Title: Lecture - Strong Gravity, PHYS 777

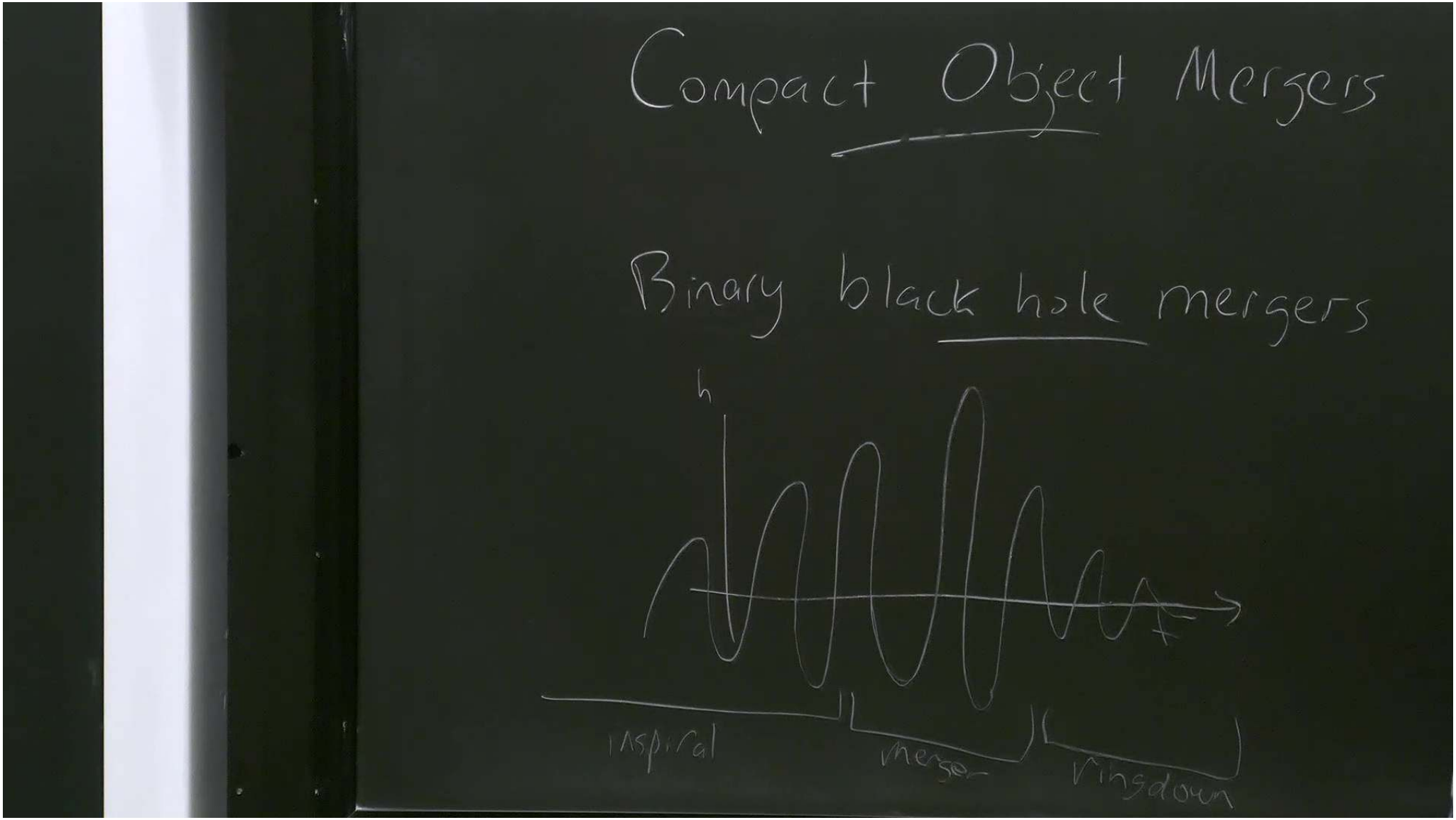
Speakers: William East

Collection/Series: Strong Gravity (Elective), PHYS 777, February 23 - March 27, 2026

Subject: Strong Gravity

Date: March 27, 2026 - 2:15 PM

URL: https://pirsa.org/26030021


Compact Object Mergers
Binary black hole mergers
h
t
inspiral
merger
ringdown

Inspiral → Post-Newtonian

$$\left(\frac{v}{c}\right)^2 \sim \left(\frac{M}{c^2 r}\right) \sim \varepsilon << 1$$

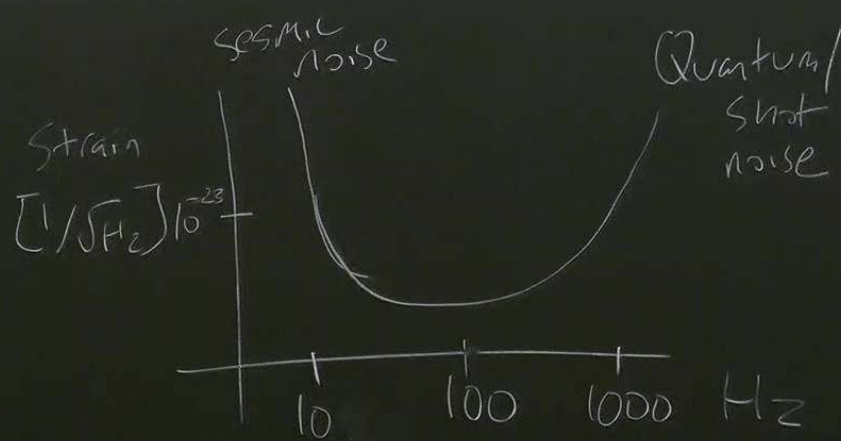
PN approximation → up to $\varepsilon^{\#}$

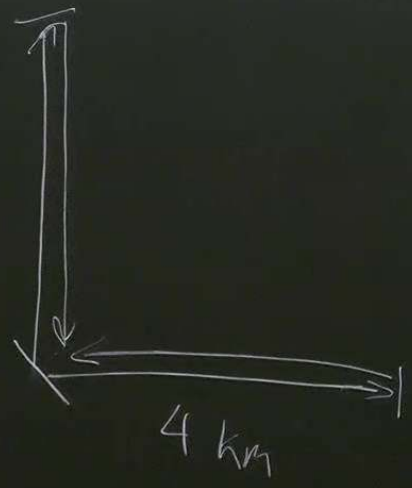
E.g. for 2-body motion

$$\frac{d\vec{v}}{dt} = \frac{GM}{r^2}\left(-\hat{n} + \frac{1}{c^2}\vec{A}_{1PN} + \frac{1}{c^4}\vec{A}_{2PN} + \dots\right.$$

Strain

$[1/\sqrt{Hz}]10^{-}$





$$A_{1PN} = \left[(4+2\tilde{\mu})\frac{GM}{r} - (1+3\tilde{\mu}^2)v^2 + \frac{3}{2}\tilde{\mu}\dot{r}^2\right]\hat{n} + (4-2\tilde{\mu})\dot{r}v$$

$$\tilde{\mu} = \frac{m_1 m_2}{(m_1+m_2)^2}$$

2PN ...

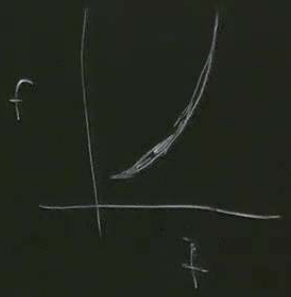
inspiral merger ringdown

Leading order

$$\dot{f}_{GW} = \frac{96}{5} f_{GW}^2 \left(\frac{\pi G \mathcal{M} f_{GW}}{c^3}\right)^{5/3}$$

$$f_{GW} = 2 f_{orb}$$

$$\mathcal{M} = \mu^{3/5} M \quad \text{Chirp mass}$$

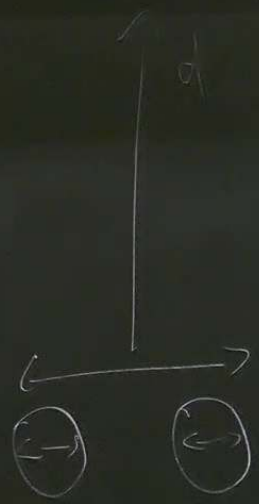


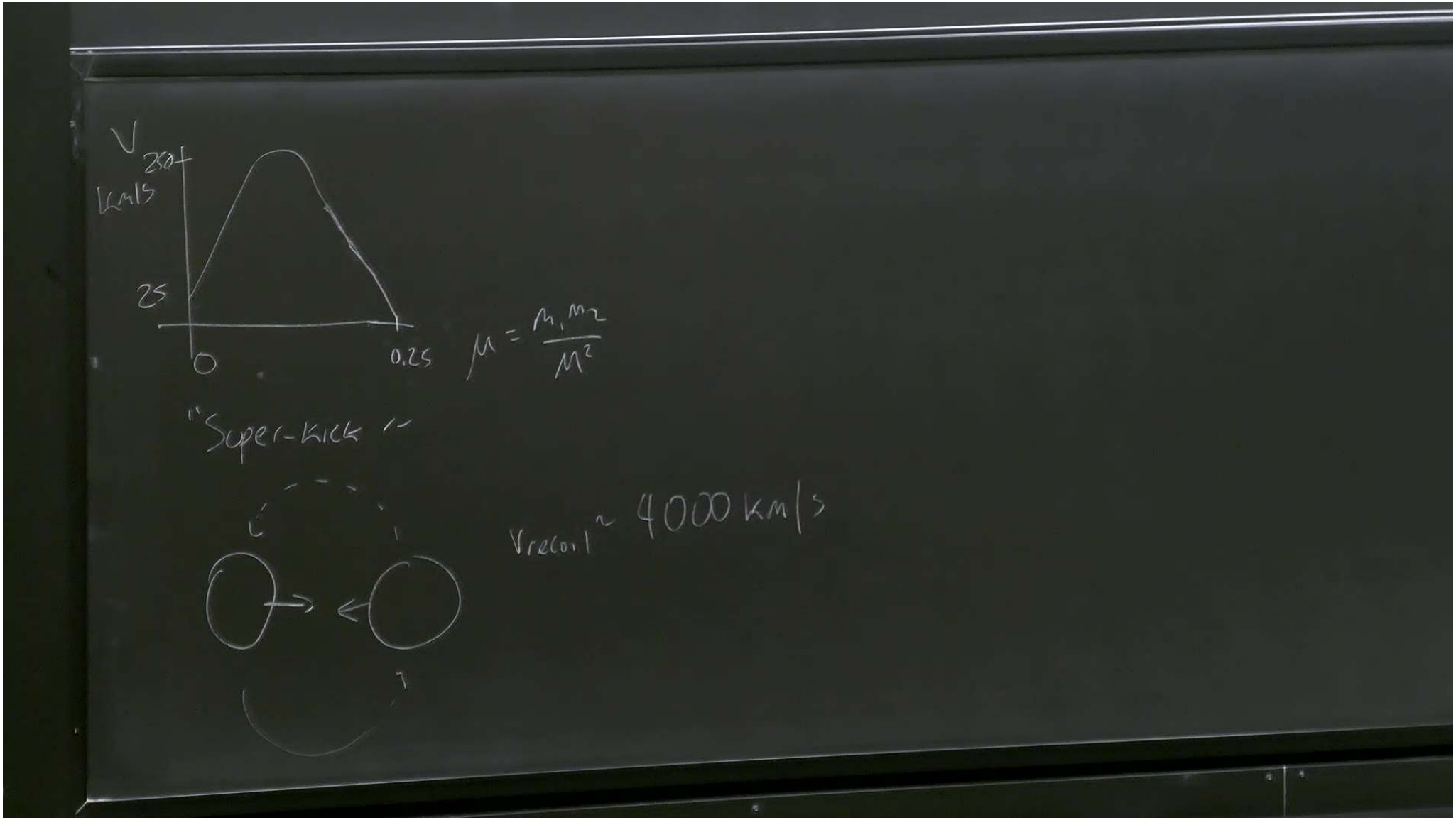
$(m_1+m_2)^2$

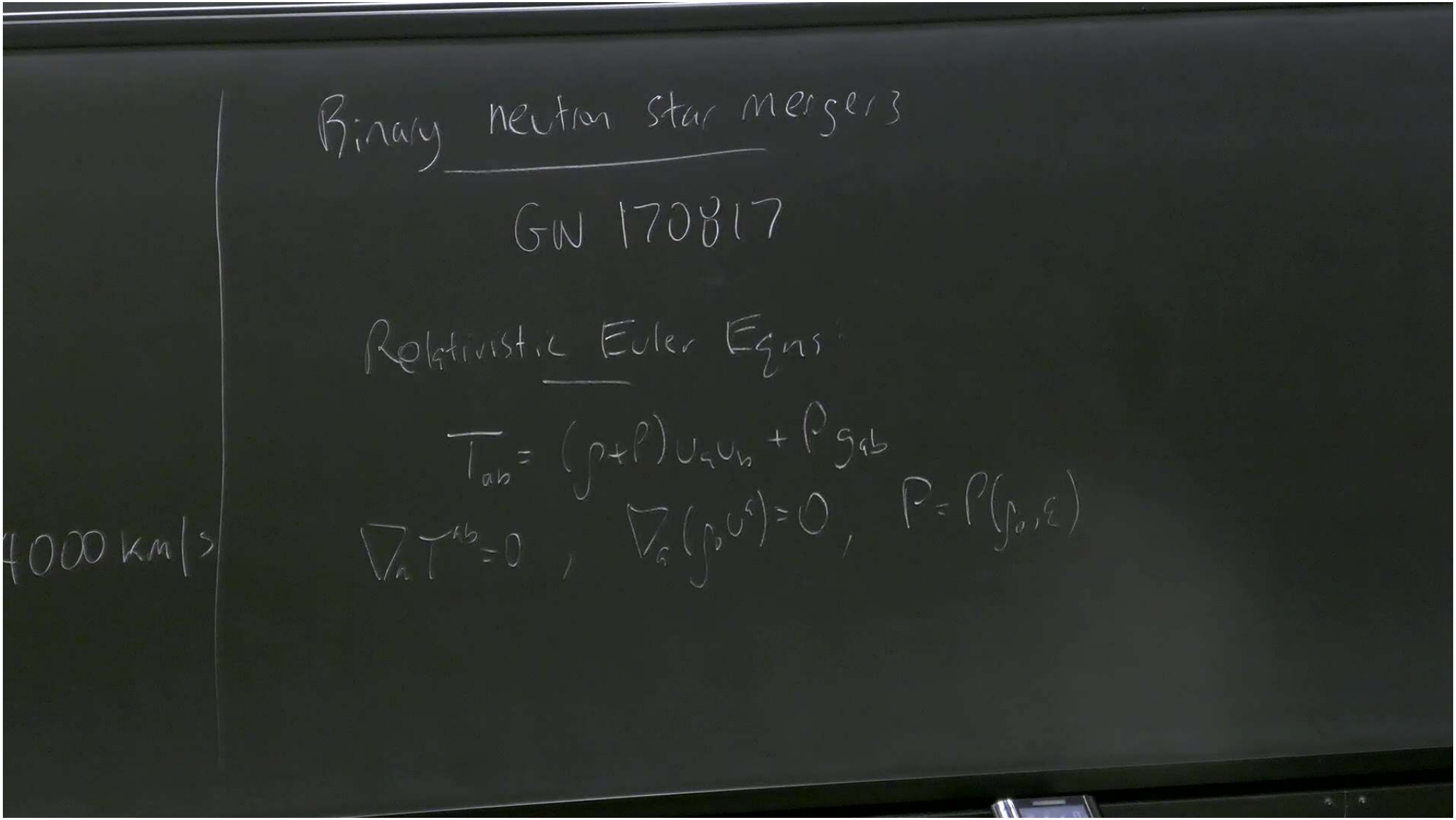
Merger - Need full solution → solve numerically

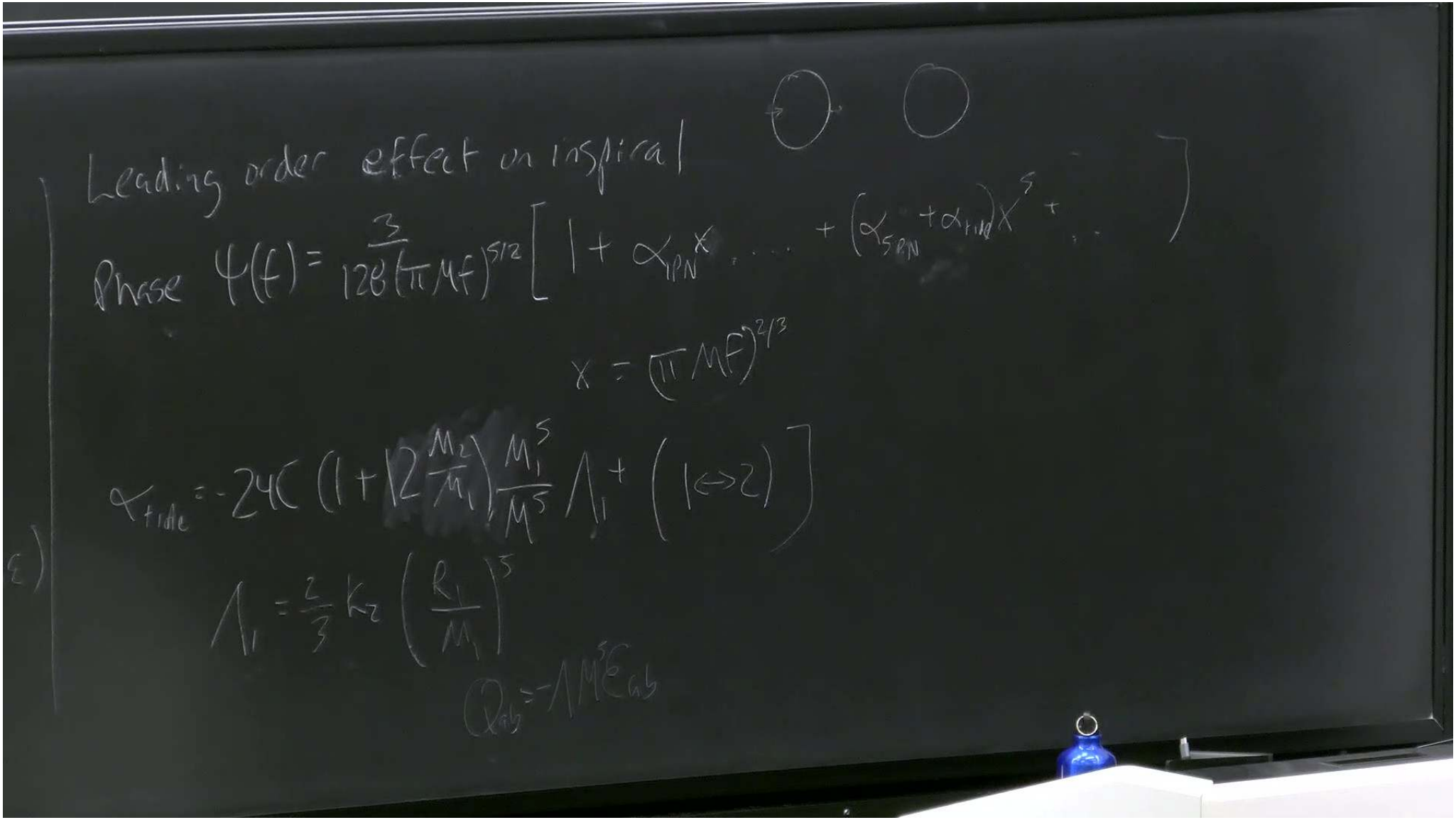
$R_{ab}=0$

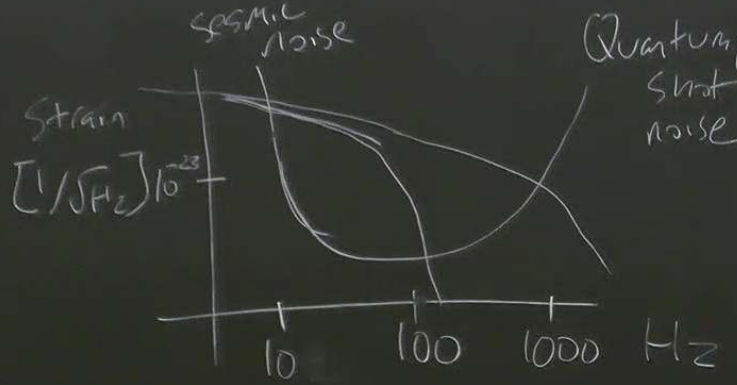
- Well-posed formulation (GH, BSSN, Z4, ...)
- Control over constraint violation
- Good ID
- Resolve disparate length scales
- Handle BH singularity

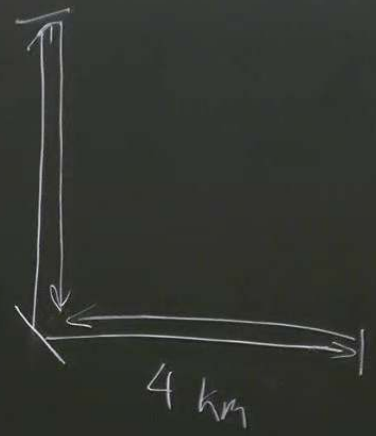



V
250
km/s
25
0
0.25
$\mu = \frac{m_1 m_2}{M^2}$
"Super-kick"
$v_{recoil} \sim 4000$ km/s


Binary neutron star mergers
GW 170817
Relativistic Euler Eqns:
$T_{ab} = (\rho + P) u_a u_b + P g_{ab}$
$\nabla_a T^{ab} = 0$, $\nabla_a (\rho u^a) = 0$, $P = P(\rho, \varepsilon)$
4000 km/s


Leading order effect on inspiral
Phase $\Psi(f) = \frac{3}{128}(\pi M f)^{5/2}\left[1 + \alpha_{1PN} x + \ldots + (\alpha_{5PN} + \alpha_{tidal}) x^5 + \ldots\right]$
$x = (\pi M f)^{2/3}$
$\alpha_{tidal} = -24\left((1 + 12\frac{M_2}{M_1})\frac{M_1^5}{M^5}\Lambda_1 + (1 \leftrightarrow 2)\right)$
$\Lambda_1 = \frac{2}{3} k_2 \left(\frac{R_1}{M_1}\right)^5$
$Q_{ab} = -\lambda M^2 \varepsilon_{ab}$

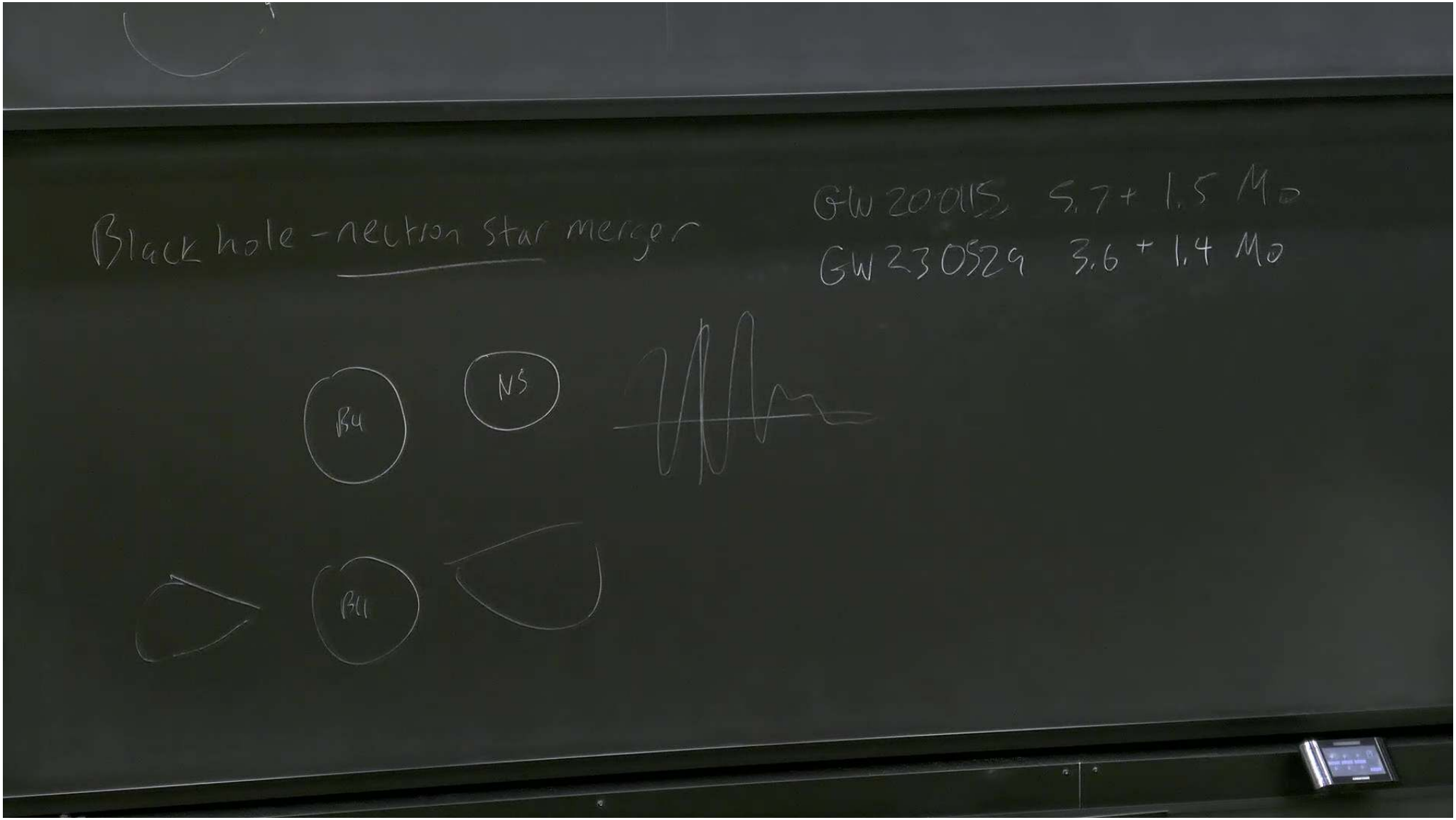


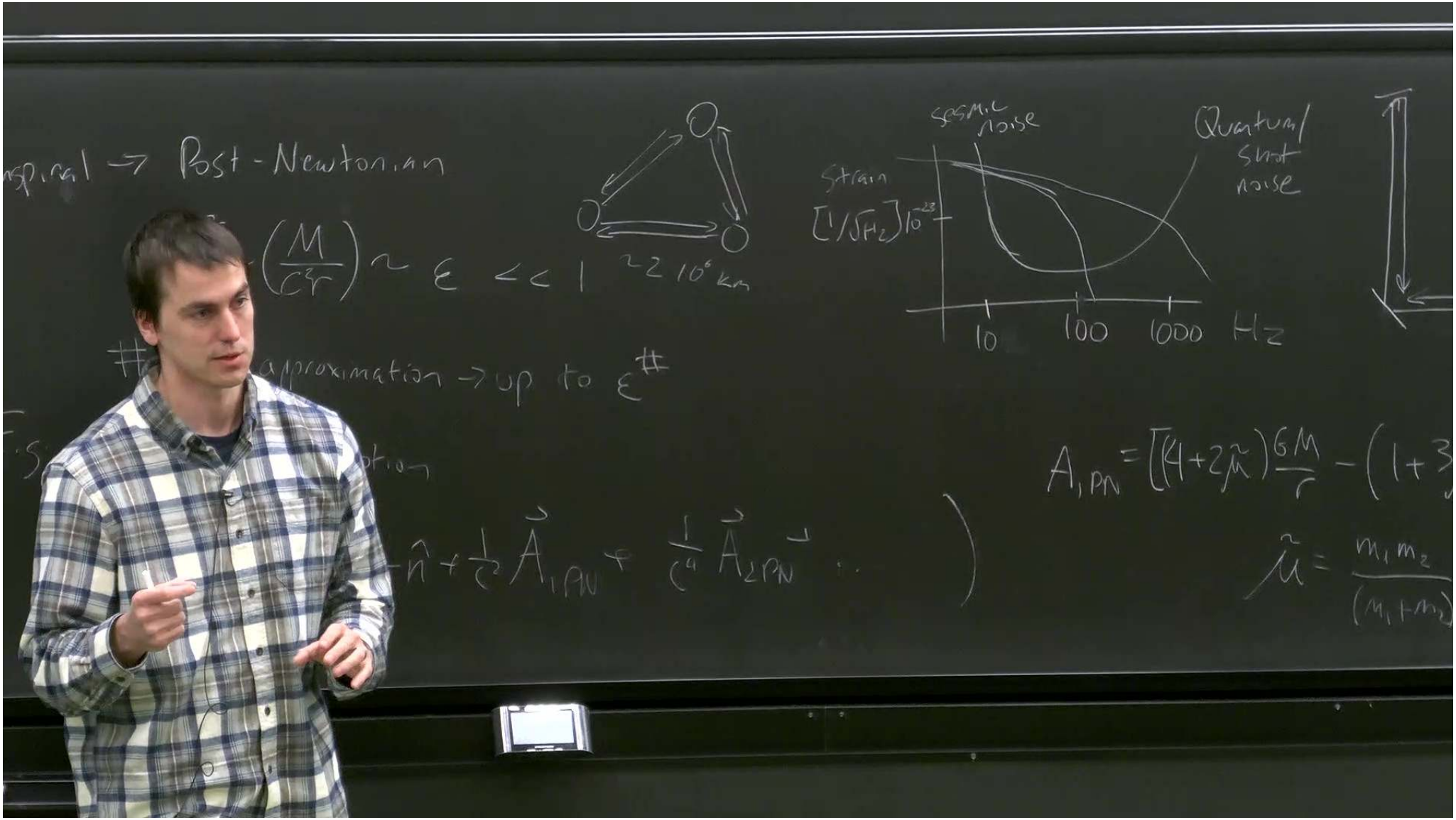


$$A_{1PN} = \left[(4+2\tilde{\mu})\frac{GM}{r} - (1+3\tilde{\mu})v^2 + \frac{3}{2}\tilde{\mu}\dot{r}^2\right]\hat{n} + (4-2\tilde{\mu})\dot{r}v$$

$$\frac{1}{c^4}\vec{A}_{2PN} \ldots)$$

$$\tilde{\mu} = \frac{m_1 m_2}{(m_1+m_2)^2}$$


Black hole - neutron star merger
GW200115 5.7 + 1.5 M⊙
GW230529 3.6 + 1.4 M⊙
BH
NS
BH


spiral → Post-Newtonian
$\left(\frac{M}{c^2 r}\right) \sim \varepsilon << 1$
$\sim 2 \times 10^6$ km
approximation → up to $\varepsilon^{\#}$
seismic noise
Quantum/ shot noise
Strain
$[1/\sqrt{Hz}]\,10^{-23}$
10
100
1000
Hz
$A_{1PN} = [(4+2\tilde{\mu})\frac{GM}{r} - (1+3$
$\tilde{\mu} = \frac{m_1 m_2}{(m_1+m_2)}$