Space Weather Imaging by the EPIC Small Explorer Mission

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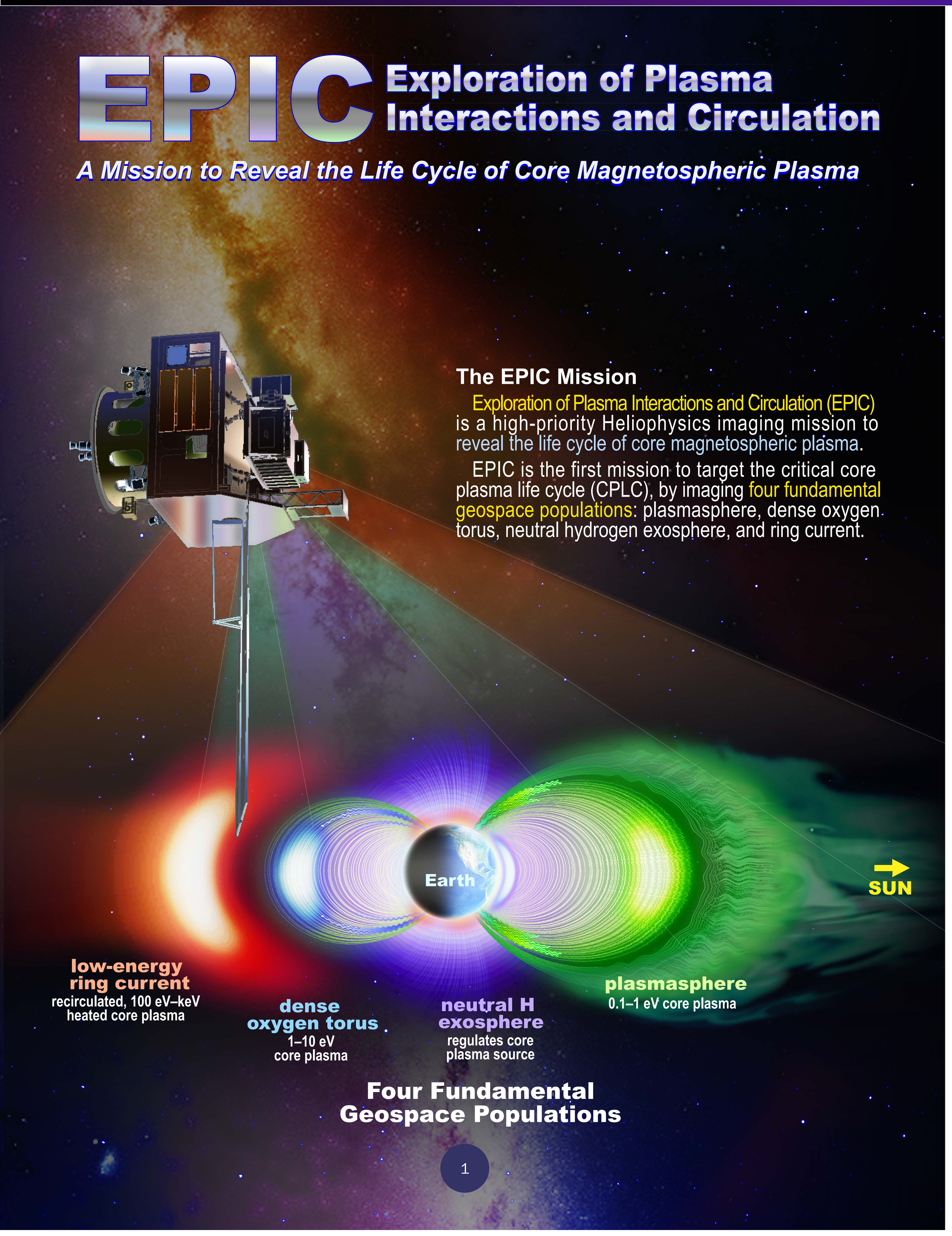

The EPIC Mission

Exploration of Plasma Interactions and Circulation (EPIC) is a high-priority Heliophysics imaging mission to reveal the life cycle of core magnetospheric plasma.

EPIC is the first mission to target the critical core plasma life cycle (CPLC), by imaging four fundamental geospace populations: plasmasphere, dense oxygen torus, neutral hydrogen exosphere, and ring current.

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Science Goal: Reveal the life cycle of core magnetospheric plasma

What is Core Plasma?

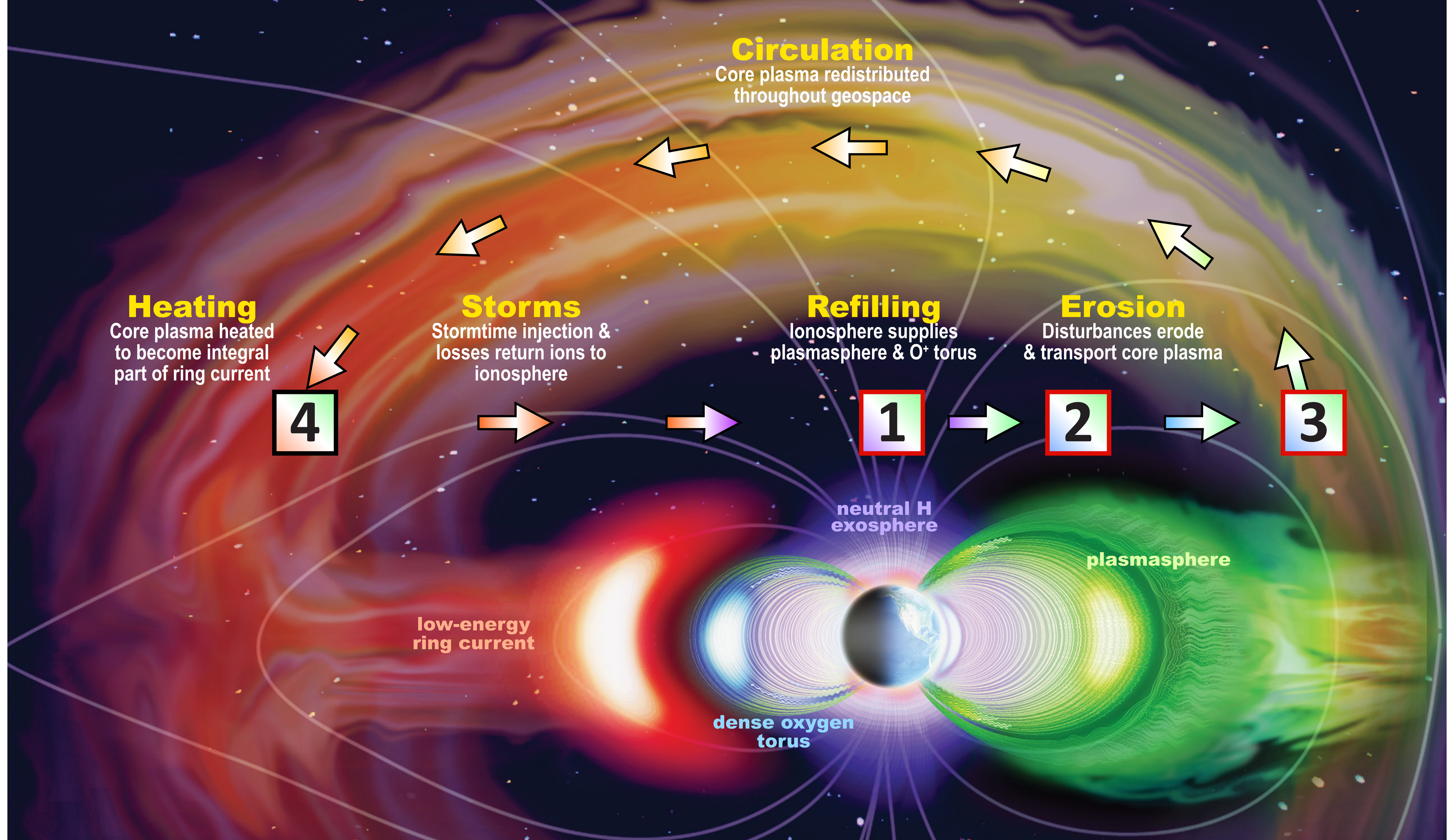
CORE PLASMA is a fundamental magnetospheric population comprising the majority of the magnetosphere's mass, 10^2–10^3 metric tons.

Core plasma is initially cold (<10 eV) within the plasmasphere and oxygen torus. During storms it is transported throughout geospace and heated to 100 eV – keV energies.

Life Cycle of Core Plasma

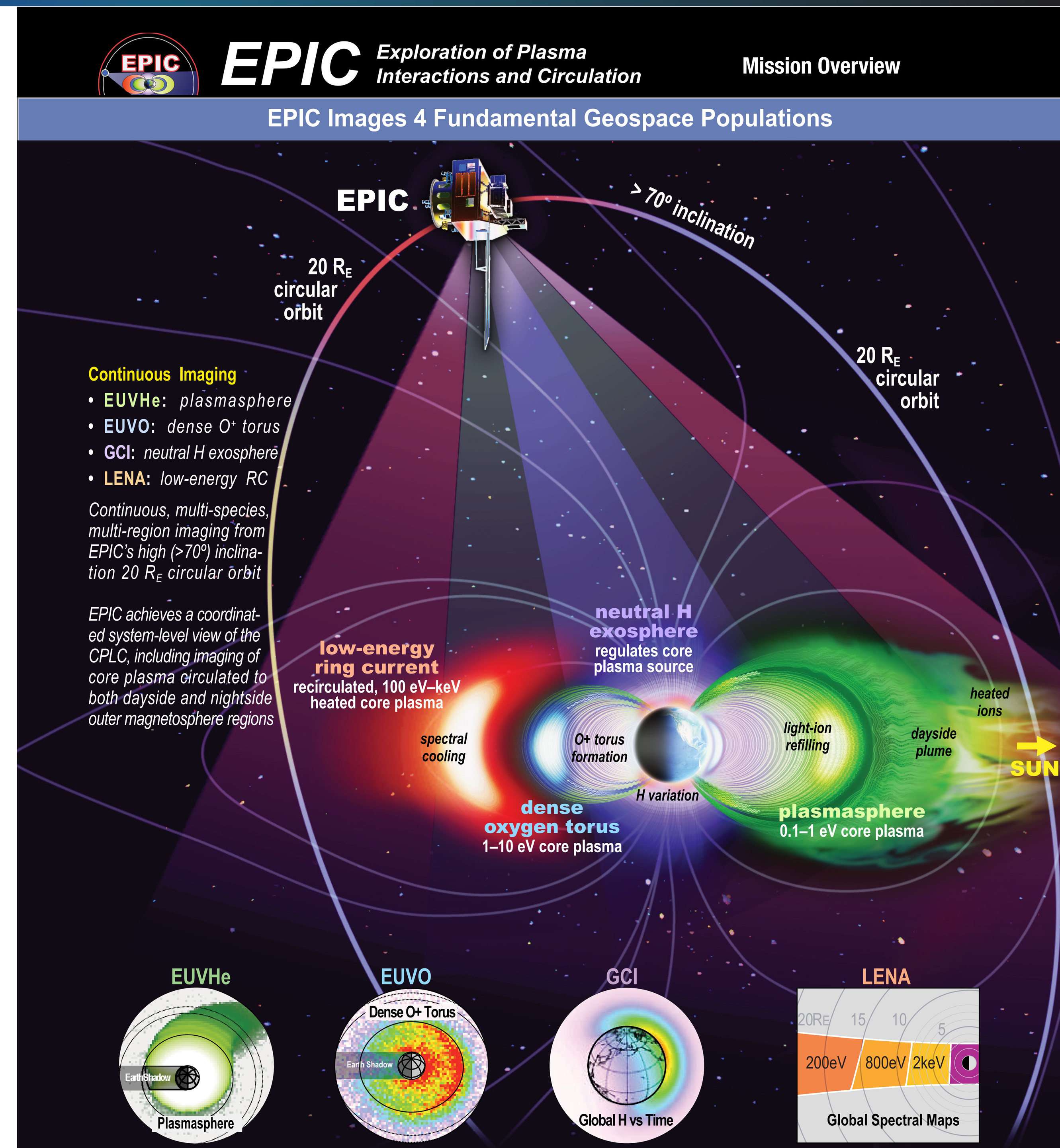
The core plasma life cycle (CPLC) is the episodic recycling of a vast plasma mass in near-Earth space. This cycle exerts control over numerous basic processes—as fundamental to geospace dynamics as solar-wind driving.

After decades of successful focus on other critical elements of geospace, the CPLC remains one of the big knowledge gaps in magnetospheric physics.



CPLC: Ionosphere to Core Regions, Then Circulation and Heating

1. **Refilling.** Core plasma comes from the ionosphere—regulated by exospheric ion-neutral interactions that control the upward H^+ and He^+ escape rate, and by heating that controls O^+ escape. Core plasma starts out very cold, and initially resides in the **core regions**, the plasmasphere and oxygen torus.
2. **Erosion.** During every geomagnetic disturbance, tens to hundreds of metric tons of near-Earth core plasma are rapidly eroded away, then slowly and unevenly replenished from the ionospheric source.
3. **Circulation.** Eroded core plasma can recirculate through geospace, exerting a profound effect on numerous basic processes throughout the system.
4. **Heating / Storms.** As it is heated during its journey, core plasma can add significantly to the hotter plasmas supplying geospace storms. Heated ions precipitate back into the ionosphere, completing the cycle.



- **Plasmasphere:** first continuous 30.4 nm plasmaspheric He^+ imaging with 0.16 R_E resolution and < 2 min cadence
- **Oxygen Torus:** first-ever 83.4 nm oxygen ion imaging to finally observe its formation and global distribution
- **Exosphere:** high-resolution (200 km) images of neutral H that controls core light-ion plasmasphere refilling
- **Low-Energy Ring Current:** macroscale dynamics of ENA spectra to measure how core ion recirculation feeds storms
- EPIC also demonstrates the first plasmaspheric TEC measurement by high-altitude, space-based GPS receiver

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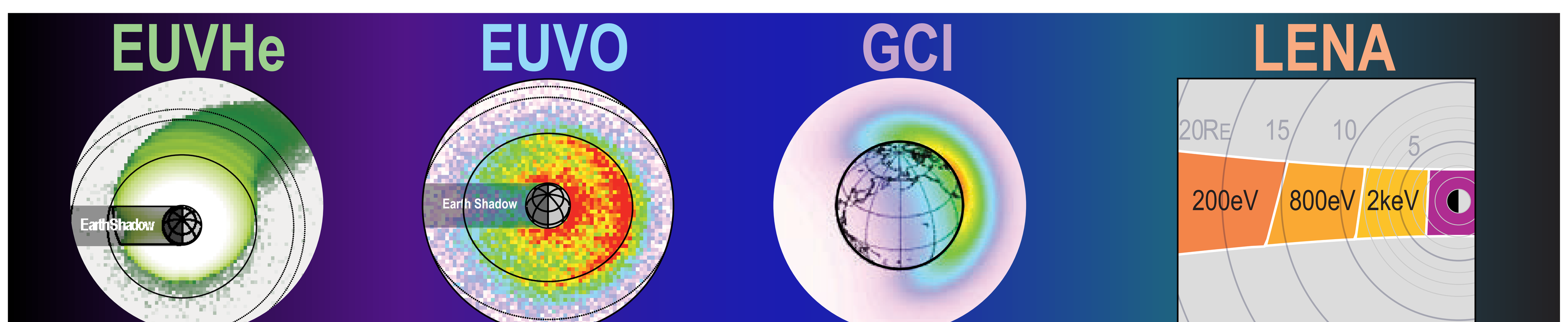

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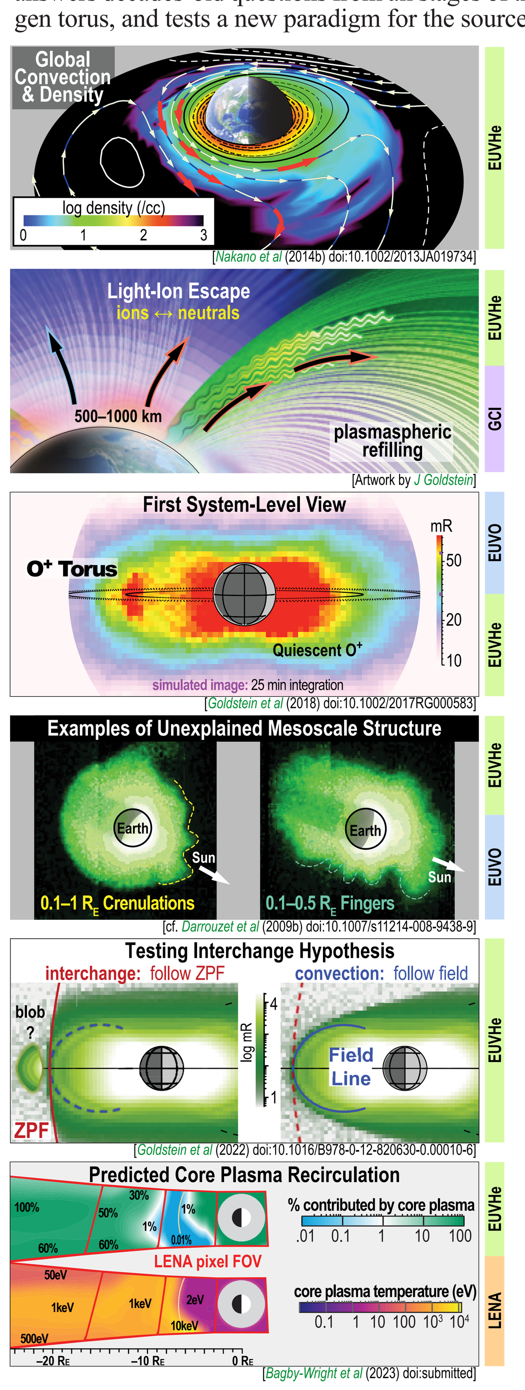
Bridging the CPLC Knowledge Gap

The core plasma life cycle (CPLC) remains a big knowledge gap in Heliophysics. To narrow the gap, EPIC answers decades-old questions from all stages of the CPLC. EPIC explains refilling, erosion, and the dense oxygen torus, and tests a new paradigm for the source of hot plasma in geospace storms.



How is the plasmasphere replenished? (Part 1) EPIC makes the first continuous observations of true field-line refilling, that is, tracking refilling along plasmaspheric convection drift paths. State-of-the-art EUVHe image inversions achieve a robust, continuous, true measurement of refilling—and determine field-aligned distributions—to finally understand its stages (early versus late).

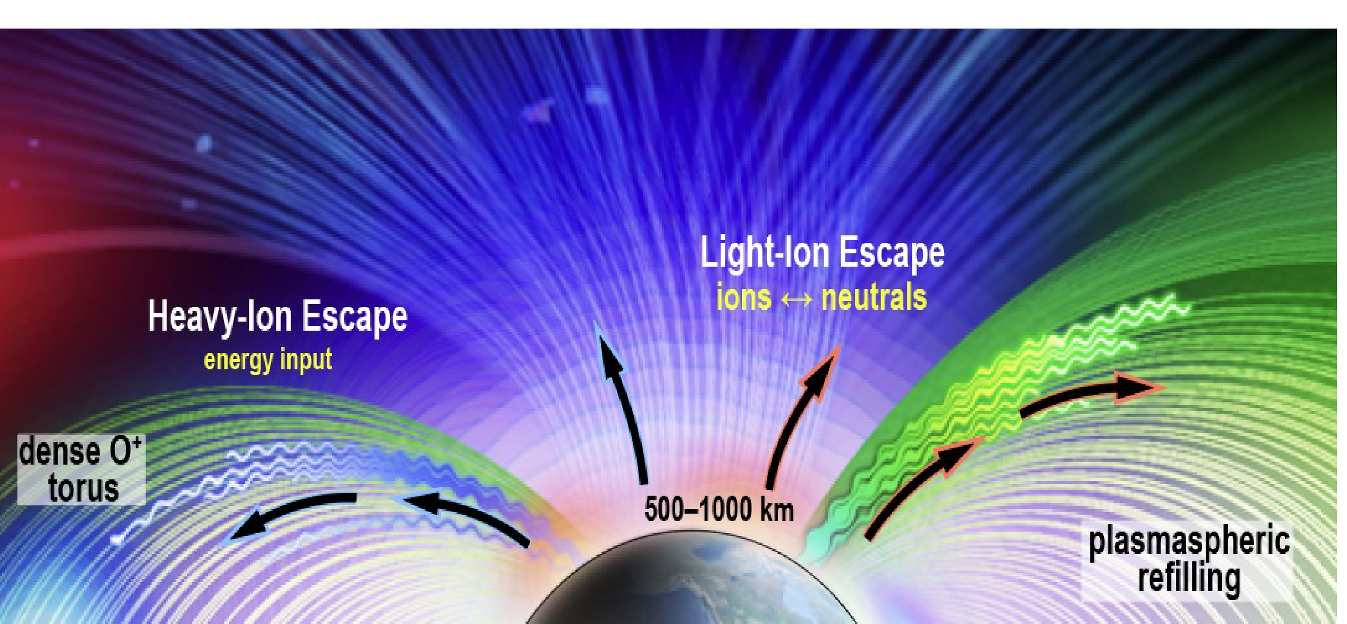
How is the plasmasphere replenished? (Part 2) In models, the neutral H exosphere is the strongest regulator of upward ionospheric H^+ escape flux, via the reaction $H + O^+ \leftrightarrow H^+ + O$. We lack critical low-altitude (<4,000 km) observations of neutral H variability that can strongly impact H^+ and He^+ refilling rates. EPIC GCI images this near-Earth H variability and EUVHe measures its effect on refilling rates.

What causes the dense oxygen torus? EPIC provides the first system-level observations to answer this enduring question. EUVO images capture O^+ torus global structure and dynamics, to establish its timing and global pathways. EUVHe flows reveal convective drivers. EPIC enables first discovery of the still-unknown torus morphology—symmetric or asymmetric, dayside or nightside peak, and distribution versus latitude.

How does convection redistribute core plasma? Despite decades of studying the convection field, we still do not understand the cause of many basic mesoscale plasma structures. EPIC EUVHe images enable a long-awaited, true accounting of core plasma transport and loss during erosion, and EUVO shows how O^+ ions participate. EPIC's polar *and* side-view images enable determination of new transport processes.

What role does interchange play in erosion? For decades, we have lacked observations needed to determine whether the centrifugal interchange instability (CII) controls erosion. The CII hypothesis predicts a plasmapause shape different than that of the dominant convection paradigm. In the CII model, the boundary follows the zero-parallel force (ZPF) surface, instead of magnetic field lines. EPIC EUVHe will finally test this paradigm-shifting CII hypothesis.

Does recirculated core plasma feed storms? Research has long suggested that heated, recirculated core plasma can supply the stormtime plasma sheet and ring current (RC). A key signature of recirculation is the delayed arrival in the RC of cooled ions (1 keV or less). EPIC makes coordinated, system-level observations of the plasmasphere (with EUVHe) and low-energy RC (LENA) to answer this question about basic understanding of geospace stormtime dynamics.



EPIC Space Weather Imaging

Exploration of Plasma Interactions and Circulation (EPIC) continuous, multi-region imaging is also extremely well suited to space weather monitoring/backcasting that can greatly improve predictive models.

EUVHe: Continuous 30.4 nm EUVHe plasmaspheric He+ imaging provides a global monitor of the coldest plasma, a population with several big space weather effects:
(1) it controls the waves that can increase or decrease the outer radiation belt,
(2) it reduces spacecraft charging, and
(3) it enables estimation of inner magnetospheric convection.

EUVO: The first-ever 83.4 nm EUVO oxygen ion imaging will finally observe the formation and global distribution of the dense oxygen torus whose mass loading controls the Alfven speed, fundamental to magnetosphere-ionosphere coupling and reconnection that govern a wide range of space weather effects.

GCI: A high-resolution (200 km) geocoronal imager (GCI) captures the neutral H exosphere that affects atmospheric escape, and charge exchange that is a major controller of storm duration.

LENA: Low-energy neutral atom (LENA) imaging captures the macroscale dynamics of ENA spectra to measure how core ion recirculation feeds storms.

Core plasma is an essential and central component of geospace weather. EPIC improves prediction of extreme conditions driven by the many CPLC-affected plasmas and phenomena throughout geospace.

EPIC's science and space weather impacts are <u>cross disciplinary</u>, targeting a plasma population whose origin is ionospheric, whose home is the inner magnetosphere, and whose fate is to be circulated to the outer magnetosphere, both dayside and nightside.

- Ionosphere and Thermosphere Research and Applications
- Geospace/Magnetosphere Research and Applications

Science Objectives & Questions

EPIC uses improved technology to make new coordinated imaging measurements that distinguish the various mechanisms proposed as CPLC drivers, and discriminate among competing hypotheses.

(1) Determine how core plasma is supplied and replenished
1A *How is the plasmasphere replenished?*
1B *What causes the dense oxygen torus?*

(2) Understand how core plasma is eroded and recirculated throughout geospace during storms
2A *How does convection redistribute core plasma?*
2B *What role does interchange play in erosion?*
2C *Does recirculated core plasma feed storms?*

EPIC is an innovative SMEX mission. Its science is cross disciplinary, targeting a plasma population whose origin is ionospheric, whose home is the inner magnetosphere, and whose fate is to be circulated to the outer magnetosphere, both dayside and nightside. EPIC's "system-of-systems" approach spans four cardinal geospace populations, each worthy of its own SMEX mission. EPIC explores plasma interactions and circulation for the entire CPLC: its source in low-altitude ion-neutral exchange, its core dynamics, and its transformation and transport.

Scientific Importance

Why Refilling? This fundamental process populates geospace with hundreds of metric tons of plasma—the dominant source of mass/inertia in the magnetosphere.

Why EPIC? Continuous EUVHe imaging of the real-time distribution of core He^+ gives quantitative, system-level data needed to track density changes within moving flux tubes. New EUVO images yield the very first global view of the dense oxygen torus. GCI neutral H imaging yields critical constraints on ion-neutral interactions in the low- altitude source region.

Why Erosion? Erosion strips away tens of tons of plasma in a few hours. An unknown fraction of this vast mass is recirculated and heated, fundamentally altering geospace inertia and possibly fueling storms.

Why EPIC? EUVHe image analysis yields a huge advance: a true accounting of stormtime plasma transport and loss. EUVHe meridional imaging of the plasmapause shape finally answers the question of what causes erosion. LENA temperature maps and spectral analysis establish causal links to storm strength and timing—a potential paradigm shift for the source of stormtime RC ions.

EPIC is a high-priority SMEX mission offering major contributions to NASA Heliophysics Goals. After decades of successful focus on other critical elements of geospace, further progress in magnetospheric physics requires a mission dedicated to the core plasma life cycle (CPLC).

Core Plasma Importance. Core plasma comprises the majority of the magnetosphere's mass, 10^2–10^3 metric tons. The CPLC is the episodic supply, removal, and recirculation of a vast plasma mass—a fundamental element of geospace dynamics that exerts control over many basic processes: (a) Alfvén waves, energy propagation, and M-I coupling; (b) wave properties affecting radiation belt electrons; (c) scattering and energy degradation of ring current ions; (d) mass loading of magnetic reconnection and solar wind coupling; and (e) charge exchange reactions that control atmospheric escape.

Critical Gap: The Core Plasma Life Cycle. The life cycle of this enormous plasma mass is as important to geospace dynamics as solar-wind driving, yet it is one of the biggest knowledge gaps. The gap spans both supply and erosion/recirculation elements of the cycle. To narrow this enduring gap, EPIC achieves 2 critical science objectives covering all stages of the CPLC. EPIC answers decades-old questions about supply, removal, and recirculation of core plasma. EPIC explains refilling, erosion, and the dense oxygen torus, and tests a new paradigm for the source of hot plasma in geospace storms.

NASA Heliophysics. EPIC explores fundamental, universal processes (NASA Heliophysics Goal HG-1) and elucidates connections of coupled geospace phenomena (HG-2). It improves prediction of extreme conditions driven by the many CPLC-affected plasmas (HG-3). EPIC also advances still-open goals of the last *Decadal Survey*. The core plasma component remains a knowledge gap on the eve of the next Decadal Survey. Progress in magnetospheric physics requires closing this gap.