Fluid Codes and Heavy Impurities -ADAS superstates implementation in the suite of codes at JET-

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- Superstates implemented in 1-D transport code SANCO
- Preliminary tests of Ni bundled in 12 superstates

Impurity Transport Codes

Standard treatment: solve the fluid equations for all Z_I ionic stages of each impurity of charge Z_I (ion stage model). Sinks and sources are provided by ionisation and recombination to and from neighbouring ionised states. These are provided by ADAS/adf11. Each equation evolves a single ionic population.

For each impurity: number of equations = Z_I and the population of equation *k* has charge *k*.

Superstates treatment: solve a number of equations, each representing a population consisting of a 'bundle' of ionised states (i.e. a 'superstate').

The undelying model of the superstates' description is that the ions bundled in each superstate are assumed to be in coronal equilibrium between each other.

Number of equations < Z_I and the population of equation *k*, representing a 'bundle' of ions, has a charge which varies with the local T_e: where T_e is lower, the population *k* is weighted towards the lower Z in the bundle *k*.

Price to pay: Z, Z^2 and Ionization potential depend on (T_e, n_e)

Implementing and testing superstates in fluid transport codes

Superstates are useful/necessary for heavy impurities (high Z):

this treatment cuts down the number of equations, and makes the numerical techniques more stable when the densities are very low;

Transport Codes: SANCO/JETTO, EDGE2D (+NIMBUS/EIRENE), COCONUT

The fluid transport codes have to be able to run both with 'fully stage-resolved' impurities (light impurities, such as C or Ne) and with 'bundled' impurities.
Also be backward compatible to recover old cases (and for comparison and testing).

This task has already been completed for the 1-D core transport: SANCO/JETTO.

SANCO/JETTO can now also run with Z ≠ number of equations.

The bundling scheme must be decided before the simulation and the appropriate ADAS datasets must exist. All the detailed information on the bundling scheme is through the ADAS/adf11 files accessed.

The program to generate the 'bundled adf11' data from the adf11 data will be released by Hugh: it will be the modeller's responsibility to generate their own bundling scheme for their own simulations

The data have to be generated ad-hoc for each bundling scheme for each impurity.

Work to bring EDGE2D and the combined code COCONUT to the same position as SANCO is under way and should be completed and tested in the next few weeks/months.

How to bundle an impurity?

- Neutral (uncharged, MonteCarlo treatment)must be kept separate from other ions

- For EIRENE (MC), the H-like ions should be kept separate

- 'natural bundling': states whose ionisation potential is close enough are bundled together: H. Summers has generated two ADAS/adf11 'natural' bundled sets of files for Ar and Ni and they are being tested by Xavier Bonnin (Ar) and myself (Ni). Natural bundling data for W will be released soon(-ish?).

- Other bundling possibilities … depending on ..?

  T_e, n_e, ∇T_e, transport barriers, .. (short-term)

  edge/core regions, time-varying bundling (long-term)

High Z (Kr, Xe, W)

The bundled treatment is a new development and gaining experience with bundled Ar and Ni and then higher Z elements must be part of the process which will lead to model W.

It is important to validate the adf11 data against the available experimental data, and then generate sets of bundled data.

This is all new territory and a figure of merit can only be set by ‘iteration’

In the following I’ll show preliminary test cases (Ni)

First SANCO (1-D) tests with Ni

- 2 impurities: C (Z=6, unbundled) + Ni (Z=28, bundled and not)
- Ni bundled into 12 ‘natural’ superstates

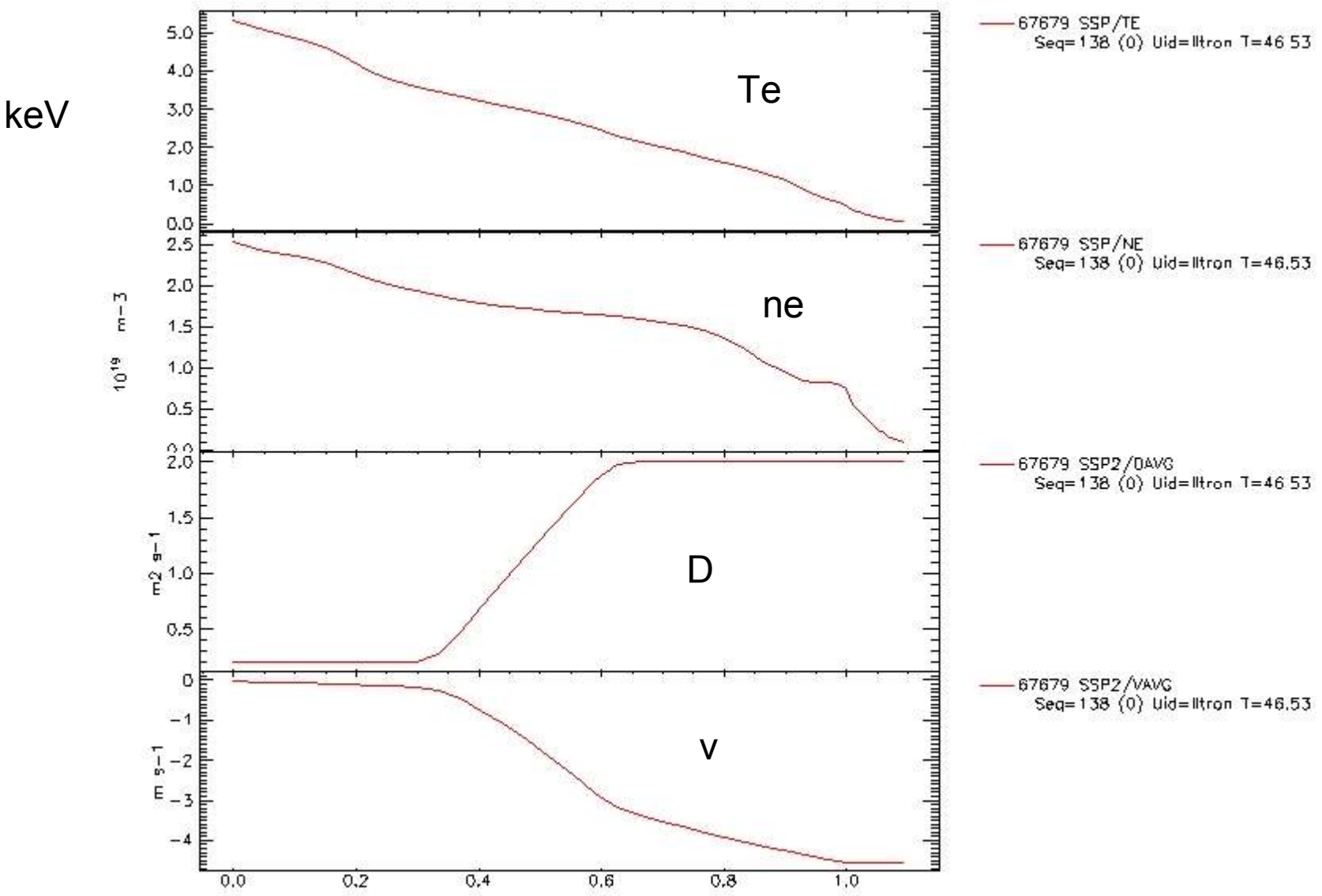
bundled	unbundled
1	1
2	2-3-4-5-6-7-8
3	9
4	10
5	11-12-13-14-15-16
6	17
7	18
8	19-20-21-22-23-24
9	25
10	26
11	27
12	28

First SANCO (1-D) simulation tests with Ni

- NO CX
- Calculation of the extra electron cooling rate, arising from the departure from coronal equilibrium of the ion states

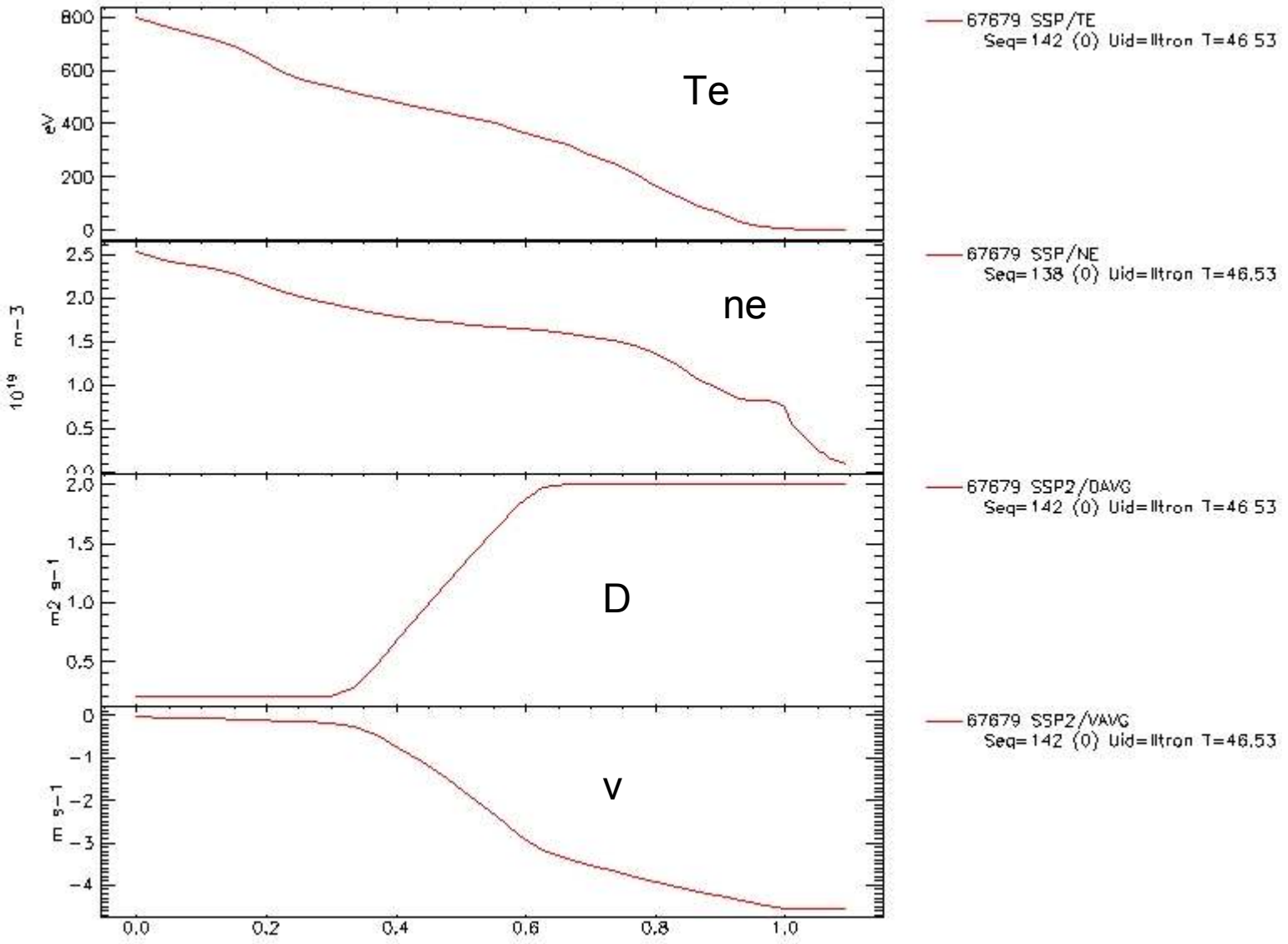
$$\propto S_Z n_Z - R_{Z+1} n_{Z+1}$$

Case 1

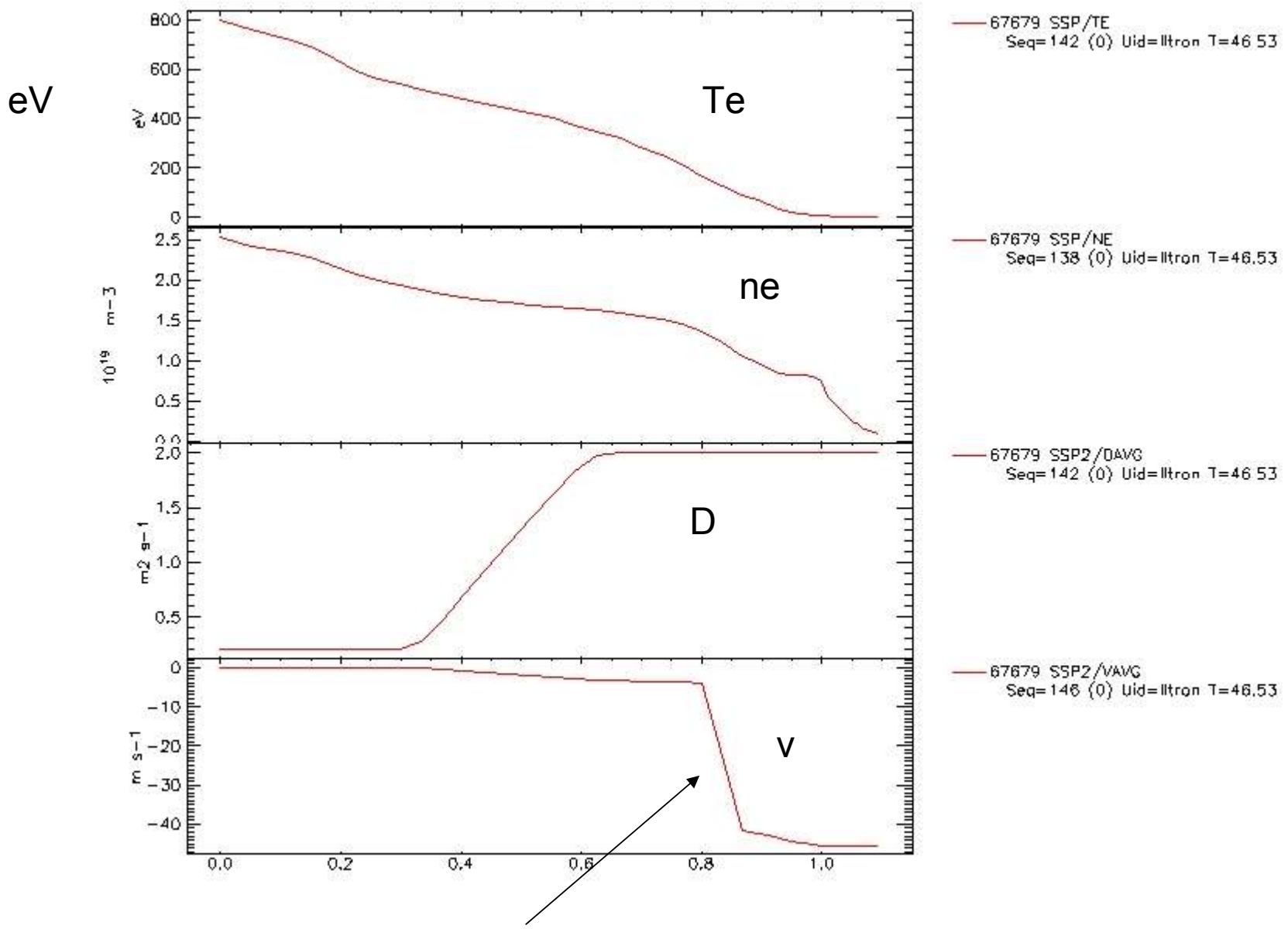

keV
Te
ne
D
v
10^19 m-3
m2 s-1
m s-1
67679 SSP/TE
Seq=138 (0) Uid=lltron T=46 53
67679 SSP/NE
Seq=138 (0) Uid=lltron T=46.53
67679 SSP2/DAVG
Seq=138 (0) Uid=lltron T=46 53
67679 SSP2/VAVG
Seq=138 (0) Uid=lltron T=46.53
Normalised minor radius

Case 2:
lower Te

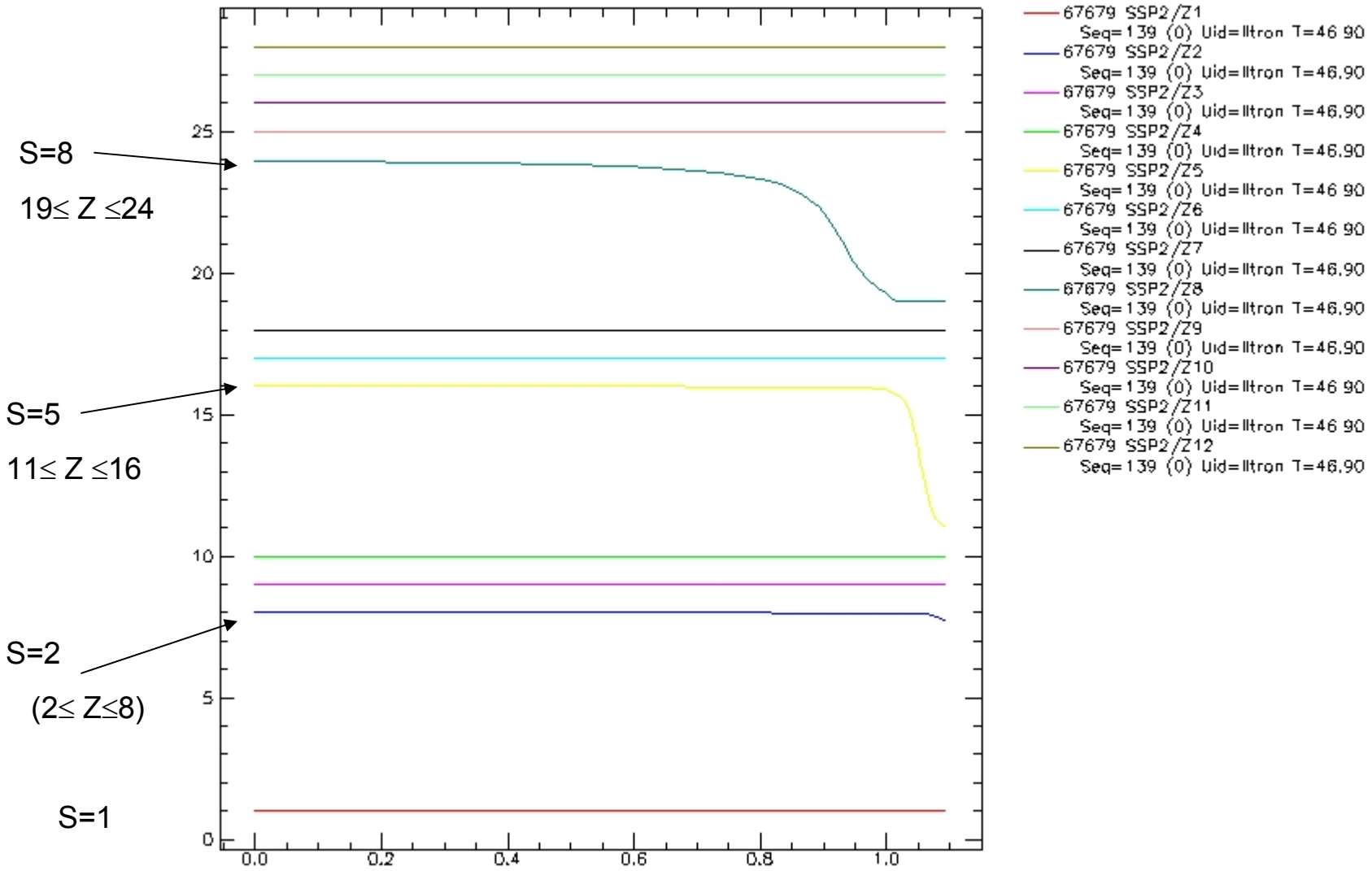
eV



Case 3: low Te and ‘transport barrier’

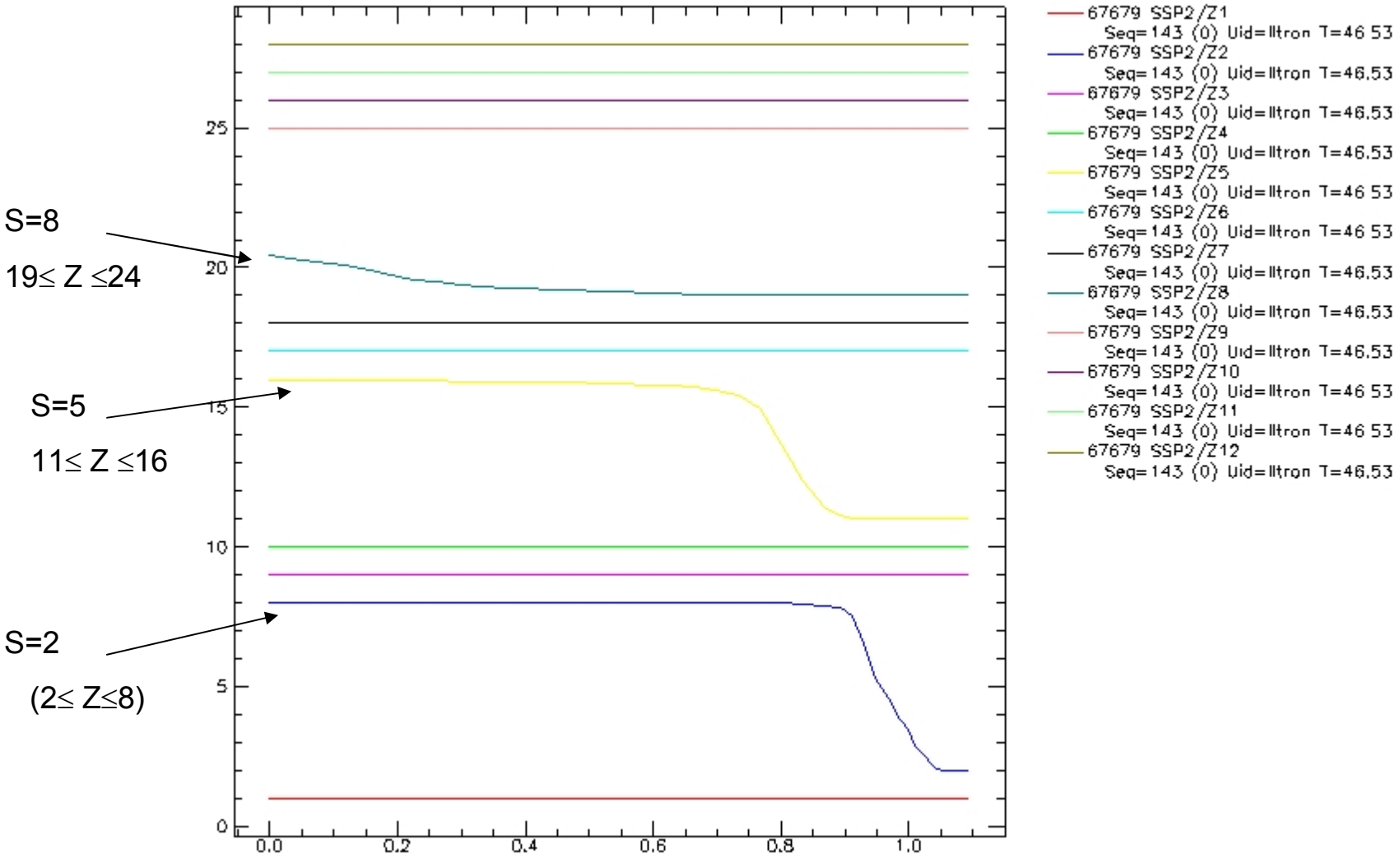


Case 1: Radial profiles of Z for bundled Ni



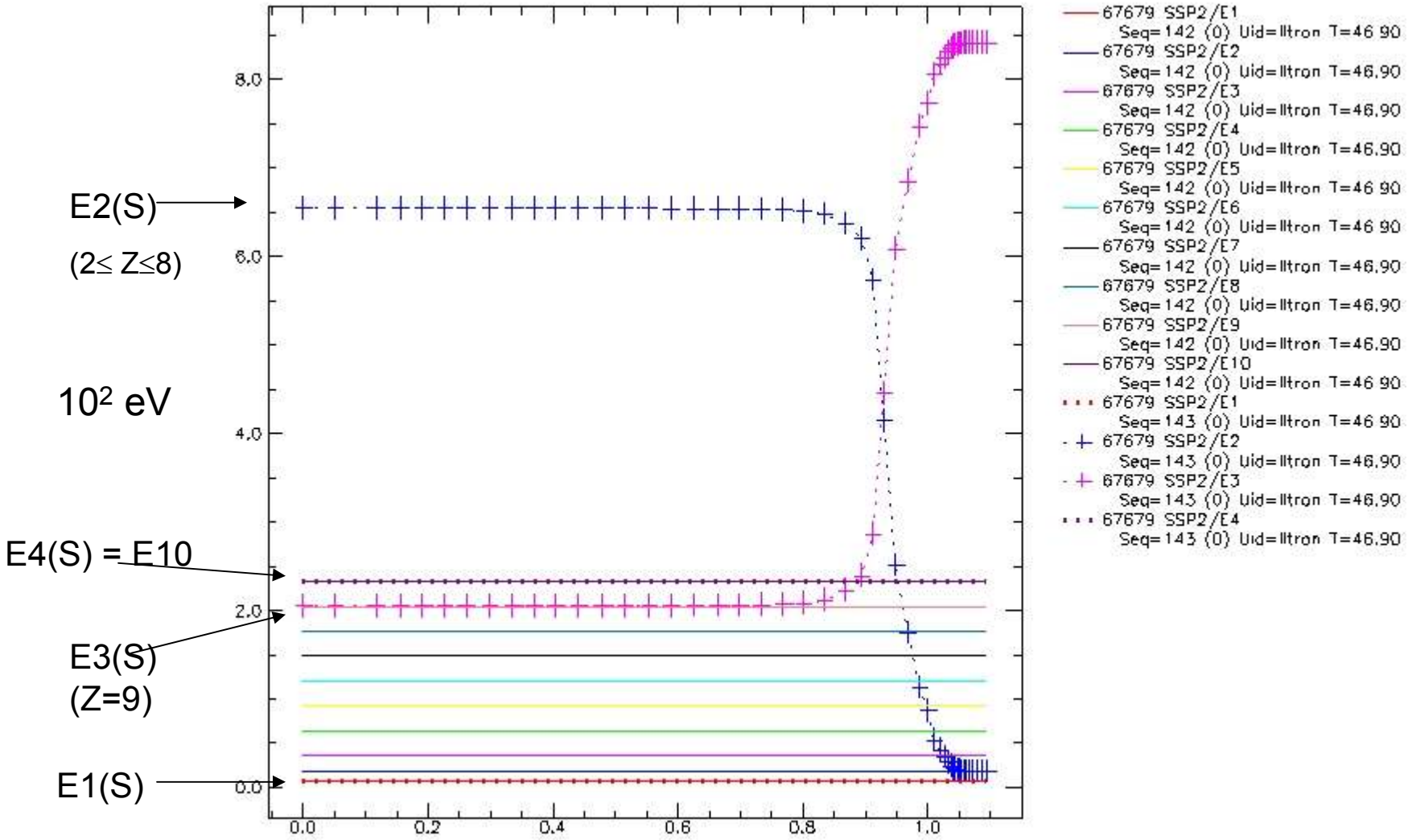
Normalised minor radius

Cases 2 and 3: lower Te - Z Radial profiles



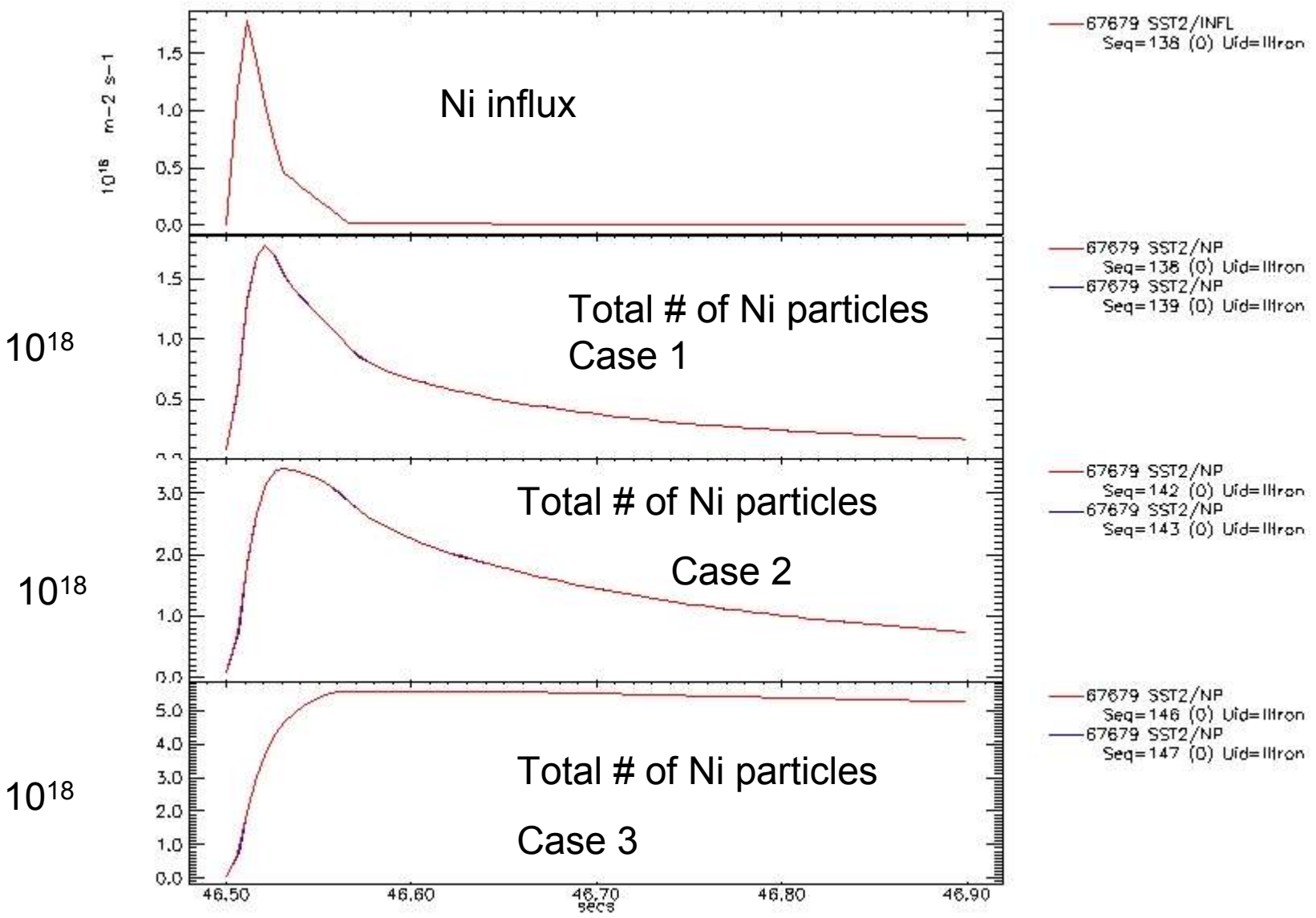
Normalised minor radius

Case 2: ionisation potentials



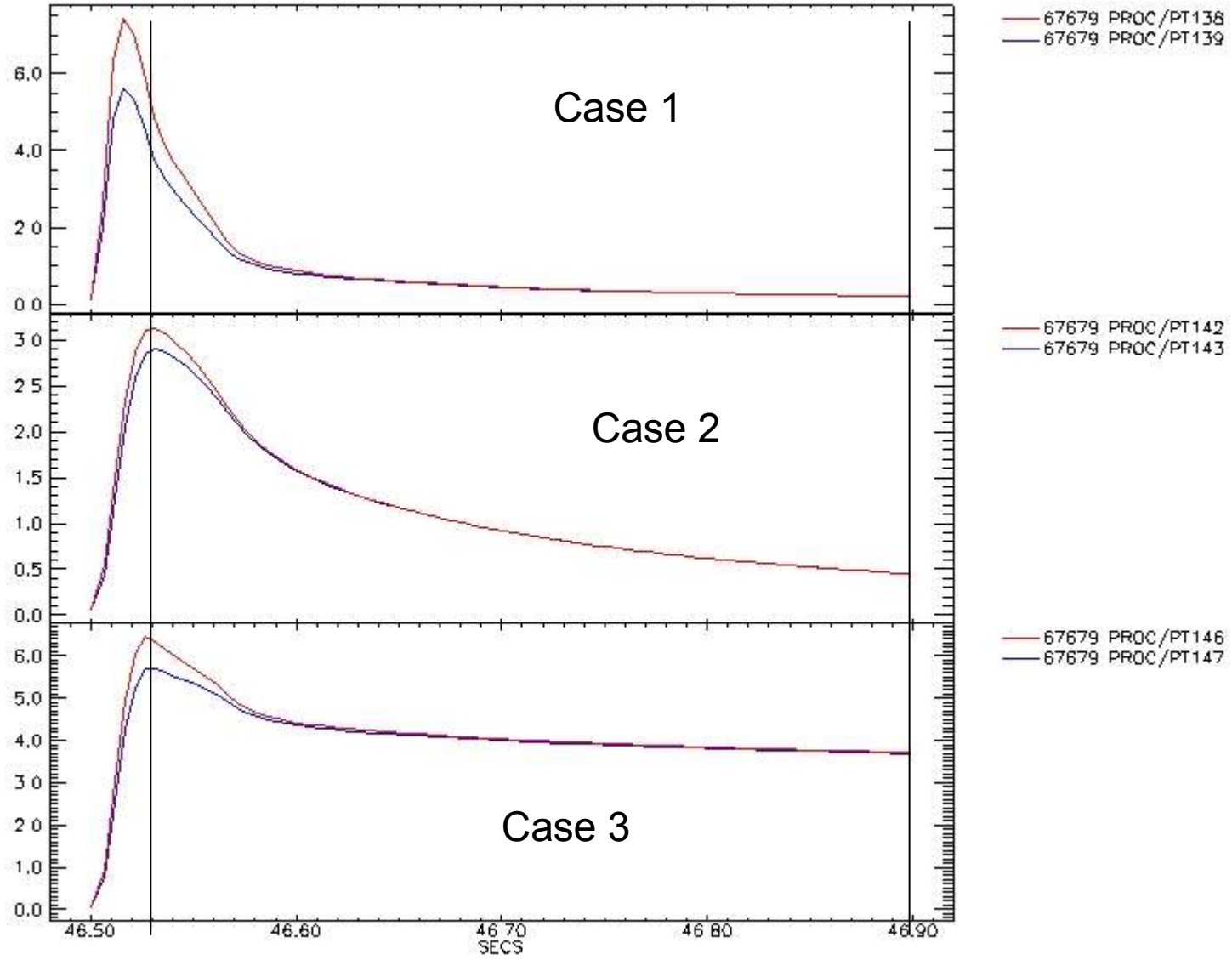
Normalised minor radius

Ni Time history



Time history - Total Power. Bundled (blue) and unbundled (red)

10^5 W

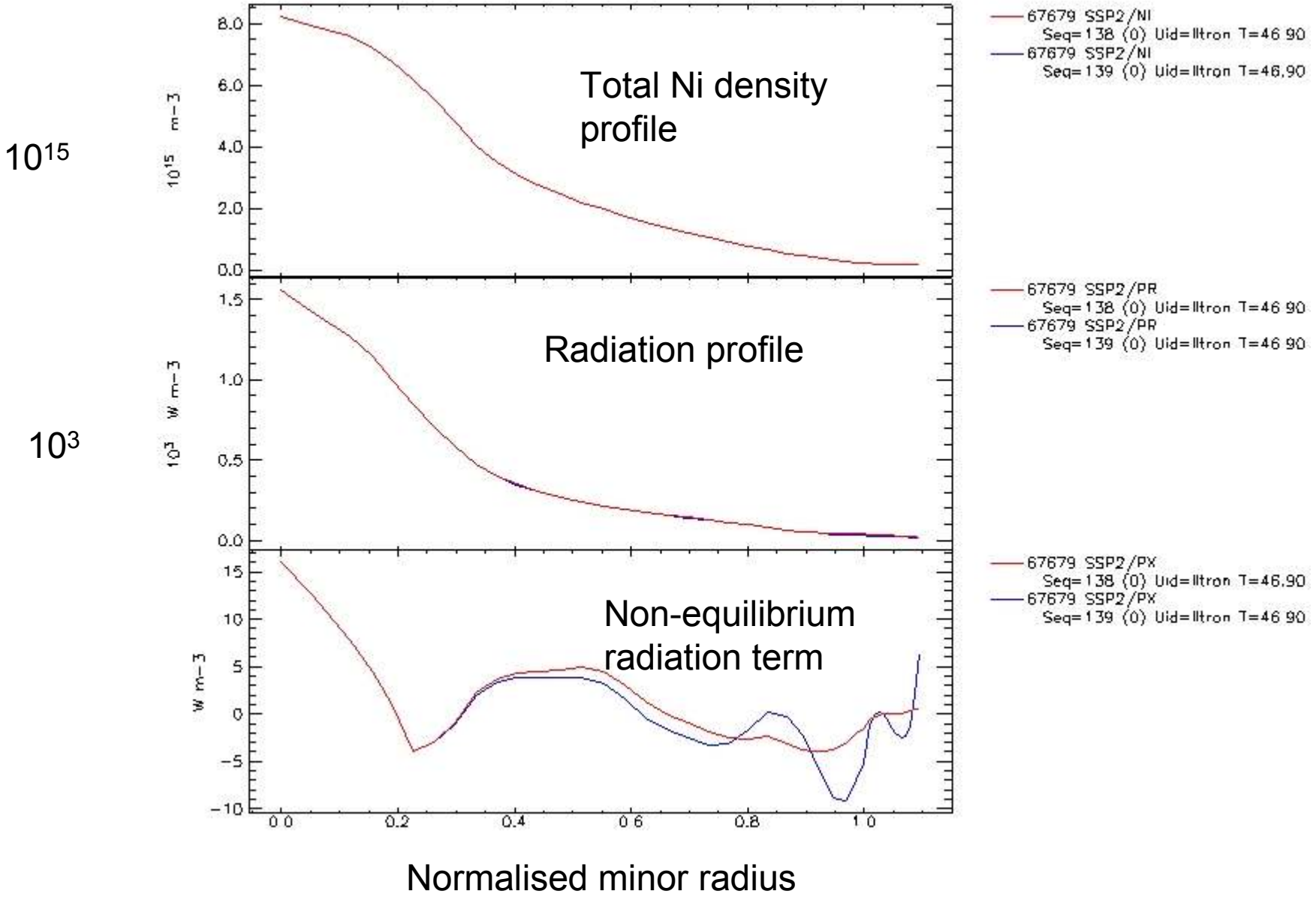


10^6 W

10^6 W

time

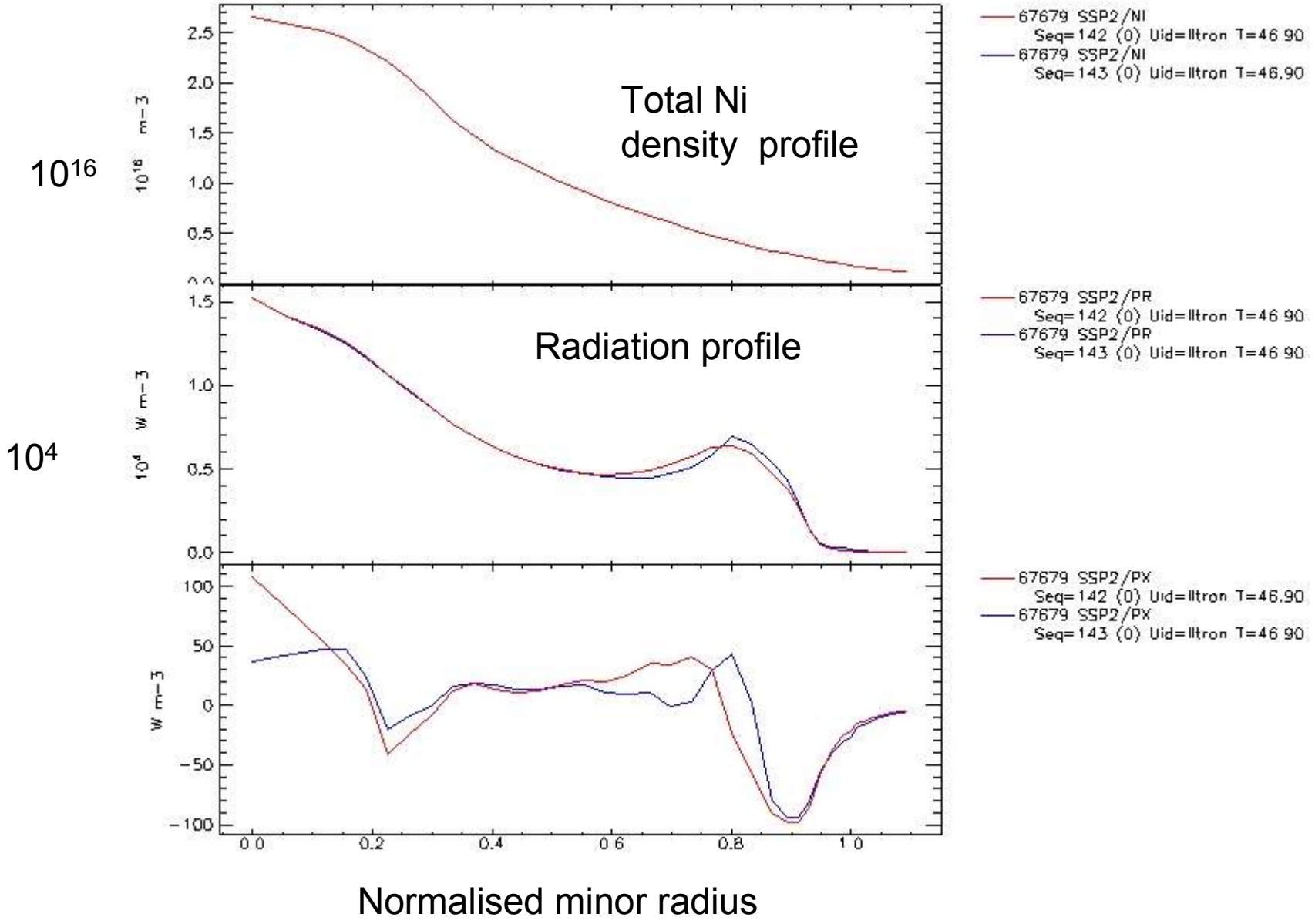
Case 1: bundled (blue) & unbundled (red) @ t=46.9



10^{15}

10^{3}

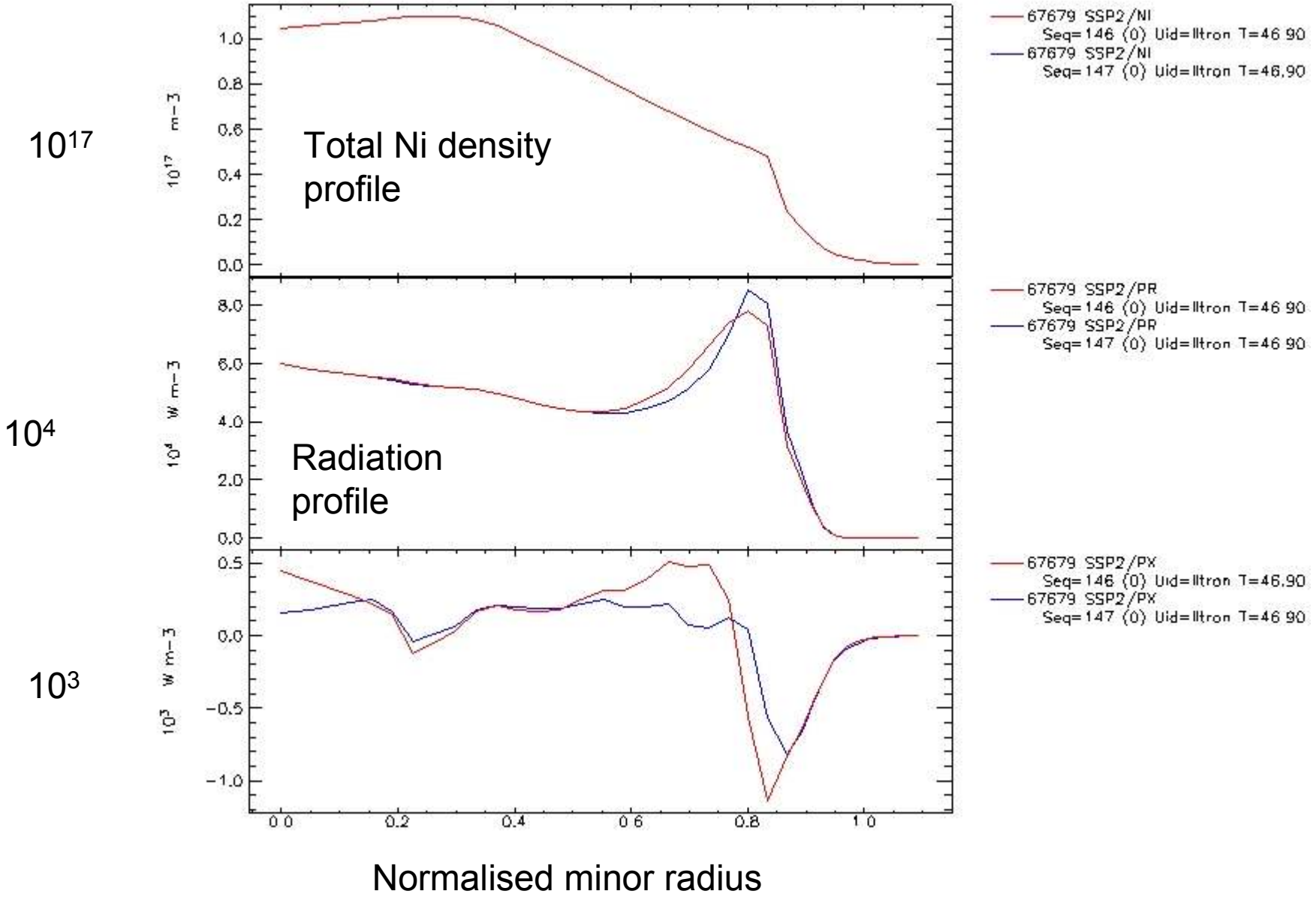
Case 2: bundled (blue) & unbundled (red) @ t=46.9



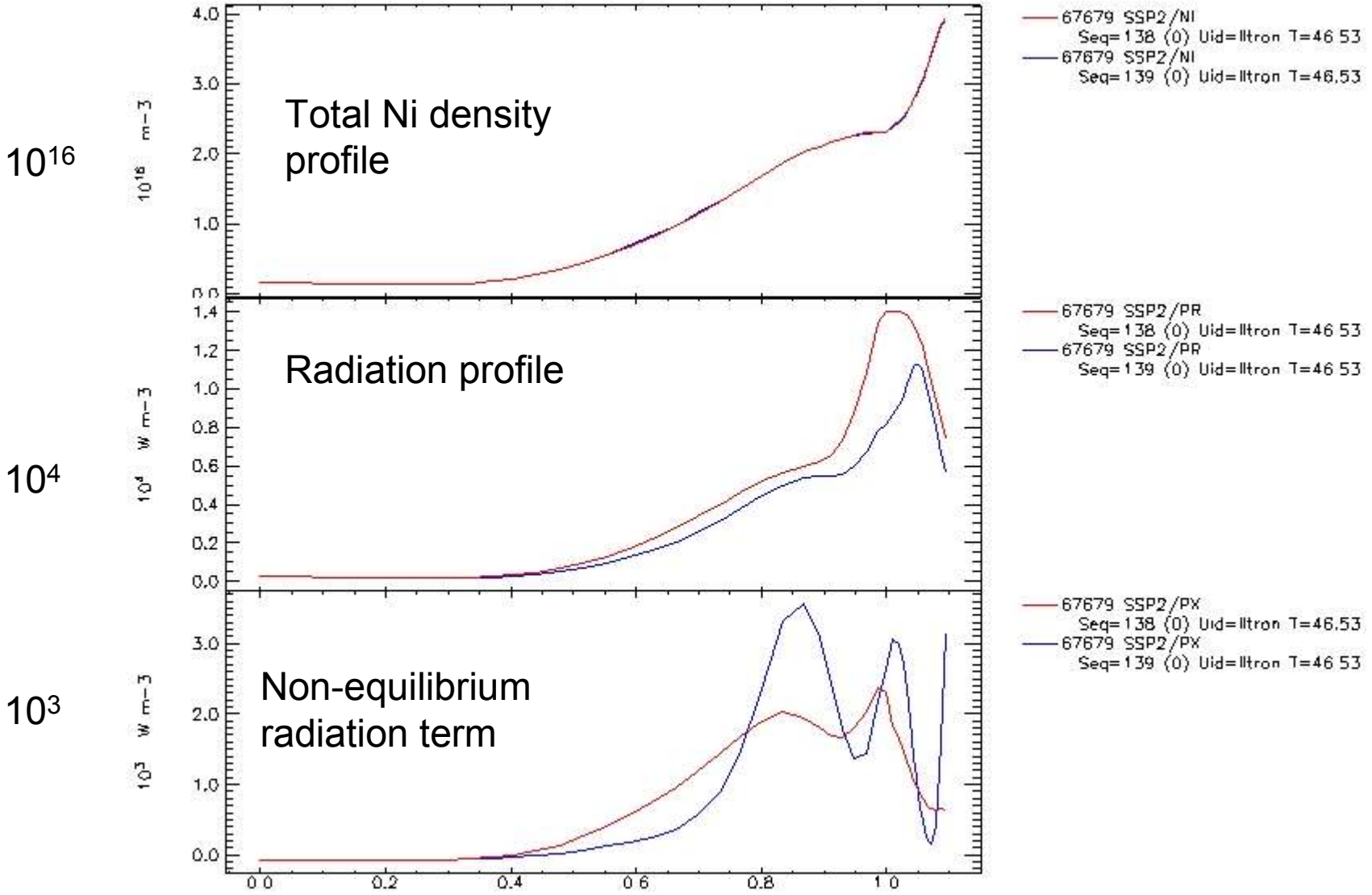
10^{16}

10^{4}

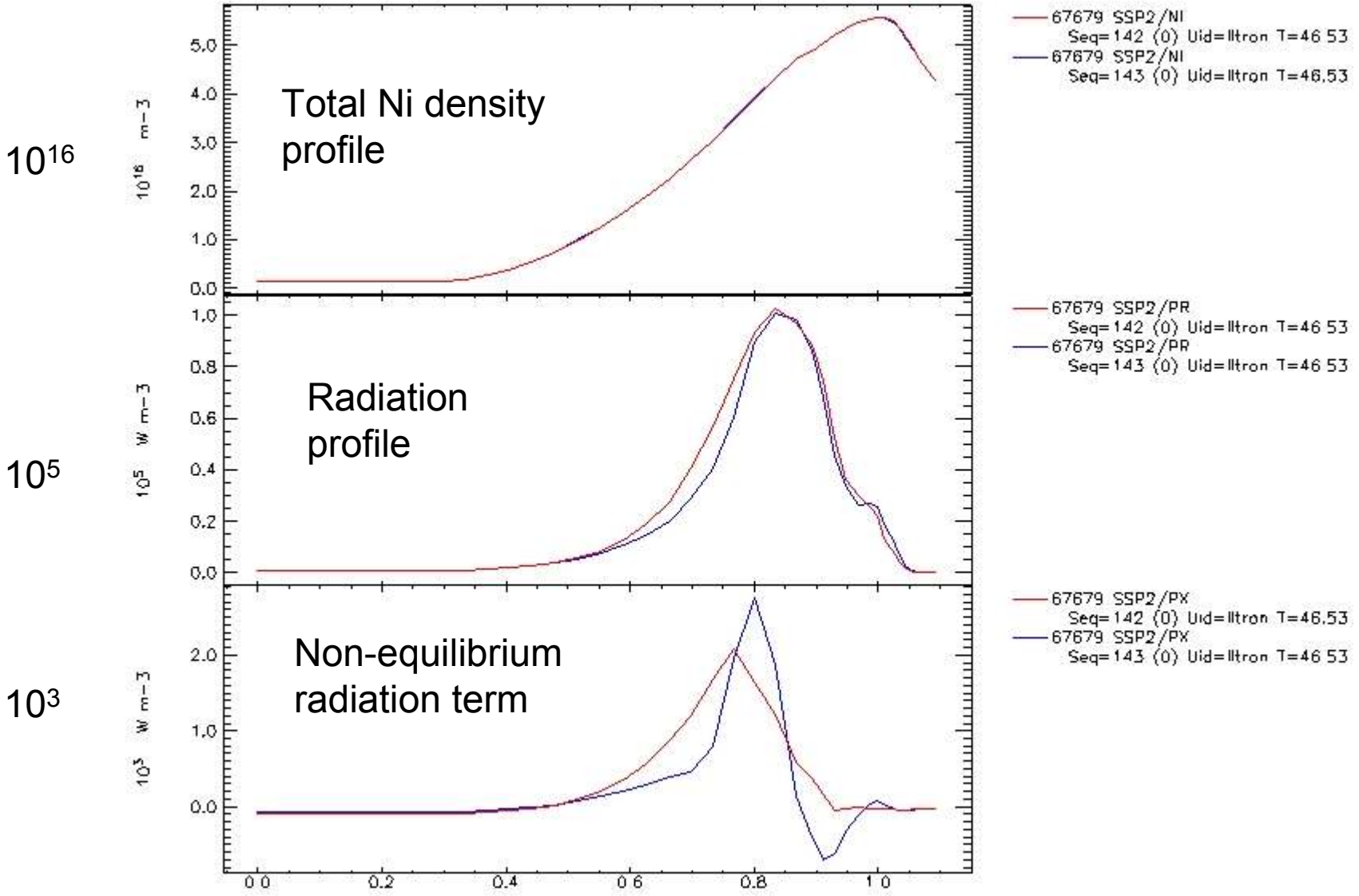
Case 3: bundled (blue) & unbundled (red) @ t = 46.9



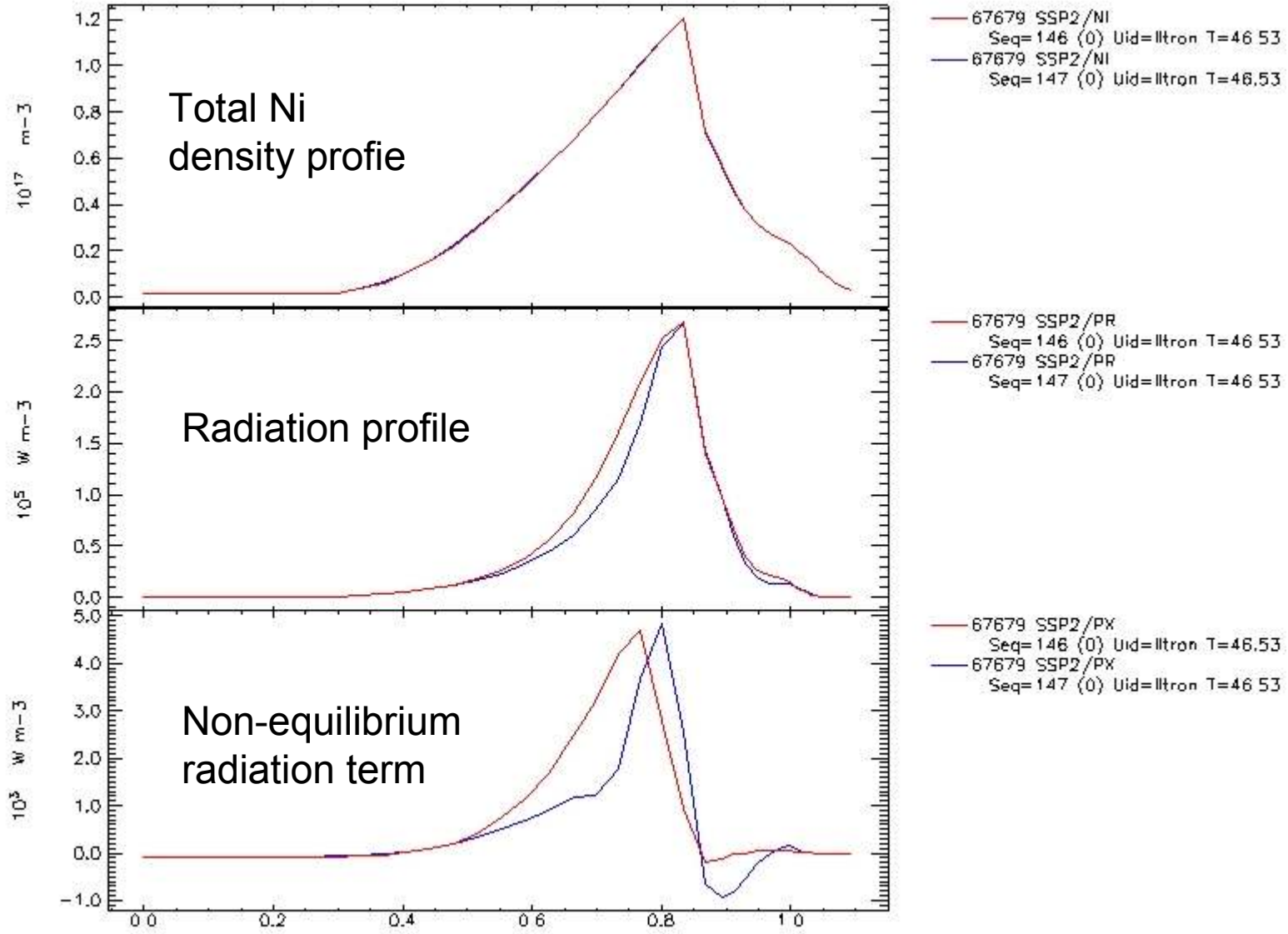
Case 1 @ t=46.53 Unbundled (red) & bundled (blue)



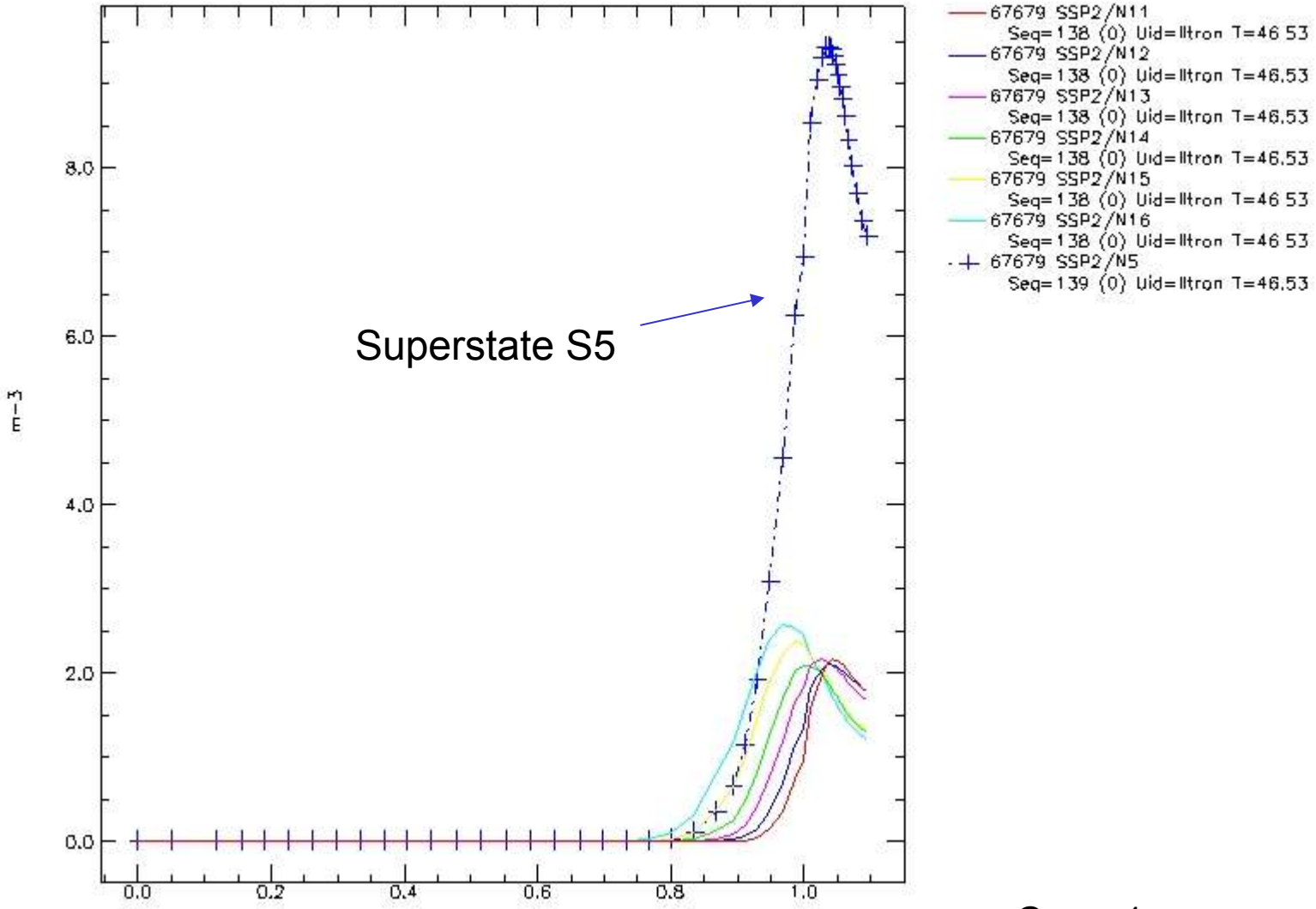
Case 2 @ t=46.53 unbundled (red) & bundled (blue)



Case 3 @ t=46.53 unbundled (red) & bundled (blue)



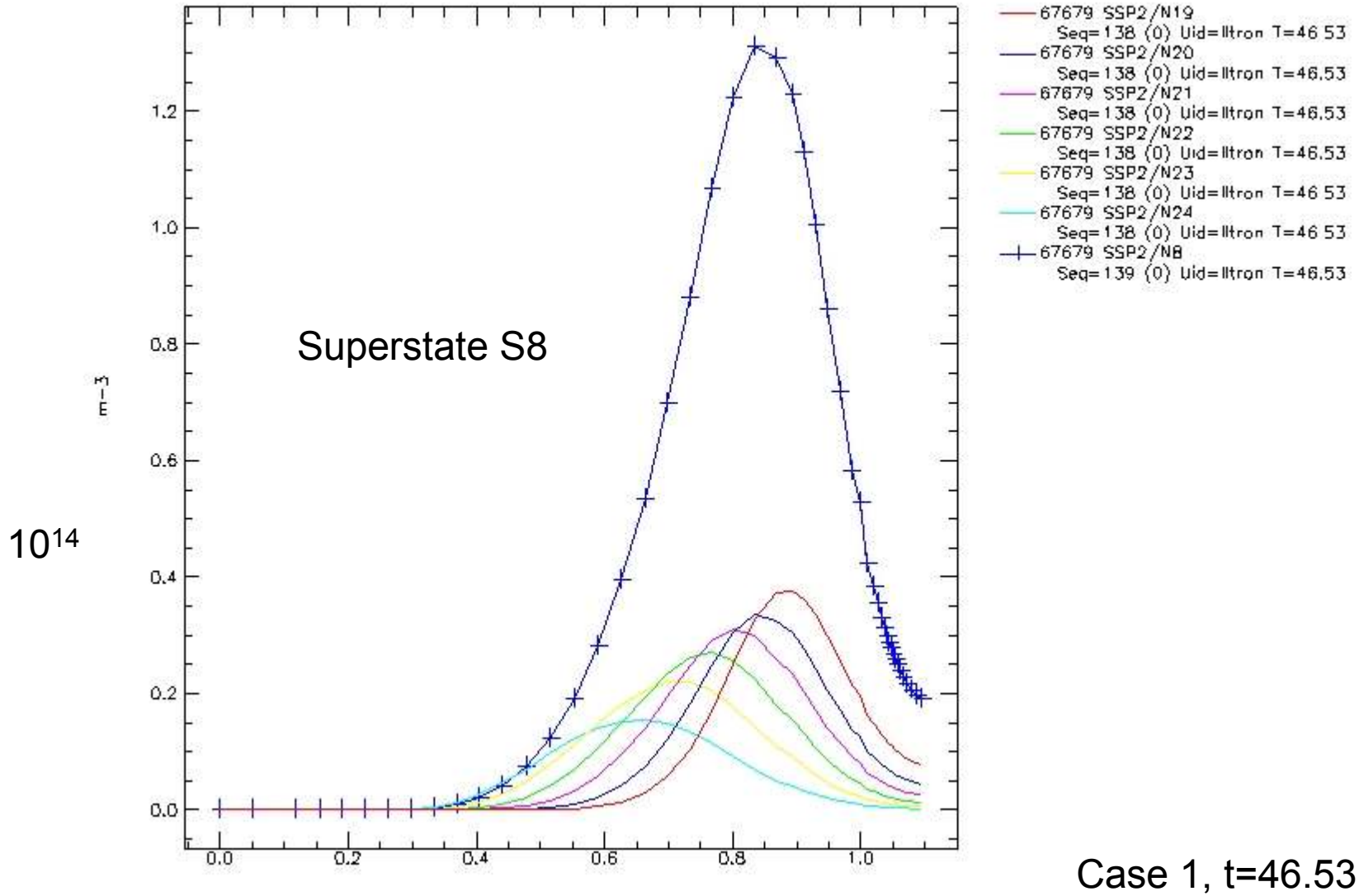
Densities of ions from 11+ to 16+,
compared with the superstate S5



10^{15}

Case 1
t=46.53

Densities of ions 19+ to 24+
compared with superstate S8



Case 1, t=46.53

Summary and Conclusions

- The 1-D impurity transport code SANCO coupled with JETTO can now run also with bundled states.
- Test cases have been shown for Ni (Z=28) without CX
- In general, the superstates description is good, with good agreement between the bundled and unbundled cases
- The calculation of the extra electron cooling radiation term, dependent on the departure from coronal equilibrium, has been added
- Normally, this extra term is ~ a few % of the radiation term
- I have shown a case when the unbundled and bundled description depart: in this situation the extra radiation term is significant. This seems to be a consequence of a departure from coronal equilibrium. This fact might be used as an indicator of the goodness of the bundling scheme employed?
- Finer radial grid?
- Work is in progress on EDGE2D.

Long term plans

- COCONUT: edge-core simulations : different bundling in different regions?
- Particularly for the edge region: time-varying bundling, i.e. vary the bundling scheme ‘on the go’, de-bundling ions and re-bundling them?