# Edge Soft X-Ray Imaging Measurements of 3D Plasma Response to Resonant Magnetic Perturbations

by
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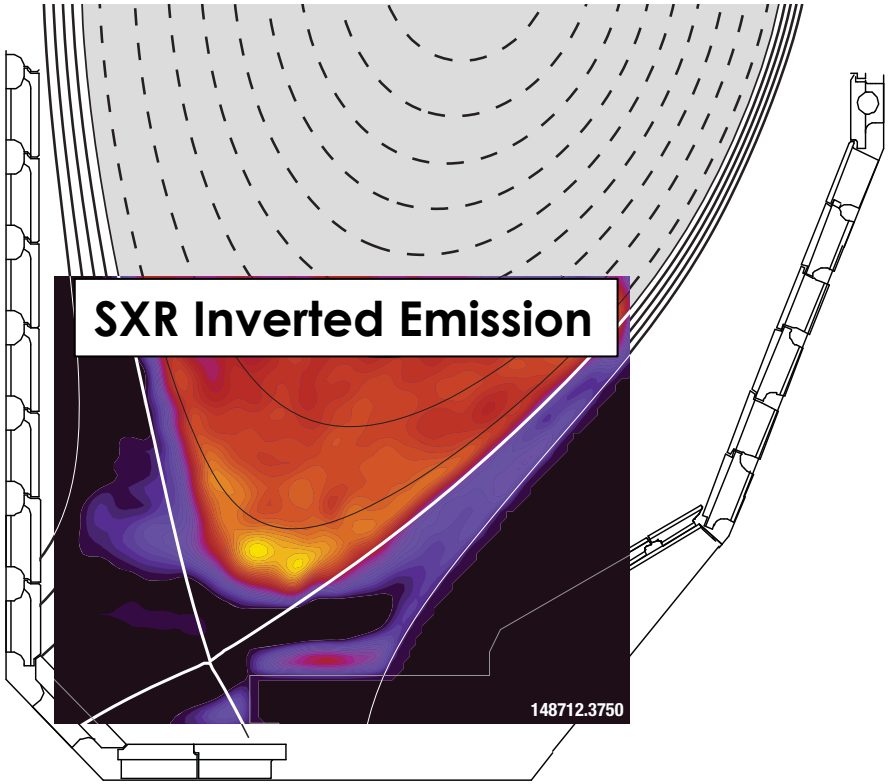
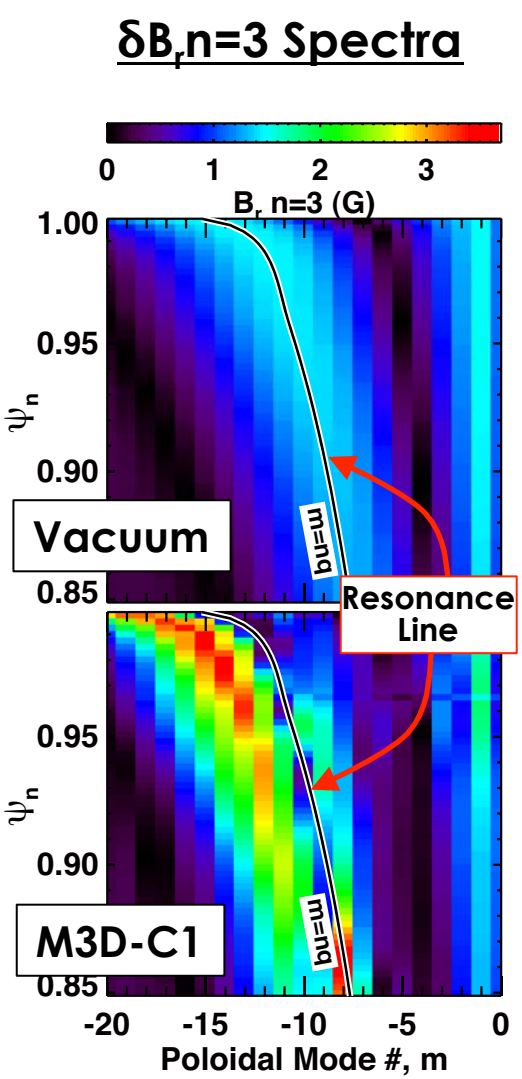
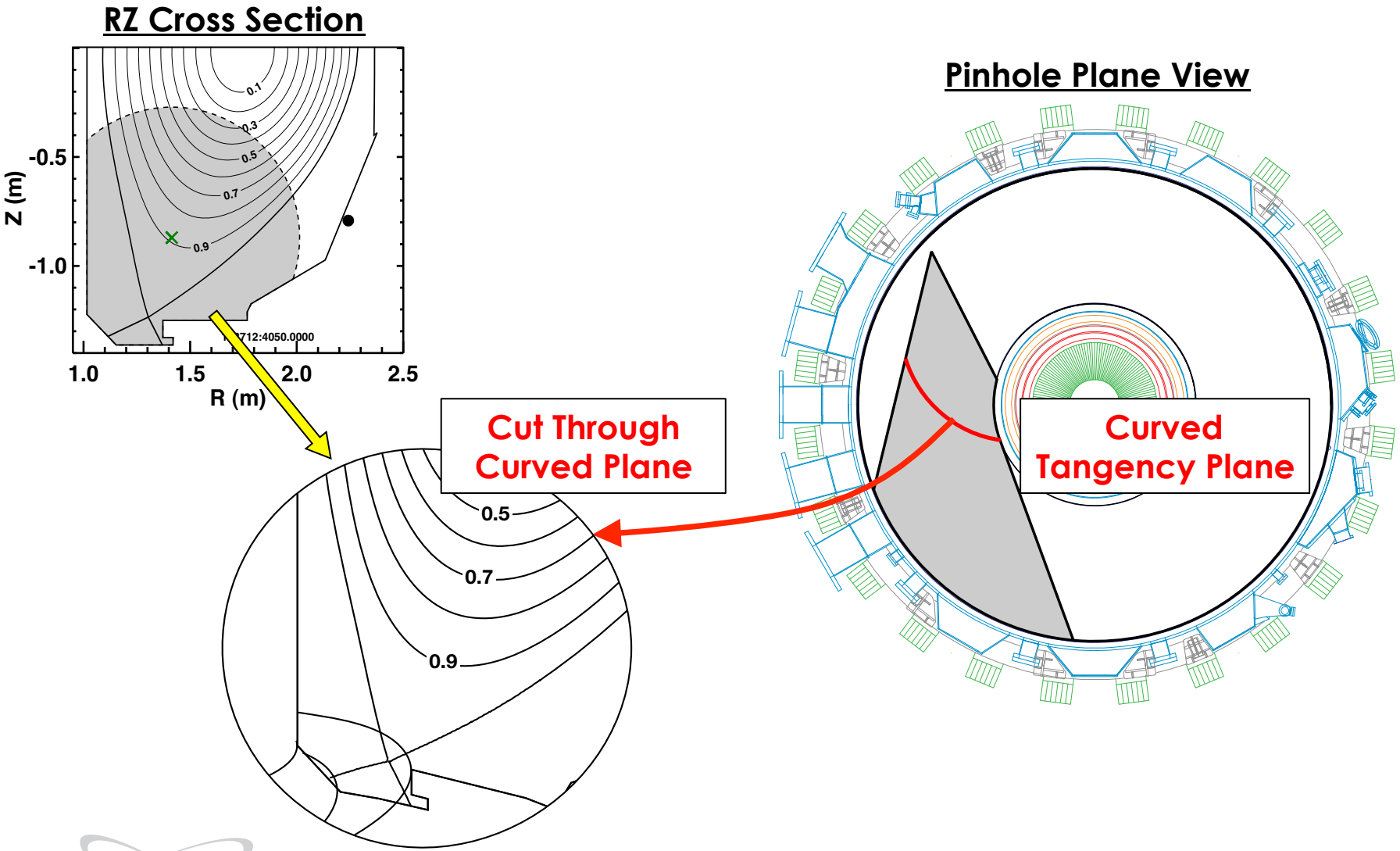


# Motivation/Outline: Measuring Plasma Response to 3D Fields

- **Models predict varying responses:**
  - Vacuum (TRIP3D): stochastic layer/ split manifolds
  - Two-fluid resistive MHD (M3D-C1): partial resonant screening + non-resonant amplification, key: $\omega_{e,\perp}$
- **New diagnostic: Tangential pinhole SXR Camera near X-point**
  - Energy filters allows for radial discrimination
- **Forward modeling with synthetic diagnostic used to compare models to data**
  - Lobes extending from the unperturbed separatrix at plasma boundary agrees well with vacuum
  - Helical displacements in the steep-gradient region inside the unperturbed separatrix: better agreement with M3D-C1



# Pinhole SXR Camera Exploits Flux Expansion at X-Point

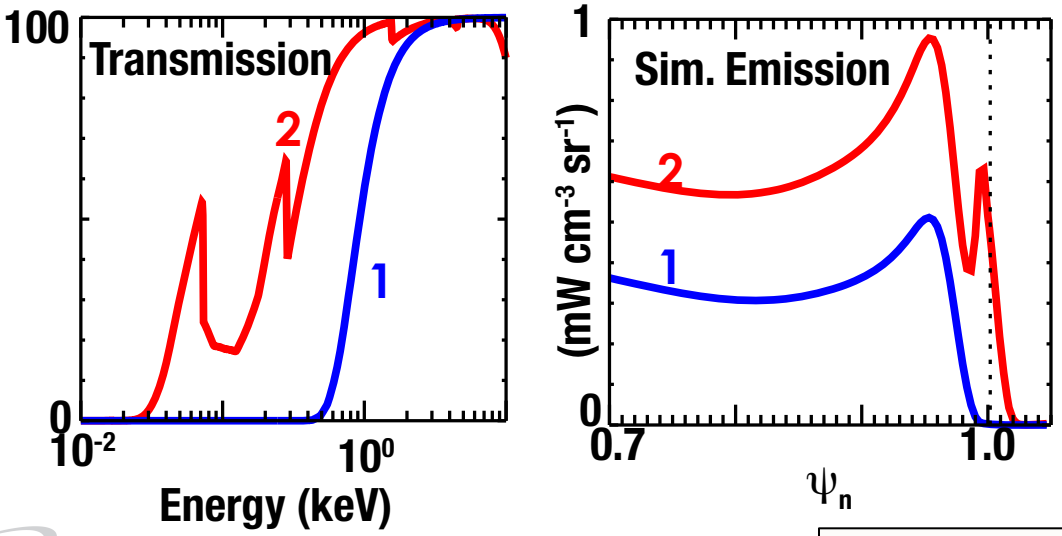


# Different Metallic Filters Provide Radial Discrimination

**1. SXR: $E_{c,10\%}$ ~ 500 eV ➔ *steep gradient region***

**2. USXR: $E_{c,10\%}$ ~ 40eV ➔ extended to *Edge/SOL***

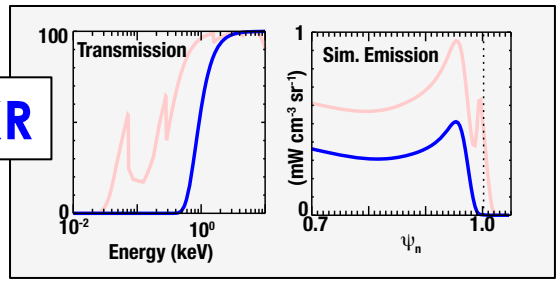
- **CHIANTI* astro code simulates spectrum**
  - Uses $n_e$, $T_e$, $n_z$ to model SXR/USXR profile



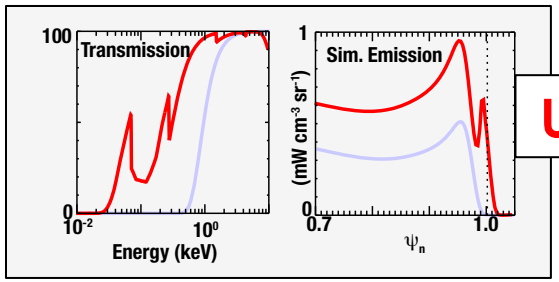

*Landi E. et al 2012 ApJ **744** 99

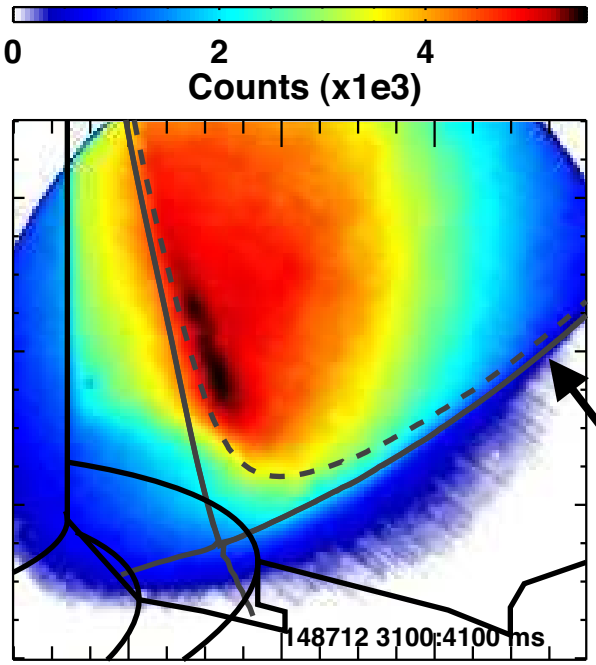
# Views with Different Filters Access Pedestal to Divertor

SXR

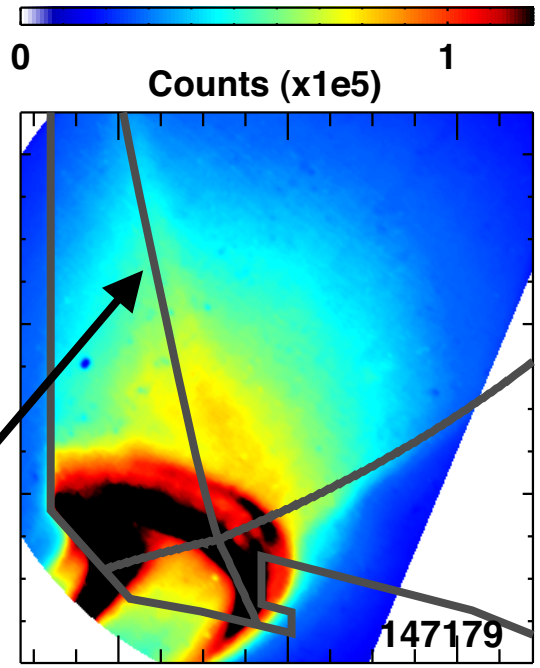



USXR



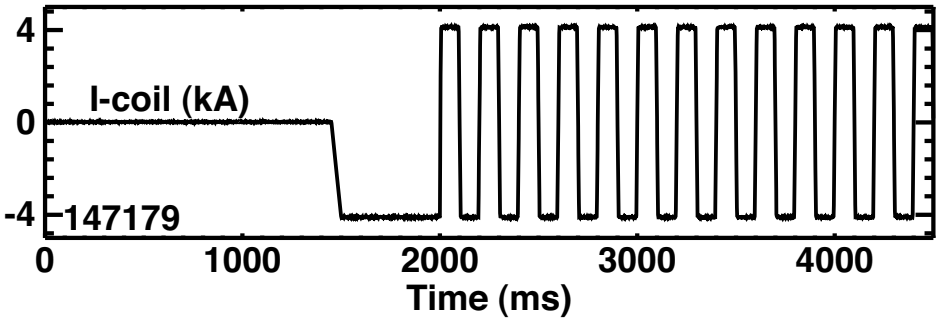

Different Scales



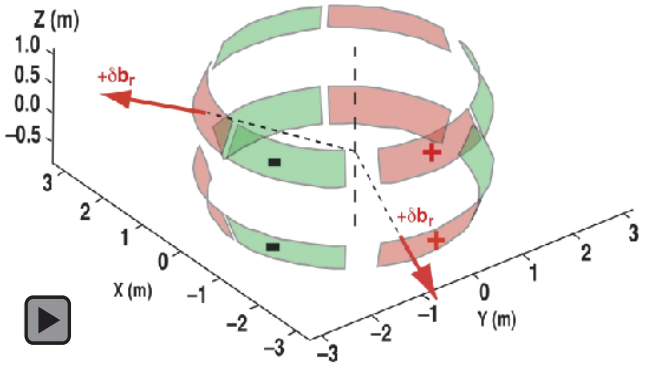

Boundaries from Curved Tangency Plane

# n=3 RMP Phase Modulation Used to Isolate Response

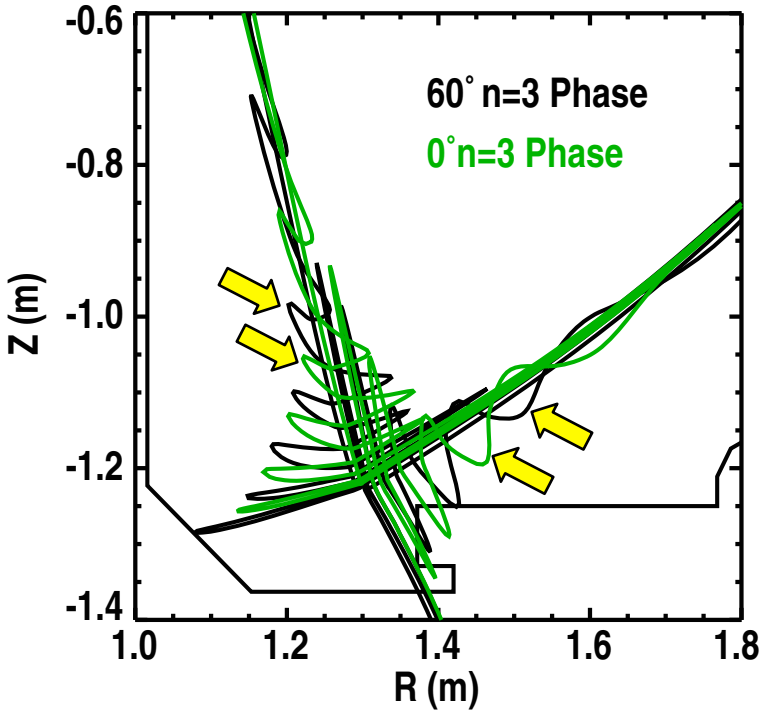
- **Standard DIII-D RMP ELM-suppression plasmas with alternating n=3 phases by 60 degrees**




**n=3 I-Coil**

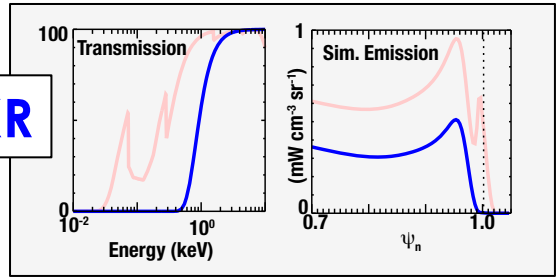



**Perturbed Separatrix**

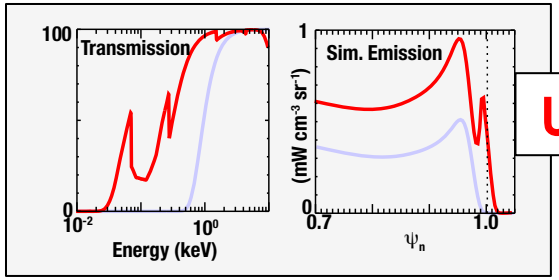


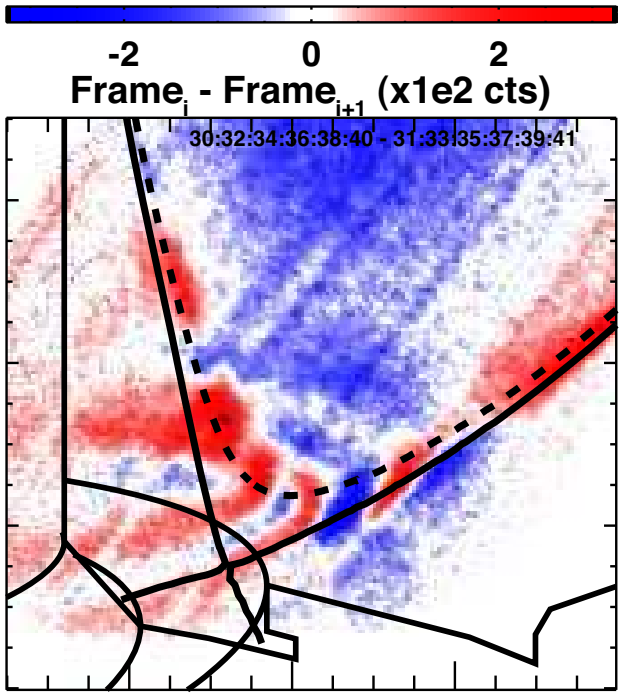
# Out-of-Phase Differential Images Isolate Response

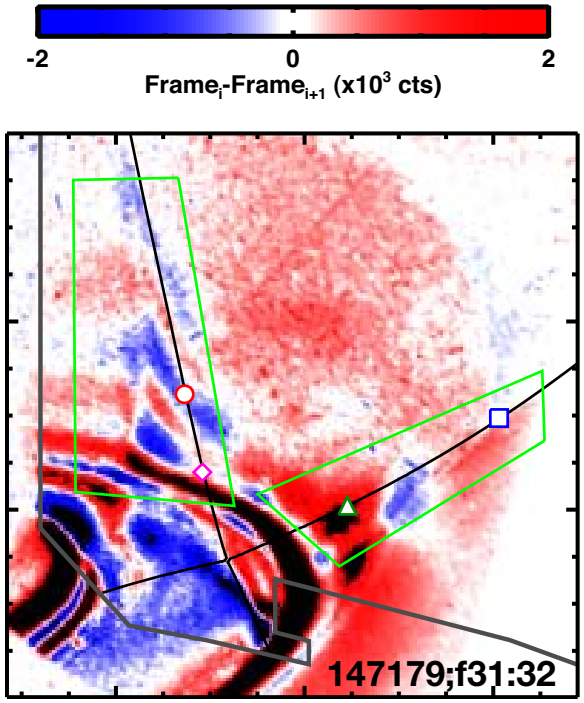
SXR




USXR



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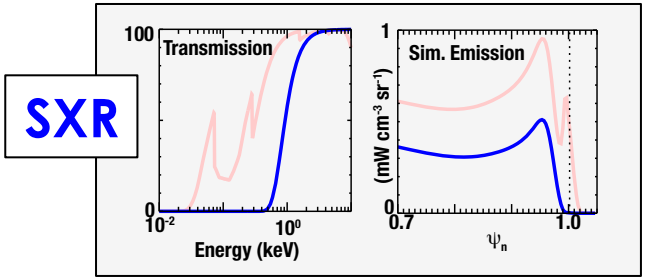


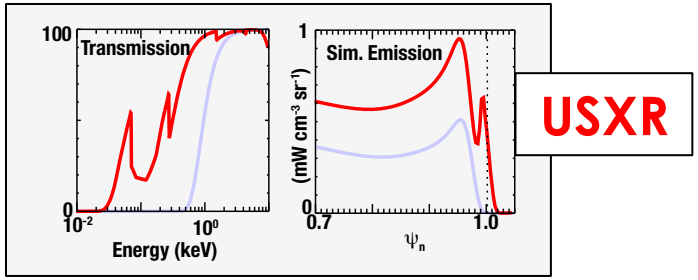


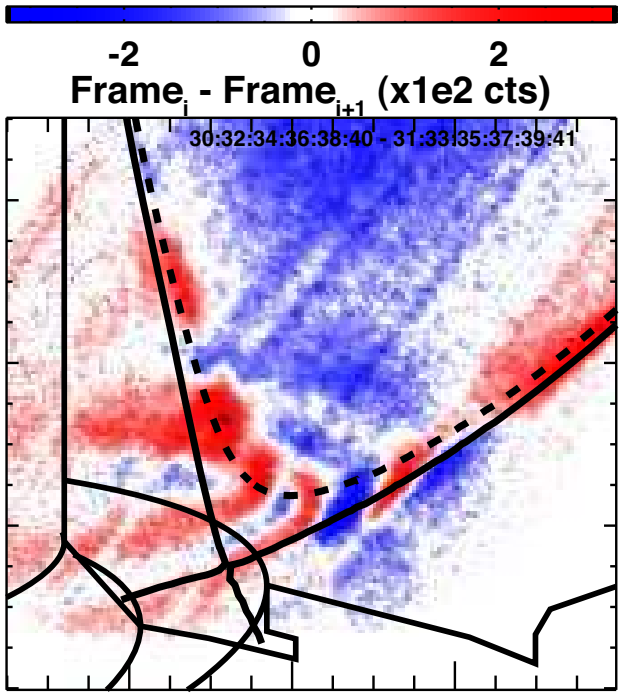


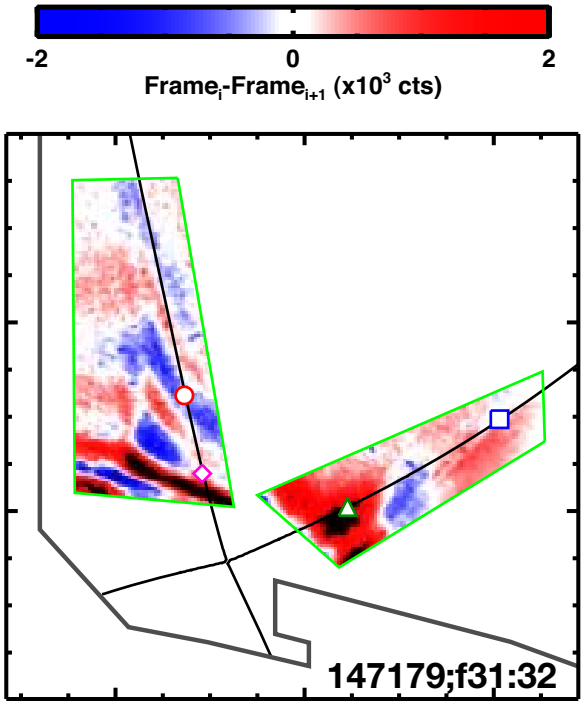

# Synthetic Diagnostic — Vacuum and Two-Fluid Resistive MHD Response Forward Modeled to SXR/USXR

- **Vacuum: TRIP3D-MAFOT**
  - Predicts: lobes / islands / stochastic regions
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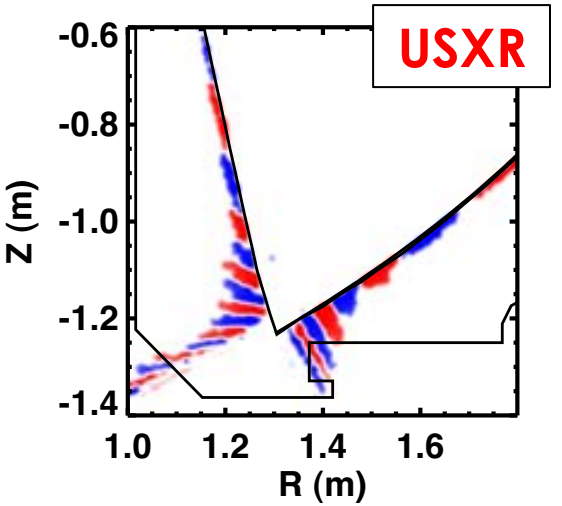
**Modeled Displacements**



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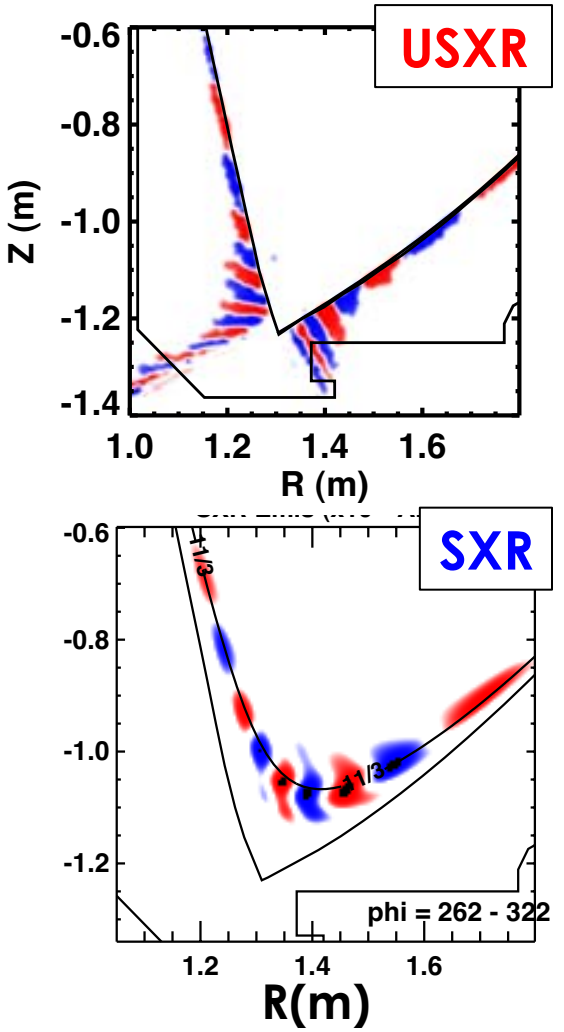
- **Two-fluid resistive linear MHD: M3D-C1**
  - Predicts: interplay of islands / kinks / screening
  - Synthetic model: Perturbed 3D fluid quantities
    - $n_e$, $T_e \Rightarrow$ 3D SXR, Apply Filter
    - Assume $n_z \sim n_e$

**Modeled Displacements**

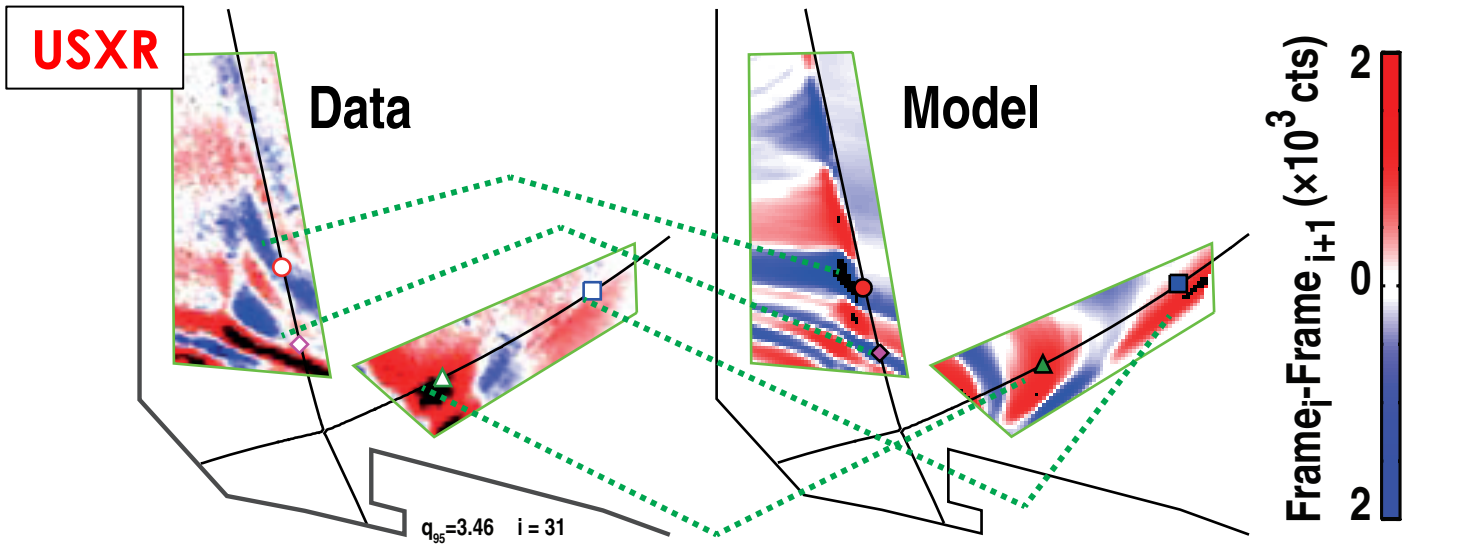


# Data/Model Comparison (USXR) — Vacuum-Predicted Lobes Observed in Data

- **Synthetic diagnostic modeling used to identify lobe structures in measurement***
  - Well matched features: gross lobe structure, line-integral effects

- **Linear M3D-C1: $T_e$ and $n_e$ still too low in lobes for USXR modeling**

## Line-Integrated Differential Images




*M.W. Shafer, Nucl. Fusion (accepted)

# Data/Model Comparison (SXR) — Measured Helical Displacements Match Well to M3D-C1 Calculations

- **Helical bands seen in both line-integrated data and modeled images**
  - High contrast results from displacement of steep gradient

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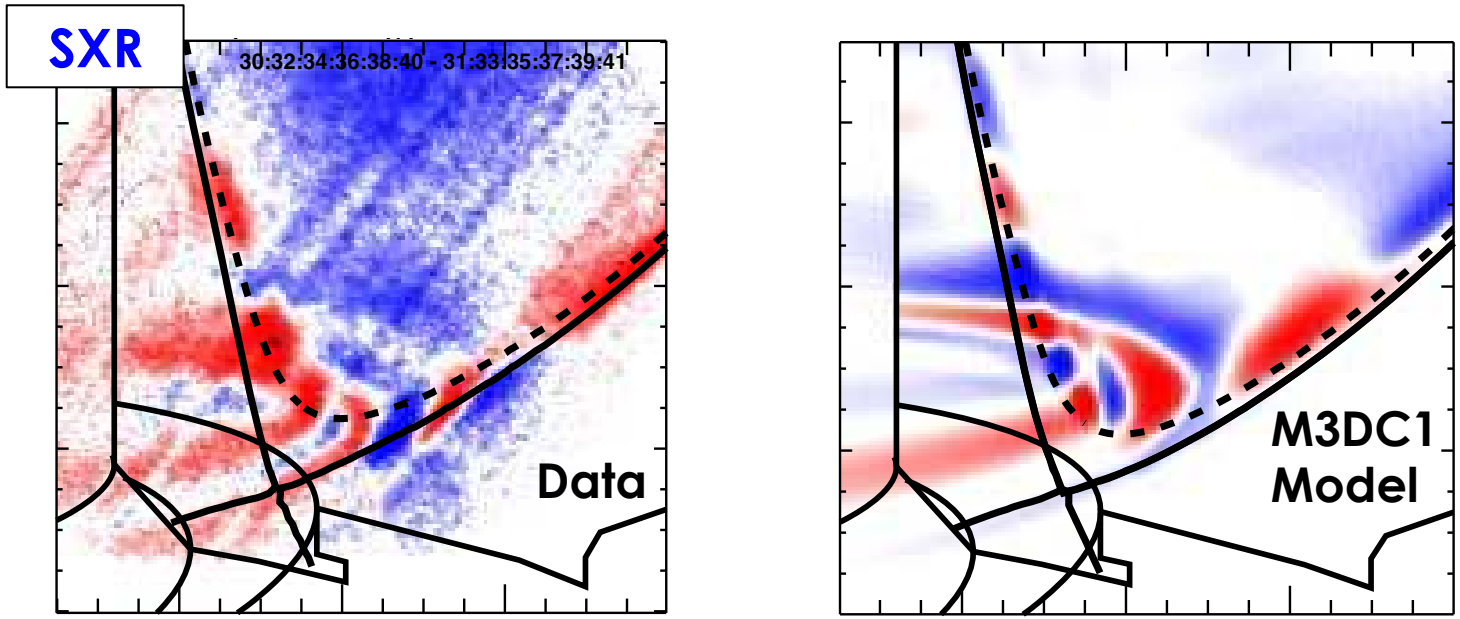

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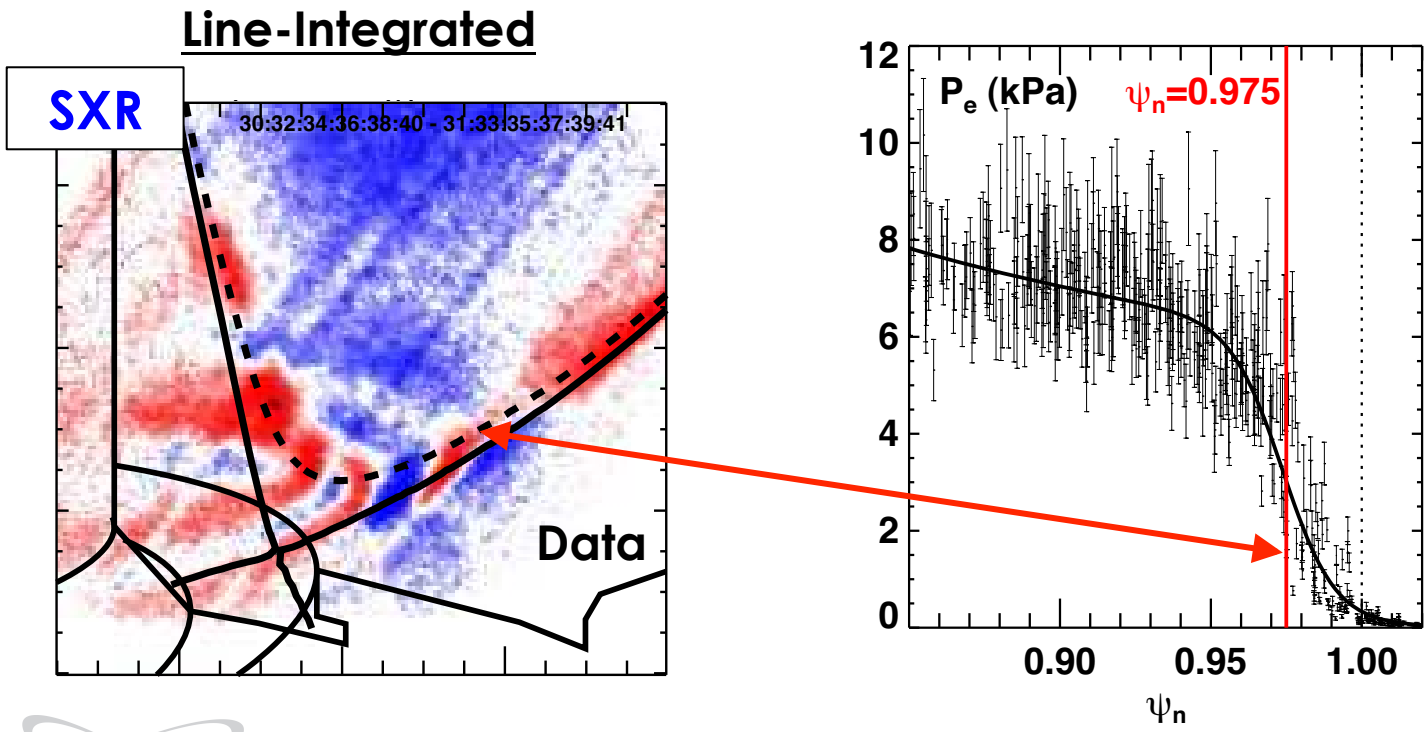
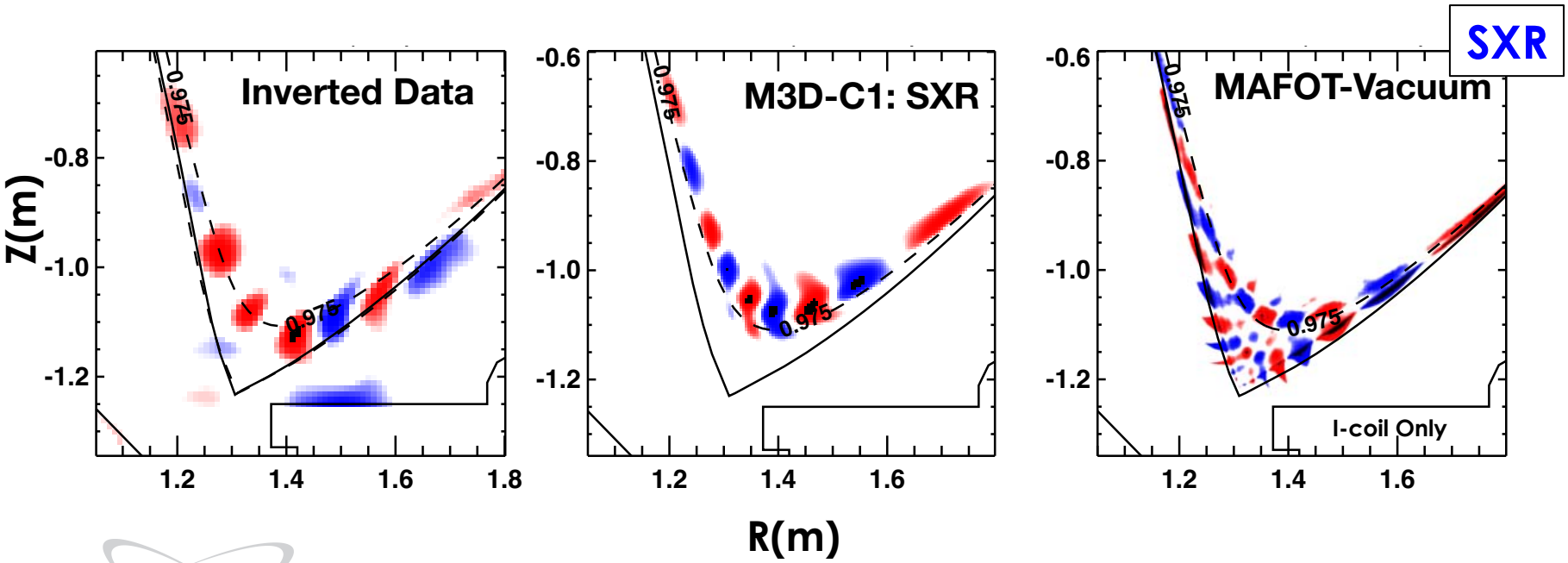


# Direct Image Inversion Used for Local Comparison

- **Inversion provides direct measure of ~5-10 cm displacements**
  - New capability (on-going testing)
- **Predicted M3D-C1 displacement has reasonable agreement**
- **Vacuum shows smaller internal structure, lobe intensity too high**



# Summary — Unique New Measurements of Plasma Response

- **Tangential Imaging of USXR and SXR provide radial discrimination of plasma response in RMP ELM-suppressed plasmas**
- **Helical displacements measured inside unperturbed separatrix**
  - Two-fluid M3D-C1 predicts strong edge perturbation consisting of partial resonant screening + non-resonant amplification with reasonable match to data
  - Vacuum indicates smaller, detailed internal structure
- **Boundary structure compare well to Vacuum-predicted lobes**
  - M3D-C1 under predicts lobe emission, may need nonlinear simulations
- **Future: Targeting pedestal top with higher energy filters**