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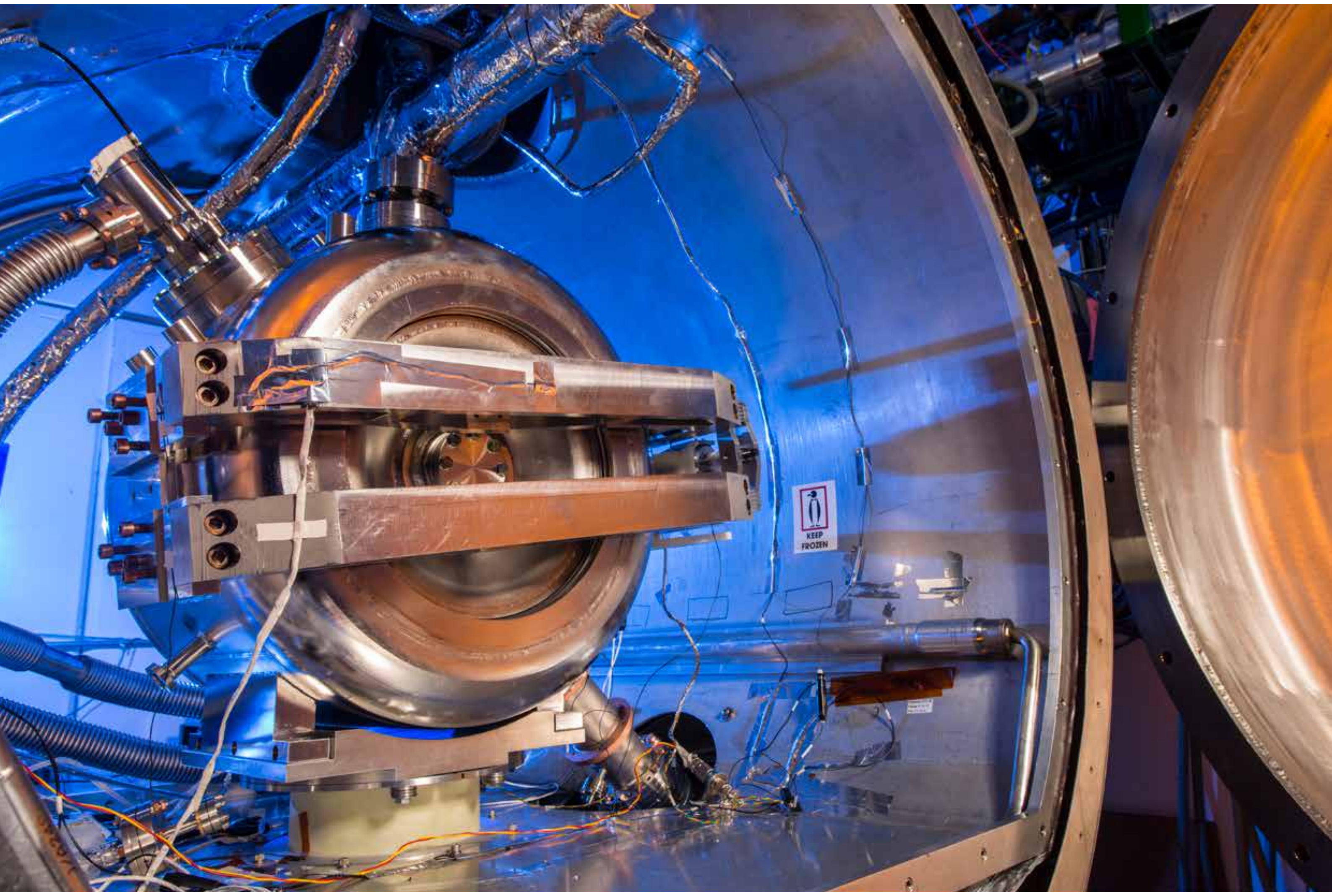
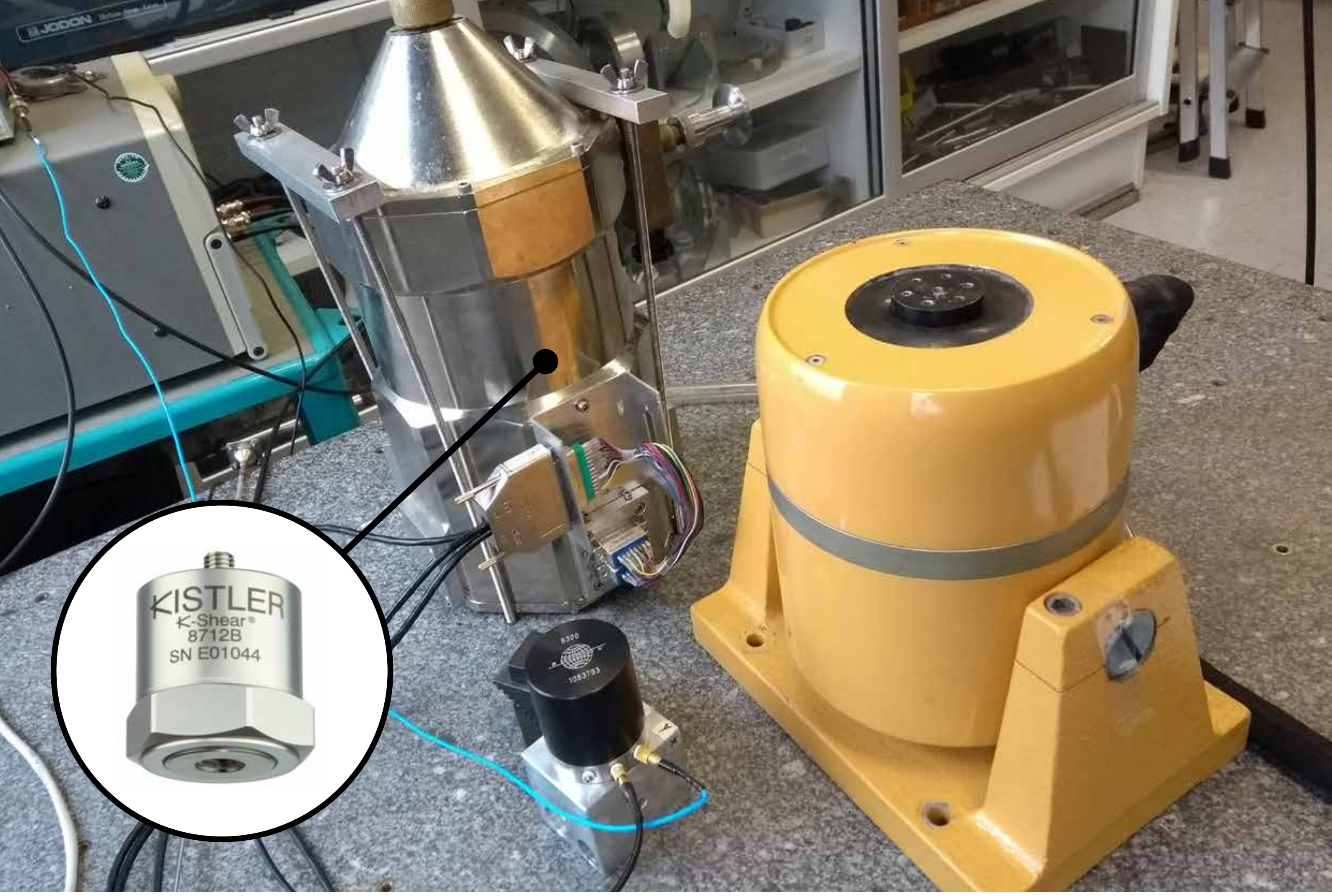


Smooth performance near absolute zero

SRON trials highly sensitive cryogenic accelerometers to detect micro-vibrations in supercold environment



Test setup of the test cryostat, shaker and reference accelerometer from Kistler clamped at an optical table.

SRON is developing a pioneering space telescope for an X-ray observatory planned by ESA (European Space Agency). They tested the highly sensitive accelerometer 8712B5D0CB from Kistler to verify that it is suitable to measure micro-vibrations under cryogenic conditions near absolute zero. The aim was to gain further insights on how micro-vibrations influence the temperature stability of the involved FPA (Focal Plane Assembly). The FPA serves to cool down the space telescope's highly sensitive heat detectors.

Scientists looking for breakthroughs in astrophysical, atmospheric and exoplanetary research need ever more sensitive space telescopes and satellites. The SRON Netherlands Institute for Space Research develops pioneering technology and advanced space instruments. A strong focus lies on cryogenic detector systems, currently the only systems reaching the extreme sensitivity that is required for future space applications.

SRON is involved in the development of the scientific X-IFU instrument (X-ray Integral Field Unit) for the European Space Agency's (ESA) Athena X-ray space observatory, which is planned for launch in the early 2030s. Athena will study hot and energetic clusters of galaxies, black holes and exploding stars. X-IFU will be at the focal point of Athena and uses highly sensitive microcalorimeters, based on transition edge sensors (TES), for measuring the tiny amount of heat released when an X-ray is absorbed.

SRON is developing the focal plane assembly (FPA), in which the TES detectors are cooled at 50 millikelvin. The TES arrays are mechanically suspended to a structure at 2 Kelvin, using an intermediate temperature level of 300 millikelvin.

Cryogenic testing of the highly sensitive accelerometer near absolute zero

The TES detectors and FPAs are being tested and calibrated in dedicated vacuum chambers in SRON's labs, which mimic the thermal environment of the spacecraft. The current mechanical design of the X-IFU's FPA includes Kevlar suspension and is based on heritage and analyses.

However, the influence of micro-vibrations on temperature stability needed further understanding. SRON therefore wanted to measure the relationship between micro-vibration levels and fluctuations at operational temperatures down to 3 Kelvin. They required a small, low mass, low dissipation and highly sensitive cryogenic accelerometer. The accelerometer 8712B5D0CB from Kistler meets all of these requirements, but to find out how the sensor behaves at very low temperatures, SRON researchers tested it in their cryogenic test environment, with the kind support of Kistler.

The goals of the research were to pinpoint how the accelerometer operates at very low temperatures, to test the robustness and to indicate the sensitivity, noise and dissipation at different cryogenic temperatures.

Results of the extreme cryogenic testing near absolute zero
The cryogenic vacuum environment – the cryostat used for testing the actual TES detector arrays, provided the first testbed for testing the accelerometers. From this test, the researchers concluded that the accelerometer still operates at a temperature of 3 Kelvin.

Another cryostat was required to monitor the other properties. In the second test cryostat the highly sensitive accelerometer was thermally cycled 10 times, from room temperature to temperatures of 77 Kelvin and 4.2 Kelvin. After this test, the researchers found no degradation of the accelerometer.

To get an indication of the sensitivity, noise and dissipation of the accelerometer with relation to the temperature, researchers placed the test cryostat on an optical table together with another accelerometer and a small shaker. They measured the response of the accelerometer from Kistler by operating the shaker at a constant low level of 0.5 g and a chosen frequency of 40 Hz, which has no influence on the dynamics of the test cryostat.

The accelerometer from Kistler was measured during warmup from the lowest temperature of 4.2 Kelvin until room temperature, without any liquid helium or liquid nitrogen which would otherwise disturb the measurements.

The dissipation was determined by measuring the bias voltage with bias currents of 2 mA and 4 mA during the warmup of the accelerometer. Finally, the researchers measured the noise at 77 Kelvin and 4 Kelvin in the test cryostat without any liquids.

From their tests, the researchers observed that the highly sensitive cryogenic accelerometer is still operating at 4.2 Kelvin, without any bias current of 2 mA and down to about 77 Kelvin the sensitivity drops with about 20% and below this temperature decreases faster down to about 65%. The loss is less at 4.2 Kelvin with a bias current of 4 mA, but this is at the expense of more dissipation.

Driven by the high dissipation at 4.2 Kelvin, the researchers now want to investigate, if the accelerometer can be read out intermittent, using the same setup for cryogenic testing, without influence on the gain stability which is shown to be temperature-dependent.

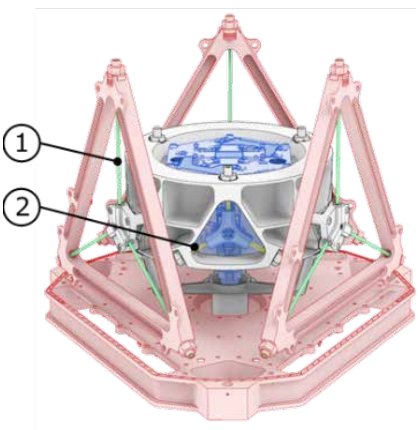
Specific acceleration sensor design
Typical vibration measurements call for usage of IEPE accelerometers (Integrated Electronic Piezoelectric). Such sensor designs are based on a piezoelectric element. When subjected to the load from a seismic mass, the element generates a charge proportional to the acceleration which in turn is converted to a voltage by the internal electronics.

Standard sensors from the market are mostly using a piezoceramic as the piezoelectric element. These designs provide an economical solution while ensuring very good performance, but unfortunately exhibit poor temperature stability performance when subjected to temperature fluctuations. In such cases, sensing elements based on quartz are preferred when the application environment is thermally active. Kistler went even one step further over the past 15 years, by developing a family of synthetic single crystals, called PiezoStar, which have unique properties.

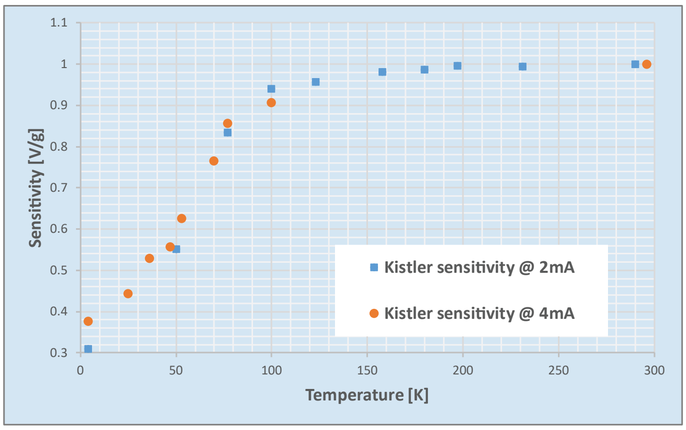
The PiezoStar family of crystals has improved with a low temperature coefficient of sensitivity and higher piezoelectric sensitivity compared to quartz requiring less mass and less electrical amplification and lower noise. Less element mass equates to higher mounted resonance frequencies, better frequency response and allows smaller overall housing designs. Some accelerometers, such as the 8712B5D0CB discussed above are available in a cryogenic version which is qualified at Kistler to measure temperatures down to –196°C.

The type 8712B5D0CB sensor requires specific IEPE electronics that can withstand temperature levels of –196°C and even lower. To do so, Kistler has developed a proprietary coating to protect the electronic components and facilitate proper performance in a cryogenic environment.

In addition, at extreme cryogenic levels such as 4 Kelvin, the IEPE sensor output bias voltage increases substantially, thus requiring a higher compliance voltage. Typically, a compliance voltage of 34 VDC (voltage direct current) or higher is required for the extreme cryogenic temperatures requiring specifically designed couplers.



3D-model of a partial FPA to indicate the different temperature levels and thermal suspension. Its stability underwent testing with a highly sensitive cryogenic accelerometer designed to detect micro-vibrations.



Graph of the sensitivity of the accelerometer from Kistler related to the temperature for 2 different bias currents during cryogenic testing

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Kistler Group
Eulachstrasse 22
8408 Winterthur
Switzerland
Tel. +41 52 224 11 11

Find your local contact at
www.kistler.com

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