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Title: Space Sciences at LANL in Support of National Security

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Space Sciences at LANL in Support of National Security

Tess Light

21 June 2021

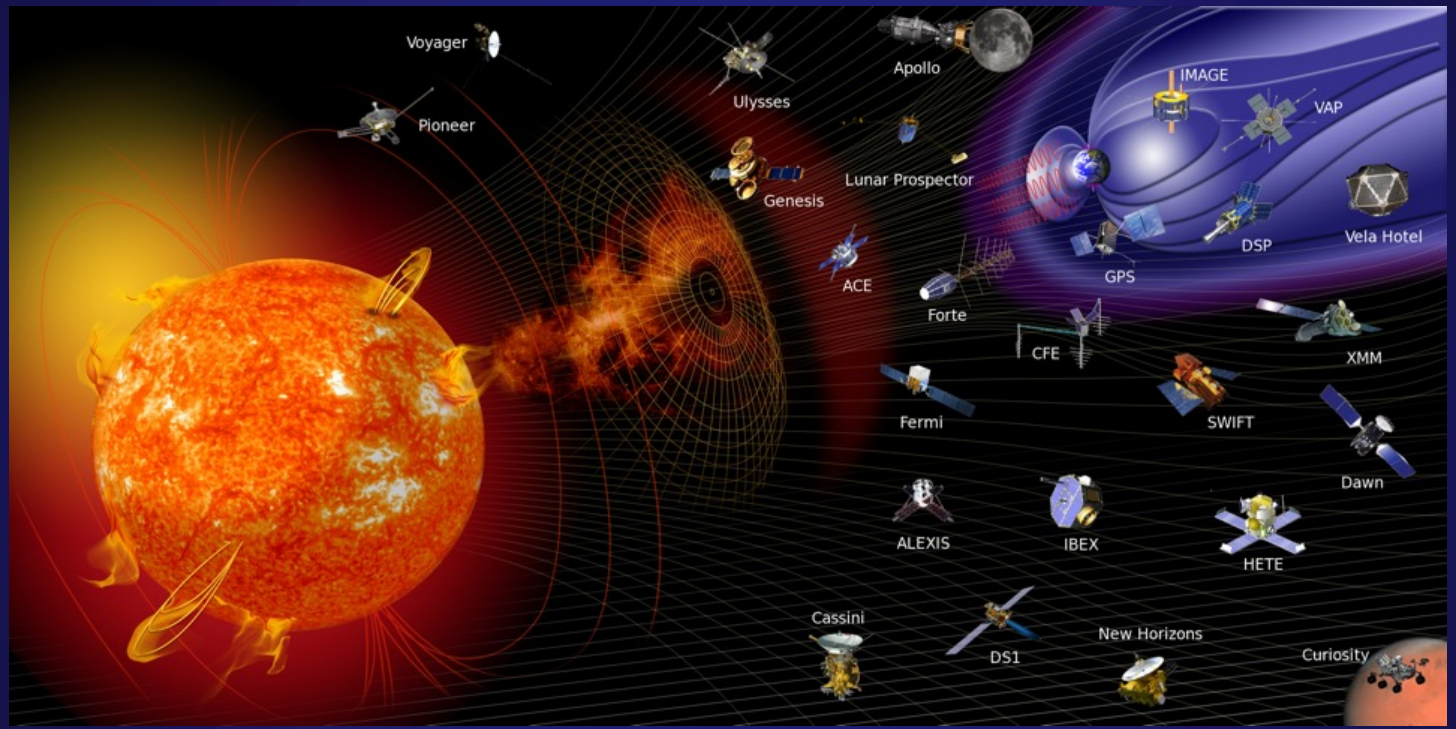
IMS Student Seminar Series

NNSA
National Nuclear Security Administration

Managed by Triad National Security, LLC for the U.S. Department of Energy's NNSA

LANL Spacecraft Involvement:

1400 sensors on
400 Instruments on
200 satellites



NASA founded in 1958
LANL space sciences started in 1959

Once Upon a Time

Origin Story

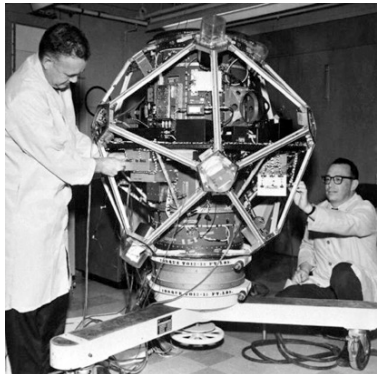
- **November 1945**: US, UK and Canada proposed creation of United Nations Atomic Energy Commission
  - Purpose: “entirely eliminating the use of atomic energy for destructive purposes.”
- **March-September 1947**: Lt. Gen. Vandenberg states need for long range detection capability; Gen. Eisenhower orders development of long range capability to detect nuclear detonations anywhere in the world.

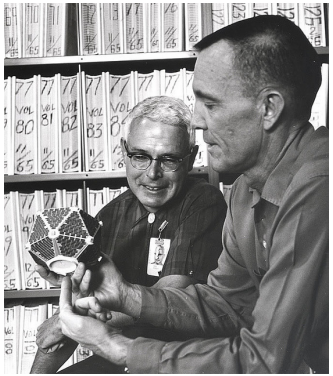

Nikita Kruschev

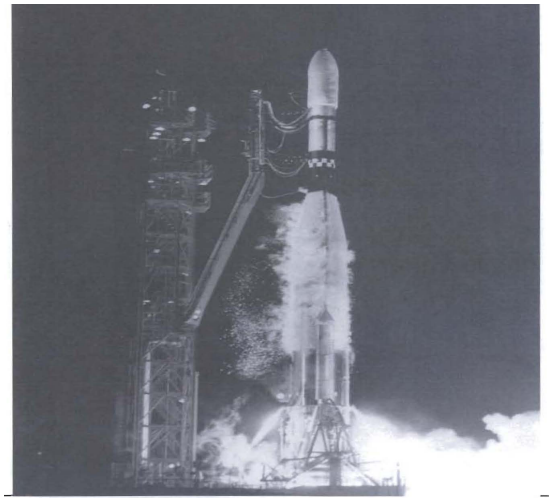
- **Meanwhile…**
- **The Arms Race is on**: for more than a decade, nuclear weapons proliferate, and pressure builds for a test ban treaty.
- **The Space Race is on: October 4 1957**: USSR launches Sputnik

And we enter the arena

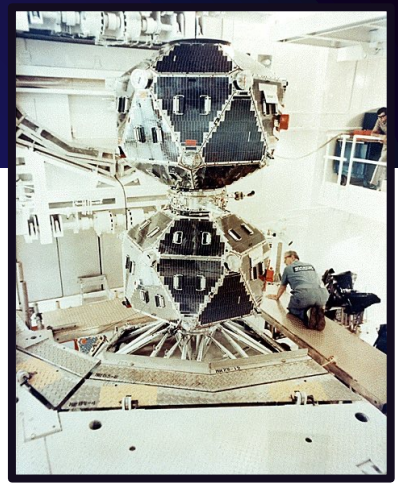
- 1959: Establishment of Advanced Research Projects Agency (ARPA) who immediately proposed the Vela, or “watchman” project:
  - Vela-Uniform for underground detonation detection
  - Vela-Sierra for ground-based detection of high altitude and space detonations
  - **Vela-Hotel for satellite-based detection of nuclear detonations**
- 10 June 1959: Los Alamos and Sandia initiate work on Vela-Hotel sensors
- October 7 1963: Limited Test Ban Treaty is signed
- October 17 1963: The first Vela-Hotel pair launched







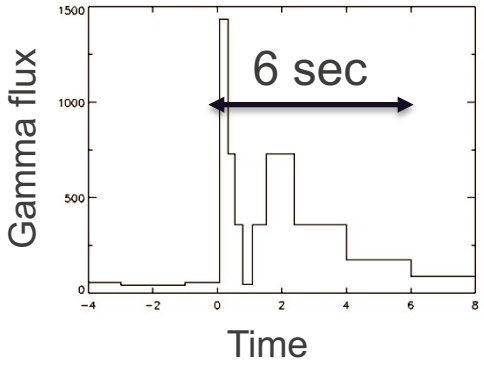
Vela-era capabilities

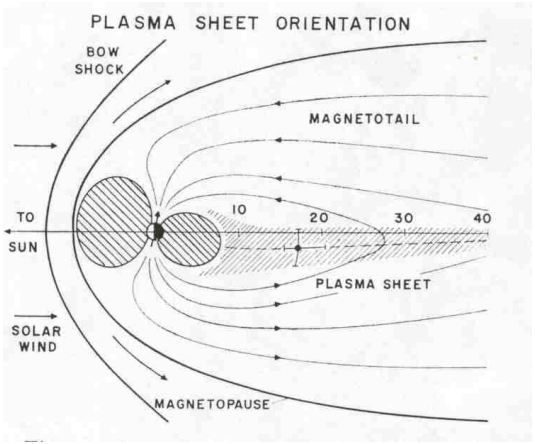


- Orbit:
  - Elliptical orbits with Apogees of 90,000 - 190,000 km (roughly)
    - outside Van Allen belts, ~1/3 distance to moon
- Sensors:
  - Vela Hotel series of 6: carried X-ray, gamma-ray, & neutron detectors, with solar panels to provide ~90 Watts
    - Air absorbs these “hard radiations” so could only detect events above the atmosphere
  - Advanced Vela series of 6: carried optical & EMP sensors to detect events within the atmosphere; now needed ~120 Watts
- 4 years from start-to-launch, without existing space-engineering capabilities
- Vela mission lasted 26 years, until1985

“In the fields of observation, chance favors only the prepared mind.” Louis Pasteur

- Science relies on serendipity
- Vela observations discovered…
  - Gamma Ray Bursts
    - Event recorded by two satellites simultaneously, but when examined, clearly not originating on the Earth or even in our solar system
    - Now understood to result from the collapse of a black hole
    - Klebesadel et al., *Ap. J. Lett,* **182**, L85-L88, 1973
  - Earth’s Plasma Sheet
    - Bame et al., 1967
  - Heavy Ions in the Solar Wind
    - Bame et al., 1968
  - X-ray Sources, Bursts, Variations…
    - Conner et al., 1969; Evans et al., 1970; Belian et al., 1976





Assured by our ability to monitor…

- 1963: Limited Test Ban Treaty
- 1967: Outer Space Treaty
- 1968: Nuclear Nonproliferation Treaty
- 1974: Threshold Test Ban Treaty
- 1990: Peaceful Nuclear Explosions Treaty
- 1996: Comprehensive Test Ban Treaty: "Each State Party undertakes not to carry out any nuclear weapon test explosion or any other nuclear explosion, and to prohibit and prevent any such nuclear explosion at any place under its jurisdiction or control."
- Per CTBTO website:
  - Signed by 185 states (of 196)
  - Ratified by 170
  - U.S. Signed 24 Sep 1996
  - U.S. has not Ratified

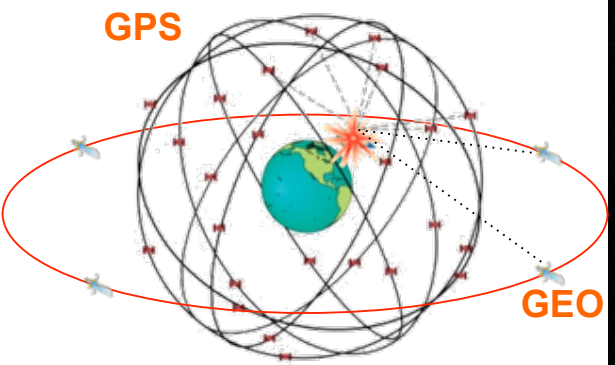
Recent US law validates enduring treaty verification missions

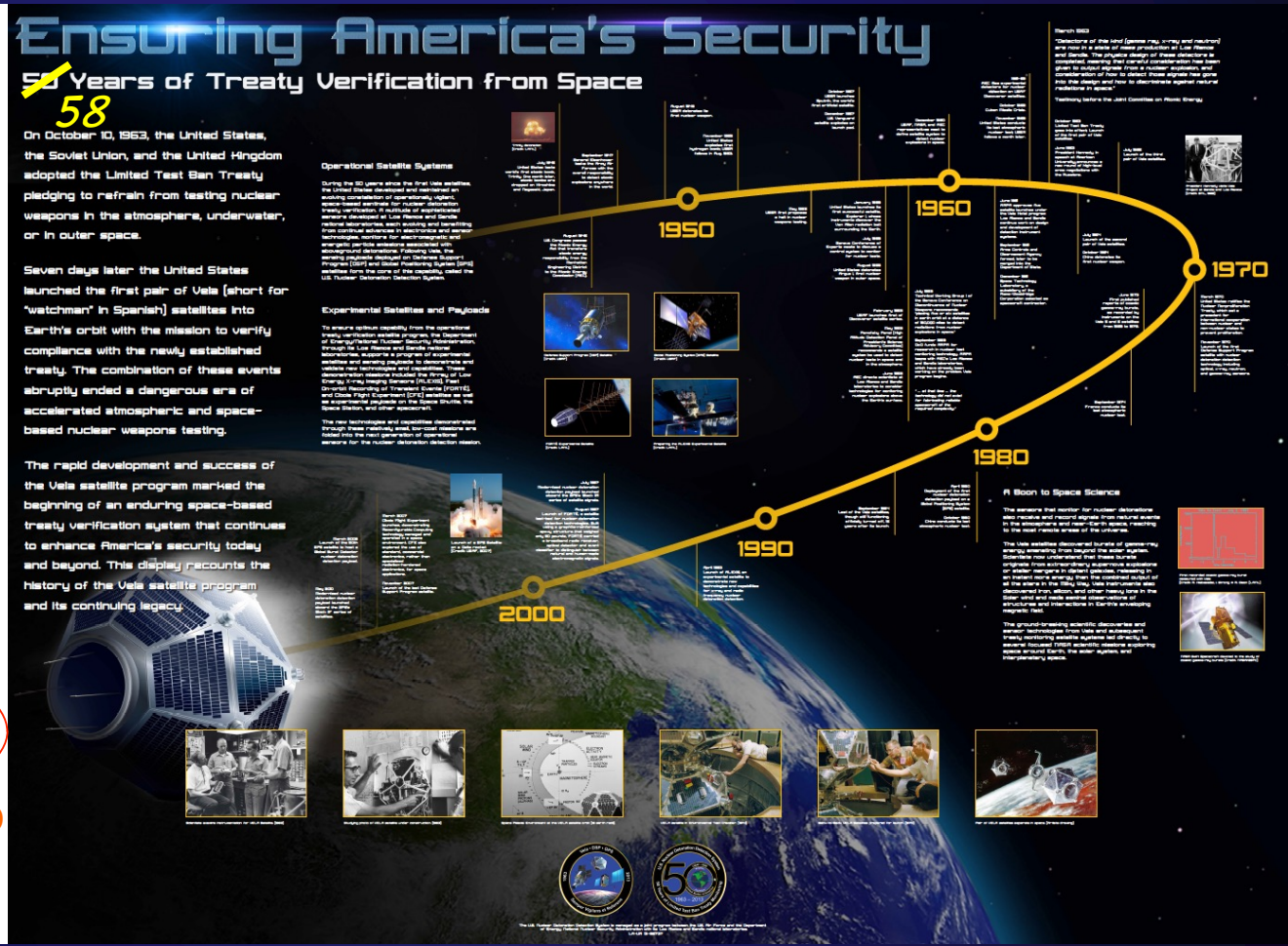
2008 US Defense Authorization Bill:

- SEC. 1065. MAINTENANCE OF CAPABILITY FOR SPACE-BASED NUCLEAR DETECTION.
  - The Secretary of Defense shall maintain the capability for space-based nuclear detection at a level that meets or exceeds the level of capability as of the date of the enactment of this Act.
- SEC. 911. SPACE PROTECTION STRATEGY.
  - (a) Sense of Congress – It is the Sense of Congress that the United States should place greater priority on the protection of national security space systems.
  - (b) Strategy – The Secretary of Defense, in conjunction with the Director of National Intelligence, shall develop a strategy, to be known as the Space Protection Strategy, for the development and fielding by the United States of the capabilities that are necessary to ensure freedom of action in space for the United States.

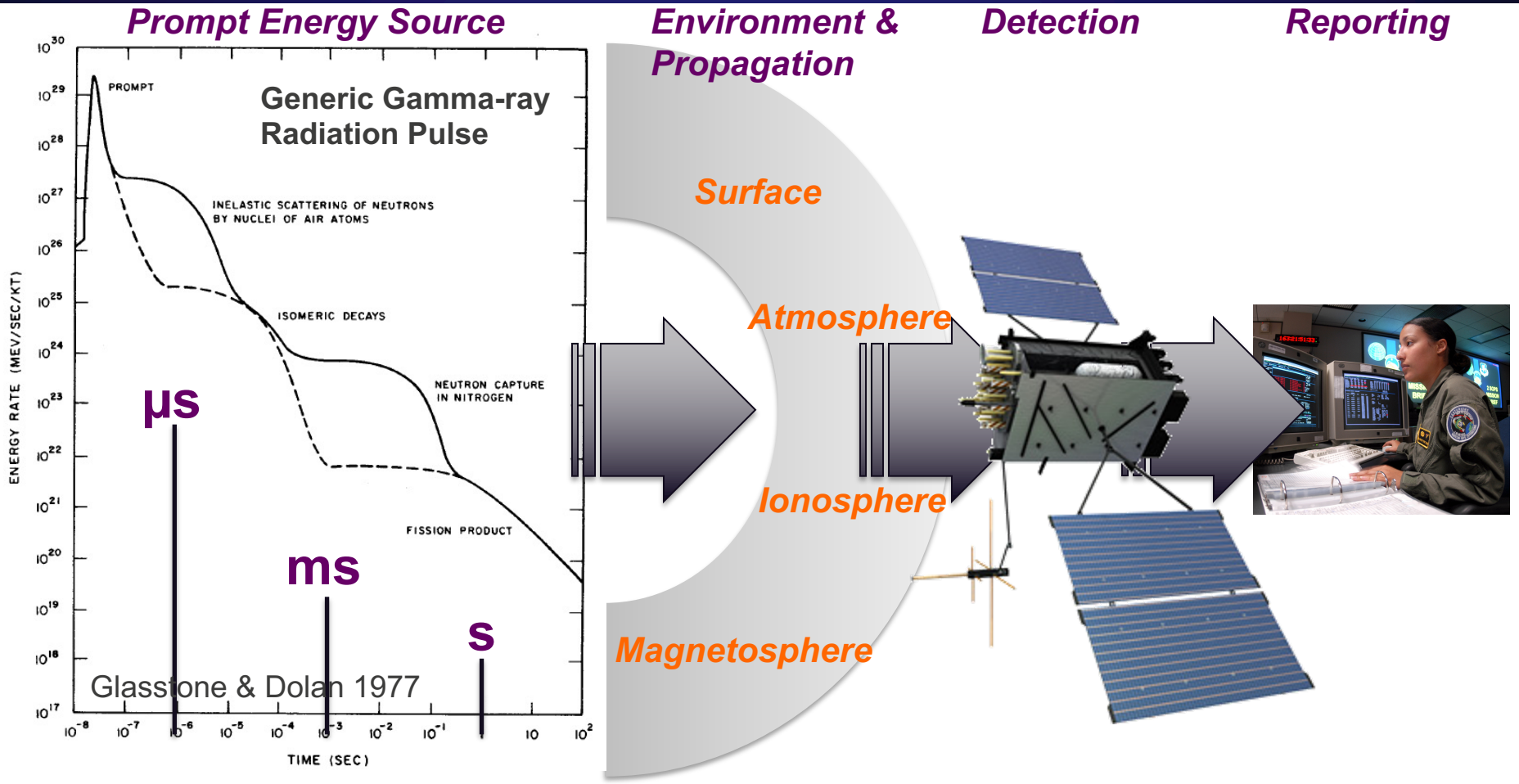
The here and now

Vela is past but the mission remains and grows



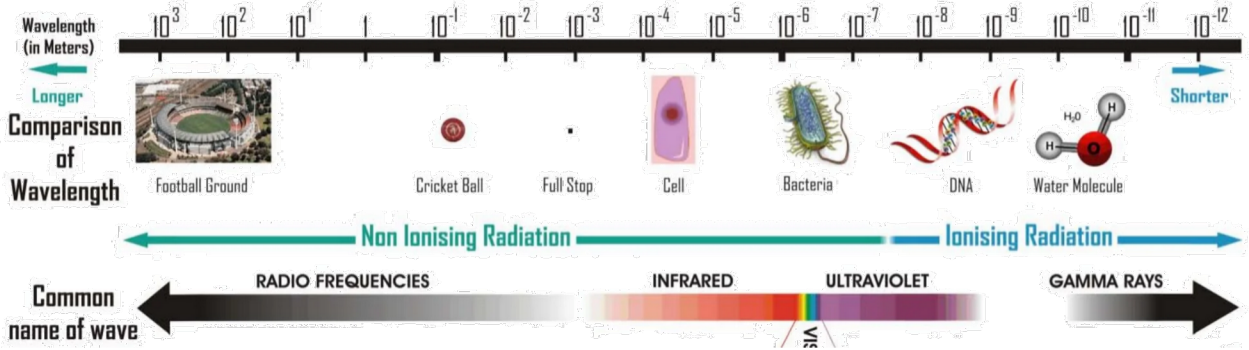


The challenge



Not to whine, but it's pretty hard

- Needs:
  - Global coverage … but precise geolocations
  - Continuous operation … with high time-resolution
  - Full spectrum coverage
  - No tolerance for mistakes – either false positives or false negatives
  - Prompt reporting
  - Complex signals modified by complex atmospheric transport
  - High cost and complexity of missions in space



Modern Monitoring System Components

Multiple signatures are used to detect and measure nuclear detonations

Key questions:

Space
- *Gamma Rays*
- *Neutrons*
- *X-rays*

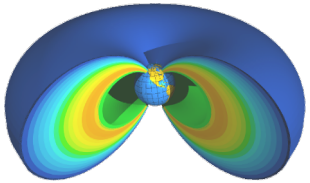
Transition Region
- *Gamma Rays*
- *Neutrons*
- *Optical*

Low Altitude
- *Optical*
- *Electromagnetic Pulse*
- *Infrasound*
- *Radionuclides*

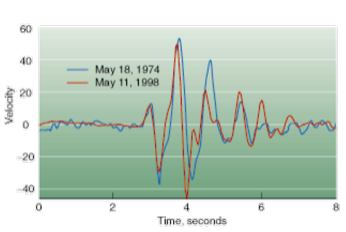
Below Ground
- *Seismic*
- *Infrasound*
- *Hydroacoustic*

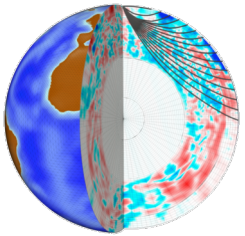
National program / system deployment

Space-based sensing systems (USNDS)



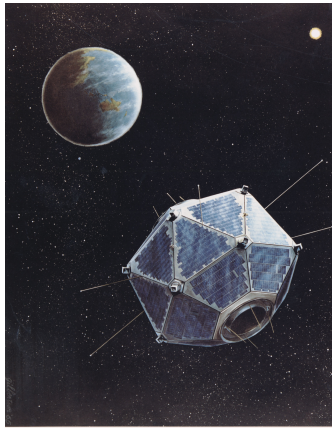
Ground-based sensing systems (USAEDS, IMS, USPDS)





Modern USNDS System

***Vela* Series**
Late 1960s – 1970s

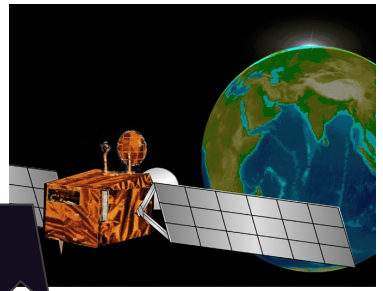


US Nuclear Detonation Detection System (USNDS)

Defense Support Program (DSP) 1975 – present

Payloads on GPS (Mid-Earth Orbit)

+



Payloads at Geosyn-chronous orbit

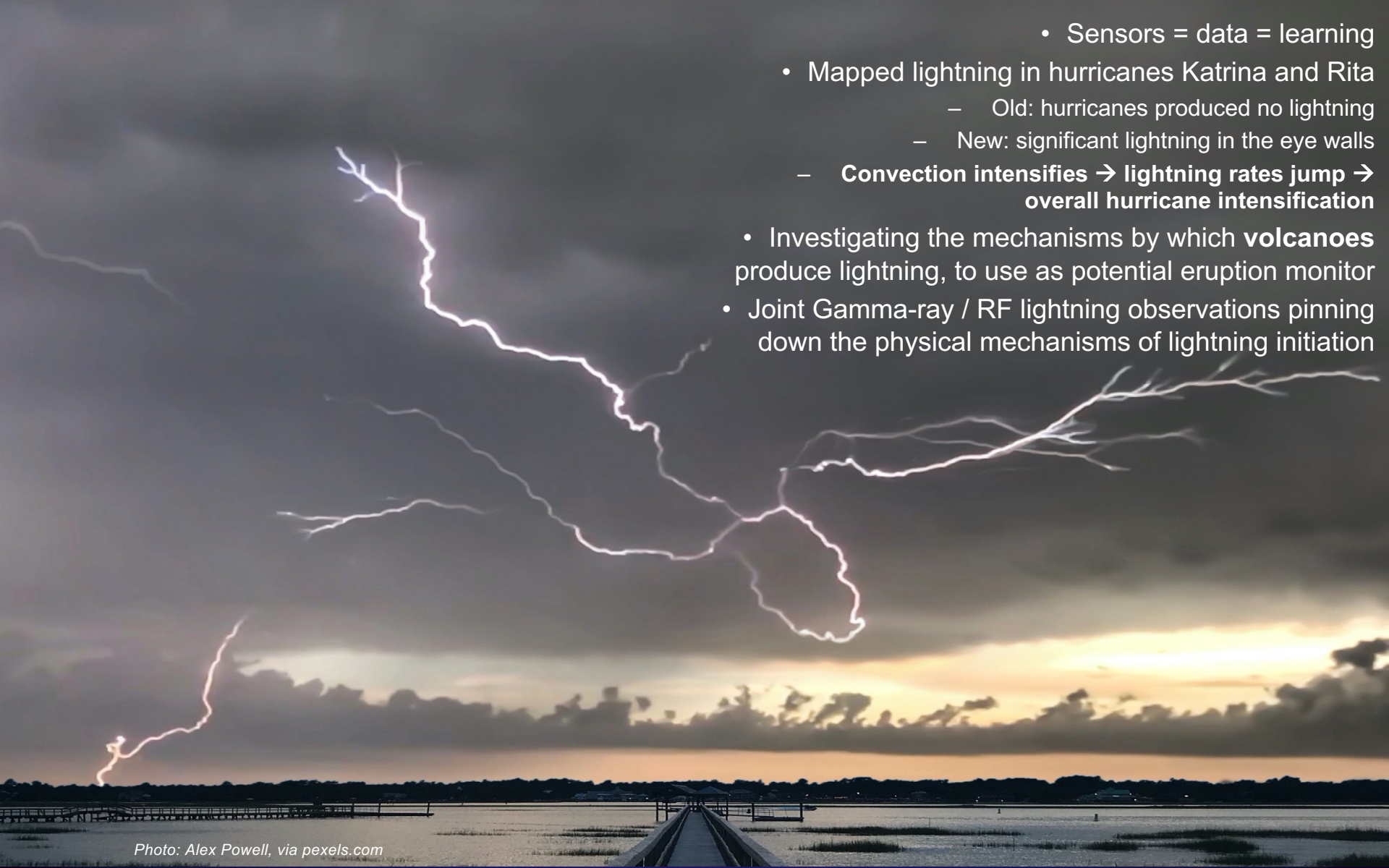
Cold War | **Post Cold War**

Evolving Geopolitical Landscape/Threats

Multi-physics problem = Multi-disciplinary team

LANL tackles the problem end-to-end	The EMP* team alone maintains expertise in:
• Source term theory and modeling • Sensor design/prototyping/qualification • Hardware fabrication, test, and integration • System deployment and operation • Analysis for R&D as well as system state of health monitoring • Current- and future-system performance simulation	• EM theory • Plasma physics • Ionospheric physics • Atmospheric physics • Lightning physics • Signal processing • Electrical and digital engineering • Antenna engineering and design • Statistics • Computer science • Analytics • Modeling and simulation

* Details henceforth will be a bit biased towards RF remote sensing / EMP examples because that's what I do



- Sensors = data = learning
- Mapped lightning in hurricanes Katrina and Rita
  - Old: hurricanes produced no lightning
  - New: significant lightning in the eye walls
  - **Convection intensifies → lightning rates jump → overall hurricane intensification**
- Investigating the mechanisms by which **volcanoes** produce lightning, to use as potential eruption monitor
- Joint Gamma-ray / RF lightning observations pinning down the physical mechanisms of lightning initiation

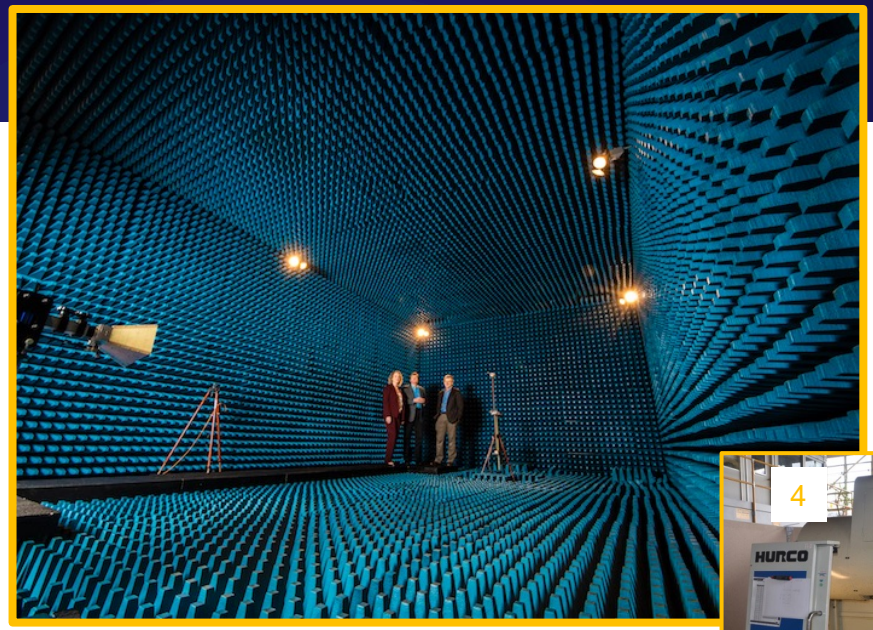
Photo: Alex Powell, via pexels.com

Meanwhile, we've got infrastructure and expertise

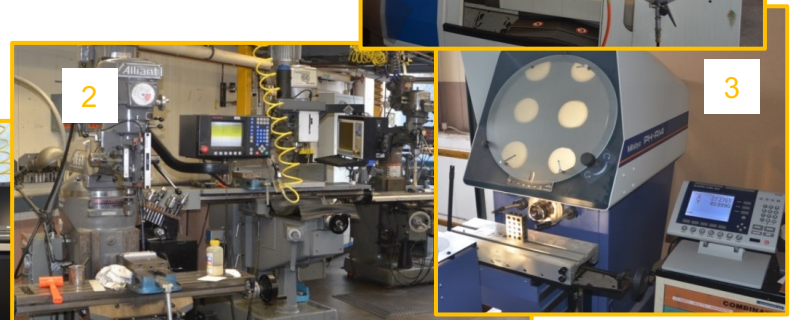
- ISR-division : A one-stop-shop for all things space!
  - X-ray, g-ray, neutron scientists (ISR-1)
  - Radio-frequency & optical remote sensing scientists (ISR-2)
  - Computer scientists and software engineering (ISR-3)
  - Engineering design (ISR-4)
  - Space-flight fabrication, quality assurance, and space qualification testing (ISR-5)
- But ISR partners widely across the Laboratory
- LANL is developing a Laboratory-wide Integrated Space Strategy in 2021

Facilities!

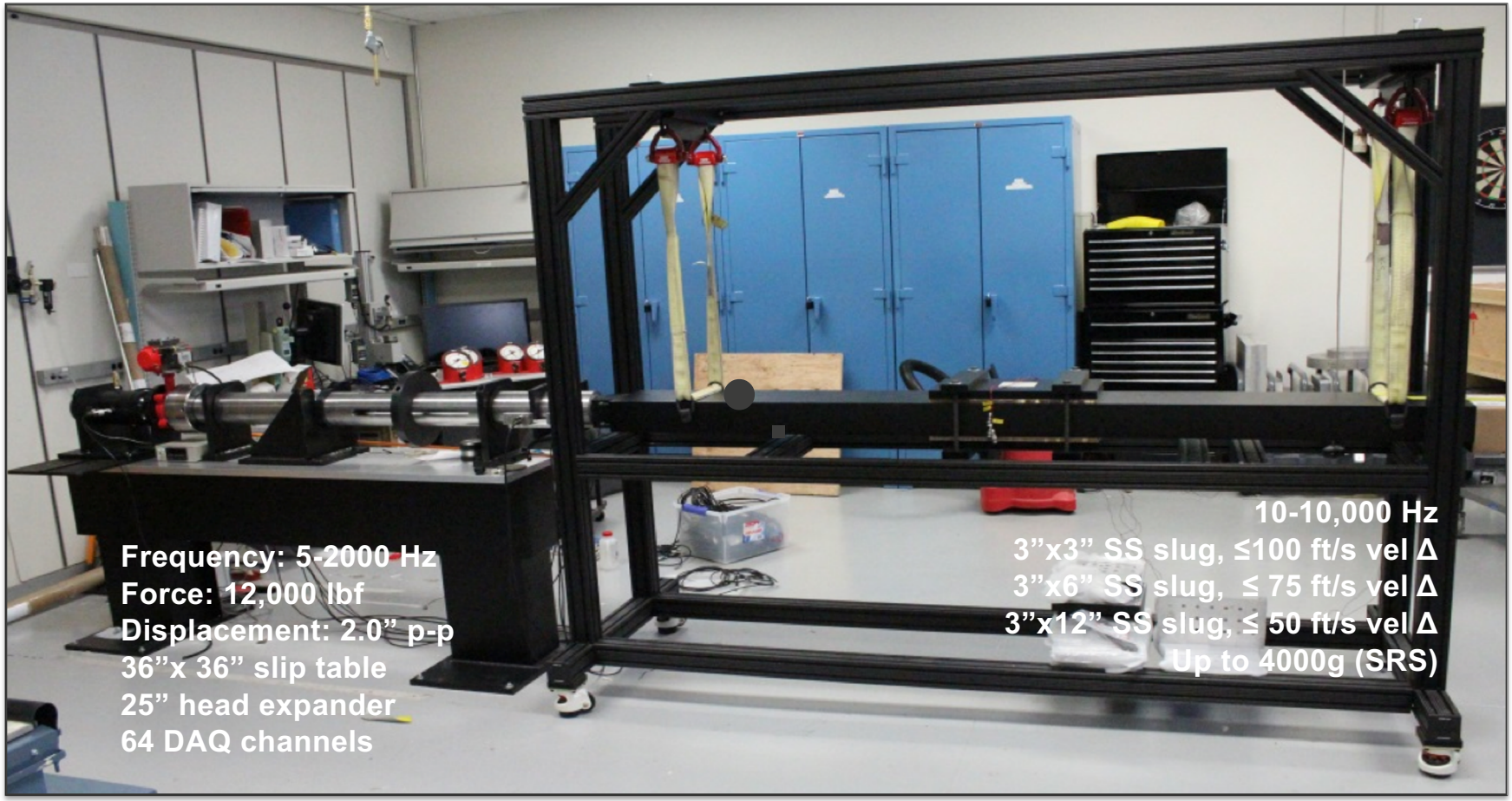
- EMI / EMC Testing (Anechoic chamber)



- Mechanical Design, Fabrication, and Quality Inspection
  - 1 – Faro arm
  - 2 – Compression msmts.
  - 3 – Optical comparator
  - 4 – 3-axis mills



Will it survive launch? – Shock & Vibe testing !



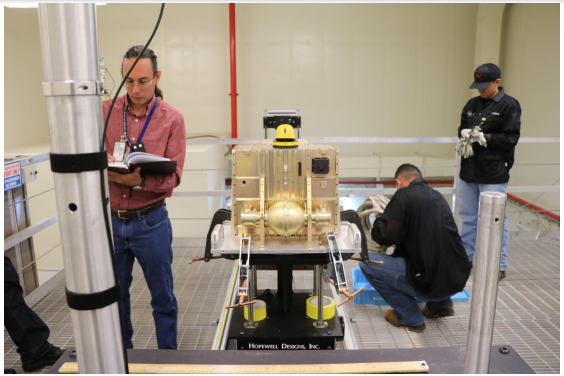
Will it survive space? – TVAC & radiation testing !

TVAC chamber:

- Temp: -150°to +150°C
- Vac: Atm. to 10^{-7} Torr (Empty Chamber)
- 60” Diameter
- Primary Platen-72”L x 36”W
- Secondary Platen- 24”L x 24”W (Independent Thermal Control)

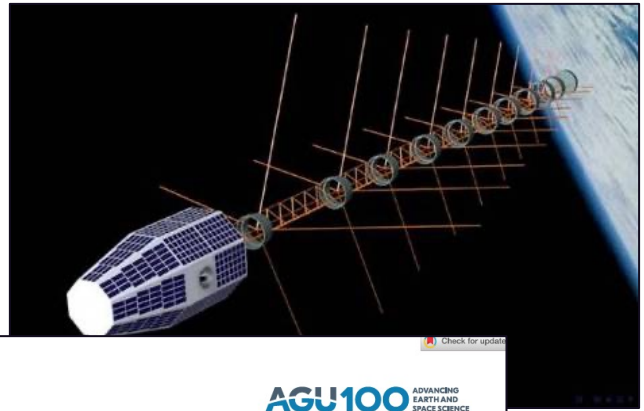
Neutron calibration work at Radiation Instrumentation and Calibration Facility

(setup in large room, away from floor/ceiling)

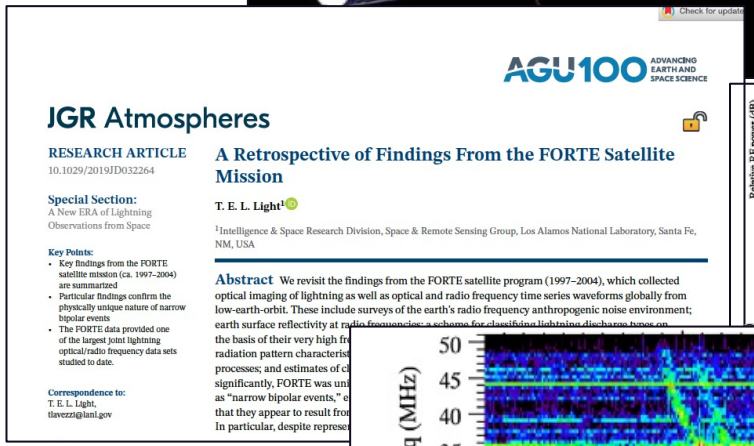


A sampling of LANL missions in space

FORTE: Fast On-orbit Recording of Transient Events



- Launched 1997
- Joint effort of Los Alamos & Sandia
  - Wideband Radio Receivers
  - Massive log-periodic antenna
  - Optical photodiode & optical imager
- Huge boon for lightning science



AGU100 ADVANCING EARTH AND SPACE SCIENCE

JGR Atmospheres

RESEARCH ARTICLE

10.1029/2019JD032264

Special Section:
A New ERA of Lightning Observations from Space

Key Points:
- Key findings from the FORTE satellite mission (ca. 1997–2004) are summarized
- Particular findings confirm the physically unique nature of narrow bipolar events
- The FORTE data provided one of the largest joint lightning optical/radio frequency data sets studied to date.

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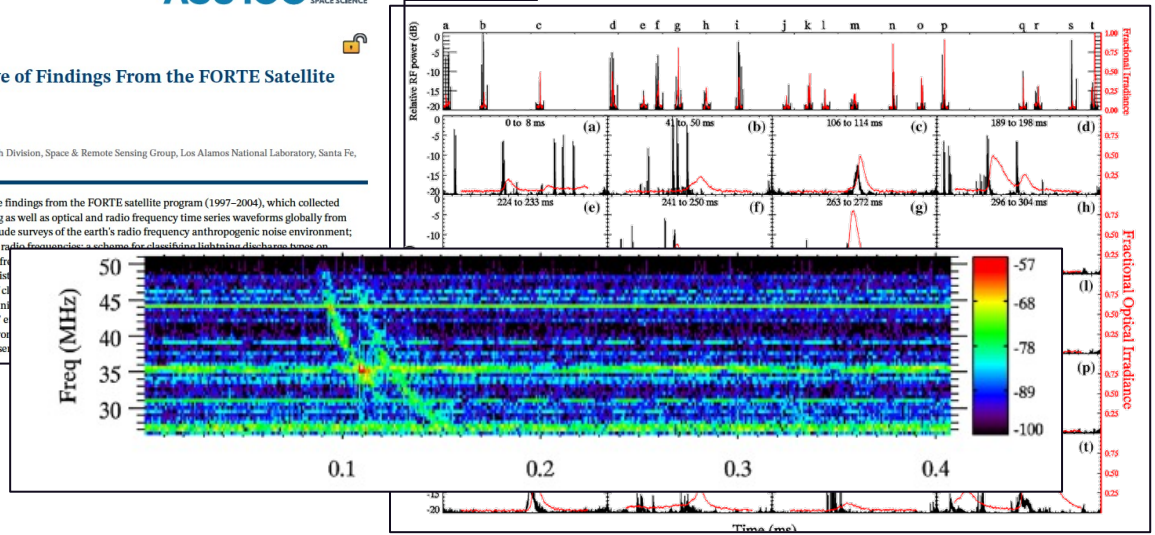
A Retrospective of Findings From the FORTE Satellite Mission

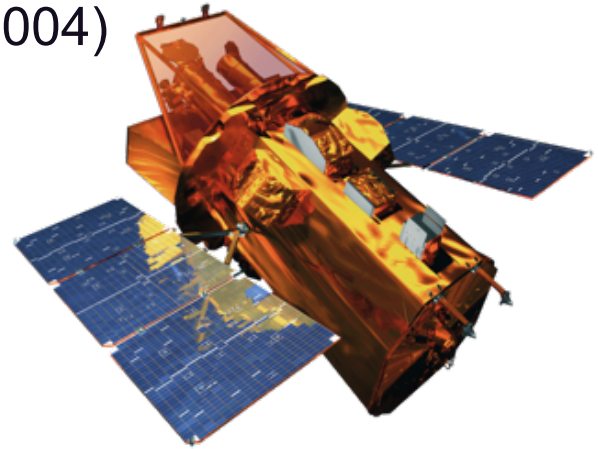
T. E. L. Light[1]

[1]Intelligence & Space Research Division, Space & Remote Sensing Group, Los Alamos National Laboratory, Santa Fe, NM, USA

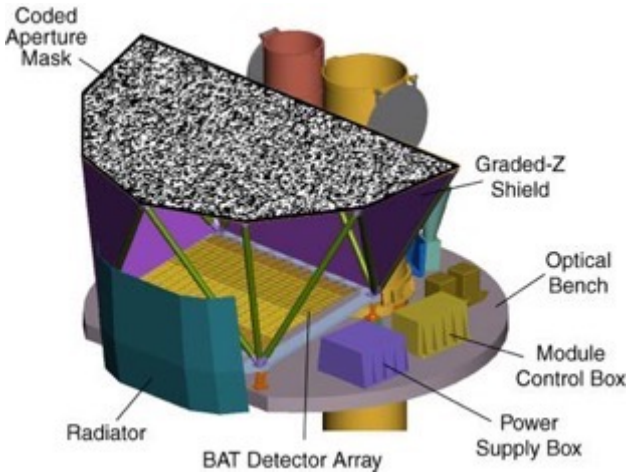
Abstract We revisit the findings from the FORTE satellite program (1997–2004), which collected optical imaging of lightning as well as optical and radio frequency time series waveforms globally from low-earth-orbit. These include surveys of the earth's radio frequency anthropogenic noise environment; earth surface reflectivity at radio frequencies; a scheme for classifying lightning discharge types on the basis of their very high fr… radiation pattern characterist… processes; and estimates of cl… significantly, FORTE was uni… as "narrow bipolar events," e… that they appear to result fro… In particular, despite represe…

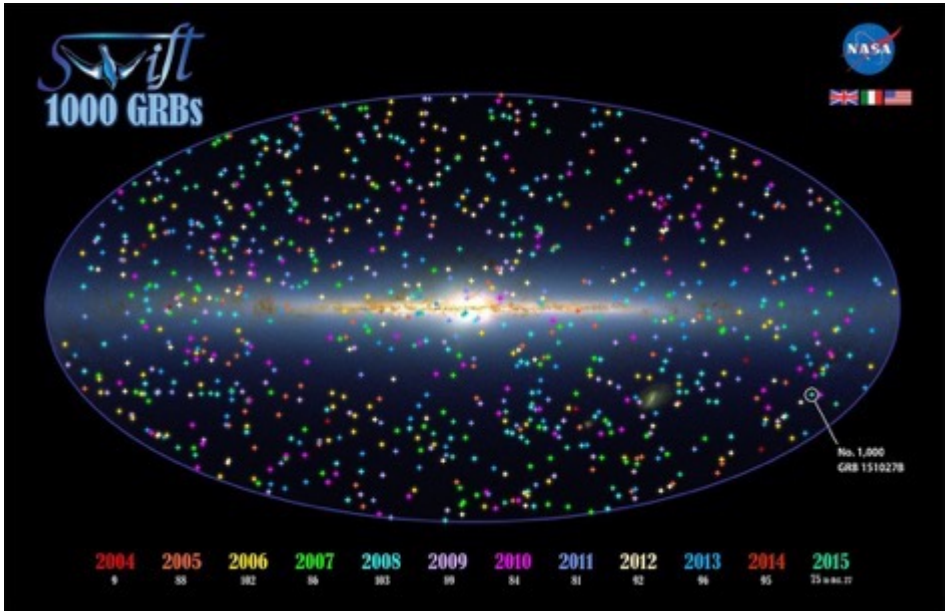


BAT: Burst Alert Telescope on Swift (launched 2004)



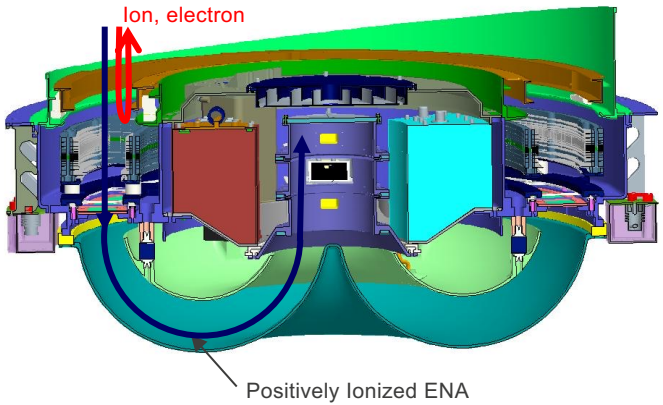
- Recall: Vela discovered GRBs
- Observe GRBs and afterglow in gamma, x-ray, UV and optical bands
- Named for rapid slew ability



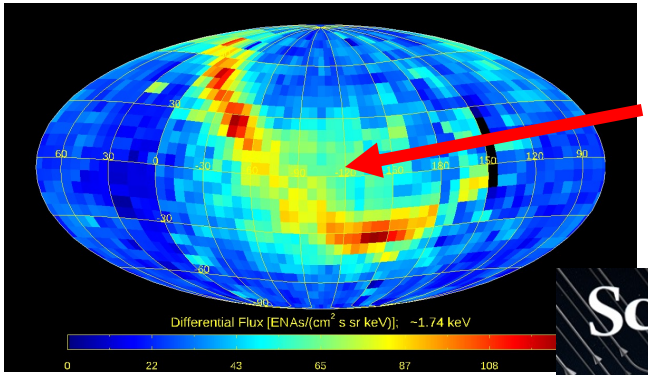


IBEX: Interstellar Boundary Explorer

- Earth-orbiting Explorer Class mission to map the interstellar boundary region by detecting energetic neutral atoms (ENAs) formed in the heliosheath
- Launched in 2008 into a highly elliptical geocentric orbit; still in operation
- Los Alamos leads the IBEX-Hi instrument, detects ENAs in 5 energy steps between 500 eV and 6 keV



IMAP-Hi has made the first-ever global maps of the interstellar boundary region



Discovery of the "*IBEX Ribbon*"

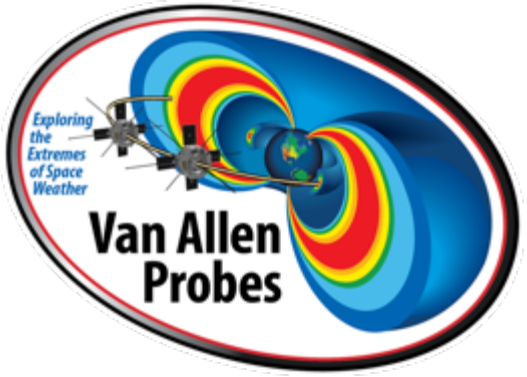
IBEX-Hi was jointly developed by LANL and Southwest Research Institute

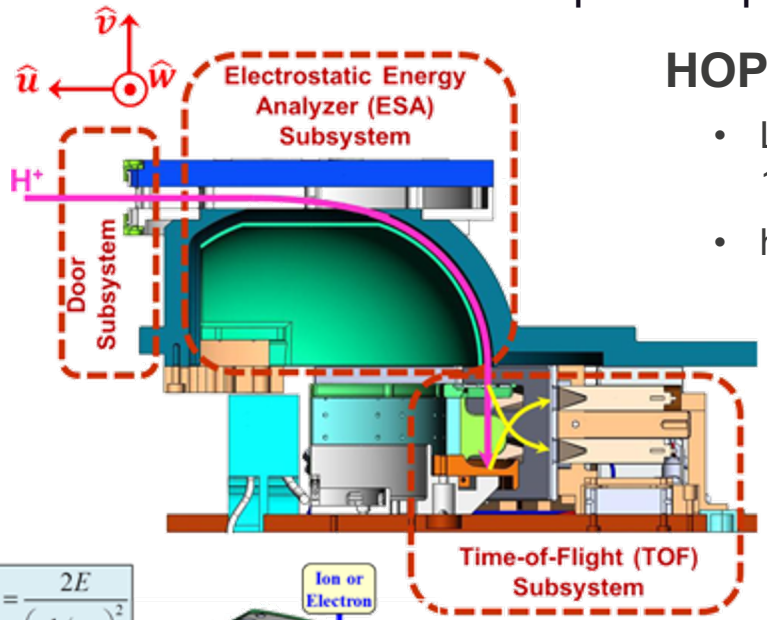
IBEX mission partners include UNH, Lockheed-Martin, U. Alabama, U. Bern, U. Bonn, Polish Space Institute

Funsten et al. 2009

Van Allen Probes (launched in 2012):

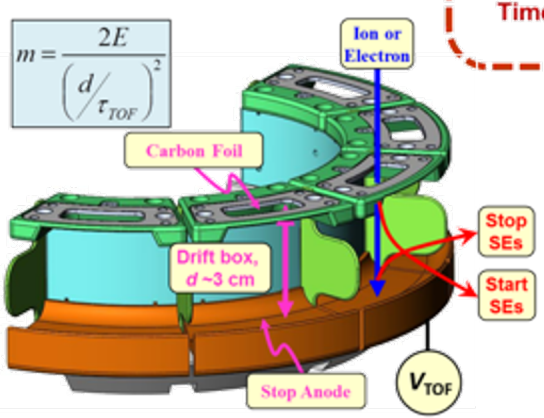
Measure radiation belts' particle populations and dynamics

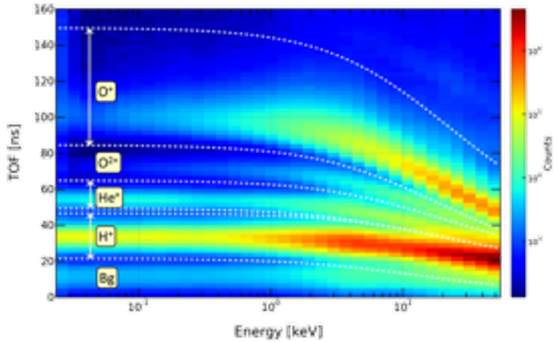


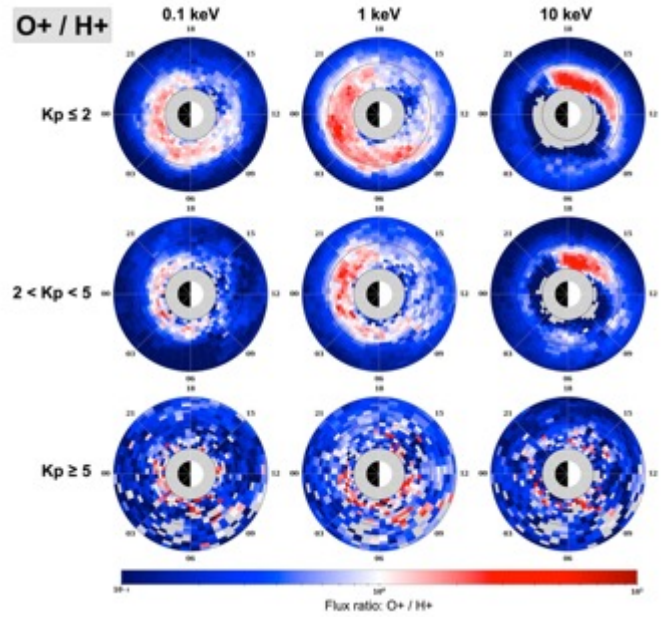


HOPE Spectrometer

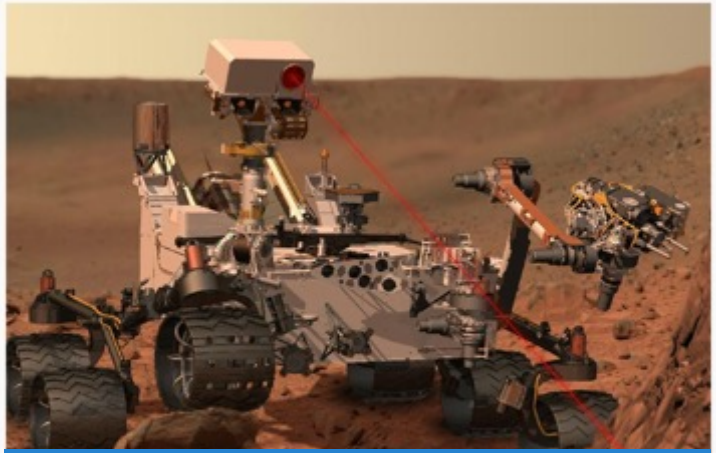
- Lower energy spectrometer
  1 eV – 50 keV
- helium, oxygen, protons, electrons







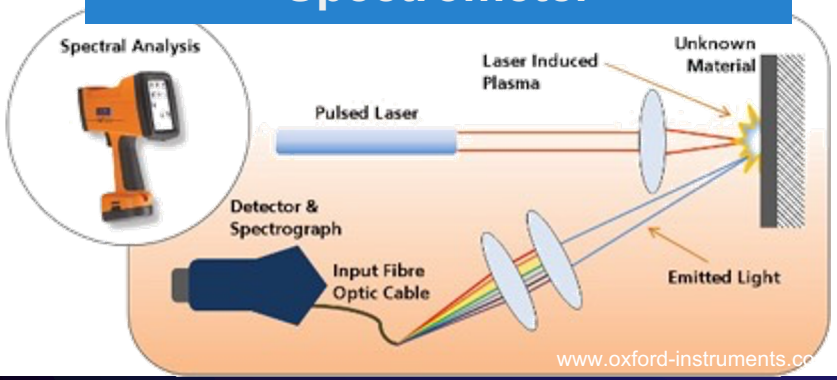
Chemcam: Instrument on Curiosity Rover, launched 2012; Understanding the biological potential, and geological and geochemical evolution of Mars

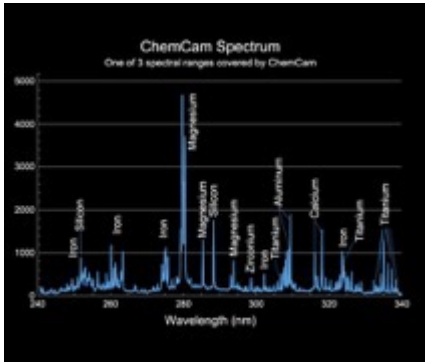


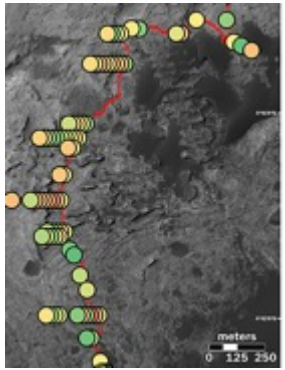
Laser Induced Breakdown Spectrometer

Mast unit

Body unit

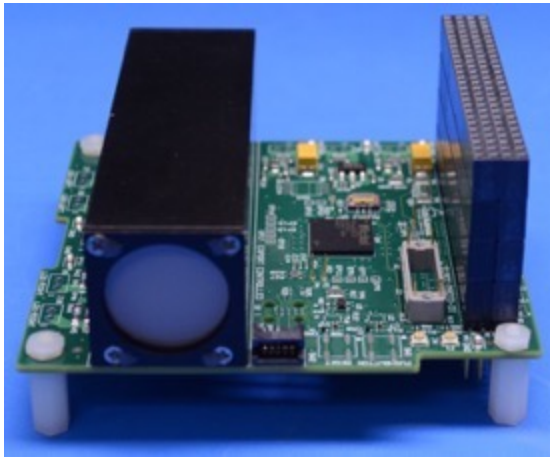




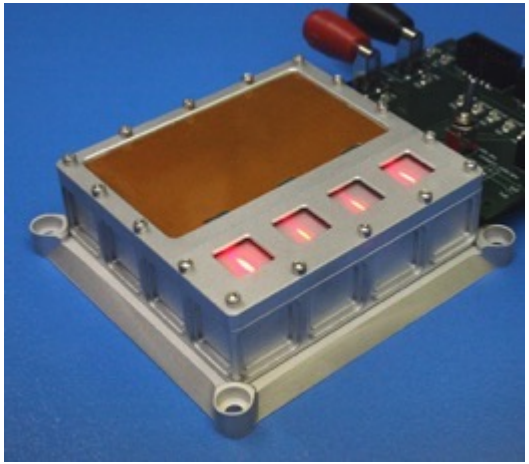


ELROI Satellite License Plate

(Extremely Low Resource Optical Identifier)



First launch 2018; next Nov 2021.



Flight units in production.

What we want it to look like.

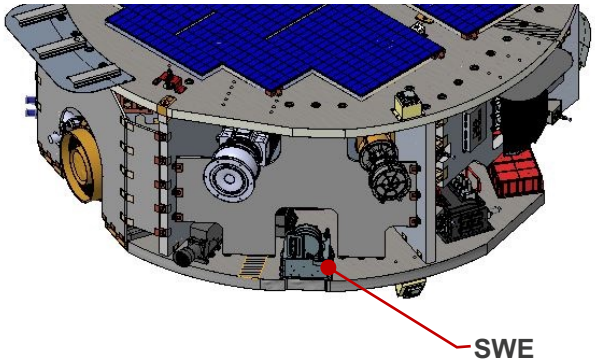
A blinking light serial number that anyone can read using a small telescope and a photon counting detector.

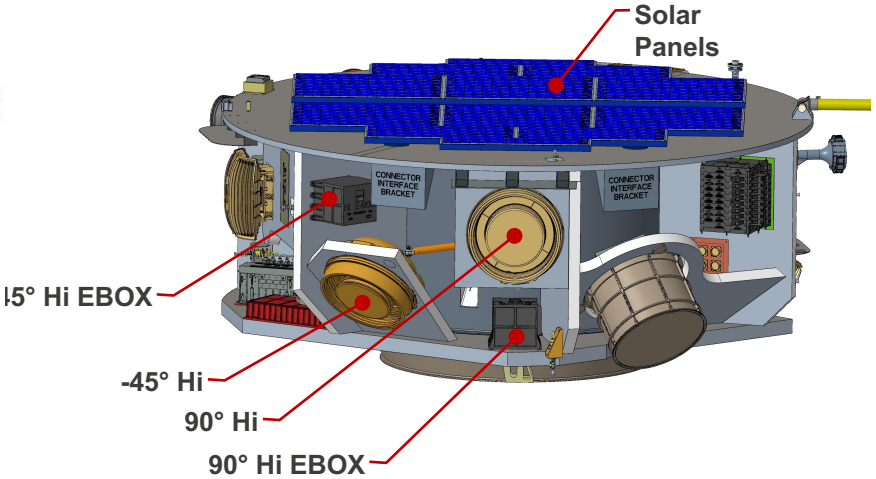
Space-to-ground ID beacon at milliwatt power levels.

IMAP: Interstellar Mapping & Acceleration Probe

Mapping the boundary of the heliosphere, and linking its properties to solar wind dynamics and energetic particle acceleration

- *Because of the success of IBEX,* IMAP was identified as the top priority mission in the 2013 NRC Heliophysics Decadal Survey
- Launch scheduled for 2025, to be stationed at the Sun-Earth L1 point
- Partners (instrumentation and science): Princeton (PI), APL (spacecraft), UColo/LASP (SOC), SwRI, UNH, GSFC, U Chicago, Imperial College London, Polish Space Institute, U Bern
- Los Alamos is providing two of the 10 payload instruments:
  - IMAP-Hi: 2 Heliospheric ENA imager heads
  - SWE: solar wind electron spectrometer

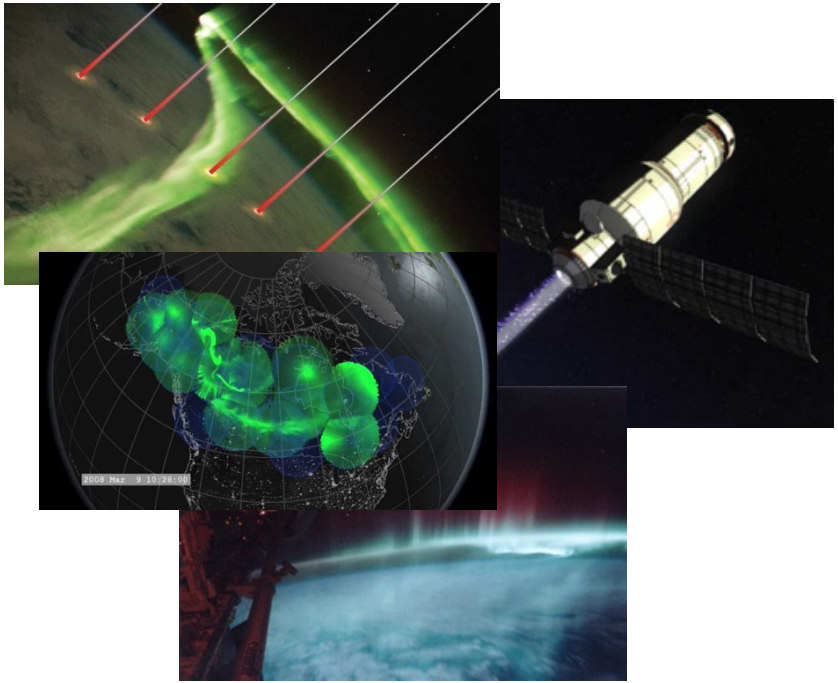


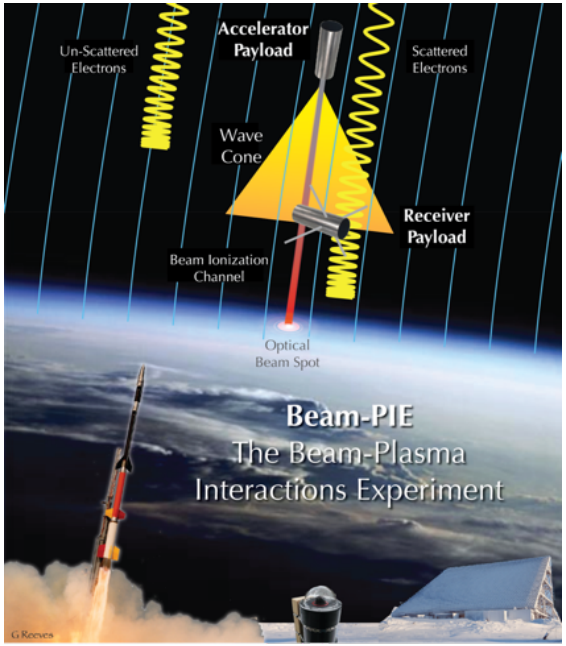


Active Experiments in Space: CONNEX & Beam-PIE

CONNEX: The Magnetosphere-Ionosphere Connections Explorer

Mission concept in development

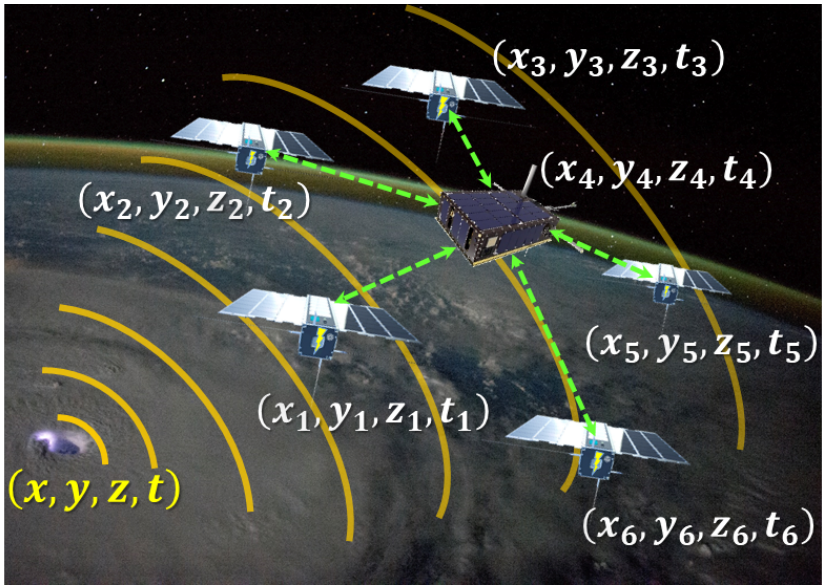




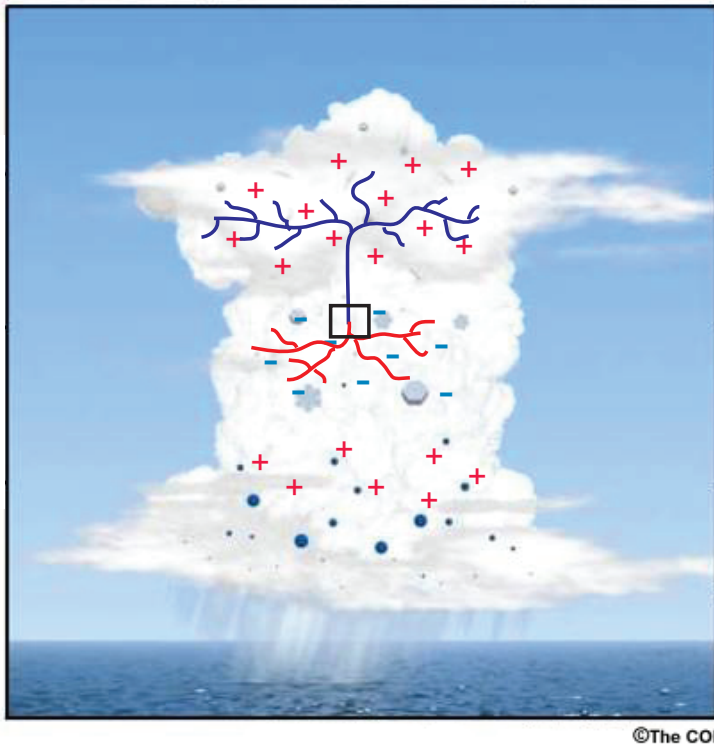
Beam-PIE: The Beam-Plasma Interactions Experiment

Launch expected ~ 2022

CubeSpark: Low Earth Orbit cube-sat constellation
(in development)



Time-difference-of-arrival location of individual radio impulses from lightning using cube-sats like a sensing array.



3-D measurements of lightning to allow detailed study of storm and lightning microphysics

And two more launches are coming this year!

Questions?

First GPS Block III Satellite Launch
December 23, 2018