Title: Limits on locality from gravitational dressing

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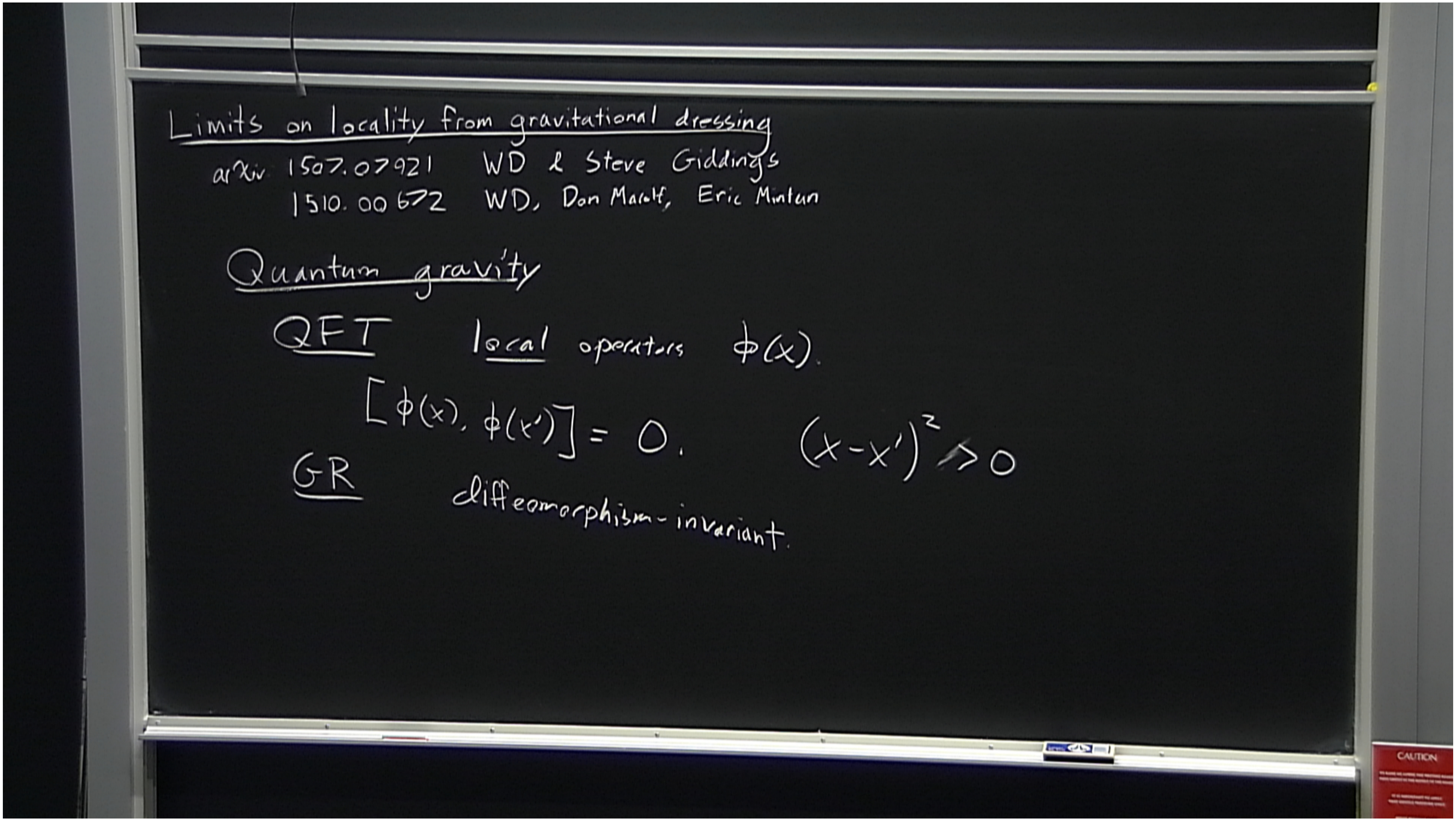
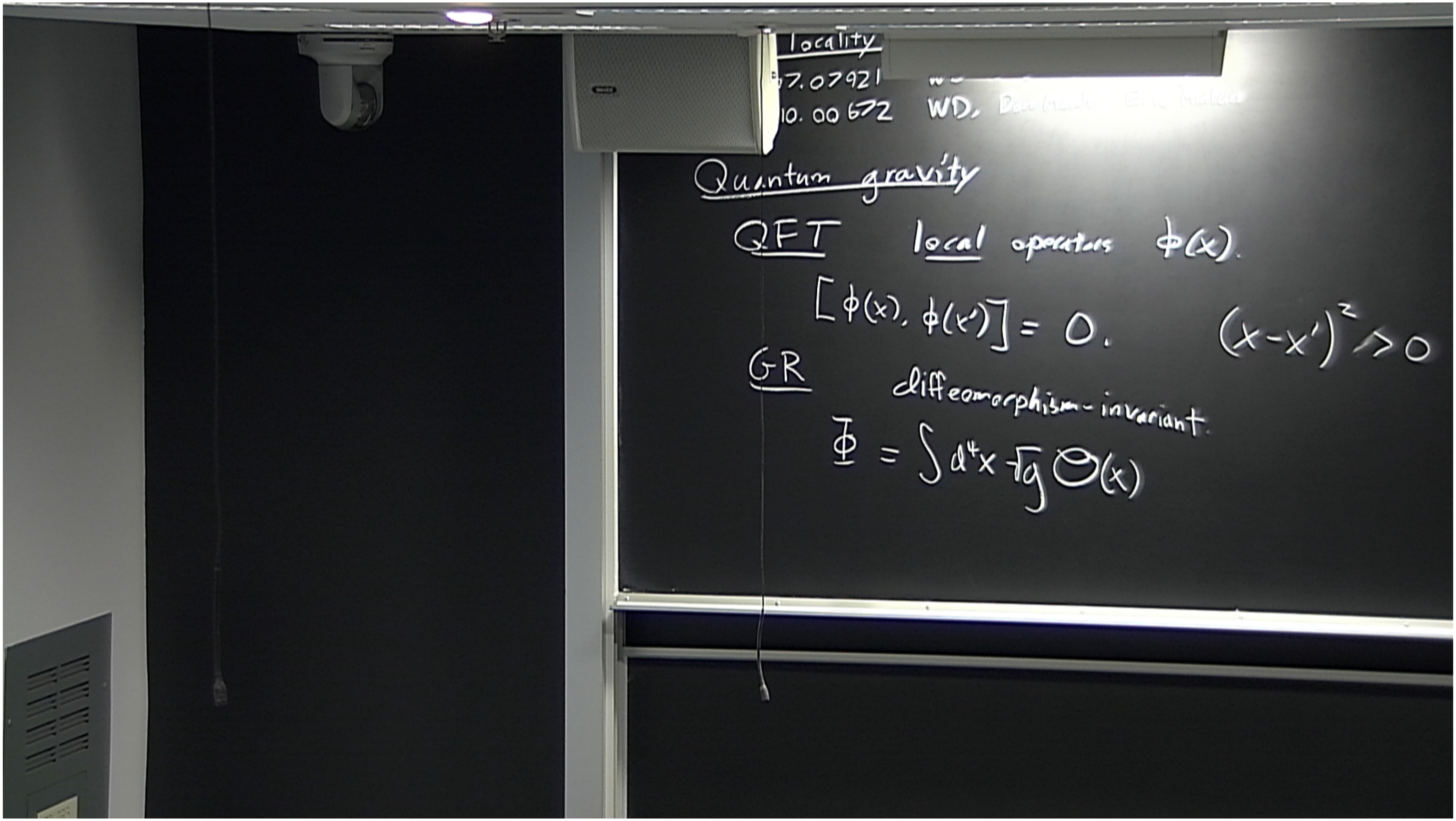
Abstract: <p>In quantum gravity, observables must be diffeomorphism-invariant. Such observables are nonlocal, in contrast with the standard assumption of locality in flat spacetime quantum field theory. I will show how to construct 'gravitationally dressed' observables in linearized gravity that become local in the weak gravity limit, and whose corrections to exact locality are characterized by the Newtonian potential. One can attempt to make these observables more local by concentrating gravitational field lines into a smaller solid angle. In AdS_3 gravity I will show that nonperturbatively there are sharp limits to how much the gravitational dressing can be concentrated.</p>

<p>Based on arXiv:1507.07921 with Steve Giddings, and arXiv:1510.00672 with Don Marolf and Eric Mintun.</p>


Limits on locality from gravitational dressing
arXiv 1507.07921 WD & Steve Giddings
1510.00672 WD, Don Marolf, Eric Mintun
Quantum gravity
QFT local operators $\phi(x)$.
$[\phi(x), \phi(x')] = 0$. $(x-x')^2 > 0$
GR diffeomorphism-invariant.


locality
7.07921
10.00672 WD,
Quantum gravity
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$\Phi = \int d^4x \sqrt{-g}\, \mathcal{O}(x)$

Plan

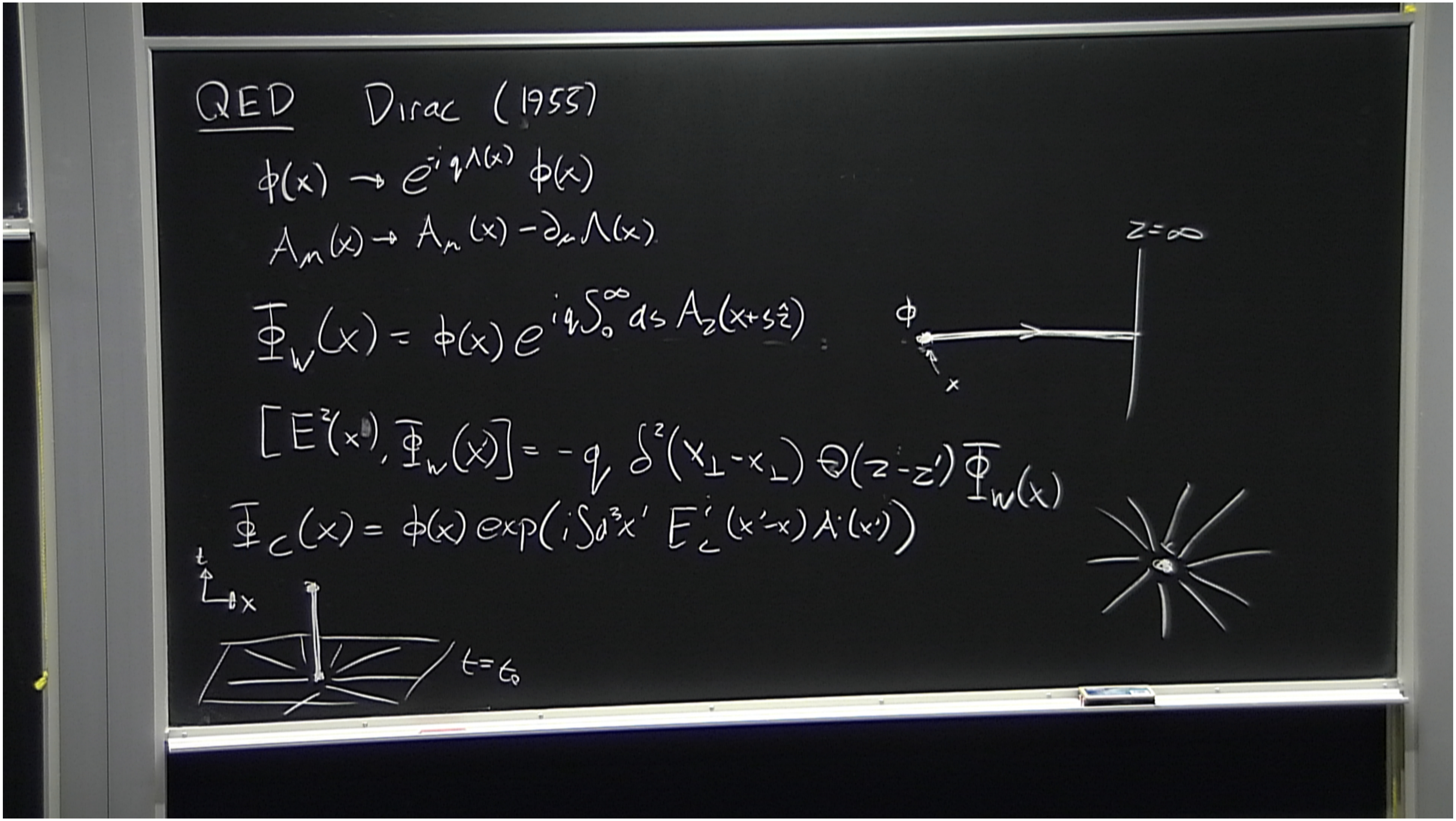
① 3+1 linearized gravity + scalar

$$\Phi(x) \xrightarrow{G\to 0} \phi(x)$$

Φ invariant.

$$[\Phi(x), \Phi(x')].$$

② 2+1 AdS.


QED Dirac (1955)
$\phi(x) \to e^{-iq\Lambda(x)}\phi(x)$
$A_\mu(x) \to A_\mu(x) - \partial_\mu \Lambda(x)$
$\Phi_W(x) = \phi(x)\, e^{iq\int_0^\infty ds\, A_z(x+s\hat{z})}$
ϕ
x
$z=\infty$
$[E^z(x'), \Phi_W(x)] = -q\, \delta^2(x_\perp - x'_\perp)\, \Theta(z-z')\, \Phi_W(x)$
$\Phi_c(x) = \phi(x) \exp\left(i\int d^3x'\, E_c^i(x'-x) A^i(x')\right)$
t
x
$t=t_0$

Gravity

$$g_{\mu\nu} = \eta_{\mu\nu} + \kappa h_{\mu\nu} \qquad \kappa = \sqrt{32\pi G}$$

$$\phi \to \phi - \kappa\, \xi^\mu \partial_\mu \phi$$

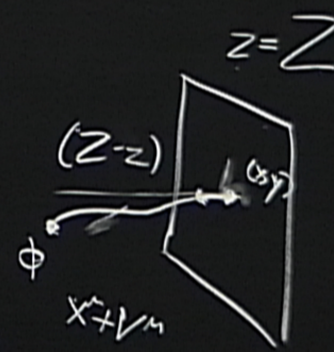
$$h_{\mu\nu} \to h_{\mu\nu} - \partial_\mu \xi_\nu - \partial_\nu \xi_\mu$$

Wilson line

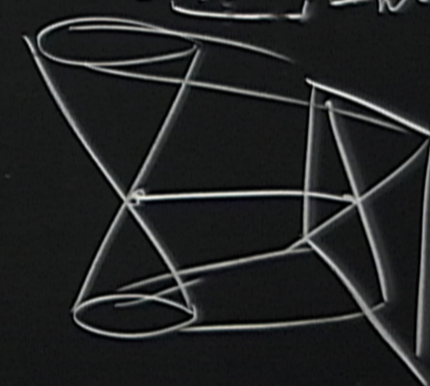
$$X^\mu(s) = x + s\hat{z} + V^\mu(s)$$

$$V^\mu_W = -\int_0^\infty ds\; s\; \Gamma^\mu_{zz}(x + s\hat{z}) + \text{s.t.}$$

$$\Phi_W(x) = \phi(x + V_W) = \phi(x) + \underline{V^\mu_W(x)\partial_\mu \phi(x)}$$



$[\underline{h_{\mu\nu}(x')}, \Phi_W(x)]$



Coulomb

$$V_C^\mu(0) = -\frac{1}{4\pi}\int d^3x\ \Gamma^\mu_{rr}\cdot\frac{1}{r}$$

$[P^\mu_{ADM}, \Phi_C$

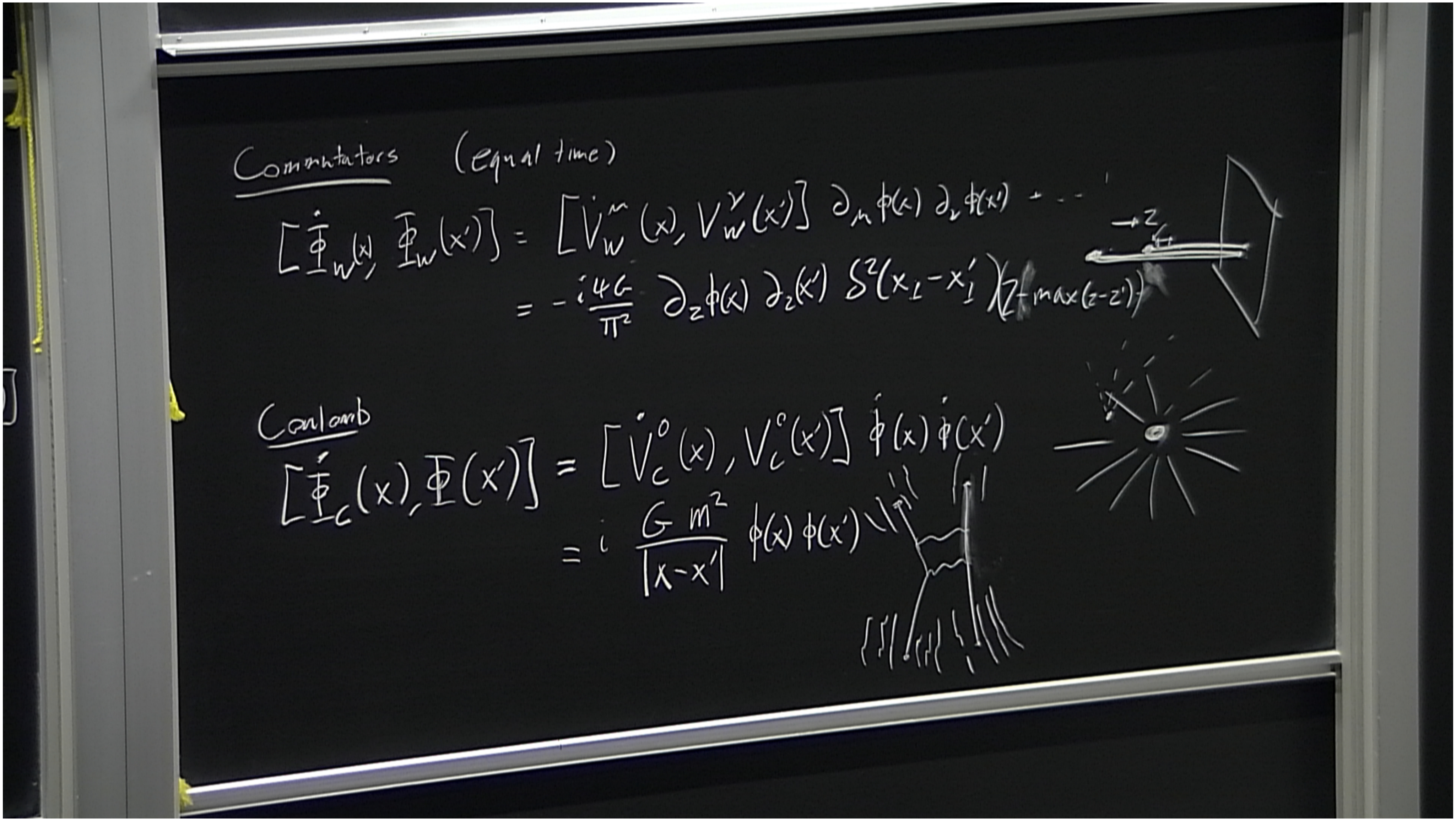
$i\partial^\mu\phi = p^\mu\phi$

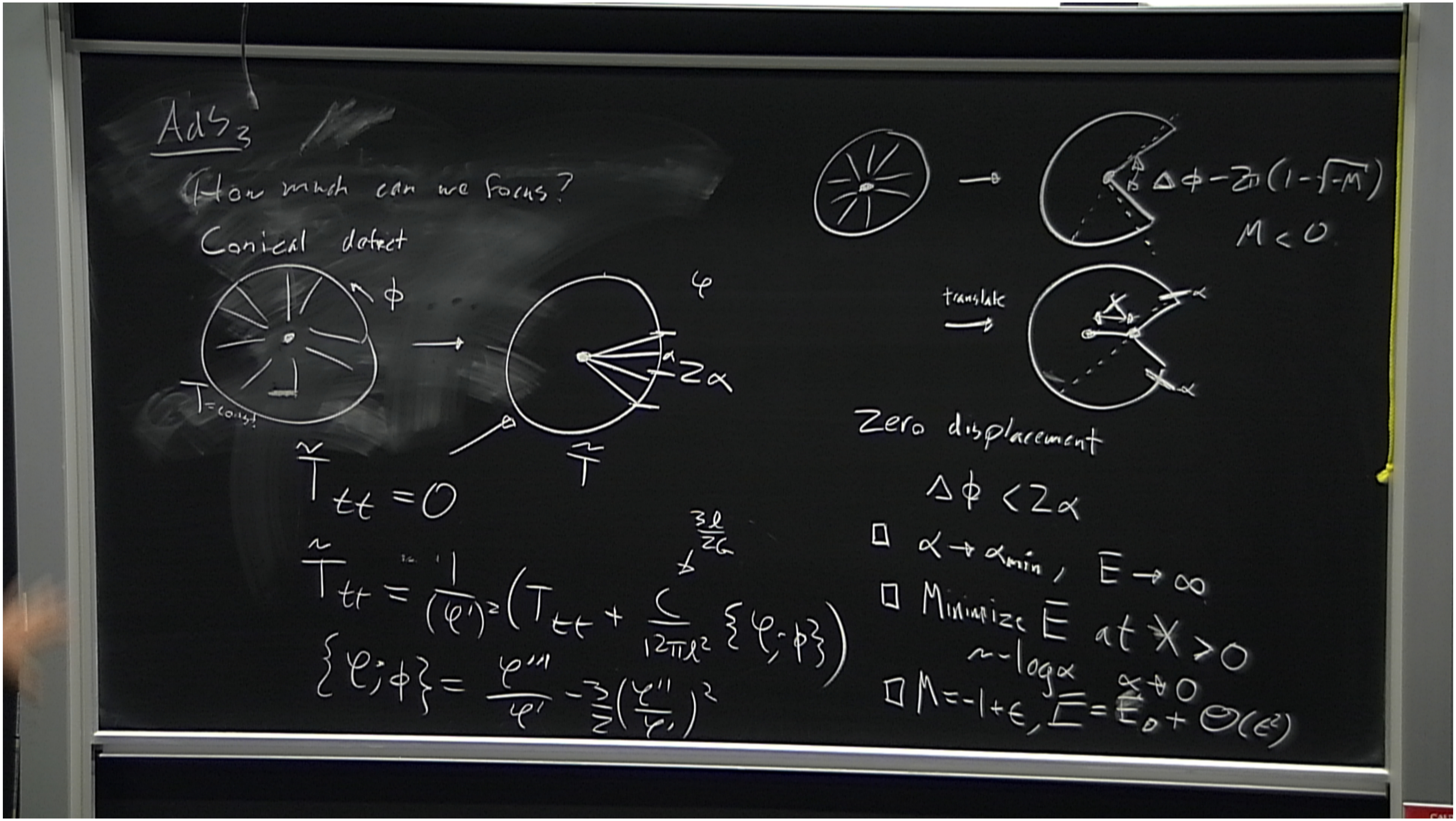
$$\Phi_C(0) = \phi(0) + V_C^\mu(0)\,\partial_\mu\phi(0)$$

$$[h_{\mu\nu}(x), \Phi_C(0)] = [h_{\mu\nu}(x), V^\lambda(0)]\,\partial_\lambda\phi(0)$$

Particle at rest $\partial_0\phi = im\phi$

$$= \Big[\underbrace{\frac{\kappa m}{16\pi r}(\hat{t}_\mu\hat{t}_\nu + \hat{r}_\mu\hat{r}_\nu)}_{\text{(lin) Schwarzschild}} + \underbrace{\partial_\mu\xi_\nu + \partial_\nu\xi_\mu}_{\text{diff}}\Big]\phi(0)$$


Commutators (equal time)
$[\dot{\Phi}_W(x), \Phi_W(x')] = [\dot{V}_W^\mu(x), V_W^\nu(x')]\, \partial_\mu \phi(x)\, \partial_\nu \phi(x') + \ldots$
$= -\frac{i 4G}{\pi^2}\, \partial_z \phi(x)\, \partial_z \phi(x')\, \delta^2(x_\perp - x'_\perp)(z - \max(z-z'))$
z
Coulomb
$[\dot{\Phi}_C(x), \Phi(x')] = [\dot{V}_C^0(x), V_C^0(x')]\, \dot{\phi}(x)\, \dot{\phi}(x')$
$= i \frac{G m^2}{|x-x'|}\, \phi(x)\, \phi(x')$


AdS3
How much can we focus?
Conical defect
T=const
φ
φ
2α
Tt t = 0
Tt t = 1/(φ')² (Tt t + c/(12πℓ²) {φ; φ})
3ℓ/2G
{φ; φ} = φ'''/φ' − 3/2 (φ''/φ')²
Δφ = 2π(1 − √−M)
M < 0
translate
Zero displacement
Δφ < 2α
α → αmin, E → ∞
Minimize E at α > 0
~ −log α
α → 0
M = −1 + ε, E = E0 + O(ε²)