Research Unit Nuclear Fusion
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Bayesian integrated estimation of tungsten concentration at WEST using soft X-ray spectroscopy

Background
- ITER: tungsten divertor
- Interaction with plasma → tungsten impurity entering the plasma
- High tungsten concentration in the plasma core → significant radiative power losses, even radiative collapses [1, 2]
- Reliable tools are required to monitor the central tungsten concentration
- Soft X-ray (SXR) radiation provides information on tungsten concentration

Soft X-ray diagnostic on WEST
- Two sets of GEM-based (gas electron multiplier) 1D cameras located in the same poloidal cross-section
- Two cameras provide horizontal and vertical views, allowing 2D tomographic reconstructions
- Time resolution: ~1ms (online) and 10ms (offline)
- Horizontal viewing lines (lines of sight): 128
- Vertical viewing lines: 75

- The system measures plasma emissivity $\varepsilon$ (W$^-$ m$^{-2}$) integrated along the lines of sight and filtered by the detector spectral response $\eta(\nu)$:
  $$d_j = \int \varepsilon(\nu) \eta(\nu) \, d\nu$$
  $d_j$: line-integrated emissivity along the line of sight $j$

Tungsten concentration
- Different species, ionization states and atomic processes contribute to the measured emissivity
- By solving the ionization equilibrium and considering the spectral response of the detector $\eta$, the total emissivity of species S can be simplified as [3]:
  $$\varepsilon_S(T_e) = \eta \cdot \varepsilon_{W} \cdot \eta_S(T_e)$$
- Considering a hydrogen plasma with dominant tungsten impurities (only 2 species):
  $$\varepsilon_{W} \approx n_e \cdot n_W \cdot \varepsilon_{W}(T_e)$$
  Then the tungsten concentration $n_W$ can be estimated from soft X-ray emissivity [3, 4]:
  $$n_W \approx \frac{\varepsilon_{W}}{n_e}$$

Bayesian inference: Gaussian process tomography
- Gaussian process prior: the smoothness of emissivity profile is imposed by correlation between pixels
- Linear forward model (line integrals) and Gaussian likelihood
- Posterior distribution $p(\theta|d)$: multivariate Gaussian distribution
- The mean and covariance of the posterior can be expressed in a closed form

Bayesian integrated estimation of tungsten concentration

Example posterior [4]:
$$p(\theta_W, \theta_E, T_e | d, SXR, ECE, d_{INT}) \propto p(d_{SXR}|\theta_W, \theta_E, T_e) \cdot p(d_{ECE}|\theta_E) \cdot p(p(\theta_W)|p(\theta_E))$$

- Bayesian modelling for all diagnostic systems
- All sources of uncertainty automatically contribute to the results
- No explicit error propagation
- Complementary or redundant measurements of the same quantity → lower uncertainty

References

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