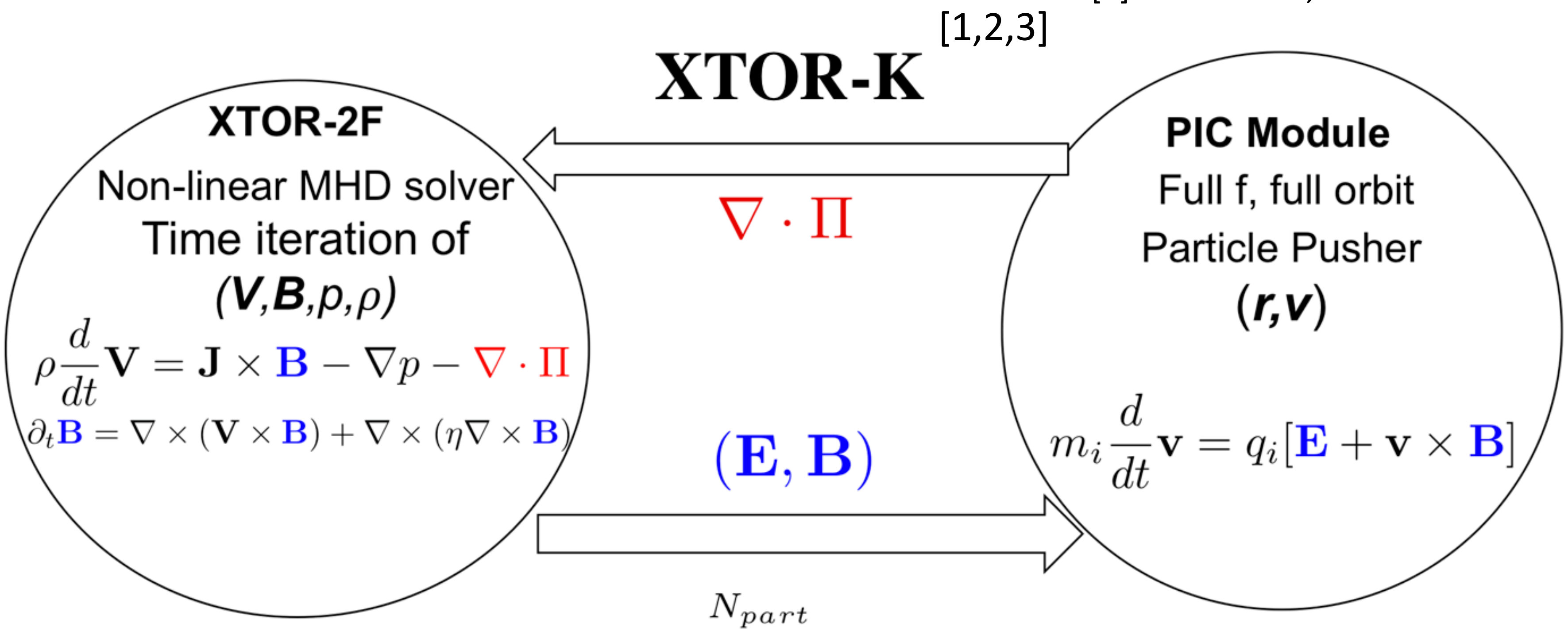
Upgrades of XTOR and tearing stability

Hinrich Lütjens

Centre de Physique Théorique, Ecole Polytechnique, IP-Paris

KINETIC-MHD HYBRID CODE XTOR-K

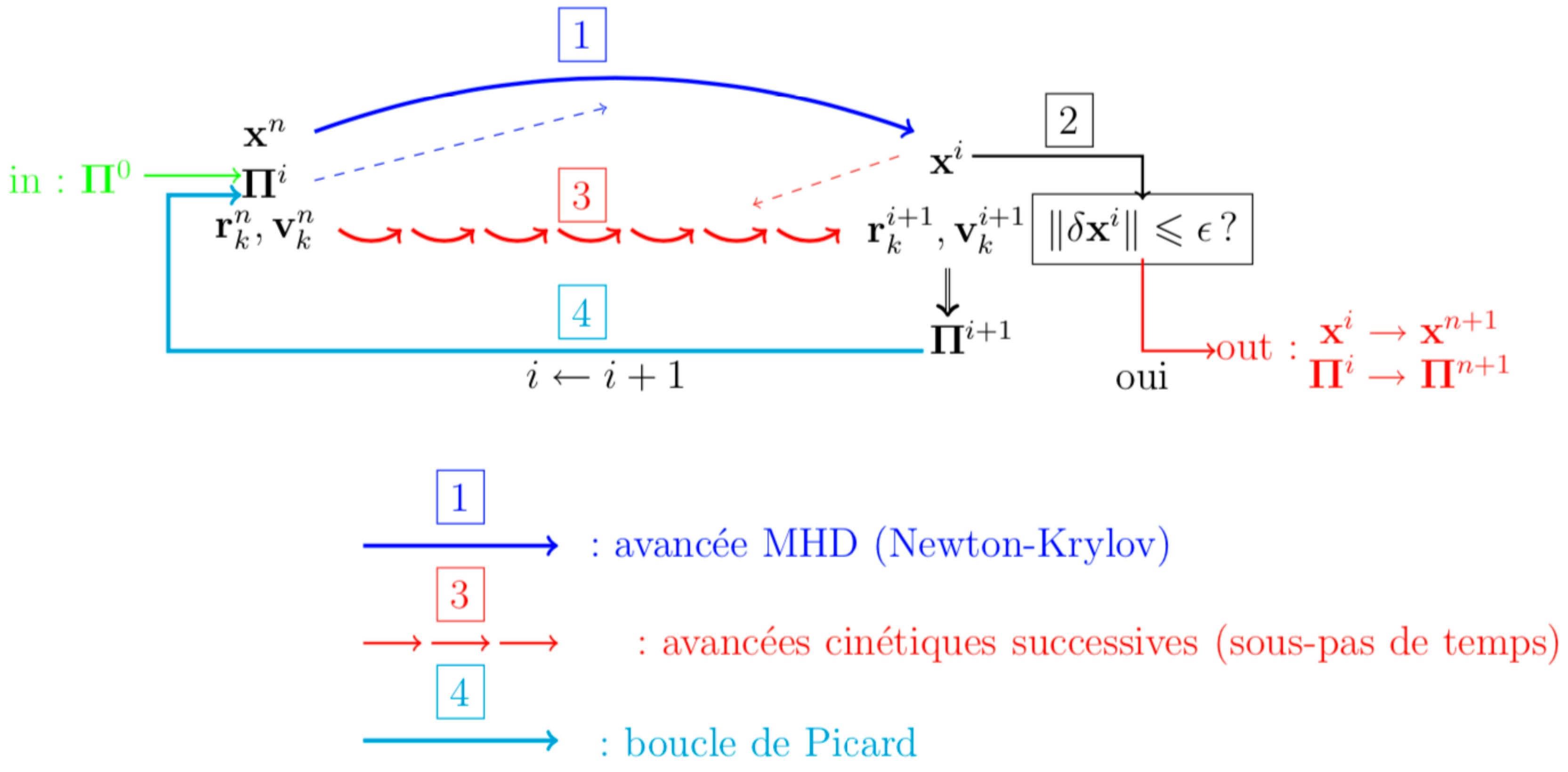
[1] *H. Lütjens et al, JCP 2012*
[2] *D. Leblond, PhD thesis 2013*
[3] *G. Brochard, PhD thesis 2019*



$$\Pi(\mathbf{r}, t) = m_i \sum_{n=1}^{N_{part}} \mathbf{v}_n \mathbf{v}_n \delta(\mathbf{r} - \mathbf{r}_n(t))$$

j

Hybrid time advance



Fluid time step is adjusted to control NK max iterations

Linear phase: Typically 100 particle time steps per fluid time step
NL phase: can drop to 1-3 particle time steps per fluid time step

NK pre-conditionning

- Physical: Based on linearized 2-fluid equations
- Diagonal in toroidal mode number n. Stored in Fourier space. Bloc-penta-diagonal
- Old method: LU decomposition

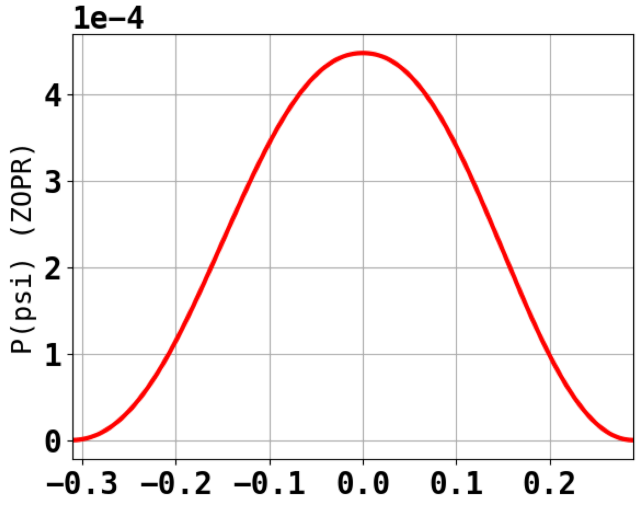
Now

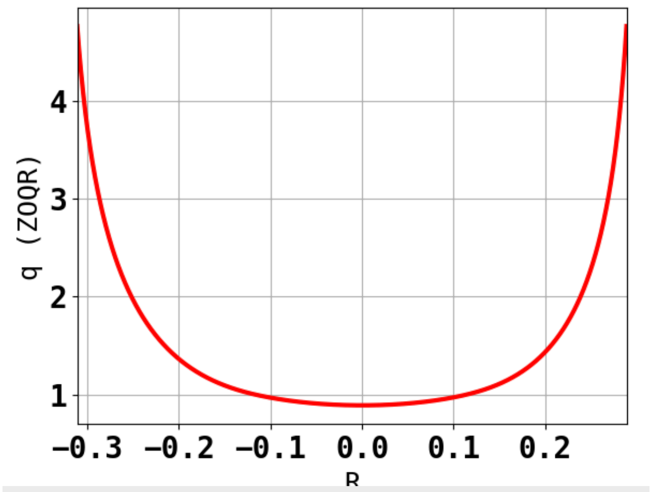
- Domain decomposition along radial direction
- SPIKE LU method (LU for every radial sub-interval + communication matrix)
- Limit: size(communication matrix) < size(sub-interval matrix)

——> 2 levels of MPI parallelization:

1) Toroidal mode number and 2-fluid operator splitting, latter needs to be optimized (Turing vs IreneAMD)
2) Radial Domain decomposition

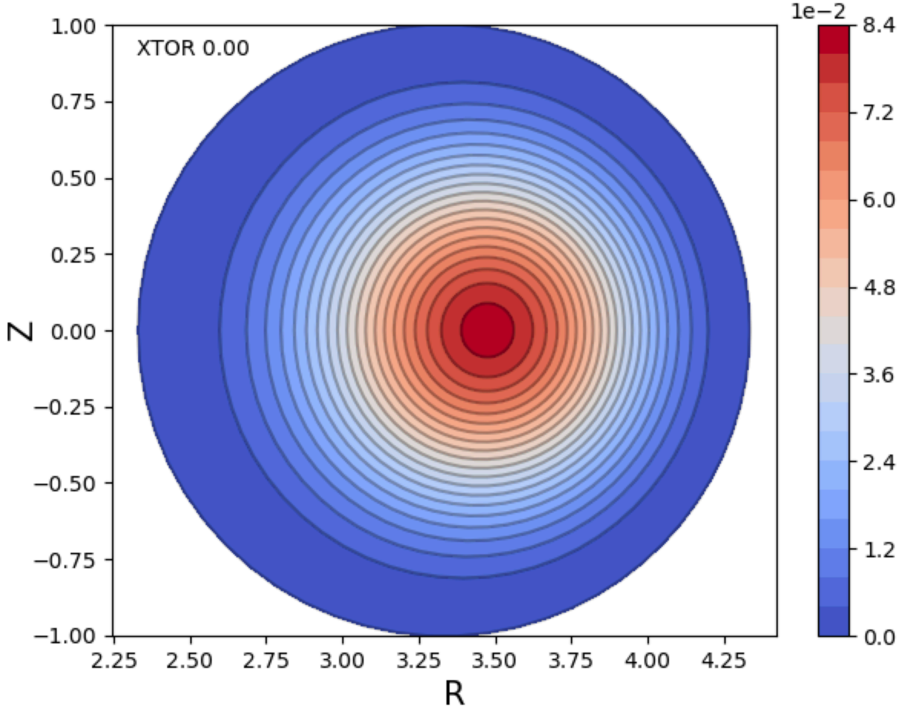
Test case: internal kink

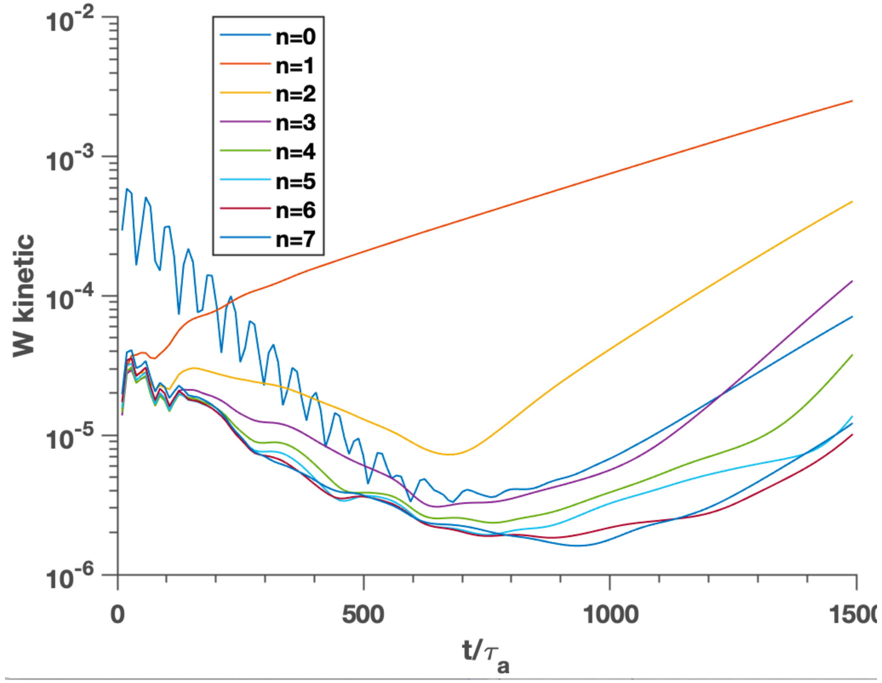


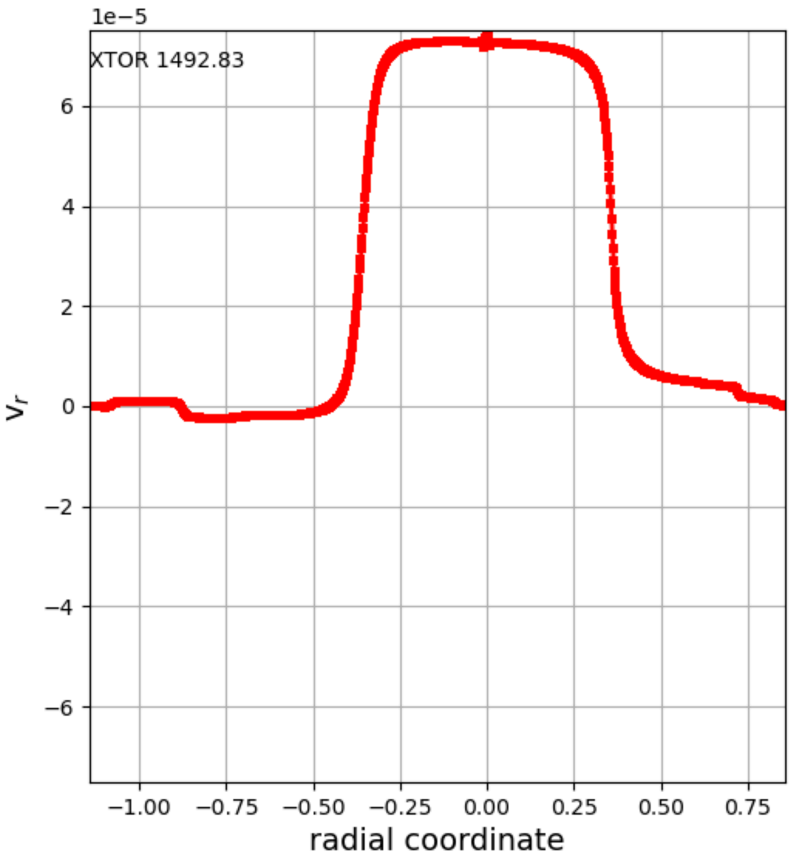


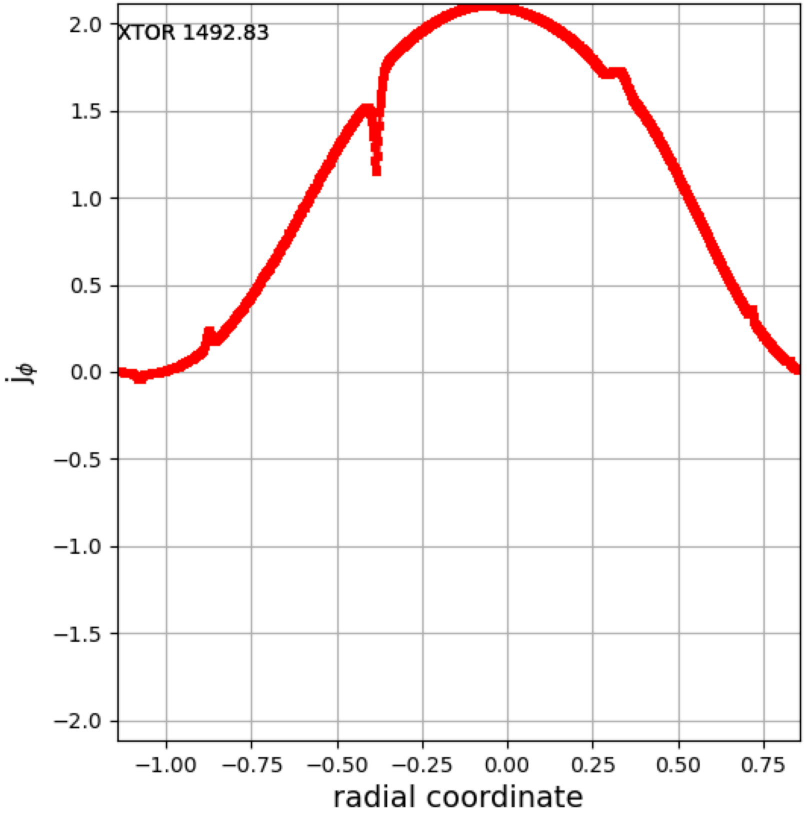
Aspect ratio: 3.33; r(q=1)=0.45; beta(axe)=2.95%

Pressure :







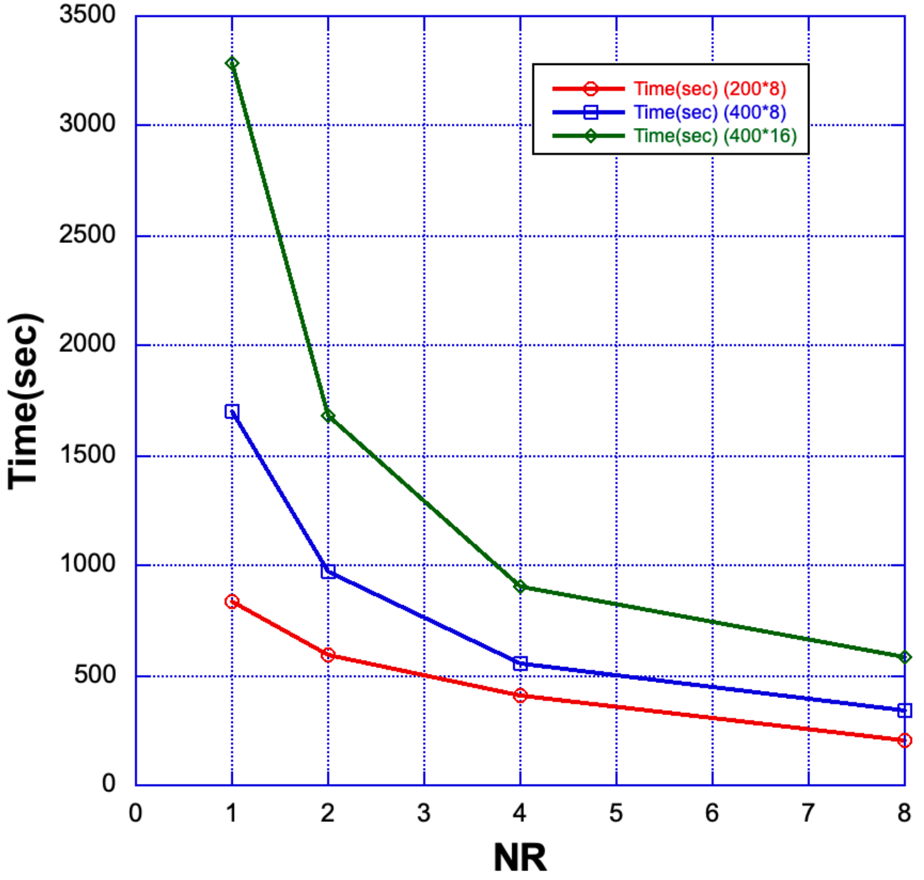


Kink ideally unstable

Beta pol total=0.78

S(axis)=3.E9; viscosity: 1.E-6

Growth rate: 5.2E-3



Speedups varying the # of radial intervals:

Small mesh: 4

Medium mesh: 5

Large mesh: 6

Not satisfying when toroidal mode number is varied:

- For the moment, only gain in memory requirement
- Operations on pre-conditioner scales correctly pre-conditioner construction and decomposition)
- Problem with 2-fluid operator splitting. Optimization to be worked on.

Embedding Fluid and kinetic solvers

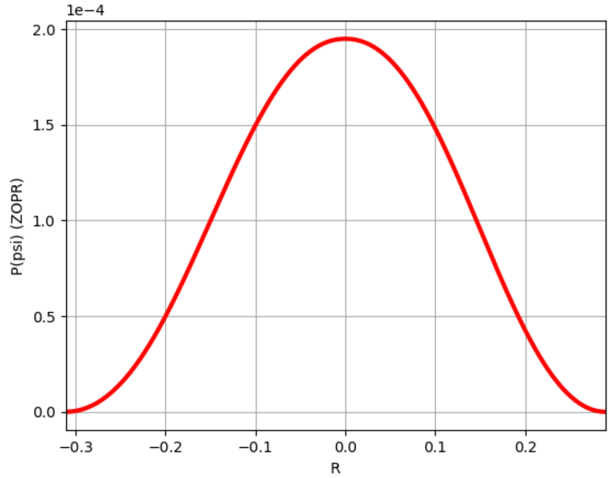
Fluid solver: ~1000-5000 cores; 64-256 MPI processes
Kinetic solver: 5000-… cores; 256-… MPI processes

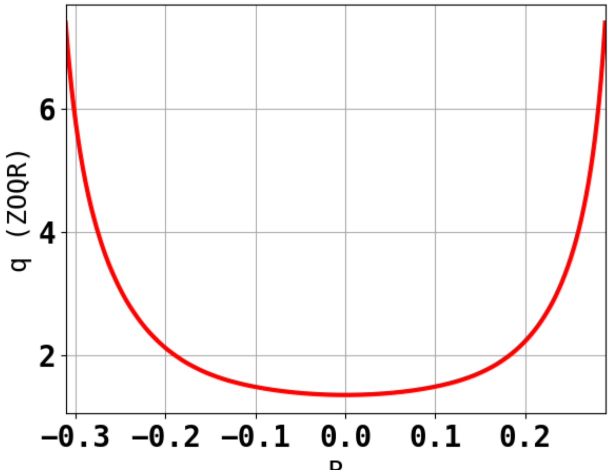
——> Fluid solver is cloned to limit inter-MPI communications

Switching back and forth from fluid toroidal radially sliced mesh towards kinetic cylindrical mesh +SPIKE solver+diagnostics creates delicate CPU charge balance problems, which become critical on new fast machines (IreneAMD, JeanZay, New Occigen)

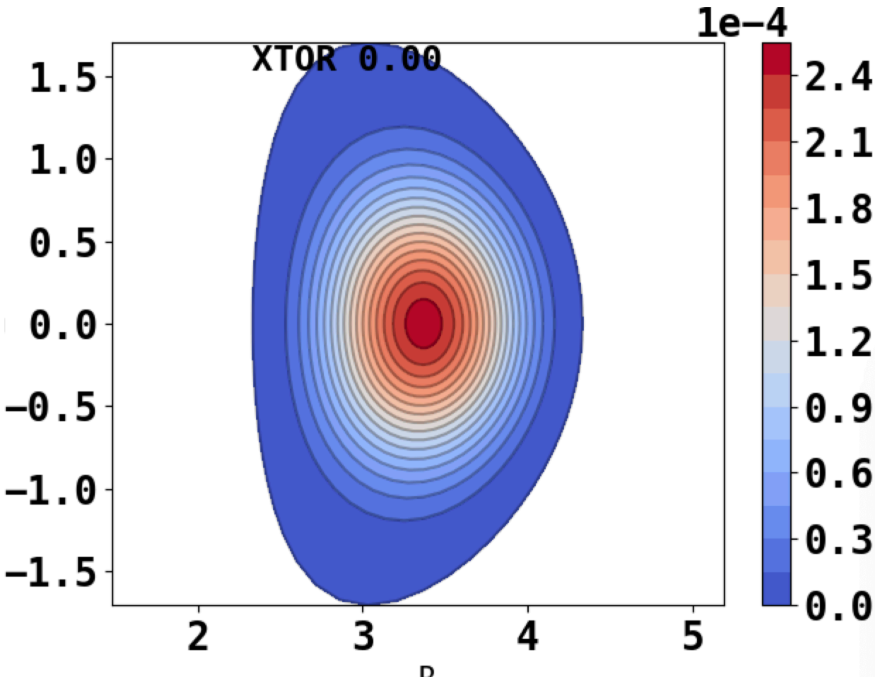
—-> solved now (not only until next generation of machines ;) !)

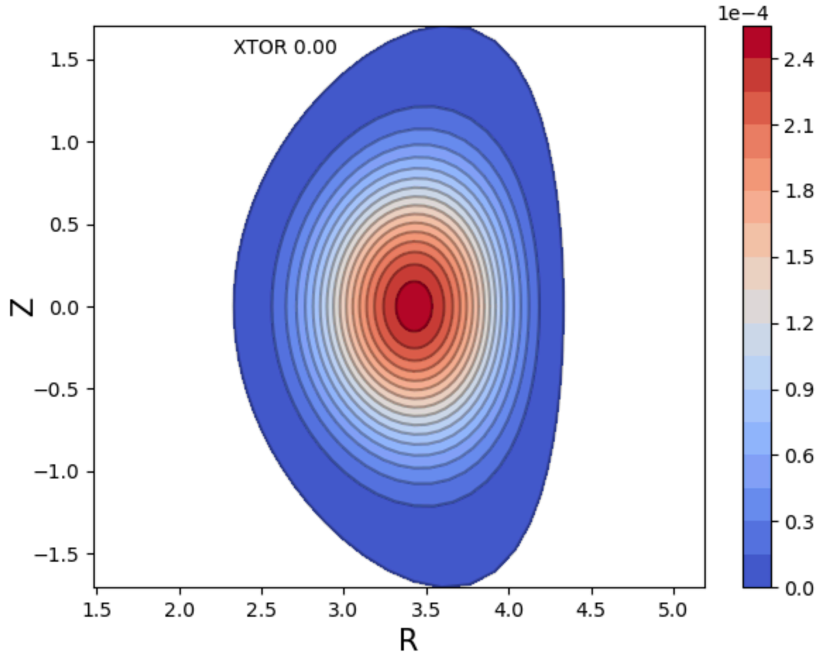
Positive and negative triangularity tearing simulations





Pressure:



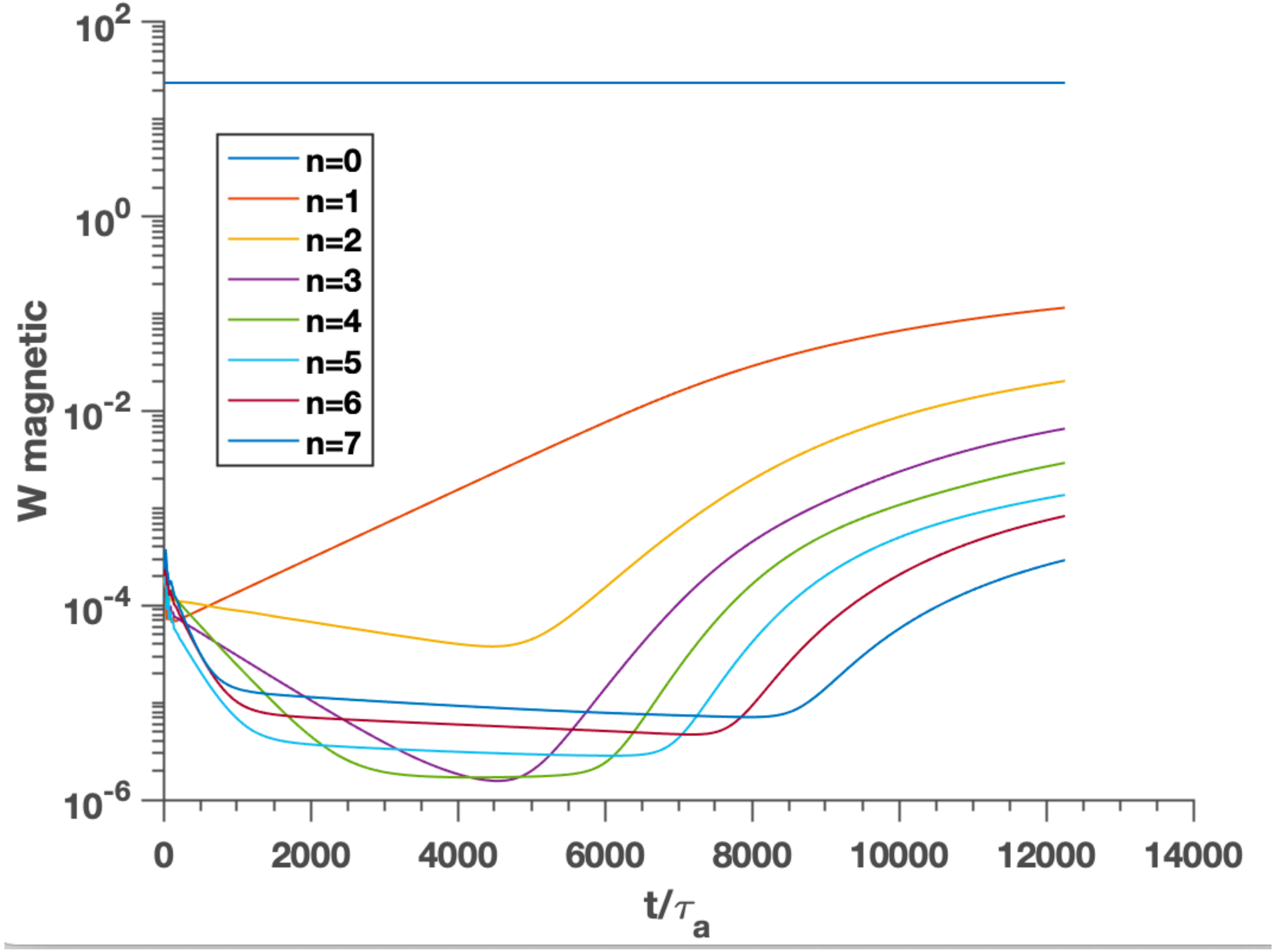


Aspect ratio: 3.33; Elongation 1.75; Triangularity=+/-0.3

S(axe)=1.E6; beta(axe)=0.039%

NB: No problems in dealing with up/down asymmetric sections

Time evolution of the toroidal modes



Evolution of the m/n=2/1 tearing

- No significant difference in energy evolutions between +/- triangularity

-In the linear growth phase

Delta=-0.3: gamma=1.66E-3

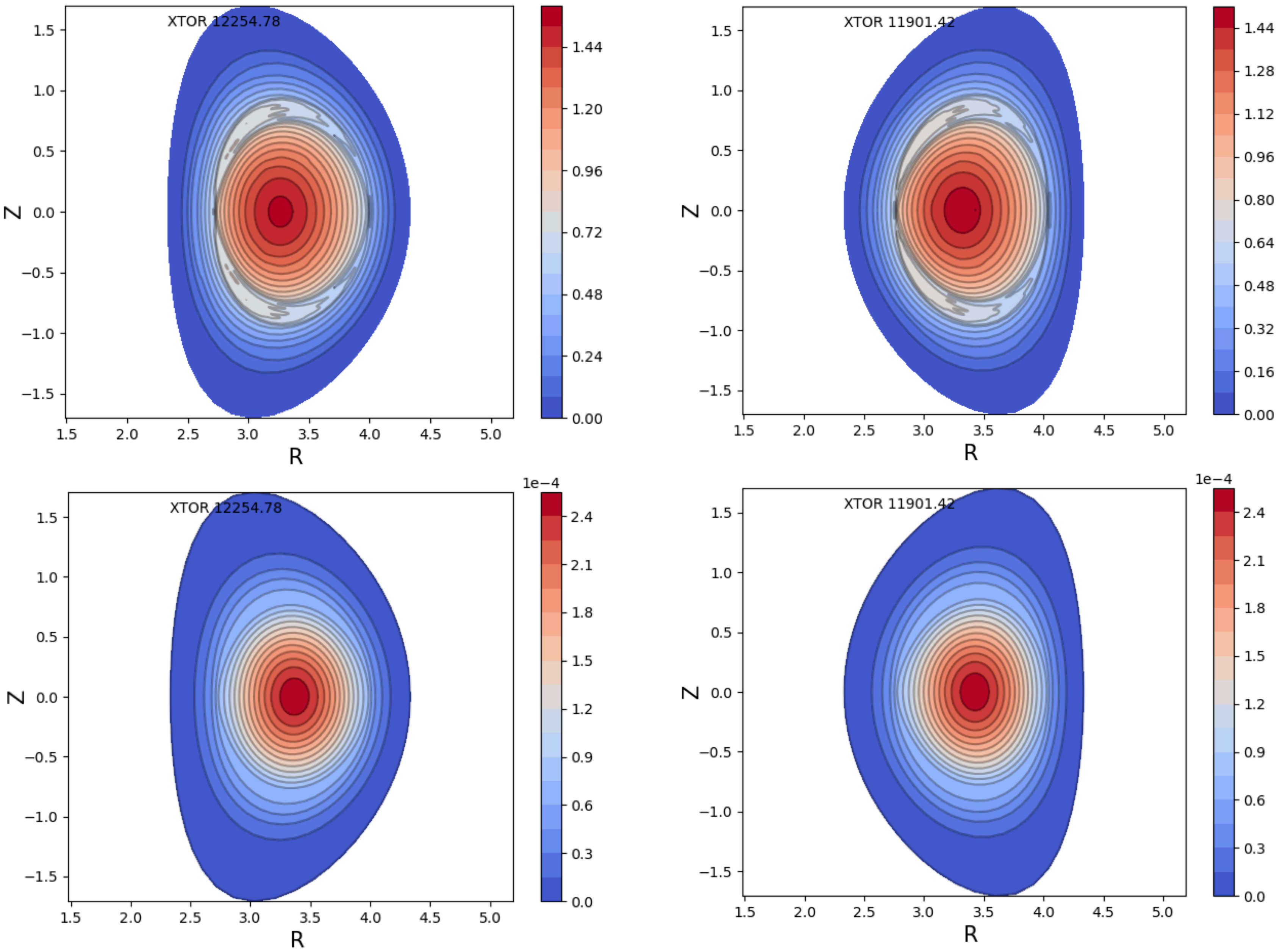
Delta=-0.3: gamma=1.72E-3

At saturation:

Toroidal current density:

Pressure:

—> No significant difference
In the m/n=2/1 island size



Problems to be solved:

-Working with experimental data fine for the plasma boundary. Fit to smooth data necessary

-Still problems with the experimental profiles

In XTOR, n(electron) is not a variable. Reconstructed at every time step from ion densities (—-> quasi-neutrality)

From CHEASE, n(electron), Zeff, T(electron), T(ion):

3 solutions with XTOR:

1) Force n(ion)=n(electron). But beta is wrong
2) Re-up the evolution of impurity density and impurity parallel velocity (cf. PHD Jae-Heon Ahn)
3) Evolve impurities with kinetic module. Still on the test bench (Domain decomposition of the kinetic (R,Phi,Z) mesh and binary collisions). Experimental impurity density envelop for initialization?

I will move toward solution 2) first since XTOR-K fluid solved has been designed to allow easy addition of supplementary equations. Solution 3) will follow asap (few month)

Problems which will be addressed

-Nonlinear stability of tearings and NTM’s

-Impurity migration in the presence of tearings/kinks with kinetic impurities

-Last optimizations of the full code

-Re-up de XTOR-2F Neo-classical module (Maget,Mellet,Février) but using 2-fluid model instead of 2-fluid MHD