Elfen

A cubesat heavy ion composition experiment

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What is the heavy ion composition of the solar wind?

- e.g. \( \text{O}^{7+} \), \( \text{O}^{8+} \), \( \text{C}^{6+} \), \( \text{C}^{5+} \)
Elfen: Why?

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

3 - 7 year mission from 2025

Depends on:
- Solar wind composition
- Solar wind flux
- Exospheric hydrogen
Elfen: Why? Q2

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

What is the heavy ion composition of the solar wind?

What is the origin of the cold dense plasma sheet?

Competing diffusion or injection processes, e.g. Kelvin Helmholtz instability Nightside reconnection

Milan+ 2020
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
Elfen instrument 1: T-FIPS

**Heritage:**
FIPS from MESSENGER (High TRL)

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

<table>
<thead>
<tr>
<th>Energy Resolution</th>
<th>Mass</th>
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</thead>
<tbody>
<tr>
<td>0.05 – 20 keV</td>
<td>5%</td>
</tr>
<tr>
<td>7 – 15%</td>
<td>10 x 20 x 30 cm</td>
</tr>
<tr>
<td>1 – 44 amu/e</td>
<td>&gt; 100 bps</td>
</tr>
<tr>
<td>1.4π</td>
<td>60s (nom) &lt; 10s (burst)</td>
</tr>
<tr>
<td>≤1500 km/s: H⁺</td>
<td>≤1100 km/s: C^{2+}, O^{6+}</td>
</tr>
<tr>
<td>≤800 km/s: Fe^{10+}</td>
<td>≤600 km/s: C^{3+}, O^{3+}, Fe^{5+}</td>
</tr>
</tbody>
</table>

Energy Resolution

- 5% (no LVPS, no DPU)

Mass

- 10 x 20 x 30 cm

Size

- > 100 bps

Bit rate

- 60s (nom) < 10s (burst)

Scan Speed

- ≤1500 km/s: H⁺
- ≤1100 km/s: C^{2+}, O^{6+}
- ≤800 km/s: Fe^{10+}
- ≤600 km/s: C^{3+}, O^{3+}, Fe^{5+}

Measured Ions

- 15 kV Post Acceleration
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 – 25 vector/s     |

Exceeded accuracy for ESA space weather product (1% cf 5%)
Elfen instrument 2: MAGIC

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

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

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
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
- Looked at various orbits; 12 Re circular equatorial, inclination 23.5°, RAAN 270°

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
Elfen: Initial tradeoffs during CDF
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, <6 kg?
Elfen: Mission team experience & philosophy

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

Undergraduate & postgraduate training
Mission studies, operations

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

Science team
Solar-terrestrial
Planetary & Heliosphere Instruments

Engineering team
Missions studies, operations
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?

Solar wind

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