3D Heliospheric Reconstructions from the SECCHI White Light Coronagraphs Onboard STEREO: Overview of the NRL Approach

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Goal

- Develop, Test, Apply 3D tomographic electron density reconstruction techniques to solar features from low corona through heliosphere to 1 AU.
- Utilize B, pB, temporal, 2D white light coronagraph images and synthetic models from 2 (3) vantage points, construct (time dependent) 3D electron density distribution.
- Investigate limitations of reconstructing optically thin plasma from only limited viewpoints - underdetermined problem.

Science - Examples

- Polar Plumes - hydrostatic equilibrium solution of density vs. height, tube expansion, statistics.
- Equatorial, helmut Streamers - projection of current sheets, effect of AR’s, compare to 3D reconstruction using tie points (Liewer 2001), density enhancements vs. folds.
- CME’s - models - prepare for SECCHI, effect of observing angle, velocity, acceleration, deceleration, polarization, structure, evolution, etc.

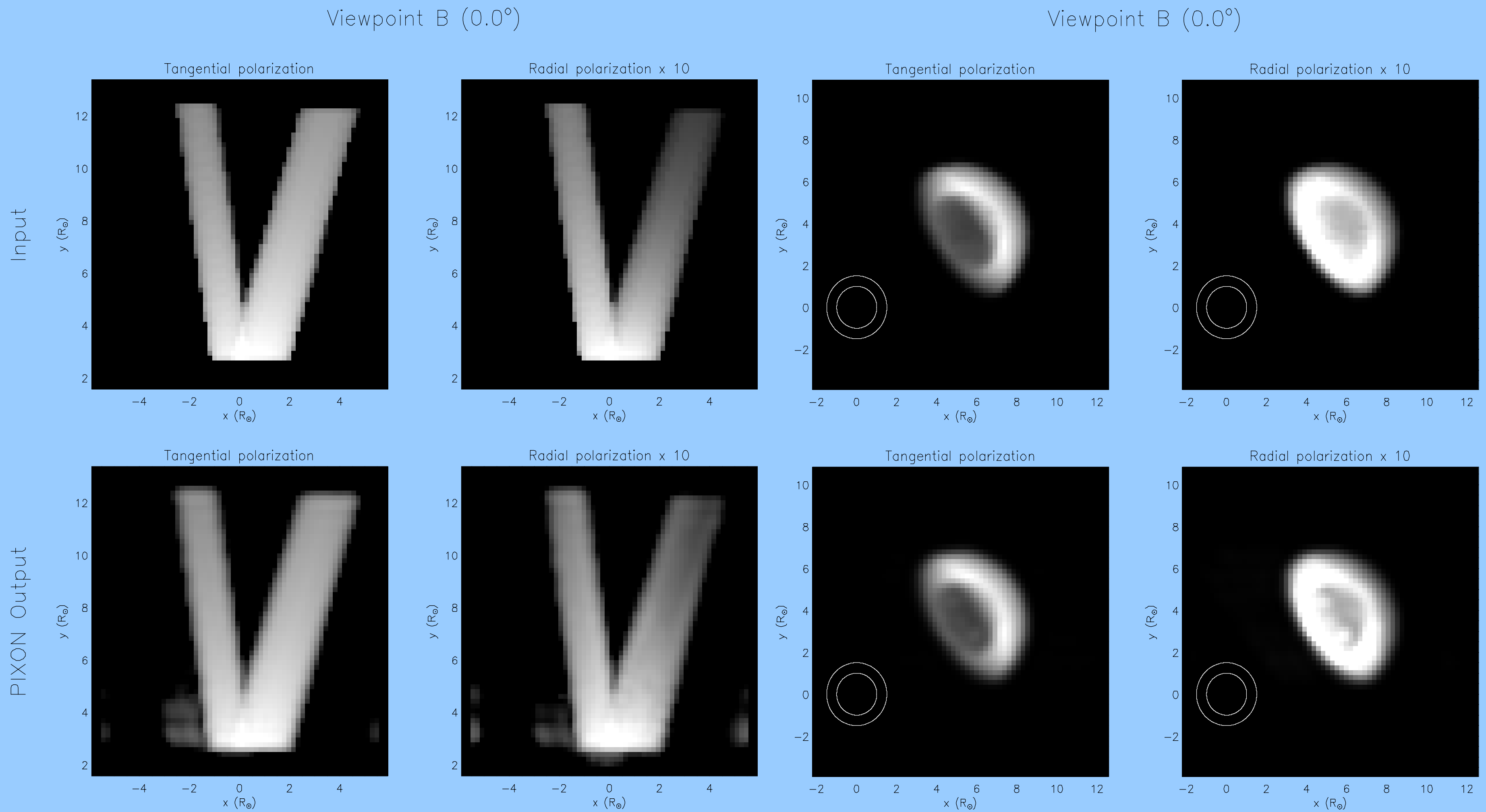
Key Aspects 1

- Renderer - Physics (Thomson scattering), tangential and radial polarization brightness, total brightness, finite viewer geometry, optically thin plasma. Details given in P. Reiser (Poster).
- Reconstruction Algorithm - PIXON (PIXON LLC), chosen for speed (large # voxels, up to 10^9).
- Visualization - 3D electron density distribution, time dependent (movies), multiple instrument, multiple spacecraft.

Key Aspects 2

- Detailed Discussion: Starter problems are simulated COR2 data, J. Cook (Poster).
- Problem 1: two cylinders (polar plumes), two and three viewpoints, infinite and finite geometry
- Problem 2: half shell (CME), two and three viewpoints, infinite and finite geometry, various S/C angular separations, various angular distance from plane of sky
- Observational DATA: LASCO polar plumes, streamers
- Model IMAGES: 3D streamer densities rendered from tie points, synthetic CME models

Sample Problems - Rendered DATA



Logarithmic [2.50e+13, 2.50e+16] photons sec^{-1} cm^{-2} sr^{-1}

Linear [0, 1.25e+16] photons sec^{-1} cm^{-2} sr^{-1}

What is PIXON?

- Pina, Puetter, Yahil (1993, 1995) - based upon minimum complexity, high performance, non-parametric, locally adaptive, iterative image reconstruction. Roughly analogous to multiscale (wavelet) methods.
- Commercial package - used in radio astronomy, Yohkoh HXT, remote sensing. Develop specific code jointly; PIXON develops tomography from limited (2, 3) views, NRL develops physics, geometry, visualization.
- Output is full 3D reconstruction of electron density- fits within noise model .

Why choose PIXON?

- Speed of 3D reconstruction: small number of iterations, intelligent guidance to declining complexity per iteration. Sample times have been 32x32x32 <15 minutes, 64x64x64 ~60 minutes, 128x128x128~6 hrs.
- Minimum complexity: As the problem is underdetermined, we must make some assumptions in order to progress. Another possibility is forward modelling, i.e. parameter fitting. Complementary approach. Questions concerning the number of parameters to number of observables. How strong are assumptions? Fine scale structure?

PIXON - Details

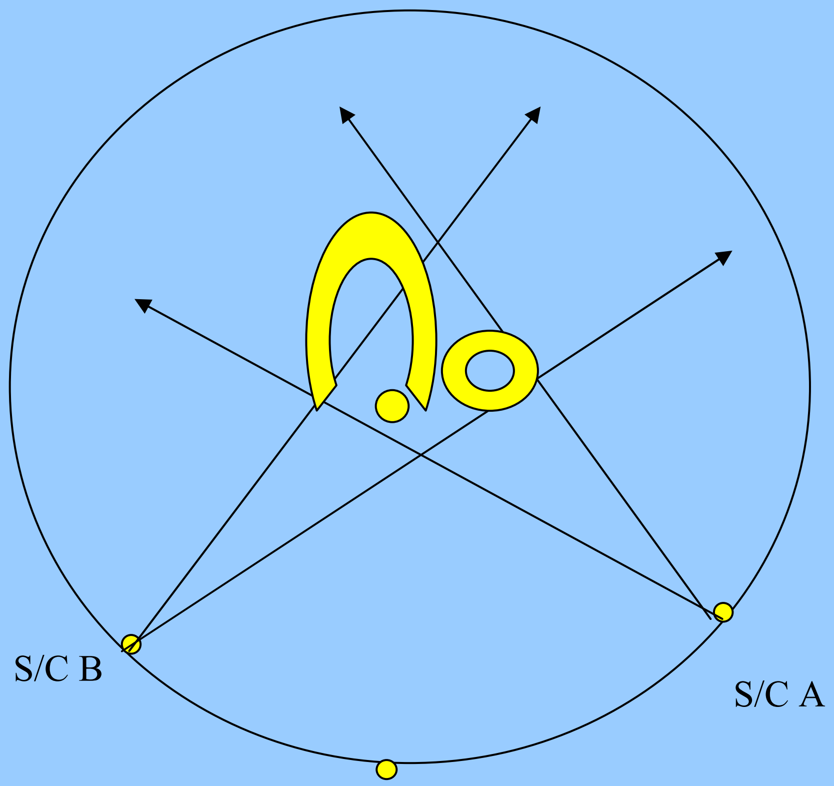
- Simple 2D Problem, DATA (D)=observation, IMAGE (I) = reconstructed image, H=PSF, K=pixon kernel, Φ=pseudoimage, N=noise

$$D(x) = \int dy H(x,y) I(y) + N(x)$$

$$I(y) = \int dz K(y,z)\, \Phi(z)$$

- 2 Step solution a) minimize χ^2 by Φ, b) minimize # pixons and maximize size locally - each part is iterative and iterate steps.
- PIXON shapes - spherical density, can change shape if necessary.

Limitations



- Limited viewpoints - underdetermined solution, best seen with multiple objects in field of view, hidden density, e.g. hollow sphere, introduction of third vantage point helps with some objects
- Limited overlap regions in viewpoints, i.e. object outside one field of view

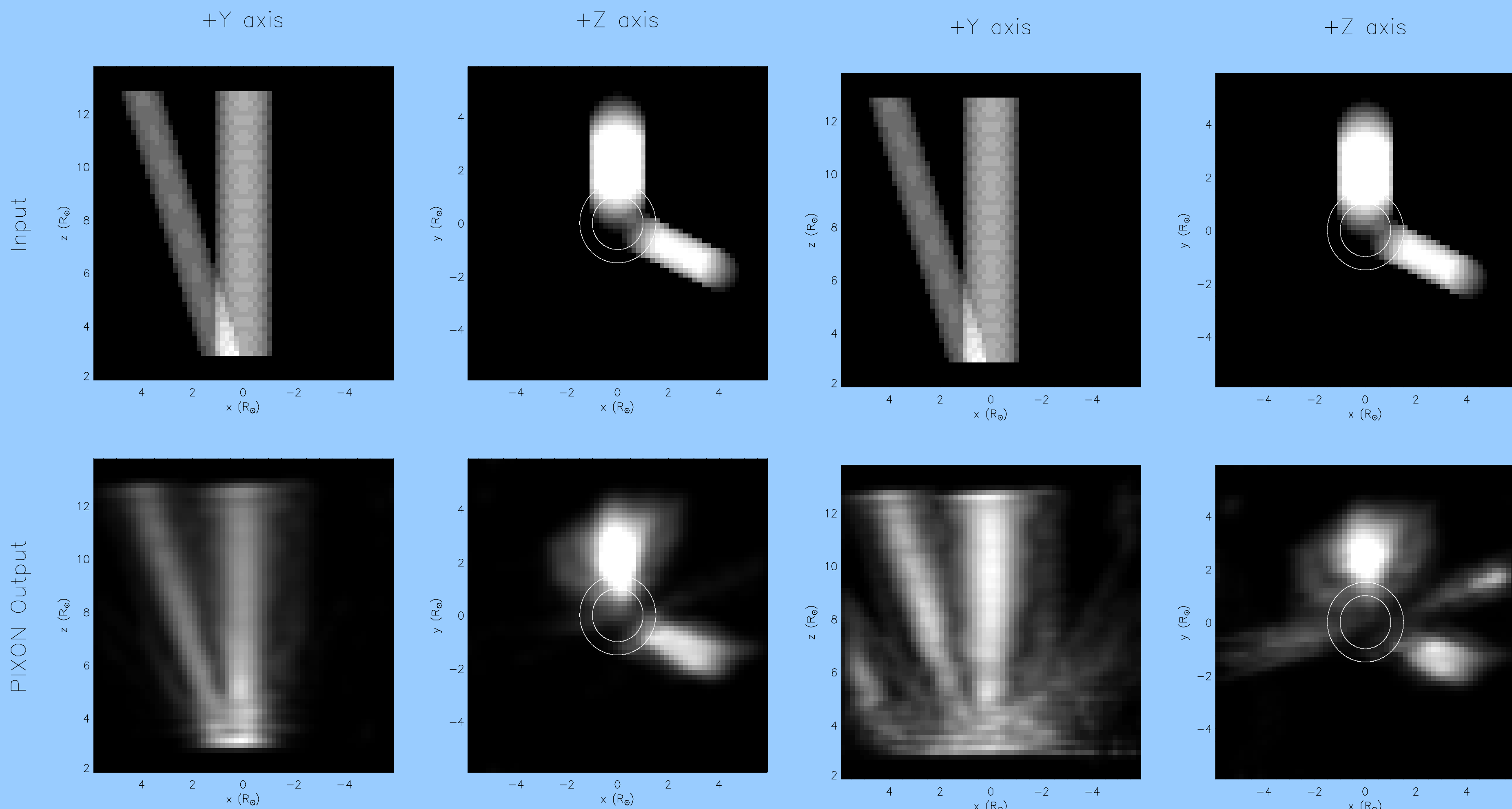
PIXON - Studies/Enhancements

- Brightness input versus polarized brightness
- Input starter electron density distributions - robustness issue
- Hierarchical algorithm - similar to adaptive gridding, reconstruct at low resolution and only finer resolution where needed, speed (large number of voxels) and hopefully guided convergence
- Tie points - difficult in WL and large angles
- 4D - addition of temporal images, question of evolution of structure vs. imposed constraints.
- Physical Model constraints, e.g. global CME models?

Visualized IMAGEs two polarizations

S/C Sep=37

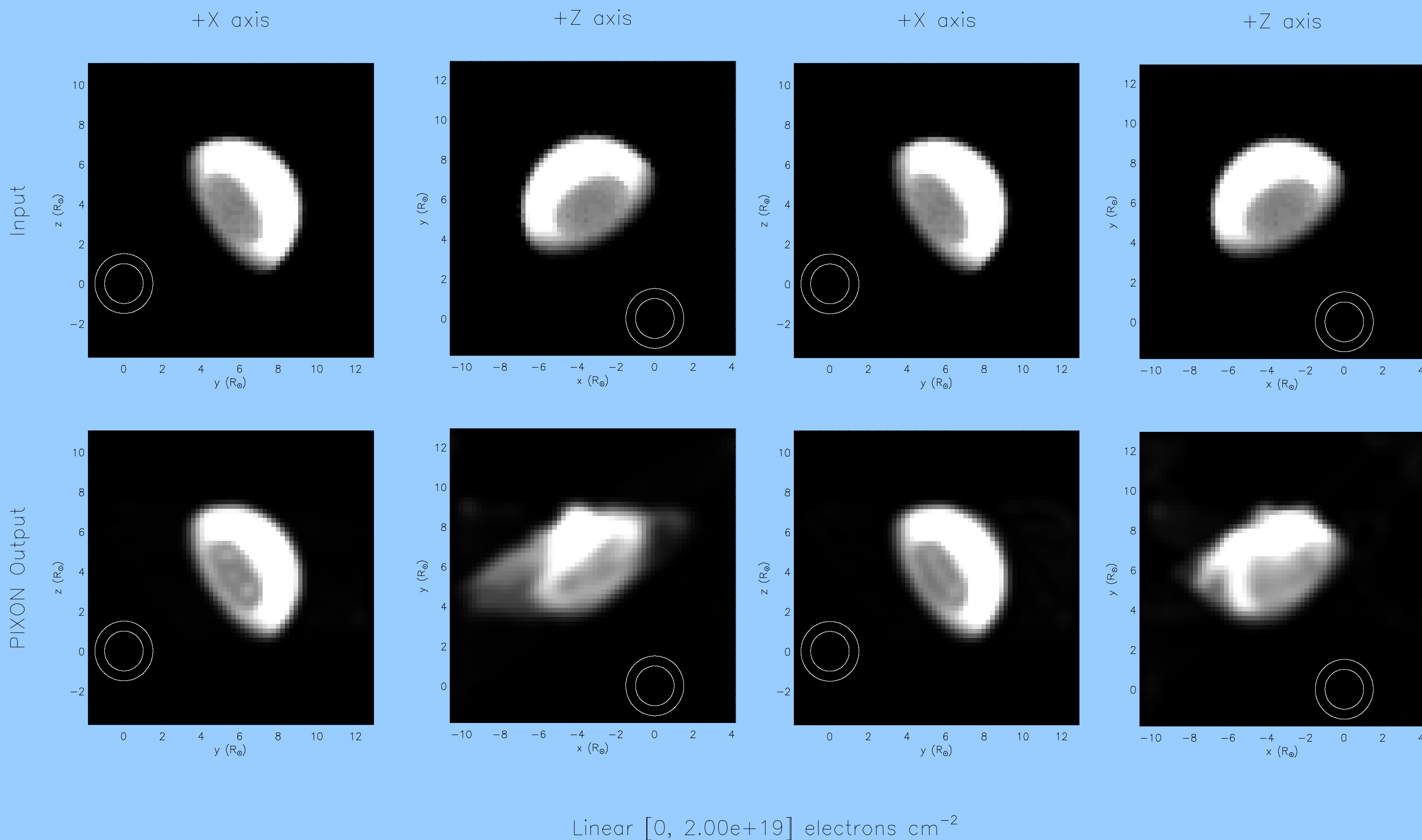
Visualized IMAGEs total Brightness



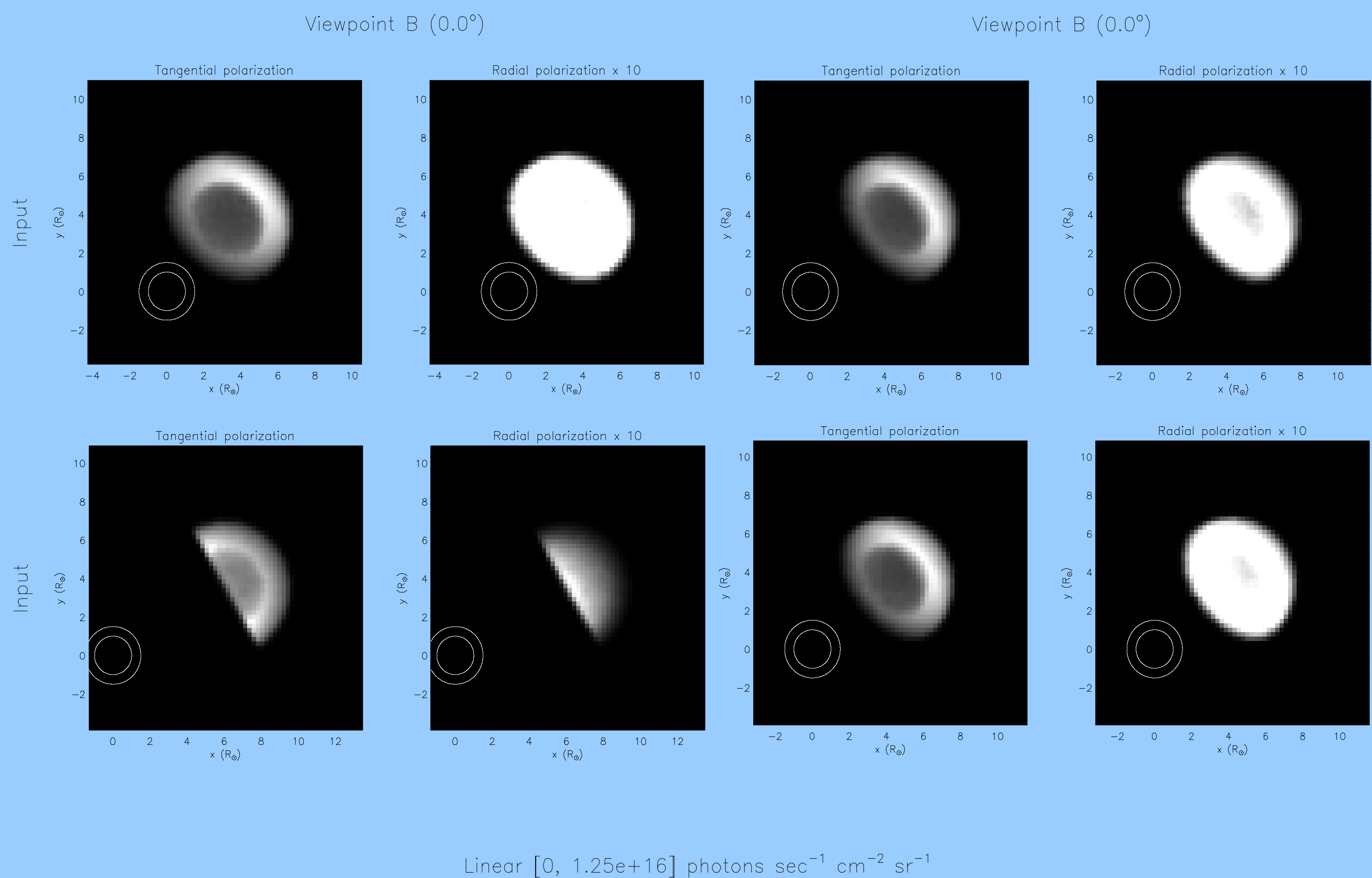
Linear [0, 3.00e+19] electrons cm^{-2}

Two Viewpoints -IMAGEs Three Viewpoints - IMAGEs

S/C separation = 37



Angle from the plane of the sky - tangential + radial polarization helps expand useable angles: 60, 45, 0, -45 degree angle - Rendered DATA



Future Work

- Continue refining reconstruction algorithm.
- Reconstructions from Heliospheric Imager: observer imbedded in viewpoint, theoretically simply a “bookkeeping” question.
- Visualization Techniques: 3D from any angle, coordination with 2D observations by SECCHI from both spacecraft, coordination with other STEREO observations, e.g. particles and fields experiments (IMPACT, SWAVES, PLASTIC), coordination with MHD models.

Conclusions

- 3D reconstructions are achievable!
- There are real limitations that we must understand and that will define which reconstructions are possible.
- Direct application to SECCHI will require substantial effort and collaboration; we truly desire help in pulling the most out of the data.
- Web Site: http://stereo.nrl.navy.mil/

  follow link to 3D R&V. This contains all necessary details to develop reconstruction methods for our sample problems.