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Recommendations for iota correction in OP2.2

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on behalf of the W7-X Task Force Leaders

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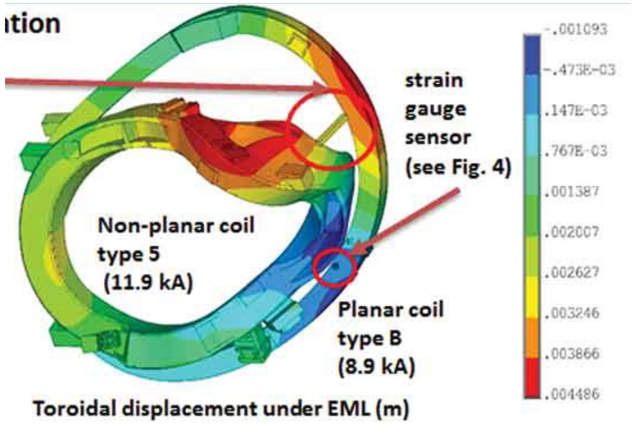
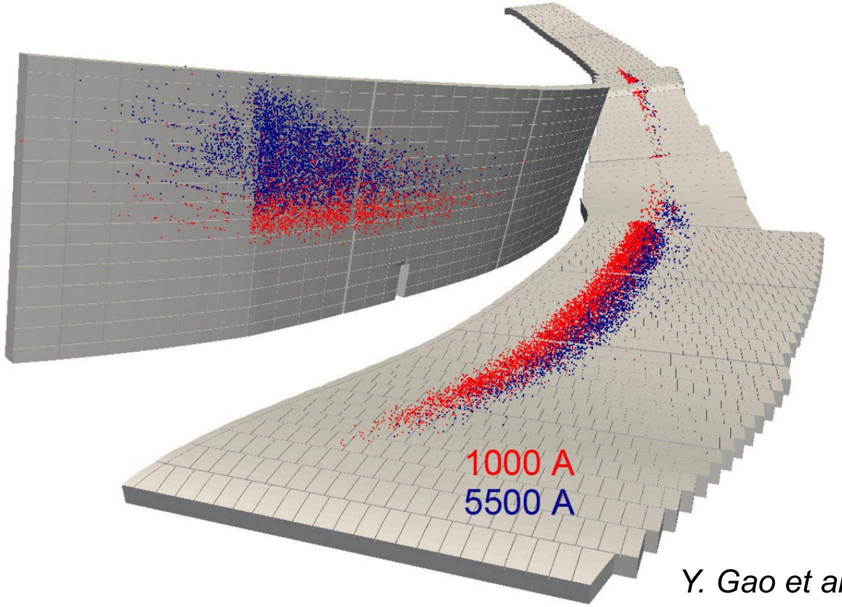
Motivation

- **Rotational transform (iota) during experiments is typically offset from the nominal value**
  - **Deformation of the coils (constant)**
  - **Plasma current (varies during a shot, and from shot to shot)**
- **Adverse effects of iota offsets**
  - **Strike lines not in expected/desired location**
  - **Overloaded components**
  - **Inconsistencies in edge diagnostic measurements**



V. Bykov et al. [1]



Y. Gao et al. [2]

[1] V. Bykov et al., *Fusion Sci. Technol.* **75**, 730 (2019)
[2] Y. Gao et al., *Nucl. Fusion* **59**, 106015 (2019)

Ways of modifying iota to correct offsets

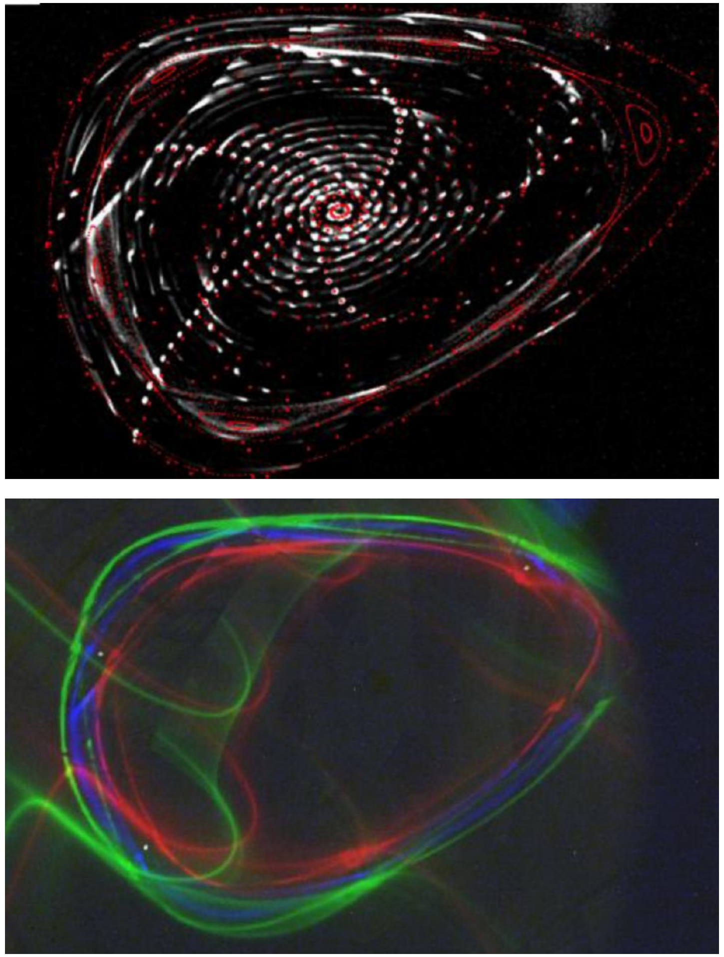
- Adjusting the planar coil currents
- Electron Cyclotron Current Drive (ECCD)
- Equivalency: -100 A in the planar coils has the same effect as 1.2 kA of plasma current (standard configuration, 2.52 T)

Objective: develop standardized recommendations for iota correction for session organizers and experimental proponents

- **Input sought from the W7-X team this spring**
  - Meeting and discussion held on May 29
  - Presentations given by T. Andreeva, E. Flom, and C. Killer available here: https://event.ipp-hgw.mpg.de/event/1419/
- **Task Force Leader recommendations account for:**
  - Benefits of operating with the correct iota
  - Difficulties of maintaining a desired iota in real time
  - Operational and scheduling considerations
- **Note: this presentation does not address *n*=1 or *n*=2 resonant error field correction**
  - Require separate correction strategies
  - Not strongly affected by planar coil current or plasma current

Planar coil current adjustments have successfully corrected vacuum iota offsets

- **Iota offsets measured by comparing flux surface images to field line tracing [3]**
- **Planar coil offsets determined to match measurement with modeling [4]:**
  - EEM+261 “OP1.1 Limiter”: I(1-5)=12800A, I(A-B)=5000A: $I(A,B)_{off} \approx -750A$
  - EIM+252 “Standard”: I(1-5)=12989A, I(A-B)=0A: $I(A,B)_{off} \approx -500A$
  - FOM001+252: I(1-5)=13602A, I(A-B)=-5000A: $I(A,B)_{off} \approx -350A$
  - FOM003+252: I(1-5)=13664A, I(A-B)=-5500A: $I(A,B)_{off} \approx -400A$
  - FPM001+252: I(1-5)=13725A, I(A-B)=-6000A: $I(A,B)_{off} \approx -300A$
  - FPM002+252: I(1-5)=13797A, I(A-B)=-6500A: $I(A,B)_{off} \approx -300A$
  - FTM+252 “High iota”: I(1-5)=13725A, I(A-B)=-9790A: $I(A,B)_{off} \approx -175A$



M. Otte et al. [3]

[3] M. Otte et al., *Plasma Phys. Control. Fusion* **58**, 064003 (2016)
[4] M. Otte et al., W7-X OP1.2b Workshop, Greifswald, 14 – 17 May 2019

Maintaining the correct iota during a discharge is not (yet) feasible

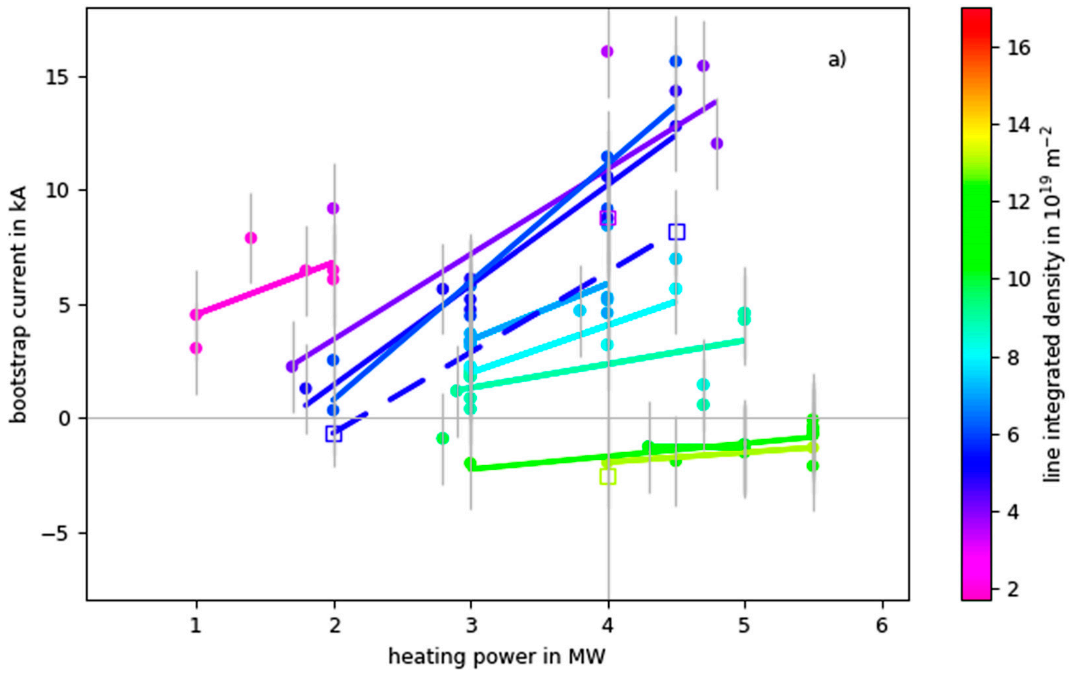
- **Would require real-time adjustments in response to plasma current**
- **Real-time I_{pc} control**
  - Currently not in segment control
  - Limited by coil current ramp rates
  - Polarity changes not possible
- **Real-time ECCD**
  - Could face device safety restrictions due to risk of fast collapses
- **Both will be investigated in experiments during OP2.2, but need further study before being used as reliable strategies**

Recommended approach to iota correction for OP2.2

- For most sessions: apply no correction
  - Use the nominal superconducting coil currents from the “paradigmatic” configuration
  - Will produce the correct iota at a certain value of I_p
  - One exception: high iota maintains correction used in OP2.1
- For sessions where consistent edge topology is critical across density and power levels: repeat some discharges with different planar coil offsets
- For sessions with specific edge topology requirements (e.g. divertor plugging): defer to proponents for specific coil currents

Standard configuration

- **Recommendation: $I_{A,B}$ = 0 A (no correction)**
  - **EIM000+2520, MID=20047**
- **Rationale**
  - **In vacuum, iota is too low; requires $I_{A,B}$ = -500 A to correct**
  - **With plasma, bootstrap current is typically positive and increases iota, often over-compensating the vacuum offsets**

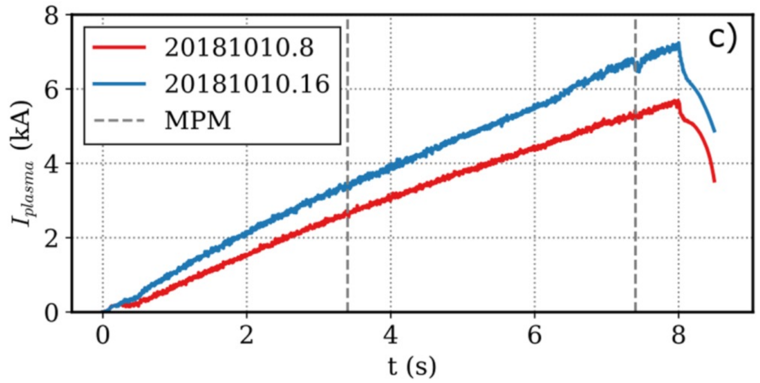


U. Neuner et al. [4]

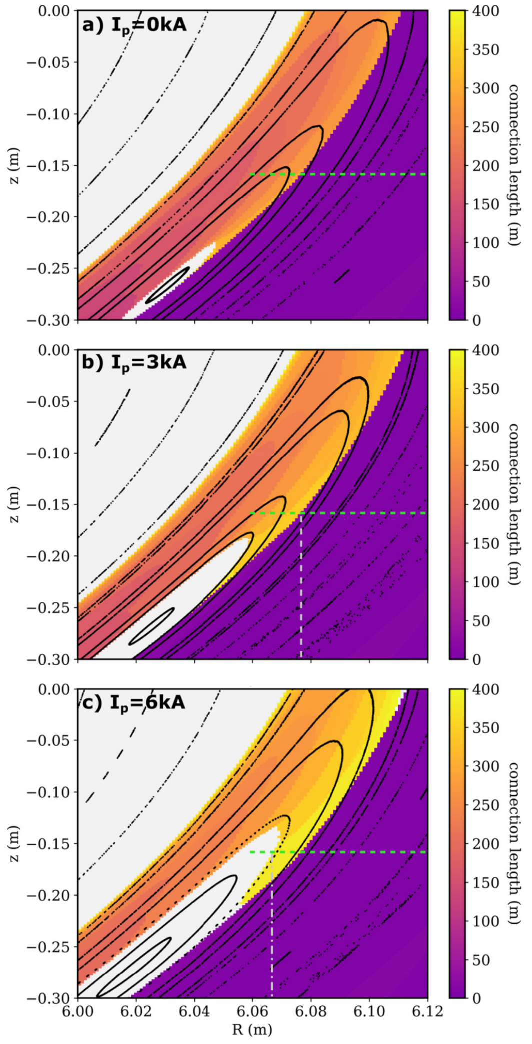
[4] U. Neuner et al., *Nucl. Fusion* **61**, 036024 (2021)

Benefits of using I_{ab} = 0 A for the standard configuration

- **Accuracy**
  - I_p = +6 kA is roughly equivalent to the vacuum correction $I_{A,B}$ = -500
  - With typical bootstrap currents, $I_{A,B}$ = 0 A results in iota closer to the correct value than $I_{A,B}$ < 0 A
  - Reduces likelihood of reaching bifurcation in edge topology
- **Operational**
  - Sessions in standard configuration may be run with any planar coil polarity, easing restrictions on scheduling



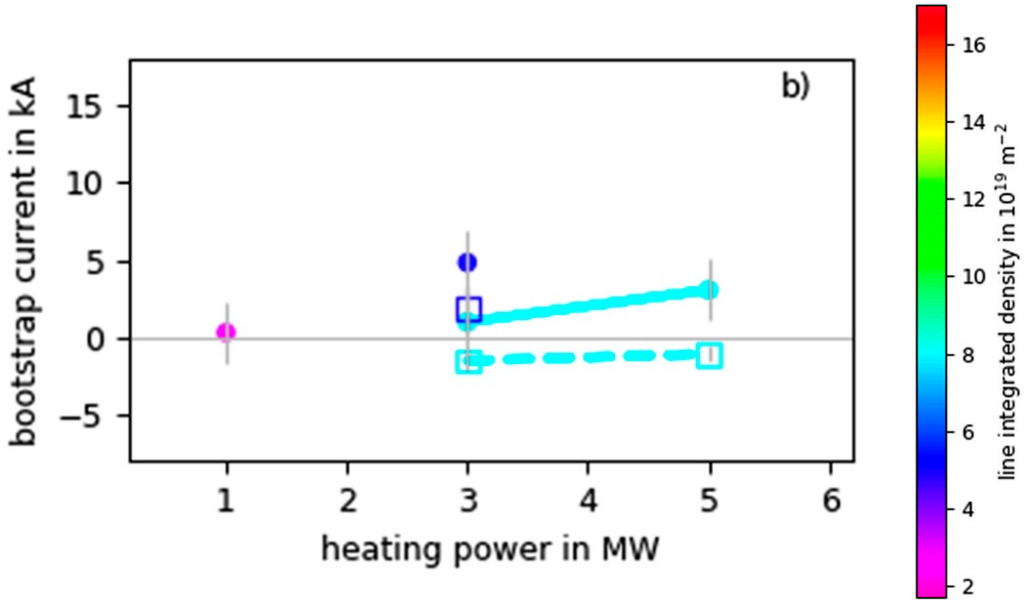
C. Killer et al. [5]



[5] C. Killer et al., *Plasma Phys. Control. Fusion* **61**, 125014 (2019)

High-mirror configuration

- **Recommendation: $I_{A,B}$ = 0 A (no correction)**
  - **KJM008+2520, MID=20049**
- **Rationale**
  - **Since bootstrap current tends to be lower and sometimes negative, the accuracy argument is not as strong as for the standard configuration**
  - **However, the operational benefit of using $I_{A,B}$ = 0 A remains in effect**



U. Neuner et al. [4]

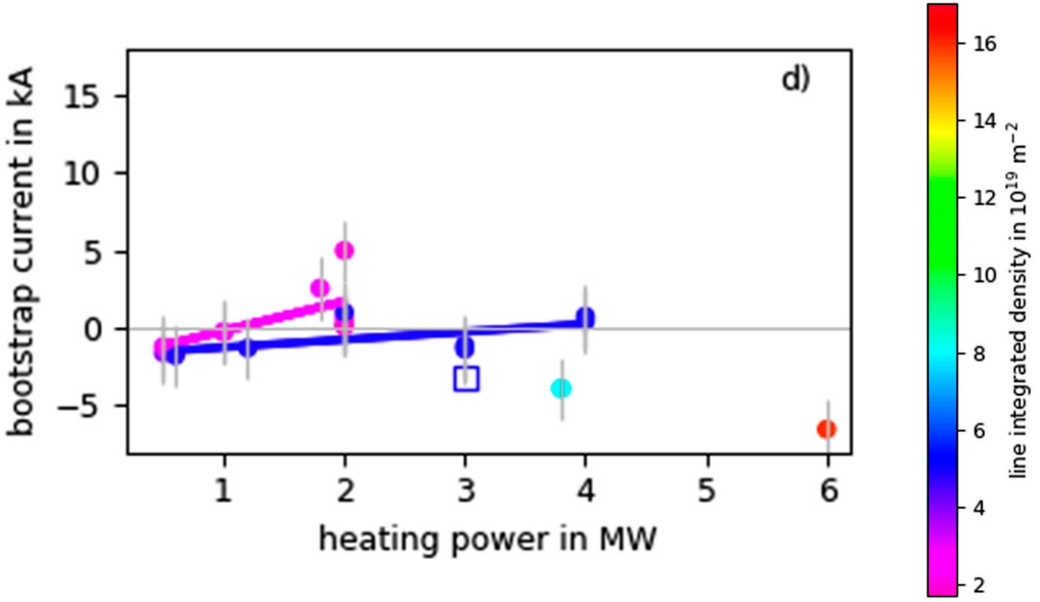
[4] U. Neuner et al., *Nucl. Fusion* **61**, 036024 (2021)

Low-mirror configuration

- **Recommendation: $I_{A,B}$ = 0 A (no correction)**
  - AIM000+2520, MID=20064
- **Rationale**
  - Precise vacuum offset is unknown
  - Operational benefit of using $I_{A,B}$ = 0 A remains in effect

High-iota configuration

- **Recommendation: $I_{A,B}$ = -10,040 A (-250 A correction)**
  - **FTM004+2520, MID=20088**
  - **Same recommendation as in OP2.1**
- **Rationale**
  - **In vacuum, iota is too low; requires $I_{A,B}$ = -175 A to correct**
  - **With plasma, bootstrap current tends to be negative and would thereby reduce iota further**
  - **It makes sense to over-correct a bit**

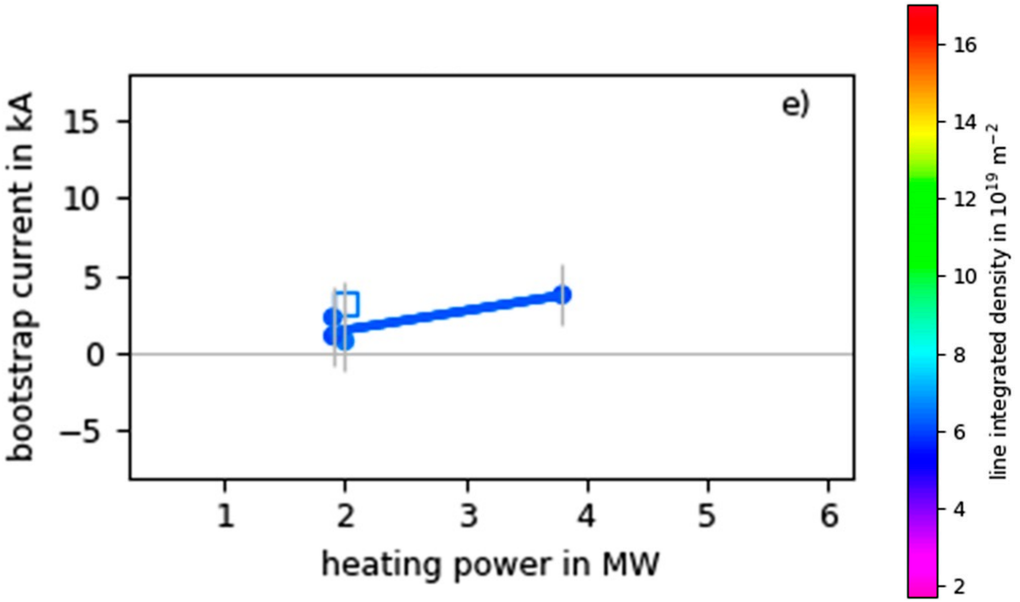


U. Neuner et al. [4]

[4] U. Neuner et al., *Nucl. Fusion* **61**, 036024 (2021)

Low-iota configuration

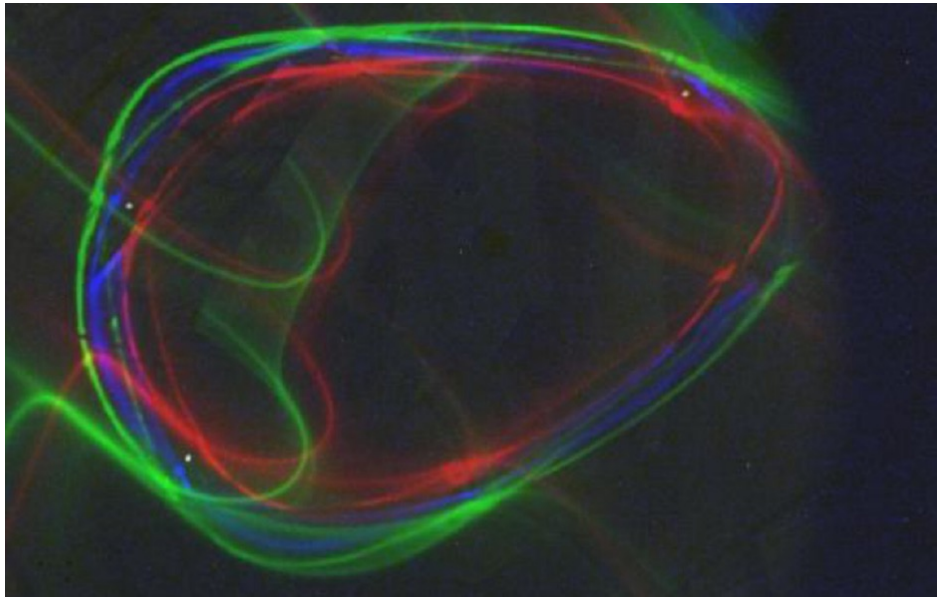
- **Recommendation: $I_{A,B}$ = 8895 A (no correction)**
  - **DBM000+2520, MID=20055**
  - **Same recommendation as in OP2.1**
- **Rationale**
  - **Vacuum offset not known to good accuracy**
    - Not possible to analyze flux surface measurements to date
    - IR measurements suggest correction of -250 A to -300 A with low I_p, but analysis is complicated by drift effects
  - **Bootstrap current tends to be positive, compensating the apparent iota offset**



U. Neuner et al. [4]

Higher and lower field strengths

- **Recommendations on previous slides are for the typical field strength of 2.52 T**
- **For higher or lower field strengths: scale all coil currents linearly with field strength**
  - **Example: if $I_{A,B}$ = 0 at 2.52 T, it would remain 0 at any other field strength**
  - **Linear scaling isn't precisely correct because iota offset varies with field strength**
  - **However, due to limitations in correction abilities, approach should be sufficient**



Images of islands at the same coil current ratios but different field strengths from M. Otte et al. [3]

Summary of recommended default configurations for iota correction in OP2.2

Name	MID	Configuration name for OP2.2	Field on axis [T]	Non-planar coil currents [A]					Planar coil currents [A]	
				I_1	I_2	I_3	I_4	I_5	I_A	I_B
Standard	20047	EIM000+2520	2.52	12985	12985	12985	12985	12985	0	0
High mirror	20049	KJM008+2520	2.52	13231	12858	12244	11639	11266	0	0
Low mirror	20064	AIM000+2520	2.52	12732	13276	13276	14365	14365	0	0
High iota	20088	FTM004+2520	2.52	14219	14219	14219	14219	14219	-10040	-10040
Low iota	20055	DBM000+2520	2.52	11863	11863	11863	11863	11863	8895	8895