EFDA EUROPEAN FUSION DEVELOPMENT AGREEMENT

Benchmarking Tokamak Edge Modelling Codes

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Introduction

- three codes in widespread use for simulating edge plasma
- two of these are compared by running the "same" cases
  - EDGE2D-NIMBUS [SIMONINI *et al.*, 1994] consists of a fluid plasma code EDGE2D coupled to a Monte-Carlo neutrals code, NIMBUS
  - SOLPS [SCHNEIDER *et al.*, 1992, REITER, 1992a, COSTER *et al.*, 2000, COSTER *et al.*, 2002] consists of a fluid code B2 [BRAAMS, 1986, BRAAMS, 1987, BRAAMS *et al.*, 1996, ROZHANSKY *et al.*, 1999, SCHNEIDER *et al.*, 2000, ROZHANSKY *et al.*, 2000], coupled to a Monte-Carlo neutrals code Eirene [REITER *et al.*, 1990, REITER, 1992b, REITER *et al.*, 1995].
- two codes are very similar in the equations they solve
- setup cases with the same grid corresponding to a particular "typical" JET high clearance discharge (# 50401), figure 1

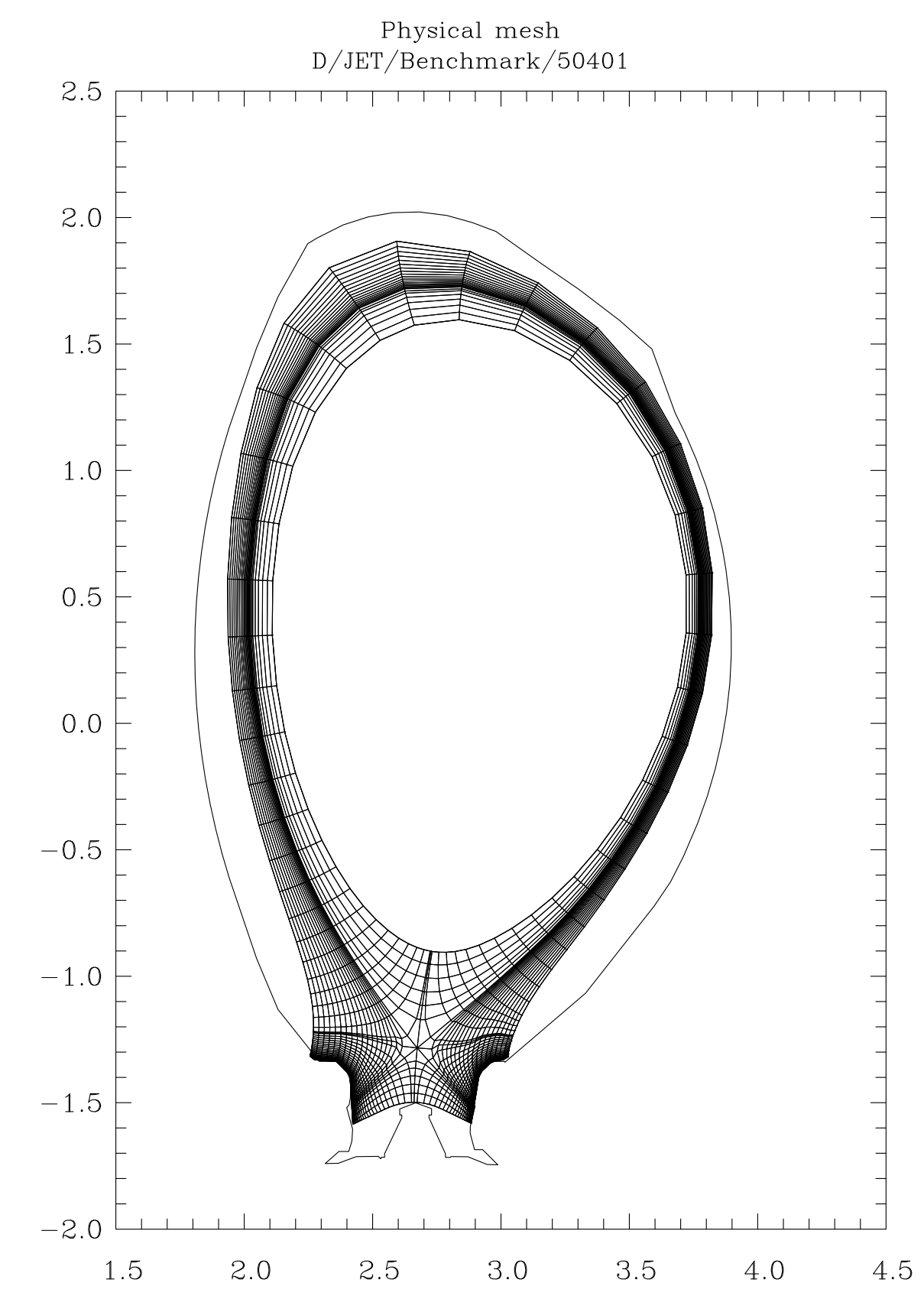

Figure 1: Common plasma grid used by EDGE-2D and SOLPS (B2-Eirene).

- build in complexity
  1. pure deuterium, no drifts [Completed]
  2. pure deuterium, drifts [Started, preliminary results]
  3. deuterium plus impurities, no drifts [After drifts case completed]
  4. deuterium plus impurities, drifts [Last]

Pure deuterium simulations

Boundary conditions

- $2.5MW$ heating power, equally split between the electrons and the ions
- separatrix density feedback controlled by a gas puff
  - $5 \times 10^{18} m^{-3}$
  - $1 \times 10^{19} m^{-3}$
  - $1.5 \times 10^{19} m^{-3}$
- "standard sheath" boundary conditions at the target plates

Initial results suggested some work lay ahead, figure 2.

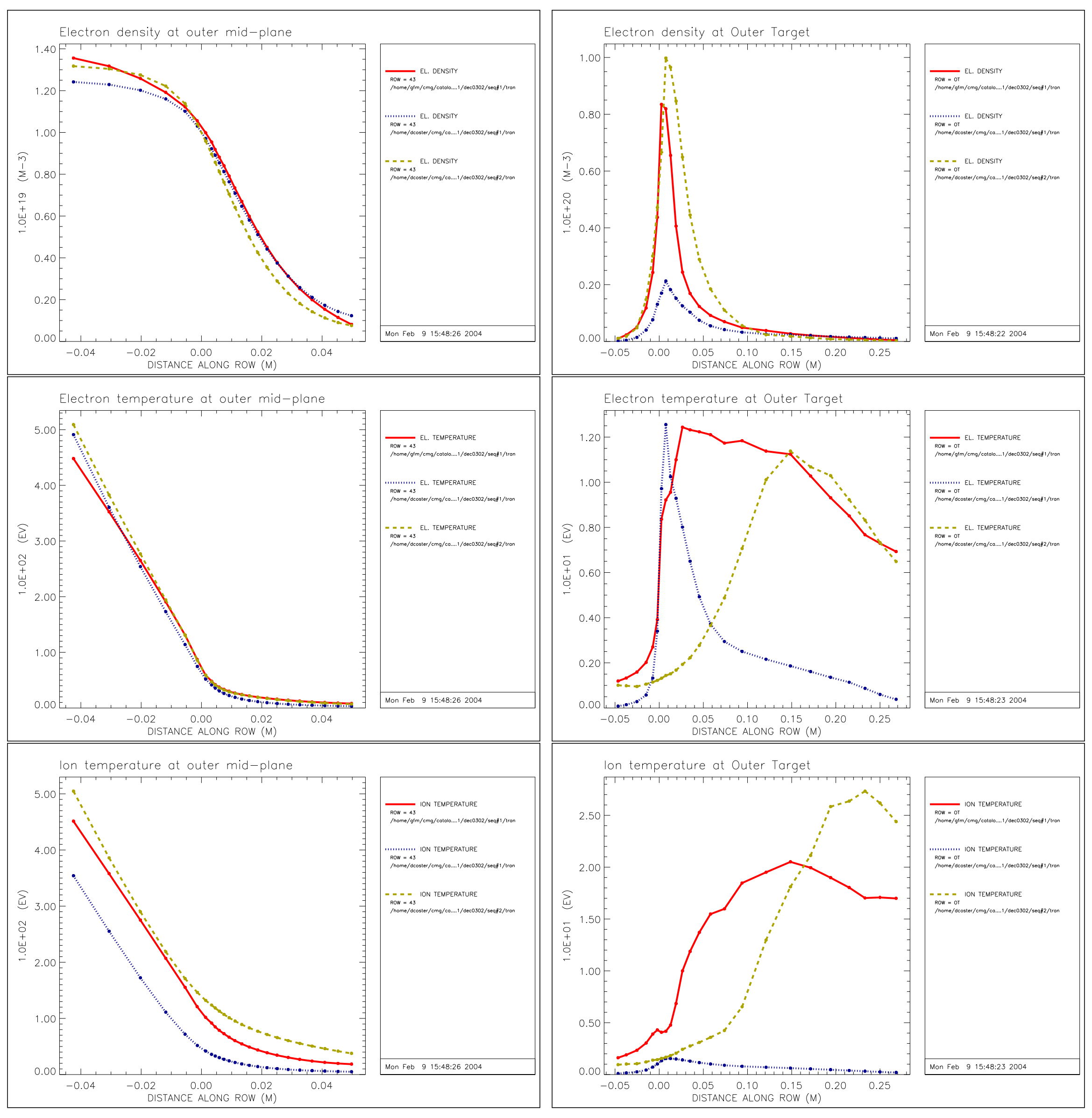

Figure 2: Outer midplane (left) and outer target (right) profiles of the electron density, electron temperature and ion temperature (top to bottom), each for EDGE2D-NIMBUS, SOLPS with fluid neutrals (B2), and SOLPS with kinetic neutrals (B2-Eirene).

Observations

- all three codes produce reasonable agreement for the upstream electron density and temperature
- the fluid neutral model is seen to underestimate the upstream ion temperature
- downstream, the two kinetic versions show some agreement
- downstream, the fluid version is completely different
- figure 3 shows a strange feature in the B2-Eirene poloidal ion temperature profile
- figure 3 also shows a difference in the target Mach number

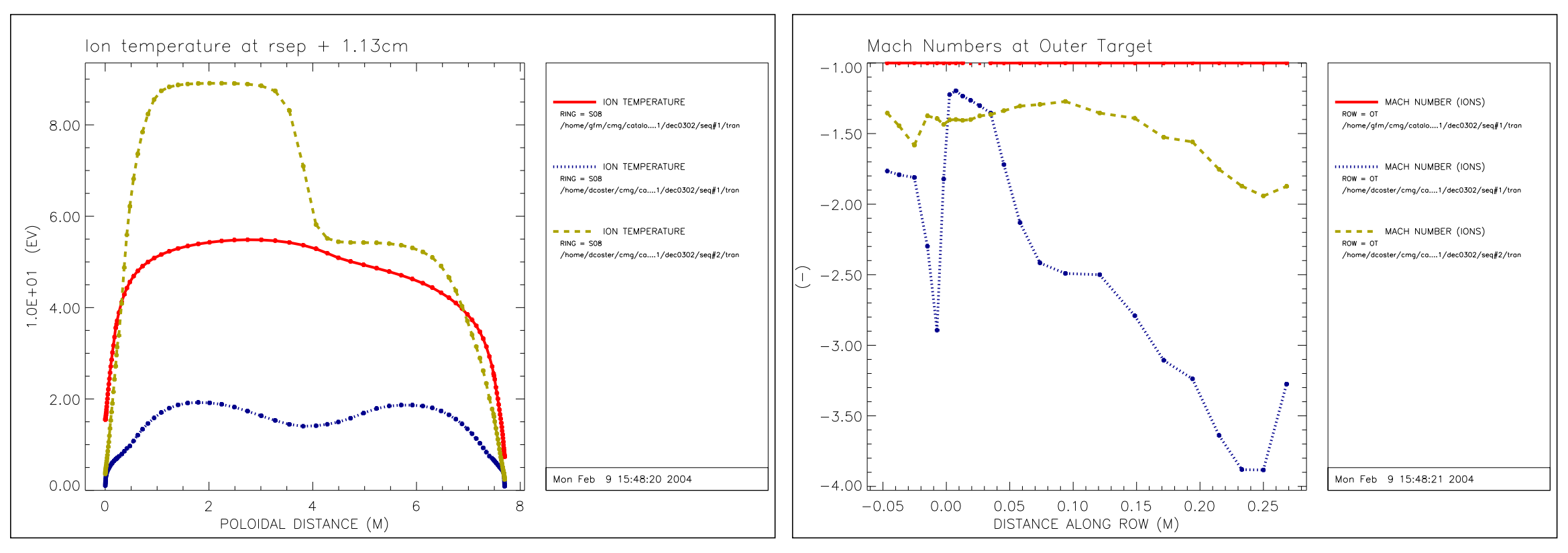

Figure 3: Poloidal profile of the ion temperature and outer target Mach number, each for EDGE2D-NIMBUS, SOLPS with fluid neutrals (B2), and SOLPS with kinetic neutrals (B2-Eirene).

Explanation

- part of the difference in the poloidal ion temperature came from
  - EDGE2D-NIMBUS was using a distributed gas puff
  - B2-Eirene was using a localised gas puff
- another part, was the differing choice of parallel energy flux limiters
  - EDGE2D-NIMBUS was being run without
  - SOLPS with these flux-limiters
  - figure 4 shows the effects of changing the flux limiters, with values of 0.15 (the original SOLPS choice), 0.2 and 10.0 (essentially off, the EDGE2D-NIMBUS initial choice)
- (The agreement with the fluid neutral model could be improved by the implementation of a fluid flux limiter, see [COSTER *et al.*, 2004].)

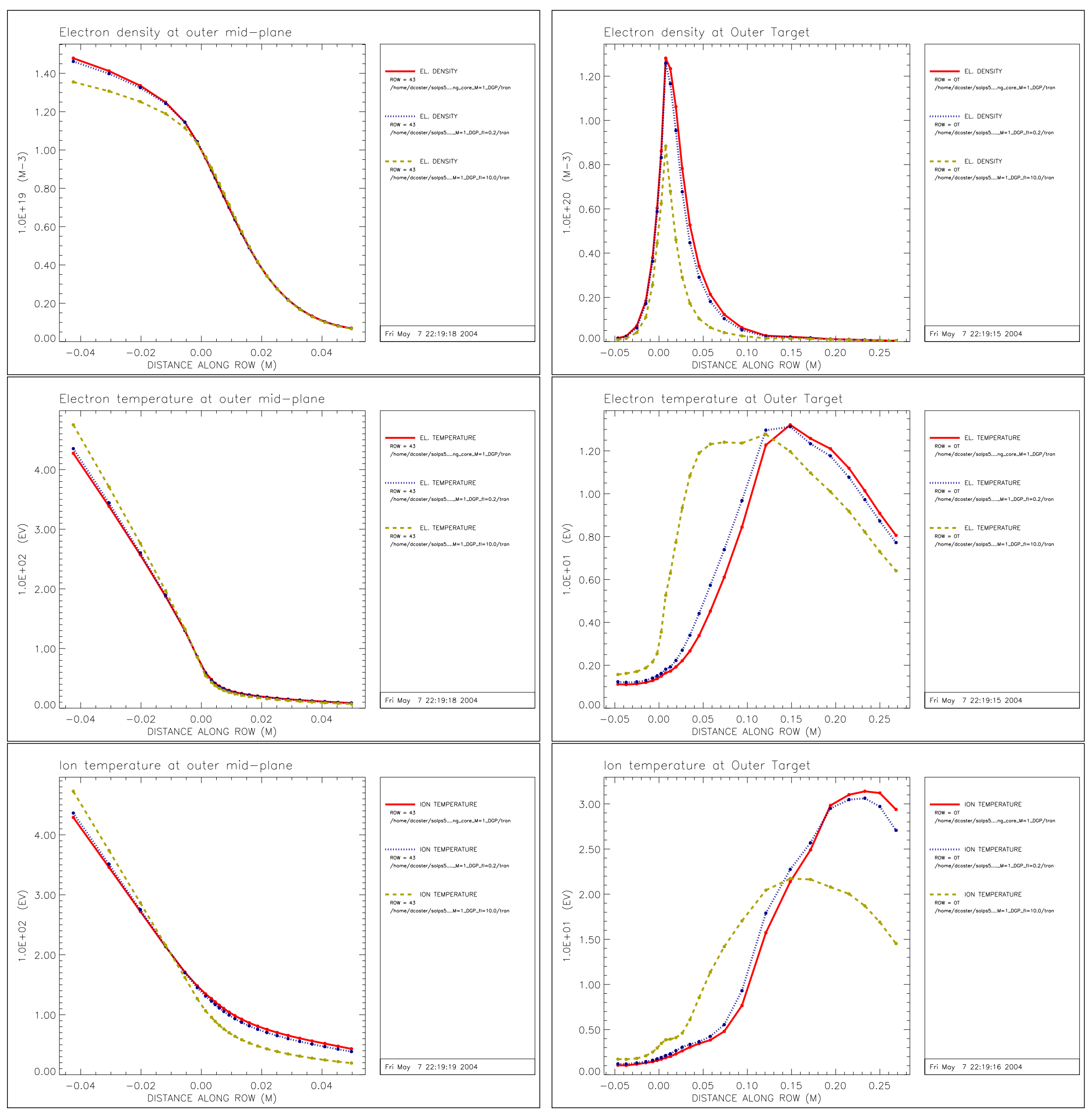

Figure 4: Outer midplane (left) and outer target (right) profiles of the electron density, electron temperature and ion temperature (top to bottom), each for SOLPS with kinetic neutrals (B2-Eirene) for a range of flux limiter values.

Observations

- the difference between the 0.15 and 0.2 cases are small
- the 10.0 case shows
  - a lower upstream SOL temperature due to the higher parallel ion energy losses
  - this in turn decreases the neutral penetration depth (because of the lower neutral energies arising from charge exchange)
  - which, in turn, lowers the electron density in the core region
  - and the core electron and ion temperatures to steepen
- at the targets, the temperature profiles have their maxima shifted towards the separatrix, the ion temperature at the target is lowered, as is the electron density
- the feature in the poloidal ion temperature also disappears, figure 5

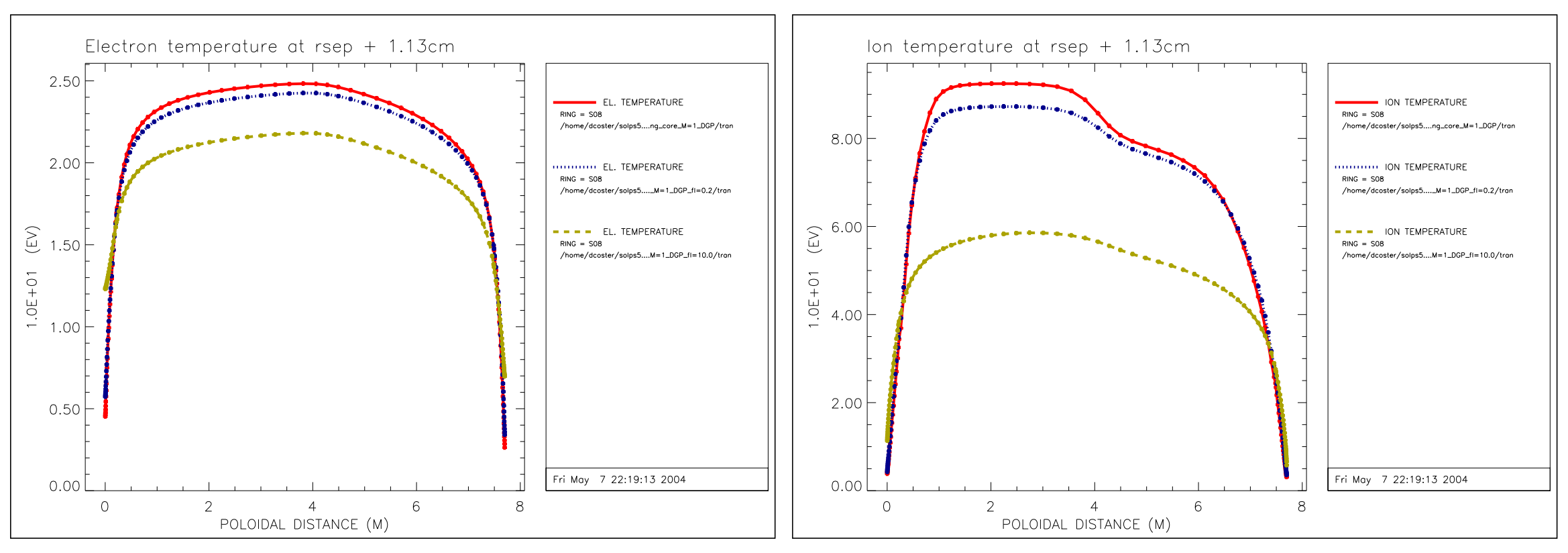

Figure 5: Poloidal profile of the electron and ion temperature, each for SOLPS with kinetic neutrals (B2-Eirene) for a range of flux limiter values.

Note

- what the "correct" value of the parallel flux limiters is, is not addressed by this comparison — the comparison does however point to the importance of the choice (particularly at lower densities)

Final version of the comparison

The final version of the pure hydrogen, no drift comparisons are shown in figures 6 and 7 for the 5×10^{18} and $1 \times 10^{19} m^{-3}$ cases, respectively.

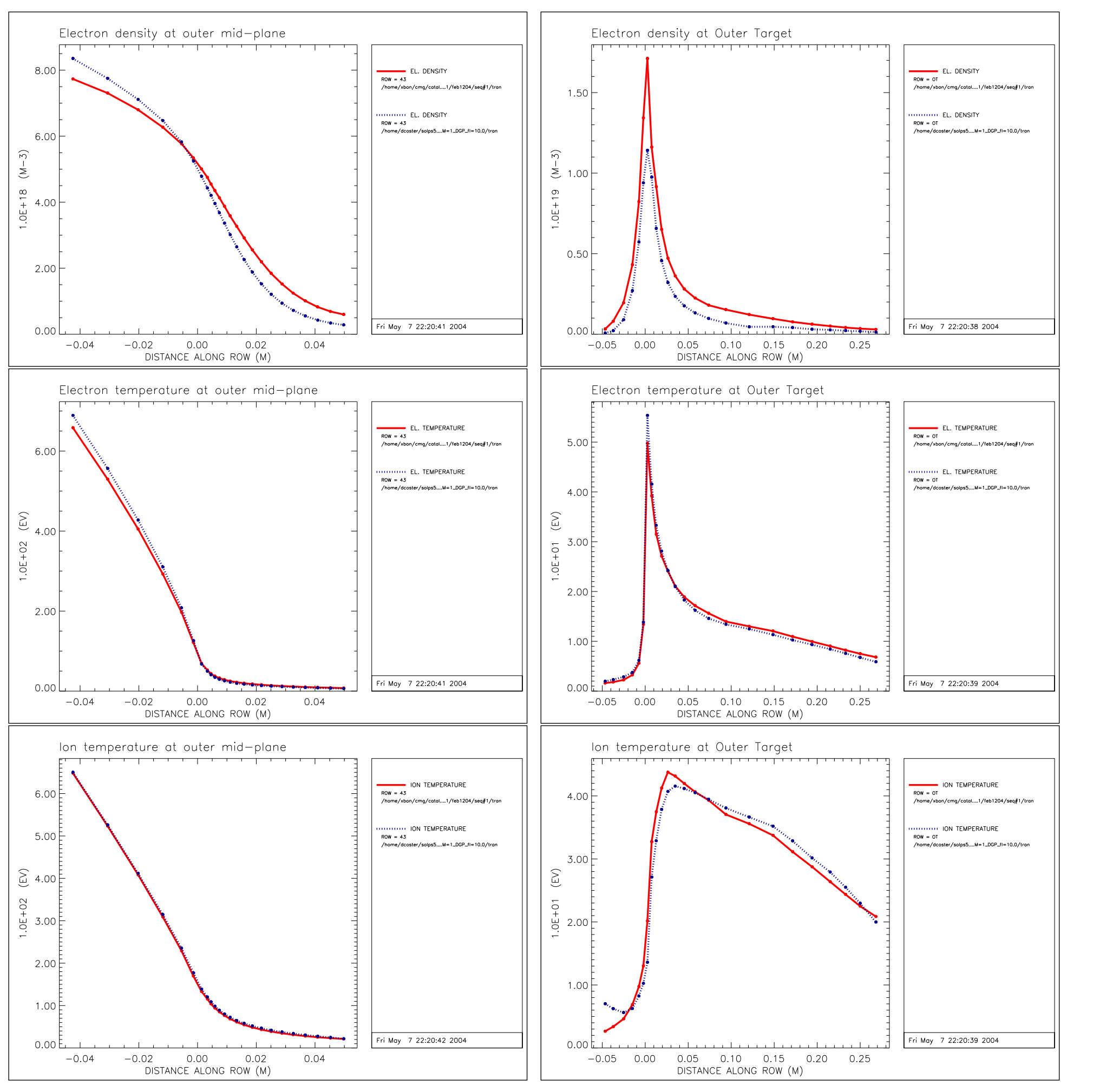

Figure 6: Outer midplane (left) and outer target (right) profiles of the electron density, electron temperature and ion temperature (top to bottom), each for EDGE2D-NIMBUS and SOLPS with kinetic neutrals (B2-Eirene), for the $5 \times 10^{18} m^{-3}$ separatrix density case.

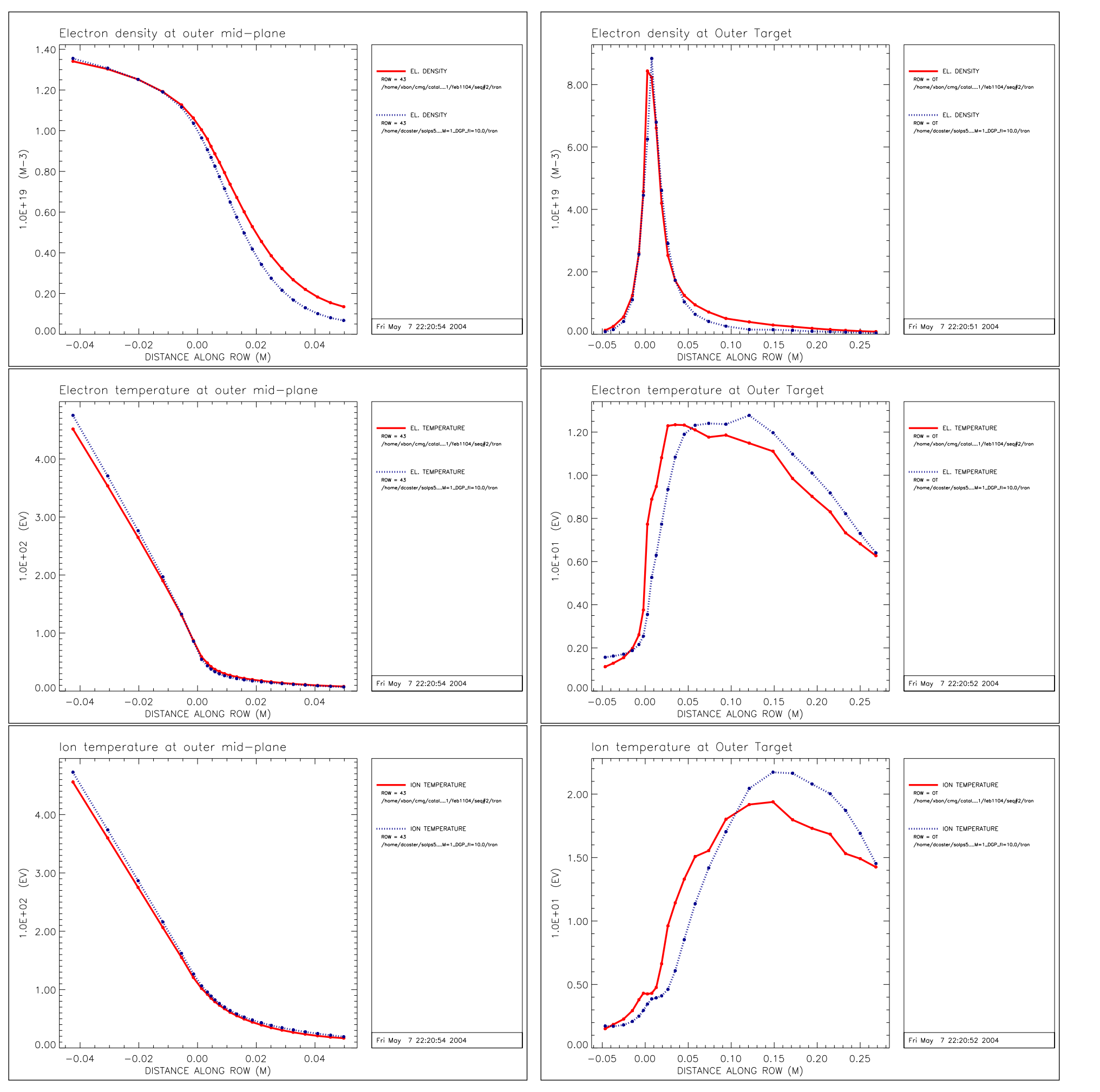

Figure 7: Outer midplane (left) and outer target (right) profiles of the electron density, electron temperature and ion temperature (top to bottom), each for EDGE2D-NIMBUS and SOLPS with kinetic neutrals (B2-Eirene), for the $1 \times 10^{19} m^{-3}$ separatrix density case.

The agreement between the two codes is now quite satisfactory.

At higher densities, figure 8, the agreement is a little worse, perhaps related to the average electron energy loss per ionization being $30.7eV$ for the EDGE2D-NIMBUS run, and 35.5 for the SOLPS run. To test that hypothesis, additional SOLPS runs were done where the energy per ionization event was decreased artificially (and uniformly independent of temperature and density), which are the additional curves in figure 8. The three have, respectively, $31.7eV$, $28.4eV$ and $25.7eV$ per ionization event electron energy loss.

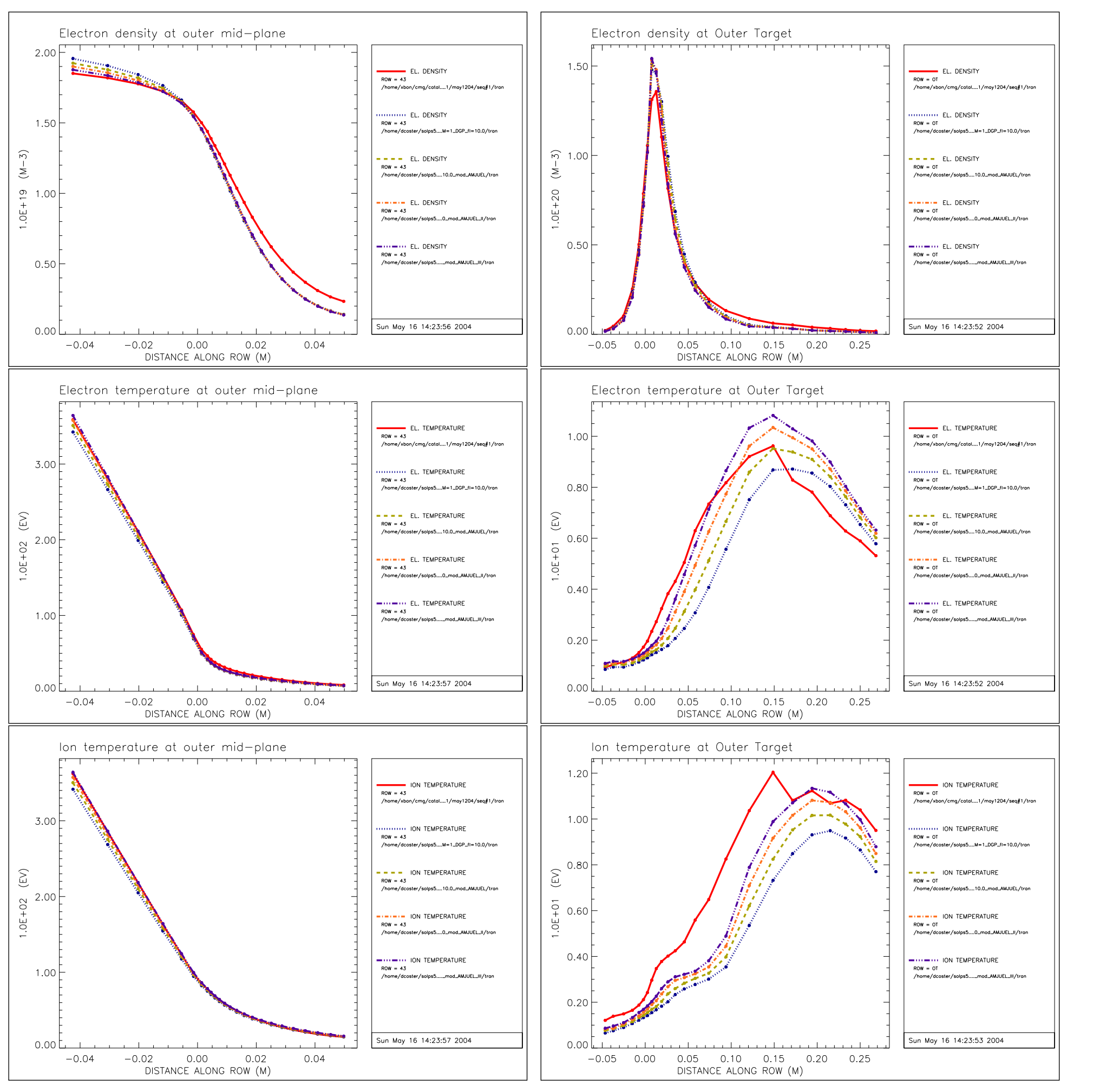

Figure 8: Outer midplane (left) and outer target (right) profiles of the electron density, electron temperature and ion temperature (top to bottom), each for EDGE2D-NIMBUS and SOLPS with kinetic neutrals (B2-Eirene), for the $1.5 \times 10^{19} m^{-3}$ separatrix density case. The first SOLPS case has the default energy per ionization event and the other three cases have successively reduced values.

Fluid neutrals

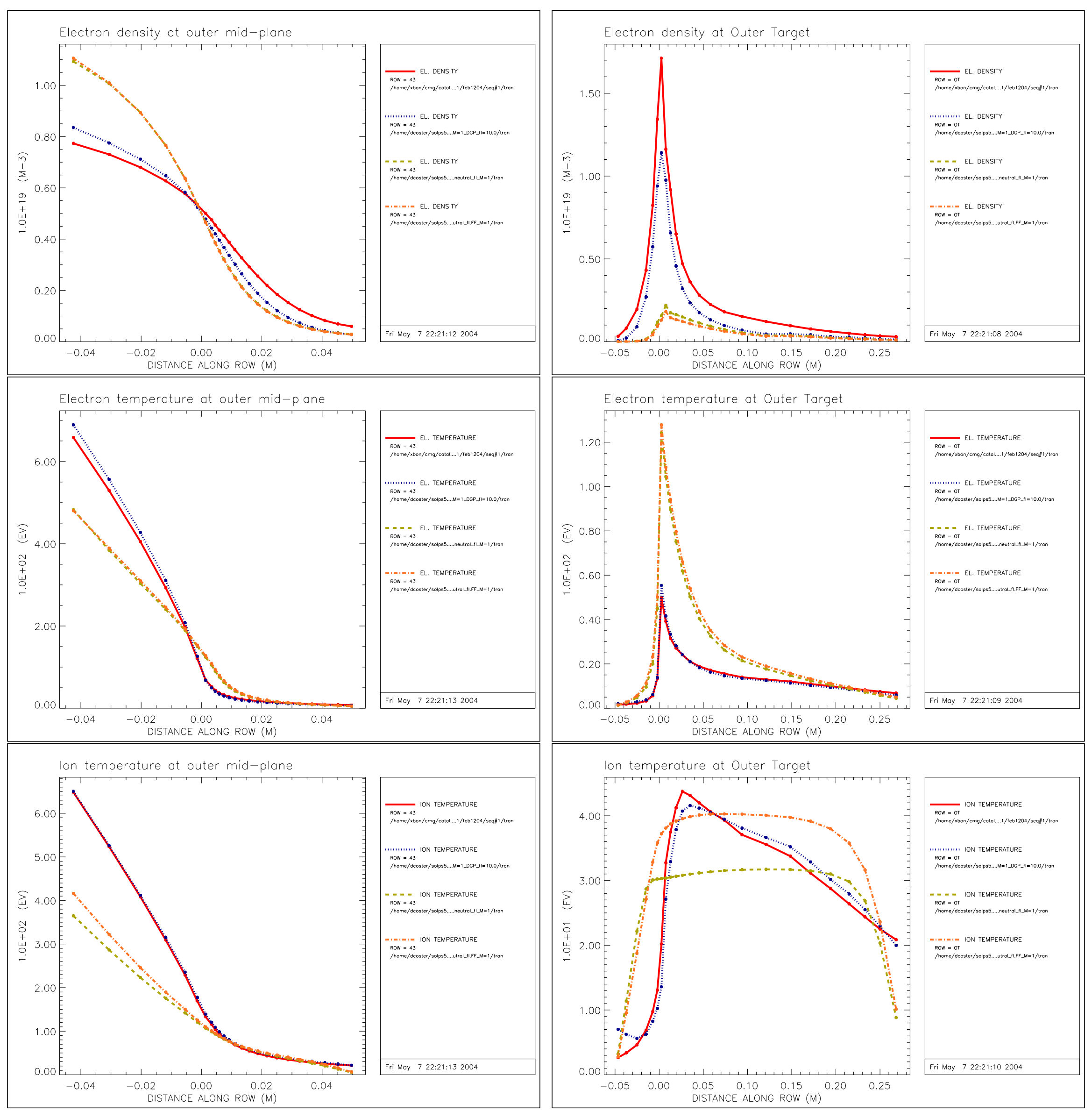

Figure 9: Outer midplane (left) and outer target (right) profiles of the electron density, electron temperature and ion temperature (top to bottom), each for EDGE2D-NIMBUS, SOLPS with kinetic neutrals (B2-Eirene) and with fluid neutrals (with and without first flight correction).

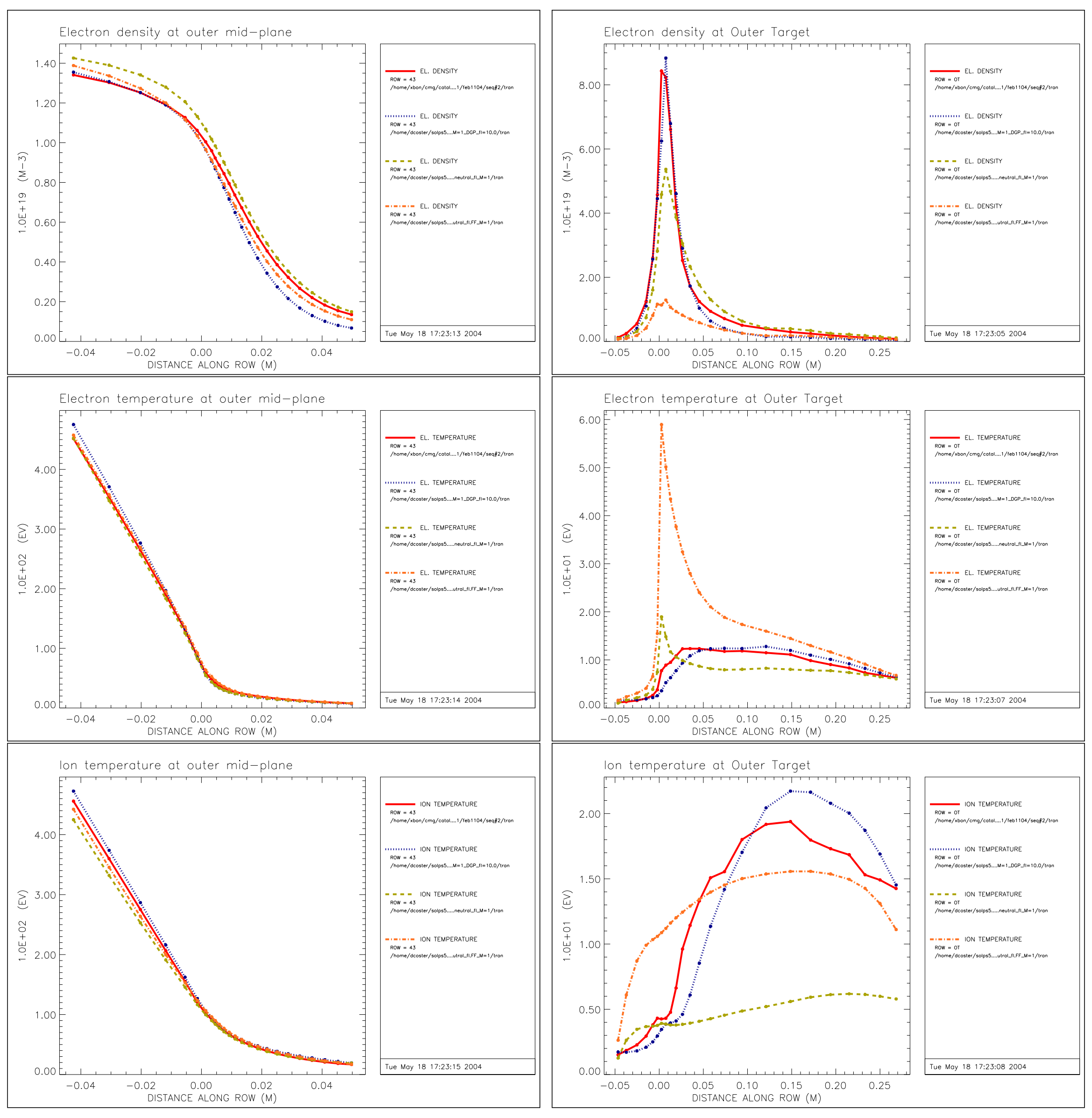

Figure 10: Outer midplane (left) and outer target (right) profiles of the electron density, electron temperature and ion temperature (top to bottom), each for EDGE2D-NIMBUS, SOLPS with kinetic neutrals (B2-Eirene) and with fluid neutrals (with and without first flight correction).

Other issues

In doing the comparisons, other differences were analysed, and found to play a relatively small role:

- EDGE2D uses a 9-pt stencil while B2 uses a 5-pt stencil
  - EDGE2D-NIMBUS runs were performed using a 5-pt stencil
  - only small differences
- the pumping models differed in the two codes
  - the "strength" of the pumps were varied by a factor of 3 in SOLPS runs
    - only small differences
- other boundary conditions were varied
  - *e.g.* decay length at the outer SOL boyndary
    - only small differences
- some of the neutral physics issues miggbt be addressed in the future by the possible development of EDGE2D-EIRENE

Observations:

- the study was strongly faciltated by having a common plotting framework
  - enabling the easy comparison of cases
- this was done using a JET specific framework which is not that portable
- MDSplus is already being used to store SOLPS output
  - want to use this for the others as well

Such code-code benchmarking can be a long drawn out process, but is important in validating the codes.

Drifts

The benchmarking of the cases with drifts has now started, and is concentrated on the open field line region (SOLPS switches off the drifts at $-3.5cm$, EDGE2D-NIMBUS at the separatrix).

Figures 11 and 12 show the results for 5×10^{18} and $1 \times 10^{19} m^{-3}$ with drifts in the forward (normal, ion grad B drift towards the X-point) and reverse magnetic field/plasma current cases.

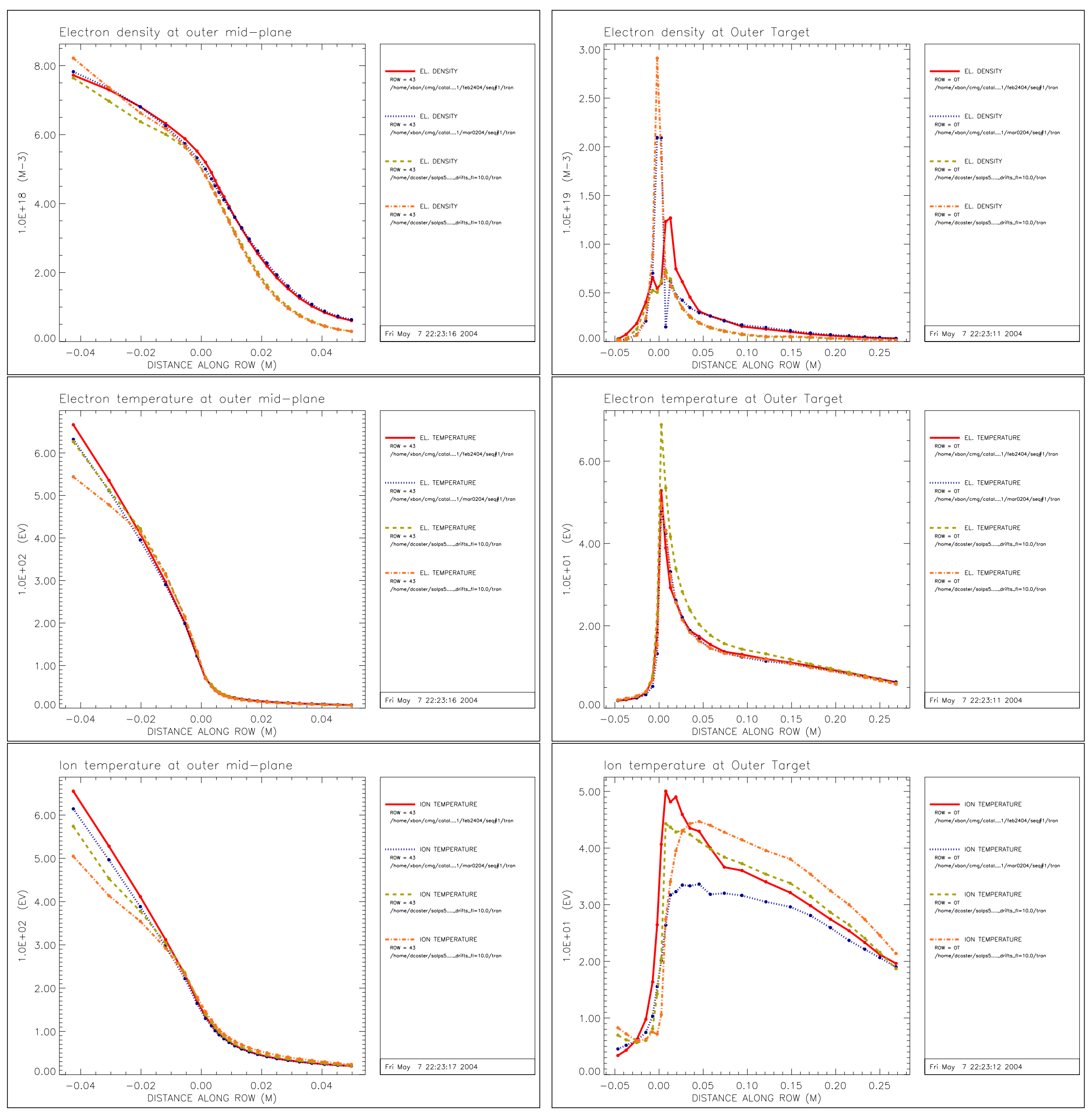

Figure 11: Outer midplane (left) and outer target (right) profiles of the electron density, electron temperature and ion temperature (top to bottom), each for EDGE2D-NIMBUS and SOLPS with kinetic neutrals (B2-Eirene), for forward and reversed field cases, for the $5 \times 10^{18} m^{-3}$ separatrix density case.

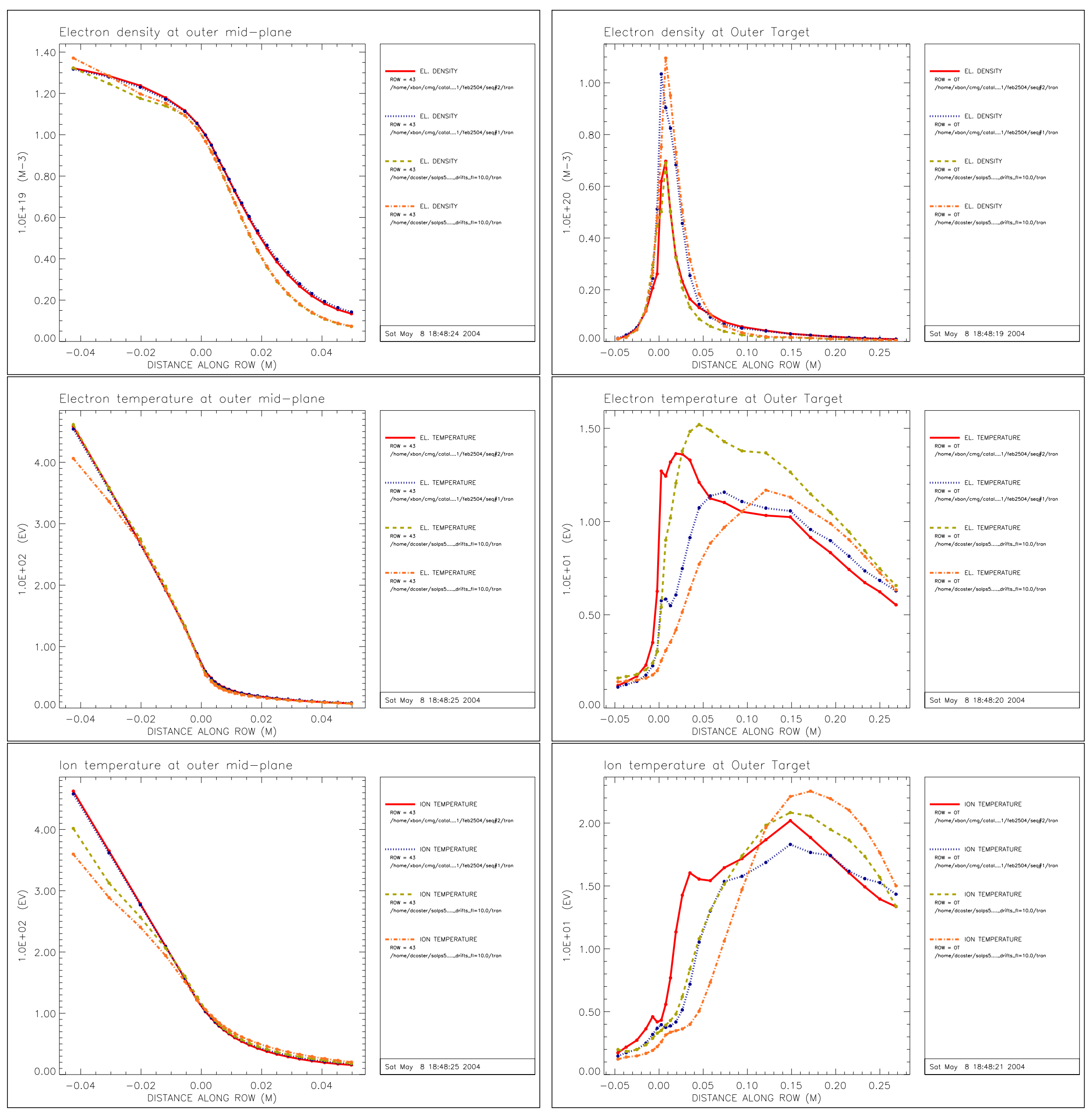

Figure 12: Outer midplane (left) and outer target (right) profiles of the electron density, electron temperature and ion temperature (top to bottom), each for EDGE2D-NIMBUS and SOLPS with kinetic neutrals (B2-Eirene), for forward and reversed field cases, for the $1 \times 10^{19} m^{-3}$ separatrix density case.

While the agreement is not quite as good as for the cases without drifts, the relatively good agreement is encouraging. Both codes, for example, show similar patters in the poloidal distribution of the parallel velocity (figure 13), a quantity quite sensitive to the direction of the drifts.

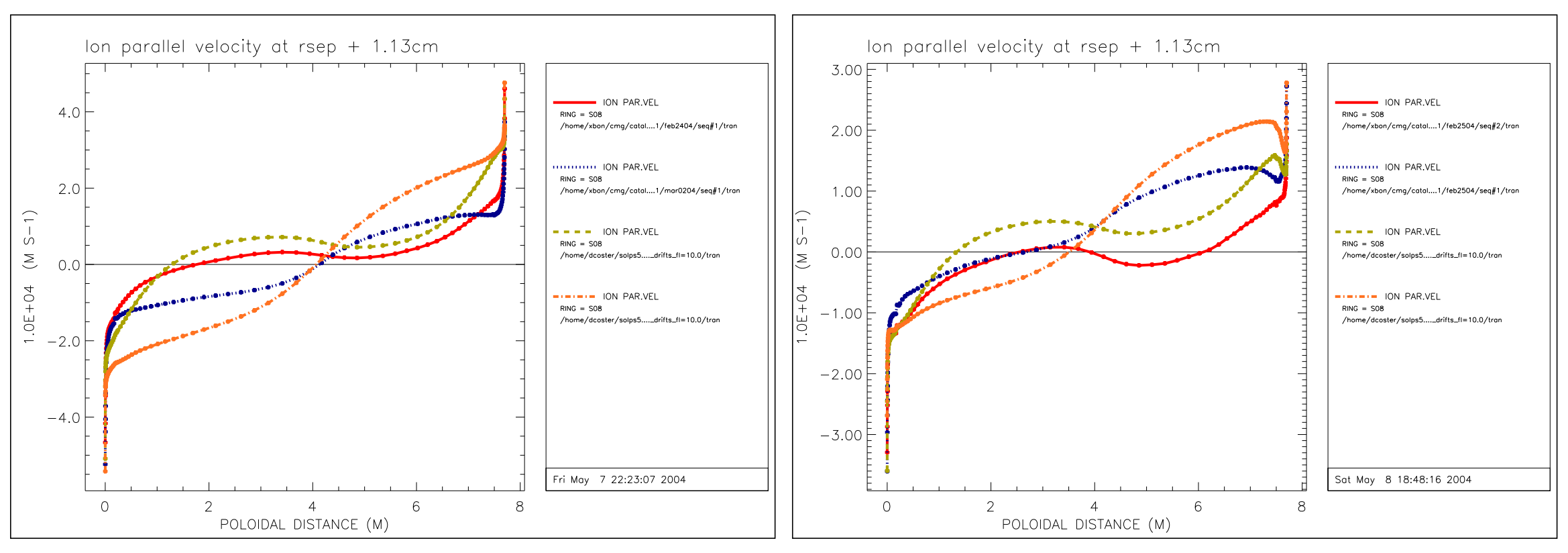

Figure 13: Poloidal profile of the parallel velocity, for the 5×10^{18} and $1 \times 10^{19} m^{-3}$ separatrix density case, each for EDGE2D-NIMBUS and SOLPS with kinetic neutrals (B2-Eirene), for forward and reversed field cases.

Summary, Conclusions, and Future Plans

- initial large differences in the simulations from EDGE2D-NIMBUS and SOLPS (B2-EIRENE) were tracked down to differing choices in
  - parallel flux limiters
  - target Mach boundary condition
  - distribution of the gas puff used to control the separatrix density
- once these effects were corrected for, the agreement for the pure deuterium, no drifts cases were very satisfactory
- agreement for the cases with drifts is not quite so good
  - will be pursued
- once this is completed (or perhaps in parallel), the studz will be extended to
  - with impurities, and no drifts
  - with imputities and drifts
  - and perhaps to include a third code, UEDGE

- the strong effect of the ion parallel heat flux limiter points to the importance of doing more kinetic work in this area
- as well as trying to verify the choice of flux limiter by careful analysis of experiments where both good upstream and downstream data are available
- in the meantime, a sensitivity analysis should be performed for predictive runs to test the role the flux limiters might play in the particular scenario

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