Development of a DAQ system for detection of Planck scale uncertainty

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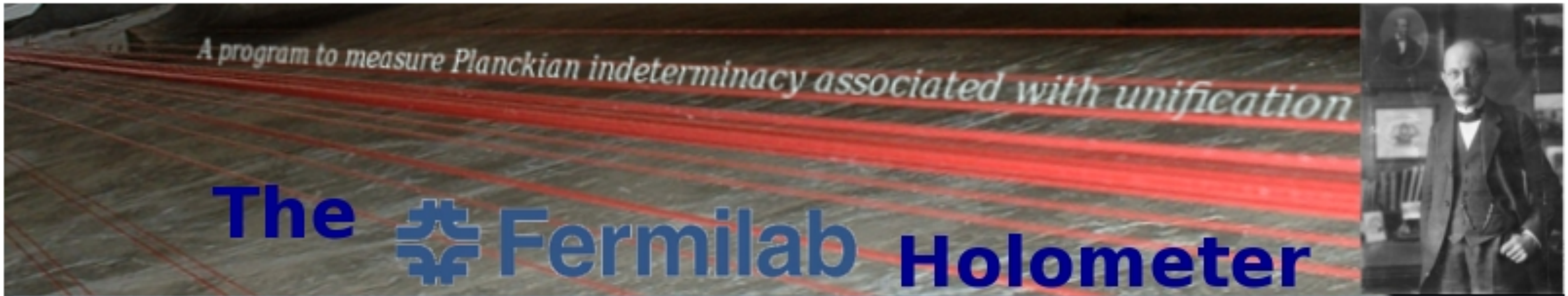

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Planck scale physics

- The Planck scale $M_{pl} \sim 10^{19}$ GeV is far out of the reach of any conceivable particle collider experiment.

- However, this dimensionful gravitational coupling immediately suggests quantization of space-time:

$$t_P \equiv l_P/c \equiv \sqrt{\hbar G_N/c^5} = 5 \times 10^{-44} \quad \text{seconds}$$

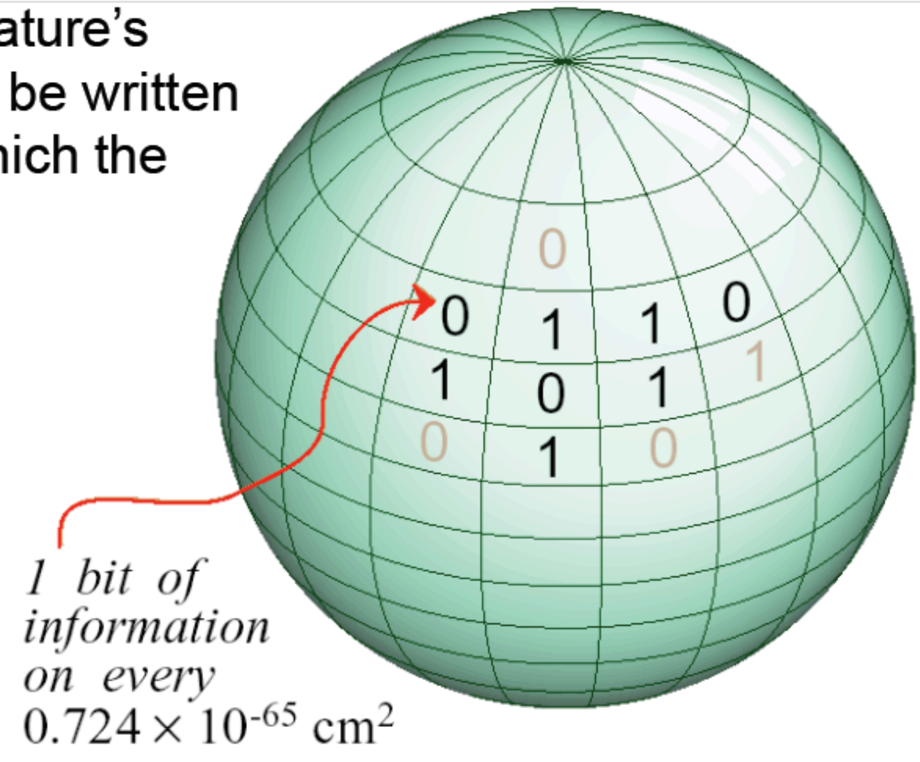
$$l_P = \sqrt{\hbar G_N/c^3} = 1.616 \times 10^{-33} \text{cm}$$

  – Effects arising from this quantization may be observable using the sensitive position measurement techniques developed for the detection of gravity waves.
  – New position measurement experiments could become the first probes of “unified” theories of fundamental physics such as **string theory** or **matrix theory**, in which space-time and mass-energy are both emergent phenomena.

Bold idea from black hole physics: the world is a hologram

"This is what we found out about Nature's book keeping system: the data can be written onto a surface, and the pen with which the data are written has a finite size."

-Gerard 't Hooft

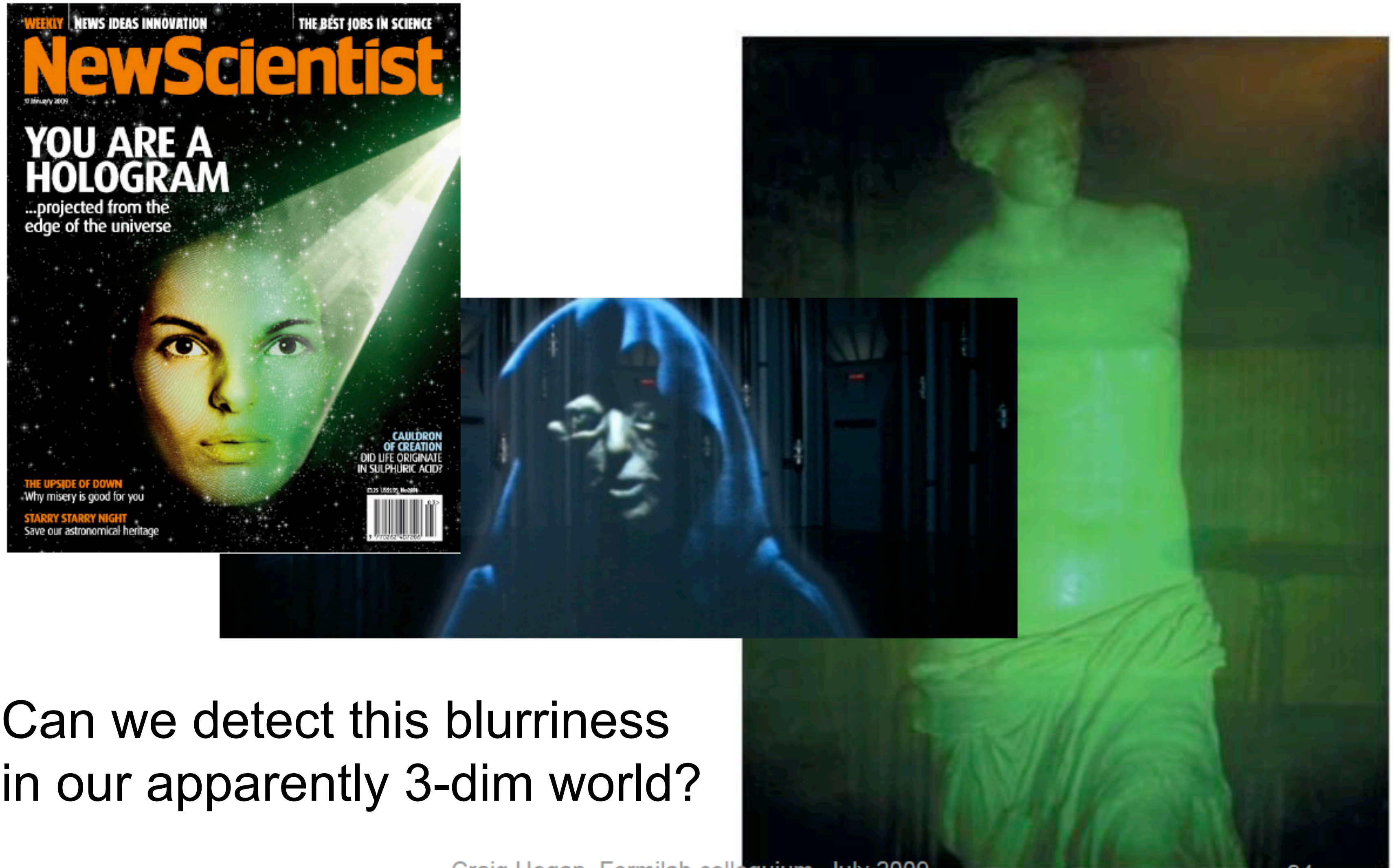


Everything is written on 2D surfaces moving at the speed of light

R. Bousso

Are there experimental consequences of this idea?

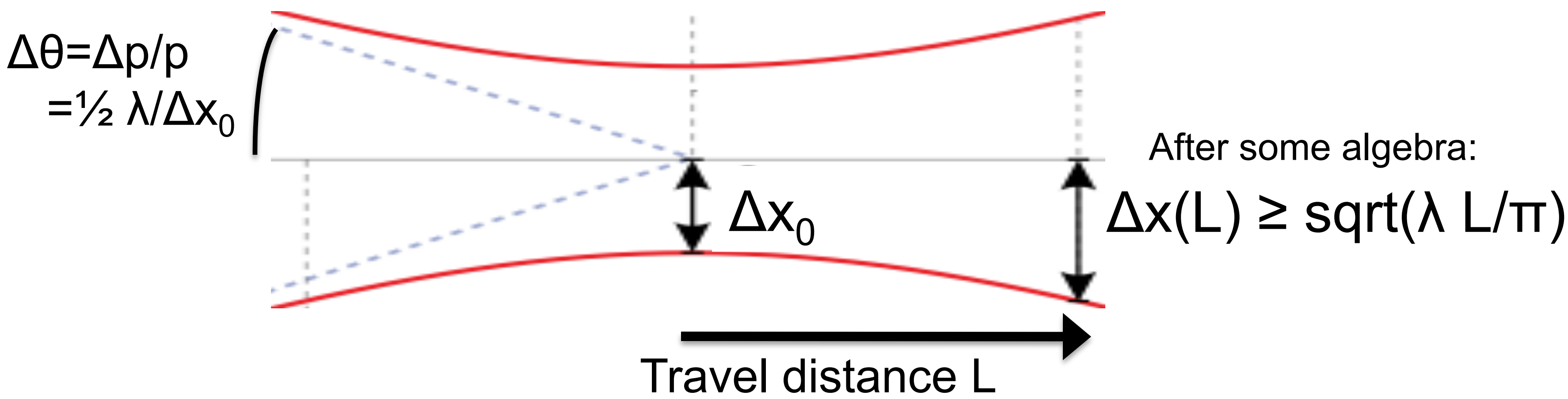
A holographic world is blurred by diffraction



Can we detect this blurriness in our apparently 3-dim world?

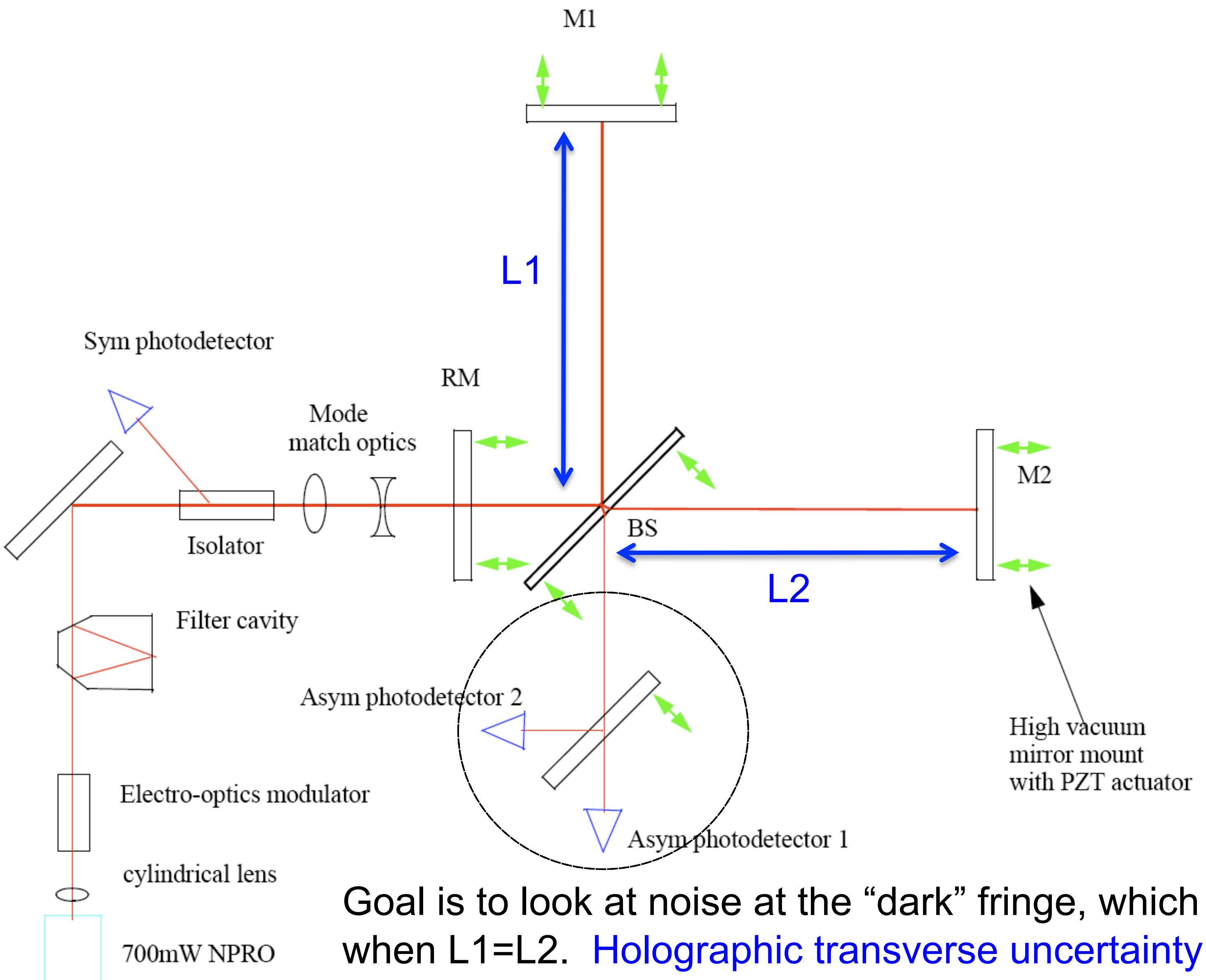
Covariant formulation: Information is holographically encoded on 2-dim light-fronts

- The transverse position resolution on a light-front is at best the Planck length $\lambda_{pl} = 1/M_{pl}$, *independently of the encoding scheme*
- Just as in an optical cavity, localizing Δx of the wave will induce an uncertainty Δp which causes Δx to grow as the wave propagates



- Since the shortest wavelength is λ_{pl}, the smallest possible transverse uncertainty is at distance L is: $\Delta x(L) \geq \mathrm{sqrt}(\lambda_{pl} L/\pi)$
- **The tiny, Planck-suppressed uncertainty can be magnified by a large propagation distance L to become detectable!**

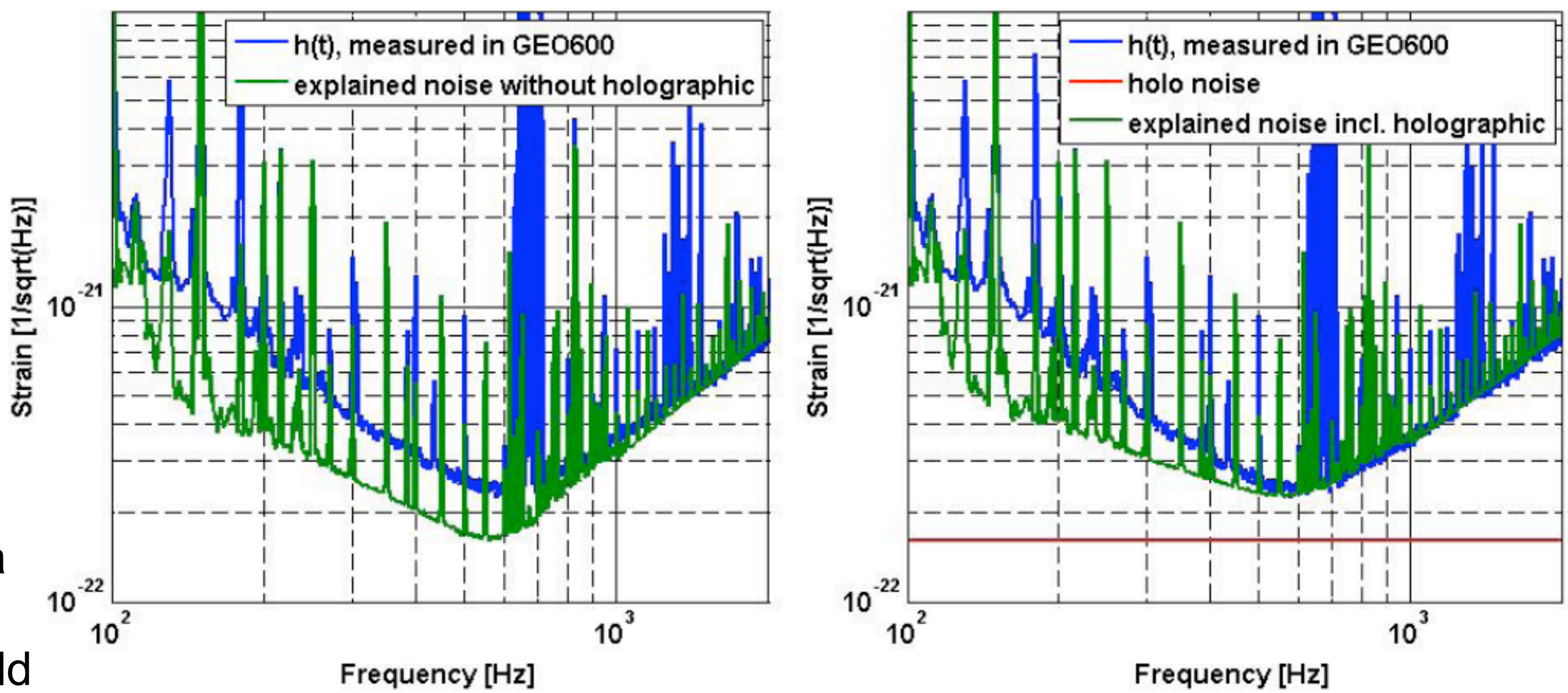
Transverse blur causes phase noise in interferometers



Goal is to look at noise at the "dark" fringe, which is dark when L1=L2. Holographic transverse uncertainty causes relative jitter in L1, L2 and hence noise at the dark port.

The GEO600 mystery noise can be explained by this minimum transverse uncertainty

Data from S.Hild



- Predicted transverse position noise power spectral density (cm^2/Hz):

$$(\Delta x)^2 = \lambda_P L\,, \quad \Delta f = 1/\Delta t = c/2L \;\rightarrow\; \Phi(f) = (\Delta x)^2/\Delta f = 4t_P L^2/\pi$$

- Strain noise in GEO:

$$\boxed{h(f) = \frac{1}{2}\sqrt{\Phi/L^2} = \sqrt{t_p/\pi} = 1.3 \times 10^{-22}/\sqrt{\mathrm{Hz}}}$$

This is a **zero-parameter** model prediction which can explains the noise!

Our Strategy: Look for correlated noise in two neighboring Michelson interferometers

The noise is a property of the underlying space-time, not the photon beam.

Therefore the noise seen in nearby devices should be identical!

Form the cross-correlation spectrum between noise in the dark fringe detectors for each interferometer

- The correlated noise signal grows **linearly** with time
- Uncorrelated noise product does a random walk and grows as **sqrt(time)**

$$(\phi_1 X \phi_2)_N = \frac{(\delta\phi_n)^2}{\sqrt{\frac{t_{obs}}{\tau_{sample}}}} + (\delta\phi_{Hogan})^2$$

- Shot noise, thermal noise, phase noise are all uncorrelated between the two devices.

Noise Calculation

The variance of the phase in an interferometer due to photon shot noise is

$$
\begin{aligned}
(\delta\phi_n)^2 &= \frac{1}{n} = \frac{1}{\dot{n}\tau_s} \\
&= \frac{hc^2}{2P_{\mathrm{BS}}L\lambda_{\mathrm{opt}}}
\end{aligned}
$$

Where n is the number of photons

P_{BS} is the power on the beam splitter

λ_{opt} is the wavelength of the laser light

Integration time

The integration time is

$$
\begin{aligned}
t_{\text{obs}} &> \tau_s \left(\frac{(\delta\phi_n)^2}{(\delta\phi_{\text{H}})^2} \right)^2 \\
&> \left(\frac{h}{P_{\text{BS}}} \right)^2 \left(\frac{\lambda_{\text{opt}}}{\lambda_p} \right)^2 \left(\frac{c^3}{32\pi^4 L^3} \right)
\end{aligned}
$$

We propose an interferometer with 40m arms, 1000 W and a wavelength of 1.06μ.

The sample time is

$$\tau_s = 2L/c = 270\,\mathrm{ns}$$

or about 4 MHz bandwidth.

The integration to S/N=1 is 3.5 minutes and 1/2 hour to reach 3 σ.

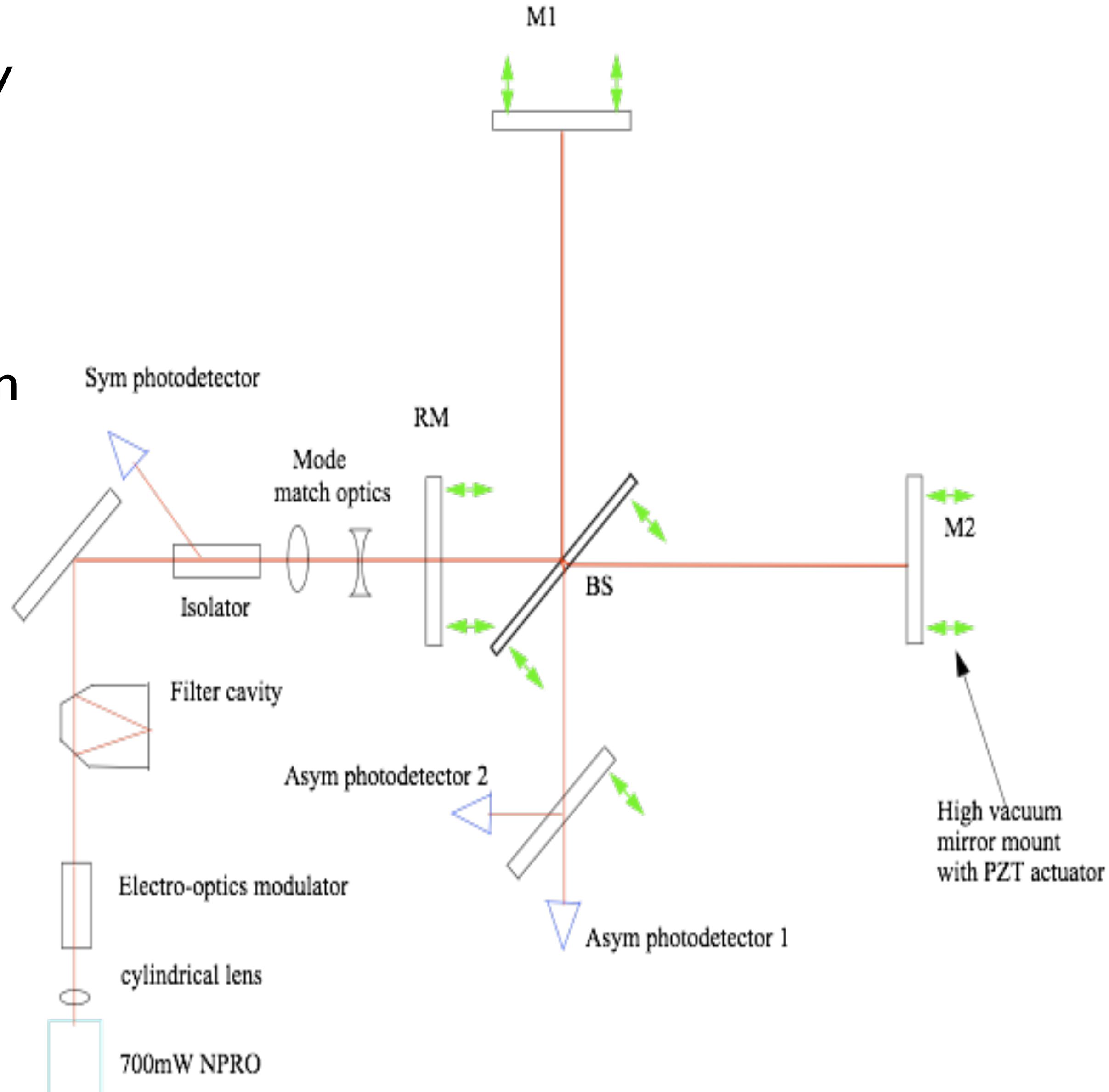
We plan typical 10 hour runs and will reach 12 σ for each run.

What is needed?

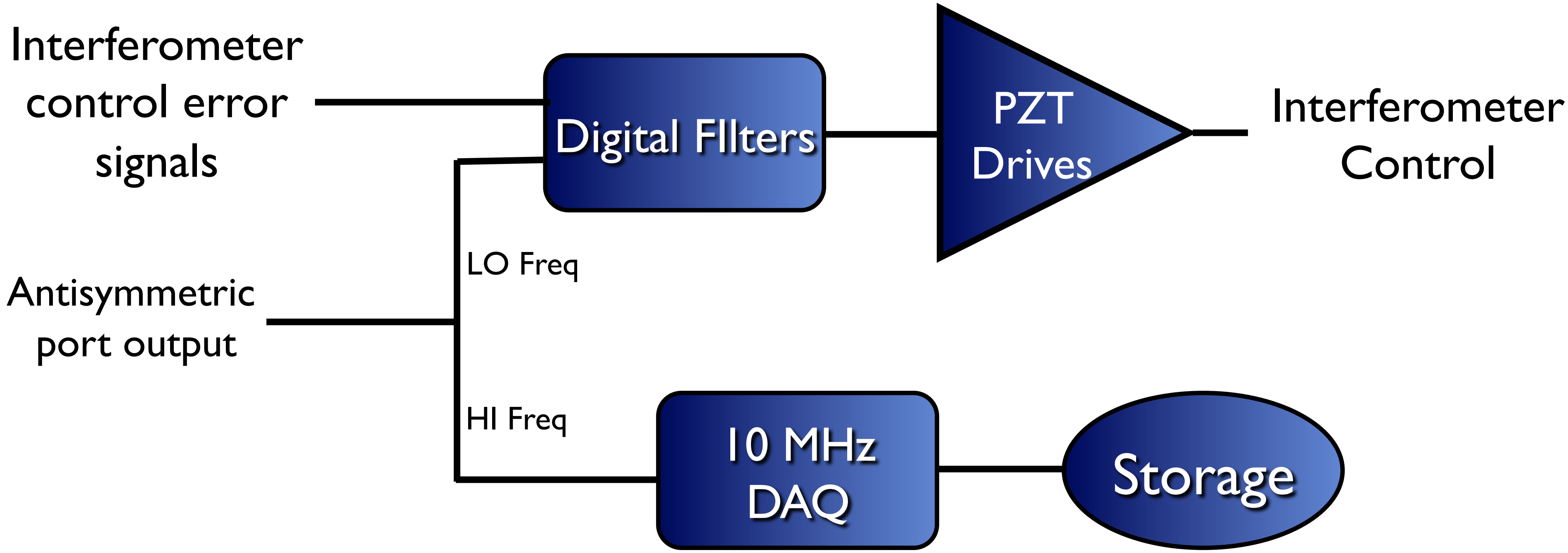
Inject 2 W laser into cavity with finesse of 500 to get 1000 W in cavity.

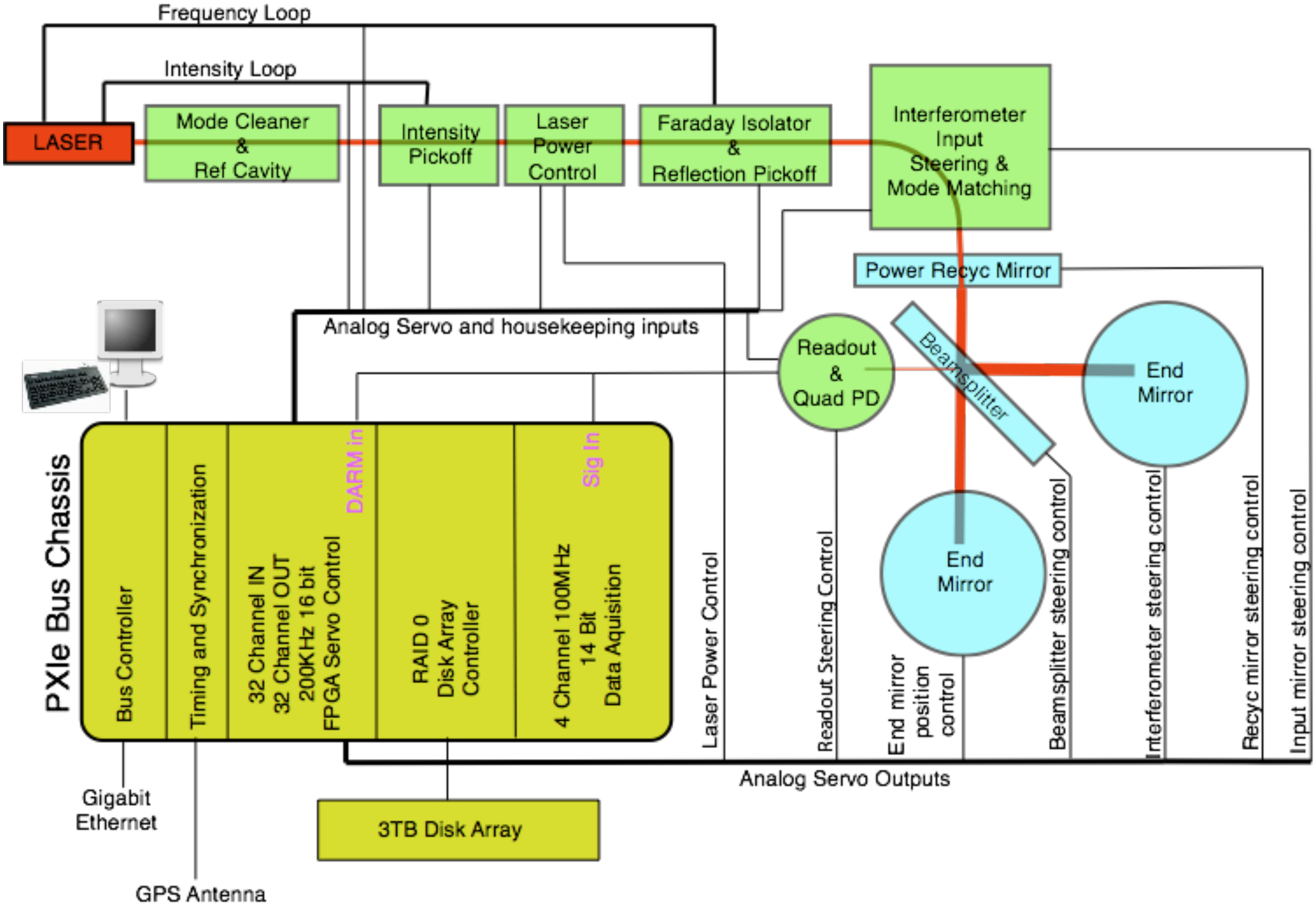
Hold the interferometer steady to small fraction of a fringe.

Record light coming from antisymmetric port at high frequencies.



Control and Data Acquisition




Frequency Loop
Intensity Loop
LASER
Mode Cleaner & Ref Cavity
Intensity Pickoff
Laser Power Control
Faraday Isolator & Reflection Pickoff
Interferometer Input Steering & Mode Matching
Power Recyc Mirror
Beamsplitter
Readout & Quad PD
End Mirror
End Mirror
Analog Servo and housekeeping inputs
PXIe Bus Chassis
Bus Controller
Timing and Synchronization
32 Channel IN
32 Channel OUT
200KHz 16 bit
FPGA Servo Control
DARM in
RAID 0
Disk Array
Controller
4 Channel 100MHz
14 Bit
Data Aquisition
Sig In
Laser Power Control
Readout Steering Control
End mirror position control
Beamsplitter steering control
Interferometer steering control
Recyc mirror steering control
Input mirror steering control
Analog Servo Outputs
Gigabit Ethernet
GPS Antenna
3TB Disk Array