DE LA RECHERCHE À L'INDUSTRIE

A spectral modelling code for VUV-XUV

R. Guirlet

with Martin's answers to many (silly) questions

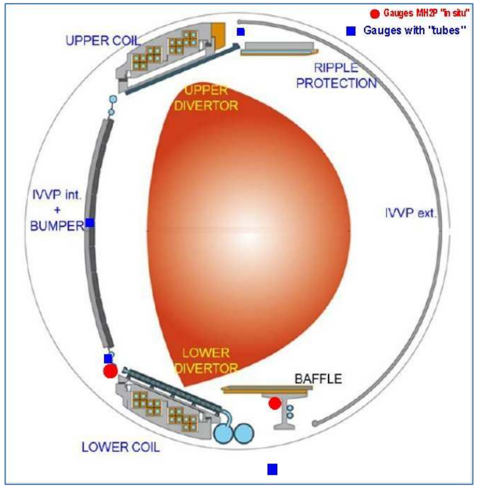
(and more to come)

ADAS workshop, Catania,1st October 2015

www.cea.fr

Context and motivations

- WEST project will change Tore Supra into an all-W tokamak for long discharges, high fluxes (ITER)
  - New spectrometers (XUV, SXR)
  - New quantities to be measured (pedestal)

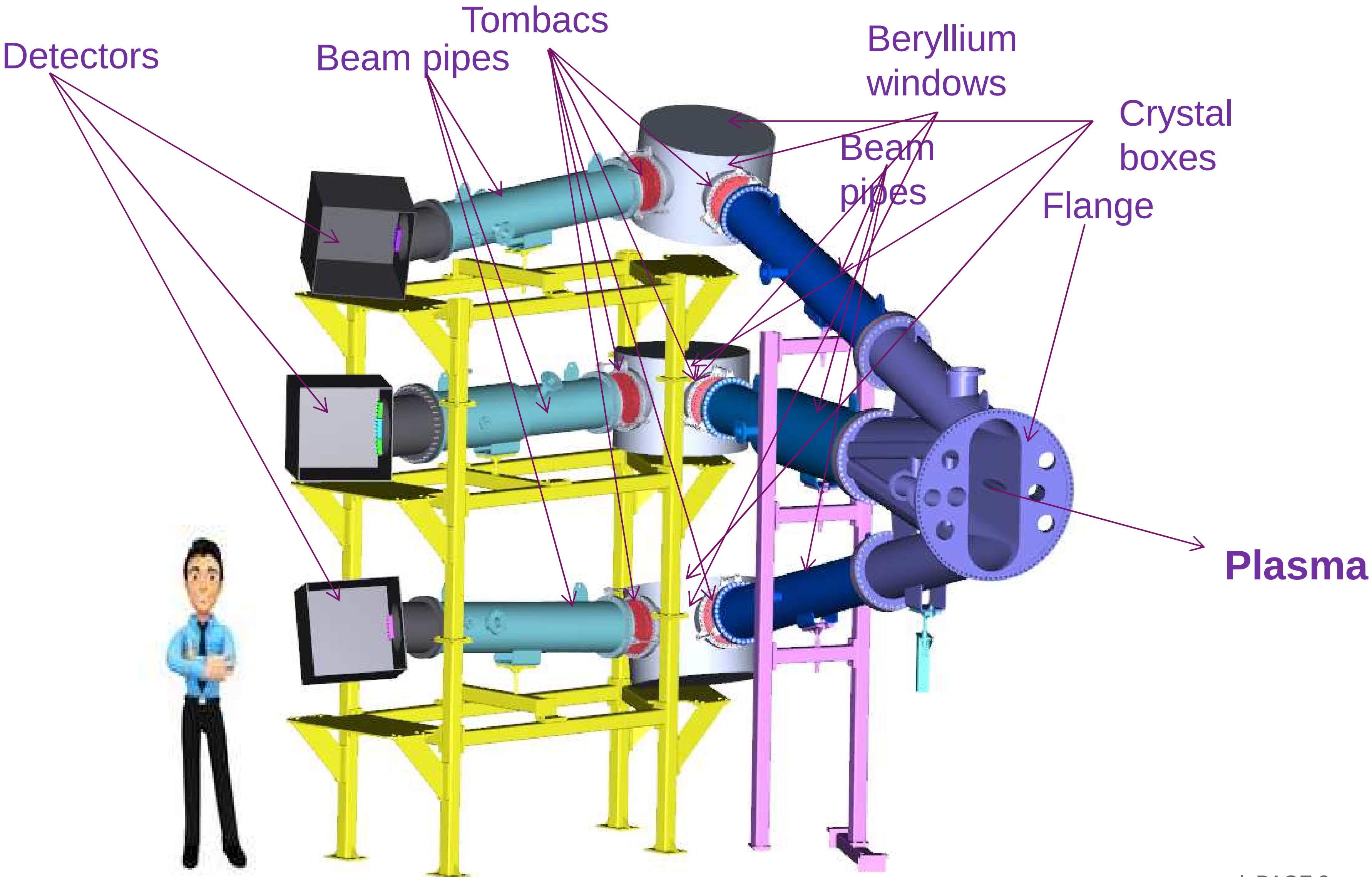


- Line identification and λ calibration

- VUV-XUV lines provide constraints for transport
  - Ratios of lines from different ionisation stages
  - Many ratios $\rightarrow$ many constraints

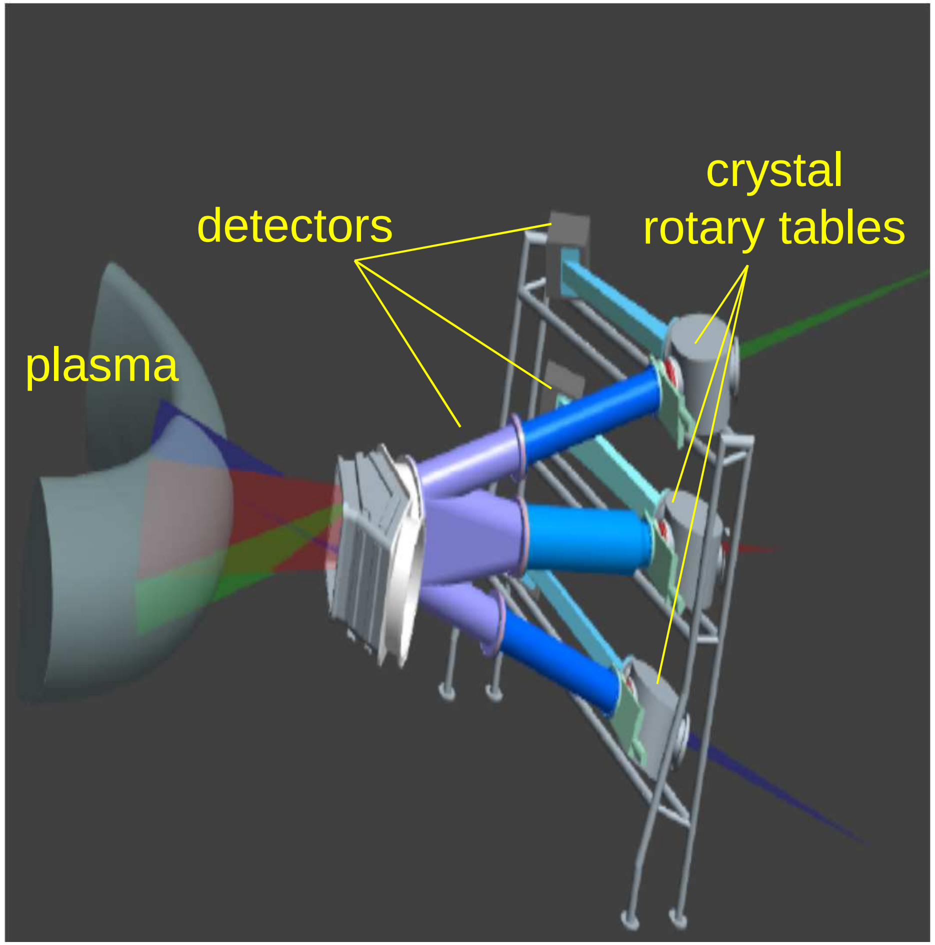
- VUV-XUV measurements help validate PEC data

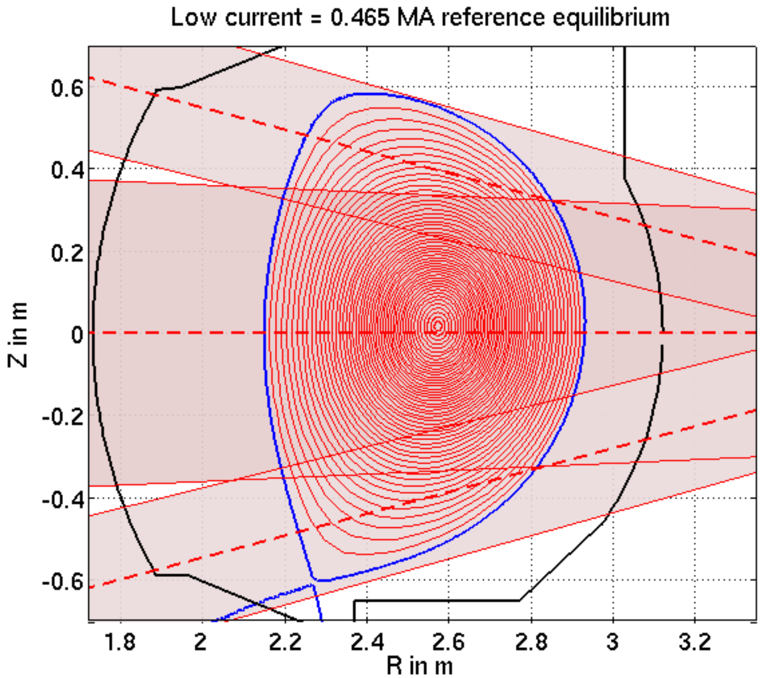
Imaging crystal spectrometer



3 independant views ⇨ 3 spectrometers

Imaging crystal spectrometer

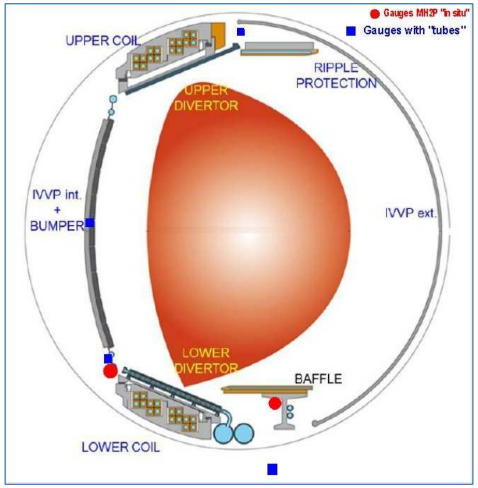




Element	Energy [keV]	Crystal	Bragg angle [°]	Rowland radius [m]
Ar XVII	3.1218	Qu (11-20)	54.0183	1.3516
Ar XVIII	3.3206	Qu (10-12)	55.0106	1.3511
F XXV	6.6685	Ge (422)	53.6045	1.3526

Context and motivations

- WEST project will change Tore Supra into an all-W tokamak for long discharges, high fluxes (ITER)
  - New spectrometers (XUV, SXR)
  - New quantities to be measured (pedestal)



- VUV-XUV lines provide constraints for transport
  - Ratios of lines from different ionisation stages
  - Many ratios $\rightarrow$ many constraints

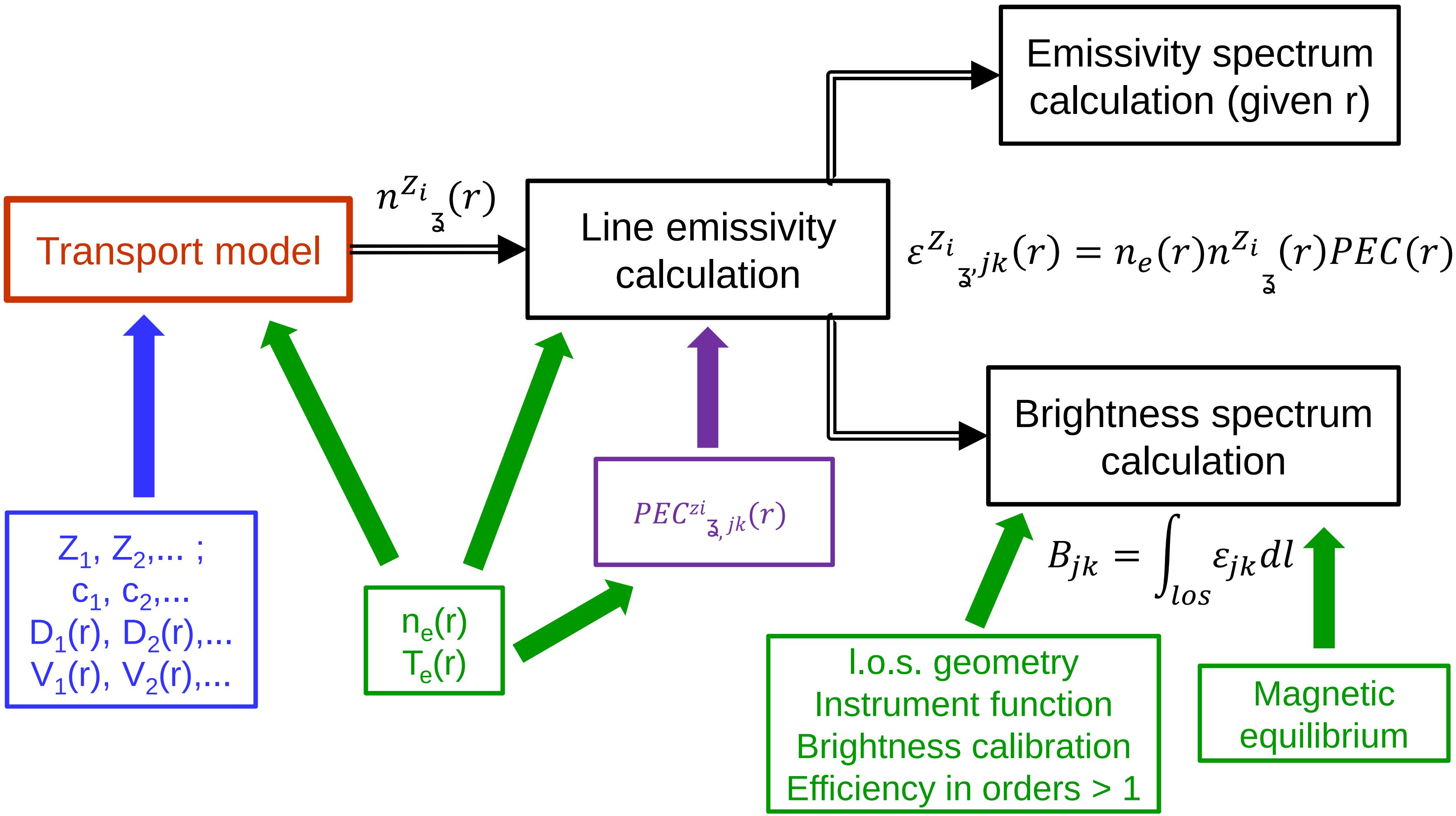
- VUV-XUV measurements help validate PEC data

- Line identification and λ calibration

LAYOUT

- Model description:
  - Transport
  - Emissivity and PECs
  - Spectral synthesis
- Testing and using the model
- Conclusion - prospects

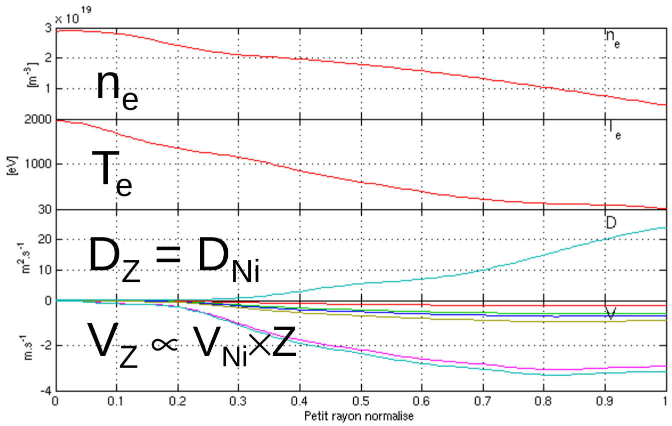
MODEL DESCRIPTION



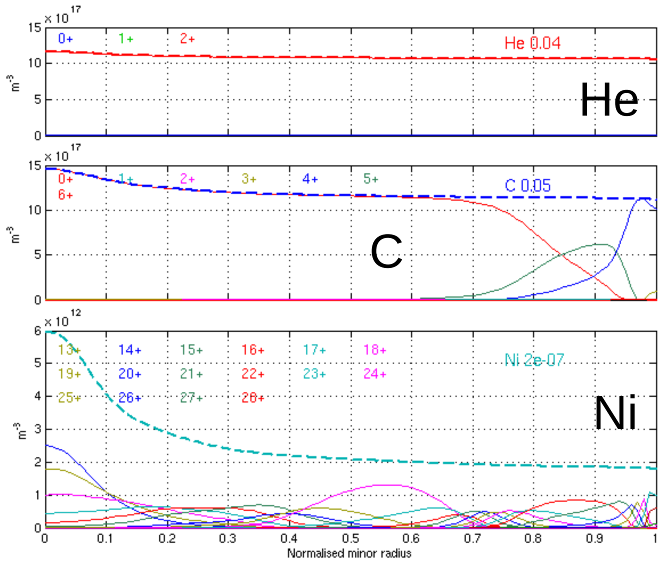
- Whatever you want
- At the moment, the code is designed for a stationary state
- For testing:
  - Continuity equation for total density of each impurity: $\Gamma_Z = -D_Z \vec{\nabla} n_Z + \vec{V}_Z n_Z$

$$\cancel{\frac{\partial n_Z}{\partial t}} + \vec{\nabla}.\vec{\Gamma}_Z = \cancel{source} \Rightarrow \frac{\nabla n_Z}{n_Z} = \frac{V_Z}{D_Z}$$

  - Local ionisation equilibrium

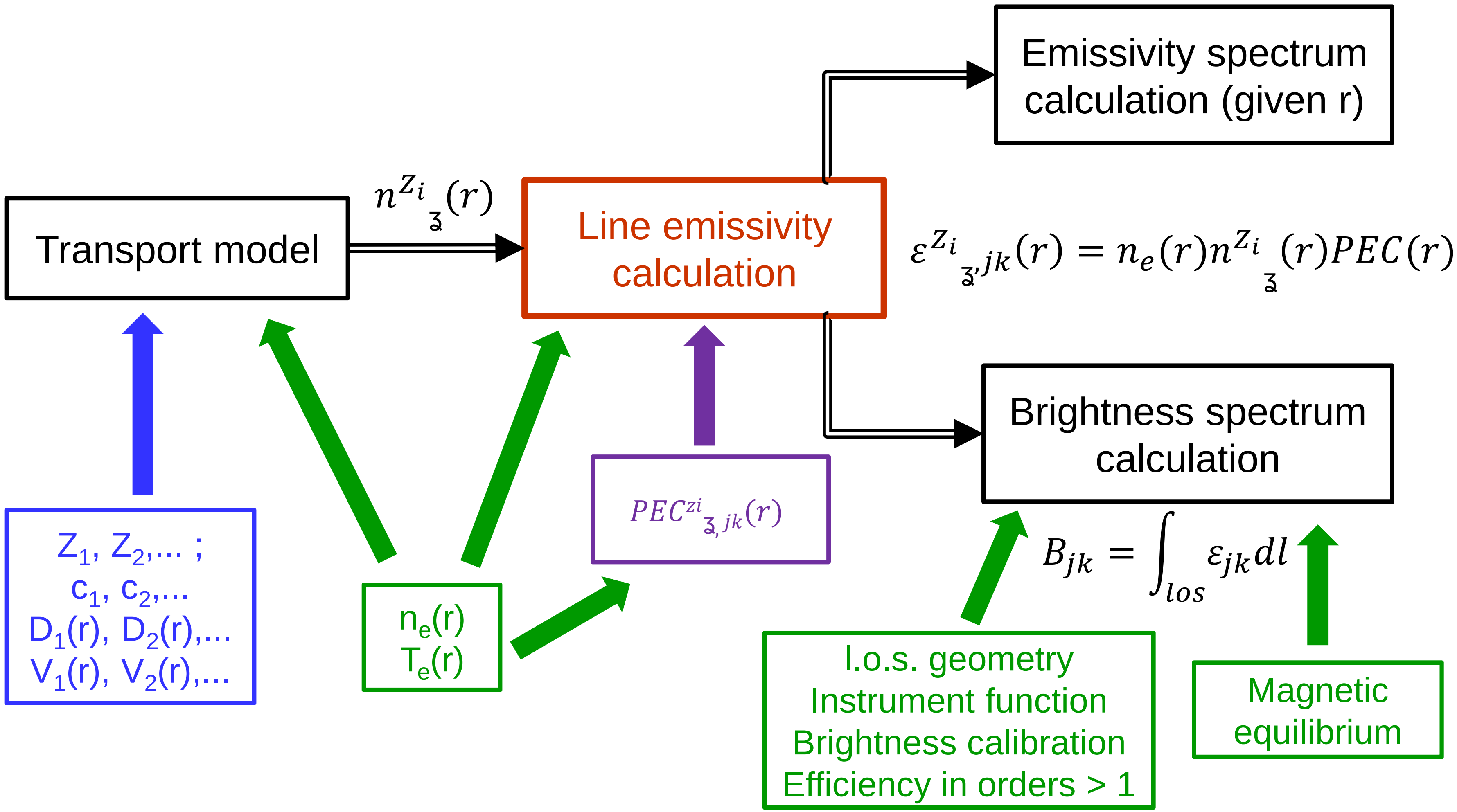


(TS40801)



- Consistent solution of continuity equations to be implemented shortly

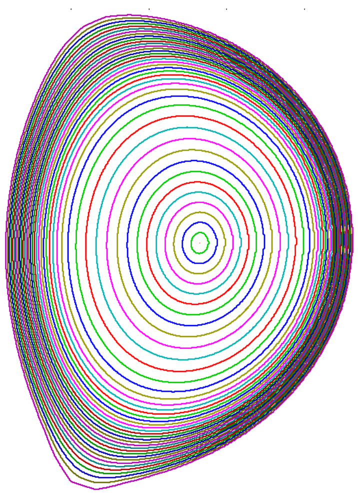
MODEL DESCRIPTION



EMISSIVITY CALCULATION

- $\varepsilon^{Zi}_{\text{ȥ}, jk}(r)$ *[photons s^{-1} cm^{-3}]* $= n_e(r) \times n^{Zi}_{\text{ȥ}}(r) \times PEC_{jk}(n_e(r), T_e(r))$ PEC *[cm^3 s^{-1}]*

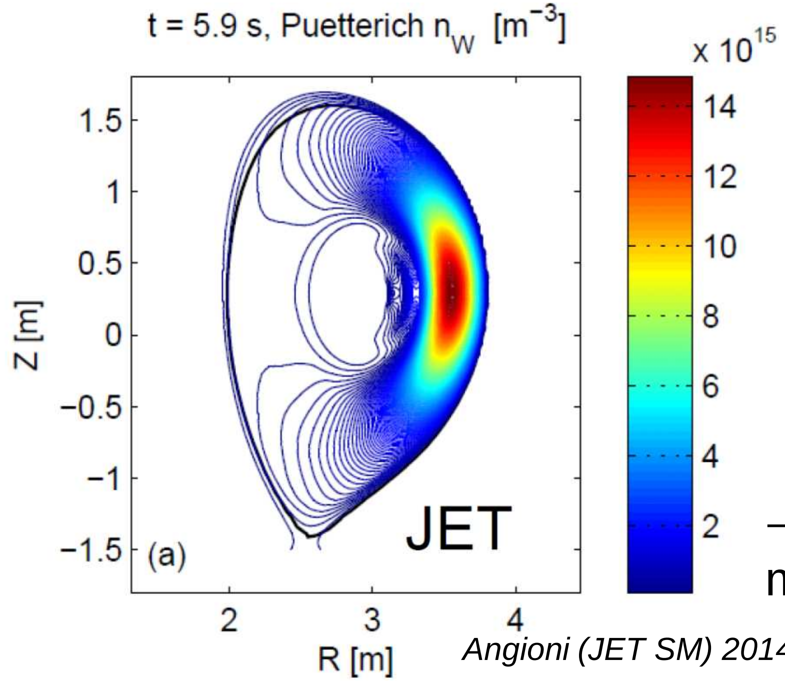
- Strong hypothesis: all quantities are uniform on a magnetic surface - no SOL



EMISSIVITY CALCULATION

- $\varepsilon^{Zi}_{\text{ʒ}, jk}(r)$ *[photons s^{-1} cm^{-3}]* $= n_e(r) \times n^{Zi}_{\text{ʒ}}(r) \times PEC_{jk}(n_e(r), T_e(r))$ PEC *[cm^3 s^{-1}]*

- Strong hypothesis: all quantities are uniform on a magnetic surface - no SOL



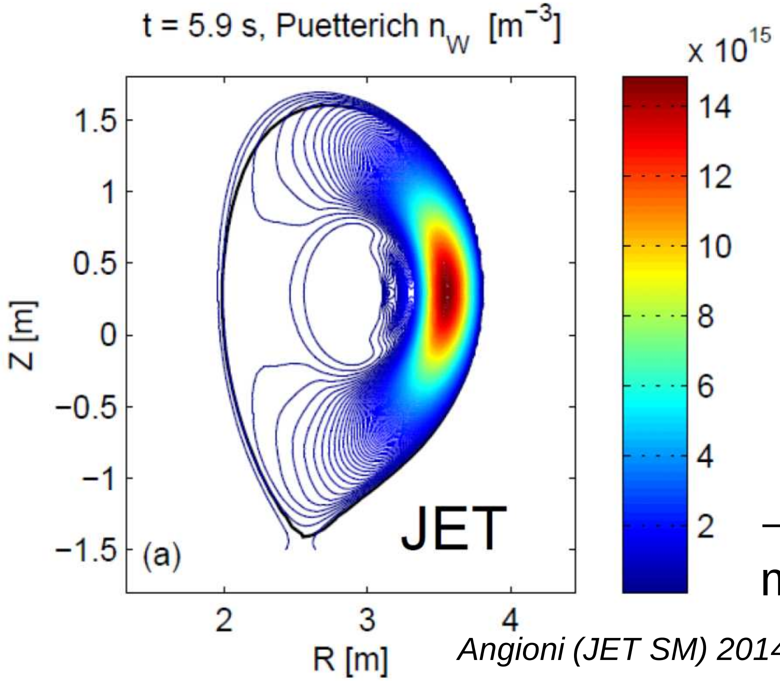
Angioni (JET SM) 2014

→ W not included in the model yet

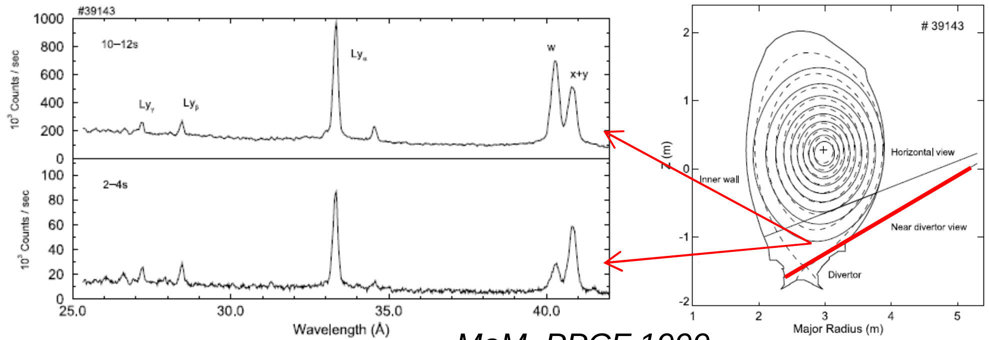
EMISSIVITY CALCULATION

- $\varepsilon^{Zi}_{\text{ʒ}, jk}(r)$ *[photons s^{-1} cm^{-3}]* $= n_e(r) \times n^{Zi}_{\text{ʒ}}(r) \times PEC_{jk}(n_e(r), T_e(r))$ PEC *[cm^3 s^{-1}]*

- Strong hypothesis: all quantities are uniform on a magnetic surface - no SOL



Angioni (JET SM) 2014



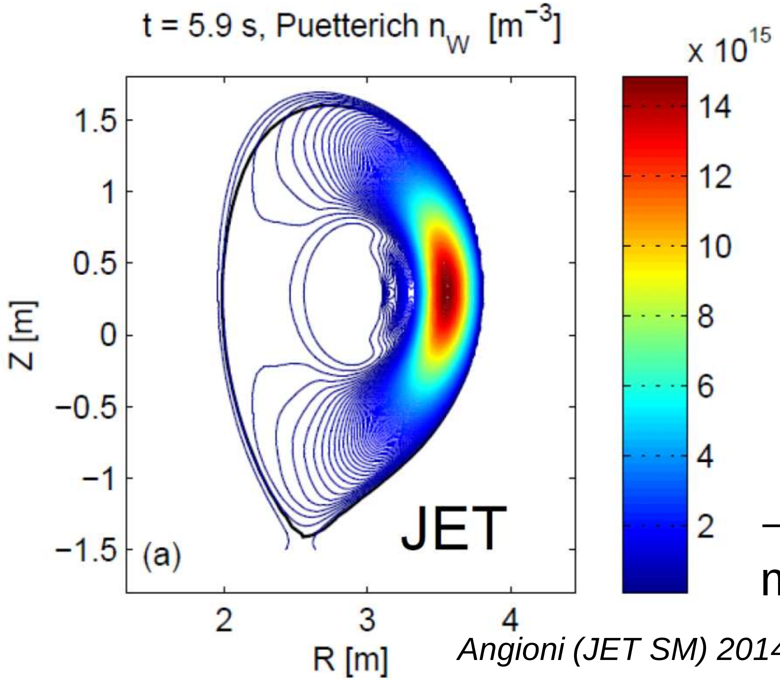
MoM, PPCF 1999

→ W not included in the model yet

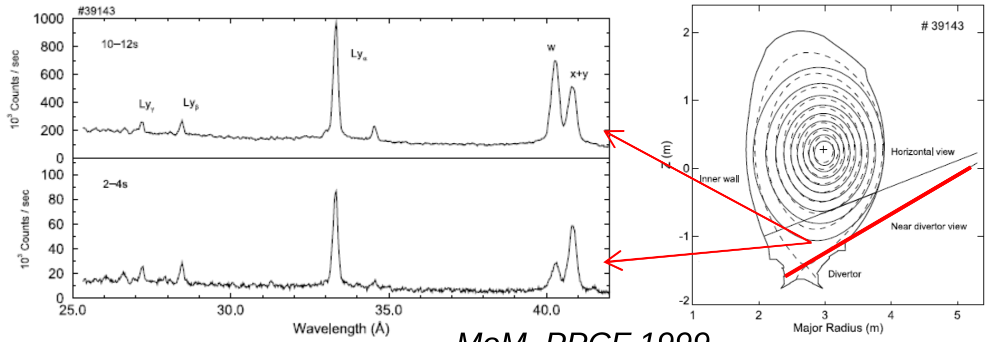
EMISSIVITY CALCULATION

- $\varepsilon^{Zi}_{z,\,jk}(r)$ *[photons s^{-1} cm^{-3}]* $= n_e(r) \times n^{Zi}_{z}(r) \times PEC_{jk}(n_e(r), T_e(r))$ PEC *[cm^{3} s^{-1}]*

- Strong hypothesis: all quantities are uniform on a magnetic surface - no SOL



Angioni (JET SM) 2014



MoM, PPCF 1999

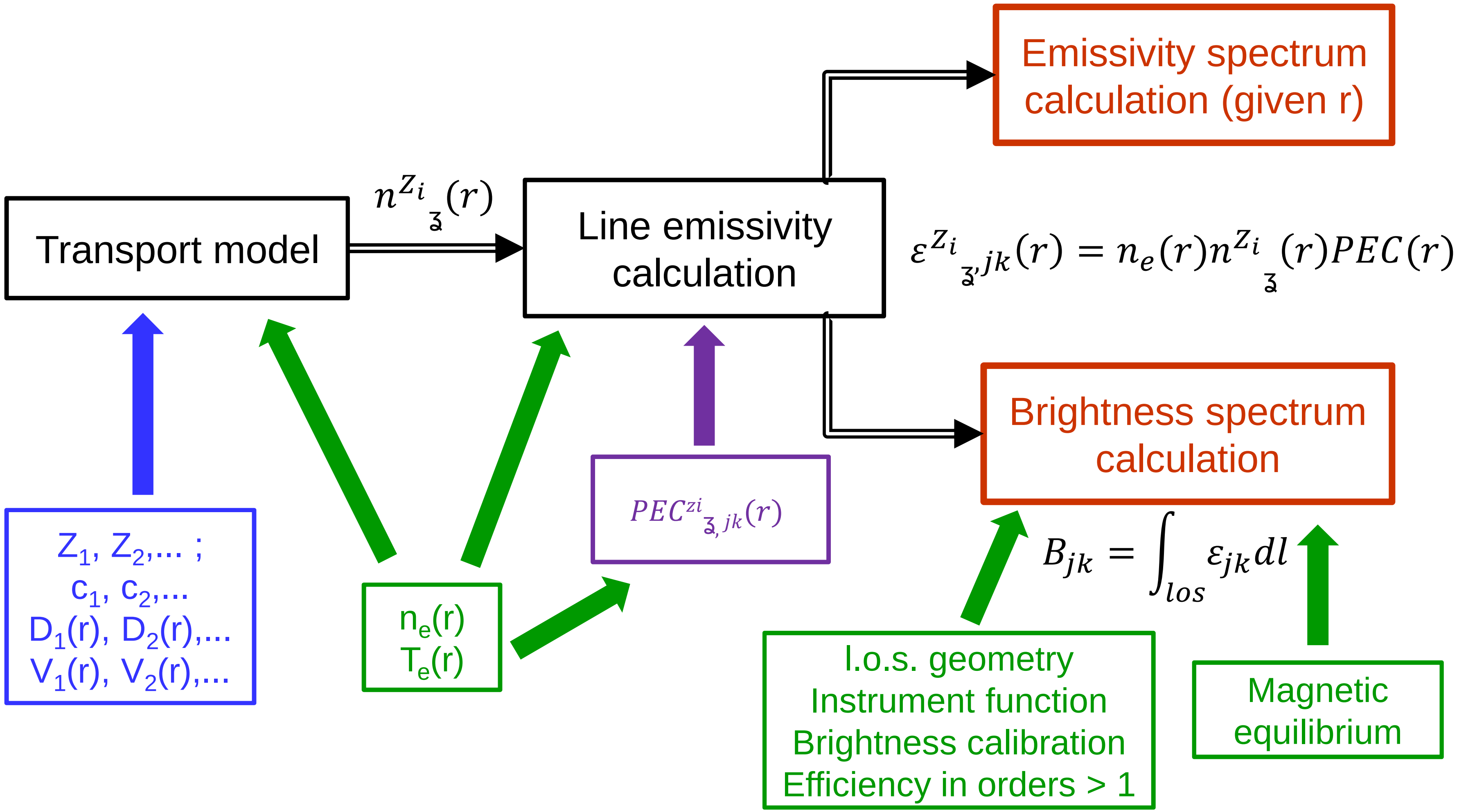
→ W not included in the model yet

- Recombination PECs not considered but could be (C V 40.73 Å $1s^2\ ^1S$ - $1s2p\ ^3P$)
- CX PECs not considered
- For W → combine results with S. Henderson & J. Hong ?

PEC data (excitation)

- J resolved data are needed
  - Ex: Ar VIII $2p^6 3s\ ^2S$ - $2p^6 3p\ ^2P \rightarrow$ 1/2 - 3/2 700.2 Å
1/2 - 1/2 713.9 Å
- Light species ($Z \leq 10$): default is 96 for historical reasons
  - He Li Be
  - C^{5+}, $N^{(3,4,6)+}$, $O^{(1-4,6,7)+}$, $Ne^{(3,4,6,8,9)+}$
- Particular cases of a few ions of light species
  - B: 93
  - N^{5+}, Ne^{7+}: 98
  - $C^{(1-4)+}$, O^{5+}: ic
- Heavier species
  - Al, Si, Cl, Fe, $Ni^{(13-15,18,20-22)+}$, Cu, Ge, Mo: ic
  - $Ar^{(6-14,17)+}$, $Ni^{(10-12,16)+}$, $Kr^{(25,26,33,34)+}$: LS

MODEL DESCRIPTION

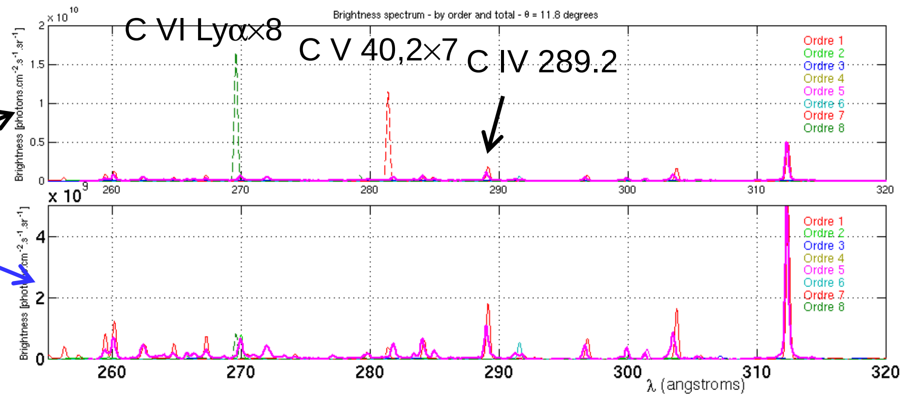


SPECTRAL SYNTHESIS

- Emissivity (i.e. local spectrum) or brightness (integrated along l.o.s.)

- Brightness spectrum must include magnetic equilibrium & spectrometer characteristics:
  - Line of sight geometry
  - Instrument function (not essential - induced from isolated lines)
  - Wavelength resolution
  - Brightness calibration: not always available - essential for wide wavelength range spectrometers (SPREDs) and to obtain quantities in physics units
  - Efficiency in diffraction orders > 1: obtained by absolute calibration or deduced from plasma measurements (but difficult!)

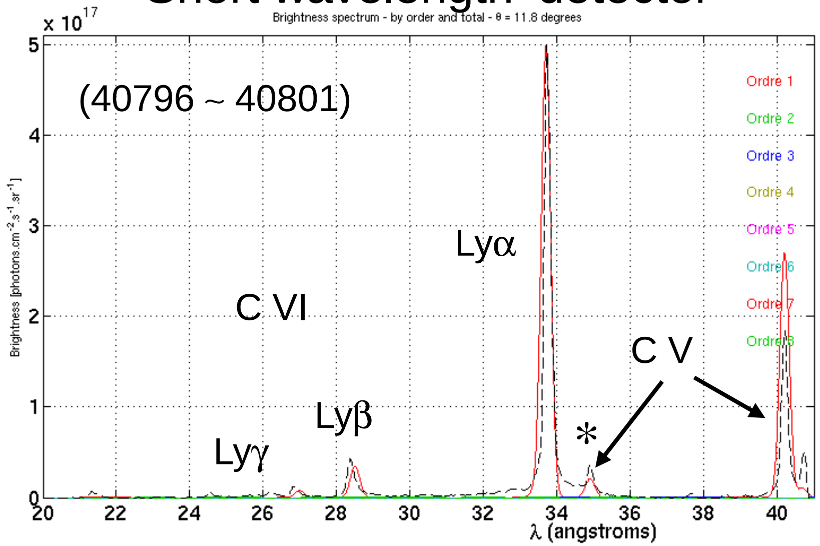
Order	1	2	3	4	5	6	7	8
Eff. %	100	15	5	10	3	1	3	2
							0.1	0.1



TESTING AND USING THE MODEL

- Test: VUV measurements + experimental transport coefficients
  - Tore Supra pulse 40801
  - Grazing incidence (Schwob) spectrometer - 2 detectors, range 15-360 Å

'Short wavelength' detector



R $(1s^2\ ^1S_0 - 1s2p\ ^1P_1)$ w

I $(1s^2\ ^1S_0 - 1s2s\ ^3S_1)$ z

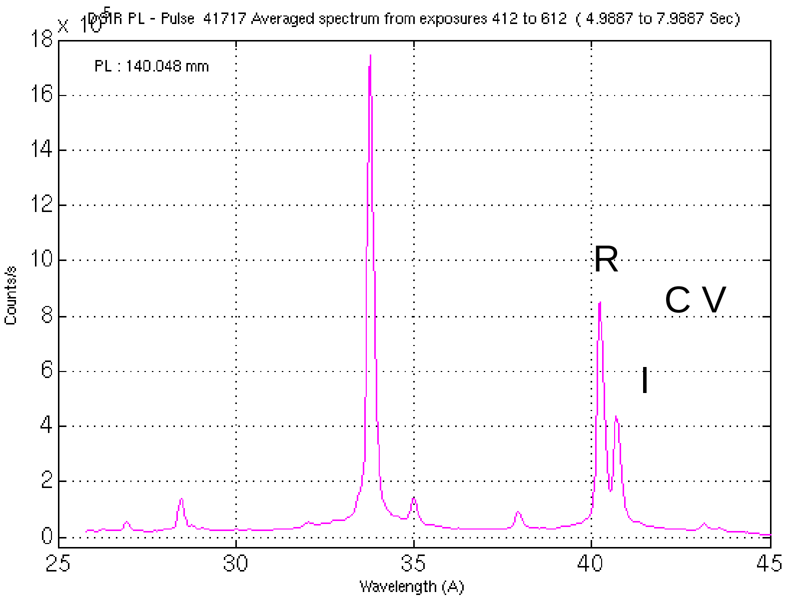
F $(1s^2\ ^1S_0 - 1s2p\ ^3P_2)$ x

* $(1s^2\ ^1S_0 - 1s3p\ ^1P_1, 1s3d\ ^1D_2)$

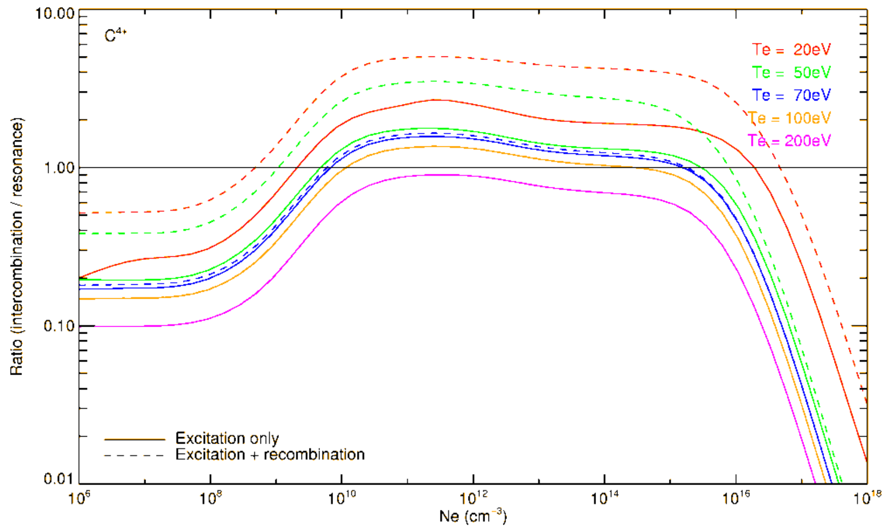
→ First 3 C VI Ly lines are well matched

→ C V is more of a problem

- C V I/R
  - Usually around 0.5 for a central chord in Tore Supra
  - I/R PEC ratio > 1 in expected (T_e, n_e) range



I/R PEC ratio (M. O'M.)

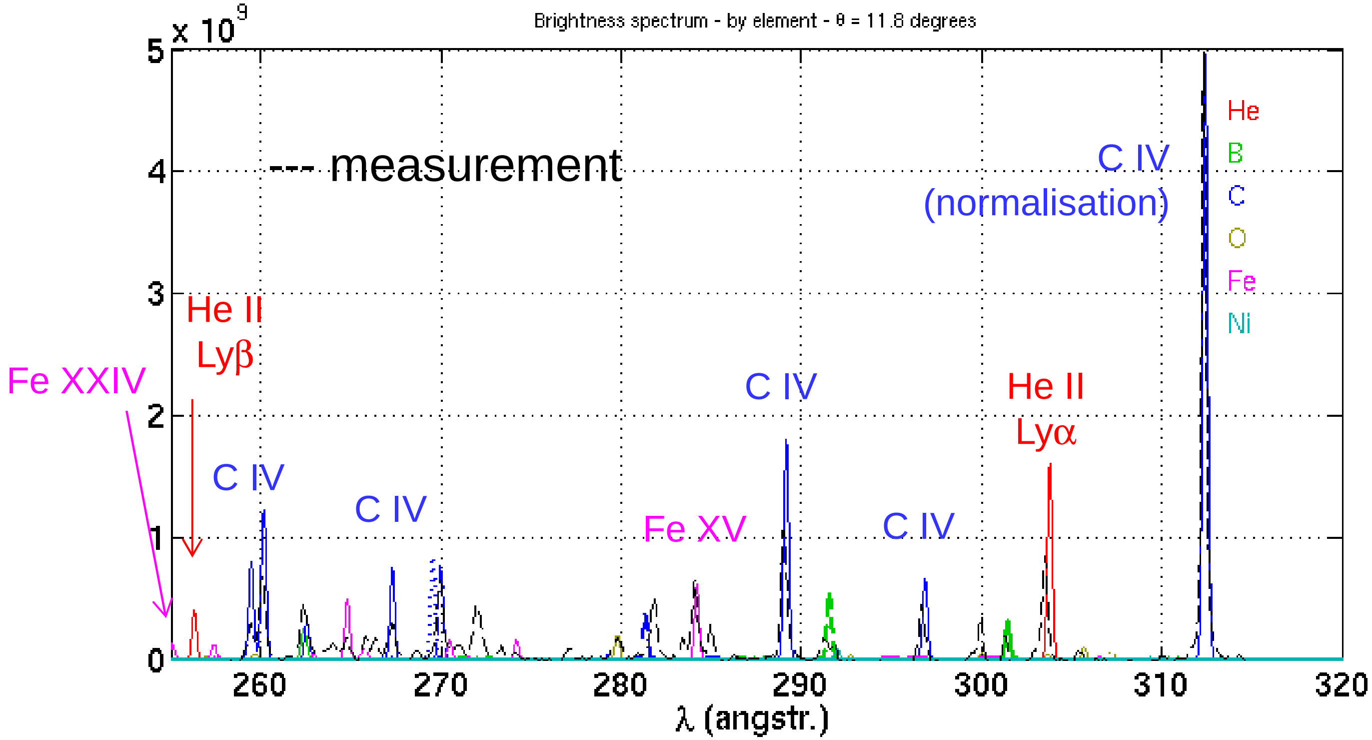


→ Adding recombination PECs for both lines: probably not enough
→ Add also CX PECs? (see JET - MoM + M. Mattioli PPCF99)

TESTING AND USING THE MODEL

- Test: VUV measurements + experimental transport coefficients
  - Tore Supra pulse 40801
  - Grazing incidence (Schwob) spectrometer - 2 detectors, range 15-360 Å

'Long wavelength' detector

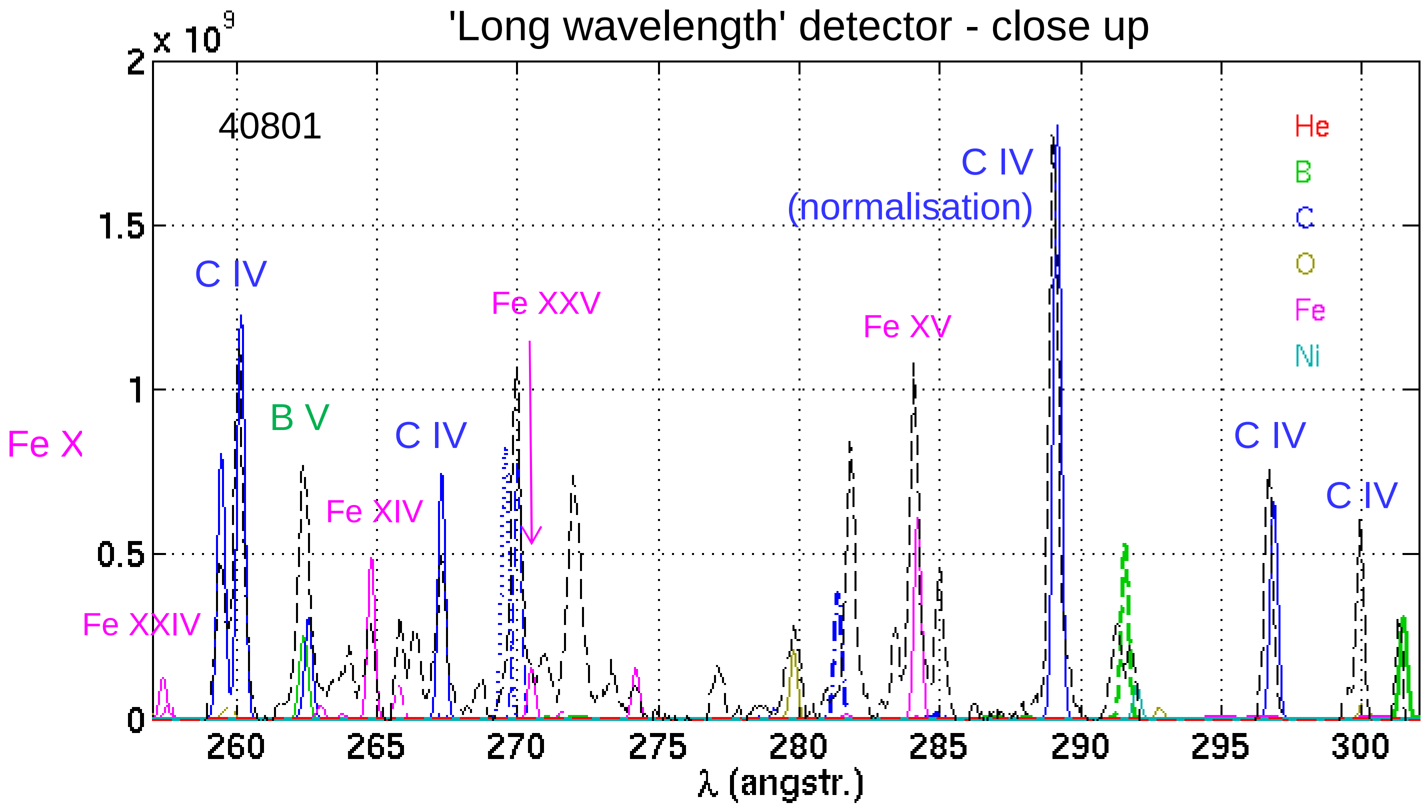


→ C IV qualit. OK

→ 312.4 Å ~50% too high?

TESTING AND USING THE MODEL

- Test: VUV measurements + experimental transport coefficients
  - Tore Supra pulse 40801
  - Grazing incidence (Schwob) spectrometer - 2 detectors, range 15-360 Å



→ C IV qualit. OK
→ 312.4 Å ~50% too high?
→ B: revise PEC or order eff.?

→ Fe XV / Fe XIV wrong by ~ 2
→ Fe XXIV / Fe XV to be checked
IP: 2 keV / 457 eV

CONCLUSIONS

- Complete model: transport $\rightarrow$ emissivities $\rightarrow$ VUV-XUV spectra (brightn. or emiss.)
- Wide collection of ADF15 (PEC) data of various origin/quality
- Free parameters: impurity nature and concentration, transport coefficients
- Efficiency in orders > 1 should be determined, preferably in lab.
- Rich information obtained from comparison modelled/measured spectra
- But effects of physical quantities mixed up with free parameters and uncertainties
- C VI Ly α-γ well reproduced
- C V I/R : need for recombination + CX PECs
- C IV : 312.4 Ǻ overestimated?
- Fe XV / Fe XIV wrong by factor 2-3: correct transport, PEC or equil. discretis.?

PROSPECTS

- Use a more sophisticated transport model:
  - consistent resolution of continuity equations
  - add time dependence
- Improve quality + consistency of ADF15 data
- Add recombination (and CX) PECs
- Add data for SXR spectral simulation (Ar to prepare the WEST imaging crystal spectrometer)
- Model other plasmas/instruments to improve the model & contribute to the physics analysis (in particular wide spectra)

- 2D model to take account of SOL integration & divertor radiation ?

Commissariat à l'énergie atomique et aux énergies alternatives
Centre de Cadarache | 13108 Saint Paul Lez Durance Cedex
T. +33 (0)4 42 25 46 59 | F. +33 (0)4 42 25 64 21

DSM
IRFM
Service

Etablissement public à caractère industriel et commercial | RCS Paris B 775 685 019