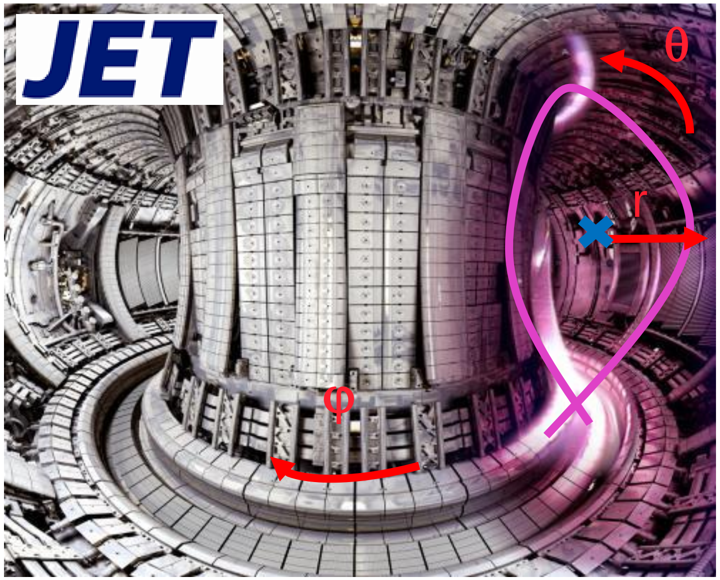
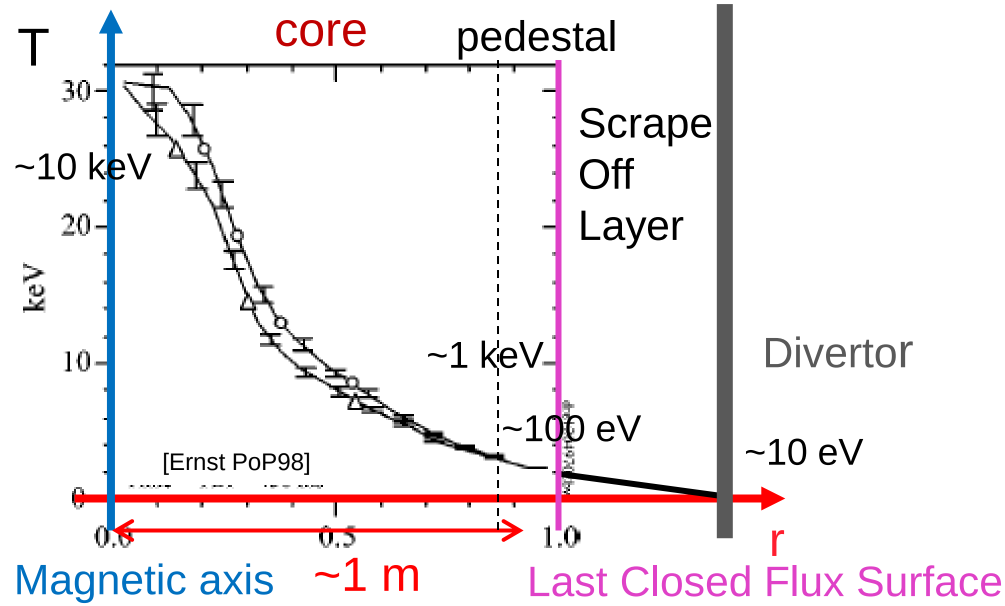
A TUTORIAL FOR QuaLiKiz USERS

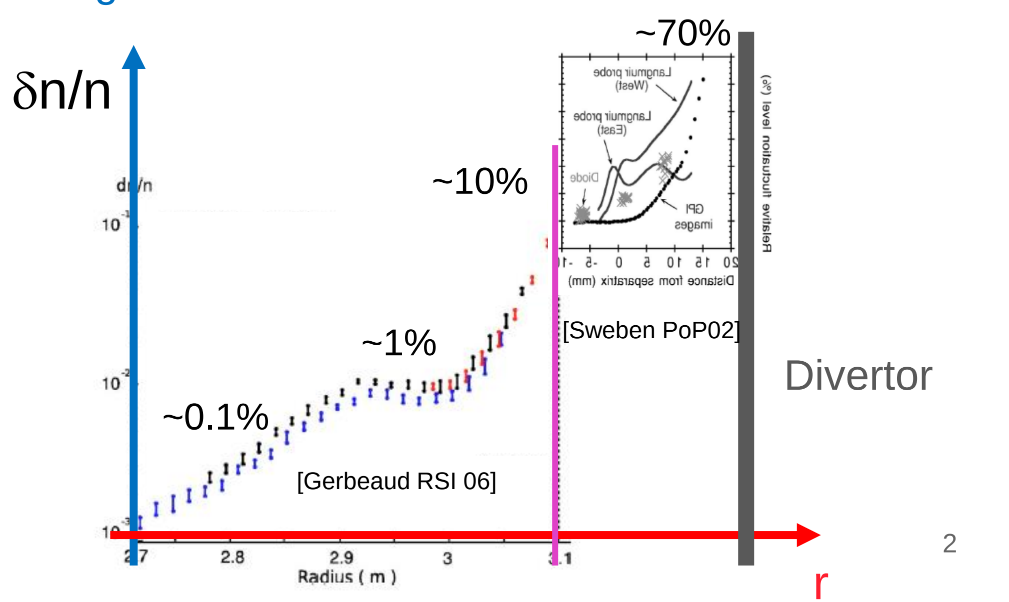
Clarisse Bourdelle, Jonathan Citrin

January 2018

ENERGY CONFINEMENT GOVERNED BY TURBULENCE





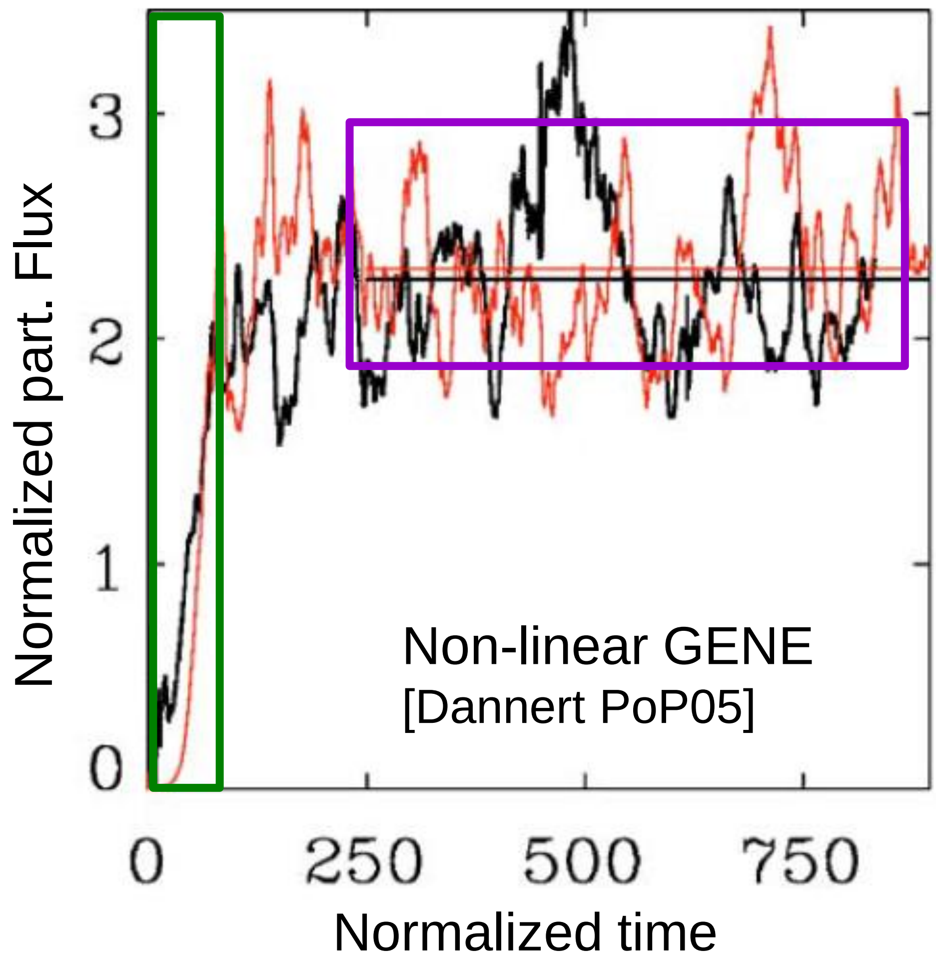


Large T and n gradients and curvature and B gradient
→ turbulence >> collisions governs transport

To maximize τ_E need to understand and predict turbulent transport

INSTABILITY: LINEAR ONSET AND NON-LINEAR SATURATION

Linear phase Saturated phase



Linear phase exponential growth as $e^{\gamma t}$ gives info on instability threshold, parametric dependences

Saturated phase resulting from non-linear interactions between modes provides turbulent particle, heat, angular momentum fluxes

Ultimate goal: fast and first principle prediction of particle, heat, ang. momentum turbulent fluxes. Need to study linear phase first.

- Linear gyrokinetic formulation
- Linear stability and experimental observations
- Deriving and validating quasilinear particle, momentum and heat fluxes
- Quasilinear fluxes vs experimental observations
- Density, temperature and rotation profiles time evolution
- Conclusions and perspectives

LINEAR KINETIC FRAMEWORK TO CALCULATE MODE FREQUENCIES AND GROWTH RATES

- In core of tokamak plasmas $\frac{\delta n}{n} < \sim 1\ \%$ fluctuations << equilibrium

distribution function of species s: $f_s = f_{s,0} + \delta f_s$

electrostatic potential: $\phi = \phi_0 + \delta\phi$ with: $\delta\phi = \sum_{\vec{n},\omega} \phi_{\vec{n}\omega}(\vec{J}) e^{i(\vec{n}.\vec{\vartheta} - \omega t)}$,

$(\vec{J}, \vec{\vartheta})$ the action and angle variables

$\omega = \omega_r + i\gamma$, ω_r is the mode frequency and γ its growth rate

- $\delta\phi$ and δf_s related through 2 equations:
    - Vlasov linearized, $\delta f \times \delta\phi$ neglected

$$f_{\vec{n}\omega}(\vec{J}) = R_{lin}(\omega)\phi_{\vec{n}\omega}(\vec{J}) = -\vec{n} \cdot \frac{df_0(\vec{J})}{d\vec{J}} \frac{1}{\omega - \vec{n} \cdot \frac{d\vec{\vartheta}}{dt} + i0^+} e_s \phi_{\vec{n}\omega}(\vec{J})$$

    - Maxwell for electrostatic case: $\sum_s e_s n_s = 0$

→ **dispersion relation** in 6D : $\sum_s e_s \langle R_{lin}(\omega)\phi_{\vec{n}\omega}\rangle = 0$

eigenfunction $\phi_{\vec{n}\omega}$ and **eigenvalue** $\omega = \omega_r + i\gamma$

SIMPLIFYING THE LINEAR KINETIC DISPERSION RELATION FROM 6D DOWN TO …

- Due to large B, cyclotron fqy >> ω and Larmor radius $\rho_L \ll L$

average on gyromotion: $\phi_{\vec{n}\omega} \rightarrow \int \phi_{\vec{n}\omega} \frac{d\vartheta_L}{2\pi}$ $\rightarrow$ 5D

- 4D by assuming toroidal axisymmetry

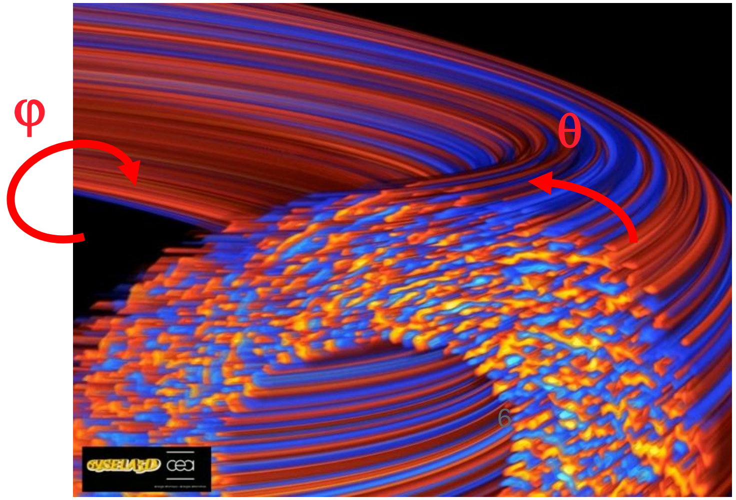
- Turbulent eddies elongated along B field lines: $k_{//} \ll k_{\perp}$

use field aligned coordinate $\varphi - q(r)\theta$,

with $q(r) \approx \frac{rB_\varphi}{RB_\theta}$

assume $\phi_{\vec{n}\omega}$ ballooned around $\theta = 0$

$\phi_{\vec{n}\omega}(r,\theta) \rightarrow \phi_{n\omega}(\theta)$ ≡ 3D



GYSELA 5D [Grandgirard JCP06]

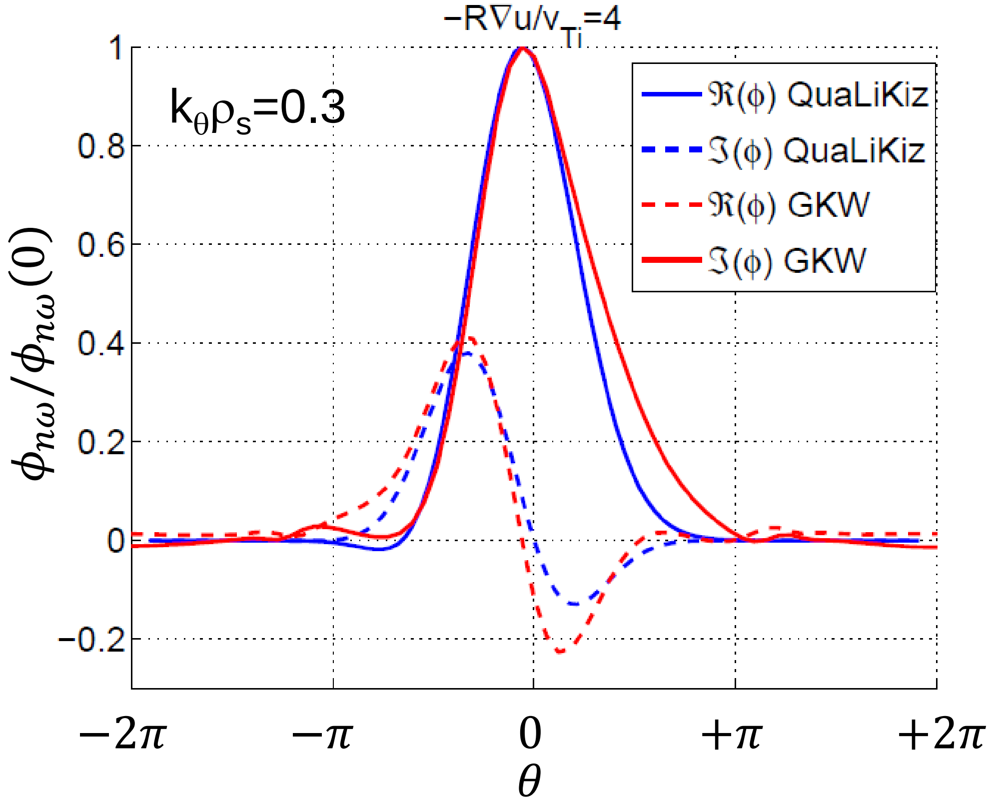
ADDITIONAL APPROXIMATIONS TO REDUCE COMPUTING TIME : QuaLiKiz

[Bourdelle, Garbet et al NF02; Bourdelle, Garbet et al PoP07]

- eigenfunction in fluid limit $\omega \gg n\frac{d\vartheta}{dt}$: a shifted Gaussian in good agreement with self-consistent eigenfunc from 4D code GKW [Peeters CPC09]

- 1/R and ∇B drift and transit frequencies simplified, assuming very trapped/passing part. and circular concentric s-α mag. equi. → 2D integrals

- Efficient search of all eigenvalues in complex plane based on residue theorem [Davies JCP86]



[Cottier, Bourdelle et al PPCF14]

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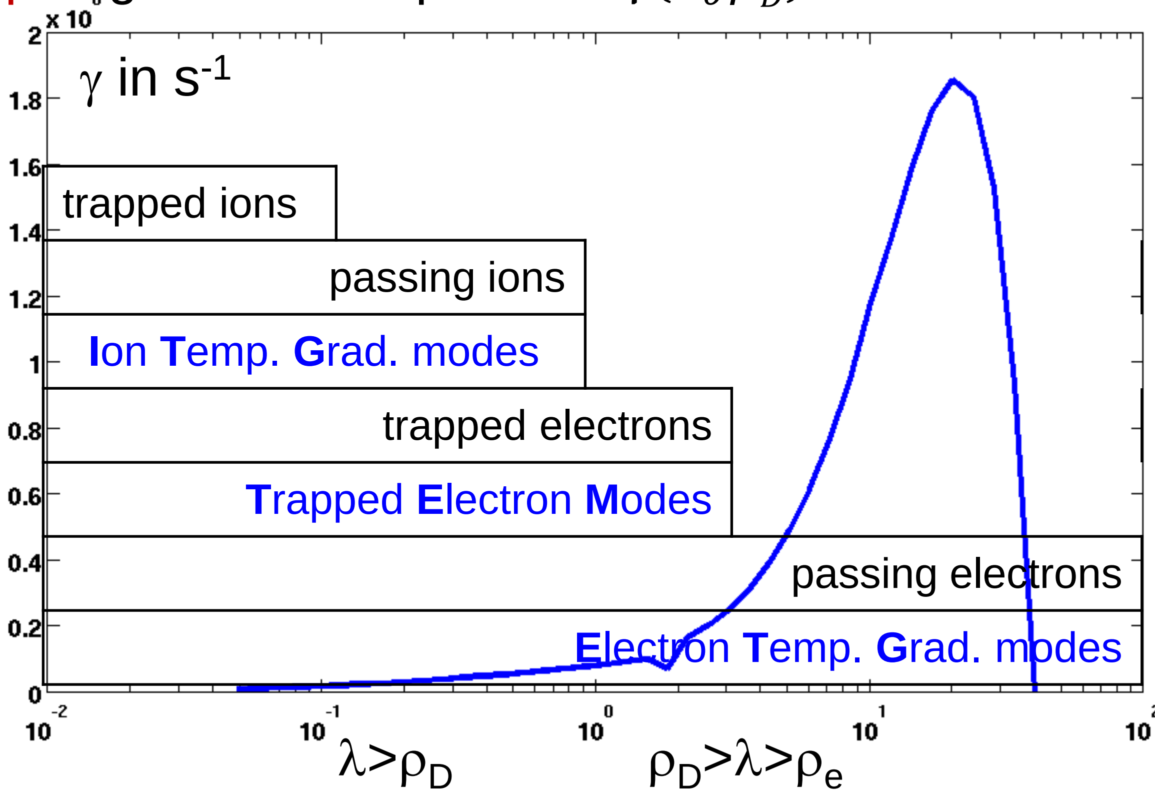
LINEAR STABILITY ANALYSIS

- To compute dispersion relation need:
  $\frac{r}{a}, \frac{R}{a}, \frac{\nabla n_s}{n_s}, \frac{\nabla T_s}{T_s}, \frac{\nabla U_{//}}{v_{th}/R}, \frac{U_{//}}{v_{th}}, \frac{\nabla E_r}{B} / \frac{v_{th}}{R}, \frac{r \nabla q}{q}, q, \frac{T_i}{T_e}, \alpha, Z_{eff}$ from:
  - fitted experimental profiles, requires team work and care
  - ad hoc values to explore parametric trends
- Output: growth rate spectrum $\gamma(k_\theta \rho_D)$



QuaLiKiz

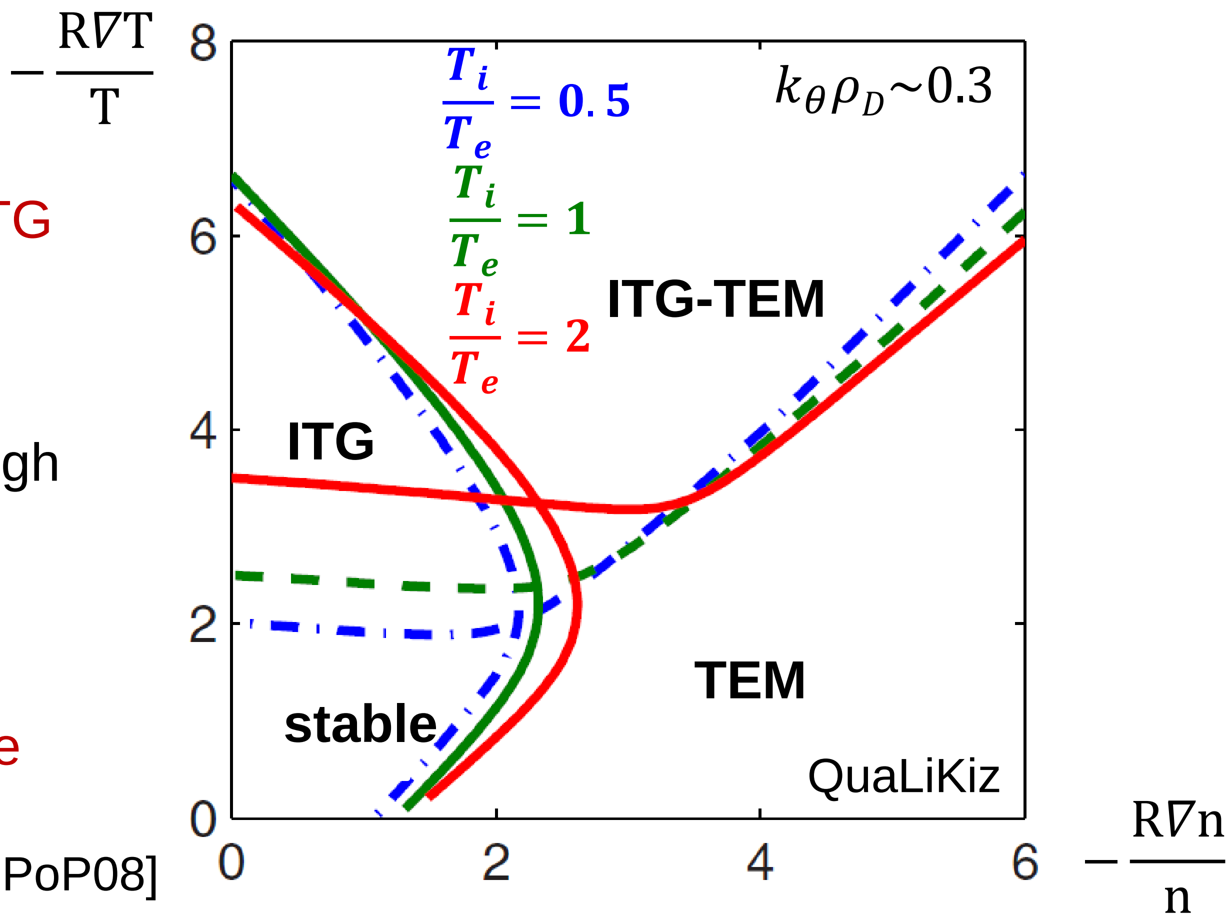
$k_\theta \rho_D = \frac{2\pi}{\lambda} \rho_D$

ONSET OF UNSTABLE MODES ABOVE A T AND n THRESHOLD, ILLUSTRATION OF T_i/T_e IMPACT

Large $\frac{T_i}{T_e}$ stabilizing for ITG at low $-\frac{R\nabla n}{n}$

but different impact at high $-\frac{R\nabla n}{n}$ and on TEM threshold

→ need gyrokinetic code



[Casati, Bourdelle et al PoP08]

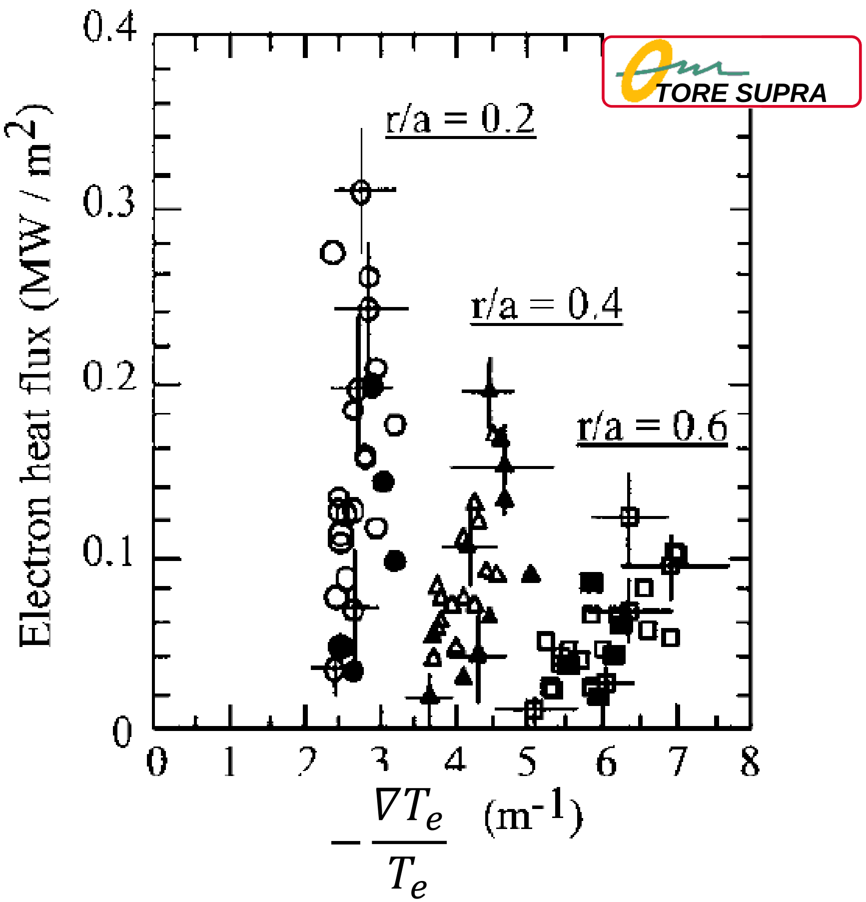
Threshold depends also on $\frac{s}{q} = -\frac{r\nabla q}{q^2}, Z_{eff}$, etc

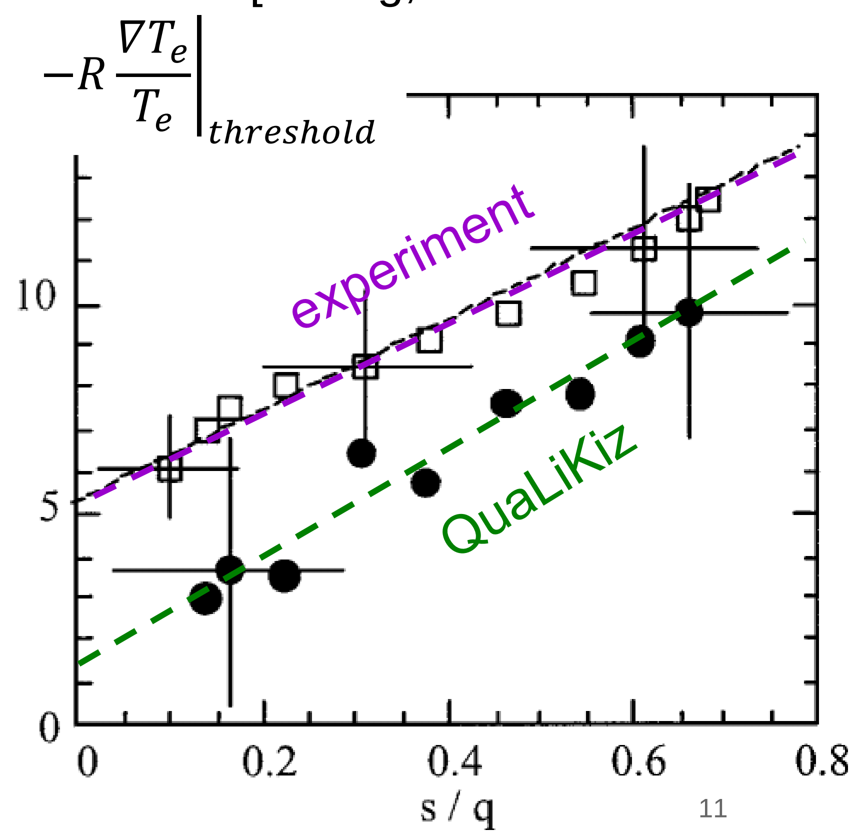
Stand alone analysis allow building up knowledge on turbulence trends

EXPERIMENTAL PROOF OF EXISTENCE OF A CRITICAL TEMPERATURE THRESHOLD

- Expected electron T threshold observed experimentally in Tore Supra [Hoang PRL01], AUG [Ryter03], TCV [Camenen05], DIII-D [DeBoo05], etc
- $-R\frac{\nabla T_e}{T_e}\Big|_{threshold}$ increases with $\frac{s}{q} = -\frac{r\nabla q}{q^2}$ as predicted

[Hoang, Bourdelle et al PRL01]





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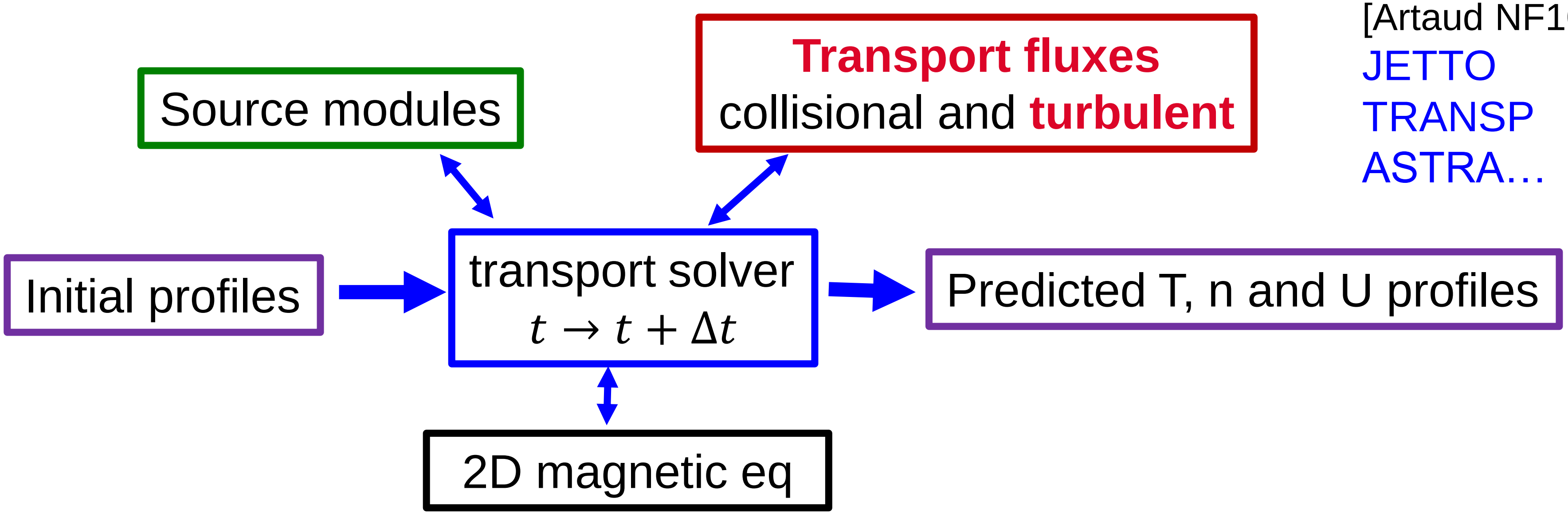
TOWARDS PREDICTING T, n AND U: CONSTRAIN ON COMPUTING TIME

$$\frac{\partial n}{\partial t} = -\vec{\nabla}.\vec{\Gamma} + S = 0,\ \Gamma = -D\nabla n + Vn = \int_0^r S\,dr_1$$

For heat, particle or momentum:

CRONOS
[Artaud NF10]
JETTO
TRANSP
ASTRA…



$$t_{integrated\ sim.} = t_{turb.fluxes} \times \frac{\overset{\text{1-1000 s}}{t_{discharge}}}{\underset{10^{-3}\text{ s}}{\Delta t_{transp.\,solver}}} \times \overset{\text{1-10}}{N_{iterations}}$$

$$t_{integrated\ sim.} \approx 10^4 \times t_{turb.fluxes}$$

INTEGRATED MODELING NEEDS FAST AND FIRST PRINCIPLE TURBULENT FLUXES

Aim: $t_{\text{integrated sim.}} \approx 10^4 \times \mathbf{t_{turb.fluxes}} < \sim\mathbf{24\ h}$ on ~30 CPU

need $\mathbf{t_{turb.fluxes}} < \sim\mathbf{5\ min}$ for 20 radial points and 10 $k_\theta \rho_s$

Gyrokinetic full-f flux driven	Gyrokinetic δf gradient driven		Gyro-Landau fluid gradient driven
GT5D [Idomura POP06], **GYSELA** [Grandgirard JCP06]	**GS2** [Kotschenreuther PoP95], **GENE** [Jenko CPC00], **GYRO** [Candy-Waltz JCP03], **GKW** [Peeters CPC09]	additional approximations: electrostatic, s-α, etc: **QuaLiKiz** [Bourdelle, Garbet et al PoP07]	calibrated to gyro-kinetic theory **TGLF** [Staebler, Waltz et al PoP05, PoP10, PRL13]
Nonlinear		**Quasilinear**	
~10 Mh	~ 50 000 h	~ 500 h	~ 30 s

easing interface with experiments

Other more approximated/faster fluid quasilinear models: Weiland/Multi-Mode Model [Weiland NF89, Rafiq PoP13] IFS-PPL [Kotschenreuther PoP95] GLF23 [Waltz PoP97]

TESTING THE QUASILINEAR APPROXIMATION

$$\boldsymbol{\Gamma_s = \langle \delta f_s \delta V_E \rangle_\tau} = \sum_{k_\theta,\omega,\omega_k} Re\left(\left\langle \delta f_s \frac{i k_\theta \delta\phi^*}{B} \right\rangle_\tau\right) \qquad f_{n\omega} = R_{lin}(\omega)\phi_{n\omega}$$

$$\boldsymbol{\Gamma_s} = -\sum_{k_\theta,\omega,\omega_k} \frac{k_\theta}{B} \boldsymbol{Im\langle R_{lin}(k_\theta,\omega,\omega_k)\rangle} \, |\boldsymbol{\delta\phi(k_\theta,\omega,\omega_k)}|^2$$

quasi-linear flux = linear response x saturated potential

Questions:

- Is the linear response valid?
- How to build the saturated potential?
- Test quasi-linear fluxes against non-linear sim. and experiments

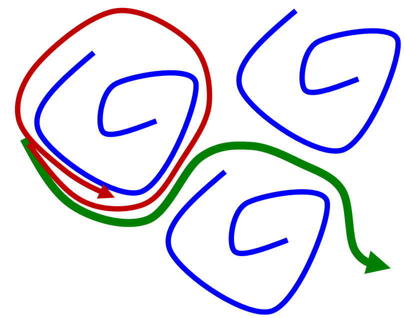
Tools:

- Non-linear gyrokinetic simulations
- Turbulence measurements and experimental results

FIELD TRAPPING OR RANDOM WALK?

quasi-linear flux = linear response x saturated potential

Is it correct to neglect non-linear coupling $\delta f \times \delta\phi$?



Turbulence auto-correlation time: $\boldsymbol{\tau_{ac}}$

vs particle "flight" time: $\tau_{flight} = \frac{\lambda_x}{\delta V_x} = \frac{\lambda_x}{\sqrt{\langle E_y^2 \rangle}/B}$

- If $\tau_{ac} < \tau_{flight}$, K>1, field trapping, need non-linear physics
- If $\tau_{flight} < \tau_{ac}$, K<1, linear response is sufficient

Run	$\sqrt{\langle E_y^2 \rangle}$	λ_x	t_{ac}	K
A: s=1	8.6	12.60	1.85	0.42
A: s=0.6	11.78	11.2	2.05	0.72
A: s=0.1	12.23	7.12	0.58	0.33
A: s=-0.4	9.66	6.94	1.85	0.86

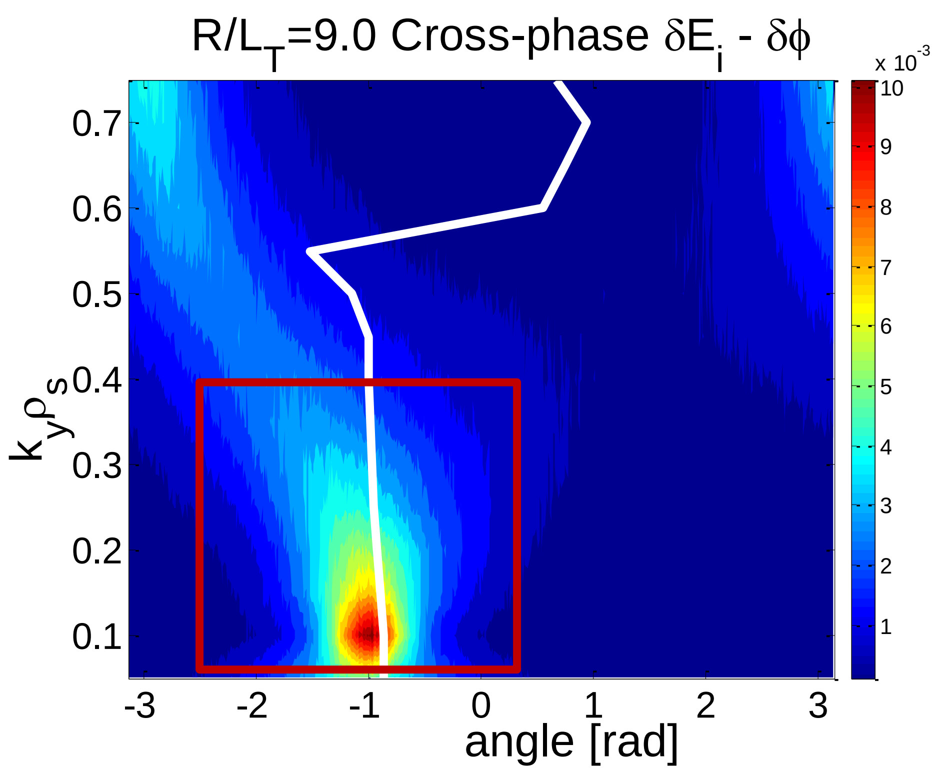
Non-linear GENE

[Citrin, Bourdelle et al PoP12]

LINEAR ≈ NON LINEAR CROSS PHASE

quasi-linear flux = linear response x saturated potential

cross phase of linear response vs
PDF of non-linear cross phase: $\Gamma_{NL}/\delta\phi^2$

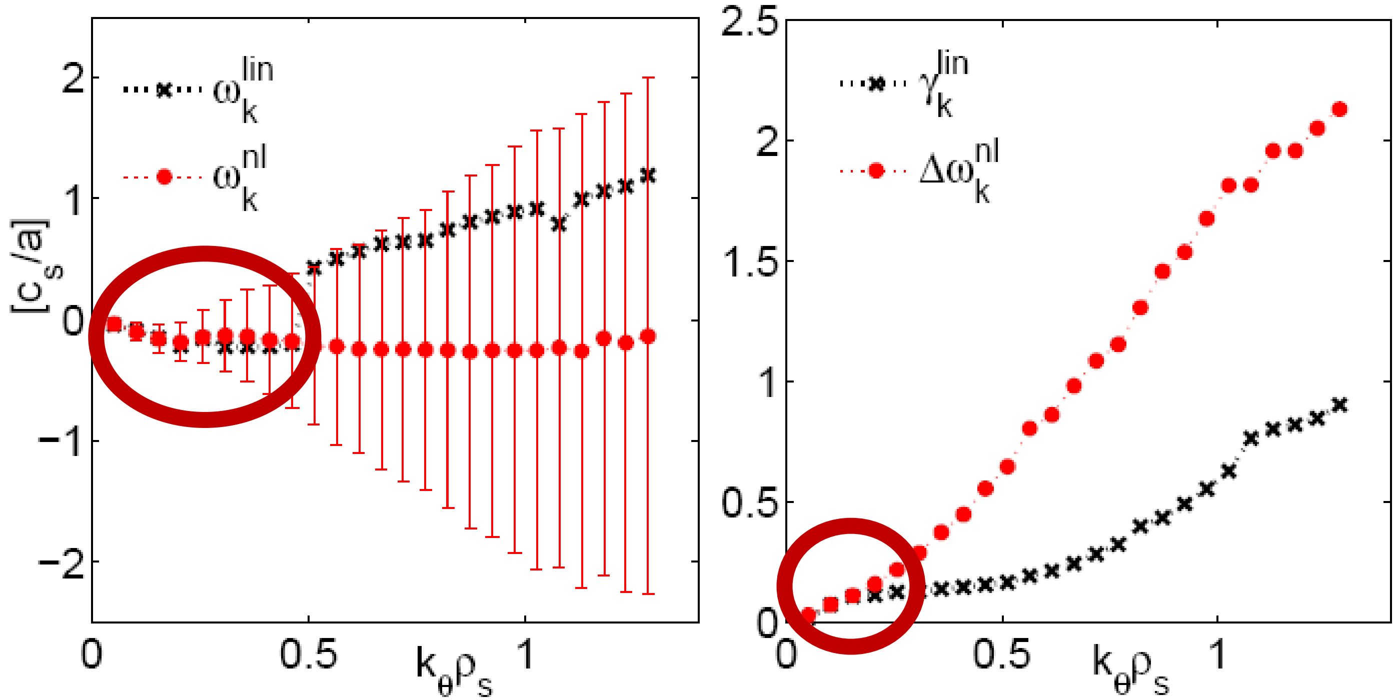


agreement at low $k_\theta\rho_s$
where most of transport

Non-linear GYRO [Casati, Bourdelle et al NF09]

LINEAR FREQUENCY WIDTH ~ LINEAR GROWTH RATE

quasi-linear flux = linear response x saturated potential



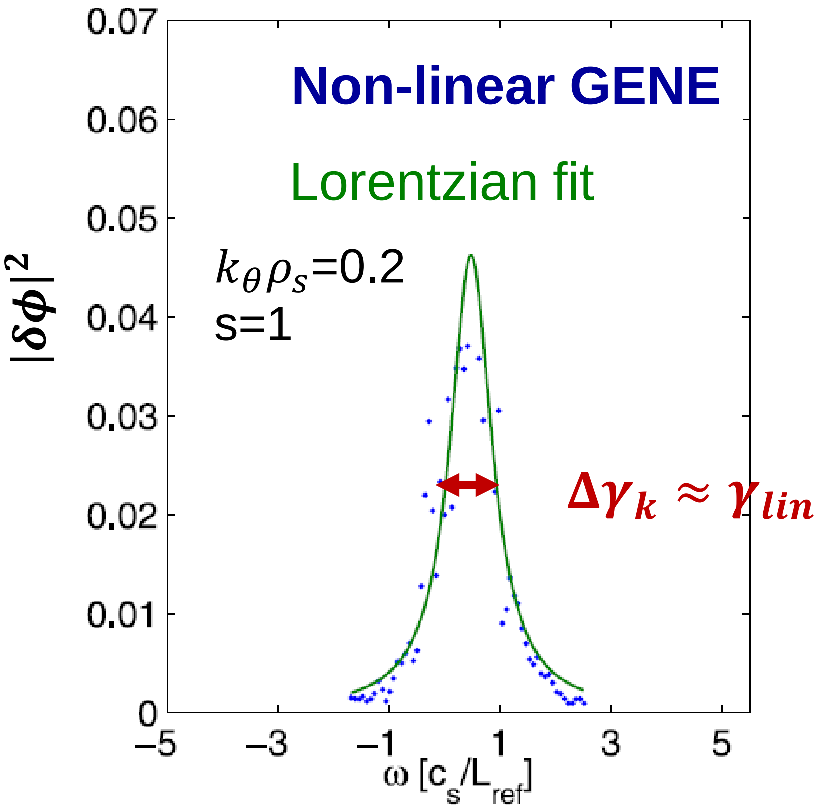
GYRO linear and non-linear

of TS39596 at r/a = 0.7 [Casati 2009 PhD]

HOW TO BUILD THE FREQUENCY SPECTRUM?

quasi-linear flux = linear response x saturated potential

$$Im\langle R_{lin}(k_\theta,\omega,\omega_k)\rangle \propto Im\left(\frac{1}{\omega - n\frac{d\vartheta}{dt} + i\Delta\gamma_k}\right) = \frac{\Delta\gamma_k}{\left(\omega - n\frac{d\vartheta}{dt}\right)^2 + (\Delta\gamma_k)^2}$$



Frequency broadening: Lorentzian of width $\Delta\gamma_k \approx \gamma_{lin}$ at low $k_\theta\rho_s$
but at higher $k_\theta\rho_s$ and for $|s| < 0.6$ interplay with zonal flow and probably with damped mode modify $\Delta\gamma_k$

Lack of 1st principle theoretical model → ad-hoc renormalization factor for $|s| < 0.6$

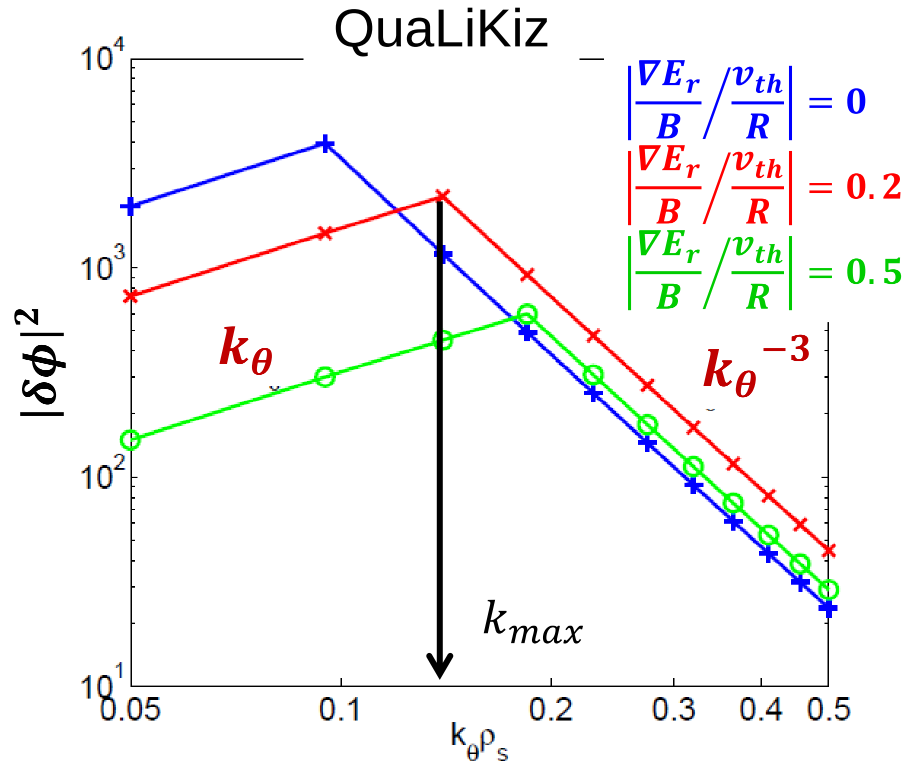
[Citrin, Bourdelle et al PoP12]

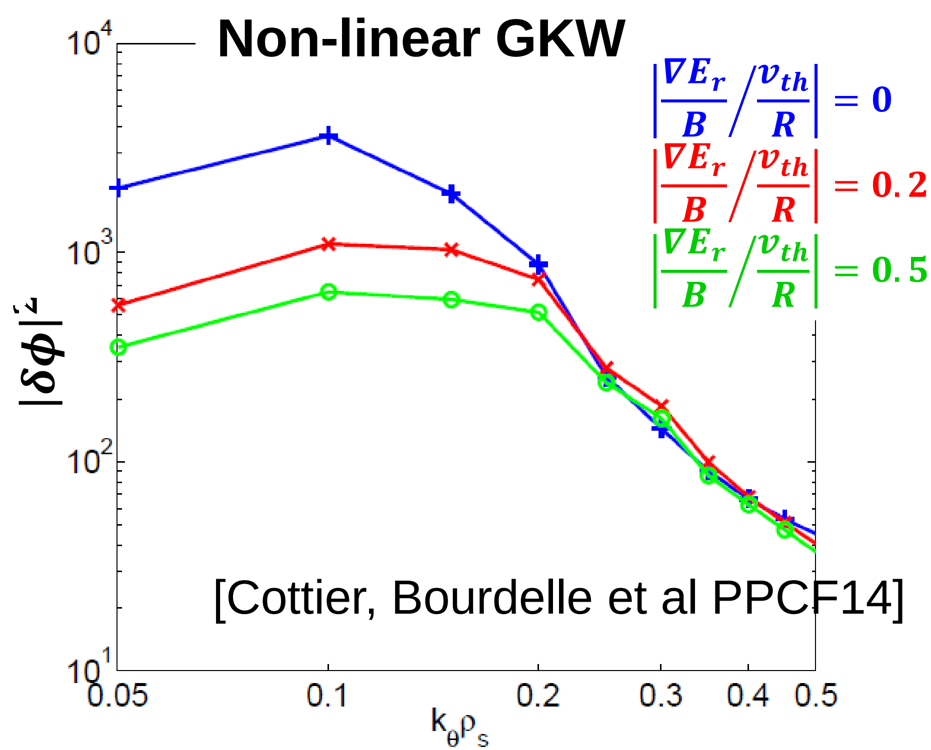
HOW TO BUILD THE k SPECTRUM?

quasi-linear flux = linear response x saturated potential

Mixing length rule: $max\left(D_{eff} \approx \frac{R\Gamma_s}{n_s}\right)\Big|_{k_{max}} = \frac{\gamma_{lin}}{\langle k_\perp^2 \rangle}\Big|_{k_{max}} \propto \boldsymbol{max}(\,|\boldsymbol{\delta\phi}|^2)$

$\langle k_\perp^2 \rangle = k_\theta^2(1 + (s-\alpha)^2\langle\theta^2\rangle)$ with $\langle\theta^2\rangle = \frac{\int \theta^2 \phi_{n\omega}(\theta)d\theta}{\int \phi_{n\omega}(\theta)d\theta}$ and $\phi_{n\omega}(\theta)$ lin. eigenfunc.





Can reproduce ExB shear impact reducing $max(\,|\delta\phi|^2)$ and shifting it to larger $k_\theta\rho_s$

QuaLiKiz REPRODUCES NON-LINEAR FLUXES OVER A WIDE RANGE OF PARAMETERS

quasi-linear flux = linear response x saturated potential

From $\sum_{k_\theta,\omega,\omega_k} Re\left(\left\langle \delta f_s \frac{ik_\theta \delta\phi^*}{B}\right\rangle_\tau\right)$

get particle flux:

$$\boldsymbol{\Gamma_s} = \sum_{k_\theta,\omega,\omega_k} Re\left(\left\langle \delta n_s \frac{ik_\theta \delta\phi^*}{B}\right\rangle_\tau\right)$$

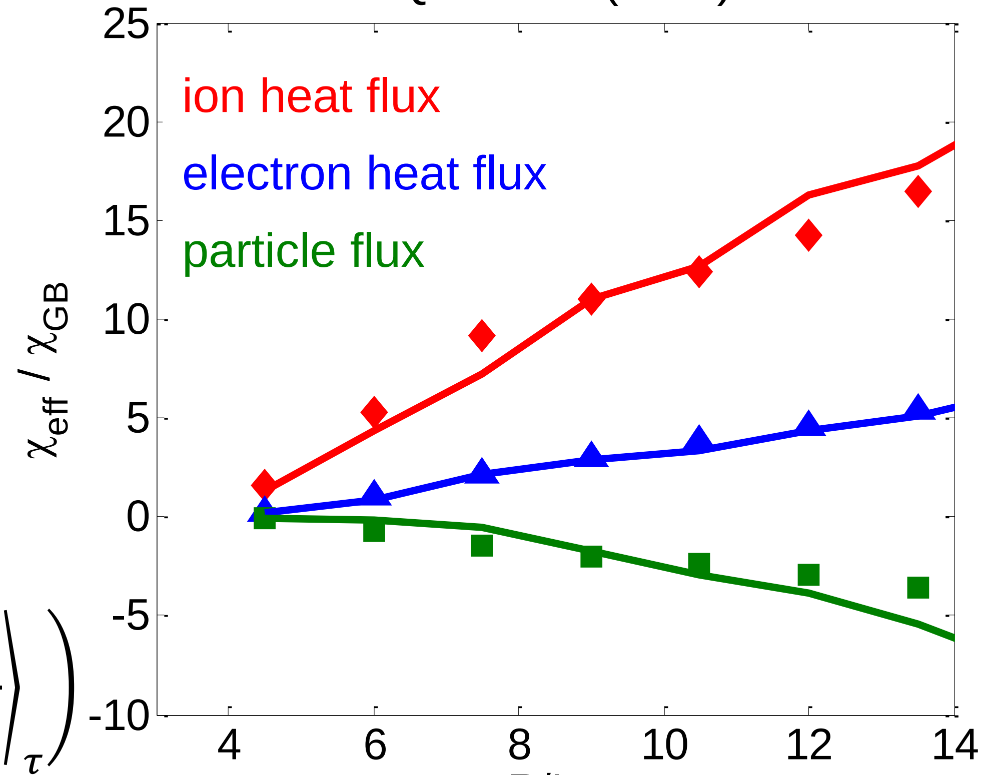
energy flux:

$$\boldsymbol{Q_s} = \sum_{k_\theta,\omega,\omega_k} Re\left(\left\langle \frac{3}{2}\delta P_s \frac{ik_\theta \delta\phi^*}{B}\right\rangle_\tau\right)$$

parallel ang. momentum flux:

$$\boldsymbol{\Pi_{//}} = \sum_{s,k_\theta,\omega,\omega_k} Re\left(\left\langle m_s R v_{//} \delta n_s \frac{ik_\theta \delta\phi^*}{B}\right\rangle_\tau\right)$$

Non-linear GYRO (symbols)
QuaLiKiz (lines)

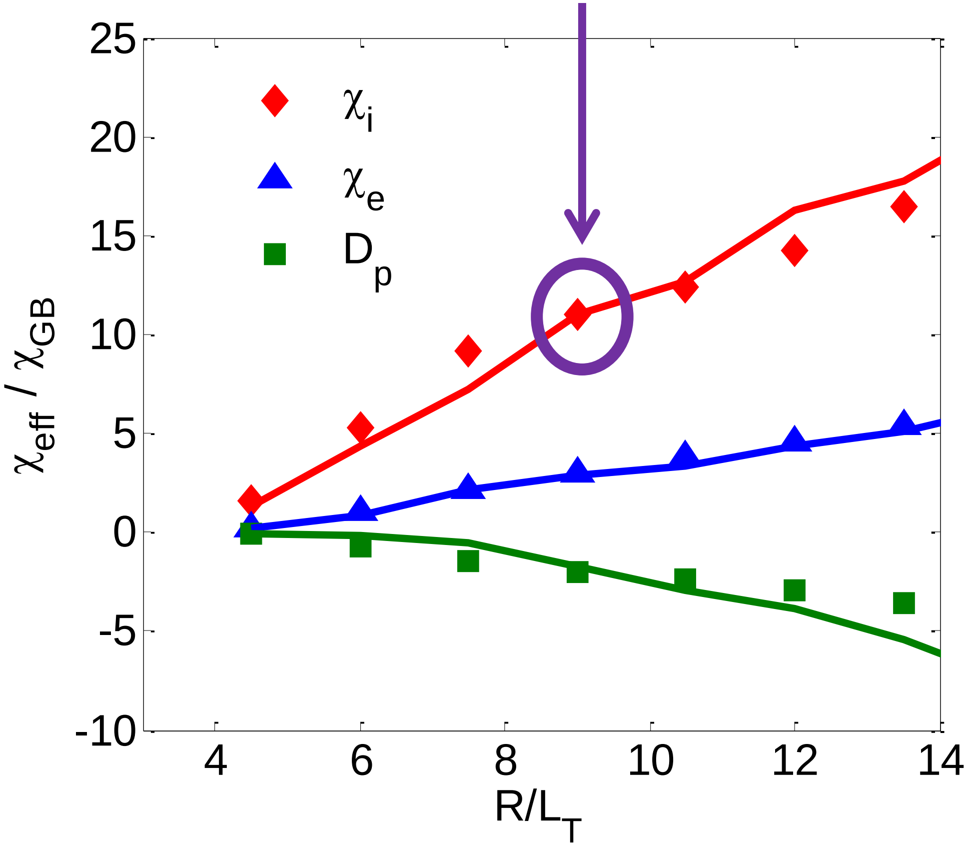


$$-R\frac{\nabla T_e}{T_e} = -R\frac{\nabla T_i}{T_i}$$

[Casati, Bourdelle et al NF09]

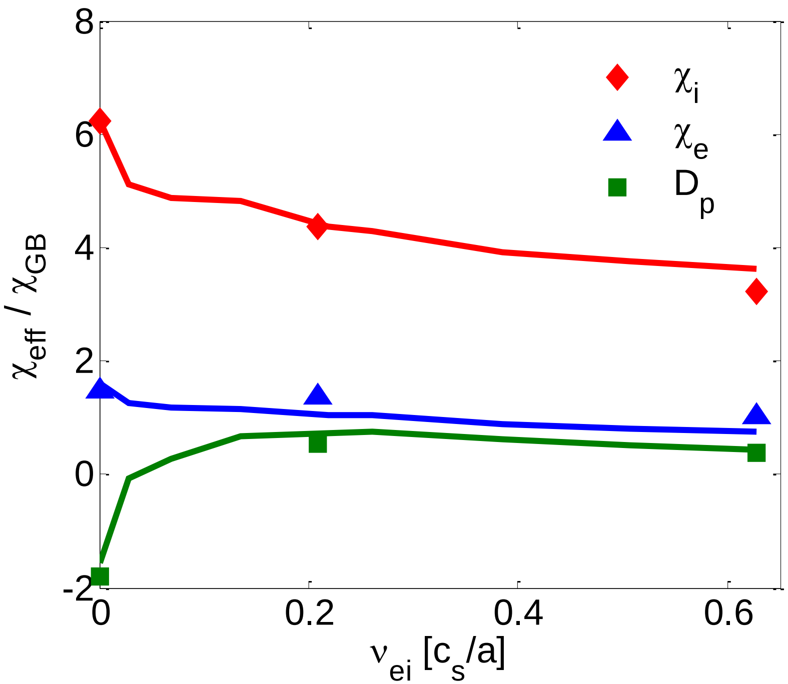
WHERE IS THE TUNING DONE??

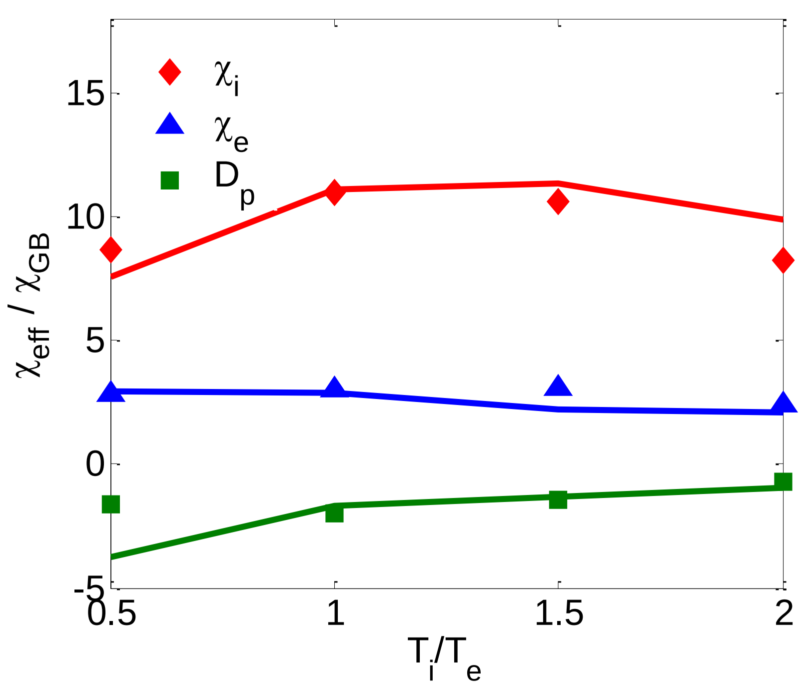
Here, and only here!



i.e. on GA standard case
ion heat flux only!

QUALIKIZ VS NON-LINEAR: AGREEMENT IN WIDE PARAMETER RANGE





Collisionality scan on

Tore Supra parameters

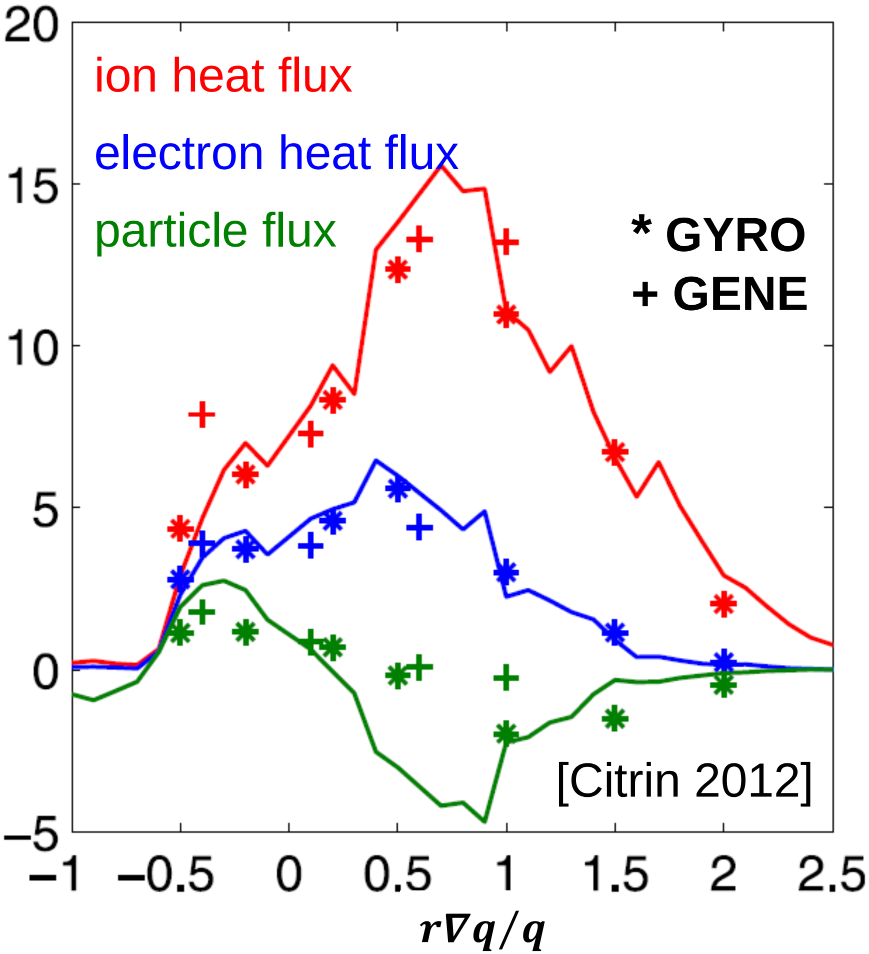
ν* session: r/a=0.5, ρ*=1/500, R/L_{Ti}=10.5, R/L_{Te}=13.4, R/L_n=4.5, q=2.0, s=1.3, T_i/T_e=1.0

T_i/T_e scan on GA-std case

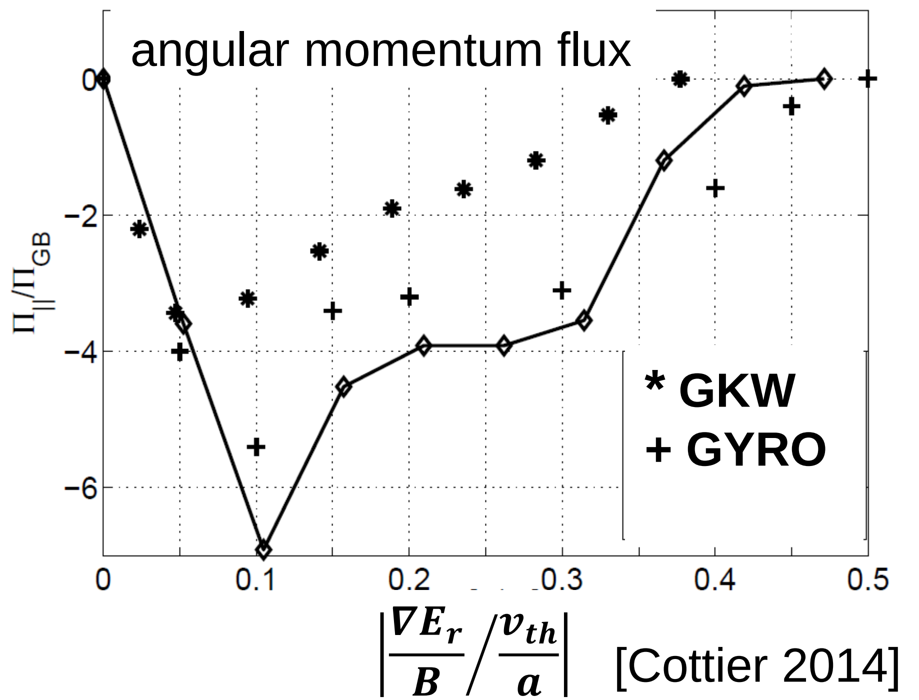
GA-std case: r/a=0.5, ρ*=1/400, R/L_{Ti}=R/L_{Te}=9.0, R/L_n=3.0, q=2.0, s=1.0, ν_{ei}=0.0

A. Casati et al., Nucl. Fus. 2009

QuaLiKiz REPRODUCES NON-LINEAR FLUXES OVER A WIDE RANGE OF PARAMETERS



Non-linear GYRO, GENE, GKW (symbols)
QuaLiKiz (lines)



[Cottier 2014]

Quasilinear + other approximations = QuaLiKiz turbulent fluxes reproduce well non-linear gyrokinetic fluxes over wide range of parameters with computing time ~ 30 s, ready for integrated modeling

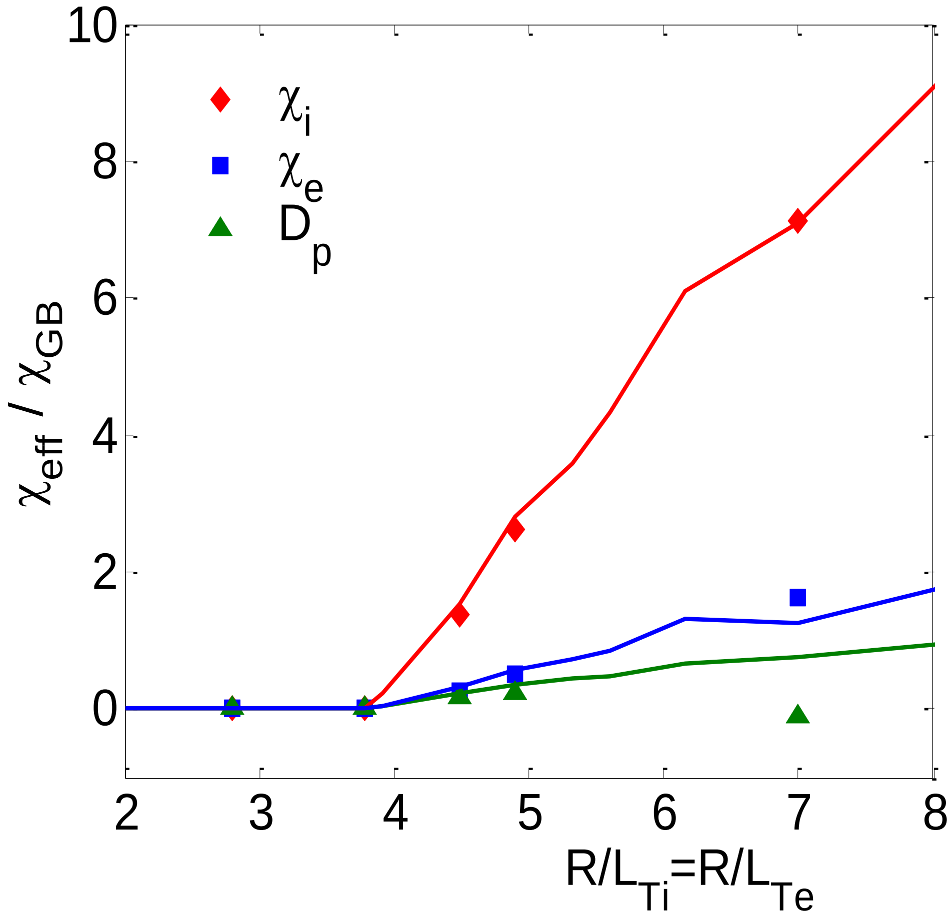
QUALIKIZ VS NON-LINEAR: AGREEMENT NEAR THRESHOLD

Cyclone base case, Dimits PoP2000, with

kinetic electron

realistic collisionality

$\rho^*=0.006$, $\beta=0.0$, $\nu_{ei}[c_s/a]=0.03$
$r/a=0.5$, $R/L_{Ti}=R/L_{Te}=7.0$,
$R/L_n=2.24$, $T_i/T_e=1.0$, $q=1.4$,
$s=0.78$, $R/a=2.8$



Consistent with high col. kin. El.
reduced shift obs. in Mikkelsen, Dorland PRL08

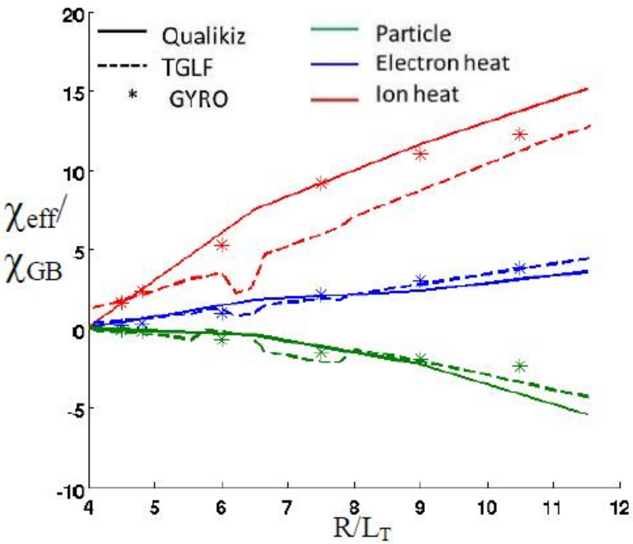
[Bourdelle PPCF 2016]

QuaLiKiz VERSUS TGLF

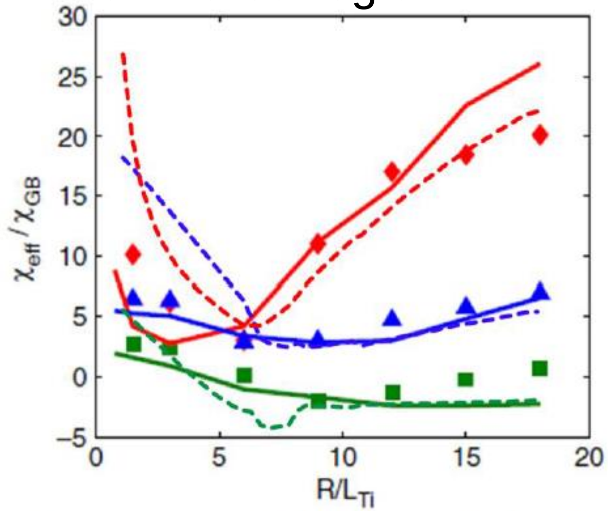
TGLF and QuaLiKiz are accurate enough to be a test of gyro-kinetic theory and are not tuned with experimental data.

- This is not true of other models: Bohm-GB, RLW, CDBM, Coppi-Tang, Multi-mode, GLF23…

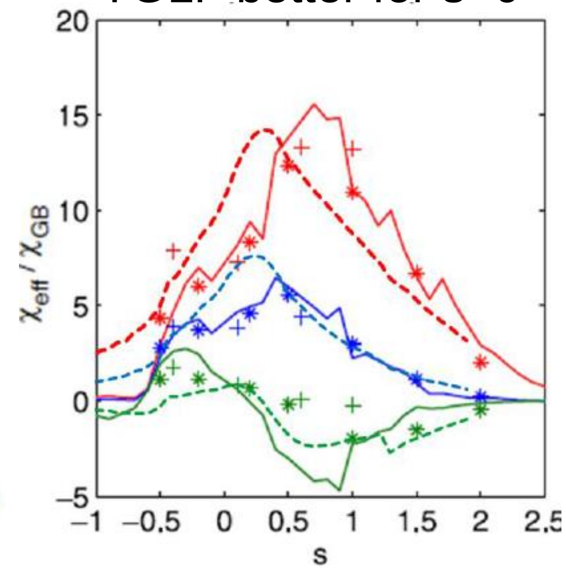
[Staebler ITPA13]



TGLF worse for TEM dominated region



TGLF better for s<0



[Baiocchi PPCF2015]

[Bourdelle PPCF 2016]

	QuaLiKiz	TGLF
Calculated fluxes	Energy, particle and momentum fluxes for unlimited number of ions and electrons	
Dispersion relation	Gyrokinetic	Fluid: 12 moments for circulating particles and 3 for trapped
	Finds all unstable modes	Finds the top two most unstable modes
	Use the ballooning representation	
	Includes trapped and passing ions and electrons, i.e. ITG-TEM and ETG	
Eigenfunctions	Estimated in the fluid limit: shifted Gaussians	Hermite basis functions, Gaussian width to maximize γ for 1–2 basis functions then refined to 4
Collisions	On electrons, use the Krook operator, energy dependent	On electrons, use a pitch-angle scattering operator, energy dependent
Equilibrium	$s - \alpha$	Bishop eikonal with Miller flux surface shape with elongation, triangularity [40]
Saturated potential: level, k and frequency spectra	Mixing length: $\gamma / < k_\perp^2 >$ with $k_\perp$ accounting for the eigenfunction	Three parameters saturation rule optimized to best fit 160 nonlinear GYRO simulations
	k_θ spectrum such that k_θ^{-3} above the maximum and k_θ below	
	Frequency spectrum: a Lorentzian which width scales as γ adjusted for $\lvert s \rvert < 0.6$	
$E \times B$	Self-consistently through modified eigenfunctions	Included in spectral shift of saturated potential based on GYRO nonlinear results
Fitted parameters	One, such that, for the GA standard case, QuaLiKiz ion energy flux matches the nonlinear GYRO ion energy flux	All of the parameters were determined by fitting to linear and non-linear theory
Verification	Against nonlinear GYRO, GKW and GENE simulations see table 3	Against 1799 linear gyrokinetic GKS runs and 160 nonlinear GYRO runs

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QuaLiKiz IN AGREEMENT WITH Ni DIFFUSIVE AND CONVECTIVE TRANSPORT

TORE SUPRA

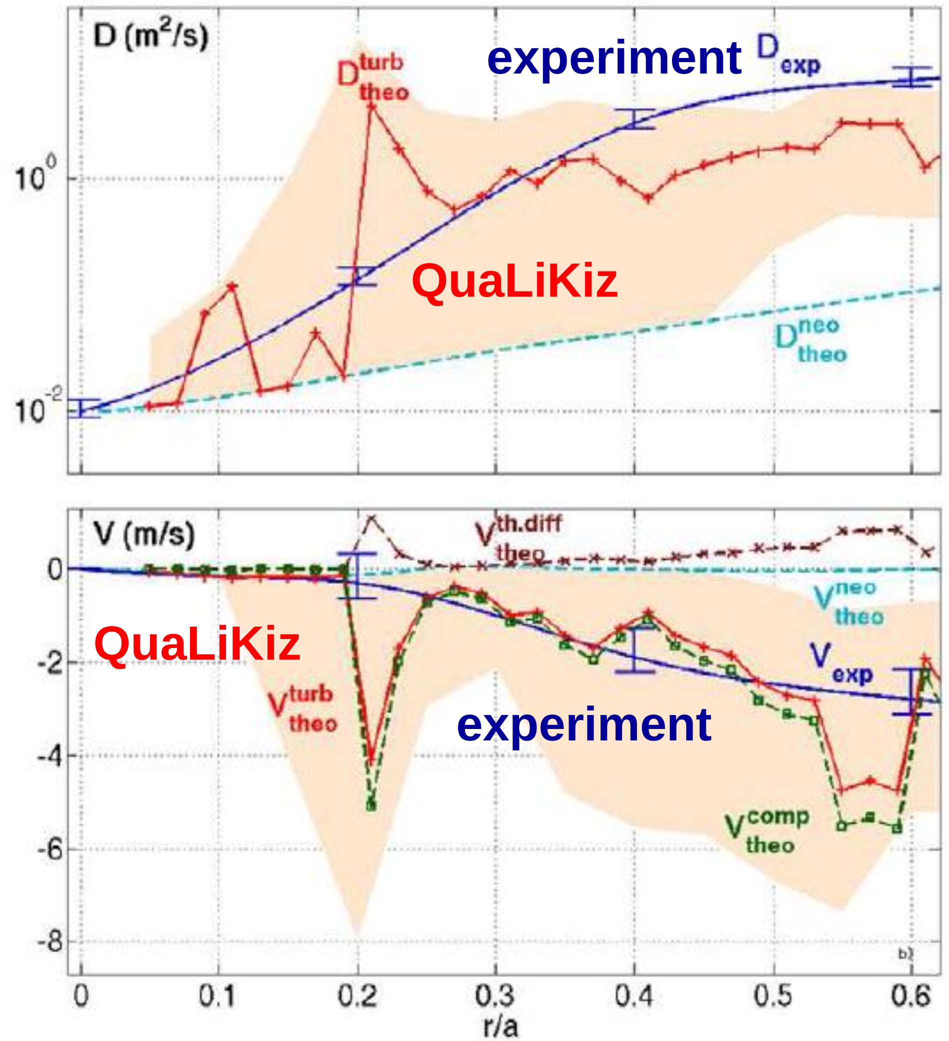
Ni laser blow-off experiments in ECRH heated plasmas

$$\Gamma = -D\nabla n + Vn$$

Ni diffusivity increases with $-\frac{R\nabla T_e}{T_e}$

Convection inward and unsensitive to $-\frac{R\nabla T_e}{T_e}$

Both trends in qualitative and quantitative agreement with QuaLiKiz diffusive and convective Ni flux. Convection dominated by compressibility term.



[Villegas, Guirlet, Bourdelle et al PRL10, NF14]

QuaLiKiz REPRODUCES JET ANGULAR MOMENTUM PINCH

NBI modulation experiment at JET [Tala PRL09] proving existence of angular momentum pinch

JET

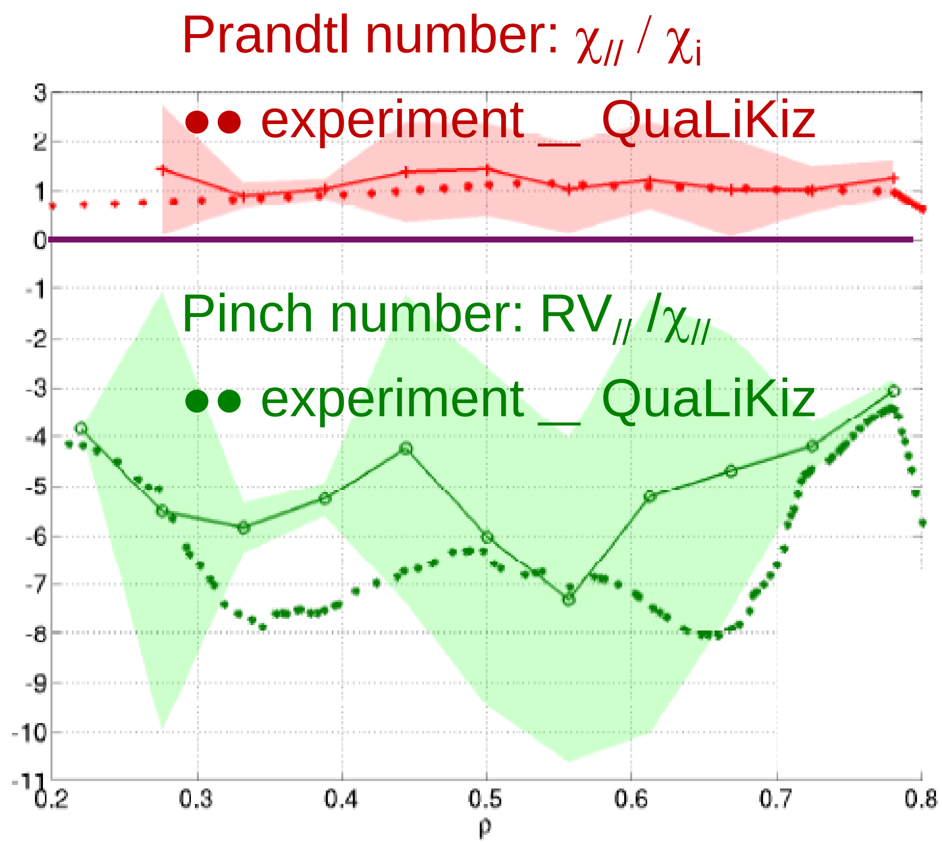
QuaLiKiz Prandtl number ~ 1

QuaLiKiz pinch number ~ -4 / -7

in fair agreement with reported experimental values

Fixed gradient approach depends on $\nabla T/T$, $\nabla n/n$, q, s, etc lead to large uncertainties on prediction

colored regions: **uncertainties on $\chi_{//}$ and V_{pinch}** impact of varying within 20% $U_{//}$, $\nabla U_{//}$ and ExB



[Cottier PPCF2014]

- Linear gyrokinetic formulation
- Linear stability and experimental observations
- Deriving and validating quasilinear particle, momentum and heat fluxes
- Quasilinear fluxes vs experimental observations
- Density, temperature and rotation profiles time evolution
- Conclusions and perspectives

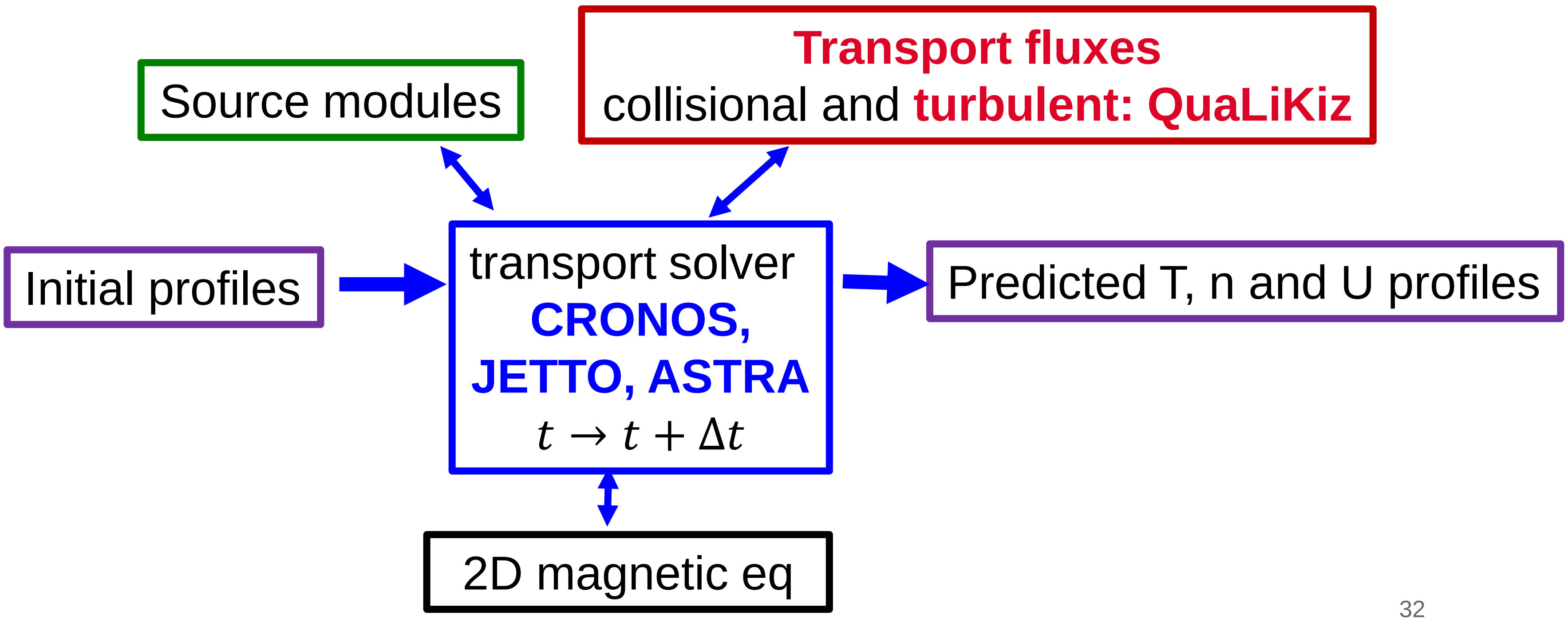
QuaLiKiz IMPLEMENTED IN CRONOS

QuaLiKiz turbulent fluxes = Quasilinear + other approximations

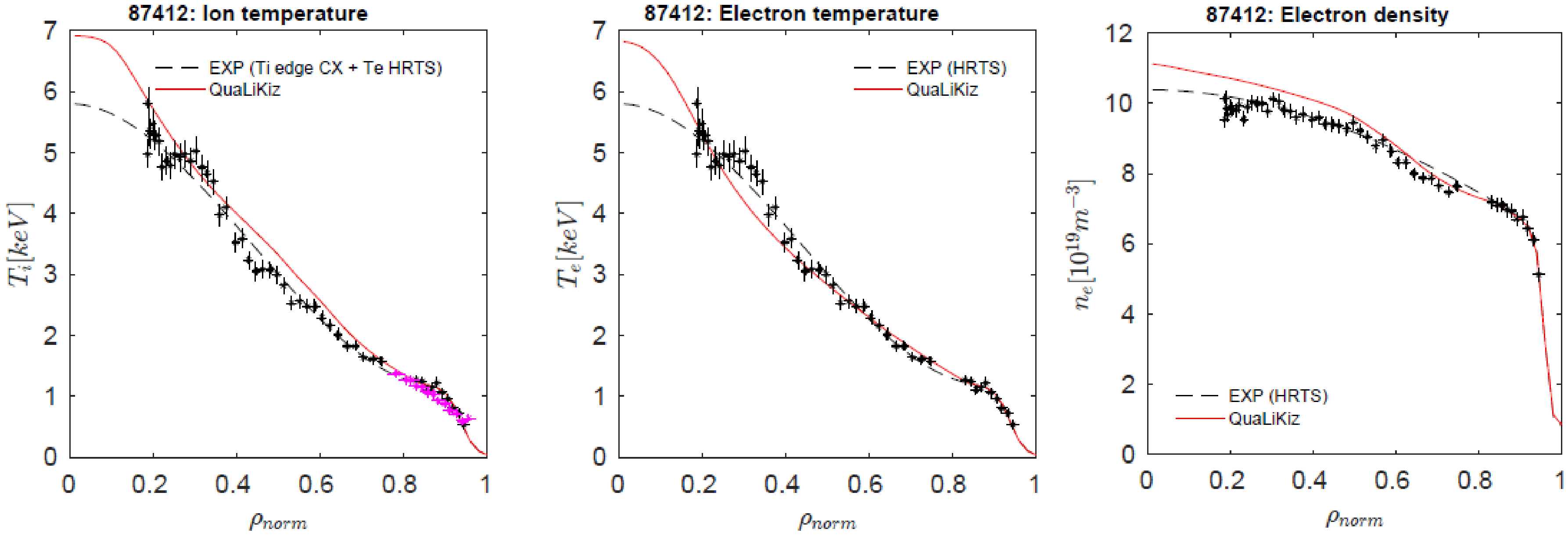
$t_{turb.fluxes} < \sim 5\, min$ for a profile i.e. 20 radial points and 10 $k_\theta \rho_s$

- reproduce well non-linear gyrokinetic fluxes over wide range of parameters in ~10^6 less computing time
- in agreement with experimental results at a given time

→ ready for integrated modeling



ILW baseline scenario JET 87412 (3.5MA/3.35T)



- Boundary condition at $\rho = 0.85$
- Stable for $\rho < 0.2$. No sawtooth model
- Assuming core measurements T_i=T_e due to poor core CX
- ETG active, leads to ~10% differences. $E \times B$ shear stabilization important (not shown due to brevity)

J.Citrin et al., PPCF 2017

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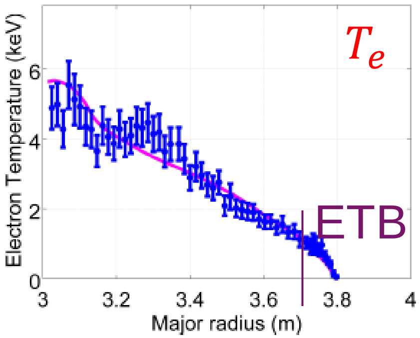
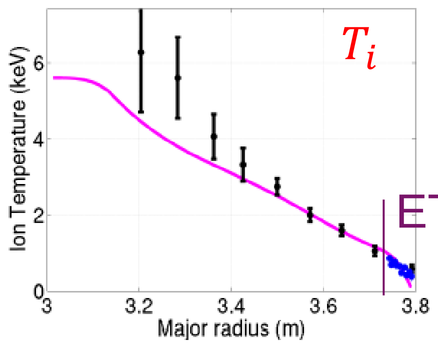
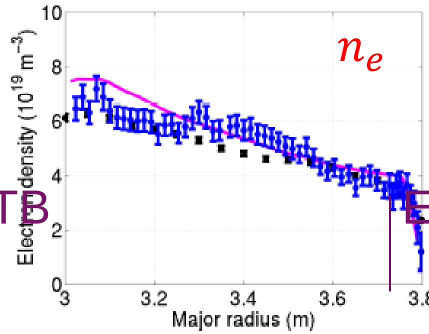
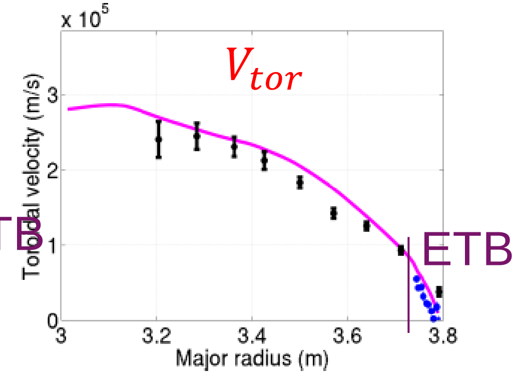
HYBRID JET-ILW #82722. JETTO-QLK-NEO, INCLUDING W

QuaLiKiz profiles **after 1.5 s (5xτ_E) of time evolution**

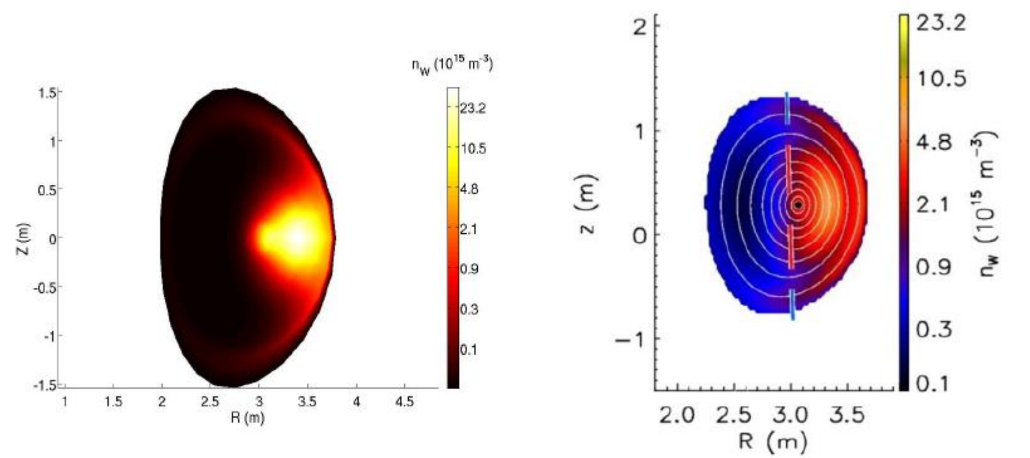








Comparison of measured and predicted 2D W-distributions at t=6.8s



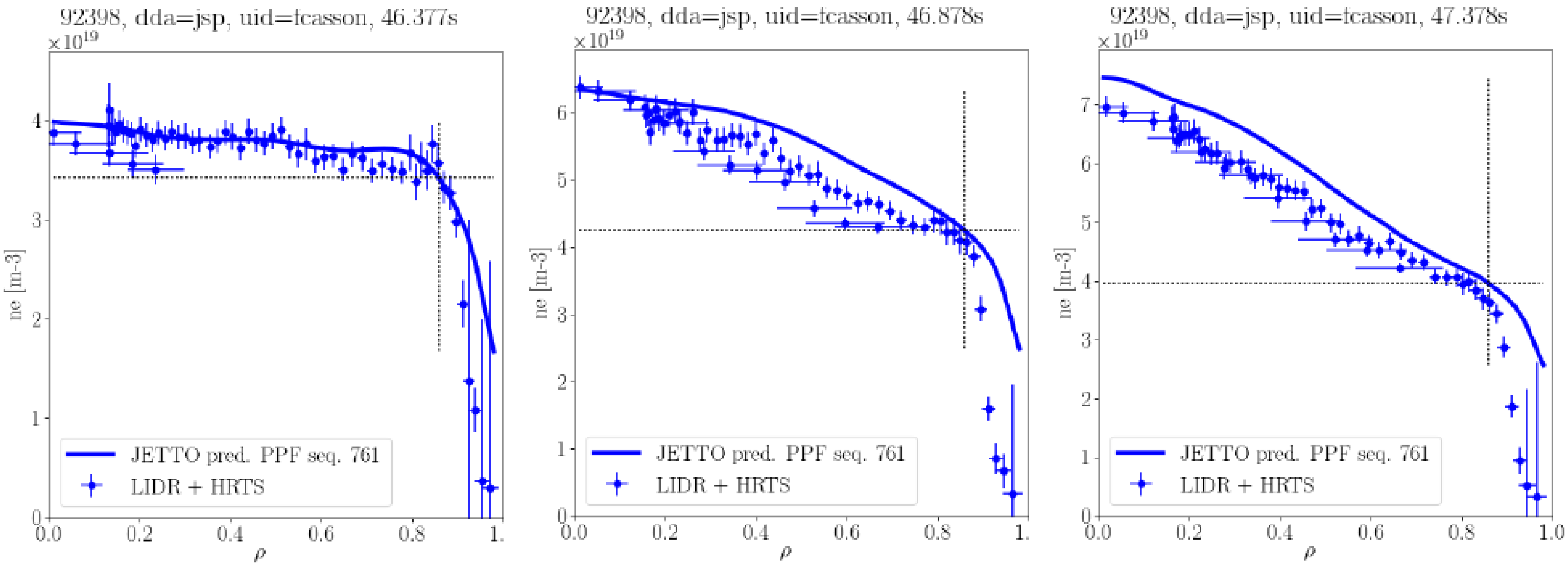
(a) Predicted n_W at t=6.8s after 1.3s of simulation.

(b) Experimental estimated n_W at t=6.8s after 1.3s of simulation.

Sarah Breton EPS 2017, to be submitted to NF

92398: SECOND HIGHEST PERFORMANCE HYBRID FROM LAST JET CAMPAIGN (C36B)

Density profile time evolution captured, Full line QuaLiKiz



- Fully predictive modelling of high performance hybrid 92398 with JETTO-SANCO-QuaLiKiz-NEO-PION-PENCIL-ESCO
- JETTO-QuaLiKiz fully predictive j,Ni,Ti,Te,Vtor + 3 Imp (including W). 8-channel simulation!
- Motivation: predicting ICRH optimisation for W accumulation control

On-going work by Francis Casson

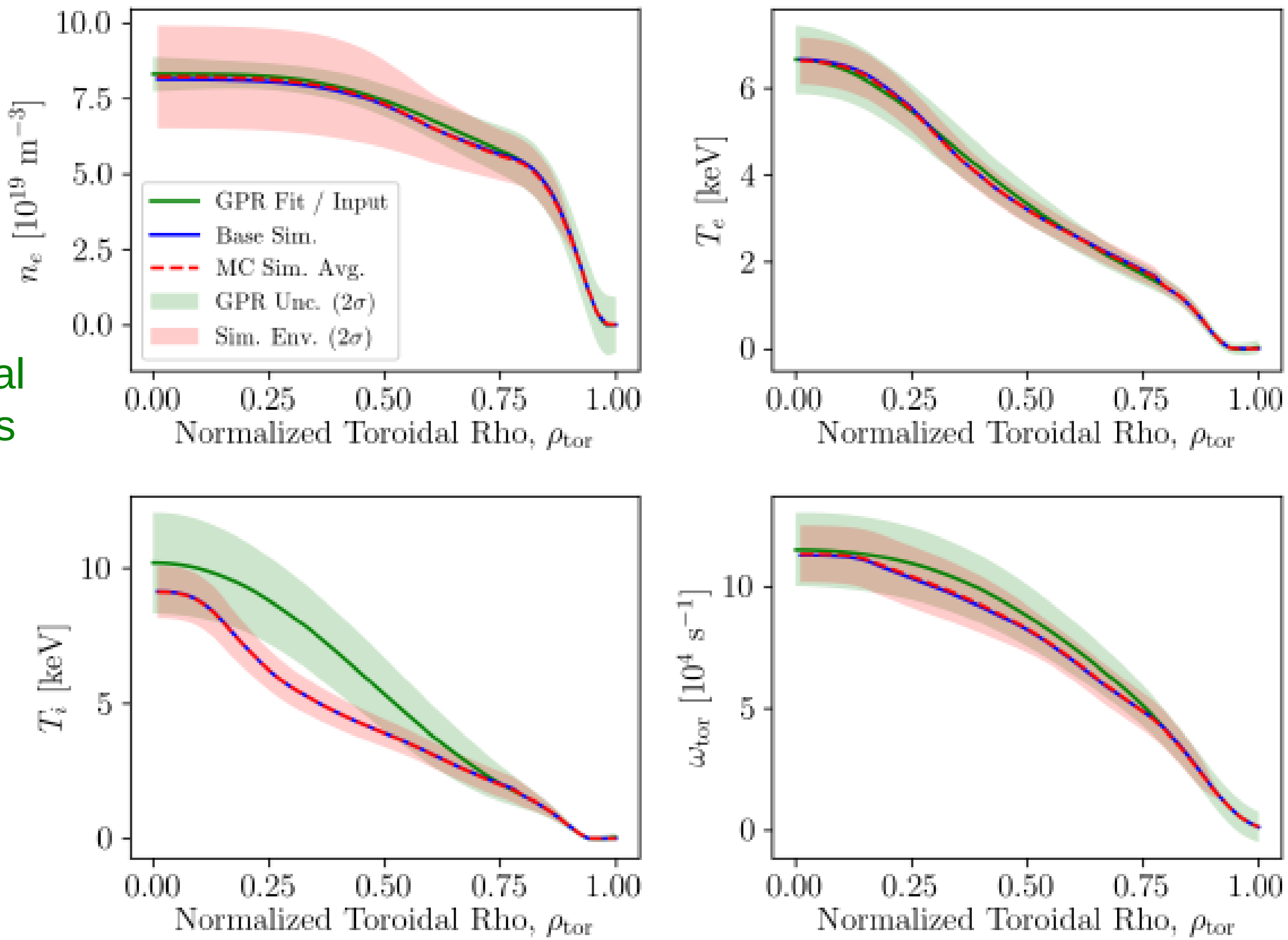
PREDICTION IN CORE SENSITIVE TO BC!

JET 92436

BC at ρ=0.85

Gaussian process regression fits of experimental measurements

JETTO-QuaLiKiz, Monte Carlo sampling of input boundary condition

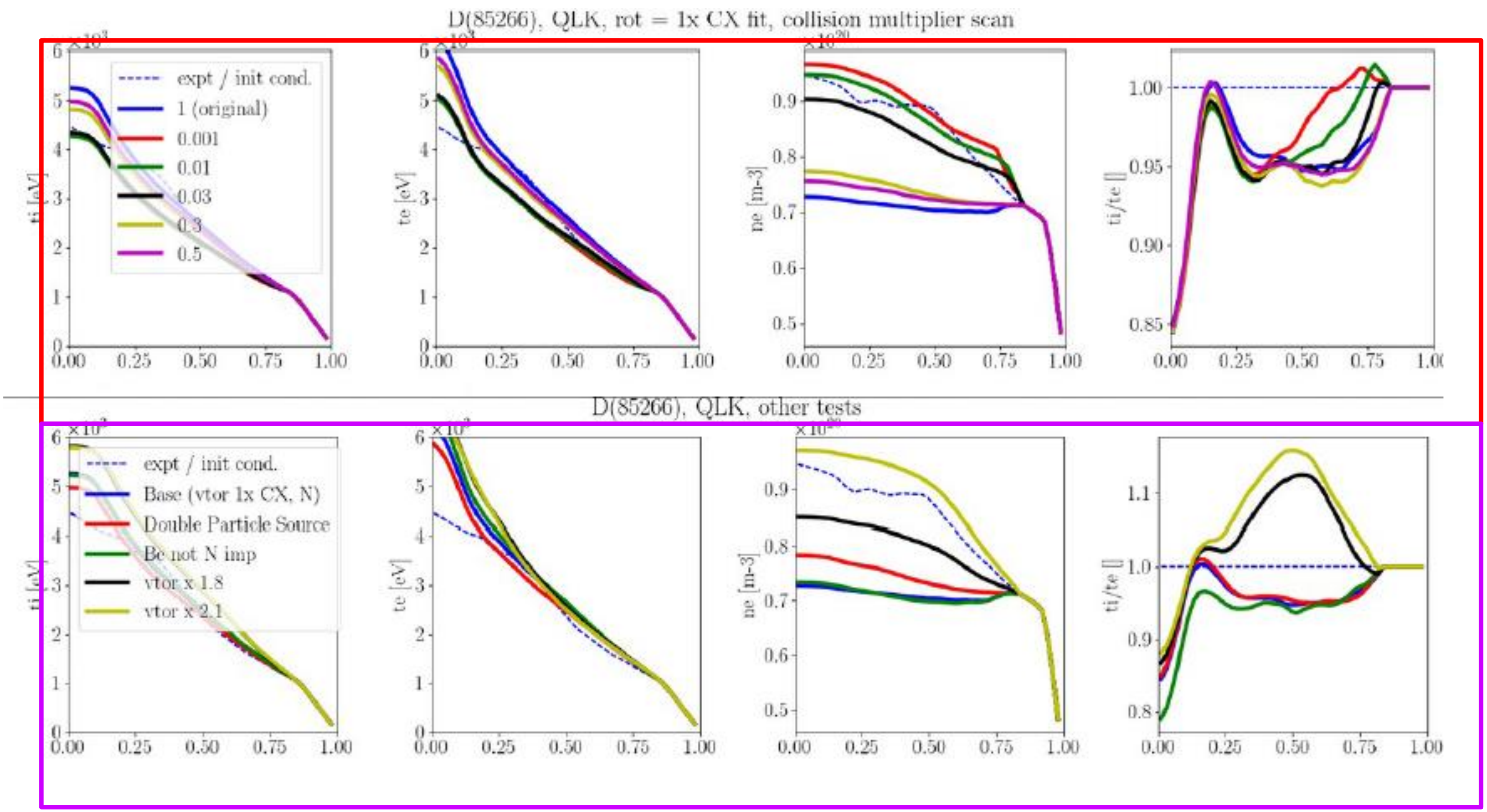


Ti underestimation being investigated

Aaron Ho EPS2017, paper in prep.

FLAT DENSITY ISSUE FOR L MODE CASE

Too flat density for an L mode case (courtesy T Bache and FJ Casson)
Peaking recoved by artificially reducing collisions or increasing Vtor



- Linear gyrokinetic formulation
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- Quasilinear fluxes vs experimental observations
- Towards density, temperature and rotation profiles prediction
- Conclusions and perspectives

CONCLUSION

- The quasilinear approximation is valid in a wide range of parameters, extensively checked [Casati 2009, Citrin 2012, Angioni's, Jenko's work (see ref in Casati 2009 for example)]

- 2 existing quasilinear codes that are CPU compatible with integrated modelling needs: QuaLiKiz [us] and TGLF [Staebler, Waltz, Kinsey GA, USA]

- Successful multi channels and multiple confinement time predictions by quasilinear codes [Citrin PPCF2017, Breton to be submitted, Linder on AUG to be submitted, Casson on-going]

- But….

STILL IMPROVEMENTS OF QuaLiKiz TO BE CARRIED OUT

- **In integrated modeling framework:**
- Understand the cause of the overestimated density profile flattening in some L mode cases
- Is the LOC-SOC transition reproduced? [Bourdelle EPS2017, on-going]

- **In stand alone framework:**
- s-α interchange modes stabilization overestimated in QuaLiKiz vs GENE [Linder internship report 2016] pb for steady-state regimes with flat and reversed q profiles (ITB) [Citrin PPCF 2017]
- W turbulent transport: impact of trace assumption for poloidal asym. At which level of W concentration the assumption fails (QuaLiKiz vs GKW) [Citrin PPCF 2017]
- roto-diffusion forced to 0 because strange behavior: significative for heavy ions nonetheless. Need to understand pb [Citrin PPCF 2017]
- Add Impact of elongation (K), test Weiland's s_hat=sqrt(2s-1)+K^2(s-1)^2 on R/Ln, R/LT values vs GENE/GKW

HOW DO I STAY TUNED?

www.qualikiz.com

Open source code, available on GitHub.

- Links to key publications, where the detailed QuaLiKiz derivation can be found
- all above issues in « issue tracker », and anyone should open an issue tracker whenever encountering a bug or strange behaviour related to QuaLiKiz
- All published integrated modeling runs to be archived and documented also on this page whether JETTO/ASTRA/CRONOS/METIS/RAPTOR. 1st level table being prepared.

HOW DO I GET STARTED?

JETTO-QuaLiKiz info is available on JETTO wiki pages:

https://users.euro-fusion.org/tfwiki/index.php/JETTO_Qualikiz

Will be improved further soon.

And also there, a table with catalogued published JETTO-QuaLiKiz cases has to be made for all users