Status of XTOR-K simulations

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Outline:

- Numerical work on XTOR-K
- ITPA TAE and NL internal kink
- Internal kink simulations: MHD with alpha’s
- Ongoing work and perspectives

Numerical work on XTOR-K

- Step 1 (2021) : Introduction of SPIKE algorithm. Domain decomposition of fluid part. Typical gain: factor 10 for purely fluid simulations.

- Step 2 (First month of 2022): SPIKE adapted and validated in full XTOR-K (both domain cloning and domain decomposition PIC).

  -> Gain of an overall (hybrid) factor 2.5

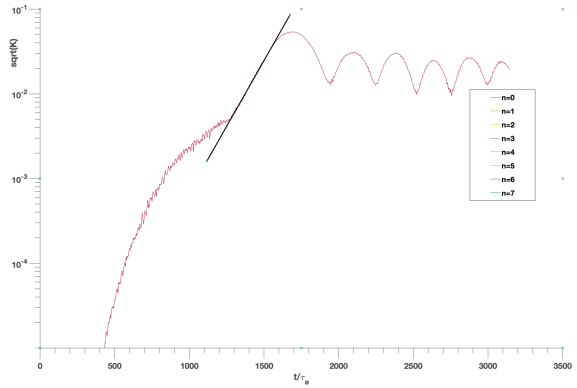
- Particle sorting before moment deposition: with another (hybrid) factor 2.

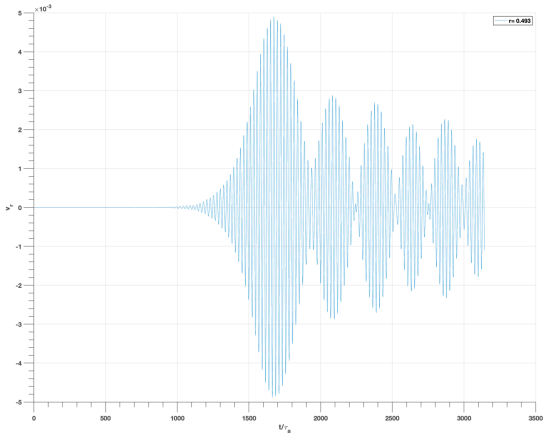
  with Domain decomposition and collisions: no gain

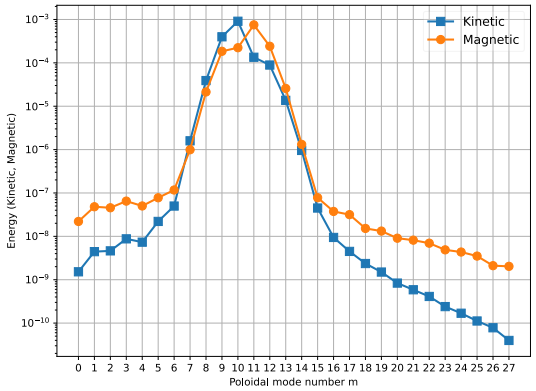
- Computer speed-up between Occigen and Jean-Zay/ Irene Rome: factor 3.

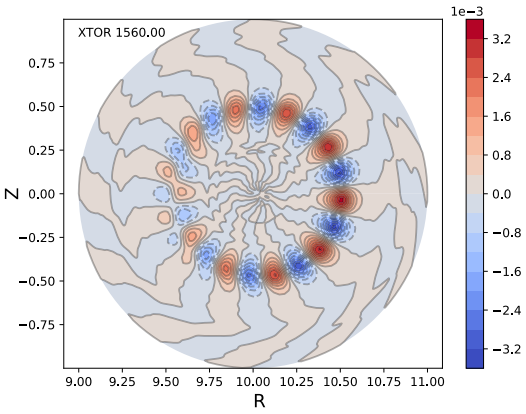
Result: about a factor 7 to 15 speedup between 2019 and now.

ITPA/Mishchenko TAE test case









n=6 TAE evolution:

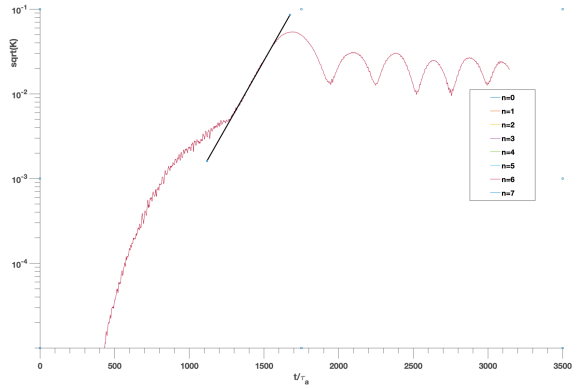
Gamma = 2.18 x 10^4 s^{-1}
Omega = 0.399 x 10^6 rad/s

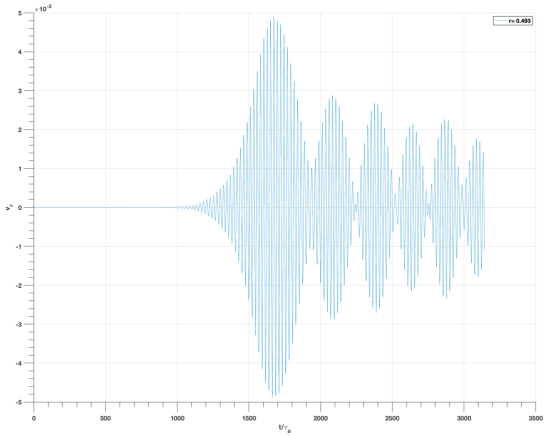
Compares well with
[Mishchenko 2009, Könies 2018]:

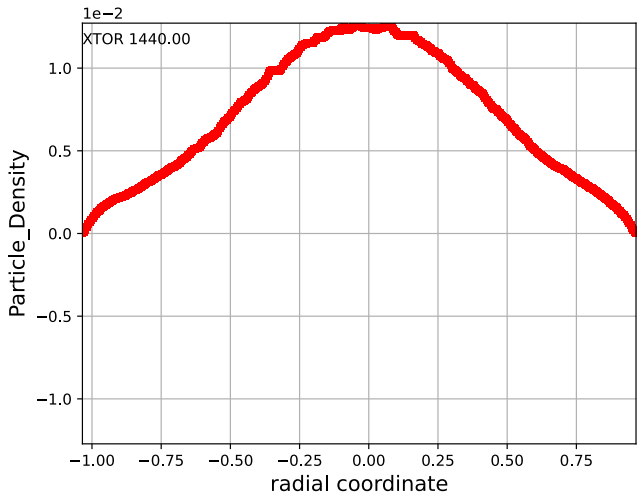
Gamma = 2.3 x 10^4 +/-10% s^{-1}
Omega = 0.42 x 10^6 rad/s

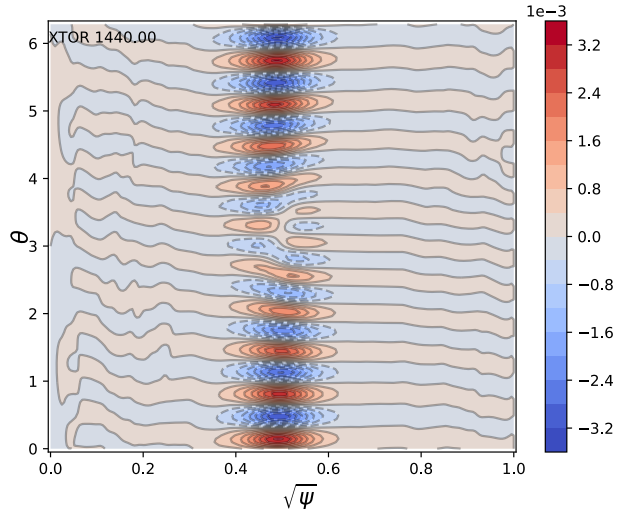
Omega ideal MHD eigenvalue code (CAS3D):
Omega = 0.401 x 10^6 rad/s

ITPA/Mishchenko TAE test case









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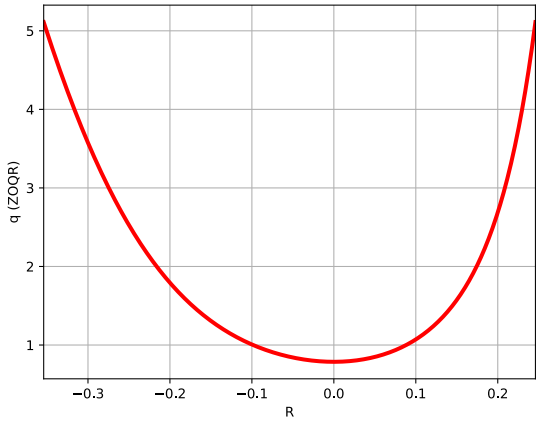
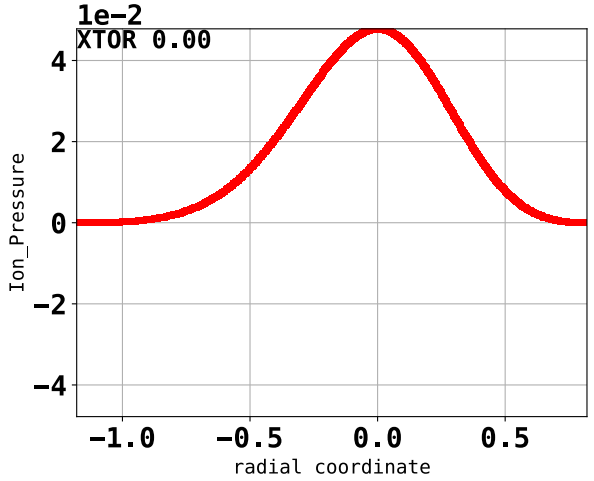
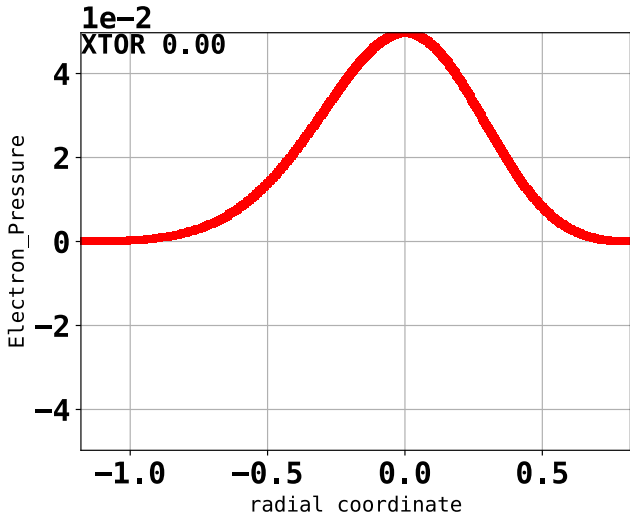
Loss of 25% of the kinetic Ions:

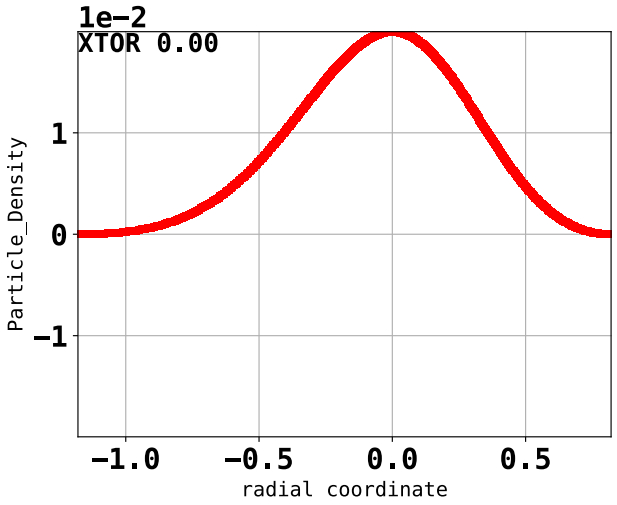
-> Would be good to compare with a vanishing Kinetic density case at plasma edge

Internal kink simulations (MHD+alphas)

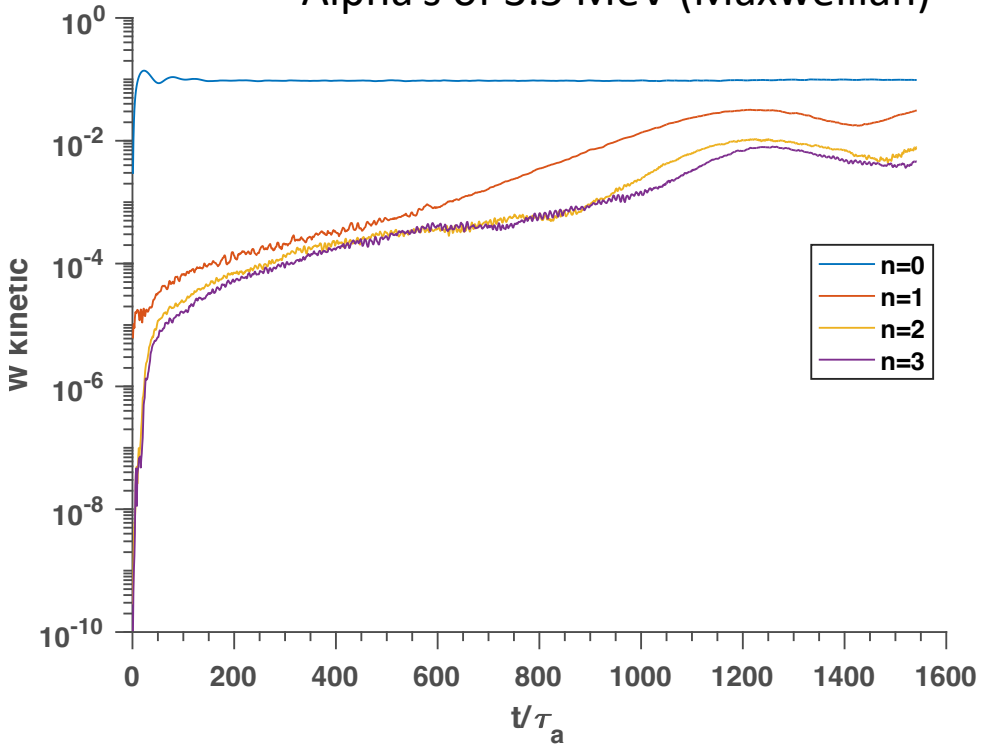




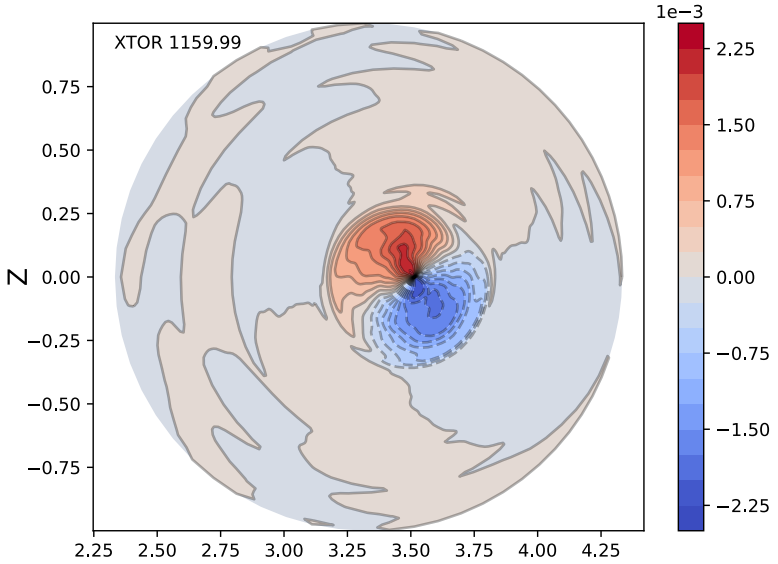




Ni0=ne0=2 10^19 m-3
Ti0=Te0=30KeV
Nf0=4.10^17 m-3
Alpha's of 3.5 MeV (Maxwellian)



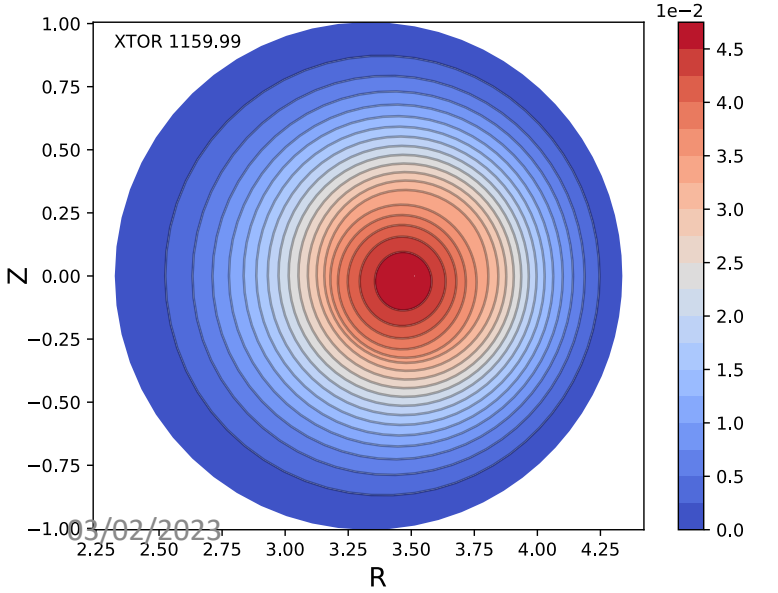
Internal kinKink simulations (2) : Hybrid simulation with 2Mev Fusion alphas

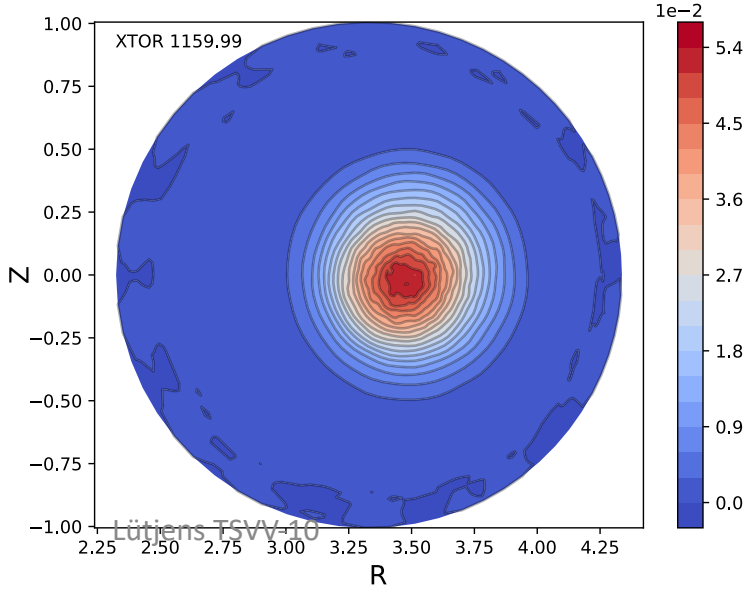


V_r(phi=0)

Ni0=ne0=2 10^19 m-3
Ti0=Te0=30KeV
Nf0=4.10^17 m-3
Beta_pol=0.78;
r(q=1)=0.45
S=3.e6
Chi//=1., Chi_perp=1.e-6

Fluid and kinetic ion pressures

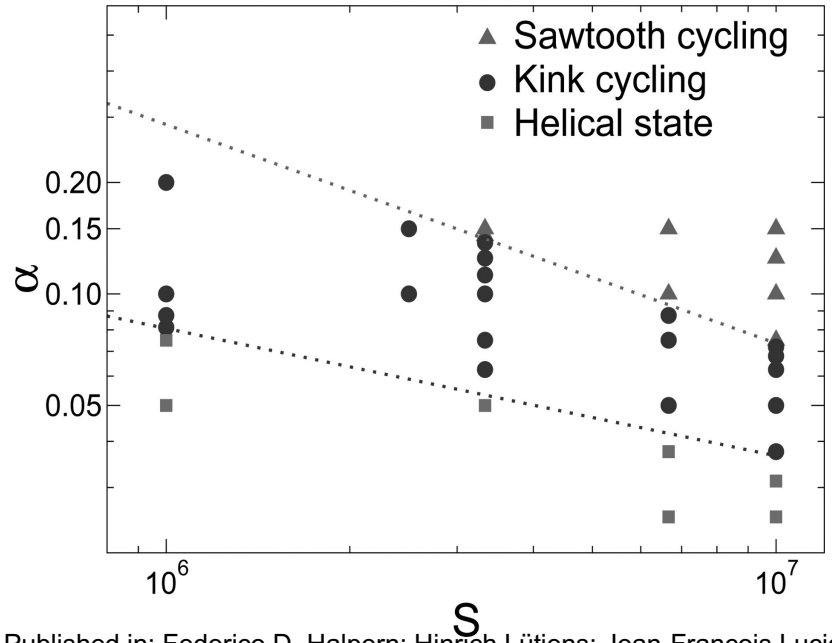




Comparison with 2-fluid sawtooth simulations:

3 regimes in Halpern:

- Saturated helical m=n=1 equilibrium
- Oscillating kinks
- Sawtooth (with ω* effects)



Cyclic regimes found as a function of $\alpha = (\omega_{ci}\tau_a)^{-1}$ and $S = 1/\eta$.

In the hybrid simulation, S=3.e6, ω* effects= 0

-> We are in the **saturated helical equilibrium state**

Published in: Federico D. Halpern; Hinrich Lütjens; Jean-François Luciani; *Physics of Plasmas* **18,** 102501 (2011)
DOI: 10.1063/1.3646305

➢Higher order corrections of fluid equations necessary for :

- Sawtooth simulations (Halpern et al., Phys. Plasmas 18 (10) 102501)
- Tearing simulations (all our work with P. Maget from CEA)

→Probably very sensitive in weak kinetic drive situations

➢ »Gyroviscuous cancelation »:

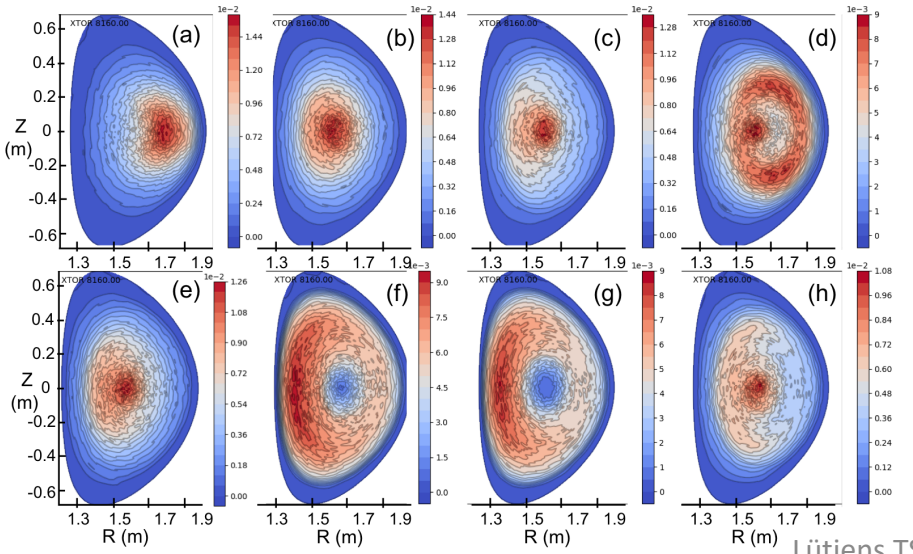
- XTOR-2F (JCP 229 (21) 8130) only $\left(\mathbf{v}_\mathbf{i}^* . \nabla\right)\mathbf{v}_\perp$ kept in Eq. of motion.
- Must be refined ? (Ramos, Phys. Plasmas 12 (5) 112301)

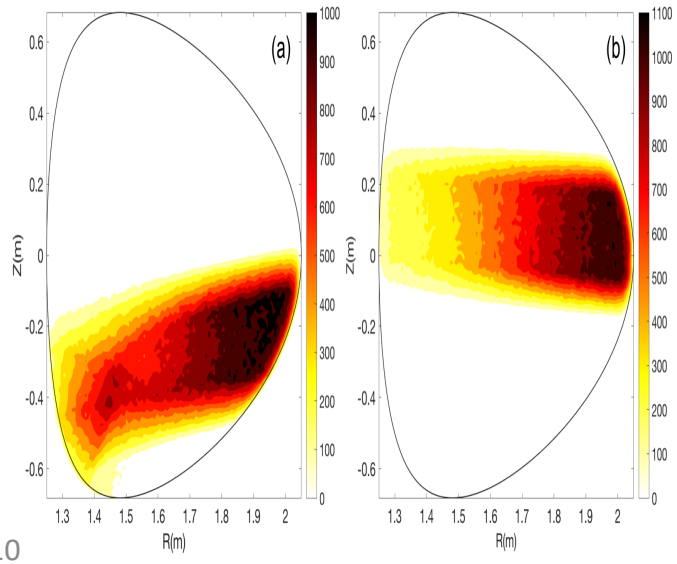
Ongoing work and perspectives

- Latest XTOR-K now contains both
  - Realistic model of Neutral Beam Injection, including modeling of the ionization process (recovered from Orain)
  - Collisions between species (binary) and and particles and background plasma (Langevin)

- Possible to generate realistic PDFs of energetic particles
  - Mohamed Rekhis' PhD thesis: stability investigations with self-consistent energetic particles populations

- Work on more generalized fluid equations in progress





[Orain et al., ArXiv 2020]

Ongoing work and perspectives

- NLED-AUG in progress. Corrections in CHEASE done for XTOR-K, first simulations with XTOR started this week. Simulations need some tuning for these equilibria and family of instabilities.

- XTOR-K is now ready for long time simulations in the presence of kinetic ion populations :

  - Shaping effects on tearing/internal kink instabilities, interactions with fast particles or impurities

  - Sawtooth cycling simulations in the presence of fusion alphas will begin from now on.

- Inclusion of an equilibrium plasma sepratrix in progress.

- Start a project with GENCI to move Particles on GPU.