Bi-Sat Observations of the Lunar Atmosphere above Swirls (BOLAS):

Tethered SmallSat Investigation of Hydration and Space Weathering Processes at the Moon

Tim Stubbs, Michael Collier, Bill Farrell, John Keller, Jared Espley, Michael Mesarch, Dean Chai, Michael Choi, Richard Vondrak, Michael Purucker, & David Folta (*NASA/GSFC*)
Ben Malphrus, Aaron Zucherman (*Morehead State U.*), Robert Hoyt (*Tethers Unlimited*), Michael Tsay (*Busek*), Jasper Halekas (*U. Iowa*), Tom Johnson (*NASA/WFF*), Pam Clark (*NASA/JPL*), Georgiana Kramer (*LPI*), Shahab Fatemi *(IRF)*, Jan Deca *(UC Boulder)*, Dave Glenar, Jacob Gruesbeck, & Jason McLain (*U. Maryland*)

Planetary Science Deep Space SmallSat Mission Concepts

BOLAS Science Targets and Rationale

The overarching science goal of the BOLAS mission is to determine the role of the solar wind in space weathering and the creation of water products on the surface of the Moon by investigating crustal magnetic fields and the swirl patterns that typically accompany them.

Primary science:

- **Space weathering** – regolith exposure to solar wind protons
- **Lunar water cycle** – role of solar wind in forming OH/water
- **Solar wind interaction with crustal fields**

Secondary science:

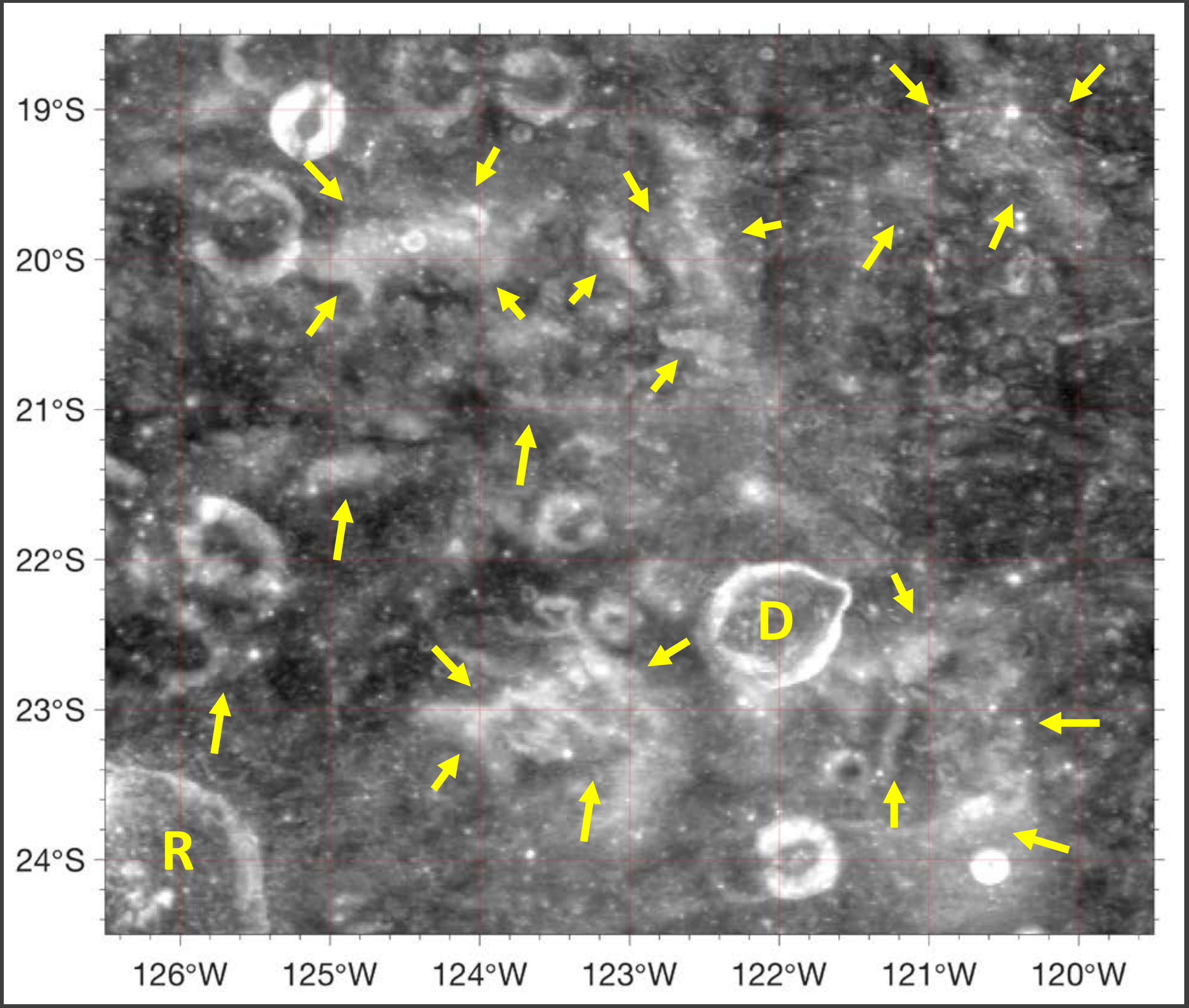
- **Crustal magnetism**
- **Effect of impacts on regional magnetism**
- **Moon's global interaction with the solar wind**
- **Exospheric dust transport**
- **Lunar ionosphere**

Primary target:

Gerasimovich – amongst strongest crustal magnetic fields with extensive swirl patterns. Located on farside around 21°S, 123.5°W

BOLAS Science – Swirls, Space Weathering and Water

WAC Reflectance (643 nm)

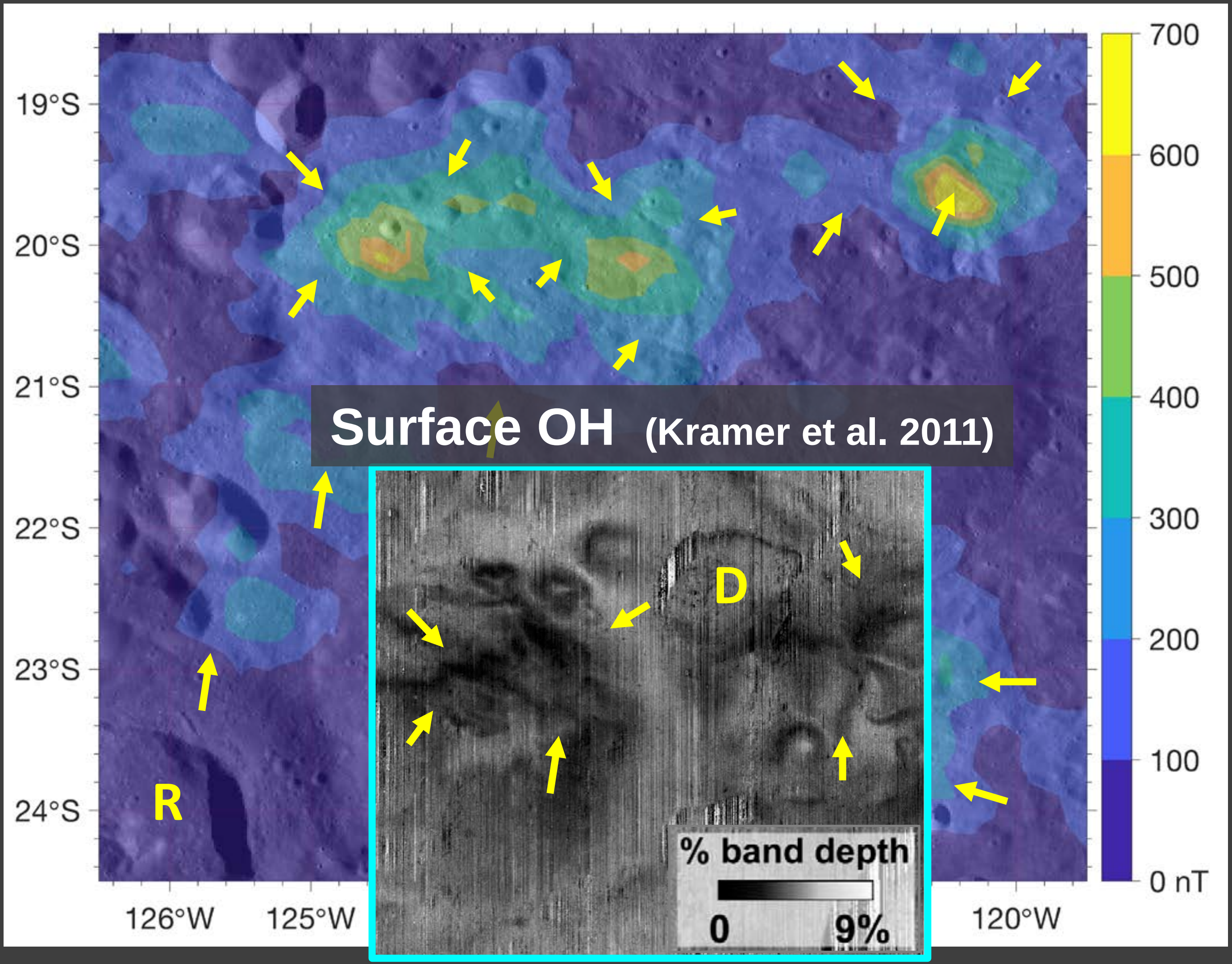


Gerasimovich

visibly bright "pristine" swirl patterns

BOLAS Science – Swirls, Space Weathering and Water

Surface Magnetic Field [nT] (Tsunakawa et al. 2015)



Gerasimovich

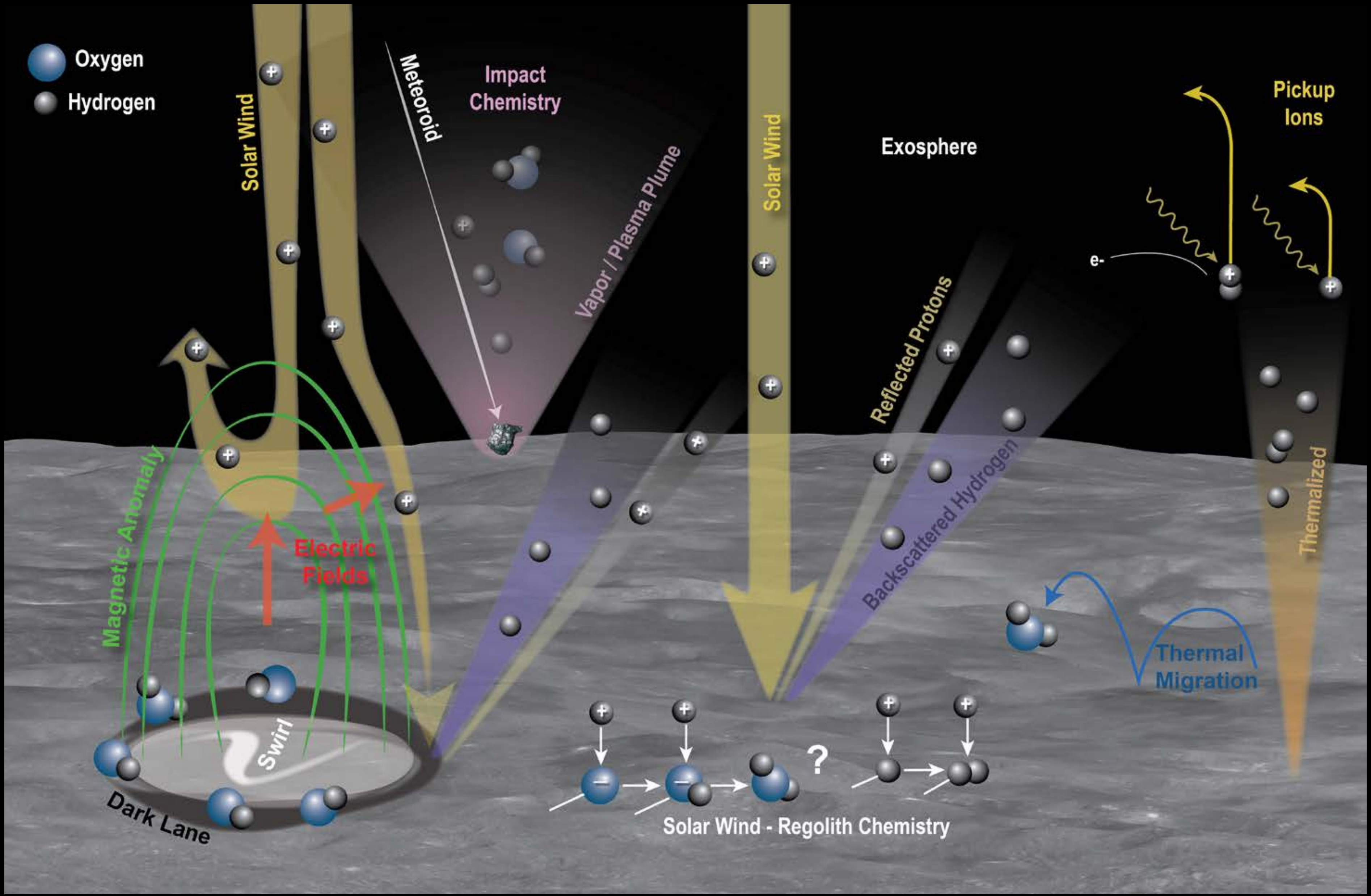
visibly bright "pristine" swirl patterns

coincide with strong crustal magnetic fields

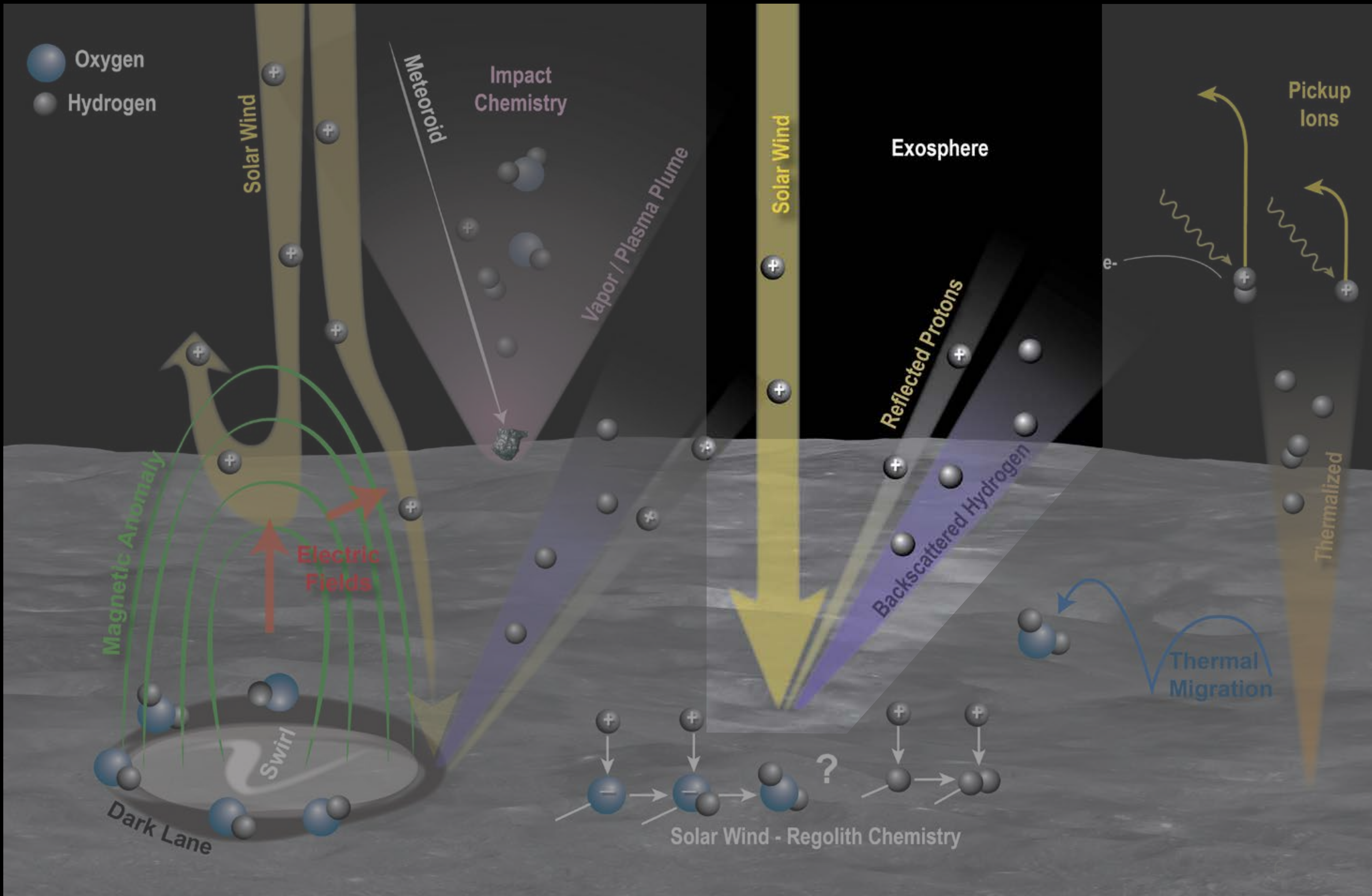
coincide with absence of OH

indicates that crustal fields shield surface regolith from space weathering and OH formation by the solar wind

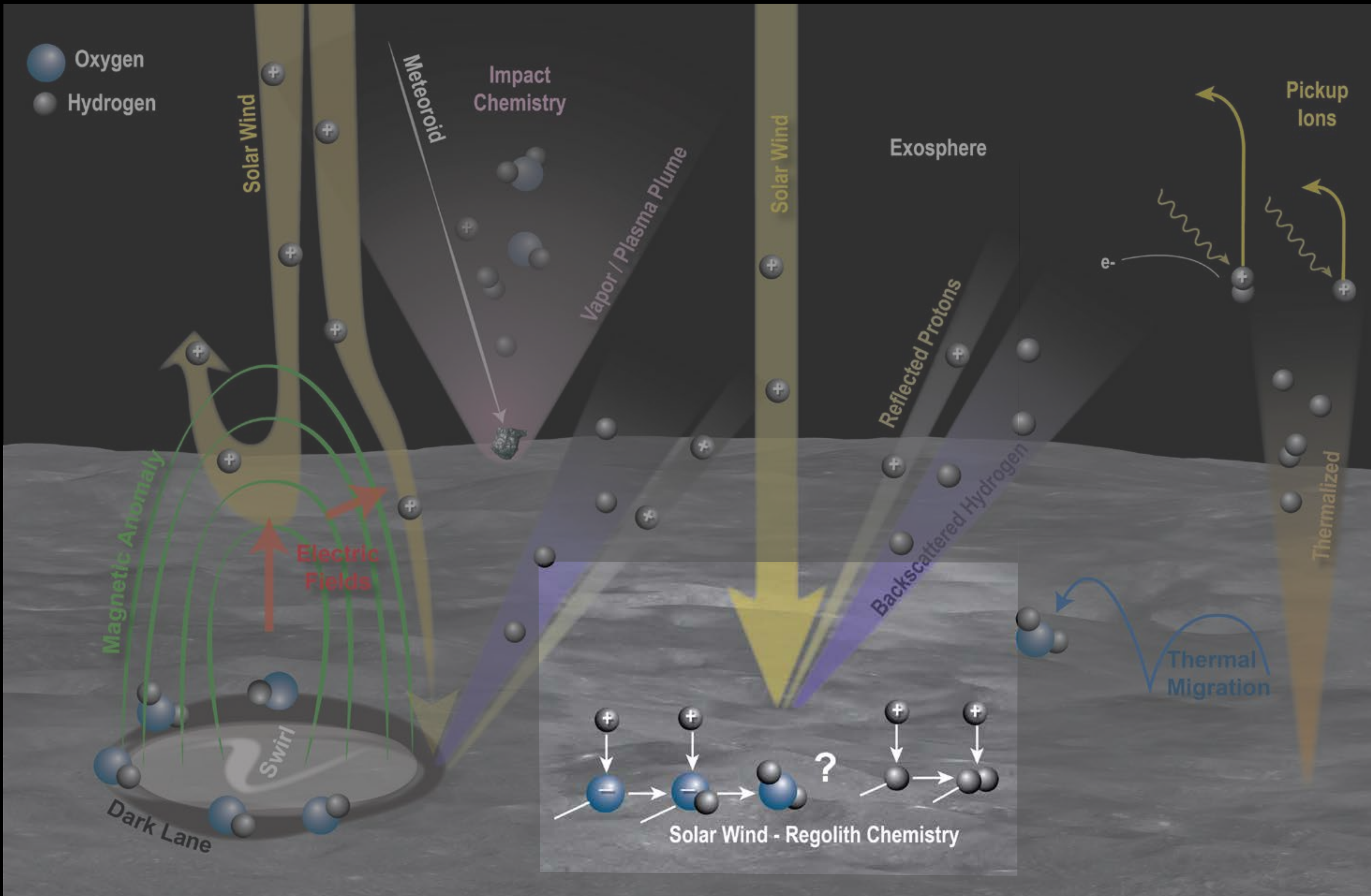
BOLAS Science – Physical and Chemical Processes



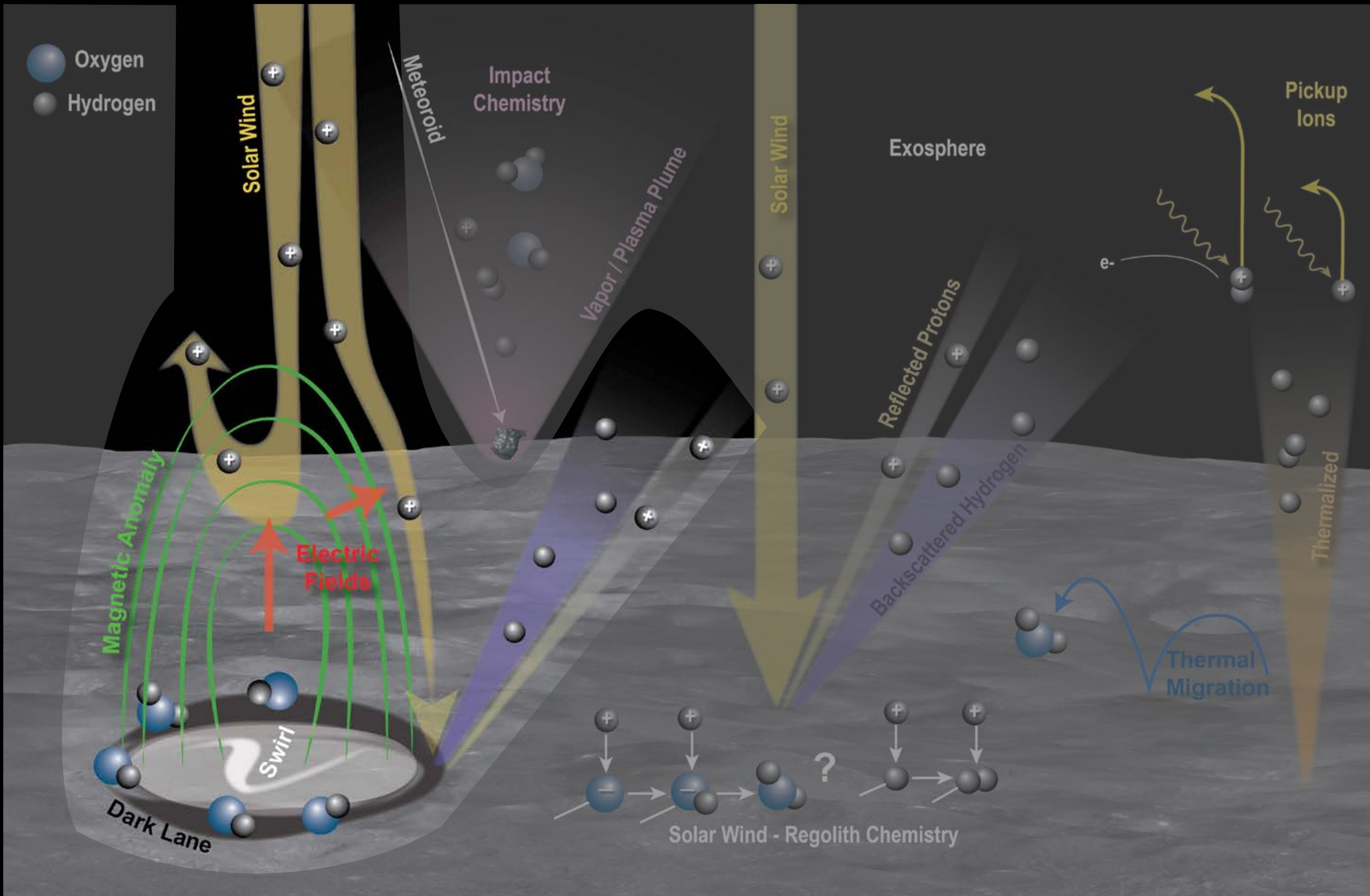
BOLAS Science – Physical and Chemical Processes



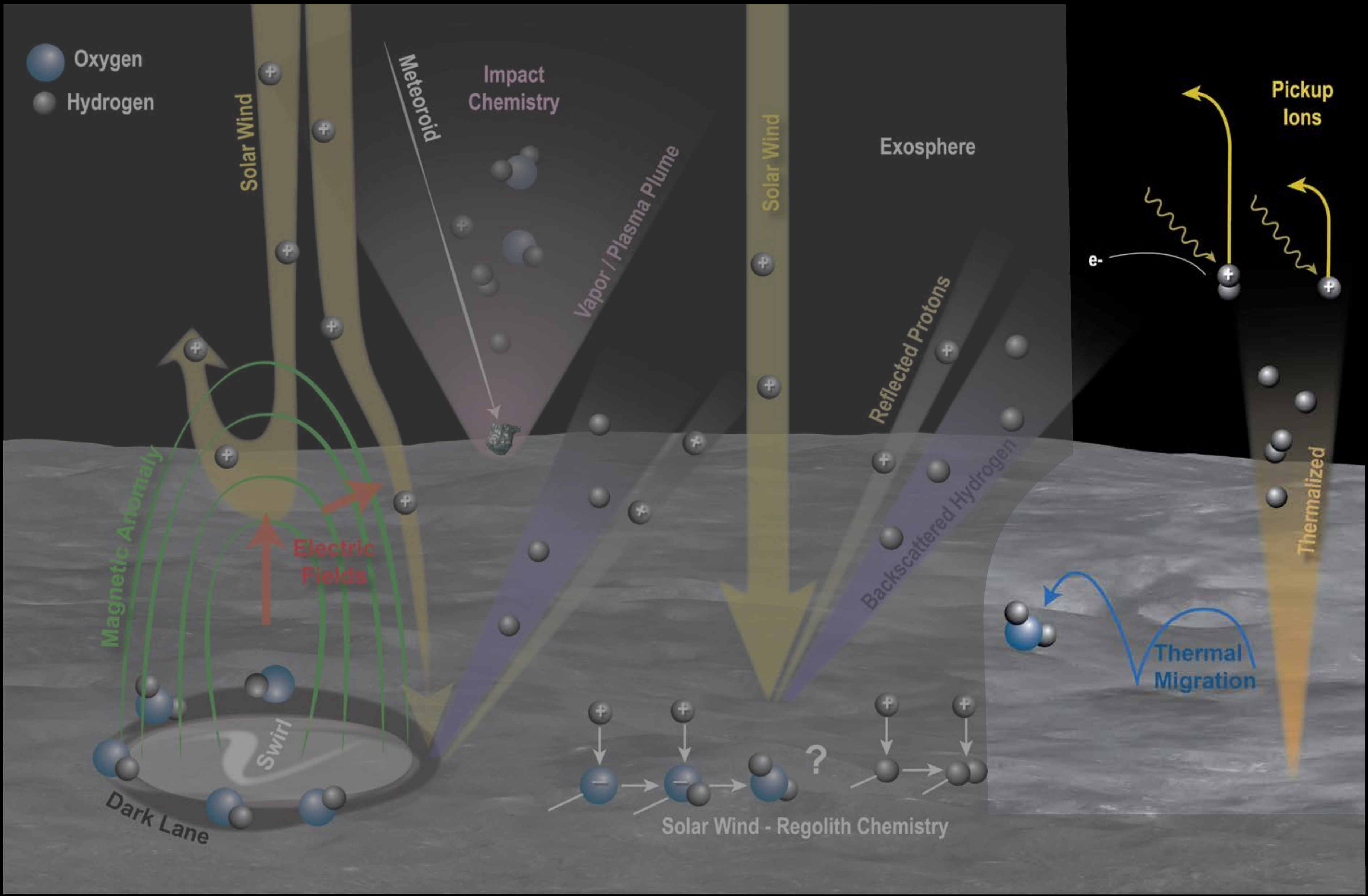
BOLAS Science – Physical and Chemical Processes



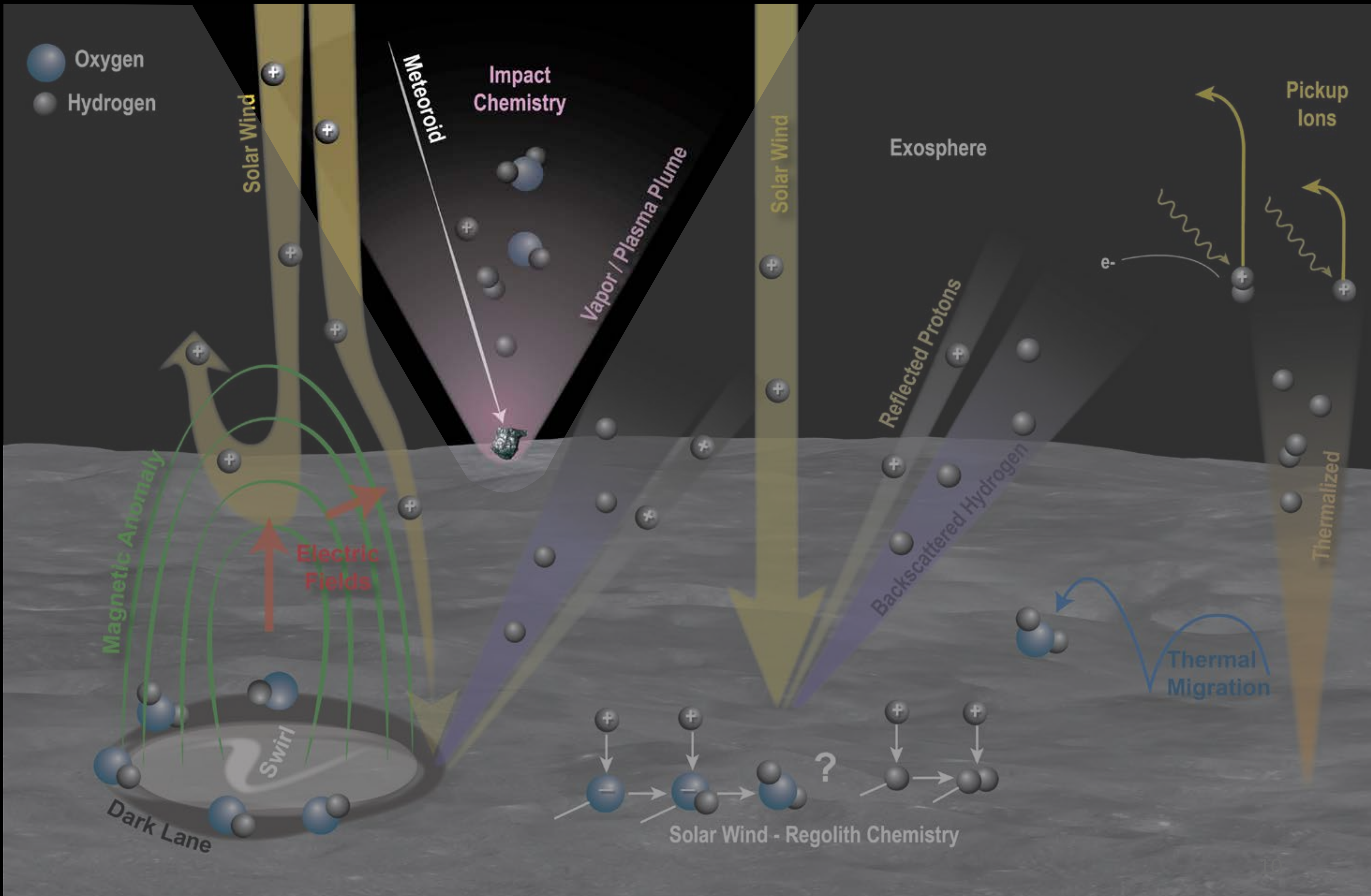
BOLAS Science – Physical and Chemical Processes



BOLAS Science – Physical and Chemical Processes

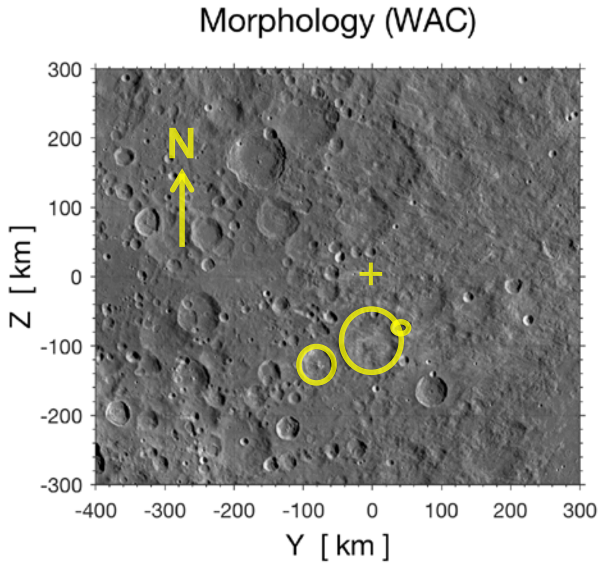


BOLAS Science – Physical and Chemical Processes



BOLAS Science – 3D Hybrid Simulation of Gerasimovich

SURFACE

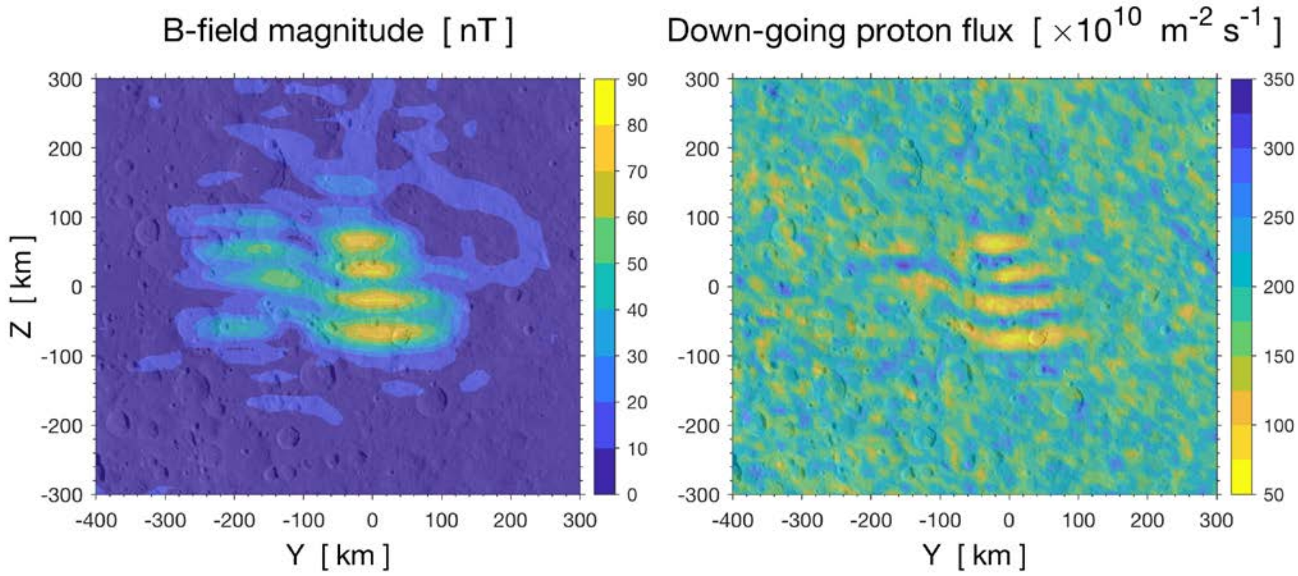


Results from 3D self-consistent hybrid code (Fatemi et al., 2015)

- **Uses realistic crustal field (Purucker and Nicholas, 2010)**
- **10 × 10 km resolution at the surface (Y – Z plane)**

BOLAS Science – 3D Hybrid Simulation of Gerasimovich

SURFACE

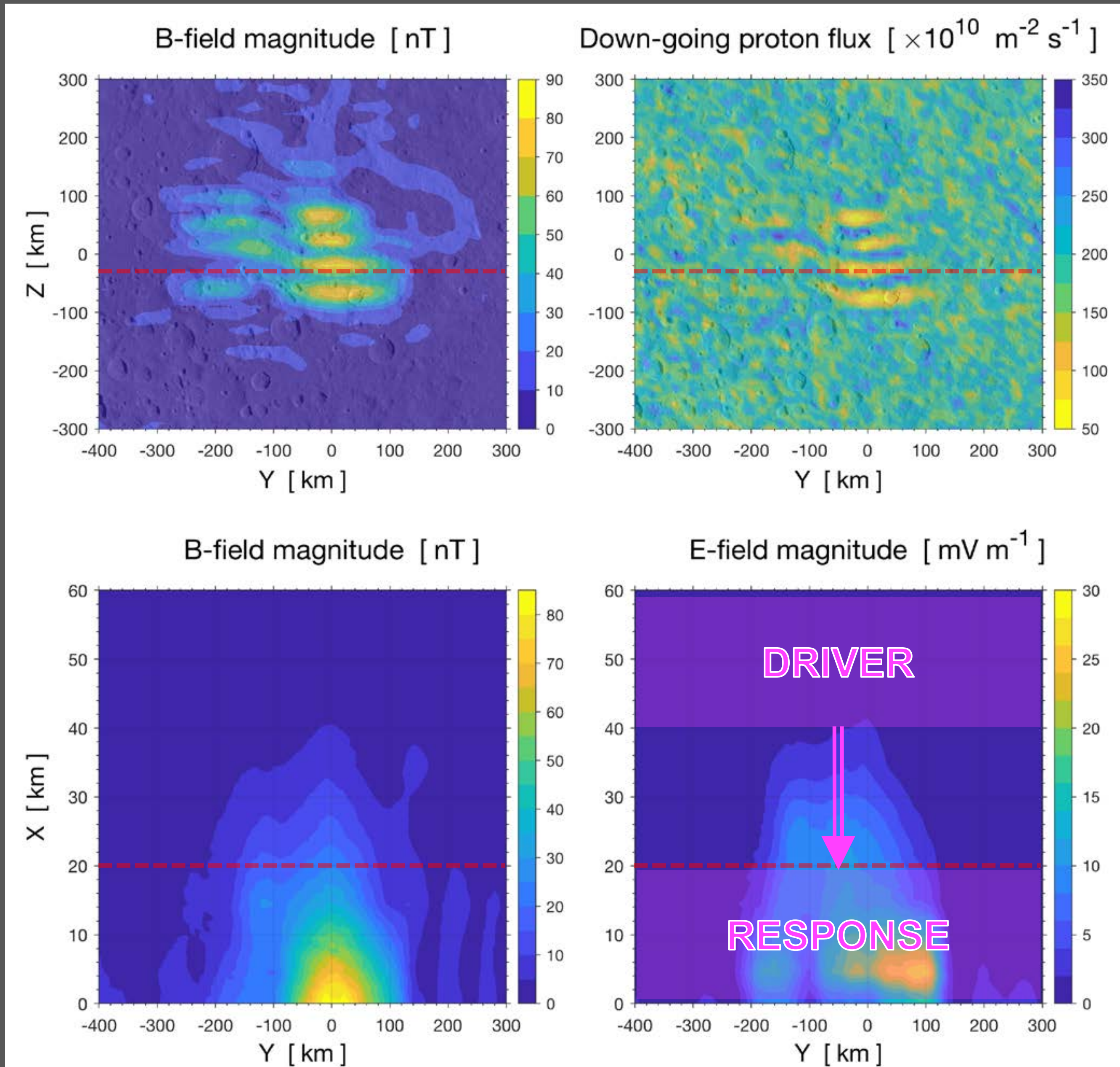


10 km resolution at the surface captures the modulation of solar wind proton flux within crustal field region

BOLAS Science – 3D Hybrid Simulation of Gerasimovich

SURFACE

ALTITUDE PROFILE



10 km resolution at the surface captures the modulation of solar wind proton flux within crustal field region

Altitudes < 20 km required to observe processes responsible for decelerating, deflecting and reflecting solar wind protons

Vertically-aligned, dual-point measurements required to determine cause and effect

BOLAS Instrumentation

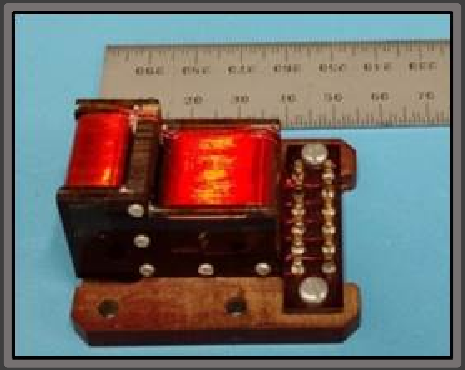
Leveraging development of miniaturized instrumentation for CubeSats with high TRL

Primary Payload

Ion Spectrometer (Univ. of Iowa)
Incident and reflected proton energies and fluxes

Energetic Neutral Atom (ENA) Imager (GSFC)
Backscattered neutral hydrogen (and ambient electrons)

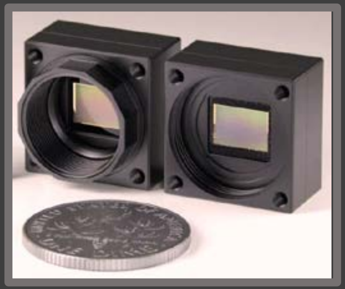
Mini-magnetometer (GSFC)
Ambient magnetic fields



Plasma Wave System (GSFC)
Electron densities, electric fields and dust impacts

Secondary Payload

Miniaturized Cameras
Tether diagnostics & surface imaging.



BOLAS – Frozen Science Orbit

Low-altitude lunar orbits are made difficult by "mascons" – fuel mass required for station-keeping is typically prohibitive.

"Frozen" orbits are stable, elliptical orbits that can reach low altitudes (e.g., LRO) and do not require station-keeping.

Stable for > 1 year

- **Observe annual cycles and occasional events; e.g., meteoroid streams and coronal mass ejections (CMEs)**
- **Full local time coverage of surface targets every 6 months**

Frozen orbit discovered with 30º inclination – equatorial – and mean altitude of 90 km

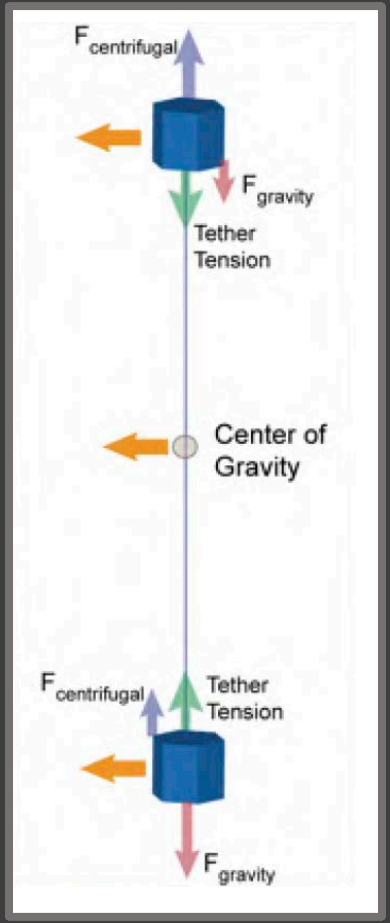
- **Periapsis fixed around 30º S**
- **Covers all strong crustal fields (≳ 300 nT at surface)**
- **Variable periapsis – minimum true altitude = 14.5 km**

Periapsis at Gerasimovich – minimum true altitude = 23.8 km

Frozen orbit not low enough over Gerasimovich for science requirements (altitude ≲ 20 km)

BOLAS Tethered Microsat Dynamics

Gravity gradient aligns and stabilizes tethered formation



Collier et al. (2016)

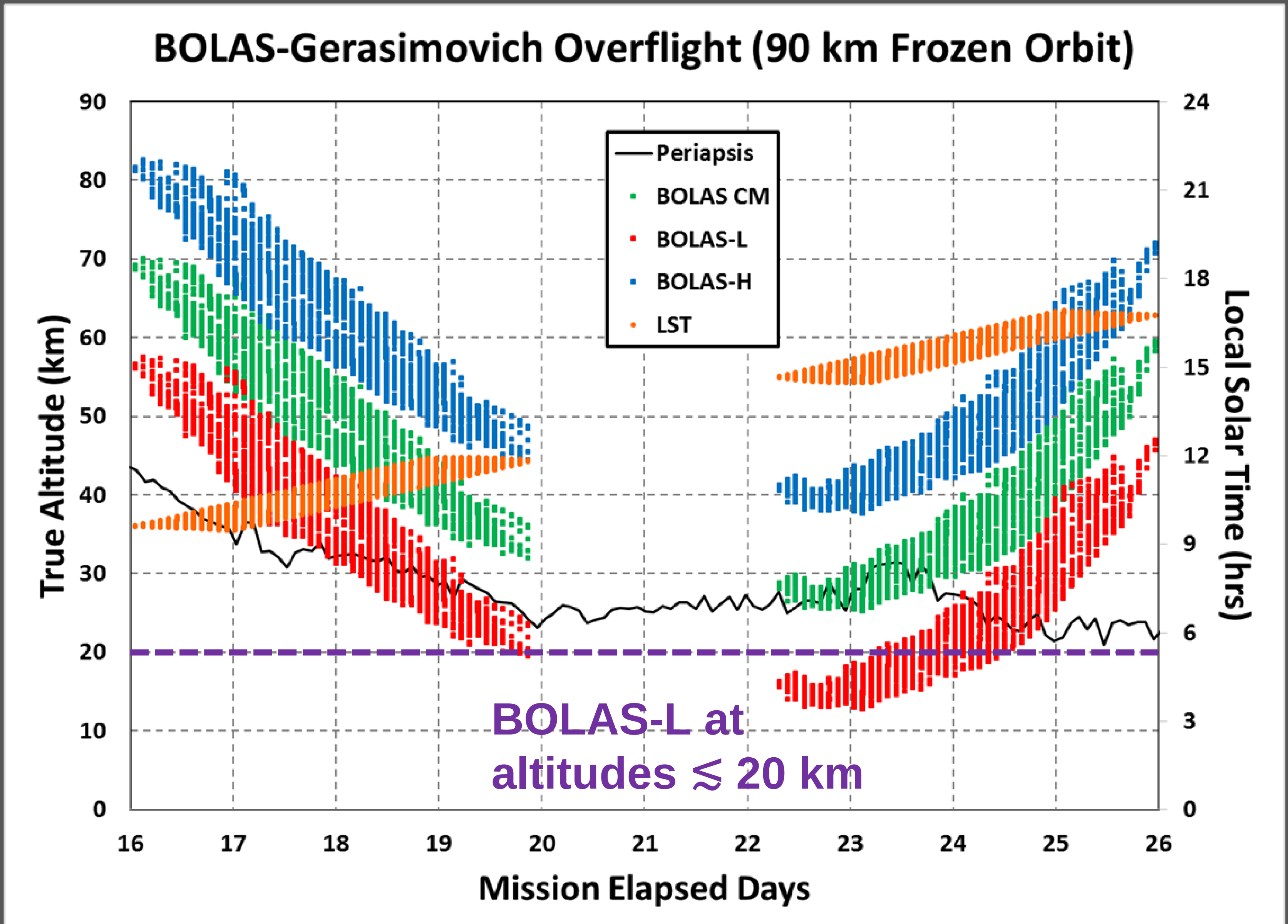
Tethered formation of two microsats enables lower spacecraft to obtain measurements closer to the Moon, while the center-of-mass of the formation follows the stable, frozen orbit.

BOLAS has 25 km-long tether, giving BOLAS-L

- **Periapsis true altitude = 2 km**
- **Gerasimovich periapsis true altitude = 11.3 km**

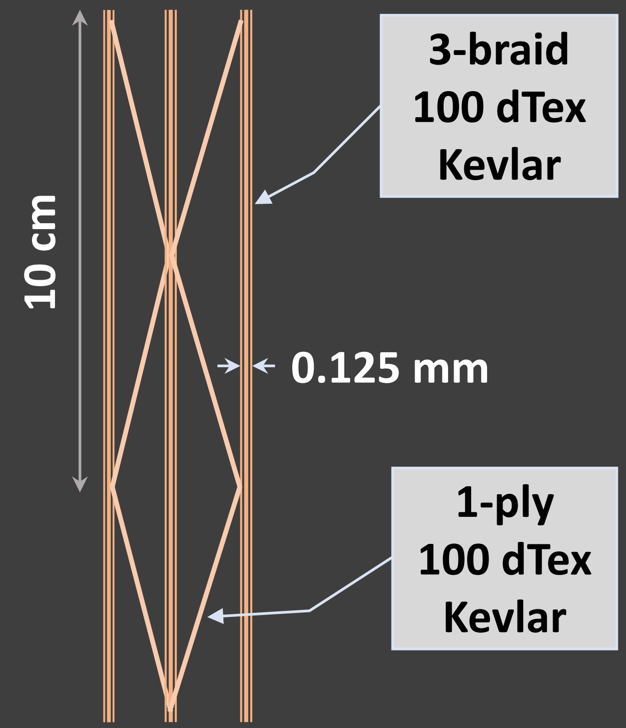
Addresses BOLAS science requirements for vertically-aligned, dual-point, low altitude ($\lesssim$ 20 km) measurements at Gerasimovich

BOLAS – Tethered Frozen Science Orbit

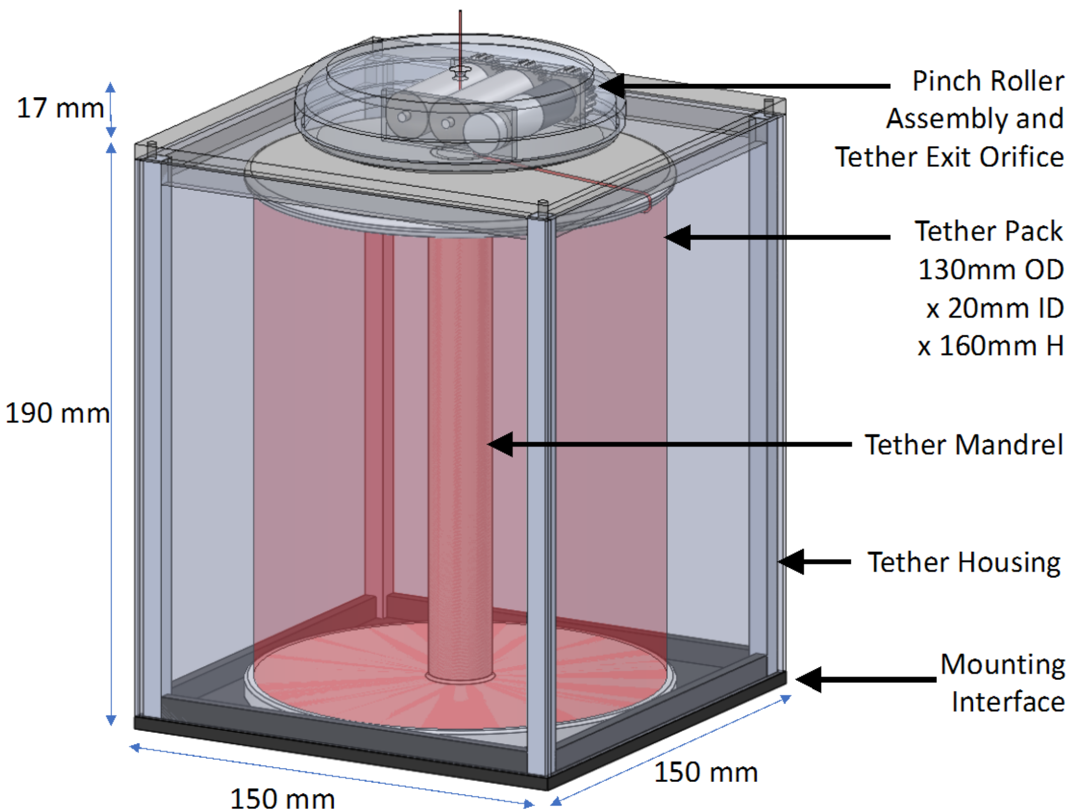


BOLAS – Tether and Deployer

Tether – Kevlar yarns braided into multi-line "Hoytether" structure to provide redundancy to survive meteoroid and exospheric dust impacts

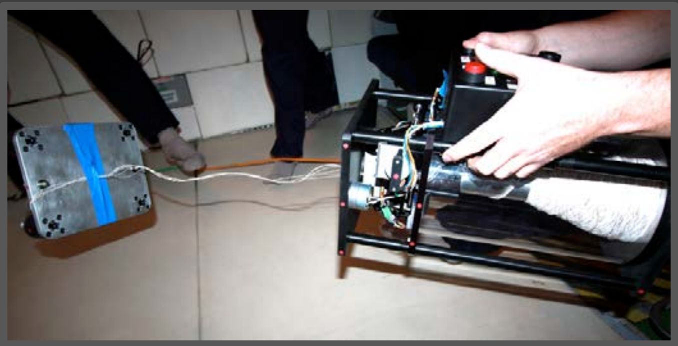


Tether Deployer System

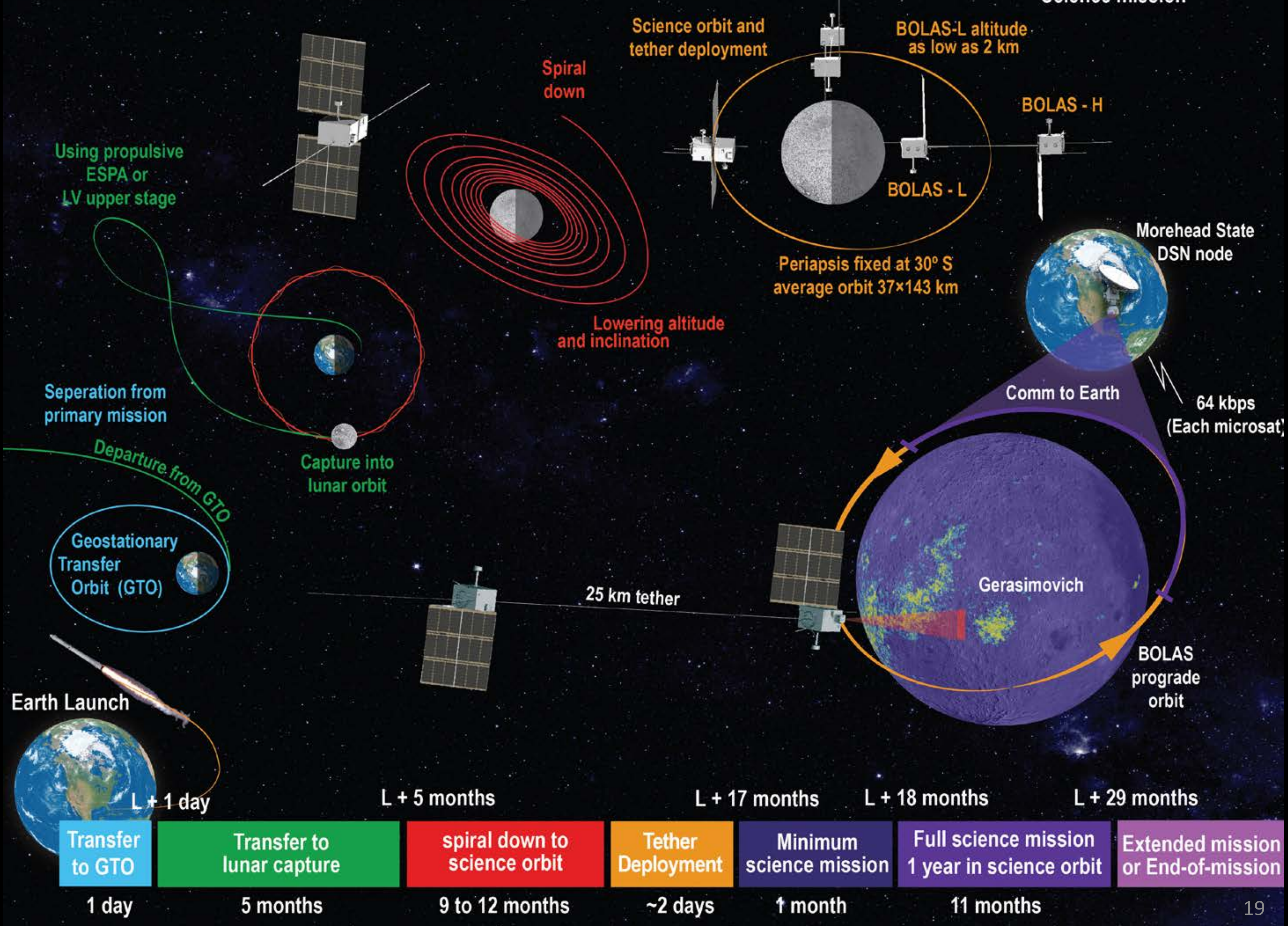


Tethers Unlimited, Inc.

Similar Deployer Tested in Microgravity for LOKI Program

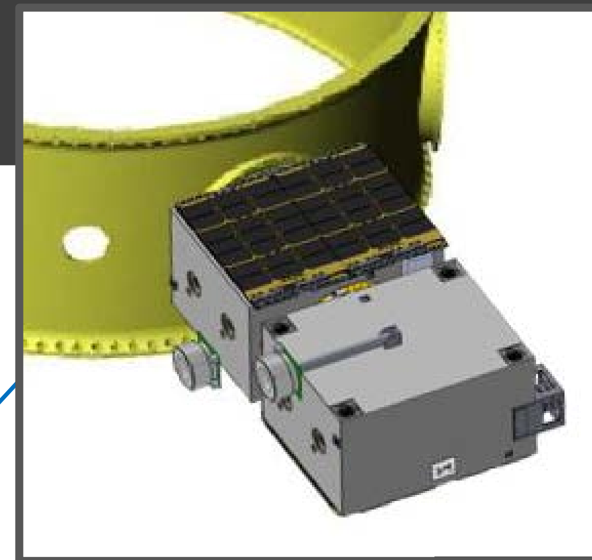


BOLAS Tethered Microsat ConOps

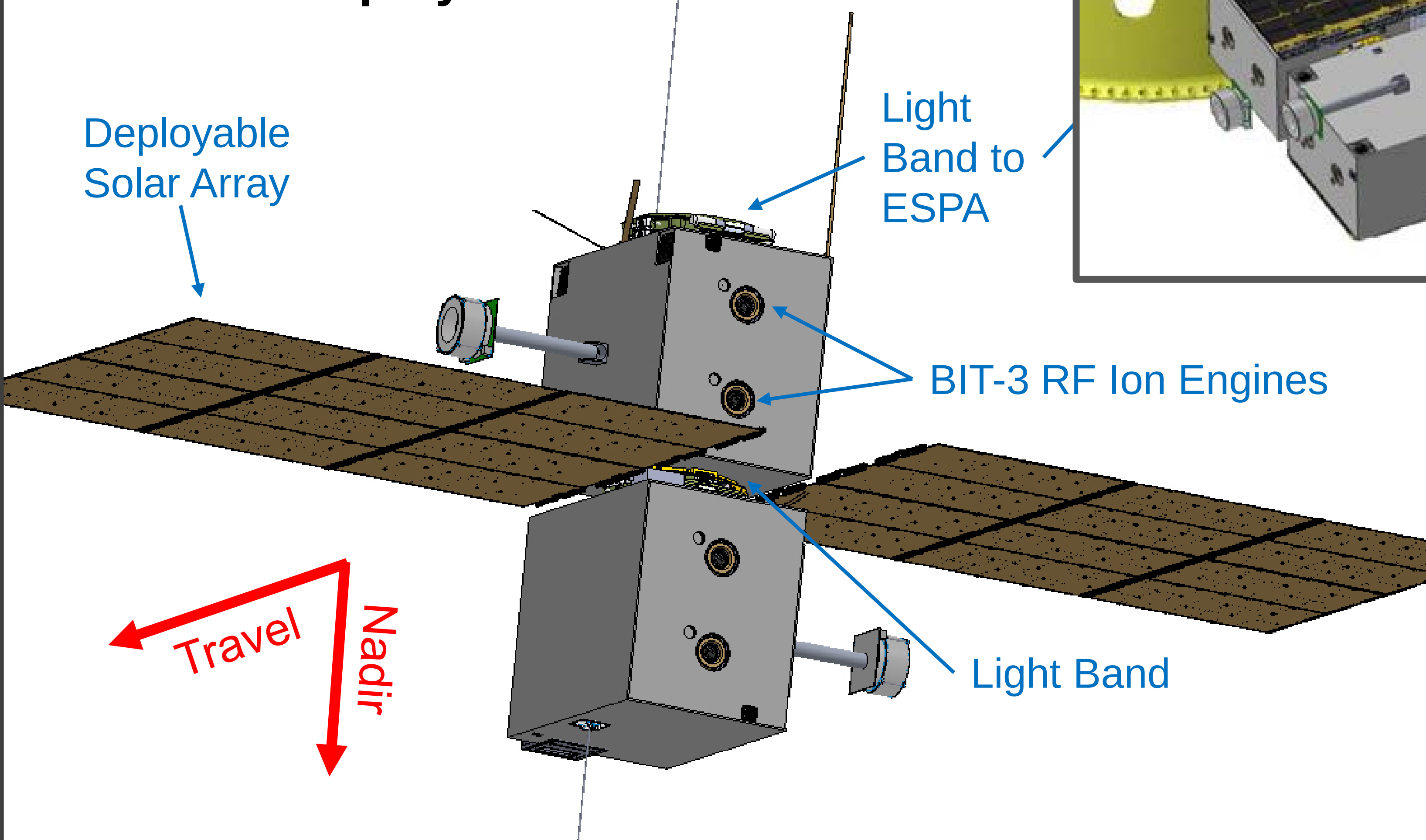


BOLAS Microsat Design

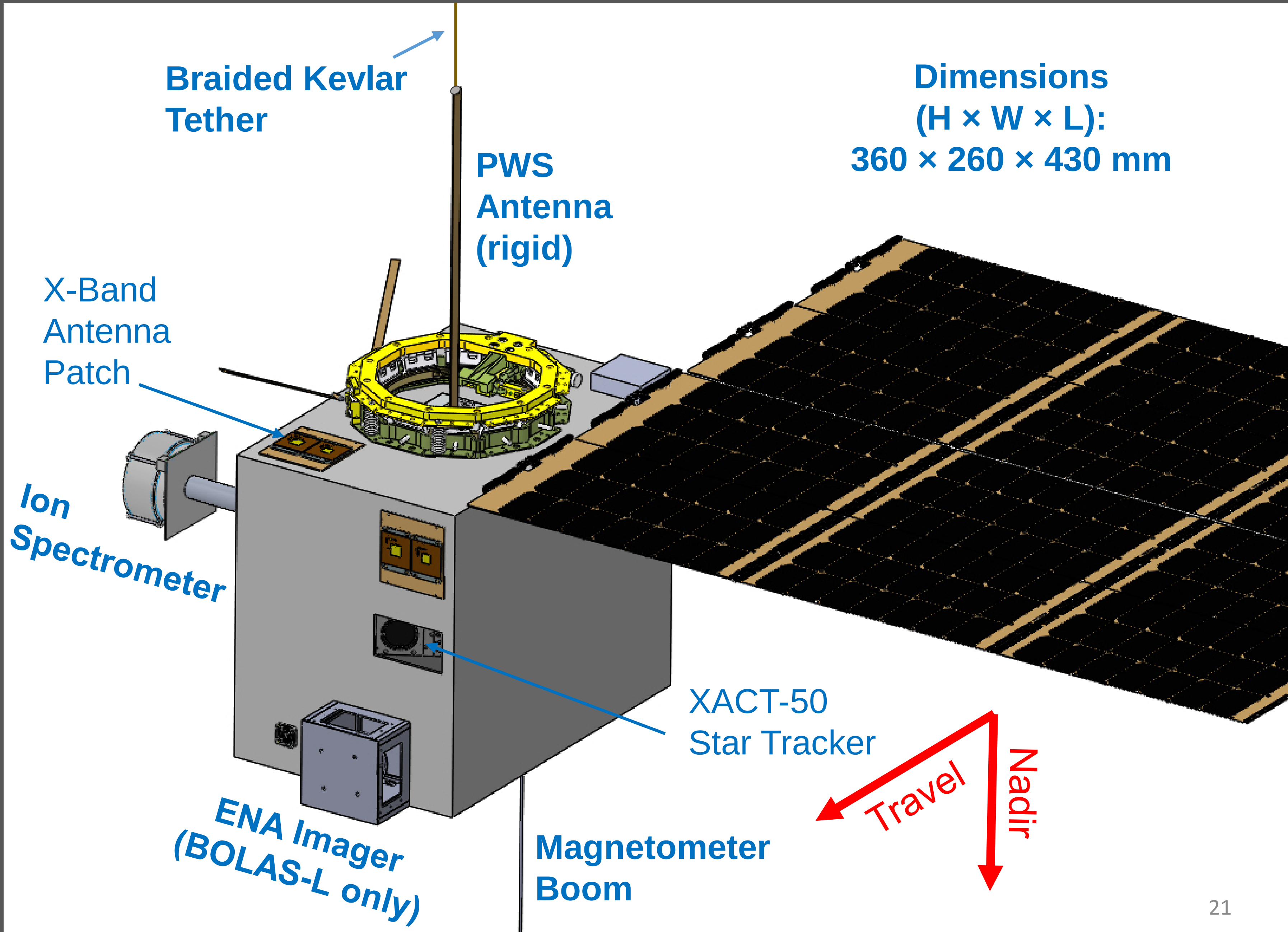
Stowed on ESPA ring



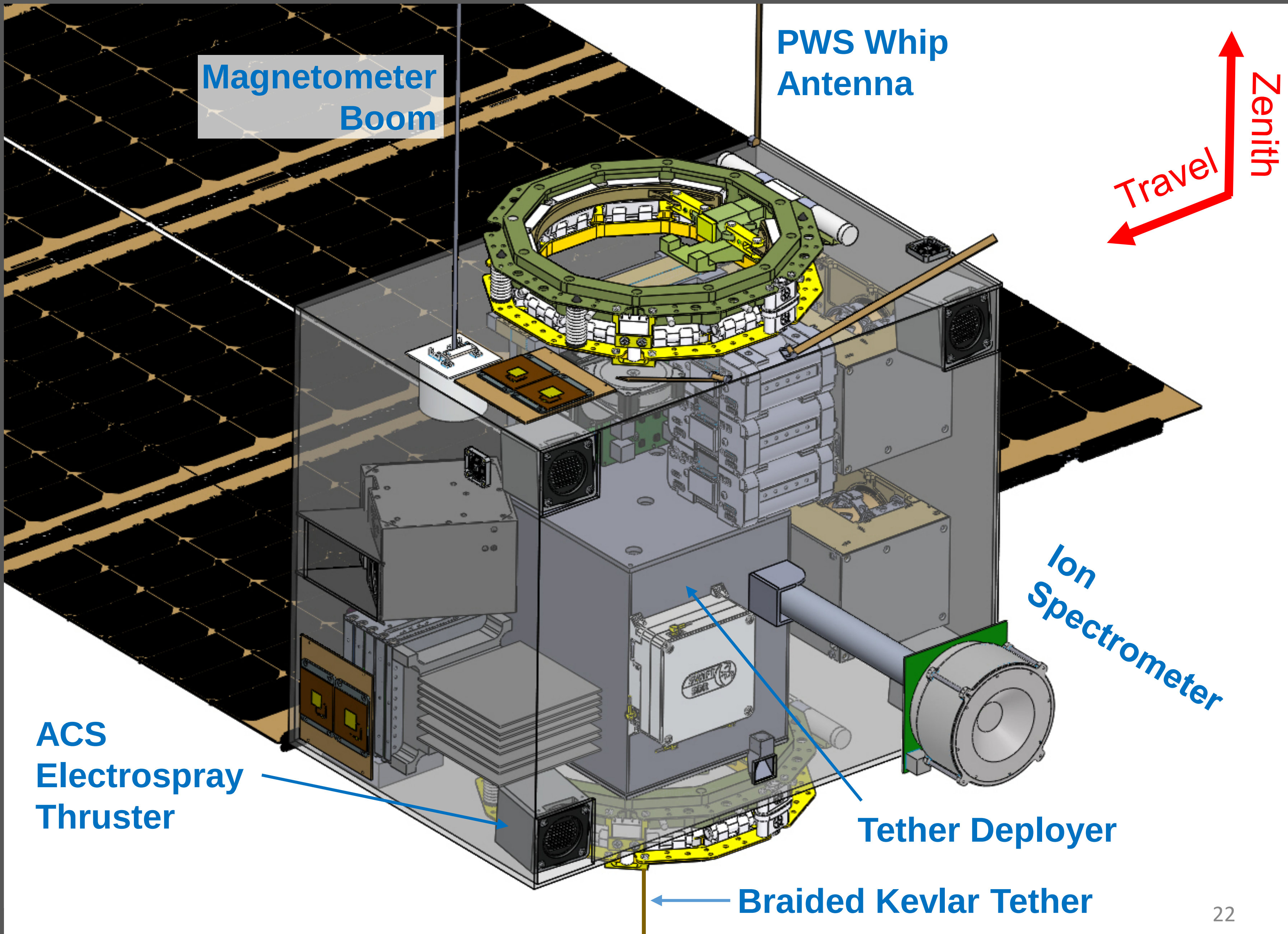
Configuration during Spiral Down



BOLAS-L – Post-Tether Deployment



BOLAS-H –Post-Tether Deployment



BOLAS Resources

Microsat	BOLAS-L	BOLAS-H
Mass [kg]	26.7	30.4
Peak power available [W]	240	240
Peak power required [W]	155	155
Telemetry available [kbps]	64	64
Telemetry required for primary science * [kbps]	39	39

* Assuming: 25% transponder duty cycle (~6 h per day)
10 / 90% split between burst and reduced modes

- Well within ESPA-class mass and volume limits
- Meets power and telemetry requirements
- Orbit-tether-instruments exceed science requirements

BOLAS Tethered Microsat ConOps