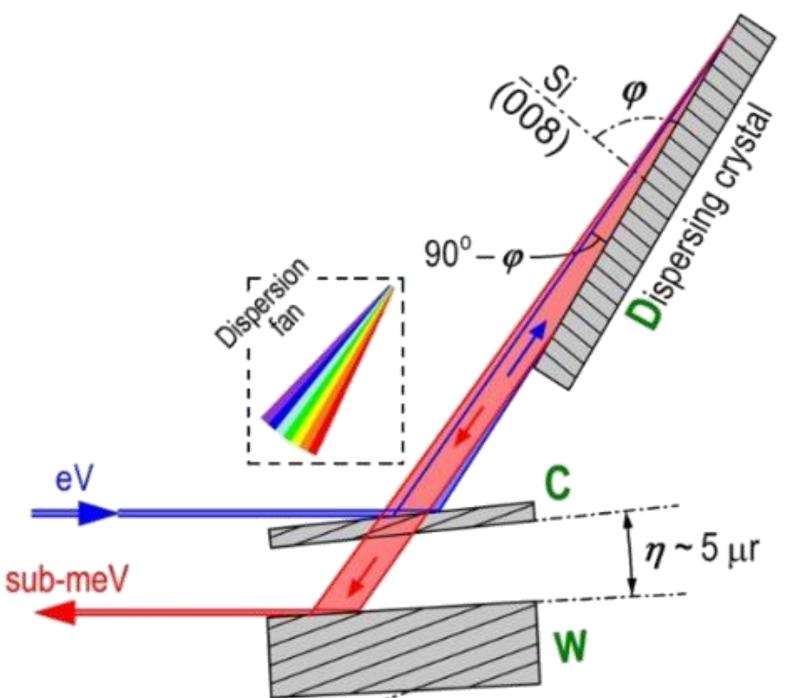
## TEMPERATURE CONTROL OF CRYSTAL OPTICS FOR ULTRAHIGH-RESOLUTION APPLICATIONS

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The temperature control of crystal optics is critical for ultrahigh-resolution applications such as those used in meV-resolved Inelastic X-ray Scattering (IXS). Due to the low count rate and long acquisition time of these experiments, for 1-meV energy resolution at ~10 keV, the absolute temperature stability of the crystal optics must be maintained below 4 mK for days to ensure the required stability of the lattice constant, thereby ensuring the energy stability of the optics. Furthermore, the temperature control with sub-mK resolution enables setting the absolute temperature of the individual crystal, making it possible to align the reflection energy of each crystal's rocking curve in sub-meV precision thereby maximizing the combined efficiency of the crystal optics.



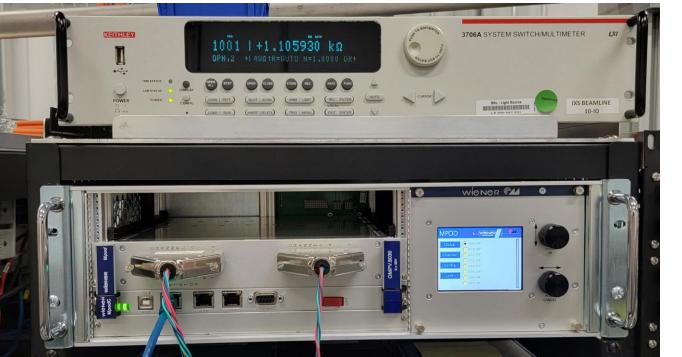


Figure 2: Keithley 3706A (top), and MPOD power supply (bottom).

CH 25 ON OHM 4W	RAW:	1105.5247800000 онм
Ch25 desc OFF	CALC:	27.0001739887 Ch25 Units
CH 26 ON OHM 4W	RAW:	1106.0526990000 онм
Ch26 desc OFF	CALC:	27.1352503646 Ch26 Units
CH 27 ON OHM 4W	RAW:	1105.8437060000 онм
Ch27 desc OFF	CALC:	27.0817762198 Ch27 Units
CH 28 ON OHM 4W	RAW:	1105.9398740000 онм
Ch28 desc OFF	CALC:	27.1063823146 Ch28 Units
CH 29 ON OHM 4W	RAW:	1105.7417500000 онм
Ch29 desc OFF	CALC:	27.0556891743 Ch29 Units
CH 30 ON OHM 4W	RAW:	1105.9665010000 онм
Ch30 desc OFF	CALC:	27.1131952511 Ch30 Units

Attached heater

Figure 6: Crystal housing assembly showing the heater and sensor attachment to the D-crystal. Figure 3: Temperature PVs read from Keithley 3706A for each PT1000 sensor.

URA PI	D: XF:10ID-C	T{FbPid:01}	PID	
DESC EPID feedback		EGU C		PREC 5 C
Wiener Power 😑 🛛 DT	10.00000 C	10 second	MDT	0.00000 C
EPID input				
27.00000 C set	point (VAL)			
- 26.99994 C	input calc			
0.00006 C follo	wing error (FE)			
EPID output	Or	n P	יוD	Max/Min (



Figure 1. Schematic layout of the analyzer crystal optics employed at the meV-IXS spectrometer of the IXS 10-ID beamline at NSLS-II.

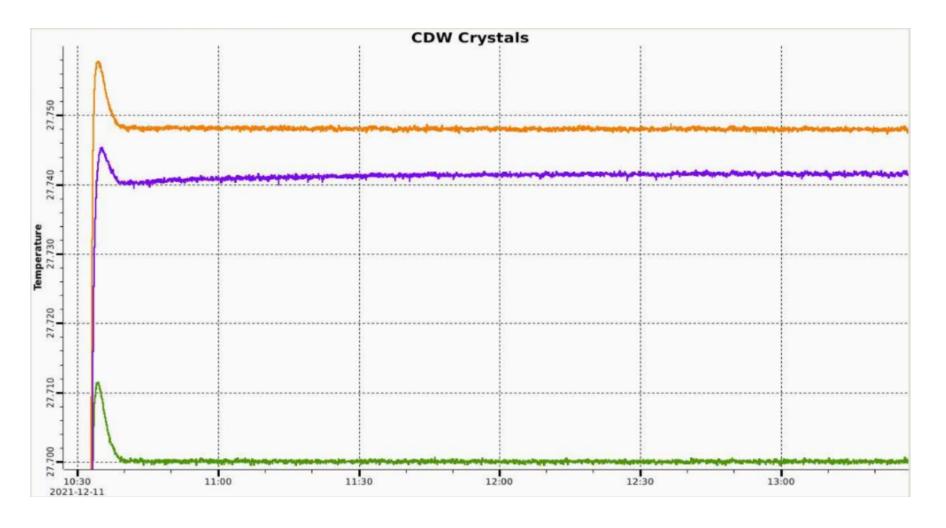
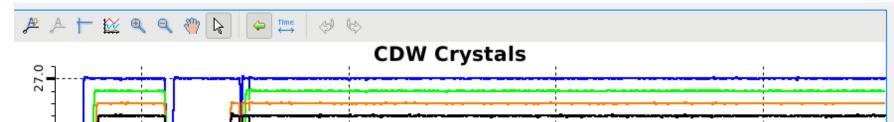


Figure 8: Temperature response of one of the D-crystals. The three PT1000 sensors were mounted at the control point, and each of the two crystal ends respectively



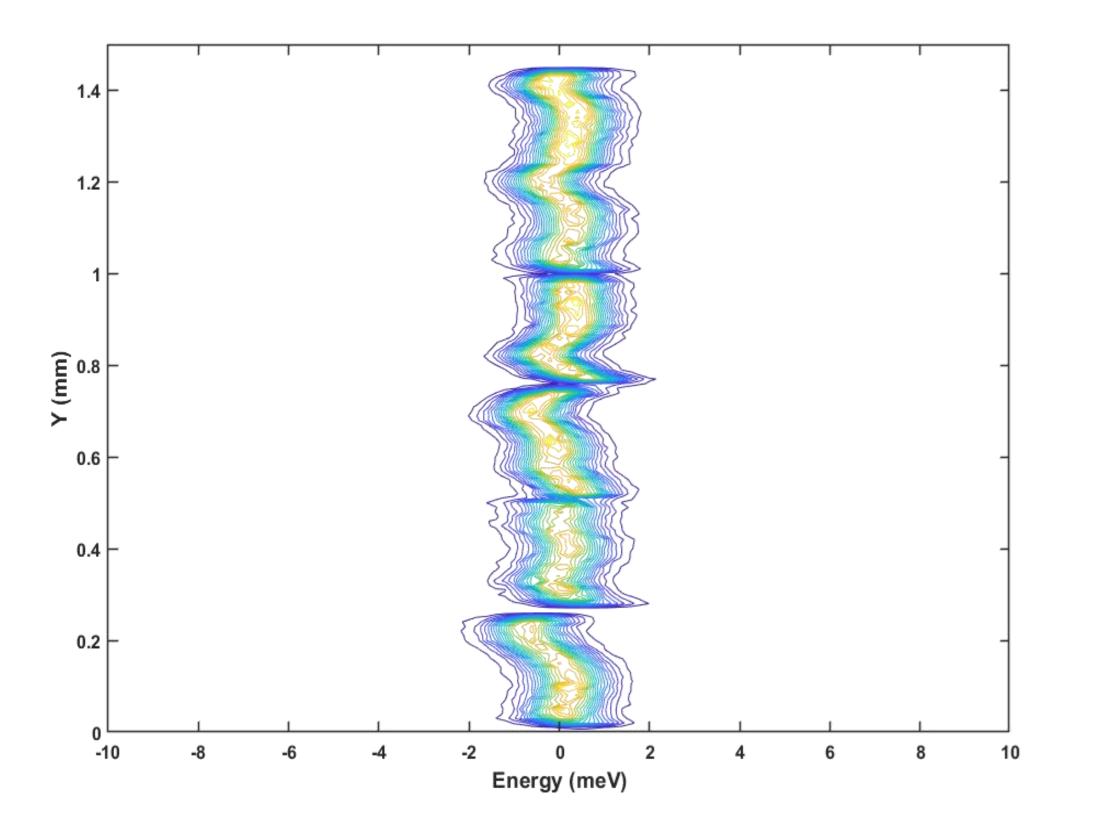


Figure 7: The reflectivity contour of the temperaturestabilized and energy-aligned D-crystals vs. energy resolution. The Y axis corresponds to the beam height for each of the 6 D-crystals in the analyzer.

KP 10.00000 C	0.00055 C P	P = KP * FE
KI 0.00200 C	+ 1.43811 C I	I = KP * KI * sum(FE*DT)
KD 10.00000 C	+ -0.00061 C D	D = KP * KD * (FE[i] - FE[i-1])/DT
0.01000 C	<= 1.43805 C	<= 10.00000 C output calc
'enable' calc	output buffer calc	output calc resume calc

Figure 4: ePID EPICS record computes output power to specific MPOD power supply channel.

HV Supplies	LV Supplies	System			
HV u0 voltag	e <u>ON</u>	OFF	Voltage	: 1.442 V	1.450 V
HV u1 voltag	e <u>ON</u>	OFF	Voltage	: 1.723 V	1.727 V
HV u2 voltag	e ON	OFF	Voltage	: 1.726 V	1.727 V
HV u3 voltag	e ON	OFF	Voltage	: 1.762 V	1.763 V
HV u4 voltag	e ON	OFF	Voltage	: 1.778 V	1.780 V
HV u5 voltag	e ON	OFF	Voltage	: 1.744 V	1.745 V
HV u6 voltag	e ON	OFF	Voltage	: 0.000 V	0.000 V
HV u7 voltag	e ON	OFF I	Voltage	: 0.000 V	0.000 V

Figure 5: MPOD Power supply voltage fed from the ePID EPICS record controls the power delivered to the D-crystals.

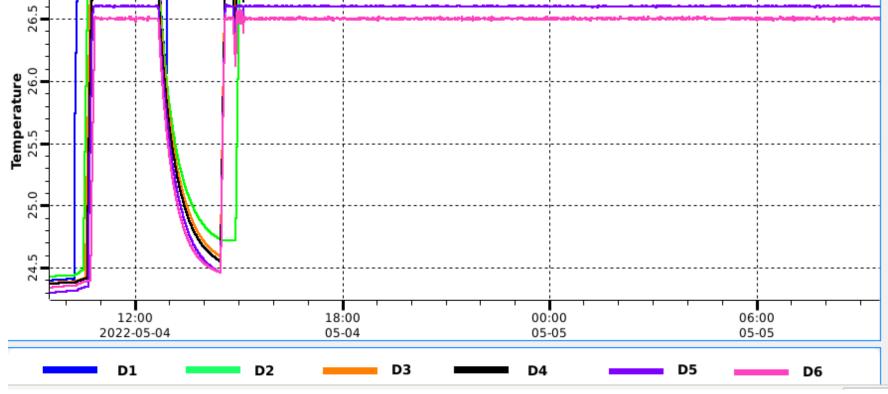


Figure 9: Temperature response of the 6 D-crystals with and without ePID temperature control.

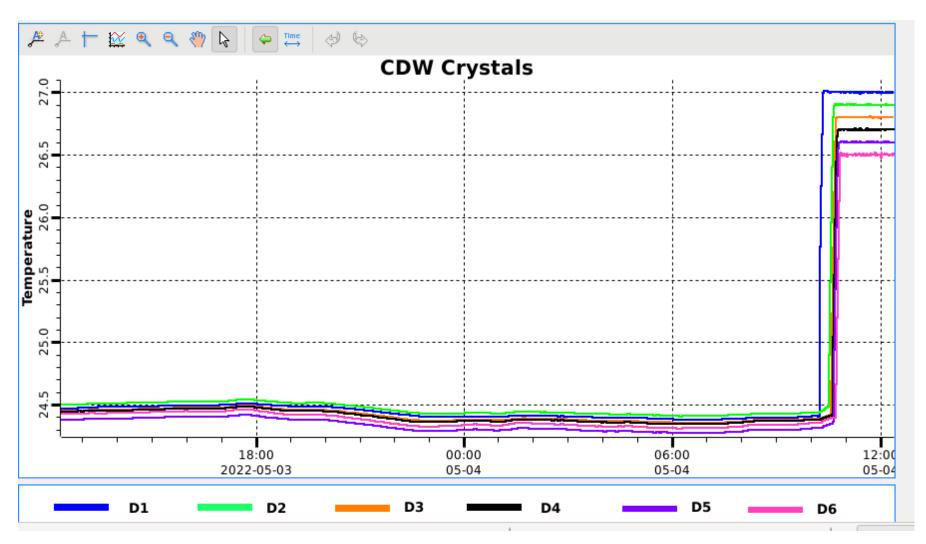


Figure 10: Temperature stability with and without ePID feedback.

CDW Crystals

Using EPICS ePID control we achieved the required 4 mK temperature stability of the Dcrystals for the analyzer crystal optics of the meV-IXS spectrometer for the NSLS-II IXS 10-ID beamline. The temperature stability is less than 1 mK during a typical one-week measurement. Without ePID EPICS temperature control, the temperature stability has been within 100-500 mK. The resulting energy resolution of the IXS 10-ID beamline is now limited by the perfection of crystal optics to about 1.4 meV.

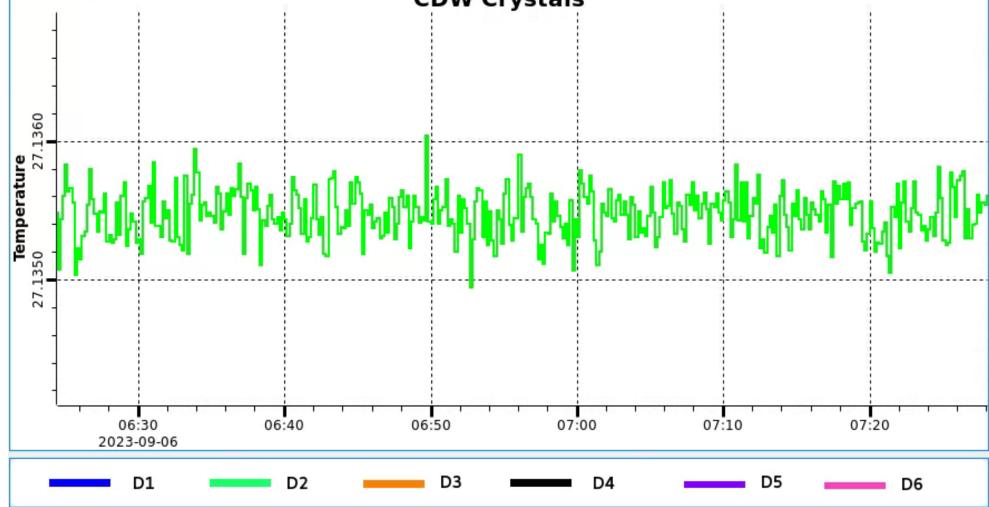


Figure 11: Temperature stability of one of the D crystals with ePID feedback, showing a stability of below 1 mK.

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