Ion Temperature Gradient Scale Length in C-mod: Theory and Experiment

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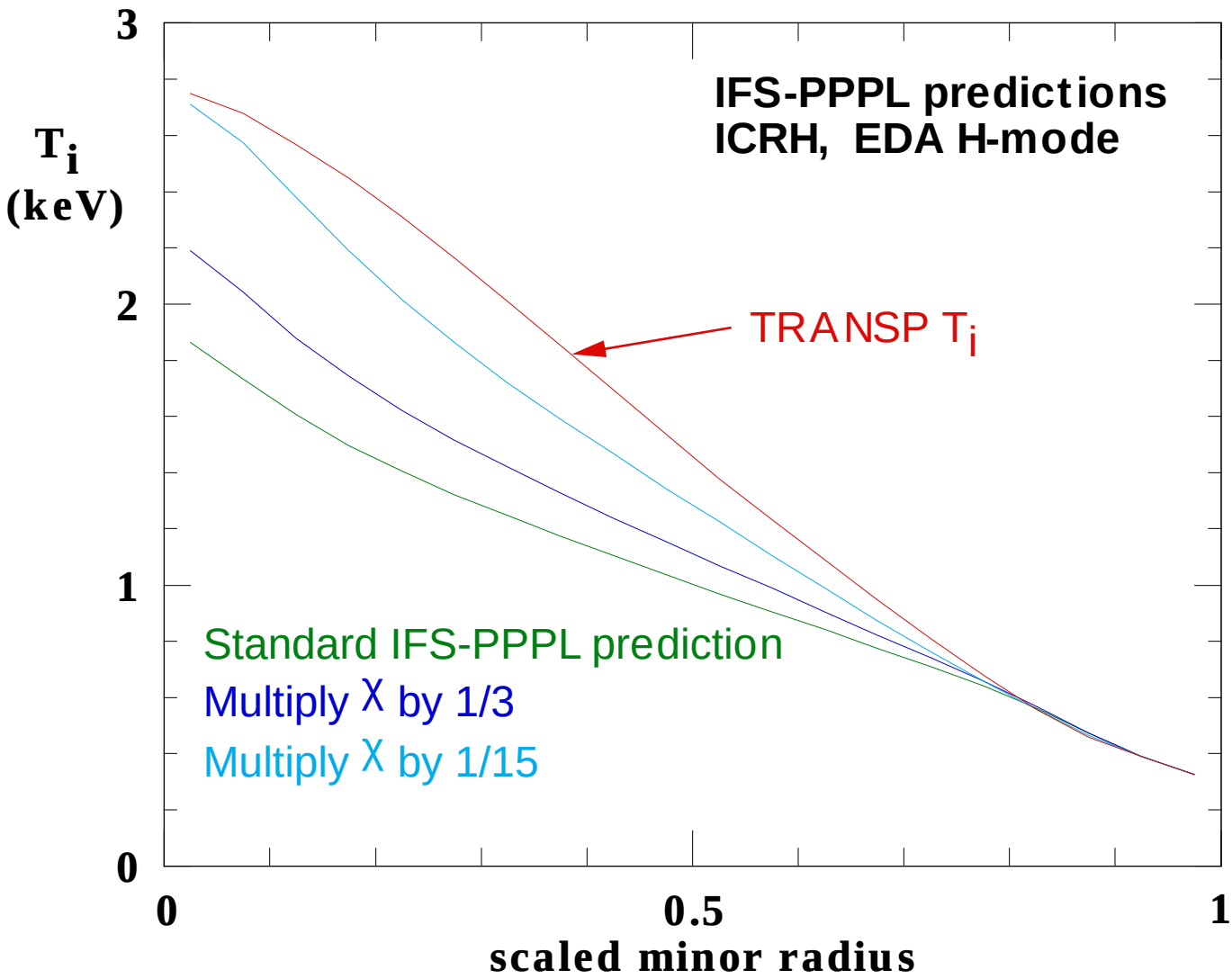
Introduction

- C-mod temperature predictions by IFS-PPPL (&Multi-mode) too low.
  Implies that the model's thermal diffusivities are too large.
  IFS/PPPL model 'correction factor' of 1/2 to 1/3 is not enough.

- C-mod generally expected to be close to marginal stability (Schachter)
  Experimentally based L_T < critical L_{Ti} in typical C-mod discharges.

- Deeper problem for theory: is the critical L_{Ti} too large ?
  Temp. predictions test IFS/PPPL model's analytic fit to critical L_{Ti} .
  It is partially validated by the GS2 gyrokinetic stability code.
  General agreement on linear stability of the toroidal ITG mode.
  Linear stability calculations are not compatible with C-mod data.

Predicted T_i for C-mod is typically too low



Predictions use TRANSP's OH & ICRH profiles, and measured T_e, n_e, and Z_{eff}.

All tested model's predictions are low.

IFS-PPPL predicts marginally stable Ti profiles.

Uncertainty of the actual L_{Ti}

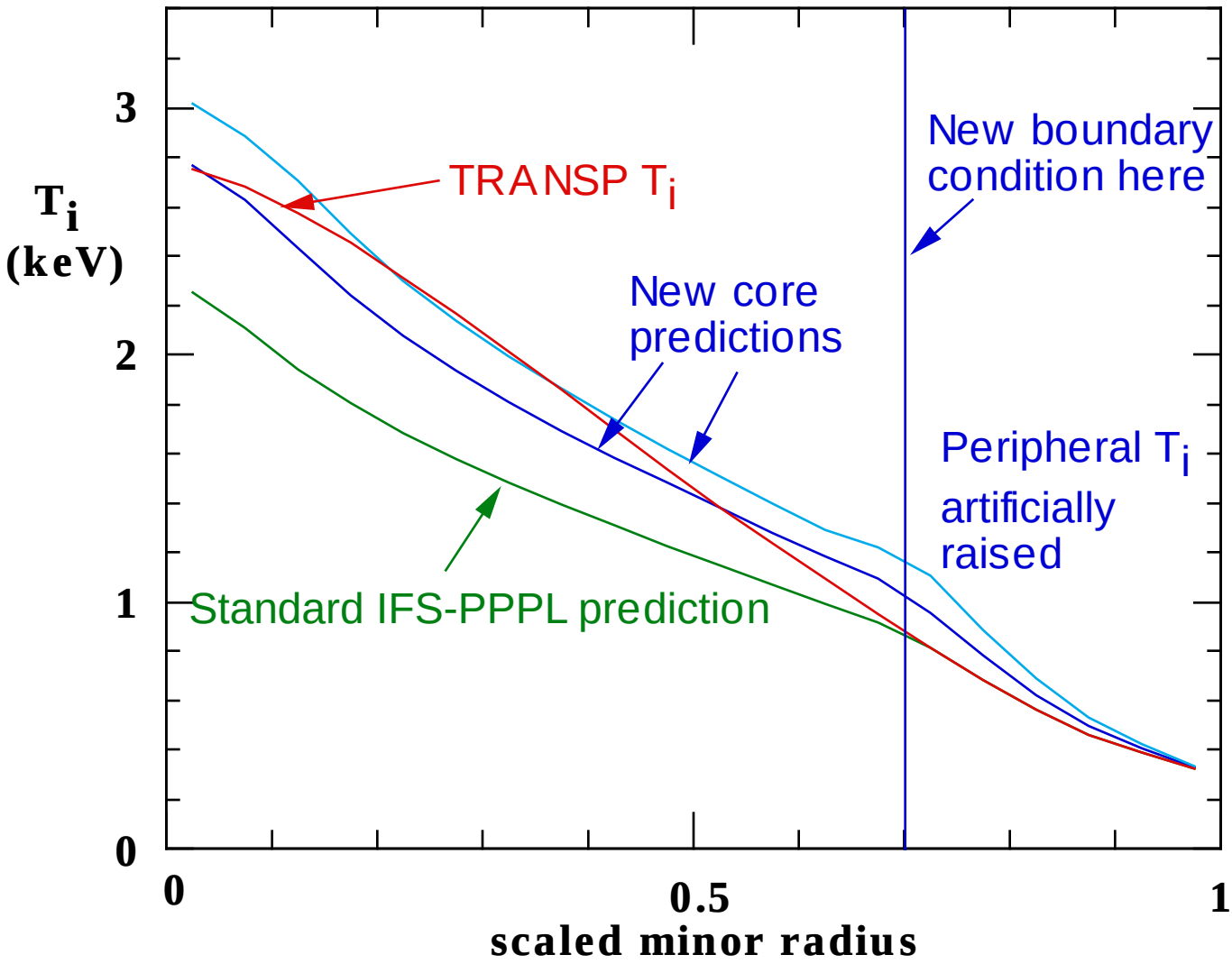
- Presently use the T_i calculated by TRANSP from ion power balance. Neutron-based estimate of core T_i is matched by TRANSP. Collisional temperature equilibration closely couples T_i and T_e.

- Available T_i profile measurements support the TRANSP algorithm. Spectroscopic $T_i(r)$ agree with neutron-T_i and are close to ECE T_e.

- Need a measurement of T_i in the plasma periphery (nothing now). Raising peripheral Ti transfers problem from core to periphery.

- Need a dedicated experiment with careful T_i profile measurements.

Core can be saved with unphysical periphery



Raising peripheral T_i raises boundary condition, so predicted core T_i matches neutrons & spectroscopy

But, Q_{ie} in periphery is as large as P_{heat}.

Predicted conducted power in periphery is huge !

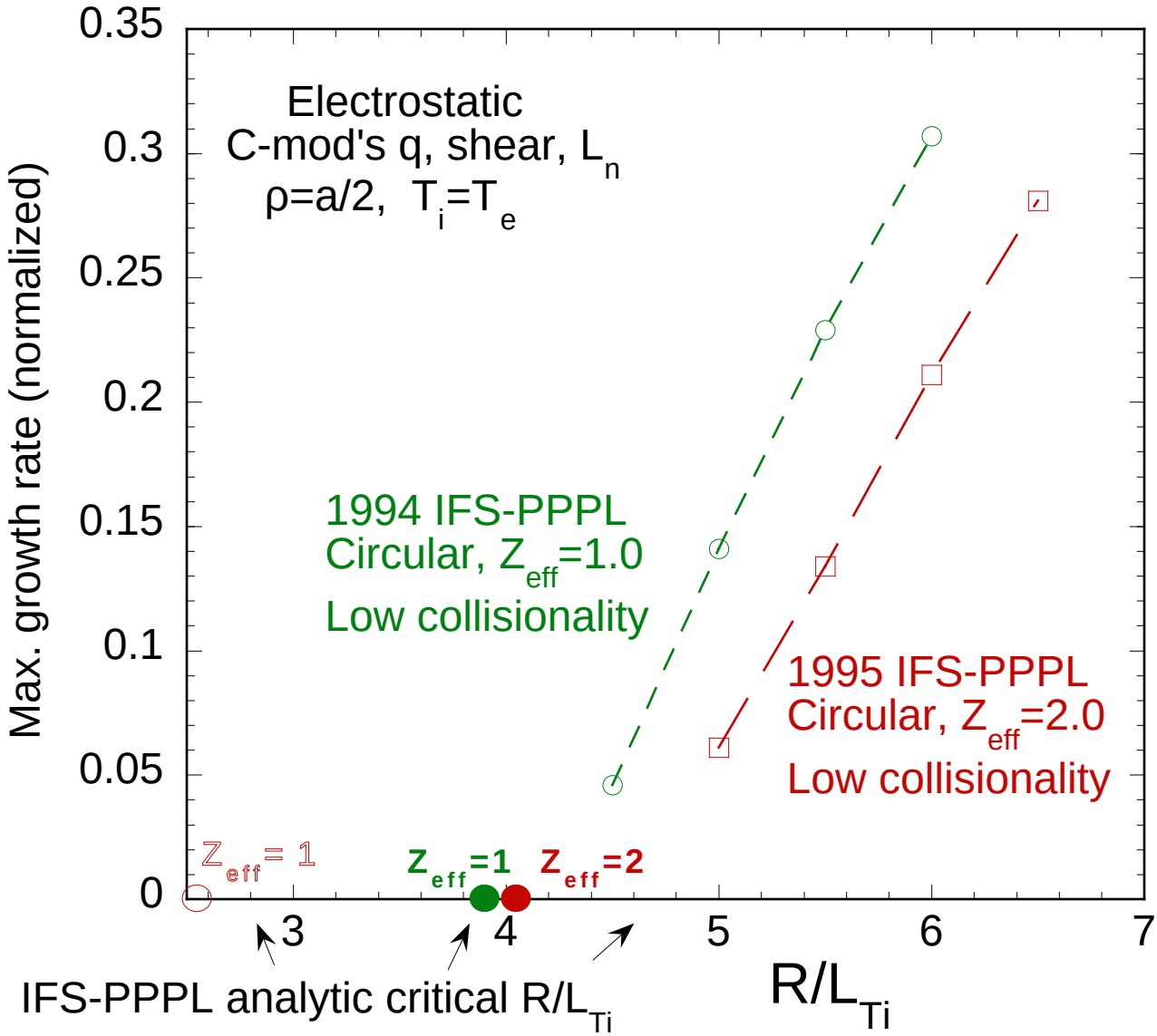
Uncertainty of the theoretical critical L_{Ti}

- Jeff Schachter: small effect from uncertainty of L_{ne}, q, $\hat{s}$, Z_{eff}, and ω_{ExB} associated with v_φ made a very small change in T_i.

- How accurate is the IFS/PPPL analytic fit for the critical R/L_{Ti} ?
  Based on simulations using circular magnetic surfaces.
  Employed many simulations over a 'typical' range of parameters.
  C-mod's collisionality is beyond the range used for the fits.
  Fit errors are generally 10-20%, but least accurate for low Z_{eff}.

- Run GS2, a high-n gyrokinetic stability code (fits based on ancestor).
  Benchmarked against a number of other gyrokinetic stability codes.
  Directly calculate the critical R/L_{Ti} for C-mod discharge parameters.

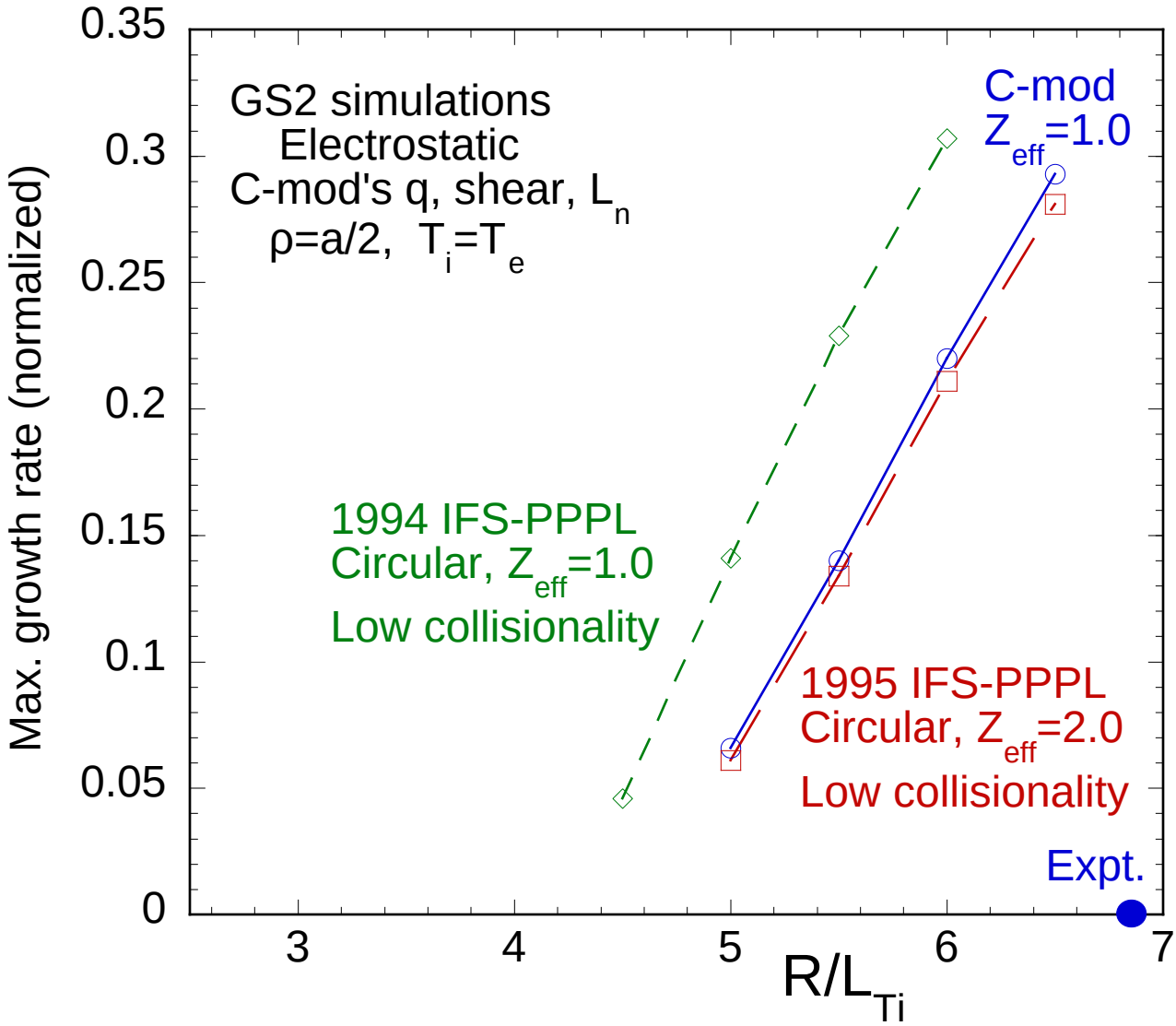
GS2 vs. IFS-PPPL analytic fits



Analytic fits good to 15% at reference Z_{eff}, but Z_{eff} dependence is too strong.

IFS-PPPL crit. R/L_{Ti} is 40% low for Z_{eff}=1.

Use C-mod collisionality and geometry

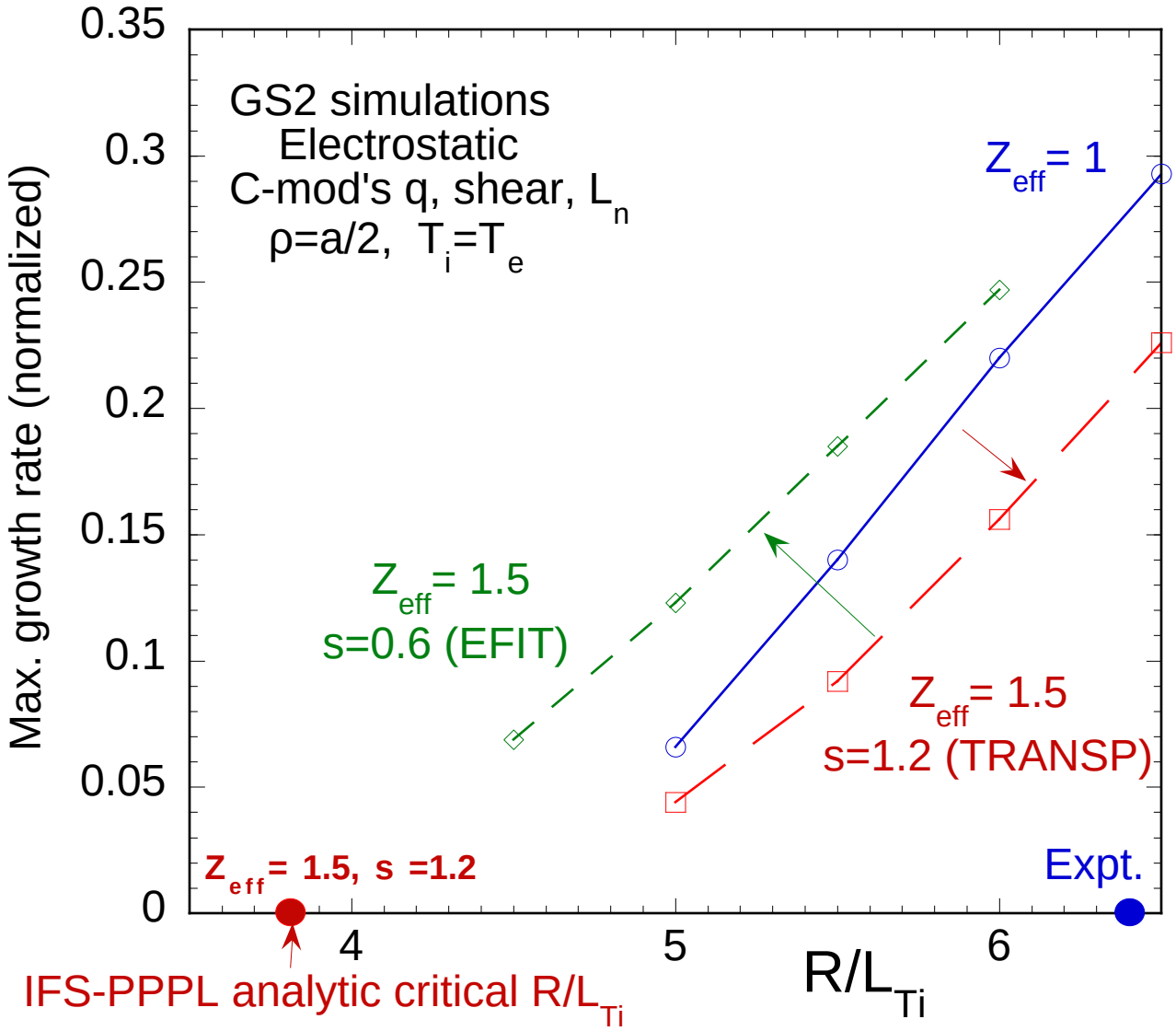


High collisionality shifts critical R/L_{Ti}

Non-circular geometry has smaller effect.

Need still more stabilization.

Need more stabilization to match experiment.



IFS-PPPL analytic fit is 25% low at Z_{eff}= 1.5

Dilution by low Z impurities is stabilizing.

EFIT's lower magnetic shear is destabilizing.

Summary

- GS2 partially validates the IFS-PPPL analytic fit.
  Analytic fit to critical R/L_{Ti} accurate to ~15%, at reference $Z_{eff} = 2$,
  but Zeff dependence is too strong, critical R/L_{Ti} too long at low Zeff.

- GS2 results for C-mod parameters are not close to the estimated R/L_{Ti},
  but experimental uncertainties are too large for a definitive test.
  Need a dedicated experiment with careful T_i profile measurements.

- Need new DNB based diagnostics in 2000 to remove 'wiggle room':
  If peripheral $T_i > T_e$, discrepancy may be moved to periphery.
  Need a direct measurement of magnetic shear.

- Do zonal flows increase the effective critical R/L_{Ti} ? (Z. Lin)
  Are zonal flows severely damped by the high collisionality?
  Need nonlinear simulations (with collisionality) to settle this issue.

GS2 gyrokinetic stability code

- High-n gyrokinetic stability code; implicit; initial value algorithm.
- Benchmarked against FULL code of Rewoldt and Tang; see
  Kotschenreuther, Rewoldt,Tang, Comp. Phys. Comm. **88**,128, '95
- GS2 and FULL have comparable physics content.
  Arbitrary number of fully gyrokinetic ion species.
  Maxwellian or slowing down distributions, plus electrons.
  Fully electromagnetic, including compressional Alfven waves.
  Momentum conserving, Lorentz (pitch-angle scattering) operator
  General geometry (presently restricted to axisymmetric systems).
  GS2 can do non-linear calculations.

- Using new public distribution version of GS2:
  Object-oriented programming practices adopted.
  Full power of Fortran 90 language used.
  Parallelized using MPI.
  'Thick flux tube' terms added.

Uncertainty of GS2 inputs

Potential sources of larger uncertainty in GS2 results:

- Magnetic shear is poorly constrained, but MSE expected in 2000.
- R/L_{ne} was poorly constrained in the past; believed to be ~1.
  Recent TS profiles show R/L_{ne} ~ 3+; but this is not stabilizing.
- ExB shearing associated with poloidal rotation?

Smaller uncertainties in GS2 results expected from these:

- Elongation, triangularity, Shafranov shift and their radial derivitives
- Dilution of hydrogenic species by low Z impurities.
- ExB shearing associated with toroidal rotation.

GS2 results

- GS2 with C-mod parameters validates IFS/PPPL analytic fit.
  New parameters are K, δ; collisionality higher than previous range.
  Analytic fit to critical R/L_{Ti} accurate to ~10%, except
  the Zeff dependence is too strong.

- Preliminary GS2 results still not consistent with estimated R/L_{Ti} .

- Propagate the experimental uncertainties through GS2:
  Higher magnetic shear reduces the discrepancy.
  If peripheral $T_i > T_e$, discrepancy may be removed.

- There is a potentially large source of theoretical uncertainty:
  Seeing a nonlinear upshift of critical R/L_{Ti} caused by zonal flows?

GS2 parameters for 960116027

- Taken from International Profile Database files at 0.9 seconds.

rhoc=0.179
qinp=1.3
shift=-0.088
akappa=1.28
akkappri=0.24
tri=0.12
tripri=0.30
fprim = 1.16
s_hat_input=1.16
T_e/T_i = 0.99
Z_{eff} = 1.5
vnewk = 0.65 (IFS-PPPL formula's ν = 24).
beta=0.0082
beta_prime_input=-0.118 (for tprim=6.0)