Bringing the golden standard into the silicon age
(aka TRANSP status and plans)

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TRANSP is a 1.5D equilibrium and transport solver for tokamak plasma simulations

Particle:
\[ \frac{\partial}{\partial t} (nV') - \frac{\partial}{\partial \rho} \left( |\nabla \rho|^2 V' D \frac{\partial n}{\partial \rho} \right) = V' \left( S_{\text{gas}} + S_{\text{beam}} - L_{c-x, \text{recomb, etc}} \right) \]

Energy (e⁻):
\[ \frac{\partial}{\partial t} \left[ \frac{3}{2} V' n_e k T_e \right] + \frac{\partial}{\partial \rho} \left[ V' \langle |\nabla \rho|^2 \rangle n_e k \left( T_e v_e - \chi e \nabla T_e \right) \right] = V' \left( P_{\text{OH}} + P_{\text{beam}} - P_{\text{ie}} - P_{\text{rad}} \right) \]

Momentum:
\[ \frac{\partial}{\partial t} \left( n_i m_i V' \langle R^2 \rangle \omega \right) + \frac{\partial}{\partial \rho} \left[ V' \Gamma \omega \right] = V' \left( \Sigma T_{\text{input}} - \nabla \cdot \Pi - \frac{m n R (\omega - \omega^*)}{\tau_{\text{damp}}} \right) \]

**Interpretive:** INPUT: \( T_e, T_i, n_e, v_\phi \ldots \) OUTPUT: \( D_{e,i}, \chi_{e,i,\phi} \ldots \)

**Predictive:** INPUT (model): \( \chi_{e,i}, D_{e,i} \ldots \) OUTPUT: \( T_{e,i}, n_e \ldots \)
With a large pool of users, national and international

~150 users at end of 2018
... and growing ...

thanks to the effort of our PPPL team at DIII-D who have developed a user-friendly interface to prepare, submit and plot TRANSP runs
This presentation will (incoherently) touch three topics

- Step-wise modernization of the code
- Support to users => including training
- Physics development => engage the community
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We are doing our best to keep our users happy

- Partner with the OMFIT team for interfaces to prepare/submit/plot
  - DIII-D, JET, MAST-U, TCV already onboard
  - In progress at KSTAR and EAST
    => benefit consistency in preparation of runs
    => device-specific templates uniform across users
- Easier to navigate new website, tutorials, FAQ, master classes
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Modernizing TRANSP … sounds like a broken record?

- Better SQA already in place
  - TRANSP registered in DOEC ode
  - Moved to GIT
  - TSHARE no longer available to users
  - Regular (quarterly) and documented releases of the code (R19.1 this month)
- A container-based image of the code ready for distribution
  - Users can run on their local cluster (e.g. BEAST runs during experimental campaigns)
  - It allows users from China to run TRANSP in the absence of a trusted connection
- More to come …
In over thirty years TRANSP has evolved from an interpretive code for transport analysis ...
... to a code for transport, heating and current drive predictions
And it even does a pretty good job...

- Density, temperature and current reproduced within acceptable uncertainties (in most cases)

- Uncertainties typically from:
  - limitations of the models available (transport)
  - absence of critical physics (stability)
However, physics development has not been accompanied by modernization

**THREAT: rescue the developers!**

- TRANSP has grown in complexity and scope
  - misplaced code => added modules w/o refactoring
  - computationally ineffective => inherited interfaces that are not suited for our purposes
- It is becoming a monster that is slowly strangling us …

**It is time to take action!**
However, physics development has not been accompanied by modernization

- **TRANSP** has grown in complexity and scope
  - misplaced code => added modules w/o refactoring
  - computationally ineffective => inherited interfaces that are not suited for our purposes

- It is becoming increasingly strangled

**THREAT: rescue the developers!**

*Figure source: C. Ferenbaugh, HPC Best Practices Web Seminar*
The #1 rule of good housekeeping … DECLUTTER

- Remove obsolete modules (already mid-way through)
- Change code base in place, step-wise (not a new code)
- Deprecate/remove (not-so-needed) switches and calls
- Find misplaced code and move it (e.g. pedestal module)
- Replace file-based interfaces, optimize performance (GENRAY/CQL3D)
- Move towards a cleaner, simpler design
- Identify what the interface should look like for new modules, stop piling-up (e.g. new MHD and EP stability modules)
An example: the magnetic equilibrium mapping

TRANSP calculates equilibrium

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GENRAY
re-map
equilibrium

CQL3D
re-map
equilibrium

TORIC
re-map
equilibrium

....

---

New MHD/EP modules, old approach

DCON/GPEC
re-map
equilibrium

ORBIT
re-map
equilibrium

NOVA-K (?)
re-map
equilibrium
An example: the magnetic equilibrium mapping

TRANSP calculates equilibrium

GENRAY re-map equilibrium

CQL3D re-map equilibrium

TORIC re-map equilibrium

....

New MHD/EP modules, old approach

DCON/GP0C re-map equilibrium

PRM re-map equilibrium

NOVA-K re-map equilibrium
An example: the magnetic equilibrium mapping

Existing RF and new MHD/EP modules, new approach

- TRANSP calculates equilibrium
- DCON maps it
- GENRAY Uses it
- CQL3D Uses it
- ORBIT/NOVA-K Use it

- ensures consistency among modules => critical for stability calculations
- reduces walltime ...
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Expand the scope of TRANSP and involve the community

- Physics development => engage the community
  - Align development priorities with PPPL leadership on domestic and international collaborations, not only based on requests from users
  - Put in place procedure to support partnership and research publications
    => motivates collaborators to contribute their codes

- We need help from:
  - Experimentalists, to help us with verification and validation
  - Theorists, to share their codes and “reduce” their models
  - Computational scientists, to help optimize modules and algorithms
The core of TRANSPP (its solver) is its strength

What is seen from the outside world as a *black box* is what makes TRANSPP robust:

the hierarchy of time scales
Source => geometry => transport

*Code modernization should not break this robustness*
The heating and current drive sources are the best available today in a time-dependent solver.

They are also our strongest selling point in domestic and international collaborations.
Invest on TORIC, GENRAY/CQL3D and expand their scope

- **Strength:** our unique selling point for scenario development on long pulse tokamaks
- **Weakness:** very inefficient interface => we have a plan in place
- **Opportunities (link to SciDAC):**
  - Synergies between RF sources and between RF and fast ions
  - Extension to runaways
  - ECE calculations => link to MHD modules and control
- **Threat:** external support => strengthening partnership with CompX for future development
The absence of a Scrape-Off-Layer model is a large hole

Why: a SOL model is needed for:
- calculation of RF losses
- fast ion losses
- ionization/recombination, fueling

Path forward: partnership with LLNL to couple UEDGE.
Critical projects and strategic priorities (FY19-FY21)

- Fast-ion physics
  - AFID (reduced models)
  - Extend NUBEAM to the SOL
  - MHD calculations
  - AEs stability calculations
  - SOL model+adaptive grid+2D neutrals model

- RF physics
  - RF-fast ions
  - All synergies
  - Close loop TORIC/NUBEAM
  - CQL3D extension, modernization

- Particle transport
  - Impurity transport
  - Pellet fueling

Francesca Poli, FES-PPPL meeting, January 2019
Priorities support PPPL leadership in domestic and international collaborations

- **Fast-ion physics**
  - AFID (reduced models)
    - TORIC/NUBEAM
  - Extend NUBEAM to the SOL
    - MHD calculations
    - Any tokamak using NBI
  - SOL model + adaptive neutrals model

- **RF physics**
  - RF-fast ions
    - Any tokamak using IC-NBI
    - CQL3D extension, modernization

- **Particle transport**
  - All synergies
  - Impurity transport
  - Pellet fueling
    - JET (DT extrapolation)

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How far are we from a “Whole Device Model”? 

**Confined plasma**
(closed magnetic field lines)
- MHD equilibrium/instabilities,
- microturbulence,
- energetic particles

**Scrape-Off Layer plasma (SOL)**
(open field lines)
- Microturbulence,
- ionization, recombination
- radiation

The plasma is surrounded by solid structures:
- Plasma-material interactions

**External heating**
- Radiofrequency waves
- Neutral beams

**Fueling**
- Gas injection
- Pellets
Not too far, if we can get a little extra help ...

Some ideas for brainstorming:

- a reduced model for ELMs (Nate)
- a reduced model for the L-H transition (CS, Seung-Hoe)
- a better model for the pedestal (Ammar)
- a reduced model for intrinsic rotation (Tim)
- a reduced model for the onset of NTMs (Allan)
- a reduced model for NTV (Zhirui, Nik)
Not too far, if we can get a little extra help ...
A tokamak simulator needs to connect fast (transport) and slow (current diffusion) time scales