Title: Gravitational waves via Kerr/CFT

Date: Nov 17, 2016 01:00 PM

URL: http://pirsa.org/16110029

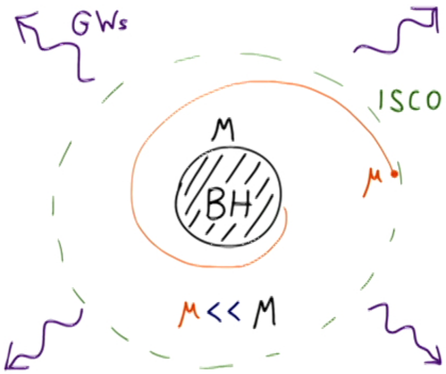
Abstract: <p>Massive objects orbiting a near-extreme Kerr black hole plunge into the horizon after passing the innermost stable circular orbit, producing a potentially observable signal of gravitational radiation. The near horizon dynamics of such rapidly rotating black holes is governed by a conformal symmetry. In the talk I will show how this symmetry can be exploited to analytically compute the gravitational waves produced by a variety of orbits. I will also discuss an application to gravitational self-force and comment on the holographic interpretation of the process.</p>

Motivation

- Enhanced symmetry: Kerr/CFT

Guica, Hartman, Song, Strominger '08

- GWs in EMRI & plunge



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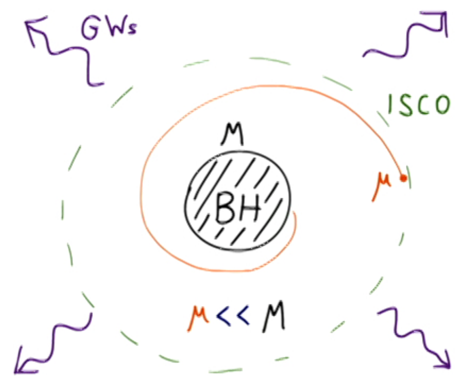


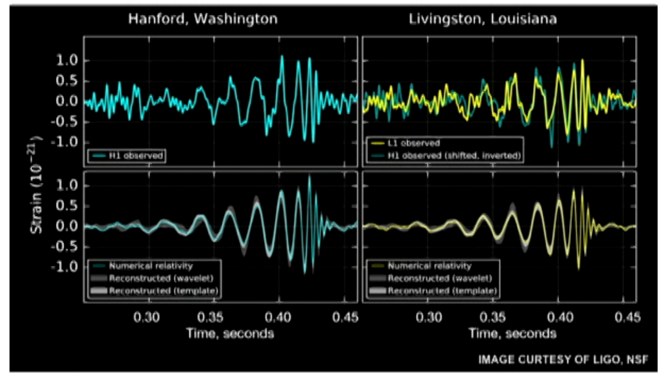
- **Applied holography for astrophysics**

Kerr/CFT

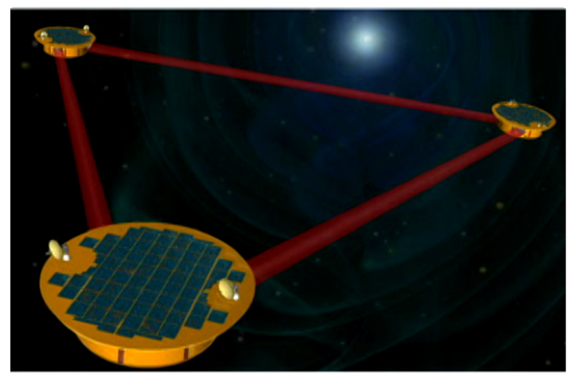
- Conjecture ("strong Kerr/CFT"): Kerr BH is holographically dual to a (1+1)D CFT.
- Tests: BH entropy, scattering off Kerr.
- Problems: GHSS boundary conditions, CFT details unknown.
- Fact ("weak Kerr/CFT"): All physics in (near-extreme) Kerr constrained by conformal symmetry.

Gravity Waves

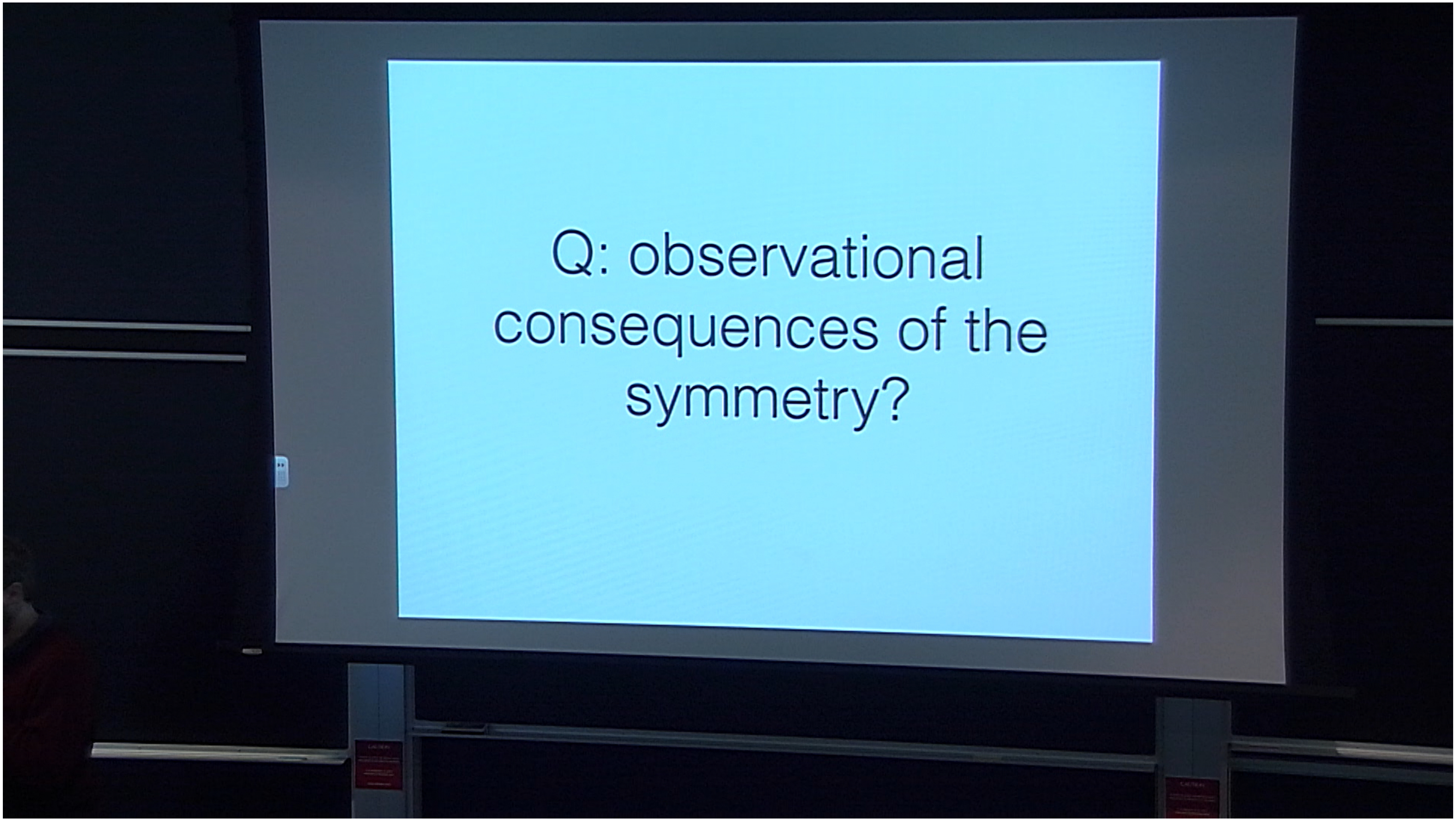
- From idea to observed signal in 100 years
- New era of experimental BH physics: **"spectroscopy"**
- Our analysis: relevant for **eLISA**

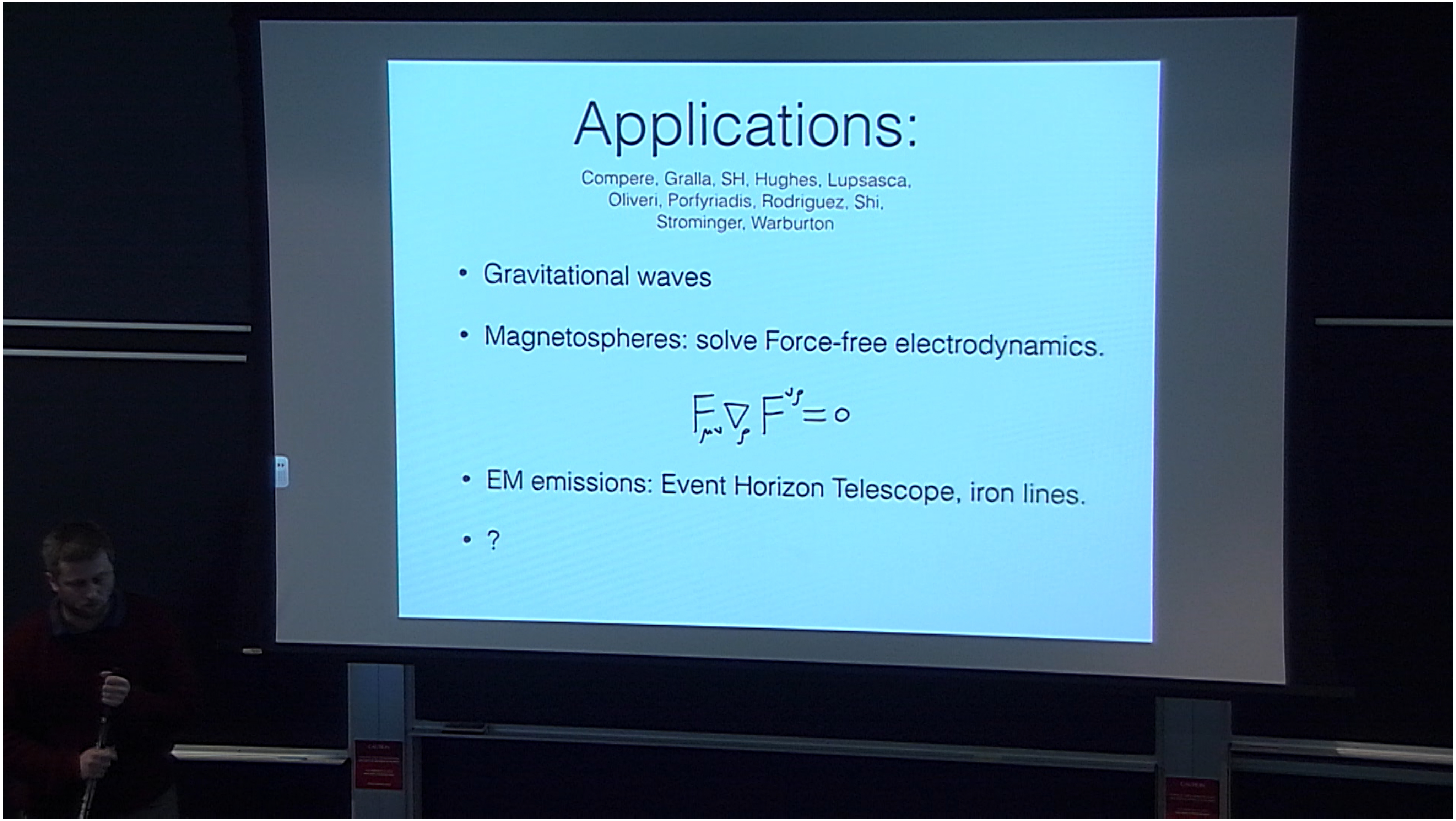


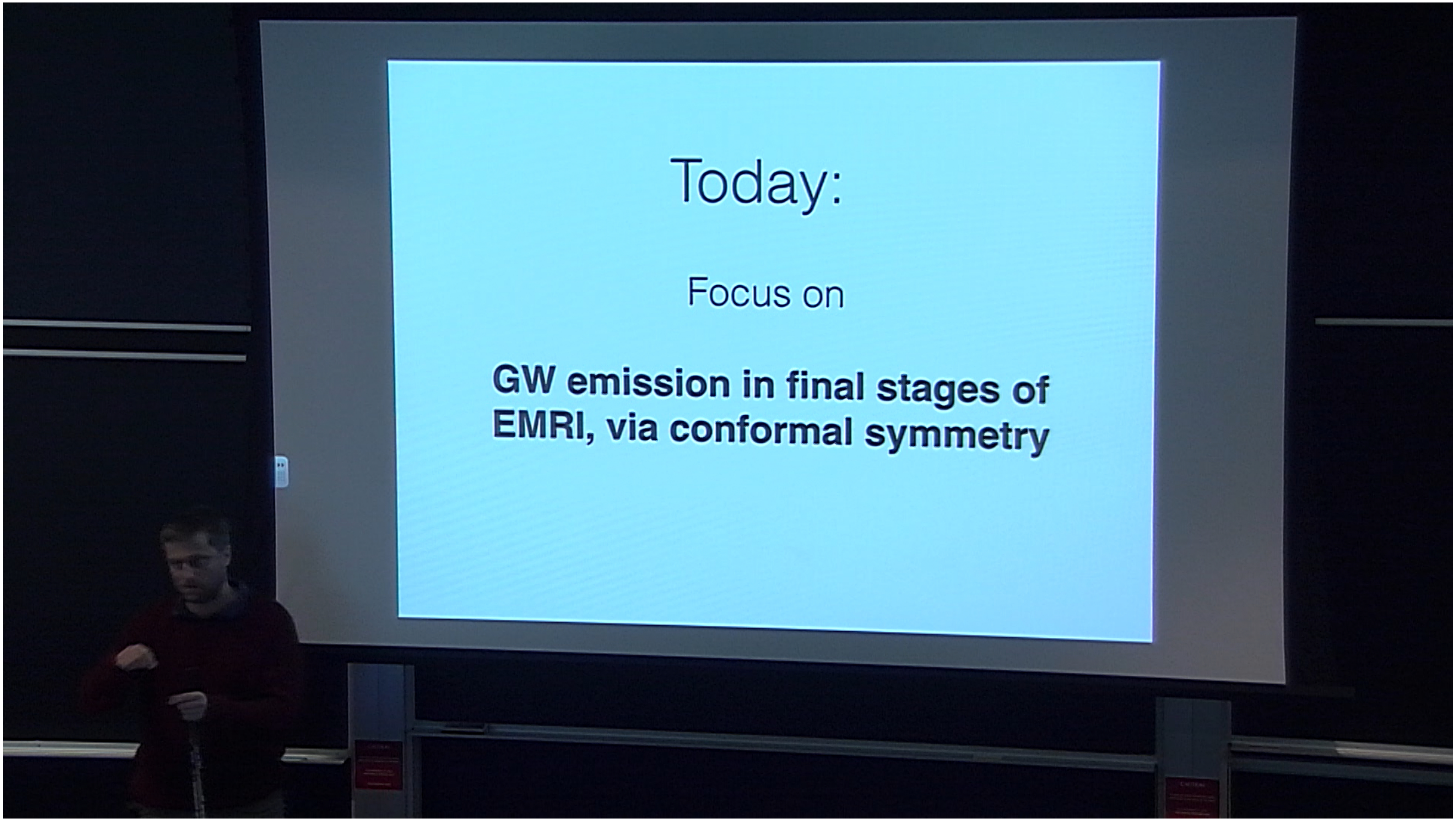
LIGO: stellar mass



eLISA: supermassive


Q: observational
consequences of the
symmetry?


Applications:
Compere, Gralla, SH, Hughes, Lupsasca,
Oliveri, Porfyriadis, Rodriguez, Shi,
Strominger, Warburton
• Gravitational waves
• Magnetospheres: solve Force-free electrodynamics.
$F_{\mu\nu} \nabla_\rho F^{\nu\rho} = 0$
• EM emissions: Event Horizon Telescope, iron lines.
• ?


Today:
Focus on
GW emission in final stages of EMRI, via conformal symmetry

Rapidly rotating BHs

- (near-) Extremal Kerr $\delta \equiv \sqrt{1-\frac{a^2}{M^2}} << 1$
- Close to horizon $\epsilon \equiv r_{BL} - r_+ << 1$

NHEK = near horizon extreme Kerr

$$ds^2 = 2M^2\Gamma(\theta)\left[-R^2 dT^2 + \frac{dR^2}{R^2} + d\theta^2 + \Lambda(\theta)^2(d\Phi + R dT)^2\right]$$

Bardeen & Horowitz '99

- Enhanced isometry
  - Kerr: $\mathbb{R} \times U(1)$
  - NHEK: $SL(2,\mathbb{R}) \times U(1)$

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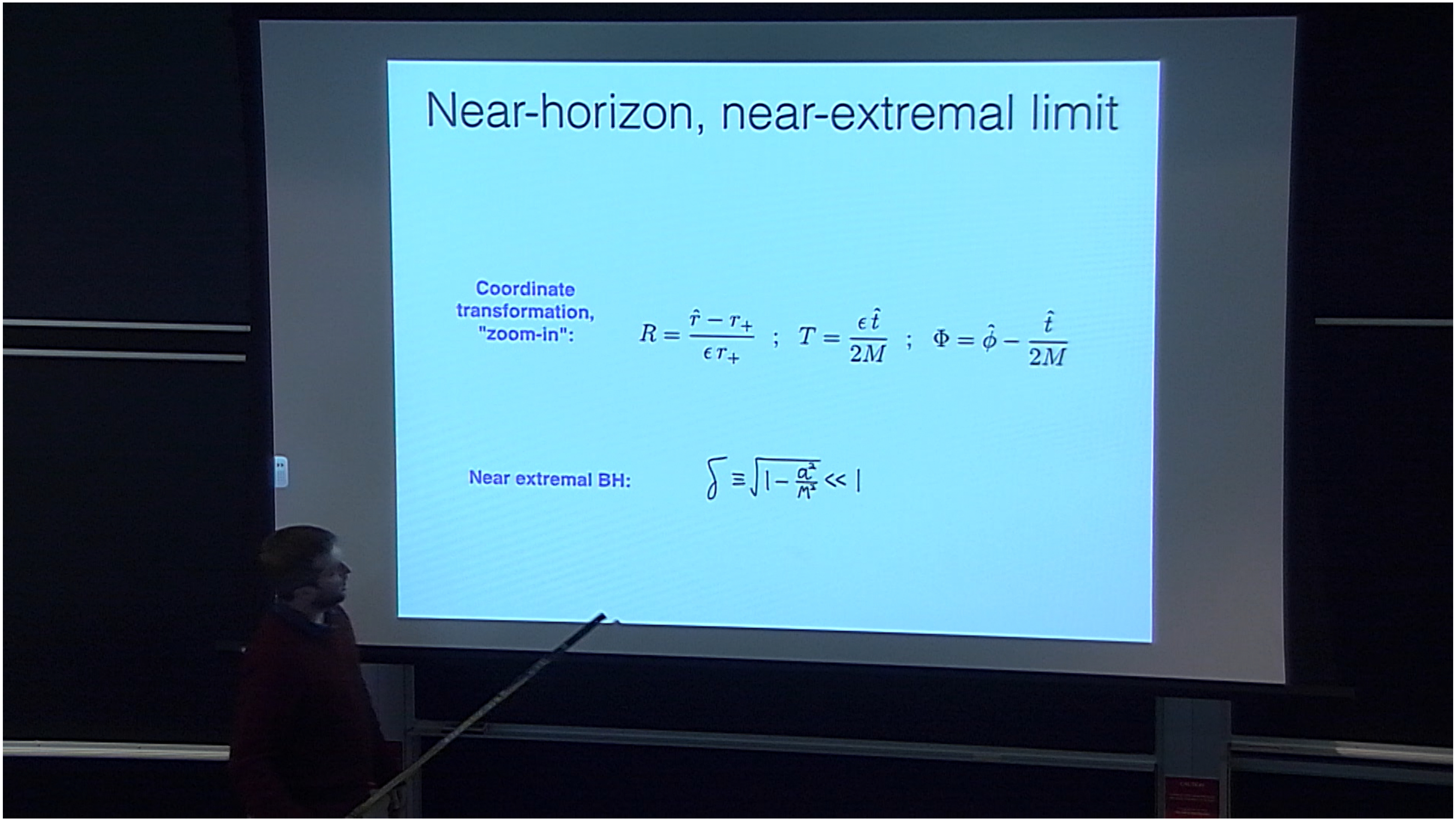
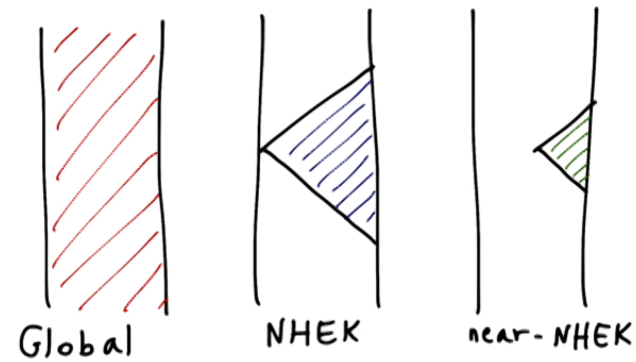

Near-horizon, near-extremal limit
Coordinate transformation, "zoom-in":
$R = \frac{\hat{r} - r_+}{\epsilon r_+}$; $T = \frac{\epsilon \hat{t}}{2M}$; $\Phi = \hat{\phi} - \frac{\hat{t}}{2M}$
Near extremal BH:
$\delta \equiv \sqrt{1 - \frac{a^2}{M^2}} << 1$

NHEK & near-NHEK

NHEK: $\delta = 0$, $\epsilon \ll 1$

$$ds^2 = 2M^2\Gamma(\theta)\left[-R^2dT^2 + \frac{dR^2}{R^2} + d\theta^2 + \Lambda(\theta)^2(d\Phi + RdT)^2\right]$$



Near-NHEK: $\delta = \kappa\epsilon \ll 1$

$$ds^2 = 2M^2\Gamma(\theta)\left[-r(r+2\kappa)dt^2 + \frac{dr^2}{r(r+2\kappa)} + d\theta^2 + \Lambda(\theta)^2(d\phi + (r+\kappa)dt)^2\right]$$

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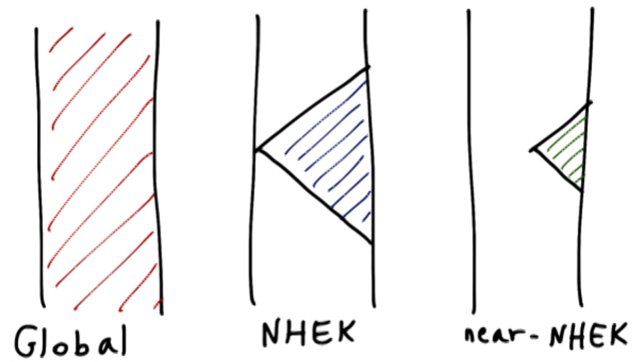

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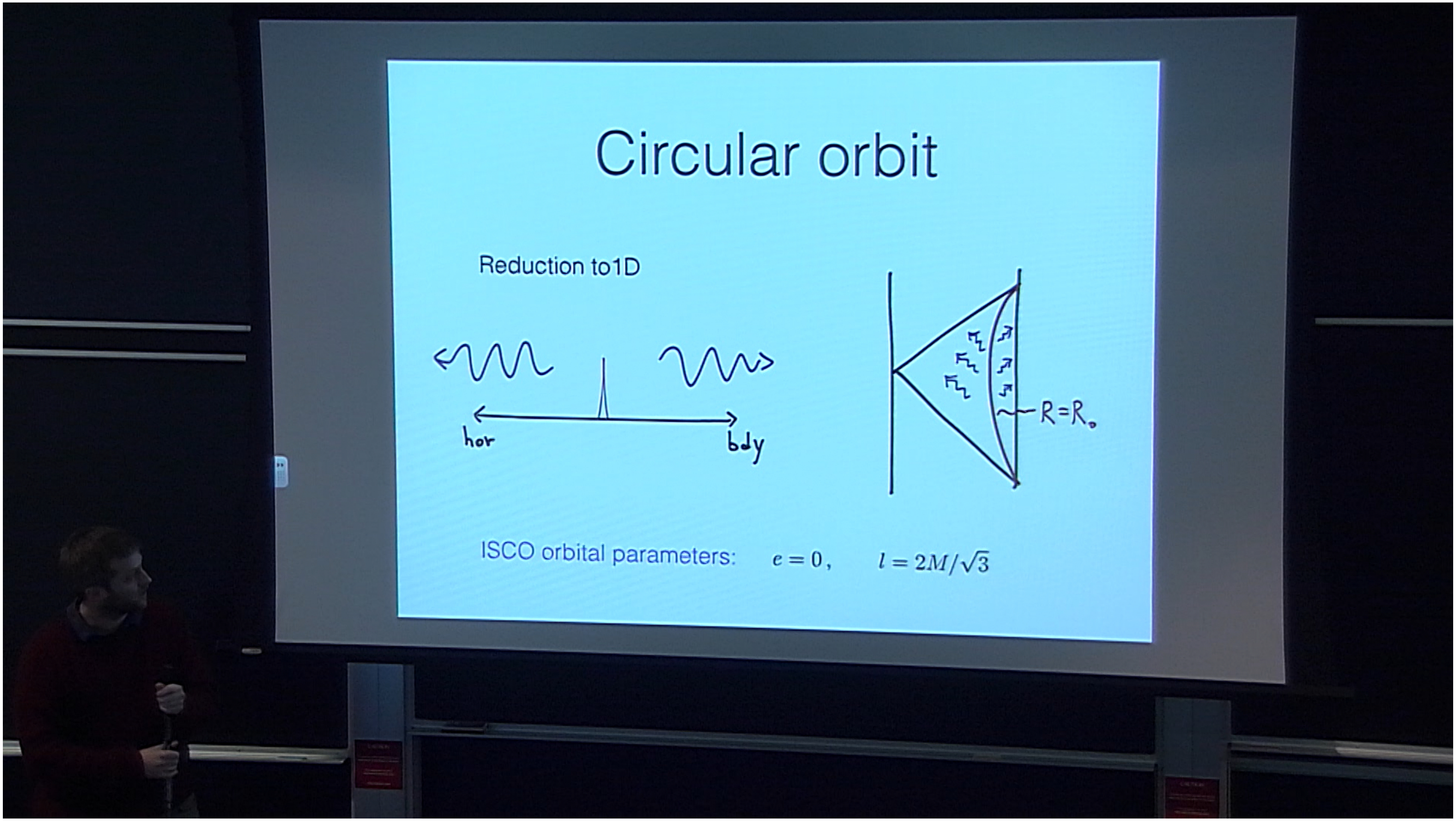
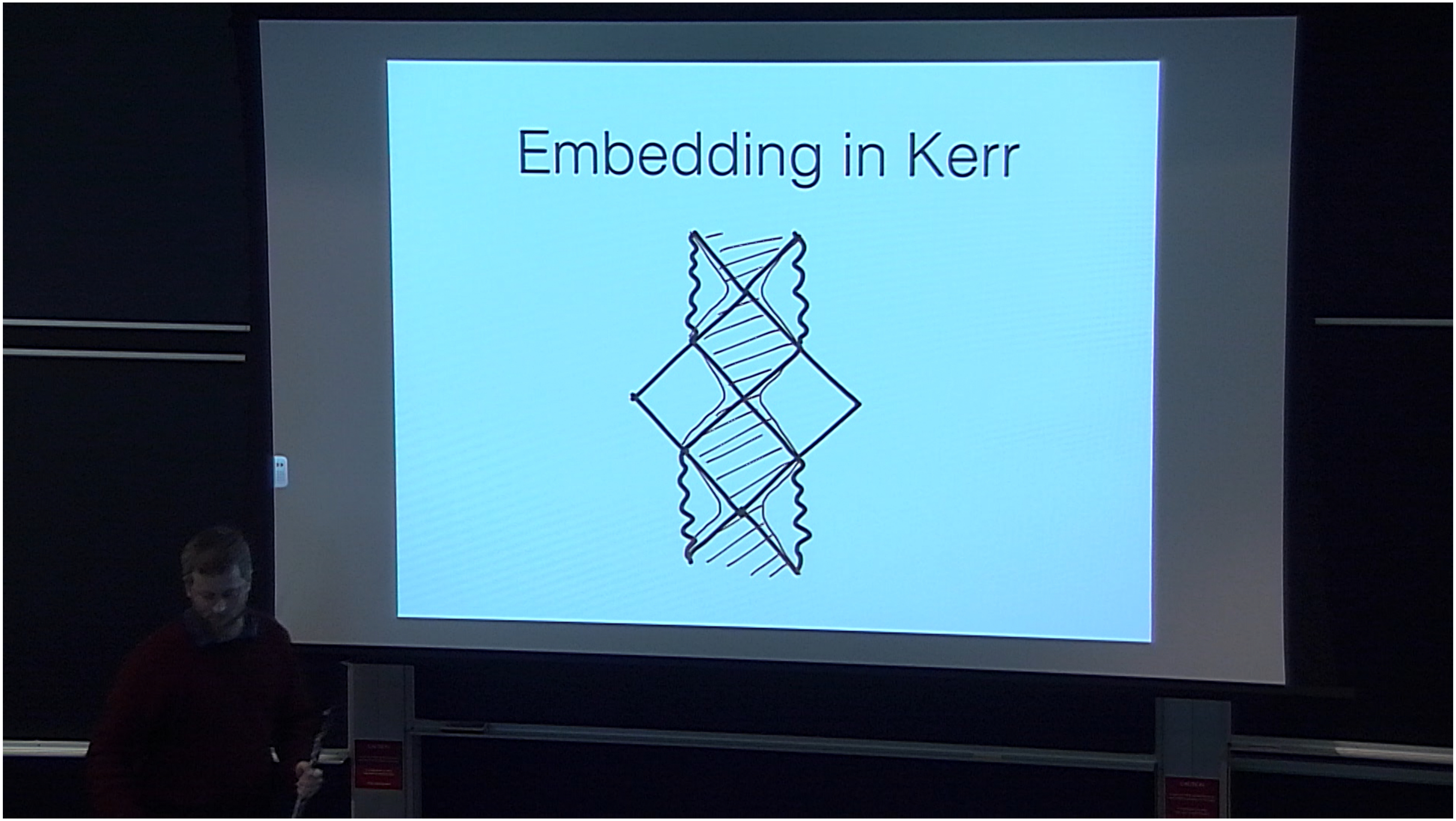
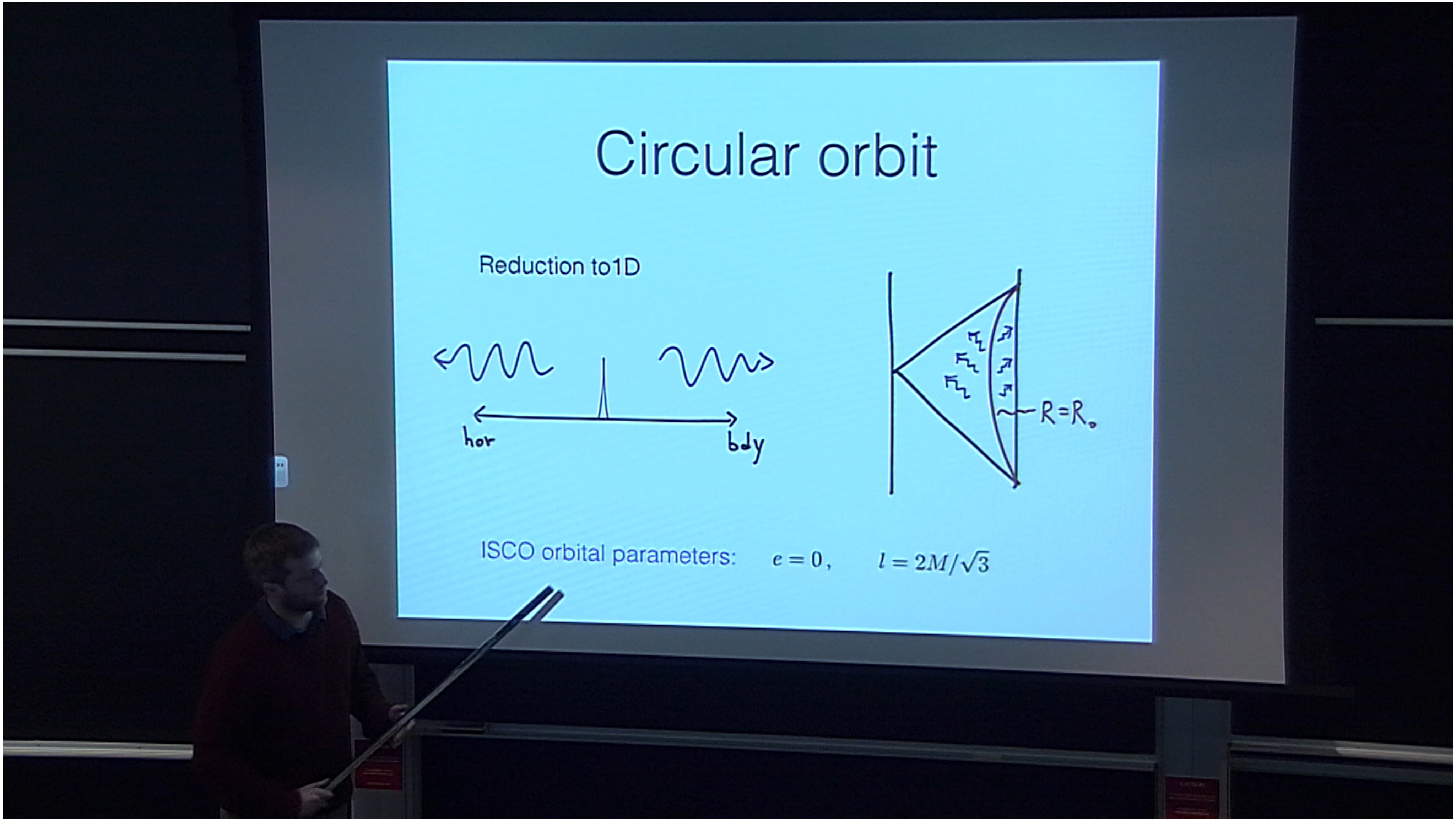

Circular orbit
Reduction to1D
hor
bdy
$R=R_0$
ISCO orbital parameters: $e=0\,,\quad l=2M/\sqrt{3}$


Embedding in Kerr


Circular orbit
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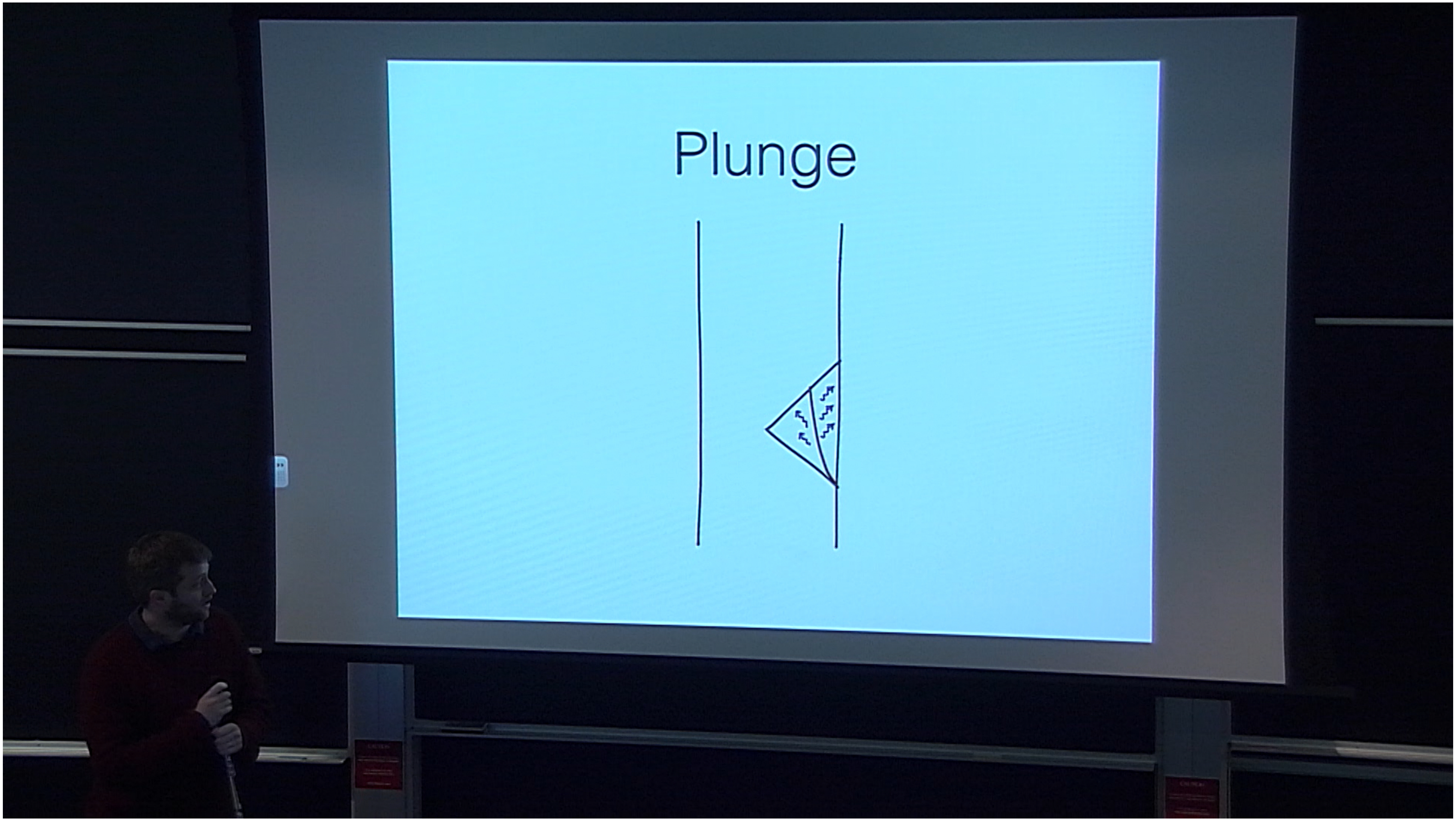
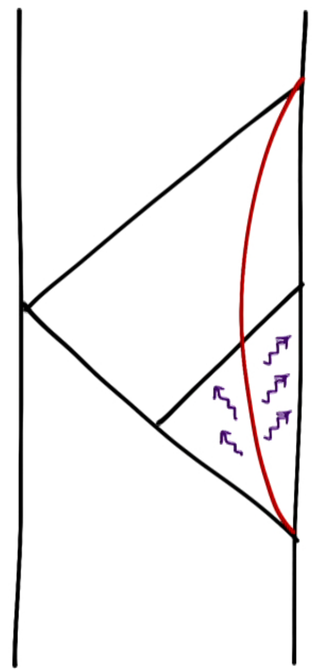

Plunge

Plunge



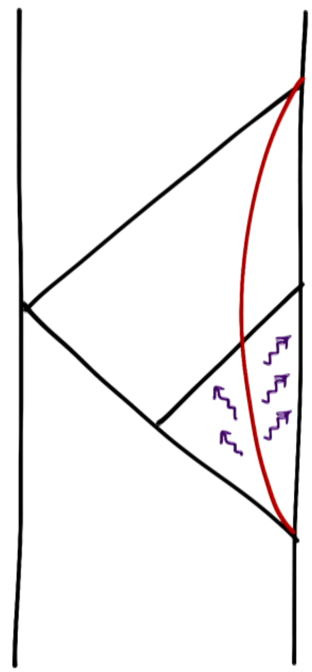
Plunge

Transformation

$$T = -e^{-\kappa t}\frac{r+\kappa}{\sqrt{r(r+2\kappa)}}\,,$$

$$R = \frac{1}{\kappa}e^{\kappa t}\sqrt{r(r+2\kappa)}\,,$$

$$\Phi = \phi - \frac{1}{2}\ln\frac{r}{r+2\kappa}\,.$$



Circular in NHEK

$$R = R_0\,,$$

$$\Phi(T) = -\frac{3}{4}R_0 T + \Phi_0\,,$$

Plunge in near-NHEK

$$t(r) = \frac{1}{2\kappa}\ln\frac{1}{r(r+2\kappa)} + t_0\,,$$

$$\phi(r) = \frac{3r}{4\kappa} + \frac{1}{2}\ln\frac{r}{r+2\kappa} + \phi_0\,,$$

"Post-ISCO plunge" parameters: $e = 0\,,\quad l = 2M/\sqrt{3}$

CFT interpretation

- Orbiting object dual to external driving:

$$S = S_{CFT} + \int \mathcal{O} J$$

- Induces nonzero transition rate out of the vacuum state of CFT, dual to flux into horizon.

Flux: $$\mathcal{F} = \int \sqrt{-g} J^r \, d\theta d\phi \,, \quad J^\mu = \frac{i}{8\pi} \left(\Psi^* \nabla^\mu \Psi - \Psi \nabla^\mu \Psi^* \right)$$

Transition rate: $$\mathcal{R} = \int d\omega \sum_{\ell,m} |J_{\ell m \omega}|^2 \int d\phi \, dt \, e^{-im\phi + i\omega t} \langle \mathcal{O}^\dagger(\phi, t) \mathcal{O}(0,0) \rangle_T$$

$$\mathcal{R} = \mathcal{F}$$

CFT interpretation

- Plunge CFT: via boundary conformal transformation!
- Mapping on boundary:

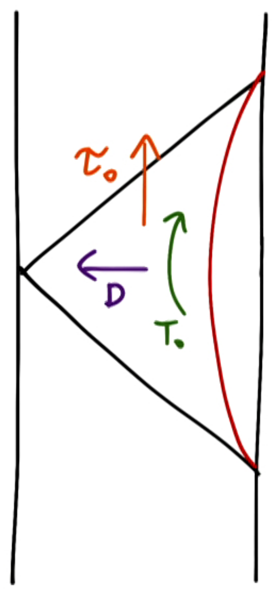
$$
\begin{aligned}
T &= -e^{-\kappa t}, \\
\Phi &= \phi,
\end{aligned}
\quad \Longrightarrow \mathcal{J} \to \left(\kappa e^{-\kappa t}\right)^{1-h} \mathcal{J}
$$

h - conformal weight of $\mathcal{O}$

$$\mathcal{R} = \mathcal{F}$$

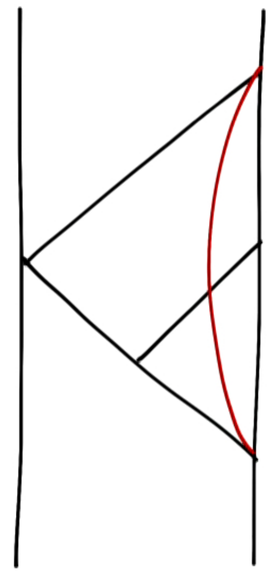
More mapping fun

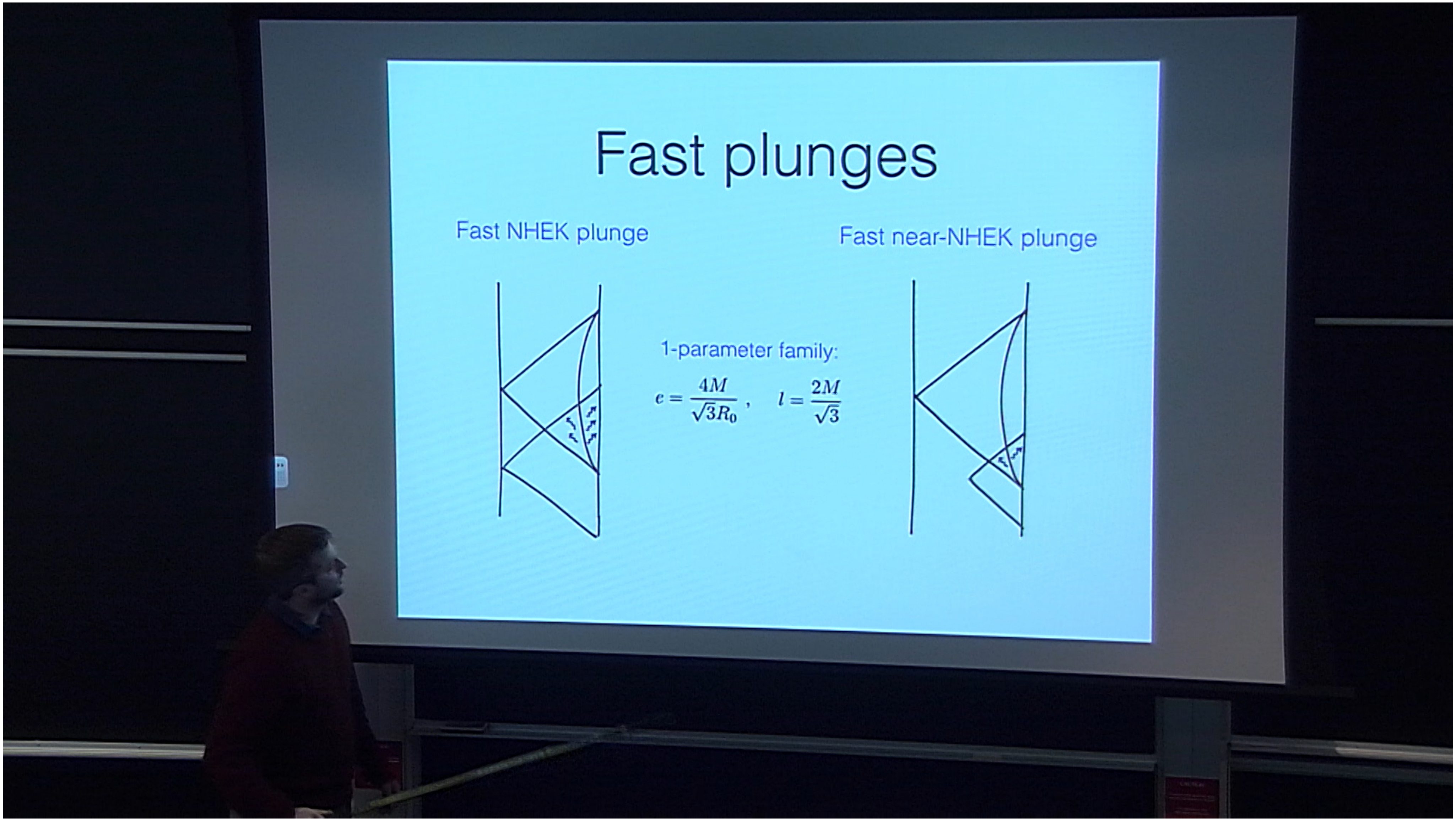
SL(2,R) operation



- Global time translations
- Poincare time translations
- Dilatations

"Rindler" cutting

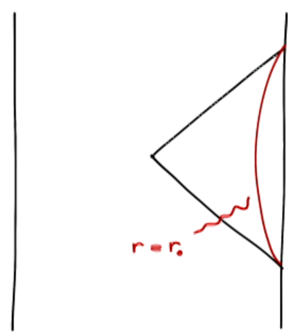



Fast plunges
Fast NHEK plunge
Fast near-NHEK plunge
1-parameter family:
$e = \frac{4M}{\sqrt{3}R_0}\,, \quad l = \frac{2M}{\sqrt{3}}$

Generic orbits

- Generalize to any equatorial plunge?
- L invariant under SL(2,R)*U(1)

Unstable circular orbits
in near-NHEK

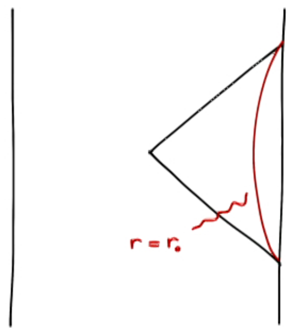


1-parameter family

$$l = \frac{2M(R_0 + \kappa)}{\sqrt{3R_0^2 + 6R_0\kappa - \kappa^2}}$$

Generic orbits

Unstable circular orbits

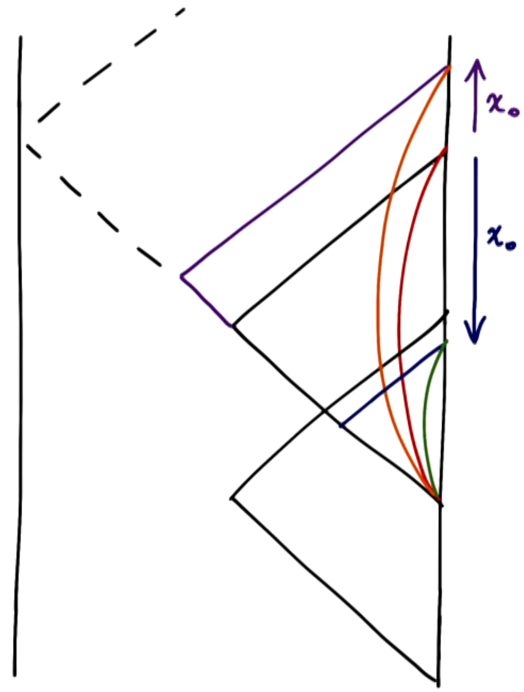


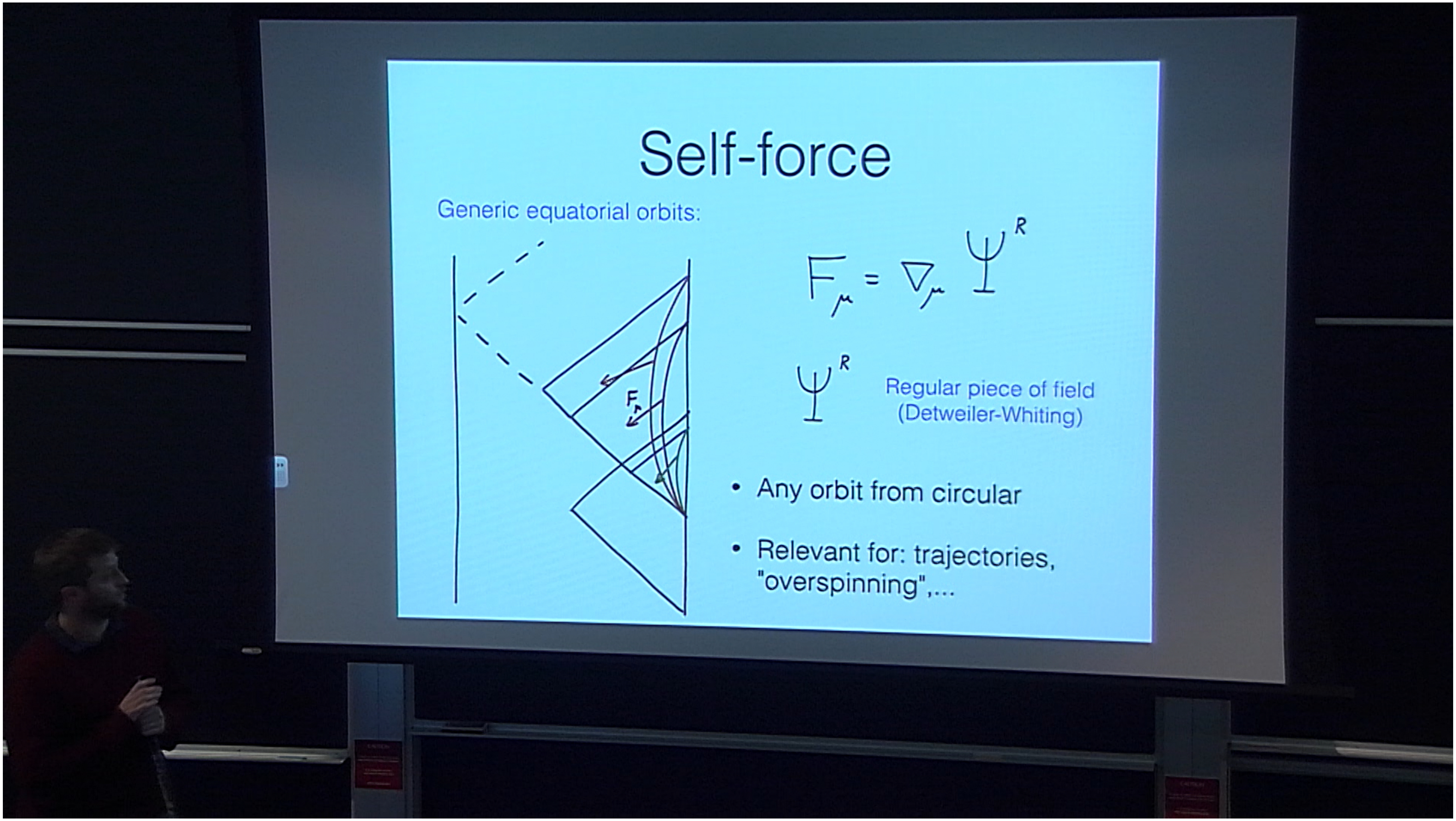
2-parameter family:

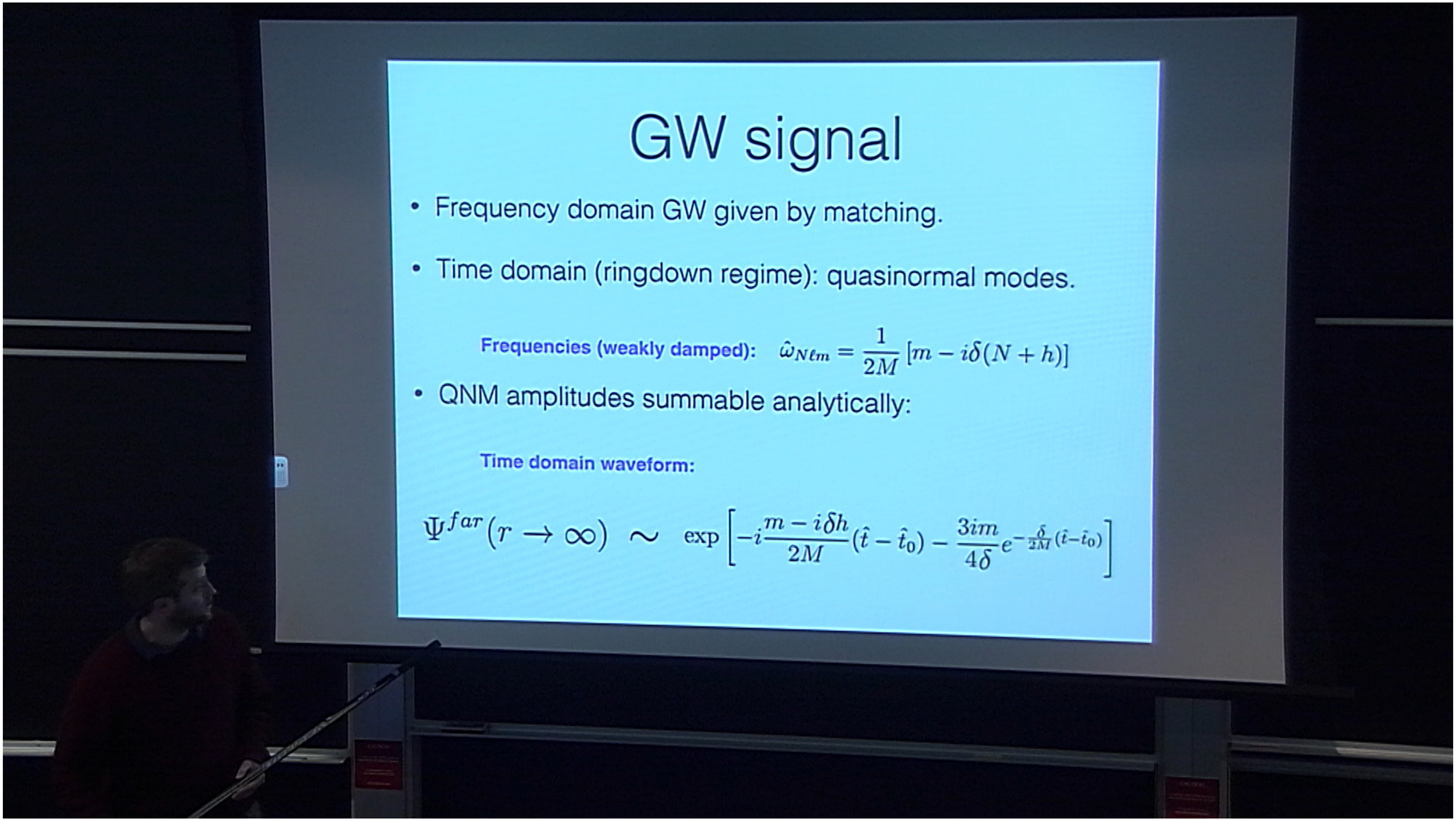
$$l = \frac{2M(R_0+\kappa)}{\sqrt{3R_0^2+6R_0\kappa-\kappa^2}}$$

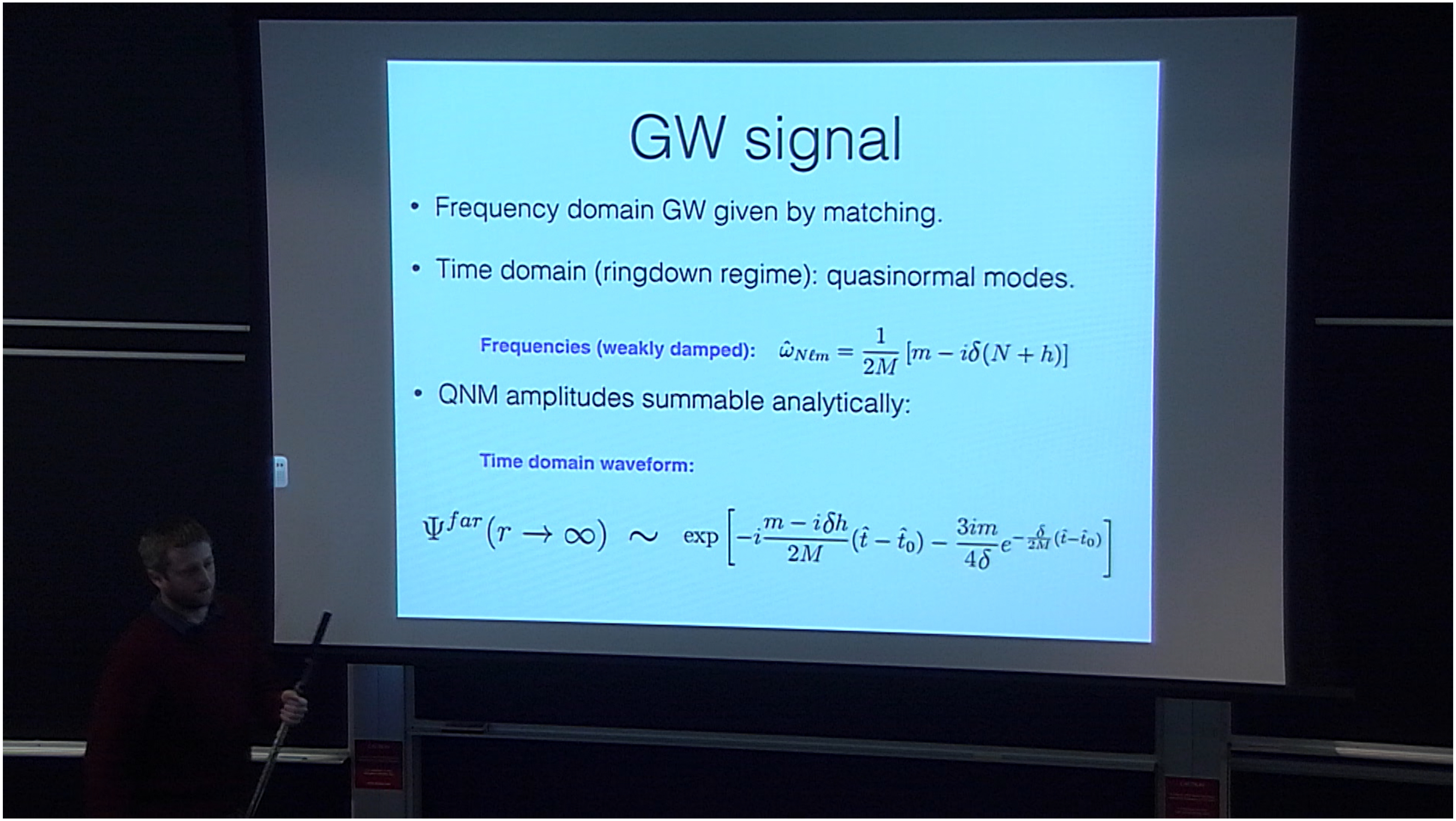
$$e = \frac{2M\kappa^2\,\chi_0}{\sqrt{3R_0^2+6R_0\kappa-\kappa^2}}$$

Generic near-NHEK plunge




Self-force
Generic equatorial orbits:
$F_\mu = \nabla_\mu \Psi^R$
Ψ^R
Regular piece of field
(Detweiler-Whiting)
• Any orbit from circular
• Relevant for: trajectories,
"overspinning",...


GW signal
• Frequency domain GW given by matching.
• Time domain (ringdown regime): quasinormal modes.
Frequencies (weakly damped): $\hat{\omega}_{N\ell m} = \frac{1}{2M}\left[m - i\delta(N+h)\right]$
• QNM amplitudes summable analytically:
Time domain waveform:
$\Psi^{far}(r \to \infty) \sim \exp\left[-i\frac{m - i\delta h}{2M}(\hat{t} - \hat{t}_0) - \frac{3im}{4\delta}e^{-\frac{\delta}{2M}(\hat{t} - \hat{t}_0)}\right]$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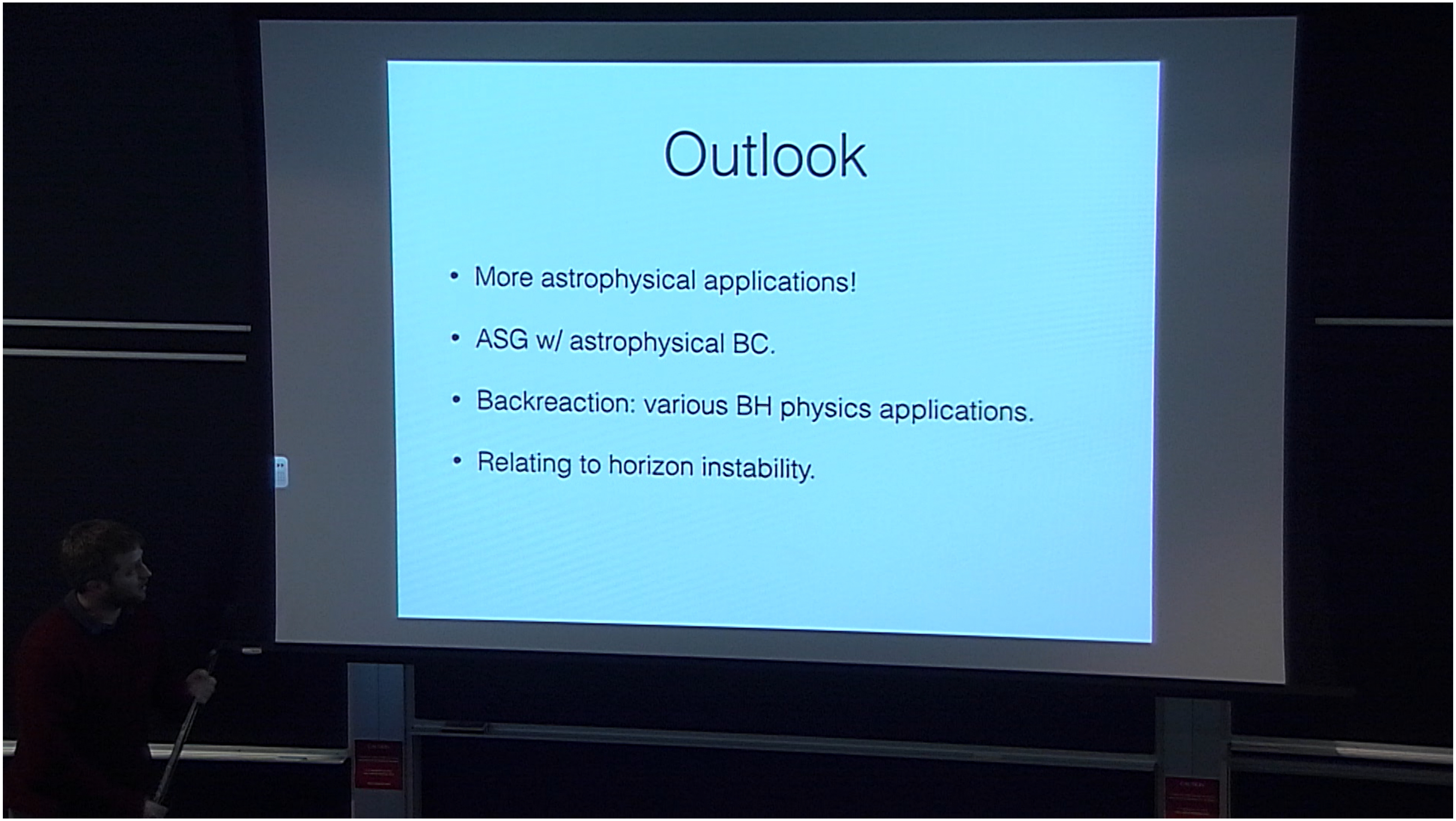
Outlook
More astrophysical applications!
ASG w/ astrophysical BC.
Backreaction: various BH physics applications.
Relating to horizon instability.