STEREO 3D Reconstruction Studio

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This is a technical report on our suite of tools that set up and solve reconstruction problems. Our software does non-parametric tomographic inversion, with a little bit of forward modeling capability. 3D Reconstruction in general finds the density distribution that best reproduces the observed data. Tomographic solutions are often non-unique, but the more distinct views from different angles you use, the greater the confidence in your solution. Our primary method of tomographic inversion, Pixon, is sensitive to the signal-to-noise ratio, and typically requires an S/N > 10. It fits according to per-pixel photometric information and requires accurate calibration and geometric placement.

Our reconstruction software is called 'S3DRS' for STEREO 3D Reconstruction Studio and will be delivered to SolarSoftware as a package ($SSW/packages/s3drs). The package includes:

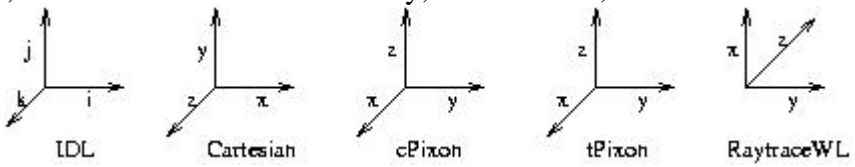
- IDL routines including the GUI, a stand-alone renderer and backprojection, and tools.
- C-code for the optional (faster) renderer
- A compiled IDL save object containing Amos's Pixon library

The GUI can be used to sset up reconstruction problem geometries with real data or synthetic model data, optionally creating an initial back-projected limiting volume for potential solutions. Users can apply Pixon or forward modeling, or export the problem into their own solver.

The package currently assumes you are using coronagraph data from STEREO and/or LASCO, also requires secchi_prep and related SECCHI routines. Adaption for EUVI or other data is conceptually possible but has never been tested. Use with HI is not yet available because the software assumes a sun-centered frame of overlapping views. Work to date have focused on CMEs seen by COR2, but in theory reconstruction of streamers, other features, and the quiet corona is also possible.

AXES, GEOMETRY AND DENSITY CUBES

We use the term 'data' for 2D satellite observations, synthetic data, or a mix, and 'image' to refer to the 3D density cube solutions. Reference frames are a constant headache in reconstruction. Teams use different reference frames for positions, primarily differing on whether they are ecliptic or solar plane, and relative or absolution. Most popular are Carrington and Heliospheric Aries Ecliptic (HAE), with HEEQ, Stonyhurst, and others also used. Internally, we use HAE, which is akin to the STEREO plane.



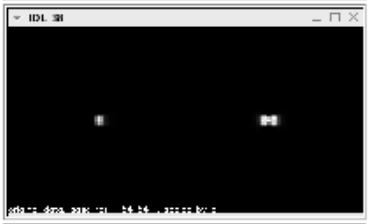
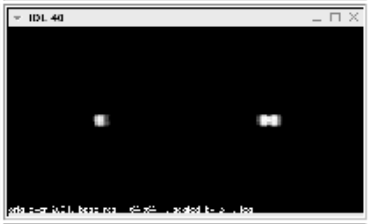
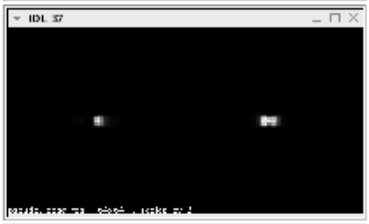
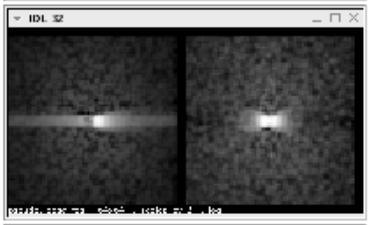
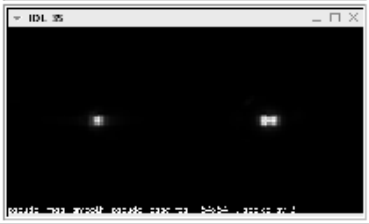
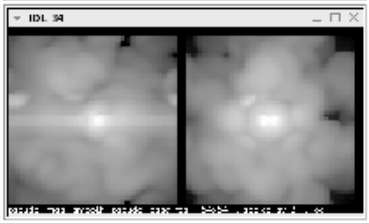
For exchanging density cubes, the "densitycube.pro" routine creates a FITS file that includes WCS coordinates. This has worked for delivering products (especially Arnaud's FMs) to the Tom Bridgman in the SVS group at GSFC. The densitycube routine are checked in with the S3DRS package.

Visualizing density cubes can be done as a quick diagnostic X-Y-Z (mass sum or rendered) projections, making a flyby (mass sum or rendered) movie, using the wireframe rotator 'render_rot_gui', or using IDL's internal 'slicer' or 'slicer3' to do isosurface contours. We will discuss these during the demo.

PIXON AND OTHER METHODS

Pixon has been well-covered in earlier presentations. Briefly, it fits using the fewest Pixon elements, which are similar to supervoxels of varying extent. Typically one pixon element covers several hundred voxel elements. The attached figure compares a fit using just a gradient minimization with pixels, versus using the Pixon elements for the minimization, on linear and log scales. Below, we use the wide log scale to artificially enhance the fitting artifacts for the two methods.

Illustration of Voxels/Pixels vs Pixons

Run	Data	log(Data)
Original data		
Pseudo-only step		
Single smoothing: Pseudo, Smooth, Pseudo		

Reconstruction algorithms include Pixon Inversion, Forward Modeling, and backprojection minimization. Pixon is a proprietary non-parametric method to find the least complicated underlying distribution. Forward modeling rotates and resizes a chosen shape to reproduce the data. (Note that due to the IDL 'powell' algorithm, FM runtimes are lengthy.) Backprojection minimization is a one-pass method to define the maximum spatial extent of the distribution, typically used to get a 1st order solution.

There are several ways that the community may end up using S3DRS. Most commonly, people will use it with Pixon to do non-parametric inverse reconstructions. Users can also explore forward modeling using the occasionally tedious 'powell' method, which can both position a model and alter the model's parameters, but which can be ineffective if you ask it to do both at the same time. I have also written a rotational tomography module, to add to the GUI as a minimally-tested feature, should time allow. This would be useful for researchers such as Rich Frazin, who might otherwise need to write their own SECCHI ingest routines or renderers.

RENDER AND VALIDATION

We use a renderer, now called 'pr_render', conceived by Paul Reiser, both within reconstruction and as a stand-alone utility. The name can mean either "Pixon Renderer" or "Paul's Renderer". There is both an pure IDL version and a faster version that requires a compiled C routine. My primary contribution was to calibrate this (originally off by 10x) and to enable it to do 3D geometry (versus the near-planar restrictions it had originally). We tested the renderer against book values for a Saito background, and also against RaytraceWL, to good results (Figure, below).

The renderer assumes pixel:voxel uniformity and has problems rendering if the pixel-to-voxel resolution is far from 1:1. This causes trouble when combining very different detectors, e.g. COR1 and COR2 together, or when assuming a specific detector (COR2) then doing an approach 'flyby' simulating zooming into the target.

The renderer includes an equivalent backprojection method 'pr_backproject' necessary for some reconstruction methods, including Pixon. Forward modeling does not require backprojection.

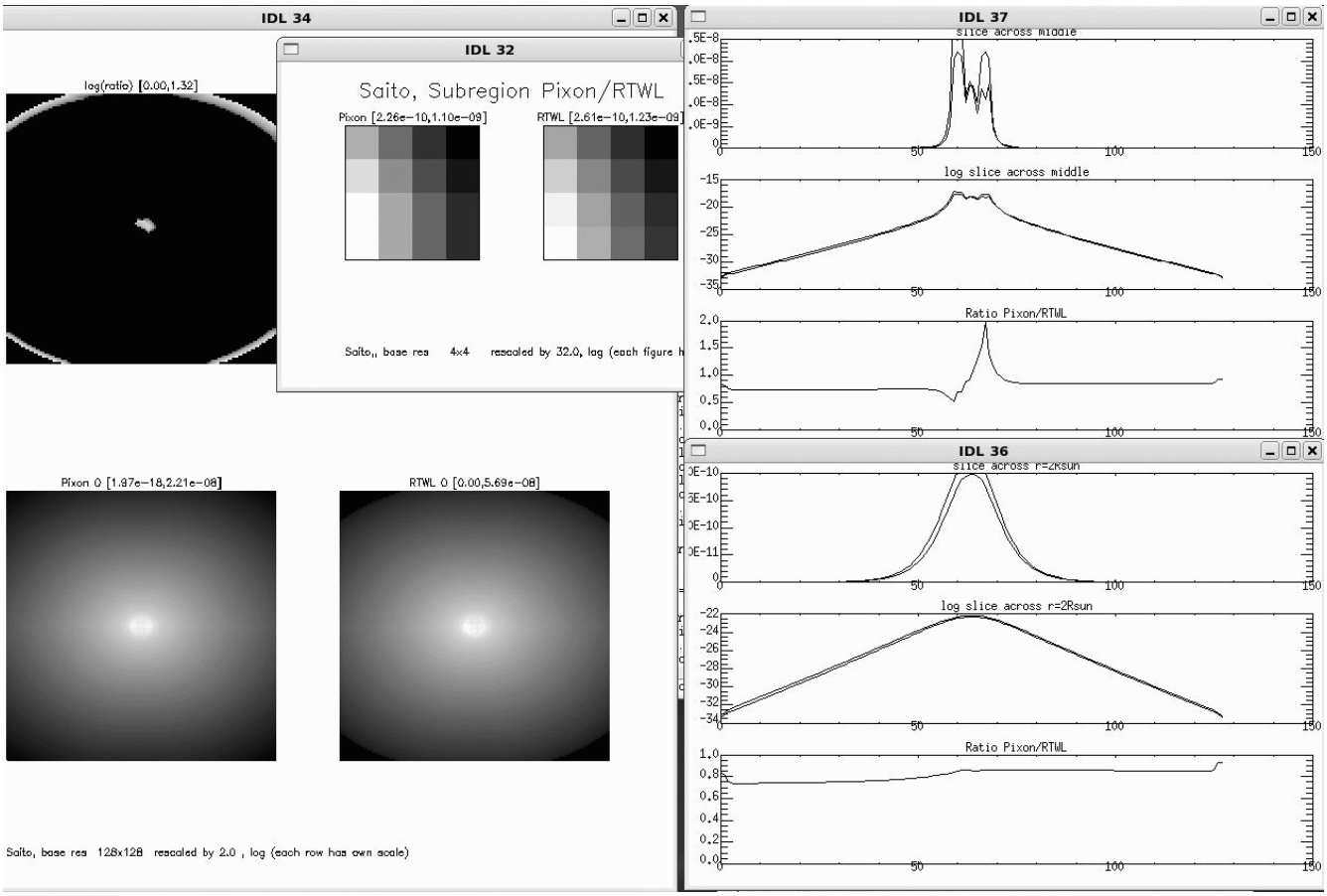


FIGURE: A Saito model background rendered with pr_render and RaytraceWL, including a zoom in to a region and, on the right, plots across a single row of the image for both renderers.

If improvements are desired, the lab can consider switching to RaytraceWL which is supported by NRL. However, PIXON and some other methods do require a backprojection method, which RaytraceWL does not yet have.

S3DRS GUI

The GUI walks through the reconstruction problem basically the way we spec-ed it out 3 years ago:

1) select either real or synthetic data
2) define the data (real: by date and instrument, synthetic: set positions and instruments)
3) (optional) add additional masking to focus on a specific region
4) (optional, recommended) adjust the S/N ratio to artificially enhance the signal
5) Choose a reconstruction method, run it, then look at the visualizations

At the bottom of each screen is a button near an arrow, which will take you to the next step. You can go back to any step at any time. We update the data as currently pre-processed at each step. On the final visualization page, we also include orthogonal X/Y/Z mass projections of the solution. The full problem input & output is automatically saved. We also auto-save the solution image in FITS format.

Developers can add their own algorithms or methods directly into our software, using our developer's guide to help with the modifications. Since our software handles data ingest, geometry, problem setup, and solution visualization, it is a good framework to try different inversion minimizations. PIXON is, after all, only one method of several already implemented.

The IDL tools within the package also include widgets, visualization tools, and 3D density cube manipulations that may be of general use to the IDL community.

DISSEMINATION AND LICENSING

We will disseminate the package via SolarSoftware. We will send email the STEREO team and send a notice of the release to the SPA Section Newsletter. I would like to get a short paper out to either ApJL or Experimental Astronomy. I am open to other avenues of mention as well.

We have worked out license terms with Amos Yahil verbally and are waiting for email confirmation. The terms are that we can freely disseminate a compiled (IDL save file) version of Pixon within our package via SSW, so long as we use a 'click-through' license where users agree to the Pixon terms. The terms are 'must acknowledge in papers' and 'please email us paper titles that used Pixon'.

In addition, I have added a click-through for use of this lab's S3DRS package in general, asking for an acknowledgment in any published papers.

Documentation will ultimately be in the SECCHI wiki at http://secchi.nrl.navy.mil/wiki/

VISUALIZATION , STANDARD DIAGNOSTICS, AND SCIENCE

Density cubes can be viewed as X-Y-Z (mass sum or rendered) projections, as a flyby (mass sum or rendered) movie, interactively in the wireframe rotator 'render_rot_gui', or using IDL's internal 'slicer' or 'slicer3' to do isosurface contours. We will discuss these in the demo, and present some sample science results using our standard diagnostics package.