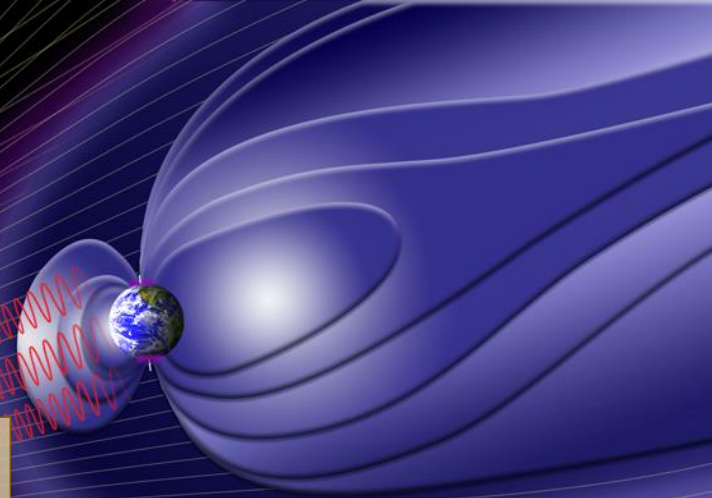
Grand Challenge

UNIVERSITY OF COLORADO **BOULDER**

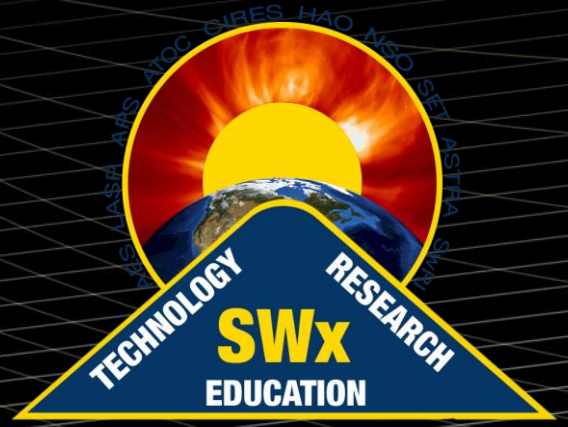
SPACE WEATHER CENTER



Space Weather Technology, Research, and Education Center

SWx-TREC

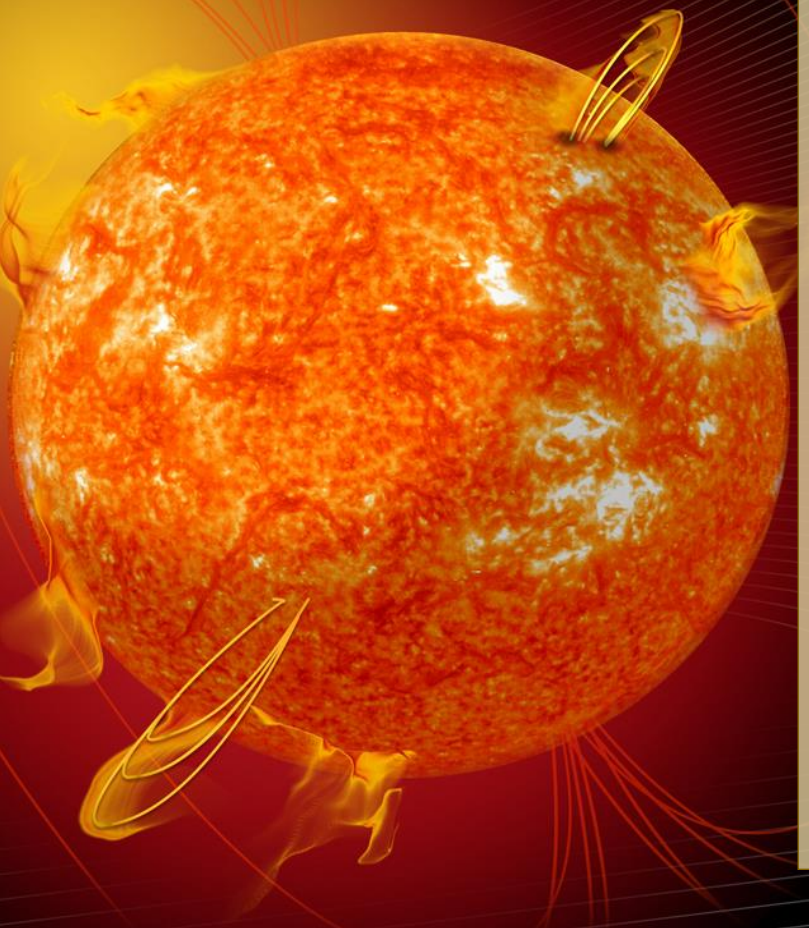
Prof. Jeffrey P. Thayer
University of Colorado
Ann and H.J. Smead Aerospace
Engineering Sciences Department



Grand Challenge

UNIVERSITY OF COLORADO **BOULDER**

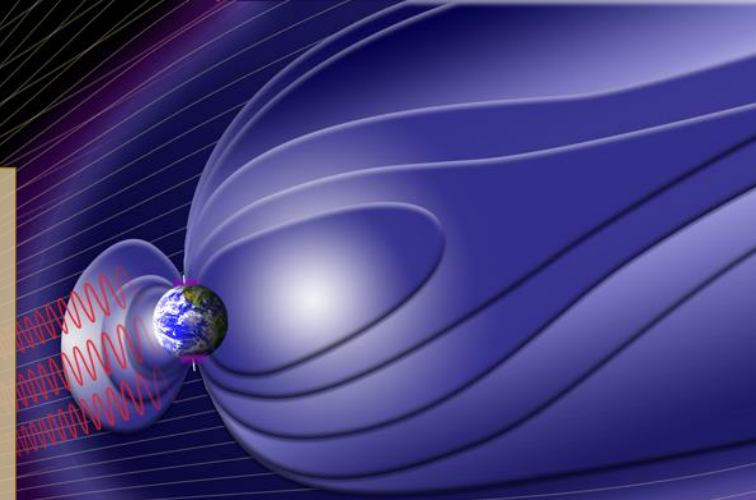
SPACE WEATHER CENTER



SWx-TREC

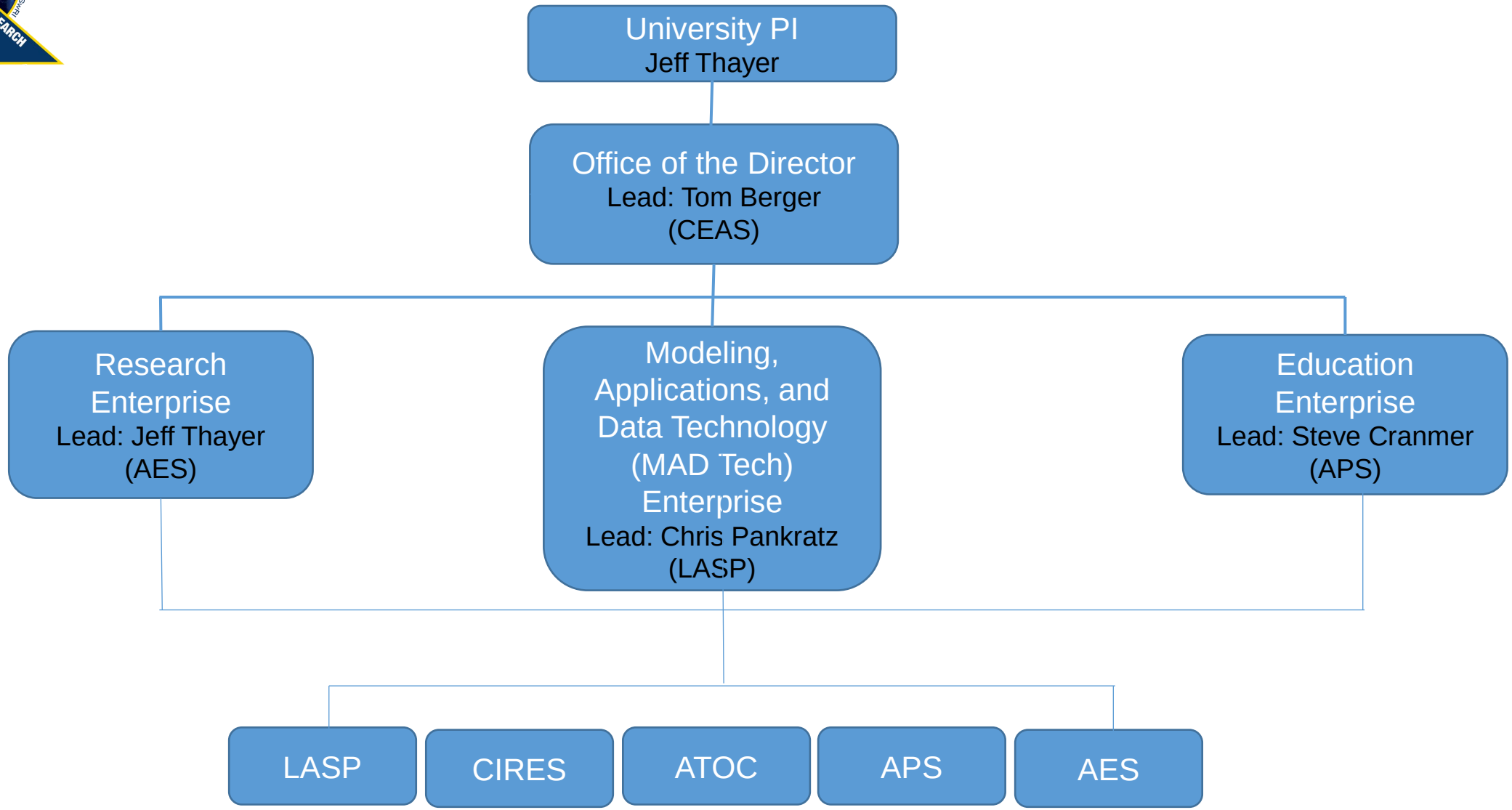
Jeffrey P. Thayer, PI (AES), Tom Berger, Director (CEAS), Dan Baker (LASP), Steven Cranmer (APS), Chris Pankratz (LASP), Tim Fuller-Rowell (CIRES), Nils Halverson (APS), and Cora Randall (ATOC)

TREC is a new academic initiative to serve as a national center of excellence in cross-disciplinary research, technological innovation and education in space weather. As an academic endeavor, SWx TREC provides new pathways for federal agencies, academia, commercial partners and industry to collaboratively address the nation's evolving space weather forecasting, mitigation and response needs.

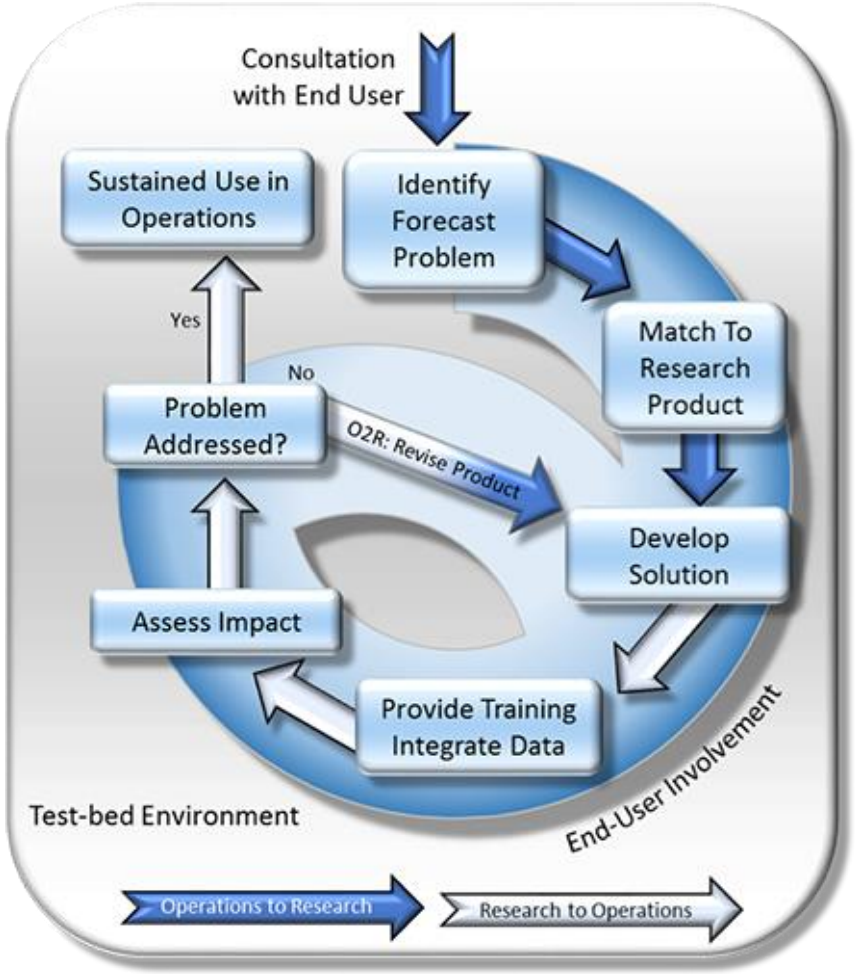


TECHNOLOGY RESEARCH SWx EDUCATION

SWx-TREC Organization



The R2O and O2R Cycle



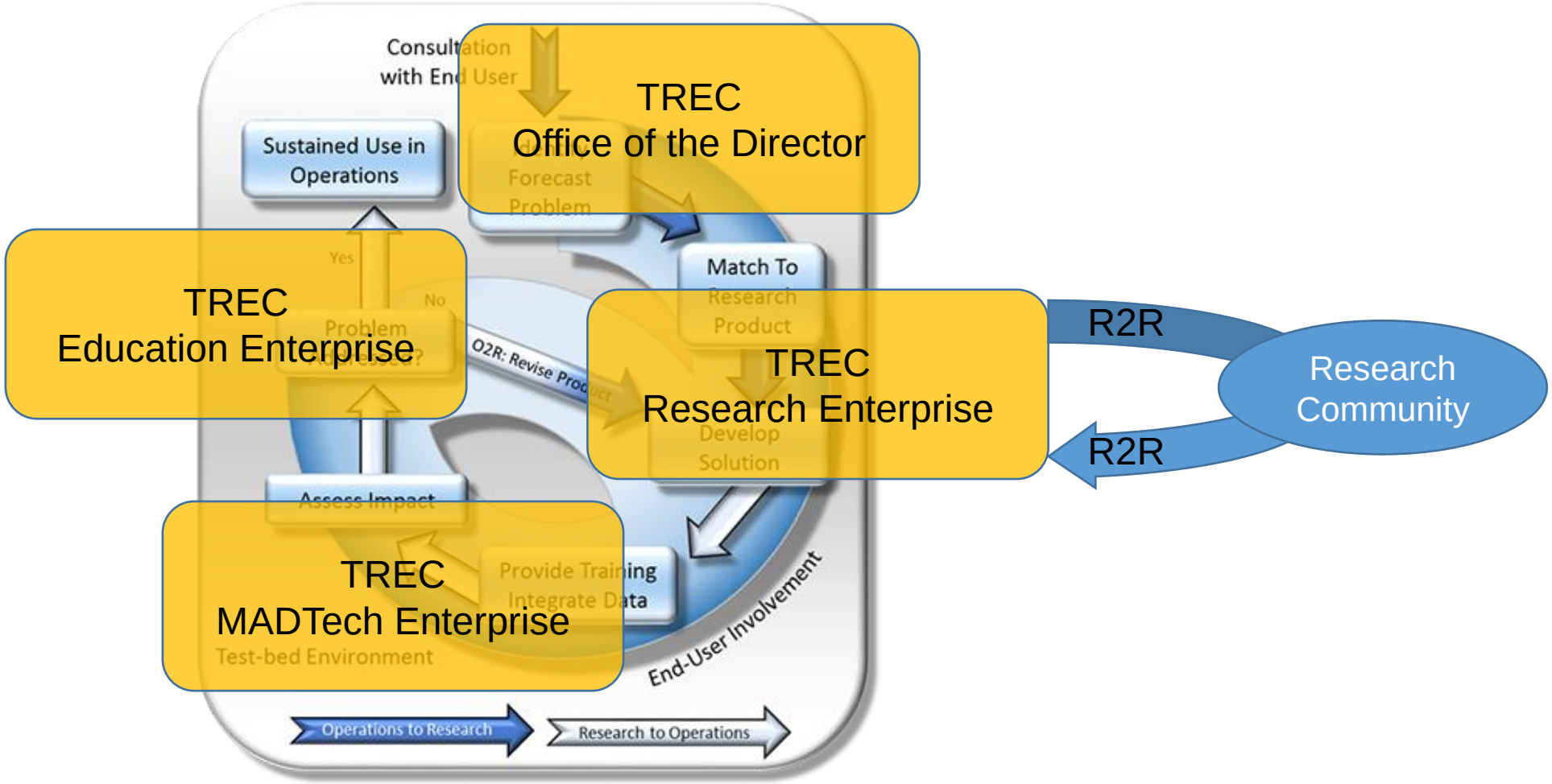
Jedlovec, 2013: the SPoRT Paradigm

To accelerate R2O, need to support O2R and provide researchers access to operational models, data assimilation systems, and observations:

"Keep R2O and O2R coupled"

SWORM R2O Workshop Report, 2016

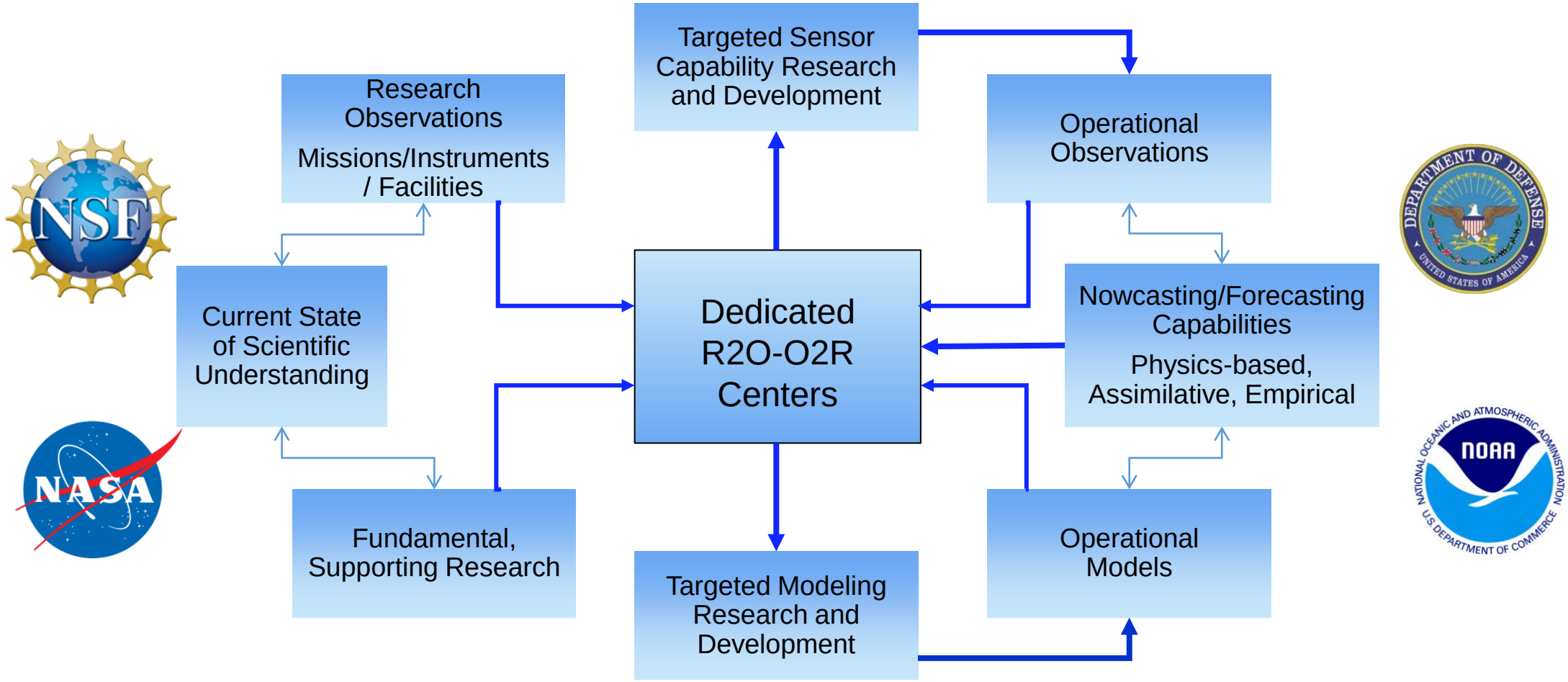
The R2O and O2R Cycle



Jedlovec, 2013: the SPoRT Paradigm

Addressing R2O and O2R Problems

R2O-O2R Center Version

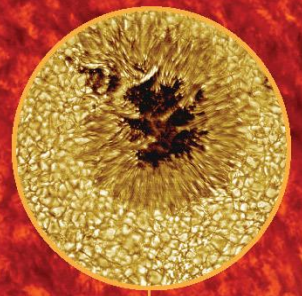


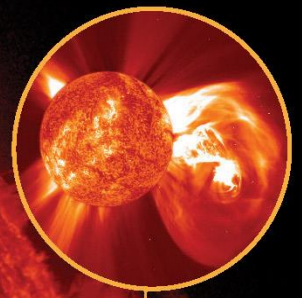
Space Weather

Space weather refers to the variable conditions on the Sun and in the space environment that can influence the performance and reliability of space-based and ground-based technological systems, as well as endanger life or health. Just like weather on Earth, space weather has its seasons, with solar activity rising and falling over an approximate 11 year cycle.

Sunspots

Sunspots are comparatively cool areas at up to 7,700° F and show the location of strong magnetic fields protruding through what we would see as the Sun's surface. Large, complex sunspot groups are generally the source of significant space weather.



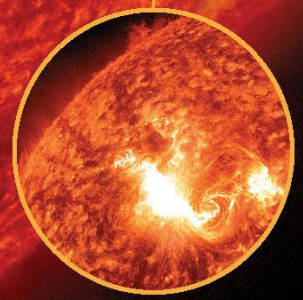


Coronal Mass Ejections (CMEs)

Large portions of the corona, or outer atmosphere of the Sun, can be explosively blown into space, sending billions of tons of plasma, or superheated gas, Earth's direction. These CMEs have their own magnetic field and can slam into and interact with Earth's magnetic field, resulting in geomagnetic storms. The fastest of these CMEs can reach Earth in under a day, with the slowest taking 4 or 5 days to reach Earth.

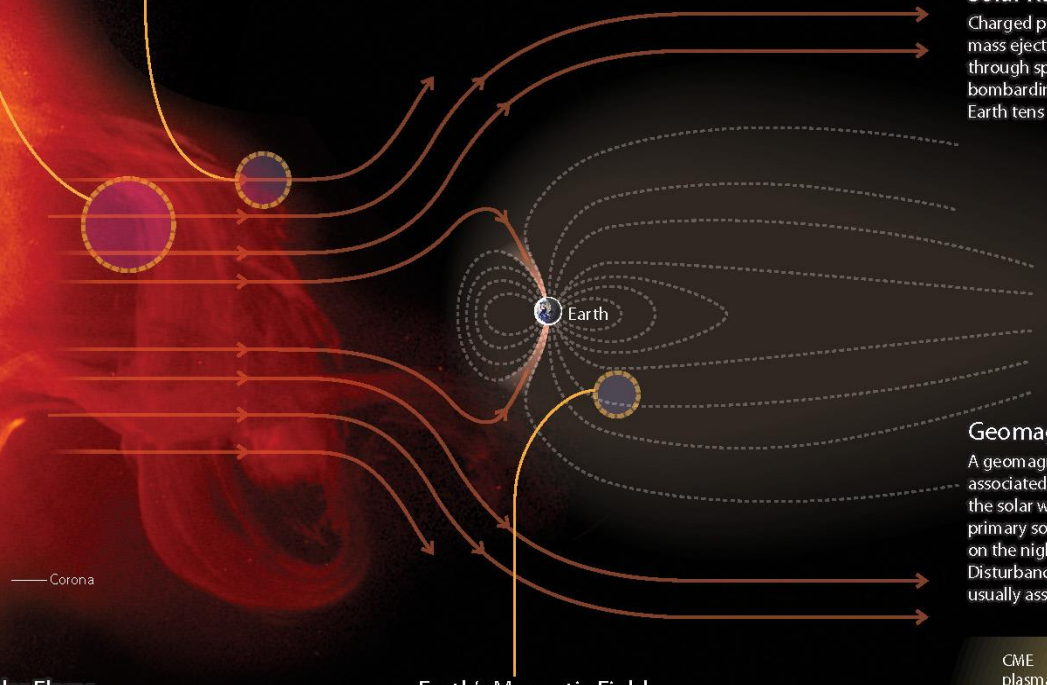
Solar Wind

The solar wind is a constant outflow of electrons and protons from the Sun, always present and buffeting Earth's magnetic field. The background solar wind flows at approximately one million miles per hour!



Solar Flares

Reconnection of the magnetic fields on the surface of the Sun drive the biggest explosions in our solar system. These solar flares release immense amounts of energy and result in electromagnetic emissions spanning the spectrum from gamma rays to radio waves. Traveling at the speed of light, these emissions make the 93 million mile trip to Earth in just 8 minutes.



Earth's Magnetic Field

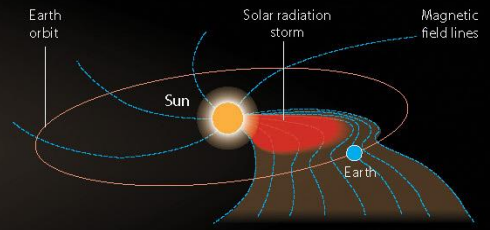
Earth's magnetic field, largely like that of a bar magnet, gives the Earth some protection from the effects of the Sun. Earth's magnetic field is constantly compressed on the day side and stretched on the night side by the ever-present solar wind. During geomagnetic storms, the disturbances to Earth's magnetic field can become extreme. In addition to some buffering by the atmosphere, this field also offers some shielding from the charged particles of a radiation storm.

Sun's Magnetic Field

Strong and ever-changing magnetic fields drive the life of the Sun and underlie sunspots. These strong magnetic fields are the energy source for space weather and their twisting, shearing, and reconnection lead to solar flares.

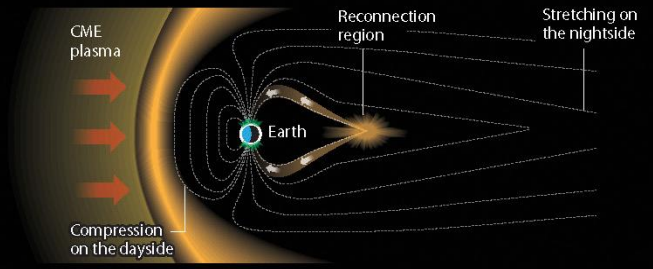
Solar Radiation Storms

Charged particles, including electrons and protons, can be accelerated by coronal mass ejections and solar flares. These particles bounce and gyrate their way through space, roughly following the magnetic field lines and ultimately bombarding Earth from every direction. The fastest of these particles can affect Earth tens of minutes after a solar flare.



Geomagnetic Storms

A geomagnetic storm is a temporary disturbance of Earth's magnetic field typically associated with enhancements in the solar wind. These storms are created when the solar wind and its magnetic field interacts with Earth's magnetic field. The primary source of geomagnetic storms is CMEs which stretch the magnetosphere on the nightside causing it to release energy through magnetic reconnection. Disturbances in the ionosphere (a region of Earth's upper atomosphere) are usually associated with geomagnetic storms.



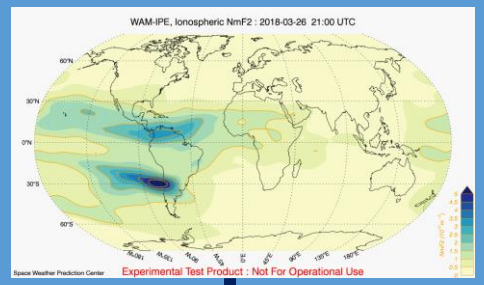
Source images: NASA, NOAA.

NOAA Space Weather Prediction Center – www.spaceweather.gov

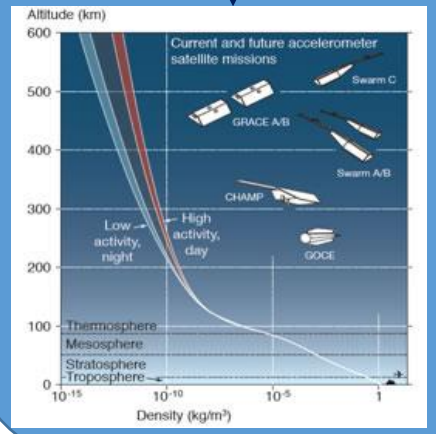
TREC Research Enterprise

Improving and applying existing models, enabling missions, and developing new capabilities to improve space weather forecasting.

MODELS

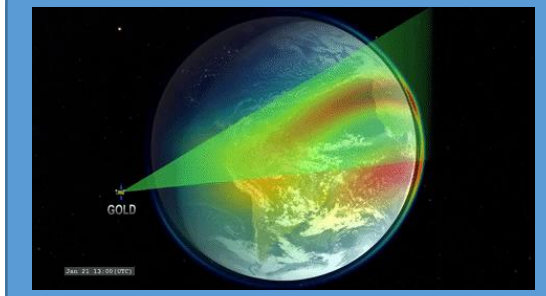


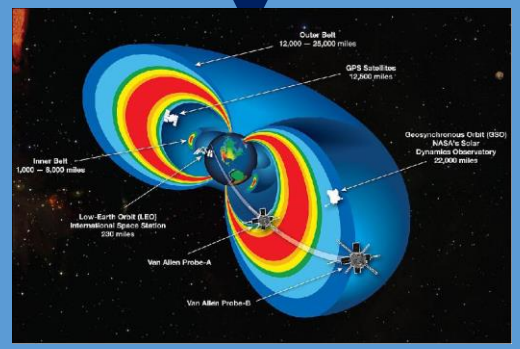
WAM/IPE
CTIP-e
TIEGCM



Physics-based drag modeling

MISSIONS / DATA





GOLD
Van Allen Probes
MAVEN
JUNO
MINXSS
CSSWE
…

CAPABILITIES

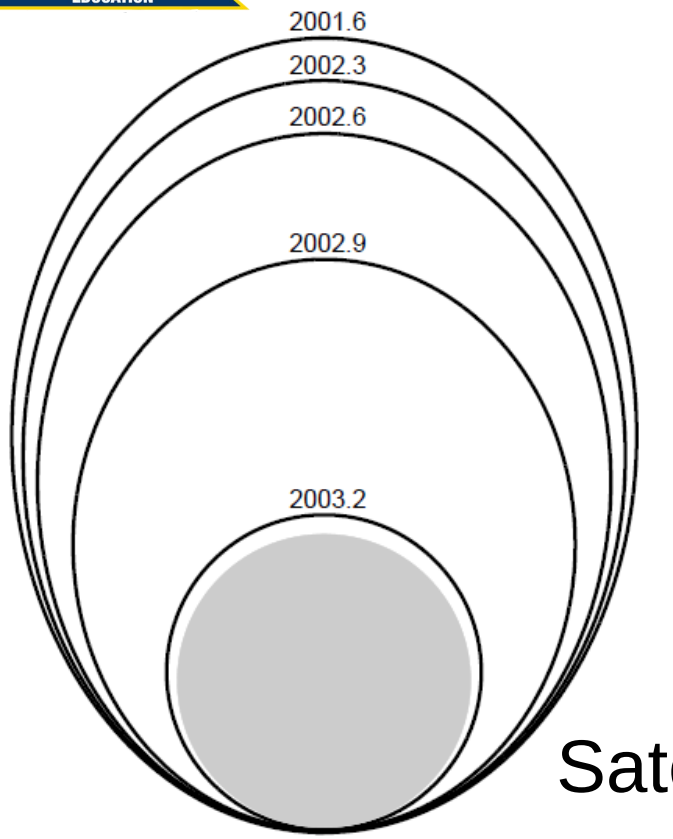
- Space physics research
- Solar physics research
- Space instrumentation and mission design
- Aerospace engineering
- CubeSat developments
- Astrophysical and planetary Sciences
- Geospace modelling and data assimilation
- Satellite and mission data management

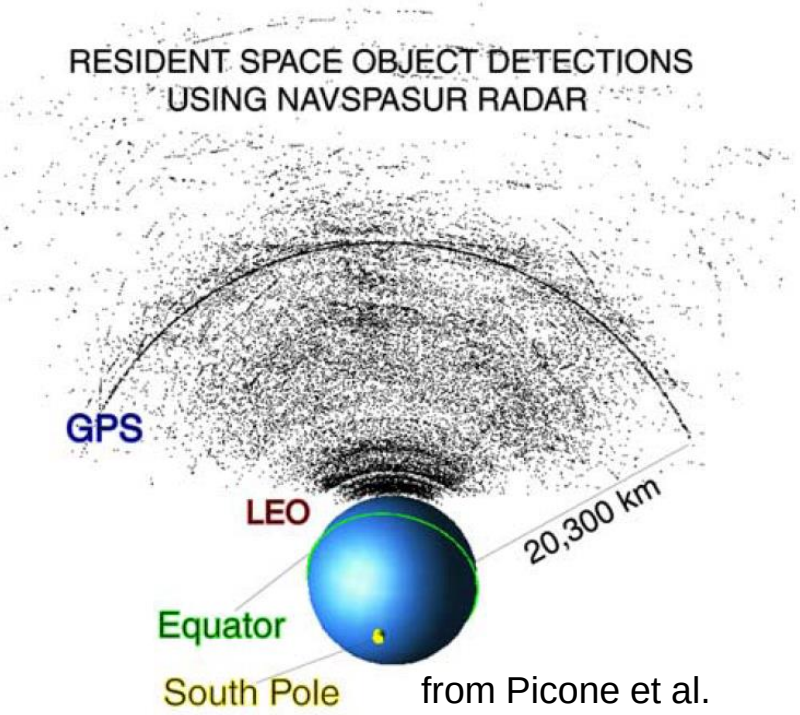
University of Colorado Boulder

Problem Statement

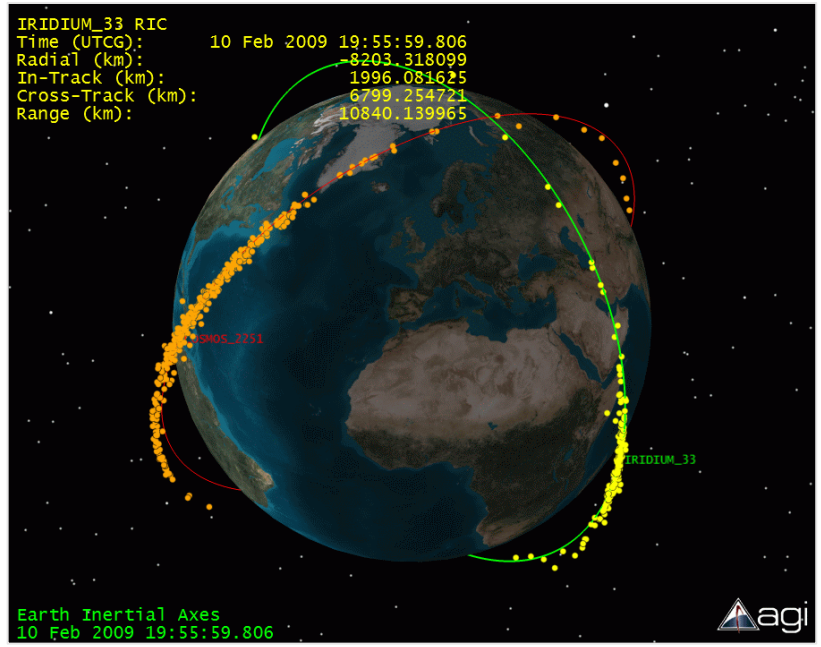
Transition of new Research models, mission data, and tools to Operational Forecasting is inefficient. "R2O problem"

Satellite Drag



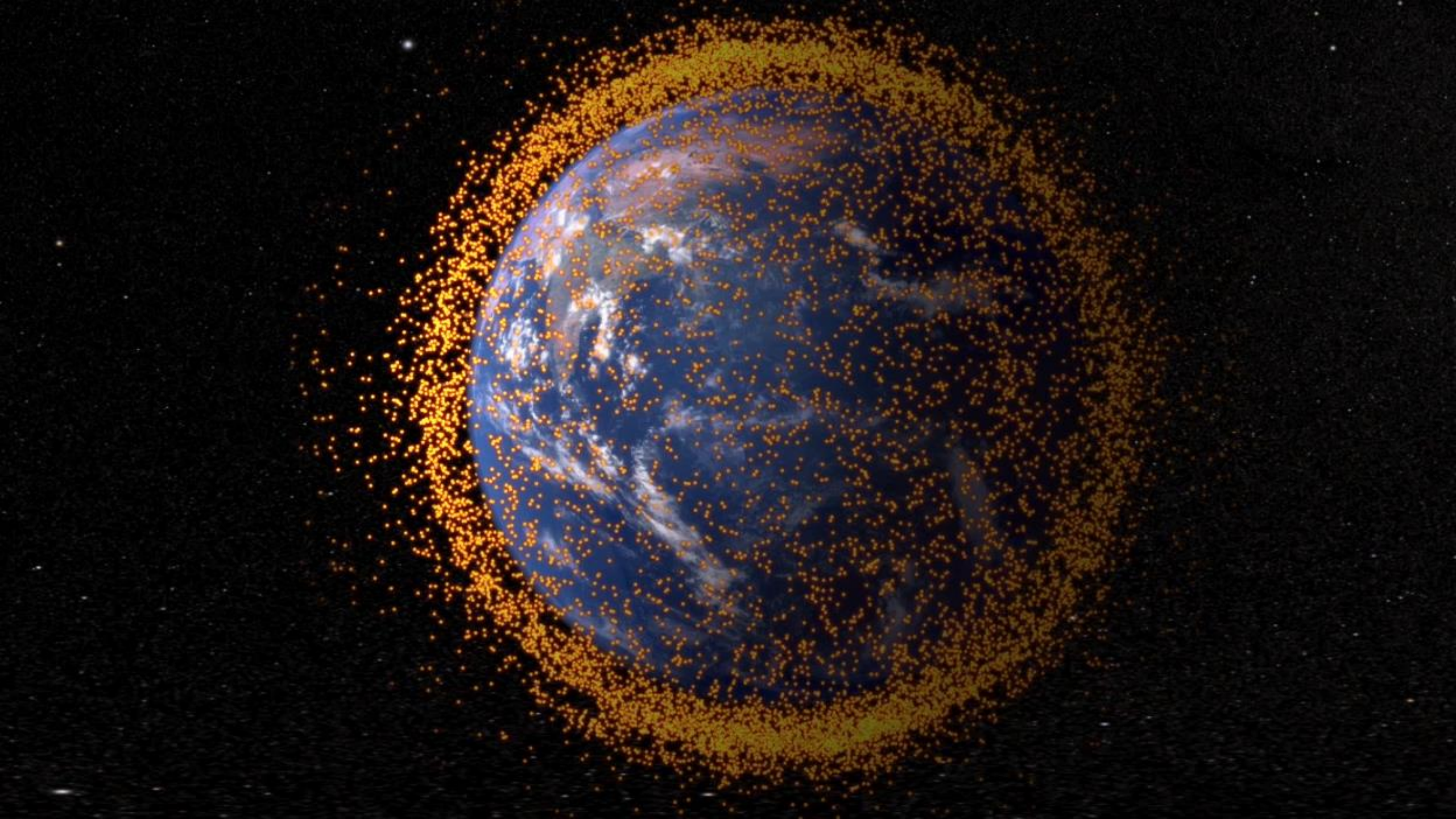


from Picone et al. 2005

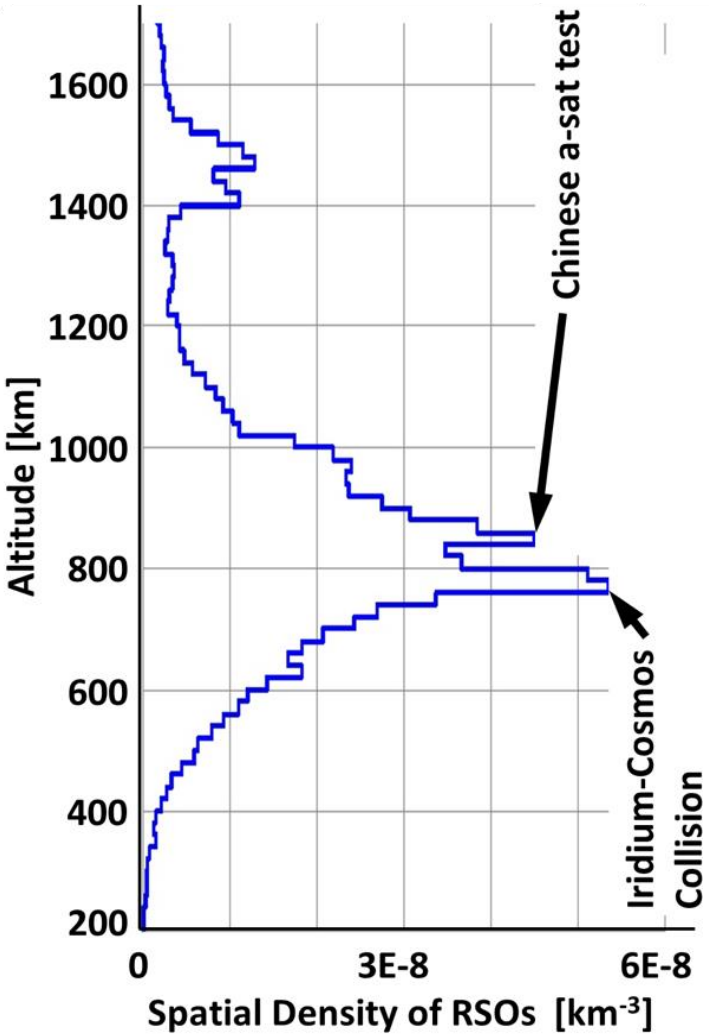


Satellite drag errors degrade capability to:

- Maintain accurate catalog of all space objects
- Predict and avoid space collisions
- Predict satellite reentry time & location

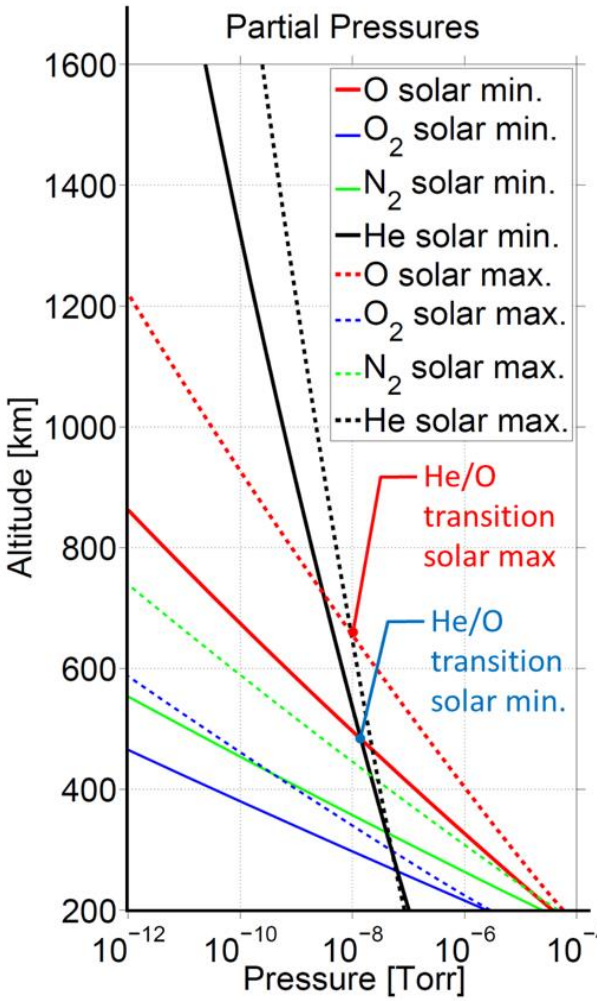


Satellite Drag and the Upper Atmosphere



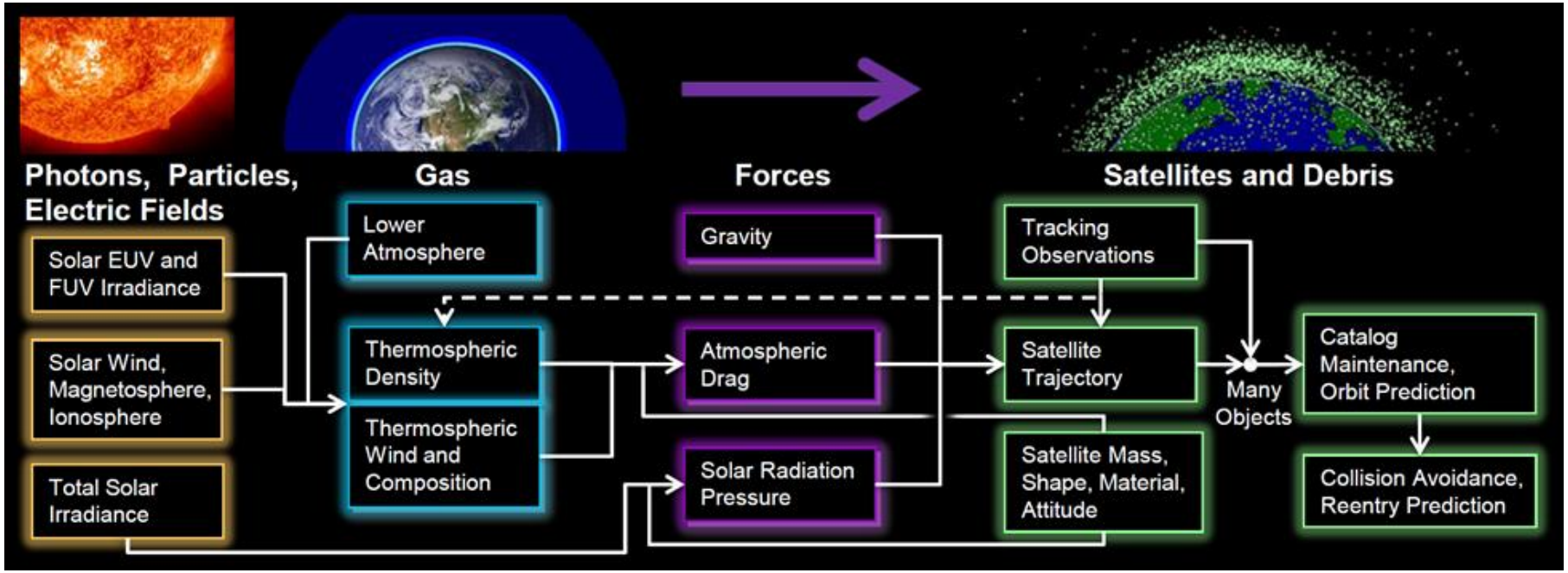
Large uncertainties in atmospheric mass densities, composition, temperature, and winds lead to unwanted differential drag of orbiting objects

C_D Variability driven by composition changes in orbit



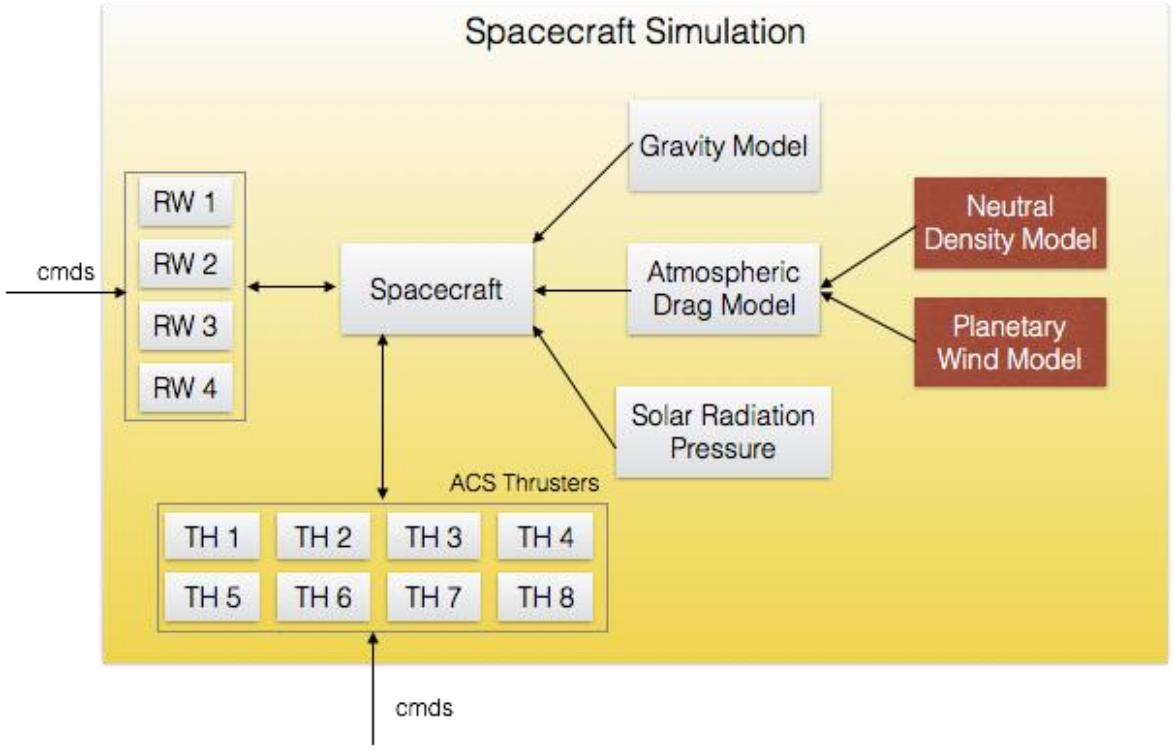
TREC Research
Physics-Based Satellite Drag

Atmospheric drag on low-earth-orbiting (LEO) satellites and debris (< 1000km) is the primary source of uncertainty in affecting their attitude and orbit due to significant natural variability in upper atmosphere mass density and winds.



Consequently continuous precise orbit determination, conjunction assessment, and collision avoidance actions that involve not only the spacecraft response to atmospheric drag but the differential drag response of all the other space objects in LEO.

TREC Research
Physics-Based Vehicle Dynamics
Astrodynamics Simulation Software



Modular software framework allows for science modules to be readily exchanged without recompiling.

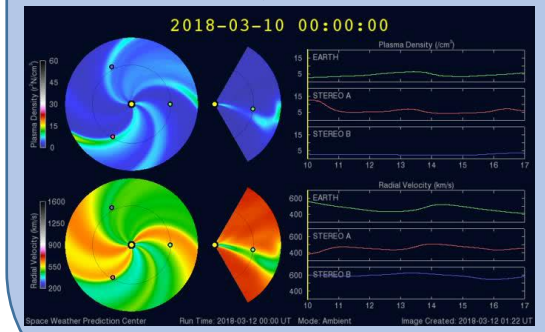
Permits a tight integration of the space weather science solutions and the astrodynamics analysis.

TREC MADTech

Developing technology to provide parallel operational model testbeds, create new data exploitation/forecasting applications, and merge data for researchers and model developers.

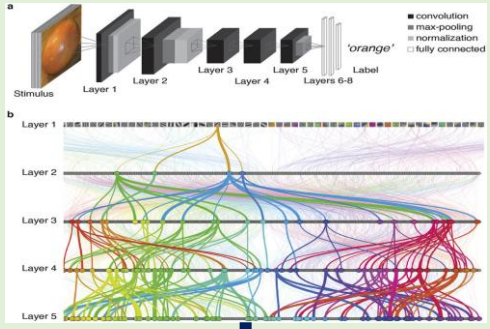
MODEL TESTBED

Operational Models:
- WAM/IPE
- WSA/*Enlil*



Improved Forecasting

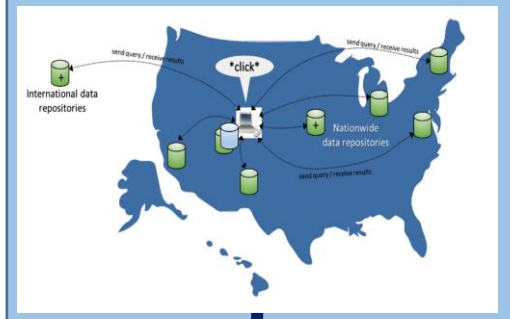
APPLICATIONS



Deep Neural Networks

Solar Eruption Forecast

DATA PORTAL



Research & Operational Datasets

Research

Operations

University of Colorado Boulder

MADTech: SWx Testbed

Enabling SWx O2R

Operational Model Copies

Near-Real-Time Operational Data

SWx Data Portal and Archive

Data Improvements

Model Improvements

Tool Innovations

Operationally Validated Result

SWx-TREC Education Enterprise

Lead: Steven Cranmer (CU Dept. of Astrophysical & Planetary Sci.)

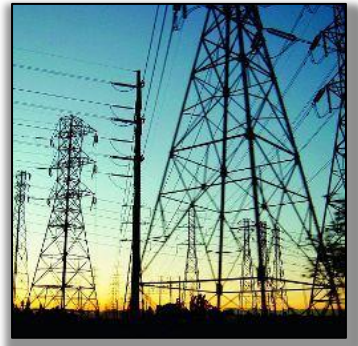
Undergraduate & Graduate Curricula

Focused SWx Science Topic Workshops

SWx Summer School Contributions

Operational Forecasting Focused Workshops

Student CubeSat Programs



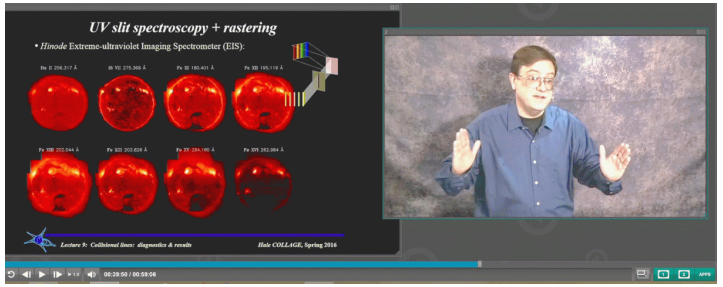
Critical Infrastructure & Policy Makers Communications Programs

SWx-TREC Education Enterprise

New Courses and Certificates

Graduate Education:

- In development: new ***Space Weather Engineering & Science Certificate (SWx ESC).***
- Consists of 4−6 courses drawn from the Aerospace Engineering, Physics, Astrophysics, & Atmospheric/Oceanic Sci. Departments.
- Flexible combinations of in-person & online course work.
- Existing material to be adapted from National Solar Observatory's (online) Collaborative Graduate Education (COLLAGE) program.



Undergraduate Education:

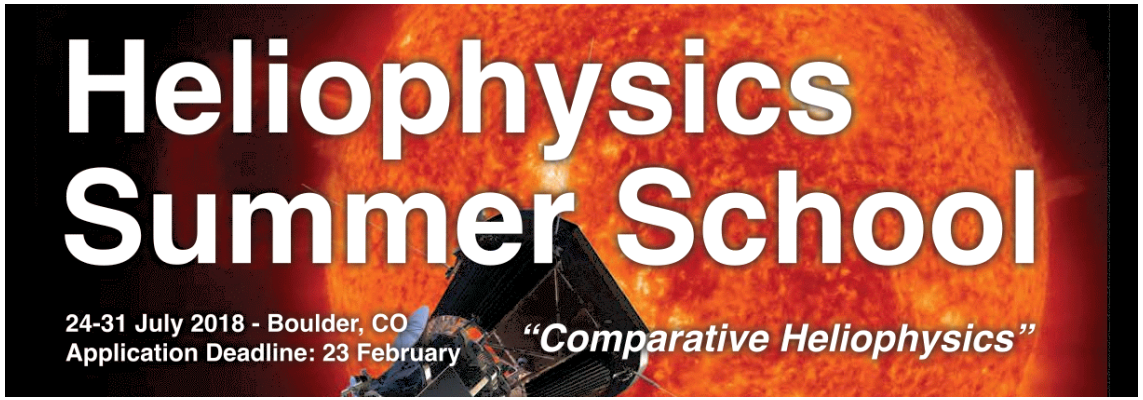
- Continued development of "feeder courses" to research projects, internships, or grad school.
- Collaboration with CU's successful ***Space Minor*** curriculum.

SWx-TREC Education Enterprise

Summer Student Programs

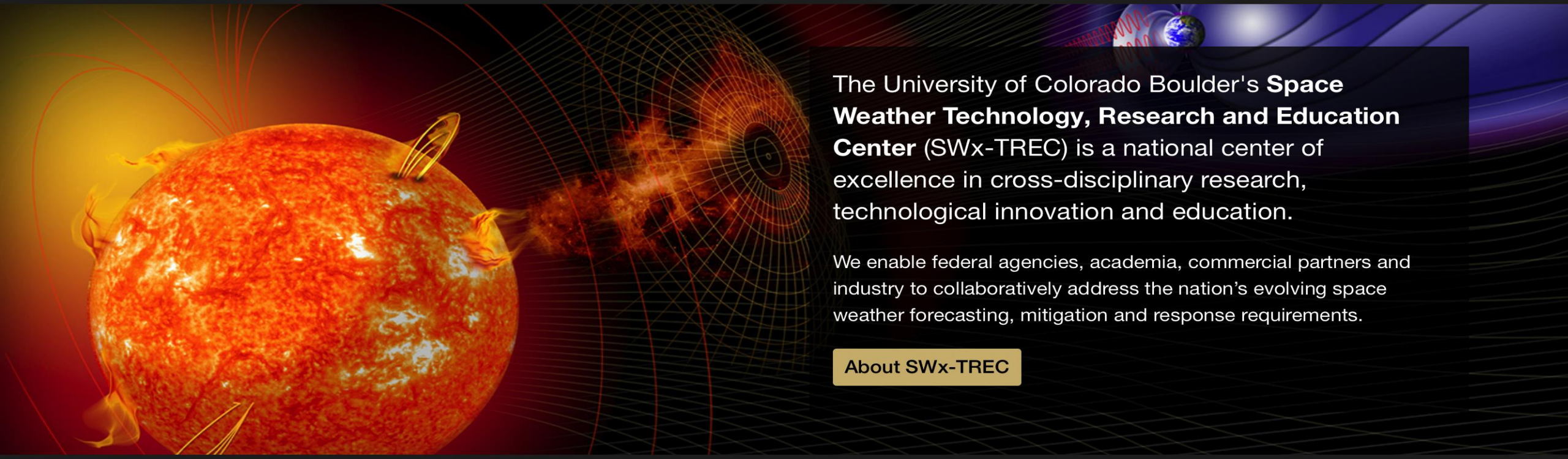
- Now in its 18th year
- July 9-20, 2018 Boulder CO
- New leadership:
  Stan Solomon (NCAR) &
  Steven Cranmer (CU, TREC)

- July 24- 31, 2018 Boulder CO
- TREC is a part of a new ***Curriculum Committee*** that aims to help US universities adopt & teach the material in the textbooks.



Space Weather Technology, Research and Education Center
UNIVERSITY OF COLORADO **BOULDER**

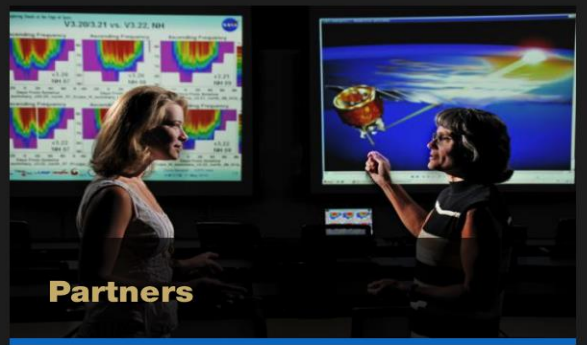
www.colorado.edu/spaceweather



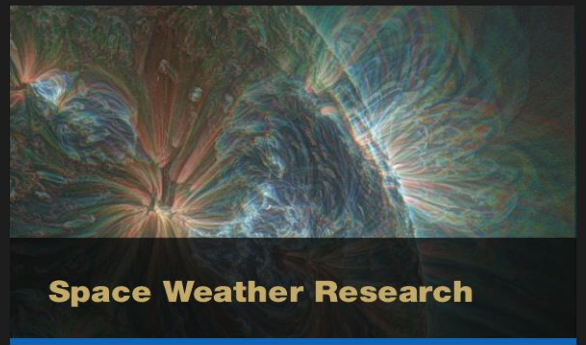
The University of Colorado Boulder's **Space Weather Technology, Research and Education Center** (SWx-TREC) is a national center of excellence in cross-disciplinary research, technological innovation and education.

We enable federal agencies, academia, commercial partners and industry to collaboratively address the nation's evolving space weather forecasting, mitigation and response requirements.

About SWx-TREC



Partners



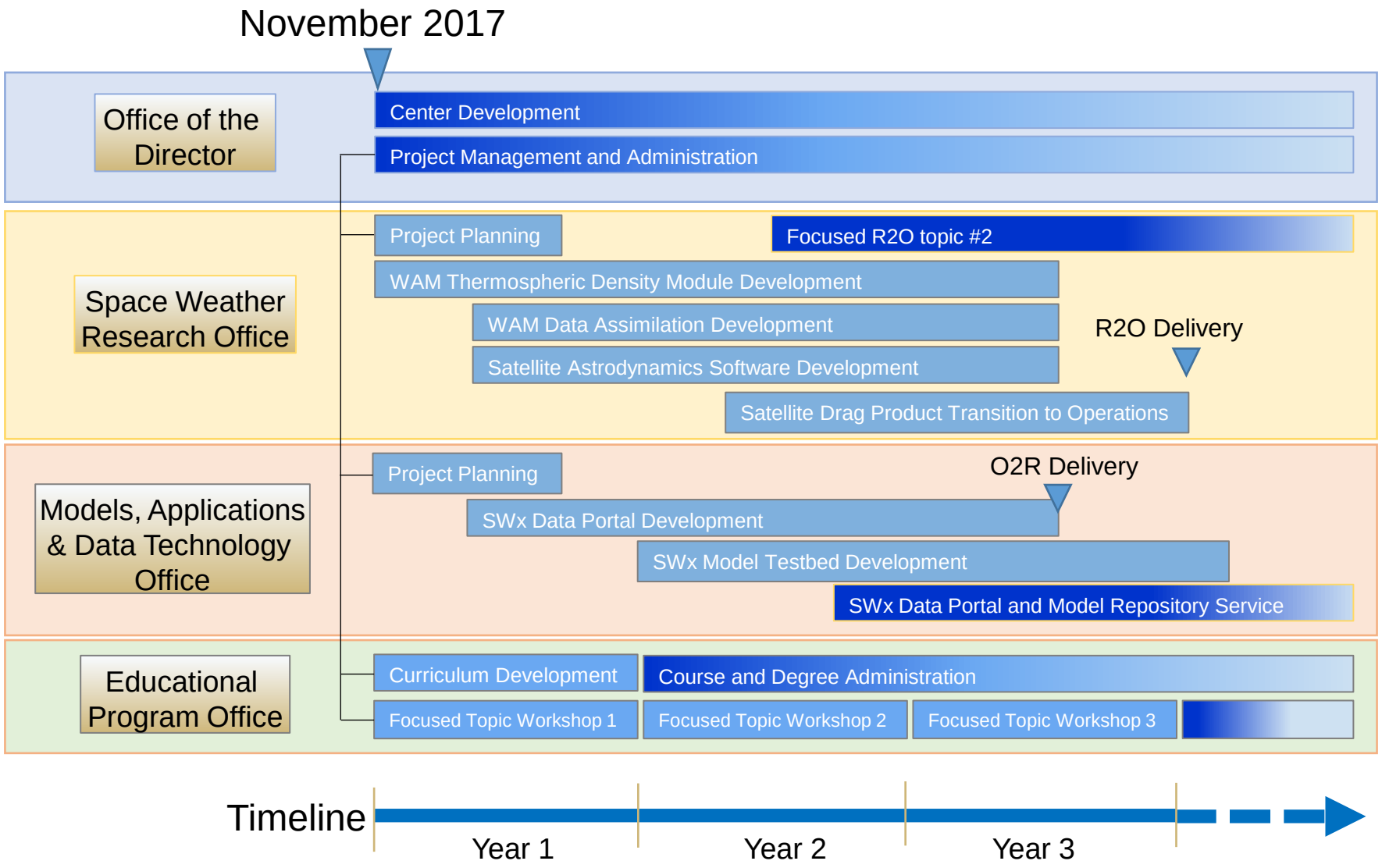
Space Weather Research

MADTech

Education Office

Backup Slides

SWx TREC 3-Year Plan



Space Weather

NOAA GOES-16

- LASP involvement in GOES-R, TSIS, MinXSS, Parker Solar Probe missions.
- CCAR combined expertise in space weather, space environment, astrodynamics, GPS, GNSS, small satellite systems, and orbital debris
- CIRES partnerships with NOAA Space Weather Prediction Center (SWPC) to build solar and ionospheric forecasting capabilities.
- National Solar Observatory co-location with LASP on CU Boulder campus.
- High Altitude Observatory solar and space physics collaborator in Boulder.

NOAA/SWPC Forecasting Center

Key Faculty/ Researchers

- Jeff Thayer, Aerospace Engineering Sciences
- Dan Baker, Laboratory for Atmospheric and Space Physics (LASP)
- Nils Halverson, APS
- Cora Randall, ATOC
- Frank Eparvier, LASP
- Delores Knipp, Aerospace Engineering Sciences
- Jade Morton, Aerospace Engineering Sciences
- Tim Fuller-Rowell, Cooperative Institute for Research in the Environmental Sciences (CIRES)
- David Stone, CIRES

Core Capabilities

- Remote sensing of the ionosphere, atmosphere, and Earth's surface
- Geomagnetic activity and its effects at the Earth's surface and throughout Geospace
- Measurement and prediction of solar activity and irradiance
- Space weather information technology and data systems
- Modeling, data systems, satellite anomaly information support
- Expertise in space environment, astrodynamics, GPS, GNSS, small satellite systems, orbital debris.
- Planetary systems and space physics

Projects

- LASP designed and built the GOES-R (16) EXIS instrument to detect solar soft X-ray irradiance (XRS) and solar extreme ultraviolet spectral irradiance. XRS helps predict proton events and monitors solar flares. **PI: Frank Eparvier**
- A team led by CU Boulder found the mechanism behind the sudden onset of a "natural thermostat" in Earth's upper atmosphere that dramatically cools the atmosphere after it has been heated by violent solar activity. **PI: Delores Knipp**

Collaborators

ACSWA, NASA, NSF, JPL Jet Propulsion Laboratory, NOAA, HARRIS, Ball Aerospace, NSO, HAO High Altitude Observatory

Our Space. Our Future.

For over 50 years, CU Boulder has been a leader in Earth and space sciences. We have sent instruments to every planet in our solar system and are among the world's leading public universities in producing astronauts. We explore our own planet from the depths of the ocean to the upper limits of the atmosphere.

What will the next 50 years bring?

About the Grand Challenge

Latest News

Climate Change & Health Symposium spotlights CU opportunity to collaborate on emerging global issue

Researchers from the University of Colorado Anschutz and the University of Colorado Boulder led a Climate Change and Health Symposium on the Anschutz Medical Campus on March 12 to explore the imminent challenges and opportunities arising from the nexus of these two interdependent arenas. Read more

Daily Camera: CU Boulder 'Grand Challenge' puts space weather research front and center

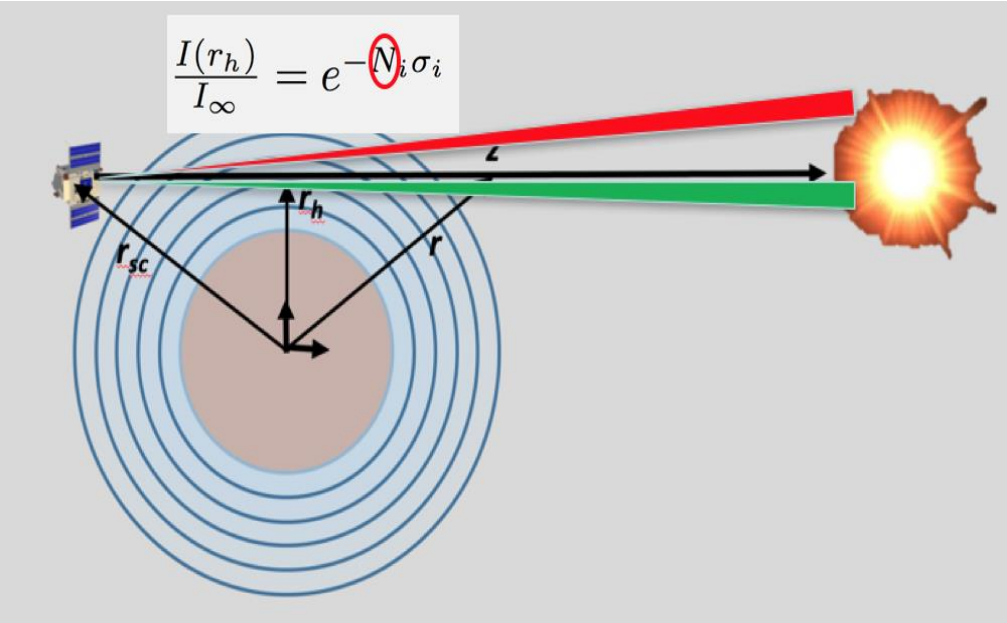
The Great American Eclipse has come and gone, but the fiery star of that show remains a crucial target of scientists' continuing investigations, and is a central player in studies to be fueled by the newly announced Grand Challenge winners at the University of Colorado. Read more

Grand Challenge expands portfolio with three new projects

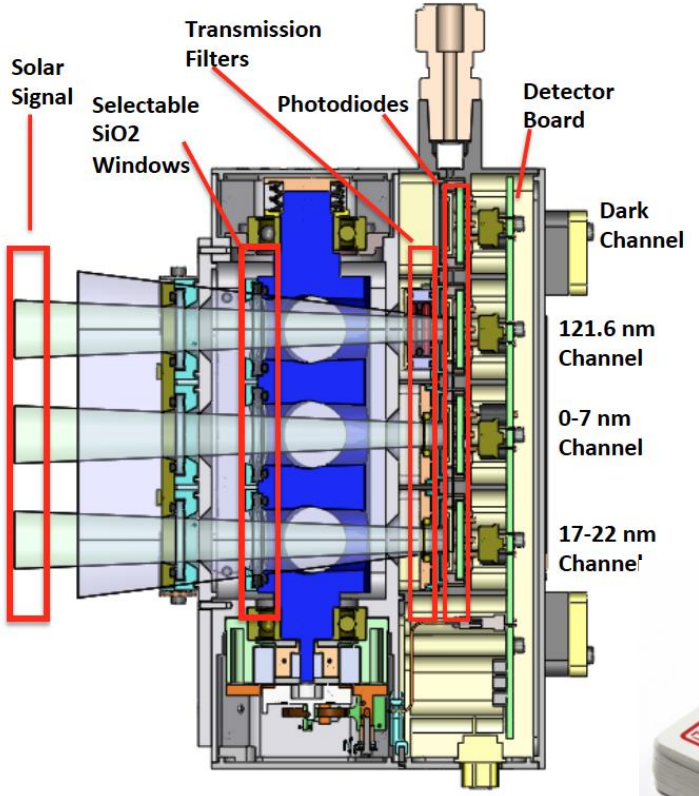
The cross-campus Grand Challenge initiative this week announced the selection of three new additions to the Grand Challenge portfolio starting this fall. The call for proposals, which was announced in June, funded one large research initiative at approximately $1 million per year and two smaller projects at $250,000 per year, each for at least three years. Read more

TREC Research: Missions

Thermospheric Density from Solar EUV Occultation CubeSats



1-U Cubesat constellation



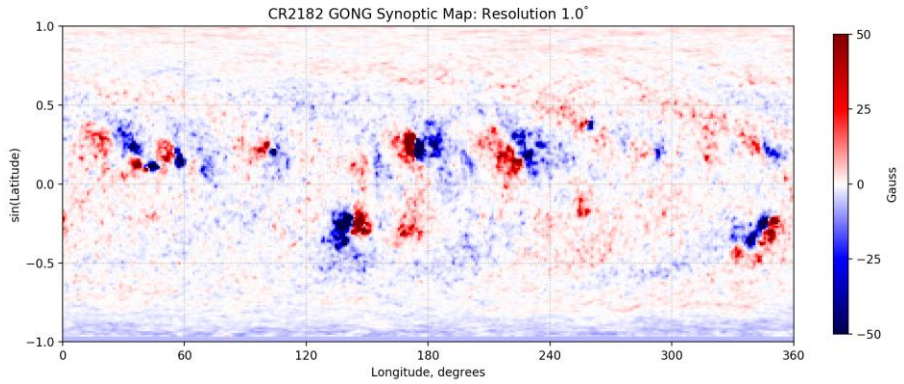
Heritage

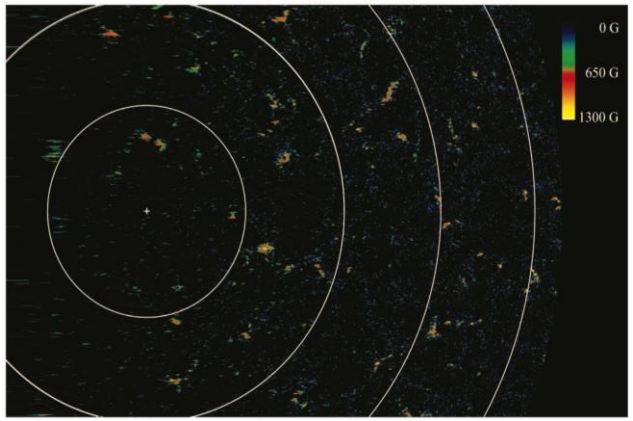
- SORCE and TIMED XPS
- PROBA2 LYRA (ESA)
- MAVEN EUVM

Thiemann+ *JGR Space/Planets* (2018)

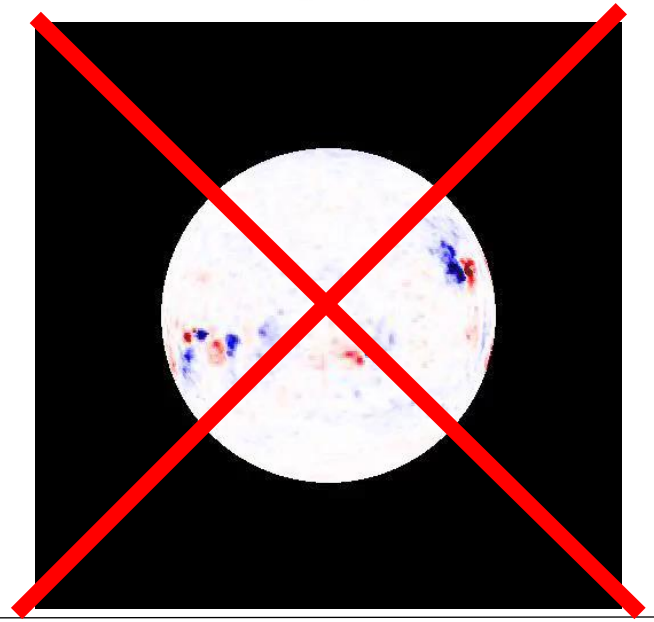
TREC Research: Missions

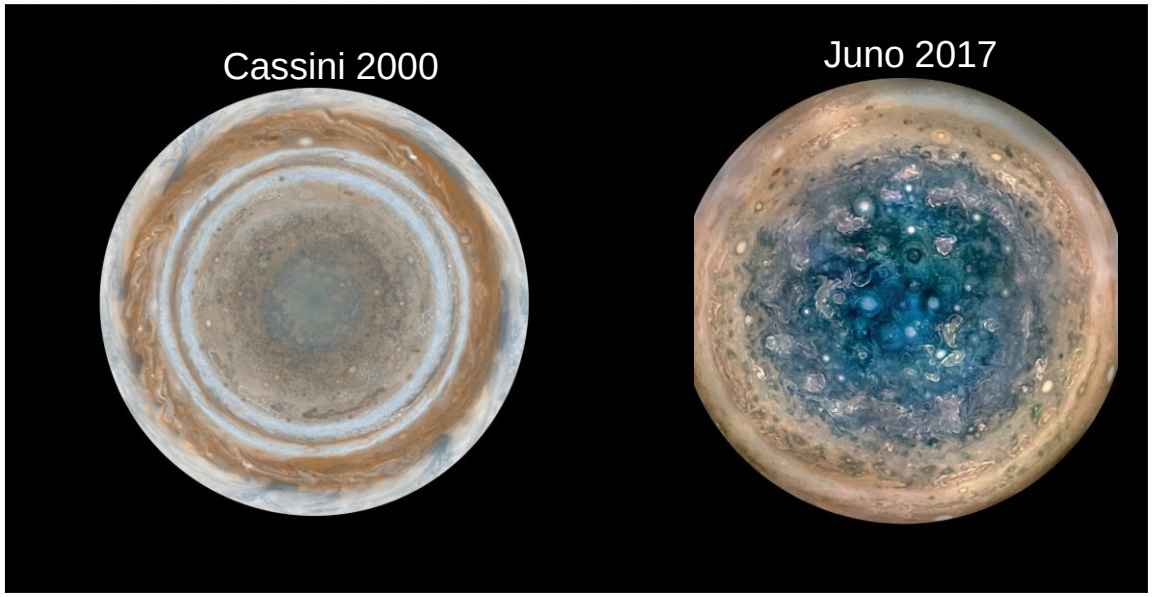
Solar Polar Explorer



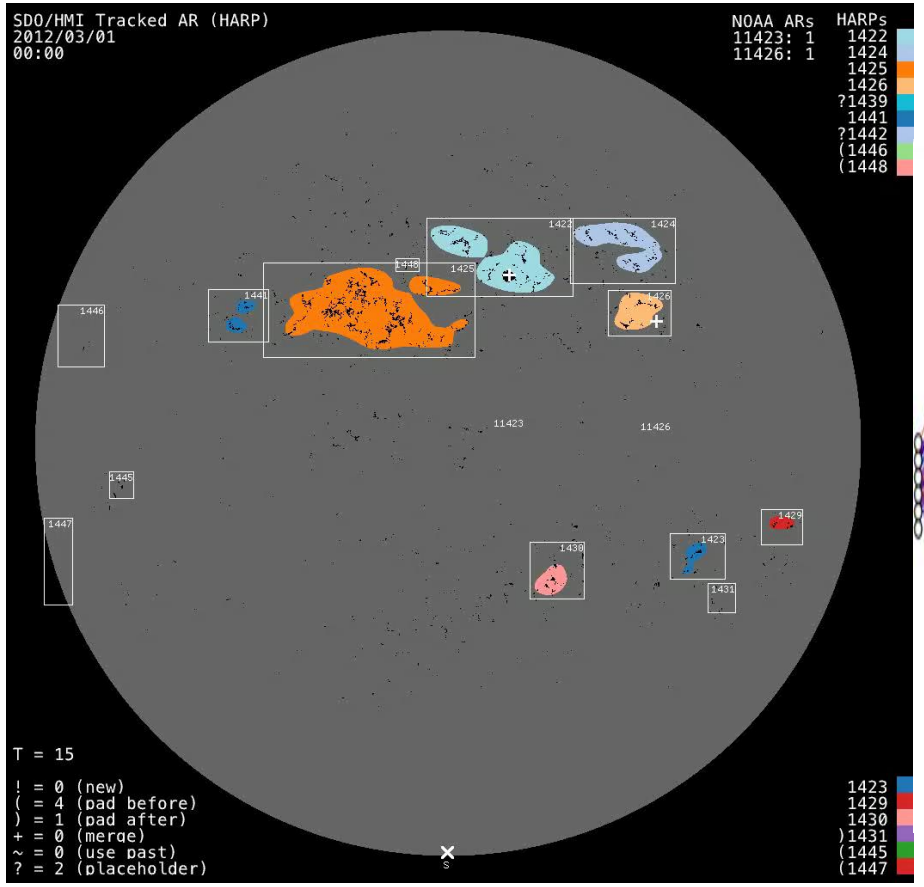


Hinode/SOT

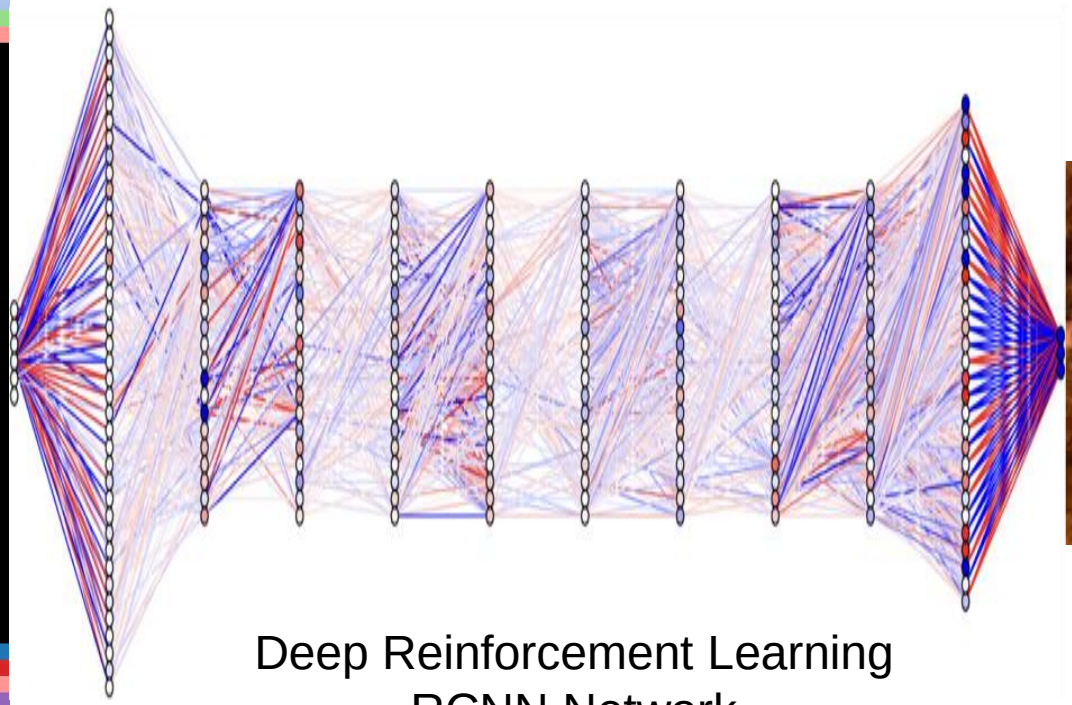




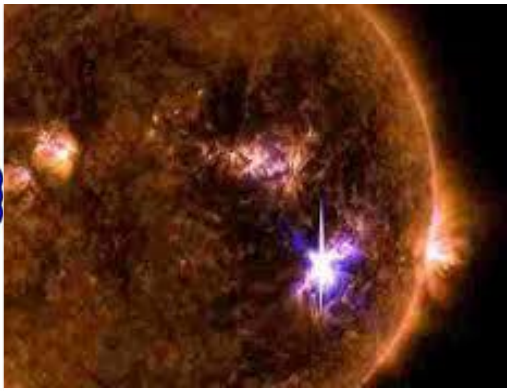
MADTech: Deep Learning



SDO SHARPS product
HMI + AIA + EVE



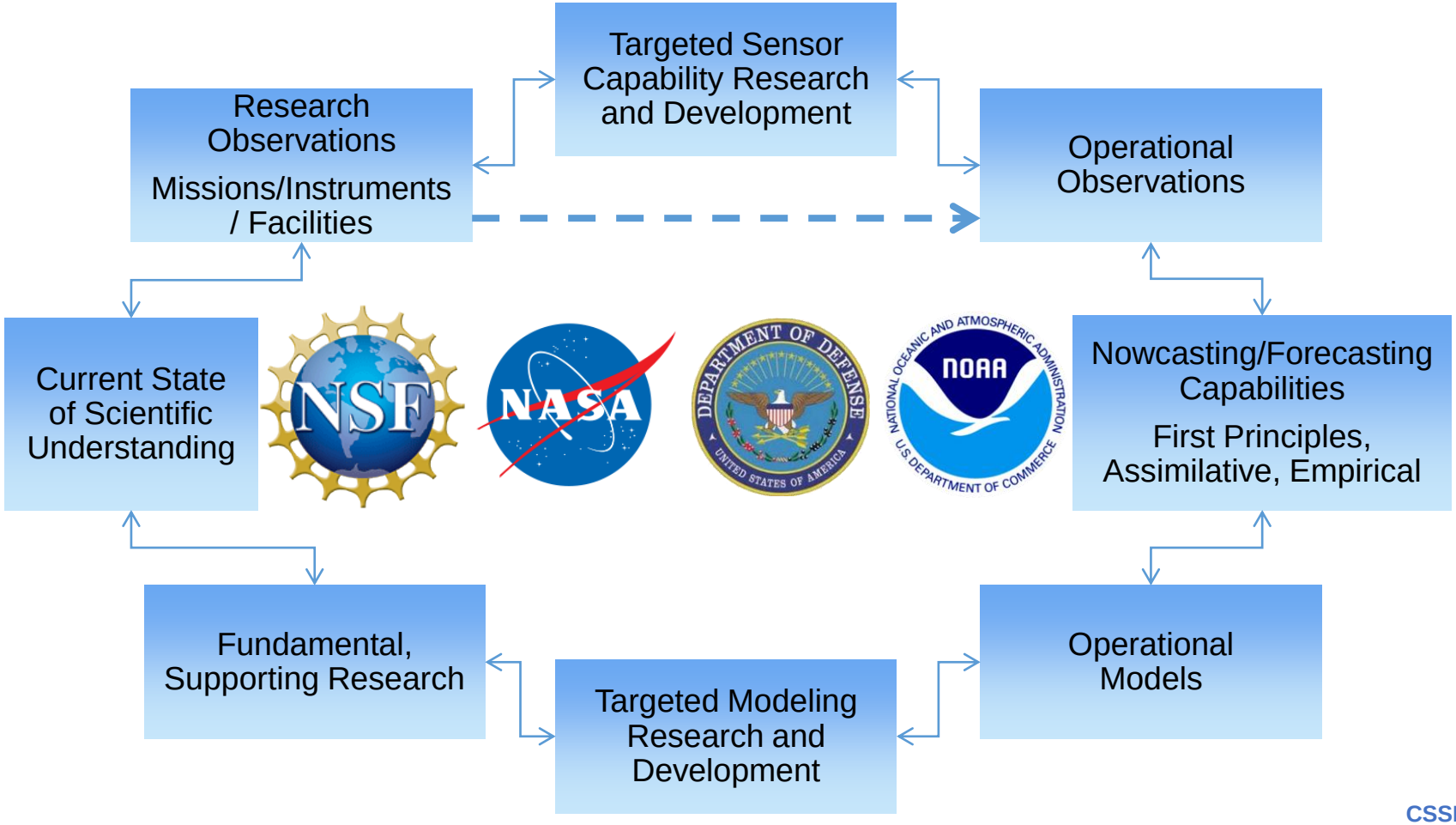
Deep Reinforcement Learning
RCNN Network



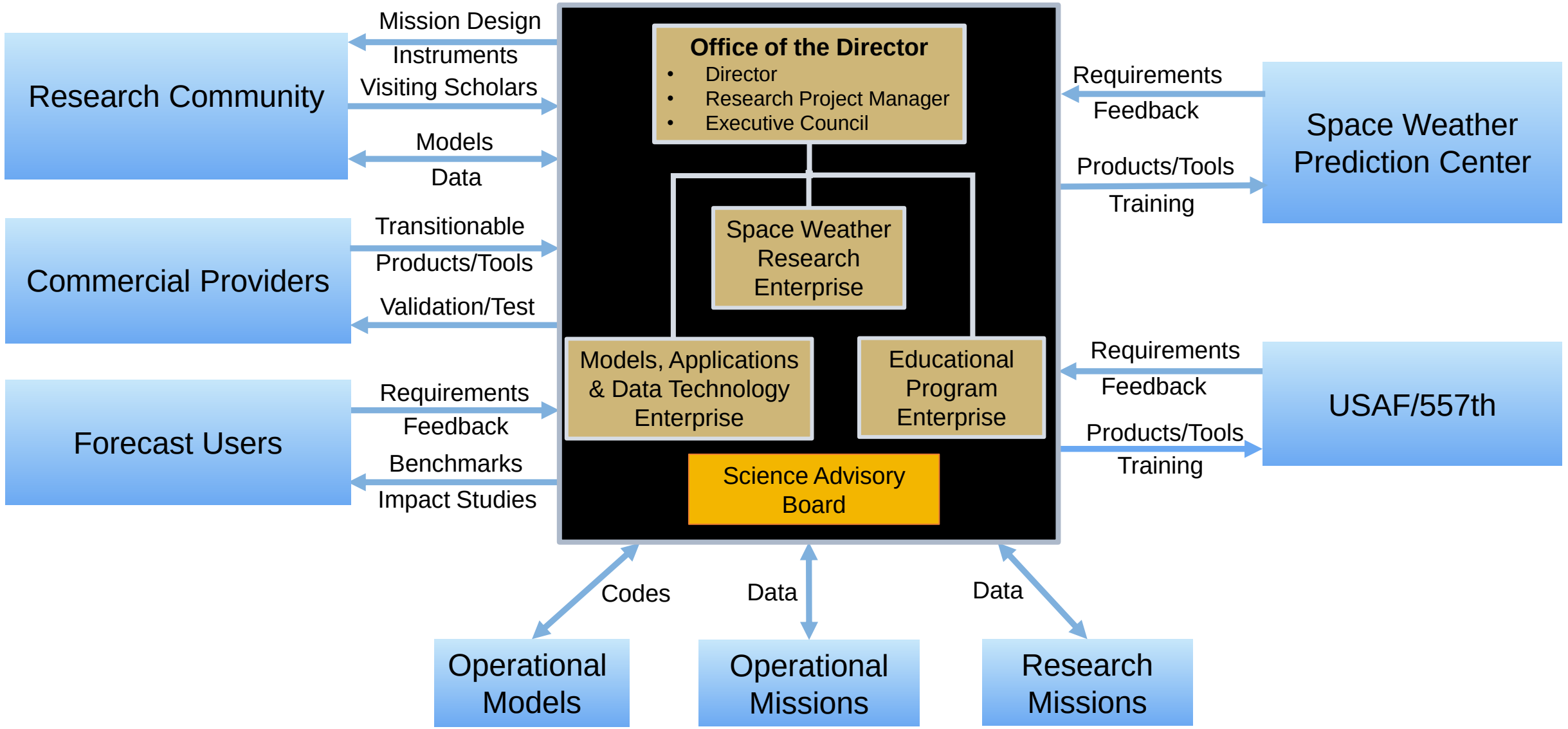
Bayesian Probability
Eruption Forecast

Addressing the R2O and O2R Problems

Original Version



SWx TREC: Bridging R & O



SWx TREC Mission Statement

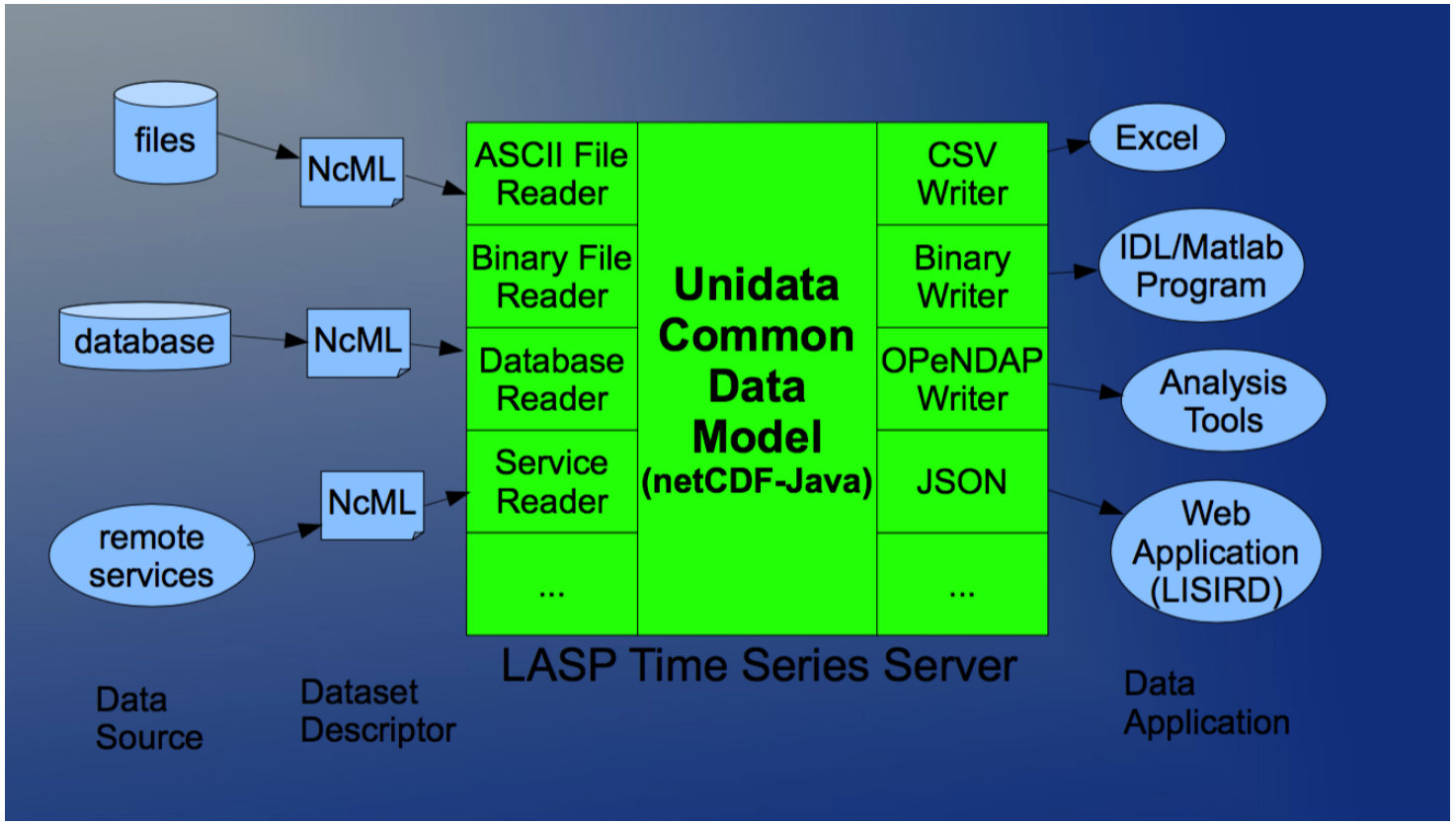
The University of Colorado SWx-TREC is a national center of excellence in cross-disciplinary research, technology innovation, and education, enabling federal agencies, academia, commercial partners, and industry to collaborate in addressing the nation's evolving space weather forecasting, mitigation, and response requirements.

SWx-TREC produces breakthrough applied research and innovative mission technologies that are **directly tied to the needs of the operational forecasting enterprise** to ensure closure of the R2O* and O2R* loop. This will result in new models, tools, missions, and data that will significantly advance our ability to understand and predict space weather phenomena, from the Sun to the Earth.

*R2O = Research-to-Operations O2R = Operations-to-Research

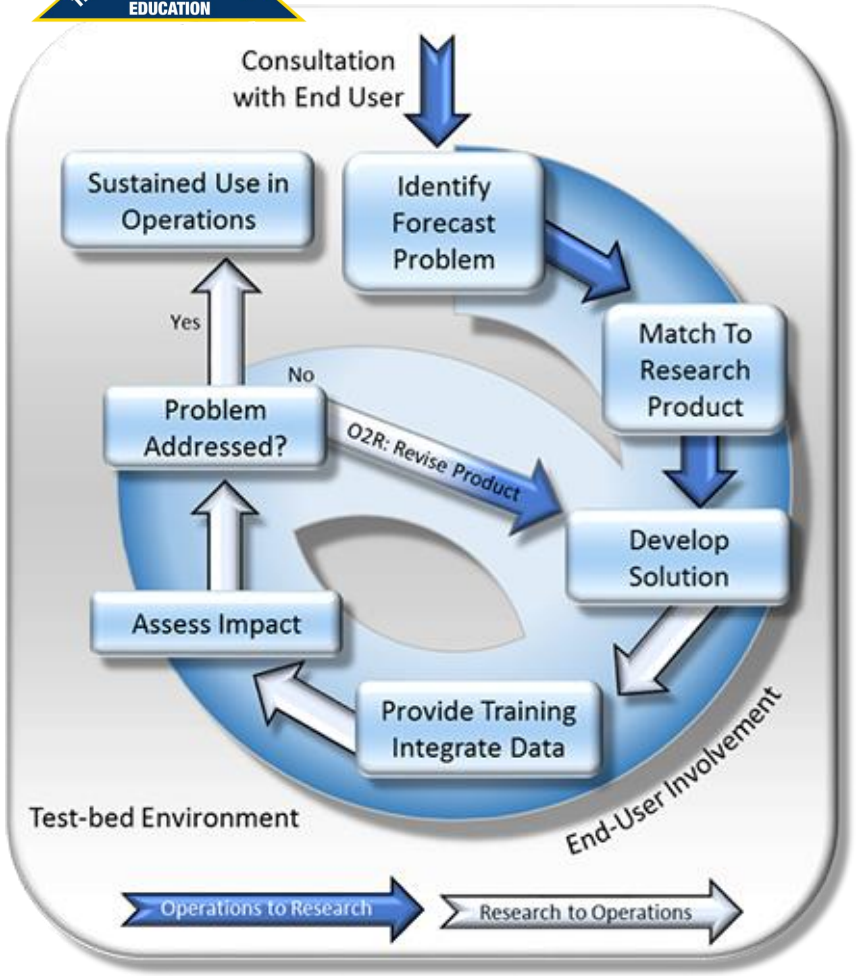
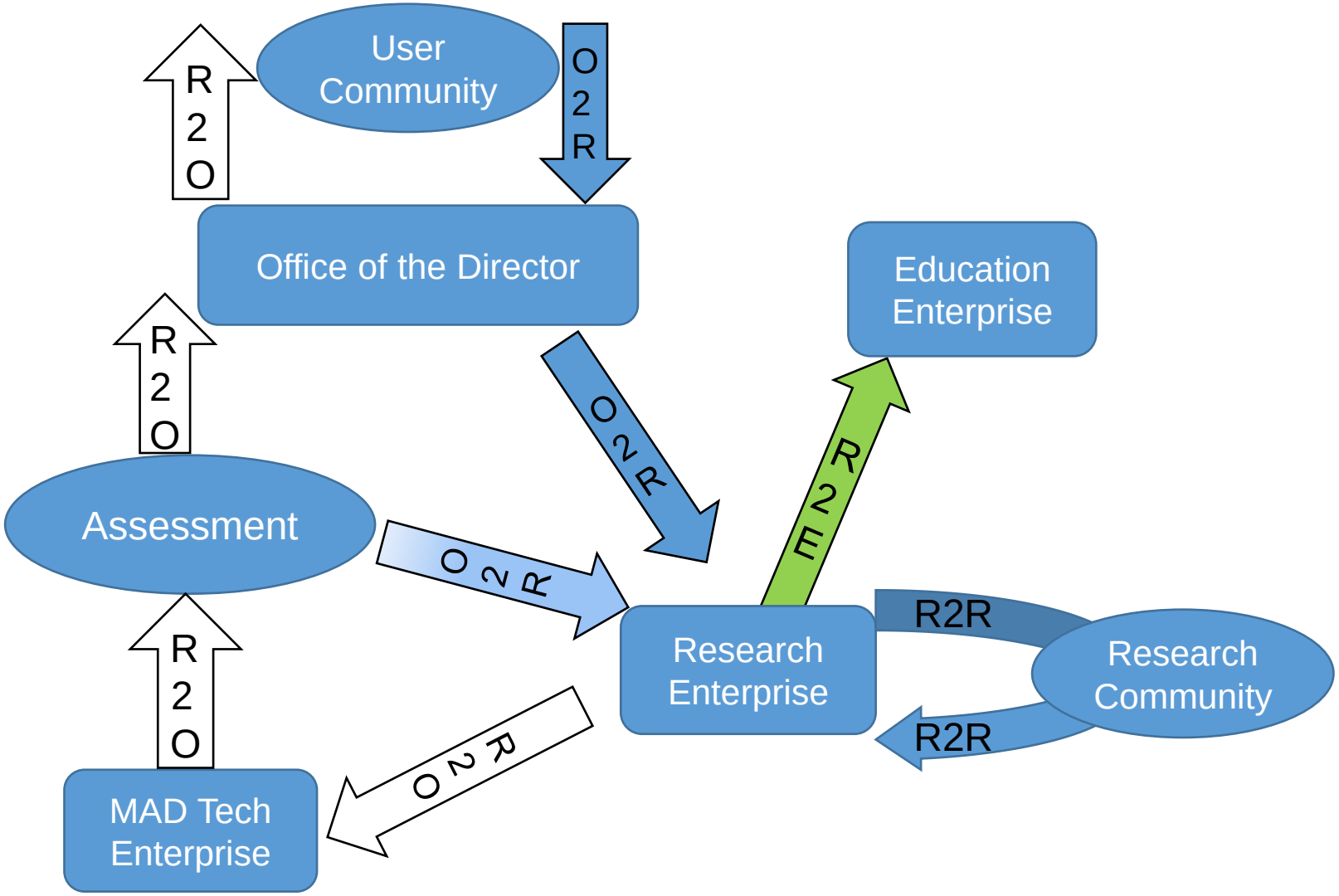
MADTech: SWx Data Portal

Enabling SWx R2O



Based on established LaTIS architecture

SWx TREC Functionality
The R2O and O2R Cycle



Jedlovec, 2013: the SPoRT Paradigm