Investigation of Energetic Particle induced Geodesic Acoustic Modes

The control of turbulent transport reveals essential to achieve a successful fusion reactor. Together with turbulence, energetic particles (EP) are ubiquitous in mag. fusion reactors. Anisotropy in the energy distribution function of EP population is able to excite oscillations from the continuous spectrum of geodesic acoustic modes (EGAMs) [GG'88, Nakanishi'08].

EGAMs are particularly attractive in the framework of turbulence regulation, since their oscillatory radial electric shear can potentially saturate the turbulence, while EP can be controlled via heating methods. However, in recent years, numerical simulations have shown, that turbulent transport might also be enhanced in the presence of EGAMs [D.Zarroso'13].

1. Basics and gyrokinetic tool GTS:

- **GAM** (Orlov'56):
  - Frame rotation + Ohm's law + \( \nu \rightarrow \nu + \nu_0 \)
  - Compressibility + a continuity eq. for \( \phi \)
  - Momentum eq. + \( \phi \rightarrow \phi + \phi_0 \)
  - No drive via radial gradients (due to \( \phi \) = const)
  - Nonlinear drive by turbulence or \( \phi \rightarrow \phi + \phi_0 \) of EP population.

- **EGAM** [Fu'08]: Global mode (due to large EP orbits) can be excited, while GAMS is strongly Landau damped.

2. Benchmark of new Implementation:

For this project, GTS has been extended in a general way for multi ion species. Possible distribution functions are:

- Maxwellian: \( f \rightarrow f + f_0 \)\( \phi \)
- Shifted Maxwellian: \( \exp(-\nu-|u|)/(|2\pi|) \)

Linearly benchmarked against the codes NEMORB, GYSELA [Biancalani'14]

3. Theoretical Study of EGAM Drive:

What determines the radial structure of the EGAM?

- **GAM** continuous \( \omega_{\text{gam}} = \frac{\nu_0 + \frac{1}{2} \nu_0^2}{B} \) depending on \( B \) for fixed \( (\nu, \Lambda) \) due to \( \Lambda = \frac{\Lambda_0}{B} (1 - \frac{\nu}{\nu_0}) \)
- Banana orbit width, depending on pitch \( \Lambda \) and \( \phi \)
- Radial EP distribution function \( n_0(E) \)

- **EGAM** structure follows the EP density peak; no EGAM for slim on-axis EP peak
- With EP density peak moving towards lower radii, EGAM freq. goes down and growth rate goes strongly up (max. around \( n=0 \))
- When changing \( f(E) \), growth rate strongly decreases with increasing \( \Lambda_0 \) and even stronger with increasing \( \Delta \Lambda \) (decaying vel. space gradient)
- **EGAM** radial structure only slightly affected: broader with

4. Investigate EGAMs in ASDEX Upgrade scenarios:

Dedicated experiments at ASDEX Upgrade show robust excitation of the EGAM in off-axis NBI-heated plasmas (AUG#31213) [Horvath'16]

- Full n, T profiles for bulk, EP, \( \nu \)
- Adiabatic electrons, D ions
- Slowing-down distribution function: \( \Lambda > 0.5, \Lambda_0 = 0.2 \)
- turbulence avoided by filtering \( n=0 \)

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