Stereographic Analysis of Coronal Features for the STEREO Mission

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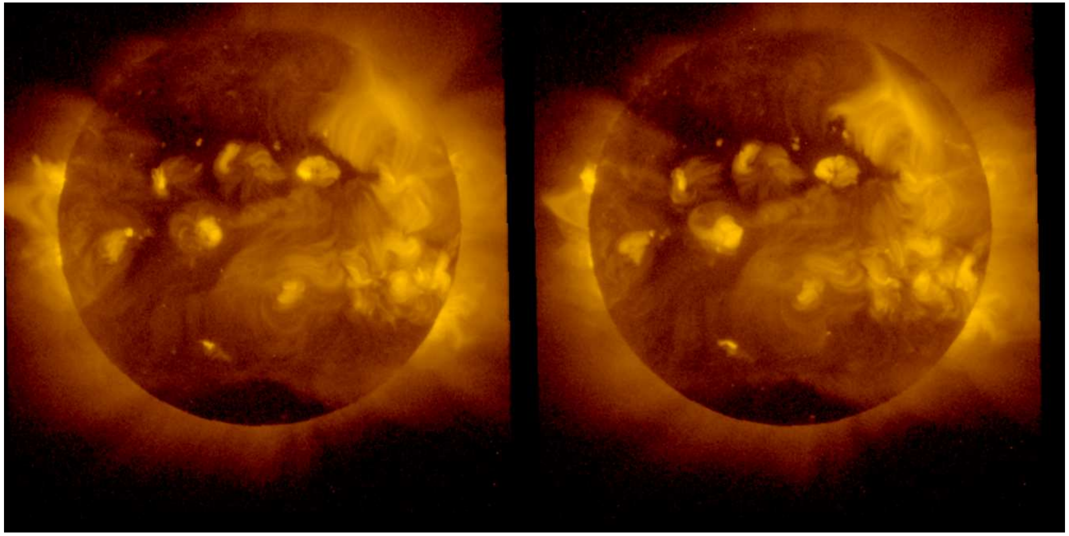
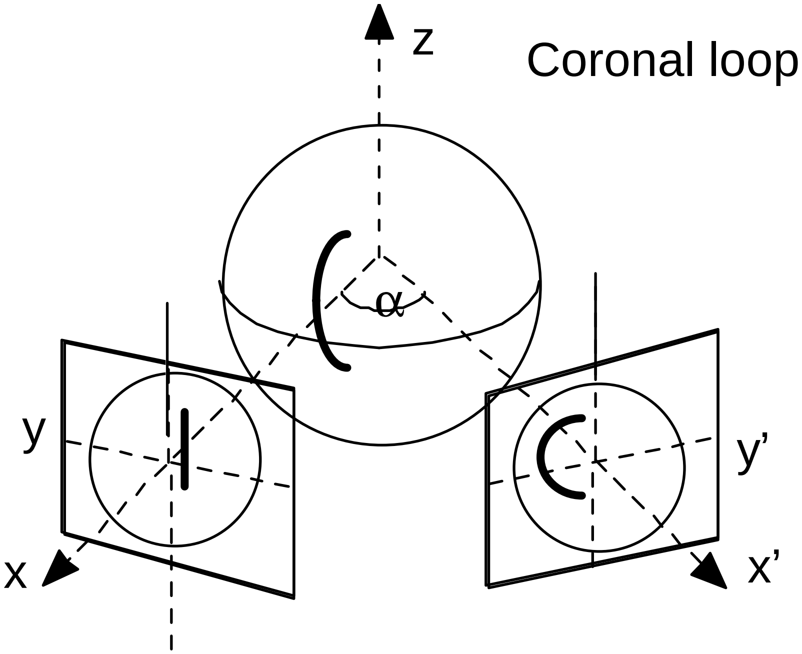


Outline

- STEREO analysis using triangulation
- Progress on Automatic Feature Tracking
    - *Test stereo loops and their 3D reconstruction*
    - *Coronal EUV loop feature tracking*
    - *Coronal Mass Ejection (CME) tracking*

Determination of 3D Geometry from Stereo Image Pairs

Triangulation: Determine 3D location of a point seen from two known locations



Coronal loop viewed from two angles separated by α

Coordinates of two views related by
simple rotational transform

$x = x'\cos\alpha + y'\sin\alpha$

$y = y'\cos\alpha - x'\sin\alpha$

$z = z'$

Stereo Images give y,y’ , Solve for x,

$$x = \frac{y' - y\cos\alpha}{\sin\alpha}$$

- In principle, two views determines completely (x,y,x) solar coordinates of loop
- For same Ņfeature Ó in time sequence of images, determine (v_x, v_y, v_z)
- Technique limited by ability to locate same Ņfeature Ó in both image

Tiepointing Tools for Triangulation of Solar Features

Tiepointing tools to locate the same “feature” in both images

Tiepointing by Hand & Eye

- Use commercial software (ENVI) on conventional workstation
- Use 3D Cursor Tiepointing Tool *(developed at JPL)*
  - *Needs workstation supporting stereo viewing*
- ***Tools tested using synthetic stereo image pairs***

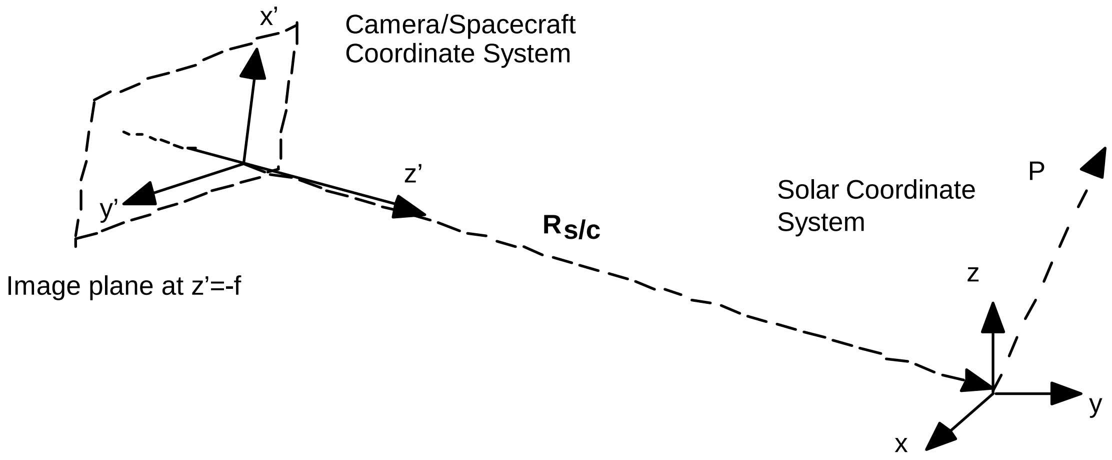
Present Research: Automatic Tiepointing using Automatic Feature Tracking

•Feature tracking for loops - test loops and real data
•Feature tracking for CMEs - real data

XYZSUN - 3D Solar Coordinates from Image Tiepoints

Computes transformation from solar coordinates to telescope coordinates
& projection on image plane

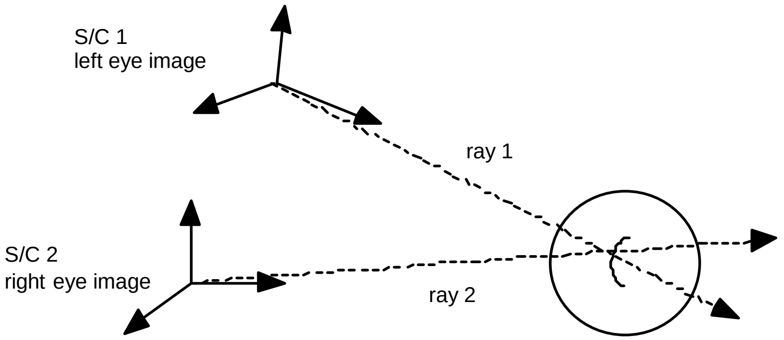
Uses software developed at JPL for planetary image processing



$P' = M\,P + R_{s/c}$

where M is transformation matrix
P' is point P in camera frame

“Location” is point of closest approach of rays computed from 2 images



Only perfect data would have two tiepoints map to exact same 3D location

Sources of Error in Triangulation

1. Ability to identify a feature in both images

Feature will look different from different angle

Integrated line-of-sight effects contribute to this

ŅFeatureÓ may not be real Š may be line-of-sight effect

2. Error in 3D determination depends on x-y error and angle

Resulting error in feature height z is magnified by 1/sinα (α=stereo angle)

=> Error in height $\Delta z/R_{sun} = \Delta x/(R_{sun} \sin \alpha)$

Take error $\Delta x = 1$ pixel *(requires excellent registration and feature identification)*

For STEREO/EUVI image with $R_{sun} \sim 700$ pixels, $\Delta x/R_{sun} = 0.15\%$

$\alpha = 15°$ => $\Delta z/R_{sun} \sim 0.6\%$ $\Delta z = 4200$ km

$\alpha = 45°$ => $\Delta z/R_{sun} \sim 0.2\%$ $\Delta z = 1400$ km

x-y (Δx) error is very sensitive to both knowledge of spacecraft pointing and resolution of image

- **Implication of 1+2 together**

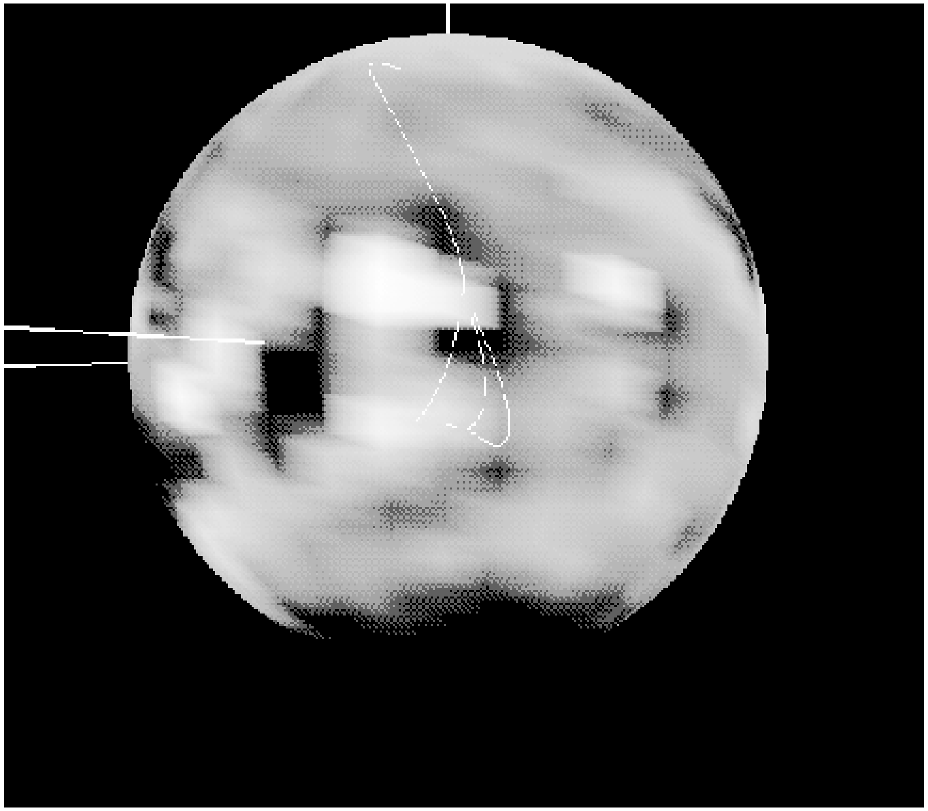
  Angles $15° < \alpha < 20°$ may prove better than $25° < \alpha < 35°$

Automatic Feature Tracking for Coronal Loops as seen in EUV and Soft X-ray

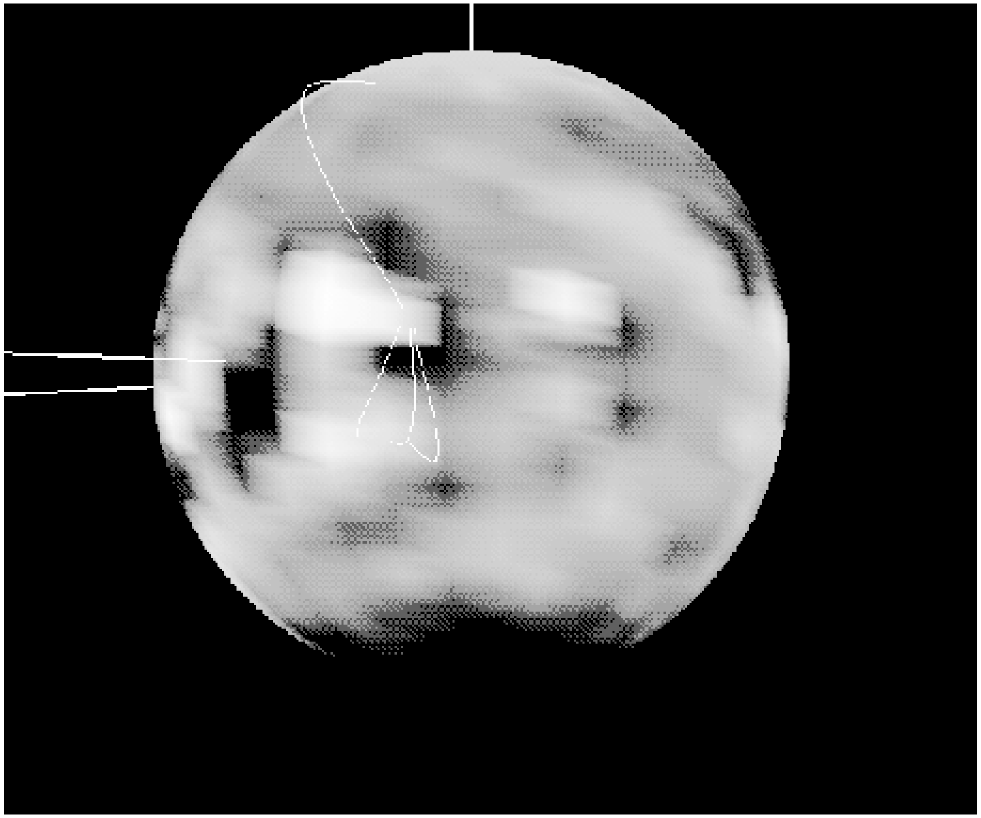
A. Test Loops - Case 1 of 2

Original Stereo Data - 2 Views of 3D Coronal Loops (angle=15º)

Loops computed from measured solar magnetic fields at photosphere*



SUN: 17May1994 CML=125 °

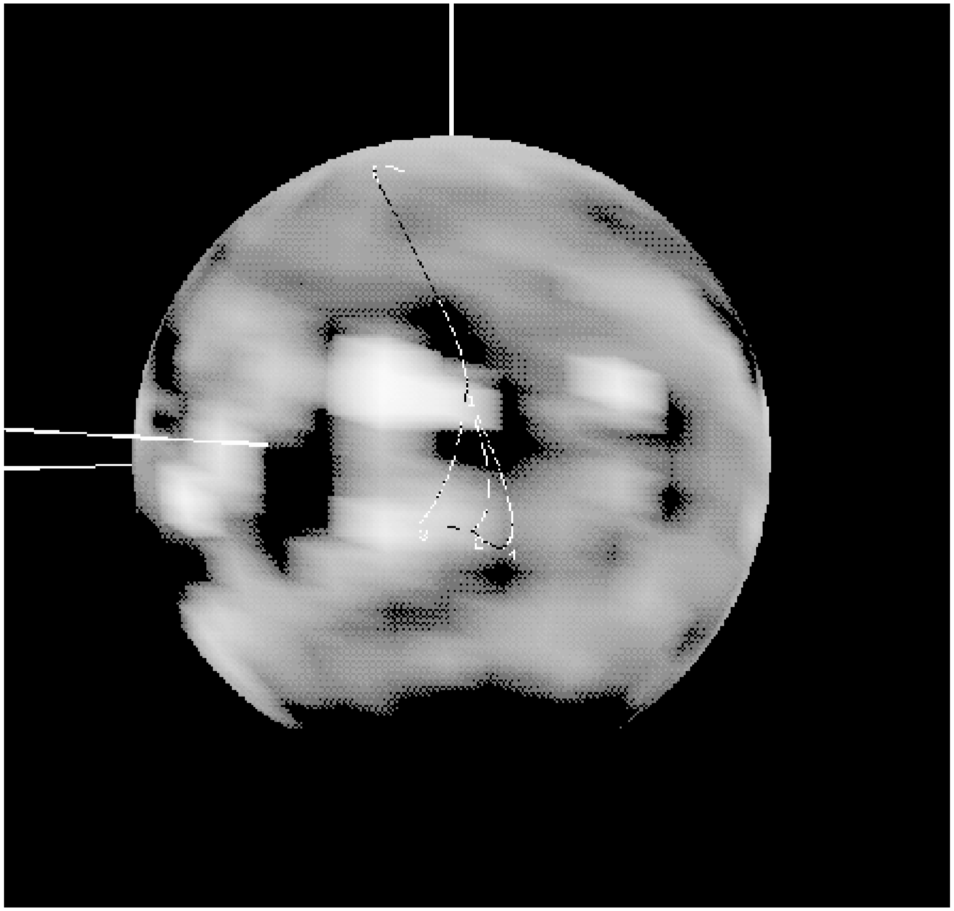


SUN: 16May1994 CML=140°

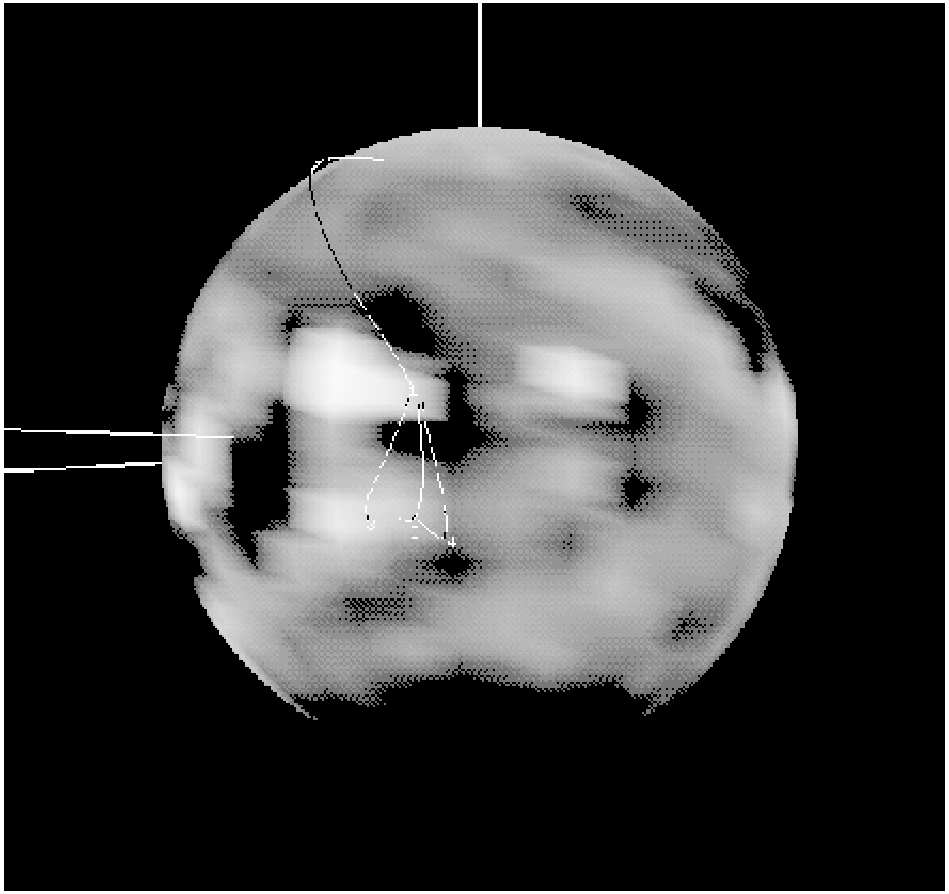
** Pattern on sphere shows magnetic field at photosphere (magnetogram)*

Results for Automatic Stereo Feature Tiepointing

Algorithm: Follow along bright features *Dark Segments on Loops are Matched Stereo Points**



SUN: CML=125 °

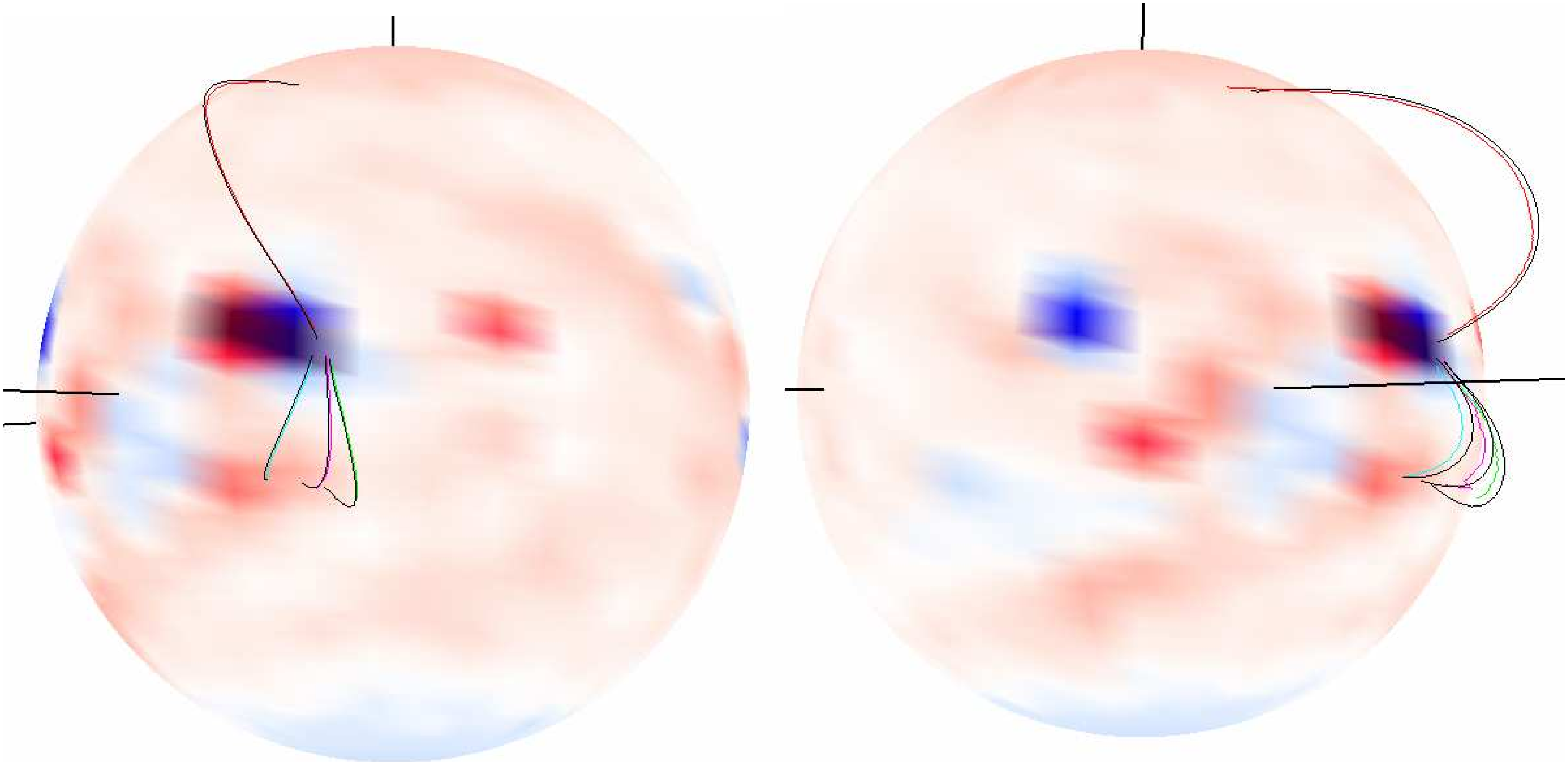


SUN: CML=140 °

* *Matched Stereo Points: Rays from the two points cross near the Sun*

Comparison of Reconstructed 3D Loops with Original

3D loops reconstructured from tiepoints shown as colored loops overlying original black loops



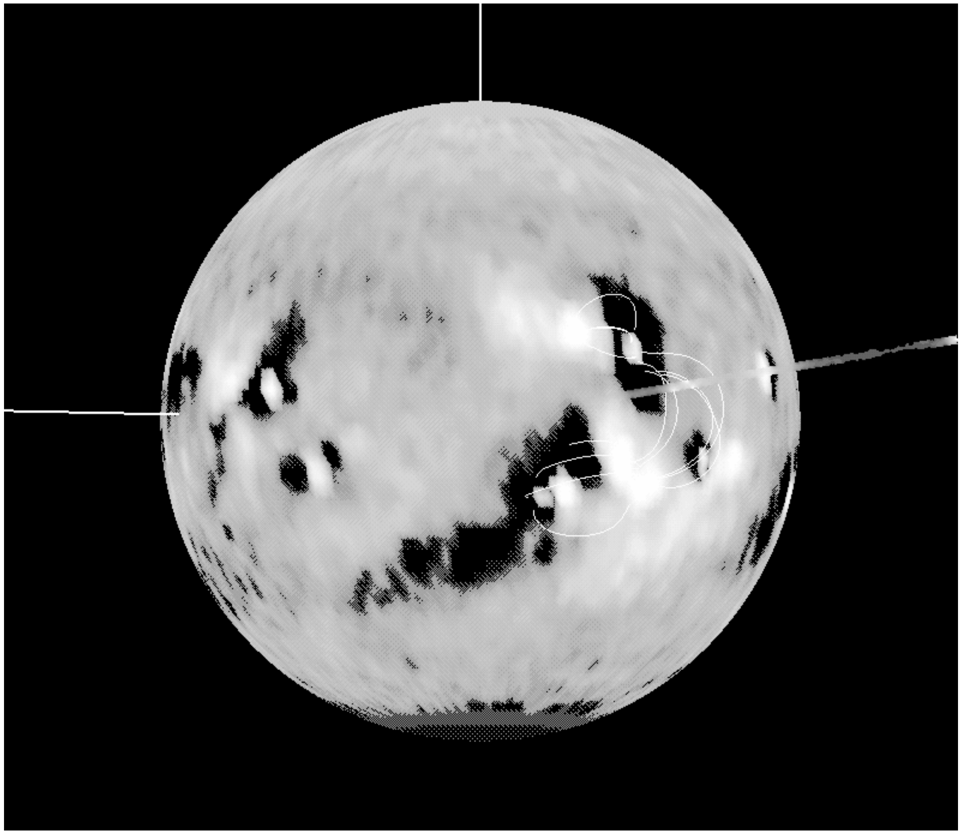
Successful Automatic 3D reconstruction of loops from stereo pair using automatic tiepointing and XYZSUN

Automatic Feature Tracking for Coronal Loops as seen in EUV and Soft X-ray

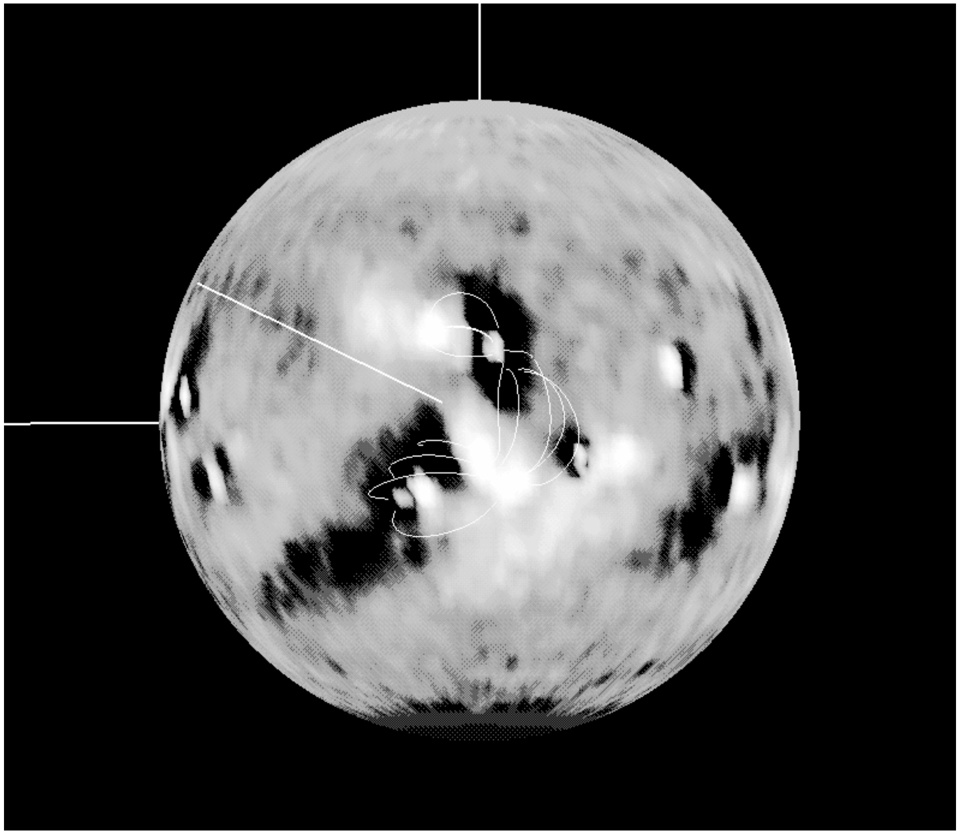
A. Test Loops - Case 2

Original Stereo Data - 2 Views of 3D Coronal Loops (angle=26º)

Loops computed from measured solar magnetic fields at photosphere*



SUN: 5January1994 CML=70 °

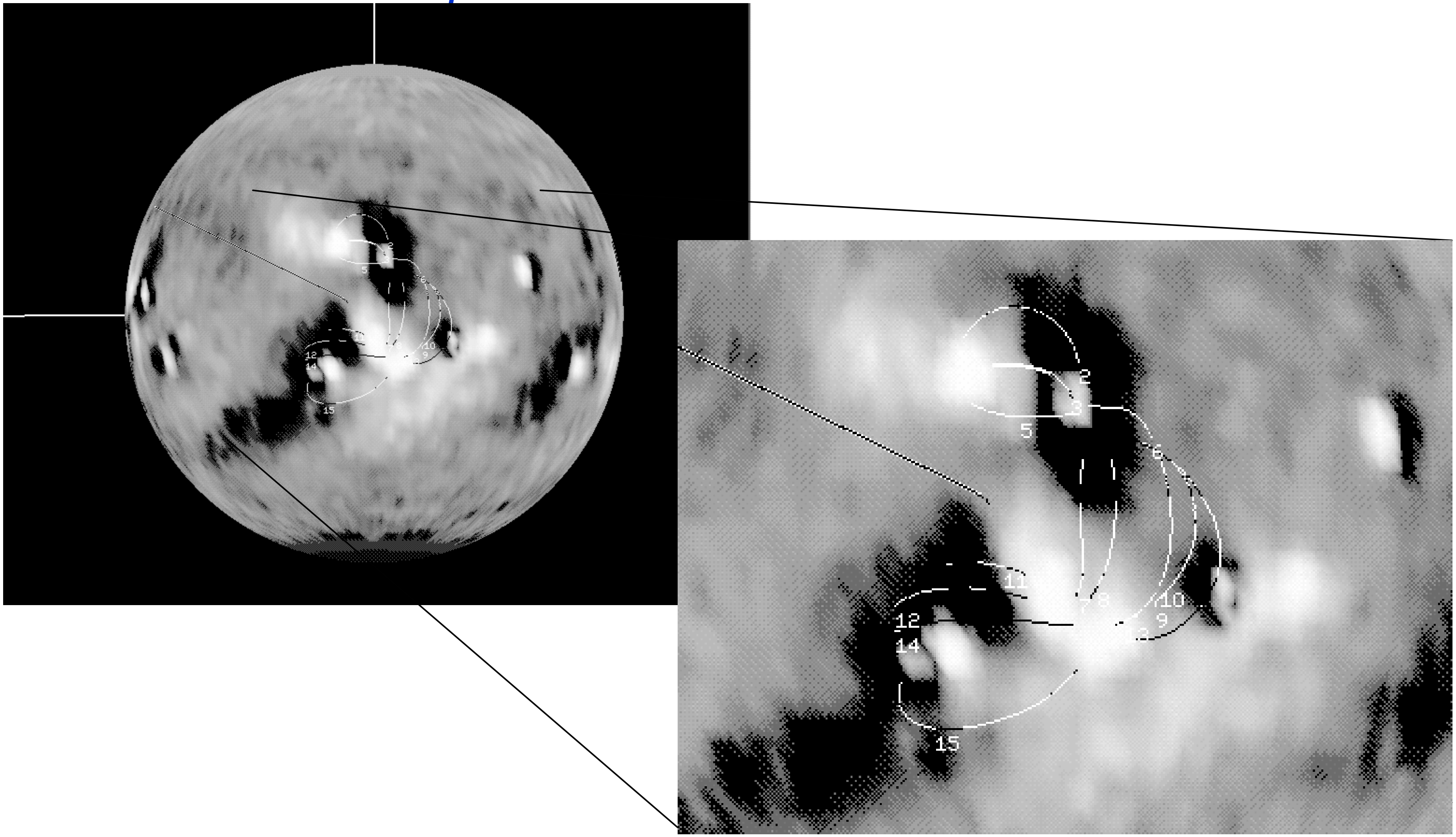


SUN: 3January1994 CML=96°

** Pattern on sphere shows magnetic field at photosphere (magnetogram)*

Results for Automatic Stereo Feature Tiepointing

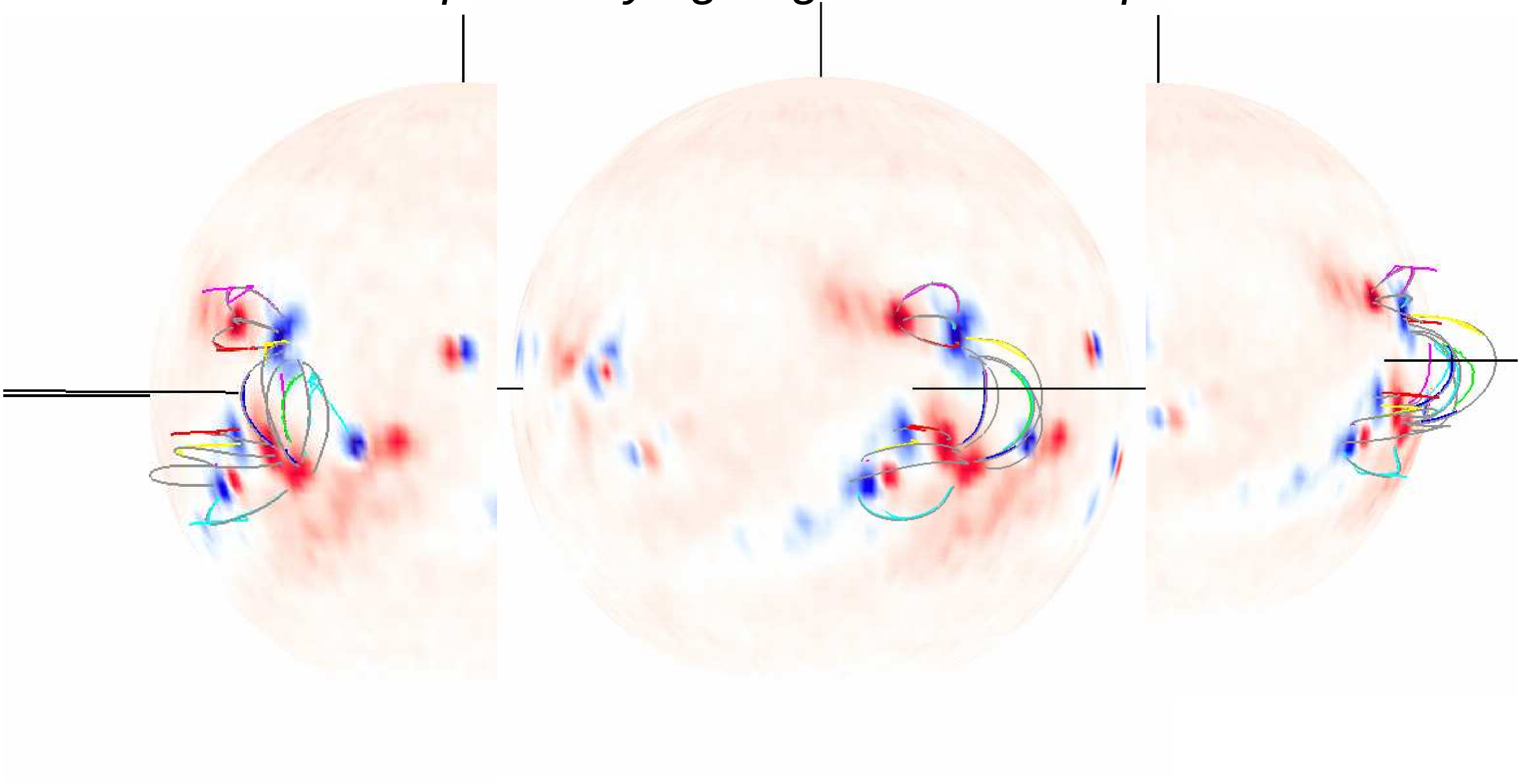
Algorithm: Follow along bright features *Dark Segments on Loops are Matched Stereo Points**



** Matched Stereo Points: Rays from the two points cross near the Sun*

Comparison of Reconstructed 3D Loops with Original

3D loops reconstructured from tiepoints shown as colored loops overlying original black loops



Too many loops leads to false tiepoints

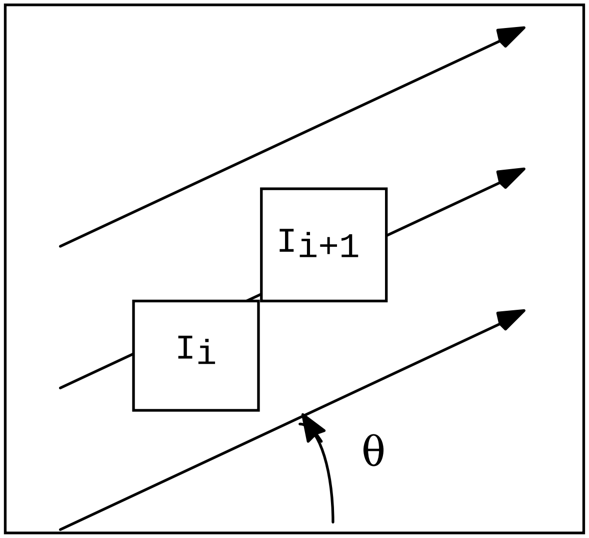
Rays from different loops in the two images happen to cross near SUN

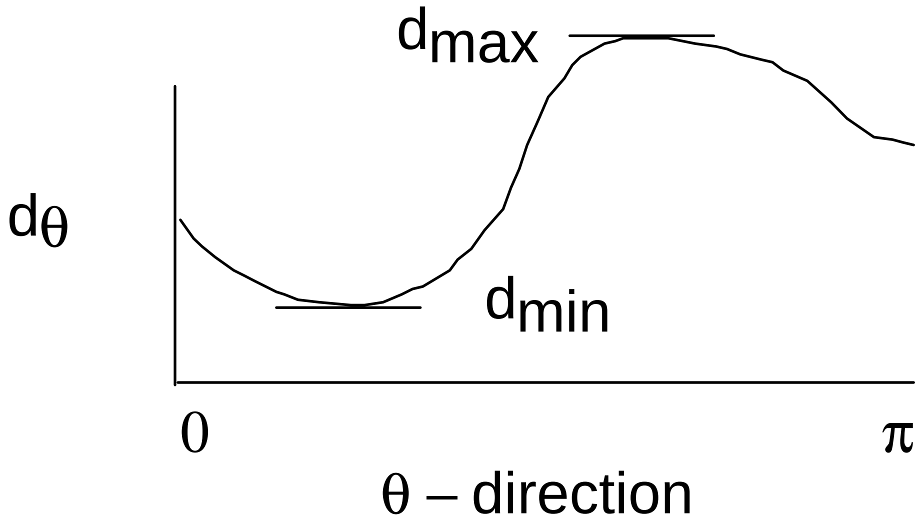
Progress in Automatic Feature Tracking

Goal: Automatic location of “features” in two or more images and creation of tiepoints for triangulation

Now developing using concepts of **direction and Directionality:**
What direction of motion in image minimizes changes in intensity I_i?

Moving window centered at pixel (x,y)





$$d_\theta = \sum_{window} \left| I_{i+1} - I_i \right|$$

Automatic Feature Tracking using Directionality

For each pixel have

- *direction* θ *which minimizes change in intensity regardless of intensity*
- *Directionality D(x,y) Š measures how much this direction is preferred*

First stage - find Ņfeatures Ó or Ņsegments Ó in an image:

1. Create an image with Directionality D(x,y) as the intensity of pixel (x,y)
2. Loop through pixels starting with highest Directionality D

   Create a feature or Ņsegment Ó by connecting to neighboring pixels (pixel window) with nearly the same direction θ

   Continue unless intersect another Ņsegment Ó

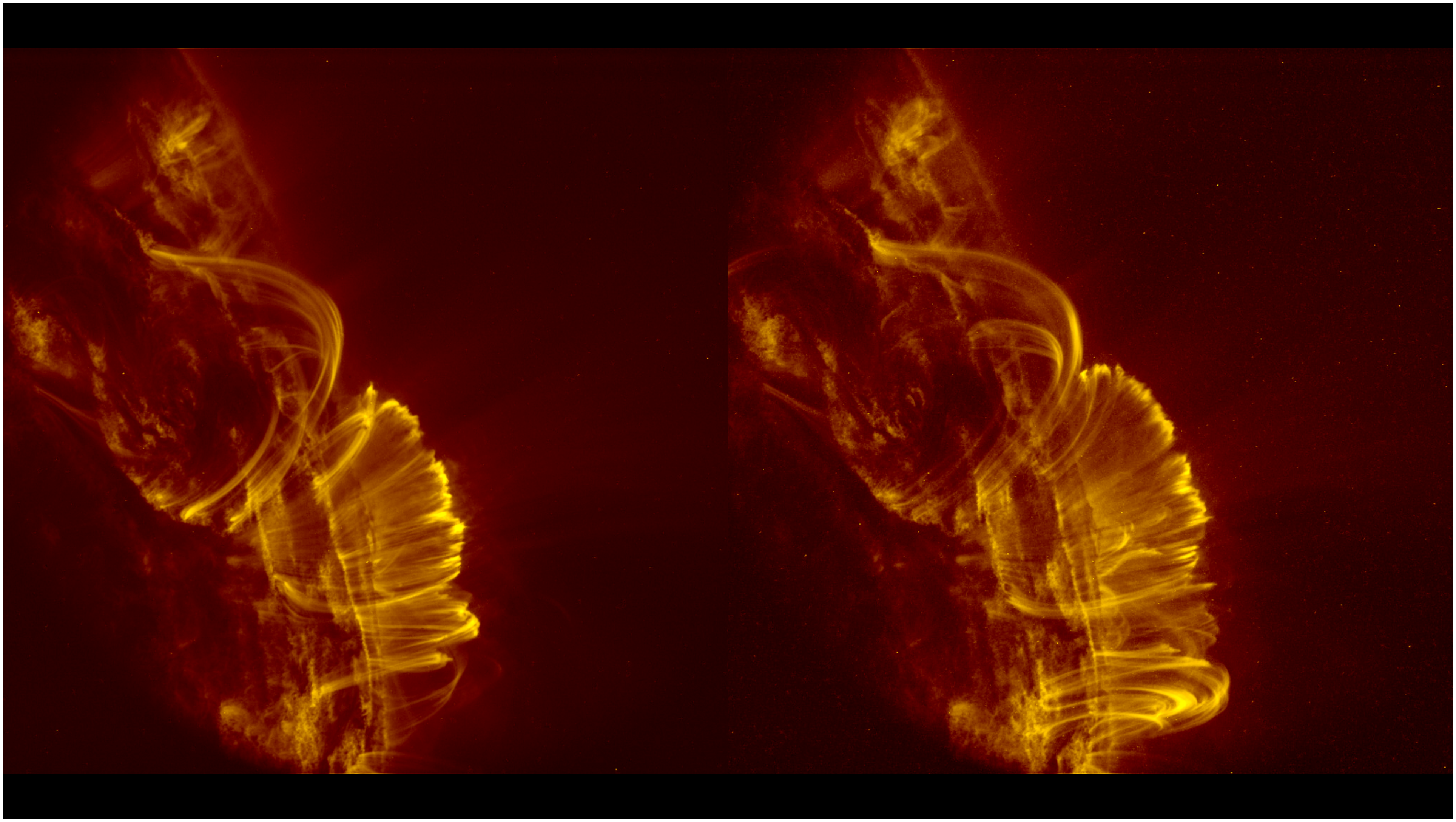
End product: File of pixels for each segment/feature

Automatic Feature Tracking using Directionality

Second Stage Š Finding same segment in second image

For each segment/feature in 1st image,
- Loop over pixels in the segment:
  - Create Ņbar codeÓ intensity pattern for each pixel by moving perpendicular to direction θ –– Óbar codeÓ is now a correlation ŅwindowÓ
  - Locate pixel in 2nd image correcting for solar rotation (SC motion)
  - Search around this pixel for a pixel with a Ņbar codeÓ with a high correlation
    - *If correlation exceeds threshold, mark this pixel as same segment/feature*

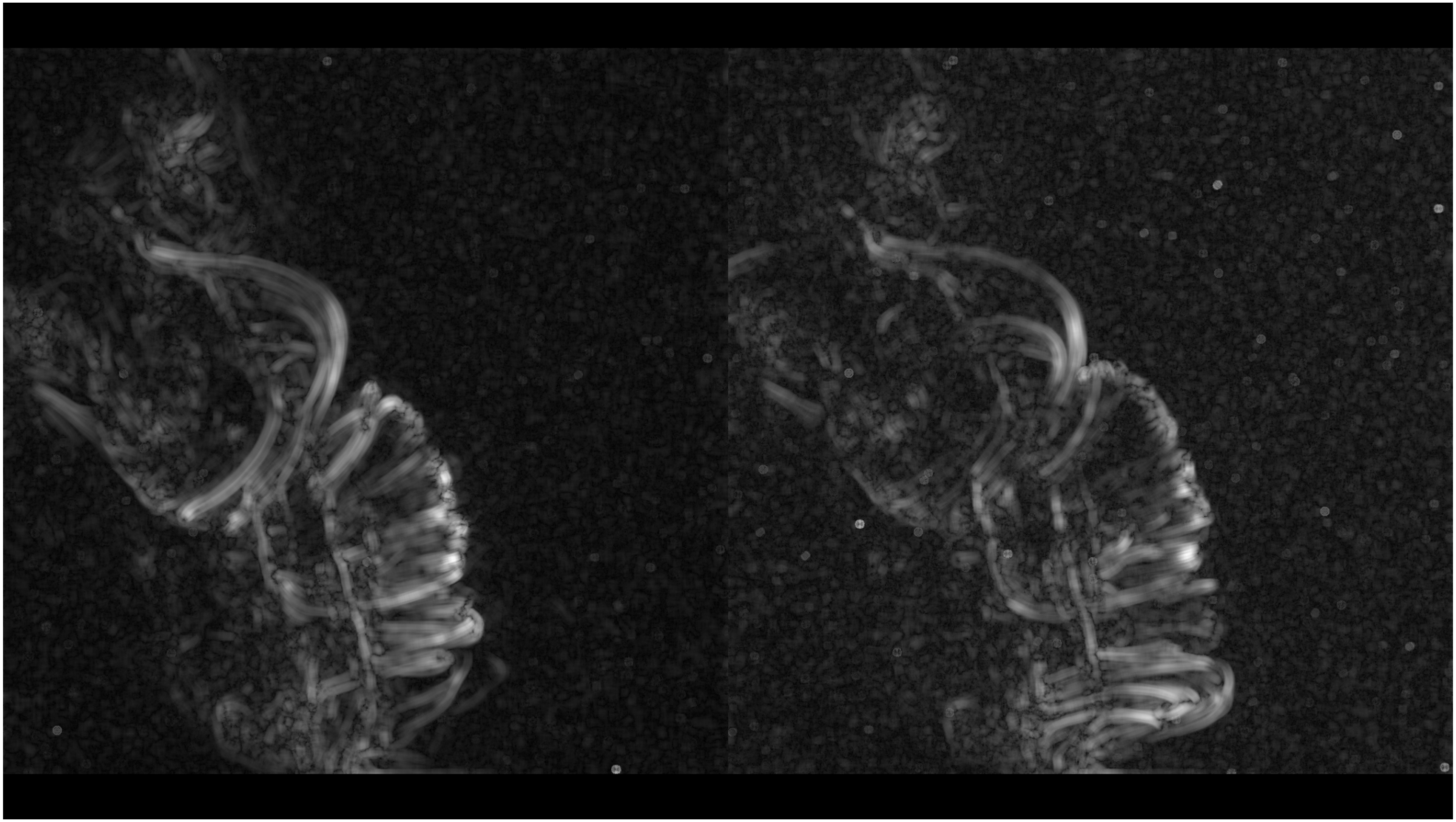
End product: file of pixels for corresponding segment/feature in 2nd image



trb_20001109_021021

trb_20001109_030008

Original TRACE Image Pair - 1 hour separation



Directionality Images

Traced Segments

Left: Traced Segments (Image 1)   **Right: Correlated Segments (Image 2)**

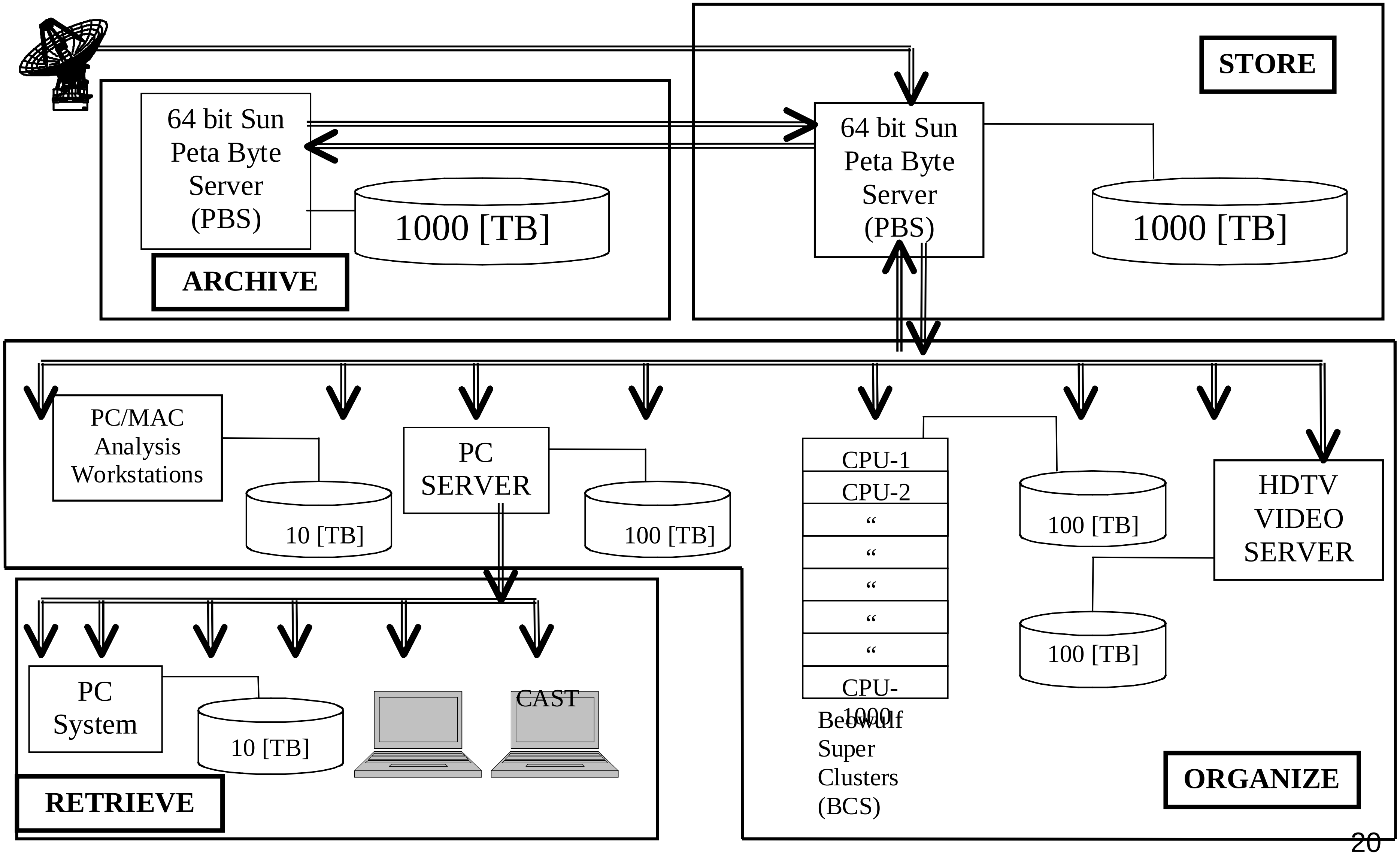
Conclusions

- **Stereoscopy (*a.k.a.* triangulation) can be used to determine 3D geometry/location of coronal features**
- **Tools and software to determine 3D location tested on synthetic white light and EUV image pairs**
- **Tiepointing Ņby handÓ demonstrated using commercial software on conventional workstations and in 3D using SGI with stereo viewing using liquid crystal goggles**
- **Demonstrated Automatic Feature tracking between two images using new method based on ŅDirectionalityÓ**

Successful tests on TRACE data with 15^{min} & 1^{hr} separations

Test with 2^{hr} separations identified very few common features

Store Organize Archive and real-time Retrieve (SOAR)



64 bit Sun Peta Byte Server (PBS)

1000 [TB]

ARCHIVE

STORE

64 bit Sun Peta Byte Server (PBS)

1000 [TB]

PC/MAC Analysis Workstations

10 [TB]

PC SERVER

100 [TB]

CPU-1

CPU-2

“

“

“

“

“

CPU-1000

Beowulf Super Clusters (BCS)

100 [TB]

HDTV VIDEO SERVER

100 [TB]

ORGANIZE

PC System

10 [TB]

CAST

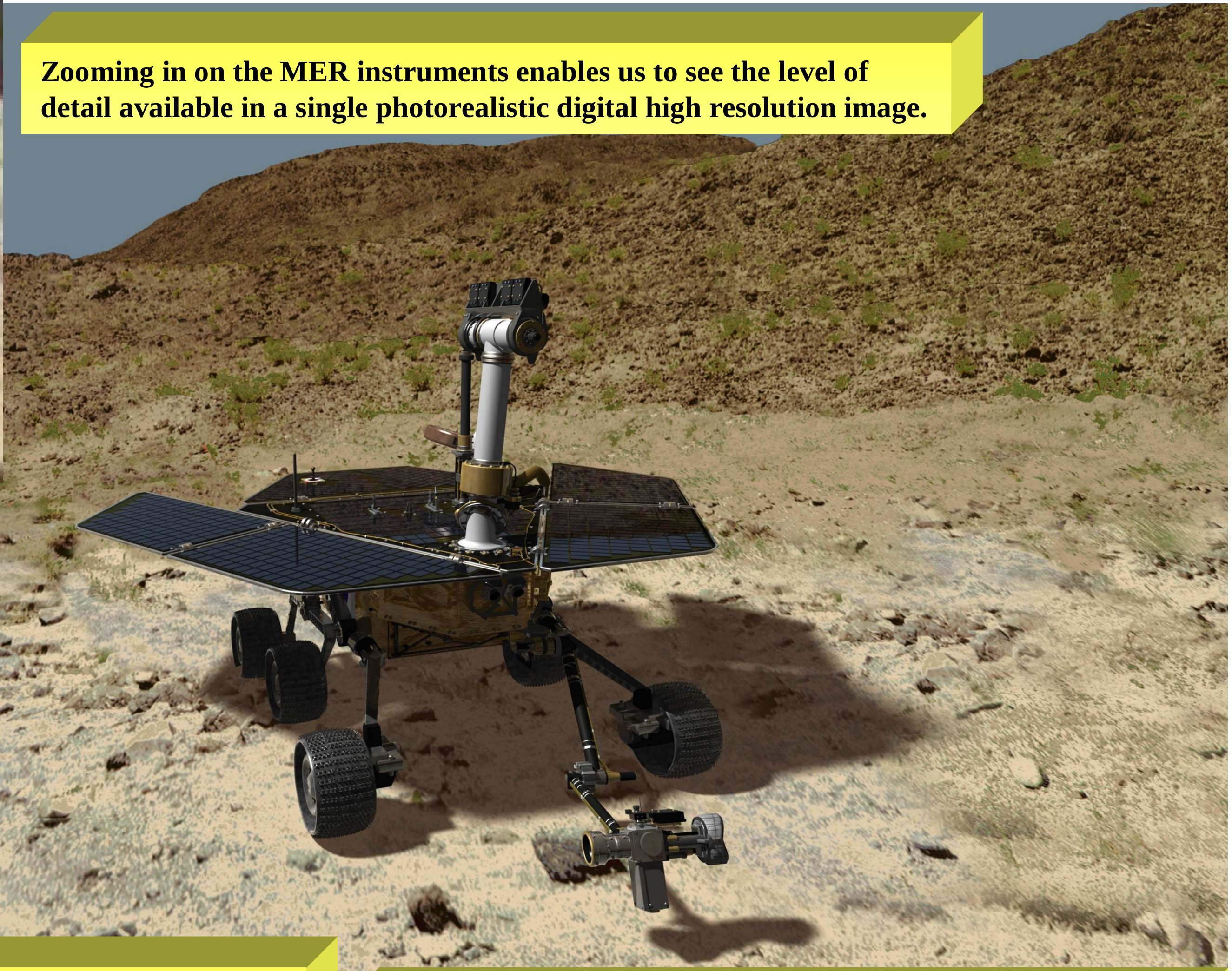
RETRIEVE

Store Organize Archive and real-time Retrieve (SOAR)

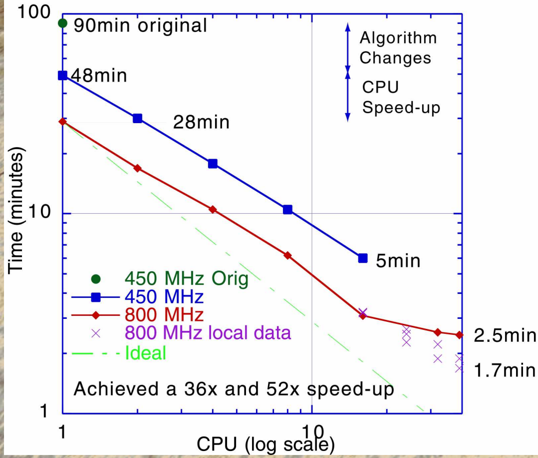
Visualization and Analysis Testbed VAT

FY	%	Nodes	**HDTV [TB]**	**DISK [TB]**
03	1	10	1	10
04	2	20	2	20
05	4	40	4	40
06	8	80	8	80
07	10	100	10	100
08	20	200	20	200
09	40	400	40	400
10	60	600	60	600
11	80	800	80	800
12	100	1000	100	1000

Adapting Virtual Rover (VR) tools to SECCHI and STERO Instruments



Zooming in on the MER instruments enables us to see the level of detail available in a single photorealistic digital high resolution image.



One work year was required to produce this 36 x Cluster Computing Mosaic Generation speed-up. A significant "Virtual Rover" challenge is to automate the speed-up and control of similar processes to achieve real-time performance.

Zareh Gorjian combines a 3D terrain model, constructed from FIDO "Pancam" field test images, with Dan Maas' rover model to create this simulated view of MER desert operations.