Imaging the Earth from the Moon – FUV Imaging of the Earth's Space Weather

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Making Observations of the Earth from the Moon Makes Sense

- Once we choose to go to the Moon, we gain a unique and invaluable vantage point for studying the Earth's upper atmosphere.
  - From the Moon we can observe the entire planet at all local solar times.
  - We do not have this coverage now yet we do need it to address basic research questions and to improve the predictive capability of models.
  - The cost for the delivery of the payload to the lunar surface should be less than an MOO and must be less than a dedicated free flyer.
- The Earth's upper atmosphere (above 130 km) is where the major impacts of space weather are evident.
  - Space weather is generated by the interaction of the solar atmosphere and radiation field with the geospace environment.
- Why do we study the Earth's upper atmosphere?
- What questions to we still have?
- How can we do a better job from the Moon?
- What can we learn?
- What are the practical and societal benefits?
- I will discuss a very simple instrument, with proven heritage, that could address these questions.

We Seek an Understanding of the Atmosphere of the Earth and Other Planets

- UV remote sensing provides us an important technique for understanding, as well as testing our understanding of, the connections between the upper atmosphere and
  - The Sun
  - The magnetosphere
  - The ring current and plasmasphere
  - The lower atmosphere

as well as the connections between the ionosphere and the thermosphere.

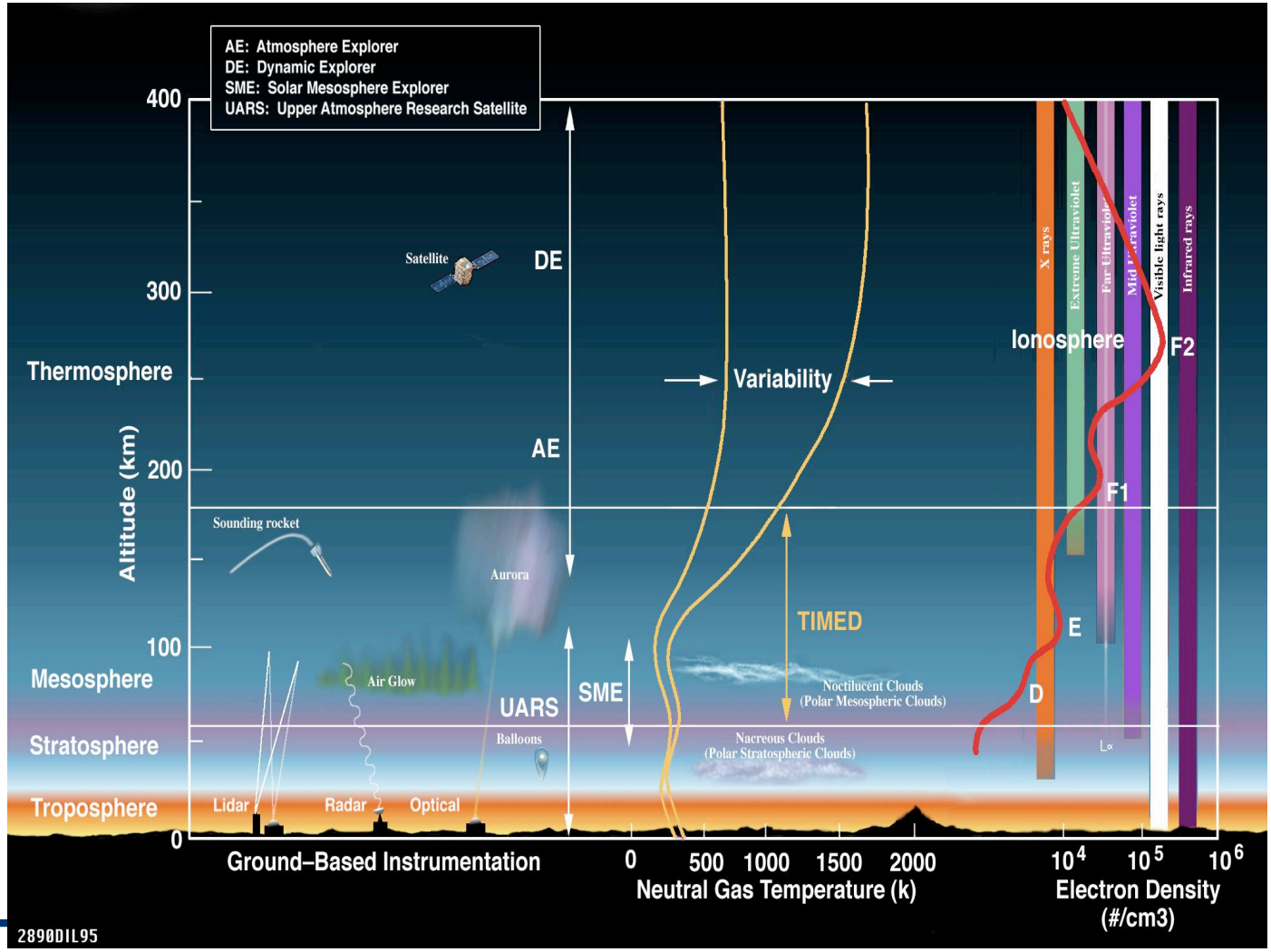
- In this talk I will focus on the Far Ultraviolet (115 to 180 nm) because this spectral region offers opportunities to address important issues with compact, relatively inexpensive, instruments well-suited for human exploration of the Moon.
- FUV imagery has quantitative as well as qualitative information.
  - The Earth's lower atmosphere and surface are black at these wavelengths.
  - There is a significant heritage as well as current capability that makes this a cost-effective spectral region to choose.

Fundamental Questions Persist About the Earth's Atmosphere – We Need a Global Perspective

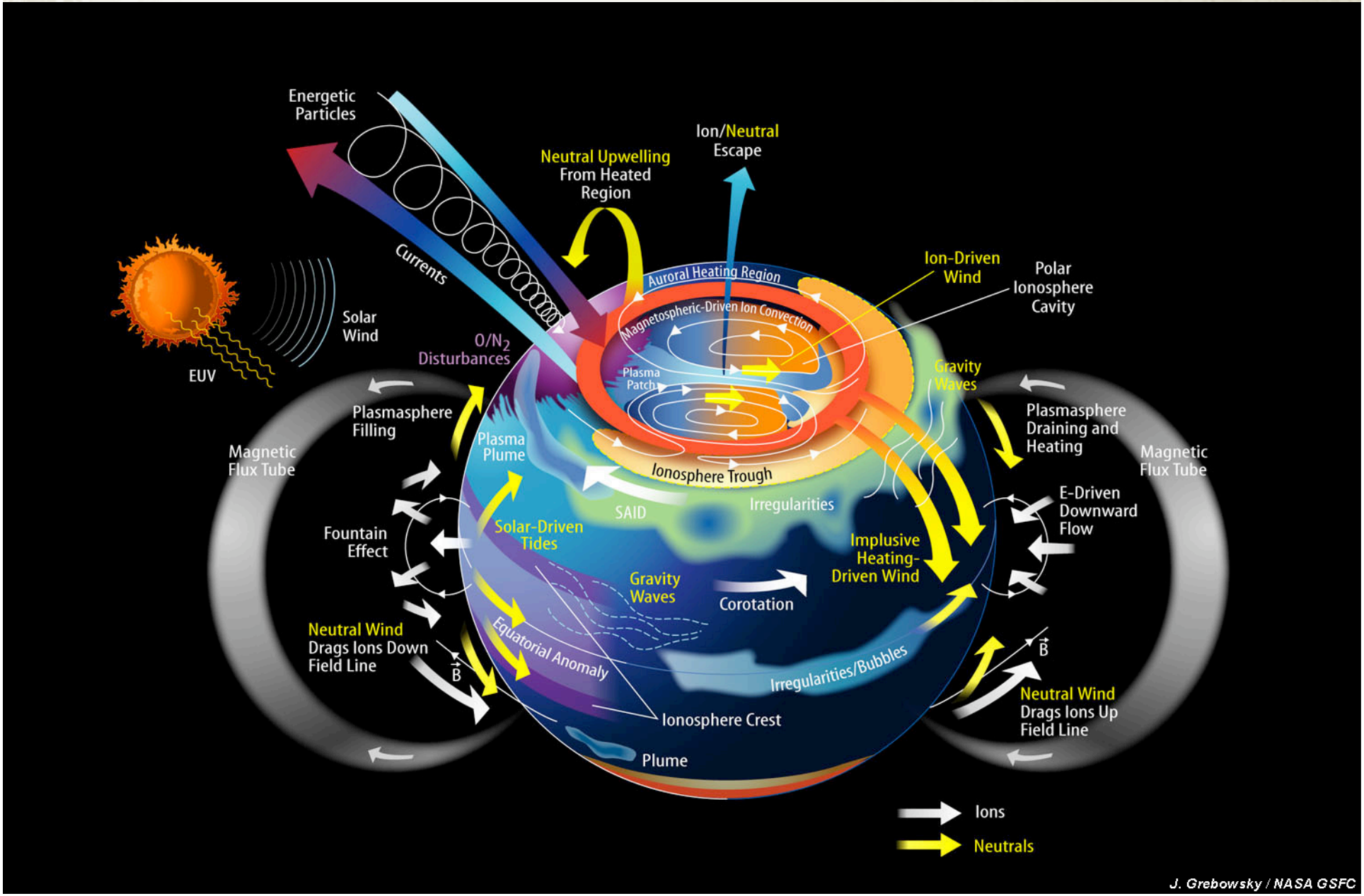
Early science missions have slowly evolved from a 0D to a 1D view of the phenomena.

LEO constrains one to a time-aliased 2D view of the phenomena.

We need a global perspective on the system.



The Near-Earth Space Environment is Externally Forced and Many of the These Processes Have UV Signatures



The START-IT Mission Will Study the Global Response of the Coupled I-T System from the Moon

- Storm-Time Atmosphere Response and Trends in the Ionosphere and Thermosphere
  START IT - will be a compact FUV imager/spectrographic imaging system – placed on the Moon by humans.
- How does the ionosphere and thermosphere respond as a coupled system to geomagnetic storms and changing solar inputs?
- What are the sources and characteristics of irregularities in the ionosphere and thermosphere?
- What are the scales for these irregularities and which are the most important for determining our ability to forecast ionospheric conditions?
- What are the space weather effects of this variability?
- Is there a long-term change in the upper atmosphere and is there a human-driven component to this change?

FUV Spectral Region Exhibits the Signatures of Space Weather in the Upper Atmosphere

- **FUV spectral features were identified and interpreted during 30 years of rocket and spacecraft missions.**

	HI (121.6 nm)	OI (130.4 nm)	OI (135.6 nm)	N_2 (LBHs)	N_2 (LBHI)
Dayside Limb	H profiles and escape rate[1]	Amount of O_2 absorption[1]	O altitude profile	Amount of O_2 as seen in absorption	N_2, Temperature
Dayside Disk	Column H	Amount of O_2 absorption[1]	Used with LBHs to form O/N_2	N_2, Solar EUV	Solar EUV
Nightside Limb	H profile and escape rate	Ion/ENA precipitation	EDP HmF2 NmF2 T_{plasma}	Ion/ENA precipitation characteristic energy	Ion/ENA precipitation characteristic energy
Nightside Disk	Geocorna and Ion/ENA precipitation	Ion/ENA precipitation	$\int n_e^2 ds$ (line of sight) and $\int n_e dz$ (vertical TEC) Ion/ENA precipitation	Ion/ENA precipitation	Ion/ENA precipitation
Auroral Zone	Region of proton precipitation	Auroral Boundary and amount of column O_2 present[1]	Region of electron and (possibly) proton precipitation	Used with LBHI to form Eo and the ionization rate and conductance information	Measure of the effective precipitating flux, used with LBHI to form Eo and the ionization rate and conductance information

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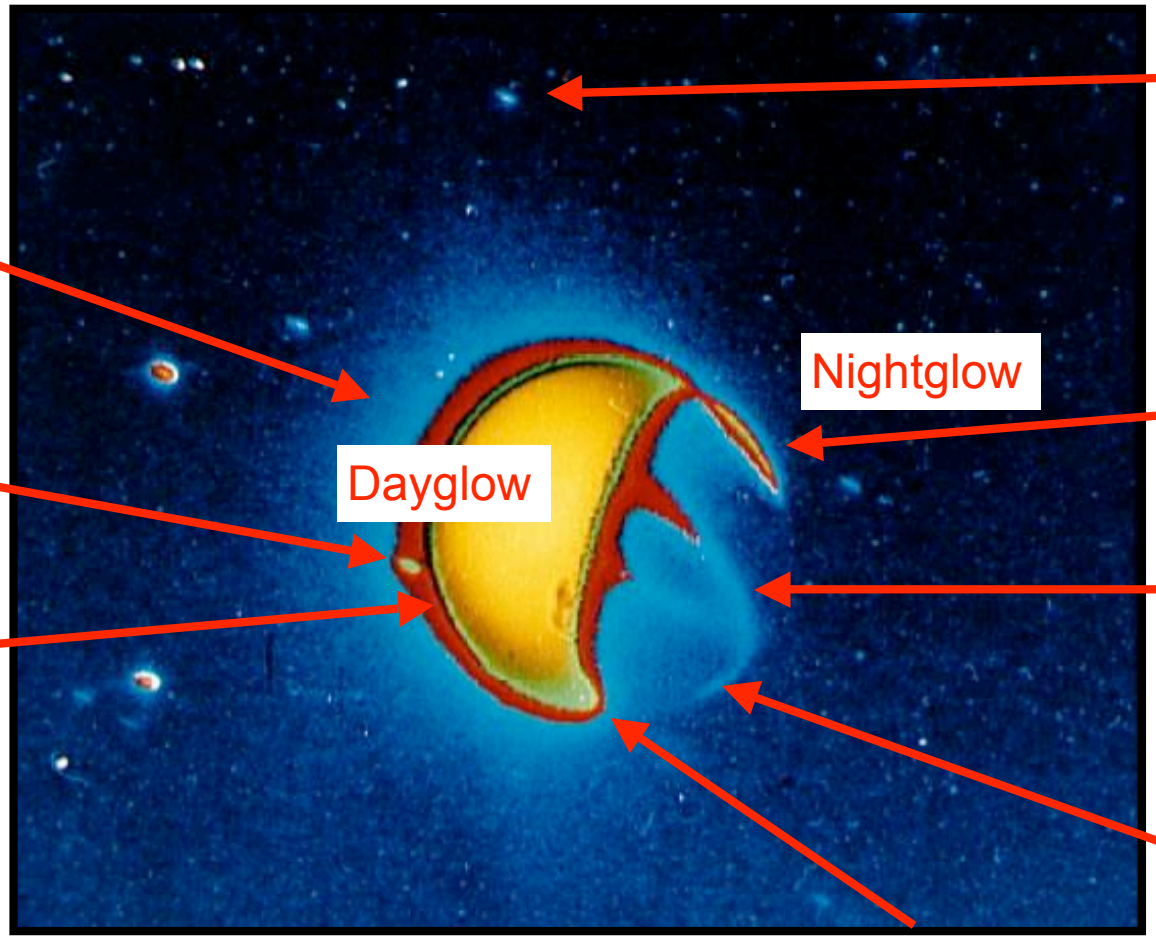
The Earth in the FUV: The Object of this Talk



First FUV image of the Earth- taken from the Moon by the Apollo 16 crew
Carruthers and Page, 1972

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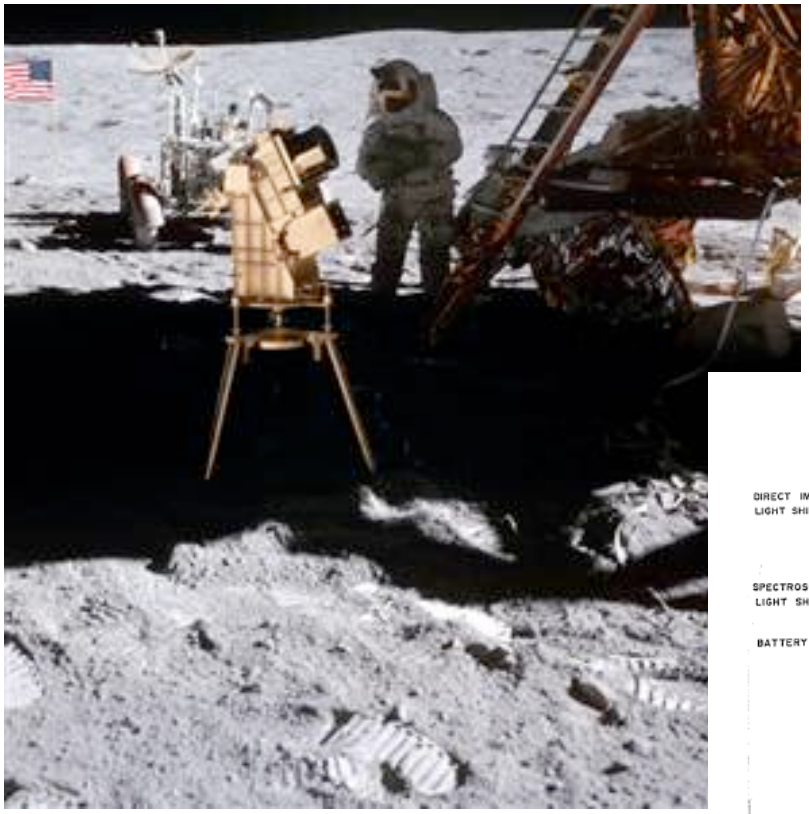
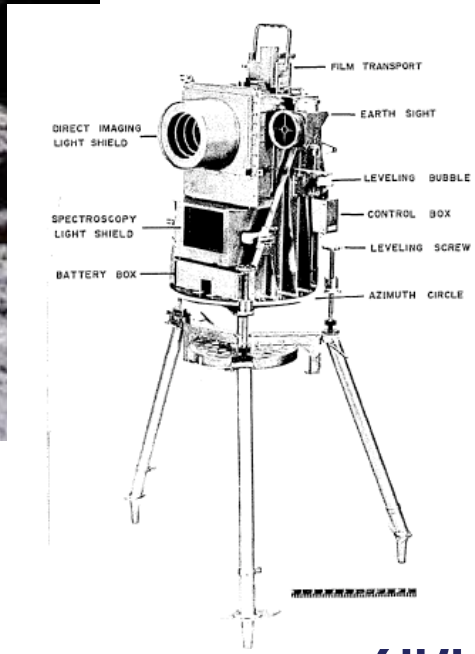
START-IT Would Start Small and Grow as the Infrastructure Grows

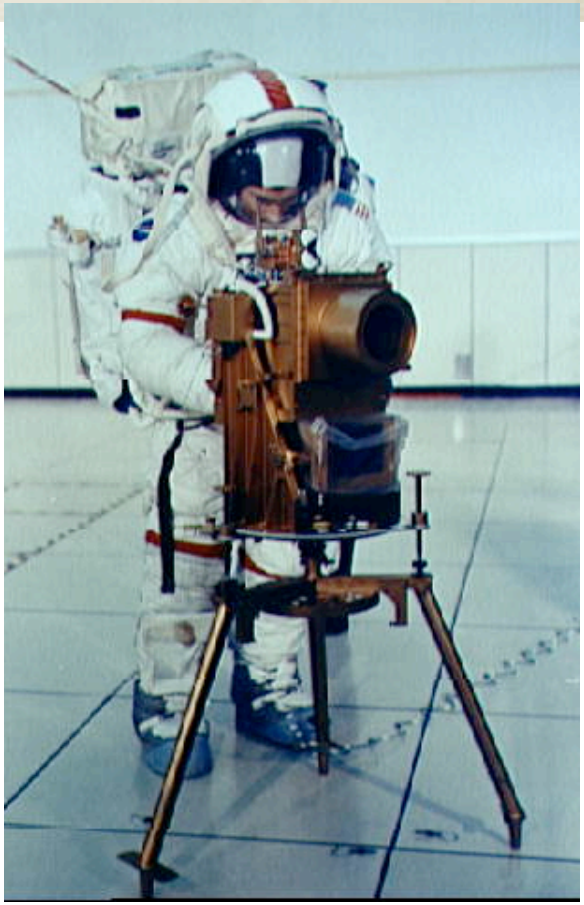
- The goal of this study was to determine whether a simple system could be designed for deployment on the Moon.
- The Carruthers FUV Camera experiment used on Apollo 16 illustrates the starting point on an evolutionary path that would end with a hyperspectral imaging capability.





UV Instrumentation can be Compact Portable and Readily Operated and Aligned on the Lunar Surface

- The design parameter space can be defined to meet practical and scientific goals.
- The first generation instrument could be the Apollo 16 UV Imager "on steroids".
- Future generations would build upon the operations heritage and expand the customer base.
- Challenges include long-term operation, data store/forward, and enhancing the value of the experiment.
- FUV imaging from the Moon is an ideal starting point for any technology demonstration projects that address the longer-term collection of remotely operated instrumentation.



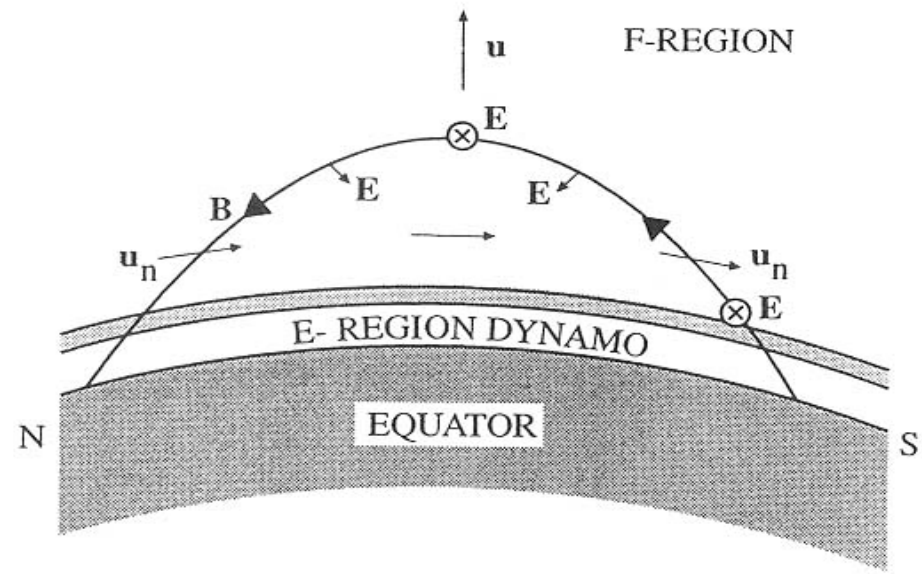
Astronaut John W. Young, commander of the Apollo 16 lunar landing mission, participates in lunar surface extravehicular activity (EVA) training in the Flight Crew Training Building at the Kennedy Space Center (KSC). Young adjusts a training model of a Far Ultraviolet Camera/Spectroscope, an instrument which will be placed on the Moon during the Apollo 16 EVA. Image # S72-19739

How Big Would START-IT Have to be?

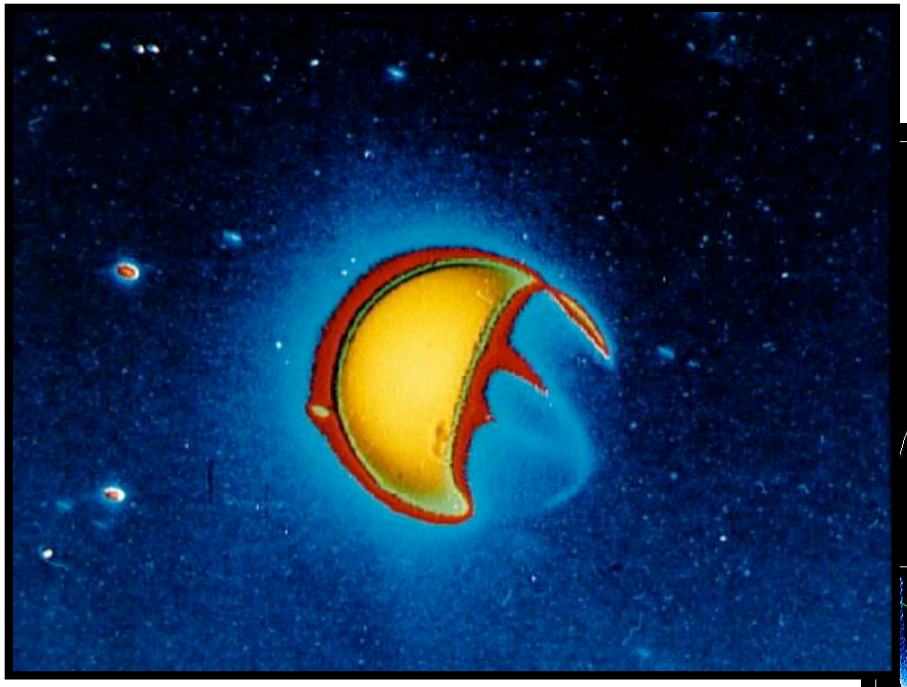
- A first generation system could be similar to the Apollo 16 FUV camera.
  - A simple Schmidt camera with a ¼ meter aperture operating at f/3 would allow us to image almost all I/T phenomena including the nightside ionosphere with an integration period of 5 min.
  - The data rate is low – averaging less than 1kB/s
  - The system could be packaged into a suitcase-size container and placed and aligned by an astronaut on the surface.
    - Mass 30kg
    - Power 10W (not counting heaters)
  - The lifetime of the system would be limited only by the availability of power/heat.
- The next generation would be a ½ meter f/3 system with a hard mount. This would increase the ability to delineate structures on the nightside of the Earth.

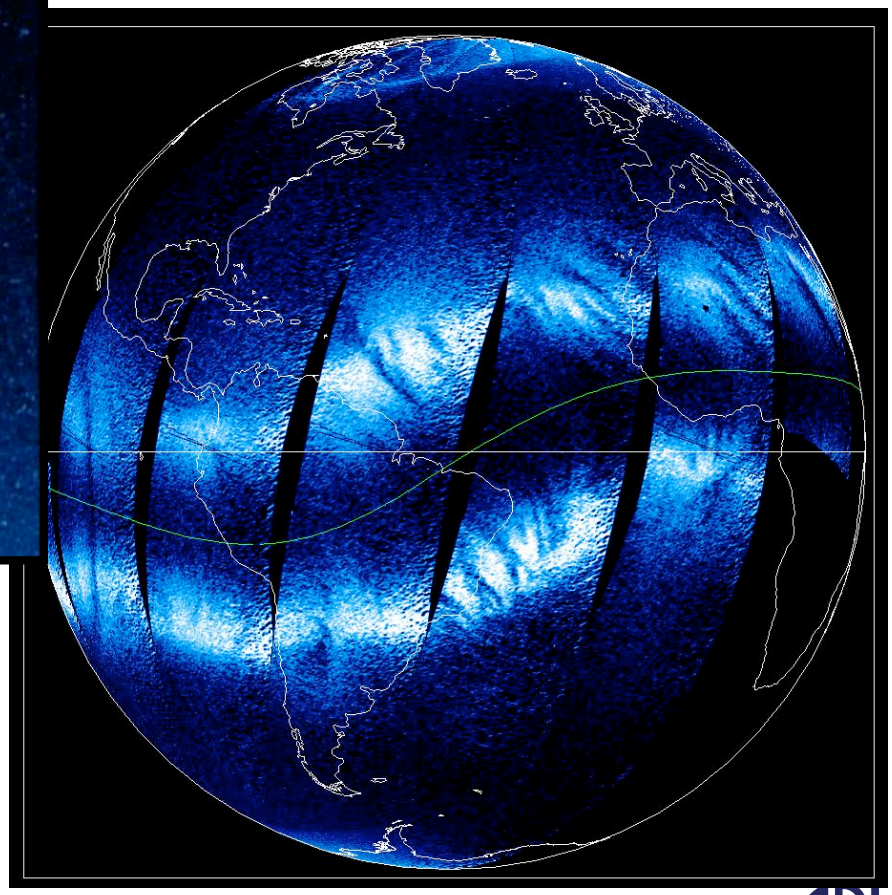
The Equatorial Ionosphere Shows the Global Coupling of the IT System

- Neutral winds in the low latitude E-region generate dynamo E-field as ions are dragged across B-field.
- Dynamo E-field is transmitted to F-region altitudes.
- Meridional neutral winds induce field-aligned plasma drifts at F-region altitudes.
- Corotational E-field causes the plasma to ExB drift to the east with the corotation speed.



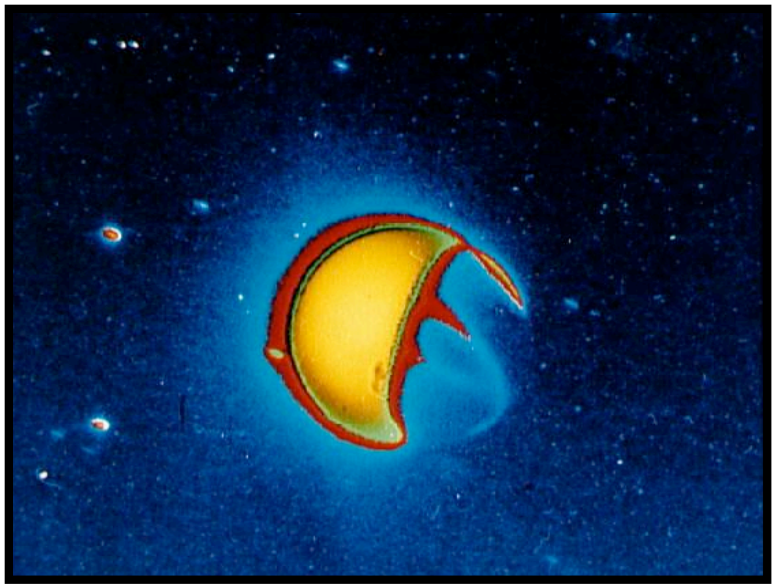
A Simultaneous, Global Picture of the Ionosphere at High Spatial Resolution is Needed

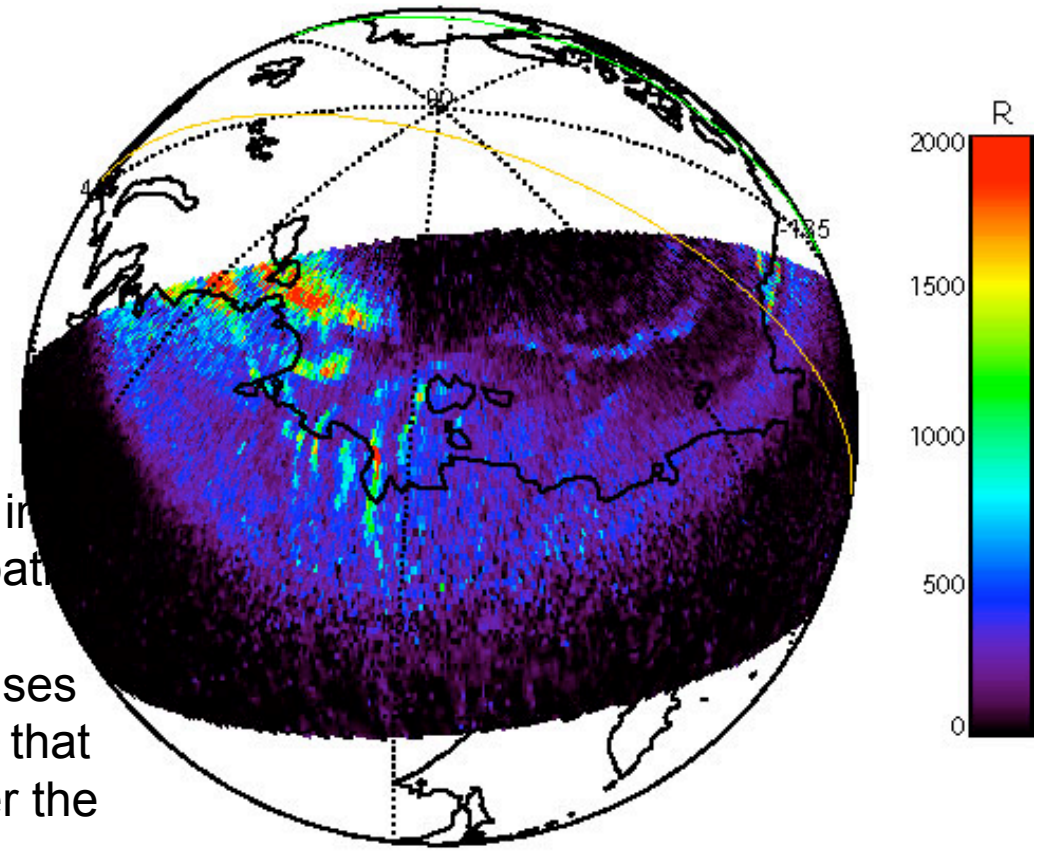




Ionospheric irregularities that affect RF communications.
Each pixel has a 25km resolution – the ionospheric bubbles imaged here have length scales of 100s to 1000s of km.

Auroral Imagery from the Moon Would Enhance our Understanding of the High Latitude Inputs that Drive the I/T and Couple it to Geospace





Even from a lunar perspective we can i
the aurora continuously and at high spat
resolution.

Energy deposited at high latitudes causes changes in the neutral and ion density that propagate toward the equator and alter the global circulation pattern of the upper atmosphere.

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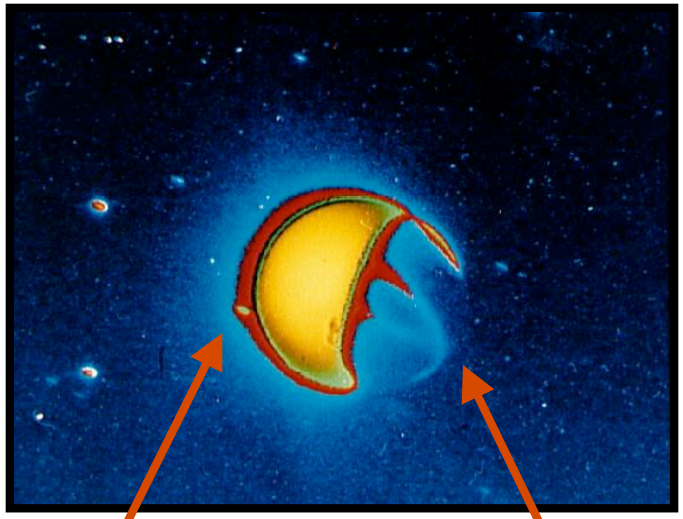
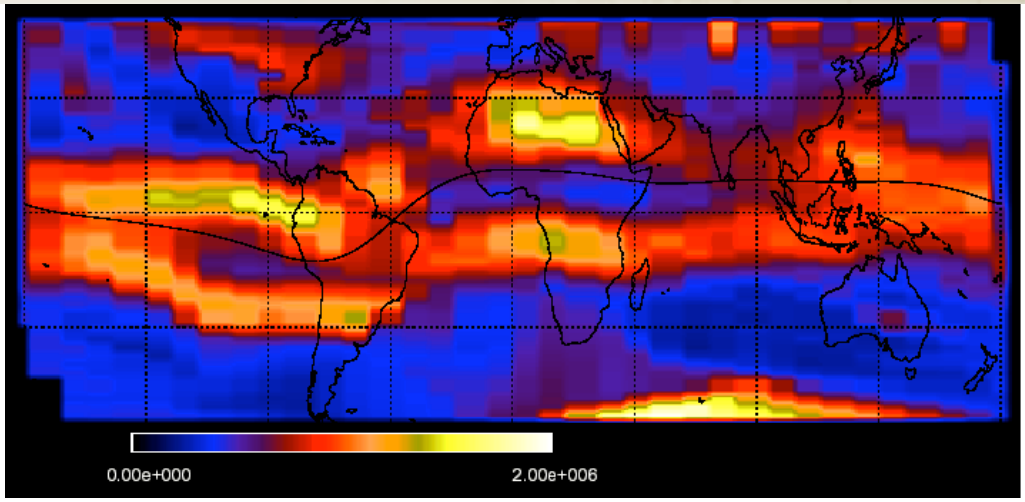
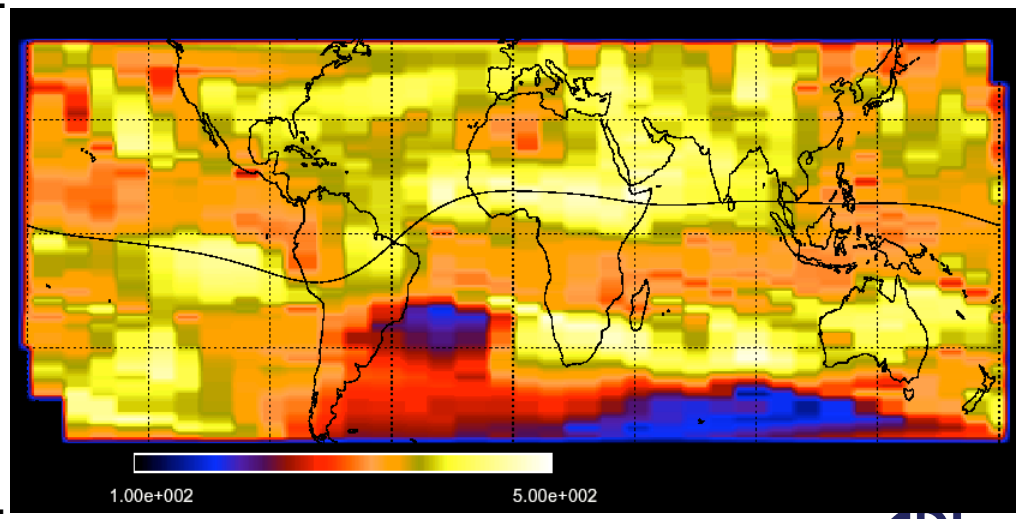
A Continuous Imaging of the Limb Would Enable us to Construct Maps of Ionospheric Key Parameters



NmF2



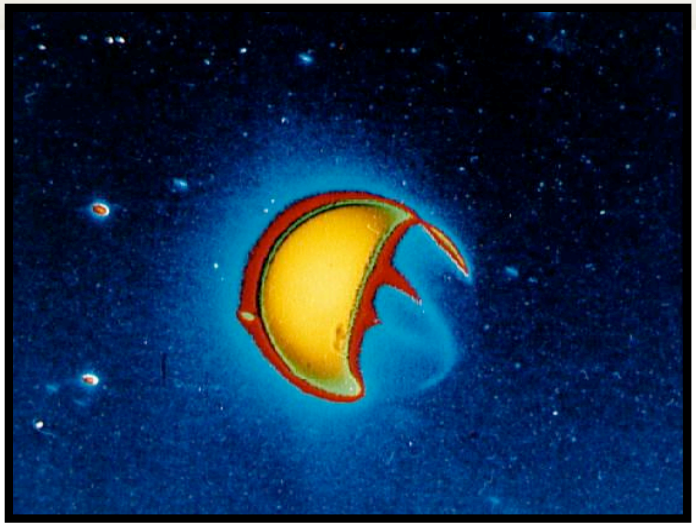
HmF2

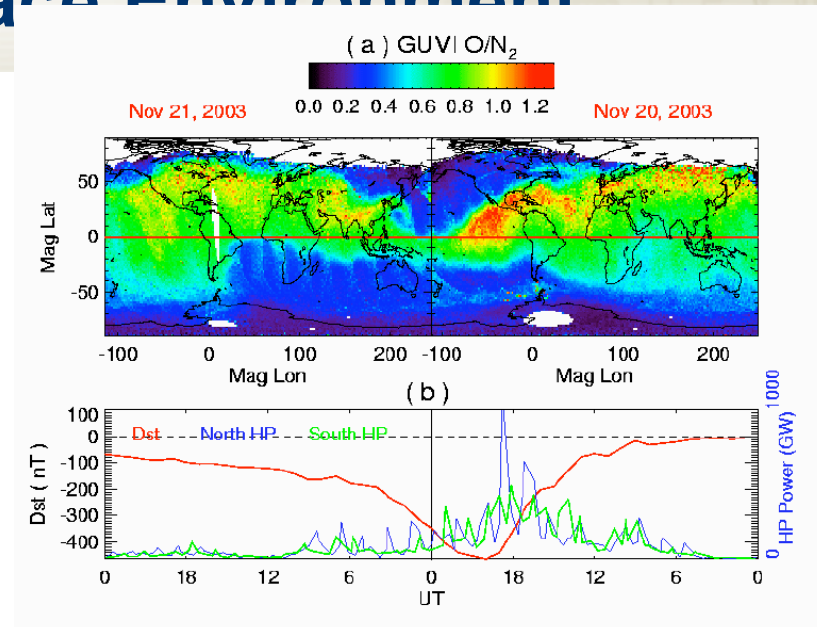


Dayside limb has information about the ionosphere above 300km. The dayside signature is the combination of the dayglow and the ionospheric signature.

The nightside limb is readily converted into ionospheric products.

Imaging the Dayside will Provide us a Unique Opportunity to Study the Coupling of the Upper Atmosphere to the Geospace Environment





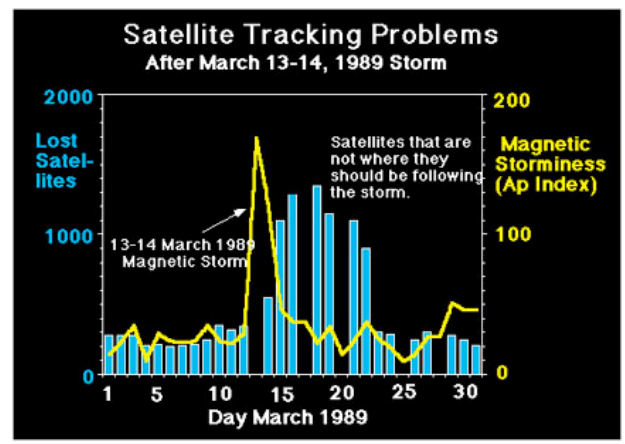
We see that during a geomagnetic storm composition changes propagate equatorward from the poles.

Why is the response asymmetric?

How does it vary as a function of local solar time?

Why can't our models reproduce the behavior (what are we missing)?

What is the effect of changes in atmospheric composition on orbit propagation products?



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The START-IT Program Would Benefit NASA and Other National Programs

- START-IT would be able to provide products to the space weather community in real-time.

Day	Night	Aurora
Integrated solar flux that ionizes the F-region (5-45 nm)	Total electron content (TEC)	Images for morphological studies
Composition changes (O/N_2)	Strength of the integrated EXB drift	Boundary determination as estimate of hemispheric power
	Effect of the meridional winds on ion distribution	Auroral E-region ionosphere

Exospheric (geocoronal) H can be imaged and may provide direct evidence of changes in the biogeochemical cycle in the lower atmosphere/surface

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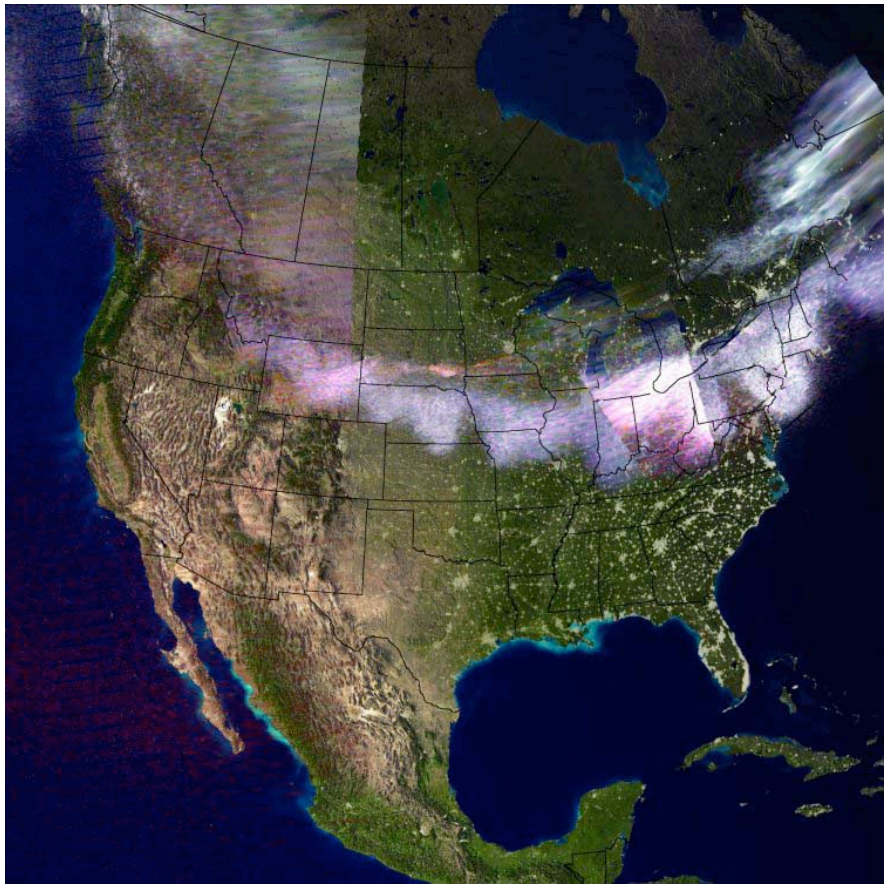
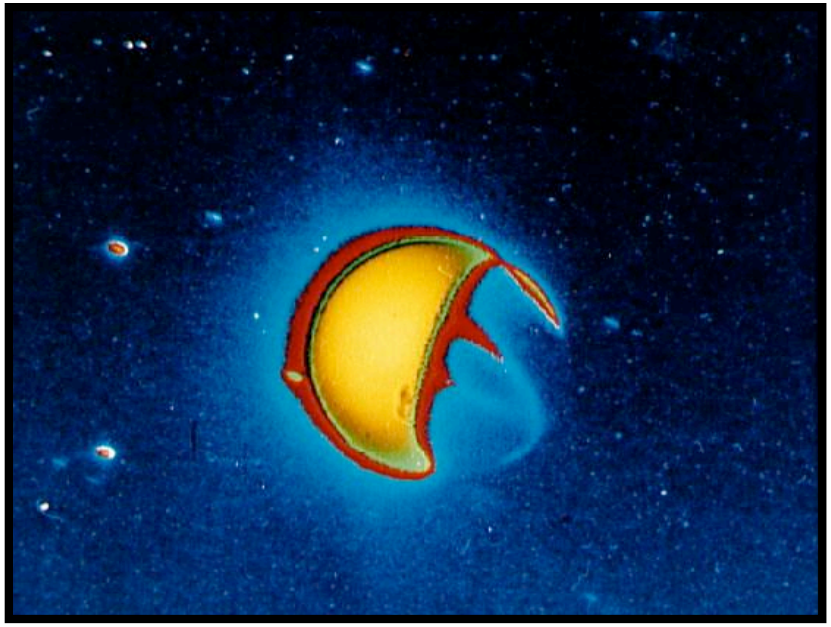
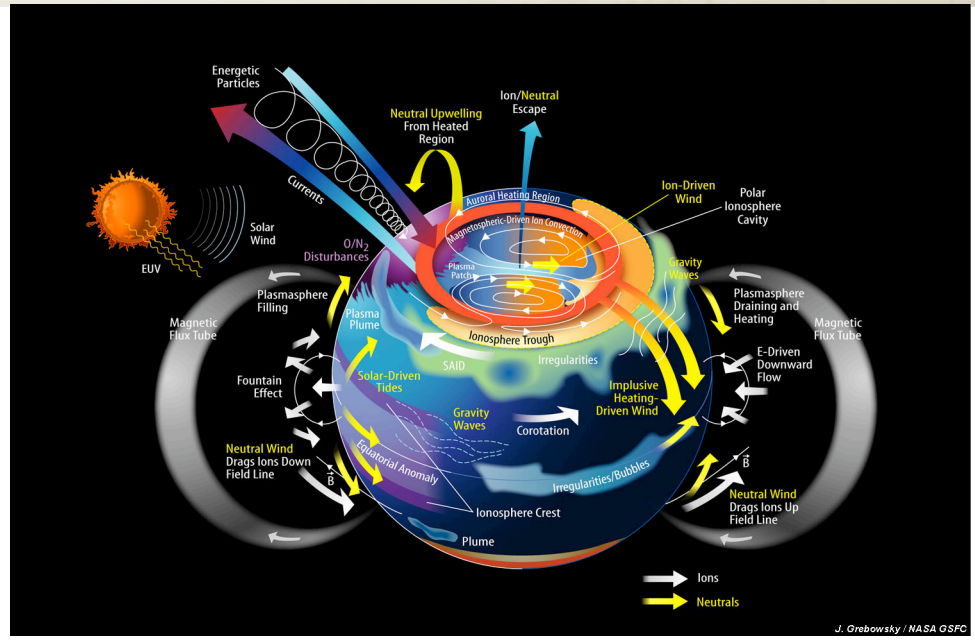
START-IT Could be a Cornerstone Mission for a Joint NASA-DoD-DoC-DoT Cooperative Mission

- START-IT data products could be piped to users in real-time:
  - DoD users at Air Force Weather Agency
  - DoC users at the NOAA Space Environment Center
    - Include power companies and the airlines
  - FAA activities would be supported through NOAA SEC.
  - The principal space weather products are atmospheric drag and ionospheric effects on RF propagation.
- The START-IT instrument can be quite simple as the radiance products can be used as inputs to assimilative models rather than having to produce single-sensor algorithms.
  - This is a new capability that has arisen within the broader I/T community within the last few years.



We've Talked About Many of The Processes in the Coupled IT System and How UV Remote Sensing Can Be Used to Inform Our Exploration of Geospace





FUV remote sensing is a tool that has evolved over the last 35 years.

We have the tools and means in place to address the fundamental processes that shape the ionosphere-thermosphere (I/T) system and connect the I/T to the rest of geospace and the lower atmosphere.

FUV Imaging from the Moon is the Ideal Starting Point for Proving the Value of a Lunar Observatory

- The instruments can be readily designed for the lunar environment – and past performance indicates that they can be used for science as well as operational support.
- The initial infrastructure requirement can be "zero".
  - We can do good and important things with a "suitcase science" approach.
- As more infrastructure becomes available the scalable architecture for Earth observations can take advantage of this.
  - Key issues for a more capable system will be data delivery to Earth and continual operations.
  - Larger aperture provides higher spatial resolution (for a given SNR).
  - Increasing the number of colors imaged improves the products – this may be accomplished by a more complex design.