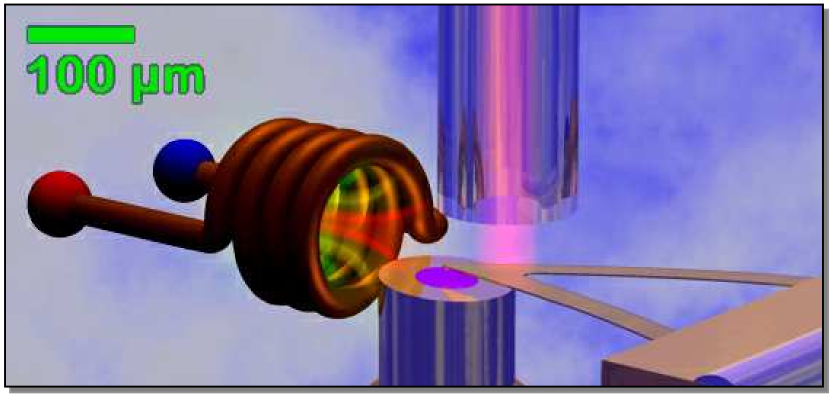
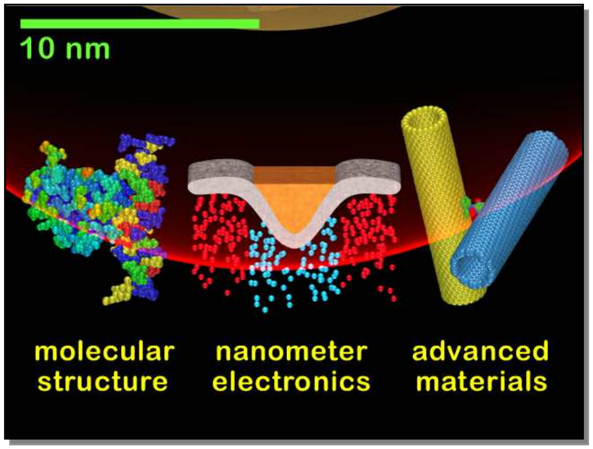
University of Washington
Quantum System Engineering Group

- People:
  - Joseph L. Garbini: *mechatronics & control*
  - John P. Jacky: *software engineering*
  - Doug Mounce: *program operations*
  - John A. Sidles: *QM and "utility player"*
  - Students: *Dorothy Caplow, Kristi Gibbs, Tom Kriewal, Tony Norman, Mark Peeples*



- Core funding and affiliations:
  - NIH/BRSTP: (R01-RR08820-09)
  - NSF/ENG: MRE #0097544
  - DARPA/IBM: subcontract
  - Center for AIDS Research (CFAR)



UW LSC Membership Application
At: LIGO Livingston Laboratory
Date: March 18, 2004
Presenter: John Sidles
URL: http://courses.washington.edu/goodall/MRFM

LIGO-G040161-00-Z

The draft LSC MOU

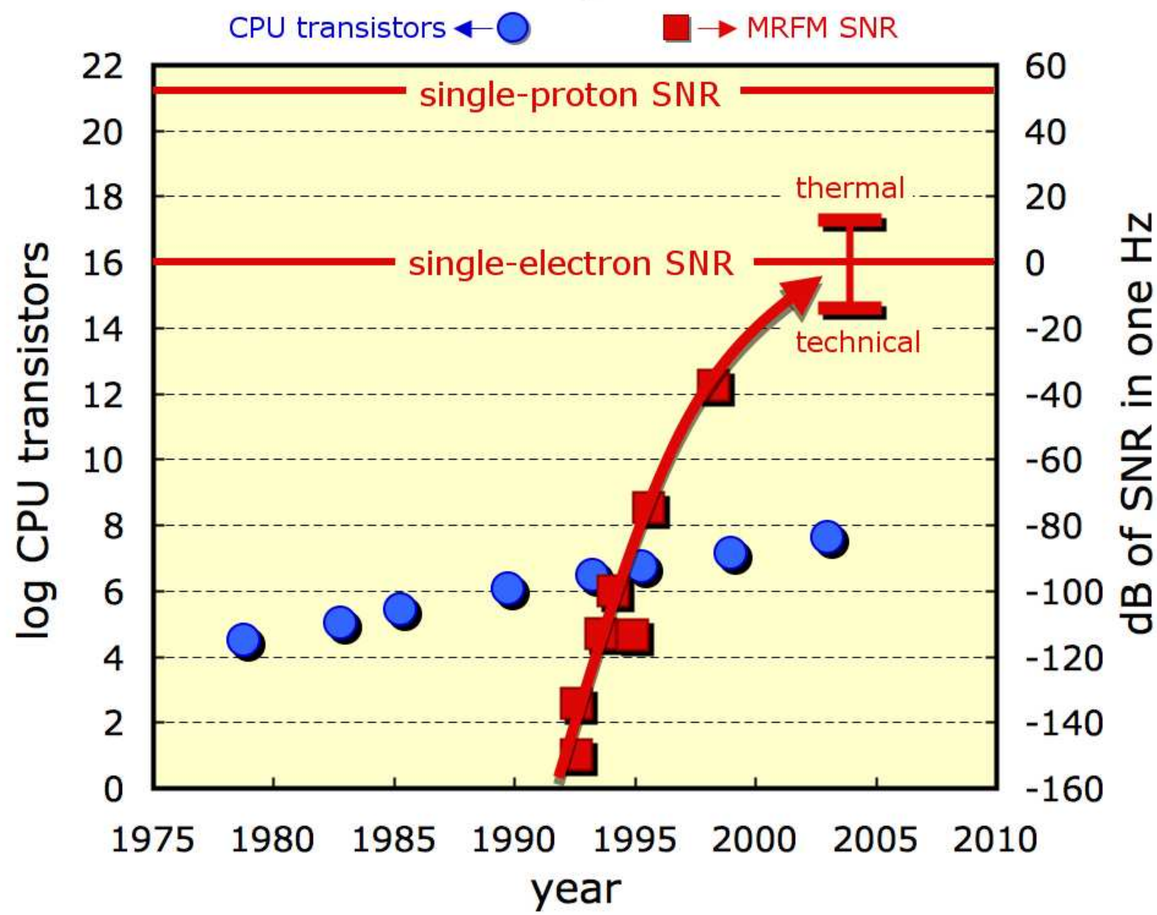
1) Finalize for publication in Physics Letter A the work described in LIGO Document P030055-B-D, "Optical Torques in Suspended Fabry-Perot Interferometers", by J. A. Sidles and D. Sigg.

2) Continue work on the efficient quantum simulation techniques described in quant-ph/0401165, "Positive P-Representations of the Thermal Operator from Quantum Control Theory", by J. A. Sidles.

3) Work to establish the formal equivalence (or alternatively, the inequivalence) of the above formalisms to operator-based and field-theoretic quantum descriptions of test mass observation.

4) Identify quantum measurement phenomena in single-spin observation by magnetic resonance force microscopy (MRFM) that are relevant to beating the standard quantum limit in future GW interferometers.

Moore’s Law Progress in MRFM



Moore’s Law design rules

$$S_\mu = \frac{m}{g^2\tau}\,2k_\mathrm{B}T \quad \begin{cases} m & \text{cantilever mass} \\ T & \text{temperature} \\ g & \text{magnetic gradient} \\ \tau & \text{damping time} \end{cases}$$

- *smaller*
- *colder*
- *sharper*
- *cleaner*

UW Design Rules for Quantum System Engineering

- Heat baths are control loops
- Coherent states are *einselected* (Zurek)
- The SQL is rigorously enforced
- Process noise is the Hilbert Transform of measurement noise
- **IBM** / iOSCAR is semi-classical

Design e2e with confidence:
Quantum microscopy
is going to work.

- Designing for the future
  - 10^3 coords/second ⇐ Nat. Nanotech. Init.
  - Tabletop device ⇐ Oxford Inst.
  - Terabyte database ⇐ PLOS
  - Petaflop animation ⇐ IBM's "Blue Gene"

control bath total noise

$$S^{\text{total}}_{f_{\mathrm{N}} f_{\mathrm{N}}} = \frac{2m\omega_0}{Q}\, \hbar\omega_0 \coth\left(\frac{\hbar\omega_0}{k_{\mathrm{B}} T}\right)$$

einselection rate equation

$$\operatorname{tr} E[\dot{\boldsymbol{\sigma}}] = -\operatorname{tr} E[\boldsymbol{\sigma} \cdot \boldsymbol{\sigma}^{\star}]$$

positive P-representation

$$P_j(\hat{\boldsymbol{t}}) = Q^{-1}_{j+1}(-\hat{\boldsymbol{t}})$$

Standard quantum limit (SQL)

$$S_{f^{\mathrm{N}} f^{\mathrm{N}}}(\omega) S_{q^{\mathrm{N}} q^{\mathrm{N}}}(\omega) = \left(\tfrac{1}{2}\hbar\right)^2$$

Hilbert Correlation (HC)

$$S_{q^{\mathrm{N}} f^{\mathrm{N}}}(\omega) = \tfrac{1}{2} i\hbar \operatorname{sgn} \omega$$

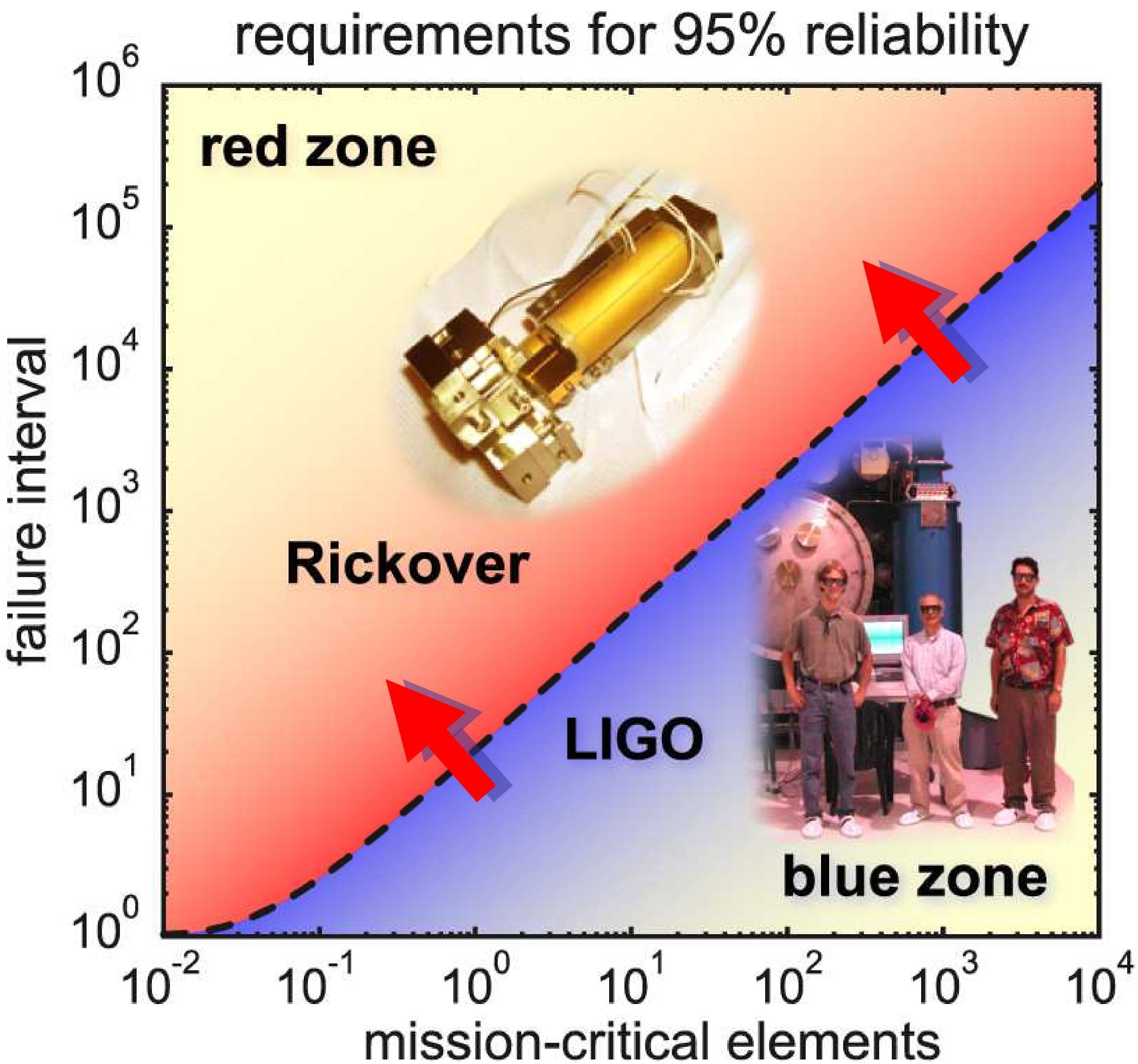
SNR for iOSCAR energy filter

$$\mathrm{SNR} = \frac{32}{\pi^4} \left(\frac{f^2_{\text{spin}}}{S^{\text{total}}_{f_{\mathrm{N}} f_{\mathrm{N}}}}\right)^2 T_{\text{mod}} T_{\text{av}}$$

Positive P-Representations of the Thermal Operator from Quantum Control Theory

arXiv:quant-ph/0401165 v1 27 Jan 2004

Quantum System Engineering: Making It Work



- System Engineering
  - Commitment
  - Cooperation
  - Discipline
  - Engagement
- Quantum System Engineering (QSE)
  - Perfection (!)
- LIGO/LSC role model
  - The NSF's first great QSE project.

Thanks.