Helium abundance in the corona with joint Metis/EUI observations

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Helium abundance measurements

Convective envelope: 8.5% (e.g.: Asplund et al., 2009)

Cromosphere - lower Transition Region:
- \( \sim \) photospheric (He/O, \( \gamma \)-ray spectroscopy)
- (Madzhavidze et al., 1997; 1999)
- 6.5-8.5% (He/H, EUV to IR spectroscopy)
- (Andretta et al., 2008)

Near-surface, off-limb corona:
- 7% (He/H, \( R/R_{\text{sun}} < 1.2 \))
  (Gabriel et al., 1995)
- 4-5% (He/O, \( R/R_{\text{sun}} < 1.05 \))
  (Laming & Feldman, 2001; 2003)

Solar wind:
- <5% correlated with solar activity
  (e.g: Ogilvie & Hirshberg, 1974; Aellig et al., 2001)
- occasional measurements >10%
  (e.g.: Borrini et al. 1982)
Helium abundance: what we know

Compared to its value in the solar convective envelope, the helium abundance in the in-situ measurements of the fast and slow solar wind has long been known to be depleted relative to hydrogen, with occasional, transient exceptions.

In the slow solar wind, the degree of depletion has been shown to depend upon the wind speed and the level of solar activity.

Measurements of the helium abundance can therefore provide useful constrains on the mechanisms for the release, heating, and acceleration of the solar wind, in particular of the slow solar wind, and allow identification of its source regions.
Helium abundance in the corona

SPACELAB 2 MEASUREMENT OF THE SOLAR CORONAL HELIUM ABUNDANCE

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ABSTRACT

The abundance of helium relative to hydrogen has been measured with the "Coronal Helium Abundance Spacelab Experiment" (CHASE) from the space shuttle Challenger in 1985. Previous solar measurements have proved difficult due to the temperature-sensitivity of the electron excitation rates for the observed lines. In this approach scattered Lyman Alpha (Lyα) radiation of helium and hydrogen formed in the corona were measured with a grazing-incidence spectrometer and compared with the intensity of the illuminating flux from the solar chromosphere. The abundance ratio by number of atoms was found to be 0.070 with an uncertainty of 0.011. Scattered light in the telescope is the main source of error.

INTRODUCTION

The collisional excitation rates in the temperature region of He line formation are unusually sensitive to temperature. This leads to significant error in the deduced abundances. Lines produced by photon impact excitation eliminate the temperature sensitivity. The effect was first observed during a total solar eclipse where the Lyα line was observed as the brightest line in neutral hydrogen illuminated by the very intense chromospheric Lyα radiation (Gabriel 1971). Calculations (Patchett et al 1981) showed that the only other line similarly dominated by resonance fluorescence in the inner corona below 1.3 Å is He II Lyα at 30.4 nm. Regarding the chromospheric emission of the two lines as light sources, the coronal emission of
Helium abundance in the corona

Assumption: both H I and He II Ly-α are dominated by scattering of disk radiation
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What Solar Orbiter can measure

**Metis**

Corona in the range $R/R_{\text{Sun}} > 1.6^\circ$

- $\text{H I} \ 1216 \ \text{Å (Ly-\(\alpha\))}$, narrow-band imaging
- Visible-light, broadband polarized (pB) imaging

**EUI/FSI**

Corona in the range $R/R_{\text{Sun}} < 3.8^\circ$

- $\text{He II} \ 304 \ \text{Å}$, narrow-band imaging
- 174 Å narrow-band imaging
Metis and EUI Field of View

Distance: 0.28 AU

Distance: 0.4 AU

Y / degrees

X / degrees

Y / degrees

X / degrees
EUI: Using an occulting disk...

- Simple occulter design OK @ 174 & 304
- Door modifications are implemented
- Limited number of operations
  - Campaign mode
  - Only when far from the Sun (>0.4 A.U.)

N.B.: Early design. Door is now rotating
What Solar Orbiter can measure

Metis diagnostics
- **UV**: H I 1216 Å
- **VL**: Electron density *(simultaneous)*
  Also:
  - **UV**: Radial velocity

EUI/FSI diagnostics
- **EUI FSI304**: He II 304 Å
  Also:
  - **EUI FSI174**: Emission Measure at $\sim 10^6$ K *(quasi-simultaneous)*
What Solar Orbiter can measure

**Metis diagnostics**
- **UV**: H I 1216 Å
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Dolei et al., 2018, A&A 612, A84
What Solar Orbiter can measure

Metis diagnostics
- **UV**: H I 1216 Å
- **VL**: Electron density

EUI/FSI diagnostics
- **EUI FSI304**: He II 304 Å
- Also:
  - **EUI FSI174**: Differential Emission Measure (quasi-simultaneous)

Complete characterization of the properties and dynamics of the main components of the solar wind: Electrons, hydrogen and protons, and helium

Dolei et al., 2018, A&A 612, A84
Adding SPICE to the recipe ...

SPICE Composition (FIP) map (being updated):

Profiles:
- Mg VIII 78.23 nm (TBC)
- Mg IX 70.6 nm
- Ne VIII 77.04 nm
- S V+O IV 78.65+78.7 nm

Total intensity:
- O VI 103.6-103.7

Raster: 4” slit, 16x11’ (TBC)
... and PHI, and more ...

SOOP:
L_FULL_HRES_MCAD_Coronal_He_Abundance

PHI Default mode (TBC):
PHI_synoptic_FDT_4
(coronal extrapolations)

SWA
(α/p density ratio)
... and PHI, and more ...

SOOP:
L_FULL_HRES_MCAD_Coronal_He_Abundance

PHI Default mode (TBC):
PHI_synoptic_FDT_4
(► coronal extrapolations)

SWA
(► α/p density ratio)

Ground based support, e.g.:
DKIST:
(► He I 10830, B_{cor}, N_e)
Problem: Si XI 303 Contribution to the EUI 304 band
Ratio Si XI 303/He II 304

SOHO/CDS spectra
Since EUI/FSI is a single bounce design, the spectral response is quite wide and several lines other than Si XI can contribute as much, especially Mg VIII and Si VIII lines. These are cool and may actually pick up at large distances in the corona.
Constraints from EUI/FSI174?
HECOR + EIT composite

Plumes $1.7 R_s$

Streamer $\sim 3 R_s$

“Horns”

Good match with EIT
Evidence for resonant scattering

EIT

HECOR

Intensity (ph.cm\(^{-2}\).s\(^{-1}\).sr\(^{-1}\))

Distance to sun center (solar radii)
Evidence for resonant scattering

![Graph showing intensity vs distance to sun center](image)

**Intensity (ph.cm$^{-2}$.S$^{-1}$.sr$^{-1}$)**

**Distance to sun center (solar radii)**

EIT  <->  HECOR
Expected signal

30.4 nm corona: \( \sim 10^8 \text{ photon.cm}^{-2}.\text{s}^{-1}.\text{sr}^{-1} \) @ 3 Rs

HeCOR \( 1.7 \times 10^{-10} \text{ DN.photon}^{-1}.\text{cm}^{2}.\text{sr} \)
FSI \( 5 \times 10^{-13} \text{ DN.photon}^{-1}.\text{cm}^{2}.\text{sr} \)

x340 → small pupil & two filters in FSI

Bin 4x4 → x16
Exposure time x20 → 2400 seconds (20 minutes)

Resonant scattering → brighter corona during maximum of activity

Detection of Helium up to 3 Rs possible in 20 minutes
DKIST coronal observations

DKIST coronal diagnostics during early operations

- Emphasis on bright line observations with greatest magnetic field sensitivity.
- Corresponding peak temperature coverage: 1 to 1.6 MK
- Filter availability can be expanded in the future.

**Maximum FOV: 2.8 arcmin -- Coordinated Operations**

**DL-NIRSP Spectropolarimetry**
- Fe XI $\lambda 7892$ ; Log(T) $\sim$ 6.13
- Fe XIII $\lambda 10747$ ; Log(T) $\sim$ 6.22
- Fe XIII $\lambda 10797$ ; Log(T) $\sim$ 6.22
- He I $\lambda 10830$ ; Log(T) $\sim$ 4*
- Si X $\lambda 14300$ ; Log(T) $\sim$ 6.13

**VBI Imaging**
- Fe XI $\lambda 7892$ ; Log(T) $\sim$ 6.13

**VISP Spectropolarimetry**
- Various lines: 380 to 900 nm
- Including FeXIV 5303, FeX 6375, (green + yellow lines)

**Cryo-NIRSP Spectropolar.**
- Fe XIII $\lambda 10747$ ; Log(T) $\sim$ 6.22
- Fe XIII $\lambda 10797$ ; Log(T) $\sim$ 6.22
- He I $\lambda 10830$ ; Log(T) $\sim$ 4*
- Si X $\lambda 14300$ ; Log(T) $\sim$ 6.13
- Si IX $\lambda 39350$ ; Log(T) $\sim$ 6.04

**Cryo-NIRSP Context Imager**
- Fe XIII $\lambda 10747$ ; Log(T) $\sim$ 6.22
- He I $\lambda 10830$ ; Log(T) $\sim$ 4*
- Si IX $\lambda 39340$ ; Log(T) $\sim$ 6.04