Integrated ITER scenario modelling and density evolution prospects

Collaborators:
S.Wiesen,P.Belo,F.Koechl, L.Garzotti, V.Parail,G.Corrigan,M.Valovic,J.Lonnroth, S.Saarelma, V.Kotov
and members of ITM ITER scenarios modelling group (ISM)

1.Introduction, historic Modelling (Kukushkin, Pacher, Kotov et al)

2.Modelling of the ITER SOL and divertor for H-mode scenarios in steady-state
2.1 EDGE2D-EIRENE simulation model setup
2.2 Transport model of SOL and plasma edge
2.3 Boundary conditions
2.4 Results: Steady-state ITER reference scenarios

3.Integrated modelling of ITER scenarios with JINTRAC
3.1 JINTRAC transport model setup
3.2 Results: Steady-state scenarios with cont. pellet ablations in time
3.3 Results: Time-dependent modelling of discrete pellet ablations
3.4 Results: Divertor operation compatibility in case of discrete pellets

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historic modelling w/ B2-EIRENE/SOLPS4

- **Kukushkin 2002**: First 2D multi-fluid modelling studies w/ B2-EIRENE of the current ITER reference design using an early neutral transport model (EIRENE96): ITER operation in L-mode, focus on divertor operational regime: partial detachment

- **Pacher 2003**: first consistent core-edge modelling attempt: combine previous B2-EIRENE results with ASTRA. B2-EIRENE provided BCs for ICPS plasma model (separatrix or top pedestal conditions as functions of P_{SOL}, p_{div}, f_{core})

- **Kukushkin 2003**: sensitivity study w/ SOLPS4(B2-EIRENE) to derive new scaling relations for n^{spx}, T_e^{spx}, T_i^{spx} still assuming non-transient L-mode scenarios (result: T_i,T_e are weak functions of all input parameters except P_{SOL}). Here P_{SOL} depends not only on fusion product but also on transport assumptions

- **Kukushkin 2005, Kotov 2007**: new EIRENE model (EIRENE04) coupled to B2 includes much more molecular physics (molecule-ion elastic collisions, molec.assisted recombination, neutral viscosity, Lyman-line radiation opacity) → the same scalings for upstream conditions can be applied when including a correction for the neutral pressure in the divertor p_{div}

- **Kukushkin 2007**: further sensitivity studies: varying gas-puff location and effect on plasma fuelling, variations in divertor dome geometry and effect on p_{div}

code-code benchmarking

Preparational work done within the ITM & ISM activity (2007-):

- re-investigation of existing database on ITER edge plasma scenarios: SOLPS4 simulation → scaling laws for L-mode ITER scenarios (cf. A.Kukushkin, V.Kotov, et al…)

necessary condition: partial detachment, critical limit 10 MW/m^2

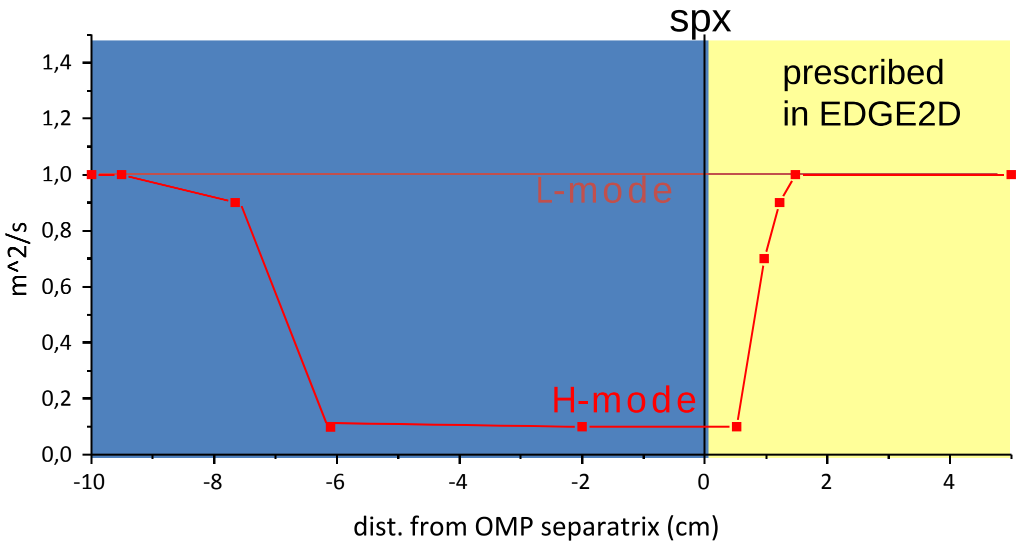
- benchmark EDGE2D-EIRENE w/ ITER version of SOLPS4 (S.Wiesen, V.Kotov through IMP3 and ISM)
→ refinement of atomic and molecular physics necessary for Lmode scenarios

here: we assume that we can amend neutral pressure in divertor affecting level of detachment simply by increasing gas-puff rate in the model
→ "emulation of revised SOLPS4 molecular physics model"

- setting up of H-mode baseline scenario with EDGE2D-EIRENE (also SOLPS5), transport model modification: transport barrier

→ seeded impurities necessary to get rid of extra heat in SOL:
combined seeded and intrinsic impurities radiative power loss: 20-60 MW

Radial transport model of SOL and plasma edge



- assume that turbulent diffusive/advective transport in the edge is suppressed (ETB)
- remnant: neo-classical transport theory predicts (low-ν* banana regime):

$$D^{neo} \approx \frac{q^2}{\varepsilon^{3/2}} \nu_e \rho_e^2 \propto \frac{n}{B^2 T} \qquad \chi_e^{neo} \approx D^{neo} \qquad \chi_i^{neo} \approx \left(\frac{m_D}{m_e}\right)^{1/2} D^{neo} \approx 60 D^{neo}$$

- but at this point: ELM averaging procedure, enhance transport artificially to be compatible with previous MHD stability and transport analysis (JETTO/MISHKA, continuous ELM-model, Cadarache 2008)
- two sets of transport coefficients:

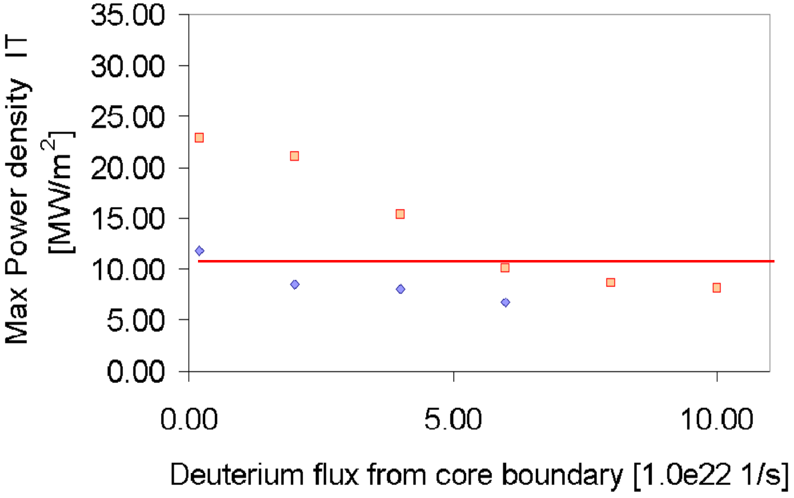
moderate confinement: $\chi_e = \chi_i = 0.3$ m^2/s, D = 0.1 m^2/s, no pinch

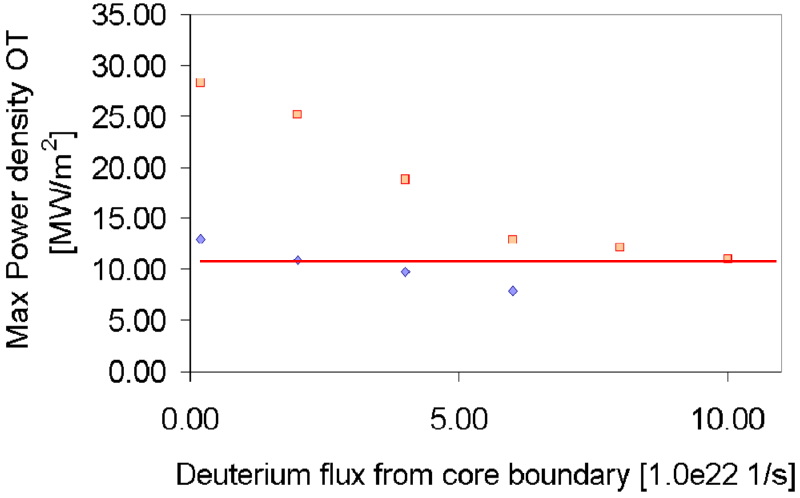
good confinement: $\chi_e = \chi_i = 0.2$ m^2/s, D = 0.07 m^2/s, no pinch

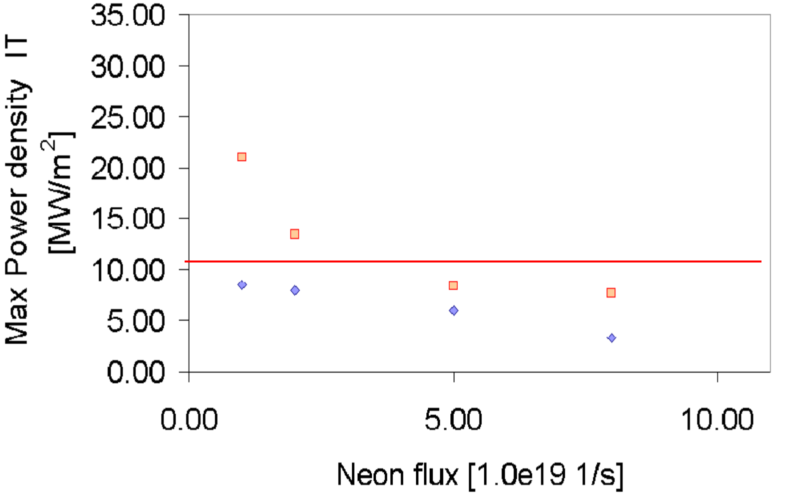
EDGE2D-EIRENE results: target heat-loads w/ ETB

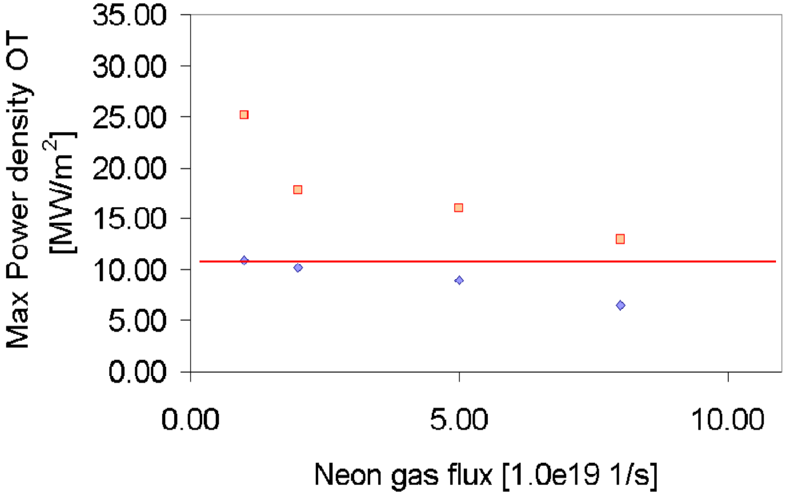
Inner target

Outer target









Integrated ITER baseline scenario density evolution modelling

- 2D tool: EDGE2D-EIRENE (and other, like SOLPS)

→ can provide separatrix conditions to core models:

ne, Te, Γ_0, Γ_{imp}

as function of upstream conditions:

P_{SOL}, Γ_{SOL} from core

plus necessary limitations and constraints:

detached divertor ($P_{target} < 10 MW/m^2$ in steady-state)
neutral molecular physics (not scalable!), pump efficiency
avoidance of density limits and MARFEs (over-/underfuelling)
impurity transport and radiation (seeded and intrinsic),…

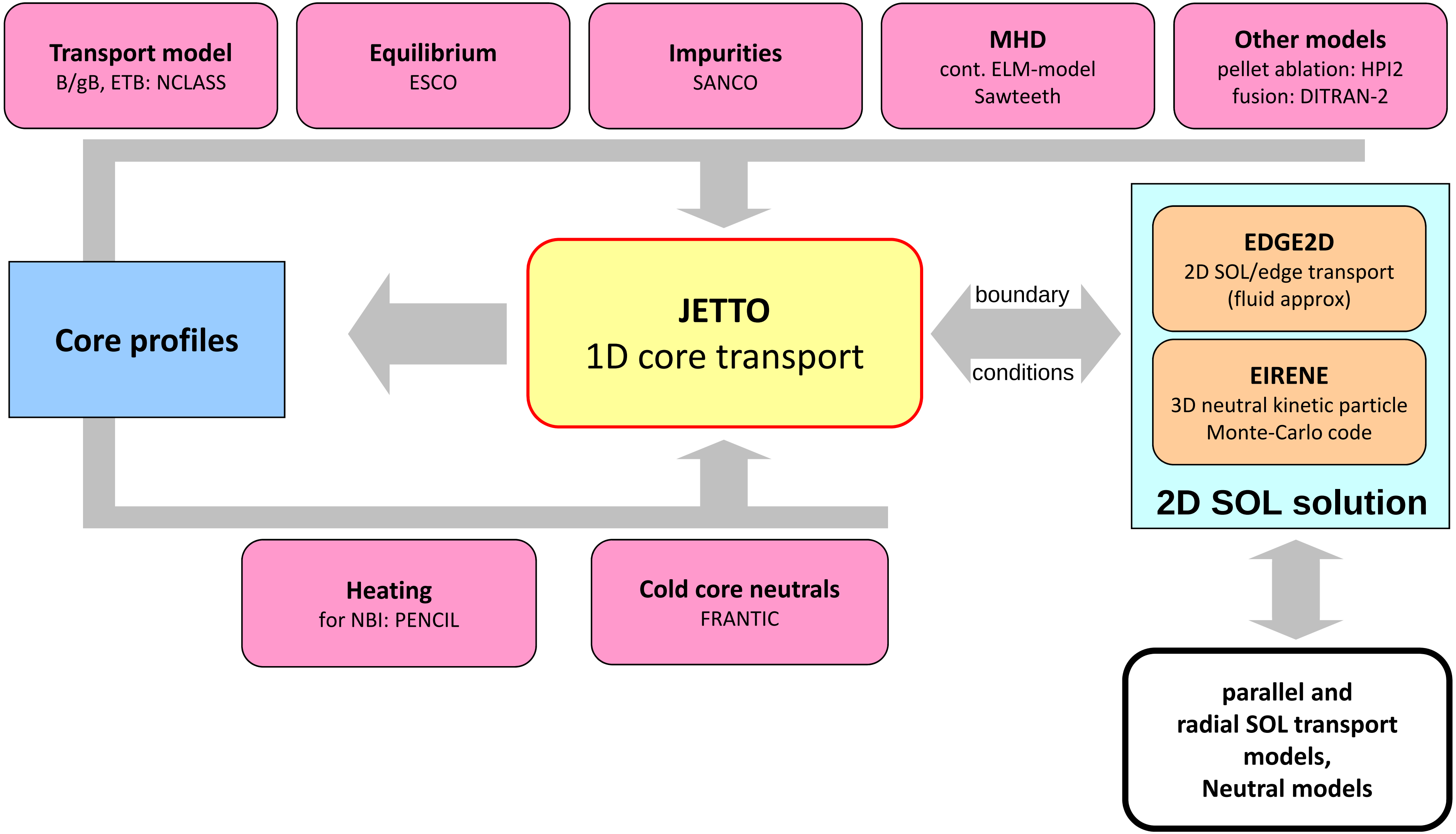
above approach not self-consistent, example: transient pellets or ELMs

→ upstream conditions vary strongly in time

→ use a more integrated approach, ie combine core and SOL physics

- currently available tool within ISM: JINTRAC/COCONUT (ie JETTO + EDGE2D) (later possibly ETS and Kepler)

JINTRAC simulation suite



Transport model
B/gB, ETB: NCLASS

Equilibrium
ESCO

Impurities
SANCO

MHD
cont. ELM-model
Sawteeth

Other models
pellet ablation: HPI2
fusion: DITRAN-2

Core profiles

JETTO
1D core transport

boundary
conditions

EDGE2D
2D SOL/edge transport
(fluid approx)

EIRENE
3D neutral kinetic particle
Monte-Carlo code

2D SOL solution

Heating
for NBI: PENCIL

Cold core neutrals
FRANTIC

parallel and
radial SOL transport
models,
Neutral models

JINTRAC steady-state simulations for ITER baseline scenario

Starting point: steady pellet fuelling (as before, ie. no transients)

- modified Bohm/gyroBohm transport in core
- in the edge: cont. ELM-model, critical pressure gradient $\alpha_{crit} = 1.7$

- P_{aux} = 33 MW, P_{fusion}: DITRAN-2 → target P_{fus} ~ 500 MW (Q ~ 10)
- Z_{eff}=1.7 (P_{rad} = 43MW fixed)

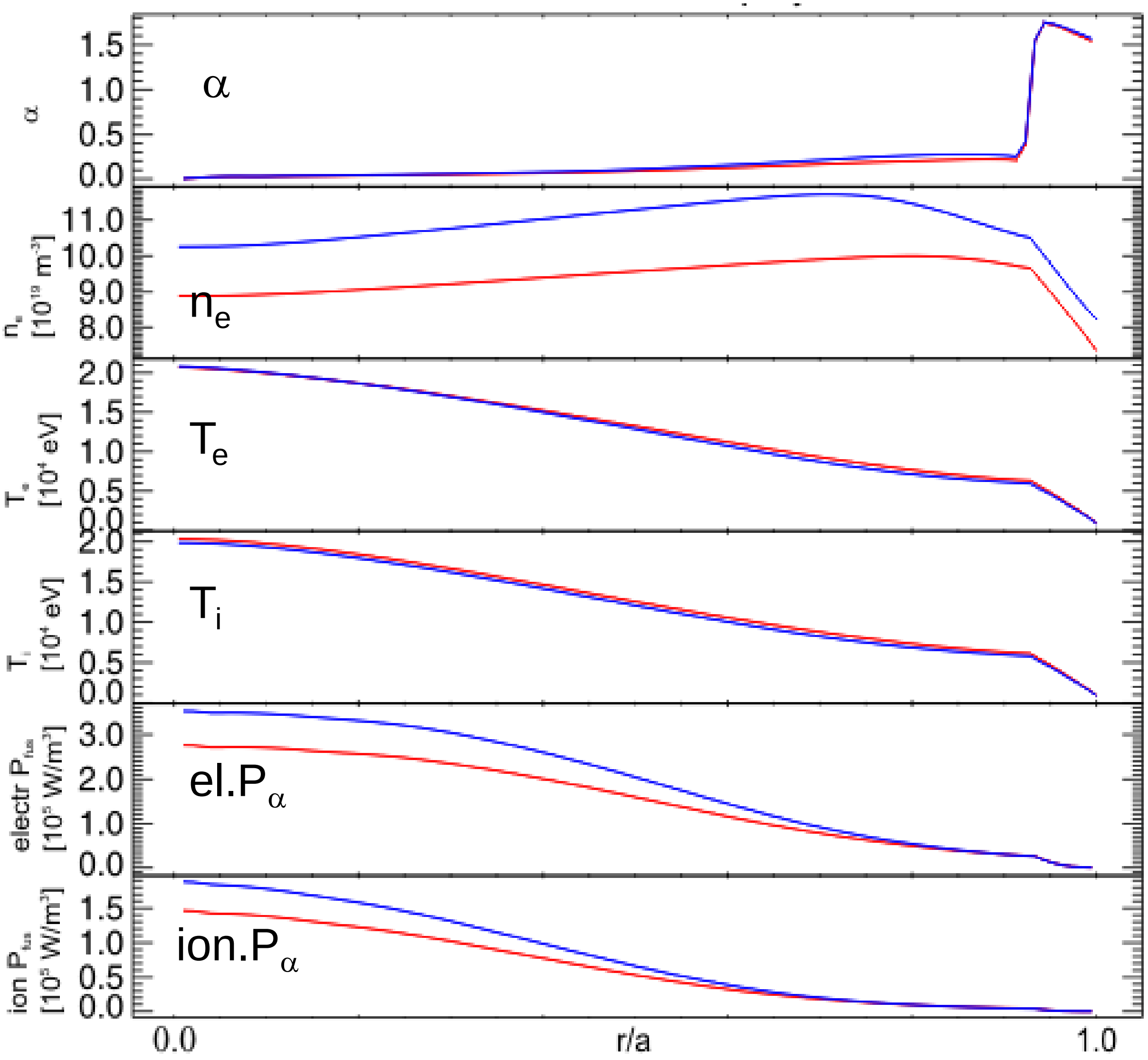
- cont.pellet model: fixed gaussian source profile in time
- $S_{pellet} = 1.5e22\ s^{-1}$, $\Delta_{pellet}=0.1$, $\rho_{pellet}= 0.9$ (case A), 0.8 (case B) (plasmoid drift)

- in far-SOL: fixed transport: D=0.3 m^2/s, $\chi_i=\chi_e=1.0 m^2/s$
- in near-SOL: ETB transport prolonged into SOL (0.5cm @ omp)

- DT-flux coming from plasma core (JETTO) combined into single D-flux into SOL: $\Gamma_D^{EDGE2D} = \Gamma_D^{JETTO}+\Gamma_T^{JETTO}$

- neutral recycling flux Γ_{D0} from SOL split up 50/50 Γ_{D0}/Γ_{T0} when entering core

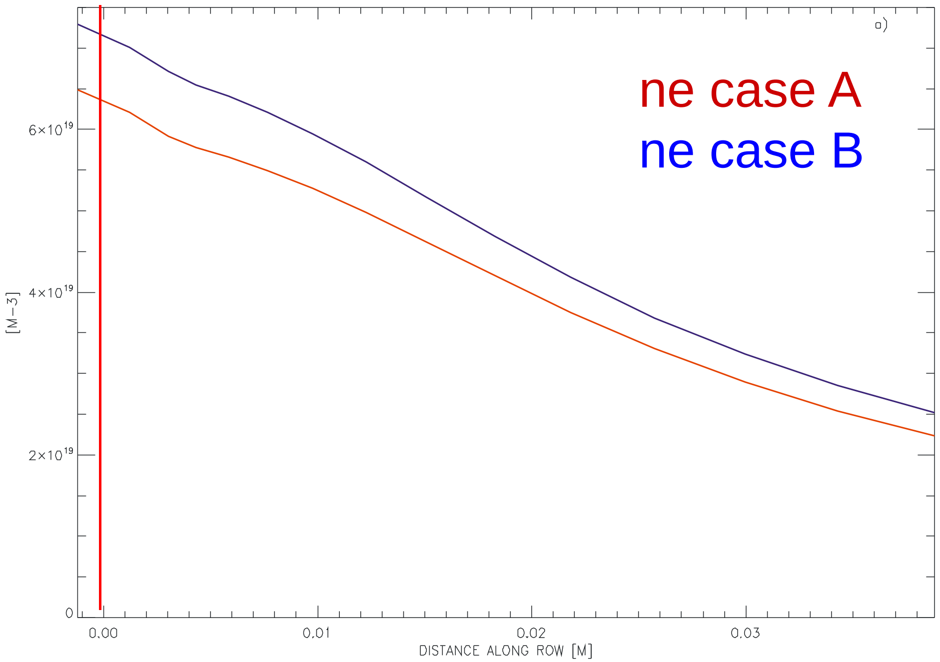
JINTRAC results, steady-state case (1)

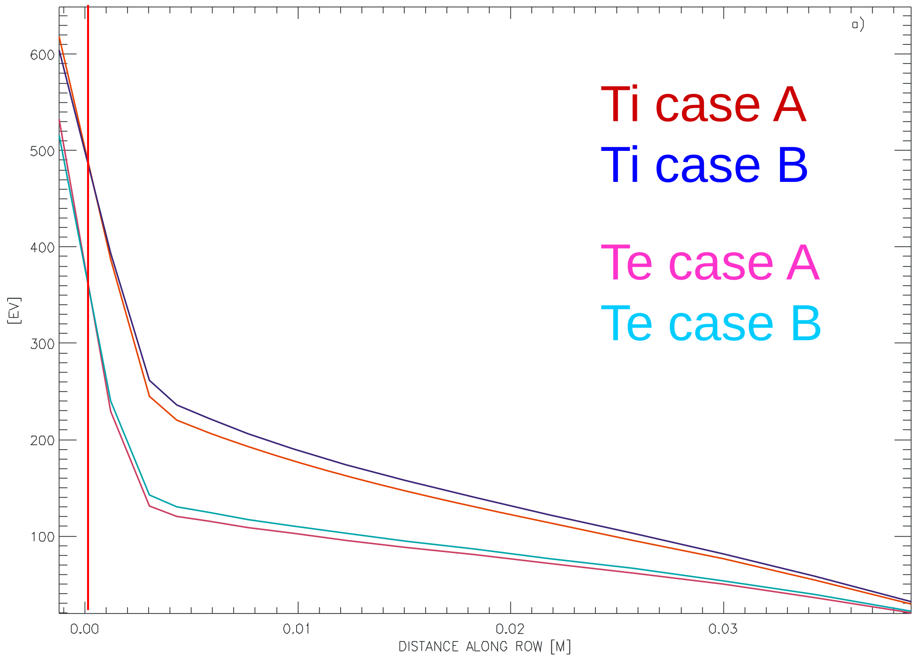


case A
case B

JINTRAC results, steady-state case (2)

Outer-midplane profiles

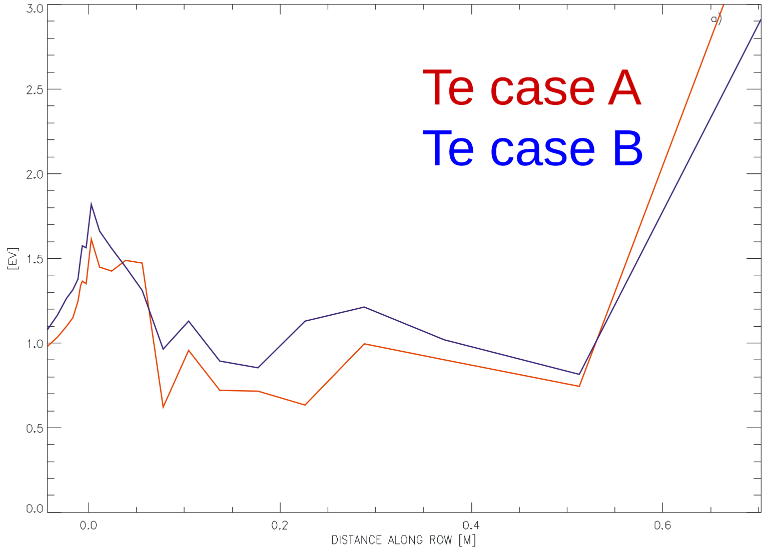


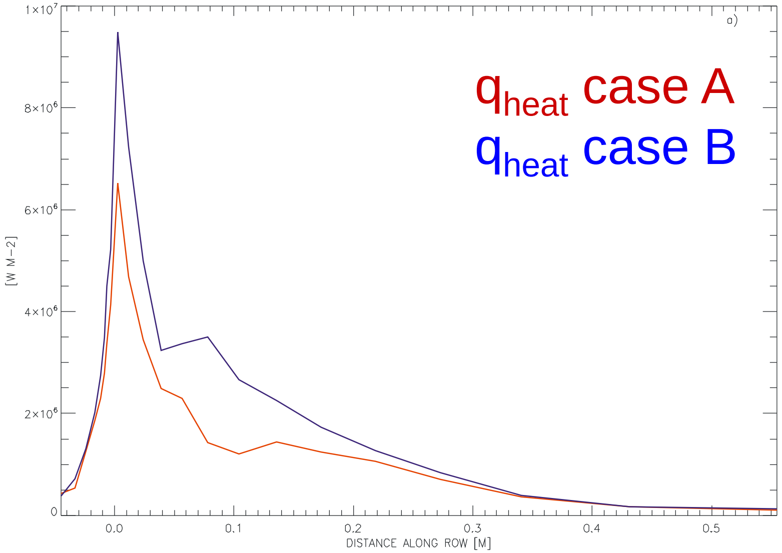


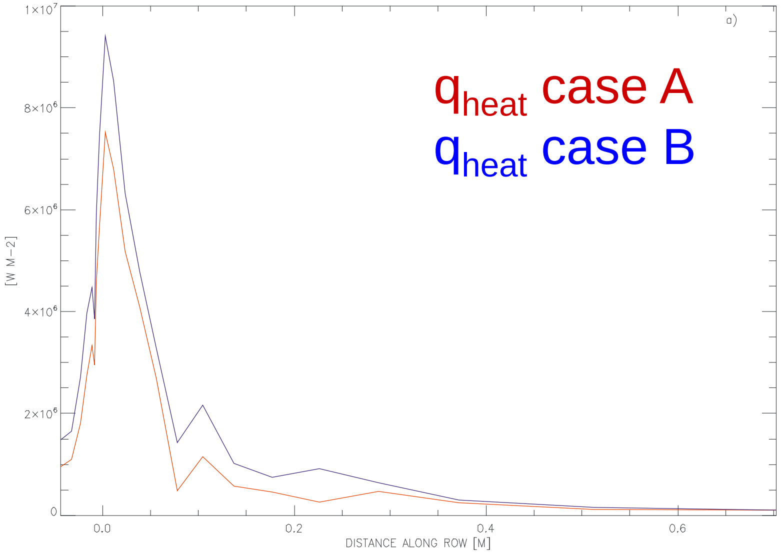
JINTRAC results, steady-state case (3)

inner target

outer target







Transient modelling of ITER baseline density evolution

- new feature: transient pellet ablation model HPI2

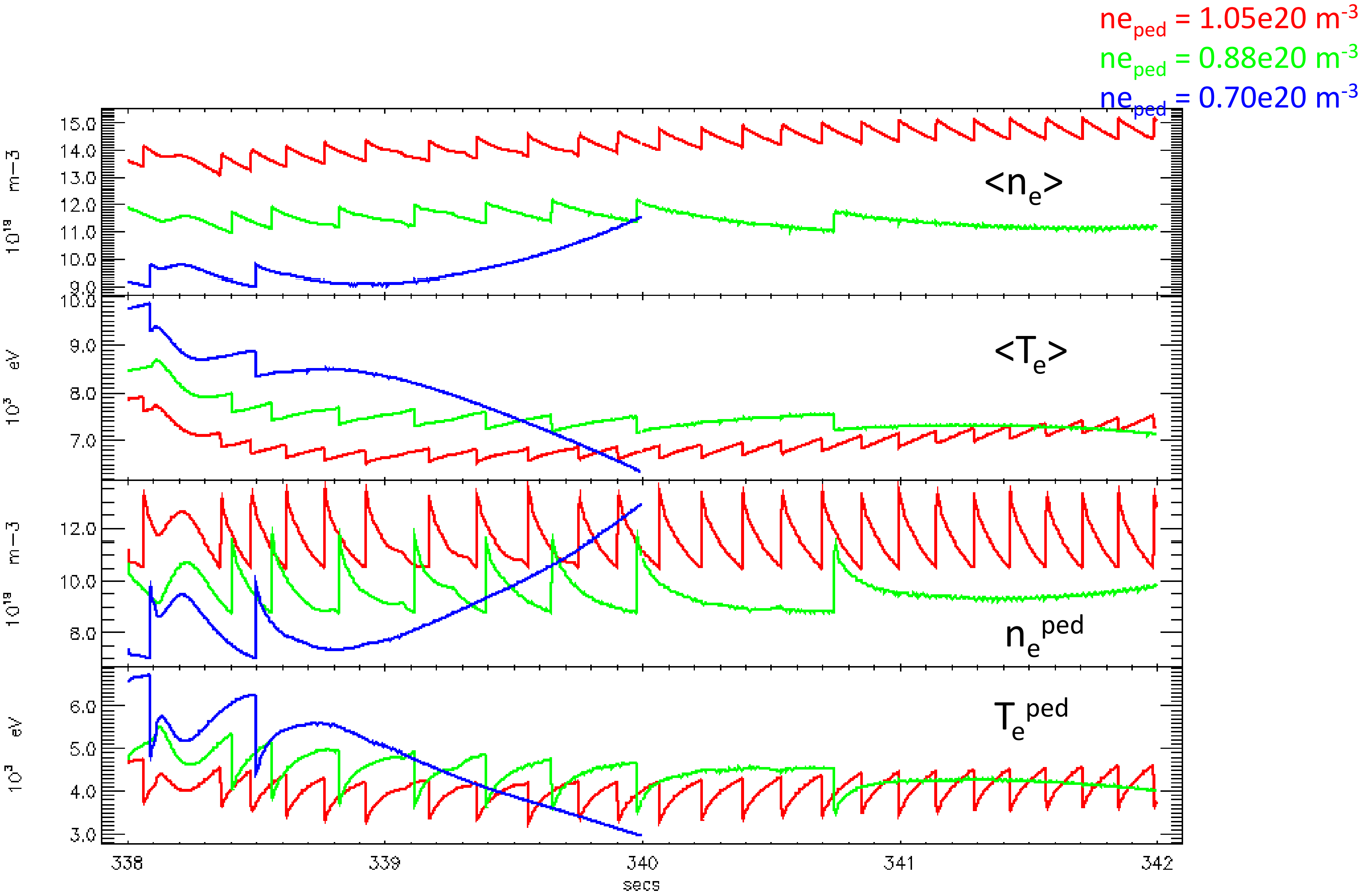
→ provides time-dependent source profiles for given pellet injection configuration

- pellets from high-field side, 6e21 atoms per pellet 50/50 D/T at v=300m/s
- assume plasmoid drift: 100%, 50%
- pellet trigger thresholds: minimum top pedestal density: 1.05, 0.88, 0.70 [$10^{20}m^{-3}$]

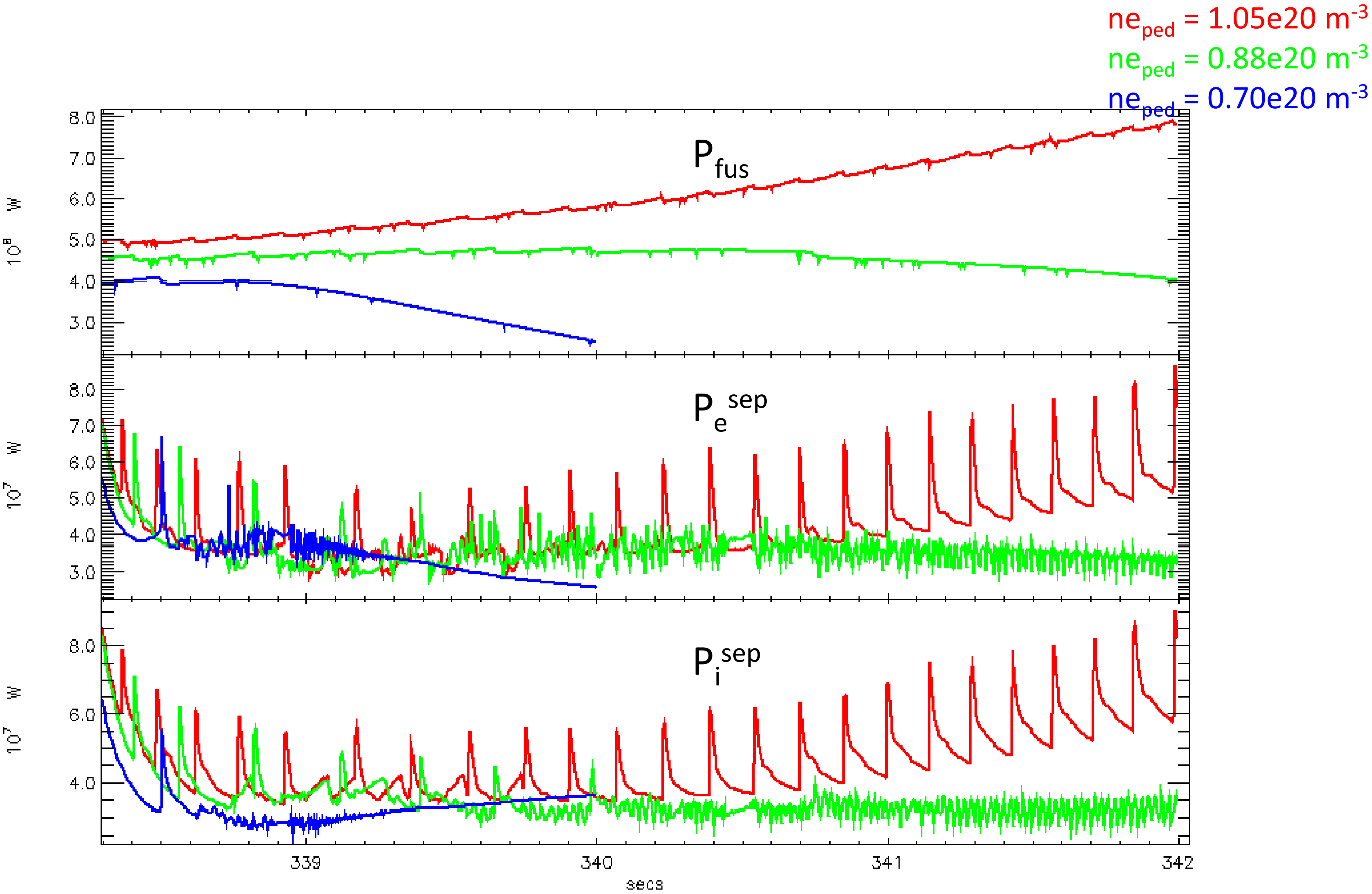
- JETTO transport model: B/gB, sawteeth, cont. ELM model: α_{crit} = 1.7 (1.5,1.3)
- fusion product: DITRAN-2
- NBI aux power: 33MW PENCIL, P_{rad}^{core}=43MW fixed (Z_{eff}=1.7 flat)

- EDGE2D-EIRENE transport model: as before, Γ_{gas}=1.4e23s^{-1} fixed, P_{rad}^{SOL}=60MW fixed (no impurity transport yet)

50% plasmoid drift (1)



50% plasmoid drift (2)



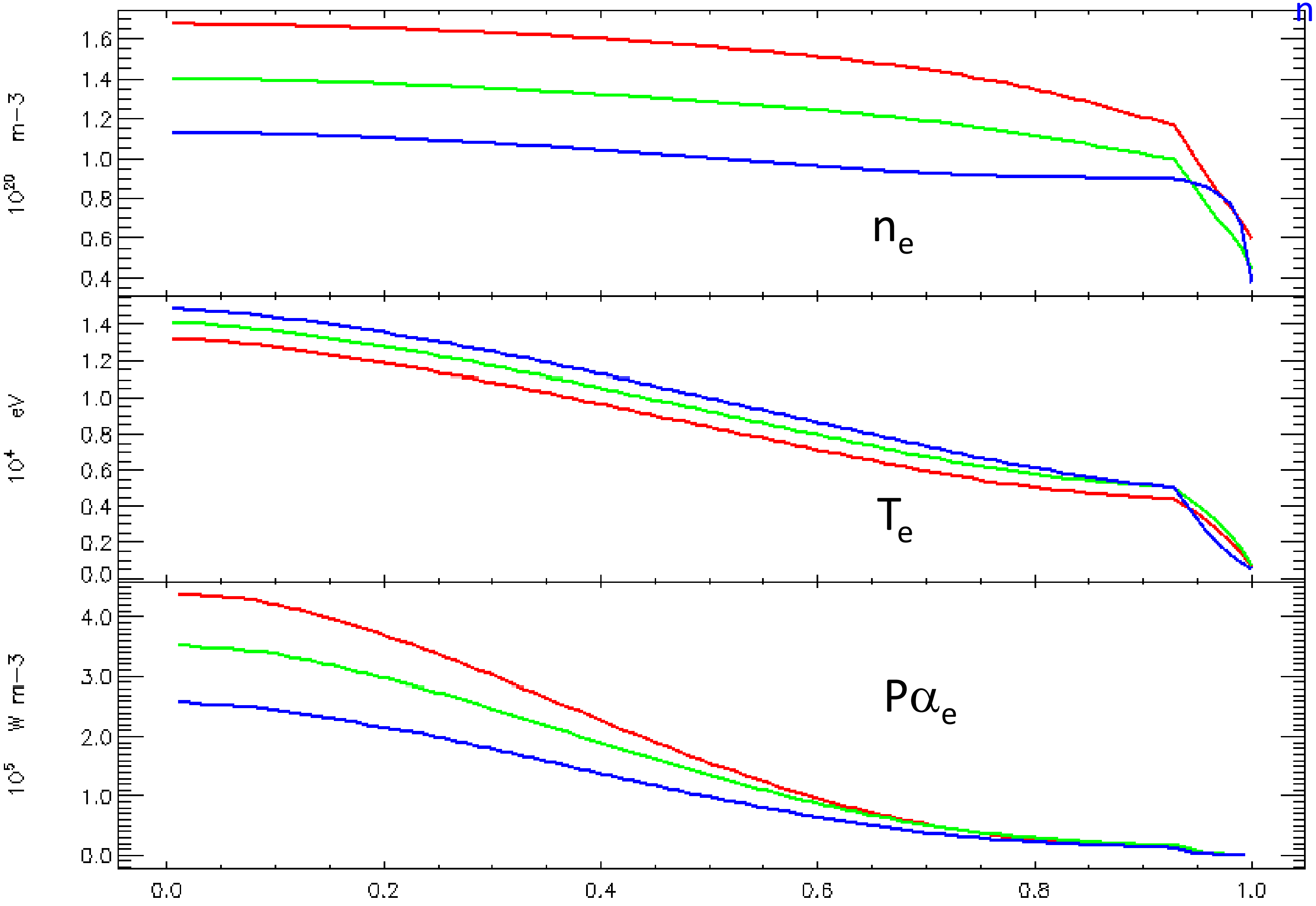
50% plasmoid drift (3)

t = 339.3s

ne_{ped} = 1.05e20 m^{-3}

ne_{ped} = 0.88e20 m^{-3}

ne_{ped} = 0.70e20 m^{-3}



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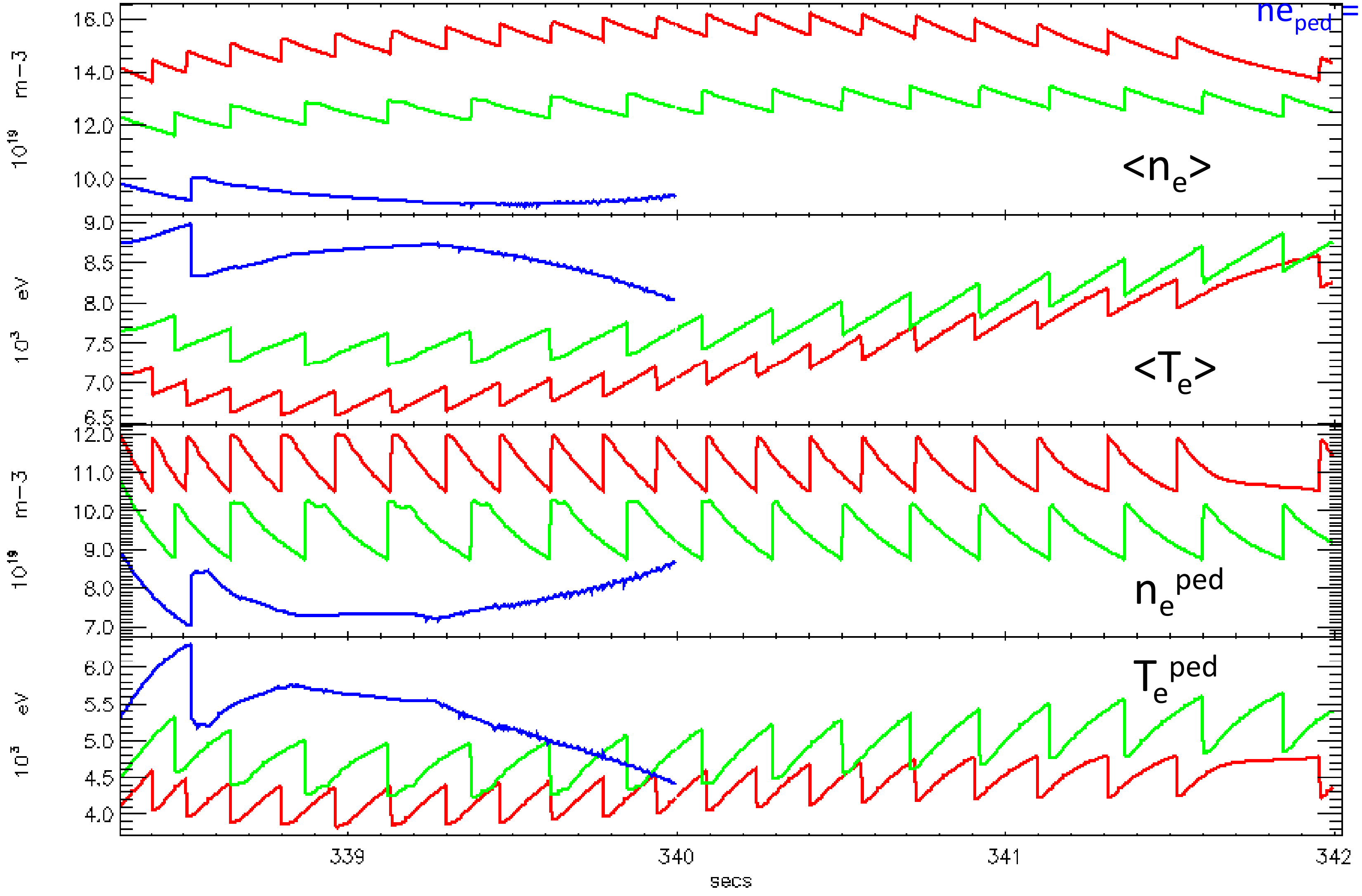
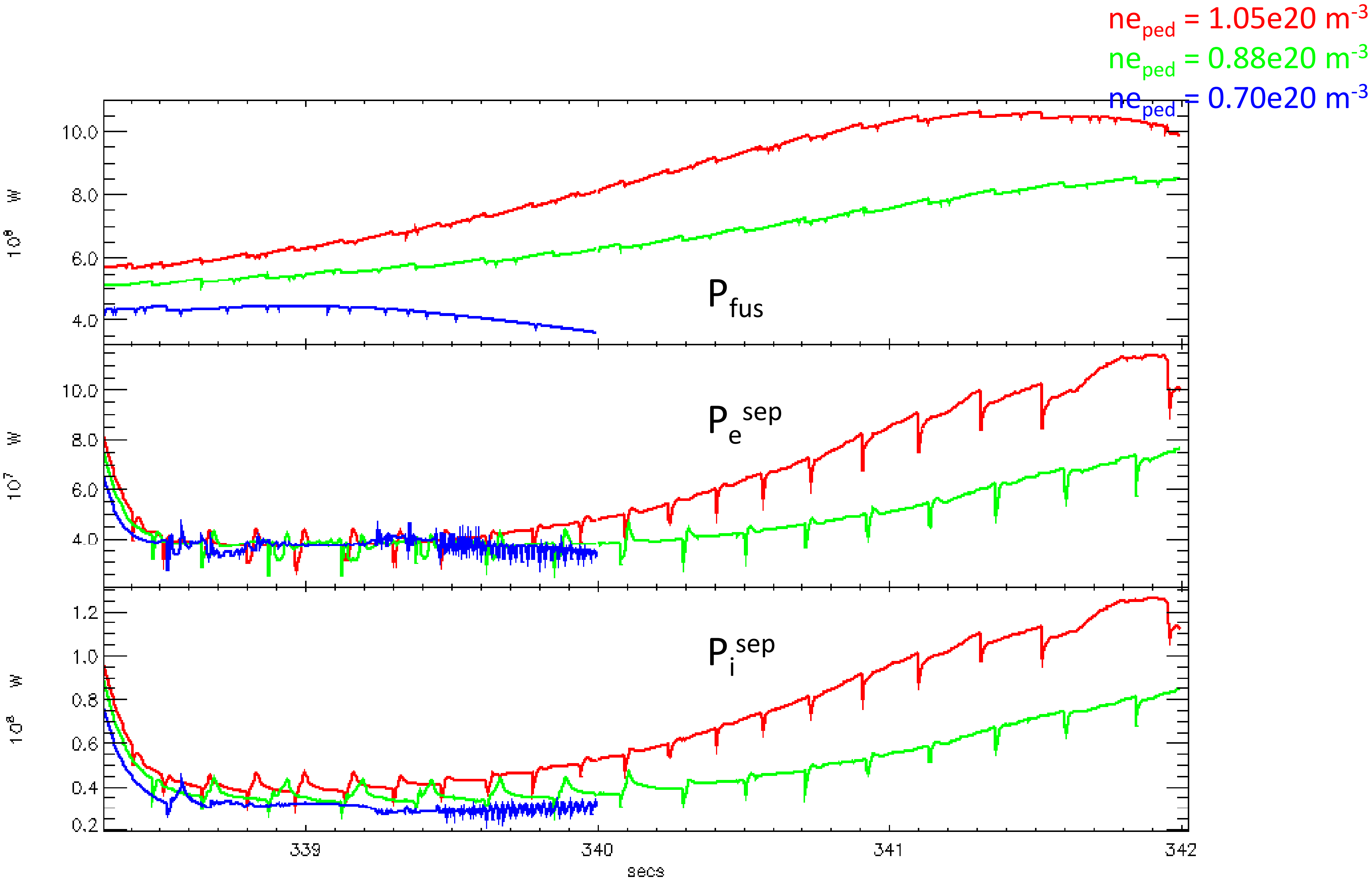


100% plasmoid drift (2)



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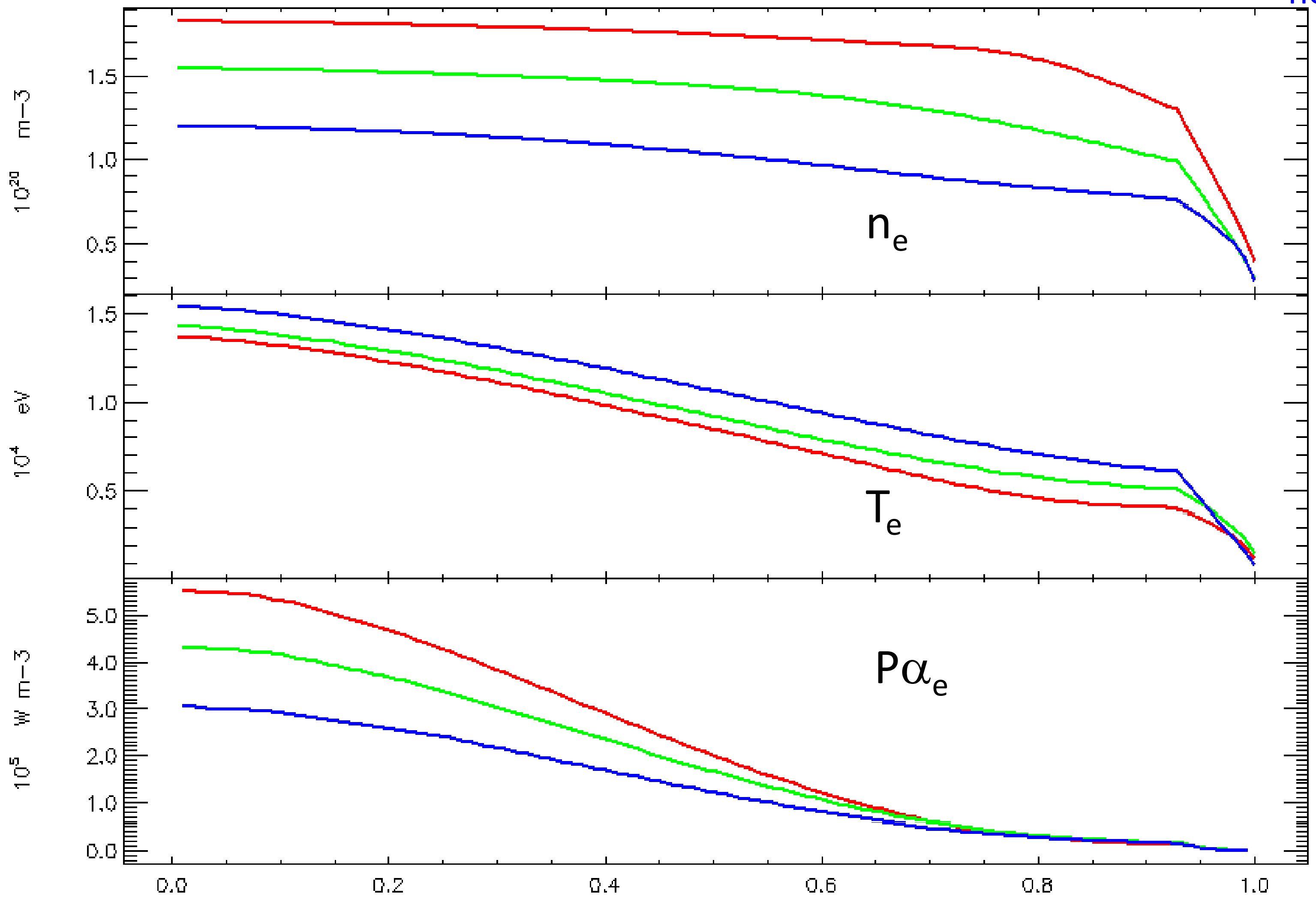
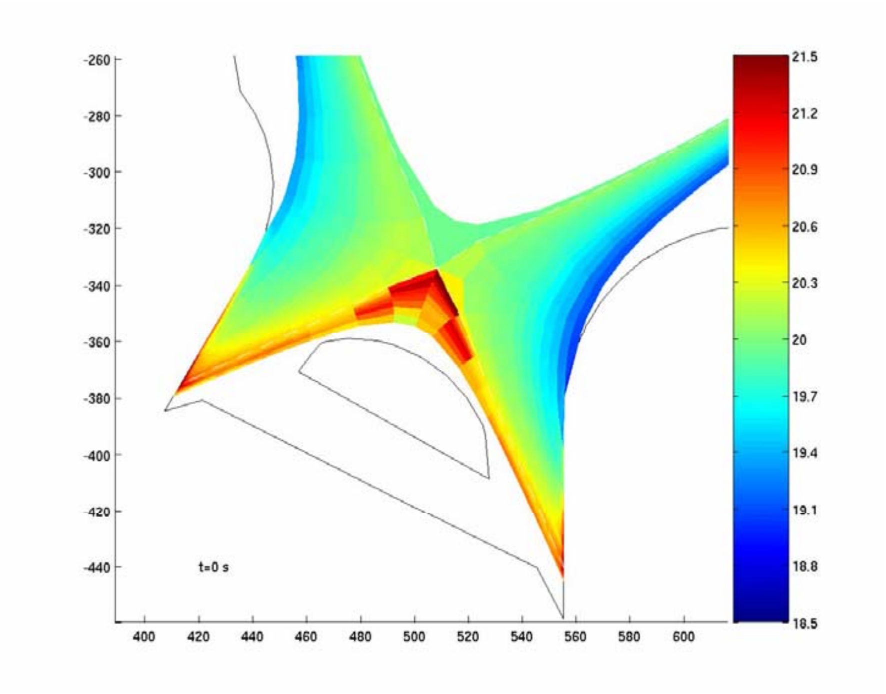
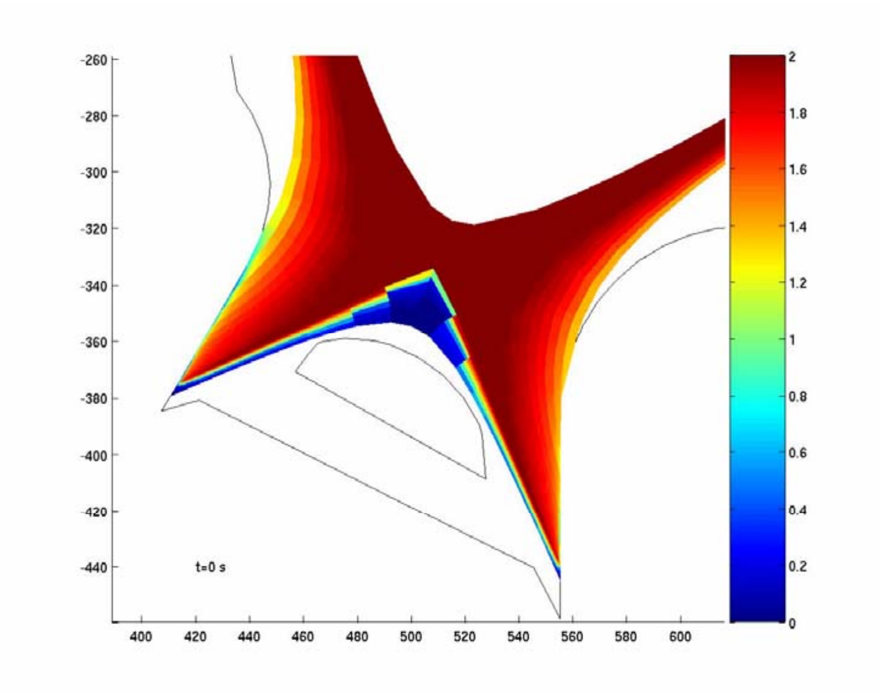


SOL response on pellets

High density case, 50% plasmoid drift



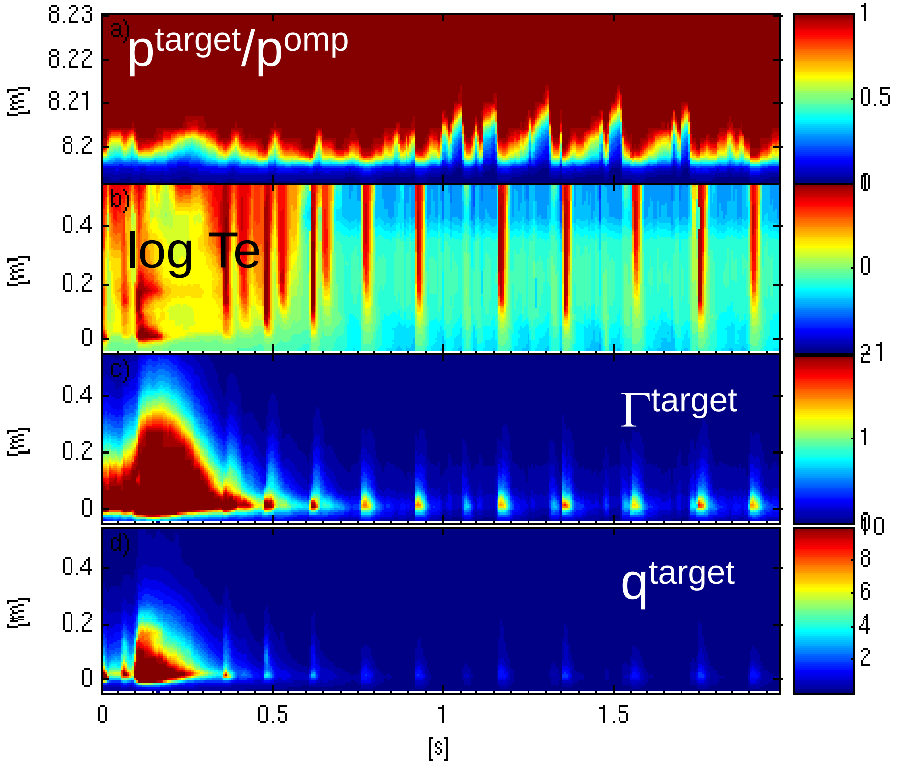
log n_e



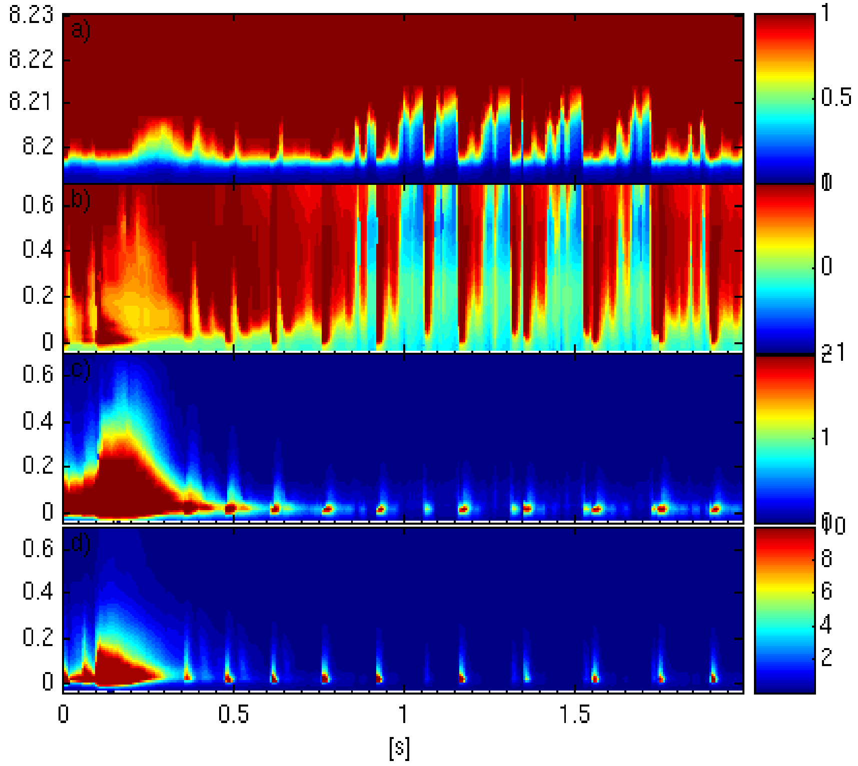
log T_e

High-density case, 50% plasmoid drift

Inner target



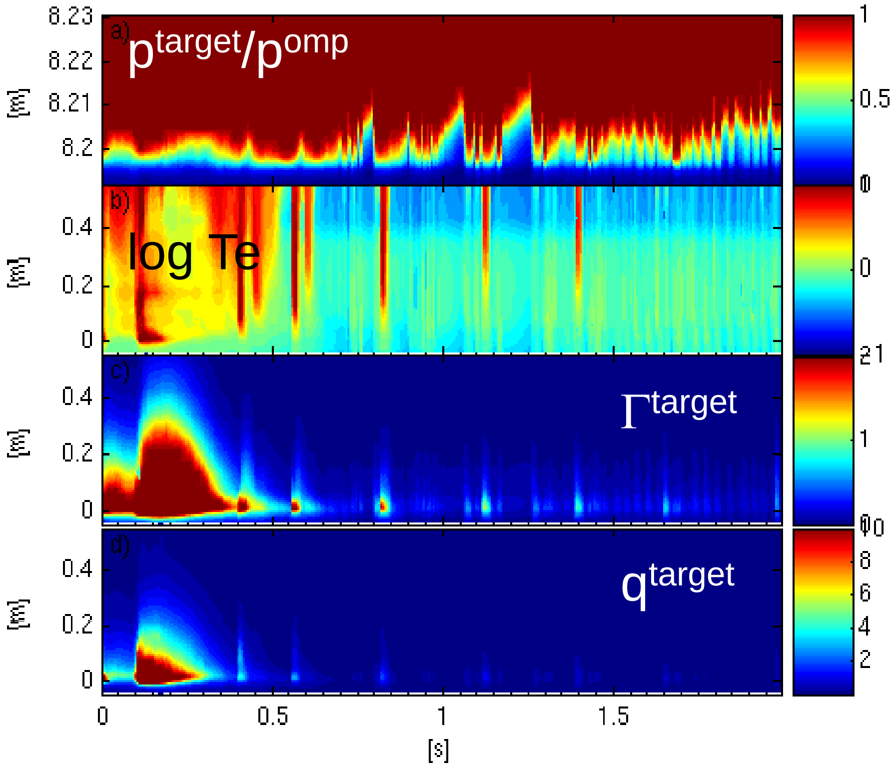
Outer target



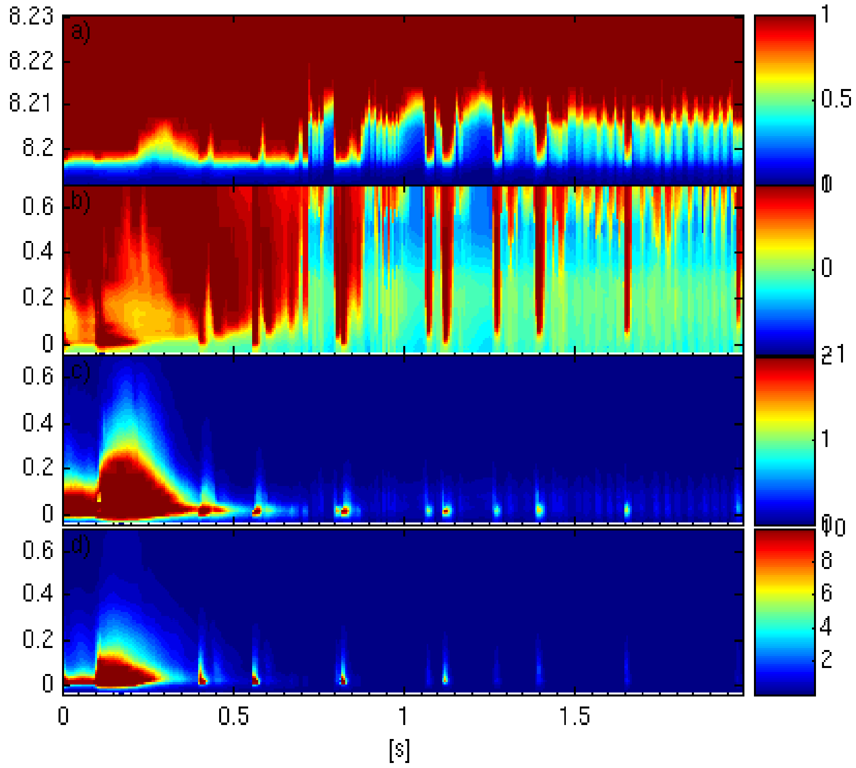
- both targets re-attach when pellet ablation peaks since PSOL increases significantly due to high fusion product in high-density

medium-density case, 50% plasmoid drift

Inner target



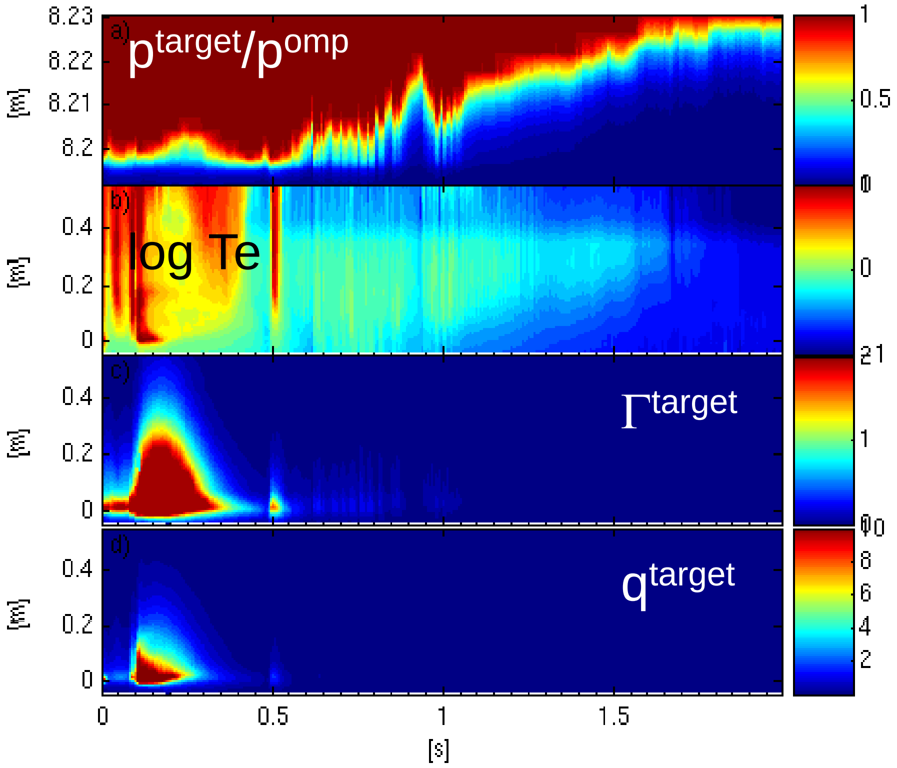
Outer target



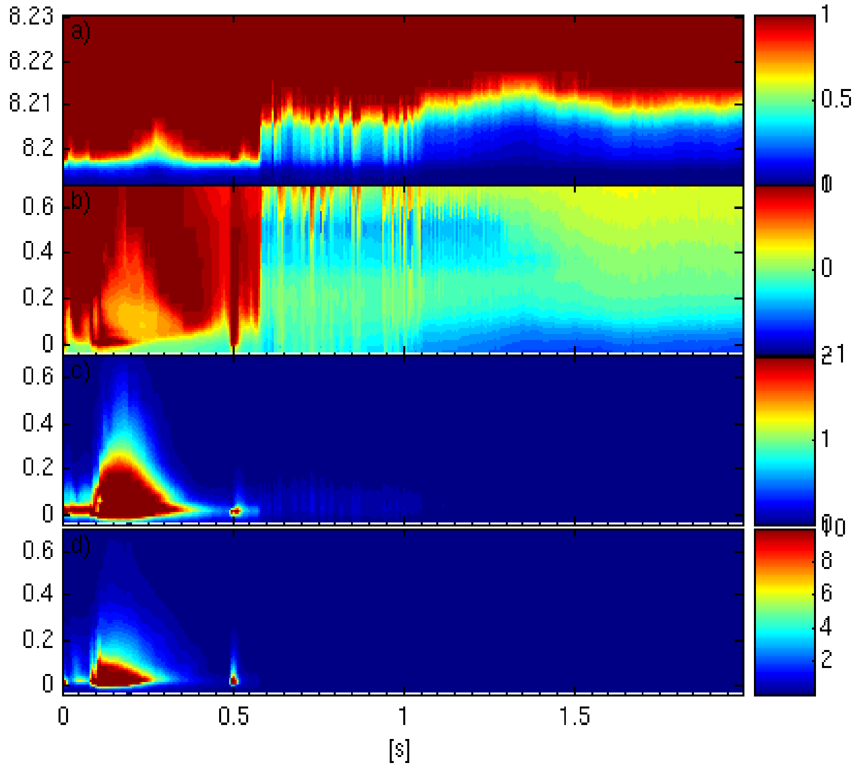
- the inner target stays detached whilst the outer target reattaches at pellet ablation time

low-density case, 50% plasmoid drift

Inner target



Outer target



- in the low-density case both targets are completely detached → very difficult to control
- in simulation: core density rises monotonically → density limit (the latter not treated correctly, no MARFEs: fixed P_{rad}^{SOL}=60MW)

New (redefined) ISM-P3-2011-08 project

ISM Task description

Task name: Integrated modelling of ITER H-mode scenario including impurities (seeded and intrinsic)

Project : P3 (Predictive scenario modelling for ITER, JT-60SA, DEMO…)

Task reference: ISM-P3-2011-08

Version: 1

Date of revision:

Start date: 2010

Tentative completion date: 2011 or later

Physicist involved: S. Wiesen, F. Koechl, L.Garzotti, P. Belo, J. Lonnroth, V. Parail

Codes involved and version: JINTRAC (JETTO/SANCO, EDGE2D-EIRENE)

Machine and pulses numbers: ITER baseline

Detailed Task description:

Previous integrated core-pedestal-SOL modelling of ITER H-mode baseline scenario has been performed for pure D-T plasma with pellets. This task will be extended to include the impurity evolution in self-consistent simulations for testing the impurity effect on plasma performance: radiation, dilution, impurity dependent transport (if theory-based models are used?).
Density limit, MARFEs, refine neutral model (molecular processes), discrete ELMs

xxxx

Introduction (1): historic modelling w/ B2-EIRENE/SOLPS4

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- **Kukushkin 2007**: further sensitivity studies: varying gas-puff location and effect on plasma fuelling, variations in divertor dome geometry and effect on p_{div}

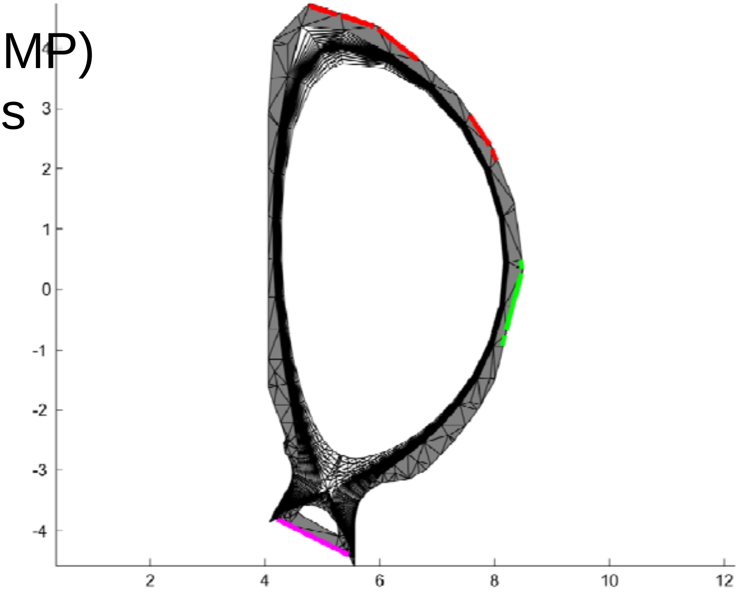
EDGE2D-EIRENE simulation model setup

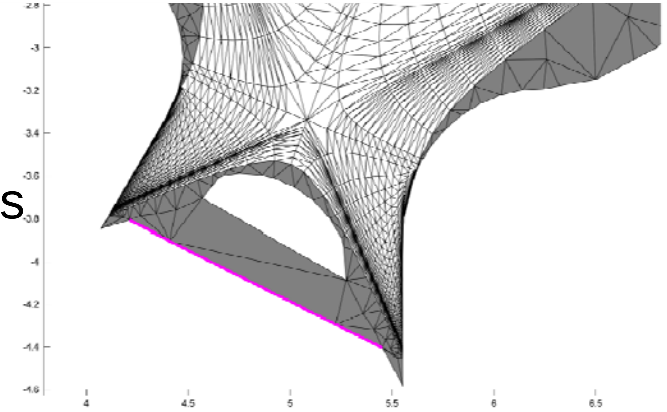
- 2D simulation domain extends into edge (6cm@OMP)
- parallel transport classical, flux limited for electrons
- sheath physics at targets (Bohm-criteria)
- adhoc radial transport model (cf. next slide)

- particle sources:
  - core (mimic pellets): Γ_{core} =2e21..1e23 s^{-1}
  - top D2 gas flux: Γ_{gas} = 1.4e23 s^{-1} fixed
  - omp Neon gas flux: Γ_{Ne} = 1e19..8e19 s^{-1}

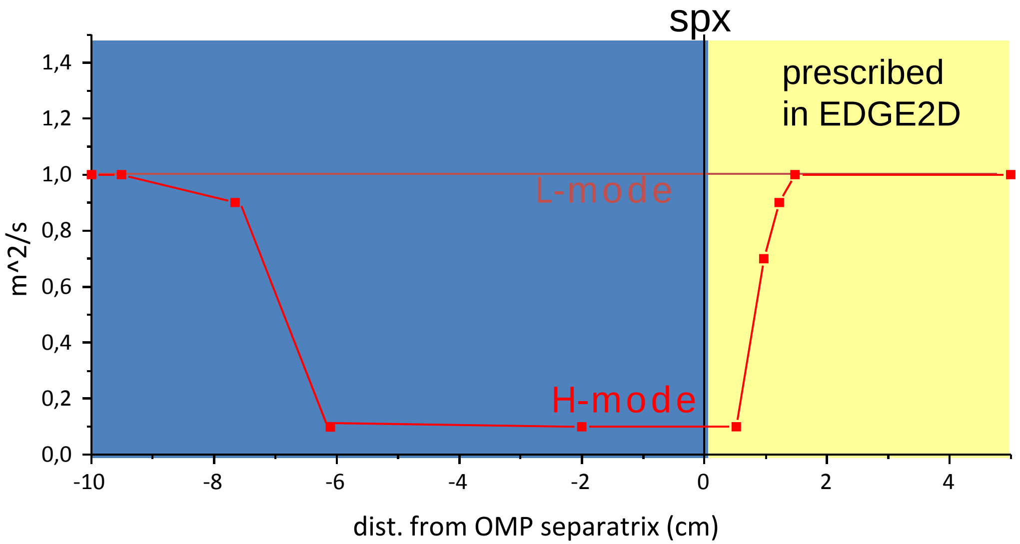
- particle sinks:
  - pumping surface below divertor dome:
  - albedo = 0.94
  - → L = A (1-albedo) 36.38 (T_{D2}/4) ~ 790 m^3/s

- heat sources: P_{edge}=80MW (1:2 ratio ions/els)





Radial transport model of SOL and plasma edge



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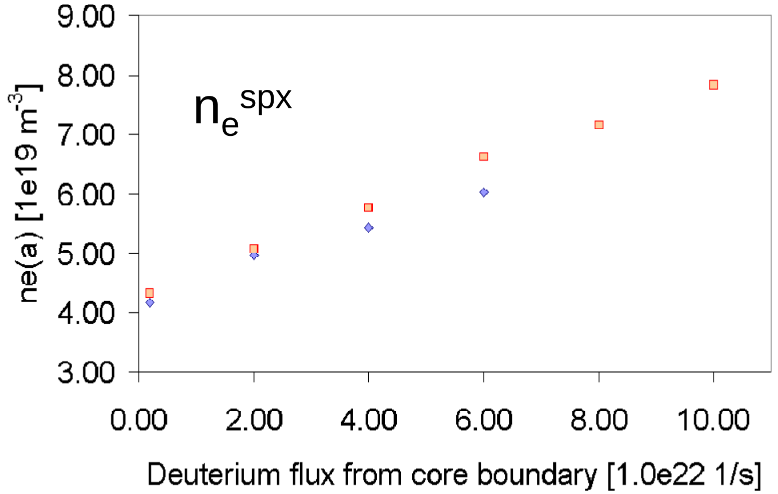
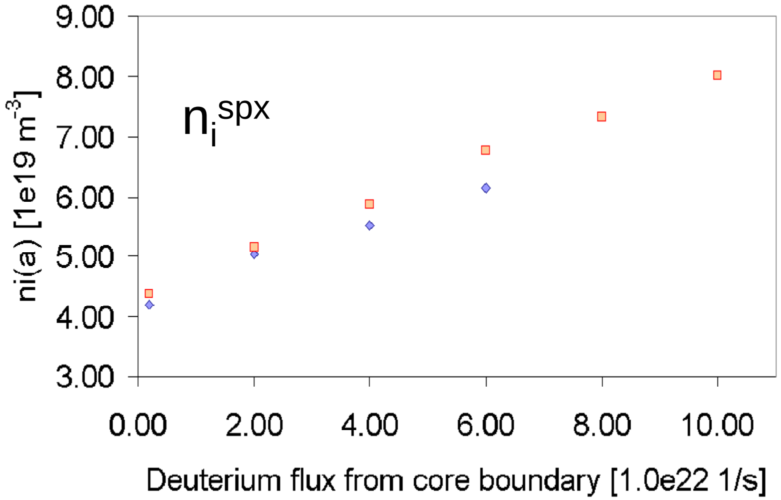
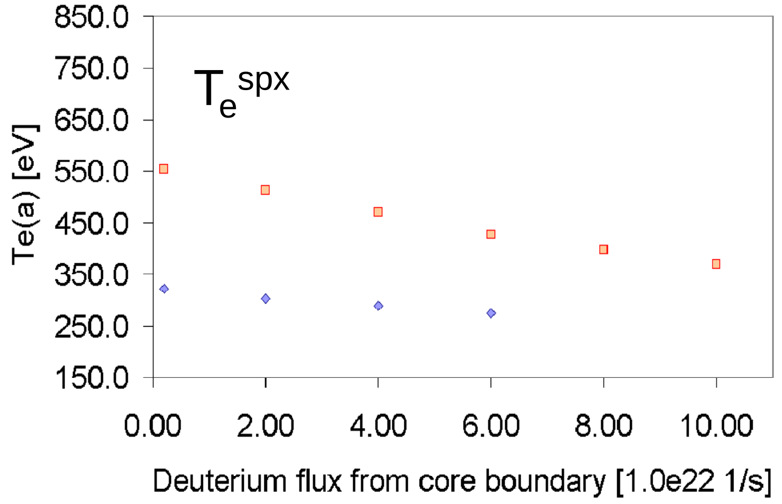
good confinement: $\chi_e = \chi_i = 0.2$ m^2/s, D = 0.07 m^2/s, no pinch

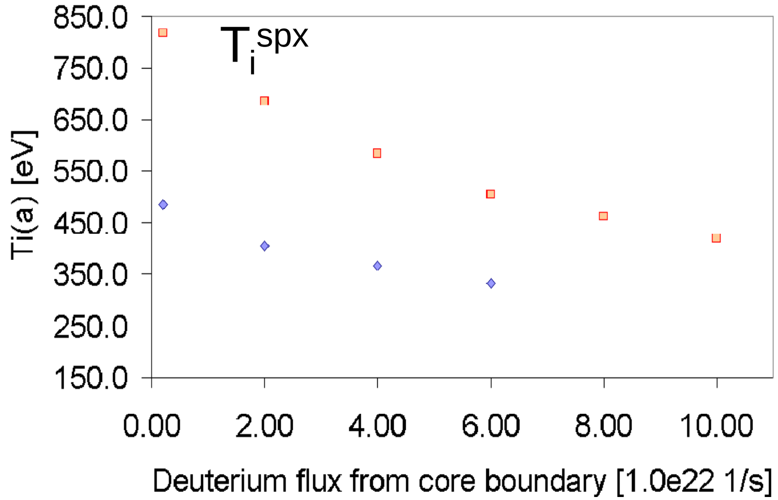
EDGE2D-EIRENE results (1): separatrix quantities

pellet induced non-transient ion-flux scan, fixed Γ_{Ne} = 1e19 s^{-1}





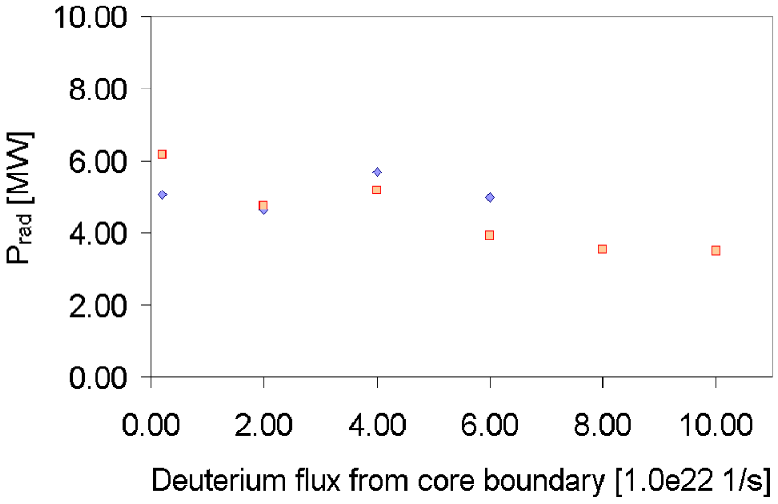




EDGE2D-EIRENE results (2): SOL radiative fraction

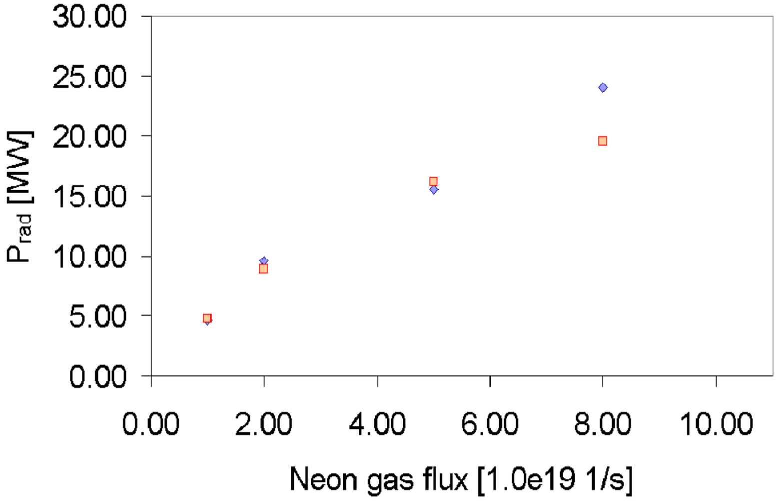
pellet induced ion-flux scan

fixed $\Gamma_{Ne} = 1e19\ s^{-1}$



seeded Neon gas scan

fixed $\Gamma_{core} = 2e22\ s^{-1}$

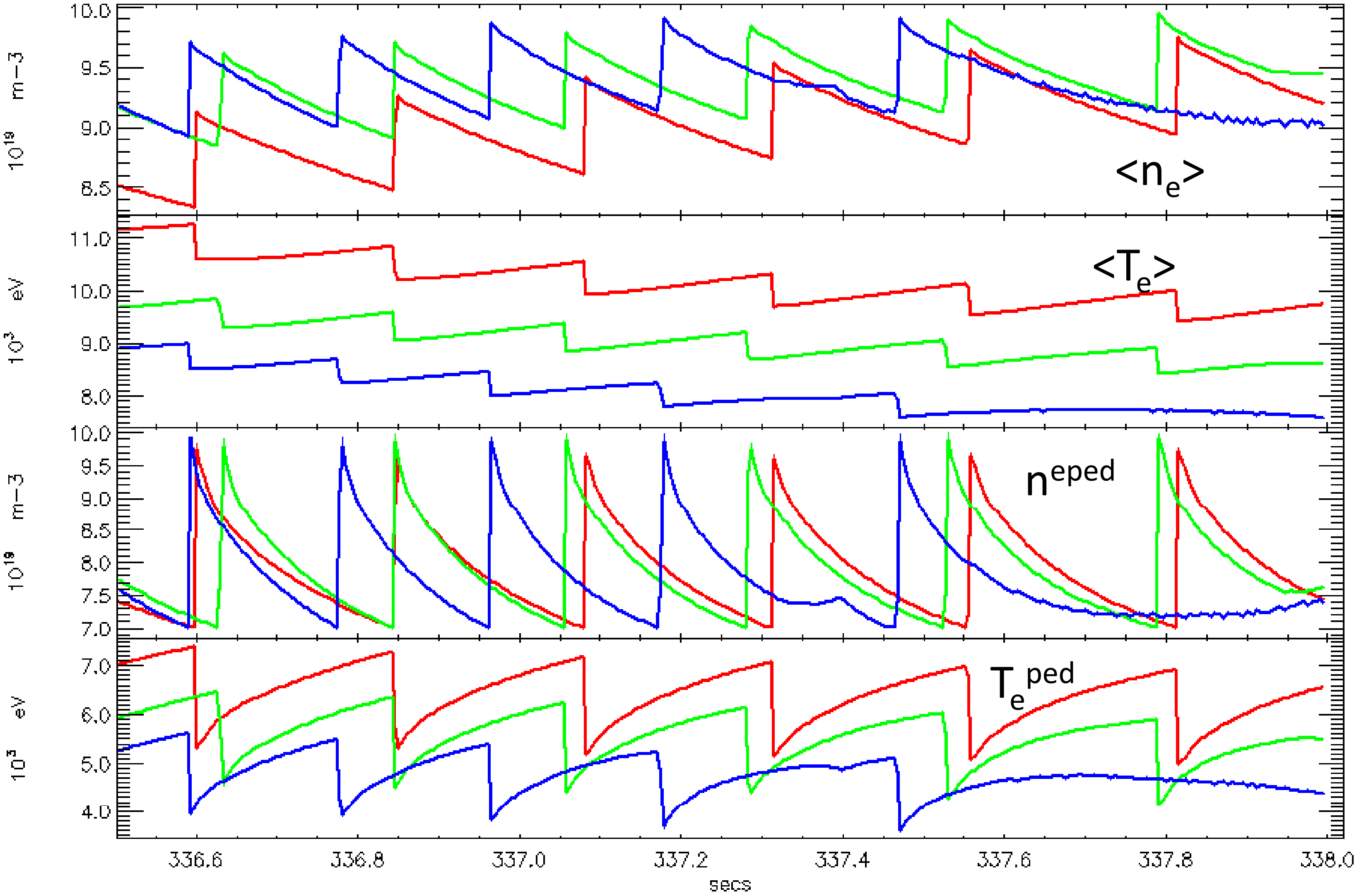


50% plasmoid drift, low density case,α_{crit} variation (1)

α_{crit} = 1.7

α_{crit} = 1.5

α_{crit} = 1.3

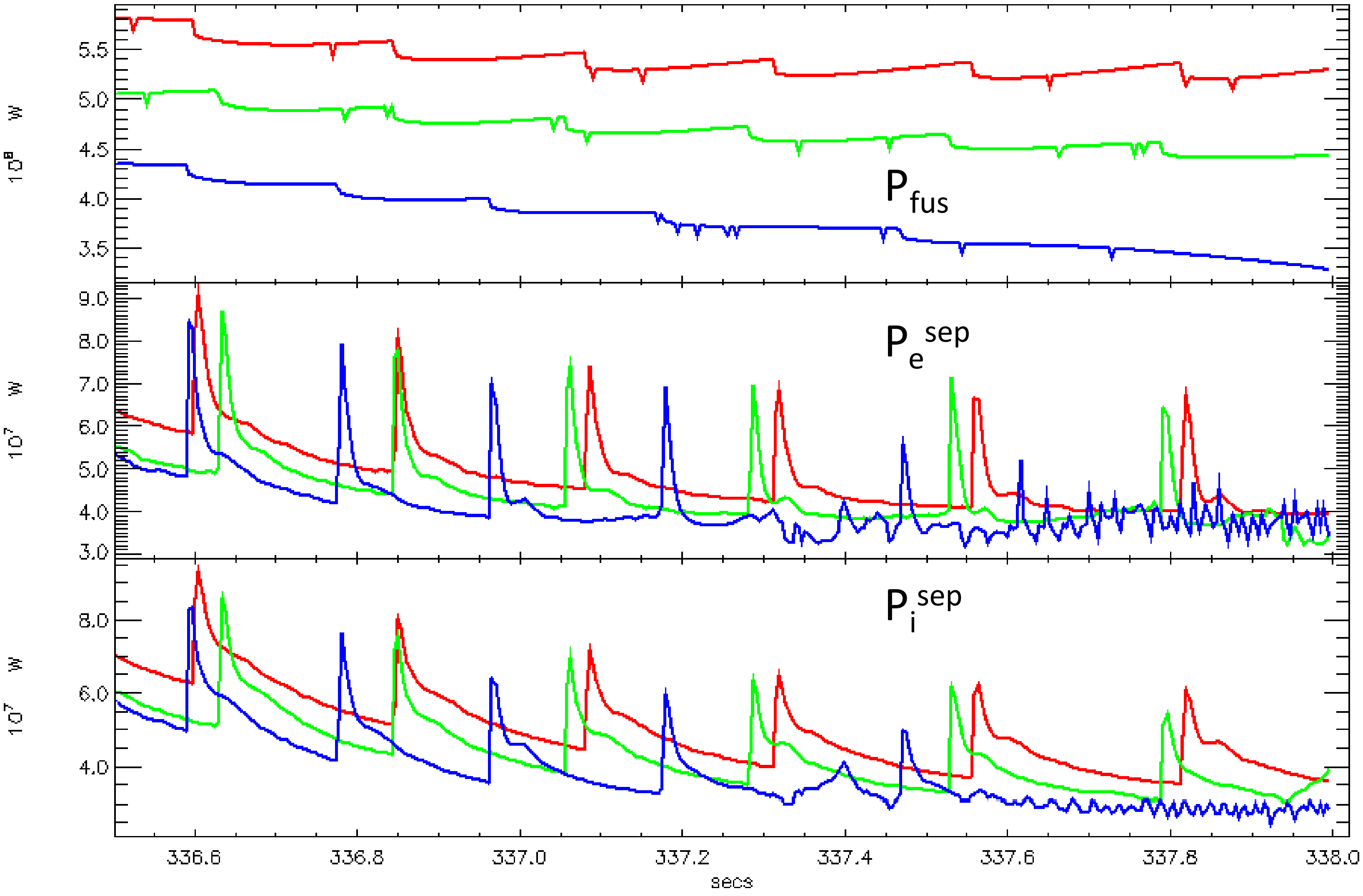


50% plasmoid drift, low density case,α_{crit} variation (2)

α_{crit} = 1.7

α_{crit} = 1.5

α_{crit} = 1.3



50% plasmoid drift, low density case, α_{crit} variation (3)

t = 337.75s

α_{crit} = 1.7

α_{crit} = 1.5

α_{crit} = 1.3