

A long, cylindrical cryogenic storage tank is the central focus, stretching from the foreground into the distance. The tank is dark and appears to be made of metal. The background is a vast, flat desert landscape under a dramatic sky. The sun is low on the horizon, creating a bright orange and yellow glow that transitions into a deep blue. The ground is covered in sparse, dry vegetation. In the distance, a small, dark rectangular building and a forklift are visible on the right side.

Facility compatibility with cryogenics: what it means for the CE facility

2nd Cosmic Explorer Symposium,
4/24/2024, Stefan Ballmer



Flexibility is key

- Detectors are **guaranteed to evolve** over their life
 - Example: iLIGO / eLIGO / Advanced LIGO / A+ / A#:
 - Large output mode cleaner
 - Stable recycling cavities
 - Laser enclosures
 - Squeezing vacuum tanks
 - Filter cavity
 - ...
 - **BIG BUILDINGS & LAND** around them
 - But: LIGO arms are **untouched** in $\frac{1}{4}$ century!
- ➔ **Need to build in flexibility** from the start

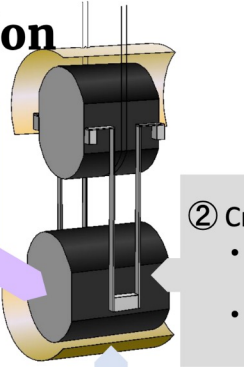


Proposed Cryogenics technologies

Cold Quad Suspension

① Amorphous silicon coating

- Reduces thermal noise. Prospect of $\sim 5\times$ reduction (ASD) from aLIGO level
- Favors $2\ \mu\text{m}$ wavelength



③ Radiative cooling (quiet)

- Efficient at $123\ \text{K}$
- Suspension design not constrained by cryogenics

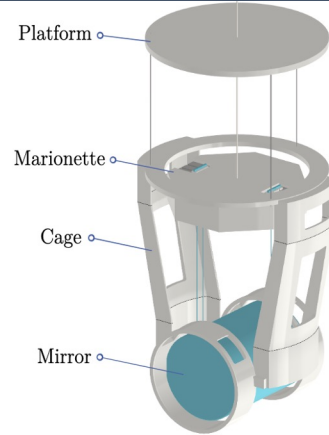
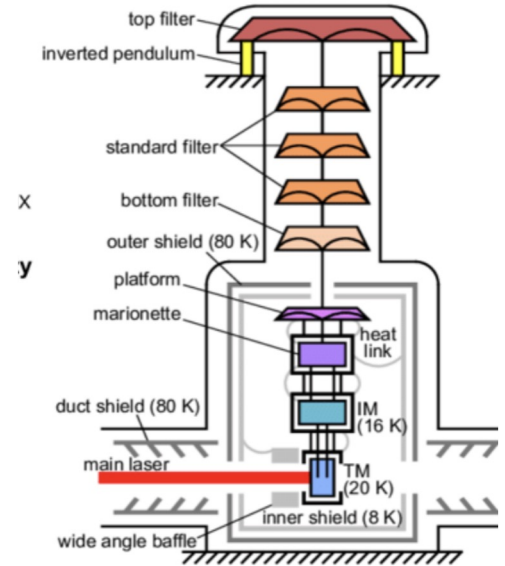


FIG. 2: Baseline design of the ET-LF cryogenic payload based on the AdVirgo double pendulum design.

ET-LF
Silicon @ $10\ \text{K}$, 1550nm



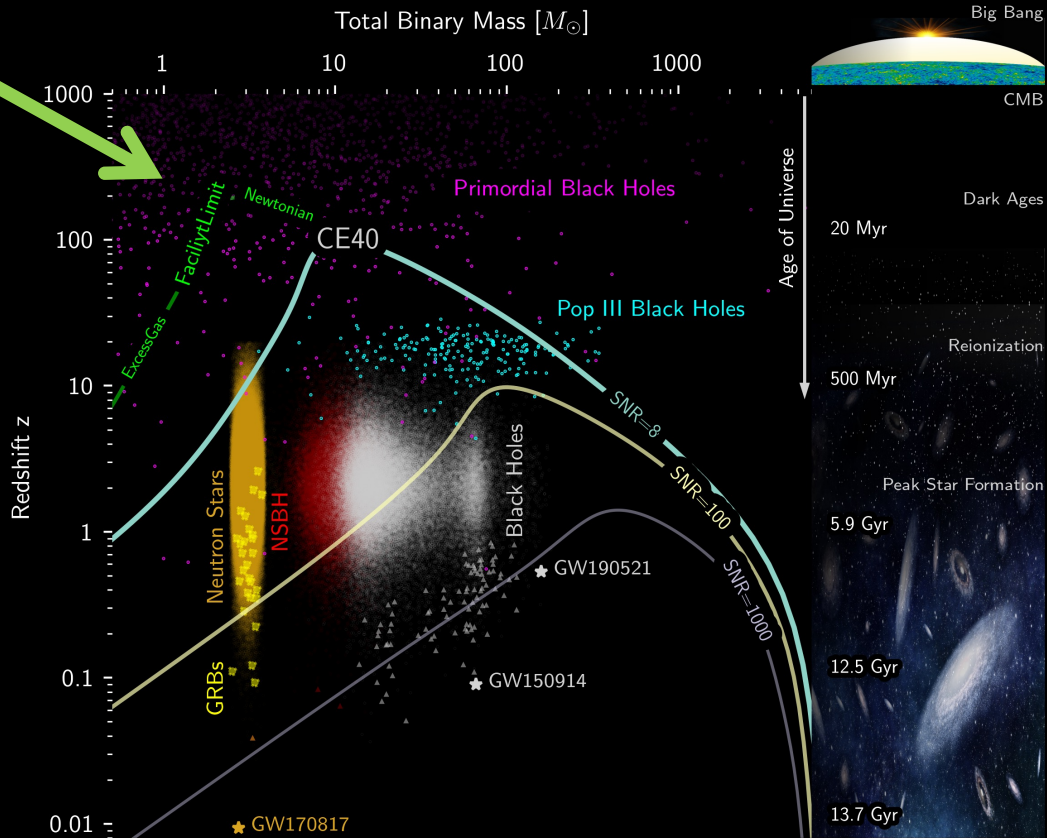
KAGRA technology,
Sapphire @ 20K , $1\ \mu\text{m}$

Voyager technology,
Silicon @ 123K , $2\ \mu\text{m}$

Big Picture: Anticipating Technology Needs

- i/e/a/+/# -LIGO all run on **same basic technology**
 - 1064nm light, SiO₂ optics (...)
- Cosmic Explorer plans to use the **same basic technology**, but alternatives utilizing cryogenic technology have been proposed
 - 123K Si and <20K Si (or Sapphire)
 - Si band gap requires **$\lambda > \sim 1.5 \mu\text{m}$** , maybe 2 μm .
- Facility **should accommodate potential upgrades**

Reaching the Far Shores of the Cosmic Ocean



The LIGO logo features the word "LIGO" in a bold, blue, sans-serif font. To the left of the text are several concentric, white, curved lines that resemble the ripples of a gravitational wave.

LIGO

Handoff

- to Den Martynov





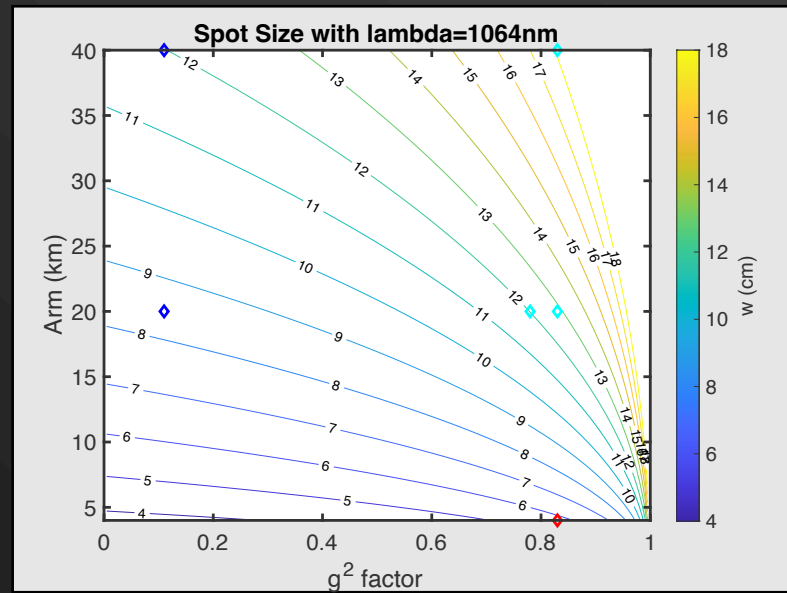
Back to Making Facilities Flexible..

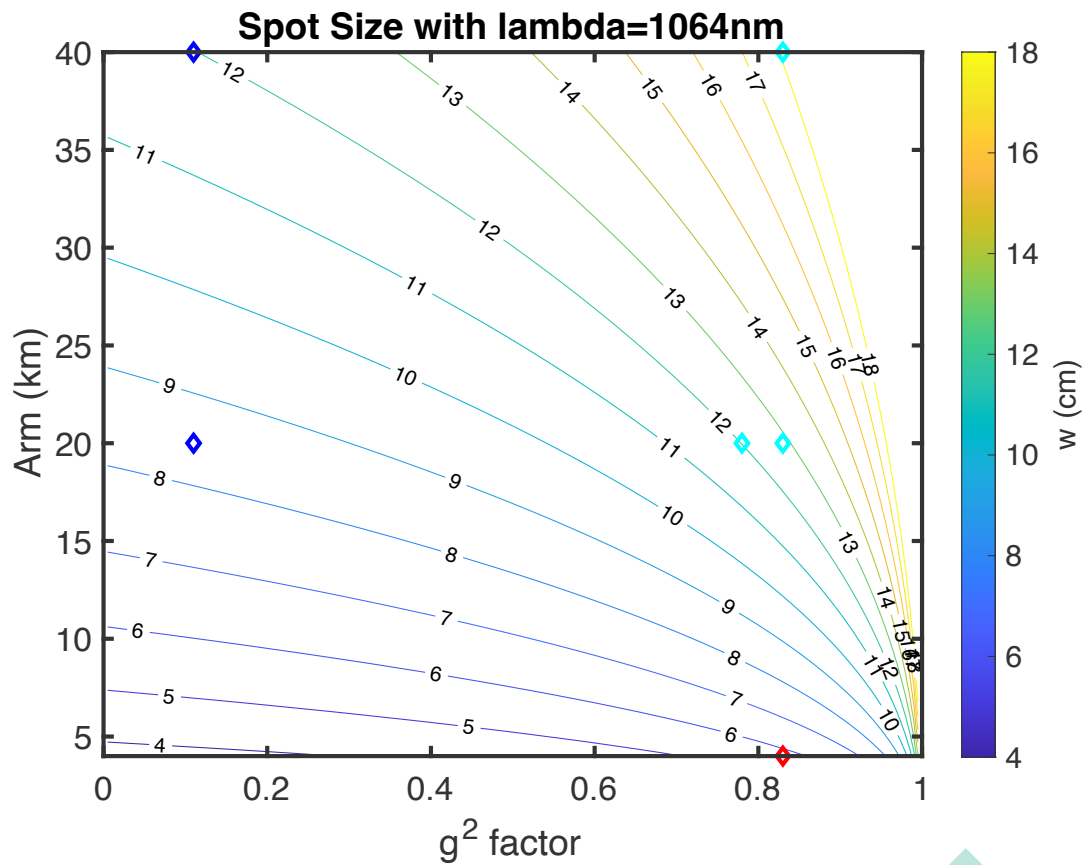
Photo: Robert Ward / Stefan Ballmer (2016/03/12)

Arms!

- $w_{min} = \sqrt{\frac{L\lambda}{\pi}}$, about 12cm for 40km, 1.064um,
- Si → longer wavelength → larger beams → bigger tubes,

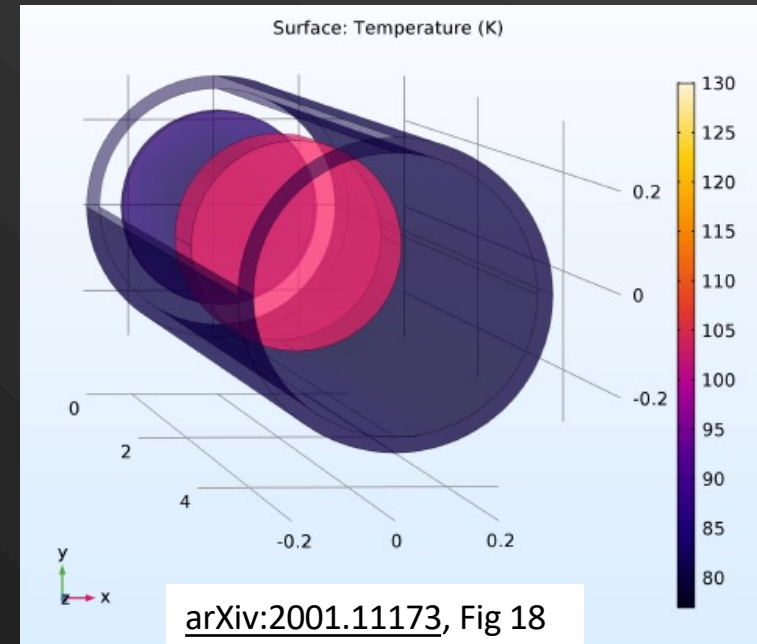
- Choice of beam tube diameter is fixed **very early** in the project!
- Bigger tubes mitigate risk in other ways:
 - CTN reduction with bigger sports at 1um
 - Extra scattering noise margin
 - But cost is high...

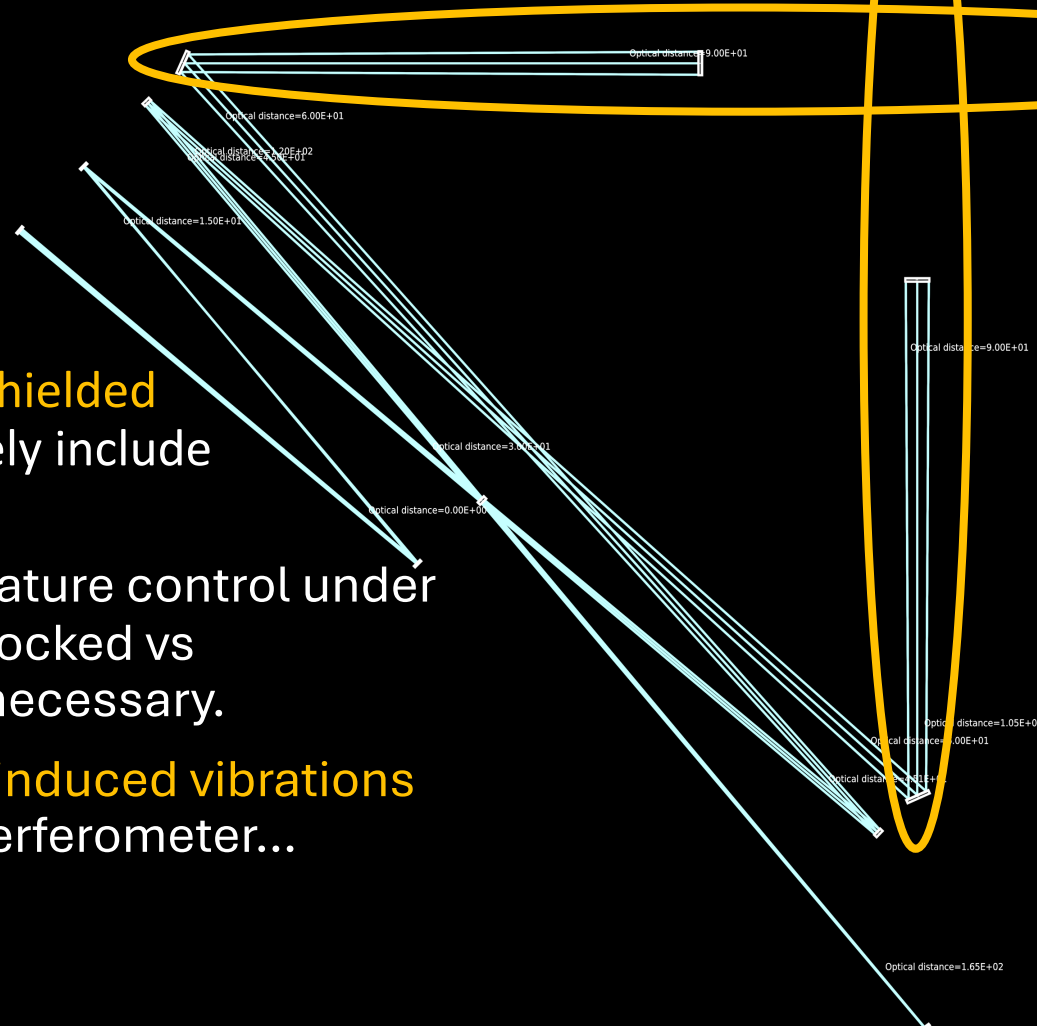




Cryogenic beam tube shields and baffling!

- **Radiation:** Cryogenic beam tube shield required for O(50m)
 - Otherwise: environmental heating > laser absorption
 - Needed behind ITM as well
 - Cryogenic Reaction mass
 - Cryogenic folding mirrors? Beam splitter?
- **Gas:** Cryogenic baffling required further out to avoid ice build-up?

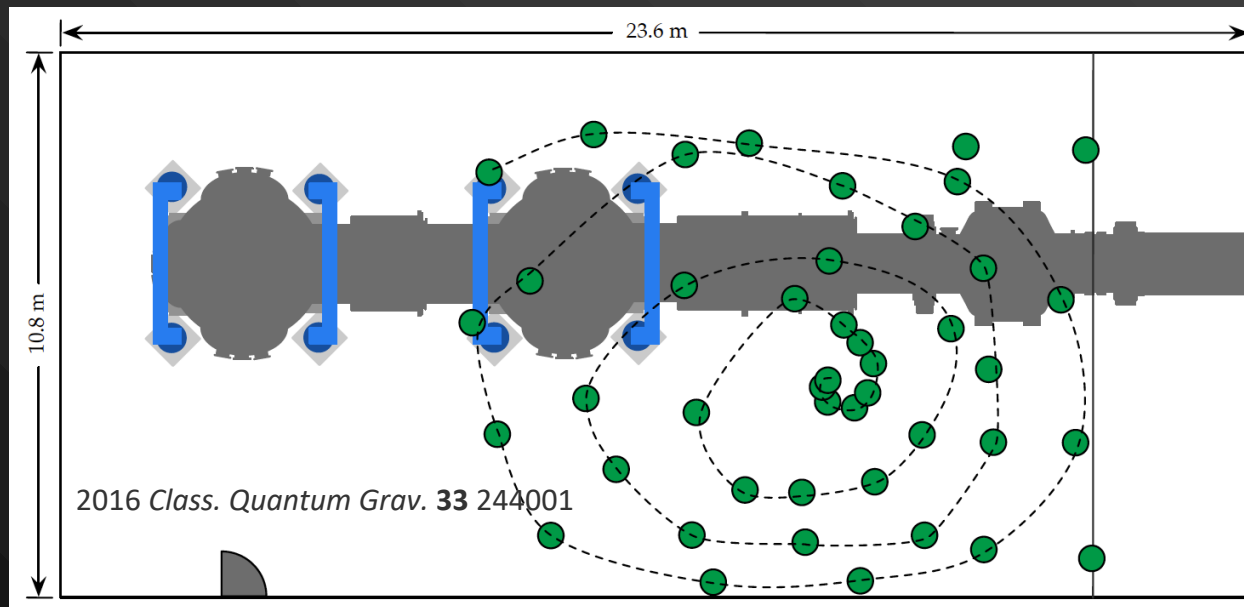




- Cryogenically shielded area would likely include folding mirrors
- Active temperature control under varying load (locked vs unlocked) is necessary.
- Keep cooling-induced vibrations away from interferometer...

Newtonian Noise Cancellation vs Cryogenics?

- Newtonian Noise Cancellation arrays are required in exactly the same area



Other Operational and Design Constraints

- Long cooling times (month) make rapid interventions impossible
- Interferometer alignment will change during cooling
- Substrate choice
 - Float Zone vs. Czochralski (has size limit)
- Coating choice
 - aSi

Take-away points

- **Flexibility** is key for success, not just nice-to-have
 - For cryogenics and other potential new technology
- For **Arms / Vacuum** System size
 - Will likely come down to a tough **cost vs flexibility** argument
- For **Corner / End Stations** (LVEA)
 - Reserving in extra floor space and land around the building is **comparatively cheap**