Title: Causal properties of evaporating black holes

Date: Apr 19, 2018 02:30 PM

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Abstract: <p>The causal structure of spacetimes containing fully evaporated black holes is considered from the perspective of Lorentzian geometry. The starting point is provided by theorems, due to Kodama, Geroch and Wald, that derive non-global hyperbolicity from a set of premises relating two partial Cauchy surfaces that are thought of as, respectively, lying before and after the evaporation. Here, we consider the Geroch-Wald theorem in the setting of a conformally embedded spacetime a la Penrose and show, under the assumption that complete null geodesics outside the black hole reach the boundary, that there exists visible incomplete null geodesics and that causal continuity fails.</p>

<u>Causal Properties of Evaporating B.H.</u> (based on work upcoming (sole auth.))

Punchline of the talk: What might be said about evap. BH should one restrict oneself to Lorentz geom.

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1. Causal Ladder
2. Old Results (79 Kod., 83/4 Geroch)
3. New Results

1. Causal Ladder

glob hyp

$\Downarrow$

causal simplicity

$\Downarrow$

causal continuity

$\Downarrow$

stable causality $\Longrightarrow$ strong causality

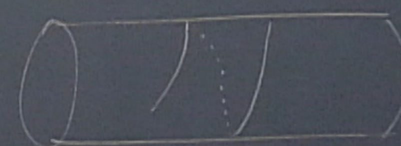
strong causality $\Uparrow$ distinguish $\Uparrow$ non total imprisonment

non total imprisonment $\Longrightarrow$ causality $\Longrightarrow$ chronology

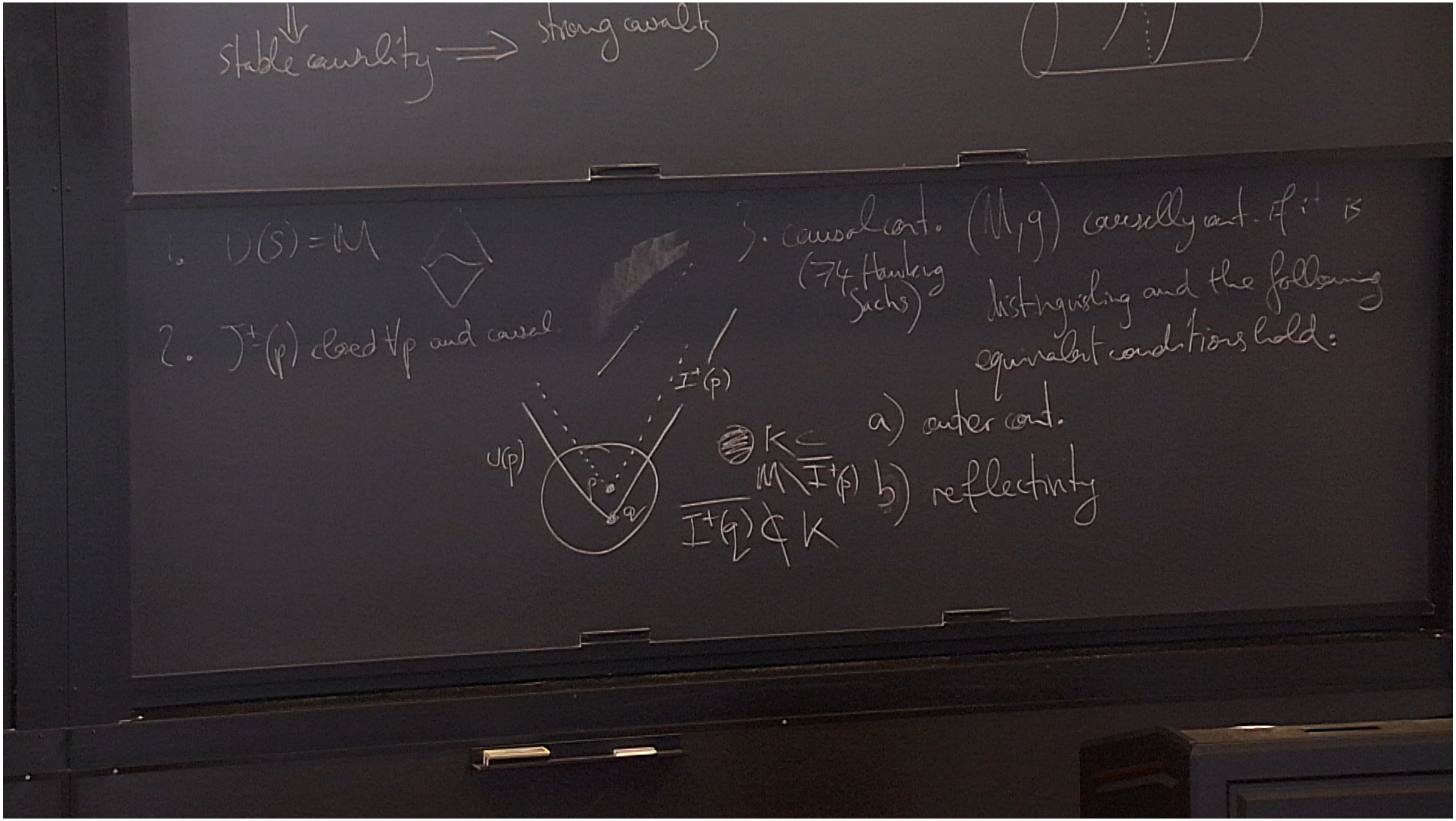
$\Downarrow$

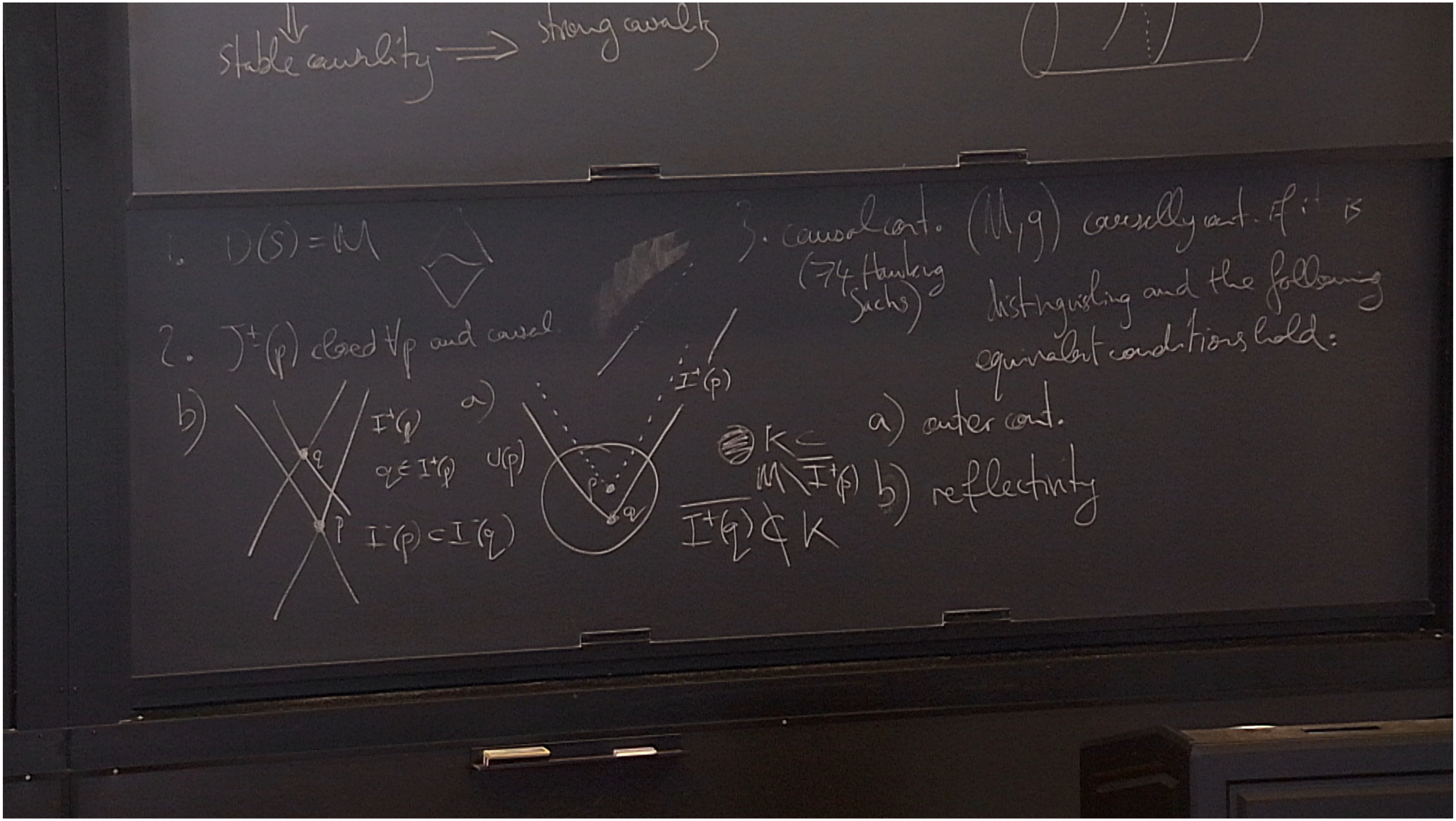
non totally vicious

$\left(I^{\pm}(p) = M \;\; \forall p \right)$



$S^1 \times \mathbb{R}$


stable causality ⟹ strong causality
1. D(S) = M
2. J^±(p) closed ∀p and causal.
3. causal cont. (74 Hawking Sachs)
(M,g) causally cont. if it is distinguishing and the following equivalent conditions hold:
a) outer cont.
b) reflectivity
I^+(p)
U(p)
p
q
K ⊂ M \ I^+(p)
I^+(q) ⊄ K



stable causality ⟹ strong causality
1. D(S) = M
2. J±(p) closed ∀p and causal
b) I+(q)
q ∈ I+(p)
I−(p) ⊂ I−(q)
a) U(p)
I+(p)
K ⊂ M \ I+(p)
I+(q) ⊄ K
3. causal cont. (74 Hawking Sachs)
(M, g) causally cont. if it is distinguishing and the following equivalent conditions hold:
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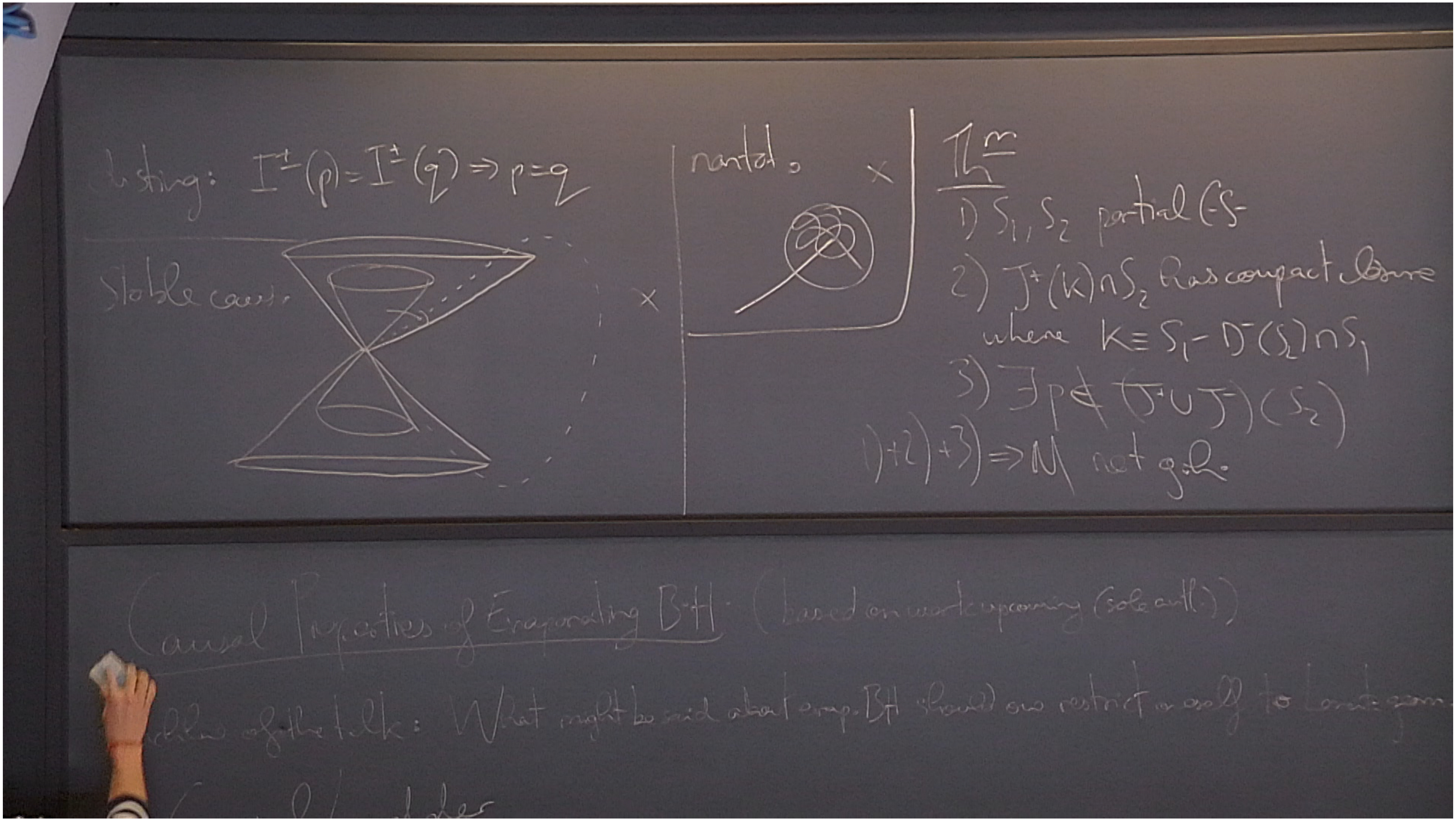
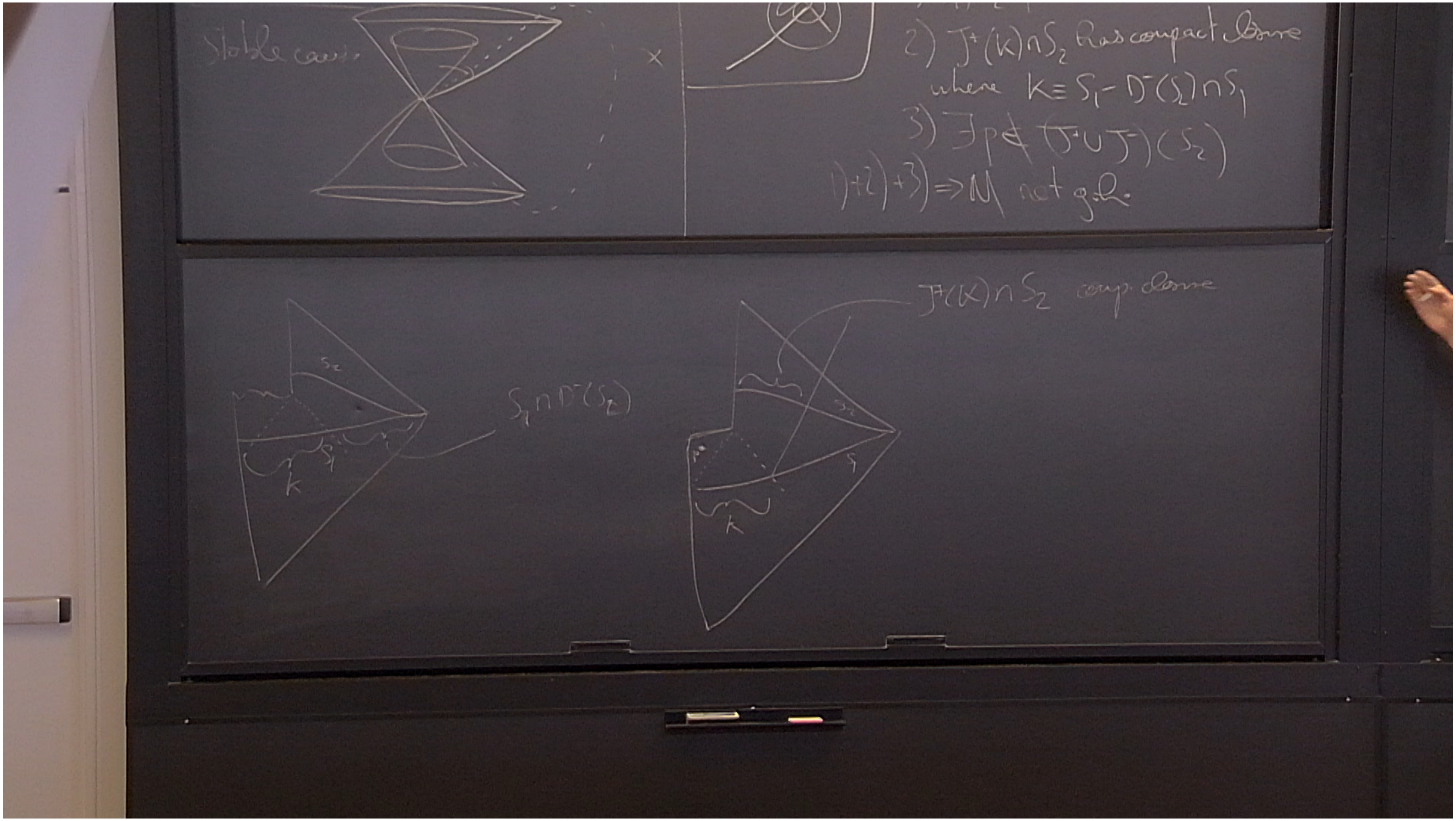
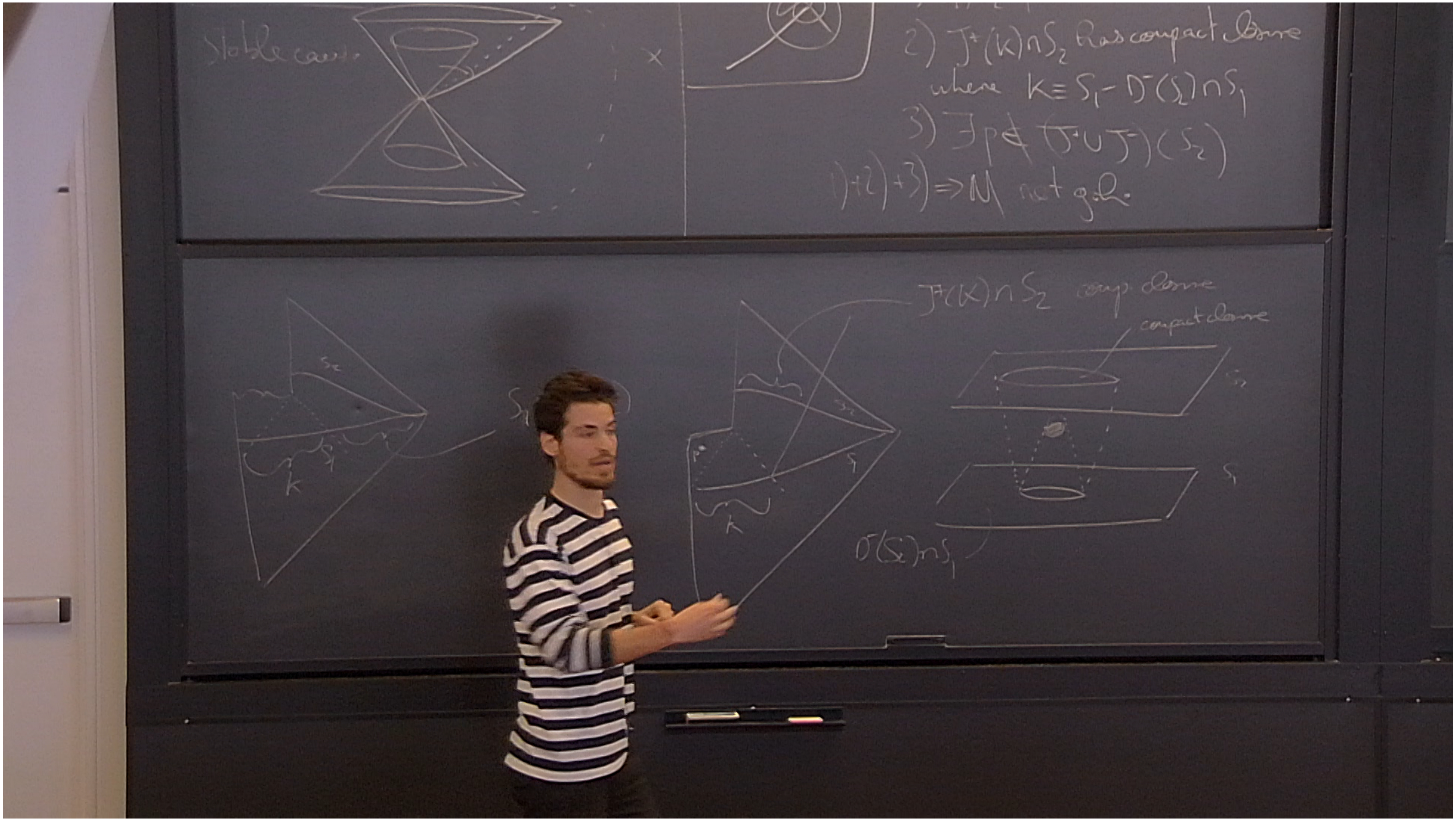

sting: I±(p) = I±(q) ⇒ p = q
Stable causal.
Thm
1) S1, S2 partial C.S.
2) J+(K)∩S2 has compact closure
where K ≡ S1 − D−(S2)∩S1
3) ∃ p ∉ (J+ ∪ J−)(S2)
1)+2)+3) ⇒ M not g.h.
Causal Properties of Evaporating B.H.


Stable caus.
2) $J^+(K) \cap S_2$ has compact closure
where $K \equiv S_1 - D^-(S_2) \cap S_1$
3) $\exists\, p \notin (J^+ \cup J^-)(S_2)$
1)+2)+3) $\Rightarrow$ M not g.h.
S_2
S_1
K
$S_1 \cap D^-(S_2)$
$J^+(K) \cap S_2$ comp. closure
p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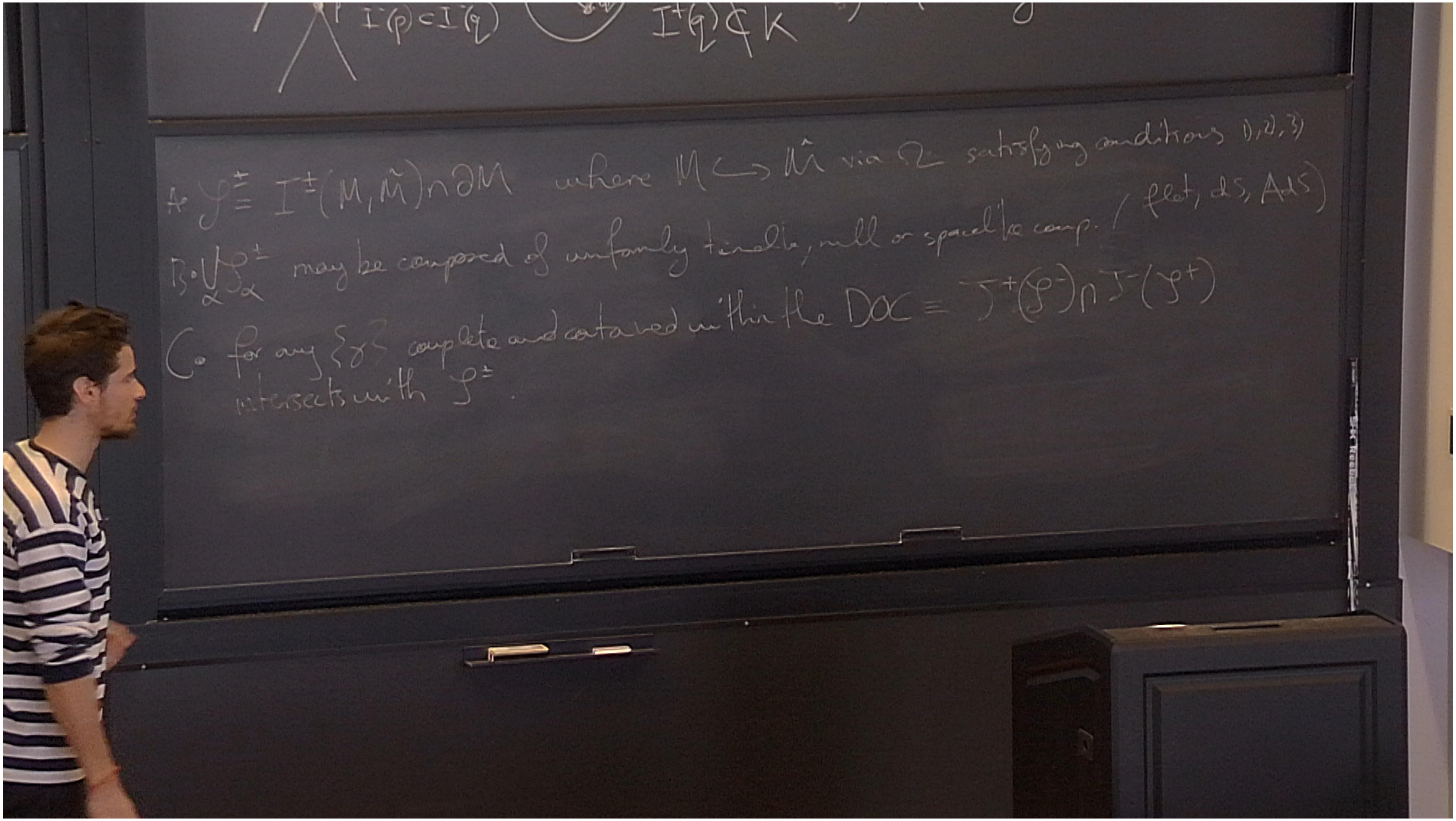
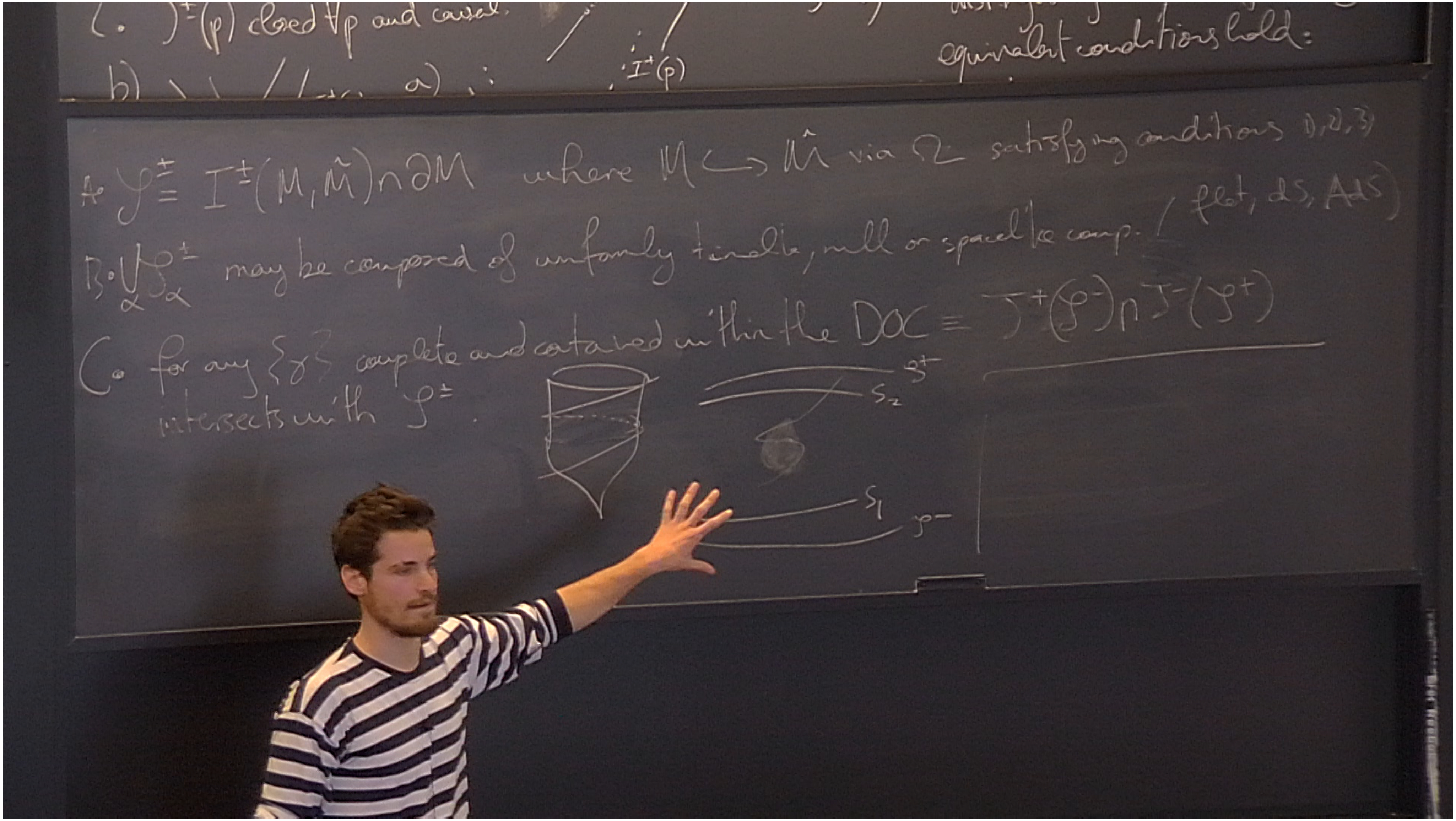
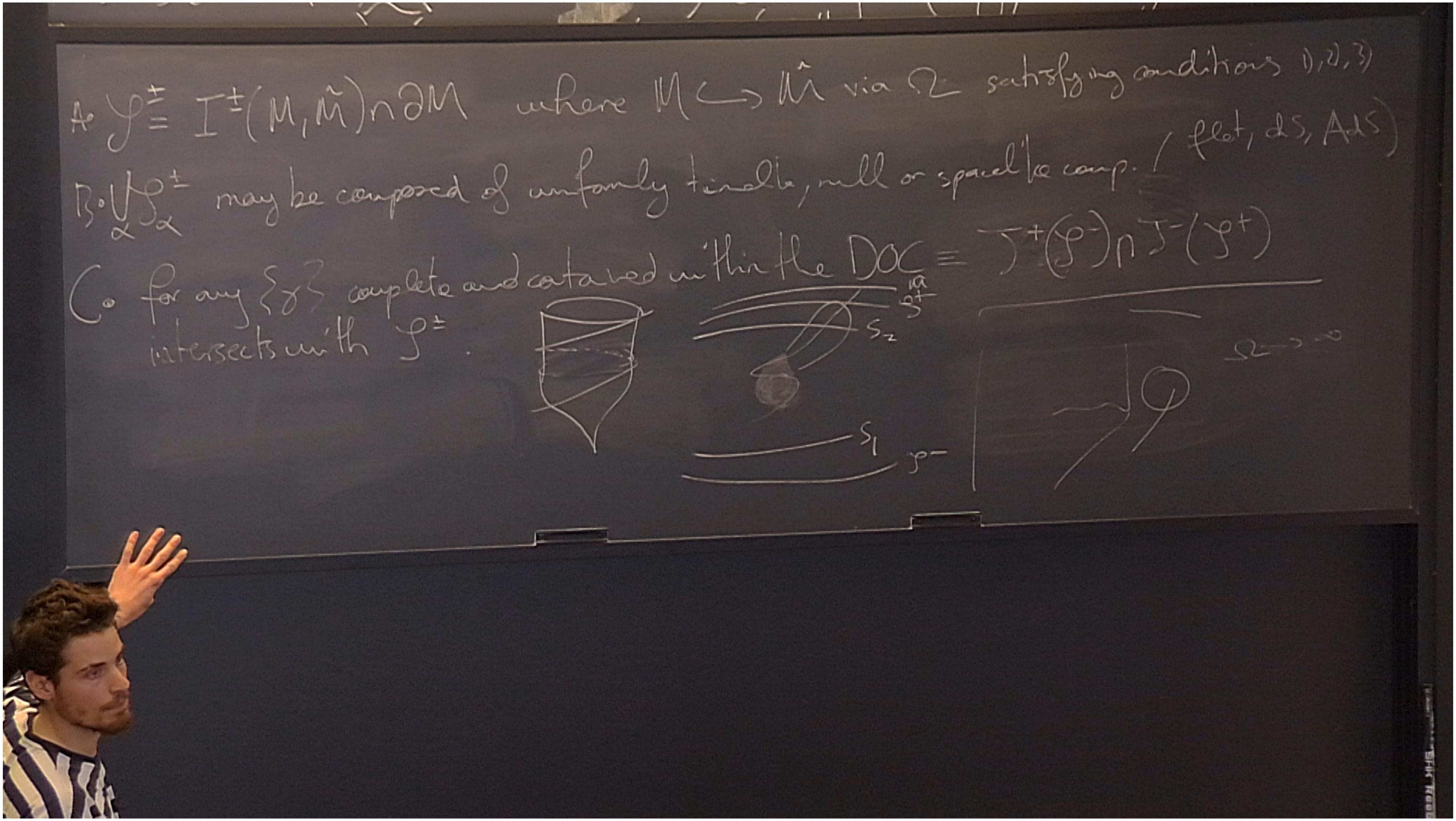
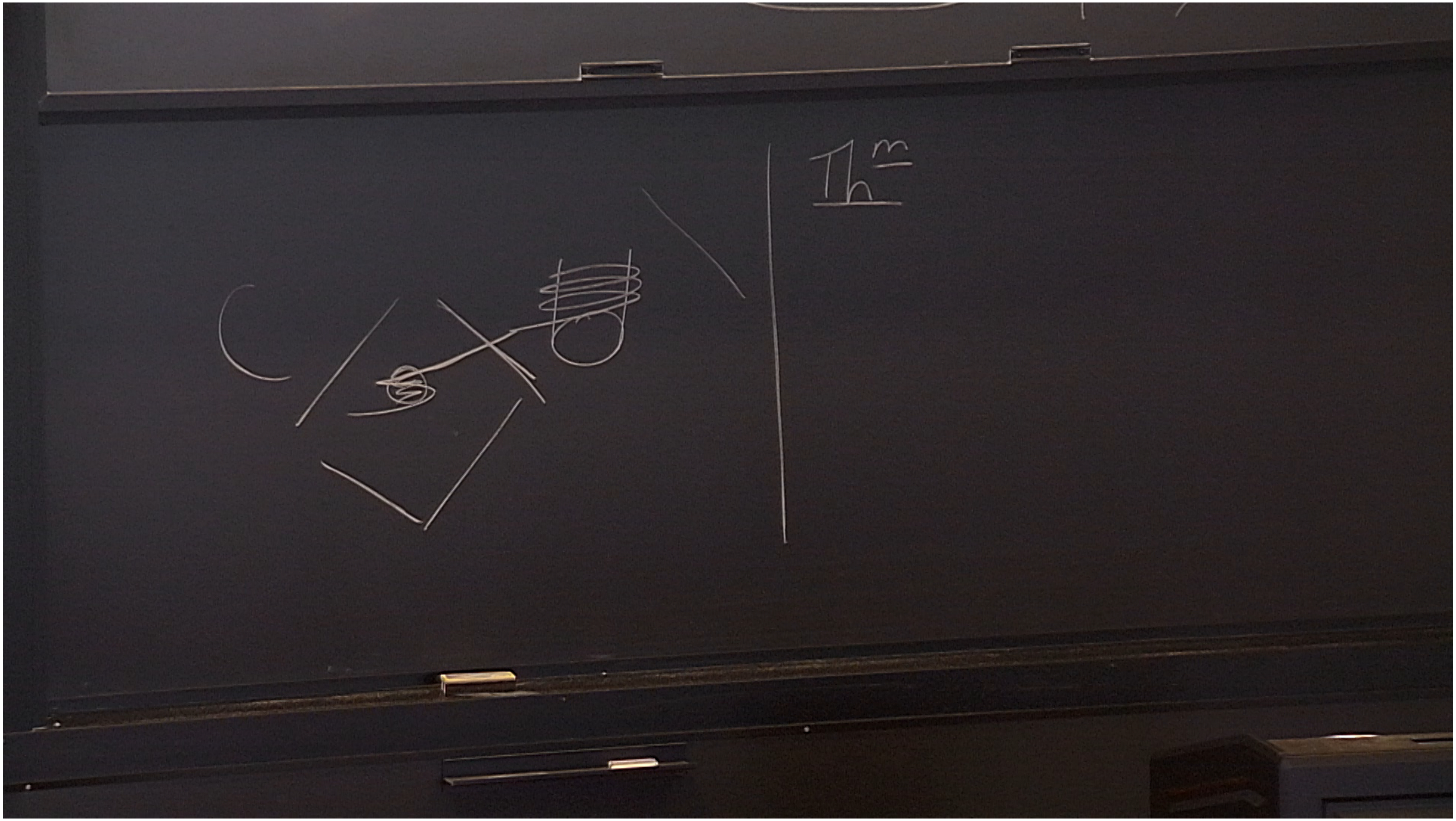
1)+2)+3) $\Rightarrow$ M not g.h.
$J^+(K)\cap S_2$ comp. closure
compact closure
$D^-(S_2)\cap S_1$
S_2
S_1
K


I⁻(p) ⊂ I⁻(q)
I⁺(q) ⊄ K
A. 𝒥± = I±(M, M̂) ∩ ∂M where M ↪ M̂ via Ω satisfying conditions 1), 2), 3)
B. ⋃α 𝒥±α may be composed of uniformly timelike, null or spacelike comp. / (flat, dS, AdS)
C. for any {γ} complete and contained within the DOC ≡ J⁺(𝒥⁻) ∩ J⁻(𝒥⁺)
intersects with 𝒥±.



$J^\pm(p)$ closed $\forall p$ and causal.
$I^+(p)$
equivalent conditions hold:
satisfying conditions 1), 2), 3)
A. $\mathscr{I}^\pm = I^\pm(M,\tilde{M}) \cap \partial M$ where $M \hookrightarrow \hat{M}$ via Ω
(flat, dS, AdS)
B. $\bigcup_\alpha \mathscr{I}^\pm_\alpha$ may be composed of uniformly timelike, null or spacelike comp.
C. for any $\{\gamma\}$ complete and contained within the DOC $\equiv J^+(\mathscr{I}^-) \cap J^-(\mathscr{I}^+)$
intersects with $\mathscr{I}^\pm$.
$\mathscr{I}^+$
S_2
S_1
$\mathscr{I}^-$


A. $\mathcal{I}^{\pm} \equiv I^{\pm}(M, \tilde{M}) \cap \partial M$ where $M \hookrightarrow \hat{M}$ via Ω satisfying conditions 1), 2), 3)
B. $\bigcup_{\alpha} \mathcal{I}^{\pm}_{\alpha}$ may be composed of uniformly timelike, null or spacelike comp. (flat, dS, AdS)
C. for any $\{\gamma\}$ complete and contained within the DOC $\equiv J^{+}(\mathcal{I}^{-}) \cap J^{-}(\mathcal{I}^{+})$
intersects with $\mathcal{I}^{\pm}$.
$\mathcal{I}^{+}$
S_2
S_1
$\mathcal{I}^{-}$
$\Omega \to \infty$


Thm

caus. simp

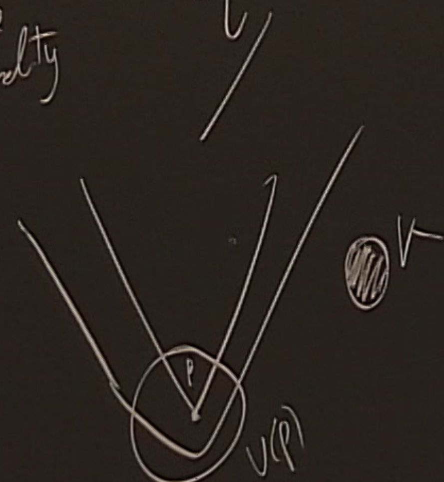
$\Downarrow$

caus cont. $\equiv$ disting + either following equiv. conditions

$\Downarrow$

stable causality

cont / cont



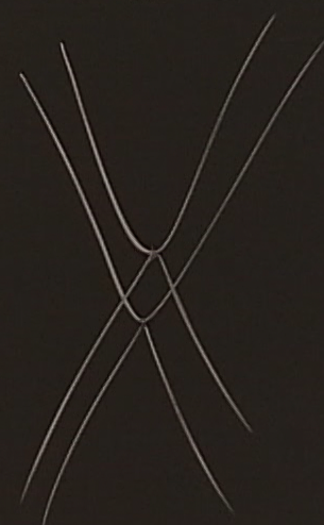
disting.

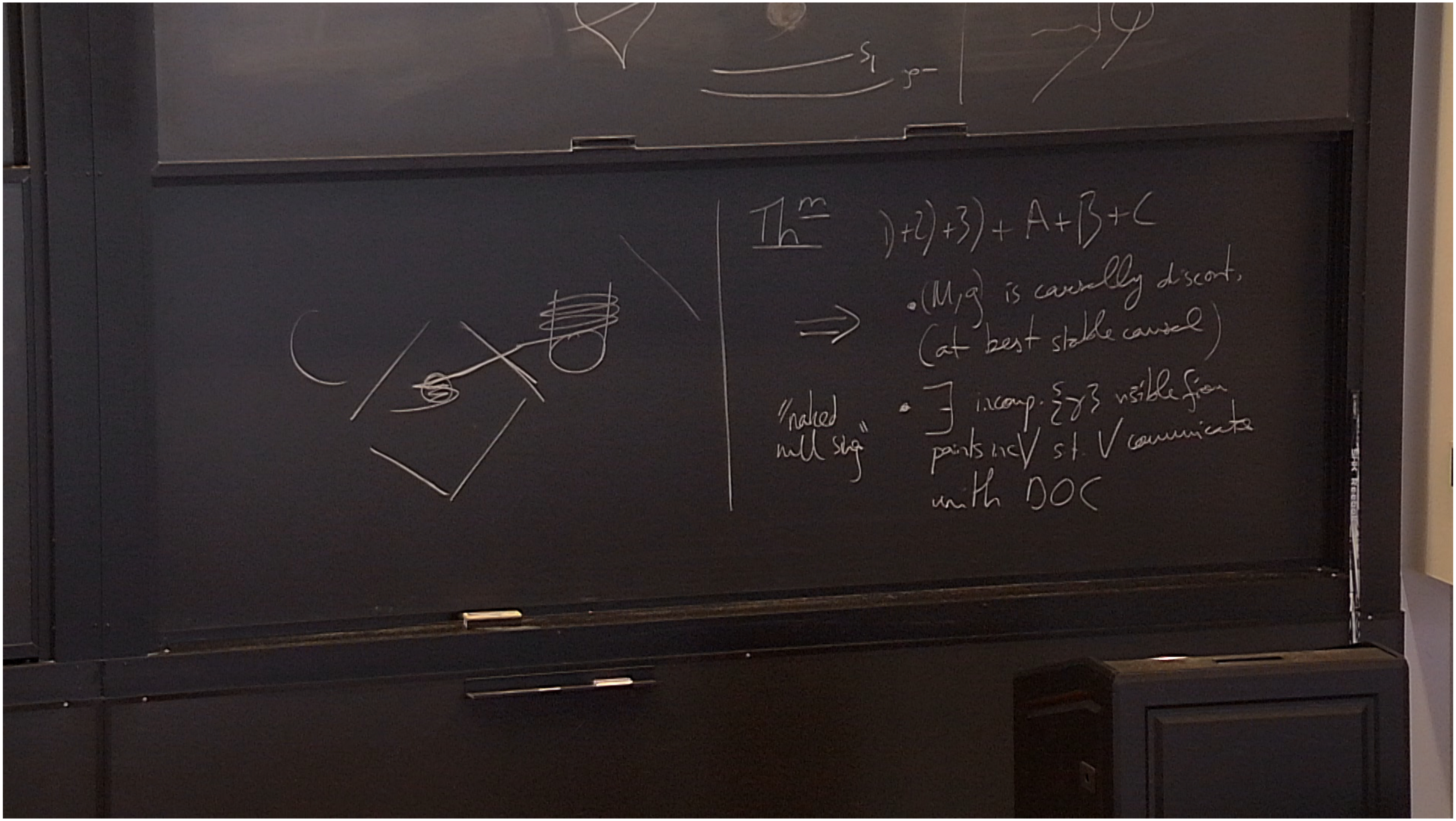
$\Downarrow$

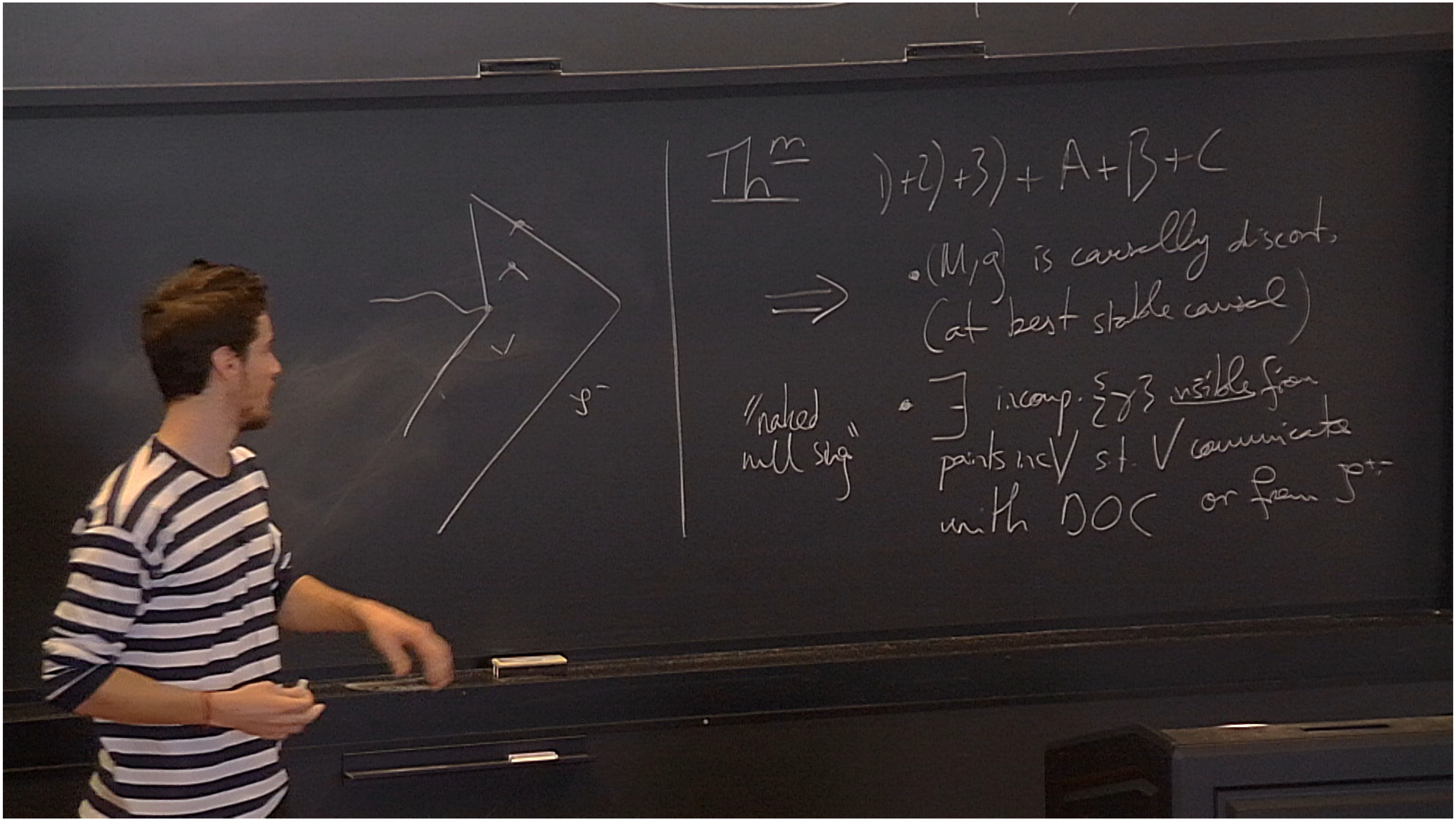
not. tot. impris

$\Downarrow$

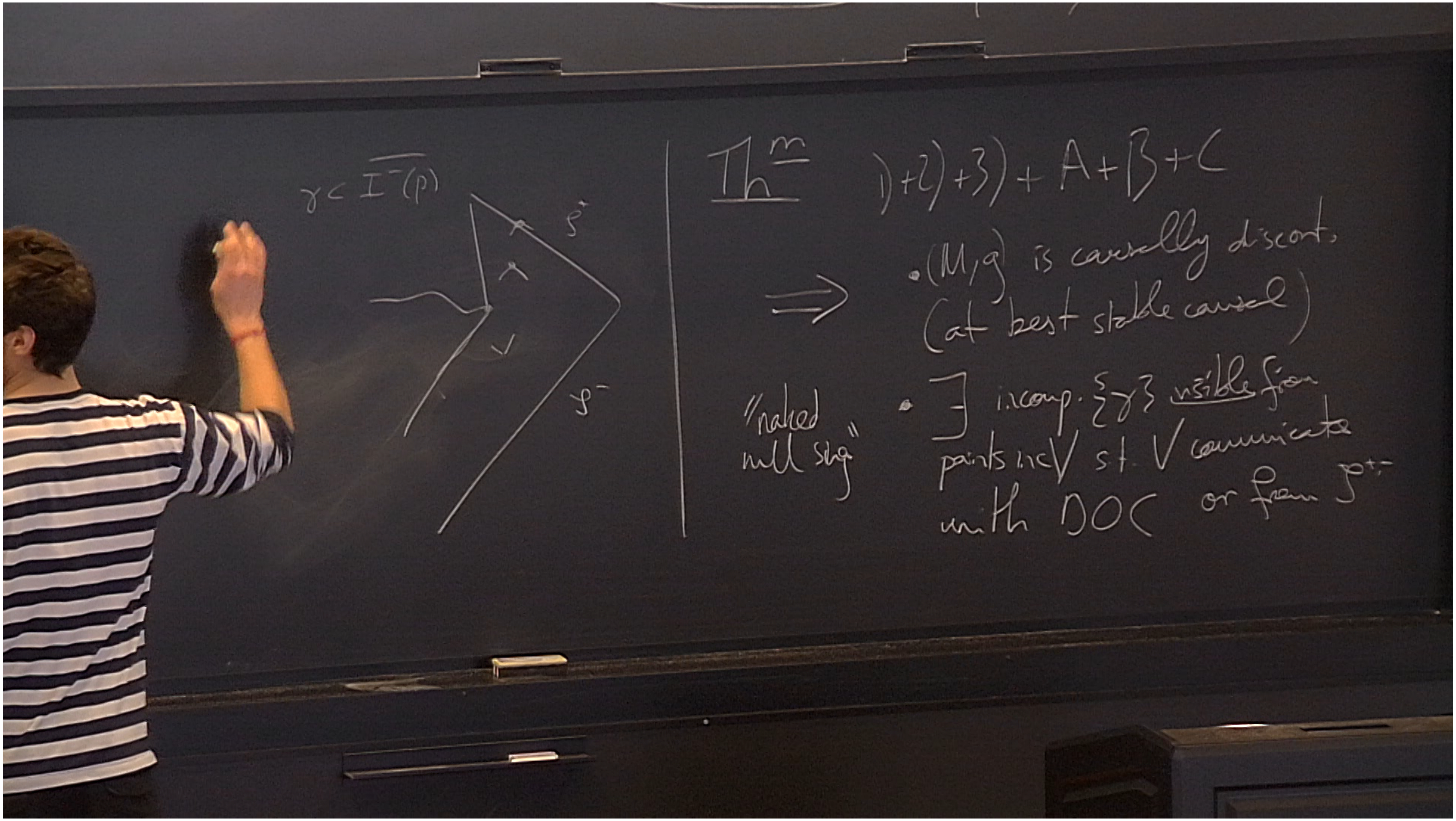
causality

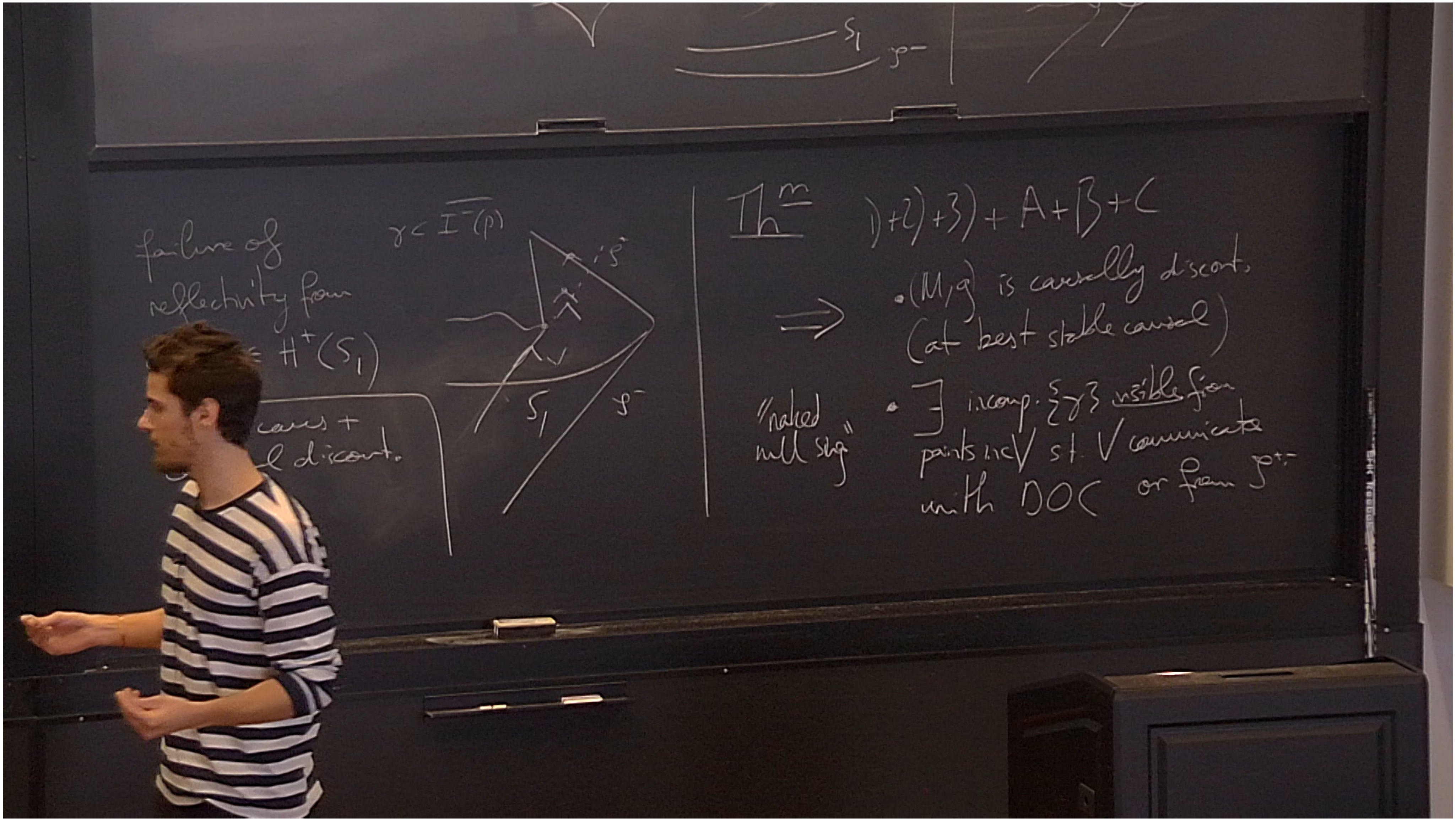


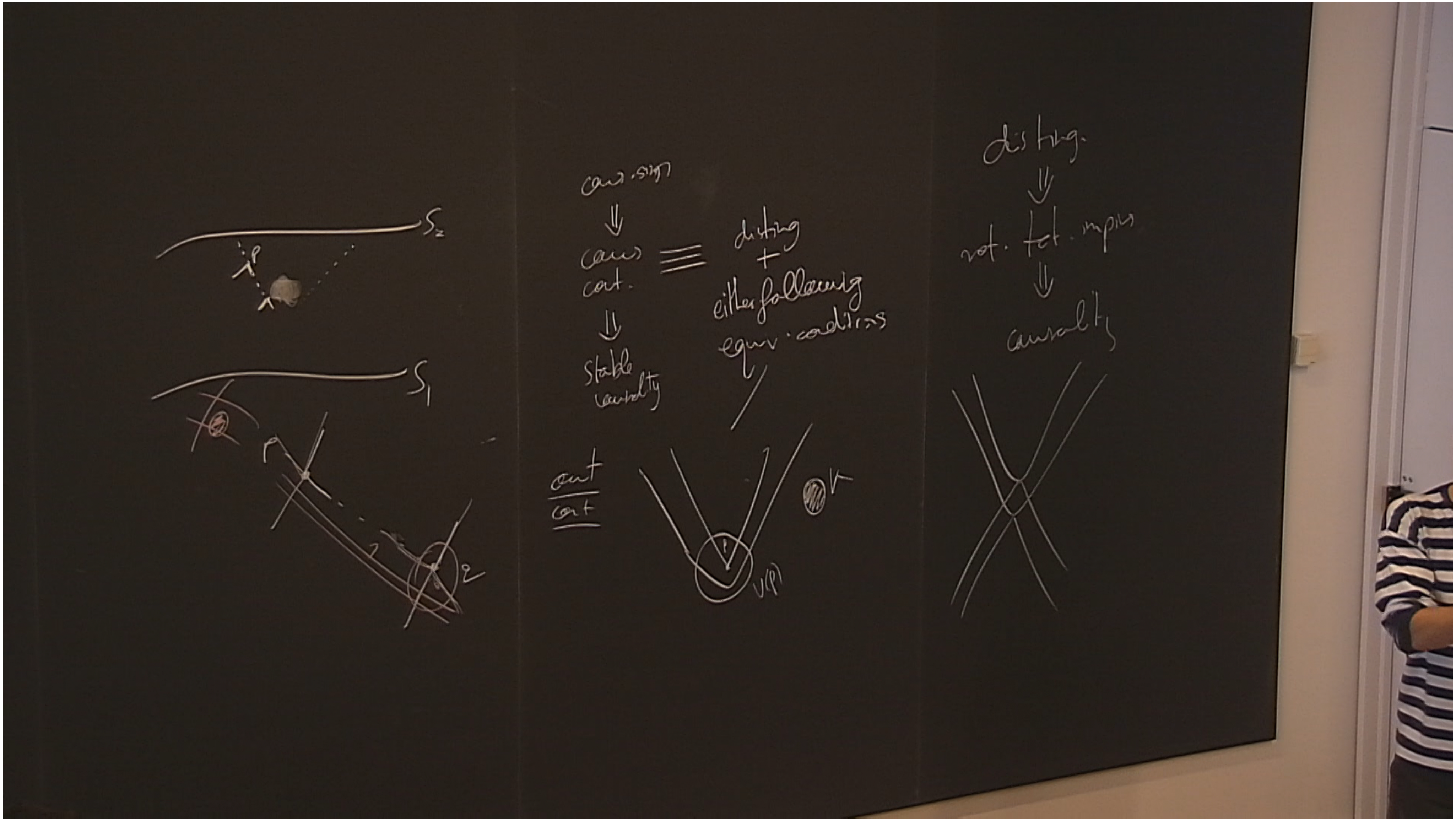

Th^m 1)+2)+3)+A+B+C
⟹ • (M,g) is causally discont.
(at best stable causal)
"naked null sing"
• ∃ incomp. {γ} visible from points in V s.t. V communicates with DOC

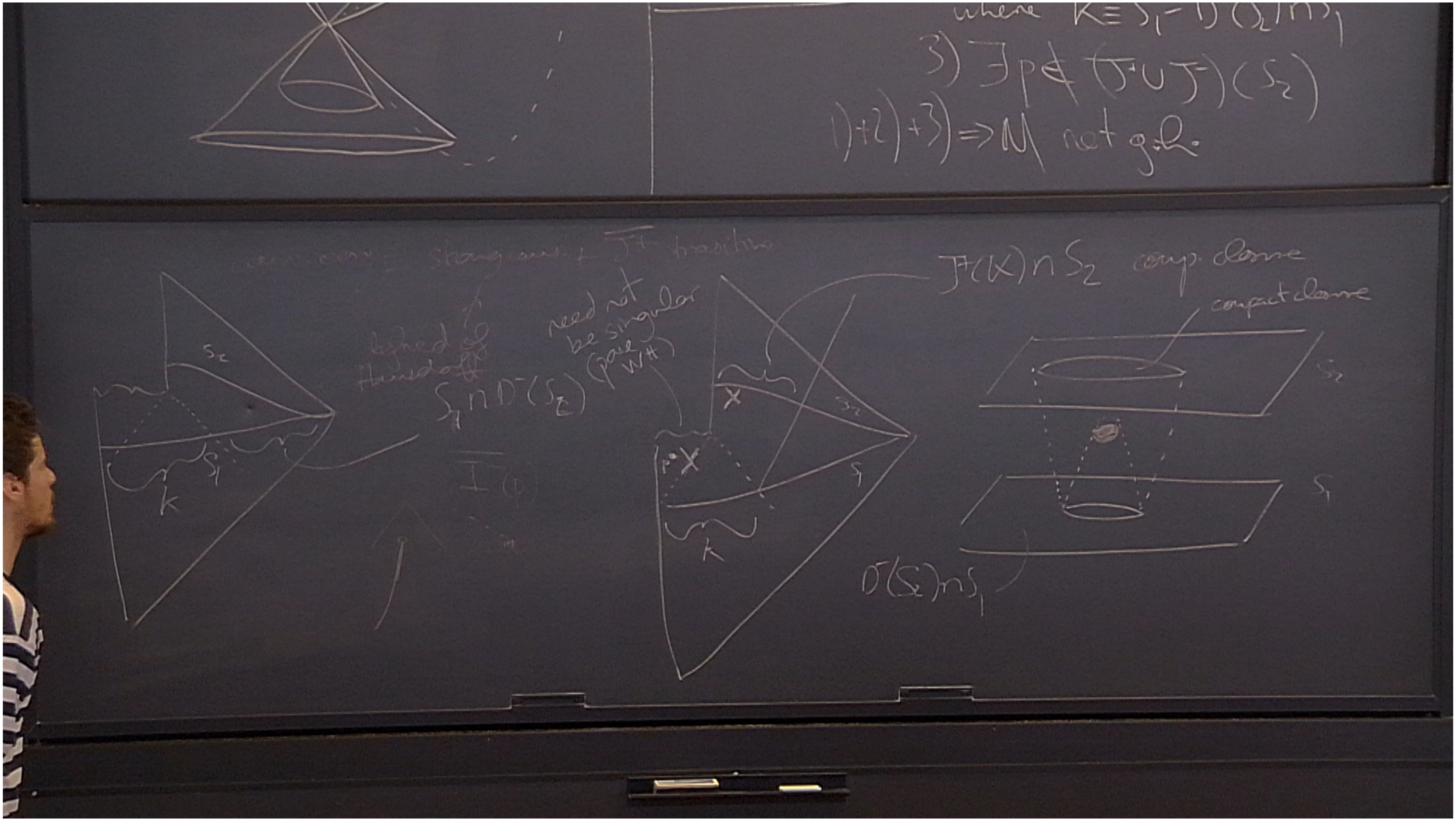


Th^m 1)+2)+3)+A+B+C
• (M,g) is causally discont.
(at best stable causal)
"naked null sing"
• ∃ incomp. {γ} visible from points in V s.t. V communicate with DOC or from


γ ⊂ I⁻(p)
𝒥⁺
𝒥⁻
Thm 1)+2)+3) + A+B+C
⟹
• (M,g) is causally discont.
(at best stable causal)
"naked null sing"
• ∃ incomp. {γ} visible from points in V s.t. V communicate with DOC or from 𝒥⁺,⁻


failure of
reflectivity from
$H^+(S_1)$
$\gamma \subset \overline{I^-(p)}$
S_1
$\mathscr{I}^-$
Th$^{\underline{m}}$ 1)+2)+3) + A+B+C
⟹
• (M,g) is causally discont.
(at best stable causal)
"naked null sing"
• ∃ incomp. $\{\gamma\}$ visible from points in V s.t. V communicate with DOC or from $\mathscr{I}^{+,-}$


S2
S1
caus. sign
caus cat.
stable causality
disting
either following
equiv. conditions
V(p)
disting.
causality


where K ≡ S1 − D(S2) ∩ S1
3) ∃ p ∉ (J+ ∪ J−)(S2)
1)+2)+3) ⇒ M not g.h.
J+(K) ∩ S2 comp. closure
compact closure
need not be singular (pure WH)
S1 ∩ D−(S2)
S2
S1
K
D−(S2) ∩ S1