

Physics Issues Related to RF Models in The Ion Cyclotron and Lower Hybrid Range of Frequencies

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Slow MHD Meeting

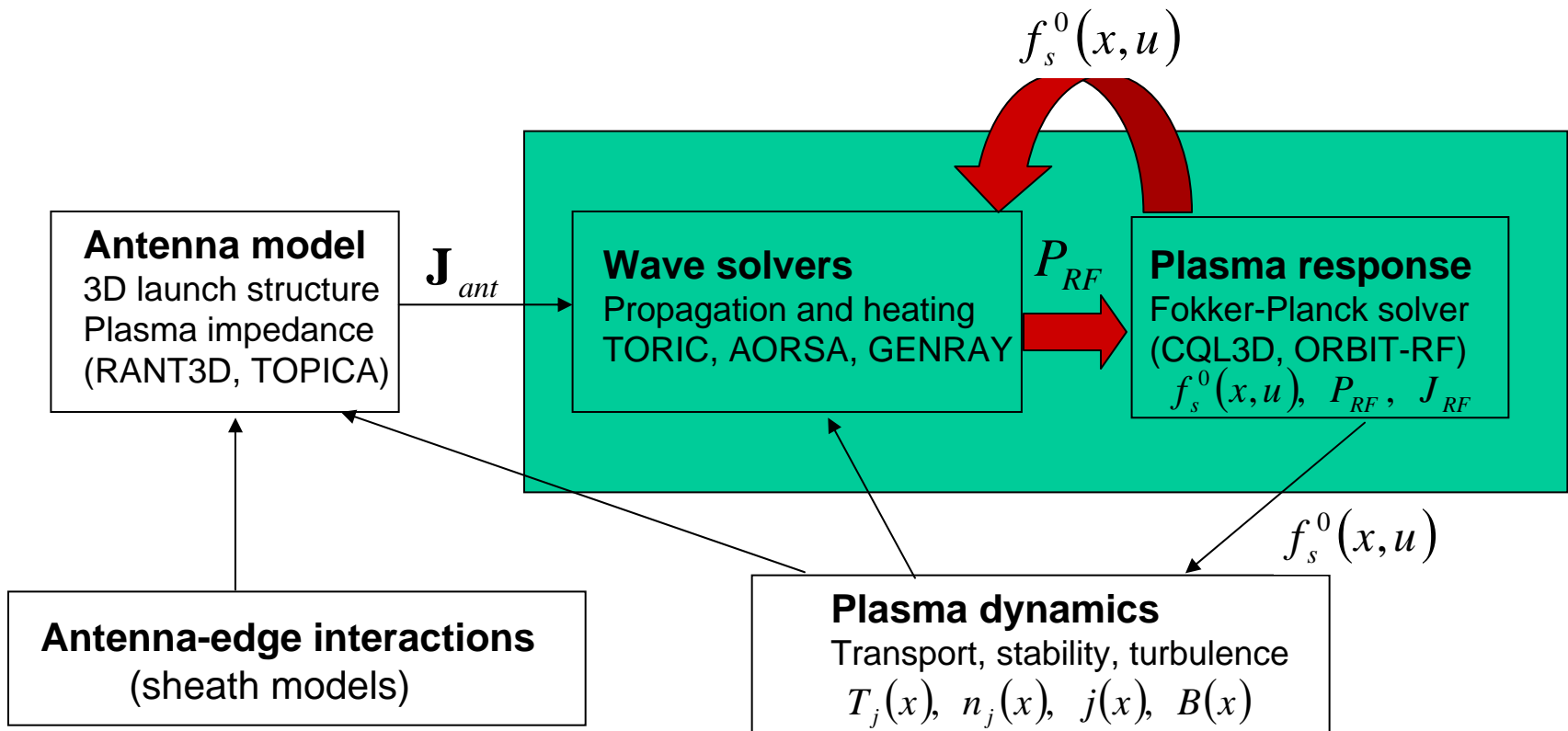
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Outline

- Short tutorial on the ICRF and LHFR physics modules:
 - Wave propagation
 - Fokker Planck
- Answers to Questions on the “Schnack List”
 - What do the RF modules produce?
 - What data can be supplied/produced by RF codes?
 - What RF codes are to be used?
 - Are modifications to RF codes necessary to achieve physics goals?

Iteration Scheme for Self-Consistent Computation of the Nonthermal Particle Distribution Functions



Status of ICRF Wave Propagation and Fokker Planck Solvers

- Full-wave calculations:
 - Minority heating in 2D is routine and in 3D is possible.
 - Mode conversion in 2D is now practical.
 - Mode conversion in 3D still problematic.
 - General (non-Maxwellian) ion distributions from Fokker Planck solvers have been used to formulate the RF conductivity in wave codes, providing for full self-consistency.
 - $Q(\mathbf{E}, f_i)$ from calculation of $\partial W / \partial t = (\text{Absorbed Power} + \text{Kinetic Flux})$
- Fokker Planck solvers:
 - Self-consistent coupling between zero orbit width Fokker Planck code (CQL3D) and full-wave solver (AORSA) has been achieved (coupling to full-wave solver TORIC is now underway through RF SciDAC).
 - Self-consistent coupling between Monte Carlo orbit code (ORBIT RF) and full-wave solvers (AORSA & TORIC) is now underway through RF SciDAC.
- **Larger memory and higher processing capability of massively parallel architectures was largely responsible for these advances.**

Status of LHRF Wave Propagation Codes

- Ray tracing still the preferred method:
 - GENRAY, ACCOME, LSC, CURRAY etc.
 - Calculations in 2D and 3D are routine
 - Self-consistent coupling to FP solvers is done
 - $Q(E, f_i)$ from simplified power flow relation, $\Sigma_k = v_{gk} U_k$, where U_k is the energy density in the wave fields and Σ_k is the flux of power.
- Full-wave studies (2D) using TORIC are now elucidating important physics effects (focusing and diffraction) not easily included in geometrical optics treatments [e.g., Pereverzev, NF (1992)].
 - Self-consistent coupling of TORIC to FP solver (CQL3D) is under way through RF SciDAC Project.

Combined 3-D(p_{\perp} , p_{\parallel} , r) Fokker Planck – Ray Tracing Models: CQL3D-GENRAY [1,2]

- The long time scale response of the plasma distribution function is obtained from the bounce averaged Fokker-Planck equation:

$$\frac{\partial}{\partial t}(\lambda f_s) = \nabla_{\mathbf{u}_s} \cdot \Gamma_{\mathbf{u}_s} + \langle\langle S \rangle\rangle + \langle\langle R \rangle\rangle,$$

$$\nabla_{\mathbf{u}} \cdot \Gamma_{\mathbf{u}} = C(f_s) + Q(\mathbf{E}, f_s)$$

- **Ray tracing and FP solver iterate until a self-consistent D_{rf} and f_e are obtained – this system is highly nonlinear !**
- Fokker Planck codes provide f_e
- Wave propagation codes provide $D_{rf} \rightarrow Q(\mathbf{E}, f_s)$
- J_{rf} and S_{rf} are computed from appropriate moments of f_e

Fokker Planck Solution via a Response Function [3] – Ray Tracing Approach: ACCOME [4] and LSC [5]

- Define and solve an “Adjoint Problem” for the Spitzer - Harm function (χ_s):

$$J_{rf} = \int d^3 \mathbf{p} \frac{\partial \chi_s}{\partial \mathbf{p}} \bullet \Gamma_{rf} \qquad \Gamma_{rf} = -\mathbf{D}_{QL} \bullet \frac{\partial f_s}{\partial \mathbf{p}}$$

- The response function χ_s contains all the physics effects already in the numerical 2D and 3D FP solvers such as particle trapping, DC electric field effect, and momentum conserving corrections in $C(f_e)$
- (J_{rf} / S_{rf}) can be found accurately, but computation of J_{rf} requires separate knowledge of Γ_{rf} and f_s .
- Γ_{rf} and f_s are evaluated from a 1-D ($p_{||}$) solution of the FPE [ACCOME and LSC].
- **Method is only applicable when distortion to f_s is minimal !**

ICRF Summary

Wave Propagation	Fokker Planck
<p>Input: MHD equilibrium Plasma Profiles f_e, f_i</p>	<p>Input: MHD equilibrium Plasma profiles $Q(E, f_i)$</p>
<p>Output: $Q(E, f_i)$ from calculation of W-dot (for full-wave) Output: $Q(E, f_i)$ from simplified power flow relation: $\Sigma_k = v_{gk} U_k$ (ray tracing)</p>	<p>Output: $f_i(\mathbf{v})$ J_{rf}, S_{rf}, W_{rf} from moments of $f_i(\mathbf{v})$</p>
<p>Full-wave: AORSA (2D, 3D) TORIC (2D)</p>	
<p>Ray Tracing: GENRAY (2D, 3D)</p>	

LHRF Summary

Wave Propagation	Fokker Planck
Input: MHD equilibrium Plasma Profiles f_e, f_i	Input: MHD equilibrium Plasma profiles $Q(\mathbf{E}, f_i)$
Output: $Q(\mathbf{E}, f_i)$ from simplified power flow relation: $\Sigma_{\mathbf{k}} = v_{g\mathbf{k}} U_{\mathbf{k}}$ (ray approach)	Output: $f_i(\mathbf{v})$ J_{rf}, S_{rf}, W_{rf} from moments of $f_i(\mathbf{v})$
Full-wave: TORIC (2D) Not yet coupled to FP !	
Ray Tracing: GENRAY ACCOME, LSC (2D, 3D)	

References

- [1] HARVEY, R.W. and McCOY, M.G., Proceedings of the IAEA Technical Committee Meeting on Advances in Simulation and Modeling of Thermonuclear Plasmas, Montreal, 1992, p. 489-526, IAEA, Vienna (1993); US DOC-NTCC Doc. No. DE93002962.
- [2] SMIRNOV, A.P. and HARVEY, R.W., Bull. Am. Phys. Soc. **40**,1837 (1995).
- [3] KARNEY, C.F.F. and FISCH, N.J., Physics of Fluids **28**, 116(1985).
- [4] DEVOTO, R.S., *et al.*, Nuclear Fusion **32**, 773 (1992).
- [5] IGNAT, D.W., Nuclear Fusion **34** 837 (1994).