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A Suggestion for a focused topical initiative: a feasibility study for 6d kinetic simulation of edge plasmas

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edge simulation laboratory

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The motivation

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- Issues with gyrokinetics for the edge
  - The current edge gyrokinetic projects (CPES and ESL) are working with equations derived for the core
  - The underlying assumptions of spatial scale separation and smallness of perturbations become questionable in the edge.
  - Attempts to derive gyrokinetic equations with less restrictive orderings lead to much more complicated equations
    - Difficult and expensive to implement without additional approximation
    - Don't have consensus on the right equations (or if there even ARE right eqs.)
  - Addition of extra physics, e.g. collisions or neutral-gas interaction, is complicated by the finite-orbit gyro-averaging
- Full-dynamics kinetic simulation has some appealing features
  - We know (and believe) the equations
    - They are relatively simple, so maybe full dynamics is not so much more expensive?
  - Straightforward to add collisions or neutrals
  - Maybe a good match for exascale computers

However:

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- There are issues, e.g.
  - Extra dimension ⇒more particles needed for PIC, more cells for continuum.
  - That extra dimension is gyrophase ⇒ substantial timestep constraint or implicit methods to get around it.
    - What do various implicit methods do to accuracy of solution (e.g. drifts and proper solution at surfaces)?
    - What are the effects of implicit methods or resolving gyro motion on particle noise?
  - Use an "off the shelf" 6D kinetic code? Probably not because of need for field-line-following coordinates & diverted edge geometry
- We kicked this idea around at a recent in-house discussion among FES and math people at LLNL as a possible direction for next phase of ESL (following an earlier discussion at an ESL team meeting), and the consensus was "interesting but too scary" in the absence of a feasibility study. So….

What might be accomplished in a topical initiative

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- Establish feasibility (or not) of a 6D edge code on platforms likely to be available in the forseeable future
- Assess memory and run-time resource requirements
- Devise implicit schemes and analyze for impact on solution accuracy (without and with physics add-ons like collisions and neutrals) and noise
- Ecumenical: examine for both PIC and continuum
- Develop one or more small prototype codes in simplified geometry to demonstrate conclusions
  - Compare large- and small-timestep solutions, and compare with gyrokinetics
  - Possibility of (experimental) validation for an appropriately chosen geometry/problem.
- Resource needed: ~ 1 person-year?

Summary

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- This is a modest proposal that can reduce the risk of developing edge kinetic codes
  - A valid gyrokinetic equation set for the edge is likely to be extremely complicated and maybe non-existent
  - Full-dynamics kinetics is a potential alternative but presents serious challenges
  - This project would assess the feasibility of this alternative