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

Francesca Poli for the TRANSP development team:

J. Breslau, L. Glant, M. Gorelenkova, J. Sachdev, (G. Wright), X. Yuan

PRINCETON PLASMA PHYSICS LABORATORY

PRINCETON UNIVERSITY

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

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

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

Momentum: $$\frac{\partial}{\partial t}\left(n_i m_i V'\left\langle R^2\right\rangle \omega\right) + \frac{\partial}{\partial \rho}\left[V'\Gamma_\Omega\right] = V'\left(\Sigma T_{input} - \nabla\cdot\Pi_\phi - mnR(\omega-\omega^*)\tau_{damp}^{-1}\right)$$

Interpretive: INPUT: T_e, T_i, n_e, v_ϕ,..... OUTPUT: $D_{e,i}$, $\chi_{e,i,\phi}$,.....

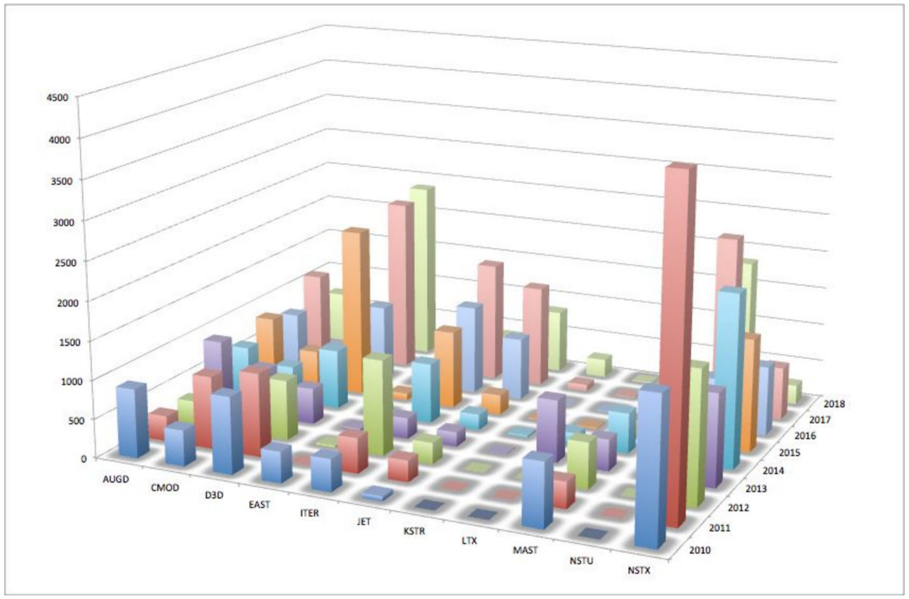
Predictive: INPUT (model): $\chi_{e,i}$, $D_{e,i}$, ... OUTPUT: $T_{e,i}$, n_e,.....

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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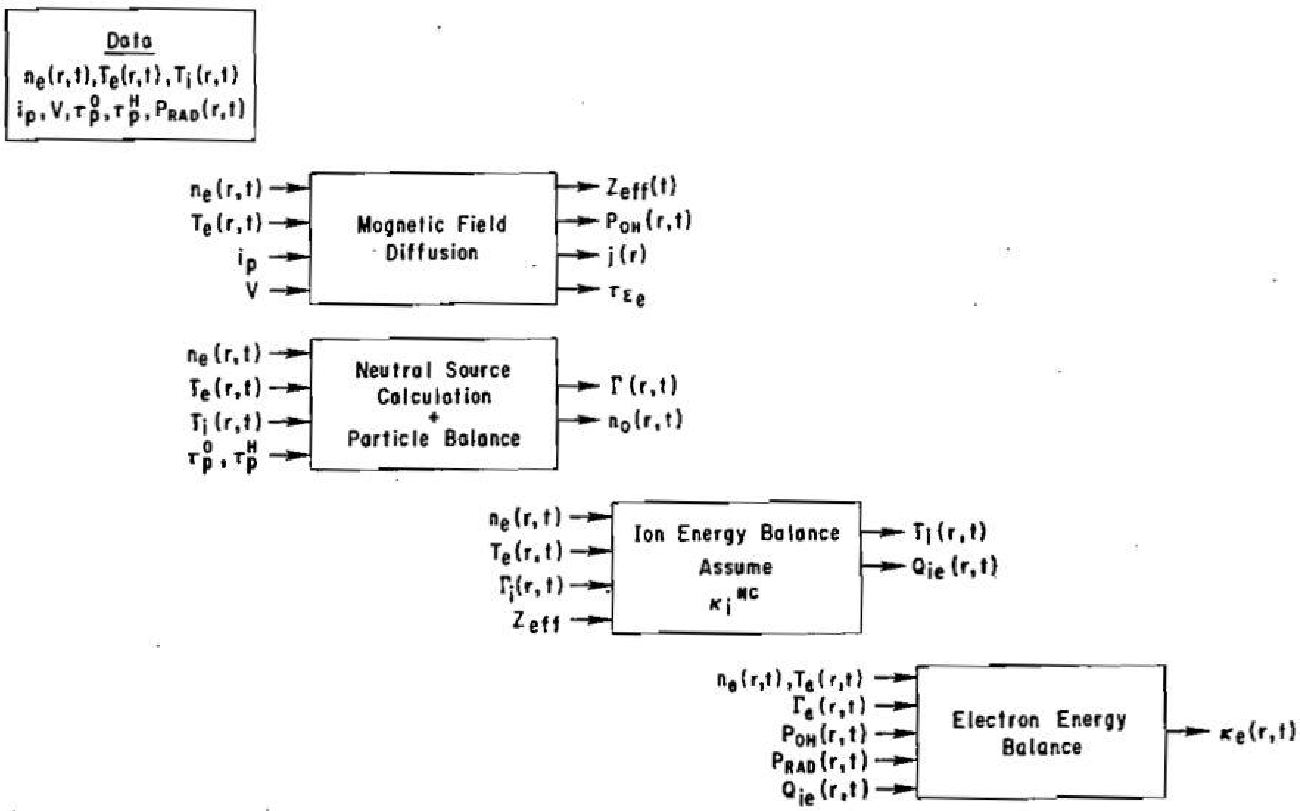
Modernizing TRANSP … sounds like a broken record?

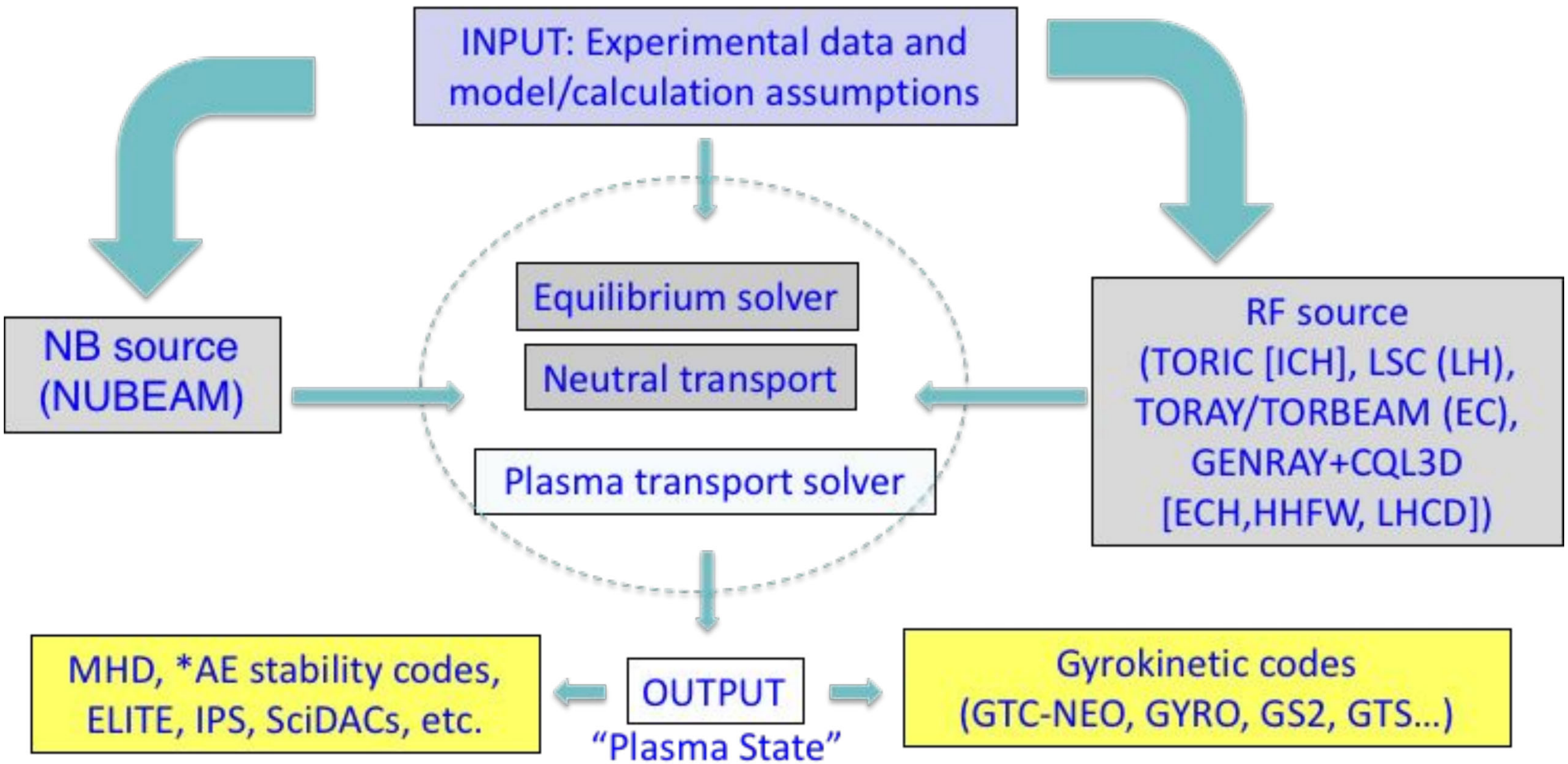
- Better SQA already in place
  - TRANSP registered in DOECode
  - Moved to GIT
  - TSHARE no longer available to users
  - Regular (quarterly) and documented releases of the code (R19.1 this month)
- A container-based image of the code ready for distribution
  - Users can run on their local cluster (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 ...



This is the original figure, taken from the paper by R. Hawryluk

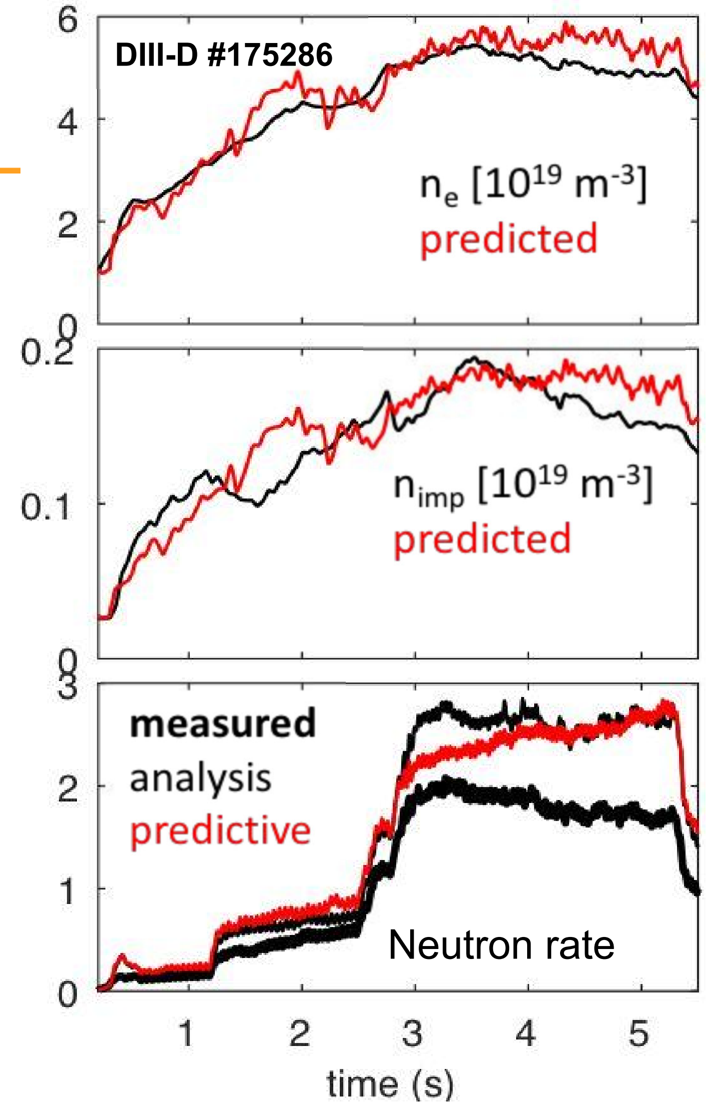
… to a code for transport, heating and current drive predictions



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 !

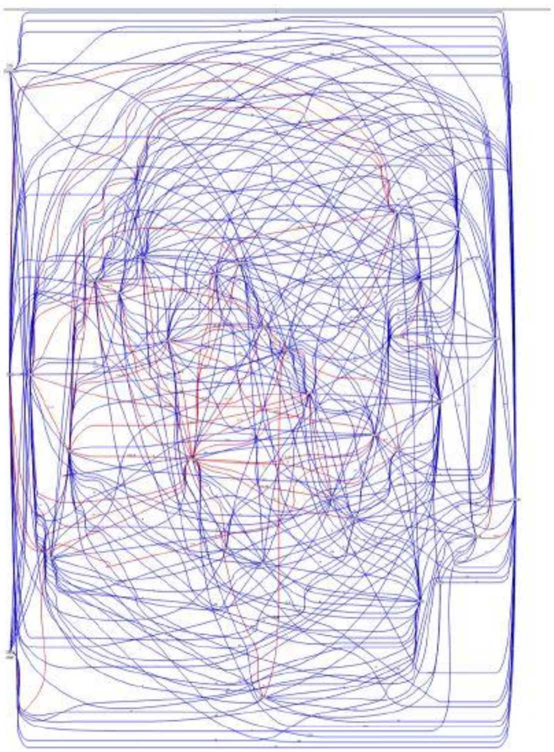


Figure source: C. Ferenbaugh, HPC Best Practices Web Seminar

- 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 !

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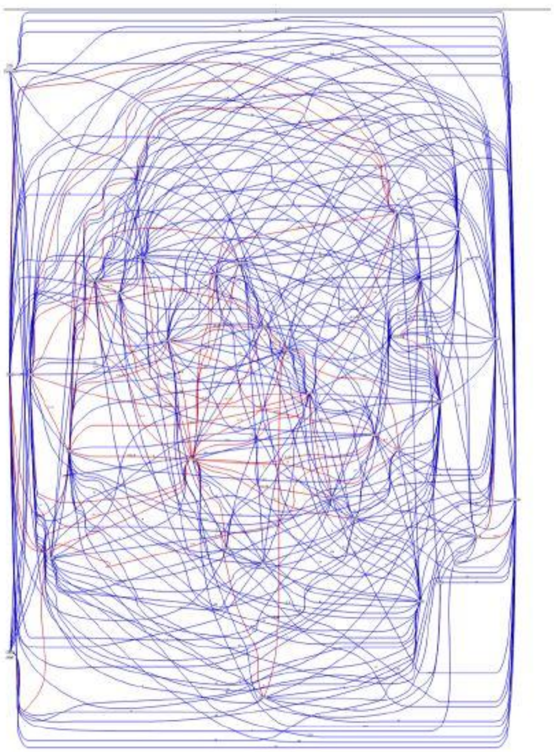

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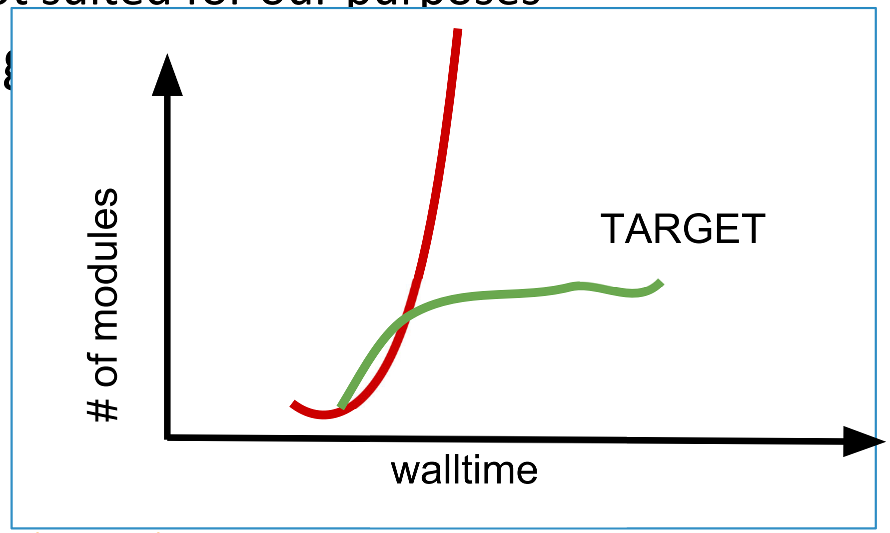

The #1 rule of good housekeeping … DECLUTTER

- 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

New MHD/EP modules, old approach

TRANSP calculates equilibrium

GENRAY re-map equilibrium

CQL3D re-map equilibrium

TORIC re-map equilibrium

....

DCON/GPEC re-map equilibrium

ORBIT re-map equilibrium

NOVA-K (?) re-map equilibrium

An example: the magnetic equilibrium mapping

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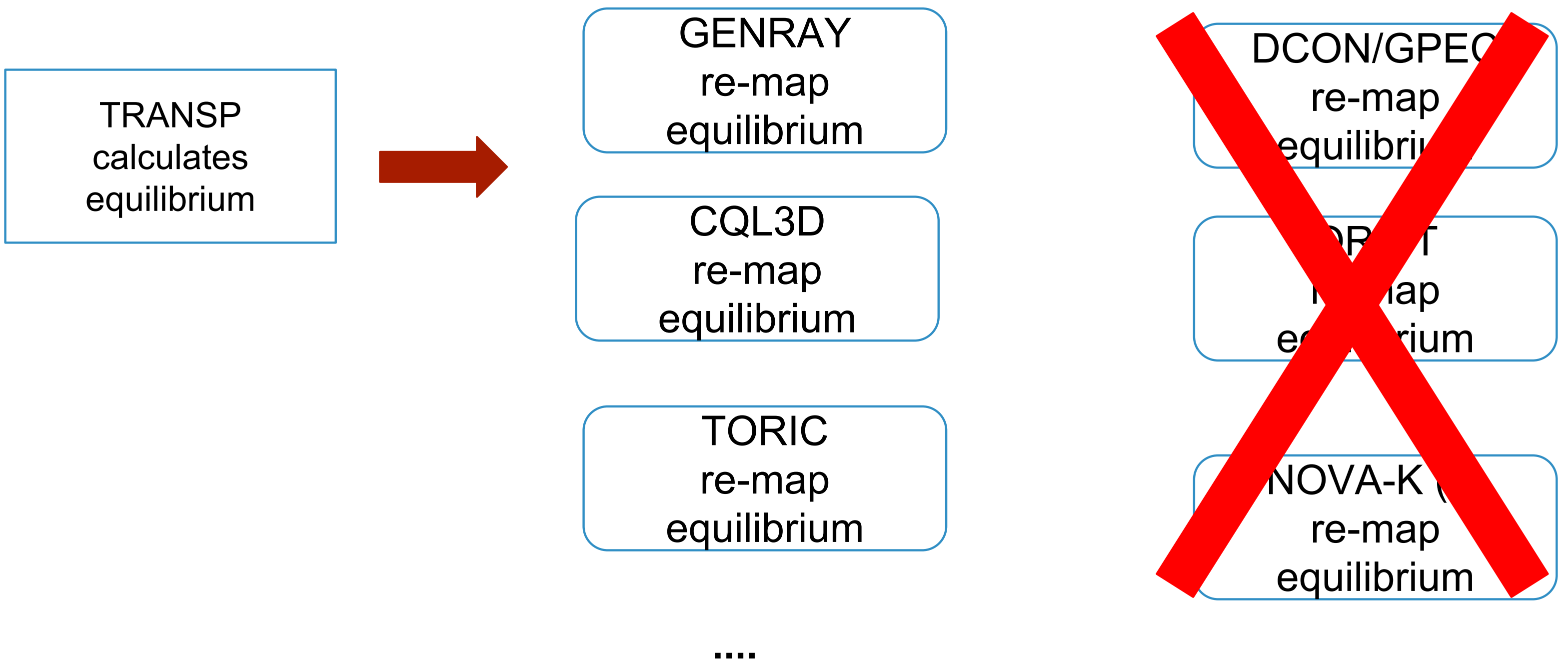
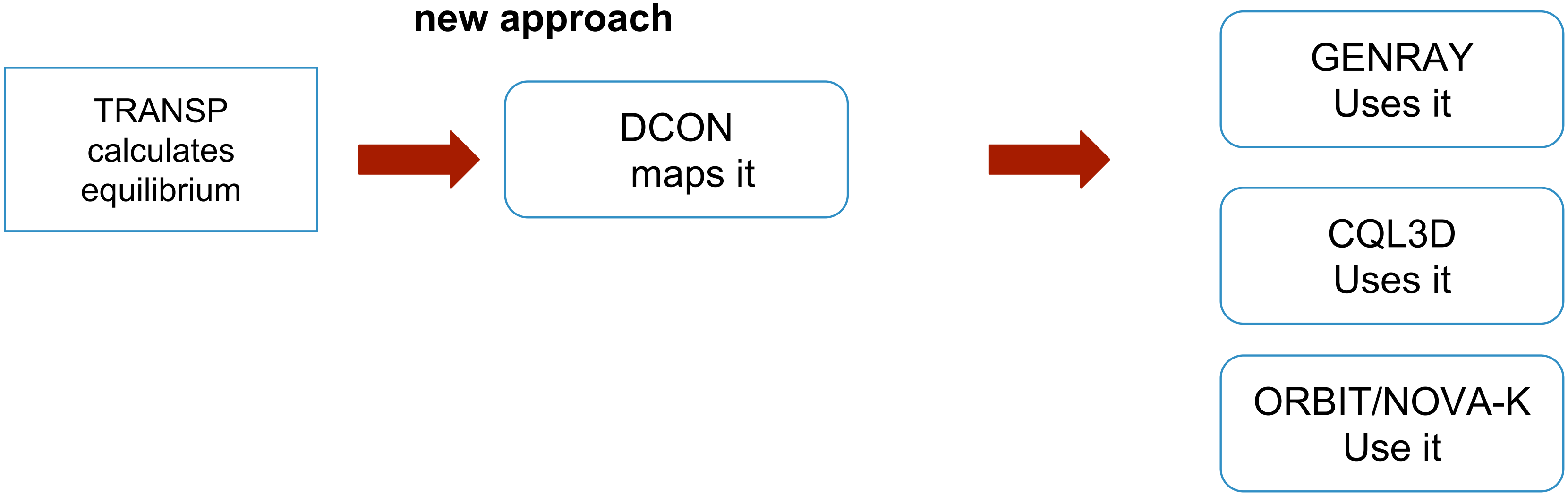


An example: the magnetic equilibrium mapping

Existing RF and new MHD/EP modules, new approach



- ensures consistency among modules => critical for stability calculations
- reduces walltime ...

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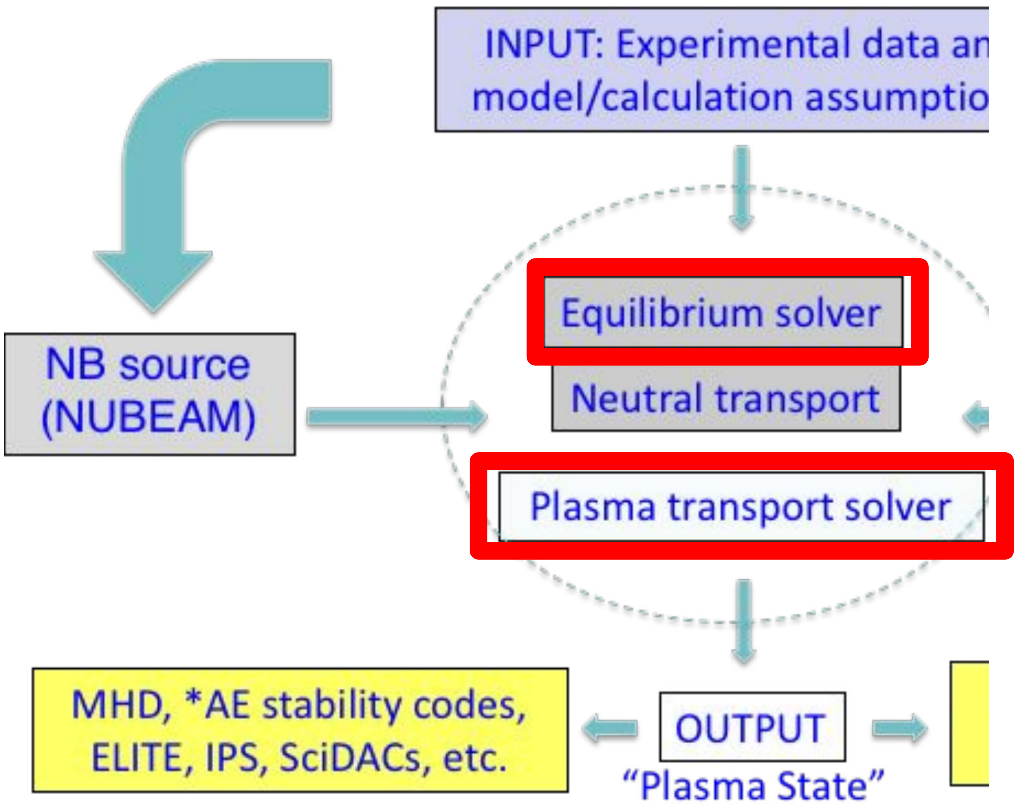
Expand the scope of TRANSP and involve the community

- 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 TRANSP (its solver) is its strength



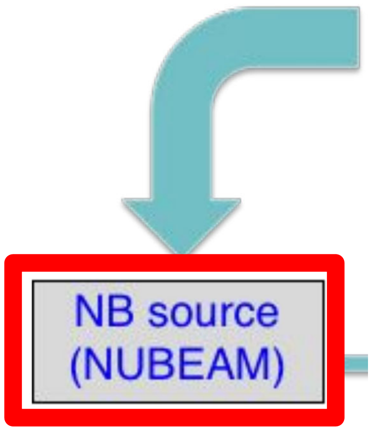
What is seen from the outside world as a *black box* is what makes TRANSP robust:

the hierarchy of time scales

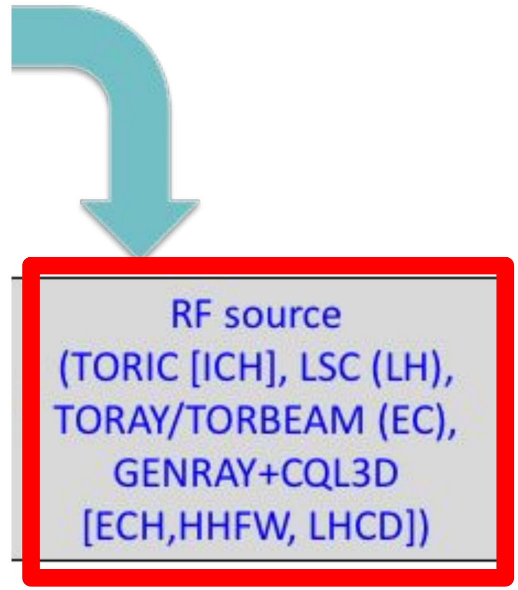
Source => geometry => transport

Code modernization should not break this robustness

The heating and current drive sources are the best available today in a time-dependent solver



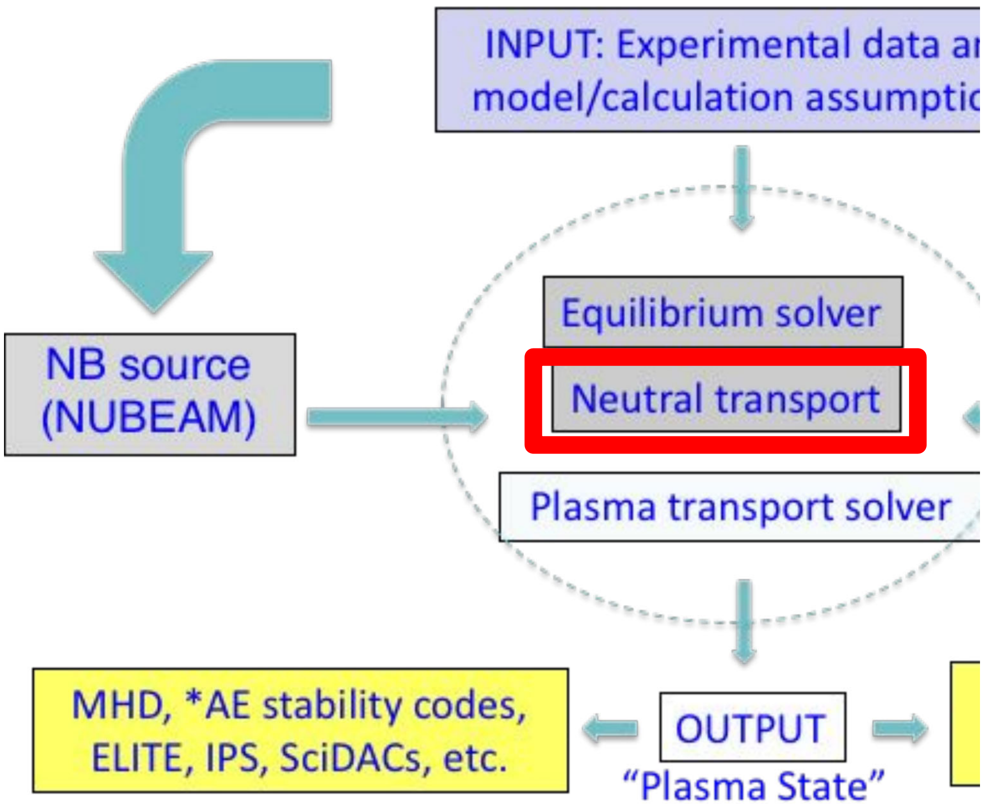
They are also our strongest selling point in domestic and international collaborations.



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

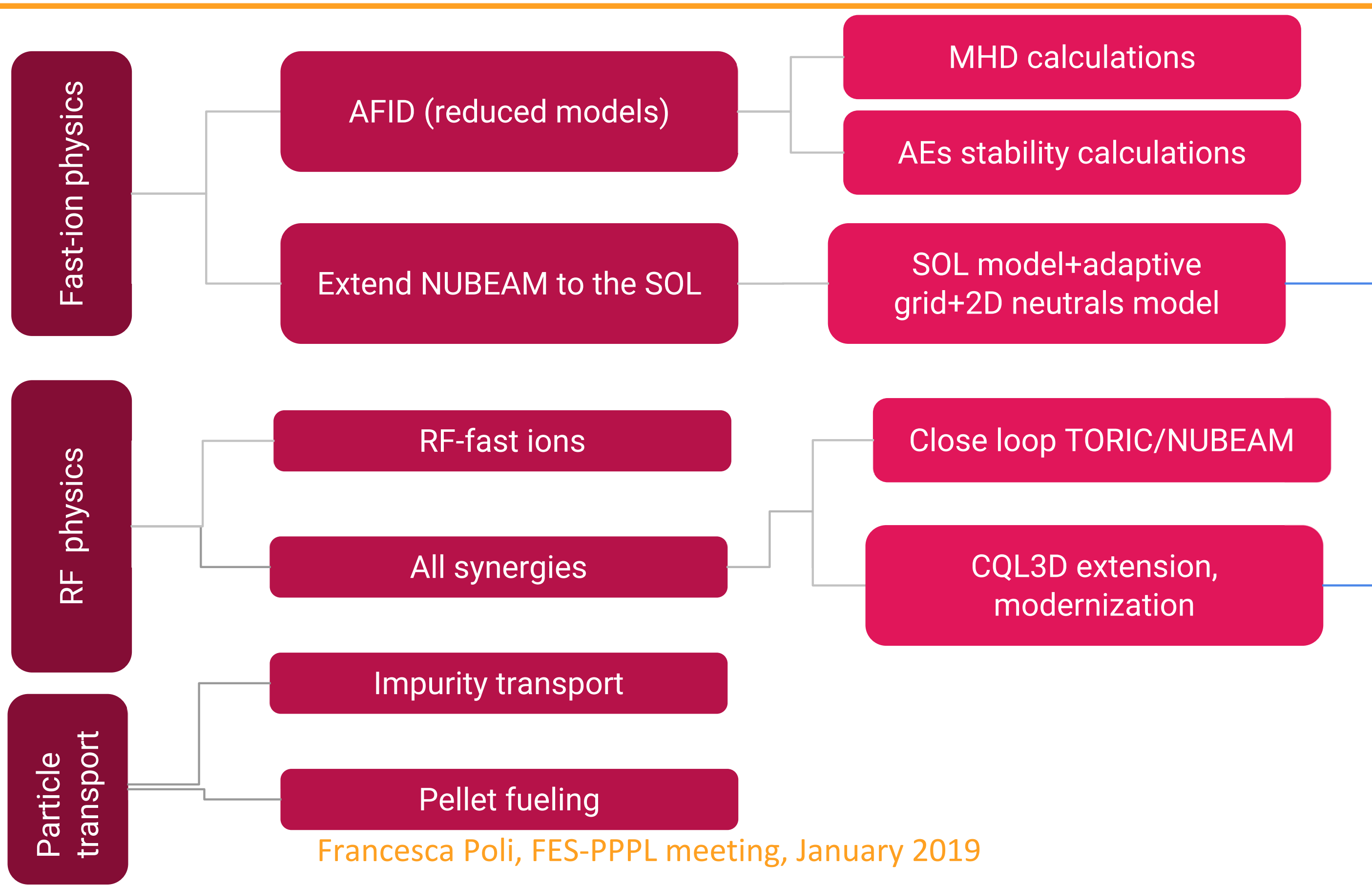


Why: a SOL model is needed for:

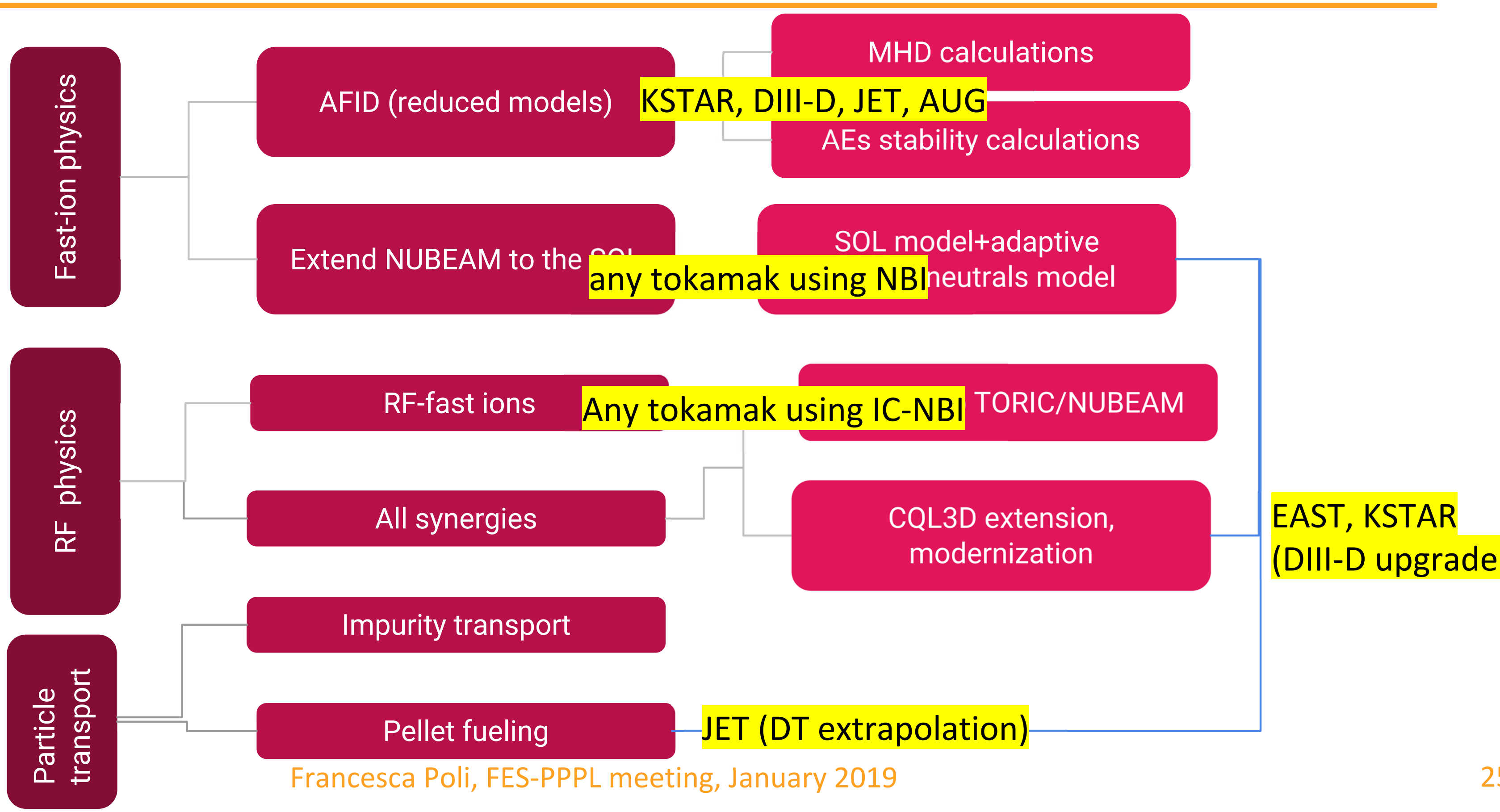
- calculation of RF losses
- fast ion losses
- ionization/recombination, fueling

Path forward: partnership with LLNL to couple UEDGE.

Critical projects and strategic priorities (FY19-FY21)



Priorities support PPPL leadership in domestic and international collaborations



TRANSP PPPL

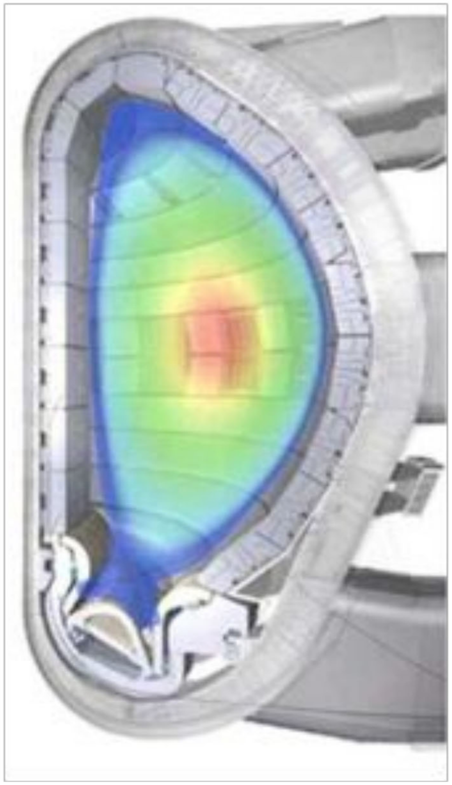
How far are we from a “Whole Device Model”?

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)

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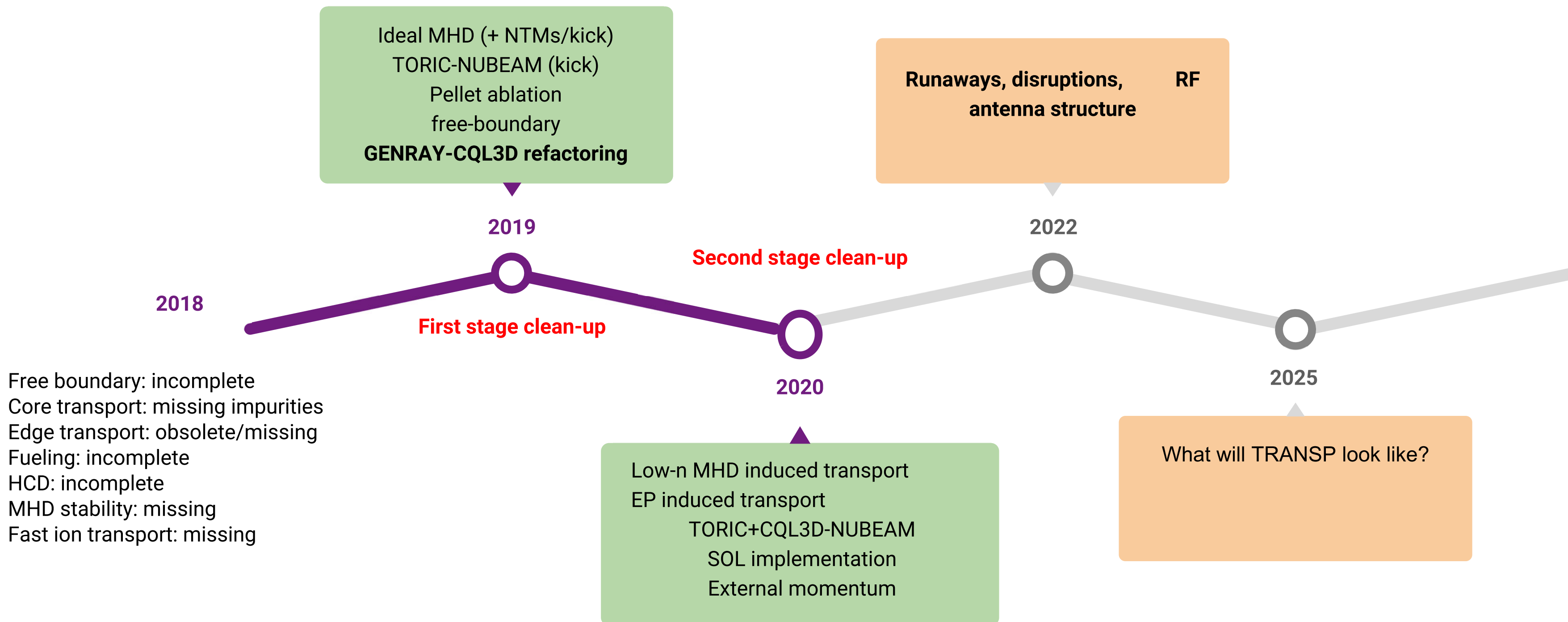
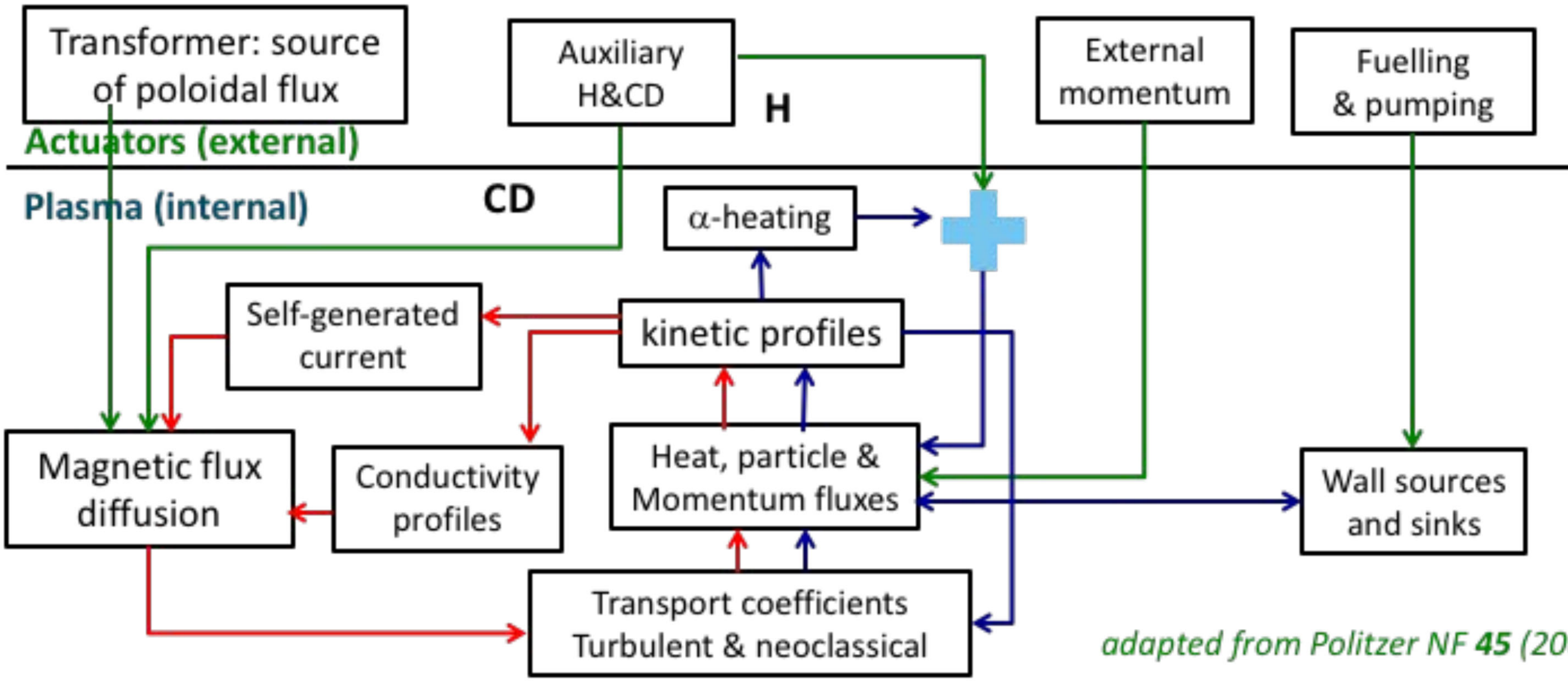


A tokamak simulator needs to connect fast(transport) and slow (current diffusion) time scales



*adapted from Politzer NF **45** (2005)*