NSTX

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Imaging the Pedestal Island Structure during the Application of 3D Magnetic Perturbations

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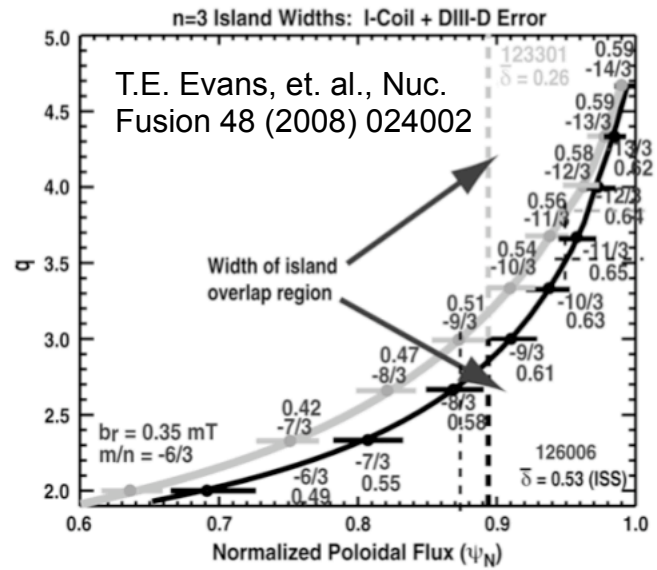
- Motivation: Are 3D magnetic perturbations shielded or amplified within a tokamak plasma?
  - Part of the bigger question: What mechanisms lead to the modification of ELM stability in the presence of 3D magnetic perturbations?
- Proposal: Image the 3D magnetic structure inside the tokamak plasma and compare to models
- Progress: Built a model to evaluate diagnostic designs and analysis techniques
- Update on postdoctoral research at NSTX

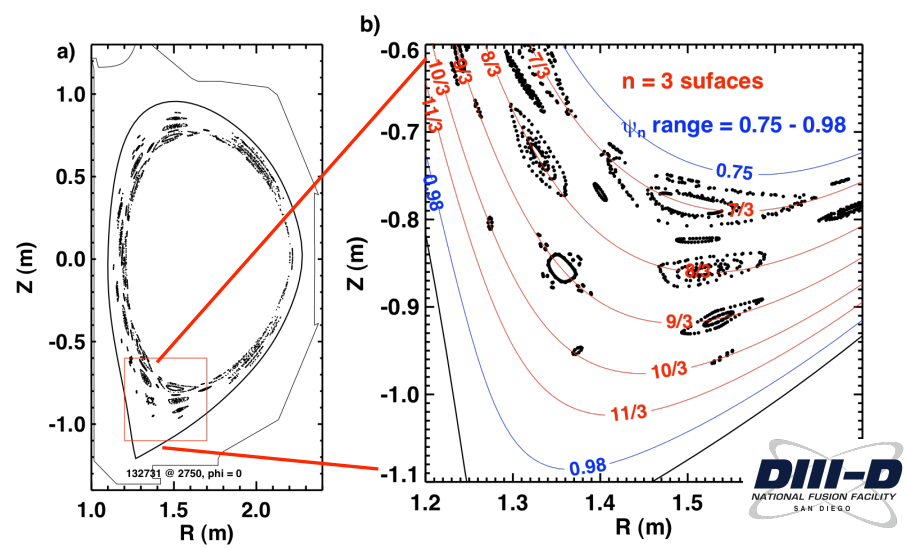
3D magnetic perturbations may provide a tool for ELM control in tokamak reactors

- Tokamak reactors must avoid type-I ELMs, yet may need small ELMs for impurity exhaust
  - This requires that the ELM size and frequency is actively controlled
- Externally applied 3D field perturbations ($\delta B/B \sim 10^{-4} - 10^{-3}$) are an effective tool for altering ELM stability
  - ELM suppression (DIII-D) and triggering (NSTX) have been demonstrated
- Extrapolation to ITER (and beyond) requires a more complete physics model
  - Presently, no model describes the full range of results seen in experiments

Vacuum field calculations predict the formation of small, edge localized resonant islands

- Stochastic edge region due to overlap of resonant islands
  - Believed to modify transport in the H-mode pedestal, altering ELM stability
- Intact islands deeper into plasma
  - Islands are largest near x-point due to flux expansion
  - Vacuum calculation: Islands are typically 1 - 20 cm wide
- The vacuum model is sufficient only if the plasma response is negligible





2-D SXR imaging of the edge plasma may elucidate the plasma response to 3D fields

- Full model of ELM stability modification via 3D fields must incorporate the plasma response, including:
  - Screening from plasma flows (especially important at high β)
  - Resonant field amplification and mode coupling

- Goal: Image the 3D island structure inside of the stochastic region to benchmark plasma response models
  - Imaging allows the entire critical region to be measured
  - Islands are stationary
    - Cannot use temporal filters (FFT, SVD, etc.)
    - Must have a large measurement area (islands won't rotate into field of view)
    - Measurement can be slow (10s – 100s ms)
  - VUV or SXR wavelengths to image islands inside the H-mode pedestal (T_e > 1 keV) with acceptable signal-to-noise

A coordinated effort is being pursued on NSTX and DIII-D to image the edge island structure

- SXR edge imaging diagnostics are planned for both NSTX and DIII-D
  - Planned diagnostics image SXR emission using pinhole and scintillator conversion to visible wavelengths
  - Image plasma near the x-point where the island size largest
  - Projects share modeling and analysis resources

- Diagnostics motivated by results from TEXTOR-DED and NSTX
  - SXR pinhole cameras measured spatial and temporal characteristics of rotating core MHD
  - Sufficient sensitivity for frame rates up to 20 kHz

TEXTOR-DED m/n =3/1 Island

Ohdachi, Plasma Sci & Tech. (2006) 45

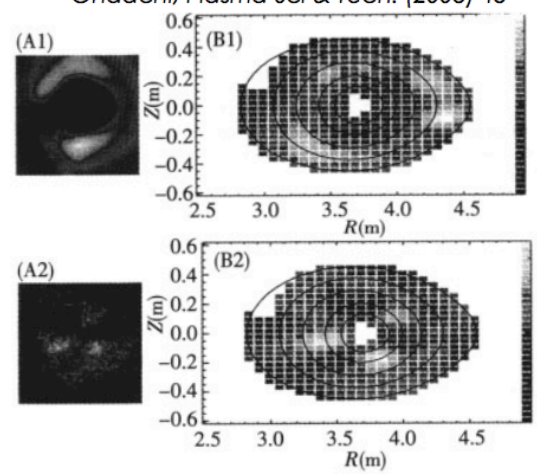
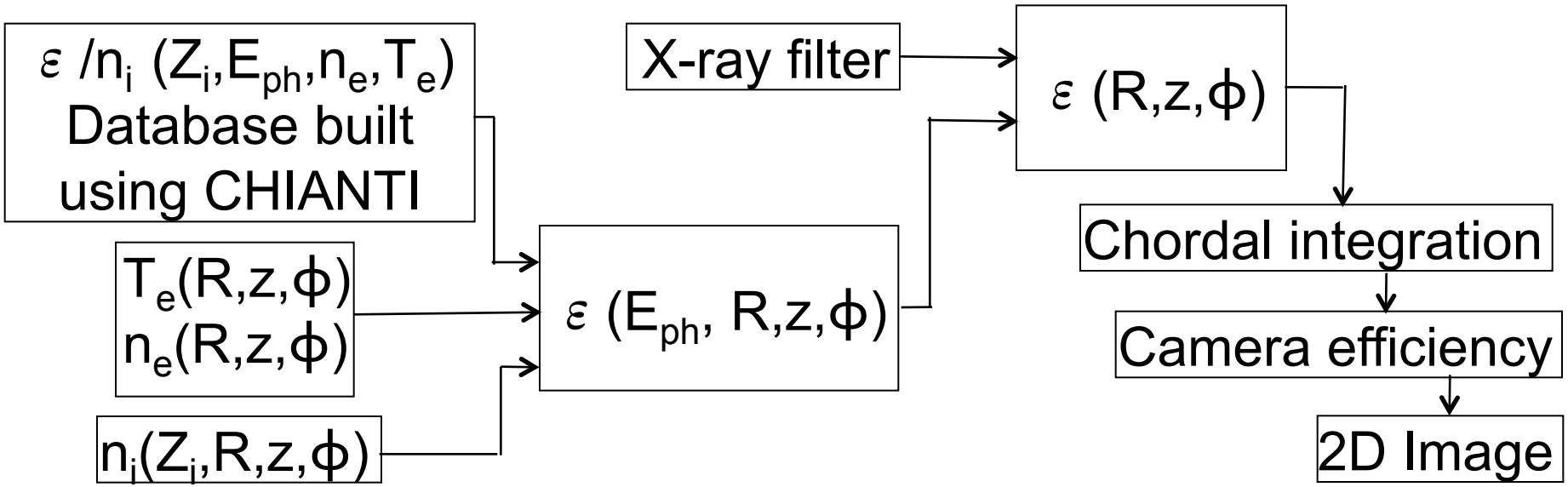


Fig.8 Singular value decomposed TOPOS (A) and the reconstructed images (B)

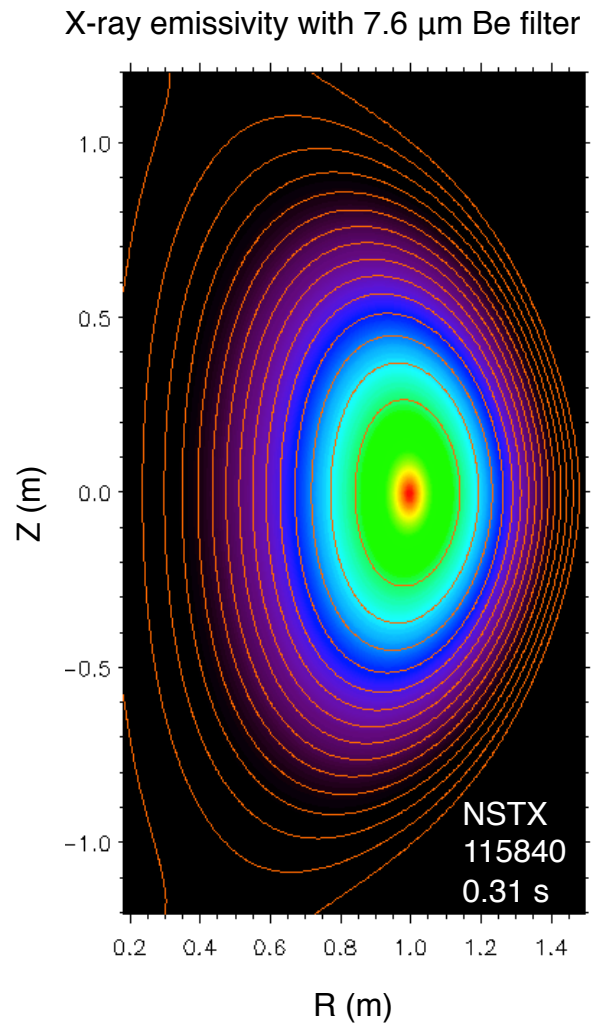
SXR model developed to guide diagnostic design



- X-ray emissivity spectrum database calculated using CHIANTI
  - Dere et al., A&AS **125** (1997) 149, Dere et al., A&A **498** (2009) 915
  - Includes free-free, free-bound, and recombination emission
  - Assumes isothermal plasma
- X-ray filter transmission calculated using LBL database

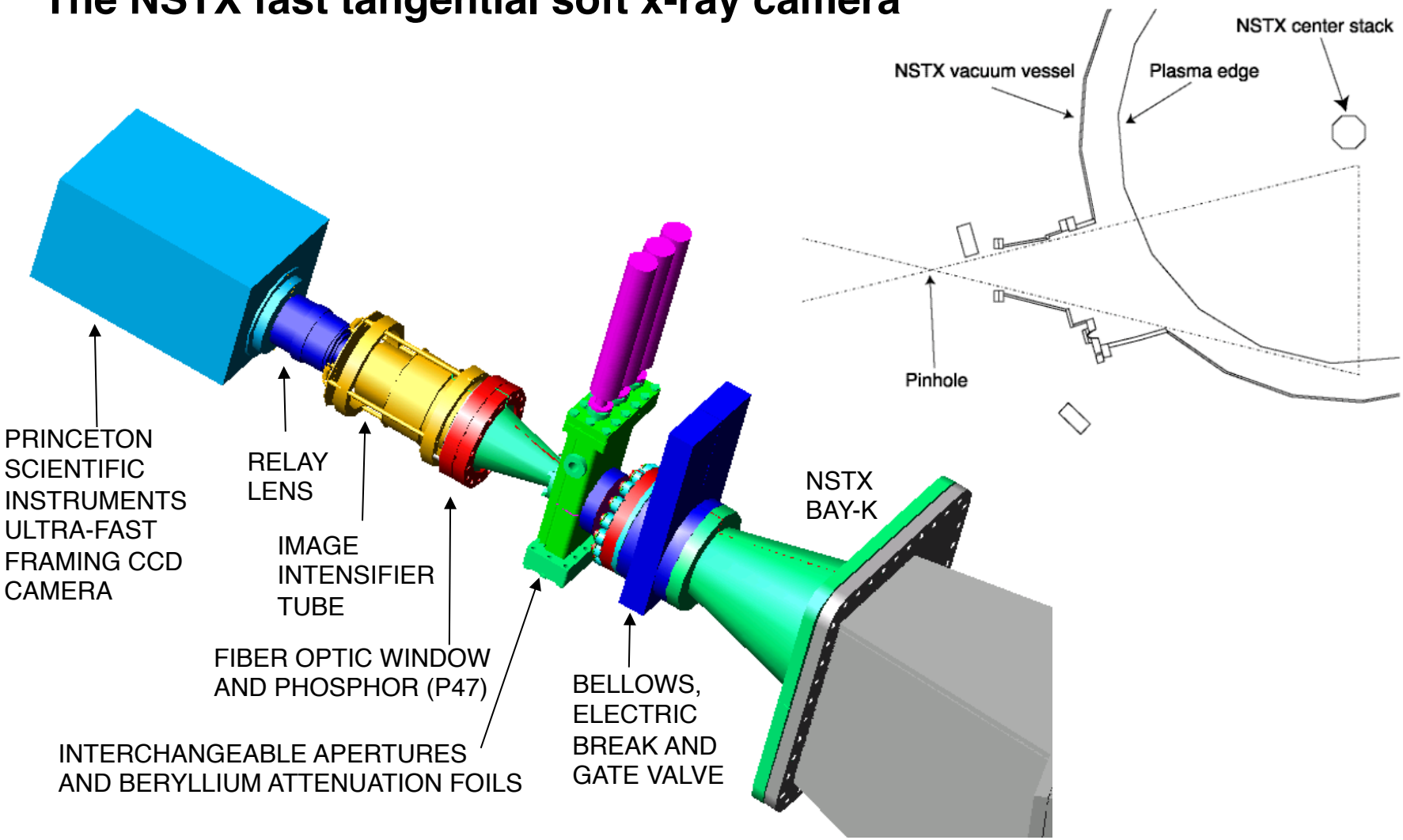
Simple model: Assume x-ray emissivity is constant along a flux surface

- Use kinetic EFIT + 1D profiles
  - $T_e(R)$ and $n_e(R)$ from Thomson scattering diagnostic
  - n_{CARBON} from CHERS – assume all other impurities are negligible
  - X-ray spectrum for each flux surface retrieved from database
- Calculate emissivity for wavelengths of interest
  - Plot on right shows a poloidal slice of the total emissivity for x-rays > ~ 1 keV



The simple model is benchmarked against data from the SXR camera system on NSTX

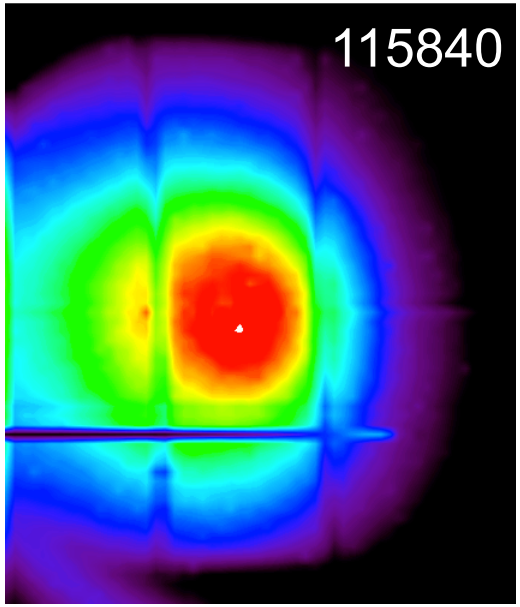
The NSTX fast tangential soft x-ray camera

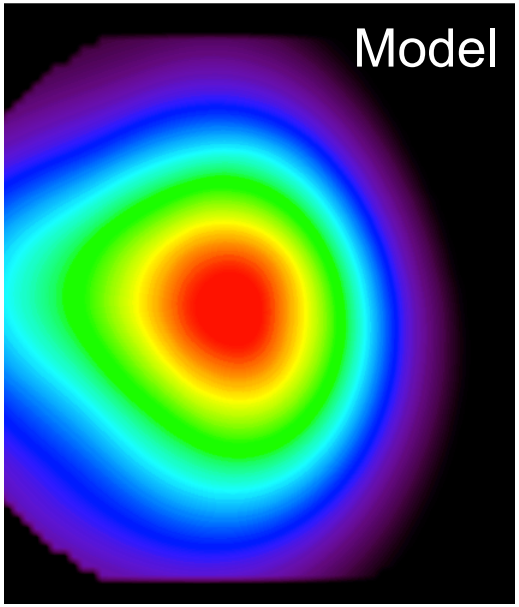


The synthetic diagnostic is in good agreement with experimental data

Comparison of CCD image and model (same color scale)

NSTX
L-mode 900 kA
3 mm pinhole
20 kHz fps
7.6 μm Be filter





- Pencil-ray approximation used for line integrals
- Good agreement provides confidence that the model can be used as a tool for testing diagnostic designs

Perturbation to T_e, n_e and n_i from 3D fields is estimated using two different methods

1) EMC3-EIRENE
   - Full transport calculations in 3D magnetic geometry
   - Currently unable to simulate transport barrier
   - Requires a large effort to run

2) TRIP3D + 1D profiles
   - TRIP3D calculates $\psi_N(R,z,\phi)$ in presence of perturbation field
   - Does not include plasma effects (i.e., vacuum field calculation)
   - Profiles mapped to EFIT solution to get $T_e(\psi)$, $n_e(\psi)$, and $n_i(\psi)$, which are then mapped to ψ_N from TRIP3D
   - Incorporates transport barrier via the 1D profiles
   - Method assumes $\chi_{par} >> \chi_{perp}$
   - The code is relatively easy to setup and run

Method 1: EMC3-EIRENE calculates the self-consistent 3D T_e and n_e in the presence of RMPs

- Self-consistent 3D fluid model that includes:
  - Particle momentum
  - Parallel momentum
  - Electron and ion energy transport
  - Recycling
  - Kinetic neutral particle transport
  - Local magnetic field

- Used to model DIII-D discharge with n=3 RMP

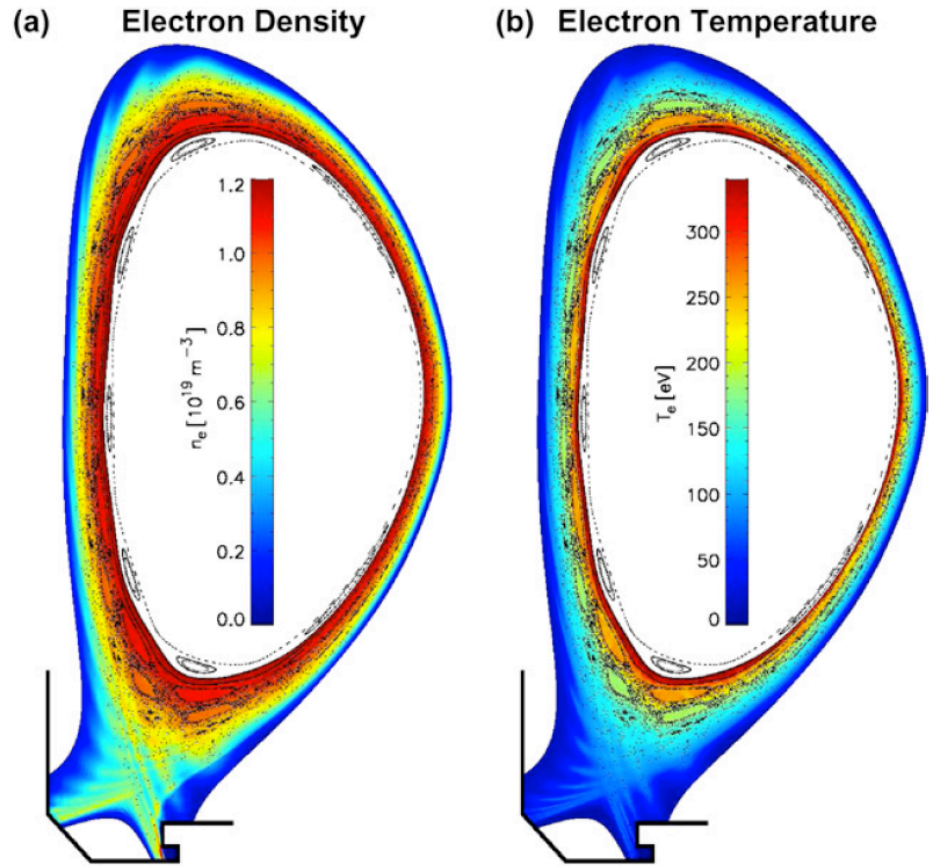
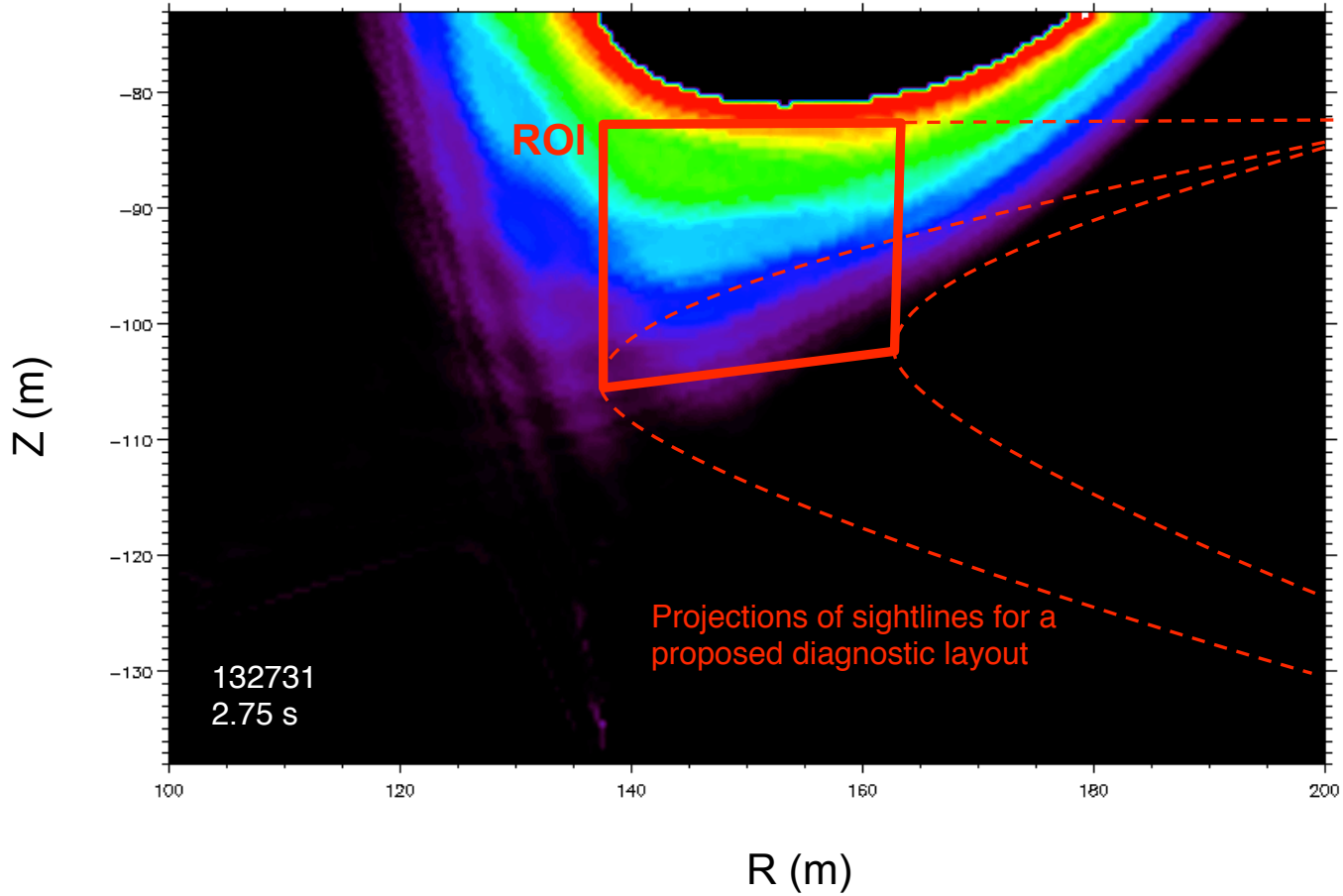


Figure 4. 2D cuts of the electron density n_e (a) and electron temperature T_e (b) at a reference plane $\varphi = 0°$ with overlaid Poincaré plots (black dots).

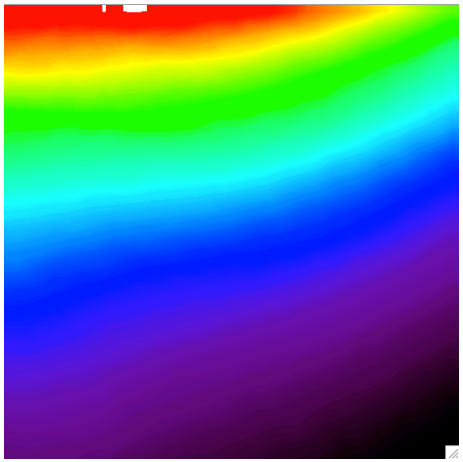
H. Frerichs, et. al., Nucl. Fusion **50** (2010) 034004

Estimated SXR emissivity near DIII-D X-point

Total X-ray emissivity
5 μm Be filter, $n_C \sim 0.02\ n_D$

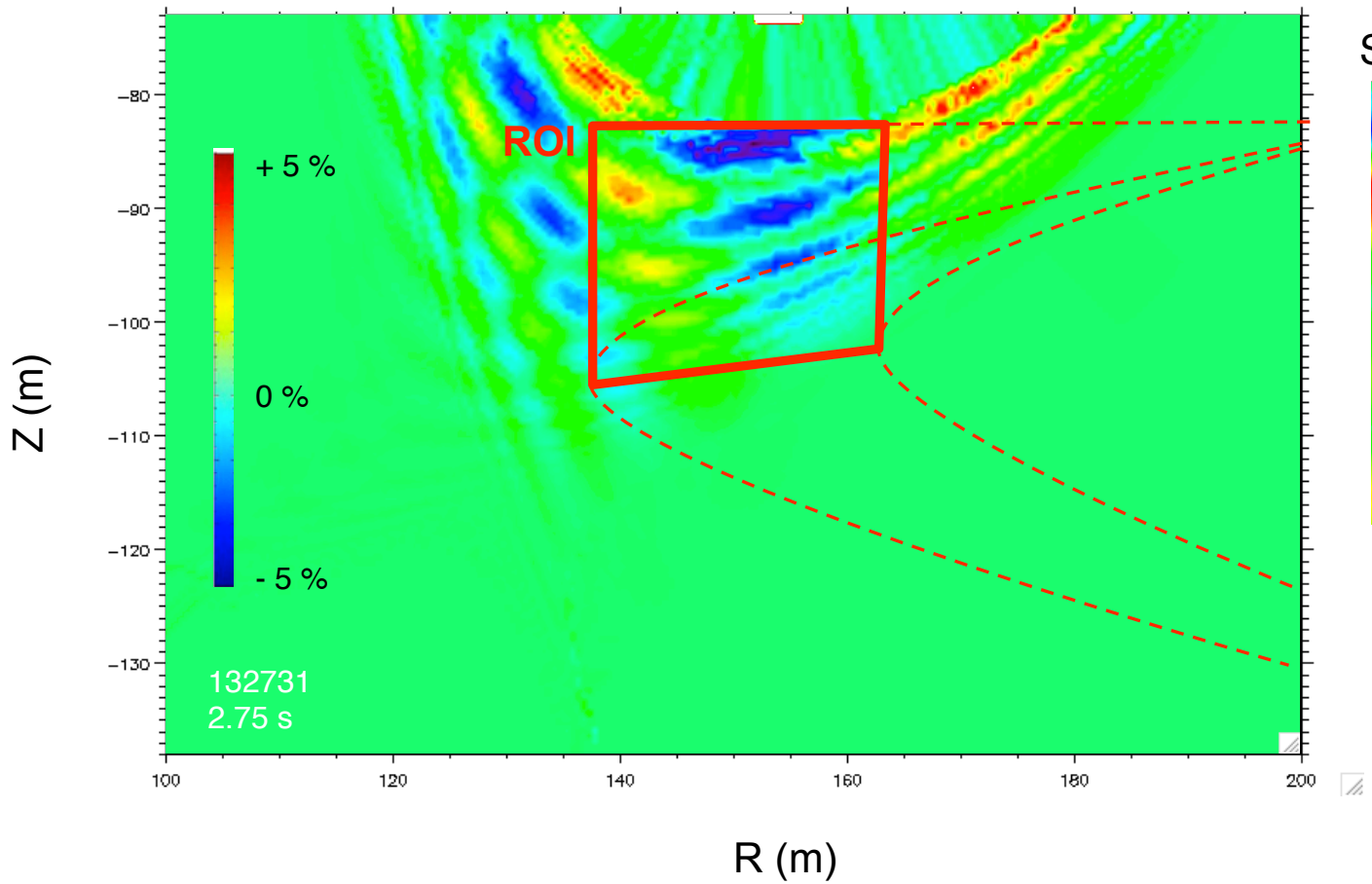


Synthetic diagnostic data

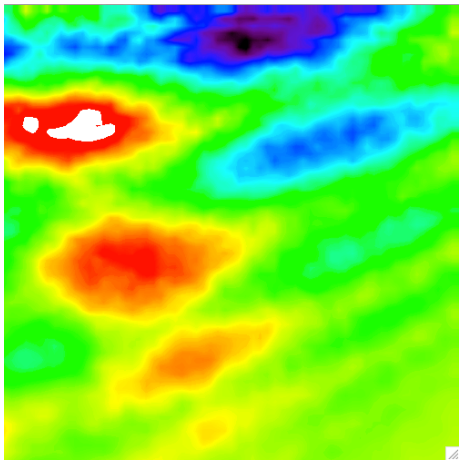


The impact of the n=3 RMP is evaluated by subtracting off the toroidal average (i.e. n = 0)

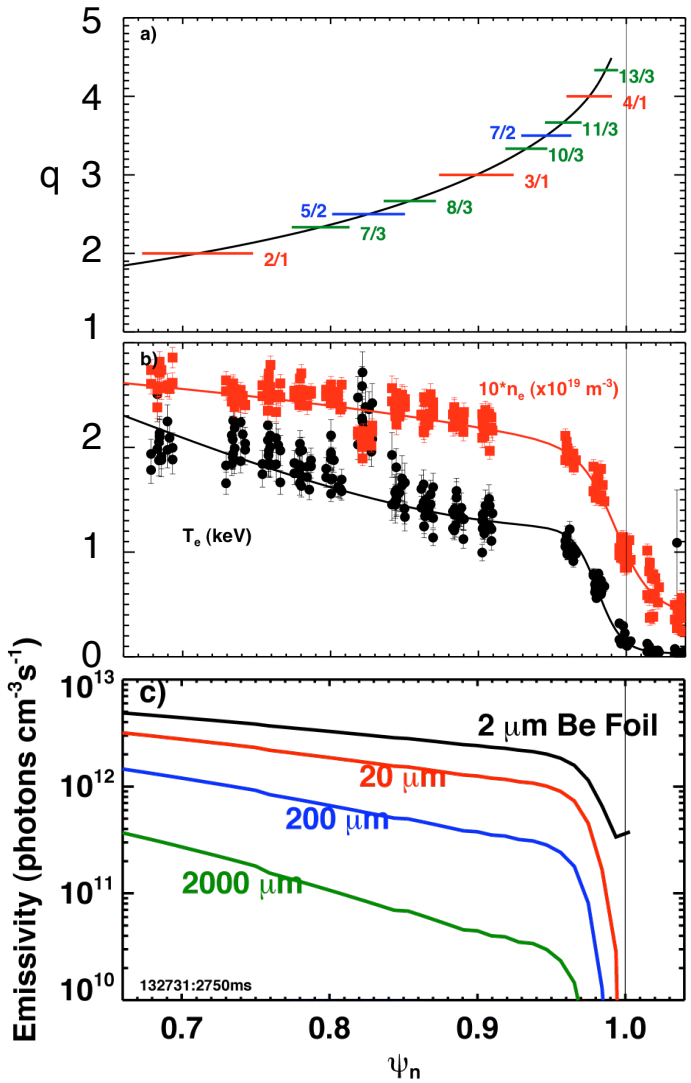
Differential X-ray emissivity: n = 3 component
5 μm Be filter, $n_C \sim 0.02\ n_D$



Synthetic diagnostic data

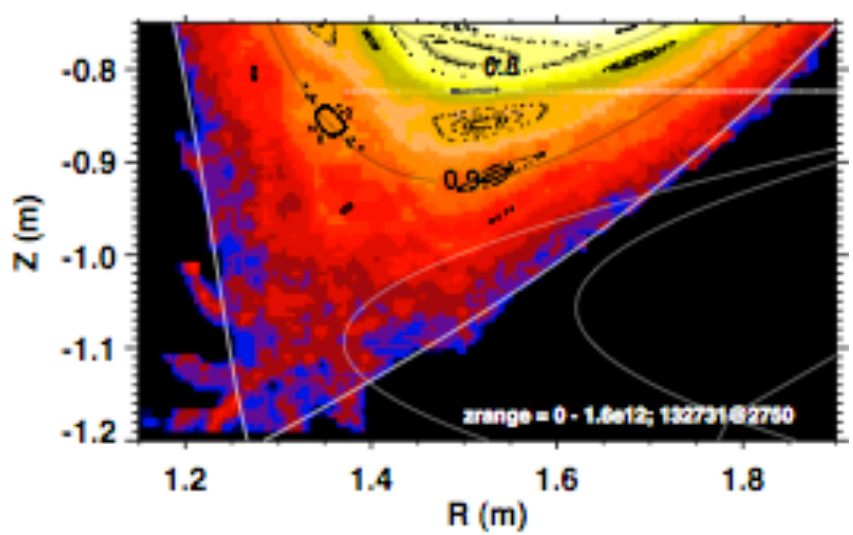


Method 2: T_e and n_e profiles are mapped to 3D ψ_N calculated using TRIP3D



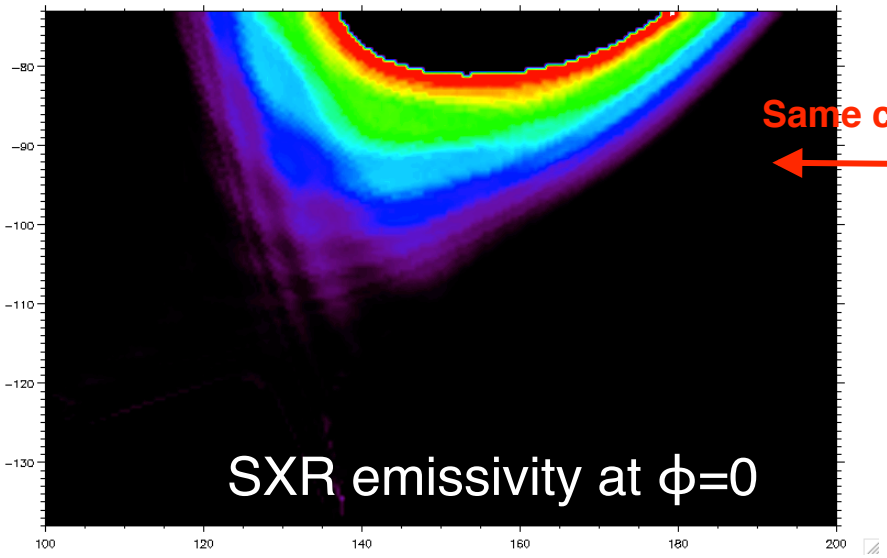
- Midplane profiles: tanh fit of TS data
- TRIP3D computes field line trajectory
  - Up to 200 transits in each direction
  - Assume ε set by starting point of field line

ψ_N with Poincare Plot overlaid



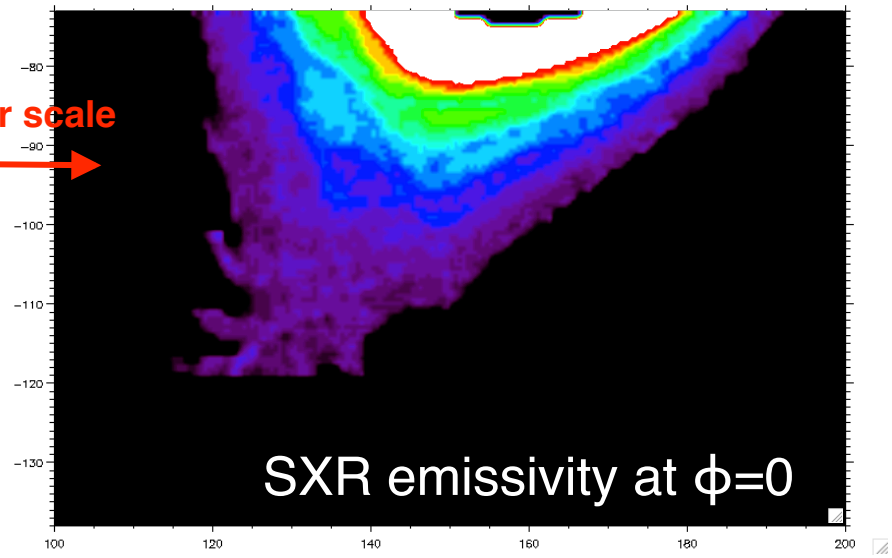
Method 3 is an adequate approximation for the full transport calculation using EMC3-EIRENE

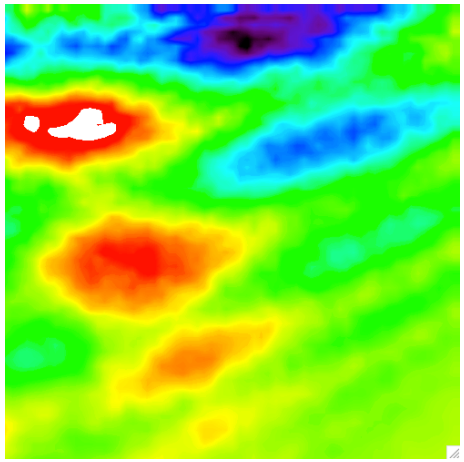
Method 2: EMC3-EIRENE



Same color scale

Method 3: TRIP3D

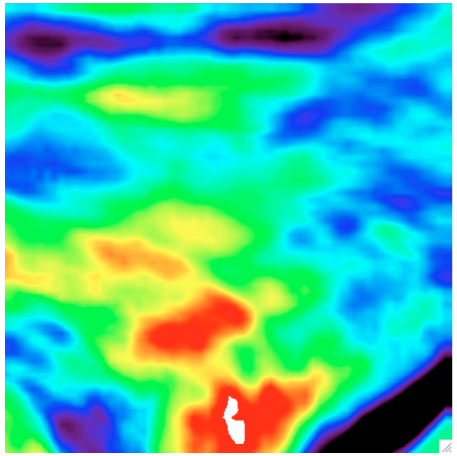




n=3 component

Same color scale

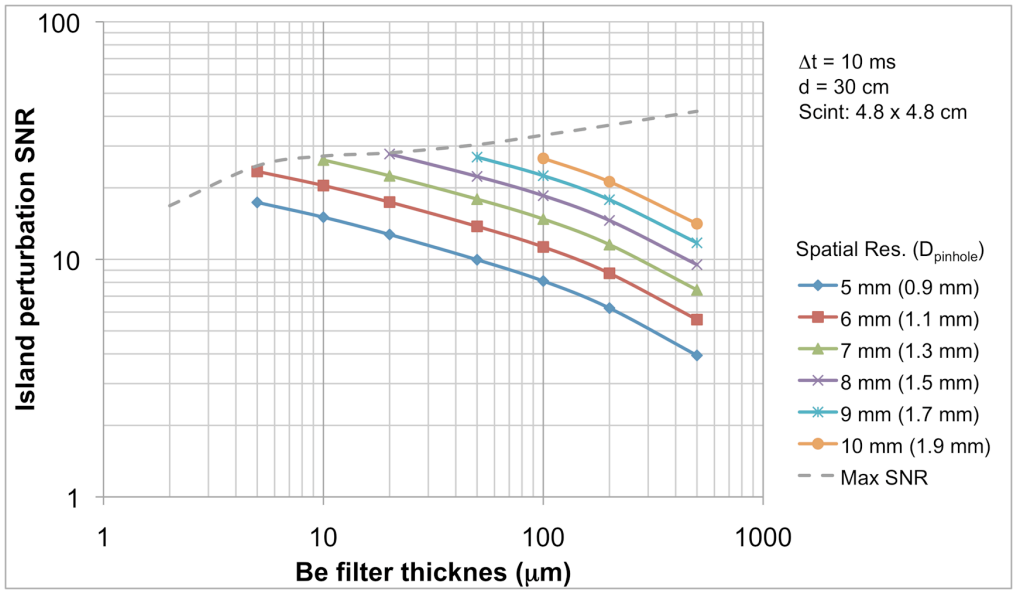
Midplane profiles for T_e and n_e matched for the two calculations



n=3 component

A conceptual design for SXR cameras on DIII-D and NSTX is presently underway

- The model is run for different views, plasma conditions and 3D perturbation field strength

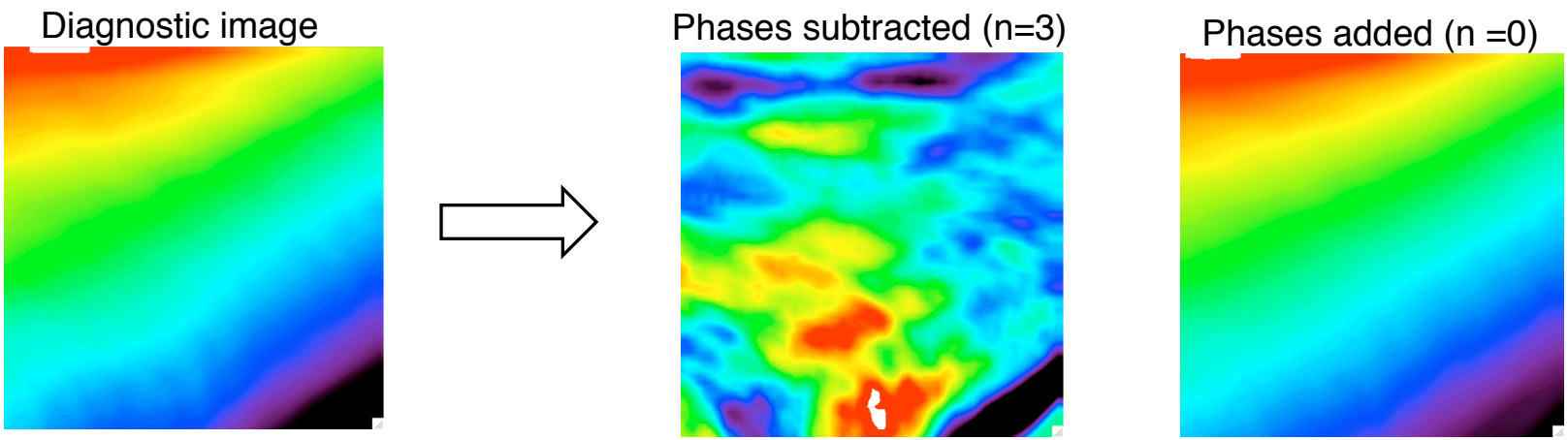


- The results guide the optimization of the diagnostic for detecting the edge islands

- Initial estimates suggest proposed systems could achieve sub-cm resolution with acceptable SNR

Techniques for benchmarking plasma response models are also under development

- Design experiment to oscillate phase of n=3 applied field



- Use inversions to transform diagnostic signal into island width measurements
  - One method: assume emissivity is constant along a field line with helicity *q* (S. Ohdachi, et al., Plasma Science & Tech. **8** (2006) 45)
  - Another method: assume magnetic structure is a superposition of n=3 island chains that flatten the local T_e and n_e (J. Menard, et al., Nuclear Fusion **45** (2006) 539)

Summary

- A complete physics model for ELM stability modification using 3D magnetic perturbations requires a description of the plasma response to the external fields

- SXR imaging of the predicted edge island structure would provide a benchmark for plasma response models
  - A coordinated effort on DIII-D and NSTX aims to implement similar diagnostics in order to test the models over a range of plasma parameters

- A SXR emission model was built to demonstrate the feasibility of the measurement and optimize the proposed diagnostic systems
  - Axisymmetric calculations were benchmarked against existing SXR imaging data from NSTX
  - The effect of the 3D fields on the local SXR emissivity was simulated using two methods: a full transport model (EMC3-EIRENE) and a vacuum perturbation model (TRIP3D)

Update on other work at NSTX (page 1)

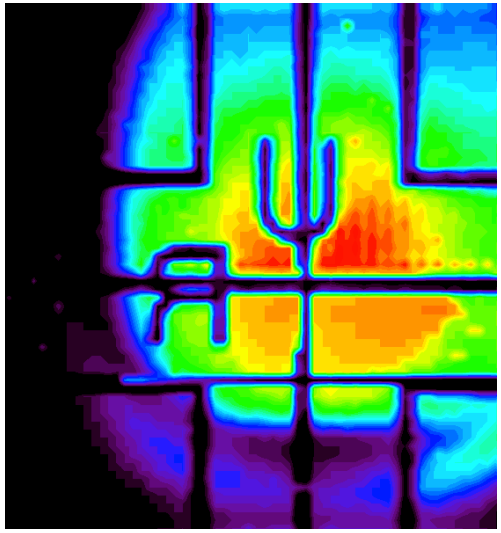
- LH transition studies
  - Will lead 1 day experiment to measure differences in turbulence and power thresholds in D and He plasmas near the LH transition
  - Working to quantify impact of low recycling walls on LH transition
    - Can the change in P_{LH} be correlated to the edge neutral density, T_e or n_e profiles, edge rotation, etc?

- Edge neutral density measurement
  - Resurrected D_β diagnostic (CCD camera system)
  - Supports LH studies and TRANSP calculations
  - Proposal for a summer undergraduate to develop inversion and analysis codes was accepted

- ELM suppression on NSTX
  - 1/2 day experiment to apply “off-midplane” 3D fields on NSTX

Update on other work at NSTX (page 2)

- Operate 2D SXR camera
  - Resurrected 2D SXR camera and software
  - Goals:
    - Demonstrate measurement and analysis techniques for future edge imaging device
    - Contribute to core MHD, LH transition, disruption, ELM studies



- SOLPS calculations
  - Investigate impact of low-recycling walls for NSTX and LTX

- NSTX Physics Operator
  - In charge of discharge development via PCS
  - Four new physics operators (3 PPPL postdocs + me)
  - Already put in two solo sessions