Title: Soft photons, gravitons, and their quantum information content

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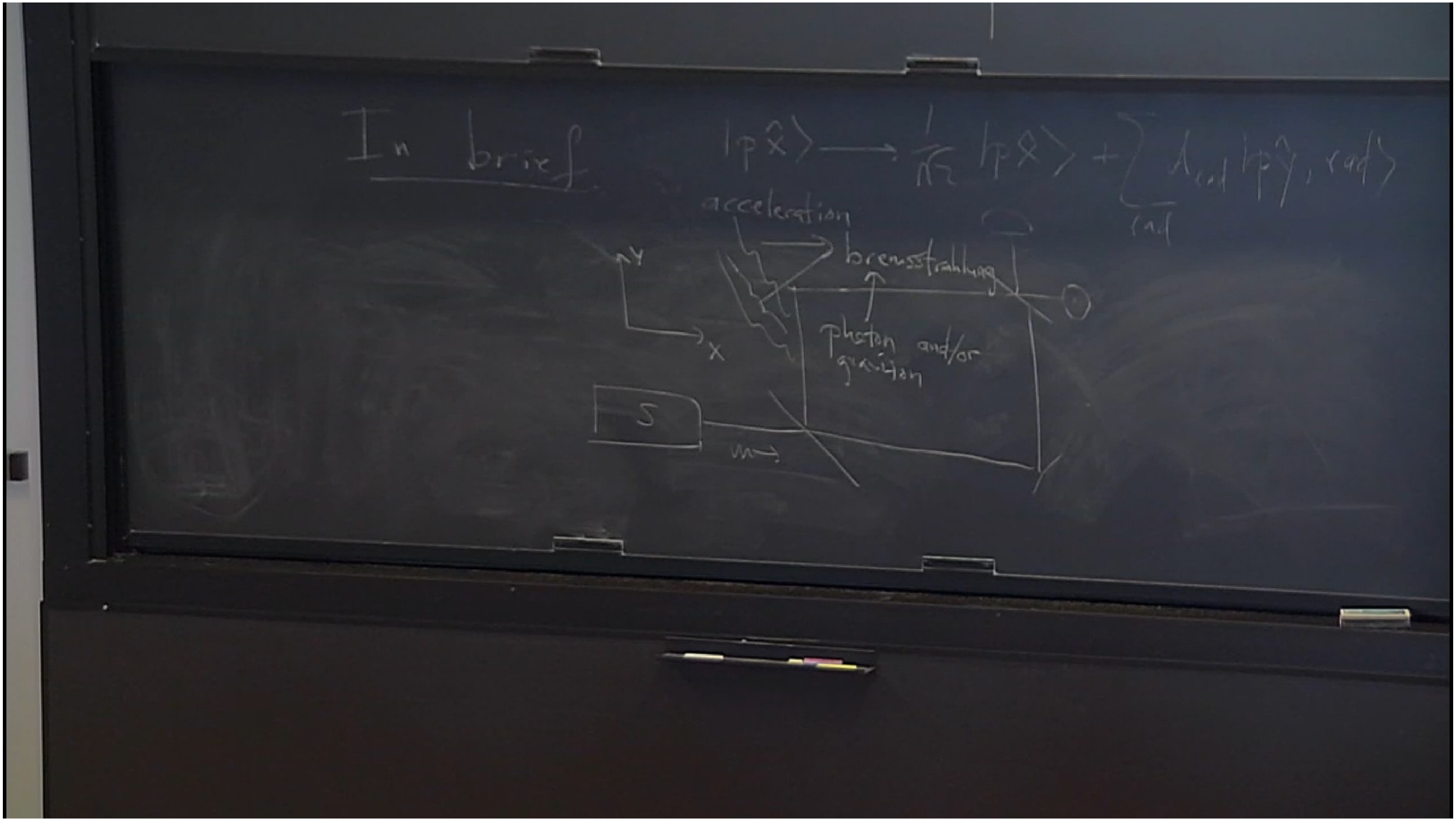
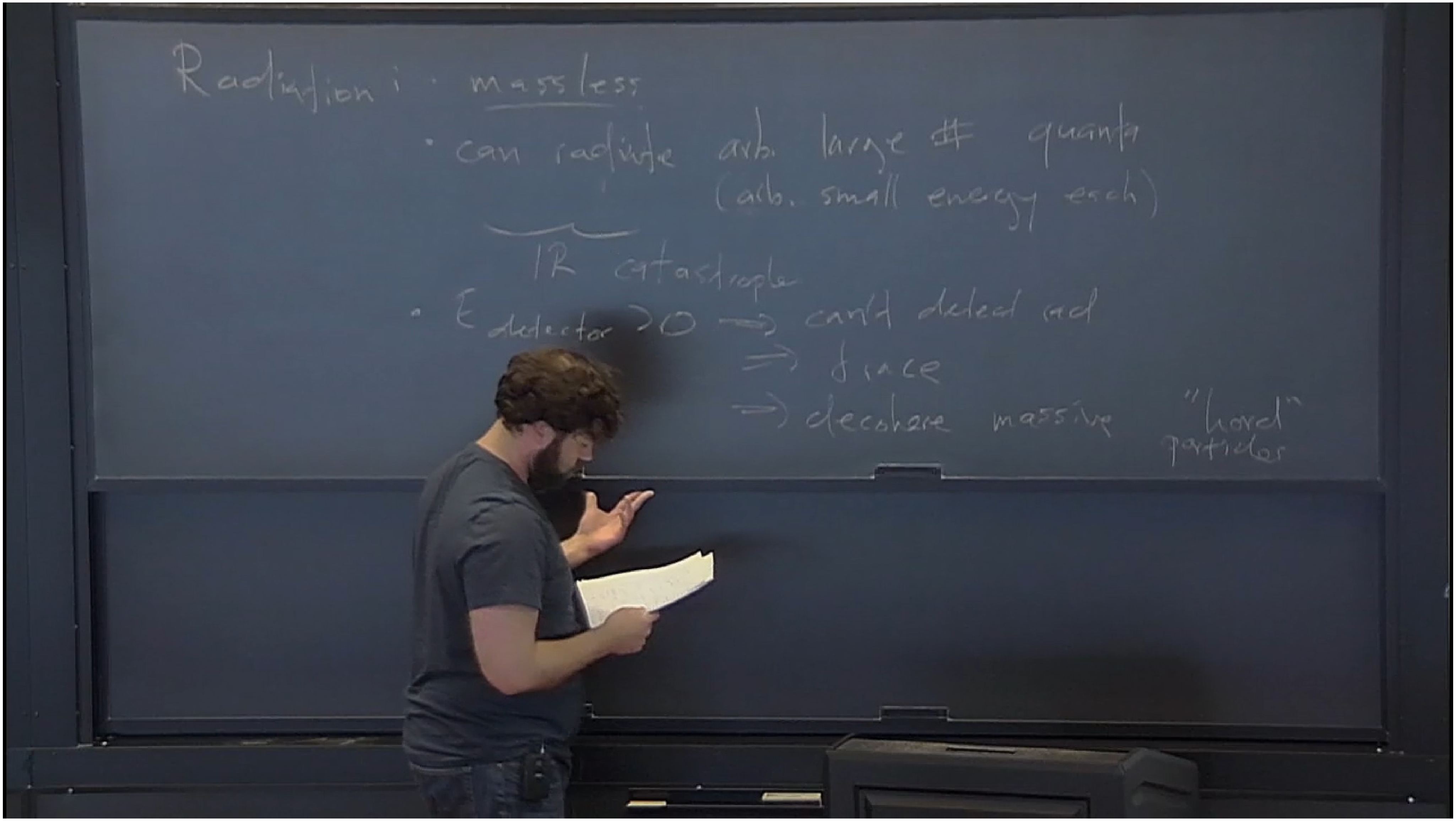
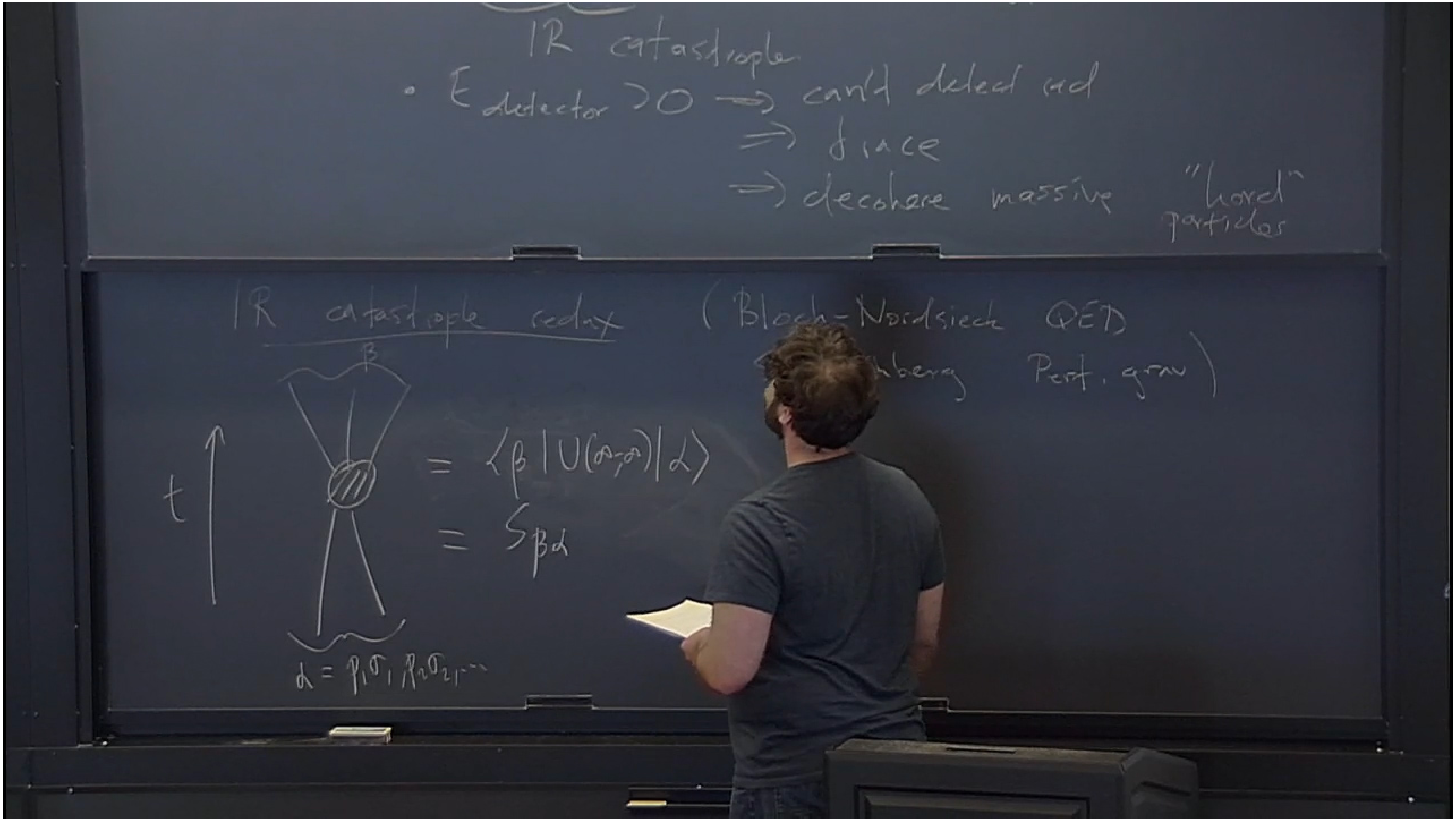
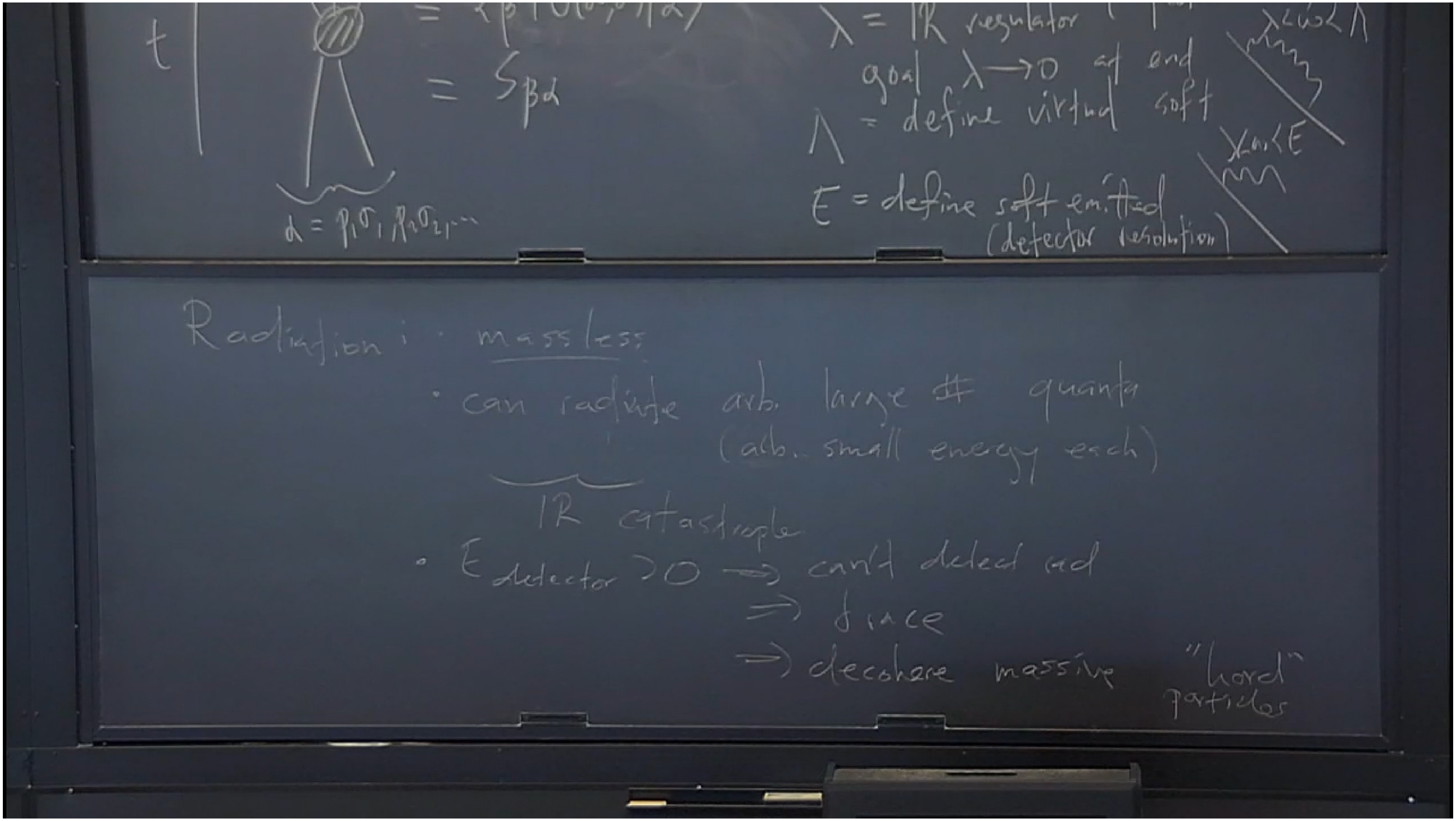
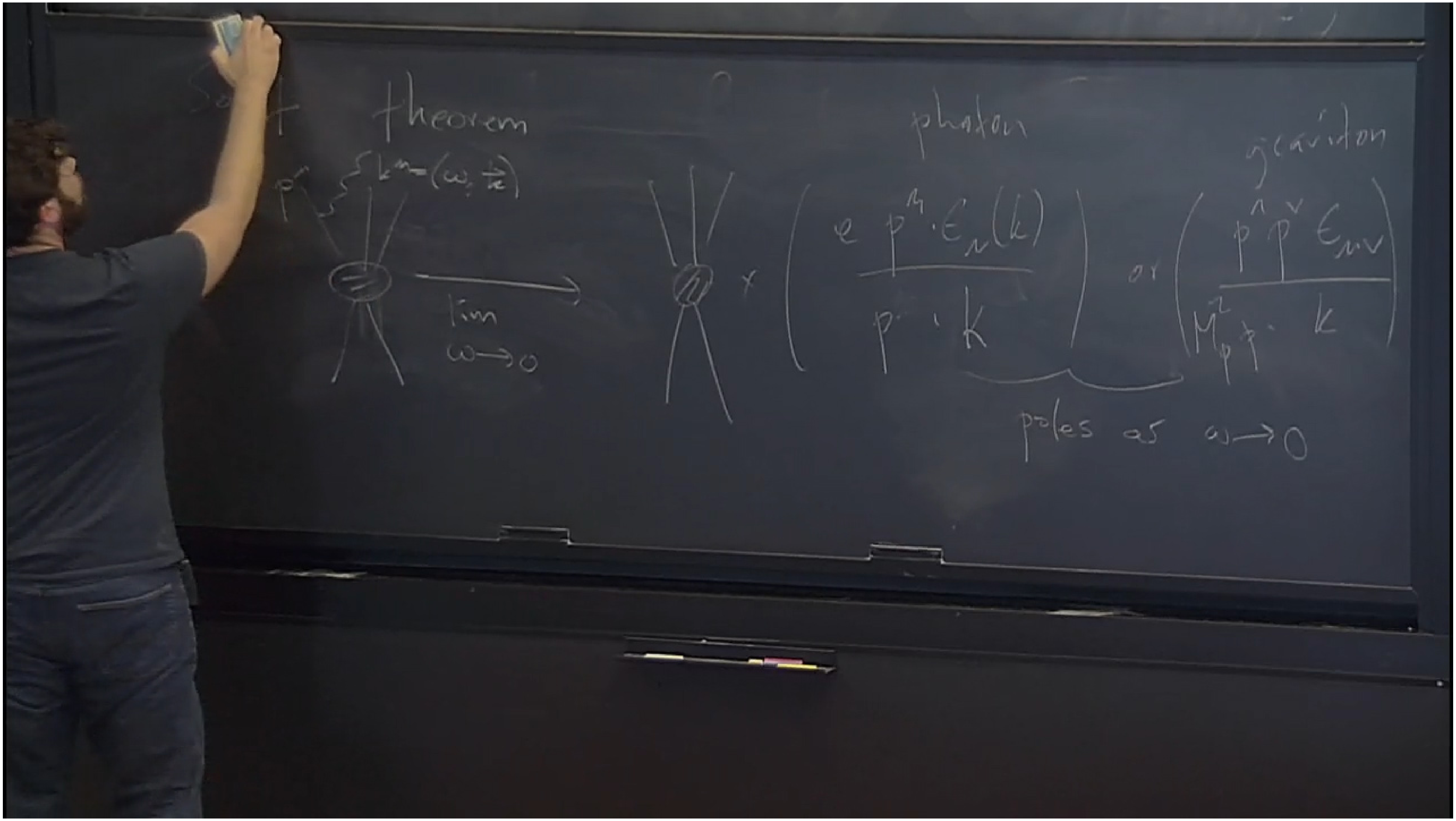
Abstract: <p>When a particle is accelerated, as in a scattering event, it will radiate gravitons and, if electrically charged, photons. The infrared tail of the spectrum of this radiation has a divergence: an arbitrarily small amount of total energy is divided into an arbitrarily large number of radiated bosons. Each of these in turn carries a momentum and a helicity degree of freedom, and thus this radiation carries significant amounts of quantum information. I will demonstrate that the infrared bosonic radiation causes nearly complete decoherence of the final state of the hard particles into the momentum basis. When applied to radiation coming from the incoming state, it appears that the entire dynamical history of the process will be distinguishable by the radiation, thus causing a loss of any interference effects between branches of an incoming momentum superposition, such as in a wavepacket. I will explain how infrared dressed states, in the framework of Fadeev and Kulish, evade this issue. Finally, I'll conclude with some remarks on the potential relevance of these issues to black hole information loss</p>

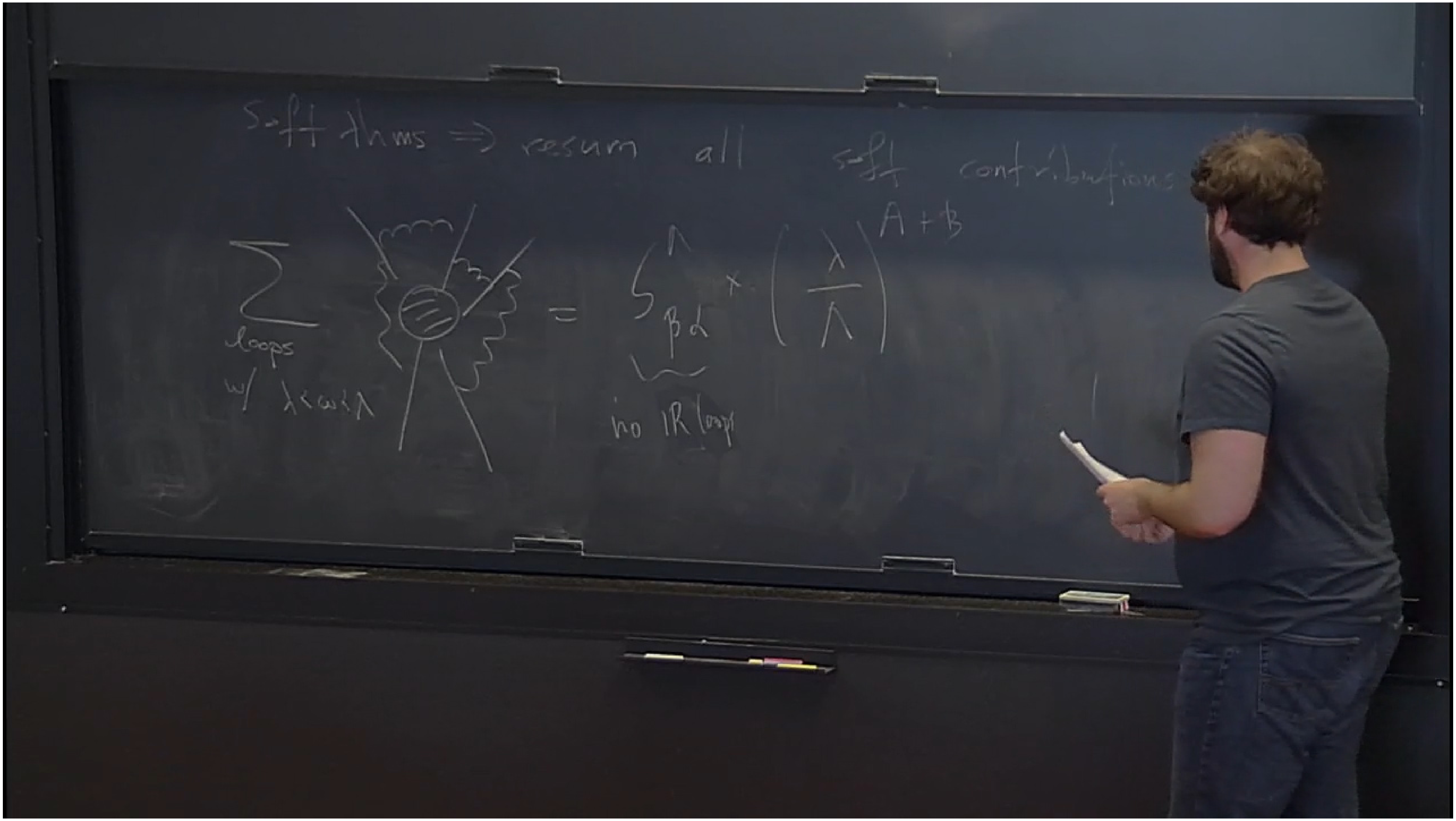

In brief
acceleration
bremsstrahlung
photon and/or graviton
y
x
S

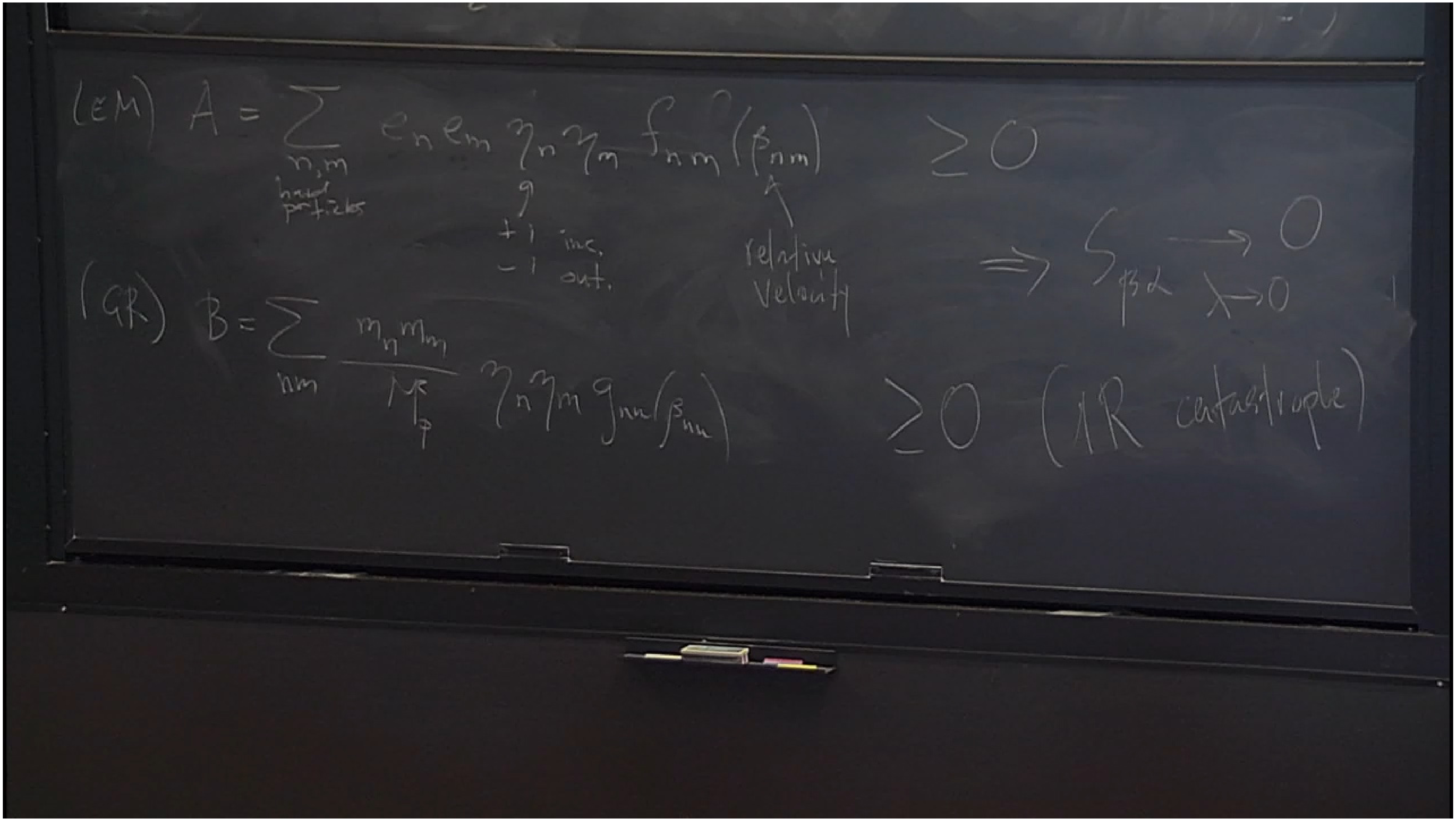

Radiation: · massless
· can radiate arb. large # quanta
(arb. small energy each)
IR catastrophe
· E detector > 0 ⇒ can't detect rad
⇒ trace
⇒ decohere massive "hard" particles

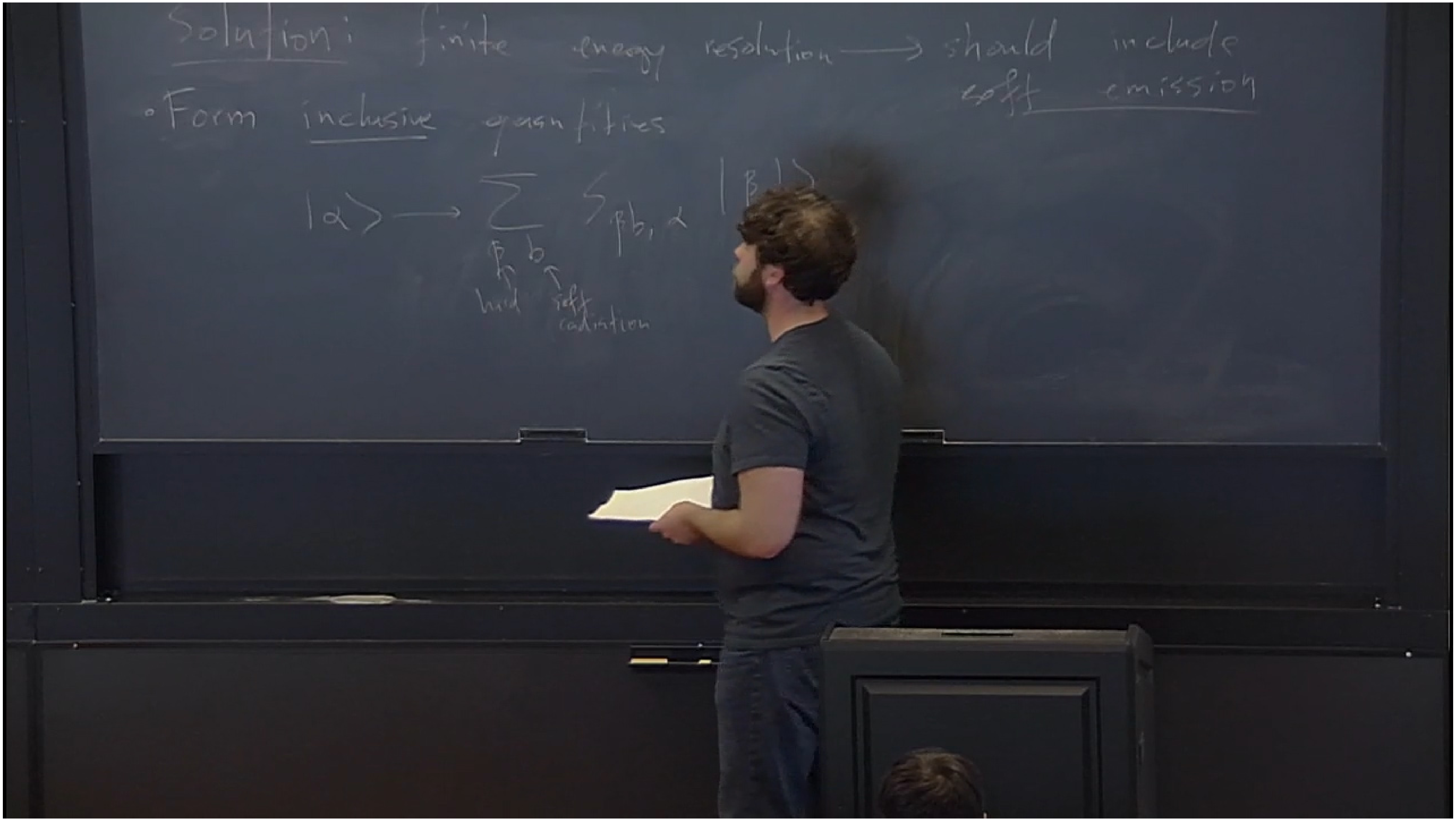

IR catastrophe
• E detector > 0 ⟹ can't detect rad
⟹ trace
⟹ decohere massive "hard" particles
IR catastrophe redux
(Bloch-Nordsieck QED
Pert. grav)
β
t
= ⟨β|U(∞,−∞)|α⟩
= S βα
α = p1σ1, p2σ2, ...

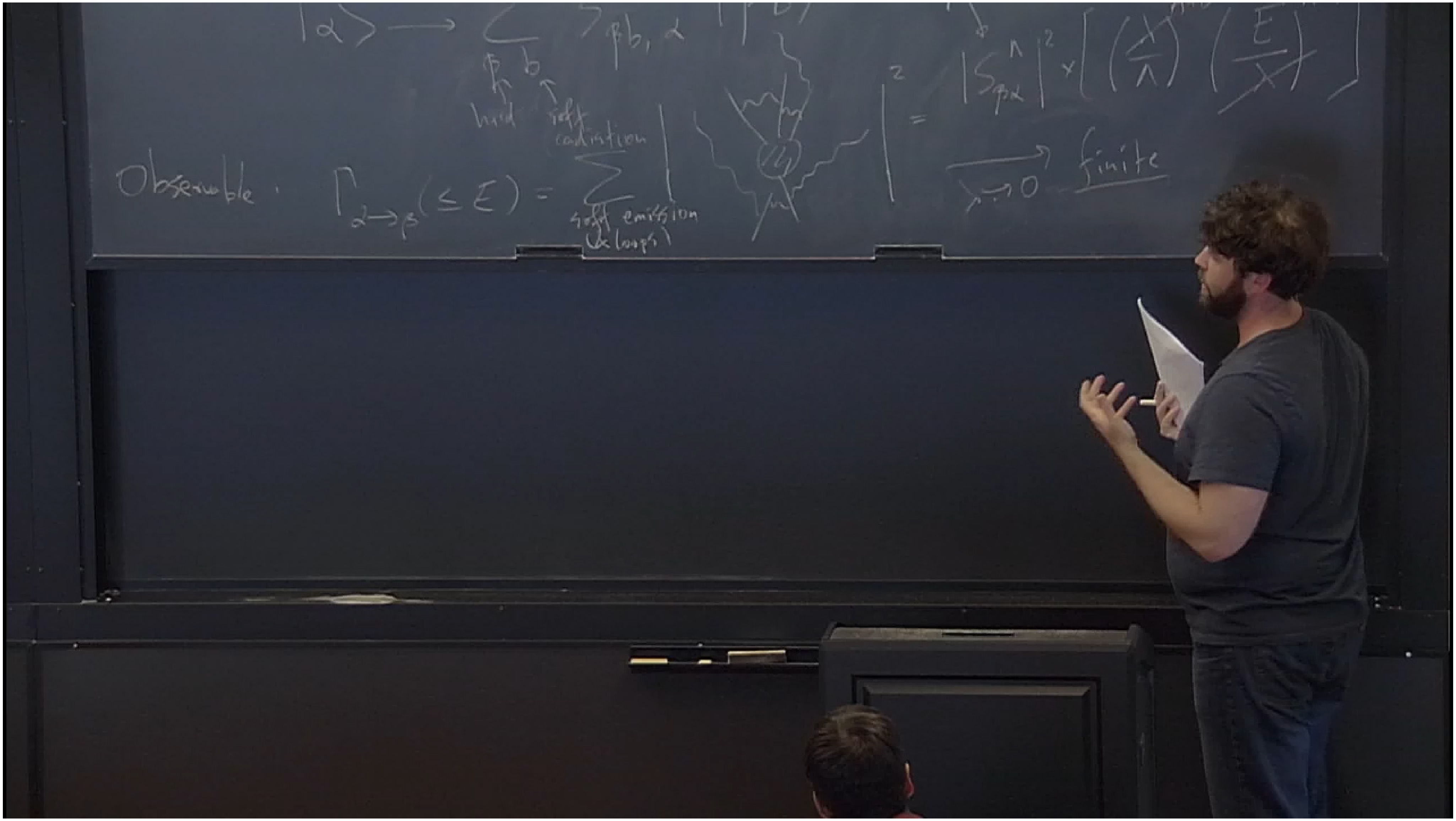

t
= ⟨β|U(∞,−∞)|α⟩
= S_βα
α = p₁σ₁, p₂σ₂, ...
λ = IR regulator
goal λ → 0 at end
Λ = define virtual soft
λ < ω < Λ
E = define soft emitted
(detector resolution)
λ < ω < E
Radiation: massless
· can radiate arb. large # quanta
(arb. small energy each)
IR catastrophe
· E detector > 0 ⇒ can't detect rad
⇒ trace
⇒ decohere massive "hard" particles

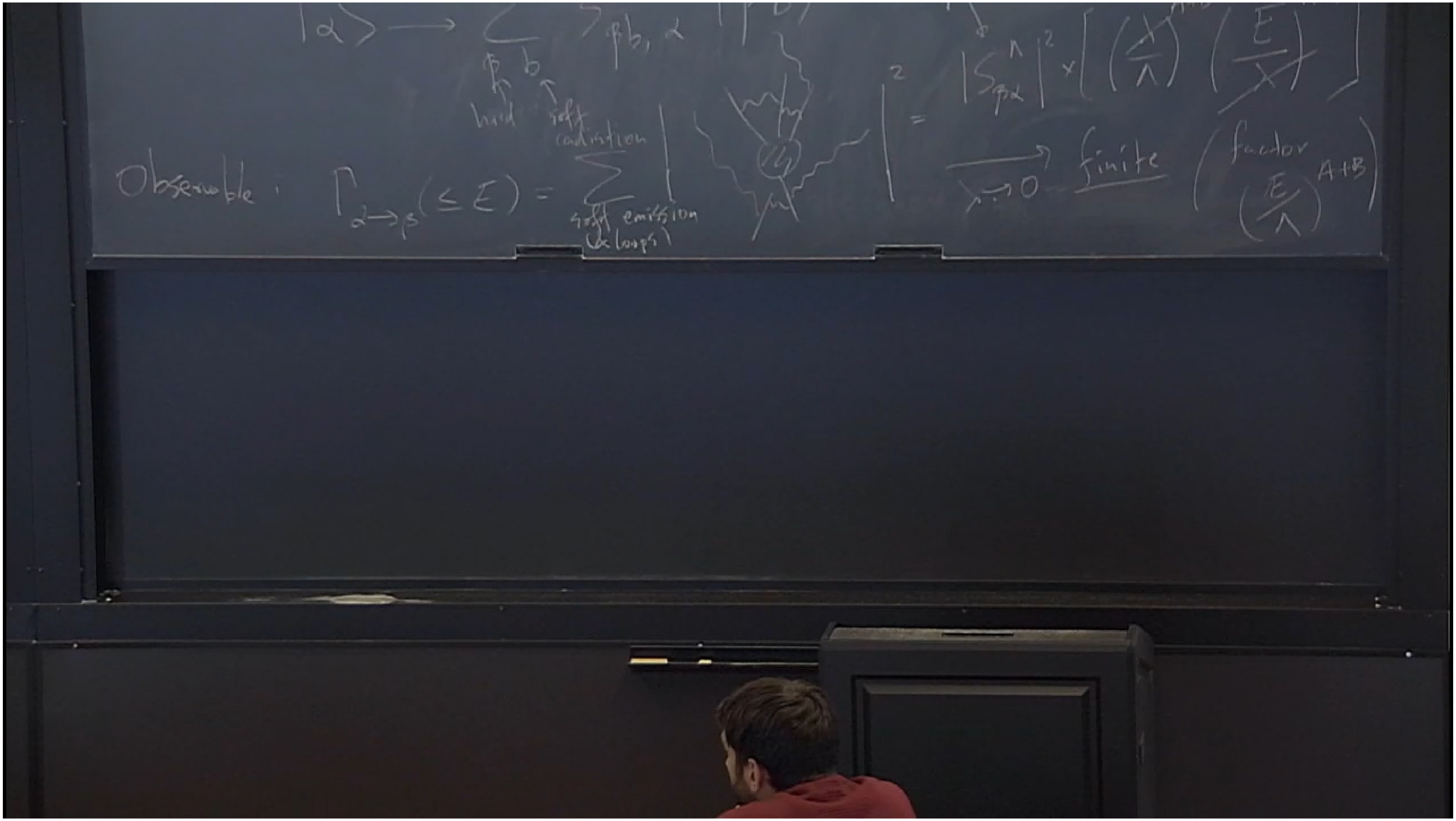

theorem
photon
graviton
lim ω→0
or
poles as ω→0

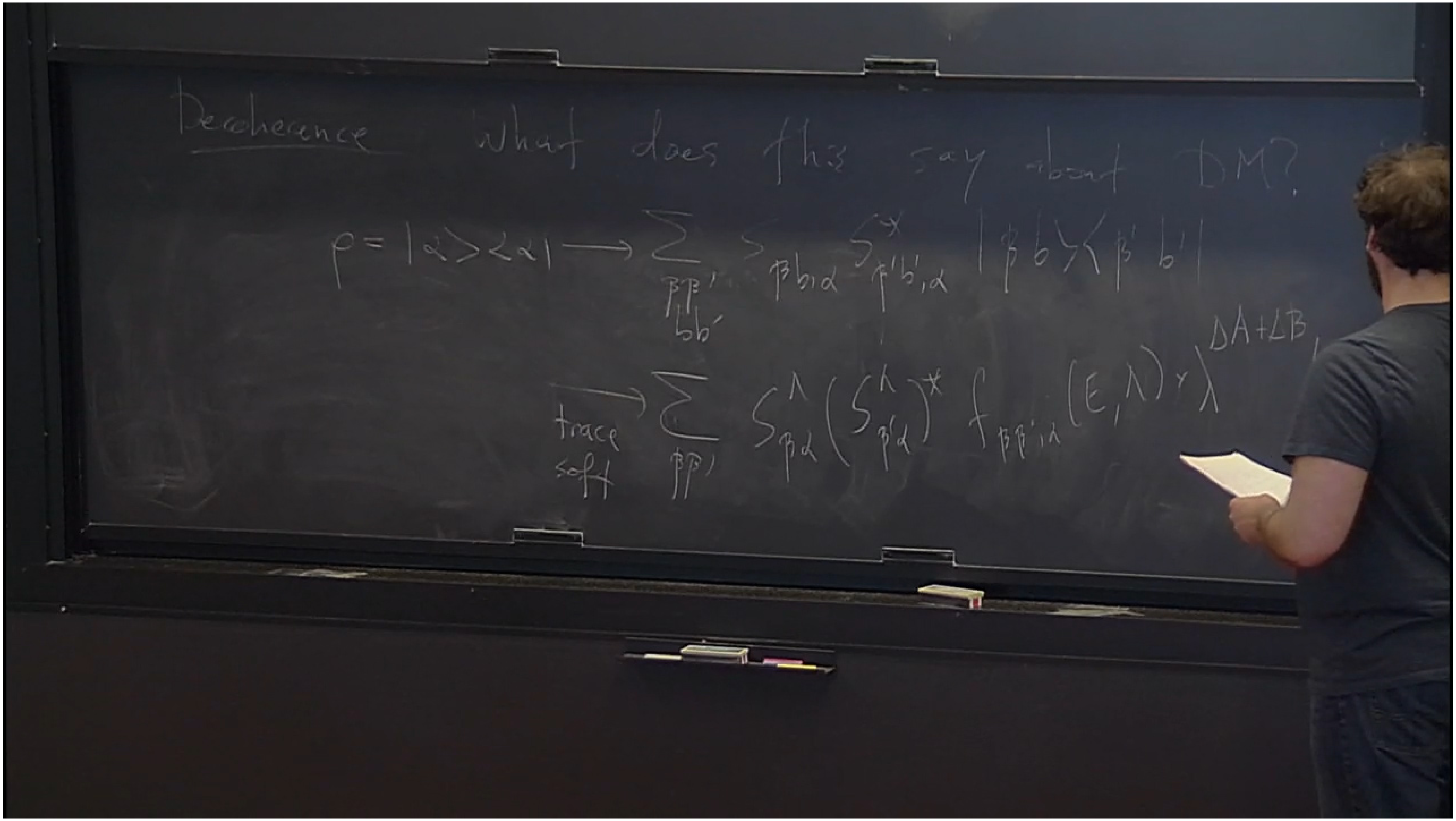

soft thms ⇒ resum all soft contributions
loops w/ λ < ω < Λ
no IR loops
A + B

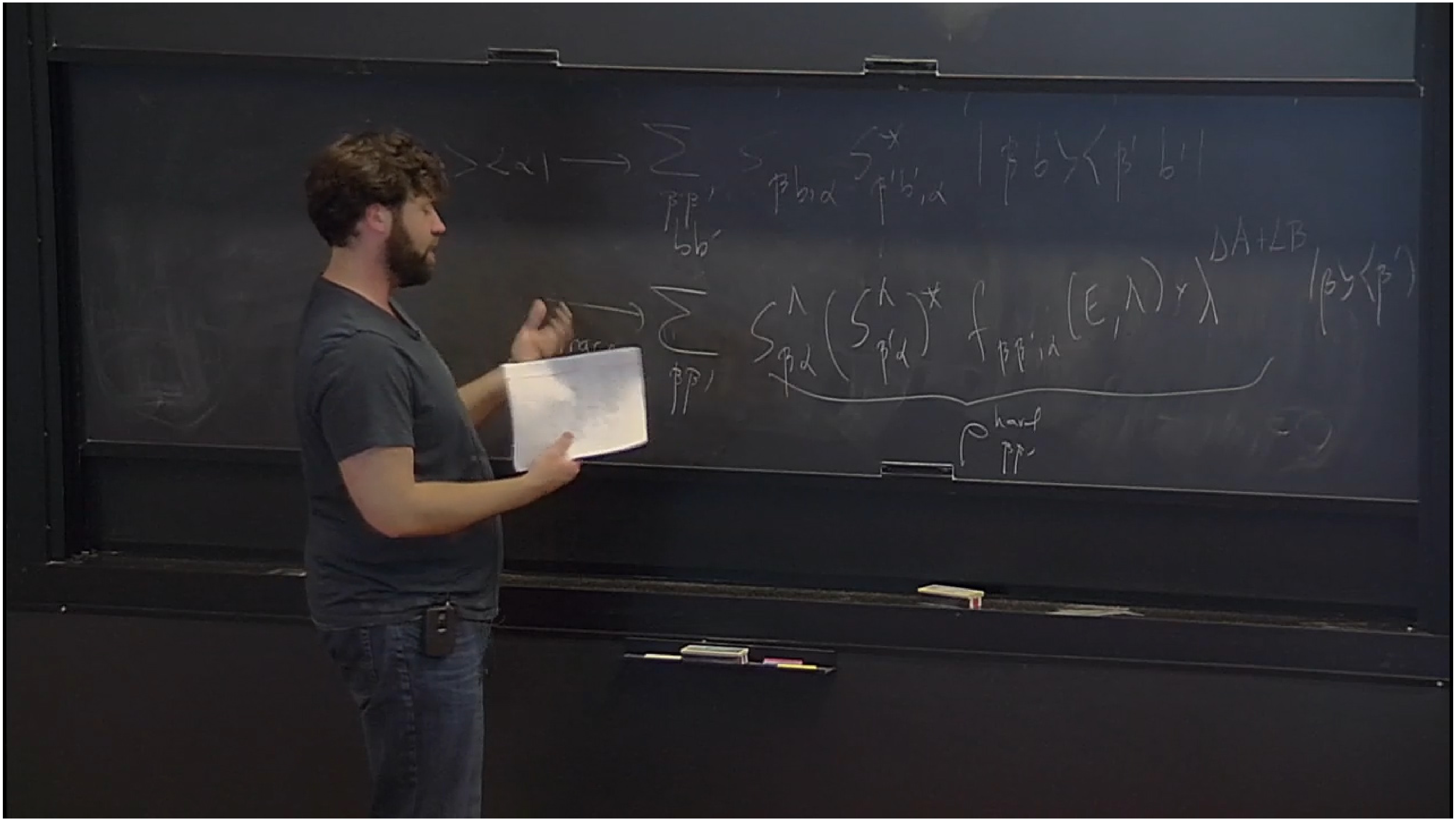

(EM) $A = \sum_{n,m} e_n e_m \eta_n \eta_m f_{nm}(\beta_{nm}) \geq 0$
hard particles
+1 inc.
−1 out.
relative velocity
$\Rightarrow S_{\beta\alpha} \xrightarrow[\lambda \to 0]{} 0$
(GR) $B = \sum_{nm} \frac{m_n m_m}{M_p} \eta_n \eta_m g_{nm}(\beta_{nm}) \geq 0$
(IR catastrophe)

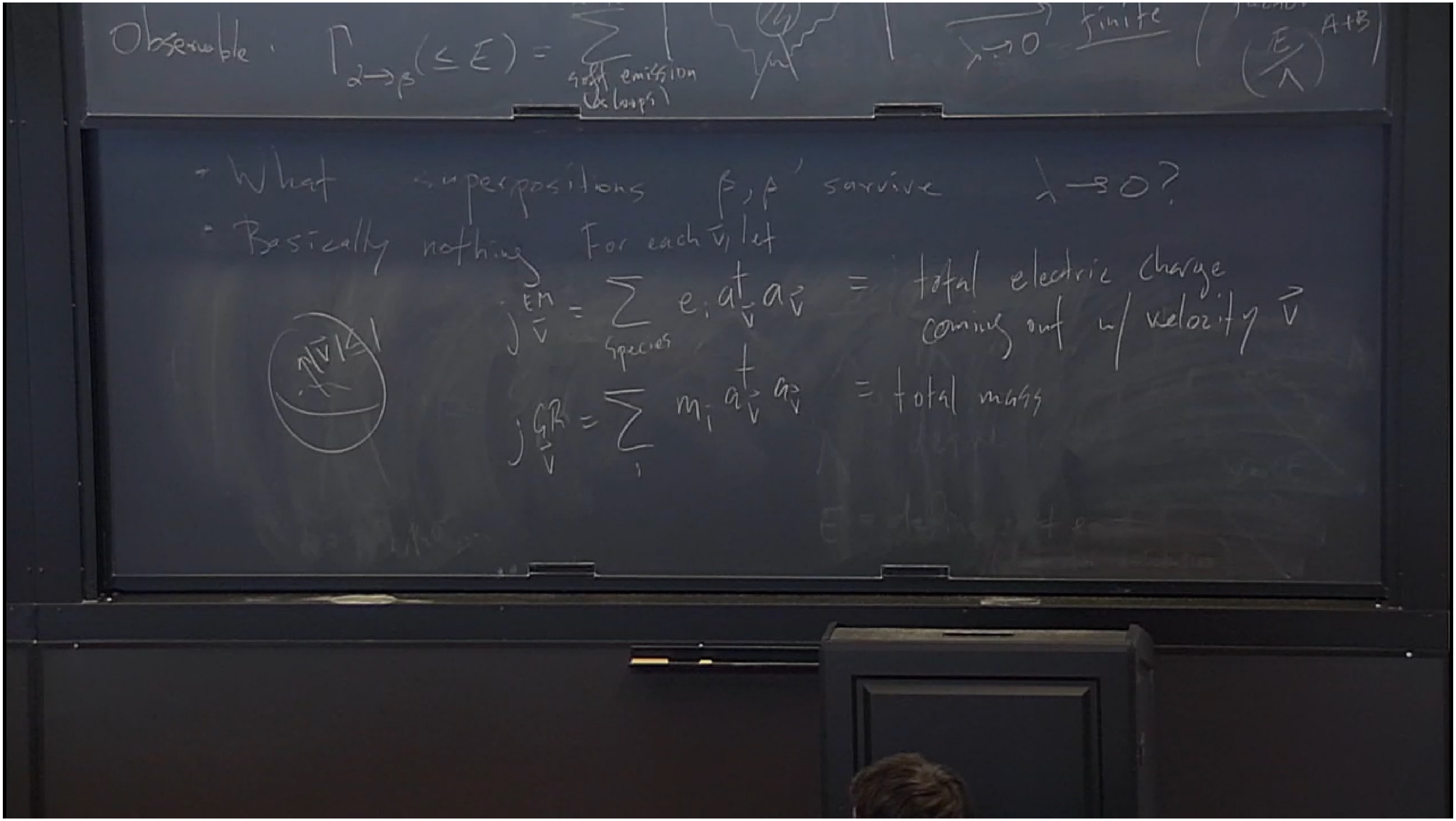

Solution: finite energy resolution → should include soft emission
• Form inclusive quantities
|α⟩ → Σ S βb, α |β
hard
soft radiation

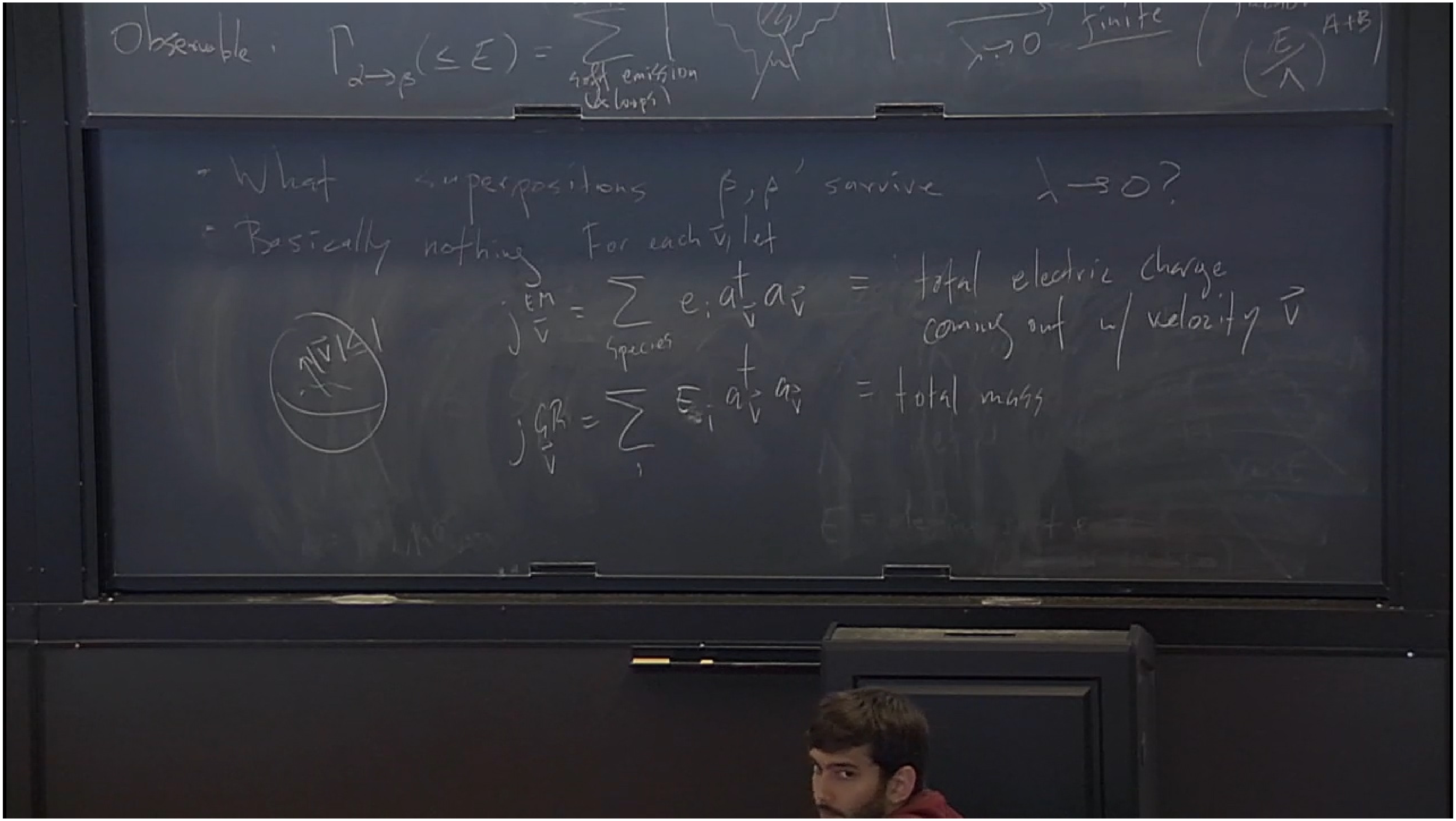


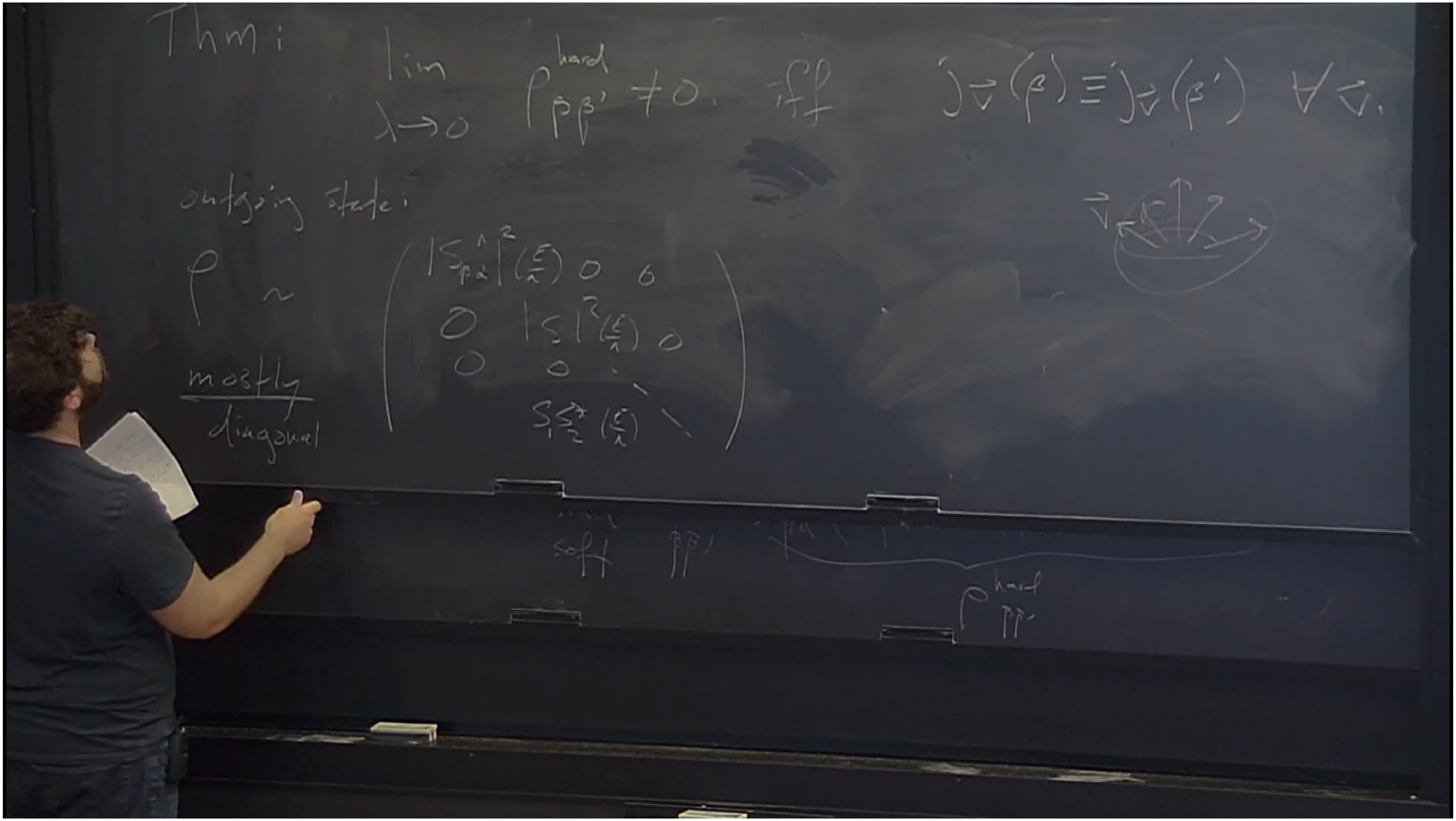

Observable
hard
soft
radiation
soft emission
finite
factor
A+B

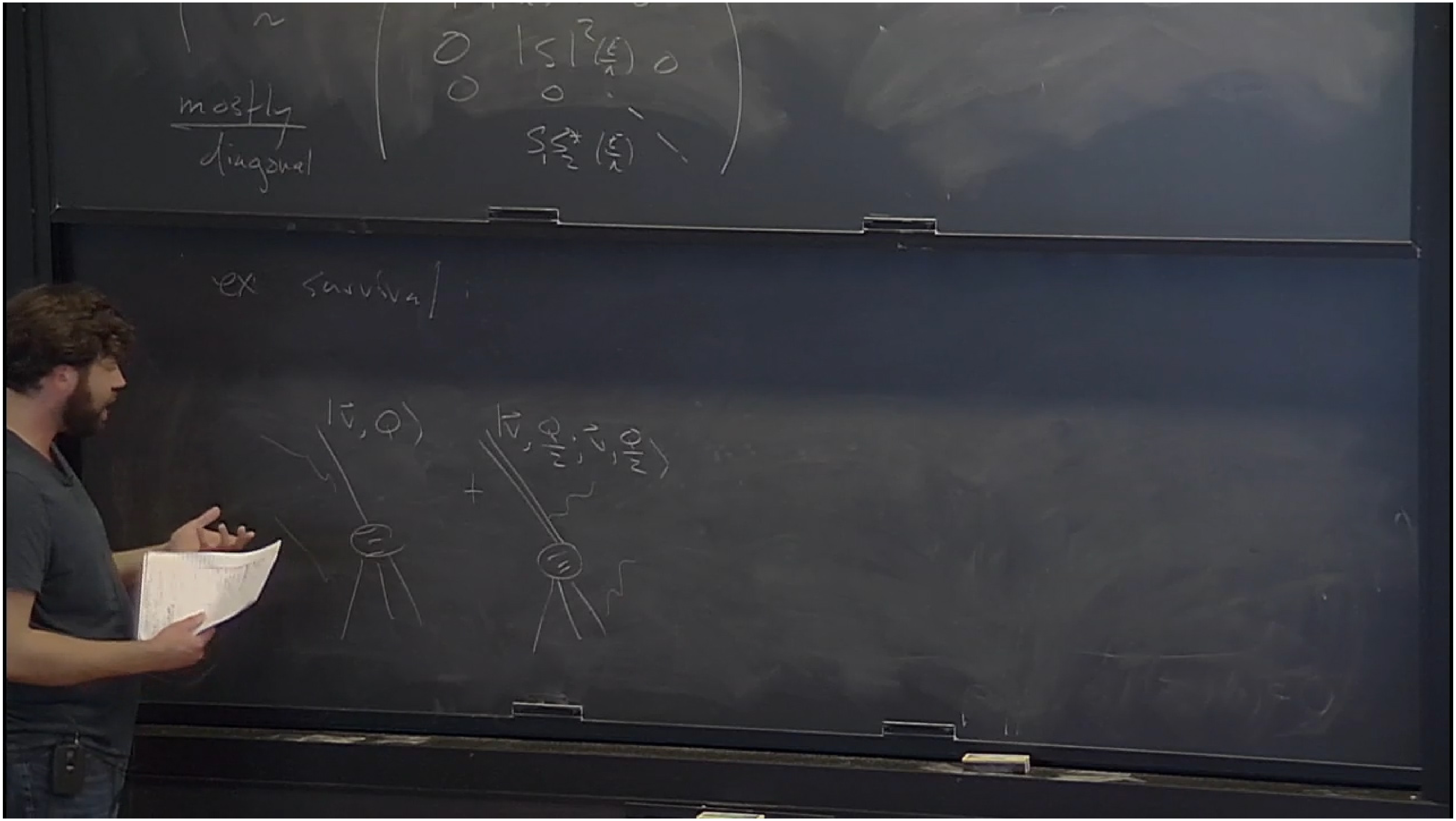

Decoherence
What does this say about DM?
trace
soft

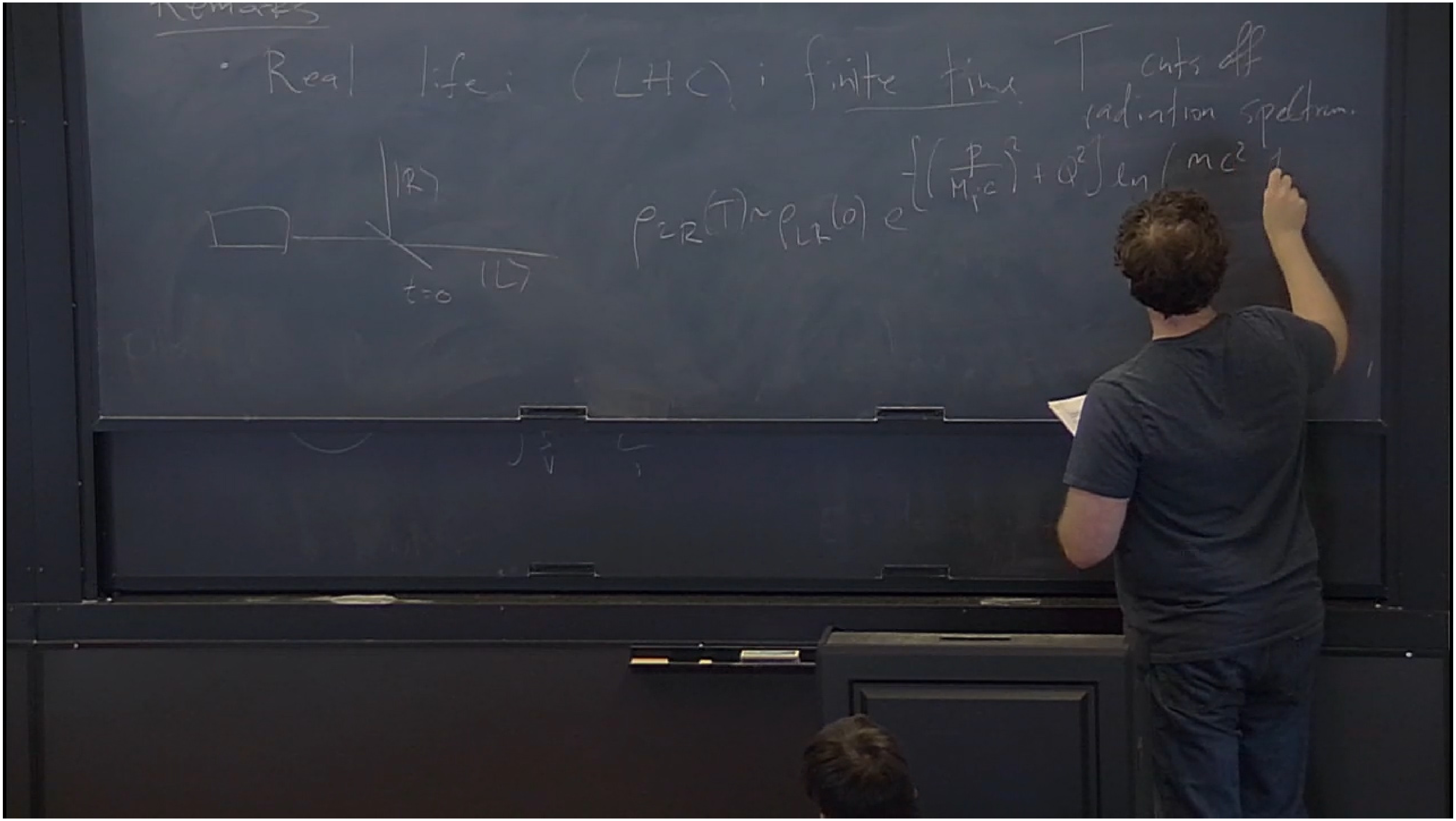

DA+LB
hard

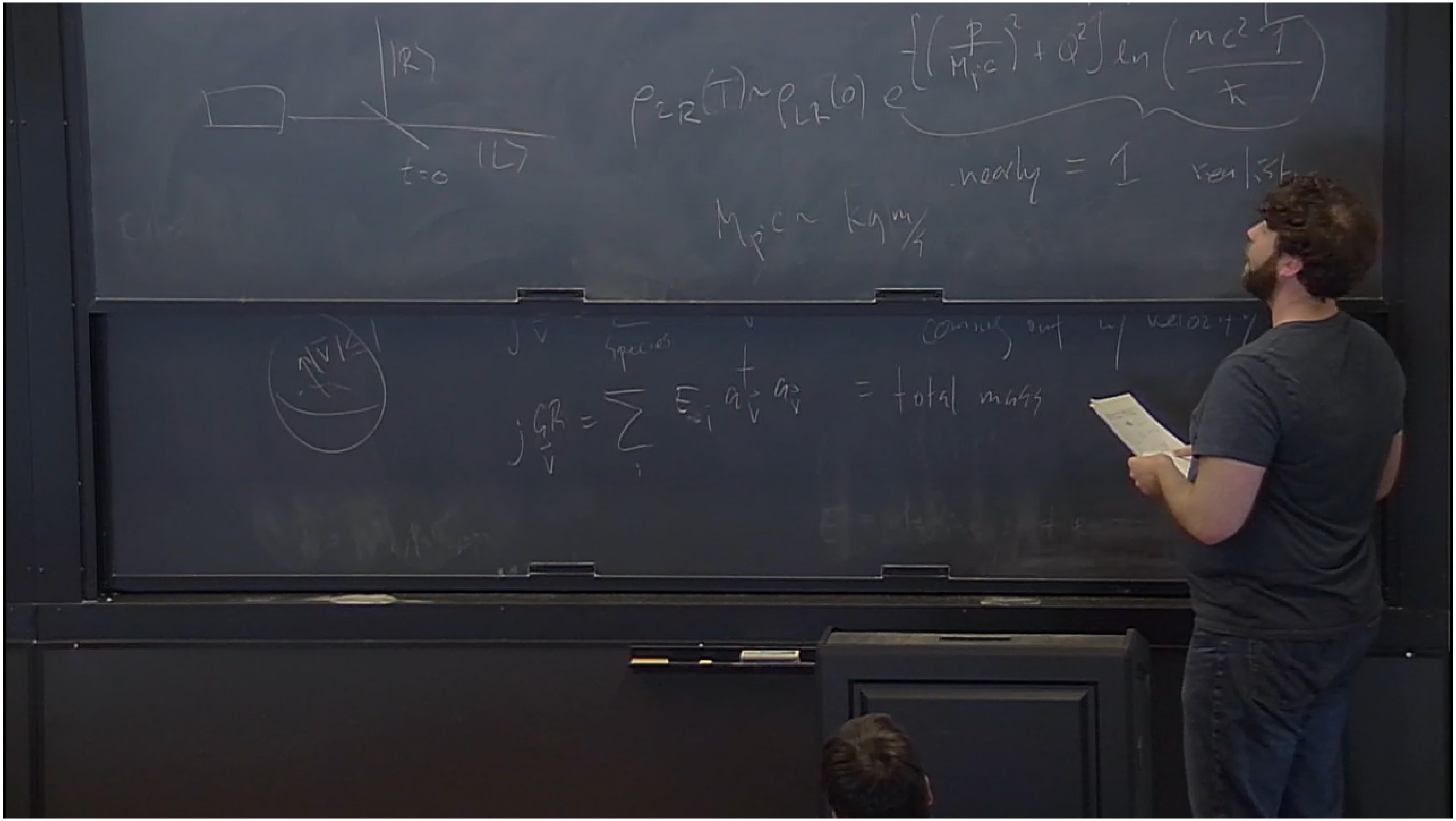

Observable : Γ α→β (≤ E) = Σ soft emission (& loops)
λ→0
finite
(E/Λ)^A+B
• What superpositions β, β' survive λ→0?
• Basically nothing. For each v, let
j EM v = Σ species e_i a†v av = total electric charge coming out w/ velocity v
j GR v = Σ i m_i a†v av = total mass
|v| ≤ 1


Observable : Γ α→β (≤ E) = Σ soft emission (& loops)
λ→0 finite
(E/Λ)^A+B
• What superpositions β, β' survive λ→0?
• Basically nothing. For each v⃗, let
j^EM_v⃗ = Σ_species e_i a†_v⃗ a_v⃗ = total electric charge coming out w/ velocity v⃗
j^GR_v⃗ = Σ_i E_i a†_v⃗ a_v⃗ = total mass
|v⃗| ≤ 1

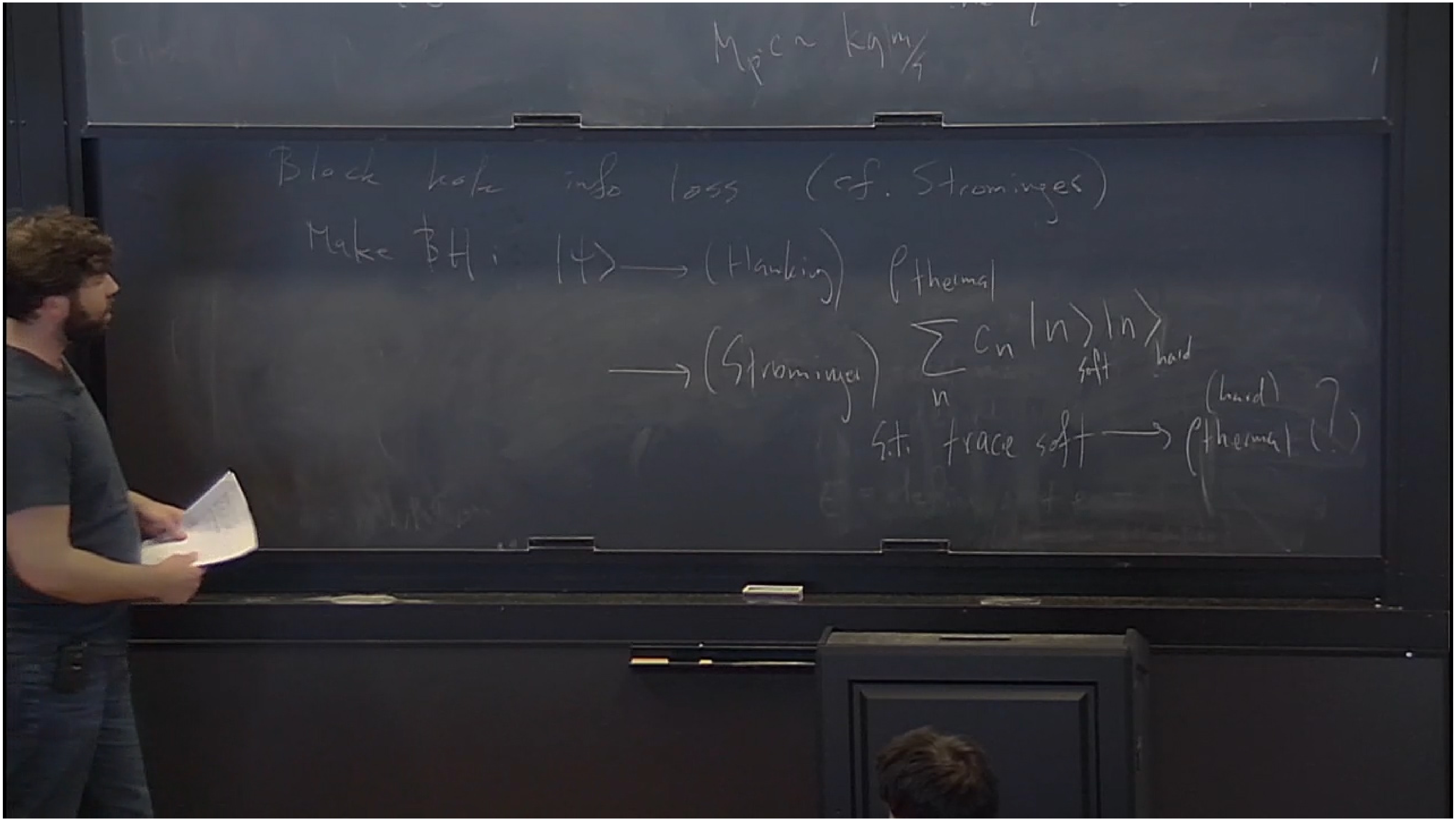

Thm:
iff
outgoing state:
mostly
diagonal
soft
hard


mostly
diagonal
ex survival


Remarks
• Real life: (LHC): finite time T cuts off radiation spectrum.
|R⟩
|L⟩
t=0



|R⟩
|L⟩
t=0
nearly = 1
total mass
coming out w/ velocity


M_pl c ~ kg m/s
Black hole info loss (cf. Strominger)
Make BH: |ψ⟩ → (Hawking) ρ thermal
→ (Strominger) Σ_n c_n |n⟩_soft |n⟩_hard
s.t. trace soft → ρ thermal (hard) (?)