AXUV synthetic diagnostic for ASDEX Upgrade and its application for SPI simulations

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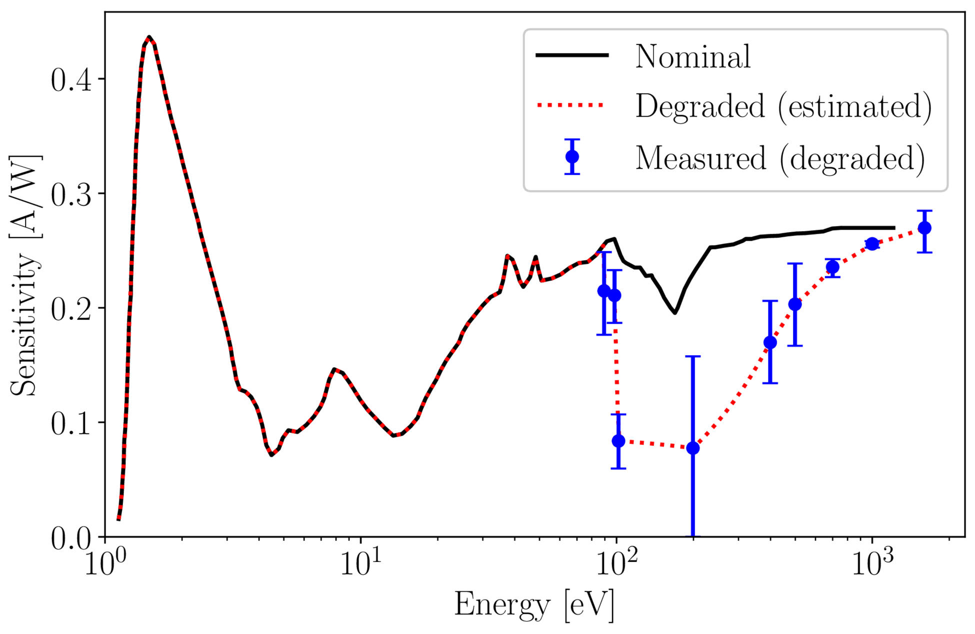
Motivation

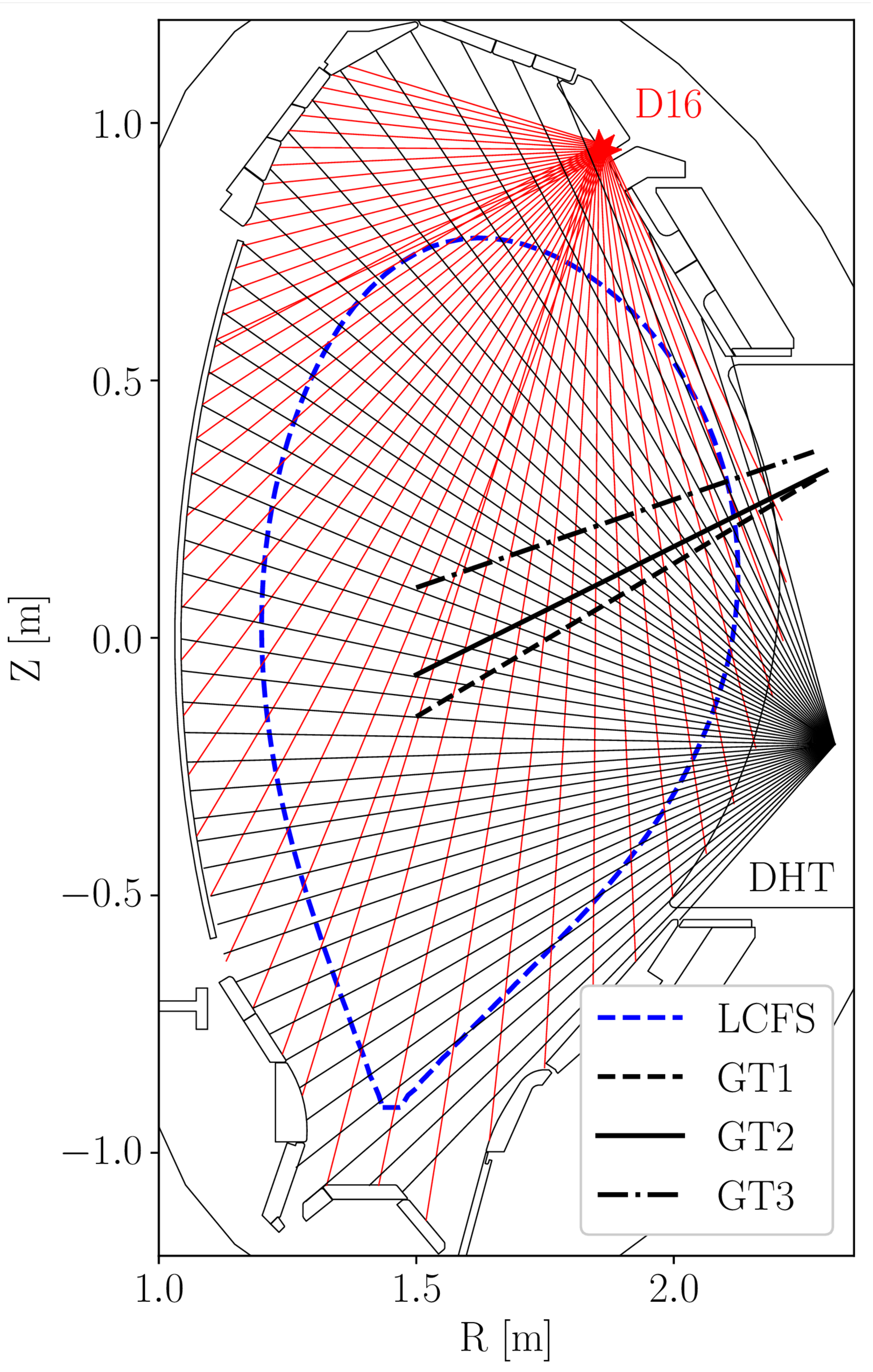
- AXUV diodes detect **broad-spectrum radiation** at **μs time resolution** — ideal for fast events such as **shattered pellet injection (SPI)**
- Their **spectral responsivity** is non-uniform and **degrades** during operation [1] → absolute power has large systematic error
- In the 2022 AUG SPI campaign **>50% of pellets contained Ne**, with line radiation in the sensitive spectral range
- The **emitted spectrum evolves** through the disruption → effective response changes strongly in time
- With unknown relative degradation between channels, **tomography is not viable** → match radiation **features**, not absolute power
- **Goal 1:** a **3D synthetic AXUV diagnostic** in Cherab to **connect simulations with experiments**
- **Goal 2: simulation validation**



Manufacturer (black) and post-campaign degraded (red) AXUV spectral responsivity used in this work [1]

AXUV diodes at AUG

- **4 cameras** in 2 toroidal sectors:
  D16, DHT (sector 16, SPI)
  DVC, DHC (sector 5, ~110° away toroidally)



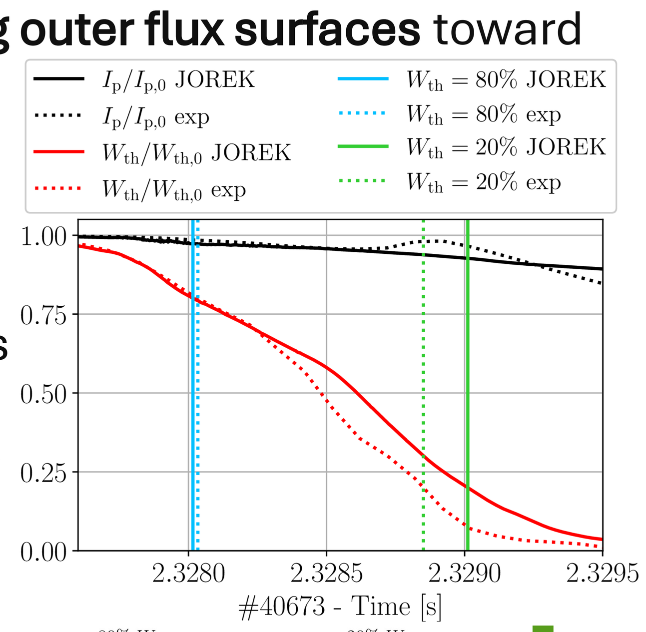
AUG poloidal cross-section with the vertical (D16, red) and horizontal (DHT, black) AXUV LOS in sector 16, the LCFS (#40673), and the SPI guide-tube (GT) vectors.

Sector	S16	S16	S5	S5
Type	vertical	horizontal	vertical	horizontal
Name	**D16**	**DHT**	**DVC**	**DHC**

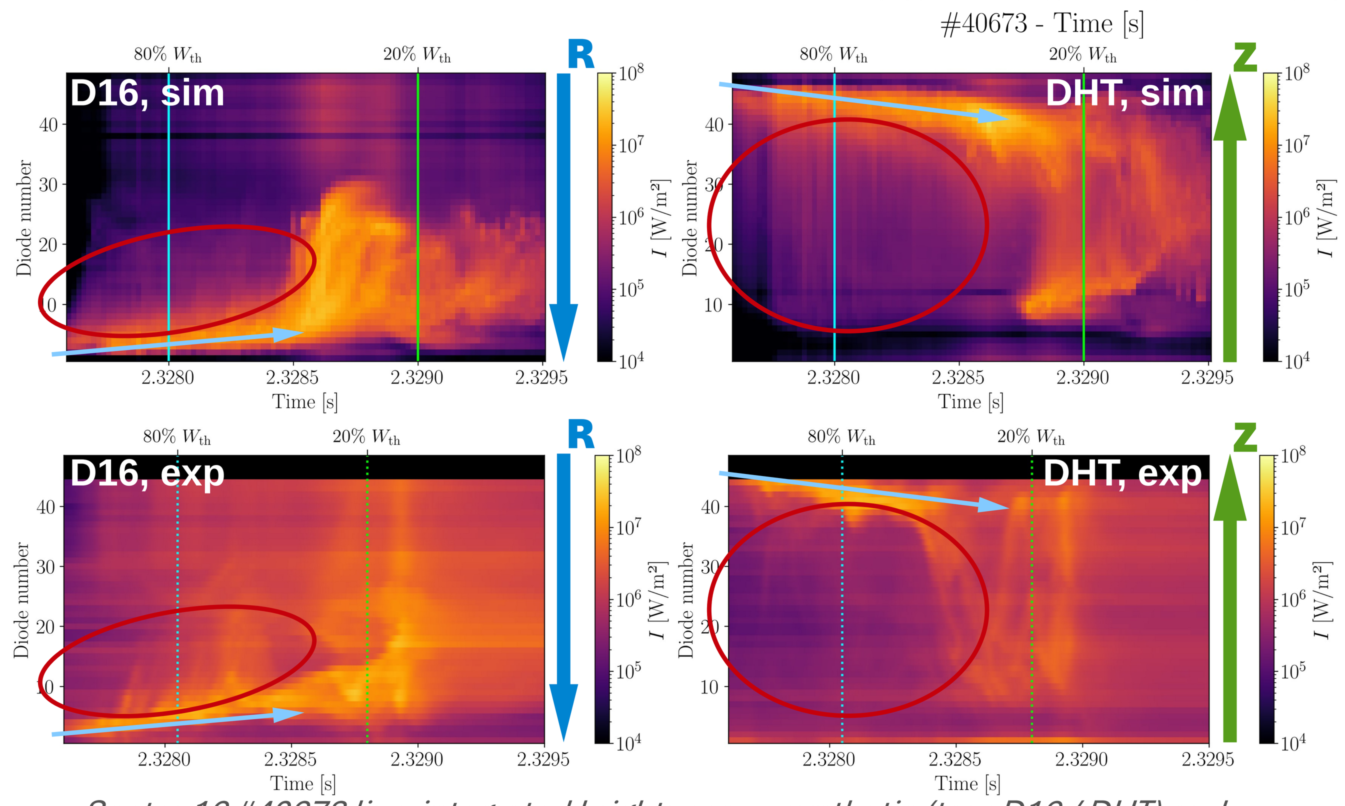
Summary table of AXUV cameras.

10% Ne — AUG #40673 – S16

- **JOREK 3D SPI** simulations [5] post-processed through the synthetic diagnostic (10 mol% Ne and 0.17 mol% Ne)
- Initial inward **trajectory and amplitude match** between synthetic (top) and experiment (bottom) up to t ≈ 2.3285 s
- Fine **radiation structures along outer flux surfaces** toward the HFS visible in both
- Significant **poloidal mixing** seen in both the simulation and the experiment
- After $t_{0.2W}$ the radation patterns become smoother



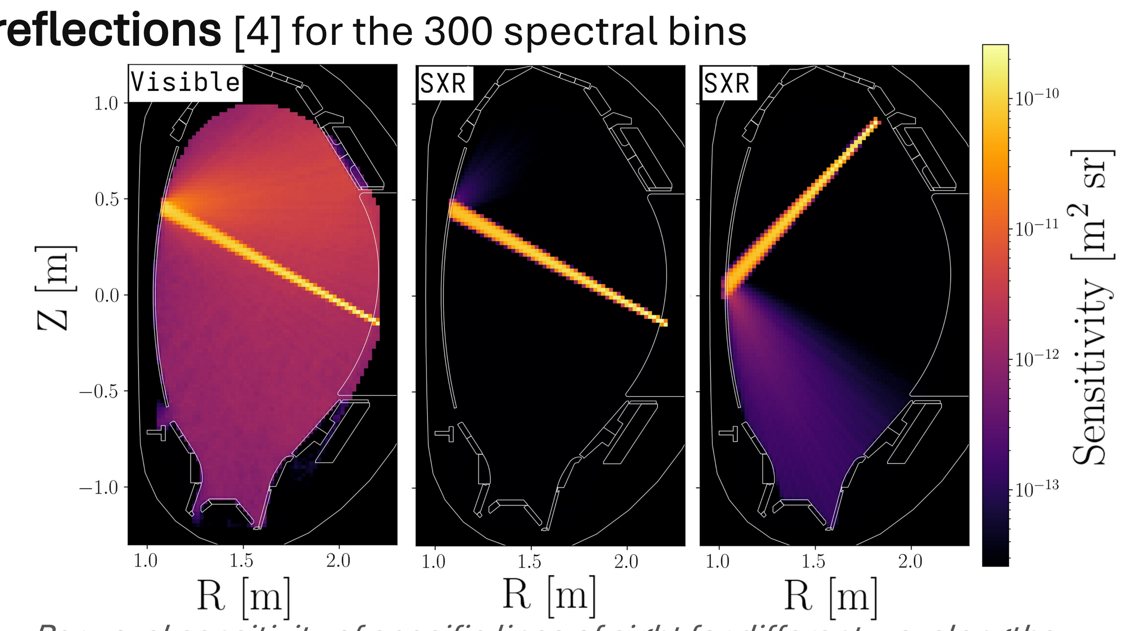
Plasma parameter time traces with solid lines for the simulation and dashed lines for the AUG experiment #40673.



Sector-16 #40673 line-integrated brightness — synthetic (top: D16 / DHT) and experimental (bottom). Same colour scales as before.

3D synthetic diagnostic

- Built on **Cherab / Raysect** [2, 3]: diode BolometerFoil and slit objects placed based on AUG geometry data
  → **Extended with spectral modelling**: 1 eV – 1.24 keV
  - 3, logarithmically placed spectral regions in energy
  - 100 spectral bins in each → total of 300 bins
- **Ray transfer method:** 10^6 rays/diode through an axisymmetric voxel grid (2×2 cm) → **per-voxel sensitivities**
- Detected radiation = per-voxel sensitivity matrix × emission
- Raysect Spectrum objects linearly binned in wavelength
  → 3 logarithmic parts as 3 Spectrum objects
- **Full AUG CAD geometry** of W PFCs
  → **reflections** [4] for the 300 spectral bins

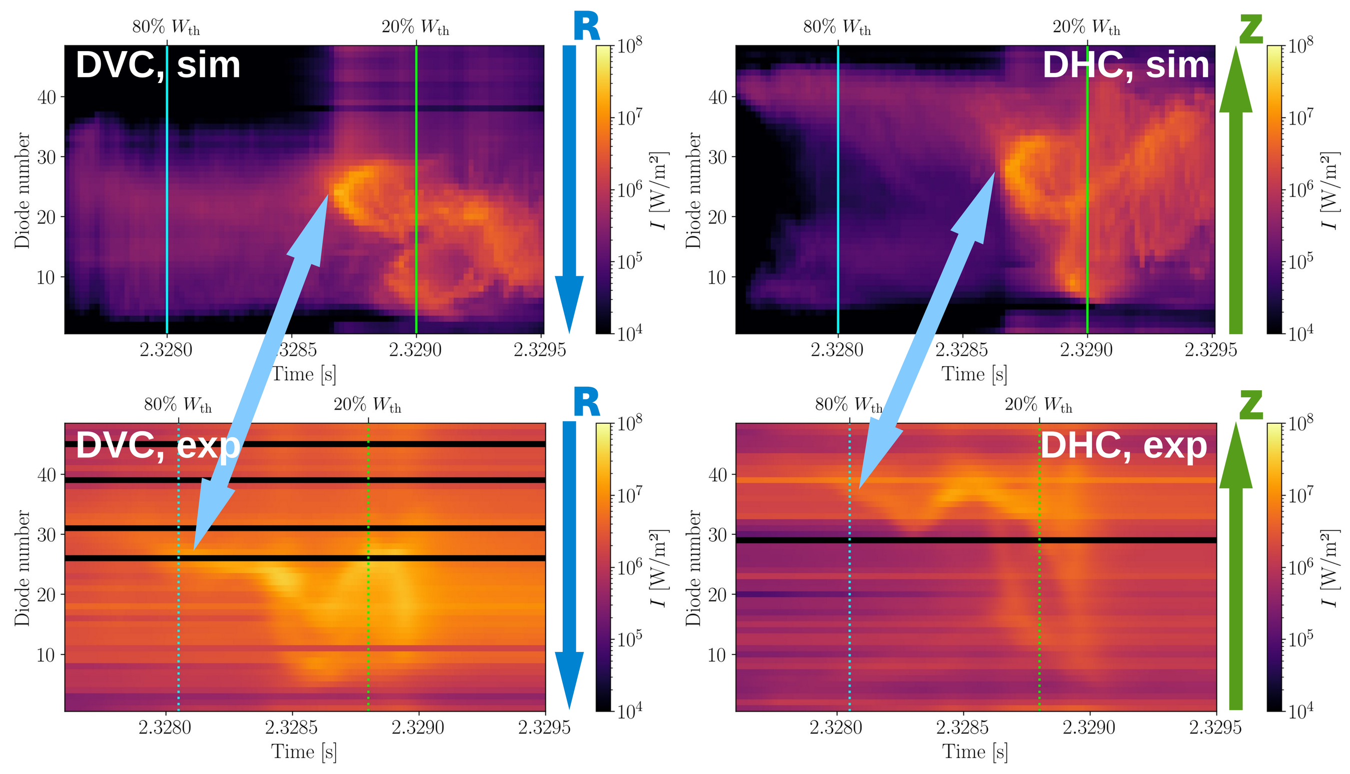


Per-voxel sensitivity of specific lines of sight for different wavelengths.

- **Line of sight geomtery verified**
- **Etendues match the AUG analytic values**
- Also used independent measurement pipeline in Cherab

10% Ne — AUG #40673 – S5

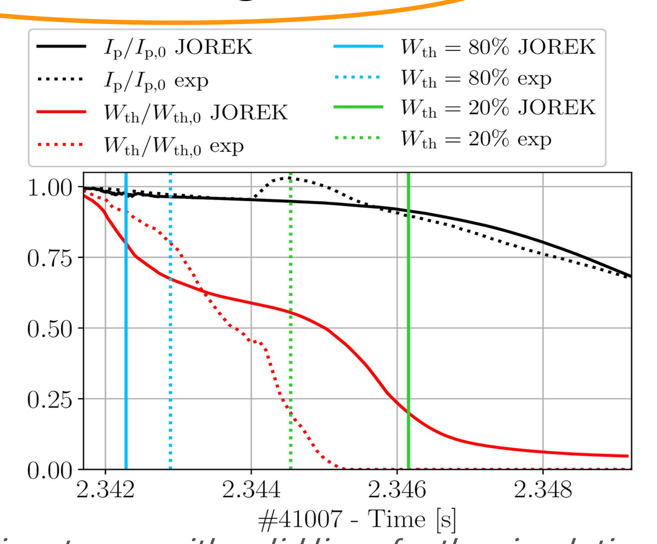
- In Sector 5, the background radiation in the experimental signals comparable to the Ne radiation
- Background impurities not present in JOREK [5]
- **Higher magnitude background radiation** clearly visible **in the experiment**
- Equilibrium toroidal flow not included in JOREK simulations →Ne radiation appears later in sector 5 in the simulation



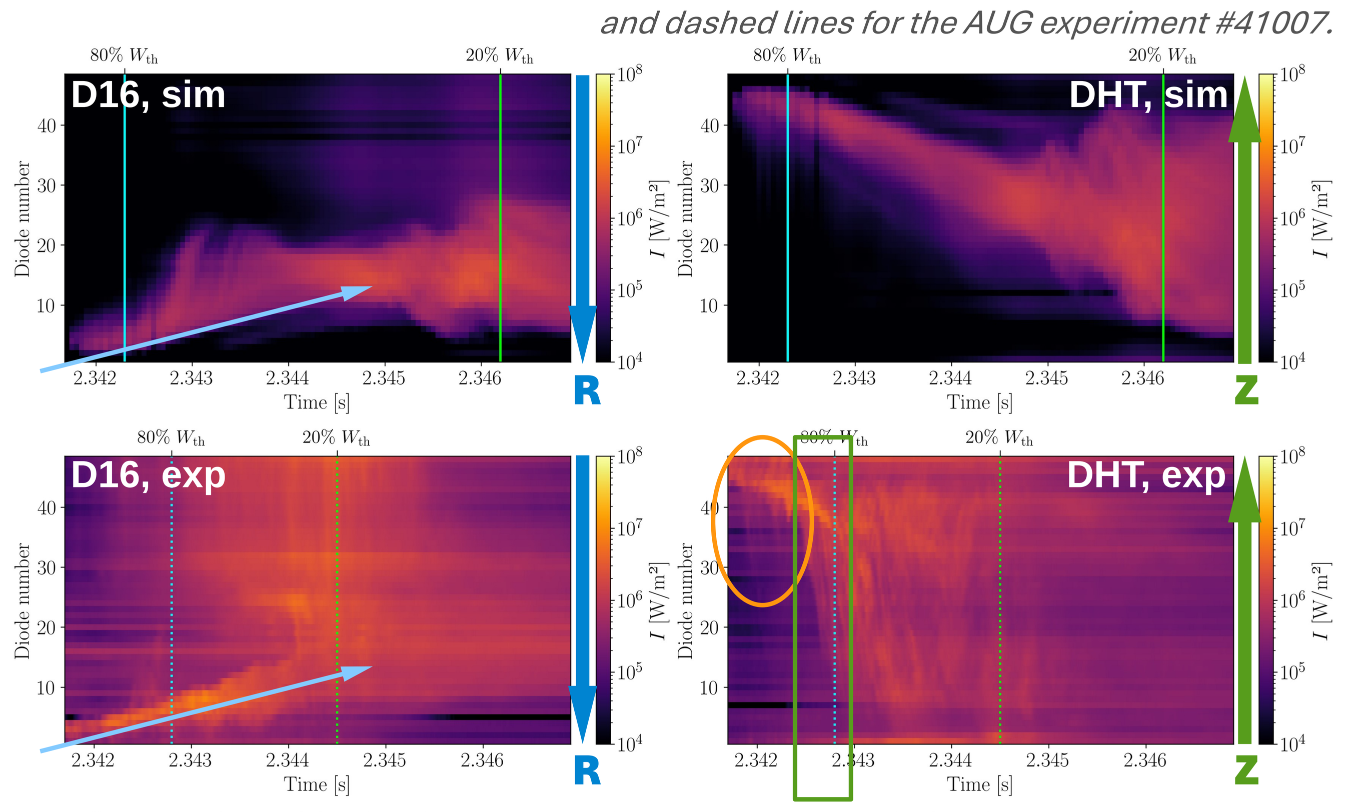
Sector-5 #40673 line-integrated brightness — synthetic (top: DVC / DHC) and experimental (bottom). Same colour scales as before.

0.17% Ne — AUG #41007

- Initial inward trajectory **match** between synthetic (top) and experiment (bottom)
- Low-Ne pellet: expected **rocket effect, plasmoid drift** [6,7]; **not in the JOREK run** [5]
- Experiment shows fine **downward-drifting structures** until t ≈ 2.3425 s, then abrupt downward motion
- Background **intrinsic W radiation** is comparable to the Ne radiation; **absent from the simulation**
- **Recommendation:** include **rocket effect & plasmoid drift**



Plasma parameter time traces with solid lines for the simulation and dashed lines for the AUG experiment #41007.



Sector-16 #41007 line-integrated brightness — synthetic (top) and experimental (bottom). Same colour scales.

Conclusions

- Cherab/Raysect **3D AXUV synthetic diagnostic** 192 LOS, full-CAD tungsten PFCs with reflections for AUG
- **Verified** geometry, etendues, and measurement pipeline
- Applied to JOREK SPI: **qualitative & partial quantitative match** for 10% and 0.17% Ne cases
- Validates **simulation inputs** and motivates **improved physics** (rocket effect, plasmoid drift)
- Effect of missing equilibrium toroidal flow visible in S5
- Can be extended to other fusion devices

References

[0] F. Lengyel et al. AXUV synthetic diagnostic for ASDEX Upgrade and its application for SPI simulations, to be submitted to J. Plasma Phys. (2026).
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