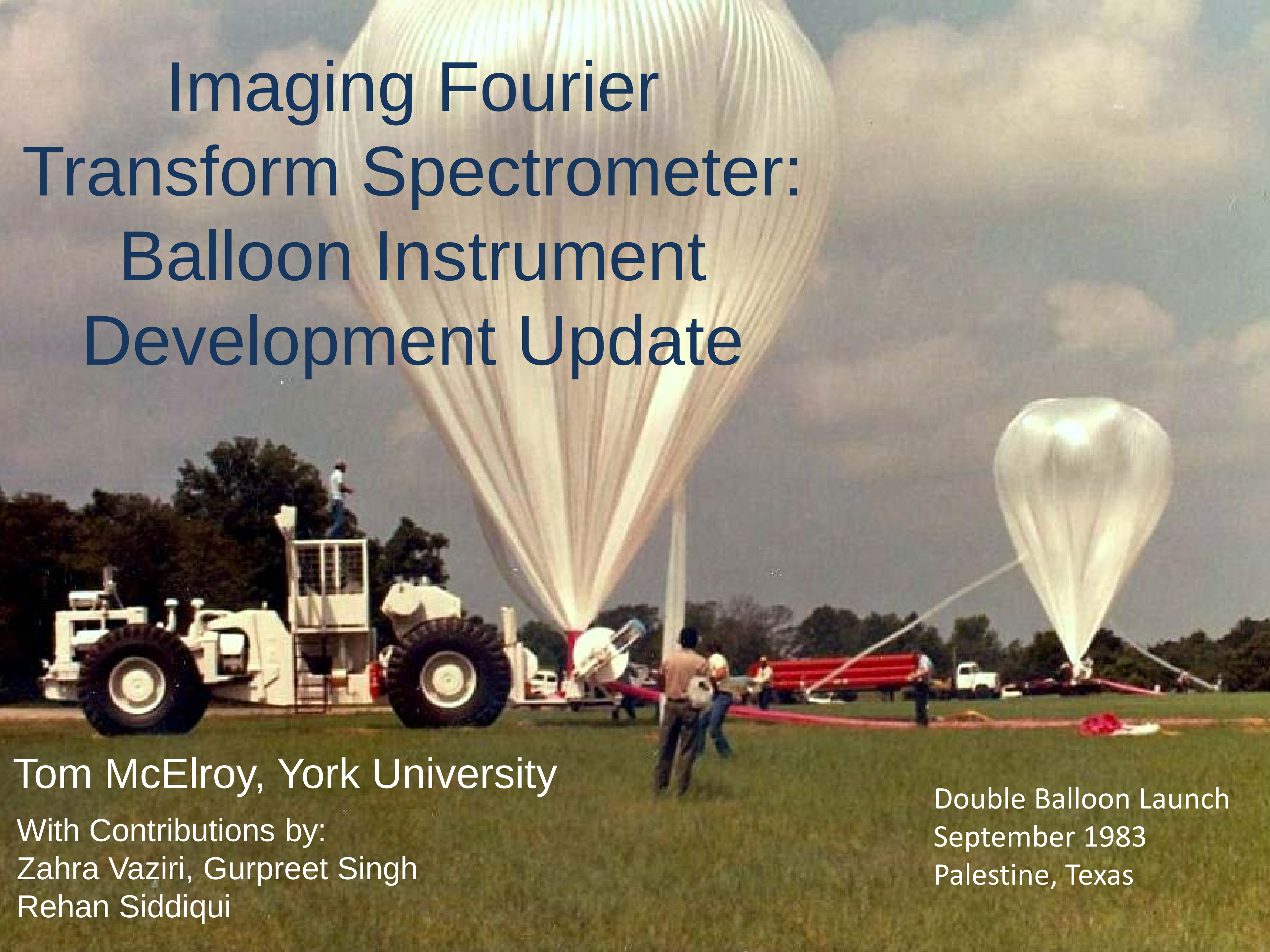
Imaging Fourier Transform Spectrometer: Balloon Instrument Development Update



Double Balloon Launch
September 1983
Palestine, Texas

Tom McElroy, York University

With Contributions by:
Zahra Vaziri, Gurpreet Singh
Rehan Siddiqui

Imaging Fourier Transform Spectrometer Topics for Today:

- Background
- Development Team
- Science Goals
- Hardware development
- The path forward
- Acknowledgements

Development Team

- Zahra Vaziri Ph.D. candidate and project leader
  - Mechanical design
  - Instrument operating software (data acquisition)
  - Pointing system design and test
- Gurpreet Singh M.Sc. Candidate
  - Interferometer testing
  - Data acquisition and analysis
- Rehan Siddiqui Post Doctoral Fellow
  - Data analysis
  - Line-by-line model and retrieval software (just started)
- Chen Zheng Post Doctoral Fellow
  - Pointing system software (moved on)
- David Barton M.Sc. Research Associate
  - Electronics support
  - Logistics
  - Student supervision

Arctic Science

Thermal balance in the Arctic: $F = \sigma T^4$

If the temperature changes, the flux changes by: $dF/dT = 4\,\sigma T^3$

So the change in temperature needed to rebalance after a change in F

$$dT = dF / (4\,\sigma T^3)$$

So the change in **temperature** needed for a given **dF** is larger for a system at lower temperature.

Example: Compare midlatitudes at 273 K to the Arctic at 225 K

$$(273/225)^3 = 1.79$$

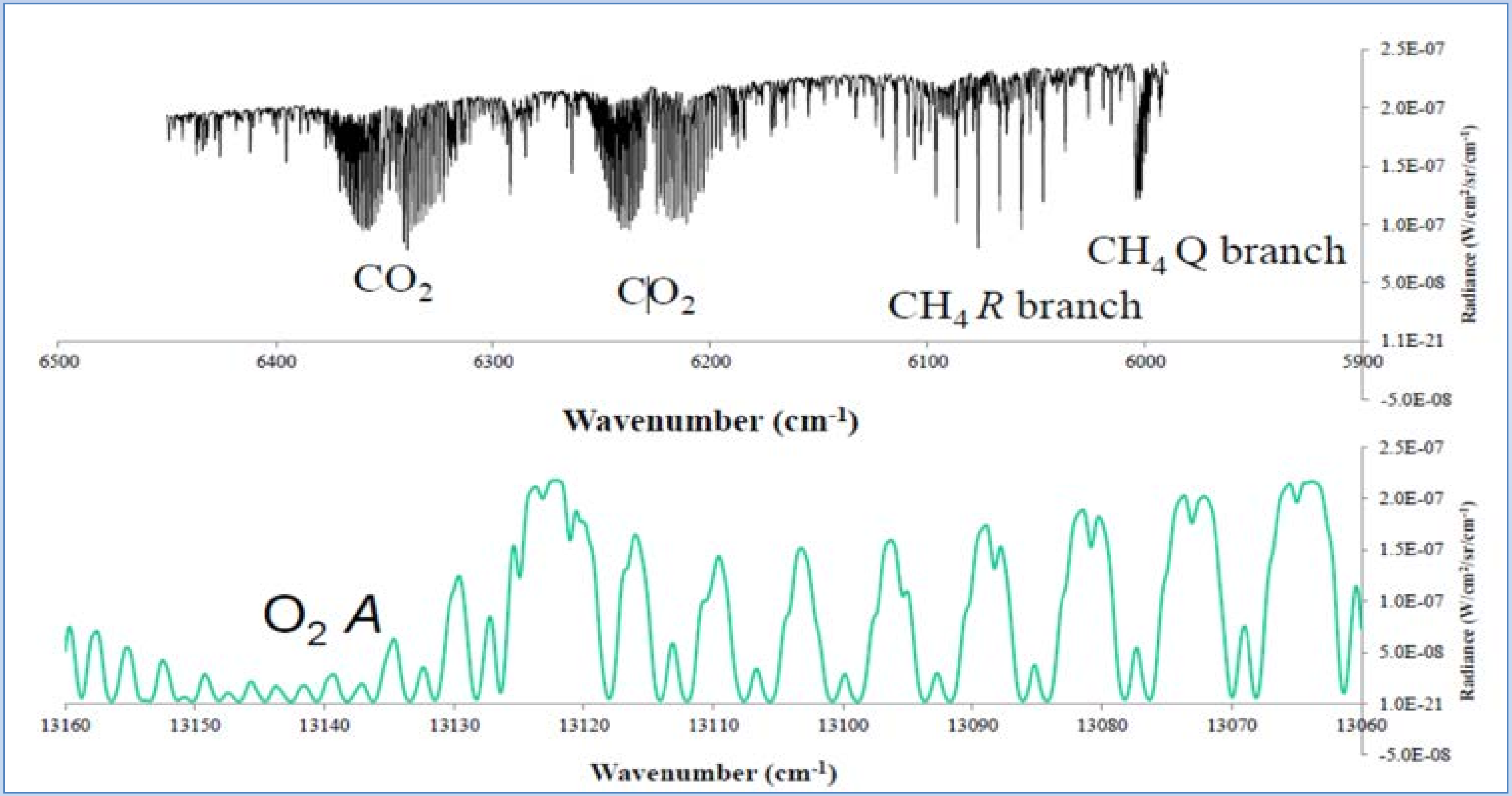
Of course this is multiplied by the effect on radiation as the ice melts (in summer)

Concern: Melting permafrost might release CH_4 and CO_2

Measurements

- Concept originally discussed at a workshop in Banff in 2006
- The PHEOS mission put forward by Jack McConnell and McElroy in 2011
- Went through several phases as a possible add-on to PCW (Polar Communications and Weather Satellite) but PCW went on hold under the Harper government
- CSA funded the work presented here in 2014 to investigate instrument performance issue
- An independent system study is being funded by CSA at ABB with input from Environment and Climate Change Canada (R. Nassar, C. McLinden)

1.6 micron and 762 nm



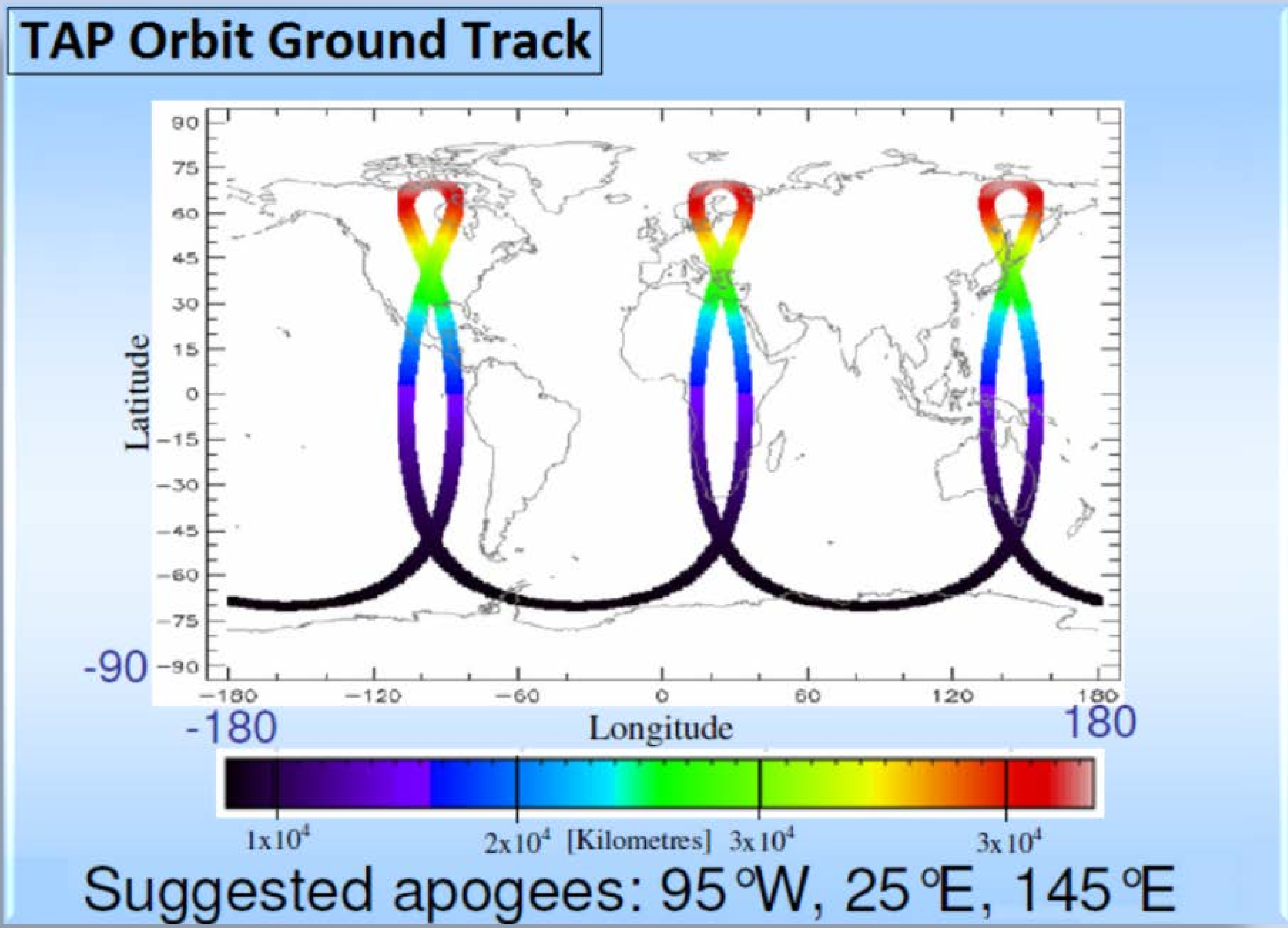
PHEOS
Polar Highly Elliptical Orbit Science

Proposed space mission (PHEOS Alone):

- Environment and Climate Change Canada Initiative
- Two satellites in a three-apogee, highly elliptical orbit
- Quasi-geosynchronous, continuous temporal coverage
- Weather and atmospheric composition data
- Science Payload: Polar Highly Elliptical Orbit Science-Weather Climate and Air quality (PHEOS-WCA)
- Composed of
  - **Imaging IR Fourier transform Spectrometer (IFTS)**
  - Possibly including a UV-VIS spectrometer
  - Weather imager

Three Apogee Orbit

Goal: Geosynchronous-like view of the Arctic

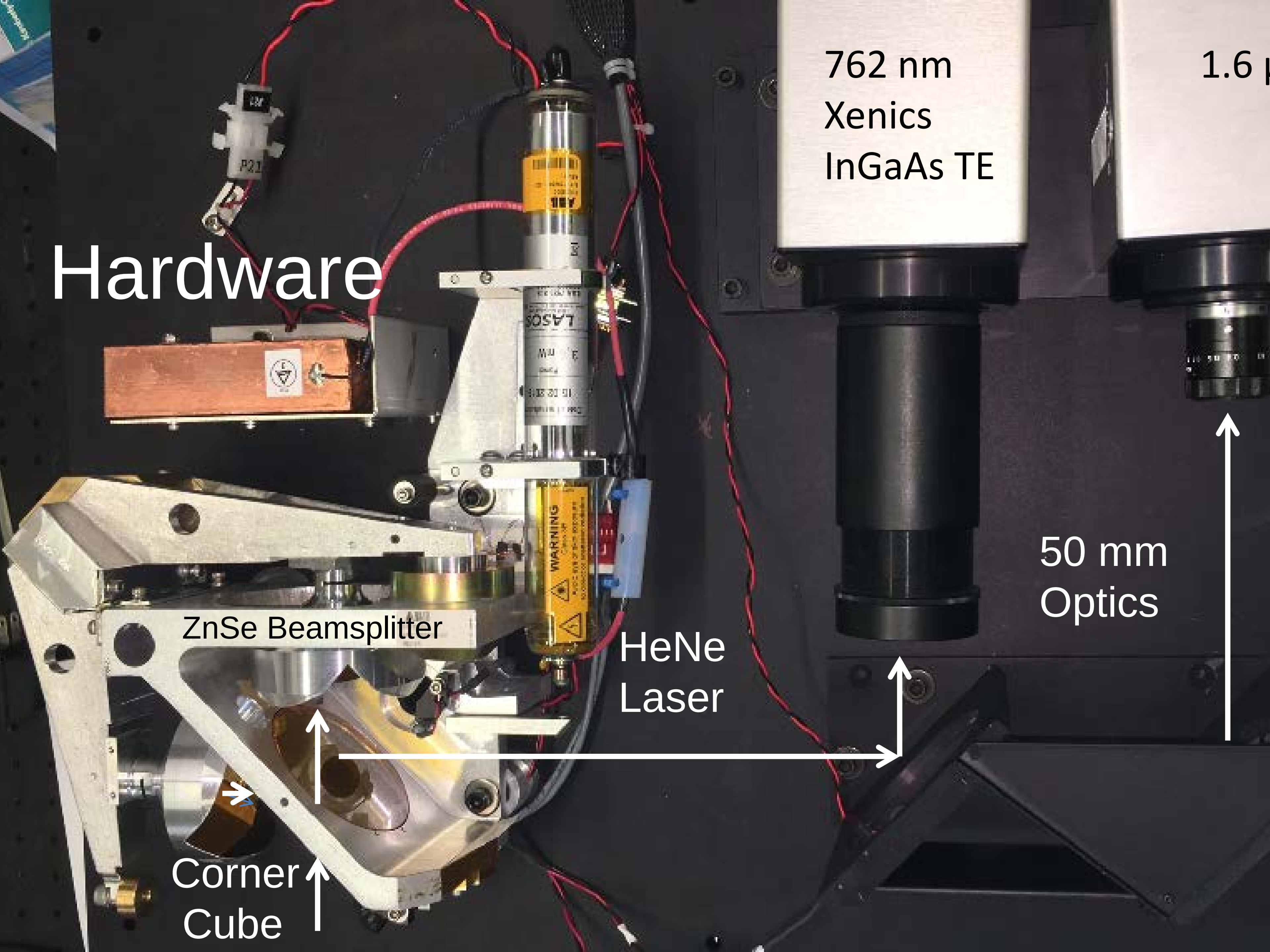


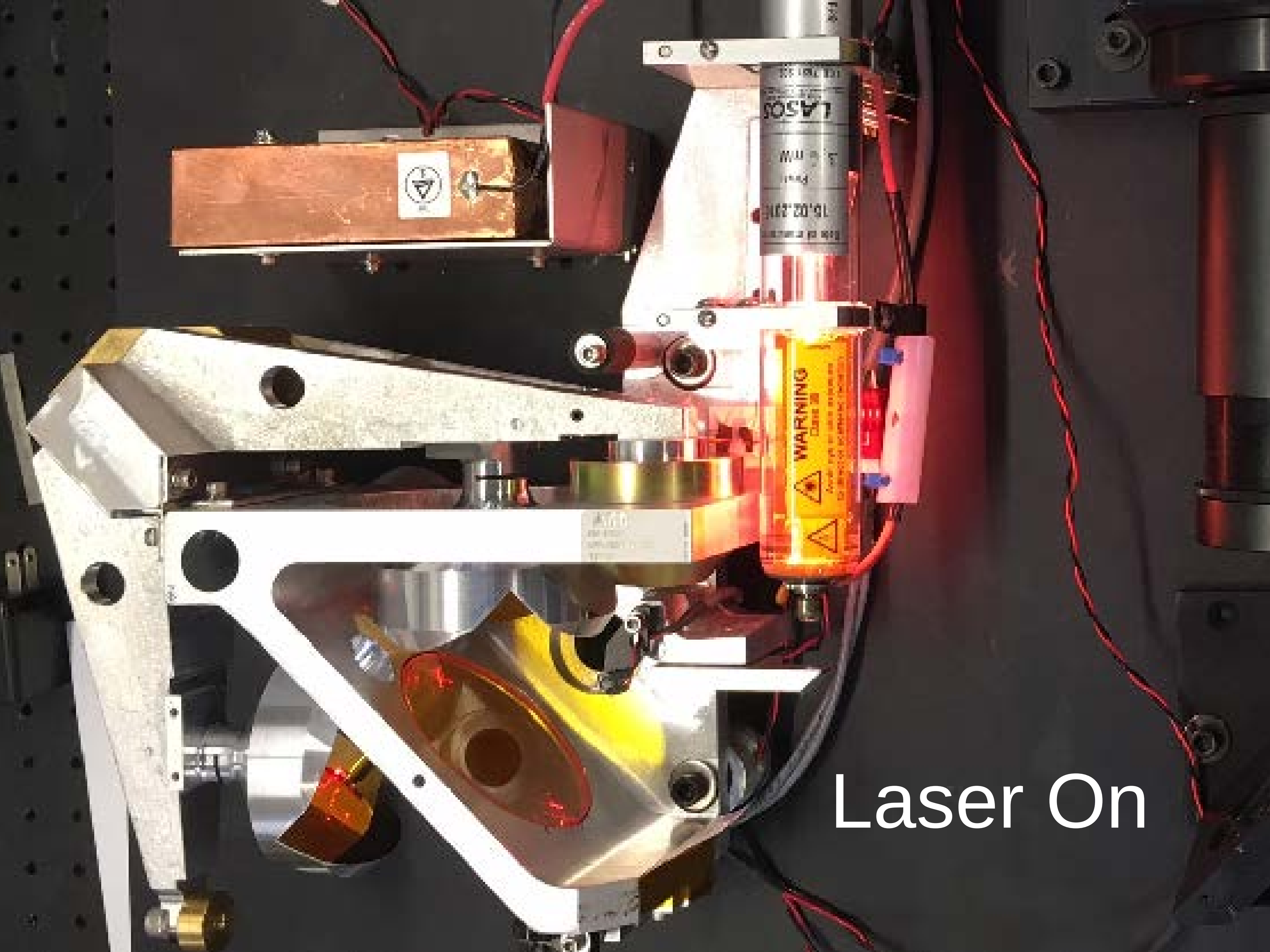
Balloon Project

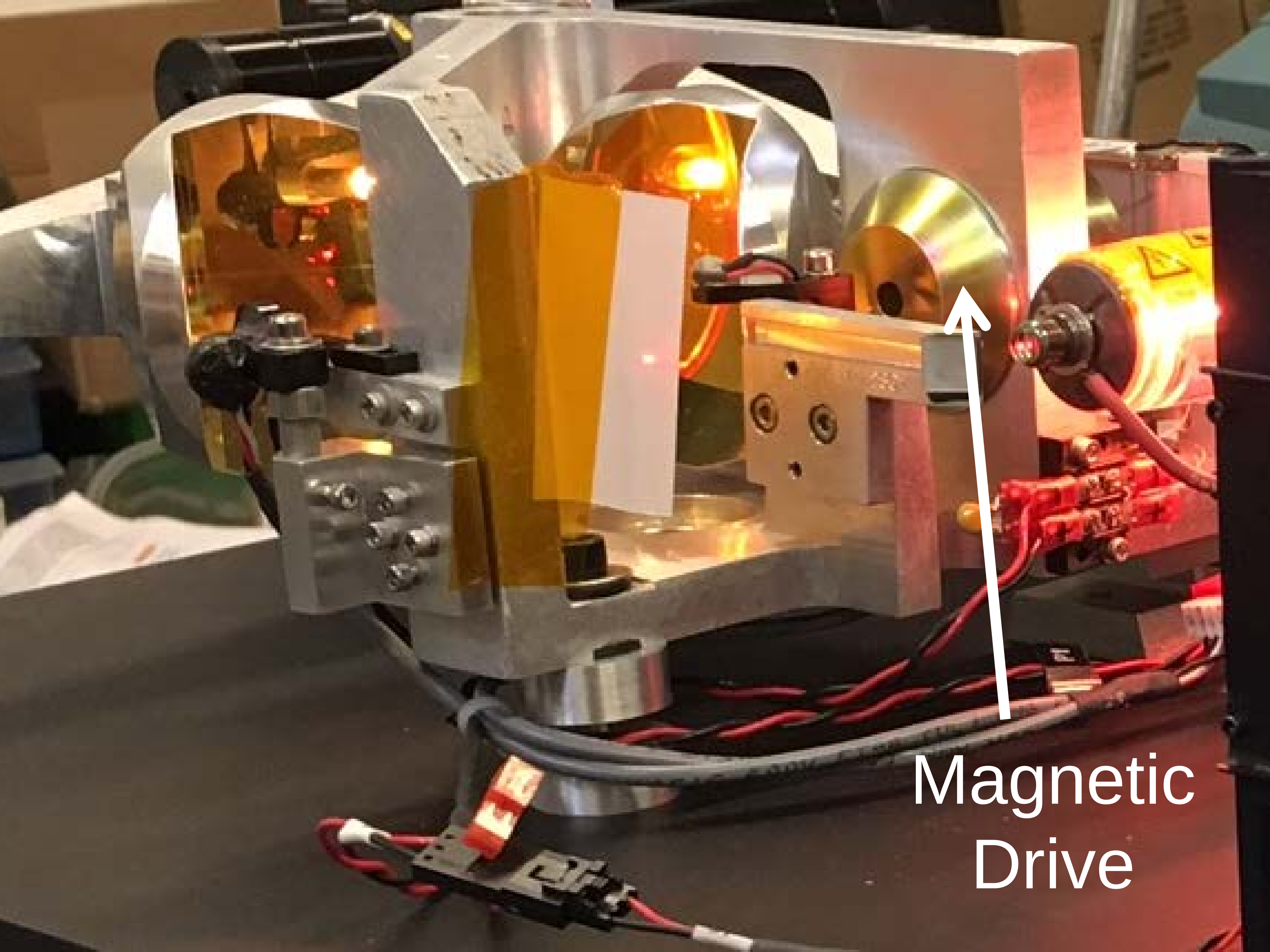
Improve the technical readiness of the Imaging Fourier Transform concept

Supported by a grant from the Canadian Space Agency (CSA) to develop a balloon-based demonstrator

The proposal includes developing a pointing mirror system and an IFTS


Hardware
762 nm
Xenics
InGaAs TE
1.6
ZnSe Beamsplitter
HeNe
Laser
50 mm
Optics
Corner
Cube


LASOS
WARNING
Laser On


Magnetic
Drive

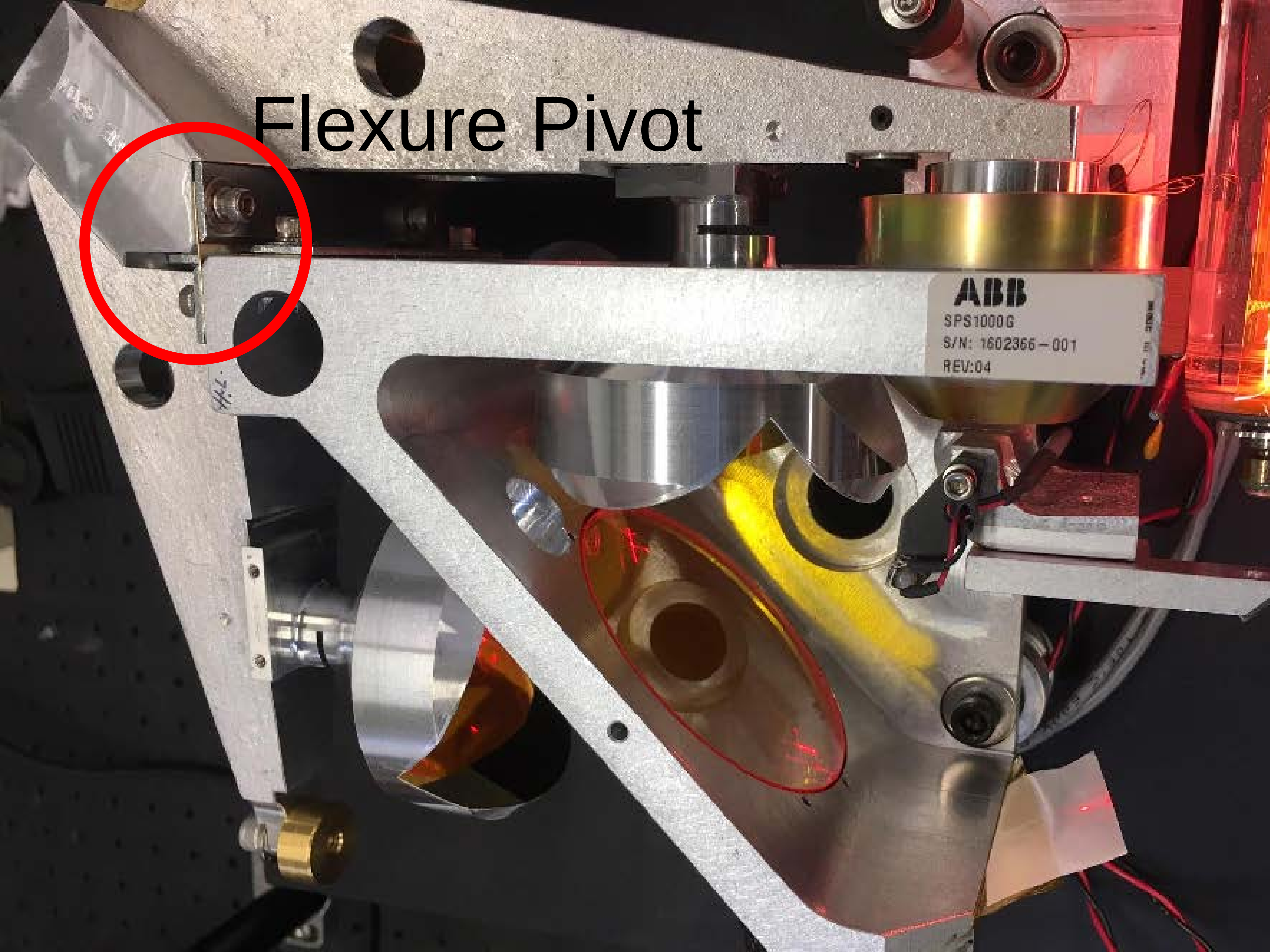
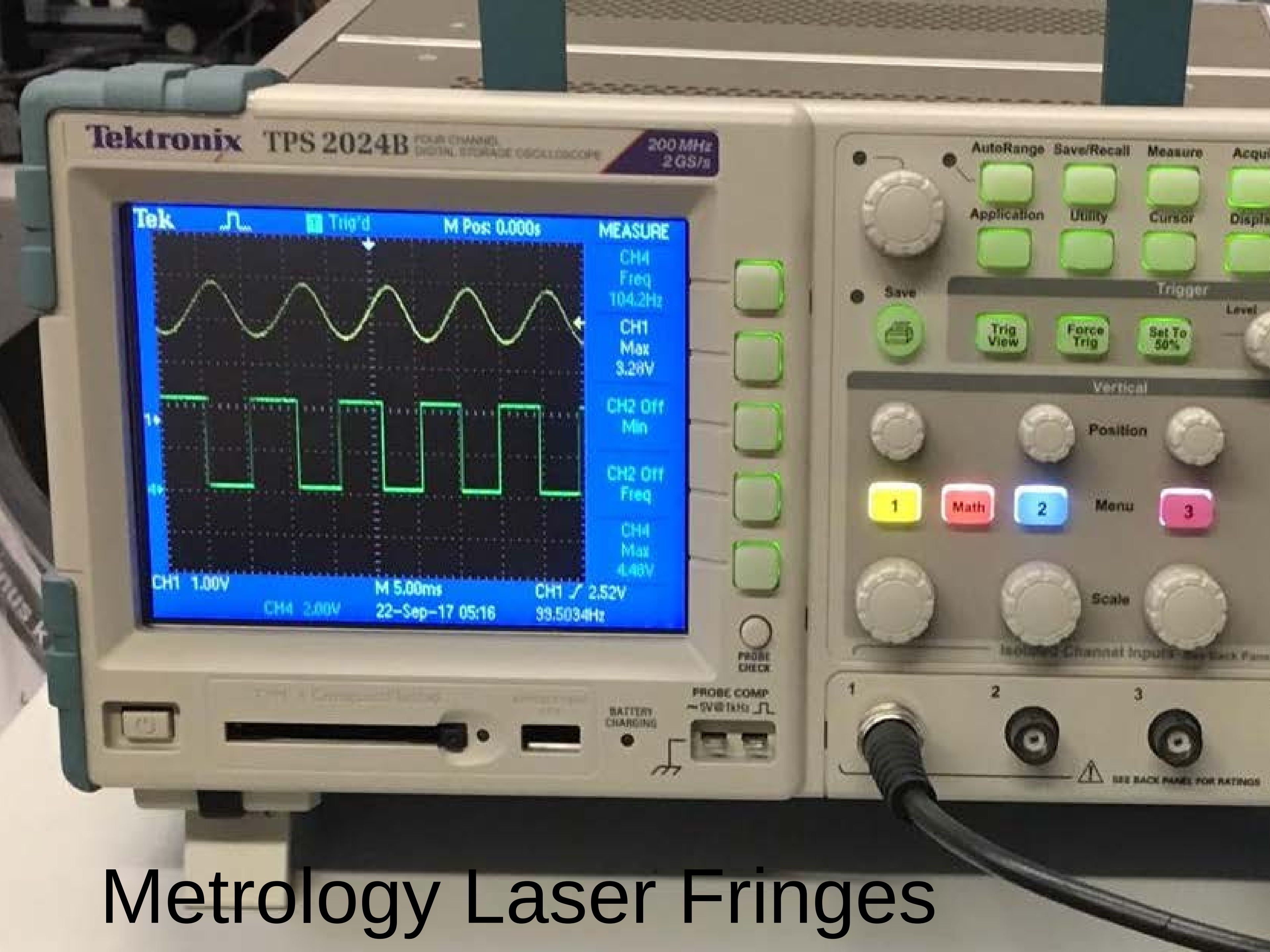

Flexure Pivot
ABB
SPS1000G
S/N: 1602366-001
REV:04

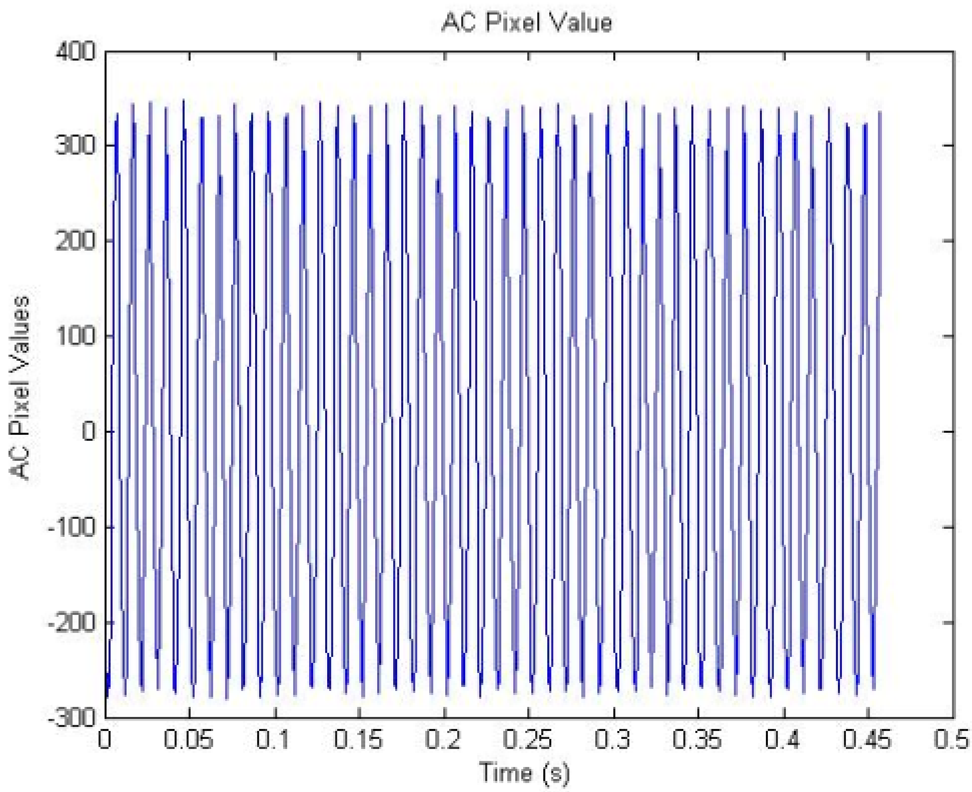

ABB Control Box
POWER
SCAN
DATA
LASER METROLOGY
FRINGE (Analog)
J1
DEPHASE (Analog)
J2
J3
UTILITY SIGNALS
SAMPLING WINDOW
J5
ZPD
J6
SCAN DIRECTION
J7
SPARE
MOTOR & TEMP



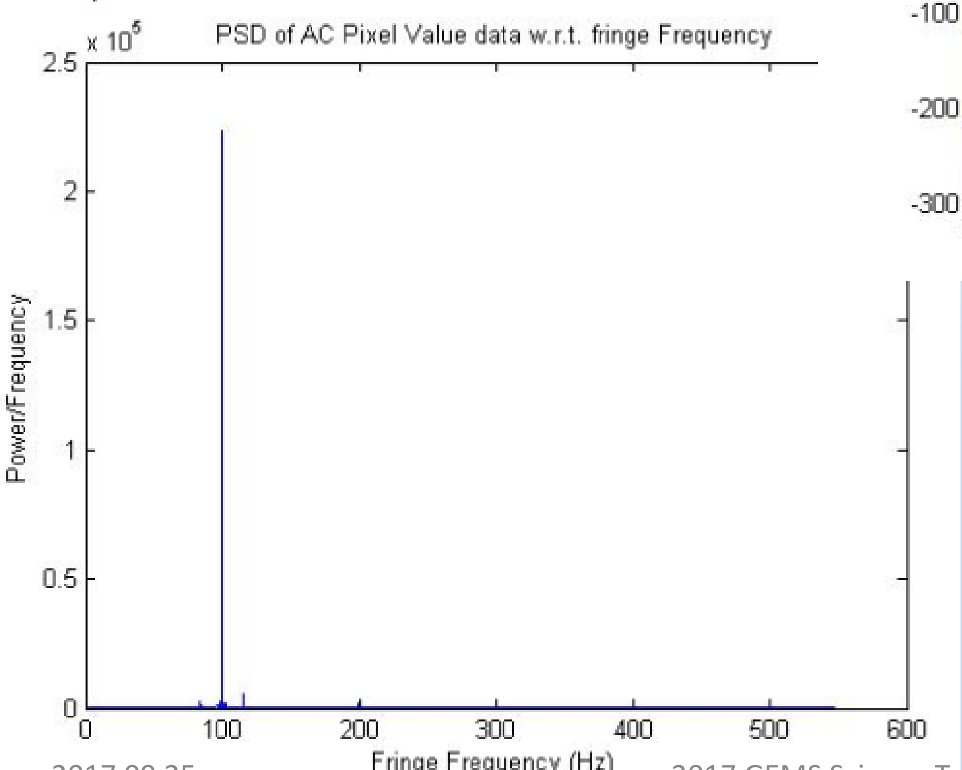
Metrology Laser Fringes

Laser Output

With 500 data points:



With 10,000 points:



The Path Forward

- The original plan was to be flying the instrument with Geoff Toon on a Mk IV interferometer flight in September (like NOW!)
- Delays in getting components and problems integrating the cameras led to delays
- The election of Donald Trump made Zhara PNG
- Decision was made to take the pressure off the students and do ground-based testing instead

Status

- Pointing system was validated on a balloon flight in September of 2015
- A heliostat mount was designed and installed in the roof hatch of the lab at York (will borrow U of T heliostat
- Resolution tests (spectral and spatial) will be carried out in the coming months.
- Retrievals of the gases will be done using solar spectra of diffuse light scattered off a spectralon diffuser in the lab
- If the situation at York permits, we will seek support for a balloon flight next year


Thank You for
Your Attention
The End!

Funding for this work was provided by:

The CSA/ABB/NSERC Industrial Research Chair in Atmospheric Remote sounding at York University

CSA	ASC
The Canadian Space Agency	Agence spatiale canadienne

ABB Incorporated, Quebec City, Canada

Natural Sciences and Engineering Research Council of Canada	Conseil de recherches en sciences naturelles et en génie du Canada

Acknowledgement:
David Barton, York University

Camera Specs

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Xenics Infrared Solutions

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Xeva-1.7-320 TE3 | Info | Features | Specifications | Accessories | Cam

Array Specifications | Camera Specifications

Array Specifications	Xeva-1.7-320 TE3
Array type	InGaAs
Spectral band	0.9 µm to 1.7 µm (VisNIR optional 0.4 to 1.7 µm)
Resolution	320 x 256
Pixel pitch	30 µm
Array cooling	TE3-cooled
Pixel operability	> 99 %

Xenics Specifications

All cameras are equipped with a 320 by 256 InGaAs array

ALL DATA ARE TYPICAL VALUES AND CAN VARY FROM DETECTOR TO DETECTOR

NOTE THAT ALL CAMERAS HAVE A 14-BIT ADC EXCEPT FOR CERTAIN DEMO CAMERAS

Camera model	XEVA USB 100Hz	
USB 2.0 interface		
Thermo-electric cooler - note 1	**TE1**	**TE1**
Gain	LOW	HIGH
ADC [bits]	12	12
Tsat [sec] - note 5	300	15
Cfb [fF] (integration capacitor)	200	10
Vout [V] of the ADC	3	3
Qsat full well [#electrons]	3750000	187500
dQsat/dt [C/sec]	2E-15	2E-15
Idark [electrons/sec]	12500	12500
QE	0.8	0.8
Flux [photons/sec] - note 2	15625	15625
Vout per ADU [V/ADU]	0.000732422	0.000732422
Sensitivity [V/electron]	0.0000008	0.000016
Sensitivity [electrons/ADU]	915.5273438	45.77636719
Sensitivity [photons/ADU]	1144.40918	57.22045898
Noise		
ADUrms (MEASURED; Tint=100us)	1.2	2.5
Vrms	0.000878906	0.001831055
electrons	1098.632813	114.440918
NEW - note 3	1.94238E-16	2.02332E-17
NEP (Tint=1msec)	1.94238E-13	2.02332E-14
S/N ratio [dB]	70.66357404	64.28839879
RO Noise @ 250 K [electrons] - note 4	380	50

Note 1: TE1 detector temperature is 250K
Note 2: this is the photon flux as represented by the dark current
Note 3: just for intermediate calculation purposes
Note 4: in general the Read-Out Noise is lower than the system noise
Note 5: For practical reasons the camera limits the integration time to 8 msec in HG and 200 msec in LG

Camera model	XEVA with CameraLink 100 Hz	
CAMERALINK interface		
Thermo-electric cooler - note 1	**TE1**	**TE1**
Gain	LG	HG
ADC [bits]	14	14
Tsat [sec] - note 5	300	15
Cfb [fF] (integration capacitor)	200	10
Vout [V] of the ADC	3	3
Qsat full well [#electrons]	3750000	187500
dQsat/dt [C/sec]	2E-15	2E-15
Idark [electrons/sec]	12500	12500
QE	0.8	0.8
Flux [photons/sec] - note 2	15625	15625
Vout per ADU [V/ADU]	0.000183105	0.000183105
Sensitivity [V/electron]	0.0000008	0.000016
Sensitivity [electrons/ADU]	228.8818359	11.4440918
Sensitivity [photons/ADU]	286.1022949	14.30511475
Noise		
ADUrms (MEASURED; Tint=100us)	6.3	13.9
Vrms	0.001153564	0.002545166
electrons	1441.955566	159.072876
NEW - note 3	2.54938E-16	2.81241E-17
NEP (Tint=1msec)	2.54938E-13	2.81241E-14
S/N ratio [dB]	68.3015878	61.42810278
RO Noise @ 250 K [electrons] - note 4	380	50

Note 1: TE1 detector temperature is 250K
Note 2: this is the photon flux as represented by the dark current
Note 3: just for intermediate calculation purposes
Note 4: in general the Read-Out Noise is lower than the system noise
Note 5: For practical reasons the camera limits the integration time to 8 msec in HG and 200 msec in LG
Note 6: ADUrms measured with 12 bits rather than 14 bits for CL vs. USB.