DIII-D TRANSP Users Meeting

by

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Presented at

DIII-D TRANSP Users Meeting

June 8, 2021

Agenda

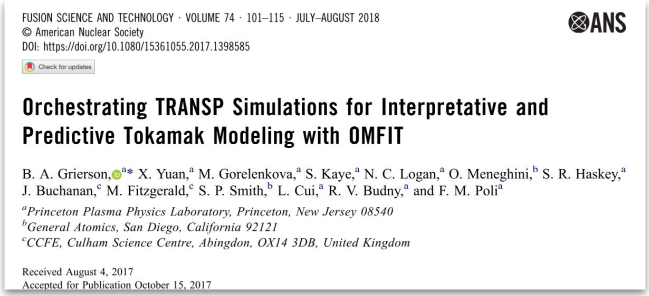
- TRANSP Users Kickoff
- TRANSP Code Update
- Introductory topic: Follow the power, from injected power to heat diffusivities
- Q&A and discussions

Why Have a TRANSP Users Group and Meeting?

- **There are (currently) 115 DIII-D researchers who have identified as TRANSP users and receive emails at d3d-transp@fusion.gat.com**
  - There are 129 user directories in /fusion/projects/codes/transp/
- **TRANSP has been evolving and will continue to evolve**
  - Major code modernization has occurred in the background without impact on the user community
- **OMFIT has made basic TRANSP submissions at DIII-D relatively easy**
  - There are capabilities well beyond the standard "interpretive" TRANSP run, and you have the power to unlock these capabilities with appropriate effort and commitment
  - Even though best efforts have been made by the scientific staff (us/you), special cases will always appear (i.e. mixed H/D plasmas one recent example)

TRANSP is a Comprehensive, Natively Time-Dependent Interpretive and Predictive Equilibrium, Power, Particle and Momentum Balance Code

- **Natively time-dependent**
  - All equations solved incorporate *d/dt* terms
    - Poloidal flux diffusion, particle, energy and momentum balance, heating, fueling and current drive sources
  - Neutral beam slowing down treated numerically with NUBEAM rather than asymptotically
- **Equilibrium from input (gEQDSK), self-consistent Grad-Shafranov (TEQ) or free-boundary (ISOLVER)**
- **Heating, fueling and current drive sources mapped to sqrt. normalized toroidal flux ρ for solving flux-surface average transport equations**
- **Flexibility to select what is <u>input</u> and what is <u>output</u>**
  - Interpretative (specify EQ, ne, Te, Ti, etc…) vs. predictive (EQ, TGLF, EPED1-NN, …)
- **TRANSP Website has references and links**
  - Also see https://doi.org/10.1080/15361055.2017.1398585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Check for updates

Orchestrating TRANSP Simulations for Interpretative and Predictive Tokamak Modeling with OMFIT

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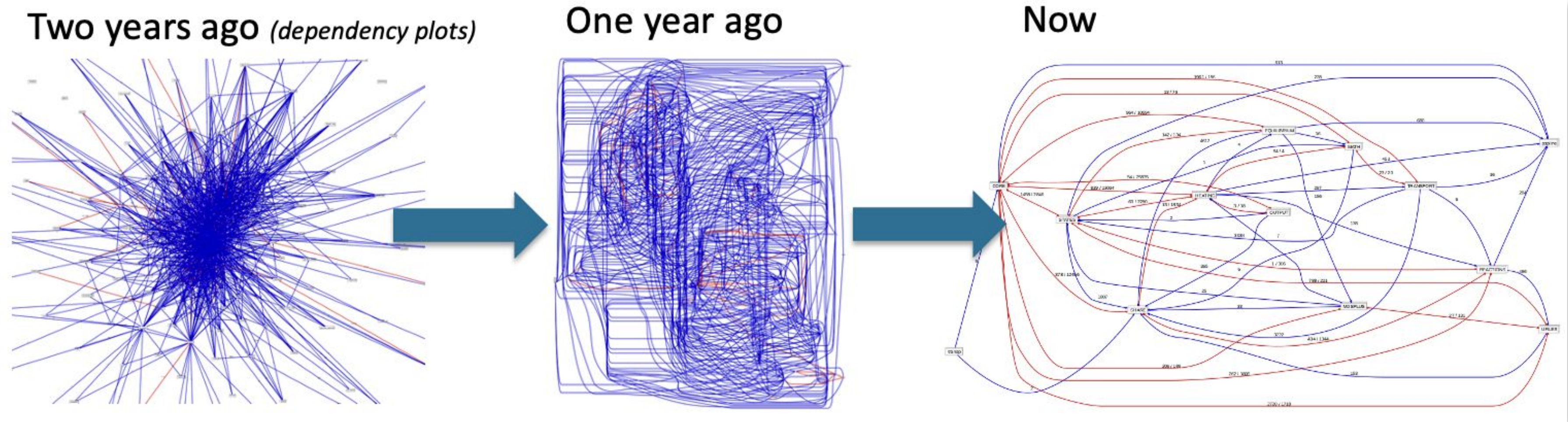
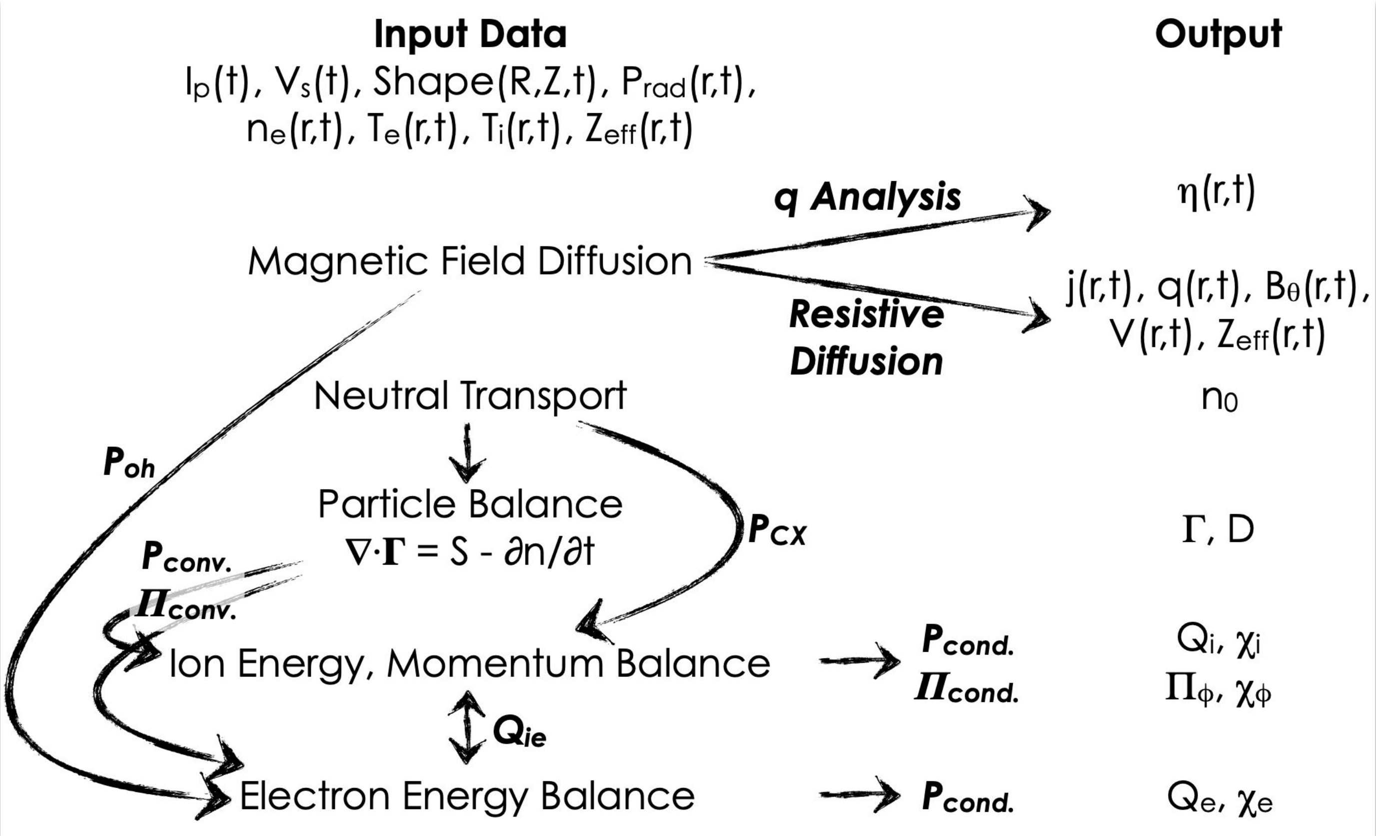
TRANSP is Fundamentally New and Very Powerful



- TRANSP team is Francesca Poli, Jai Sachdev, Marina Gorelenkova, Josh Breslau, Alexei Pankin, Gopan Perumpilly + hundreds of users (you!)
- Refactoring work continues: Not legacy Fortran

Introductory Topic: Follow the power, from injected power to heat diffusivities

One Common Flowchart of how TRANSP is Run for Analysis (q Analysis) and Kinetic EFITs (Resistive Diffusion)



MDSplus shows Pinj, Thomson and CER give me temperature profiles, how does TRANSP turn that into a heat diffusivity?

- **First a sketch, for quantity X, flux F and sources and sinks s_j^+, s_j^-**
  - i.e. X = energy (3/2nT), F = energy flux , s = heating and radiation

$$\frac{\partial X}{\partial t} + \nabla \cdot \mathbf{F} = \sum_{j} s_j^+ - s_j^-$$

Time evolution of plasma fluid variable such as density, temperature, rotation.
Example: your fit to Thomson density or CER Ti on rho or psi in time
Watch out for large d/dt!

Sources of heat, particles, momentum.
Losses such as radiation.
Example: NBI heating to ions and electrons and fueling in NUBEAM, EC heating using TORAY, recycling particle flux from FRANTIC, CX losses from FRANTIC, radiation losses from your Prad fits

MDSplus shows Pinj, Thomson and CER give me temperature profiles, how does TRANSP turn that into a heat diffusivity?

- **From divergence of flux, integrate numerically to get the flux**

Use divergence theorem $\quad \int \nabla \cdot \mathbf{F} dV = \oint \mathbf{F} \cdot d\mathbf{A}$

$$F = \underbrace{\frac{1}{A} \int \Big(\underbrace{\sum_j s_j^+ - s_j^- - \frac{\partial X}{\partial t}}_{\text{Divergence of flux}} \Big) dV}$$

Volume integrating the divergence of a flux is the same as a surface integral of the flux dotted into area vector. For tokamak radial transport, this is simply F*A where A is the area of the surface.

Cumulative volume integral of sources minus sinks minus dX/dt is the particle, energy and momentum "flow"

MDSplus shows P_{inj}, Thomson and CER give me temperature profiles, how does TRANSP turn that into a heat diffusivity?

- **Assume purely diffusive transport to arrive at particle, heat, momentum diffusion coefficient**

$$\text{Fick's Law} \qquad F = -D\nabla X$$
$$D = -F/\nabla X$$

Diffusion is the flux (integral of source-sink-d/dt) divided by the gradient of the profile
Derivatives of profiles can be very uncertain!

Heat diffusivities oft-quoted in the literature, identifying regions of improved or degraded confinement, etc...

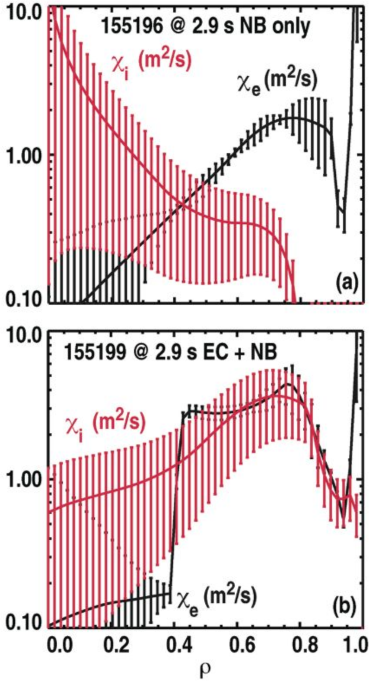
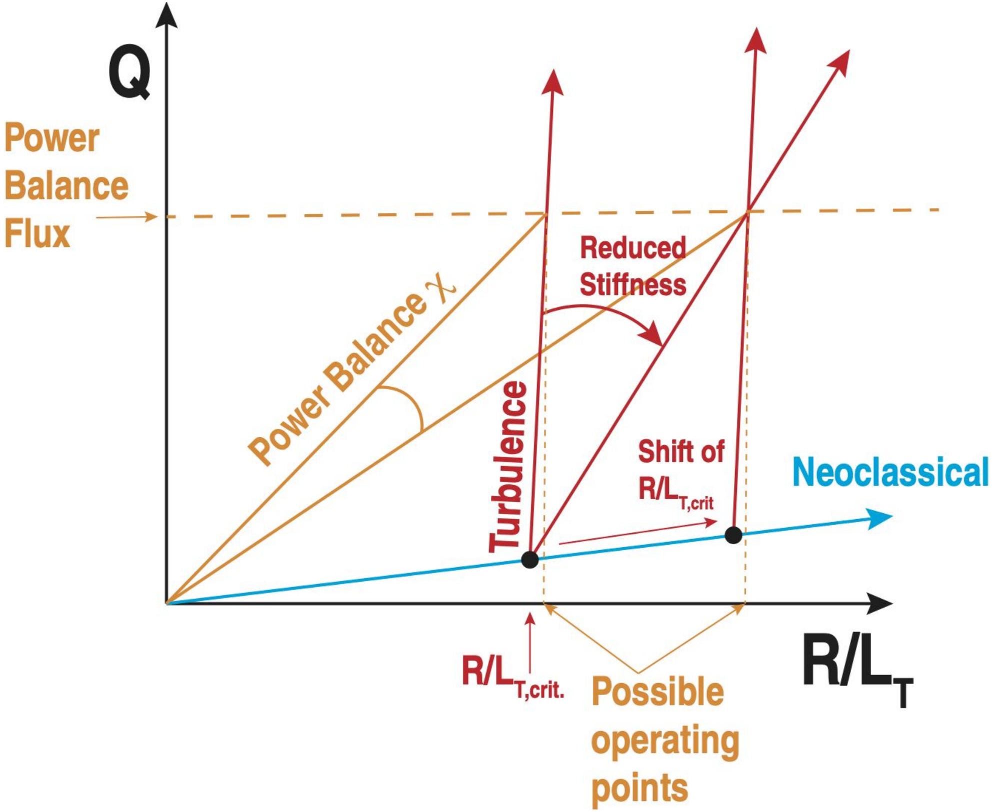


Figure 3. Deduced ion and electron heat diffusivities from TRANSP for NB-only (a) and NB+ECH (a) cases.

R. Pinsker et. al. EPJ Web of Conferences **87** 02003 (2015)

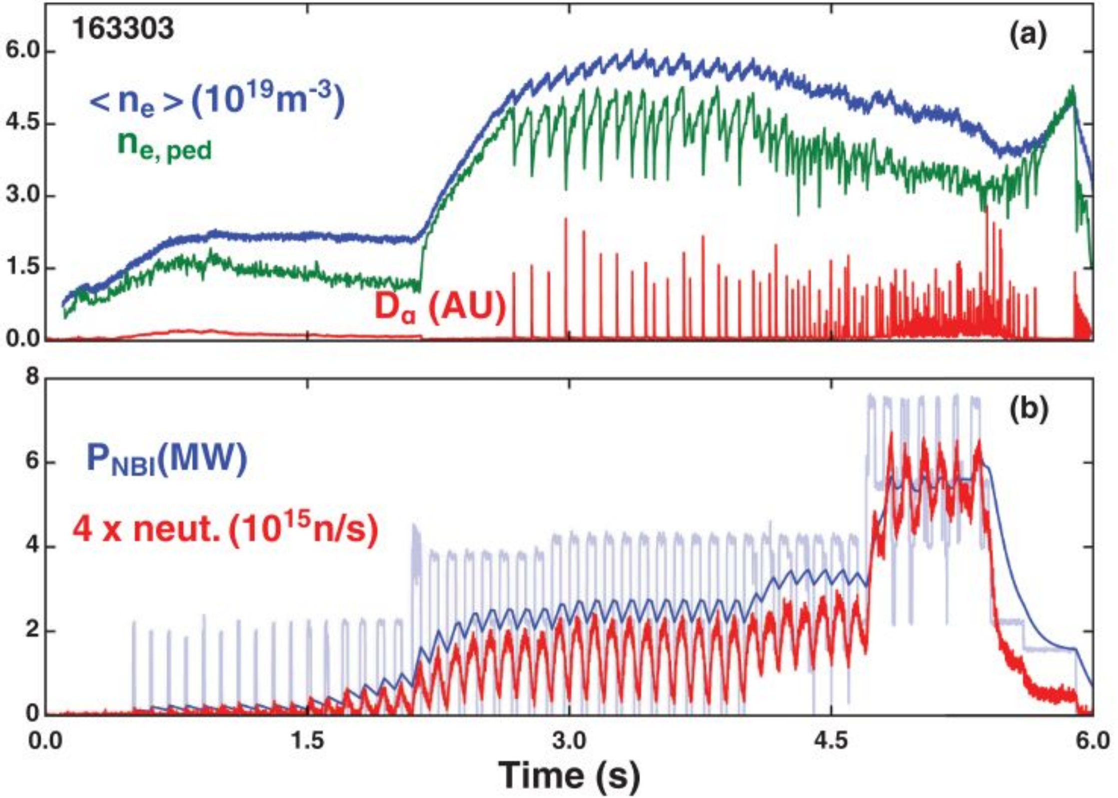
Aside: Fick's Law vs. Stiff Transport

- **Balance equivalent to drawing a straight line from the origin to the intersection of flux and gradient**
  - Slope is D, χ
- **Does not uniquely determine a change in either stiffness or critical gradient**



Worked Example: DIII-D Daily Morning Reference Shot

- **Power ramp**
- **L-mode, H-mode phases**



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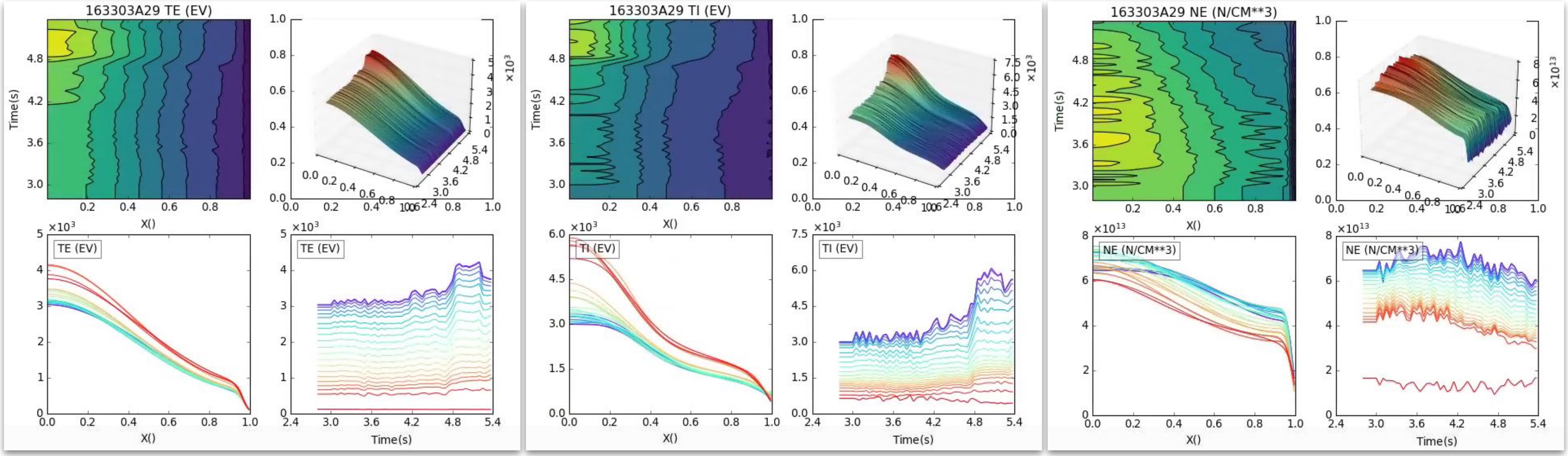
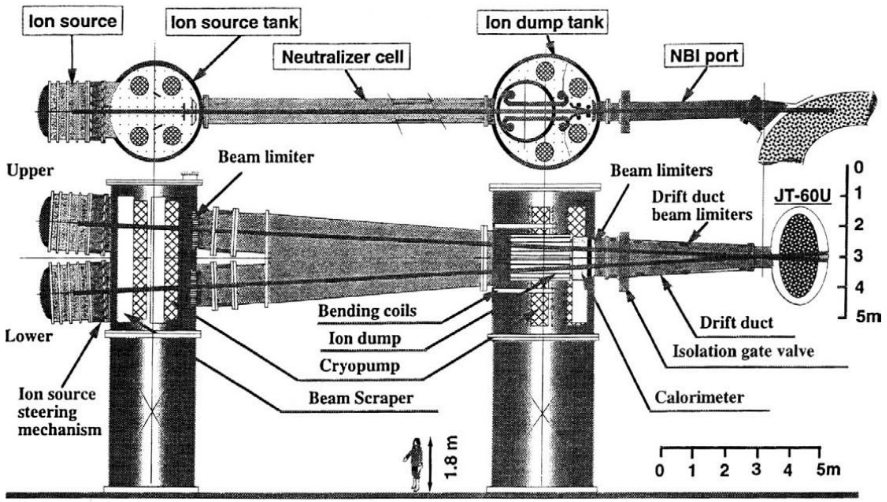


- **Profiles fit on 20 ms EFIT timebase with +/- data window**
  - Oscillations evident from time history, could be data quality, could be NBI modulation
  - Dynamic phase clear during power ramp at 4.8 seconds

Dominant Heating Source is NBI; NUBEAM Used

- **NUBEAM Inputs**
  - Geometry
    - Time independent
    - Position of sources, distance to plasma, shape of aperture, focus, divergence
  - Injection
    - Time dependent
    - Voltage, species mix, power

A. Pankin et al. / Computer Physics Communications 159 (2004) 157–184



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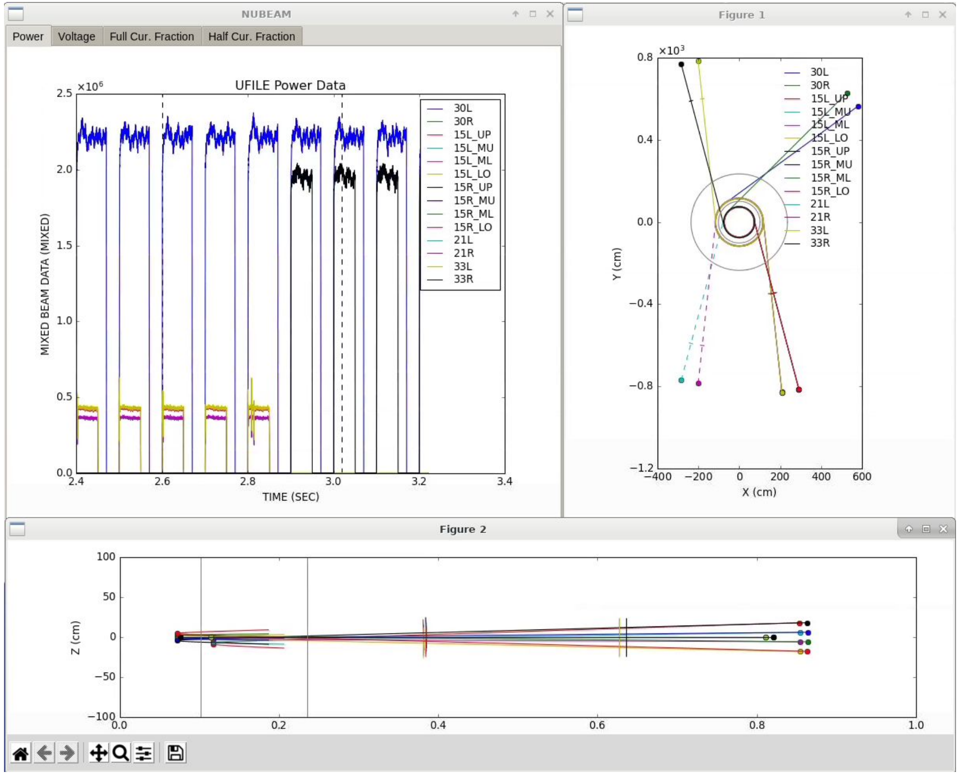
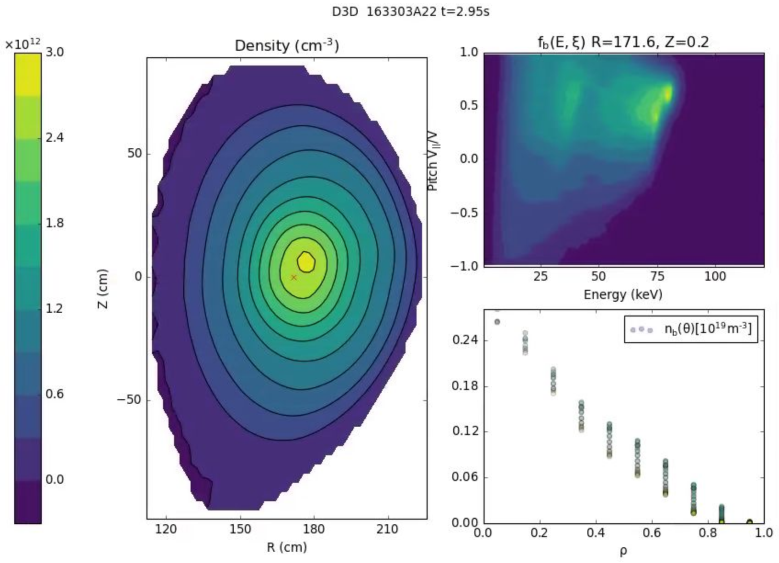
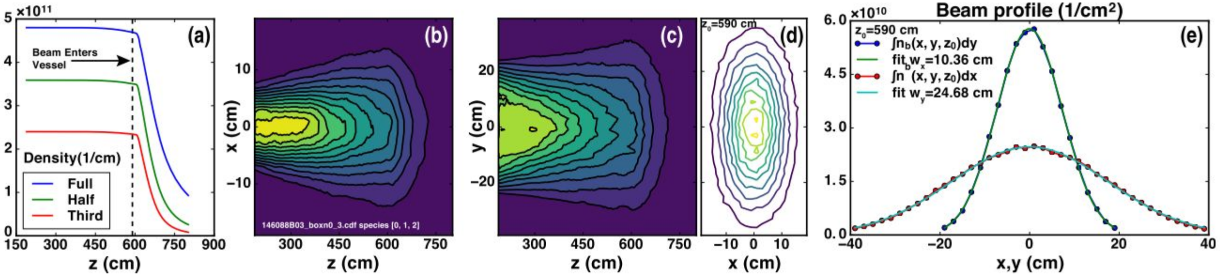


Dominant Heating Source is NBI; NUBEAM Used

- **NUBEAM Outputs**
  - Beam losses due to orbits, shine-thu, internal and external CX
  - Beam neutral distribution in 3D
  - Fast-ion distribution function
  - Heating to ions and electrons
  - Fueling of ions and electrons
  - Neutron rate
  - Fusion power



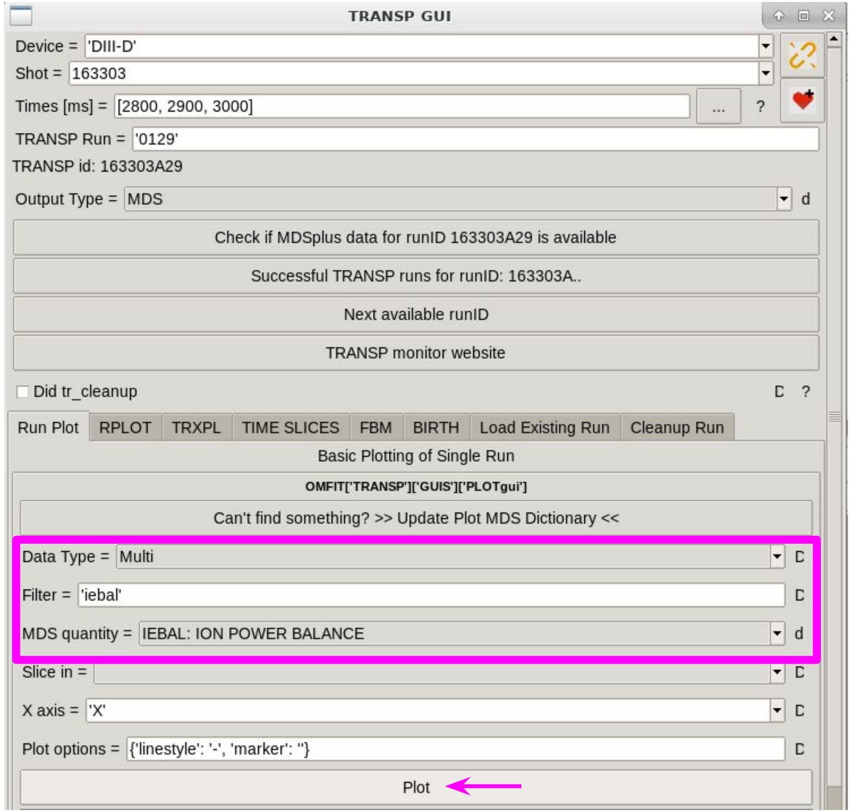


Follow the Power
This is intended to be useful for things such as total injected power, total heating power (absorbed), and total transport power (sources-sinks).

$$\frac{\partial X}{\partial t} + \nabla \cdot \mathbf{F} = \sum_j s_j; (s_j^+, s_j^-)$$

What's the Best Way to Investigate the Power Balance?

- **Many terms in power balance, hard to remember them all and variable names**
- **TRANSP has built-in "Multiplots" that show all terms for each TRANSP run**
- **Key ones are**
  - EEBAL, IEBAL, EPBAL, MOBAL
- **Summing the balance terms with appropriate signs is the divergence of the flux**



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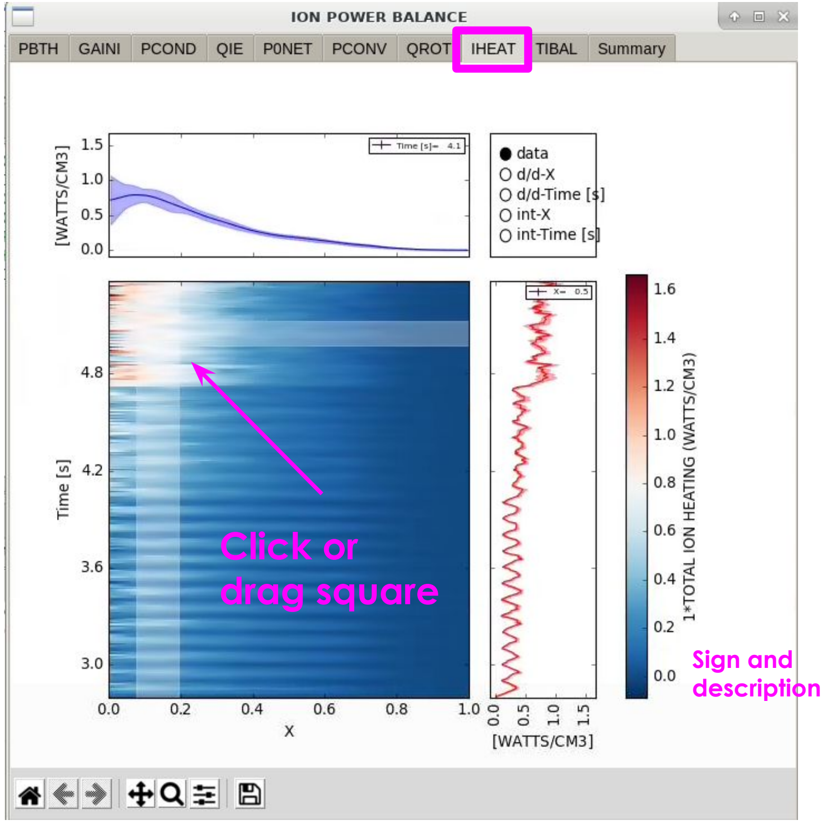

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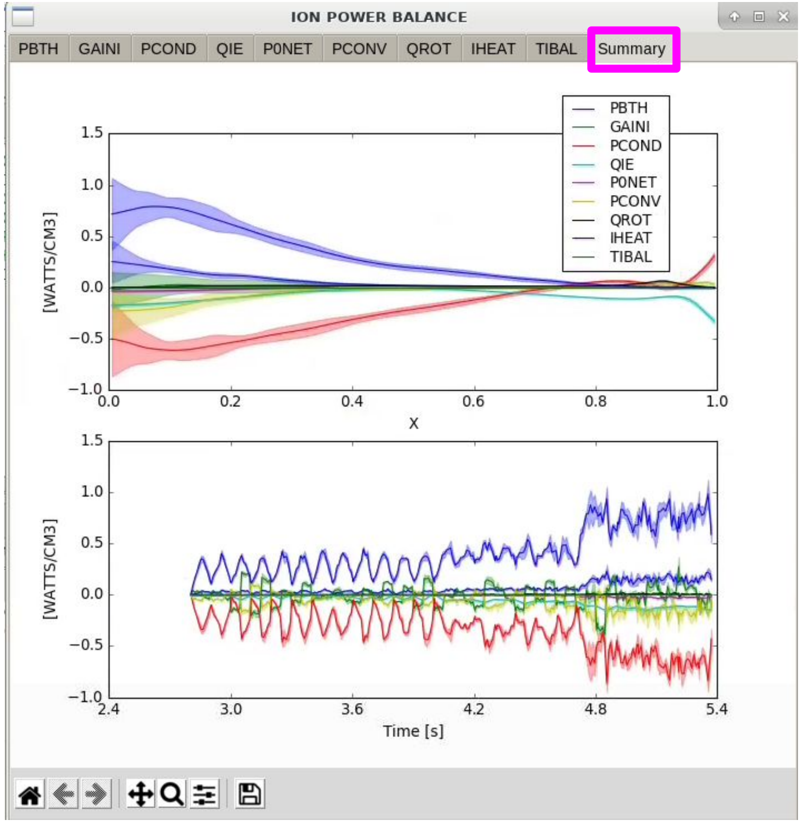
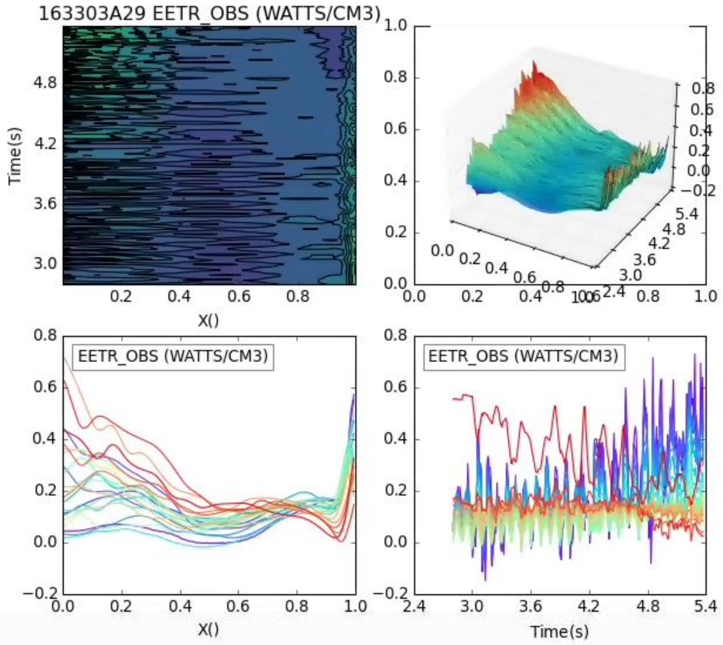
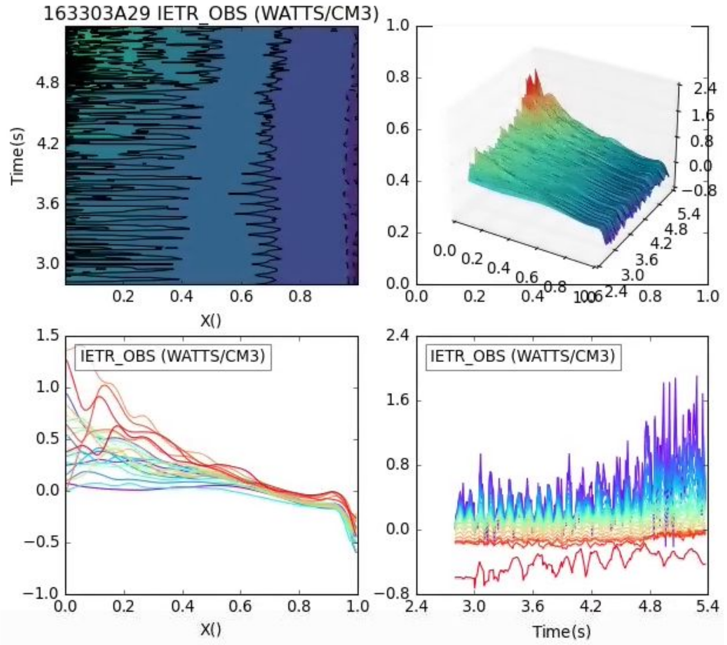


What's the Best Way to Investigate the Power Balance?

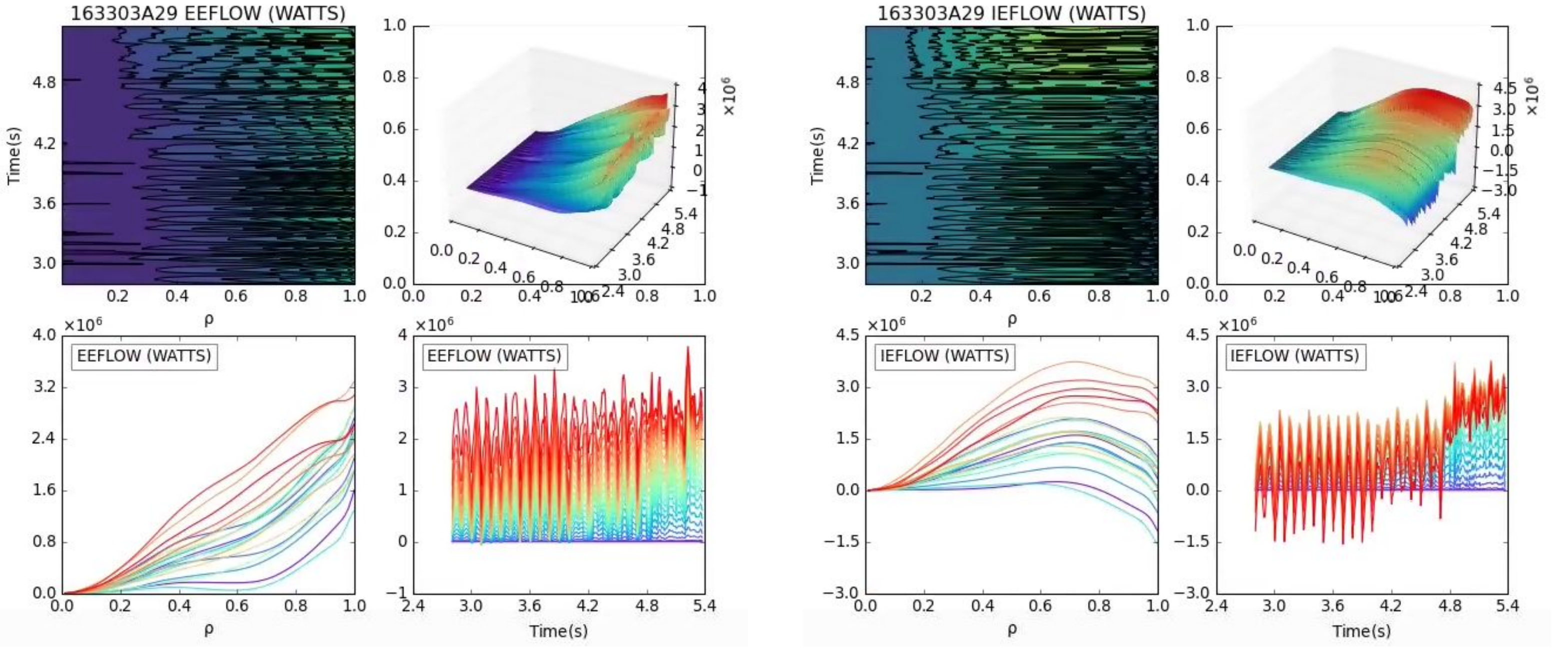
- **Divergence of flux**
  - EETR_OBS, IETR_OBS, EPTR_OBS, AMTR_OBS





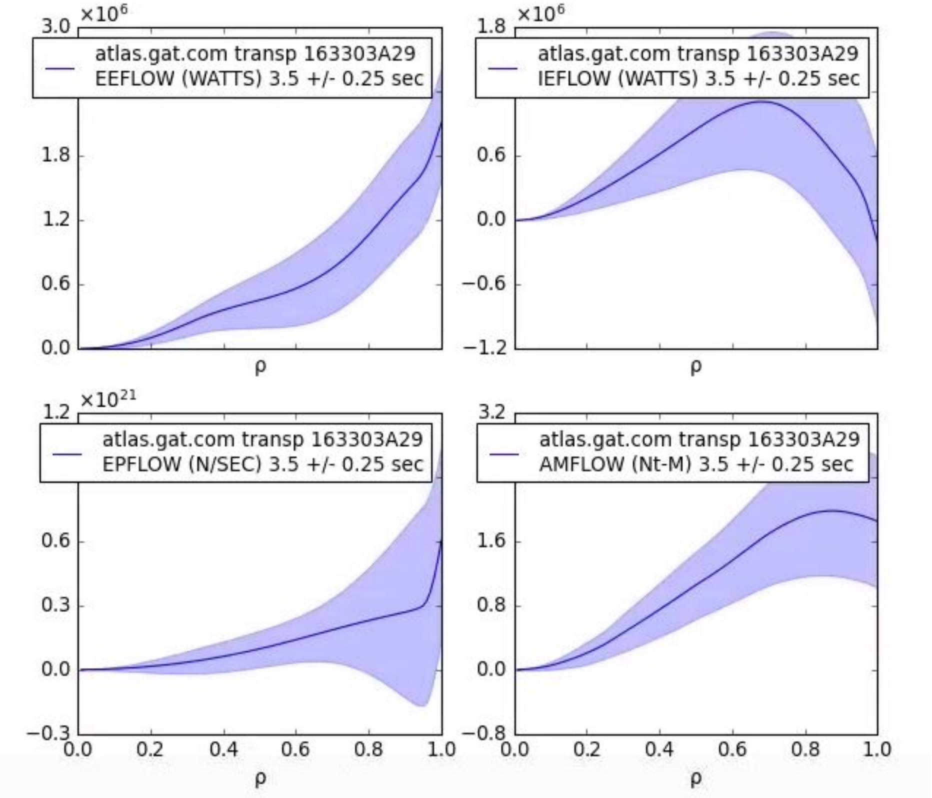
What's the Best Way to Investigate the Power Balance?

- **Volume integral of divergence of flux is the power flow**



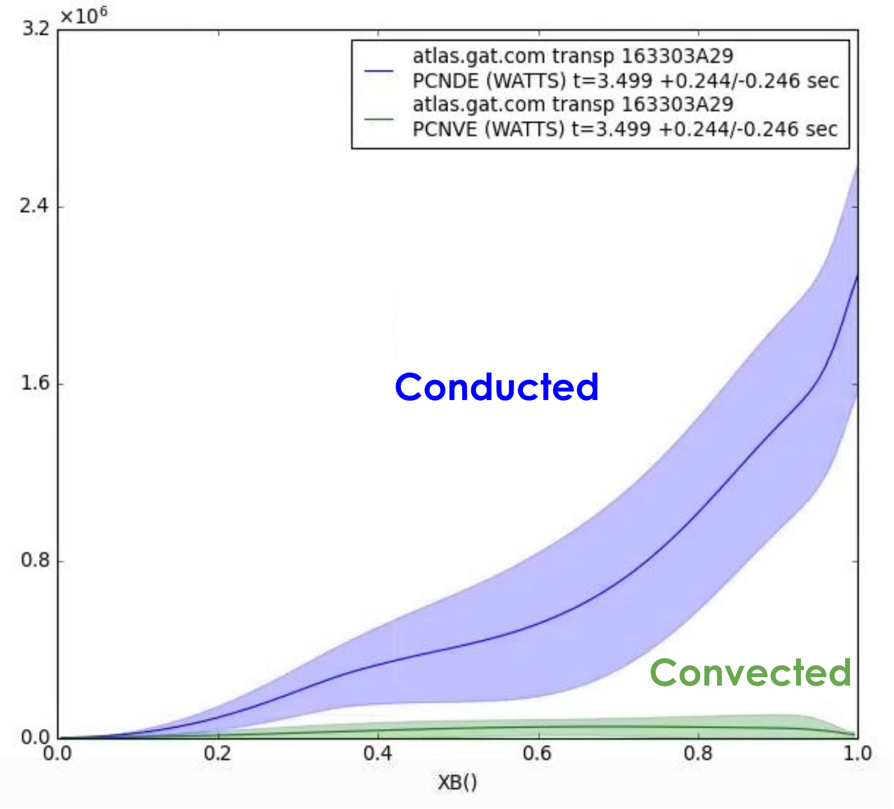
Let's Look at a Time Window that's More or Less Stationary

- **Power/particle/momentum flows through surface**

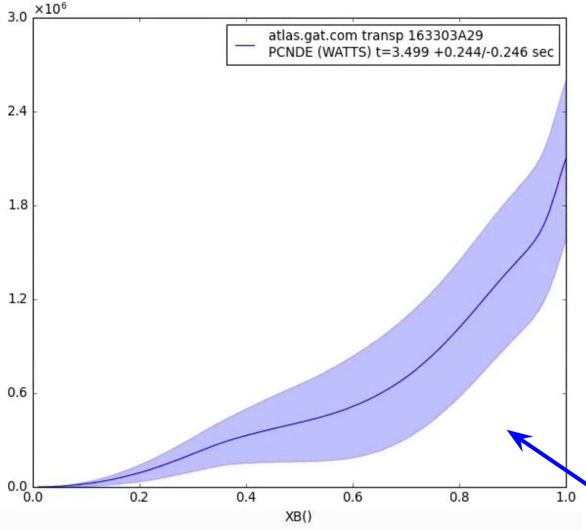


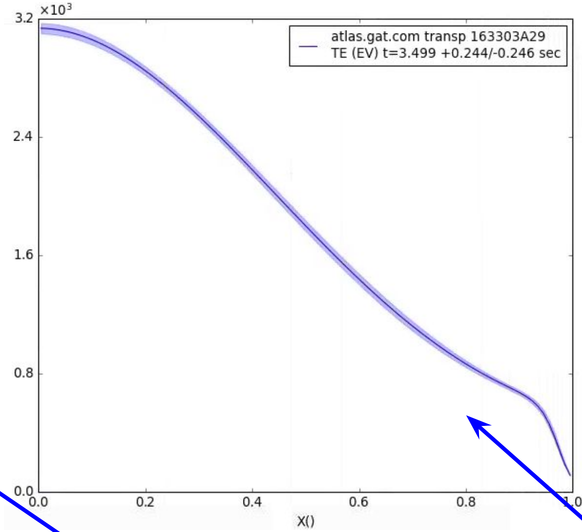
Total Power Flow is Split Between Conducted and Convected (from Particle Balance)

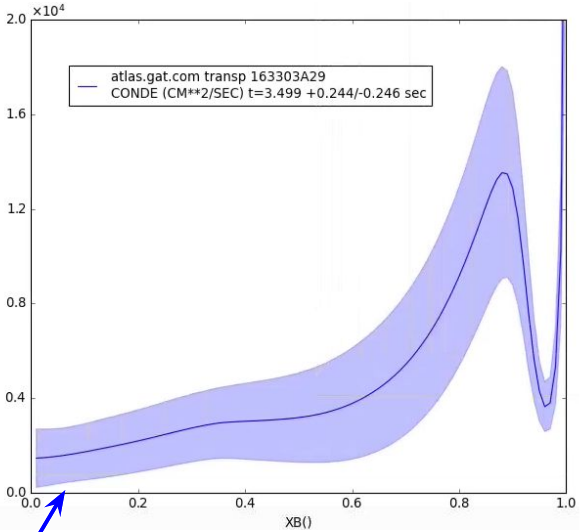
- **For this example, we have set the particle confinement time to be long (~ second)**
  - Results in little recycling particle flux
  - Results in little convected energy flux
- **Accurate recycling needed for accurate conducted flux and heat diffusivity at the edge**
  - Transition region from use of core vs boundary codes
  - Directly impacts arguments like ratio D/χ



Putting the Pieces Together; Once Conducted Electron Power is Computed, Heat Diffusivity is Calculated from Geometric Terms and Temperature Gradient



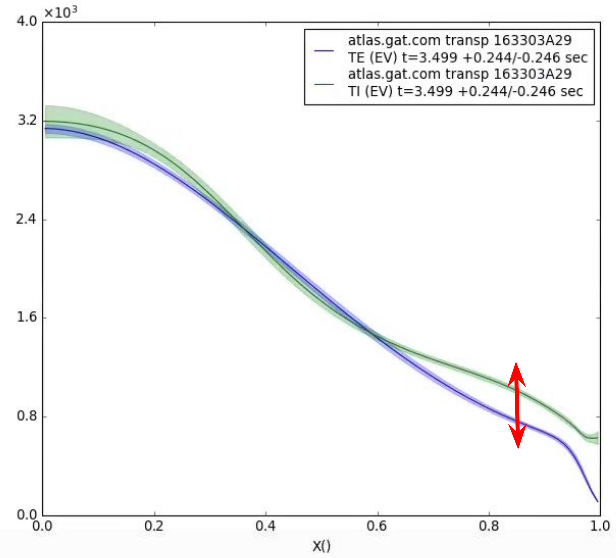


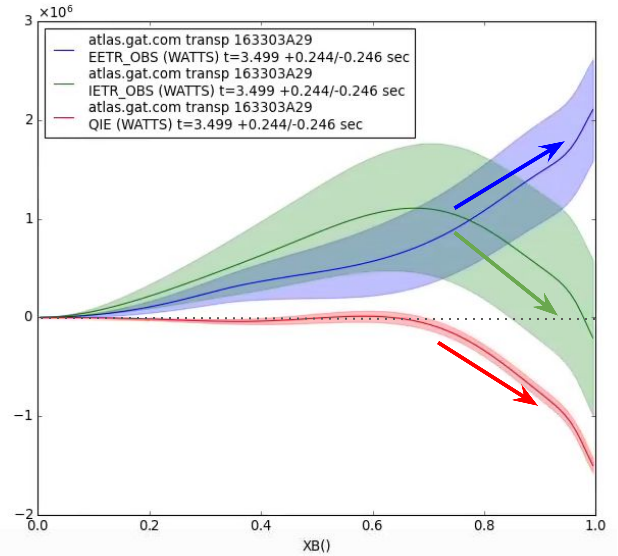


$$\frac{1}{S}\boxed{\int_0^{\xi} \delta V(\xi')PCNDE(\xi')d\xi'} = -n\boxed{\chi}\frac{\partial \boxed{T}}{\partial \xi}\langle|\nabla\xi|\rangle$$

Similar for ion power balance

Aside: Ti/Te and Ion-Electron Exchange





Magnitude of Q_e and Q_i ***dominated*** by your profile fits to T_e and T_i ***not*** the heating power

- **Power balance includes "exchange" or "equipartition" flux, transferring power between ions and electrons $q_{i\rightarrow e} \sim n_e^2/T_e^{3/2}(T_i - T_e)$**
- **Big where n big, T small, pulls temperatures together (edge!)**
- **Recent work at DIII-D refining edge T_i for this reason**

Summary of Simple Example of DIII-D Power Balance

- **The balance equations require accurate heating and fueling sources**
  - Directly affect the power and particle source densities
- **The balance equations require accurate measurements of the profiles**
  - Both time (d/dt included in power balance) and space (derivative used for diffusivities)
- **We have worked a simple example following the power from beam injection → absorption → slowing down → heating → power flow → conduction → finally arriving at heat diffusivity**

Path Forward and User Feedback

TRANSP Submission will be Updated Soon

- **The way that we submit and retrieve TRANSP runs from DIII-D will change in the near future (but we will still support with OMFIT of course, may be unchanged experience for many users).**
- **The use of globus certificates for submission to the PPPL computing cluster (aka TRANSP Grid) will no longer be supported.**
- **There are other options that will be supported.**
  - A "container" for TRANSP that can be executed on a local computing cluster (i.e. iris) or on a cloud-based server. This is how some of our colleagues around the world run TRANSP.
  - Login to a HPC user facility where a version of TRANSP is built and maintained. Here a login will be required for that facility.
- **If you have a strong opinion about one of these it may help us prioritize and identify the required follow-up actions.**

Some User Feedback and and Recommendations

- Request to improve how NUBEAM handles fast ions in the SOL
- Regardless of how submissions/runs change, preserve archival of TRANSP data in mdsplus and/or a central location
- Requests to gain access to source code to understand how quantities are calculated
- Modernization, in its solution methods, I/O, speed, and capabilities
- A better way of plotting output (with sophisticated scripting, smoothing, and calculations like the TRANSP RPLOT)
- One of the fast NUBEAM alternatives to be available (RABBIT, for example).
- Improved and updated documentation
- Adding capabilities for interpreting LLAMA measurements for more accurate transport calculations in the pedestal
- Updated and/or add new transport models
- Advanced fueling (assume this means pellets, SMBI, realistic gas puff)
- Self-consistent edge and SOL model; reduced or higher fidelity

Conclusions

- **Key strength of TRANSP is the engaged user community**
- **Intended to have more regular DIII-D TRANSP Users Meetings**
  - Note TRANSP office hours offered every Monday, 9:00 a.m. Pacific on Zoom
- **Requesting suggestions for upcoming topics**
  - Particle balance (incl. mixed isotopes)?
  - Momentum balance (collisional torque, JxB torque, ripple, NTV)?
  - Predictive TRANSP (equilibrium, core, pedestal)?
  - Heating and current drive?
  - DT fusion power simulations?