

Title: Secondary Anisotropy Contributions to the Bispectrum

Date: Mar 08, 2008 05:45 PM

URL: <http://pirsa.org/08030055>

Abstract:

No Signal

VGA-1

No Signal

VGA-1

No Signal

VGA-1

$$\theta = \nabla T(\hat{n})$$

$$\langle \theta^2 \rangle \neq 0$$

$$\frac{dT}{dt} \text{ ISW}$$

$$z = 1100$$

$$\theta = \nabla T(\hat{n})$$

$$\langle \theta^2 \rangle \neq 0$$

$$\frac{dT}{dt} \text{ ISW}$$

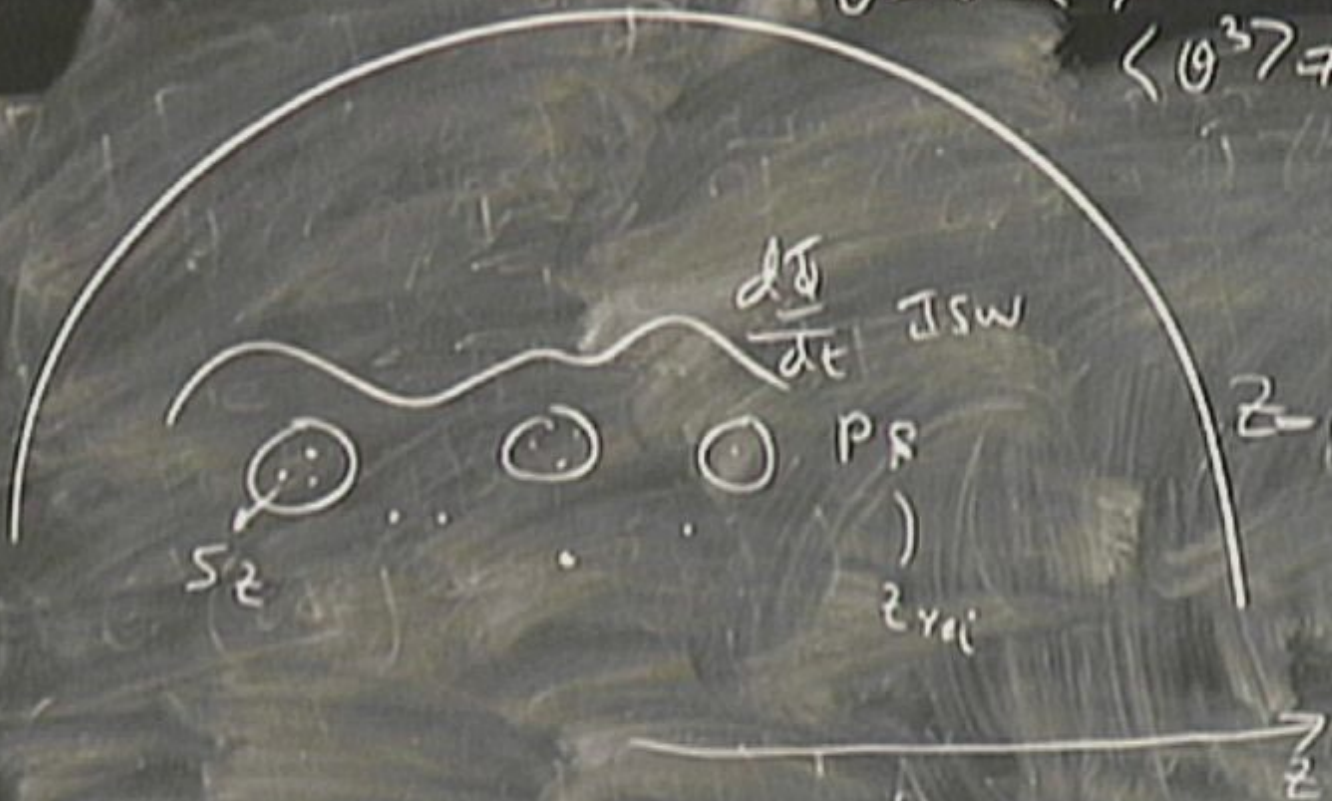
PR

$z \approx 1100$

s_2

$$\theta = \nabla T(\hat{n})$$

$$\langle \theta^3 \rangle \neq 0$$



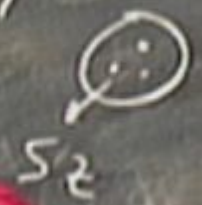
$$\frac{dT}{dt} \text{ MSW}$$

$$z = 1160$$

$$\theta = \nabla T(\hat{n})$$

$$\langle \theta^2 \rangle \neq 0$$

↓ Dipole / quadrupole / patchy reionization
 $\frac{d\theta}{dt}$ ISW



PR

z_{rei}

$z = 1160$



0_y

$$\theta = \nabla T(\hat{n})$$

$$\langle \theta^3 \rangle \neq 0$$

$$\sigma_T(\hat{n} \cdot \vec{v}) n_e$$

$$\bar{n}_e(14\delta)$$

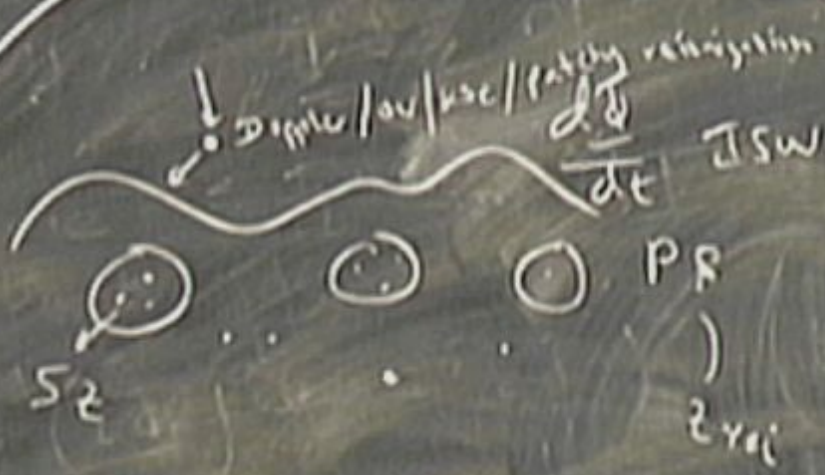
$$\delta n_e$$

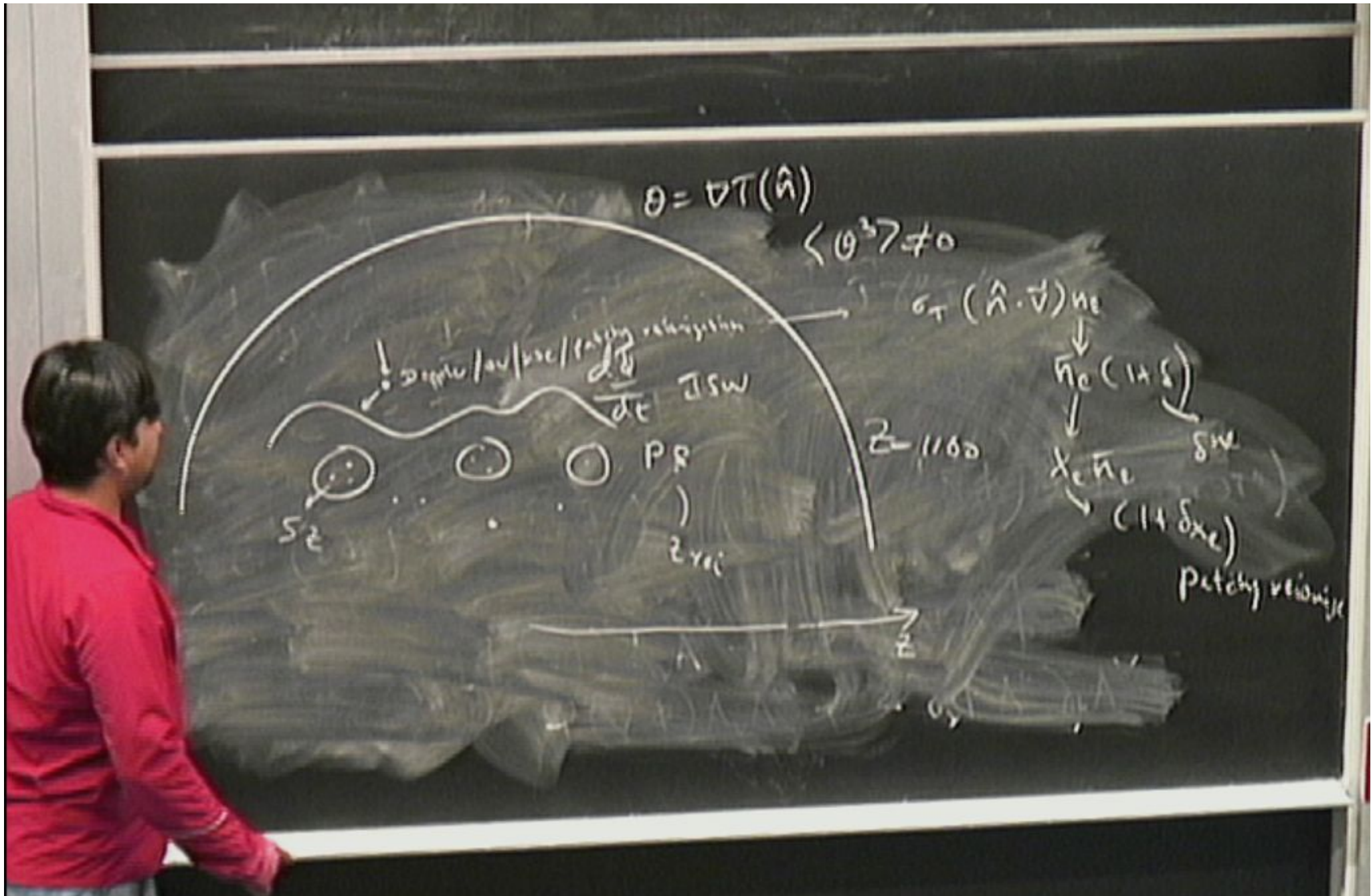
$$x_e \bar{n}_e$$

$$(14\delta x_e)$$

patchy re

$z = 1100$





$$\theta = \nabla T(\hat{n})$$

$$\langle \theta^2 \rangle \neq 0$$

$$\sigma_T (\hat{n} \cdot \vec{v}) n_e$$

$$n_e (14 S)$$

$$X_e n_e$$

$$(14 S n_e)$$

patchy reconnection

dimple / surface / patchy reconnection
 $\frac{d}{dt} \int SW$

PR

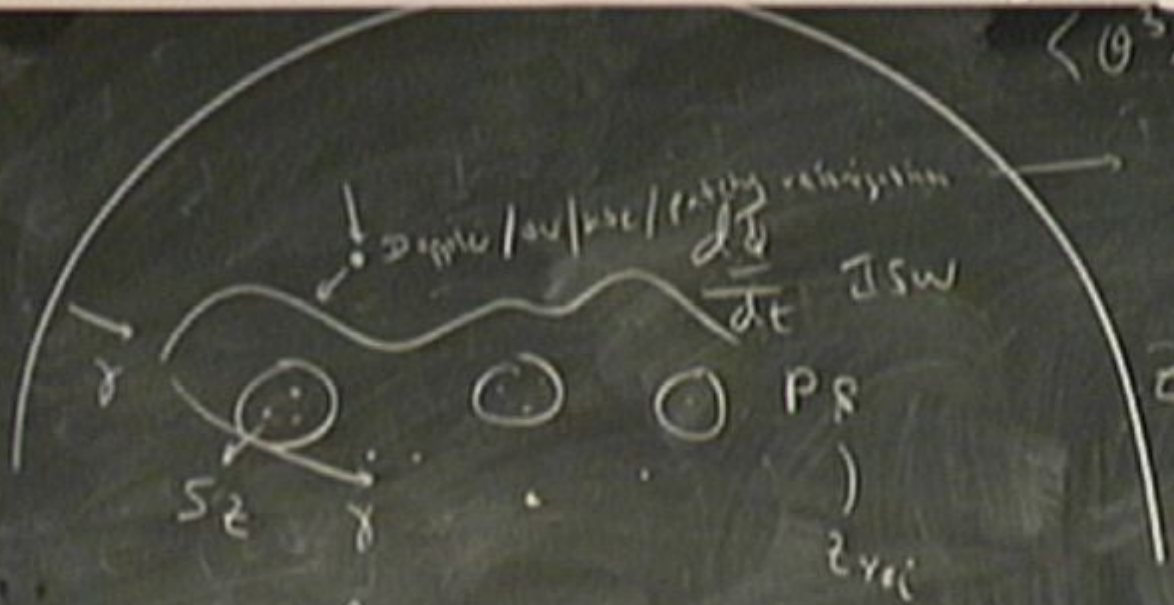
S2

zrec

z=1100

z

$$\langle \theta^2 \rangle \neq 0$$



$$\sigma_T (\hat{n} \cdot \vec{v}) n_e$$

$$\bar{n}_e (1 \pm \delta)$$

$$z \approx 1100$$

$$x_e \bar{n}_e$$

patchy reionization

$$(1 \pm \delta x_e)$$

Lensing

$$\theta(\hat{n}) = \theta(\hat{n} + \hat{\alpha})$$

α deflection angle.

$$\alpha = \nabla\phi$$

$$\phi = \int \delta x W(x) \mathcal{I}(\hat{n}, \gamma\hat{n})$$

$$d_A(x_{1100} - x)$$

$$d_A(x_{1100}) d_A(x)$$

Lensing

$$\theta(\hat{n}) = \theta(\hat{n} + \hat{\alpha})$$

α deflection angle.

$$\alpha = \nabla\phi$$

$$= \theta(\hat{n}) + \nabla_i \theta \partial^i \phi$$

$$+ \frac{1}{2} \nabla_i \nabla_j \theta \partial^i \phi \partial^j \phi$$

$$\phi = \int dx W(x) \Psi(\hat{n}, \gamma\hat{n})$$

$$d_A(x_{1100}, x)$$

$$d_A(x_{1100}) d_{\gamma}(x)$$

lensing

$$\theta(\hat{n}) = \theta(\hat{n} + \hat{\alpha})$$

primordial

α deflection angle.

$$\alpha = \nabla \phi$$

$$= \theta(\hat{n}) + \nabla_c \theta \nabla^c \phi$$

$$+ \frac{1}{2} \nabla_c \nabla_j \theta \alpha^i \alpha^j$$

$$\phi = \int dx W(x) \Psi(\hat{n}, \gamma \hat{n})$$

$$d_A(x_{100}, x)$$

$$d_A(x_{100}) d_A(x)$$

lensing

$$\theta(\hat{n}) = \theta(\hat{n} + \hat{\alpha})$$

primordial

$$= \theta(\hat{n}) + \nabla_{\perp} \theta \cdot \nabla_{\perp} \phi$$

α deflection angle.

$$\alpha = \nabla \phi$$

$$+ \frac{1}{2} \nabla_{\perp} \nabla_{\perp} \theta \cdot \nabla_{\perp} \phi \cdot \nabla_{\perp} \phi$$

$$\phi = \int dx W(x) \Psi(\hat{n}, \gamma \hat{n})$$

$$d_A(x_{100} - x)$$

$$d_A(x_{100}) d_{\lambda}(x)$$

lensing

$$\theta(\hat{n}) \stackrel{\text{genisch}}{=} \theta(\hat{n} + \hat{\alpha})$$

$$\stackrel{\text{primordially}}{=} \theta(\hat{n}) + \nabla \theta \cdot \nabla \phi$$

α deflection angle.

$$\alpha = \nabla \phi$$

$$\phi = \int dx W(x) \Psi(\hat{n}, \gamma \hat{n})$$

$$+ \frac{1}{2} \nabla_i \nabla_j \theta \partial_i \phi \partial_j \phi$$

$$\langle \theta(\hat{n}_1) \cdot [\nabla \theta \cdot \nabla \phi] \rangle$$

$$d_A(x_{100} - x)$$

$$d_A(x_{100}) d_A(x)$$

lensing

$$\theta^{\text{observed}}(\hat{n}) = \theta(\hat{n} + \hat{\alpha})$$

$$= \theta(\hat{n}) + \underbrace{\nabla \theta \cdot \nabla \phi}_{\text{primordial}}$$

$$+ \frac{1}{2} \nabla_i \nabla_j \theta \nabla_i \phi \nabla_j \phi$$

$$\langle \theta(\hat{n}_1) \cdot [\nabla \theta \cdot \nabla \phi] \theta^{\text{sec}} \rangle$$

α deflection angle.

$$\alpha = \nabla \phi$$

$$\phi = \int dx W(x) \Psi(\hat{n}, \gamma \hat{n})$$

$$d_A(x_{1100} - x)$$

$$d_A(x_{1100}) d_A(x)$$

consing

$$\theta(\hat{n}) = \theta(\hat{n} + \hat{\alpha})$$

α deflection angle.

$$= \theta(\hat{n}) + \nabla\theta \cdot \nabla\phi$$

$$\alpha = \nabla\phi$$

$$+ \frac{1}{2} \nabla \cdot \nabla \theta \cdot \nabla \phi \cdot \nabla \phi$$

$$\phi = \int dx W(x) \Psi(\hat{n}, \gamma\hat{n})$$

$$\langle \theta(\hat{n}) \cdot [\nabla\theta \cdot \nabla\phi] \rangle_{\text{sec}}$$

$$\frac{d_A(x_{100} - x)}{d_A(x_{100}) d_A(x)}$$

$$\mathcal{B}_{l_1, l_2, l_3} \propto \begin{pmatrix} \text{prim} \\ l_1 \end{pmatrix} \begin{pmatrix} \phi\text{-sec} \\ l_2 \end{pmatrix} \frac{(l_1 + l_2) l_3}{f(l_1, l_2, l_3)}$$

Bending

$$\theta(\hat{n}) = \theta(\hat{n} + \hat{\alpha})$$

primordial

$$= \theta(\hat{n}) + \nabla\theta \cdot \nabla\phi$$

α deflection angle.

$$\alpha = \nabla\phi$$

$$\phi = \int dx W(x) \Psi(\hat{n}, \gamma\hat{n})$$

$$+ \frac{1}{2} \nabla_i \nabla_j \theta \nabla_i \phi \nabla_j \phi$$

$$\langle \theta(\hat{n}) \cdot [\nabla\theta \cdot \nabla\phi] \theta^{sec} \rangle$$

$$B_{l_1 l_2 l_3} \propto \left(\frac{l_1 + l_2}{l_3} \right) f(l_1, l_2, l_3)$$

l_1 l_2 l_3

$$\frac{d_A(x_{100} - x)}{d_A(x_{100}) d_A(x)}$$

$$\hat{S} = \sum_{\alpha \alpha'} B_{\alpha}^{\text{theory}} \rightarrow B_{\alpha'}^{\text{data}}$$



$$\hat{S} = \sum_{\alpha\alpha'} B_{\alpha\alpha'}$$

$$W = \sum_{\alpha\alpha'} B_{\alpha\alpha'}$$

$$B_{\alpha}^{\text{theory}}$$

$$C_{\alpha\alpha'}$$

$$\hat{B}_{\alpha\alpha'}^{\text{data}}$$

$$B^{\text{theory}} =$$

$$B_{\alpha}^{\text{theory}}$$

$$C_{\alpha\alpha'}^{-1}$$

$$B_{\alpha}^{\text{theory}}$$



$$\hat{S} = \sum_{\alpha} B_{\alpha}^{\text{theory}}$$

$$\hat{S} = \sum_{\alpha} B_{\alpha}^{\text{data}}$$

$$B_{\alpha}^{\text{theory}} = B_{\alpha}^{\text{prim-loc}}$$

$$B_{\alpha}^{\text{theory}} = f_{\text{NL}} B^{\text{local}}$$

$$\hat{S}_{\text{NL}} = \frac{\hat{S}}{2}$$

CAUTION
 Please do not write on the board
 if you have any questions, please ask the lecturer

$$\hat{S} = \sum_{\alpha \alpha'} B_{\alpha}^{\text{theory}}$$

$$N = \sum_{\alpha \alpha'} B_{\alpha}^{\text{theory}}$$

$$\hat{f}_{NL} = \frac{\hat{S}}{N}$$

$$C_{\alpha \alpha'} \rightarrow \hat{B}_{\alpha}^{\text{data}}$$

$$C_{\alpha \alpha'}^{-1} B_{\alpha}^{\text{theory}}$$

$$B^{\text{theory}} = B^{\text{prim-local}}$$

$$\hat{B}_{\alpha}^{\text{data}} = f_{NL} B^{\text{local-shape}}$$

$$\hat{B}_{\text{data}} = f_{NL} B^{\text{local-shape}}$$



$$\hat{S} = \sum_{\alpha} B_{\alpha}^{\text{theory}}$$

$$N = \sum_{\alpha} C_{\alpha}^{-1} B_{\alpha}^{\text{theory}}$$

$$\hat{f}_{NL} = \frac{\hat{S}}{N}$$

$\hat{B}_{\alpha}^{\text{data}}$

$$B^{\text{theory}} = B^{\text{prim-loc}}$$

$$\hat{B}_{\text{data}} = \int_{NL} B^{\text{local-shape}}$$

$$B^{\text{data}} = \int_{NL} B^{\text{local-shape}} + B^{\text{sec}} + B^{\text{foreground}}$$

consing

$$\theta(\hat{n}) = \theta(\hat{n} + \hat{\alpha})$$

primordia

$$= \theta(\hat{n}) + \nabla\theta \cdot \nabla\phi$$

α deflection angle.

$$\alpha = \nabla\phi$$

$$\phi = \int dx W(x) \mathcal{F}(\hat{n}, \gamma\hat{n})$$

$$\left\langle \theta(\hat{n}_1) \cdot \left[\nabla\theta \cdot \nabla\phi \right] \theta^{sec} \right\rangle$$

$+ \frac{1}{2} \nabla_i \nabla_j \theta \nabla_i \phi \nabla_j \phi$

$$B_{l_1 l_2} \propto \left(\frac{1}{l_1} \right) \left(\frac{1}{l_2} \right) \left(\frac{l_1 + l_2}{f(l_1, l_2, l_3)} \right) l_3$$

$\phi - sec$

$$\frac{d_A(x_{100} - x)}{d_A(x_{100}) d_A(x)}$$

Lensing

$$\theta(\hat{n}) \stackrel{\text{Densich}}{=} \theta(\hat{n} + \hat{\alpha})$$

primordial

$$= \theta(\hat{n}) + \nabla\theta \cdot \nabla\phi$$

α deflection angle.

$$\alpha = \nabla\phi$$

$$\phi = \int dx W(x) \Psi(\hat{n}, \gamma\hat{n})$$

$$\left\langle \theta(\hat{n}_1) \cdot \left[\nabla\theta \cdot \nabla\phi \right] \right\rangle_{\text{sec}}$$

$$+ \frac{1}{2} \nabla_i \nabla_j \theta \nabla_i \phi \nabla_j \phi$$

$$B_{\ell_1 \ell_2} \propto \left(\text{primordial} \right) \frac{(\ell_1 + \ell_2) \ell_2}{f(\ell_1, \ell_2, \ell_3)}$$

ℓ_1 ℓ_2 ℓ_3

$$\frac{d_A(x_{1100} - x)}{d_A(x_{1100}) d_A(x)}$$

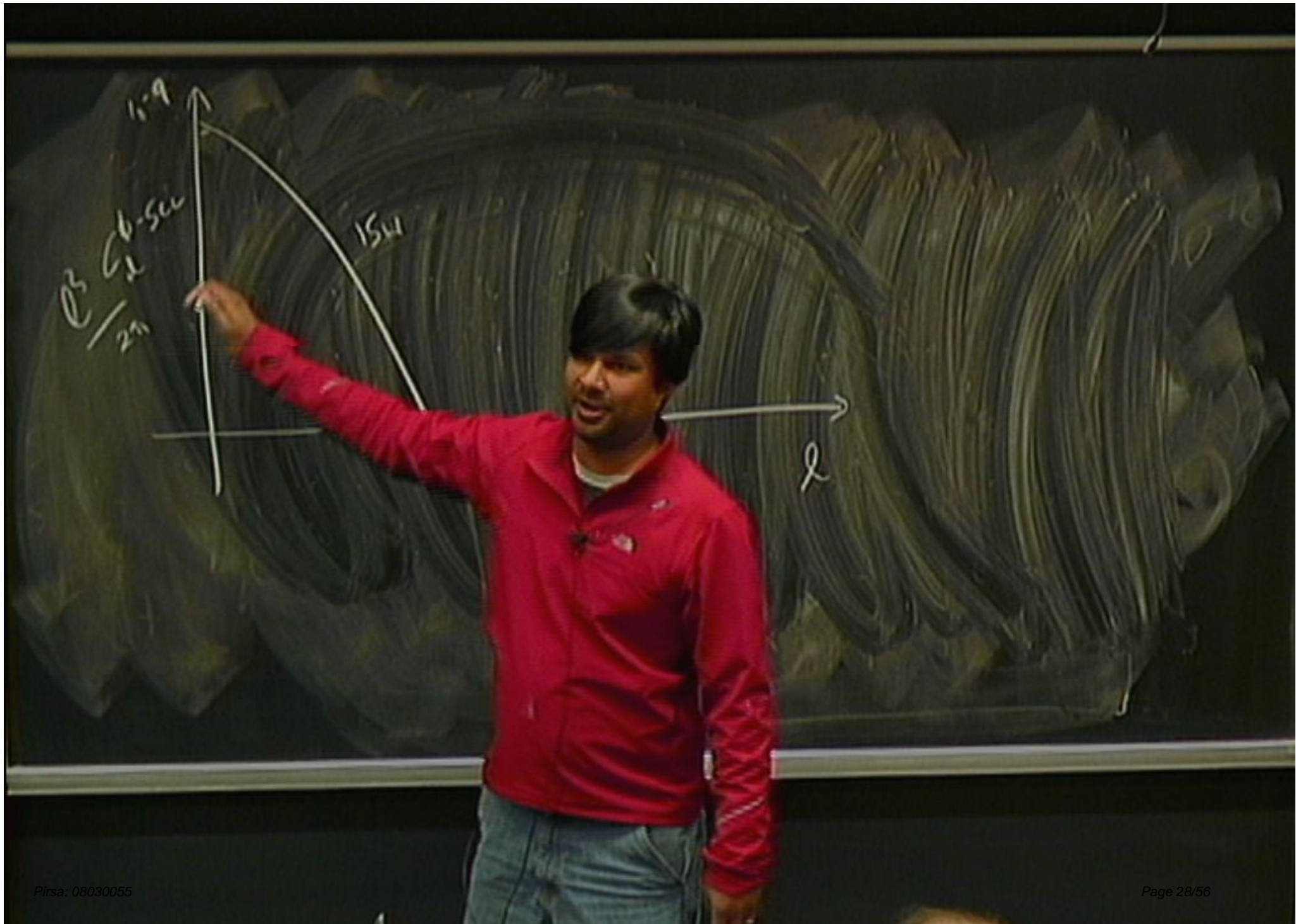
$\hat{S} = \sum_{\alpha} B_{\alpha}^{theory}$ C_{data}^{-1} $\begin{bmatrix} \hat{A}_{data} \\ \hat{B}_{data} \end{bmatrix}$ $B^{theory} = B^{prime data}$

$N = \sum_{\alpha} B_{\alpha}^{theory}$ C_{data}^{-1} B_{α}^{theory} $\hat{B}_{data} = f_{NL} B^{local-shape}$

$\hat{f}_{NL} = \frac{\hat{S}}{N}$ $\hat{B}_{data} = f_{NL} B^{local-shape} + B^{basic} + B^{foreground}$

$\Delta f_{NL} = \sum_{\alpha} B_{\alpha}^{foreground}$ $C^{-1} [B_{\alpha}^{extra}]$



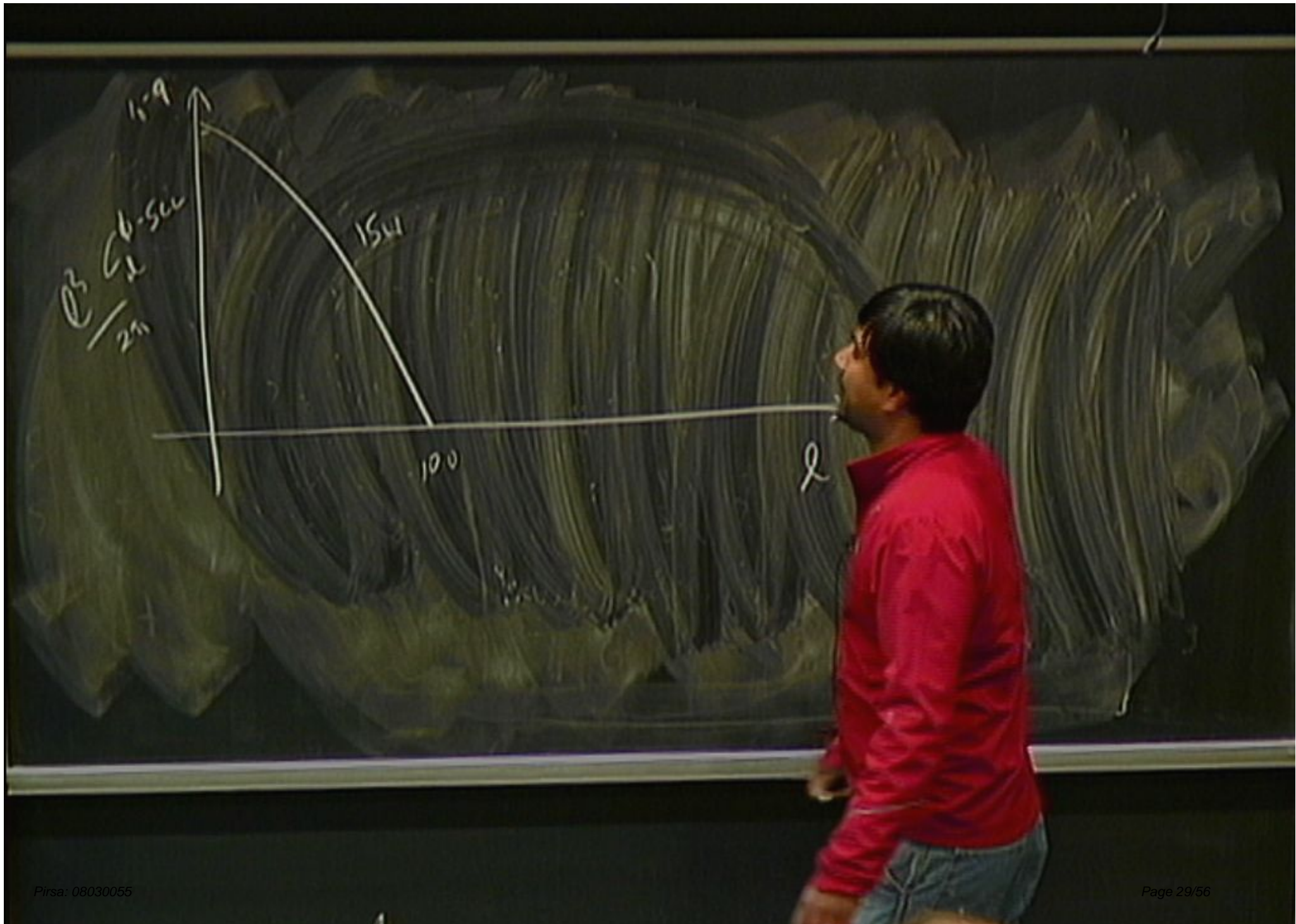


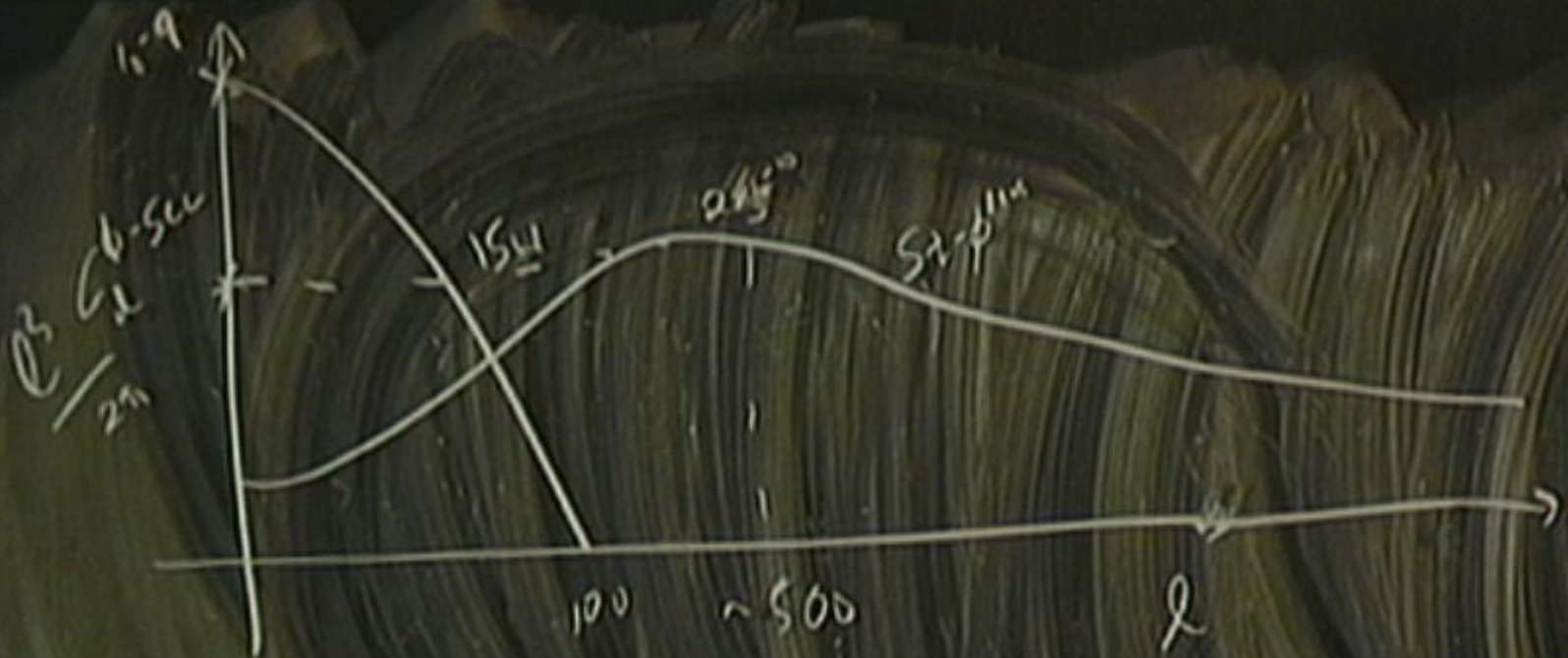
$e^3 / 2^4$

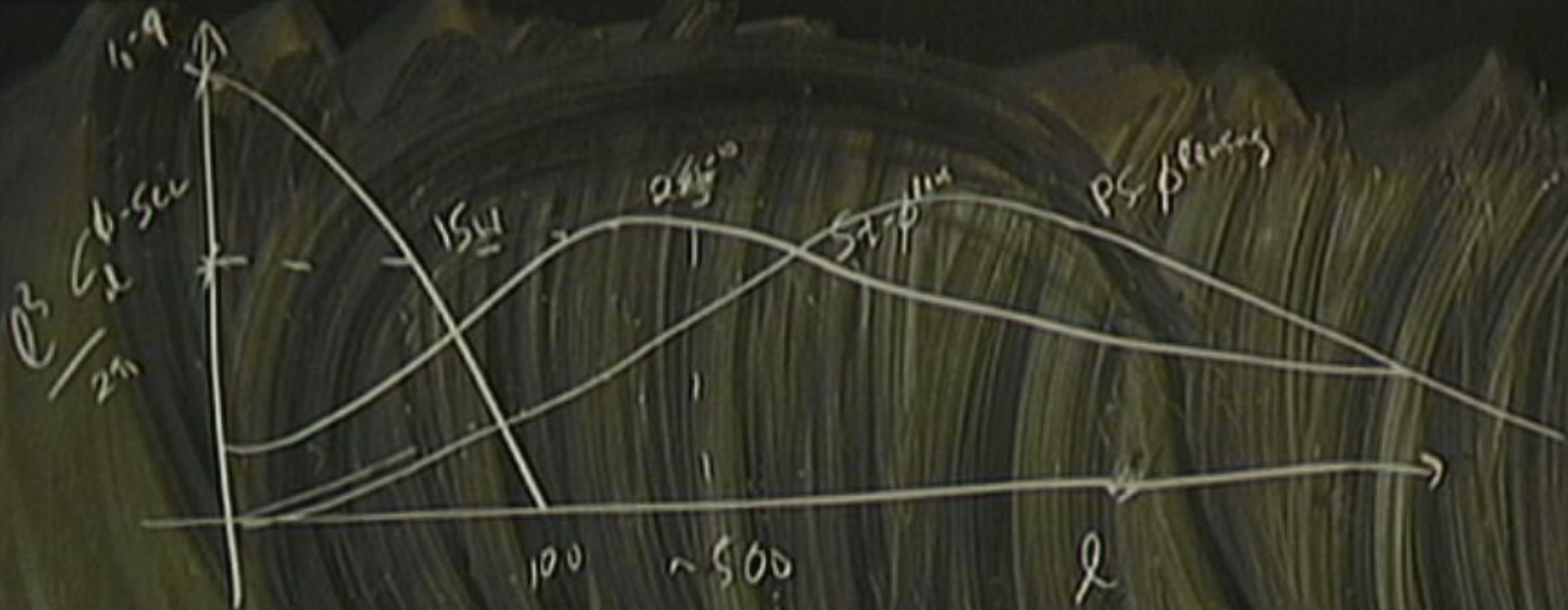
1.9

15W

l







$$\langle S_k - S_k - P(S) \rangle$$

$$\langle S_k - S_k - S_k \rangle$$

$$\langle S_k - 15W - 15W \rangle$$

$\langle S_2 - S_2 - P_5 \rangle$

$\langle S_2 - S_2 - S_2 \rangle$

$\langle S_2 - 15W - 15W \rangle$

halo model



$\langle S_2 - S_2 - P_5 \rangle$

halo model

$\langle S_2 - S_2 - S_2 \rangle$

$\langle S_2 - MS_1 - S_2 \rangle$



$\langle S_2 - S_2 - P_5 \rangle$

$\langle S_2 - S_2 - S_2 \rangle$

$\langle S_2 - 1SW - 1SW \rangle$

$\langle P_5 - P_5 - P_5 \rangle$

→ 3 halo term
 $\propto 6^3$

halo model



$\langle S_L - S_L - P_S \rangle$

$\langle S_L - S_S - S_L \rangle$

$\langle S_L - I_{SW} - I_{SW} \rangle$

$\langle P_S - P_S - P_S \rangle$

→ 3 halo term
 $\propto \int \beta_{PT-grav}$

$\propto J(k_1, k_2) P_S(k_1) P_S(k_2)$

halo model



$\langle S_L - S_L - P_S \rangle$

$\langle S_L - S_S - S_L \rangle$

$\langle S_L - I_{SW} - I_{SW} \rangle$

$\langle P_S - P_S - P_S \rangle$

→ 3 halo term

$\propto \int \beta^{PT-grav}$

$$\propto \int J(k_1, k_2) P_S(k_1) P_S(k_2)$$

halo model



$\langle S_L - S_L - P_S \rangle$

$\langle S_L - S_L - S_L \rangle$

$\langle S_L - I_{SW} - I_{SW} \rangle$

$\langle P_S - P_S - P_S \rangle$

halo model



→ 3 halo term
 $\propto b^3 \beta^{PT-grav}$

$\propto \int J(k_1, k_2) P_S(k_1) P_S(k_2)$

+ 1 halo term
 $\frac{1}{h_g} \int dM \frac{dn}{dM} \frac{\langle S_1^3 \rangle}{M^3}$

$\langle S_L - S_L - P_S \rangle$

$\langle S_L - S_L - S_L \rangle$

$\langle S_L - 15W - 15W \rangle$

$\langle P_S - P_S - P_S \rangle$

→ 3 halo term

$\propto \beta^3 \beta^{PT-grav}$

$$\propto \int J(k_1, k_2) P_S(k_1) P_S(k_2)$$

halo model



+ 1 halo term

$$\frac{1}{M^3} \left(\frac{dM}{dM} \right) \frac{dM}{dM} \frac{\langle S_L^3 \rangle}{M^3}$$

Expansion

$$\Theta(\hat{\psi}) = \Theta(\hat{\psi} + \hat{\alpha})$$

primordial

$$= \Theta(\hat{\psi}) + \nabla_i \Theta \nabla^i \phi$$

$$+ \frac{1}{2} \nabla_i \nabla_j \Theta \nabla^i \phi \nabla^j \phi$$

consistency

$$\theta(\hat{h}) = \theta(\hat{h} + \hat{\alpha})$$

primordial

$$= \theta(\hat{h}) + \nabla \theta \cdot \nabla \phi$$

$$+ \frac{1}{2} \nabla_i \nabla_j \theta \nabla^i \phi \nabla^j \phi$$

$$\langle \theta(\hat{h}) \theta(\hat{h}') \rangle$$

$$C_{\theta} =$$

lensing

$$\theta(\hat{h}) = \theta(\hat{h} + \hat{\alpha})$$

$$= \theta(\hat{h}) + \nabla_i \theta \nabla^i \phi$$

$$+ \frac{1}{2} \nabla_i \nabla_j \theta \nabla^i \phi \nabla^j \phi$$

$$\langle \theta(\hat{h}) \theta(\hat{h}') \rangle$$

lensed

prim

$$\int_{\mathcal{L}}$$

$$\int_{\mathcal{L}}$$

$$+ \int \frac{d^2 \ell'}{4\pi^2} \frac{1}{|\ell - \ell'|} \theta(\ell) \theta(\ell')$$

$$- \int \frac{d^2 \ell'}{4\pi^2} \frac{1}{|\ell - \ell'|^2} \theta(\ell) \theta(\ell')$$

lensing

$$\theta(\hat{n}) \stackrel{\text{lens}}{=} \theta(\hat{n} + \hat{\alpha})$$

$$\stackrel{\text{primordial}}{=} \theta(\hat{n}) + \nabla \theta \cdot \nabla \phi$$

$$+ \frac{1}{2} \nabla_i \nabla_j \theta \nabla^i \phi \nabla^j \phi$$

α deflection angle.

$$\alpha = \nabla \phi$$

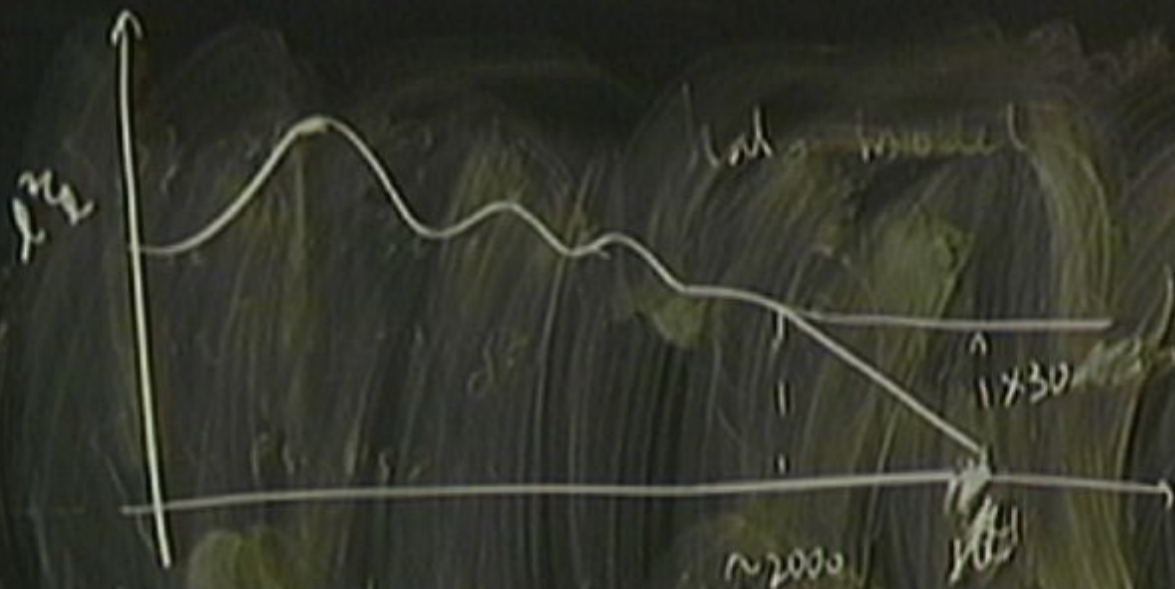
$$\phi = \int dx W(x) \mathcal{I}(\hat{n}, \gamma \hat{n})$$

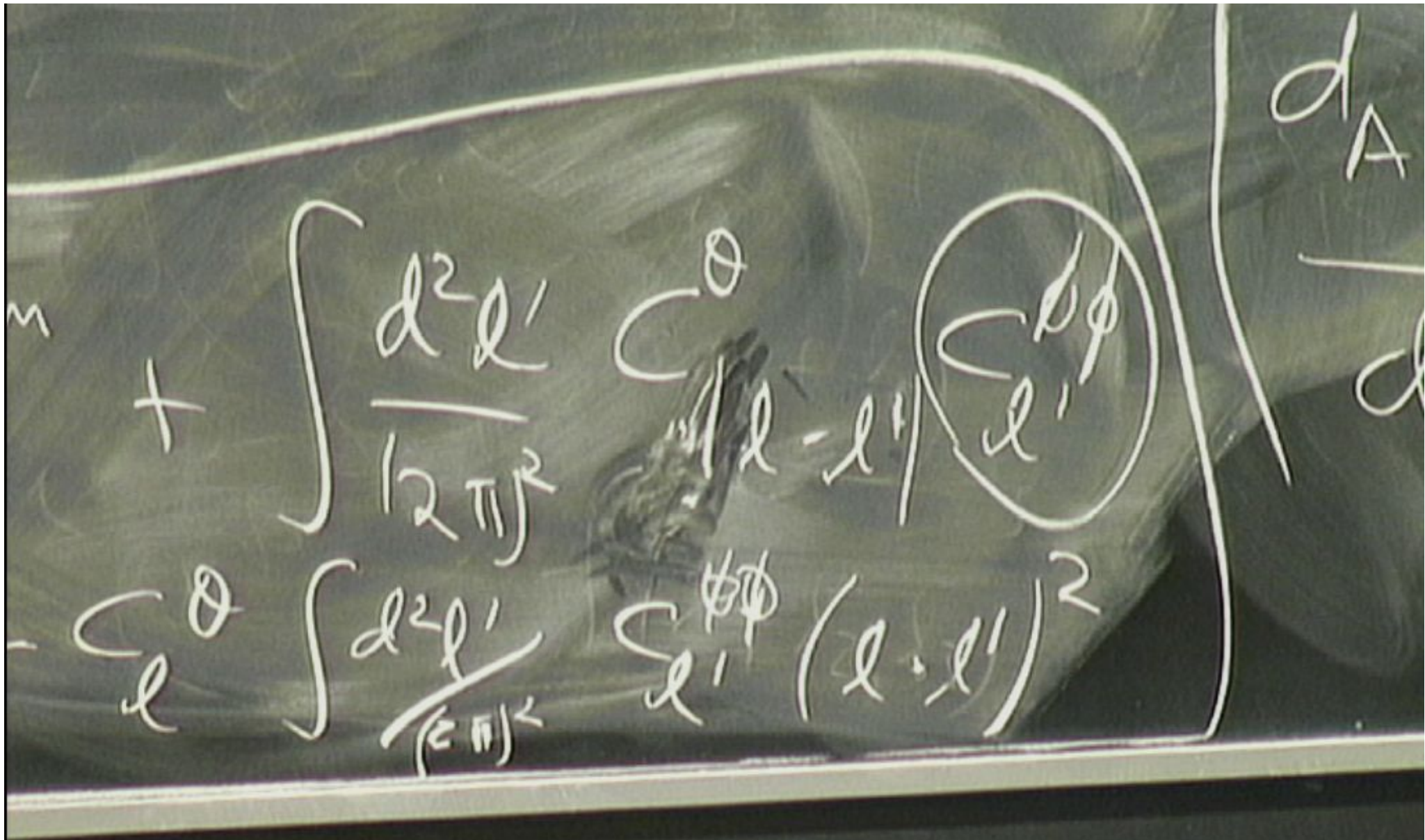
$$d_A(x_{100} - x)$$

$$d_A(x_{100}) d_A(x)$$

$$\langle \theta(\hat{n}) \theta(\hat{n}') \rangle$$

$$\ell = \underbrace{\dots}_{\text{lensed}} + \underbrace{\dots}_{\text{prim}} + \int \frac{d^2 \ell'}{4\pi \ell'^2} \dots - \int \frac{d^2 \ell'}{4\pi \ell'^2} \dots$$





m

$$+ \int \frac{d^2 l'}{(2\pi)^2} C^0 \circledast C^0$$

$$C^0 \int \frac{d^2 l'}{(2\pi)^2} C^0 (l \cdot l')$$

d
A



lat model

1×30

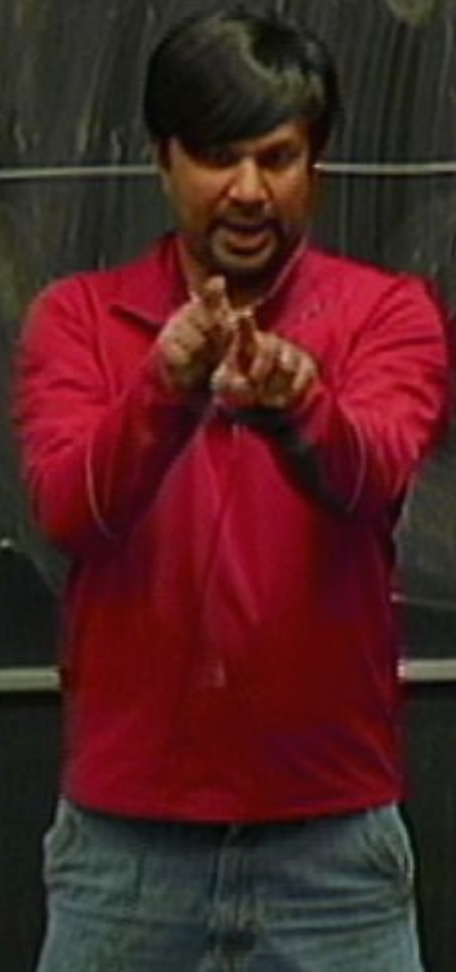
~ 2000

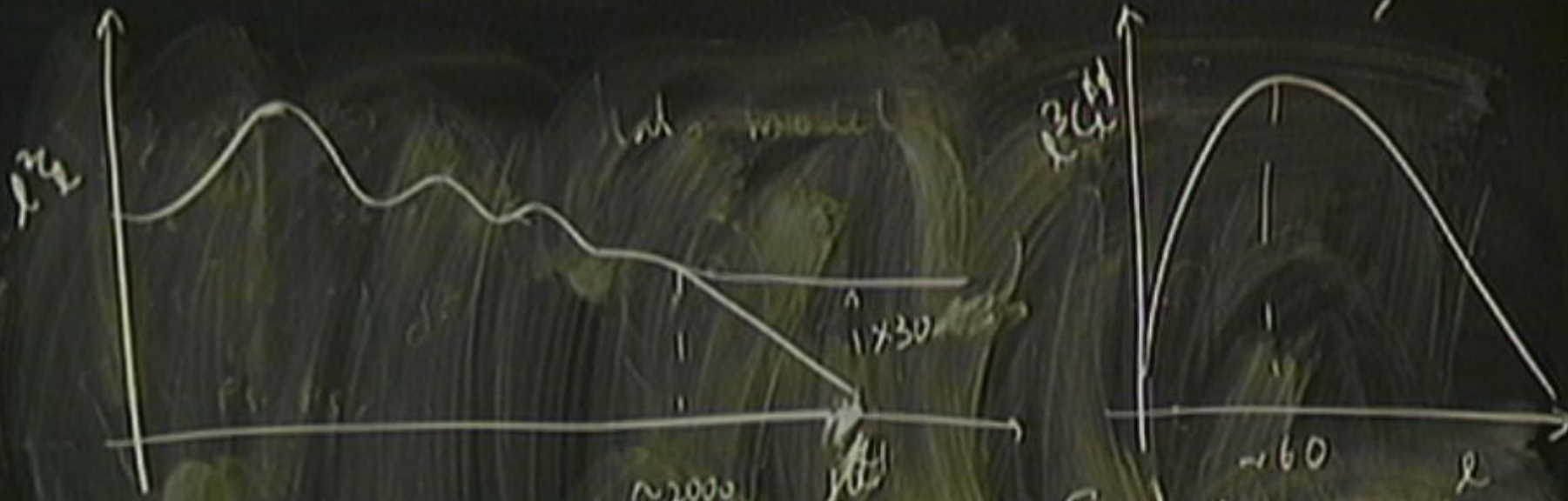
~ 60

$$\sigma_{rms}^2 \sim \int dl l^2 \rho C_{\rho\rho}(l)$$

$$\sim 10^{-4}$$

$$\sigma_{rms} \sim 2.5' \text{ LCDM}$$





lat. model

~ 2000

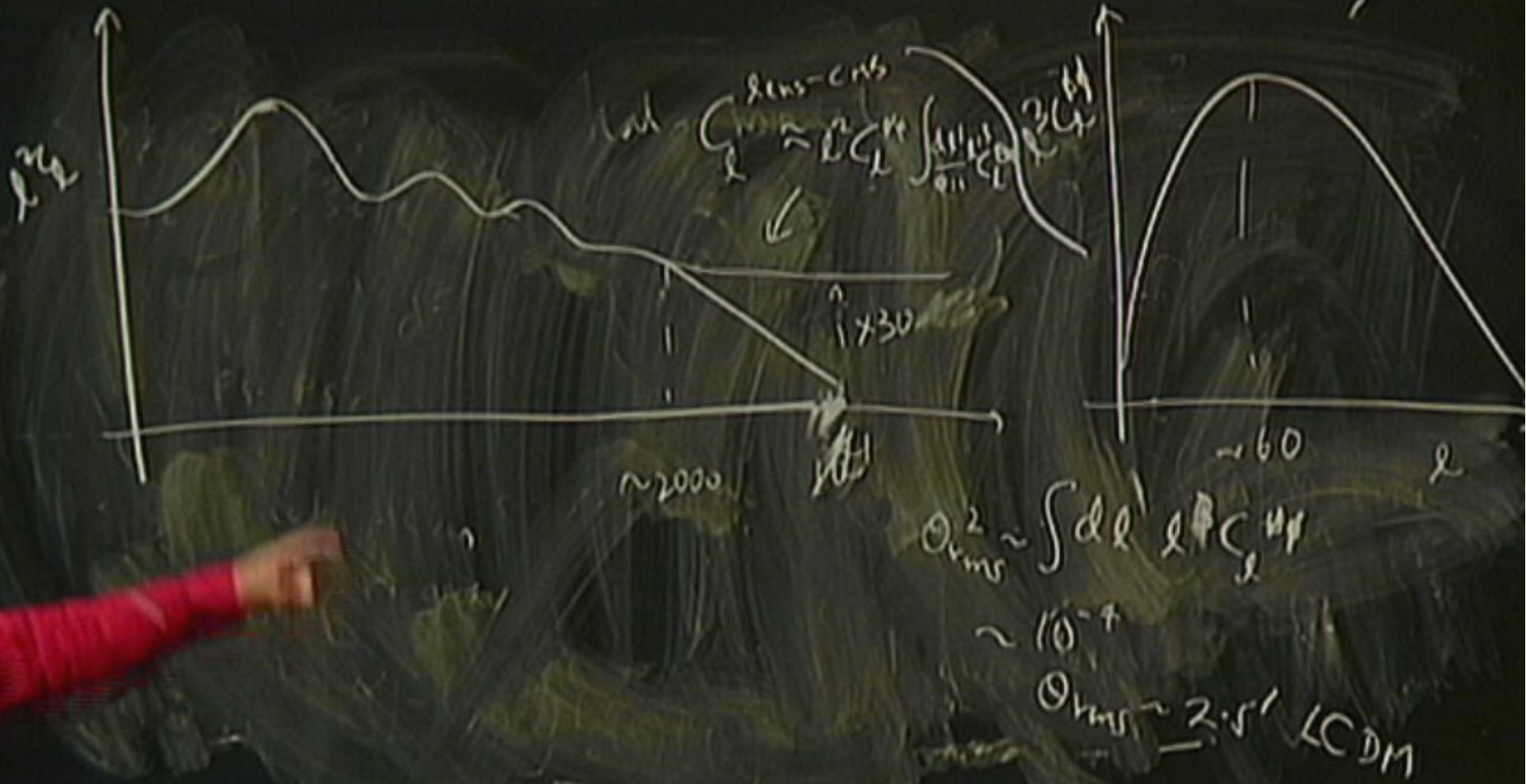
1×30

~ 60

$$\sigma_{rms}^2 \sim \int dl' l' C_{\delta}^2$$

$$\sim 10^{-4}$$

$$\sigma_{rms} \sim 2.5' \text{ LCDM}$$



lensing

$$\theta(\hat{n}) = \theta(\hat{n} + \hat{\alpha})$$

$$= \theta(\hat{n}) + \nabla \theta \cdot \nabla \phi$$

$$+ \frac{1}{2} \nabla_i \nabla_j \phi \nabla_i \nabla_j \phi$$

α deflection angle.

$$\alpha = \nabla \phi$$

$$\phi = \int dx W(x) \mathcal{I}(\hat{n}, x)$$

$$d_A(x_{1100} - x)$$

$$d_A(x_{1100}) d_A(x)$$

$$C_{\ell}^{prim} + \int \frac{d^2 \ell'}{4\pi \ell'^2} C_{|\ell - \ell'|}^{\phi} \frac{C_{\ell}^{\phi}}{\ell'^2} - C_{\ell}^{\phi} \int \frac{d^2 \ell'}{4\pi \ell'^2} C_{\ell'}^{\phi} (\ell \cdot \ell')^2$$

$$\langle \theta(\hat{u}_1) | \theta(\omega) \theta(\hat{u}_2) \rangle$$

Fourier - bi-spec

$$= \int \frac{d^4 \ell_1}{(2\pi)^4} B_{\ell_1, \ell'_1}^{prim}(\theta_1, \theta) \frac{d^4 \ell_2}{(2\pi)^4} f(\ell_2, \ell_1, \ell_3, \ell_1)$$

$$\langle \theta(\hat{u}_1) \theta(\hat{u}_2) \theta(\hat{u}_3) \rangle$$

Rosen - bispec

$$B_{l_1 l_2 l_3} = \int \frac{d^4 \ell_1}{(2\pi)^4} B_{l_1 l_1' - (0 \text{ or } \theta)}^{prim} \frac{1}{|\ell_2 - \ell_1|} f(\ell_2, \ell_1, \ell_3, \ell_1)$$

$$\langle \theta(\hat{a}_1) | \theta(\hat{a}_2) | \theta(\hat{a}_3) \rangle$$

Bochner - bispec

$$B_{l_1 l_2 l_3} = \int \frac{d^d \ell_1}{(2\pi)^d} B_{l_1, \ell_1}^{prim} \frac{C_{l_2}}{|\ell_2 - \ell_1|} f(l_2, \ell_1, \ell_3, \ell_1)$$

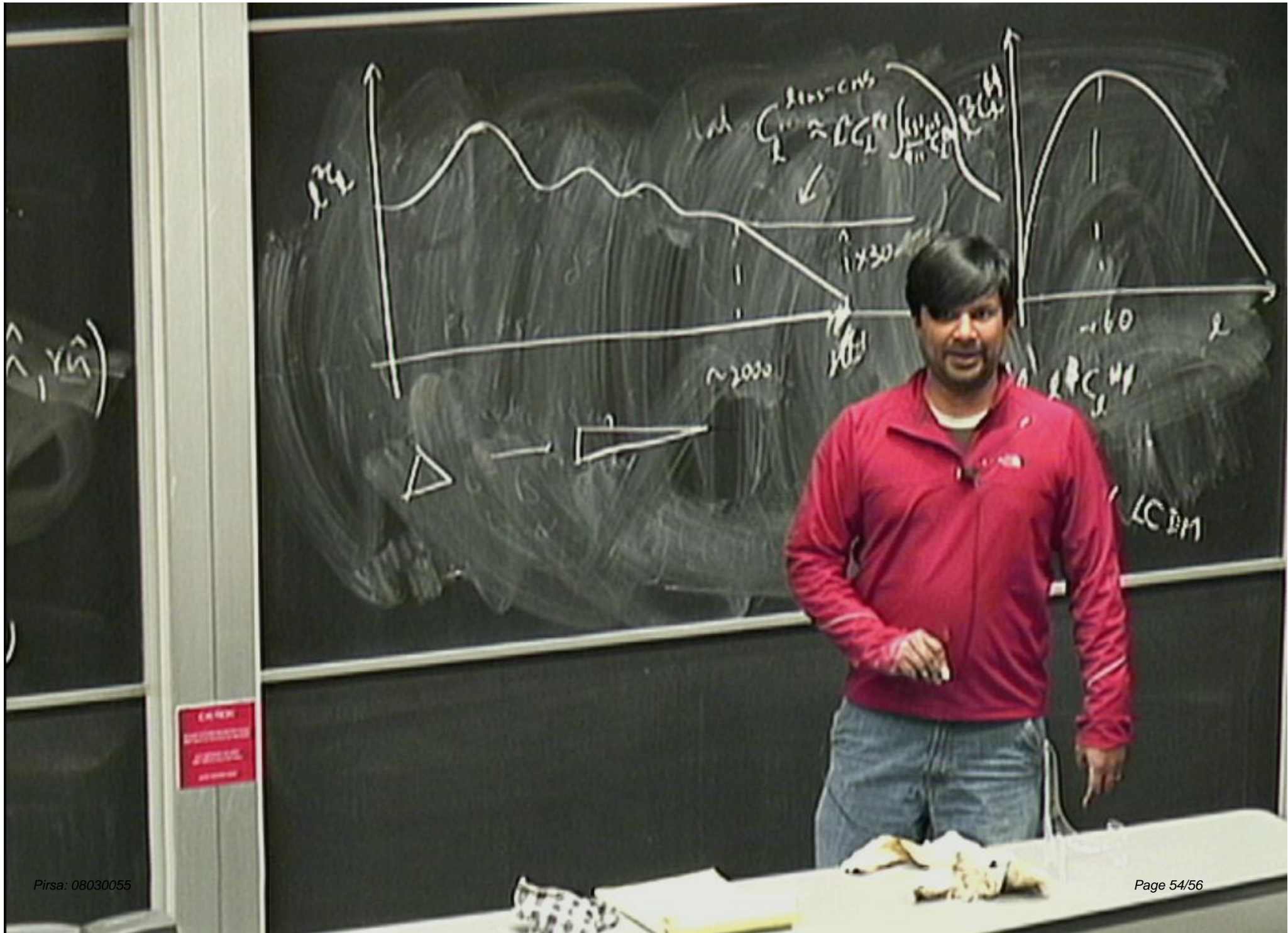
Perm.

$$\langle \theta(\hat{u}_1) \theta(\hat{u}_2) \theta(\hat{u}_3) \rangle$$

Random - bosonic

$$B_{l_1 l_2 l_3} = \int \frac{d^3 \ell_1}{(2\pi)^3} B_{l_1, \ell_1 - (0, \pi, 0)}^{prim} \frac{1}{|\ell_2 - \ell_1|} f(\ell_2, \ell_1, \ell_3, \ell_1)$$

$$= \sum_{perm} B_{l_1 l_2 l_3}^{prim} \int \frac{d^3 \ell_1}{(2\pi)^3} S_{\ell_1}^{HD} (\ell_1 \cdot \ell_2)^2 + Perm$$

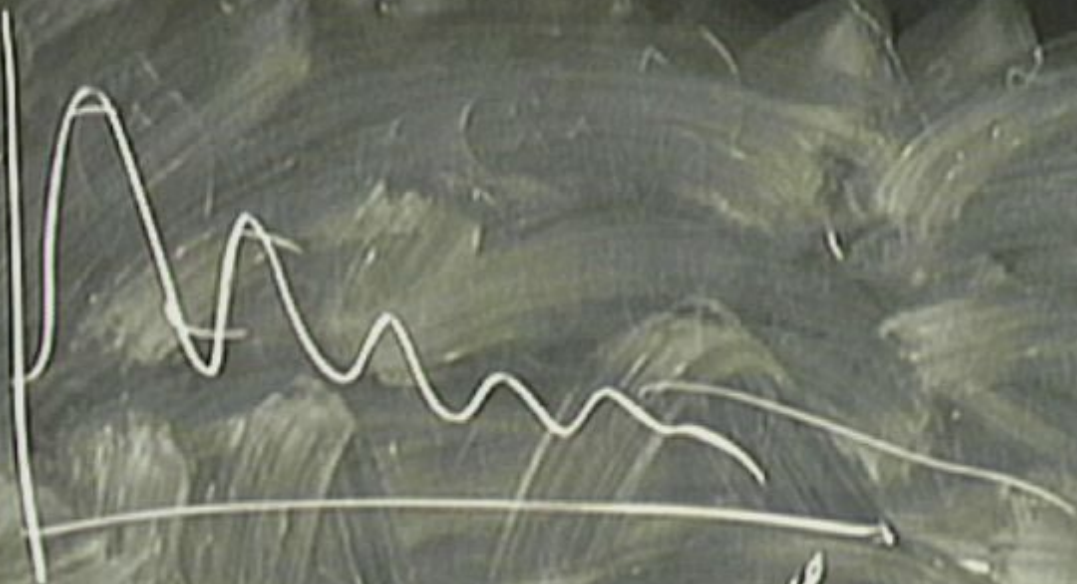


β Be



α

β Be



x