Title: Generating RVB states in cavity-QED experiments

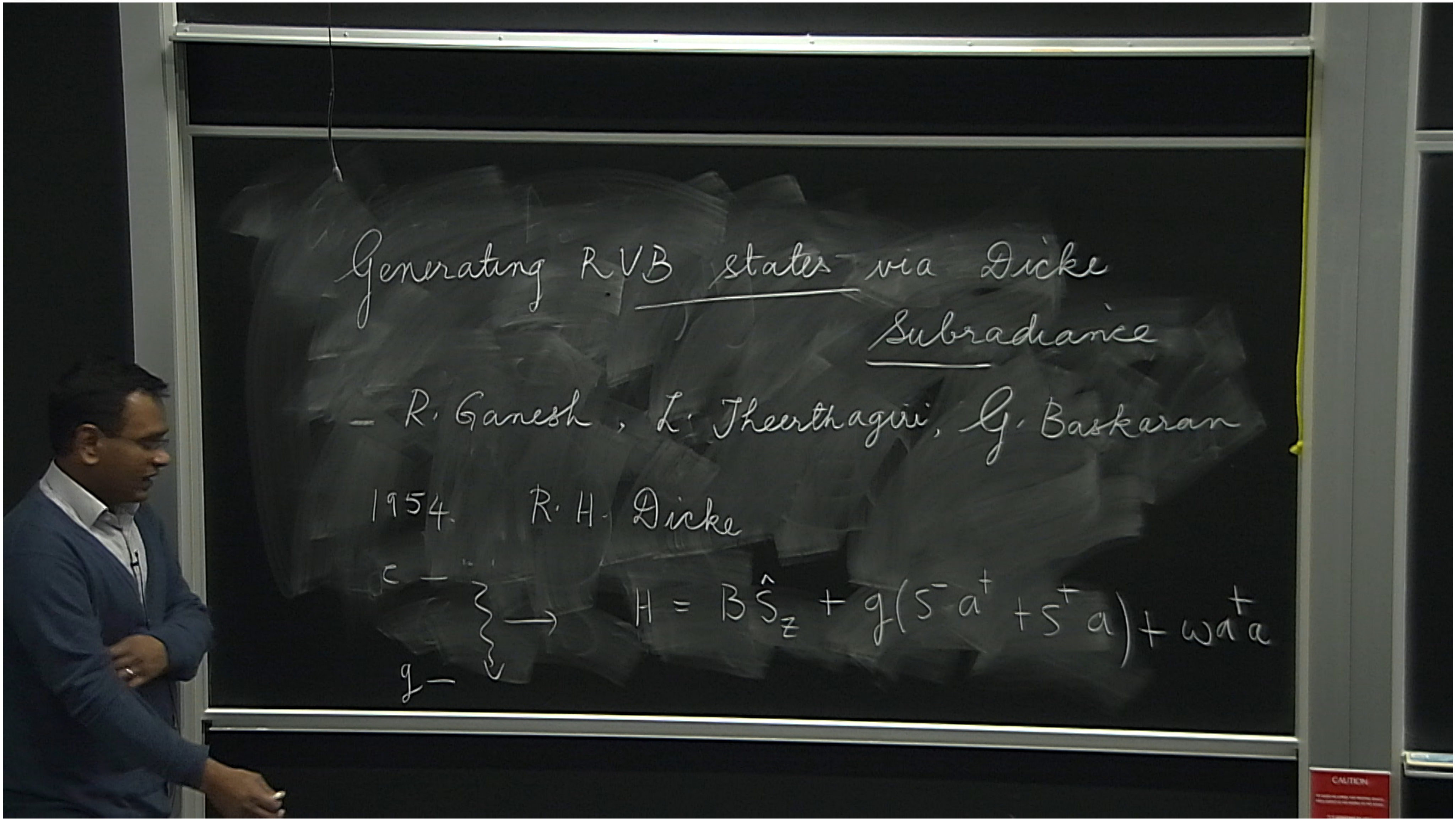
Date: Feb 07, 2017 03:30 PM

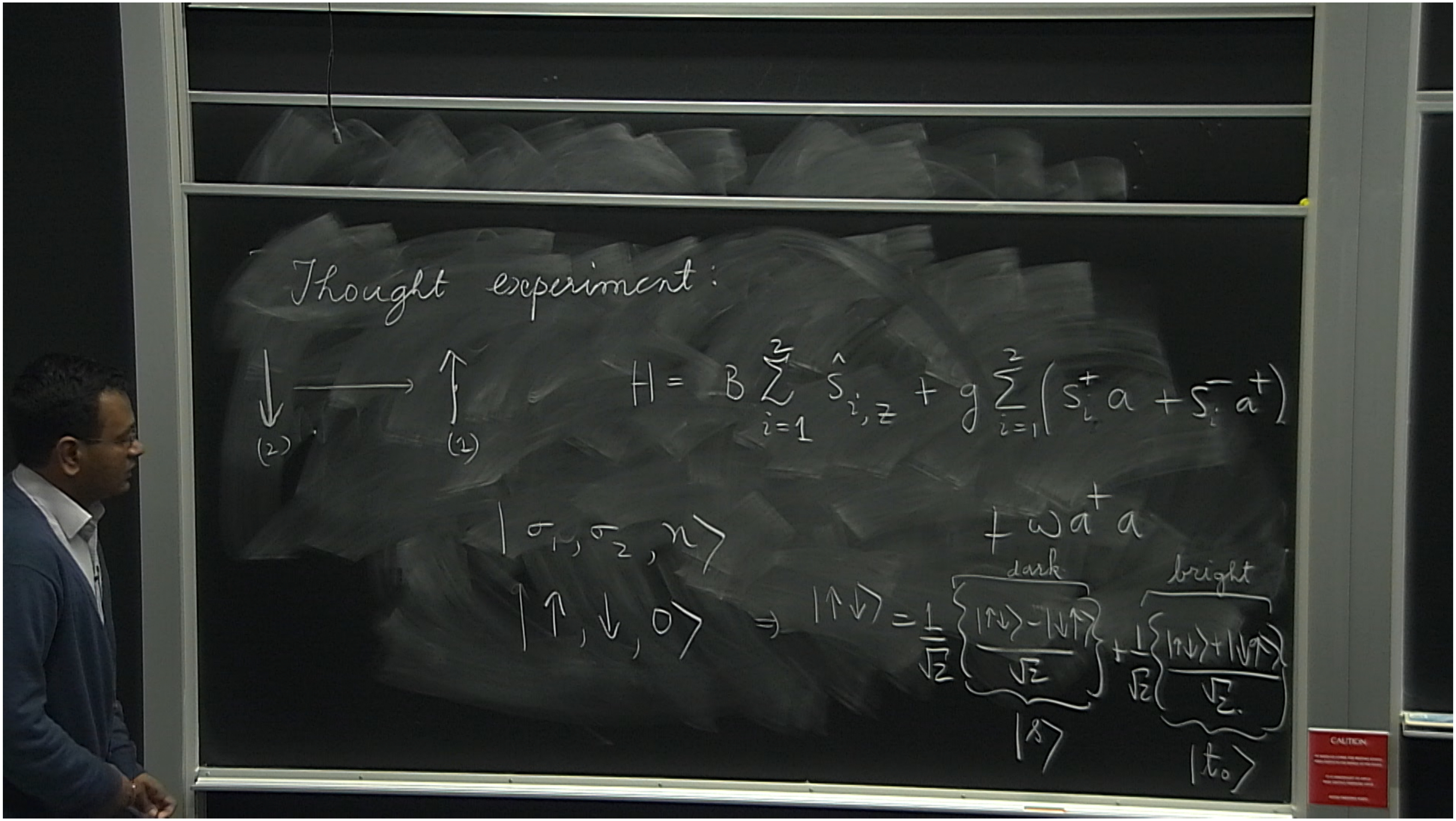
URL: http://pirsa.org/17020025

Abstract: <p>Dicke's seminal 1954 paper introduced the notion of `superradiance' in a system of spins coupled to a common photon mode.</p>

<p>Certain quantum states of the spins dominate the radiation process so that the spins radiate coherently. Dicke's original thought experiment has recently been recreated in the lab using cavity-QED setups with two spins. I will explore extending this experiment to N spins and show that the radiation process naturally gives rise to entangled states. This suggests a new experimental tool to create multi-particle entanglement in the lab. In particular, a null-observation (non-observation of emitted photon) can be used to collapse the wavefunction onto a dark state. Remarkably, this dark state has resonating valence bond character. We show that the probability of collapse onto RVB state scales as N^{-1}, making it possible to generate entangled states of more than 20 spins.</p>

<p>Reference: arXiv:1609.04853</p>


Generating RVB states via Dicke
Subradiance
— R. Ganesh, L. Theerthagiri, G. Baskaran
1954. R. H. Dicke
e —
g —
$H = B\hat{S}_z + g(S^- a^+ + S^+ a) + \omega a^+ a$


Thought experiment:
(2)
(1)
H = B Σ_{i=1}^{2} Ŝ_{i,z} + g Σ_{i=1}^{2} (S_i^+ a + S_i^- a^+)
+ ω a^+ a
|σ_1, σ_2, n⟩
|↑, ↓, 0⟩
⇒ |↑↓⟩ = 1/√2 {(|↑↓⟩ − |↓↑⟩)/√2} + 1/√2 {(|↑↓⟩ + |↓↑⟩)/√2}
dark
bright
|S⟩
|t_0⟩

$|t_0\rangle$

Extension to N spins

$$(\sigma_1 \ \sigma_2 \ \dots \ \sigma_N)$$

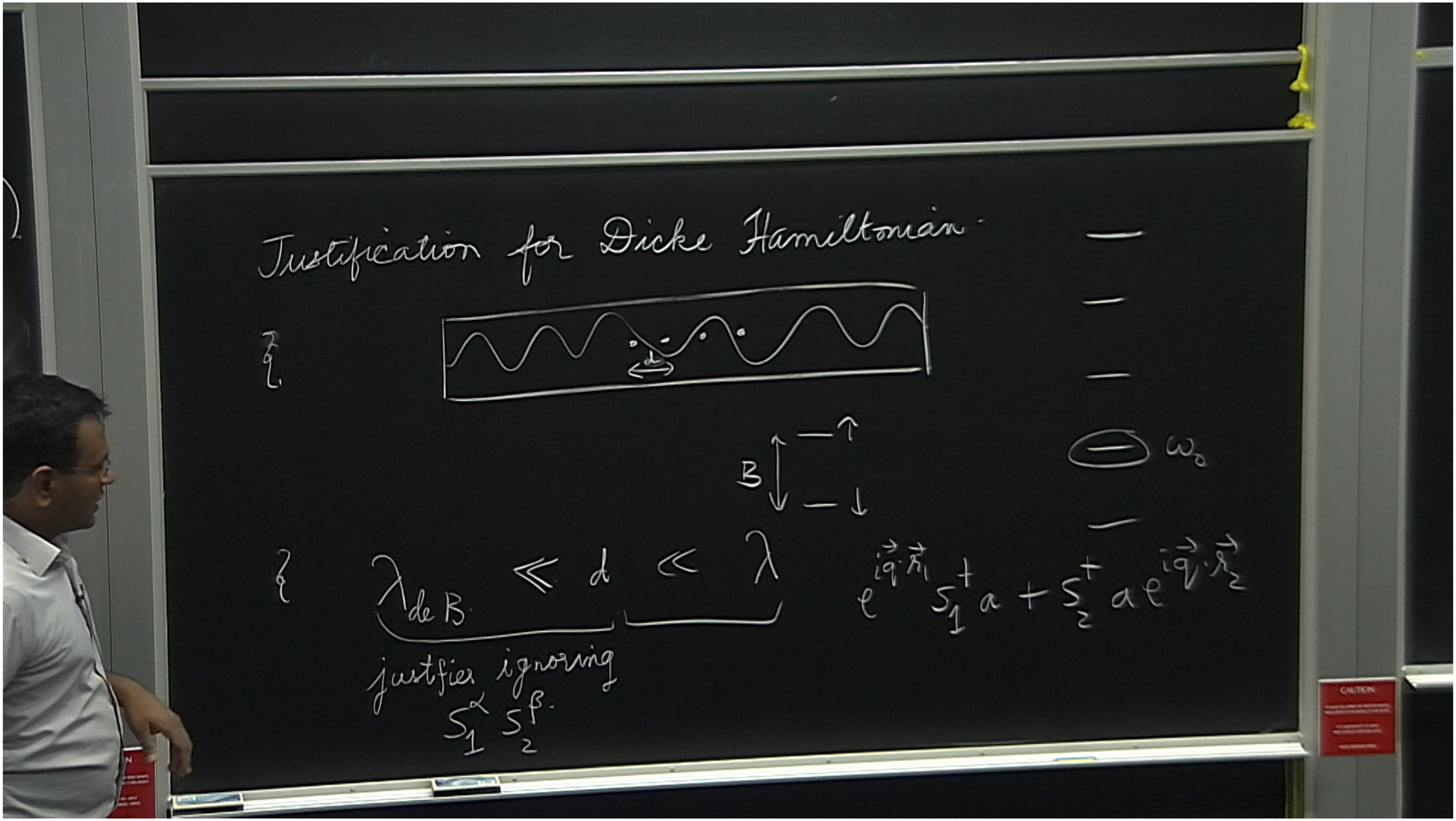
$|S_{tot}, m_{tot}; 0\rangle \longrightarrow$ Emission rate is maximum for

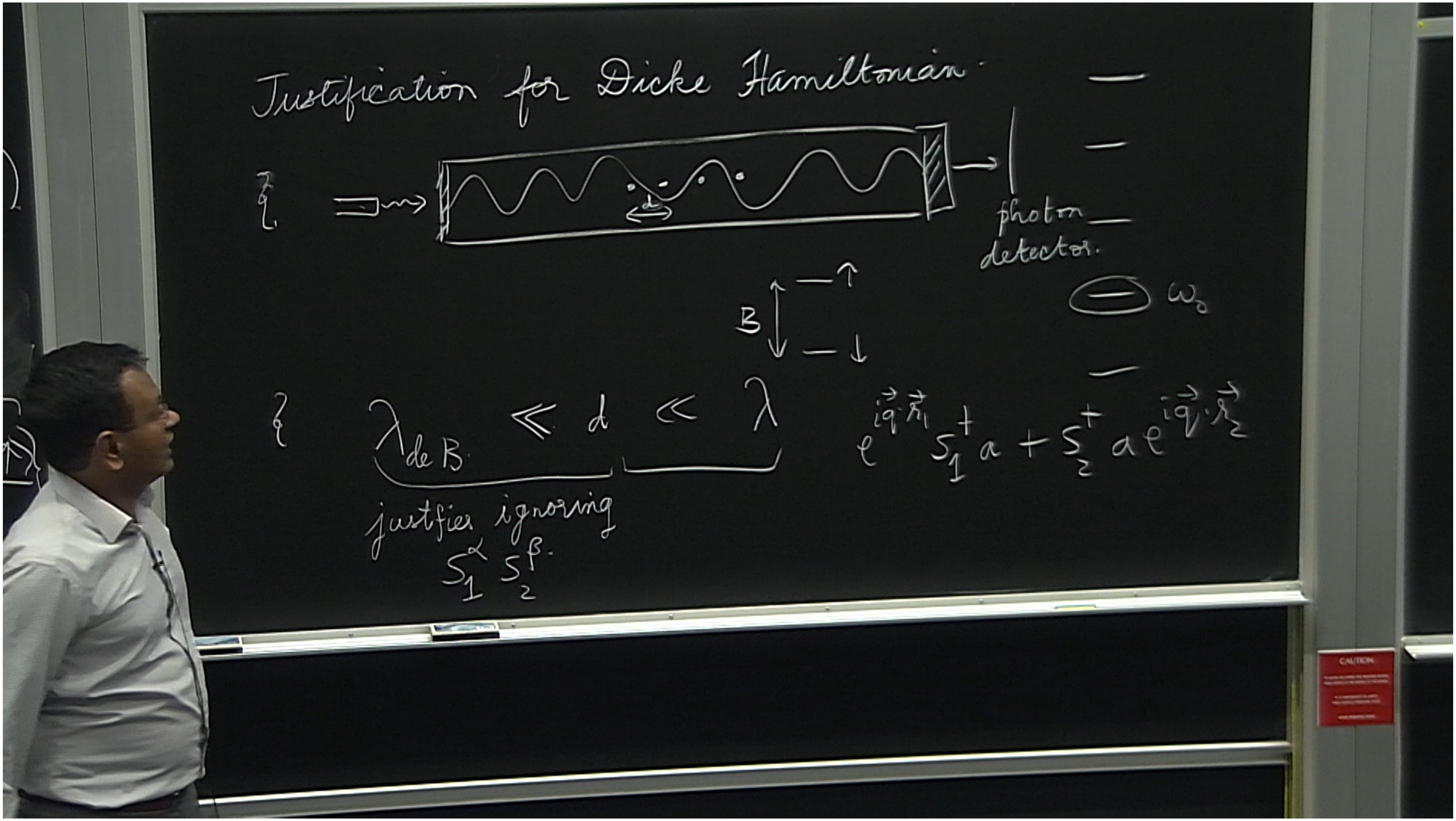
$S_{tot} = N/2$; $m_{tot} = 0$.

rate $\propto N^2 \rightarrow$ superradiant

Subradiant:

$S_{tot} = 0, m_{tot} = 0$


Justification for Dicke Hamiltonian.
d
B
ω_0
$\lambda_{de B} \ll d \ll \lambda$
justifies ignoring
$S_1^{\alpha} S_2^{\beta}$
$e^{i\vec{q}\cdot\vec{r}_1} S_1^{+} a + S_2^{+} a e^{i\vec{q}\cdot\vec{r}_2}$



Justification for Dicke Hamiltonian.
d
photon detector.
B
ω_0
$\lambda_{deB} \ll d \ll \lambda$
justifies ignoring
$S_1^\alpha S_2^\beta$.
$e^{i\vec{q}\cdot\vec{x}_1} S_1^+ a + S_2^+ a e^{i\vec{q}\cdot\vec{x}_2}$

justfies ignoring
$S_1^{\alpha} S_2^{\beta}$.

2014 - Mlynek et al → experimental realisation
of Dicke's thought experiment

ξ Lossy cavity limit.

justifies ignoring $S_1^\alpha S_2^\beta$.

2014 - Mlynek et al → experimental realisation of Dicke's thought experiment

(3) Lossy cavity limit.

rate of loss from cavity $\gg$ rate associated with spin-photon coupling

Proposed protocol ; (goal: create a subradiant state)

1. Initialise spins in a direct product state (e.g. $|\uparrow\downarrow\rangle$).

2. Observe is a photon is emitted.

3. If a photon is observed, discard run - go back to 1.

4 If no photon is seen for sufficiently long, Conclude that spins are in a subradiant state.

4 If no photon ... Conclude that spins are in a ... state.

$$|\uparrow\downarrow\rangle = \frac{1}{\sqrt{2}}|s\rangle + \frac{1}{\sqrt{2}}|t,0\rangle$$

$|s\rangle \rightarrow n_{ph} = 0$

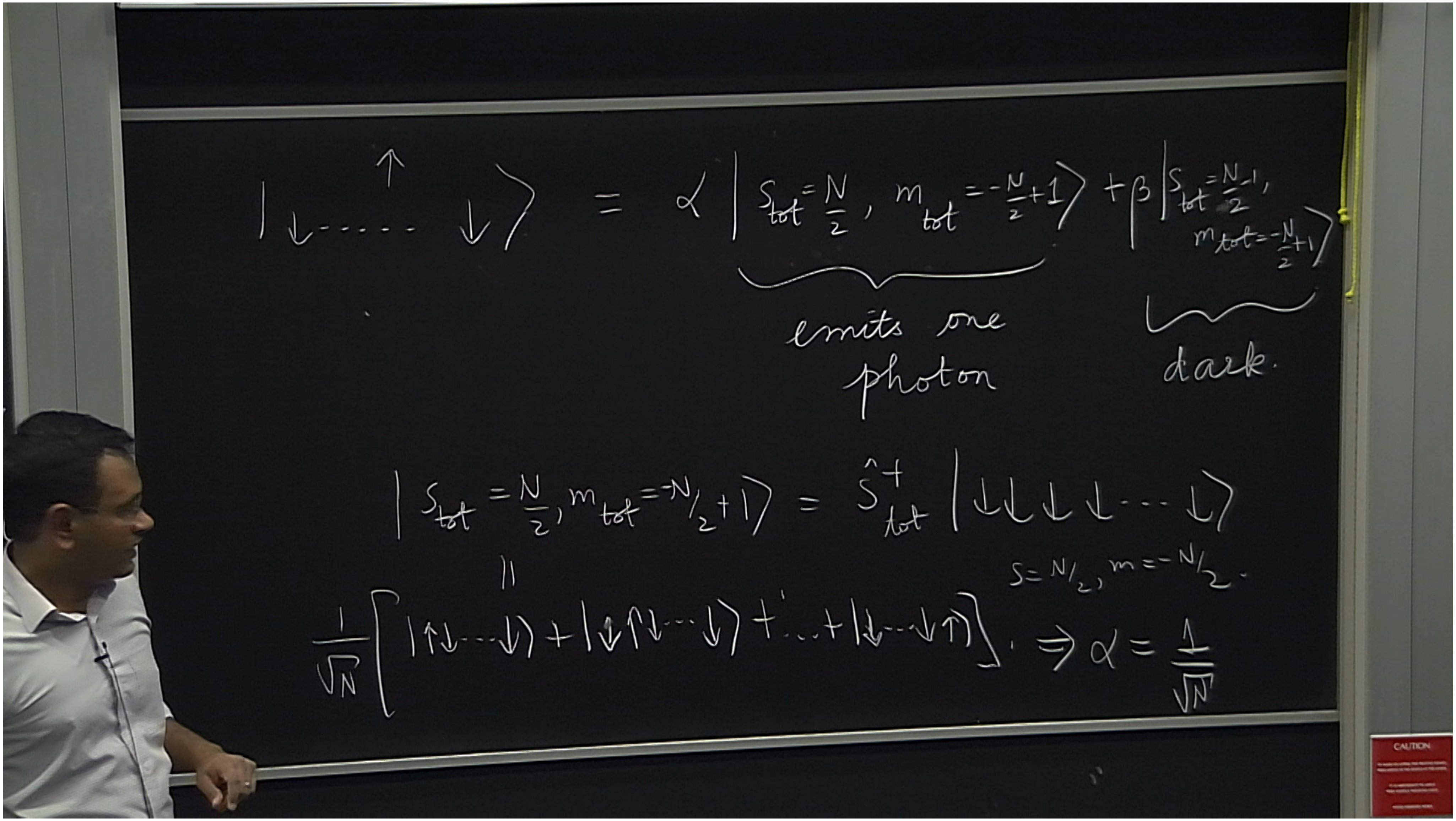
$|t,0\rangle \rightarrow n_{ph} = 1.$

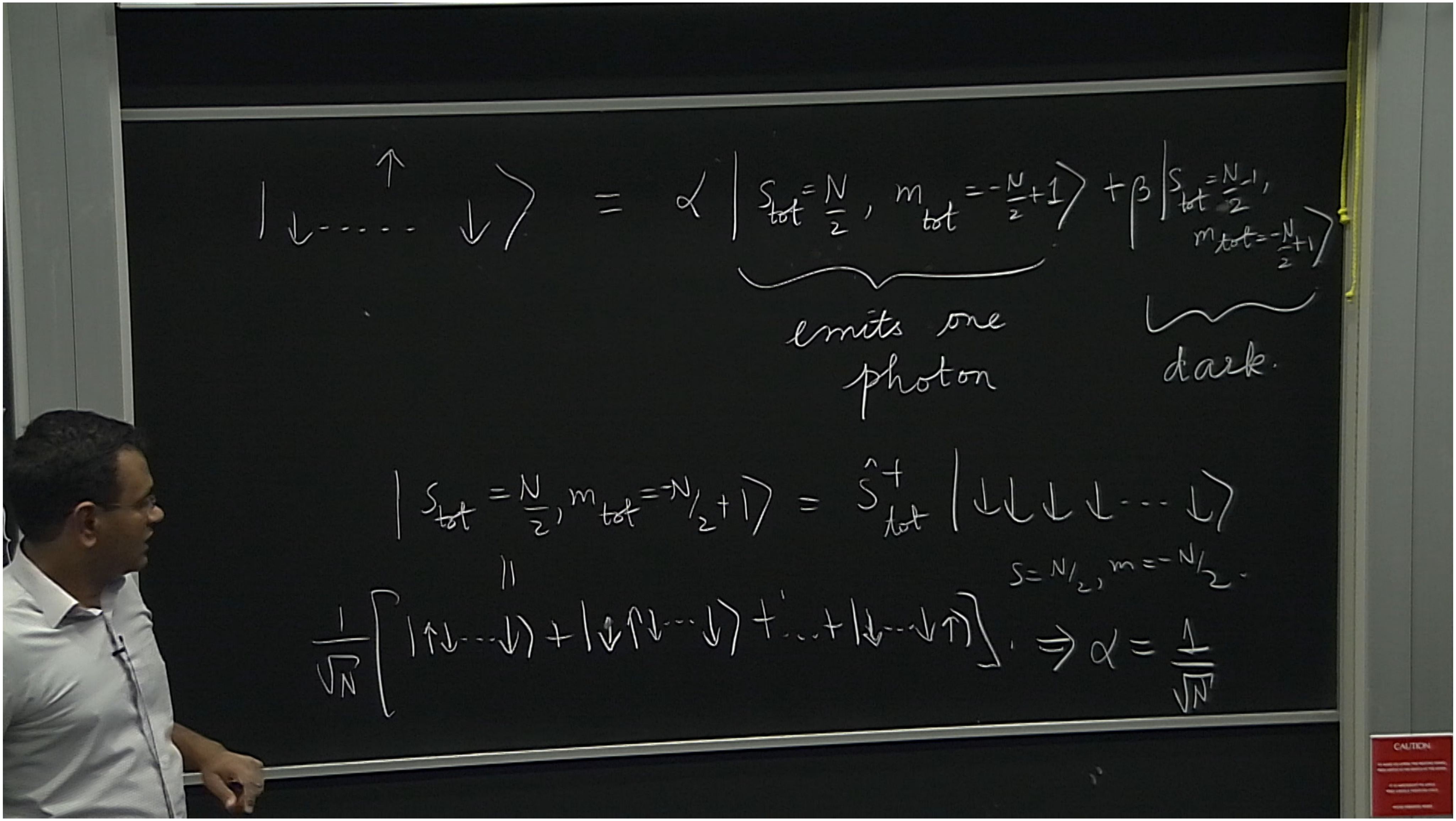
$|t,-1\rangle$

Two cases:

(A) Initial state $|\downarrow\downarrow\overset{\uparrow}{\downarrow}\downarrow\cdots\downarrow\rangle$

$m_{tot} = -N/2 + 1 \Rightarrow S_{tot} = 0, 1, 2, \ldots, N/2 - 1, N/2$


$|\downarrow \cdots \overset{\uparrow}{\cdot} \cdots \downarrow\rangle = \alpha \underbrace{|S_{tot} = \frac{N}{2}, m_{tot} = -\frac{N}{2}+1\rangle}_{\text{emits one photon}} + \beta \underbrace{|S_{tot} = \frac{N}{2}-1, m_{tot} = -\frac{N}{2}+1\rangle}_{\text{dark.}}$
$|S_{tot} = \frac{N}{2}, m_{tot} = -N/2+1\rangle = \hat{S}^{+}_{tot} |\downarrow\downarrow\downarrow\downarrow \cdots \downarrow\rangle$
$S = N/2, m = -N/2.$
$\frac{1}{\sqrt{N}}\left[|\uparrow\downarrow\cdots\downarrow\rangle + |\downarrow\uparrow\downarrow\cdots\downarrow\rangle + \cdots + |\downarrow\cdots\downarrow\uparrow\rangle \right] \Rightarrow \alpha = \frac{1}{\sqrt{N}}$


$|\downarrow \cdots \overset{\uparrow}{\cdot} \cdots \downarrow\rangle = \alpha \underbrace{\left|S_{tot}=\frac{N}{2},\ m_{tot}=-\frac{N}{2}+1\right\rangle}_{\text{emits one photon}} + \beta \underbrace{\left|S_{tot}=\frac{N}{2}-1,\ m_{tot}=-\frac{N}{2}+1\right\rangle}_{\text{dark.}}$
$\left|S_{tot}=\frac{N}{2}, m_{tot}=-N/2+1\right\rangle = \hat{S}^{+}_{tot}|\downarrow\downarrow\downarrow\downarrow\cdots\downarrow\rangle$
$S=N/2,\ m=-N/2.$
$\frac{1}{\sqrt{N}}\left[|\uparrow\downarrow\cdots\downarrow\rangle + |\downarrow\uparrow\downarrow\cdots\downarrow\rangle + \cdots + |\downarrow\cdots\downarrow\uparrow\rangle\right] \Rightarrow \alpha = \frac{1}{\sqrt{N}}$

$$|\downarrow \cdots \overset{\uparrow}{\cdot} \cdots \downarrow\rangle = \alpha\,\underbrace{\left|S_{tot}=\tfrac{N}{2},\ m_{tot}=-\tfrac{N}{2}+1\right\rangle}_{\text{emits one photon}} + \beta\,\underbrace{\left|S_{tot}=\tfrac{N}{2}-1,\ m_{tot}=-\tfrac{N}{2}+1\right\rangle}_{\text{dark.}}$$

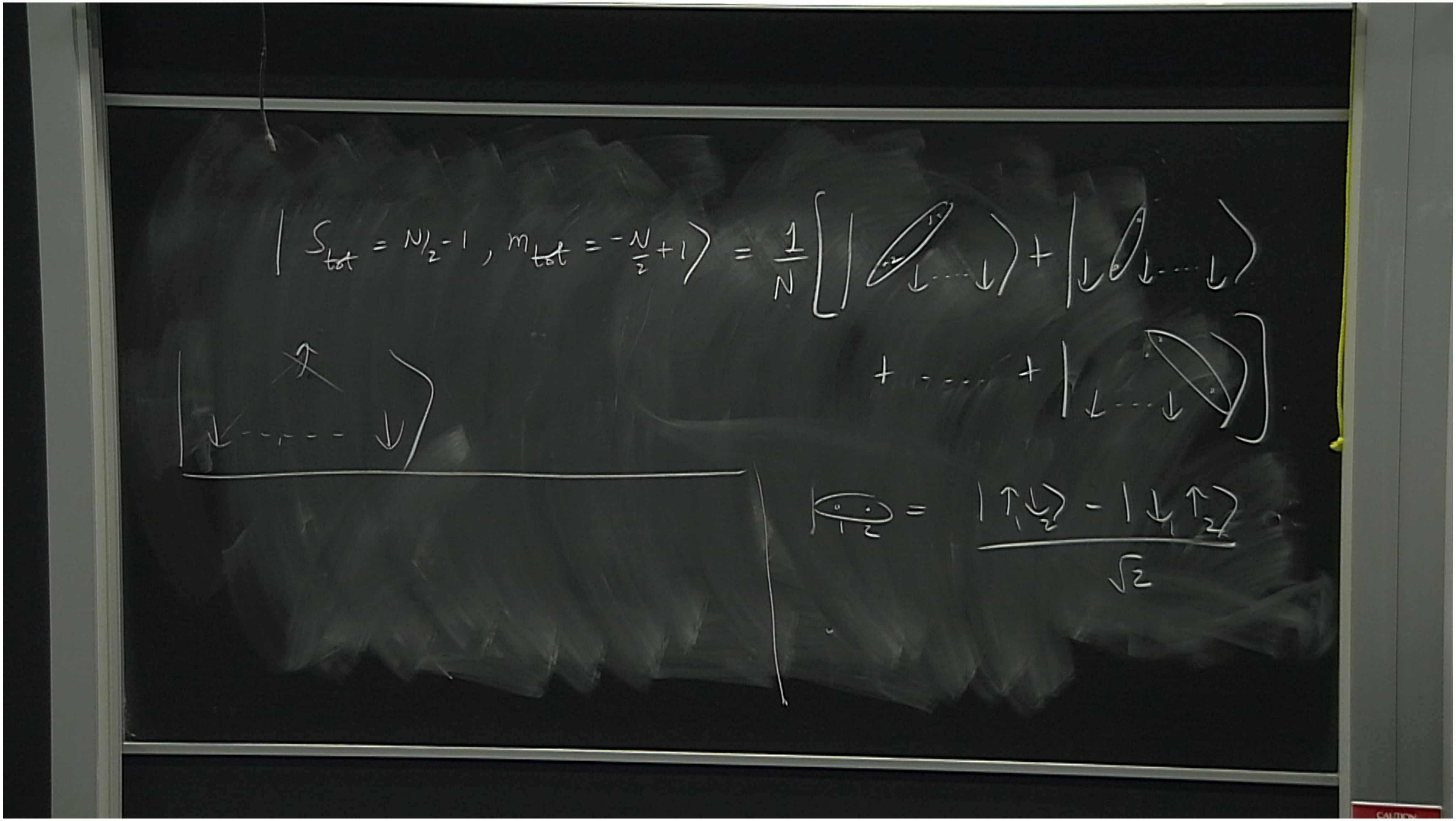
$$\boxed{\begin{array}{l}\text{Tavis Cummings 1968}\\ \rightarrow \text{radiation trapping}\end{array}}$$

$$\left|S_{tot}=\tfrac{N}{2},\ m_{tot}=-N/2+1\right\rangle = \hat{S}^{+}_{tot}\,|\downarrow\downarrow\downarrow\downarrow\cdots\downarrow\rangle$$

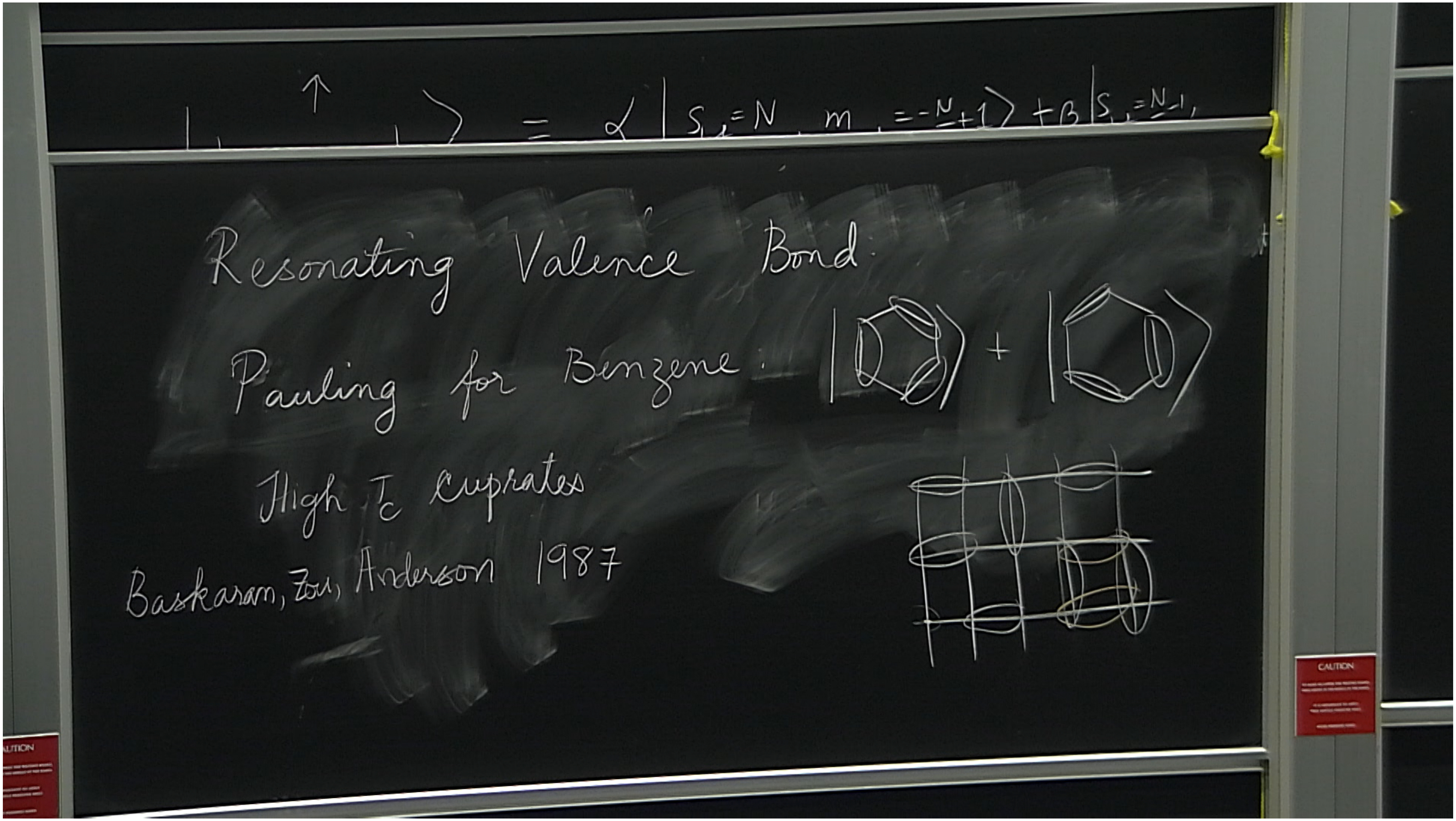
$S = N/2,\ m = -N/2.$

$$\| $$

$$\frac{1}{\sqrt{N}}\Big[\,|\uparrow\downarrow\cdots\downarrow\rangle + |\downarrow\uparrow\downarrow\cdots\downarrow\rangle + \cdots + |\downarrow\cdots\downarrow\uparrow\rangle\Big]. \Rightarrow \alpha = \frac{1}{\sqrt{N}}$$



$|S_{tot} = N/2 - 1, m_{tot} = -\frac{N}{2} + 1\rangle = \frac{1}{N}\left[|\;\downarrow \cdots \downarrow\rangle + |\downarrow\;\downarrow \cdots \downarrow\rangle + \cdots + |\downarrow \cdots \downarrow\;\rangle \right]$
$|\downarrow - - - - \downarrow\rangle$
$|\;\rangle = \frac{|\uparrow_1 \downarrow_2\rangle - |\downarrow_1 \uparrow_2\rangle}{\sqrt{2}}$


Resonating Valence Bond:
Pauling for Benzene:
High T_c cuprates
Baskaran, Zou, Anderson 1987

(B). Initial state : $\left|\begin{matrix}\uparrow & \uparrow & \uparrow & \cdots & \uparrow \\ \downarrow & \downarrow & \cdots & & \downarrow\end{matrix}\right\rangle$

$$m_{tot} = 0 \Rightarrow S_{tot} = 0, 1, \ldots, N/2$$

$$|\psi_{init}\rangle = A_0 \underbrace{|S=0, m=0\rangle}_{0} + A_1 \underbrace{|S=1, m=0\rangle}_{1} + \ldots + A_{N/2} \underbrace{|S=N/2, m=0\rangle}_{N/2}$$

$n_{photons}$: 0   1   ...   N/2

$$|\Psi_{dark}\rangle = \frac{1}{\alpha_N}\Big[\,\underbrace{|000\ldots0\rangle + |\otimes 0\ldots 0\rangle + \ldots + \ldots |\otimes\otimes\rangle}_{(N/2)!}\,\Big].$$

$(N/2)!$ → number of permutations of $(N/2)$ objects

$$\left|\begin{smallmatrix}\uparrow\uparrow\\ \downarrow\downarrow\end{smallmatrix}\right\rangle \longrightarrow \frac{1}{\alpha_4}\Big[|00\rangle + |\otimes\rangle\Big].$$

$$|\Psi_{dark}\rangle = \frac{1}{\alpha_N}\Big[\,\underbrace{|000\cdots0\rangle + |\otimes 0\cdots 0\rangle + \cdots + \cdots |\otimes\otimes\otimes\rangle}_{(N/2)!}\,\Big].$$

$$\boxed{|\Psi_{dark}\rangle \sim \hat{P}_{S=0}\,|\Psi_{init}\rangle}$$

$\rightarrow$ number of permutations of $(N/2)$ objects

$$\left|\begin{matrix}\uparrow\uparrow\\ \downarrow\downarrow\end{matrix}\right\rangle \longrightarrow \frac{1}{\alpha_4}\Big[|00\rangle + |\otimes\rangle\Big].$$

(B). Initial state : $\left| \begin{matrix} \uparrow \uparrow \uparrow \cdots \uparrow \\ \downarrow \downarrow \cdots \downarrow \end{matrix} \right\rangle = \left|S_{tot} = \frac{N}{4}, m_{tot} = \frac{N}{4}\right\rangle \oplus \left|S_{tot} = \frac{N}{4}, m_{tot} = -\frac{N}{4}\right\rangle$

$$m_{tot} = 0 \Rightarrow S_{tot} = 0, 1, \ldots, N/2$$

$$|\psi_{init}\rangle = A_0 \underbrace{|S=0, m=0\rangle}_{n_{photons}:\ 0} + A_1 \underbrace{|S=1, m=0\rangle}_{1} + \cdots + A_{N/2} \underbrace{|S=N/2, m=0\rangle}_{N/2}$$

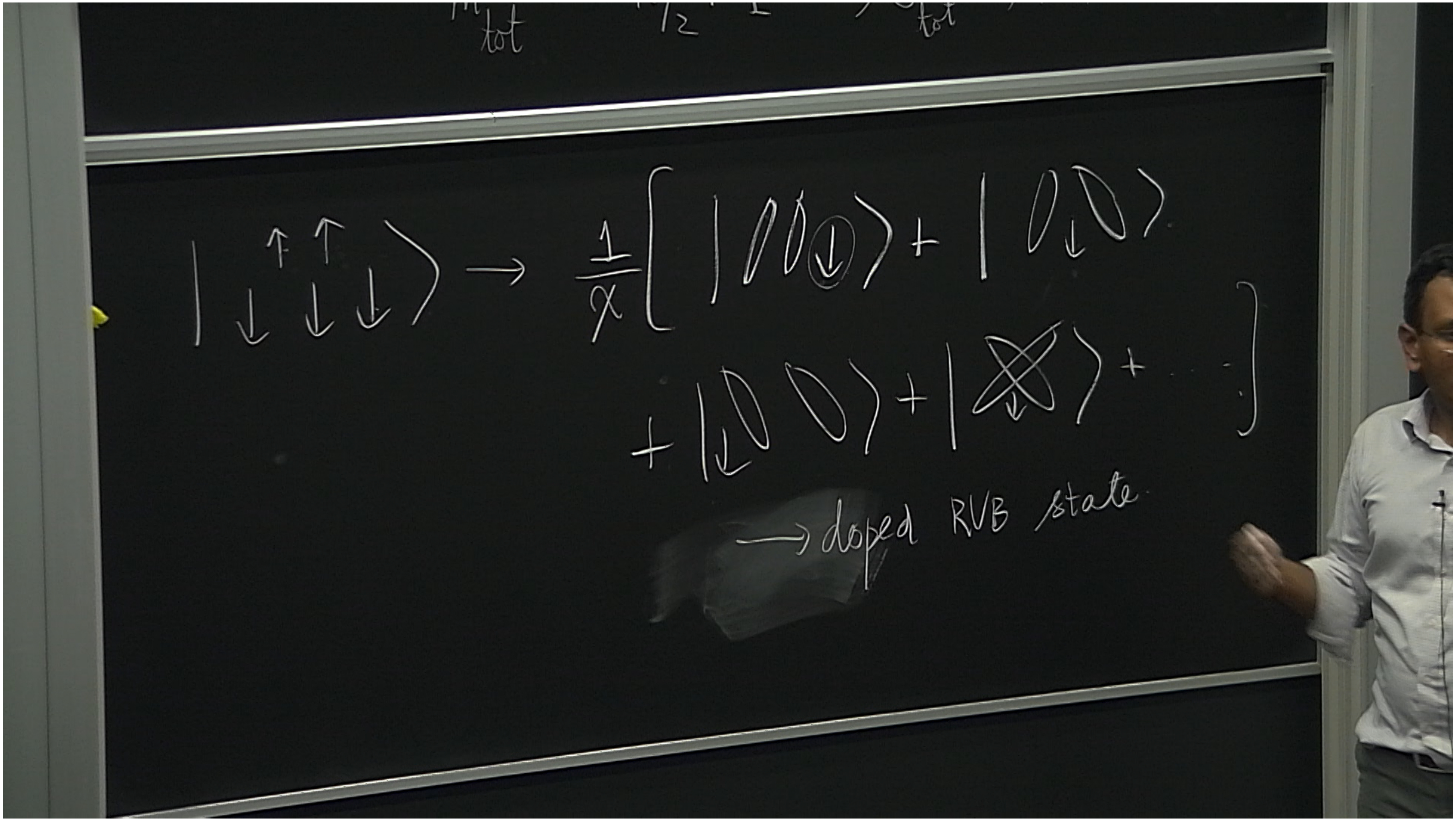
$$|s=0, m=0\rangle =$$

$$|\psi_{dark}\rangle = \frac{1}{\alpha_N}\Big[\underbrace{|000\ldots0\rangle + |X0\ldots0\rangle + \ldots + \ldots |XXX\rangle}_{(N/2)!}\Big].$$

$$\boxed{|\psi_{dark}\rangle \sim \hat{P}_{S=0}\,|\psi_{init}\rangle}$$

→ number of permutations of $(N/2)$ objects.

$$\left|\begin{matrix}\uparrow\uparrow\\ \downarrow\downarrow\end{matrix}\right\rangle \longrightarrow \frac{1}{\alpha_4}\Big[|00\rangle + |X\rangle\Big].$$


doped RVB state