EUROfusion

WPSA Project Planning Meeting

Electron Cyclotron Wall Conditioning for JT-60SA

T. Wauters, J. Buermans

Laboratory for plasma physics ERM/KMS

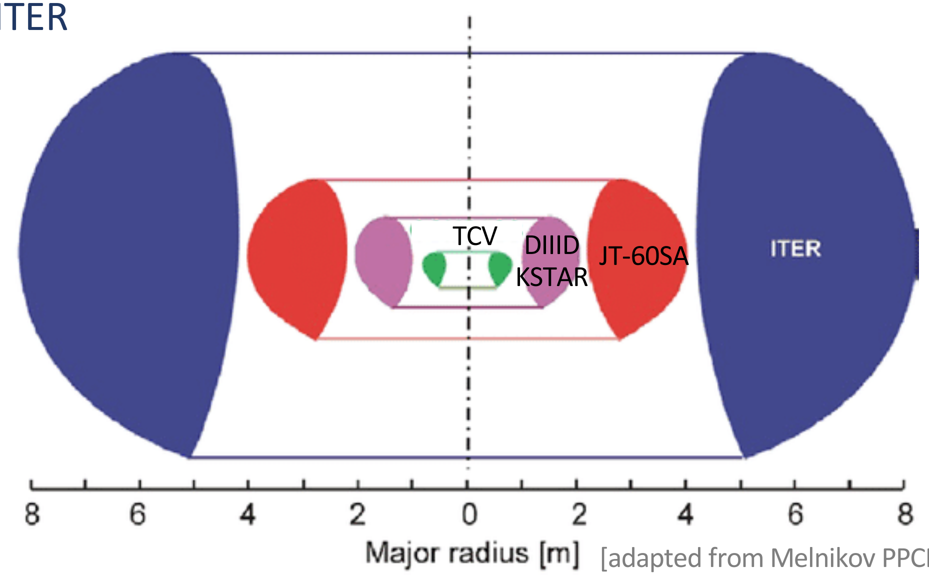
LPP
ERM - KMS

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 633053.
The views and opinions expressed herein do not necessarily reflect those of the European Commission.

- Conditioning challenge in JT-60SA commissioning phase
  - Keep up the plasma performance throughout an experimental day / week while the superconducting coils remain energized
  - Glow discharge conditioning is not operable in the presence of magnetic fields
  - ECRH plasma will be used for wall conditioning and breakdown assistance

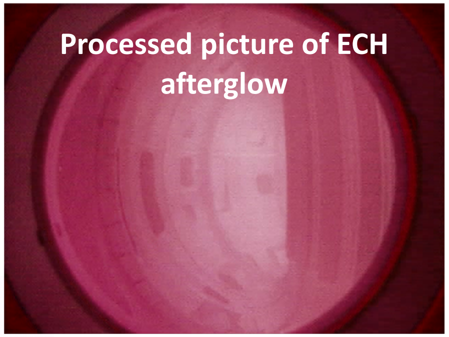
→ need to understand how ECRH plasma production works and assess role for ECWC in JT-60SA

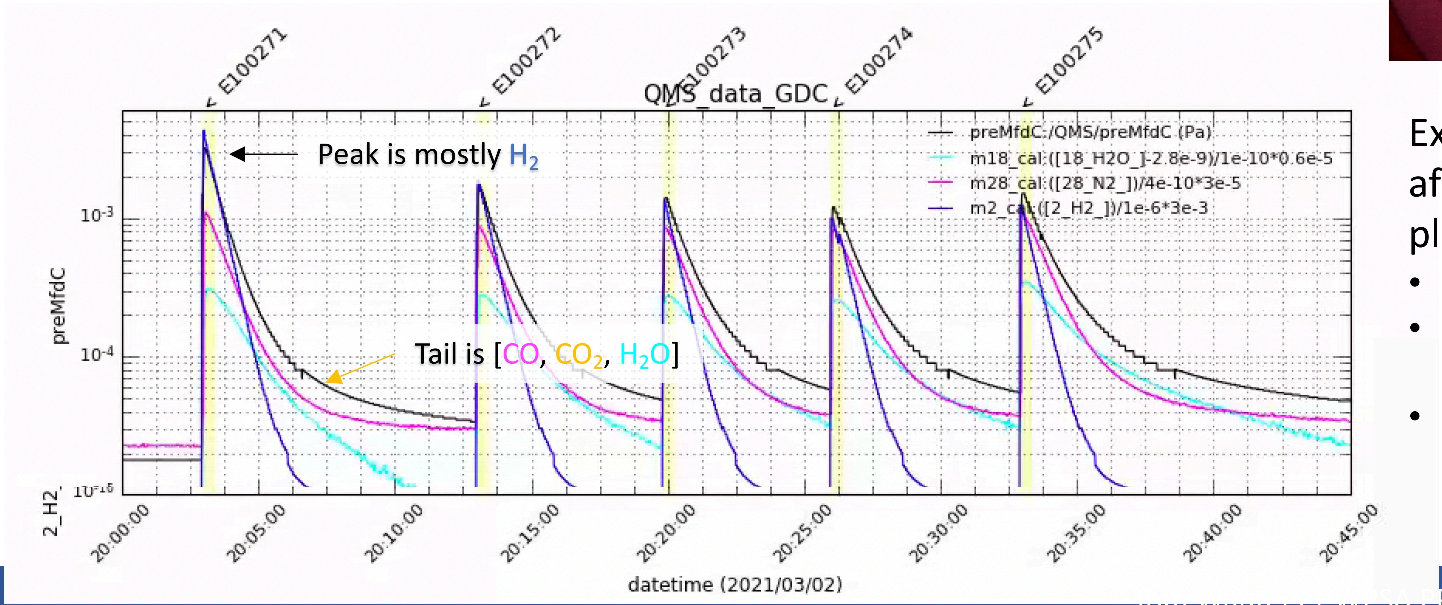
- Work plan
  - Analysis of wall conditions during JT-60SA commissioning
  - Modeling of ECWC to complement experimental observations in JT-60SA
  - Projection of ECWC experience to ITER



[adapted from Melnikov PPCF 2015]

- Assess role of ECWC in the JT-60SA wall conditioning strategy
  - Support the development of the conditioning strategy, includes baking, He/H_2-GDC, He/H_2-ECWC and boronisation
  - Assess the conditioning needs in the different commissioning phases and look for opportunities to collect consistent data sets with info on ECWC efficiency
  - Compare hydrogen and impurity removal rates to discharge parameters
    - Frequency: fundamental vs. harmonic EC
    - Poloidal field: radial/vertical vs. trapped particle configuration
    - Neutral gas pressure
  - Support development of ECWC scenario
    - Wave form, EC duty cycle, …

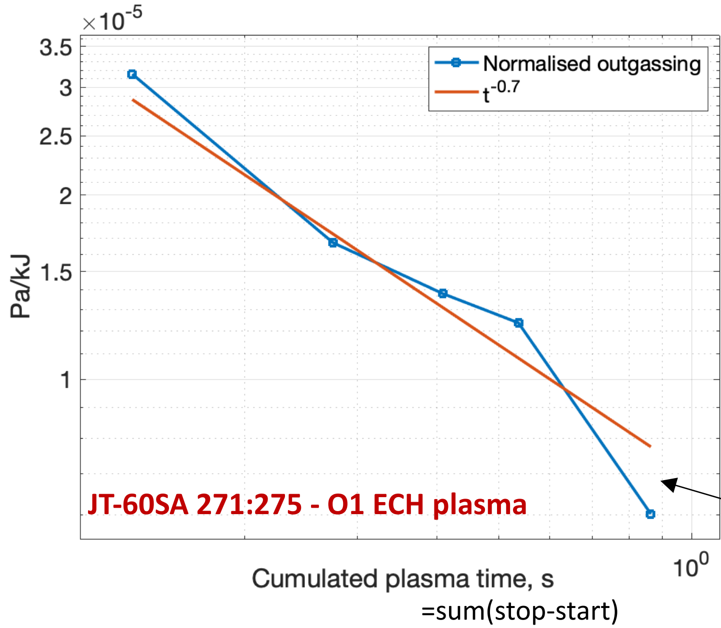




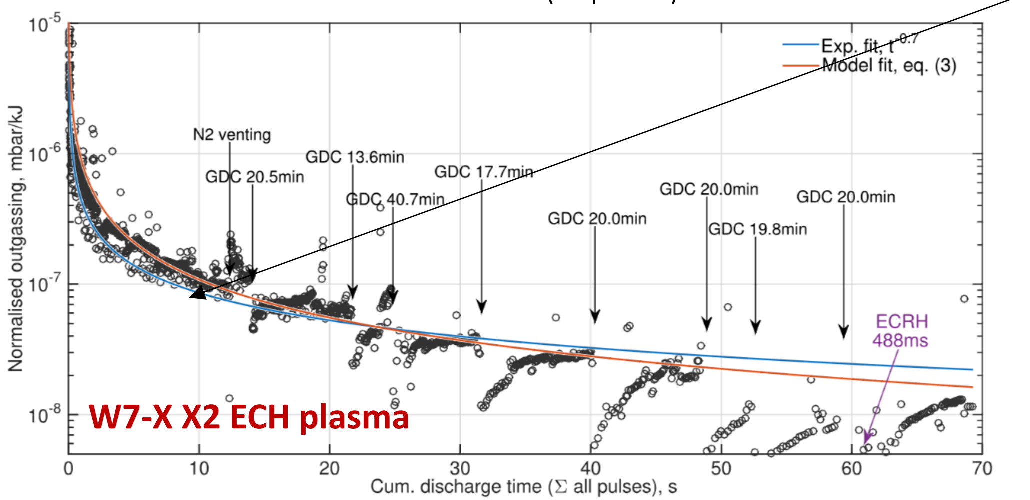
Example: outgassing after first 5x O1 ECH plasmas probes the

- Wall conditions
- Effect of ECH plasma on wall conditions
- Allows to compare effect to GDC

Normalised outgassing = p_{max} / EC energy follows ~ $t^{-0.7}$ dependency similar as W7-X OP1.1



#	H_2 : 0.9 Pam³/s	ECH O1 760 kW	Start s (LP)	Stop s (ECH)	P_max Pa (MfdC)
271	2s	0.2	0.0765	0.21	3.2e-3
272	0.5s	0.2	0.0683	0.21	1.8e-3
273	0.2s	0.2	0.0765	0.21	1.4e-3
274	0	0.2	0.0823	0.21	1.2e-3
275	0	0.4	0.0823	0.41	1.5e-3

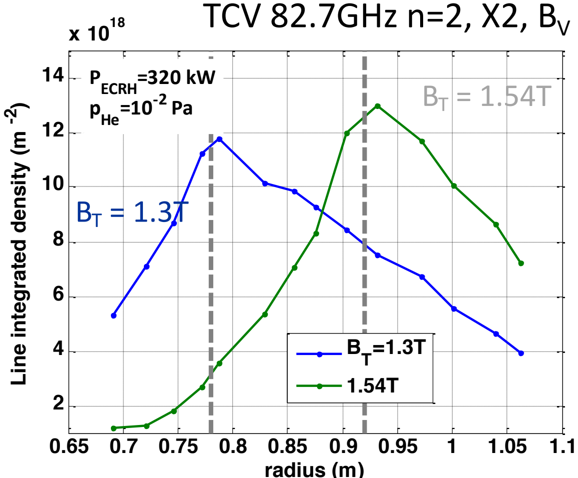


[Wauters T., Nucl. Fusion **58** (2018) 066013]

- ~ 1e-5 Pa/kJ after 10 ECH plasma seconds both in W7-X and JT-60SA
- In W7-X it was a measure for the attainable pulse duration until radiative collapse due to wall fueling.
- Acceptable conditions in W7-X: 1-3e-7 Pa/kJ obtained after 200s in OP1.1 by ECH only
- Good conditions in W7-X: <1e-7 Pa/kJ obtained with H_2-GDC in OP1.2a

- ECRH plasma: produced and sustained by localized absorption of RF power at EC resonance/harmonics
  - How to assess role of multi-pass absorption, absorption efficiency / level of stray rad.?
- Poloidal fields are applied to maximize plasma wetted area and RF absorption
  - How to assess the plasma wetted areas with limited diags in the commissioning phase

TCV 82.7GHz n=2, X2, B_V

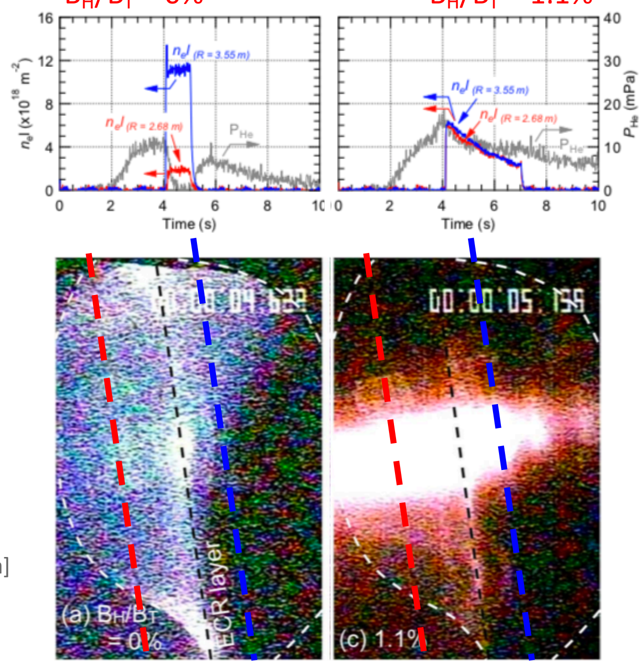


[D. Douai RCM-5 Naka]

JT-60U, X2

B_H/B_T = 0%

B_H/B_T = 1.1%



2.5MW, 1.86 T

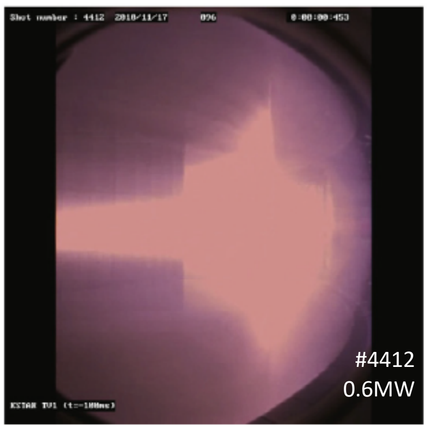
[M. Fukumoto et al, NME 2017]

Horizontal B component: B_H

Vertical B component: B_V

KSTAR, X2

B_V + B_H



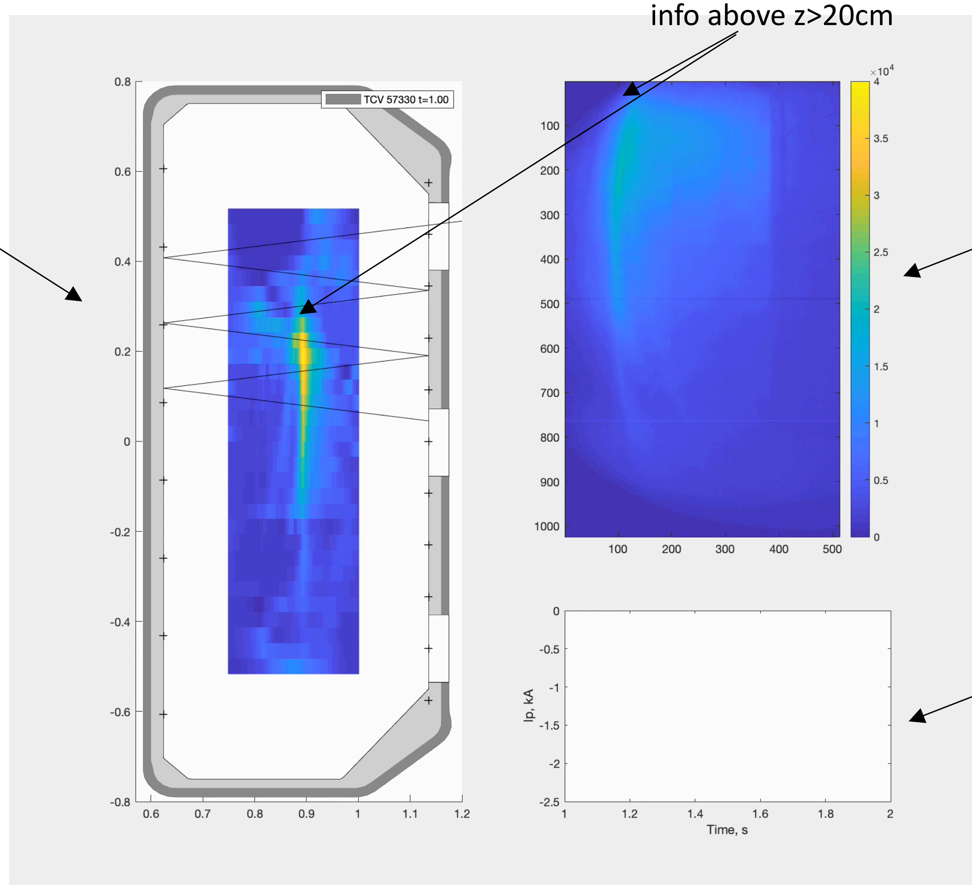
[K. Itami, S. Hong JNM 2013]

[See talk Jordan Cavalier]

- How to assess role of multi-pass absorption, absorption efficiency
  - Example TCV X2 He ECWC plasma

Vignetting at top, no info above z>20cm

Inverted plasma emission in the poloidal plane



Tangential fast camera image, no filter

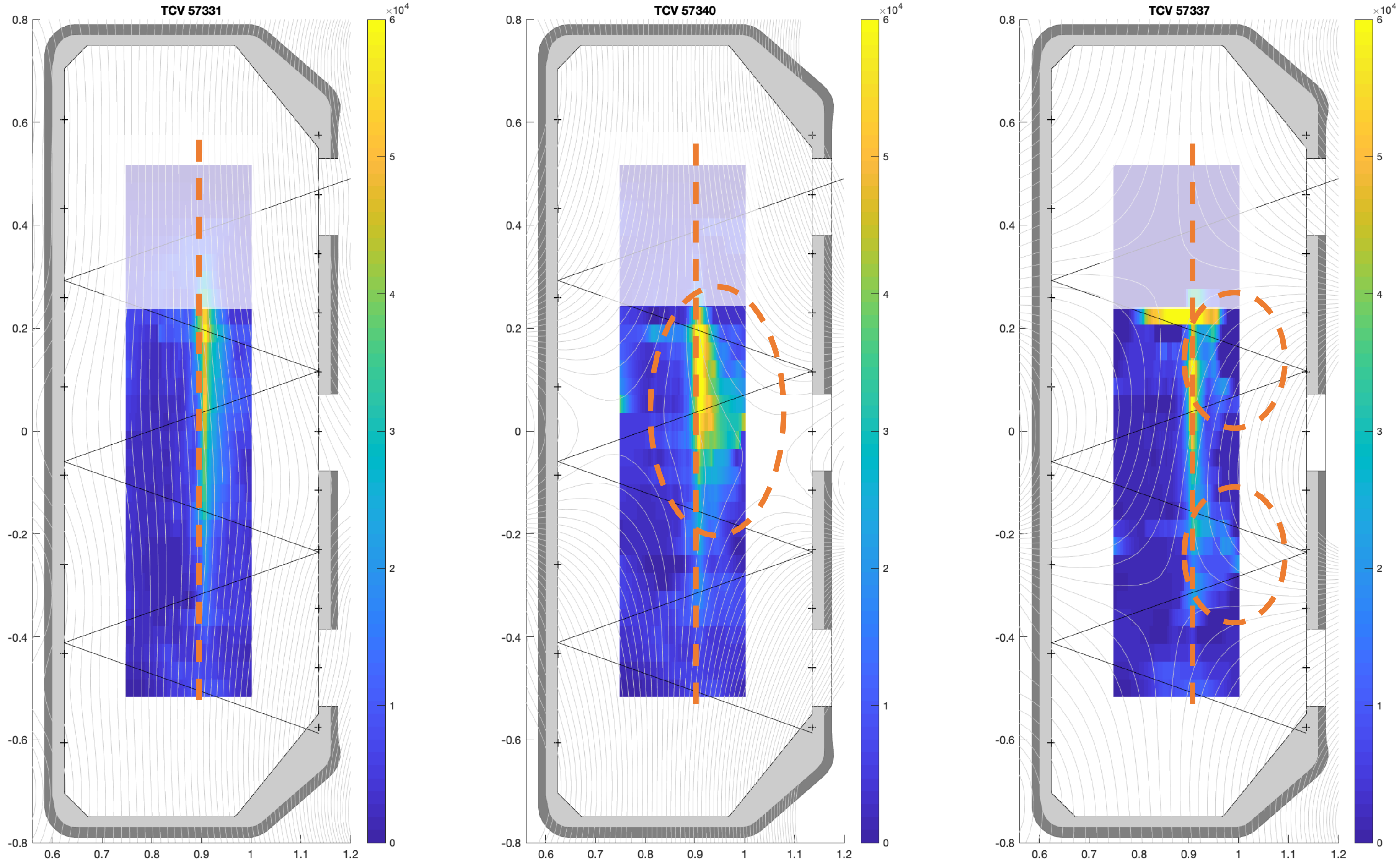
Plasma current (kA)
Small but seems to have effect on plasma position

TOMOGRAPHY OF JT-60SA EDICAM IMAGES

[See talk Jordan Cavalier]

- Assess the plasma wetted areas by poloidal emissivity maps
  - Example TCV X2 He ECWC plasma

Vertical field | TCP, quadrupole | TCP, hexapole

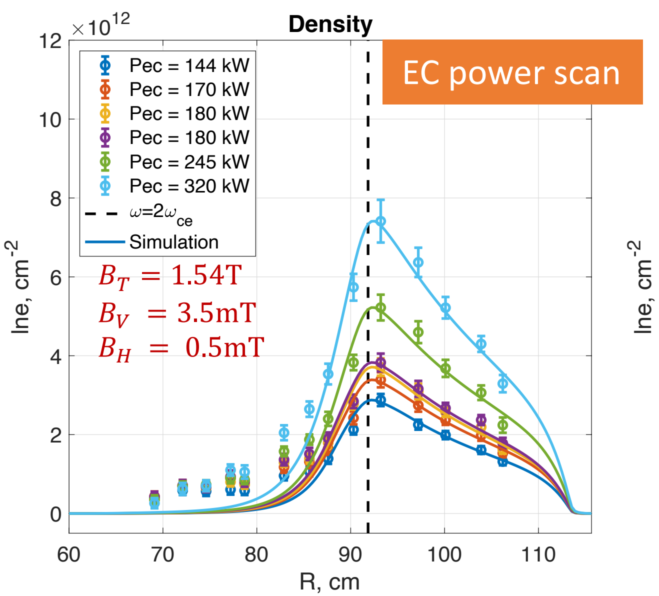


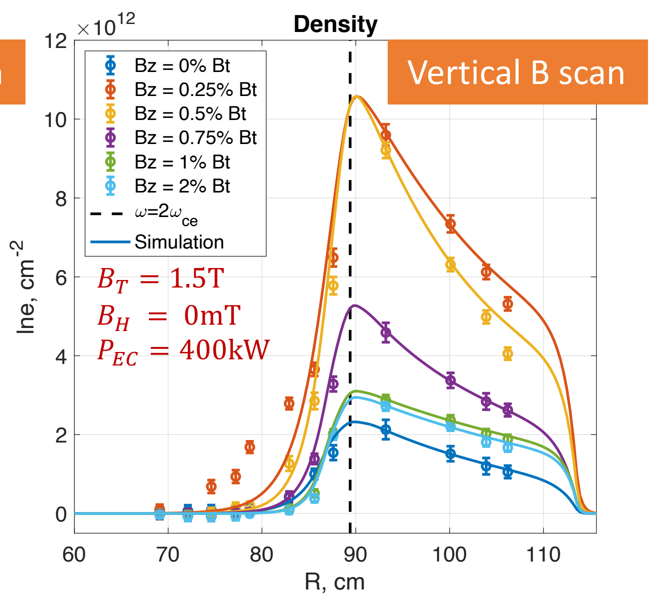
- ECWC model to complement experimental observations
  - Partially ionized plasma: He, H_2 (CI-V)
  - Reaction-Diffusion-Convection : 1D radial

$$\dot{n}(r,t) = \frac{1}{r}\frac{\partial}{\partial r} r D(r,t) \frac{\partial}{\partial r} n(r,t) - \frac{1}{r}\frac{\partial}{\partial r} r V(r,t) n(r,t) + S(r,t)$$

$$\dot{E}(r,t) = \frac{1}{r}\frac{\partial}{\partial r} r \gamma_D D(r,t) \frac{\partial}{\partial r} E(r,t) - \frac{1}{r}\frac{\partial}{\partial r} r V(r,t) E(r,t) + S_E(r,t)$$

  - Case study for TCV He-ECRH plasmas X2 @ 82.7GHz
    - Input: Experimental He and H_2 pressure, experimental density profile, vessel dimensions, toroidal and poloidal magnetic field, location of resonance layer
    - Output: Transport coefficients and absorption





	Collisional reaction	Ref.
	Electron collisions with H and H^+	
1	$e + H \rightarrow e + H^*$	[4]
2	$e + H \rightarrow e + H^+ + e$	[4]
3	$e + H^+ + e \rightarrow e + H$	[4]
4	$e + H^+ \rightarrow H + h\nu$	[4]
	Electron collisions with H_2, H_2^+ and H_3^+	
5	$e + H_2 \rightarrow e + H_2^*$	[8]
6	$e + H_2 \rightarrow e + H + H$	[4]
7	$e + H_2 \rightarrow e + H_2^+ + e$	[4]
8	$e + H_2 \rightarrow e + H + H^+ + e$	[8]
9	$e + H_2^+ \rightarrow H_2 + h\nu$	[4]
10	$e + H_2^+ \rightarrow e + H + H^+$	[8]
11	$e + H_2^+ \rightarrow H + H$	[8]
	$e + H_2^+ \rightarrow H + H^*$	[8]
12	$e + H_3^+ \rightarrow H + H + H$	[8]
	$e + H_3^+ \rightarrow H_2 + H$	[8]
13	$e + H_3^+ \rightarrow e + H^+ + H + H$	[8]
	Electron collisions with He, He^+ and He^{2+}	
14	$e + He \rightarrow e + He^+ + e$	[4]
15	$e + He^+ \rightarrow He + h\nu$	[4]
16	$e + He^+ \rightarrow e + He^{2+} + e$	[4]
17	$e + He^{2+} \rightarrow He^+ + h\nu$	[4]
	Ion impact reactions	
18	CX: $H^+ + H$	[9]
19	CX: $H^+ + H_2$	[8]
20	CX: $H_2^+ + H_2$	[8]
21	CX: $He^+ + H$	[10]
22	CX: $He^+ + He$	[8]
23	CX: $He^{2+} + H$	[11]
24	CX: $He^{2+} + He \rightarrow He^+ + He^+$	[12]
25	CX: $He^{2+} + He \rightarrow He + He^{2+}$	[8]
26	$H_2^+ + H_2 \rightarrow H_3^+ + H$	[8]
27	$H^+ + H \rightarrow H^+ + H^*$	[8]
28	$H^+ + H_2 \rightarrow H^+ + H_2^*$	[8]
29	$H^+ + H \rightarrow H^+ + H^+ + e$	[8]
30	$H^+ + He \rightarrow H^+ + He^+ + e$	[8]
31	$H^+ + H_2 \rightarrow H^+ + H_2^+ + e$	[8]
32	$H^+ + H_2^+ \rightarrow H^+ + H^+ + H$	[8]
33	$He^+ + H_2 \rightarrow He + H^+ + H$	[8]

Modeling of ECWC to complement experimental observations

- ECWC model to complement experimental observations
  - Partially ionized plasma: He, H_2 (CI-V)
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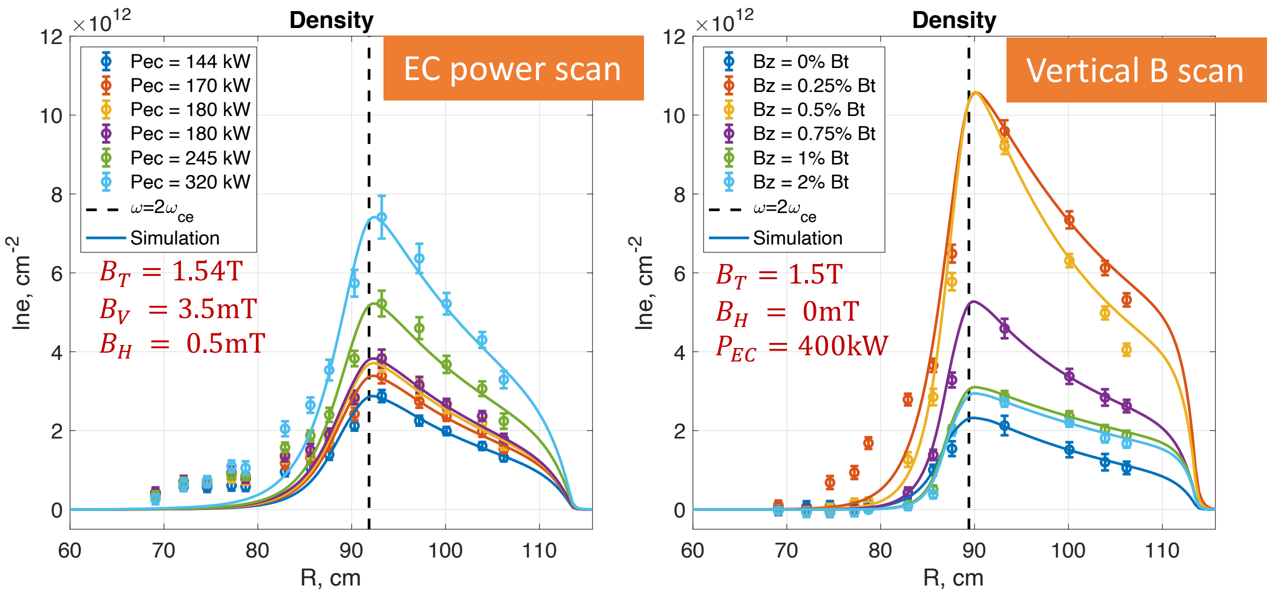


- Charge accumulation: E/B
- Neutral body with net force

$$V = f_V V(t, T, \nu, B_T, B_z)$$

$$f_{V(9.)} = 10.9 \pm 23\%$$

- Anomalous diffusion

$$D_r = f_D D(r, t, T, \nu, B_T, B_r)$$

$$f_D = 0.19 \pm 18\%$$

→ f_D = 1/16 (Bohm)
→ f_D = 0.21 (Spitzer)

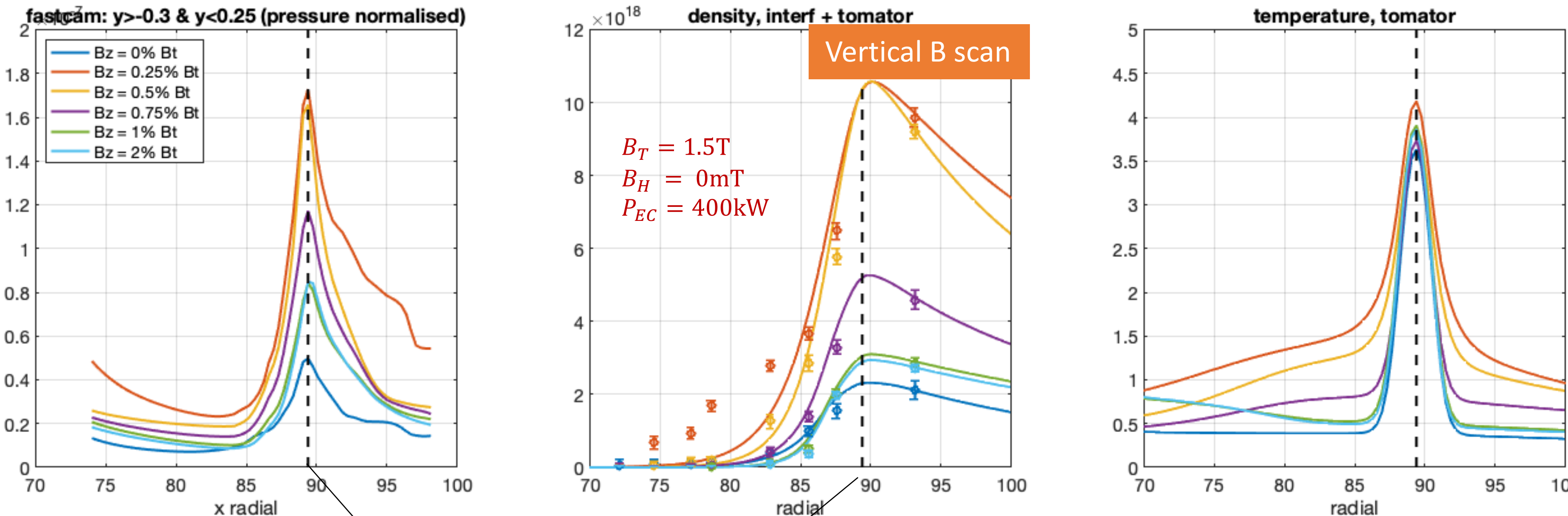
- Resonant EC absorption

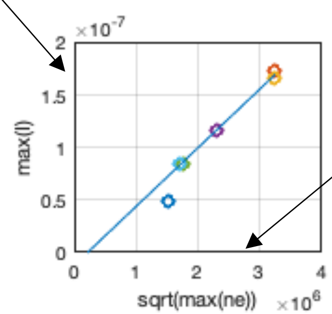
$$P_{EC,coupled} = f_P P_{EC,launched}$$

$$f_{P,TCV} < 0.25$$

[See talk Jordan Cavalier]

- Plasma emissivity profiles as input to TOMATOR-1D model
  - Qualitative agreement between density and emission maxima in TCV





Light ∝ n_0 * n_e * f(T_e)

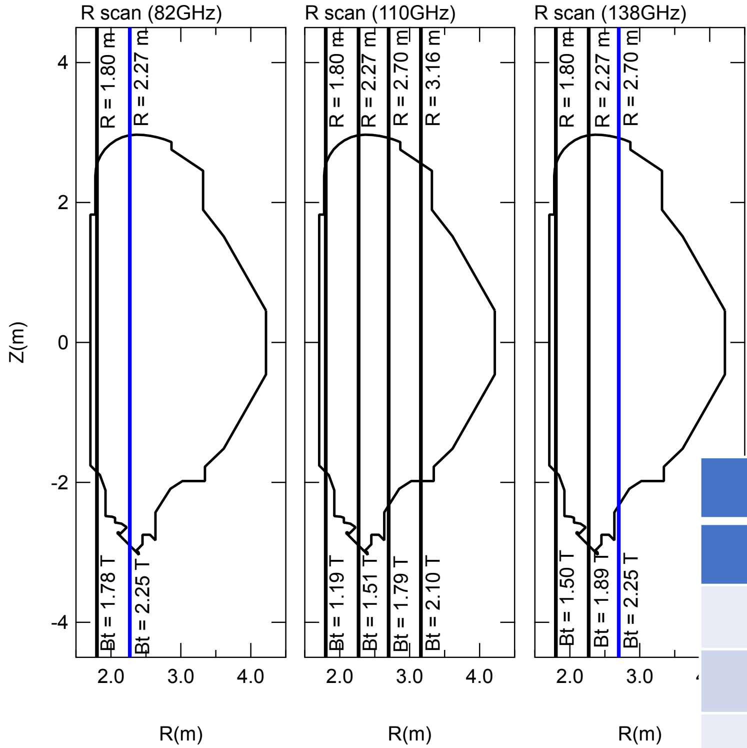
ToDo
- Relate emission to collision processes
- Find experimental approximation

EXAMPLE OF SIMULATIONS FOR JT-60SA

JT-60SA Advanced Superconducting Tokamak — BA-Satellite Tokamak Program

Parameter scan: Resonance layer position

QST



R scan or Freq. scan
R=1.8 m: 82/110/138 GHz
R=2.27m: 82/110/138 GHz
R=2.7 m : 110/138 GHz

7 min for Bt change

Ready to start working with JT-60SA input !

P	R	B	Bv	Bh	pHe	pH2
↔	2.7m	1.79T	0.5%	0%	5mPa	0.1mPa
13%	↔	↔	0.5%	0%	5mPa	0.1mPa
13%	2.27m	↔	0.5%	0%	5mPa	0.1mPa
13%	2.27m	1.51	↔	0%	5mPa	0.1mPa
13%	2.27m	1.51	0.33%	↔	5mPa	0.1mPa
13%	2.27m	1.51	0.66%	0%	↔	2%
13%	2.27m	1.51	0.66%	0%	5mPa	↔
13%	Dual-f	1.6	0.5%	0%	5mPa	0.1mPa

CONCLUSION

- Work plan
  - Analysis of wall conditions during JT-60SA commissioning
    - Assess role of ECWC in JT-60SA conditioning strategy
    - Support development and optimization of ECWC procedures in JT-60SA
    - Camera tomography to assess EC interaction and plasma uniformity
    - Mass spectrometry, optical penning gauge, plasma spectroscopy
    - Operation 1-3: 2021, 2023-2025
  - Modeling of ECWC to complement experimental observations in JT-60SA
    - Insight on Transport processes → Particle fluxes to HFS and LFS
    - Required coupled power to equilibrate the power balance → Estimation of stray radiation
    - Camera tomography will complement plasma diagnostics as input for TOMATOR-1D model
    - 2021-2025
  - Projection of ECWC experience to ITER
    - E.g. power requirement, stray radiation, lessons form routine ECWC operation
    - 2024-2025