Generalisation of two foil method for joint estimation of electron temperature and impurity content

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INTRODUCTION

This poster presents a **probabilistic** formulation of a generalised **two-foil method**.
This method uses modelling of radiation in **soft x-ray** range to determine plasma parameters (**electron temperature** and **impurity content**) from a **ratio** of intensity measurements with different **spectral filters**.

The radiation model can implement multiple impurities, however, this contribution focuses on tungsten as a first step.

This is motivated by the prominent role of **tungsten in fusion devices** and intended application at **COMPASS-Upgrade**, a compact tokamak with high field and plasma current(5T, 2MA)

RADIATION MODEL

Consists of **Bremsstrahlung** and **line radiation** compensated for detector sensitivity

Line radiation of any element can be added if appropriate atomic data are available

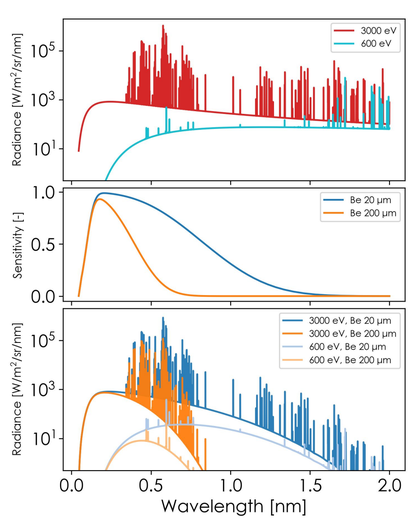
In this contribution only **tungsten** is considered

Bremsstrahlung
Uses Maxwellian Free-Free Gaunt factor [De Avillez 2015]
Computed for each ion species

Line Radiation
Currently, only tungsten included
Uses ADAS database [SUMMERS, H.P. et. al. adas.ac.uk]
Assumes zero transport for determination of ionisation balance

Detector
Photodiode array modelled as 200 μm thick silicone
Combined with beryllium filter of chosen width

Tomography
Deterministic MFR from Tomotok [Svoboda et.al 2021]



Top: Modelled spectra for two selected electron temperatures
Center: Detector sensitivity
Bottom: Spectra after application of detector sensitivity

GENERALISATION OF TWO FOIL METHOD

STANDARD TWO FOIL METHOD

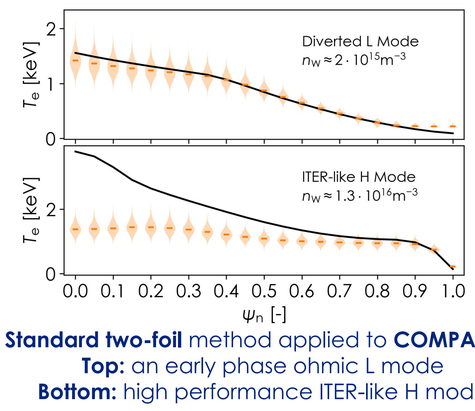
Neglects line radiation:
Ratio → electron temperature

Single ion species with effective charge

Input based on profiles from METIS simulations [JAULMES, F., et al. Nucl. Fusion 2021]

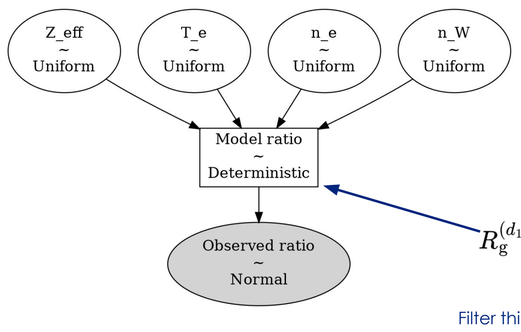
Radiation model includes Bremsstrahlung and tungsten line radiation

Metallic wall machines with substantial heavy impurity content need correction
→ generalised two foil method



Standard two-foil method applied to **COMPASS-U**
Top: an early phase ohmic L mode
Bottom: high performance ITER-like H mode

GENERALISED TWO FOIL METHOD



Backward model
- Bayesian probabilistic model
- Bremsstrahlung using effective charge simplification
- Line radiation of Tungsten
- Filtered by 200 and 20 μm Beryllium
- Emissivities ratio used as the observed quantity

$$R_g^{(d_1,d_2)}(T_e, n_e, n_W, Z_{eff}) = \frac{n_e a_{Bs}^{(d_1)}(T_e, Z_{eff}) + n_W a_{Ln}^{(d_1)}(T_e, n_e)}{n_e a_{Bs}^{(d_2)}(T_e, Z_{eff}) + n_W a_{Ln}^{(d_2)}(T_e, n_e)}$$

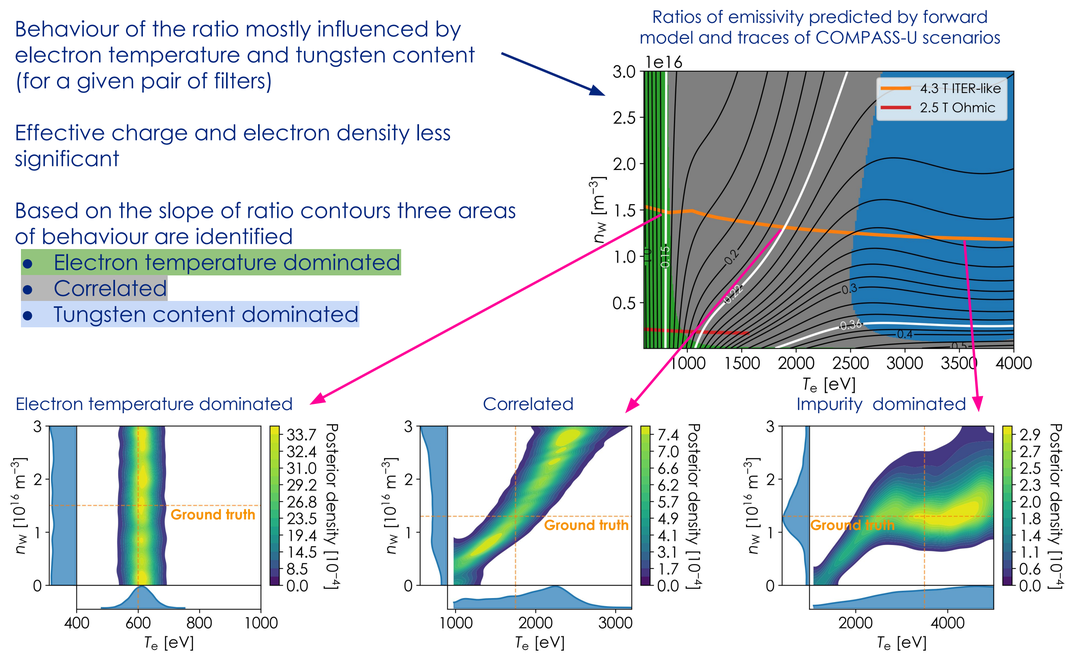
Filter thicknesses — Bremsstrahlung contribution — Line contribution

APPLICATION OF GENERALISED METHOD

Behaviour of the ratio mostly influenced by electron temperature and tungsten content (for a given pair of filters)

Effective charge and electron density less significant

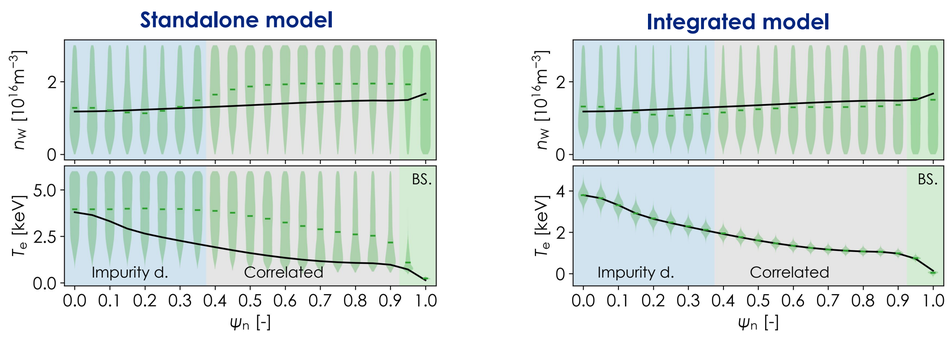
Based on the slope of ratio contours three areas of behaviour are identified
- Electron temperature dominated
- Correlated
- Tungsten content dominated



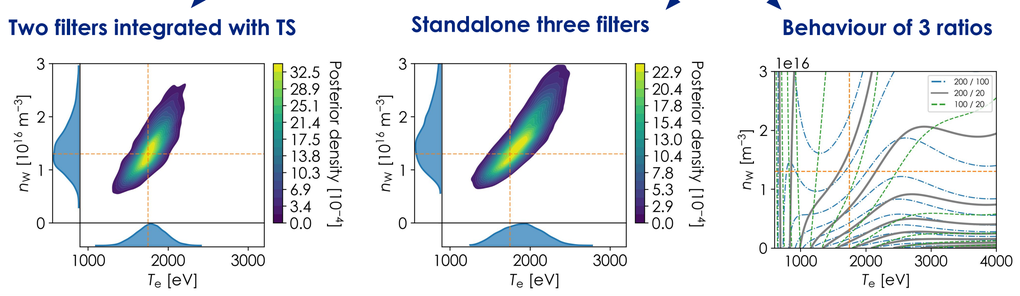
INTEGRATED ANALYSIS

Application to profiles obtained from METIS simulations of ITER-like scenario planned for COMPASS-U show significant portion of the profile to be located in the correlated area
→ Combination with additional diagnostic is foreseen

Example below shows method with **uninformative priors** and integration with Thomson scattering diagnostic approximated by **informative priors** on electron temperature and density with 10% error



ADDITIONAL FILTERS could also help to reduce uncertainty in the correlated area
Below: results using **two filters with 10% TS** and combinations of **three filters with uninformative priors**



CONCLUSIONS

- A **Bayesian model** of generalised ratio method was implemented and three distinct areas of behaviour in parameter space were identified
- Method is **extensible** for additional heavy impurities or more accurate atomic data
- **Integrated data analysis**, combination of more filters or absolute calibration can be used to **decrease uncertainty** in the correlated region

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