Title: Extended Path Intensity Correlation: Differential Astrometry with Microarcsecond Precision

Speakers: Marios Galanis

Series: Cosmology & Gravitation

Date: April 10, 2023 - 12:00 PM

URL: https://pirsa.org/23040128

Abstract: The angular resolution of a stellar interferometer, as for a single telescope, becomes better at smaller wavelengths and larger baselines. The goal for ground detectors would then be optical interferometers with baselines as long as the Earth's diameter. The latter goal has been achieved in radio, but it becomes prohibitive in the optical, as the electromagnetic field oscillates too rapidly to record and analyze directly over km-long baselines. Intensity interferometry relying on second-order correlations can make this possible: rather than the amplitude and phase of incoming light, we need only count photons. This technique has a long history and to date the best measurements of nearby stellar radii, dating back to the 1950s. Its main limitations are the need for very bright sources and its narrow field of view, restricting kilometer-long baselines to sources only a few ?as away. In this talk, I will propose an optical-path modification of astronomical intensity interferometers, which introduces an effective time delay in the two-photon interference amplitude, splitting the main intensity correlation fringe into others at finite opening angles, allowing for differential astrometry of multiple compact sources such as stars or quasar images. Together with the exponential progress in the field of single photon detection, such a modification will immensely increase the scope of intensity interferometry beyond measurements of the optical emission region morphology. I will lay out the theory and technical requirements of time-delay intensity interferometry and, time permitting, I will talk about some promising applications, which include astrometric microlensing of stars and quasar images, binary-orbit characterization, exoplanet detection, Galactic acceleration measurements and calibration of the cosmic distance ladder, all at unprecedented relative astrometric precision.

Zoom Link: TBD

Extended Path Intensity Correlation: Differential Astrometry with Microarcsecond Precision

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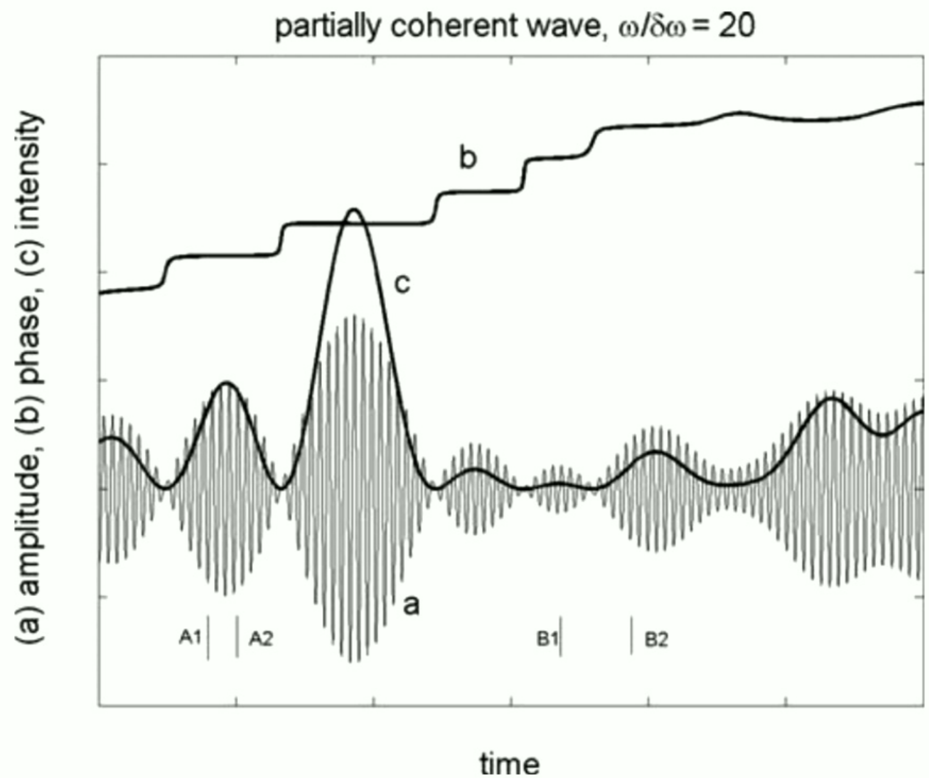
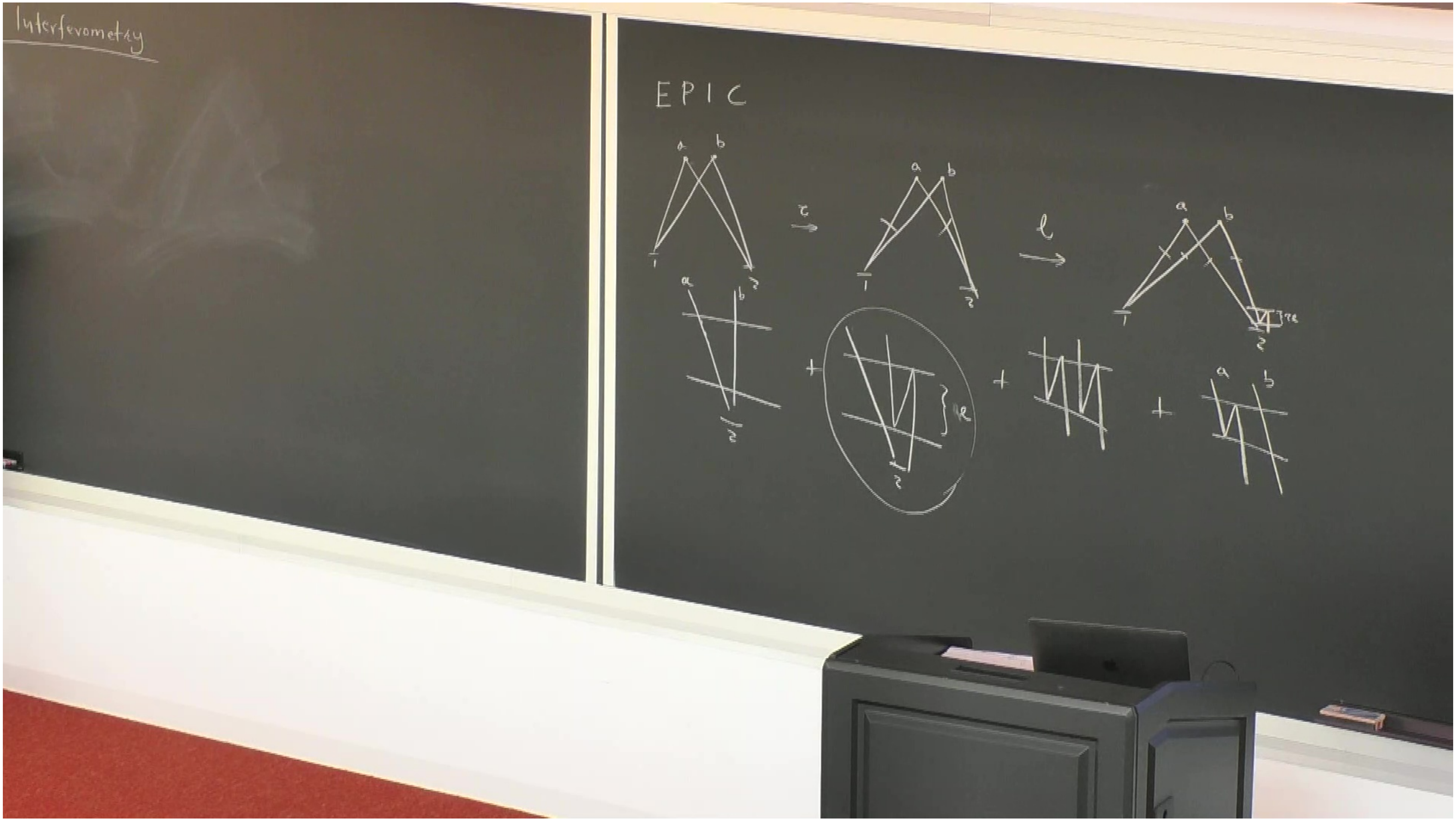
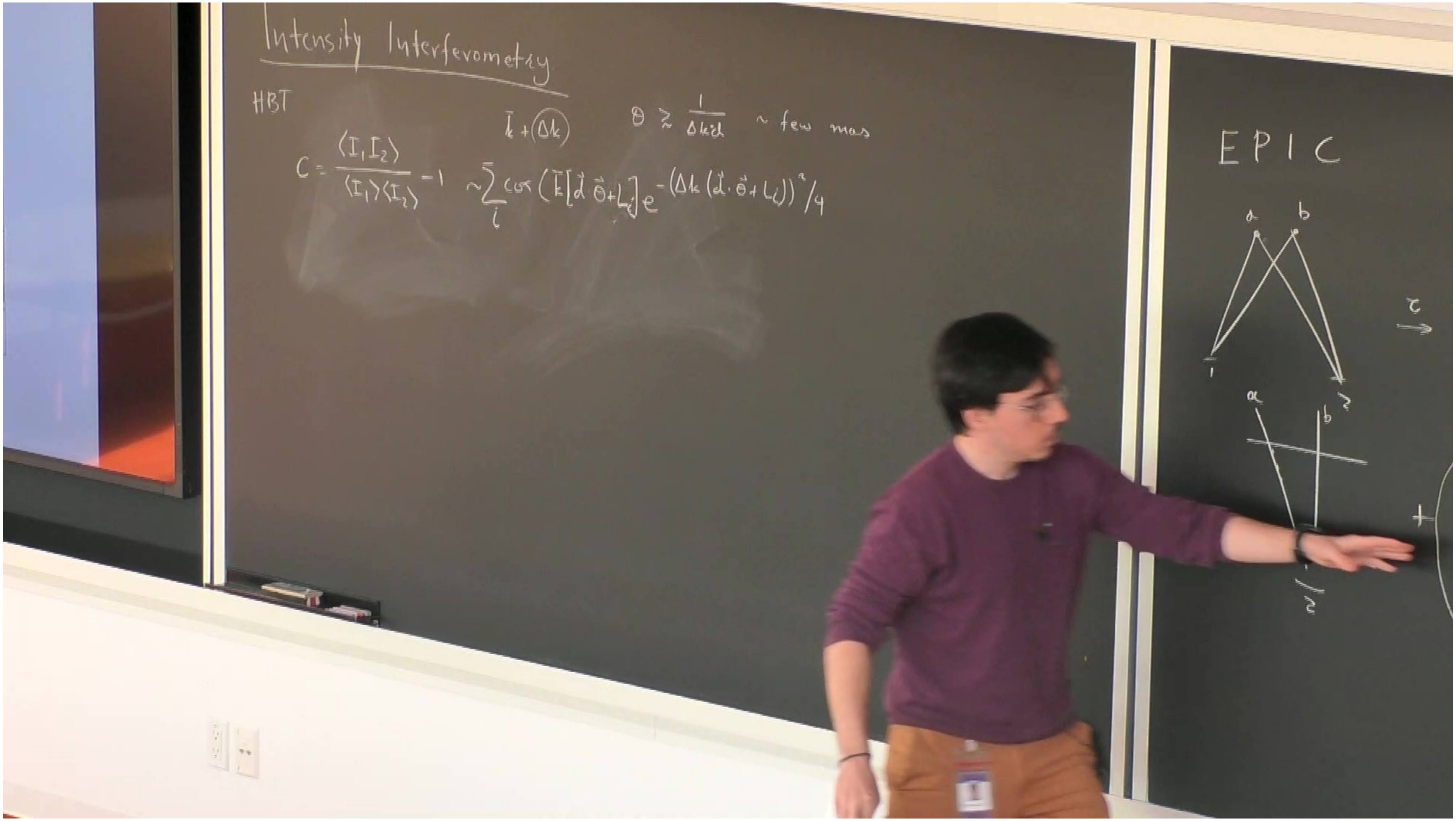
arXiv: 2304.xxxxx

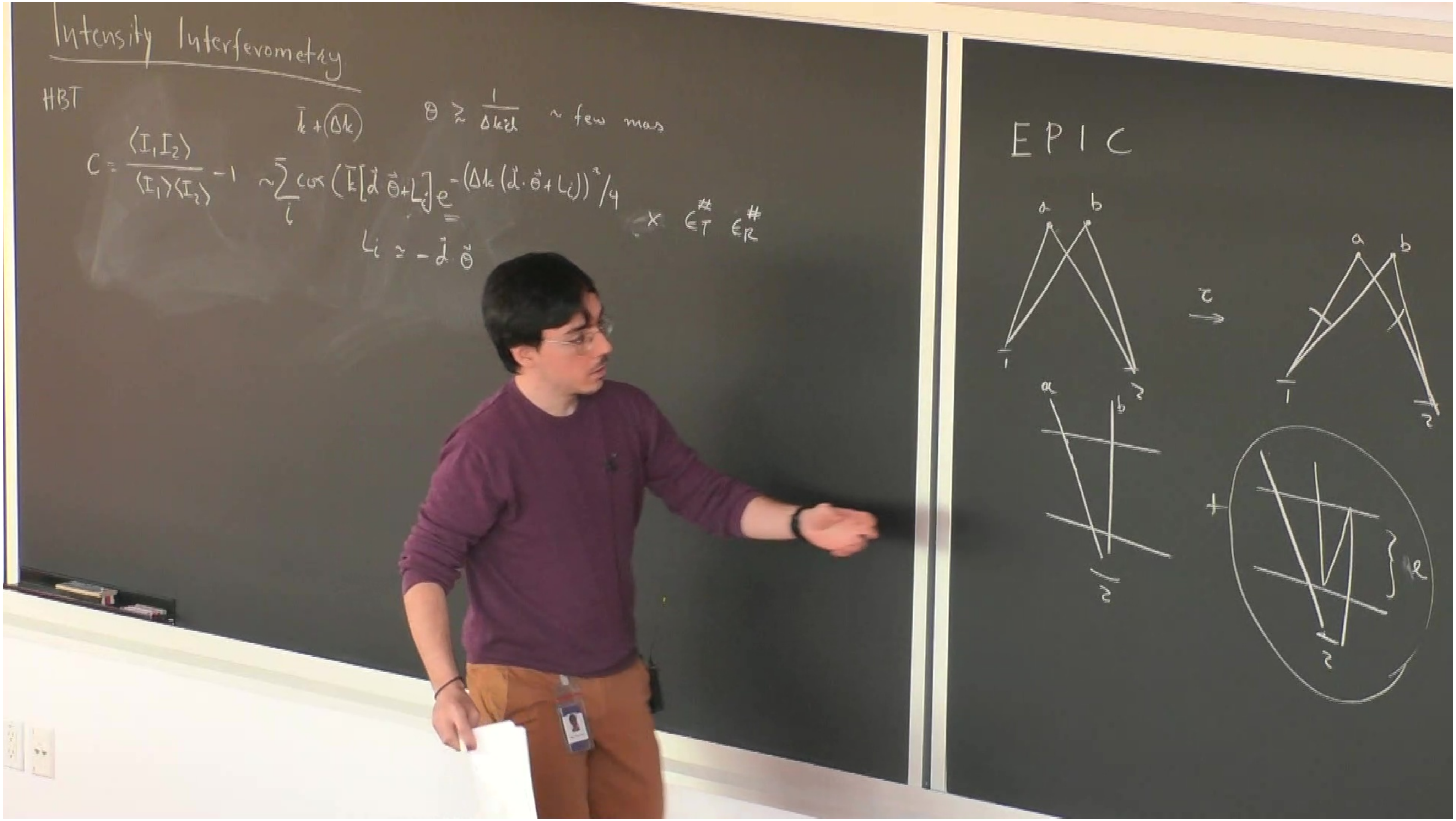
Photon Counts

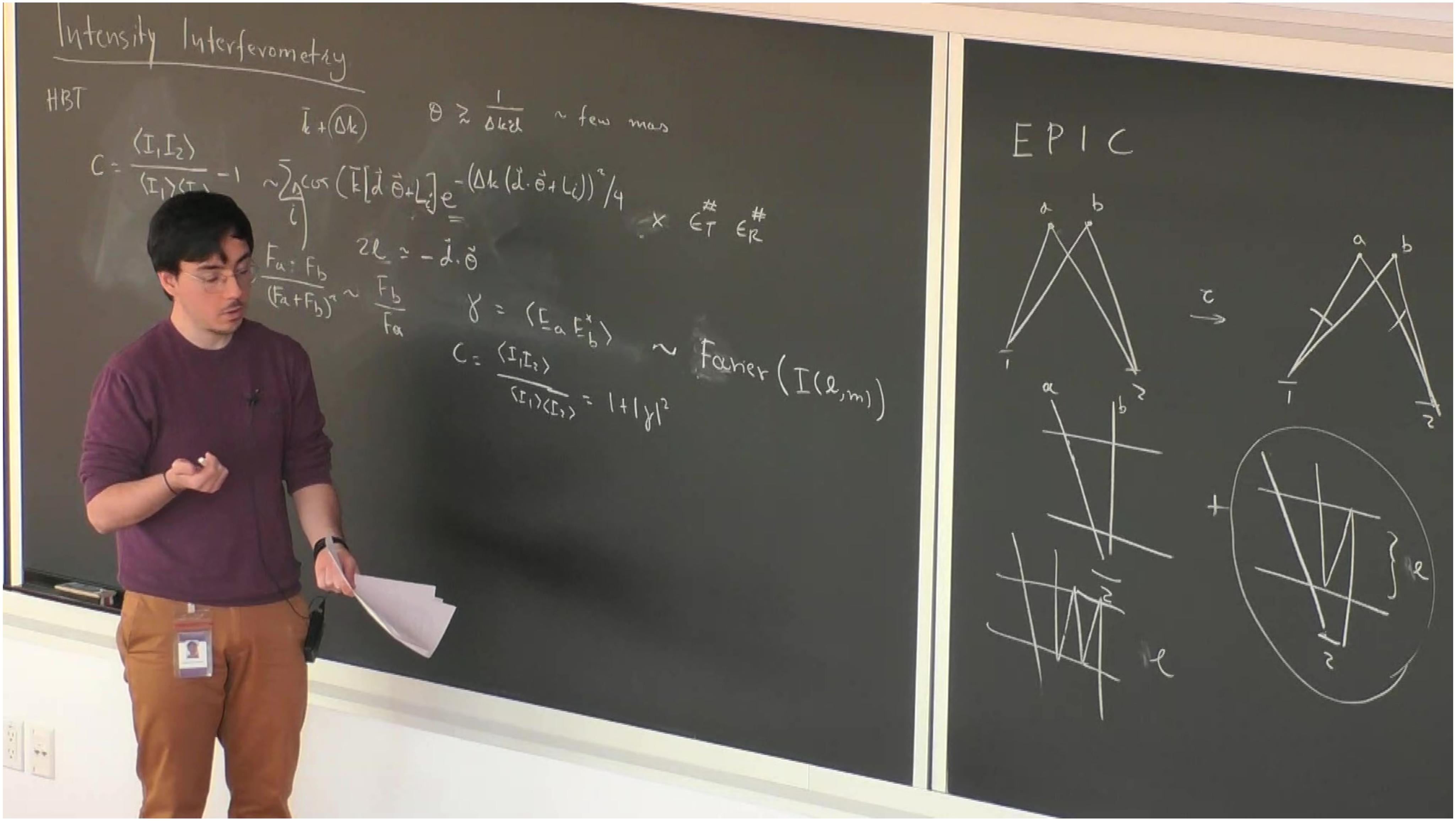


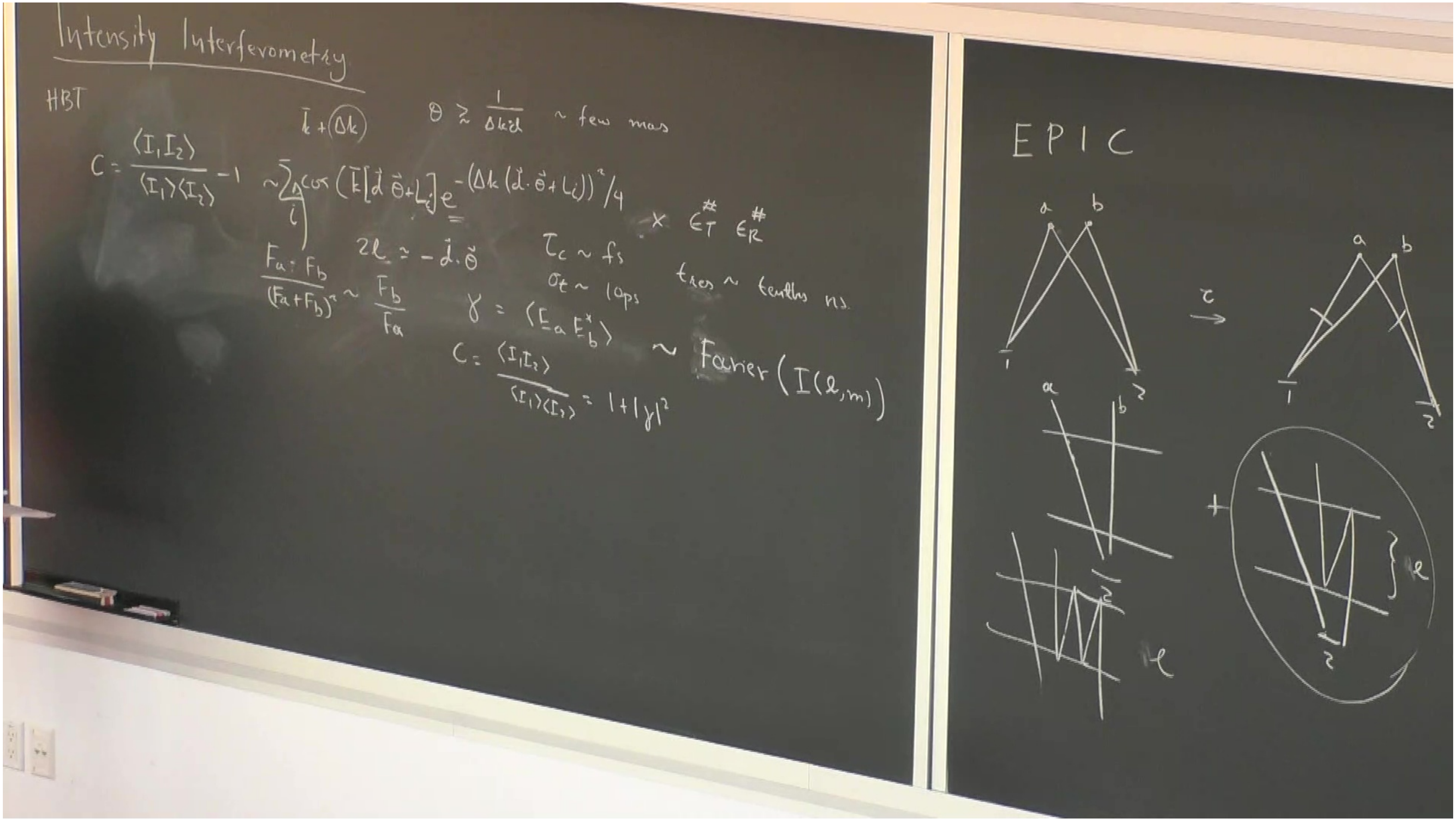

Photon Counts
partially coherent wave
(a) amplitude, (b) phase, (c) intensity
time
Intensity Interferometry
HBT

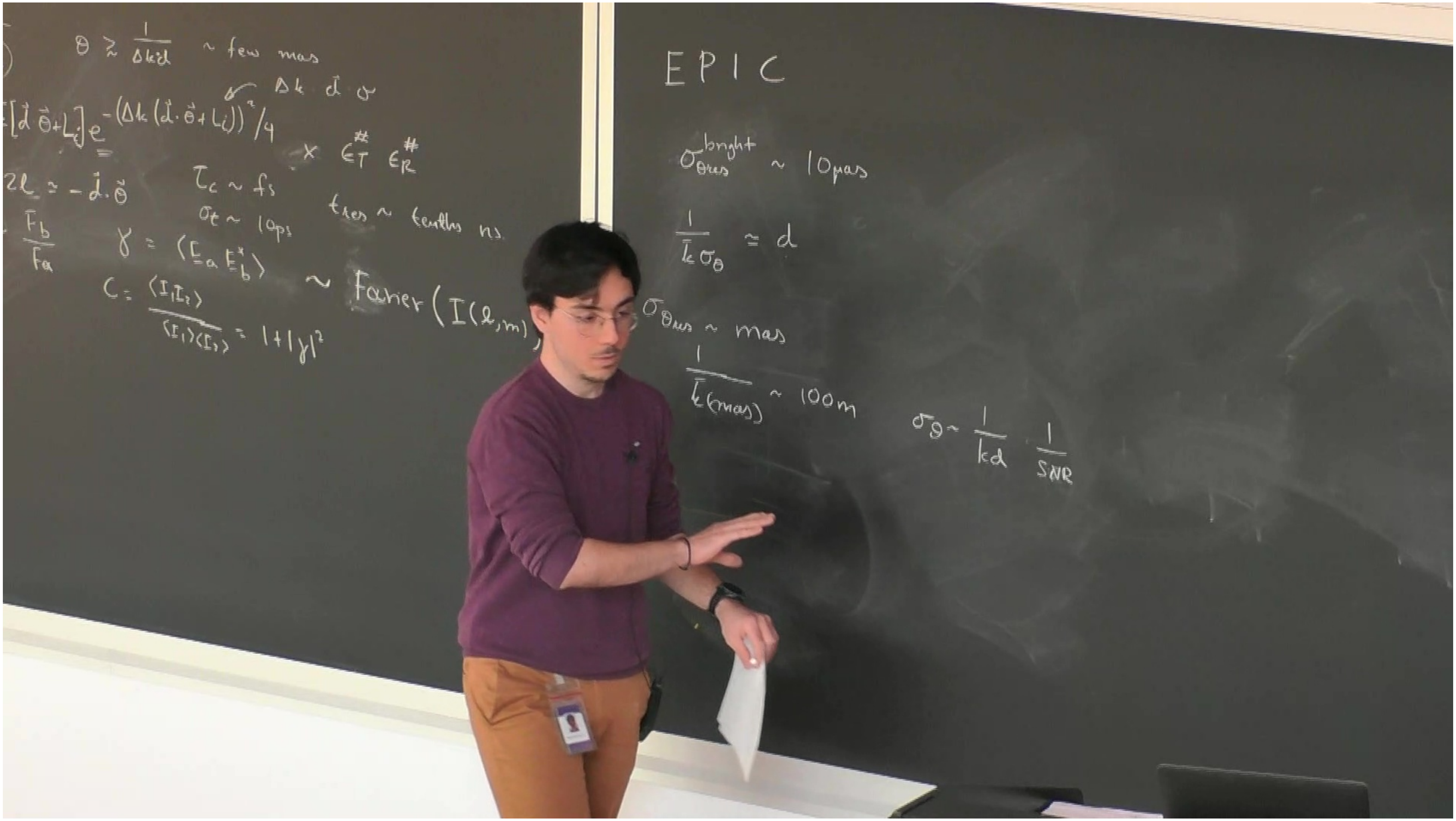

Interferometry
EPIC


Intensity Interferometry
HBT
$\bar{k} + (\Delta k)$
$\theta \gtrsim \frac{1}{\Delta k d}$ ~ few mas
$C = \frac{\langle I_1 I_2 \rangle}{\langle I_1 \rangle \langle I_2 \rangle} - 1 \sim \sum_i \cos(\bar{k}[\vec{d}\,\vec{\theta} + L_i])\, e^{-(\Delta k(\vec{d}\cdot\vec{\theta} + L_i))^2/4}$
EPIC
a
b
1
2
τ
a
b
2

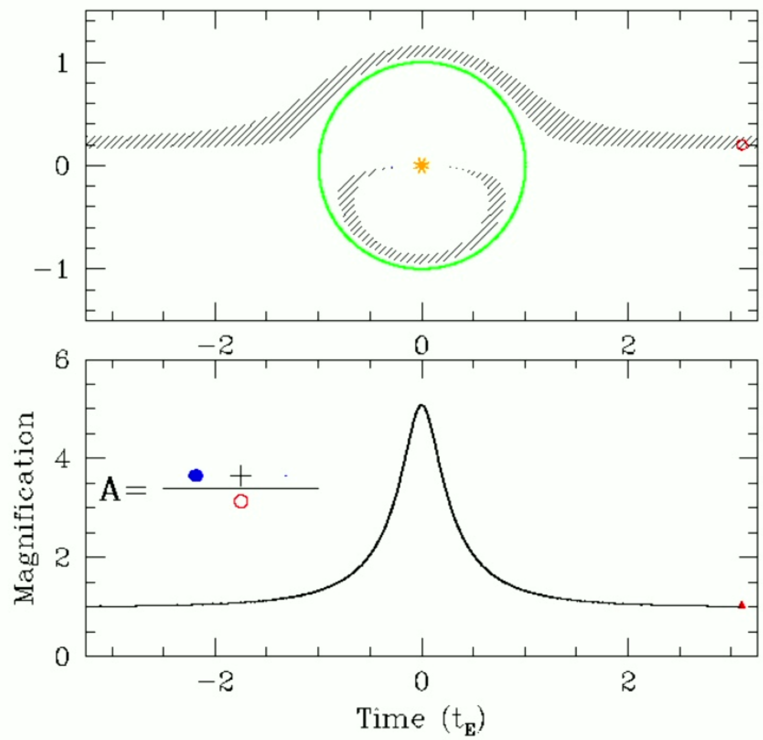

Intensity Interferometry
HBT
EPIC


Intensity Interferometry
HBT
EPIC
few mas
Fourier


Intensity Interferometry
HBT
EPIC
~ few mas
τc ~ fs
σt ~ 10ps
tres ~ tenths ns
Fourier (I(l,m))


EPIC
~ few mas
~ 10μas
~ mas
~ 100m
SNR
Fourier

Stellar Microlensing



$$\theta_E = \sqrt{\frac{4GM_L}{D_L}\frac{D_{LS}}{D_S}} \sim 3\,\mathrm{mas}\sqrt{\frac{M_L}{M_\odot}\frac{\mathrm{kpc}}{D_L}}$$

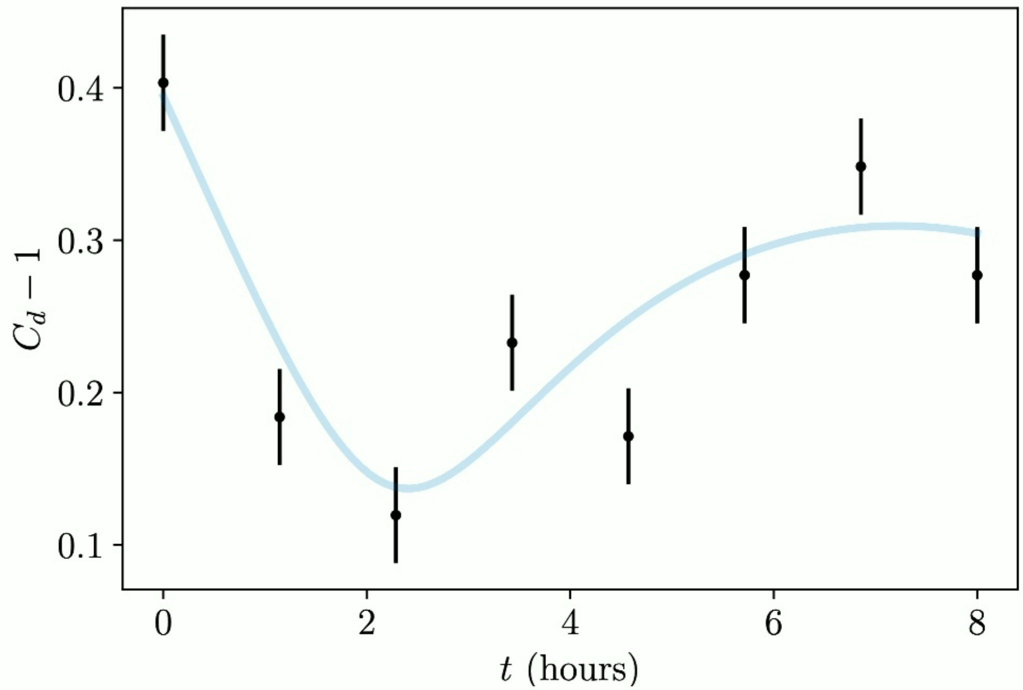
Stellar Microlensing

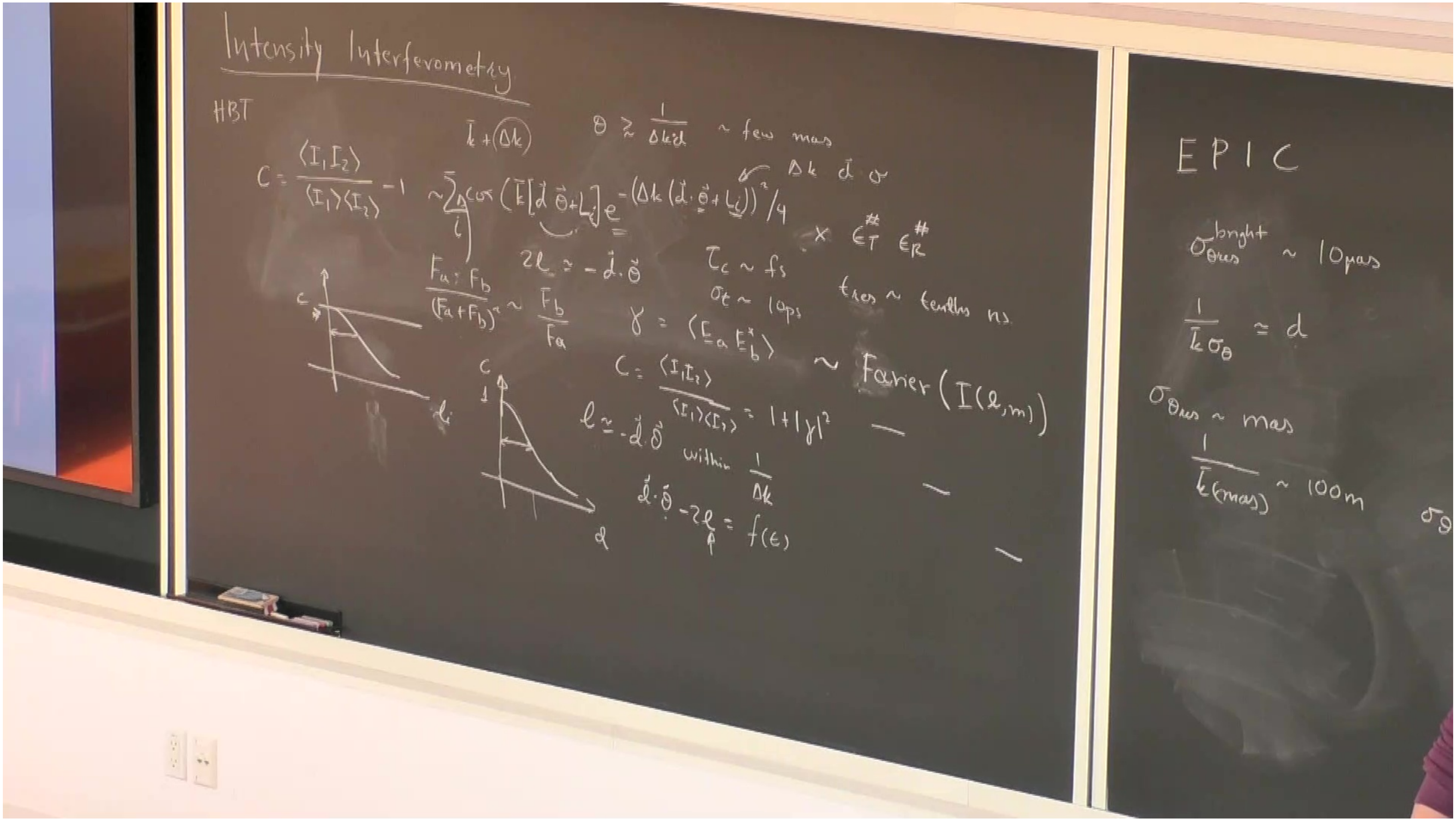
$$\boldsymbol{\theta}_{\mathrm{SL}} = \begin{pmatrix} \Delta\alpha^{\mathrm{unl}} \\ \Delta\delta^{\mathrm{unl}} \end{pmatrix} \left[\sqrt{0.5 + \frac{4\pi G M_{\mathrm{L}} \, |\Delta\varpi| / c^2}{(\Delta\alpha^{\mathrm{unl}} \, \cos\delta)^2 + (\Delta\delta^{\mathrm{unl}})^2}} \right]$$

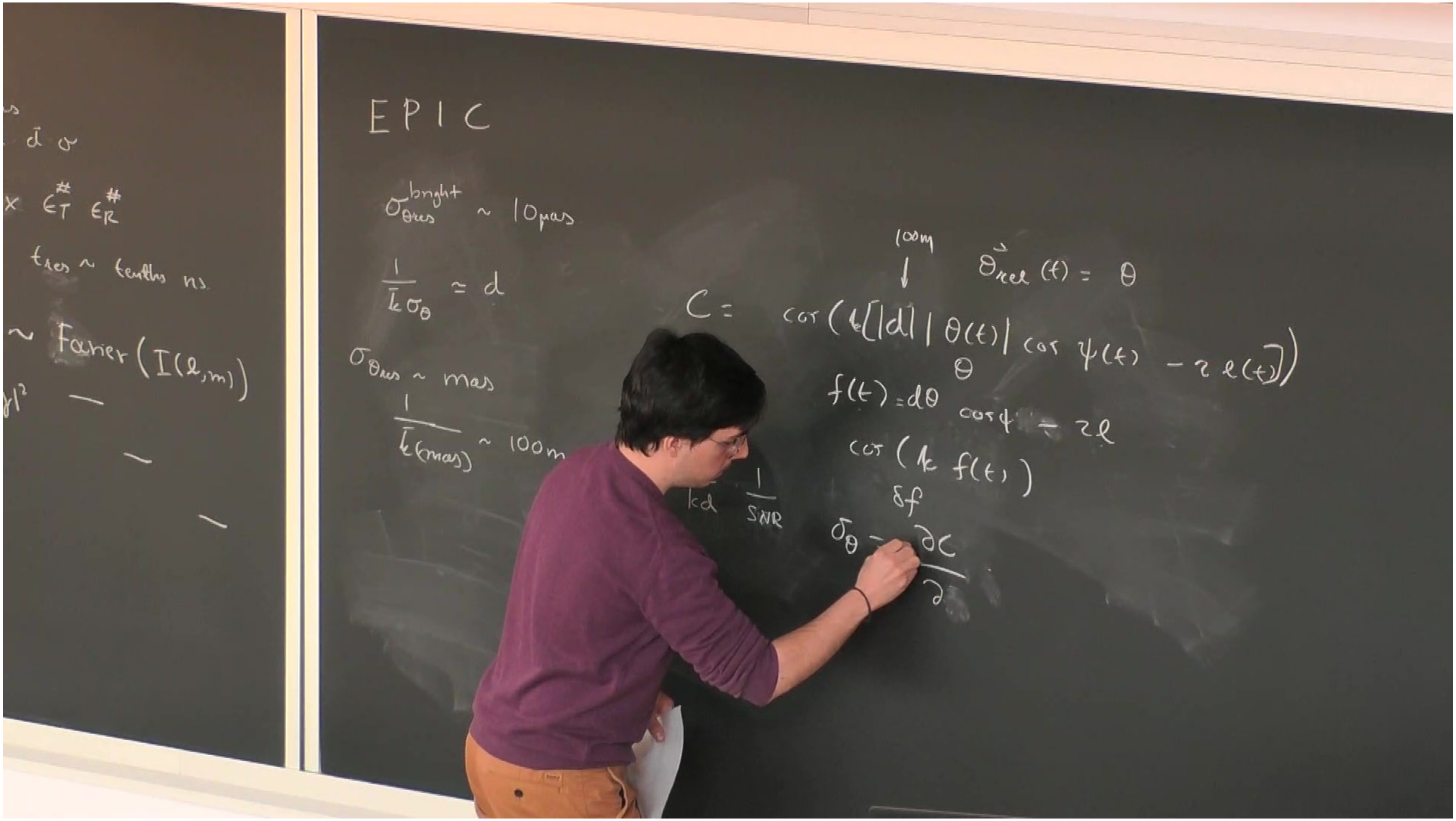
Quantity	Catalogue [84]	$d = 100$ m	$d = 800$ m
$\Delta\alpha_0$	46.7 mas	-	-
$\Delta\delta_0$	-46.5 mas	-	-
$\Delta\mu_{\alpha*,\mathrm{L}}$	108.04 mas/yr	-	-
$\Delta\mu_{\delta,\mathrm{L}}$	-118.78 mas/yr	-	-
$\Delta\varpi$	11.4 mas	-	-
M_{L}	1.3 $M_\odot$	-	-
$\sigma_{\Delta\alpha}$	0.7 mas	0.08 mas	0.013 mas
$\sigma_{\Delta\delta}$	0.57 mas	0.03 mas	0.009 mas
$\sigma_{\Delta\mu}$	$\lesssim$ 10 mas/yr	-	-
$\sigma_{\Delta\varpi}$	$\lesssim$ 1.6 mas	-	-
$\sigma_{\theta_{\mathrm{res}}}$	620 μas	54 μas	11 μas

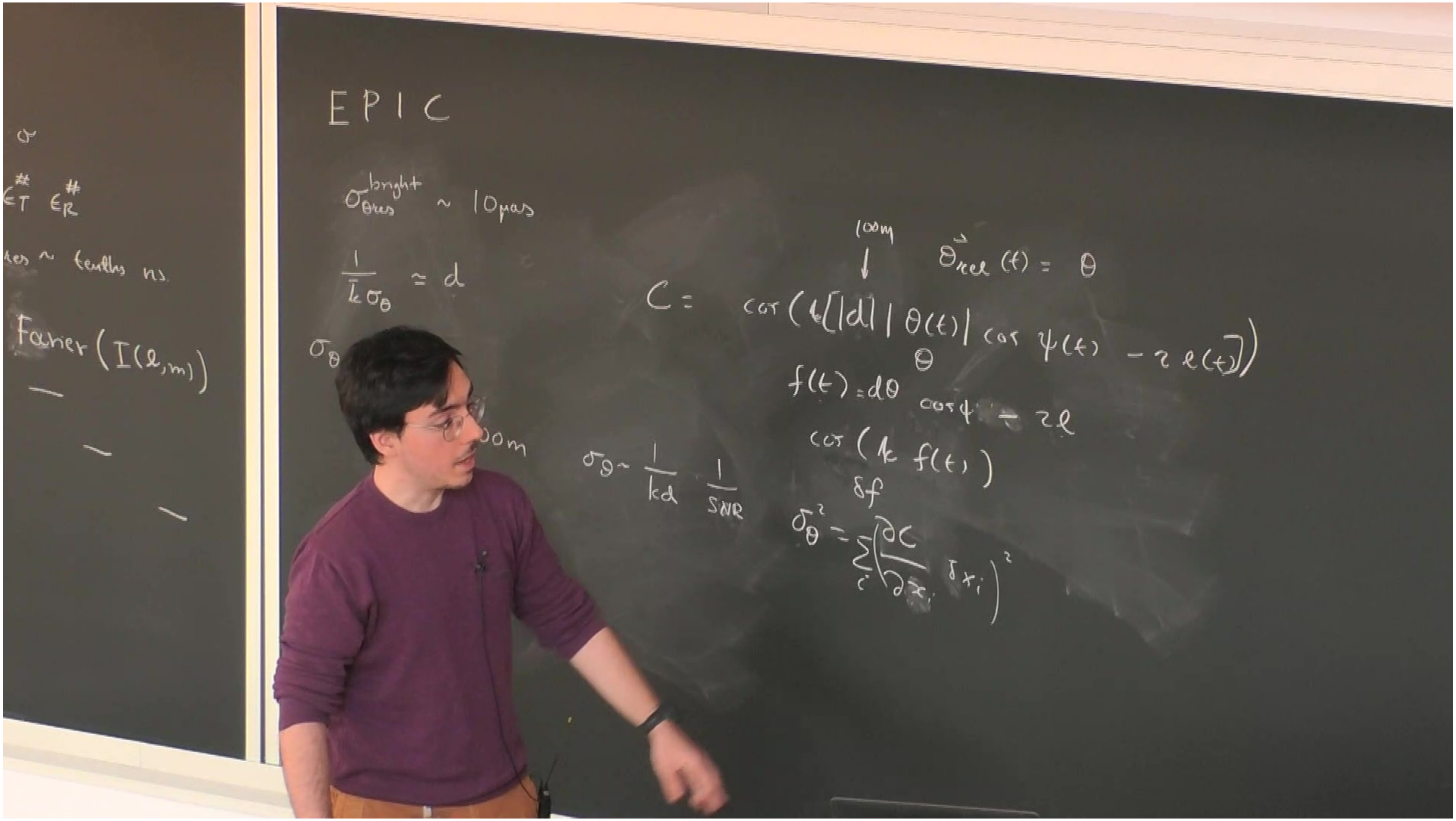
Stellar Microlensing

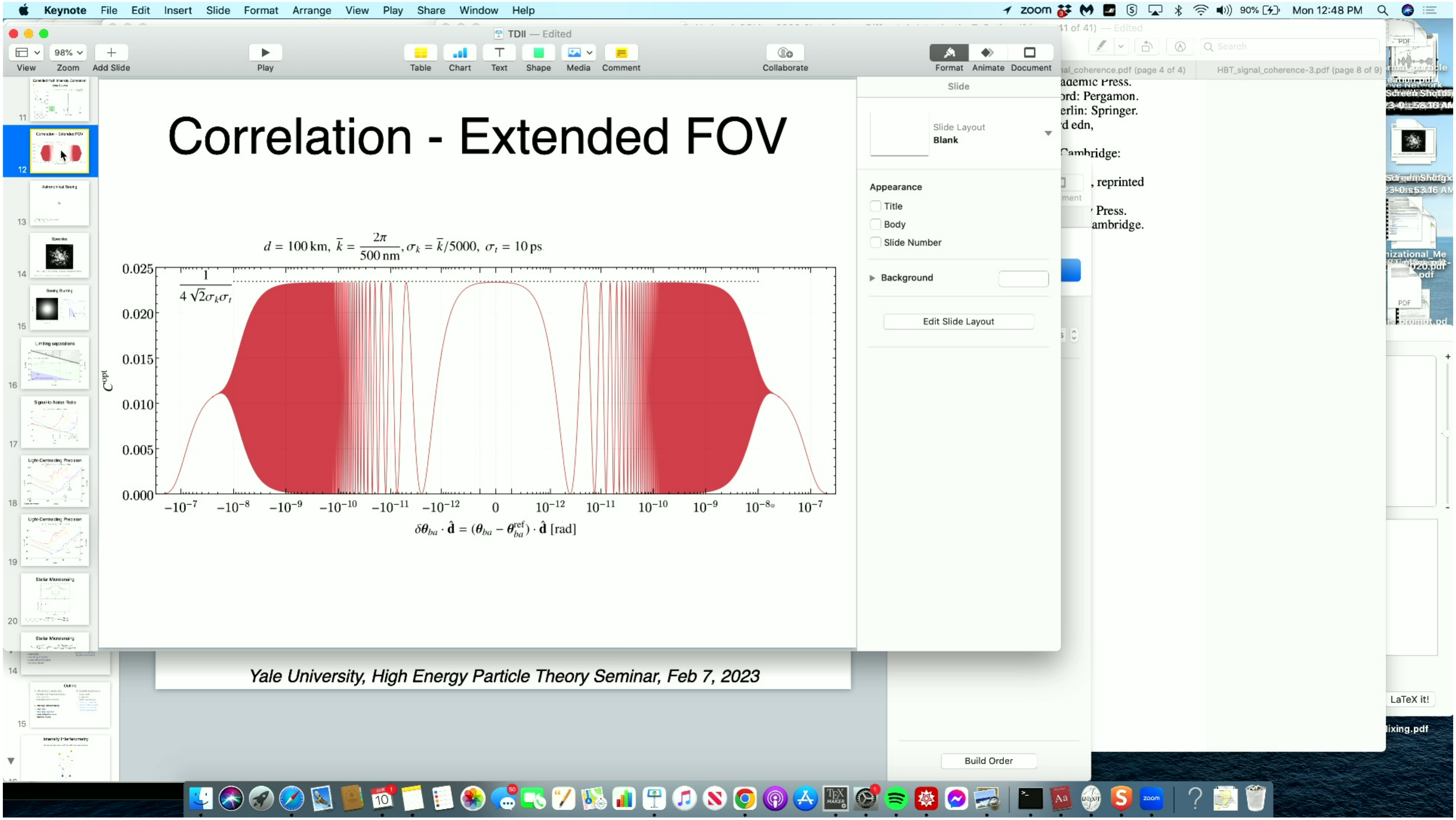
$$\boldsymbol{\theta}_{\rm SL} = \begin{pmatrix} \Delta\alpha^{\rm unl} \\ \Delta\delta^{\rm unl} \end{pmatrix} \left[\sqrt{0.5 + \frac{4\pi G M_{\rm L} \, |\Delta\varpi| / c^2}{(\Delta\alpha^{\rm unl} \, \cos\delta)^2 + (\Delta\delta^{\rm unl})^2}} \right]$$




Intensity Interferometry
HBT
EPIC
~ few mas
Δk d σ
τc ~ fs
σt ~ 10ps
tres ~ tenths ns
Fourier (I(l,m))
within
~ 10μas
~ mas
~ 100m


EPIC
~ 10μas
tenths ns
Fourier
mas
~ 100m
100m
C =
SNR


EPIC
tenths ns
Farier (I(l,m))
100m
C =
f(t) = dθ
δf
kd
SNR


Keynote File Edit Insert Slide Format Arrange View Play Share Window Help
TDII — Edited
Correlation - Extended FOV
$d = 100\,\mathrm{km},\ \bar{k} = \frac{2\pi}{500\,\mathrm{nm}}, \sigma_k = \bar{k}/5000,\ \sigma_t = 10\,\mathrm{ps}$
$\frac{1}{4\sqrt{2}\sigma_k\sigma_t}$
C^{opt}
$\delta\theta_{ba} \cdot \hat{\mathbf{d}} = (\theta_{ba} - \theta_{ba}^{\mathrm{ref}}) \cdot \hat{\mathbf{d}}$ [rad]
Slide Layout
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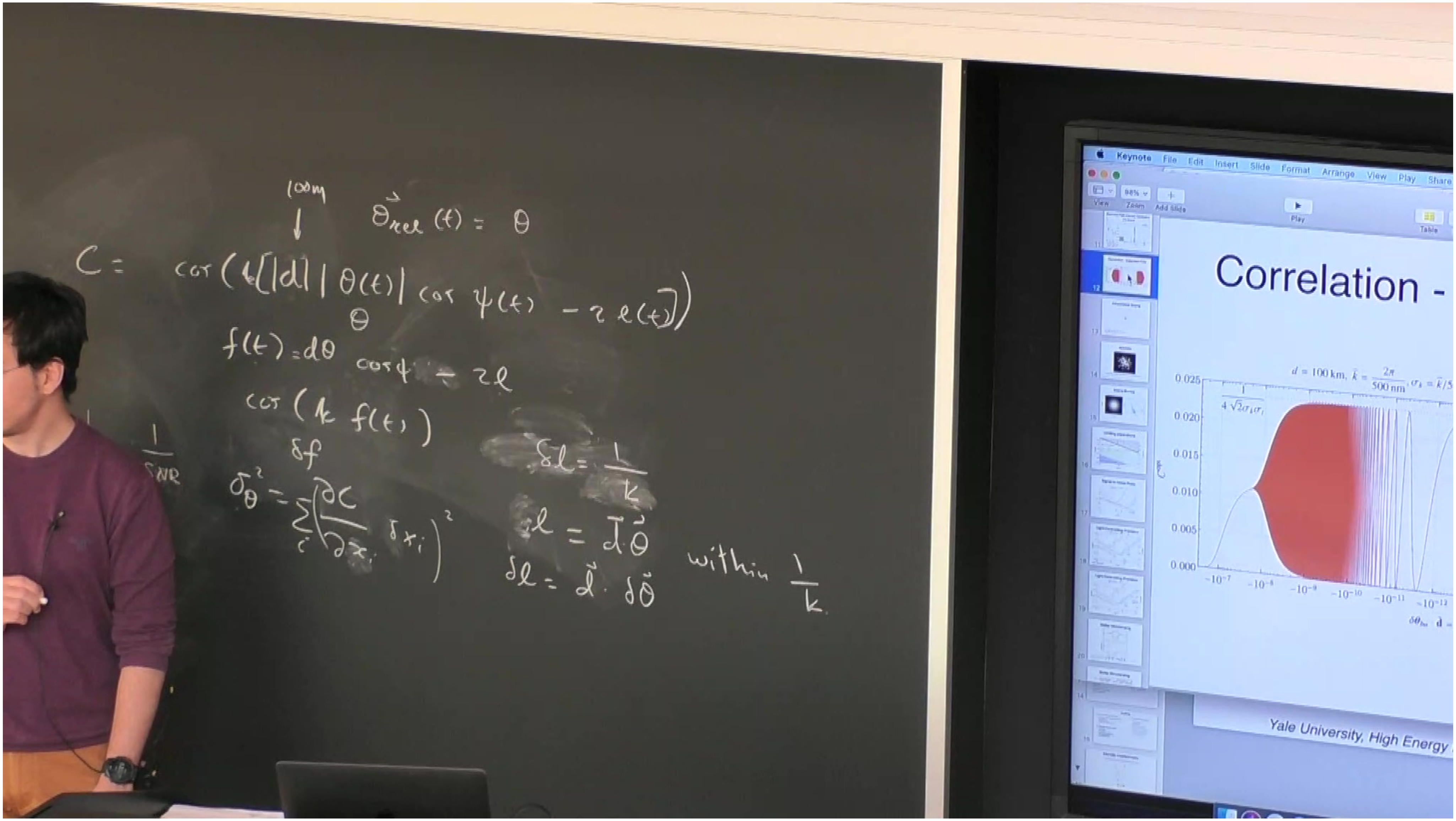
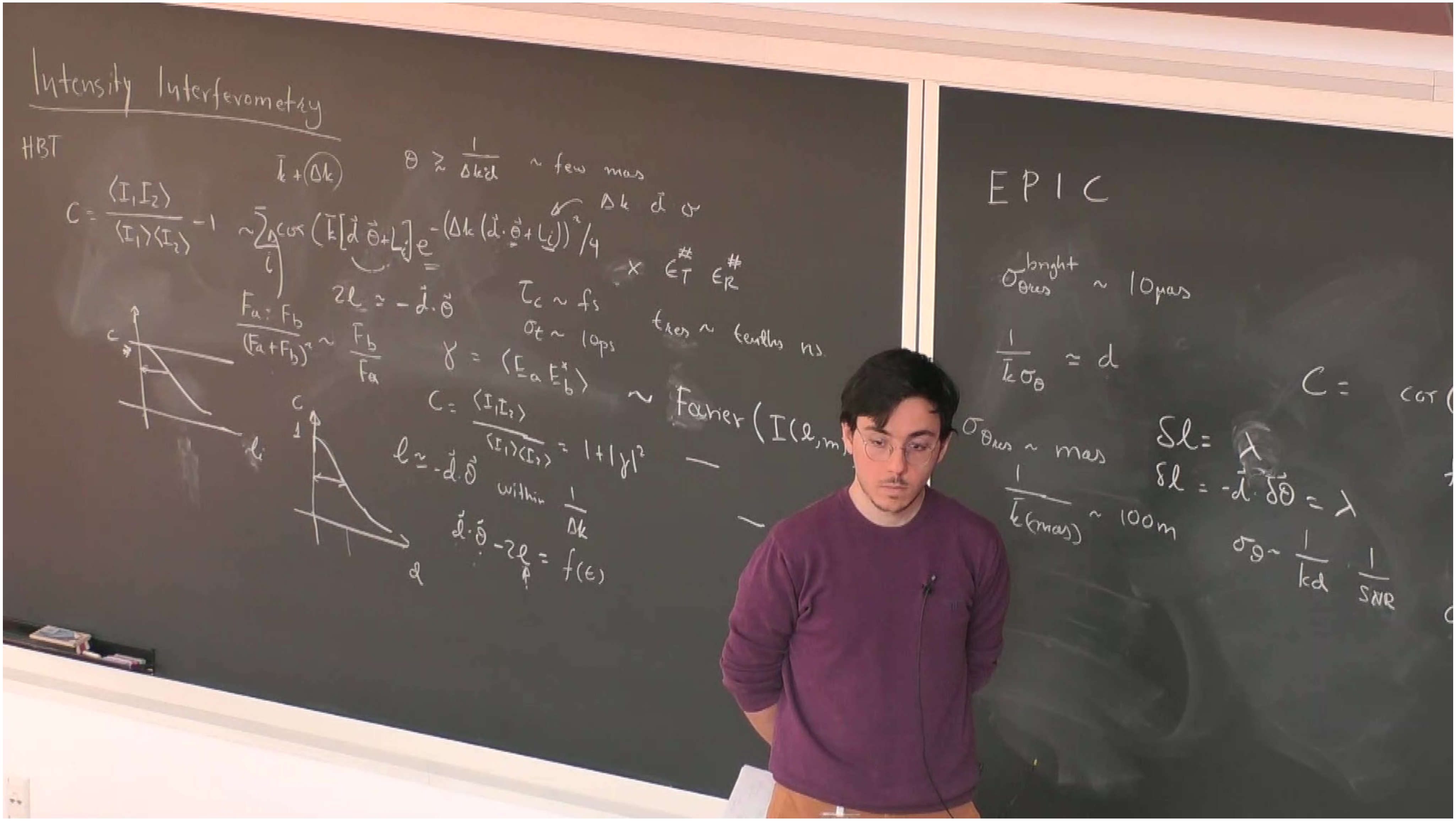
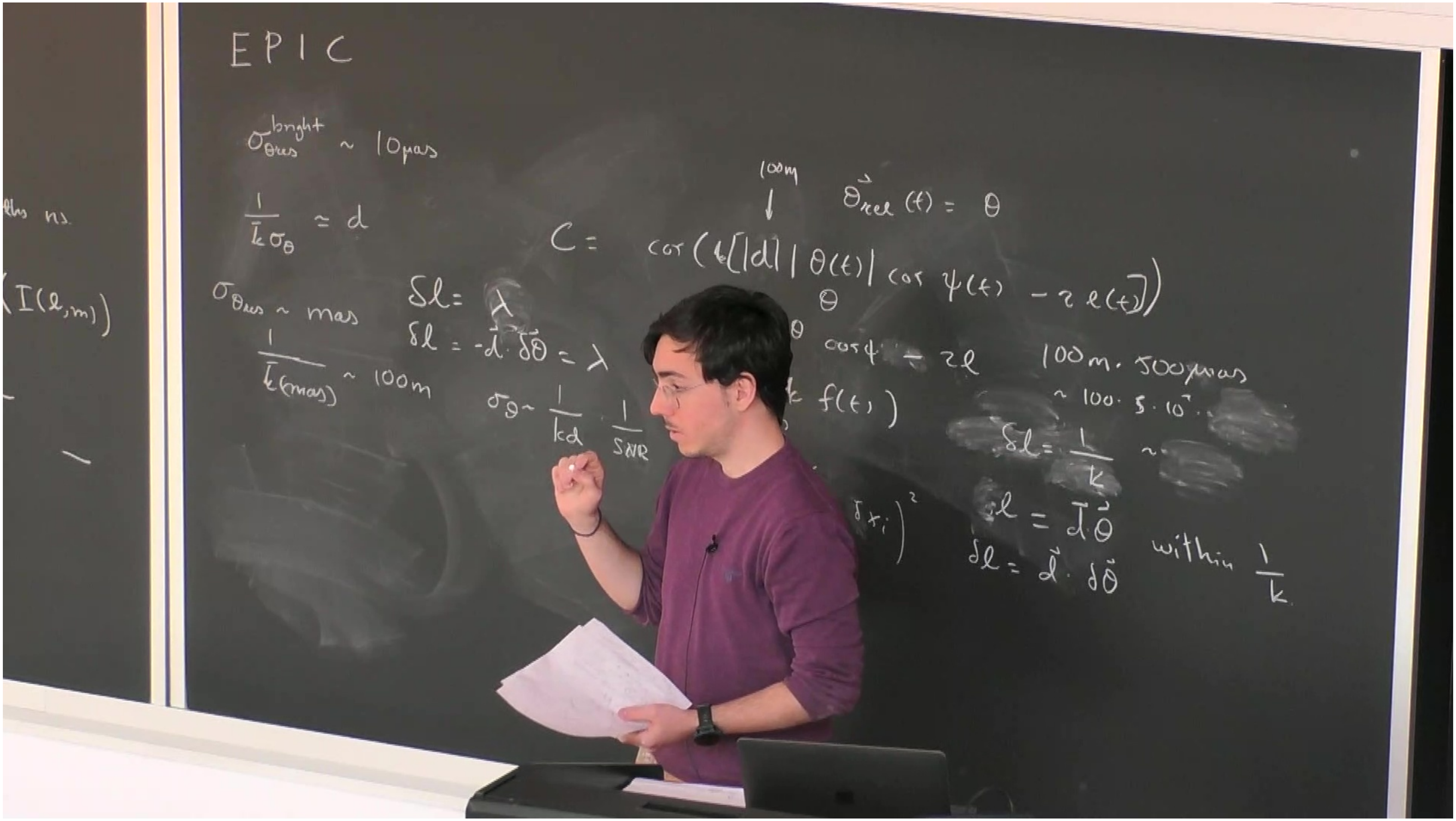
Build Order
Yale University, High Energy Particle Theory Seminar, Feb 7, 2023

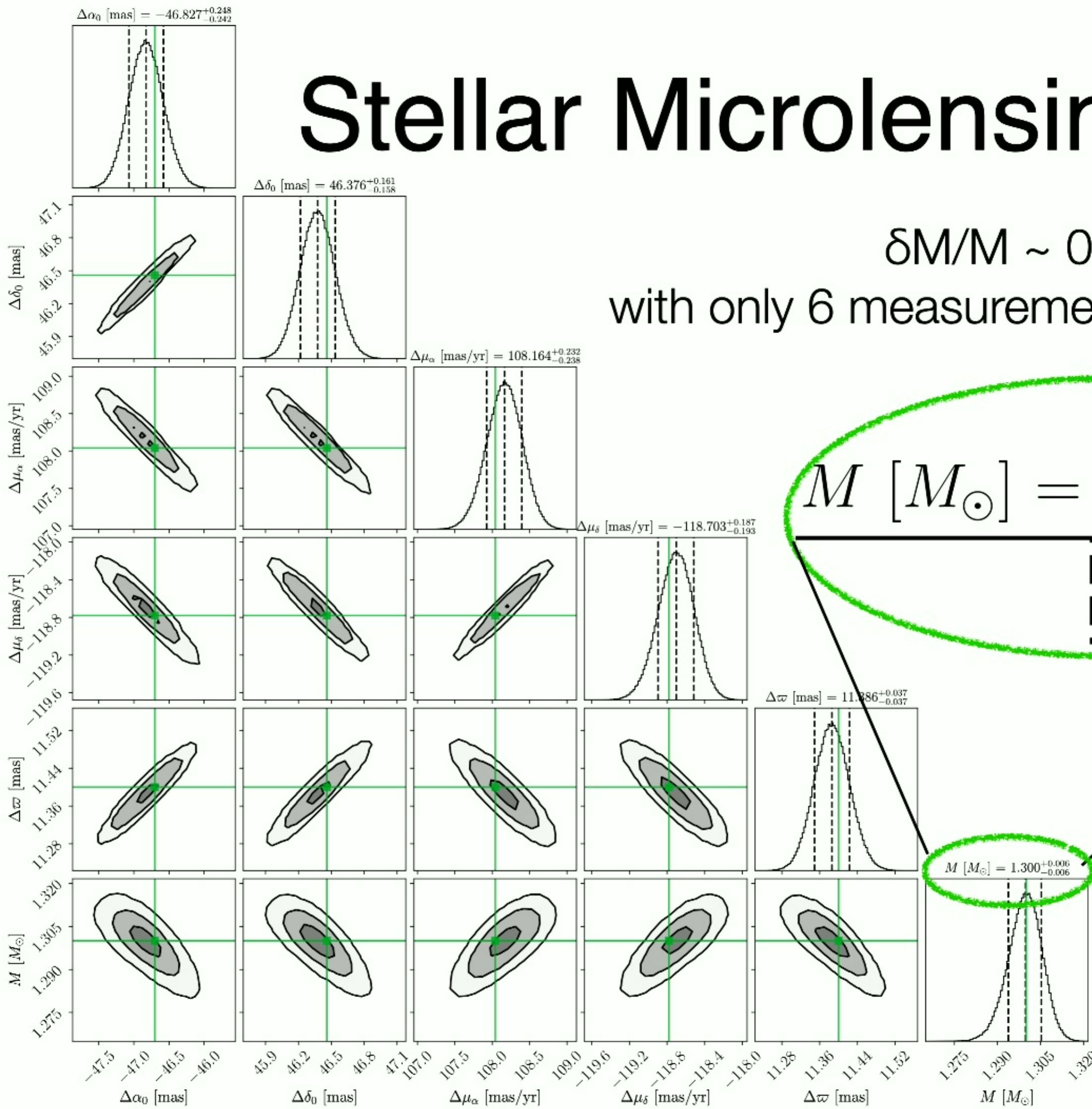

Keynote File Edit Insert Slide Format Arrange View Play Share
Correlation -
Yale University, High Energy
within 1/k

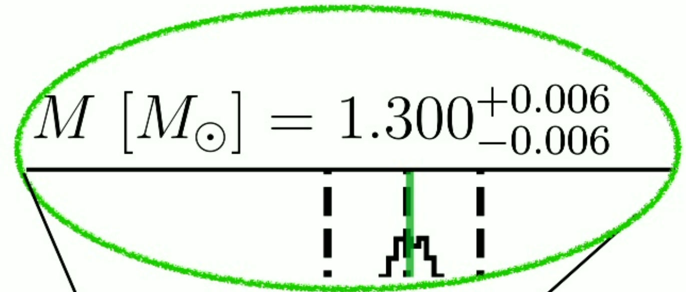

Intensity Interferometry
HBT
EPIC


EPIC
$\sigma_{\theta_{res}}^{bright} \sim 10\mu as$
$\frac{1}{k\sigma_\theta} \simeq d$
$\sigma_{\theta_{res}} \sim mas$
$\frac{1}{k(mas)} \sim 100m$
$\delta l = \lambda$
$\delta l = -\vec{d}\cdot\delta\vec{\theta} = \lambda$
$\sigma_\theta \sim \frac{1}{kd}\cdot\frac{1}{SNR}$
100m
$\vec{\theta}_{rel}(t) = \theta$
100m · 500μas
$\delta l = \vec{d}\cdot\delta\vec{\theta}$ within $\frac{1}{k}$

Stellar Microlensing

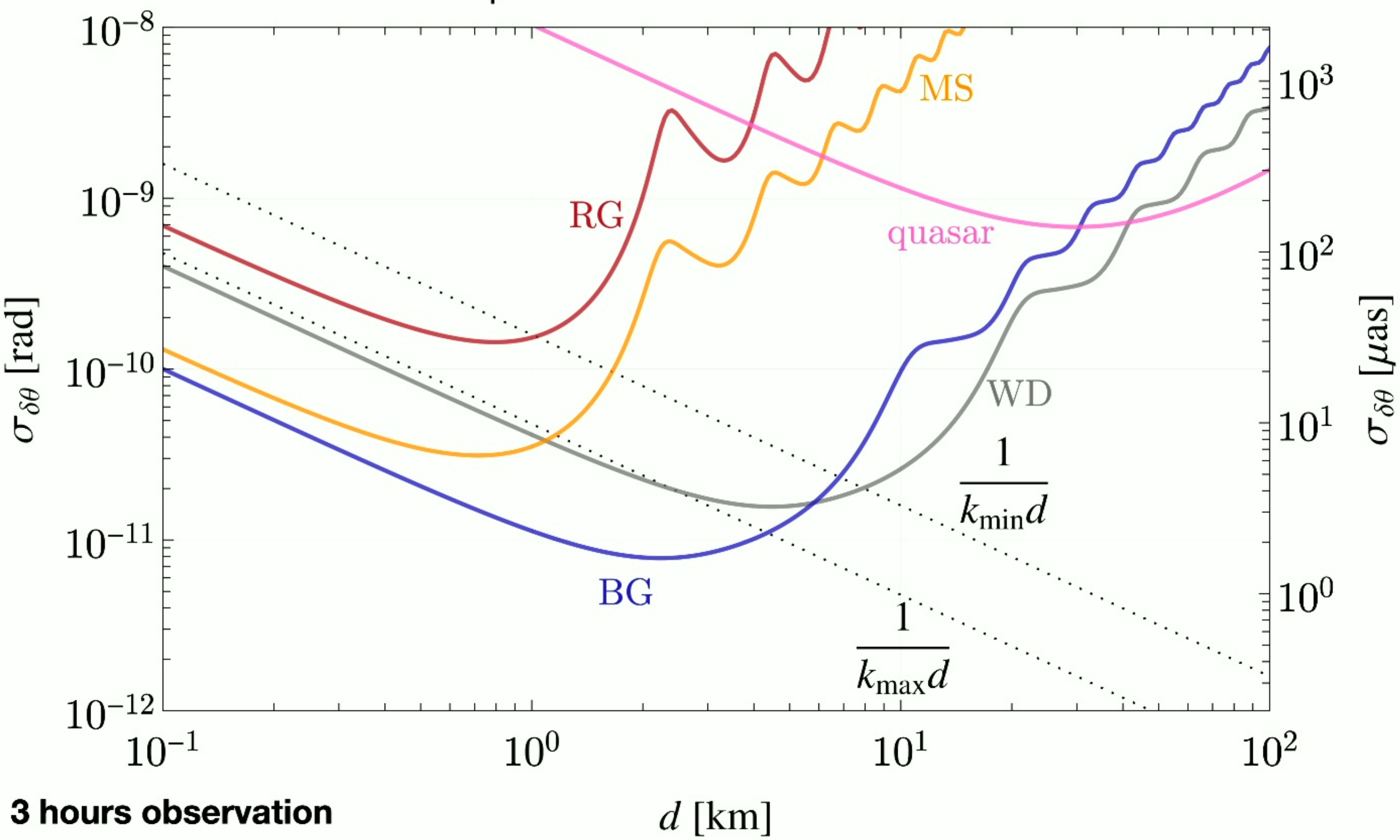
δM/M ~ 0.4%
with only 6 measurements at δθ~10μas!



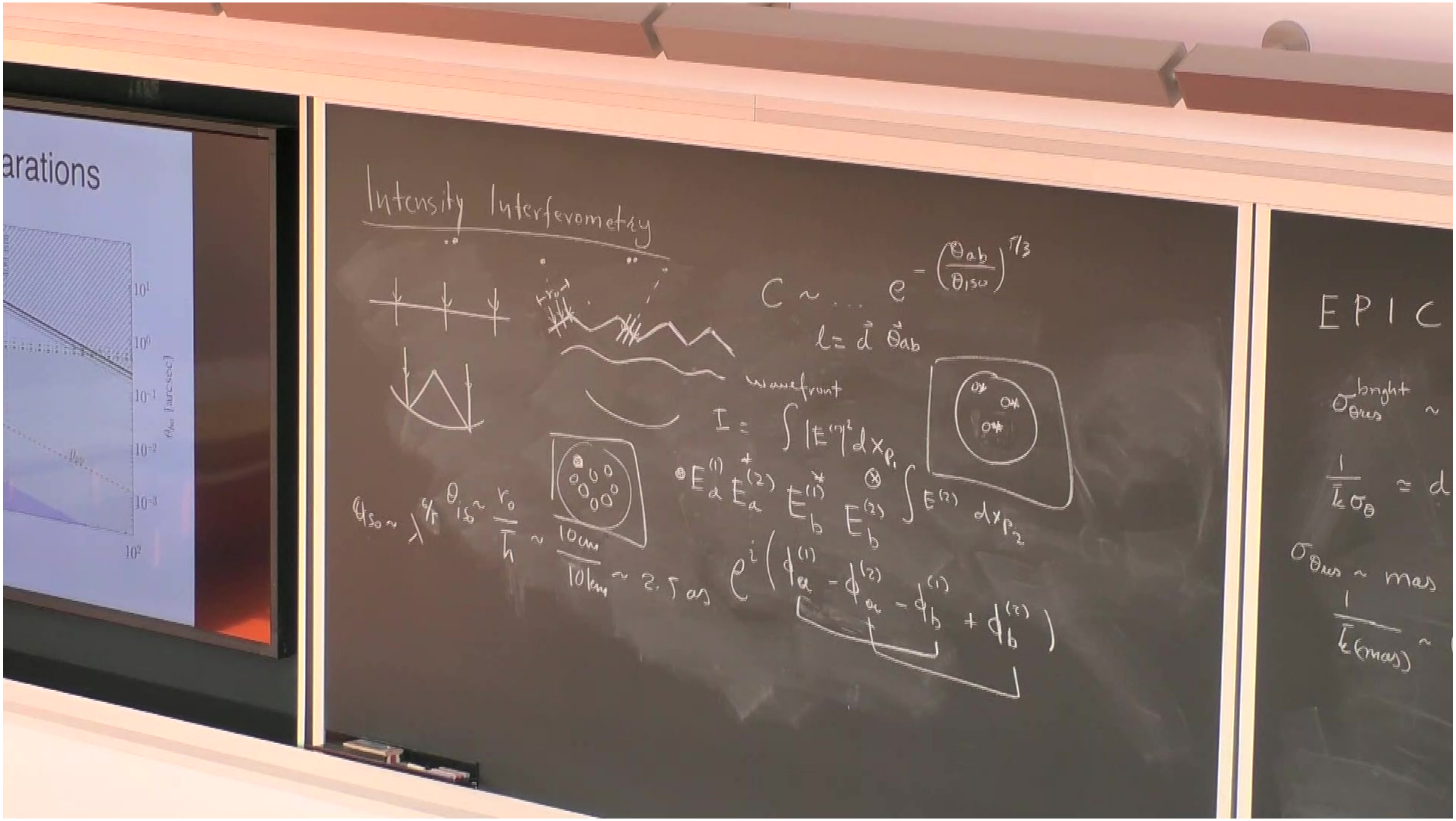


Light-Centroiding Precision

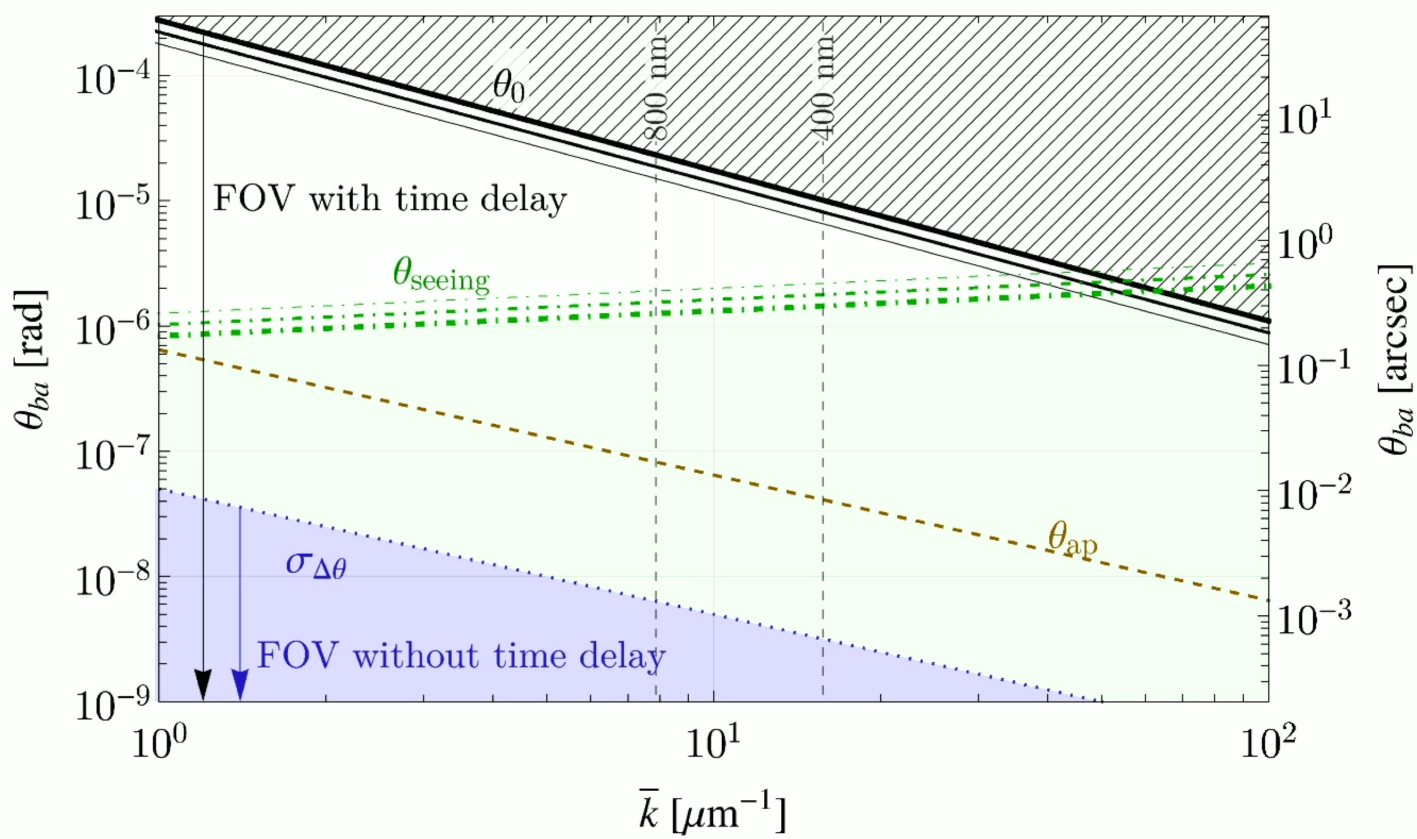
$A = \frac{\pi}{4}(4\,\mathrm{m})^2, \bar{k}/\sigma_k = 5000, \sigma_t = 10\,\mathrm{ps}$



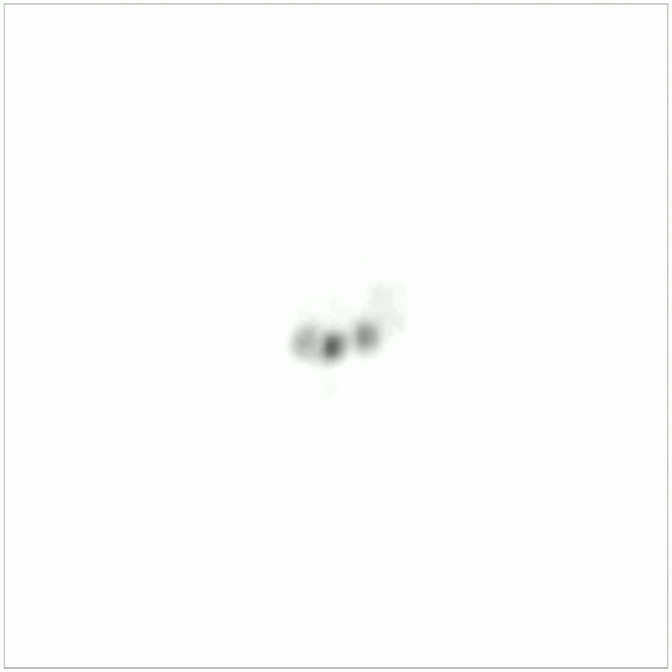
3 hours observation


arations
Intensity Interferometry
wavefront
EPIC
mas

Limiting separations



Astronomical Seeing



$r_0 \lesssim 30\,\mathrm{cm} \Rightarrow \sigma_{\theta_{\mathrm{res}}} \gtrsim 0.4\,\mathrm{arcsec}$

Seeing Blurring