Particle Physics, Cosmology, and Supersymmetry

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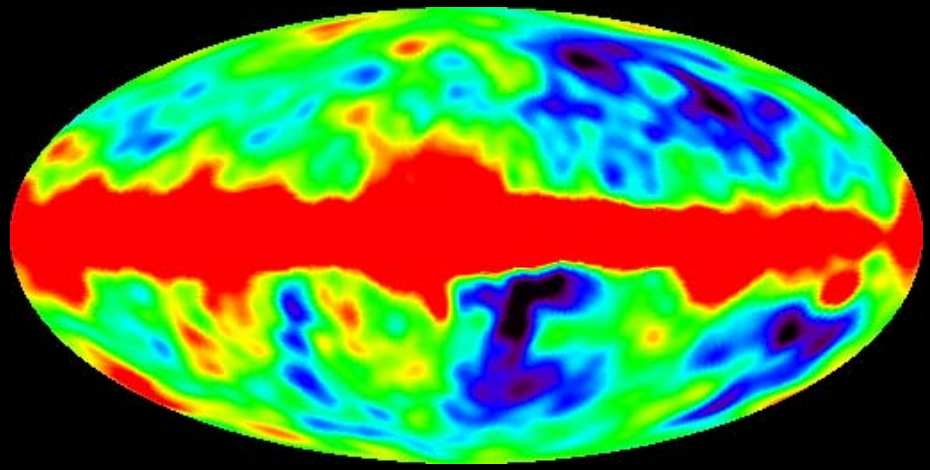
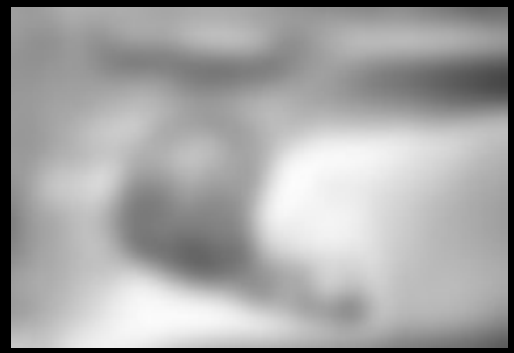
Recent progresses in cosmology

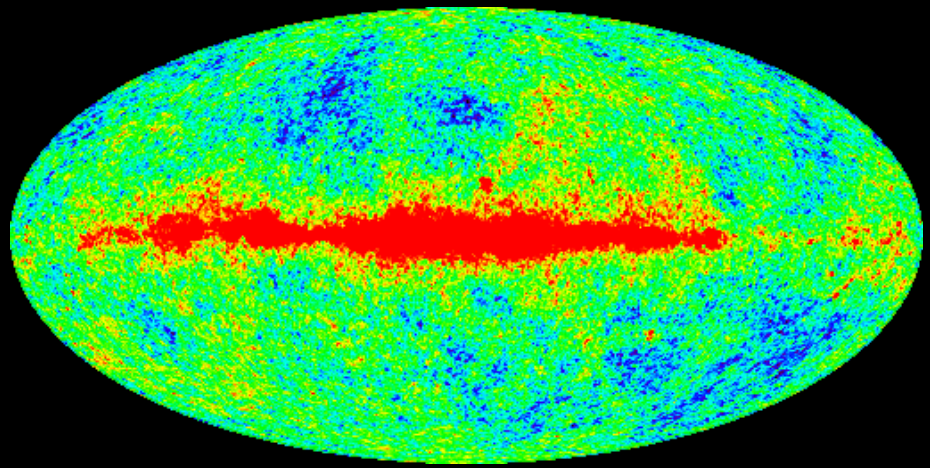
Precise observations of the universe

- Anisotropy of the cosmic microwave background (CMB)
- Cosmological constant
- Hubble constant
- Many more…

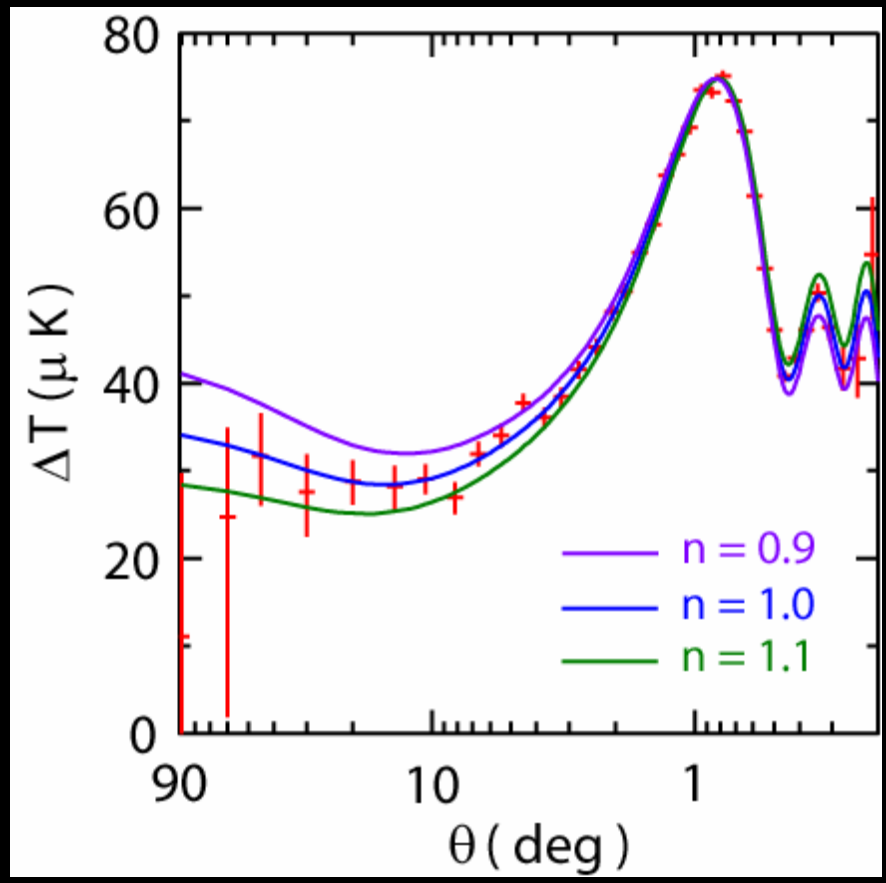
Map of the sky (before/after the WMAP)







CMB anisotropy from the inflation



⇒ Primordial fluctuation with n ~ 1 is needed

Today's talk:

Particle-physics explanation of the origin of the cosmic density fluctuations

$\Rightarrow$ A model of inflation and its possible test

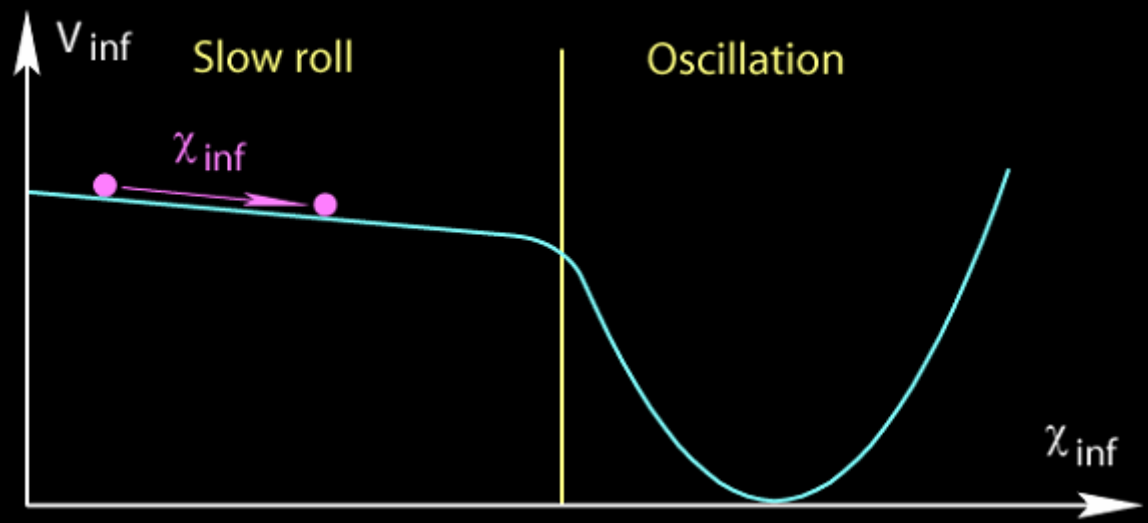
(Some of the) roles of supersymmetry in particle physics and cosmology

Example of an interplay of particle physics and cosmology

Origin of the cosmic density fluctuations

Inflation is the most famous scenario

If the universe is filled with some scalar field (called inflaton), universe rapidly expands



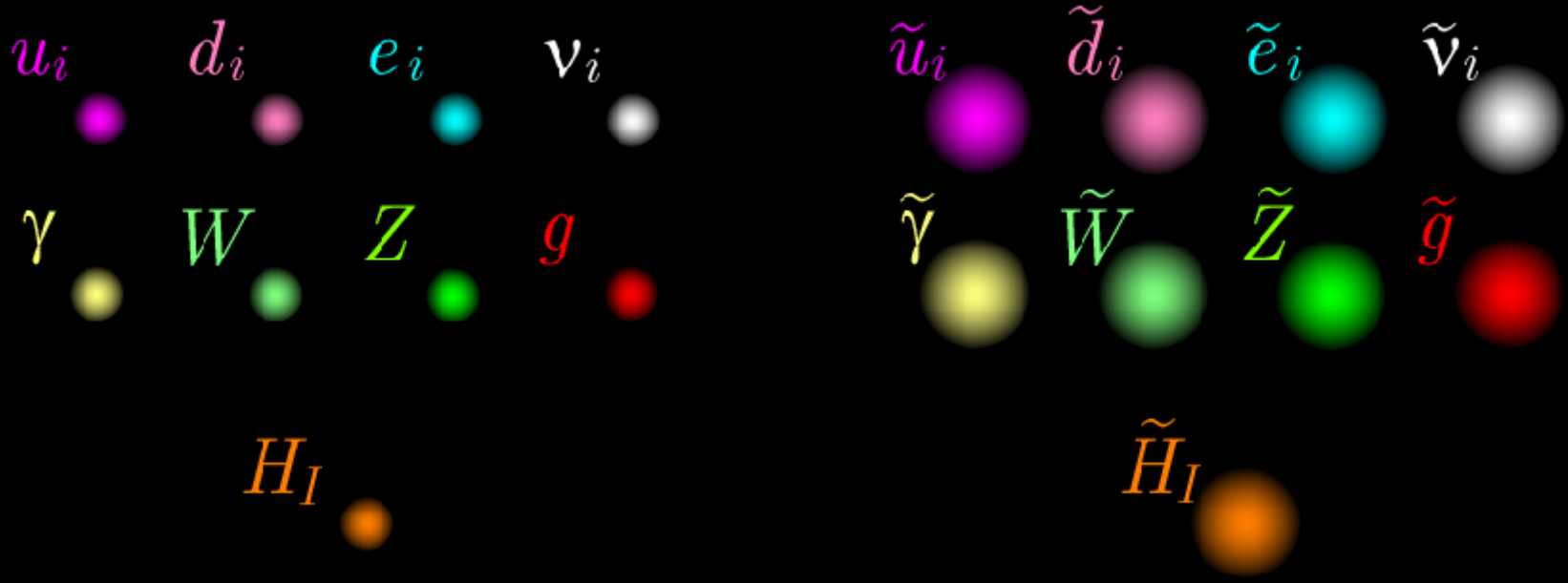
Way to a viable model of inflation

Flat potential:
easily disturbed by radiative corrections

$\Rightarrow$ Supersymmetry (SUSY)

- Symmetry between boson and fermion
- Radiative corrections cancel between the bosonic and fermionic loops

Supersymmetric standard model



$\Rightarrow$ Is there the inflaton in this list?

What is the inflaton?

To generate the density perturbation of the observed size, interaction of the inflation should be very weak

- Up-squark as the inflaton
- Right-handed sneutrino as the inflaton
- or we should introduce exotic particle(s)

Interaction of the up-squark

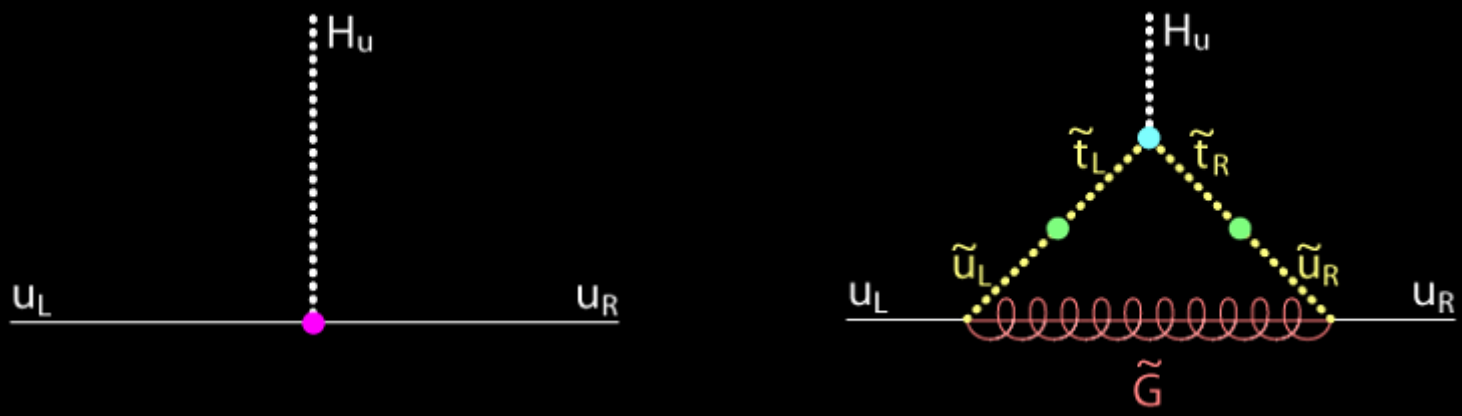
$L_{mass} \sim Y_u u_L u_R H + h.c.$

- To generate $m_u \sim$ a few MeV, $Y_u \sim 10^{-5}$
- $V \sim Y_u^2 |(\text{up-squark})|^4$

Inflation may occur when the amplitude of the up-squark is ~ Planck scale

In order to generate density perturbations of the observed size, $Y_u^2 \sim 10^{-12}$

Radiatively-generated up-quark mass



$\Rightarrow$ If the up-quark mass originates from supersymmetric loop diagram, $Y_u^2 \sim 10^{-12}$ can be realized

Up-squark as the inflaton

Very exotic, but this scenario is experimentally testable

Predictions:

- Supersymmetry
- $n \sim 0.96$
- Large (non-standard) flavor violations

Key word: Supersymmetry (SUSY)

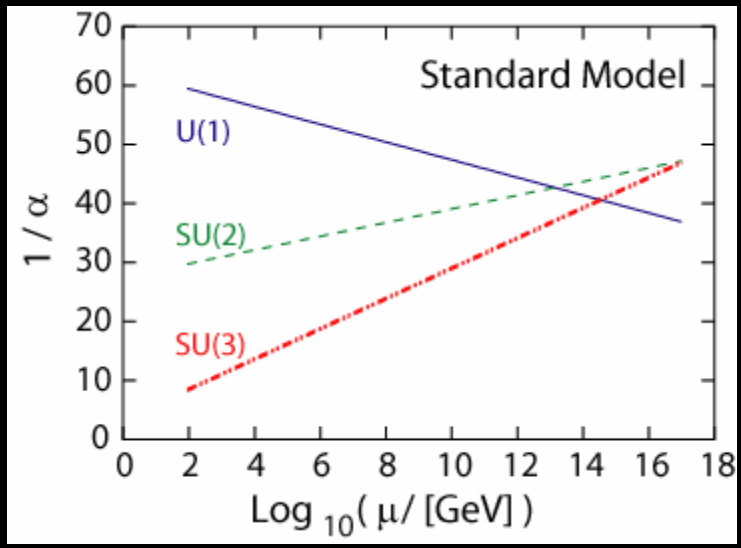
Supersymmetry will play very important roles in cosmology

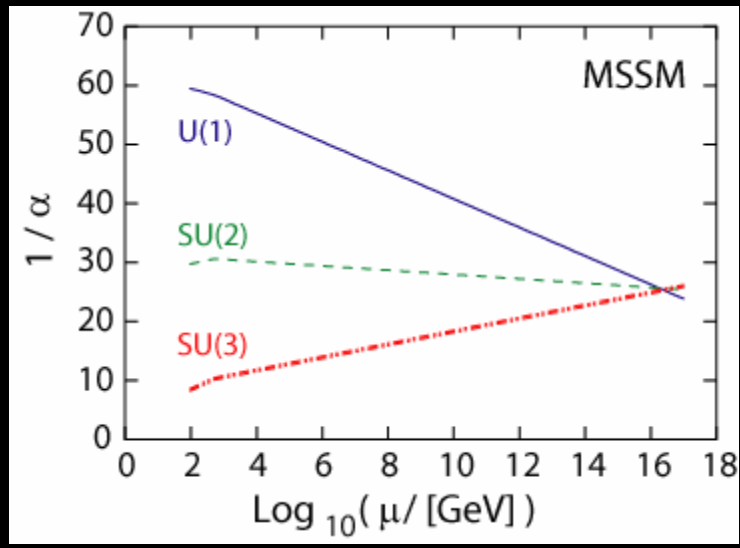
- Inflation
- Baryogenesis
- Cold dark matter

Of course, supersymmetry is important also in particle physics

SUSY: also important for particle physics

Grand unification

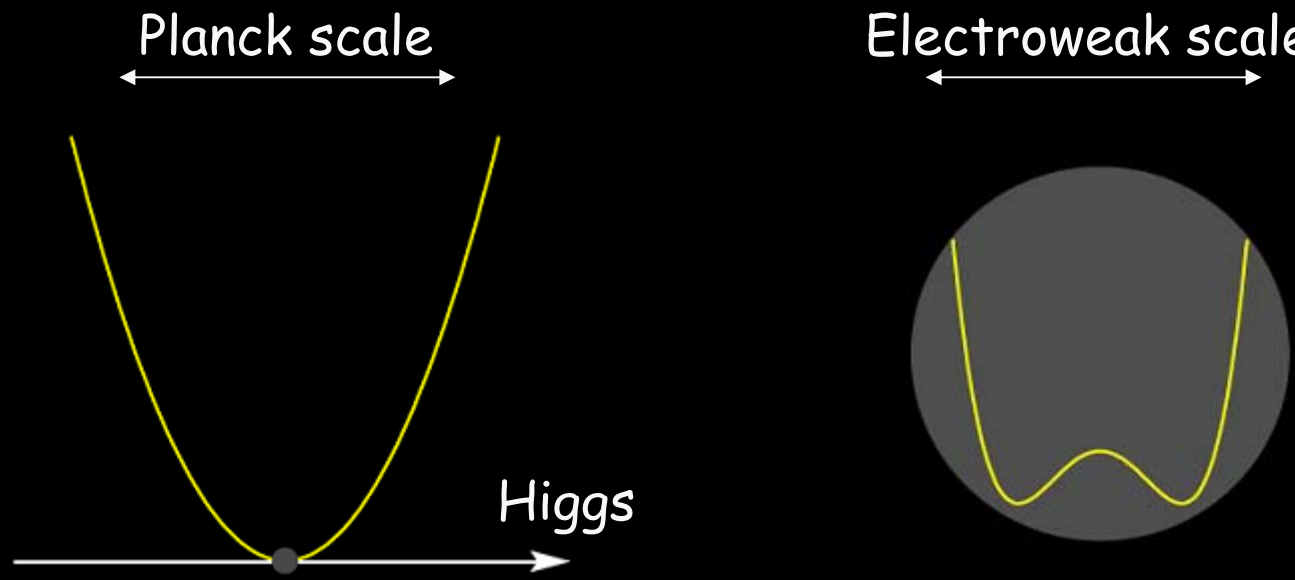




⇒ SUSY helps gauge-coupling unification

SUSY can solve the hierarchy problem

How to understand $M_{Pl} / M_{EW} \sim 10^{16}$?



⇒ SUSY can protect the smallness of the electroweak scale

Other important issue: neutrino physics

Neutrino oscillations are the first evidences of the physics beyond the standard model

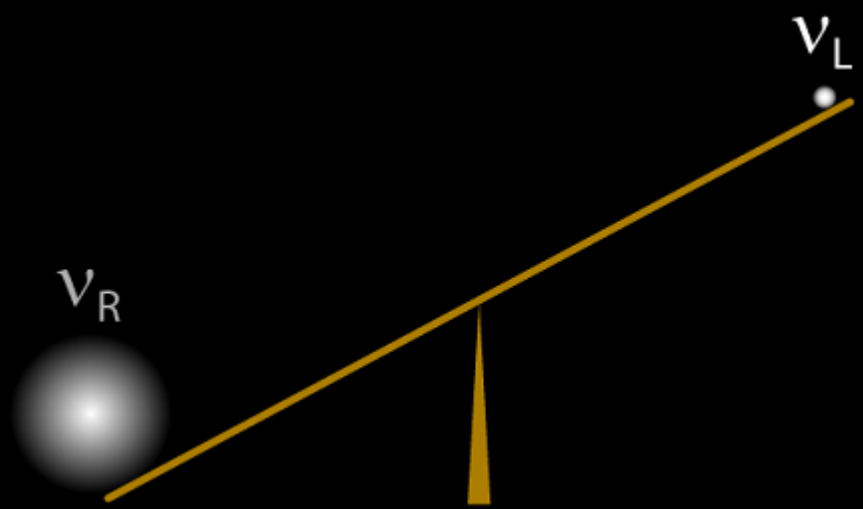
Neutrino masses are very small, but (probably) non-vanishing

- Masses of the neutrinos are much smaller than those of other fermions

Seesaw mechanism for neutrino mass

$$\mathcal{L} = -\frac{1}{2}(\nu_L \nu_R) \begin{pmatrix} 0 & y_\nu \langle H \rangle \\ y_\nu \langle H \rangle & M_{\nu_R} \end{pmatrix} \begin{pmatrix} \nu_L \\ \nu_R \end{pmatrix}$$

$$\Rightarrow \quad m_{\nu_R} = M_{\nu_R}, \quad m_{\nu_L} = \frac{y_\nu^2 \langle H \rangle^2}{M_{\nu_R}}$$



$\Rightarrow$ Right-handed neutrinos seem to exist

Supersymmetry + right-handed neutrinos

In unified models, flavor mixing of the neutrinos and those of the quarks are correlated

$\Rightarrow$ Flavor violation may be embedded into the scalar-down mass matrix via RG effect

(Exotic) CP and flavor violations

In SUSY models with right-handed neutrinos, exotic CP and flavor violations may exist

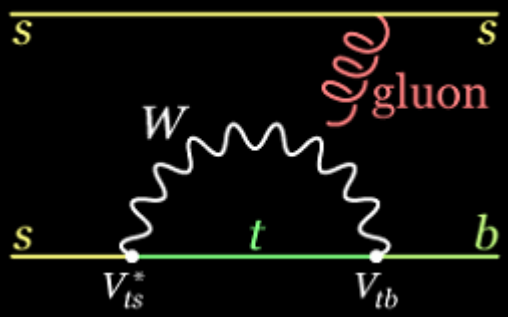
$\Rightarrow$ One interesting mode: $B^0 \to \phi K^0$

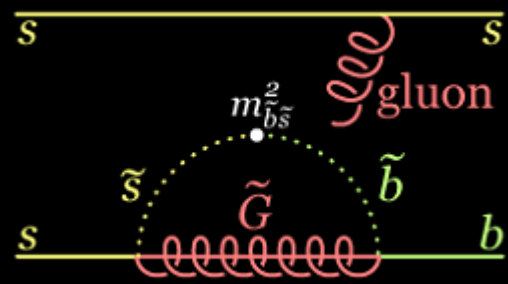
Currently measured values of $S(B^0 \to \phi K^0)$

$-$ 0.96 $\pm$ 0.50 (Belle)

$+$ 0.45 $\pm$ 0.43 (BaBar)

SUSY contribution to $S(B^0 \to \phi K^0)$





$S_{SUSY}(B^0 \to \phi K^0)$ can be $O(0.1)$

$\Rightarrow$ SUSY contribution can be sizable enough to be seen at B-factories

My perspectives

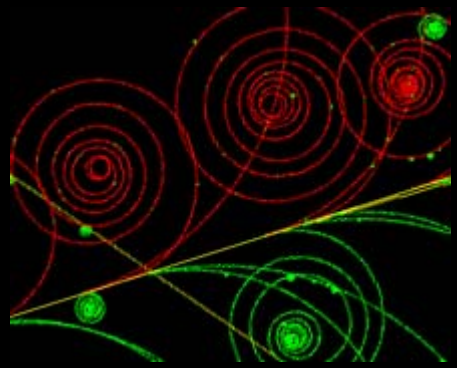
Now, it is important to study particle physics and cosmology simultaneously

$\Rightarrow$ Their interplay will be very important

Supersymmetry will play very important roles

$\Rightarrow$ Discoveries of the superparticles (and Higgs) will be the next step

Summary



Particle Physics

Cosmology

Supersymmetry