Status of Drift Kinetic MHD

	Theoretical Foundation		Relevant Instabilities	
Species	Core	Edge	Core	Edge
Electrons	Ramos 2010 (slow modes)	Simakov-Catto DKE most appropriate but not CEL form	TMs,Sawteeth, RWMs	ELMs (w/ caveats)
Ions	Ramos 2011 (slow modes)			
Hot ion particles	Hazeltine form used. Not all fluid terms kept.		RWMs, TAEs sawteeth, TMs	

Numerical implementation:

•Benchmark with NEO (steady state) implies collision operators crucial. Also appropriate for the slow modes we are targeting.

•Numerical methods for free streaming operator AND collision operators over full collisionality range with reasonable resolution is the active of are targeting

What to do about the edge

- Edge plasmas and their typical instabilities violate the Ramos orderings in several ways:
  - Edge plasma ranges from low-to-high collisionality
  - Equilibrium gradient scale lengths are small
  - Instabilities are fast
- Ramos: Having 1 DKE do both core and edge is impossible
- What physics do we need?
  - EPED has two components: PB, KBM
  - What physics important for KBMs: GyroLandau fluid
    - Landau-fluid: Free-streaming operatoring in DKE
    - Gyro: Gyro-orbit effects through "the Bessel function terms"

3-field isothermal gyrofluid model* for ELM simulation generalized for the large density gradient at H-mode pedestal

$$\frac{d\varpi_G}{dt} + \mathrm{V}_E\cdot\nabla\varpi_{G0} \boxed{- eB(\mathrm{V}_{\Phi T} - \mathrm{V}_{ET})\cdot\nabla n_{iG}} = B\nabla_\parallel J_\parallel + 2\mathrm{b}_0\times\boldsymbol{\kappa}\cdot\nabla\tilde{P}_G + \mu_{i,\parallel}\partial_\parallel^2\varpi_G$$

$$\frac{d\tilde{P}_G}{dt} + \mathrm{V}_E\cdot\nabla P_{G0} \boxed{+ T_0(\mathrm{V}_{\Phi T} - \mathrm{V}_{ET})\cdot\nabla n_{iG}} = 0$$

$$\frac{\partial A_\parallel}{\partial t} + \partial_\parallel\phi_T = \frac{\eta}{\mu_0}\nabla_\perp^2 A_\parallel - \frac{\eta_H}{\mu_0}\nabla_\perp^4 A_\parallel$$

$$\varpi_G = eB\left(\Gamma_0^{1/2}\tilde{n}_{iG} - n_0(1-\Gamma_0)\frac{e\phi}{T_0} + \boxed{\frac{e\rho_i^2}{T_0}\nabla n_0\cdot\nabla(\Gamma_0-\Gamma_1)\phi} - \tilde{n}_{iG}\right)$$

Padé approximation

$$\begin{cases} \Gamma_0^{1/2} \approx \dfrac{1}{1+b/2} \\ \Gamma_0 \approx \dfrac{1}{1+b} \qquad , \quad b = -\rho_i^2\nabla_\perp^2 \\ \Gamma_0 - \Gamma_1 \approx 1 \end{cases}$$

$$d/dt = \partial/\partial t + \mathrm{V}_{ET}\cdot\nabla,\ \mathrm{V}_{ET} = \frac{1}{B}\mathrm{b}_0\times\nabla\phi_T,\ \phi_T = \phi_0+\phi,\ \nabla_\parallel f = B\partial_\parallel\frac{f}{B},\ \partial_\parallel = \partial_\parallel^0 + \delta\mathrm{b}\cdot\nabla,\ \delta\mathrm{b} = \frac{1}{B}\nabla A_\parallel\times\mathrm{b}_0,\ J_\parallel = J_{\parallel 0} + \tilde{J}_\parallel,\ \tilde{J}_\parallel = -\nabla_\perp^2 A_\parallel/\mu_0$$

$$\frac{d\varpi}{dt} = B\nabla_\parallel J_\parallel + 2\mathrm{b}_0\times\boldsymbol{\kappa}\cdot\nabla\tilde{P} + \mu_{i,\parallel}\partial_\parallel^2\varpi$$

$$\frac{d\tilde{P}}{dt} + \mathrm{V}_E\cdot\nabla P_0 = 0$$

$$\frac{\partial A_\parallel}{\partial t} + \partial_\parallel\phi_T = \frac{\eta}{\mu_0}\nabla_\perp^2 A_\parallel - \frac{\eta_H}{\mu_0}\nabla_\perp^4 A_\parallel$$

$$\varpi = \frac{m_i n_0}{B}\left(\nabla_\perp^2\phi + \frac{1}{en_0}\nabla_\perp^2\tilde{P}_i + \frac{1}{n_0}\nabla n_0\cdot\nabla\phi\right)$$

two-fluid equations

Relation between two-fluid vorticity and gyrokinetic vorticity

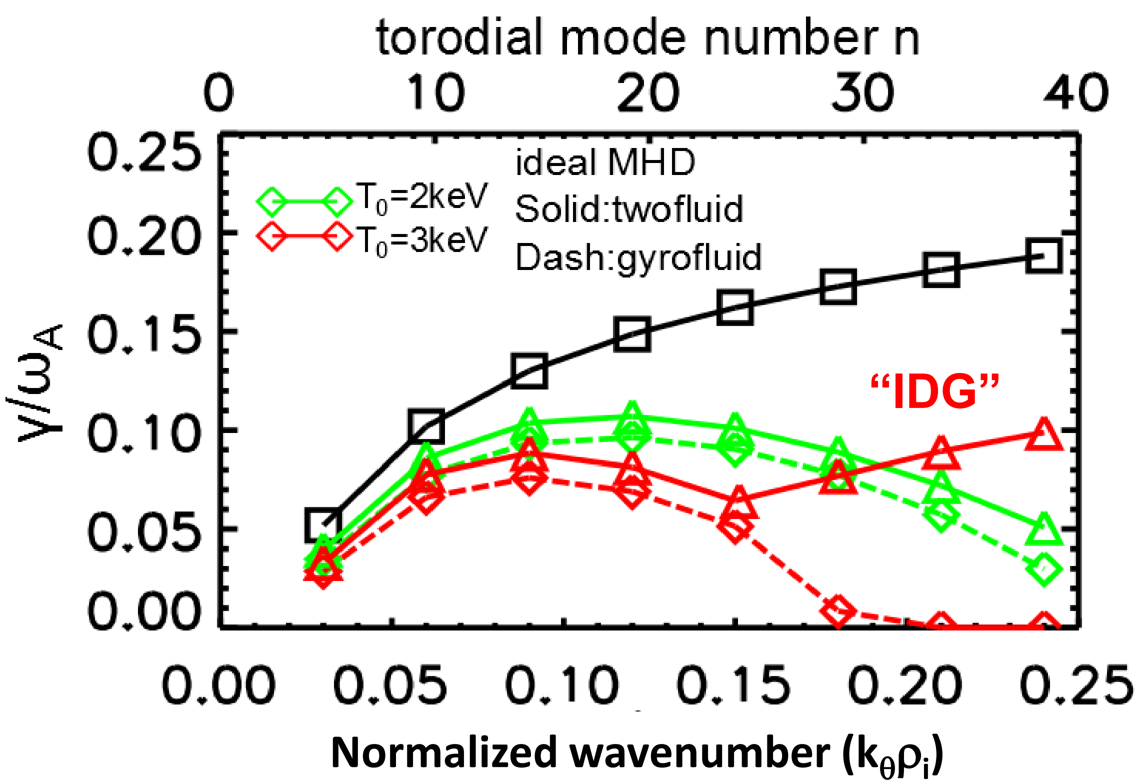
$$\varpi \approx \varpi_G + \frac{1}{2en_0}\nabla_\perp^2\tilde{P}_{iG}, \qquad \rho_i^2\nabla_\perp^2 << 1$$

* P. B. Snyder and G. W. Hammett, *Phys. Plasmas* **8**, 3199 (2001)

In the presence of large density gradient, gyro-fluid and two-fluid model show qualitative difference when $k_\perp \rho_i$ is large

Consider the **large density gradient** at H-mode pedestal, when ion temperature ↑ :

- Two-fluid model: **no stabilizing** of high-n modes,
- Gyro-fluid model: **strong FLR stabilizing** of high-n modes.
- **What causes the disappearance of stabilizing in two-fluid model?**



GP8.00116: P.W. Xi, et al, Gyro-fluid Simulations of Edge-Localized-Modes

Adding the gyro-orbit effects into our extended MHD

- Adding analytic Bessel function terms is attractive
  - Simple extension of gyroviscosity already implemented
  - Avoids solving full gyrokinetic equation
  - Forms in Snyder and Hammett difficult to translate to our equations
  - BOUT++ does not appear to conserve energy, but is interesting case to follow
  - Also of interest in ITG modes that Dalton is studying

Status of Kinetic MHD: Numerics

- Continuum:
  - Advantage: Hope for implicitness, more accurate collision operators appropriate for long time scale modes (NTMs, RWMs)
  - Disadvantages: Very complicated! Linear algebra is going to be scary. Verification is crucial
- Particle methods:
  - Advantages: Captures resonant effects easily. Simple to implement
  - Disadvantages: CFL limits: Will we ever do 800 keV tails? 4 MeV alphas?
- Best instabilities for particles for production runs? Sawteeth and Edge modes: crazy orbits, fast growing, etc.