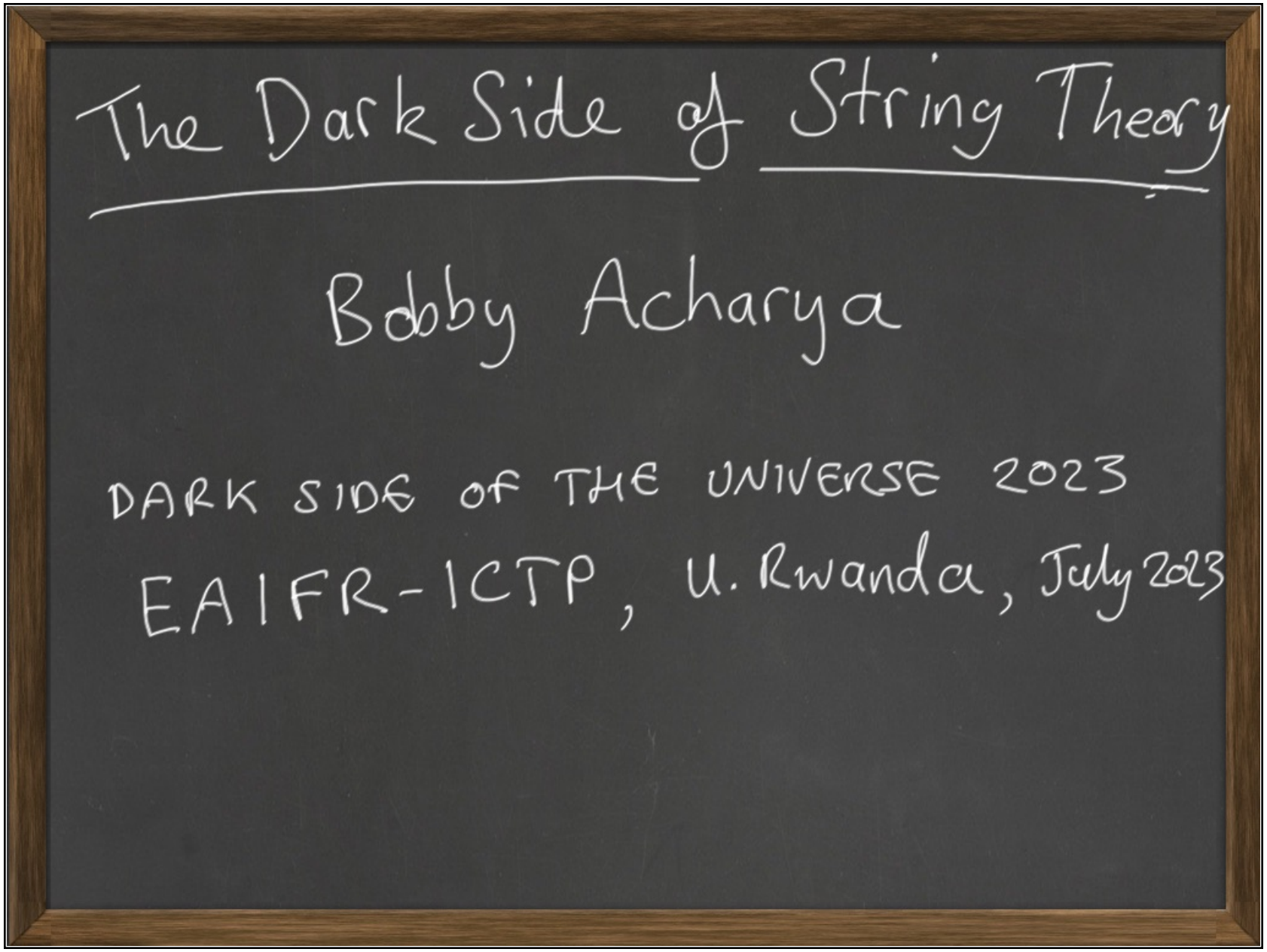
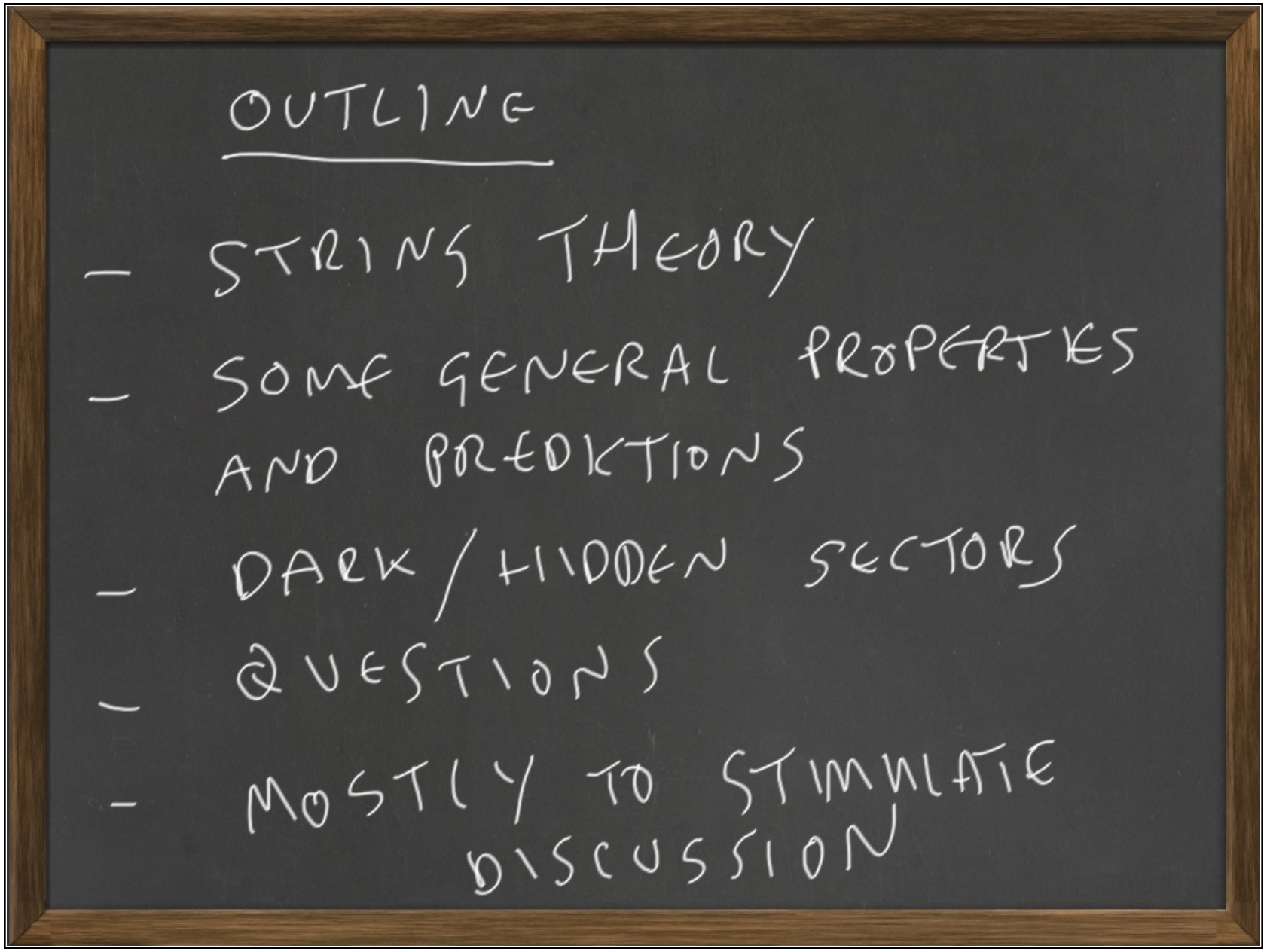
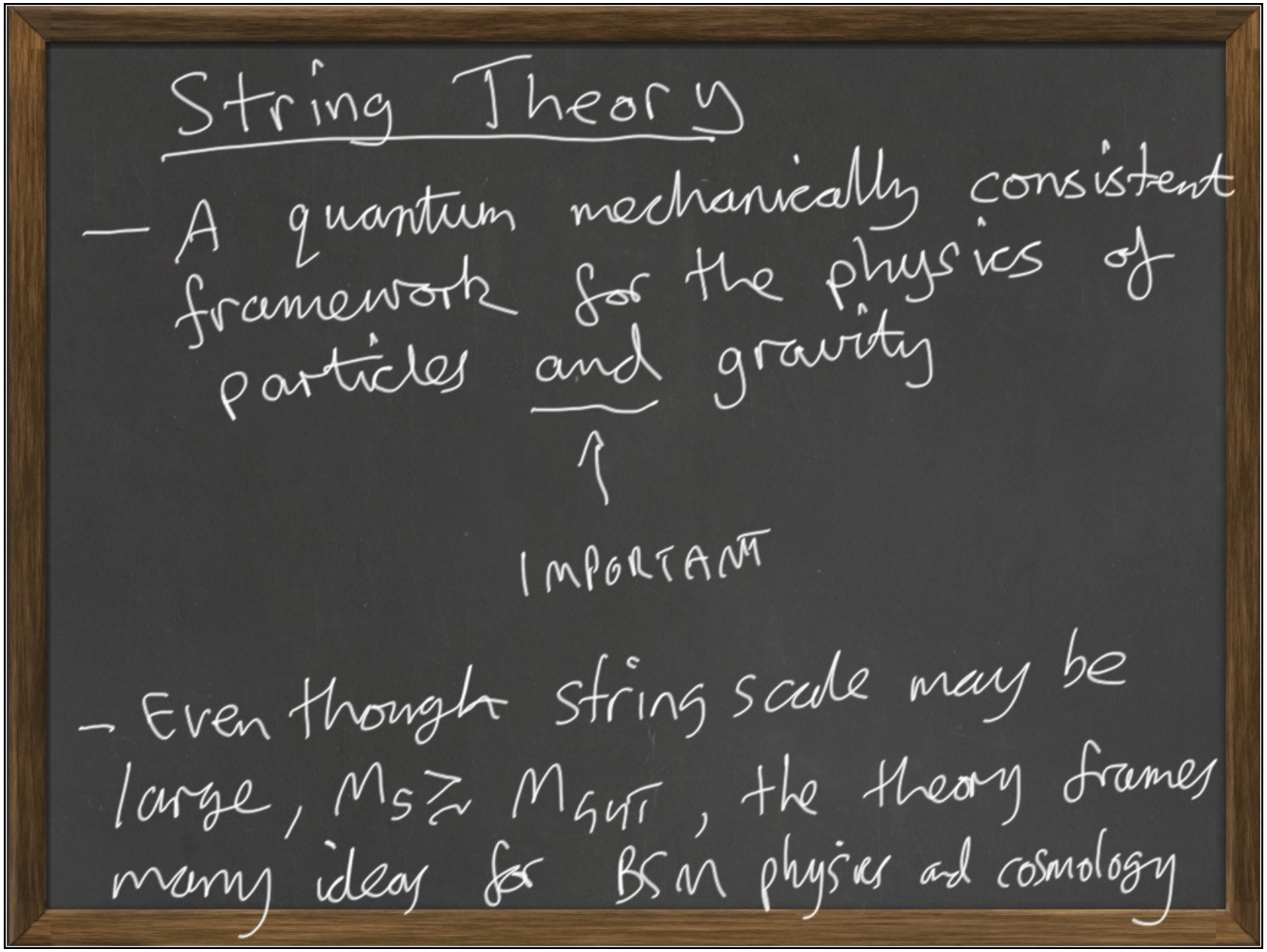
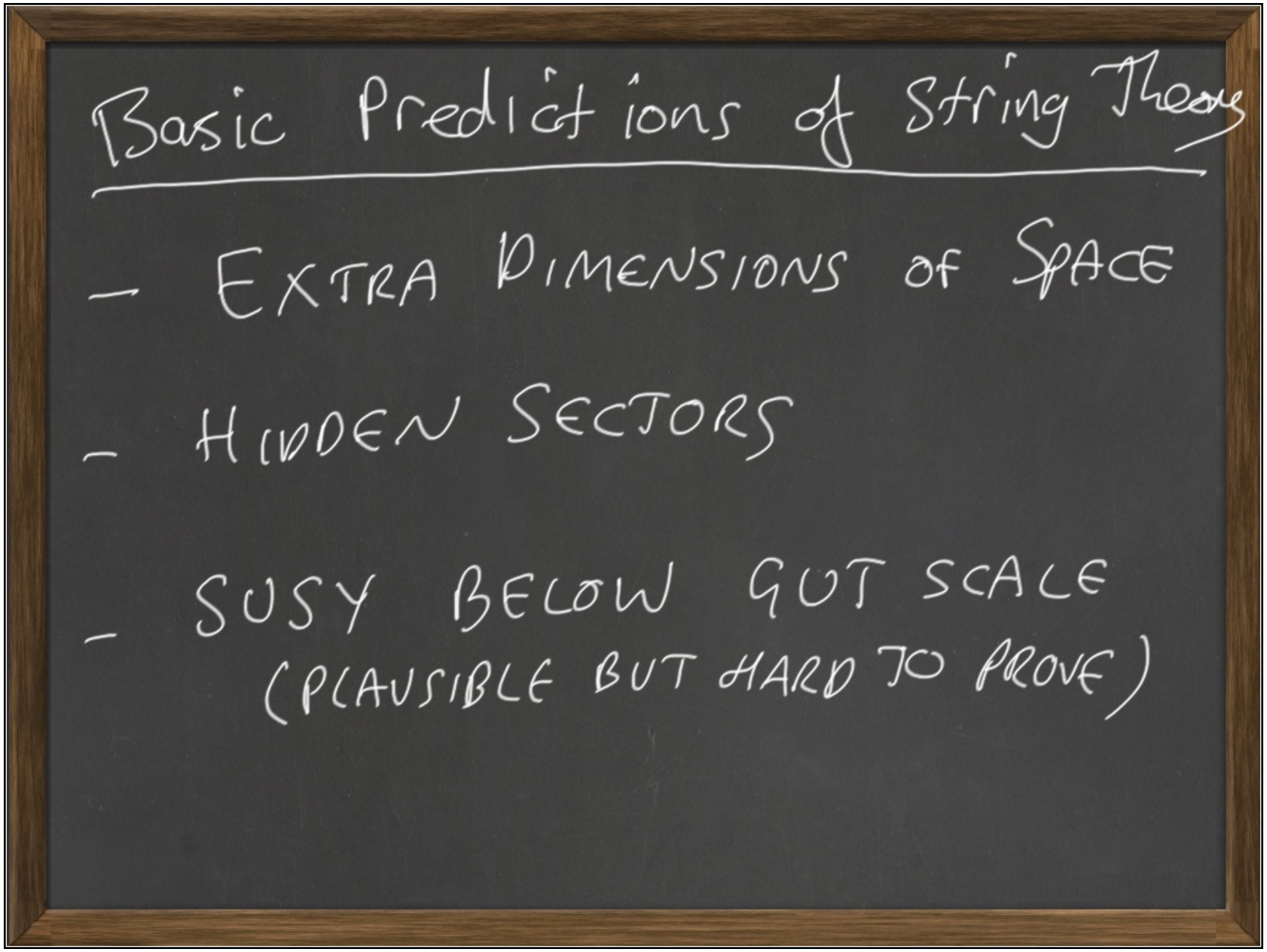
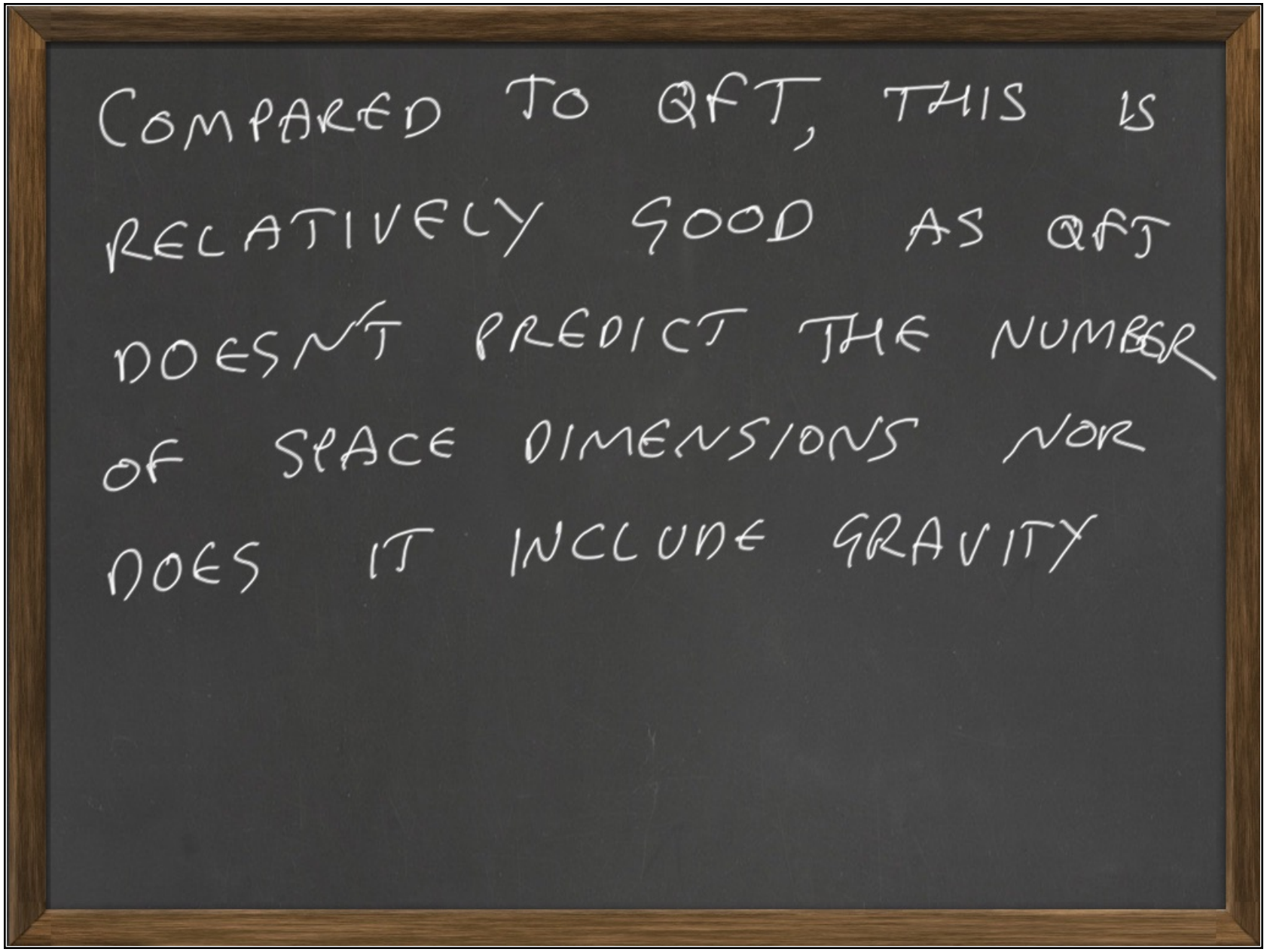
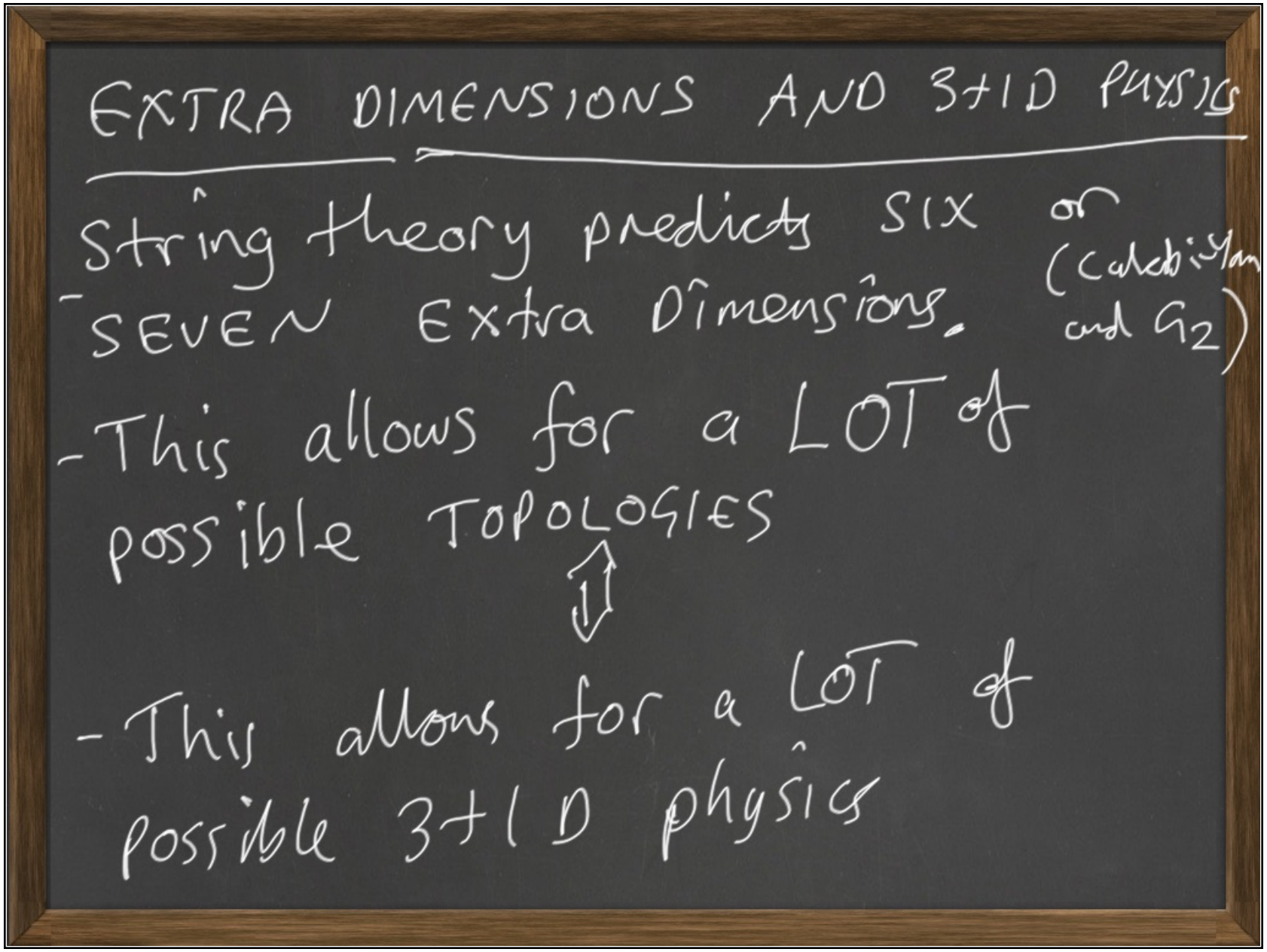

The Dark Side of String Theory
Bobby Acharya
DARK SIDE OF THE UNIVERSE 2023
EAIFR-ICTP, U. Rwanda, July 2023

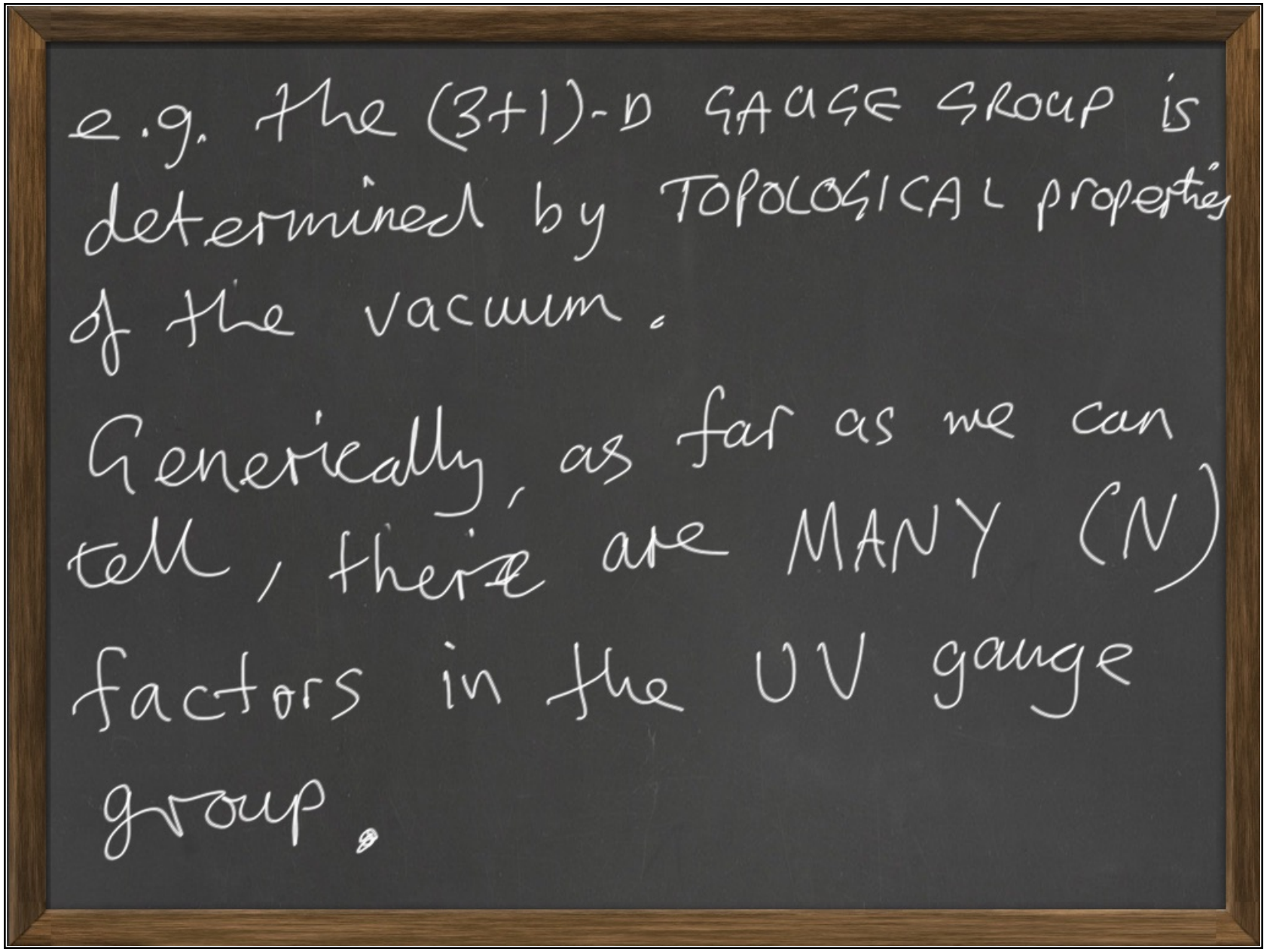

OUTLINE
- STRING THEORY
- SOME GENERAL PROPERTIES AND PREDICTIONS
- DARK / HIDDEN SECTORS
- QUESTIONS
- MOSTLY TO STIMULATE DISCUSSION

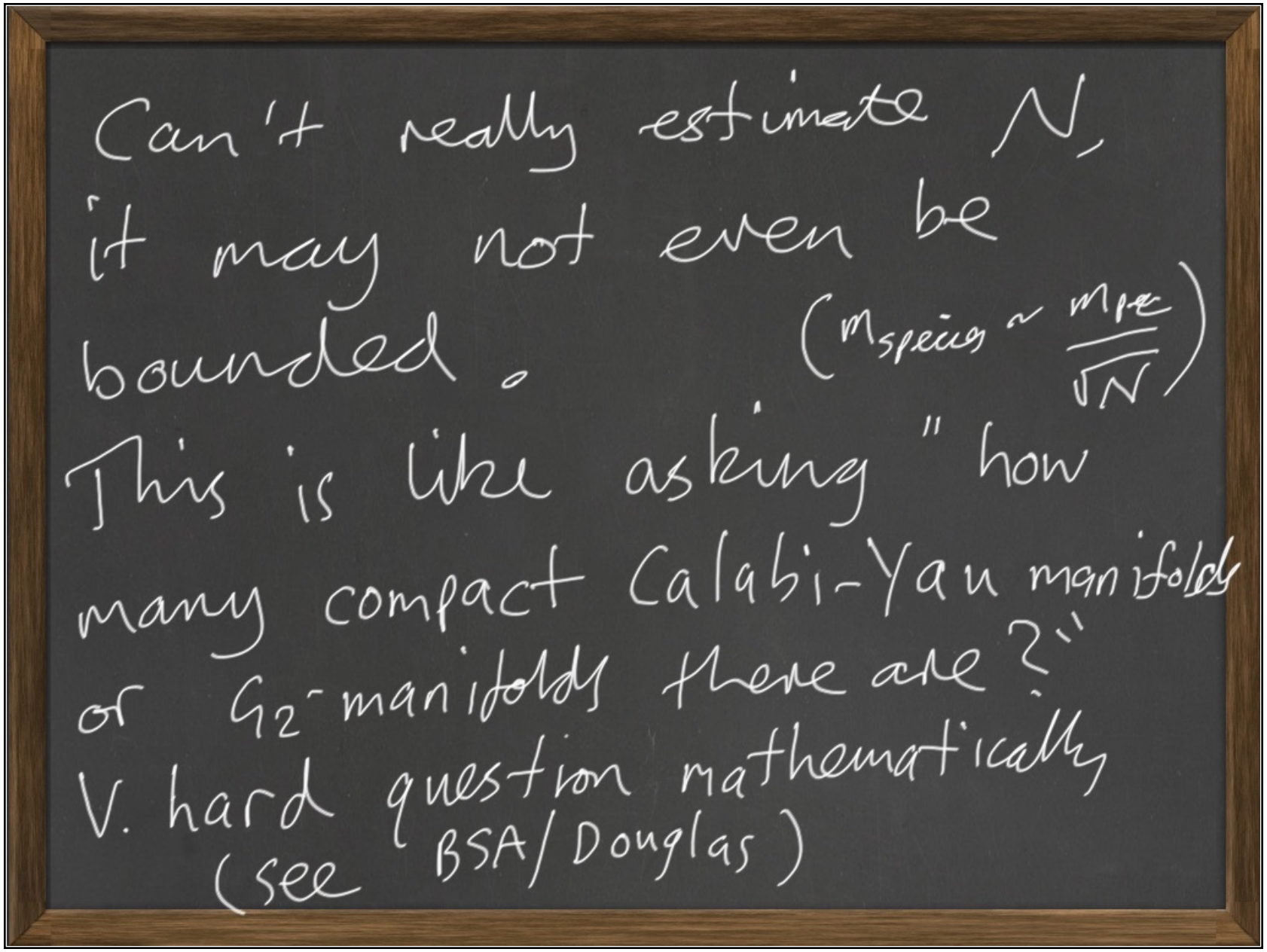

String Theory
— A quantum mechanically consistent framework for the physics of particles and gravity
IMPORTANT
- Even though string scale may be large, $M_s \gtrsim M_{GUT}$, the theory frames many ideas for BSM physics and cosmology

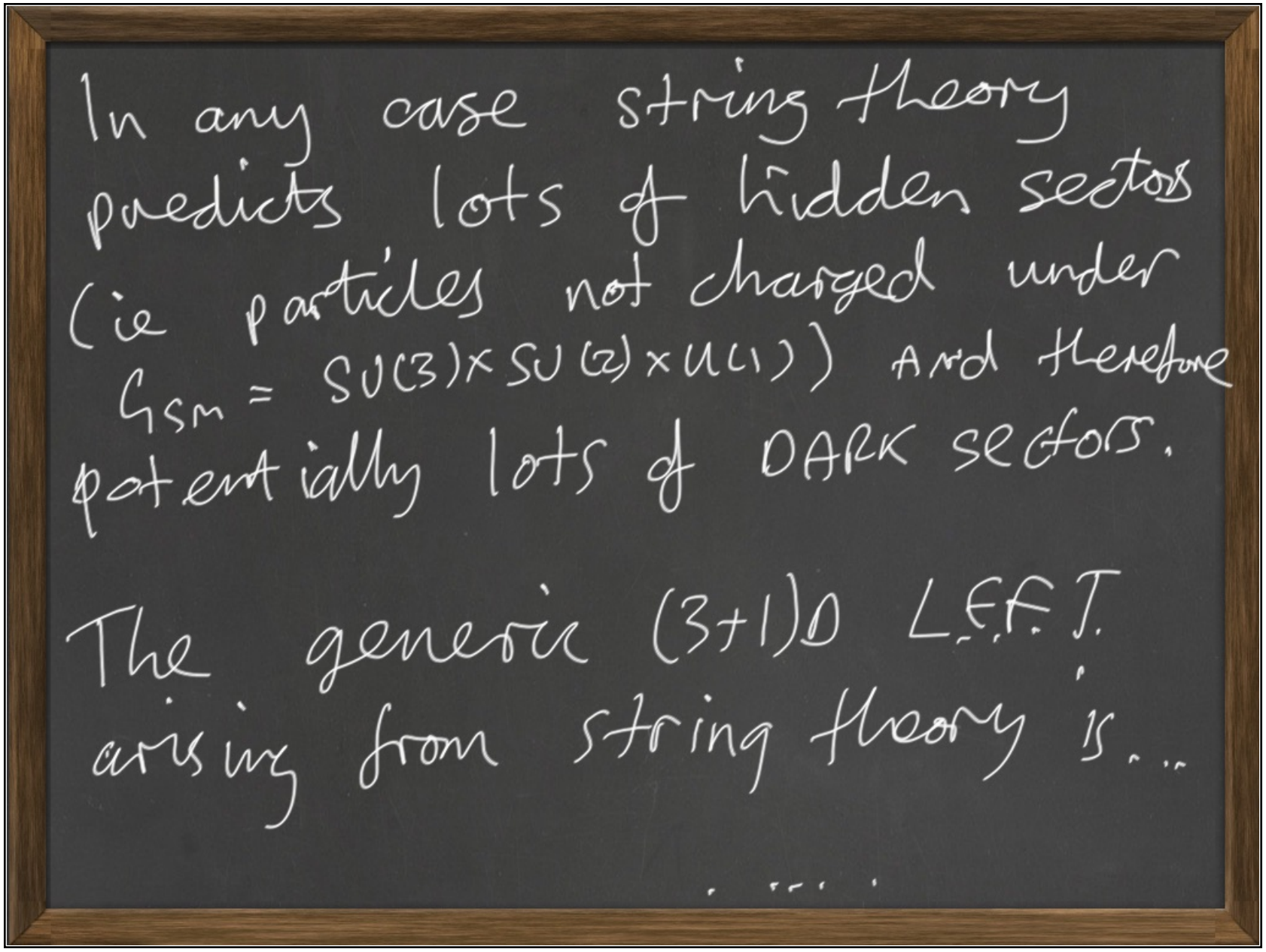

Basic Predictions of String Theory
- EXTRA DIMENSIONS of SPACE
- HIDDEN SECTORS
- SUSY BELOW GUT SCALE
(PLAUSIBLE BUT HARD TO PROVE)

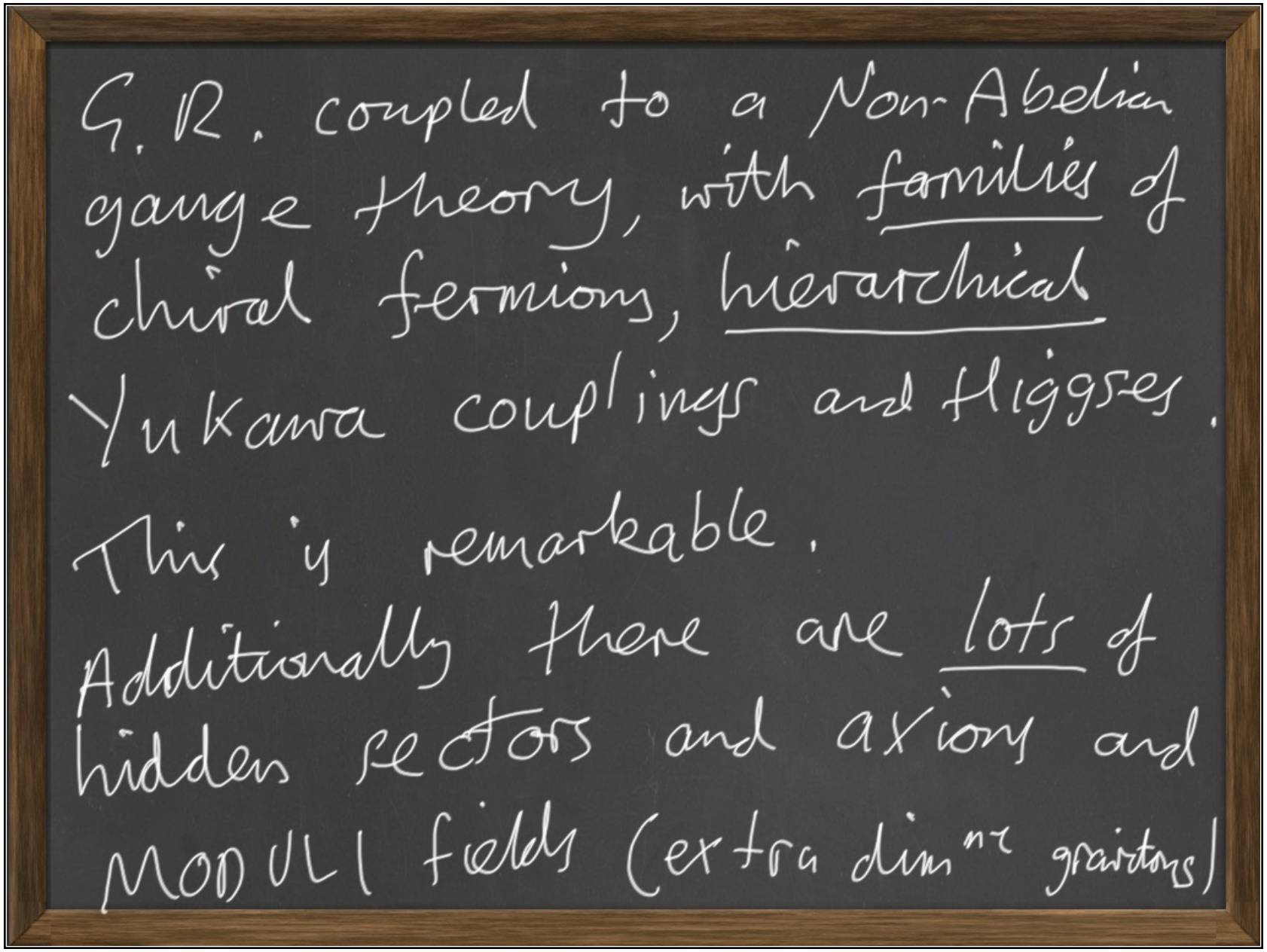

COMPARED TO QFT, THIS IS
RELATIVELY GOOD AS QFT
DOESN'T PREDICT THE NUMBER
OF SPACE DIMENSIONS NOR
DOES IT INCLUDE GRAVITY

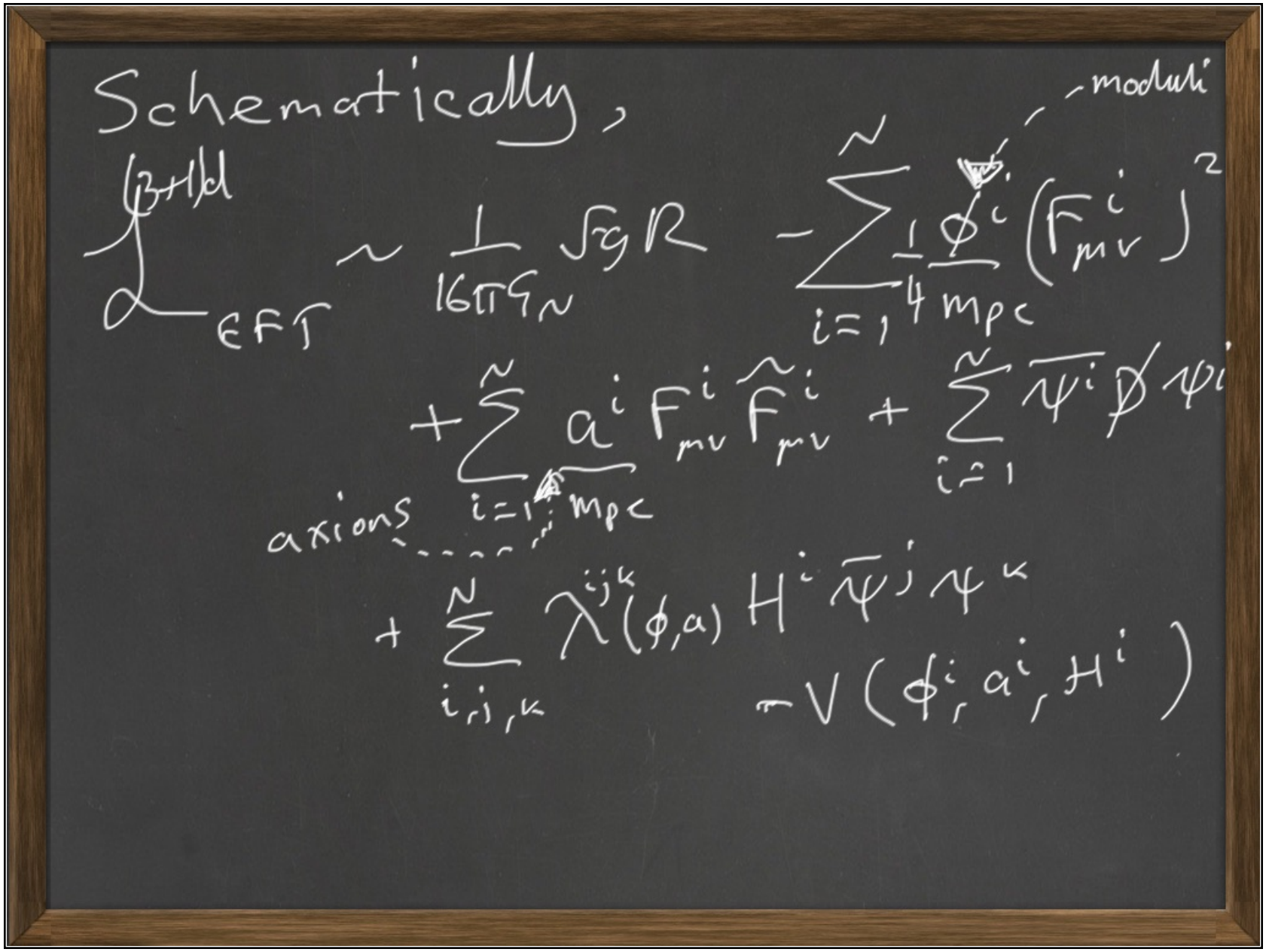

EXTRA DIMENSIONS AND 3+1D PHYSICS
String theory predicts SIX or SEVEN Extra Dimensions. (Calabi-Yau and G_2)
- This allows for a LOT of possible TOPOLOGIES
- This allows for a LOT of possible 3+1D physics

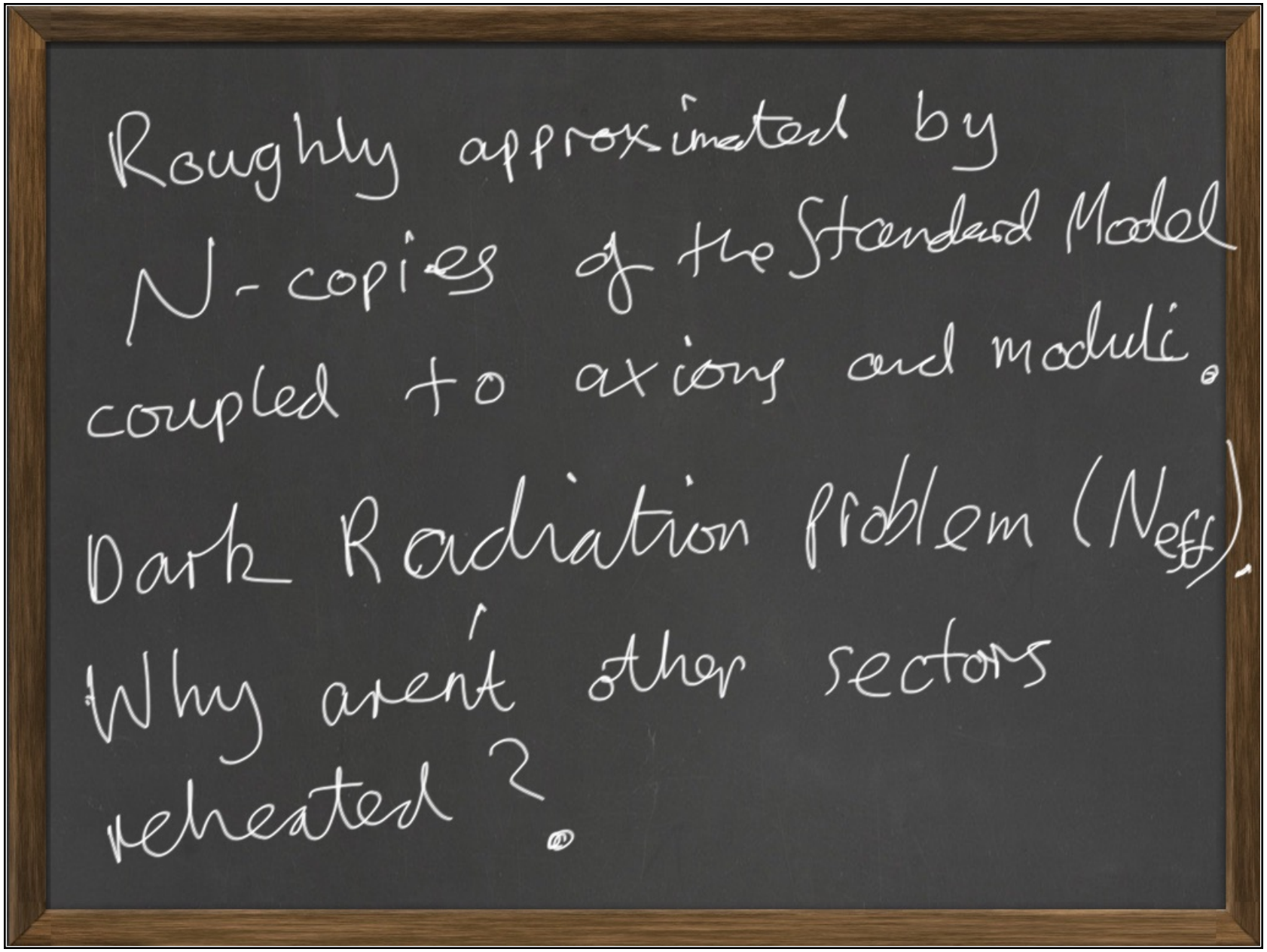

e.g. the (3+1)-D GAUGE GROUP is determined by TOPOLOGICAL properties of the vacuum.
Generically, as far as we can tell, there are MANY (N) factors in the UV gauge group.

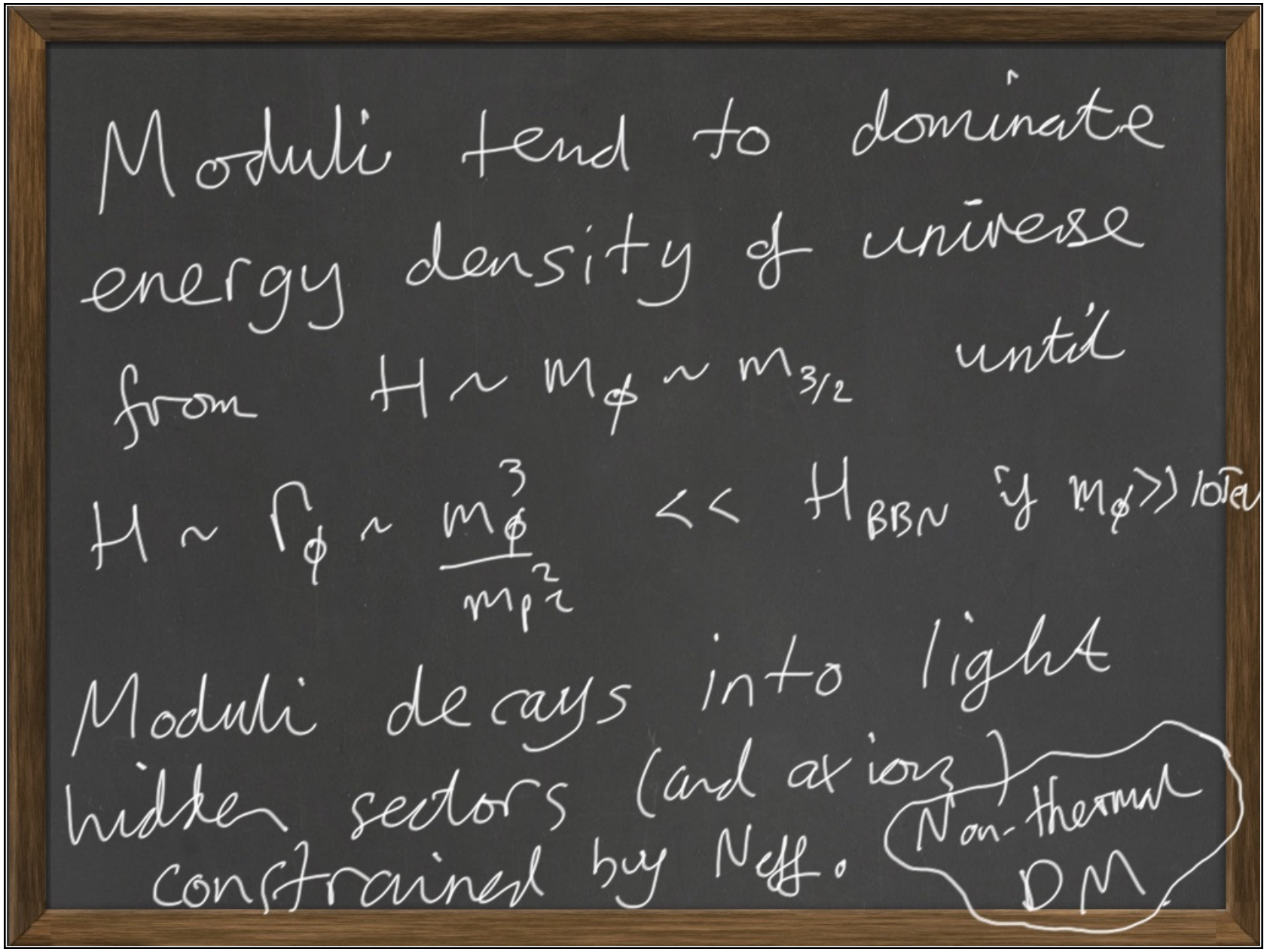

Can't really estimate N,
it may not even be
bounded. ($m_{species} \sim \frac{m_{pl}}{\sqrt{N}}$)
This is like asking "how
many compact Calabi-Yau manifolds
or G_2-manifolds there are?"
V. hard question mathematically
(see BSA/Douglas)

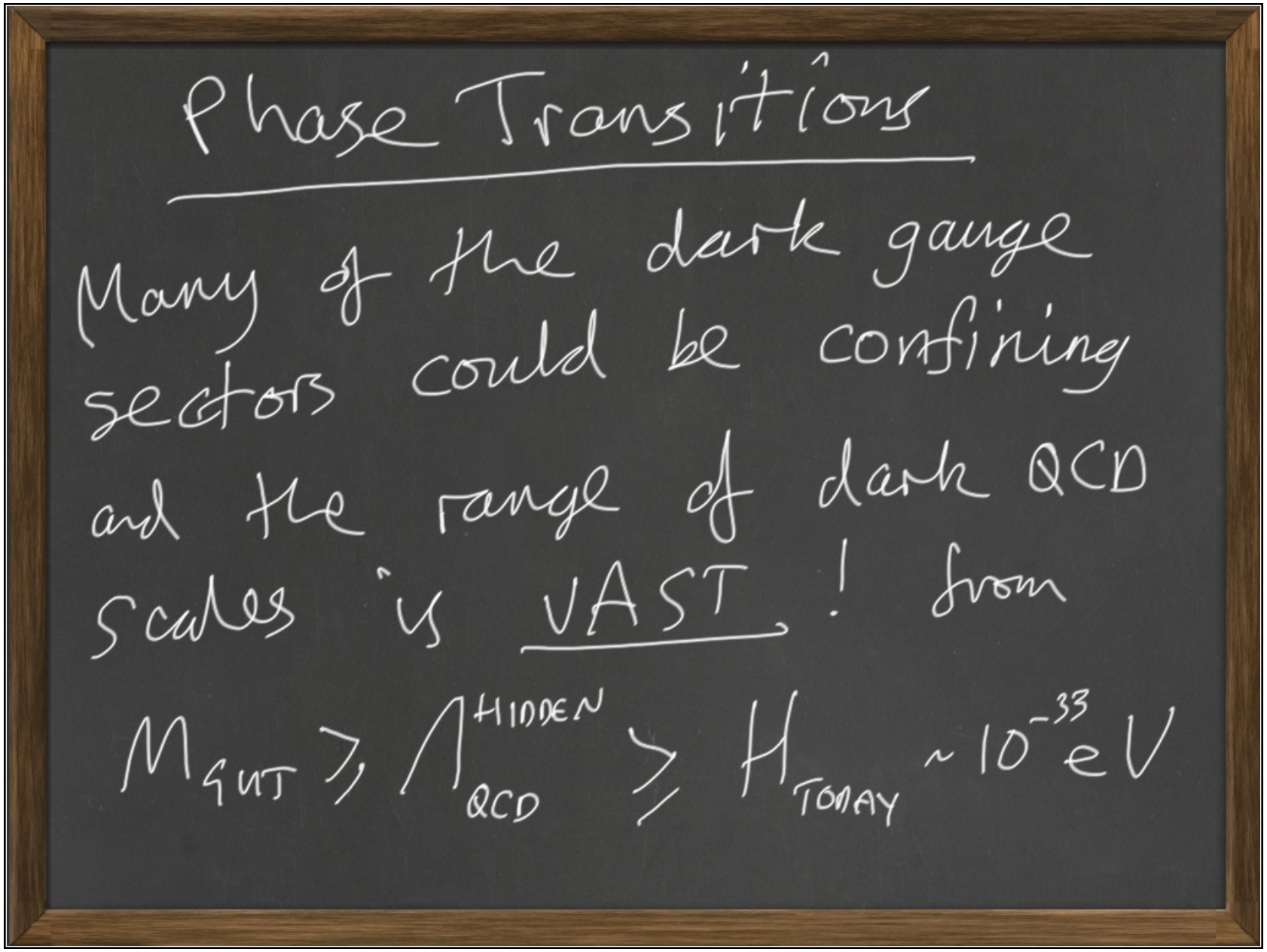

In any case string theory
predicts lots of hidden sectors
(ie particles not charged under
$G_{SM} = SU(3) \times SU(2) \times U(1)$) And therefore
potentially lots of DARK sectors.
The generic (3+1)D L.E.F.T.
arising from string theory is...
. ... .

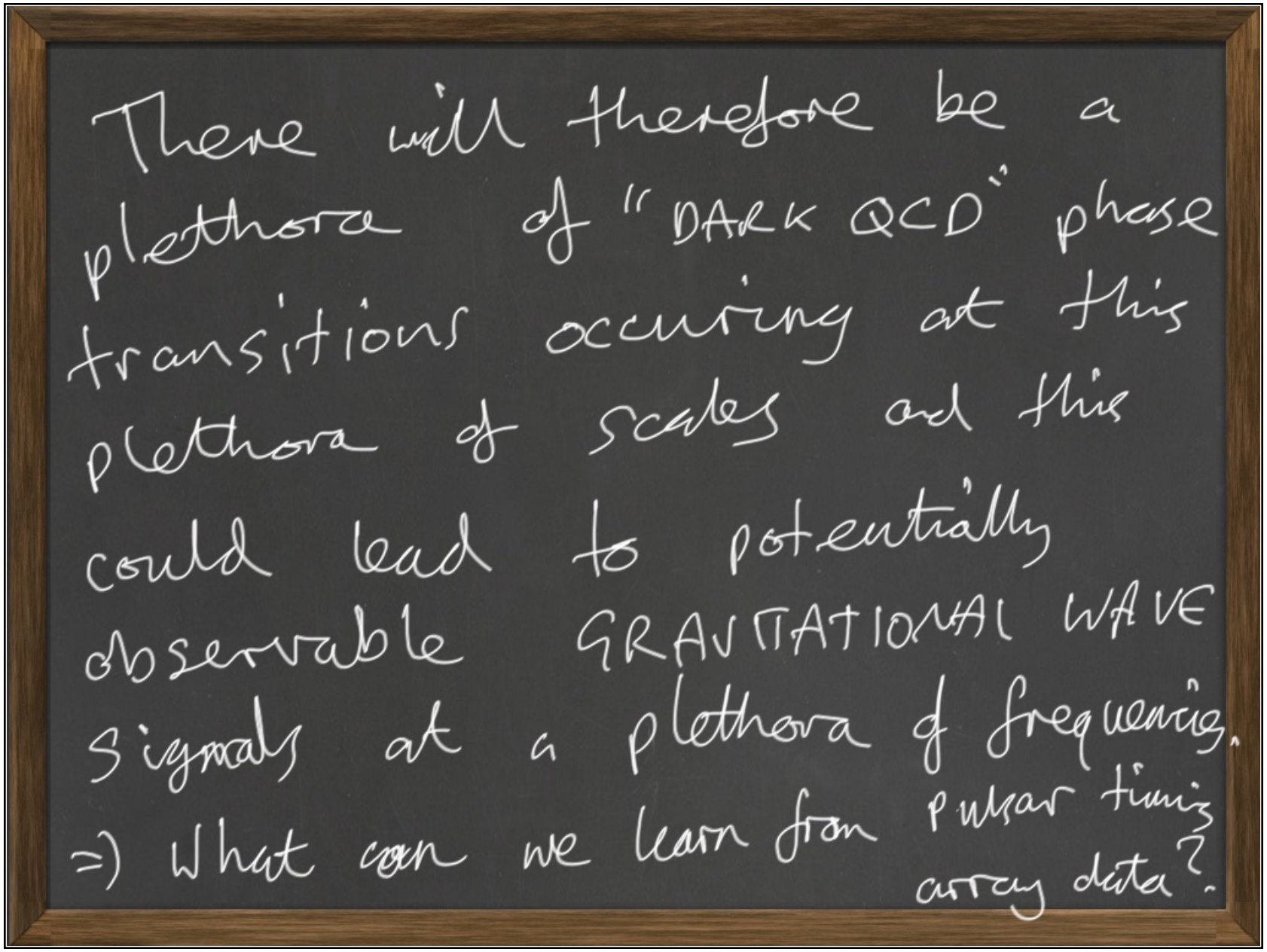

G.R. coupled to a Non-Abelian
gauge theory, with families of
chiral fermions, hierarchical
Yukawa couplings and Higgses.
This is remarkable.
Additionally there are lots of
hidden sectors and axions and
MODULI fields (extra dim^ns gravitons)

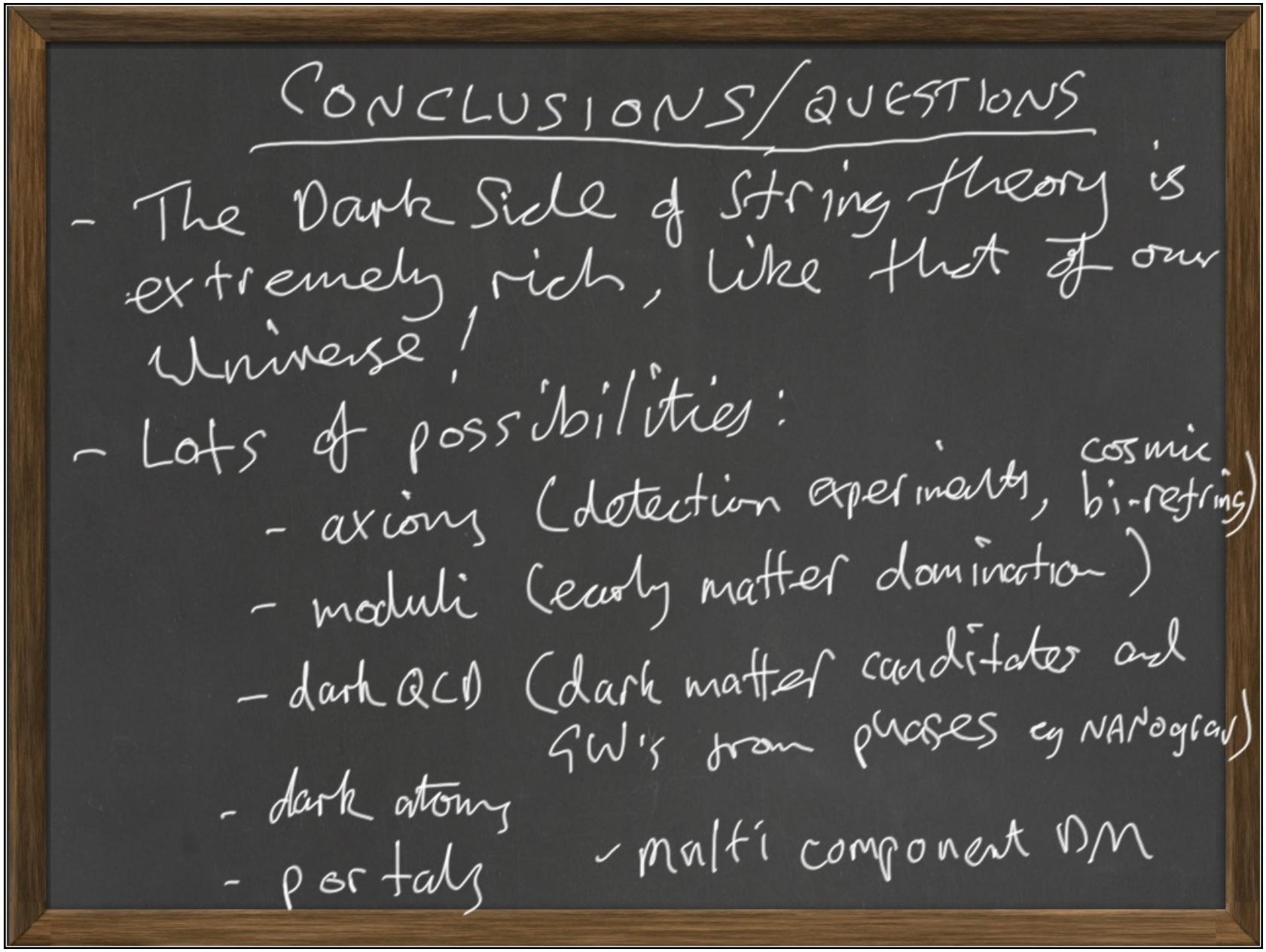

Schematically,
moduli
axions

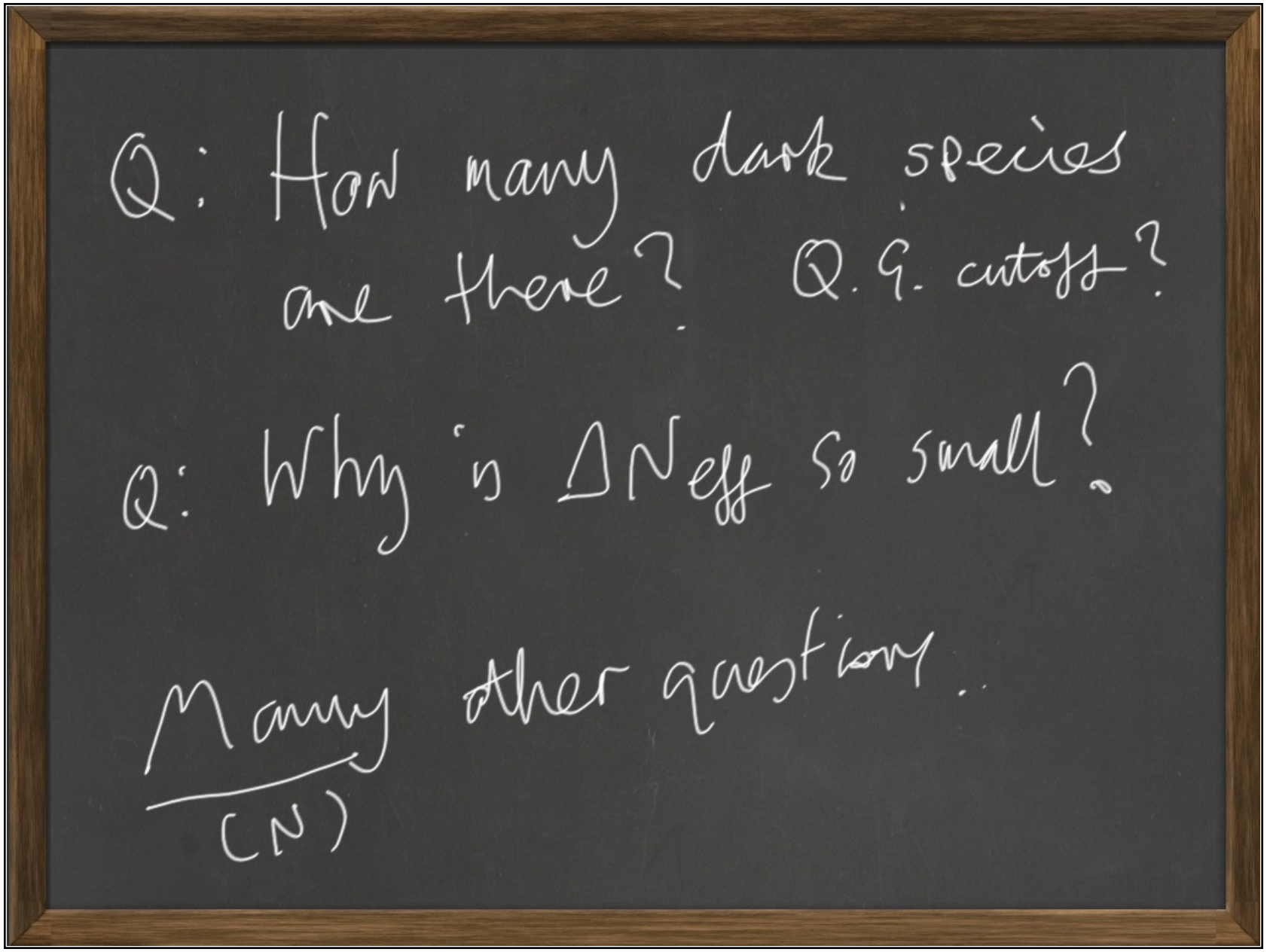

Roughly approximated by
N-copies of the Standard Model
coupled to axions and moduli.
Dark Radiation problem (N_{eff}).
Why aren't other sectors
reheated?


Moduli tend to dominate
energy density of universe
from $H \sim m_\phi \sim m_{3/2}$ until
$H \sim \Gamma_\phi \sim \frac{m_\phi^3}{m_{pl}^2} \ll H_{BBN}$ if $m_\phi \gg 10$TeV
Moduli decays into light
hidden sectors (and axions)
constrained by N_{eff}.
Non-thermal
DM


Phase Transitions
Many of the dark gauge sectors could be confining and the range of dark QCD scales is VAST ! from
$M_{GUT} \gtrsim \Lambda_{QCD}^{HIDDEN} \gtrsim H_{TODAY} \sim 10^{-33}$ eV


There will therefore be a plethora of "DARK QCD" phase transitions occuring at this plethora of scales and this could lead to potentially observable GRAVITATIONAL WAVE signals at a plethora of frequencies.
=) What can we learn from pulsar timing array data?


CONCLUSIONS/QUESTIONS
- The Dark Side of String theory is extremely rich, like that of our Universe!
- Lots of possibilities:
- axions (detection experiments, cosmic bi-refring)
- moduli (early matter domination)
- dark QCD (dark matter candidates and GW's from phases eg NANOgrav)
- dark atoms
- portals
- multi component DM


Q: How many dark species are there? Q. q. cutoff?
Q: Why is ΔNeff so small?
Many other questions..
(N)


Thank You !