Observational Tests for Non–Equilibrium Ionization in the Solar Transition Region and Corona

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Scientific Justification

Non–equilibrium ionization may be produced by a variety of processes in the solar corona, for example, by mass flows through the steep temperature gradients of the transition region or by impulsive heating and cooling. Deviation from equilibrium ionization would have a significant effect on the radiation from the corona and on the interpretation of solar observations. Therefore, it is important to determine observational signatures of non–equilibrium.

Departures from ionization equilibrium imply changes in the temperature of the peak abundance of the various ions, so that the corresponding lines would be formed at temperatures significantly different from the formation temperature deduced from equilibrium. This changes considerably the temperature–dependent Boltzmann factors appearing in the excitation rate coefficients for the spectral lines, which results in changes of the populations of the upper levels and, hence, the line ratios. Therefore, allowed transitions arising from the same ground level may prove effective for detecting non–equilibrium ionization in the solar transition region and corona plasma.

Spadaro et al. (1994) examined several temperature sensitive line ratios which can be used as such signatures: C IV (1548.2 Å)/(312.4 Å), O IV (789.4 Å)/(554.4 Å), O V (629.7 Å)/(172.2 Å), O VI (1031.9 Å)/(173.0 Å), O VI (1031.9 Å)/(150.1 Å). These line ratios were calculated for four coronal loop models which have a steady siphon flow producing significant departures from equilibrium ionization. In general, non–equilibrium causes a considerable reduction in the line ratios with respect to equilibrium, more than an order of magnitude in the loop model with the largest mass flows. In particular, the C IV line ratio is the most

sensitive to non–equilibrium.
The considered line ratios were also calculated recently for a steady flow model developed by Rosner & Vaiana (1977), which describes the initial acceleration of the solar wind in the transition region and inner corona segment of coronal holes. The results show an analogous, although smaller, reduction in the line ratios calculated without the assumption of ionization equilibrium.

We propose to apply this test to coronal loops and coronal holes observed jointly by CDS and SUMER, selecting appropriate targets on the limb and disc, particularly those where the lines exhibit strong Doppler shifts. Co-pointing of CDS and SUMER as accurate as possible is required in order to observe the same target. EIT images are necessary to select the targets and to have information on the location and morphology of the observed structures. The observed line intensities and ratios will be compared with those synthesized from hydrodynamic models with a consistent treatment of the ionization balance and of total radiative losses, according to the most recent and accurate theoretical atomic data. Owing to possible uncertainties on calibration and atomic rates, it is better to take at least 3 lines from each ion, rather than depending on a single line pair from each ion.

References

Rosner, R., & Vaiana, G.S., 1977, ApJ, 216, 141.

Spadaro, D., Leto, P., & Antiochos, S.K., 1994, ApJ, 427, 453.

The CDS part of the investigation

We plan to carry on two observing phases, using the CDS NIS during the first phase for about 13 minutes, and the CDS GIS during the second phase for about 40 minutes. The time required for the total CDS observation is about 55 minutes.

Study details

Phase 1

Spectrometer:	Normal Incidence
Slit:	2×240 arcsec
Raster Area:	30 arcsec by 4 arcmin
Step (DX, DY):	2 arcsec, 0 arcsec
Raster Locations:	15×1
Exposure Time:	50 s
Duration of raster:	1000 s (incl. overheads)
Number of rasters:	1
Total duration:	13 min approximately
Line selection:	C IV (312.4 Å), O IV (554.4, 608.4 Å), O V (629.7 Å) plus other strong lines (He I 537.03 Å, Mg IX 368.06 Å, Mg X 624.94 Å) to identify the loop
Bin Across Line:	21
Telemetry/Compression:	truncate to 12 bits 18 s/exposure= 6 lines $\times$ 21 bins $\times$ 120 pixels $\times$ 12 bits/10 kbits/s
Pointing:	to a loop location, if known. If not known, a 4×4 arcmin NIS raster may be needed to search
Flags:	Will not be run in response to inter-instrument flag and will not be run with CDS as flag Master
Solar Feature Tracking:	Not necessary

Phase 2

Spectrometer:	Grazing Incidence
Slit:	2 × 2 arcsec
Raster Area:	30 × 10 arcsec
Step (DX, DY):	2 arcsec, 2 arcsec
Raster Locations:	15 × 5
Exposure Time:	30 s
Duration of raster:	2400 s
Number of rasters:	1
Total duration:	39 min approximately
Line selection:	Full GIS output. Lines used: C IV (206.64, 212.4, 307.81, 312.4 Å), O IV (238.4*, 238.6*, 789.4 Å), O V (172.2, 220.35* Å), O VI (150.1, 183.9, 184.1, 173.0 Å), plus other strong lines (O III 702.98 Å, Ne VII 465.22Å, He II 303.78 Å, Fe XI 188.22 Å, Fe XII 195.12 Å) to identify the loop and flows *GI3 2nd order
Bins Across Line:	N/A
Telemetry/Compression:	straight copy 13 s/exposure= 4 bands × 2048 bins × 16 bits/10 kbits/s
Pointing:	a 'leg' of a coronal loop. The same location as in Phase 1.
Flags:	N/A
Solar Feature Tracking:	OFF
Comment:	Near Real Time commanding
Grand Total Duration:	52 minutes

Product:

Phase 1: 30 arcsec × 4 arcmin image in seven lines. Phase 2: 30 × 10 arcsec image along the leg of the loop.

Joint Observations:

SUMER (co–pointing)

EIT

The SUMER part of the investigation

We plan to carry on four operational sequences (A, B, C, D), selecting different wavelength bands on the detector A of the spectrometer. The operational sequence A must be performed simultaneously to the CDS phase 1 (NIS), scanning the raster correspondingly to the respective CDS/NIS scan. The other three sequences must be performed in succession during the CDS phase 2 (GIS).

Operational Sequence A

Initial Pointing:	to the same loop location selected by CDS
Slit:	1×120 arcsec (slit 4)
Scan Area:	30 arcsec $\times$ 2 arcmin
Step Size:	0.76 arcsec
Number of Scan Locations:	40
Dwell Time:	2 – 5 s
Duration of Scan:	80 – 200 s
Number of Scans:	1
Number of Mirror Settings:	1
Repointing:	None
Total duration:	Ca. 200 s (384 s are required for data trasmission)
Line Selection:	C IV 1548.2 Å (1st order),
	O IV 789.4 Å (2nd order)
Binning:	Spatial: 1 px
	Spectral: 1 px
Reference Pixel:	750 (1548.2 Å)
Image Format:	$2 \times 25 \times 120$ px (uncompressed)
Co–operation Requirements:	CDS (co–pointing)
	EIT

Operational Sequence B

Initial Pointing:	to the same loop location selected by CDS
Slit:	1 × 120 arcsec (slit 4)
Scan Area:	30 arcsec × 2 arcmin
Step Size:	0.76 arcsec
Number of Scan Locations:	40
Dwell Time:	2 – 5 s
Duration of Scan:	80 – 200 s
Number of Scans:	1
Number of Mirror Settings:	1
Repointing:	None
Total duration:	Ca. 200 s (576 s are required for data trasmission)
Line Selection:	O V 629.7 Å and O IV 609.3 Å (2nd order), plus N V 1238.82 Å (1st order) and Mg X 609.79 Å (2nd order) to identify flows
Binning:	Spatial: 1 px Spectral: 1 px
Reference Pixel:	550 (1238.82 Å)
Image Format:	3 × 25 × 120 px (uncompressed)
Co–operation Requirements:	CDS (co–pointing) EIT

Operational Sequence C

Initial Pointing:	to the same loop location selected by CDS
Slit:	1 × 120 arcsec (slit 4)
Scan Area:	30 arcsec × 2 arcmin
Step Size:	0.76 arcsec
Number of Scan Locations:	40
Dwell Time:	2 – 5 s
Duration of Scan:	80 – 200 s
Number of Scans:	1
Number of Mirror Settings:	1
Repointing:	None
Total duration:	Ca. 200 s (192 s are required for data trasmission)
Line Selection:	O VI 1031.9 Å(1st order)
Binning:	Spatial: 1 px Spectral: 1 px
Reference Pixel:	500 (1031.9 Å)
Image Format:	25 × 120 px (uncompressed)
Co–operation Requirements:	CDS (co–pointing) EIT

Operational Sequence D

Initial Pointing:	to the same loop location selected by CDS
Slit:	1 × 120 arcsec (slit 4)
Scan Area:	30 arcsec × 2 arcmin
Step Size:	0.76 arcsec
Number of Scan Locations:	40
Dwell Time:	2 – 5 s
Duration of Scan:	80 – 200 s
Number of Scans:	1
Number of Mirror Settings:	1
Repointing:	None
Total duration:	Ca. 200 s (192 s are required for data trasmission)
Line Selection:	O IV 554.4 Å (2nd order)
Binning:	Spatial: 1 px
	Spectral: 1 px
Reference Pixel:	500 (554.4 Å, 2nd order)
Image Format:	25 × 120 px (uncompressed)
Co–operation Requirements:	CDS (co–pointing)
	EIT

The EIT part of the investigation

Full EIT images are required to locate the targets. Moreover, we plan to select 200 $\times$ 200 pixel regions containing the observed structure, in order to study the evolution of its morphology and EUV brightness. Sequences of images in the four EIT wavelength bands will be taken every 2–3 minutes, as long as CDS and SUMER observations last. An exposure time of 10 s is planned for each image, which could be downlinked in about 12 s, assuming a compression factor of 10.