Title: Fuzzy dark matter and the H_0 gravitational lensing measurement

Speakers: Luca Teodori

Series: Particle Physics

Date: February 13, 2024 - 1:00 PM

URL: https://pirsa.org/24020065

Abstract: Fuzzy dark matter can form cored density distributions, named solitons, at the center of galaxies. Such cores can be viewed as approximate mass sheets and can affect the time delay cosmography Hubble constant (H_0) measurement via the mass sheet degeneracy. We show that a subdominant component of fuzzy dark matter can yield a 10 percent shift in the inferred H_0, if the particle mass is of order 10^-25 eV. The sensitivity of time delays on such cores (difficult to spot otherwise) may give a further probe in constraining the fuzzy dark matter scenario, if an H_0 prior is assumed.

Zoom link

Conversazione in corso:

Fuzzy dark matter and the H_0 gravitational lensing measurement

Mostly based on Blum, Teodori 2021 [2105.10873]

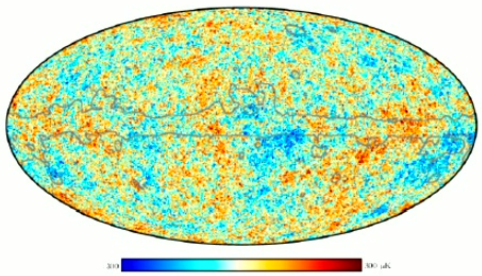
Teodori Luca

Perimeter Institute, February 2024

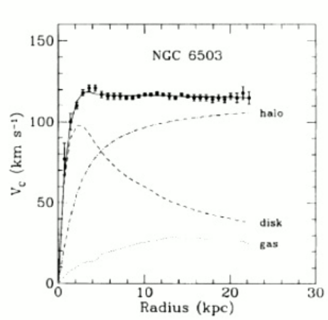
Dark matter

$m_{\rm dm}\,[\rm eV]$ $\quad 10^{-20} \quad 10^{-18} \quad 10^{-16} \;\wr\wr\; 10^{6} \quad 10^{8} \quad 10^{10} \quad 10^{12} \quad 10^{14} \;\wr\wr\; 10^{53} \quad 10^{55} \quad 10^{57}$ $\quad \sim 10^{-9} M_\odot$

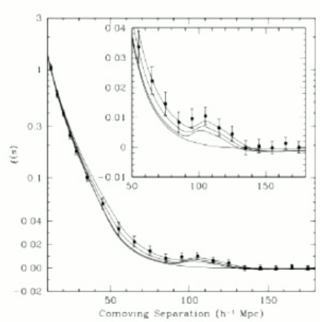
- Dark matter is an “easy” problem!
- What can gravity alone tell us?



Planck 2018 [1807.06205]



K. Freese 2008 [0812.4005]

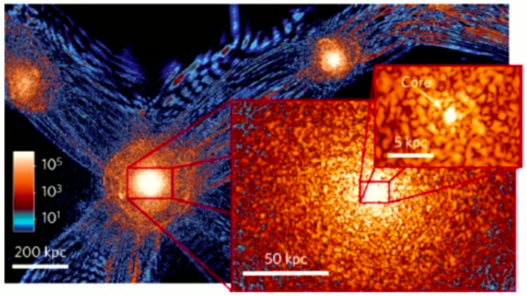


Eisenstein et al 2005 [astro-ph/0501171]

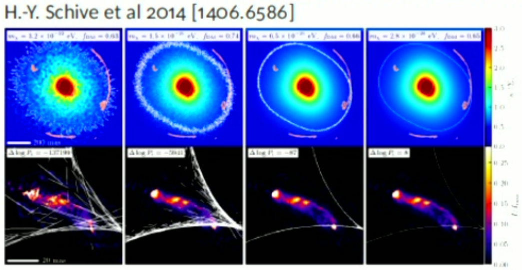
MACS 0416 (Nasa, Esa)

Effects of FDM

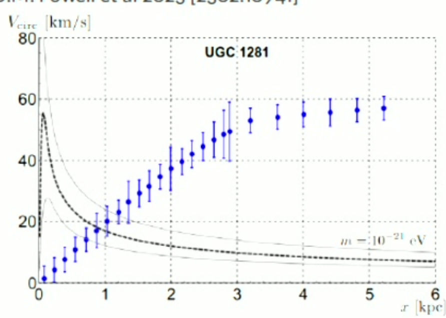
Conversazione in corso: Perin



H.-Y. Schive et al 2014 [1406.6586]

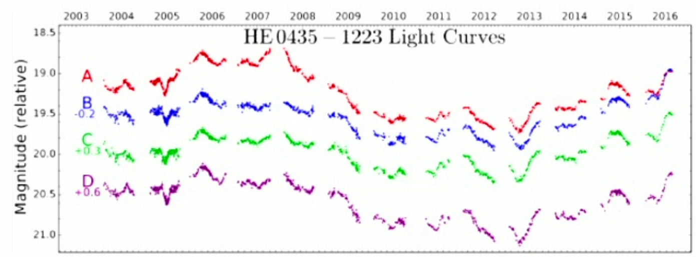


D.M. Powell et al 2023 [2302.10941]



N. Bar et al 2018 [1805.00122]

- Main features: wave-interference phenomena and inner cored profile (solitons)
- Lyman-alpha forest
- Dynamical heating
- Galaxy rotation curves (Soliton-halo relation)
- Gravitational lensing anomalies
- Gravitational lensing: time delays and H_0 from FDM cores

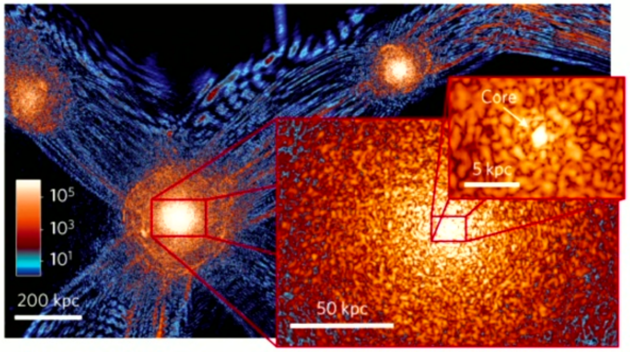


V. Bonvin et al 2016 [1607.01790]

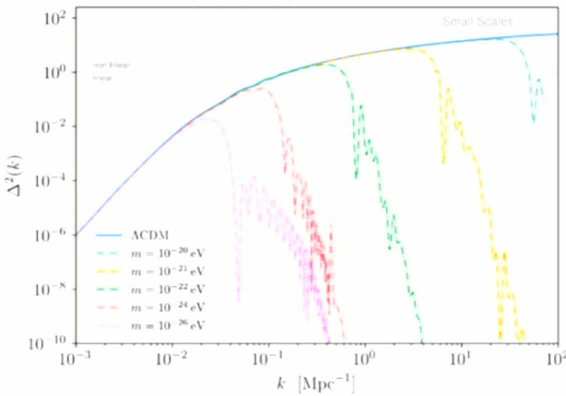
Outline

- Solitons in FDM
- H_0 from time delays (?)
- Soliton profile affecting time delays inference
- Can we constrain the FDM paradigm with an H_0 prior?

Fuzzy Dark Matter essentials



H.-Y. Schive et al 2014 [1406.6586]



E.G.M. Ferreira 2021 [2005.03254]

- De-Broglie relevant in astrophysics scales

$$\lambda = \frac{2\pi}{k} = \frac{2\pi}{mv} \simeq 3.8\,\mathrm{pc}\left(\frac{10^{-20}\,\mathrm{eV}}{m}\right)\left(\frac{10^2\,\mathrm{km\,s^{-1}}}{v}\right)$$

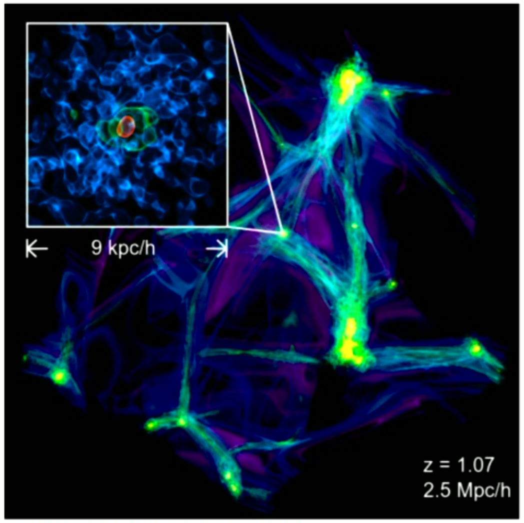
- Cannot squeeze too much mass in little volume (from uncertainty principle): small scales power spectrum suppression, plus formation of cored profiles
- Huge occupation number $\Longrightarrow$ classical field

$$\mathcal{N} \simeq \frac{\rho_{\rm dm}}{m(mv)^3} \simeq 10^{84}\left(\frac{\rho_{\rm dm}}{0.4\,\mathrm{GeV\,cm^{-3}}}\right)\left(\frac{10^{-20}\,\mathrm{eV}}{m}\right)^4$$

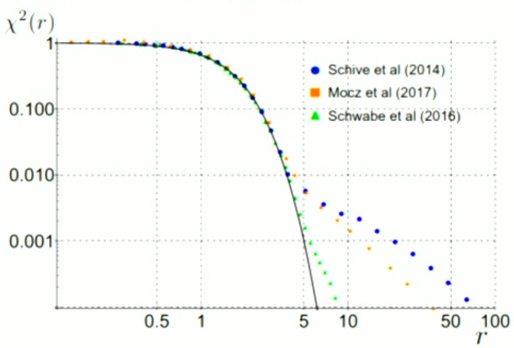
- In NR limit, we have Schrödinger-Poisson equations

$$i\partial_t\psi = -\frac{\nabla^2\psi}{2m} + m\Phi\psi\,,$$
$$\nabla^2\Phi = 4\pi G|\psi|^2\,.$$

Solitons



J. Veltmaat et al 2018 [1804.09647]



N. Bar et al 2018 [1805.00122]

- Ground state solution of Schrödinger-Poisson

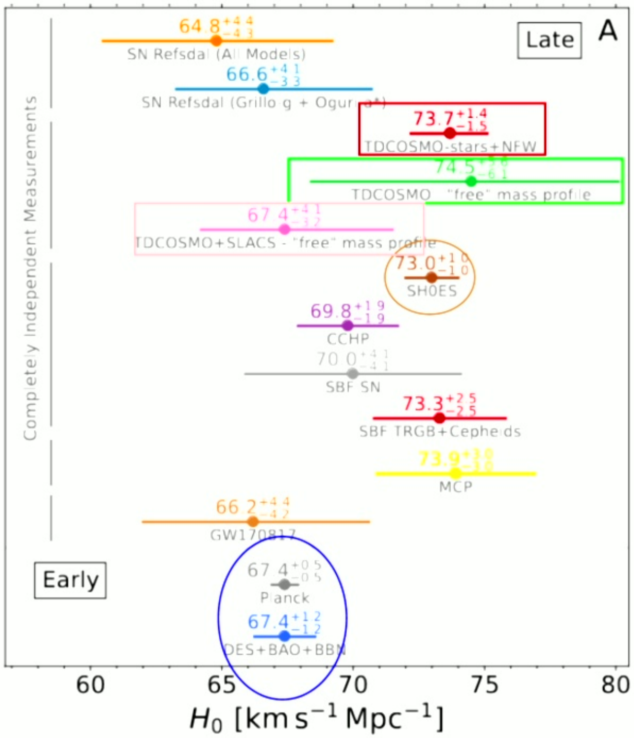
$$\psi(\vec{x},t) = \frac{mM_{\rm pl}}{\sqrt{4\pi}} e^{-i\gamma mt}\chi(\vec{x}) \,, \; x = rm$$

$$\partial_x^2\chi + \frac{2}{x}\partial_x\chi = 2(\Phi + \Phi_{\rm ext} - \gamma)\chi$$

$$\partial_x^2\Phi + \frac{2}{x}\partial_x\Phi = \chi^2$$

- Can cores affect time delays?

The H_0 tension



P.L. Kelly et al 2023 [2305.06367]

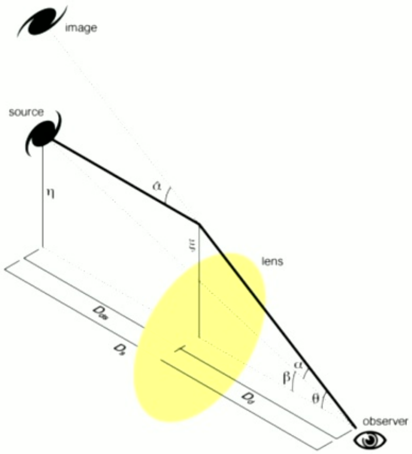
- CMB and LSS (early);
- Distance ladder (late);
- Strong gravitational lensing from TDCOSMO (COSMOGRAIL, HoLiCOW, STRIDES, SHARP, COSMICLENS);
- Use SLACS lenses to put priors on lens population parameters.

Galaxy	H_0
PG1115	$81.1^{+8.0}_{-7.0}$
RXJ1131	$78.2^{+3.4}_{-3.4}$
WFI2033	$71.6^{+3.8}_{-4.9}$
HE0435	$71.7^{+4.8}_{-4.5}$
DESJ0408	$74.2^{+2.7}_{-3.0}$
B1608+656	$71.0^{+2.9}_{-3.3}$
J1206	$68.9^{+5.4}_{-5.1}$

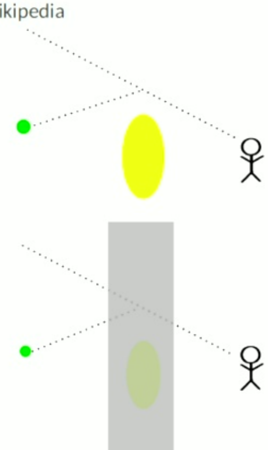
Adapted from M. Millon et al 2019 (TDCOSMO I) [1912.08027]

Conversazione in corso: Perin

Cores affecting time delays?



credit: Wikipedia

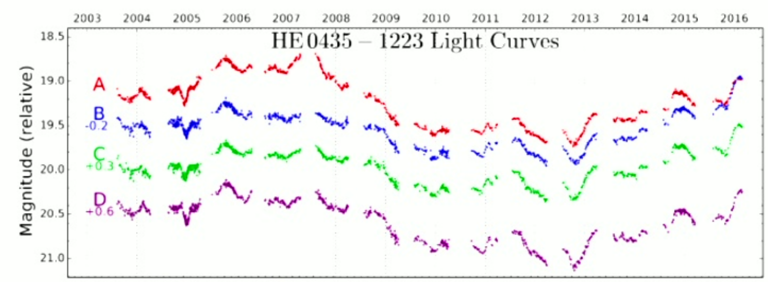


- $\hat{\alpha} = 2 \int \nabla_\perp \Phi \, d\lambda \implies \vec{\beta} = \vec{\theta} - \frac{D_{LS}}{D_S} \hat{\alpha}(\vec{\theta})$
- Convergence $\kappa \sim \int dz \, \rho$.
- Lens model + time delay measurement

$$\Delta t_{ij} \propto \frac{1}{H_0} \, .$$

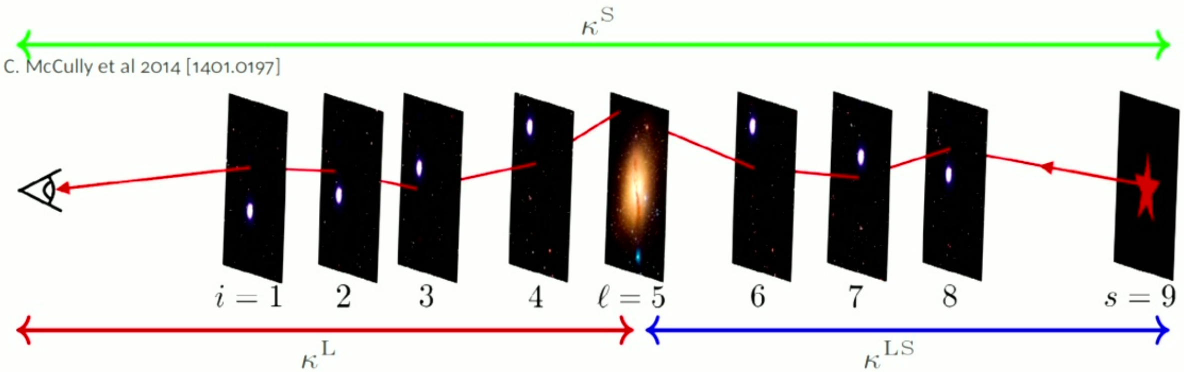
- Degeneracies (mass sheet degeneracy): source position and mass of galaxy unknown

$$\vec{\beta} \to \lambda \vec{\beta} \, , \; \kappa \to \lambda \kappa + (1 - \lambda) \implies H_0 \to \lambda H_0$$

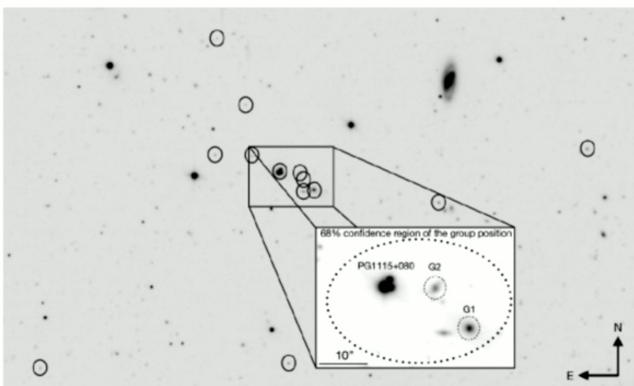


V. Bonvin et al 2016 [1607.01790]

Examples of mass sheets



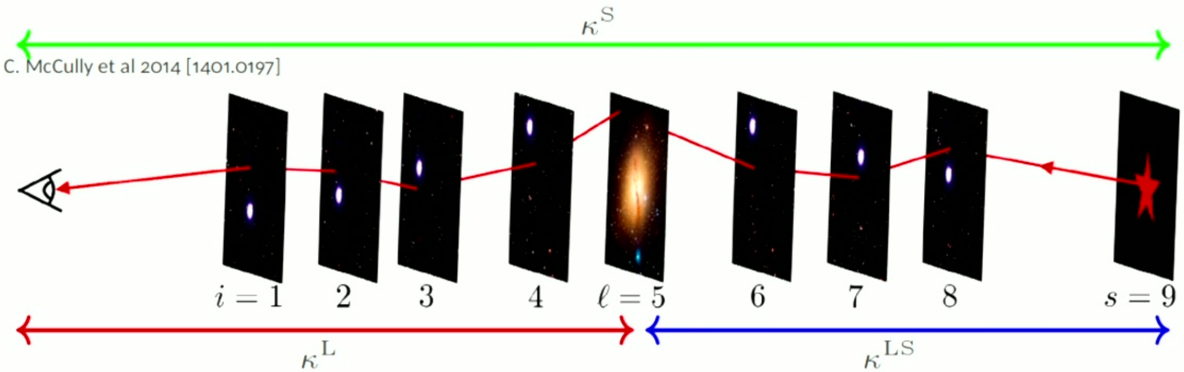
C. McCully et al 2014 [1401.0197]



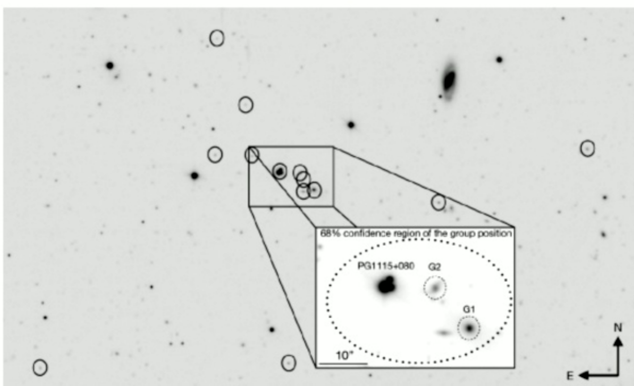
G.C.-F. Chen et al 2019 [1907.02533]

- LSS on the line of sight;
- Host dark matter halo from group/cluster;
- Stellar and galaxy kinematics $\Longrightarrow$ proxy for real mass.
- All the previous was (sort of) accounted in TDCOSMO I, but what about a mass sheet on the dark matter halo of the lens galaxy itself?

Examples of mass sheets



C. McCully et al 2014 [1401.0197]



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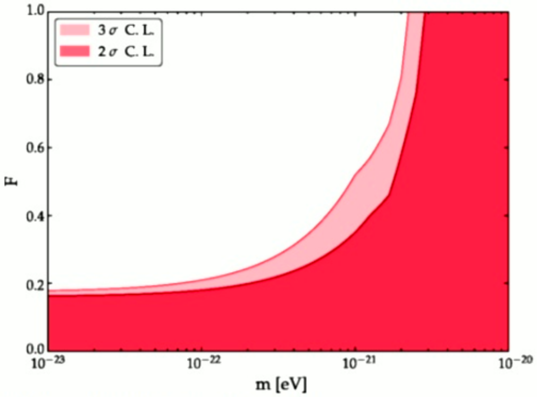
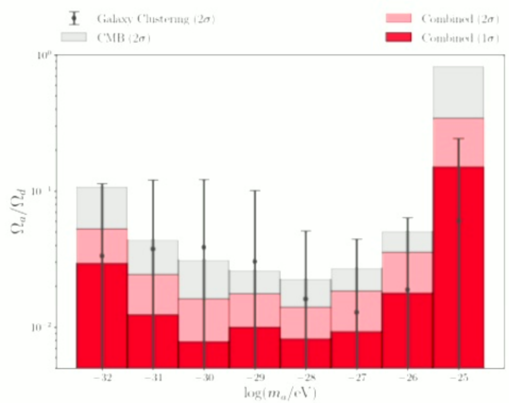
ULDM cores as approximate Mass Sheets?



T. Kobayashi et al 2017 [1708.00015]



A. Laguë et al 2021 [2104.07802]

- Soliton has core-like density profile

$$\rho = \frac{\beta^4 m^2}{4\pi G}\chi_1^2\,, \quad \chi_1 \simeq \frac{1}{(1+a^2r^2)^b}$$

- To make the idea work, one needs:

$$\delta_{\rm E} := \frac{\alpha_{\rm c}(\theta_{\rm E})}{\theta_{\rm E}} - \kappa_{\rm c}(\theta_{\rm E}) \lesssim 0.01\,,$$

$$1-\lambda = \kappa_{\rm c}(0) \sim 0.1 = \frac{\delta H_0}{H_0} \sim \frac{\beta^2 m}{4\pi G \Sigma_{\rm crit}}\,,$$

$$\theta_{\rm core} \sim \frac{1}{\beta a m D_{\rm l}} > \theta_{\rm E}$$

$$m \lesssim 10^{-24}\,{\rm eV}\left(\frac{1''}{\theta_{\rm E}}\right)^{3/2}\left(\frac{1\,{\rm Gpc}}{D_{\rm d}}\right)\left(\frac{\delta H_0/H_0}{0.1}\right)^{-1/2}$$

- ULDM whole DM: needs $m \sim 10^{-24}$ eV, tension with Lymann-α forest and CMB.
- Subdominant ULDM: $m \sim 10^{-25}$ eV

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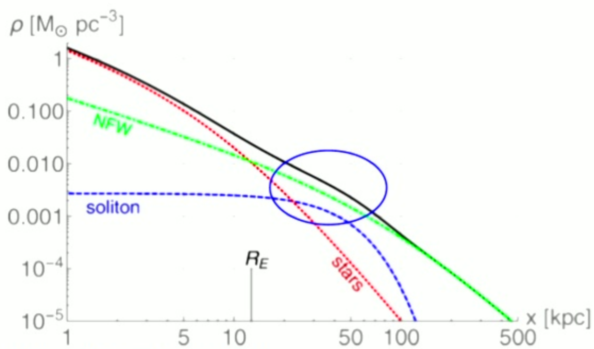
An explicit example



K. Blum, LT 2021 [2105.10873]

- An example: subdominant $m = 2 \times 10^{-25}$ component with $M_{sol} \sim 10^{12} M_\odot$, $M_{200} = 2 \times 10^{13} M_\odot$ (resembles DESJ0408 system)
- Enough to give a 10% shift in H_0
- Kinematics measurements fundamental to constrain MSD
- With H_0 prior: sensitivity to galaxy features which are hard to probe otherwise.

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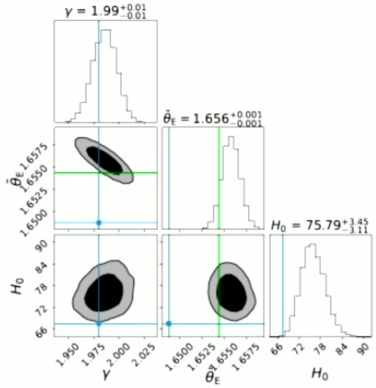
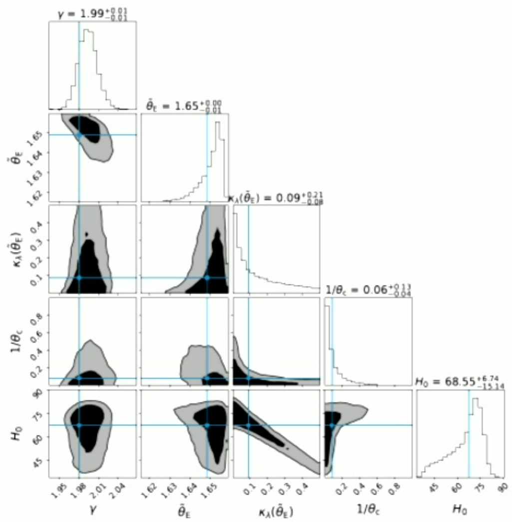
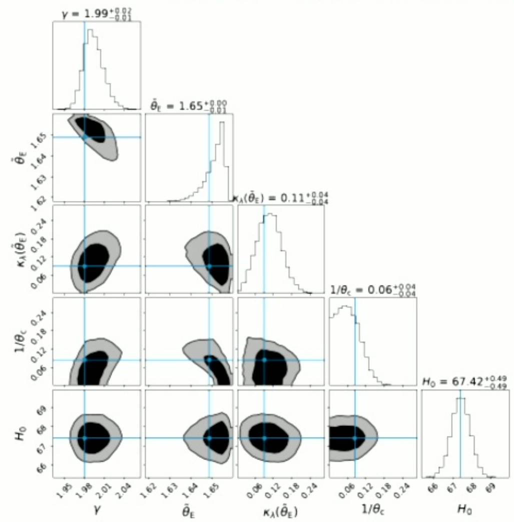
Conversazione in corso: Perin

Mock analysis

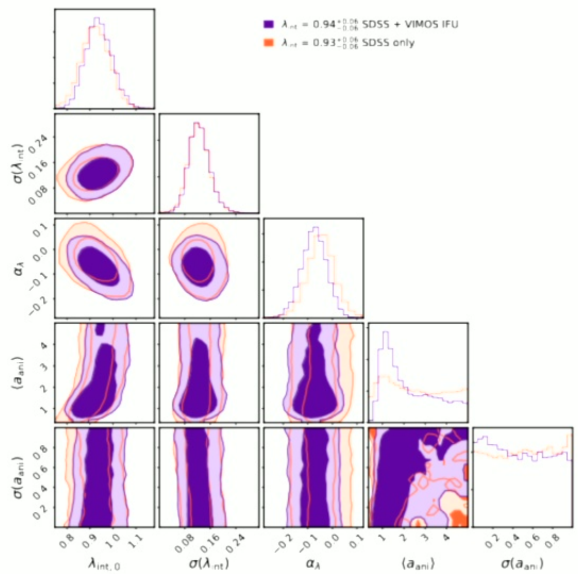


- Is our $\delta_{\rm E}$ criterium good enough?
  Yes, actually conservative
- Use `lenstronomy` utilities to see if the idea could work
- Mock: subdominant $m = 2 \times 10^{-25}$ component with $M_{\rm sol} \sim 10^{12} M_\odot$, $M_{200} = 2 \times 10^{13} M_\odot$ and $H_0 = 67.4$ km/s/Mpc
- Can we "relax" so much mass in the soliton?

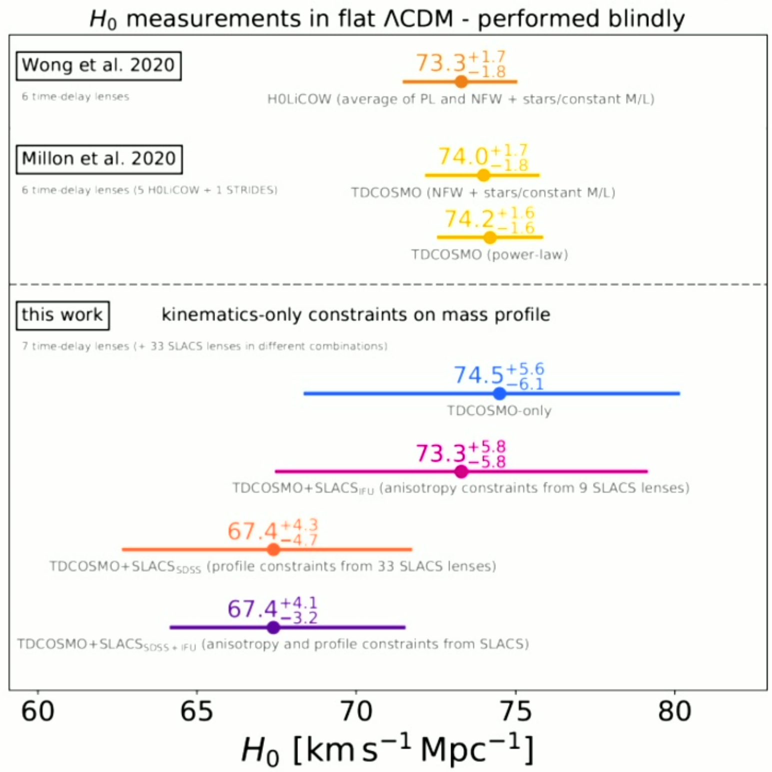




TDCOSMO IV



S. Birrer et al 2020 (TDCOSMO IV) [2007.02941]



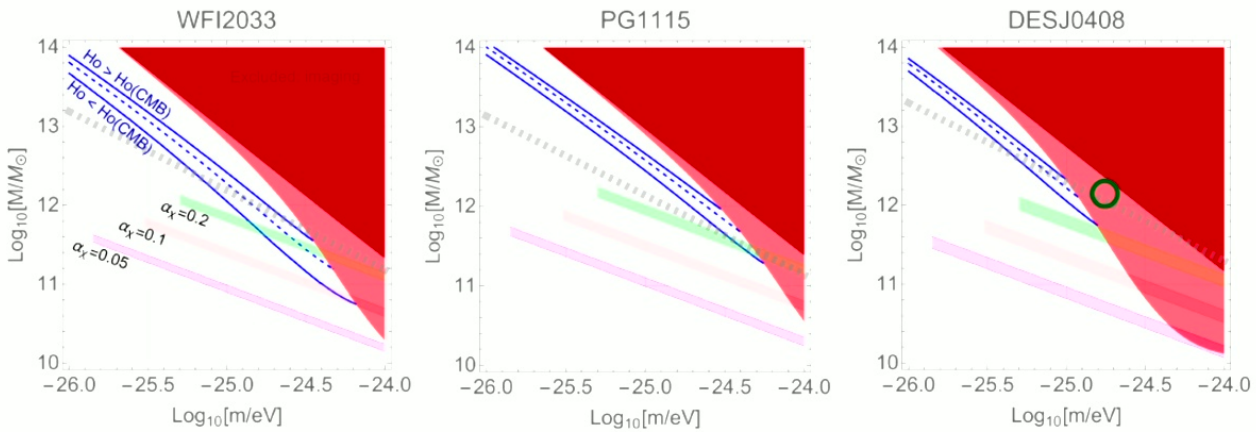
Can we relax such a mass?
Comparison with TDCOSMO systems

- Gravitational relaxation time scale from kinetic theory

$$\tau(R) = b\frac{\sqrt{2}}{12\pi^3}\frac{m^3\sigma^6(R)}{G^2\alpha_\chi^2\rho^2(R)\Lambda}$$

- $\tau(R) < t_{\rm gal} \implies$ find R , $M_{\rm sol} < \alpha_\chi M_{\rm halo}(R)$
- An isothermal power-law with constant σ yields the bound ($M_{\rm halo} \simeq \sigma^2 R/G$)

$$M_{\rm sol} \lesssim 10^{12} M_\odot \left(\frac{\alpha_\chi}{0.1}\right)^{3/2}\left(\frac{m}{5\times10^{-25}\,{\rm eV}}\right)^{-3/4}\left(\frac{\sigma}{200\,{\rm km\,s^{-1}}}\right)^{3/2}\left(\frac{t_{\rm gal}}{10\,{\rm Gyrs}}\right)^{3/2}$$



K. Blum, LT 2021 [2105.10873]

Summary

- We discuss the possibility that the H_0 tension in strong gravitational lensing measurements could come from an unaccounted approximate mass sheet degeneracy
- A possible physical dark matter model which can yield this is ULDM
- To make it work, one must consider ULDM as a subdominant part of the whole dark matter
- Scenario: $\mathcal{O}(0.1)$ fractions, $m \lesssim 1 \times 10^{-25}$ eV
- Refine estimates with simulations (work in progress)
- With an H_0 prior, time delays can be used to probe features of DM halos, difficult to spot otherwise, and possibility to put bounds on FDM scenario

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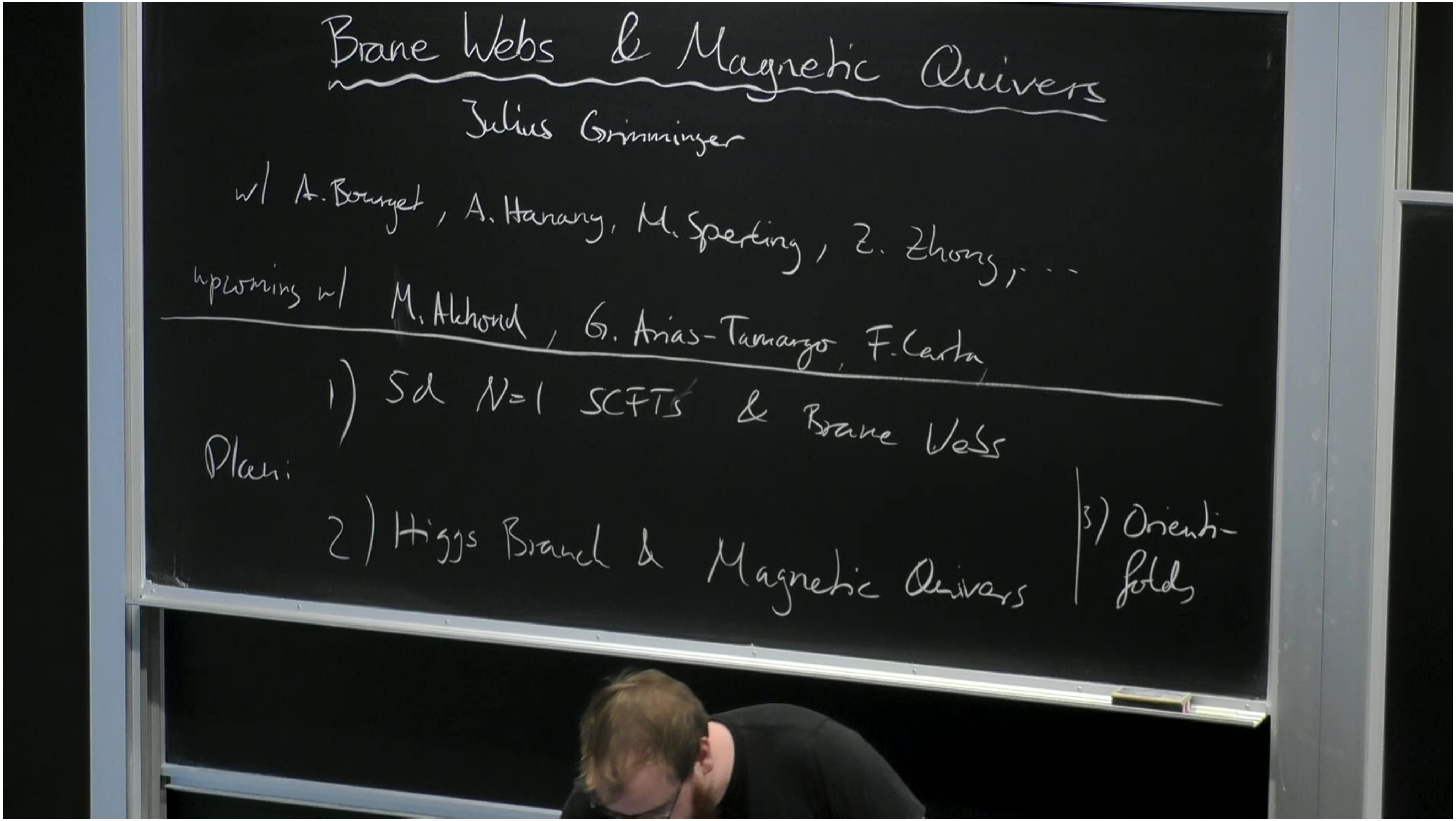

Brane Webs & Magnetic Quivers
Julius Grimminger
w/ A. Bourget, A. Hanany, M. Sperling, Z. Zhong, ...
upcoming w/ M. Akhond, G. Arias-Tamargo, F. Carta,
Plan:
1) 5d N=1 SCFTs & Brane Webs
2) Higgs Branch & Magnetic Quivers
3) Orienti-folds

Plan:

2) Higgs Branch & Magnetic Quivers

3) Orienti-folds

5d SCFT

$\updownarrow$

5d Gauge Th. EFT

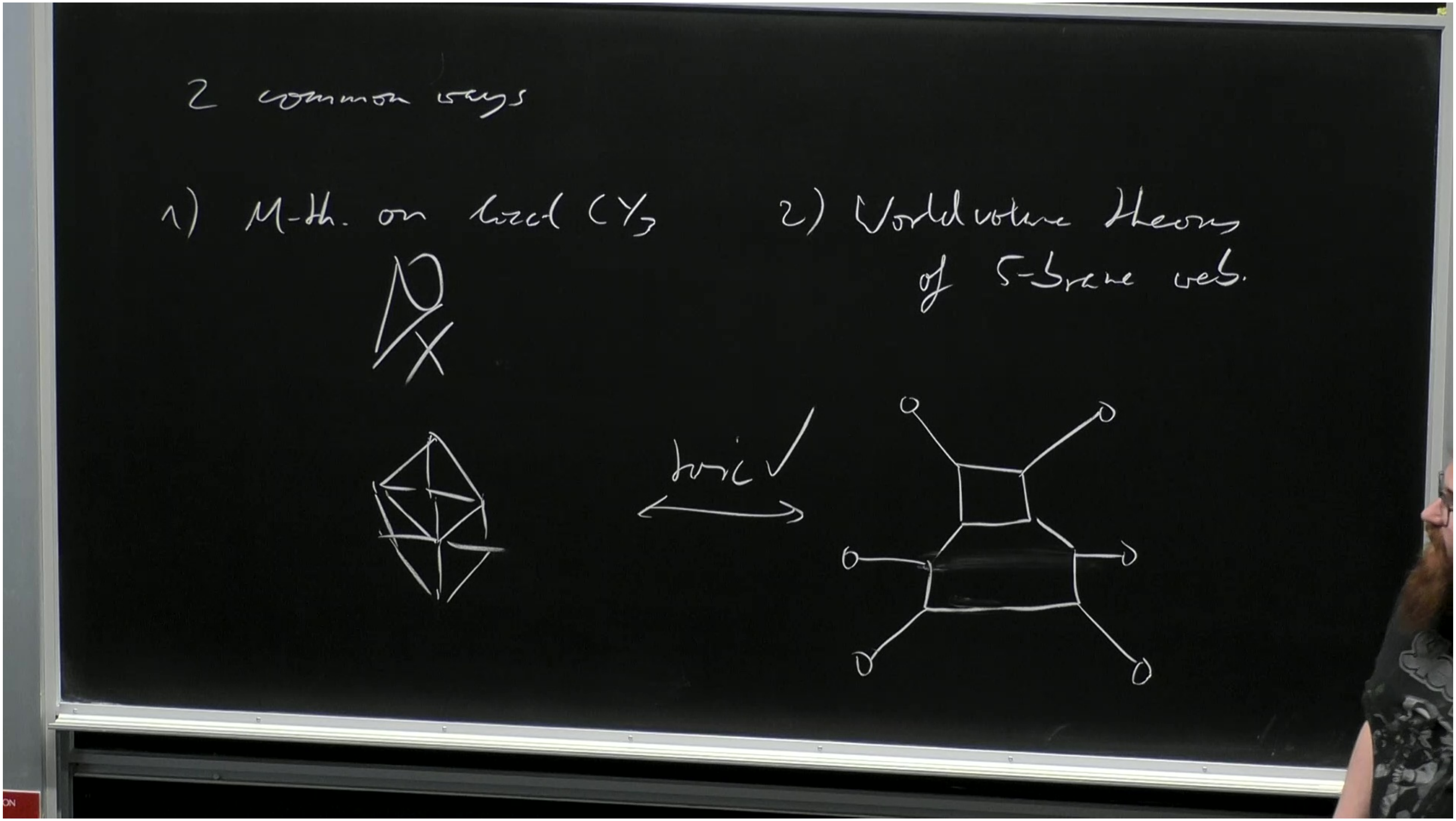
5d $\mathcal{N}=1$

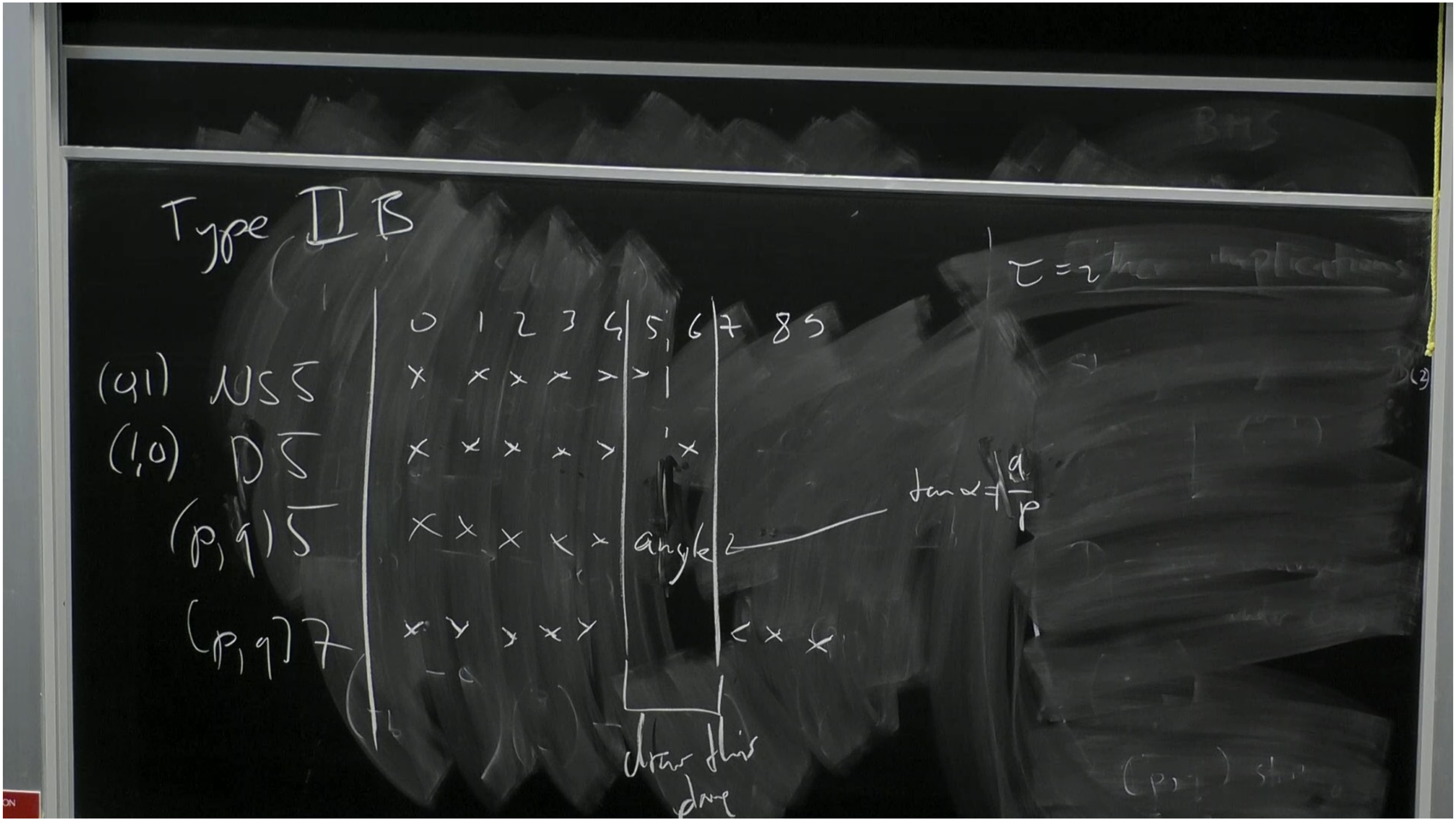
rank-1 E_N

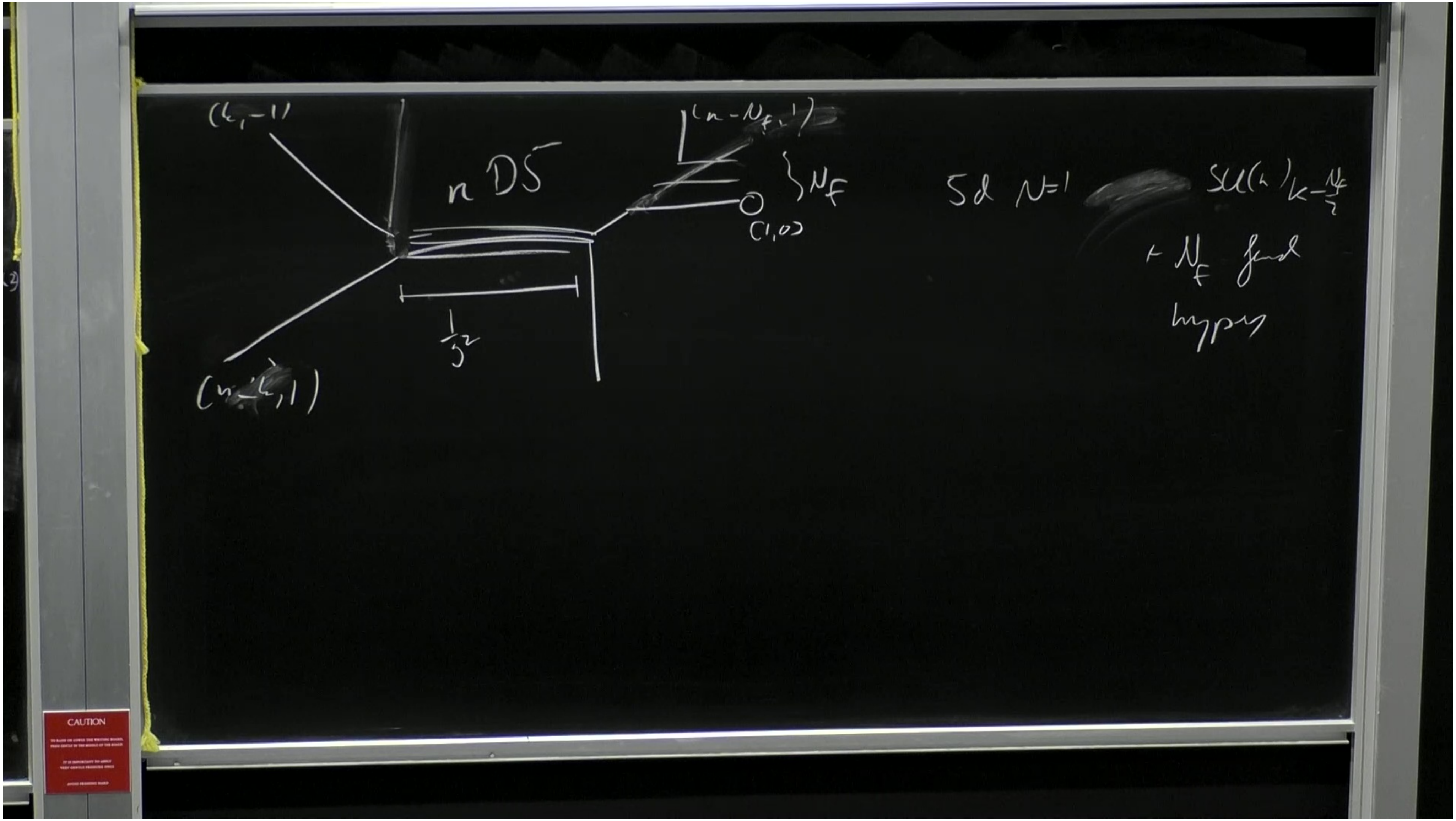
$SU(2) + (N-1)$

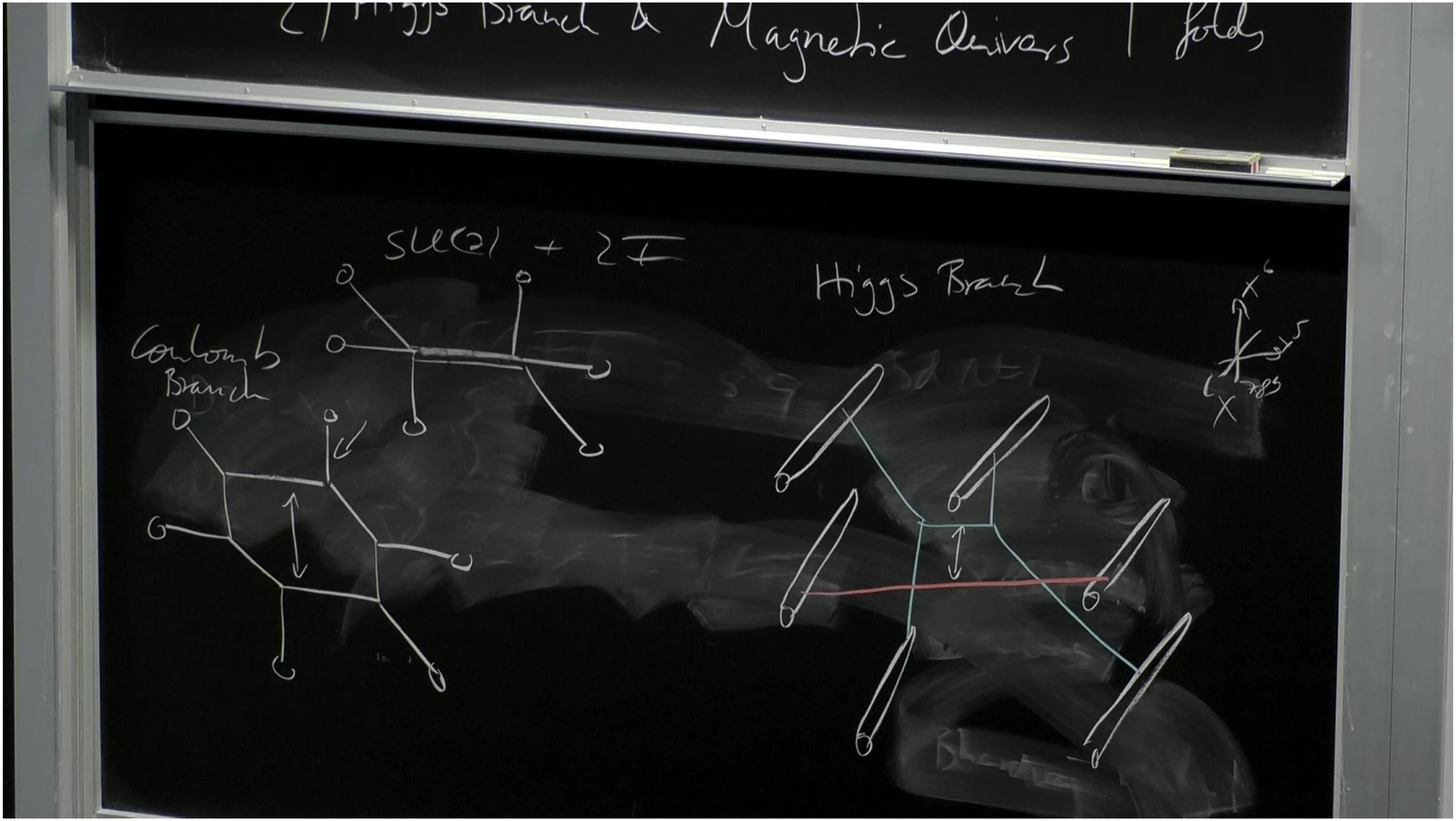
Seiberg

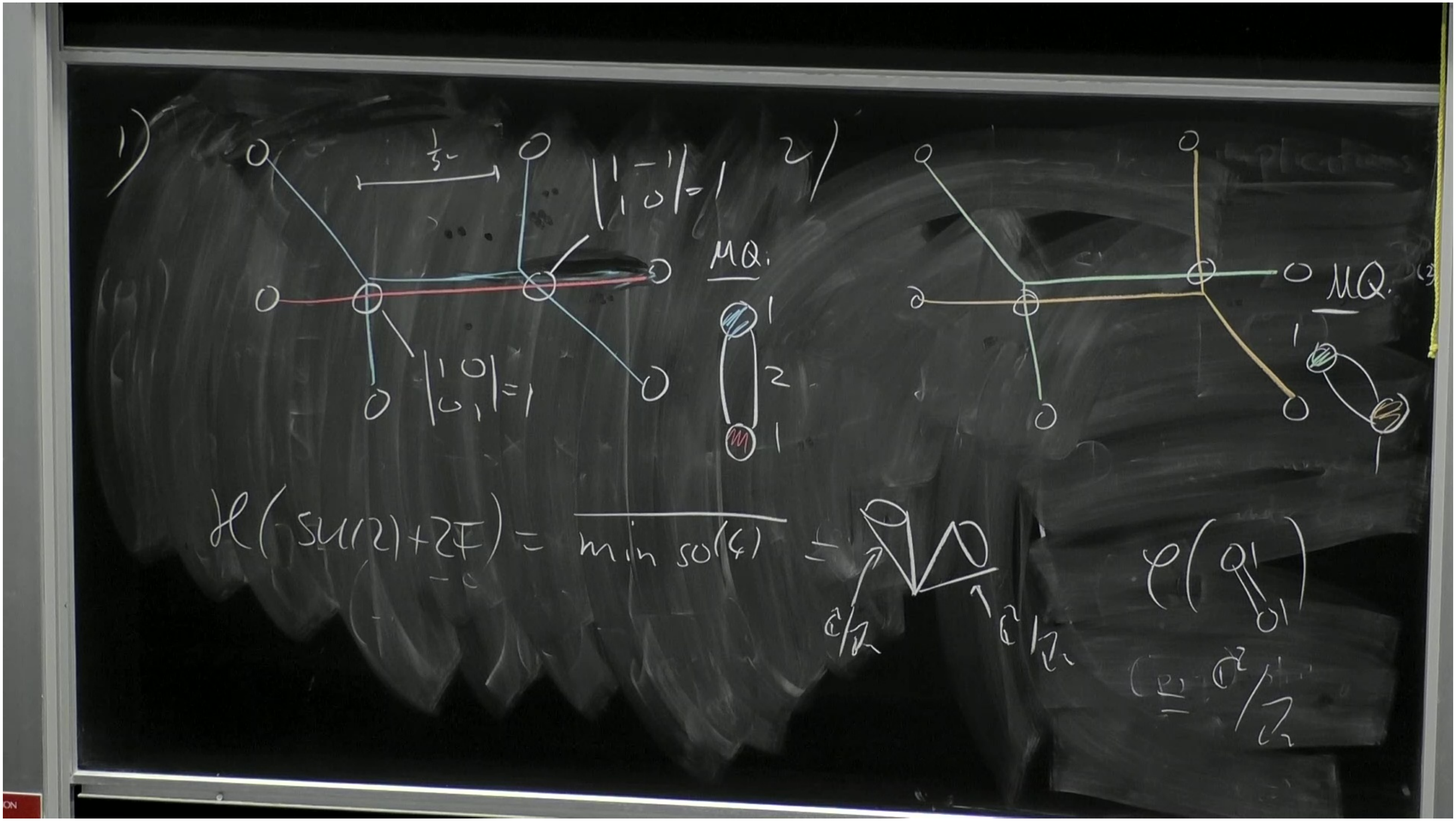
Bhardwaj rank-1


2 common ways
1) M-th. on local CY3
2) Worldvolume theory
of 5-brane web.
toric ✓

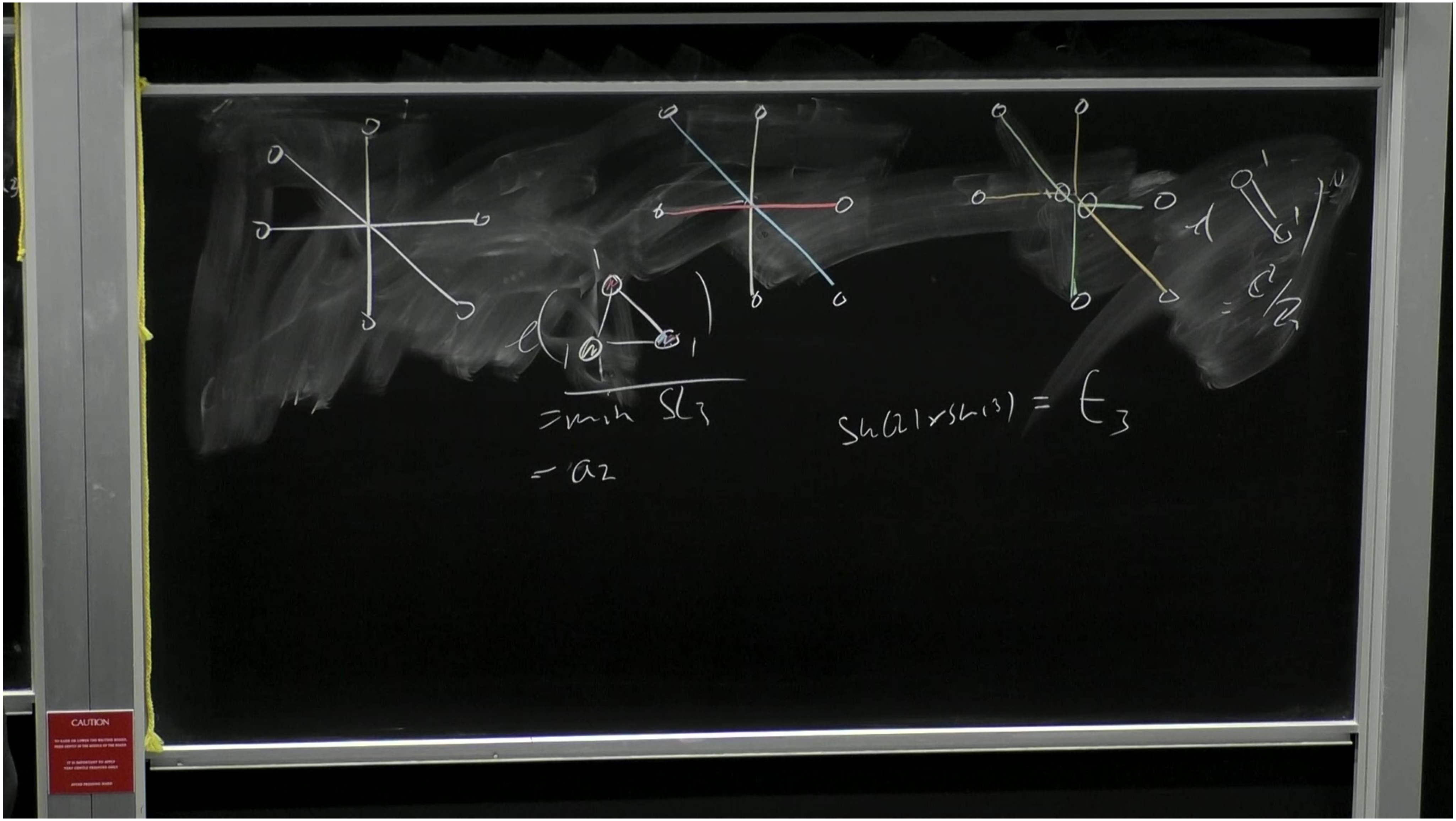

Type IIB
0 1 2 3 4 5 6 7 8 9
(0,1) NS5
(1,0) D5
(p,q) 5
(p,q) 7
angle
tan α = q/p
τ = i

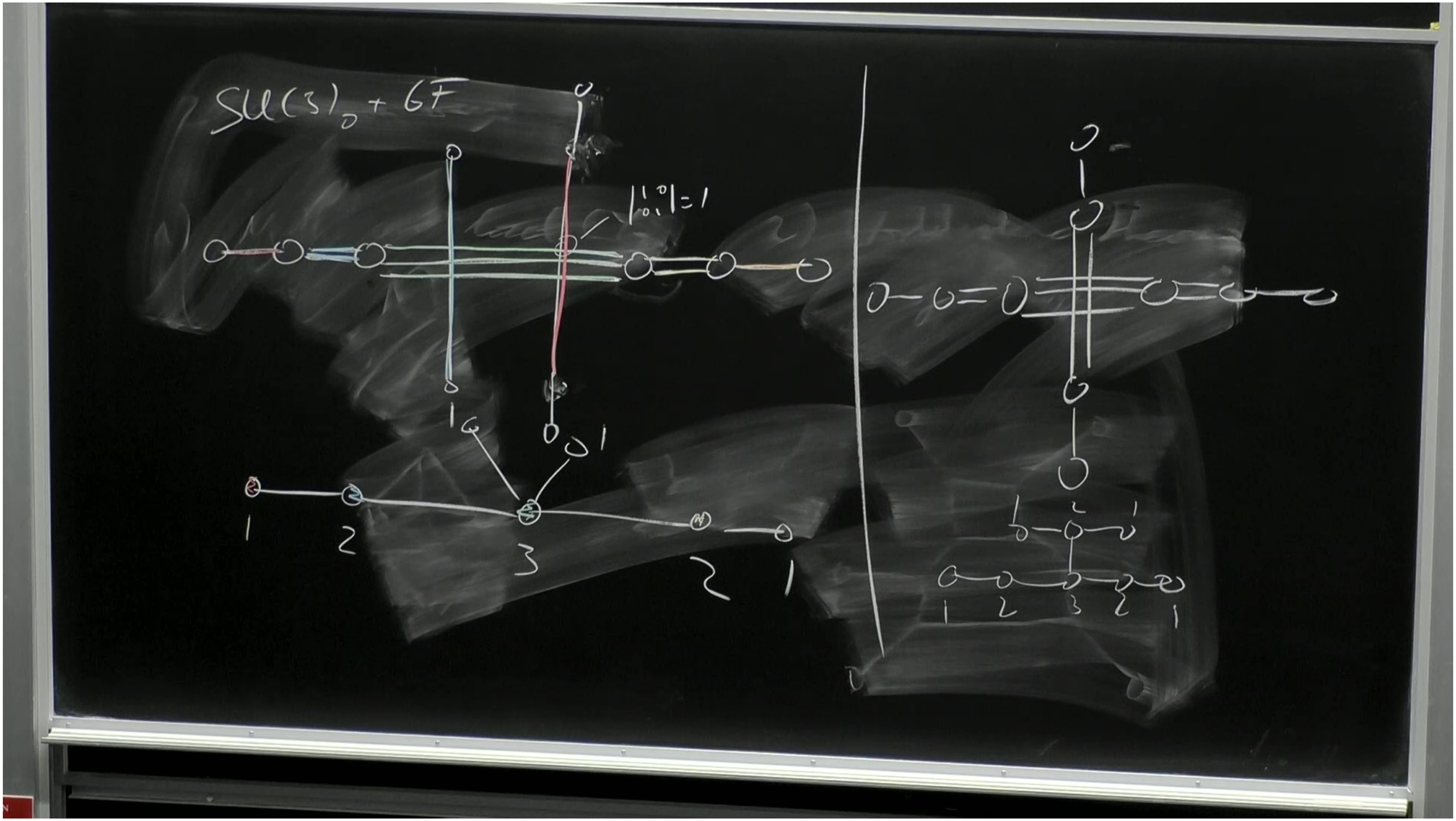

n D5
5d N=1
+ N_f fund
hyper


Magnetic Quivers
SU(2) + 2F
Higgs Branch
Coulomb Branch

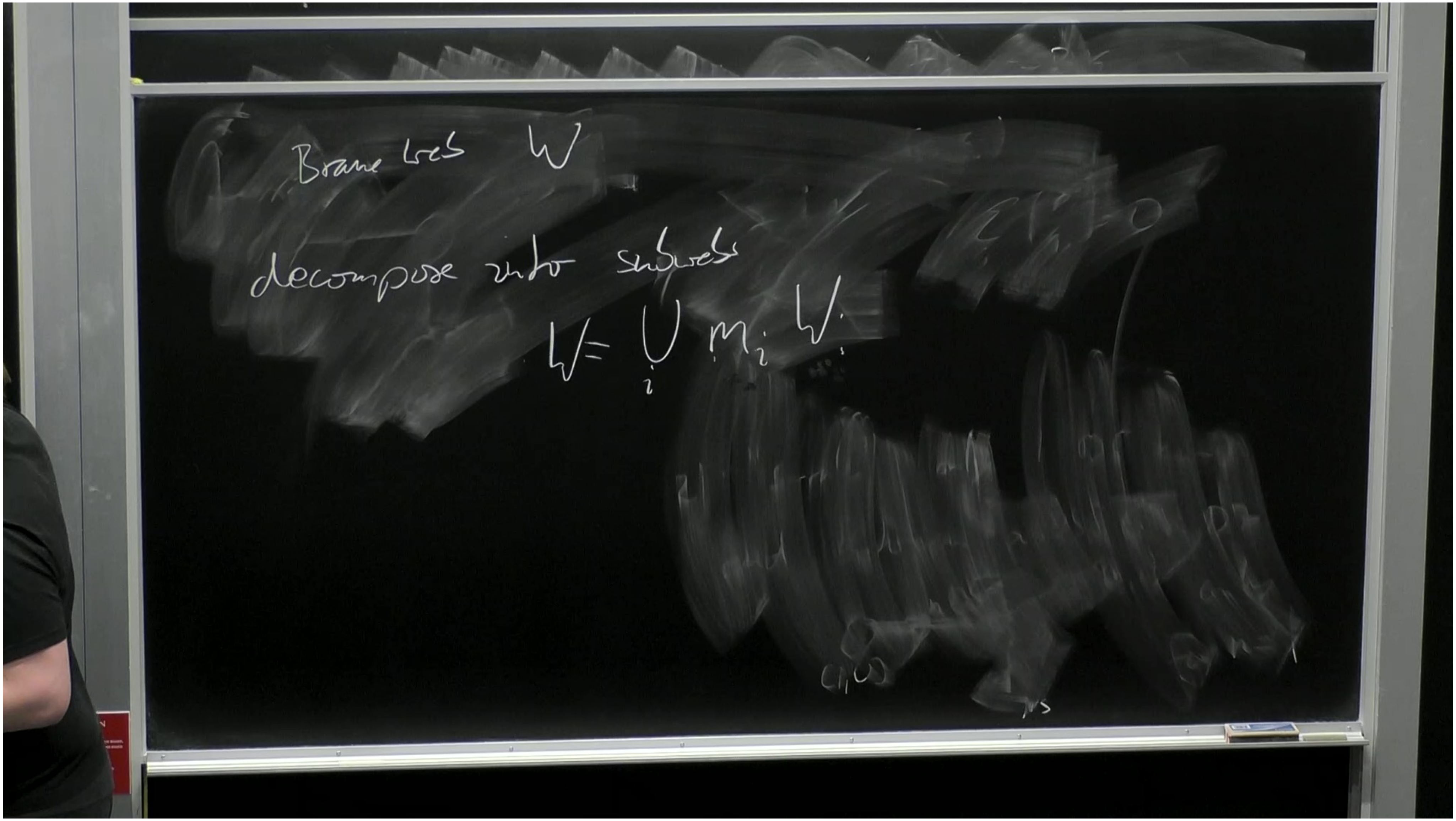


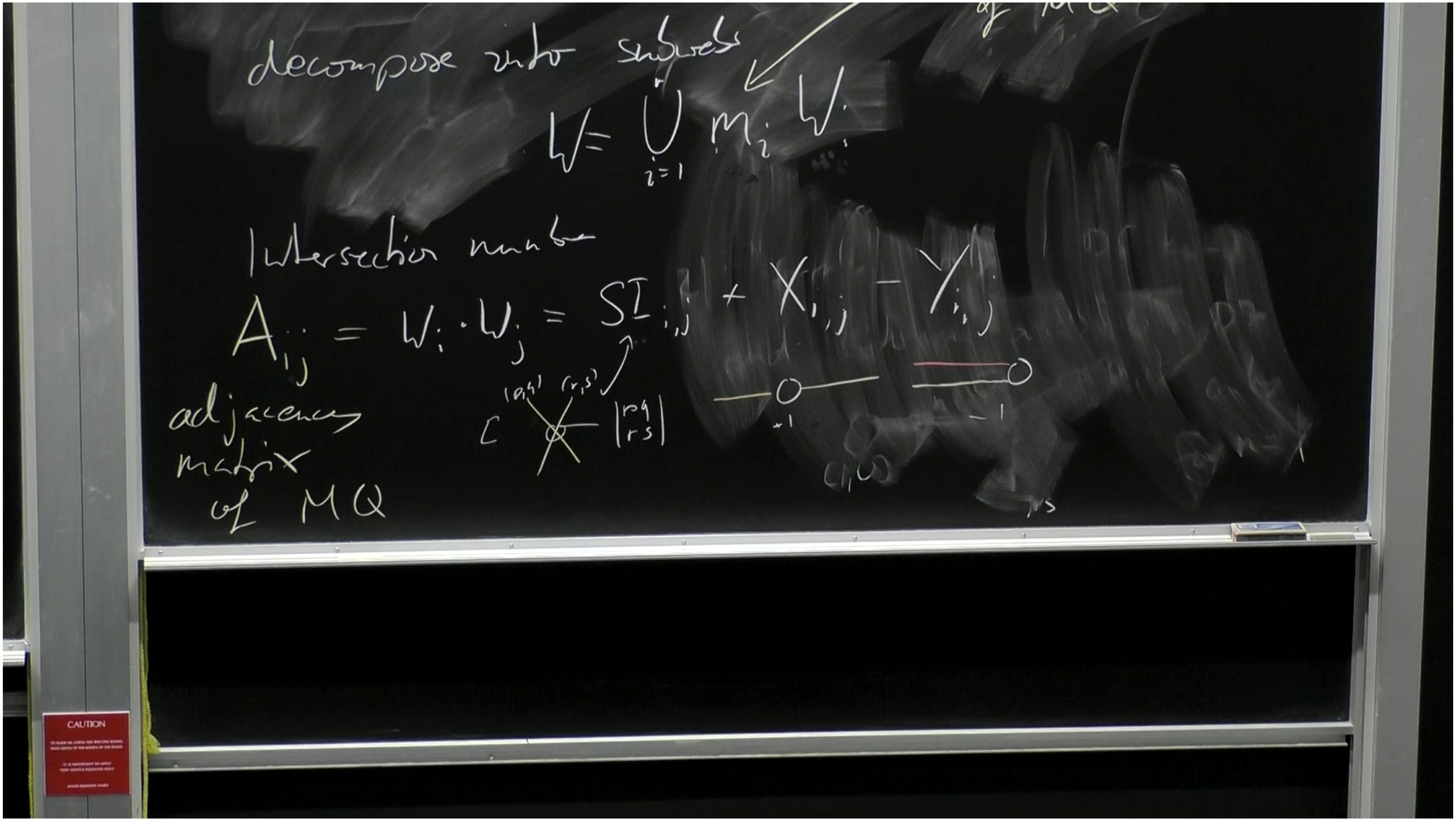
MQ:
MQ.

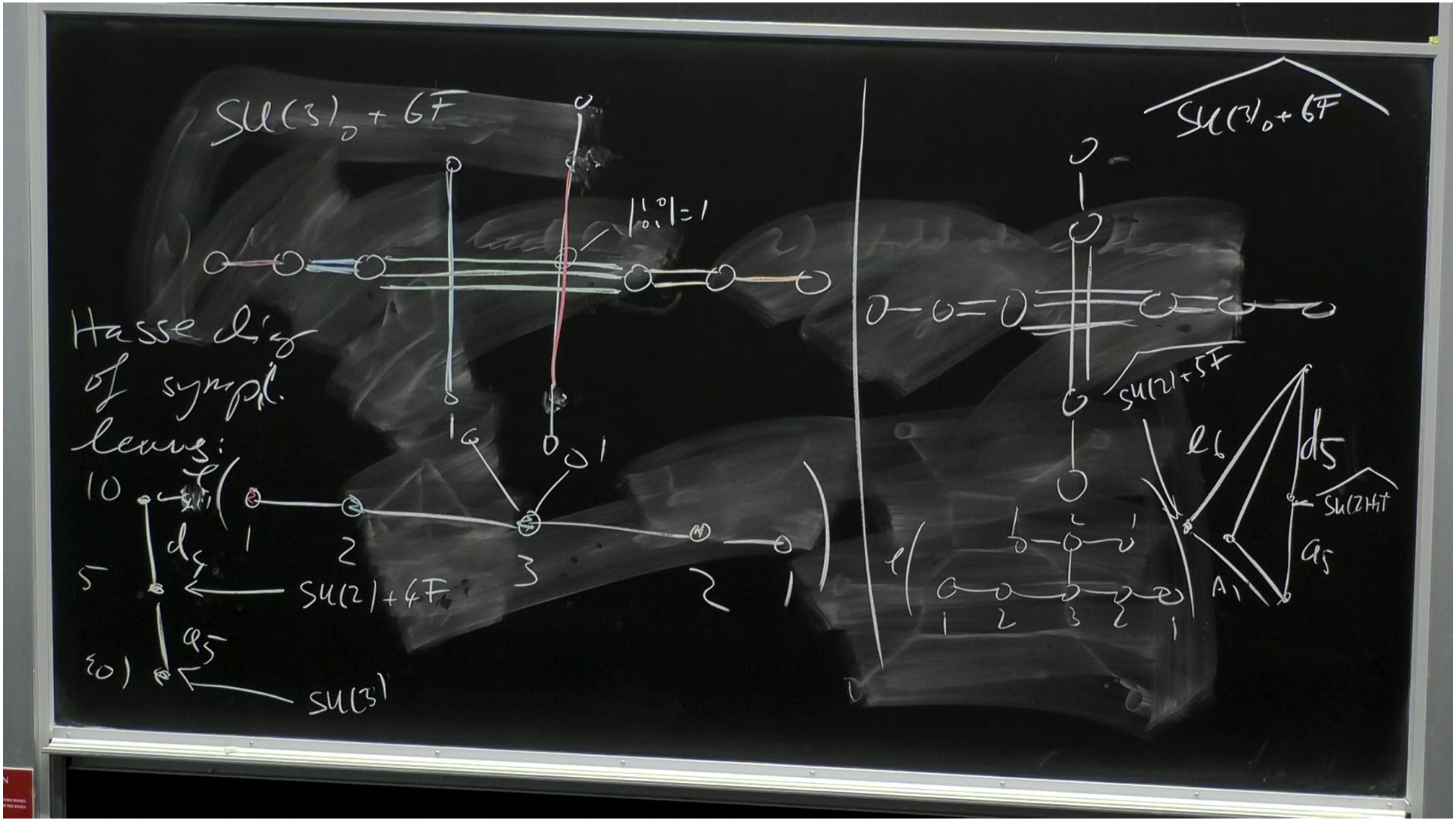

= a2



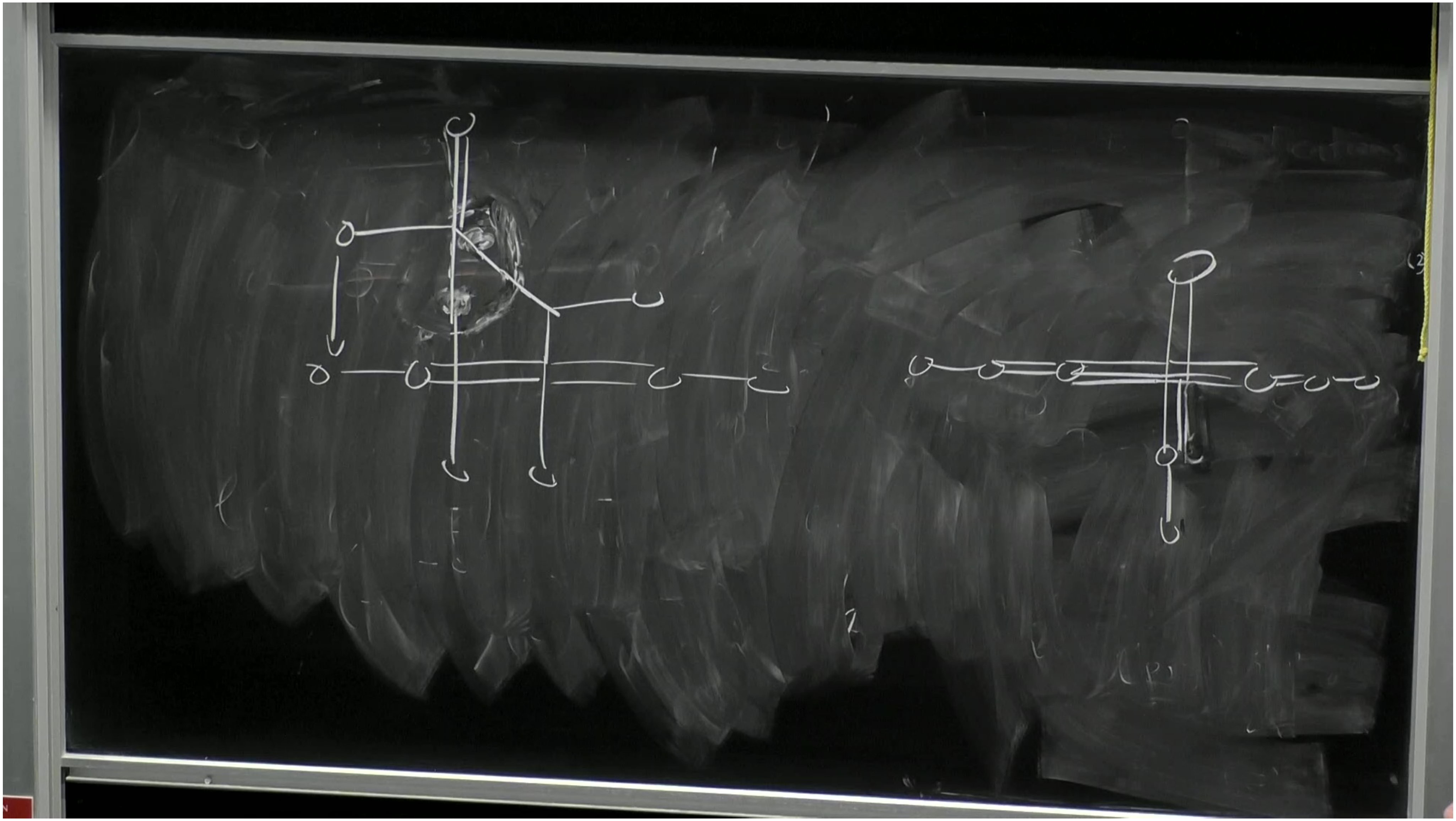
SU(3)_0 + 6F

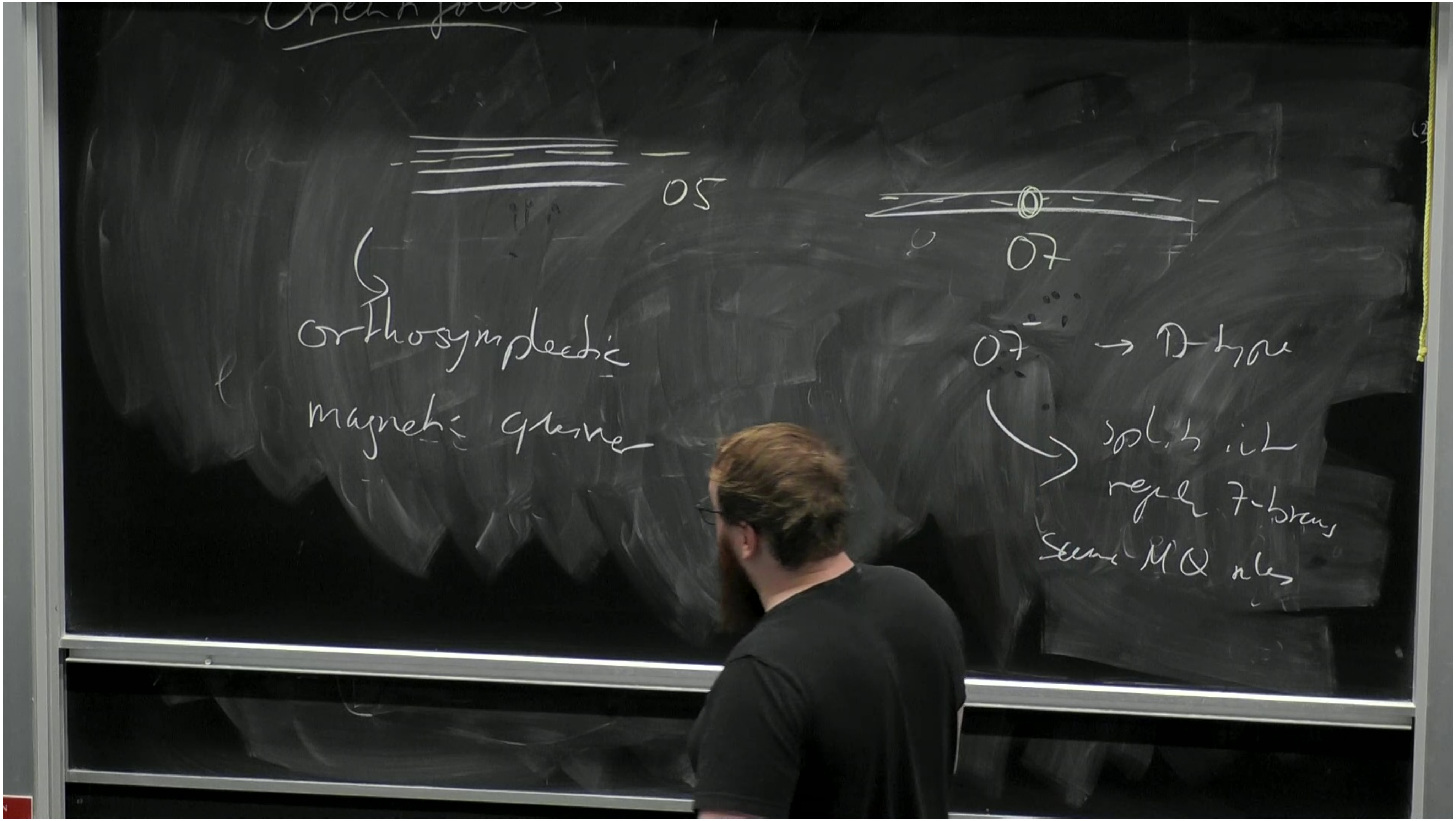

Brane webs W
decompose into subwebs
W = ⋃ m_i W_i

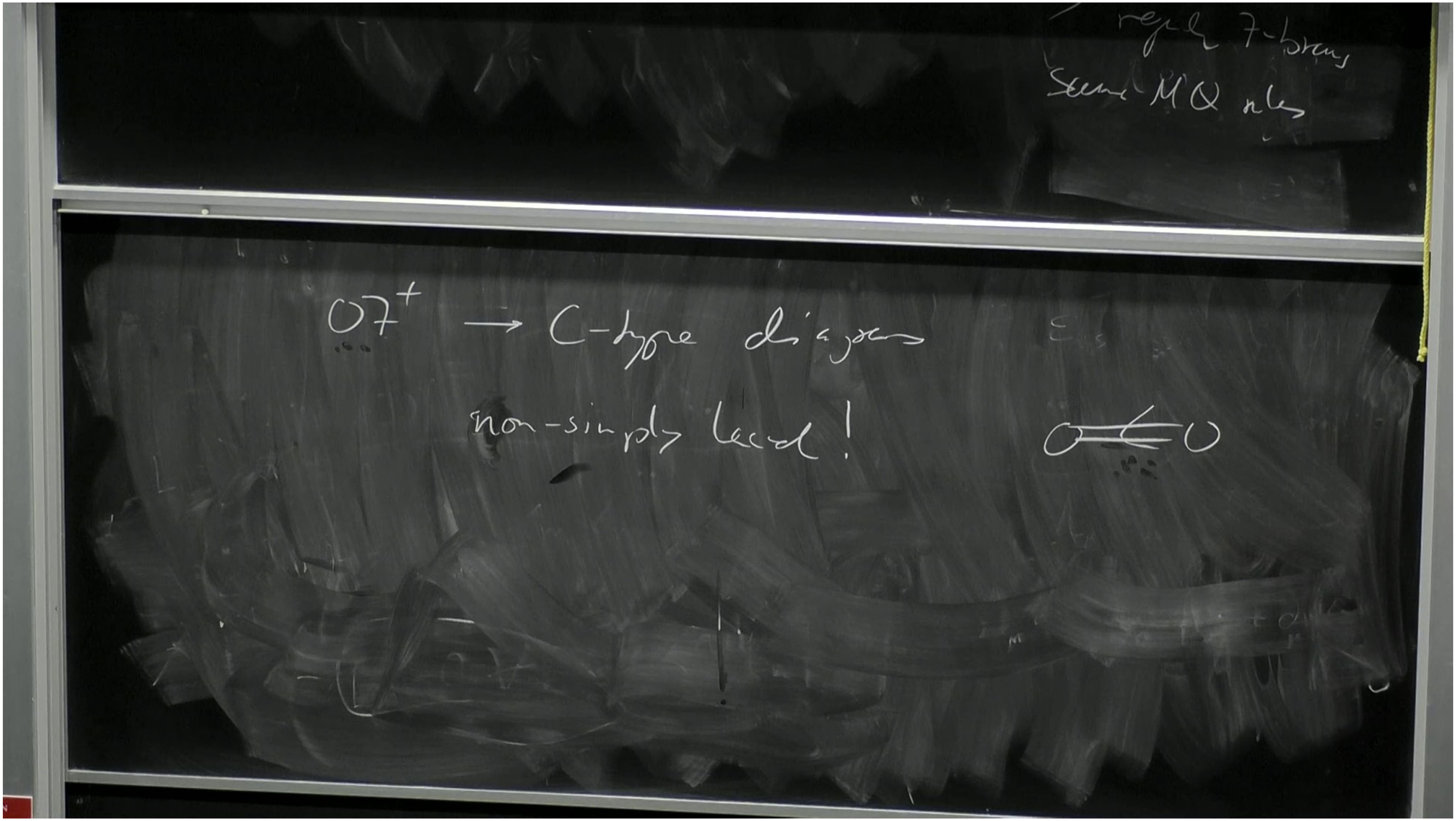

decompose into subwebs
W = ⋃ m_i W_i
i=1
Intersection number
A_ij = W_i · W_j = SI_i,j + X_i,j − Y_i,j
adjacency matrix of MQ
(p,q) (r,s)
|p q|
|r s|
+1
−1
CAUTION

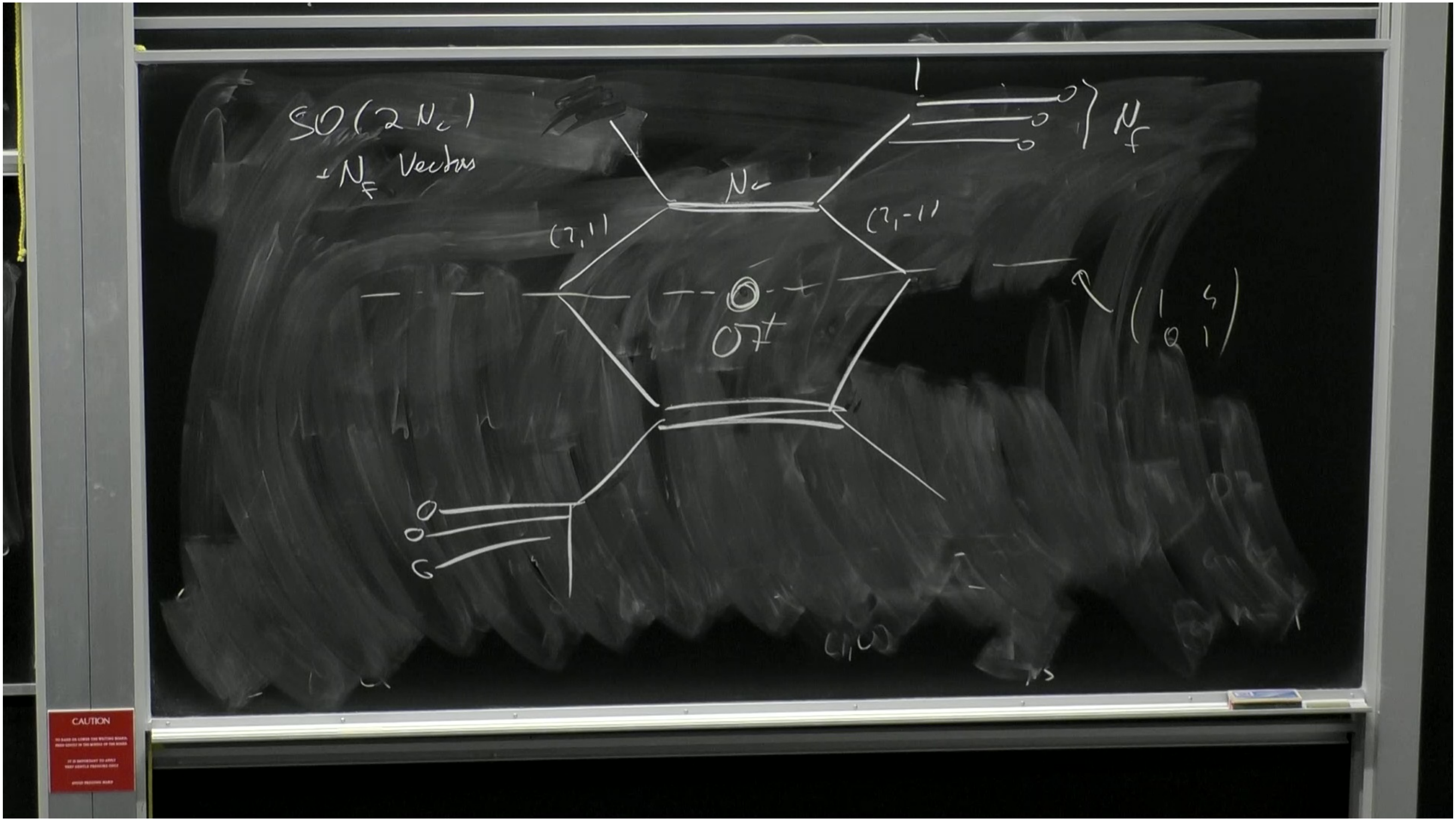


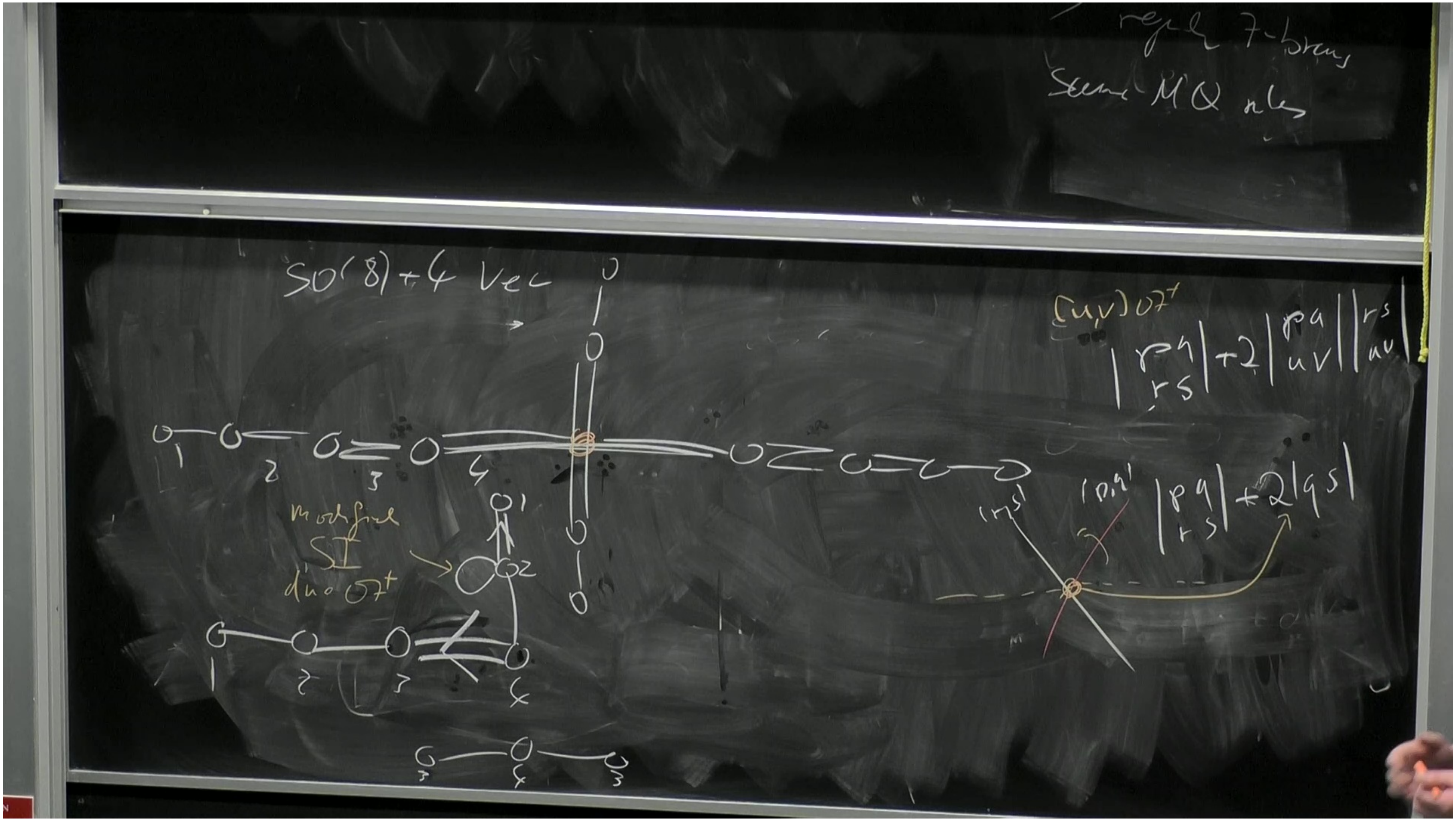
SU(3)_0 + 6F
Hasse diag of sympl. leaves:
10
5
d_4
a_5
SU(2)+4F
SU(3)
1 2 3 2 1
SU(3)_0 + 6F
SU(2)+5F
e_6
d_5
a_5
A_1
1 2 3 2 1



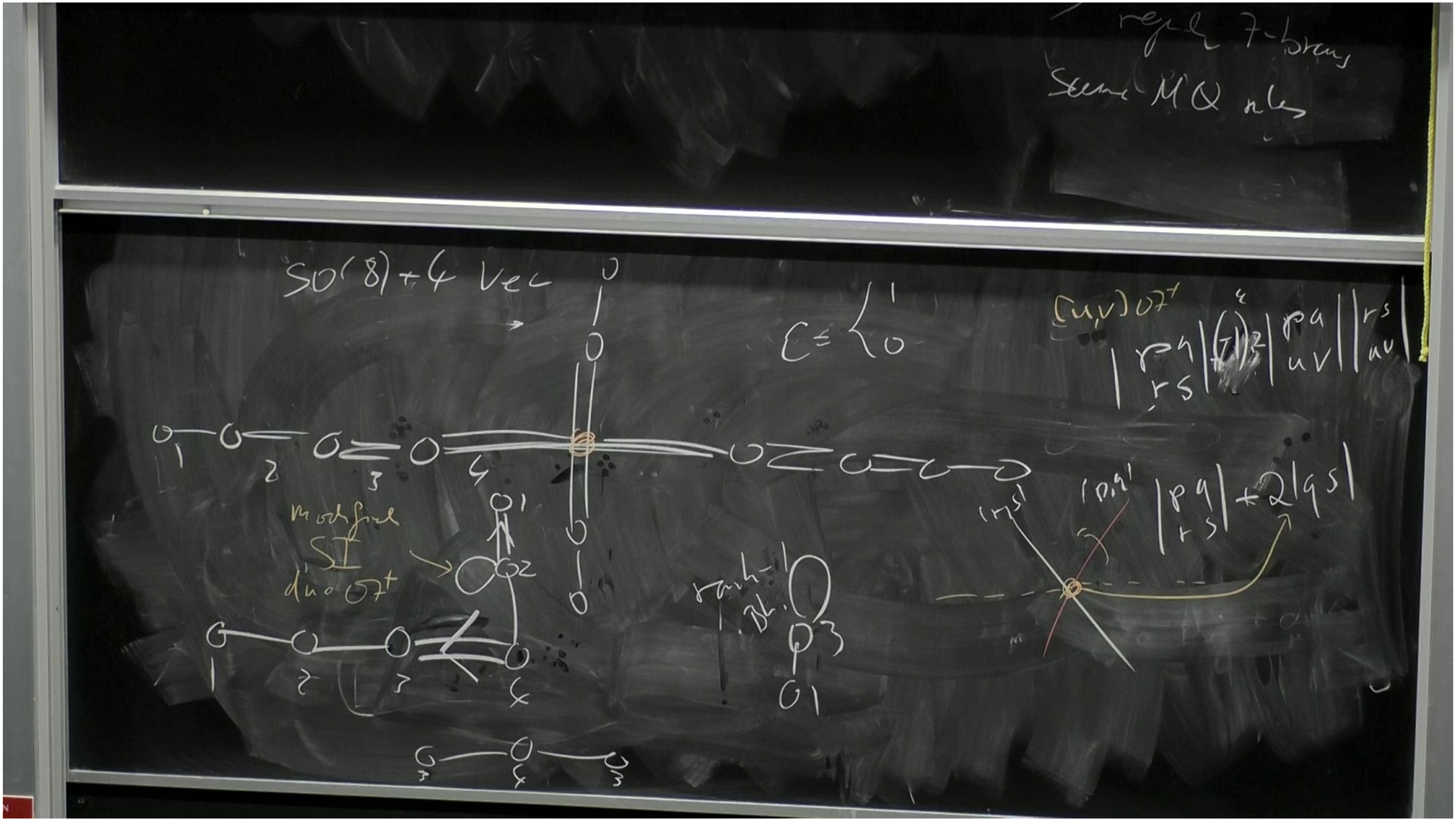

O5
O7
orthosymplectic
magnetic quiver
O7

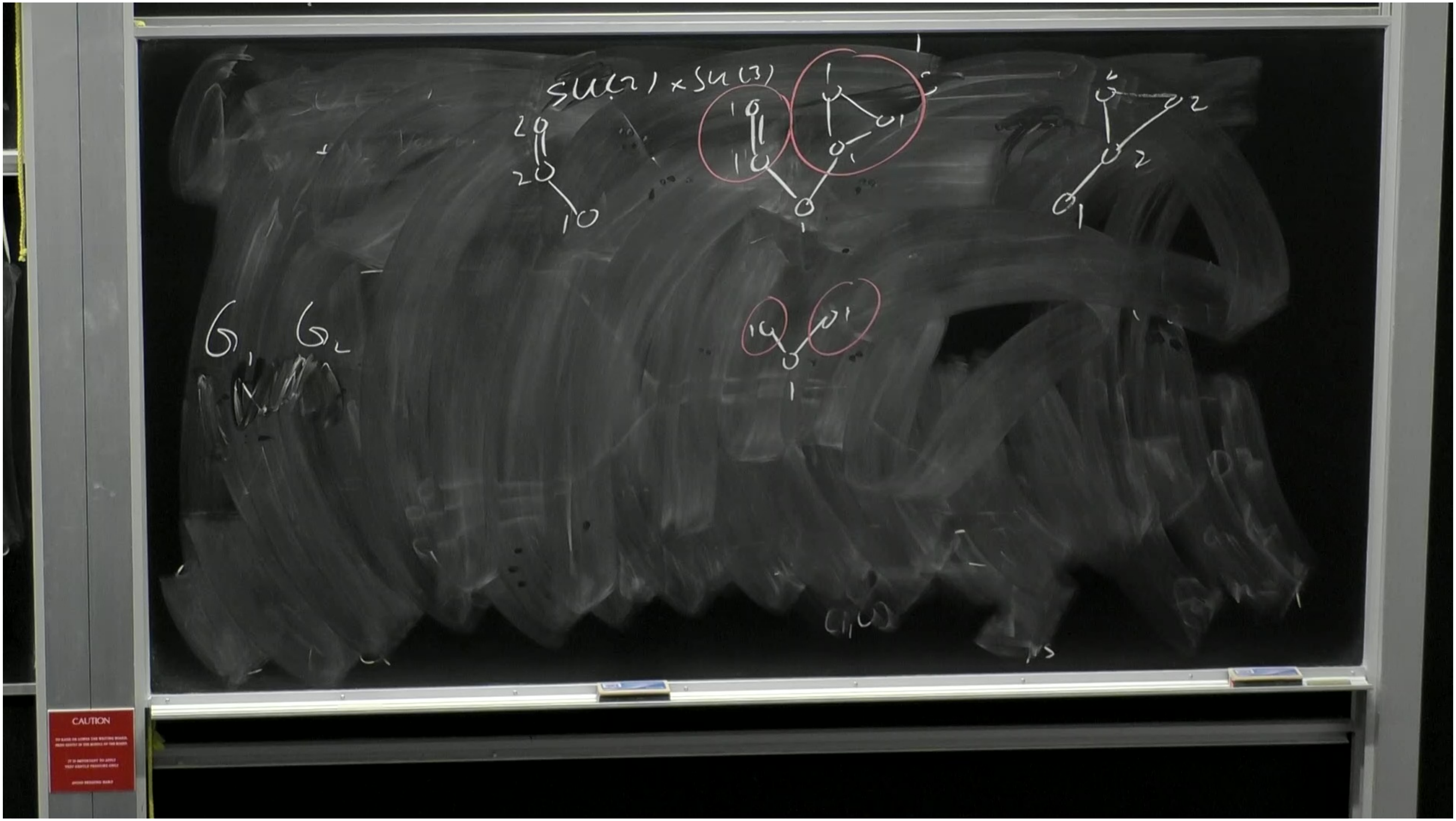

O7+ → C-type diagrams
non-simply laced !


SO(2Nc)
+ Nf Vectors
Nc
Nf
(7,1)
(7,-1)
O7+
(1,0)



Seems MQ rules
SO(8)+4 Vec
(u,v) O7⁺
modified SI dual O7⁺


Seems MQ rules
SO(8) + 4 Vec
modified SI dual O7+
[u,v] O7+


SU(2) × SU(3)