



# Space Weather Research Program

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# NSF's Role in Research Efforts



- NSF is the only U.S. federal agency with a mission to support all fields of fundamental science and engineering, except medical sciences*
- NSF, unlike many other federal agencies, does not directly operate its own laboratories or similar facilities.*
- NSF supports scientists, engineers, and educators through their home institutions*
- NSF's mission is to advance science frontiers, provide funding to support research endeavors, and create educational and training opportunities for next generation scientists and engineers*



# Space Weather

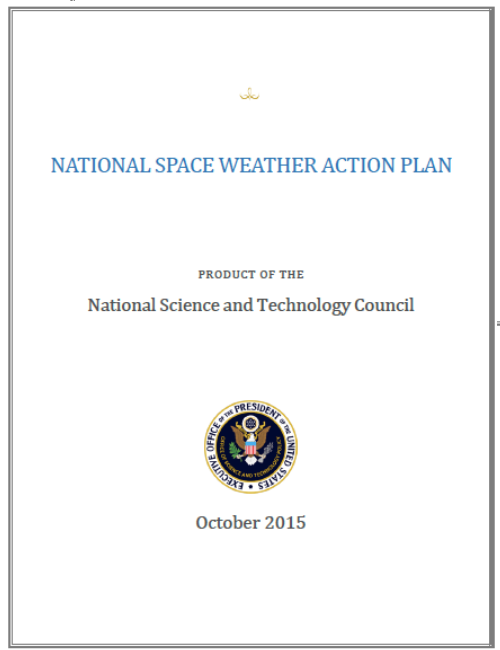
- *Space Weather refers to conditions in space that can influence the performance and reliability of space-borne and ground-based technological systems and can pose risk to human health*
- *Preparing for space weather requires a strong commitment to:*
  - *basic research, development of predictive models, advancement of state-of-the-art instruments, creative experiments exploiting space- and ground-based sensors*





# National Space Weather Strategy and Plan

- Nov 2014 – Space Weather Operations, Research, and Mitigation (SWORM) Task Force was established
- Tasked to develop:
  - National Space Weather Strategy
  - National Space Weather Action Plan
- ***National Space Weather Strategy***
  1. Establish benchmarks for SWx events
  2. Enhance Response and Recovery Capabilities
  3. Improve protection and mitigation efforts
  4. Improve assessment, modeling, and prediction of impacts on critical infrastructure
  5. Improve SWx services through advancing understanding and forecasting
  6. Increase international cooperation
- ***National Space Action Plan***
  - Each goal has specific actions with deliverables and timelines
  - Each action has an agency/department in charge and participating agencies

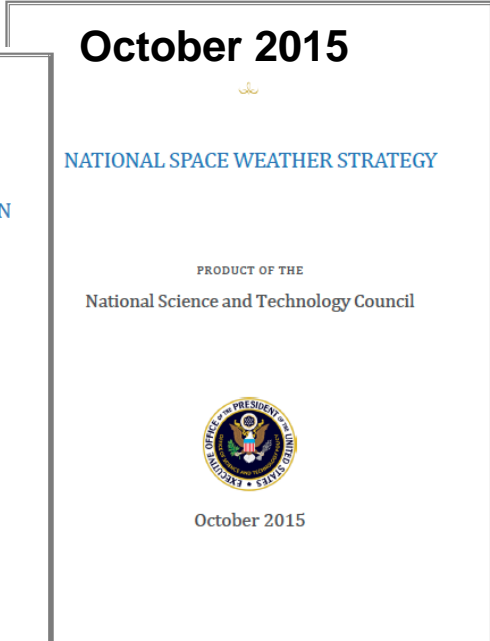
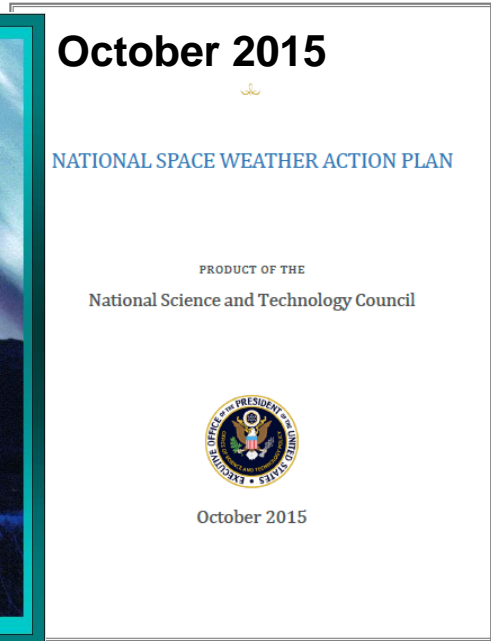
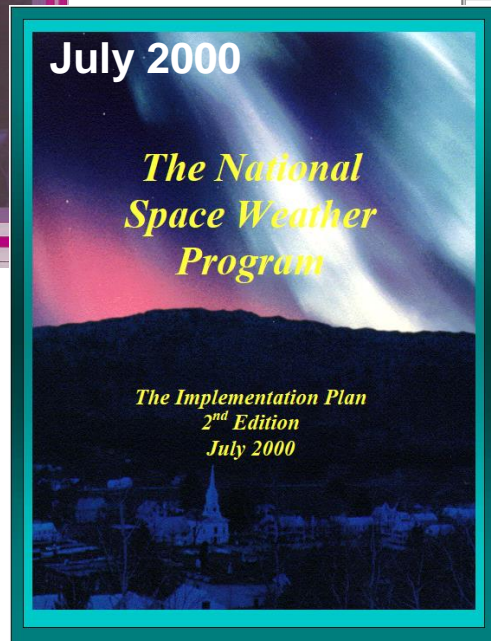




# NSF Contributions to the National Space Weather Plan



- Space Weather research was first supported by NSF in 1995
- Action 5.5.1: NSF lead agency for prioritizing space weather related research and identifying R&D opportunities





## Action 5.5.1 prioritize and identify opportunities for research and development (R&D) to enhance the understanding of space weather and its sources

- NSF in collaboration with NASA, DOC and DOD, will lead an annual effort to prioritize and identify opportunities for research and development (R&D) to enhance the understanding of space weather and its sources.
- This effort will include modeling, developing, and testing models of the coupled sun-Earth system and quantifying the long- and short-term variability of space weather.
- These activities will be coordinated with existing national-level and scientific studies.
- Community input on research priorities will be sought through RFIs

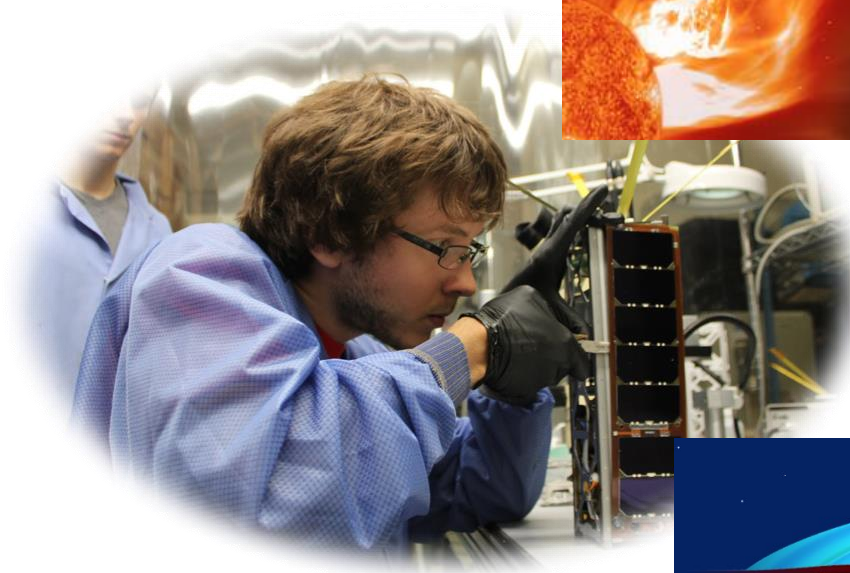


# NSF's Role in Space Weather Research

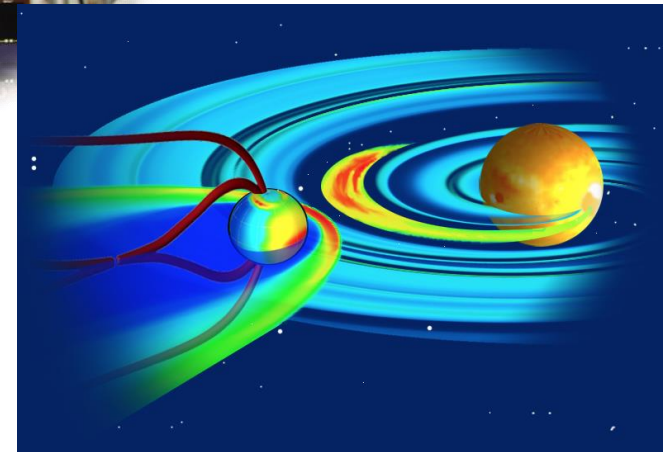
- Advancing fundamental knowledge



- Education

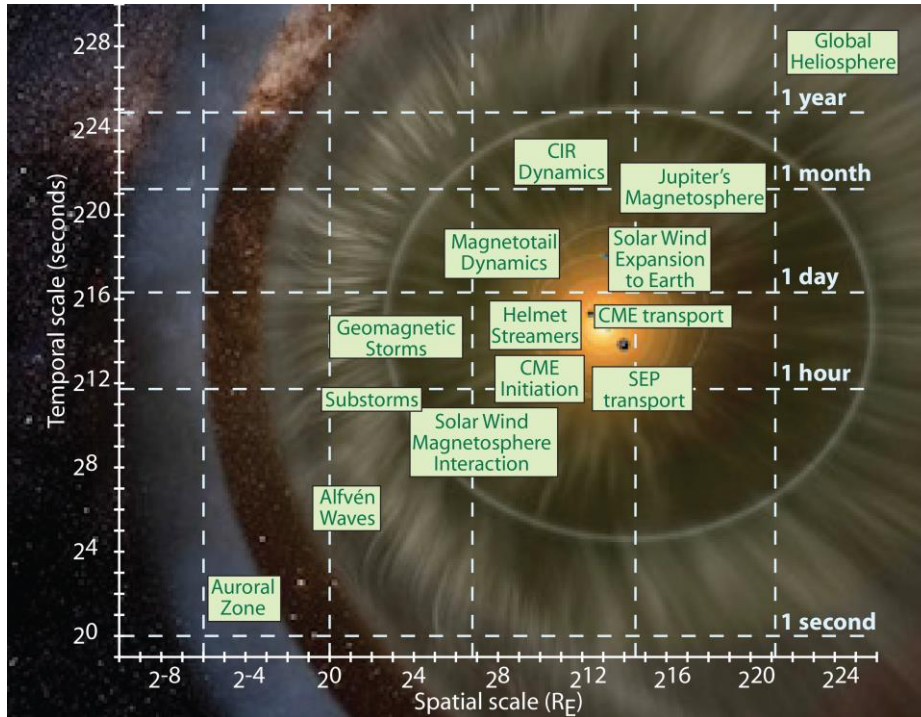


- Interagency Partnership





# Space Weather is Multi-Scale and Multi-Domain



- Multi-scale

- Temporal range:  $2^{28} \sim 2.7 \times 10^8$
- Spatial range:  $2^{28} \sim 2.7 \times 10^8$
- Cell volume range:  $2^{84} \sim 1.9 \times 10^{25}$

- Multi-physics – from kinetic to MHD

- Solar interior and dynamo
- Transition region
- Corona
- Geospace
- Magnetosphere
- Ionosphere-upper atmosphere
- Ground currents

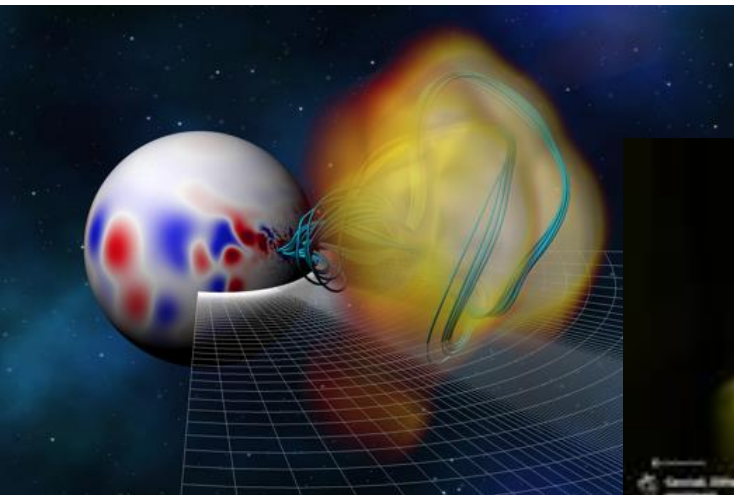
Courtesy: Tamas Gombosi, U. Michigan



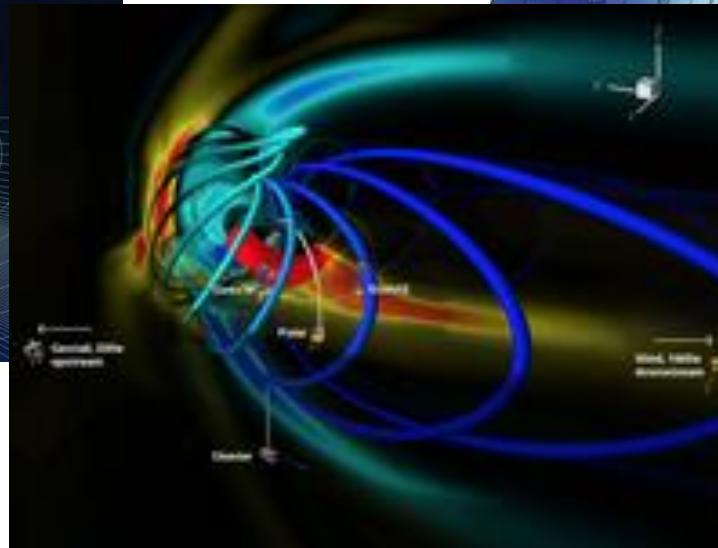


# Space Weather Modeling

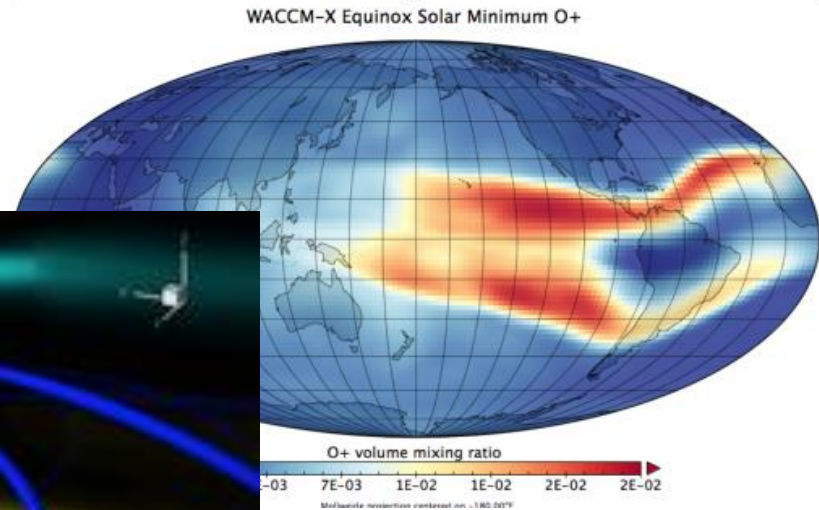
- Support for numerical modeling of the complete Sun-to-Earth chain
- Many of the NSF-funded '*research*' models now transitioned to CCMC for community use and to NOAA SWPC for operational support
- Continue support for capability building for Space Weather prediction



PSI – CME Modeling



SWMF – Geospace Model



WACCM-X –  
Ionosphere/Thermosphere



# Space Weather Observations

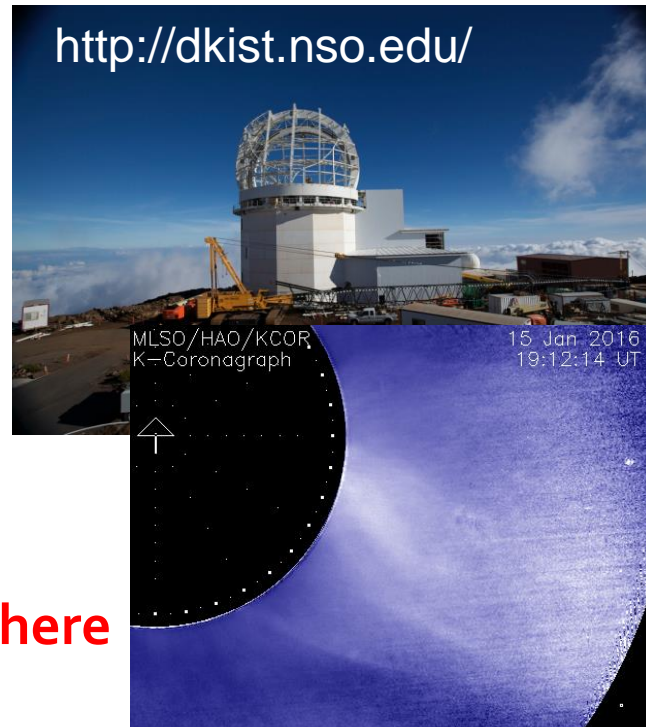
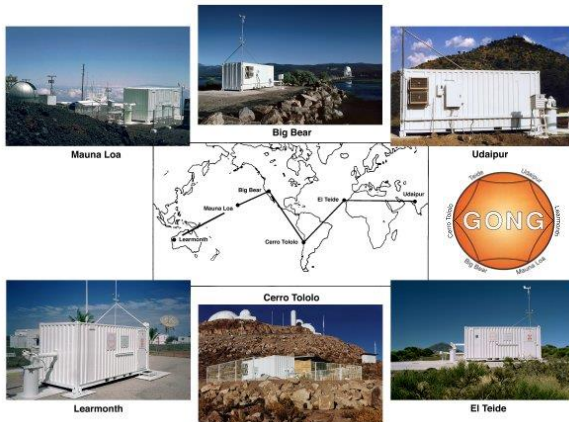
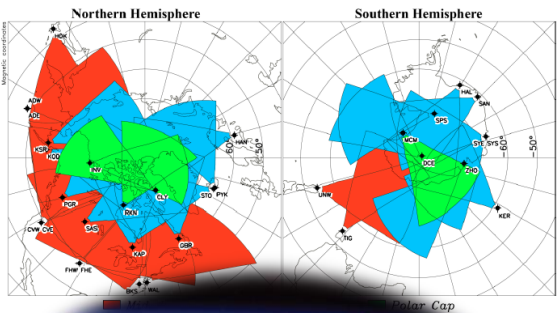


## SuperDARN

Super Dual Auroral Radar Network



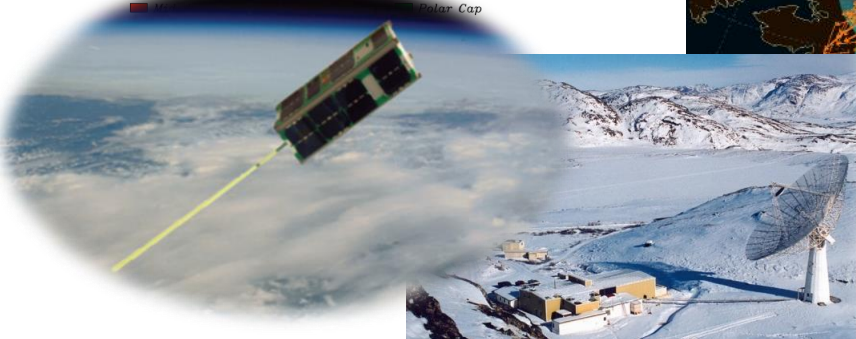
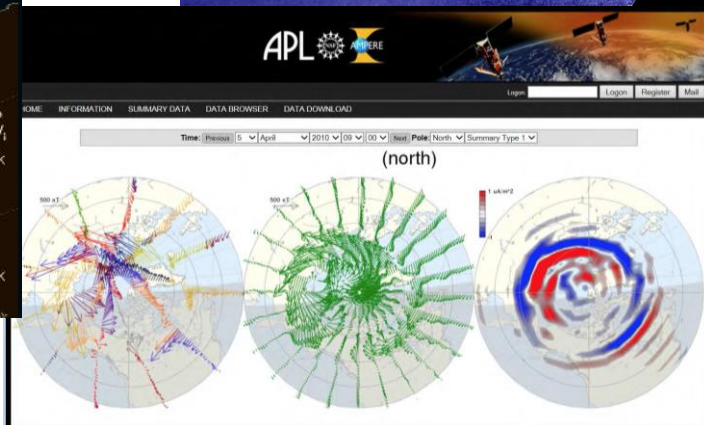
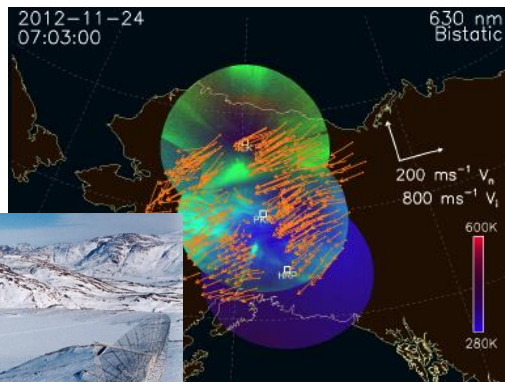
An International Radar Network for Studying the Earth's Upper Atmosphere, Ionosphere, and Connection into Space



<http://dkist.nso.edu/>

15 Jan 2016  
19:12:14 UT

- Sun
- Magnetosphere
- Ionosphere/Thermosphere

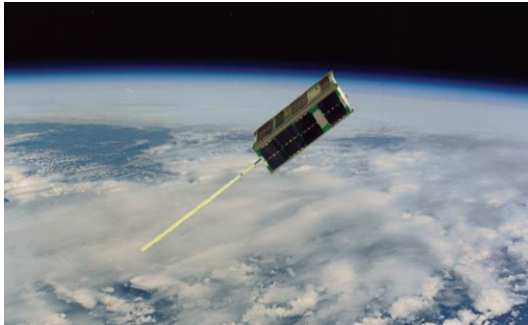




# NSF CubeSat Missions

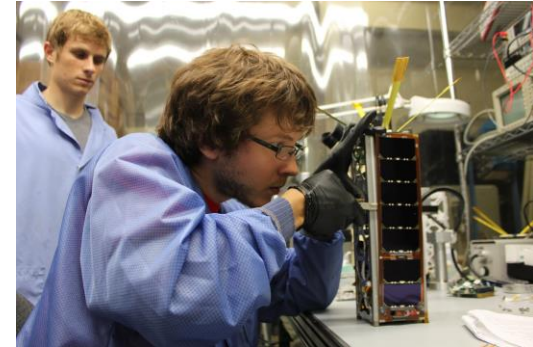
14 missions to date  
20 CubeSats

CSSWE

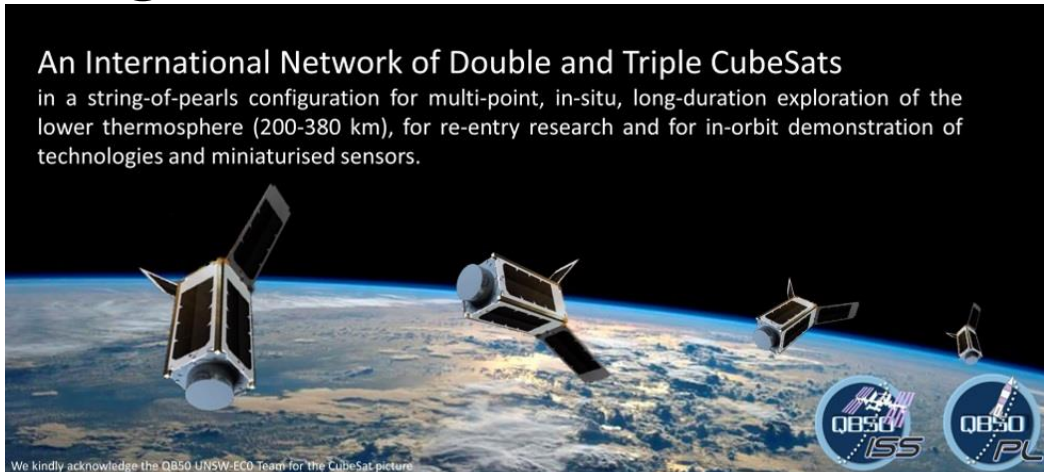


CADRE and MINXSS  
Released May 2016

RAX – Auroral Turbulence



QB50



An International Network of Double and Triple CubeSats in a string-of-pearls configuration for multi-point, in-situ, long-duration exploration of the lower thermosphere (200-380 km), for re-entry research and for in-orbit demonstration of technologies and miniaturised sensors.

We kindly acknowledge the QB50 UNSW-ECO Team for the CubeSat picture

QBUS

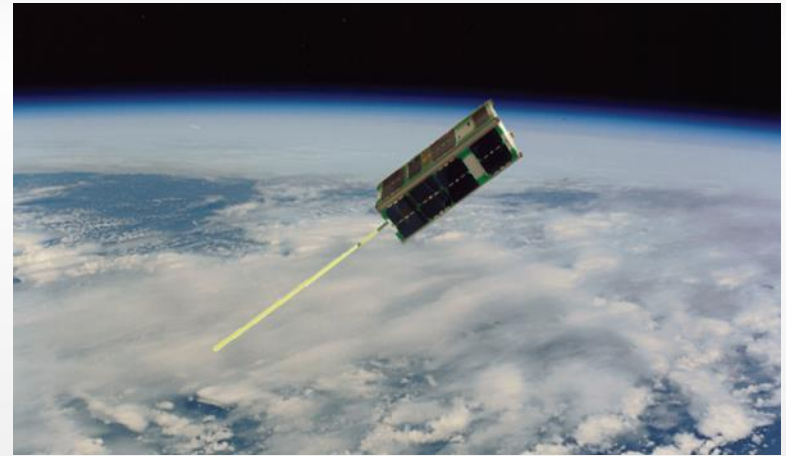
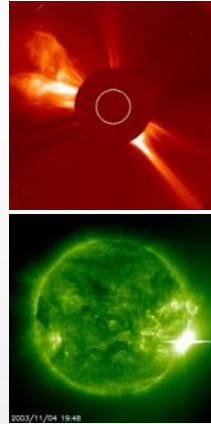


- US QB50 Consortium
  - Four Universities
  - ITM science expertise
  - Over 100 students involved

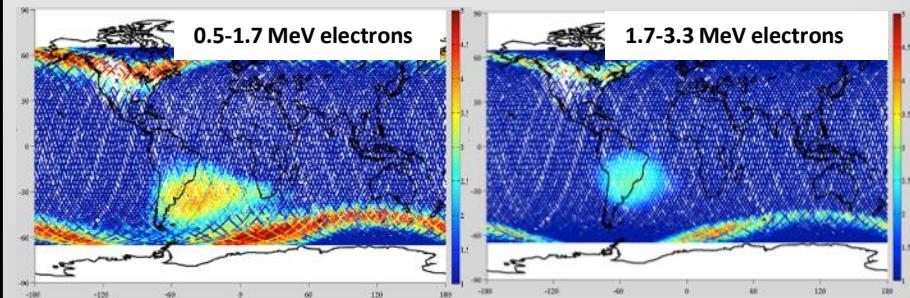
# The Colorado Student Space Weather Experiment

## Objectives

To understand the relationships between solar energetic particles (SEPs), flares, and coronal mass ejections (CMEs), and to characterize the variations of the Earth's radiation belt electrons.



- Funded by the NSF (\$900K) and launched in 2012
- Generated over 19 peer reviewed publications
- Measurements of electrons & protons provided a clear picture of the global distribution energetic particles in the near Earth environment





# Interagency Collaborations

- MOU with NASA under review
- NSCI pilot AGS with AST, PHY, CISE, and NASA
- O2R pilot under development (NSF-NASA-NOAA)
- DRIVE centers in partnership with NASA (RFI was released in July)



# Workshops



- **NSF has a long tradition of sponsoring educational events/workshops on space weather**
- **National and international workshops on Space Weather**
  - Annual Space Weather Workshop (Broomfield, CO)
  - Applied Space Environment Conference (Huntsville, AL, 2017)
  - International Heliophysical Year (IHY) (Addis Ababa, Ethiopia, 2007)
  - AGU Chapman conference for Earth & Space sciences (Addis Ababa, Ethiopia, 2012)
  - AGU Chapman conference on Dayside Magnetosphere Interactions (Chengdu, China, 2017)



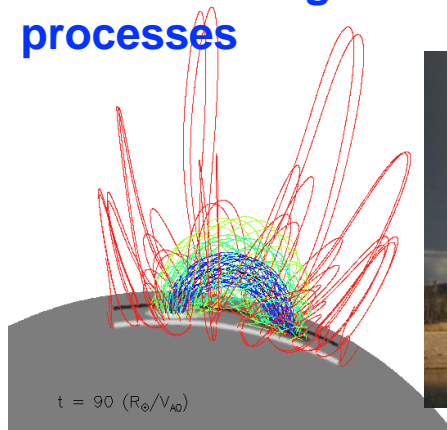


# Conclusions

## Advancing Fundamental Knowledge

Tackling the key science questions

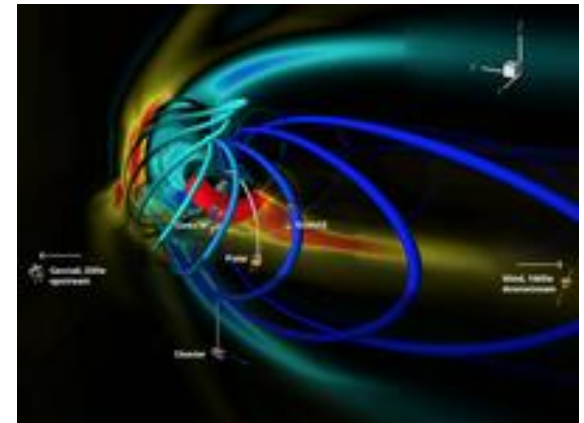
Understanding processes



Better observations



Improved Sun to Earth models



- Space Weather is a global concern
- NSF recognizes that R2O-O2R is important for Space Weather preparedness
- Fundamental understanding of Space Weather processes is critical for improving predictive capabilities
- NSF is committed to supporting cutting-edge research that will enable the global community to become *Space Weather Ready*