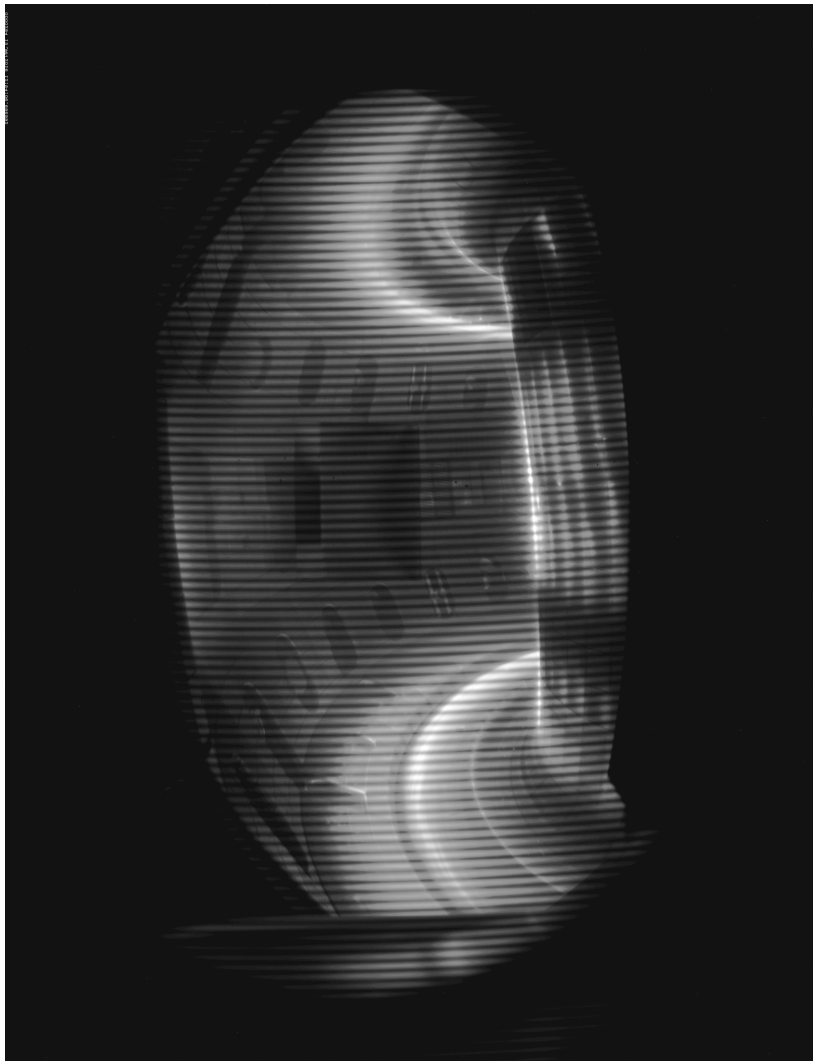
Analysis of Doppler Coherence Imaging Spectroscopy Images from the DIII-D Tokamak*

William Meyer

Casis Workshop May 17th, 2017



***Prepared by LLNL under Contract DE-AC52-07NA27344. This material is based upon work supported by the U.S. DOE, Office of Science, Fusion Energy Sciences.**

DIII-D NATIONAL FUSION FACILITY

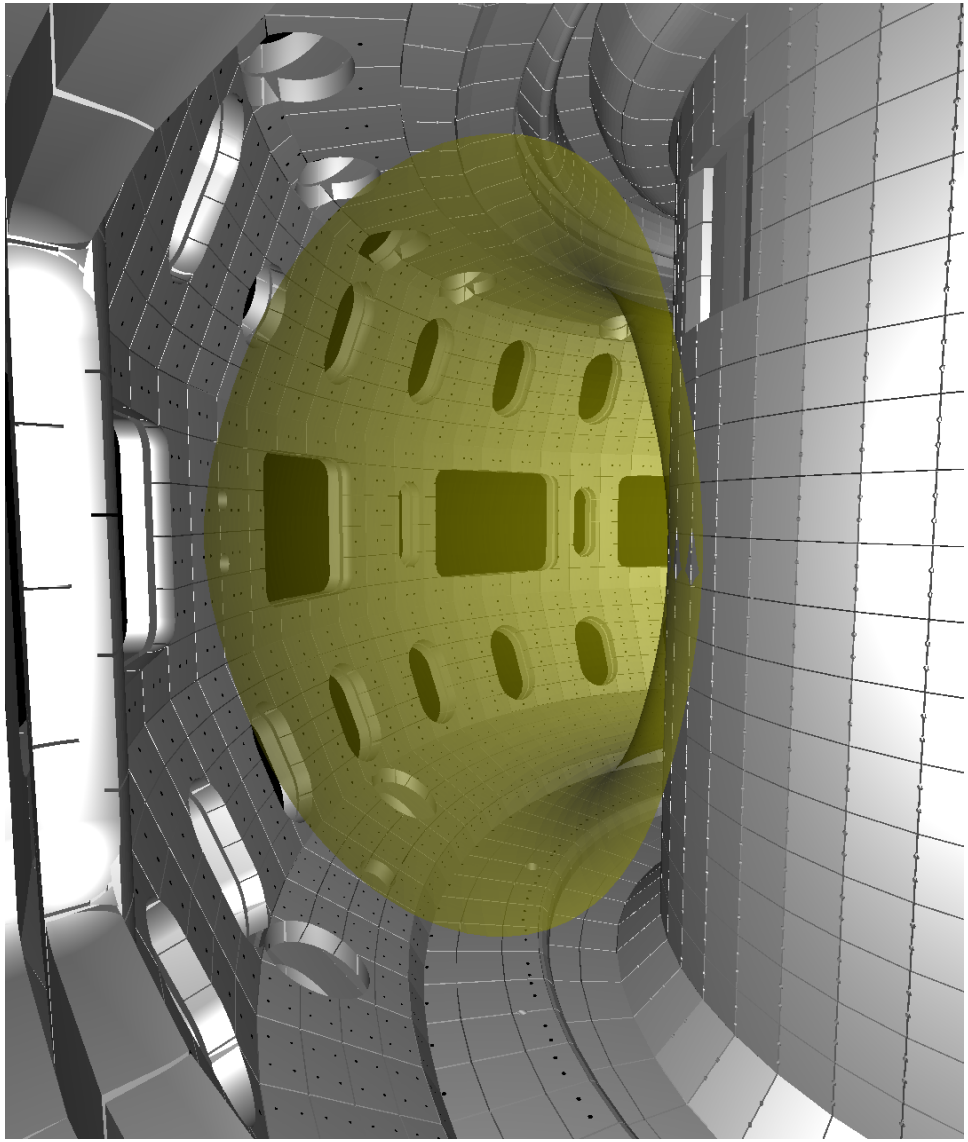
Fusion Energy Sciences

Tomography on DIII-D

- Fan Beam (Soft X-Ray, Bolometers)
  - Number of fans limited by port access
  - Truncated series in flux coordinates

- Tangential Cameras
  - Visible light (CII, CIII, Dalpha)
  - Coherence Imaging Spectroscopy

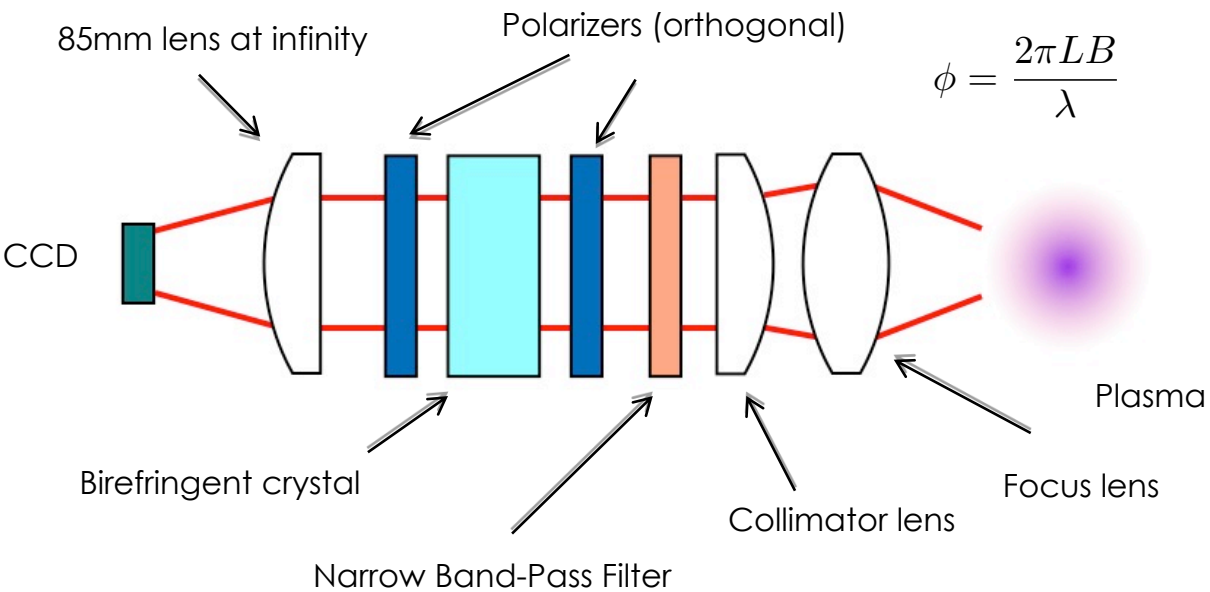
Toroidal Symmetry



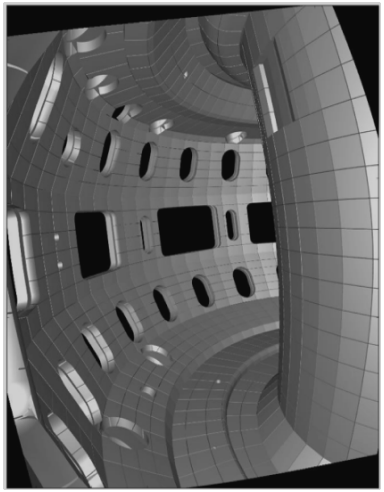
DIII-D NATIONAL FUSION FACILITY

Fusion Energy Sciences

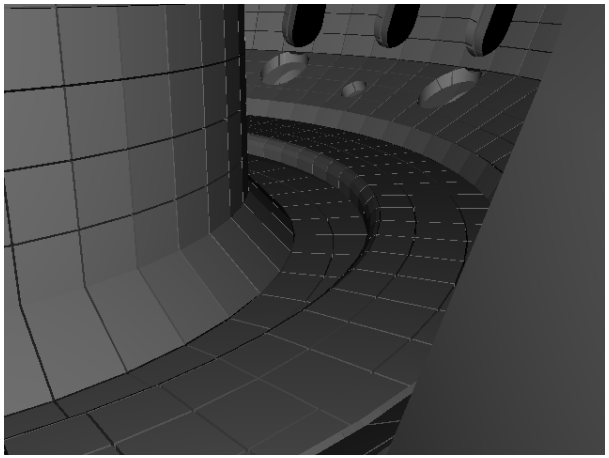
Doppler Coherence Imaging Interferometer Diagnostic



Periscope View



Lower Divertor View



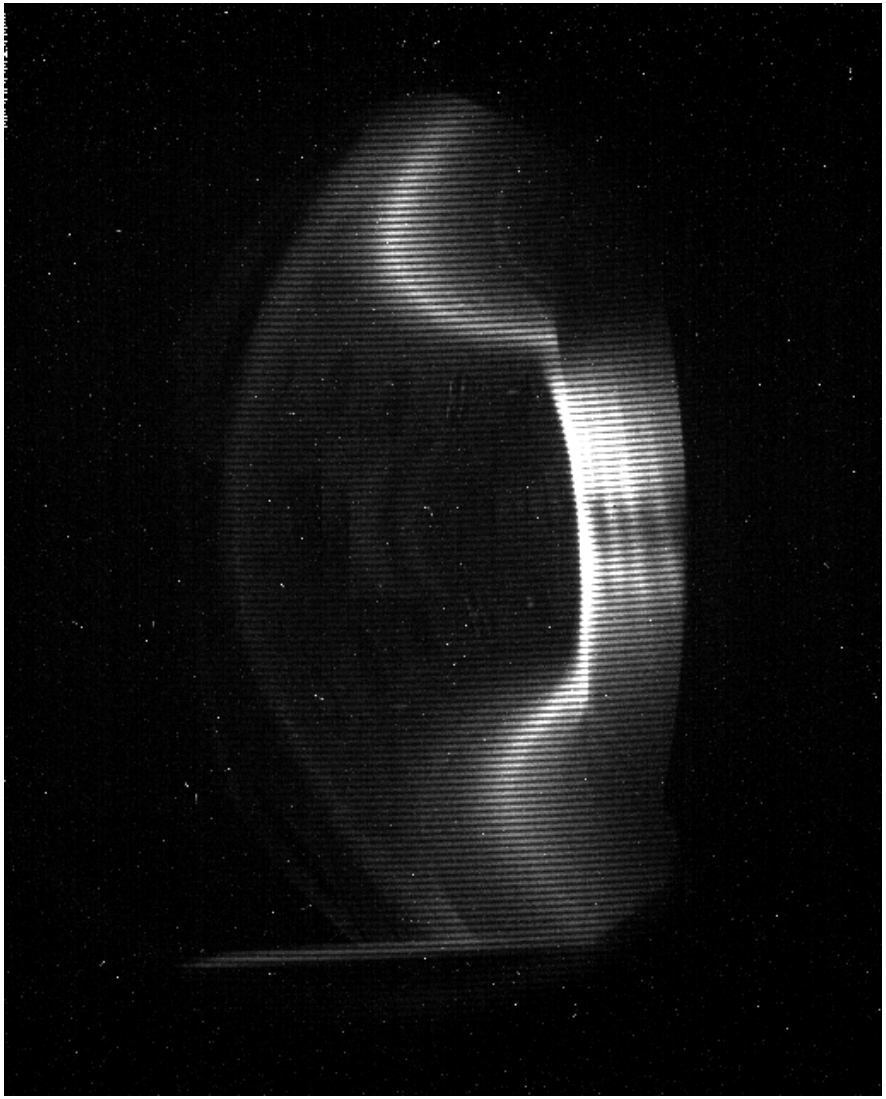
DIII-D CIS Raw Diagnostic Data

4Mpixel frames

100-300 frames per shot

15 minute shot cycle

165274



DIII-D NATIONAL FUSION FACILITY

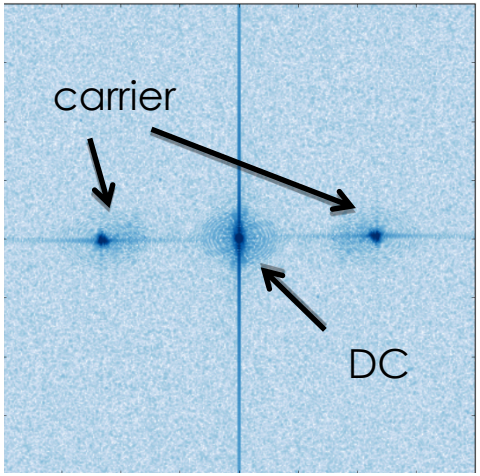
Fusion Energy Sciences

Fringe Encoded Line Integrated Intensity and Flow

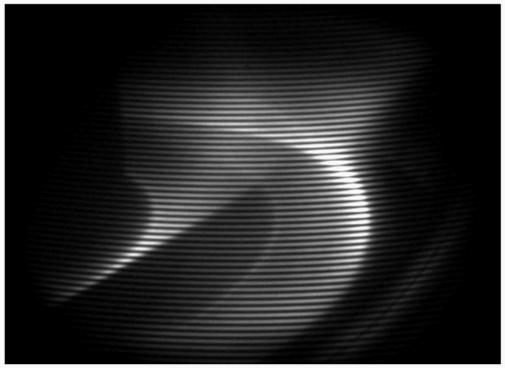
Fourier analysis of the interferogram is used to extract Doppler information of emitting species.

$$\frac{\phi_D}{\hat{\phi}_0} = \frac{1}{e_0 c \zeta_D} \int_L I_0(\mathbf{r}) \exp\left[\frac{-T_s(\mathbf{r})}{T_C}\right] \boldsymbol{v}_D . d\boldsymbol{l}$$
$$\approx \frac{1}{e_0 c} \int_L I_0(\mathbf{r}) \boldsymbol{v}_D . d\boldsymbol{l}$$

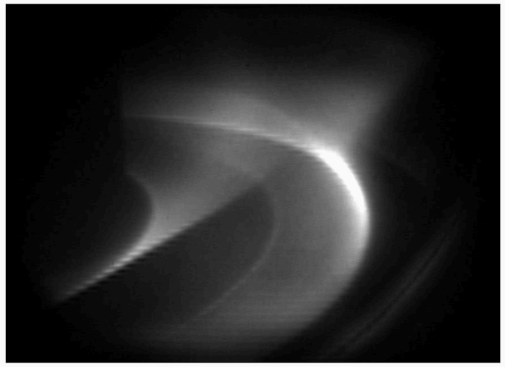
FFT



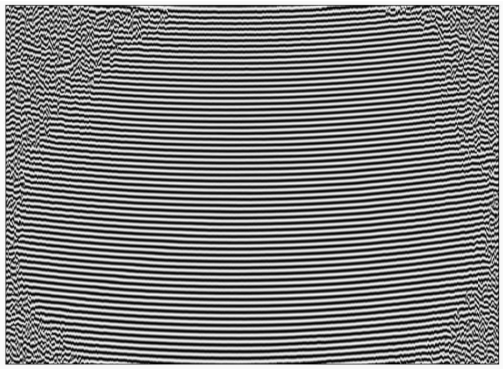
Raw



DC



Interferogram

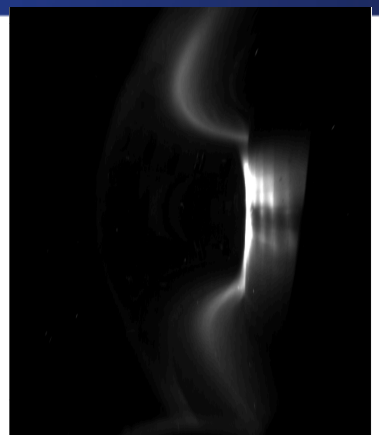


Howard, Plasma Phys. Control. Fusion 45 (2003)

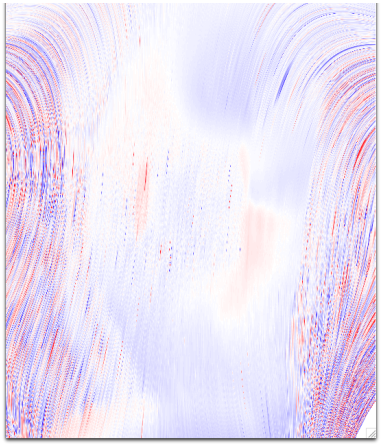
DIII-D NATIONAL FUSION FACILITY

Fusion Energy Sciences

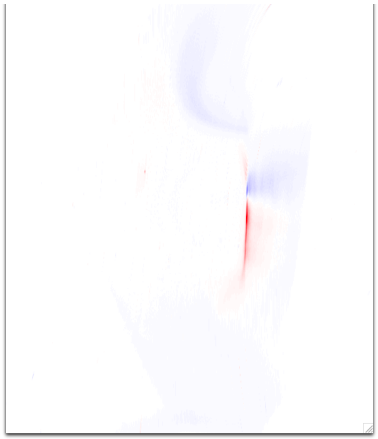
CIS Demodulation



- DC
  - Low-pass convolution mask
- Phase
  - Reference image taken just before shot
    - Temperature controlled laser
    - Lab sphere moved into optical path just prior to shot
  - Band-pass convolution mask
  - Hilbert transformation demodulation



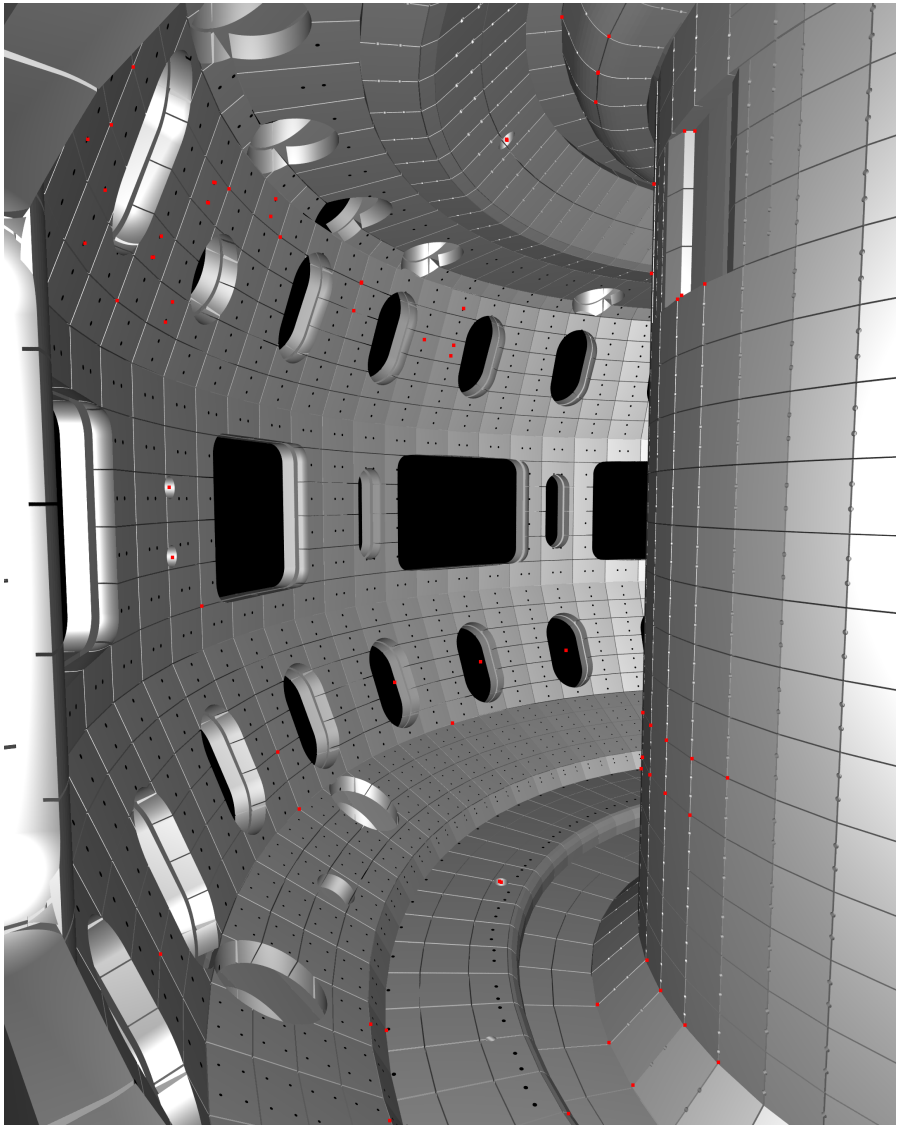
- Intensity weighted

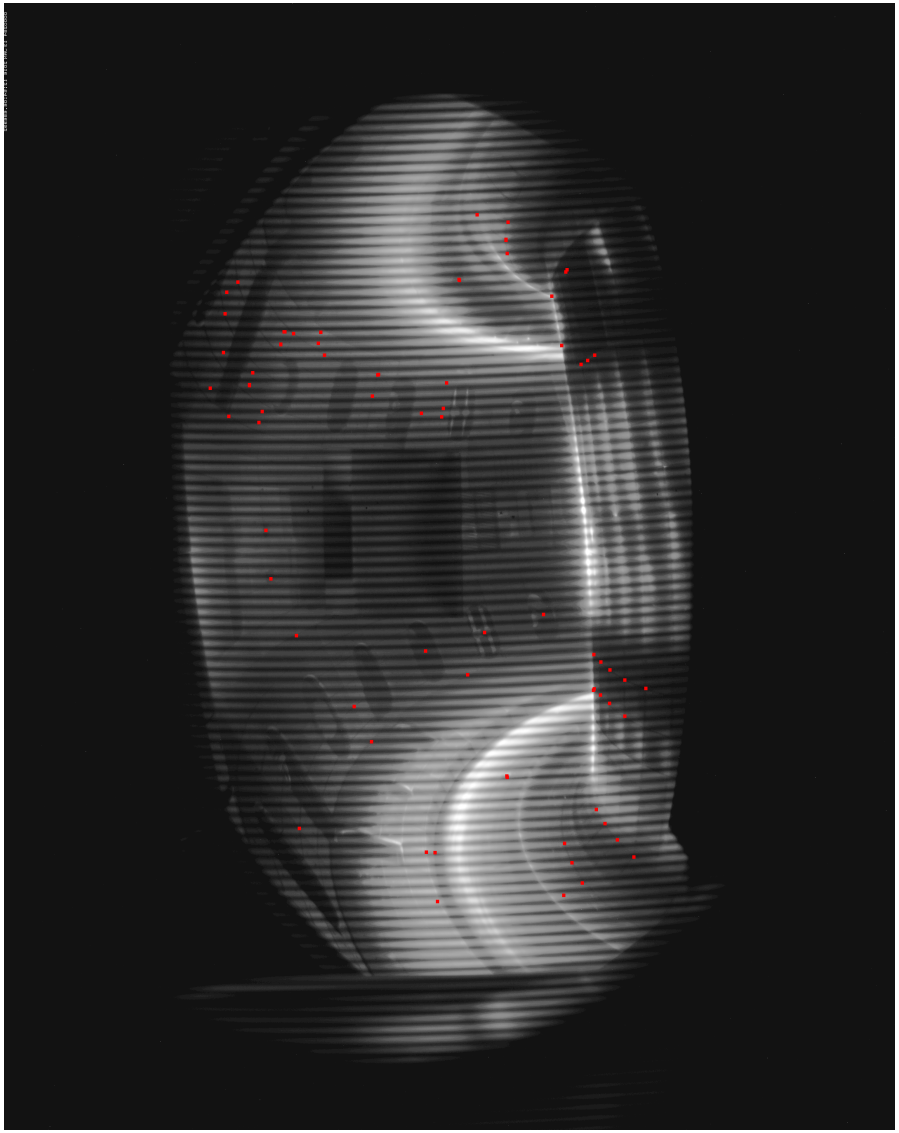


DIII-D NATIONAL FUSION FACILITY

Fusion Energy Sciences

Periscope View Spherical Aberration

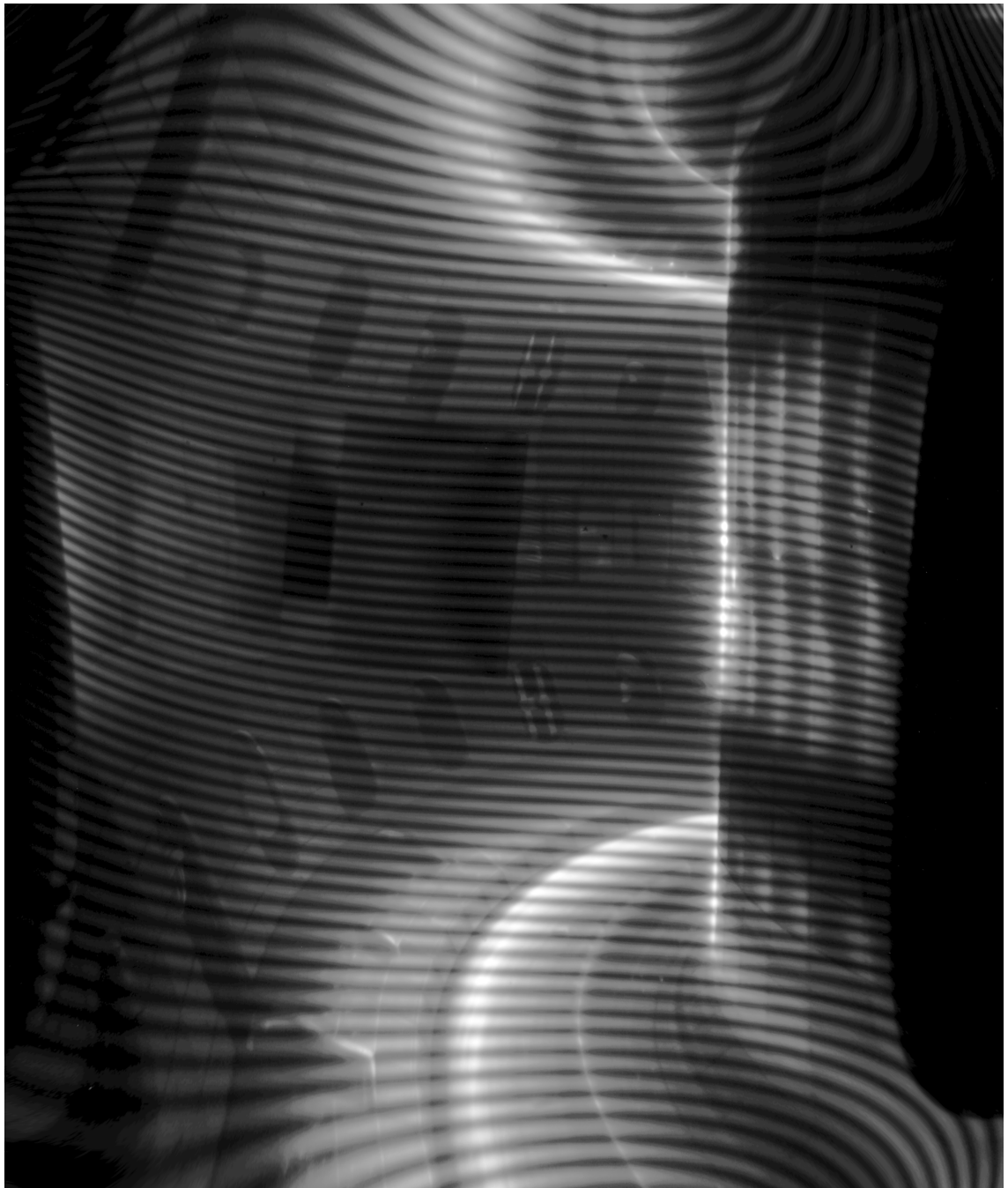




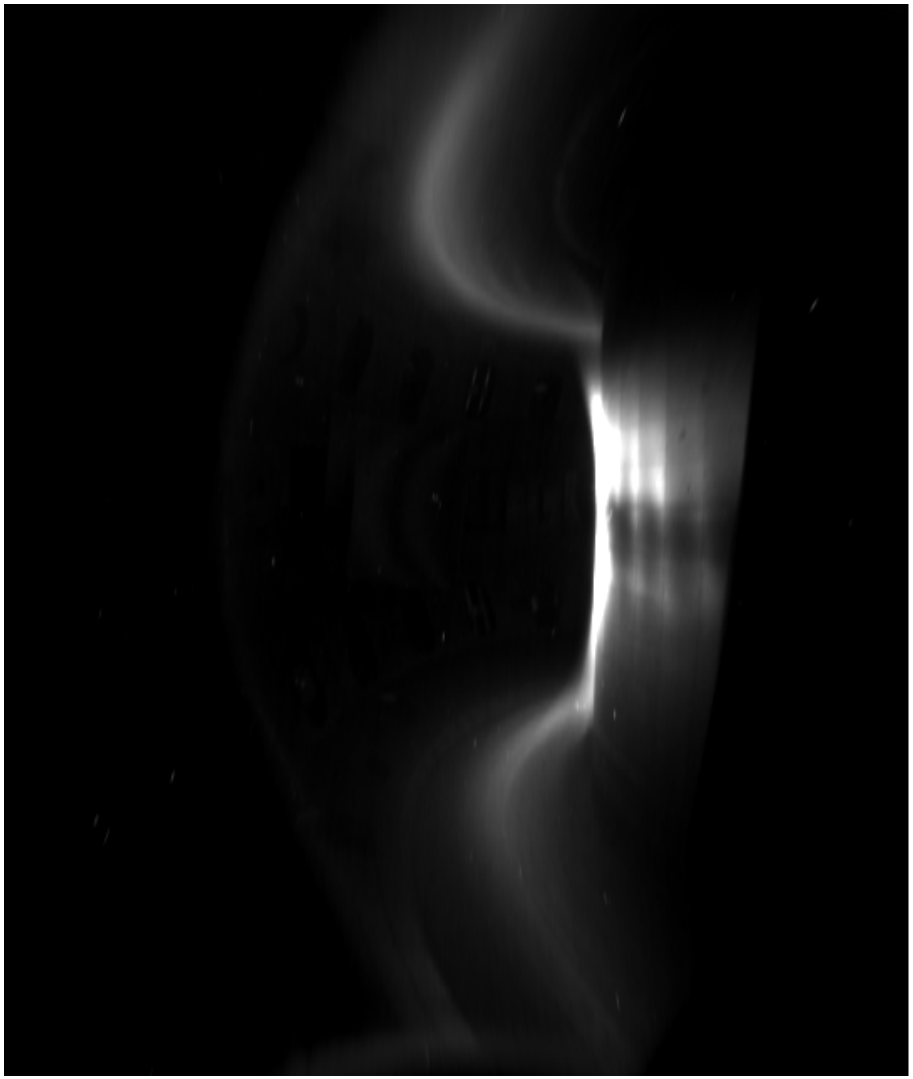
DIII-D NATIONAL FUSION FACILITY

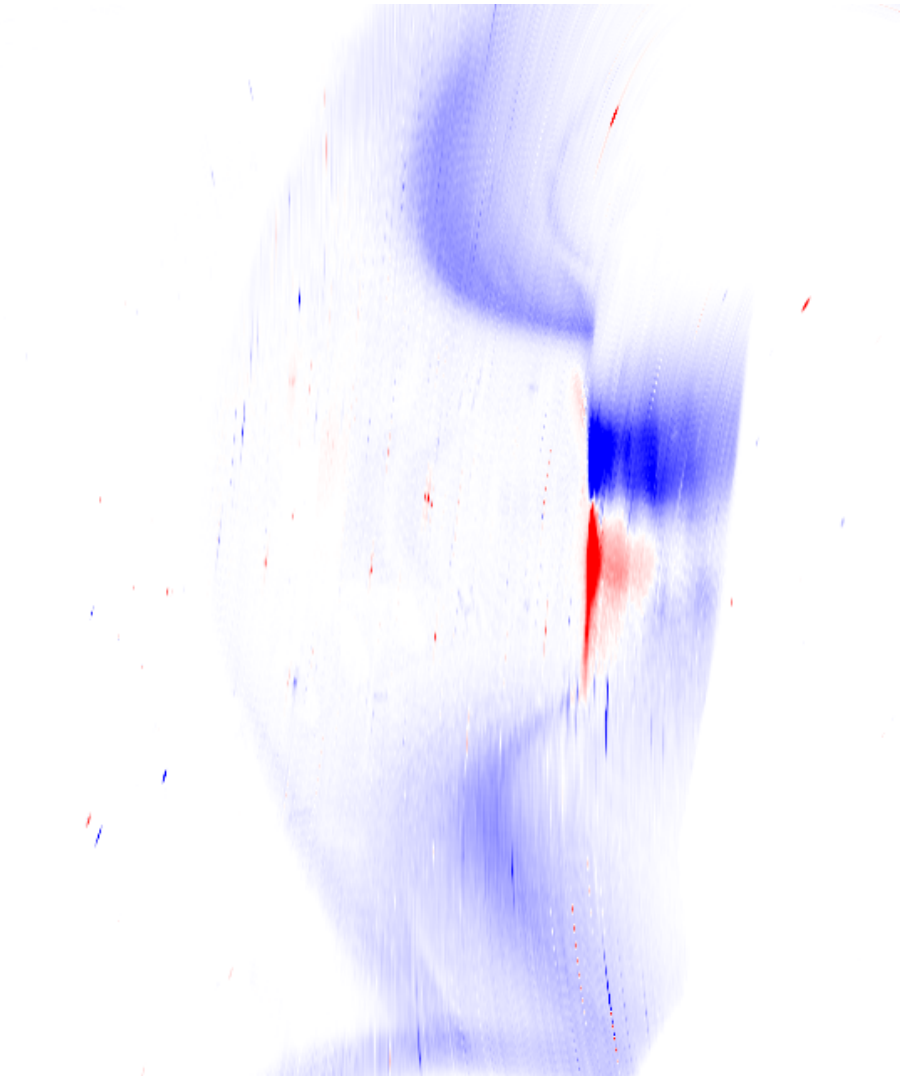
Fusion Energy Sciences

Spherical Aberation Corrected



DIII-D CIS Demodulated Diagnostic Data





DIII-D NATIONAL FUSION FACILITY

Fusion Energy Sciences

DIII-D Flow Reconstruction*

$$\underbrace{\frac{\Phi_D}{\Phi_0}}_{Phase} \approx \frac{1}{I_0 c}\int_L I\,(r)\overrightarrow{v_D}\cdot\overrightarrow{dl} \qquad \underbrace{I_0 = \int_L I\,(r)dl}_{Intensity}$$

$$\frac{\Phi_{D_j} I_{0_j} c}{\Phi_{0_j}} = \sum_{i=1}^{N} I(r_i) v_{D_i} \int_{L_j} \delta\,(r - r_i)\hat{B}_i \cdot \overrightarrow{dl}$$

$$= \sum_{i=1}^{N} I(r_i) v_{D_i} \left[B_{t_i} \underbrace{\int_{L_j} \delta\,(r - r_i)\hat{\phi}\cdot\overrightarrow{dl}}_{\Phi} + B_{r_i} \underbrace{\int_{L_j} \delta\,(r - r_i)\hat{r}\cdot\overrightarrow{dl}}_{R} + B_{z_i} \underbrace{\int_{L_j} \delta\,(r - r_i)\hat{z}\cdot\overrightarrow{dl}}_{Z} \right]$$

- Four response matrices calculated, from camera spatial calibration, and saved.
- For specific equilibrium, Φ, R, Z component matrices combined during SpMV and SpMV_t steps
- Solved with Algebraic Reconstruction Techniques

*Howard, J., Diallo, A., Creese, M., Allen, S.L., Ellis, R.M., Meyer, W., Fenstermacher, M.E., Porter, G. D., Brooks, N. H., Van Zeeland, M. E. and Boivin, R. L. (2011), Coherence Imaging of Flows in the DIII-D Divertor. Contrib. Plasma Phys., 51: 194–200. doi: 10.1002/ctpp.201000062

DIII-D NATIONAL FUSION FACILITY

Fusion Energy Sciences

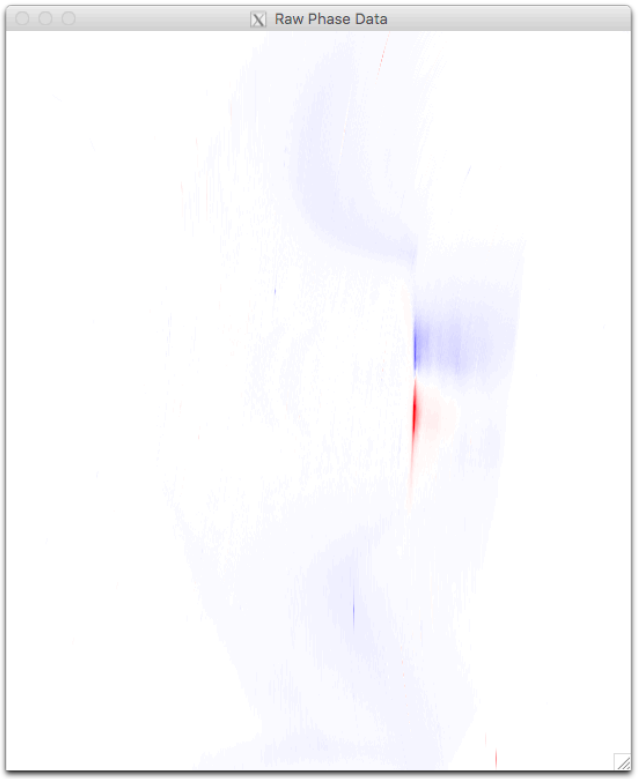
Parallel SpMV and SpMV_t

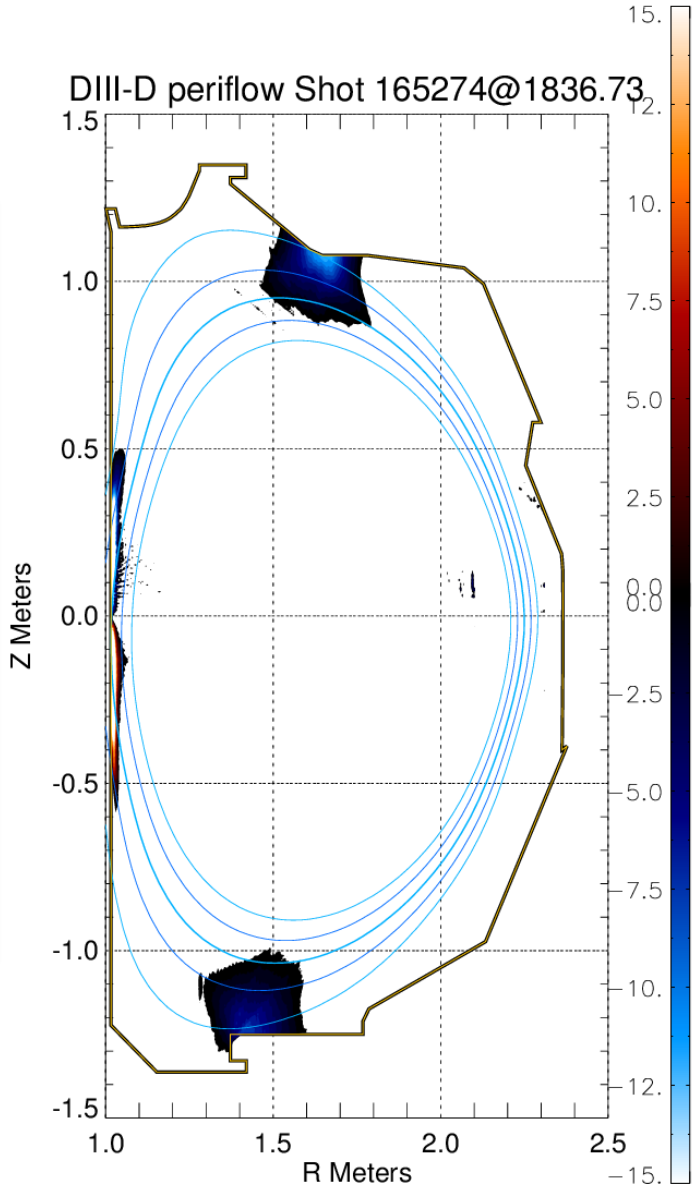
- Posix Thread Pool
  - Several Posix threads are created at start of analysis and after initialization wait on a mutex lock
  - Matrices staged in memory
    - Coordinate ordering
    - Compressed sparse row ordering
  - Frame of data moved into threads and control code (SpMV vs SpMV_t) set
  - Thread pool mutex unlocked
  - SpMV good performance
  - SpMV_t race condition limits performance
    - Working on sparse block order (Morton order within blocks)
    - Will be used for GPU implementation

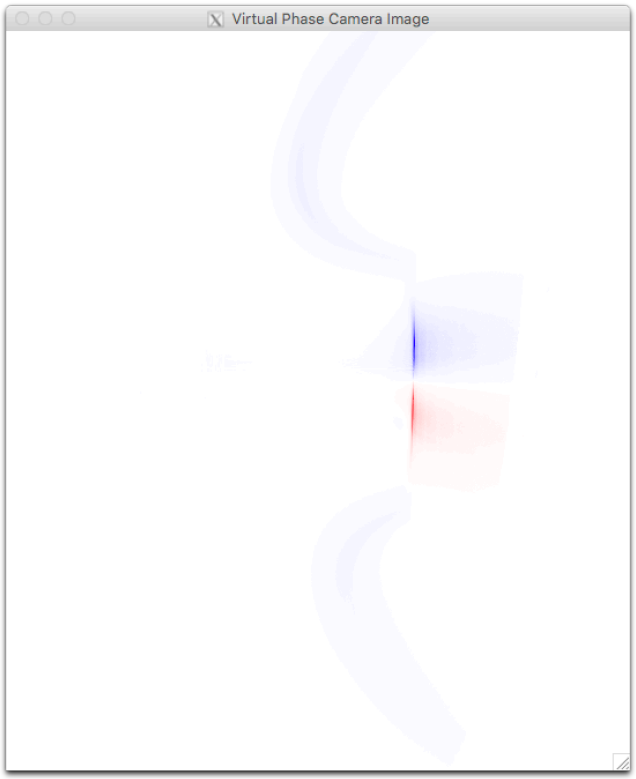
DIII-D NATIONAL FUSION FACILITY

Fusion Energy Sciences

Reconstructed Flow







DIII-D NATIONAL FUSION FACILITY

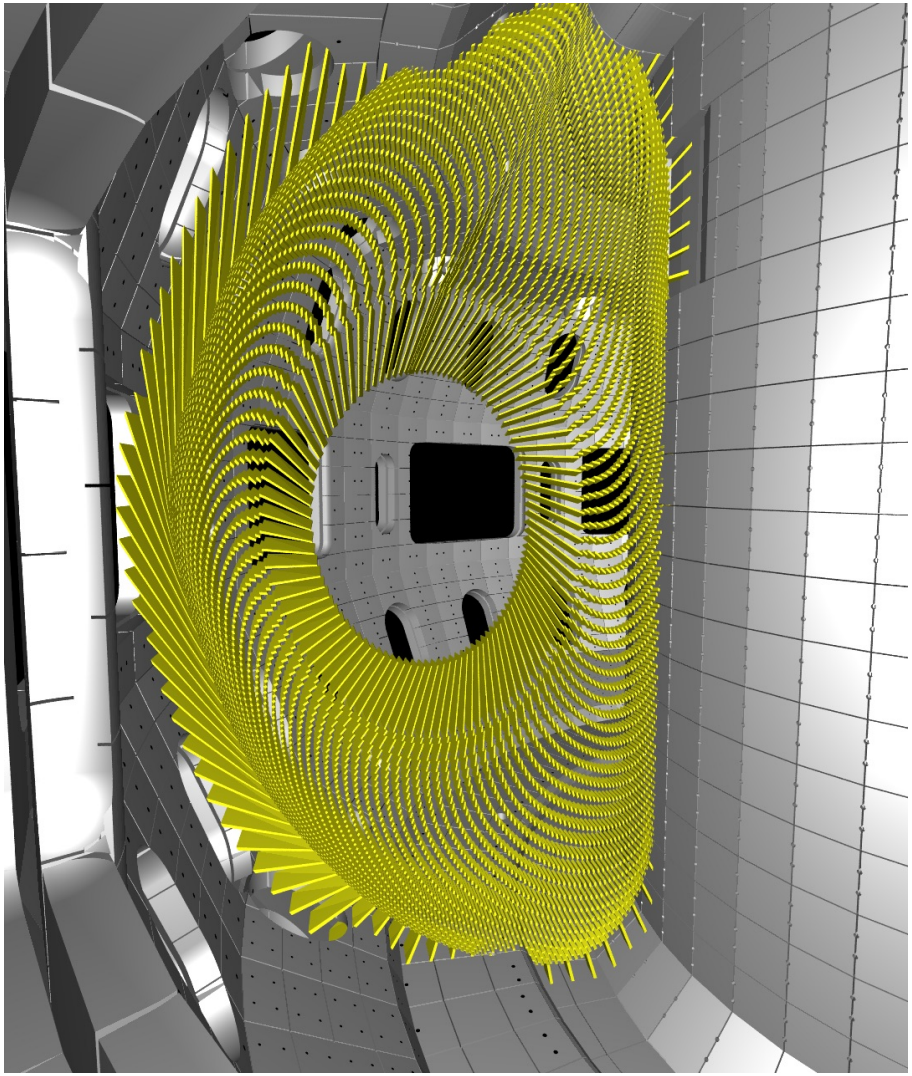
Fusion Energy Sciences

Synthetic Diagnostics

- Forward projection of theory code solutions
  - Direct comparison to diagnostic demodulated images
- Theory code grids too fine for diagnostic data to resolve for backprojection
  - Backprojection problem currently uses a 261x544 grid (.5cm)
  - Forwardproject problem only limited by our ability to calculate the response matrix
- Theory codes may include 3-D effects
  - Violate the toroidal symmetry requirement needed to solve the backprojection problem

EMC3-Eirene

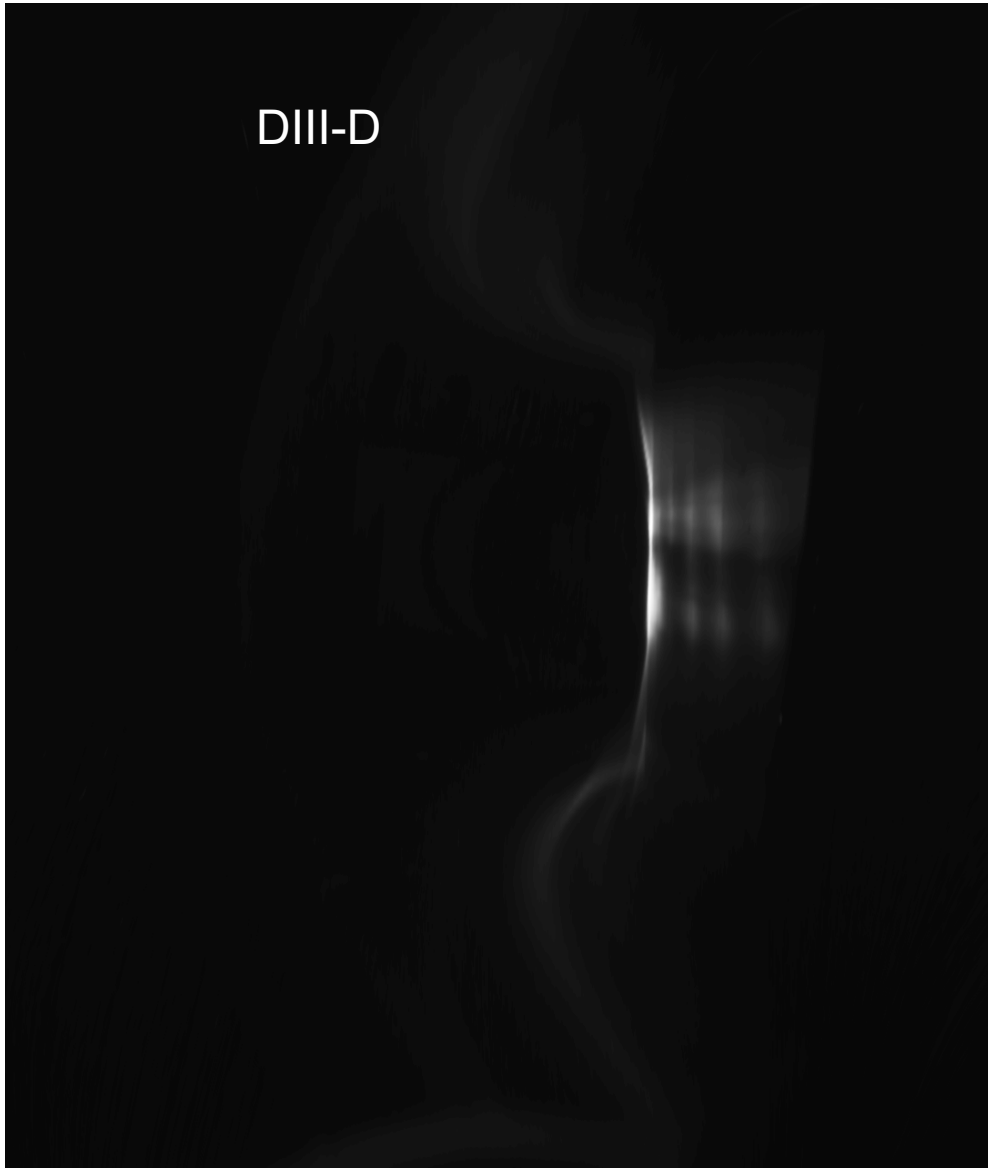
- 3D plasma edge transport code
- Grid 60x720x150
  - 11-sided polyhedrons
- Virtual camera 1280x1024
- Matrix is < 0.005% filled

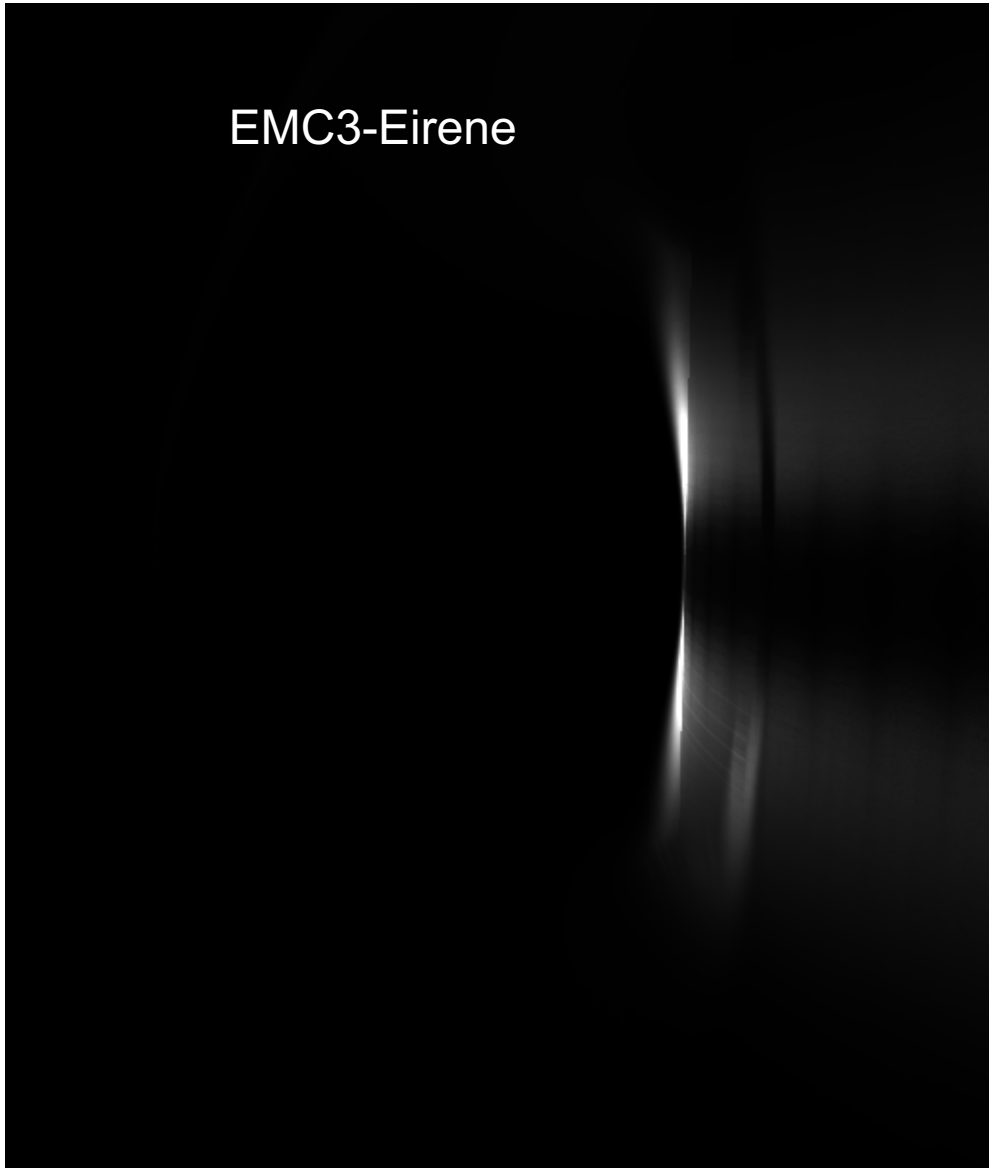


DIII-D NATIONAL FUSION FACILITY

Fusion Energy Sciences

EMC3-Eirene CIII





DIII-D NATIONAL FUSION FACILITY

Fusion Energy Sciences

Summary

- **We have a serial code for analyzing CIS data and solving the line integrated intensity and flow reconstruction problem**
  - We use a rendering model to correct for abberations
  - Framework for Posix thread pool parallel processing
  - Working on GPU based processing

- **Working on synthetic CIS diagnostic for EMC3-Eirene solutions**

DIII-D NATIONAL FUSION FACILITY

Fusion Energy Sciences