MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

ORB5 β and EP stabilization (and PSZS)

Thomas Hayward-Schneider
Max Planck Institute for Plasma Physics, Garching

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EUROfusion

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Outline

β and EP stabilization

- Case setup
- Growth rates
- Shift to rational surfaces
- Ongoing effort to separate β and EP effects

Phase Space Zonal Structures in ORB5

- PSZS background
- Implementation in ORB5
- PSZS Example

Scenario[1]

Hydrogen plasma ($T(0) = 4.4\,\mathrm{keV}$, $n(0) = 9.478 \times 10^{17}\,\mathrm{m}^{-3}$)

$B = 1\,\mathrm{T}$

$R0 = 10\,\mathrm{m}$

$a = 1\,\mathrm{m}$

$\bar{q} = 1.1 + 0.8\frac{r}{a}^2$

$\rho_*(s = 0.5) = 1/180$

$m_\mathrm{e}/m_\mathrm{i} = 1/200$

$\kappa_{n,i} = 0.3$ (a/Lx)

$\kappa_{T,i} = 2.0$

$\kappa_{T,e} = 2.0$

$s_\mathrm{ref} = 0.5$

$\Delta_s = 0.2$

[1] PPCF 64 (2022) 104009 A Mishchenko et al.

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EPs (when present):
$T_\mathrm{f}/T_\mathrm{e} = 10$
$< n_\mathrm{f} > / < n_\mathrm{e} >= \mathrm{scan}$ (1%, 2%, 5%, 10%)
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Play with thermal beta, and EP beta to understand physics

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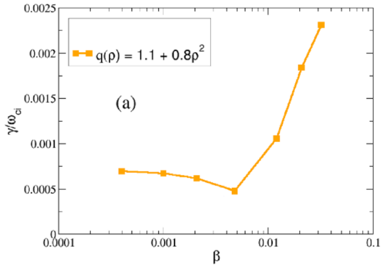
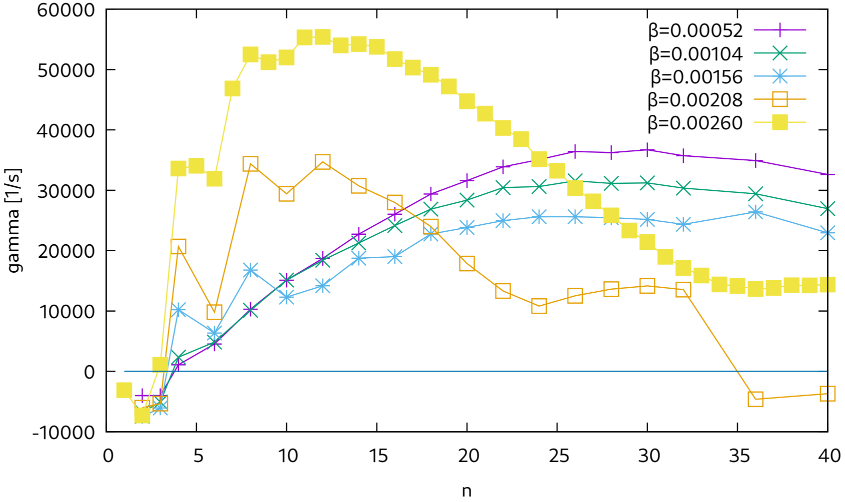
Background (Alexey)

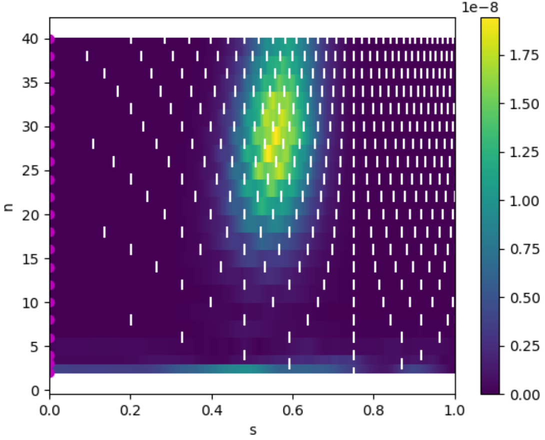
- Alexey studied this case in paper last year, “ITG-KBM” transition with increasing β
- Here showing integral over all modes during linear phase of NL simulations
- My goal is to study the linear phase in detail



β scan

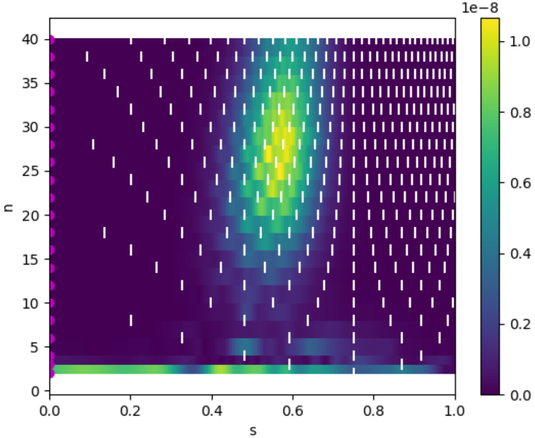

60000
50000
40000
30000
20000
10000
0
-10000
gamma [1/s]
0
5
10
15
20
25
30
35
40
n
β=0.00052
β=0.00104
β=0.00156
β=0.00208
β=0.00260

Rational Surfaces



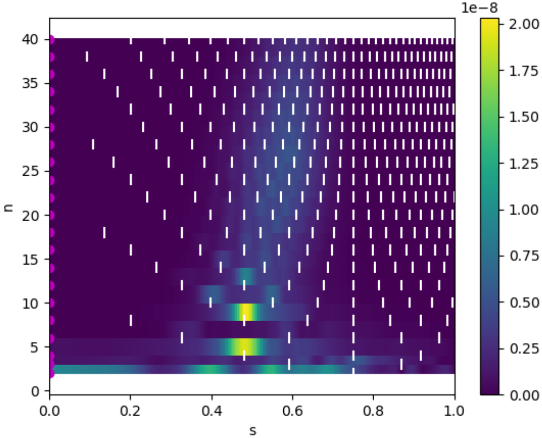
$\beta_{\mathrm{e,ORB5}} = 0.00052$

Rational Surfaces



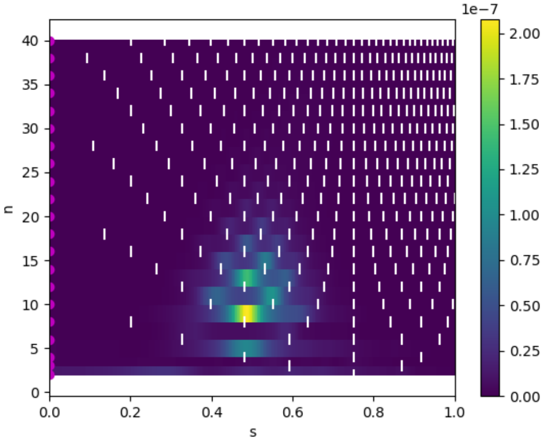
$$\beta_{\mathrm{e,ORB5}} = 0.00104$$

Rational Surfaces



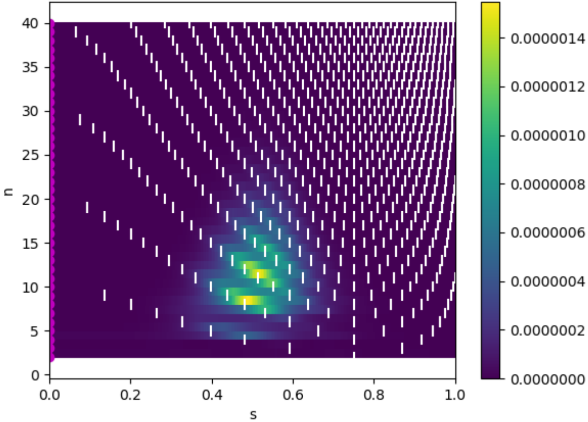
$$\beta_{\mathrm{e,ORB5}} = 0.00156$$

Rational Surfaces



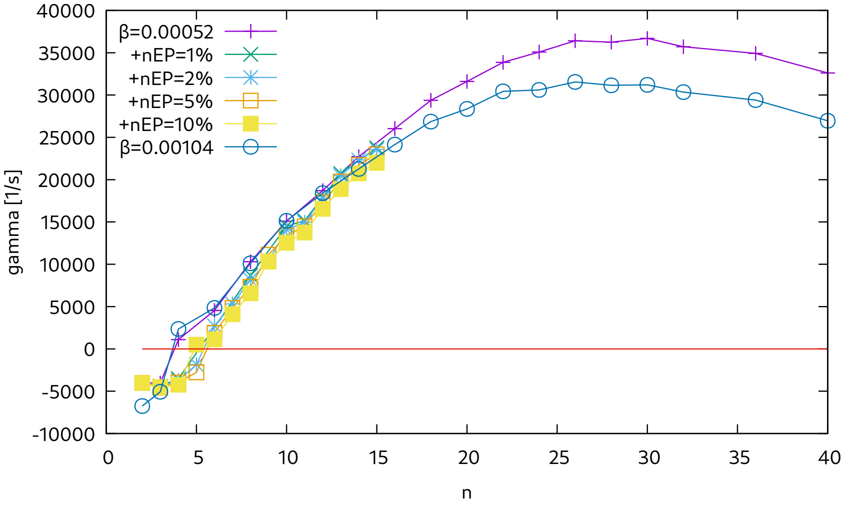
$$\beta_{\mathrm{e,ORB5}} = 0.00208$$

Rational Surfaces

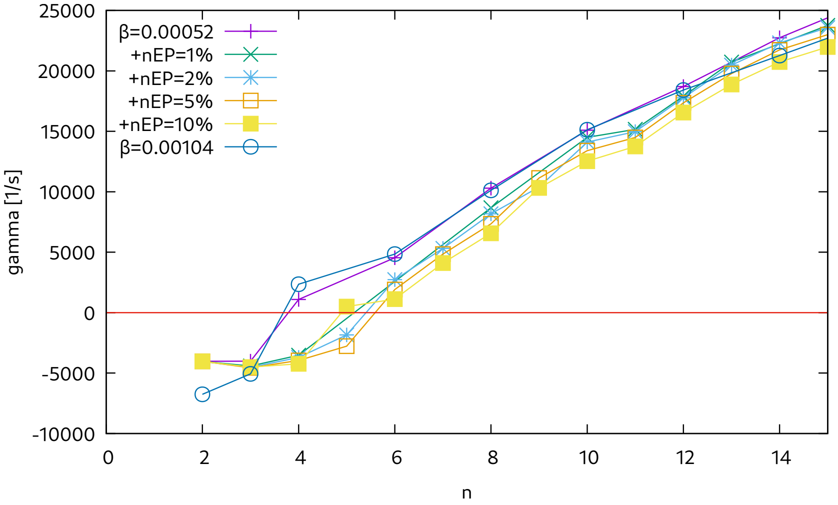


$$\beta_{\mathrm{e,ORB5}} = 0.00260$$

EP scan ($\kappa_{T,f} = 2.$)



EP scan ($\kappa_{T,f} = 2.$)



Conclusions (part 1)

- Starting from simple largest aspect ratio tokamak
- Adding β reduces most unstable “high-n” modes
- Adding β destabilizes lower-n modes
- high-β modes move to rational surfaces
- Role of EP-β seems to differ from bulk-β
    - Goal is a model for effect of EP at constant total-β

Phase Space Zonal Structures

- Tokamaks have equilibrium constants of motion (CoMs)
  $\dot{\mu} = 0$, $\dot{E}_0 = 0$, $\dot{P}_{\varphi 0} = 0$
- CoMs define orbits
- "Background" distribution function which is constant in time should depend only on these[2]
  examples include canonical Maxwellian ($n(P_\varphi)$, $T(P_\varphi)$), but not local Maxwellian ($n(\psi)$, $T(\psi)$)
- Any "transport" of (EPs) can be thought of as a change in the distribution function in CoMs
- These "PSZS", retain only the slow part of the distribution function – the "nonlinear equilibrium" [Falessi, Zonca, et al]

[2] For passing particles, we also have the sign of $v_\parallel$, but I ignore that for now

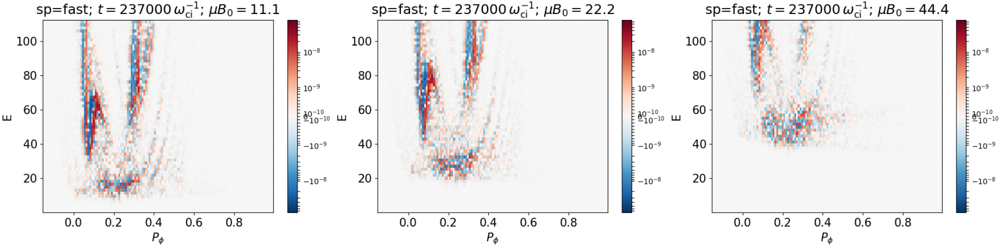
PSZS implementation in ORB5[4]

- We want an orbit-integrated version of our distribution function
- Unlike Eulerian codes, we do not have F(5D) in PIC codes
- Akin to obtaining 3D (real-space) charge density, deposit weights onto spline basis via projection
  B-Splines in non-periodic (μ, E, P_φ) space
  - To obtain PSZS, then just need to solve a mass-matrix problem
  - Just store coefficients – typically solved offline for memory and efficiency reasons[3]
- Some non-CoM coordinates alternative options for the diagnostic $(P_\varphi \to s = \sqrt{\psi_N};\ \mu \to v_\parallel;\ \ldots)$
- Also choice in COMs in principle $(\mu \to \Lambda = \frac{\mu B_0}{E})$ – requires Jacobian for each choice.

[3] We use huge banded matrices and a direct LAPACK solver, as is typically done in ORB5 for much smaller matrices. A true sparse solver would be undoubtedly more efficient

[4] Bottino et al., JPCS 2022

PSZS example



PSZS from pair of TAE modes ($n = 18, 19$) in ITER

Comparison to ATEP (LIGKA + HAGIS) on-going – qualitatively excellent

$\mu \rightarrow \Lambda$ done in postprocessing