ST&FI

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ST&FI
String theory and Fundamental Interactions

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Research: Attempt to connect String Theory to observations

→ String Phenomenology and String Cosmology

ST&FI
String theory and Fundamental Interactions

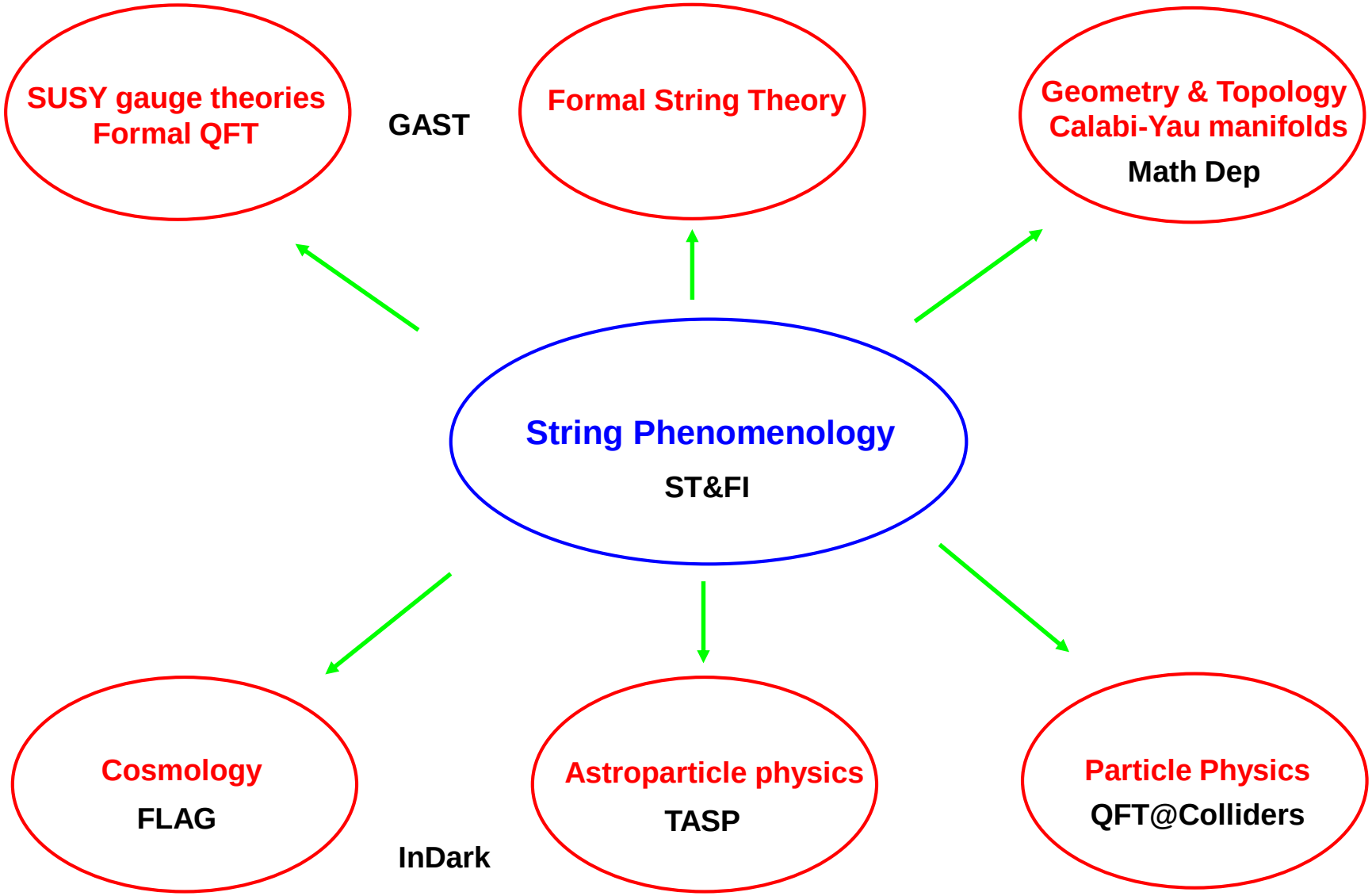
Selected activities:

- Funding: Leadership of WG on **WISPs Model Building** in European COST action **COSMIC WISPers in the Dark Universe: Theory, astrophysics and experiments** started in October 2022
- Organisition: Organising Committee of International Conference **String Phenomenology 2024**, Padova, 24-28/6/2024

Main international collaborations:

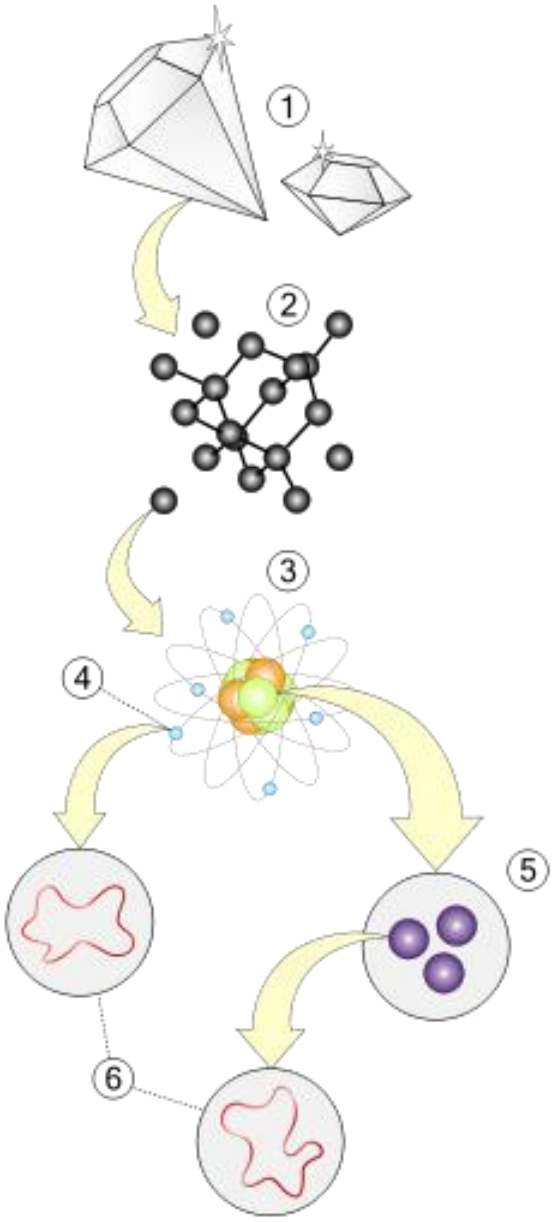
- University of Cambridge
- University of Oxford
- Perimeter Institute Canada
- ICTP Trieste
- DESY Hamburg
- Heidelberg University
- CNRS Paris
- HRI India
- University of New Mexico
- Texas A&M
- Oklahoma University
- Liverpool University

The world as seen by a string phenomenologist



String theory: the idea

Change point of view:
substitute point-like particles with 1D objects

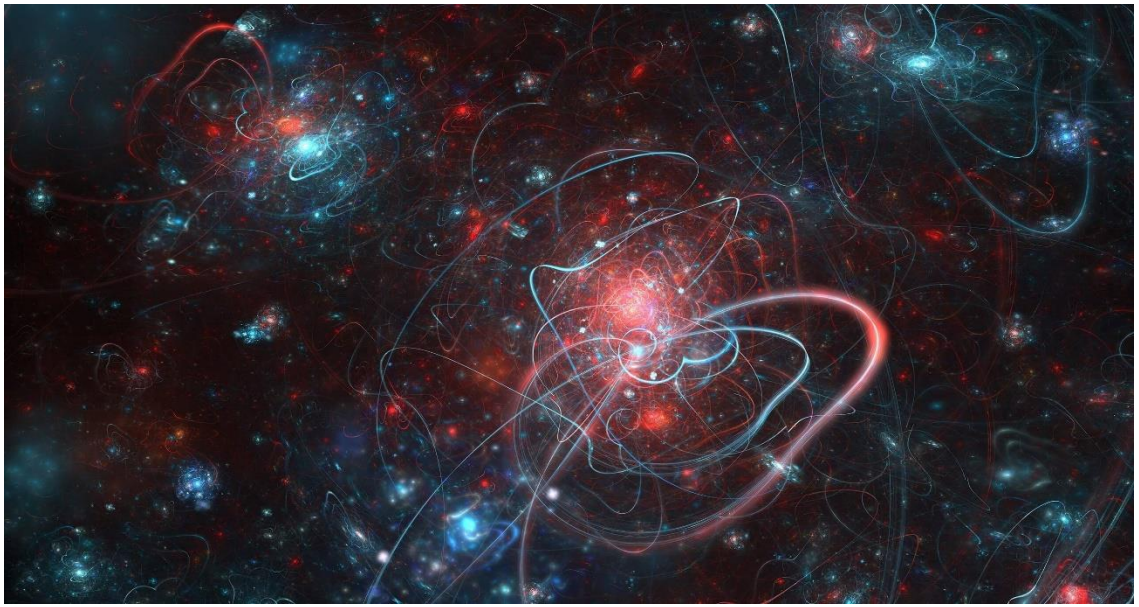


1) All particles are different vibration modes of the same string
2) Unification of matter and interactions
3) Consistently includes quantum gravity
4) Just 1 parameter, the string length ℓ_s, from which everything can be derived
5) At low energies contains general relativity, supersymmetry and gauge theories like the Standard Model

Extra dimensions

String theory predicts the number of space-time dimensions

Result: 9 spatial dimensions + 1 time

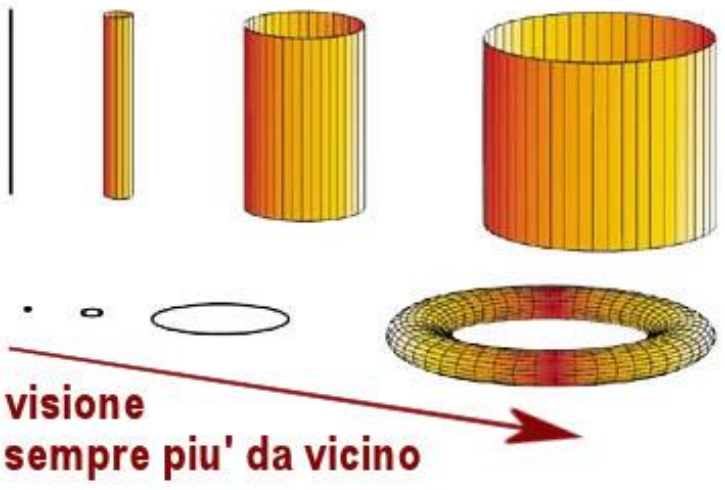


But the observed number is
3 spatial dimensions
+ 1 time

Falsifiable or false?

Small extra dimensions

- Universe: 10D = 4D large + 6D very small with $d < 10^{-18}$ m



Crucial to predict the size of extra dimensions!

⟶ given by value of moduli ϕ

new 4D spin-0 particles with gravitational couplings

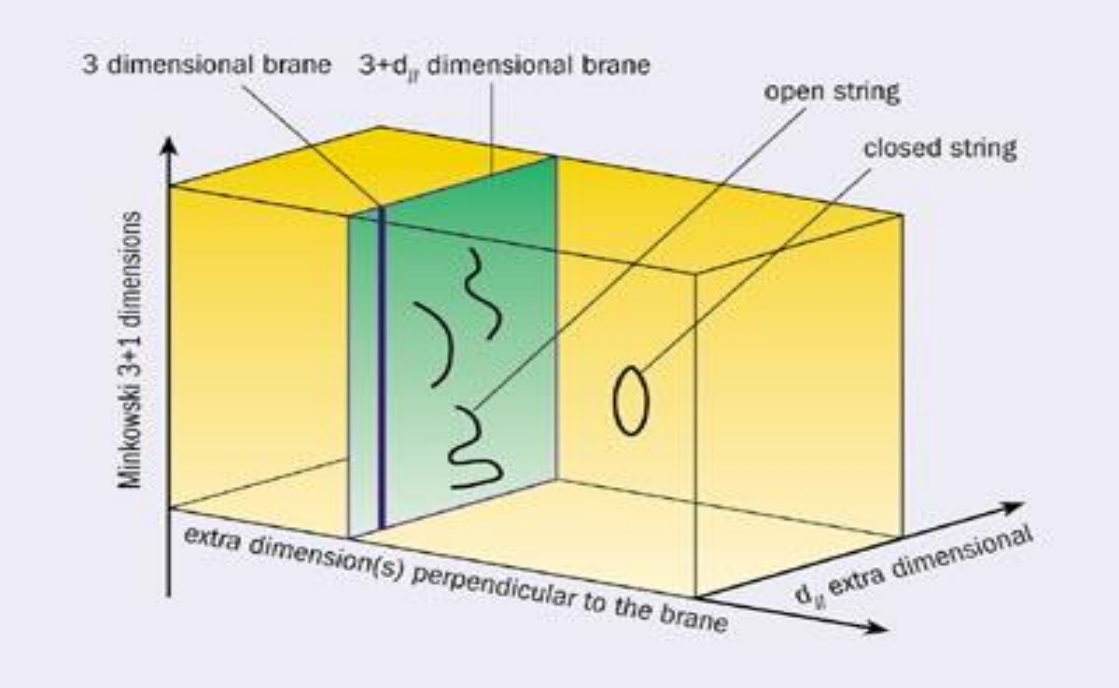
- Moduli ϕ massless at classical level ⟶ flat potential $V(\phi) = 0$ ⟶ ϕ unfixed!
- 2 problems:

i) Unobserved long-range fifth forces (for $m < 1$ meV)

ii) Unpredictability as g_{YM}, Y_{ijk}, mass spectrum, SUSY breaking, Λ depend on ϕ

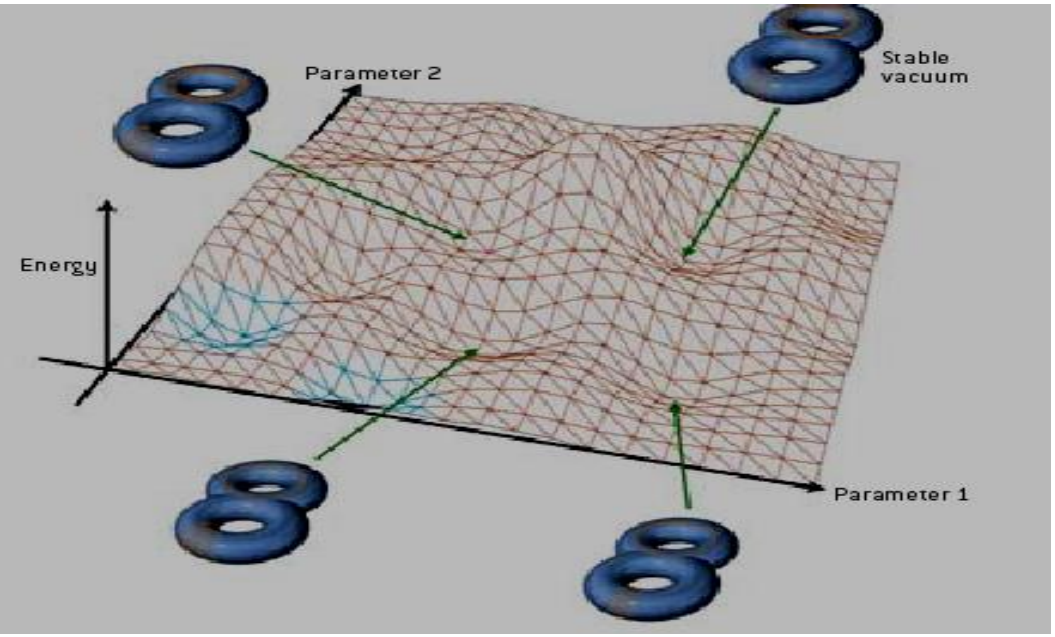
⟶ develop $V(\phi) \neq 0$ via fluxes/quantum corrections which fix ϕ
landscape of string vacua ~ 10^{500}
$m > 50$ TeV via moduli stabilisation to avoid cosmological problems

Large extra dimensions



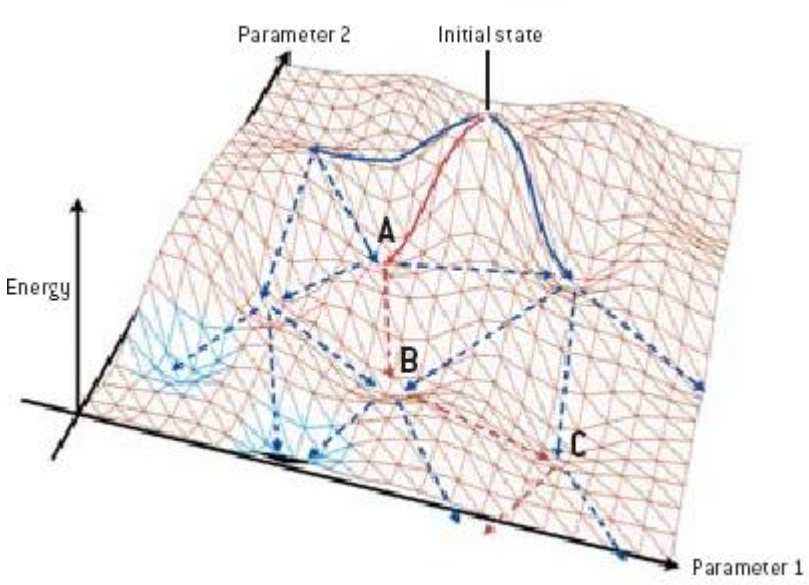
- Open strings trapped on branes which provide non-Abelian gauge theories and chiral matter
- Closed strings (moduli and graviton) move freely in spacetime
- All particles and interactions (except for gravity) confined on branes (SM or MSSM/GUT)
- Large extra dimensions detectable via modifications of gravity at micron scale
- Strings might not be so far from TeV scale

String landscape

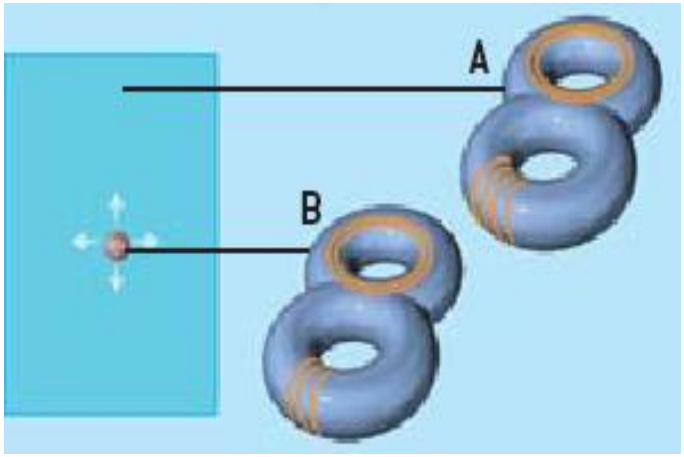


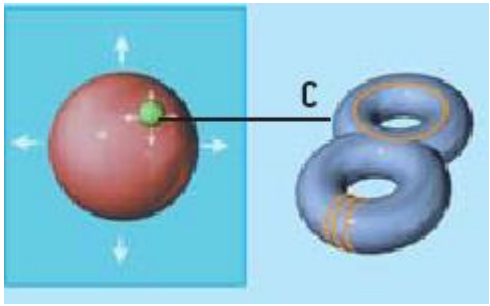
Plethora of vacua with different size and shape of extra dimensions (different moduli values)

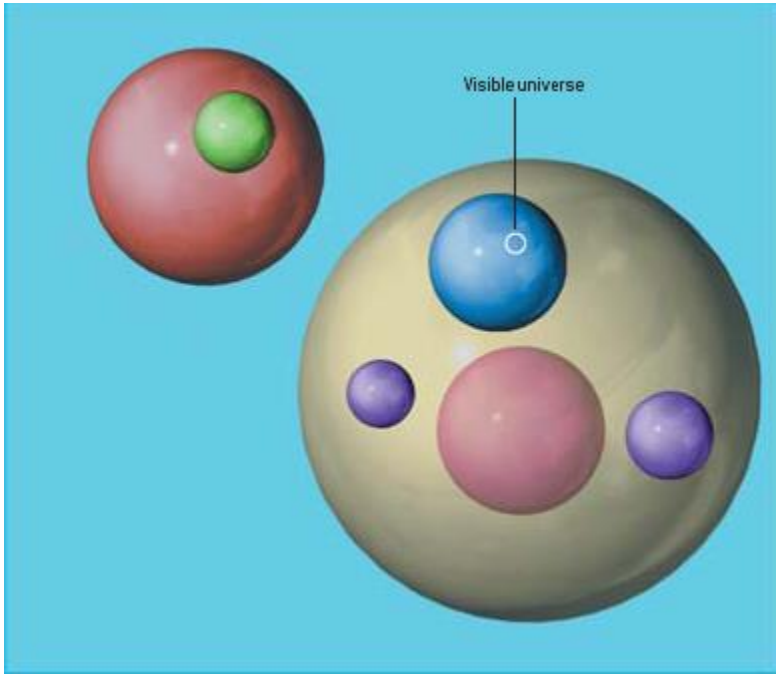
Quantum transitions (tunneling effect or inflation)



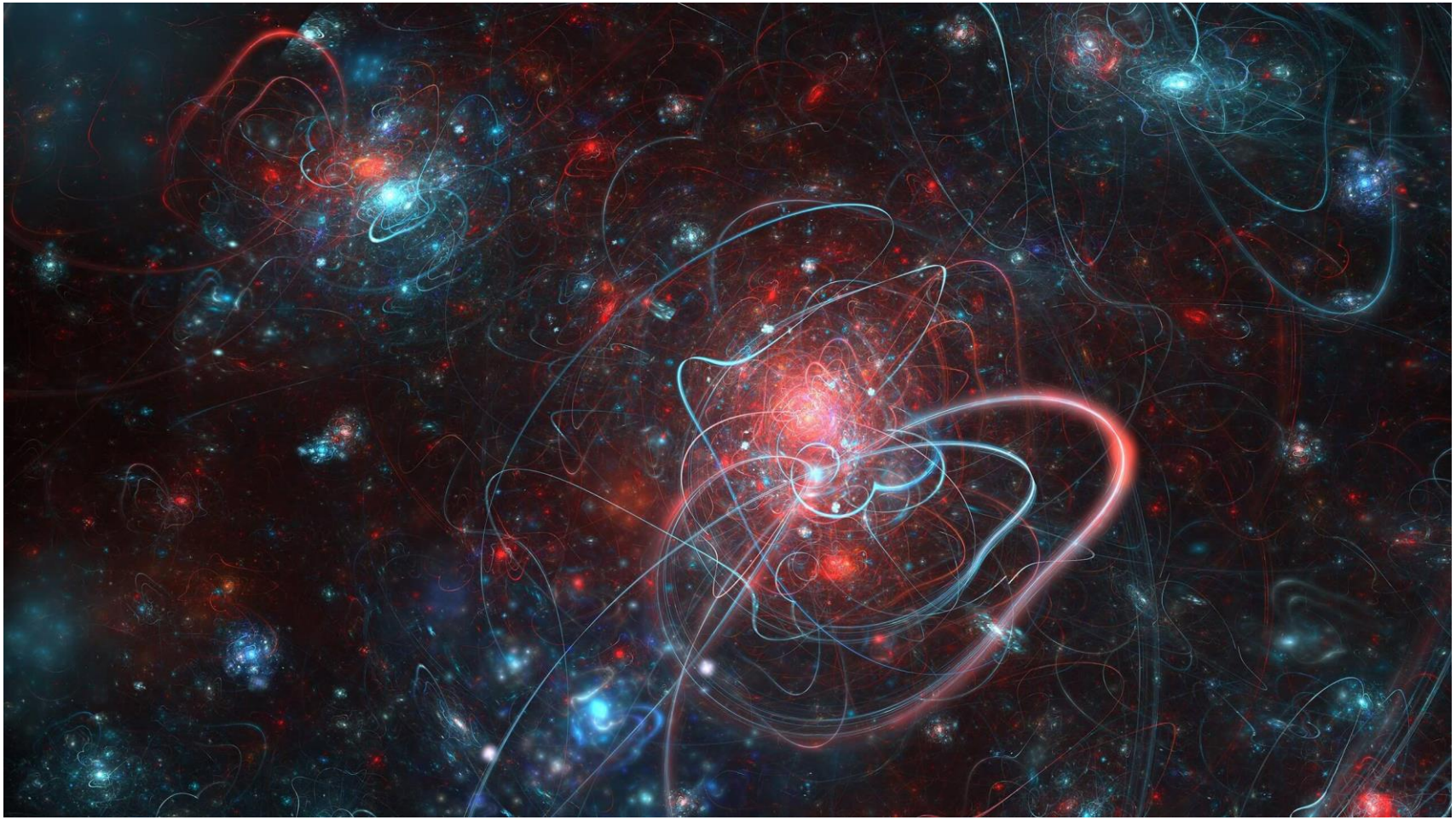
A multiverse?







…but what does string theory predict?



Testing string theory?

- String theory (like QFT) is a framework, not a model (like SM)
- Generic features: strings and extra dimensions but unlikely to be tested with accelerators
  → focus on low-energy 4D applications

- String theory yields a landscape of 4D vacua
  i) are they actual solutions?
  ii) how are they connected?
  iii) is there a selection principle?
  } need full quantum dynamics of string theory

- 2 approaches in absence of complete answers:

1) Focus on a vacuum
   - pro: explicit computation
   - con: lamppost effect

2) Extract statistics
   - pro: find generic features
   - con: trustability of results (moduli stabilisation?)

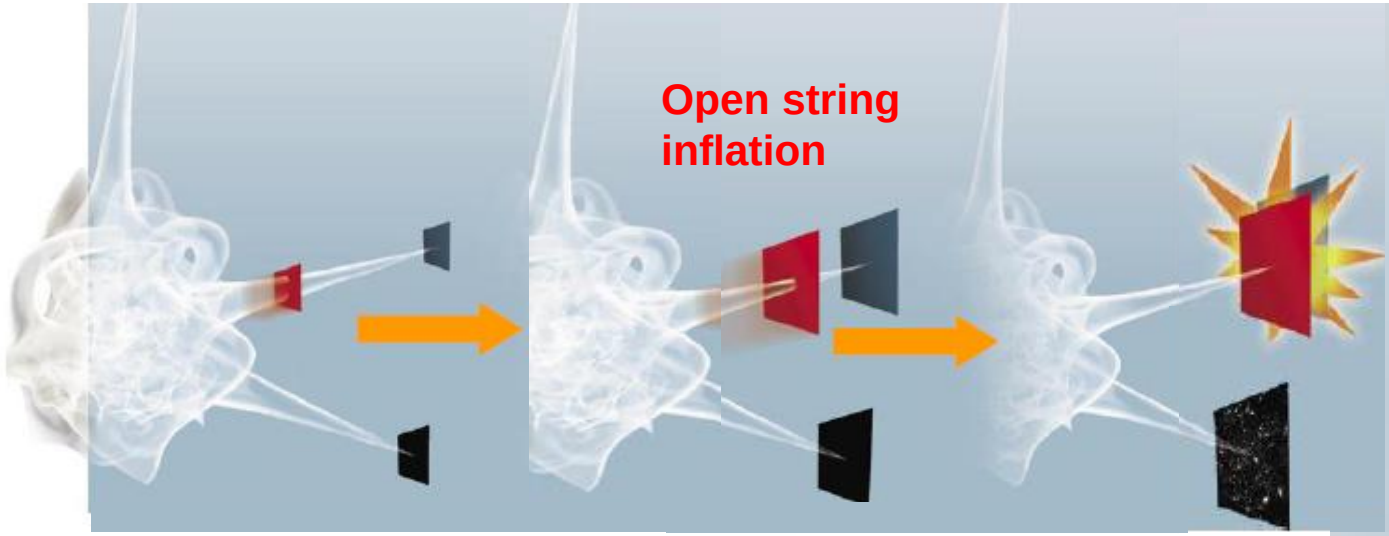
- Look for:

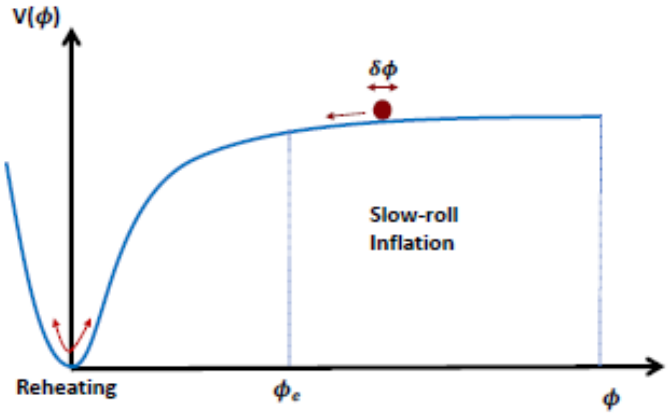
1) Non-generic features of 4D string models
   ex: inflation with large GWs and low SUSY, thermal WIMP DM, $N_{eff} = 3$, …

2) Generic features of 4D string models that are not well motivated in QFT
   ex: many WISPs (moduli, ALPs,..), matter domination, non-thermal DM, extra U(1)s …

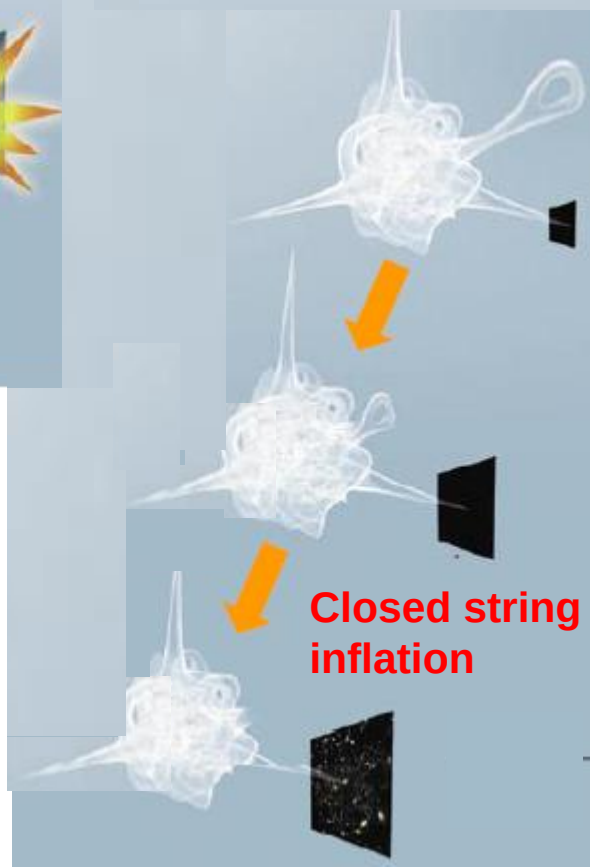
String inflation

- String theory provides for free many scalars which can drive inflation
- Inflation is UV sensitive: need a UV complete embedding to trust models
- Hard to get models with large r ($r \lesssim 0.01$) due to difficulty to get trans-Planckian field ranges





String model	n_s	r
Fibre Inflation	0.967	0.007
Blow-up Inflation	0.961	10^{-10}
Poly-instanton Inflation	0.958	10^{-3}
Aligned Natural Inflation	0.960	0.098
N-Flation	0.960	0.13
Axion Monodromy	0.971	0.083
D7 Fluxbrane Inflation	0.981	5×10^{-6}
Wilson line Inflation	0.971	10^{-8}
D3-$\overline{\text{D3}}$ Inflation	0.968	10^{-7}
Inflection Point Inflation	0.923	10^{-6}
D3-D7 Inflation	0.981	10^{-6}
Racetrack Inflation	0.942	10^{-8}
Volume Inflation	0.965	10^{-9}
DBI Inflation	0.923	10^{-7}



Supersymmetry and its breaking

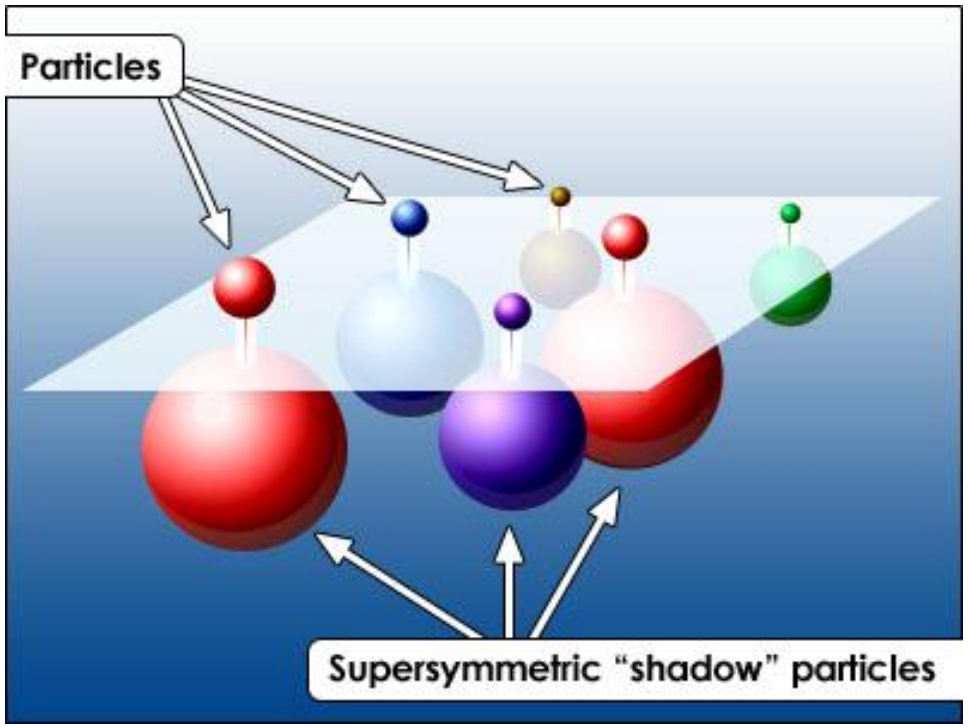
- Supersymmetry naturally present in string theory for consistency
- Each particle as a superpartner with same mass but different spin
- Symmetry not seen in Nature → must be broken
- Supersymmetry can explain:

  i) Higgs mass around 125 GeV
  ii) Unification of non-gravitational forces
  iii) Dark matter

- Moduli dynamics breaks supersymmetry
- Generate mass of superpartners via gravity interactions

  → Can make predictions

- 2 scenarios:
  i) non-sequestered: $m_{SUSY} \lesssim M_{inf}$
  ii) sequestering: $m_{SUSY} << M_{inf}$

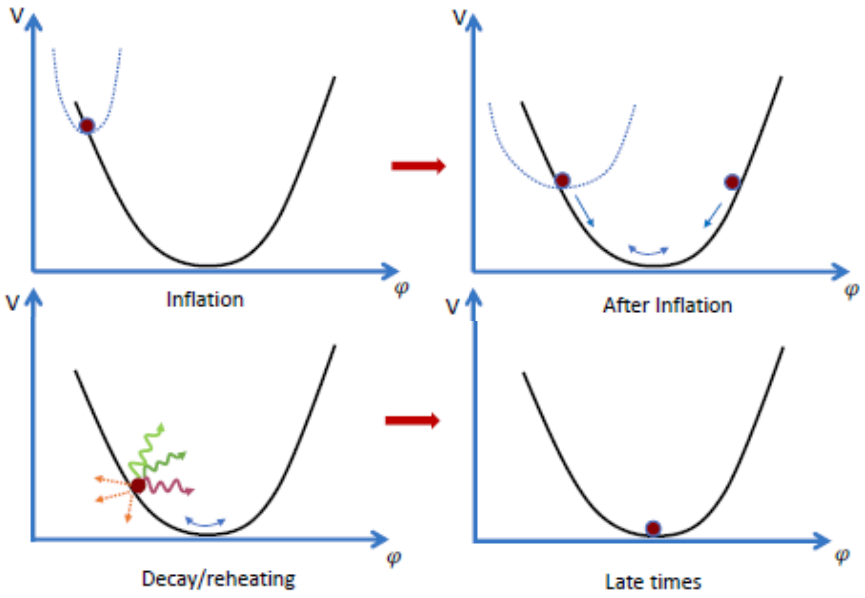


Reheating and moduli oscillations

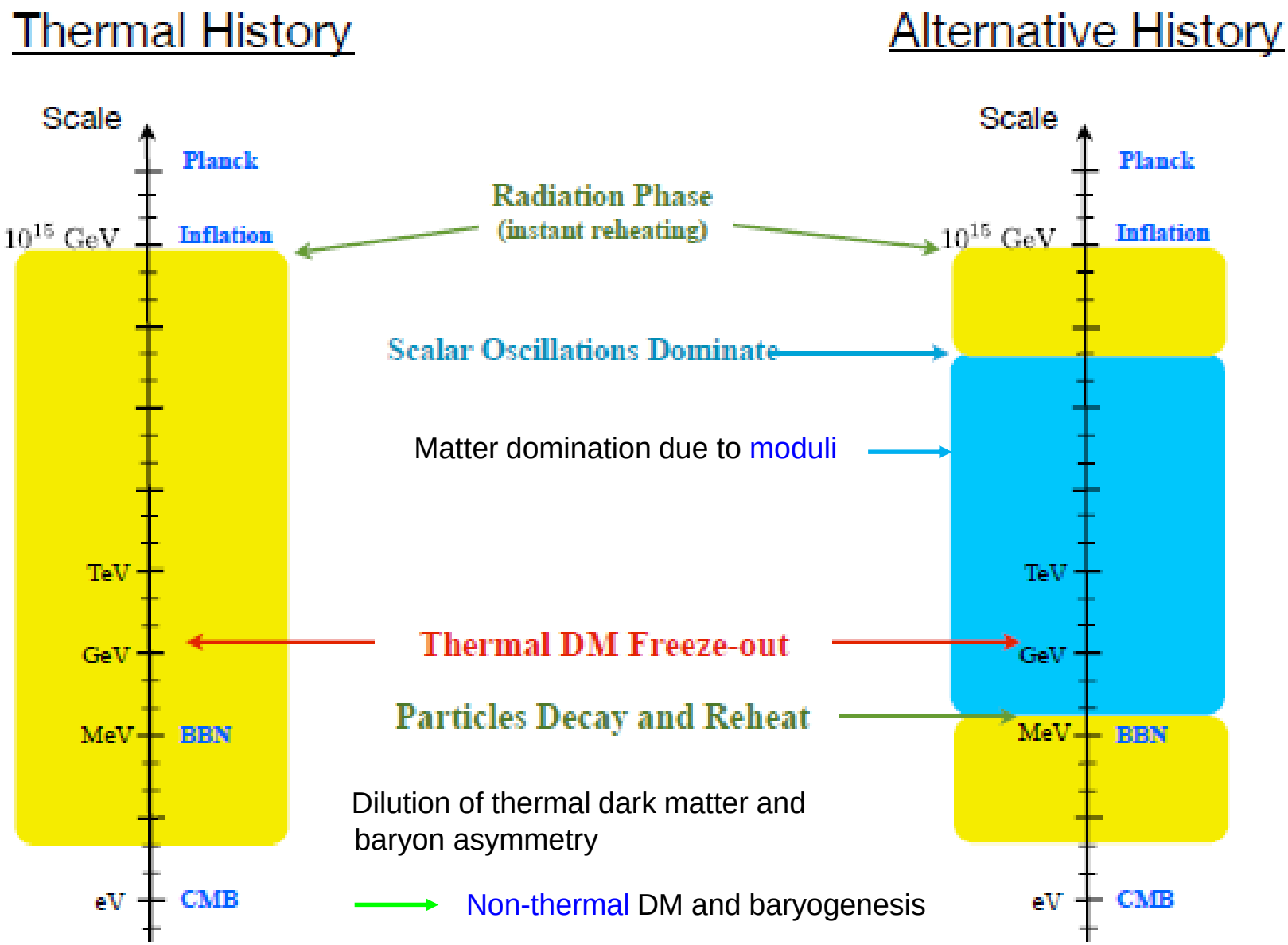
- Reheating: production of SM fields from inflaton decay after the end of inflation

  → radiation domination

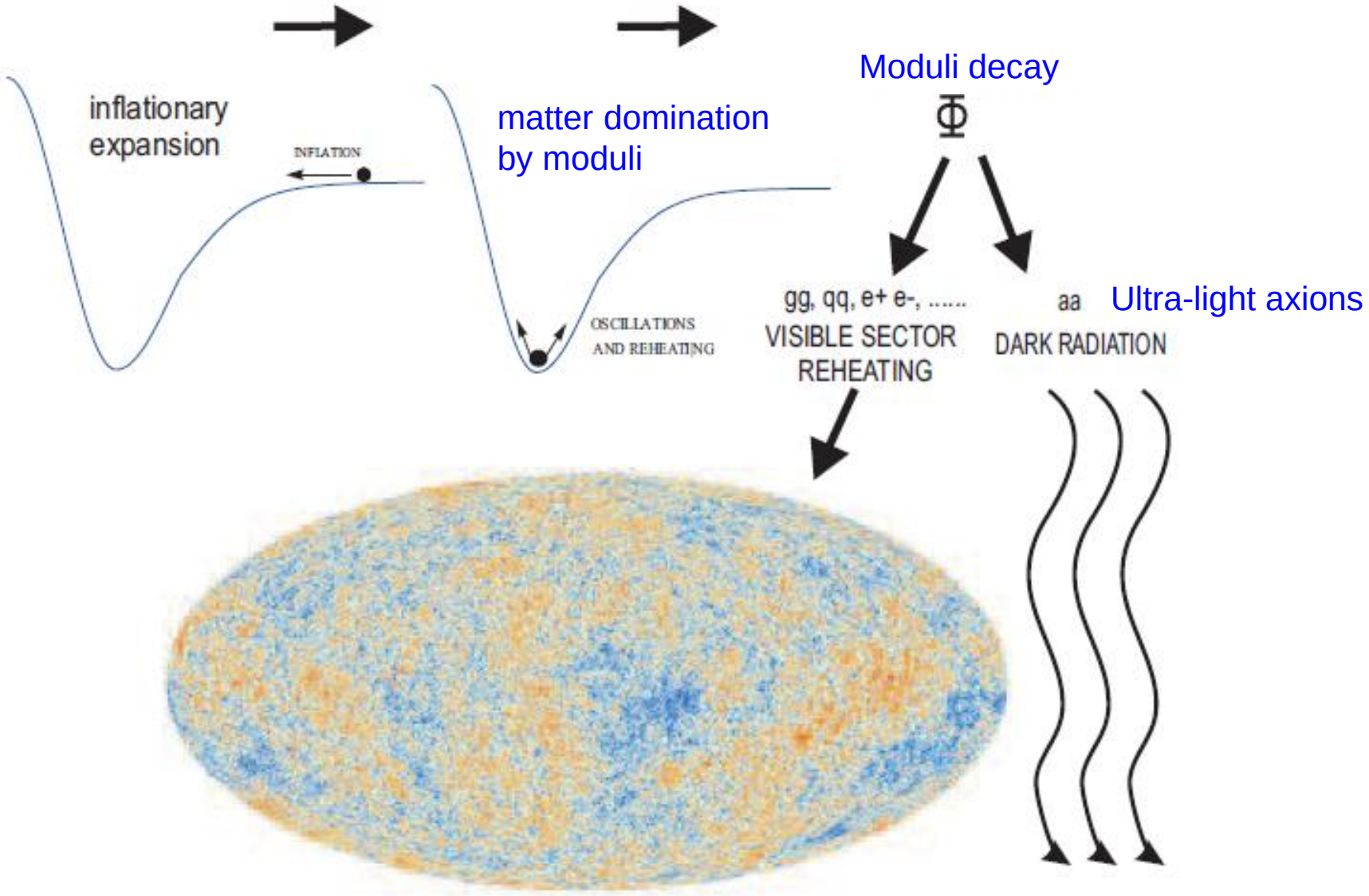
- Early epoch of matter domination due to moduli oscillations prior to BBN



Non-standard cosmology from strings



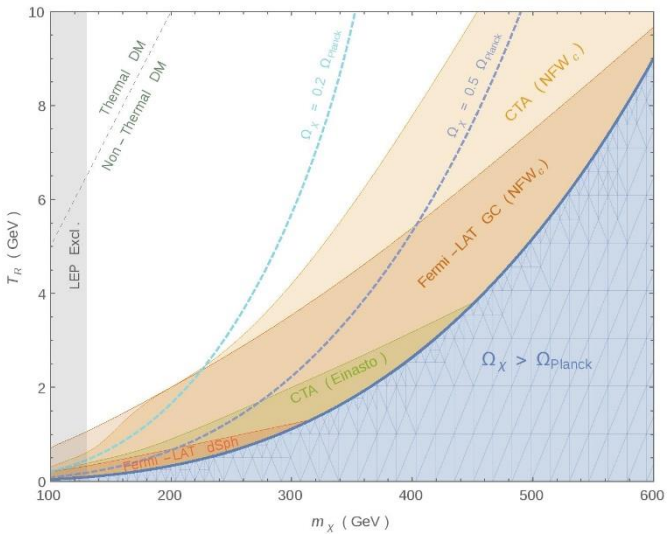
Axionic dark radiation



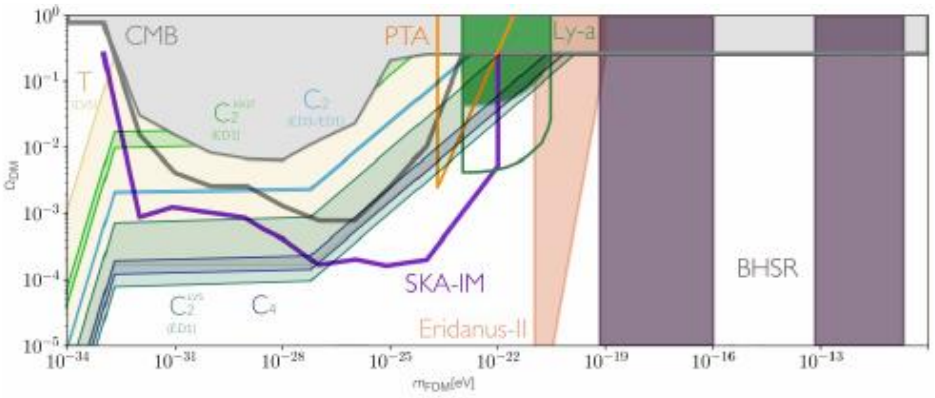
Prediction: $N_{eff} > 3$

Non-standard dark matter

Non-thermal WIMPs



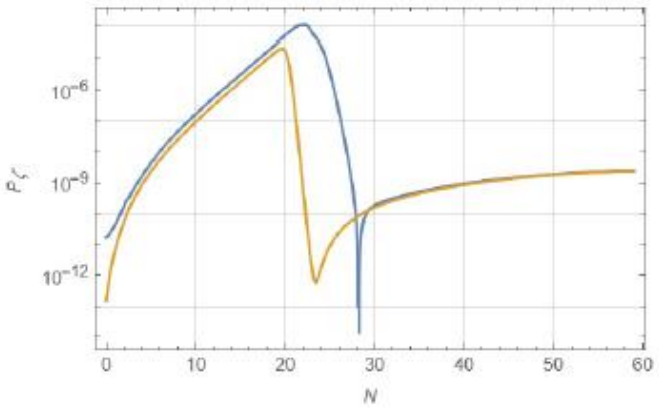
Fuzzy DM



Fuzzy DM from ultra-light ALPs with m ~10^{-22} eV

Higgsino DM with m~300 GeV or WIMPs with m~10^{10} GeV

PBH DM



Detectable secondary GWs