Differential Emission Measure:

parameter range extension and transient behaviour

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Introduction and motivation

- The current quality of fundamental atomic cross section data allows extension of the scope of Differential Emission Measure (DEM) analysis.

- Collisional-Radiative models, which handle comprehensively the issue of density and level truncation, permit a complete solution.

- Recent solar observations validate DEM at higher densities and anticipate further investigation with the new instrumentation, especially the Interface Region Imaging Spectrograph (IRIS) and the Spectral Imaging of the Coronal Environment (SPICE) onboard Solar Orbiter.

- Studies on laboratory plasma give inside on the interpretation of high cadence measurement such as those possible on IRIS.

Differential Emission Measure (DEM) and line ratios

- Differential Emission Measure (DEM)
- Ratios of lines emitted from the same ion

Differential Emission Measure (DEM)

The DEM describes the temperature and density structure of the solar atmosphere emitting plasma

$$I_i = \frac{A(Z)}{4\pi} \int_{T_1}^{T_2} G_i(T)\Phi(T)\,dT$$

$$\Phi(T)\,dT \approx N_e^2\,dV$$

$$G_i(T) = \sum PEC_i (N^{z+}/N^{tot})_{eq}$$

It requires:

- Measurements in EUV range $\rightarrow I_i$
- Sophisticated atomic model $\rightarrow G_i(T)$

Ratios of lines emitted from the same ion

- For deducing electron density
- As a support to the DEM analysis

$$\frac{I_1}{I_2} = \frac{\int G_1(T, N_e)\Phi(T)dT}{\int G_2(T, N_e)\Phi(T)dT}$$

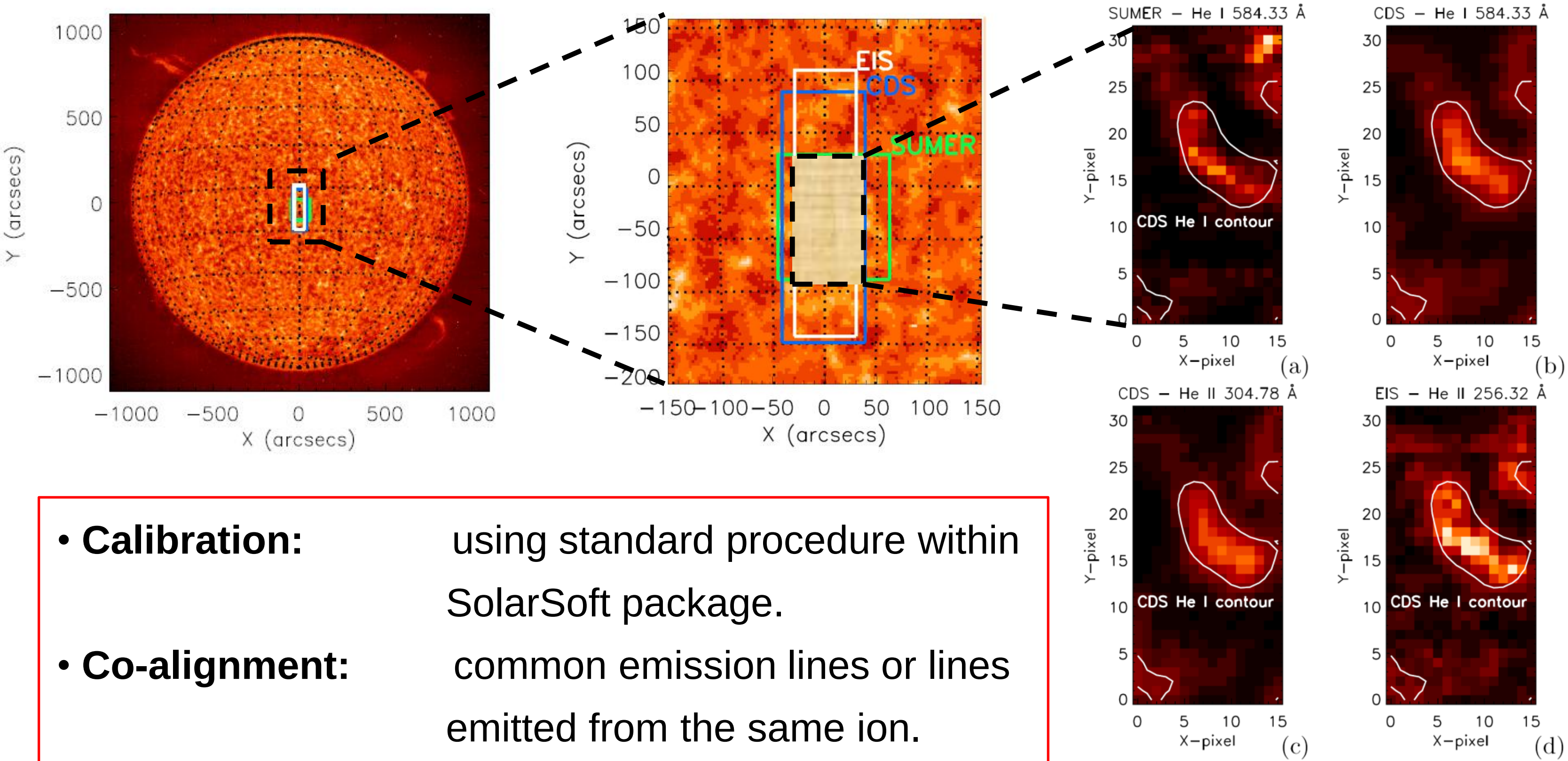
⇩

$$\frac{I_1}{I_2} = \frac{\int_{\Delta T} G_1(T, N_e)dT}{\int_{\Delta T} G_2(T, N_e)dT}$$

⇩

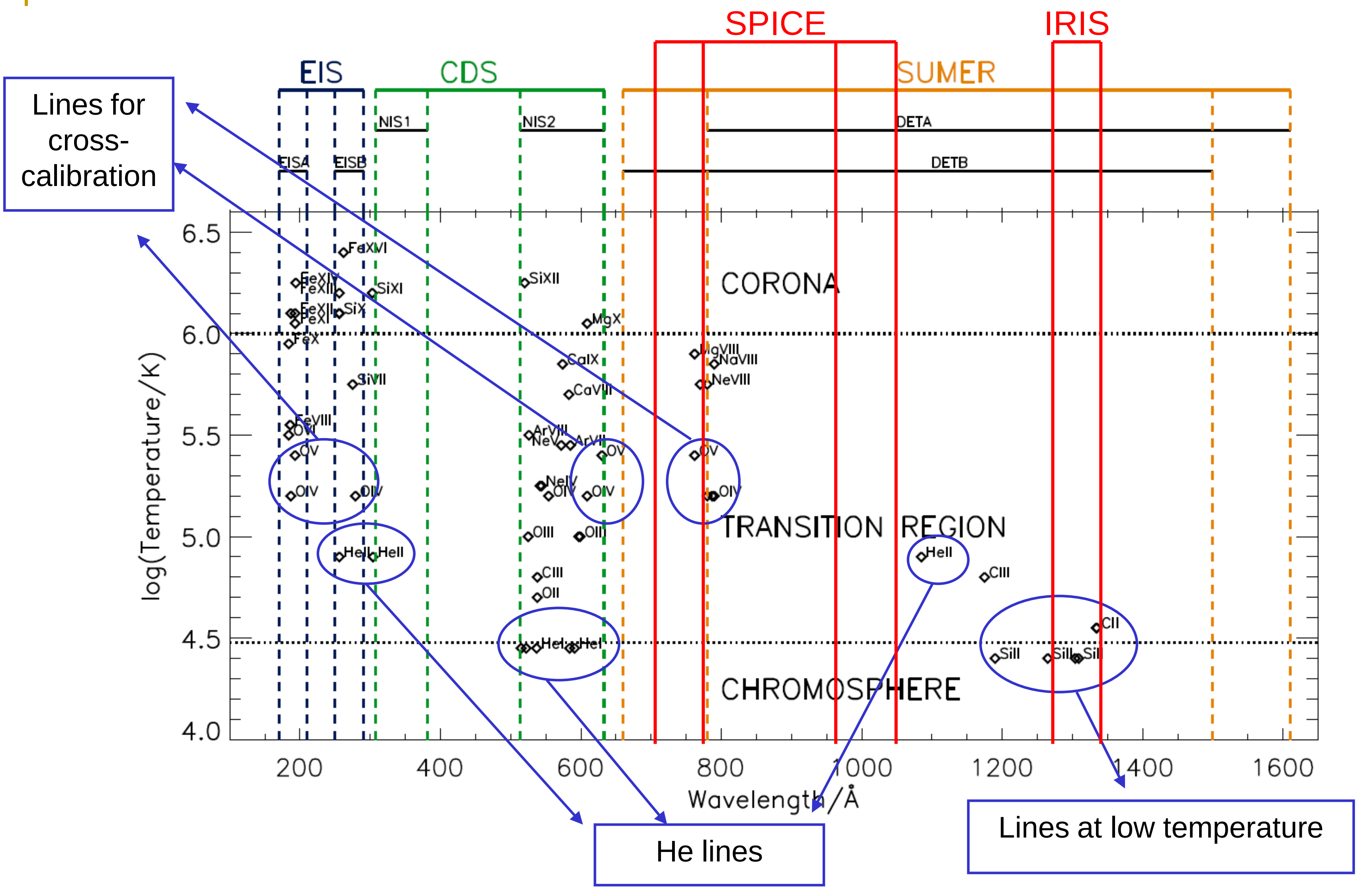
$$\frac{I_1}{I_2} = \frac{PEC_1(T^{peak}, N_e)}{PEC_2(T^{peak}, N_e)}$$

Joint observations of April 2009: SUMER-CDS-EIS



- **Calibration:** using standard procedure within SolarSoft package.
- **Co-alignment:** common emission lines or lines emitted from the same ion.
- **Cross-calibration:** direct line comparison and spectroscopic methods.

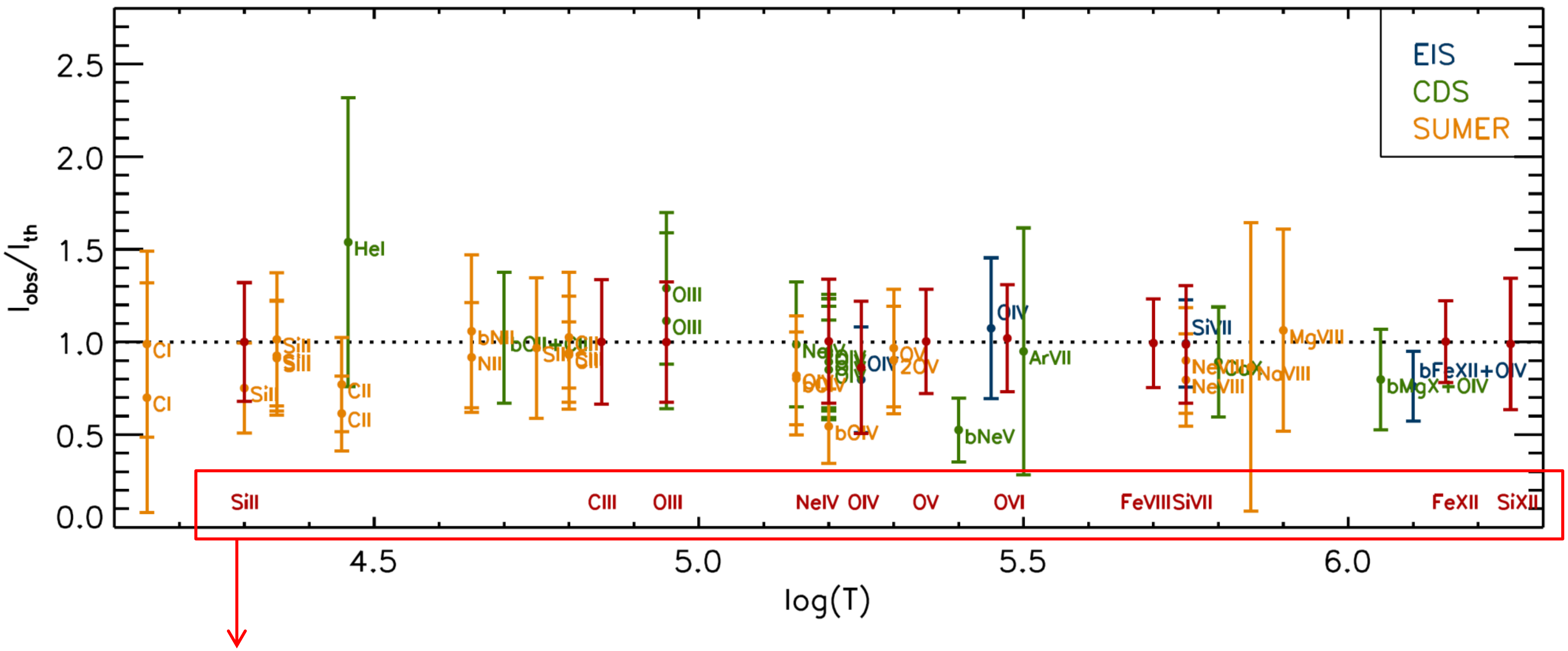
Atomic data connection



Observations and theoretical models:

DEM results extended to the high density upper chromosphere

Comparison between the joint SUMER-CDS-EIS observations and the intensities reconstructed through a revised DEM analysis using ADAS601 (model with constant electron pressure $P_e = 10^{15}$ cm^{-3} K).



Lines used for the inversion

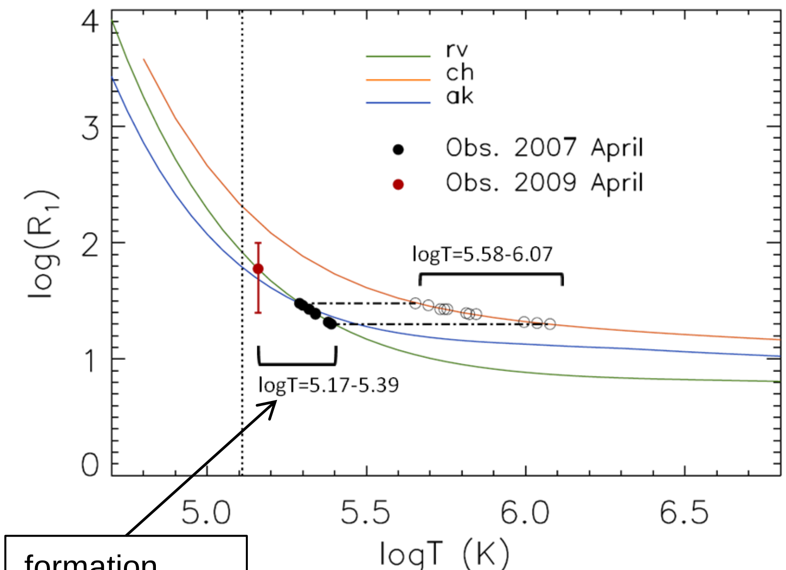
Observations and theoretical models:

O IV line ratios, truncation and He enhancement factors

Study of O IV line ratios as observed by SUMER and EIS:

Giunta et al. (2012)

O IV I(787.7 Å)/I(279.9 Å) ratio



formation temperature

rv = Revised

ch = CHIANTI

ak = Aggarwal & Keenan

EUV helium line enhancement factors and comparison with previous literature:

Ratio between observed and predicted intensities

Source	He I	He II
Jordan (1975)	15	5.5
Macpherson & Jordan (1999)	10-14	13-25
Pietarila & Judge (2004)	2-5	2-13
Present work	0.5-2	5-13

Towards transient modelling

Plasma environment model:

- Basic model of non-thermal electron beam.
- Initial plasma conditions (upper chromosphere): T_e=2 x 10^4 K; N_e=10^{11} cm^{-3}

Atomic model:

- Non equilibrium occurs when the plasma electron temperature or density changes on timescale shorter than the atomic ionisation stage fractional abundance relaxation.
- The assumption of ionisation equilibrium in calculating fractional abundances in not appropriate in transient events.
- Time-dependent ionisation balance must be determined:

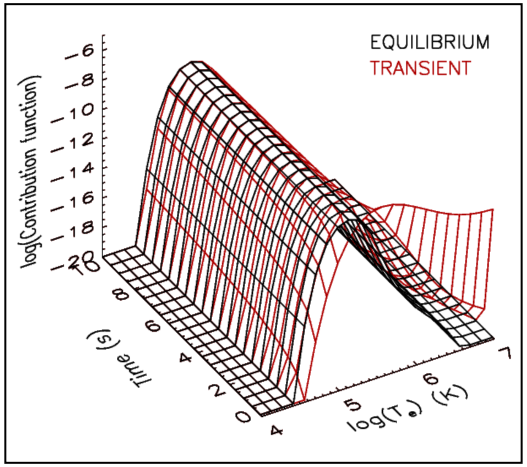
$$\frac{dN^{(z)}}{dt} = N_e[S^{(z-1)}N^{(z-1)} + (S^{(z)} + \alpha^{(z)})N^{(z)} + \alpha^{(z+1)}N^{(z+1)}]$$

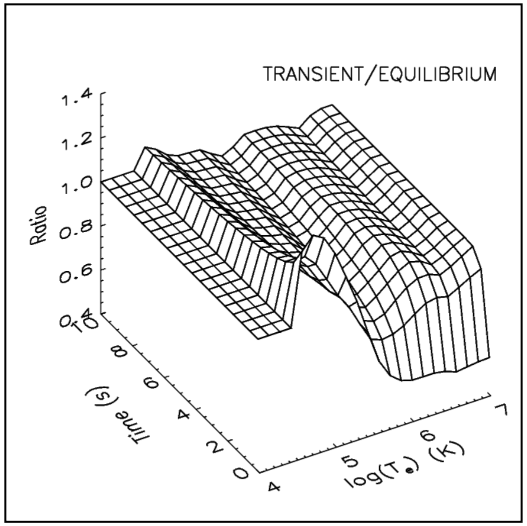
- The transient contribution function in its general form becomes:

$$G^{(z)}_{j\to i}(T_e, N_e, t) = \mathcal{PEC}^{(exc,z)}_{j\to i}\frac{N^{(z)}(t)}{N^{(Z)}} + \mathcal{PEC}^{(rec,z)}_{j\to i}\frac{N^{(z+1)}(t)}{N^{(Z)}}$$

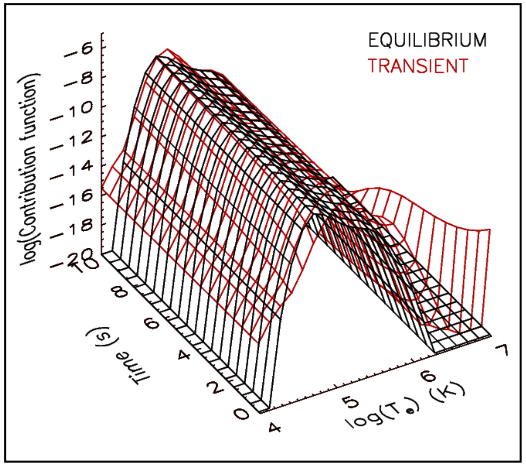
Towards transient modelling: *test case*

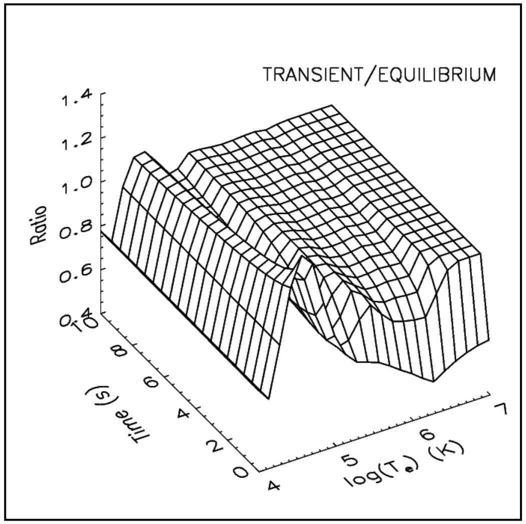
O IV 787.4 Å Contribution function
(SUMER, SPICE)





Si IV 1396.7 Å Contribution function
(SUMER, IRIS)

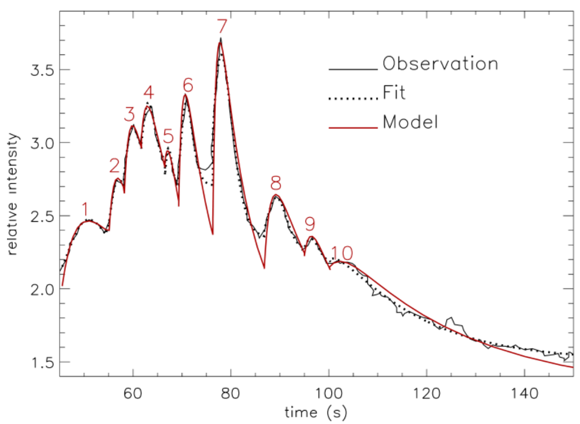


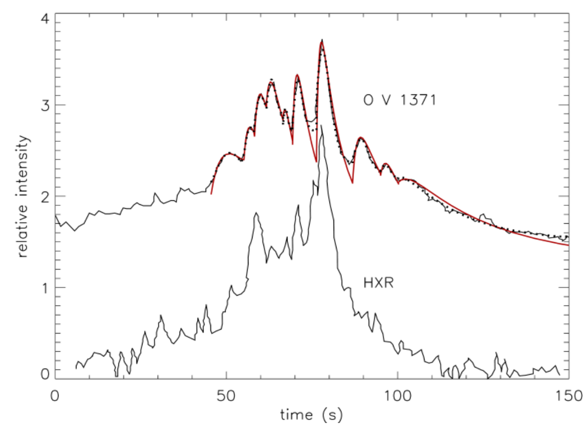


Initial applications and validations

Modelling of solar flare observations (UVSP, HXRBS)

Doyle, Giunta et al. (2012)

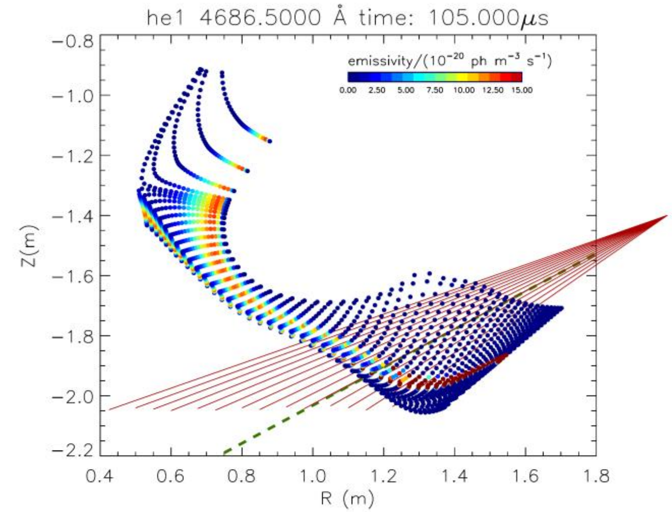


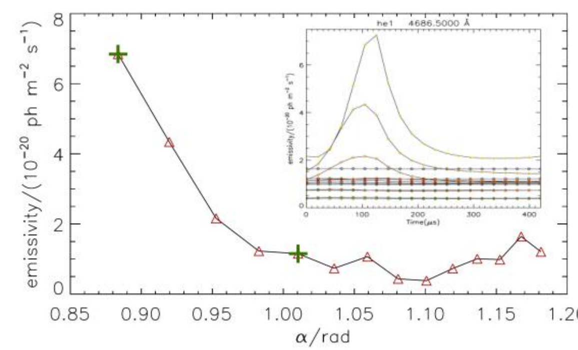


same transient plasma model applied to different temperature, density and time scales

Modelling of simulation for MAST Super-X divertor upgrade in the fusion domain

Simulation provided by J. Harrison





Conclusion and future work

- The transient studies and test case provided suggest the development of a model where solar observations are of a clumped medium with dynamic events and probable optical thickness in clumps. Assuming that transient events occur in the clumps, the unresolved emission can be integrated over transient cycles with T_e/N_e excursions and a duty cycle.

- At upper chromosphere/lower transition region densities optical thickness should be taken into account: moderate optical depth can be handled by the escape factor approach and applied to a clumped medium with a filling factor.

- The new space-borne instrumentation, especially SPICE on the future mission Solar Orbiter, together with the most up-to-date atomic data and modelling, will allow the extension of DEM analysis to the double differential variant form.

- The forthcoming IRIS observations will permit exploration and testing of the transient model suggested with verification in laboratory environment (MAST Upgrade SuperX divertor).