《托卡马克射频波加热与电流驱动下的阿尔芬本征模与高能粒子模的研究》

课题中期总结

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内容提纲

- 课题研究工作主要进展
- 人才培养、合作交流、数据共享情况
- 经费使用情况

主要研究进展

- 编写了环位型下的二维本征值程序GTAW（General Tokamak Alfven Waves）
- 亮点：由EFIT反演出的一般实验平衡位型（拉长形变、三角形变、上下不对称),NOVA不能处理上下不对称平衡
- 用GTAW分析了EAST典型运行模式（EAST#38300@3.9s)下的阿尔芬本征模
- 研究发现：EAST平衡位型的上下不对称性使得阿尔芬本征模在中平面径向产生相差，这与一般的上下对称的平衡位型显著不同。这一结果为EAST上的阿尔芬本征模的实验诊断与模式识别提供重要信息

Alfvén Eigenmodes (AEs) are important for burning plasmas

- AEs can be excited by Energetic Particles (EPs)
- AEs influence EPs confinement and thus are important for burning plasmas.
- High frequency, $10^2\mathrm{kHz}$, easily detectable with
  - $\rightarrow$ Mirnov coils measuring signal $\propto \omega B_1$
  - $\rightarrow$ microwave reflectometers
  - $\rightarrow$ beam-emission spectroscopy (BES)
  - $\rightarrow$ ECE

A new code studying AEs: GTAW

- GTAW was developed to calculate AEs in general tokamak equilibria
- GTAW improves NOVA code by extending to up-down asymmetric equilibrium
- GTAW uses directly equilibria reconstructed by EFIT from experiments
  - $\longrightarrow$ makes the comparison of the results with experimental observations easy
  - $\longrightarrow$ includes full toroidal geometry effects: Elongation, triangularity, up-down asymmetry

Benchmark of GTAW

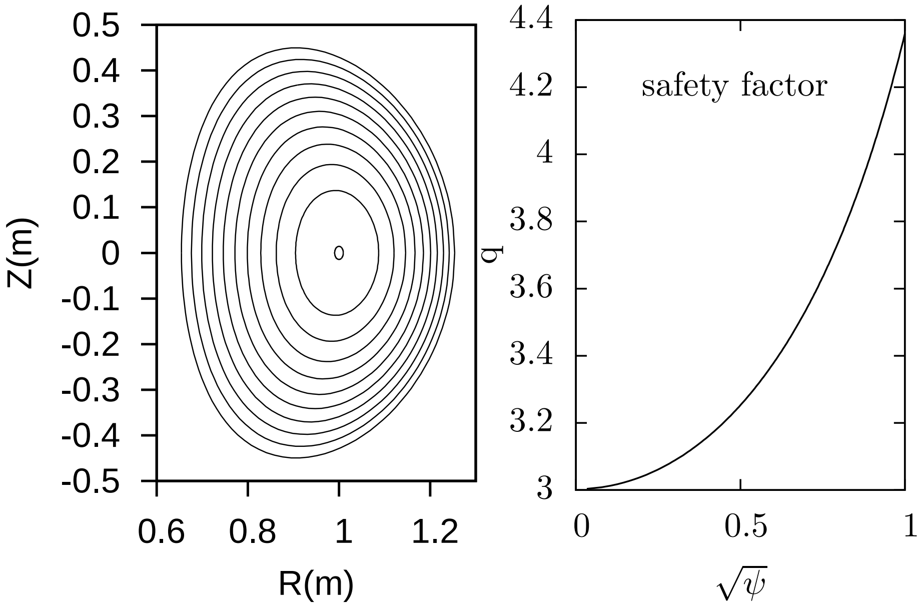

Figure 1. Solovév analytic equilibrium used in the benchmark case.

Alfvén continua calculated by NOVA and GTAW agree with each other

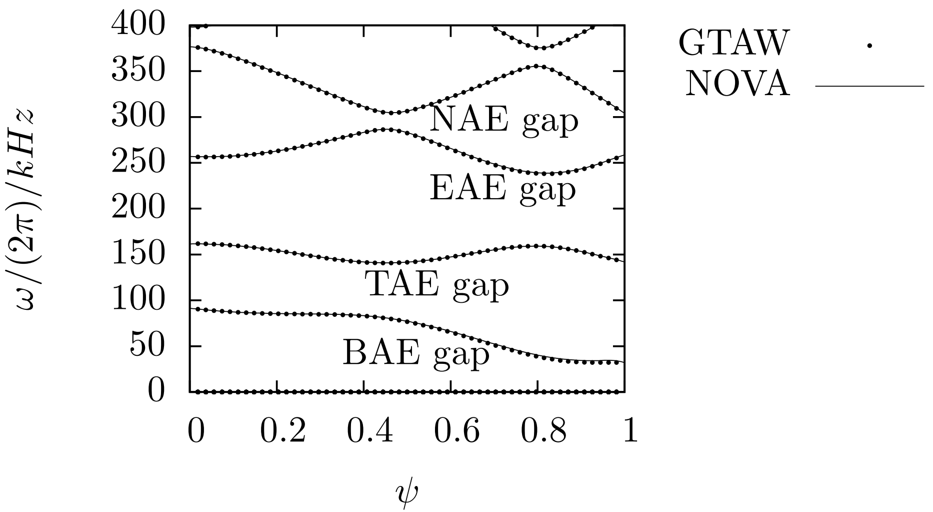

Figure 2. Comparison of the $n = 1$ Alfvén continua calculated by NOVA and GTAW

Mode structure calculated by GTAW and NOVA agree with each other

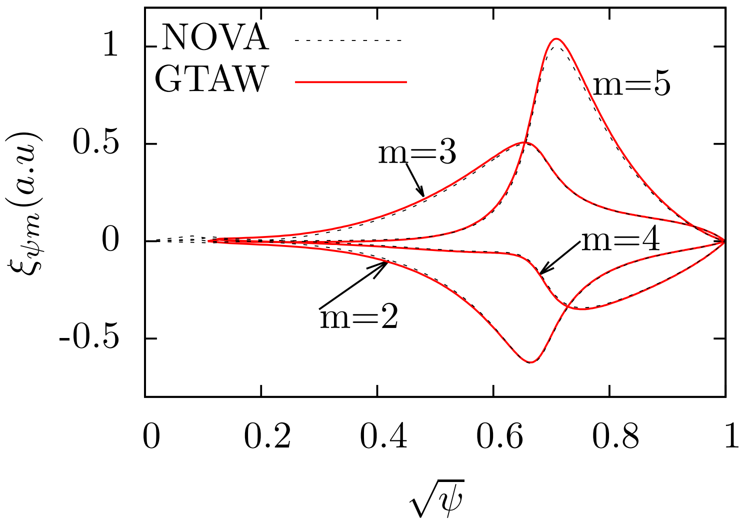

Figure 3. The dominant poloidal harmonics ($m = 2, 3, 4, 5$) of the radial displacement of an $n = 1$ NAE. $f = 297\mathrm{kHz}$.

Equilibrium of EAST discharge #38300

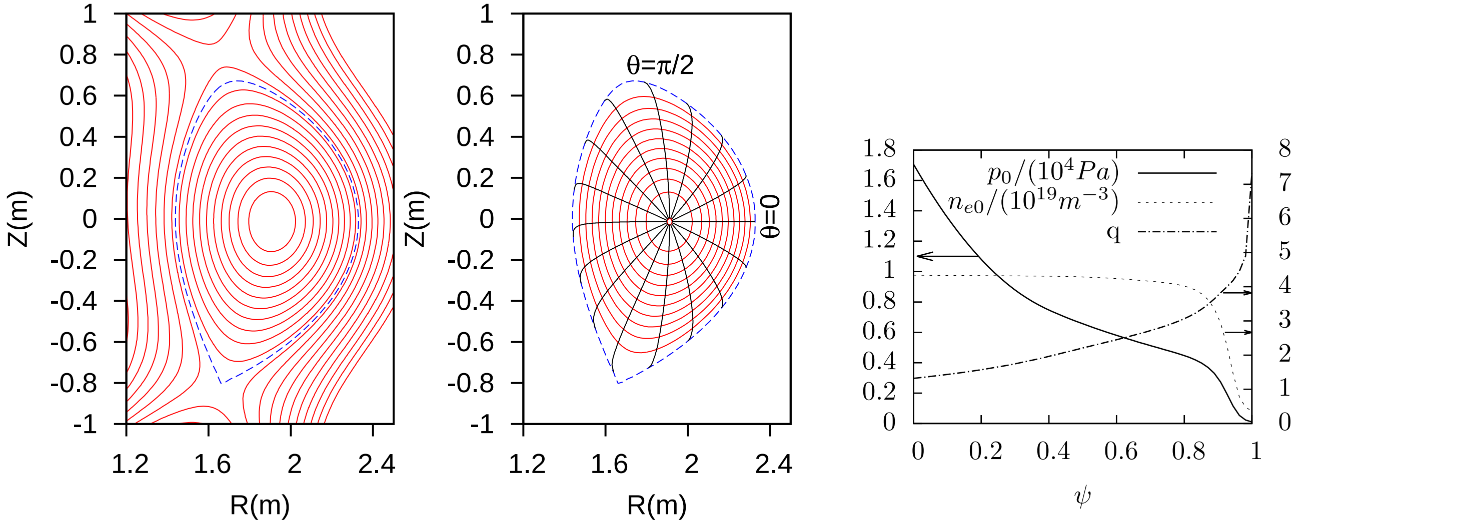

Figure 4. EAST equilibrium reconstructed by EFIT by using constraints from experimental diagnostics in EAST discharge #38300 at 3.9s

Alfvén Continua provide useful information for experimental observation of AEs: approximate frequency and location of AEs

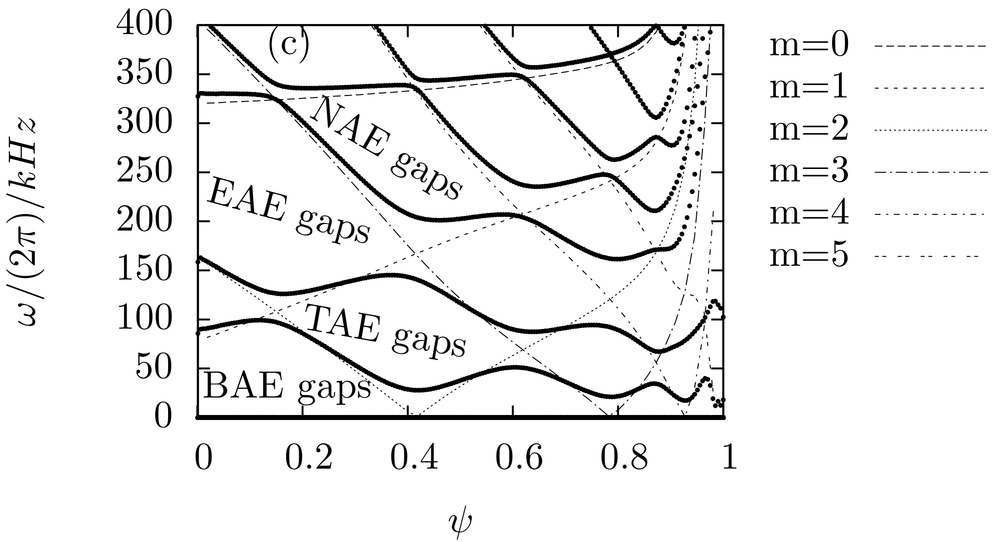

Figure 5. $n = 1$ Alfvén continua for EAST discharge #38300 at 3.9s.

TAEs in EAST discharge #38300 at 3.9s

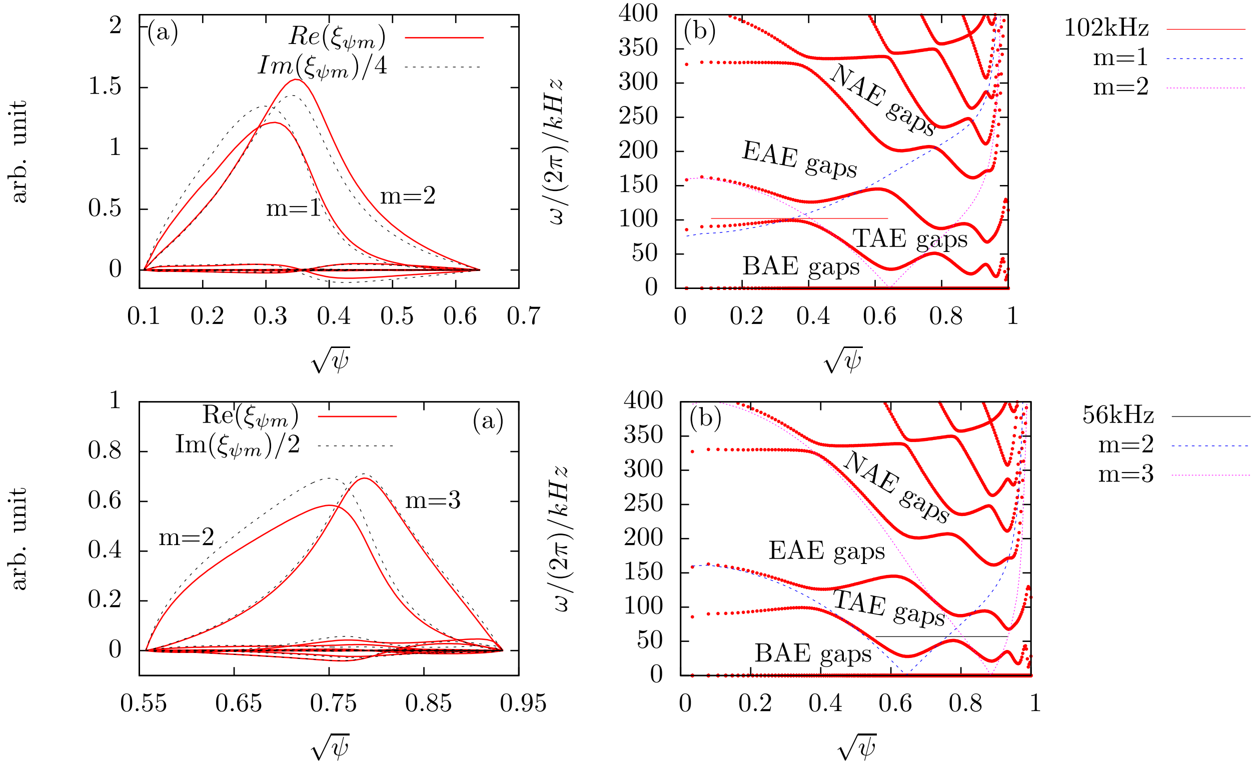

Figure 6. Even TAEs

Plans for comparing theory with experiments

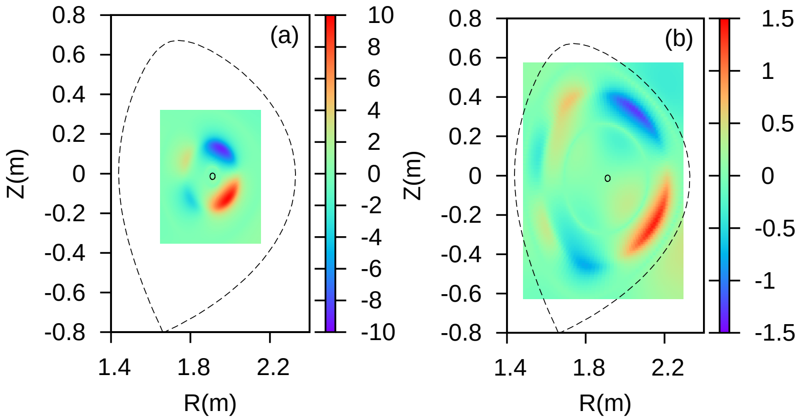

Figure 7. Ballooning structure of the even TAEs.

$$\frac{n_{e1}}{n_{e0}} = -\frac{1}{n_{e0}}\frac{dn_{e0}}{d\Psi}\xi_\psi$$

$$\frac{T_{e1}}{T_{e0}} = -\frac{1}{T_{e0}}\frac{dT_{e0}}{d\Psi}\xi_\psi,$$

Microwave reflectometers, BES, and ECE measurements planned for the next campaign of experiments on EAST

New feature of TAEs in up-down asymmetric equilibria

- For up-down symmetric equilibria, Ideal MHD theory predicts that TAEs have constant phase across the major radius on the midplane

- However, ECE measurements show that the phase of AEs changes across the radius.

- The change can be due to various effects, including kinetic and geometric effects

- In this work, we demonstrate that up-down asymmetry induces radial phase variation in the eigenfunction

The phase variation increases with the increasing of the degree of up-down asymmetry

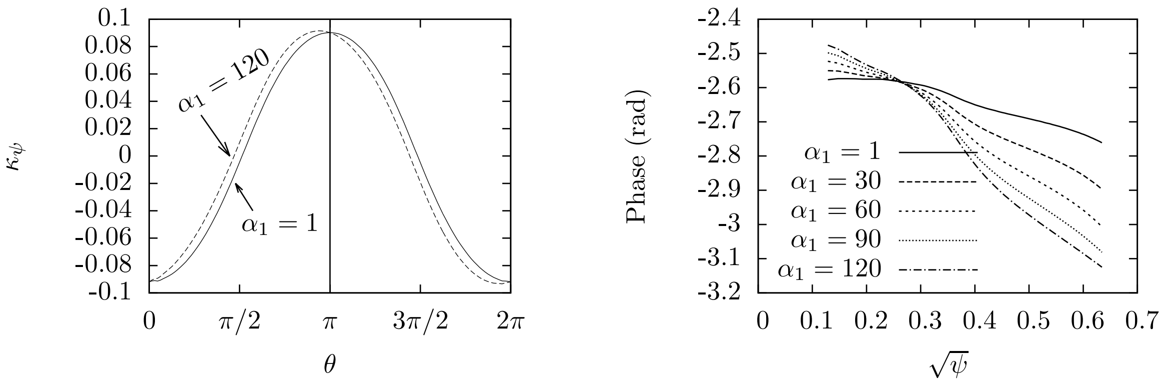

Figure 8. (a) Normal magnetic curvature. (b) phase variations across the radius on the midplane for different values of the degree of up-down asymmetry.

发表论文与近期计划

已发表论文:

- Numerical study of Alfven eigenmodes in the EAST tokamak, Youjun Hu, Guoqiang Li, N. N. Gorelenkov, Huishan Cai, et al., Phys. Plasmas 21, 052510 (2014).

近期工作计划:

- 用MEGA程序(MHD+EPs)分析EAST中性束注入的高能粒子与磁流体波相互作用：(1) Alfven eigemodes+EPM激发 (2)高能粒子损失

人才培养与合作交流

- 研究生培养：课题组2014年新增两名研究生，主攻方向为高能粒子与MHD相互作用

- 国内合作：（1）等离子体所聚变堆总体研究室(李国强，任启龙)
  等离子体平衡重构与EAST诊断数据分析.
  （2）核工业西南物理研究院陈伟、丁玄同研究小组，
  了解学习HL-2A上的相关实验数据.
  （3） SUNIST阿尔芬波实验

- 国际合作：（1）美国PPPL傅国勇、N.Gorelenkov,NOVA-K程序
  （2）日本NIFS,高能粒子与磁流体波非线性相互作用,
  MEGA程序(MHD+EPs)

经费使用情况

- 本课题自2013年4月启动直接，共获得资助86万元
- 截至目前，实际发生费用为61.56万元，主要用于购买高性能计算集群的计算节点。

谢谢！
请各位老师批评指正！