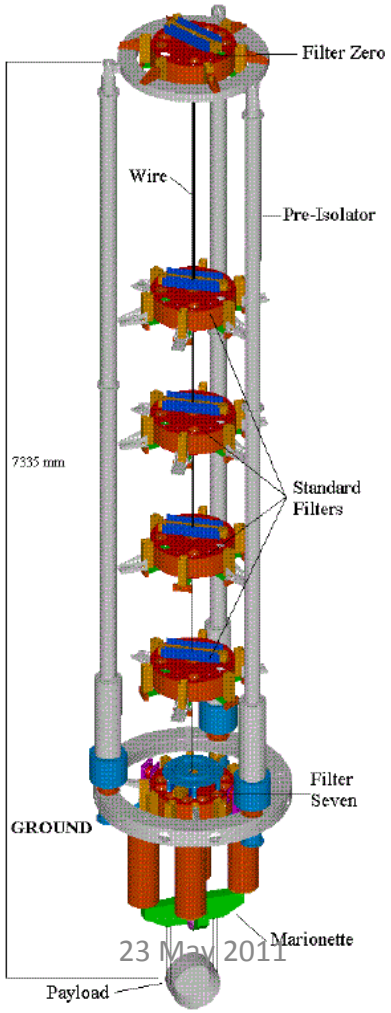
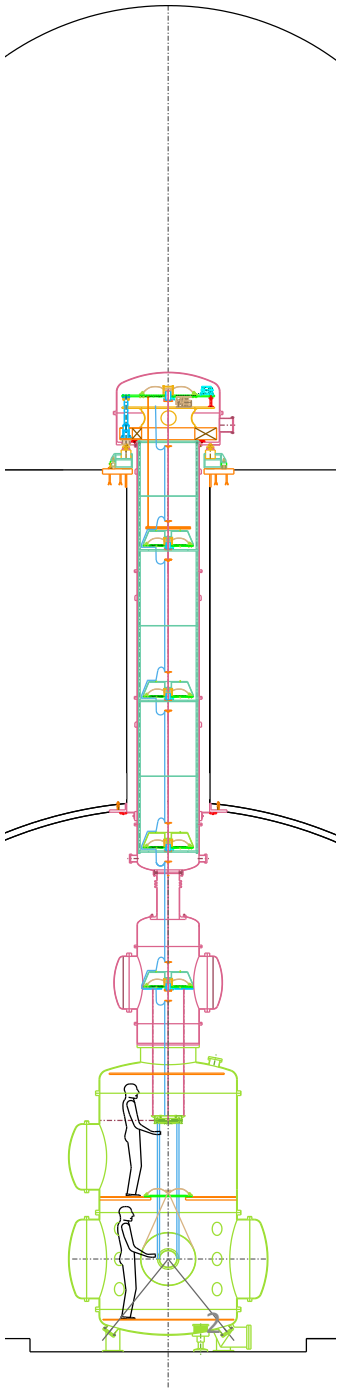
Dangers of controls with cryogenic links

The LCGT-SAS Seismic Attenuation System



- i-LCGT
  is a modern, simplified and improved version of the
  Virgo Superattenuators
- Inertial controls of Inverted Pendulum and locking make the test masses fully inertial



Virgo's safety margin

- Virgo's control noise OK
- Ad - Virgo's control noise probably OK
- Many people working on it
- LCGT seismic conditions better than Virgo's

- LCGT (warm) is virtually guaranteed OK
- LCGT with larger warm masses can already perform better than Ad-Virgo or ad-LIGO

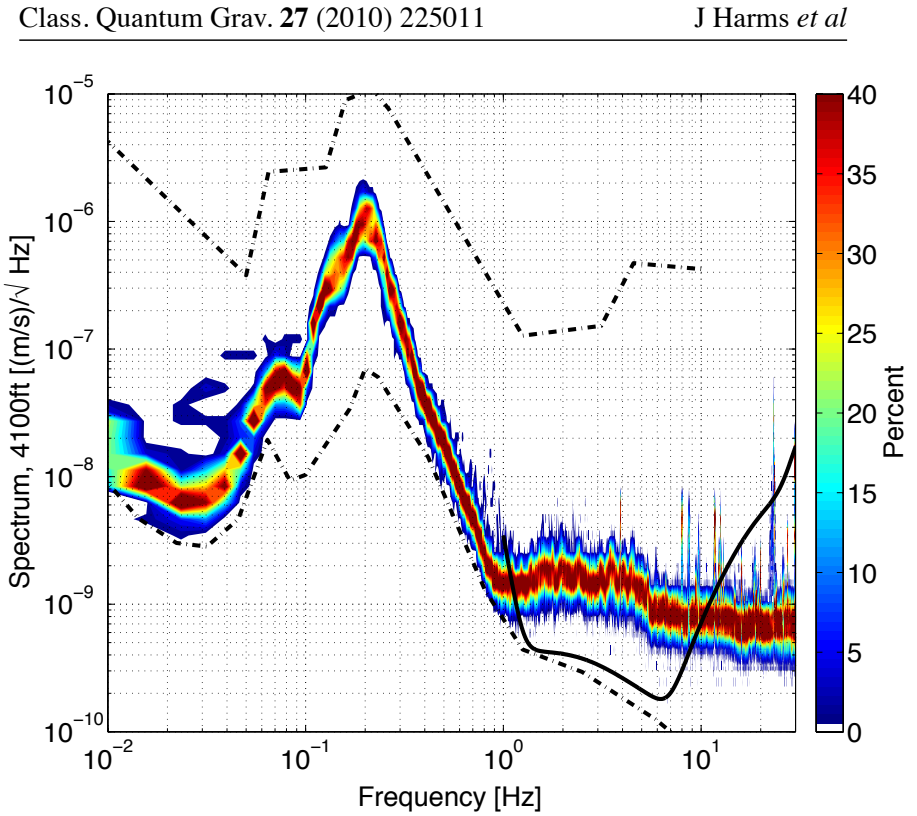
Sources of control noise

- Mechanical noise through attenuator
- Mechanical noise through heat links
- Electronics control noise
  - (typically 10^{-6} 10^{-8} of control authority)
- Sensing noise in feedback loops

- Evaluation of the seismic noise force injected by the cryo links

How large is microseismic noise

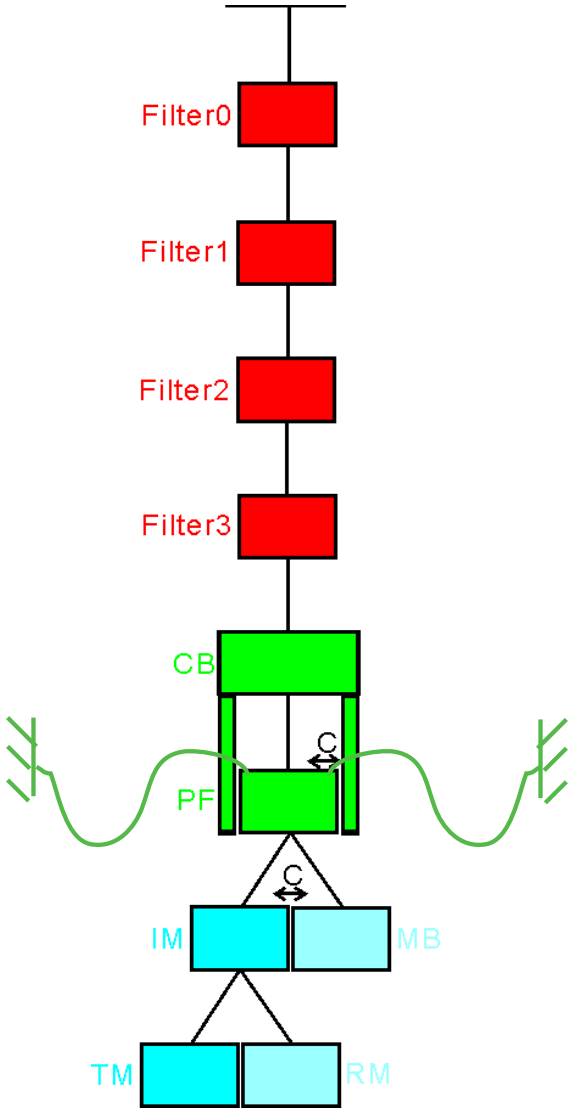
- Measurement
- 1200 m underground, 3000 km from the ocean
- About 1 micron r.m.s.
- As much as 10 micron r.m.s. in times of rough sea waves
- Same or worse at Kamioka



The linear spectral density of the seismic velocity field at the 4100 ft level spectral variation over one day (31 January) at the Sanford Lab. The two dashed curves correspond to the Peterson low- and high-noise mode

Seismic Force transmission

- Elastic constant of cryo links
  30 mHz on 300kg payload (?*)
- Negligible force transmission
  > 10 Hz
- 10% force transmission
  @ 100 mHz
- Full force transmission
  ≤ 30 mHz

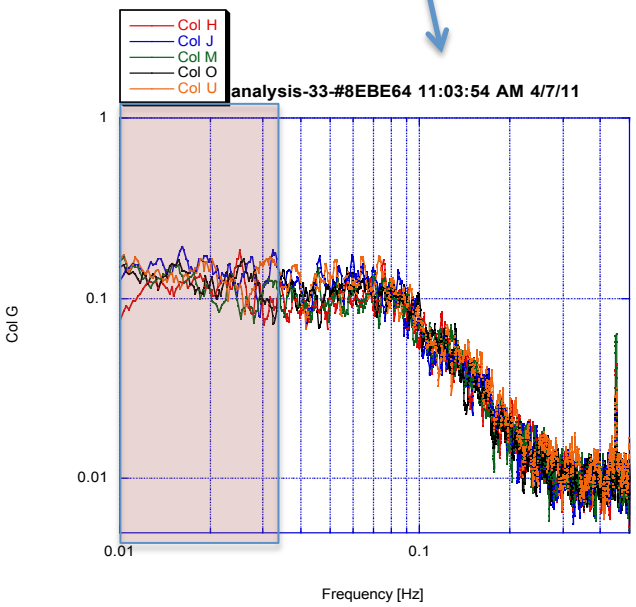


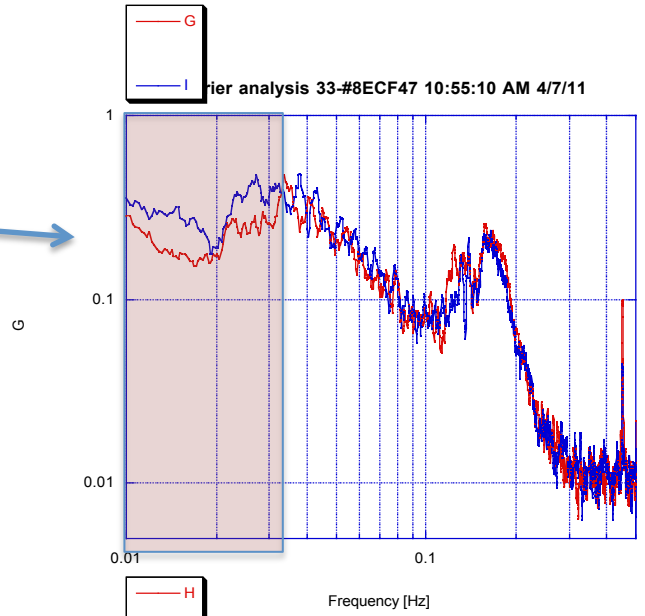
(*) Note: Aso, G1000108 focussed on in-band noise
Mostly ignored control noise. Found less coupling

Down-conversion from dislocation SOC

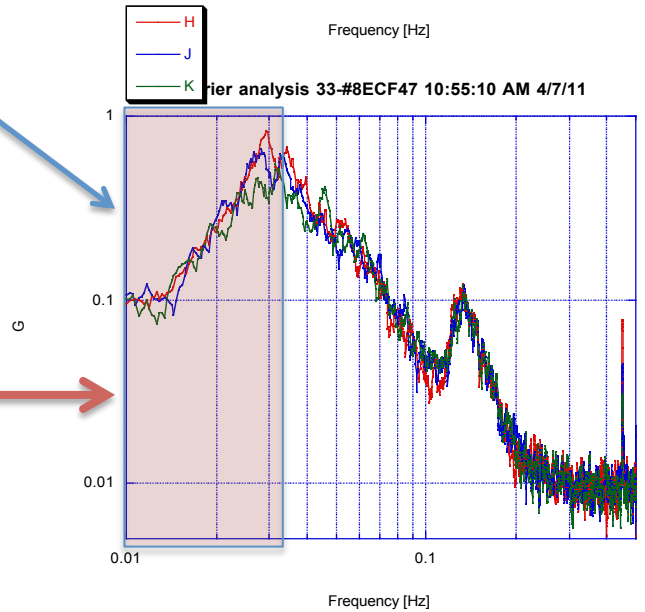
- Three days at Pasadena

- High waves
- Middle waves
- Small waves





Full force transmission



Down-conversion problem

- Metals converts mechanical noise to lower frequency, where full transmissivity exists
- Just smack in the control band

- How much noise really injected?

- This is pure mechanical noise deep in the attenuation chain ! ! !

Will cryo links produce downconversion?

- Very difficult to say for sure but, . . .
- Cryo links very pure and deeply annealed Al
- Plastic => Hysteretic
- Ideal for long-distance dislocation motion

- Dislocation avalanches are stress driven, not thermally driven
- Cryogenics is unlikely to eliminate SOC noise.
- Very likely there will be up- and down-conversion

Amount of mechanical noise injected

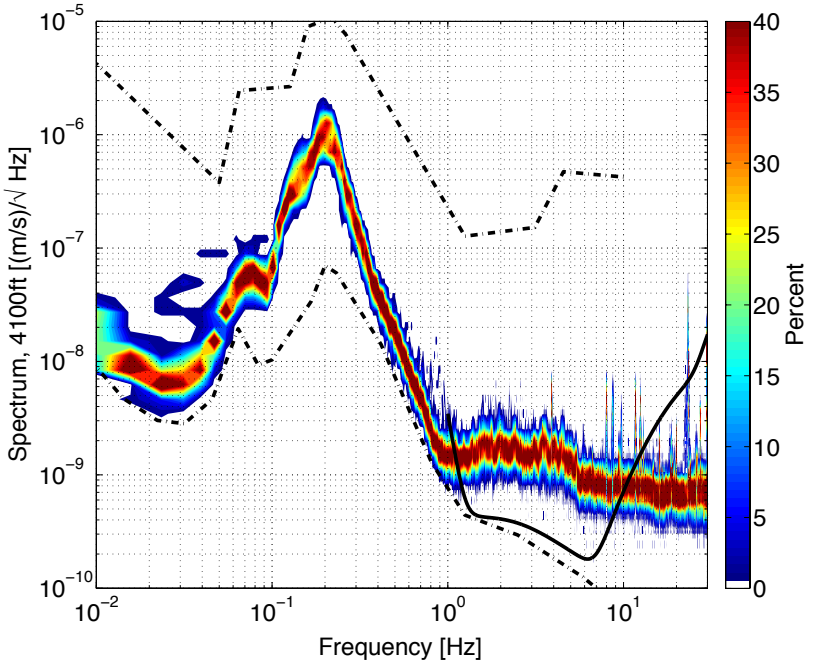
$$\omega = \sqrt{\frac{k}{M}}$$

$$m = 300kg$$

$$f = 30mHz$$

$$k = M(2\pi f)^2 = 10.6N / m$$

- F = k x
- F = *1-100 μN*



Homestake, SD
1200 m depth

–Maybe 10x less (Aso simulation)

Allowable amount of authority

- **From:** Franco franco.frasconi@pi.infn.it
- **Subject: Force on VIRGO Marionette**

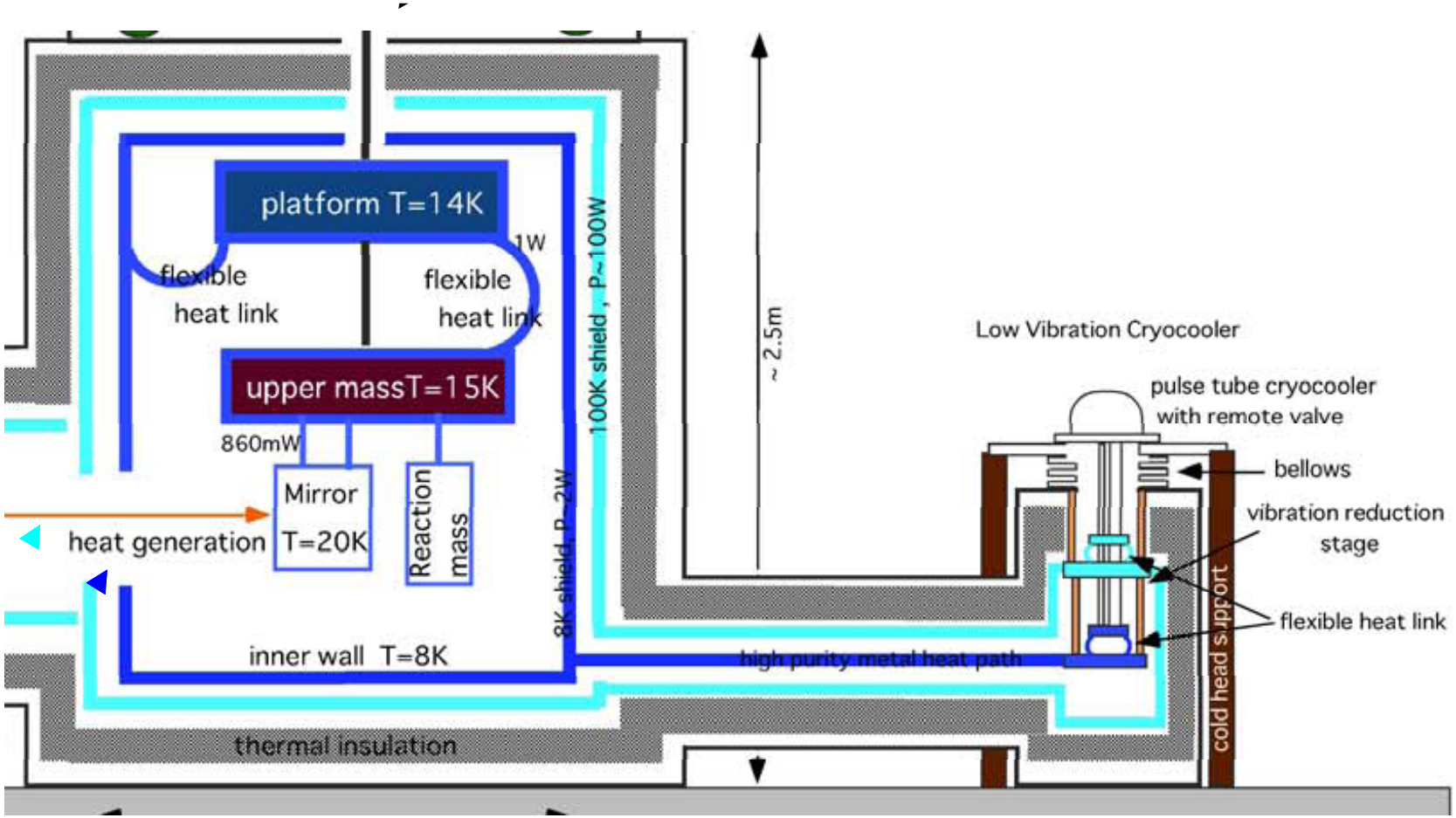
- Dear Riccardo,
- Following our discussion on LCGT suspension system at the Elba Island, I carefully checked the electrical parameters of our coil-magnet pairs mounted at the marionette level of the Virgo monolithic payload.
- Here below I am reporting the typical values of all our suspension systems:
- DC correction on Marionette: 100-200 mV
- Calibration factor: 28 mN/A
- Coil impedance: 10 ohm
- DC force applied: 280-560 $*10^{-6}$ N
- Please, be aware that the force reported above is mainly used for alignment purpose while the feedback action requires much smaller values (the residual motion with the active Inertial Damping loops is of the order of 0.1 micron (R.M.S.) at the suspension point level).
- Sincerely, Franco.

Allowable amount of authority

- DC force applied: 280-560 *μ N
- force mainly used for static alignment
- feedback action requires much smaller values at the suspension point level.
    - Franco Frasconi.
- Control noise < 10^{-6} authority
- Actual control noise < nN
- Injected mechanical noise ~ μN

Probably bad

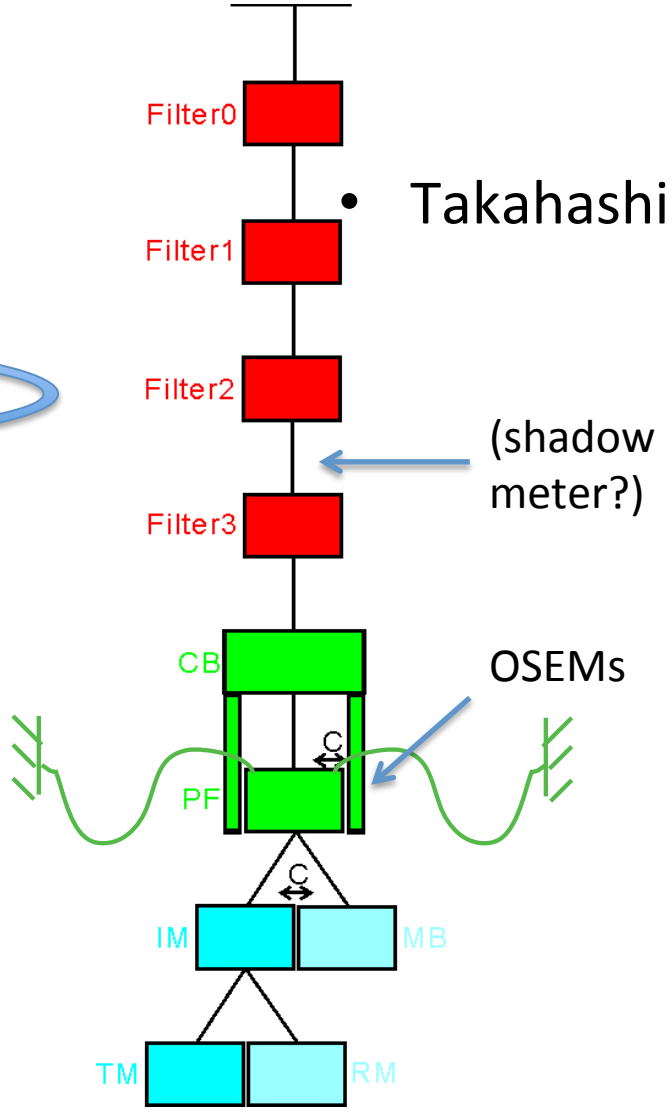
- Suzuki



Maybe good enough

- One additional layer of actuation => enough authority
- What is the real problem?
- What is the feedback signal
- No feedback signal =>
- => no lock !!

- Do we have sufficient simulations
- Will simulations be sufficient?



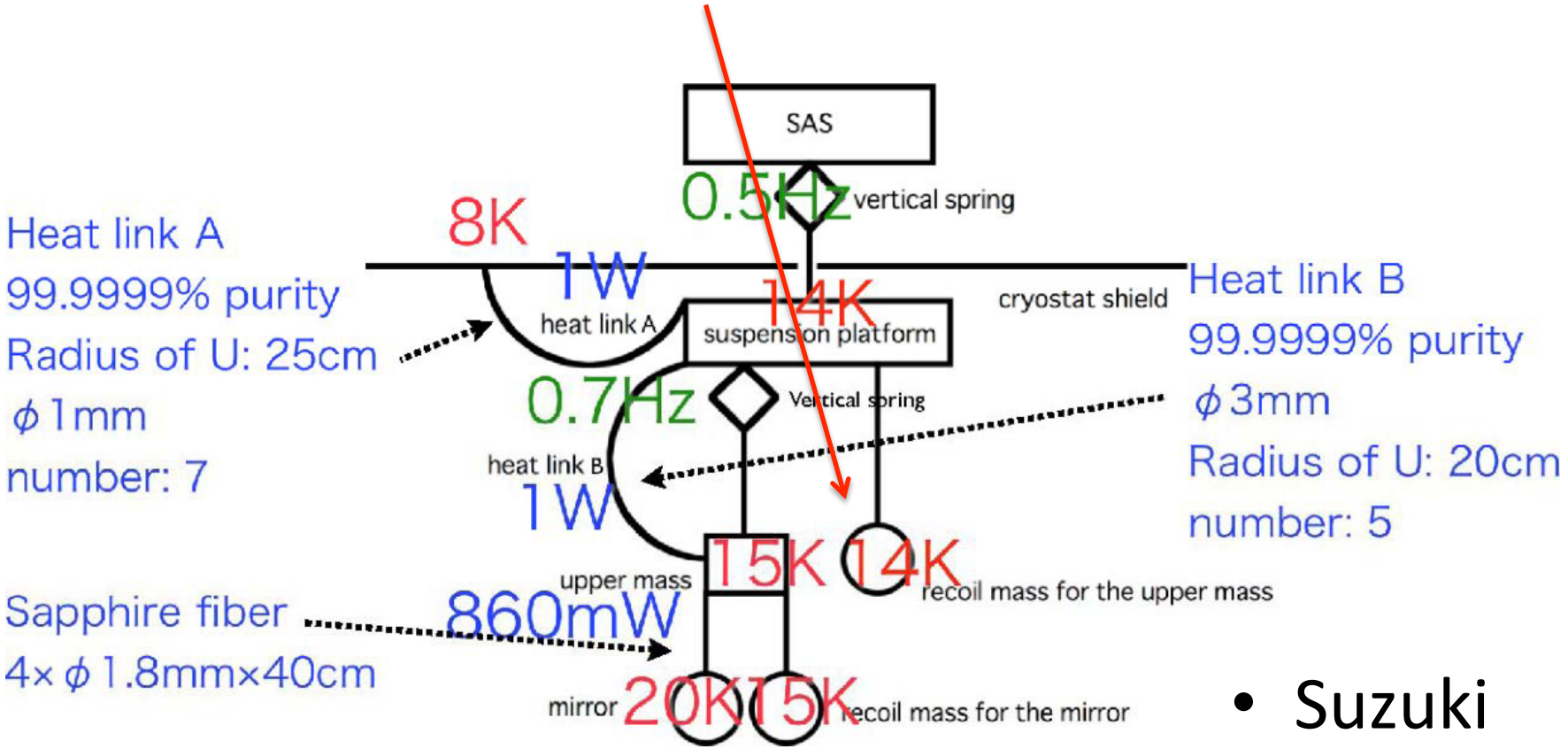
Allowable amount of authority

- Required 10^{-12} -10^{-14} m absolute positioning to maintain lock
- There seems to be sufficient authority to offset the injected seismic noise
- But there is no obvious way to generate a clean signal to control such correction

- Not clear to me that we can achieve or maintain lock

question

- Recoil mass absorbs much more (scattered) light than mirror
- How can it not be 20 to 30°K



- Suzuki

Other worries

- The 3 mrad tilt of the tunnel will also add noise from the vertical noise
- The necessity of a vertical low frequency seismic attenuation is a large unknowns

Other worries

- One of the main reasons at LIGO we abandoned sapphire, was difficulty of super-super polishing and scattering of light
- Scattered light (several Watts) is an enormous problem in a cryostat
  - Power absorption
  - Changing thermal gradients