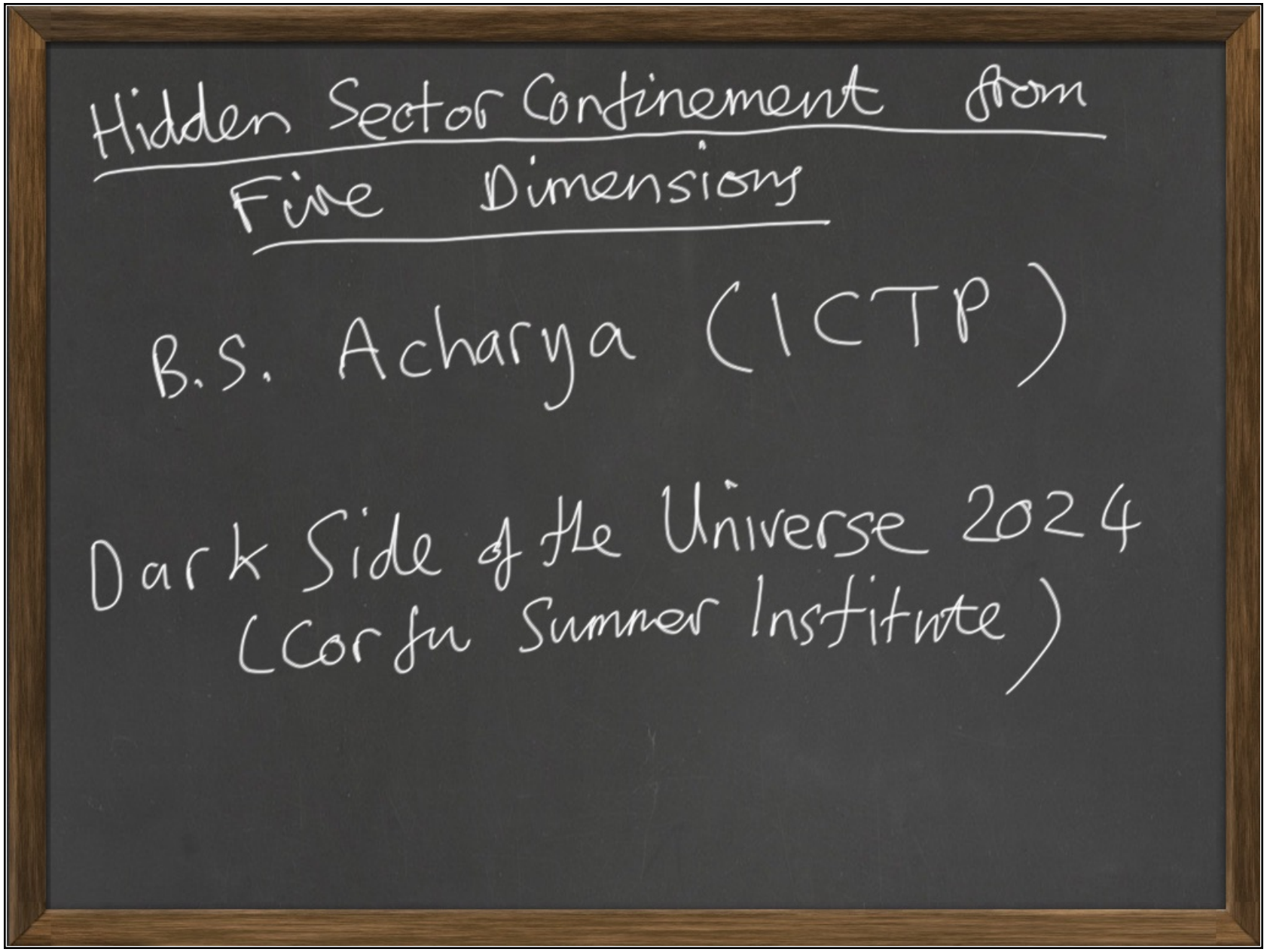
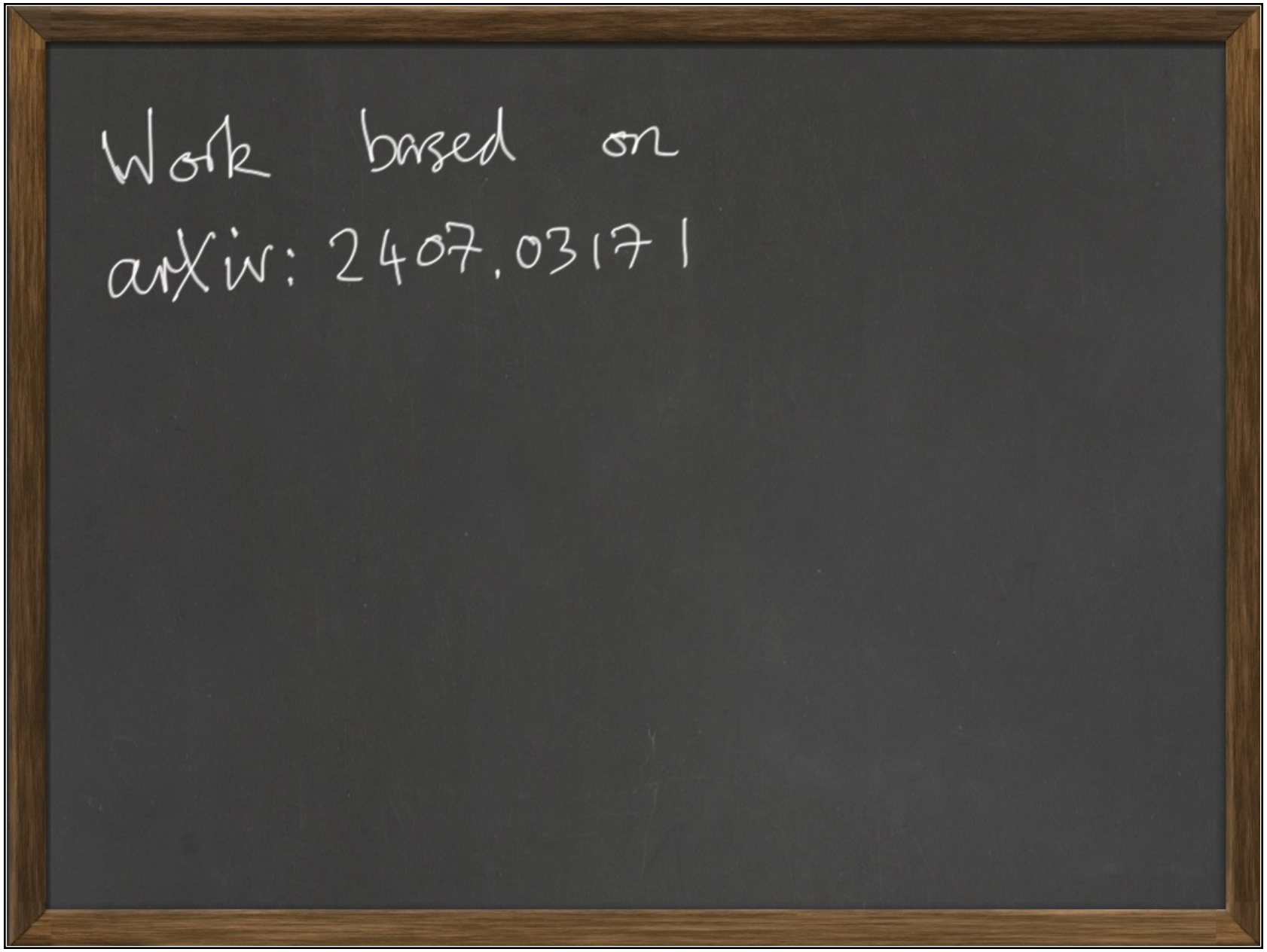
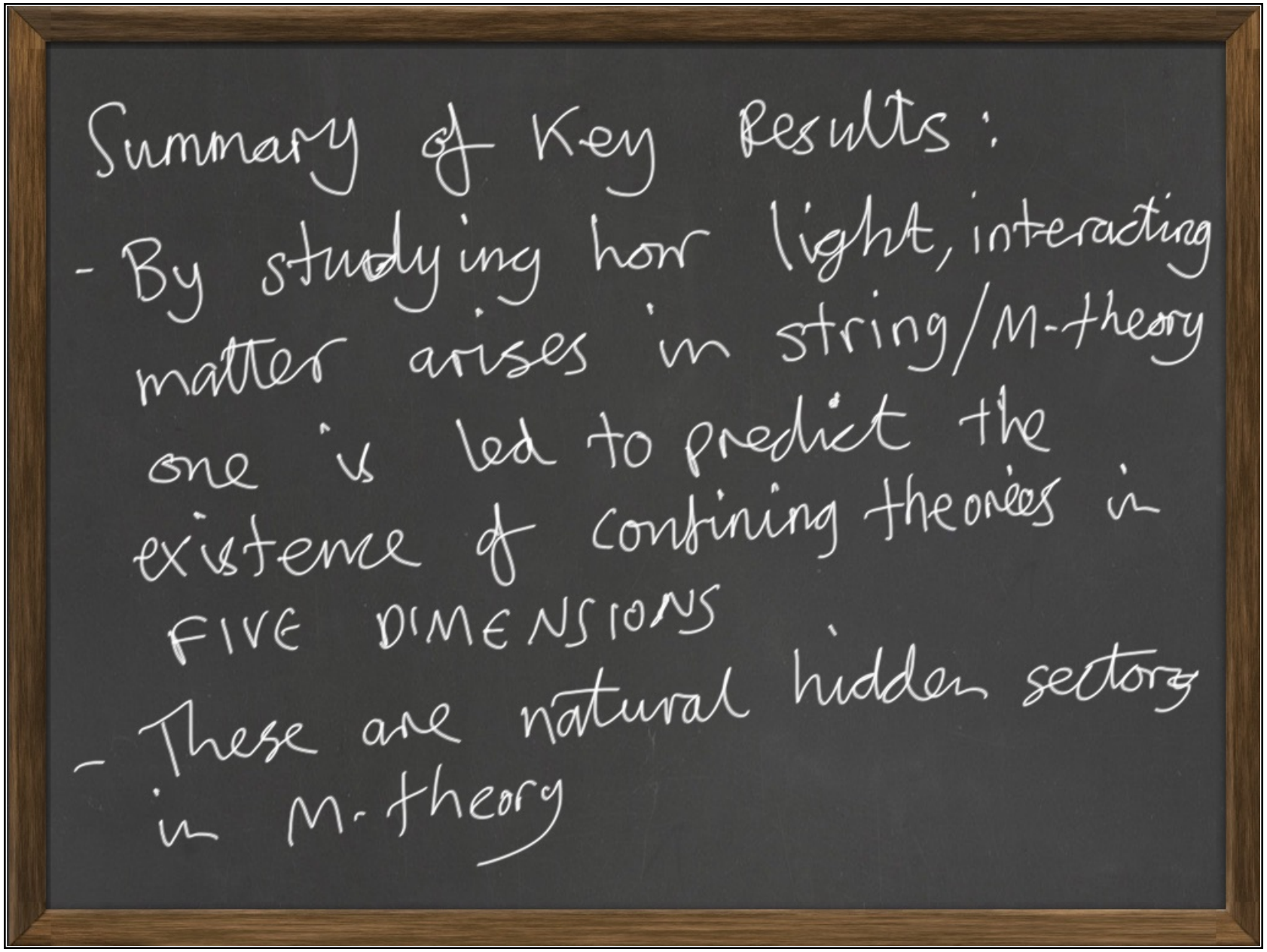
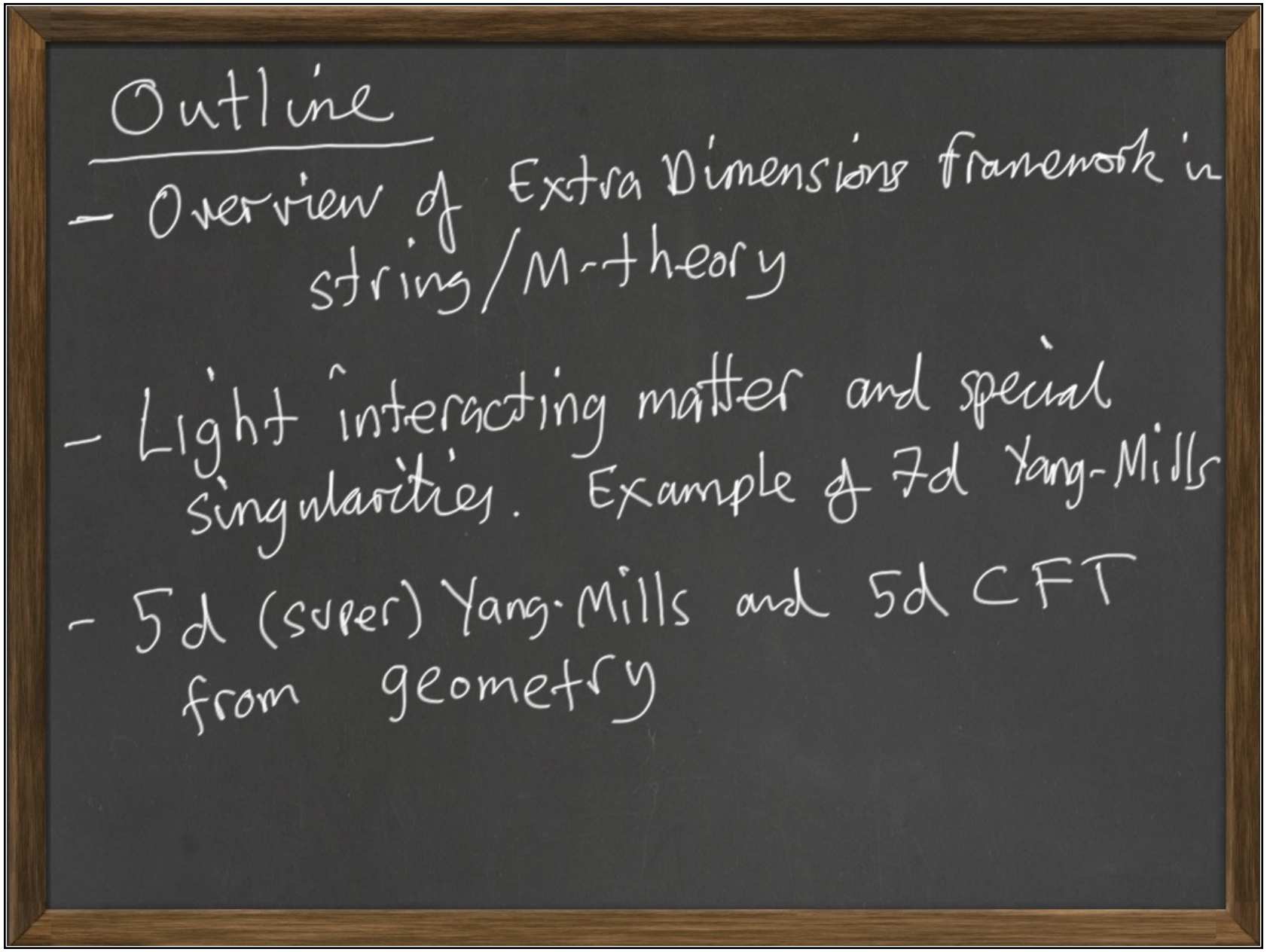
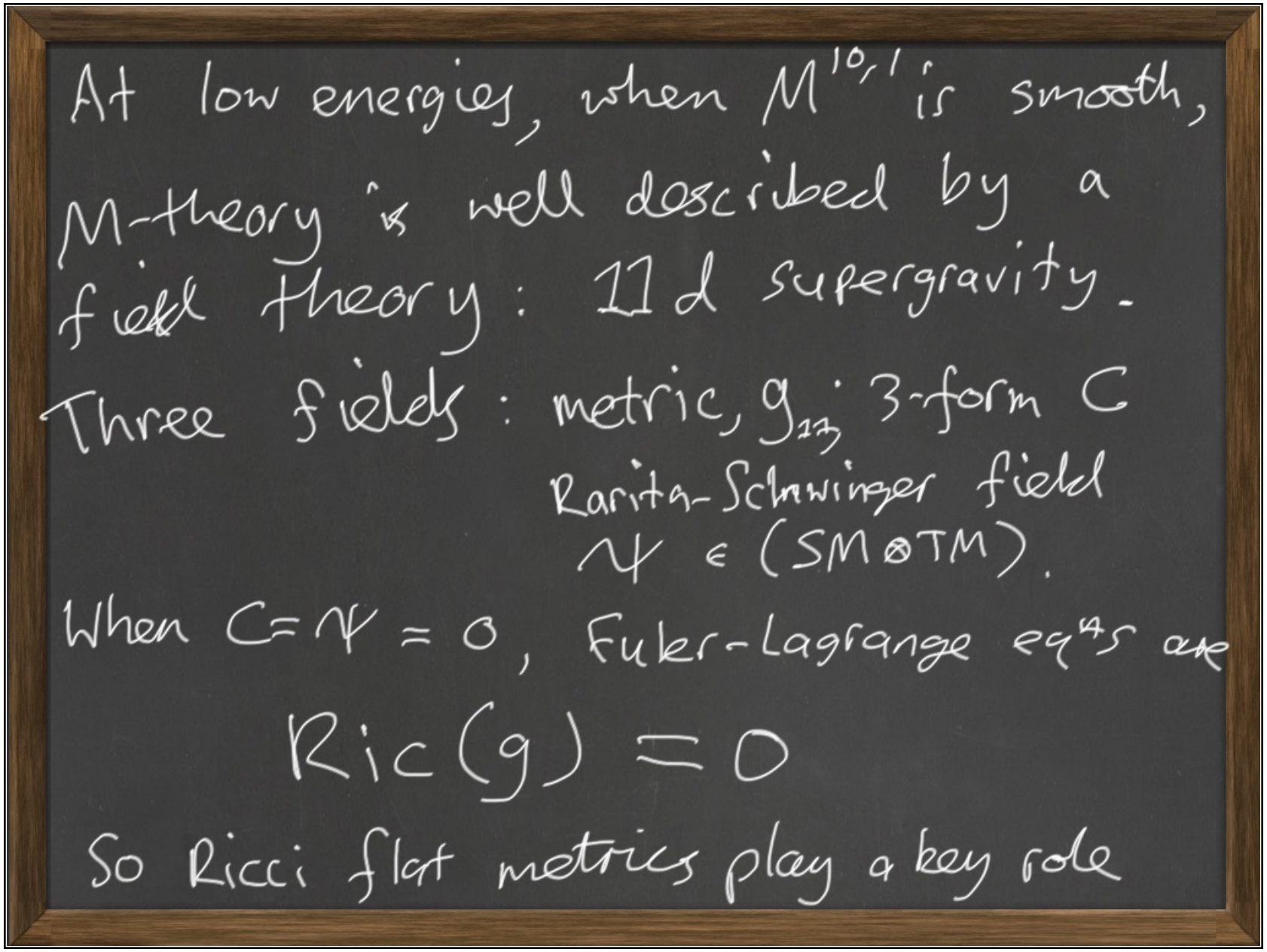

Hidden Sector Confinement from Five Dimensions
B.S. Acharya (ICTP)
Dark Side of the Universe 2024
(Corfu Summer Institute)


Work based on
arXiv: 2407.03171


Summary of Key Results:
- By studying how light, interacting matter arises in string/M-theory one is led to predict the existence of confining theories in FIVE DIMENSIONS
- These are natural hidden sectors in M-theory


Outline
- Overview of Extra Dimensions framework in string/M-theory
- Light interacting matter and special singularities. Example of 7d Yang-Mills
- 5d (super) Yang-Mills and 5d CFT from geometry


At low energies, when $M^{10,1}$ is smooth,
M-theory is well described by a
field theory: 11d supergravity.
Three fields: metric, g_{11}; 3-form C
Rarita-Schwinger field
$\psi \in (SM \otimes TM)$.
When $C = \psi = 0$, Euler-Lagrange eq^{n}s are
$Ric(g) = 0$
So Ricci flat metrics play a key role

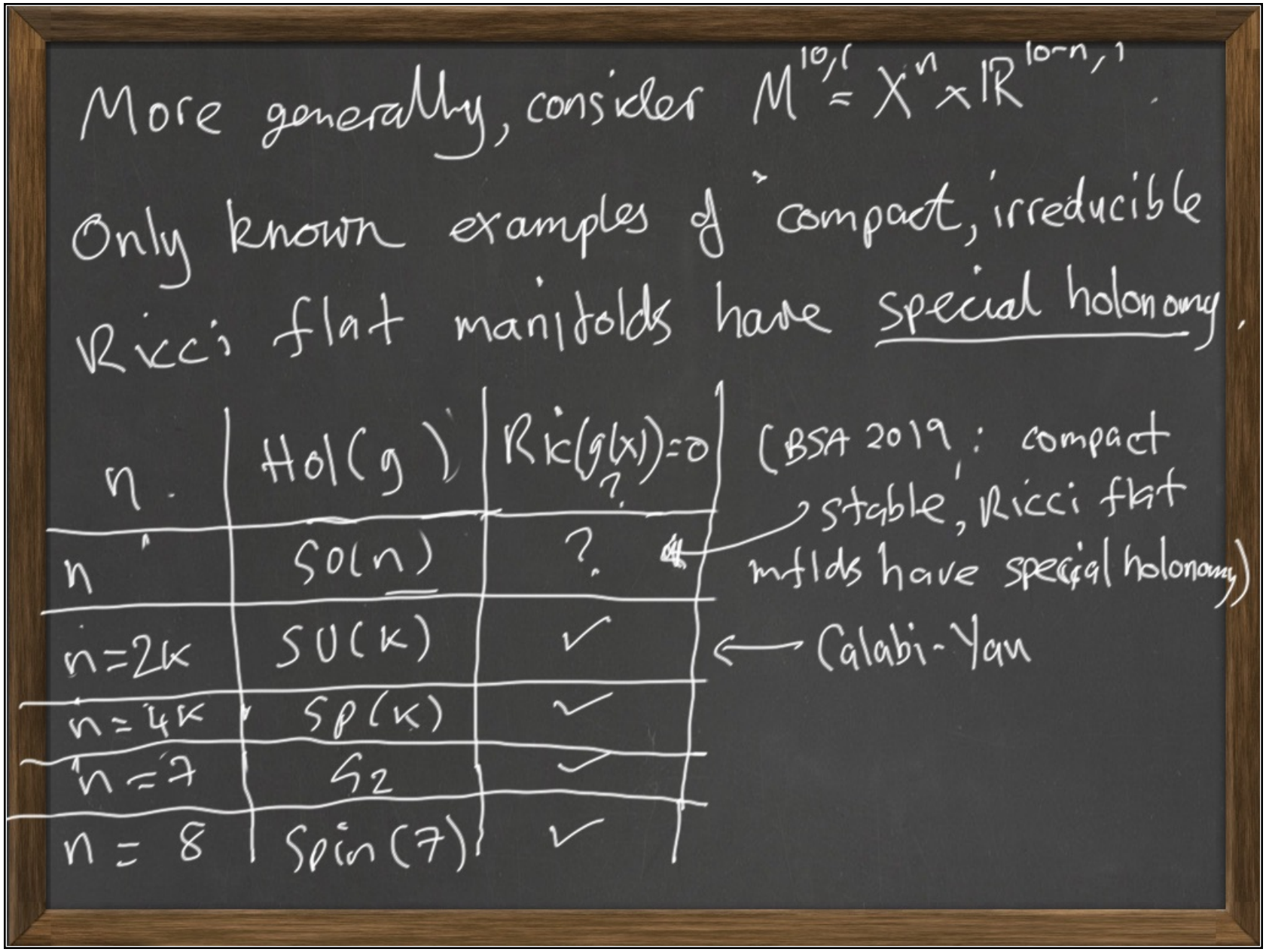
Since our Universe $(M^{3,1})$ is apparently four dimensional, we are interested in

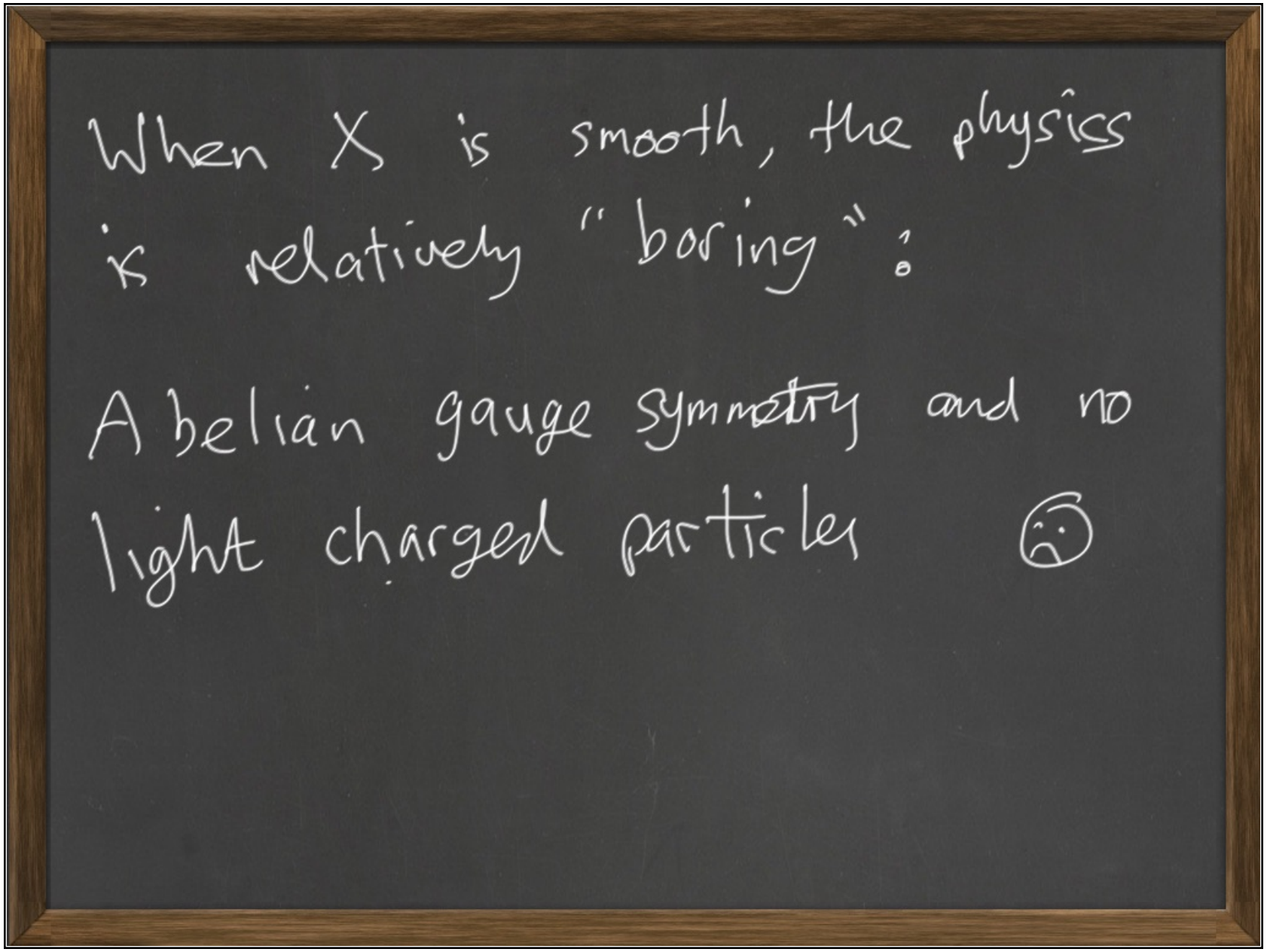
$$(M^{10,1}, g_{11}) = \left(X^7 \times M^{3,1},\ g(X) + \eta(M^{3,1})\right)$$

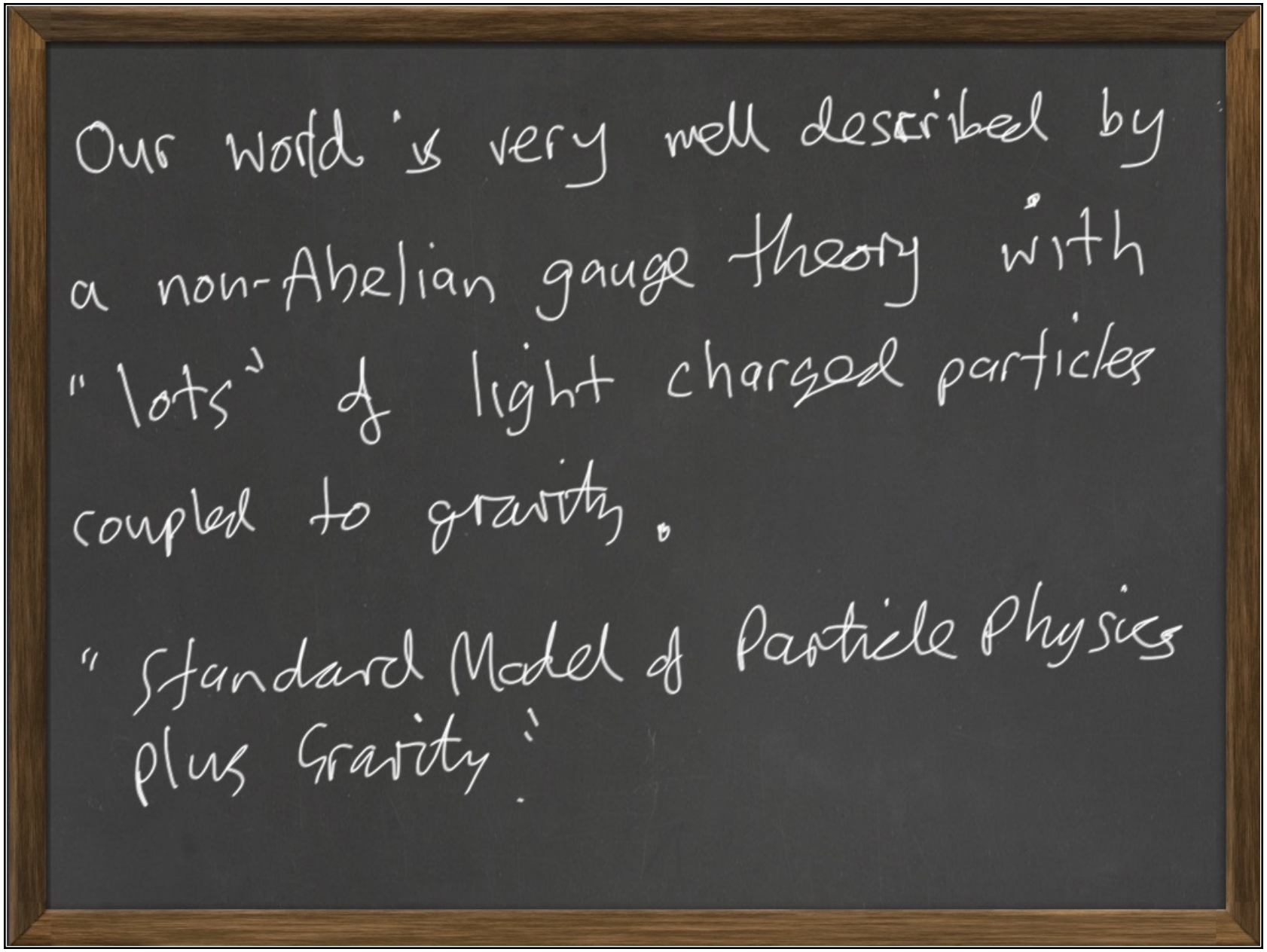
where X^7 is "small" and compact and

$$\mathrm{Ric}(g(X^7)) = 0 = \mathrm{Ric}(\eta(M^{3,1}))$$

So compact Ricci flat manifolds play a key role in M-theory.

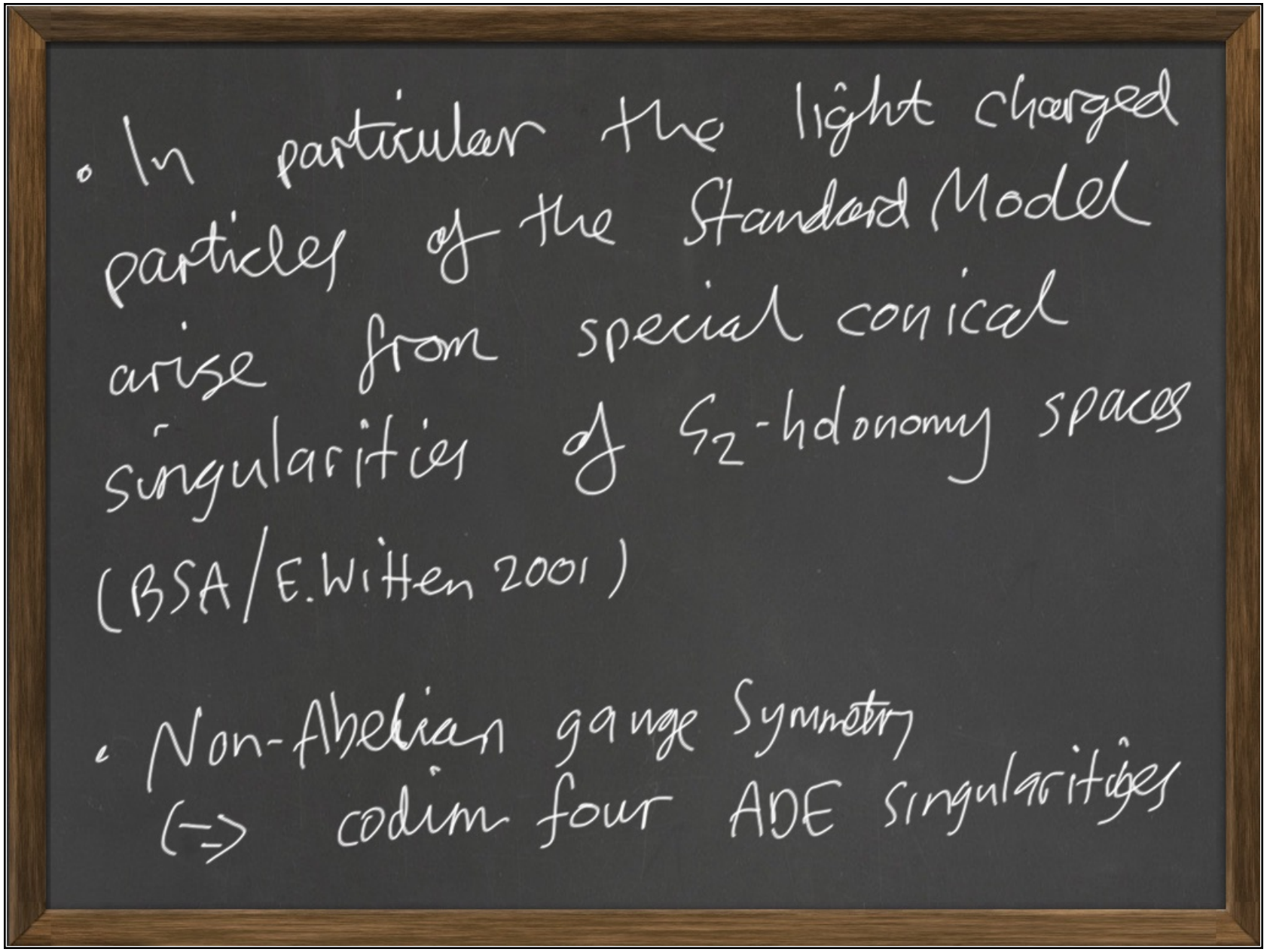

More generally, consider $M^{10,1} = X^n \times \mathbb{R}^{10-n,1}$.
Only known examples of compact, irreducible Ricci flat manifolds have special holonomy.
n
Hol(g)
Ric(g(x))=0
?
n
SO(n)
?
n=2k
SU(k)
✓
n=4k
Sp(k)
✓
n=7
G2
✓
n = 8
Spin(7)
✓
(BSA 2019: compact stable, Ricci flat mflds have special holonomy)
← Calabi-Yau

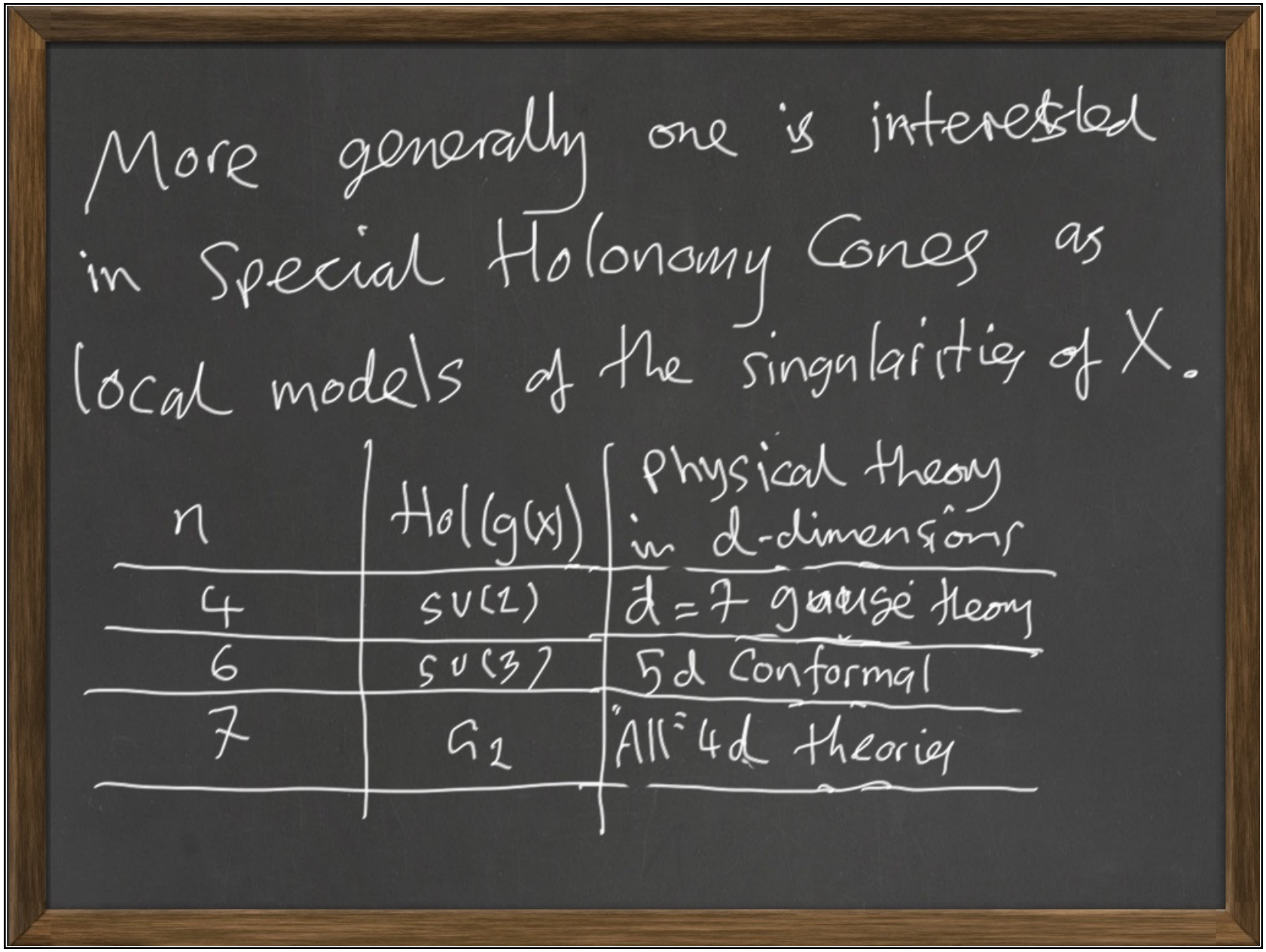

When X is smooth, the physics
is relatively "boring":
Abelian gauge symmetry and no
light charged particles

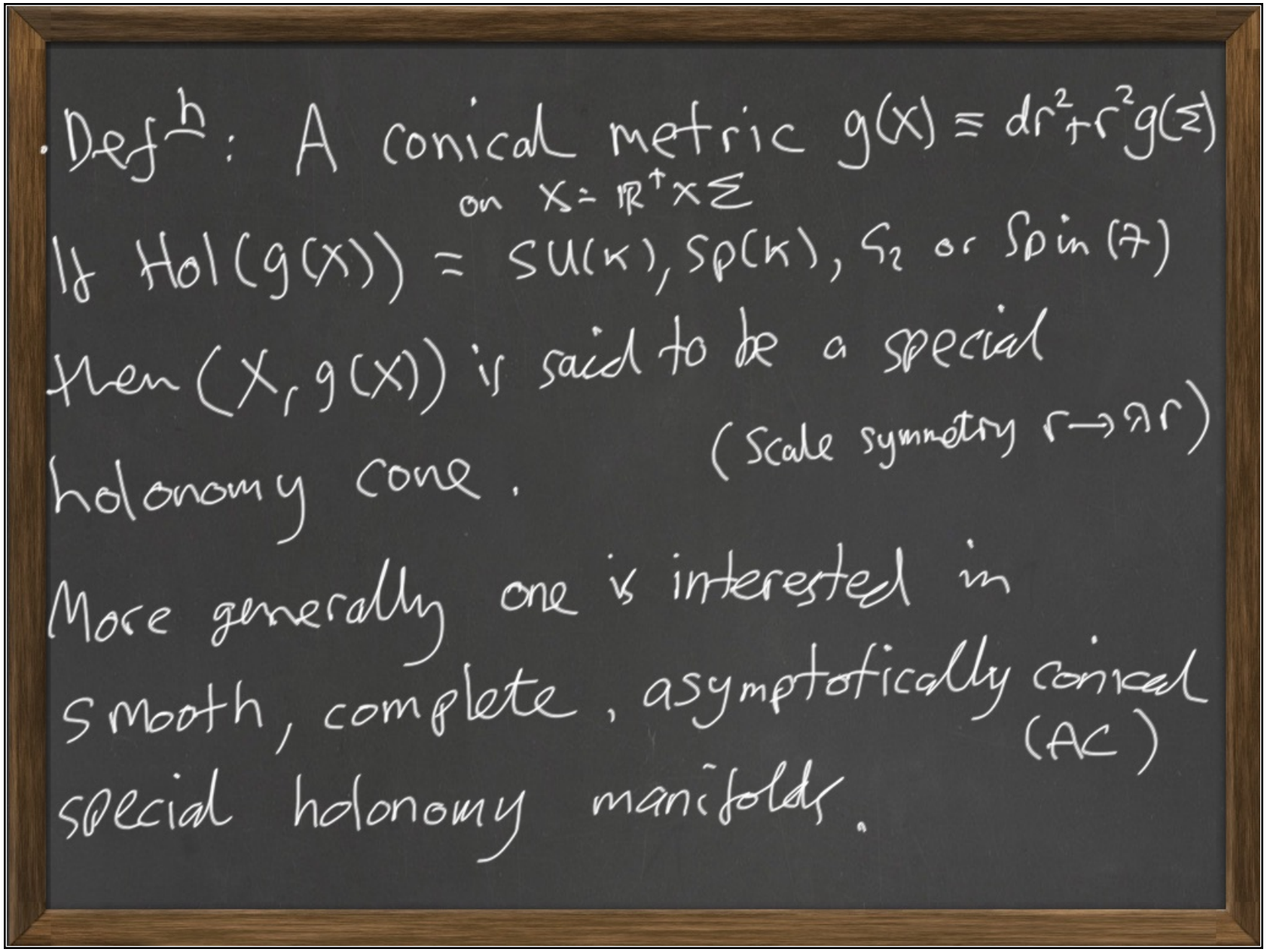

Our world is very well described by
a non-Abelian gauge theory with
"lots" of light charged particles
coupled to gravity.
"Standard Model of Particle Physics
plus Gravity"

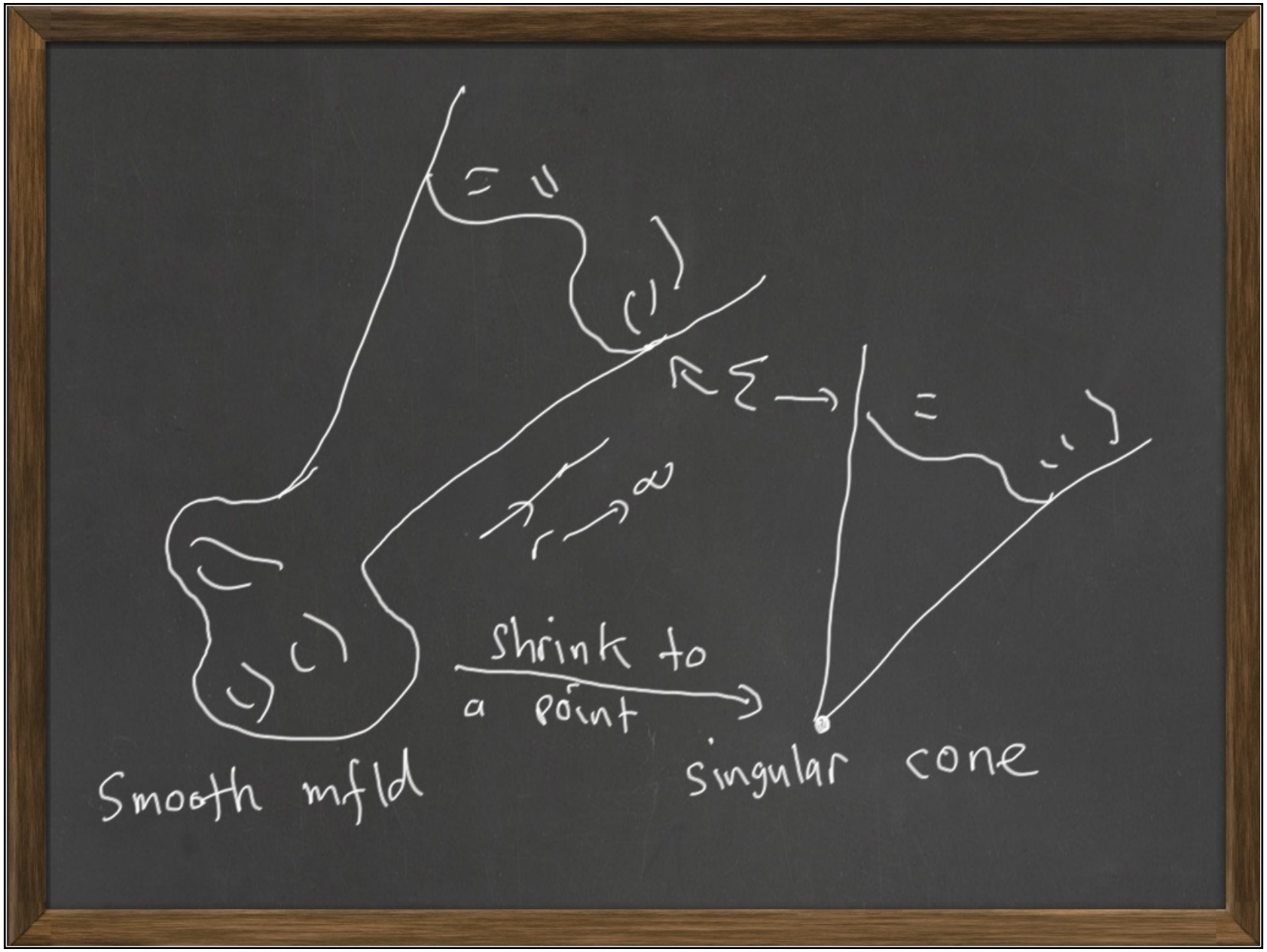
Remarkably, M-theory solves this problem by predicting that $(X, g(x))$ develops rather special kinds of singularities.

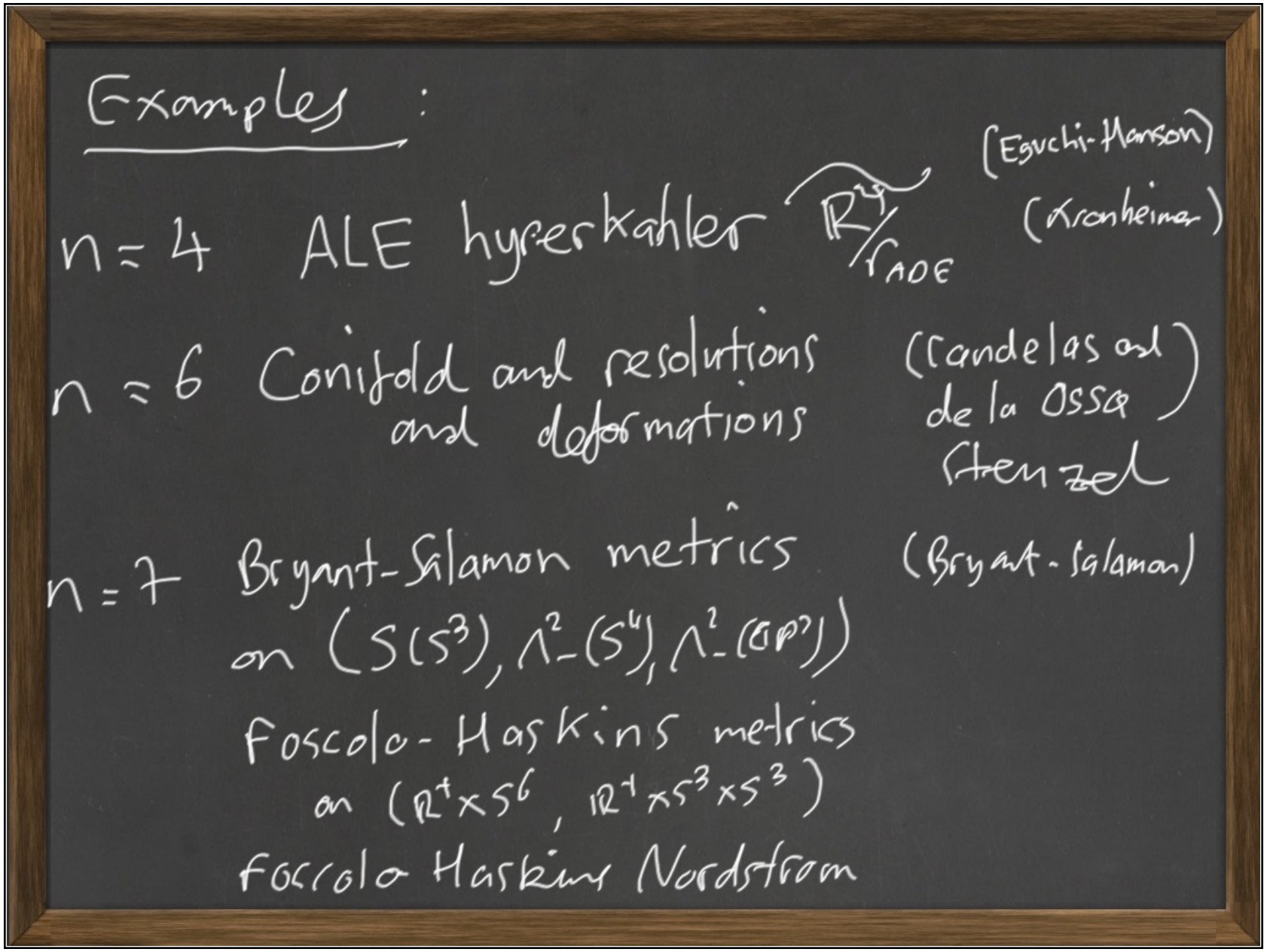
Physically, "branes" wrapped on vanishing cycles $c \subset X$ become light at these singularities.

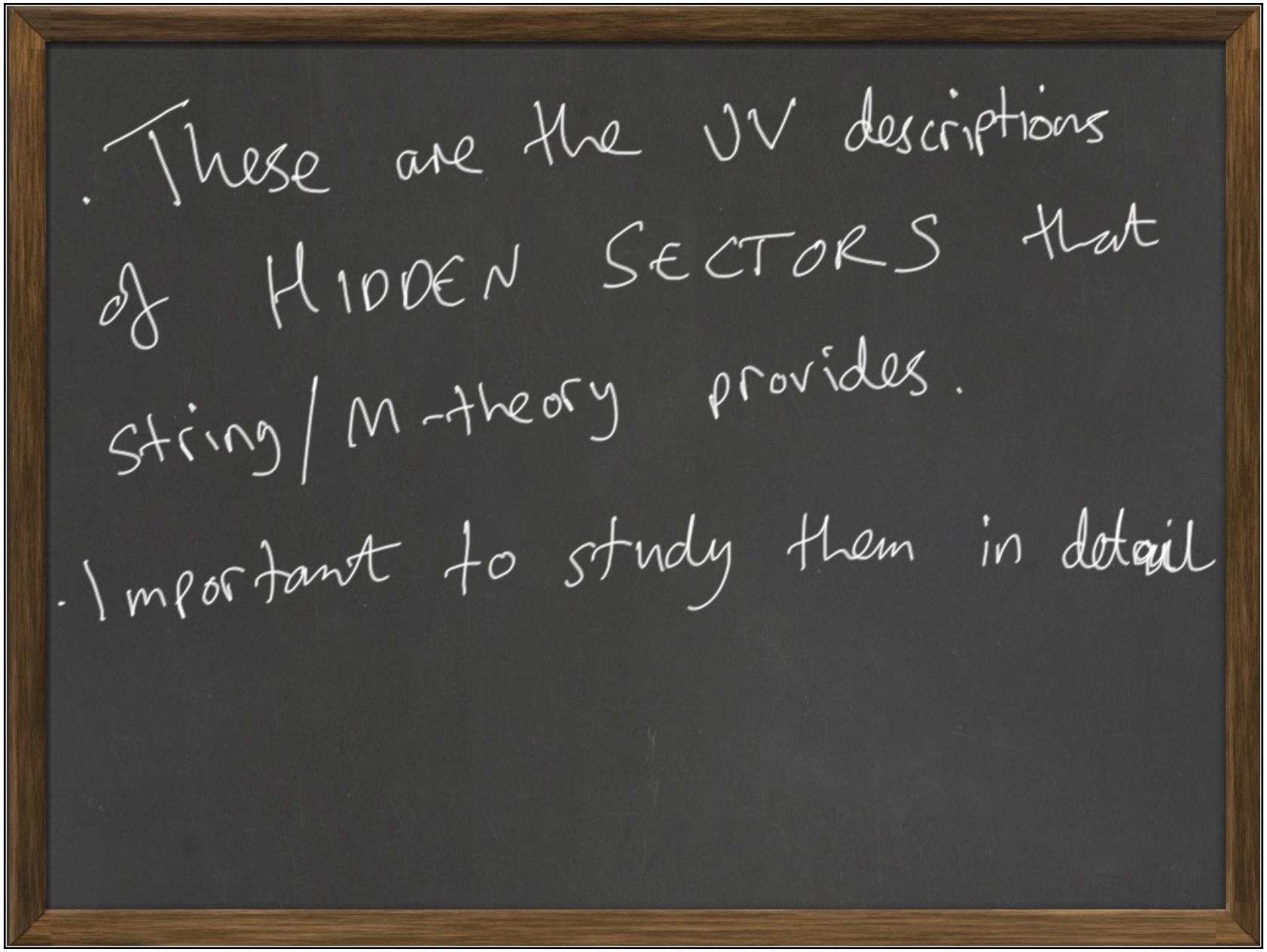

• In particular the light charged particles of the Standard Model arise from special conical singularities of G_2-holonomy spaces (BSA/E. Witten 2001)
• Non-Abelian gauge Symmetry (=> codim four ADE singularities

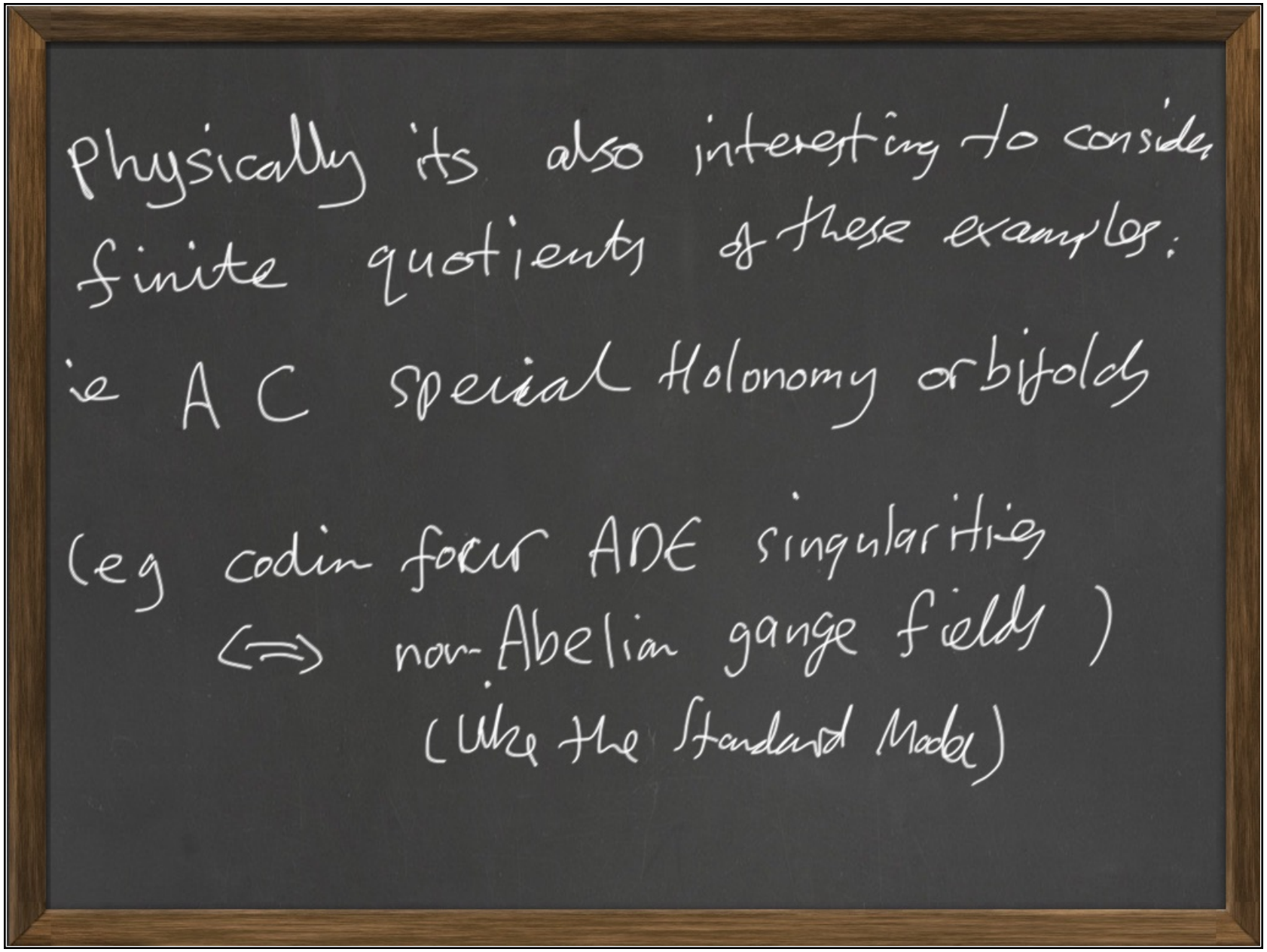

More generally one is interested in Special Holonomy Cones as local models of the singularities of X.
n
Hol(g(x))
Physical theory in d-dimensions
4
SU(2)
d=7 gauge theory
6
SU(3)
5d Conformal
7
G2
"All" 4d theories

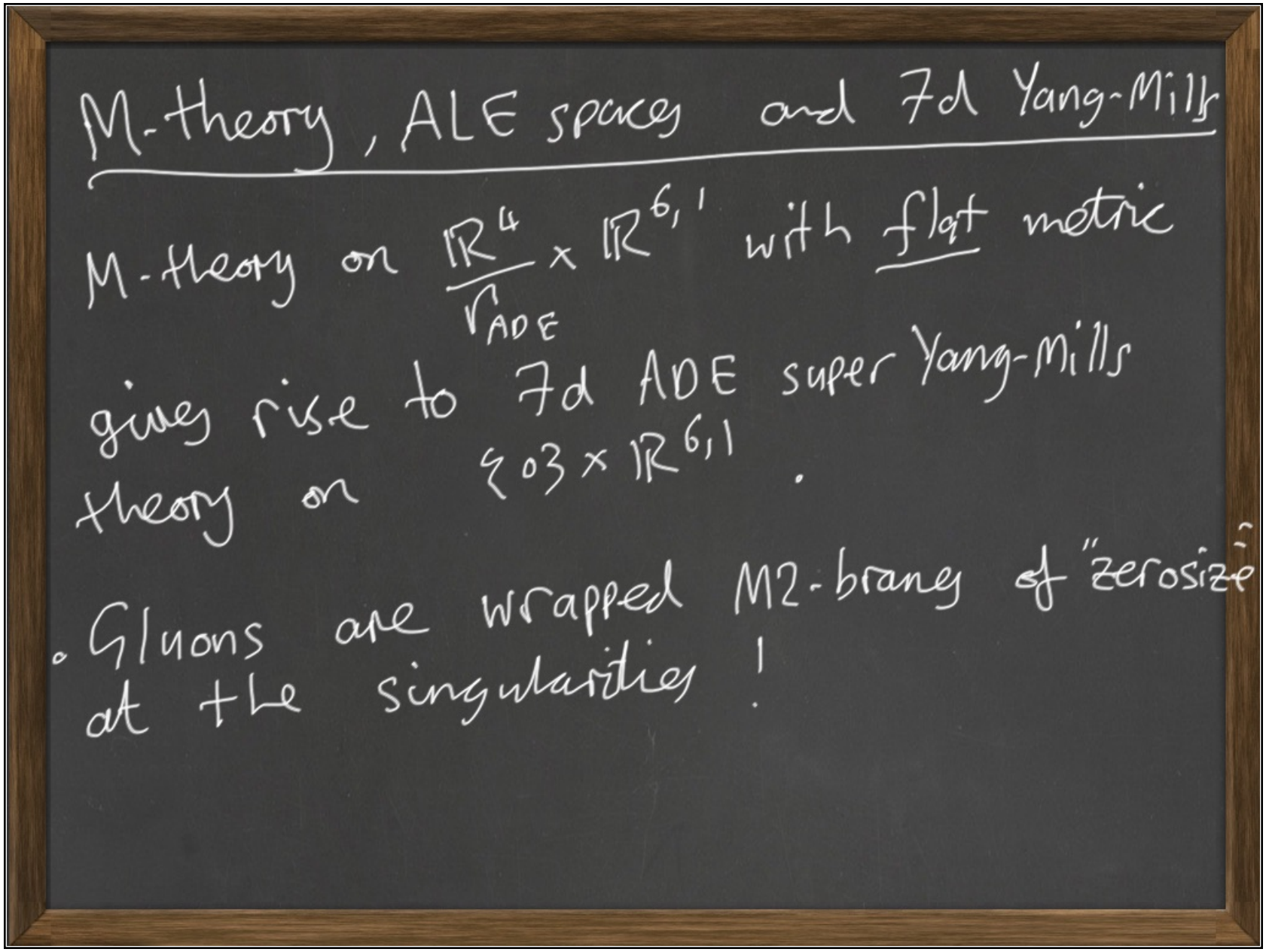

Def^{n}: A conical metric $g(X) \equiv dr^2 + r^2 g(\Sigma)$
on $X \doteq \mathbb{R}^+ \times \Sigma$
If $Hol(g(X)) = SU(n), Sp(n), G_2$ or $Spin(7)$
then $(X, g(X))$ is said to be a special
holonomy cone. (Scale symmetry $r \to \lambda r$)
More generally one is interested in
smooth, complete, asymptotically conical (AC)
special holonomy manifolds.

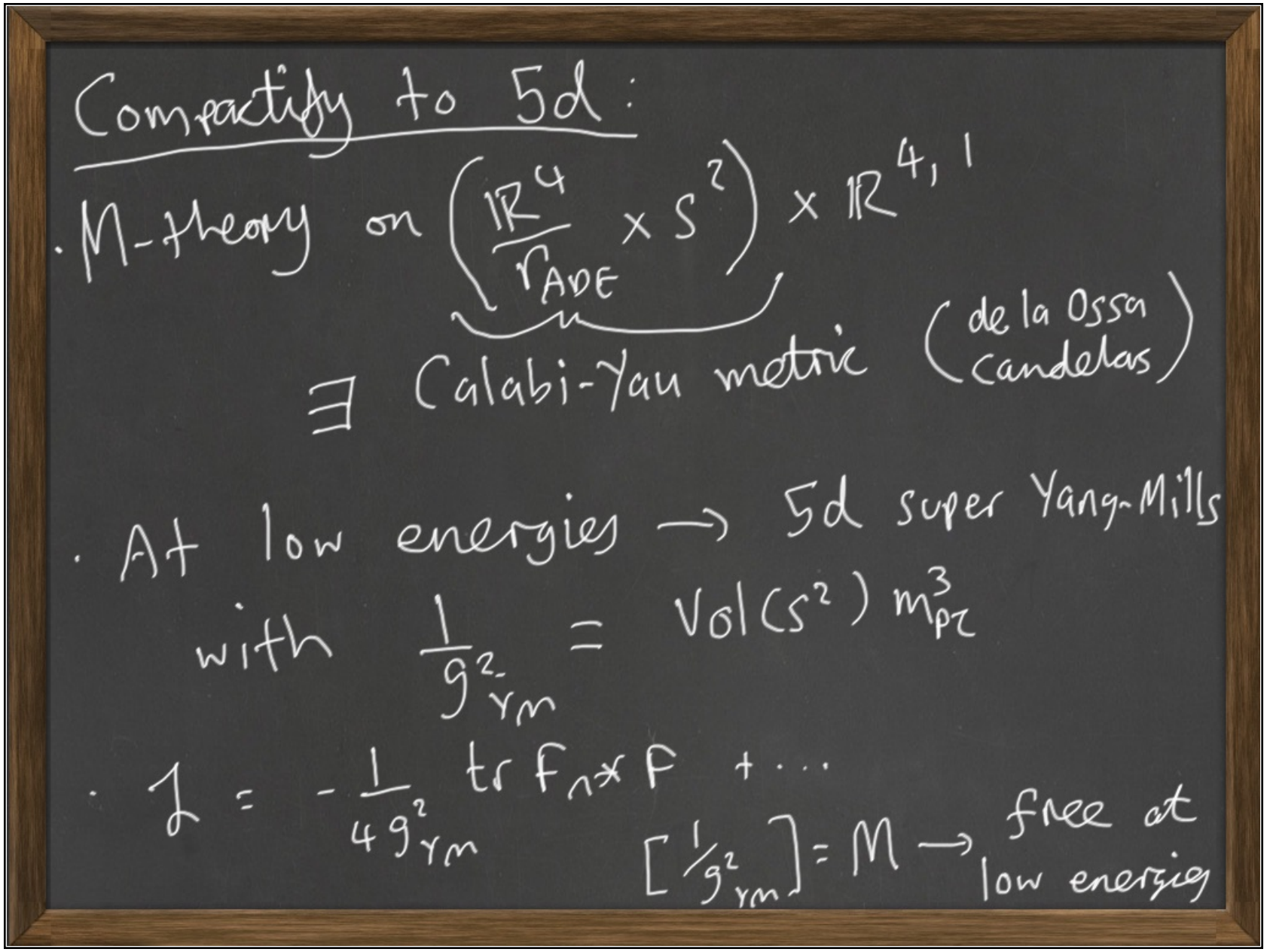

shrink to
a point
Smooth mfld
singular cone

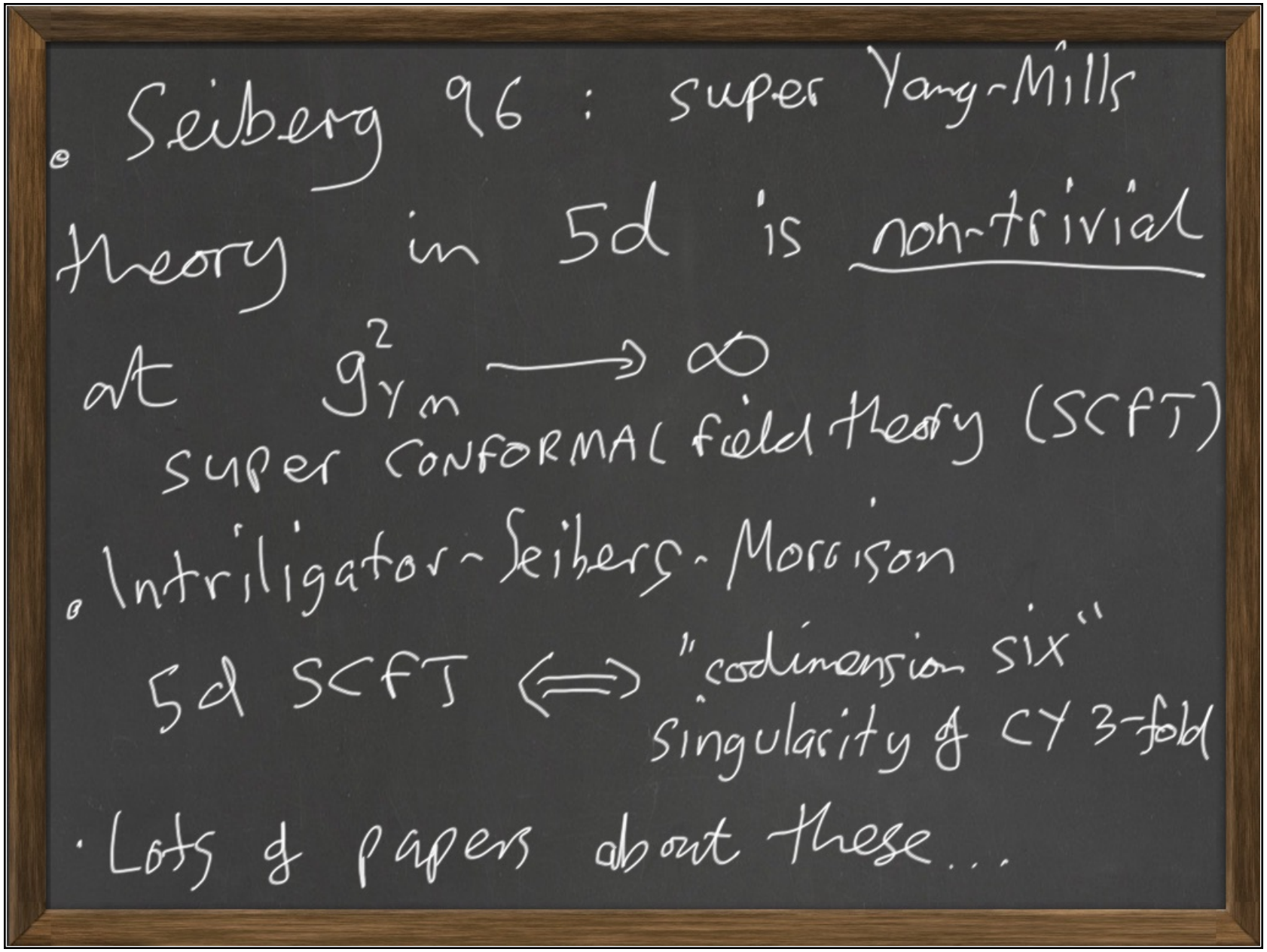

Examples :
n = 4 ALE hyperkahler $\mathbb{R}^4/\Gamma_{ADE}$ (Eguchi-Hanson) (Kronheimer)
n = 6 Conifold and resolutions and deformations (Candelas and de la Ossa Stenzel)
n = 7 Bryant-Salamon metrics on $(S(S^3), \Lambda^2_-(S^4), \Lambda^2_-(\mathbb{CP}^2))$ (Bryant - Salaman)
Foscolo - Haskins metrics on $(\mathbb{R}^+ \times S^6, \mathbb{R}^+ \times S^3 \times S^3)$
Foscolo Haskins Nordstrom

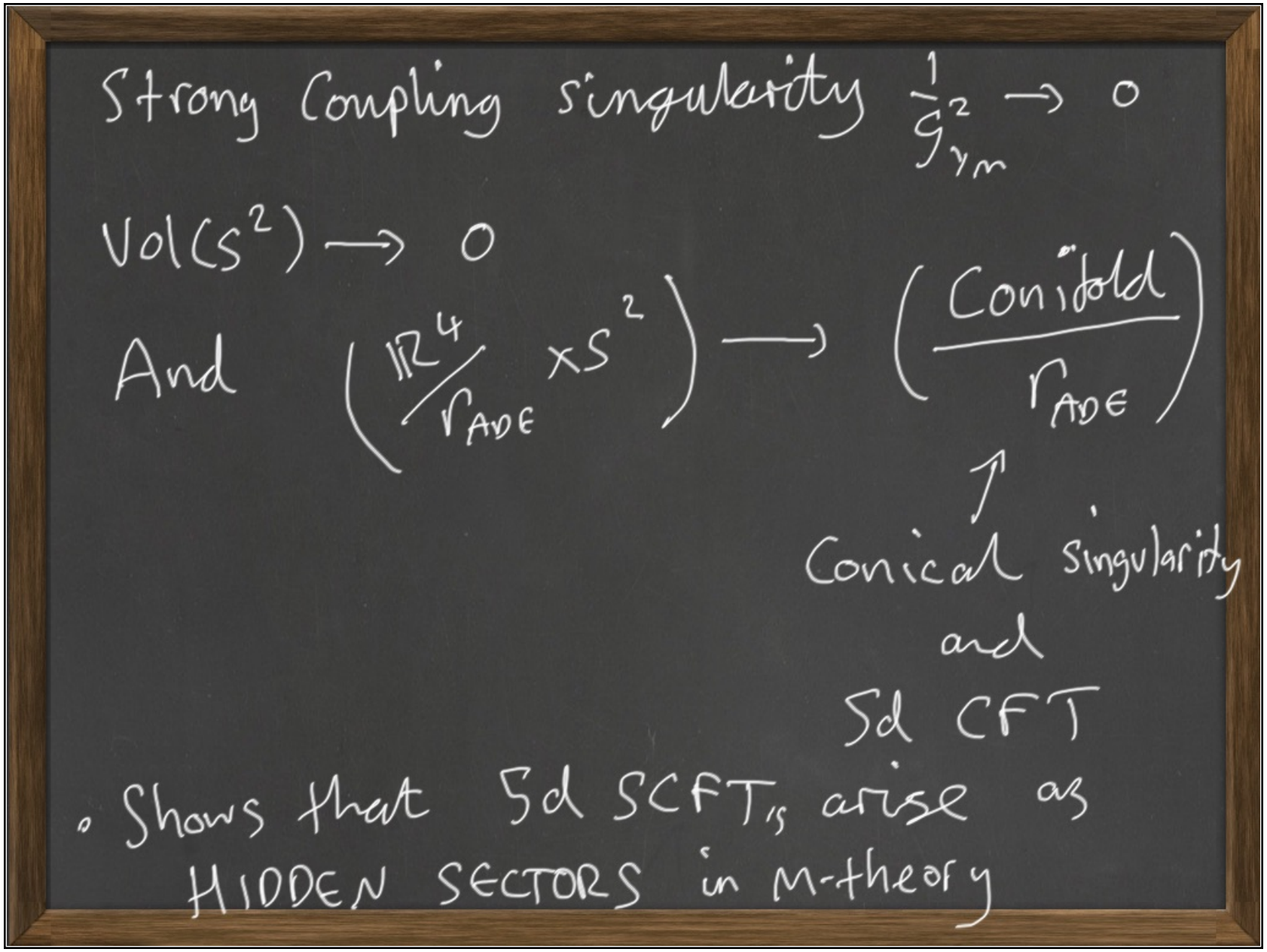

. These are the UV descriptions
of HIDDEN SECTORS that
string/M-theory provides.
. Important to study them in detail

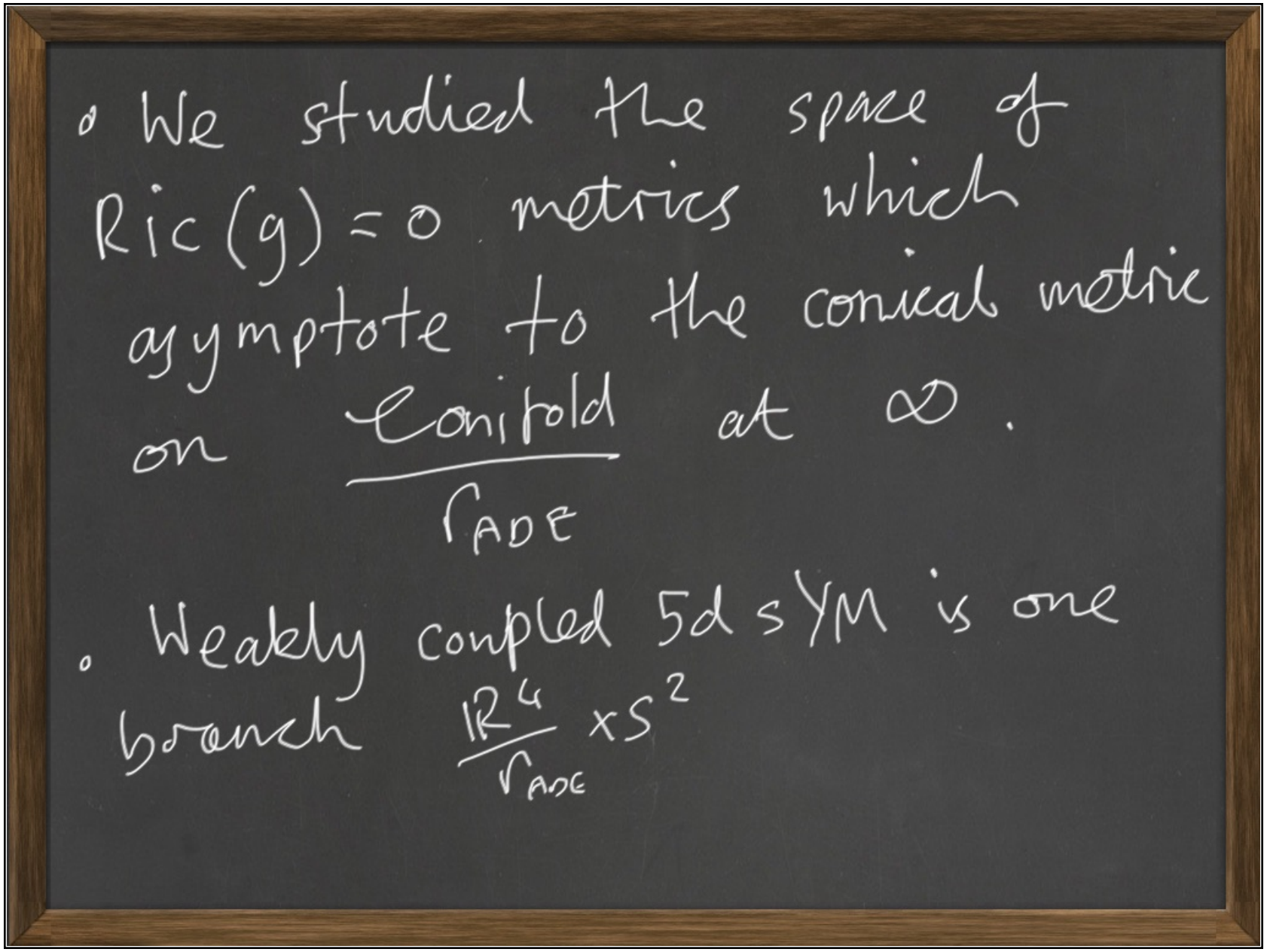

Physically its also interesting to consider
finite quotients of these examples:
ie AC special Holonomy orbifolds
(eg codim four ADE singularities
⟺ non-Abelian gauge fields)
(like the Standard Model)

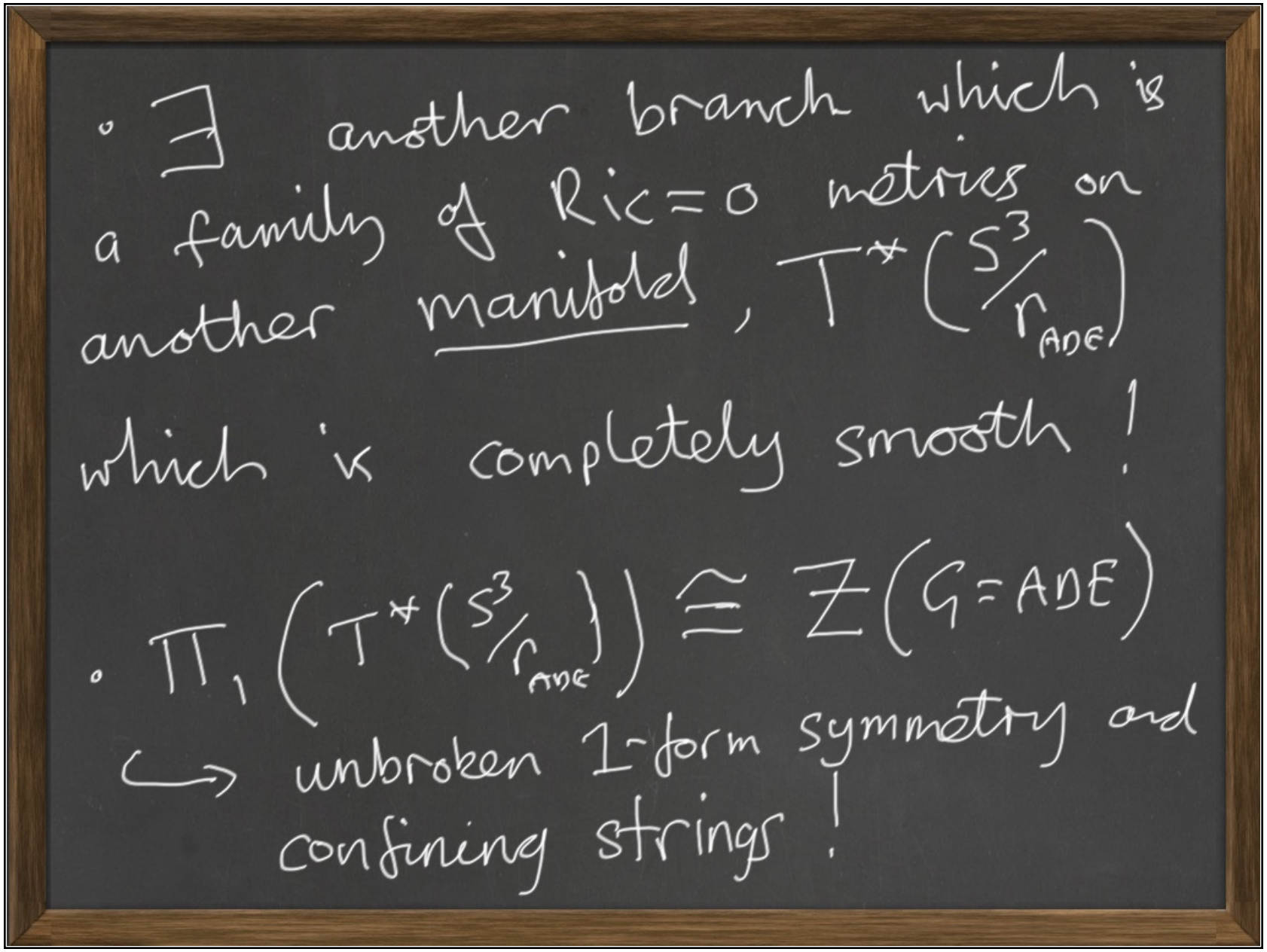

M-theory, ALE spaces and 7d Yang-Mills
M-theory on $\mathbb{R}^4/\Gamma_{ADE} \times \mathbb{R}^{6,1}$ with flat metric
gives rise to 7d ADE super Yang-Mills theory on $\xi 03 \times \mathbb{R}^{6,1}$.
• Gluons are wrapped M2-branes of "zerosize"
at the singularities!

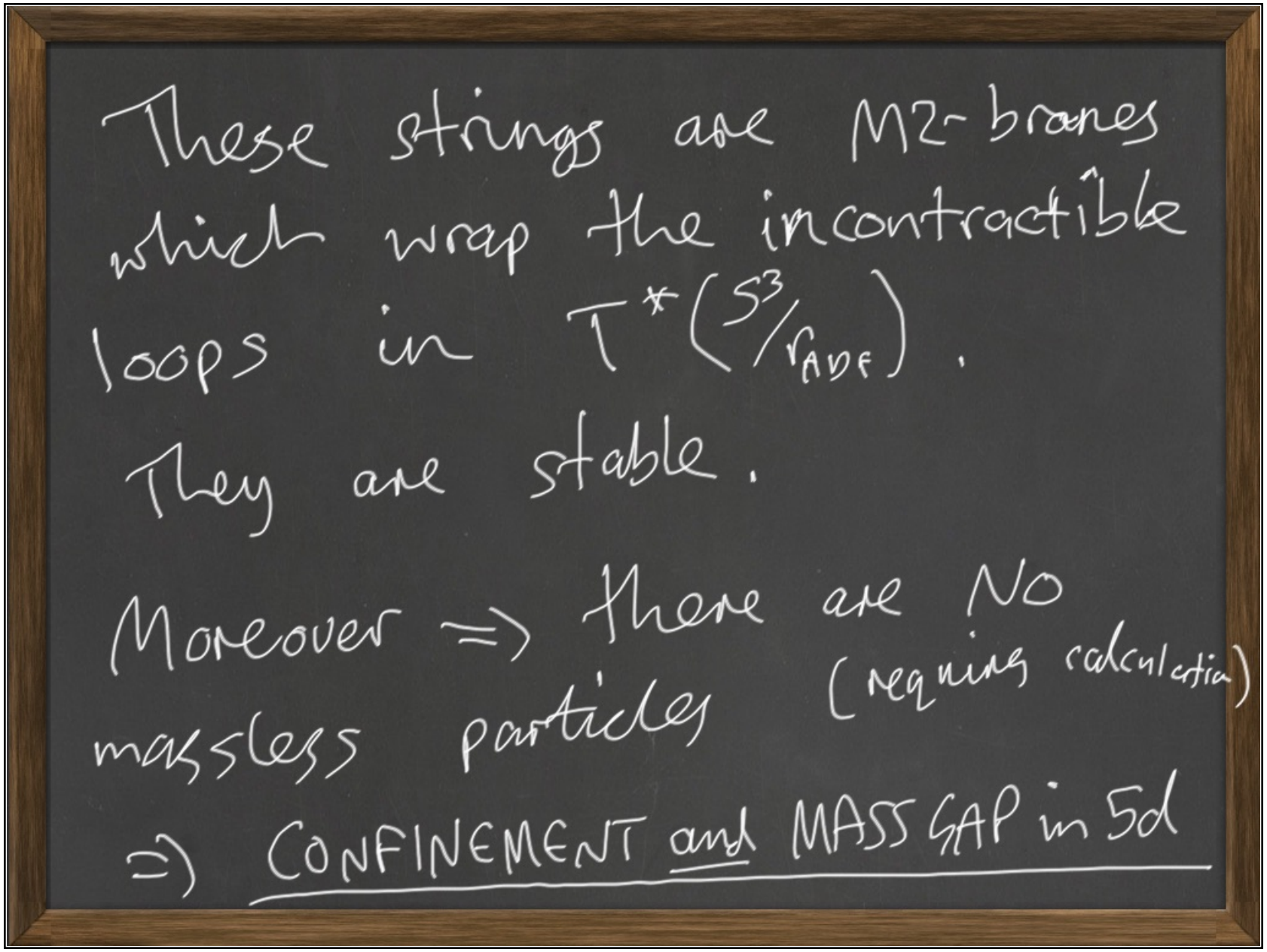

Compactify to 5d:
. M-theory on $\left(\frac{\mathbb{R}^4}{\Gamma_{ADE}} \times S^2\right) \times \mathbb{R}^{4,1}$
$\exists$ Calabi-Yau metric (de la Ossa Candelas)
. At low energies → 5d super Yang-Mills
with $\frac{1}{g^2_{YM}} = \mathrm{Vol}(S^2)\, m_{Pl}^3$
. $\mathcal{L} = -\frac{1}{4g^2_{YM}} \mathrm{tr}\, F \wedge *F + \ldots$
$\left[\frac{1}{g^2_{YM}}\right] = M$ → free at low energies

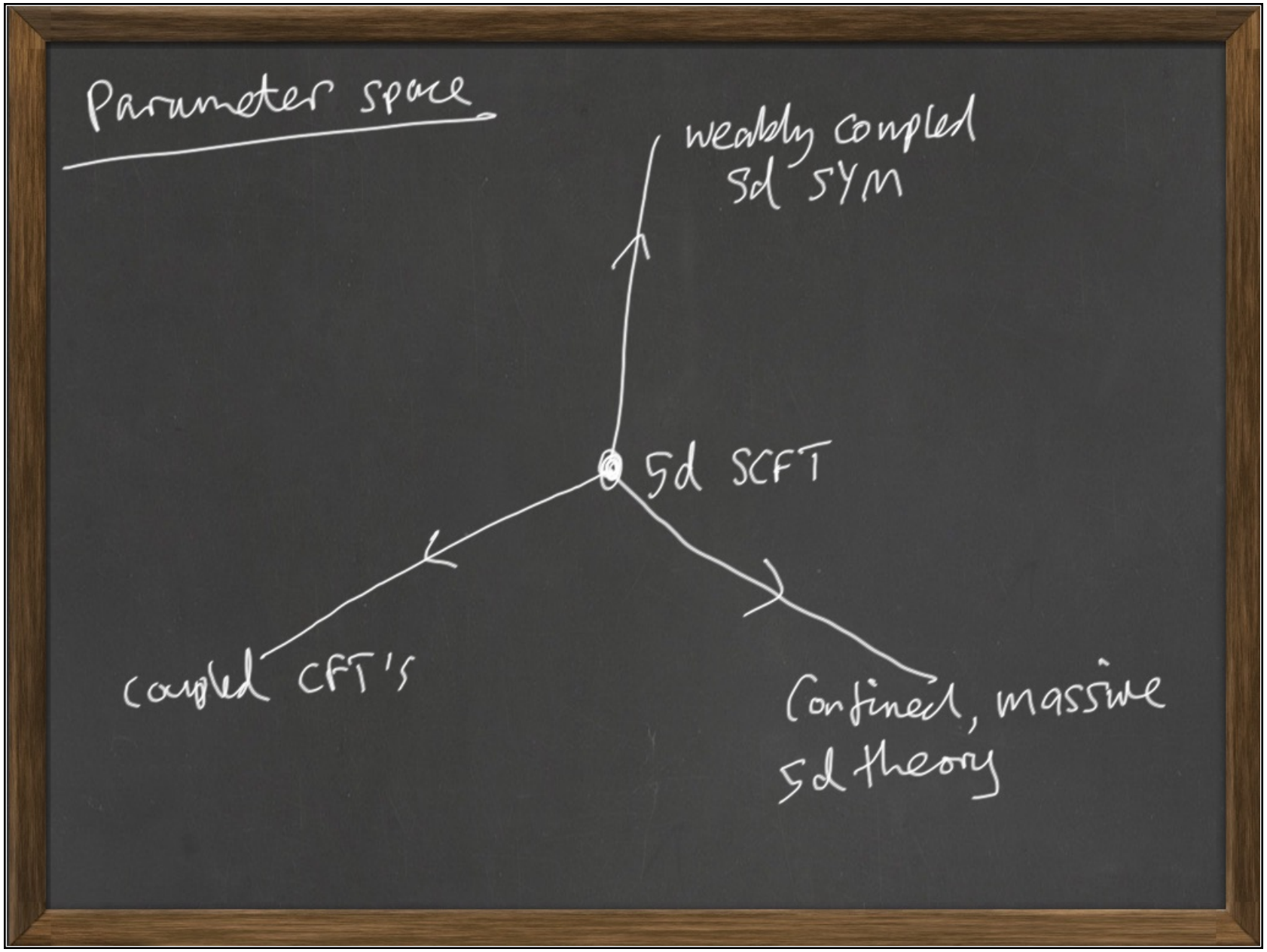

• Seiberg 96 : super Yang-Mills
theory in 5d is non-trivial
at $g^2_{YM} \longrightarrow \infty$
super CONFORMAL field theory (SCFT)
• Intriligator-Seiberg-Morrison
5d SCFT $\Longleftrightarrow$ "codimension six"
singularity of CY 3-fold
• Lots of papers about these...

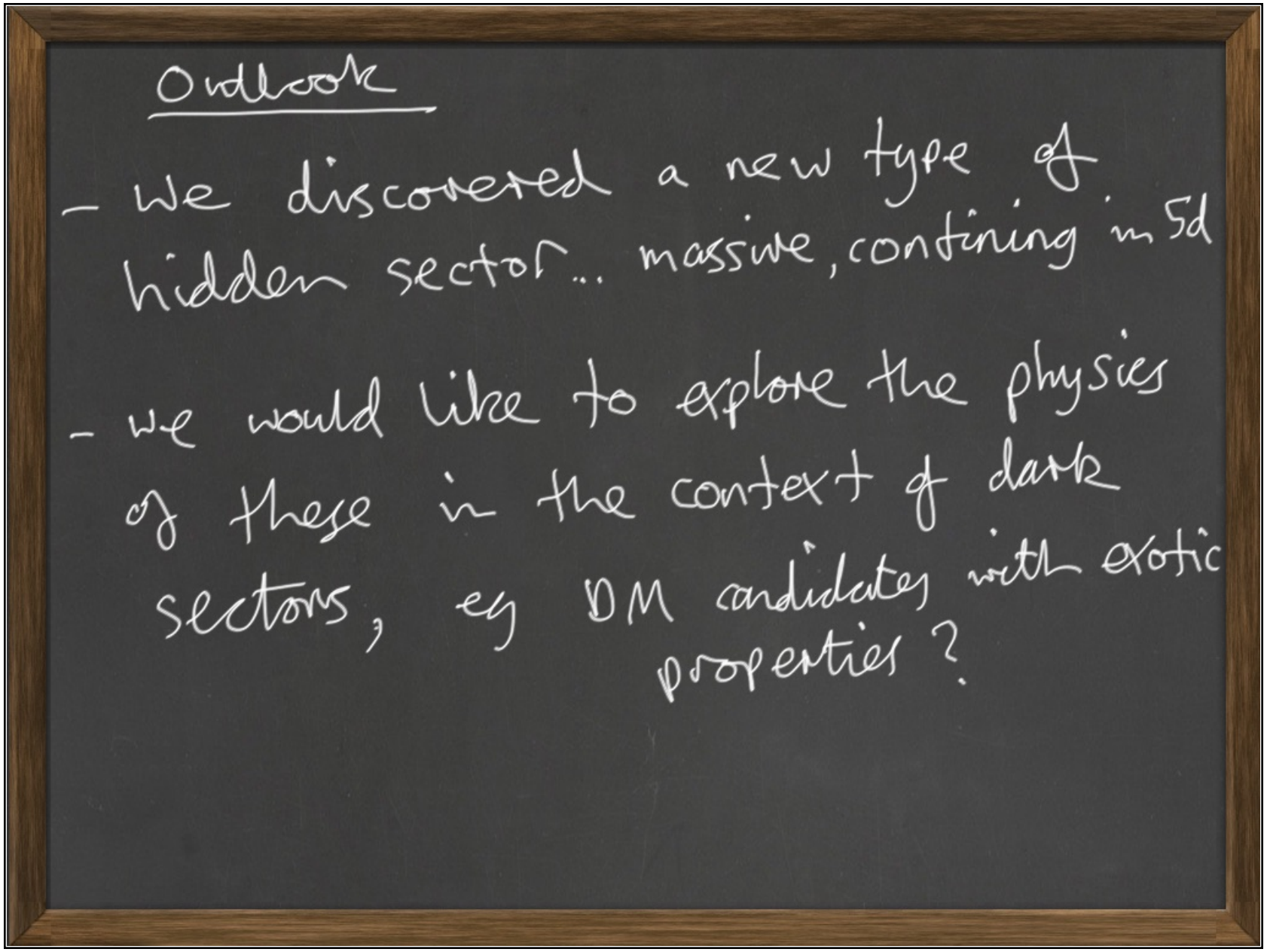

Strong Coupling singularity $\frac{1}{g^2_{YM}} \to 0$
$Vol(S^2) \to 0$
And $\left(\frac{\mathbb{R}^4}{\Gamma_{ADE}} \times S^2\right) \to \left(\frac{\text{Conifold}}{\Gamma_{ADE}}\right)$
Conical singularity
and
5d CFT
• Shows that 5d SCFT's arise as
HIDDEN SECTORS in M-theory


• We studied the space of
Ric(g) = 0 metrics which
asymptote to the conical metric
on Conifold at ∞.
Γ_{ADE}
• Weakly coupled 5d sYM is one
branch $\frac{\mathbb{R}^4}{\Gamma_{ADE}} \times S^2$


∃ another branch which is a family of Ric=0 metrics on another manifold, $T^*\left(S^3/\Gamma_{ADE}\right)$ which is completely smooth!
$\pi_1\left(T^*\left(S^3/\Gamma_{ADE}\right)\right) \cong Z(G=ADE)$
↪ unbroken 1-form symmetry and confining strings!


These strings are M2-branes which wrap the incontractible loops in $T^*(S^3/\Gamma_{ADE})$.
They are stable.
Moreover $\Rightarrow$ there are NO massless particles (requiring calculation)
$\Rightarrow$ CONFINEMENT and MASS GAP in 5d


Parameter space
weakly coupled
5d SYM
5d SCFT
coupled CFT's
Confined, massive
5d theory


Outlook
- We discovered a new type of hidden sector... massive, confining in 5d
- we would like to explore the physics of these in the context of dark sectors, eg DM candidates with exotic properties ?

Thank You !