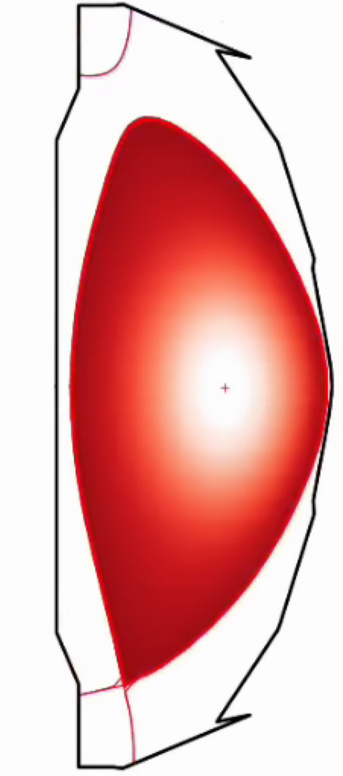
Development of a New Portable EFIT for NSTX and NSTX-U

J. McClenaghan

In collaboration with

O.M. Meneghini, K.E. Thome, G. Avdeeva, S.P. Smith

S. Kruger, T. Bechtel, L.L Lao

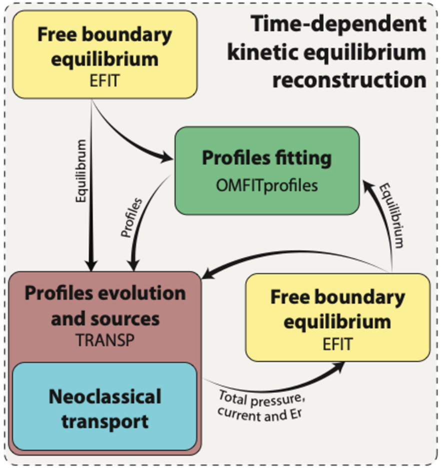


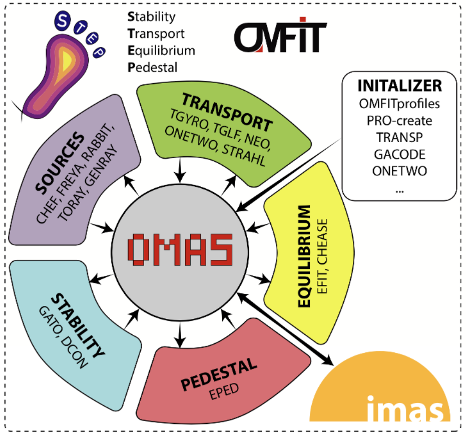
Virtually presented at the
NSTX-U/Magnetic Fusion Science Meeting
San Diego, CA
September 27, 2021

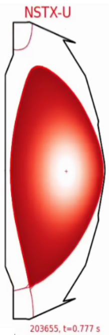
GENERAL ATOMICS

Predict-first modeling and experimental demonstration of a fully noninductive scenario in NSTX-U (Task 1)

- **Year 1:** Implement capability to perform interpretive and predictive simulations for NSTX and NSTX-U
  - Will use both STEP (single time point OMFIT module) and predictive TRANSP (for time-evolving)
- **Year 2 and 3:** Perform predictions for upcoming NSTX-U campaigns
- **Year 4:** Implement improved predictive and H&CD models based on experimental data and perform predictions for upcoming NSTX-U campaigns
- **Year 5:** Implement new TGLF version optimized for low aspect ratio and validate in high beta plasmas







GENERAL ATOMICS

EFIT-AI project is designed to accelerate EFIT reconstructions for real-time purposes

Enhanced equilibrium reconstruction with ML/AI assisted kinetic profiles, Bayesian framework, and MOR-base physics-informed models to enable real-time (RT) applications

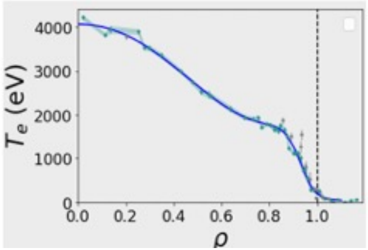
DIII-D NATIONAL FUSION FACILITY SAN DIEGO

JET

KSTAR

EAST

NSTX-U



ML uses DIII-D data for improved control and stability

iter
china eu india japan korea russia usa

Make EFIT device independent and more portable → Use machine learning to accelerate EFIT → Develop new EFIT-AI tool

Gather existing equilibrium reconstructions from various devices → Use machine learning to accelerate EFIT

EFIT-AI

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EAST

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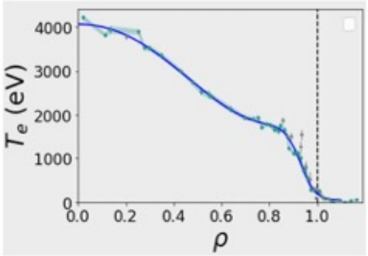

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DIII-D
NATIONAL FUSION FACILITY
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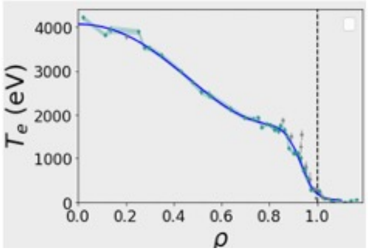
EAST

NSTX-U

A. Pankin



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EFIT-AI

EFIT is being modernized and made portable

- Hosted on https://gitlab.com/efit-ai/efit
- CMake used as build system to enable enabling/disabling I/O and machine-specific information
- Compatible with modern GNU, INTEL, PGI Fortran compilers
- Continuous integration and continuous delivery using gitlab.com to ensure every push can run in production

S. Kruger and T. Bechtel

Continuous integration and continuous delivery automatic regression testing

- **Tests Magnetic, MSE, Er Correction, and kinetic EFITs, and generation of Green’s function tables**

- **Currently there is no regression for NSTX**
  - Require mhdin.dat & kEQDSK file on gitlab

```
[(base) mcclenaghan@F-C02Z321ML build % make test
Running tests...
Test project /Users/mcclenaghan/programming/efit/build
      Start  1: green
 1/12 Test  #1: green ............................   Passed   23.76 sec
      Start  2: green-results
 2/12 Test  #2: green-results ....................   Passed    0.06 sec
      Start  3: efit01
 3/12 Test  #3: efit01 ...........................   Passed    0.76 sec
      Start  4: efit01-results
 4/12 Test  #4: efit01-results ...................   Passed    0.05 sec
      Start  5: efit02
 5/12 Test  #5: efit02 ...........................   Passed    1.15 sec
      Start  6: efit02-results
 6/12 Test  #6: efit02-results ...................   Passed    0.05 sec
      Start  7: efit02er
 7/12 Test  #7: efit02er .........................   Passed    1.23 sec
      Start  8: efit02er-results
 8/12 Test  #8: efit02er-results .................   Passed    0.05 sec
      Start  9: rfile
 9/12 Test  #9: rfile ............................   Passed    0.60 sec
      Start 10: rfile-results
10/12 Test #10: rfile-results ....................   Passed    0.04 sec
      Start 11: kineticEFIT
11/12 Test #11: kineticEFIT ......................   Passed    3.06 sec
      Start 12: kineticEFIT-results
12/12 Test #12: kineticEFIT-results ..............   Passed    0.05 sec

100% tests passed, 0 tests failed out of 12

Total Test time (real) =  30.91 sec
```

The EFIT documentation is being revamped with Sphinx

- Sphinx is a documentation generator that translates a set of plain text source files into various output formats

EFIT

Search docs

- Installation
- Quick-start
- EFIT subroutines
- EFIT modules
- EFIT input namelist
- Database
- License

» Welcome to EFIT's documentation!

View page source

Welcome to EFIT's documentation!

EFIT Equilibrium Fitting code

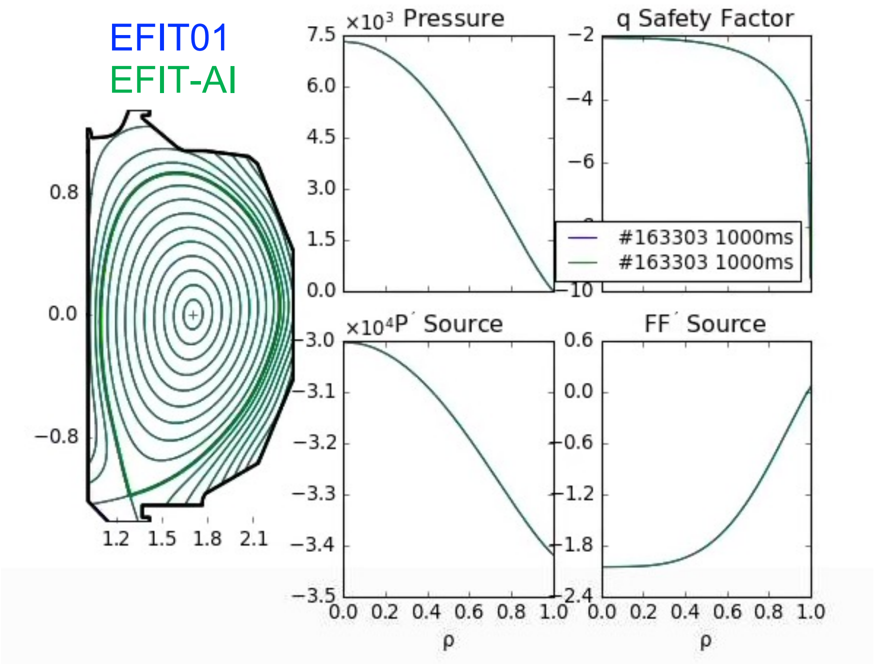
EFIT (Equilibrium Fitting) is a computer code developed to translate measurements from plasma diagnostics into useful information like plasma geometry, stored energy, and current profiles. The measuremnts are obtained from diagnostics such as external magnetic probes, external poloidal flux loops, and the Motional Stark Effect (MSE), which measures the direction of the magnetic field lines inside the plasma. The Grad-Shafranov equilibrium equation, which describes the force balance in a plasma, is solved using the available measurements as constraints on the toroidal current density. Since the current also depends on the solution of the equation, the poloidal flux function, this is a nonlinear optimization problem. The equilibrium constraint allows the two-dimensional current density to be represented by two one-dimensional stream functions (functions only of flux), which significantly reduces the complexity of the problem.

Documentation contents

- Installation
  - Public Installations
  - Installing from source
  - Configuring third-party libraries
- Quick-start
  - Executable location
  - Forming Green function tables
  - Running EFIT
  - Running tests
- EFIT subroutines
  - msels_hist.f90

EFIT-AI has been shown reproduce to standard EFIT at DIII-D

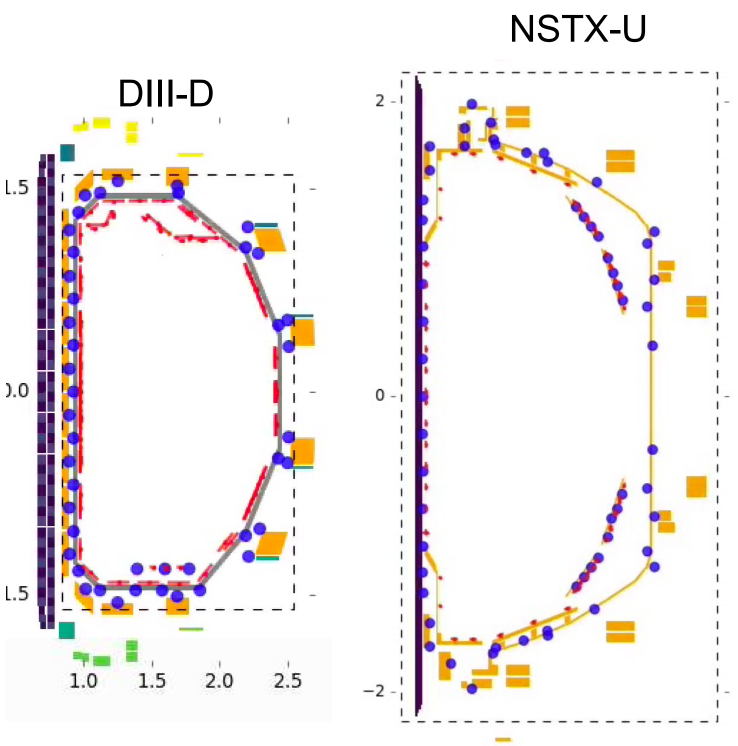
- **Identical agreement with both versions of the code down to machine precision**



GENERAL ATOMICS

EFUND generates Green's function look up tables for EFIT

- **Read external-coil, vessel, magnetic probe geometry, and computational grid, then computes magnetic responses (Green functions)**
- **Input fortran namelist (mhdin.dat)**
- **Output binary files for response (rv6565.ddd,fc6565.ddd rfcoil.ddd, ...)**



GENERAL ATOMICS

Machine dependent parameter sizes have been added to the EFUND mhdin.dat input file

- **Allocatable array sizes based on MACHINEIN**
- **dprobe.dat file is automatically generated to increase reliability**
  - Requires lumping diagnostics into one toroidal location

EFUND

```
&machinein
nfcoil = 178
nfsum = 54
nsilop = 66
magpr2 = 108
necoil = 240
nesum = 1
nvesel = 40
nvsum = 39
nrogow = 1
nacoil = 1
mgaus1 = 8
mgaus2 = 10
/
```

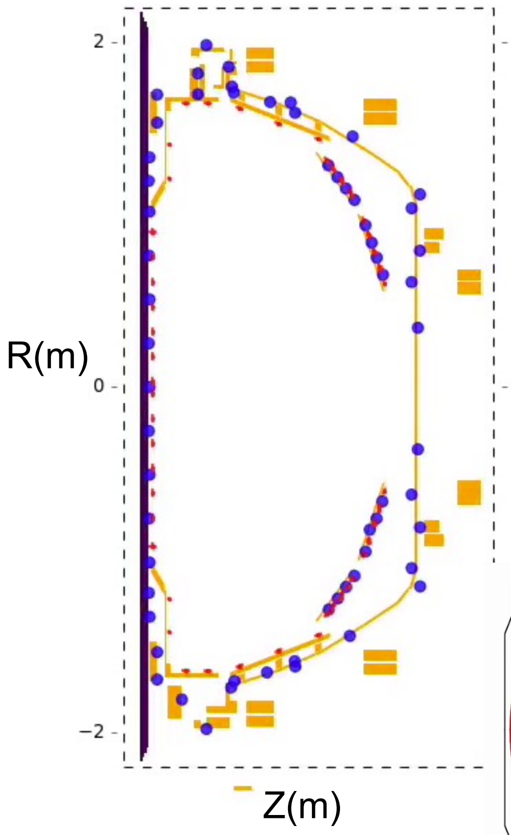
EFIT

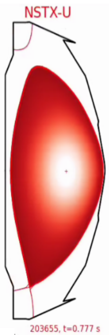
```
&MACHINEIN
NSILDS=1 ,
NSILOL=60 ,
NFCOIL=52 ,
NROGOW=1 ,
NACOIL=1 ,
MFCOIL=93 ,
NECOIL=240 ,
NVESEL=25 ,
MPRESS=201 ,
NESUM=1 ,
MAGPRI67=1 ,
MAGPRI322=66 ,
MAGPRIRDP=1 ,
MAGUDOM=1 ,
MAGLDS=1 ,
MSE315=1 ,
MSE45=0 ,
MSE15=0 ,
MSE1H=0 ,
MSE315_2=0 ,
MSE210=0 ,
LIBIM=32 ,
NMSELS=16 ,
NNECE=40 ,
NNECEIN=80 ,
NECEO=1 ,
NNNTE=801 ,
NGAM_VARS=9 ,
NGAM_U=5 ,
NGAM_W=3 ,
NLIMIT=160 ,
NLIMBD=6 ,
NANGLE=64 ,
NTANGLE=12 ,
NFBCOIL=12 ,
MCCOIL=6 ,
MICOIL=12 ,
NDATA=61 ,
NWWCUR=32 ,
NFFCUR=32 ,
NPPCUR=32 ,
NERCUR=32 ,
```

GENERAL ATOMICS

Green's function tables for EFIT-AI have been generated for NSTX and NSTX-U

- **S. Sabbagh was instrumental**
- **Green's functions stored at**
  - /p/nstx/efit_GA/efit_support_files/green
- **Available resolutions**
  - 65x65, 129x129, 257x257, 513x513
- **Proper tables chosen by shot**
  - 0 (NSTX)
  - 106806 (NSTX)
  - 112811 (NSTX)
  - 200000 (NSTX-U)



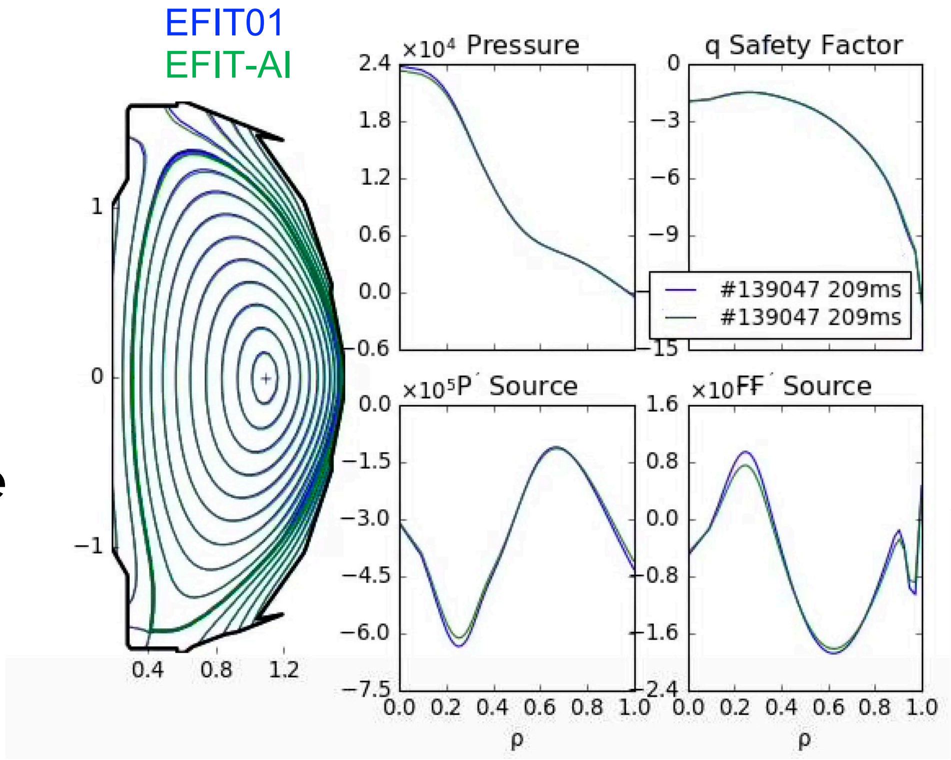


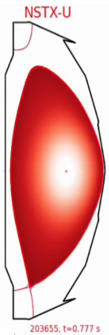
GENERAL ATOMICS

EFIT-AI shows good agreement with NSTX EFIT01

- **EFIT01** and **EFIT-AI** simulated using kEQDSK fetched from MDS+ generated by phoenix code

- Minor differences betwee the two versions of EFIT





GENERAL ATOMICS

Running EFIT-AI using the command line on portal

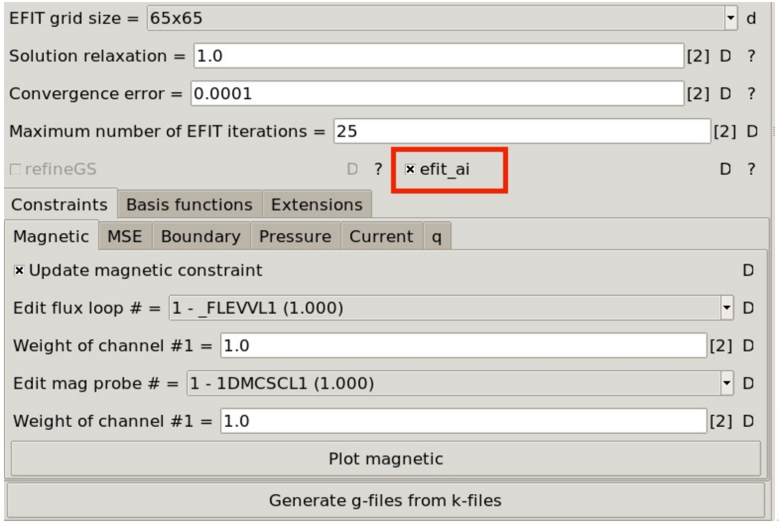
- **Starting with kEQDSK:**

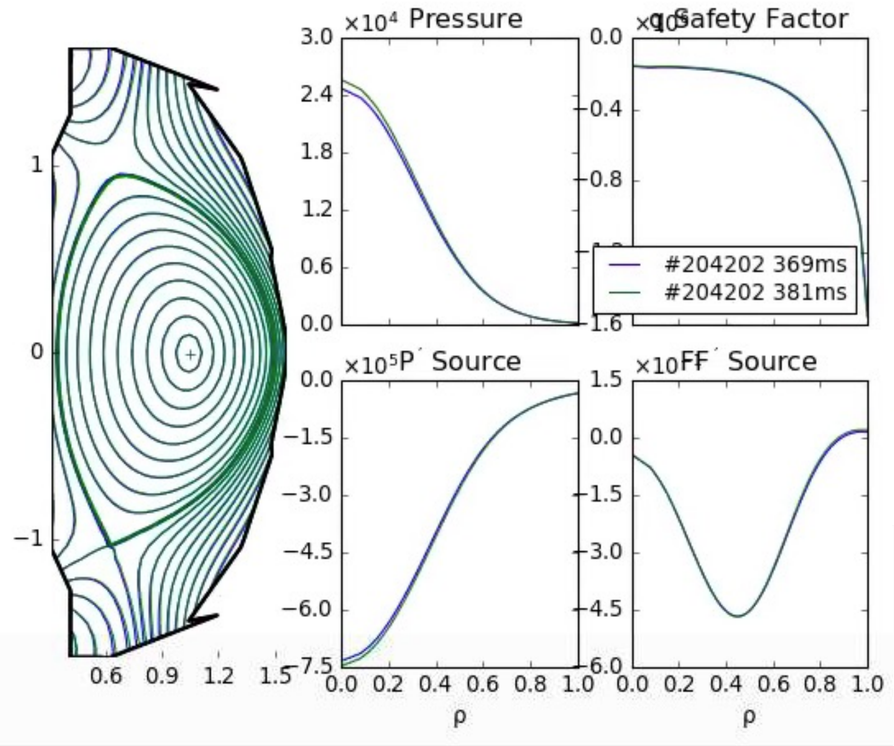
```
module purge
module load gcc/9.3.0
setenv link_efit /p/nstx/efit_GA/efit_support_files/NSTX/
/p/nstx/efit_GA/efit/build/efit/efit 129
```

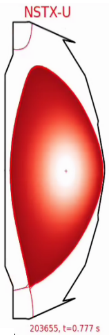
```
[jmcclena@portal-ext]% module purge
[jmcclena@portal-ext]% module load gcc
[jmcclena@portal-ext]% setenv link_efit /p/nstx/EFIT_GA/efit_support_files/NSTX/
[jmcclena@portal-ext]% /p/nstx/EFIT_GA/efit/build/efit/efit 129

          EFITD Version  11/23/2020


 type mode (2=file, 3=snap, 4=time, 5=input, 6=com file, 7=snap_ext, 8=pefit):
2

 number of time slices?
1

 type input file names:
 #
kfile
 table_di2 = </p/nstx/EFIT_GA/efit_support_files/NSTX/green/112811/>

      ******************** EFITD129 x 129  output ********************
 before save fitting weights
 adjust fit parameters based on basis function selected
 itek > 100, write out PLTOUT.OUT individually
 option to symmetrize added 8/14/91 eal
 read in limiter data

 r=  0 t=   343 it=  1 chi2=2.34E+02 zm= 3.13E-07 err=3.976E+00 dz= 3.132E-07 chigam= 0.00E+00
WARNING in findax at r=  0, t=   343: 2nd seperatrix point is not inside vessel, zeross.le.0.1
 r=  0 t=   343 it=  2 chi2=7.18E+01 zm= 1.45E-01 err=4.119E-01 dz= 1.453E-01 chigam= 7.55E+01
 r=  0 t=   343 it=  3 chi2=8.98E+01 zm= 3.27E-03 err=2.491E-01 dz=-1.421E-01 chigam= 5.54E+01
WARNING in findax at r=  0, t=   343: 2nd separatrix point is off grid
 r=  0 t=   343 it=  4 chi2=7.61E+01 zm= 4.19E-03 err=3.794E-02 dz= 9.156E-04 chigam= 4.94E+01
WARNING in findax at r=  0, t=   343: 2nd separatrix point is off grid
 r=  0 t=   343 it=  5 chi2=7.17E+01 zm= 4.83E-03 err=2.917E-02 dz= 6.354E-04 chigam= 5.50E+01
 r=  0 t=   343 it=  6 chi2=7.33E+01 zm= 5.35E-03 err=1.399E-02 dz= 5.290E-04 chigam= 5.73E+01
 r=  0 t=   343 it=  7 chi2=7.29E+01 zm= 5.87E-03 err=6.091E-03 dz= 5.119E-04 chigam= 5.84E+01
WARNING in findax at r=  0, t=   343: 2nd separatrix point is off grid
 r=  0 t=   343 it=  8 chi2=7.41E+01 zm= 6.36E-03 err=3.072E-03 dz= 4.903E-04 chigam= 5.91E+01
 r=  0 t=   343 it=  9 chi2=7.41E+01 zm= 6.83E-03 err=2.304E-03 dz= 4.731E-04 chigam= 5.93E+01
 r=  0 t=   343 it= 10 chi2=7.41E+01 zm= 7.28E-03 err=1.103E-03 dz= 4.473E-04 chigam= 5.96E+01
 r=  0 t=   343 it= 11 chi2=7.41E+01 zm= 7.70E-03 err=7.994E-04 dz= 4.189E-04 chigam= 5.96E+01
WARNING in fit at r=  0, t=   343: not converged, reached max iterations

       data used:
 37 flux loops
 48 magnetic probes(i)
  1 full rogowski
  1 diamagnetic loop
```

EFIT-AI has been setup to run inside of OMFIT

efit_ai checkbox sets Green's function tables and executable into the standard OMFIT workflow





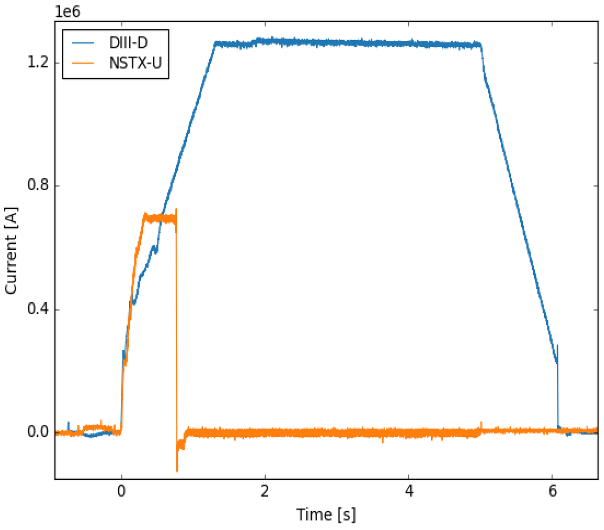


GENERAL ATOMICS

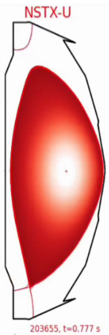
We are leveraging OMAS machine mappings and OMFIT classes to generalize creation of kEQDSK EFIT input files

- **Three steps for device independent generation of kEQDSK**
  - Dynamic map of experiments data to ITER IMAS data structure
  - Generate equilibrium IMAS constraints from experimental IMAS
  - Generate EFIT kEQDSK input files from equilibrium IMAS constraints

```
# DIII-D data
ods_d3d = ODS()
with ods_d3d.open('d3d', 168830):
    plot(ods_d3d['magnetics.ip[0].time'],
         ods_d3d['magnetics.ip[0].data'],
         label='DIII-D')

# NSTX-U data
ods_nstxu = ODS()
with ods_nstxu.open('nstxu', 204202):
    plot(ods_nstxu['magnetics.ip[0].time'],
         ods_nstxu['magnetics.ip[0].data'],
         label='NSTX-U')
```



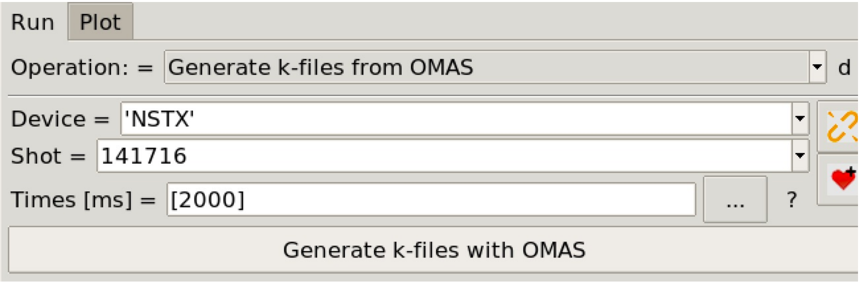
O.M. Meneghini



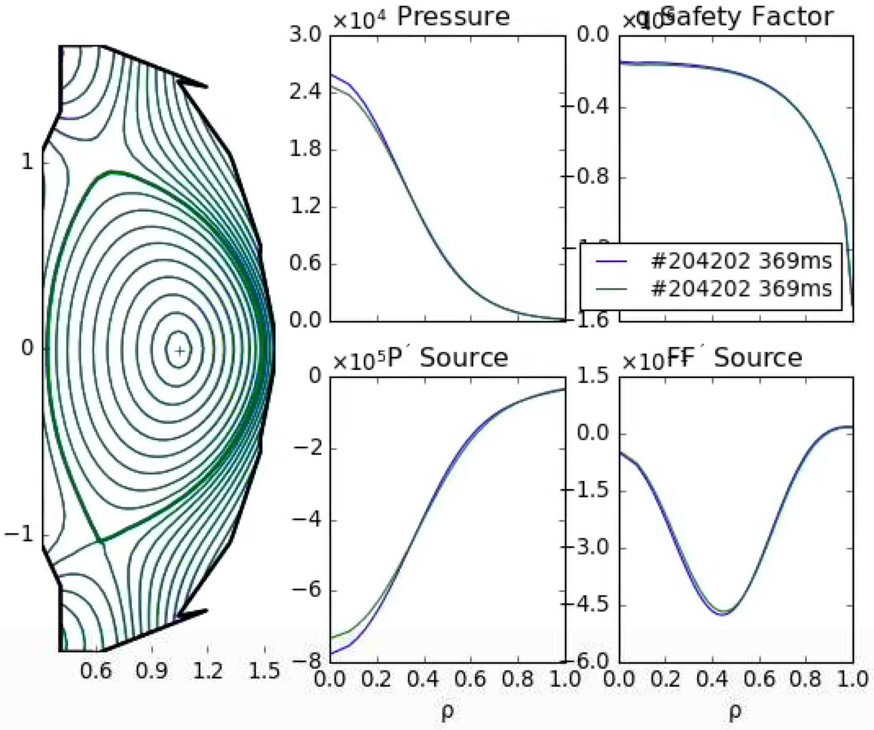
GENERAL ATOMICS

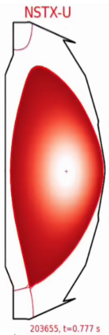
EFIT-AI equilibrium generated from OMAS kEQDSK shows good agreement with EFIT01

```python
# Generate a kEQDSK file from experimental data
ods=ODS()
with ods.open('nstxu', 204202):
    kEQDSK = OMFITkeqdsk().from_omas(ods, time=0.369)
```



- **EFIT01**
- **EFIT-AI + omas kEQDSK**

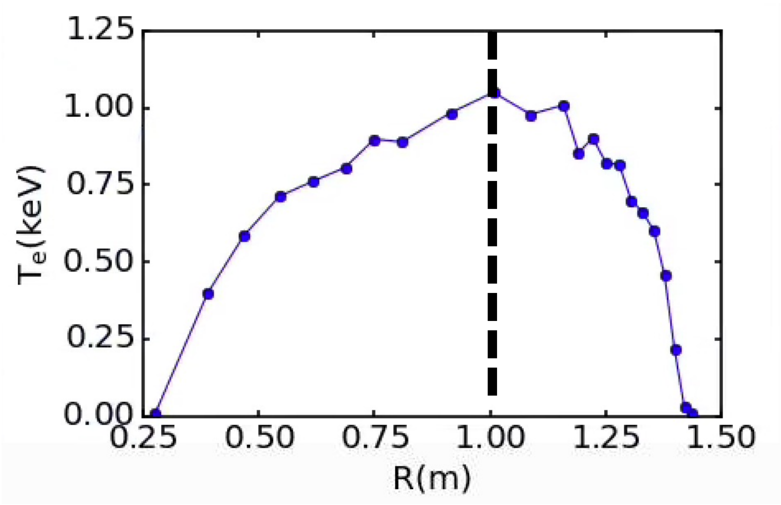


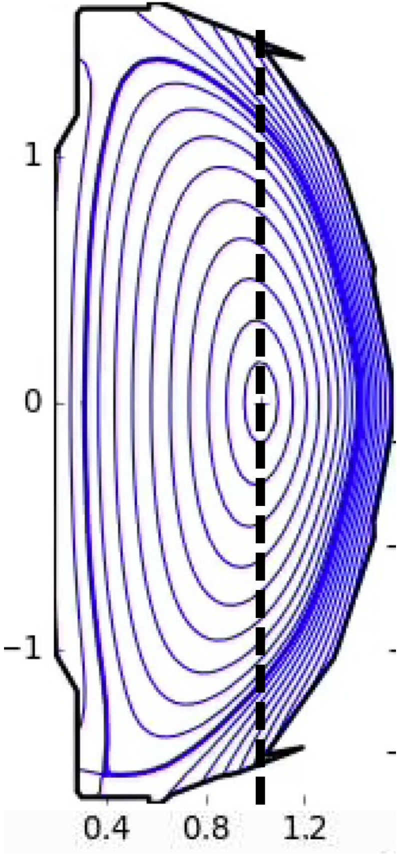


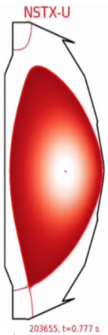
GENERAL ATOMICS

Isothermal Te constraints useful for EFIT equilibrium reconstructions

- **Thomson from HFS and LFS used to constrain equilibrium due to fast parallel heat conductivity**
- **Used regularly for NSTX(-U)**

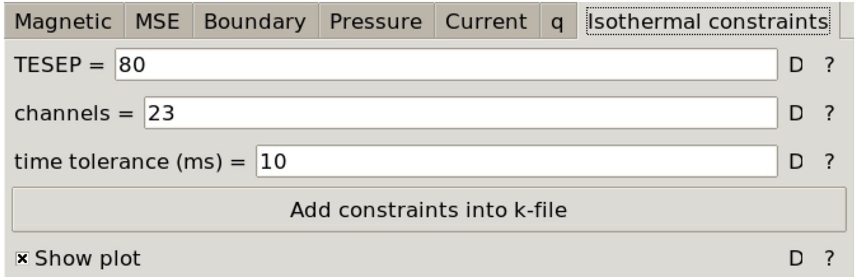


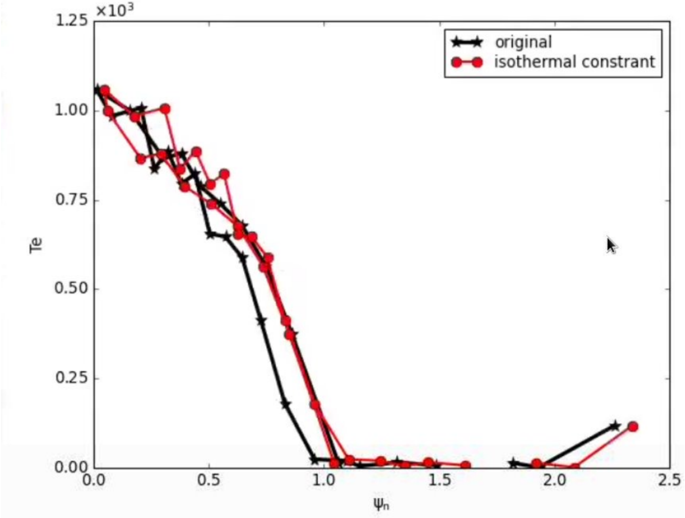




GENERAL ATOMICS

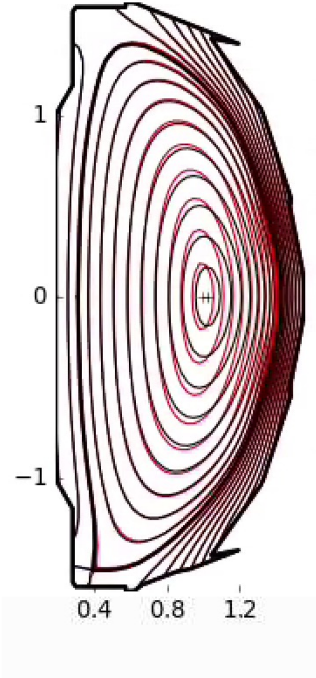
Isothermal Te constraints into EFIT has been setup in OMFIT



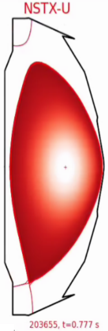


Original

Isothermal constraint



G. Avdeeva

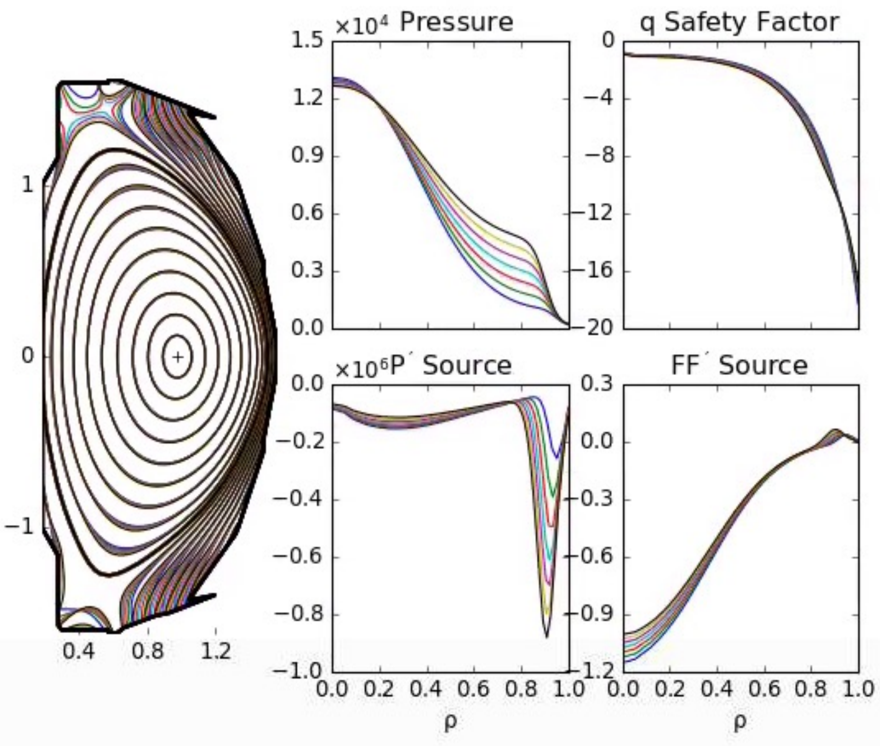


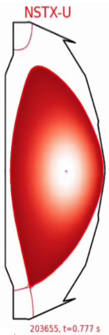
Modify equilibrium mode is available with EFIT-AI

- Take existing equilibrium, and modify it to get desired Jt and P, or change elongation

- Used extensively at GA for integrated modeling

- Example of pedestal pressure scan from the OMFIT PRO_create module



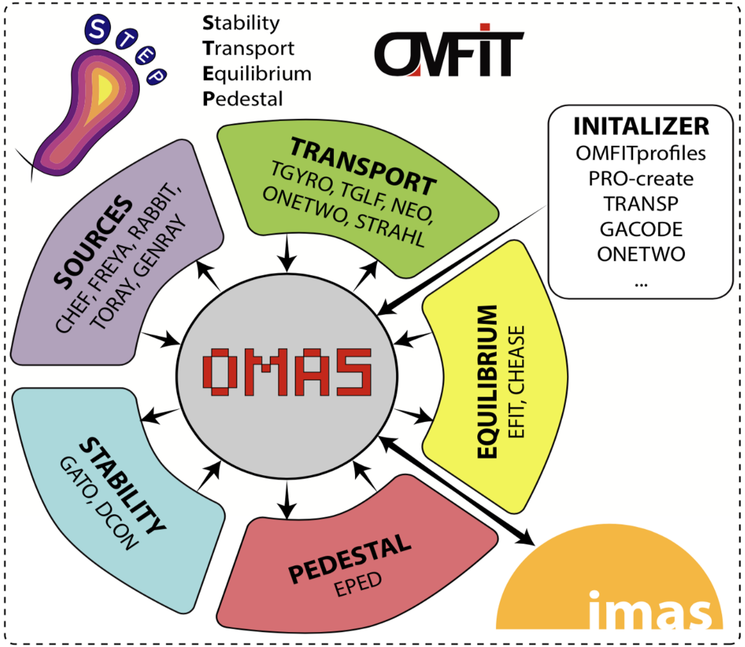


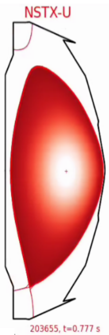
GENERAL ATOMICS

OMFIT STEP module provides useful tool that utilizes EFIT for integrated modeling for steady-state transport

- **STEP uses IMAS centralized data structure to pass information between codes**

- **A standard predictive workflow**
  - TGYRO to predict temperature, densities
  - ONETWO for current evolution (still runs on iris)
  - EFIT-AI for equilibrium (now machine independent)

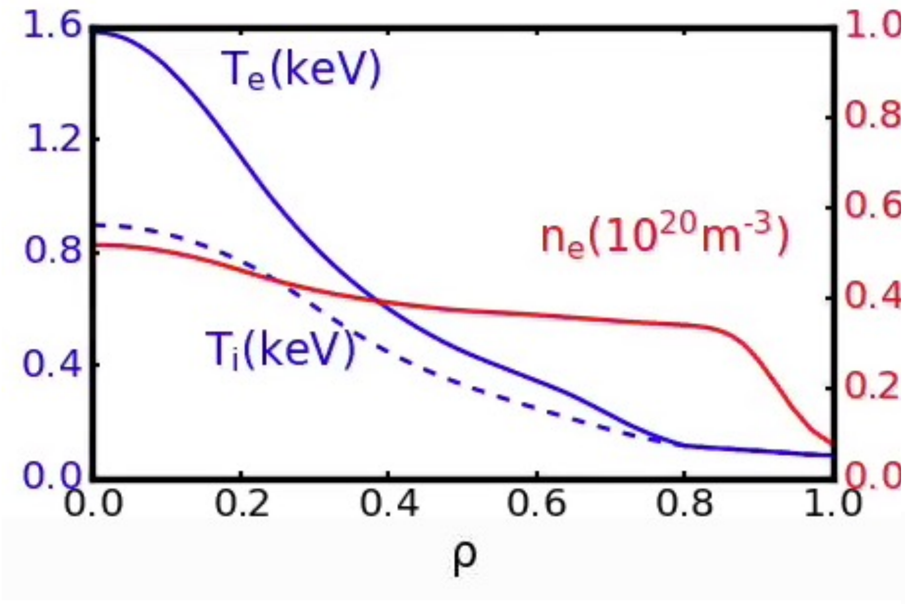


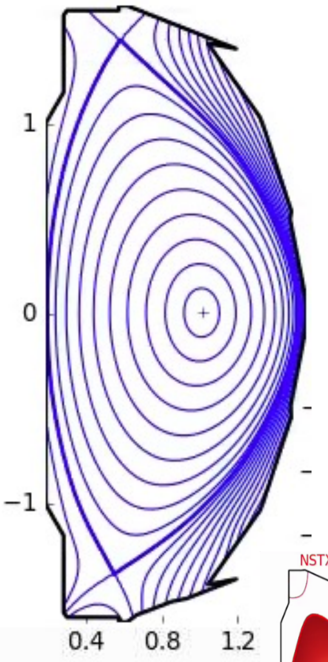


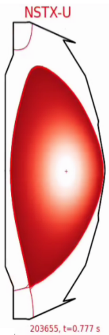
GENERAL ATOMICS

STEP standard self-consistent workflow is beginning to be applied to NTSX and NSTX-U

- **Initial test of the workflow**
- **Boundary and 2MW NBI heating taken from NSTX discharge 141716 at 470 ms**
- **Initial profiles created with OMFIT PRO_create module**







GENERAL ATOMICS

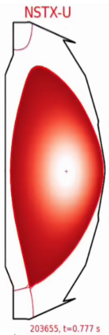
Conclusions

- **A new portable device independent version of EFIT is being developed under the EFIT-AI project**

- **Publicly available on portal**
  - `/p/nstx/efit_GA/efit/build/efit/efit`

- **NSTX(-U) users are welcome to test the version**
  - Email: mcclenaghanj@fusion.gat.com

- **EFIT-AI is being utilized for kinetic EFIT and STEP**



Where we could get some extra help

- **Gitlab regression**
  - Require mhdin.dat & kEQDSK file on gitlab.com
- **MDS+ servers**
  - Intermittent and blocked connections
  - Upgraded version to allow parallel data fetching
- **SQL server from GA**
  - Public account to have read access
- **kinetic EFIT database**