Imaging Local Soft X-Ray Emissivity at the Plasma Edge on DIII-D: First Data

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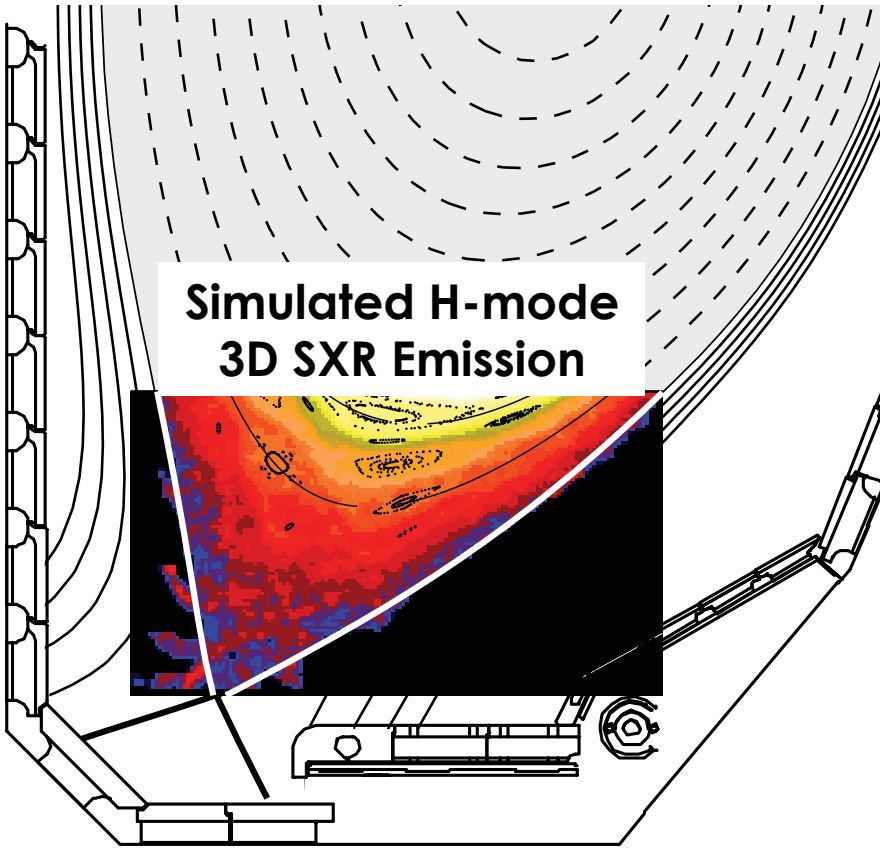


DIII-D NATIONAL FUSION FACILITY SAN DIEGO

OAK RIDGE National Laboratory

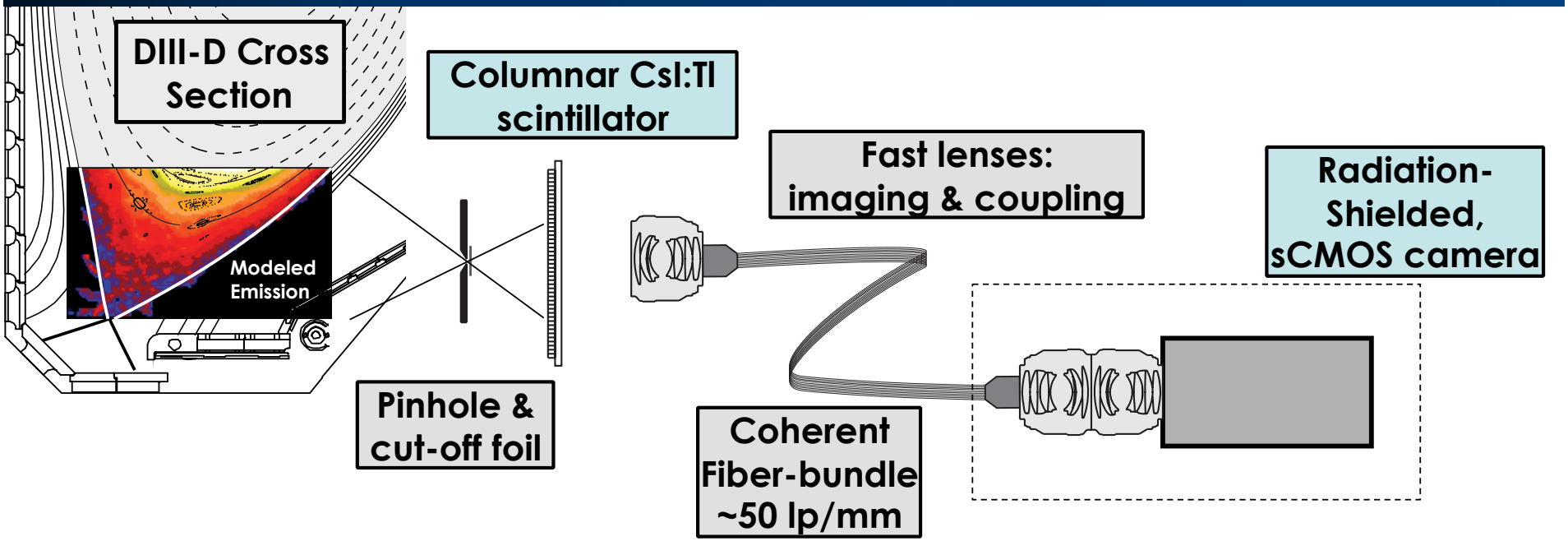
Outline; New Diagnostic with Exciting, Unique Data

- **Camera layout on the machine**
  - Filters & the implication to the data
  - Synthetic diagnostic modeling & Image processing

- **Boundary perturbations due to the RMP**
  - Data shows 'lobe' structure outside unperturbed separatrix
  - Synthetically modeled with vacuum field only models

- **3D structure inside separatrix observed (ψ_n ~ 0.97) during RMPs**
  - Structure comes and goes with Icoil perturbation
  - Model comparisons are on-going

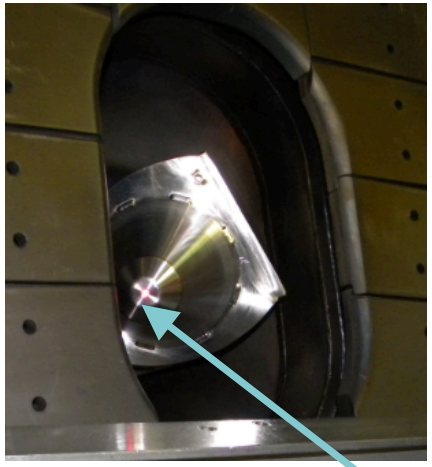
Basis of Measurement Motivated by Core Tangential SXR Systems from Many Machines: PBX-M to LHD

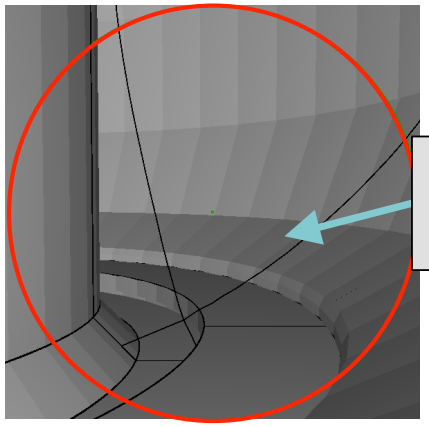


- **Similar setup used to image core islands***
- **Here, adapted to X-point region of diverted H-Mode**
  - Flux expansion ~ 10:1
- **Columnar CsI:Tl ⇒ 35 ph/keV X-ray, ~15 lp/mm, linear energy resp.**
- **Camera: 16-bit sCMOS** New technology

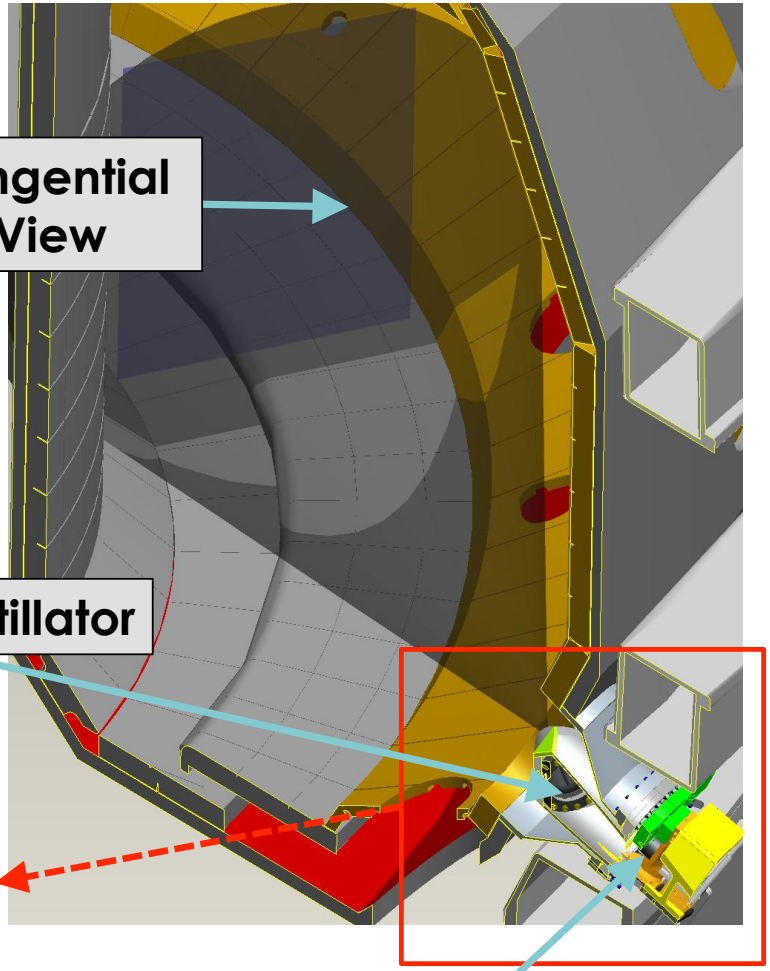
*Ohdachi, et al. Plasma Science Tech. (2006)

X-Point SXR Camera Fully Implemented During 2011 Run Campaign



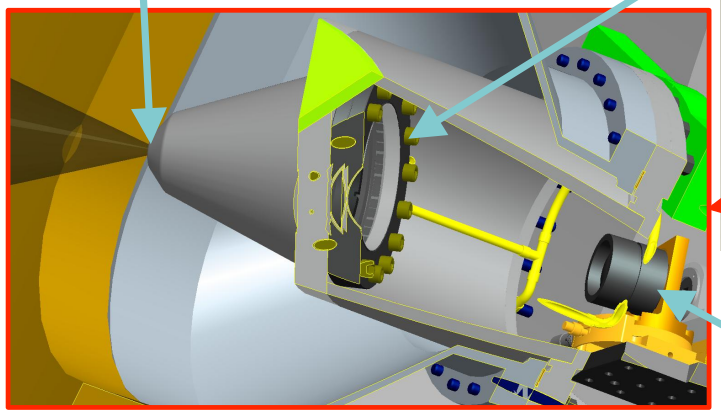


Tangential View



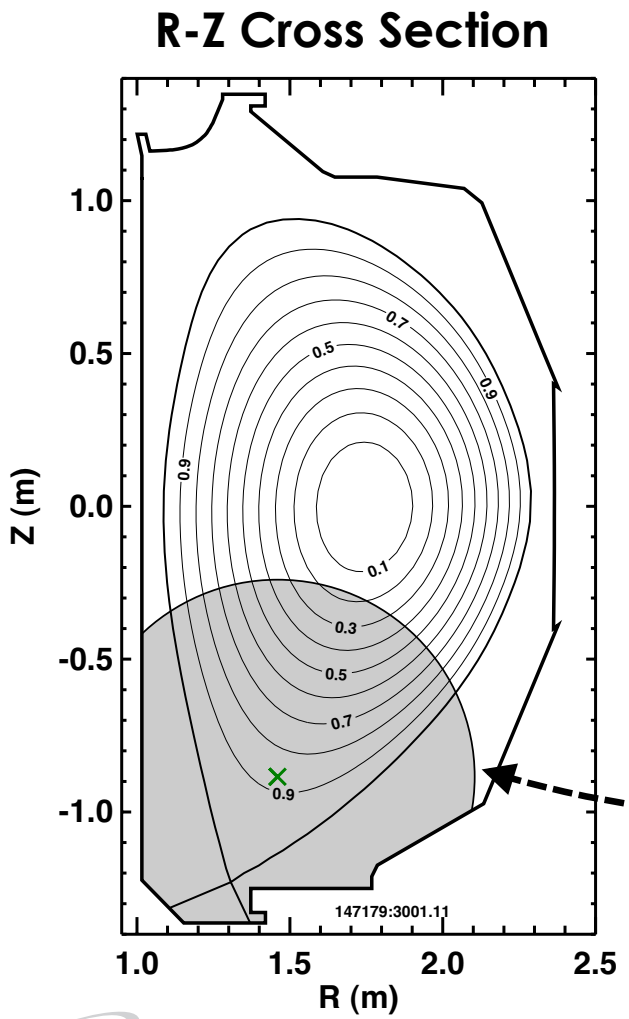
Pinhole & Foil

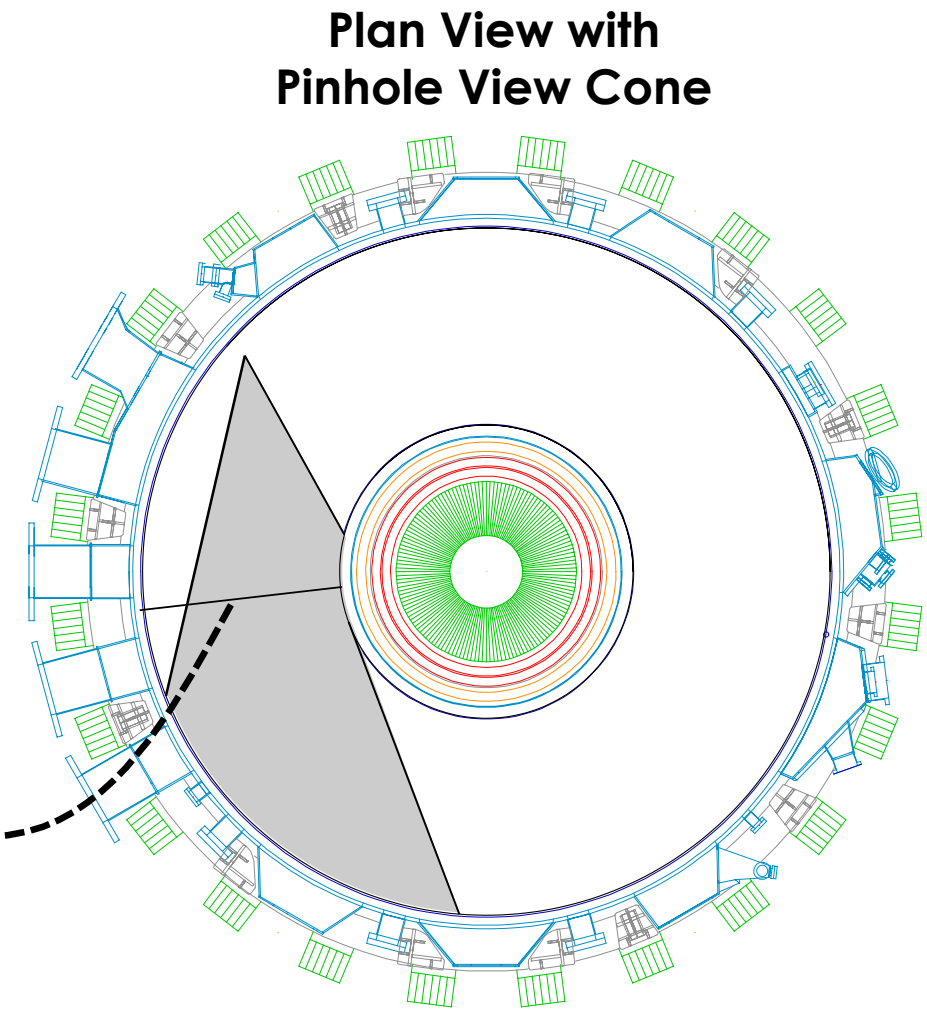
CsI:Tl Scintillator



Imaging Optics

Camera View Centered above X-Point to Exploit 10:1 Flux Expansion





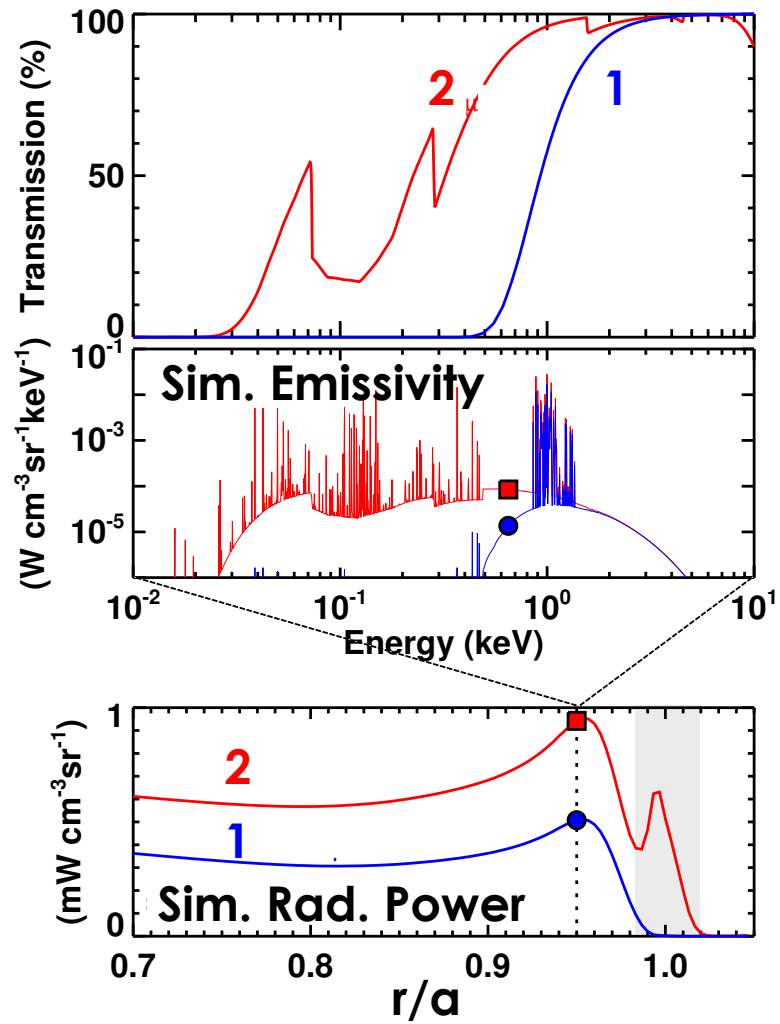
Two Different Metallic Filters Used to Radially Localize Response: SXR to USXR

1. **Beryllium (5 μ m): SXR**
   - $E_{c,10\%}$ ~ 600 eV
   - Around *steep gradient region*

2. **Al-coated (0.05 μ m) Parylene-N (0.1 μ m): USXR (SXR + EUV)**
   - $E_{c,10\%}$ ~ 40 eV
   - Extend into the *separatrix/scrape-off-layer*

- **CHIANTI* astro code simulates spectrum**
  - Continuum, line-emission
  - Uses $n_e(r/a)$, $T_e(r/a)$, $n_z(r/a)$

Filter Transmission & Spectra



*E. Landi et al., Ap.J., (2012)

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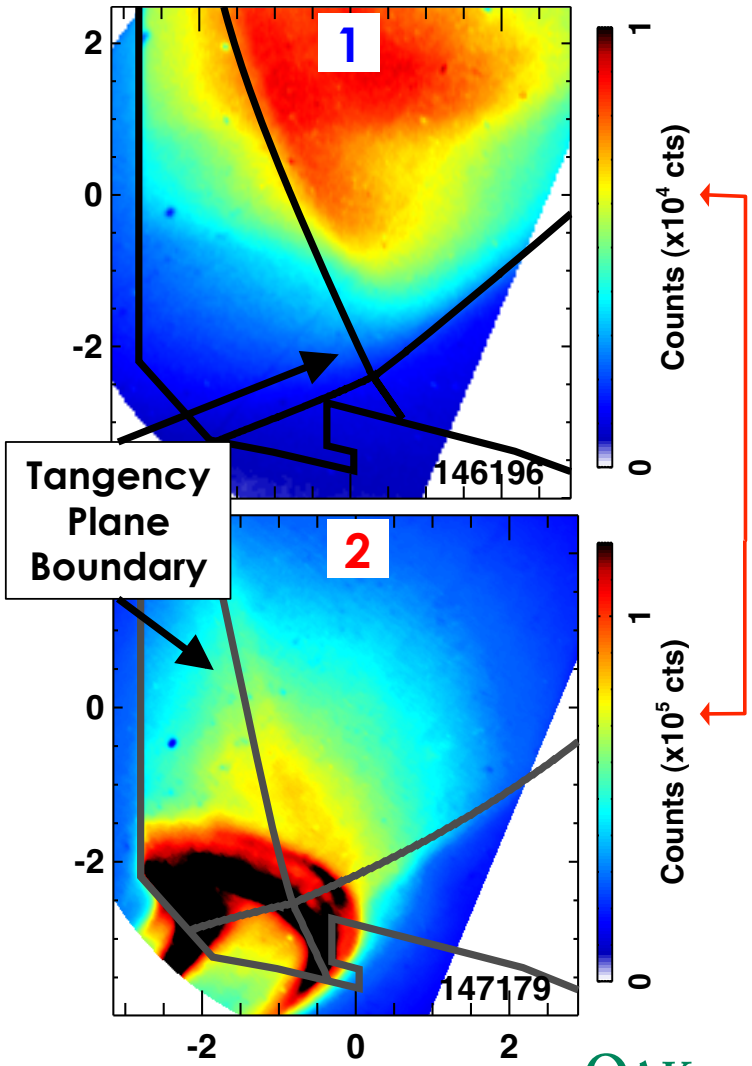
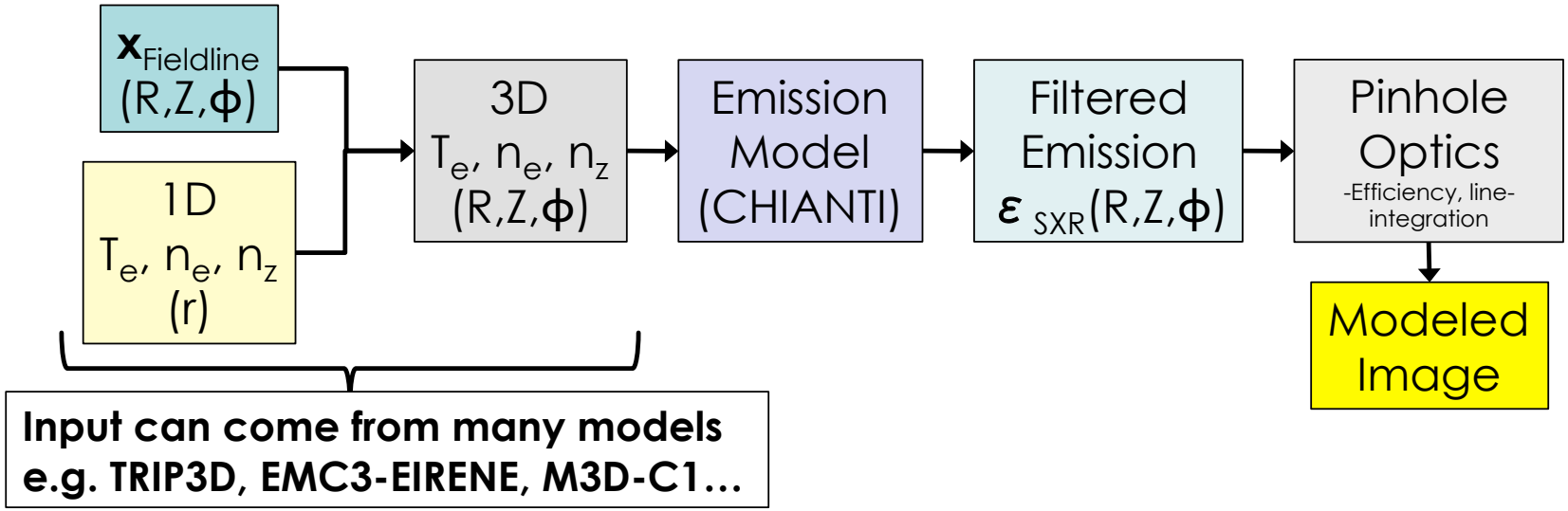
Typical Images



*E. Landi et al., Ap.J., (2012)

Modeling with Synthetic Diagnostic A Key to Analyzing Measurement



- **Synthetic diagnostic model:**
  - 1D profiles via diagnostics (e.g. Thomson Scattering, CER, etc.)
  - CHIANTI X-ray model
  - Constant emission along field lines – traced in 3D
  - Apply geometric affects
- **Major component of work to-date: Shafer's HTPD 2012 invited talk**

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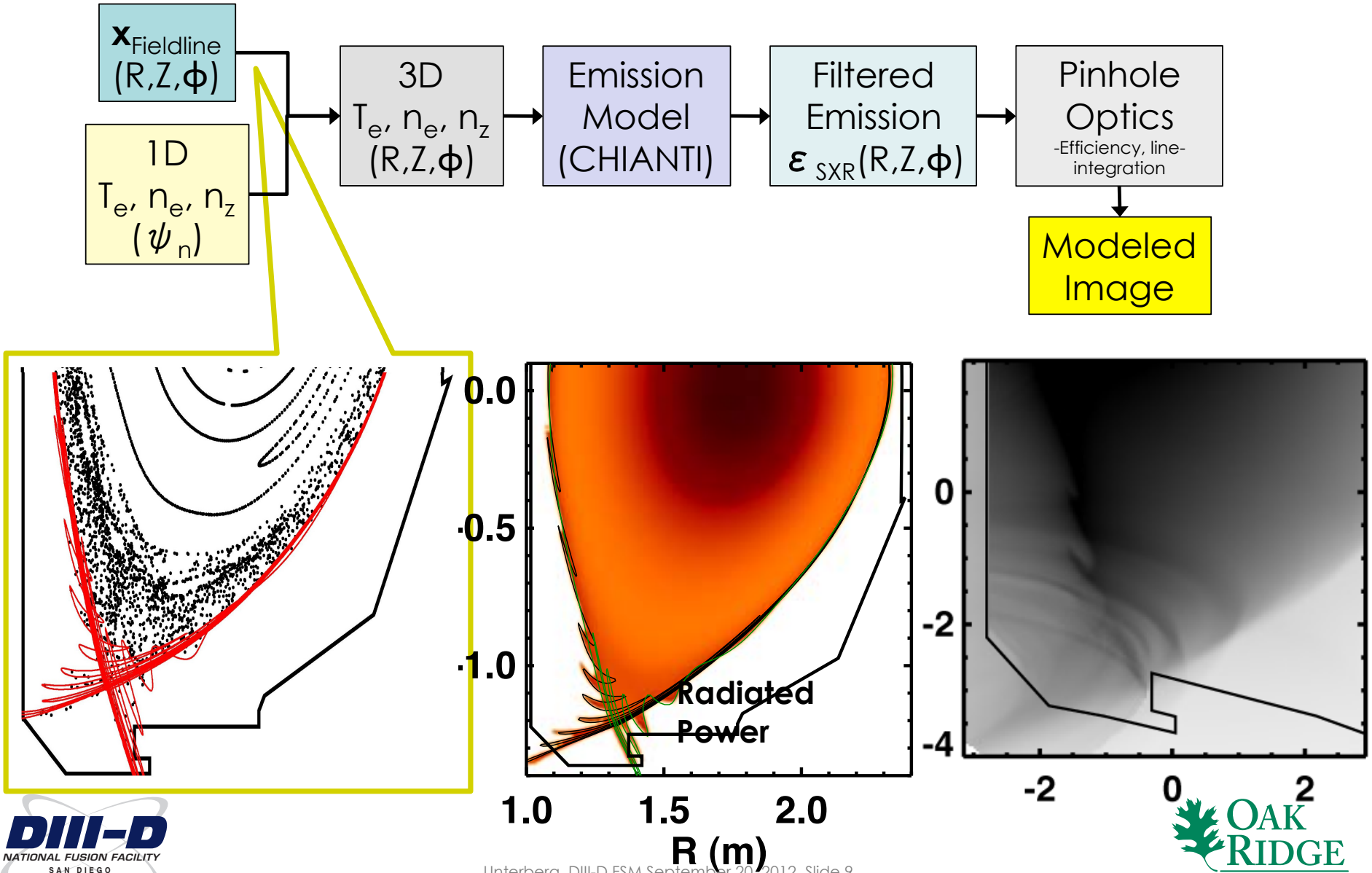

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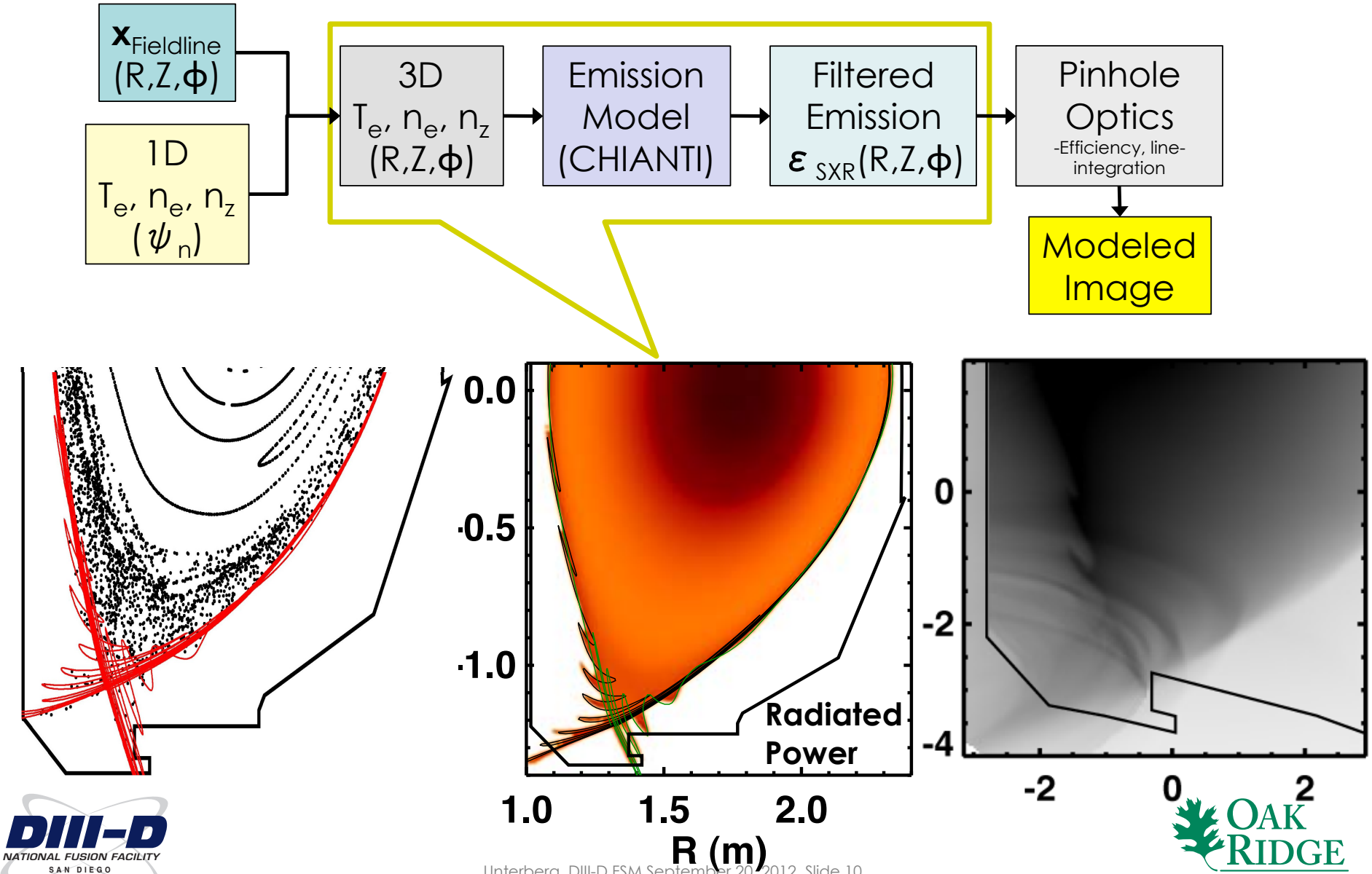

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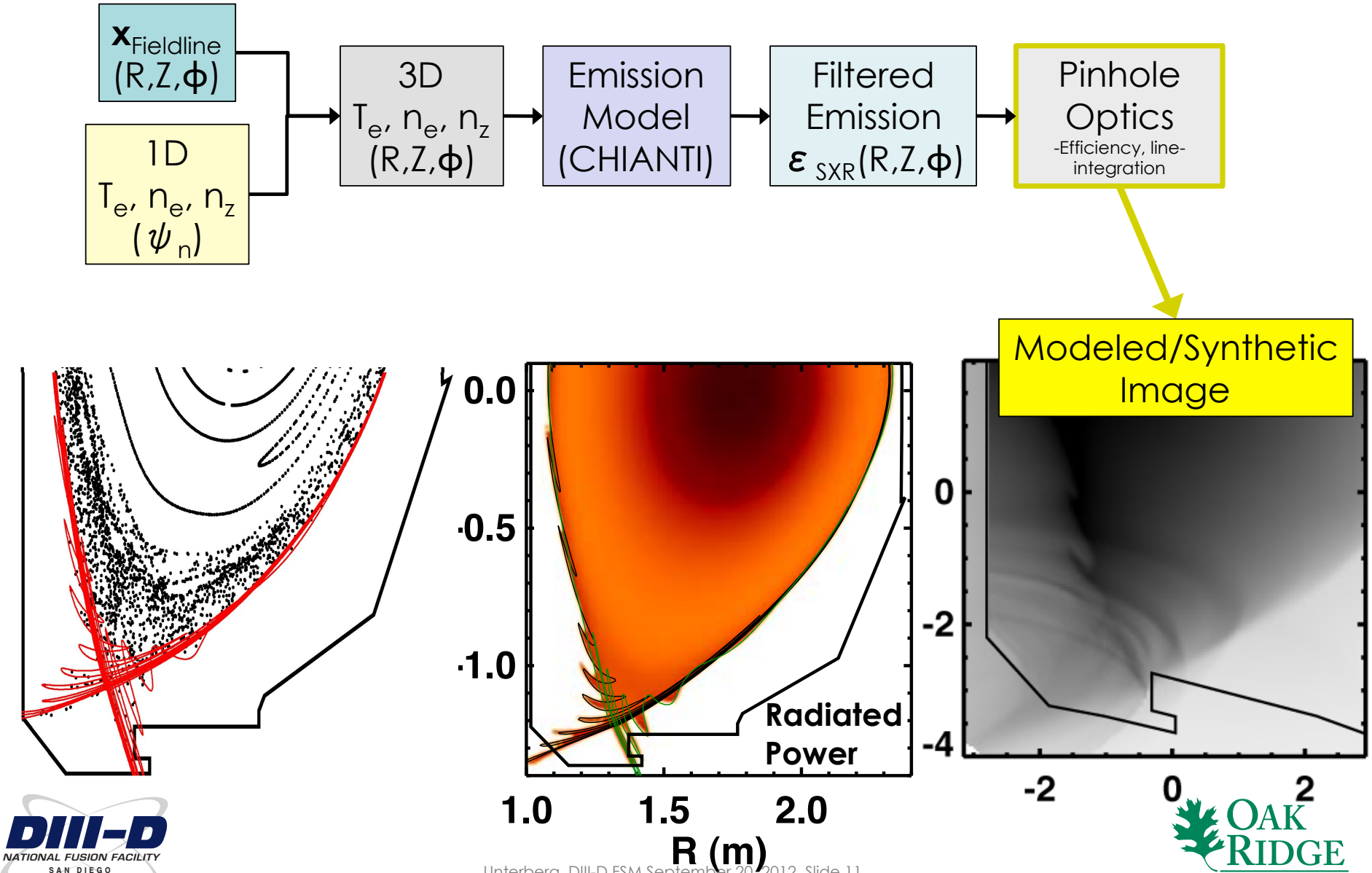
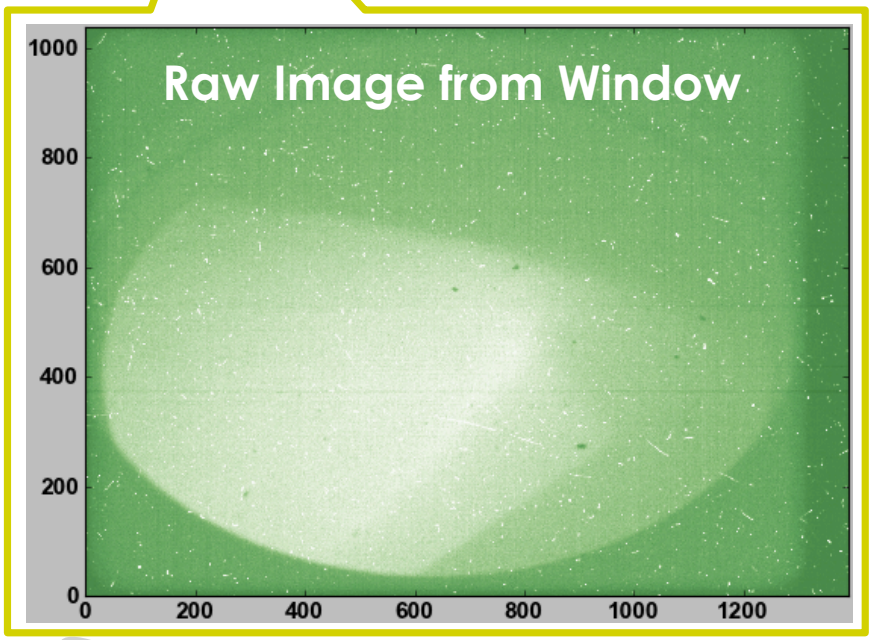
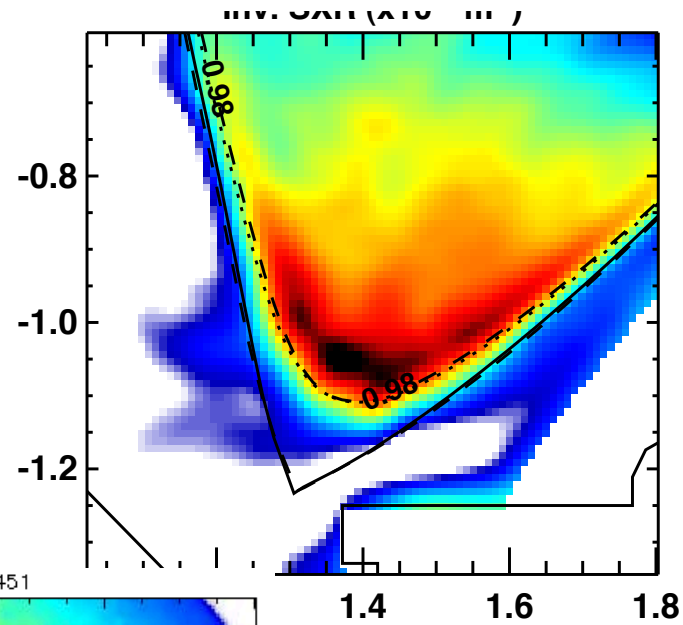
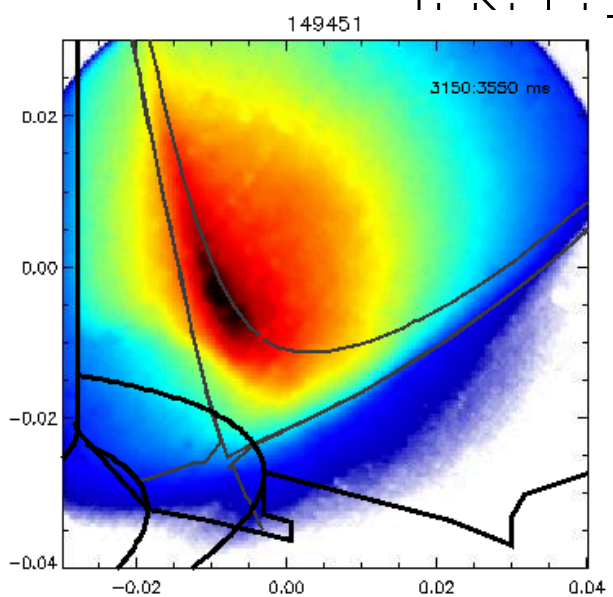


Image Processing Needed Before Data 'Looks Good'

Data From Camera → Projection Transforms + Radiation Filter (despeckle)+ Geometric Calibrations → Image Inversion







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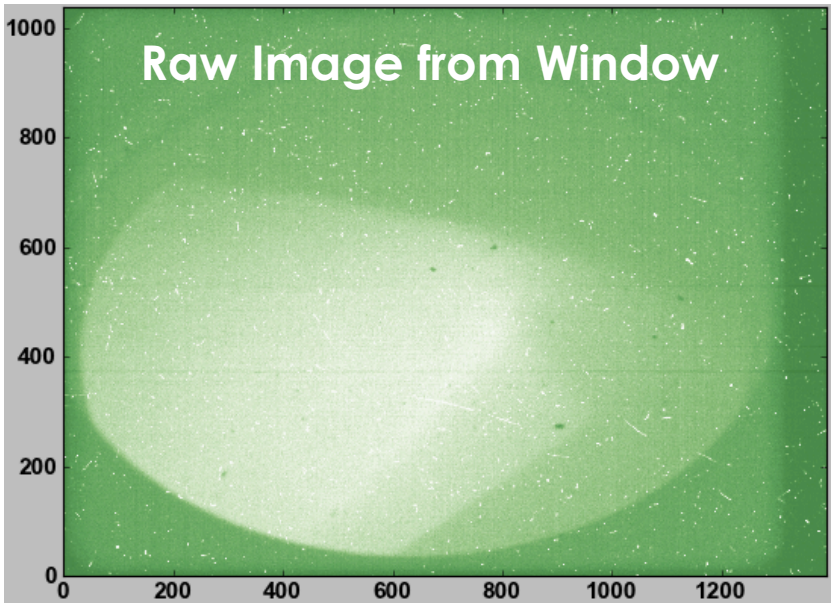

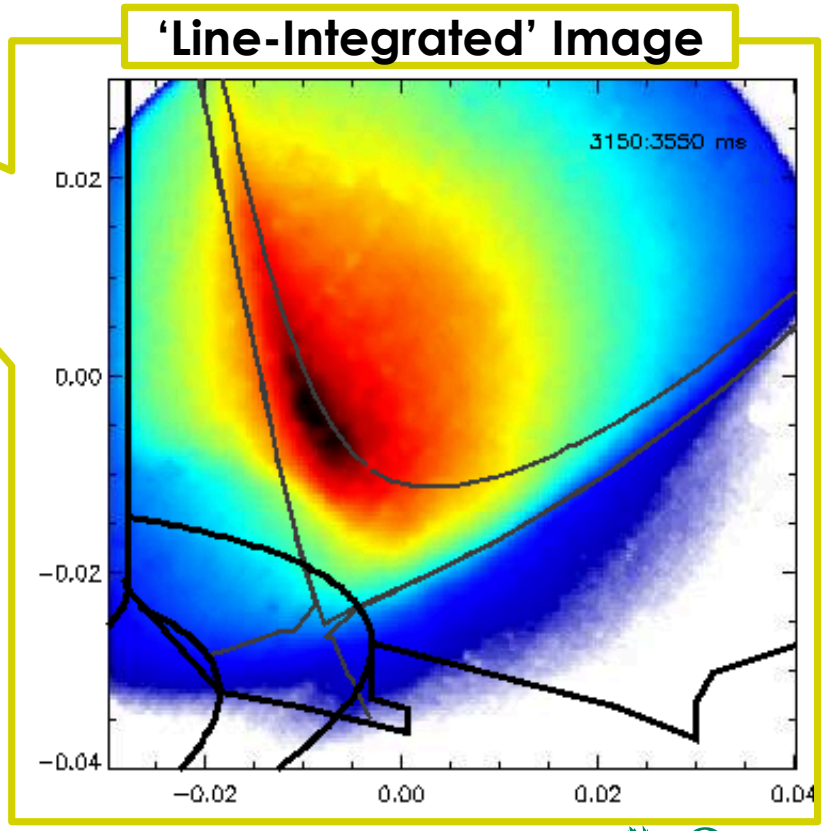

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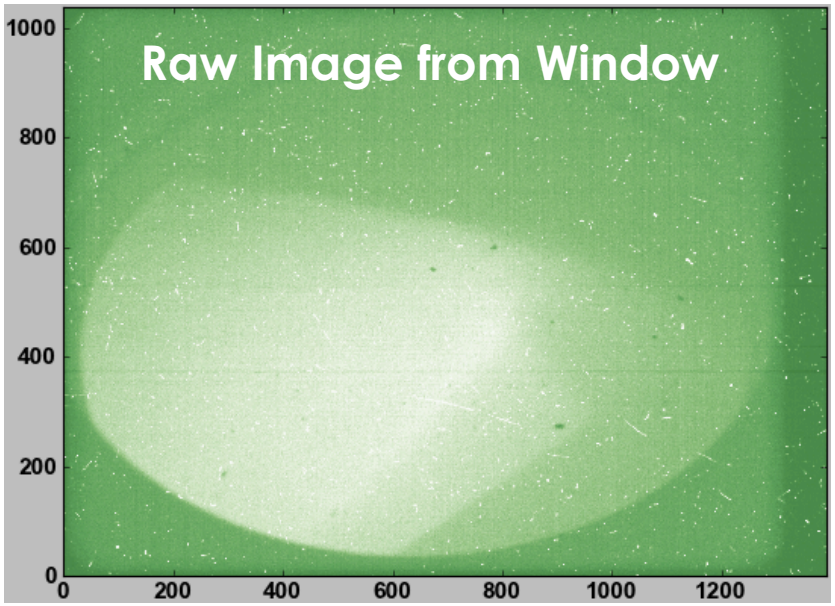
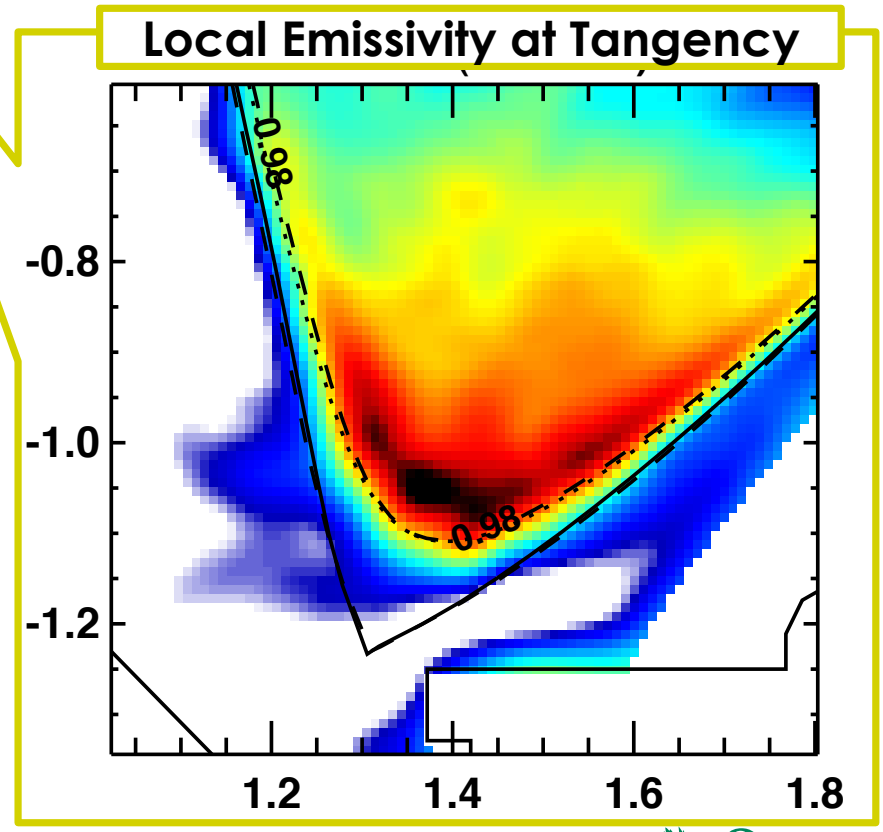
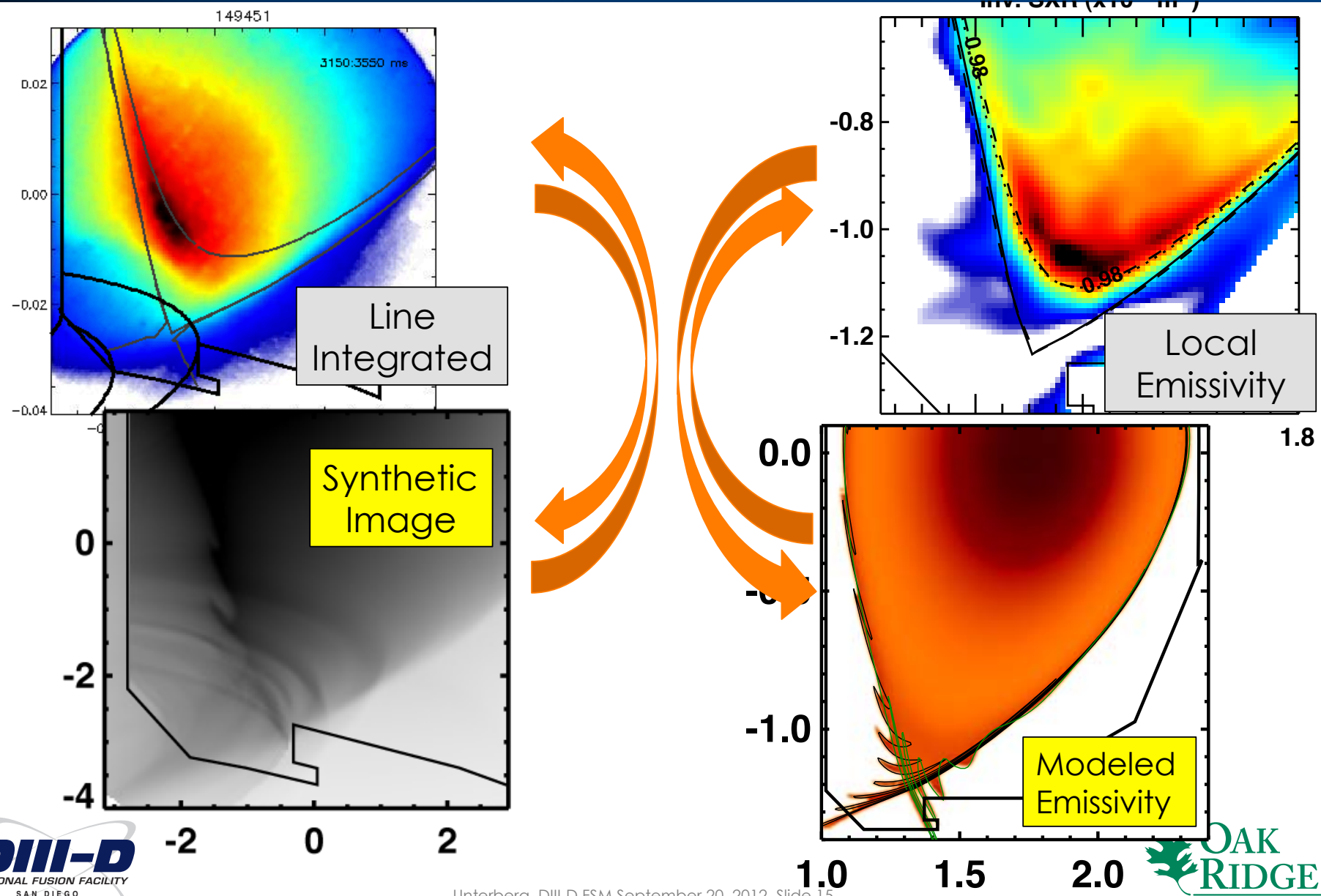




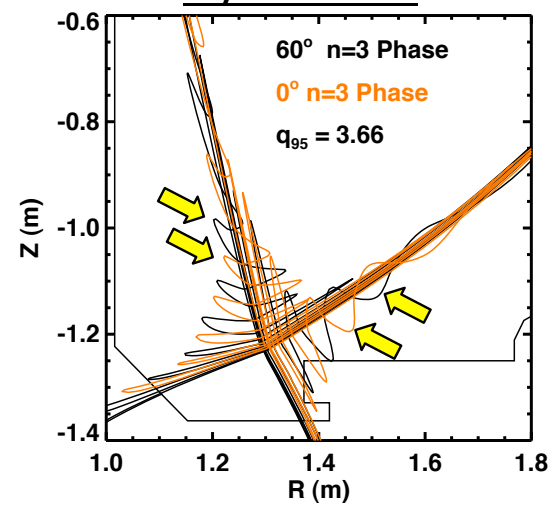
Approach is to Iterate Between Data and Models to Find "Best" Physics Answer



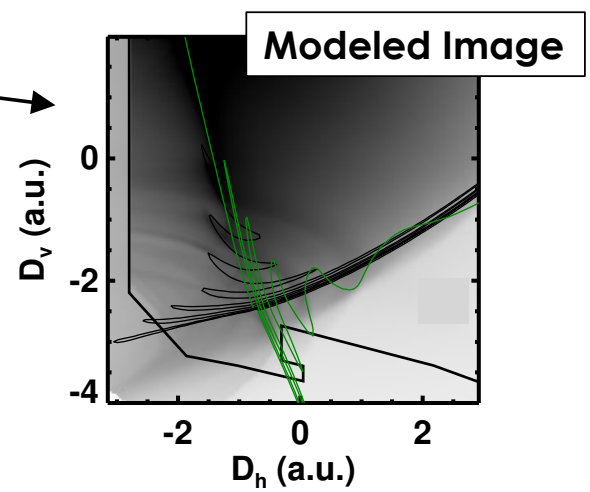
Out-of-Phase RMPs Provide Differential Capability for Lobe Structure Measurement

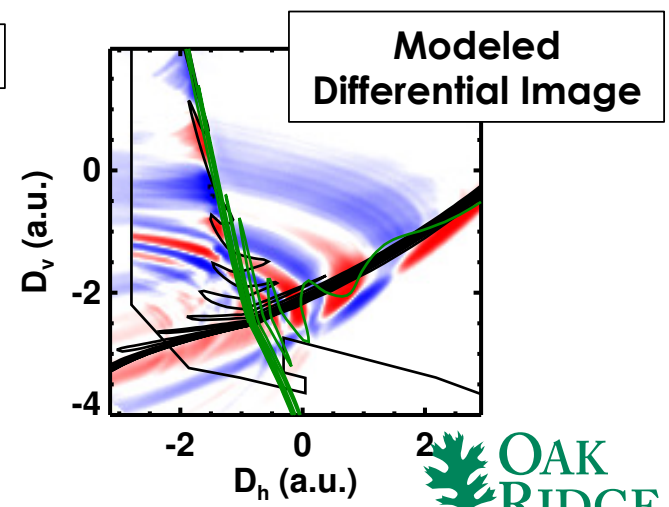
- **Shifting Phase of RMP rotates lobe structures**
  - 60° n=3 RMP ➔ Out-of-phase
- **Differential measurement used:**
  - Images w/ out-of-phase RMPs subtracted
- **Gross lobe structure dependent on q**
  - High-field lobes move downward
  - Low-field lobes constant

Manifolds Calculated w/ MAFOT



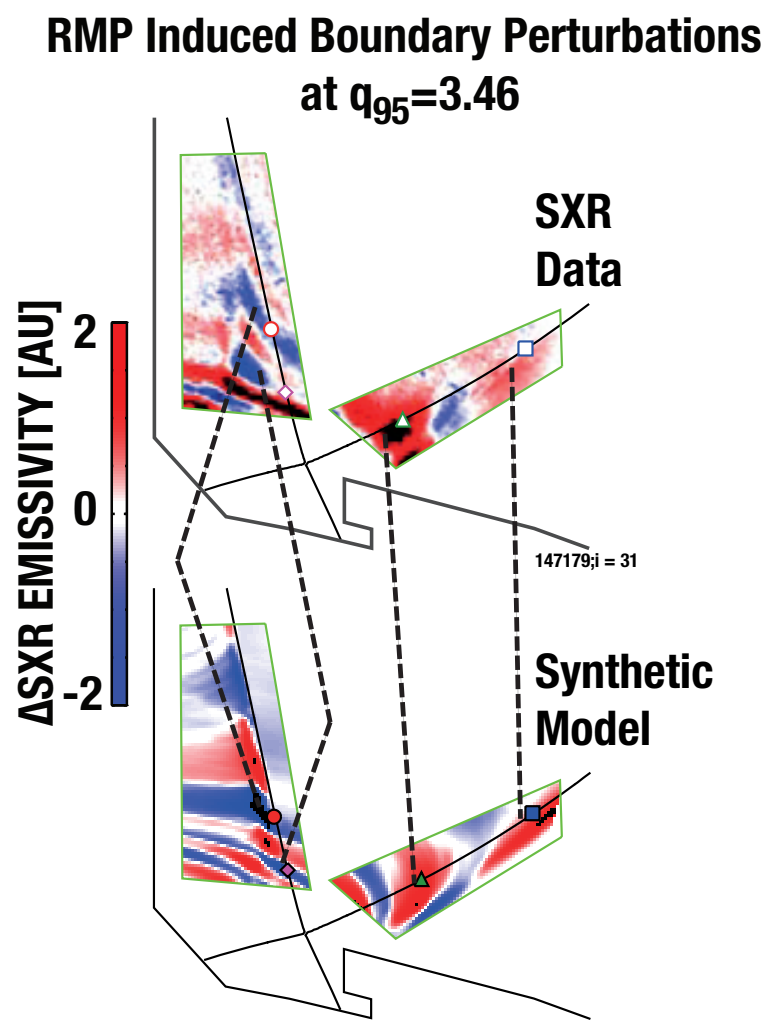
Synthetic Diagnostic Modeling





Vacuum-Predicted Lobe Structure Seen Directly in USXR Differential Images with n=3 RMPs

- **Observations confirmed with synthetic vacuum-field-based ultra-SXR diagnostic***
- **Synthetic model directly compares with data**
  - ~ Same count level
  - Similar line-integrated effects
  - Lobe movement with safety factor
- **Lobe "pattern recognition" algorithm employed to track movement**



*M.W. Shafer, Nucl. Fusion, in review (June 2012)

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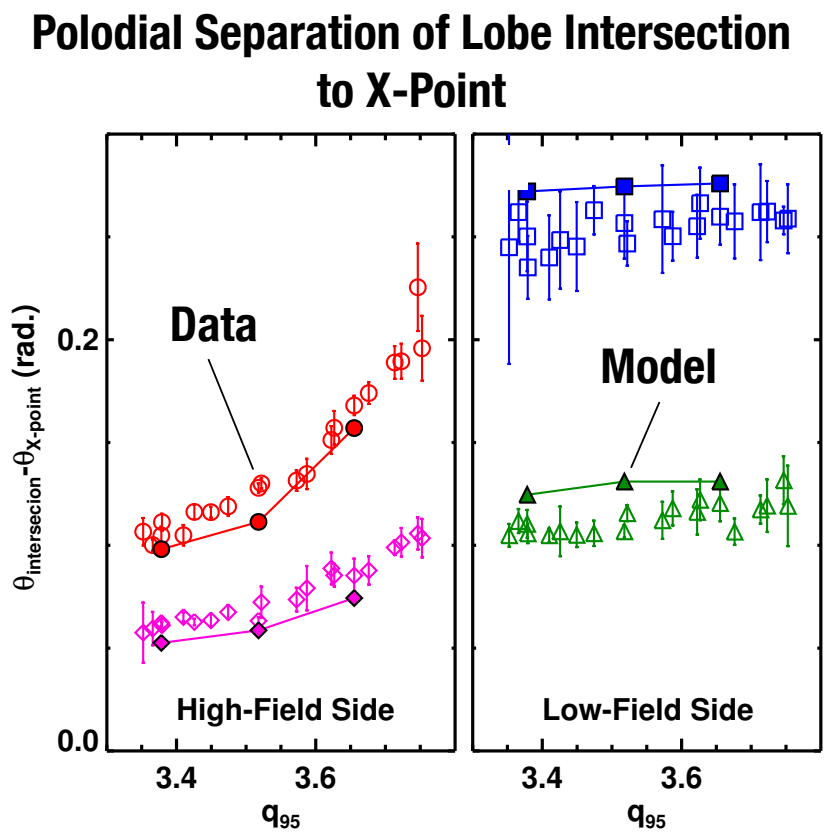

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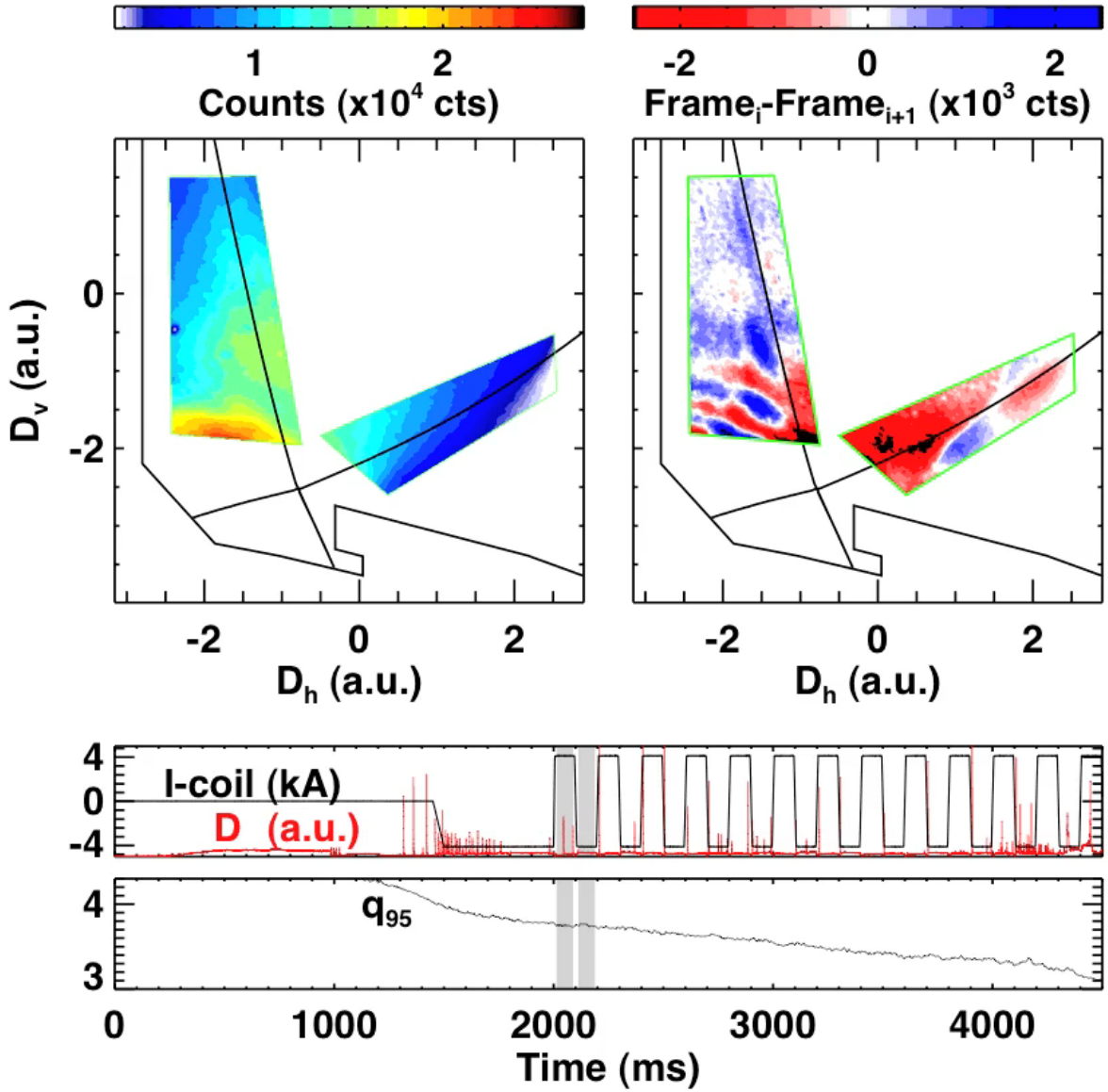
Movie: Differential Images w/ q95 Ramp

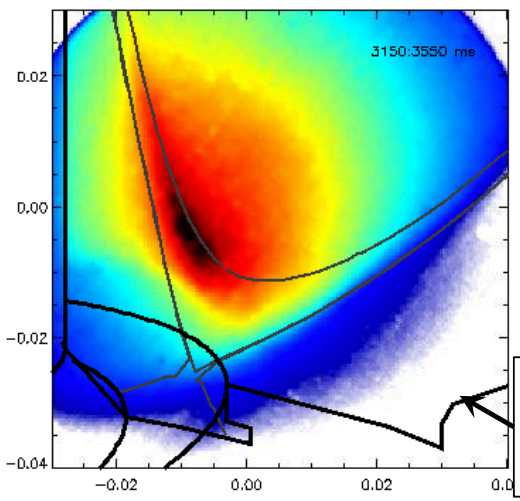


SXR Imaging: First Measurements of Internal 3D Structure during n=3 RMPs

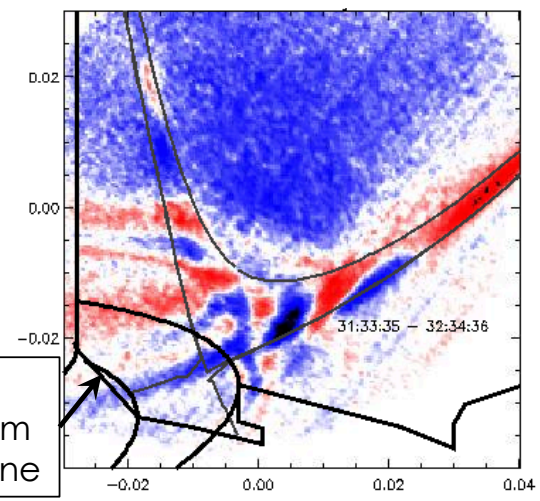
- **Higher energy filter to discriminate SOL/divertor emission**

- **Internal 3D structure seen near SXR emission peak (ψ_n ~ 0.97)**
  - Analysis ongoing to determine of source of structure

Line Integrated Image



Differential Image w/ n=3 Phase Flip



Boundaries Projected from Tangency Plane

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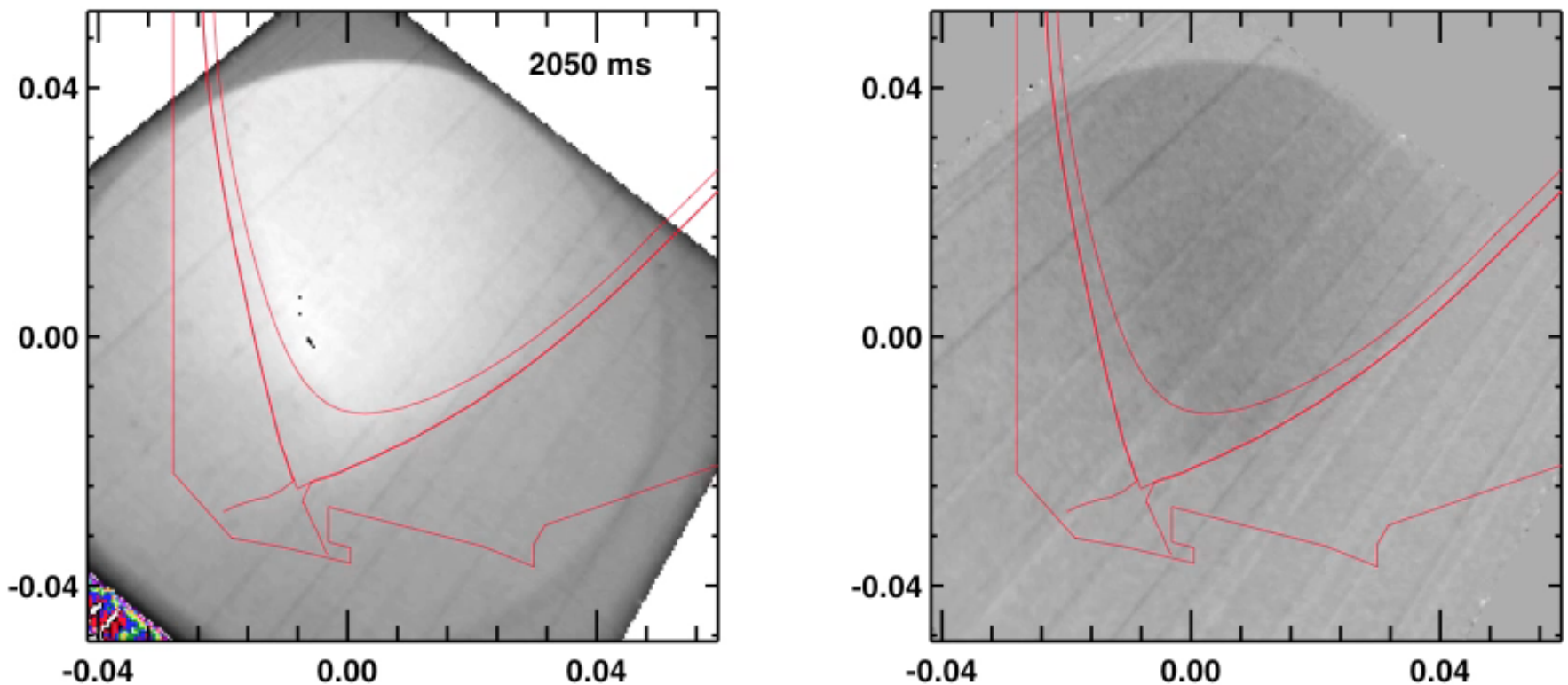
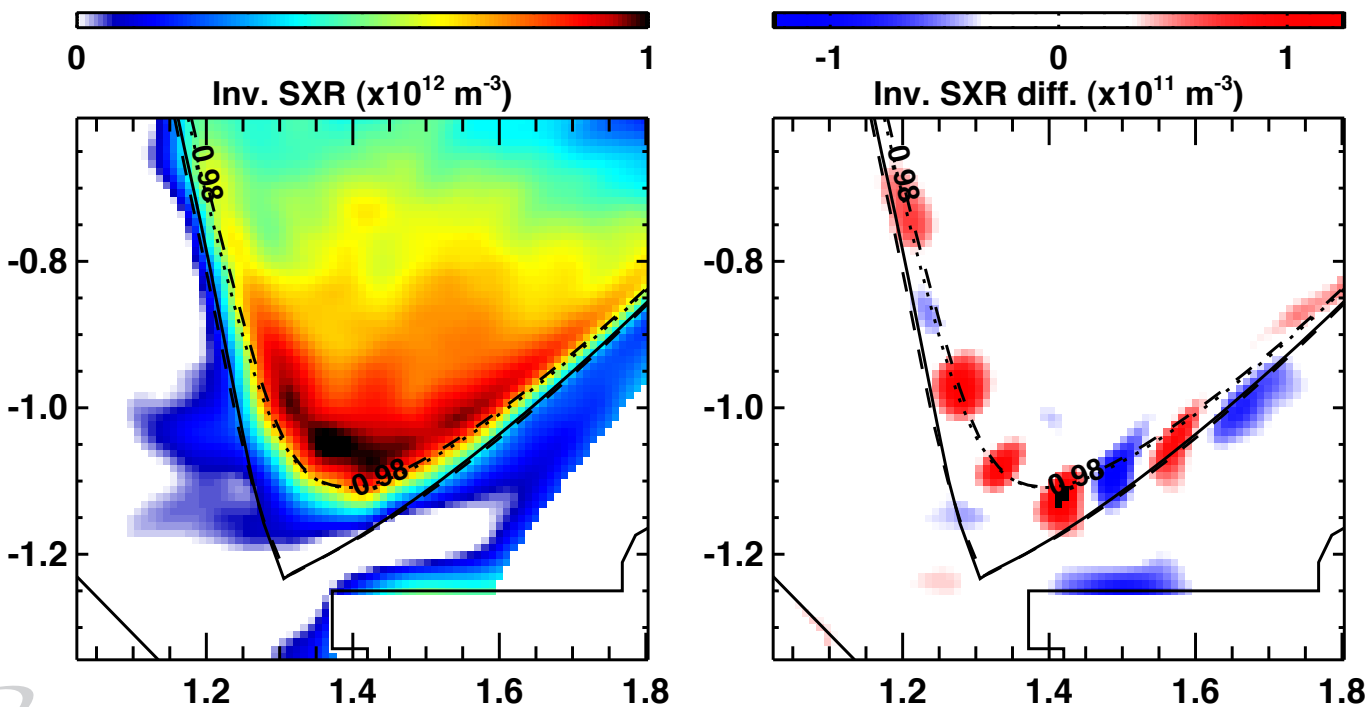
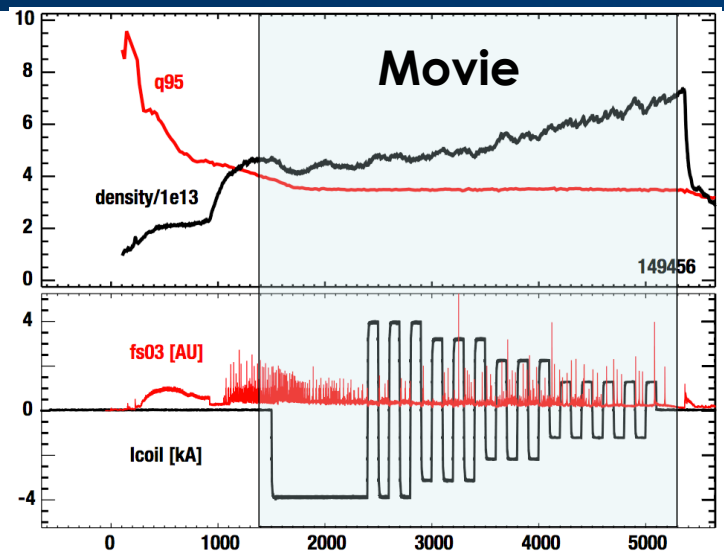


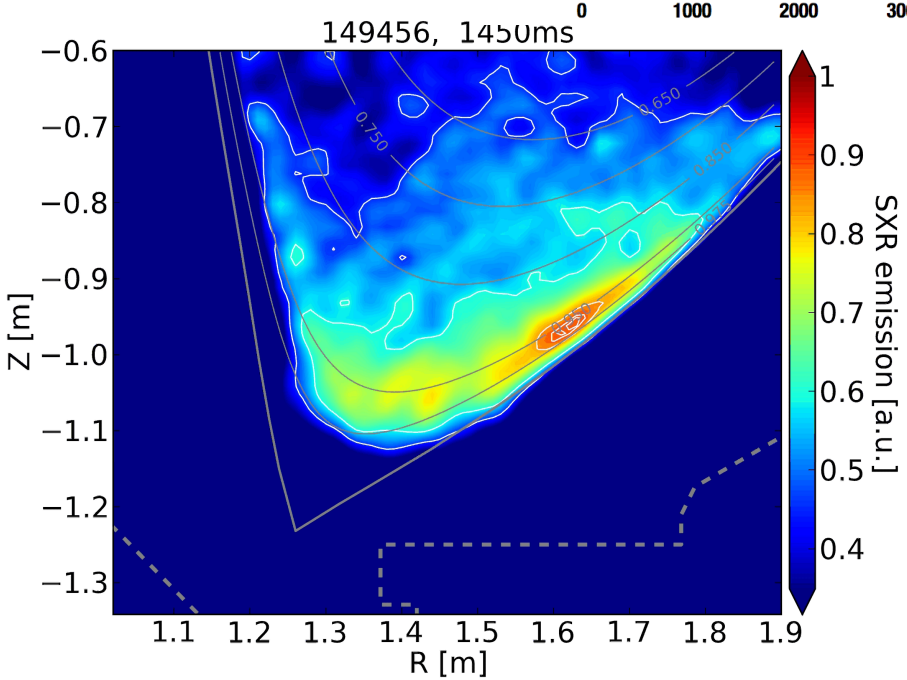
Image Inversion Done for Detailed Comparison to Code

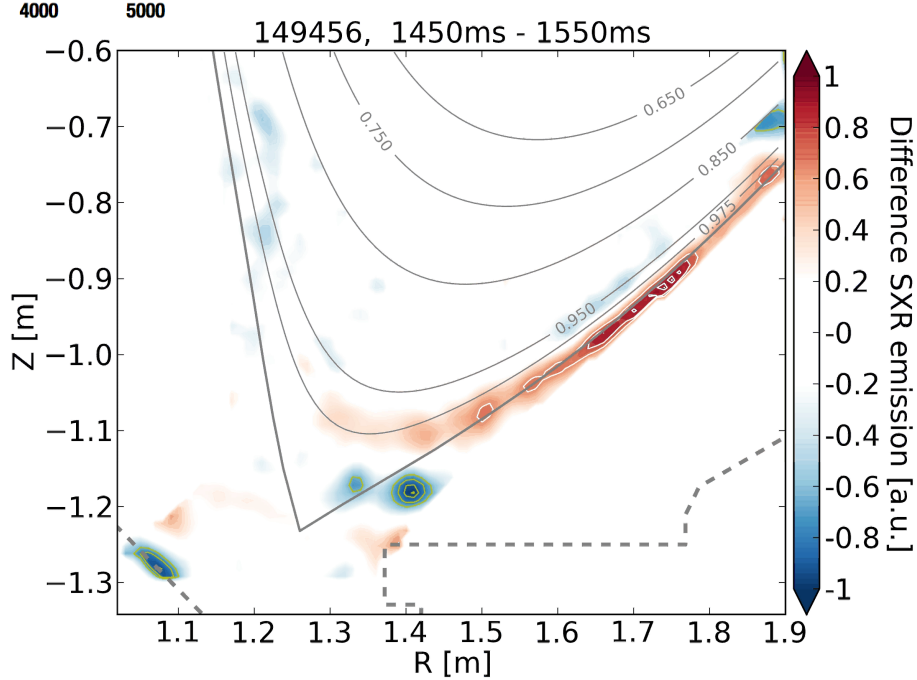
- **Image inversion done with a Phillips-Tikonov Regularization**
  - Ill-posed coupling matrix 'preconditioned' with a Laplacian smoothing operator; SVD used to find 'best' smoothing
- **Inversions show same structure at the ψ_n ~ 0.95-0.97 location**
- **Optimization of inversion technique & data SNR on-going**



Movie: Inverted Data + Frame/Frame Difference

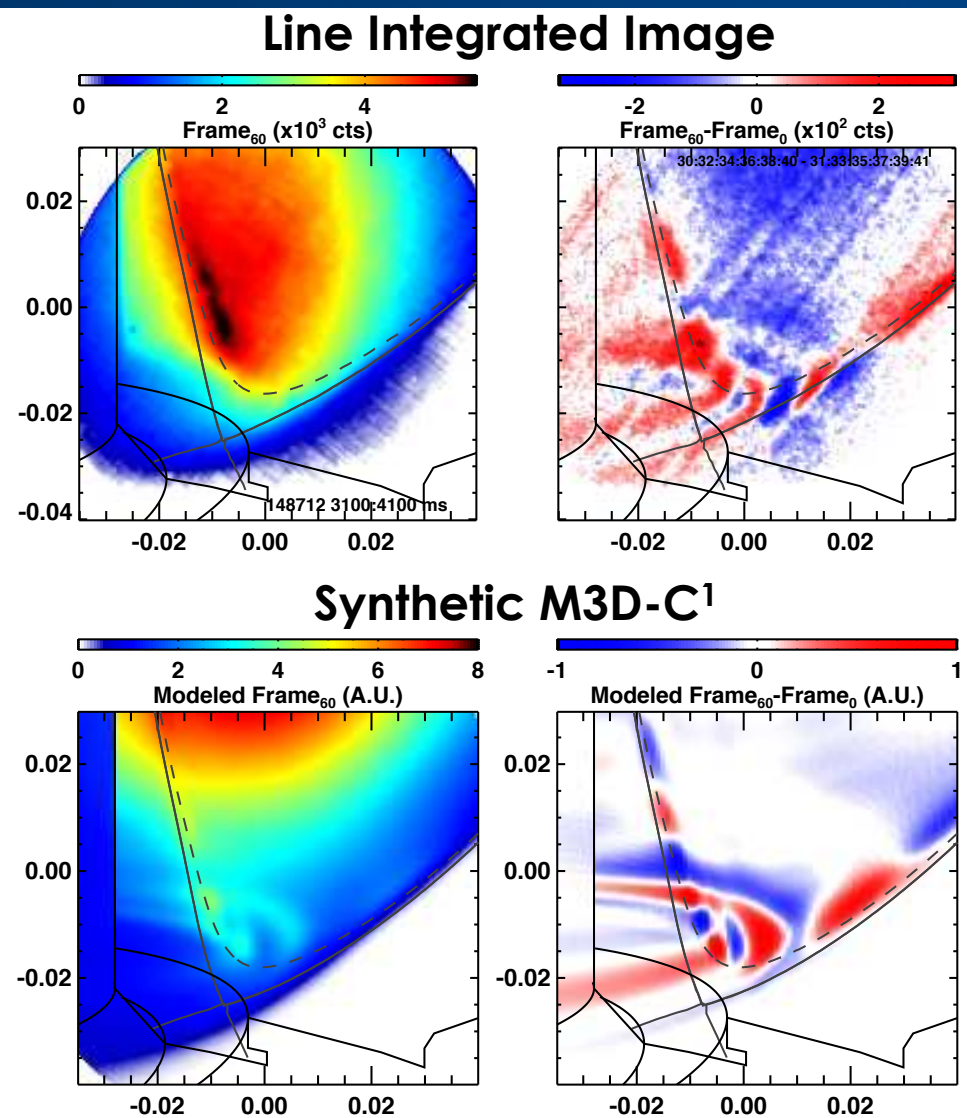






Line-integrated Images: Edge Structure Again Reproduced with Synthetic Diagnostic

- **Data and Modeling directly compared**
  - Using M3D-C[1]* & MAFOT** codes
- **First try: Qualitatively looks similar**
  - Detailed (quantitative) analysis going on now
- **Gross parameters ("big knobs") we are focusing on**
  - SXR emissivity profile in plasma
  - Fine tuning profile &/or kEFIT



*N.M. Ferraro et al., PoP, (2010)

**A. Wingen et al., PoP, (2009)

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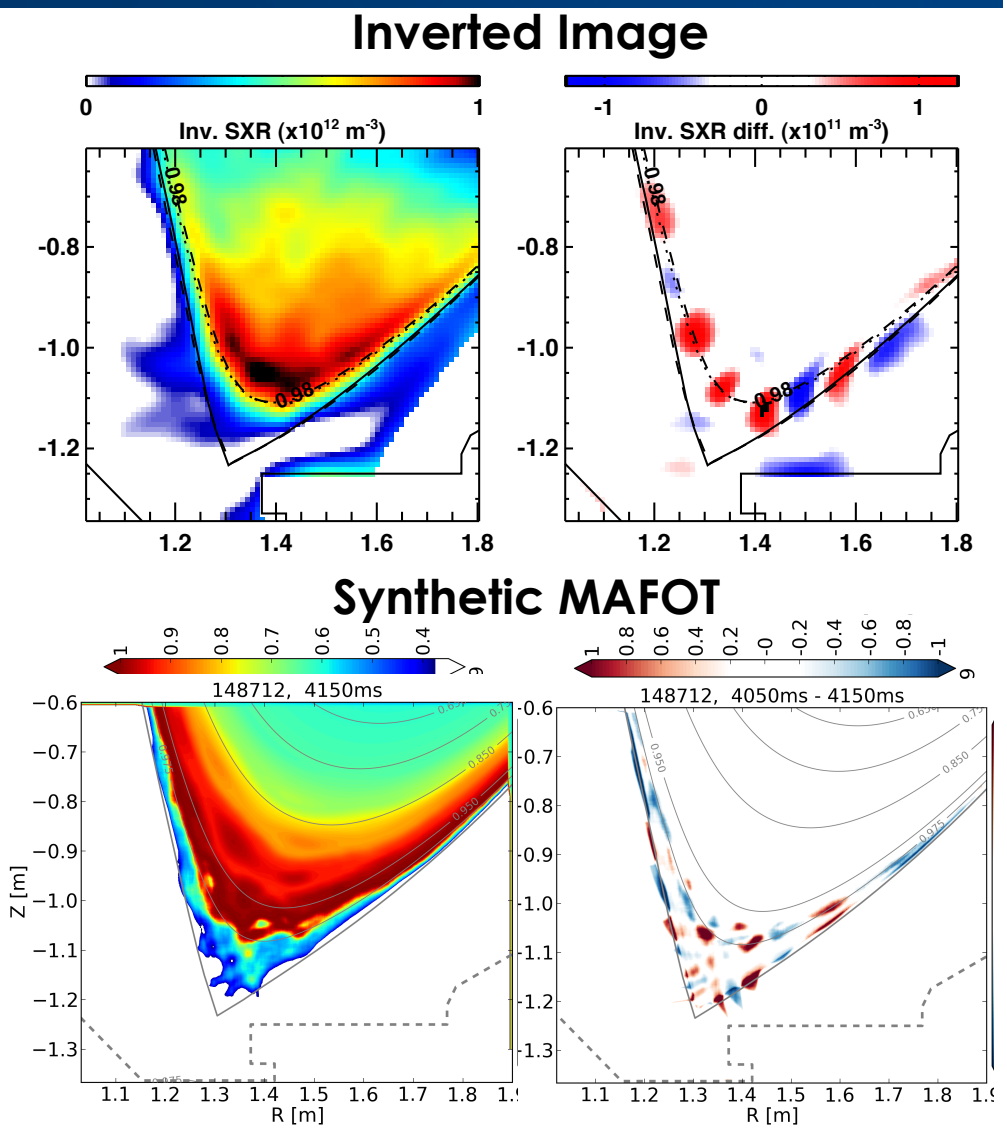

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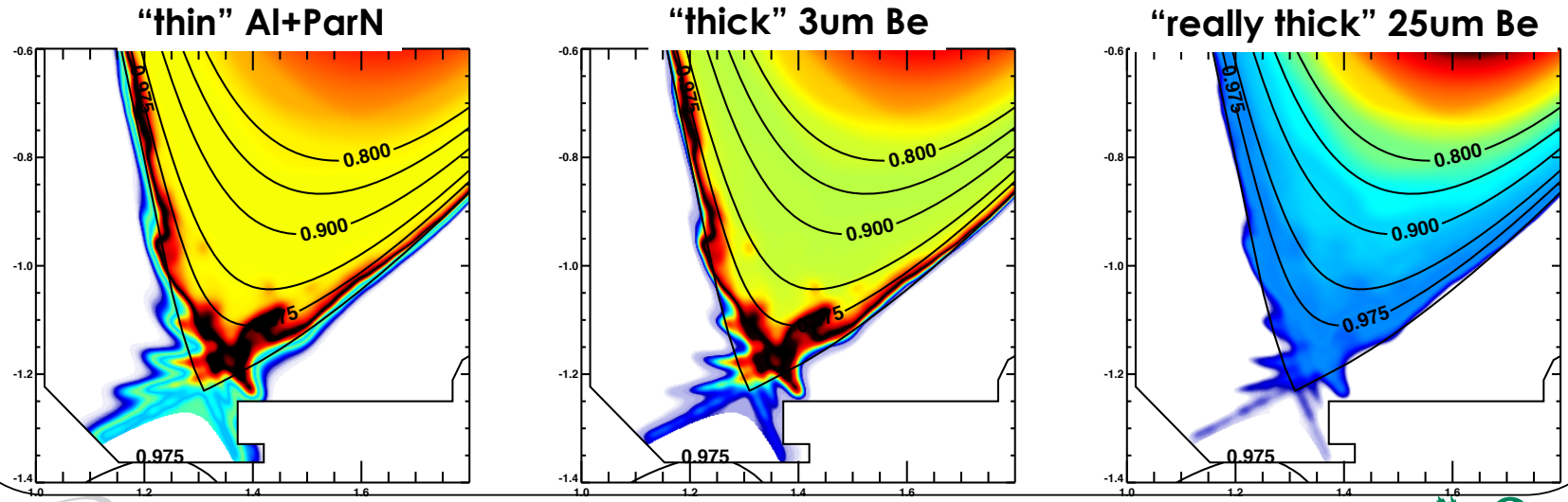
**A. Wingen et al., PoP, (2009)

Future/In-progress Work: Modeling & Diagnostic

- **Still a lot of overhead in SXRIS capability**
  - Change SXR filters for different radial ROIs
  - Increase SNR with optics mods
  - Increase signal with image intensifier
- **Synthetic diagnostics need work for quantitative analysis**
  - Uniform synthetic model emerging; but not there yet
  - Consistent picture between the MAFOT/M3DC[1] seems close

Predictive Modeling of Different filter sizes



Summary: Understanding of 3D Fields With X-Point SXR Camera

- **New X-Point SXR Camera has given interesting data in the 1.5 run campaigns it has been used**
- **Synthetic Diagnostic + 3D simulation one key to understanding data; detailed comparisons done with inverted data**
- **3D field implications so far:**
  - Data matches well to vacuum-predicted separatrix splitting
  - Helical structure interior to plasma observed during RMPs
    - Comes and goes with Icoil application
- **Next Steps:**
  - Quantitative comparisons between synthetic models & data
  - Improve signal quality & inversion quality of data