1}{50 GeV} \cdot \frac{50 GeV}{M_x}$$

SO THAT WE CAN PUT IN A REFERENCE VALUE.

REFERENCE NUMBER DENSITY (eg: this is $\frac{1}{2}$ if $M_x = 100 GeV$.)

OBSERVE: HEAVIER DARK MATTER \rightarrow LESS DENSE

WIKIPEDIA: coffee mug volume ≈ 7 L
LET'S ASSUME ONLY 100 L (BECAUSE I DRANK $\frac{2}{3}$)

THEN THE AVERAGE # OF DARK MATTER IN MY COFFEE IS

$$N_{DM} = n_{DM} \cdot V_{COFFEE} \approx 1 \times \left(\frac{50 GeV}{M_x} \right)$$

\approx ONE DARK MATTER PARTICLE IF $M_x \approx 50 GeV$.
 \rightarrow MORE FOR LIGHTER DM
 \rightarrow LESS FOR HEAVIER DM

Approx. 1 WIMP per mug of coffee

Dark Matter !

some assumptions:

- Dark matter isn't bound into dense objects (galaxies, planets)
- Dark matter behaves like a particle (WIMPs, axions, etc.)
- CARE ABOUT AVERAGE # OF DM AT ANY GIVEN MOMENT.

Thanks to [unclear] pointing this out to me! #SIDM

Weakly-Interacting Massive Particle

m_h ?

Missing Mass

Weak scale mass ~ 100 GeV

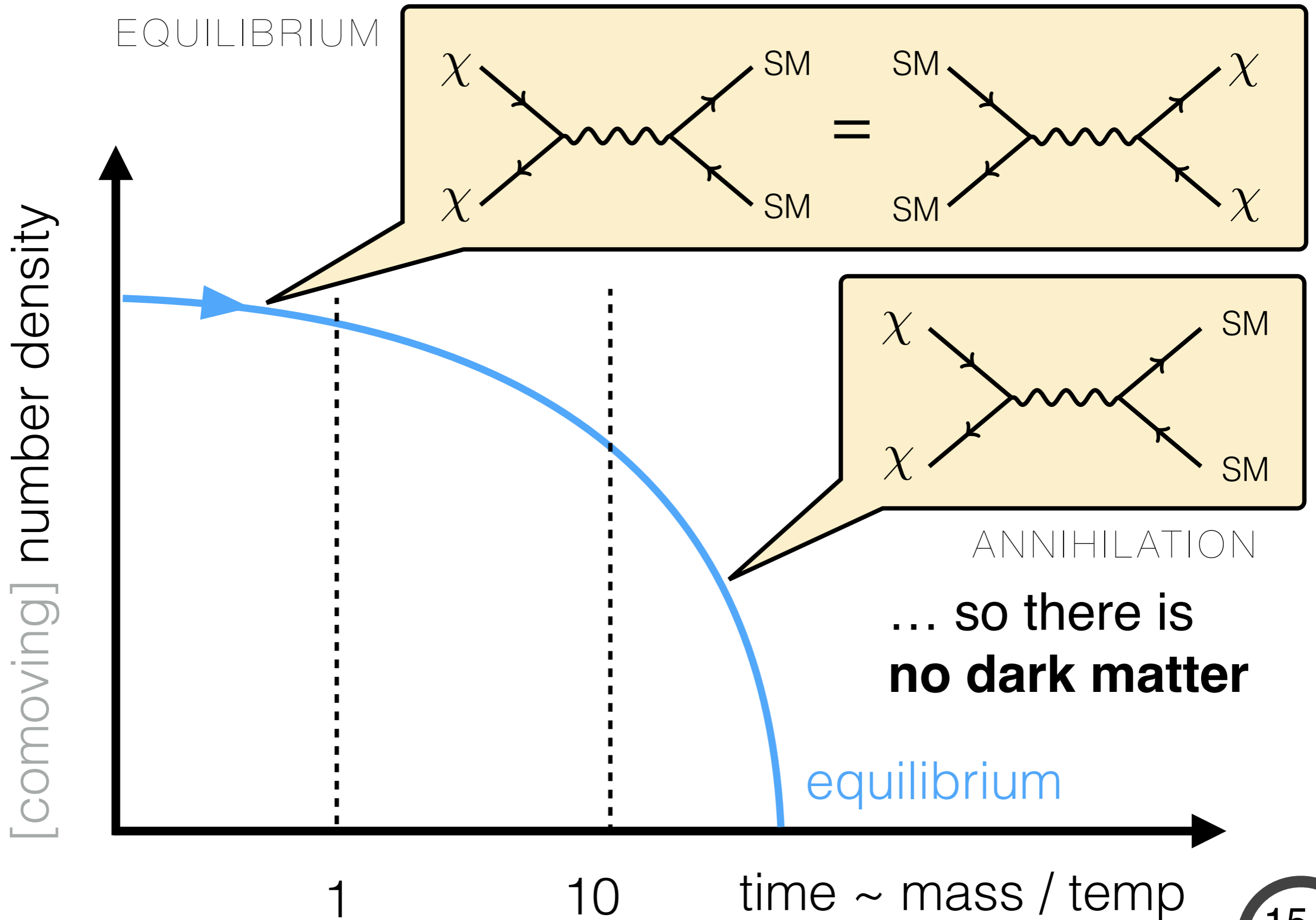
Weak scale interaction strength G_F

No additional parameters (roughly)

How much dark matter do we predict?

Dark Matter !

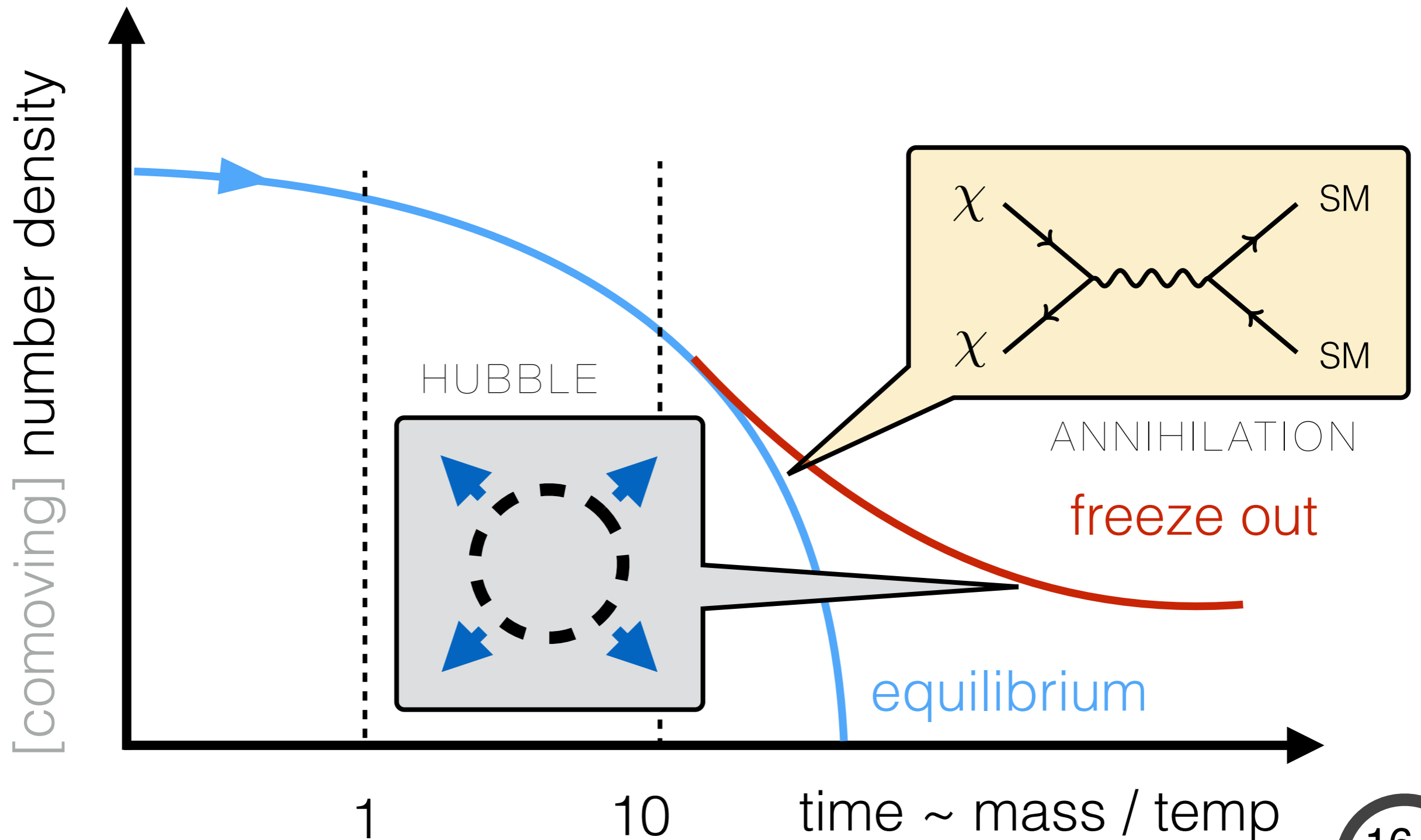
How much dark matter is there?



How much dark matter is there?

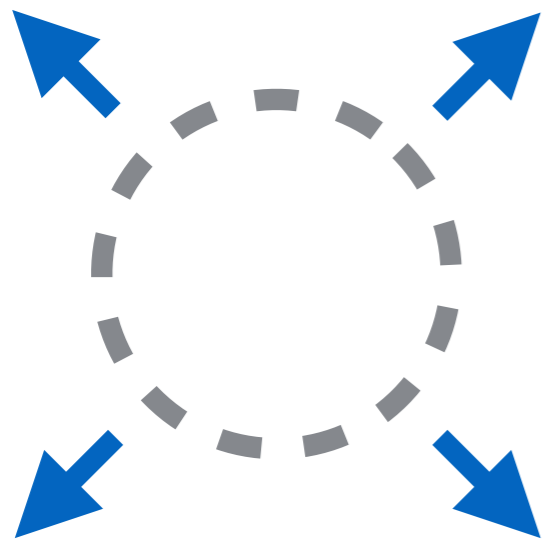
WIMP prediction: relic abundance of dark matter

[neutralino & cousins]



The “WIMP Miracle”

automatically get the correct abundance (almost)



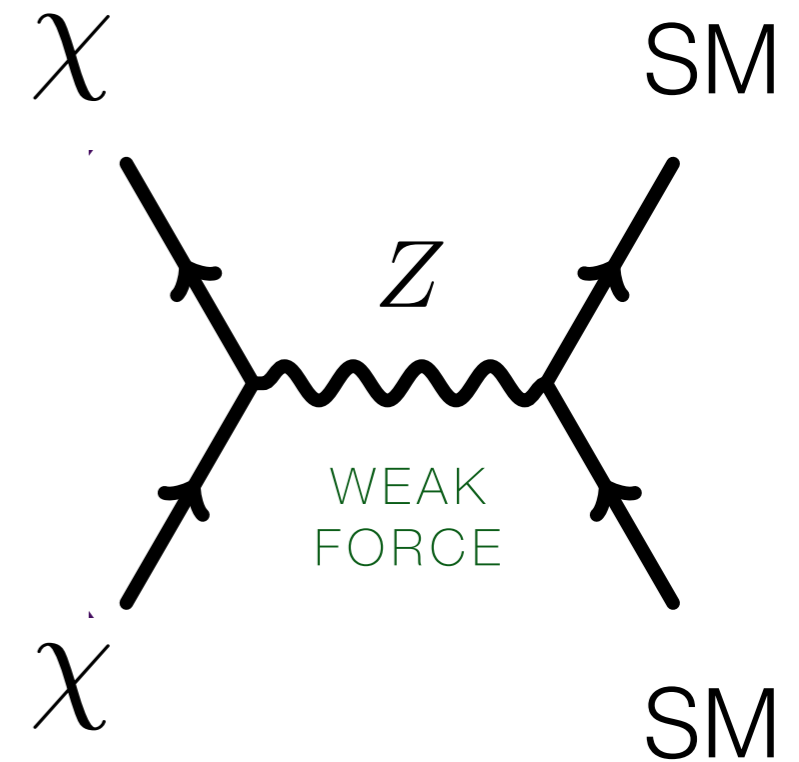
expansion of universe

PRESENT
ABUNDANCE

$$\Omega_\chi h^2 \sim \frac{0.1 \text{ pb}}{\langle \sigma_{\text{ann}} v \rangle}$$

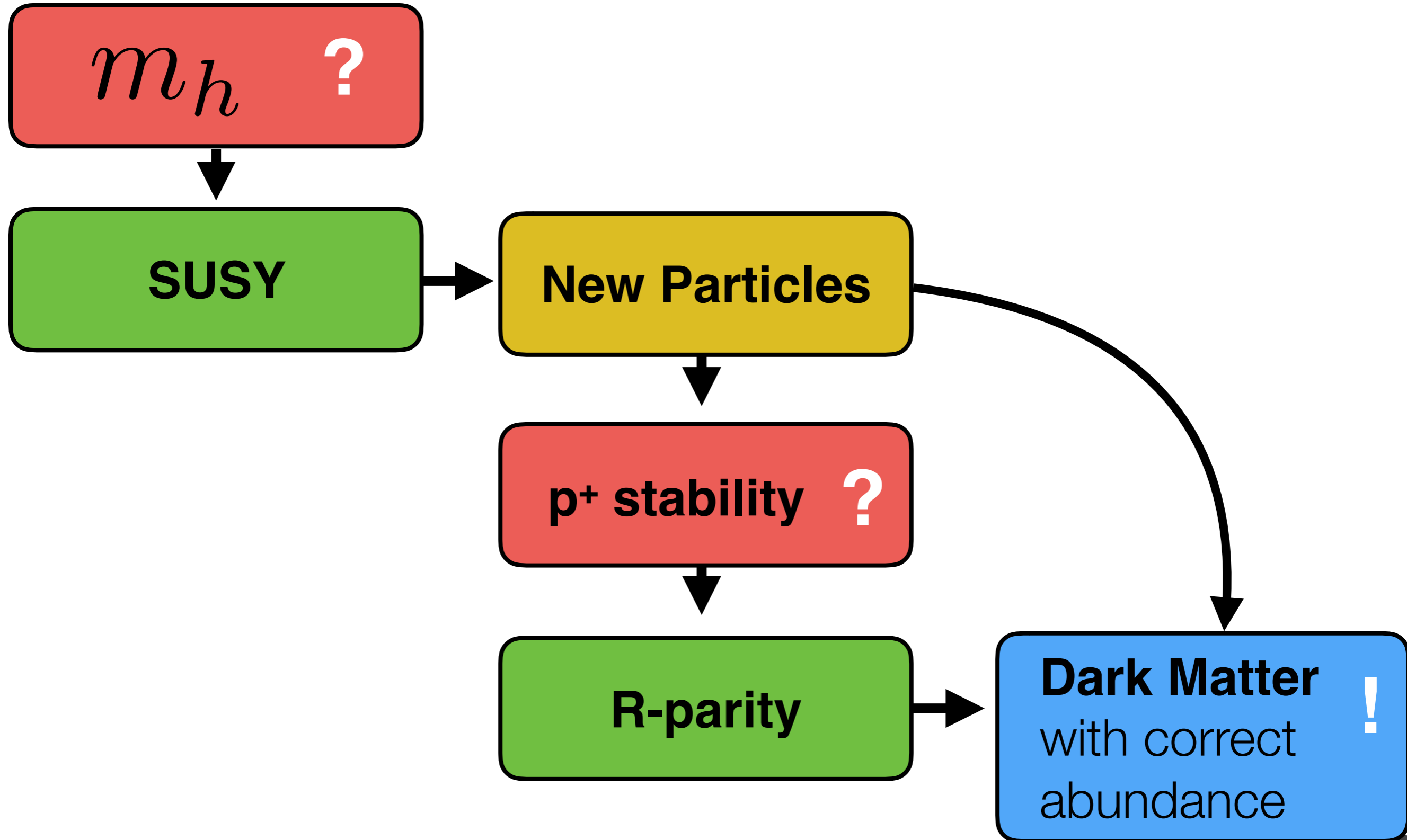
“WEAK SCALE”
ANNIHILATION RATE

“WEAK SCALE” MASS

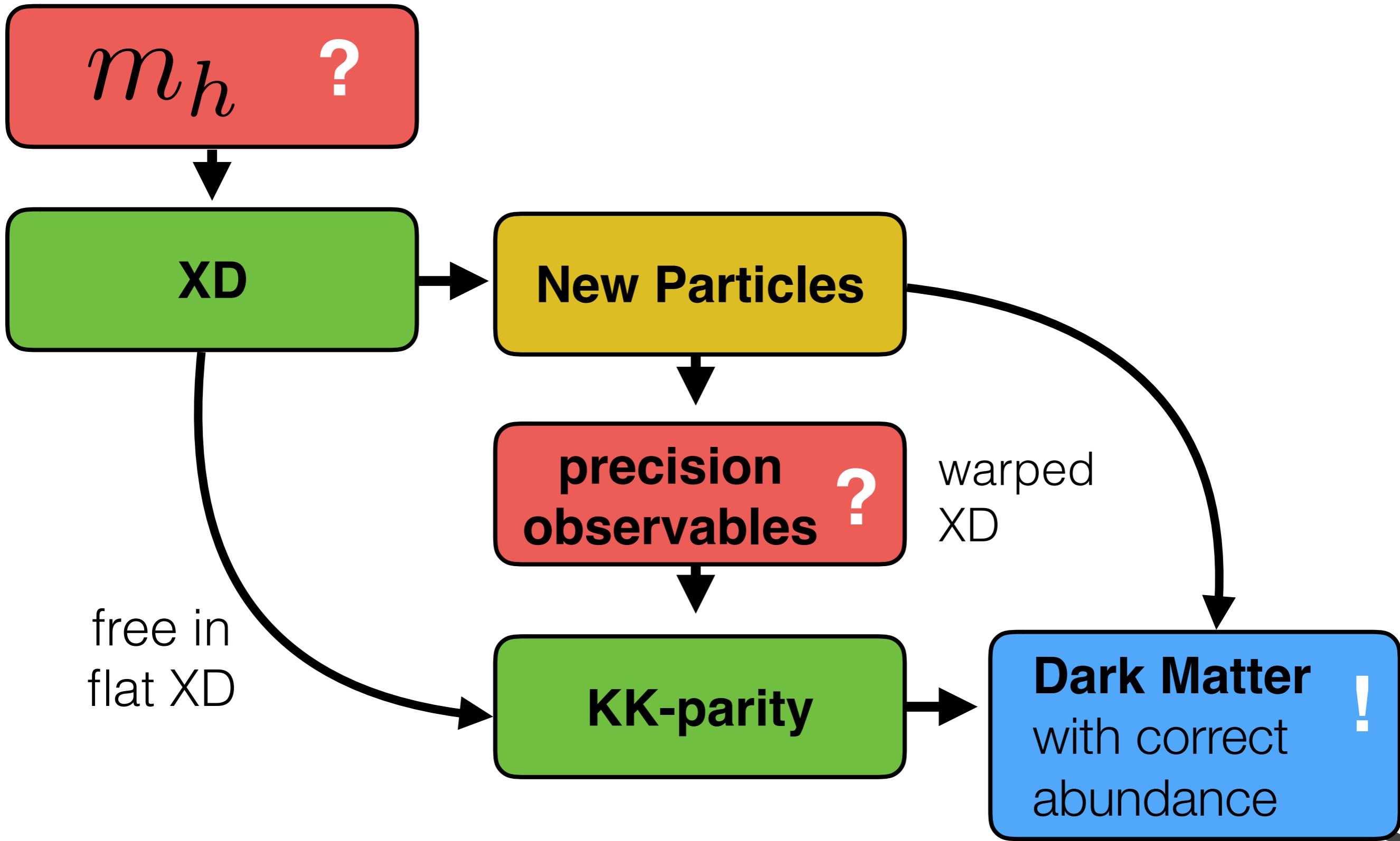


annihilation

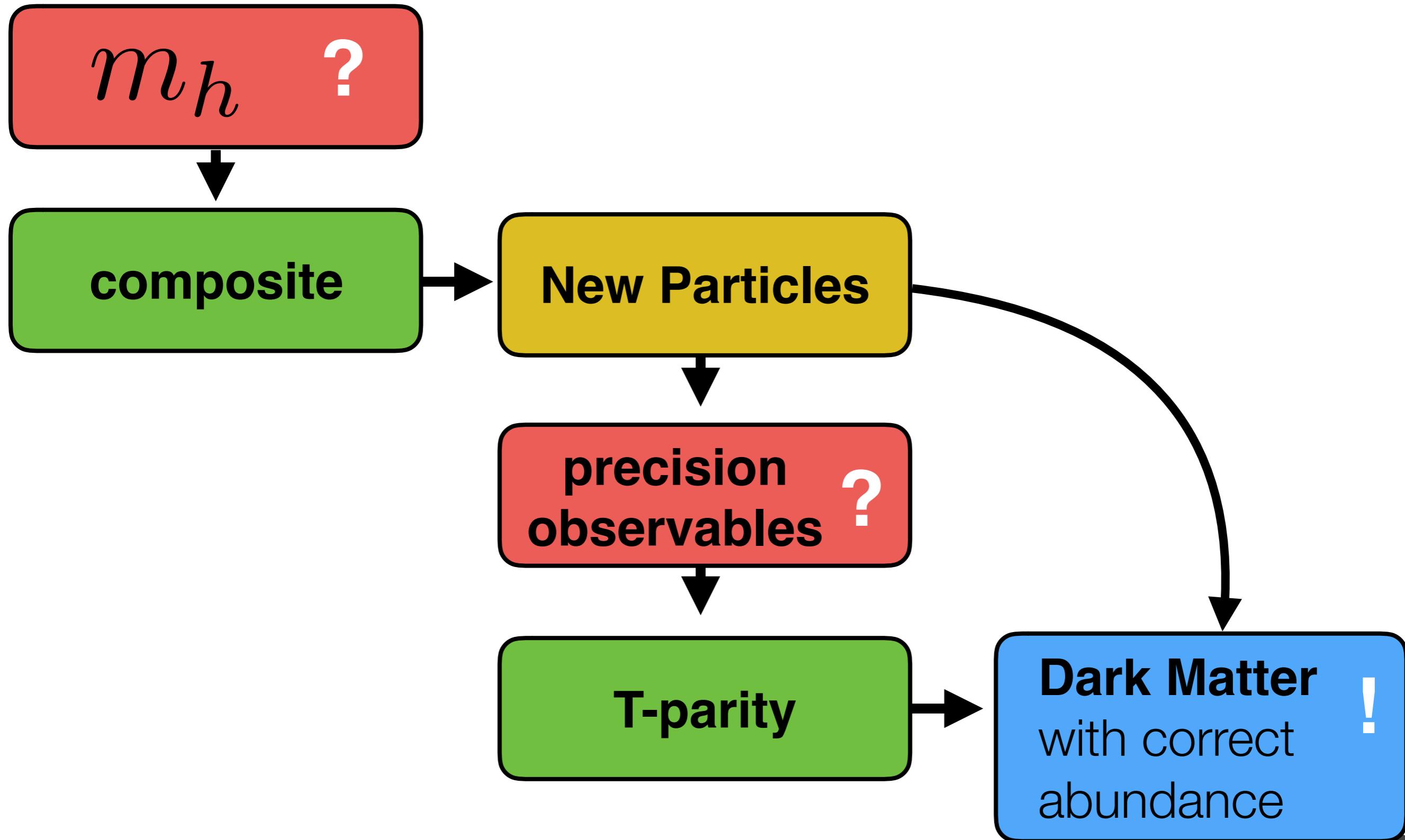
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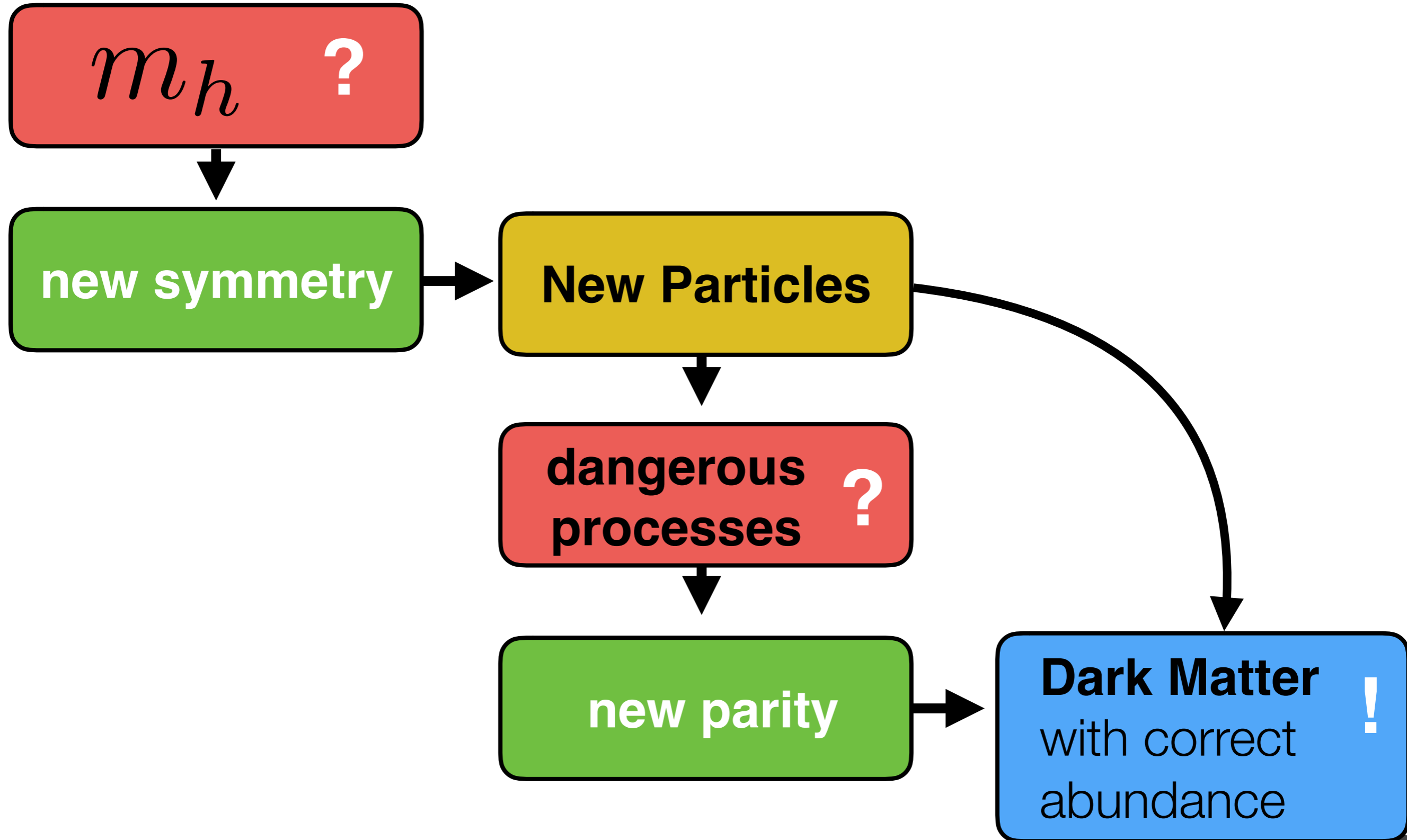
extra dimensions



compositeness



WIMP story



Direct Detection

