Evaluation of optical fibre and components at cryogenic temperatures

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Introduction

Advancement in far-infrared astronomy requires that future space telescopes employ cryogenically cooled mirrors and instruments. Although cryogenic cooling enables full exploitation of the sensitivity in state-of-the-art bolometer detectors, cryogenic operation comes with several challenges.

As not just mirrors and detectors, but entire instruments, must be cooled, every component of the instrument must be operable at cryogenic temperatures. Optical fibre and fibre components are increasing in popularity due to their low-cost, light weight, ease of installation, and ability to route optical signals to and from target areas. The performance of commercial-off-the-shelf fibre and components is well understood at room temperature, but for employment in cryogenic applications, must be understood at temperatures < 4 K.

Blue Sky Spectroscopy Inc.

Blue Sky Spectroscopy Inc. has a long heritage in the development of custom Fourier transform spectrometers (FTS) and the associated data acquisition and analysis software for both ground and space-based astronomy. Blue Sky Spectroscopy Inc. was proud to host the Data Processing and Science Analysis Software (DAPSAS) for the SPIRE FTS on the European Space Agency's (ESA) Herschel Space Observatory, launched in 2009. This ground-breaking observatory produced our first unbiased view of the far-infrared universe and has caused astronomers to re-examine their theories of star formation, provided our first large scale view of distant galaxies, and garnered national and international awards.

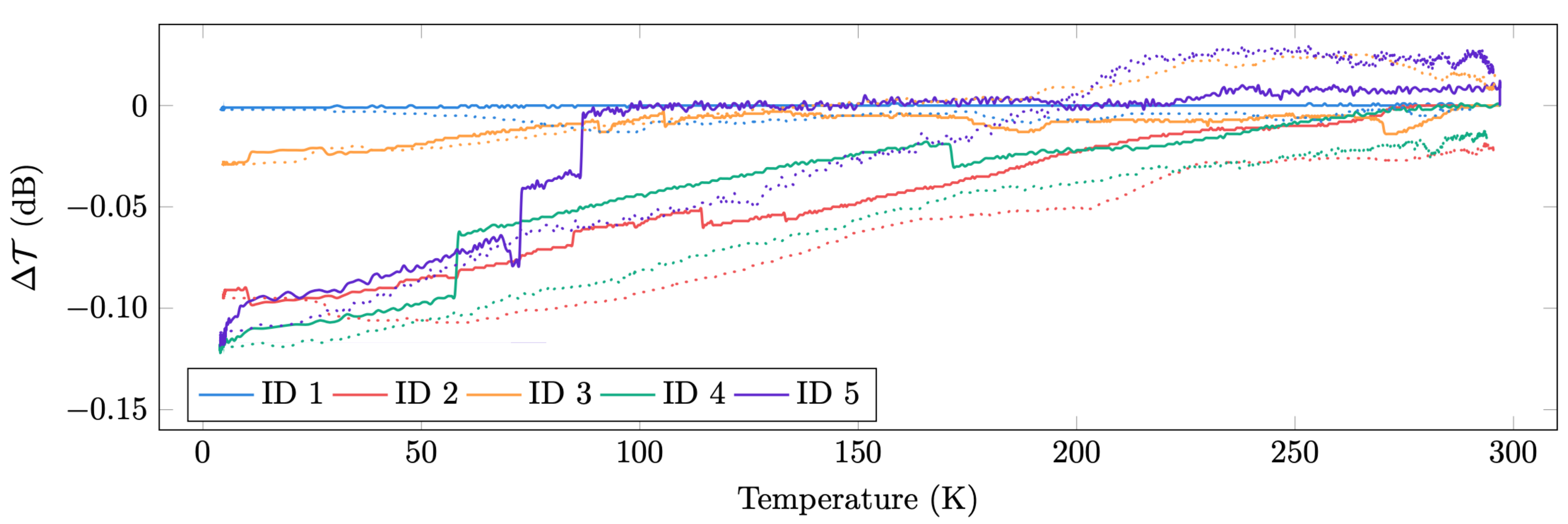
Recognizing the immense gain in sensitivity that can be achieved by cooling a Herschel type telescope, ESA and the Japan Aerospace Exploration Agency (JAXA) joined forces to develop the Space Infrared telescope for Cosmology and Astrophysics (SPICA). Blue Sky Spectroscopy Inc. was awarded Canadian Space Agency (CSA) funding under the Space Technology Development Program to develop a data processing framework for post-dispersed polarizing FTS that was a strong candidate for the SPICA/SAFARI instrument.

In collaboration with ITER-India, Blue Sky Spectroscopy Inc. is contributing an FTS for the measurement of electron cyclotron emission as a diagnostic tool in the ITER thermonuclear reactor – the largest nuclear fusion experiment ever attempted. Blue Sky Spectroscopy Inc. is exploring new and unique designs for the ITER FTS and is proudly at the forefront of Canadian contributions to ITER.

Fibre Termination and Mating

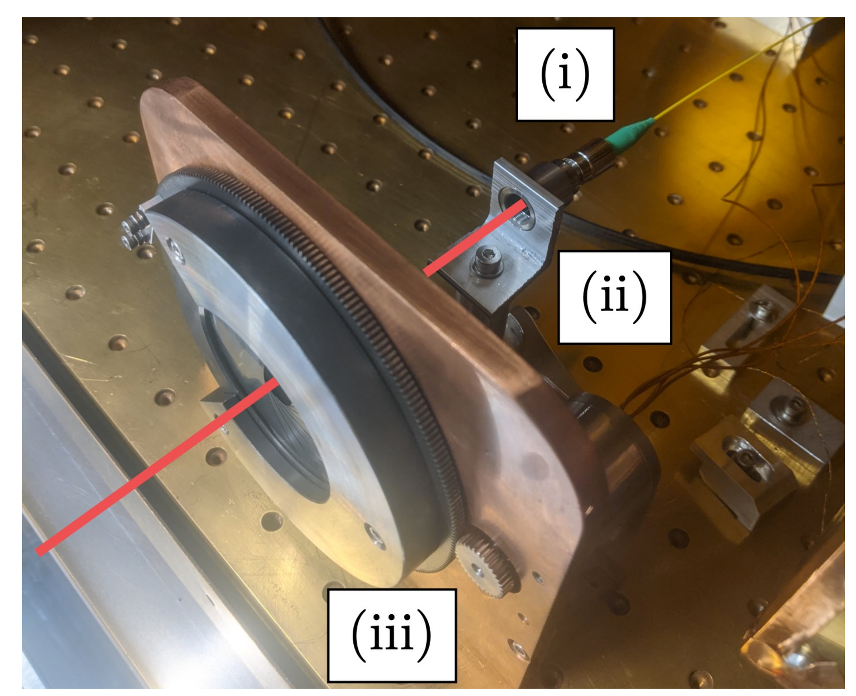
Custom 1 m SMF-28 Ultra fibre patch cables were assembled and mated using different connectors (FC/APC and FC/PC) and mating sleeves (standard two-piece and monolithic). The changes in transmission while cooling (ΔT_{cool}) and for the entire cycle (ΔT_{cyc}) were measured.

ID	Termination	Mating Sleeve	ΔT_{cool} (dB)	ΔT_{cyc} (dB)
1	—	—	-0.002 ± 0.001	-0.002 ± 0.001
2	FC/APC	Two-piece	-0.093 ± 0.001	-0.019 ± 0.001
3	FC/APC	Monolithic	-0.028 ± 0.001	$+0.015 \pm 0.001$
4	FC/PC	Two-piece	-0.118 ± 0.002	-0.014 ± 0.002
5	FC/PC	Monolithic	-0.126 ± 0.002	$+0.009 \pm 0.003$



Fibre Collimation

The beam shape and quality produced by a fibre collimator change when cooled, as the collimator lens, housing, and epoxy contract at different rates. The beam profile of a commercial-off-the-shelf stainless steel collimator and a custom Kovar collimator were cooled and monitored. In the testing apparatus (right) a collimator (i) is mounted to the 4 K plate of a cryostat (ii) and the beam passes through a cryogenic iris (iii) to be recorded by an external SWIR camera.

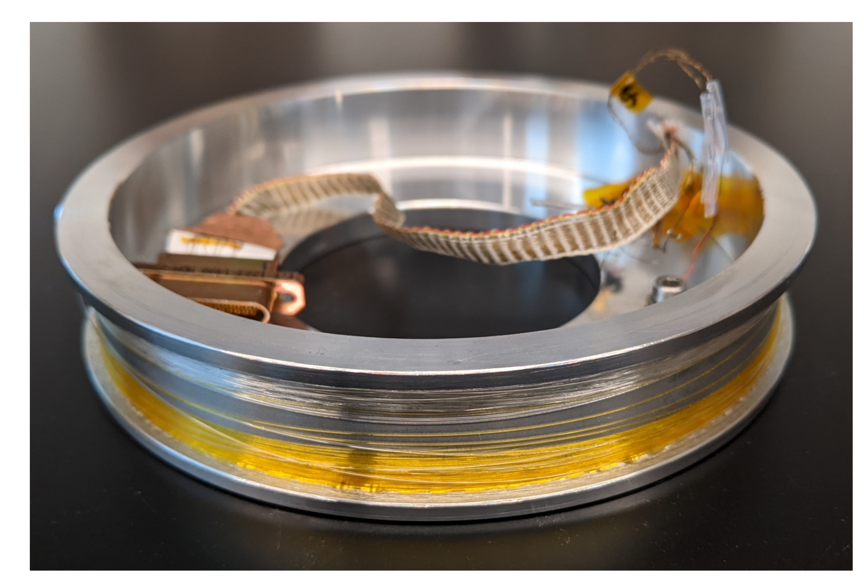


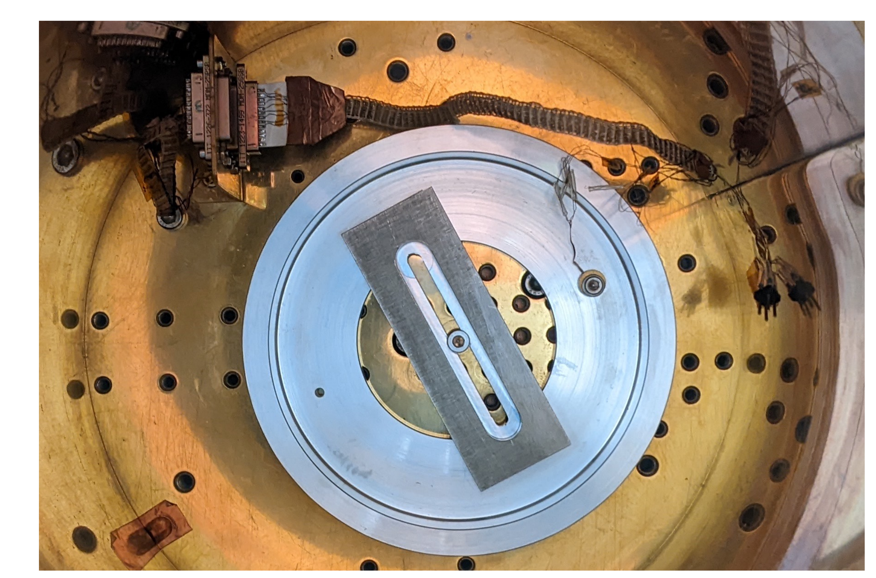
2-D Gaussian profiles were fitted during the temperature descent for both collimators. The amplitude through the Kovar collimator increased by 16%, while a decrease of 21% was observed for the stainless steel collimator. The average FWHM of the Kovar collimator decreased by 54 µm while the stainless steel increased by 22 µm. The horizontal position of the beam changed by 20 µm for Kovar collimator and 143 µm for the stainless steel, while the vertical position drifts by 1012 µm and 922µm, respectively. Vertical drift is negligible since it is due to the cryostat being pulled upwards as it contracts.

Fibre Coatings

In collaboration with OFS, the performance effects of acrylate and polyimide coatings for fibre optics are evaluated at cryogenic temperatures. Polyimide coated fibres are commonly used in high temperature applications, however, their performance at temperatures < 4 K is currently unexplored.

To guarantee the same cycling conditions for acrylate and polyimide coated fibres, a custom aluminum bobbin was constructed which can hold two 20 m lengths of fibre for simultaneous cycling. Testing includes optical loss monitoring while cooling and mechanical testing after cycling. Pictured below: (left) is the custom aluminum bobbin with 20 m acrylate (clear) and polyimide (amber) coated fibres and temperature sensor; (right) the bobbin installed in a cryostat.





References & Acknowledgements

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A. Christiansen, *et al*. "A cryogenic FMCW range-resolved laser interferometer: challenges and applications". 12008:25–38, 2022.

Conclusions

When cryogenically cooled, FC/APC fibre termination outperforms FC/PC, and there is insufficient evidence support of the more expensive monolithic mating sleeve over a standard two-piece sleeve. The divergence of the Kovar collimator decreased when cooling and outperformed the stainless steel collimator. Cryogenic testing of acrylate and polyimide coated fibres is ongoing.