Elfen

A cubesat heavy ion composition experiment

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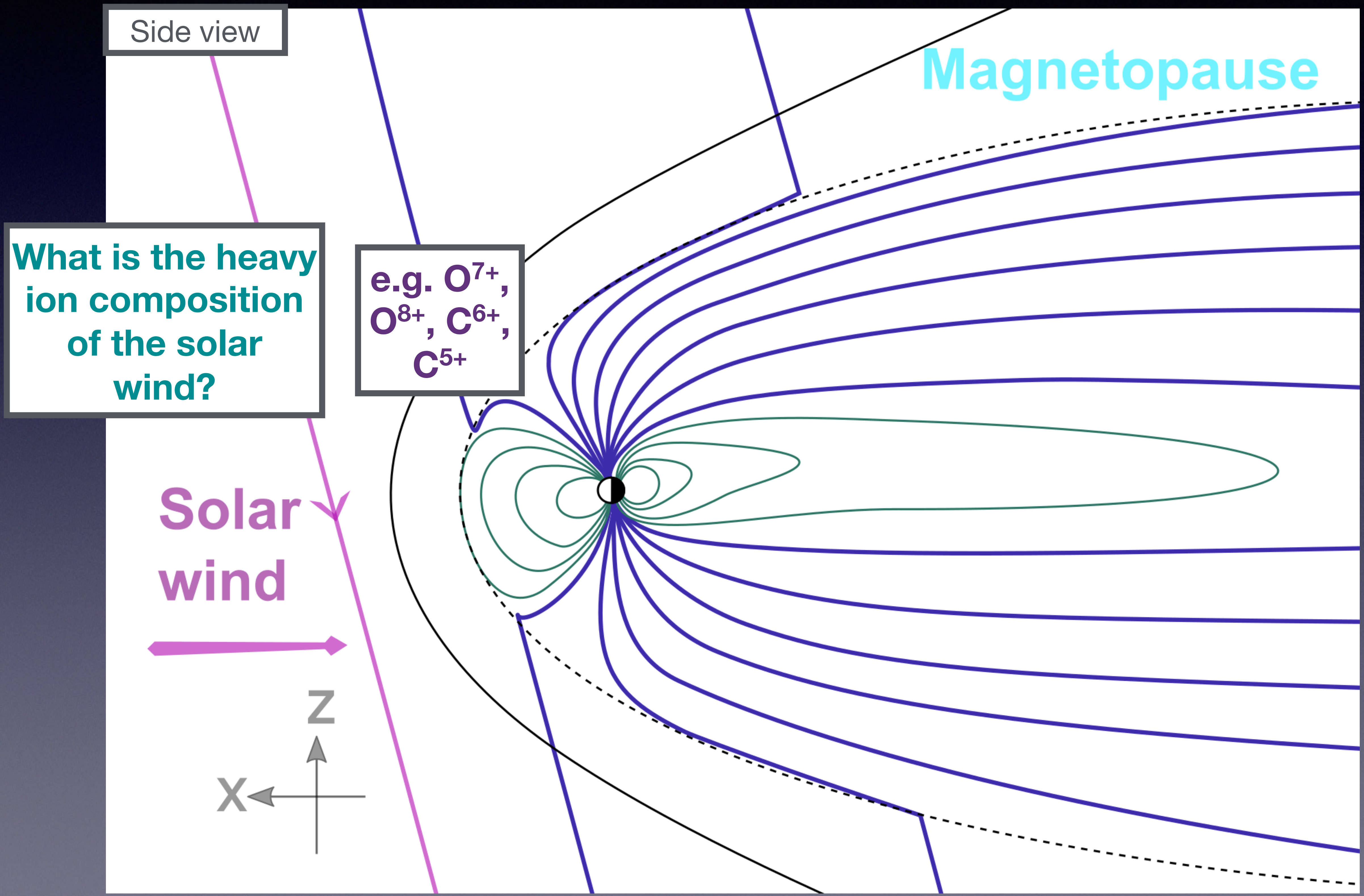
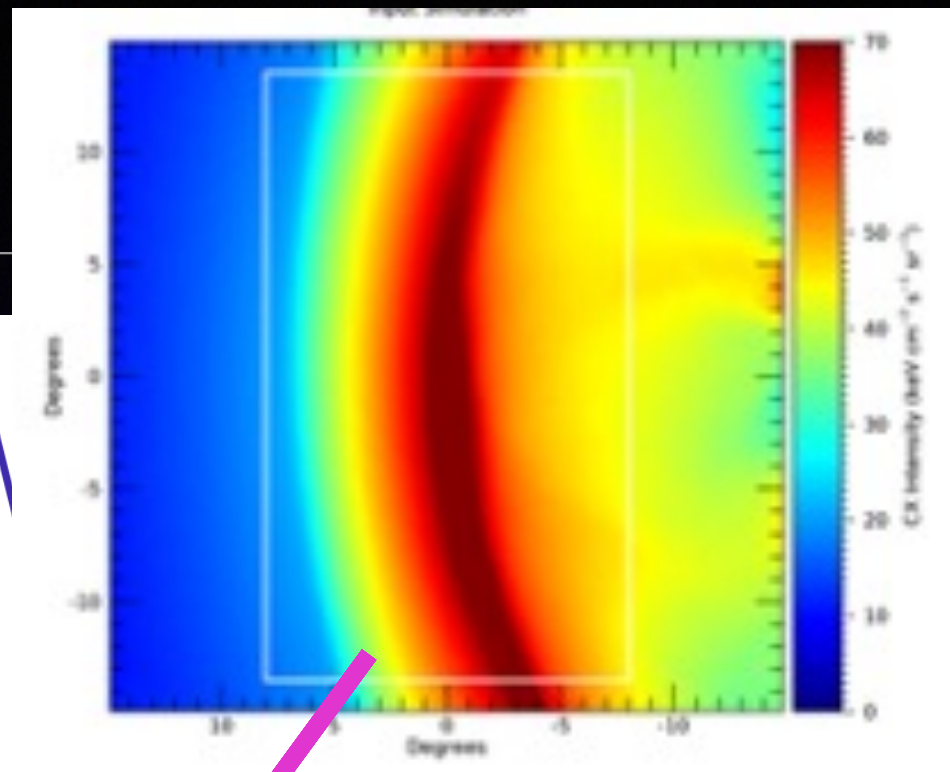
Imperial College London
University of Michigan
University of Leicester

Elfen: Why? Q1



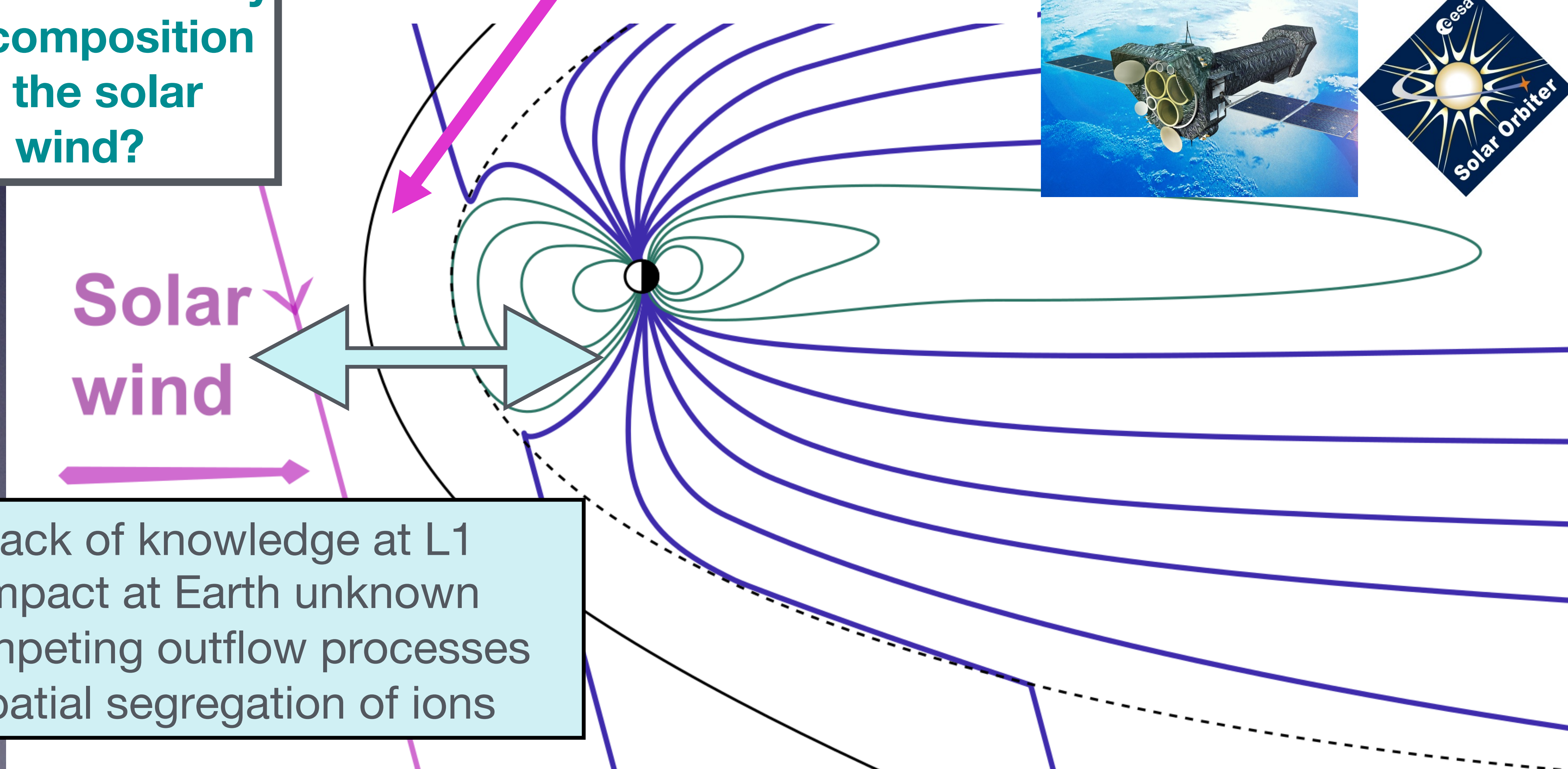
Side view
What is the heavy ion composition of the solar wind?
e.g. O^{7+}, O^{8+}, C^{6+}, C^{5+}
Magnetopause
Solar wind
Z
X

Elfen: Why?



Relevant to missions, incl.:

- SMILE
- LEXI
- LEM
- ATHENA
- Solar Orbiter



What is the heavy ion composition of the solar wind?

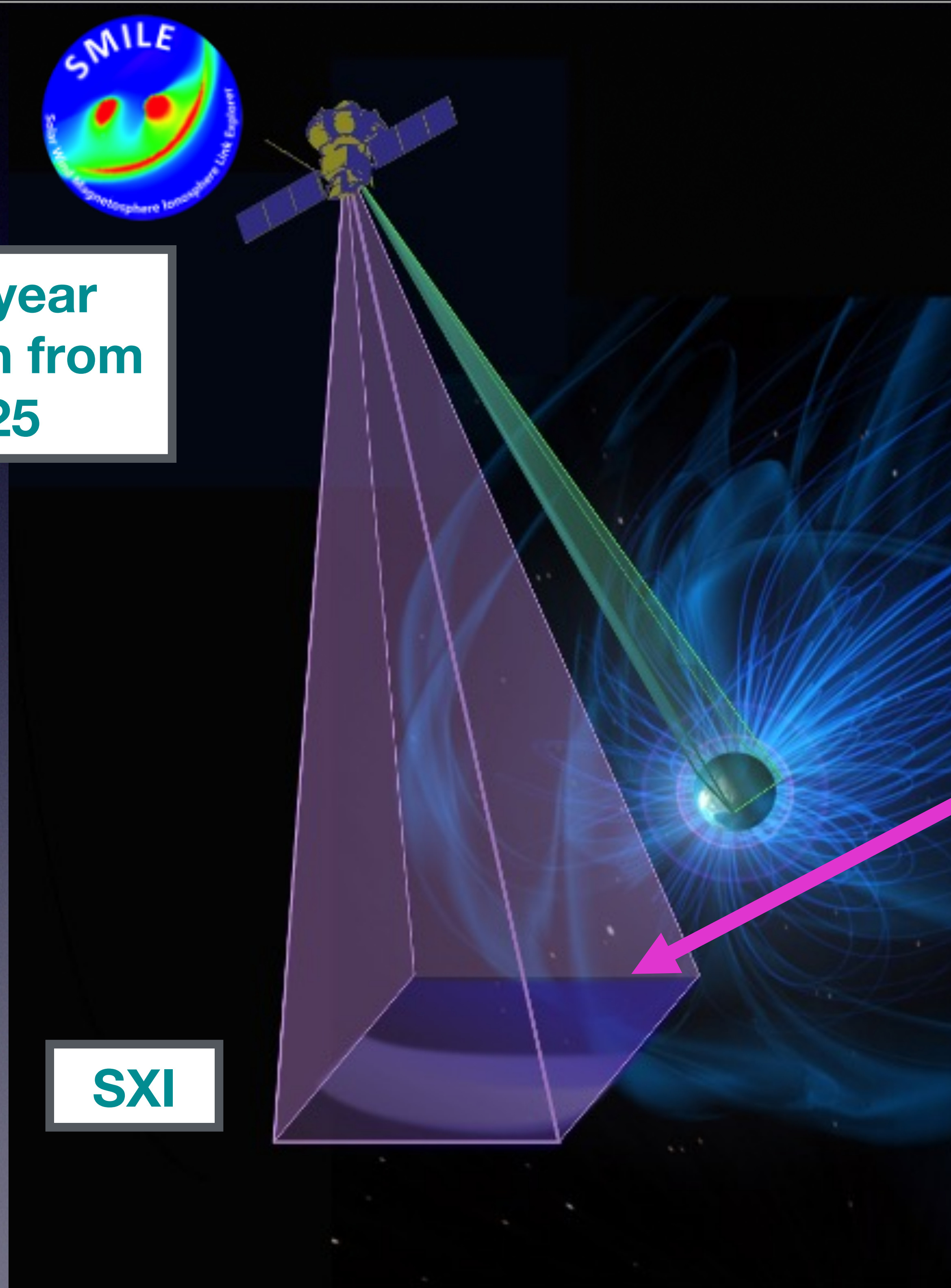
Lack of knowledge at L1
Impact at Earth unknown
Competing outflow processes
Spatial segregation of ions

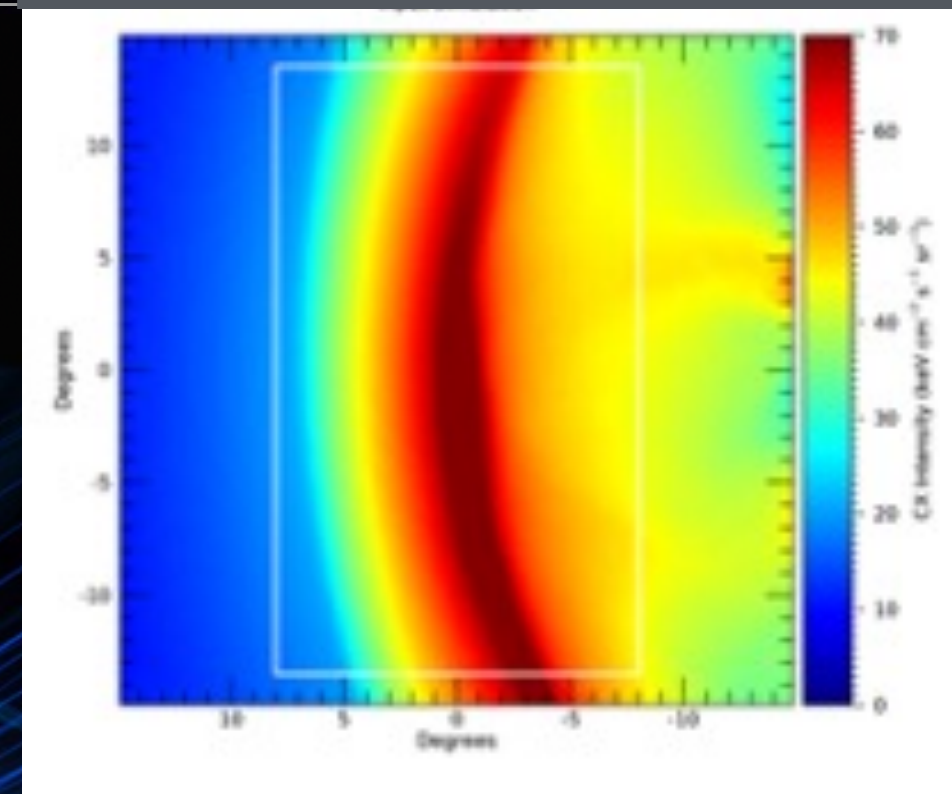
Solar wind charge exchange

Depends on:

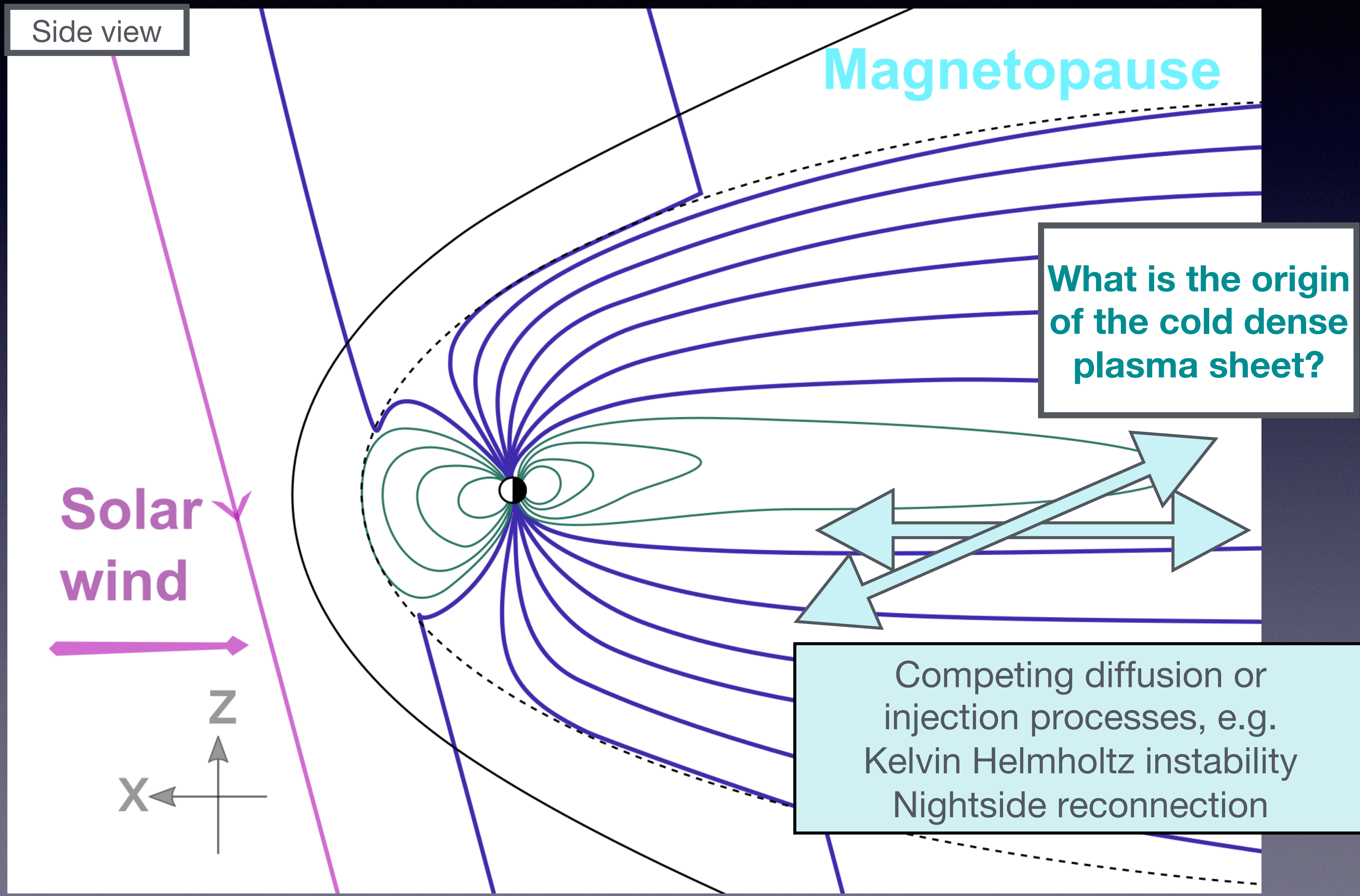
Solar wind composition
Solar wind flux
Exospheric hydrogen

3 - 7 year mission from 2025



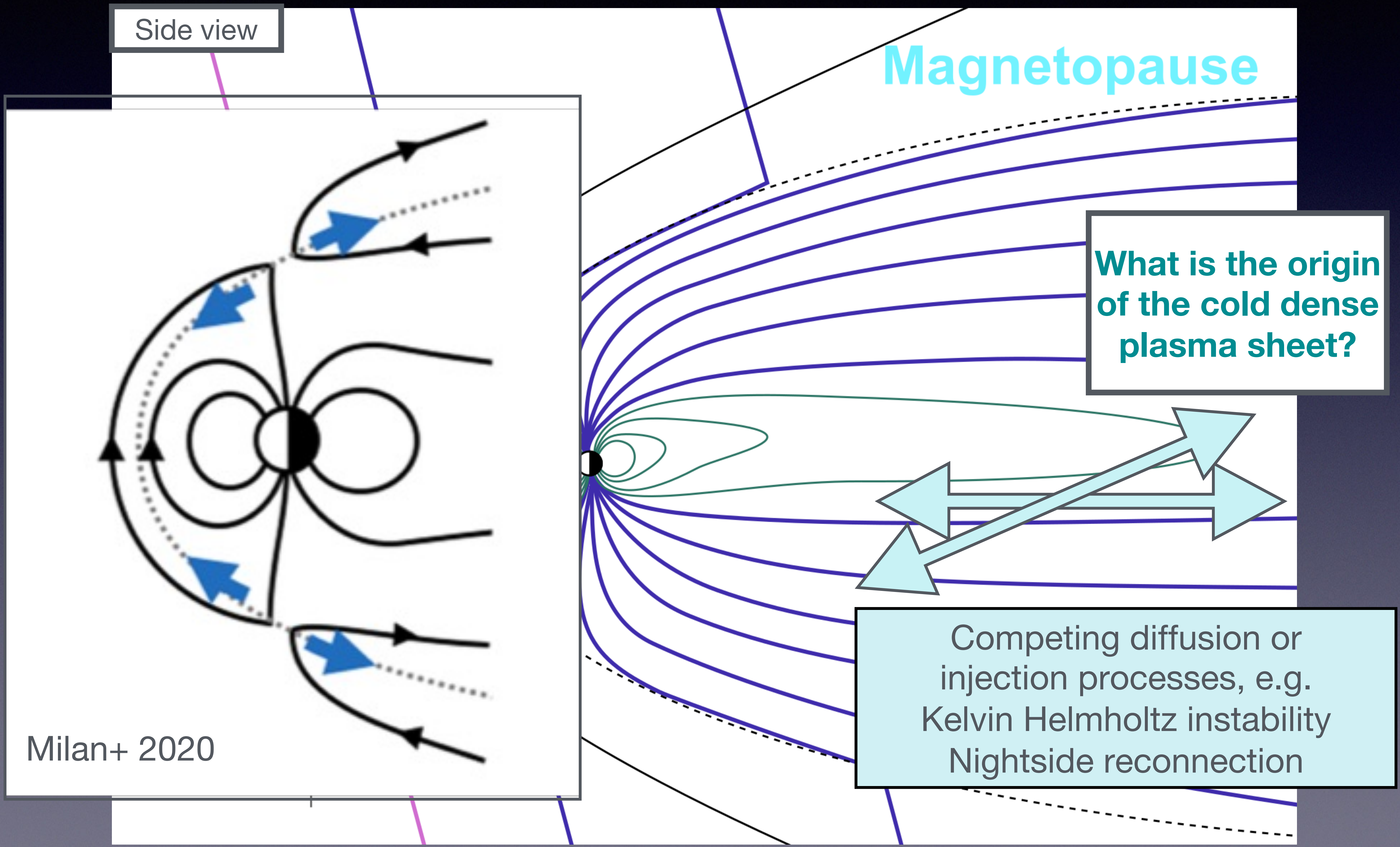


Elfen: Why? Q2

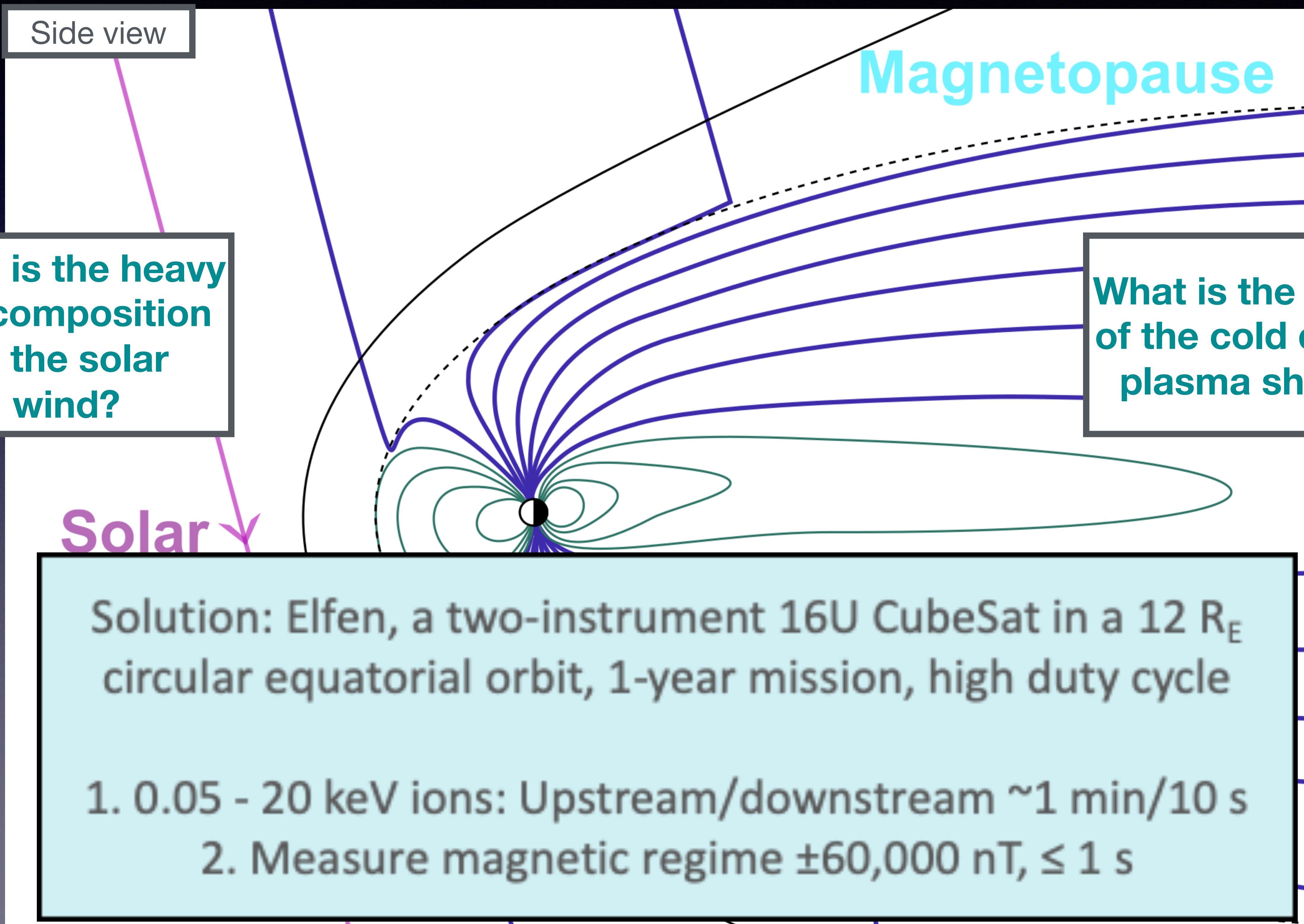


Side view
Magnetopause
Solar wind
Z
X
What is the origin of the cold dense plasma sheet?
Competing diffusion or injection processes, e.g.
Kelvin Helmholtz instability
Nightside reconnection

Elfen: Why? Q2


Side view
Magnetopause
What is the origin of the cold dense plasma sheet?
Competing diffusion or injection processes, e.g.
Kelvin Helmholtz instability
Nightside reconnection
Milan+ 2020

Elfen



What is the heavy ion composition of the solar wind?

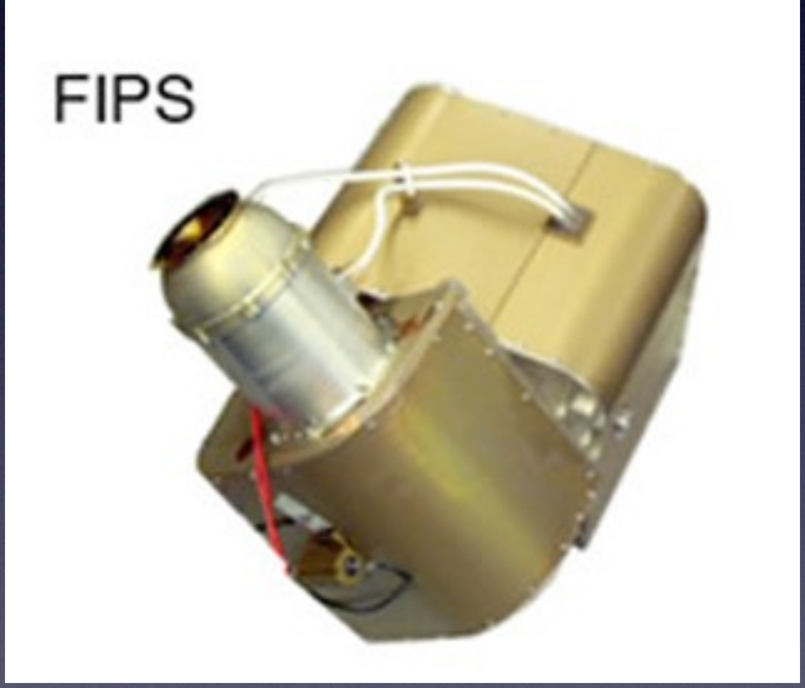
What is the origin of the cold dense plasma sheet?

Solution: Elfen, a two-instrument 16U CubeSat in a 12 R_E circular equatorial orbit, 1-year mission, high duty cycle

1. 0.05 - 20 keV ions: Upstream/downstream ~1 min/10 s
2. Measure magnetic regime ±60,000 nT, ≤ 1 s

Elfen instrument 1: T-FIPS

Heritage:
FIPS from MESSENGER
(High TRL)



Double-coincidence
measurements
ToF: E/q and m/q
Low charge-state ions

Sue Lepri, Jim Raines
UNIVERSITY OF MICHIGAN

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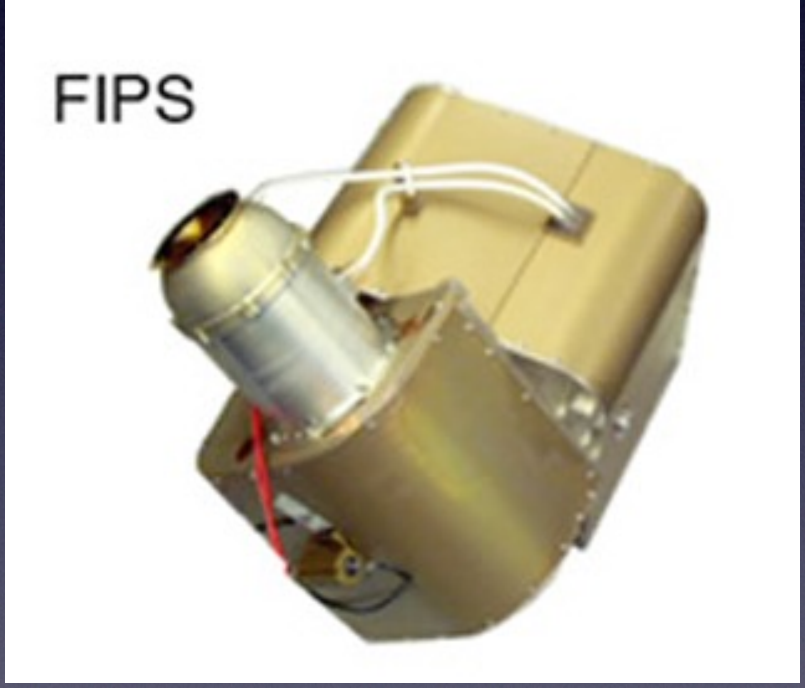


Double-coincidence
measurements
ToF: E/q and m/q
Low charge-state ions

Triple-coincidence measurements (T-FIPS)

Additional measurement
Uses SSD
Separates E, q, and m
High charge-state ions
T-shaped

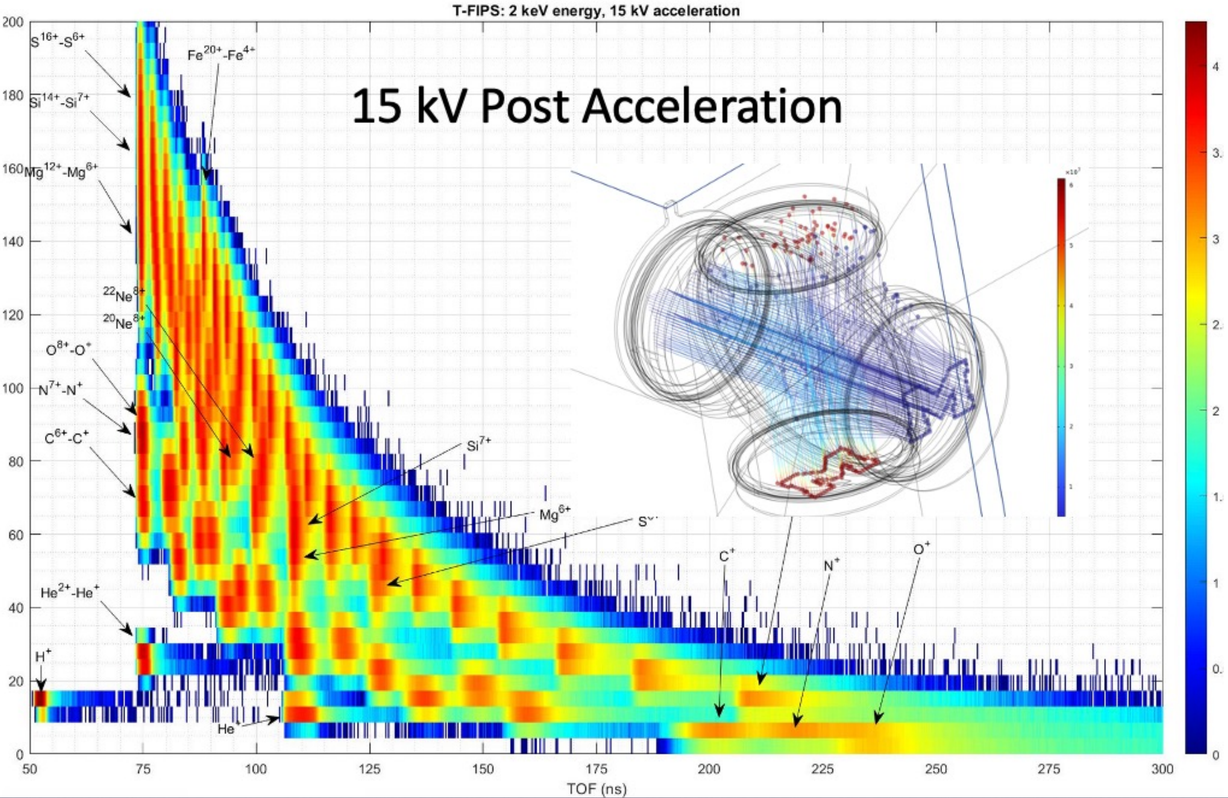
Requires incremental development

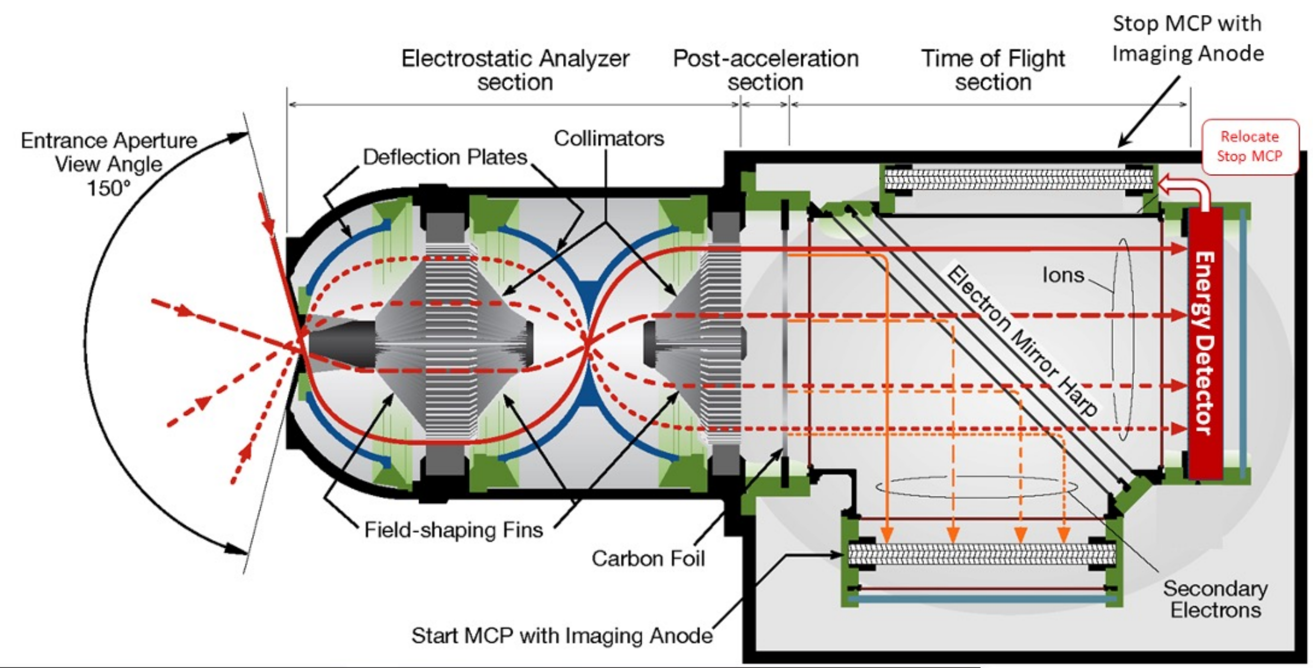
Sue Lepri, Jim Raines

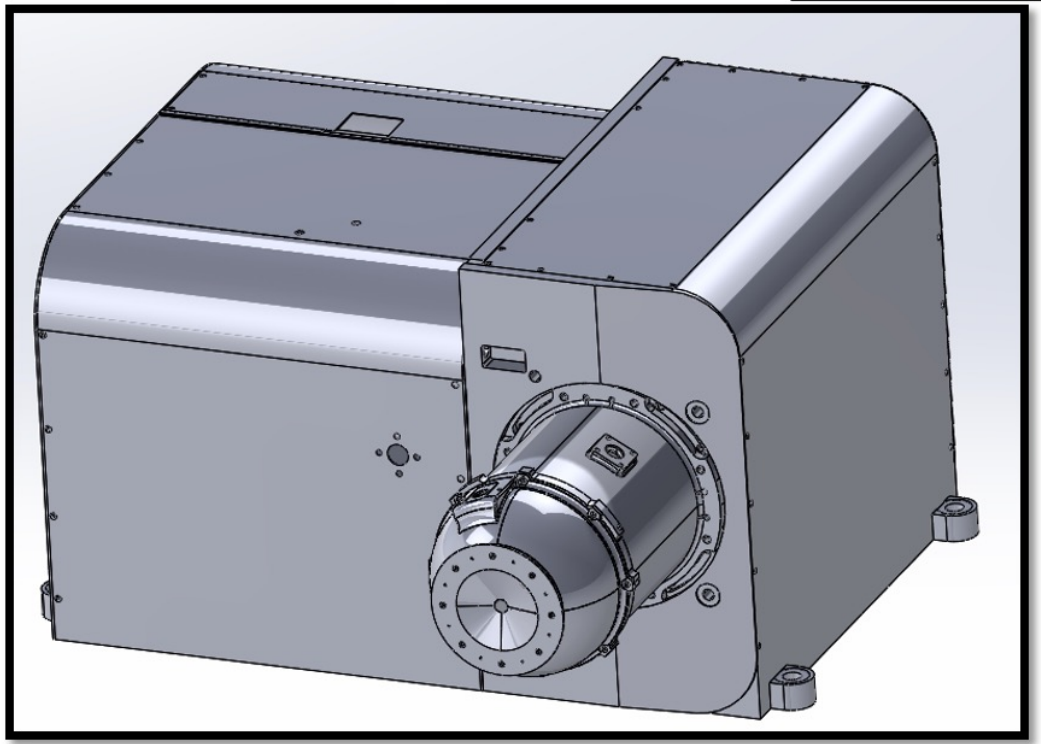
UNIVERSITY OF MICHIGAN

Elfen instrument 1: T-FIPS (Tyler Eddy, UoM)

Energy Resolution	**5%**	**Mass**	**~5 kg (no LVPS, no DPU)**
Energy Range	0.05 – 20 keV	Size	10 x 20 x 30 cm
Mass Resolution	7 – 15%	Power	~5 W
Mass Range	1 – 44 amu/e	Bit rate	> 100 bps
Field of View	1.4π	Scan Speed	60s (nom) < 10s (burst)
Angular Resolution	15°	Measured Ions	≤1500 km/s: H^+ ≤1100 km/s: He^{1-2+}, C^{4-6+}, O^{6-8+} ≤800 km/s: Fe^{10-16+} ≤600 km/s: C^{2-3+}, O^{2-5+}, Fe^{6-9+}
Geometric Factor	0.1 mm² sr eV/eV		







SPRL SPACE PHYSICS RESEARCH LABORATORY

MICHIGAN ENGINEERING UNIVERSITY OF MICHIGAN

Imperial College London

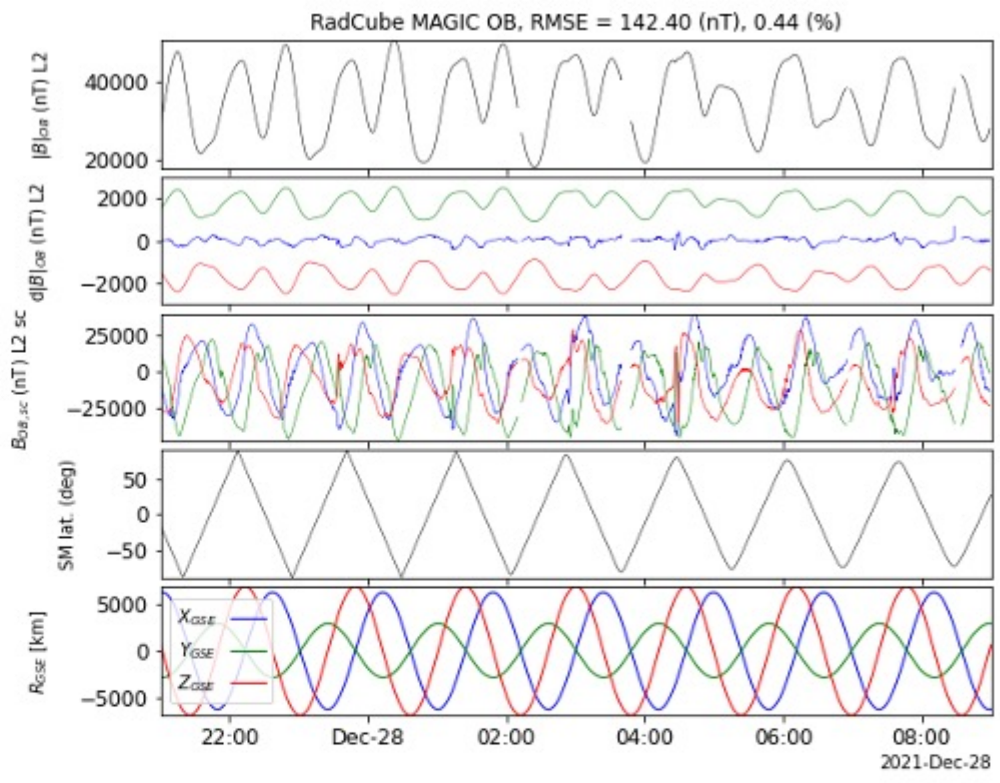
Elfen instrument 2: MAGIC (Patrick Brown, ICL)

MAGIC RadCube	
Volume	Electronics 95x86.5x10 mm^3 Sensor 21x21x12 mm^3
Mass	23 g (Sensor+harness) 38 g (Electronics)
Power	0.48 W (12V DC)
Range	± 60 000 nT
Performance	114 pT digital resolution <500 pT/√Hz at 1 Hz
Cadence	1 vector/s – 25vector/s

Exceeded accuracy for ESA space weather product (1% cf 5%)

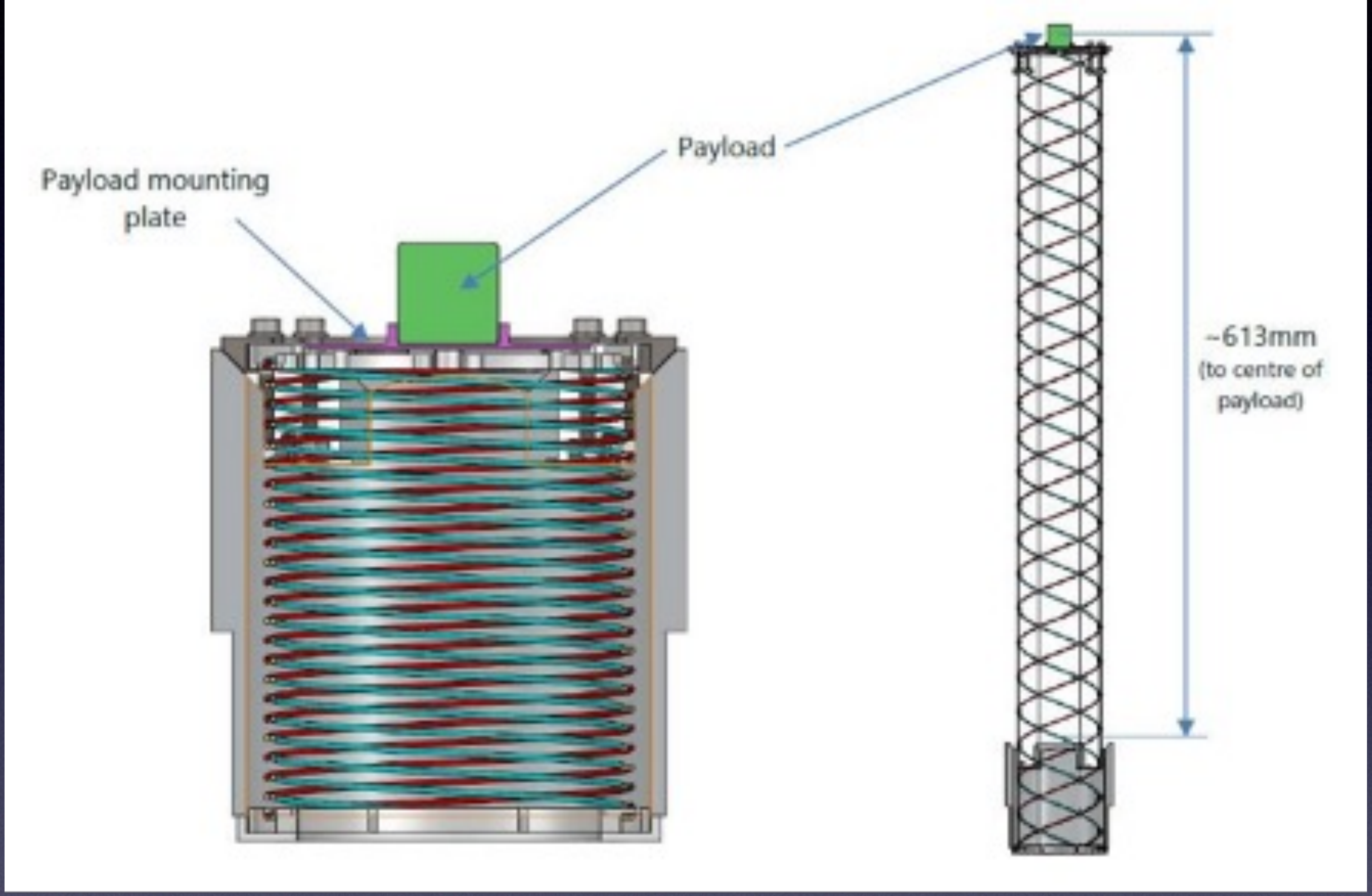
Launched in 2017

Image credit Arianespace
https://www.arianespace.com/press-release/vv19-vega-launch-success/



Elfen instrument 2: MAGIC

Heritage:
e.g. ESA RadCube Sat Space Weather Demonstrator (High TRL)



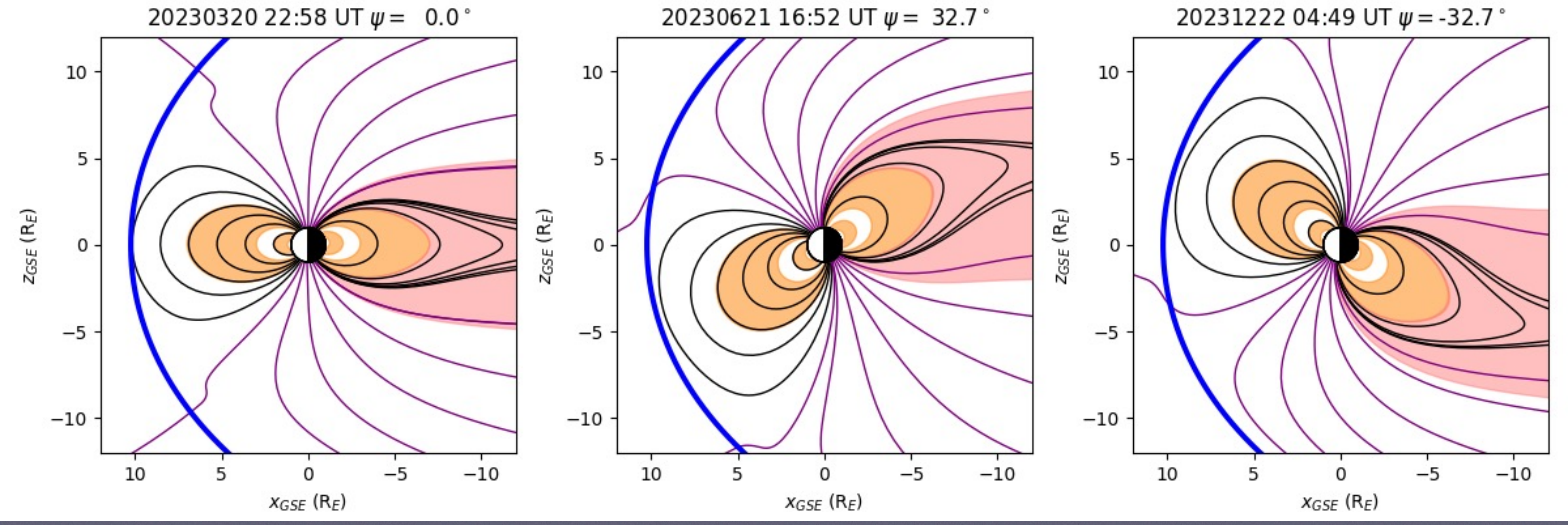
2 nT, 1 s accuracy to establish boundaries
< 1 s for waves
Outboard sensor on 0.6 m boom, Oxford Space
Inboard on electronics card for S/C field

Tri-axial dual sensor DC magnetometer
0 - 10 Hz
+/- 60,000 nT

Imperial College London

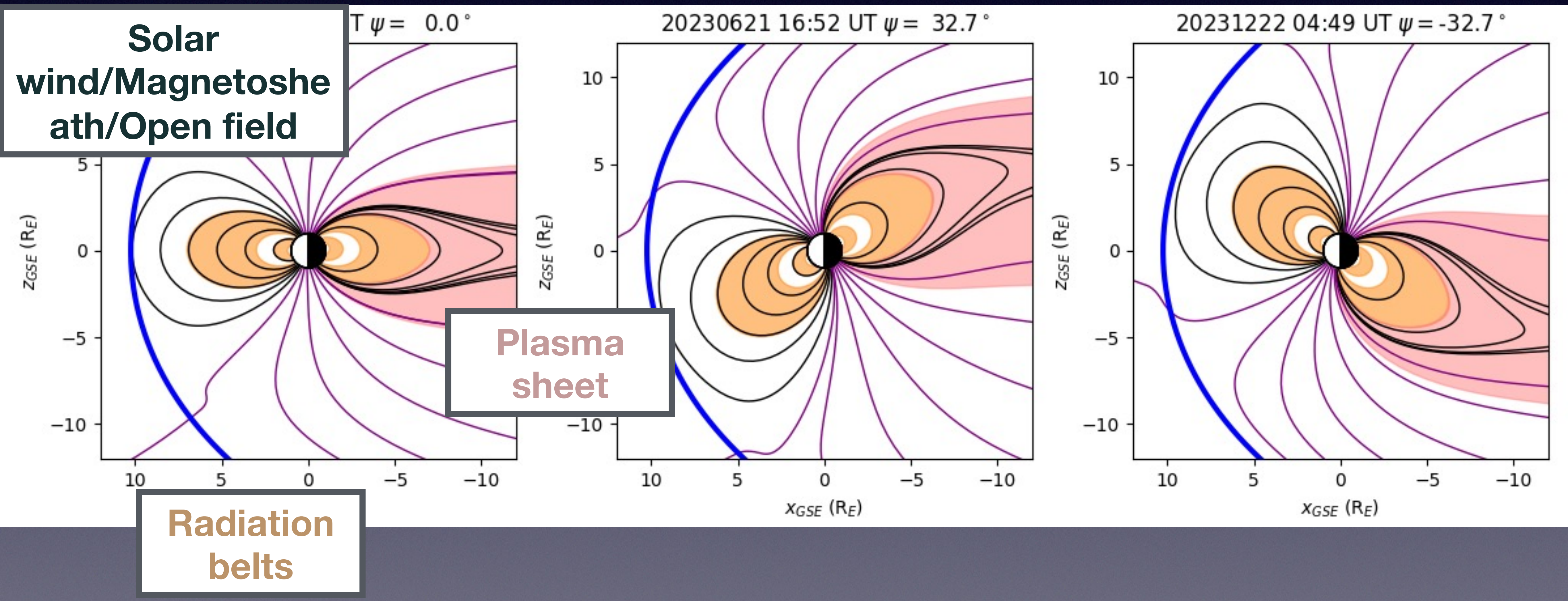
Elfen: Orbit: Season

- Tsyganenko model: Dynamic pressure, Interplanetary Magnetic Field, Ring current



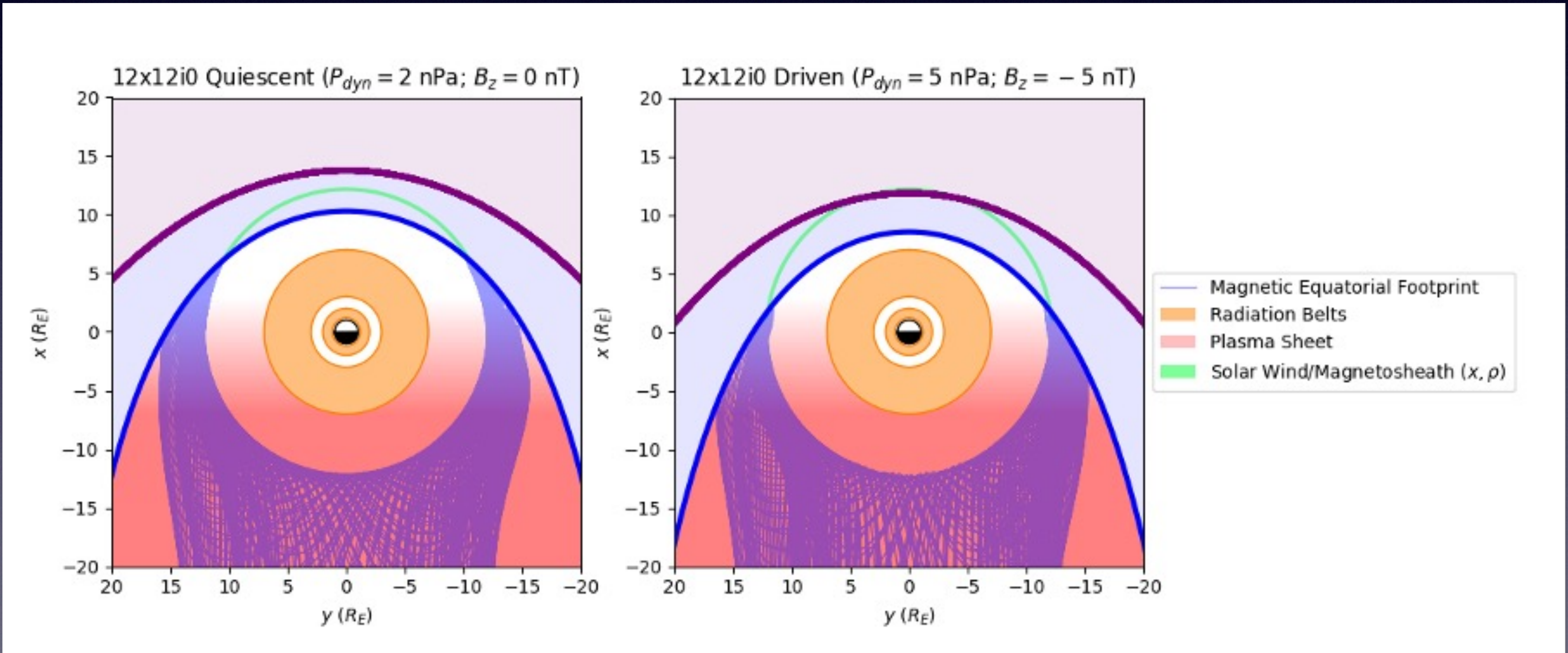
Elfen: Orbit: Season

- Tsyganenko model: Dynamic pressure, Interplanetary Magnetic Field, Ring current



Elfen: Orbit: Quiet vs Driven

- Tsyganenko model: Dynamic pressure, Interplanetary Magnetic Field, Ring current
- Looked at various orbits; 12 RE circular equatorial, inclination 23.5°, RAAN 270°



~33.5 % Magnetosheath
~66.5 % Plasma sheet

~34 % Magnetosheath + 11 % > Bow shock
~55 % Plasma sheet

Elfen: Orbit: Quiet vs Driven

- Tsyganenko model: Dynamic pressure, Interplanetary Magnetic Field, Ring current
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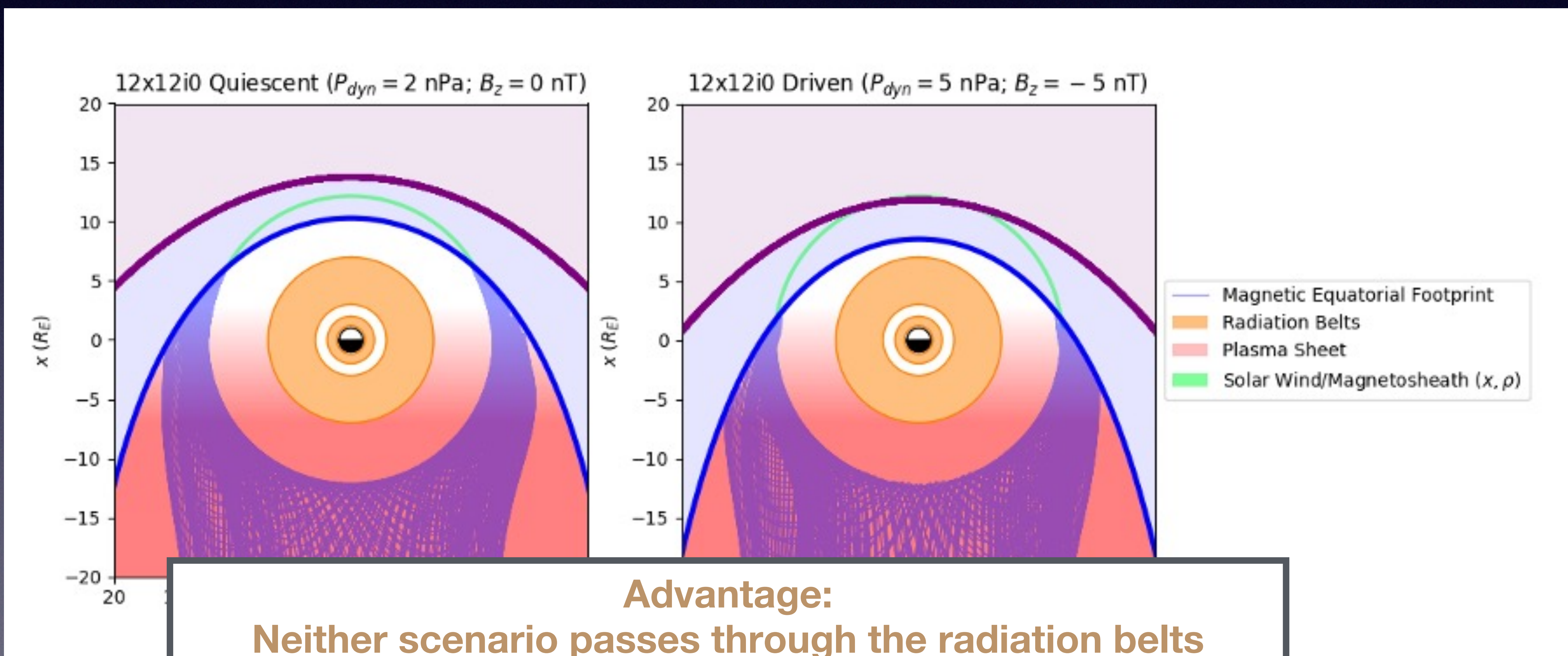


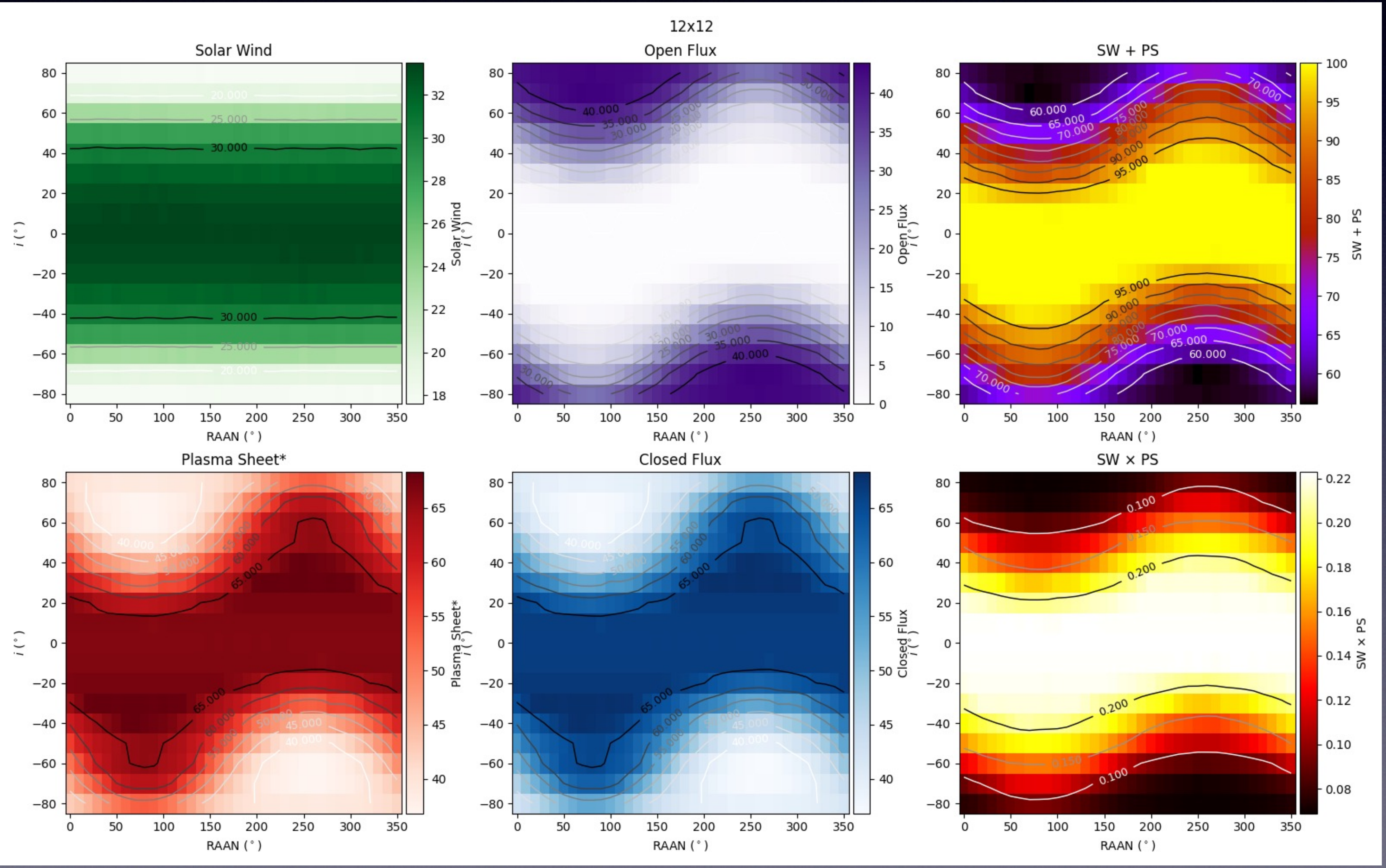
Advantage:
Neither scenario passes through the radiation belts

~33.5 % Magnetosheath
~66.5 % Plasma sheet

~34 % Magnetosheath + 11 % > Bow shock
~55 % Plasma sheet

Elfen: Orbit: Inclination trade offs

- Tsyganenko model: Dynamic pressure, Interplanetary Magnetic Field, Ring current



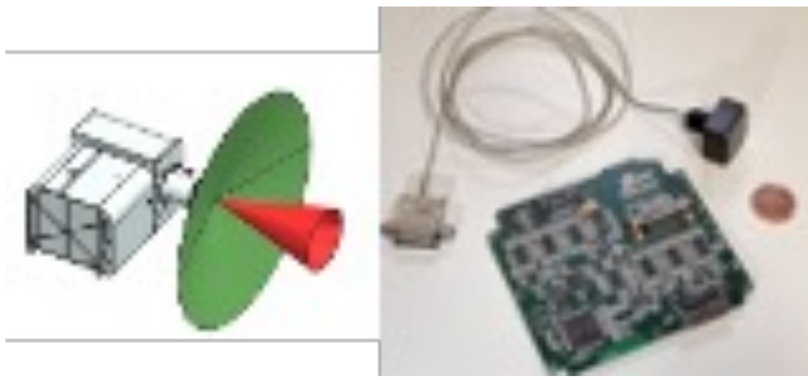
Elfen: CDF at Space Park Leicester, early 2023

- Mission chosen internally to commission CDF
- Multiple sessions over February and March 2023
- Domain Expert Studies, COMET analysis
- Significant progress beyond initial CDF

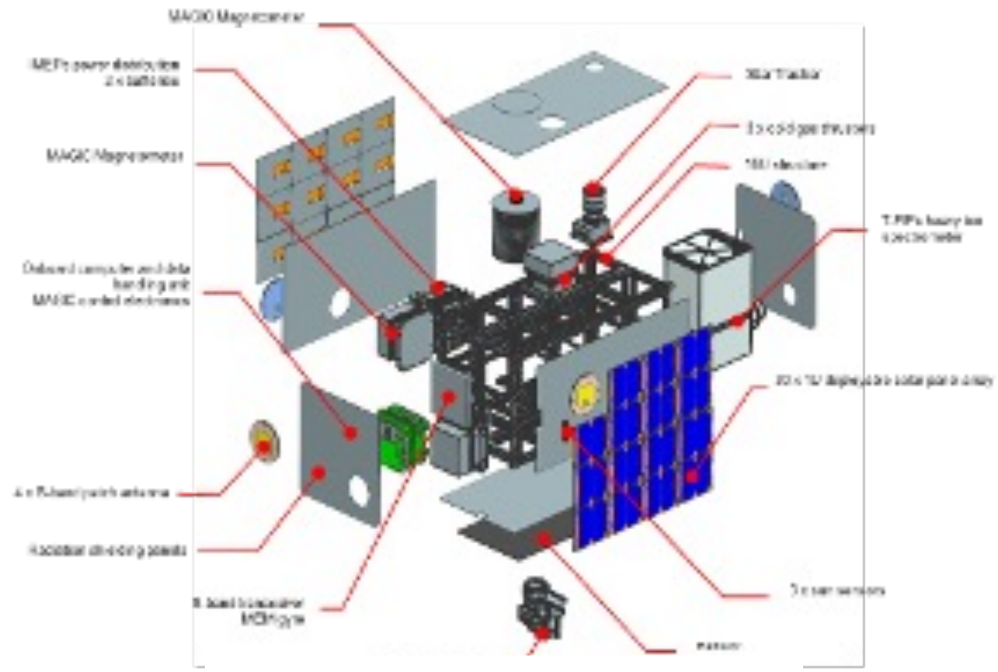
Space Park Leicester

UNIVERSITY OF LEICESTER

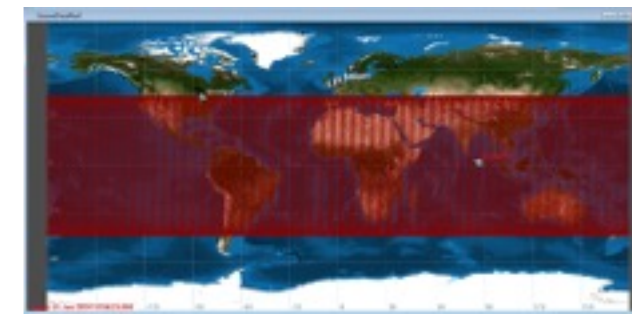
Elfen: Initial trade offs during CDF



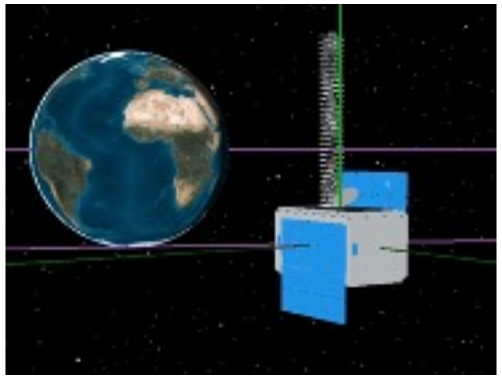
Science



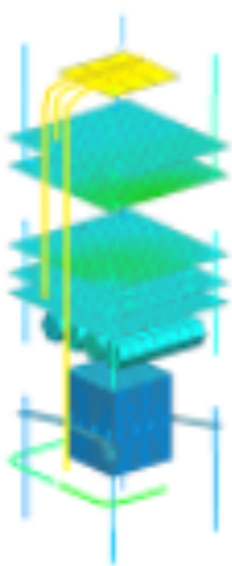
Structure & systems



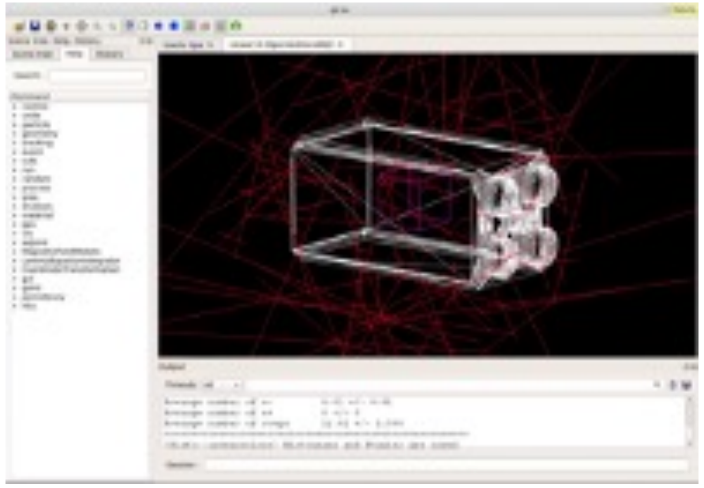
Communications



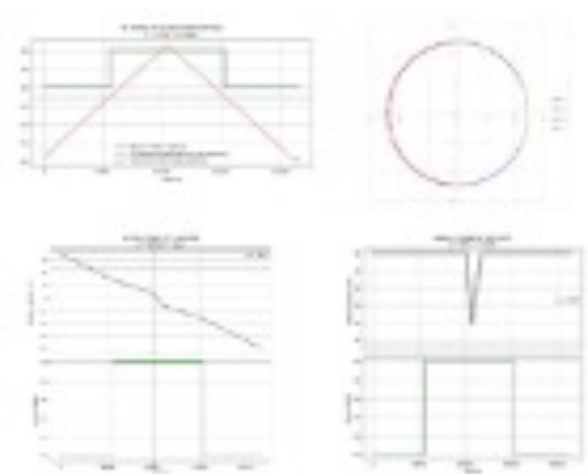
Attitude orbit control



Thermal

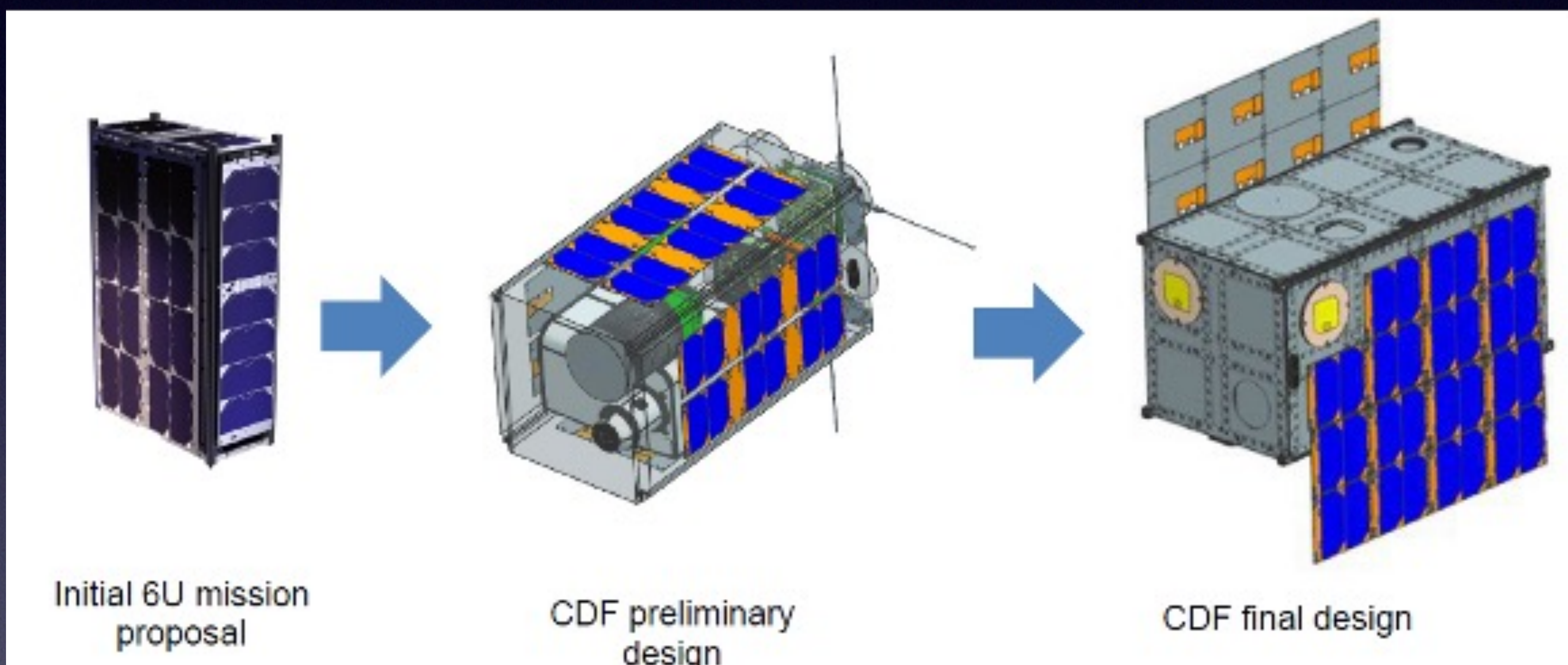


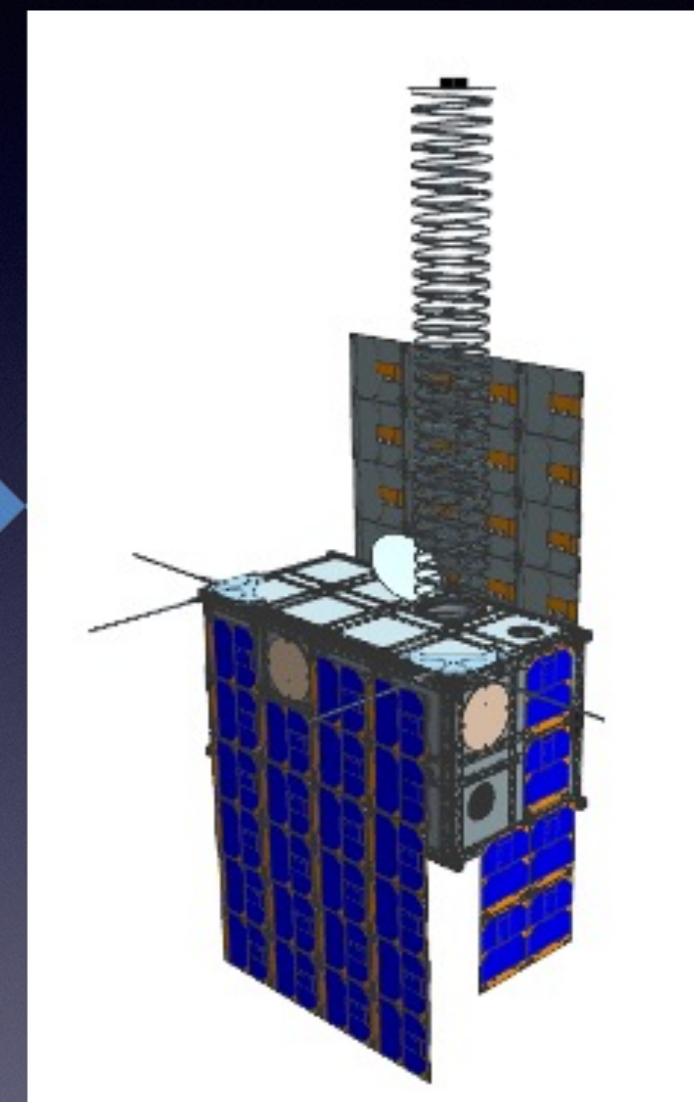
Radiation



Power

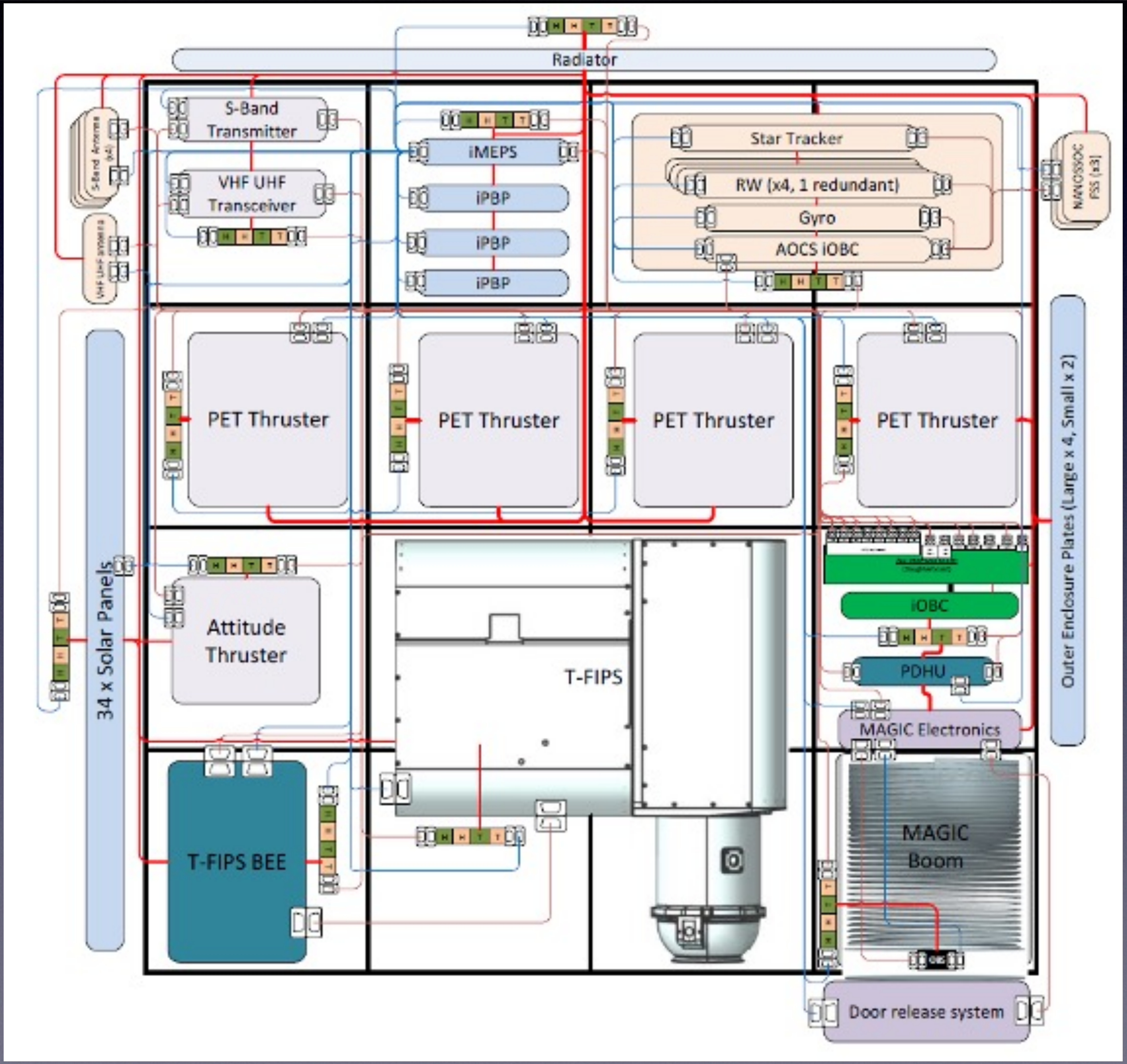
Elfen: Engineering now (B. Narasimha-Swarmy)



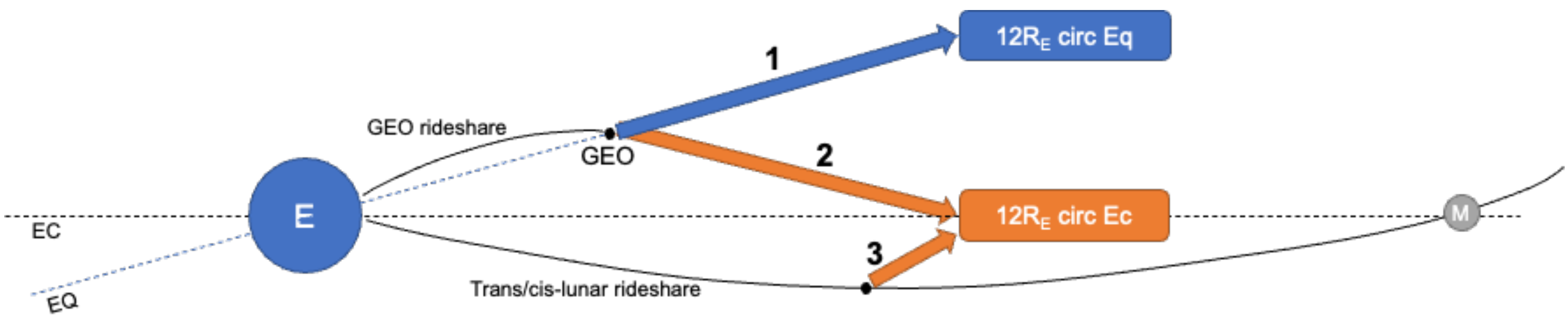


Elfen: Current

- Systems
- Science
- Payload
- Communication
- Attitude orbit control
- Power
- Radiation
- Thermal



Elfen: Launch driving mass budget



1. 19 kNs, 6 kg system
2. >19 kNs, >6 kg?
3. <19 kNs, <6kg?

Elfen: Mission team experience & philosophy

Undergraduate & postgraduate training

Mission studies, operations

Early Career Researchers

To be given early positions of responsibility, opportunities for development & training

Public engagement

Space plasmas, Earth & Sun
Space weather
Context of other missions

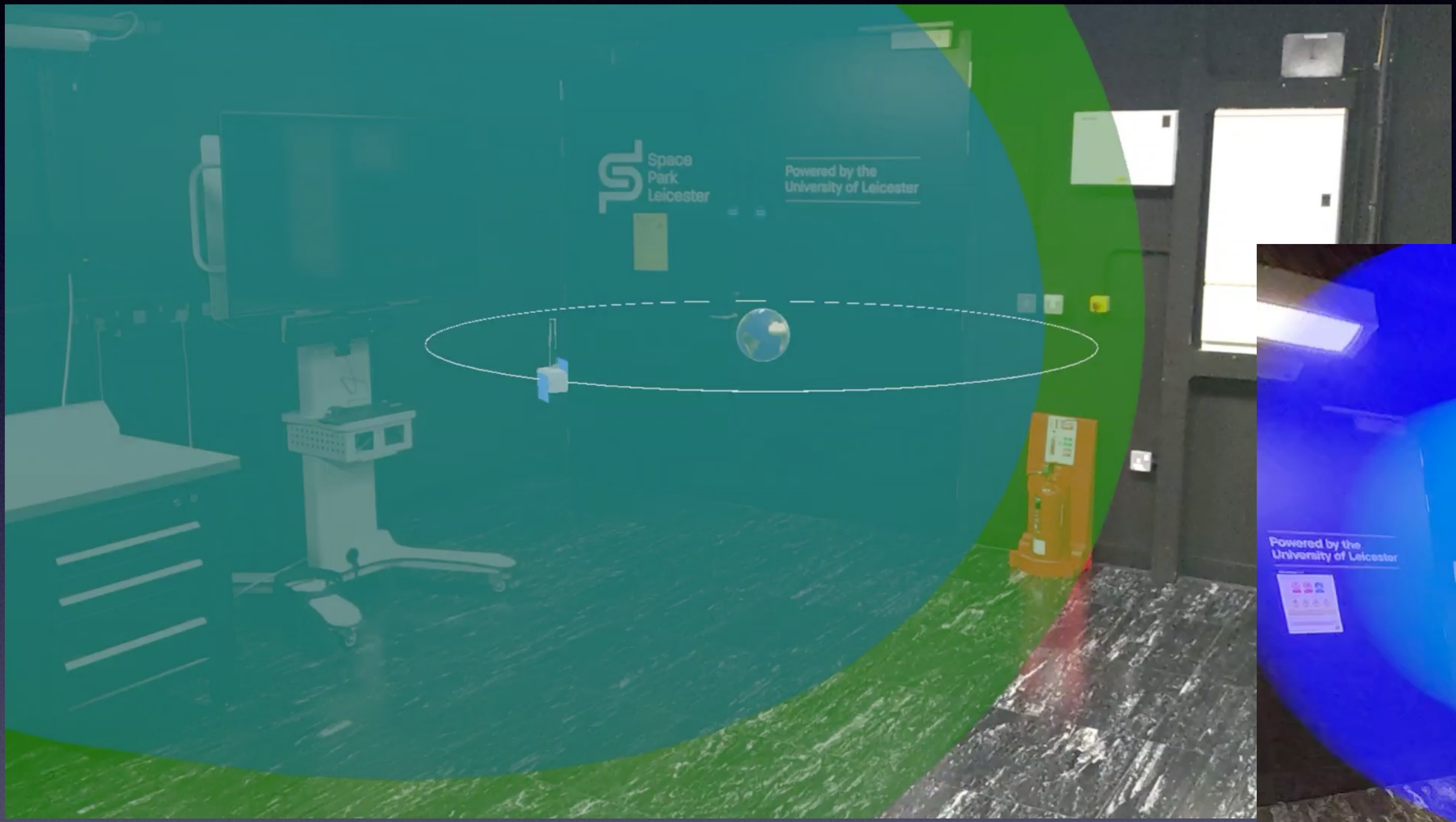
Engineering team

Missions studies, operations

Science team

Solar-terrestrial
Planetary & Heliosphere
Instruments

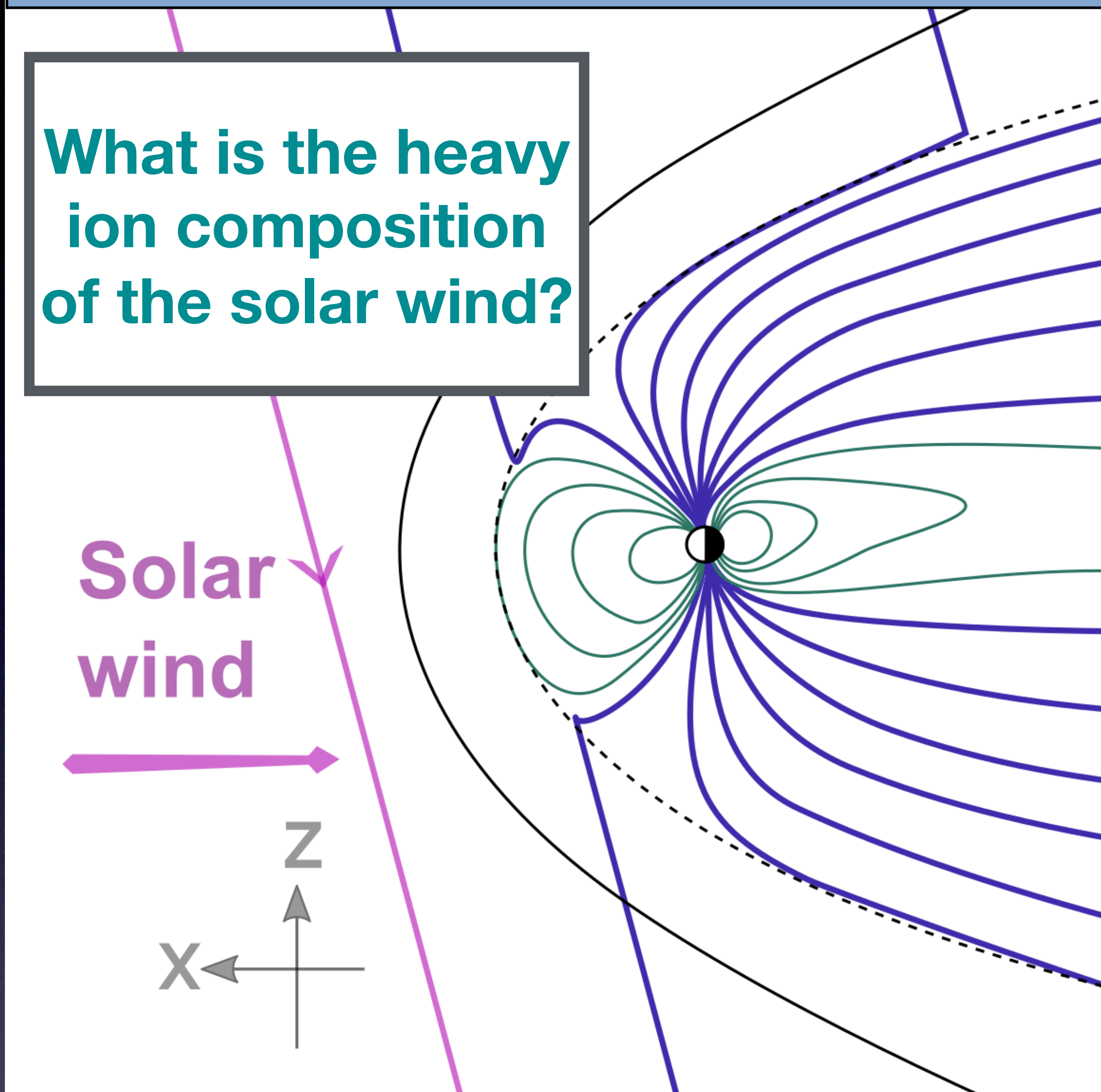
Elfen: Augmented reality at SPL: O. Blake

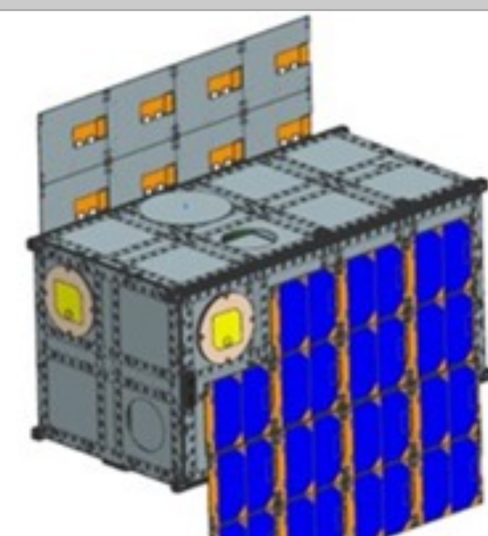


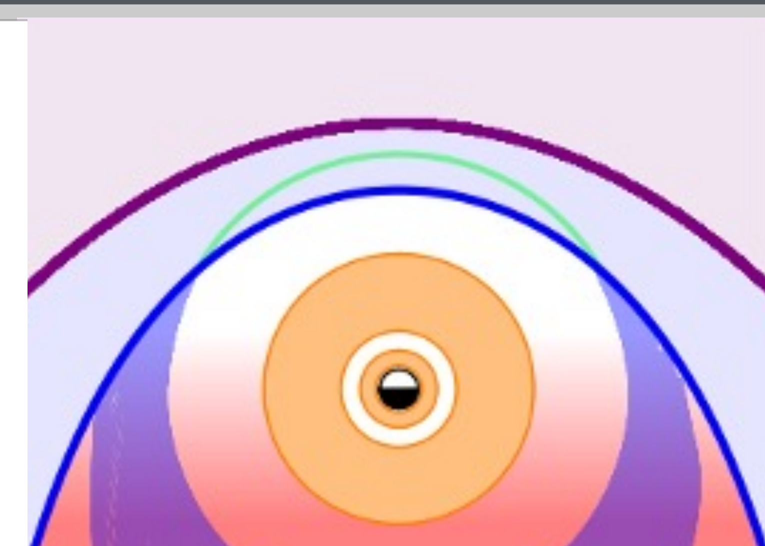
Lack of knowledge upstream + impact, competing processes

What is the heavy ion composition of the solar wind?

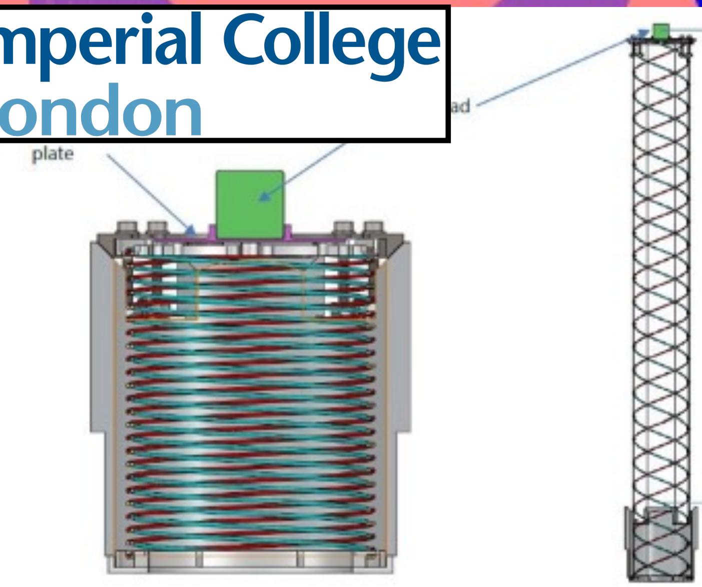
What is the origin of the cold dense plasma sheet?







T-FIPS



16U CubeSat, 12 R_E equatorial circular orbit

Two science instruments:

- **Triple coincidence Fast Imaging Spectrometer**
- **Magnetometer**

Upstream + plasma sheet composition

Relevant to upcoming and proposed missions

Funding for 2024 - 2025