EUROfusion

Novel measurements of Alfvén Eigenmode stability via active antenna excitation in JET plasmas

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VO07:00001 Magnetic Confinement: Energetic Particles & RF

JET PSFC CCFE CULHAM CENTRE FOR FUSION ENERGY EPFL LPP ERM - KMS

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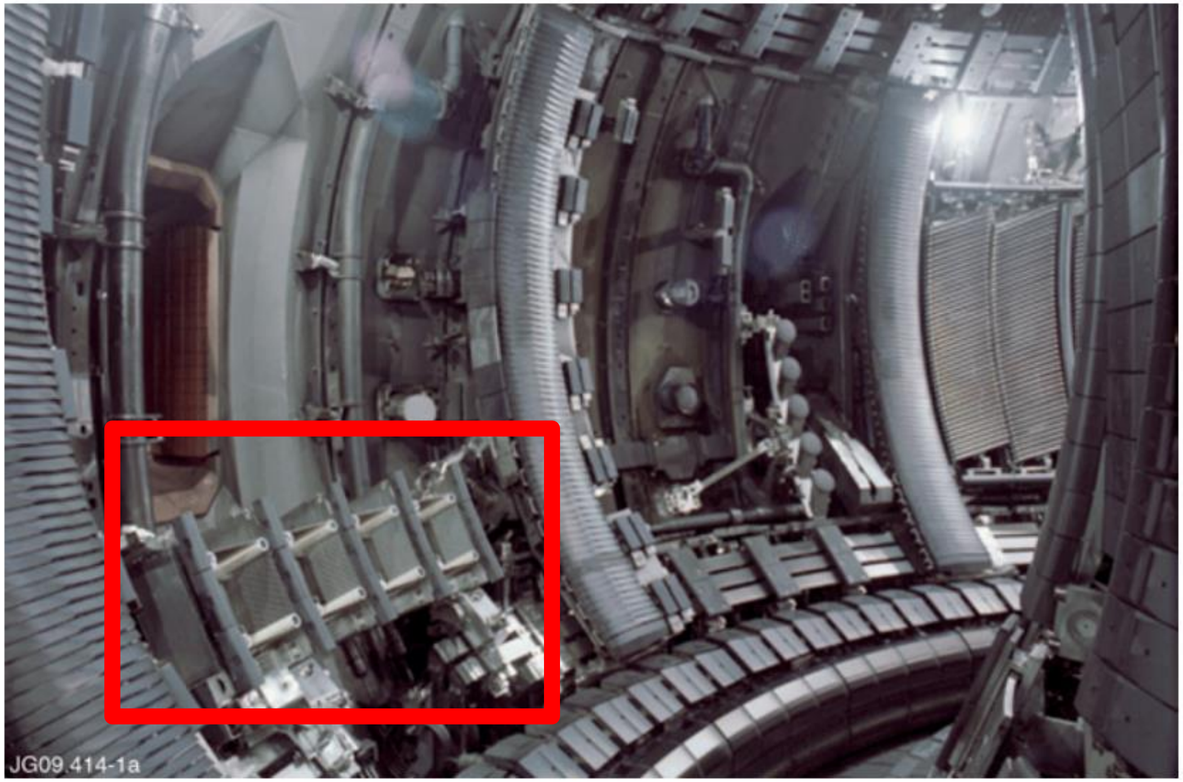
AE antenna actively probes *stable* AEs

- Eight in-vessel, toroidally-spaced antennas in JET
- Current < 10 A; independent phasing → |n| < 20
- Scan frequency ranges 25-50, 75-150, 125-250 kHz



T Panis et al 2010 Nucl. Fusion 50 084019
P Puglia et al 2016 Nucl. Fusion 56 112020

Motivation: Understand AE stability

1. **Improve predictions of fast ion drive/transport in future tokamaks**
   - Validate simulations with experimentally measured damping rates
   - Identify/quantify alpha drive with *similar measurements* in DD vs DT
   - Important if alphas do not destabilize TAEs in JET DTE2

2. **Actively excite the *same* stable AEs also destabilized by fast ions**
   - |n| ~ 5-7 expected to couple most strongly with alphas in JET
   - Inject power into |n| ~ 20 with upgraded AE antenna
   - Measure |n| < 30 with upgraded fast magnetic probes

Outline

- Novel measurements of AE stability
  1. TAEs monitored from destabilization through stabilization
  2. Stable AE tracked during high power NBI+ICRH (~25 MW)

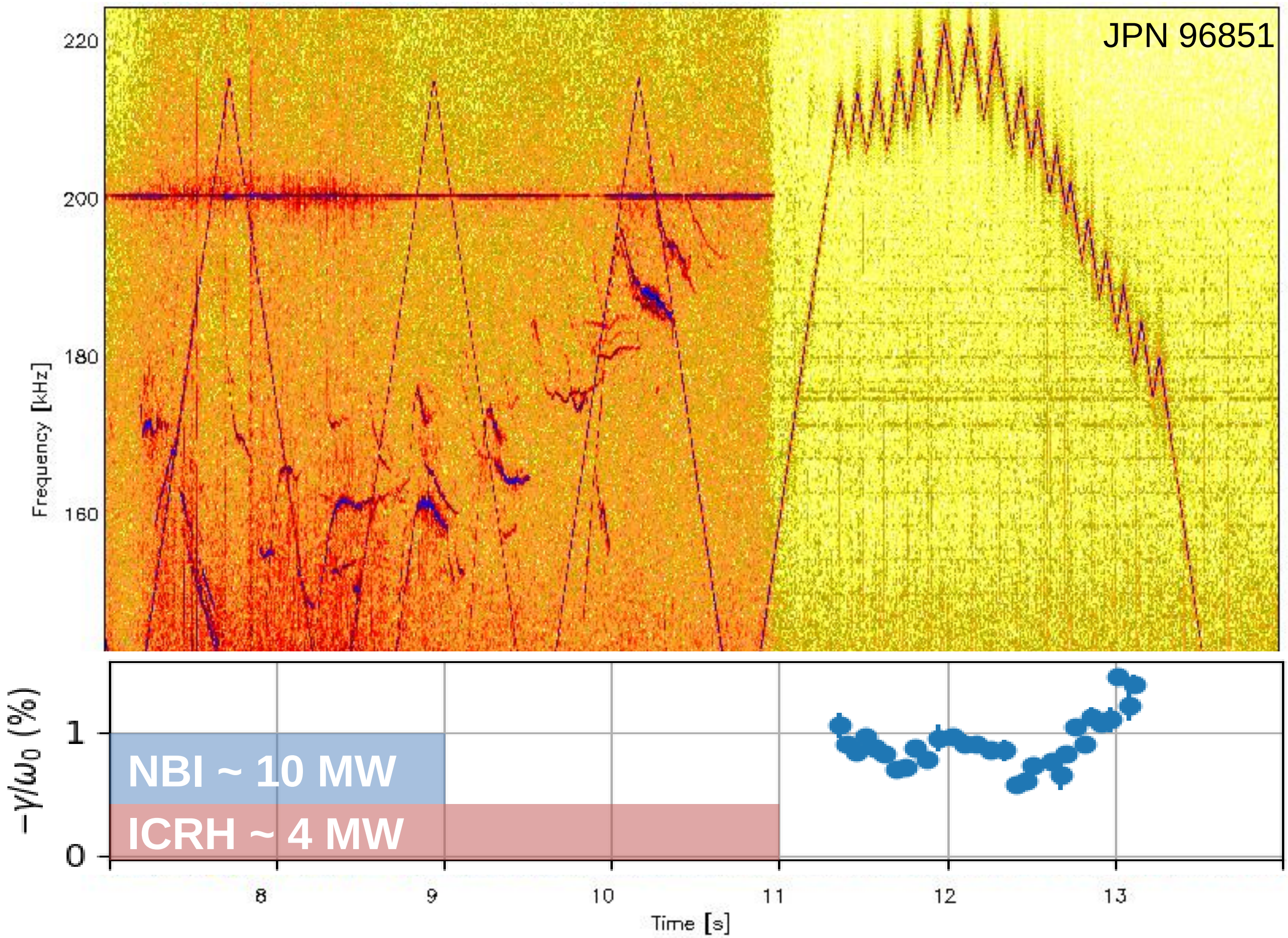
- Database of 5000+ stable AE resonances [1]

- Dedicated study of plasma-antenna coupling [2]

- Modeling with MHD and gyrokinetic codes [3]

[1] R A Tinguely et al 2020 Plasma Phys. Control. Fusion 62 115002
[2] R A Tinguely et al 2020 Nucl. Fusion doi:10.1088/1741-4326/abc7eb
[3] N Fil et al 2020 *In preparation*

TAEs (n = 2-6) destabilized by NBI+ICRH, AE antenna tracks stable mode: $-\gamma/\omega \sim 1\%$



Note: JET Energetic Particle experiments [R. J. Dumont et al 2018 Nucl. Fusion 58 082005]

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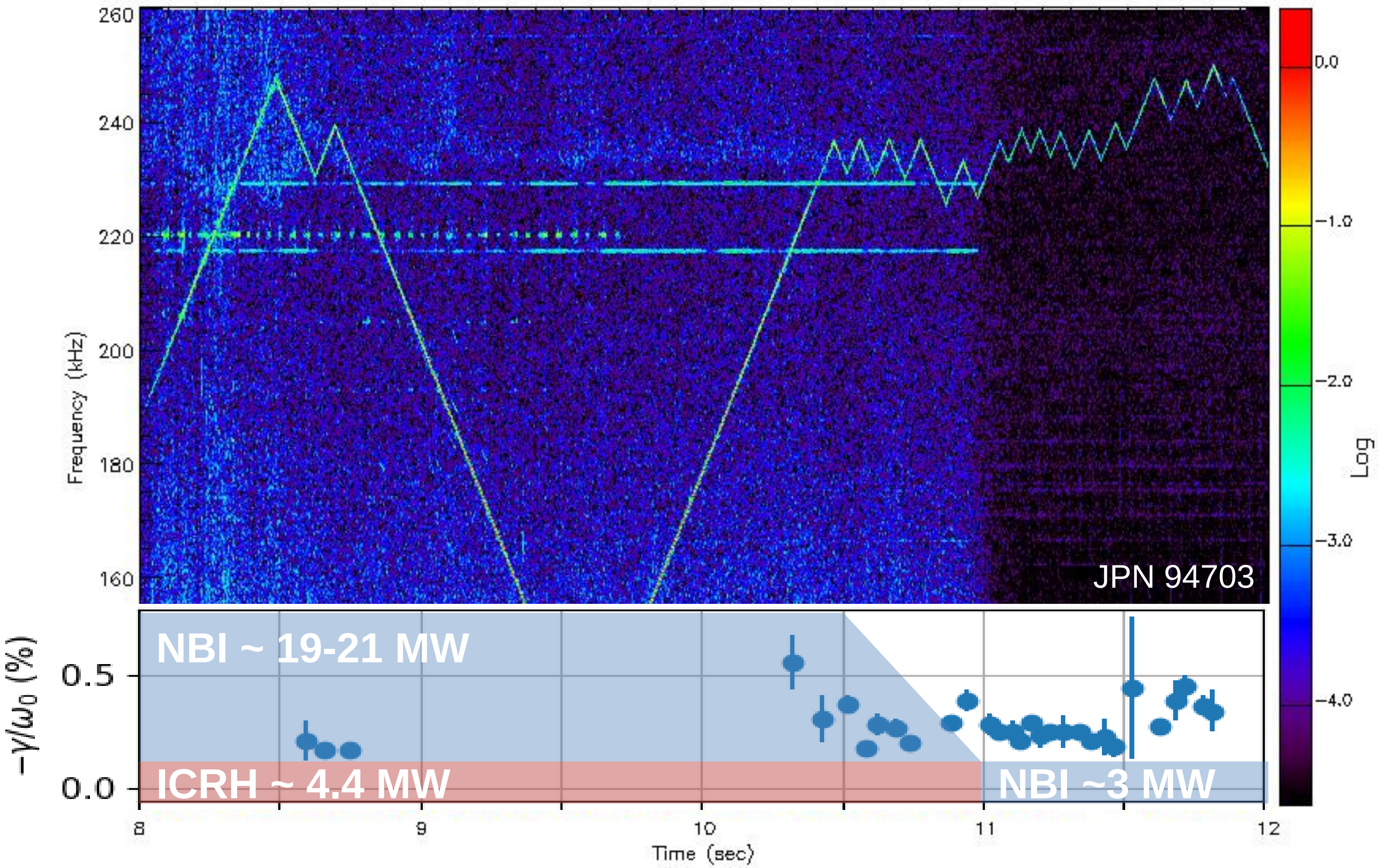
Marginally stable AE ($-\gamma/\omega$ ~ 0.25%, n = 5?) tracked during NBI+ICRH ~ 25 MW



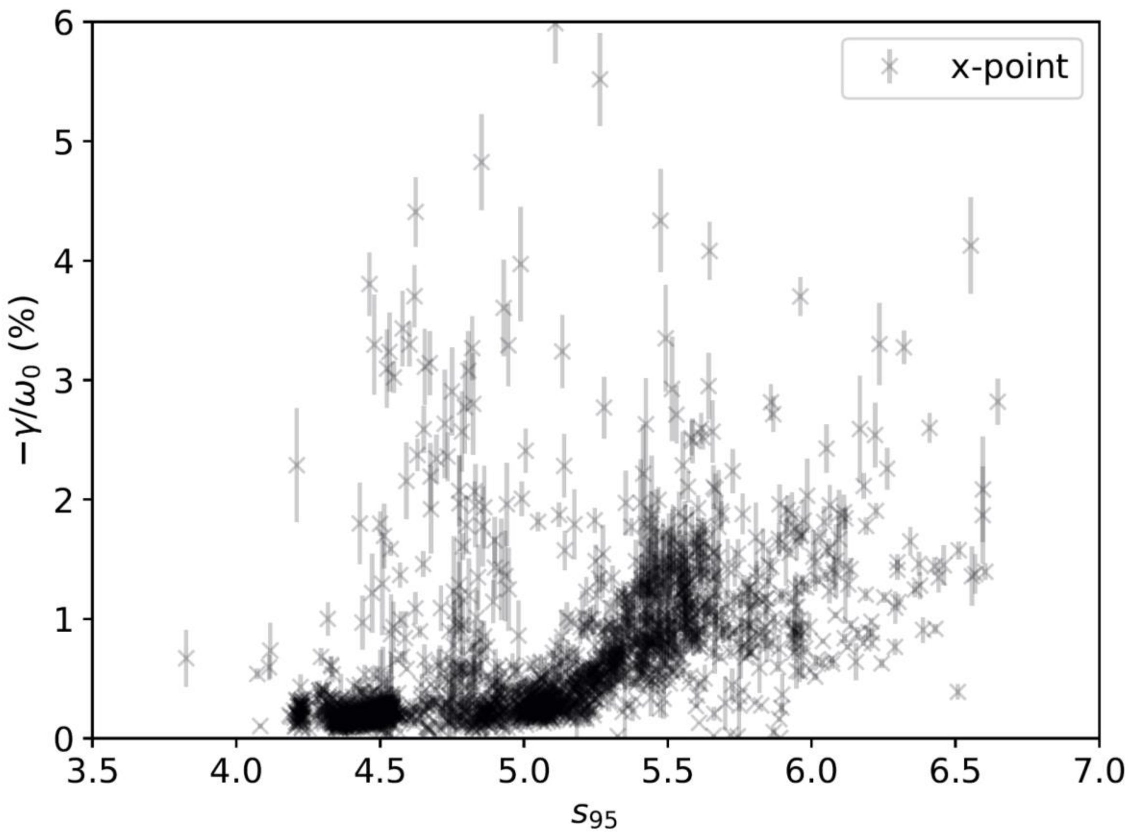
Note: D-(DNBI)-^{3}He plasma (n_{3He}/n_e ~ 23%)

[Ye. Kazakov et al 2020 Nucl. Fusion 60 112013]
[M. Nocente et al 2020 Nucl. Fusion 60 124006]

Database of 5000+ stable AEs:

frequencies (30-250 kHz), damping rates (0-13 kHz), and toroidal mode numbers (|n| < 30)

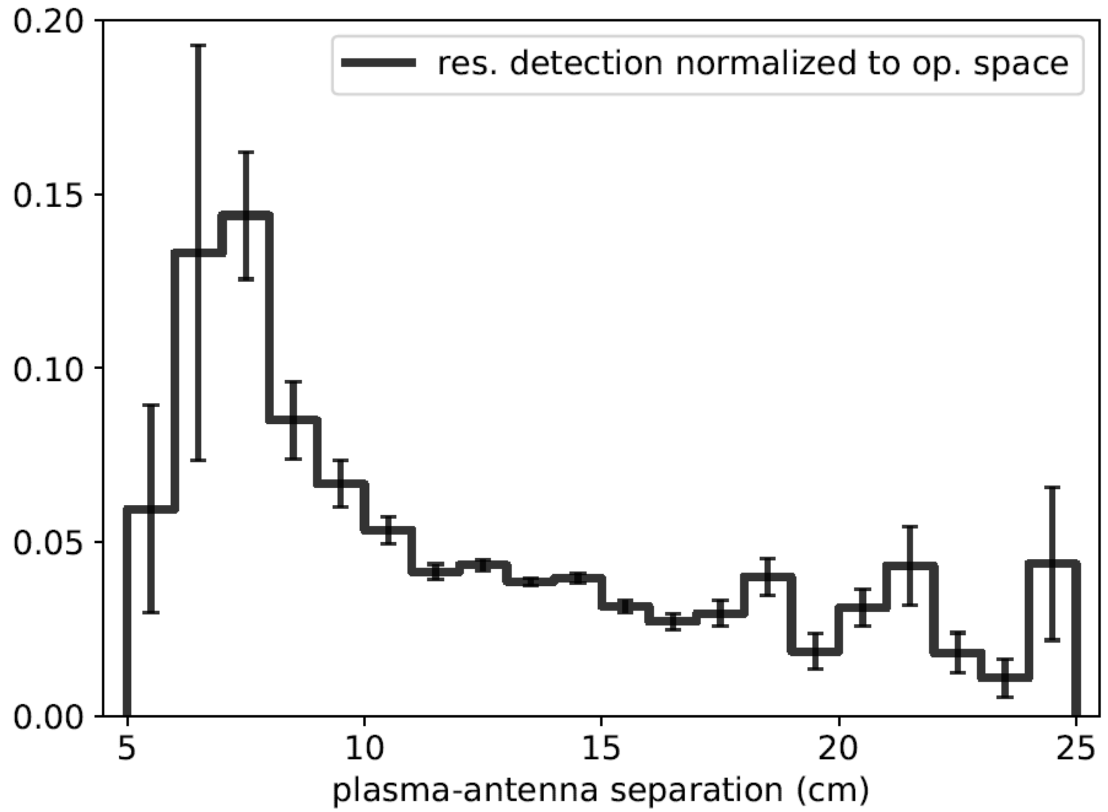
B_0	< 3.7 T
I_P	< 2.8 MA
n_{e0}	< 10^{20} m^{-3}
T_{e0}	< 7 keV
P_{NBI}	< 7 MW*
P_{ICRH}	< 7 MW



R A Tinguely et al 2020 Plasma Phys. Control. Fusion 62 115002
R A Tinguely et al 2020 Nucl. Fusion doi:10.1088/1741-4326/abc7eb

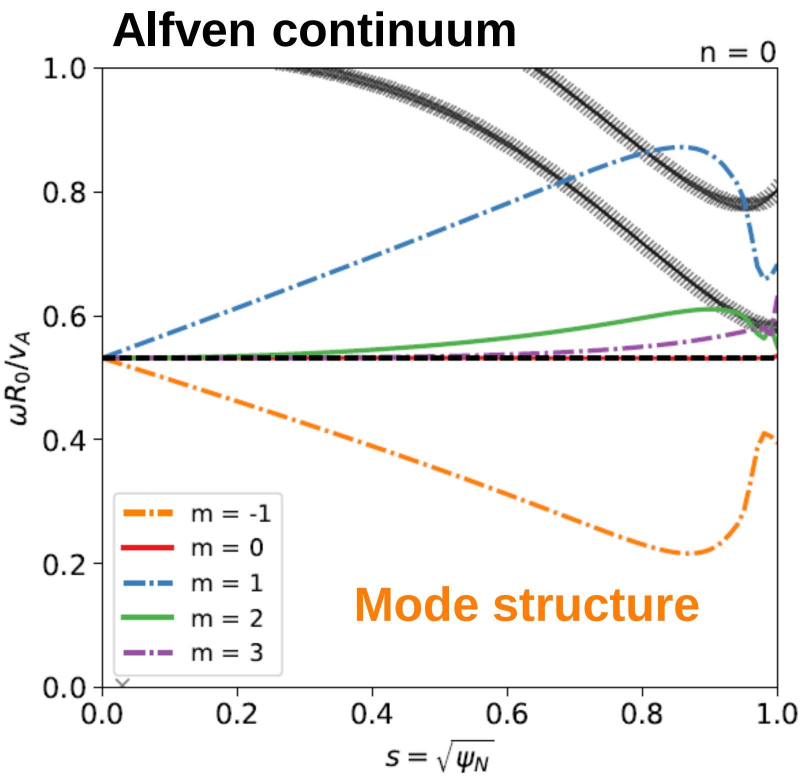
Plasma-antenna (PA) coupling decreases…
(1) as PA separation increases and
(2) in X-point vs limiter configuration

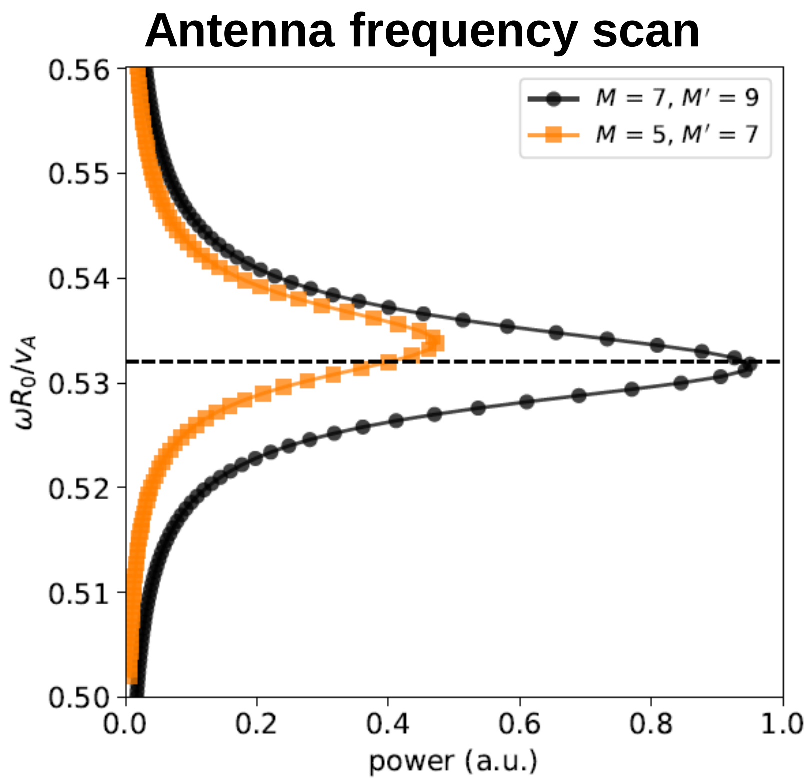
Config.	P(detection)
Limiter	62%
X-point	38%



Good agreement with simulations in A Dvornova et al 2020 Phys. Plasmas 27 012507
R A Tinguely et al 2020 Nucl. Fusion doi:10.1088/1741-4326/abc7eb

Linear, resistive MHD code CASTOR [1,2] correctly identifies n = 0 GAE resonance





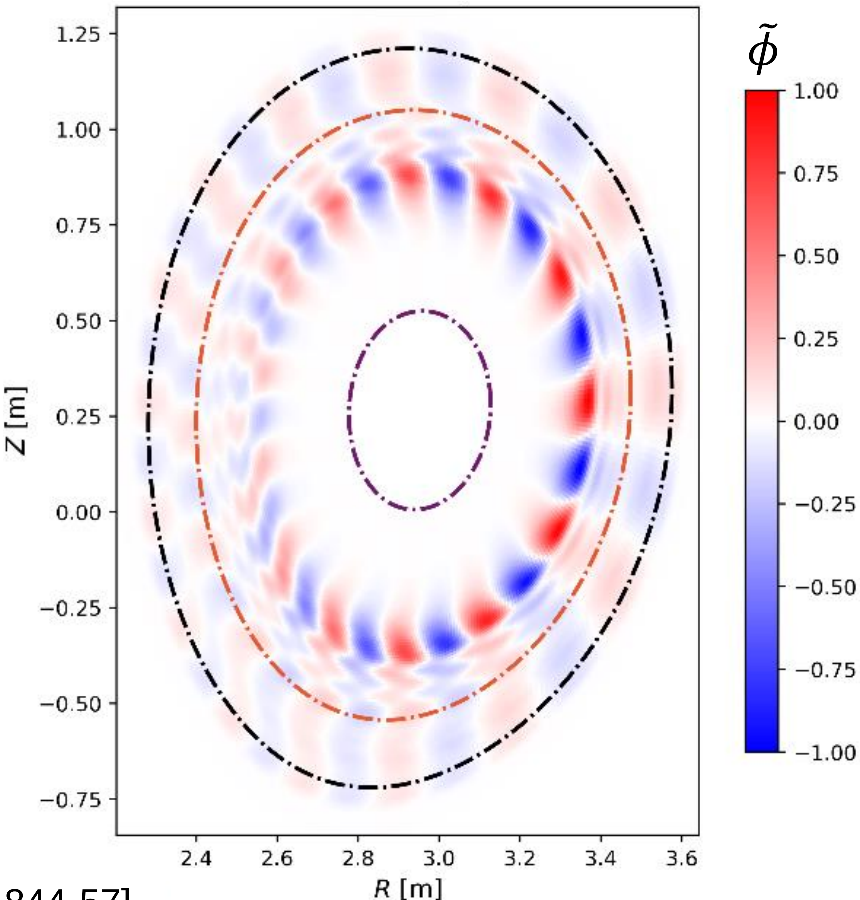
[1] G T A Huysmans et al 1995 Phys. Plasmas 2 5
[2] W Kerner et al 1998 J. Comput. Phys. 142 2
R A Tinguely et al 2020 Nucl. Fusion doi:10.1088/1741-4326/abc7eb

Linear gyrokinetic simulations with GTC agree well with measured stable n = 5 TAE

	f (kHz)	γ/ω (%)
JPN 92054	142 ± 4*	-5.2 ± 0.5
MISHKA	134	-
GTC	129	-5.1
no NBI	-	*-0.7*
NBI	-	*-4.4*

*Doppler shifted $f = f_{lab} - n \times f_{rot}$

GTC: n = 5, m = 13,14



GTC [Z Lin et al 1998 Science 281 1835]
MISHKA [AB Mikhailovskii et al Plasma Phys. Rep. 23 844-57]
N Fil et al 2020 *In preparation*

Summary and outlook

- Novel measurements of AE stability
  1. TAEs monitored from destabilization through stabilization
  2. Stable AE tracked during high power NBI+ICRH (~25 MW)
  3. Simultaneous measurements of unstable and stable AEs

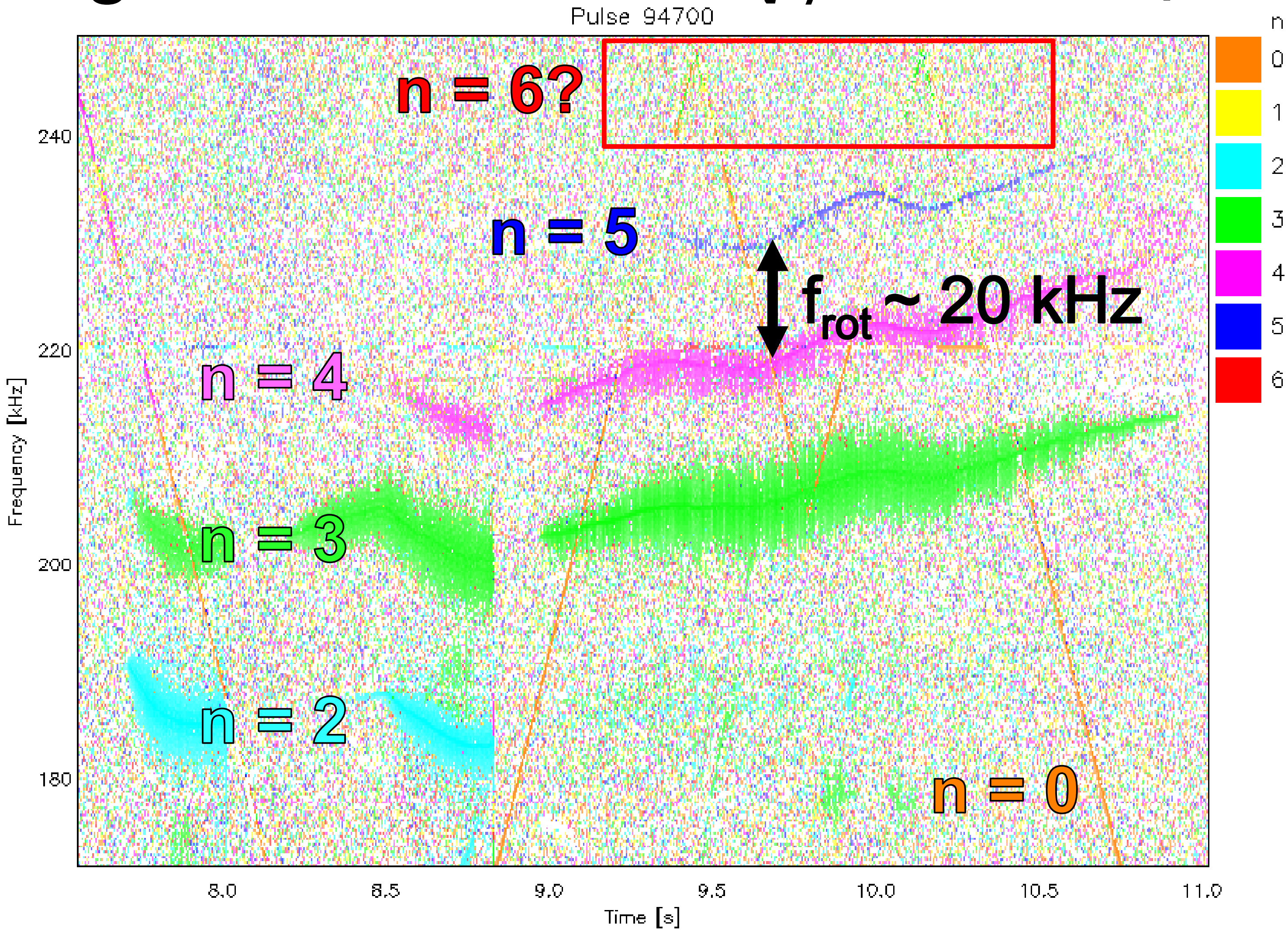
- Database of 5000+ stable AE resonances [1]
- Dedicated study of plasma-antenna coupling [2]
- Modeling with MHD and gyrokinetic codes [3]
- Isotope ratio measurements and active MHD spectroscopy [4]

→ Identify/quantify alpha contribution to AE stability from *similar measurements/experiments* in upcoming DT campaign

[1] R A Tinguely et al 2020 Plasma Phys. Control. Fusion 62 115002
[2] R A Tinguely et al 2020 Nucl. Fusion doi:10.1088/1741-4326/abc7eb
[3] N Fil et al 2020 *In preparation*
[4] PG Puglia et al 2020 *In preparation*

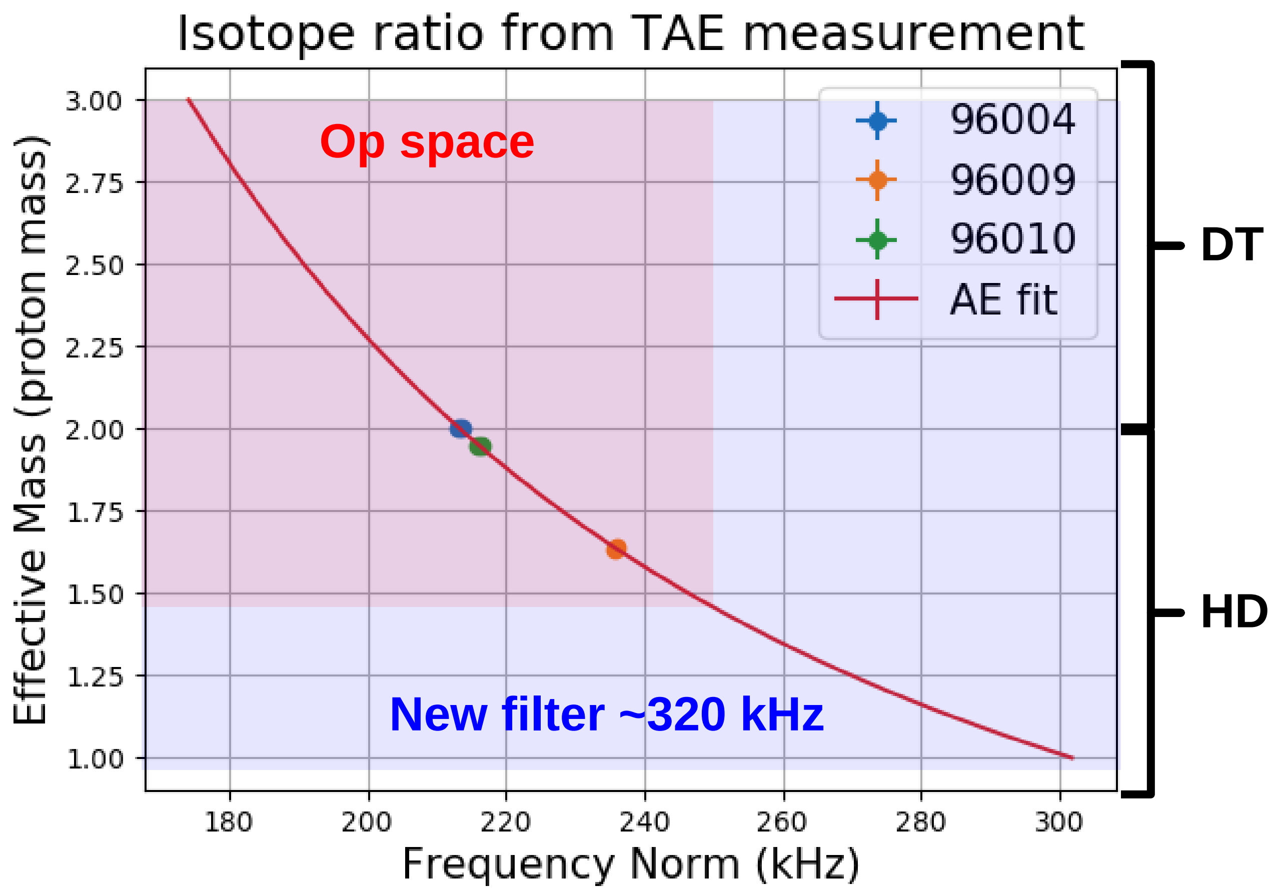
Bonus slides

TAEs destabilized by NBI+ICRH (6+6 MW), along with stable AE: $-\gamma/\omega$ ~ 1-2%, n = 6?



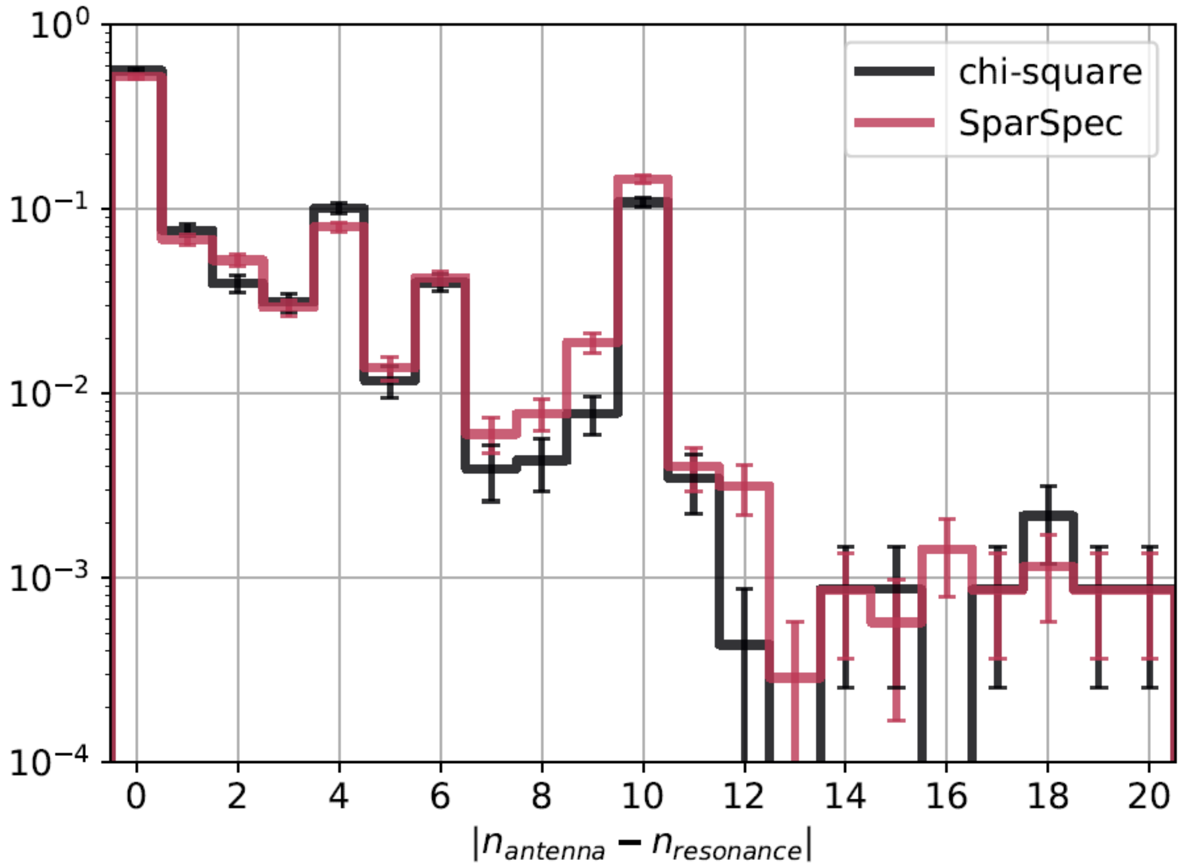
Note: D-(DNBI)-^{3}He plasma (n_{3He}/n_e ~ 27%)

Measurements of H/D/T isotope ratio with changing AE frequency



PG Puglia et al 2020 *In preparation*

AE antenna excites resonances with similar toroidal mode numbers



R A Tinguely et al 2020 Plasma Phys. Control. Fusion 62 115002