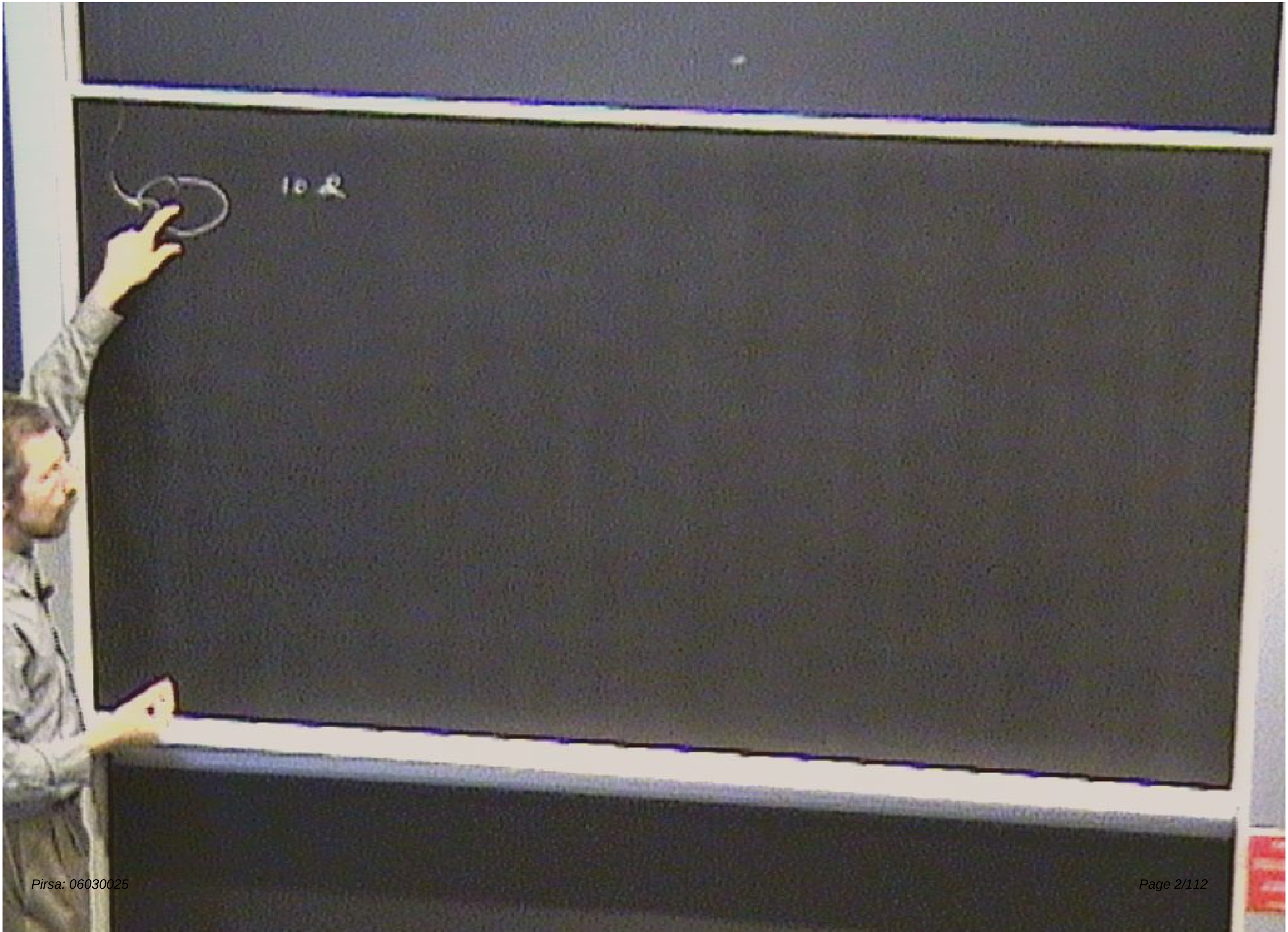
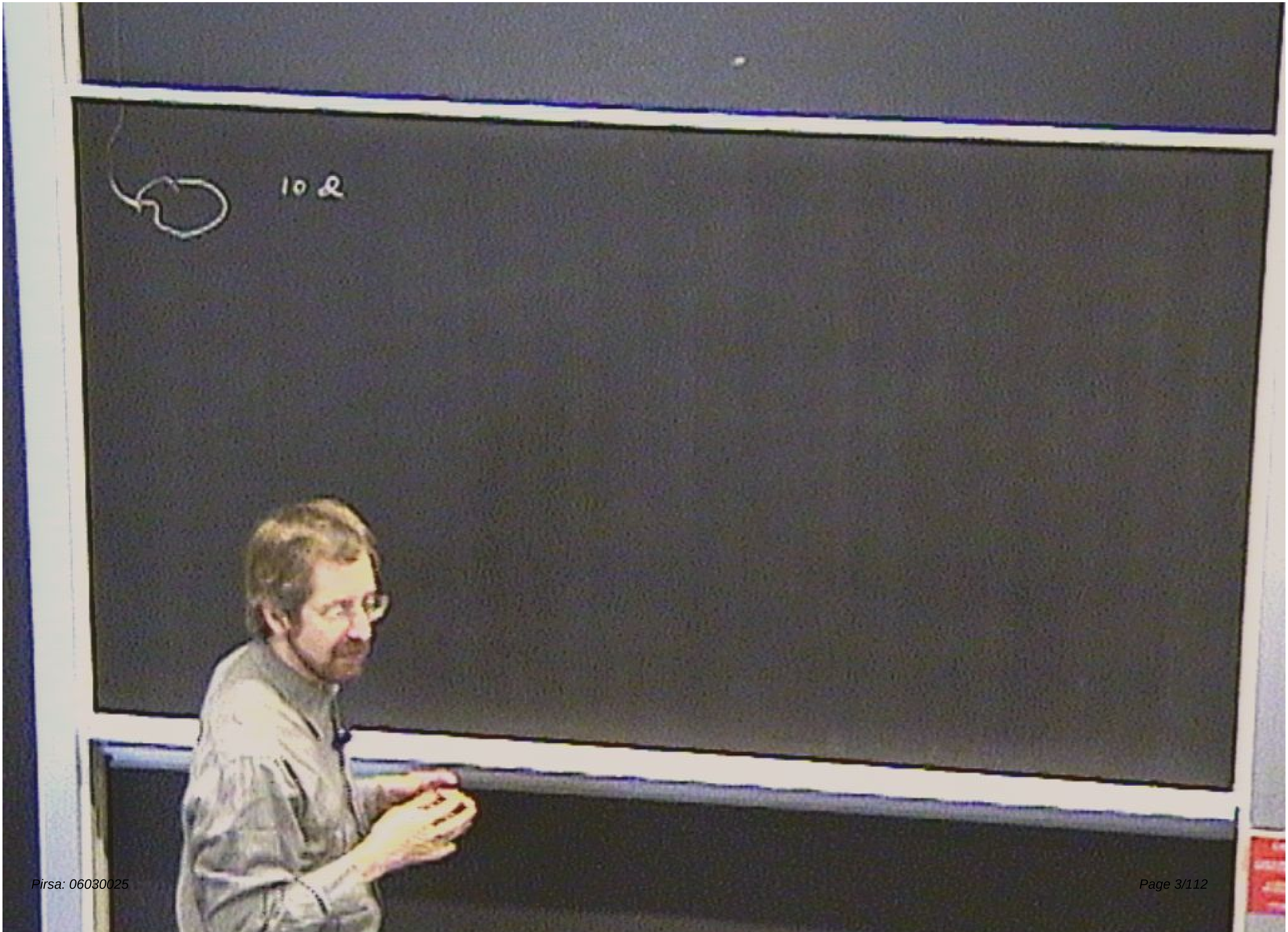
Title: Computational Complexity of the Landscape

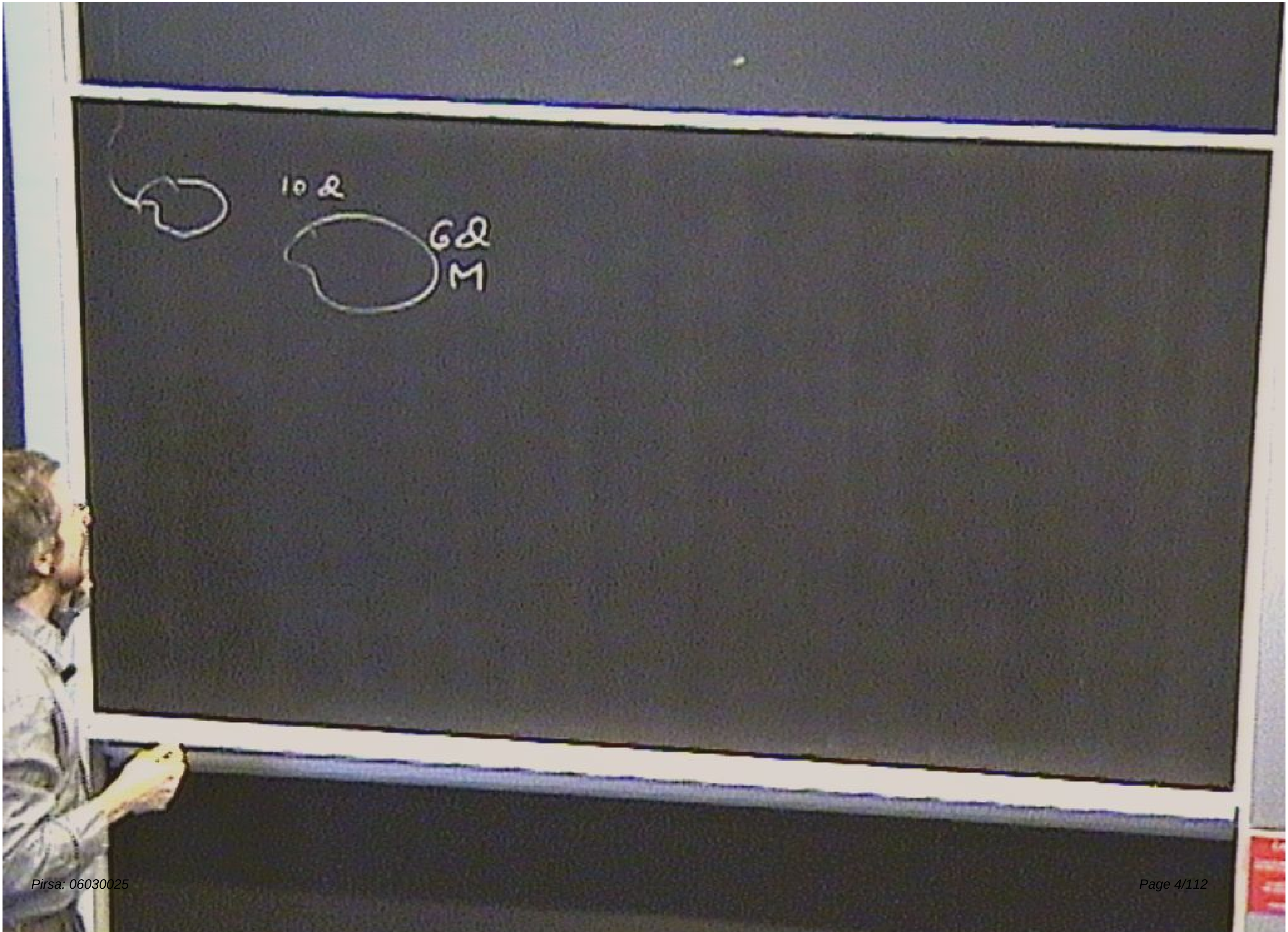
Date: Mar 29, 2006 02:00 PM

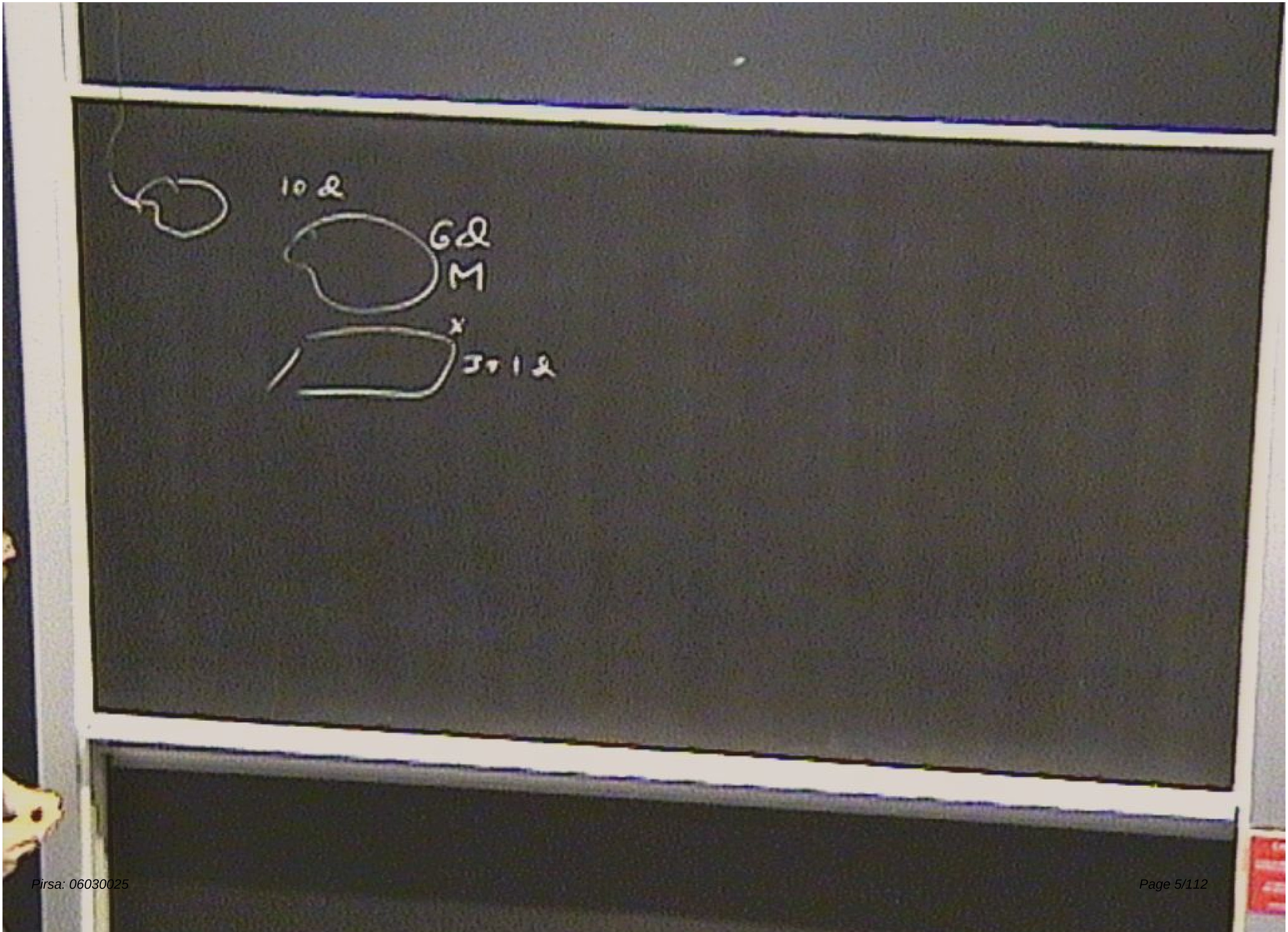
URL: http://pirsa.org/06030025

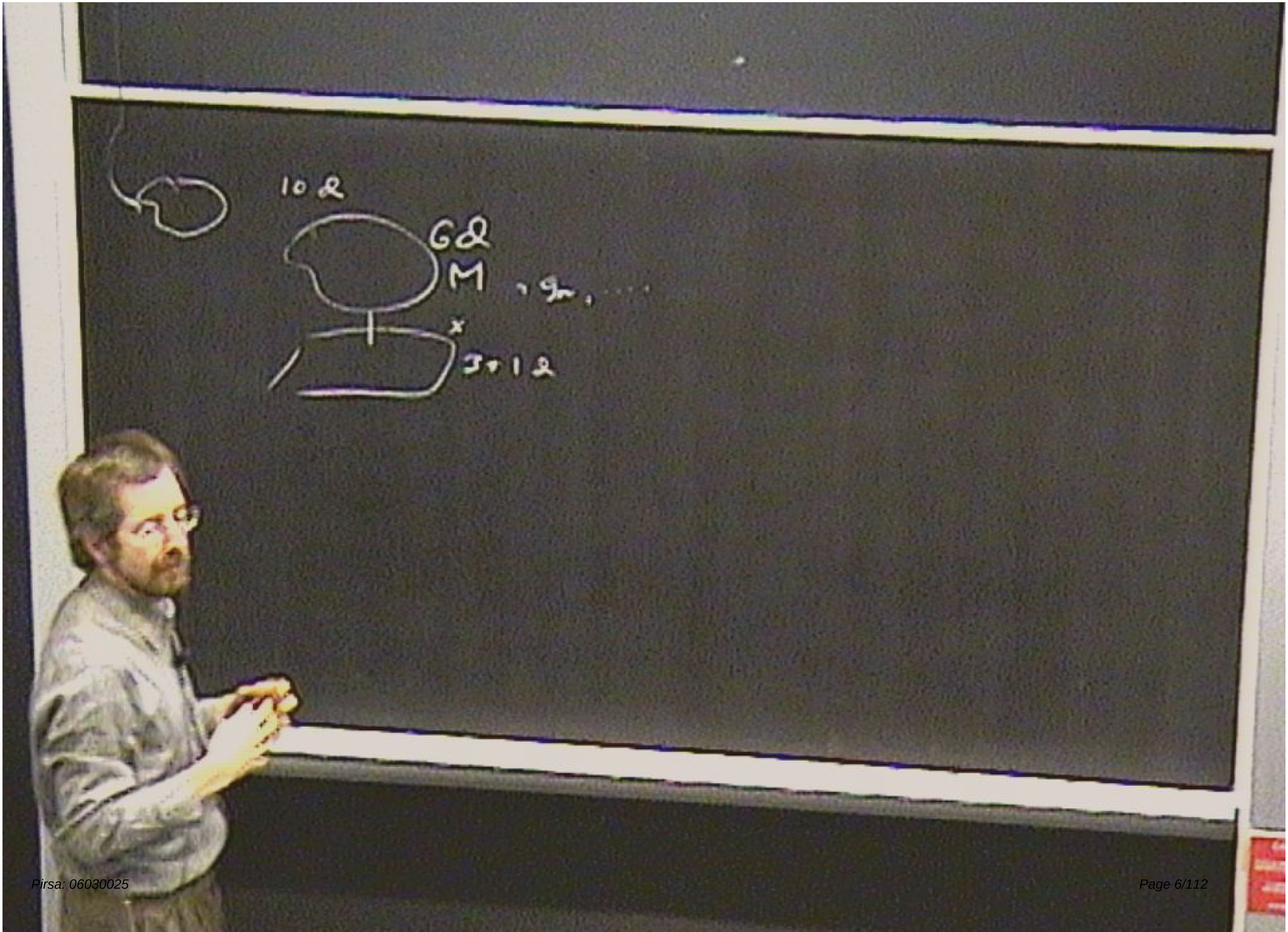
Abstract:

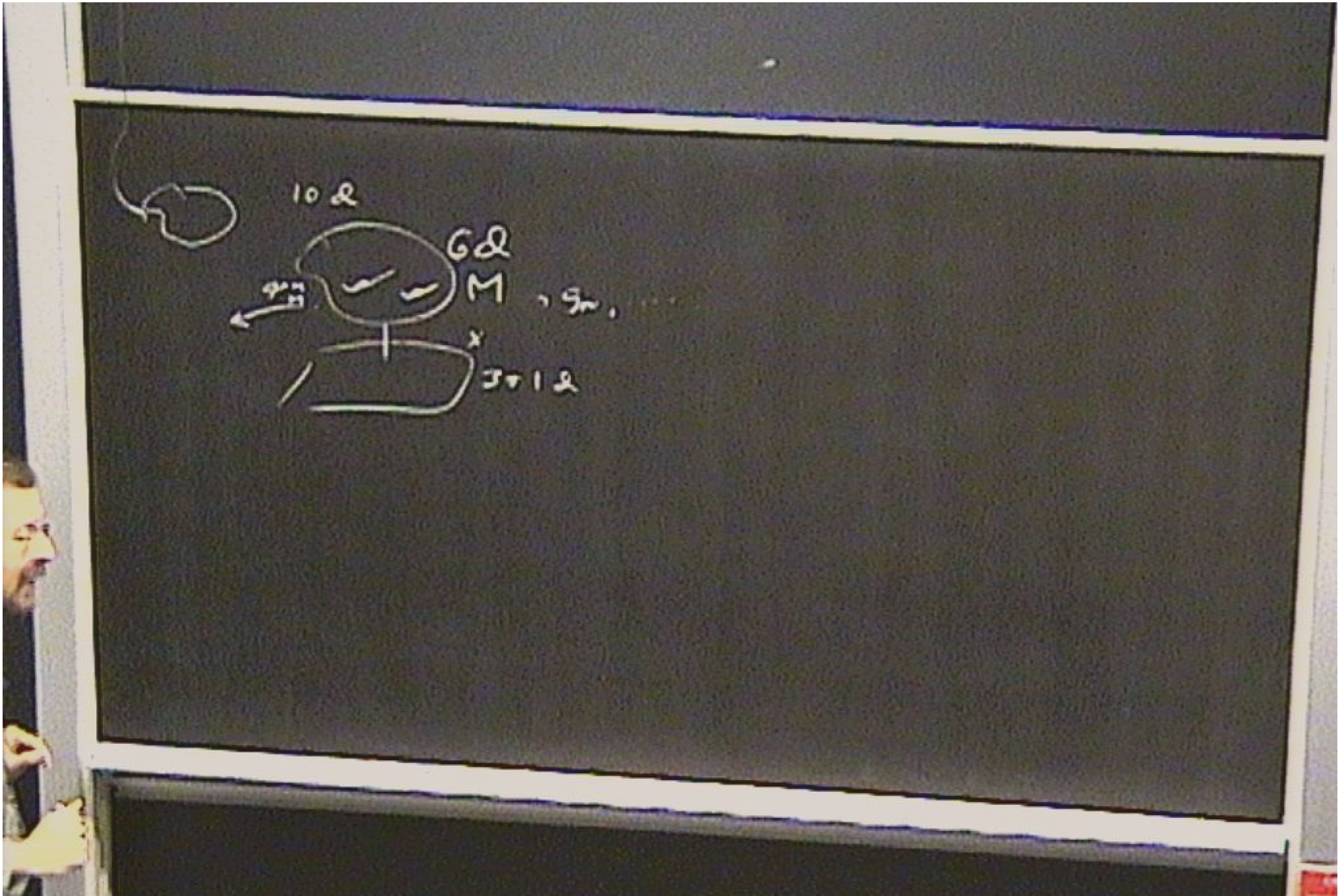





10 d
6d
M


M


10 d
6 d
M
3+1 d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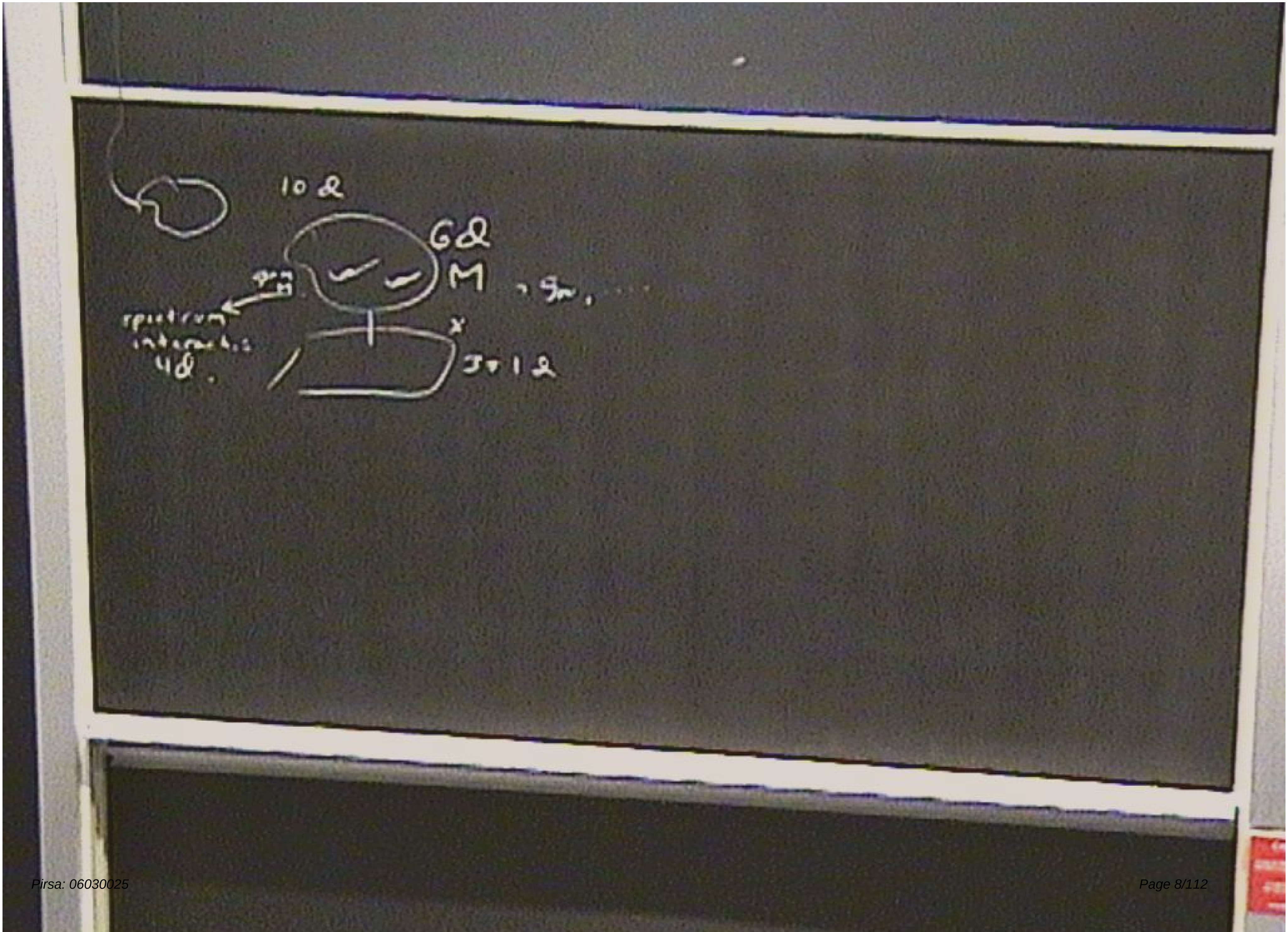
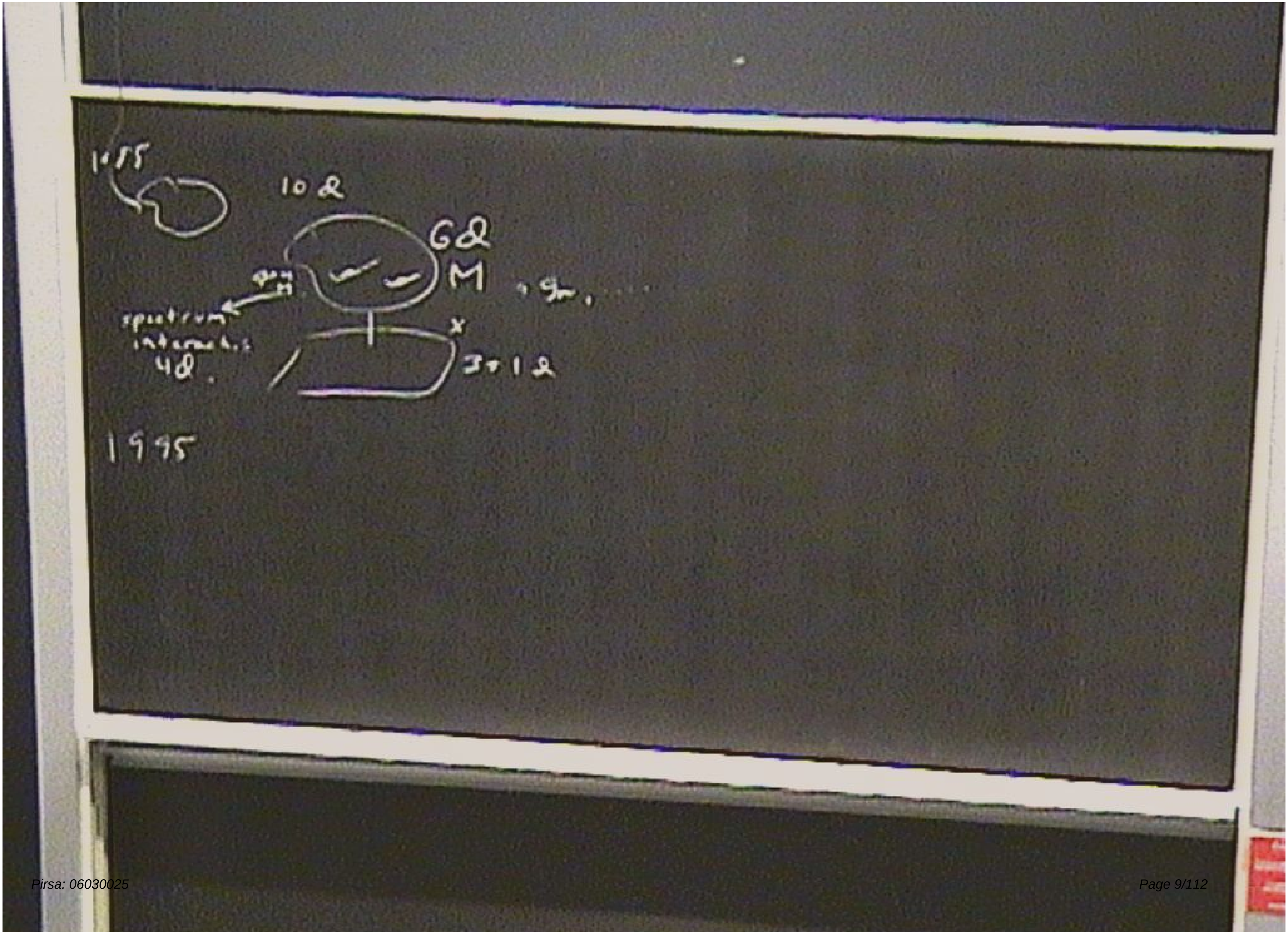
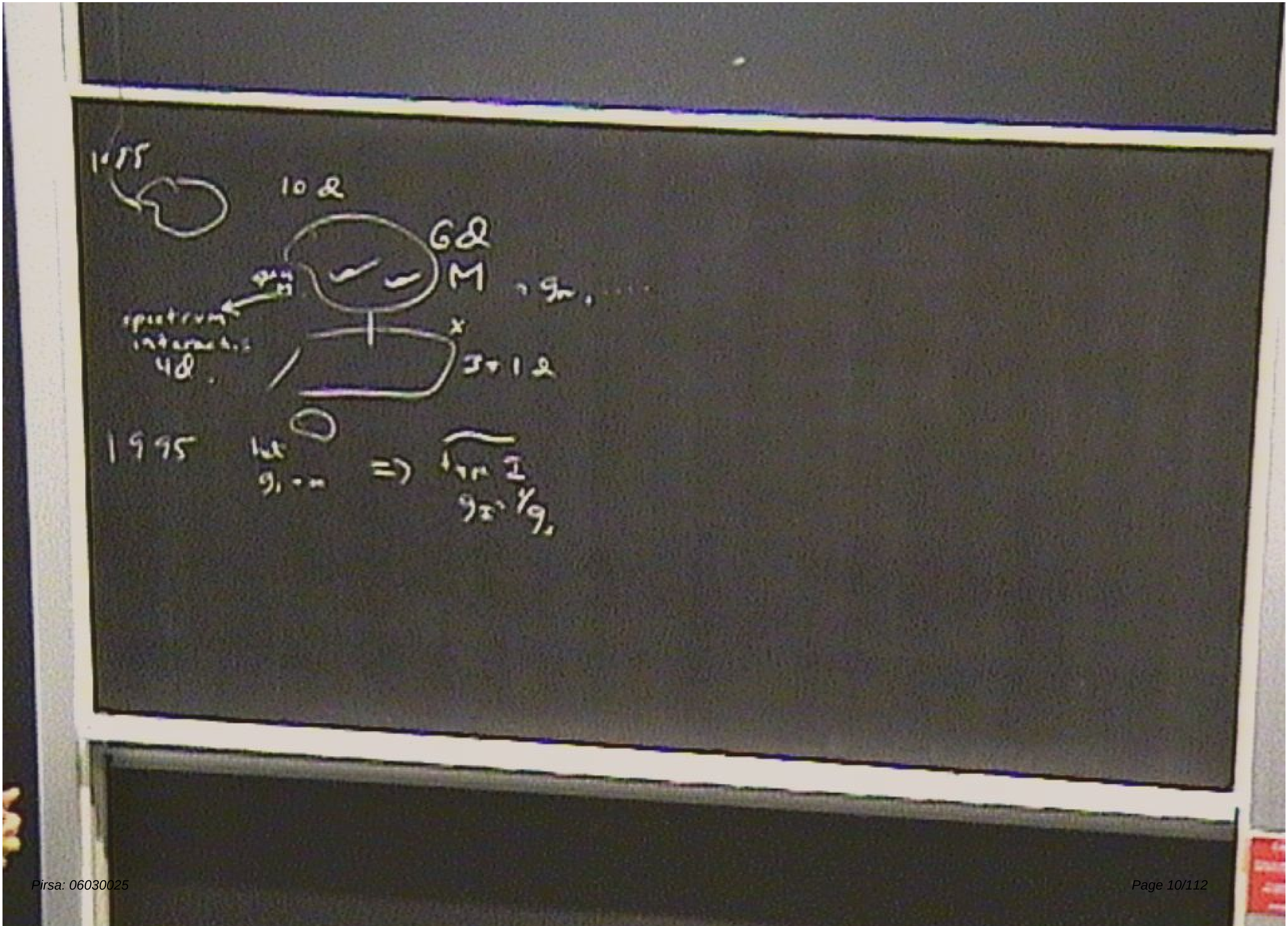
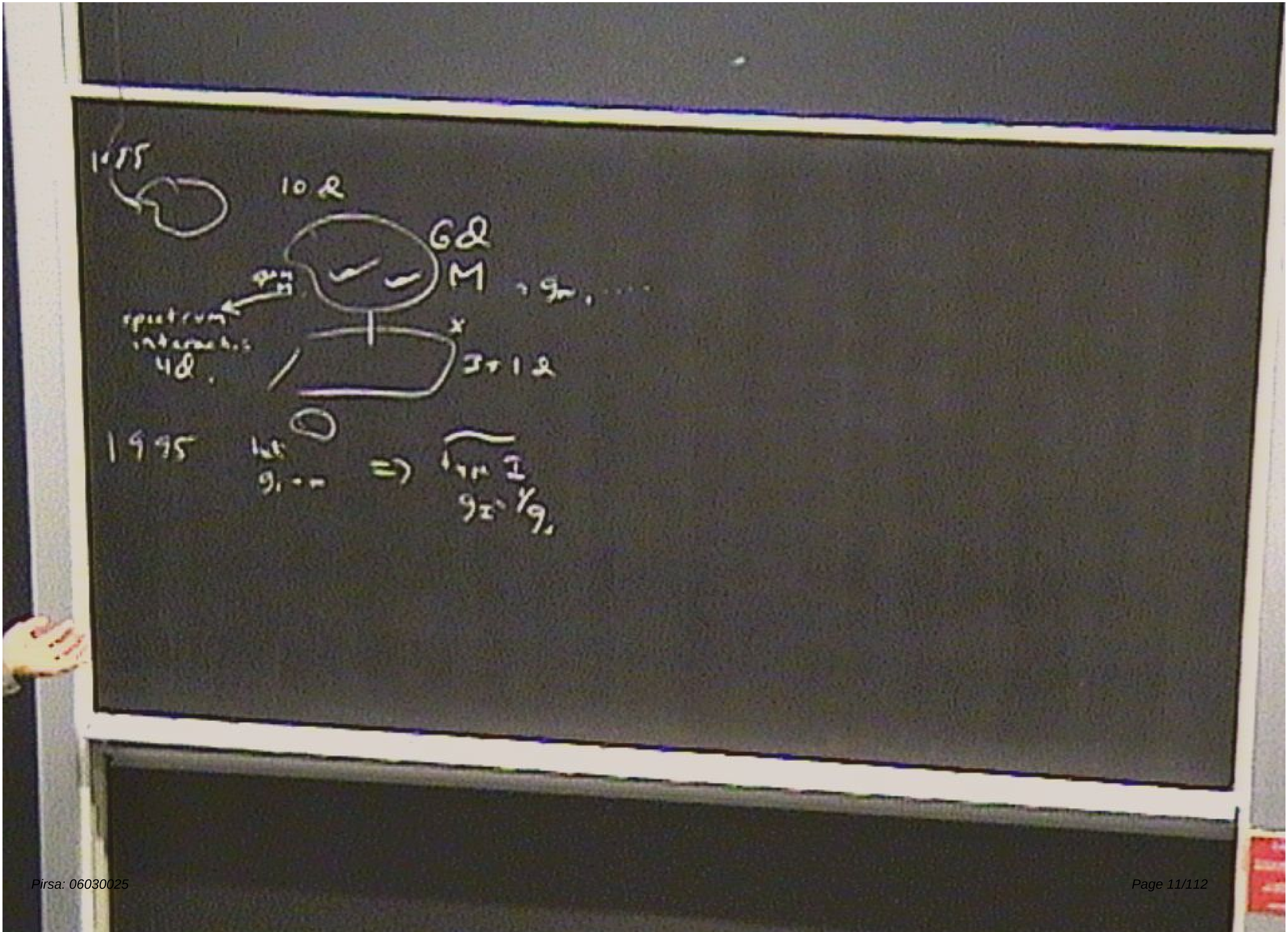
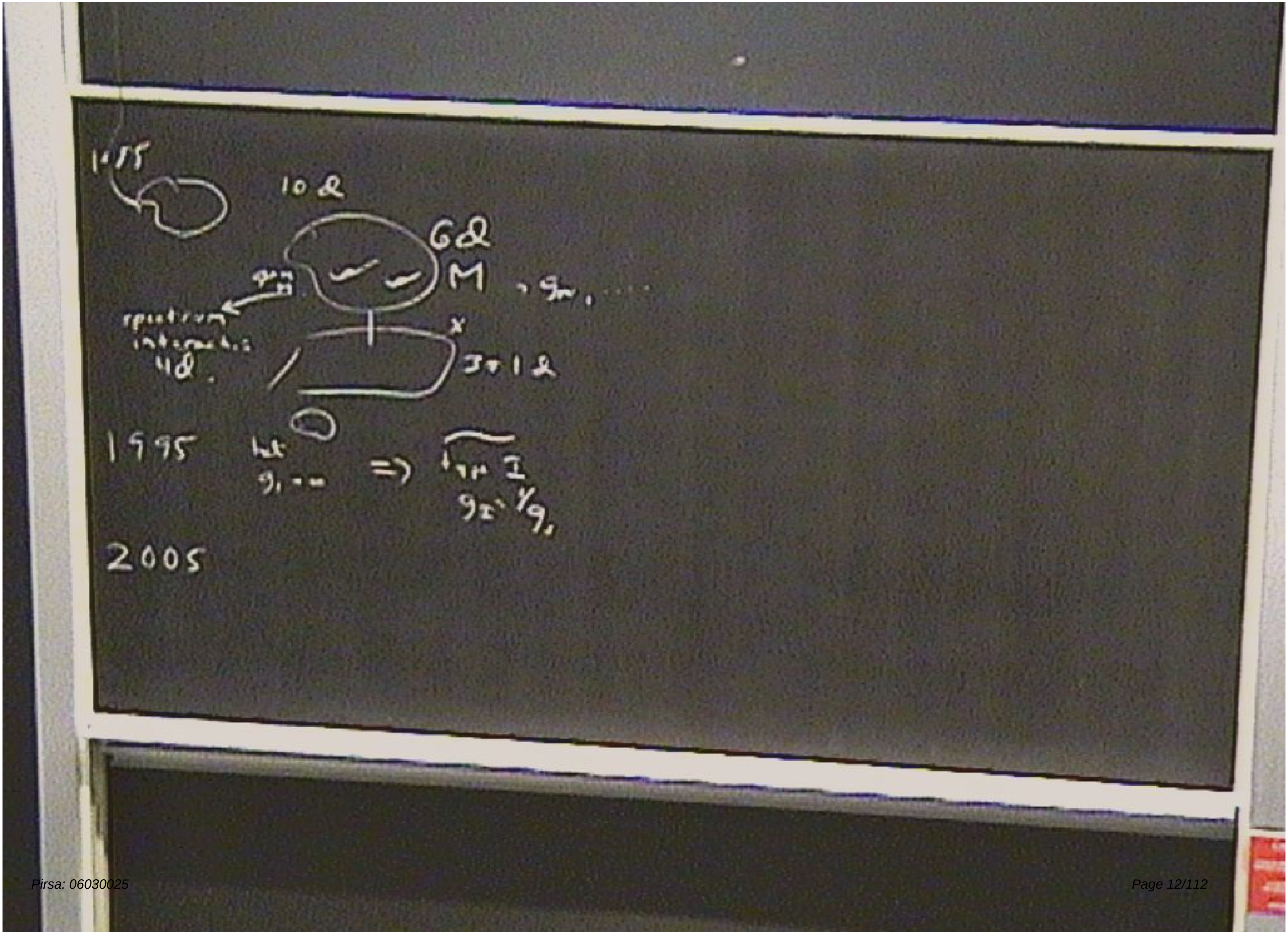
6 d
M
3+1 d

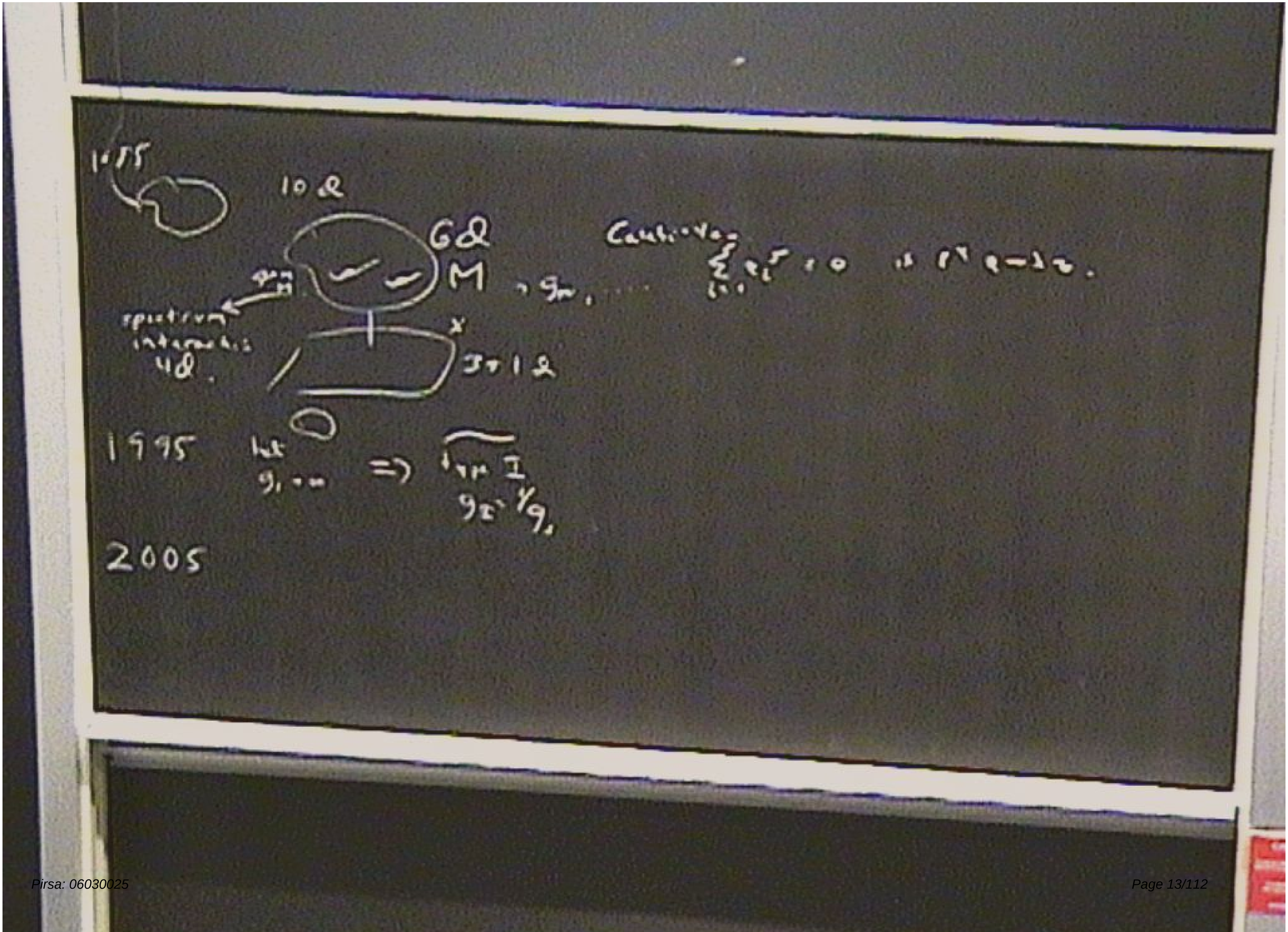

10 d
6 d
M
spectrum
4d

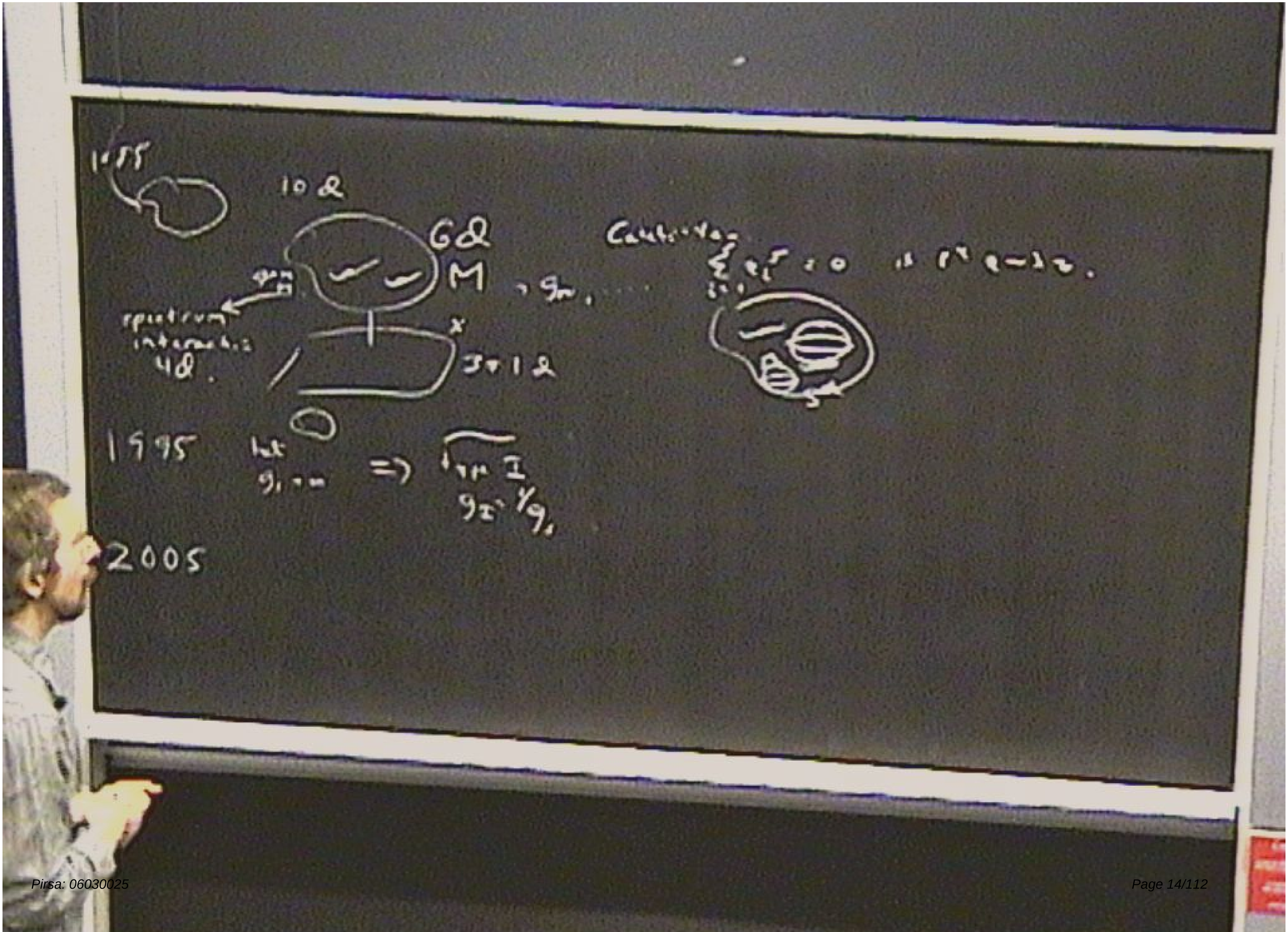

1985
10 d
6 d
M
spectrum
interactions
4 d
3+1 d
1995

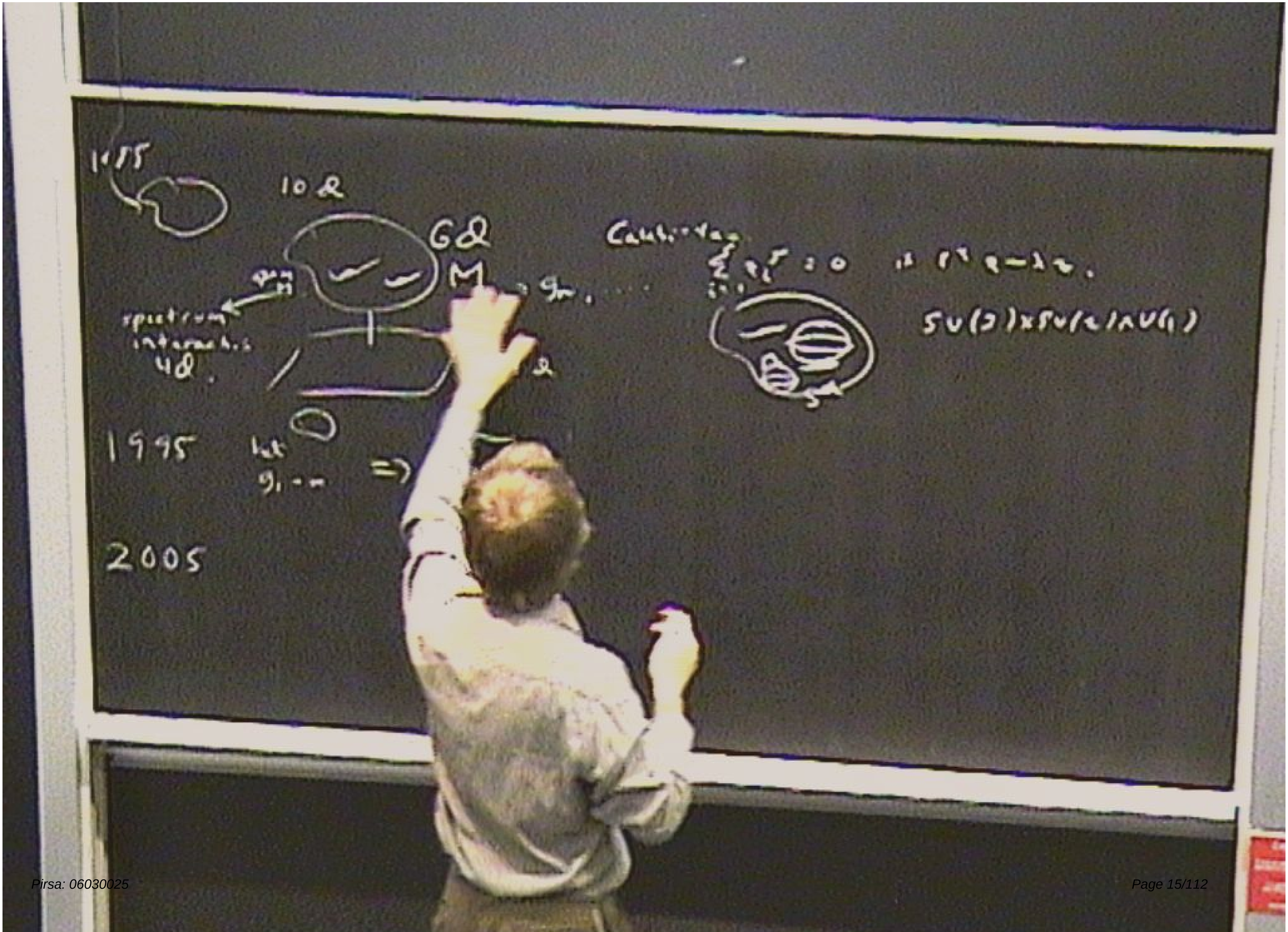

10 d
6d
M
spectrum
interactions
4d
3+1 d
1995
het
=> type I

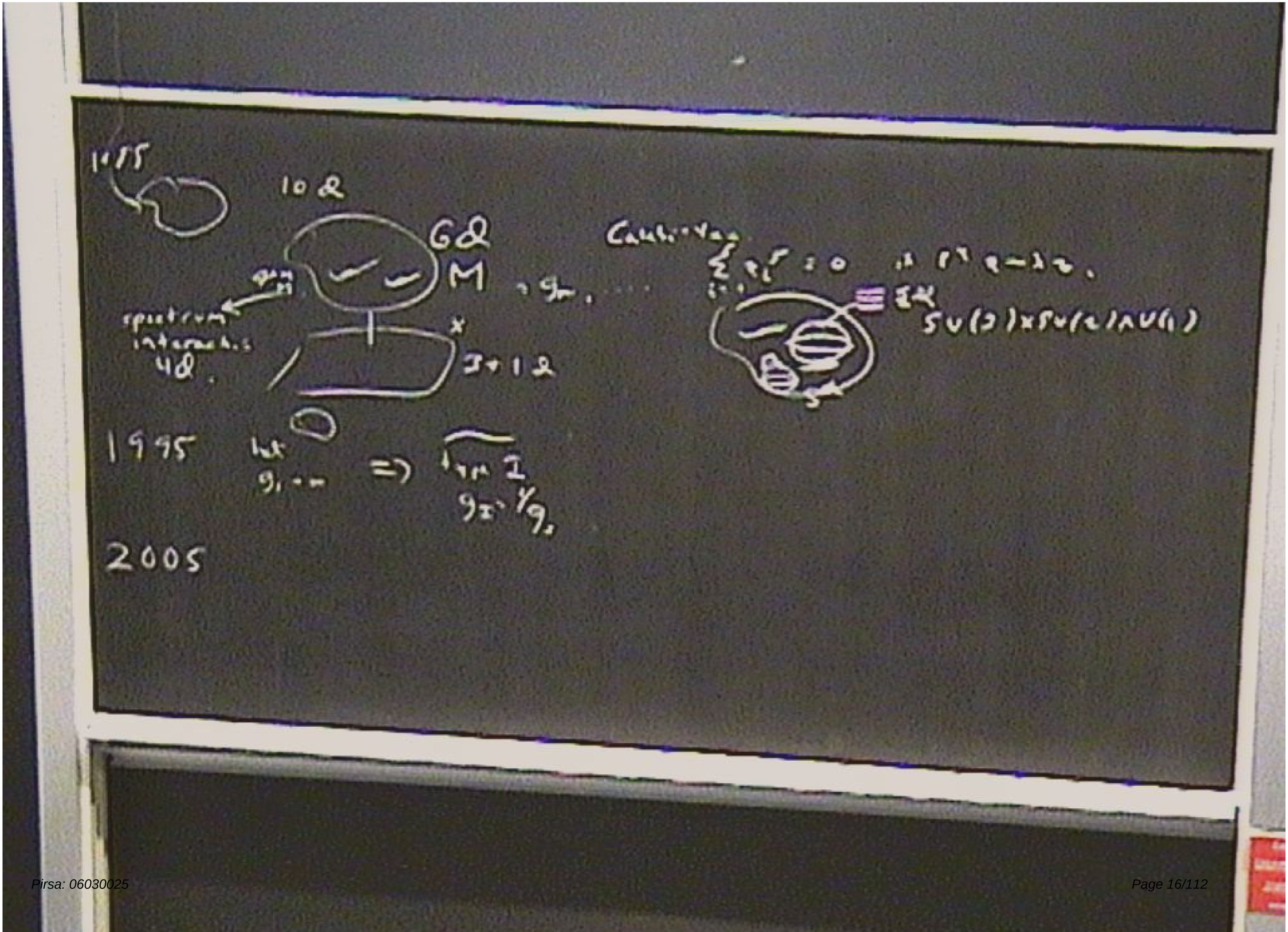

1985
10 d
6d
M
spectrum
interactions
4d
3+1 d
1995
het
type I

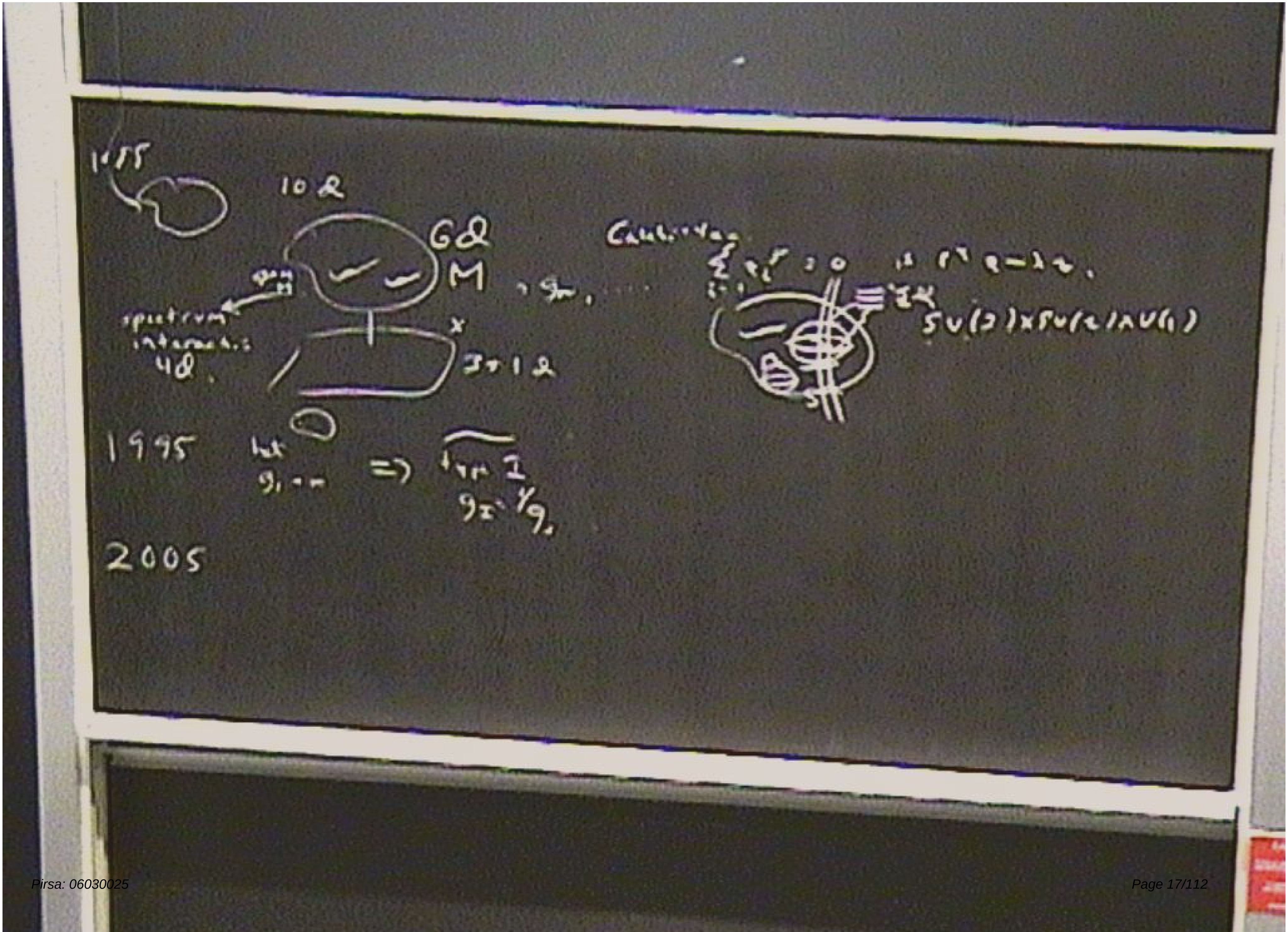

1985
10 d
6d
M
spectrum
interactions
4d.
3+1 d
1995
het
2005

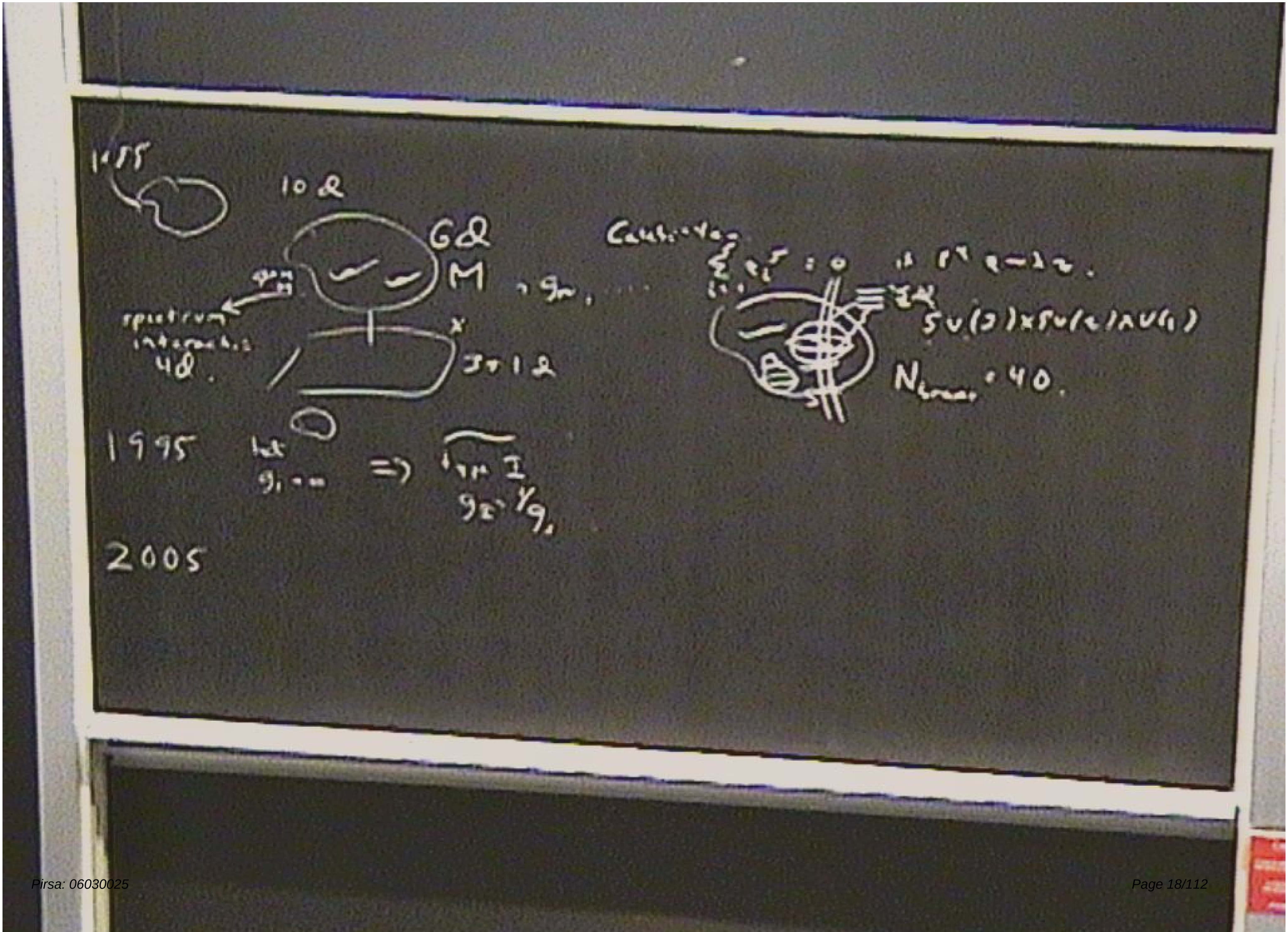

10d
6d
M
spectrum
4d
3+1 d
1995
2005

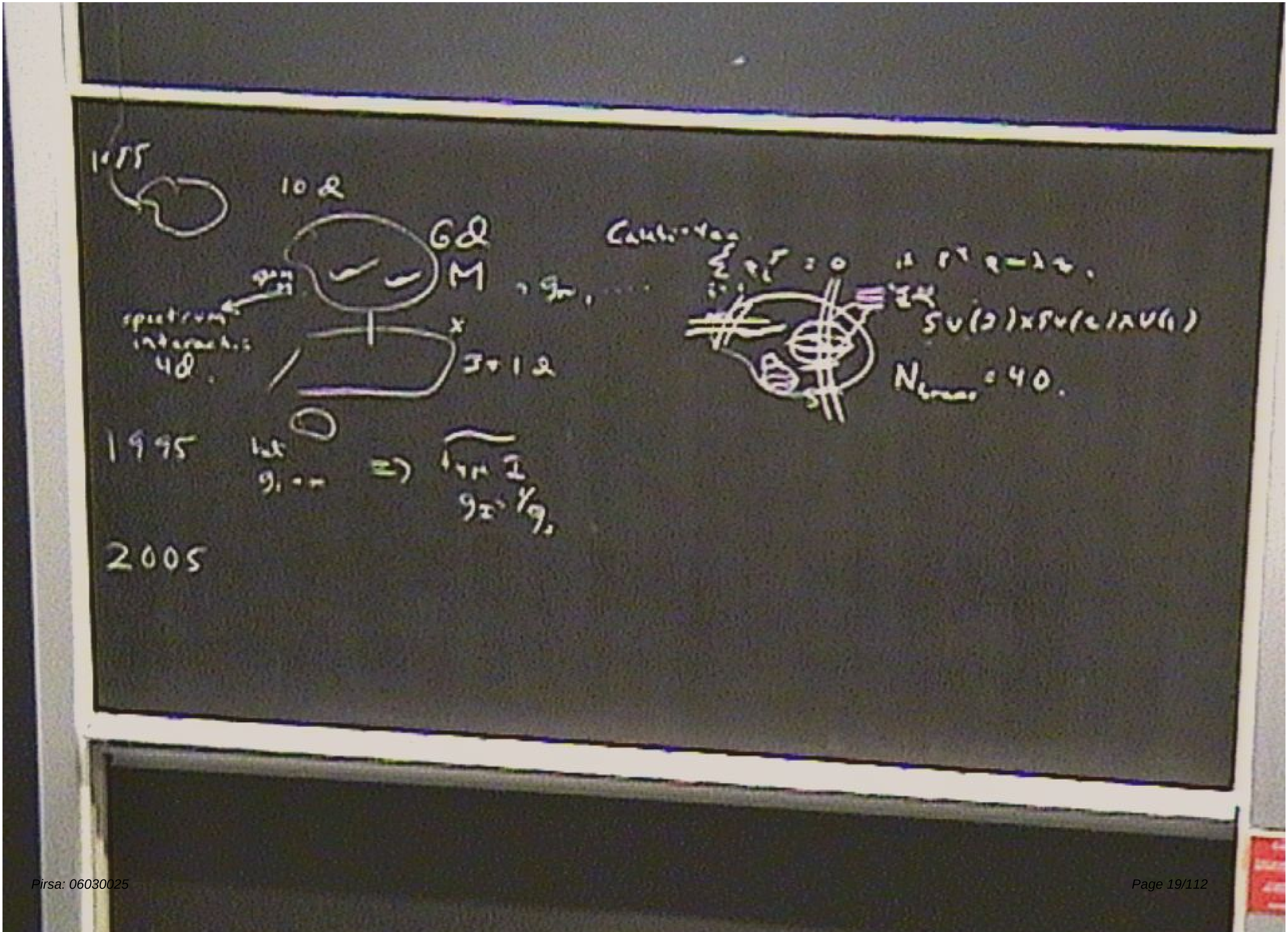

10 d
6d
M
spectrum
4d
3+1 d
1995
type I
2005

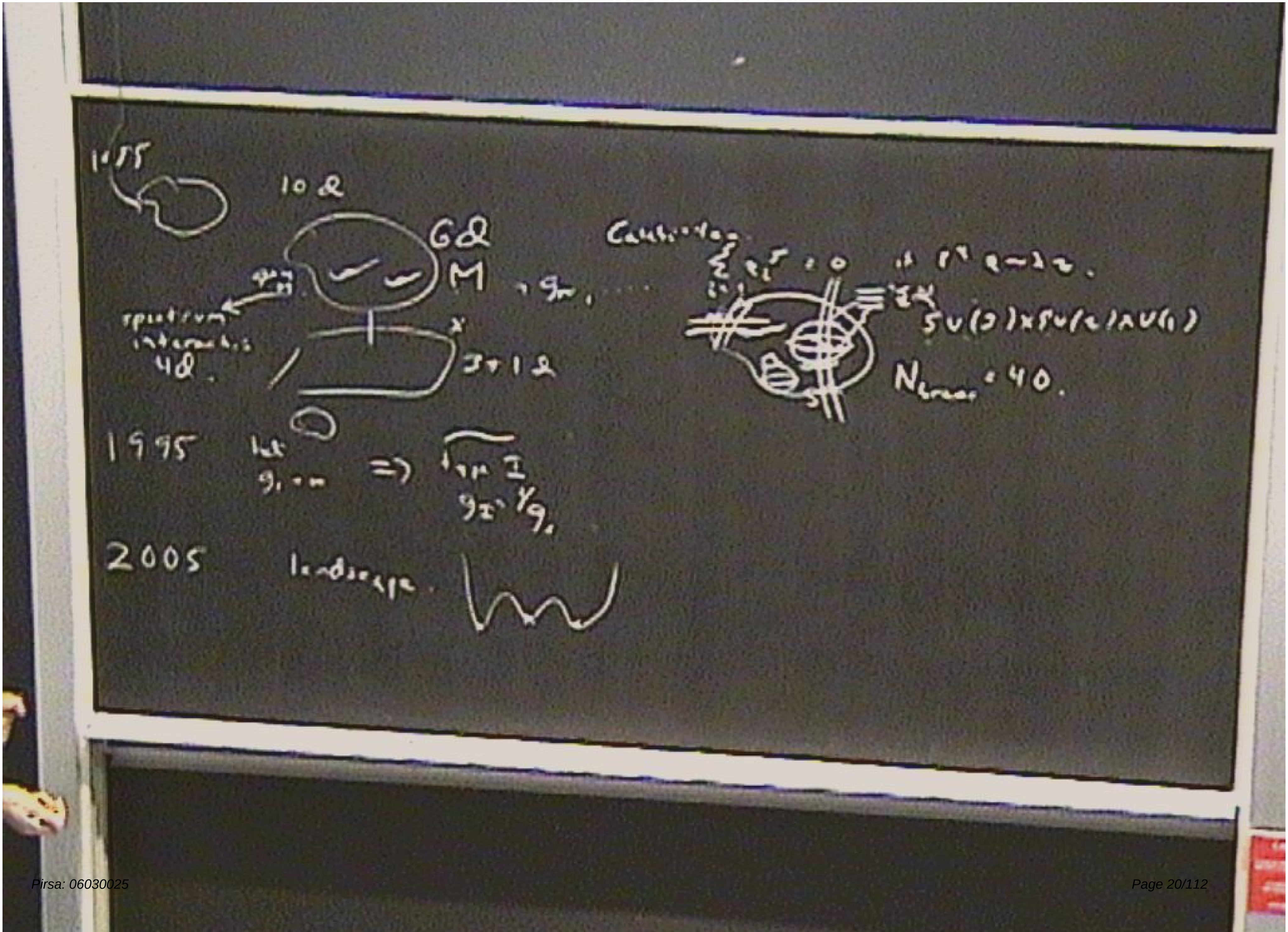

spectrum
1995
2005
SU(3)xSU(2)xU(1)


10 d
6 d
M
spectrum
interactions
4 d
3+1 d
1995
het
=> type I
2005
Calabi-Yau
SU(3)×SU(2)×U(1)

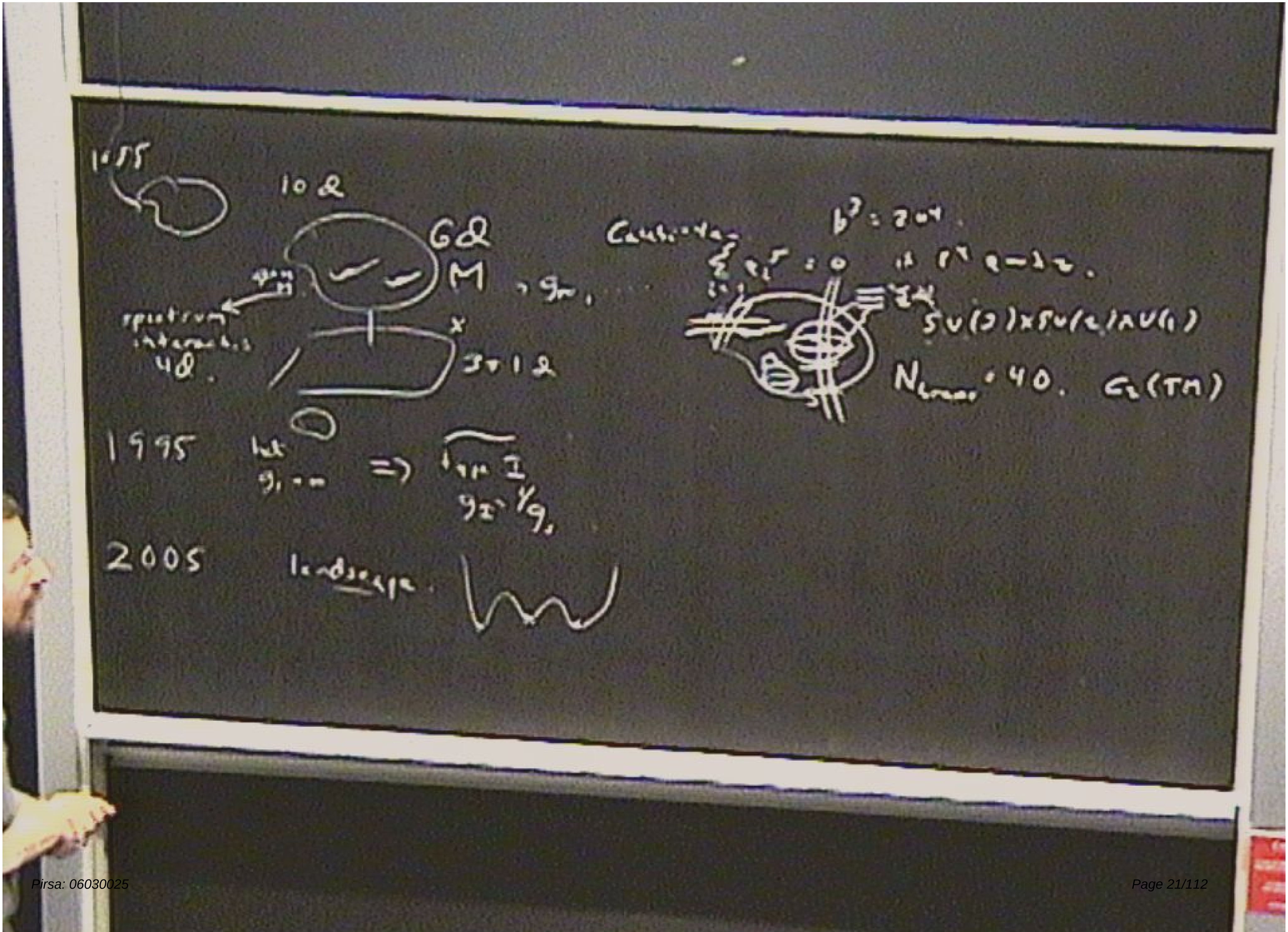

M
spectrum
1995
2005
SU(3)×SU(2)×U(1)

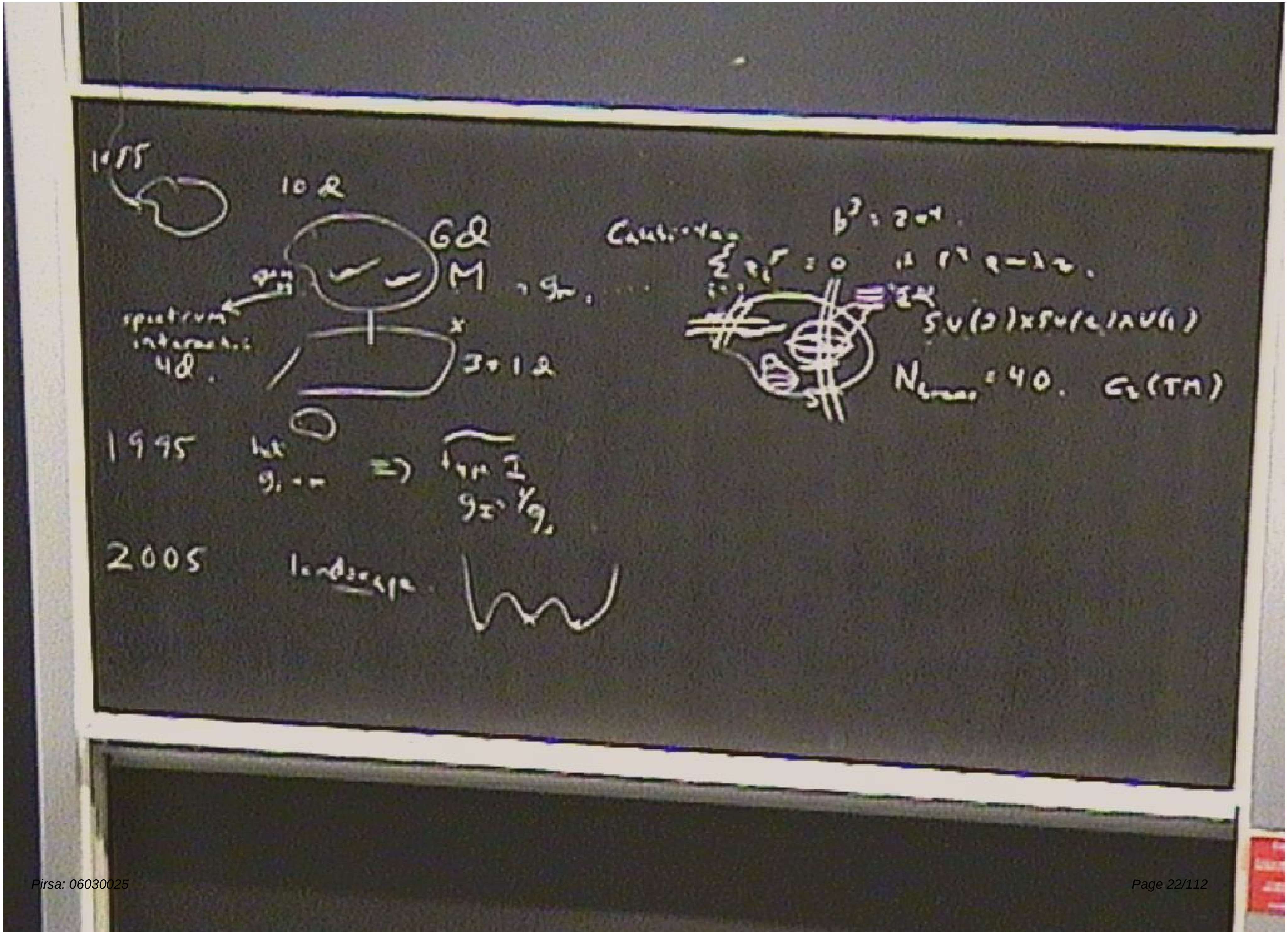

10 d
GR
M
spectrum
4d.
3+1 d
1995
2005
SU(3)×SU(2)×U(1)
N = 40.

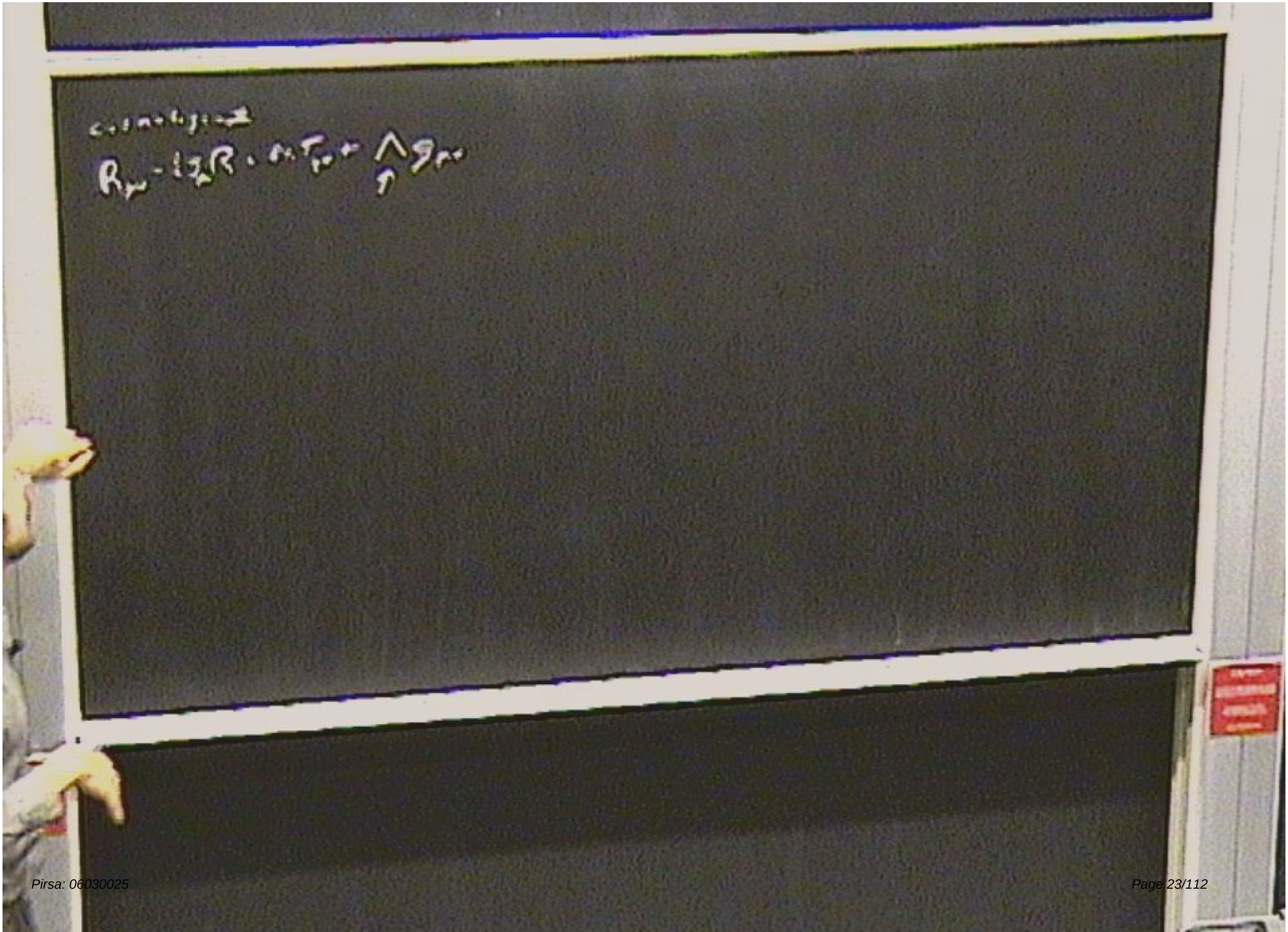

10 d
6d
M
spectrum
interactions
4d.
3+1 d
1995
2005
SU(3)xSU(2)xU(1)
40.

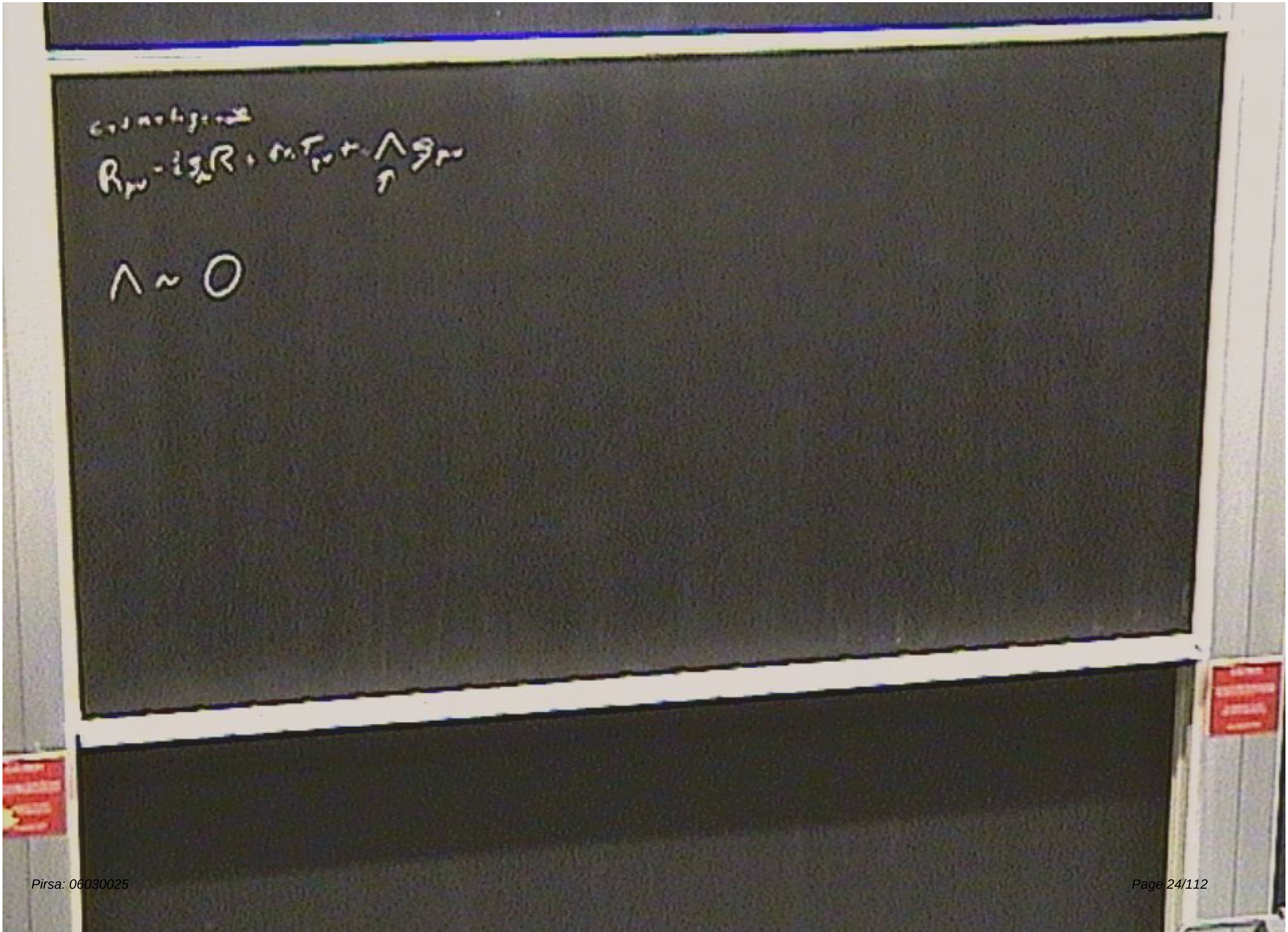


10 d
M
3+1 d
4d
1995
2005
landscape
SU(3)×SU(2)×U(1)


1985
10 d
6d
M
spectrum
interactions
4d.
3+1 d
1995
2005
landscape.
Calabi-Yau
SU(3)×SU(2)×U(1)
N
40.
G2(TM)


10 d
GR
M
spectrum
4d
3+1 d
1995
type I
2005
landscape
Calabi-Yau
SU(3)xSU(2)xU(1)
N = 40.
G2(TM)




Λ ~ 0

cosmological

$$R_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} R = 8\pi G\, T_{\mu\nu} + \Lambda g_{\mu\nu}$$

$\ll \; \ldots$

$\Lambda \sim 0$

cosmological

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G T_{\mu\nu} + \Lambda g_{\mu\nu}$$

$$\ll (100\ meV)^4$$

$$\Lambda \sim 0$$

cosmological

$$R_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} R = 8\pi T_{\mu\nu} + \Lambda g_{\mu\nu}$$

$$\ll (100\ \mathrm{MeV})^4$$

$$\Lambda \sim O \sim 10^{-122} M_{planck}^4$$

cosmological

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G T_{\mu\nu} + \Lambda g_{\mu\nu}$$

$$\ll (100\ \mathrm{km})^{-4}$$

$$\Lambda \sim 0$$

$$\sim 10^{-122} M_{planck}^4$$

$$10^{-50} M_{part}^4$$

cosmological

$$R_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} R = 8\pi G T_{\mu\nu} + \underset{\uparrow}{\Lambda} g_{\mu\nu}$$

$$\ll (100\ \mu m)^{-4}$$

$$\Lambda \sim 0$$

$$\sim 10^{-122} M_{planck}^4$$

$$10^{-50} M_{part}^4$$

late 90's

$\Rightarrow$

cosmological const

$$R_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} R = 8\pi T_{\mu\nu} + \Lambda g_{\mu\nu}$$

$$\ll (100\ \mathrm{Mpc})^{-2}$$

$$\Lambda \sim O$$

$$\sim 10^{-122} M_{planck}^4$$

$$10^{-50} M_{pert}^4$$

late 90's

$\Rightarrow$ SN ...

WMAP

cosmological

$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi T_{\mu\nu} + \Lambda g_{\mu\nu}$

$\ll (100\,\mu m)^{-4}$

$\Lambda \sim O$

$\sim 10^{-123} M_{planck}^4$

$10^{-120} M_{pl}^4$

late 90's

$\Rightarrow$ SN ...

WMAP

$\Lambda > 0$

$\sim 0.71 \rho_c$

cosmological

$$R_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} R = 8\pi T_{\mu\nu} + \Lambda g_{\mu\nu}$$

$$\ll (100\ \text{mi})^{-2}$$

$$\Lambda \sim O$$

$$\sim 10^{-122} M_{planck}^4$$

$$10^{-50} M_{part}^4$$

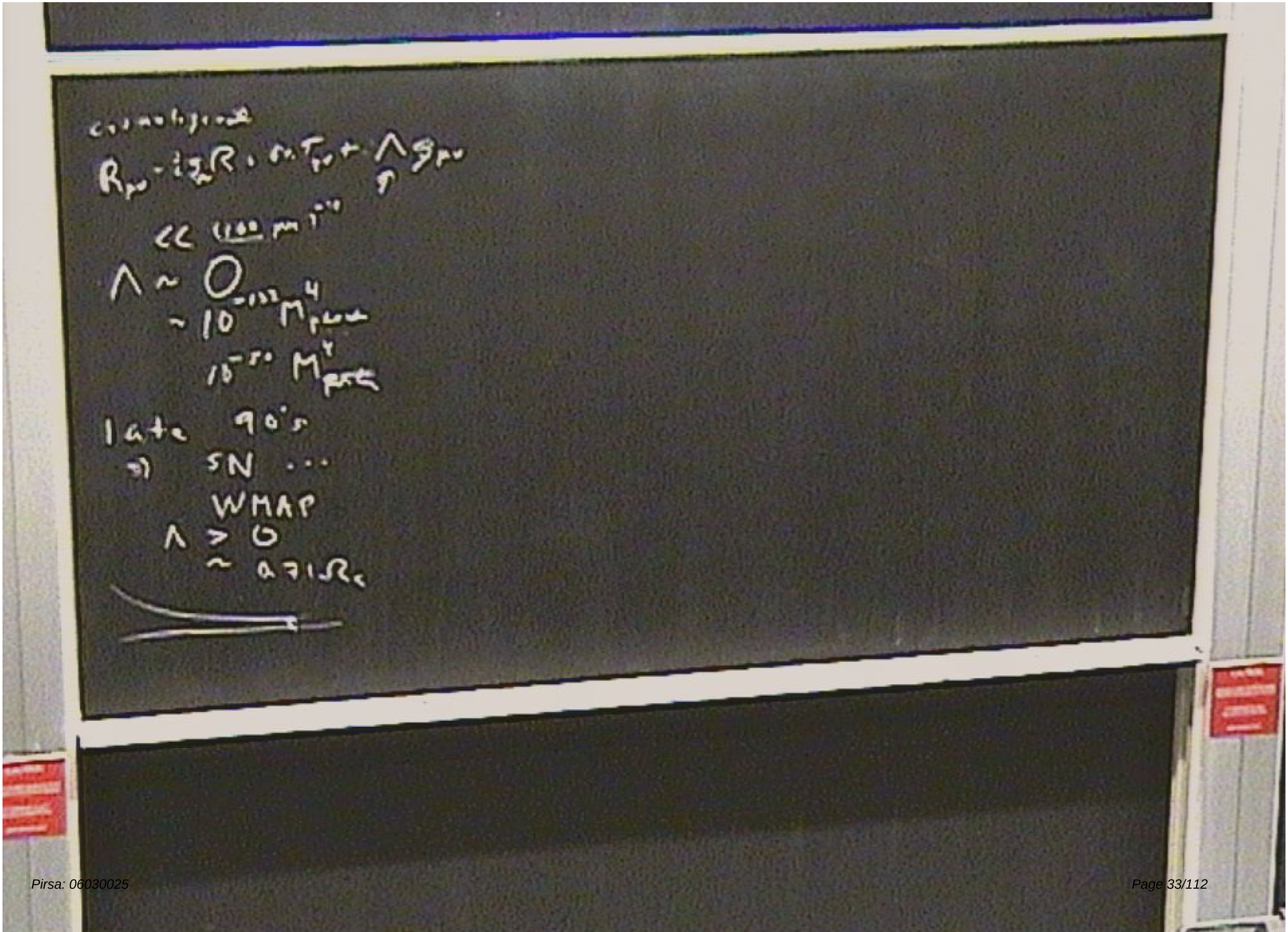
late 90's

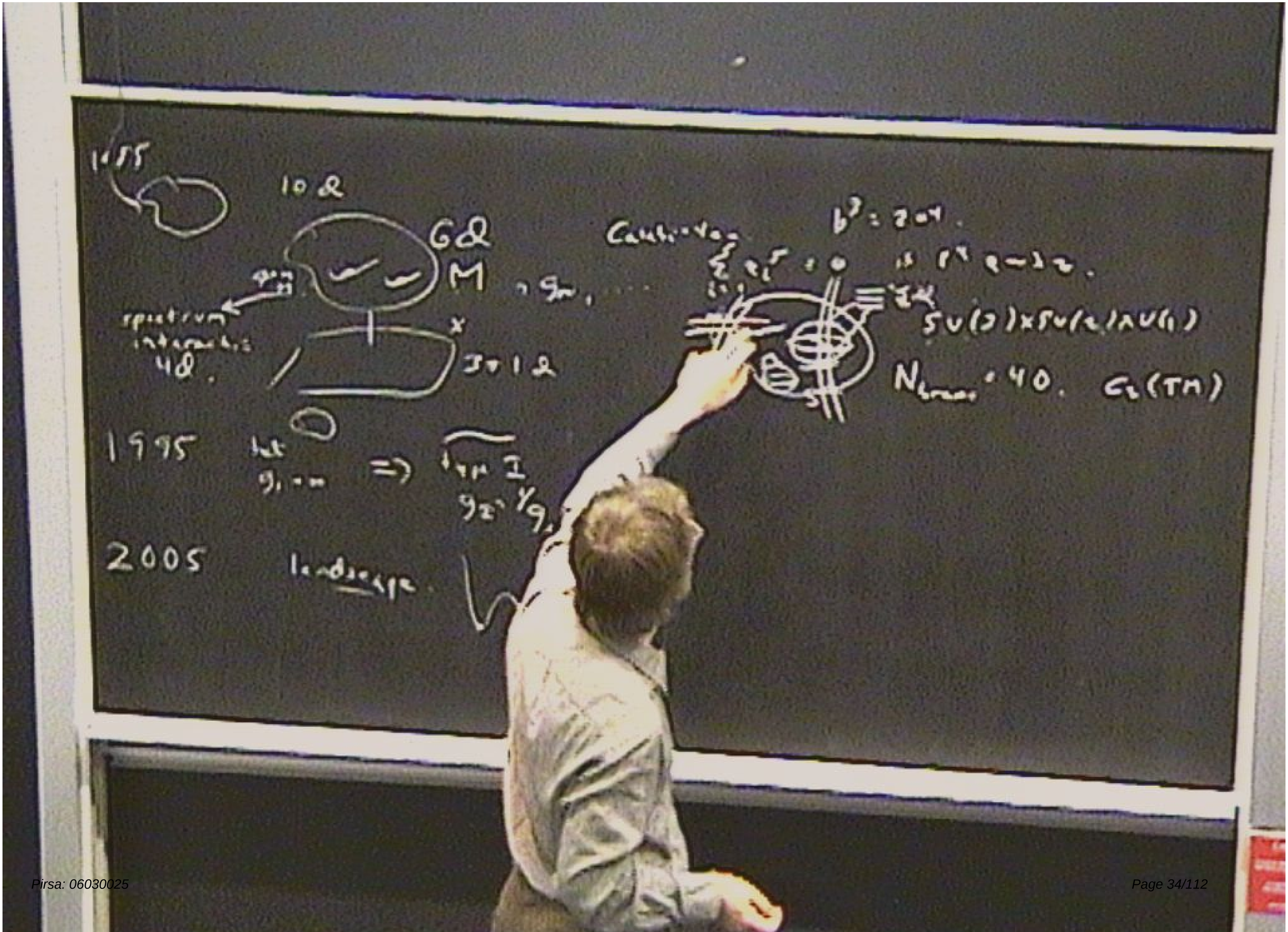
$\Rightarrow$ SN ...

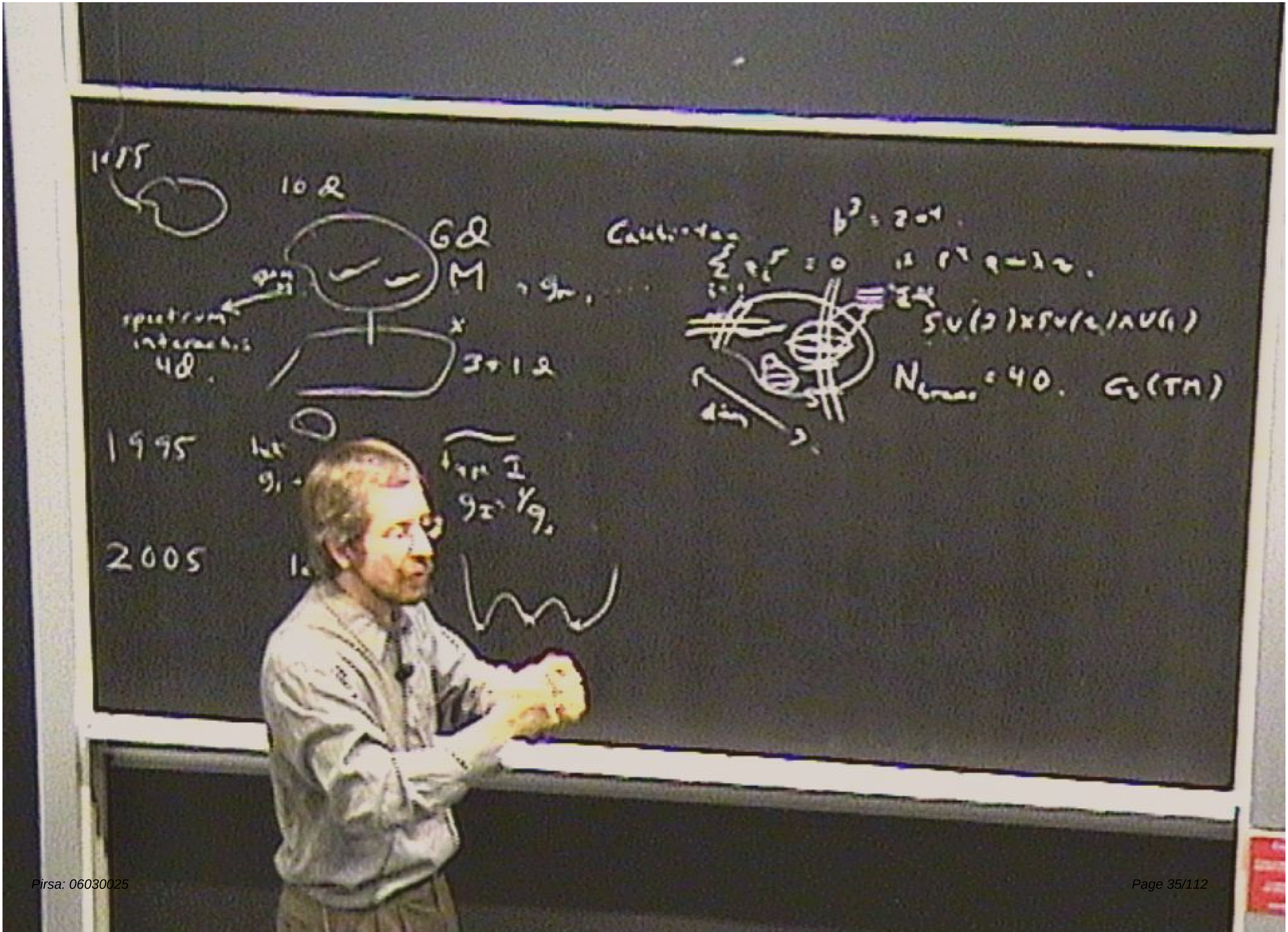
WMAP

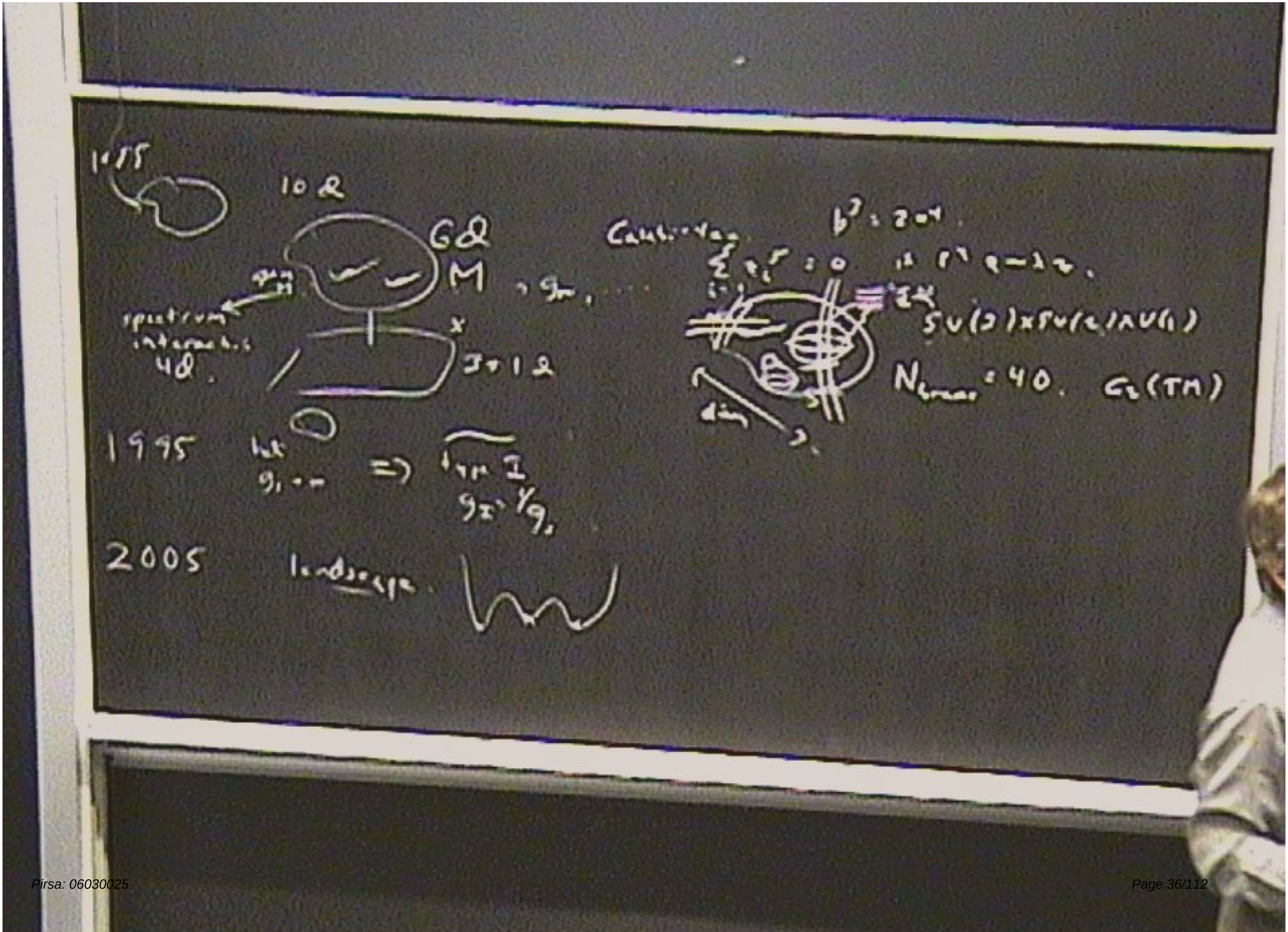
$\Lambda > 0$

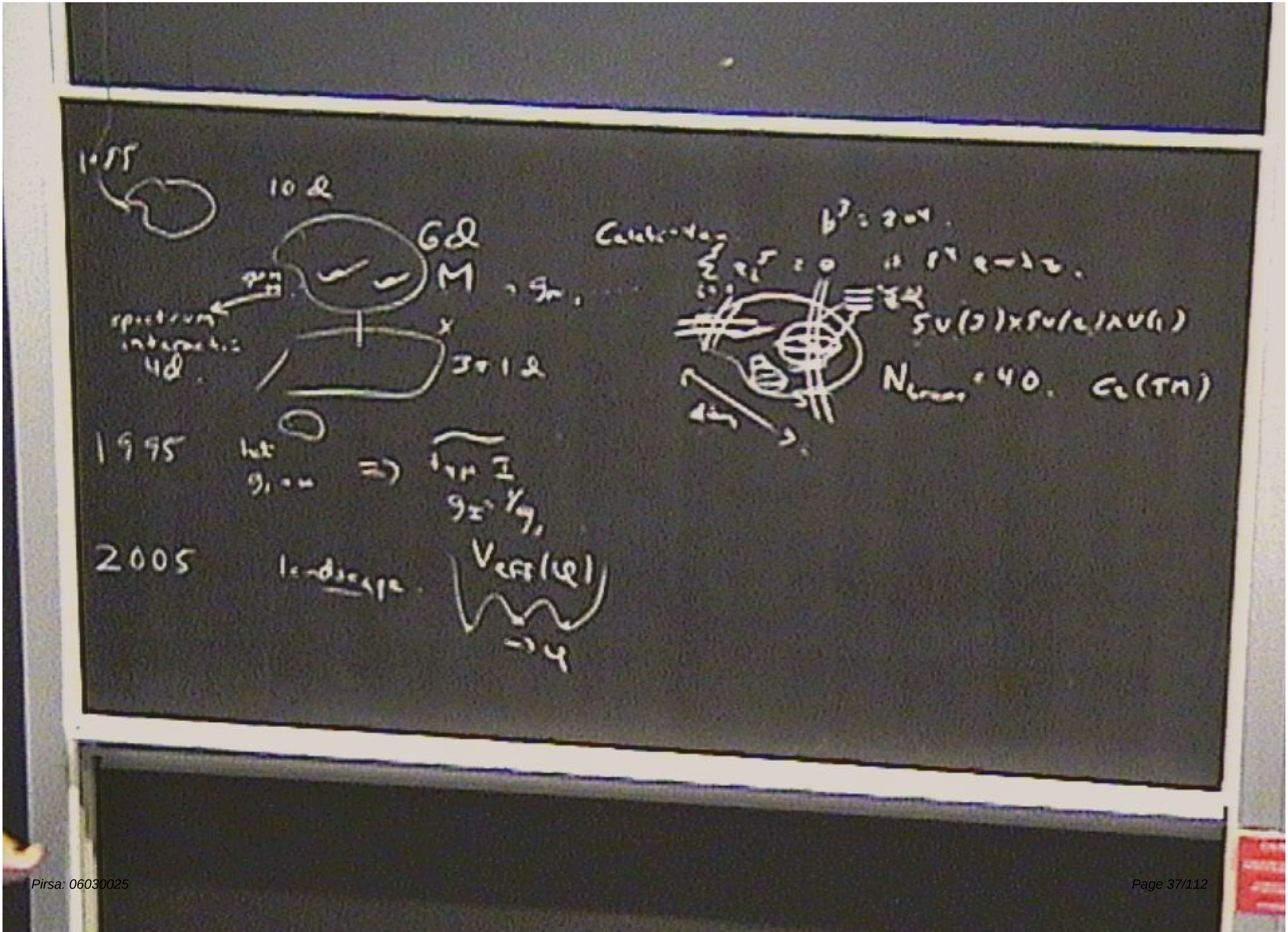
$\sim 0.71\,\Omega_c$

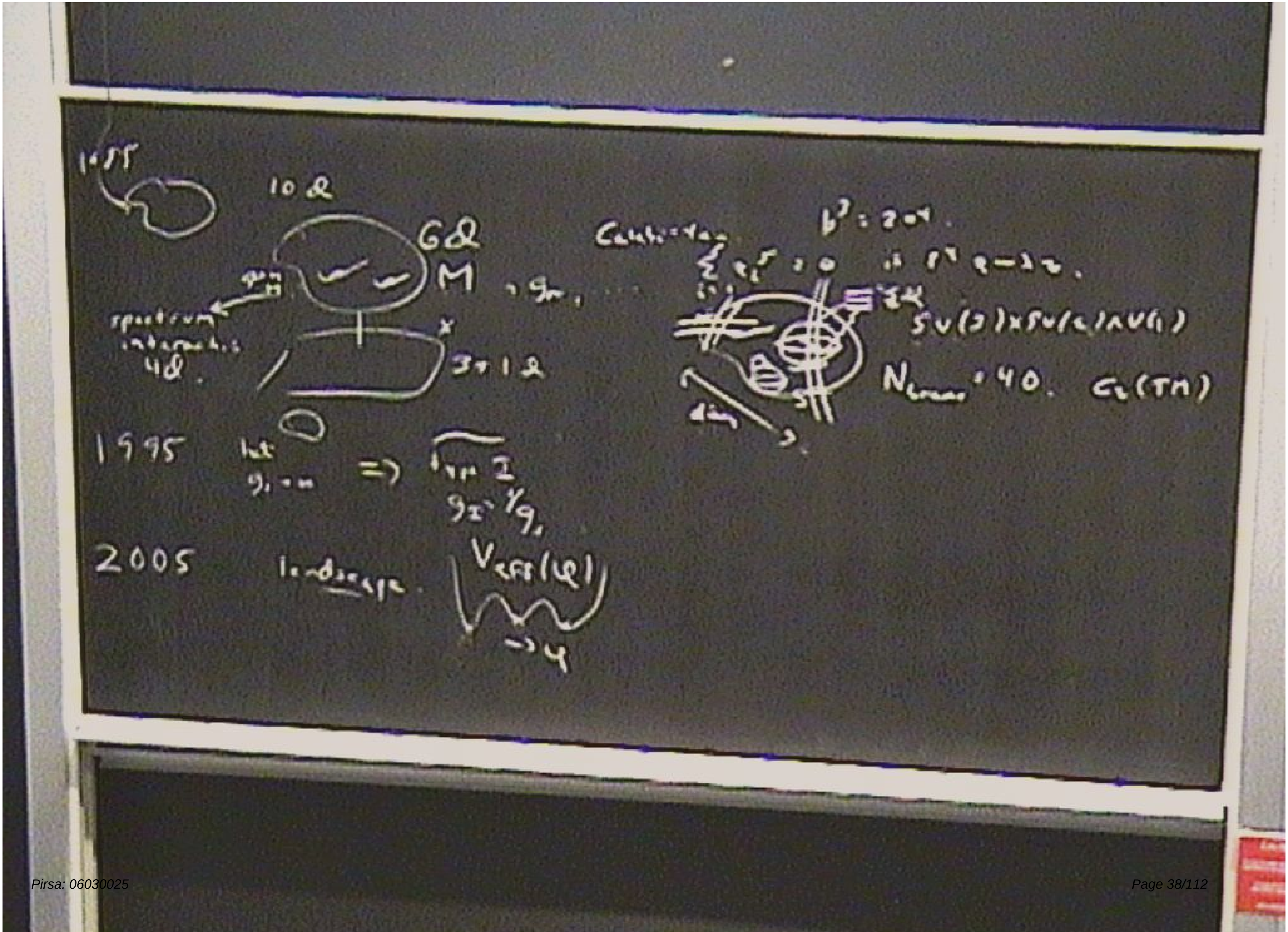

cosmological
Λ ~ 0
~ 10^-122 M_planck^4
10^-50 M_planck^4
late 90's
SN ...
WMAP
Λ > 0


1985
10 d
G d
M
spectrum
interactions
4d.
3+1 d
1995
het
$g_s \to \infty$
$\Rightarrow$ type I
$g_2 \sim 1/g_1$
2005
landscape
Calabi-Yau
$b^3 = 204$.
$\sum z_i^5 = 0$
$SU(3) \times SU(2) \times U(1)$
$N_{branes} = 40$.
$G_2(TM)$

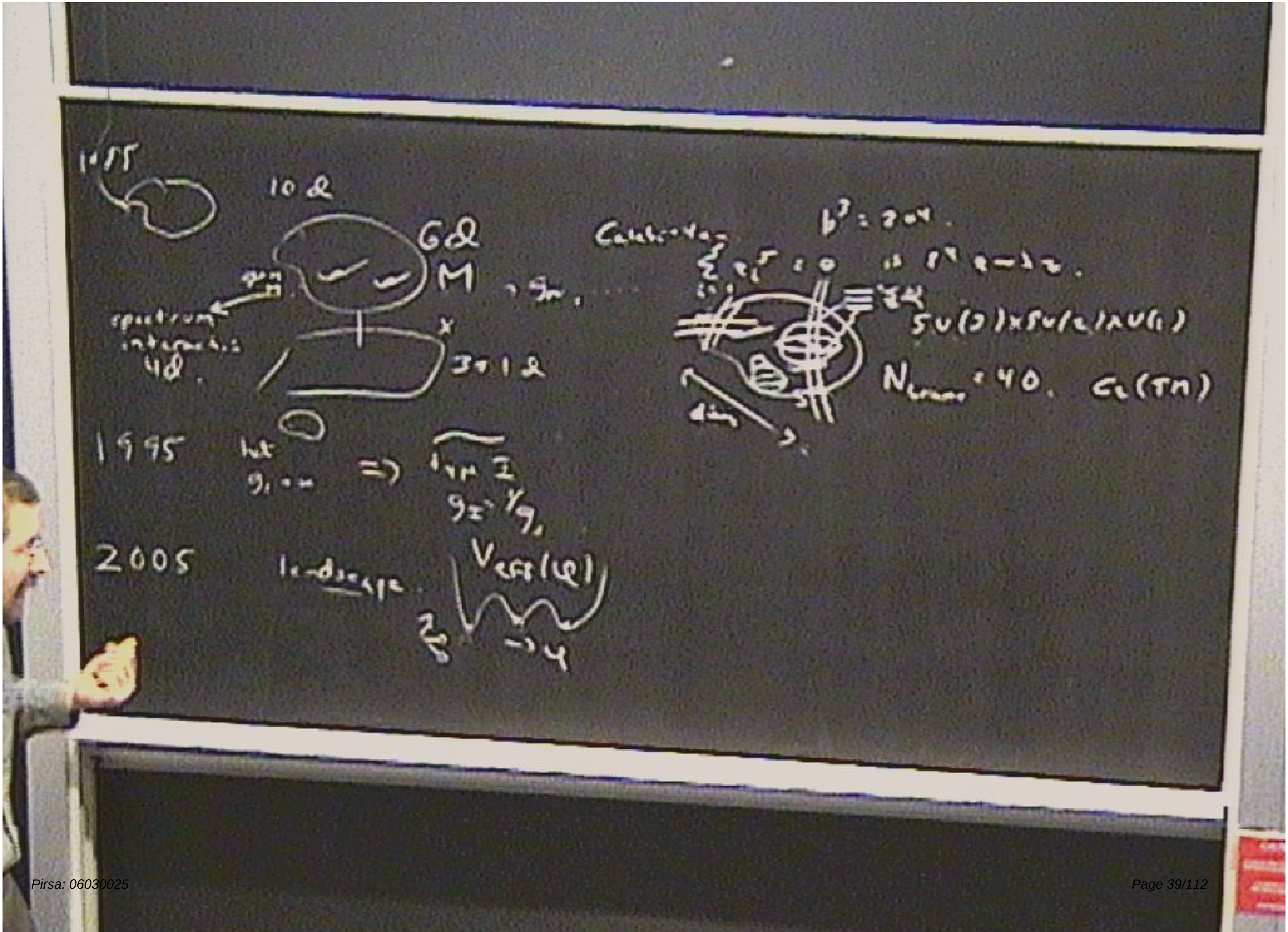

10 d
G2
M
spectrum
interactions
4d
3+1 d
SU(3)xSU(2)xU(1)
G2(TM)
1995
type I
2005


10 d
M
spectrum
4d
3+1 d
1995
type I
2005
landscape
$b^2 = 204$
$SU(3) \times SU(2) \times U(1)$
$N_{branes} = 40$
$G_2(TM)$

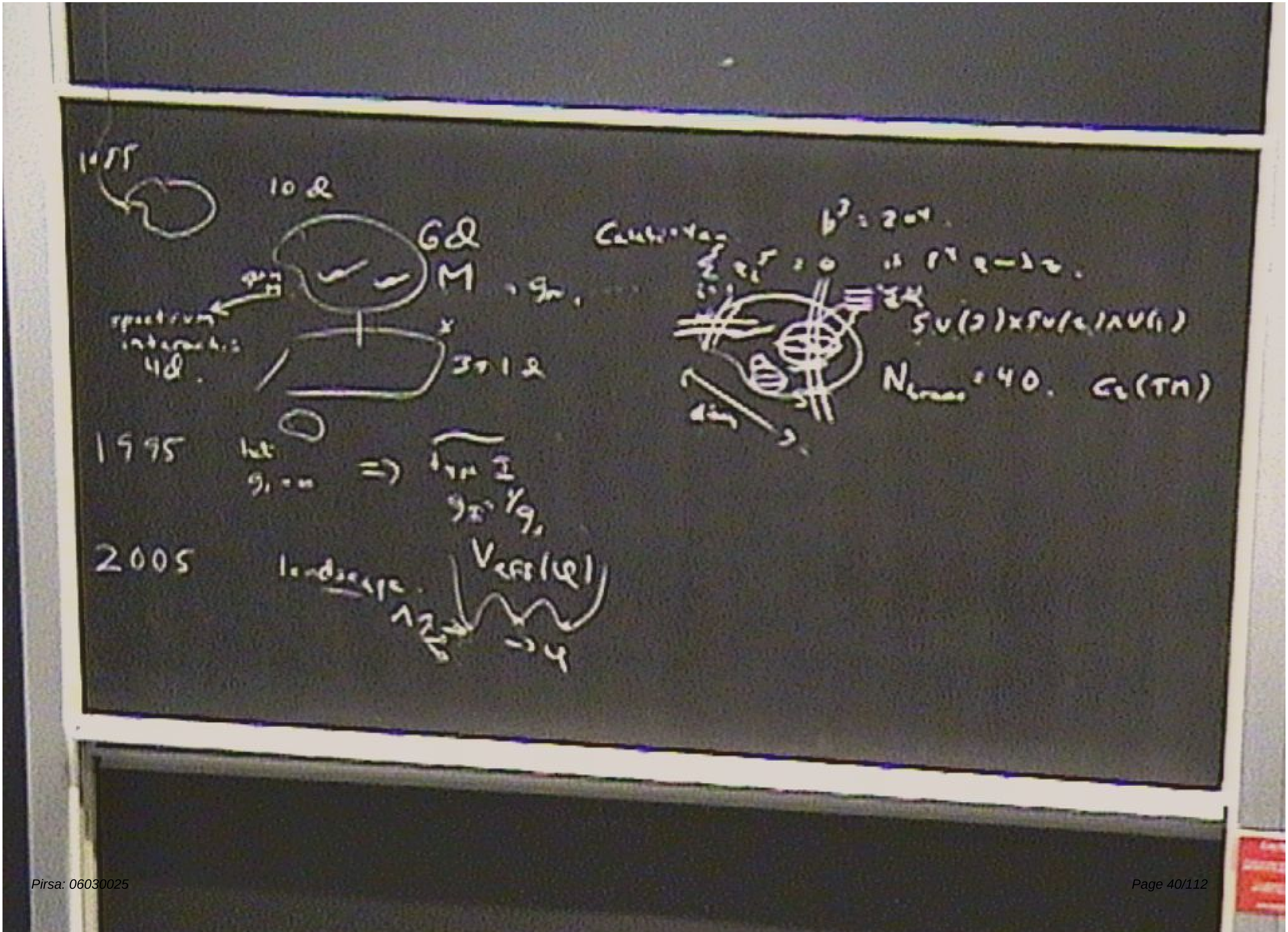

10 d
G d
M
spectrum
interactions
4d
3+1 d
Calabi-Yau
SU(3)xSU(2)xU(1)
N = 40.
1995
het
type I
2005
landscape
V_eff(φ)



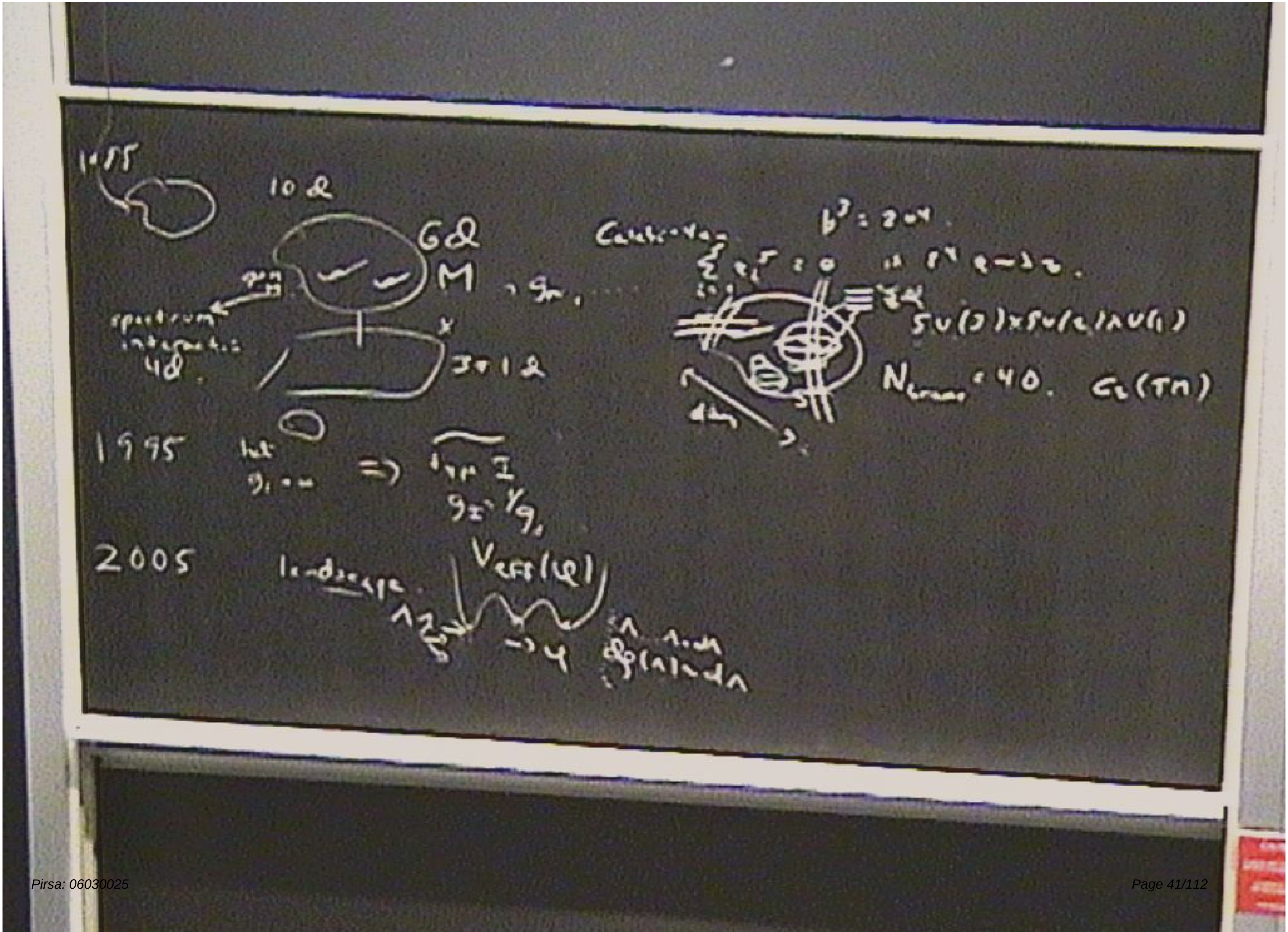
10 d
GR
M
spectrum
interactions
4d
3+1 d
1995
2005
landscape
Calabi-Yau
SU(3)×SU(2)×U(1)

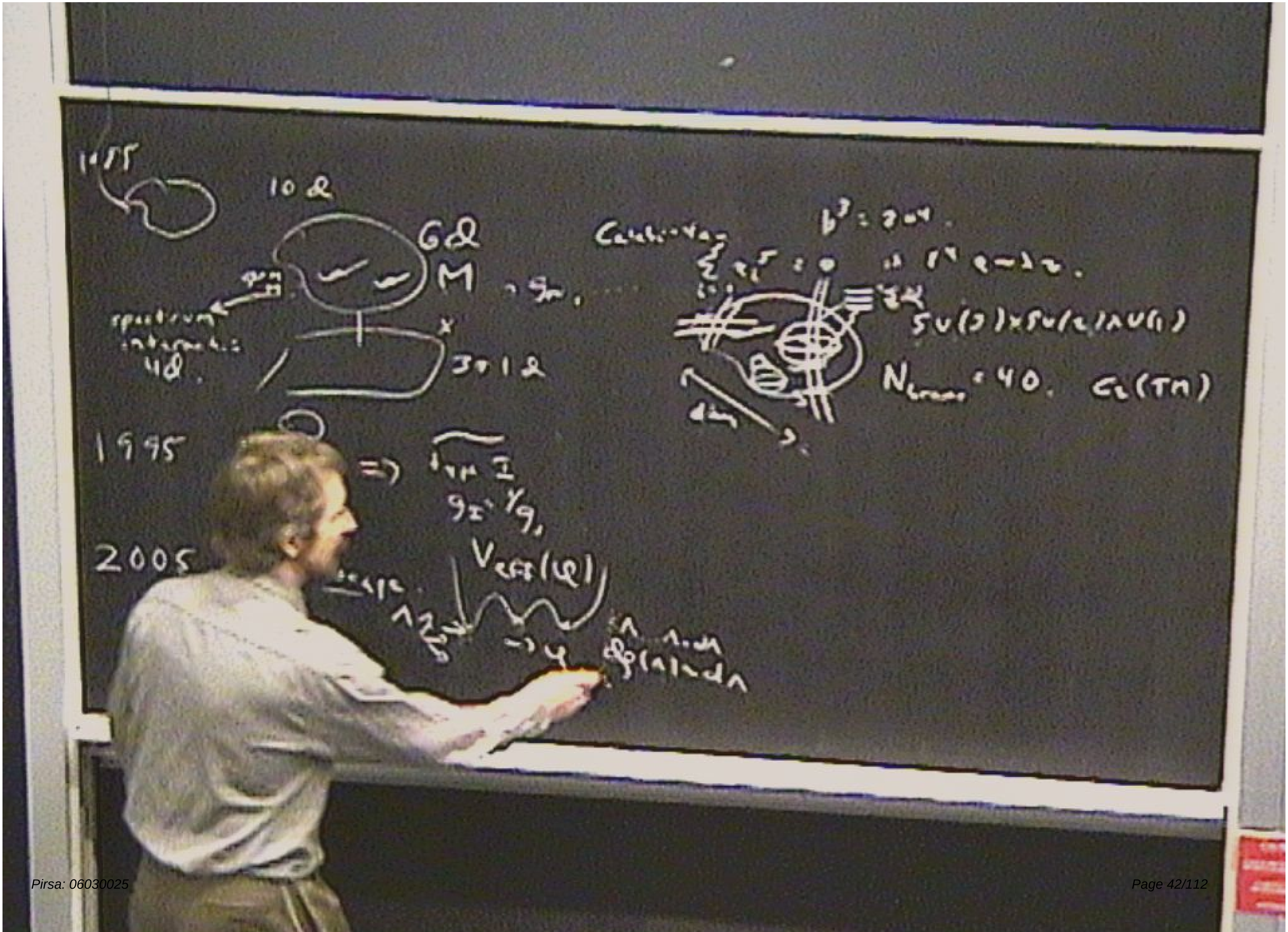


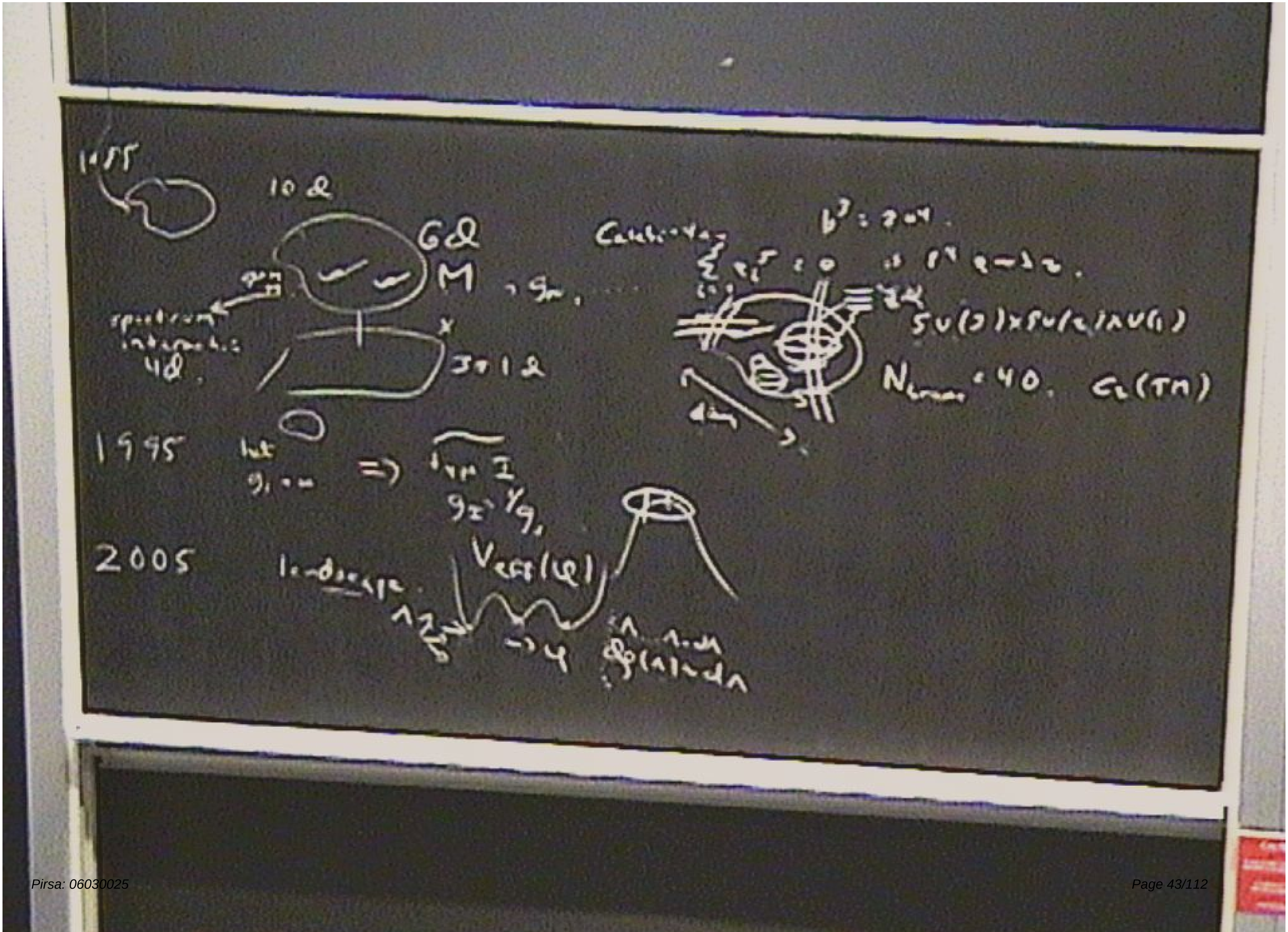
1995
2005
landscape
SU(3)×SU(2)×U(1)

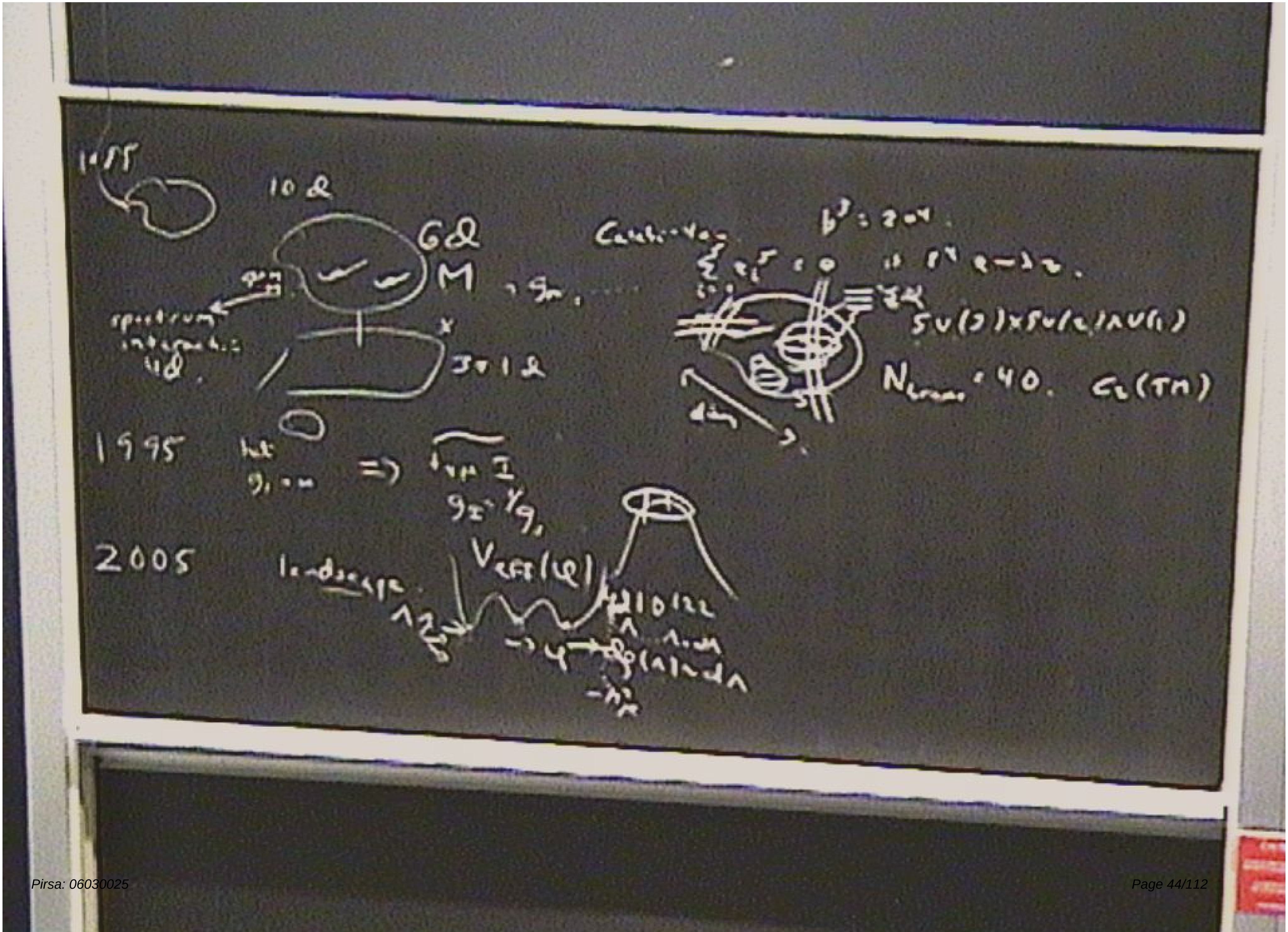


10 d
6 d
M
spectrum
interactions
4d
3+1 d
Calabi-Yau
$b^3 = 204$
$SU(3) \times SU(2) \times U(1)$
$N_{branes} = 40$
1995
het
$g_s \to \infty \Rightarrow$ type I
$g_I \sim 1/g_s$
2005
landscape
$V_{eff}(\varphi)$


10 d
M
spectrum
interactions
4d
3+1 d
1995
2005
landscape
Calabi-Yau
SU(3)xSU(2)xU(1)


10 d
G2
M
spectrum
4d
3+1 d
1995
2005
Calabi-Yau
SU(3)×SU(2)×U(1)
N = 40.
V_eff(φ)


10 d
M
spectrum
interactions
4d
1995
type I
2005
landscape
Calabi-Yau
SU(3)×SU(2)×U(1)
N = 40
Veff(φ)



10 d
6 d
M
spectrum
interactions
4d
3+1 d
Calabi-Yau
SU(3)xSU(2)xU(1)
1995
het
type I
2005
landscape
Veff(φ)
10^122

cosmological

$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi T_{\mu\nu} + \Lambda g_{\mu\nu}$

$\ll (100\ \text{meV})^4$

$\Lambda \sim O$

$\sim 10^{-122} M_{planck}^4$

$10^{-50} M_{part}^4$

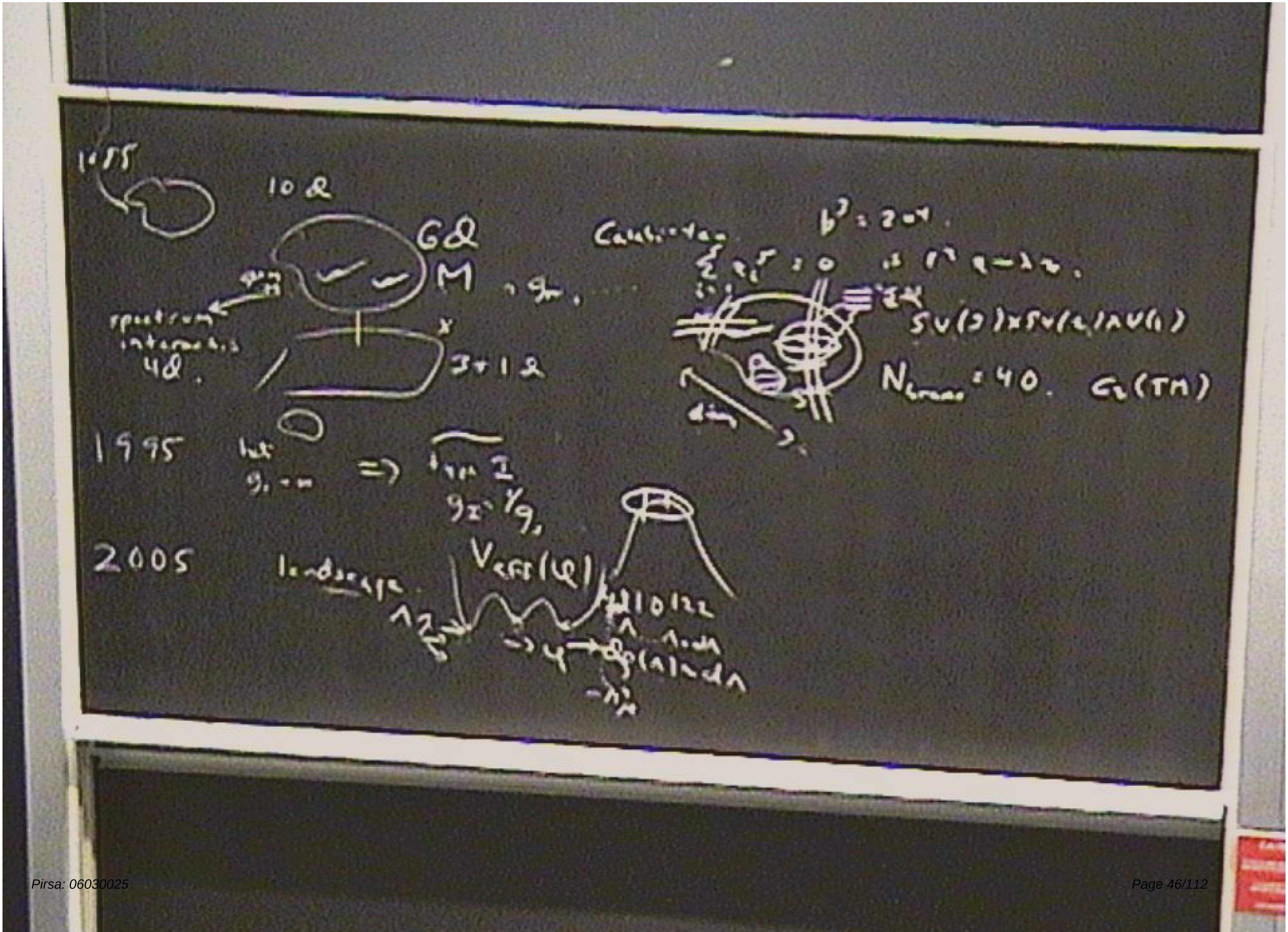
late 90's

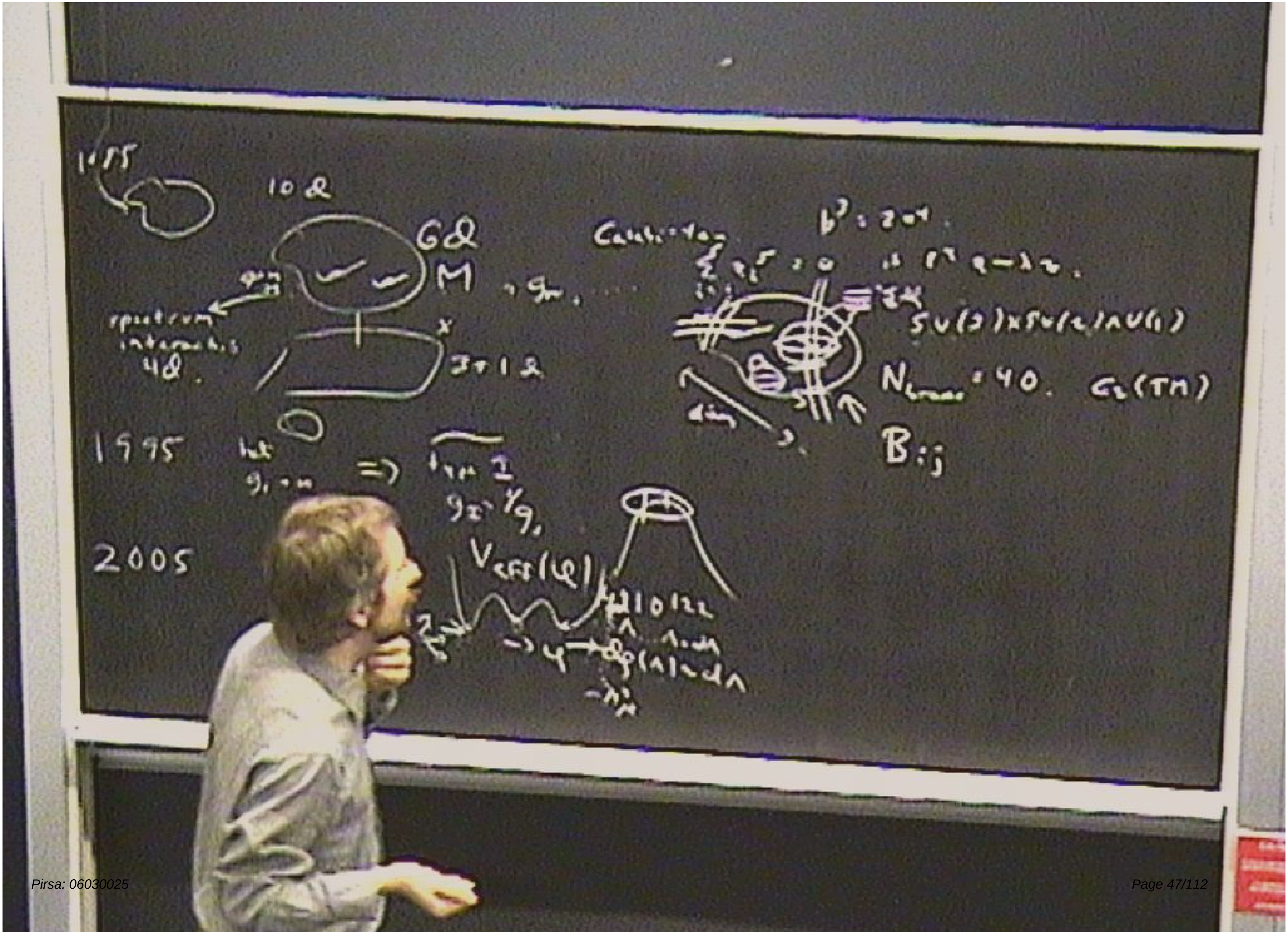
$\Rightarrow$ SN ...

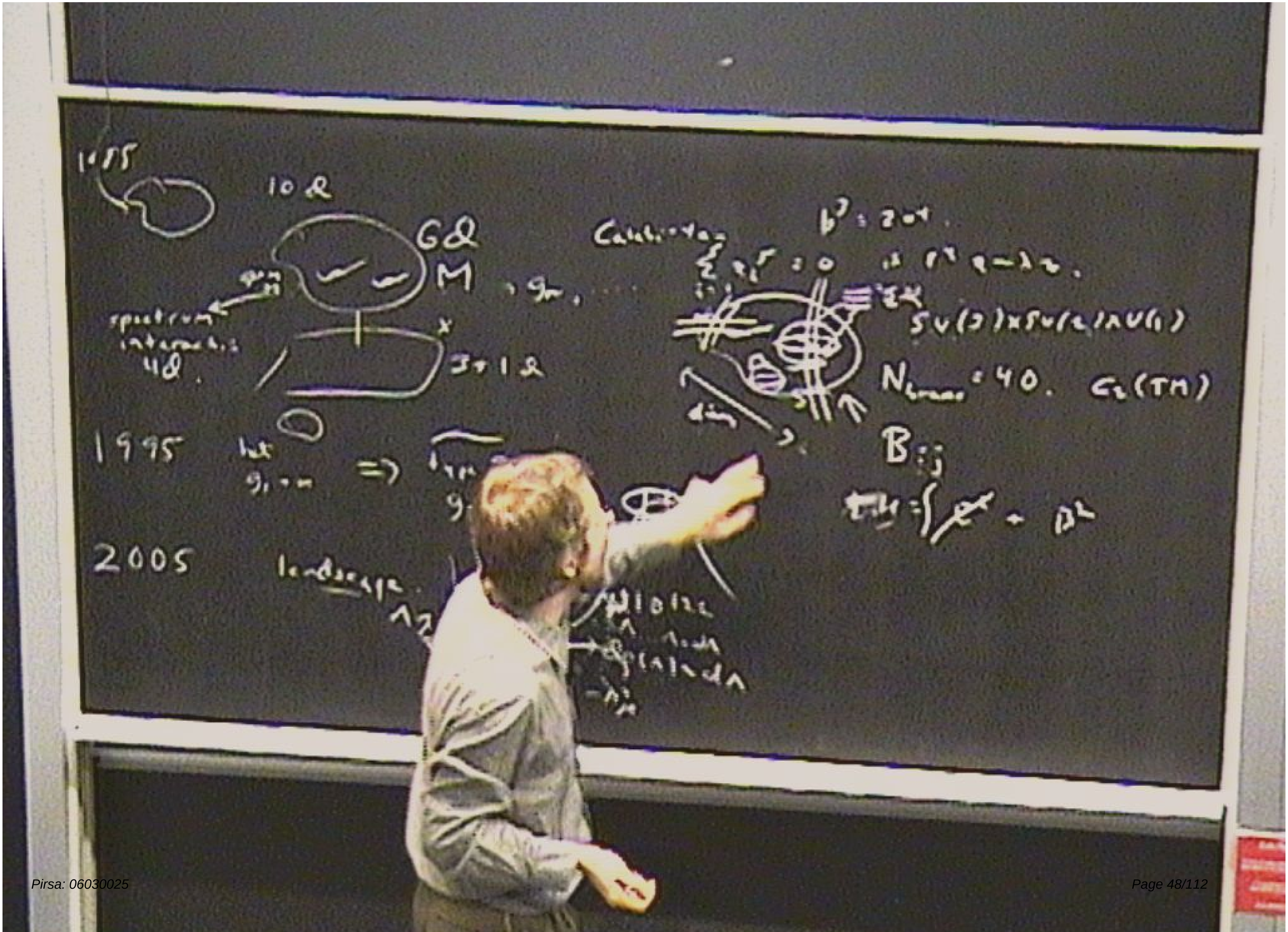
WMAP

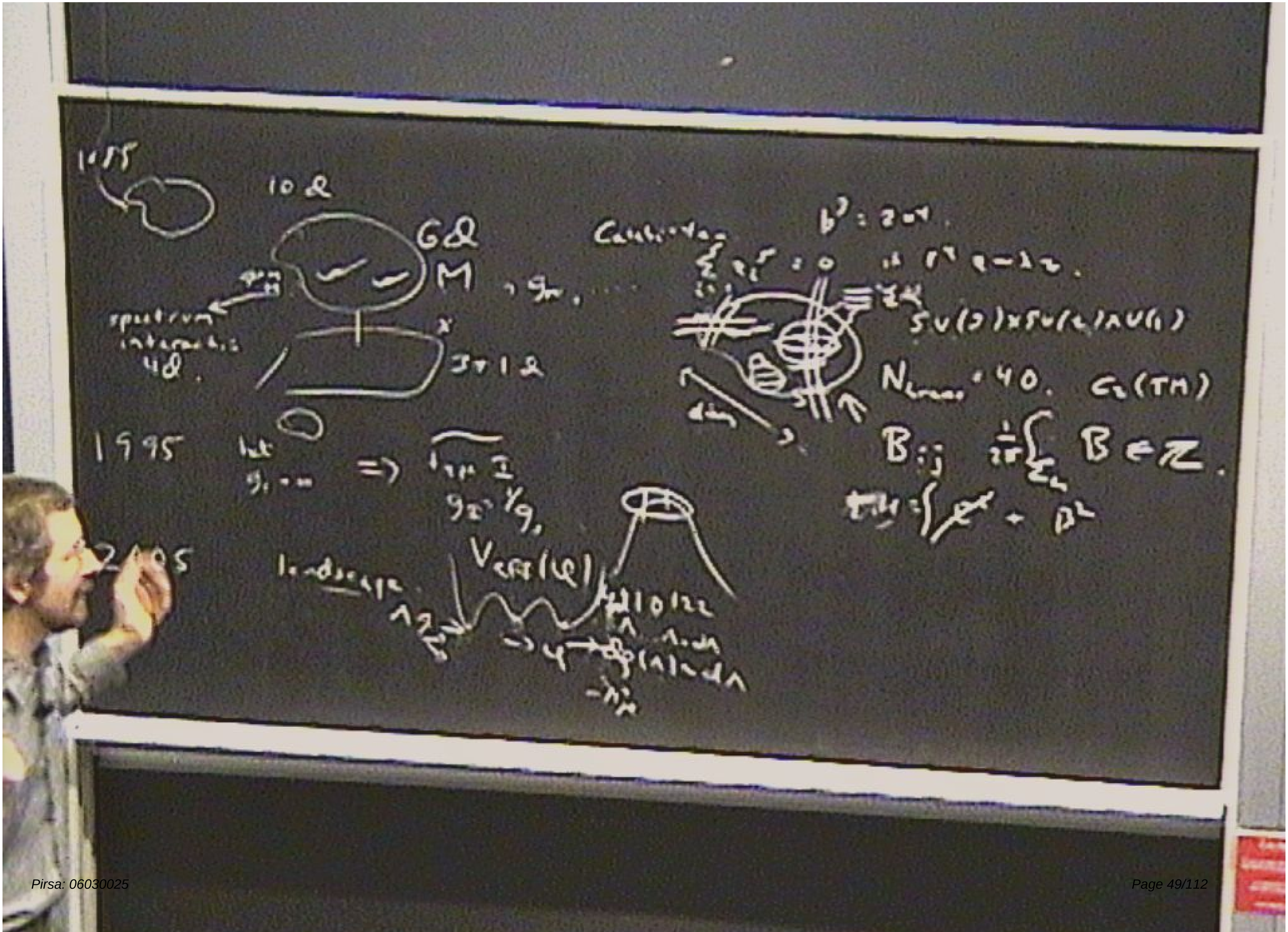
$\Lambda > 0$

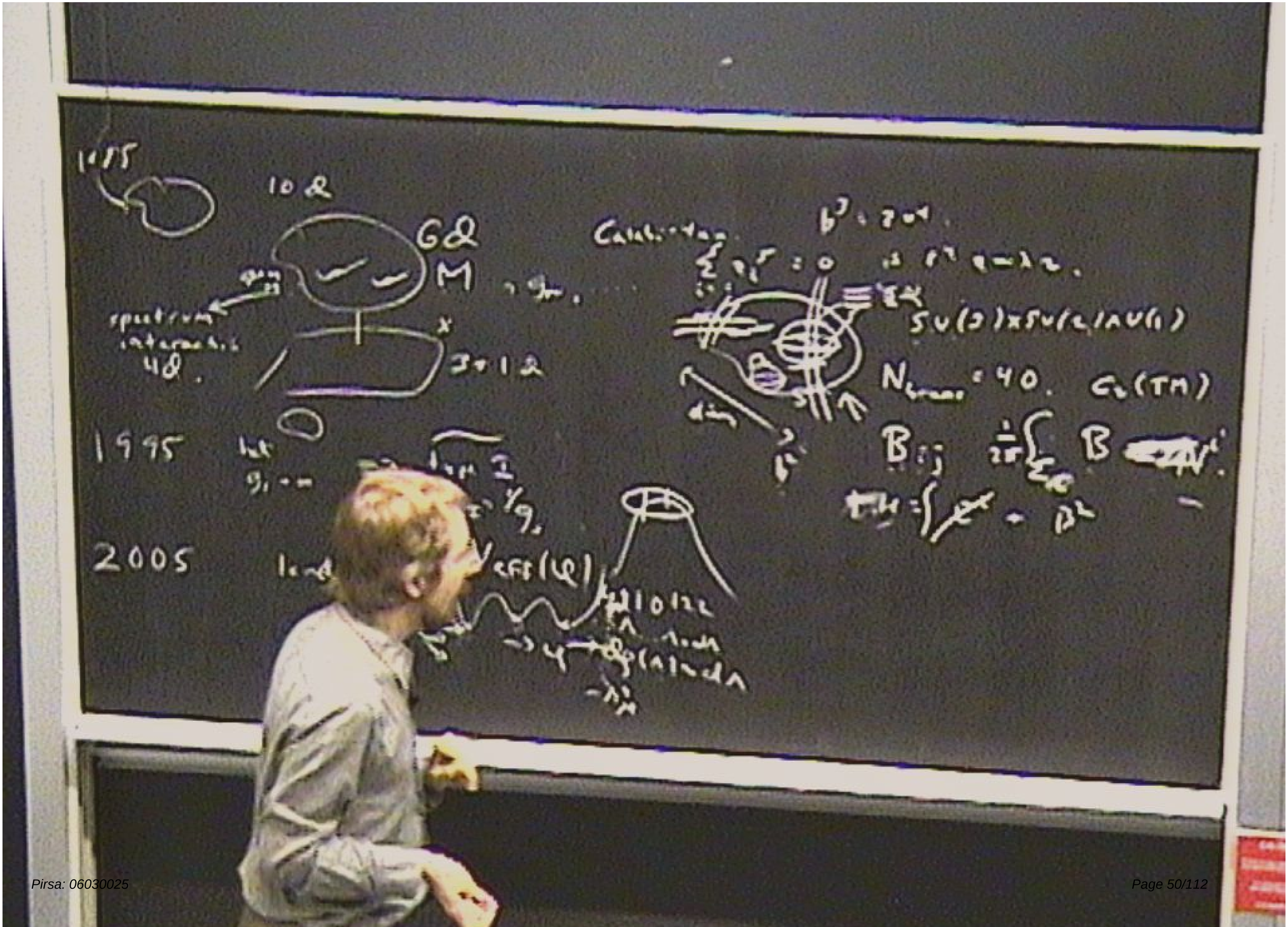
$\sim 0.71 \Omega_c$

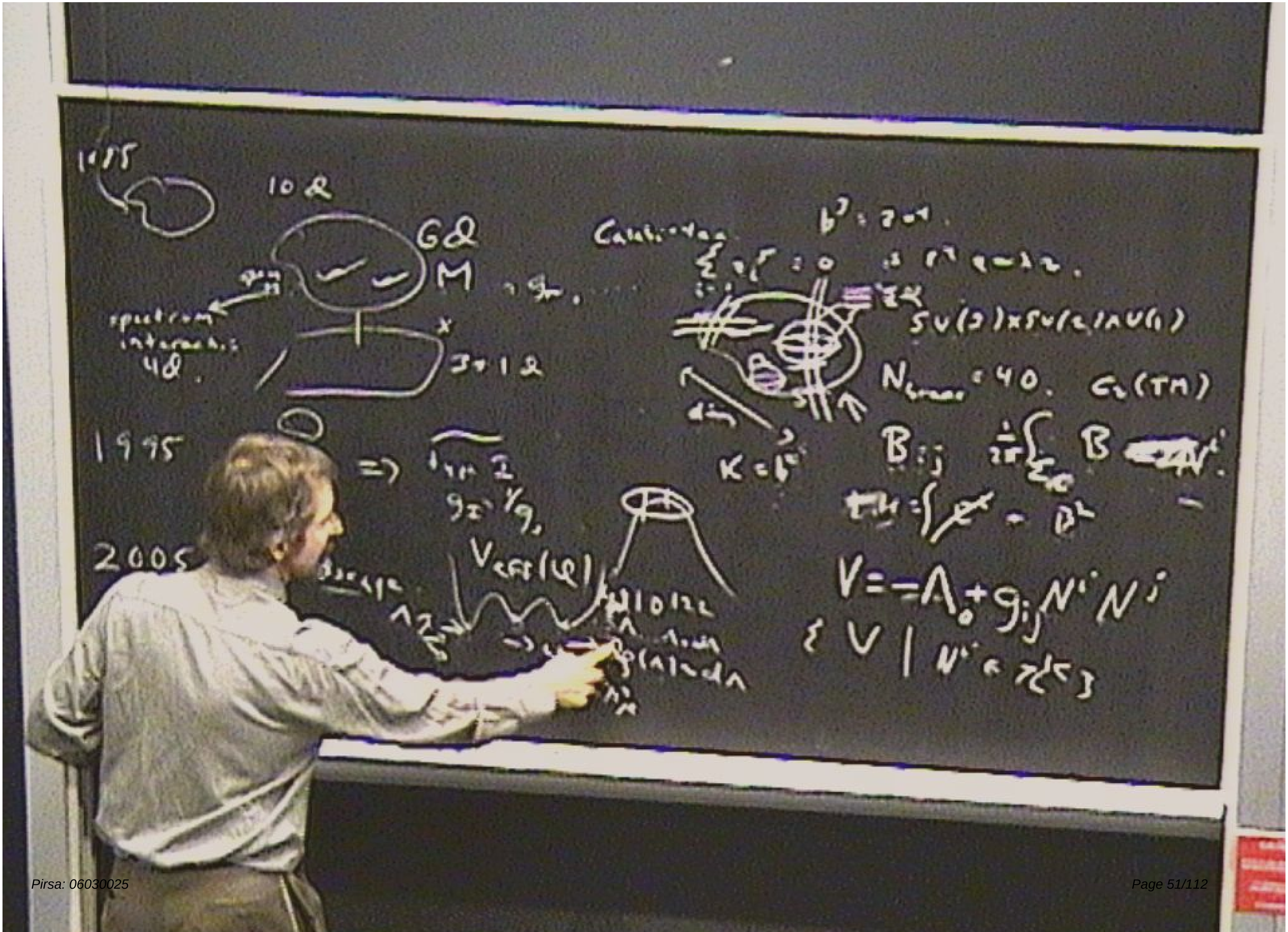

10 d
GR
M
spectrum
interactions
4d
3+1 d
Calabi-Yau
SU(3)×SU(2)×U(1)
N = 40
1995
2005
landscape
V_eff(φ)
10^122


10d
GR
M
spectrum
interactions
4d.
3+1 d
1995
2005
$V_{eff}(\varphi)$
Calabi-Yau
SU(3)xSU(2)xU(1)
N_{branes} = 40.
$G_2(TM)$

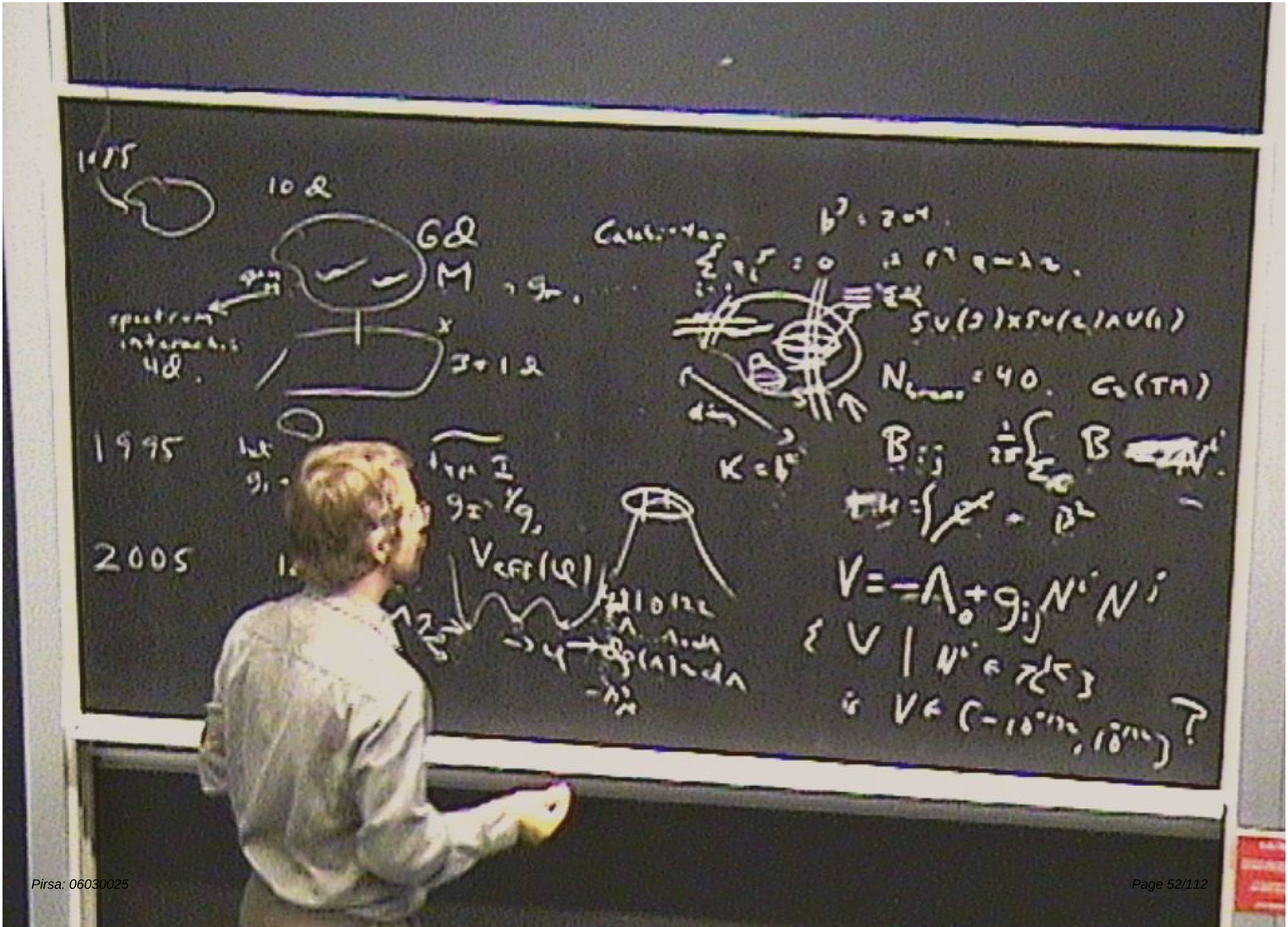

10 d
GR
M
spectrum
interactions
4d
3+1 d
1995
2005
landscape
Calabi-Yau
SU(3)xSU(2)xU(1)
N = 40
B

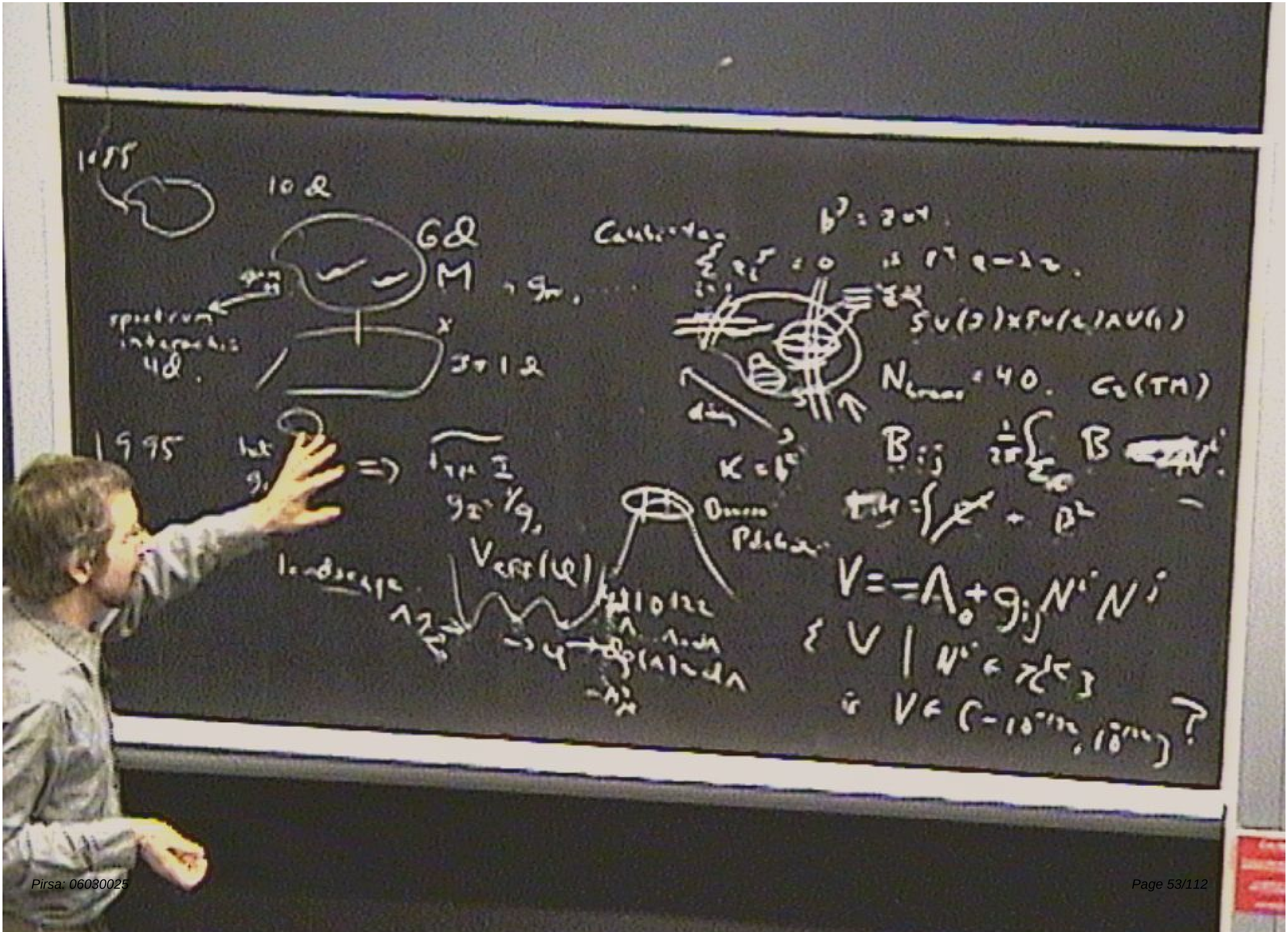

10 d
GR
M
spectrum
interactions
4d.
3+1 d
1995
Calabi-Yau
b³ = 204.
SU(3)×SU(2)×U(1)
N = 40.
c₂(TM)
B ∈ Z.
landscape
Veff(φ)

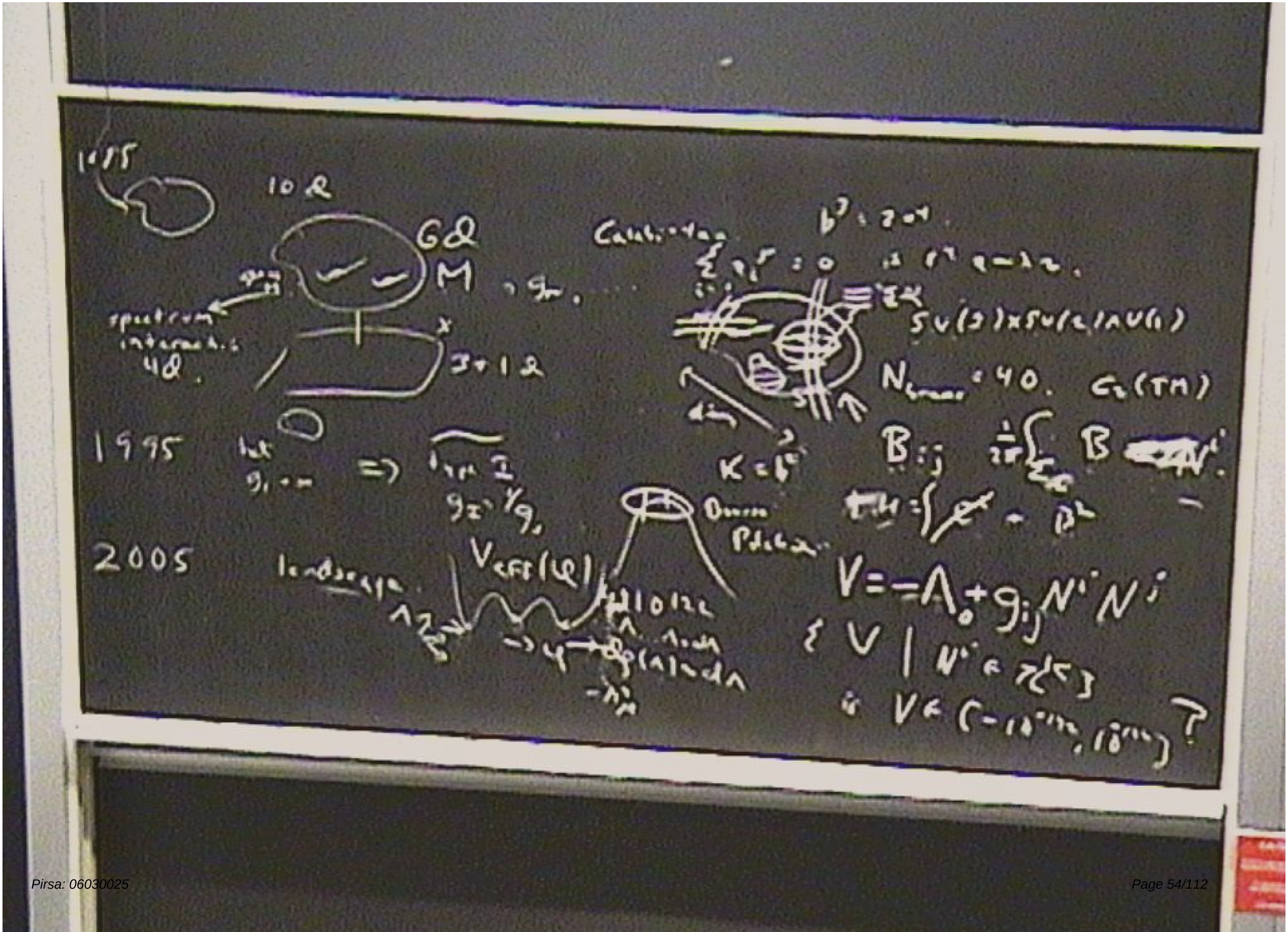

1995
2005
spectrum
SU(3)xSU(2)xU(1)

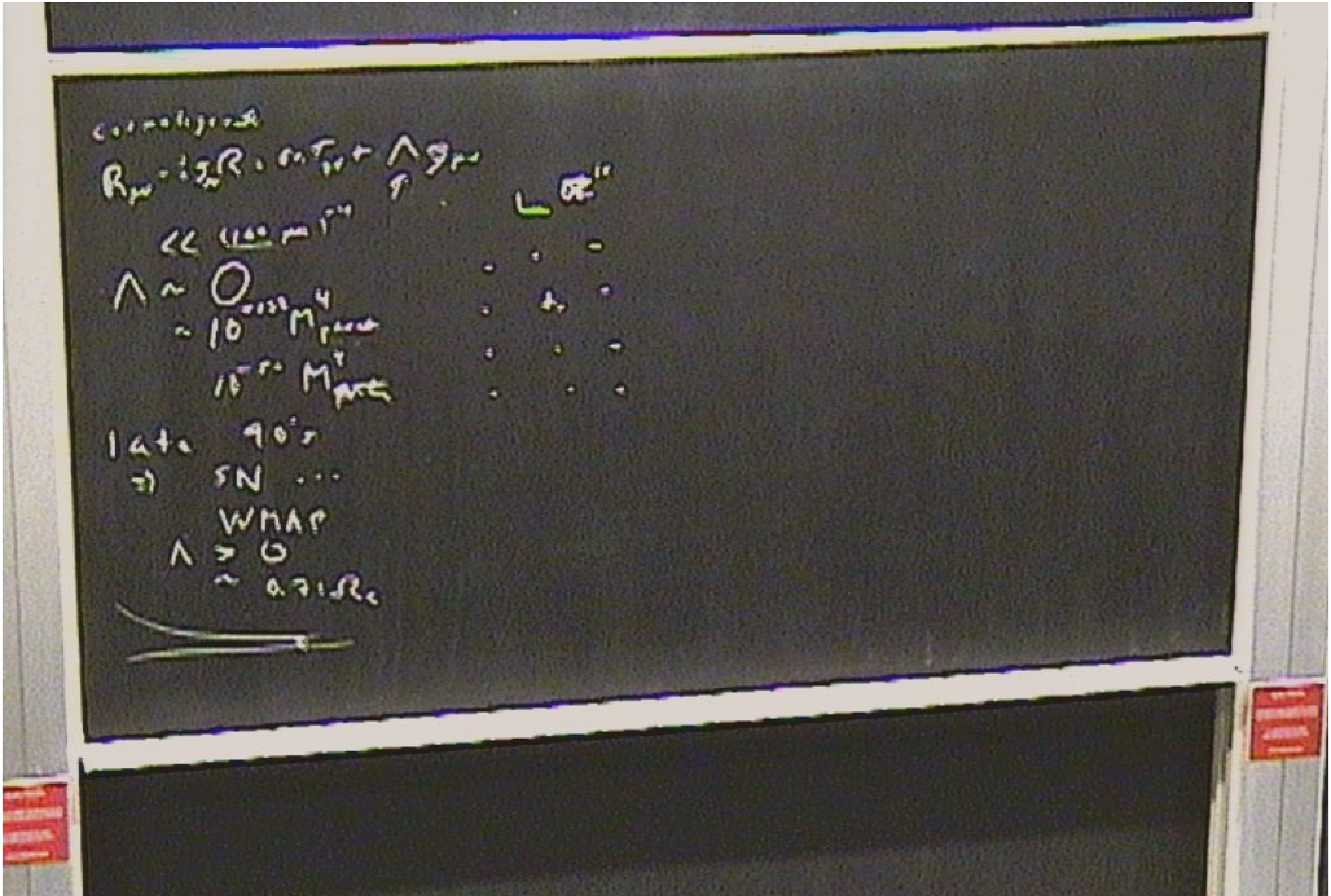


10 d
G d
M
spectrum
interactions
4d
3+1 d
1995
2005
SU(3)xSU(2)xU(1)
V_eff(φ)
V = -Λ0 + g_ij N^i N^j


10 d
GR
M
spectrum
interactions
4d
3+1 d
1995
2005
Calabi-Yau
SU(3)xSU(2)xU(1)
N = 40
V = -Λ₀ + g_ij N^i N^j


1985
10d
G2
M
spectrum
interactions
4d.
3+1 d
1995
SU(3)×SU(2)×U(1)
landscape
Veff(φ)
V = −Λ0 + gij N^i N^j


10 d
GR
M
spectrum
interactions
4d
3+1 d
1995
2005
landscape
$V_{eff}(\varphi)$
Calabi-Yau
$SU(3) \times SU(2) \times U(1)$
$N = 40$
$V = -\Lambda_0 + g_{ij} N^i N^j$


cosmological
late 90's
SN ...
WMAP
Λ > 0

cosmological

$$R_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} R = 8\pi G\, T_{\mu\nu} + \Lambda g_{\mu\nu}$$

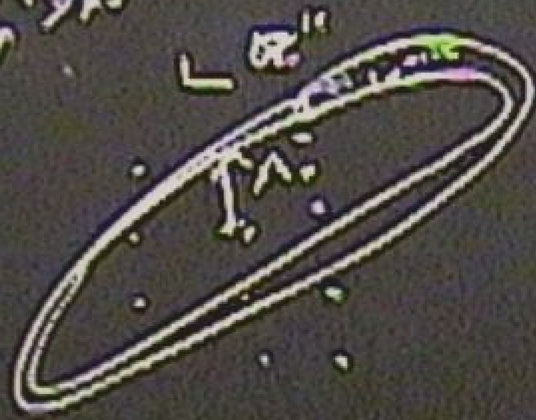
?

$\ll (100\ \mathrm{meV})^4$

$\Lambda \sim O$

$\sim 10^{-123} M_{planck}^4$

$10^{-50} M_{GUT}^4$



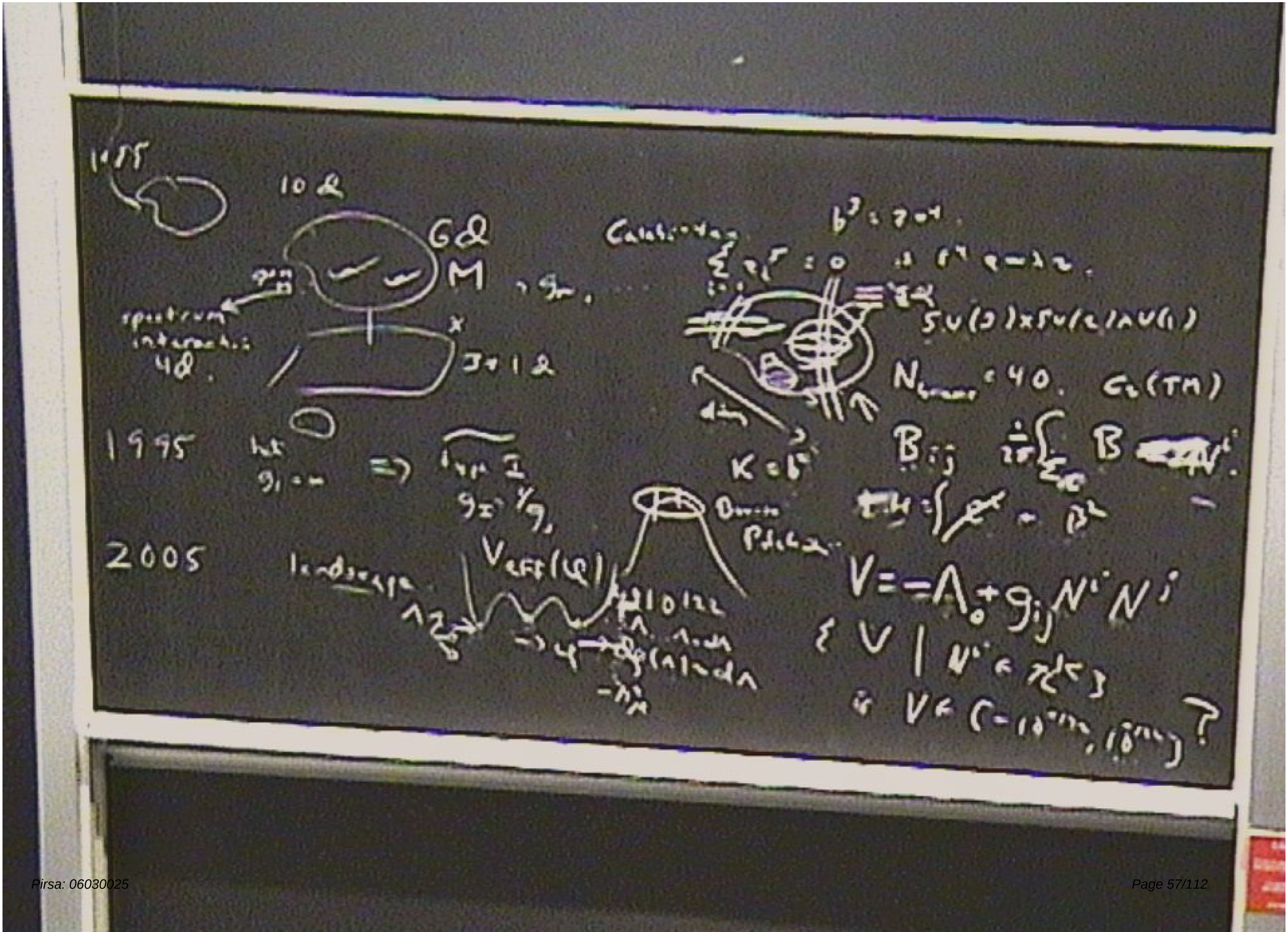
late 90's

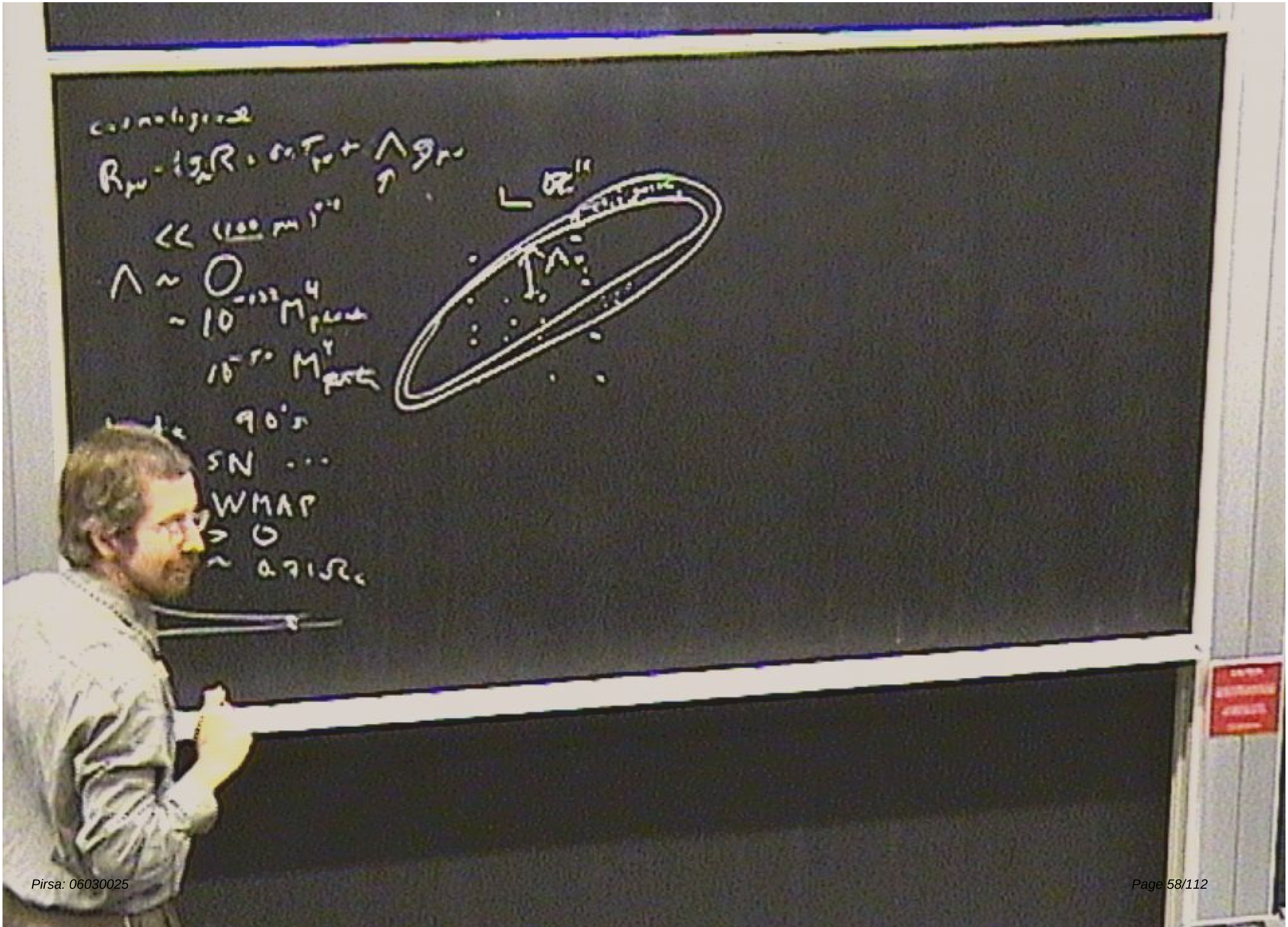
$\Rightarrow$ SN ...

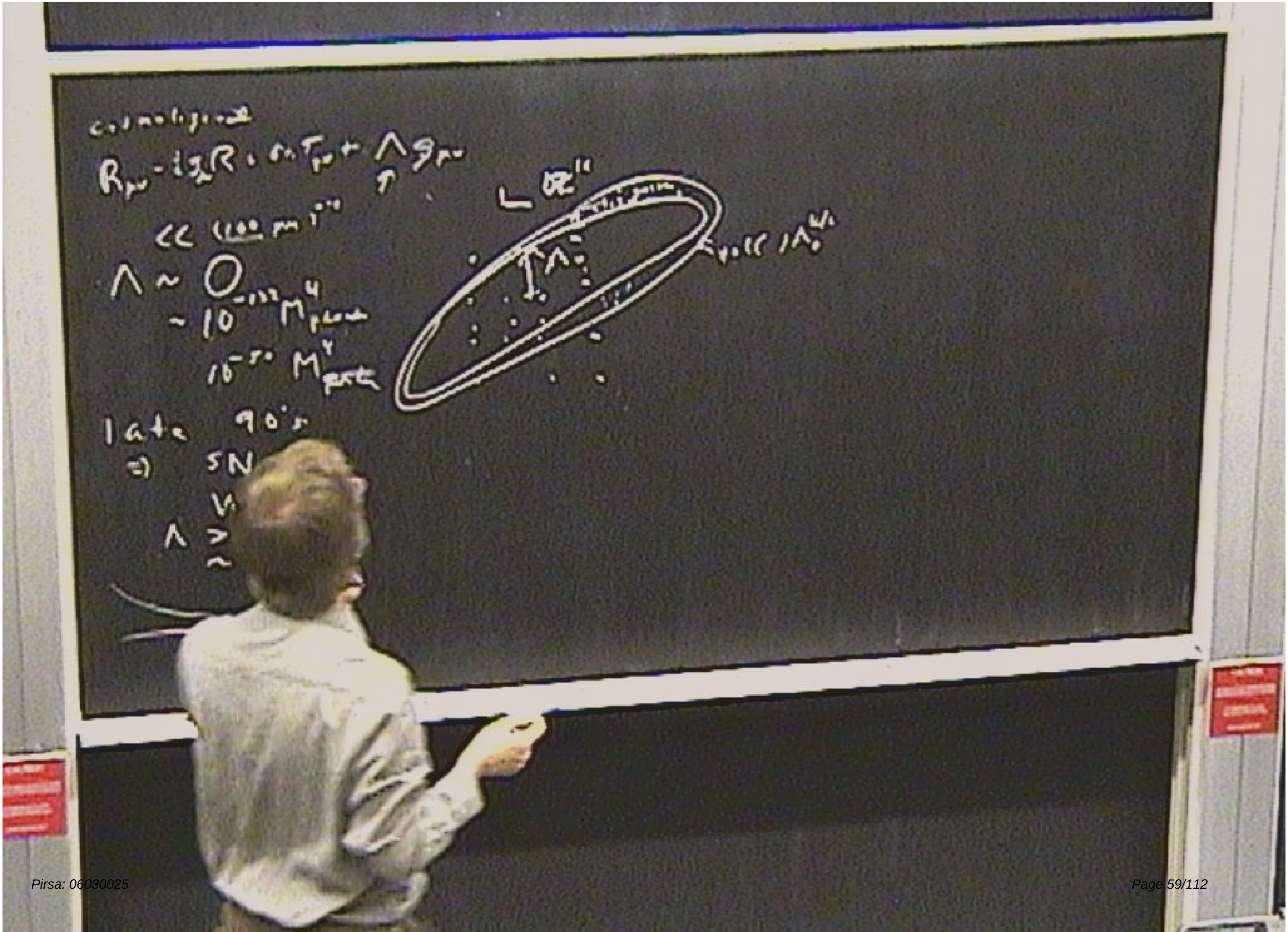
WMAP

$\Lambda > 0$

$\sim 0.71 \Omega_c$


1985
10 d
GR
M
spectrum
interactions
4d
3+1 d
Calabi-Yau
b^3 = 204
SU(3)xSU(2)xU(1)
N = 40
c_2(TM)
B_ij
K = b^3
1995
type I
2005
landscape
V_eff(φ)
10^122
V = -Λ_0 + g_ij N^i N^j


cosmological
90's
SN ...
WMAP


late 90's
SN

cosmological

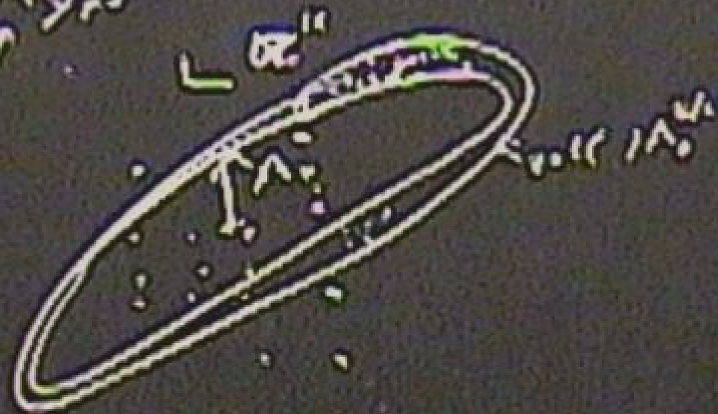
$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G T_{\mu\nu} + \Lambda g_{\mu\nu}$

$\ll (100\ \mathrm{meV})^4$

$\Lambda \sim O$

$\sim 10^{-120} M_{planck}^4$

$10^{-50} M_{part}^4$



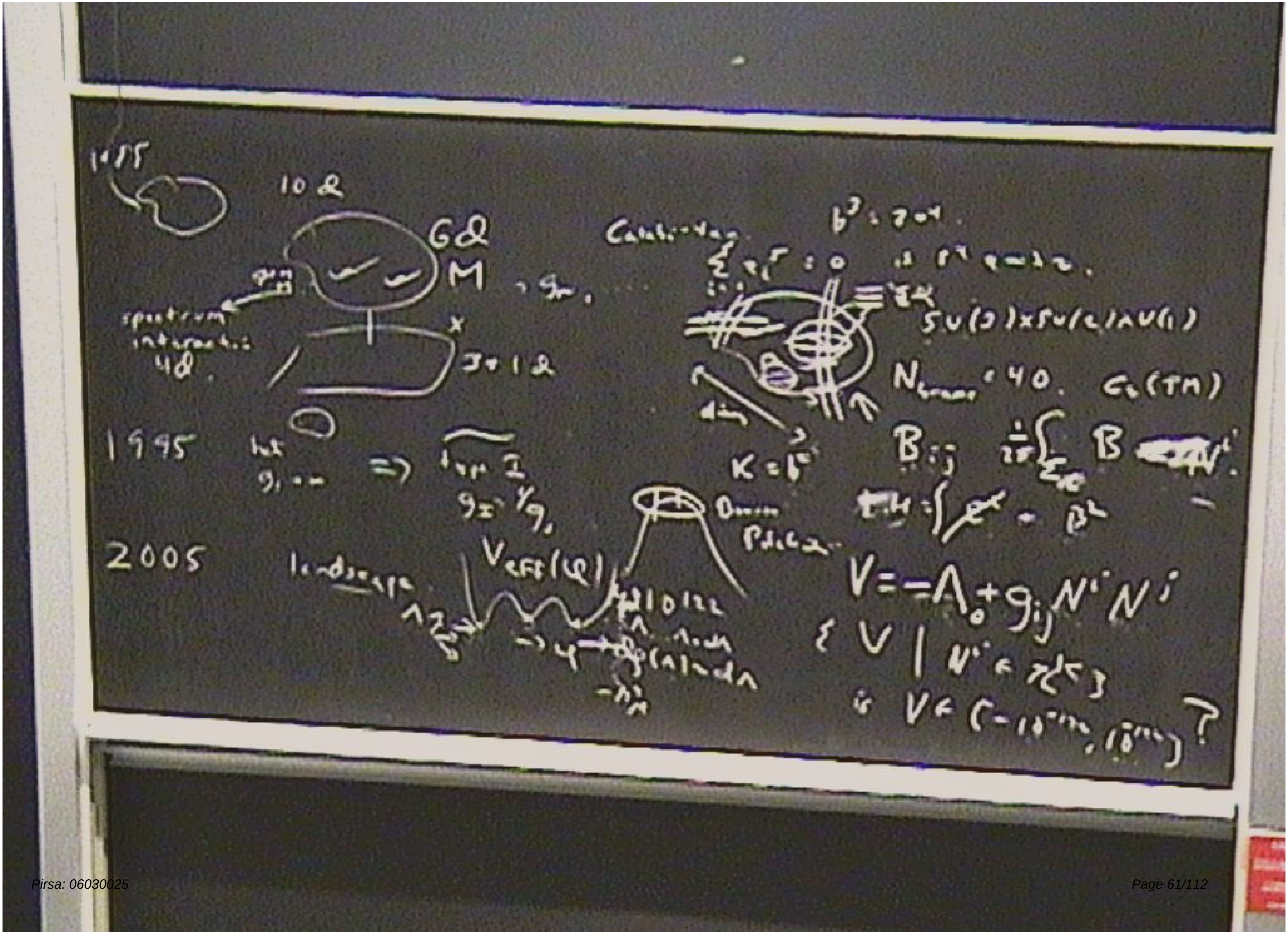
late 90's

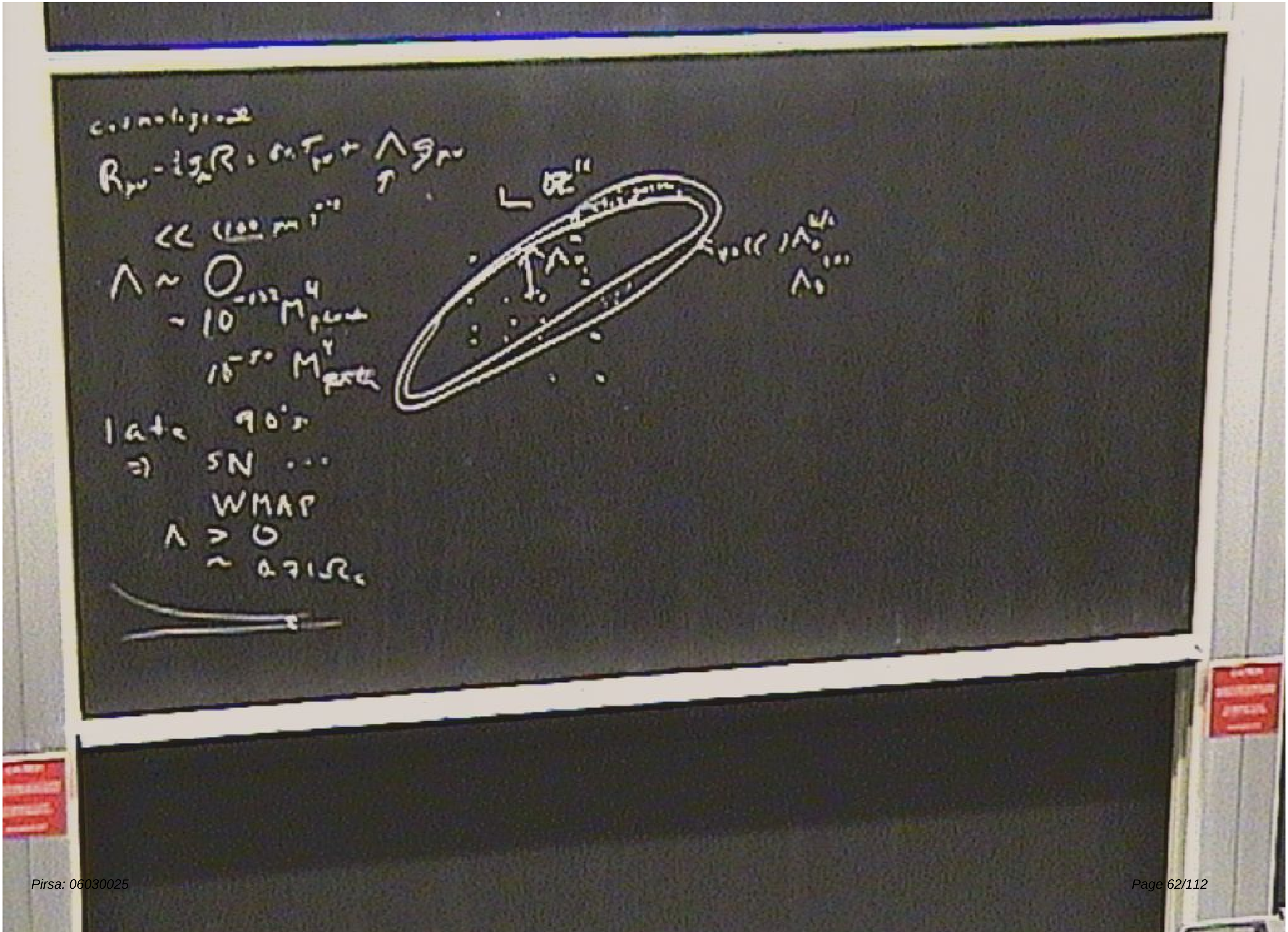
$\Rightarrow$ SN ...

WMAP

$\Lambda > 0$

$\sim 0.7 \Omega_c$


10 d
GR
M
spectrum
interactions
4d
3+1 d
1995
type I
$g_I = 1/g_1$
2005
landscape
$V_{eff}(\varphi)$
10^{122}
Calabi-Yau
$b^3 = 204$
$SU(3)\times SU(2)\times U(1)$
$N_{branes} \sim 40$
$K = b^3$
$V = -\Lambda_0 + g_{ij}N^iN^j$
$\{ V \mid N^i \in \mathbb{Z}^K \}$
?


cosmological
$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G T_{\mu\nu} + \Lambda g_{\mu\nu}$
$\ll (100\ \mathrm{meV})^4$
$\Lambda \sim O$
$\sim 10^{-122} M_{planck}^4$
$10^{-50} M_{particle}^4$
late 90's
$\Rightarrow$ SN ...
WMAP
$\Lambda > 0$
$\sim 0.71\,\Omega_c$

cosmological

$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi T_{\mu\nu} + \Lambda g_{\mu\nu}$

$\ll (100\ \mathrm{m})^{-4}$

$\Lambda \sim O$

$\sim 10^{-122} M_{planck}^4$

$10^{-50} M_{ptcle}^4$

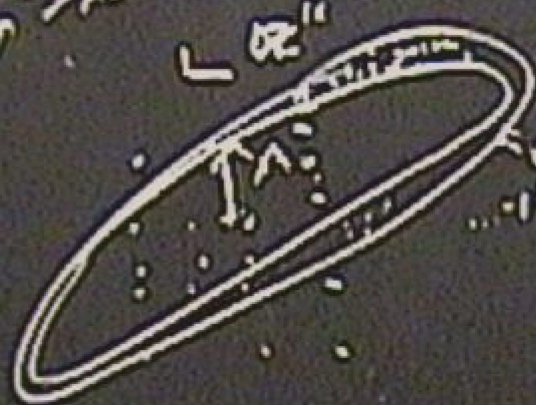
late 90's

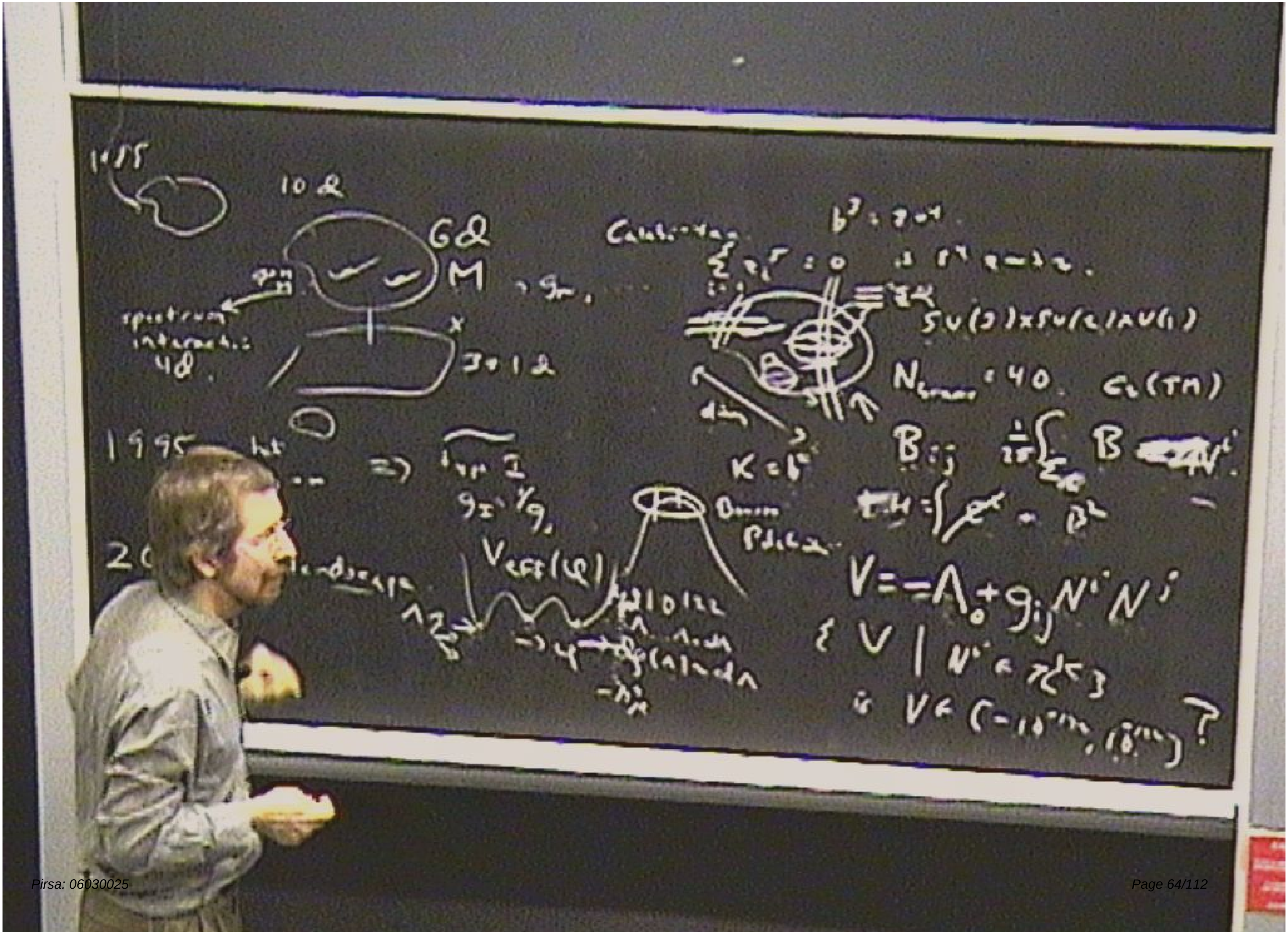
$\Rightarrow$ SN ...

WMAP

$\Lambda > 0$

$\sim 0.71\,\Omega_c$




10 d
GR
M
spectrum
interactions
4d
3+1 d
1995
Calabi-Yau
SU(3)×SU(2)×U(1)
N = 40
B
V_eff(φ)
landscape
10^122
V = −Λ_0 + g_ij N^i N^j
{ V | N^i ∈ Z }

cosmological const

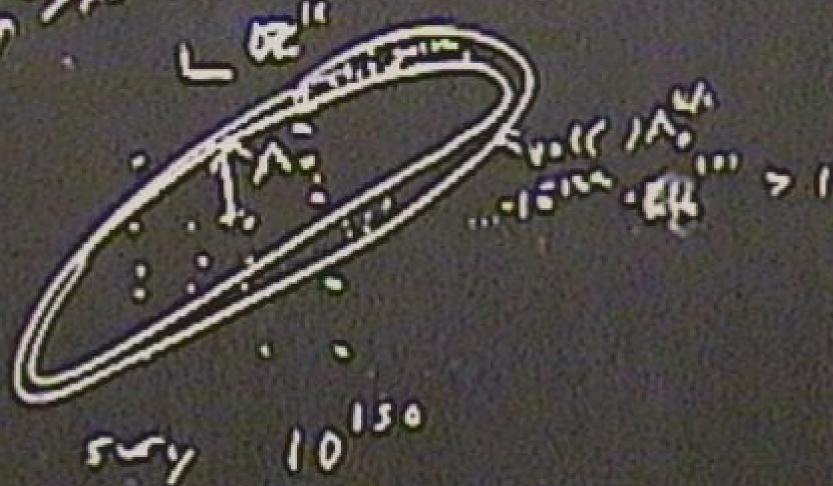
$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi T_{\mu\nu} + \Lambda g_{\mu\nu}$

$\ll (100\ \mathrm{meV})^4$

$\Lambda \sim 0$

$\sim 10^{-122} M_{planck}^4$

$10^{-50} M_{part}^4$



late 90's

$\Rightarrow$ SN ...

WMAP

$\Lambda > 0$

$\sim 0.71\,\Omega_c$

cosmological

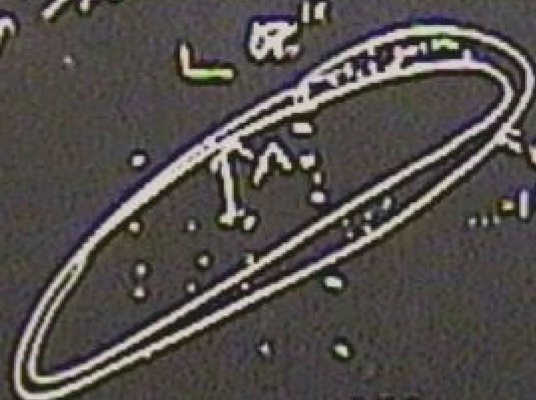
$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi T_{\mu\nu} + \Lambda g_{\mu\nu}$

$\ll (100\ \mathrm{km})^{-4}$

$\Lambda \sim O$

$\sim 10^{-122} M^4_{planck}$

$10^{-50} M^4_{part}$



$\mathrm{vol}(\ )\Lambda_0^{1/2}$

$\cdots 10^{100} \cdot \ldots > 1$

late 90's

$\Rightarrow$ SN ...

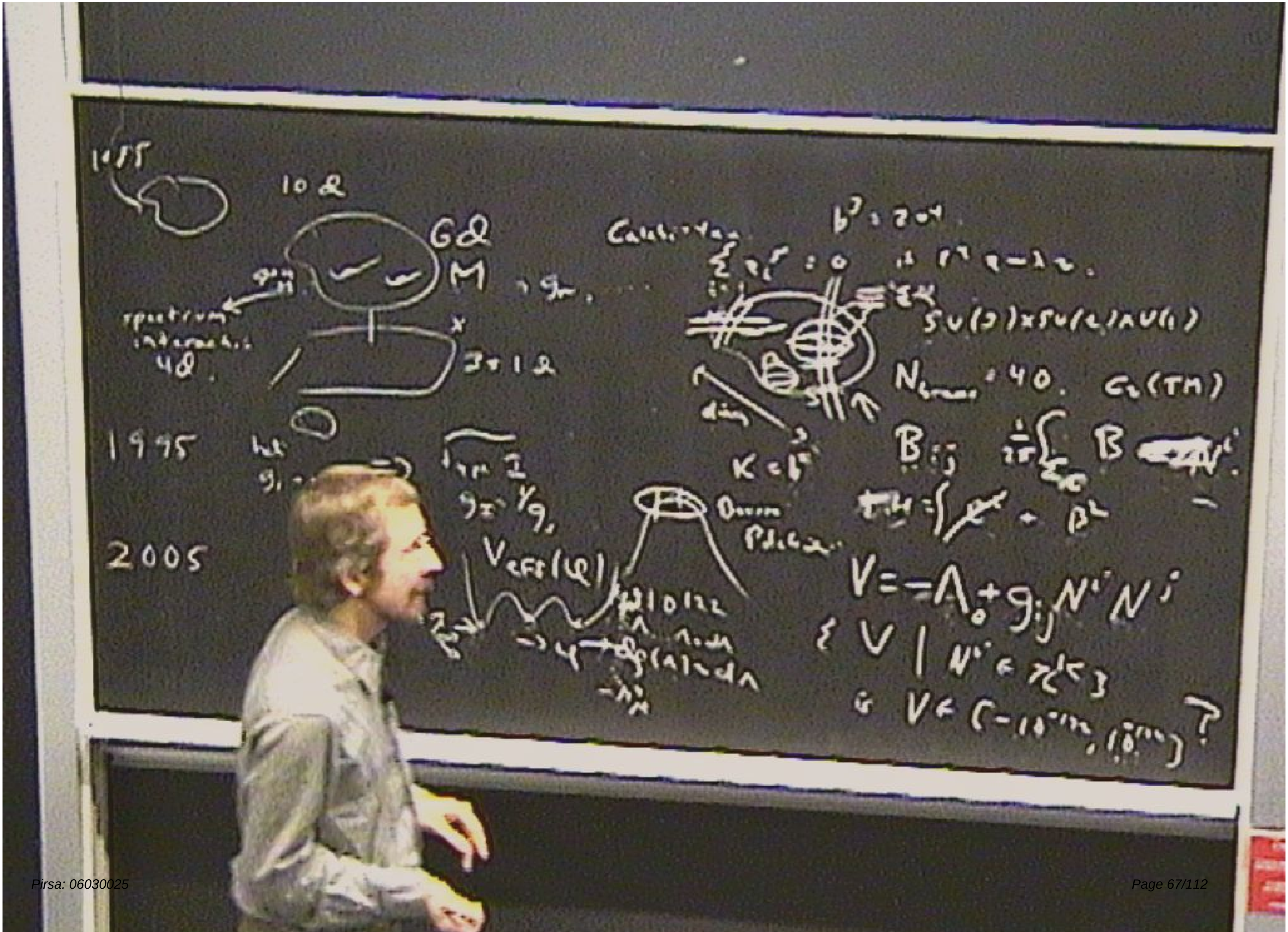
WMAP

$\Lambda > 0$

$\sim 0.71 \Omega_c$

susy 10^{150}

~~susy~~ 10^{100}



10 d
spectrum
interactions
4d
3+1 d
1995
2005
SU(3)×SU(2)×U(1)
$N_{branes} = 40$
$V = -\Lambda_0 + g_{ij} N^i N^j$

cosmological

$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G T_{\mu\nu} + \Lambda g_{\mu\nu}$

$\ll (100\ \mathrm{Mpc})^{-2}$

$\Lambda \sim 0$

$\sim 10^{-122} M_{\mathrm{Planck}}^4$

$10^{-50} M_{\mathrm{Planck}}^4$

late 90's

$\Rightarrow$ SN ...

WMAP

$\Lambda > 0$

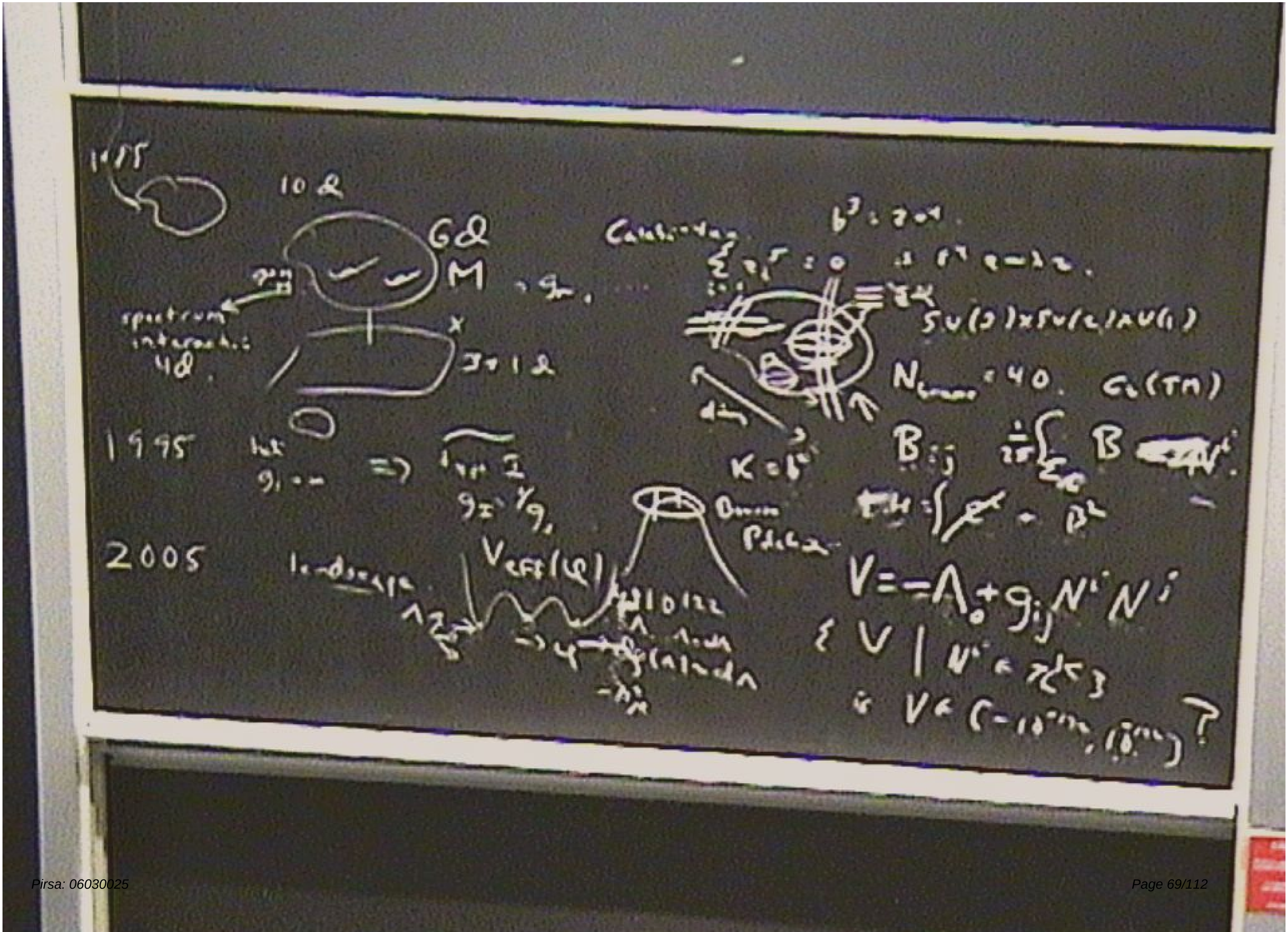
$\sim 0.7\,\Omega_c$

"Λ OK"

Λ_0

$\ldots 10^{500} \ldots \mathrm{Eff}^{100} > 1$

$\mathrm{vol}(S)/\Lambda_0^{1/4}$


10 d
GR
M
spectrum
interactions
4d
3+1 d
1995
2005
landscape
$V_{eff}(\varphi)$
10122
Calabi-Yau
SU(3)xSU(2)xU(1)
40
B
$V=-\Lambda_0+g_{ij}N^iN^j$

cosmological

$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G T_{\mu\nu} + \Lambda g_{\mu\nu}$

$\ll (100\ \mathrm{mm})^{-4}$

$\Lambda \sim 0$

$\sim 10^{-123} M_{planck}^4$

$10^{-50} M_{pert}^4$

Λ_0

vol $/\Lambda_0^{1/4}$

$\ldots 10^{120}$ eff > 1

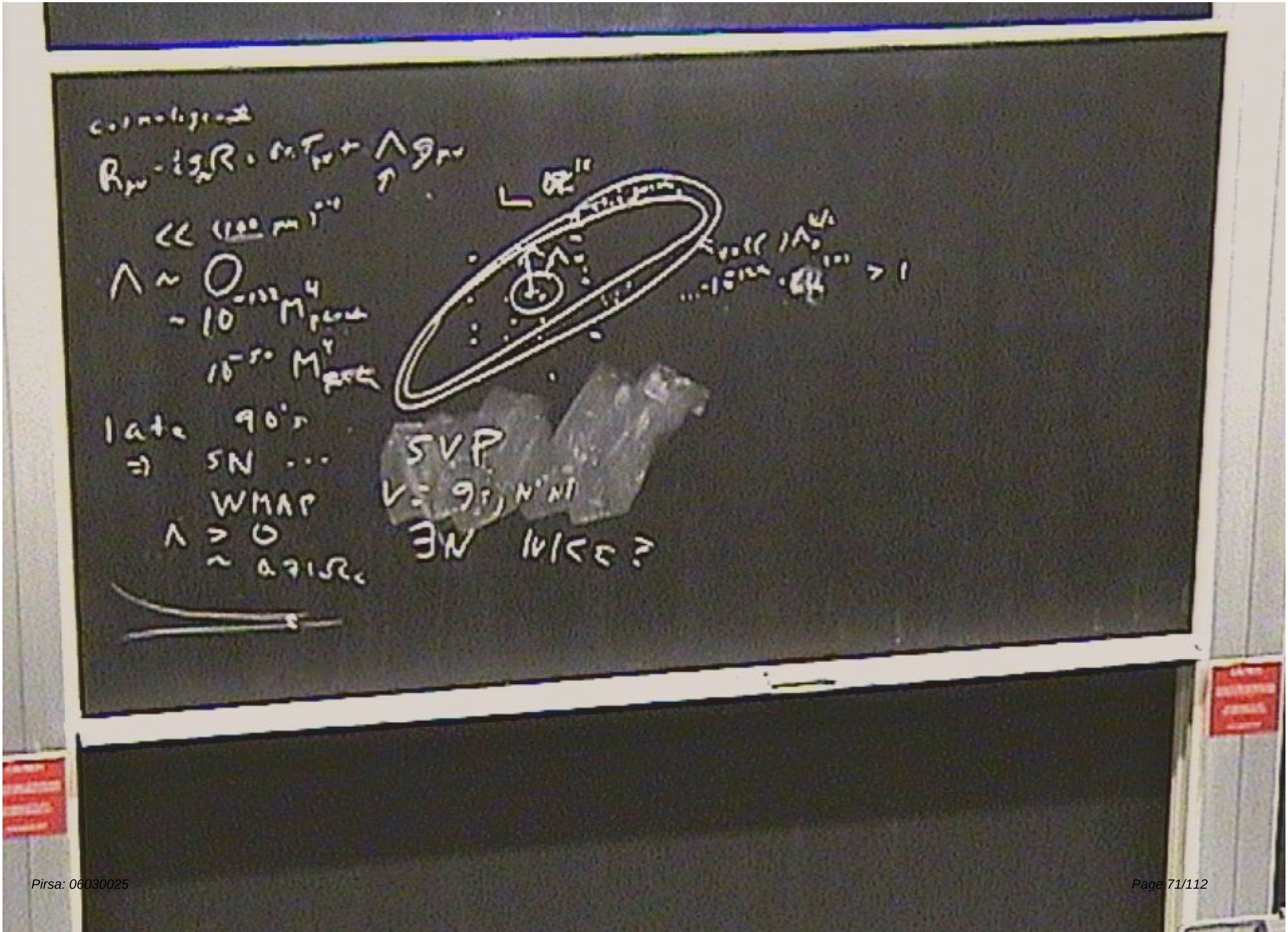
late 90's

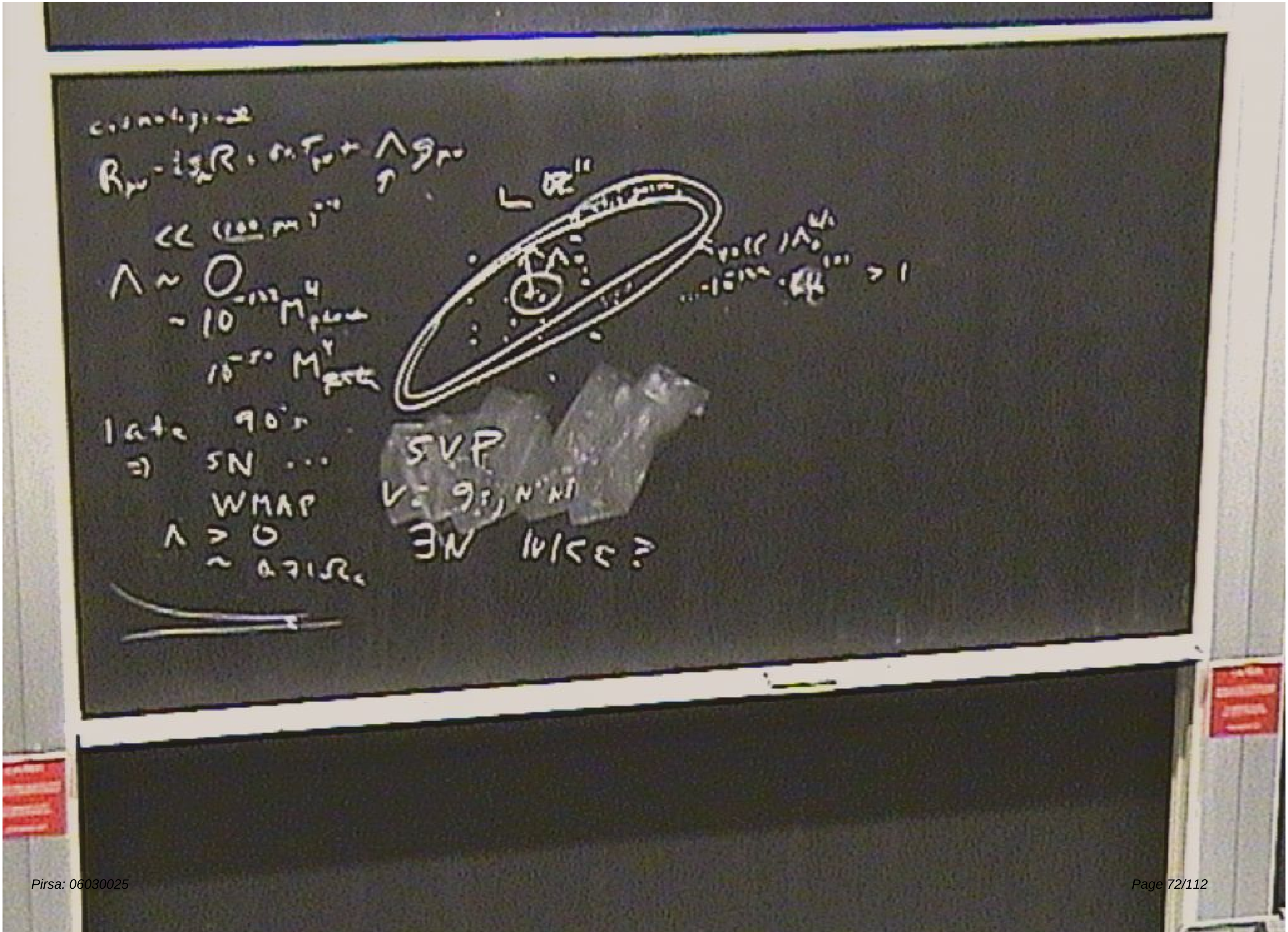
$\Rightarrow$ SN ...

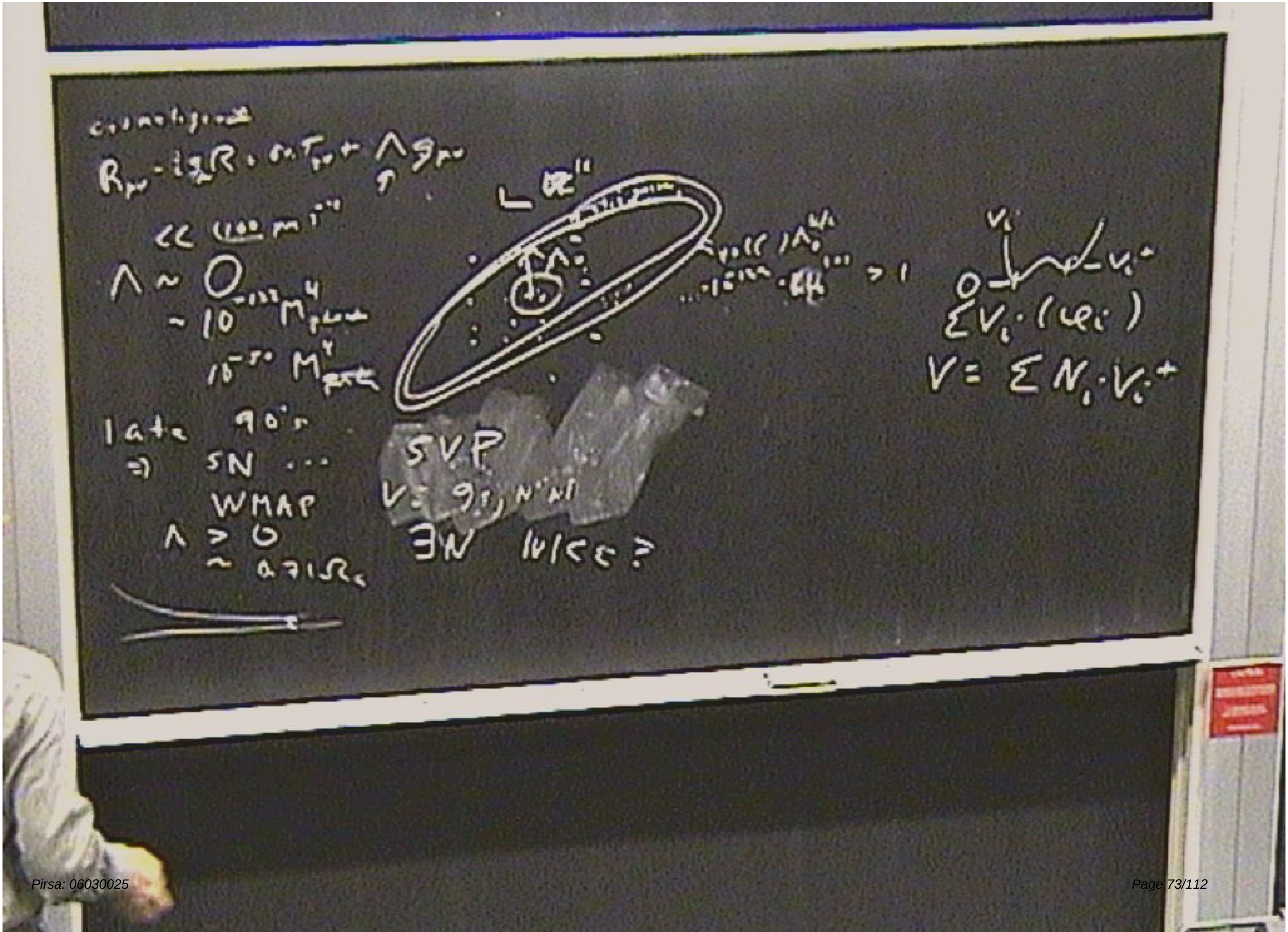
WMAP

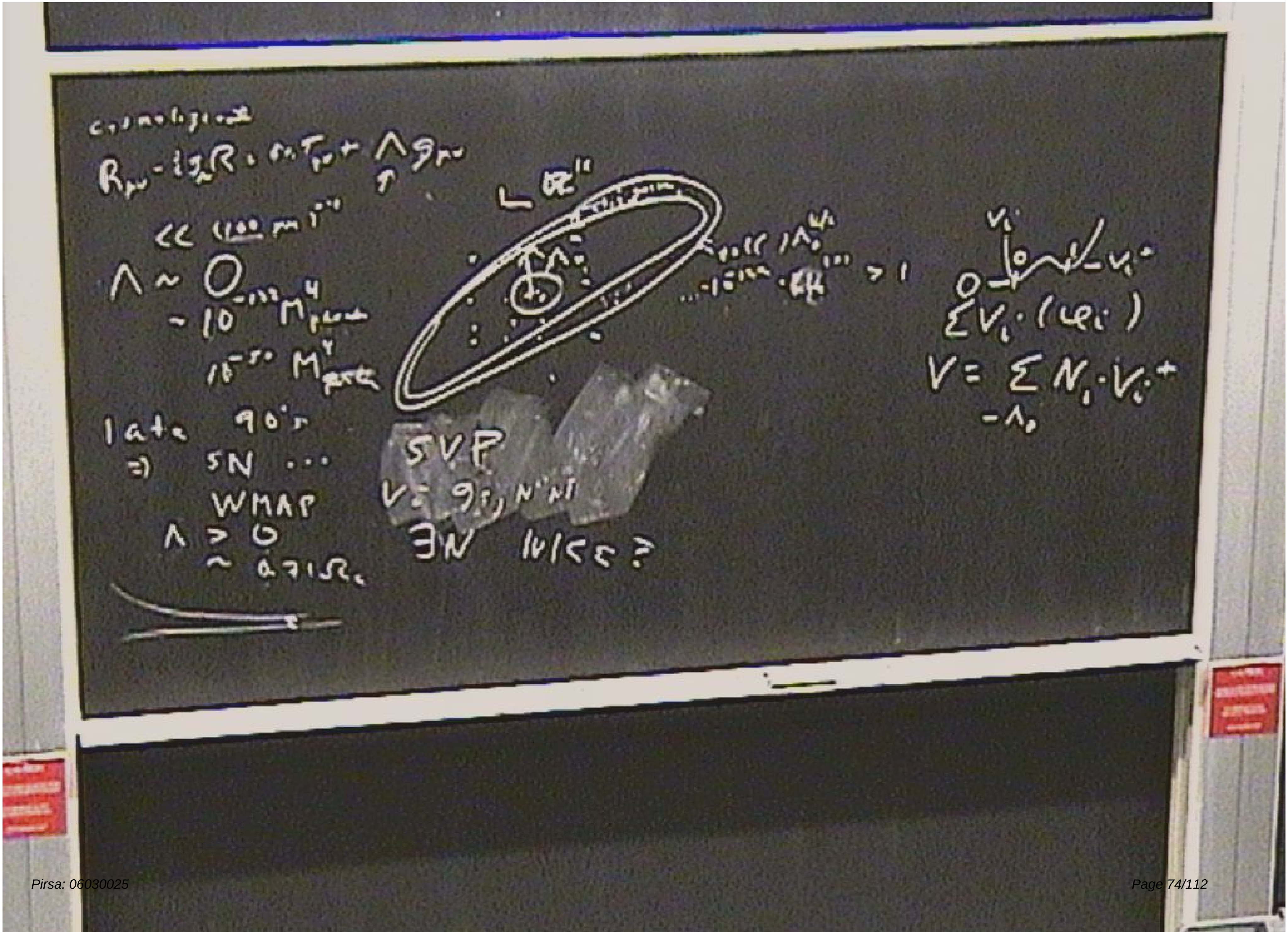
$\Lambda > 0$

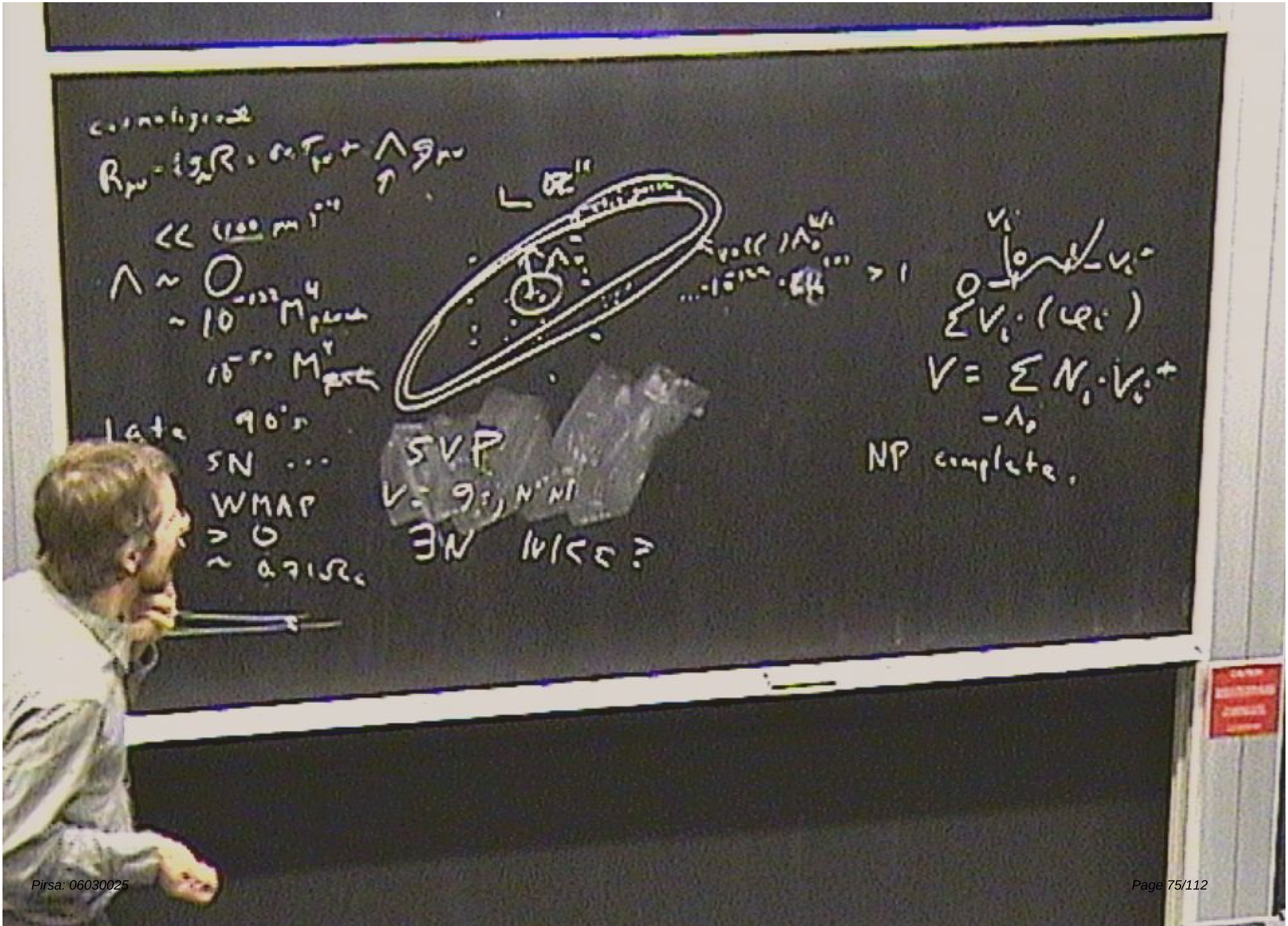
$\sim 0.71\Omega_c$

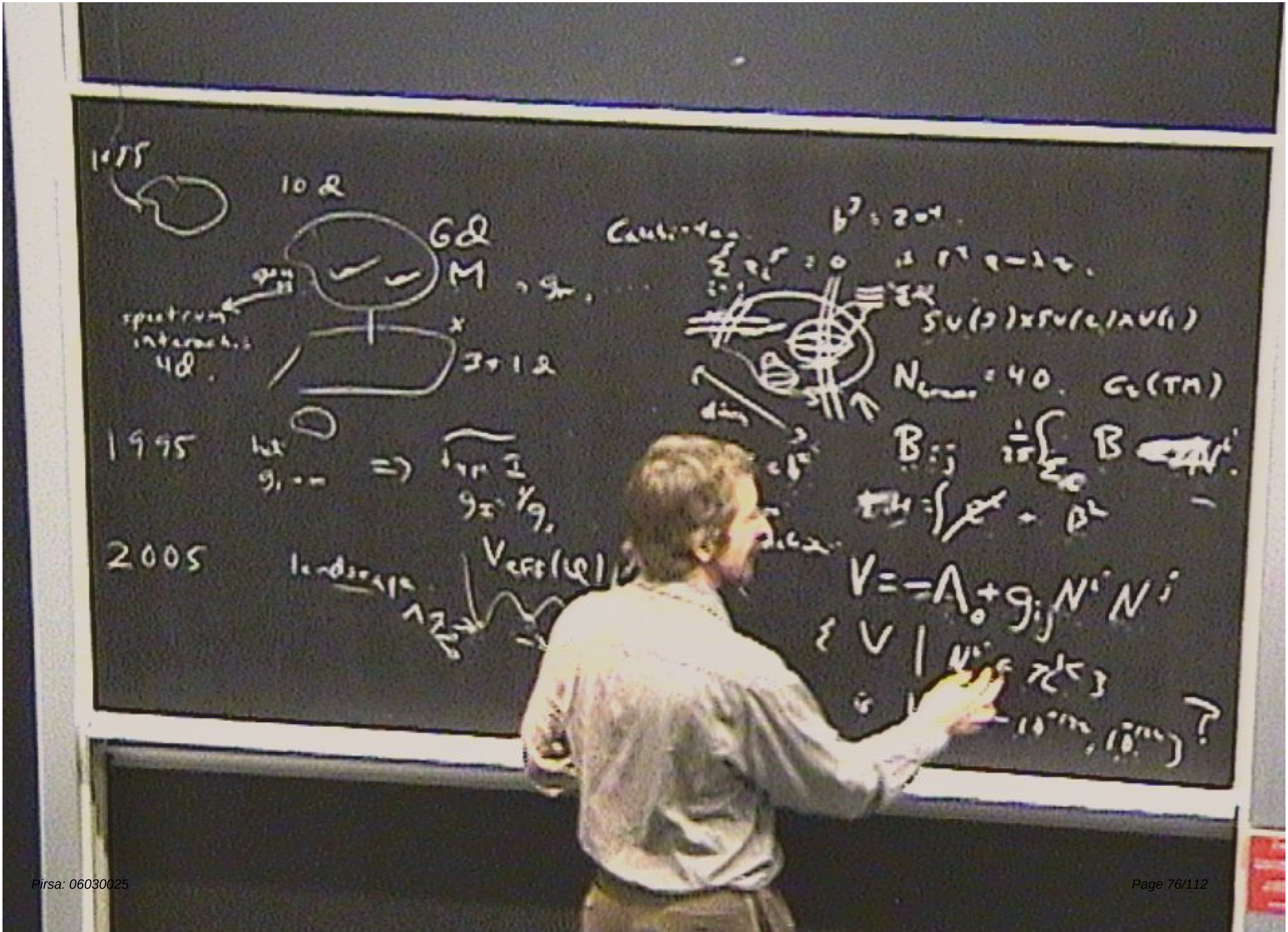

cosmological
Λ ~ 0
late 90's
⇒ SN ...
WMAP
Λ > 0
SVP
∃N |v|<c ?


cosmological
Λ ~ O
late 90's
SN ...
WMAP
Λ > 0
SVP
∃N


cosmological
late 90's
SN ...
WMAP
SVP
∃N
V = Σ N_i · V_i


cosmological
late 90's
SN ...
WMAP
SVP
∃N |v|<ε?


cosmological
$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G T_{\mu\nu} + \Lambda g_{\mu\nu}$
$\Lambda \sim O$
late 90's
SN ...
WMAP
> 0
SVP
$\exists N$ $|V| < \epsilon$?
$\Sigma V_i \cdot$
$V = \Sigma N_i \cdot V_i +$
$- \Lambda_0$
NP complete.


10 d
GR
M
spectrum
interactions
4d
3+1 d
1995
2005
landscape
Calabi-Yau
SU(3)×SU(2)×U(1)
?

cosmological

$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi T_{\mu\nu} + \Lambda g_{\mu\nu}$

$\ll (100\ \mathrm{meV})^4$

$\Lambda \sim 0$

$\sim 10^{-122} M_{planck}^4$

$10^{-50} M_{pert}^4$

late 90's

$\Rightarrow$ SN ...

WMAP

$\Lambda > 0$

$\sim 0.71 \Omega_c$

$L \sim 10^{?}$

$\mathrm{vol}(S) \Lambda_0^{4}$

$\ldots 10^{100} \cdot \ldots > 1$

V_i

$0 \quad -V_i^0$

$\sum V_i \cdot (\ldots)$

$V = \sum N_i \cdot V_i + \ldots$
$- \Lambda_0$

SVP

$V = g_{ij} N^i N^j$

$\exists N \quad |V| < \epsilon\,?$

time(input size)

NP complete.

cosmological

$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + 8\pi G T_{\mu\nu} + \Lambda g_{\mu\nu}$

$\ll (100\ \mathrm{meV})^4$

$\Lambda \sim 0$

$\sim 10^{-122} M_{planck}^4$

$10^{-50} M^4$

late 90's

$\Rightarrow$ SN ...

WMAP

$\Lambda > 0$

$\sim 0.71 \Omega_c$

vol$(\Lambda_0^{1/4})$ ... > 1

$\sum V_i \cdot (\omega_i)$

$V = \sum N_i \cdot V_i +$

$- \Lambda_0$

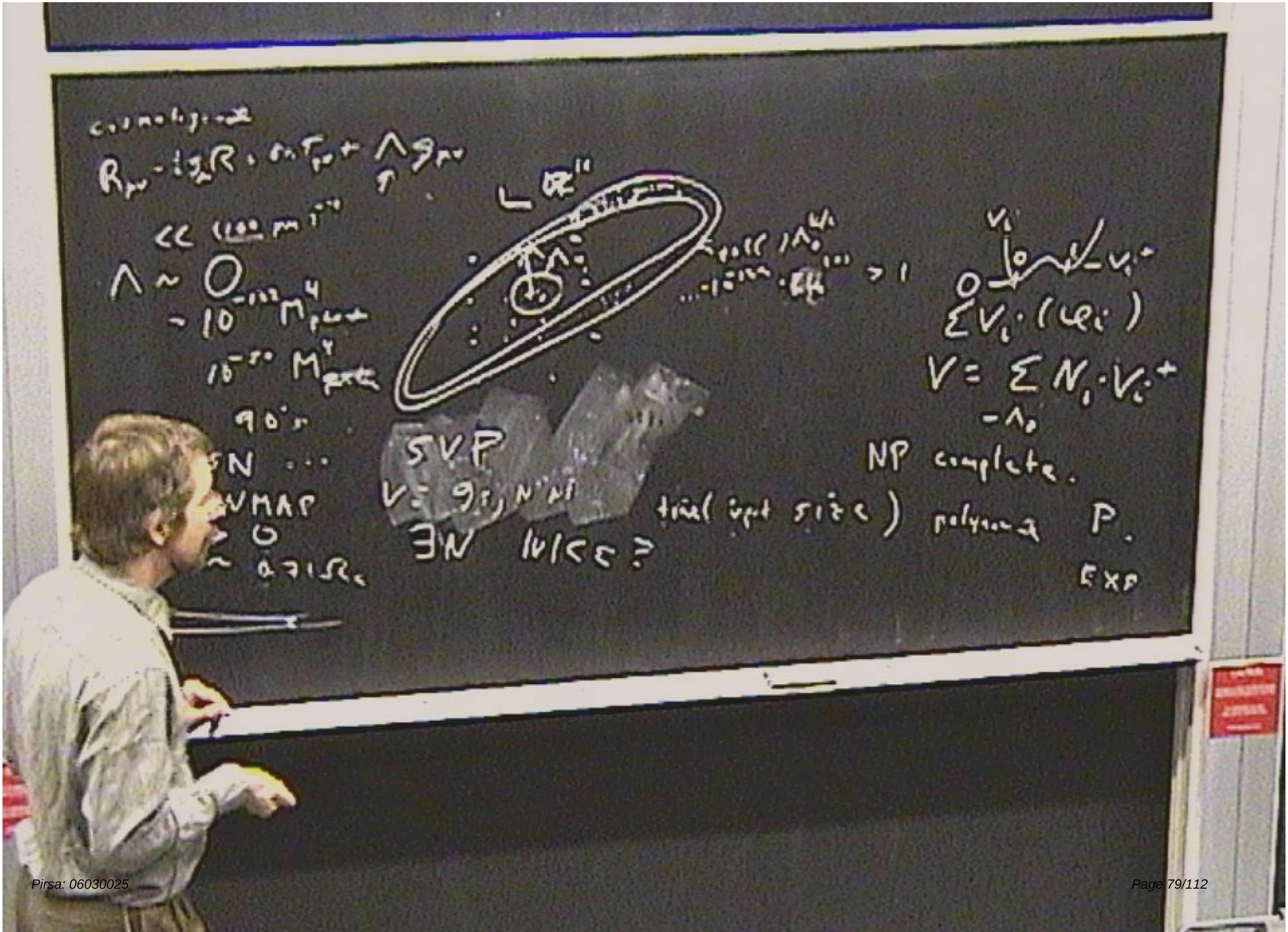
SVP

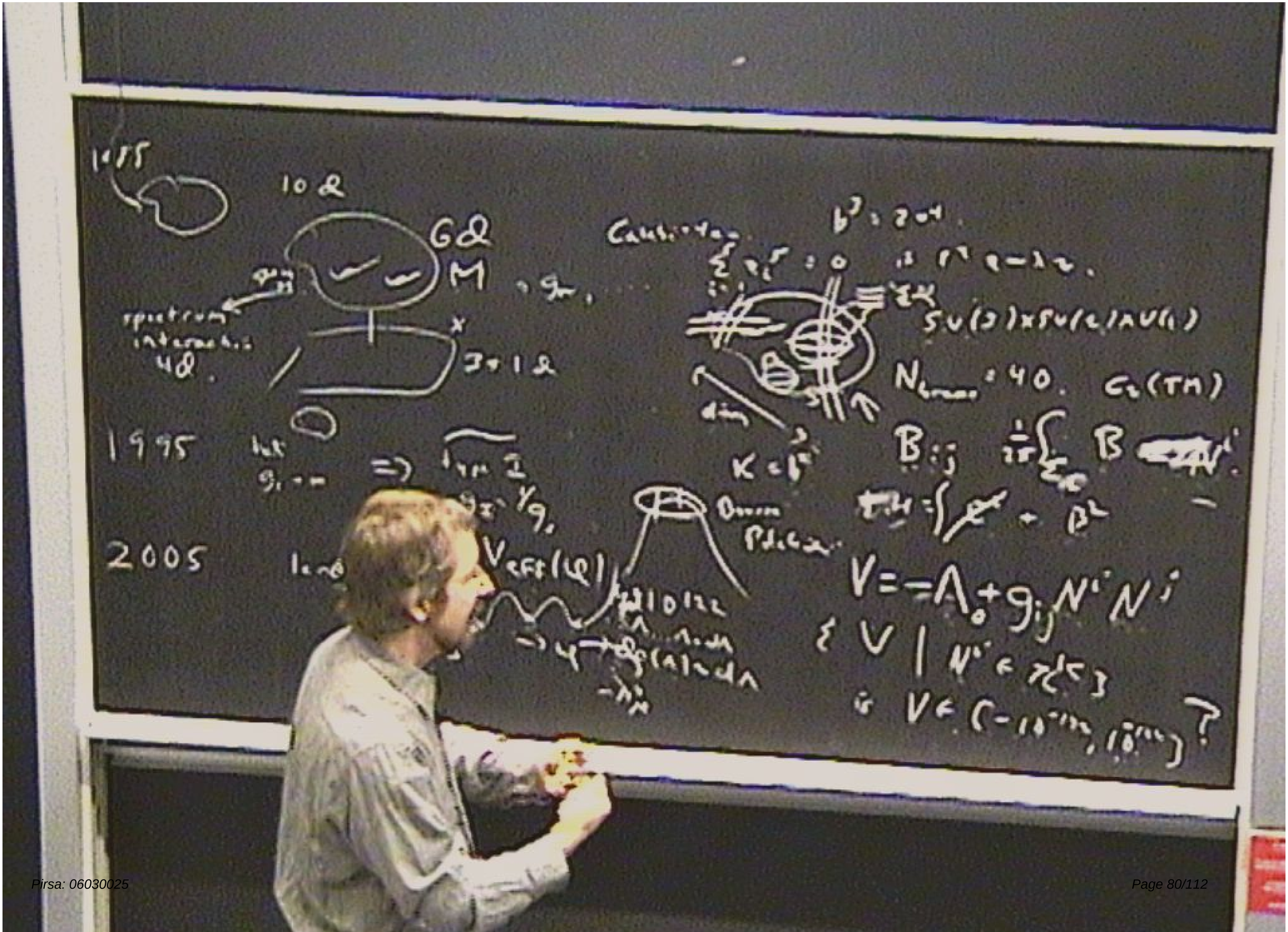
$V = g_{ij} N^i N^j$

$\exists N \ |V| < \epsilon$?

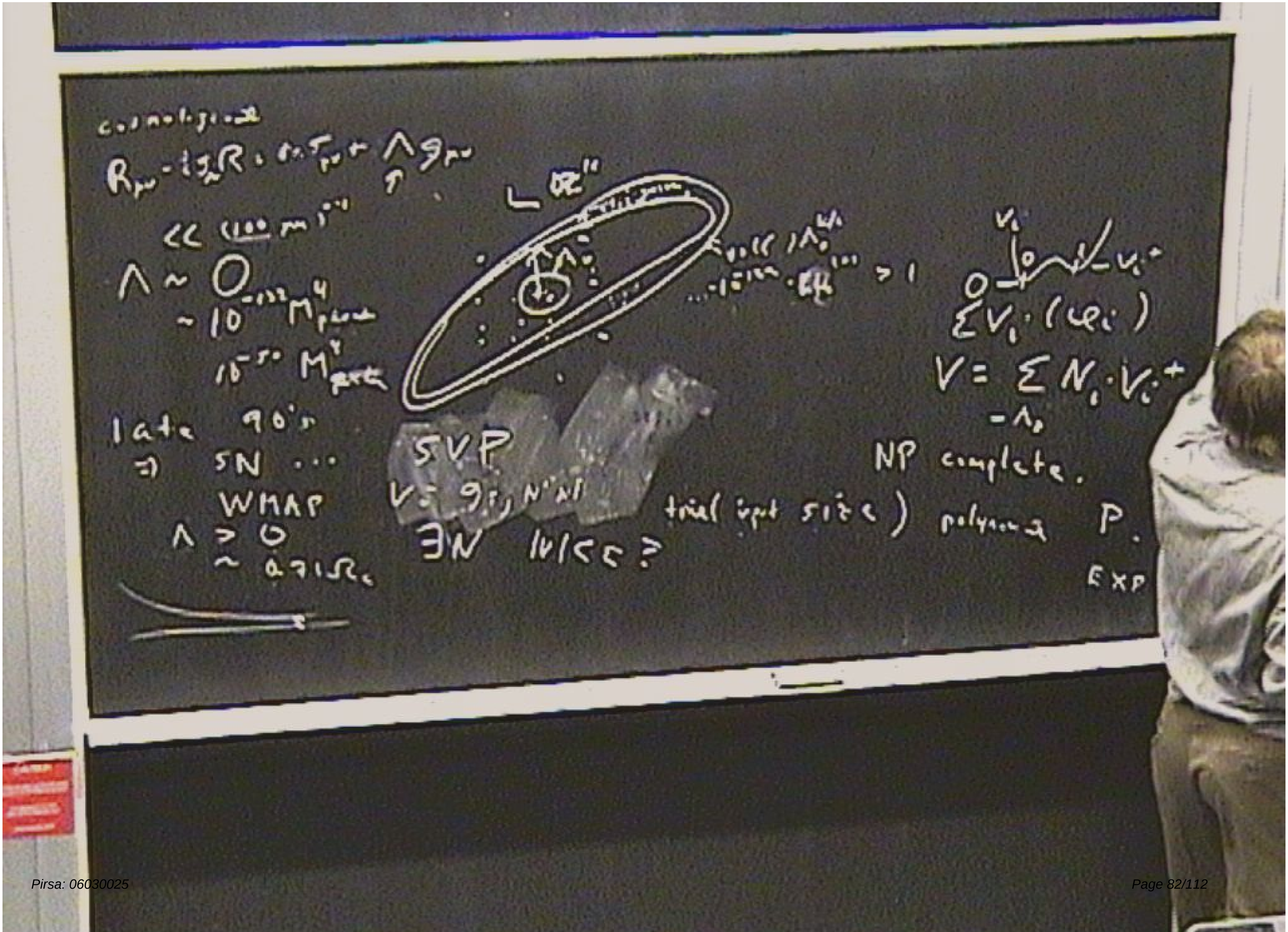
NP complete.

time(input size) polynomial P.


SVP
NP complete.
P.
EXP
WMAP


1985
10 d
GR
M
spectrum
interaction
4d
3+1 d
1995
2005
SU(3)×SU(2)×U(1)
V = −Λ₀ + g_ij N^i N^j

sol.
NP. checkable
in poly time.


late 90's
SN ...
WMAP
SVP
NP complete.
Exp

cosmological

$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi T_{\mu\nu} + \Lambda g_{\mu\nu}$

$\ll (100\ \mathrm{meV})^4$

$\Lambda \sim O$

$\sim 10^{-122} M^4_{planck}$

$10^{-50} M^4_{pl}$

late 90's

$\Rightarrow$ SN ...

WMAP

$\Lambda > 0$

$\sim 0.71 \Omega_c$

SVP

$V = g_{ij} N^i N^j$

$\exists N \quad |V| < \varepsilon$?

10^{100} ... > 1

$0 \ V_i$

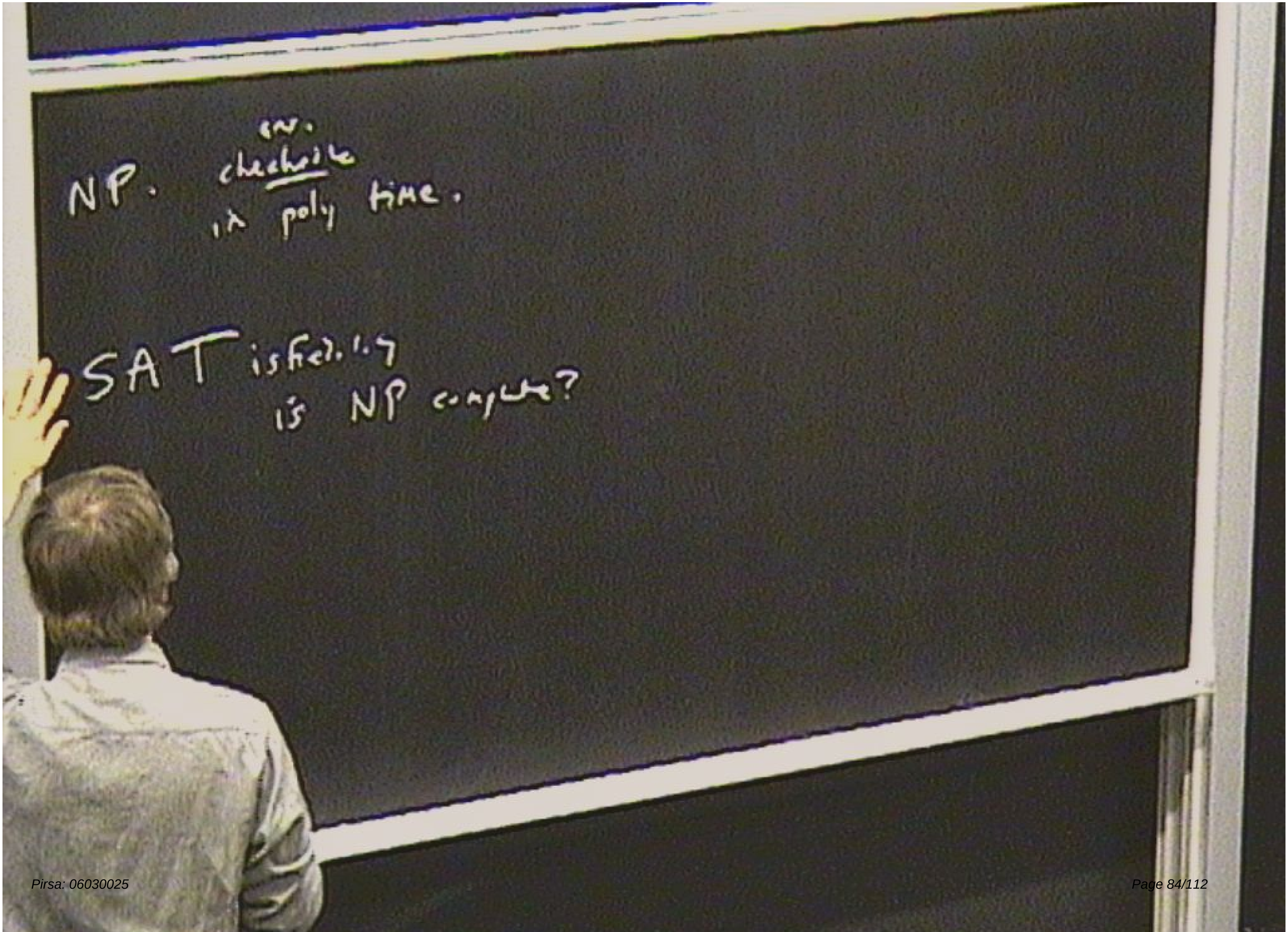
$\sum V_i \cdot (\ldots)$

$V = \sum N_i \cdot V_i + \ldots - \Lambda_0$

NP complete.

trial (input size) polynomial P.

Exp


NP. checkable in poly time.
SATisfiability is NP complete?

ans.

NP. checkable in poly time.

SAT isfiability

is NP complete?

$x_i \in \{\text{true}, \text{false}\}$

AND $\left\{ x_1 \vee \bar{x}_7 \vee x_{15} \cdots \right.$

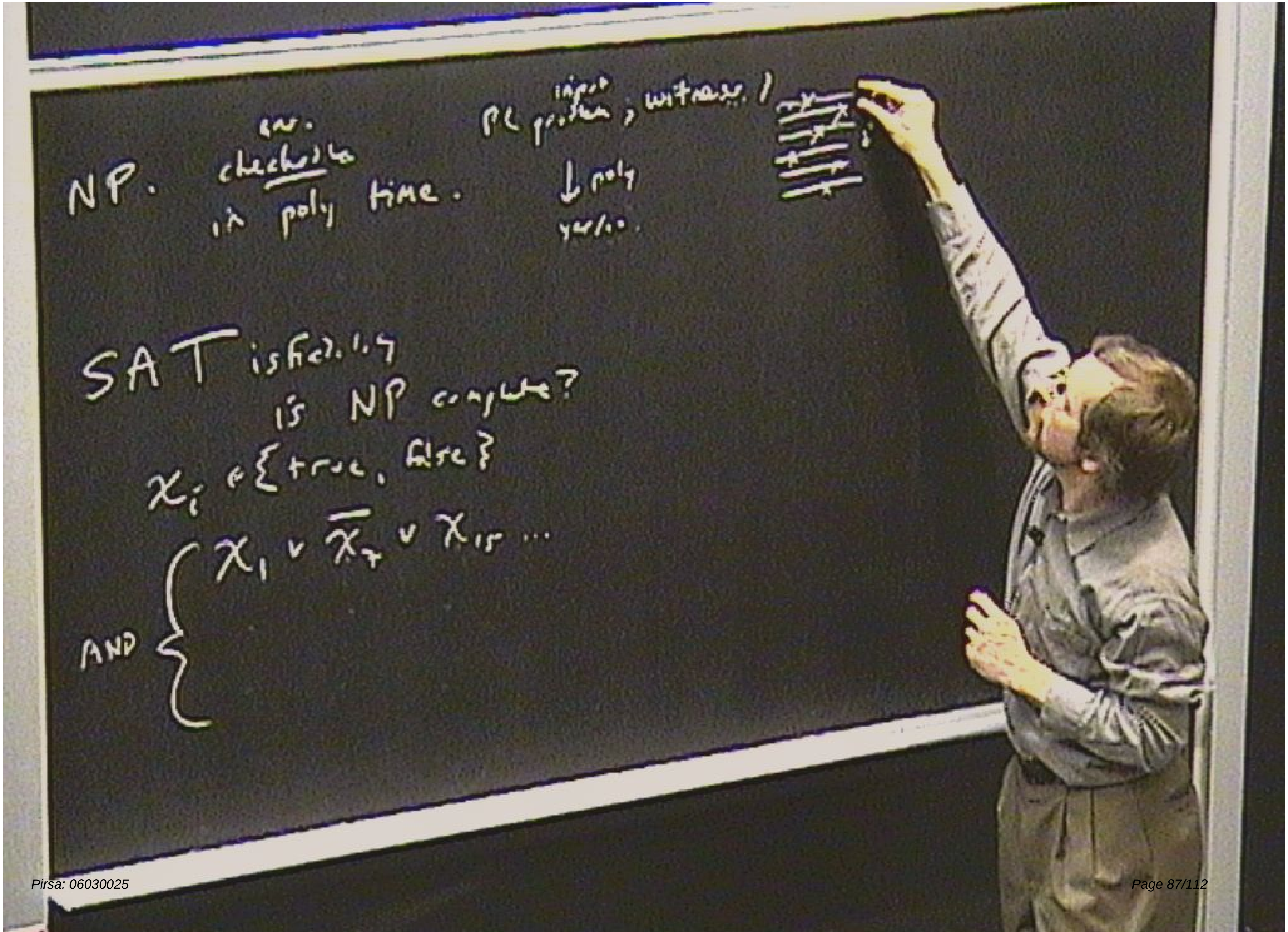
NP. checkable (eas.) in poly time.

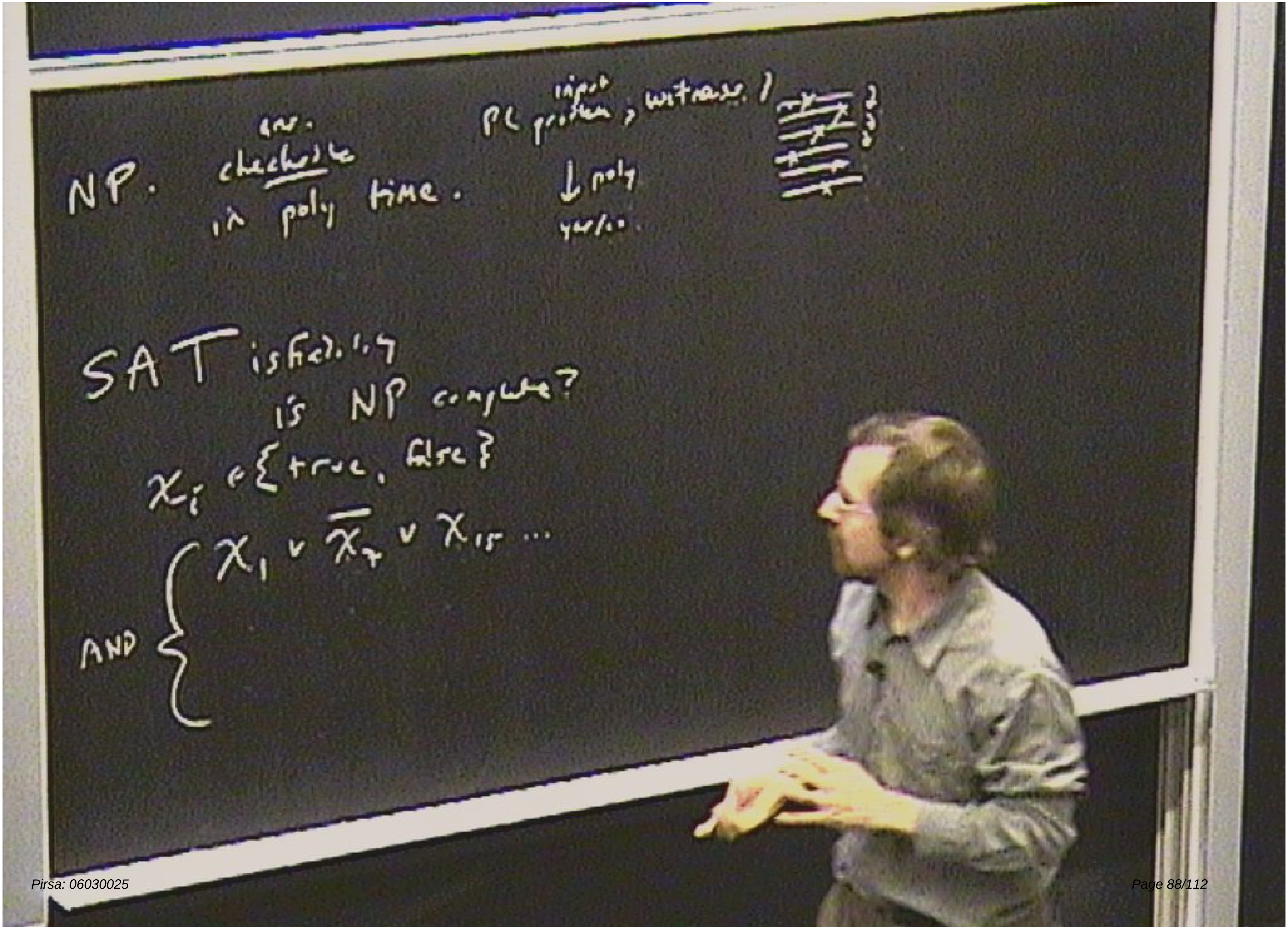
PC (problem input, witness) $\downarrow$ poly yes/no.

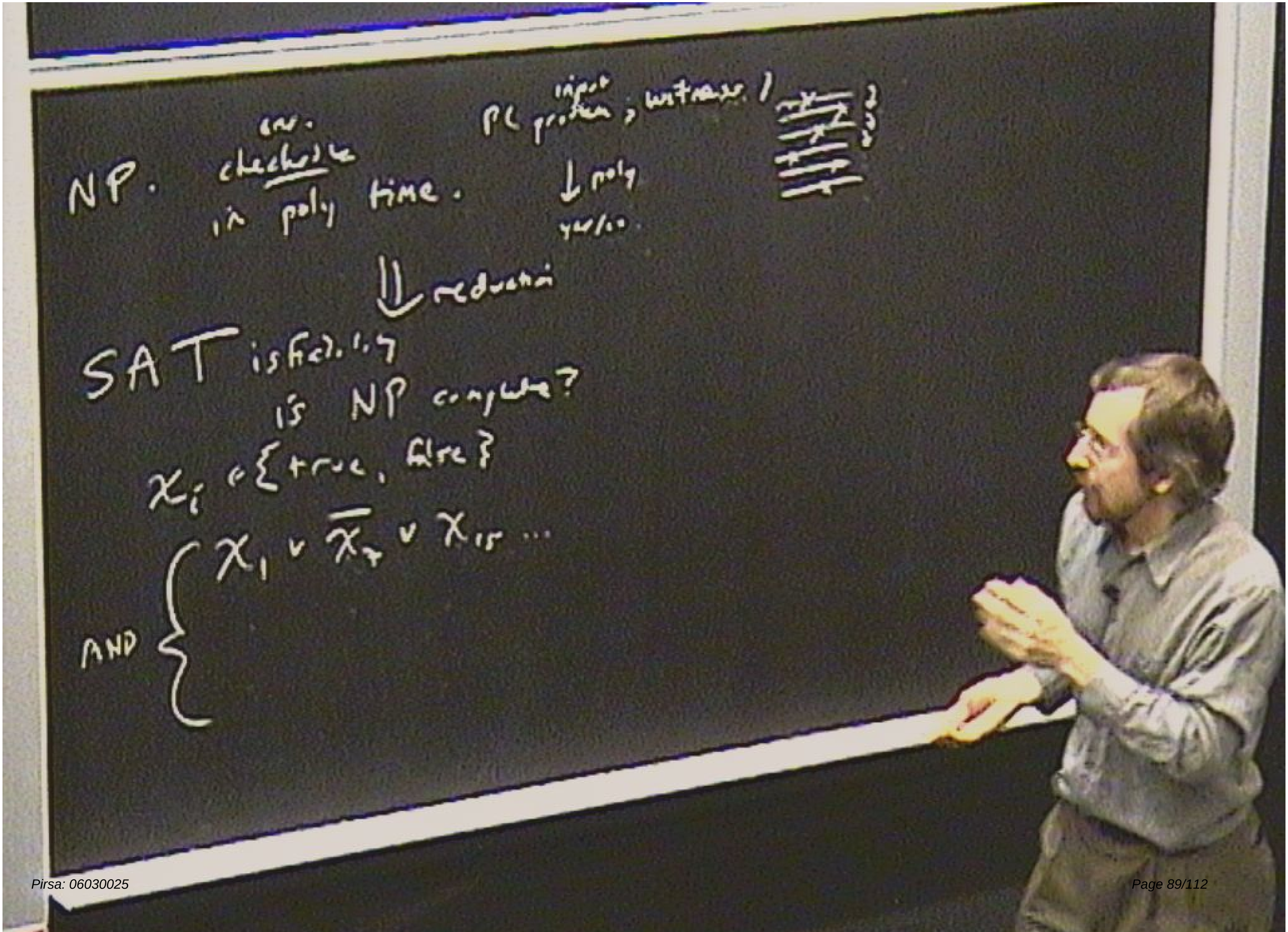
SAT isfiability is NP complete?

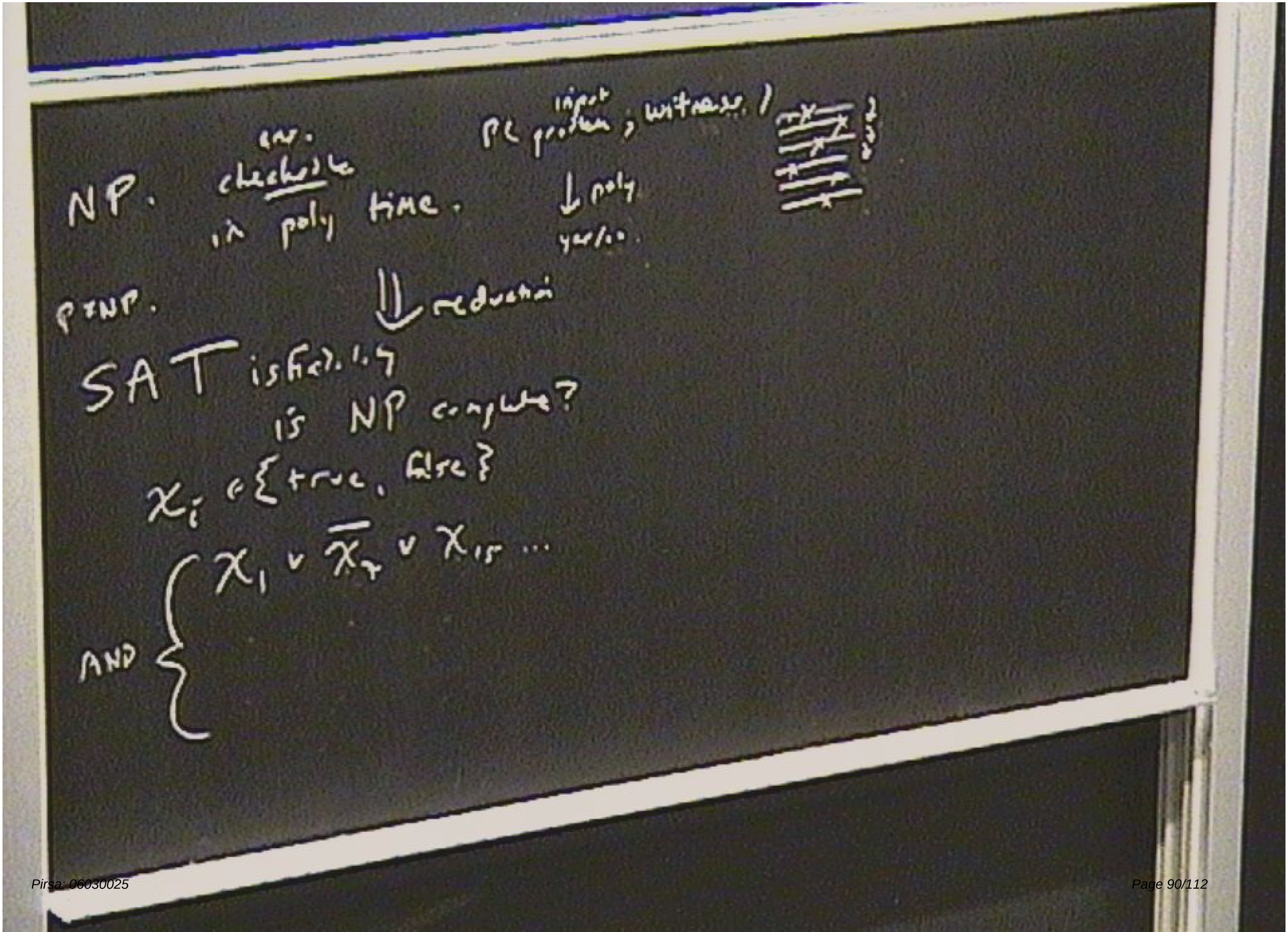
$x_i \in \{\text{true}, \text{false}\}$

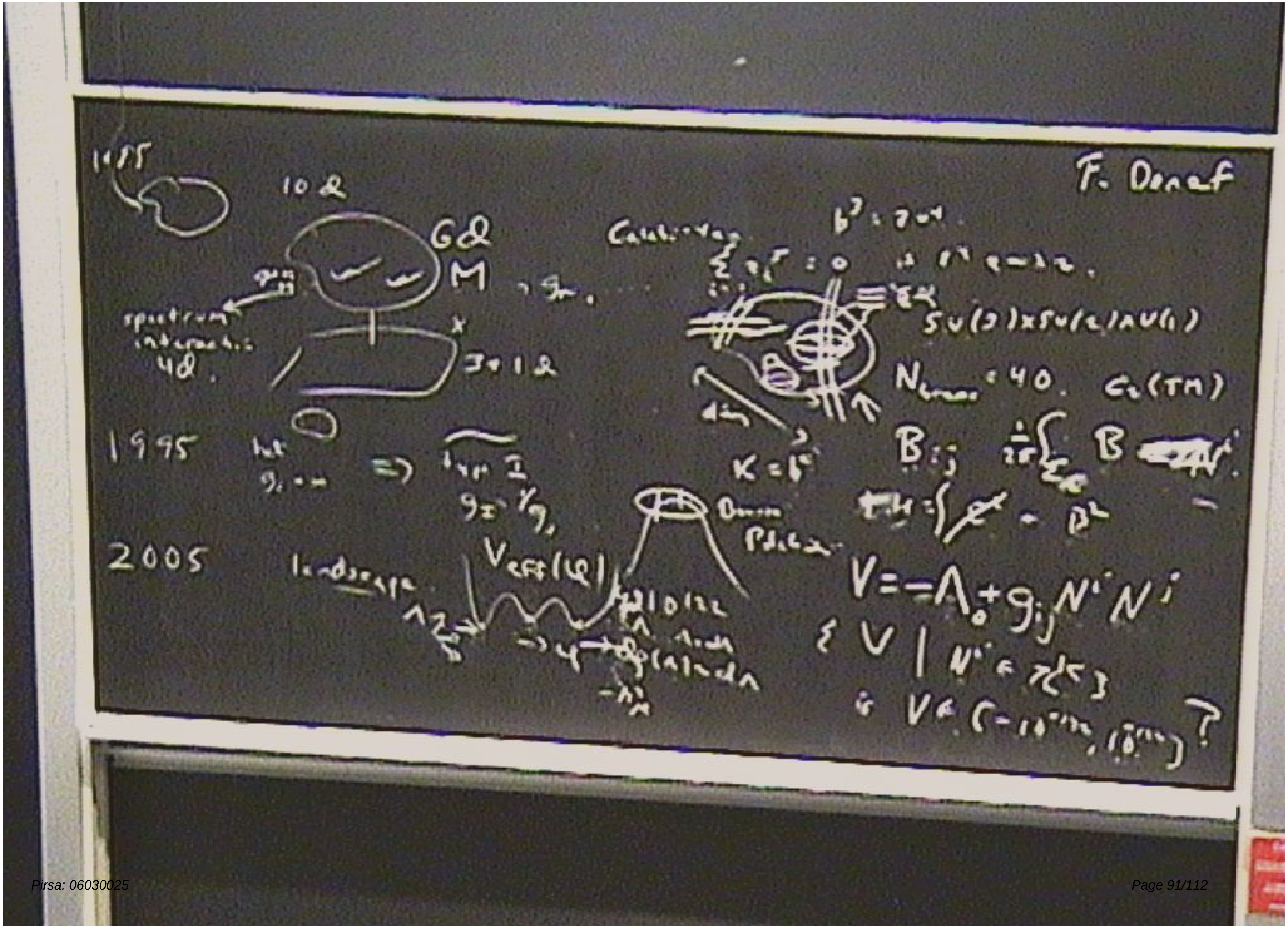
AND $\left\{ x_1 \vee \bar{x}_7 \vee x_{15} \ldots \right.$


NP.
checkable
in poly time.
poly
yes/no
SAT isfiability
is NP complete?
x_i ∈ {true, false}
x_1 v x̄_2 v x_15 ...
AND


ans.
NP. checkable in poly time.
input
PL problem, witness.
↓ poly
yes/no
SATisfiability
is NP complete?
$x_i \in \{true, false\}$
$x_1 \vee \bar{x}_2 \vee x_{15} \ldots$
AND


NP.
checkable
in poly time.
poly
reduction
SAT
is NP complete?
AND


NP. checkable in poly time.
input, witness
poly
yes/no
P≠NP.
reduction
SAT
is NP complete?
{true, false}
AND


F. Denef
10 d
GR
M
3+1 d
spectrum
interactions
4d
1995
type I
2005
landscape
V_eff(φ)
SU(3)xSU(2)xU(1)
V = -Λ_0 + g_ij N^i N^j

NP. ans. checkable in poly time.

PL problem (input), witness,)

$\downarrow$ poly

yes/no

$P \neq NP$.

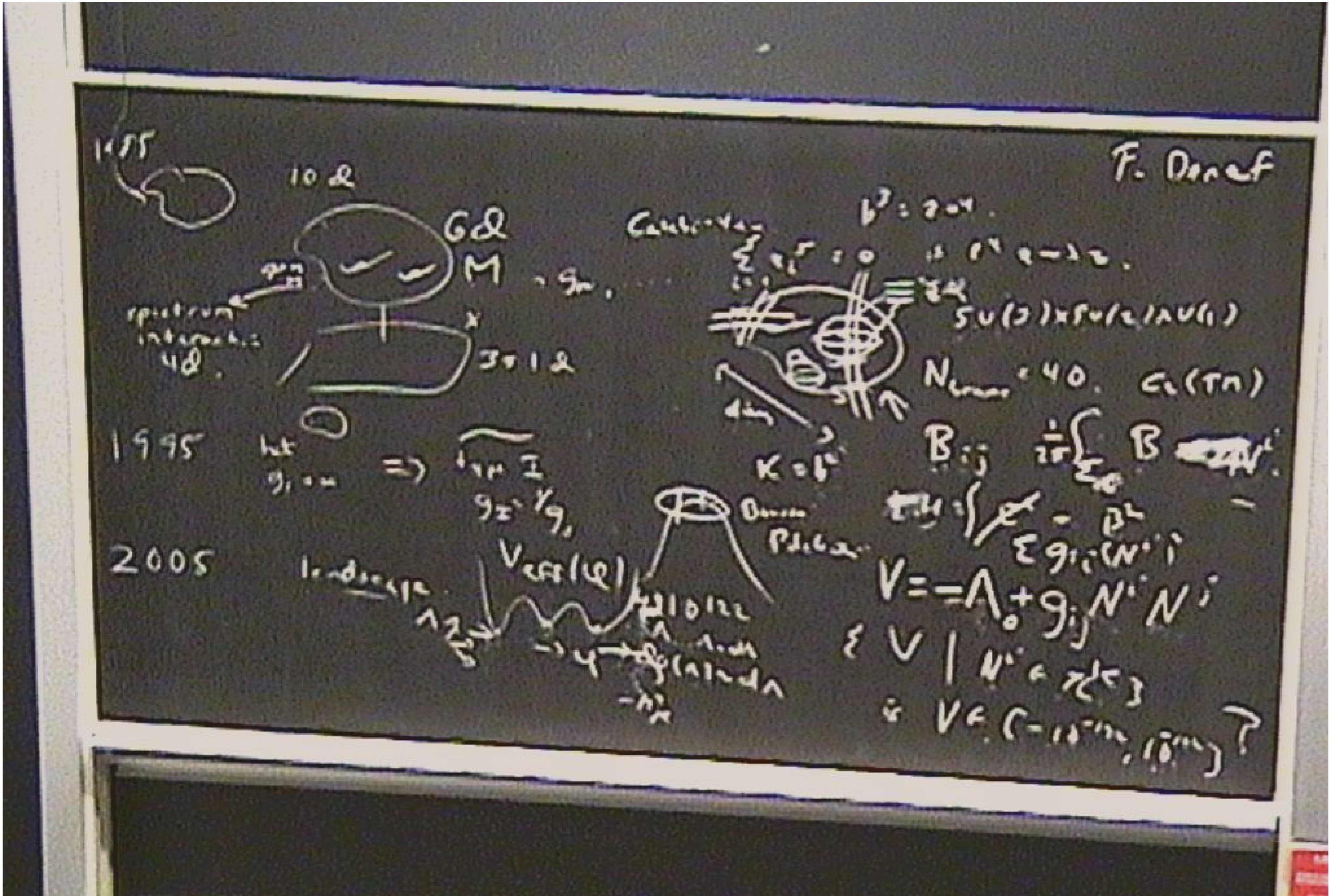
$\Downarrow$ reduction

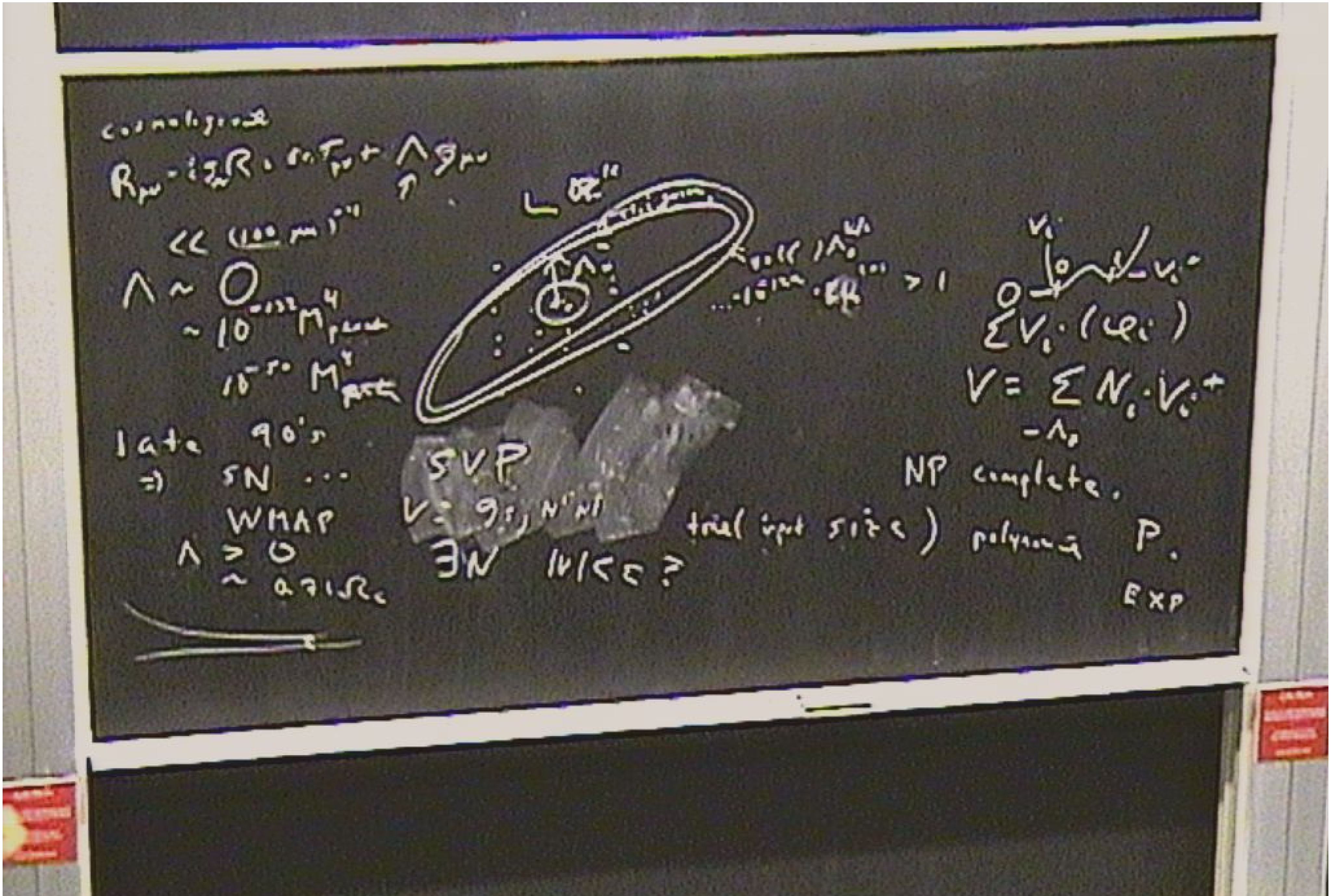
SATisfiability

is NP complete?

$x_i \in \{\text{true}, \text{false}\}$

AND $\left\{ x_1 \vee \bar{x}_2 \vee x_{15} \ldots \right.$


F. Denef
10 d
M
spectrum
4d
3+1 d
1995
2005
SU(3)×SU(2)×U(1)
N = 40
B
V_eff(φ)
10^122
V = −Λ_0 + g_ij N^i N^j


cosmological
$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi T_{\mu\nu} + \Lambda g_{\mu\nu}$
$\Lambda \sim 0$
$\sim 10^{-122} M_{planck}^4$
$10^{-50} M_{planck}^4$
late 90's
$\Rightarrow$ SN ...
WMAP
$\Lambda > 0$
$\sim 0.71 \Omega_c$
SVP
$\exists N \quad |V| < \epsilon$?
ΣV_i
$V = \Sigma N_i \cdot V_i$
$- \Lambda_0$
NP complete.
polynomial P.
EXP

NP. checkable in poly time.

input
PL problem, witness. /

$\downarrow$ poly

yes/no.

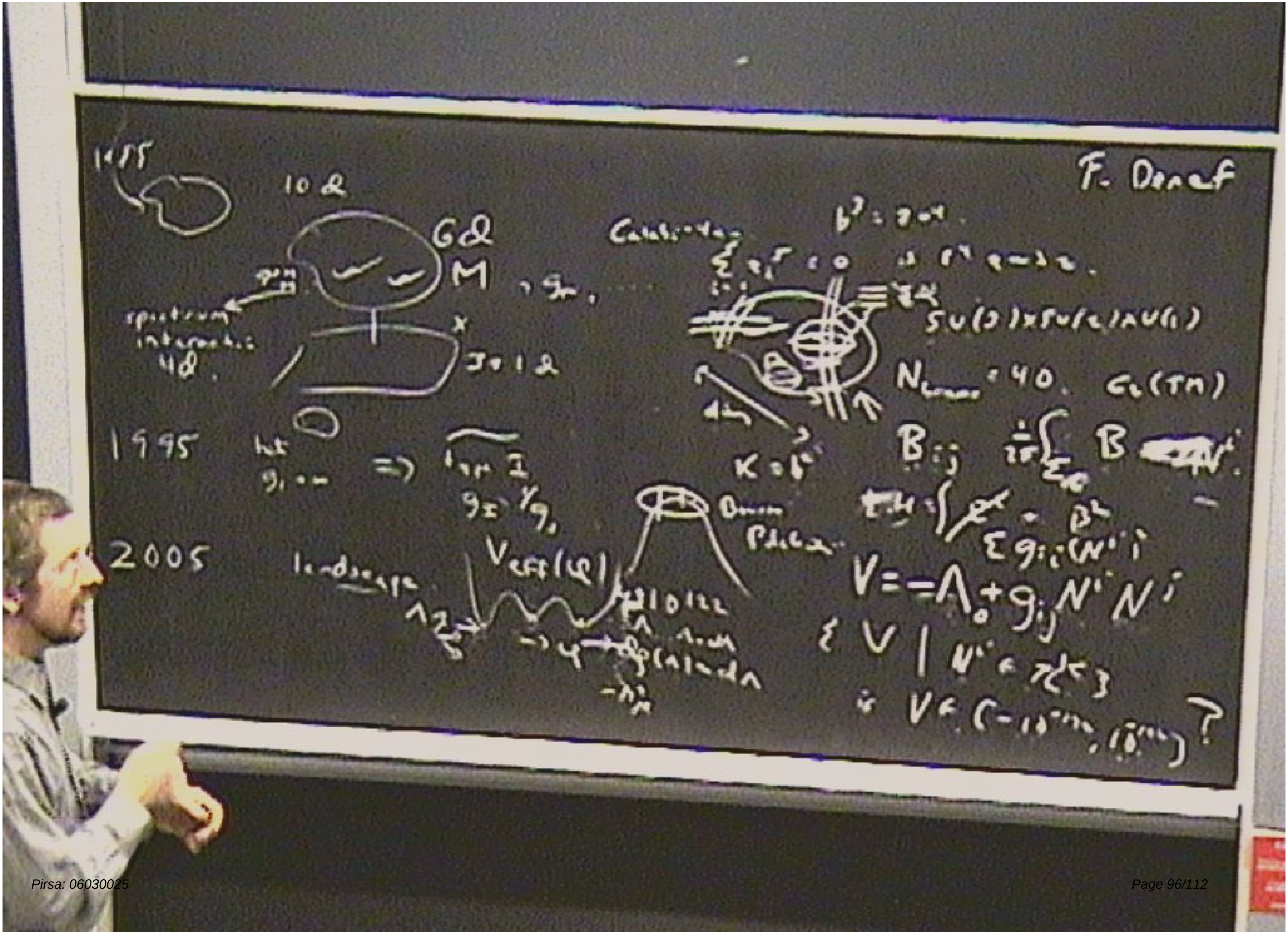
$P \neq NP$.

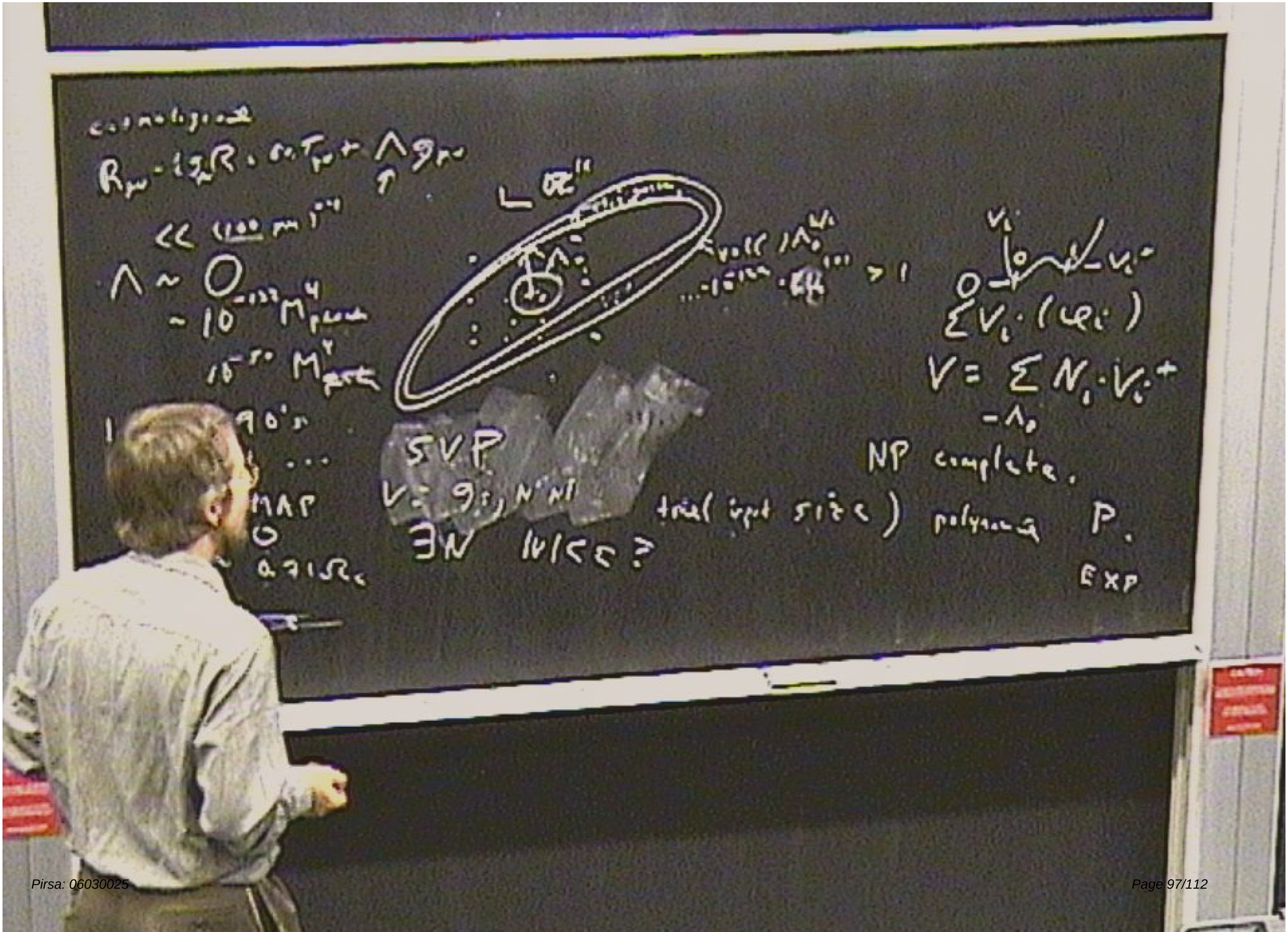
$\Downarrow$ reduction

SAT isfiability
is NP complete?

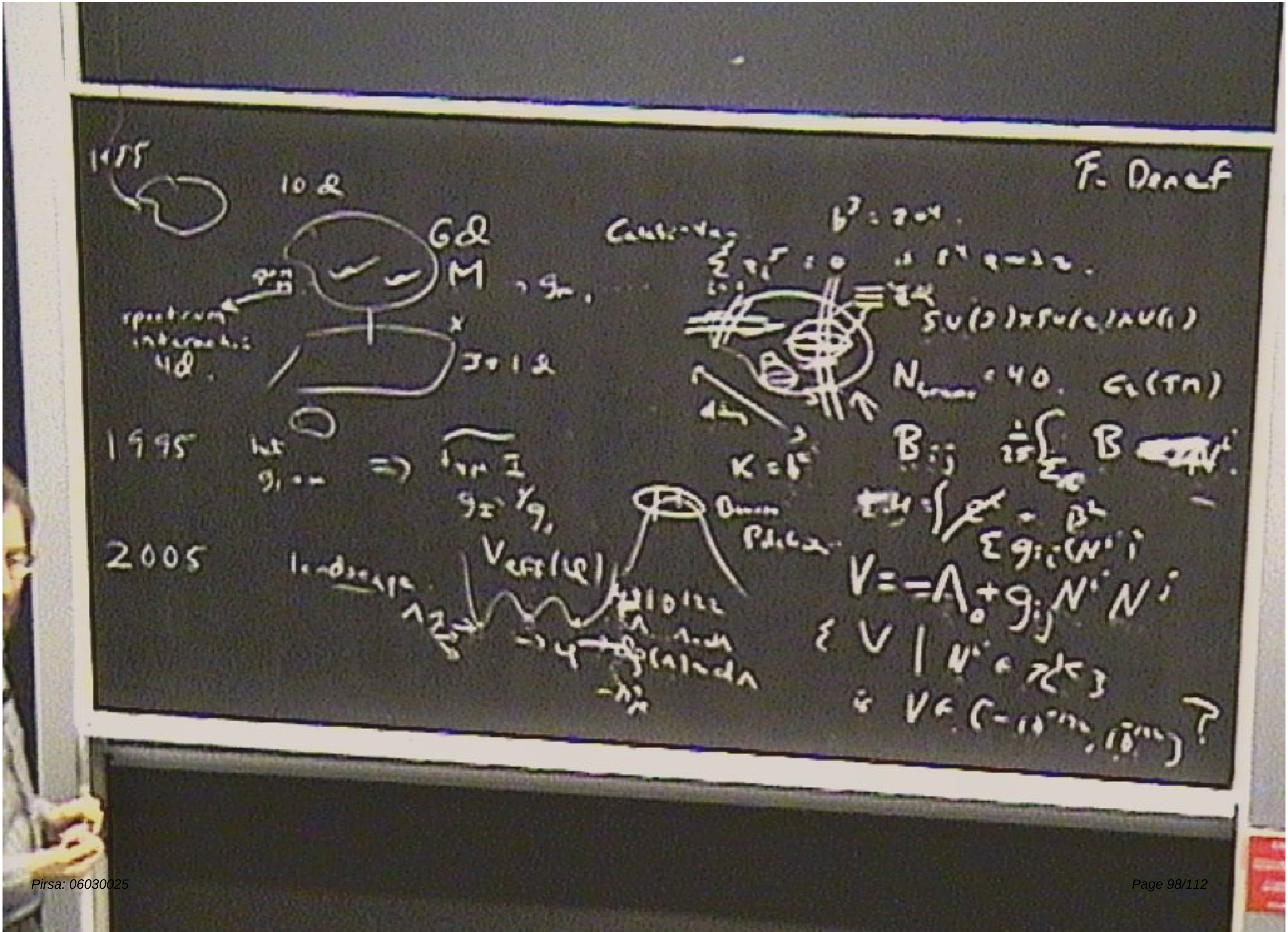
$x_i \in \{\text{true}, \text{false}\}$

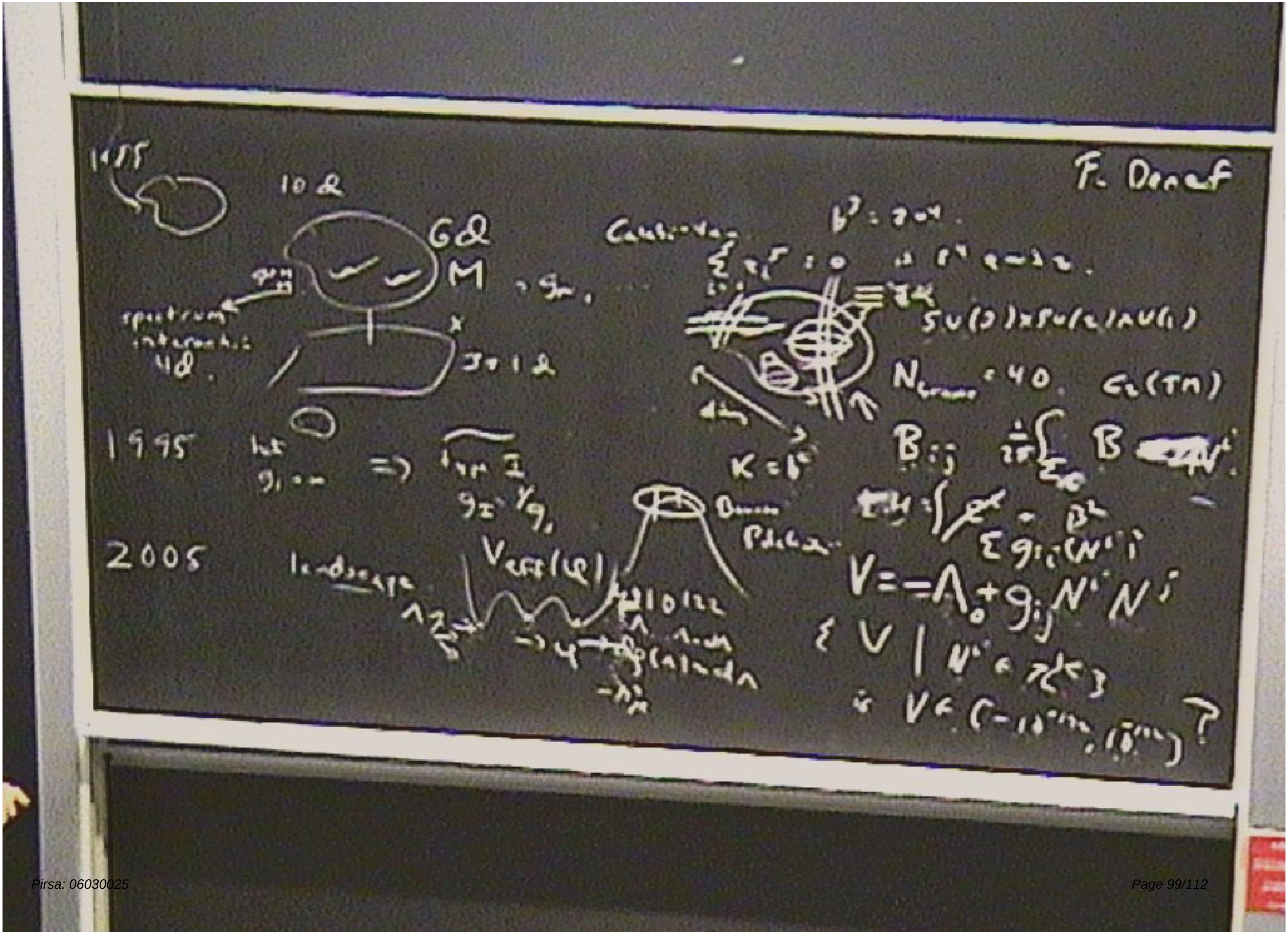
AND $\left\{ x_1 \vee \bar{x}_2 \vee x_{15} \cdots \right.$

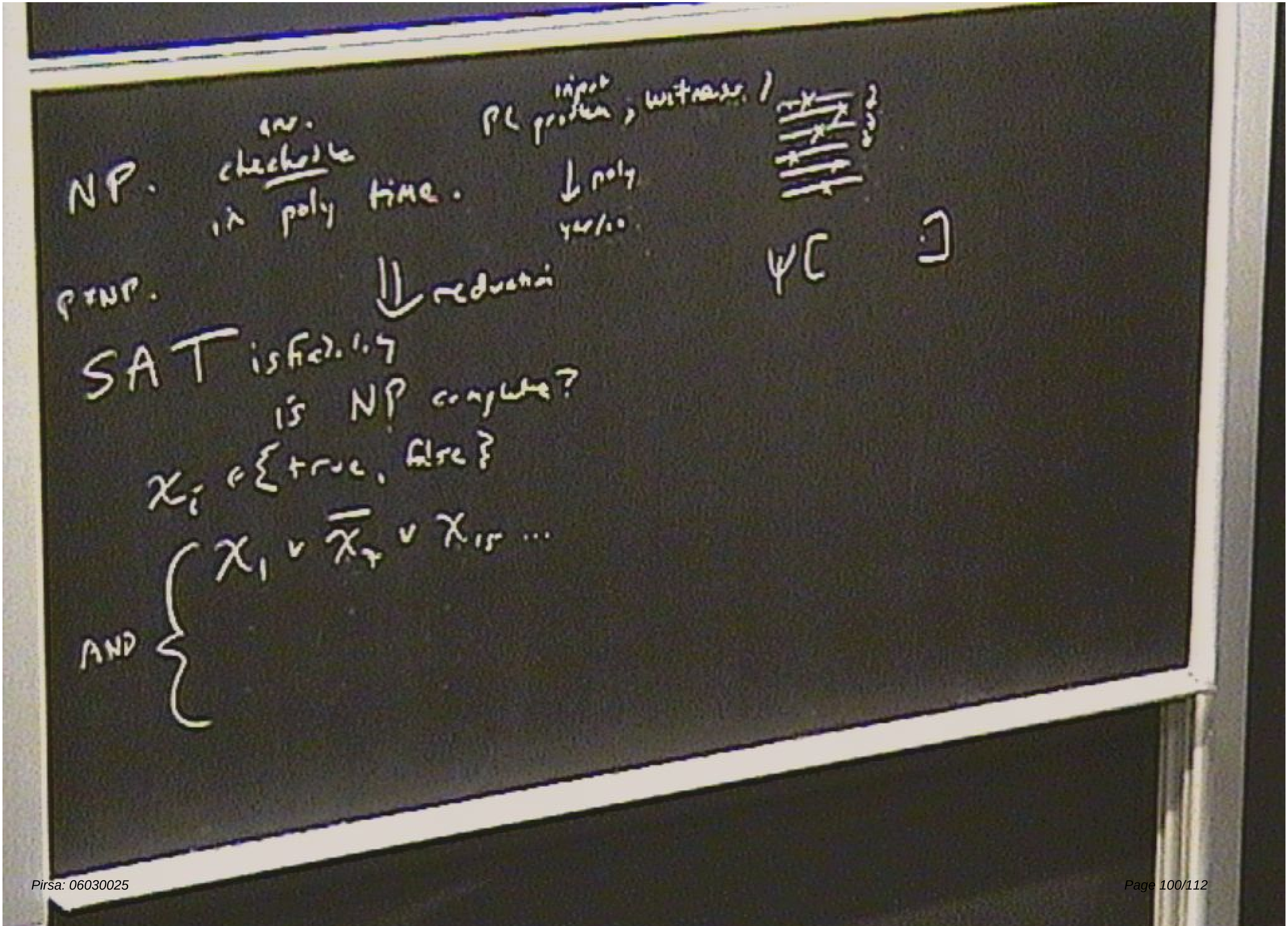

F. Denef
10 d
G2
M
spectrum
interactions
4d
Calabi-Yau
SU(3)xSU(2)xU(1)
1995
2005
landscape
V=-Λ0+gij Ni Nj



SVP
NP complete.
EXP


F. Denef
1985
10 d
G d
M
spectrum
interactions
4d
1995
2005
landscape
V_eff(φ)
Calabi-Yau
SU(3)xSU(2)xU(1)
N = 40
V = -Λ_0 + g_ij N^i N^j


F. Denef
10 d
GR
M
X
spectrum
interactions
4d
3+1 d
1995
2005
Landscape
$V_{eff}(\varphi)$
$K = b^3$
$SU(3)\times SU(2)\times U(1)$
$N = 40$
$c_2(TM)$
$V = -\Lambda_0 + g_{ij} N^i N^j$


ans.
NP. checkable
in poly time.
input
witness
↓ poly
yes/no
P≠NP.
⇓ reduction
SAT isfiability
is NP complete?
$x_i \in \{\text{true}, \text{false}\}$
$x_1 \vee \bar{x}_2 \vee x_{15} \cdots$
AND

NP. ans. checkable in poly time.

PL problem, input; witness / [illegible]

$\downarrow$ poly

yes/no

P≠NP.

$\Downarrow$ reduction

SATisfiability

is NP complete?

$x_i \in \{true, false\}$

AND $\left\{ x_1 \vee \bar{x}_7 \vee x_{15} \dots \right.$

NP. checkable in poly time.

PL problem; witness.

↓ poly

yes/no

P ≠ NP.

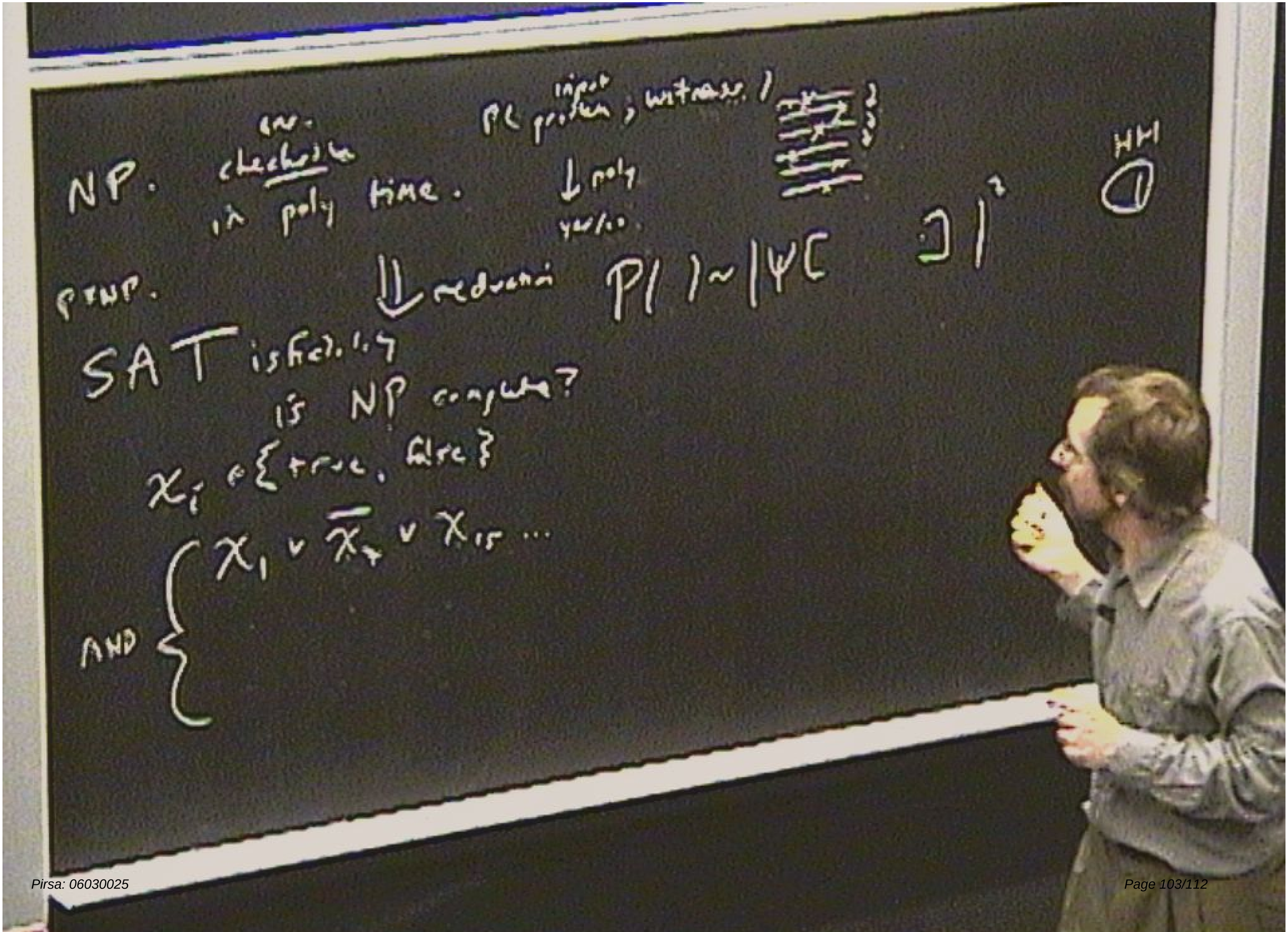
⇓ reduction

SAT isfiability

is NP complete?

$x_i \in \{true, false\}$

AND $\left\{ x_1 \vee \bar{x}_2 \vee x_{15} \cdots \right.$


NP.
checkable
in poly time.
↓ poly
yes/no
SATisfiability
is NP complete?
x_i ∈ {true, false}
x_1 ∨ x̄_7 ∨ x_15 …
AND

NP. checkable in poly time.

input PC problem; witness /

↓ poly

yes/no.

HH

P ≠ NP.

⇓ reduction

SAT isfiability

is NP complete?

$$\sim e$$

$x_i \in \{\text{true}, \text{false}\}$

AND $\left\{ x_1 \vee \bar{x}_7 \vee x_{15} \cdots \right.$

NP. checkable in poly time.

P ≠ NP.

SAT isfiability is NP complete?

$x_i \in \{\text{true}, \text{false}\}$

AND $\left\{ x_1 \vee \bar{x}_2 \vee x_{15} \cdots \right.$

PL problem, witness

↓ poly

yes/no

⇓ reduction

$P( ) \sim |\psi|^2$

$\Lambda > 0$

$\sim e^{\text{poly}/\Lambda}$ $\theta(\Lambda)$

NP. checkable (cert.) in poly time.

PC problem (input), witness /

$\Downarrow$ poly

yes/no

P ≠ NP.

$\Downarrow$ reduction

SAT isfiability

is NP complete?

$x_i \in \{\text{true}, \text{false}\}$

AND $\left\{ x_1 \vee \bar{x}_7 \vee x_{15} \cdots \right.$

$P(\,) \sim |\psi\langle$

$|\ |^2$

HH

$\Lambda > 0$

$\sim e^{\ldots/\Lambda}$

Λ

min

NP. $\underset{\text{in poly time.}}{\text{check}\ \underline{\text{solution}}}$

PL problem, witness

$\downarrow$ poly

yes/no

P≠NP.

$\Downarrow$ reduction

SAT isfiability

is NP complete?

$x_i \in \{\text{true}, \text{false}\}$

AND $\left\{ x_1 \vee \bar{x}_2 \vee x_{15} \dots \right.$

$P( ) \sim |\psi|^2$

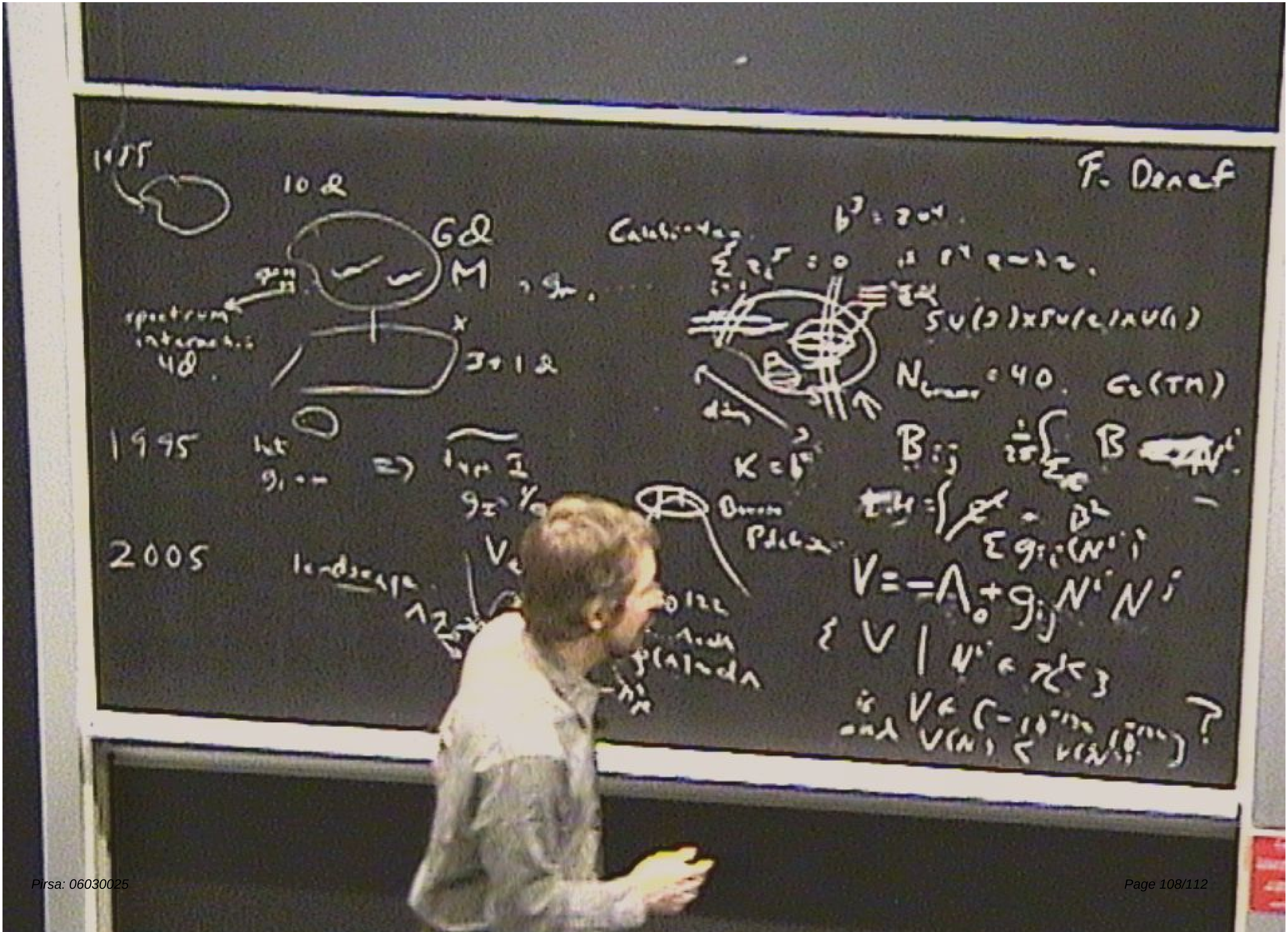
$\sim e^{\dots/\Delta}$

$\Delta > 0$

$\theta(\Delta)$

min $\Delta > 0$.

HH


F. Denef
1995
2005
landscape
spectrum
interactions
4d
3+1 d
10 d
Calabi-Yau
SU(3)×SU(2)×U(1)
$V = -\Lambda_0 + g_{ij} N^i N^j$

ans.
NP. checkable in poly time.

PL problem input, witness. /

$\downarrow$ poly

yes/no.

HH

$P \neq NP$.

$\Downarrow$ reduction

$P(\ ) \sim |\psi C \ \ ]|^2$

$\Lambda > 0$

SAT isfiability

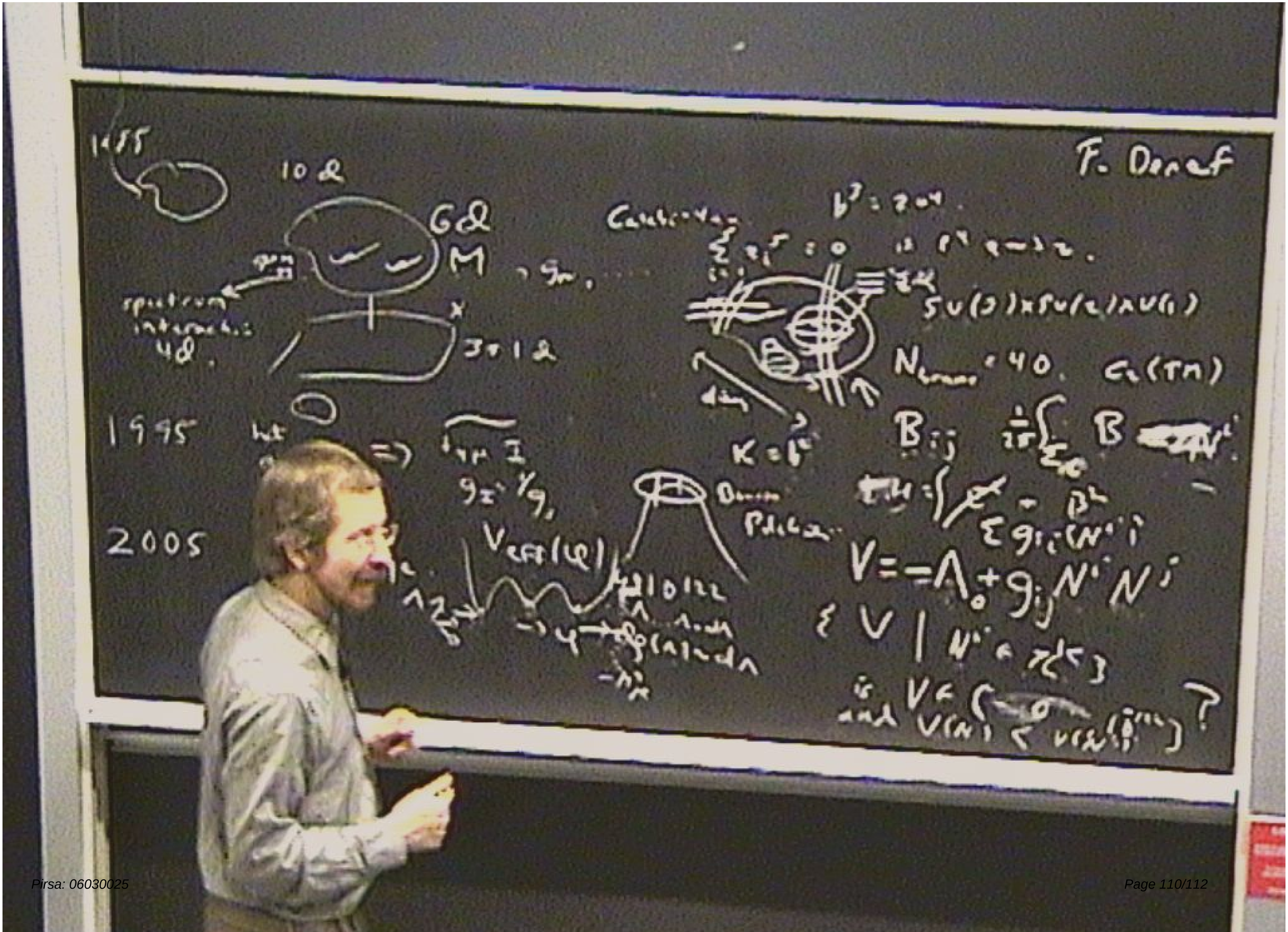
is NP complete?

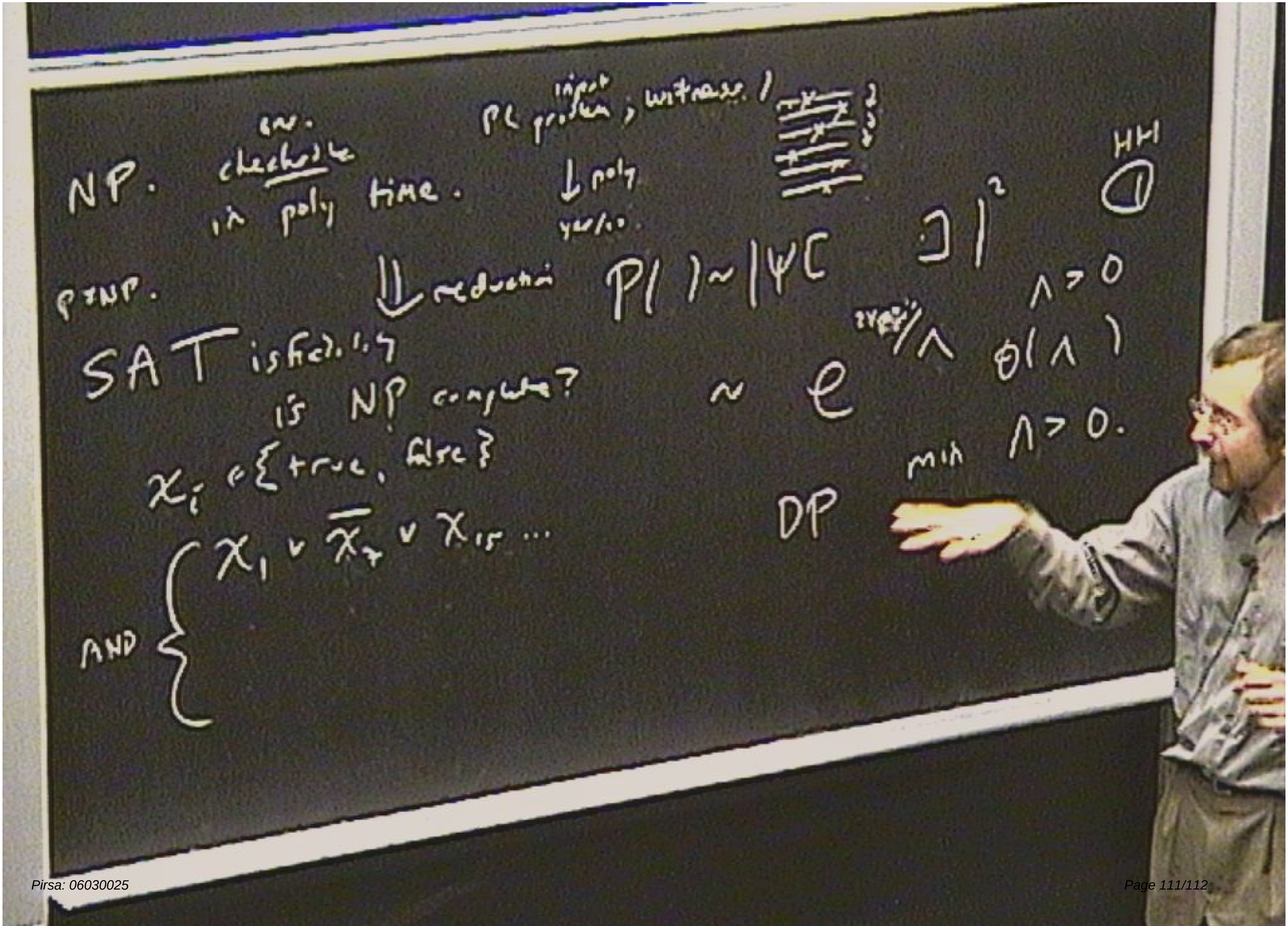
$\sim e^{\ /\Lambda}$ $\theta(\Lambda)$

min $\Lambda > 0$.

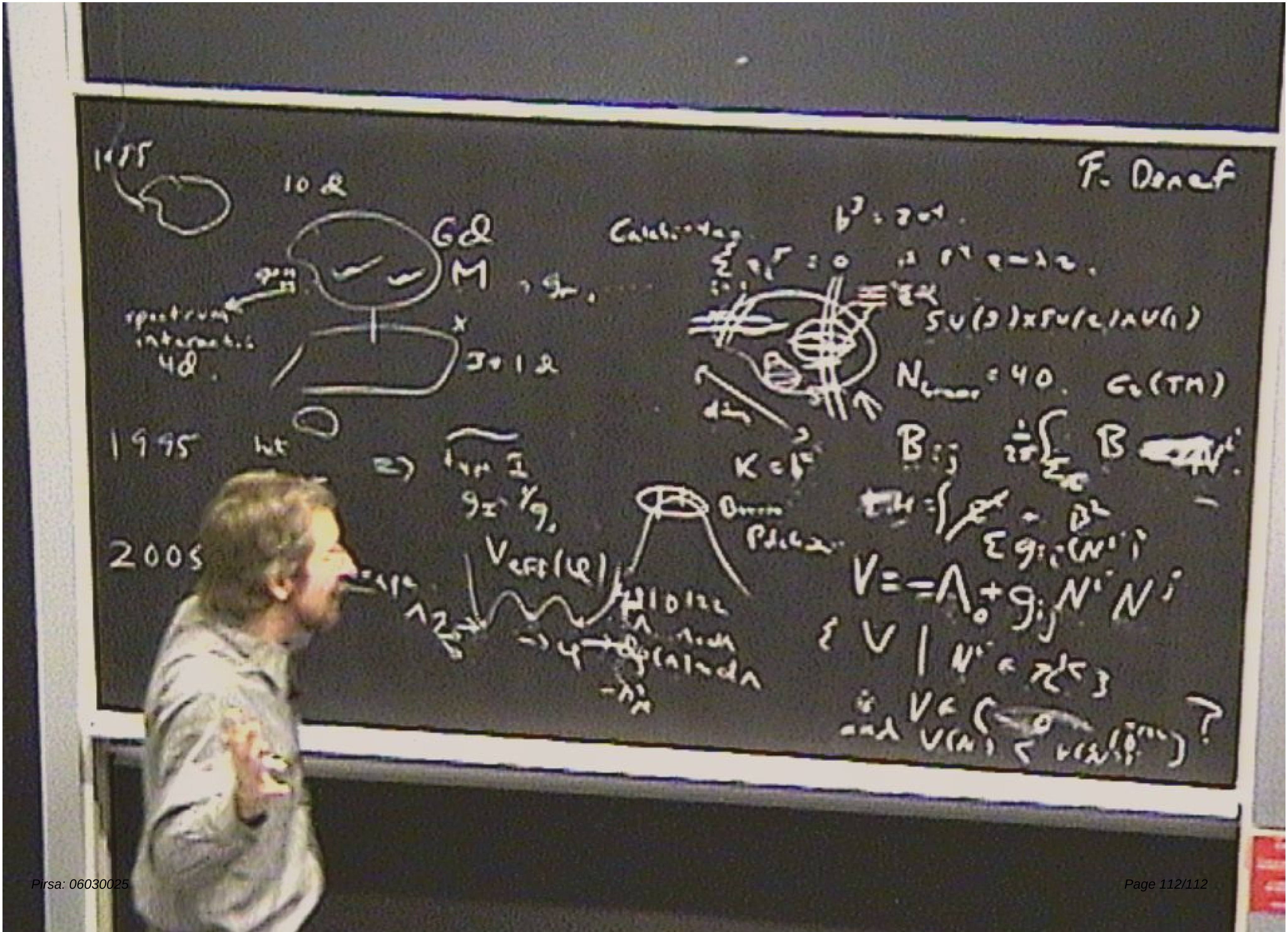
$x_i \in \{\text{true}, \text{false}\}$

AND $\begin{cases} x_1 \vee \bar{x}_7 \vee x_{15} \cdots \\ \\ \end{cases}$


F. Denef
1995
2005
10 d
spectrum
interactions
4 d
3+1 d
Calabi-Yau
$b^3 = 204$
$SU(3) \times SU(2) \times U(1)$
$N = 40$
$V = -\Lambda_0 + g_{ij} N^i N^j$



NP.
checkable
in poly time.
↓ poly
yes/no
P ≠ NP.
⇓ reduction
SAT isfiability
is NP complete?
$x_i \in \{true, false\}$
$x_1 \vee \bar{x}_2 \vee x_{15} \ldots$
AND
$\Lambda > 0$
min $\Lambda > 0.$
DP
HH


F. Denef
10 d
M
spectrum
4d
3+1 d
1995
2005
SU(3)×SU(2)×U(1)
V = −Λ₀ + g_ij N^i N^j