David’s Calm-ments

Ascona

Starting Point

Known fundamental laws:

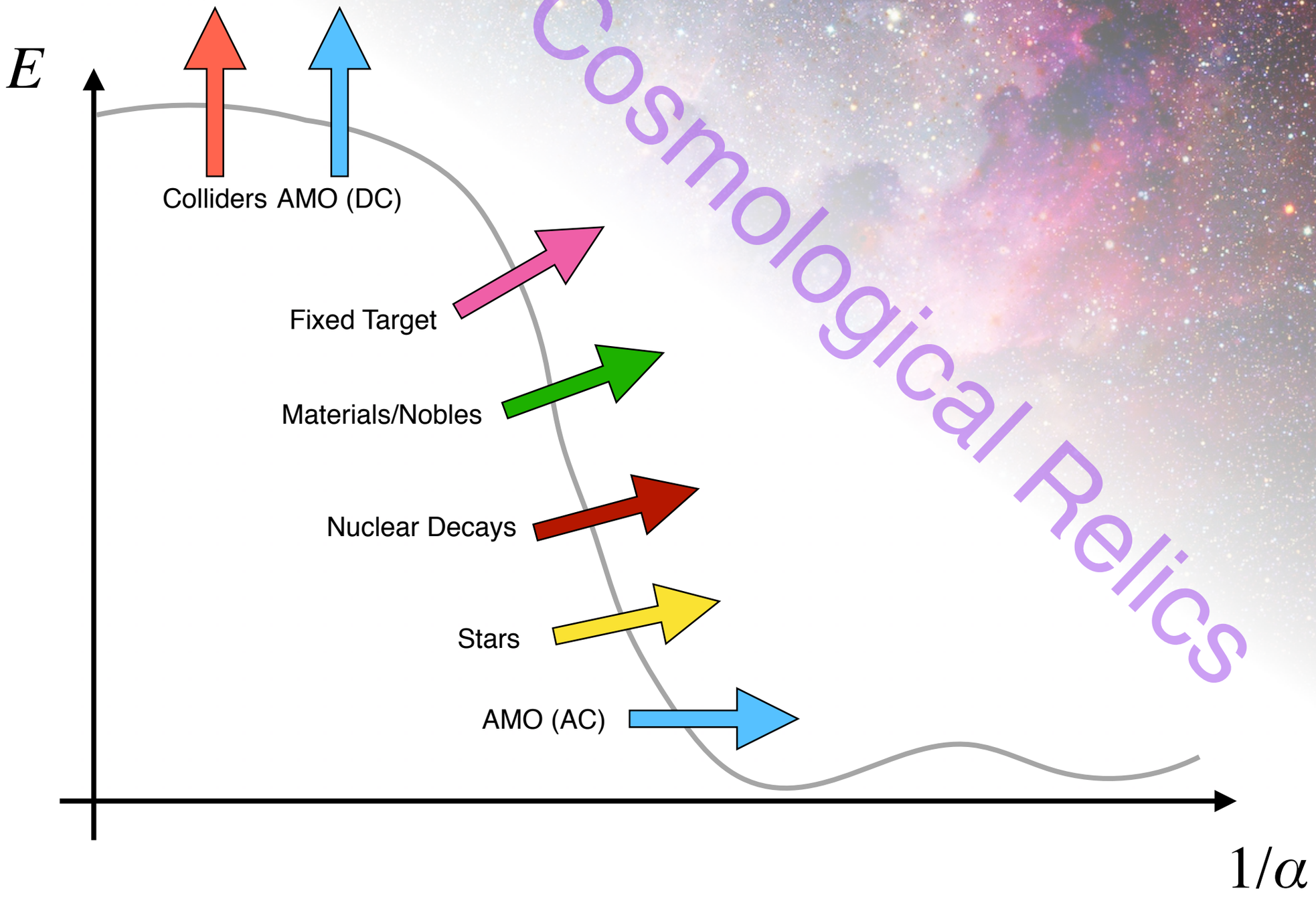
Quantum field theory

The Standard Model, including GR:

$$\mathscr{L} = \frac{1}{2}\bar{q}(i\partial_\mu + g_s G_\mu + gW_\mu + g'\frac{1}{3}B_\mu)\gamma^\mu q + \cdots + y_e h\bar{\ell}e + \cdots + m^2|h|^2 - \frac{1}{4}|h|^4 + \cdots$$

(add gravitational couplings)

The Frontier:
High Energy & Weak Coupling



Hints Beyond the SM

0.	**DARK MATTER**		BSM
1.	Cosmological Constant Problem	123	
2.	The Hierarchy Problem	32	
3.	The Strong CP Problem	10	Small Parameters
4.	Patterns in Fermion Masses	5	
5.	Neutrino Masses	?	

∞. GR UV Scale — Breakdown of Theory

(also: Hubble tension, b-physics?, g-2?, Beryllium?, neutrinos, tons of astrophysics…) — Anomalies

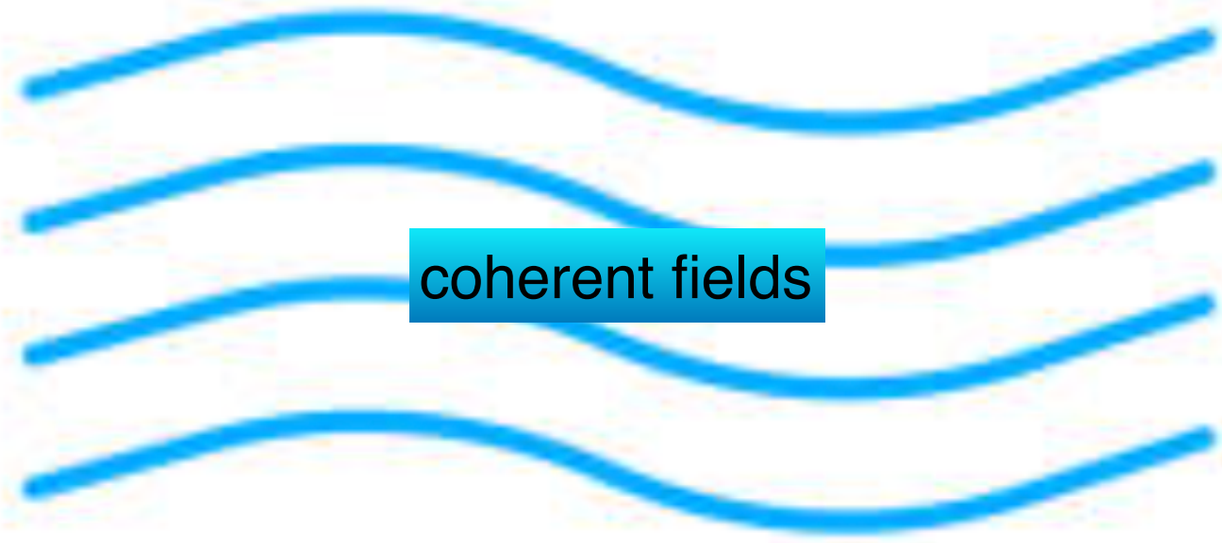
Dark Matter

MASS RANGE (energies, vs. objects.)

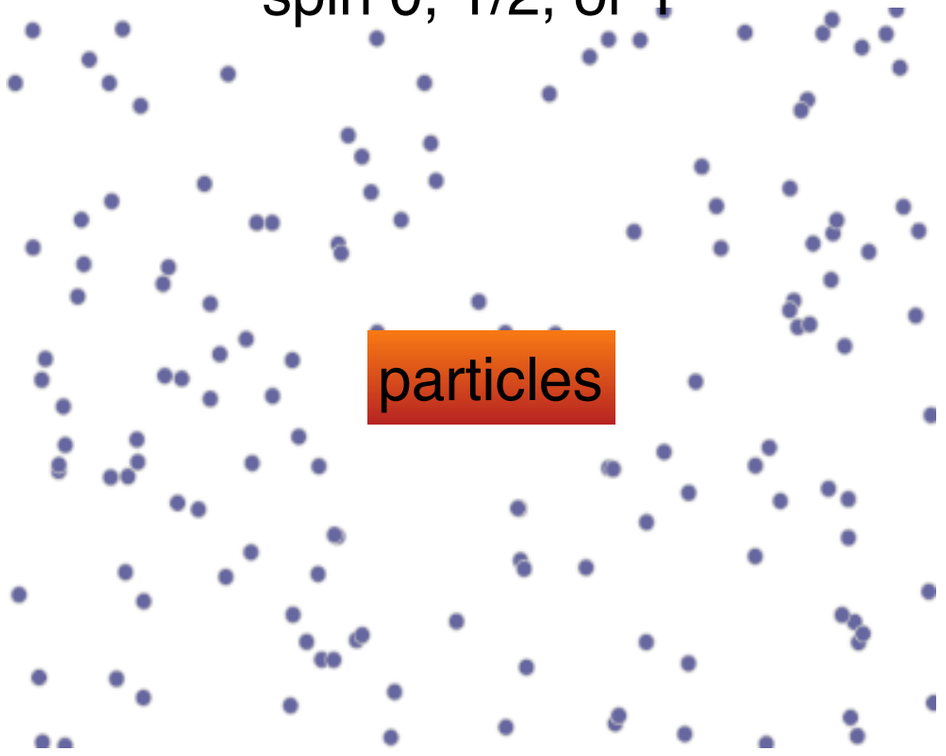
macroscopic

$10^{-31} m_p$ — 10 eV — $10^{19} m_p$

spin 0 or spin 1



spin 0, 1/2, or 1



M_{pl}: 1 DM per square meter per year

huge mass range, but object type limited

QFT — if the matter exists, the 'field' exists. The particle can be produced, the field can cause forces, etc. (Example — light!)

Light Fields: Couplings

Spin 0, 1/2, and 1

Spin 0 (like h's or π)

coupling to $p/n/e$ mass — $\phi\bar{\psi}\psi$

coupling to $p/n/e$ spin — $\partial\phi\,\bar{\psi}\gamma\gamma^5\psi$

coupling to γ kinetic — ϕFF

coupling to γ spin — $\phi F\tilde{F}$

(CP even vs CP odd — naturalness)

Spin 1 (like γ or W/Z)

mixing with γ — FF'

new charge ($p/n/e$) — $\bar{\psi}\gamma A'\psi$

dark mag moment ($p/n/e$) — $\bar{\psi}\sigma\psi F'$

coupling to $p/n/e$ spin — $\bar{\psi}\gamma\gamma^5 A'\psi$

various to ν couplings

Spin 1/2 couplings (like matter):

mixing with ν — $\bar{\nu}\chi$

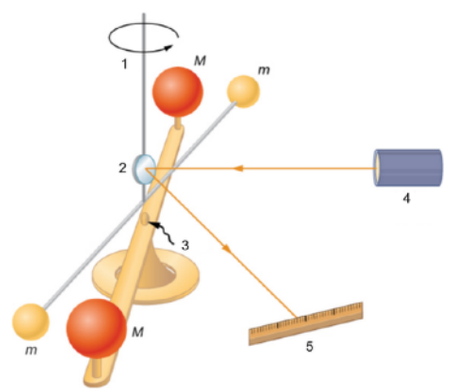
$\chi\chi$ couplings

Light Fields: Physical Effects

Forces!

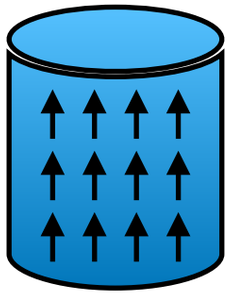
EP violating

$$\frac{1}{r^2} \rightarrow \frac{e^{-mr}}{r^2} \text{ (range} \sim \frac{1}{m}\text{)}$$

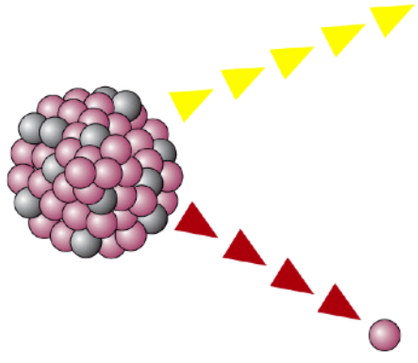


— Earth/Moon/Sun
— Earth/Lab
— Lab/Lab (cavendish)

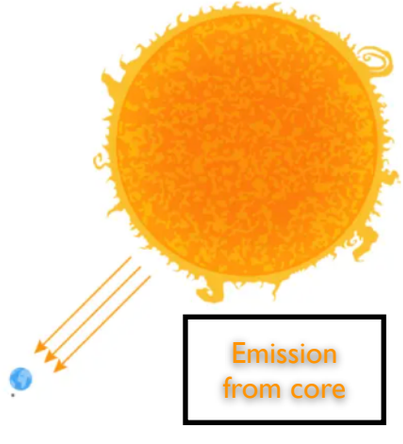
Spin-dependent forces
For polarized material



Nuclear (and atomic/hadronic) decays



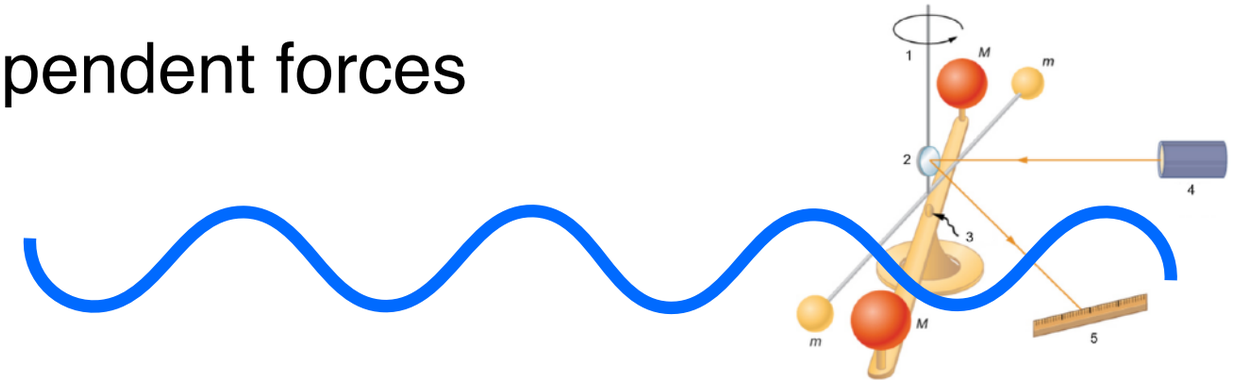
Solar/Stellar emission



Light Fields: Backgrounds

If it is DM/DE or static

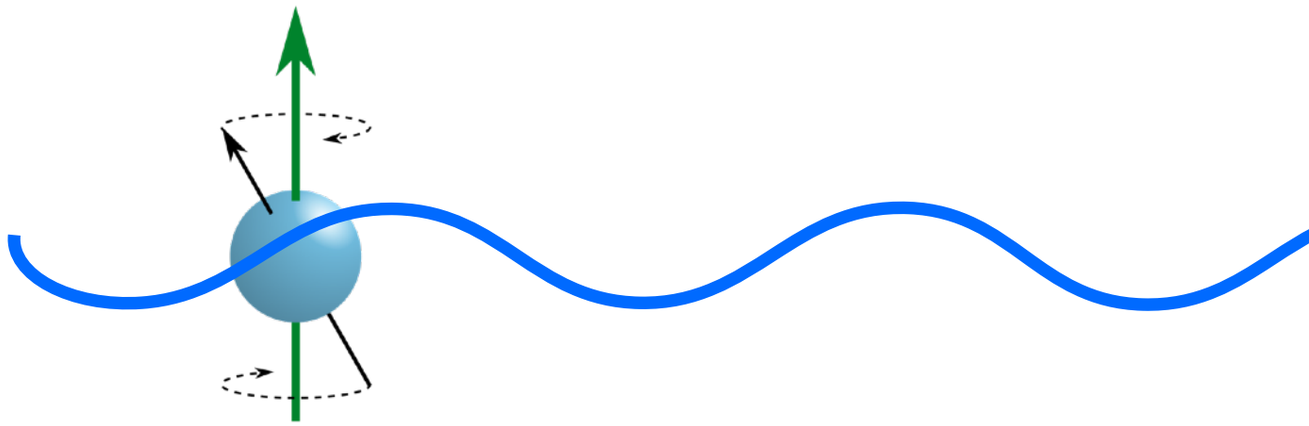
Time-dependent forces



DM robustly oscillates at a narrow frequency

Spin precession: fake B-field

$$\vec{\nabla}\phi \cdot \vec{\sigma}$$



Photon polarization rotation

Sources change Fundamental Constants (mass/coupling):

— atomic/molecular/nuclear spectroscopy: Static or dynamic!

Heavy Fields

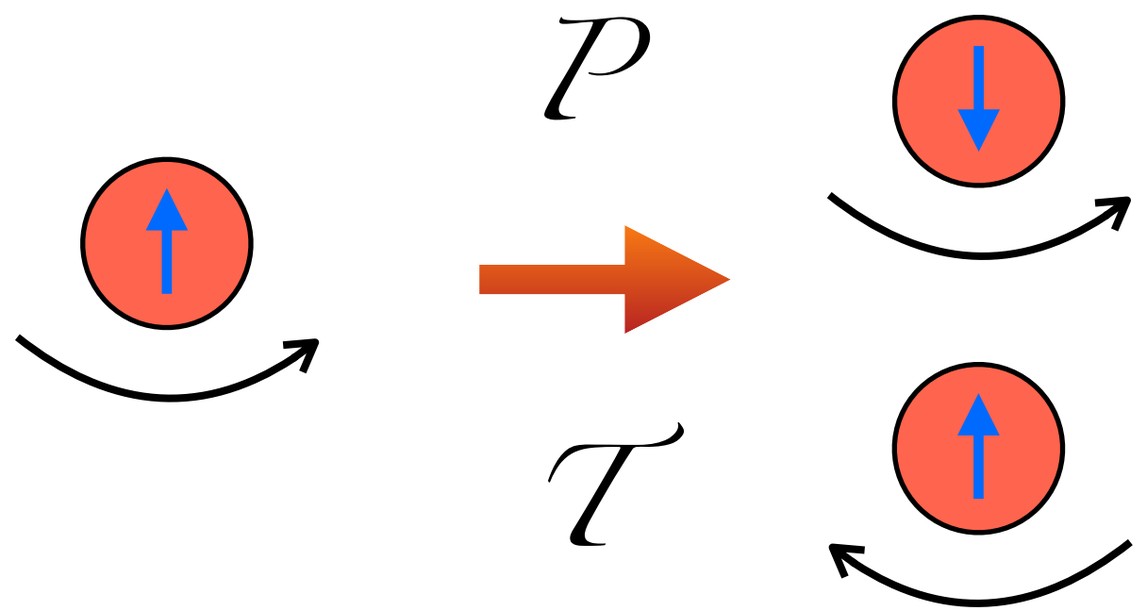
Heavy Fields (beyond colliders)

Higher-D operators: Precision measurement!

Produce ‘forbidden’ operators

EDMs

$$id_\psi \bar{\psi}\sigma\gamma^5\psi F$$



$d_e \sim$ 9 orders of magnitude above SM

$d_n \sim$ 5 orders of magnitude above SM

e.g., current constraints up to $d_n < \dfrac{m_n}{(10^6\,\mathrm{GeV})^2}$

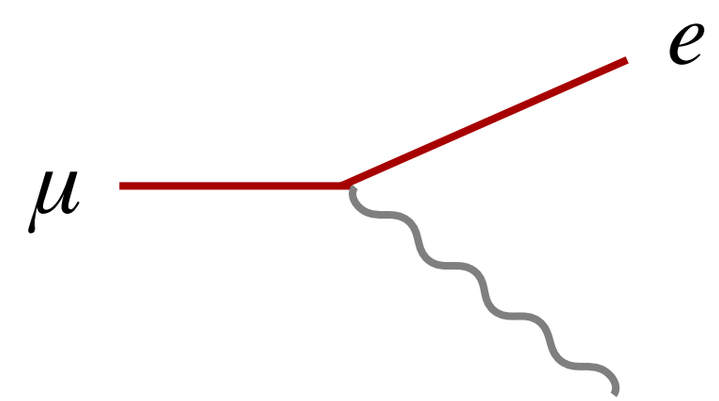
Heavy Fields

Higher-D operators: Precision measurement!

Produce ‘forbidden’ operators

FCNCs

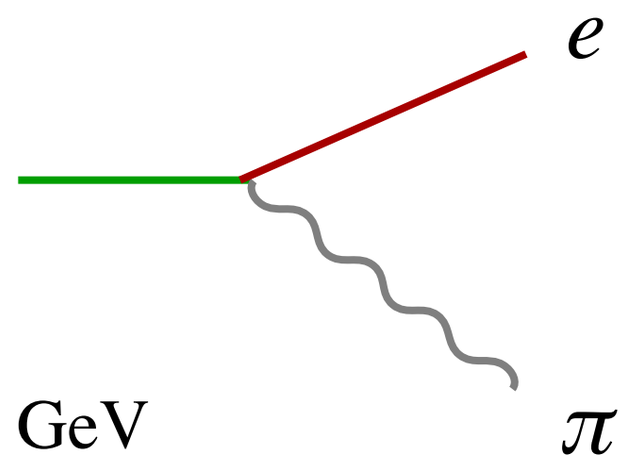
$e.g.,\ \mu \to e\gamma$



Bound on operator, approaching 10^6 GeV

Proton decay

$e.g.,\ p \to e\pi$



Bound on operator, approaching 10^{15} GeV

B-physics effects, charge radius of the proton, etc…

Violating SR

Violations of SR (Lorentz Invariance) can often be parameterized by background fields (static or dynamic)

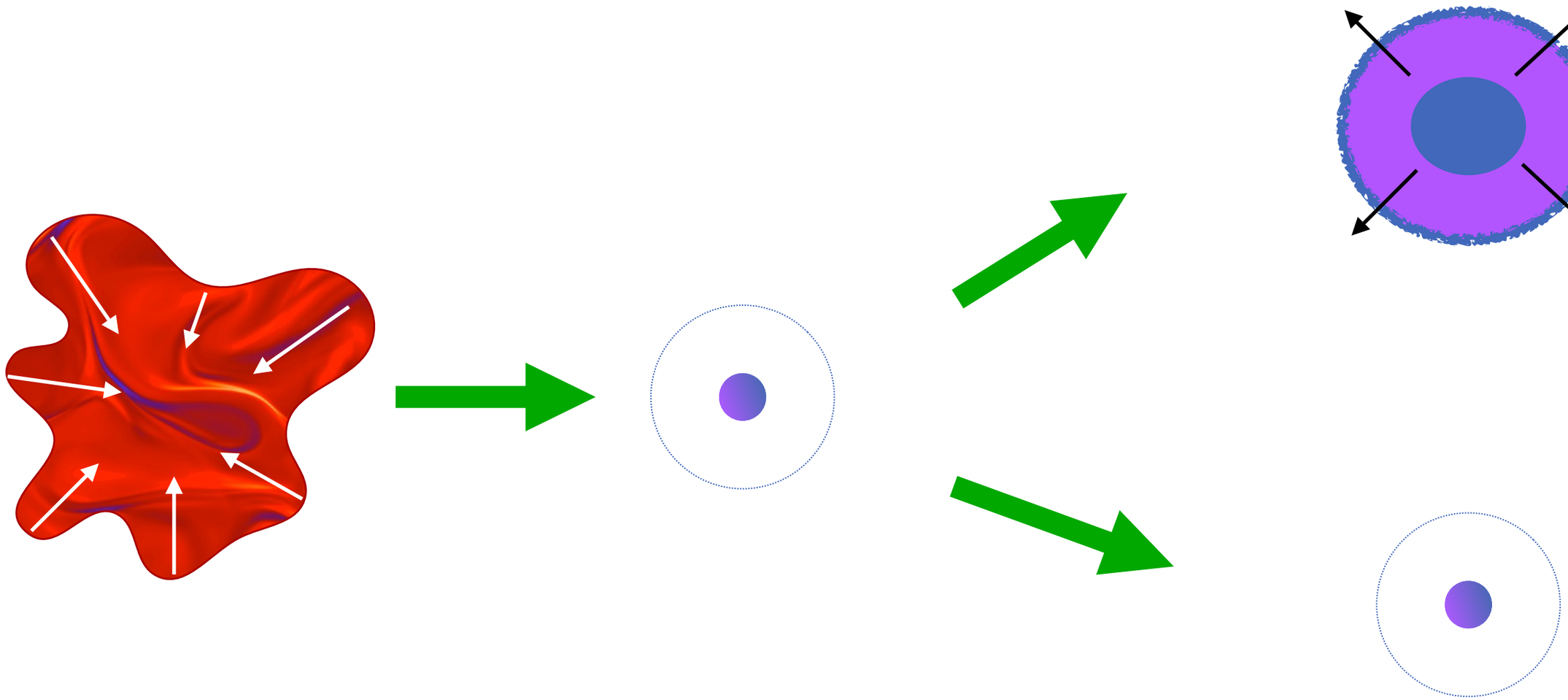
Violating GR

Violations of GR (EP violation, etc) can often be parameterized by new long-range forces

Tests of GR have only been probed to length scales of 100μm, or 10^{31} x Planck length!

QG (GR violation)

Only place in the universe we are confident GR breaks down —
center of Black Hole collapse



Study the horizon using interferometry, other tests of GR!
(light and atoms)

Violating QM

non-linear: localized wave function talking to itself:

$$i\partial_t \psi = \hat{H}\psi + \hat{\mathcal{F}}(\psi, \psi^*)\,\psi$$

—> Entanglement in “worlds” interact

Non-unitary: definite to mixed states

$$\partial_t \hat{\rho} = -i\left[\hat{H}, \hat{\rho}\right] + \hat{L}\hat{\rho}\hat{L}^\dagger - \frac{1}{2}\left[\hat{L}^\dagger\hat{L}, \hat{\rho}\right]_+$$

—> Decoherence (different from b.g. fields?)

Thank you