Synthetic diagnostics tools for identification of the L-H transition in ITER PFPO campaigns

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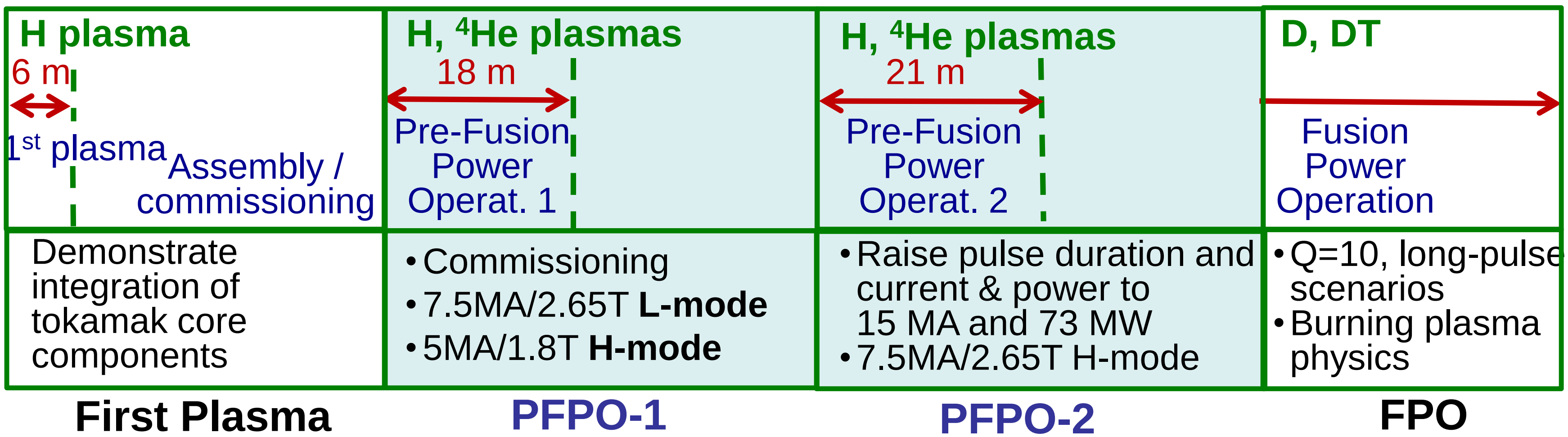
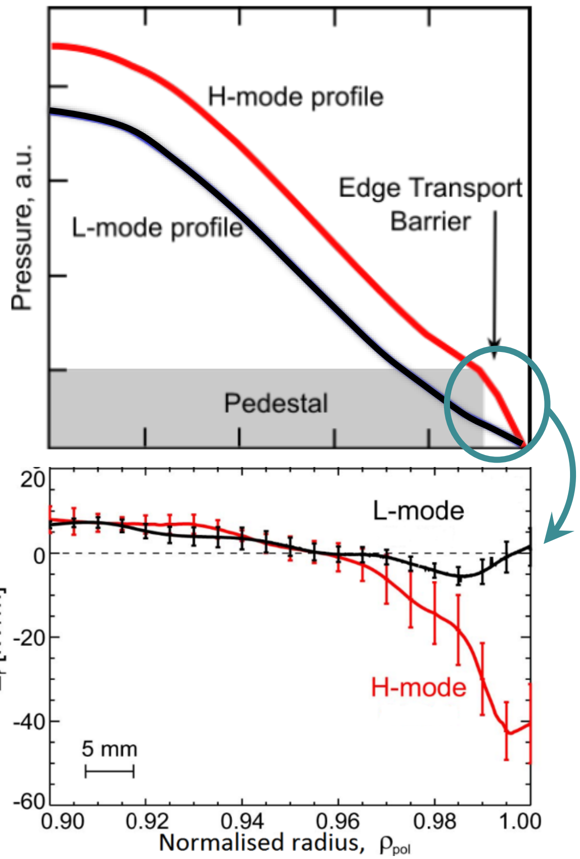
ITER Pre-Fusion Power Operation towards H-mode



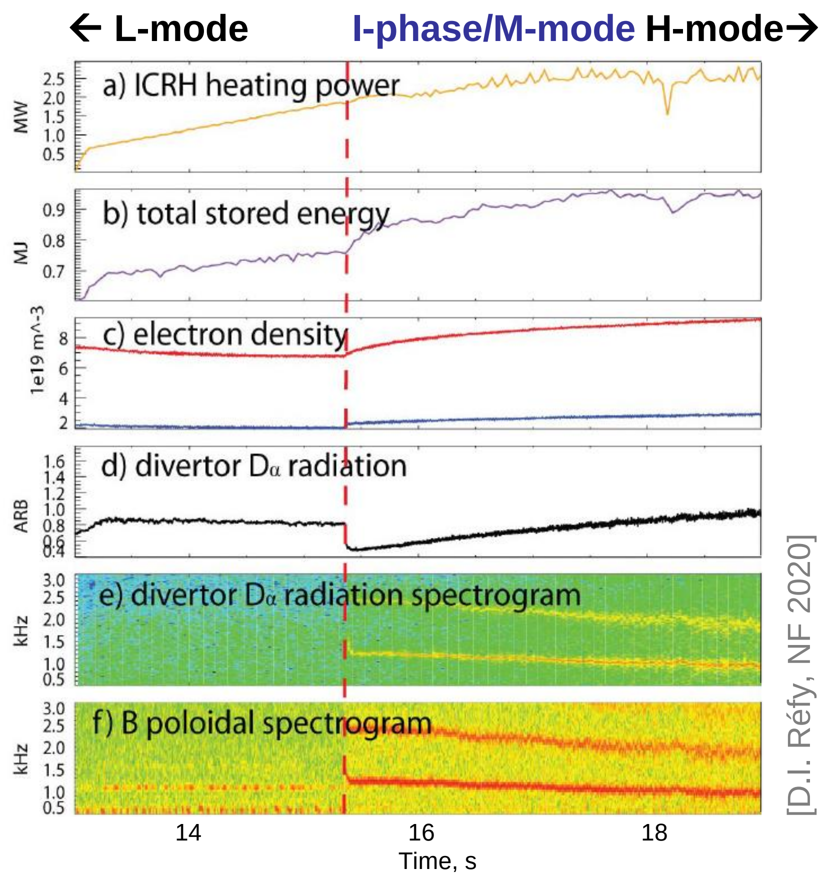
- Access conditions to H-mode
- Characterization of properties of ELMy H-modes
- Early indications of requirements for future heating and current drive upgrades

How to detect the L-H transition with available diagnostics?

Indications of the L-H transition



[E. Viezzer, PPCF 2014]



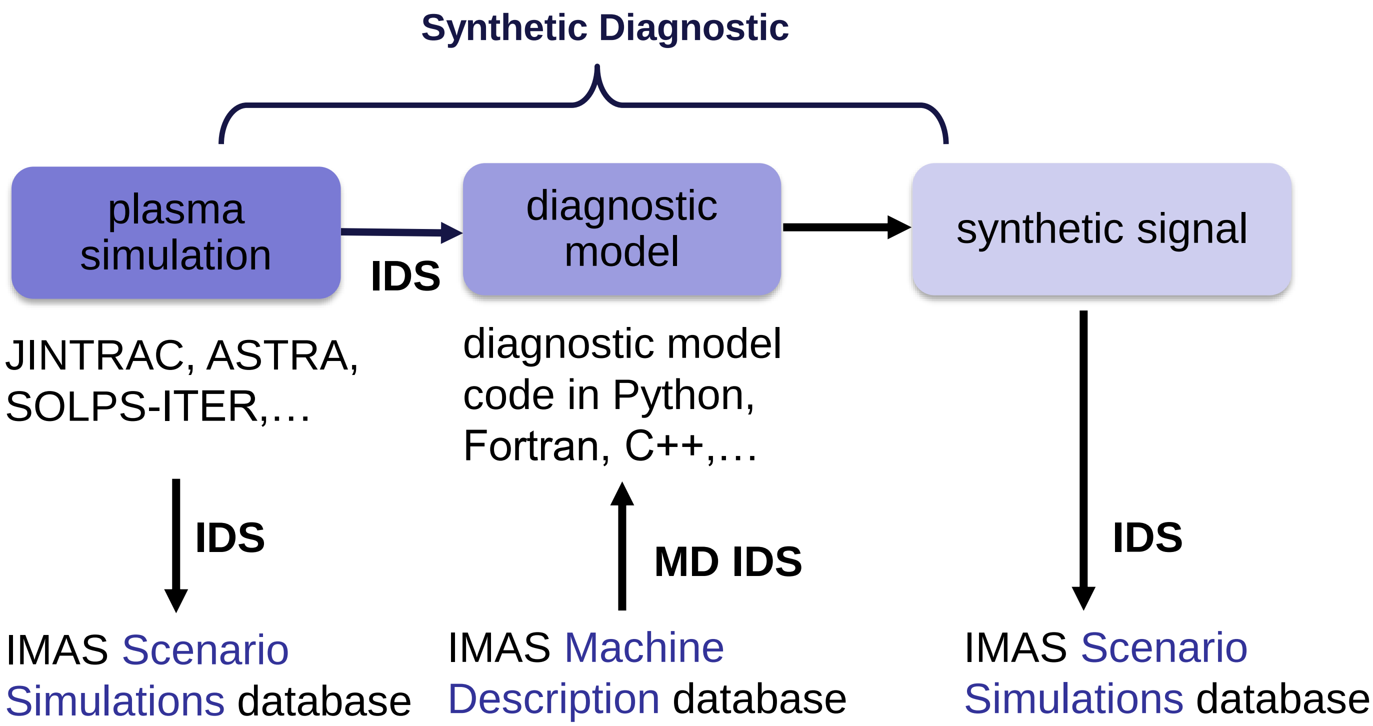
[D.I. Réfy, NF 2020]

- Heat & particle transport reduced → pressure increased
- E_r increased → poloidal rotation enhanced
- n and T increased, but fluctuation reduced
- Reduced power loads on divertor, narrowed width of power deposition on divertor
- D_α radiation reduced

ITER SD actively developed for L-H detection

	Diagnostic	Measurement	Time resolution	SD status
PFPO-1	55.F1 ECE	T_e	1 µs – 10 ms	ECRad
	55.EI X-ray Crystal Spectroscopy Edge	T_i, V_{pol}	10 – 100 ms	XICSRT+
	55.C5 TIP	line-averaged n_e	0.1 ms	DIP_TIP_POP
	55.E7 Radial X-ray Camera	$\sim n_e T_e$ ELM transients	down to 0.2 ms	ongoing
	55.E2 H-alpha + 55.E6 VSRS, 55.E4 DIM, 55.GE DFM	H_α intensity	20 µs	CASPER
	55.G7 Langmuir probes	divertor ion flux, n_e, T_e	20 µs – 2 ms	to be done
	55.EH VUV Edge	impurity influx in divertor	10 ms	to be done
	55.G6 Divertor IR thermography	surface T, power load	1 – 10 ms	ongoing
	55.D1 Bolometry	P_{rad}	10 ms	TOFU_bolo
PFPO-2	55.F9 HFS reflectometer	core n_e	5 – 24 µs	refractometer SD
	55.F2 LFS reflectometer	edge n_e, V_{pol}	5 – 24 µs	REFI
	55.EC CXRS Edge	edge T_i, V_{pol}	200 ms	CASPER
	55.C2 Edge TS	edge n_e, T_e	10 – 100 ms	ongoing

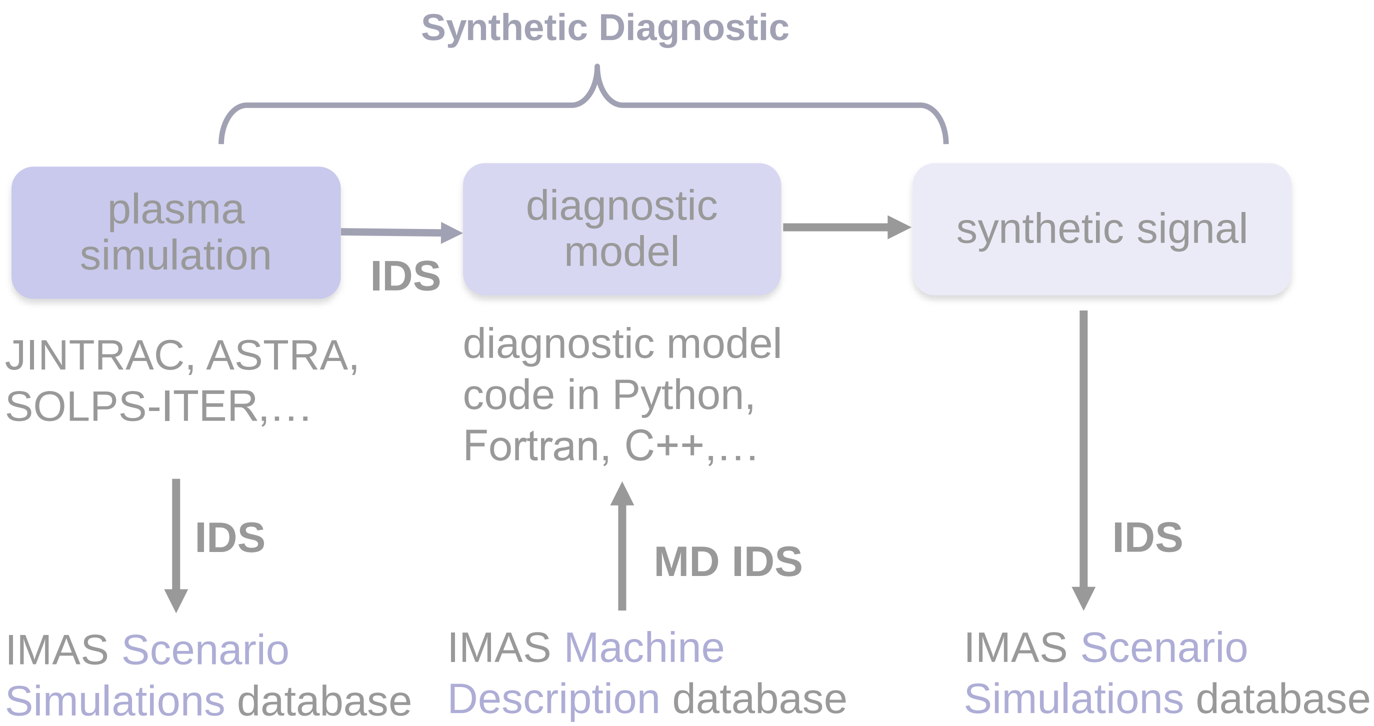
Synthetic diagnostics architecture within IMAS



- After defining diagnostic's design, diagnostic parameters should be stored in **IMAS Machine Description** database
- Diagnostic models should be adapted to IMAS and use **IDS**s
- SD should exploit **IMAS Scenario Simulations** database
- SD should produce raw signals and physical quantities into IDSs
- Additional post-processing should be done and written in IDSs

CASPER (Hα)
ECRad
DIP_TIP_POP
XICSRT+
TOFU_bolo
refractometer SD
REFI

Synthetic diagnostics architecture within IMAS



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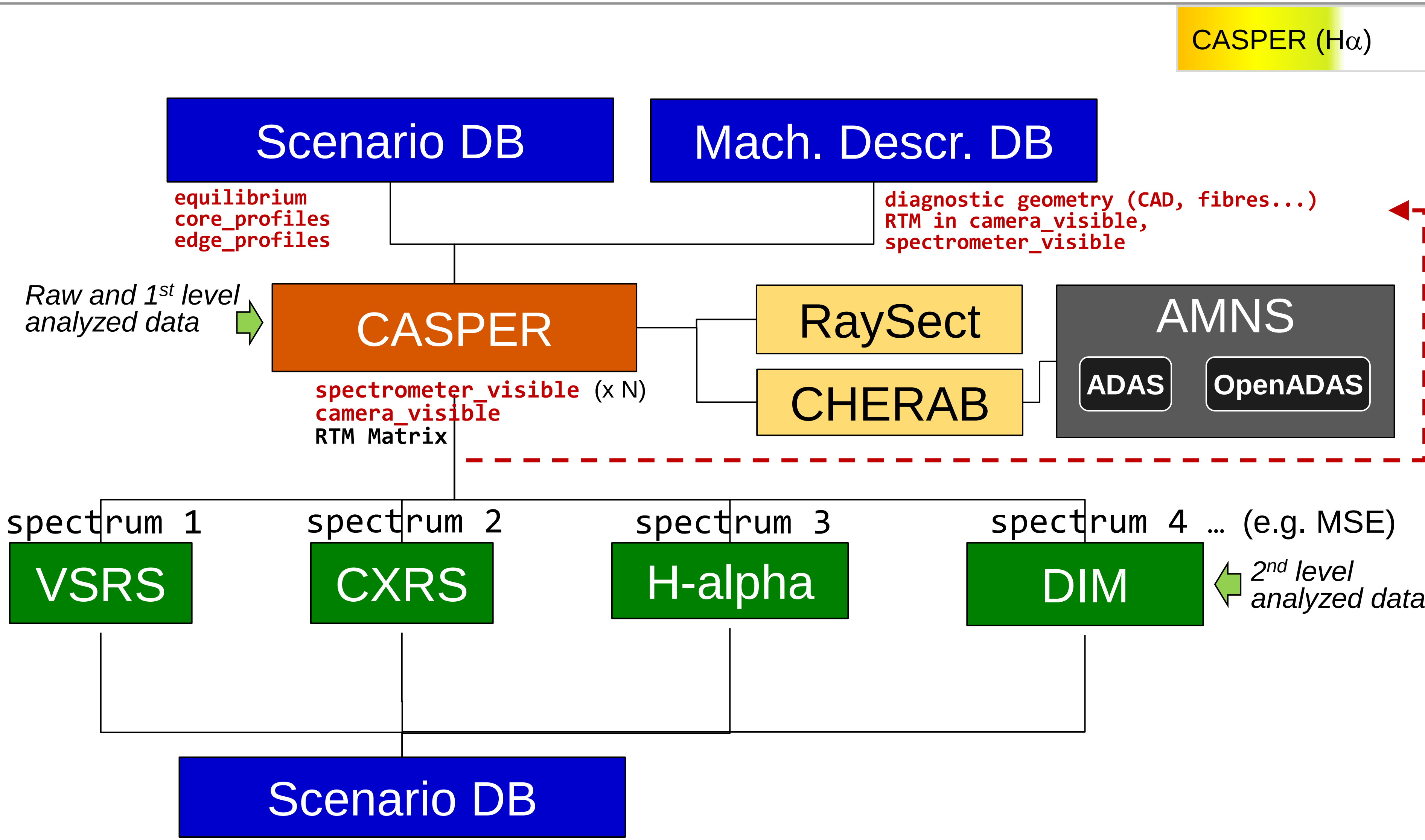
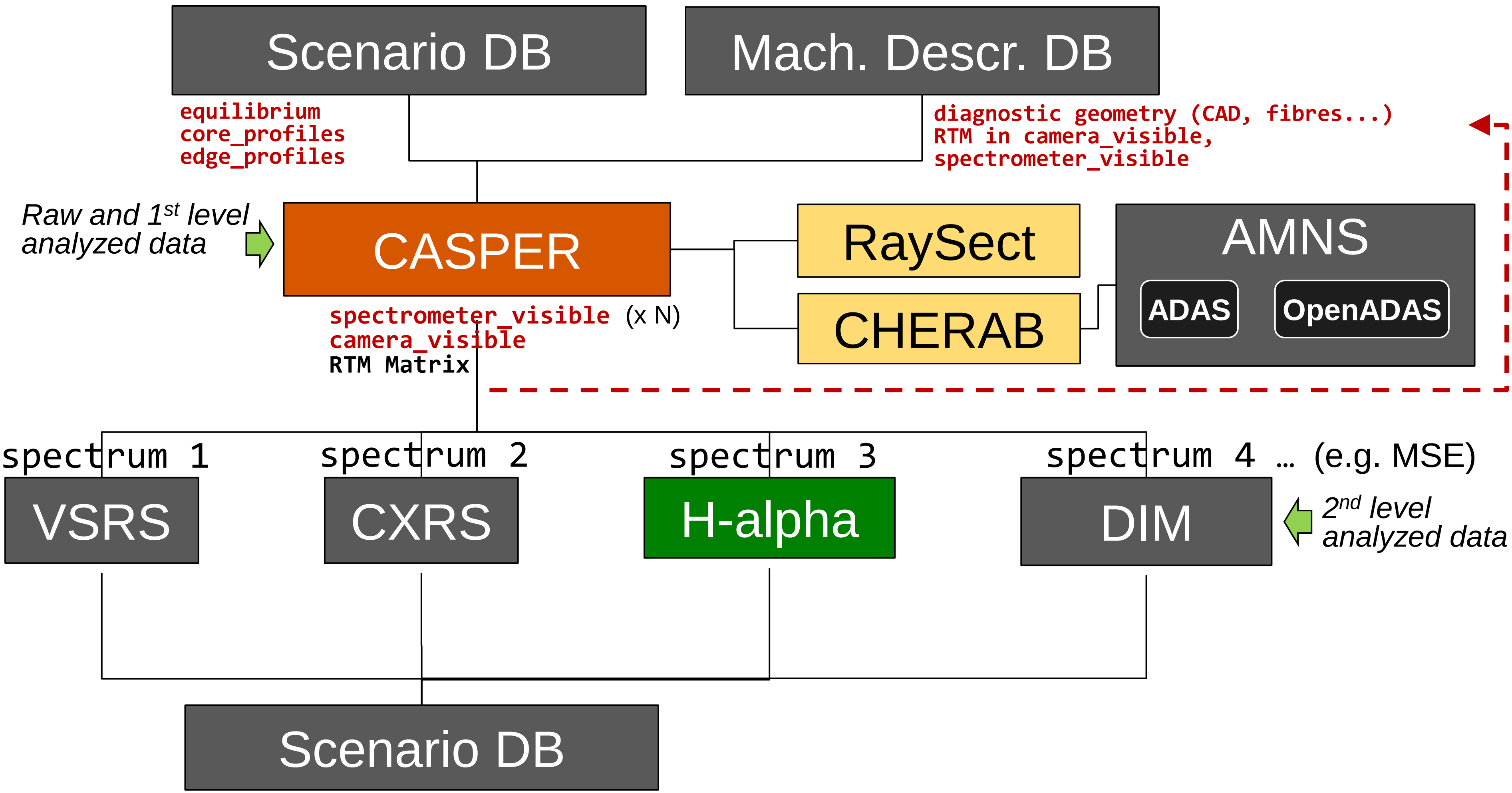
Development of CASPER workflow for spectrometry



Development of CASPER workflow for spectrometry

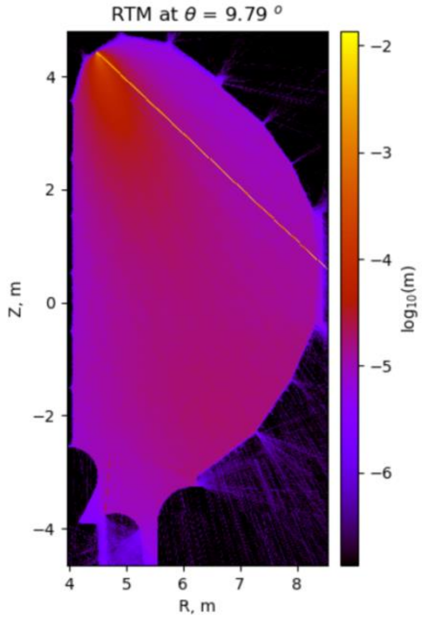
CASPER (Hα)

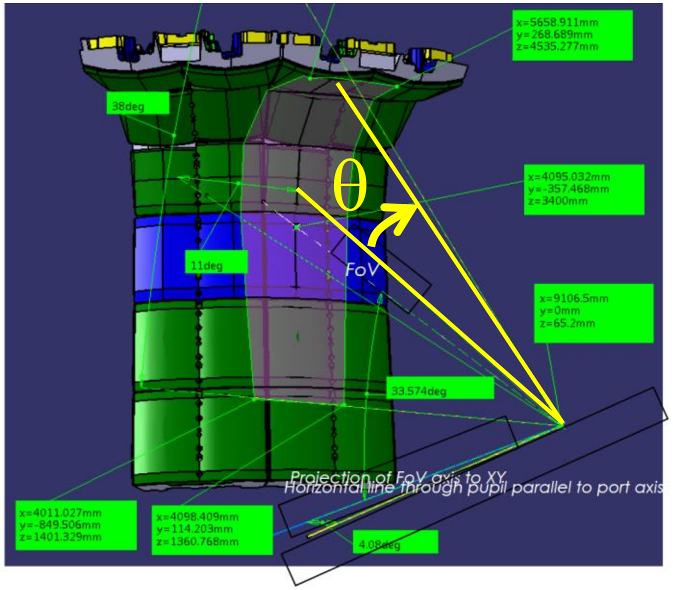


H_α SD is being integrated into CASPER

CASPER (Hα)

- For each field of view Ray Transfer Matrix (6D → 2D) can be calculated and stored to increase calculation speed
- For ITER RTM without (with) reflections :
  - 10 cm R,Z grid
  - 512×512 pixels camera
  - calculation 1 (4) CPUh
  - size 1 Gb (>10 Gb)
- Radiance calculation can be done at each SD call: 10 s on GPU, 30 min on CPU
- Results and RTM written in .npy format should be stored in MD IDSs – to do

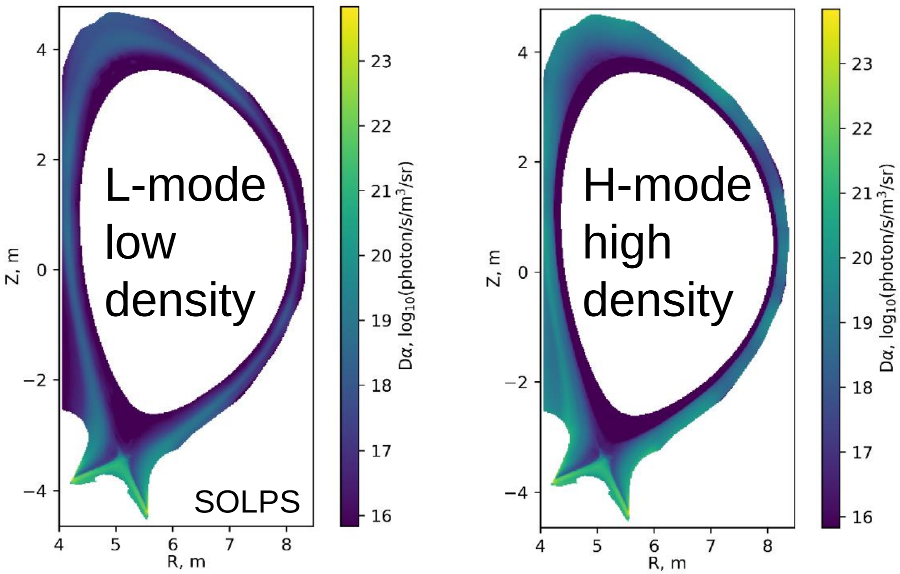




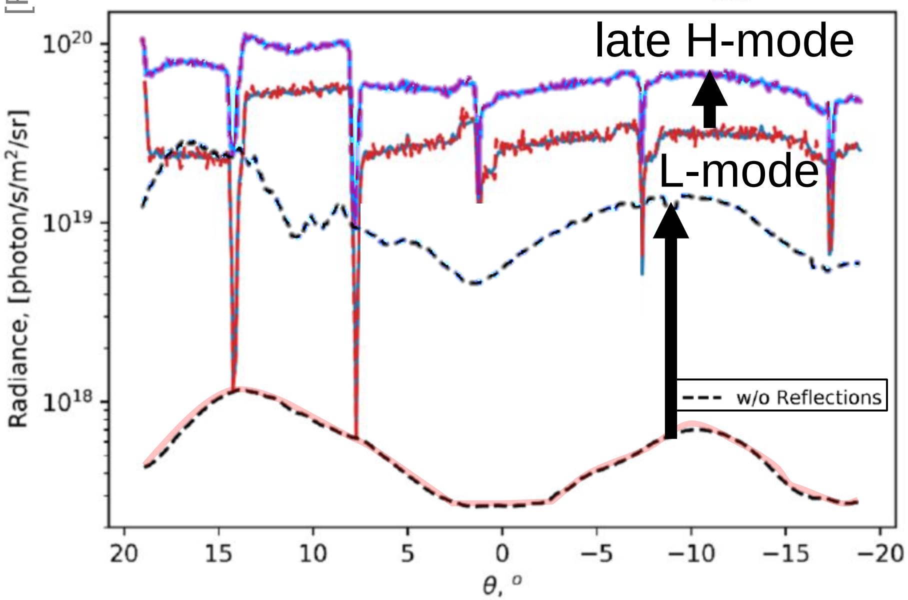
Example of H_α synthetic signals

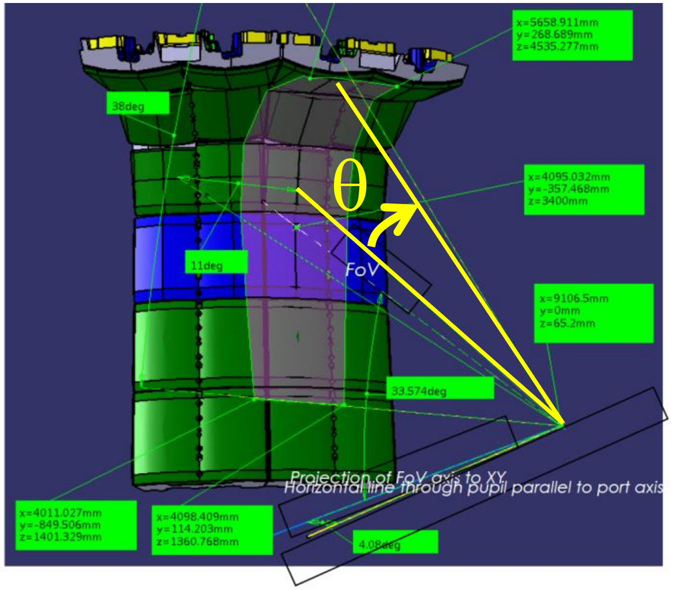
CASPER (Hα)

[R. Khusnutdinov, private communication]



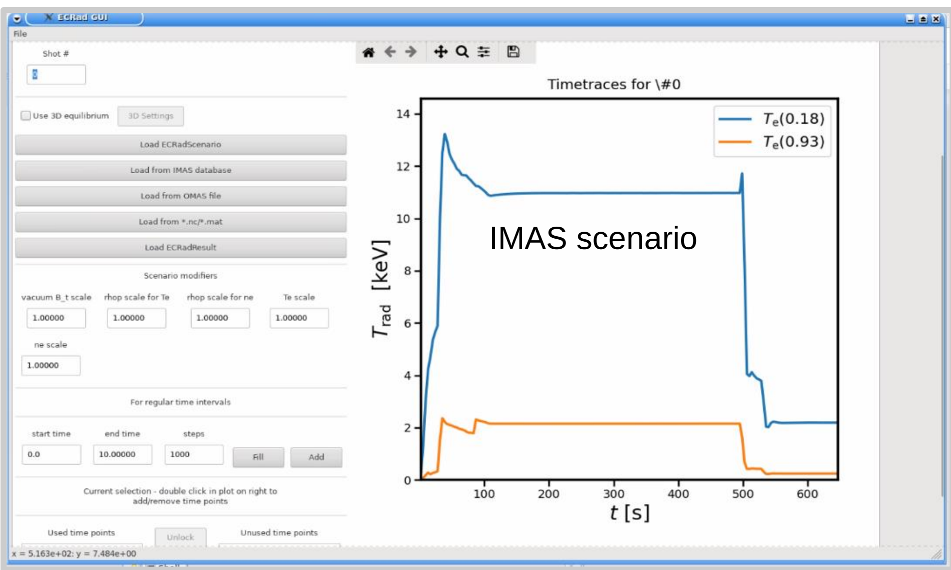
- Emission in divertor is a few orders of magnitude higher than that in the main chamber SOL, which results in divertor stray light signal
- The initial drop of H_α radiance during the L-H transition might be recovered → further simulations



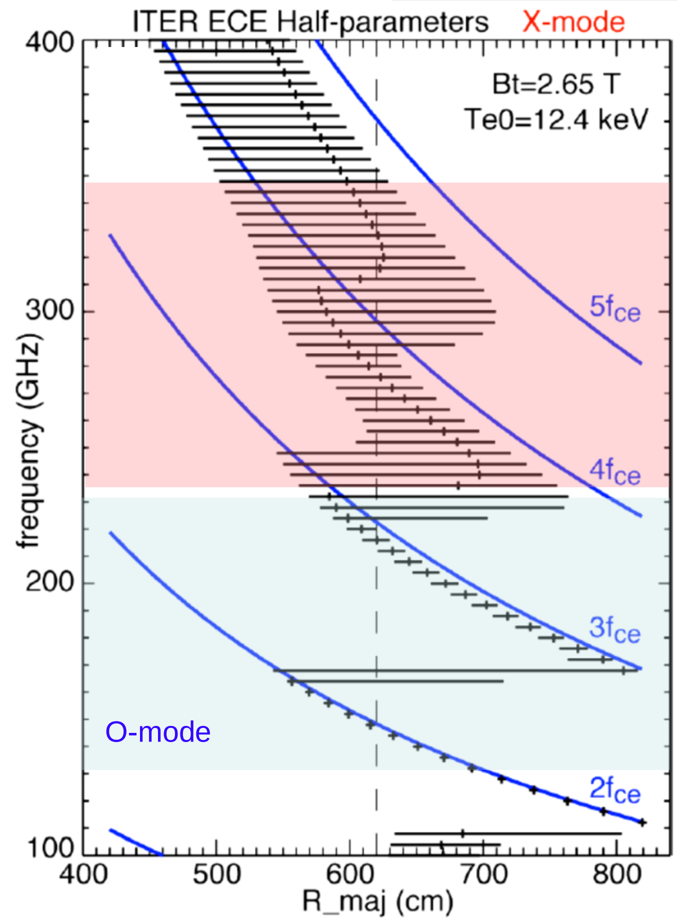


ECE design should remain flexible for PFPO

- ECRad synthetic diagnostic [S.S. Denk, CPC 2020] is adapted to IMAS and reads ITER Machine Description for radial and oblique ECE channels 123-353 GHz, O- and X-mode
- Ongoing work on its integration into the ITER SD workflow
- At present ECRad uses GUI + .nc output



ECRad

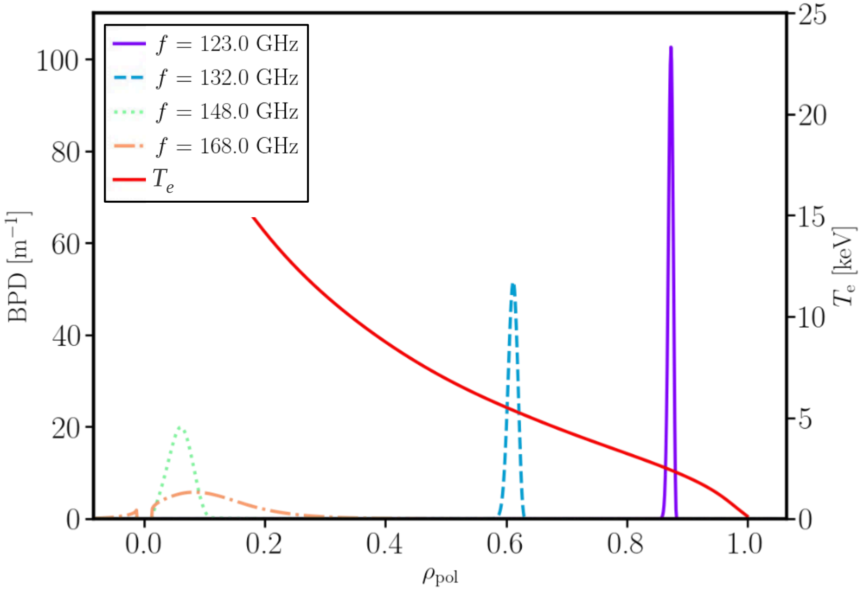


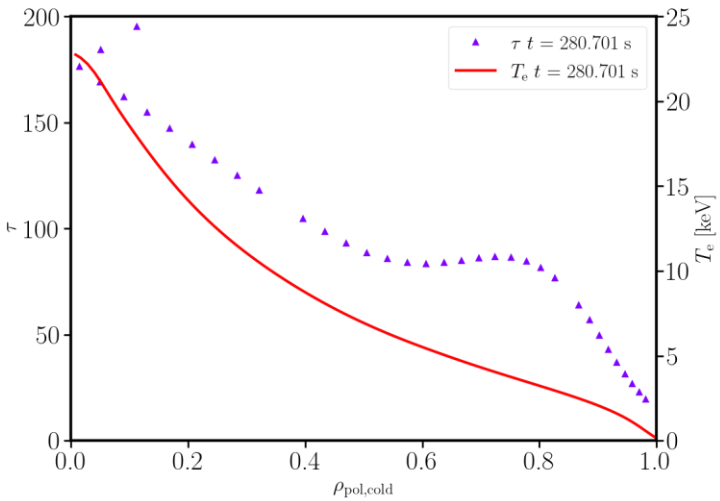
[M. E. Austin, private communication]

- The radial resolution is determined by ECE frequency broadening effects, primarily relativistic, and plasma optical depth

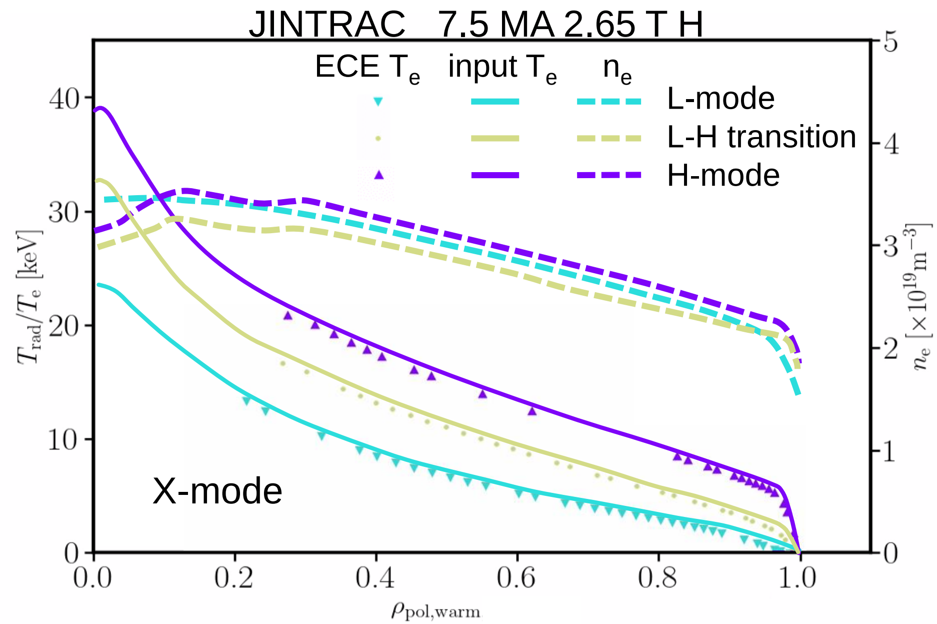
ECE can provide a measurement of the pedestal top T_e

ECRad





(see S. Denk talk)



- X-mode ECE should be recommended to use in PFPO
- ECE cannot quite achieve the target resolution of 1 cm in pedestal region → ITER should also provide for a separate high resolution edge measurement system for PFPO-1 (TS, reflectometry available in PFPO-2)

Interferometer/polarimeter synthetic diagnostic for density

```
interferometer_out = dip_tip_pop(equilibrium,core_profiles,interferometer_MD)
```

Interferometer phase shift:

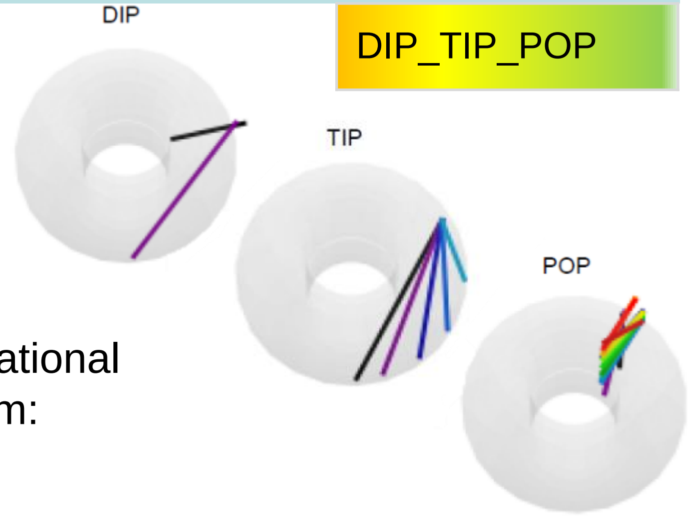
$$\Delta\phi = \frac{e^2\lambda}{4\pi\epsilon_0 m_e c^2}\int n_e\left(1-\frac{3}{2}\frac{T_e}{m_e c^2}\right)dl = 2.82\cdot 10^{-15}\lambda\cdot\int n_e dl$$

Polarimeter Faraday angle:

$$\alpha = 5.24\cdot 10^{-13}\lambda^2\int\left(1-\frac{2T_e}{m_e c^2}\right)n_e\vec{B}\cdot d\vec{l}$$

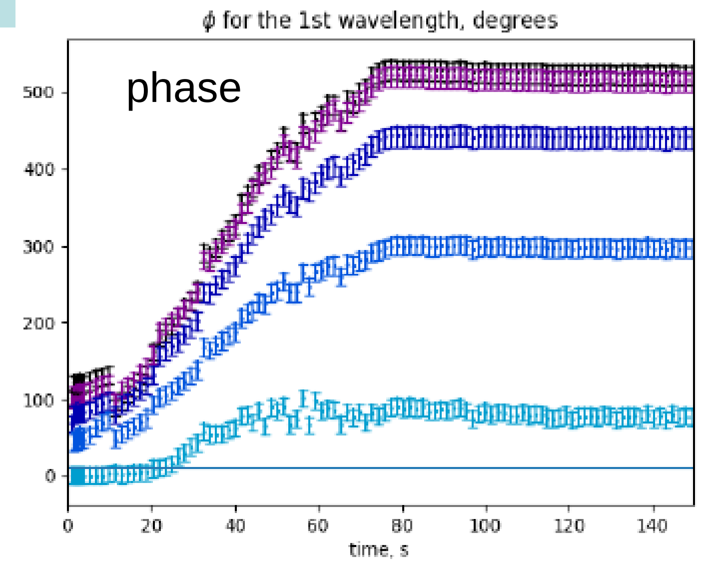
Phase includes terms with electron temperature (*A*) and vibrational noise (*B*) and can be substracted by using a 2-colours system:

$$\Delta\phi = A\lambda + B/\lambda$$



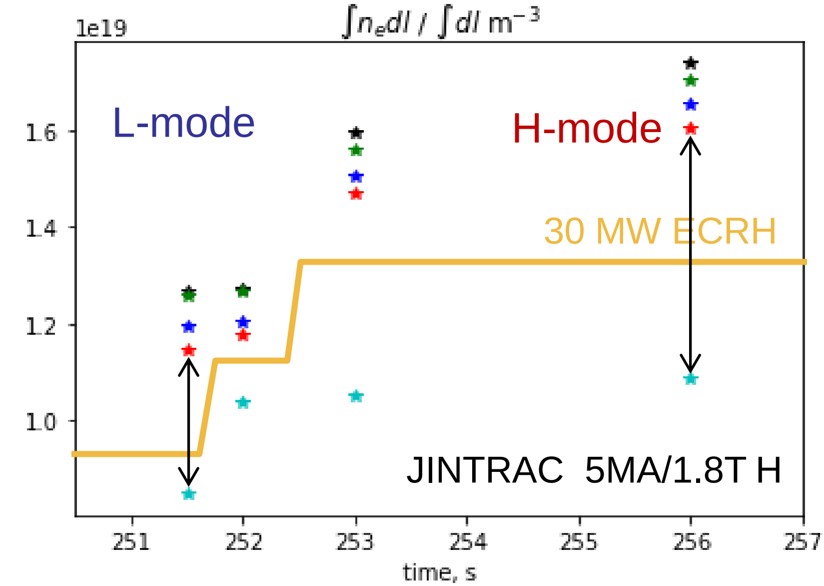

```
python DIP_TIP_POP.py -shot -run -diag -time
```

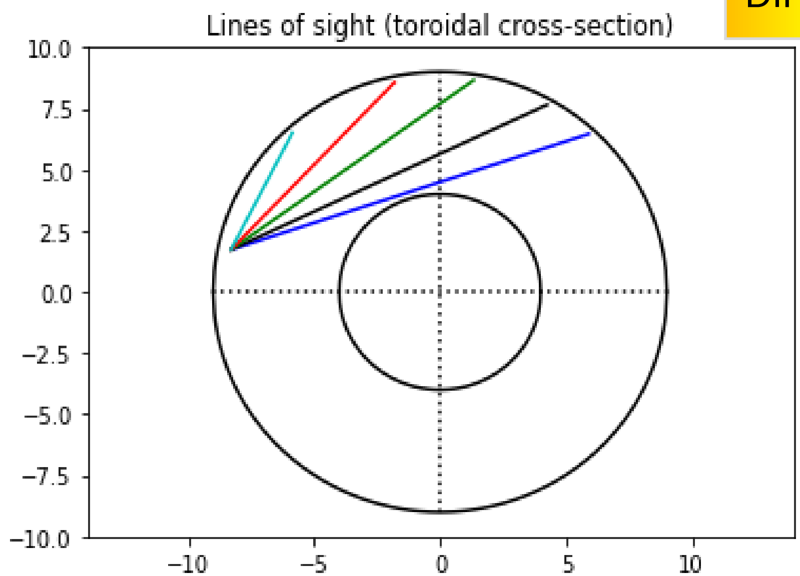
- usual run and **Minerva** application (+refractometer+magnetics+VSRS+Hα+XRCS)
- **EasyVVUQ** branch for uncertainty quantification study
  [Richardson et al. JOPS 2020]
- **IDA** use (+ECE+TS) with new DIP_TIP_POP_triple.py:
  `init_static(interferometer)` – MD
  `init_dynamic(equilibrium)` – large time step
  `evaluate(core_profiles)` – fine dynamics

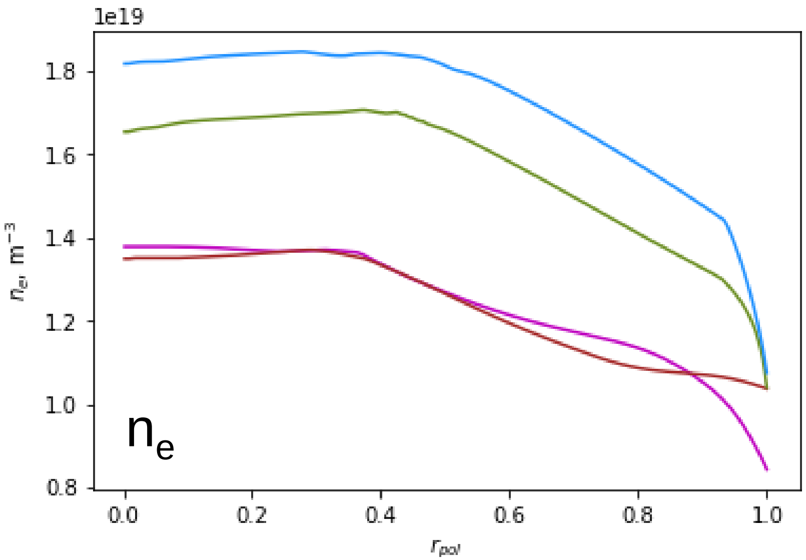


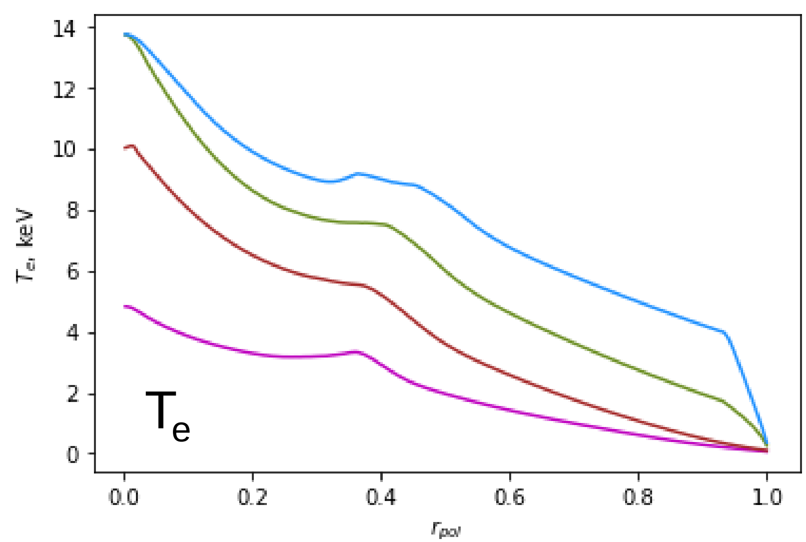
TIP line average density recovering L-H transition

DIP_TIP_POP









Conclusions and perspectives

- Assessment of the L-H transition detection is ongoing: interferometry, ECE and H_α radiation signals might provide enough information on the time evolution of the pedestal formation
- In order to fully detect an L-H transition, reflectometry and Thomson Scattering diagnostics might be necessary in addition to ECE in X-mode
- Synthetic diagnostics for the systems measuring plasma rotation, density/temperature in the edge and power load on the divertor are being actively developed
- The IMAS Machine Description database is populated with main diagnostics for the detection of L-H transition
- The IMAS Scenario Simulation database has a complete set of PFPO cases as foreseen in the ITER Research Plan
- Further development of ITER synthetic diagnostics together with Bayesian techniques will help to optimize the design of the measurement systems and to make performance predictions