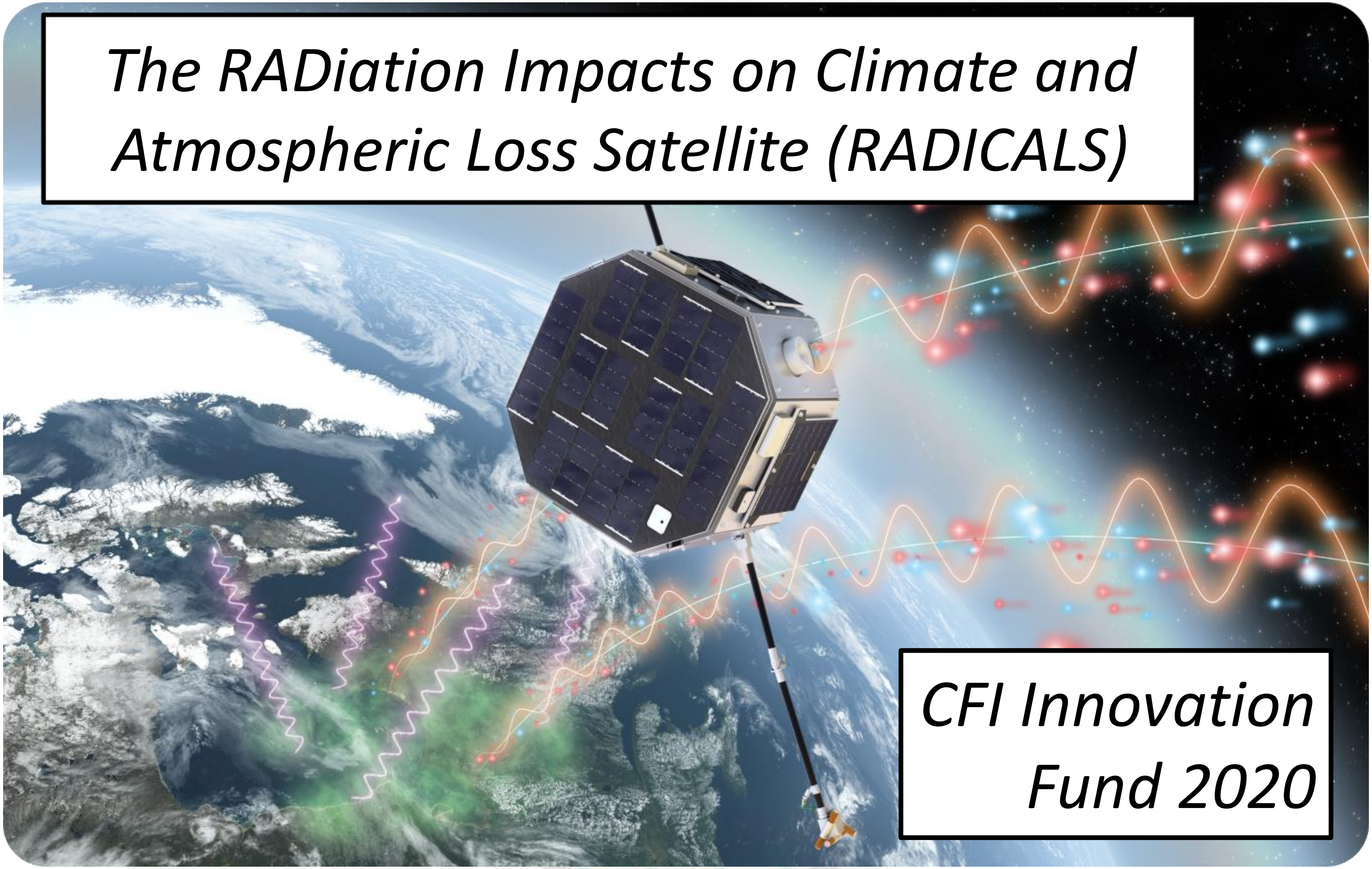
The RADiation Impacts on Climate and Atmospheric Loss Satellite (RADICALS)



CFI Innovation Fund 2020

PI: Ian R. Mann

On behalf of the RADICALS Team

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University of Alberta

RADICALS Team

INNOVATION
Canada Foundation for Innovation
Fondation canadienne pour l'innovation

CSA ASC

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UNIVERSITY OF TORONTO

Athabasca University

UNB
EST. 1785
UNIVERSITY OF NEW BRUNSWICK

Natural Resources Canada
Ressources naturelles Canada
Canada

University of Colorado Boulder

The RADICALS Mission

- The Canadian RADiation Impacts on Climate from Atmospheric Loss Satellite (RADICALS) will be a low-Earth orbiting micro-satellite mission targeting the transport of space radiation into the atmosphere, and the subsequent impact on Earth's climate.

- The RADICALS mission will focus specifically on determining which processes control the precipitation of space radiation into the atmosphere, and the related impacts on climate.

Understanding the coupled geospace system and linkages to climatic change is a major challenge

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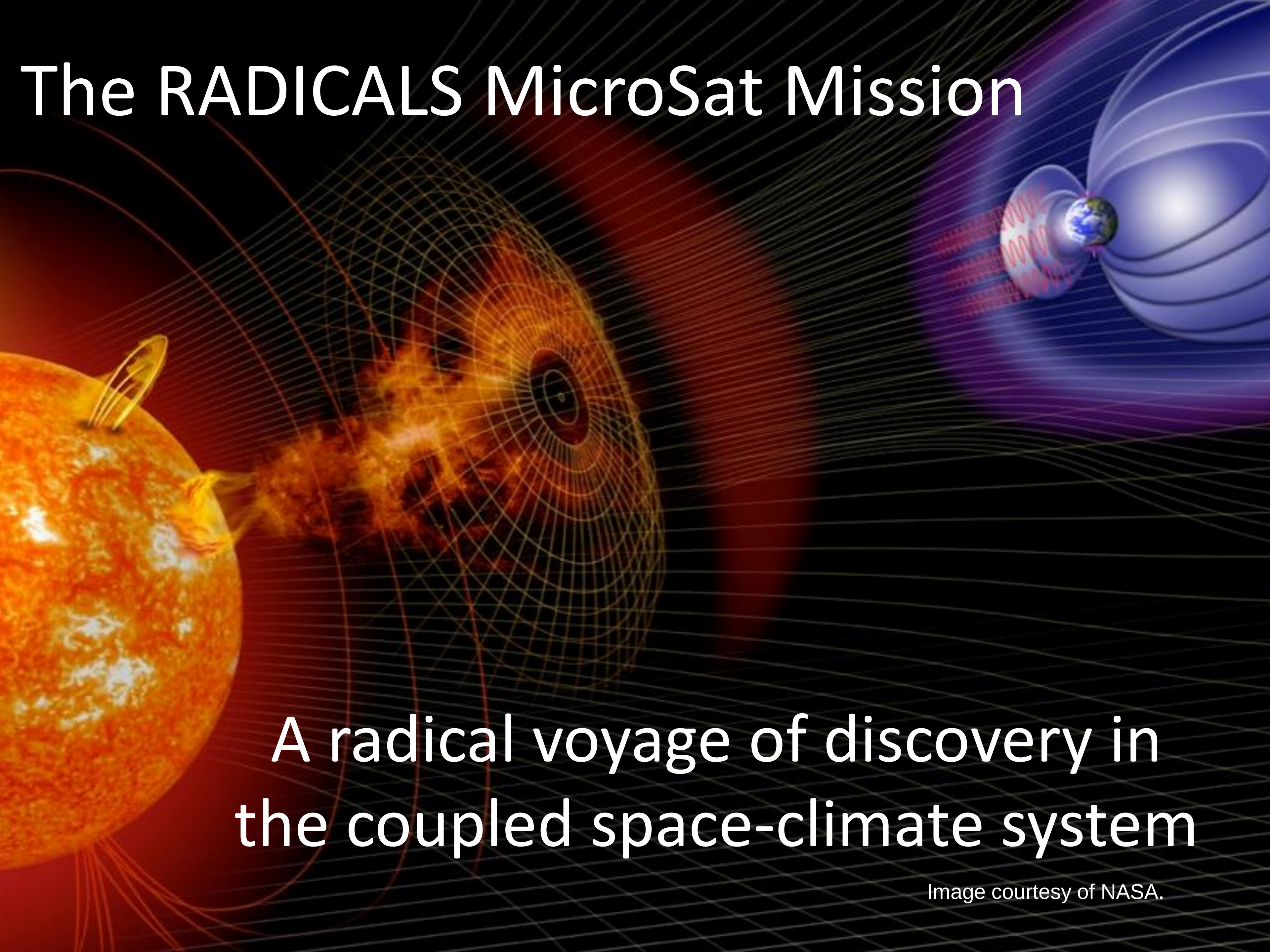
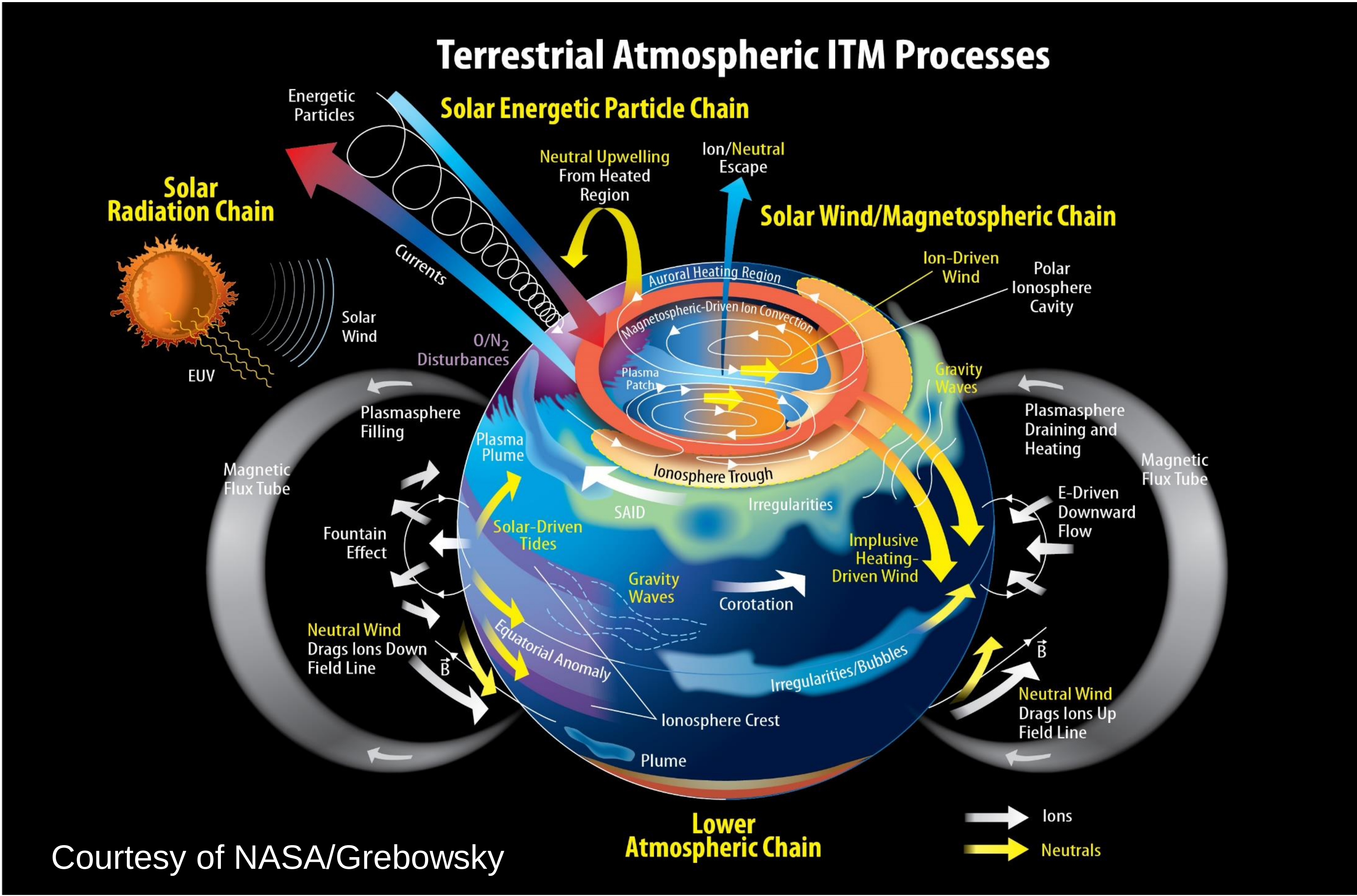
The RADICALS MicroSat Mission



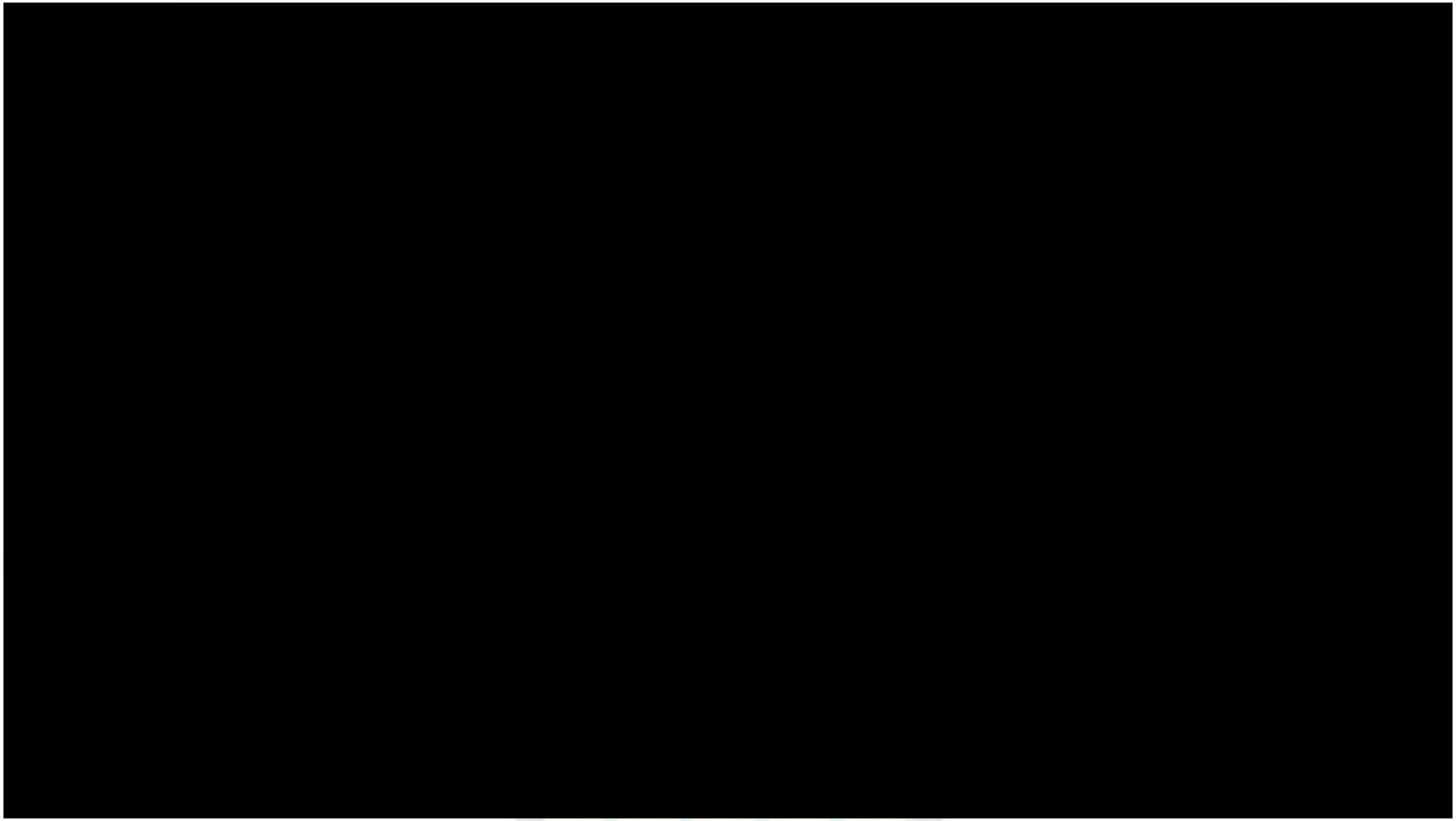
A radical voyage of discovery in the coupled space-climate system

Image courtesy of NASA.

Climate Impacts



Courtesy of NASA/Grebowsky



Space Radiation: Acceleration and Loss

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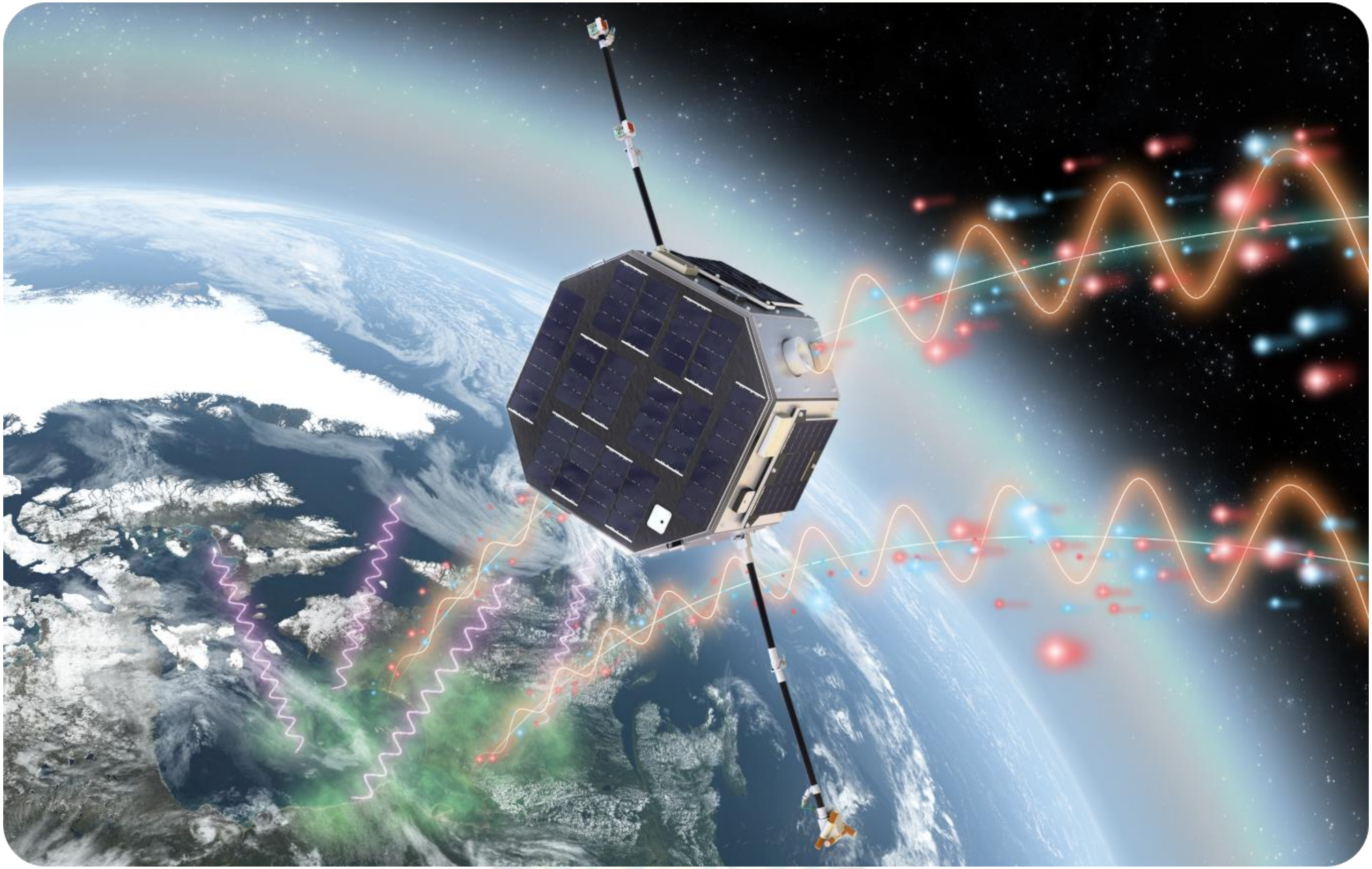

Exploring the Space Weather-Climate Link with RADICALS

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RADICALS Mission Goal

Mission goal: “*Establish the mechanisms responsible for the loss of space radiation into the atmosphere, characterise the resulting atmospheric energy input, and determine the impact on climate*.”

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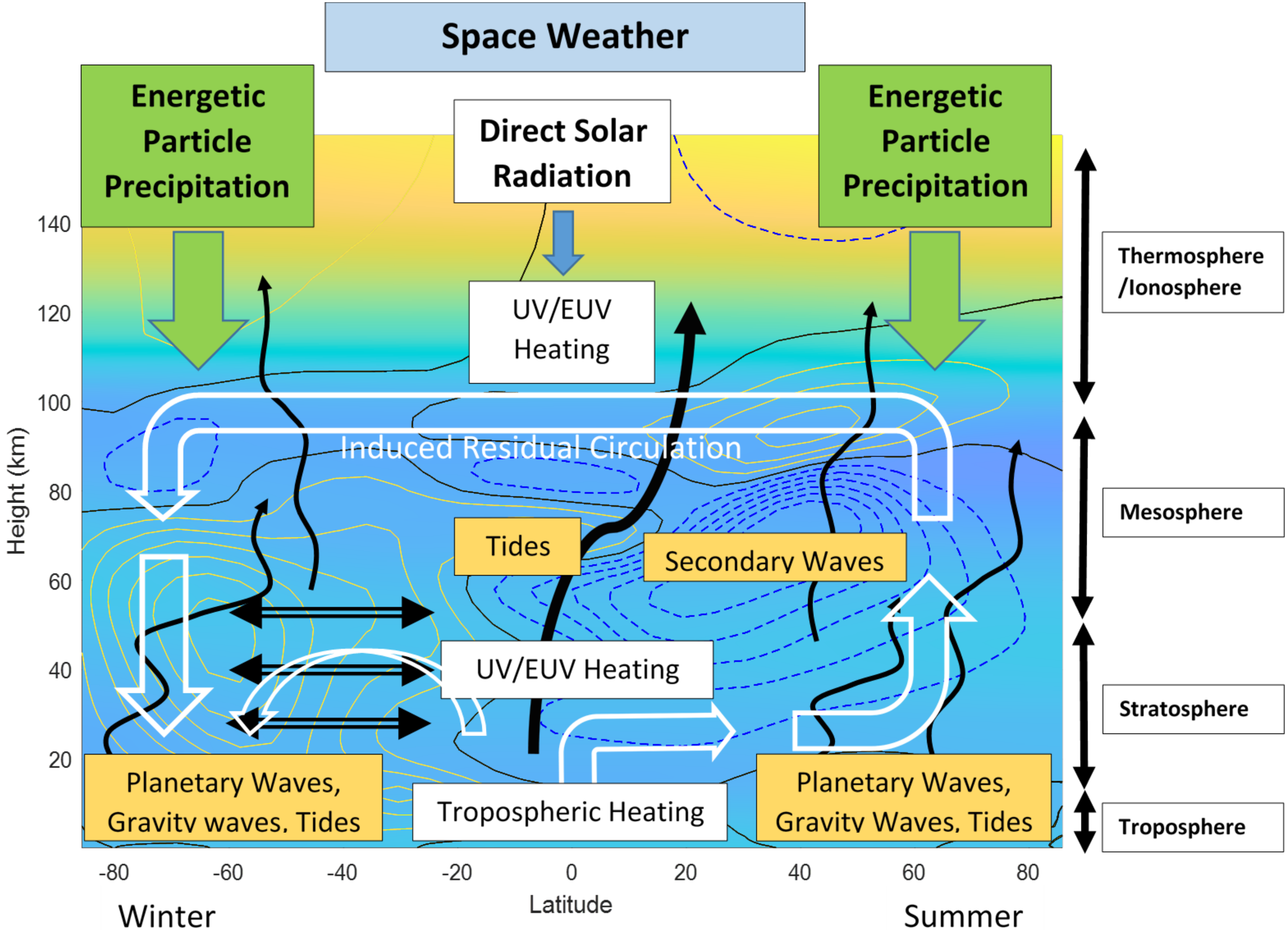
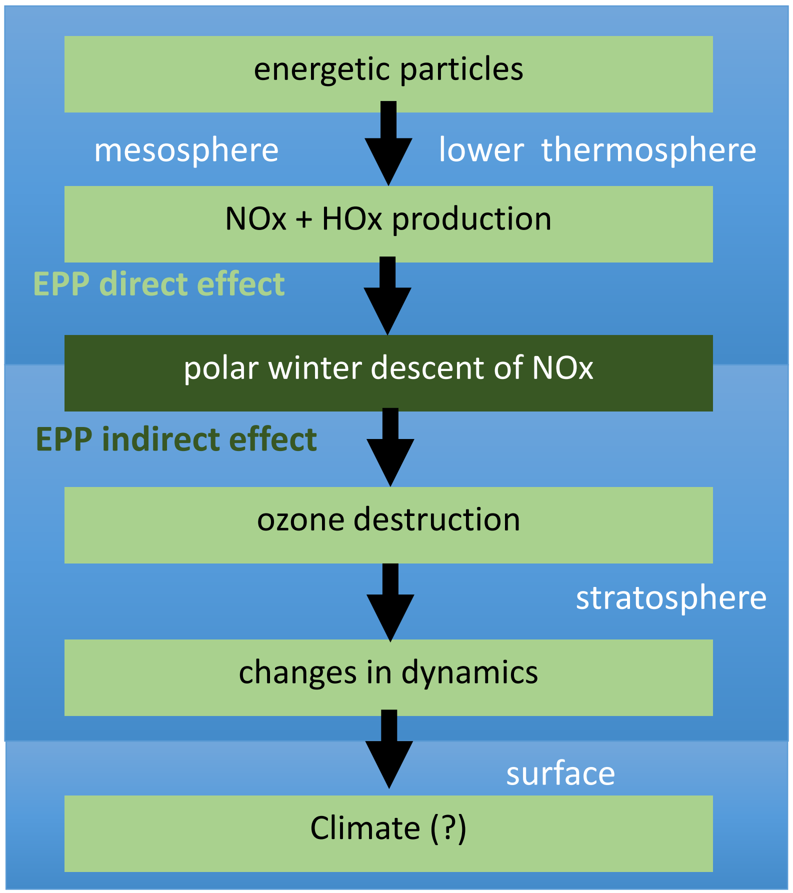


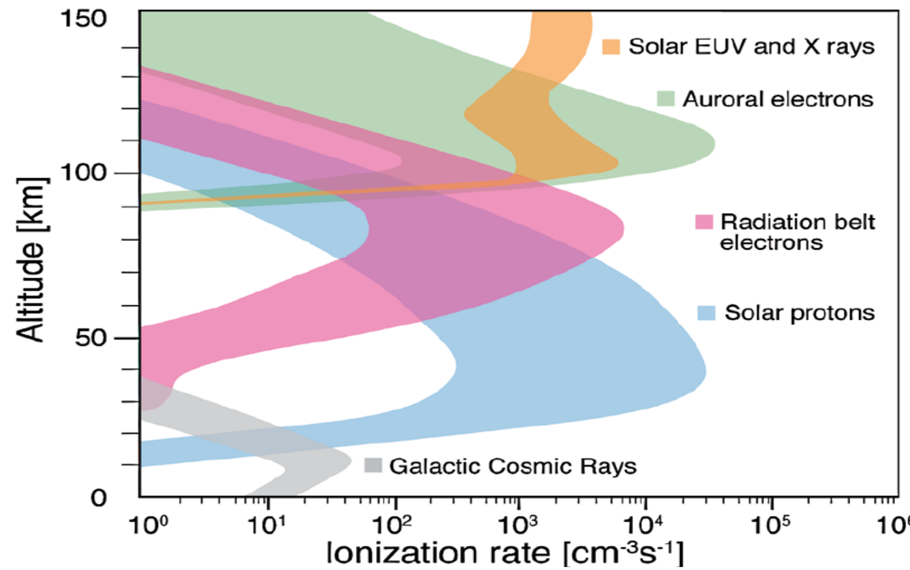
Ward et al., PEPS, 2021

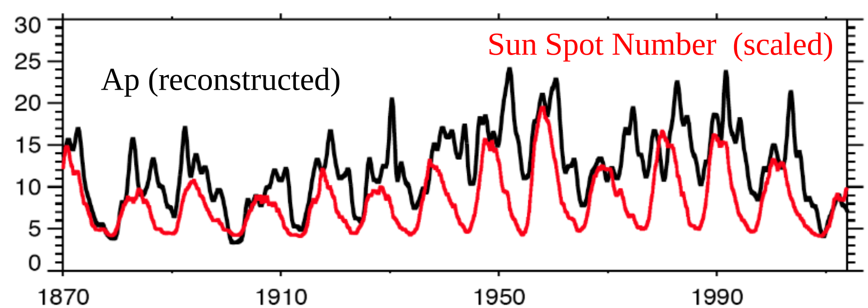
Courtesy W. Ward.

Energetic Particle Precipitation (EPP): A solar coupling pathway



adapted from Baker et al., 2012

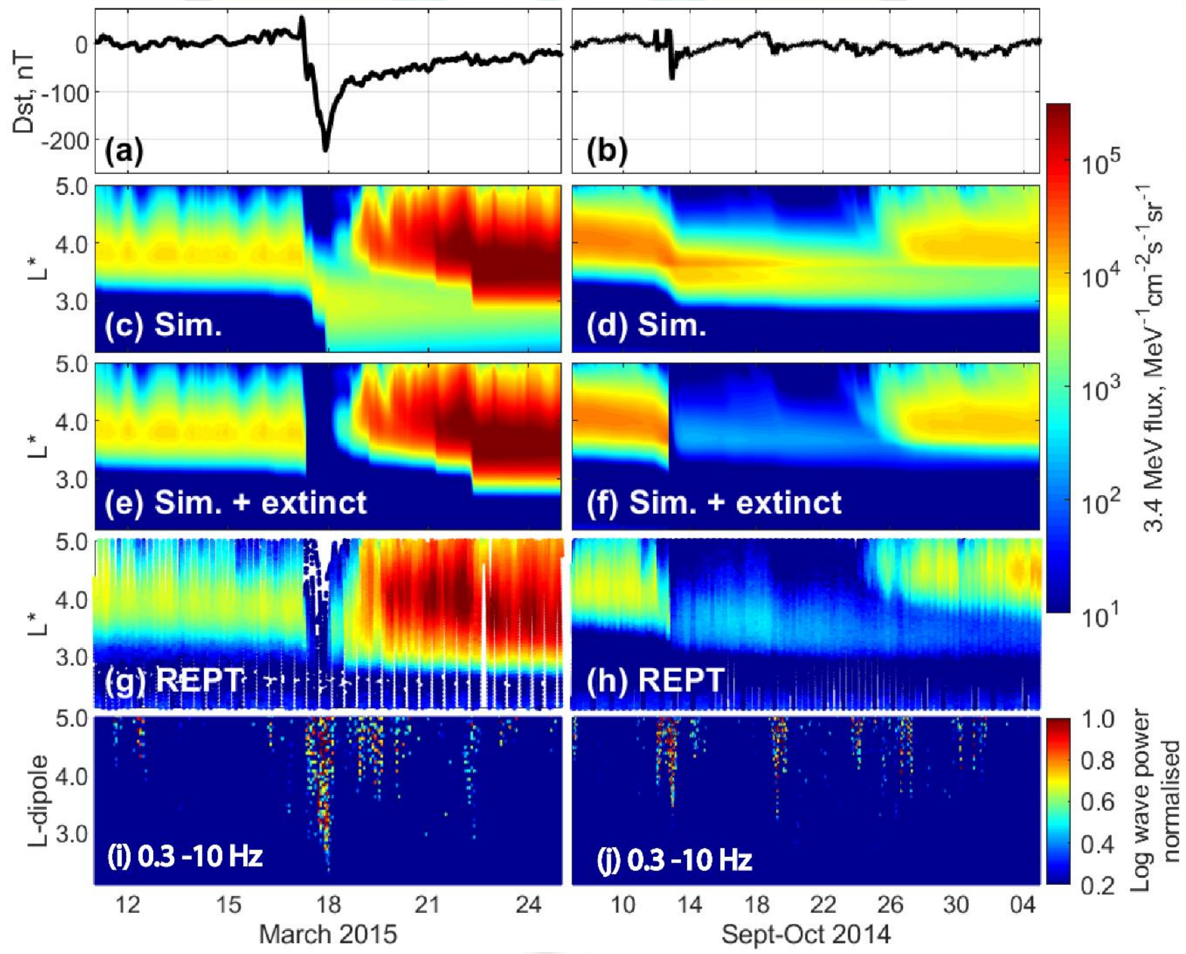




Geomagnetic forcing follows solar cycle, but 2-3 years lagged

Courtesy W. Ward.

Improved Fundamental Understanding => Better Models and Forecasts



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Improved Space Weather models

IPCC, Climate Models and Impacts

"Quantitative measurements of medium energy electron (MEE) precipitation are a key to understand the total effect of particle precipitation on the atmosphere."

Nesse Tyssoy et al. (2019)

- With absence of detailed measurements, heuristic parameterisation in model estimates of NOx/HOx destruction of ozone.
- Nesse Tyssoy et al. (2019) conclude the CMIP-6 parameterisation for electron EPP being used by IPCC introduces an "*underestimation of basic flux strength about one order of magnitude*" so medium energy electron effects are "*strongly underestimated*".

Understanding coupled climate response and climatic change is one of the major challenges of our time

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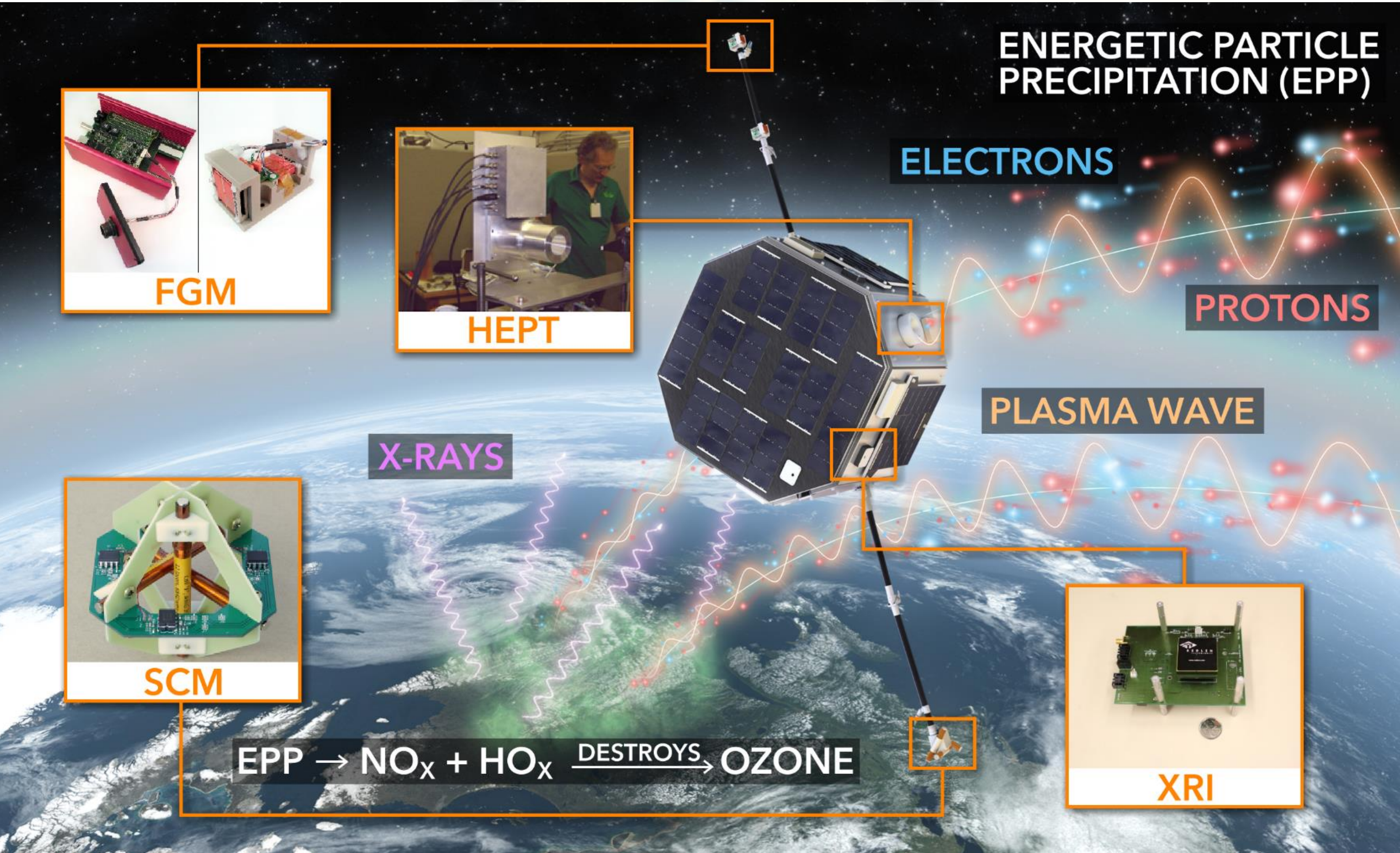
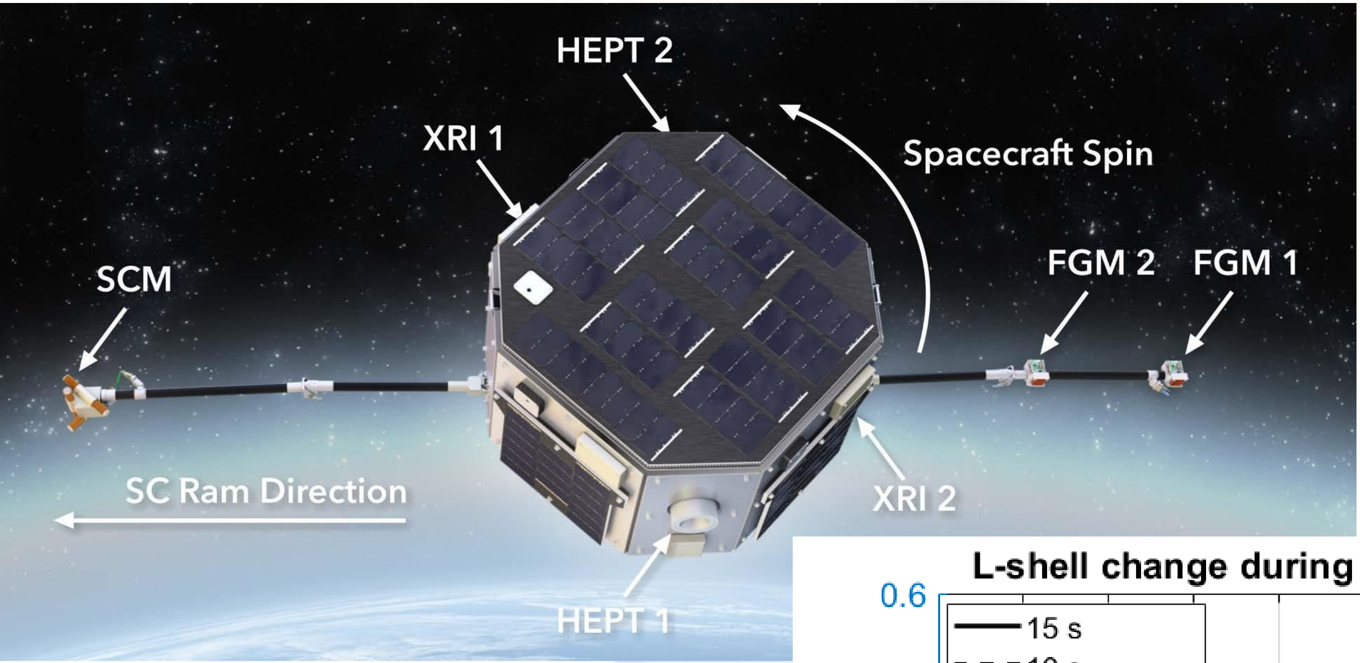
Improved Climate models

RADICALS Payload



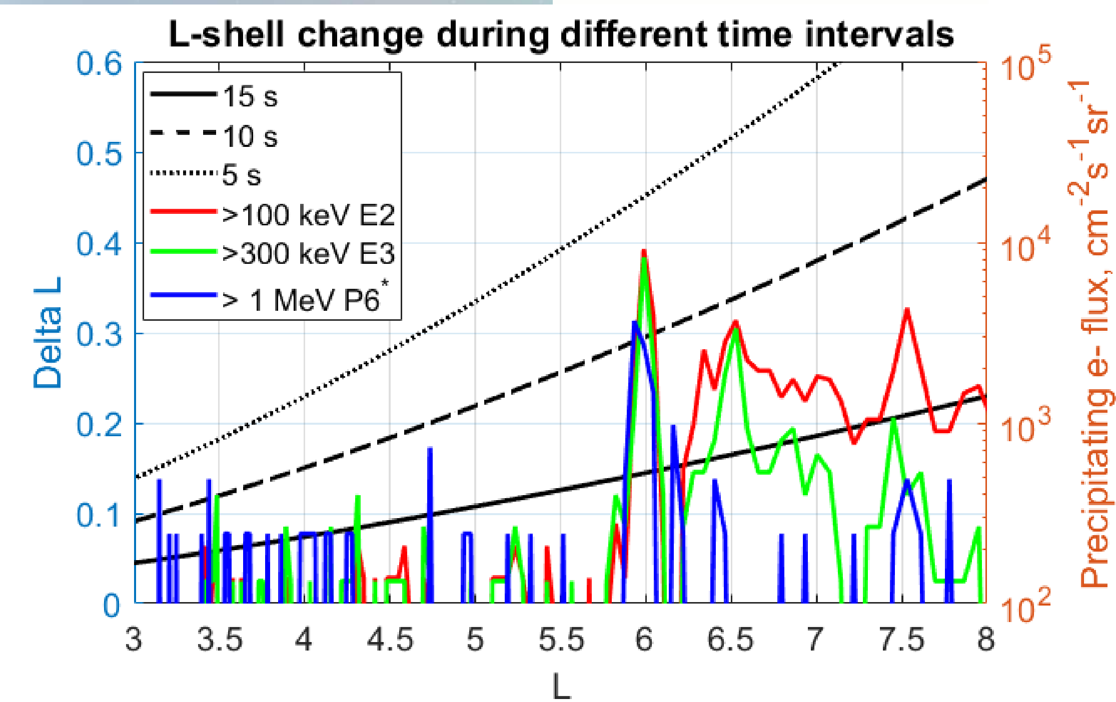
Innovative Mission Design



Polar near sun-synchronous orbit with drifting MLT.

Thomson spin-stabilised. Pitch angle resolved energetic particles and X-ray imaging twice per 30s spin.

Heritage Canadian Micro-Satellite Bus from U. Toronto UTIAS/SFL



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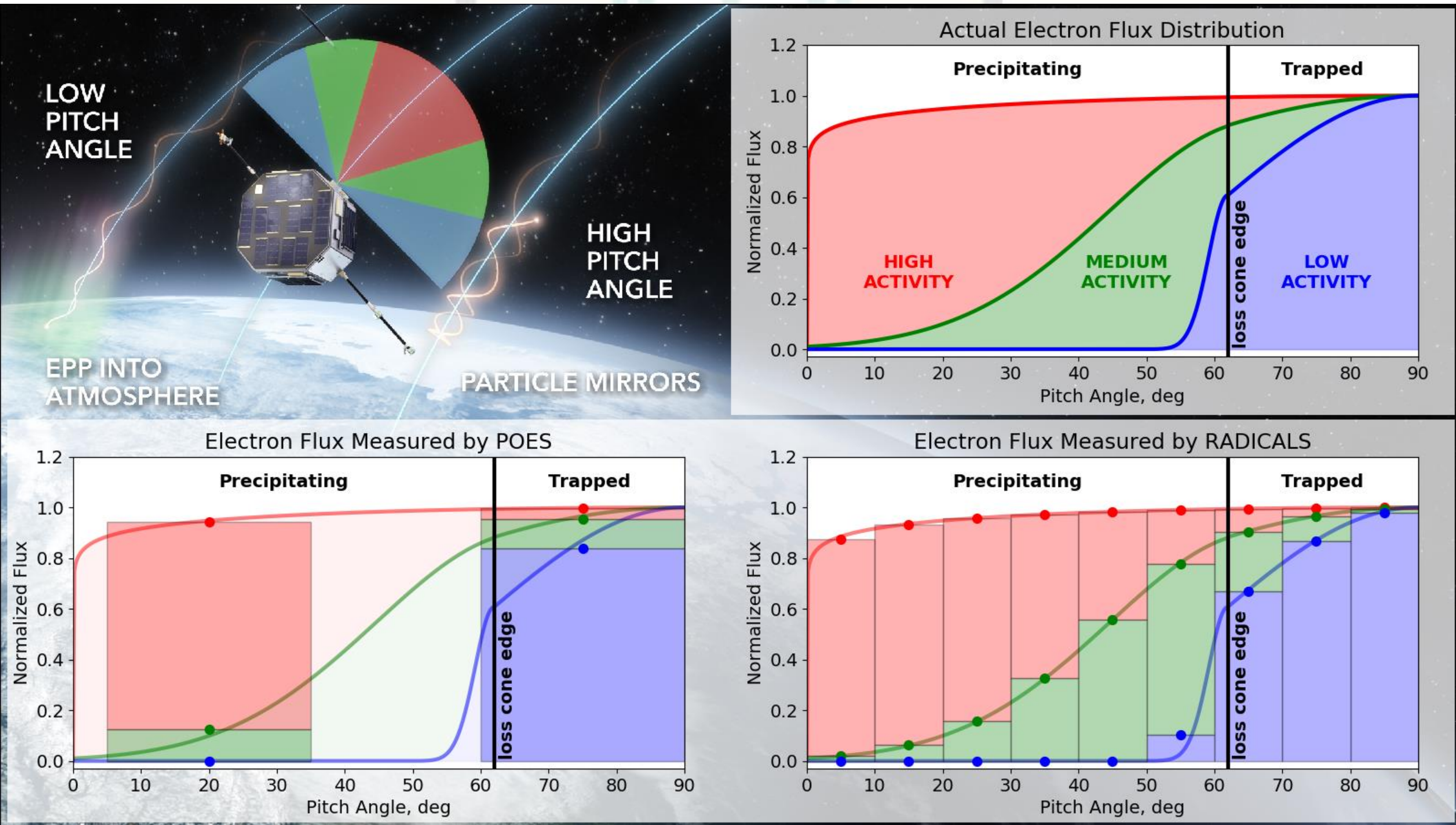
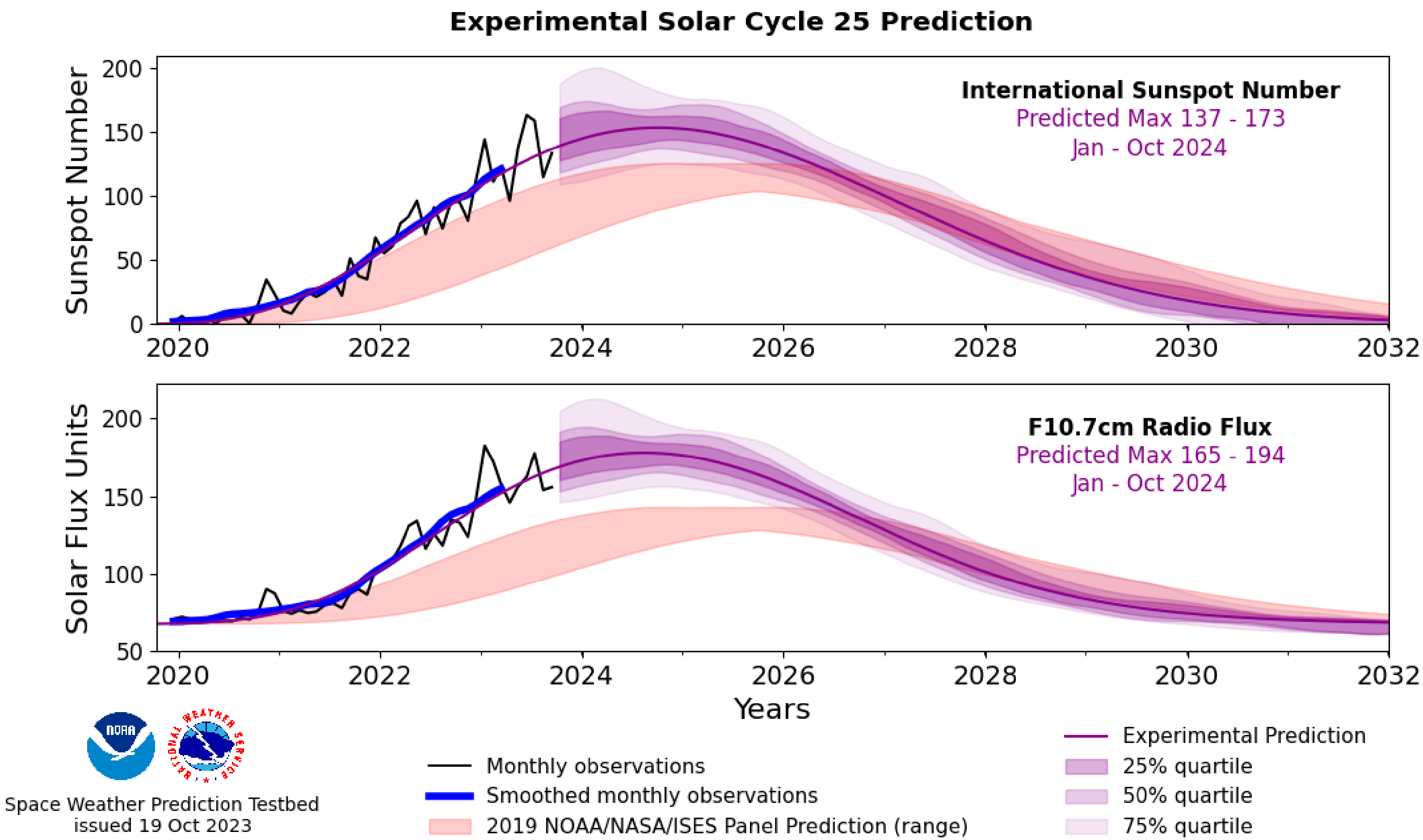
RADICAL Improvement in EPP PA Measurements and Climate Impacts



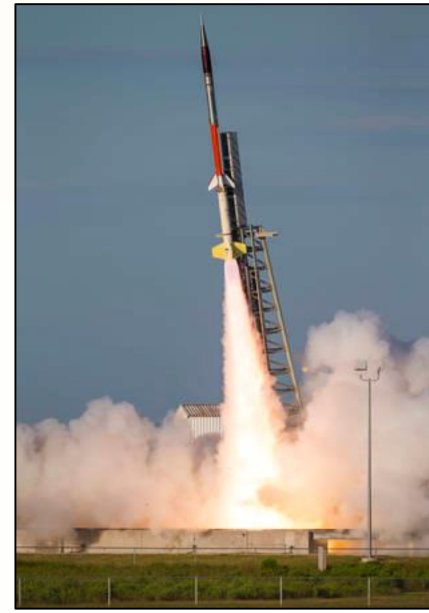
Solar Cycle 25

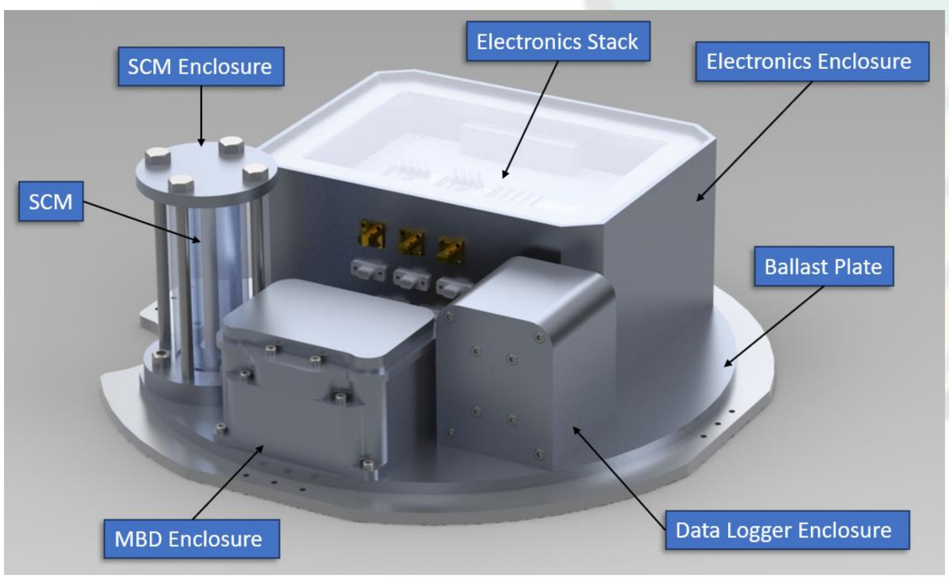
NOAA Space Weather Prediction Centre

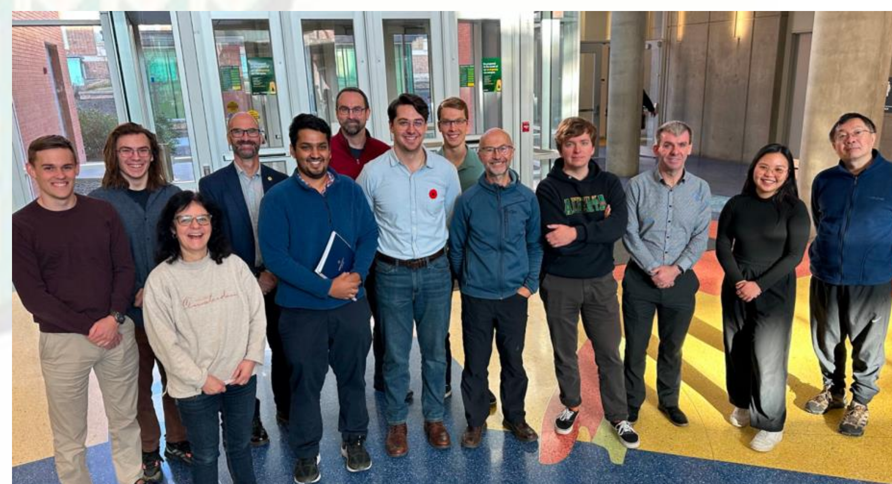


RADICALS Test: NASA Sounding Rocket RockSat-X in August 2024

- **P**ayload for **E**nergetic **P**article **P**recipitation **E**ducation and **R**esearch – e**X**periment (PEPPER-X)







Summary

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Back Up Slides

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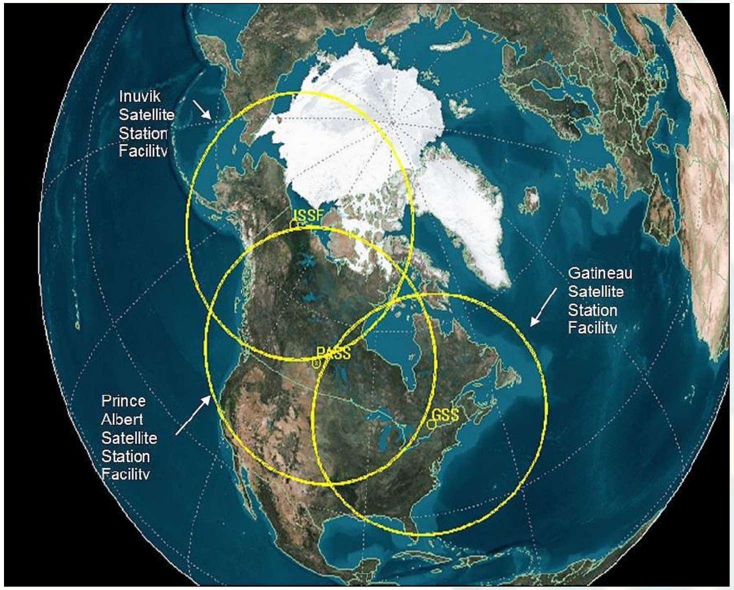
Ground Station Support and New Space Weather Data Products from NRCan



- Three ground stations from Natural Resources Canada.
- CFI Team Member from NRCan Space Weather Forecast Centre (SWFC) focussing on new SW products for users.

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NRCan CCMEO Operational Ground Station In-kind for 2yr prime + 3 yr extended mission

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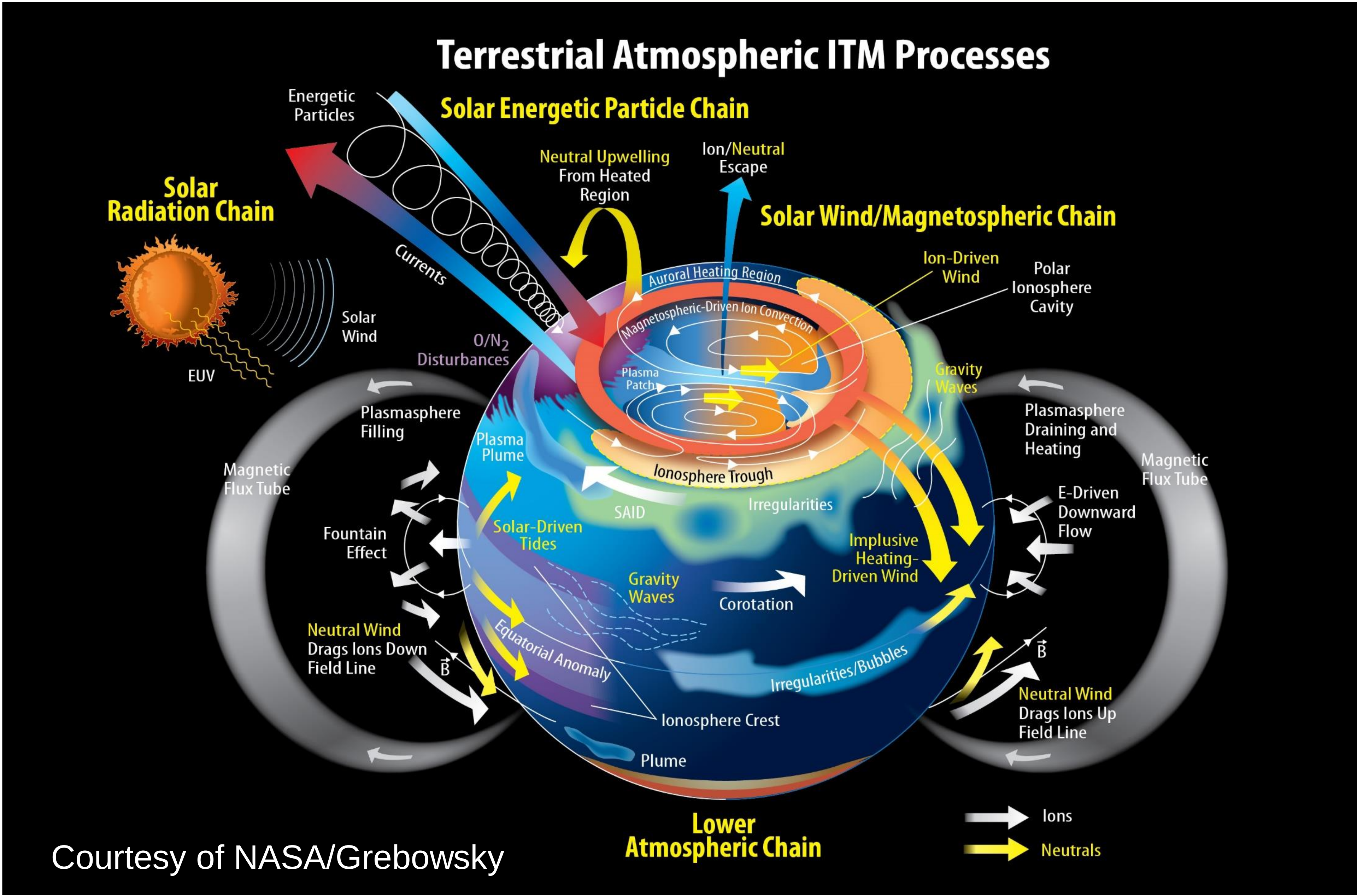
Climate Impacts



Courtesy of NASA/Grebowsky

Space is Vast: NASA Heliophysics Great Observatory

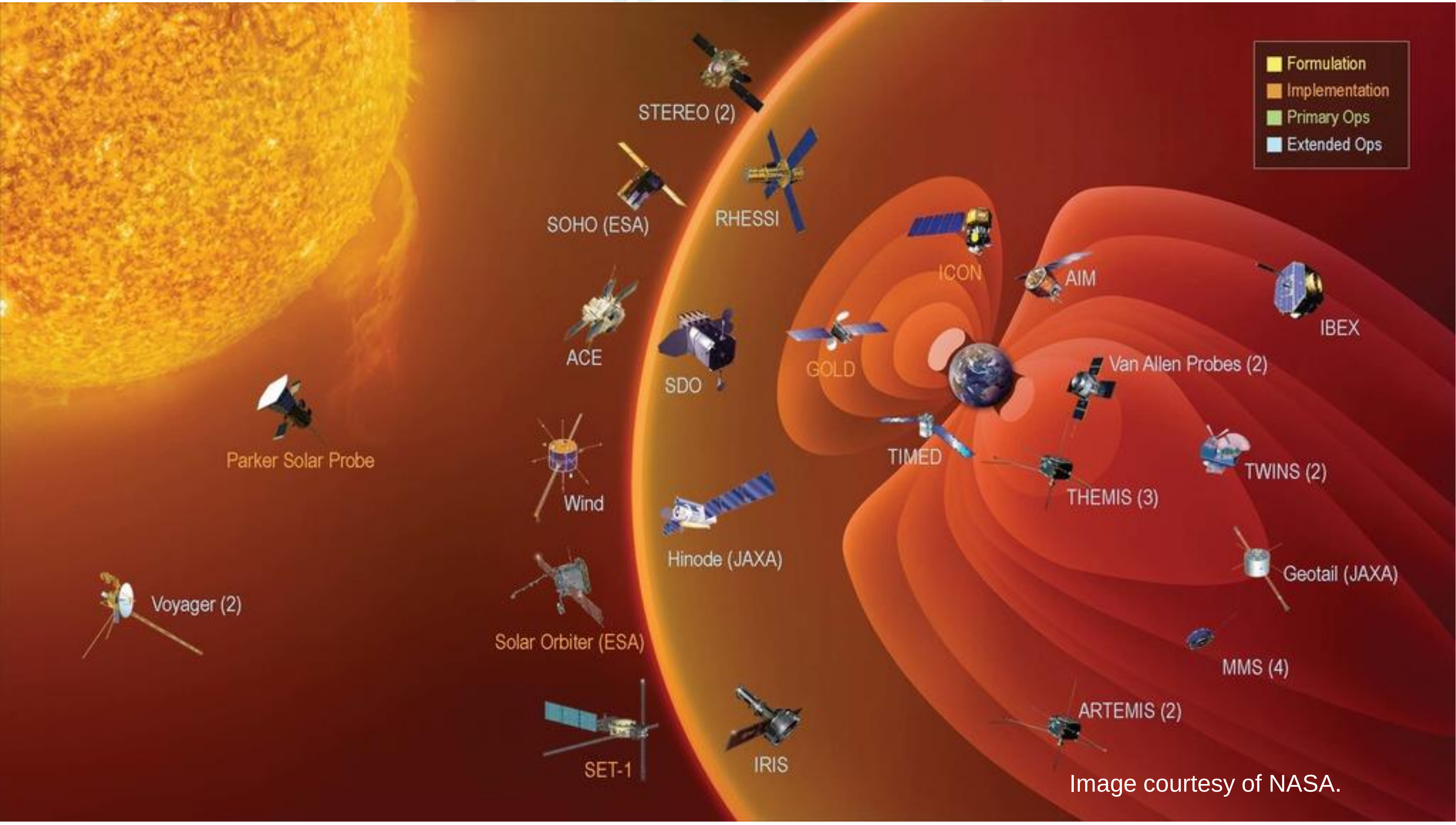
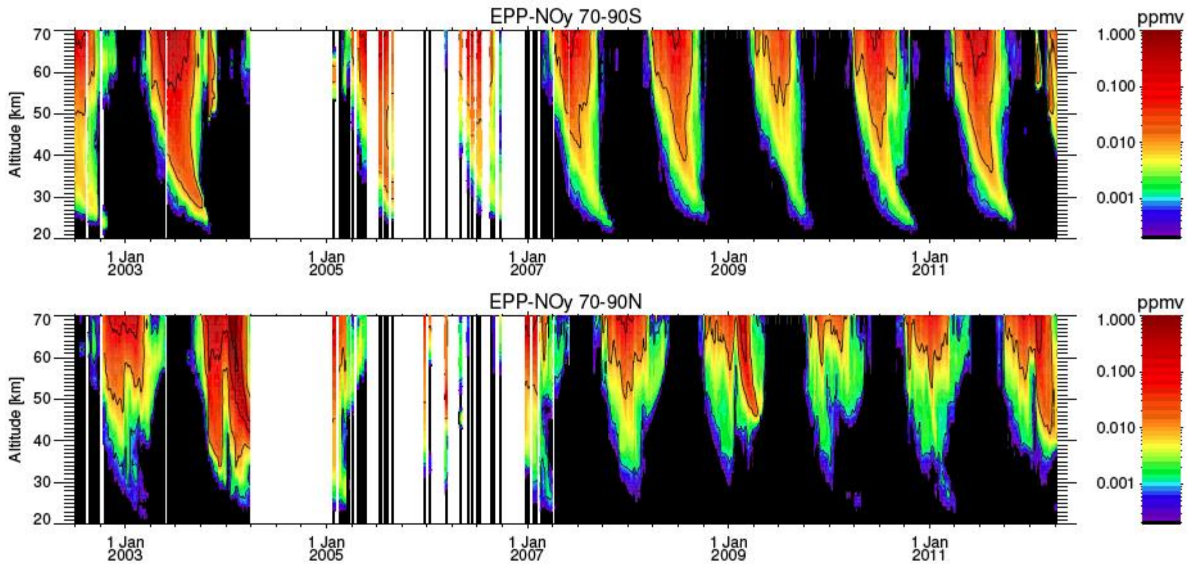


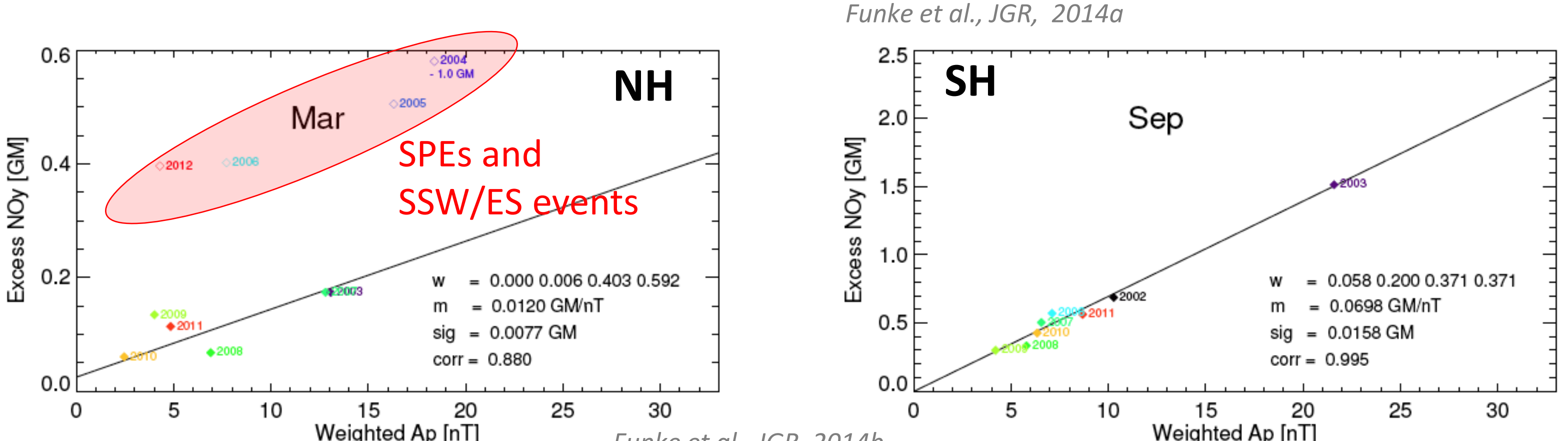
Image courtesy of NASA.

MIPAS NOy: a measure of the EPP indirect effect



- NOy enhancements in every winter due to EPP down to 25 km.
- Highly correlated with geomagnetic Ap index in the SH (when considering transport lags)
- Dynamical variability (SSW/ES) events leads to amplified responses!

Funke et al., JGR, 2014a



Funke et al., JGR, 2014b

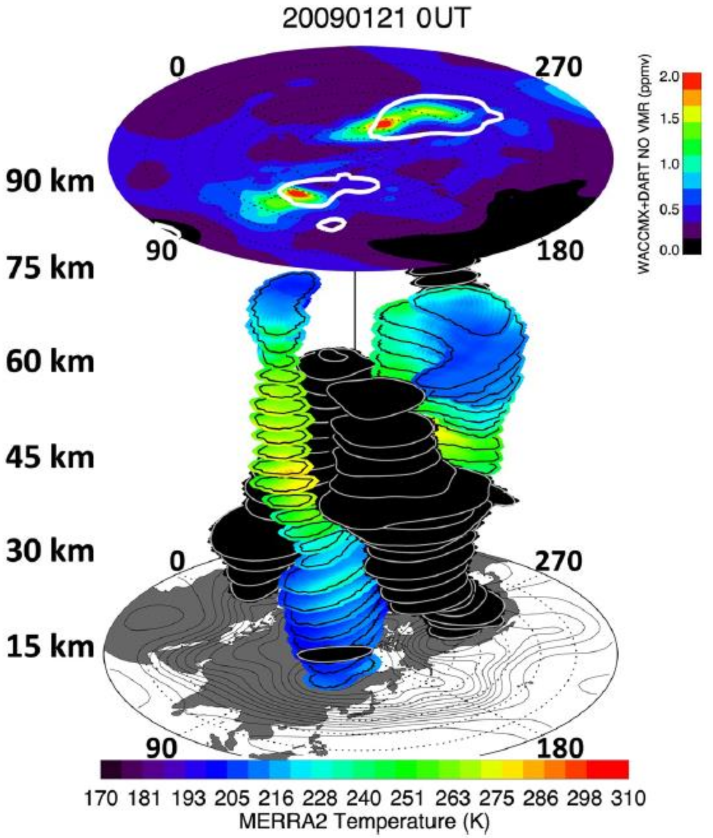


Figure 2. 3-D representation of the Arctic polar vortex (colored by temperature) and stratospheric anticyclones (colored black) on January 21, 2009, at 00 UT based on MERRA-2. An NH polar map of 90 km NO VMR from WACCMX + DART hovers above the split vortex. White contours in the NO map indicate where model GPH deviates by more than 1 km below the zonal mean, indicative of PW troughs. GPH, geopotential height; NH, Northern Hemisphere; PW, planetary wave; VMR, volume mixing ratio.

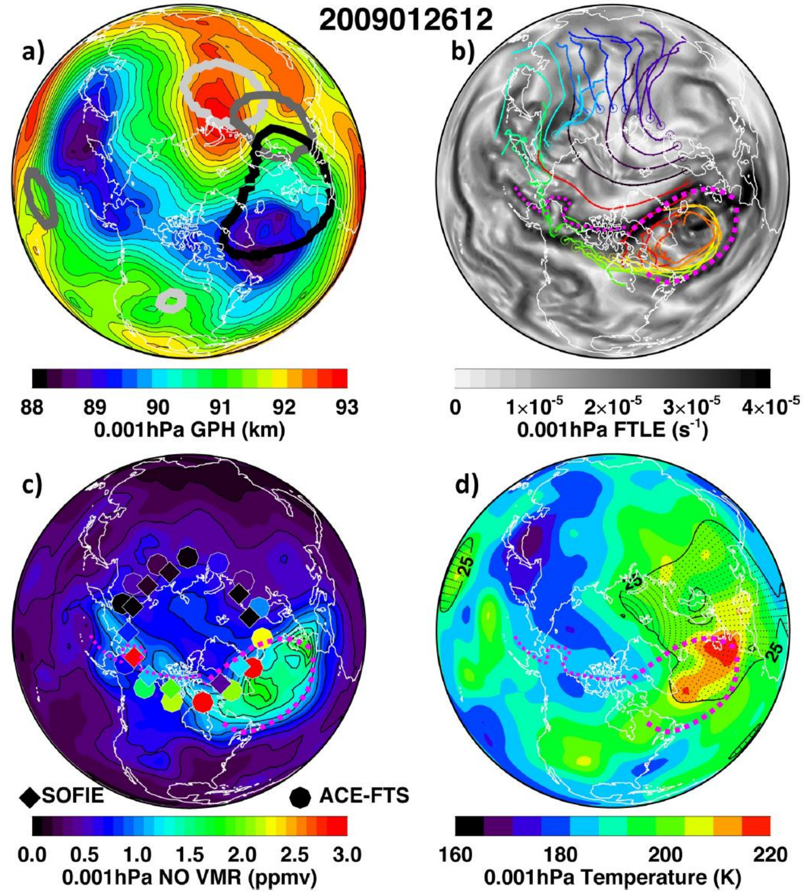


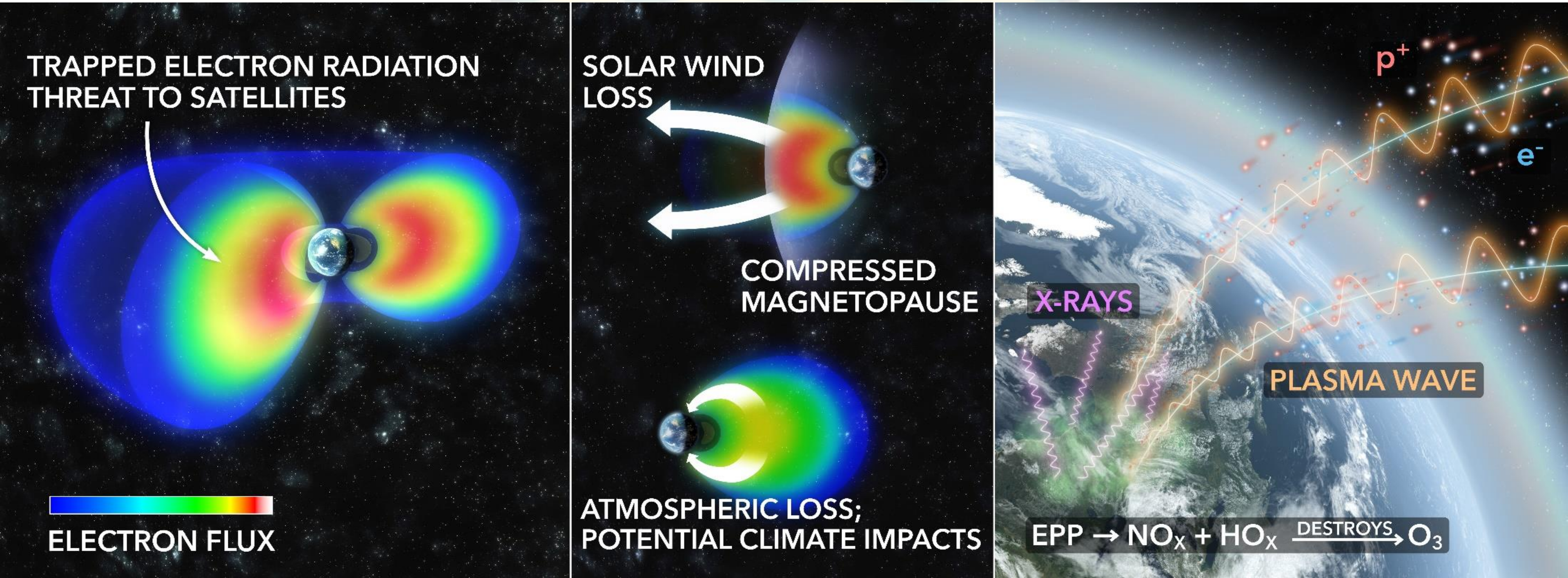
Figure 3. NH polar maps at 0.001 hPa (~90 km) on January 26, 2009 at 12 UT of (a) WACCMX + DART GPH (in color) and MERRA-2 polar vortex edges at 30 km (light gray), 50 km (dark gray), and 70 km (black), (b) simulated FTLE (light and dark gray shading) and 24-h forward trajectory paths (colored lines) for air that originated at the locations given by the open colored circles at 65°N, spaced every 10° in longitude; the pink dotted lines highlight FTLE ridges of interest and these are repeated in panels (c) and (d), (c) NO VMR in WACCMX + DART (color contoured), and NO VMR observed by SOFIE (diamonds) and ACE-FTS (octagons) (note, the ACE-FTS measurement north of Hudson Bay corresponds to a NO VMR of 4.6 ppmv which is outside the color bar range), and (d) WACCMX + DART temperature (in color) with black stippling and boundary lines indicating where the deviation of WACCMX + DART atomic oxygen is at least 25% larger than the zonal mean at each latitude. Both warm temperatures and high atomic oxygen are proxies for descent. FTLE, finite-time Lyapunov exponent; NH, Northern Hemisphere; PW, planetary wave; VMR, volume mixing ratio.

Effect of Atmospheric Dynamics on downward transport of Nitric Oxide.

Harvey et al., 2021

Mission Instrument Payload

- Flies CSA-supported high heritage payload:
  - High Energy Particle Telescope (HEPT – U. Alberta ECE, Fedosejevs et al.)
  - Fluxgate and Search Coil Magnetometers (FGM and SCM – U. Alberta Physics, Milling et al)
  - X-Ray Instrument (XRI – U. Calgary, Cully et al.)



Objectives: Science Traceability Matrix

	Science Goals	Objectives
Characterization and Prediction	What is the energetic particle (electron, proton) input to the atmosphere at seed energies (~100 keV) and radiation belt energies (~1 MeV)?	Quantify the flux, energy spectrum and spatial extent of strong (bounce loss cone-filling) and weak (drift loss cone-filling) EPP.
		Quantify the contribution of microburst precipitation at seed and radiation belt energies to the overall precipitation budget.
		Quantify the contribution of EMIC wave precipitation at seed and radiation belt energies to the overall precipitation budget.
		Quantify the rate of backscatter of energetic particles from the atmosphere at seed and radiation belt energies.
	How effectively can EPP be predicted?	Evaluate models for predicting EPP flux, spectrum and spatial extent based on ground-based, GEO, and solar wind data.
Causes	What are the dominant direct causes of EPP at seed energies (~100 keV) and radiation belt energies (~1 MeV)?	Determine the prevalence of energy-dependent precipitation corresponding to EMIC and whistler-mode scattering bands.
		Characterize the electromagnetic waves (ULF to VLF) present at LEO during these EPP events, and in non-events.
		Assess the connection between the magnitude of the trapped flux and the rates of strong and weak EPP (cf. Kennel-Petschek)
Atmospheric Effects	What are the atmospheric effects resulting from EPP?	Assess the relative importance of electron and proton precipitation to NOx and HOx production in the thermosphere (indirect effect) and stratosphere (direct effect).
Societal Effects	What are the societal effects resulting from EPP?	Determine the characteristics of the precipitating solar protons that disturb radio frequency transmissions during polar-cap absorption (PCA) events.
		Characterise the rates of radiation belt electron and proton loss as a result of EPP during different geomagnetic conditions.

RADICALS: A Canadian Mission

- Project initiated in 2016, and selected for funding by Canada Foundation for Innovation (CFI) in 2020 Innovation Fund competition.
- Partner funding from the Government of Alberta secured in 2020.
- Canadian Space Agency matching funding secured in 2022.
- Project initiation in April 2022. Launch target in Q4 2026 or Q1 2027.
- Exploits prior Canadian Space Agency investment in ALL proposed RADICALS payload instruments, and U. Toronto bus heritage.
- Targets priority international science target with "made in Canada" solution. cf. updated to NASA Heliophysics Roadmap (to 2033) target:

> *"To understand and predict how solar activity, both electromagnetic and particulate, impacts the climate of a planet with an established atmosphere;" with focus on "Energetic particle precipitation impacts on the ozone layer through the formation of nitric oxides"*

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"Made-in-Canada" Mission

Mission proposal brings together leading space science and technology experts in Canada:

Mission Leadership (U. Alberta& U. Calgary): Mann, Lipsett, Cully, Zee, Barona et al.

Spacecraft Bus (U. Toronto): Zee

Payloads: Fluxgate and Search Coil Mag. (U. Alberta): Milling, Kale; Energetic Particle Telescope (U. Alberta): Fedosejevs, Tiedje; X-ray Imager (U. Calgary): Cully.

Ground-based Data Support: McWilliams (U. Saskatchewan), Connors (Athabasca U.), Cully (U. Calgary), et al.

Space Weather Science and Data Products (NRCan): Fiori et al.

Ground-stations (NRCan): CCMEO and Hazards Divisions

Mission MOC and SOC and Operations (U. Calgary): Yau, Howarth.

Modelling: Rankin (U. Alberta), Ward (UNB)

Industry Partners: Honeywell, Magellan.

Canadian Space Agency

Extensive Canadian and international data users identified.

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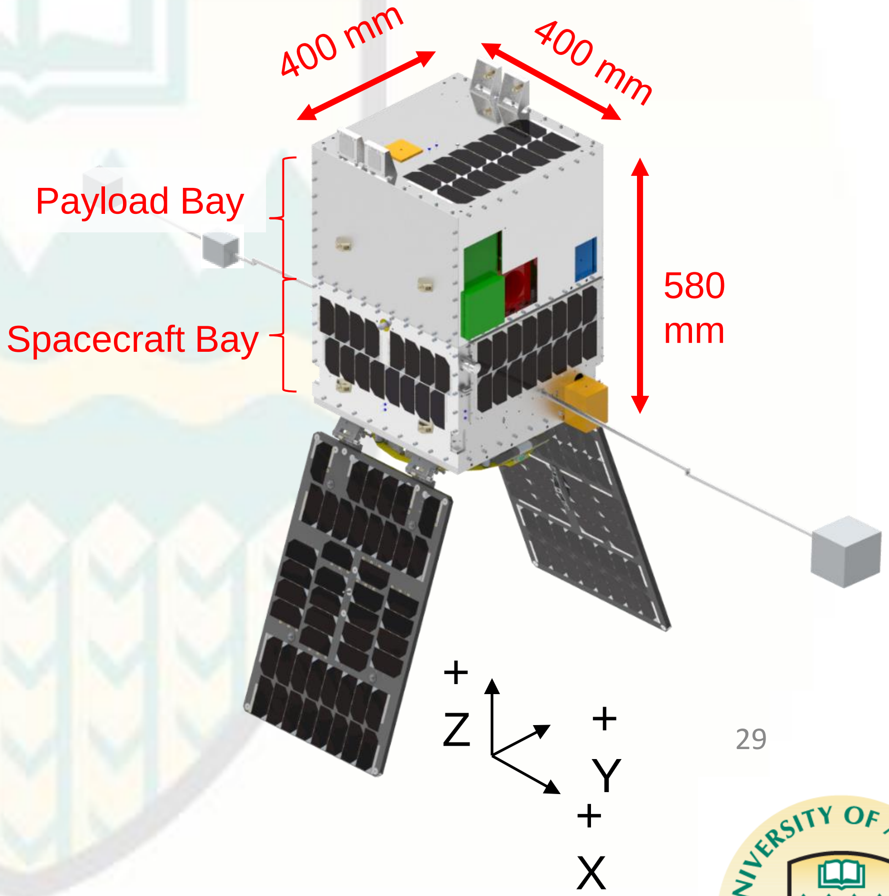
DEFIANT-XL Bus Layout

- Two primary volumes:
  - Top: Payload Bay
  - Bottom: Spacecraft/Bus Bay
- Dimensions:
  - Total Exterior: 400 mm x 400 mm x 580 mm
  - Payload Interior: 375 mm x 375 mm x 265 mm
- Load paths:
  - Spacecraft bay constitutes primary structure
  - Payload bay secures to spacecraft bay via a structural divider tray
  - Spacecraft secured to LV via launch adaptor, mounted to spacecraft bay structure



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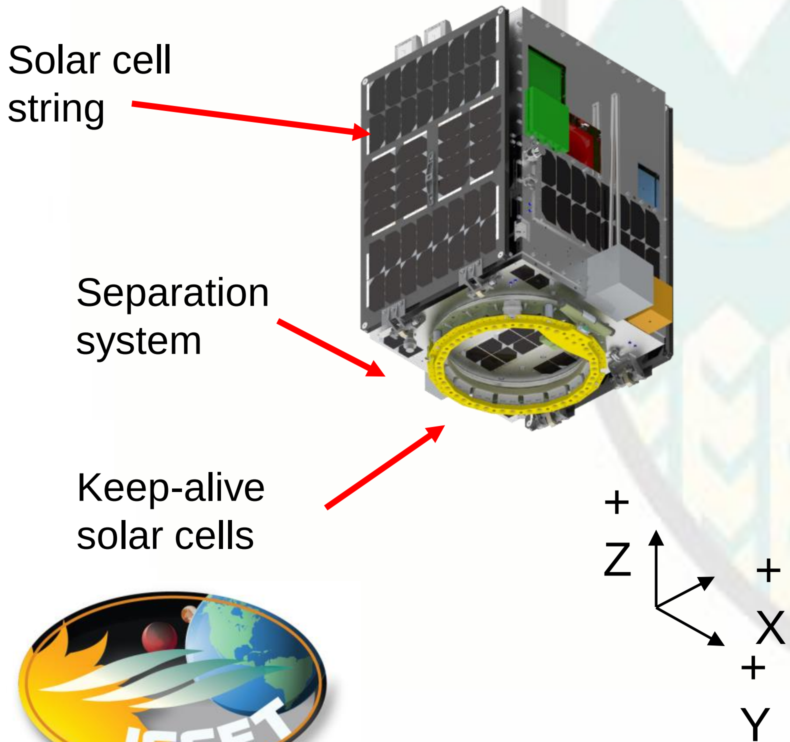
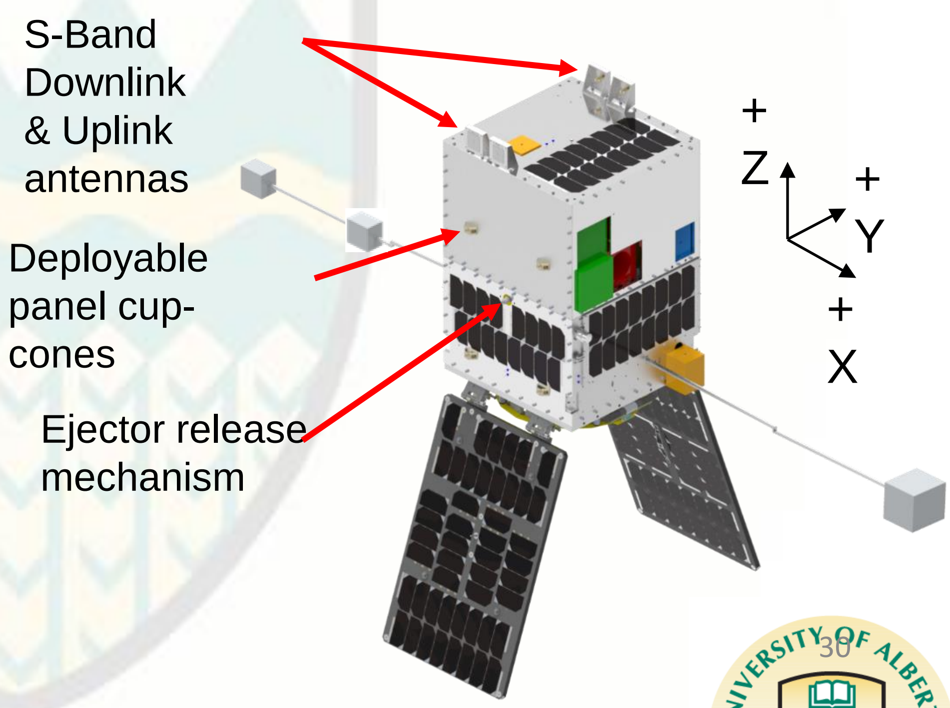
Courtesy of UTIAS SFL, University of Toronto

Solar Panel Layout for RADICALS

- Main feature of the DEFIANT-XL bus is its two large deployable solar panels.
- Solar cells installed on both sides of the deployable panel.
- Panels deployed at 70° pictured, but the angle will be optimised to the orbit we receive from the Launch Provider.





Courtesy of UTIAS SFL, University of Toronto

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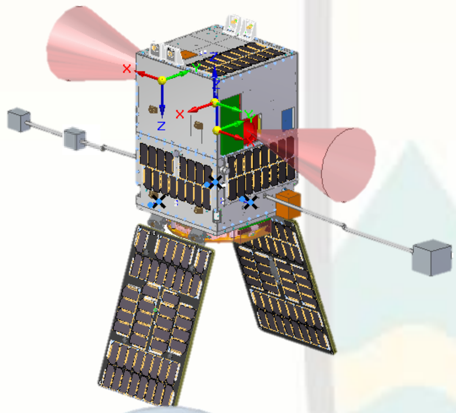
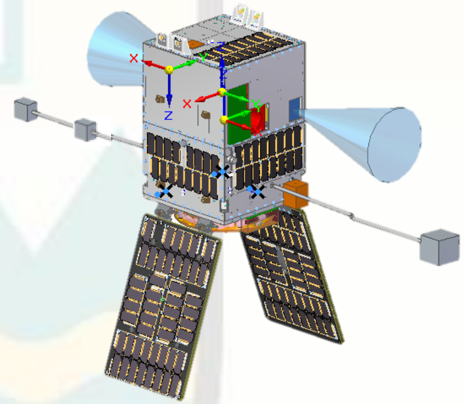
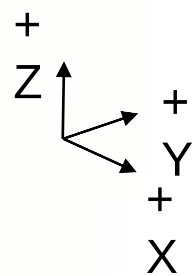
Instrument fields of view

RADHEP T-HE

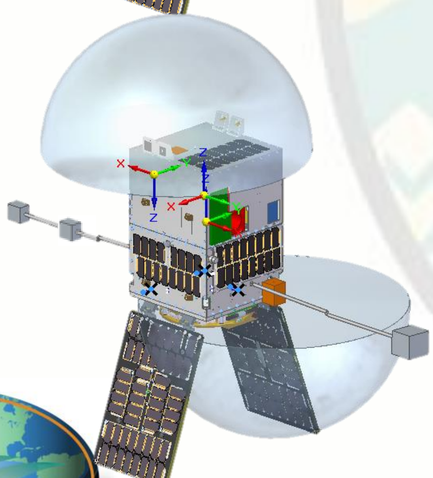


RADHE PT-LE

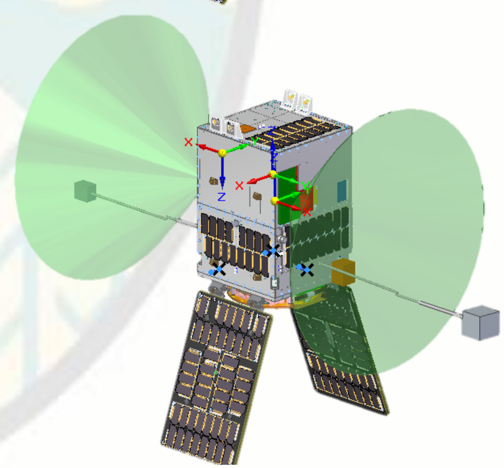




RADHEP T-MB



XRI-AB



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