EN-LoTIS Working Group Town Hall

John McCormack
CEDAR Workshop

2023-06-28

ESA-NASA Lower Thermosphere-Ionosphere Science

https://science.nasa.gov/science-news/NASA_and_ESA_Exploring_New_Joint_Satellite_Mission_Concepts

ENLoTIS Working Group Members	
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Noora Partamies	Univ. Centre in Svalbard, Norway
Gareth Perry	New Jersey Inst. of Technology, USA
Robert Pfaff	Goddard Space Flight Center, USA
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Jeff Thayer	Univ. of Colorado at Boulder, USA
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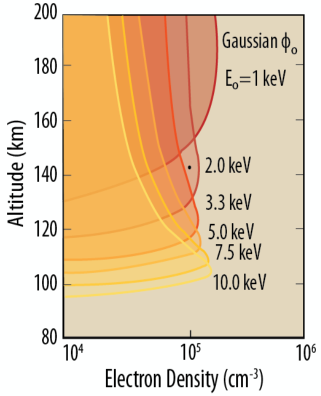
- ❑ EN-LoTIS Working Group explores agency cooperation on future lower thermosphere-ionosphere (LTI) satellite mission concepts, targeting *in situ observations* that advance understanding of neutral-ion interactions from 100 - 200 km altitude and the ionospheric E region.
- ❑ Concept of low-flying LTI mission poses unique scientific & technical challenges. Joint ESA/NASA collaboration proposed to help address these challenges.
- ❑ Initial phase of WG provides information via science study report to help agencies plan possible future joint mission development.
- ❑ **Science study report anticipated by 30 Sep 2023.**
- ❑ **Phase 2 to explore technical aspects (~ Jan 2024)**

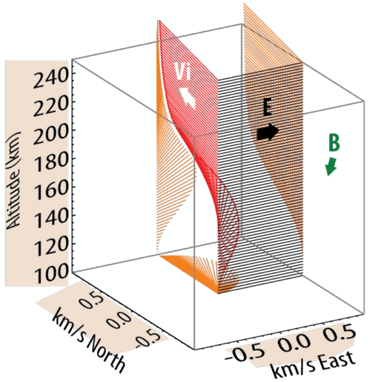
ENLoTIS Steering Committee:
John McCormack, Alex Hoffmann
David Cheney, Larry Kepko, Anja Stromme, Matt Taylor

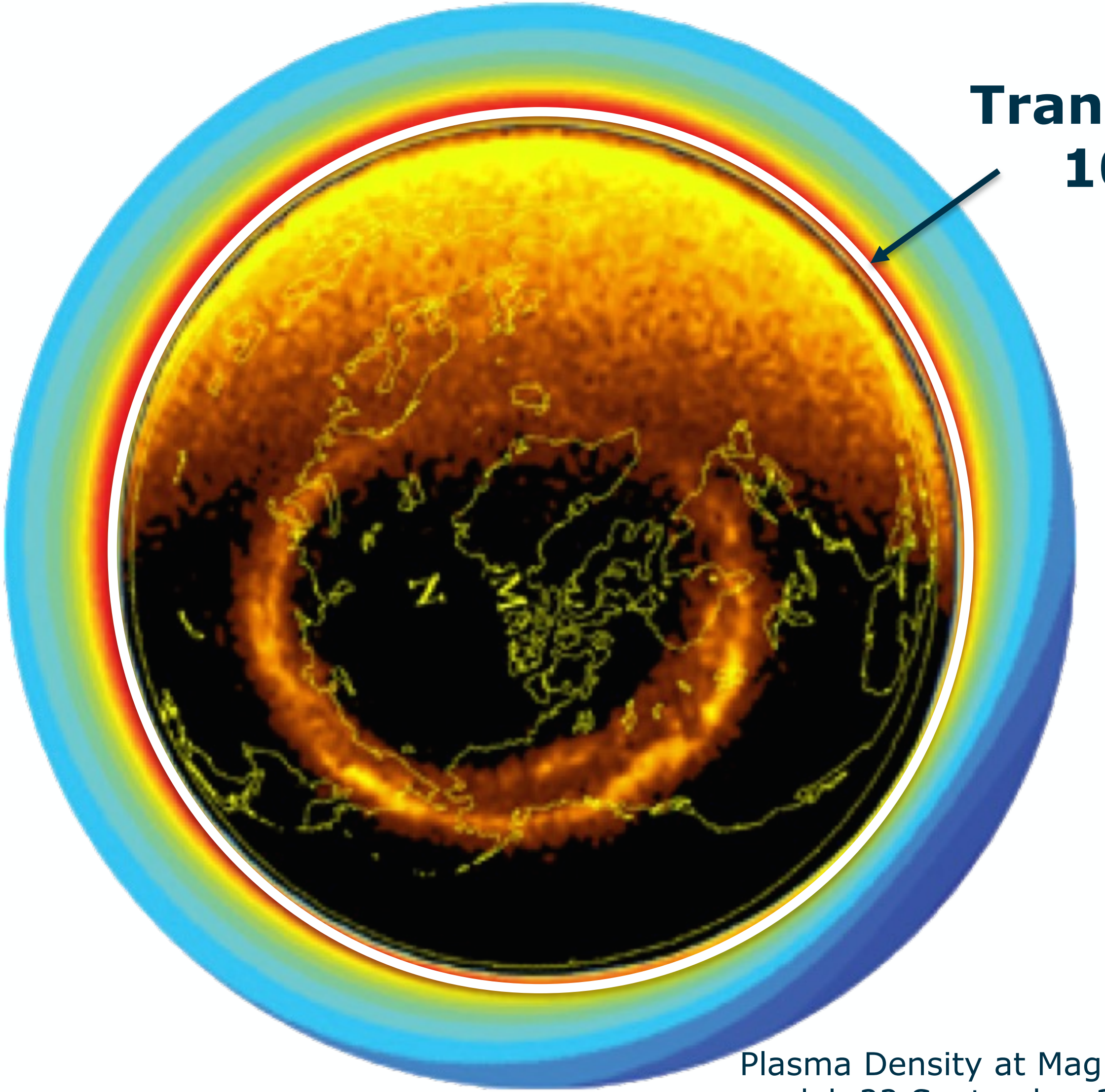
Setting the Scene: Earth's Ionosphere to scale

Thermal Plasma Created by Precipitating Electrons

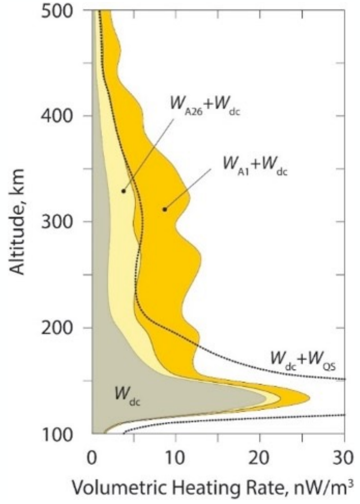


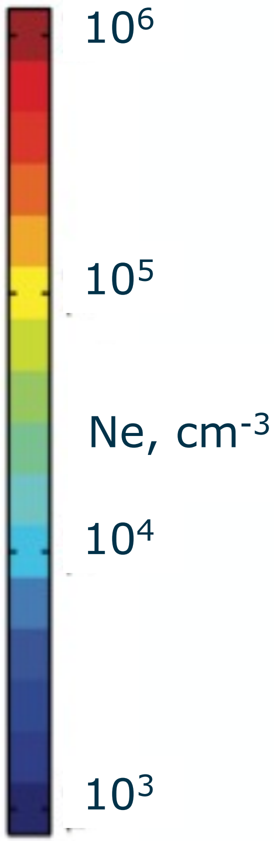
Model Ion Drifts Below 250 km
E = 50 mV/m, East





**Transition Region,
100-200 km**

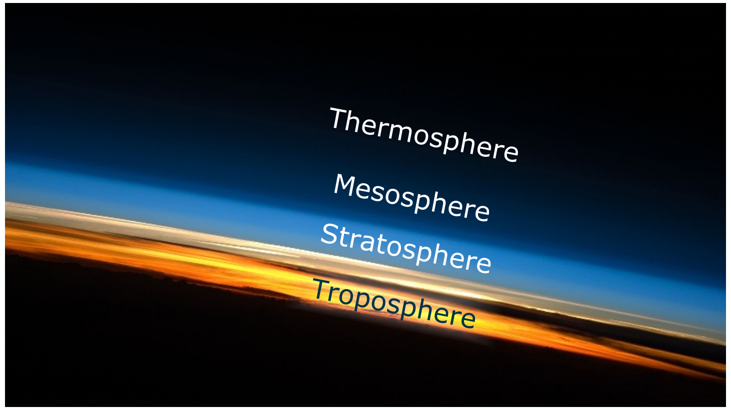




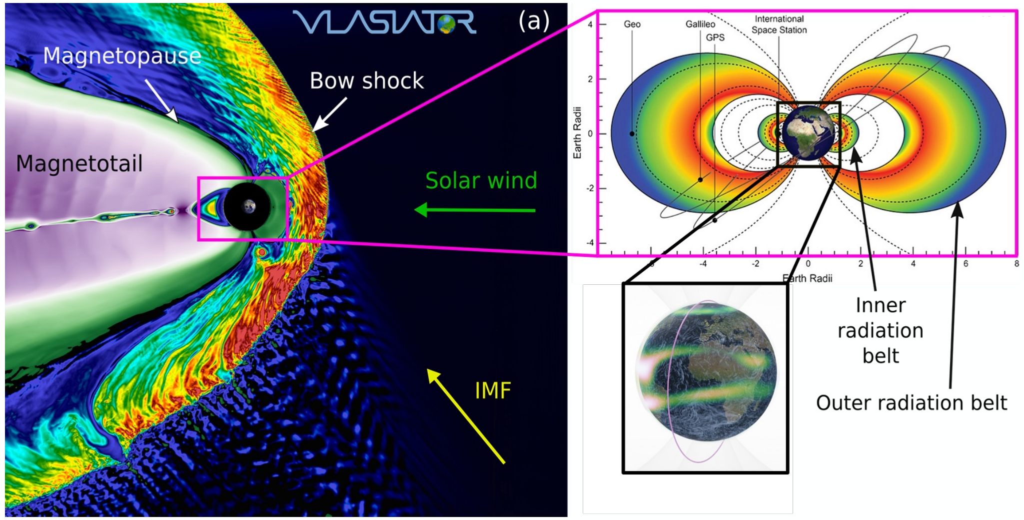
Plasma Density at Magnetic Equator, IRI-2007 model, 22 September 2004. Courtesy R. Pfaff

Why EN-LoTIS?

Inadequate knowledge of the transition from atmosphere to space …



… prevents understanding of how Earth's atmosphere and space are linked



… impedes efforts to understand the Sun-Earth system as a whole

… inhibits accurate predictions of the behavior of humanity's space-faring and space-reliant systems

EN-LoTIS WG is studying first systematic, comprehensive *in situ* exploration of a collision-dominated, neutral-plasma space environment.

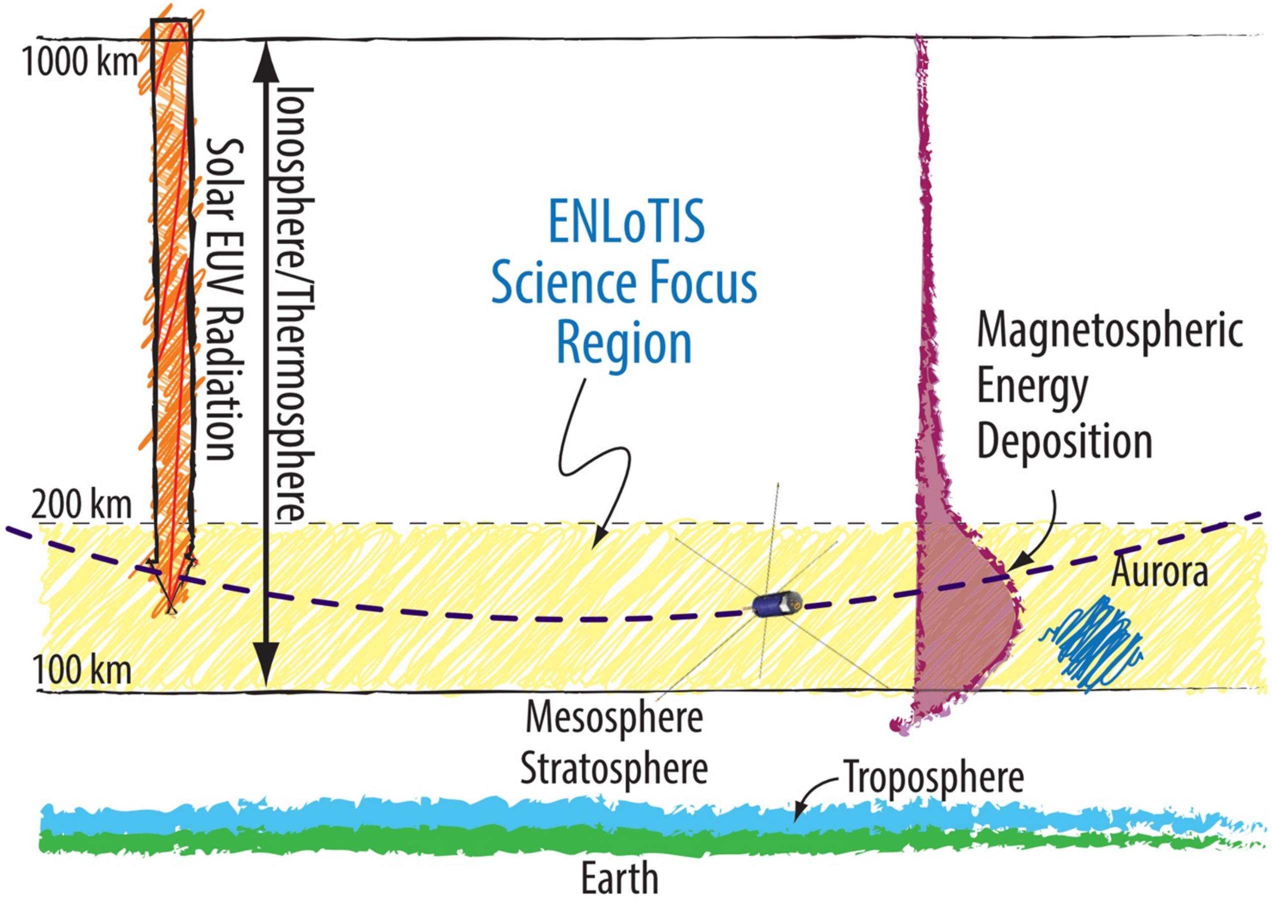
Science of Earth's Lower-Thermosphere-Ionosphere

LTI behavior consists of interactions among commingled matter and fields:

- **Neutral gas (thermosphere)**
- **Plasma (ionosphere)**
- **Electric and magnetic fields**

Frequent collisions between neutral and charged particles results in emergent behavior* not present in simpler systems

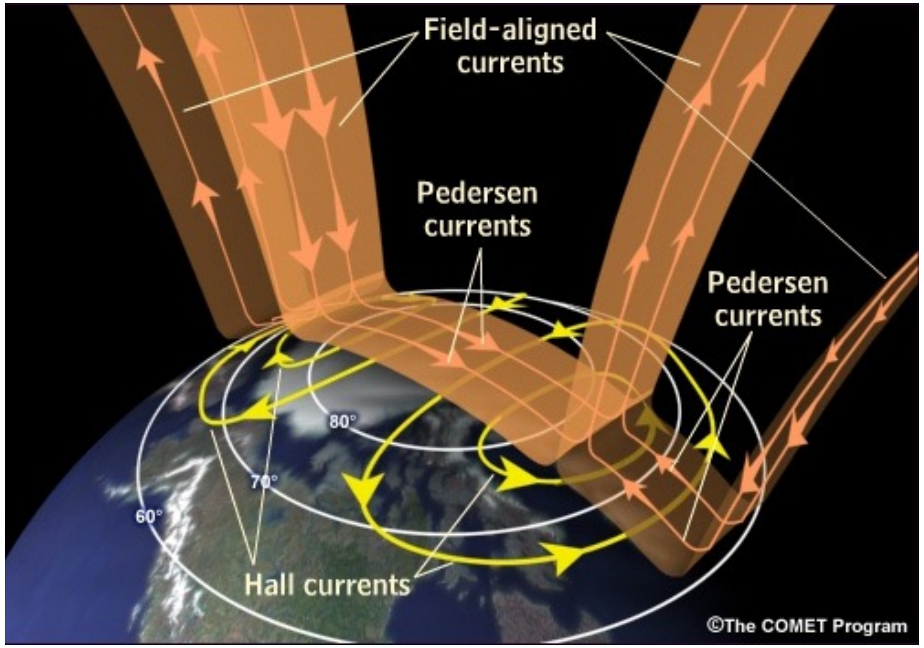
***<u>Global</u>* understanding of LTI behavior has been inhibited by lack of *in-situ, multi-property* measurements**



**Emergent behavior*: Behavior that arises out of the interactions between parts of a system and which cannot easily be predicted or extrapolated from the behavior of those individual parts.

Scientific Motivation

Electrified Geospace: LTI Collisional Electrodynamics (J)



Collisions between neutral and plasma species create emergent behavior in the neutral gas and plasma

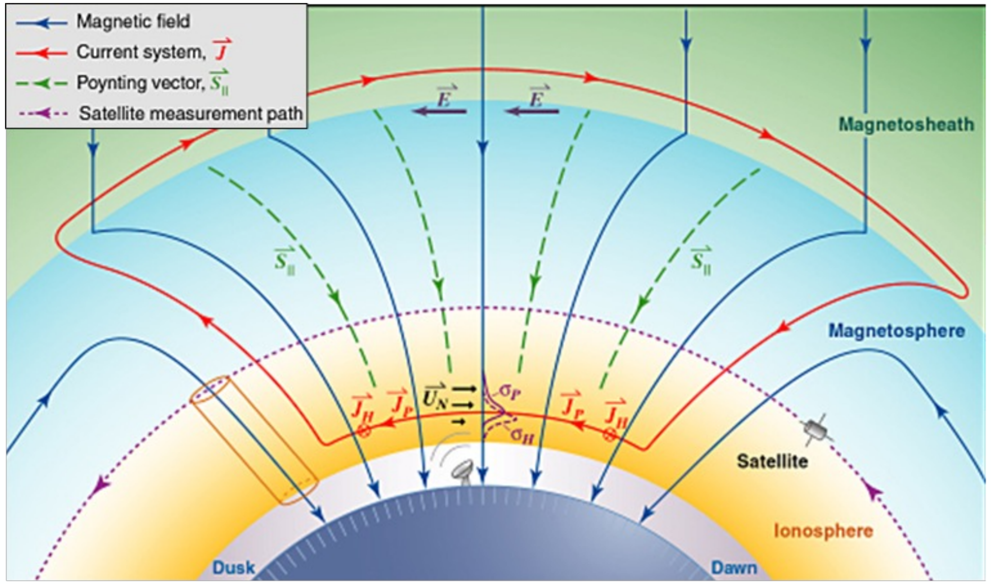
- Collisional electrodynamics give rise to cross-field conductivity, allowing currents to flow across magnetic fields in directions parallel (Pedersen current) and perpendicular (Hall current) to **E**
- Collisional electrodynamics ensure LTI currents close field-aligned currents flowing to and from the magnetosphere

Open questions include: how do LTI currents close in a reactive collisional environment, how is conductivity structured vertically and horizontally, and how do winds alter the electrodynamics?

First high-level objective:
Determine how collisions between neutral and charged species affect the electrodynamics of the LTI.

Scientific Motivation

Electrified Geospace: LTI Collisional Energetics (J·E)



Collisions between neutral and plasma species create pathways for energy conversion

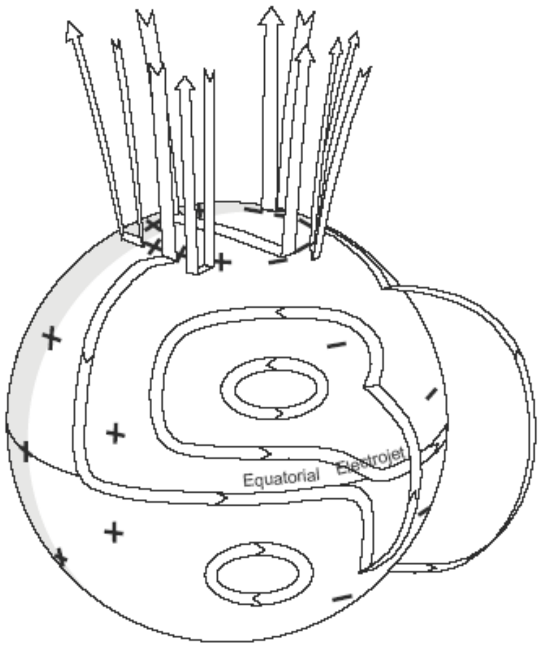
- Collisional heating converts electromagnetic energy to thermal energy
- Collisional heating converts kinetic energy from precipitating particles to thermal energy
- Collisional chemistry determines plasma density and excites neutral species that radiate infrared energy to deep space resulting in LTI cooling

Open questions include: how do Joule and particle heating depend on LTI properties, what are the pathways for heating by energetic particles, and what role does collisional chemistry play in regulating cooling?

Second high-level objective:
Determine how collisions between neutral and charged species affect the energetics of the LTI.

Scientific Motivation

Electrified Geospace: LTI Collisional Dynamics ($\mathbf{J} \times \mathbf{B}$)



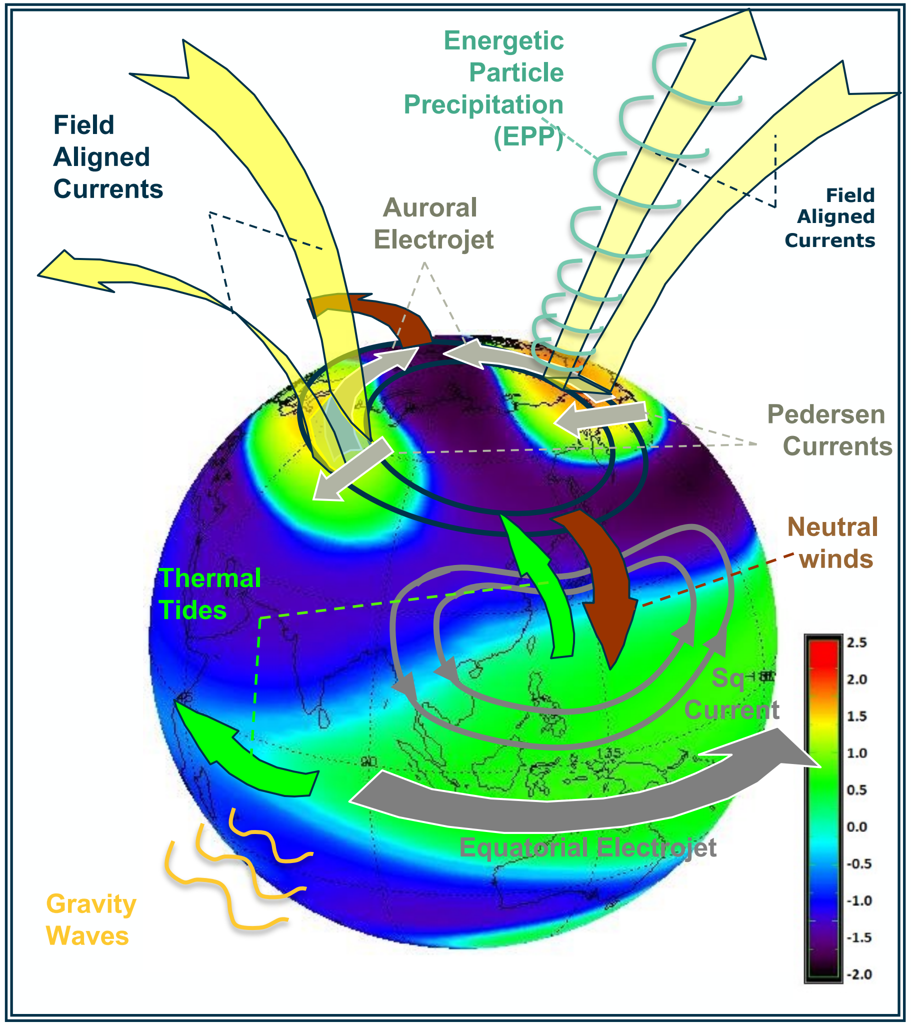
Collisions between moving neutral and plasma species transfer momentum between the two LTI states differently with altitude and location

- Collisional dynamics provides a conduit for neutral gas motion to alter currents and generate electromagnetic fields
- Collisional dynamics impresses atmospheric wave activity on the neutral gas that modifies plasma structuring and dynamics
- Collisional dynamics transports vertically LTI neutral and ion species that impact plasma chemistry

Open questions include: how do winds accelerate plasma motions and create dynamo action, how do lower atmosphere forces influence LTI dynamics, and how do collisions invoke vertical transport and chemical change?

Third high-level objective:
Determine how collisions between neutral and charged species affect the dynamics of the LTI.

Scientific Objectives



To understand how the transition from Earth's atmosphere to space is governed by the fundamental plasma-neutral interactions that are intrinsic to the lower thermosphere-ionosphere (LTI) currents.

1 Collisional Electrodynamics

SO1.1 Determine how electric currents flow and close in the LTI, and thereby couple to the magnetospheric electrodynamics.

SO1.2 Understand how the various LTI properties and processes act to determine the Hall and Pedersen conductivities.

SO1.3. Determine the effect of the neutral winds on the LTI electrodynamics.

2 Collisional Energetics

SO2.1 Determine how Joule (frictional) heating depends on scale size, altitude and neutral winds.

SO2.2 Determine how energy from energetic precipitating particles (EPP) directly heats the LTI.

SO2.3 Determine how plasma-neutral collisions cause chemical changes that affect the energetics of the LTI.

3 Collisional Dynamics

SO3.1 Determine how winds are accelerated by plasma motions via ion-neutral collisions.

SO3.2 Discover how the exchange of momentum across scales by means of lower atmospheric forcing manifest in the LTI.

SO3.3 Determine how collisional processes drive vertical transport and cause composition changes.

Scientific Requirements

Required parameter determinations

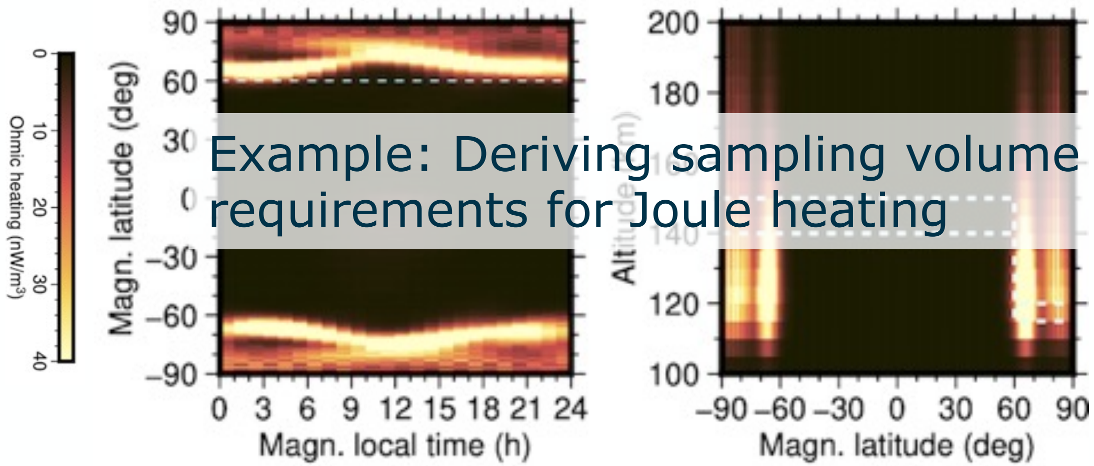
- Directly-measured parameters
- Parameters requiring physical models

	Abbreviation	Geophysical Observable
Ionosphere	$\boldsymbol{v}_i$	Ion Drift velocity
	T_i	Ion Temperature
	T_e	Electron Temperature
	N_i	Ion Number Density
	N_e	Electron Number Density
	TEC	Total Electron Content
	n_{ix}	Ion Composition
thermosphere	$\boldsymbol{u}_n$	Neutral Wind Velocity
	N_n	Neutral Number Density
	ρ	Neutral Mass Density
	a_{ng}	Non-gravitational acceler.
	T_n	Neutral Temperature
	n_{nx}	Neutral Composition
fields	$\vec{B}$	Magnetic Field
	$\vec{E}$	Electric Field
EPP	F_{le}, F_{he}, F_{li}, F_{le}	Energetic Precipitating Particles (ions, electrons)

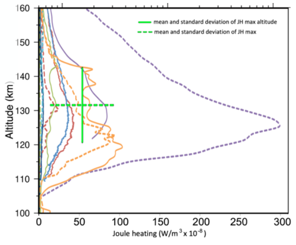
	Derived Quantity
Heating Sources	Joule Heating
	Ohmic Heating
	Frictional Heating
	Poynting Vector
	Energetic Particle Precip. heating
Currents	Perpendicular current (via $\vec{v}_i$, $\vec{v}_e$)
	Perpendicular current (via $\vec{j}_P$, $\vec{j}_H$)
	Magnetic Forcing
	Field Aligned Currents
Conductivities, Cross-Sections	Conductivities
	Ion-Neutral Cross Sections
	Ion-Neutral Collision Frequencies

Required sampling

- Sampling volume
- Sampling timing
- Sampling duration



Example: Deriving sampling volume requirements for Joule heating



Looking Ahead

Next-phase activities to advance an EN-LoTIS mission concept:

- Mission definition and feasibility studies – Definition of an EN-LoTIS mission concept that is optimized to return the most compelling science within future programmatic constraints.
- Risks – Identification and mitigation of “standard” and mission-specific scientific and technical risks.
- Programmatics – Exploration of programmatic pathways by which an EN-LoTIS mission could be realized.

Timeline

2023 July 20-21 – WG Quarterly meeting at ESA/ESTEC.

2023 September – Complete WG initial phase science report: Science definition and high-level observation requirements).

2024 January (TBC) – Kick off next-phase of WG activity, membership to be reviewed at that time.

Questions?

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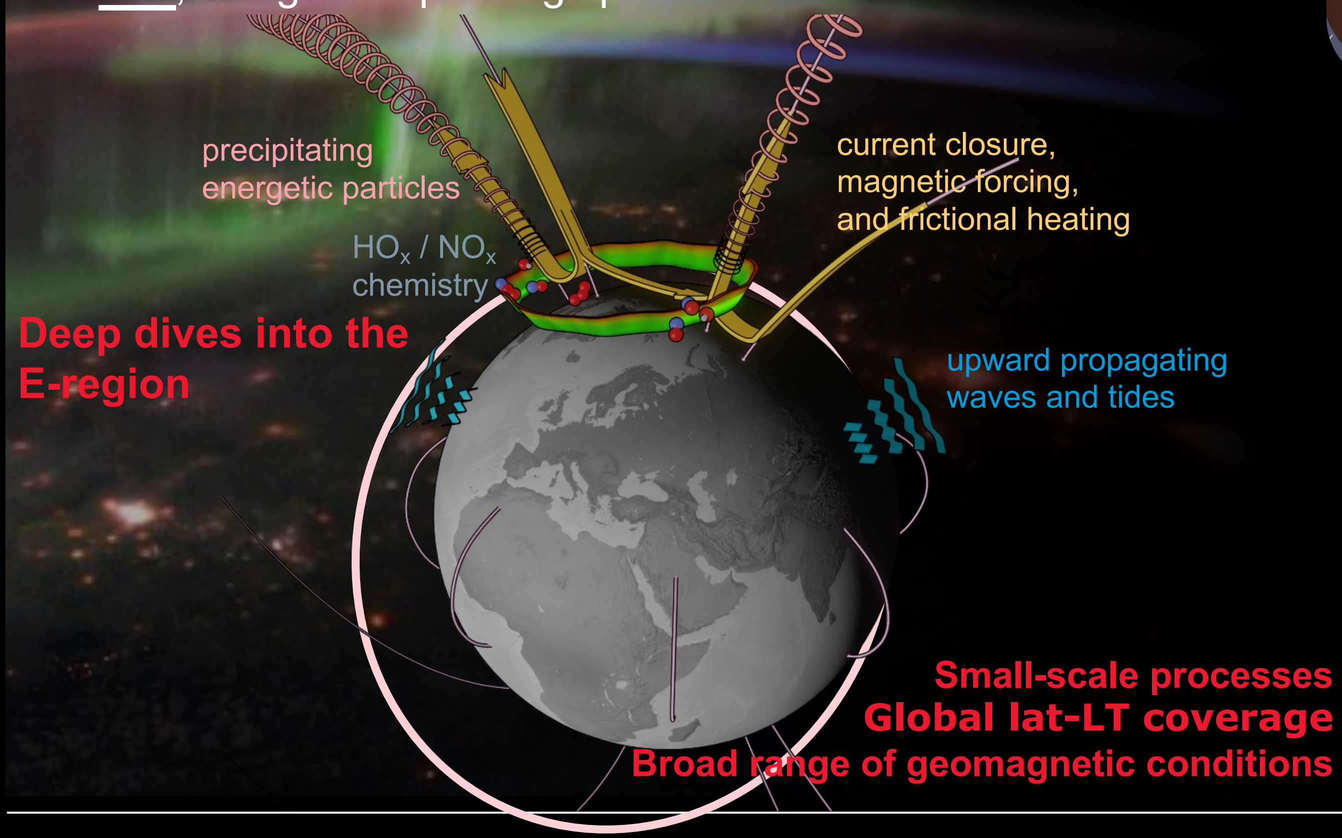
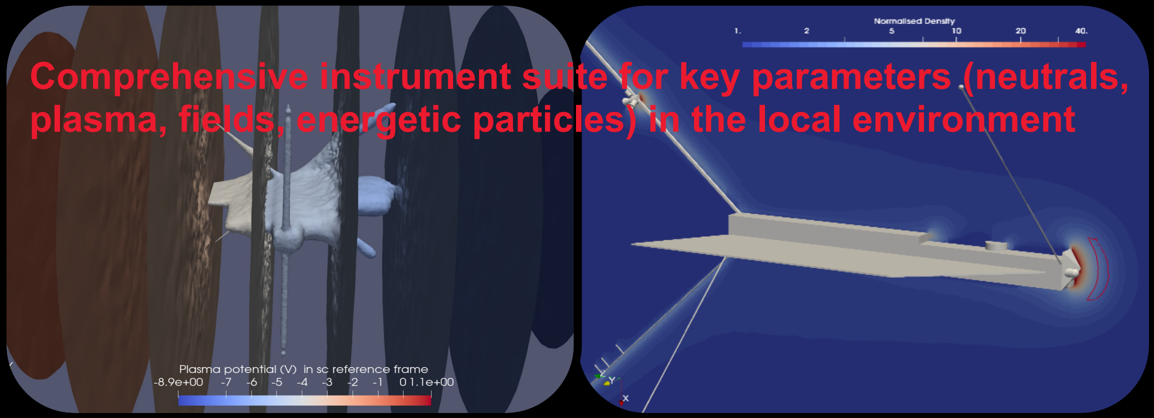
ESA POC: Alex.Hoffmann@esa.int

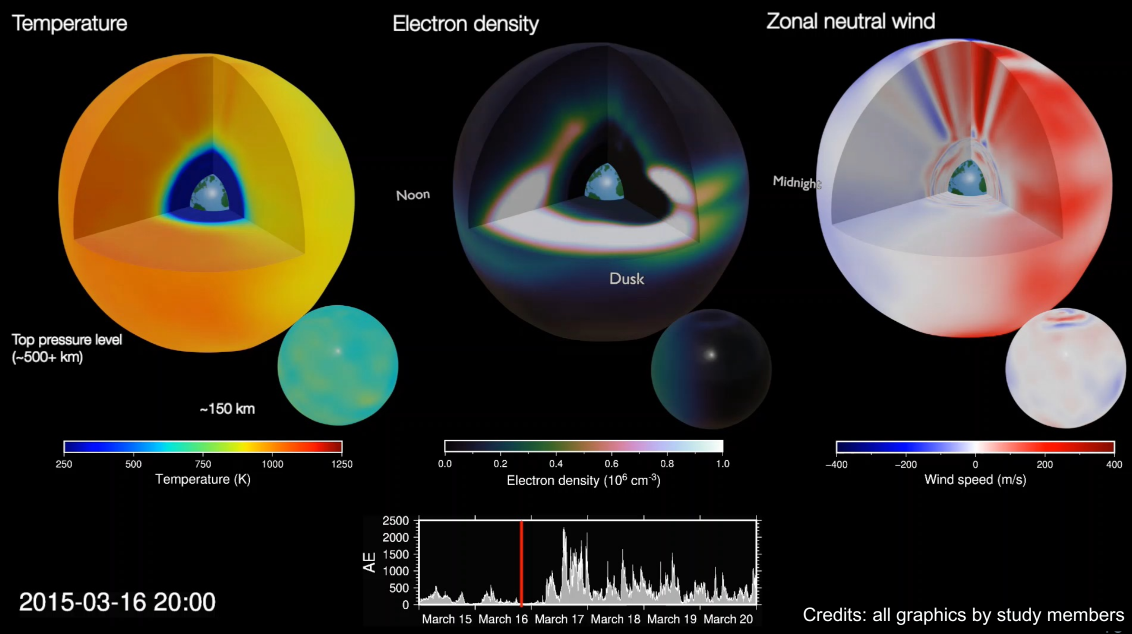
Programmatic context (ESA)

The Daedalus concept, an ESA Earth Observation Programme Earth Explorer 10 mission candidate (Phase 0)

- Targets a better understanding of the ***atmosphere-space*** (thermosphere-ionosphere) ***coupling***, to shed light on key ion-neutral interaction processes affecting structure, energetics, composition and dynamics of the upper atmosphere, by
- Exploring the ***transition region*** (~120 to 200 km altitude) ***<u>in situ</u>***, using a deep diving spacecraft.



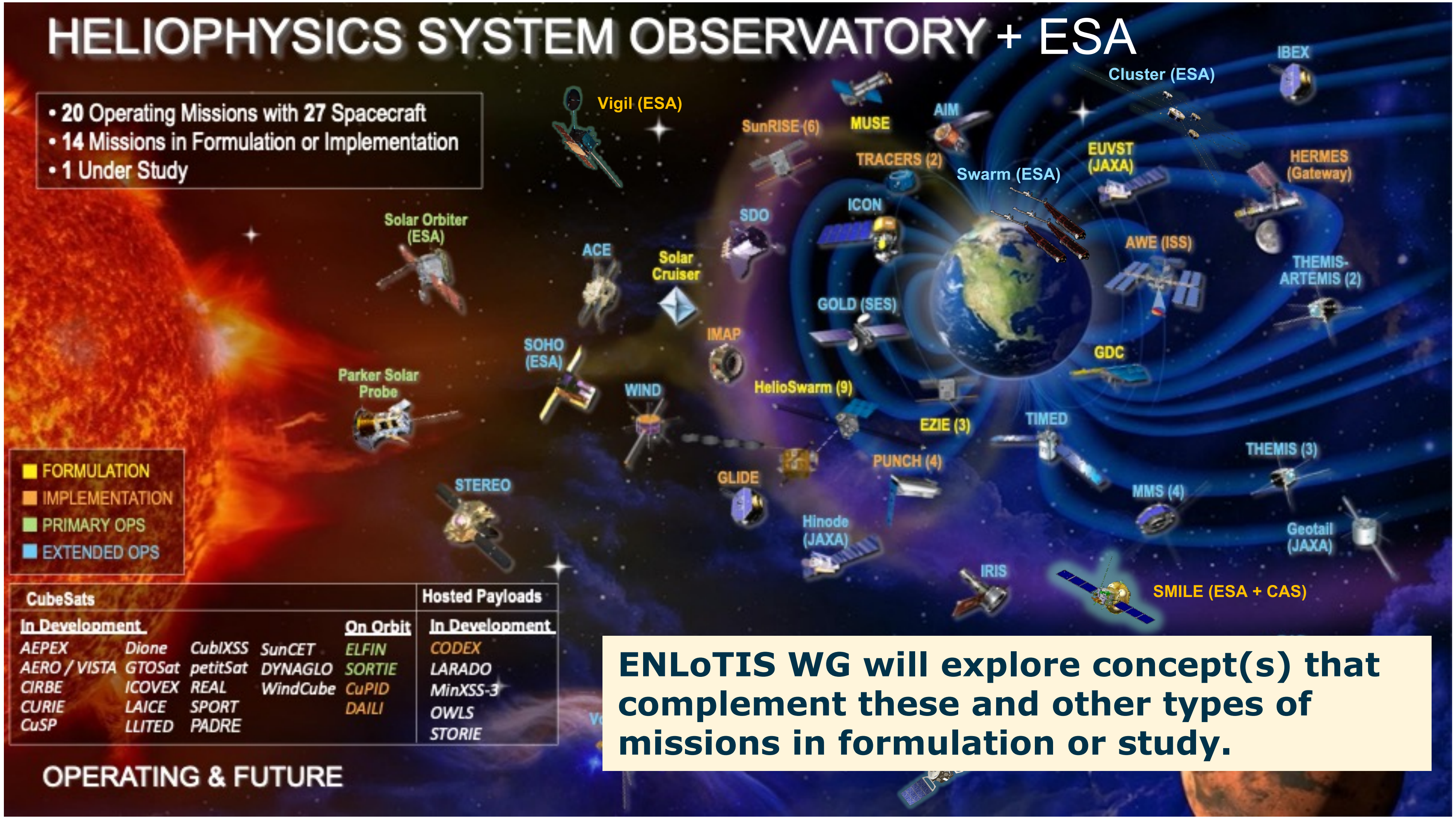




Credits: all graphics by study members

Programmatic context (NASA)

The NASA heliophysics perspective / framework



ENLoTIS WG will explore concept(s) that complement these and other types of missions in formulation or study.

Geospace Dynamics Constellation

Goal 1: Understand how the high latitude T/I system responds to variable solar wind & magnetosphere forcing.

Goal 2: Understand how internal processes in the global ionosphere-thermosphere system redistribute mass, momentum, and energy.

DYNAMIC

Advance understanding of space weather variability driven by lower-atmosphere weather on Earth using small spacecraft that can launch as a rideshare with the GDC mission.

S/C altitudes > 350 km

The WG enables ESA-NASA cooperation on future LTI satellite mission concepts by:

a) Reviewing and consolidating **consensus science questions or goals, mission objectives, and high-level mission requirements** that would inform the eventual definition and design of (a) future mission concept(s)

→ Not starting from "blank slate" – leverage knowledge from past and current mission studies

→ Input/feedback from research community throughout initial phase will be key

→From Heliophysics perspective, initial phase of ENLoTIS WG would resemble an "SDT" or Science Definition Team.

b) Identifying **scientific and technical challenges and constraints** associated with these high-level requirements from *(a)* in view of facilitating trade-offs and identifying candidate measurements.

→ Balancing science and feasibility – how low should we go vs. how low can we go?

c) Coordinating with **on-going and planned activities** between NASA & ESA supporting (a) and (b)