Institute for Fusion Studies

TACC

Dynamics and Transport in TAE compared with Magnetospheric Plasmas

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IFS, ARL and TACC

Tri Alpha Energy - the Tajima Symposium
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UC Irvine and Tri-Alpha Energy
Irvine, California, USA

IFS

TTT = Toshi Tajima the Transformer

TT is the "primary current" of a new circuit that brought in wide variety of topics from accelerators, magnetosphere and solar physics.

New Tools of big simulations …PIC simulations and Global View - Beat Wave Accelerator, Magnetosphere, Tokamaks and many New confinement geometries!

Magnetic Reconnection - both traditional Rosenbluth-Furth-Killeen problem and Rostoker's - and then Dawson's - collisionless magnetic Reconnection. 20 years at UT Austin→

Talked to all and every team: made us talk [and argue] with each other …Dan Barnes, Pat Diamond, Herb Berk, many more

Geomagnetic Plasma - hot, collisionless and generally stable with p $\approx B^2/2\mu_o$

TT asks “How Stable?” & “Dynamics of these high β plasmas?”

Magnetospheric Multi-Scale (MMS) and THEMIS spacecraft give unperturbed and perturbed 3D data of **B**, **V** and n, T_e T_i along the four tetrahedral space crafts trajectories.

Measured steady Magnetic Reconnection on scale of $\delta_i = c/\omega_{pi}$ ~ 200km << L_n, L_T ~ $\simeq$ 2000km in the dynamics of the plasma.

Learned Substorms are from collision magnetic reconnection driven by plasma flows. Drivers K-H or Flux Ropes from CME -- external events / drivers.

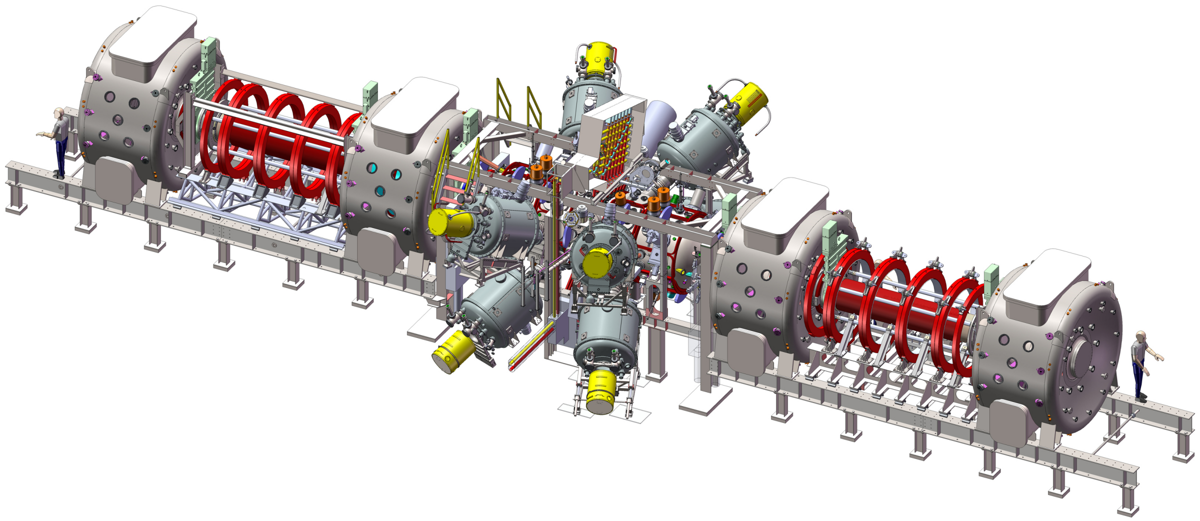
Horton, Tajima, Ricardo Galvao, Evolution of Tearing modes during magnetic reconnection, Magnetic Reconnection in Space and Laboratory Plasmas, (1984).

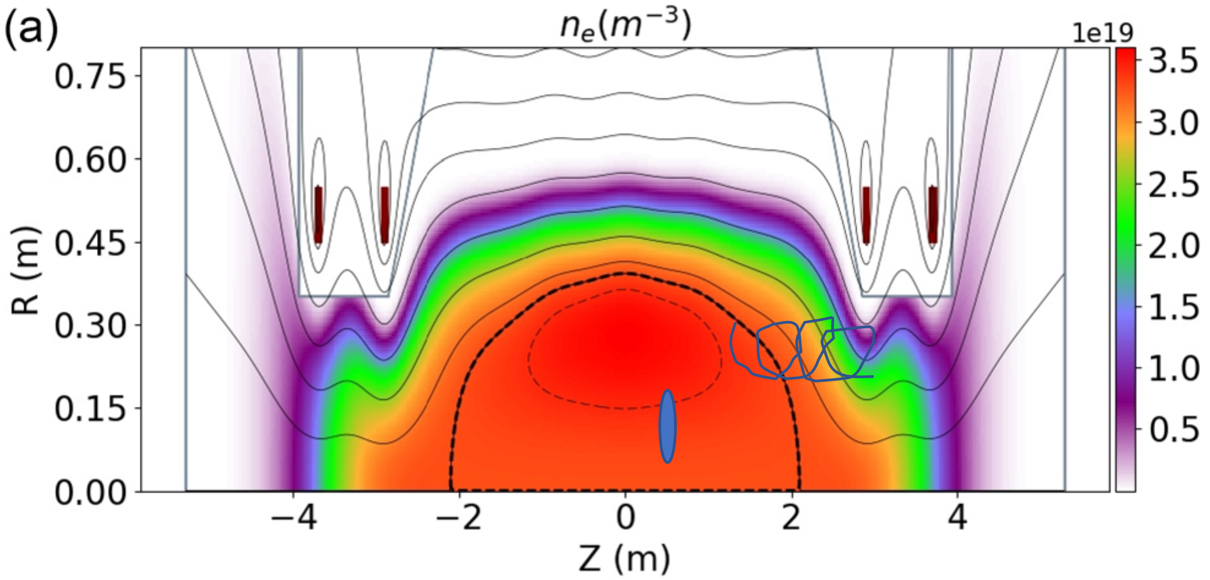
Relaxed Confinement: magnetic pressure ~ plasma pressure and FLR+ Alfven Wave Stability

- Long-time plasma confinement occurs in nature with
- Plasma Pressure $\simeq$ Magnetic Pressure …as in magnetospheres and geomagnetic tails of Earth and Jupiter...
- Achieved by magnetic reconnection and which suggests Field Reversed Confinment [FRC] plasmas.
- Confined plasmas trapped by Magnetic Compression and Magnetic Reconnection may be more relaxed and natural.
- Dominant Dynamics is Interchange + Alfven Waves with plasma maintained by Magentic Reconnection and Compressional heating with energetic ions.
- Same Principles employed in the laboratory lead to the FRC confinement.

Kishimoto, Tajima, Horton, LeBrun, Kim, Phys. Plasmas 3, 1289 (1996). ***Self organized critical transport in tokamak plasmas***

Binderbauer et al. Norman C-2W long pulses

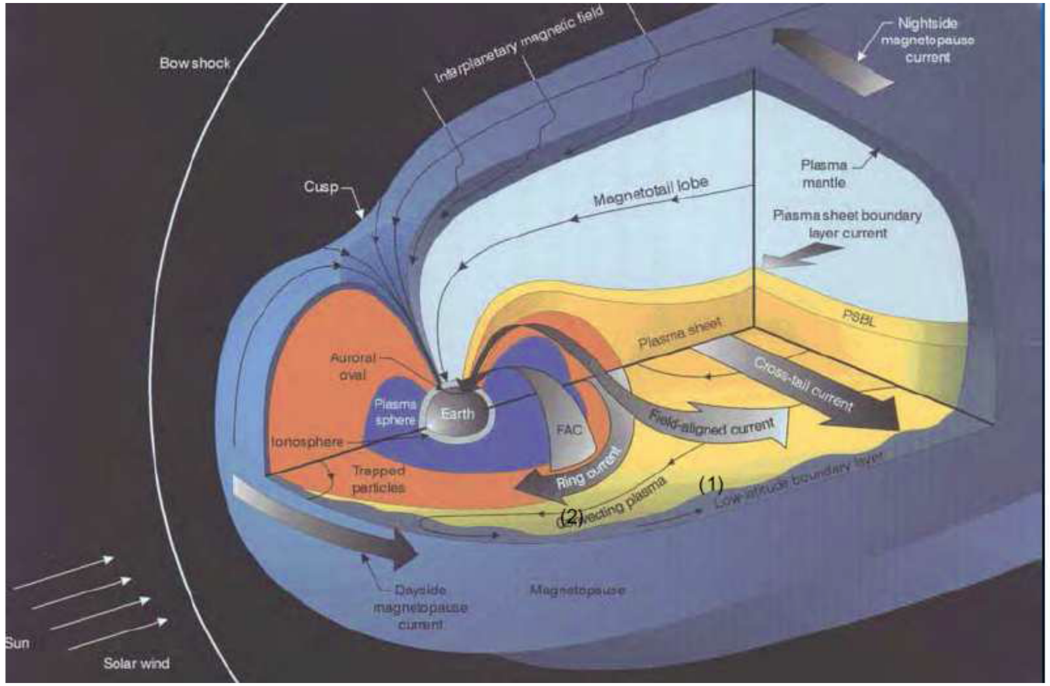


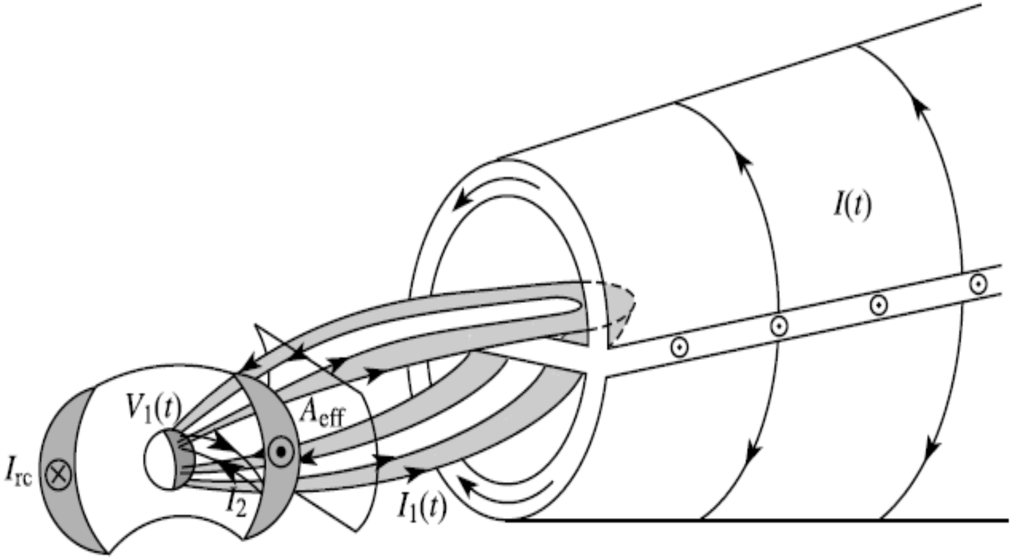


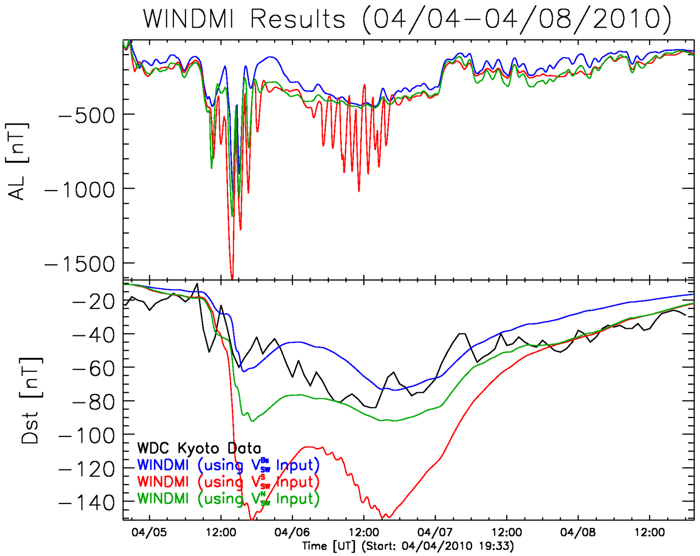
AIP Conference Proceedings **1721**, 030003 (2016); doi: 10.1063/1.4944019

ne: http://dx.doi.org/10.1063/1.4944019

Magnetic Reconnection --in high pressure plasma– is a relaxation from external forcing



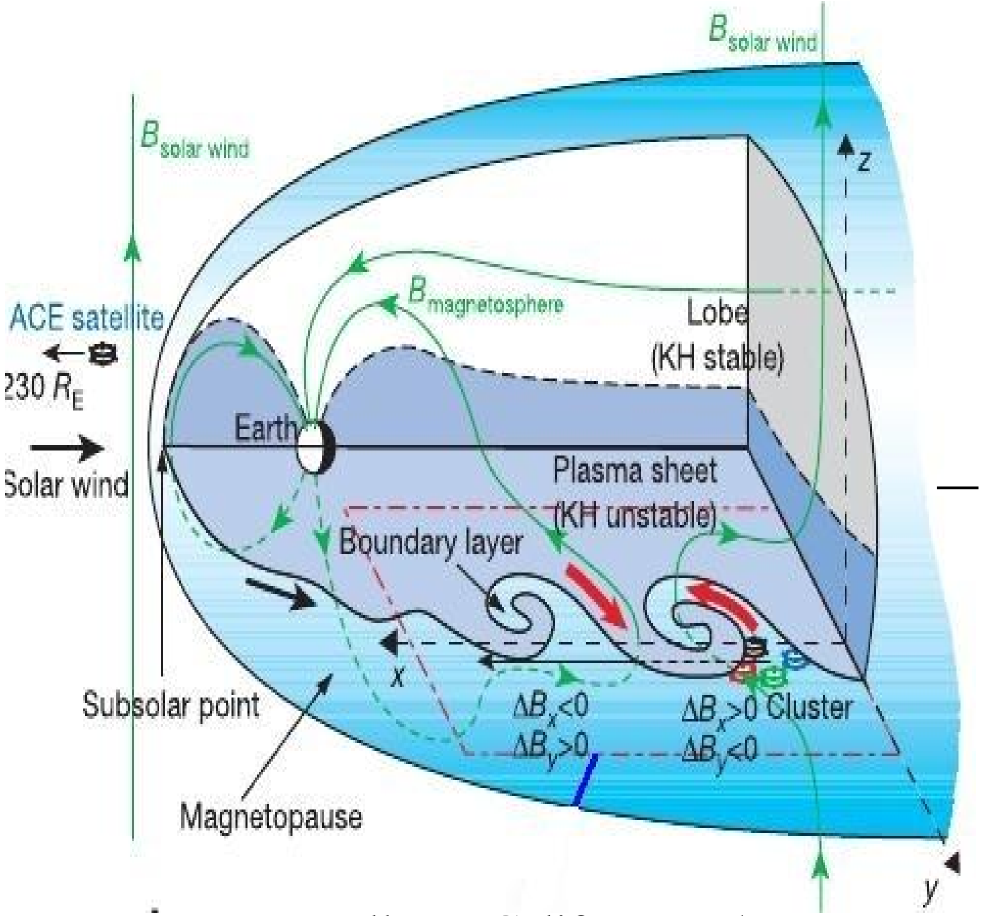


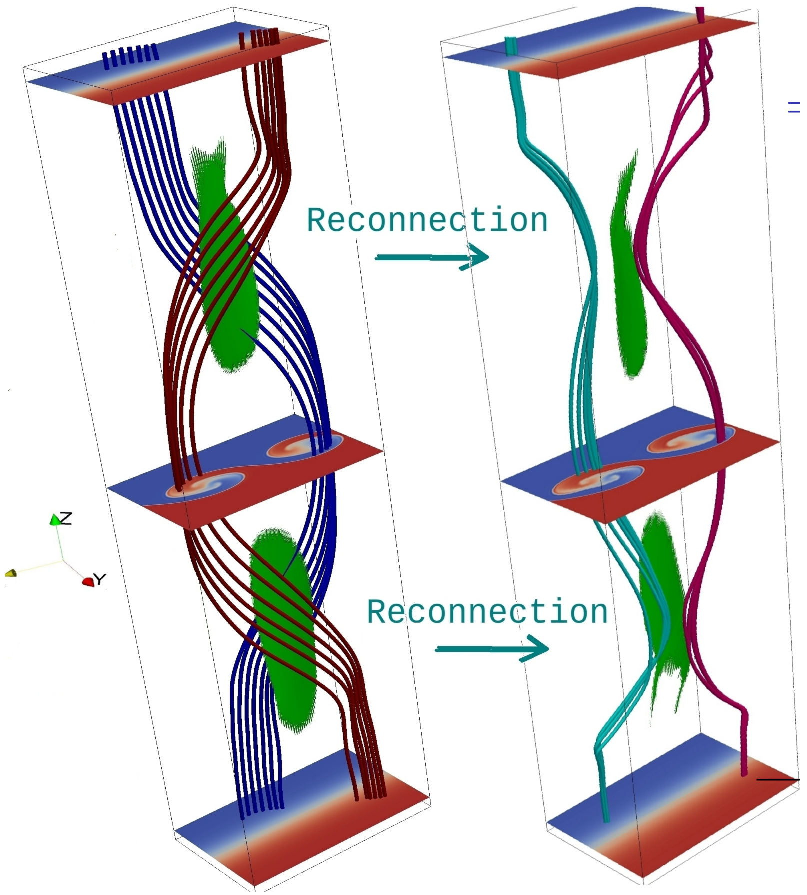


Horton, "Turbulent Transport in Magnetized Plasmas" [2012,2018]
3D works show = nonlinear interchange dynamics ->
-> evolves to magnetic islands and fast reconnection
TT introduce this Research at UT in 1990ies – with NSF grants

Kelvin-Helmholtz along the Flanks of Magnetopause produces North-South twisted magnetic fields from nonlinear boundary vortex flows

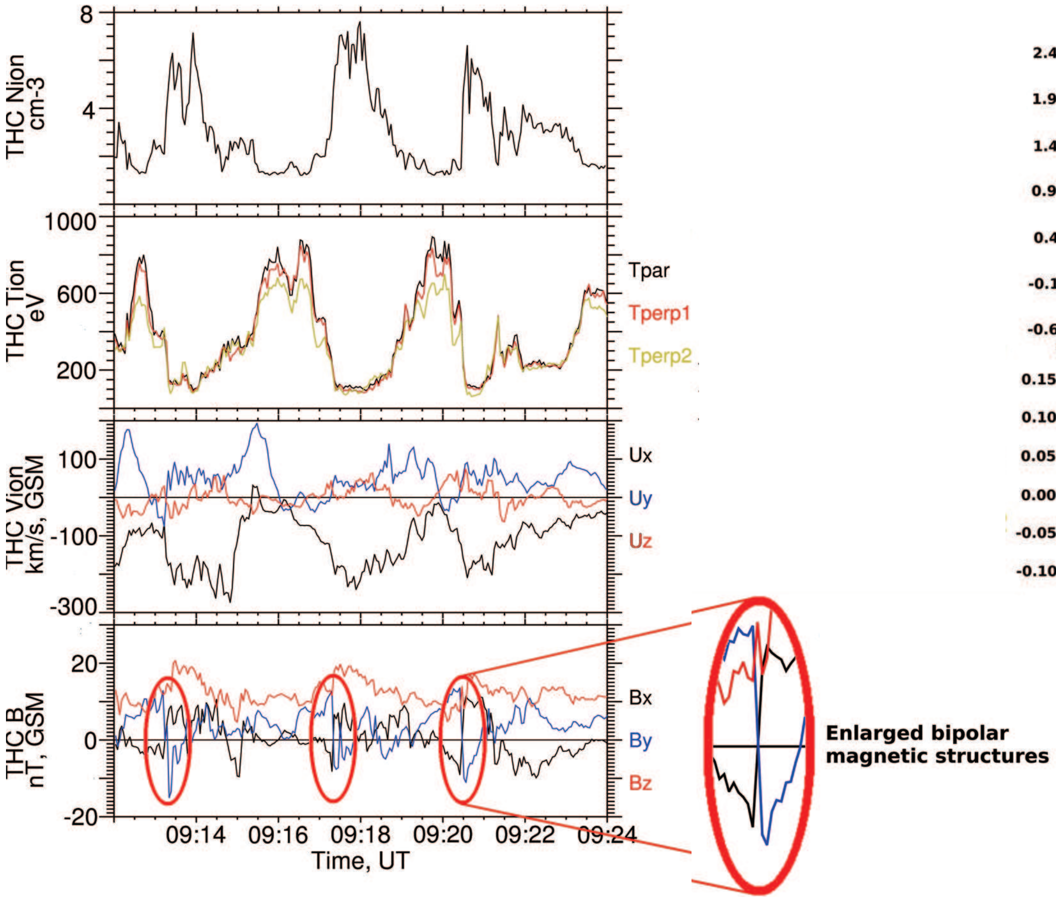
Continuation of Space Physics from TT's early team at Univ of Texas

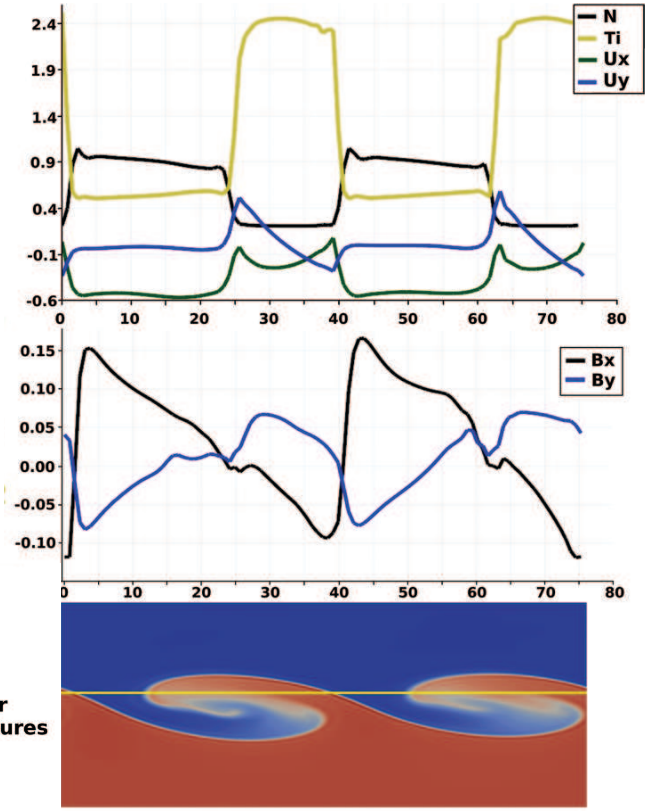




W. Horton, M. Faganello, F. Califano, and F. Pegoraro, Substorm Conference, Proceedings Oct 2017
D. Borgogno, F. Califano, M. Faganello, and F. Pegoraro, Phys. of Plasmas 22,032301(2015)
A. Otto and D. H. Fairfield, J. Geophys. Res. 105, 21175, doi:10.1029/ 1999JA000312 (2000)

Northward IMF -> Kelvin-Helmholtz twisted magnetic field from THEMIS data shows 3D reconnection

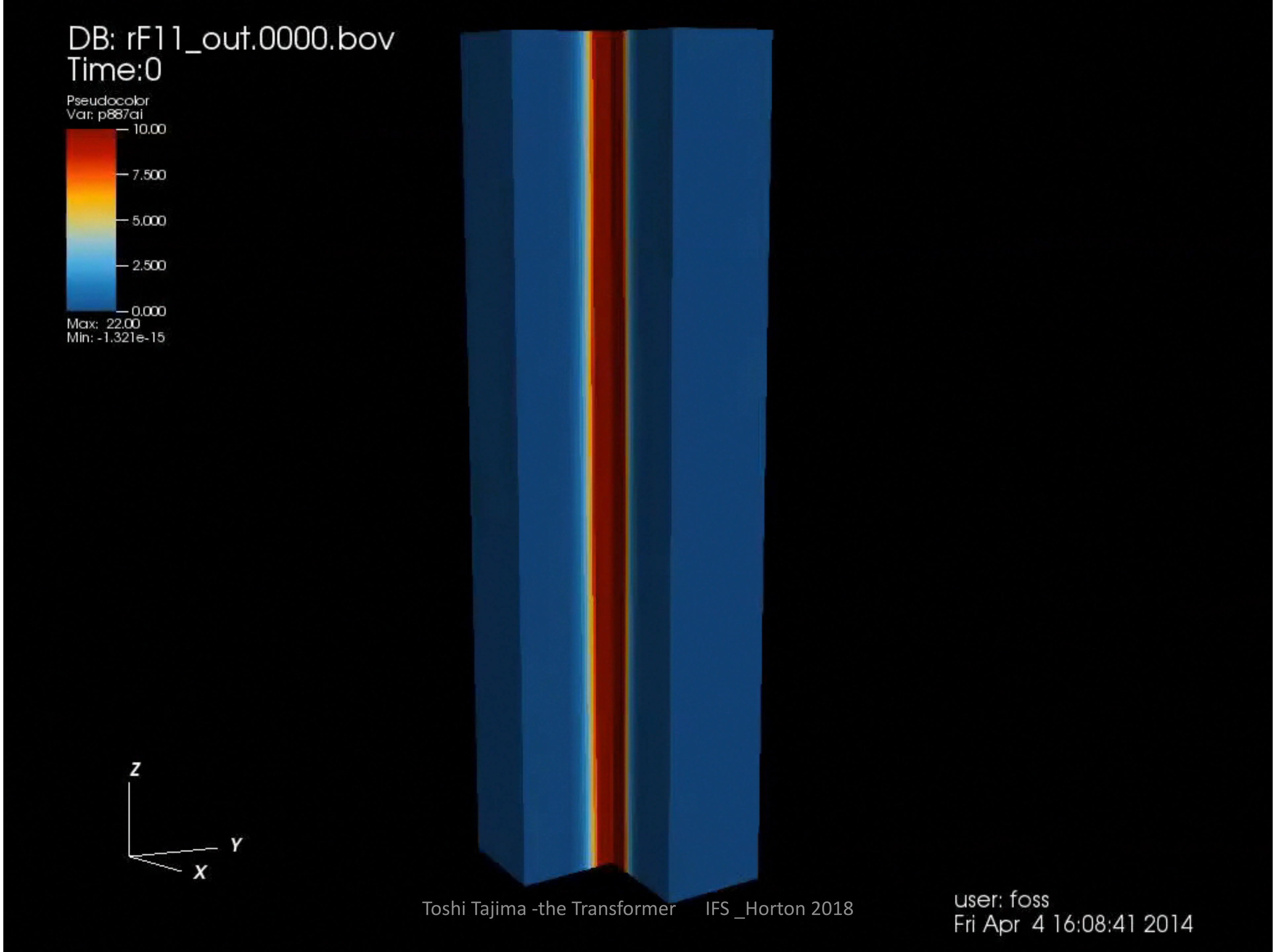




data compared with Nonlinear Simulations 3D K-H drives MRC at mid-latitudes from twisted magnetic field lines.

Horton_Faganello_Pegararo …2017 Substorm Conference

Early suggestions from Toshi Tajima while at IFS Austin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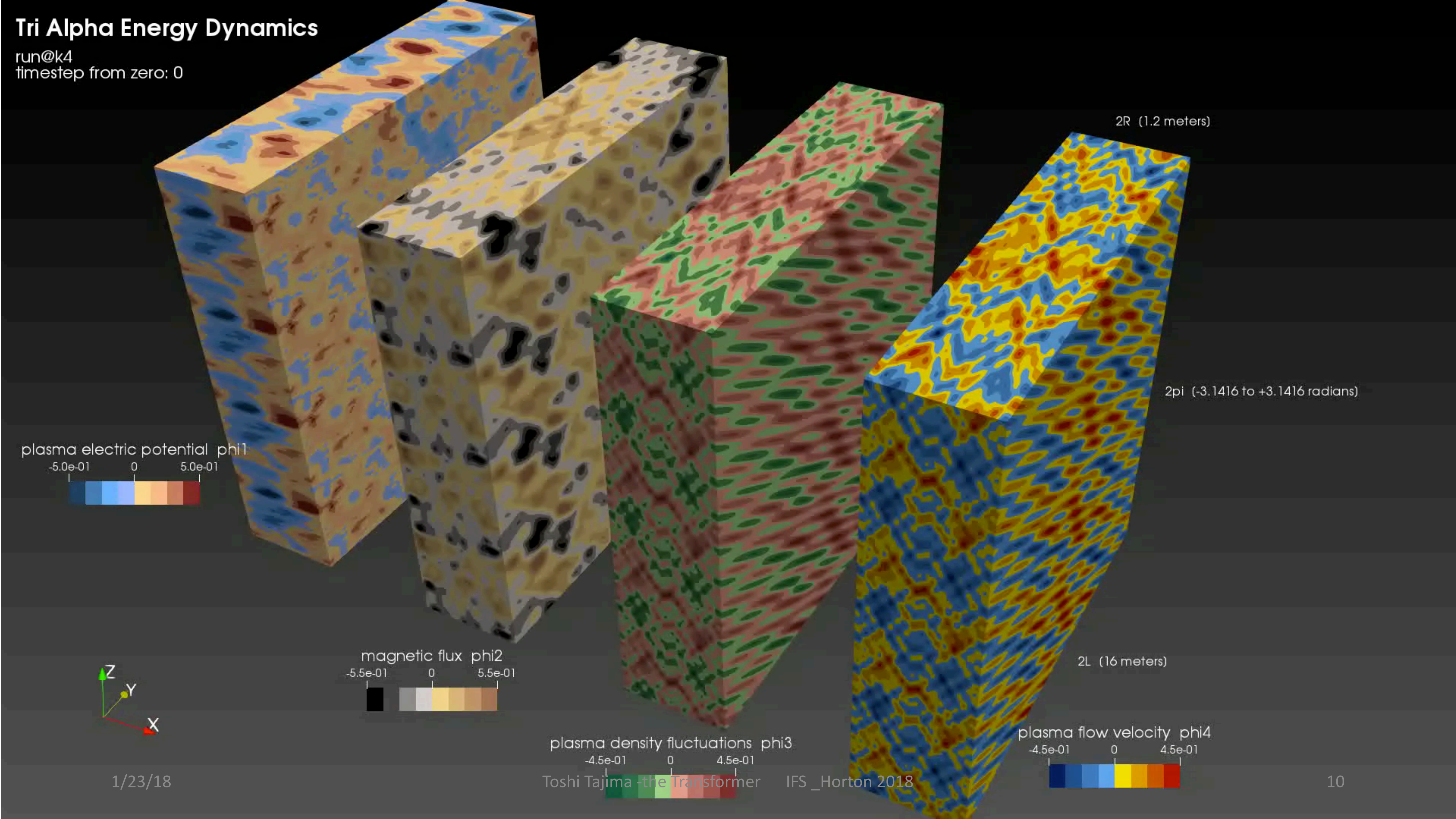
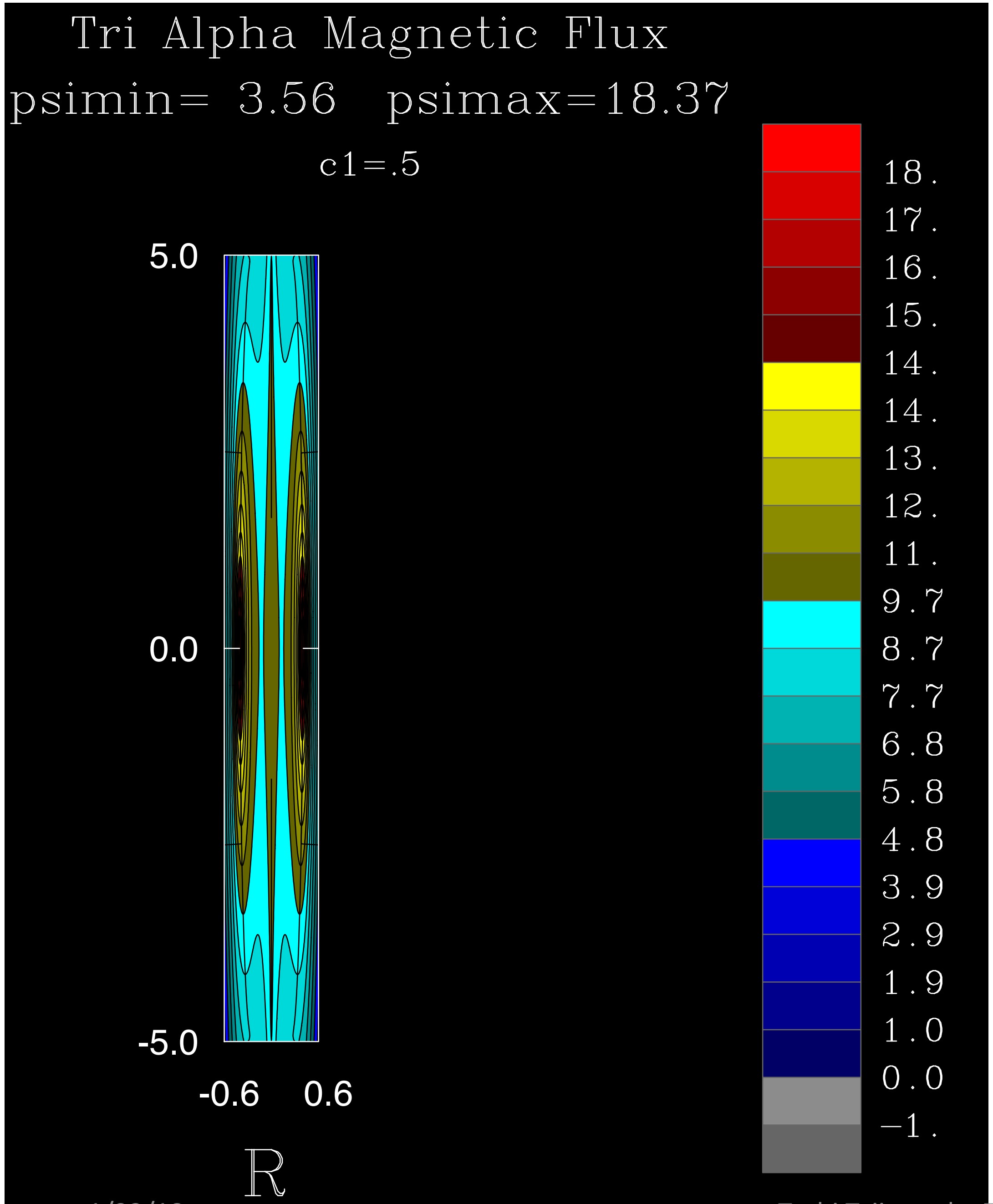
Tri Alpha Energy Dynamics





Tri Alpha Magnetic Flux
psimin= 3.56 psimax=18.37
c1=.5
5.0
0.0
-5.0
-0.6
0.6
R
18.
17.
16.
15.
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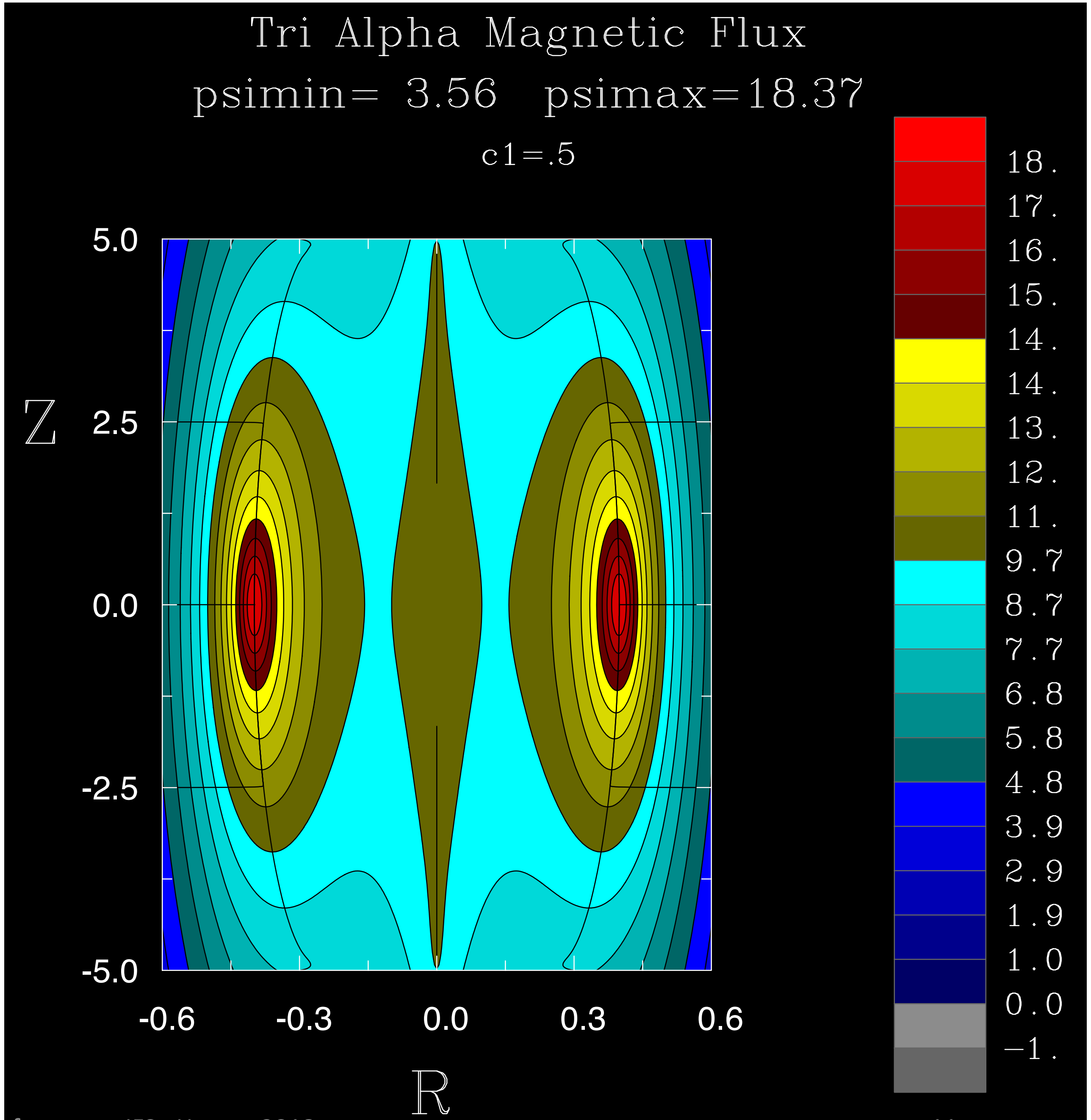

Tri Alpha Magnetic Flux
psimin= 3.56 psimax=18.37
c1=.5
Z
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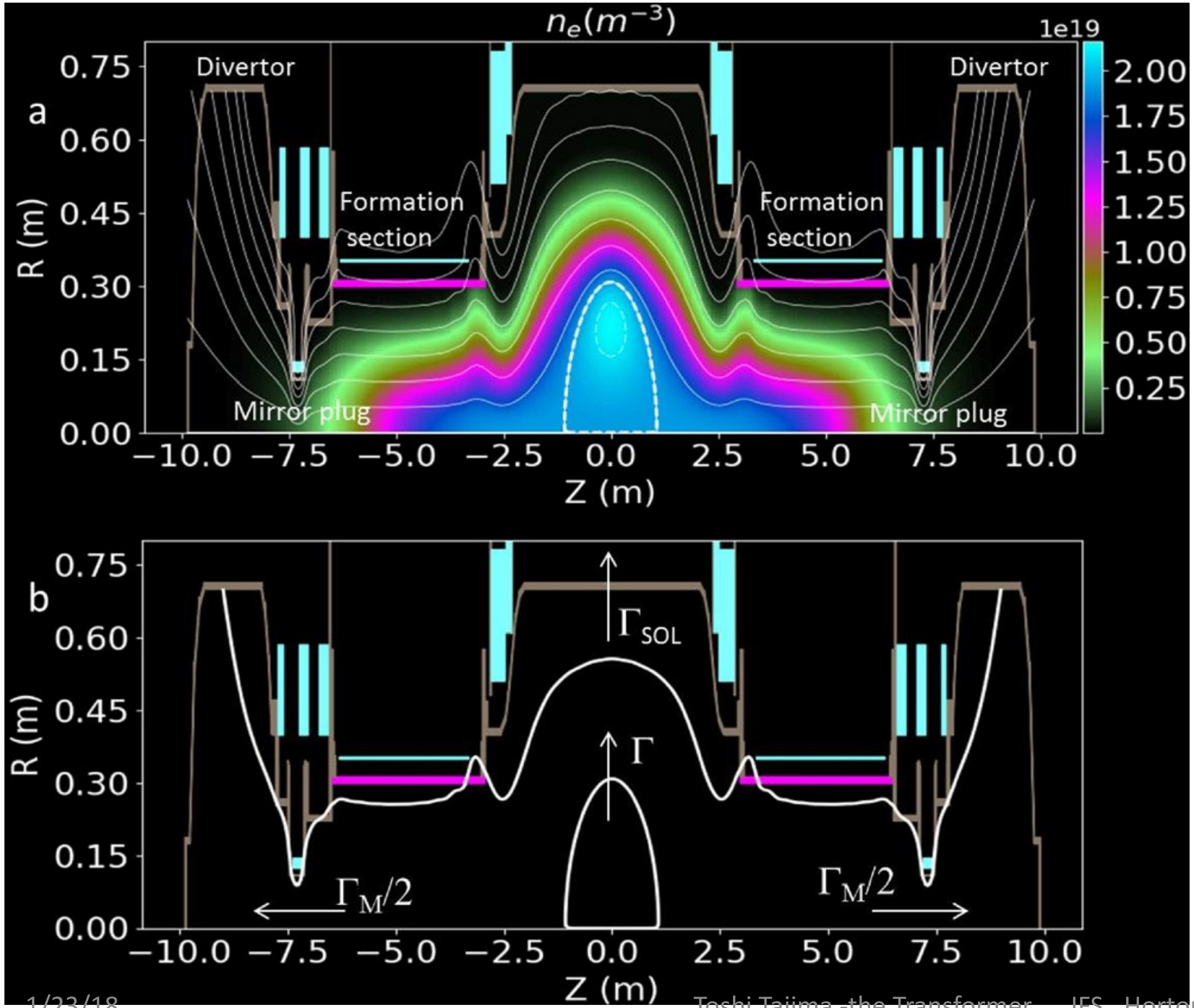
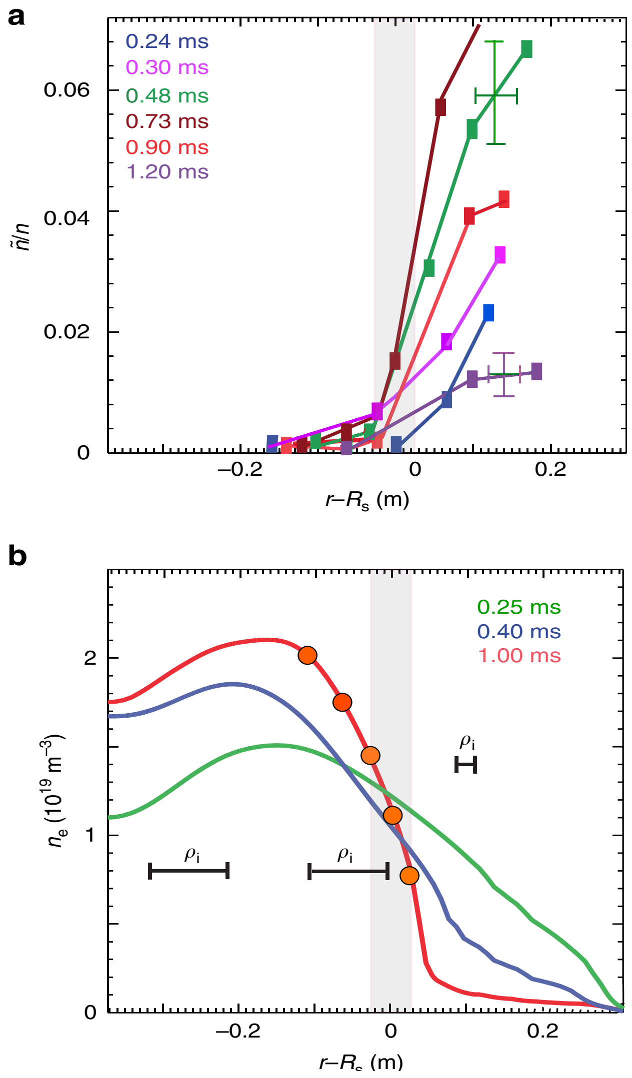
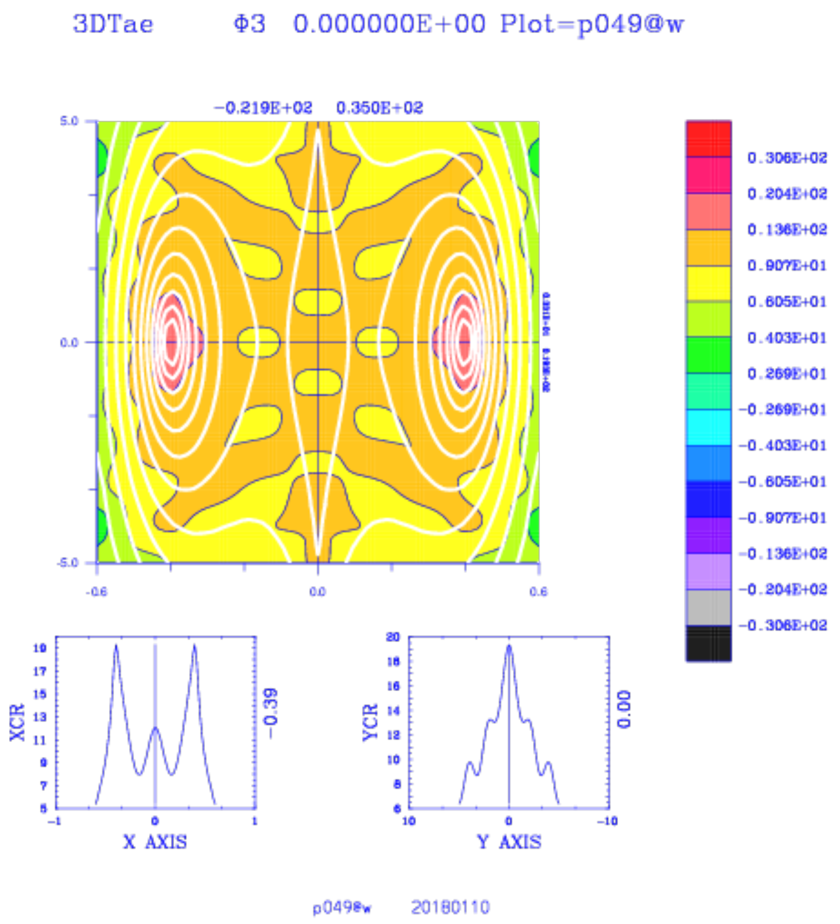
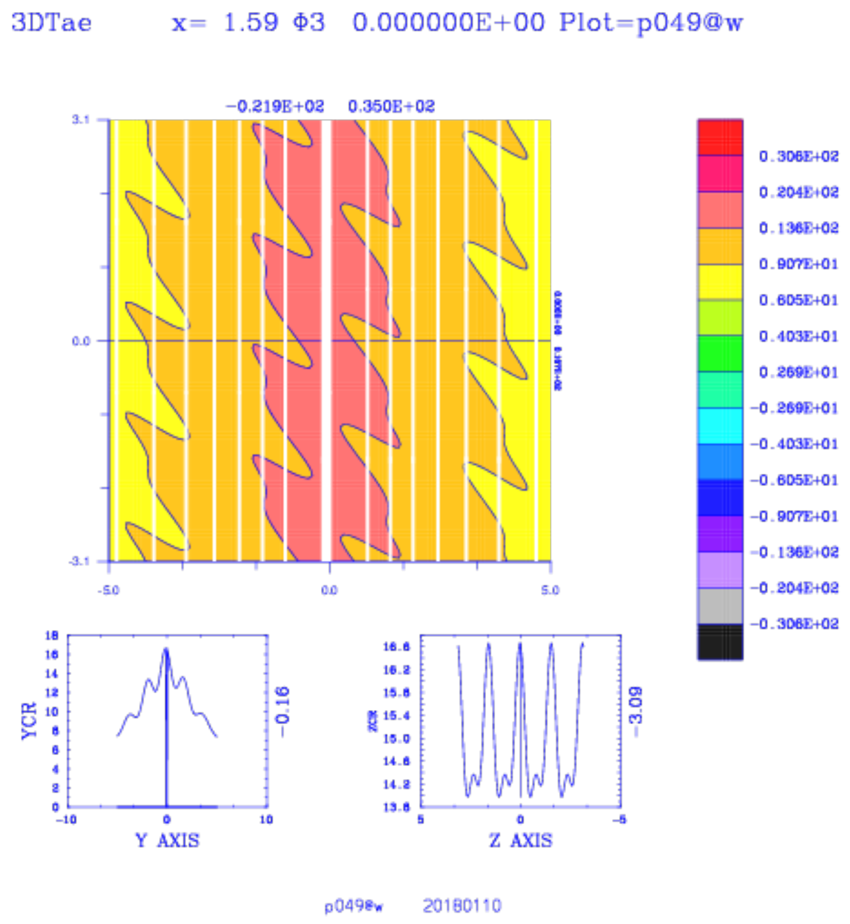
Norman C-2W Density fluctuations from the Doppler shifts Back Scattered RF X- and O-mode Beams



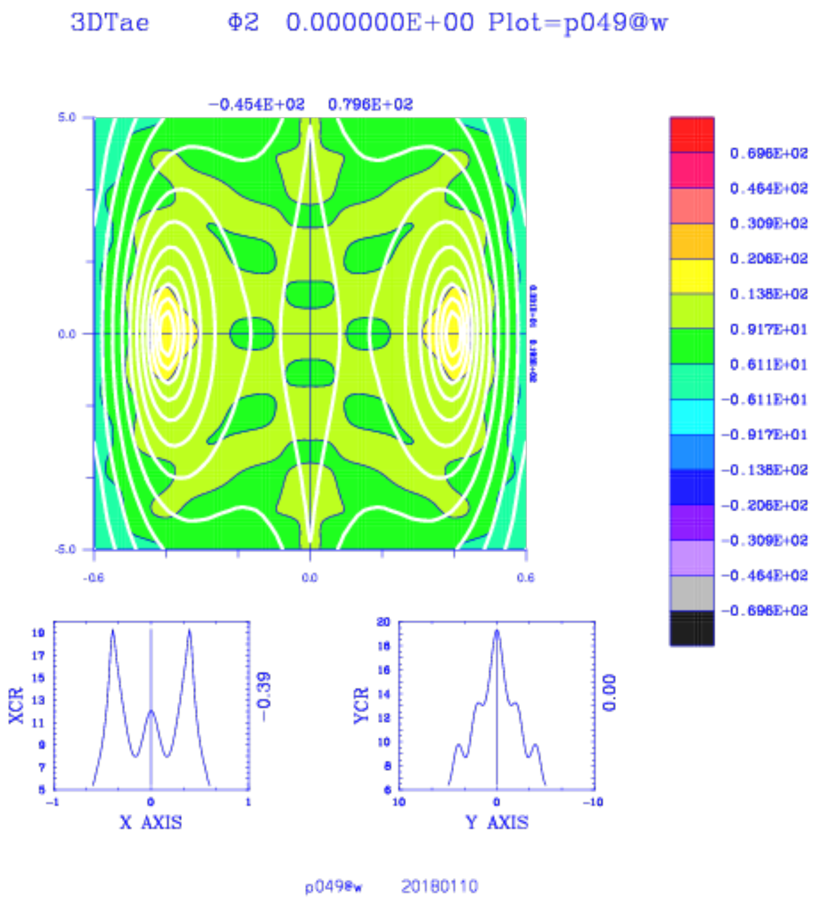


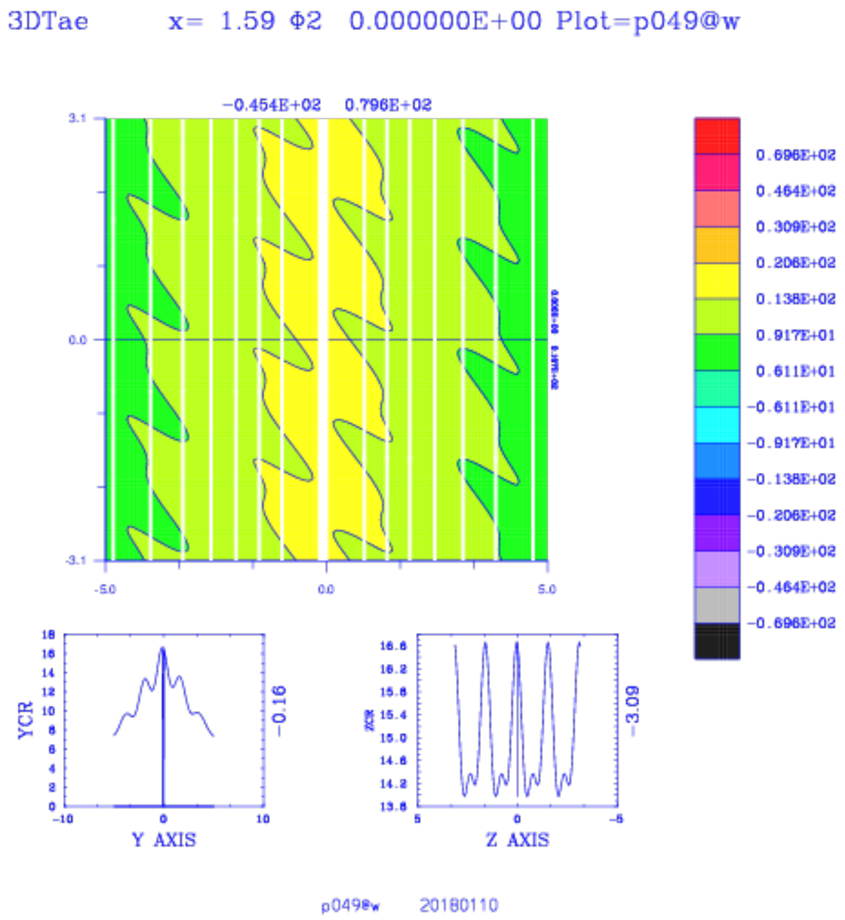
Density Waves



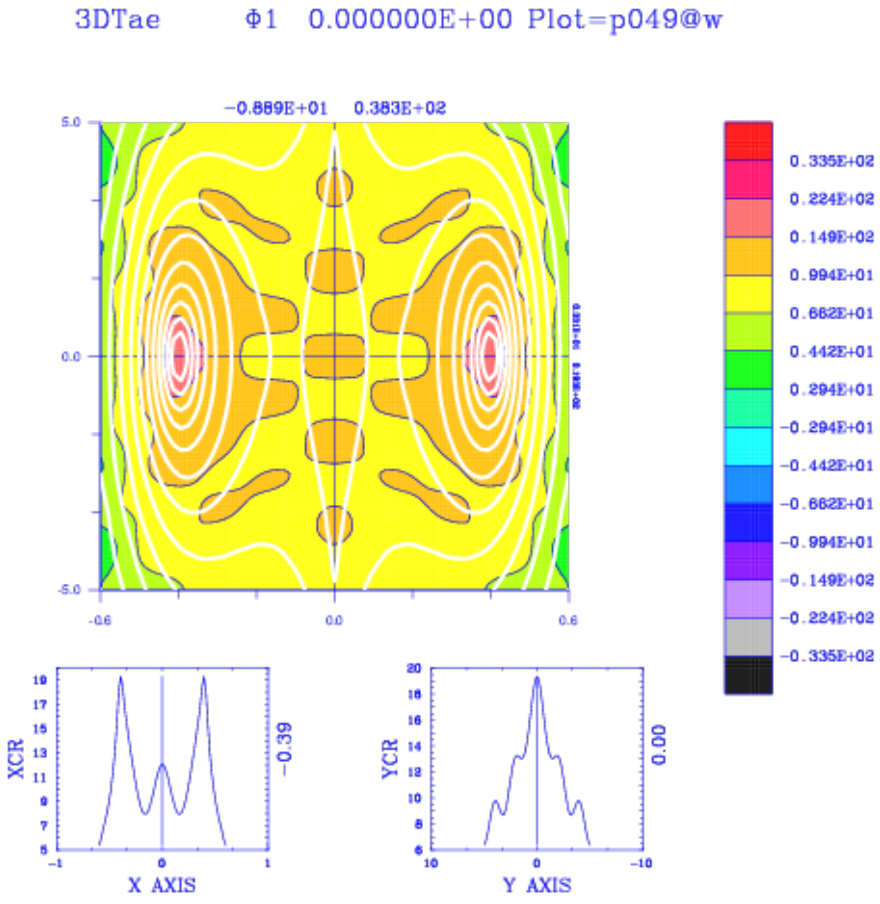


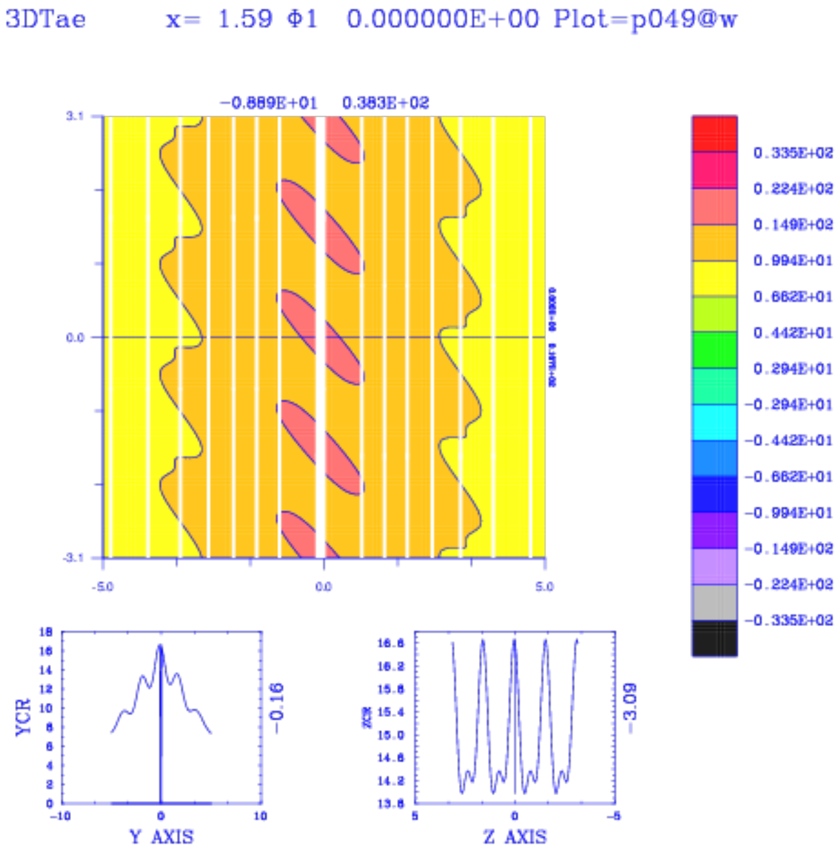
Magnetic Fluctuations \phi2



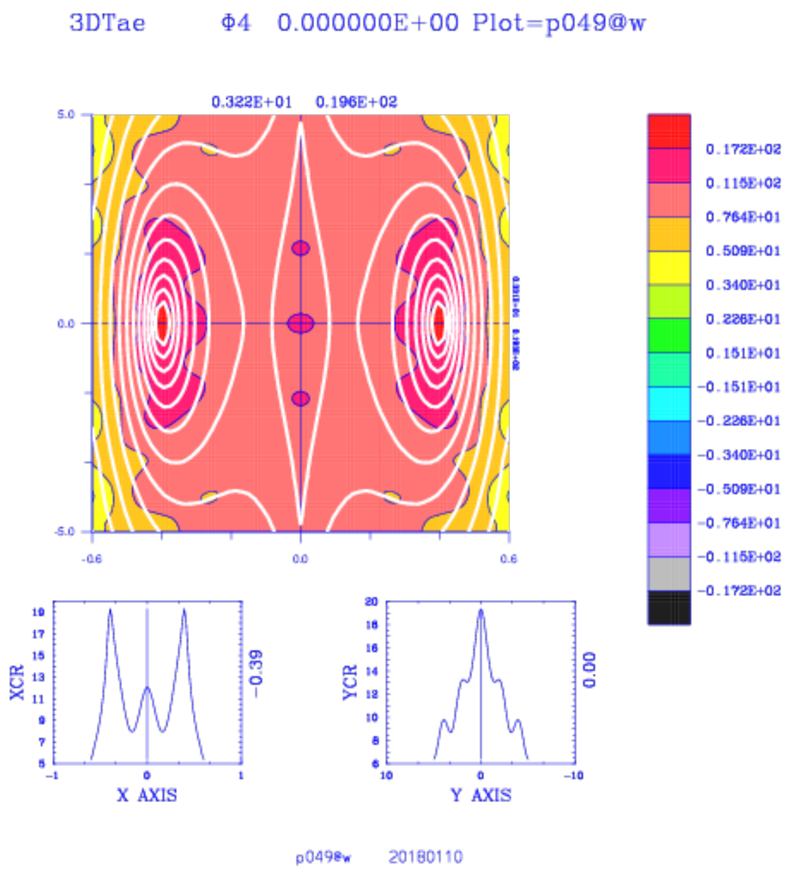


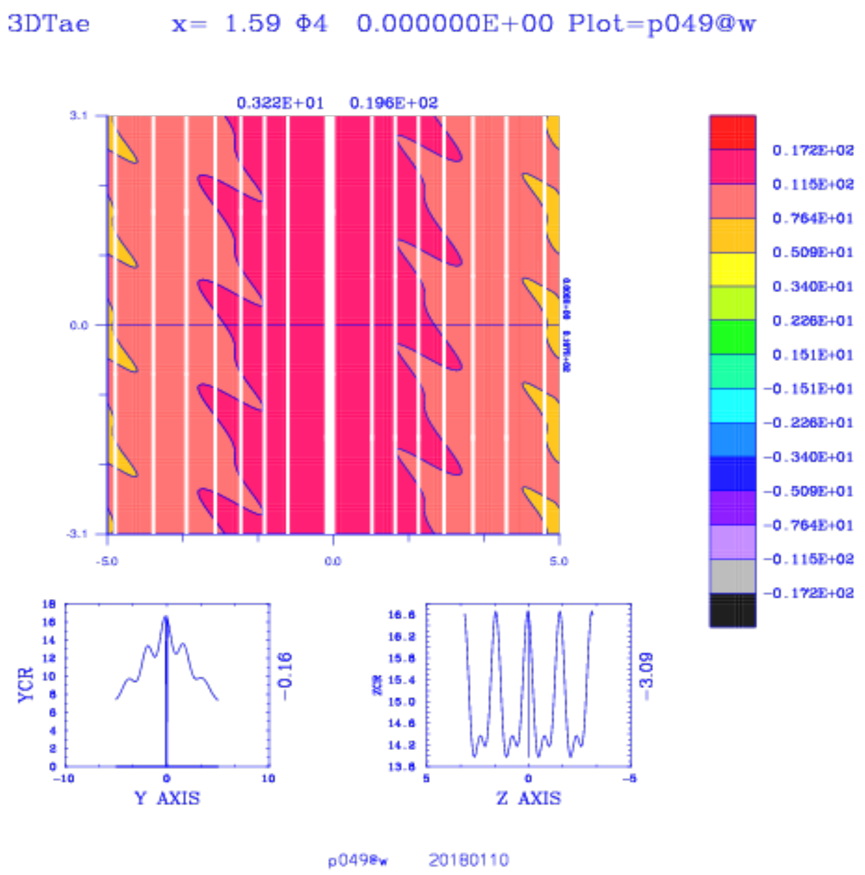
Electric Potential Fluctuations \phi1





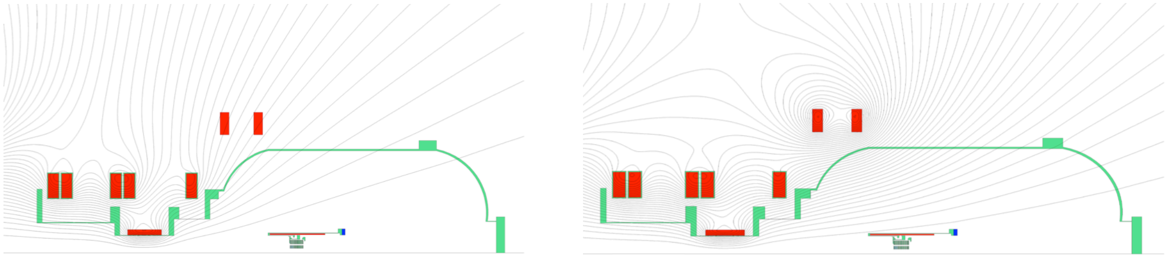
Ion Temperature Fluctuations \phi4





Mathematical Methods required for Relaxation Dynamics

- System of nonlinear PDEs for 4 to 6 plasma fields in 3D.
- Examples here for \ phi 1,2,3,4 (x,y,z,t) with a specified machine flux function we call \psi5 (x,y)

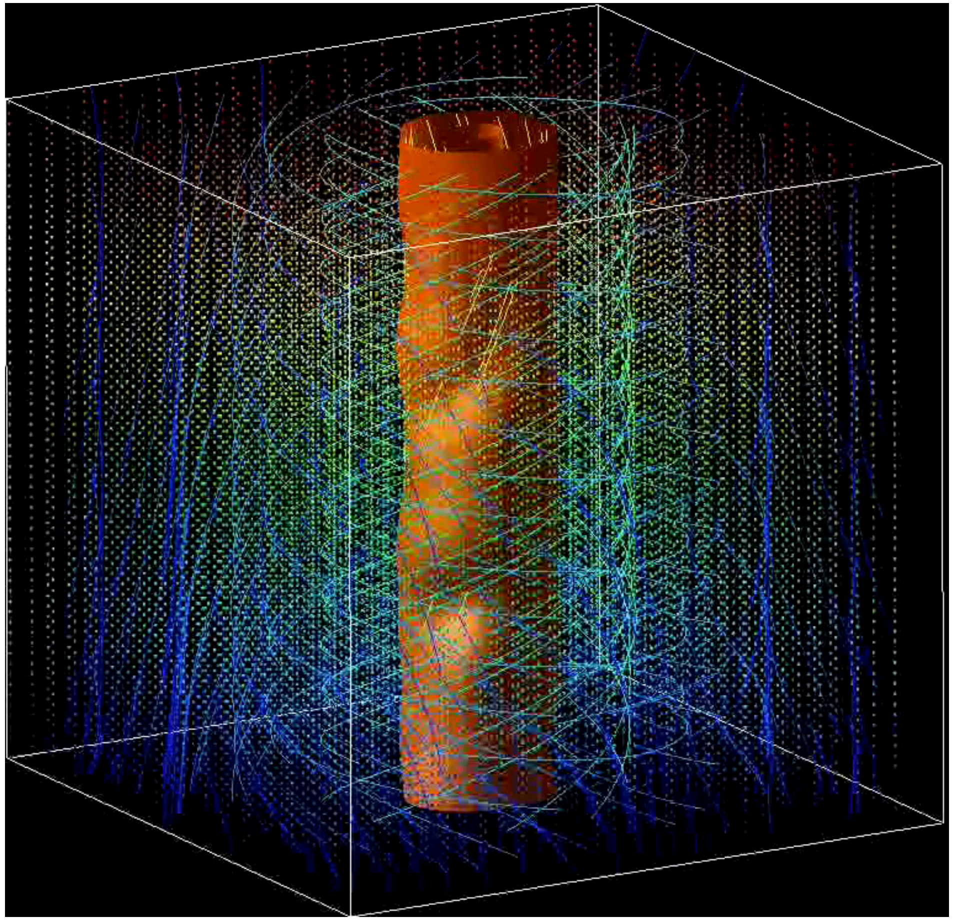


(a) (b)

radial coordinate = x
length coordinate = y and
z = angle around y axis
[aka ”tokamak –like” coordinates]

Each time step in k_x,k_y,k_z and x,y,z space = pseudo-spectral code
Boundary conditions applied with absorbing Mask shaped like the walls of the machine PDEs and a core energy-plasma sources.

Plasma Flux Tube with test particles [dust] -Goes unstable from 3D dynamics of R-T and K-H



Conclusions & Lessons from TT the Transformer

- **There is wide similarity in the plasma dynamics from the laboratory, to magnetospheres and into solar/astrophysics Plasmas. This is inspiring to all…scienitists,engineers and the public!**
- **TT teaches us Examples from accelerators, magnetospheres, solar/astrophysics [mother nature!] - helping us see that we can build and produce fusion power!**
- **New Tools -- Bigger Simulations …GK-PIC tools and Global View - Beat Wave Accelerator, Magnetosphere, Tokamaks and many New Confinement geometries!**
- **Enjoys leading and inspiring his colleagues with NEW IDEAS -- Gives us a genuine message: we are NEEDED !**

References

1. M. Tuszewski, Nucl. Fusion **28**, 2033 (1988).
2. L.C. Steinhauer, Phys. Plasmas **18**, 070501 (2011).
3. M.N. Rosenbluth, N.Krall, and N.Rostoker, Nucl. Fus. Suppl. **1**, 143 (1962).
4. H. Naitou, T. Kamimura and J. Dawson, J. Phys. Soc. Jpn. **46**, 258 (1979).
5. R. Horiuchi, T. Sato, Phys. Fluids B **1**, 581 (1989).
6. W.W. Heidbrink and G.J. Sadler, Nucl. Fusion **34**, 535 (1994).
7. M.W. Binderbauer, *et al.*, Phys. Rev. Lett. **105**, 045003 (2010).
8. M. Tuszewski *et al.*, Phys. Rev. Lett. **108**, 255008 (2012).
9. H.Y. Guo, *et al.*, Nature Communications **6**, 6897 (2015).
10. M.W. Binderbauer, *et al.*, Phys. Plasmas **22**, 056110 (2015).
11. B. H. Deng, *et al.*, Rev. Sci. Instrum. **85**, 11D401 (2014).
12. M. Onofri, *et al.*, to be submitted to Phys. Plasmas (2016).
13. M.N. Rosenbluth and M.N. Bussac, Nucl. Fusion **19**, 489 (1979).
14. S. Ohi, *et al.*, Phys. Rev. Lett. **51**, 1042 (1983).
15. T. Tajima and J.M. Dawson, Phys. Rev. Lett. **43**, 267 (1979).
16. T. Tajima and A. Necas, in this Proceedings (AIP, NY, 2016).
17. M. Binderbauer and N. Rostoker, J. Plasma Phys. **56**, 451 (1996).
18. L. Schmitz, in this Proceedings (AIP , NY, 2016).