

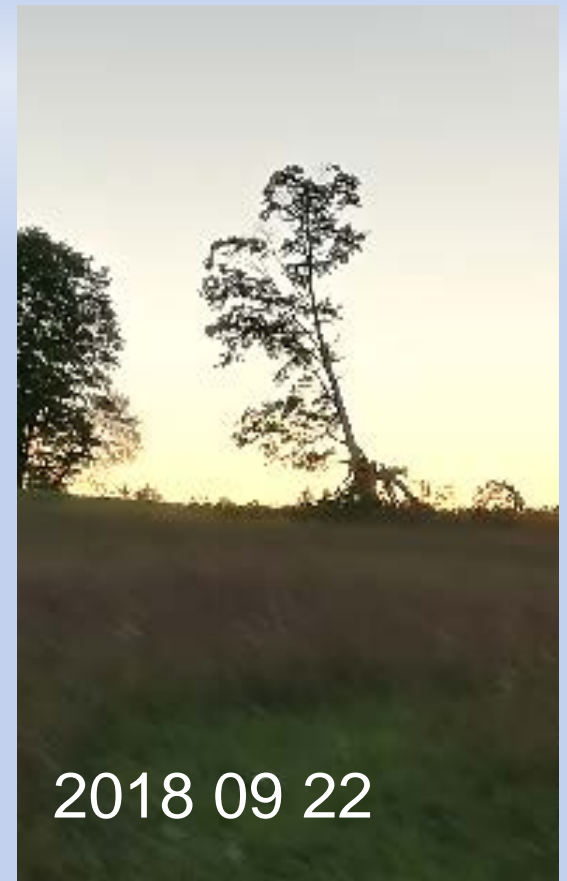
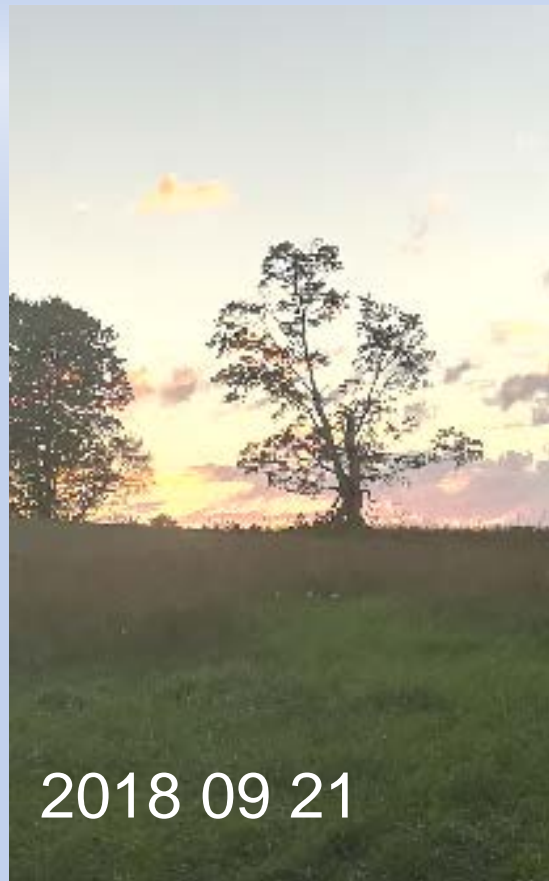
Development of an Imaging Fourier Transform Spectrometer (IFTS) and the Potential Space-based Application.

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Topics for Today

- Potential Space Mission (Environment & CC Canada)
- Mission Goals
- Value of Performance
- Global Contribution

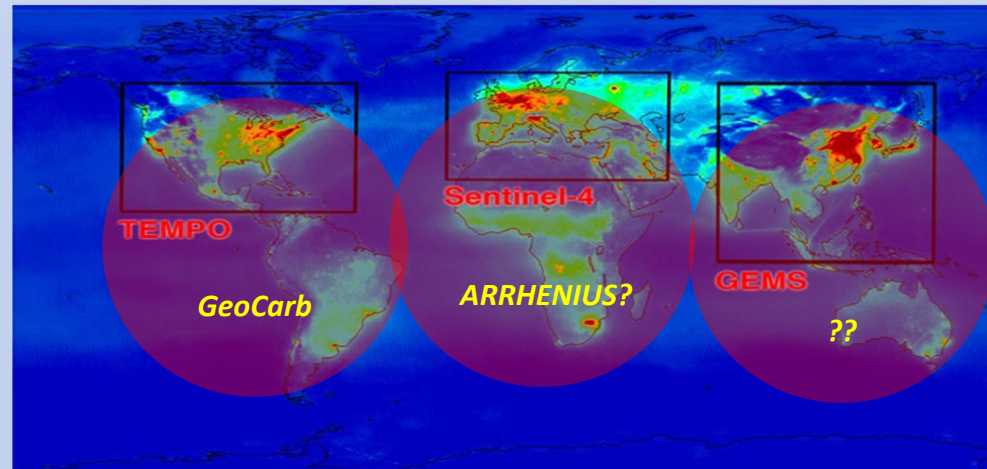
York U Contribution

- Balloon demonstrator design
- System design concept
- Pointing system concept development
- Physical model development and test
- Laboratory Measurements
- 2 new graduates



Constellation Components

- **Low Earth Orbit (LEO):** Orbit near the polar plane, gives global sampling, but each satellite has a revisit time of days to weeks
- **Geostationary Orbit (GEO):** 35,786 km altitude equatorial orbit, synchronized with Earth rotation, gives observation sub-daily revisit for region up to $\sim 50\text{-}55^\circ\text{N/S}$
- **Highly Elliptical Orbit (HEO):** An orbit that enables 'quasi-geostationary' observations of high latitudes of a single hemisphere (North or South)
- CEOS has identified that HEO would fill the gap from a LEO + GEO constellation to provide spatially and temporally dense data in high latitude regions



A Geostationary Satellite Constellation for Observing Global Air Quality: An International Path Forward, Prepared by the CEOS Atmospheric Composition Constellation, April 12, 2011 (41 pages).

A Constellation Architecture for Monitoring CO₂ and CH₄ from Space, Prepared by the CEOS Atmospheric Composition Virtual Constellation Greenhouse Gas Team, Draft Version September 2, 2018 (171 pages).

AIM-North Background and History

Atmospheric Imaging Mission for Northern Regions

- Polar Communications and Weather (PCW) mission was a HEO concept for Arctic communications and meteorology and CSA considered additional instruments under the Polar Highly Elliptical Orbit Science (PHEOS) program
- The Weather, Climate and Air quality (WCA) instrument suite was an atmospheric research option that completed Phase 0 & A in 2012 (PI: Jack McConnell, York University)
- PHEOS-WCA Instruments: Imaging Fourier Transform Spectrometer (IFTS) for TIR to SWIR ($\sim 0.25 \text{ cm}^{-1}$) and UV-Vis grating Spectrometer (UVS), combined mass $\sim 50\text{-}85 \text{ kg}$
- CSA has funded IFTS technology development (FAST, STDP), aiming for sub-orbital testing on a stratospheric balloon in the coming years
- NASA JPL IFTS studies and technology development: GEO-FTS and Mt. Wilson, California
- Mission concept study involving ECCC, CSA and industry contractors led to **AIM-North** stand-alone mission of 2 satellites in HEO
- **AIM-North** starting **Phase 0** ($\sim 2019\text{-}2020$) with selection of industrial contractor by end of 2018

AIM-North Measurement Approach

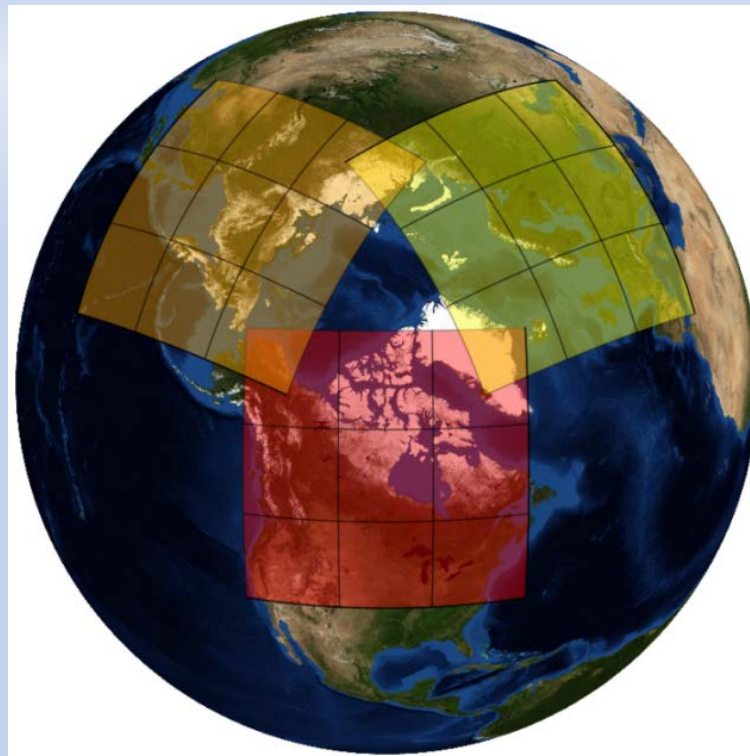
2 HEO satellites with accuracy and precision linked to GEO AQ and GHG missions

NIR-SWIR Spectrometer: CO_2 , CH_4 , CO , solar induced fluorescence (SIF), aerosol

UV-Vis Spectrometer: O_3 , NO_2 , aerosol, BrO, HCHO, SO_2 , SIF & more

Imaging $\sim 3 \times 3 \text{ km}^2$ pixels, ~ 60 -90 minute revisit during daylight where cloud permits

Cloud Imager:
for *intelligent pointing* and
real-time day
and night, hourly
cloud data $\sim 1 \times 1 \text{ km}^2$



***Frequent imaging
yields movie-like views
of daytime
atmospheric
composition!***

Overlap with GEO
coverage gives
intercalibration
opportunities beyond
LEO

*Range of possible values is due to
different orbit or instrument options

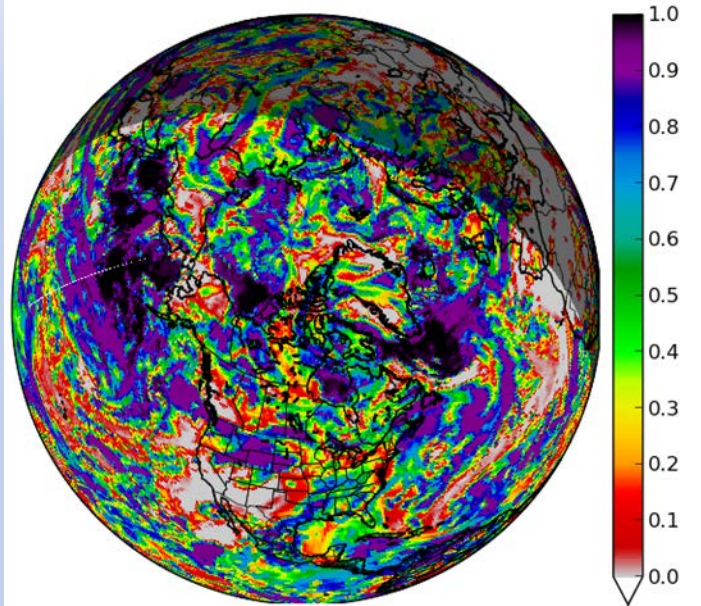
Intelligent Pointing

- Currently GHG missions reject ~90% of data due to clouds!
- Enhancing the mission with a small low-cost cloud imager (< 10 kg) could inform pointing and provide real-time cloud data for other applications
- Essentially every location is cloud-free at some time, and there is typically somewhere cloud-free to view at any time from the HEO or GEO vantage point
- Smarter pointing could focus on clear regions or just events/regions of interest

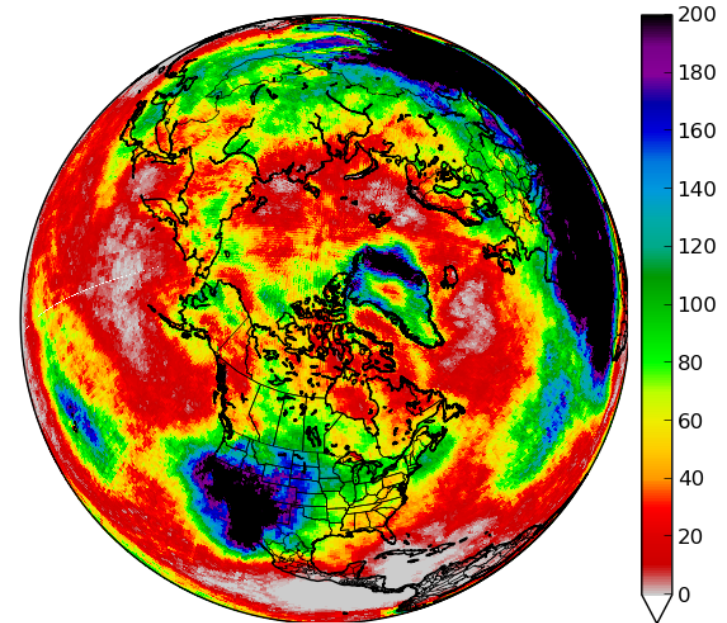
Could point the FOV to scan only in clearest regions



Maximum Cloud Fractions for June 21, 2015 at 19:30 UT



Average Number of Cloud Free Daylight Hours: June



NASA MERRA2 assimilated cloud fields (left) show few regions that would give good (cloud-free) observations at this given instant in time, while over the course of a month (right), nearly all locations could deliver some good data by pointing the IFTS field of view (FoV) at the correct time.

Moving Forward

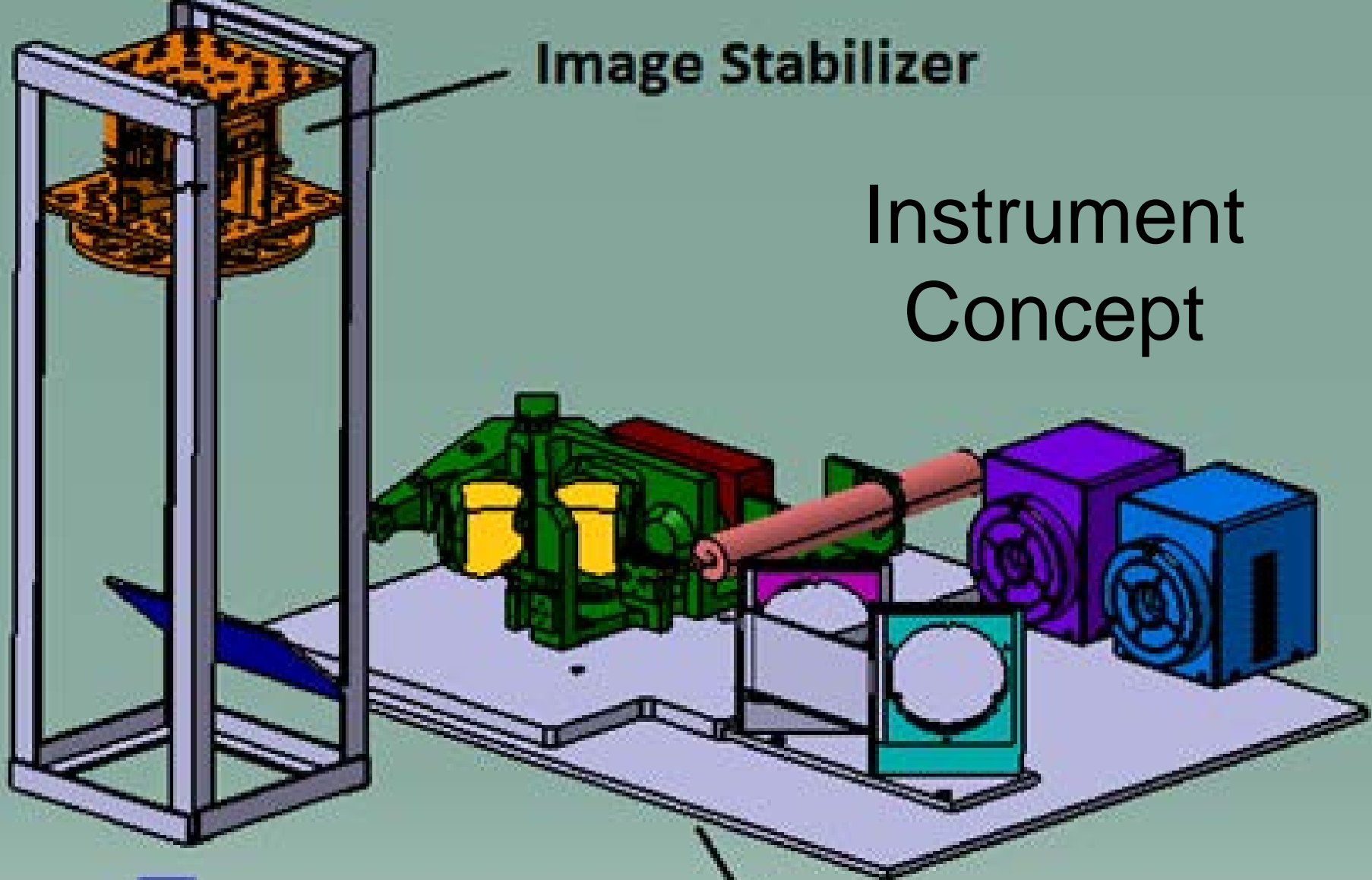
- AIM-North approved for 'Phase 0' in May 2018 with support of ECCC Deputy Minister and Canadian Space Agency President
- Phase 0 will take ~24 months (after selection of new industry team) will include technical studies by industry and new associated science activities within ECCC and Canadian universities
- Could optimistically launch in ~7 years (~2026) if selected/funded by CSA, but it would be an expensive project for Canada alone
- Potential international partnerships (NASA, ESA, FMI...) are currently being explored at the scientist level, with the hope that high level discussions can follow in the near future

York U Activities

- Design & construct a mirror pointing system (balloon)
- Develop image stabilization software (completed)
- Acquire FTS core from ABB Inc.
- Integrate commercial InGaAs cameras
- Design optics
- Provide broadband source
- Design and construct a suntracker (laboratory testing)
- Test & characterize breadboard instrument
- Develop instrument model

Image Stabilizer

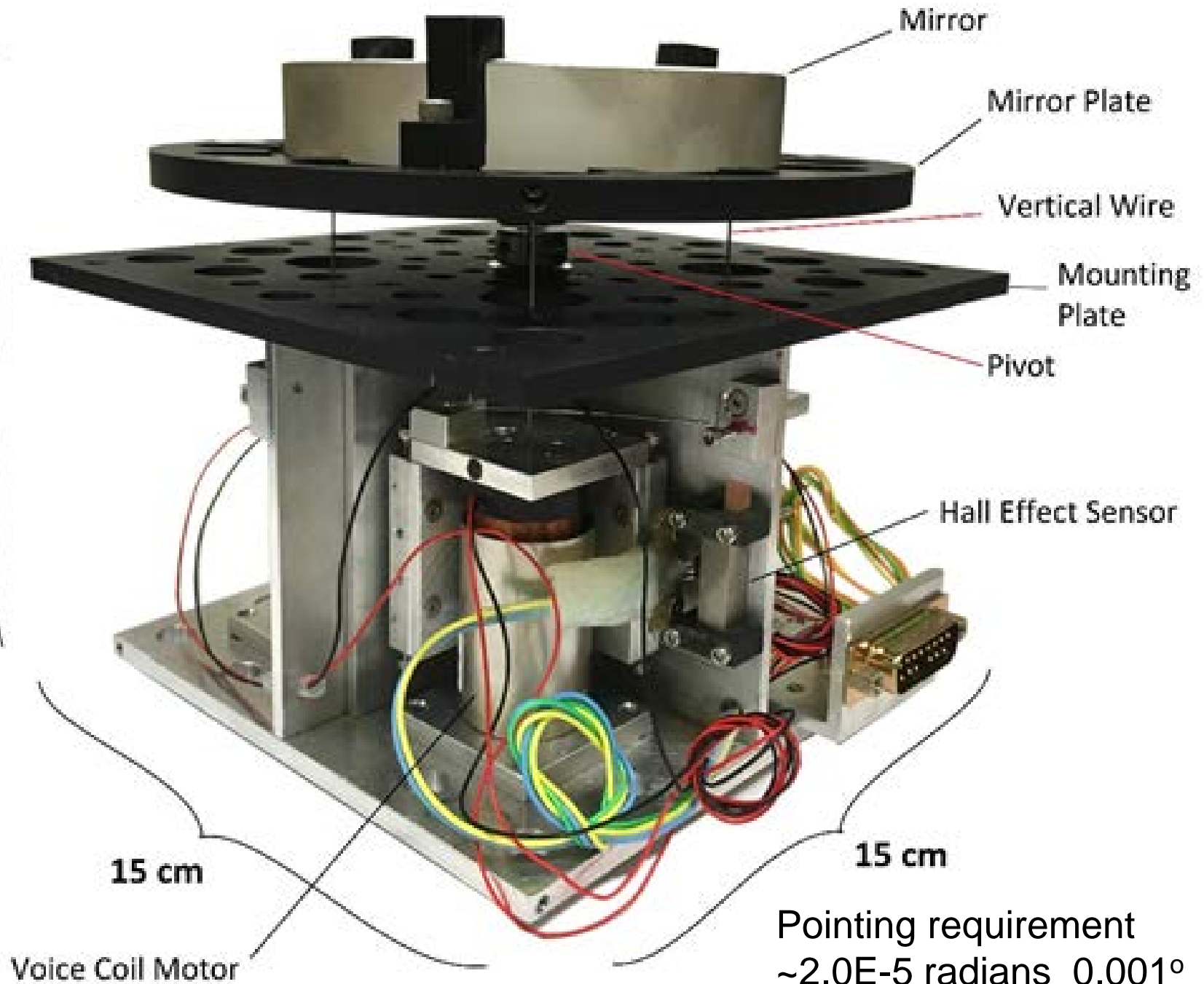
Instrument Concept



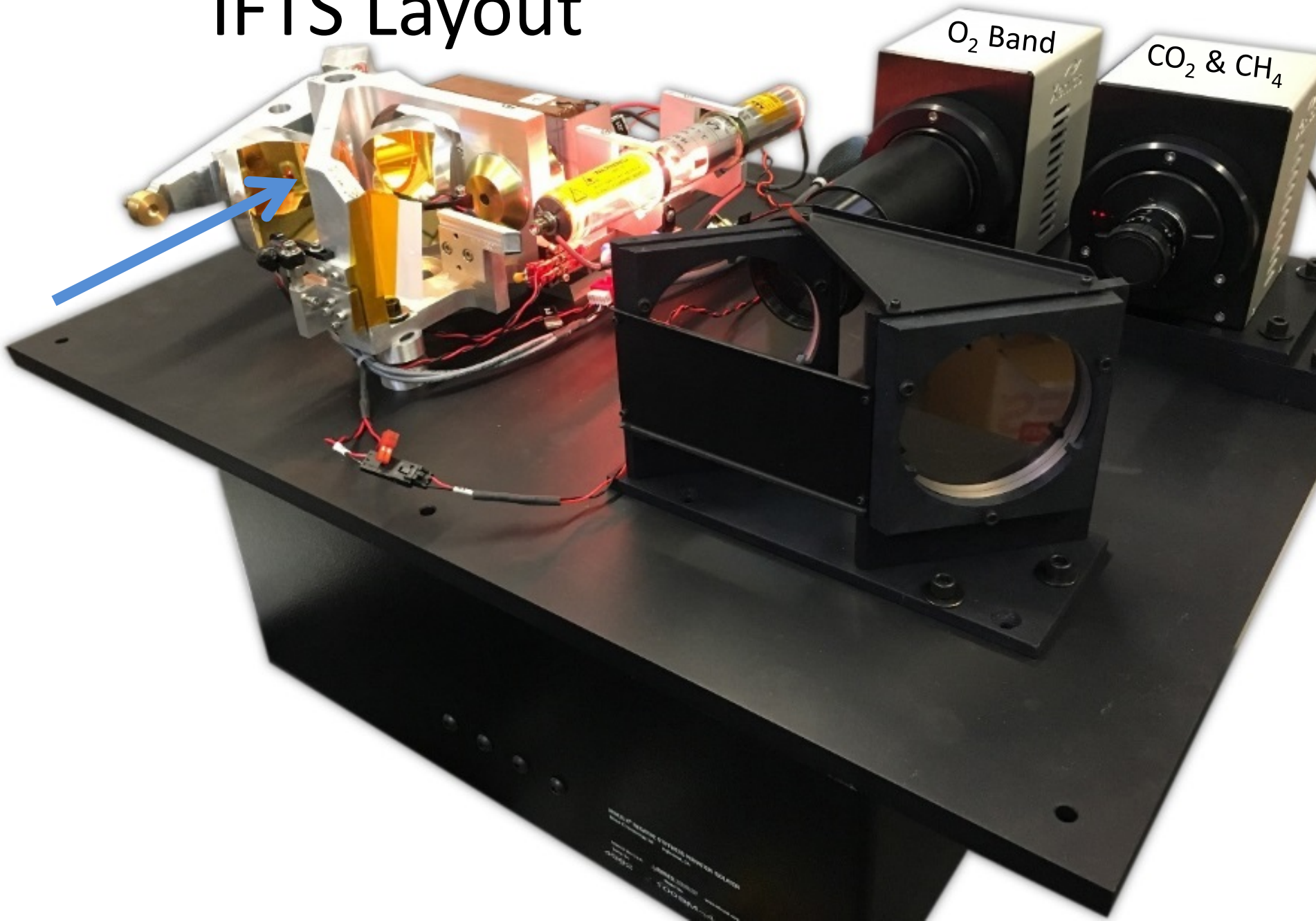
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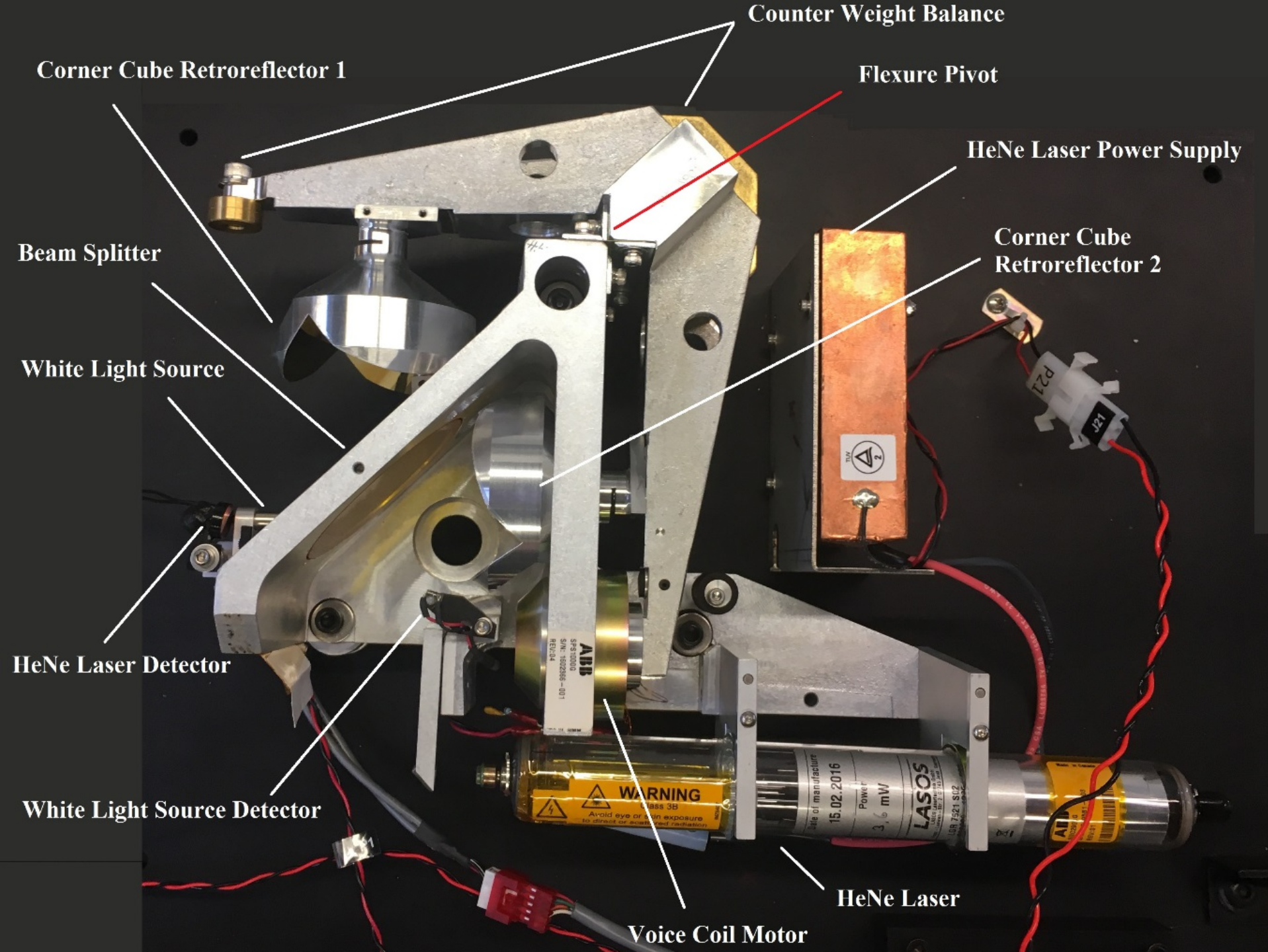
IFTS

13 cm

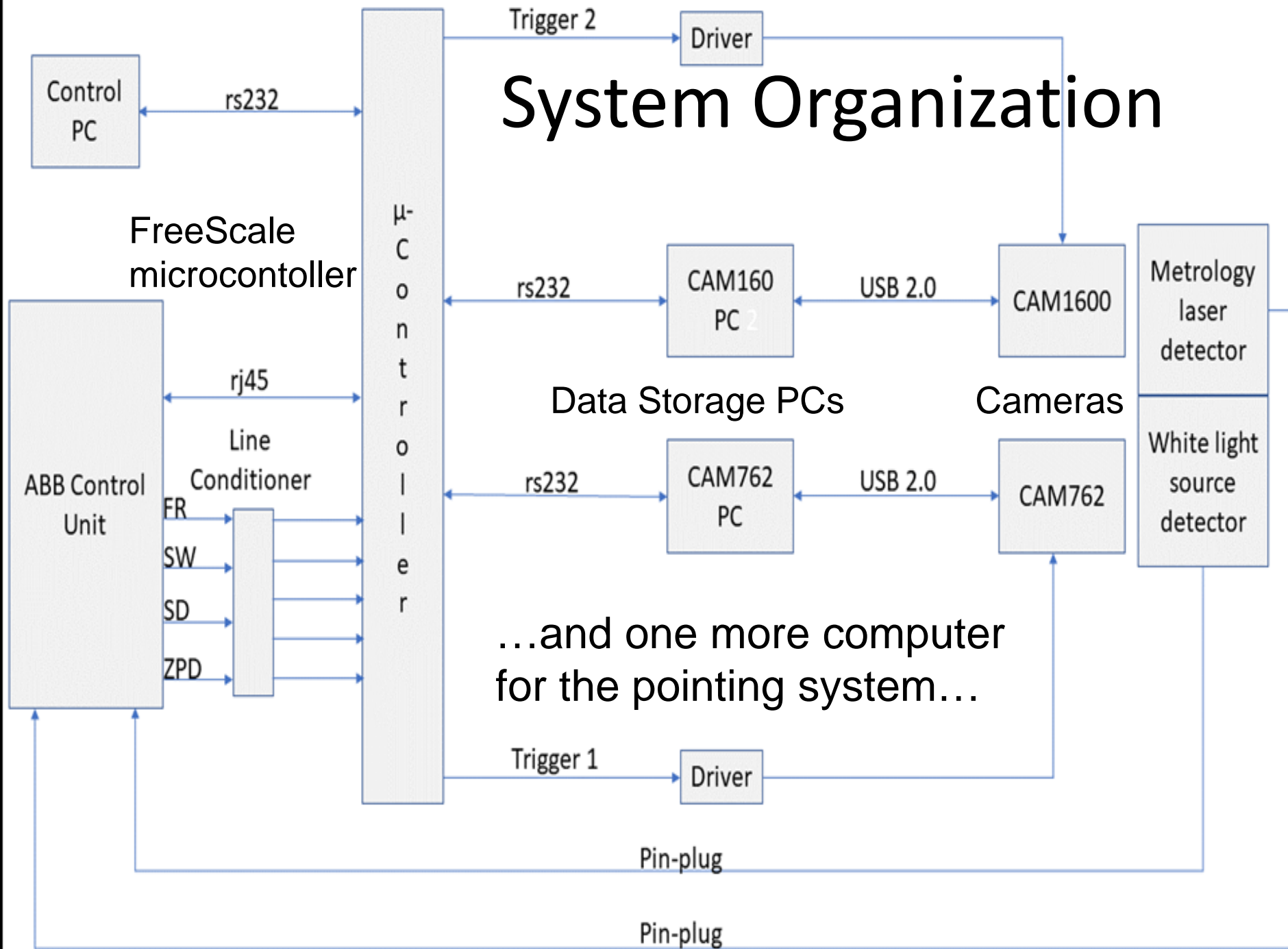


IFTS Layout





System Organization



1600 nm Interference Filter

Blue -
Manufacturer's data

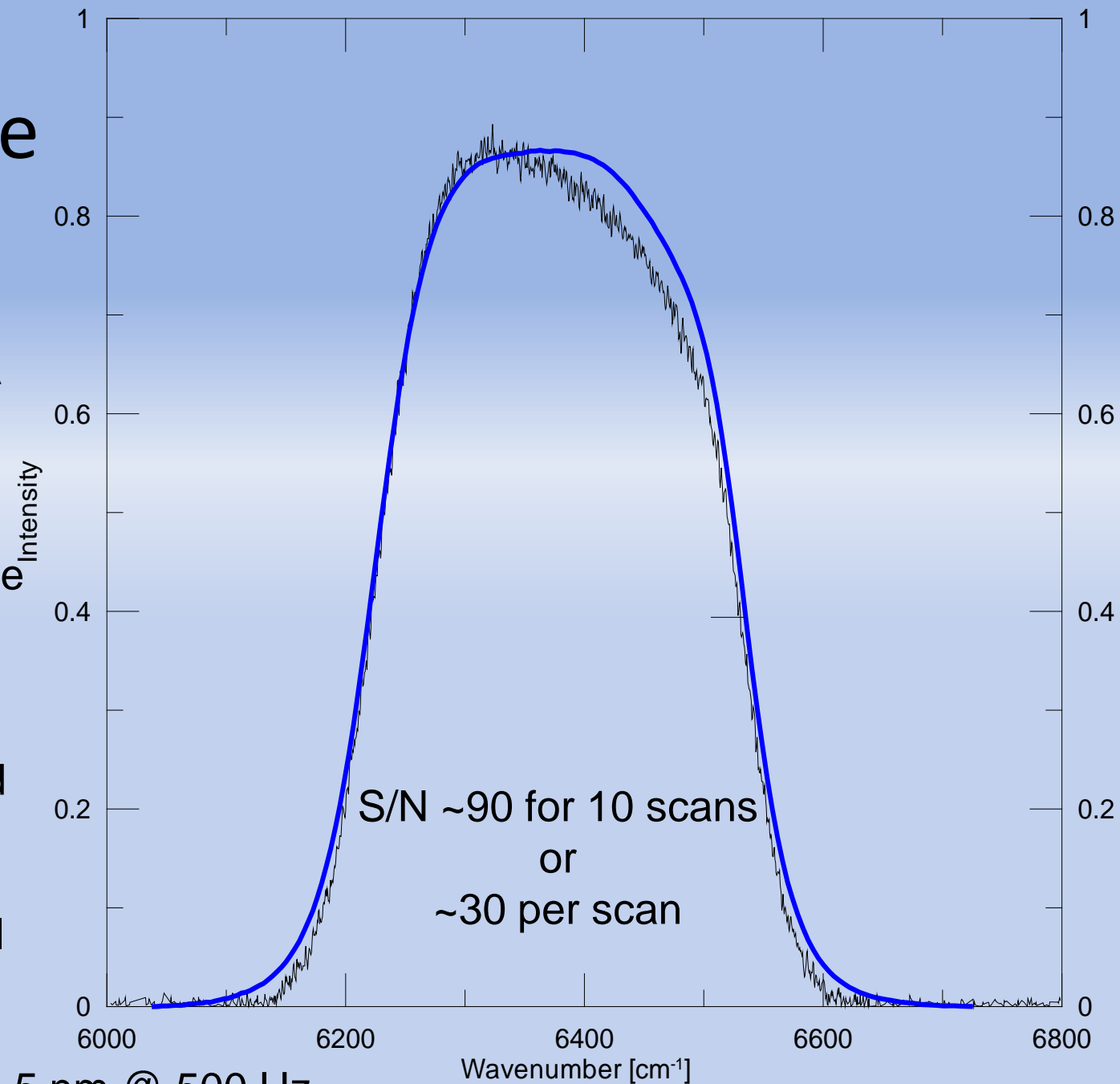
Black – IFTS

Manufacturer's curve
shifted by 5 nm

Light source –
200 W QI Lamp and
Lambertian diffuser

30 x 30 micron pixel
100 mm lens

Sample interval 631.5 nm @ 500 Hz



MAESTRO

Zahra

Gurpreet



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CSA

ASC

The Canadian Space Agency Agence spatiale canadienne

ABB

ABB Incorporated, Quebec City, Canada



Natural Sciences and Engineering
Research Council of Canada

Conseil de recherches en sciences
naturelles et en génie du Canada



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Greg Blair, Seneca College



The End
Thank You!

(Retired...sort of.)

Government of Canada Members

Ray Nassar (ECCC, Climate Research Division) – PI and greenhouse gas (GHG) observations

Chris McLinden (ECCC, Air Quality Research Division) – Air quality (AQ) species observations

Chris Sioris (ECCC, AQRD) – Retrievals and Analysis, Technical Support

Helena van Mierlo (Canadian Space Agency) – CSA Study Manager

Ryan Cooney (CSA) – CSA Study Lead

Ralph Girard (CSA) – CSA Portfolio Manager

Natasha Jackson (CSA) – Mission Design Engineer

Louis Garand (ECCC, Meteorological Research Division) – Potential meteorological enhancements

Joseph Mendonca (ECCC, CRD) – Validation and GHG Retrievals

Saroja Polavarapu (ECCC, CRD) – Modelling and Assimilation for GHGs

Felicia Kolonjari (ECCC, CRD) – Inter-departmental/International collaboration and policy

Yves Rochon (ECCC, AQRD) – Modelling and Assimilation for Air Quality

Alexander Trichtchenko (Natural Resources Canada, Canada Centre for Mapping and Earth Observation) – Orbits

Céline Boisvenue (Natural Resources Canada, Canadian Forest Service) – SIF observations over forests

Markey Johnson (Health Canada) – Air quality impacts on health

Provincial Government Members

Cristen Adams (Alberta Environment and Parks) – Air quality observations

Guillaume Drolet (Québec Ministère des Forêts, de la Faune et des Parcs) – SIF observations over forests

University Members

Tom McElroy (York University) – Pointing, Imaging FTS, sub-orbital testing

Kaley Walker (University of Toronto) – FTS and Arctic Science

Debra Wunch (University of Toronto) – GHG retrievals and GHG validation

Kim Strong (University of Toronto) – GHG retrievals and trace gas validation

Norm O'Neill (Université de Sherbrooke) – Aerosols

Dylan Jones (University of Toronto) – Modelling and Assimilation for GHGs and AQ

Feng Deng (University of Toronto) – Modelling and Assimilation for GHGs

Randall Martin (Dalhousie University) – Modelling and Assimilation for Air Quality

Doug Degenstein (University of Saskatchewan) – Air quality gas retrievals

Cameron MacDonald (University of Waterloo) – Orbits and Pointing Strategies

Zahra Vaziri (York University, student) – Pointing, Imaging FTS, sub-orbital testing

Gurpreet Singh (York University, student) – Pointing, Imaging FTS, sub-orbital testing

International Members

Johanna Tamminen (Finnish Meteorological Institute) – Analysis of GHG and AQ data

Charles E. Miller (NASA) – Arctic and Boreal Carbon Cycle Science

Stanley Sander (NASA) – Imaging FTS

William Simpson (University of Alaska at Fairbanks) – Arctic Atmosphere and Carbon Cycle

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