Title: Multi-Stream Inflation

Date: Apr 28, 2010 04:45 PM

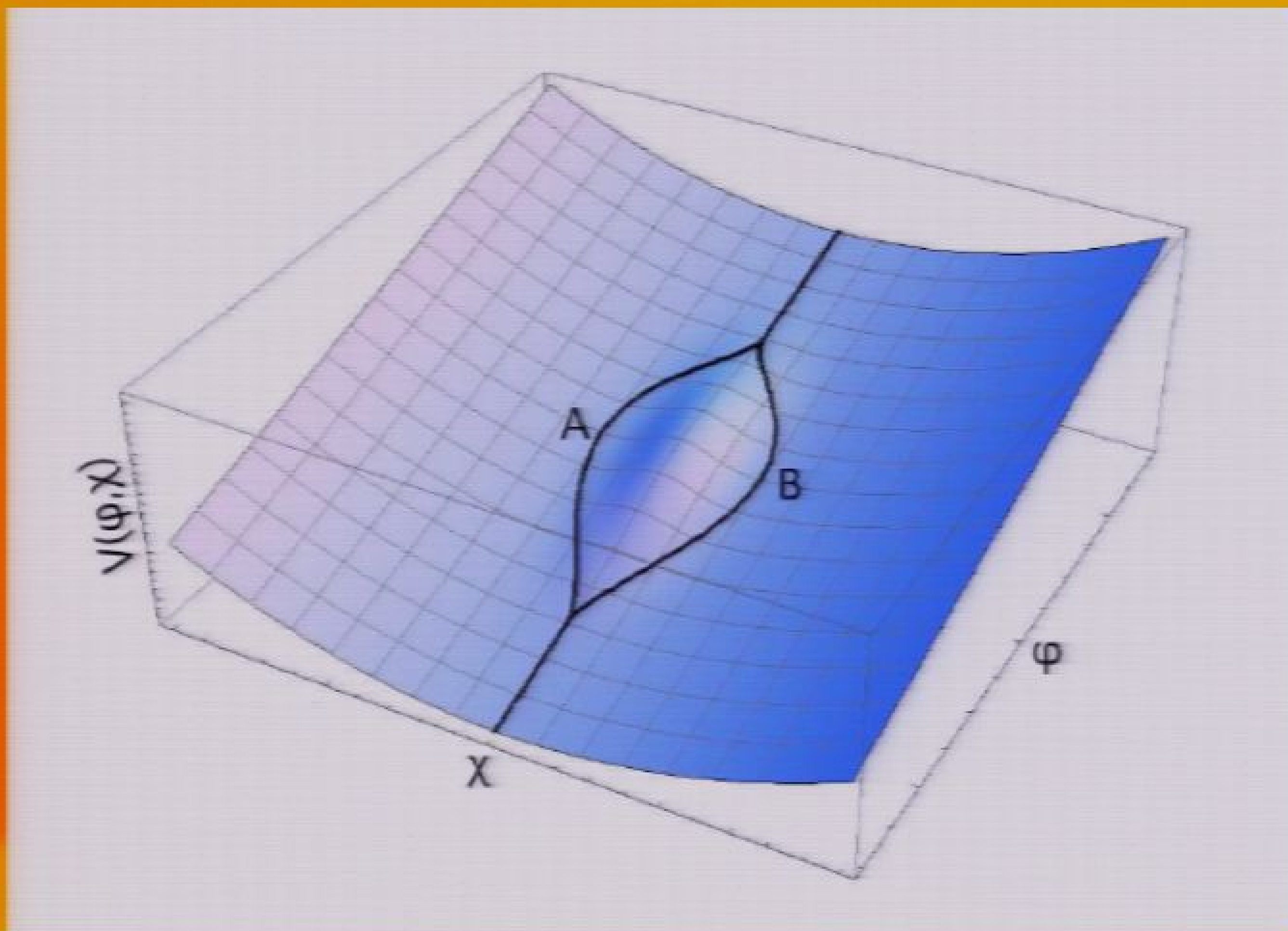
URL: http://pirsa.org/10040102

Abstract: TBA

Outline:

- Inflation which can produce bubbles of arbitrary under/over densities
- Bubbles vs voids
- The impact of such bubbles on the CMB
- The inspiration is the dreaded cold spot, but the applicability is actually much more general.

Multi-stream inflation



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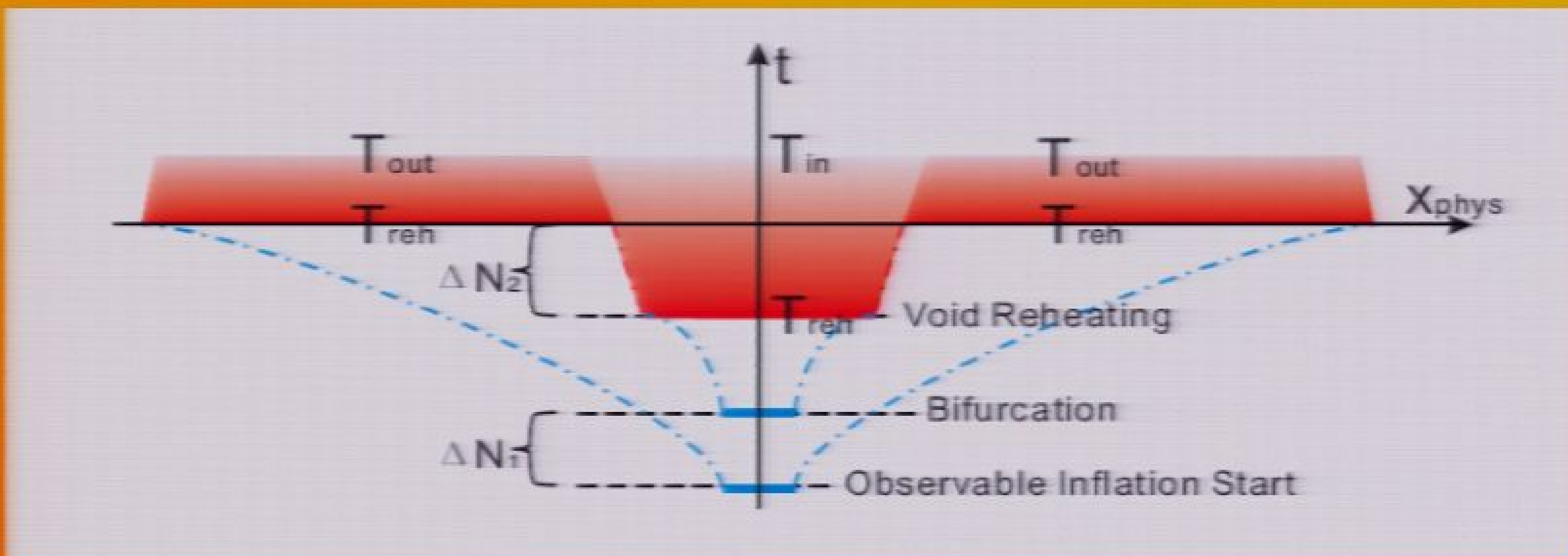

$$N_{\rm observable} = p\,(H_b/H_i)^3 e^{3\Delta N_1} = p\, e^{3(1-\epsilon)\Delta N_1} = p\, e^{3\Delta N_1^*}$$

$$R_{\rm bubble} \sim \left(\frac{1}{H_0} e^{-\Delta N_1^* - \Delta N_2}\right)$$

$$\zeta_* = -(N_{\rm bubble} - N_0) = \Delta N_2$$

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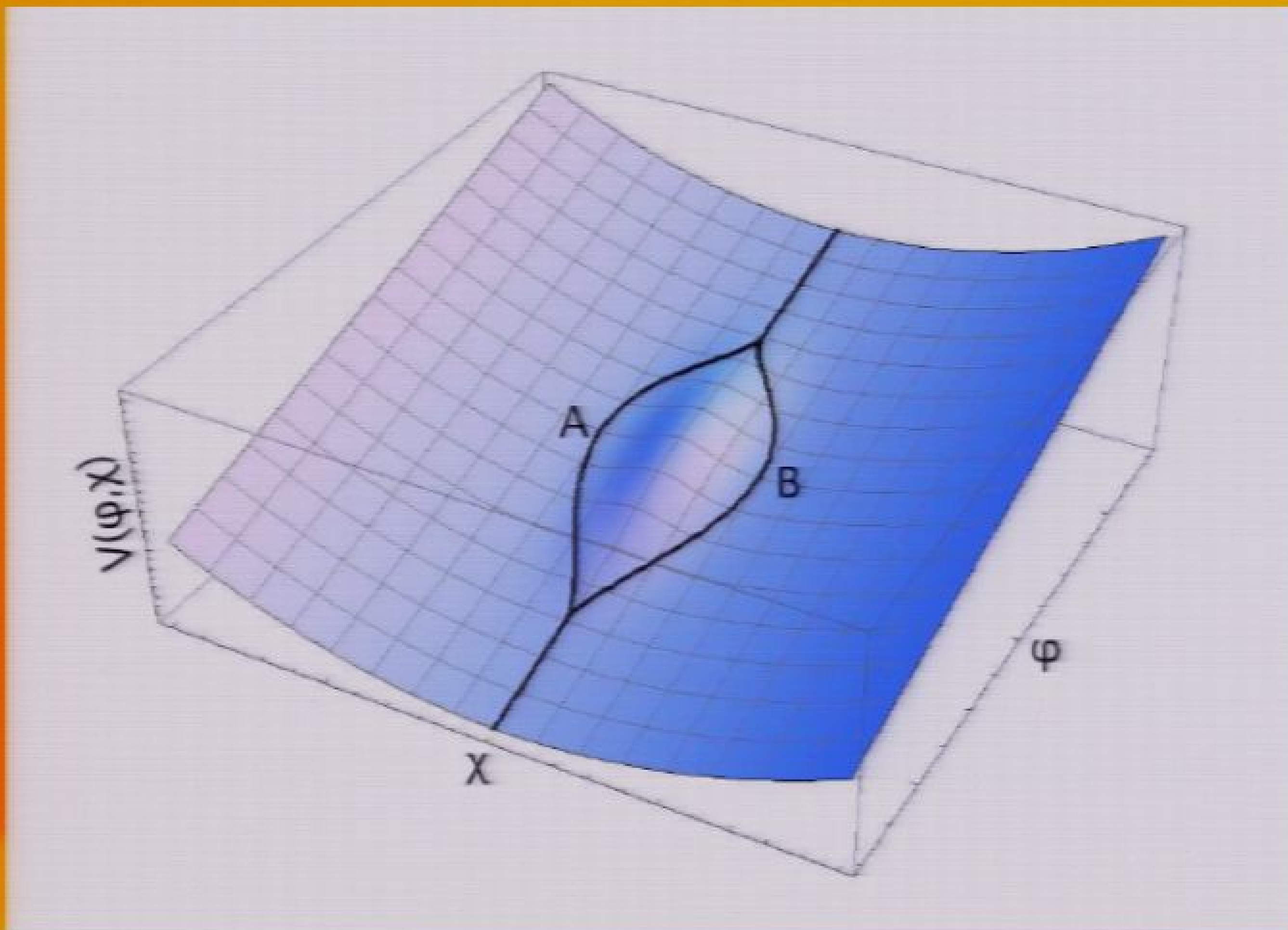

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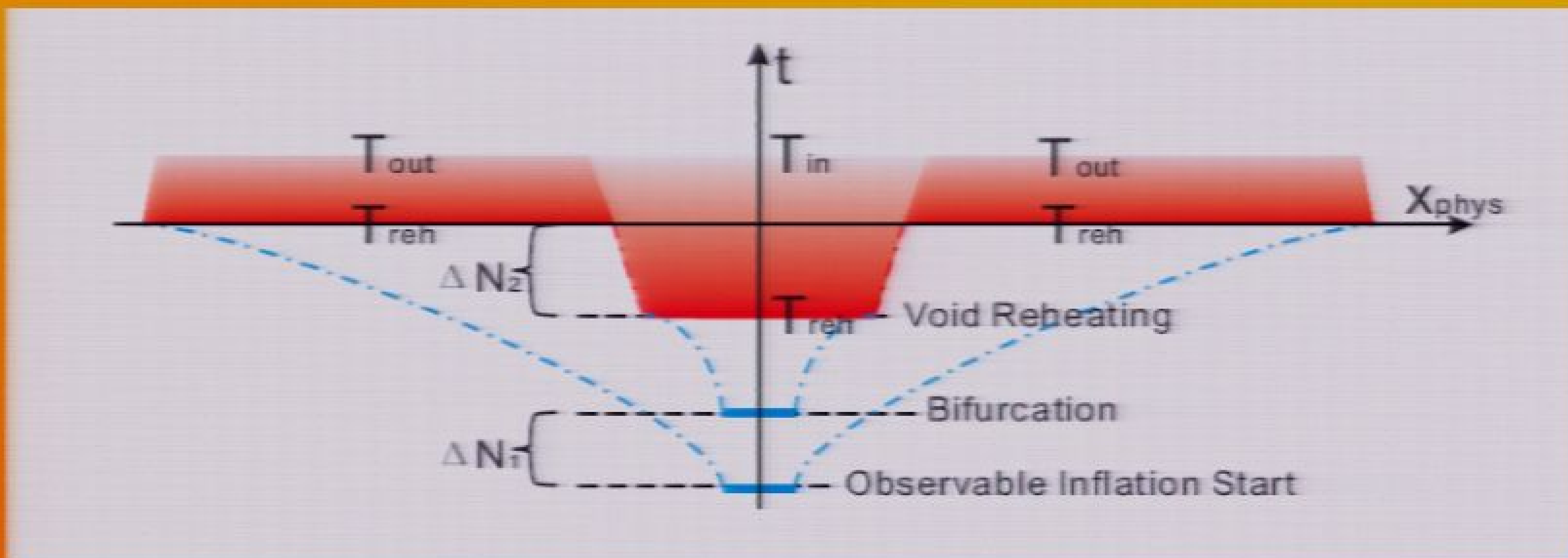

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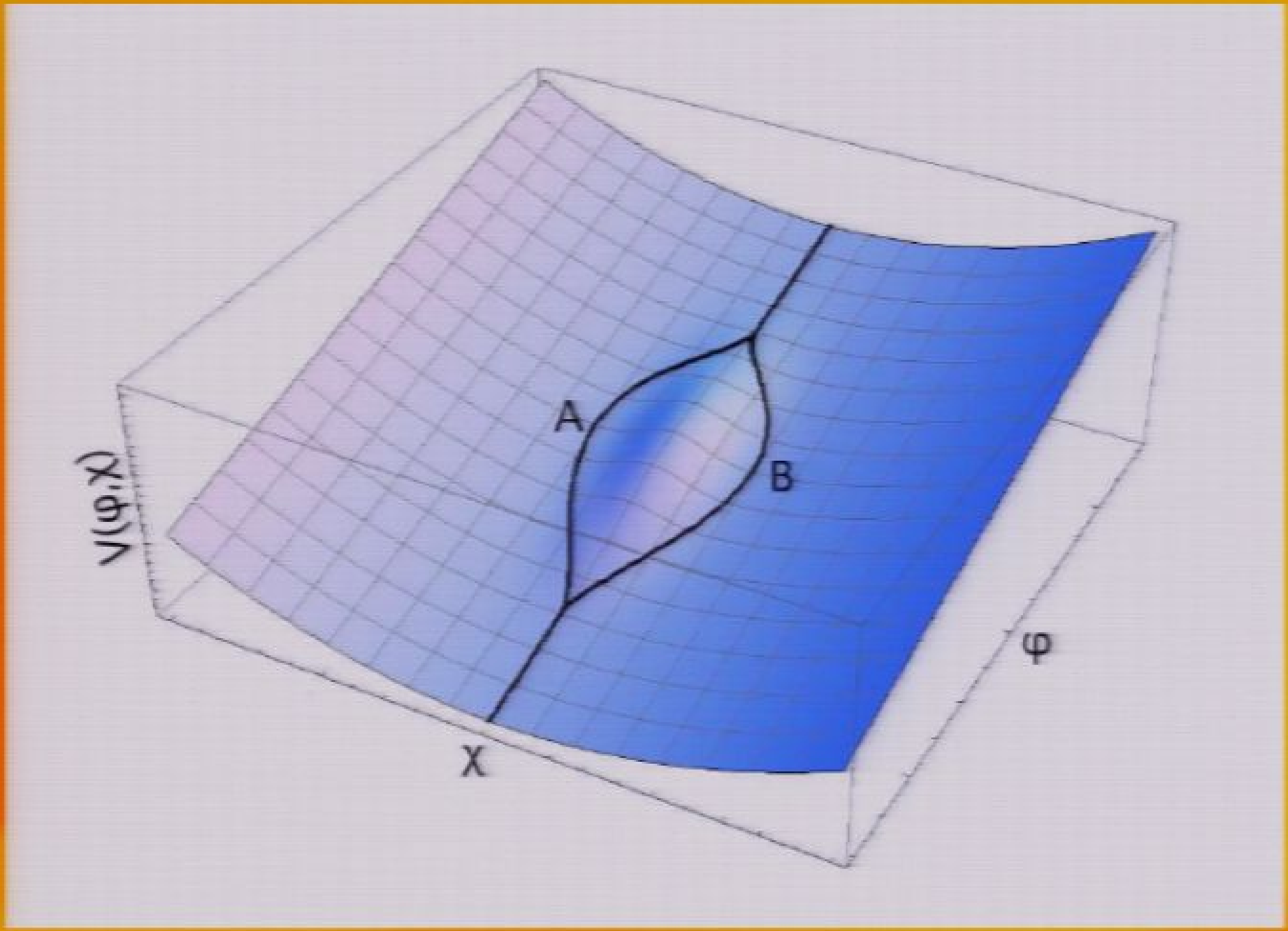
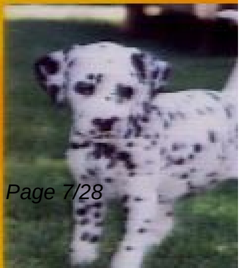
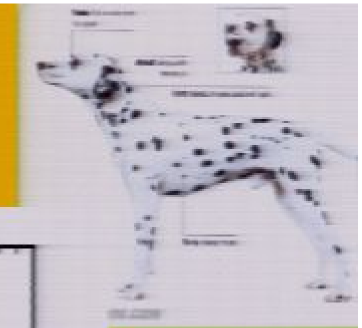
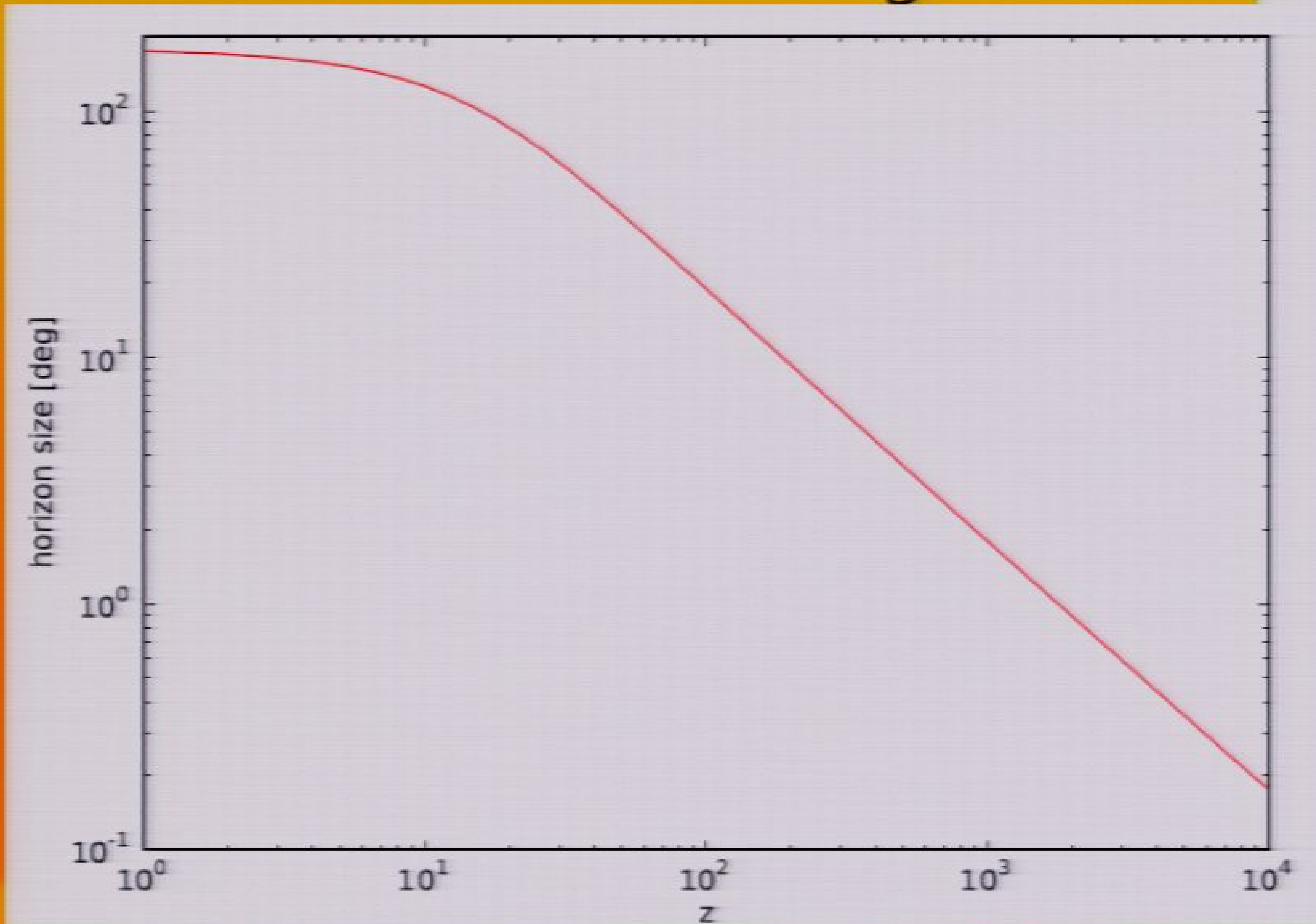




Bubble size



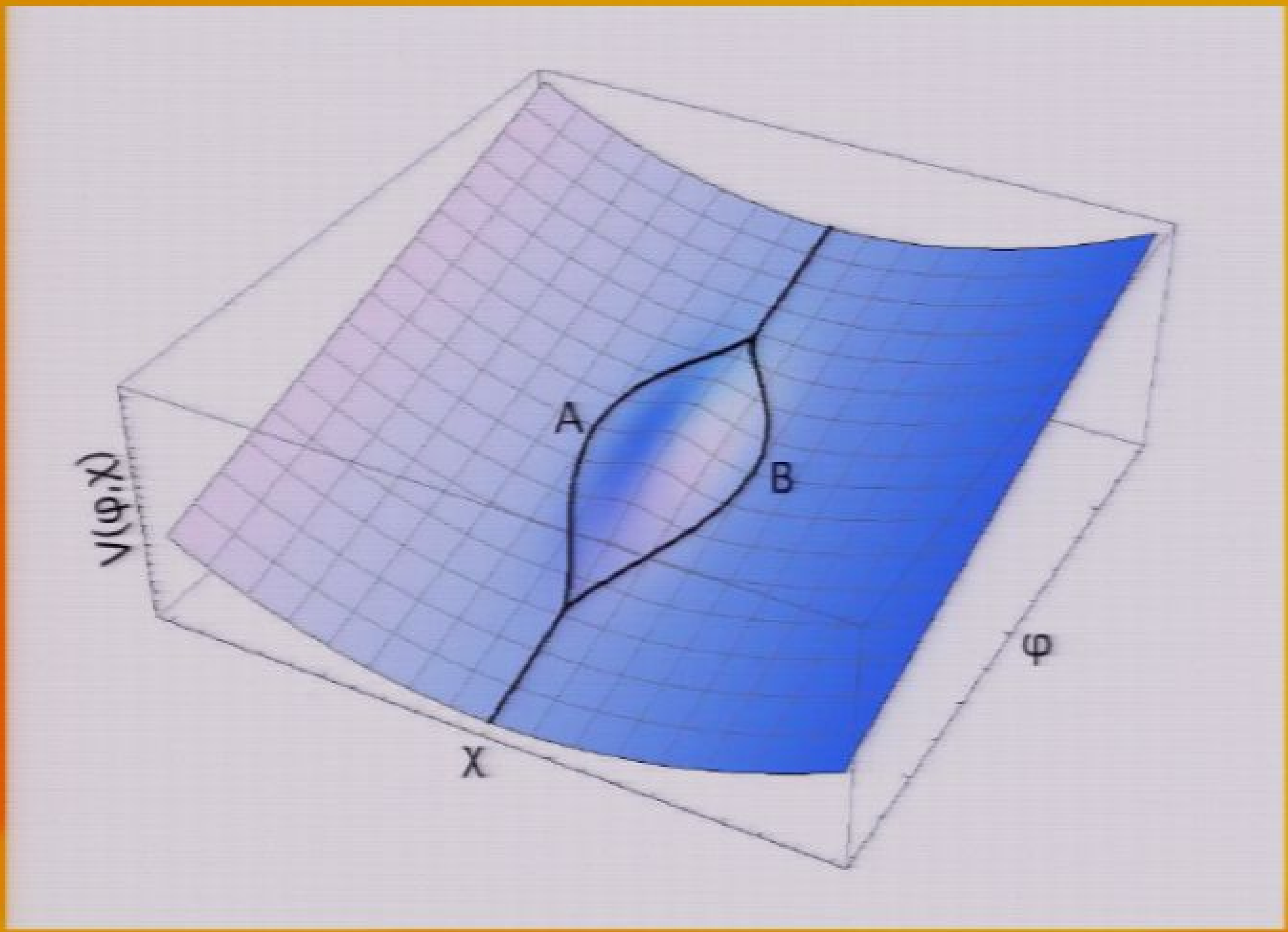


Degree scale bubbles sub-horizon unless z > few x 10

Super-horizon bubbles

- Super–horizon bubbles at high–z:
  - Characterised by uniform zeta inside the bubble
  - If photon emitted inside the void, it is affected by the Sach–Wolfe effect
  - At high redshifts radiation still not negligible – early ISW

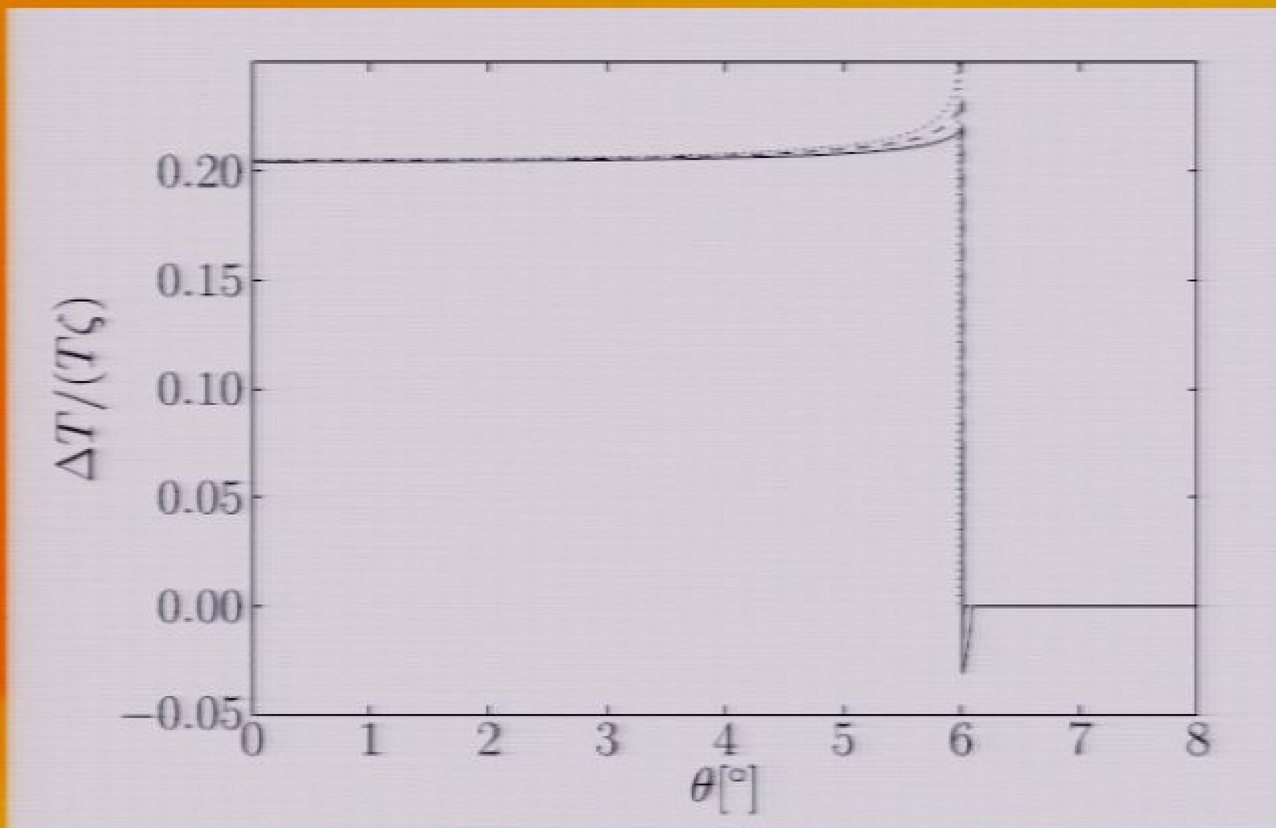
Multi-stream inflation



Super-horizon bubbles

$$\frac{\delta T(\hat{\mathbf{n}})}{T} = \psi(r_{LSS}\hat{\mathbf{n}}, \eta_{LSS}) + \Theta(r_{LSS}\hat{\mathbf{n}}, \eta_{LSS}) + 2\int_{\eta_{LSS}}^{\eta_0} d\eta \frac{\partial\psi(\hat{\mathbf{n}}(\eta_0-\eta), \eta)}{\partial\eta},$$

$$= \zeta_* \left[-\theta(\eta_{LSS}-\eta_{en})\theta(\eta_{ex}-\eta_{LSS}) + 2g(\eta_{ex})\theta(\eta_{ex}-\eta_{LSS}) - 2g(\eta_{en})\theta(\eta_{en}-\eta_{LSS})\right]$$



Gpc bubble at z=800, 1000, 1200

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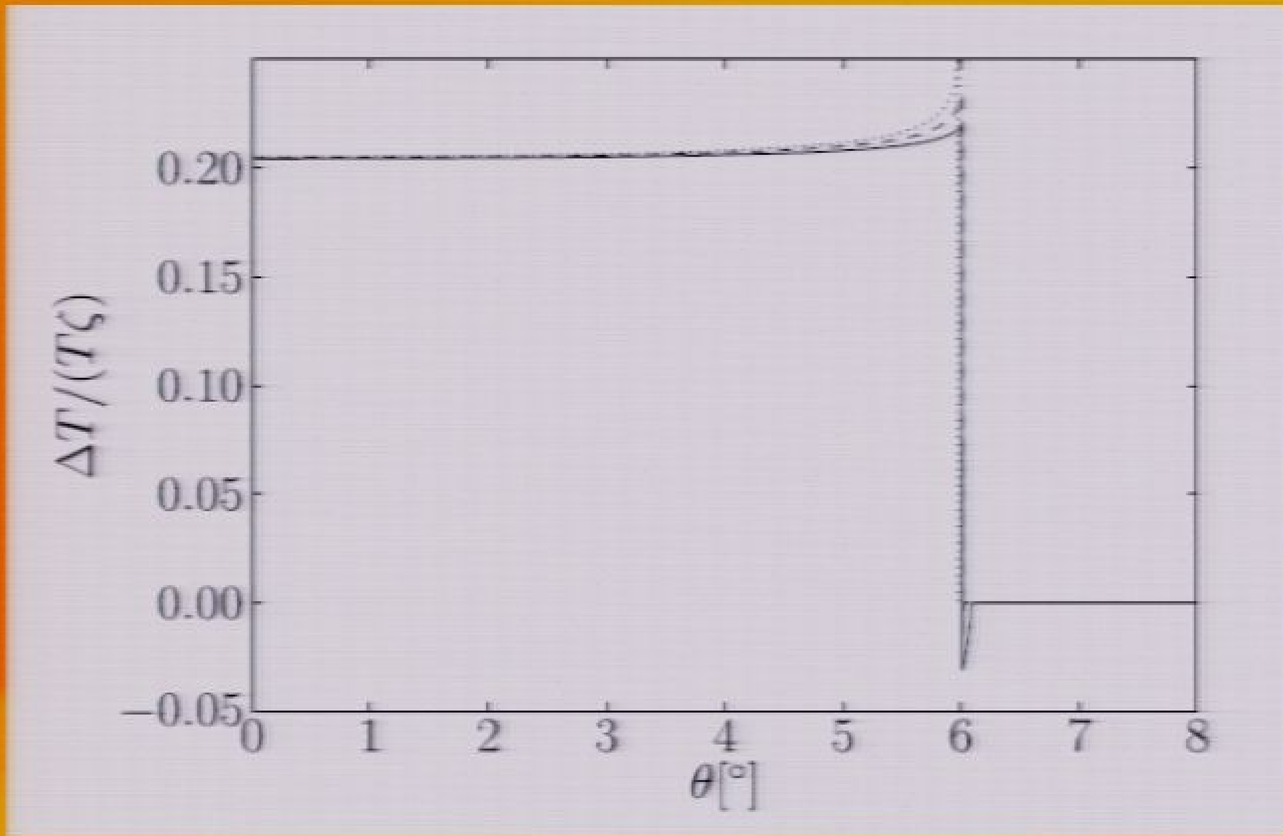

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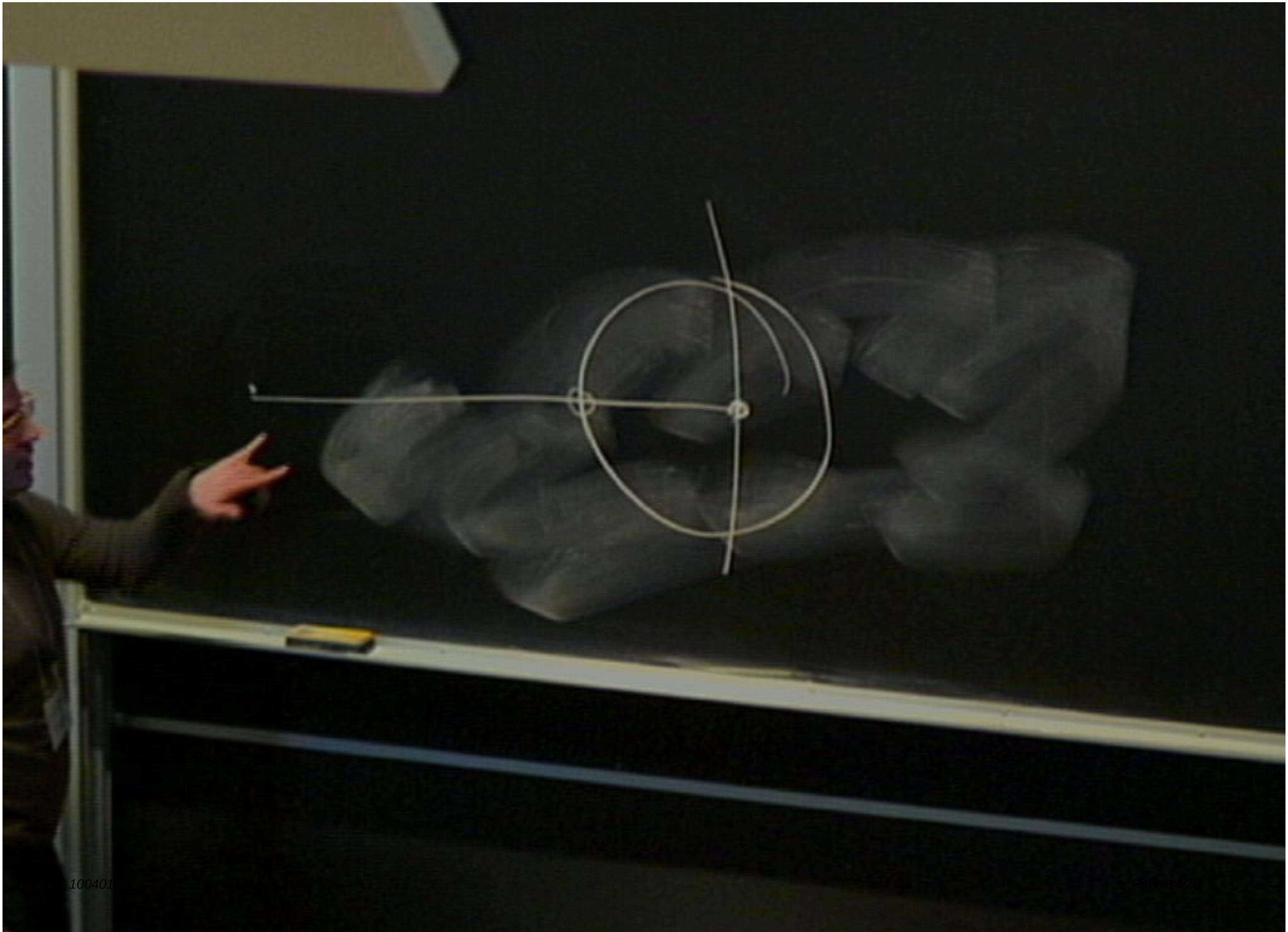
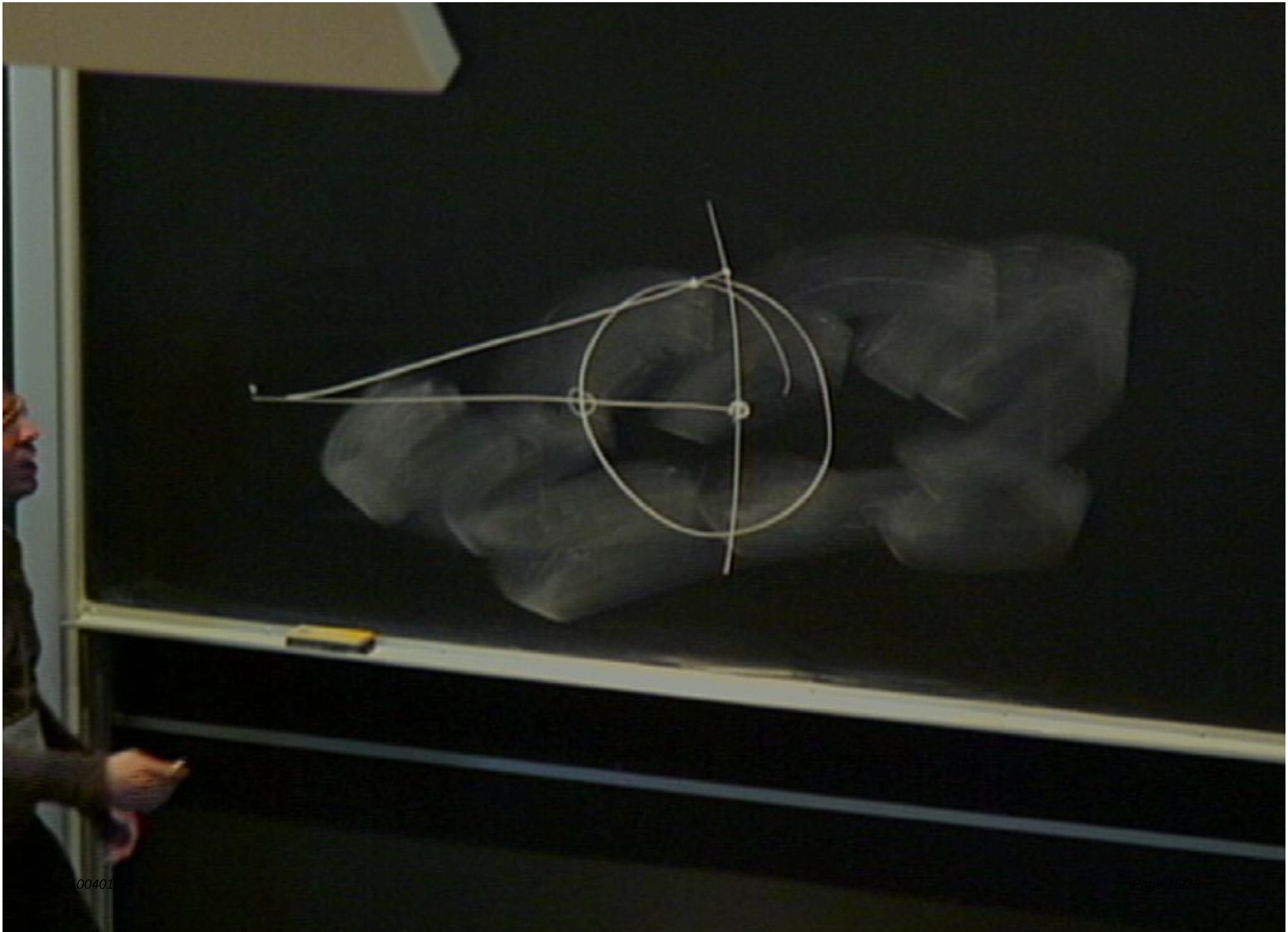
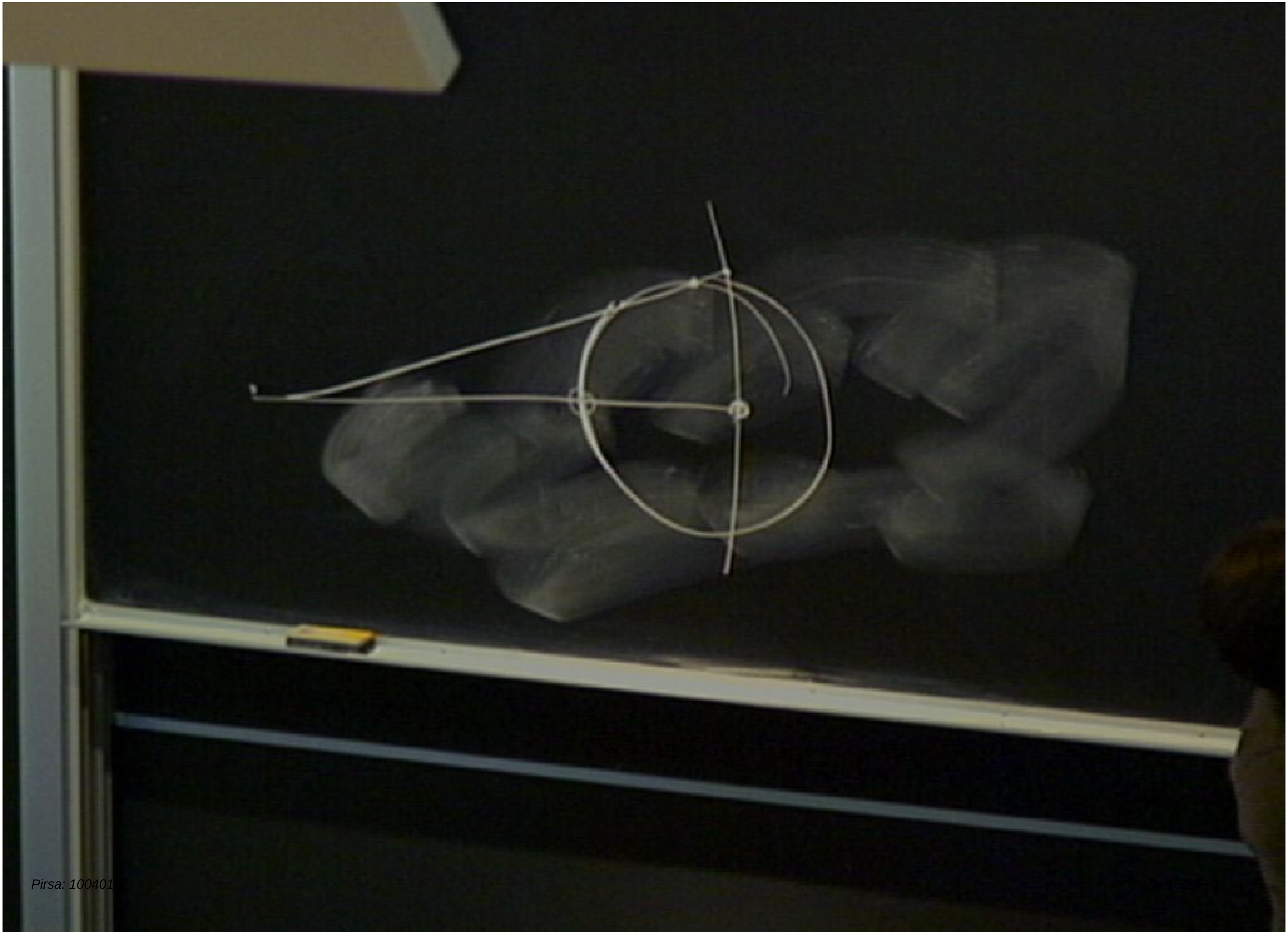
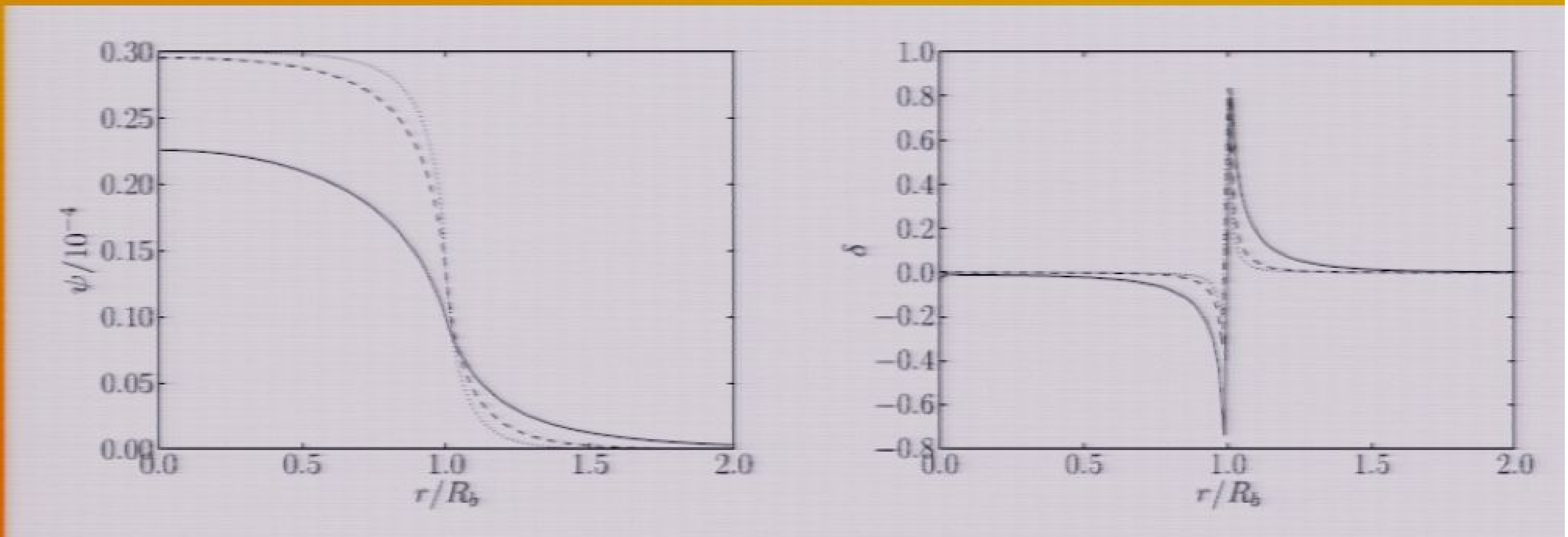






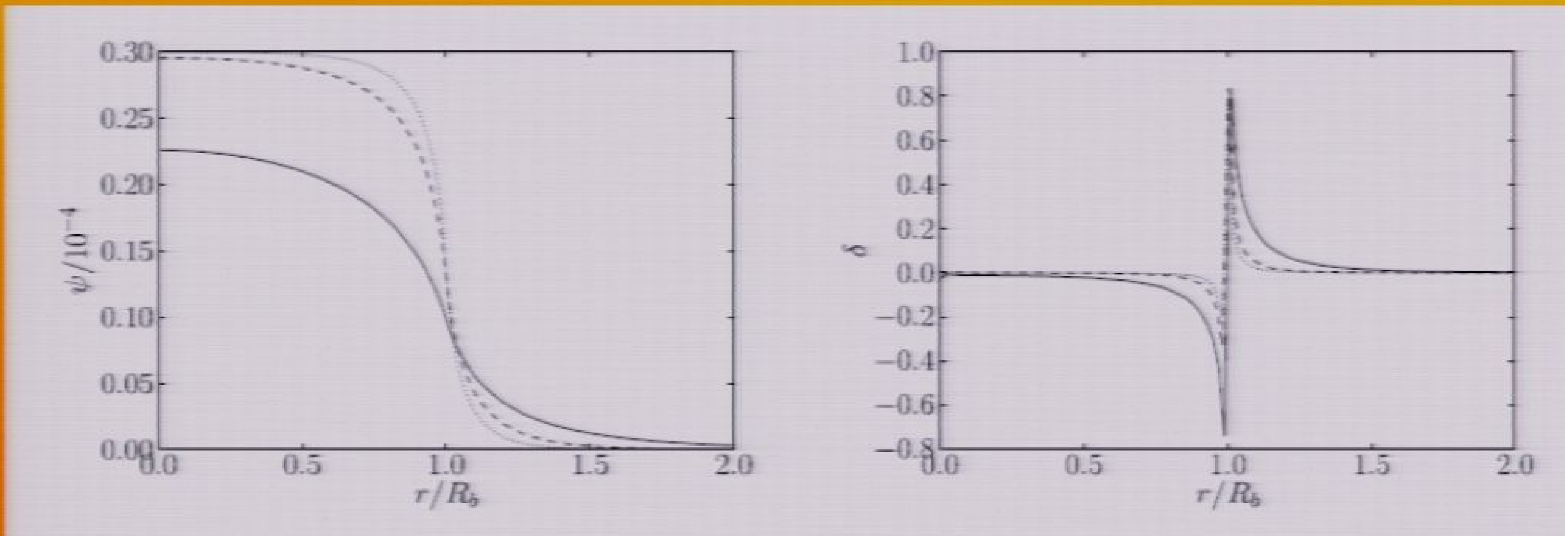
Sub-horizon bubbles



Potential is being smoothed through transfer functions.

Delta is laplacian of potential: our bubbles have cosmic mean density

Sub-horizon bubbles



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Sub-horizon bubbles

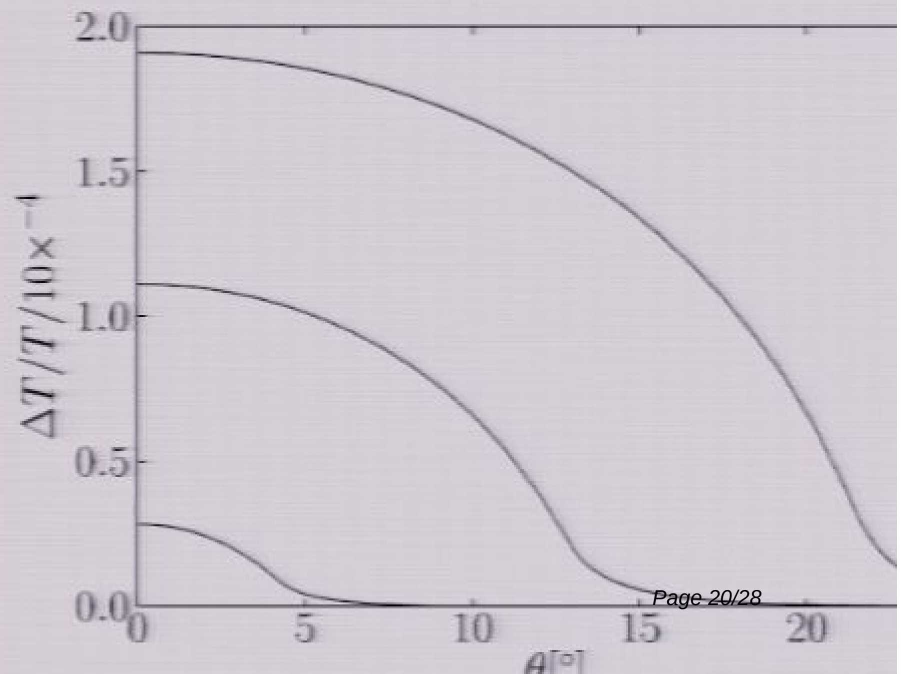
- Three possible effects:
  - Low z: Integrated Sach–Wolfe
  - High z: ISW=0, but second order effect (Rees–Sciamma)
  - Evolution of the blob requires very large coherent flows – kinetic SZ might contribute

Integrated Sach-Wolfe

- Pretty much the standard formula:

$$\left.\frac{\delta T(b)}{T}\right]_{USW} = 2\int d\eta \frac{\partial\psi}{\partial\eta} \simeq 2a\dot{g}\zeta_* \int_{-\infty}^{\infty} dy\, S\left(\sqrt{b^2+y^2}\right)$$

- S(r) is the T.F. Smoothed profile



Rees-Sciama

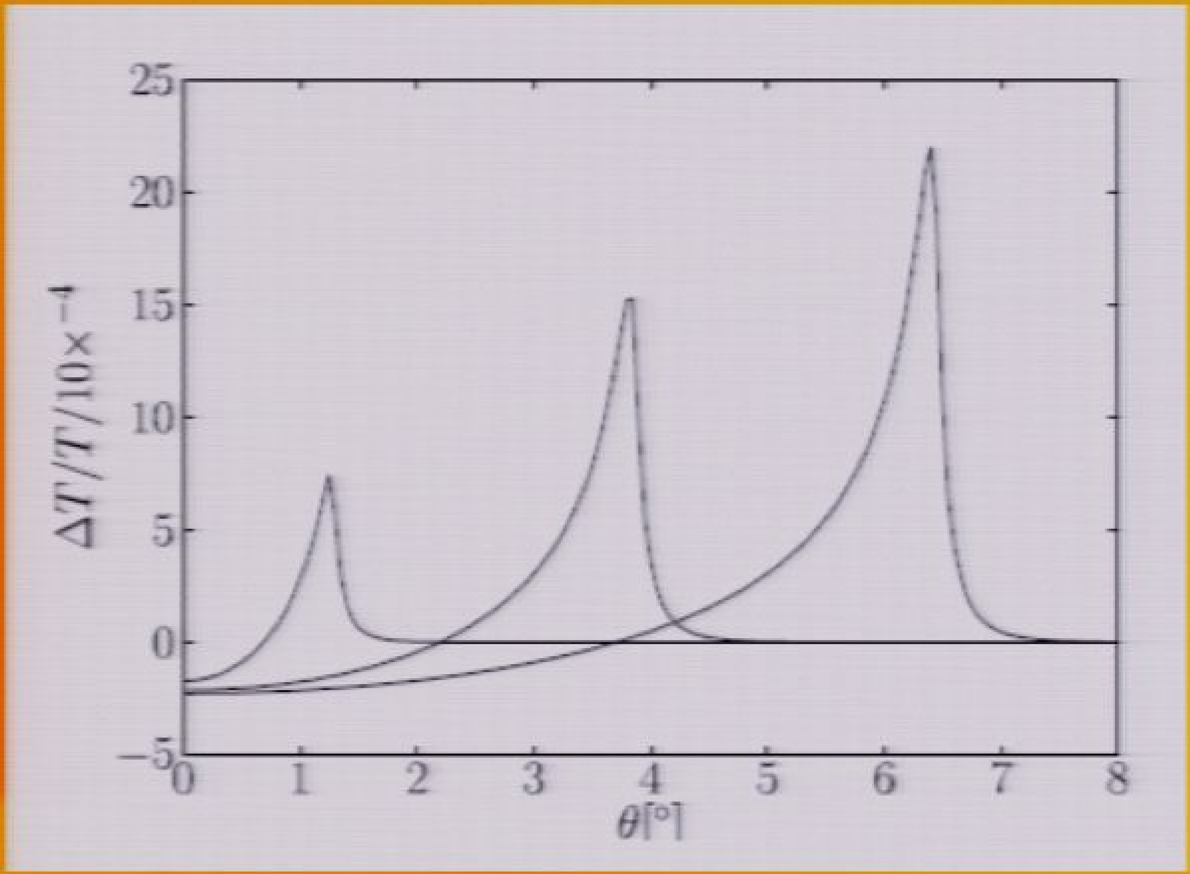
- Spherically symmetric system can be solved exactly to 2nd order:

$$\left[\frac{\delta T(b)}{T}\right]_{RS} = 2\int d\eta\, \psi'^{(2)} = \frac{36\zeta_*^2}{175aH}\int_{-\infty}^{\infty} dy\, U\left(\sqrt{b^2+y^2}\right)$$

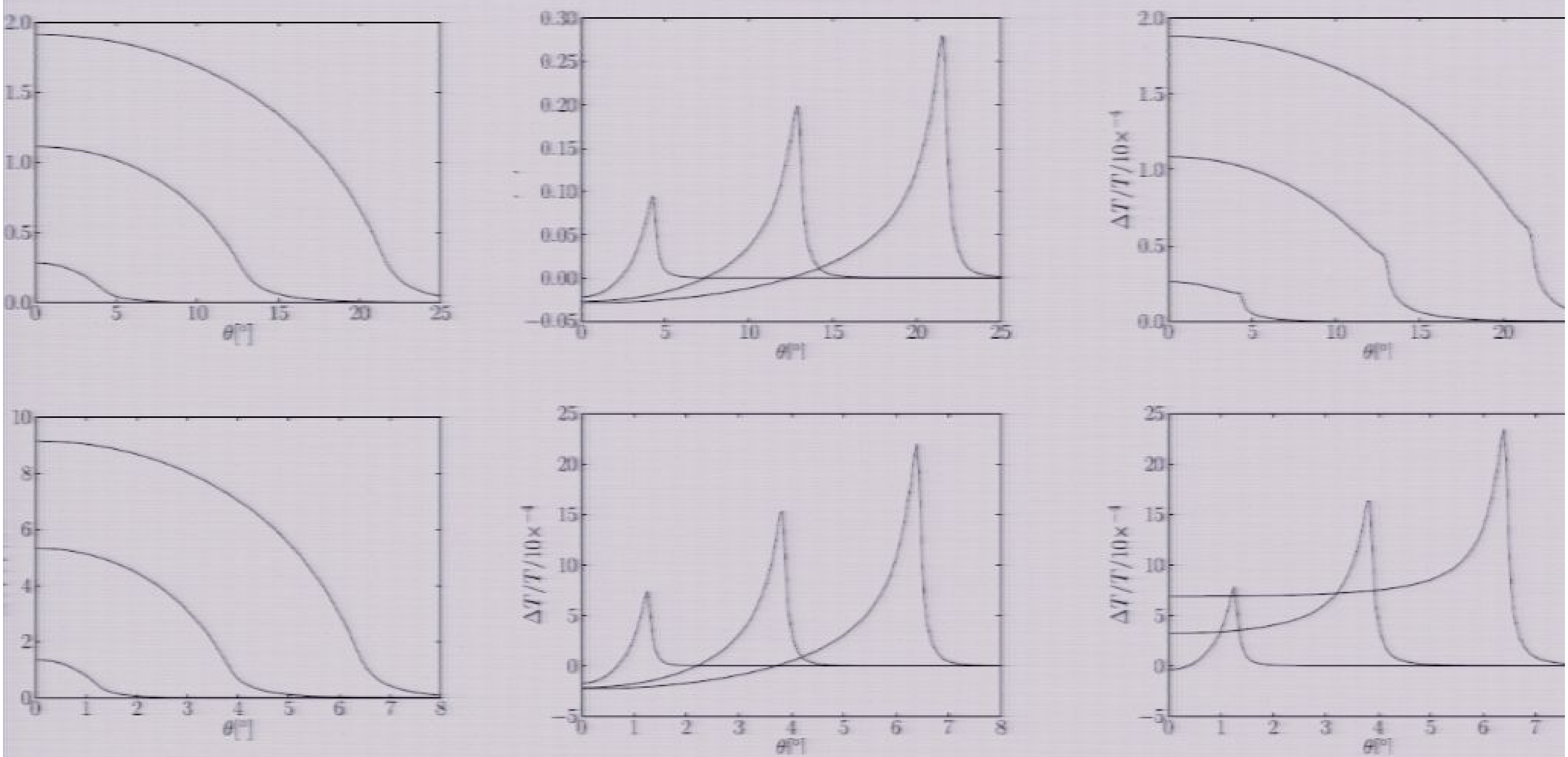
$$U(r) \equiv \frac{8}{9}\left[\frac{dS(r)}{dr}\right]^2 - \frac{4}{3}\int_r^{\infty}\frac{dr'}{r'}\left[\frac{dS(r')}{dr'}\right]^2,$$

- Rees–Sciama profile markedly different!

Rees-Sciama



Combined profile



=0.5 with zeta=1e−3 (top) and z=3.5 with zeta=1e−2

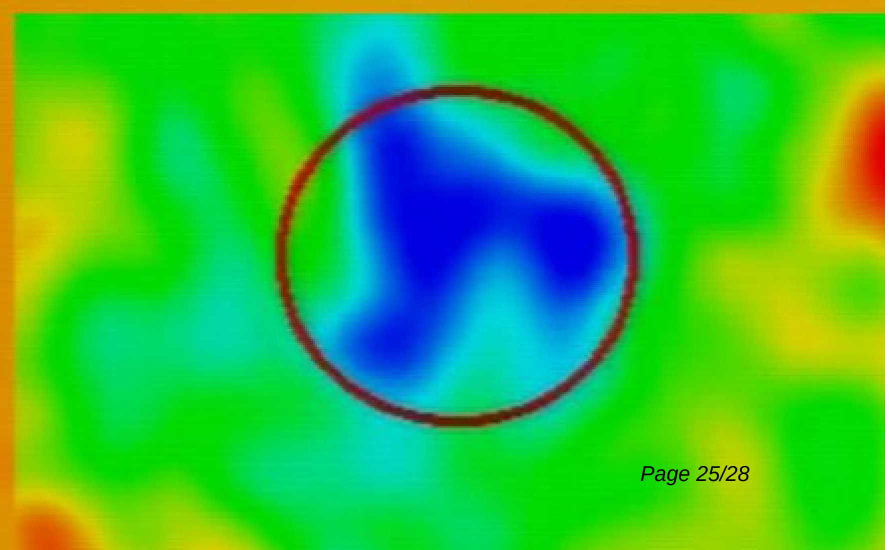
Kinetic Sunayev-Zeldovich

$$\left[\frac{\delta T(\hat{\mathbf{n}})}{T}\right]_{OV} = \frac{(1+X)\sigma_T}{8\pi G m_p c^2}\int_0^{r_{LSS}} dr\, g^{-1}\psi(r\hat{\mathbf{n}},\eta)\frac{\partial}{\partial\eta}\left[\frac{x_e}{a^2}\frac{\partial(ag)}{\partial\eta}\right]$$
$$\simeq \frac{(1+X)\zeta_*\sigma_T}{8\pi G m_p c^2}\left\{\frac{\partial}{\partial\eta}\left[\frac{x_e}{a^2}\frac{\partial(ag)}{\partial\eta}\right]\right\}\int_{-\infty}^{\infty} dy\, S\left(\sqrt{b^2+y^2}\right).$$

Same profile as ISW: which dominates?

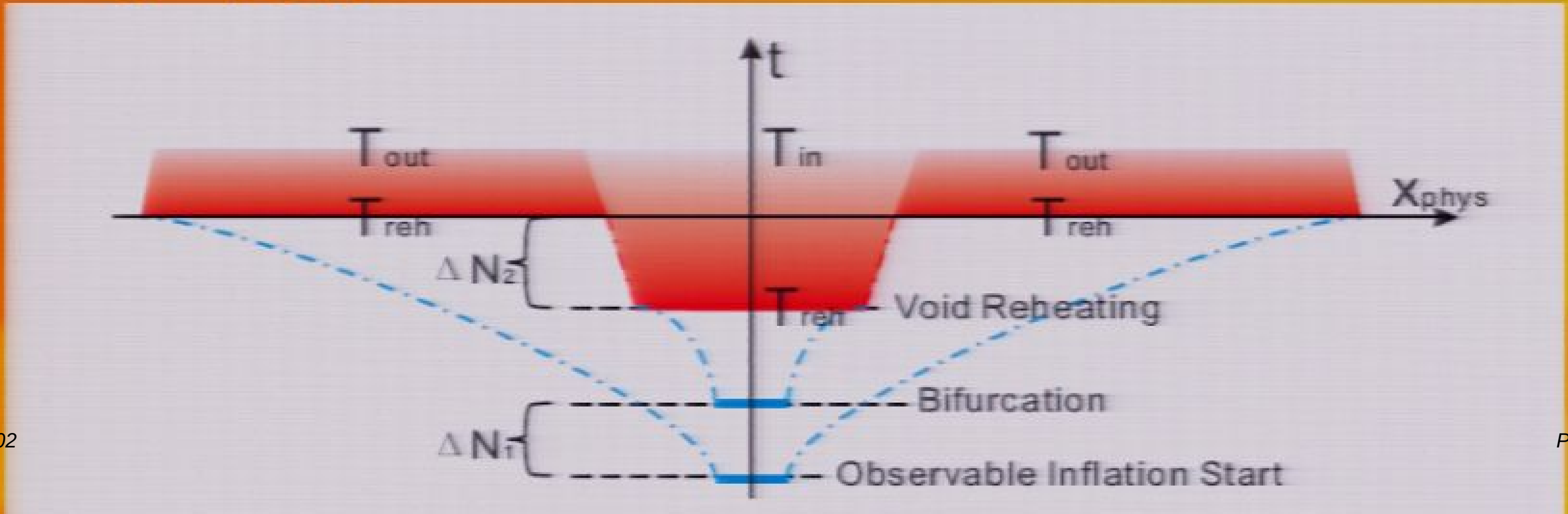
Cold spot

- Using spherical Mexican hat, detected as excess kurtosis (Cruz et al, Vielva et al, Zhang & Huterer, etc.)
- Most excess comes from a single spot
- About 10 deg across
- About 250 uK cold



Comparison with Cold Spot

- Typically need zeta=1e−5 to 1e−3, R = 100Mpc to Gpc, N=a few
- This implies N_2 small, p small, N_1 = a few



Conclusions

- Can cook-up model that can produce arbitrary sized, arbitrary over-dense and arbitrarily common bubbles
- Different effects dominate at differen redshifts
- A bubble in potential is not a bubble delta!