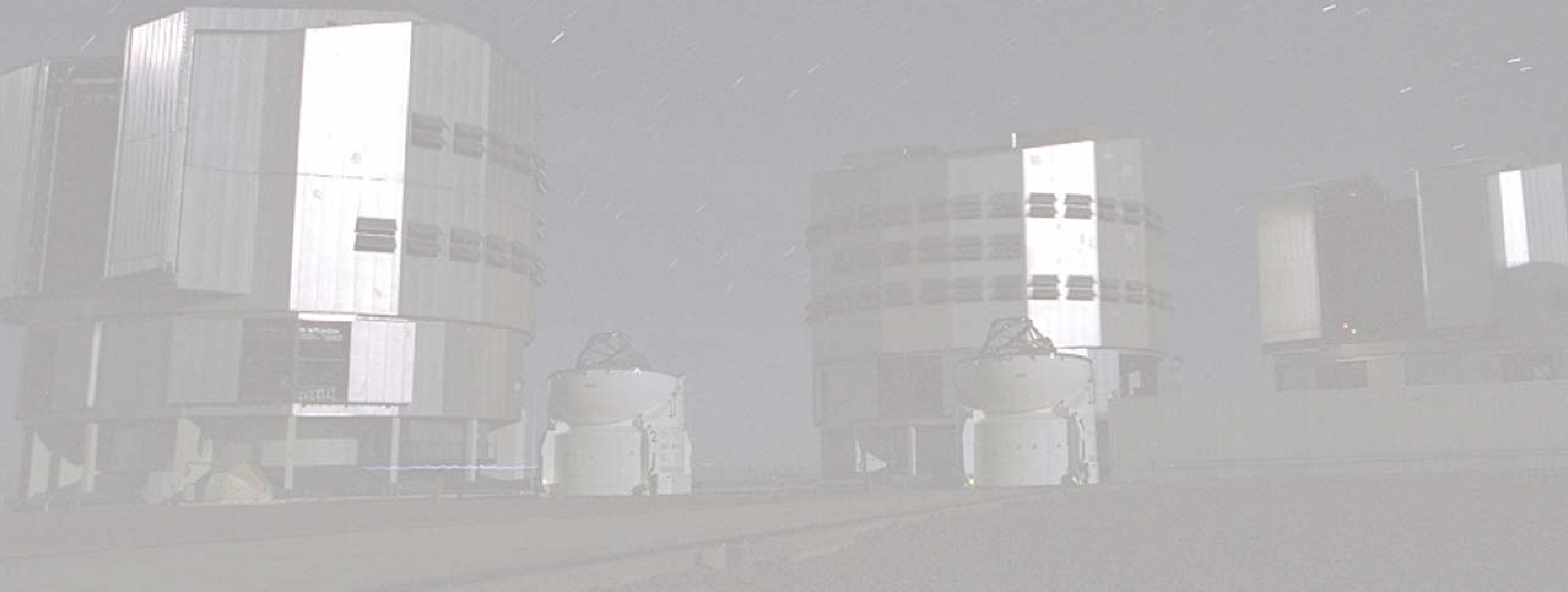
It shakes like a….

[G. Vasisht, 31 March 2006]



An Approach to Stabilizing Large Telescopes for Stellar Interferometry

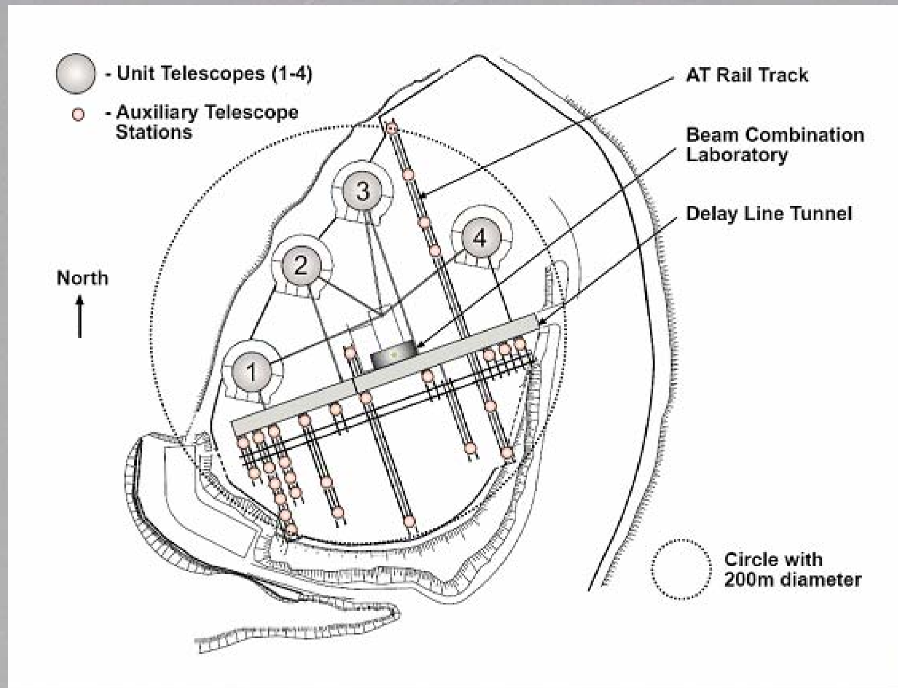
N. Di Lieto

J. Sahlmann, G. Vasisht, A. Wallander

The ESO VLT Interferometer

The VLT Array on the Paranal Mountain

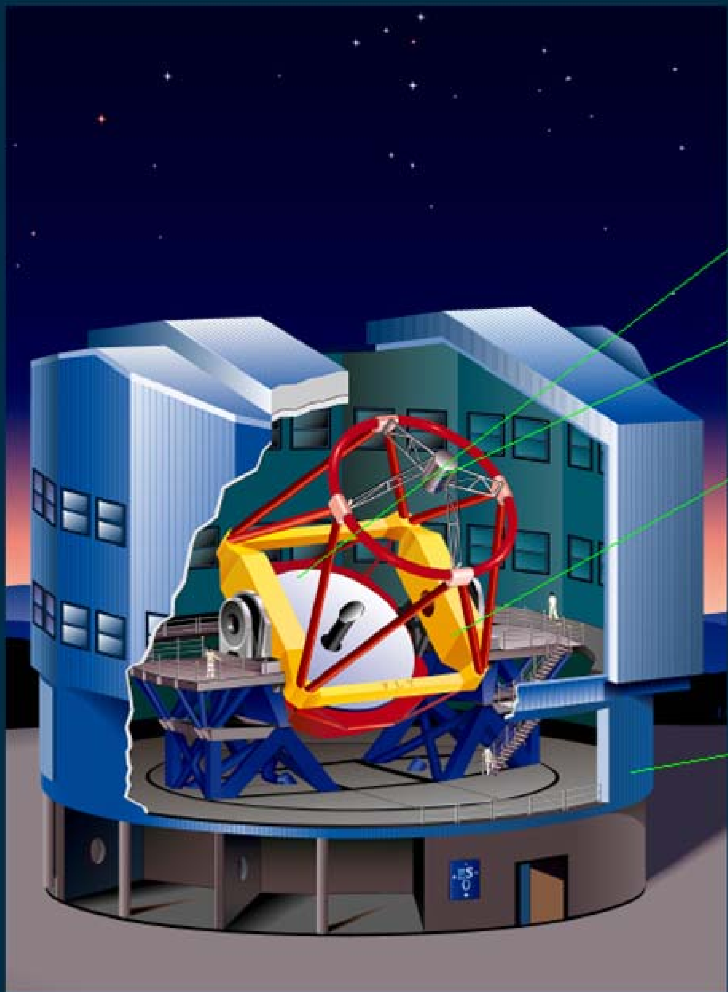
ESO PR Photo 14a/00 (24 May 2000)



- Located in Northern Chile
- ~2600 m above sea level
- Four 8.2-m Unit Telescopes
- Four 1.8-m Auxiliary Telescopes
- Six 60-m optical delay lines
- Beam combination laboratory

Unit Telescopes

THE VLT UNIT TELESCOPE

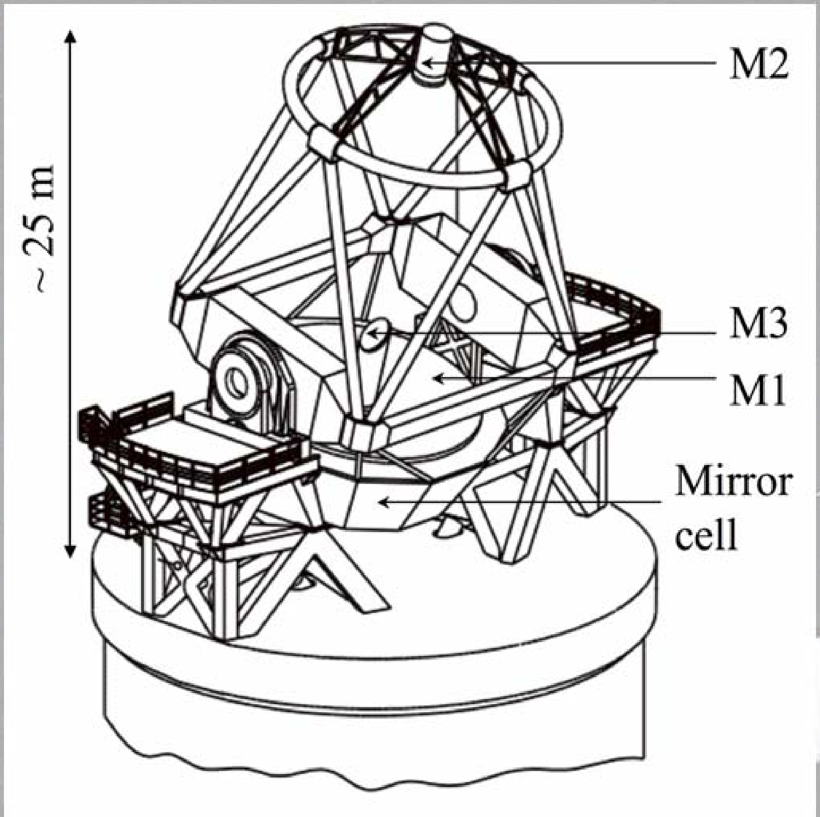


Optics:
- 8.2 m, f/1.8 primary mirror, actively supported (150 axial/64 lateral supports)
- 1.2 m chopping secondary mirror with “tip/tilt” system

Mechanical structure:
- Very high mechanical precision
- Backlash and friction free torque motor drives
- High angular resolution encoders

Enclosure:
- Designed to minimize thermal effects
- Earthquake resistent (7.8 on Richter Scale, 65 sec, 100 km dist.)

Unit Telescope 1



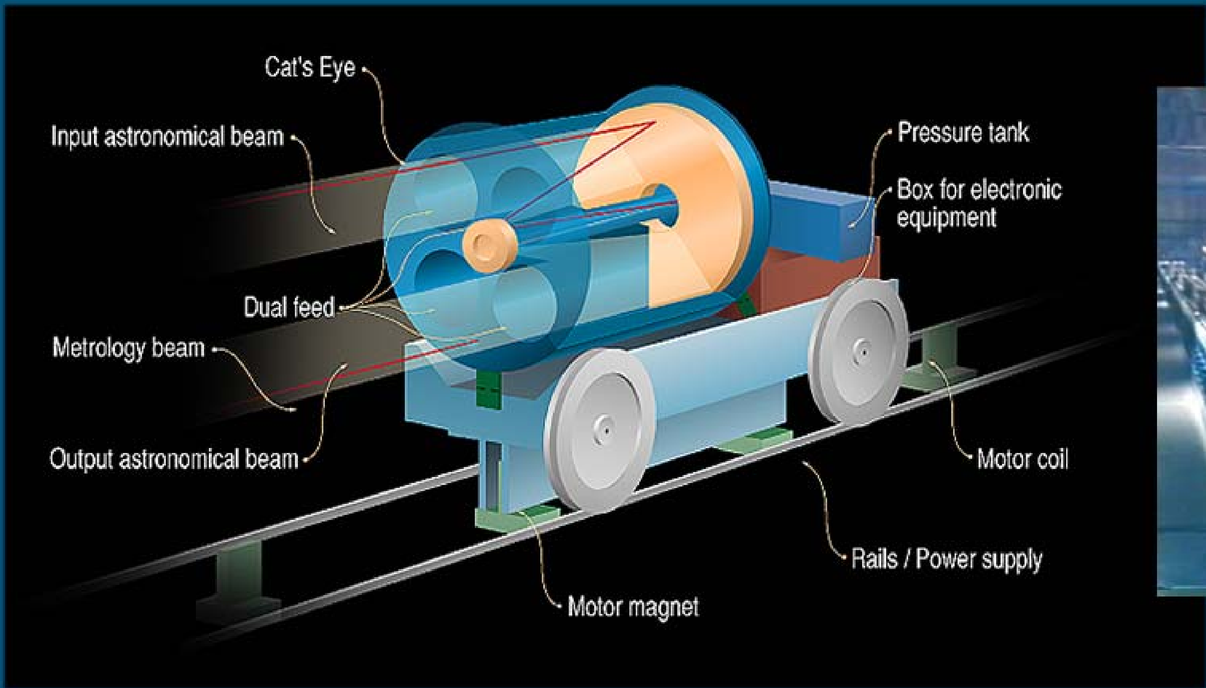
Auxiliary Telescopes

AT1 and AT2 with Open Domes

ESO PR Photo 07b/05 (14 March 2005)

Delay Lines

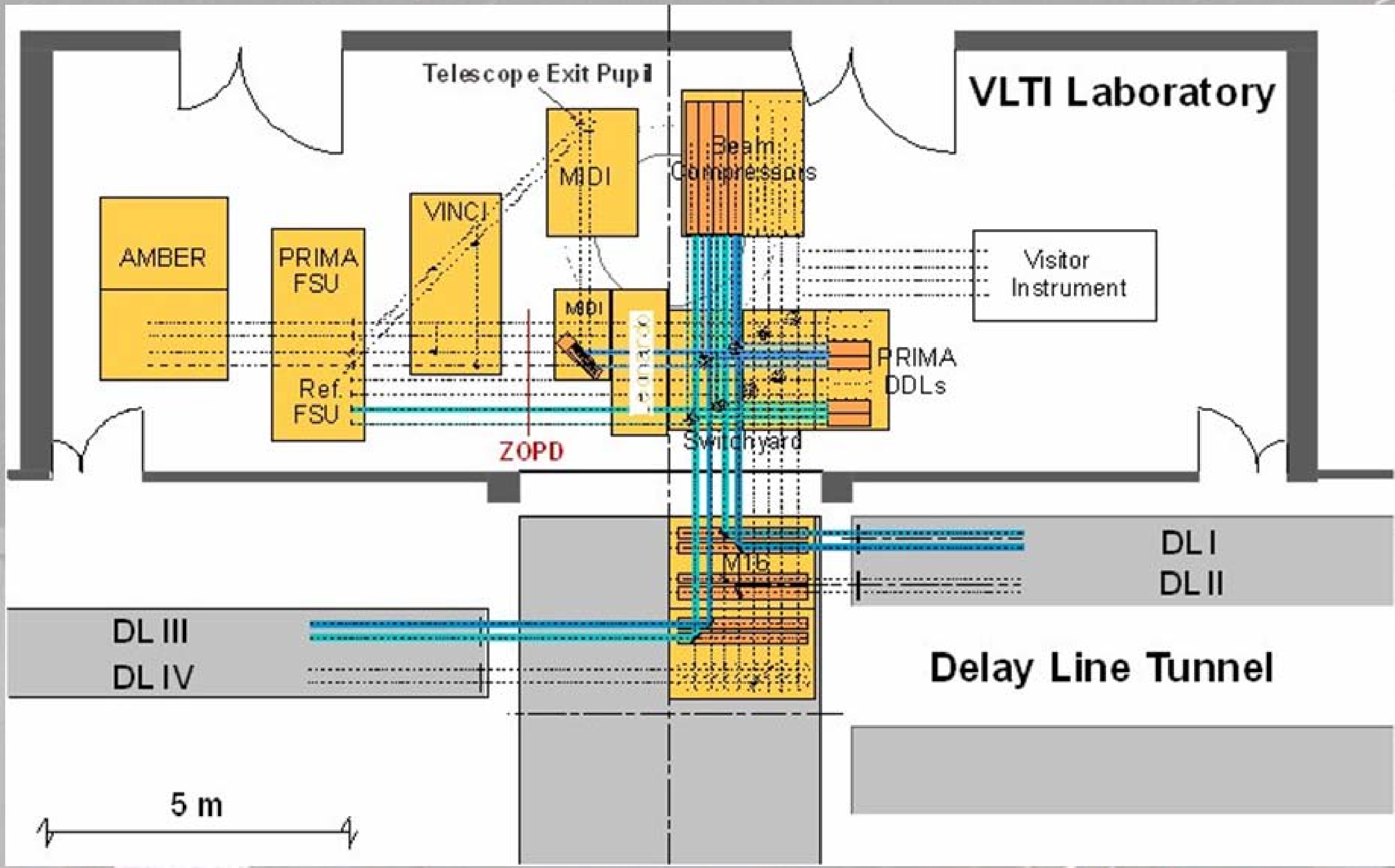
THE VLT DELAY LINES



- retro-reflector mounted on a moving base
- Ritchey-Chretien type ("Cat's Eye")

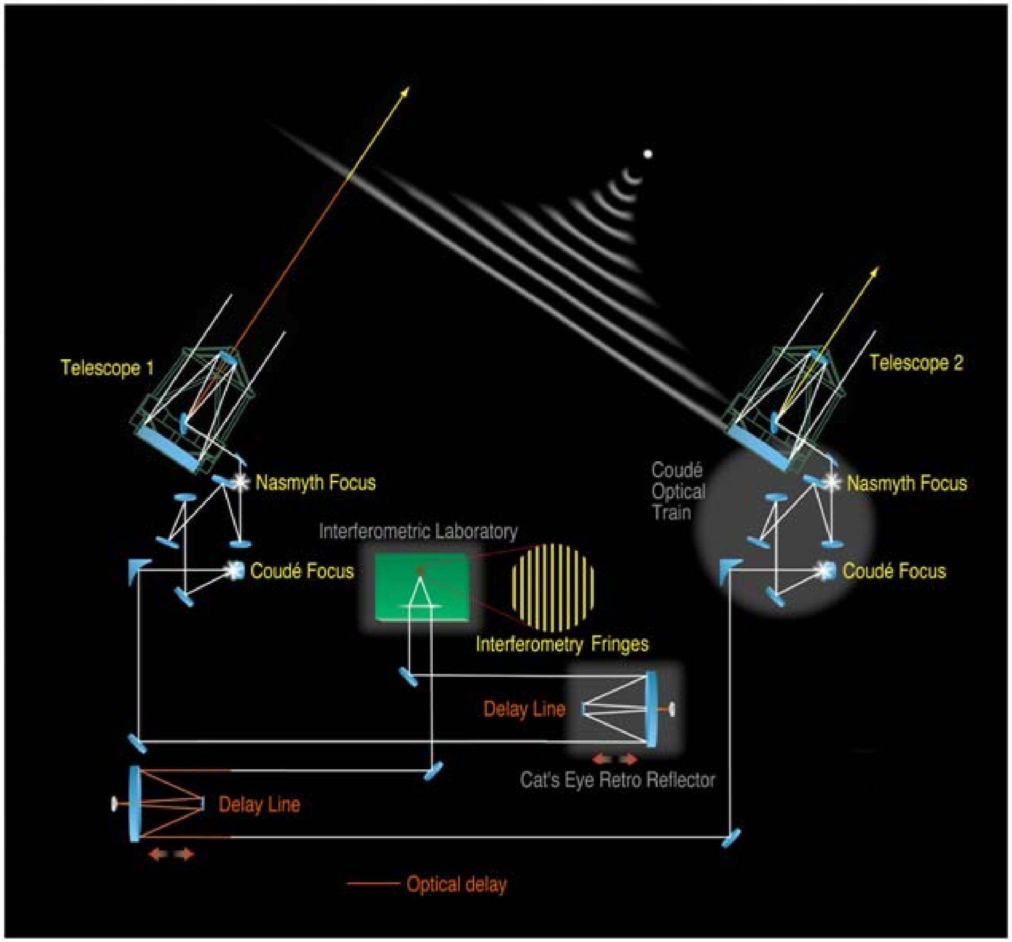
focal length:	3600.0mm
field of view:	200 arcsec
M1 diam:	550.0mm
M2 diam:	130.0 mm
M3 diam:	14.0 mm (with variable curvature down to 80 mm radius)

Beam Combination Laboratory



The VLT Interferometer

- Coherent combination of stellar light beams from two or more telescopes
- Requires real-time cancellation of Optical Pathlength Differences (OPD) to a fraction of the observing wavelength
- OPD Measurement: Fringe sensor
- OPD Actuation: Delay line (coarse linear motor + fine piezo)
- Digital distributed control system
- Accelerometers on primary, secondary and tertiary mirrors added to the system to allow vibration compensation



The VLT Interferometer (schematic)

ESO PR Photo 14b/00 (24 May 2000)

Optical Pathlength Difference sources

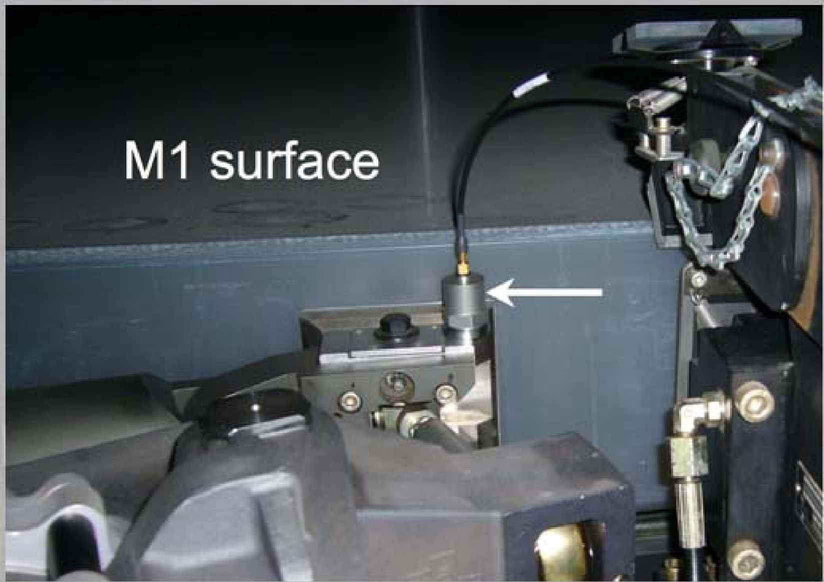
1. Telescope configuration and motion of the astronomical object due to Earth rotation
   A few meters, predictable, very slowly varying
   Cancelled using geometric feed-forward terms, imprecision taken care of by closed loop control

2. Atmospheric disturbances
   Up to 10 μm RMS, unpredictable, negligible above 10 Hz
   Measured by fringe sensor and attenuated with closed loop control by actuating the delay line

3. Mechanical vibrations
   Up to 1 μm RMS and 100 Hz, therefore above the maximum achievable closed loop bandwidth (~15 Hz)
   Measured by accelerometers and compensated by direct feed-forward to the delay line.

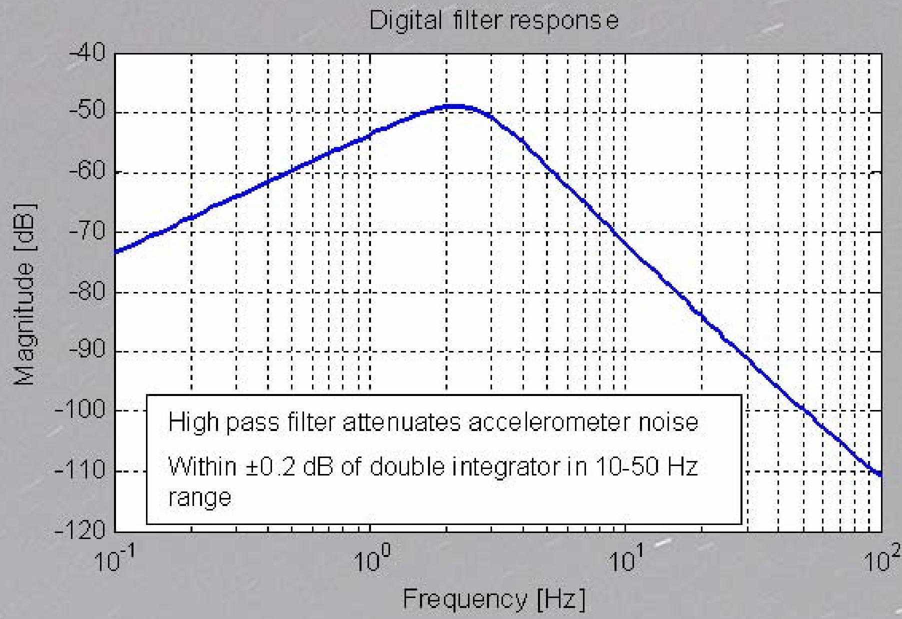
Feed-forward system installation

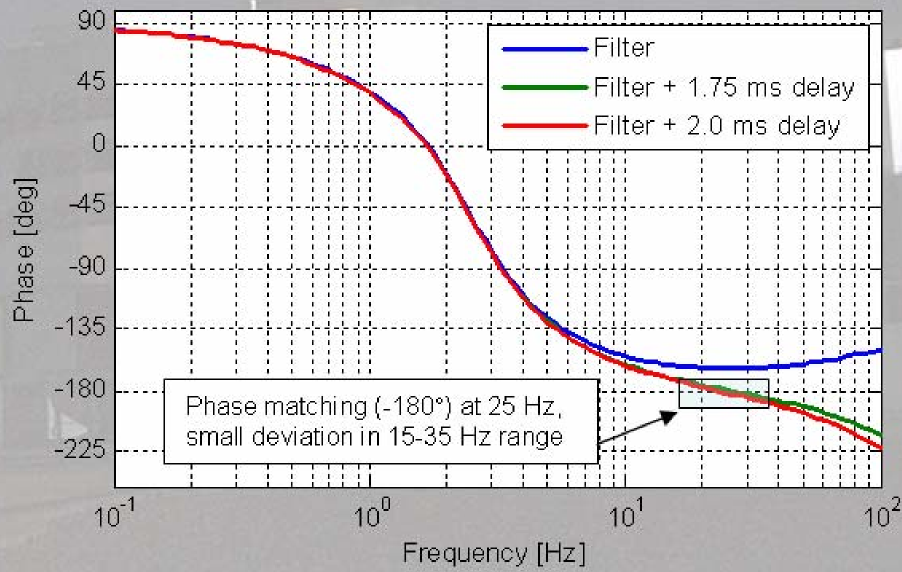
- Brüel & Kjær 4370 accelerometers on M1 (4x), M2 (1x), M3 (2x)
- Brüel & Kjær Nexus 2692 amplifiers, remotely configurable by serial link
- VME system with CPU, timing, A/D and reflective memory network modules
- Liquid cooled cabinet mounted on M1 cell
- Real time software based on VxWorks and implemented using the ESO TAC (tools for advanced control) framework



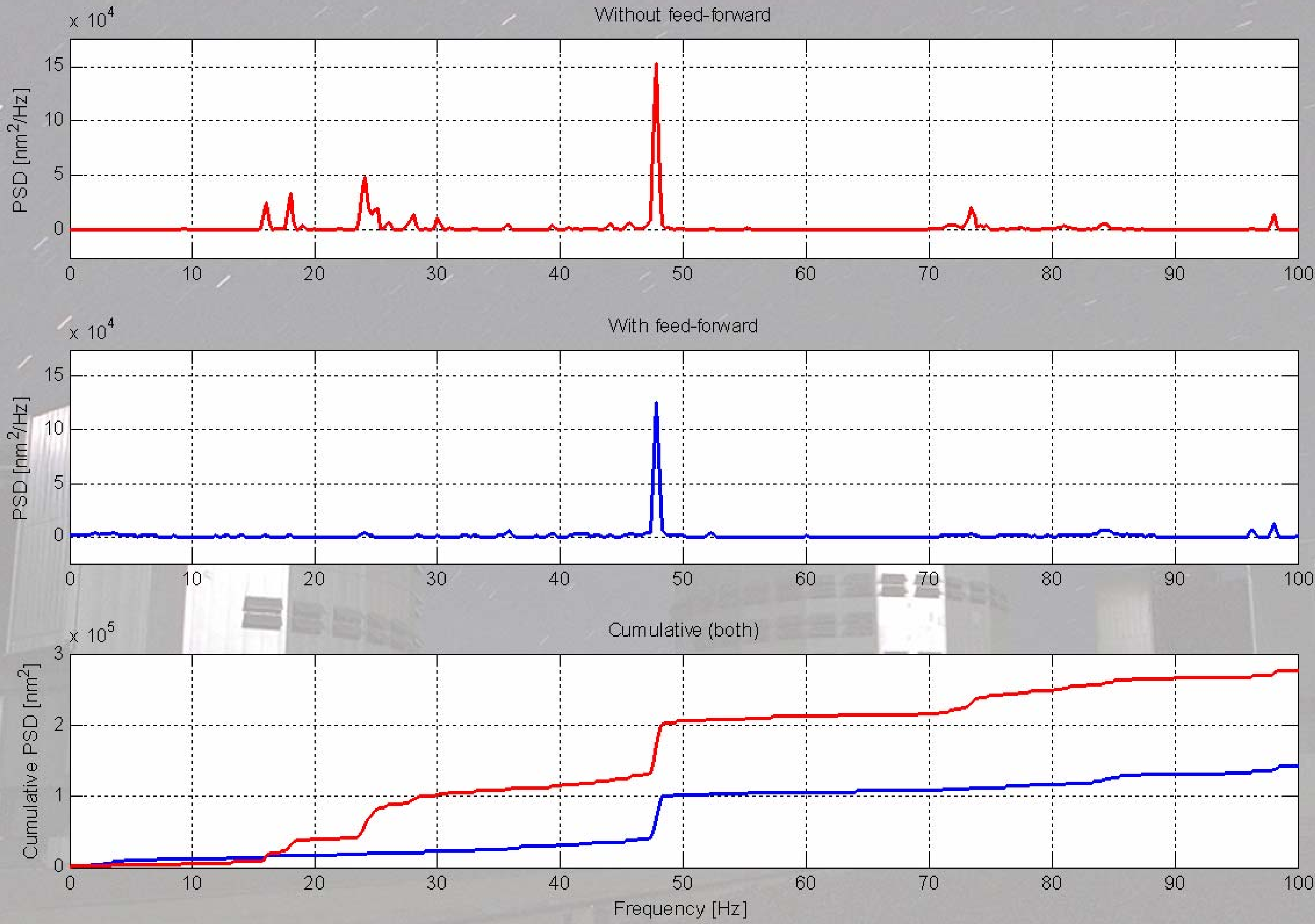
Software and signal processing

- Acquisition of the raw accelerometer signals, including validation and flagging of inconsistencies
- Position = double integral of acceleration. however, simple signal double integration cannot work because of
  - processing/actuation delays (1.75-2 ms)
  - noise at low frequency
- Need to digitally filter the acceleration signals in order to achieve
  - phase and magnitude matching in frequency range of interest (15-35 Hz)
  - noise attenuation at lower frequencies
- Linear combination, based on geometry, of the filtered position signals from M1, M2 and M3
- Publication of the combined position signal on the Reflective Memory Network (based on GE Fanuc VME-5565 boards)

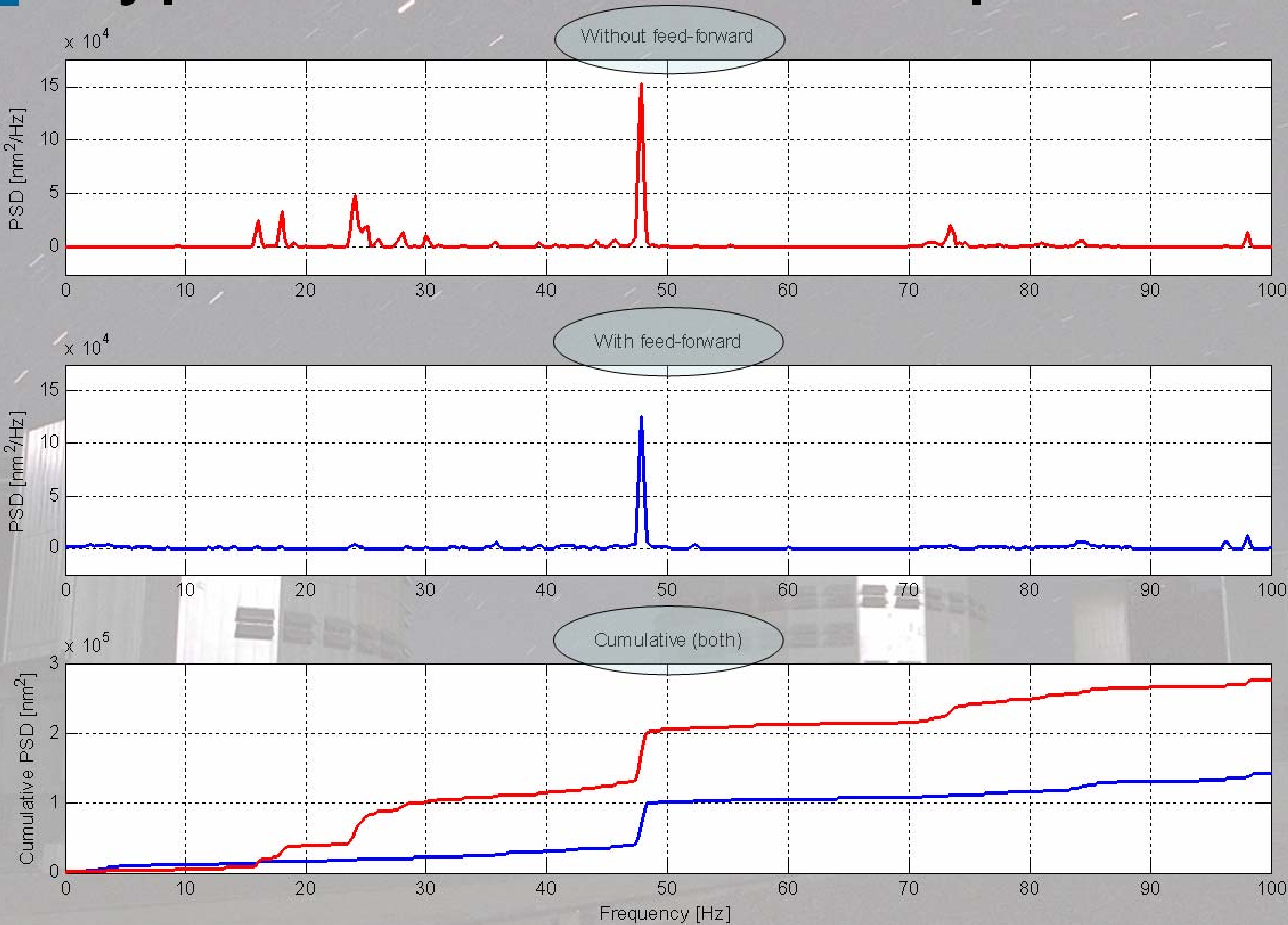




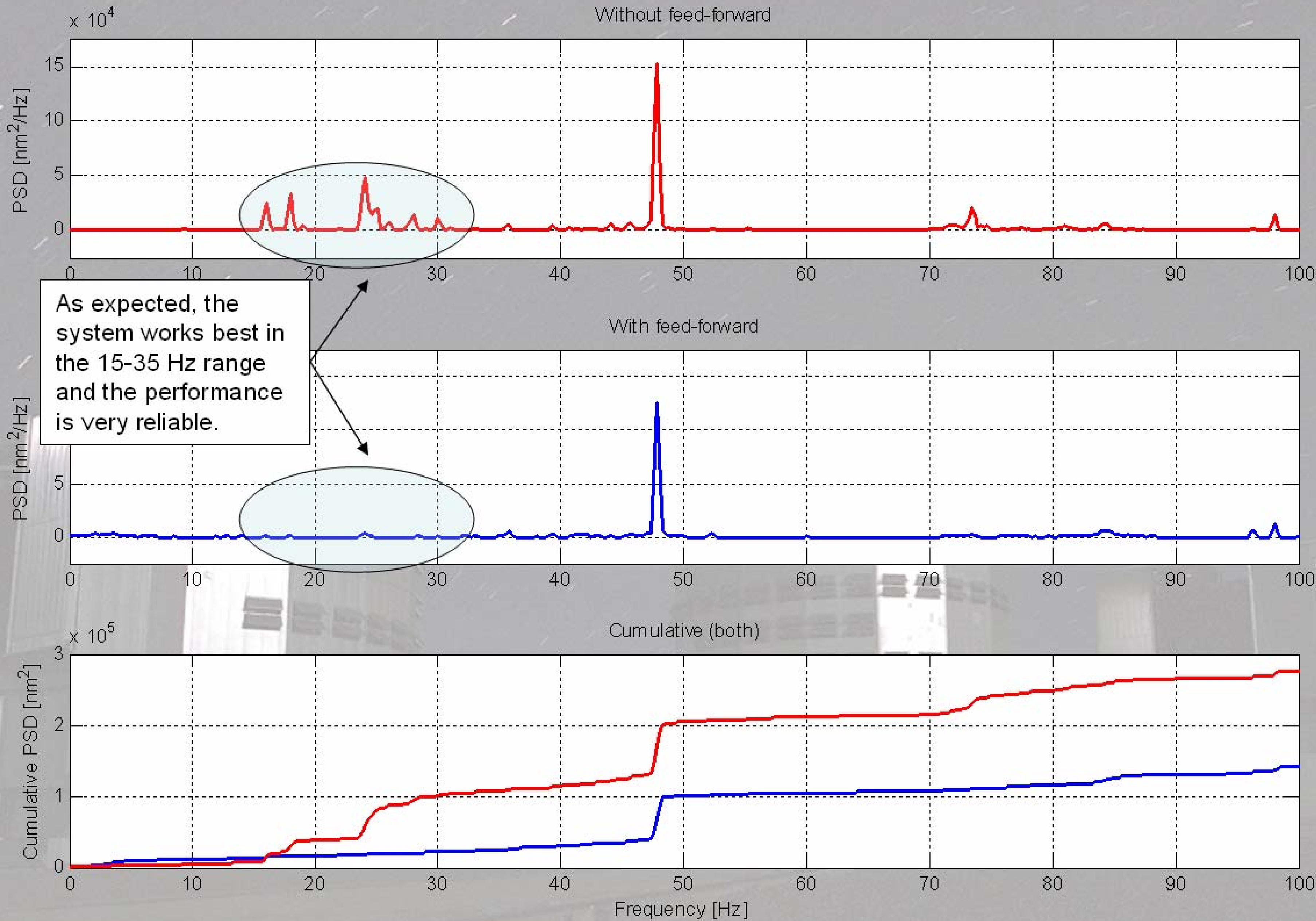
Typical OPD residual spectra



Typical OPD residual spectra

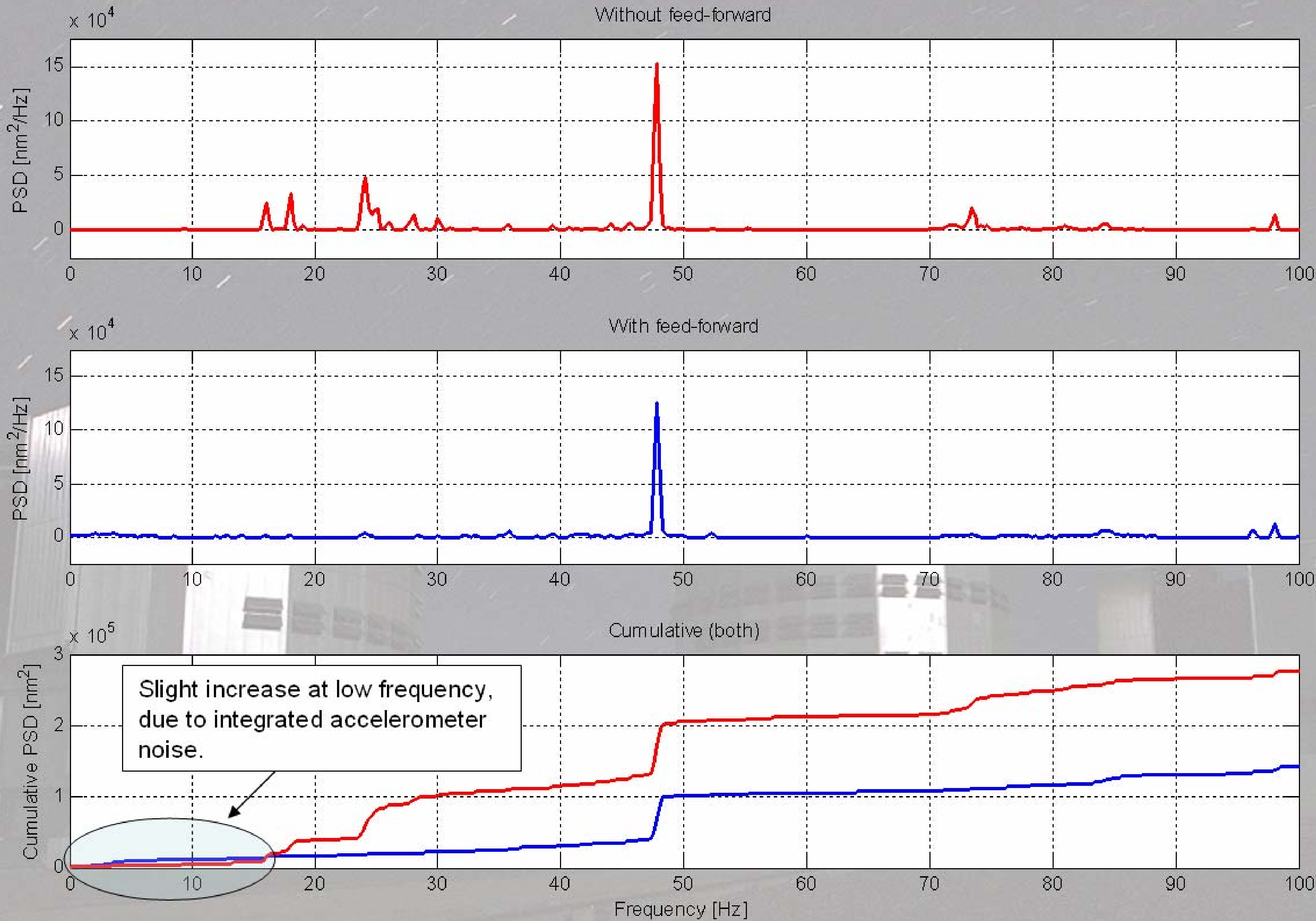


Typical OPD residual spectra

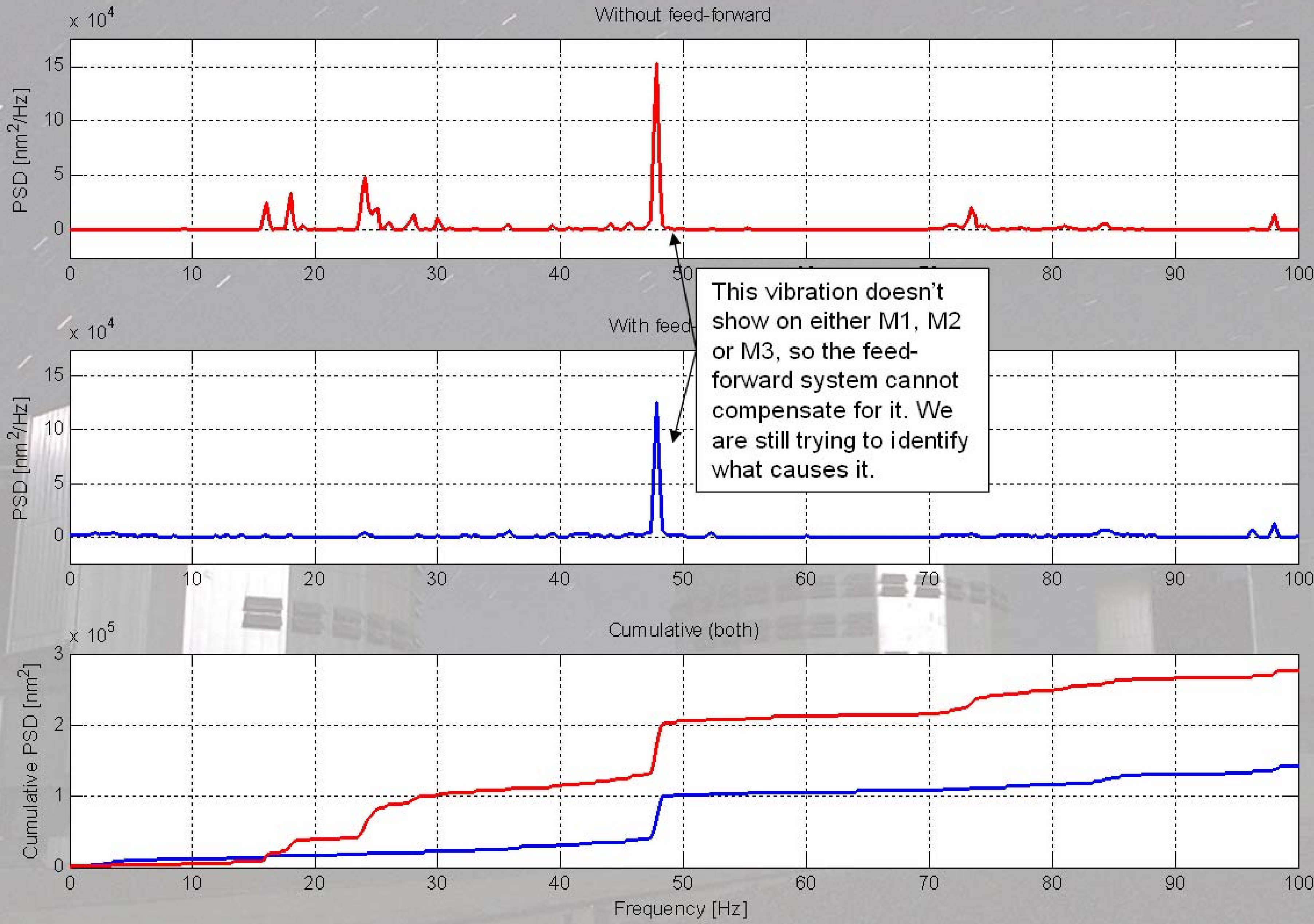


As expected, the system works best in the 15-35 Hz range and the performance is very reliable.

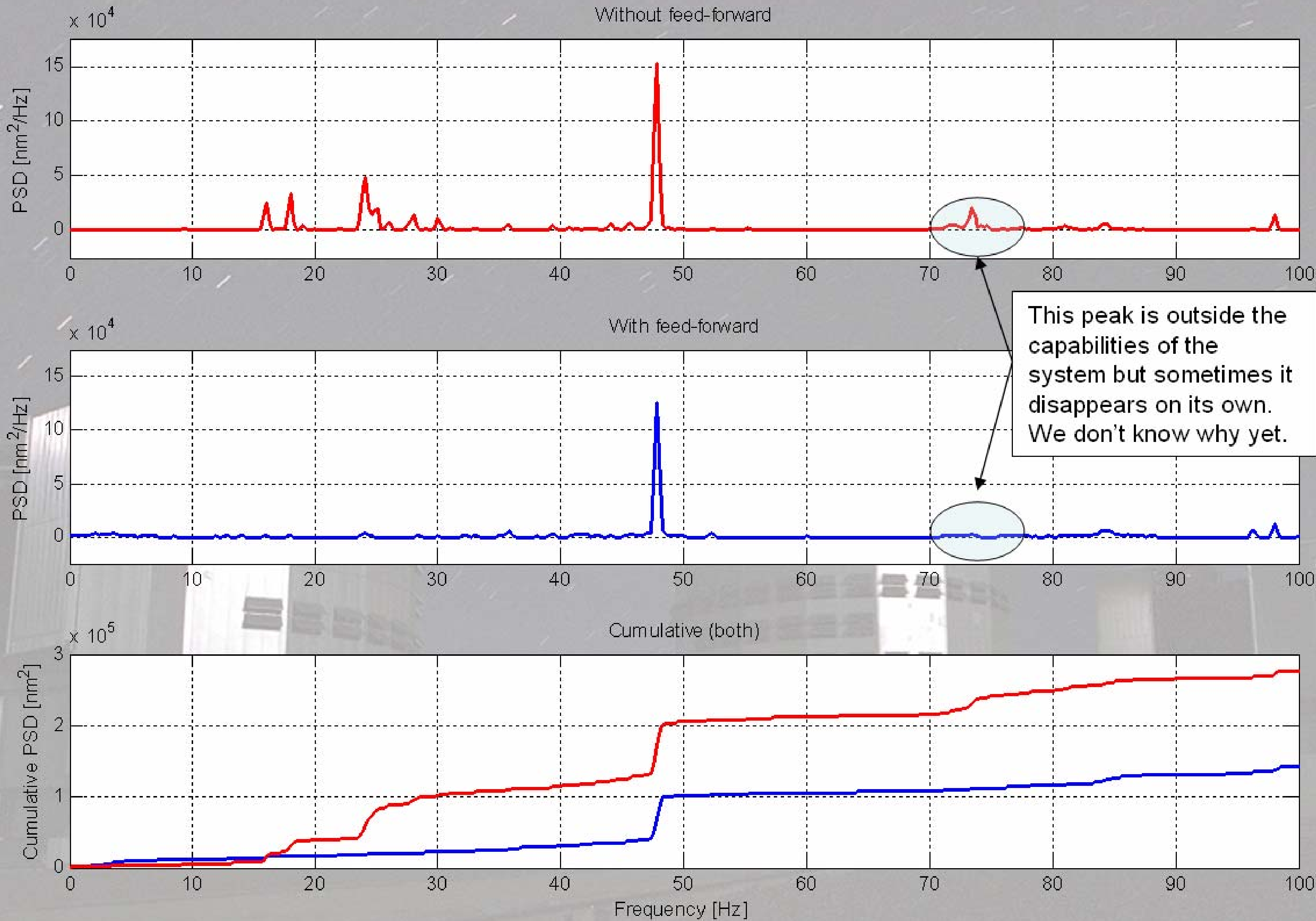
Typical OPD residual spectra



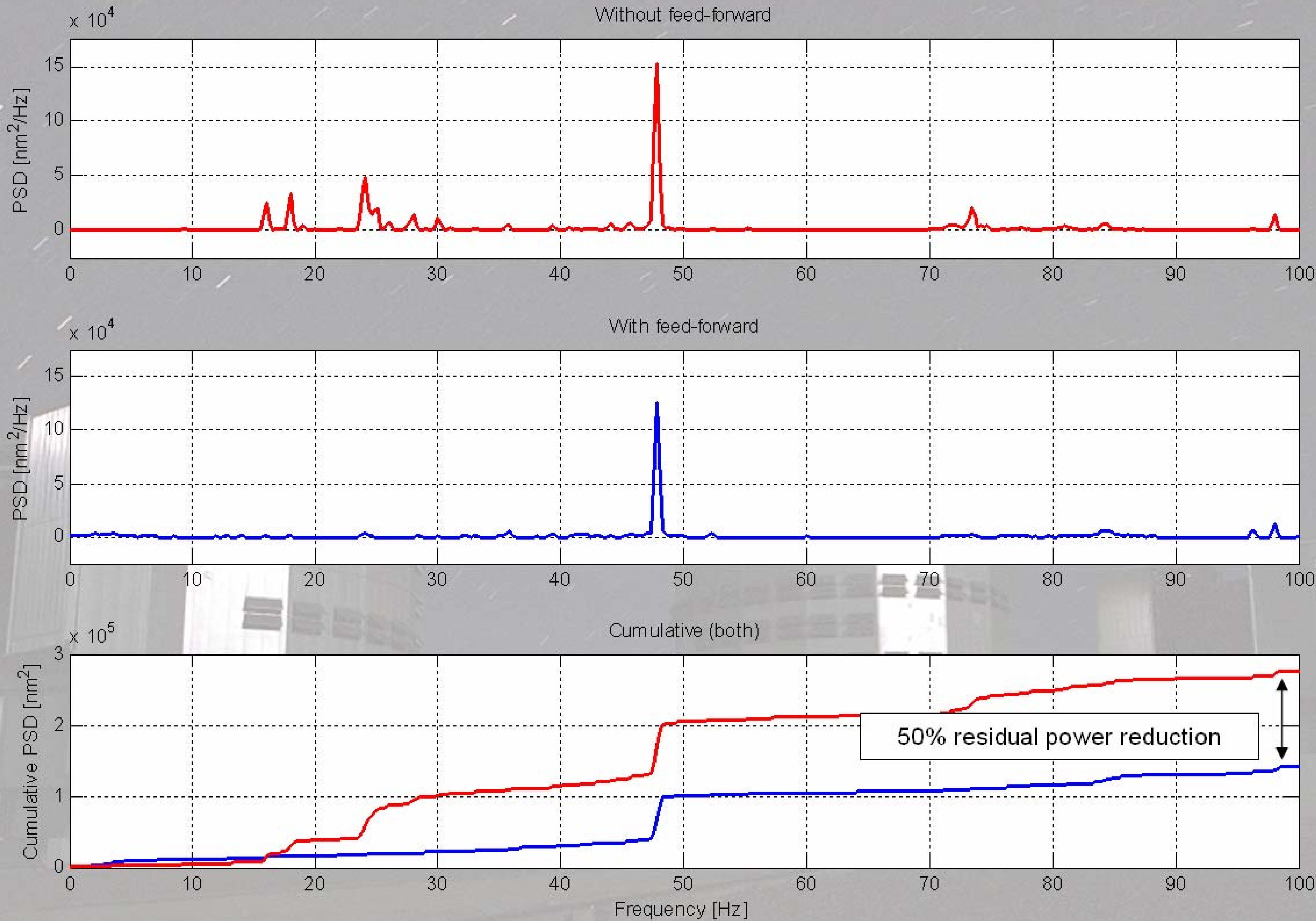
Typical OPD residual spectra



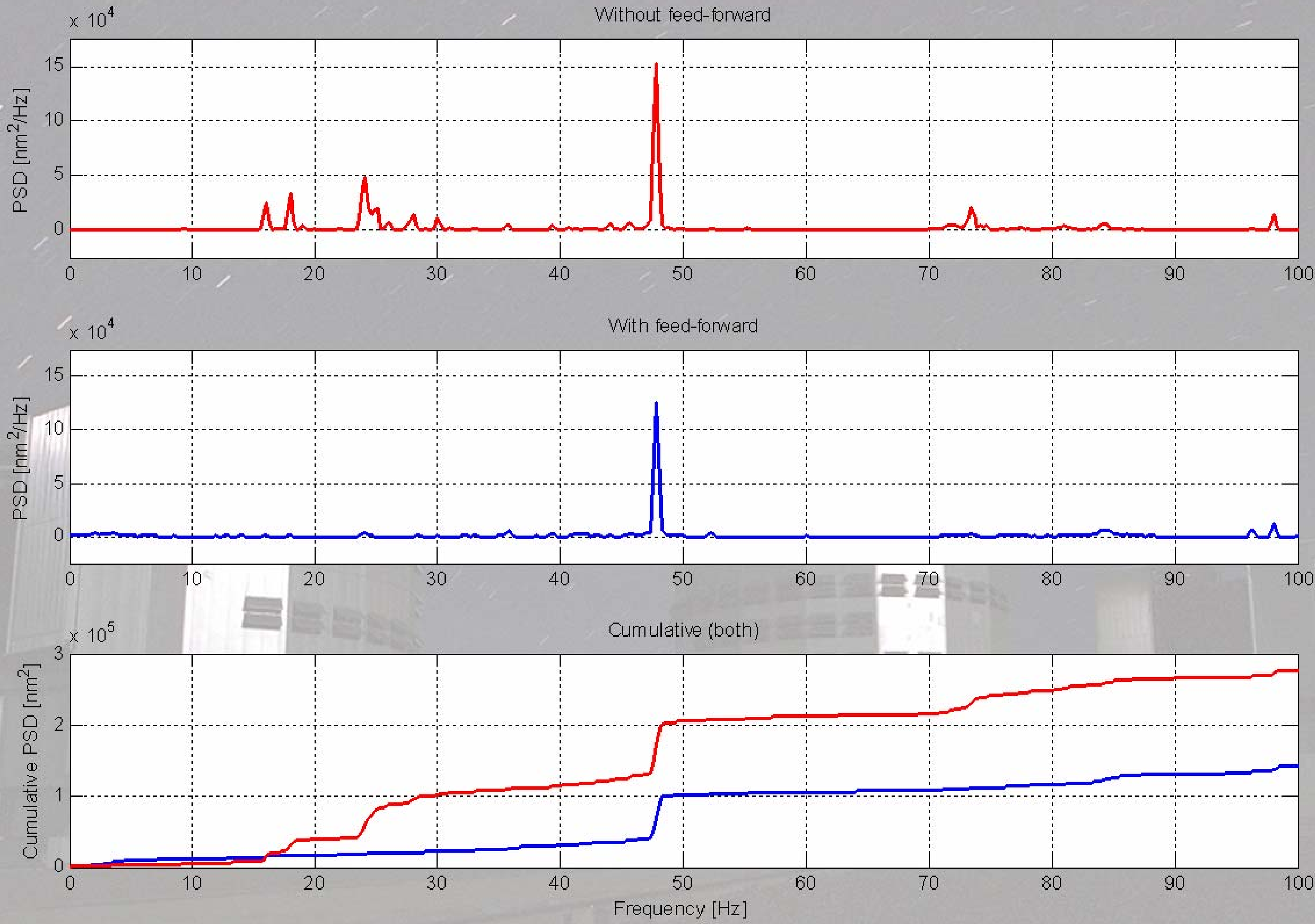
Typical OPD residual spectra



Typical OPD residual spectra



Typical OPD residual spectra



Conclusions

- Accelerometer based feed-forward cancellation is a simple, robust and effective solution to reduce the impact of vibrations on the VLT interferometer.
- The system is in current use on three out of four Unit Telescopes, where it consistently brings down OPD residuals by approximately 50% in power terms (typically from ~530 to ~380 nm rms in average conditions).
- Further effort is ongoing to identify optical surfaces responsible for uncompensated vibrations and place extra accelerometers on them.