Title: No GUTs, All Glory: Charge Quantization and the Standard Model from Nonlinear Sigma Models

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Abstract: I will present recent and ongoing work in collaboration with Tsutomu Yanagida and Simeon Hellerman (arXiv:1309.0692 and 1312.xxxx) on a new way to obtain charge quantization, without a GUT or monopole solution. In the CP^1 model, SU(2)_G/U(1)_H, consistency conditions for a charged field and its transformation properties over the entire group manifold lead to a charge quantization condition. By gauging the U(1)_H and identifying it with hypercharge, we find charge quantization in the SM without a monopole or GUT, purely from the structure and dynamics of the nonlinear sigma model. This is easily extended to CP^2 and general CP^k models. Phenomenologically, the CP^1 model has a fractionally charged stable Nambu-Goldstone boson (NGB), which has intriguing applications to nuclear physics and dark matter. The CP^2 model has the Higgs as the NGB. With some additional minor assumptions, anomaly freedom then leads to the matter content of a generation in the SM.

arXiv: 1309.0692 & 1312.xxxx

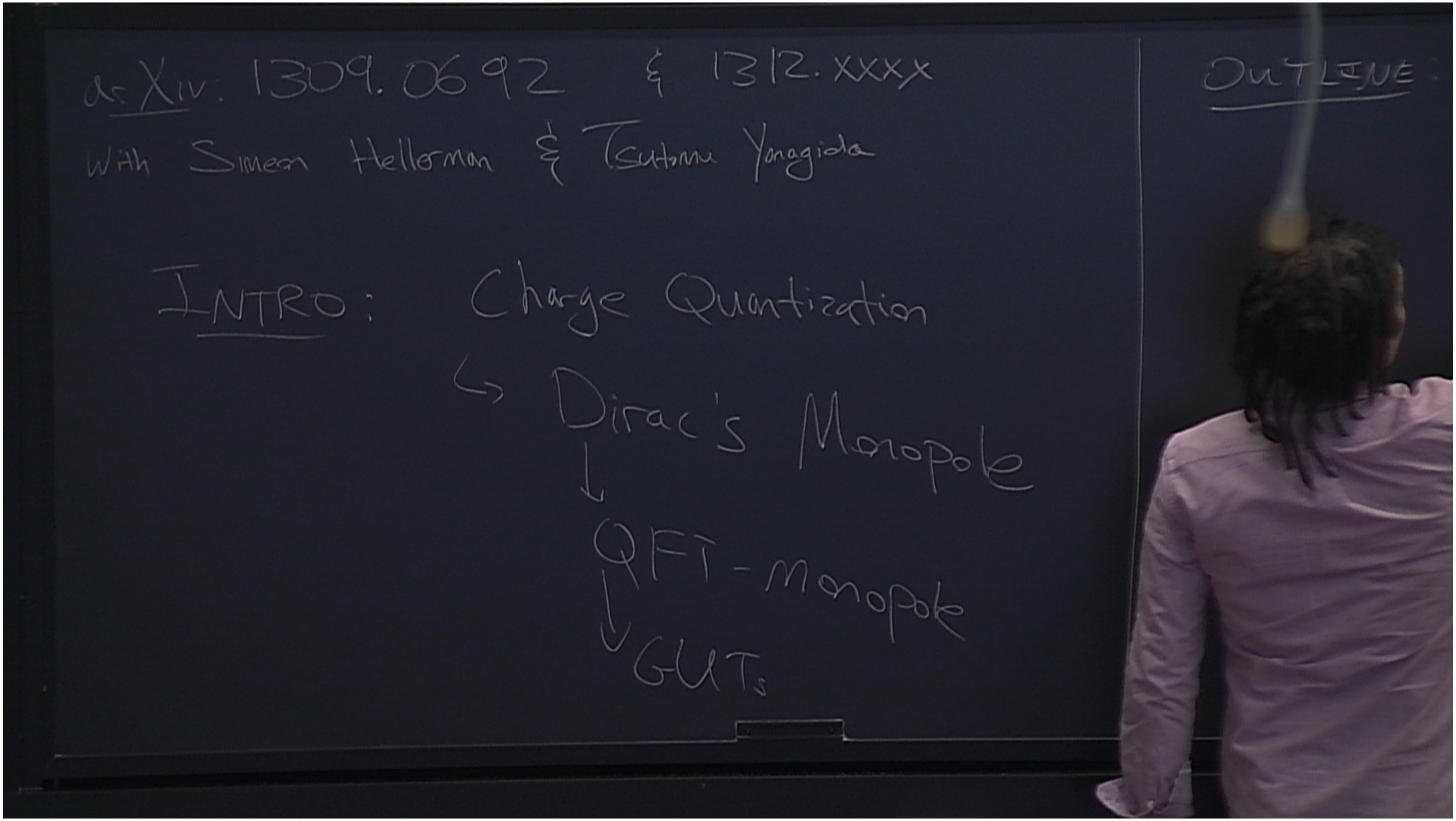
With Simeon Hellerman & Tsutomu Yanagida

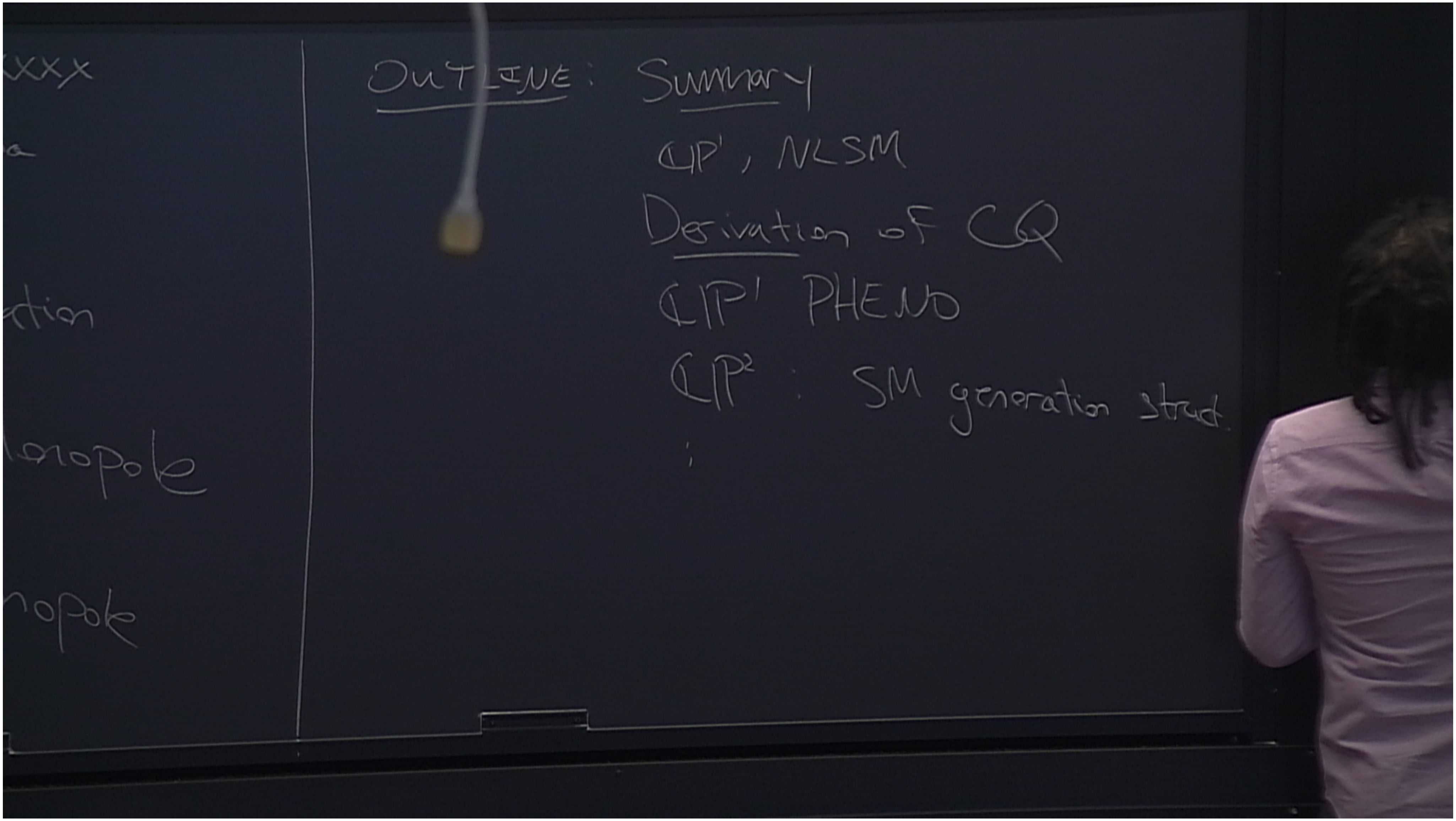
INTRO: Charge Quantization

↳ Dirac's Monopole

↓

QFT - Monopole


arXiv: 1309.0692 & 1312.xxxx
With Simeon Hellerman & Tsutomu Yanagida
INTRO: Charge Quantization
Dirac's Monopole
QFT - Monopole
GUTs
OUTLINE:


OUTLINE: Summary
CP', NLSM
Derivation of CQ
CP' PHENO
CP²: SM generation struct.

↳ $\mathbb{CP}^1$: NGB is frac charged

· NLSM : nonlinearly realized sym. G

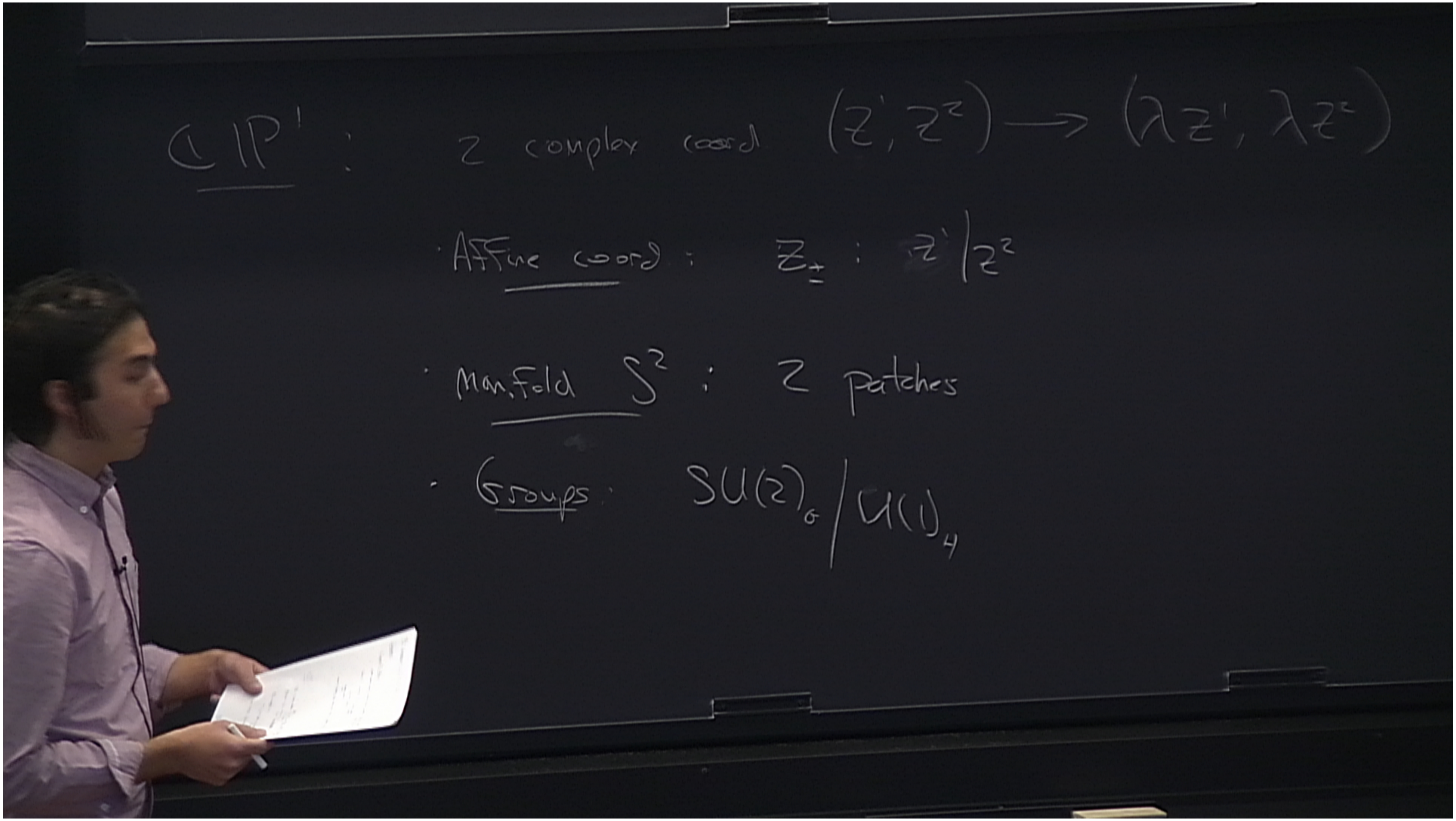
linearly " subgroup H

· G/H

$\mathbb{CP}^1$: 2 complex coord. $(z^1, z^2) \longrightarrow (\lambda z^1, \lambda z^2)$

· Affine coord : $z_{\pm} : z^1/z^2$

· Manifold S^2


$\mathbb{CP}^1$: 2 complex coord $(z^1; z^2) \longrightarrow (\lambda z^1; \lambda z^2)$
· Affine coord : $Z_\pm$: z^1/z^2
· Manifold S^2 : 2 patches
· Groups : $SU(2)_6/U(1)_4$

· Complex charged matter field χ : $SU(2)_G$ $\underline{NL}$ entire $\mathbb{CP}^1$

$U(1)_H$ L

· $z_+ \equiv \overset{\text{scale}}{v}\, z^1 / z^2$

$SU(2)_G$ gen $T_\pm, T_0$ — $U(1)_H$

$\delta T_+ \circ z_+ = -\frac{1}{v} z_+^2 \partial_{z_+}$

$\delta T_- \circ z_+ = v$;

$\delta T_0 \circ z_+ = + z_+$;

$SU(2)_G$ NL

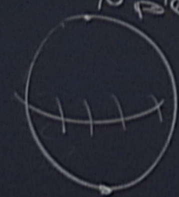
$U(1)_H$ L

entire $\mathbb{CP}^1$

S. Pole   N. Pole

$Z_+ = 0$, $Z_- = 0$

N pole



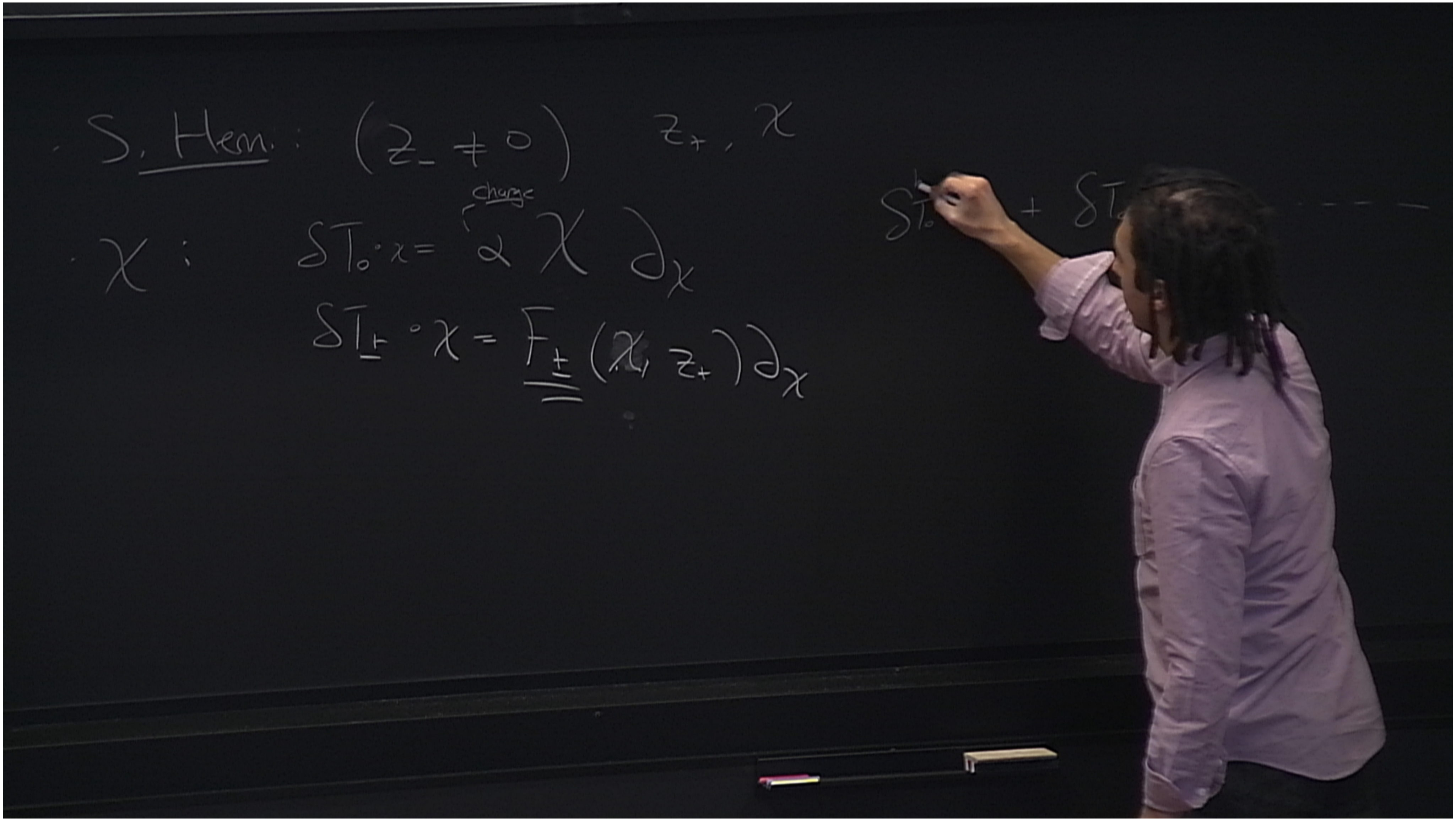
S Pole

$$[\delta T_0, \delta T_\pm] = \pm \delta T_\pm$$

$$[\delta T_+, \delta T_-] = 2\delta T_0$$

Anti-hol. :

$T_0 \to -T_0$, $T_\pm \to T_\mp$


S. Hem. : ($z_- \neq 0$) z_+, χ
charge
χ : $\delta T_0 \circ \chi = \alpha \chi \partial_\chi$
$\delta T_\pm \circ \chi = F_\pm(\chi, z_+) \partial_\chi$
δT_0 + δT

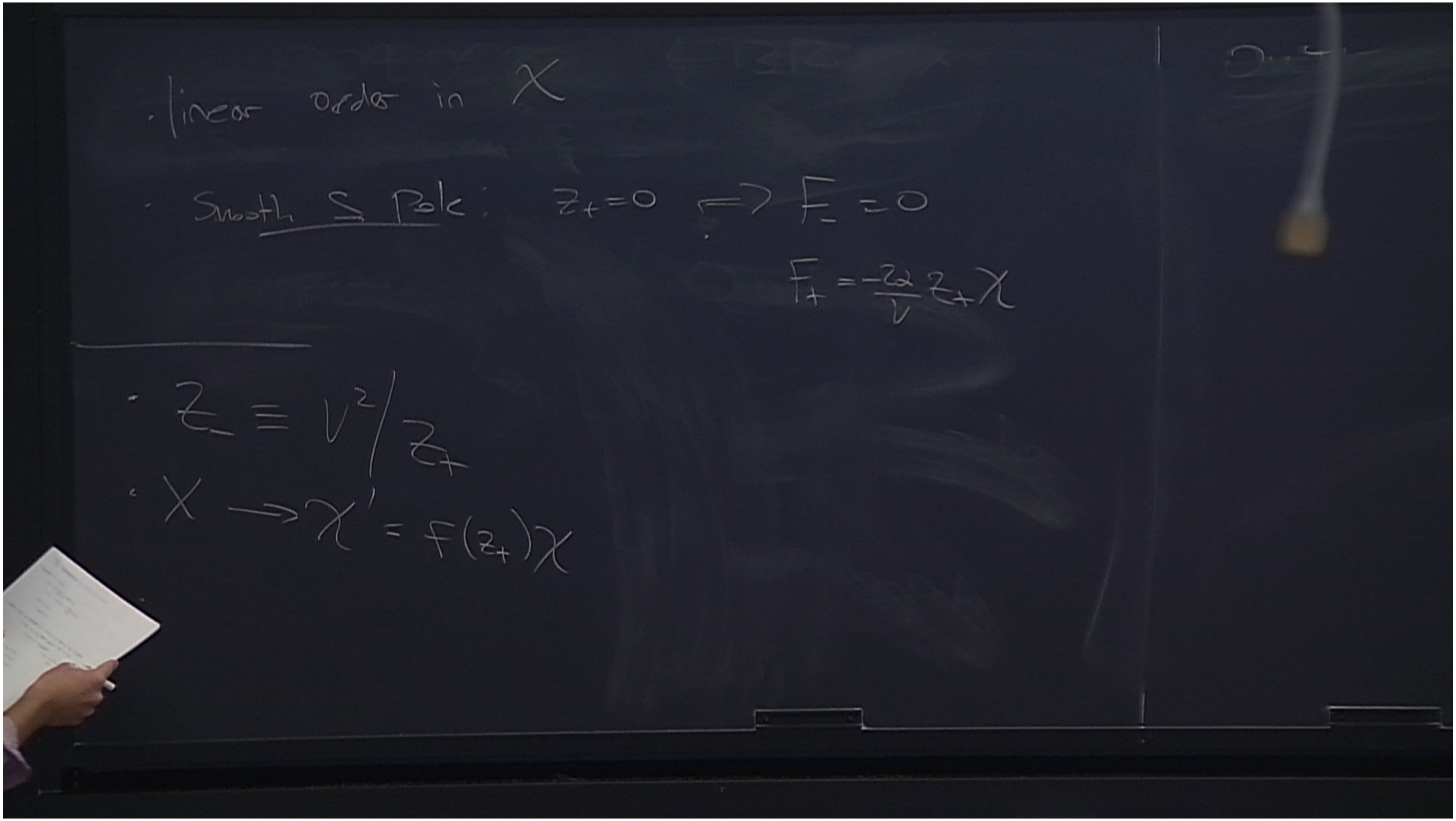
· S. Herm.: $(z_- \neq 0)$ $\quad z_+ , \chi$

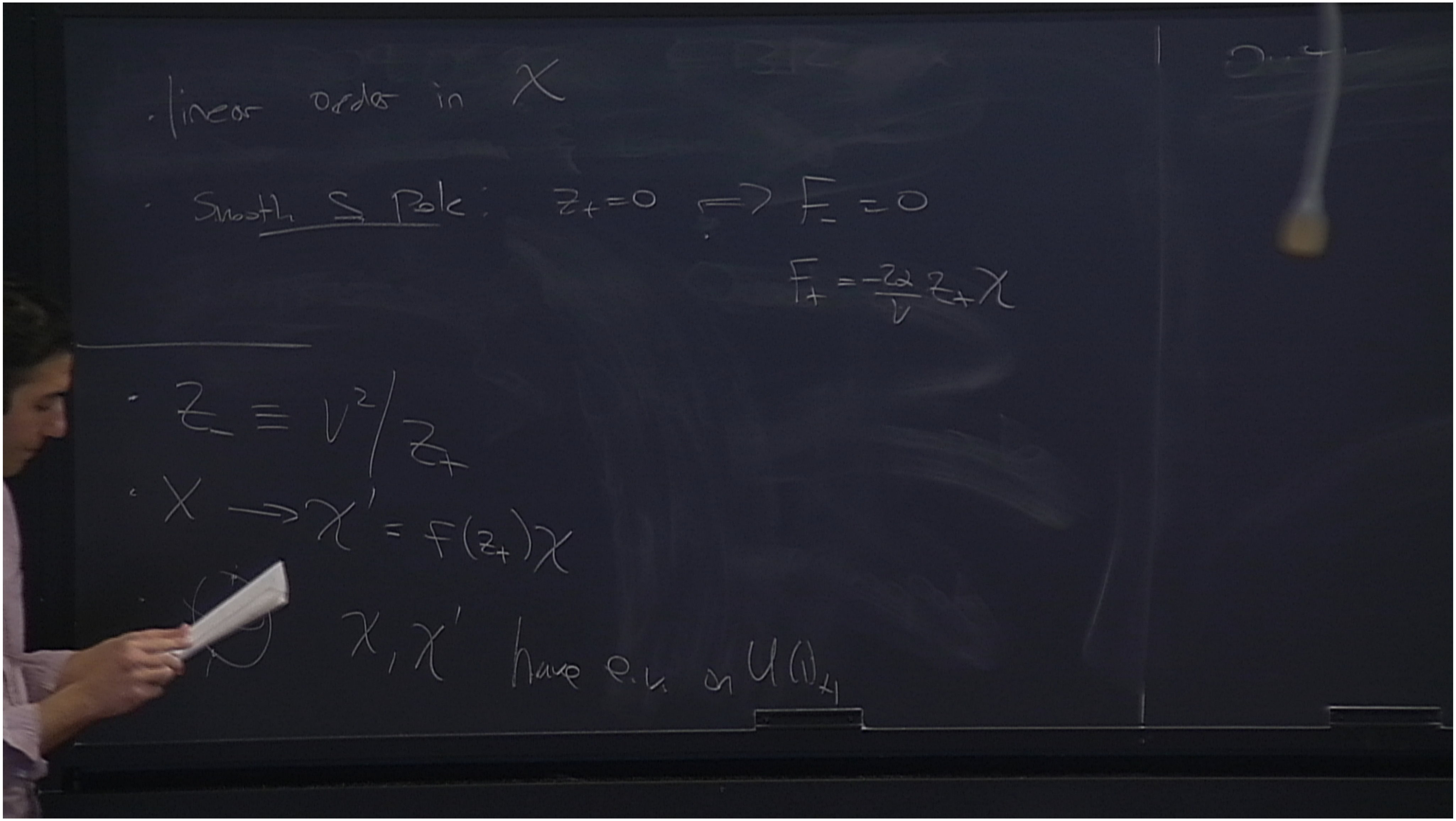
$$\delta^{(h)} T_0(\chi) + \delta^{(h)} T_0(z_+) = \text{- - - -}$$

· χ : $\quad \delta T_0 \circ \chi = \overset{\text{charge}}{\alpha}\, \chi\, \partial_\chi$

$$\delta T_\pm \circ \chi = F_\pm(\chi, z_+)\,\partial_\chi$$

$SU(2)_G$ alg. : equations for $F_\pm$

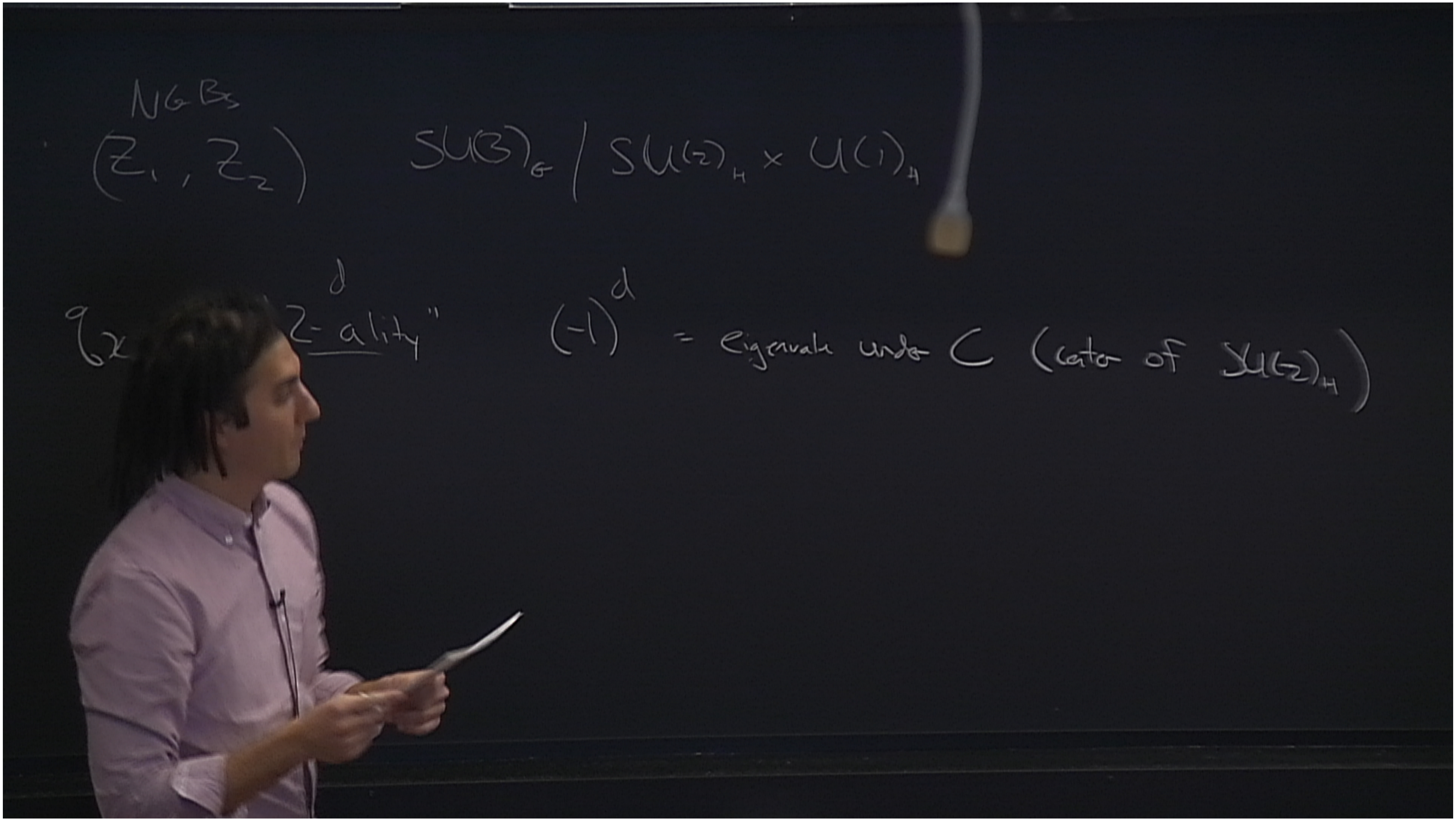

· linear order in χ
· Smooth S Pole: $z_+ = 0 \Rightarrow F_- = 0$
$F_+ = -\frac{2\alpha}{\nu} z_+ \chi$
· $z_- \equiv \nu^2 / z_+$
· $\chi \longrightarrow \chi' = f(z_+)\chi$

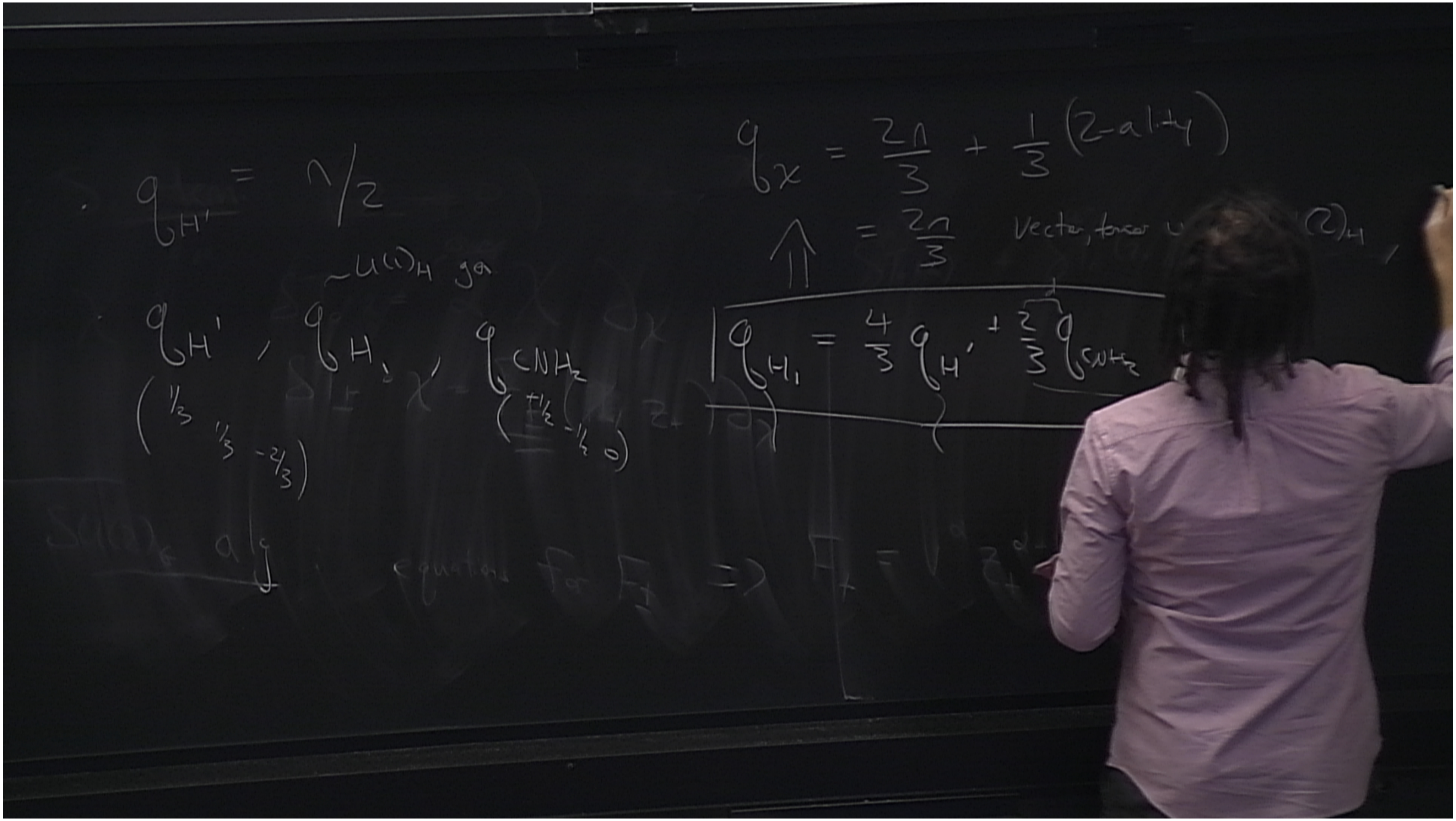

· linear order in χ
· Smooth S Pole: z+ = 0 ⟹ F− = 0
F+ = −2α/v z+ χ
· z− ≡ v²/z+
· χ ⟶ χ' = f(z+) χ
χ, χ' have e.v. on U(1)+1

NGBs

· $\underline{\mathbb{CP}^2}$: (z_1 , z_2) $\quad SU(3)_G / SU(2)_H \times U(1)_H$

· χ : q_χ , "$\overset{d}{Z}$-$\underline{\text{ality}}$" $\quad (-1)^d$ = eigenvalue un


NGBs
(Z1 , Z2)
SU(3)G / SU(2)H × U(1)H
d
Z-ality"
(-1)d = eigenvalue under C (center of SU(2)H)


q_H' = n/2
~U(1)_H ga
q_H' , q_H , χ , q_CNH2
q_x = 2n/3 + 1/3 (2-ality)
= 2n/3 Vector, tensor
q_H1 = 4/3 q_H' + 2/3 q_CNH2

$$q_x = \frac{2n}{3} + \frac{1}{3}(\text{Z-ality}) \longrightarrow \frac{kn + (T \bmod k)}{k+1} \text{ for } \mathbb{CP}^k$$

$$\Uparrow \quad = \frac{2n}{3} \text{ vector, tensor under } SU(2)_H, \quad \frac{2n+1}{3} \text{ spinor}$$

$$\boxed{q_{H_1} = \frac{4}{3} q_{H'} + \frac{2}{3} q_{CNH_2}}$$

q_{CNH_2}

$(\pm\frac{1}{2}\ \ -\frac{1}{2}\ \ 0)$

$$q_X = \frac{2n}{3} + \frac{1}{3}(2\text{-ality}) \longrightarrow \frac{kn + (T \bmod k)}{k+1} \text{ for } \mathbb{CP}^k$$

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$$\boxed{q_{H_1} = \frac{4}{3} q_{H'} + \frac{2}{3} q_{CNH_2}}$$

H ga

q_{CNH_2}

$\left(\pm\frac{1}{2}, -\frac{1}{2}, 0\right)$

Quark doublet

<u>No</u> vector-like matter

Anomaly freedom (SM)

min. reps

} SM generation matter content

$$q_x = \frac{2n}{3} + \frac{1}{3}(\text{2-ality}) \longrightarrow \frac{kn + (T \bmod k)}{k+1} \text{ for } \mathbb{CP}^k$$

$$\Uparrow \quad = \frac{2n}{3} \text{ vector, tensor under } SU(2)_H, \quad \frac{2n+1}{3} \text{ spinor}$$

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q_{CNH_2}

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Quark doublet $q_x \neq 0$

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H ga

q_{CNH_2}

$(\pm 1/2 \;\; -1/2 \;\; 0)$

$$\boxed{q_{H_1} = \frac{4}{3} q_{H'} + \frac{2}{3} q_{CNH_2}}$$

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