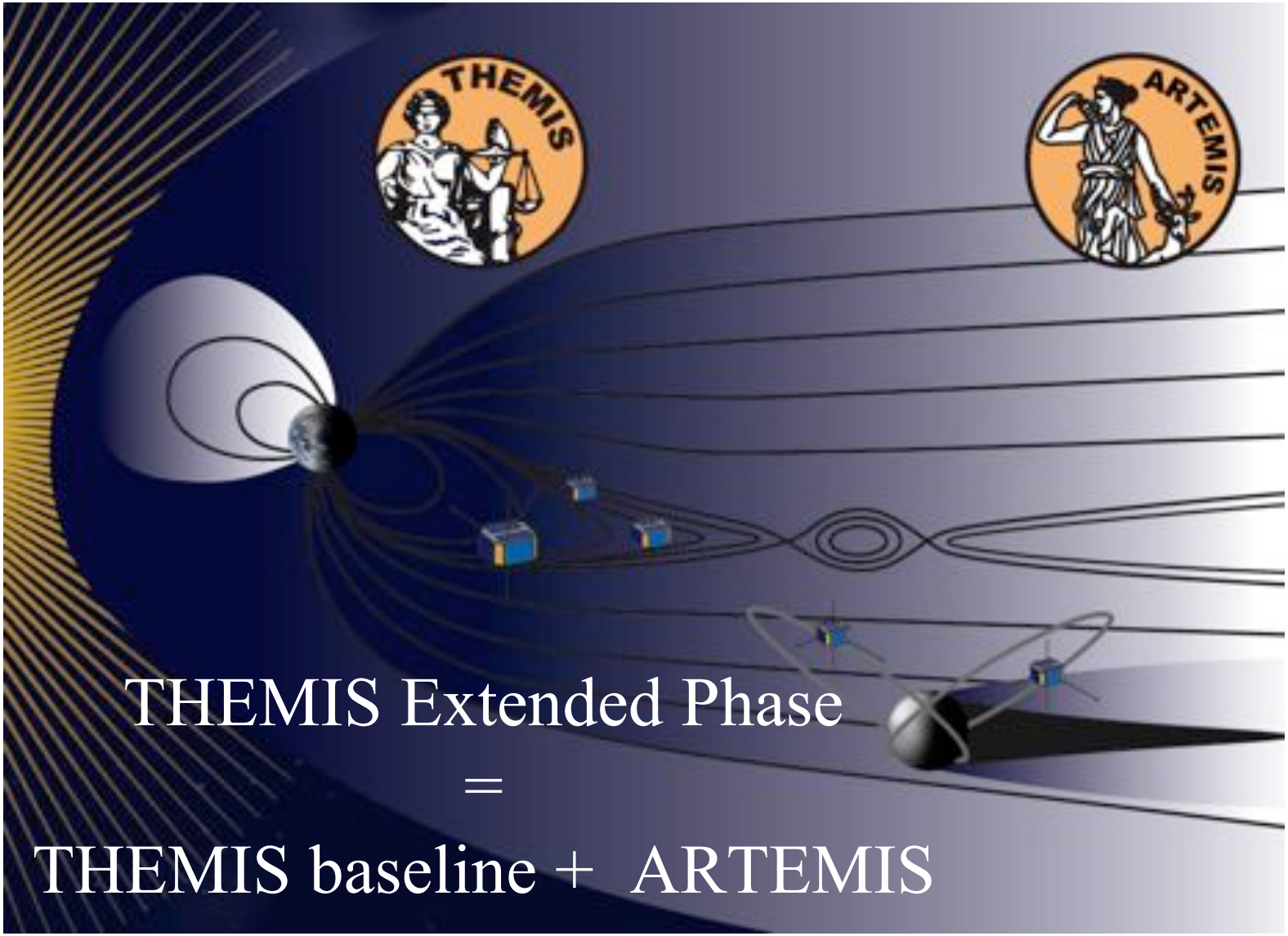
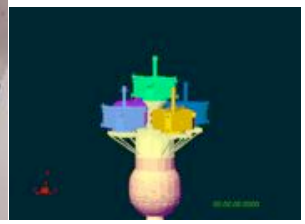
ARTEMIS Lunar Exploration



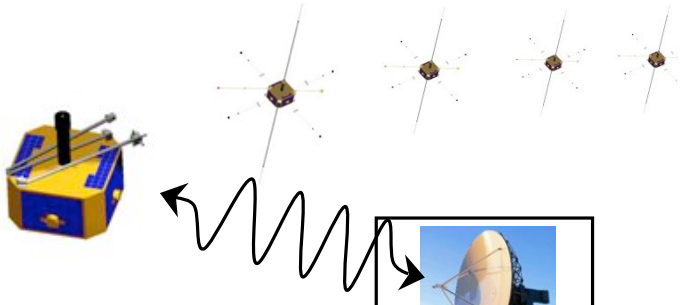
Introduction

- THEMIS is a five spacecraft Heliospheric mission in the Midsize Explorer (MIDEX) program and was launched on February 17, 2007 to resolve one of the oldest mysteries in space physics:
    - Determine what physical process in near-Earth space initiates the violent eruptions of the aurora that occur during substorms in the Earth's magnetosphere.
- The prime mission has already concluded successfully with major findings on aurorae, magnetic substorms, killer electrons and storms.
- NASA approved a three year extension of the mission FY10 through FY12.
    - Continues original THEMIS baseline (3 probes)
    - Pursues new objectives in lunar orbit (ARTEMIS, 2 outermost probes)
    - ARTEMIS was born of necessity to save the outermost probe from certain death from long duration earth shadows starting in mid 2010.
- ARTEMIS stands for Acceleration Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun and has both Heliospheric and Planetary objectives.

Mission overview: Constellation in excellent health

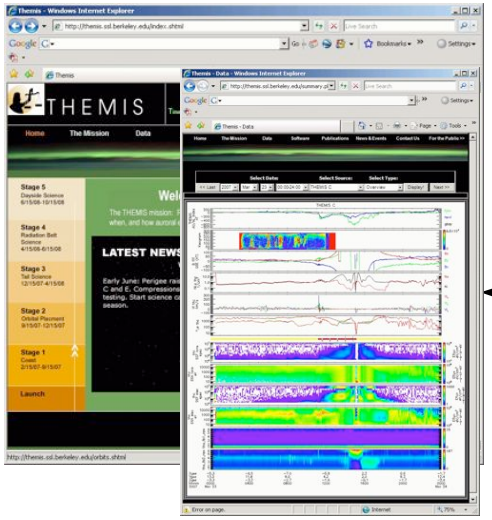


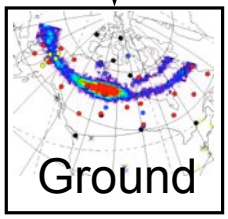
Release



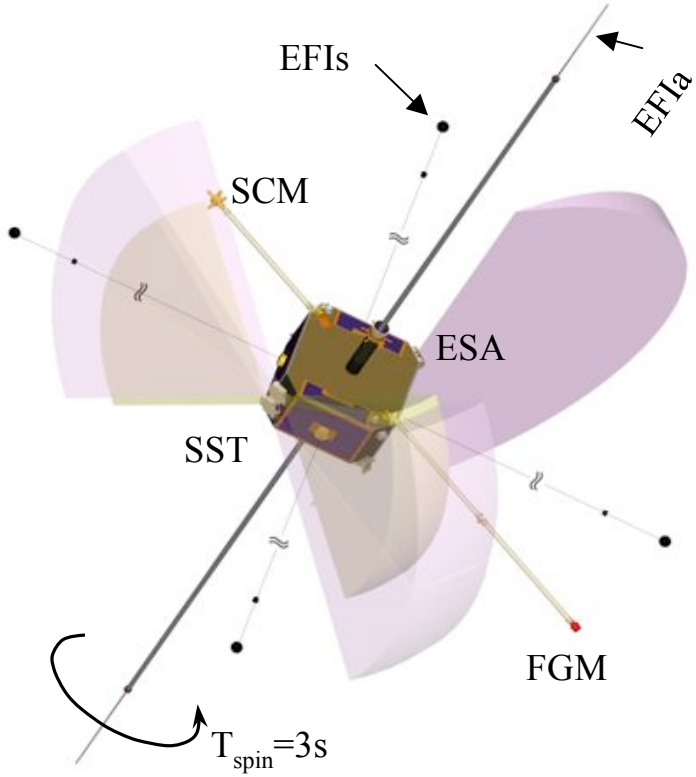
BGS

Mission Ops
UCB





Ground



Probe instruments:

ESA: ElectroStatic Analyzer
(cols: *Carlson and McFadden*)
SST: Solid State Telescopes (col: *Larson*)
FGM: FluxGate Magnetometer
(cols: *Glassmeier, Auster & Baumjohann*)
SCM: SearchCoil Magnetometer (col: *Roux*)
EFI: Electric Field Instrument (col: *Bonnell*)

PRIME MISSION (FY08 - FY09) SCIENCE GOALS:

Primary:

"How do substorms operate?"

– One of the oldest and most important questions in Geophysics

– A turning point in our understanding of the dynamic magnetosphere

RESOLVING THE PHYSICS OF ONSET AND EVOLUTION OF SUBSTORMS

First bonus science:

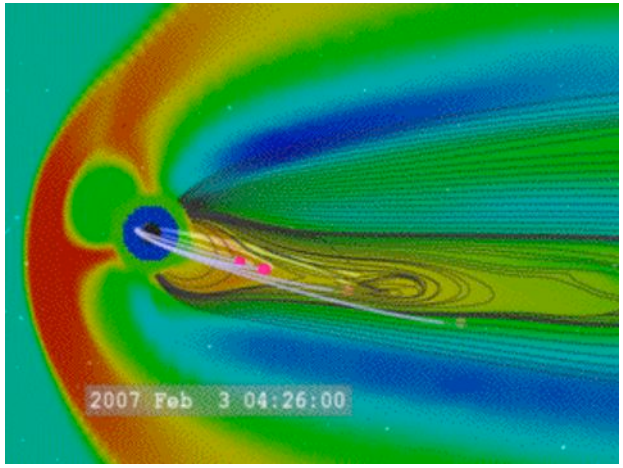
"What accelerates storm-time 'killer' electrons?"

– A significant contribution to space weather science

Second bonus science:

"What controls efficiency of solar wind – magnetosphere coupling?"

– Provides global context of Solar Wind – Magnetosphere interaction

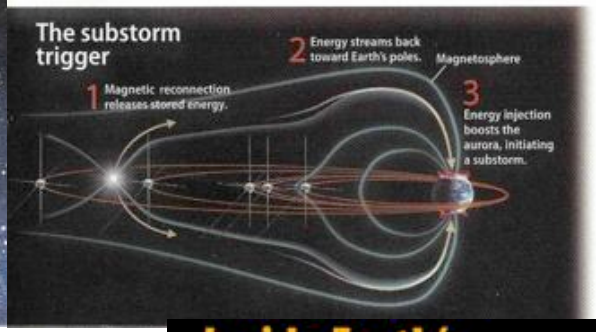


FIVE PROBES LINE UP TO TIME ONSET AND TRACK ENERGY FLOW IN THE TAIL

4 What powers auroral storms

A fleet of NASA spacecraft solved the greatest outstanding mystery of the northern and southern lights: the origin of sudden, explosive flare-ups called auroral substorms. Scientists knew substorms release energy trapped in Earth's magnetic field. However, the critical details of how and where the energy is released have remained controversial. To settle the question, NASA launched five identical spacecraft into orbit in February 2007 on the Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission.

Every 4 days, the satellites lined up along Earth's magnetosphere — the volume of space under the influence of the planet's magnetic field. The satellites monitored electrical and magnetic fields and charged particles.



On February 26, 2008, the THEMIS dragnet caught a substorm, providing researchers the data they needed. "We discovered what makes the northern lights dance," says UCLA's Vassilis Angelopoulos, lead scientist for THEMIS.

The power source for substorms is magnetic reconnection. The "solar wind" of charged particles from the Sun flows around Earth's magnetosphere. This squeezes and compresses the magnetic field, storing energy.

When the lines of magnetic force can stretch no farther, they snap and reconnect to form U-shaped loops that channel energy toward Earth's poles. This injection temporarily supercharges the aurora. The critical event — magnetic reconnection — occurs about a third to a half of the distance to the Moon's orbit, the team reported August 14 in *Science*.

THEMIS data will help scientists build more accurate models of substorms and other aspects of "space weather." Major space storms can disrupt earthly communications and even damage satellites.

THEMIS spacecraft line up at midnight over North America every 4 days. Several of the satellites caught the triggering event for an auroral substorm February 26, 2008. The satellites confirmed that a process called magnetic reconnection powers auroral substorms. NASA

The Washington Post

Scientists Unveil Discovery About the Northern Lights

By Marc Kaufman
Washington Post Staff Writer
Thursday, July 24, 2008; 5:44 PM

VIDEO

Northern Lights

The mysterious sudden brightening and wavelike movements often seen in the aurora borealis, also called the Northern Lights, are caused by periodic explosions of magnetic energy 80,000 miles above Earth, NASA researchers reported today.

The New York Times

Friday, July 25, 2008

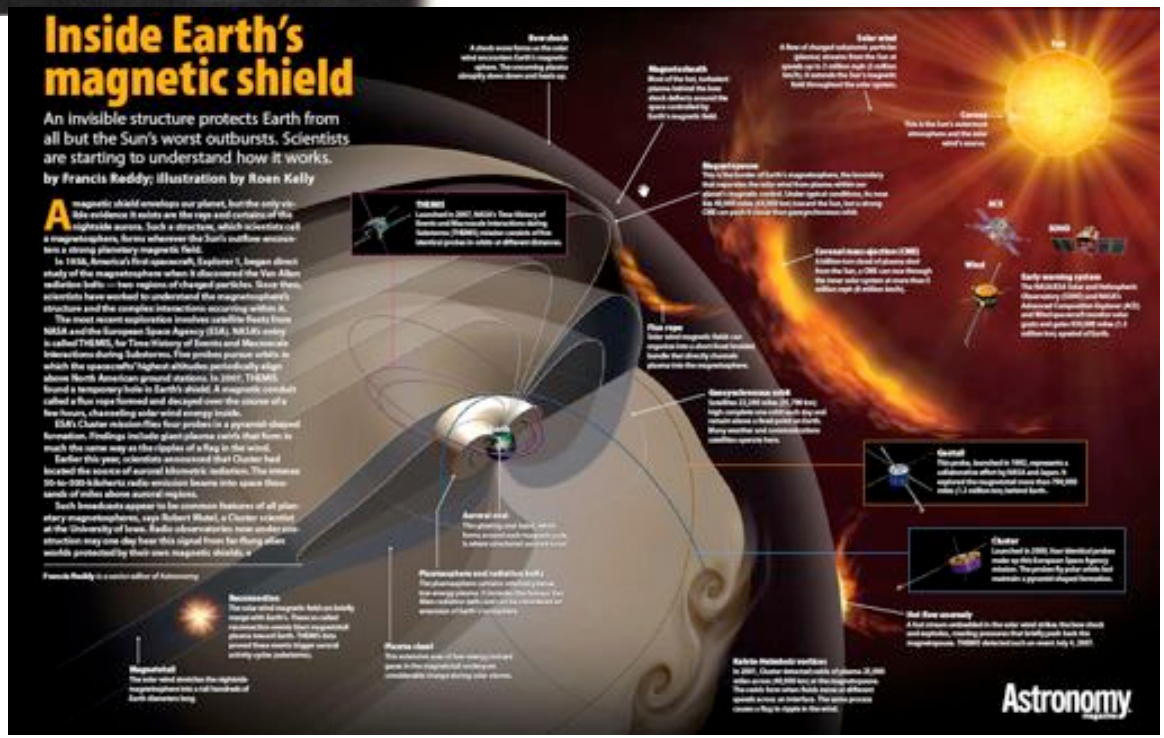
Scientists Find Trigger for Northern Lights

By KENNETH CHANG

David Bebee/Waterloo Region Record, via Associated Press

A NASA mission to study geomagnetic storms used satellites and ground observations to determine the order of events surrounding the aurora borealis, shown in Kitchener, Ontario, in 2004.

The researchers hope the finding will be a step in developing reliable forecasts of geomagnetic storms.



www.pbs.org/wgbh/nova/sciencenow/0304/02.html

SFGate.com

Energy Source of Northern Lights Found

Tuesday, December 11, 2007

(12-11) 16:36 PST SAN FRANCISCO, (AP) --

Scientists think they have discovered the energy

Magnetic-Shield Cracks Found; Big Solar Storms Expected

Victoria Jaggard in San Francisco
National Geographic News
December 17, 2008

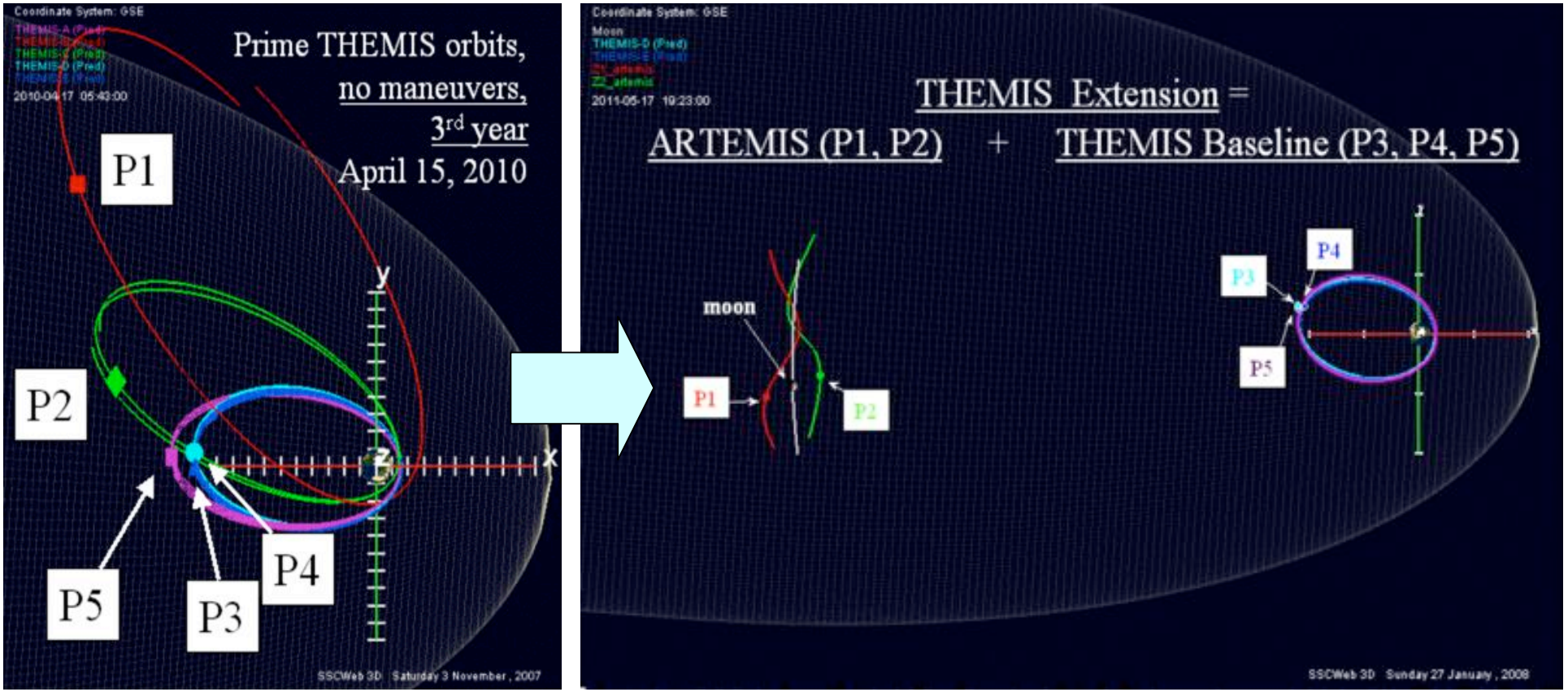
An unexpected, thick layer of solar particles inside Earth's magnetic field suggests there are huge breaches in our planet's solar defenses, scientists said.

These breaches indicate that during the next period of high solar activity, due to start in 2012, Earth will experience some of the worst solar storms seen in decades.

Solar winds—charged particles from the sun—help create auroras, the brightly colored lights that sometimes appear above the Earth's poles.

But the winds also trigger storms that can interfere with satellites' power sources, endanger spacewalkers, and even knock out power grids on Earth.

THEMIS Extension (FY10,11,12)

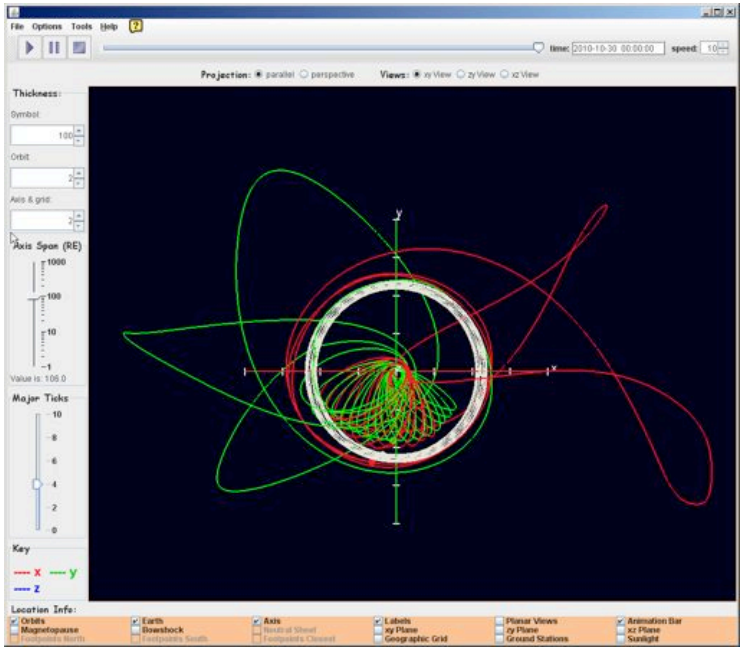


ARTEMIS Phases

Translunar injection phase (Oct ’09 – Oct ’10)

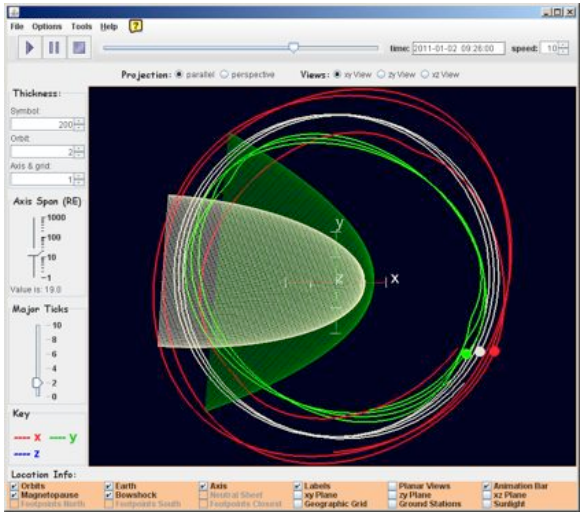
… getting there.

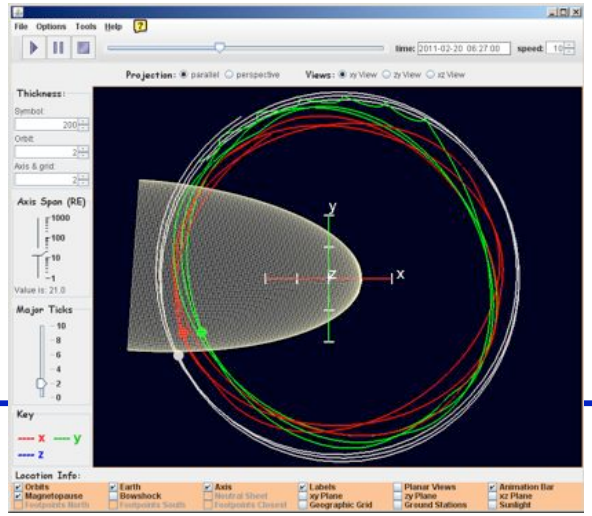
Note: Orbit Raise Maneuvers (ORMs) start: July 2009, in parallel with THEMIS 2nd dayside operations (THEMIS dayside requirements met already since 1st dayside season)



Lissajous Phase Science (Oct ’10 – Apr ’11)

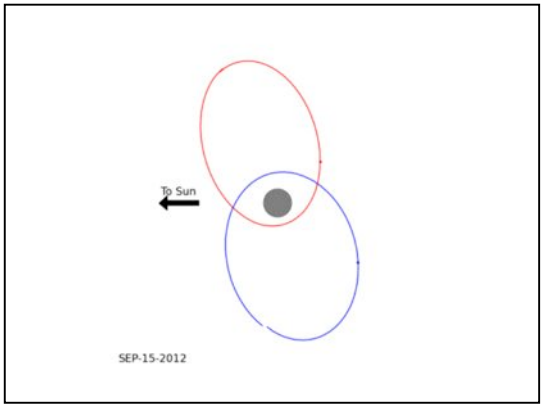
Note: First 3 months: opposite sides, Next 3 months: same side





Lunar Orbit Science (May ’11 – Sep ’12)

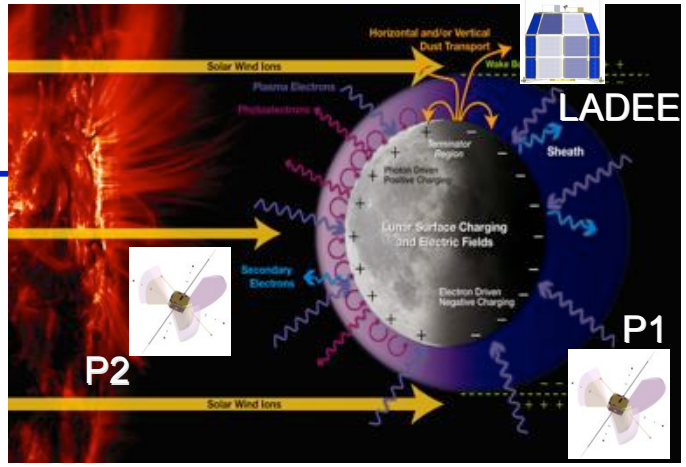
Note: P1 retrograde, and P2 prograde, such that orbital separations and separation vectors cover full parameter space



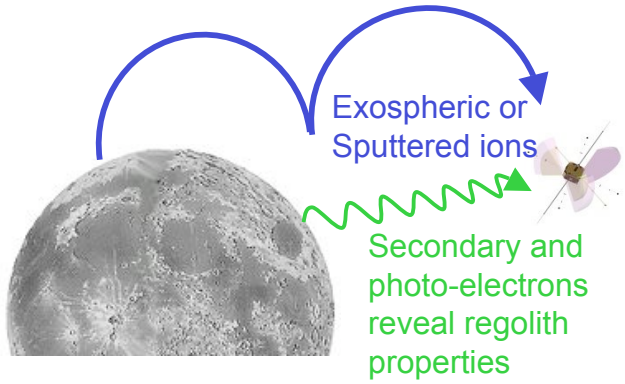
ARTEMIS: Twin Lunar Explorers

- ARTEMIS provides **two-point** measurements:
  - From the Moon
    - Earth's distant magnetopause
    - Earth's distant bow shock and magnetosheath
    - Earth's magnetotail
  - Of the Moon
    - The Moon/plasma interaction
    - The Moon's plasma wake
    - Interior structure (Electromagnetic sounding)
  - On the Moon
    - Surface composition and weathering
    - Exospheric composition, structure, and dynamics
    - Surface electric fields and dust charging
    - Support for other planetary missions (Lunar Reconnaissance Orbiter (LRO), Lunar Atmosphere and Dust Environment Explorer (LADEE), Lunar Network)

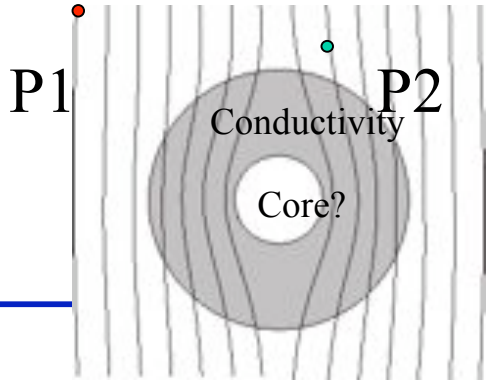
ARTEMIS Capabilities In Planetary Science



- Dust Levitation in Electric Fields:
  - Study electric field near moon with proper input
  - Study surface electric field with reflectometry
  - Provide local electric field, particles to LADEE
    - LADEE dust detector detects response to input



- Lunar Exosphere
  - Composition, distribution of:
    - exospheric ions
    - sputtered ions
    - regolith
  - Exospheric variations with solar activity, cycle



- Lunar Surface and Interior
  - Crustal magnetic fields
  - Conductivity depth profile
  - Surface charging

Lunar surface charging

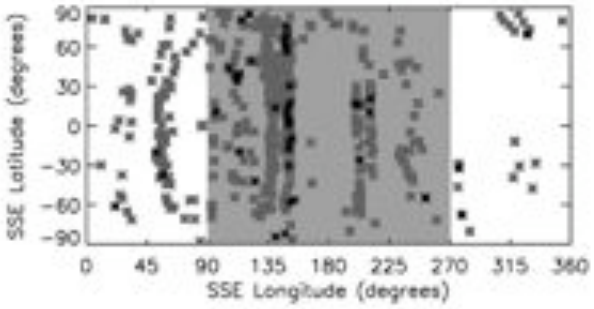


Figure 3. Locations of magnetic connection to the lunar surface when beams of energies >500 eV (grey) and energies >1 keV (black) are observed, in SSE coordinates. Background corresponds to illumination condition.

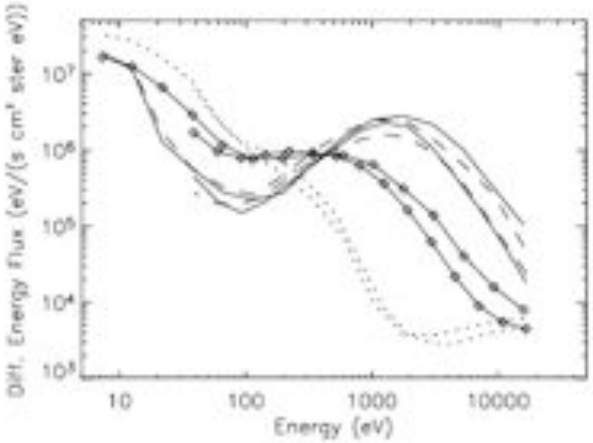
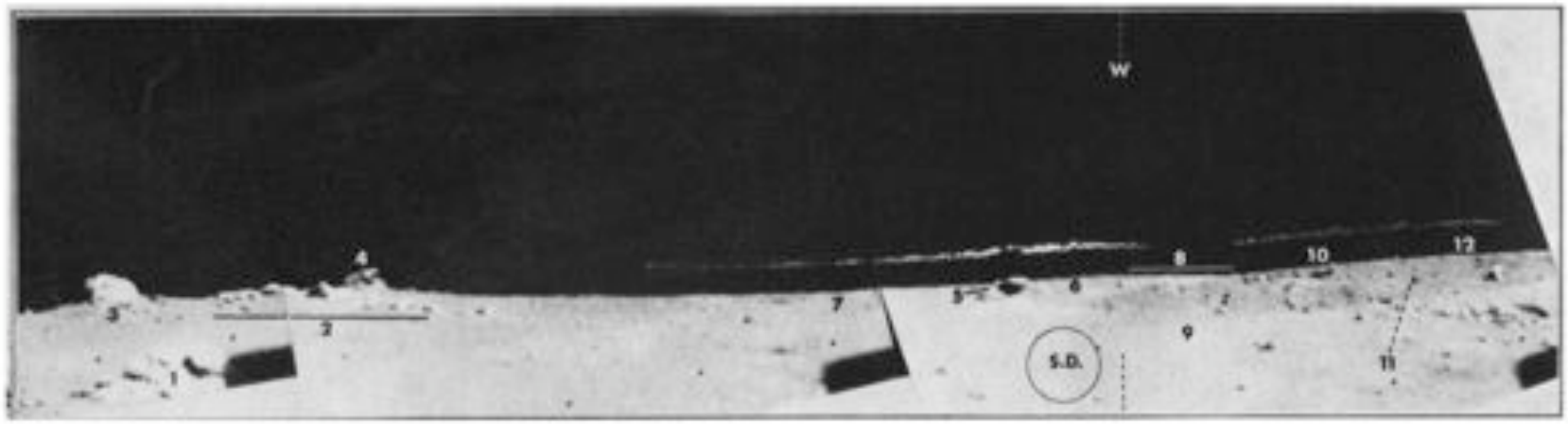


Figure 5. Median incident spectra in the tail lobes (dotted), plasma sheet (diamonds), and when beams of energies >500 eV (dashed) and energies >1 keV (solid) are observed, all in sunlight.

Halekas et al 2005 (Lunar Prospector data)

Strongest charging events occur on the night side in the Earth's magnetotail. However during SEP events up to 4.5 keV charging can occur on the day side.

Dust Levitation in Electric Fields



Lunar horizon glow as seen in a composite of five photographs

Modeling suggests that dust concentrations range from ~$10^5/m^3$ near the surface to ~$10/m^3$ at 100 km.

Dust Levitation in Electric Fields

Zook and McCoy [1991]

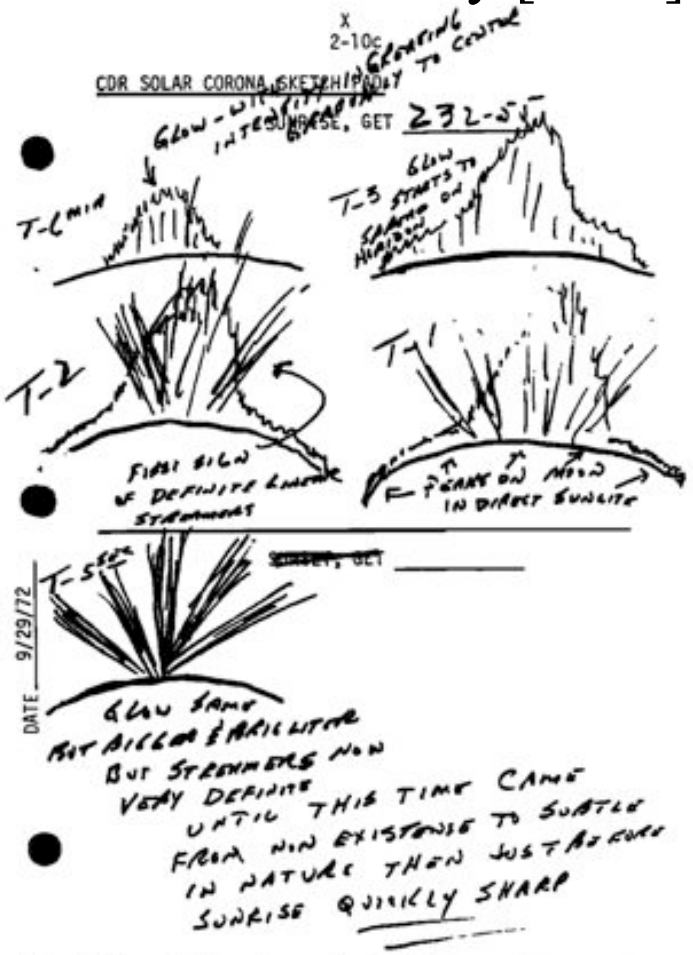
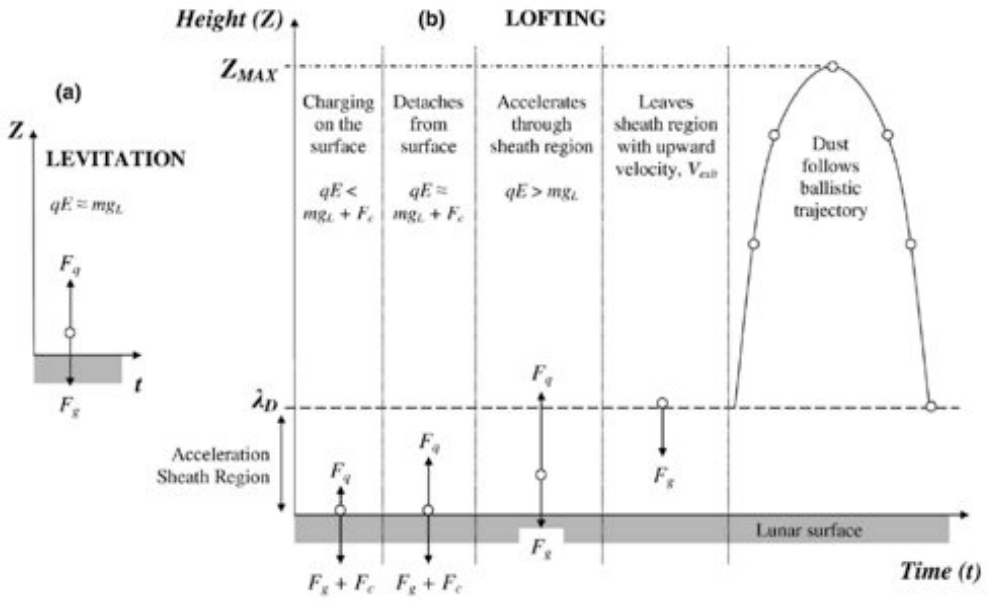


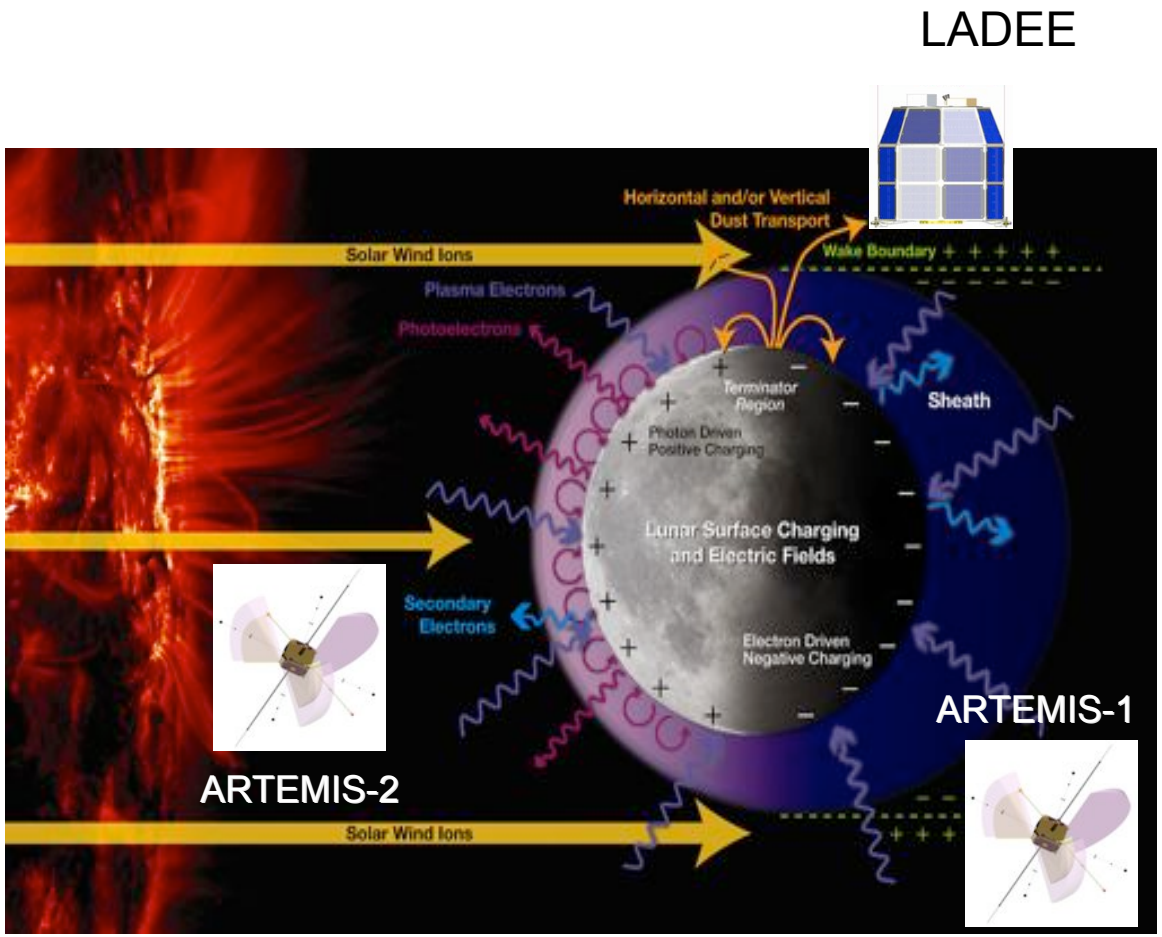
Fig. 1. Five sketches drawn by E. A. Cernan (Commander) of sunrise as viewed from lunar orbit during the Apollo 17 mission. The times in minutes (i.e. T-6, T-3, T-2, and T-l) and seconds (i.e. T-5 sec) refer to the time before first appearance of the sun.

- Apollo astronauts saw dust elevated above the lunar surface to possibly high altitudes.



Dynamic fountain model of Stubbs et al. 2006

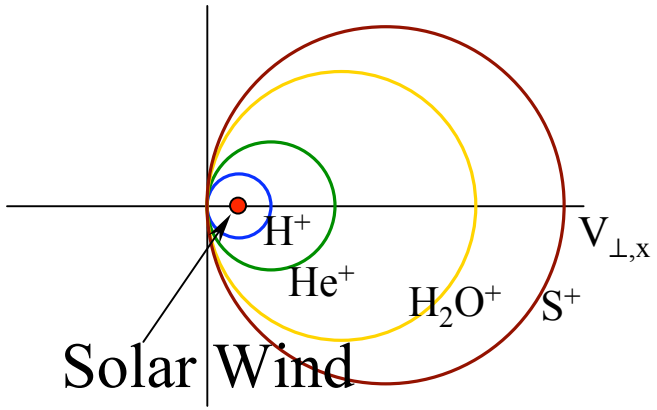
Dust Levitation in Electric Fields



- LADEE will probably have a dust detector, but has no capability of measuring the solar wind electric and magnetic fields.
- ARTEMIS measures the solar wind velocity and the interplanetary magnetic field and hence the solar wind electric field. It also can measure surface potentials with electron reflectometry.
- ARTEMIS plus LADEE will enable us to determine the response of charged lunar dust to the lunar and solar wind electric fields.

Volatile Inventory and Lunar Outgassing

- Apollo's ALSEP package contained a suprathermal ion detector (SIDE) that detected ions accelerated by the electric field toward the lunar surface.
- The temporal history of these ion fluxes suggested that the moon might be episodically outgassing.
- Recently Chandrayaan-1 and Cassini have provided evidence of surface water derived from action of solar wind on the Moon rocks and exhibiting temporal and spatial variations.
- ARTEMIS has an ion detector and measures the solar wind electric field so it can test the SIDE hypothesis of an outgassing moon. Water group ions can be detected by the ion detector and by the magnetometer from ion cyclotron waves.



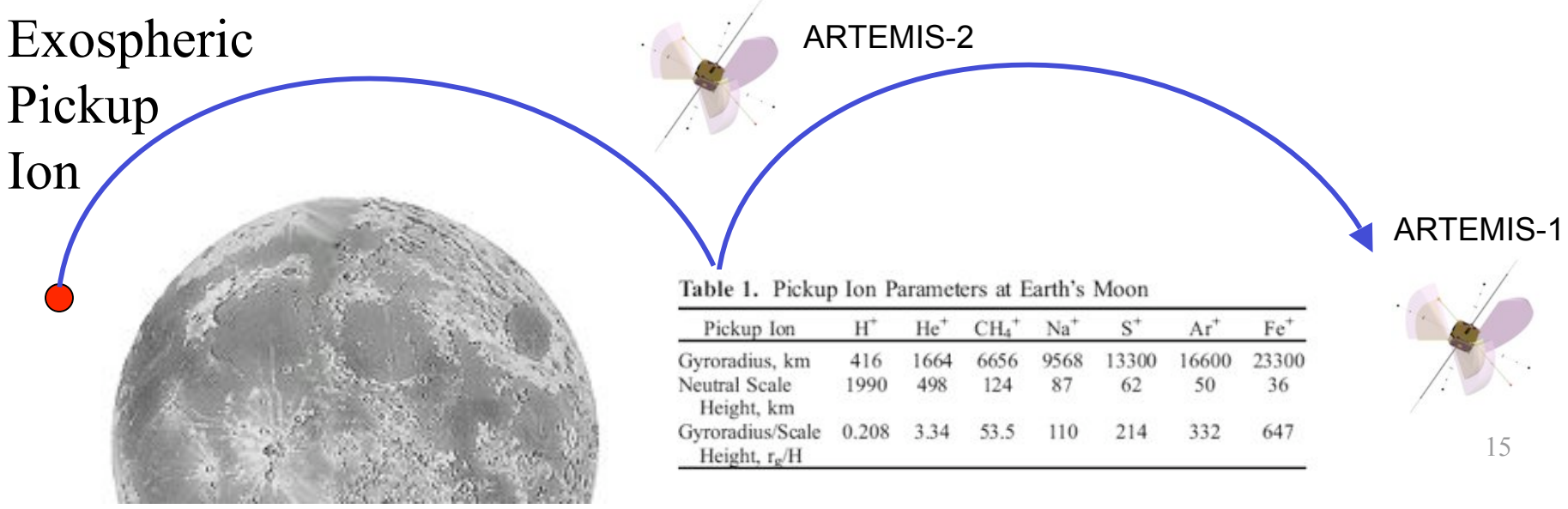
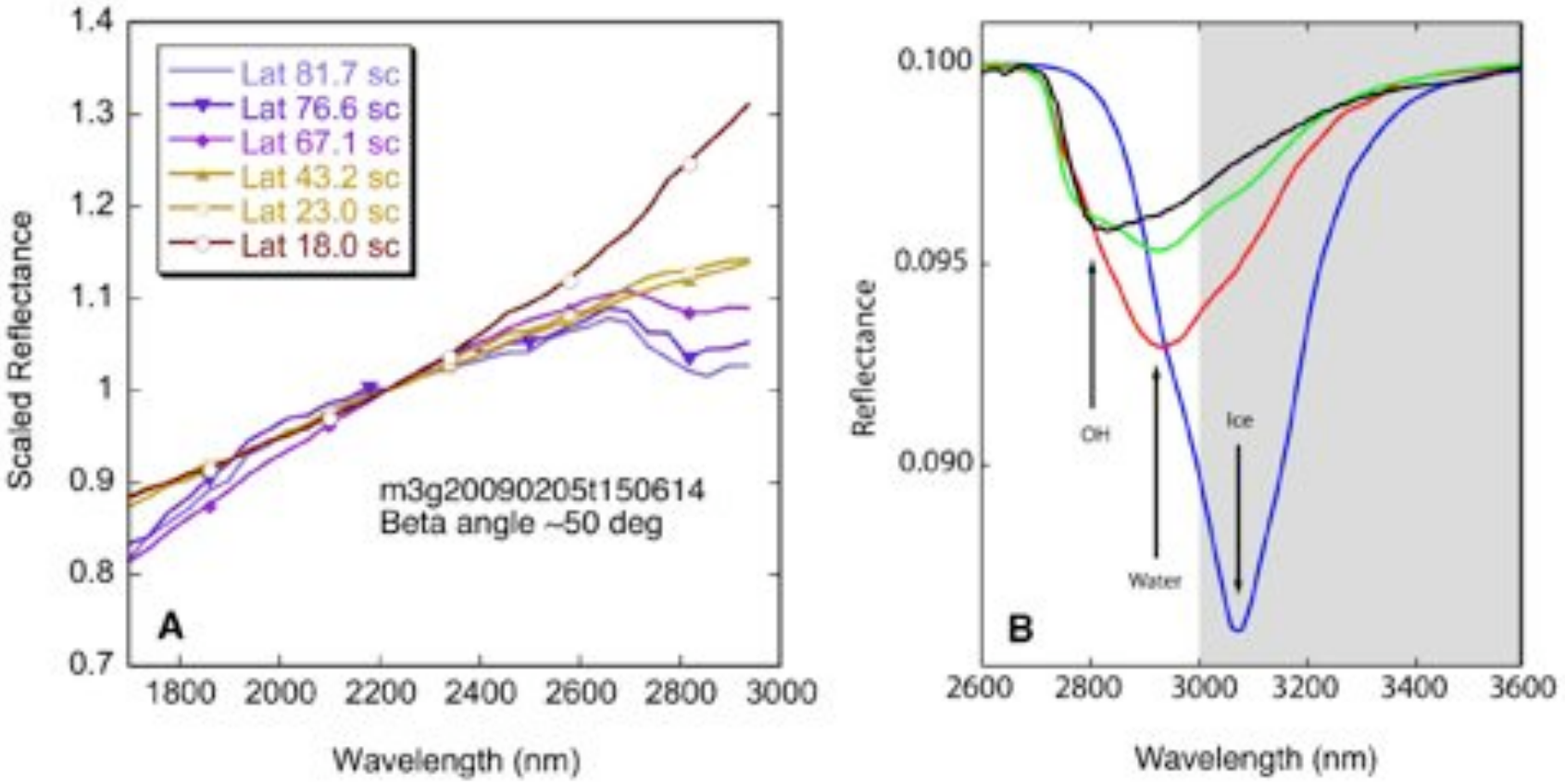


Table 1. Pickup Ion Parameters at Earth's Moon

Pickup Ion	H^+	He^+	CH_4^+	Na^+	S^+	Ar^+	Fe^+
Gyroradius, km	416	1664	6656	9568	13300	16600	23300
Neutral Scale Height, km	1990	498	124	87	62	50	36
Gyroradius/Scale Height, r_g/H	0.208	3.34	53.5	110	214	332	647

Water on the Moon



Pieters et al (2009) from M^3 on Chandrayaan-1

SELENE (Kaguya) measured ions derived from Lunar surface

Figure courtesy
Yoshifumi Saito
(ISAS/JAXA)

Launched 14 September 2007

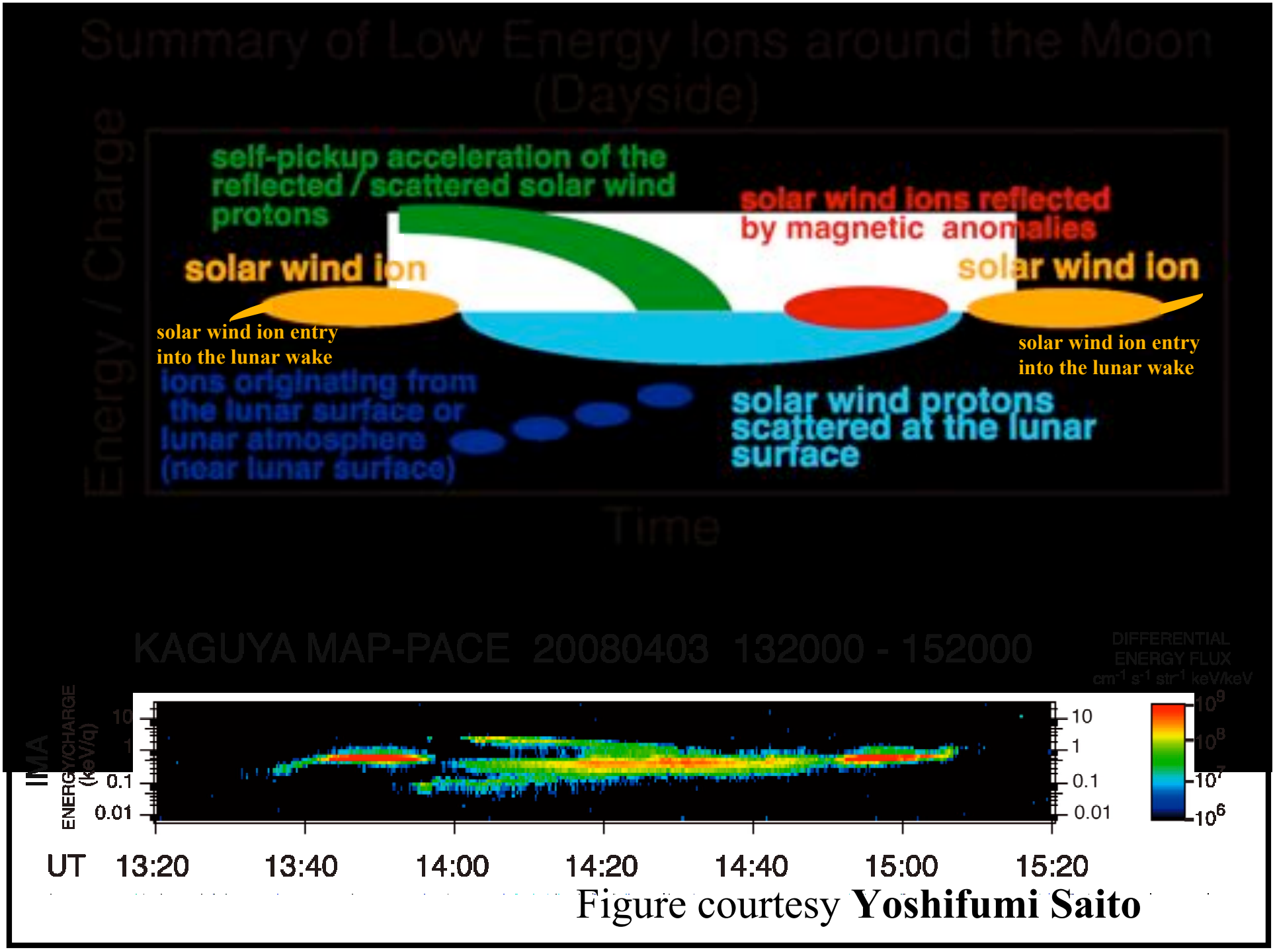
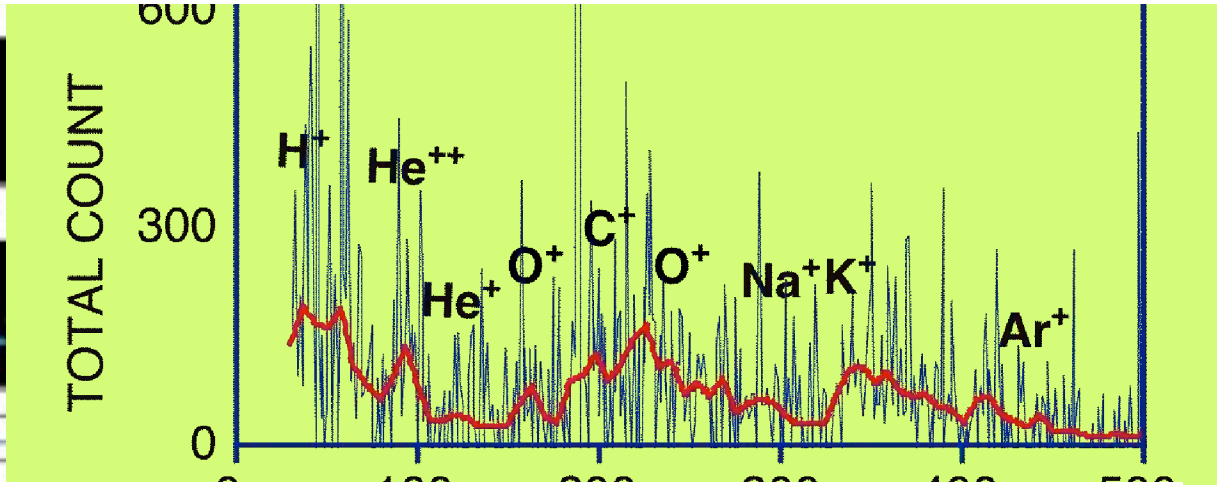


Figure courtesy **Yoshifumi Saito**

source of the alkali ions is
not only the solar wind sputtering



photon stimulated desorption
thermal desorption

Fig courtesy
fumi Saito

Human Activities: Effect on the Atmosphere

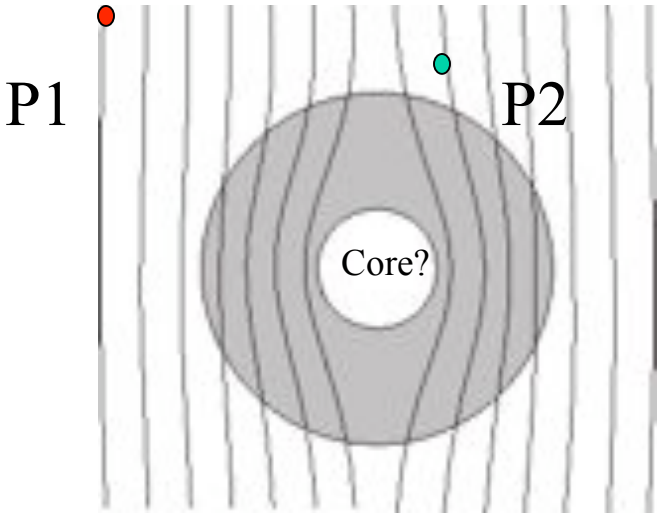
- The Moon is now the subject of rapidly increasing exploration: now robotic, soon human.

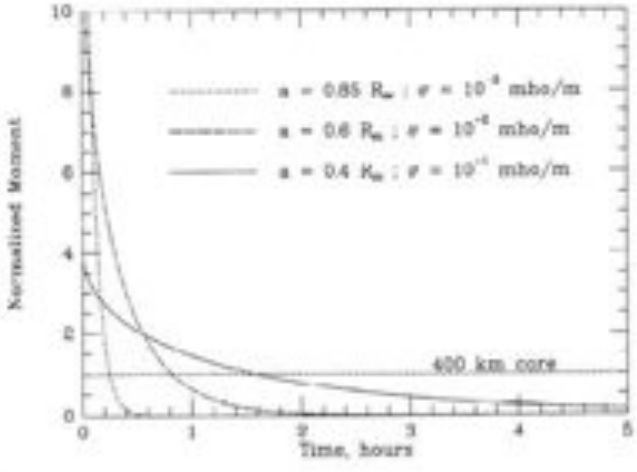
- These activities will alter the thin lunar atmosphere, changing its composition and density.

- We need to understand the present atmosphere, its sources and losses, before it is altered. This knowledge will help us to predict losses of the new gases introduced to the Moon.

- Artemis with its ion detector and magnetometer enables a “mass” spectroscopic study of the lunar atmosphere utilizing solar photons to ionize the neutral atmosphere.

Interior Structure of the Moon



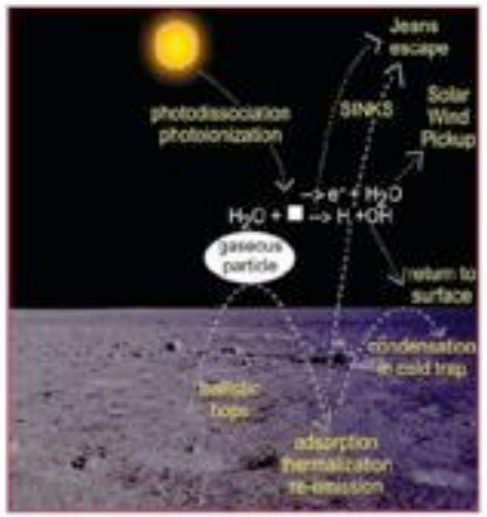


- Apollo orbital measurements provided evidence of an iron core of about 400 km radius.
- Lunar Prospector made similar (single instrument) measurements and confirmed the Apollo subsatellite result.
- Two-point measurements are needed to go beyond the current two-layer model of the interior electrical conductivity.
- ARTEMIS will provide measurements of both the “exciting” field and the resulting induced magnetic field at about 100 km over a range of frequencies and sound the electrical conductivity profile above the core.

ARTEMIS and Support for other Planetary Missions

- In support of LRO:
  - ARTEMIS provides comprehensive monitoring of lunar space environment
  - Complements LRO/CRATER measurements below 200keV

- In support of LADEE:
  - ARTEMIS provides comprehensive monitoring of plasma conditions and lunar surface electric fields
  - Allows study of the response of the lunar exosphere and dust to external drivers



- In support of Lunar Network
  - ARTEMIS would provide solar wind and IMF monitoring

Summary

- ARTEMIS consists of two well-instrumented spacecraft measuring the Moon's plasma and magnetic environment.
- ARTEMIS will help determine:
  - How solar wind is captured and lost by the Moon (including water on the Moon)
  - How the surface is charged and the dust is levitated
  - The interior electrical conductivity of the Moon
  - Whether the Moon has significant outgassing episodes
  - The effect of the exploration program on the lunar exosphere
- Need guidance from the community on the best orbit strategy (lower orbits/shorter mission in support of LRO and LADEE or higher orbits/longer mission to support the electromagnetic sounding from lunar network in future.

Program Status

- ARTEMIS mission approved to proceed in FY10
  - Plans for second half of FY10 and FY11-12 are tentative
  - ARTEMIS Heliophysics funding uncertain in FY10
  - Approved mission encoutered fiscal difficulties at HPS/HQ
- ARTEMIS spacecraft on their way to the moon now
  - 4 lunar flybys in December – April
- ARTEMIS Planetary funding requested in FY10
  - Depends on Heliophysics approval in FY10
  - Planetary investigation to be considered concurrently
- 2010 Senior Review process will determine ARTEMIS fate
  - For both Heliophysics and Planetary goals of investigation

Recommendations

- ***We ask for endorsement from the Inner Planets Panel for the continued operation of the ARTEMIS Mission at the Moon with full funding for the operations and data analysis programs of the mission both from the Heliospheric and Planetary science directorates.***

- ***This would enable us to:***

1. *Realize the benefits from the extremely high inherent sensitivity of field and plasma instruments in characterizing the environment and the interior of the Moon.*

2. *Exploit the power of simultaneous multipoint spacecraft observations to distinguish between temporal and spatial gradients and thus obtain unambiguous information on the exospheric, surface and interior properties of the Moon.*

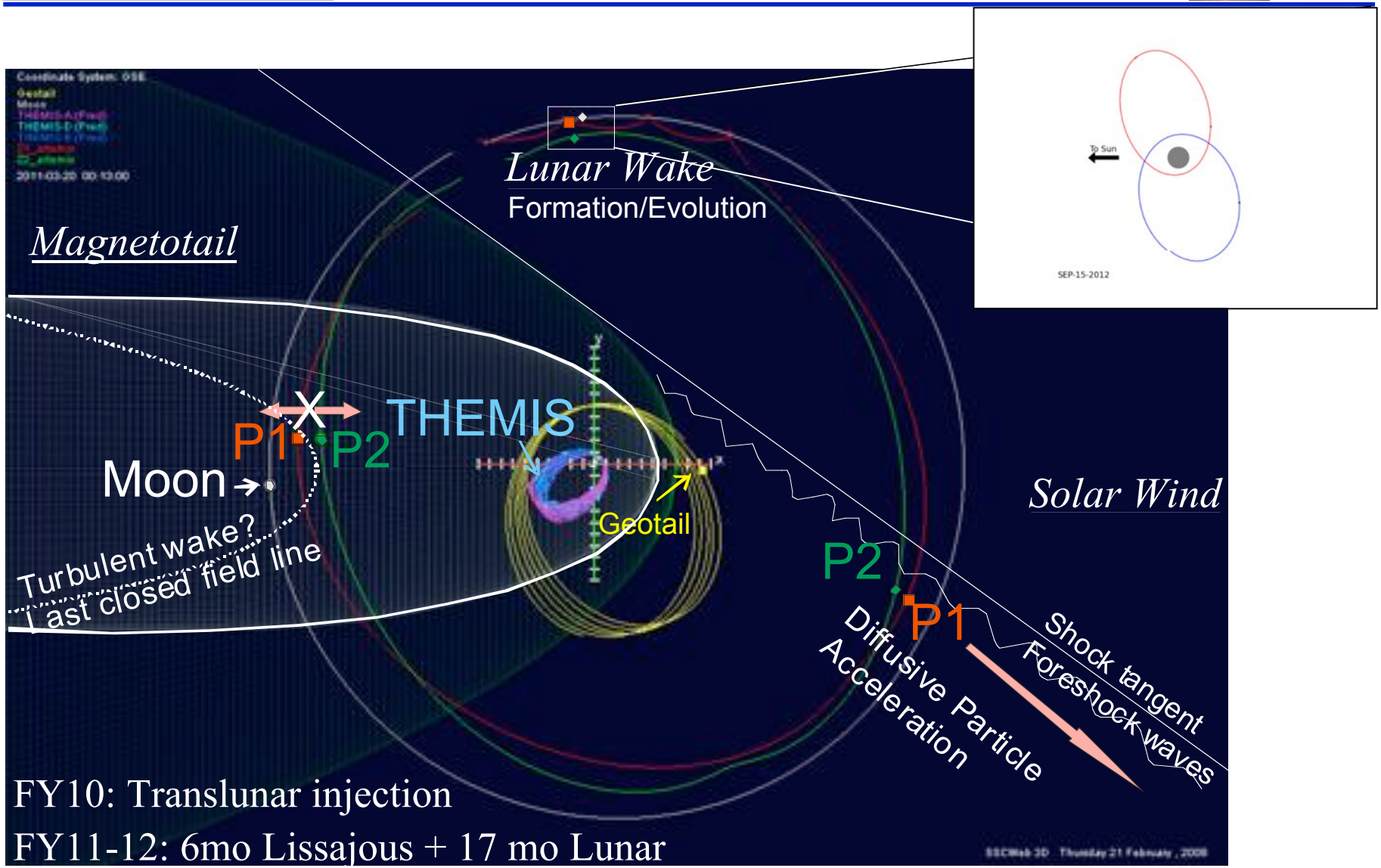
3. *Enhance the science return of future missions such as LRO and LADEE by exploiting the field and plasma measurement capabilities of ARTEMIS that these missions lack.*

4. *Realize the potential for high science return per dollar from the reuse of an existing mission such as ARTEMIS.*

5. *Augment the electromagnetic sounding capabilities of International Lunar Network by obtaining continuous magnetometer measurements of the driver induction signal in the solar wind from spacecraft such as ARTEMIS.*

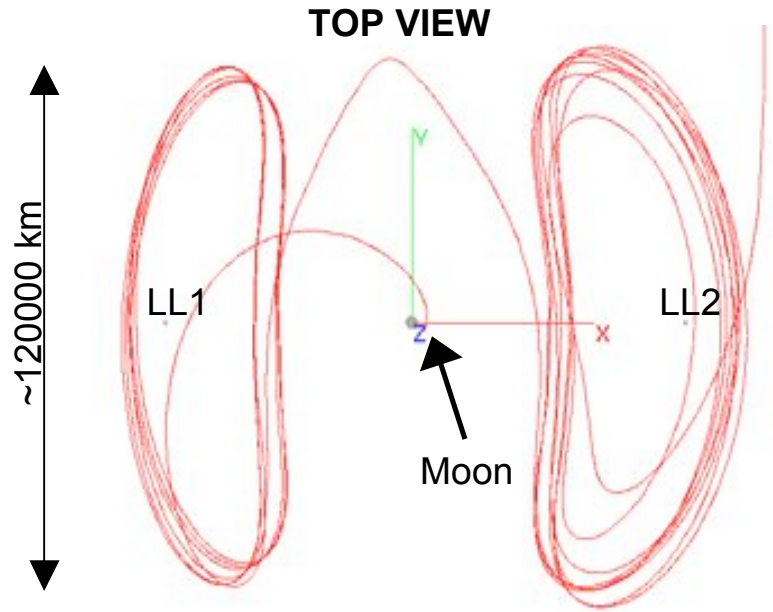
Reserve slides follow

ARTEMIS (P1,P2): FY10,11,12



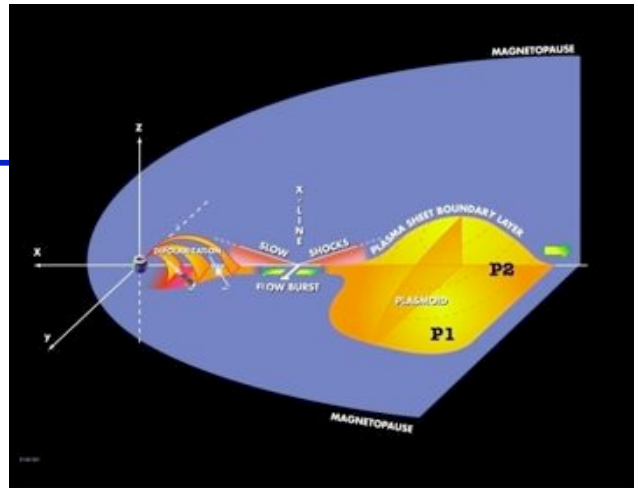
ARTEMIS: Additional benefits to Exploration

- First operational use of Lunar Lissajous orbits (LL1 & LL2), provides:
  - Good estimate of station-keeping fuel requirements for future missions
  - Proof of operational requirements (frequency/magnitude of thrusts)

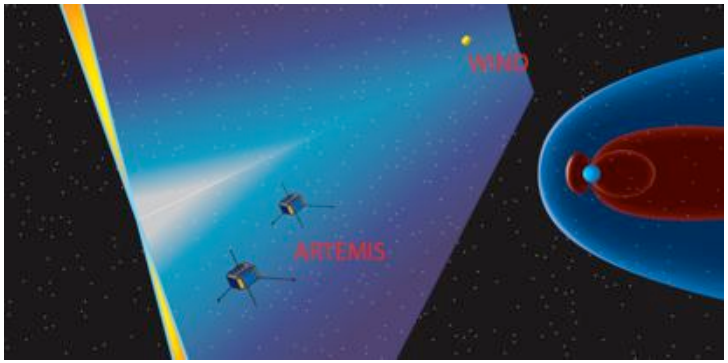


- Validate NASA G/N for Current and Future Exploration Missions
  - Already used with White-Sands, USN; helped certify SSC, DLR dishes, LRO
  - Can provide “calibration standard” for 3-way Doppler for future missions

Heliophysics ARTEMIS Science Objectives

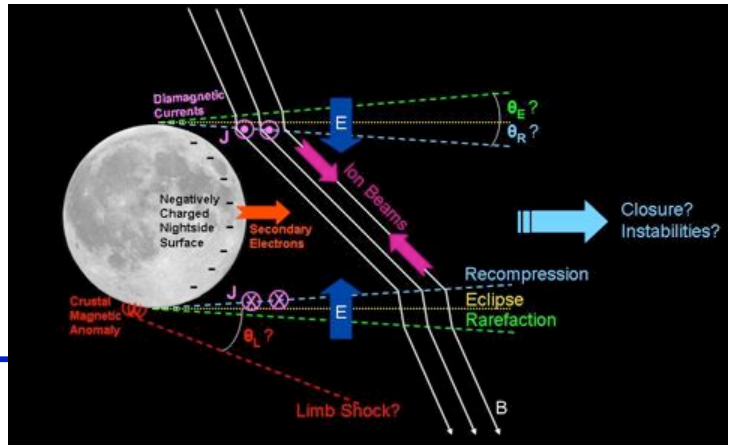


- When moon is in the Magnetosphere:
  - Particle acceleration at lunar environment
  - Reconnection: 3D character; global effects
  - Turbulence: Drivers and effects

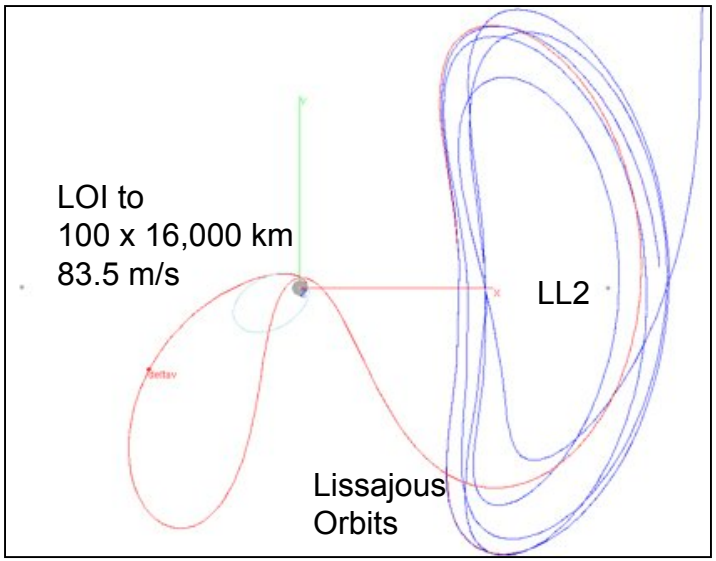


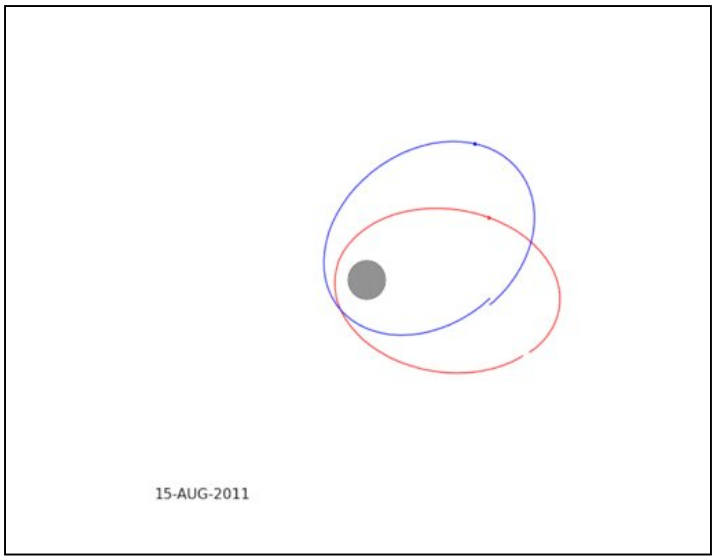
- When moon is in the Solar Wind:
  - Seed population for solar energetic particles
  - Nature of elusive low-shear reconnection
  - Properties of inertial range of turbulence

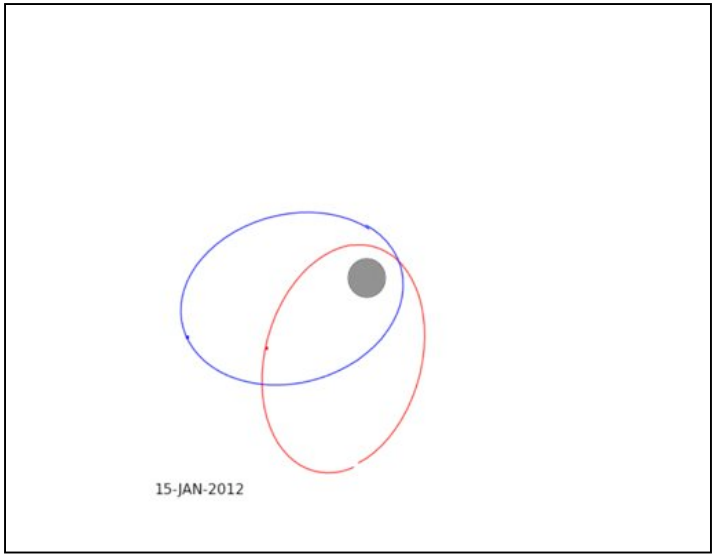
- Near the Moon:
  - Study the structure and evolution of lunar wake
  - Understand particle acceleration at wake
  - Understand formation of wake electric fields

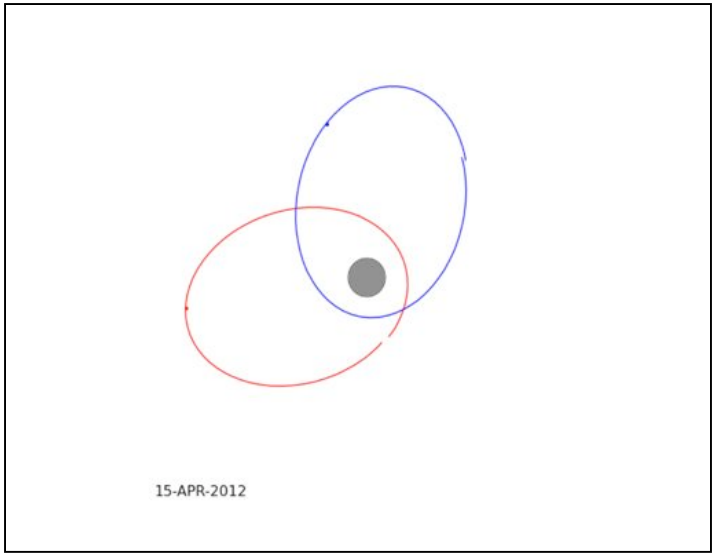


ARTEMIS Lunar Orbit









- 6 Mo. Lissajous Orbit:10-30 RL
- 17 Mo. Lunar Orbit
  - Periapsis: 100-1500 km
  - Apoapsis: 10 R_L
- Orbit stable for >10 years