Observations and Modeling of Solar Coronal Structures Using High-Resolution Eclipse Images and Space-based Telescopes with Wide Field of View

Muzhou Lu[1] Class of '13

Advisors:
Jay Pasachoff[1]
Yingna Su[2]
Adrian van Ballegooijen[2]
Daniel Seaton[3] '01

[1]Hopkins Observatory and Department of Astronomy, Williams College
[2]Harvard-Smithsonian Center for Astrophysics, Cambridge, MA
[3]Solar Influences Data Analysis Center, Royal Observatory of Belgium

Observations and Modeling of Solar Coronal Structures Using High-Resolution Eclipse Images and Space-based Telescopes with Wide Field of View

I. Motivation

II. High-Resolution Eclipse Images

III. Potential Field Model

IV. 2012 Total Solar Eclipse

V. Processing SWAP Images

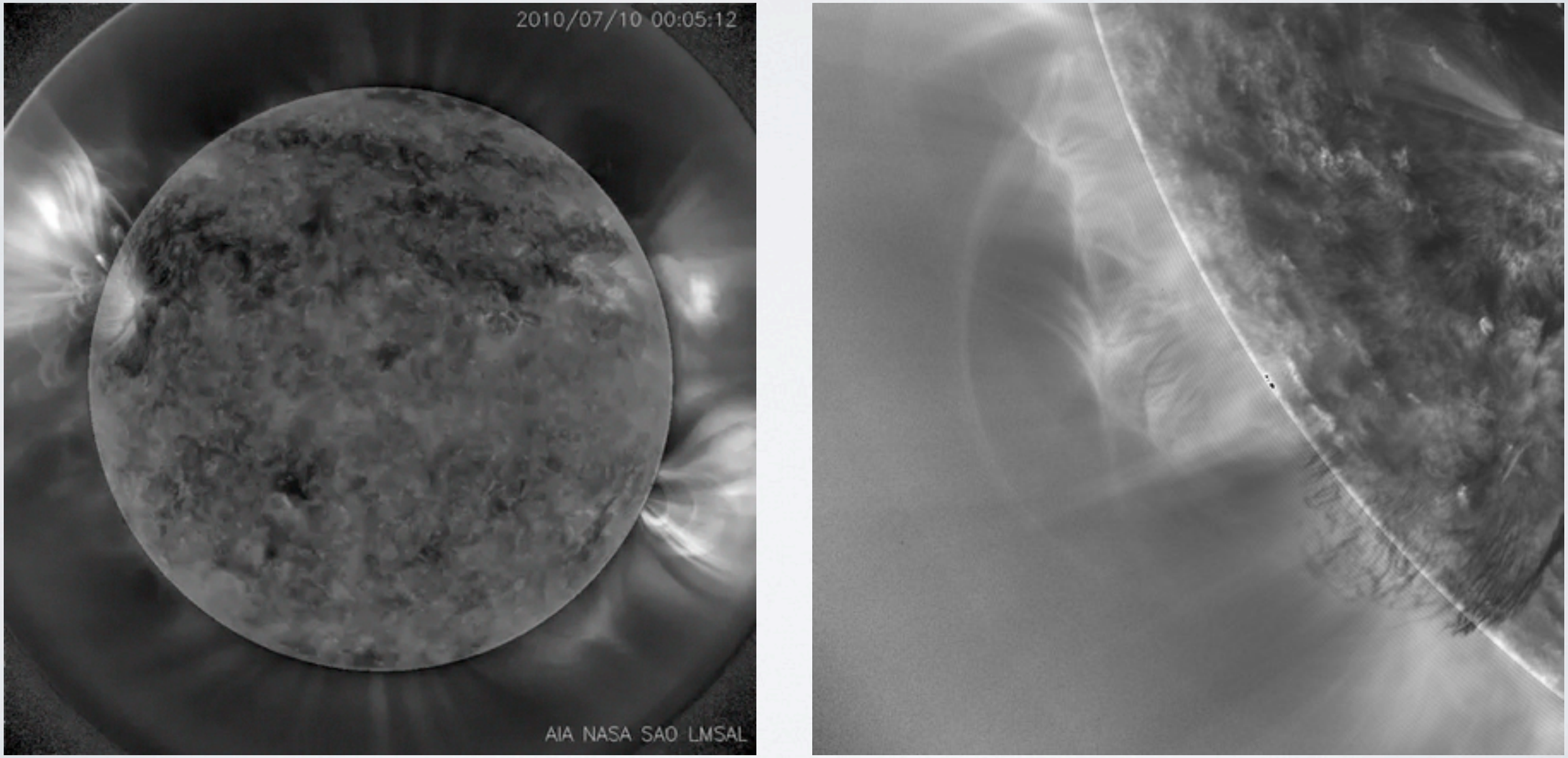
VI. Comparisons of Large Coronal Structures

I. MOTIVATION

I. MOTIVATION: IMAGES FROM SDO/AIA*

*<u>S</u>olar <u>D</u>ynamics <u>O</u>bservatory's <u>A</u>tmospheric <u>I</u>maging <u>A</u>ssembly

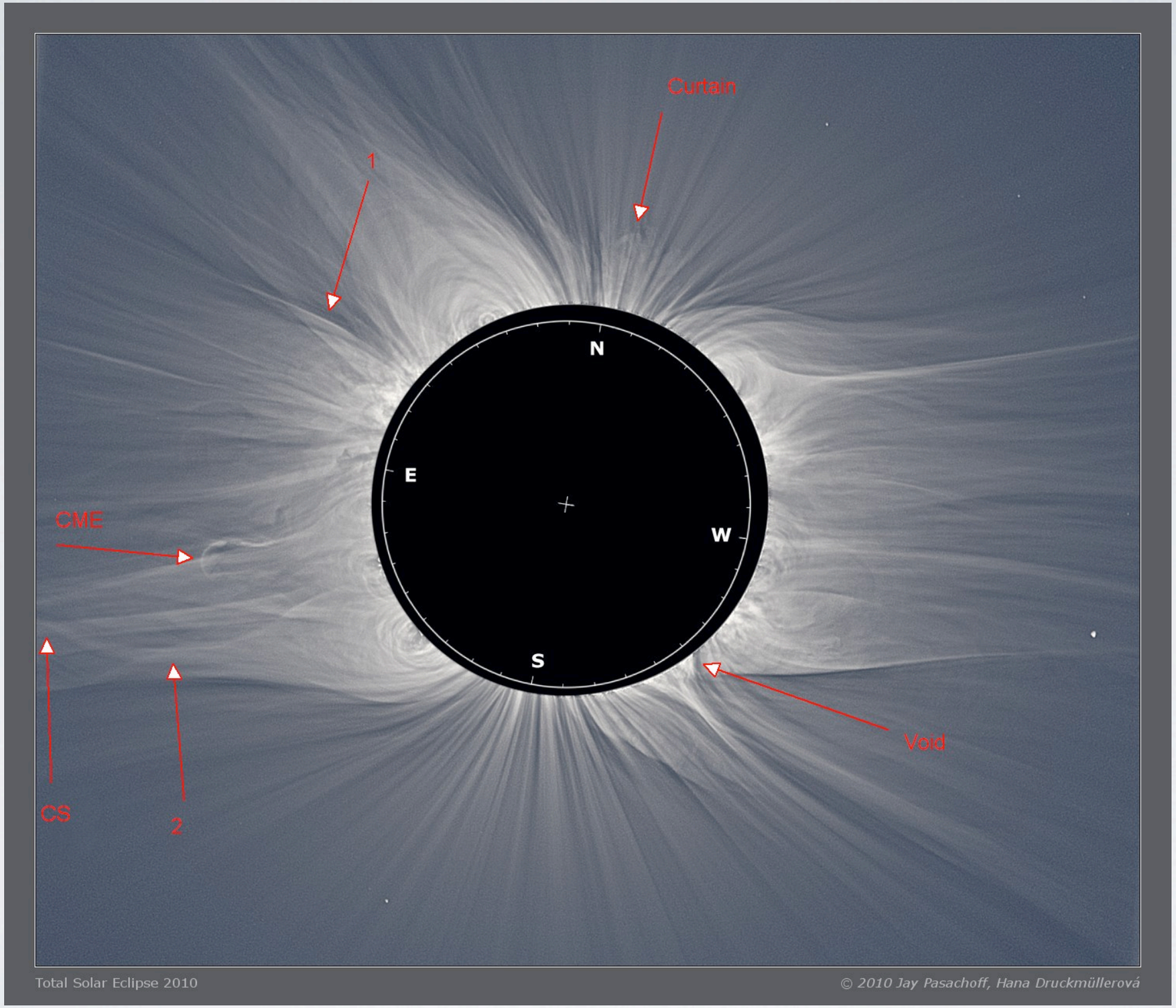
Many coronal structures, especially those in the "quiet Sun," are often simulated with a potential-field model. New space-based telescopes, as well as our processed eclipse images, have achieved higher imaging resolution than any previous effort. As a result, we discovered some "discrepancies" between our potential field models and observations. One example is revealed here by recent observations with AIA on SDO satellite.



Raw AIA images (4096 by 4096 on the left and close up on the right) processed with our radial-filter algorithm.

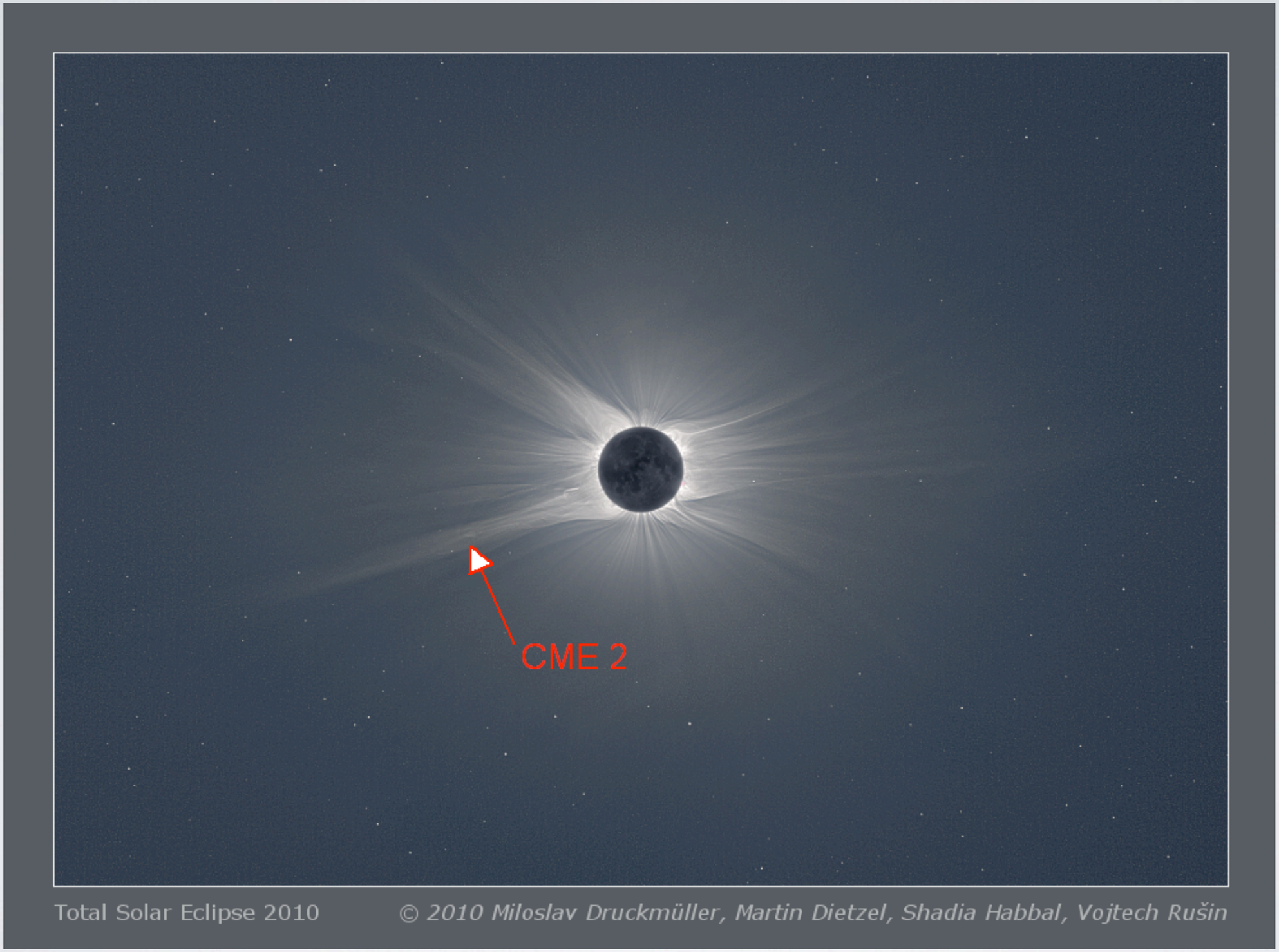
II. HIGH-RESOLUTION ECLIPSE IMAGES

II. HIGH-RESOLUTION ECLIPSE IMAGES



- With "Phase-Correlation" Image Registration, eclipse images can resolve fine structures.

II. HIGH-RESOLUTION ECLIPSE IMAGES

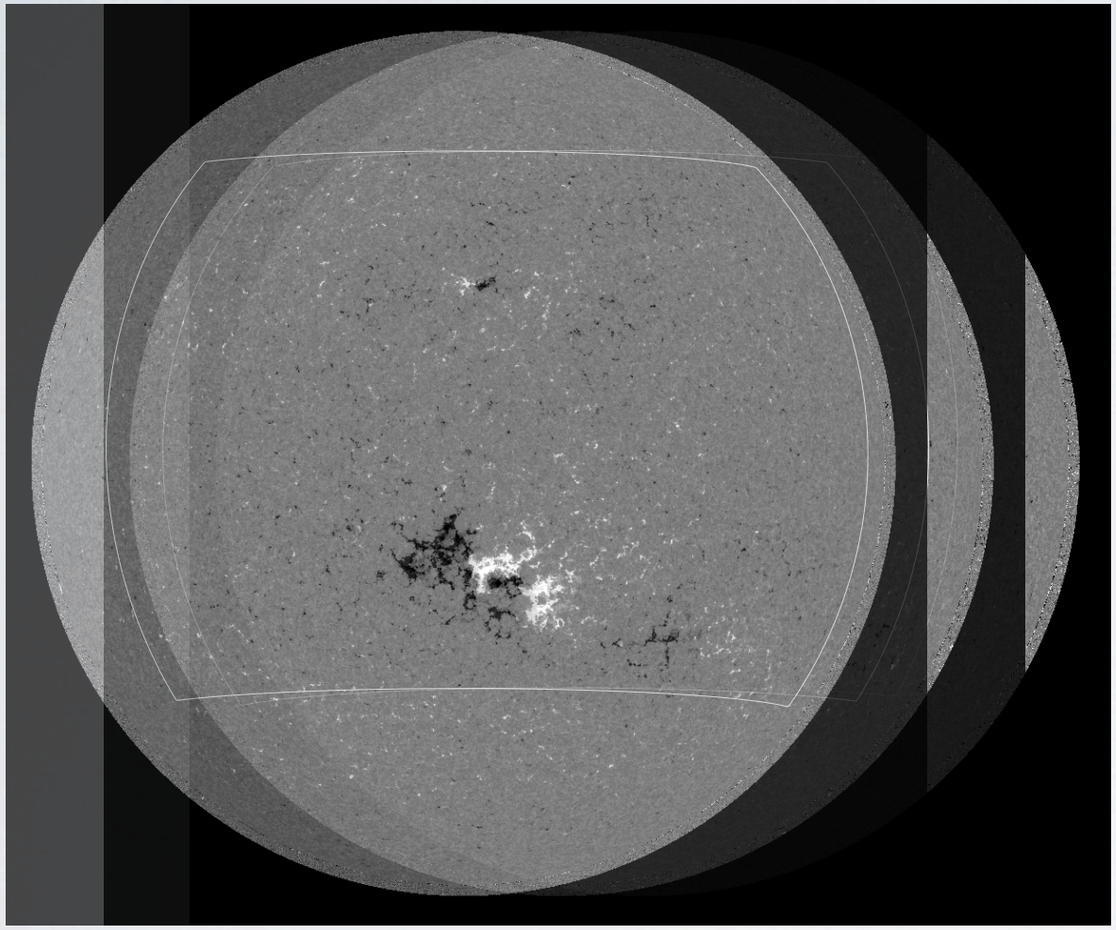


- Based on ground setup, images can reveal the extended corona up to 20 solar radii.

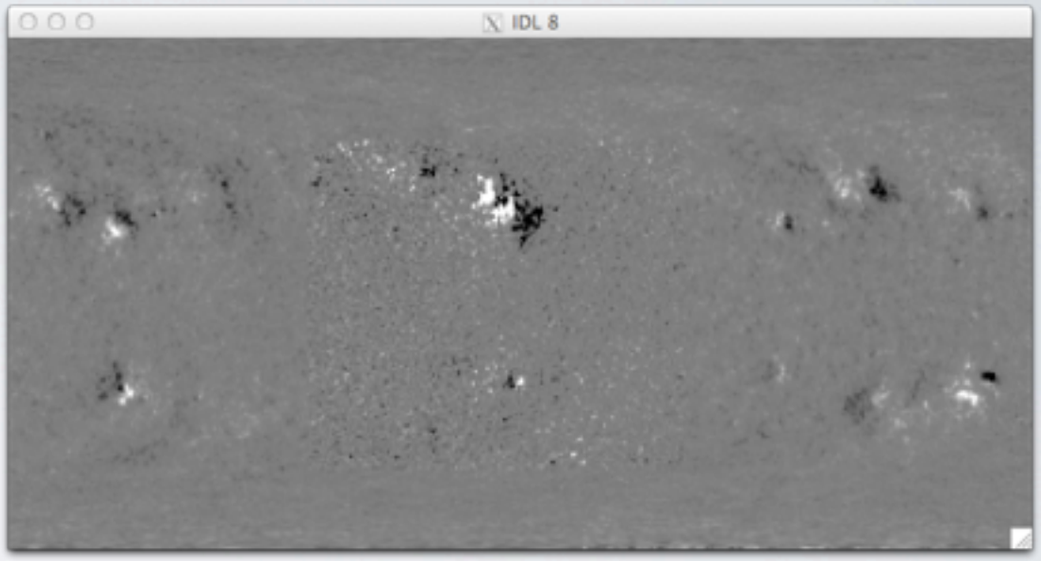
III. POTENTIAL FIELD MODEL

III. BUILDING A POTENTIAL FIELD MODEL: STEP ONE

Before coming to ROB, I had built potential magnetic field models of the Sun at the time of the 2010 total solar eclipse using SDO's Helioseismic and Magnetic Imager (HMI) data and corresponding multi-wavelength extreme ultraviolet (EUV) images from AIA.



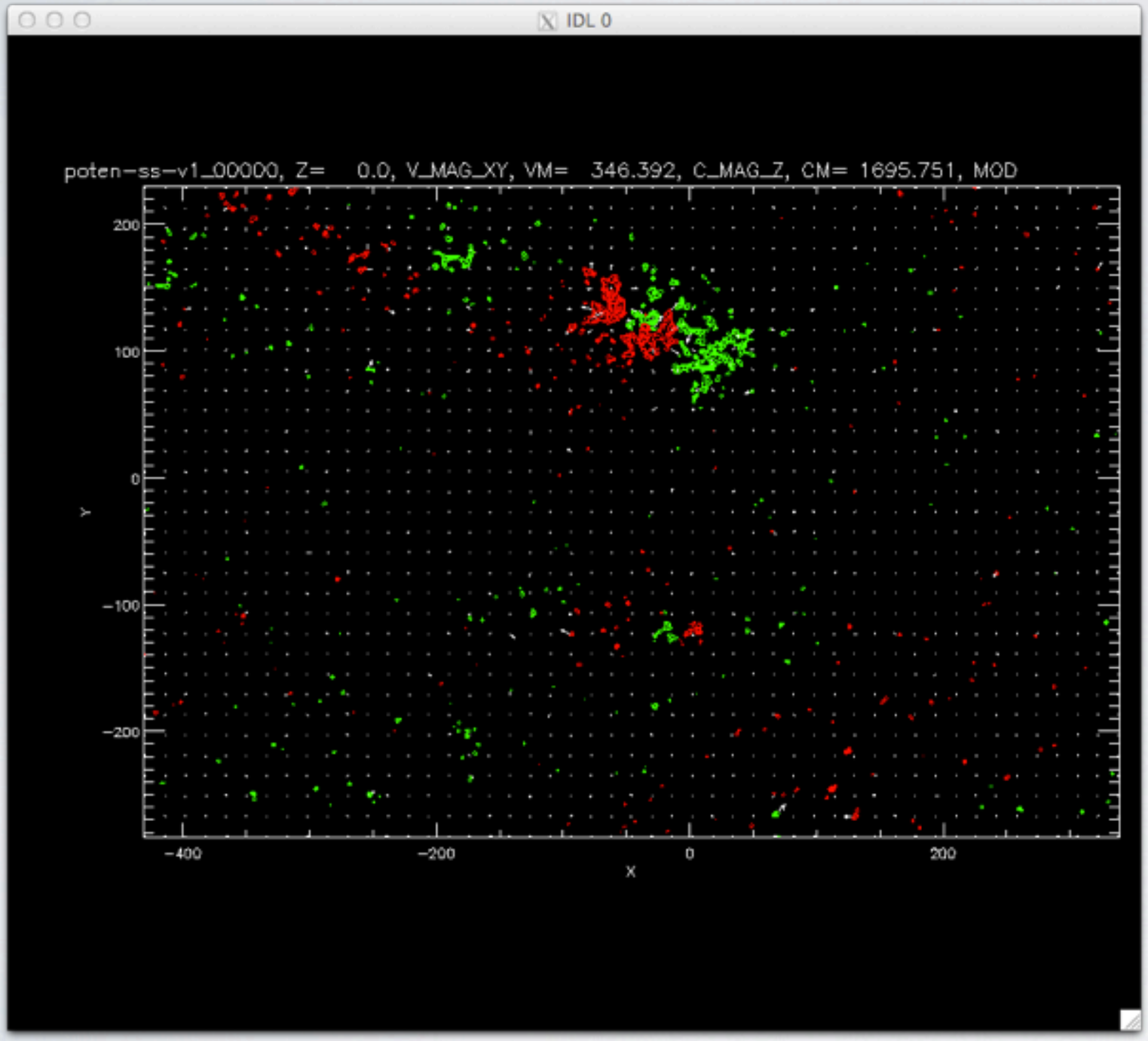
⬆ A HMI map of the radial magnetic field $Br(R\odot,\theta,\varphi)$ as function of longitude and latitude on the solar surface ($r = R\odot$).



⬆ Three separate HMI images on the left were used to make the vector magnetogram since the radial field is only accurate when the field is in the line of sight.

III. BUILDING A POTENTIAL FIELD MODEL: STEP TWO

Compute Field Potential using CMS2



In the Coronal Modeling System V2.0 (CMS2), an imposed photospheric flux distribution consists of two parts:

- One from a low-resolution synoptic map (from GONG), $B_{r,glob}(\varphi,\lambda)$
- One from a high resolution map (from HMI/SDO) in a limited region, $B_{r,HIRES}(\varphi,\lambda)$

Both GLOBAL and HIRES regions extend from the solar surface ($r = R_\odot$) up to a "source surface" ($r = R_{max}$) where the magnetic field becomes radial.

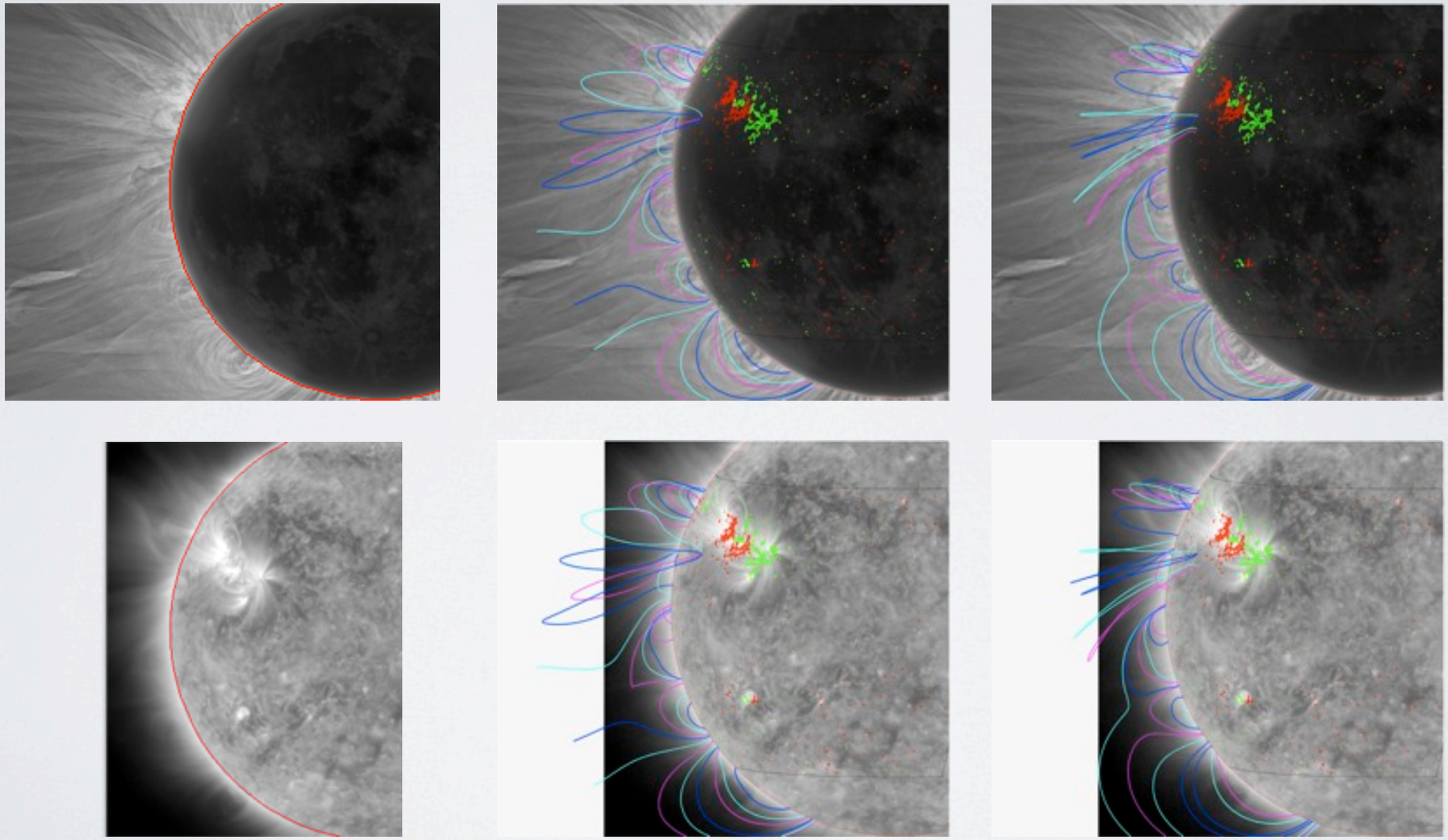
The global potential field is computed using spherical harmonics.

The potential field in the HIRES region is computed by solving for the eignemodes of a grid* (van Ballegooijen et al. 2000).

*Spherical grid, with cells increasing in size radially to maintain high resolution and efficiency.

III. BUILDING A POTENTIAL FIELD MODEL: STEP THREE

Past literature (Altschuler et al. 1969) suggests a source surface of ~2.5 solar radii would best match observations empirically. I found that a source surface of 1.6 solar radii can create field lines that better match our eclipse observations and AIA images. This finding was later improved with processed SWAP images.



SS=1.6 R⊙

SS=2.5 R⊙

IV. 2012 TOTAL SOLAR ECLIPSE

IV. 2012 TOTAL SOLAR ECLIPSE - CAIRNS AUSTRALIA

Camera type	Set M	Set S	Set L
Canon EOS 1D, 1Ds Mark II, III, 5D, 5D Mark II, Nikon D3, D700	500 – 1000 mm	200 – 500 mm	1000 – 1600 mm
Canon EOS 1D Mark II, II N, III	400 – 750 mm	150 – 400 mm	750 – 1200 mm
Canon EOS 10D, 20D, 30D, 40D, 50D 300D, 350D, 400D, 450D, 1000D	300 – 600 mm	135 – 300 mm	600 – 1000 mm
All Nikon digital SLR cameras except for D3 and D700	300 – 650 mm	135 – 300 mm	650 – 1000 mm

Table 1: Recommended focal lengths of camera optics

Aperture	Exposure [sec]												
	1/500	1/250	1/125	1/60	1/30	1/15	1/8	1/4	1/2	1	2	4	8
F/11	0	2	3	4	4	4	4	4	5	5	5	5	5
F/8	2	3	4	4	4	4	4	5	5	5	5	5	0

Table 2: Set M – recommended minimal numbers of images for a moving paralactic mount

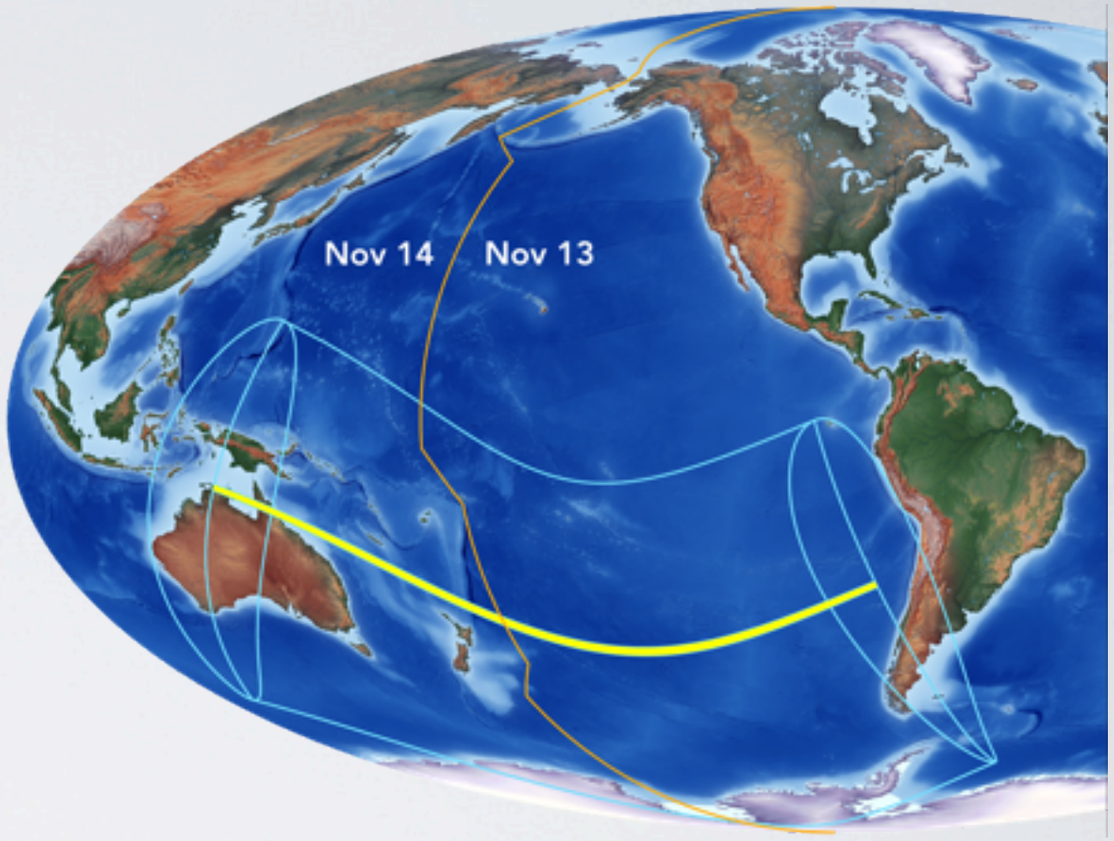
Aperture	Exposure [sec]														
	1/1000	1/500	1/250	1/125	1/60	1/30	1/15	1/8	1/4	1/2	1	2	4	8	16
F/8	0	0	1	2	2	2	2	3	4	4	4	4	4	4	2
F/5.6	0	1	2	2	2	2	3	4	4	4	4	4	4	5	2
F/4	1	2	2	2	2	3	4	4	4	4	4	4	5	5	0

Table 3: Set S – recommended minimal numbers of images for a moving paralactic mount

Aperture	Exposure [sec]											
	1/250	1/125	1/60	1/30	1/15	1/8	1/4	1/2	1	2	4	8
F/16	0	2	2	3	4	4	4	4	5	6	6	6
F/11	2	2	3	4	4	4	4	5	6	6	6	0

Table 4: Set L – recommended minimal number of images for a moving paralactic mount

Courtesy of Miloslav Druckmüller



© Michael Zeiler

This total solar eclipse begins in Arnhem Land of northern Australia, crosses the Gulf of Carpentaria, passes over northern Queensland, and then sweeps over the span of the Pacific Ocean. Once totality exits the Great Barrier Reef in the vicinity of Cairns, no further landfall is made. Norfolk Island is close to, but just south of the path of totality. New Zealand will experience a deep partial eclipse.

VIEWS FROM THE AIR

Nikon D3x
AF vr-nikkor 80-400mm 1:4.5-5.6d

Views from the ground

top: Grism spetrograph 0.6Å/pixel
red epic 5k (“imax” camera)

Bottom: Takahashi Fsq 106mm f=530
red epic 5k (“imax” camera)

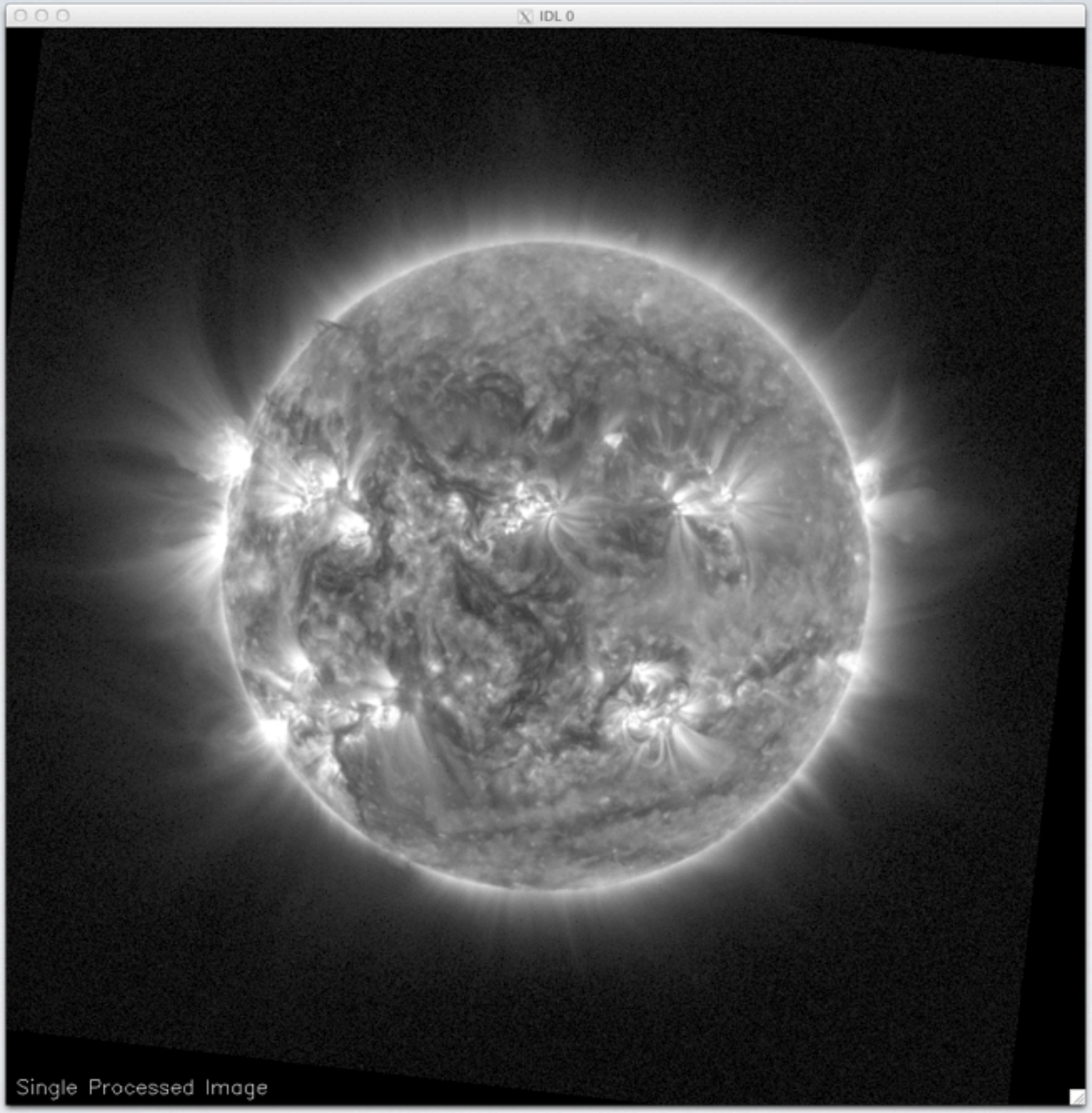
Takahashi Fsq 106mm f=530
red epic 5k (“imax” camera)

Jean-marc Laverière

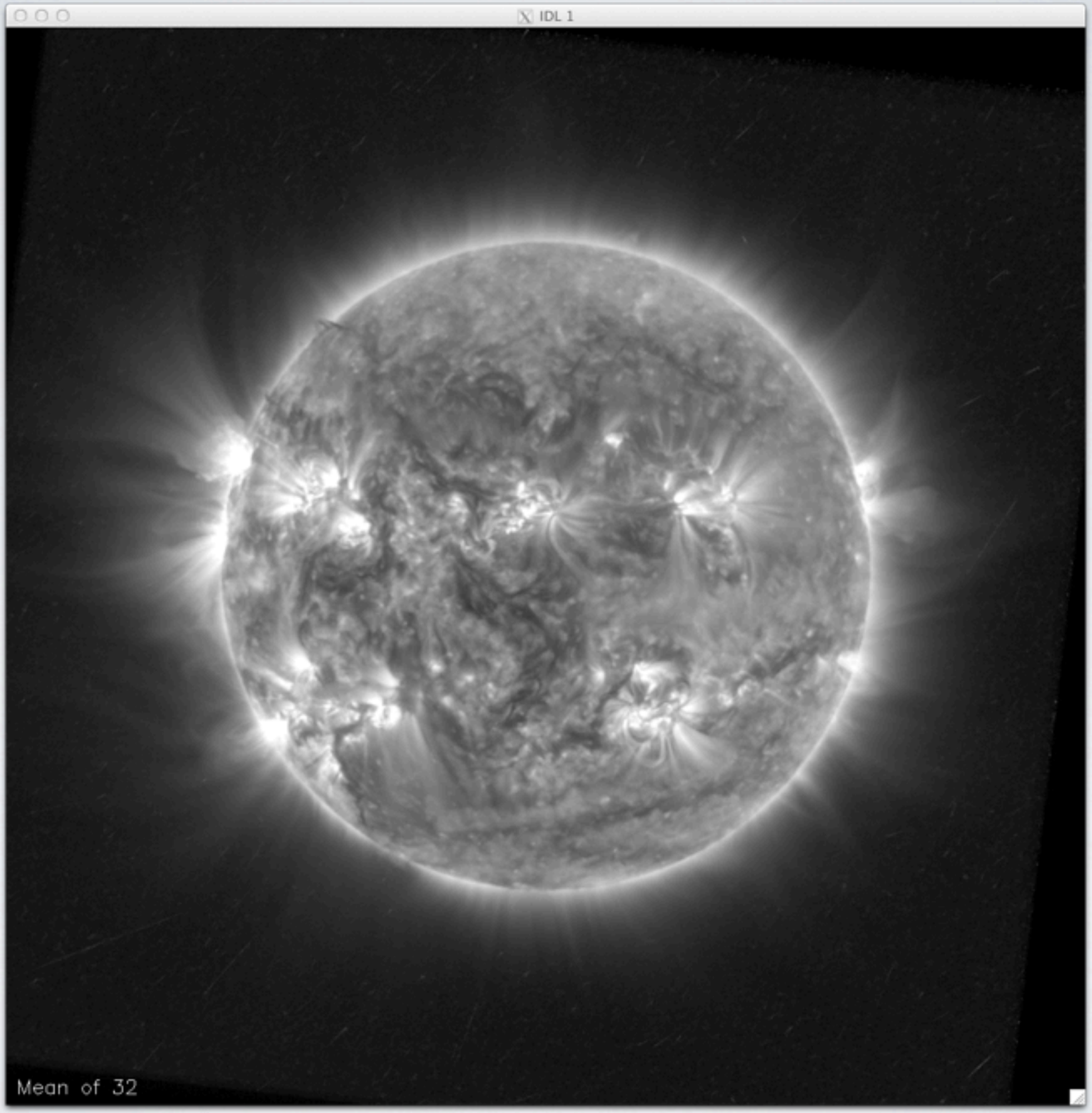
Total Solar Eclipse 2012

V. PROCESSING SWAP IMAGES

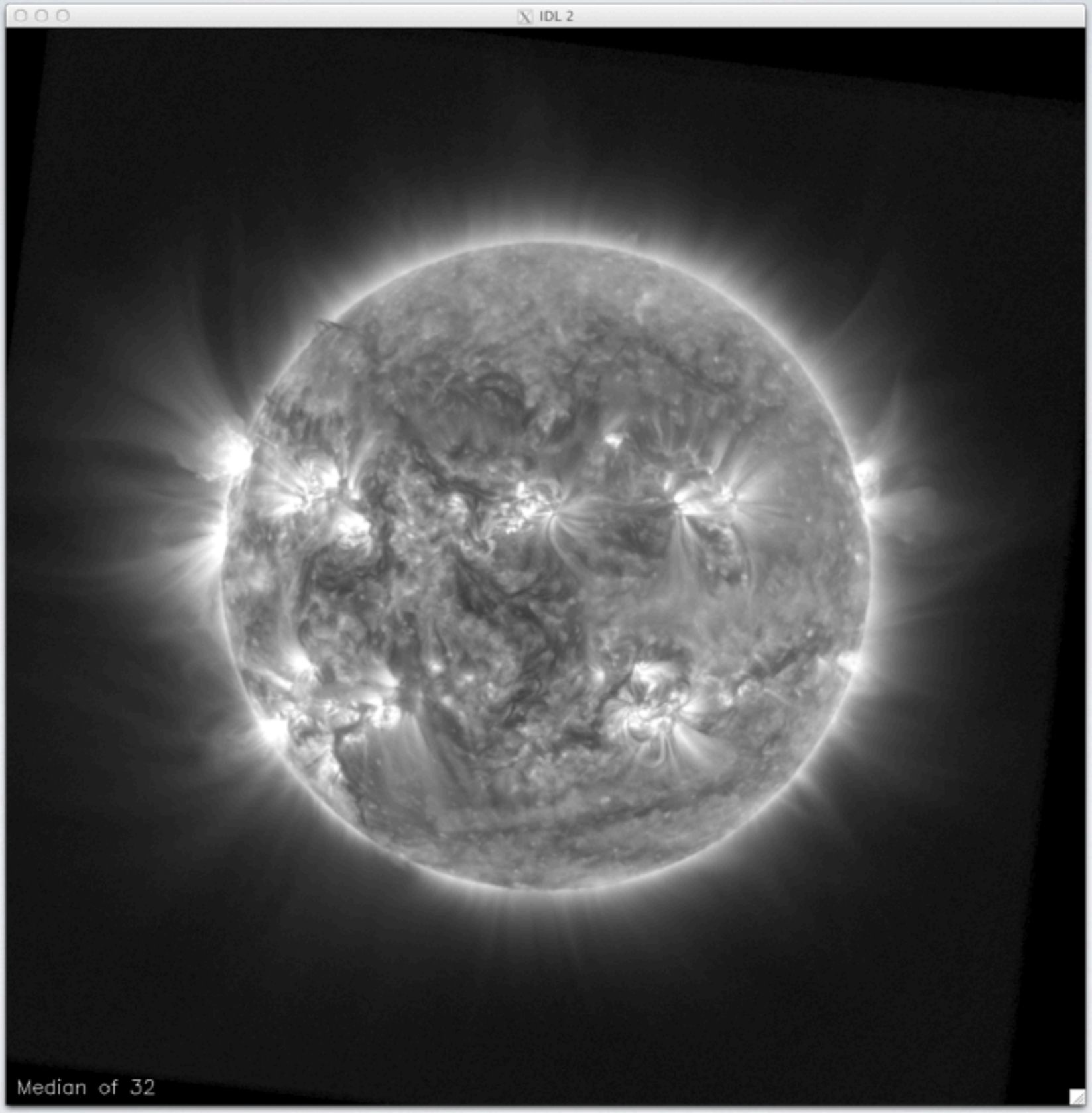
V. PROCESSING SWAP IMAGES: PREP



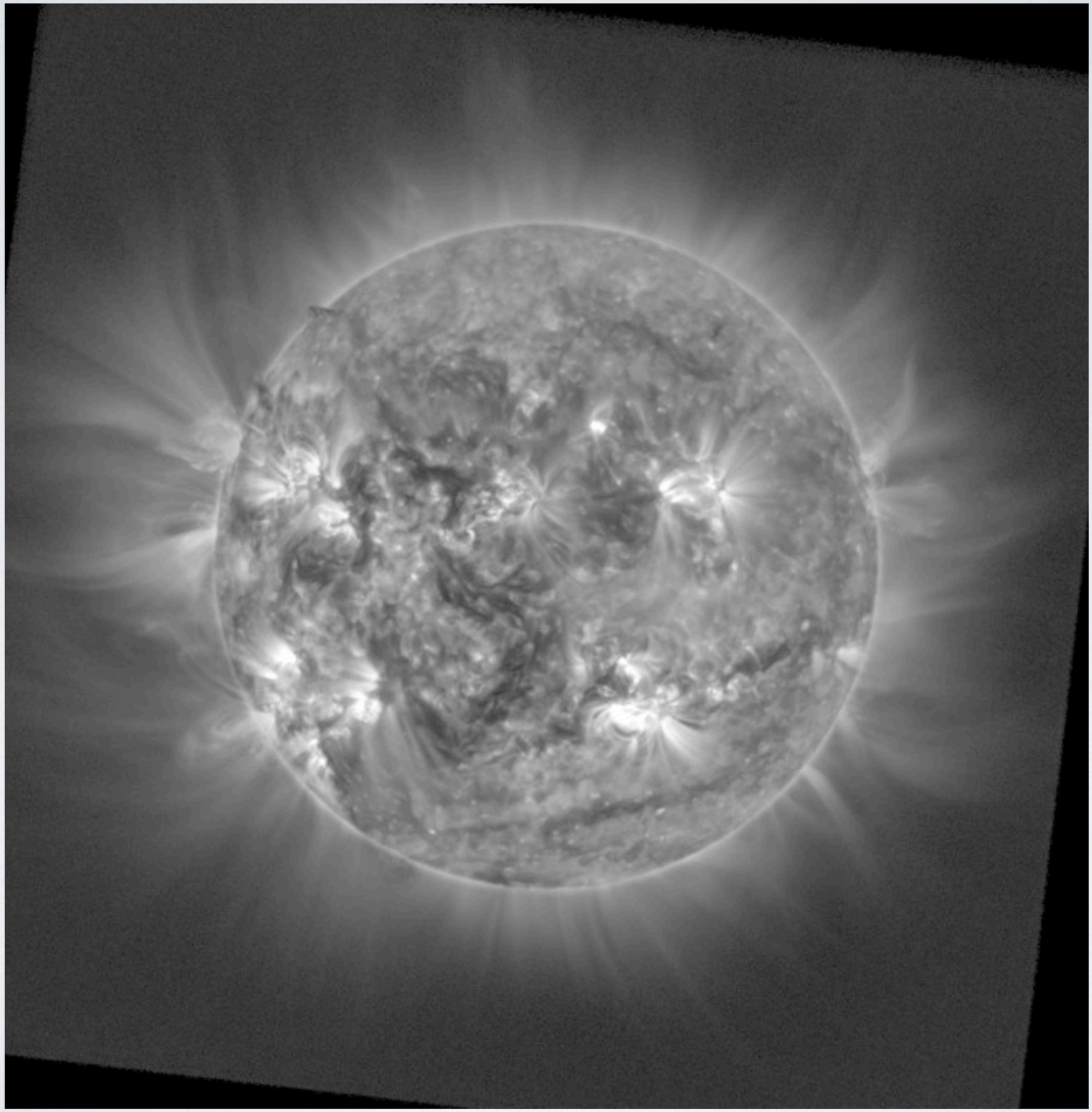
V. PROCESSING SWAP IMAGES: STACKING: MEAN



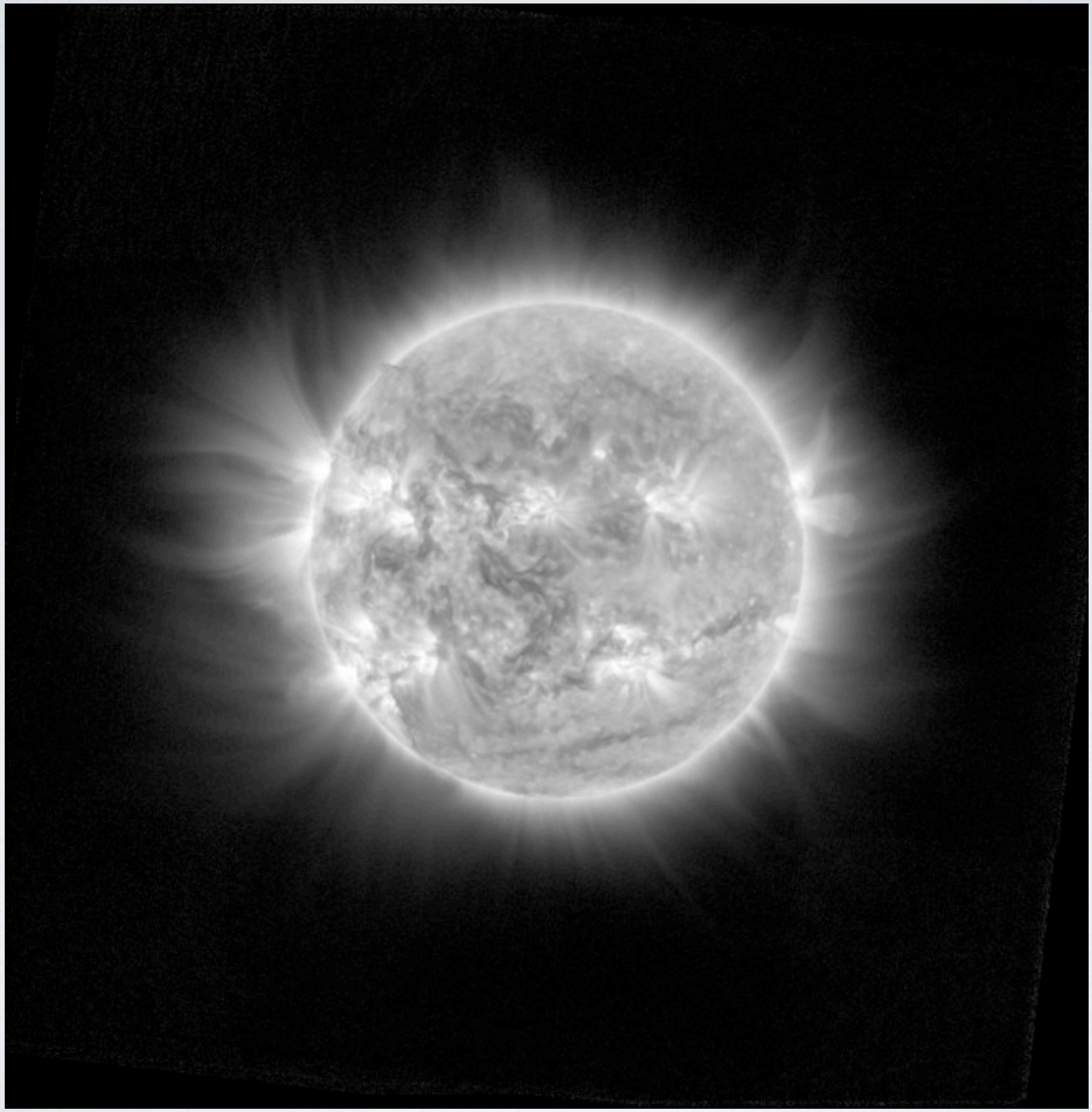
V. PROCESSING SWAP IMAGES: STACKING: MEDIAN



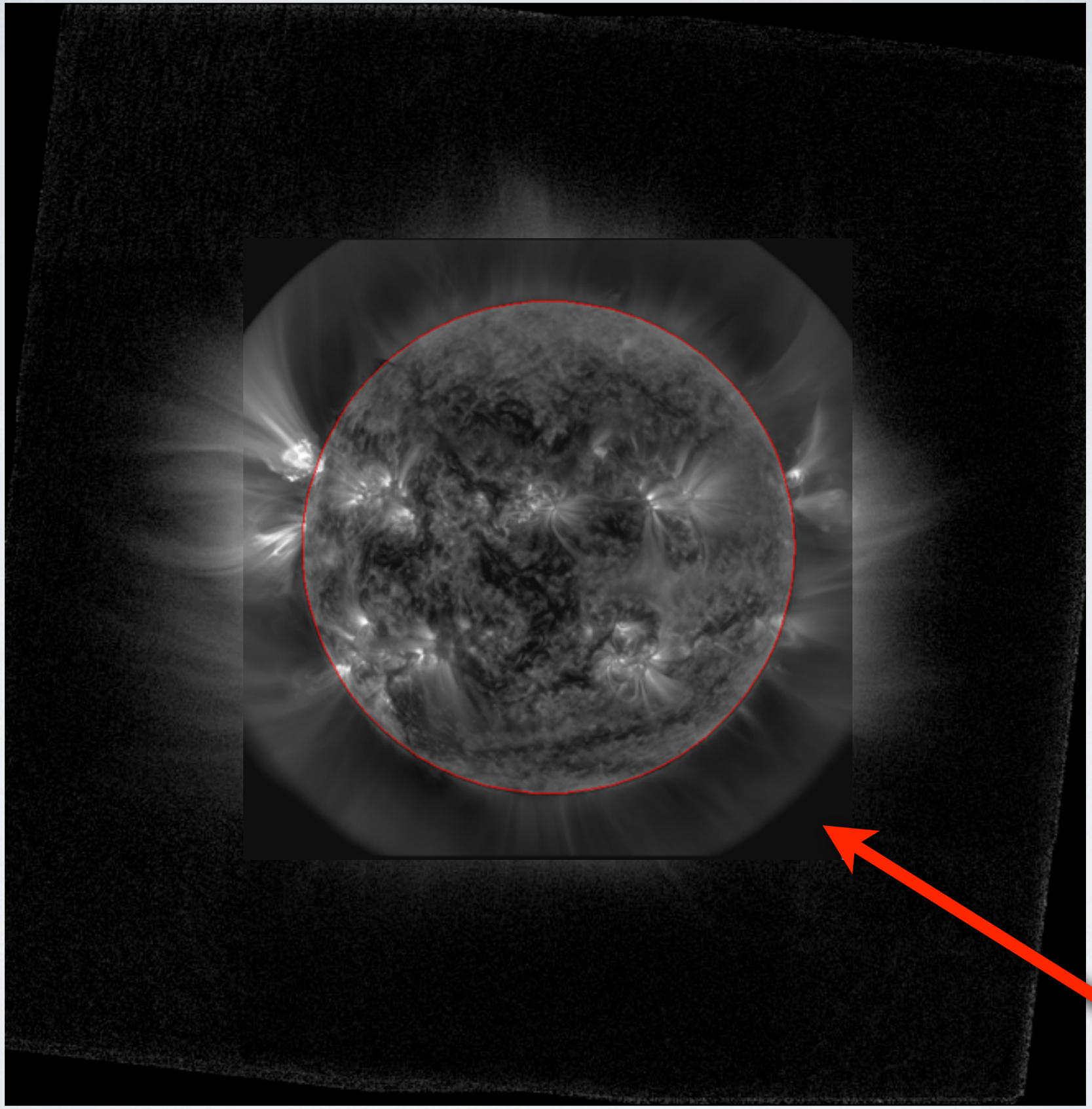
V. PROCESSING SWAP IMAGES: STACKING: R-FILTER



V. PROCESSING SWAP IMAGES: STACKING: MOSAIC

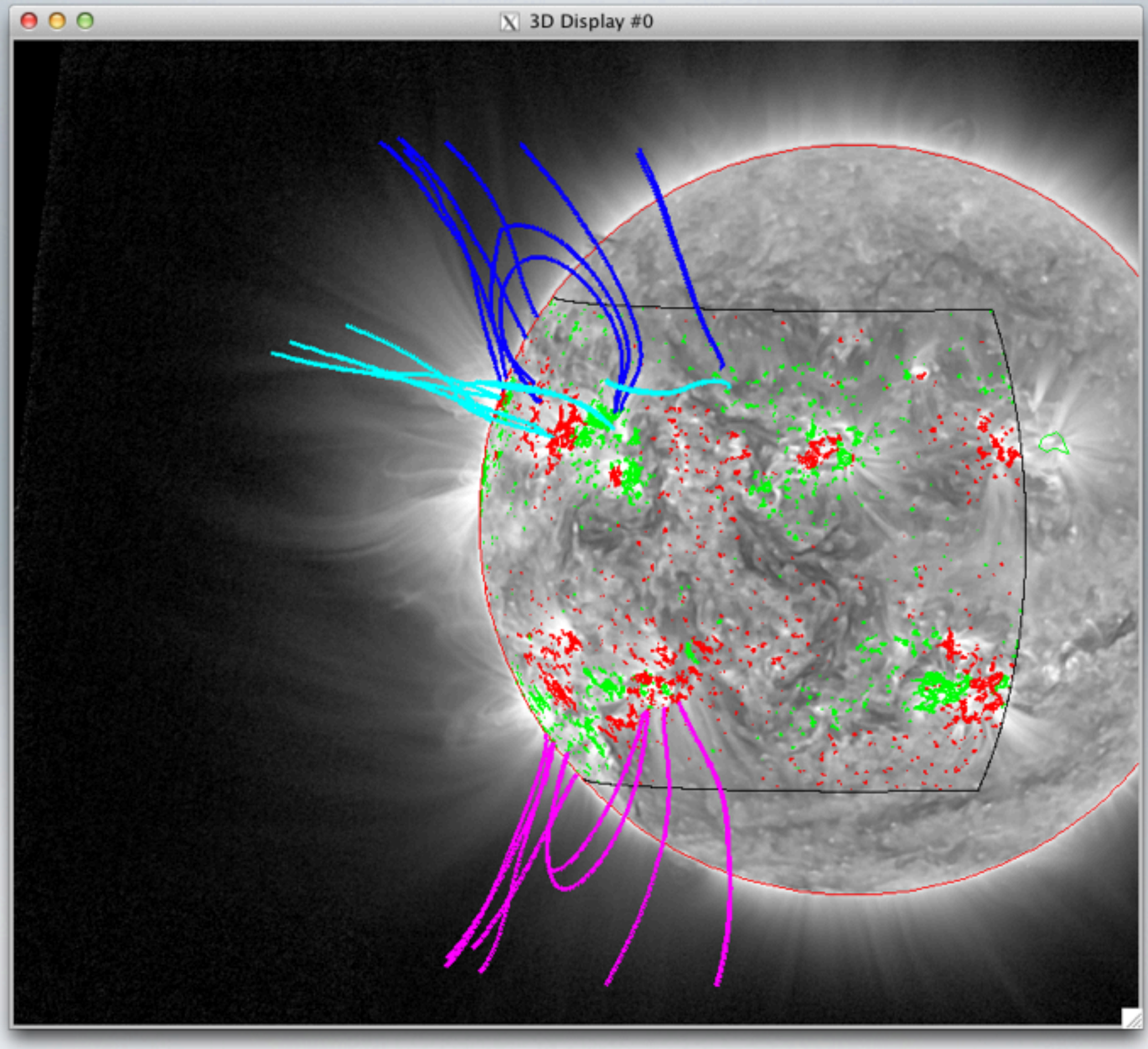


V. PROCESSING SWAP IMAGES: STACKING: MOSAIC: R-FILTER



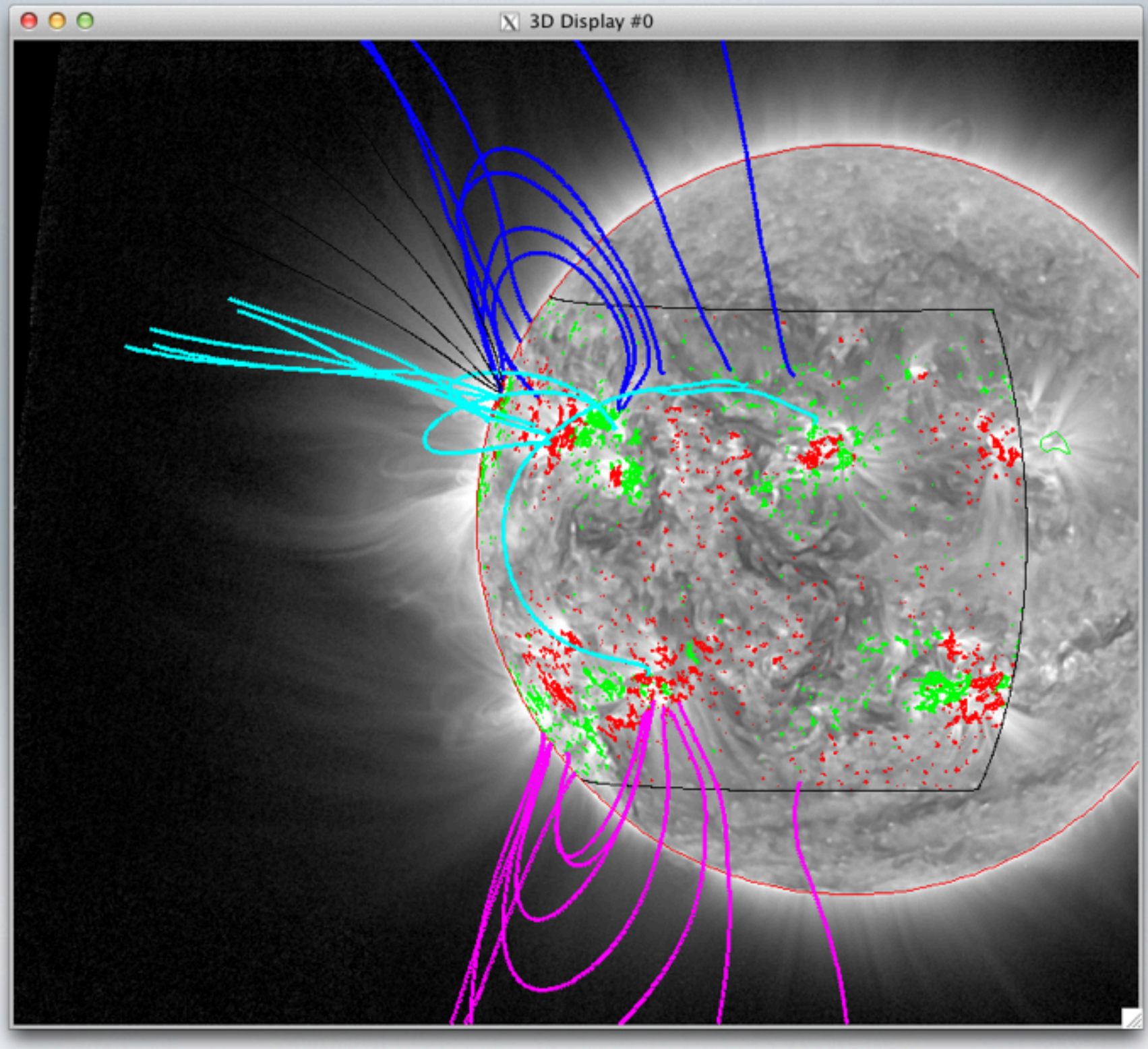
VI. SWAP vs MODEL

RE-EVALUATING SOURCE SURFACE WITH SWAP



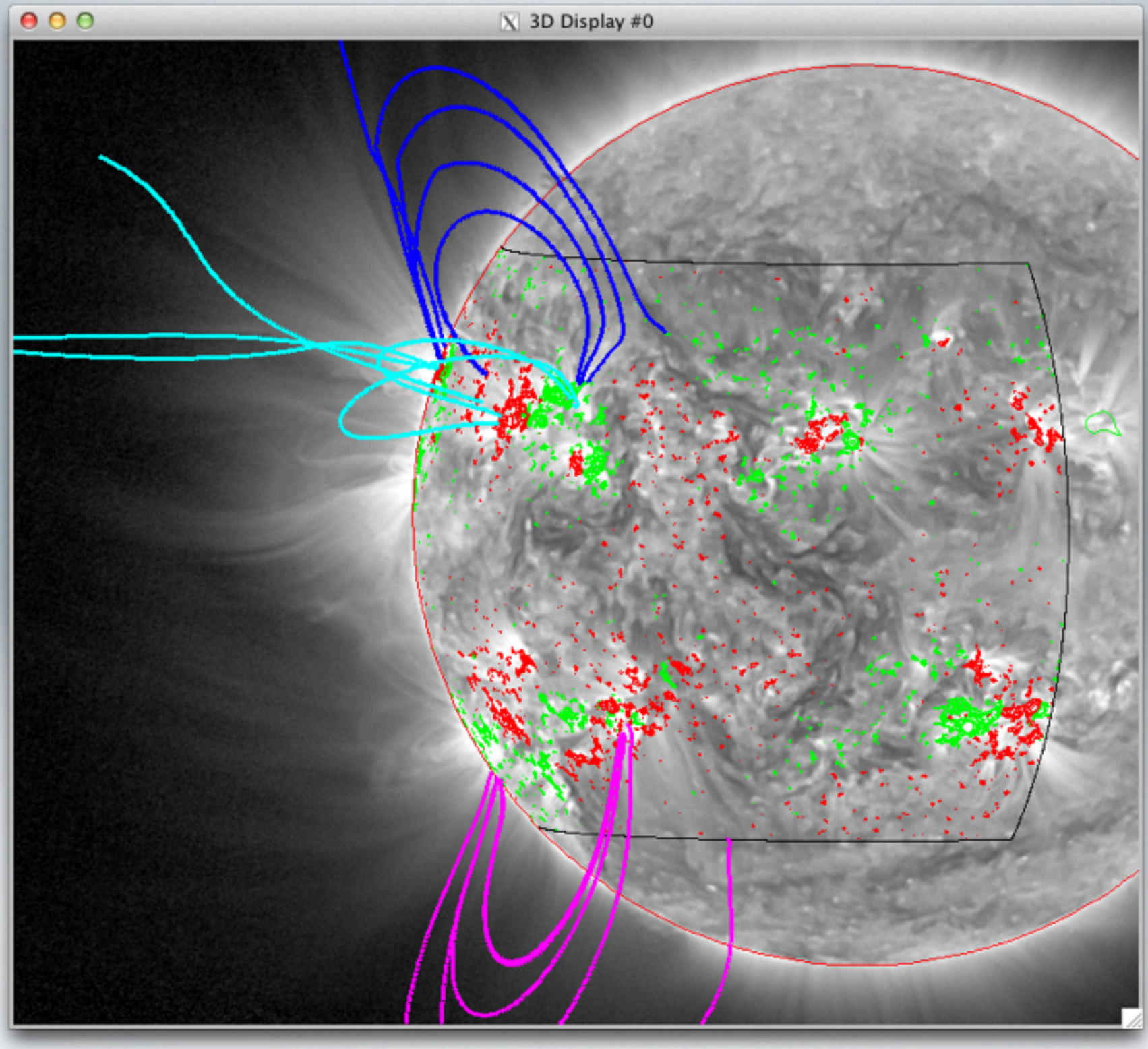
SS=1.62 R⊙

RE-EVALUATING SOURCE SURFACE WITH SWAP



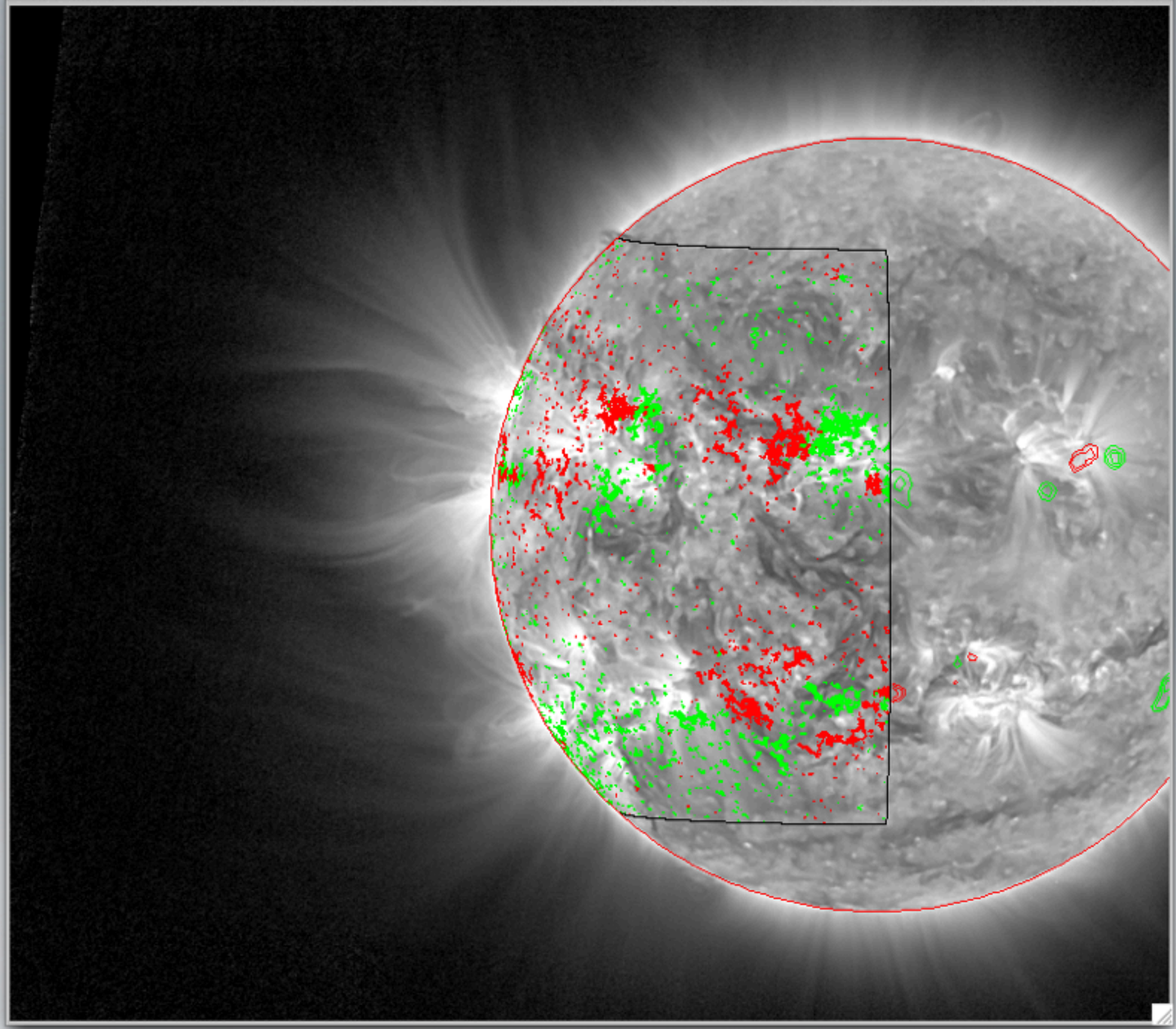
SS=1.99 R⊙

RE-EVALUATING SOURCE SURFACE WITH SWAP

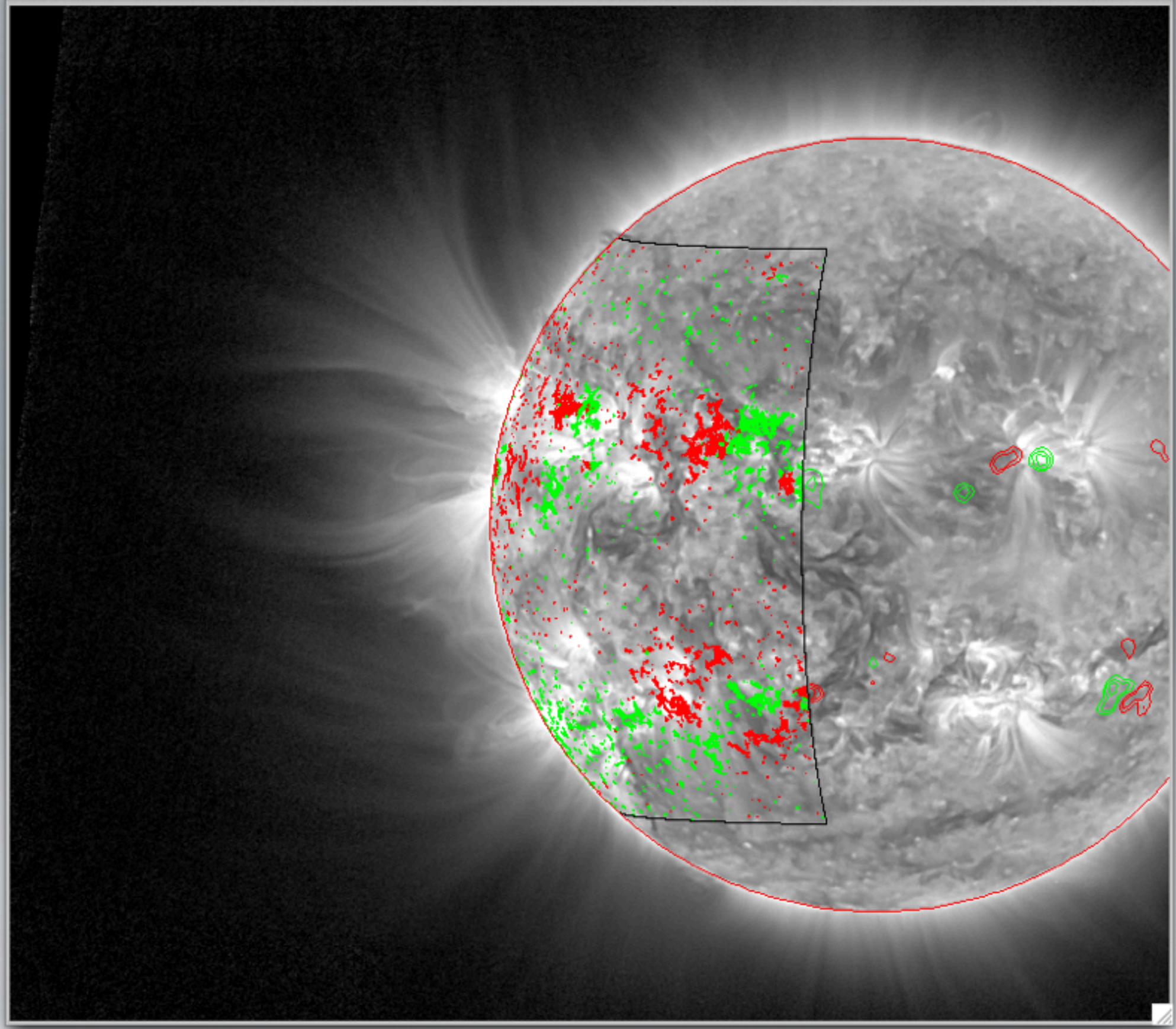


SS=2.46 R⊙

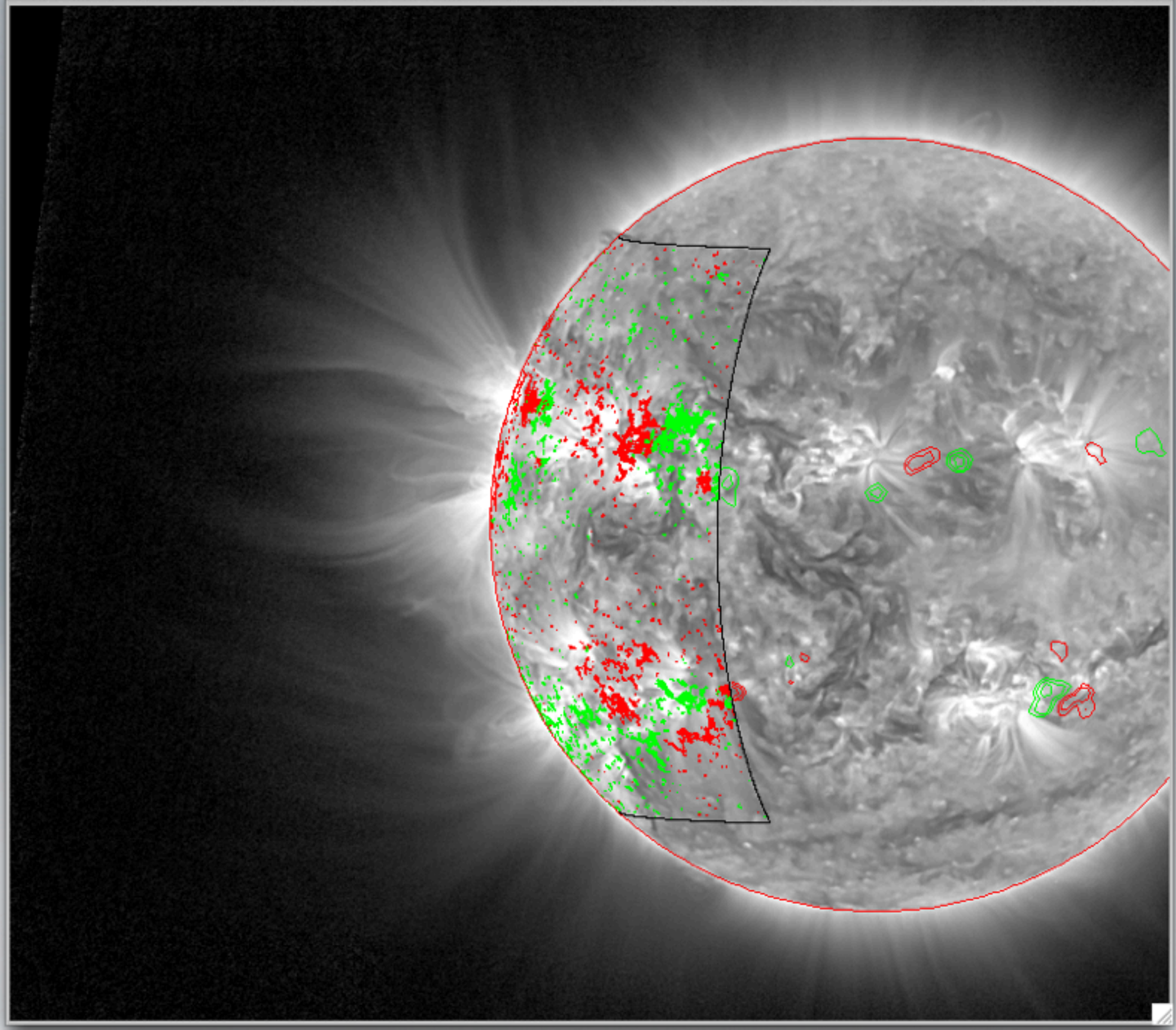
3D Display #0



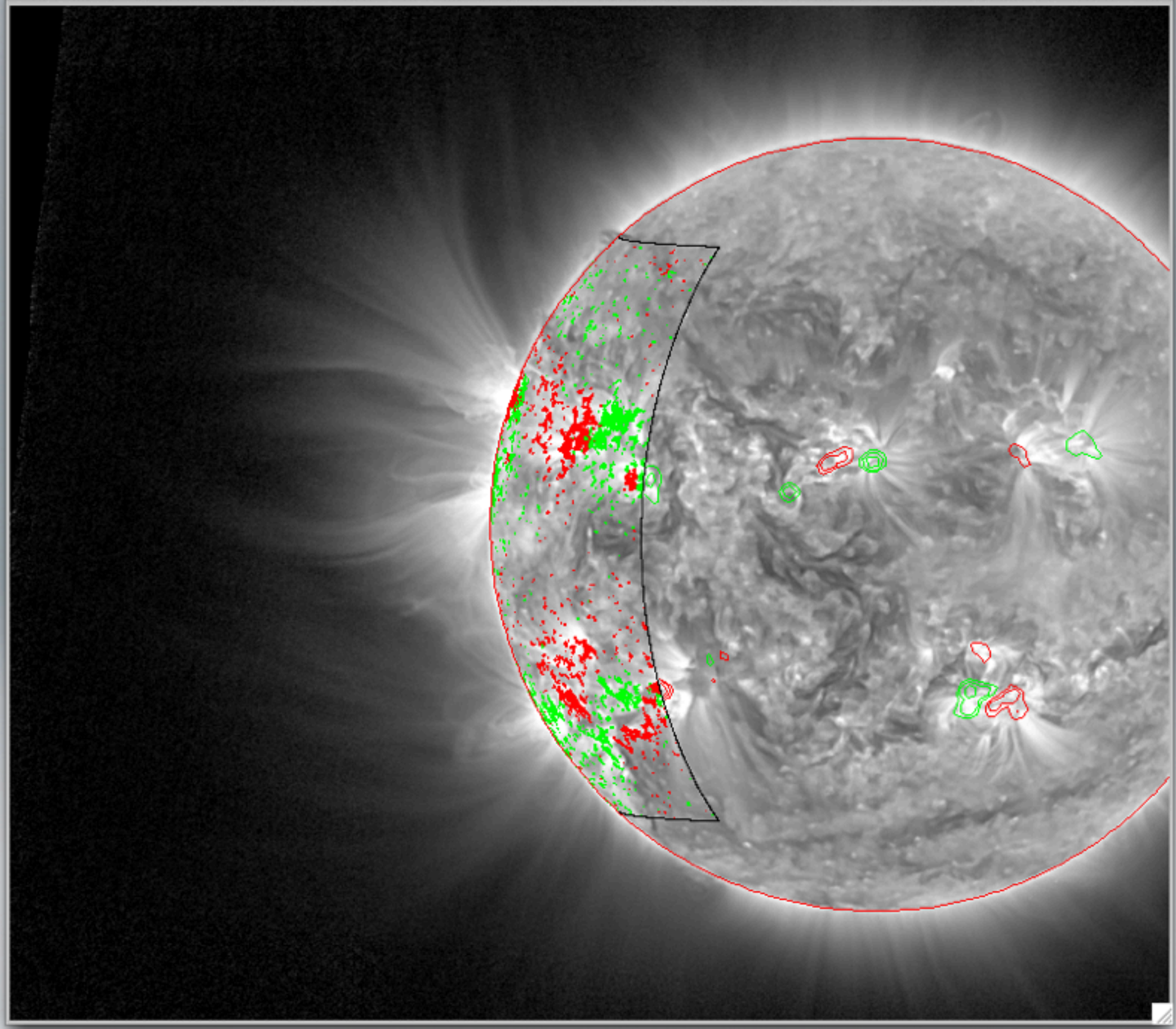
3D Display #0



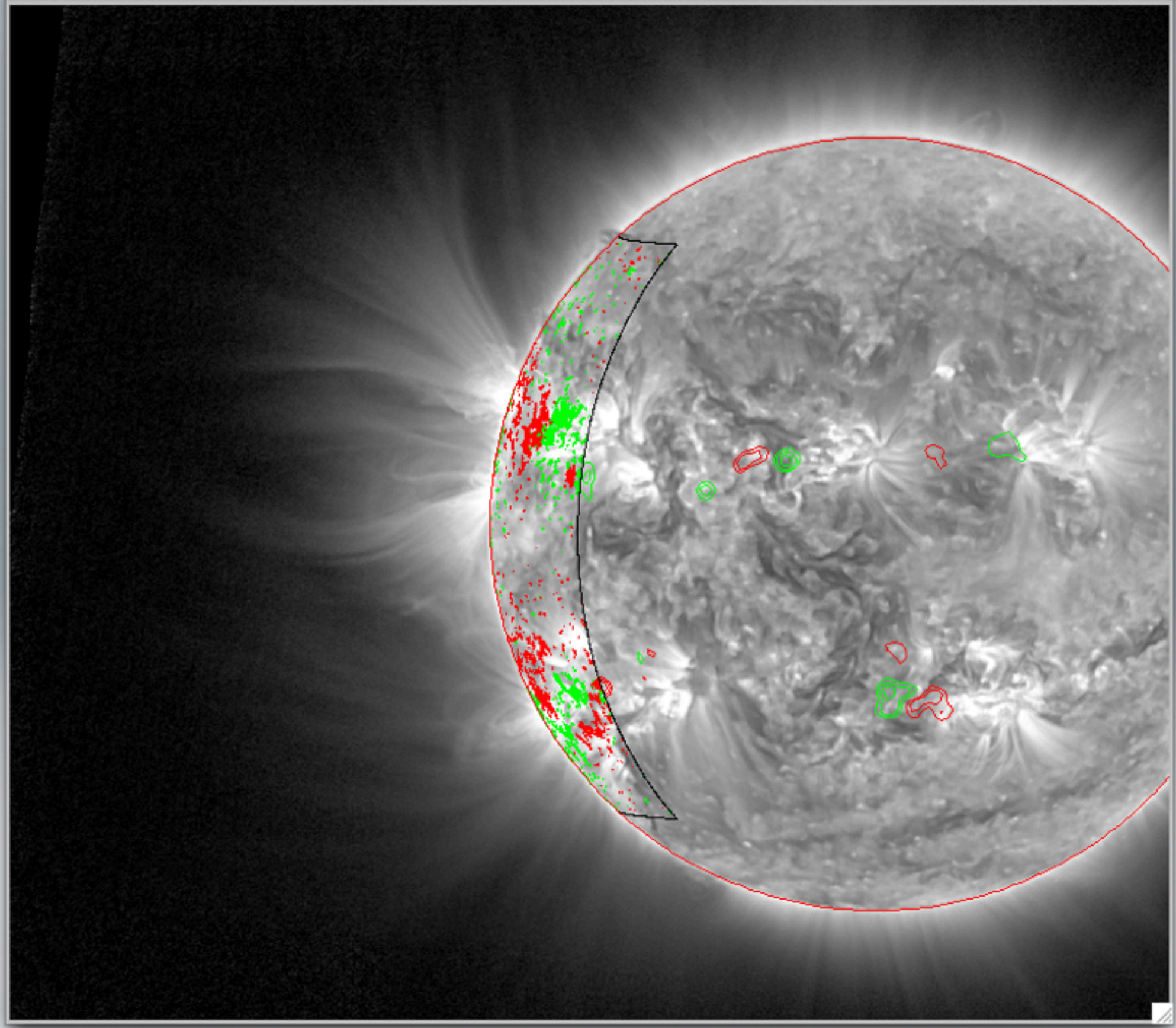
3D Display #0



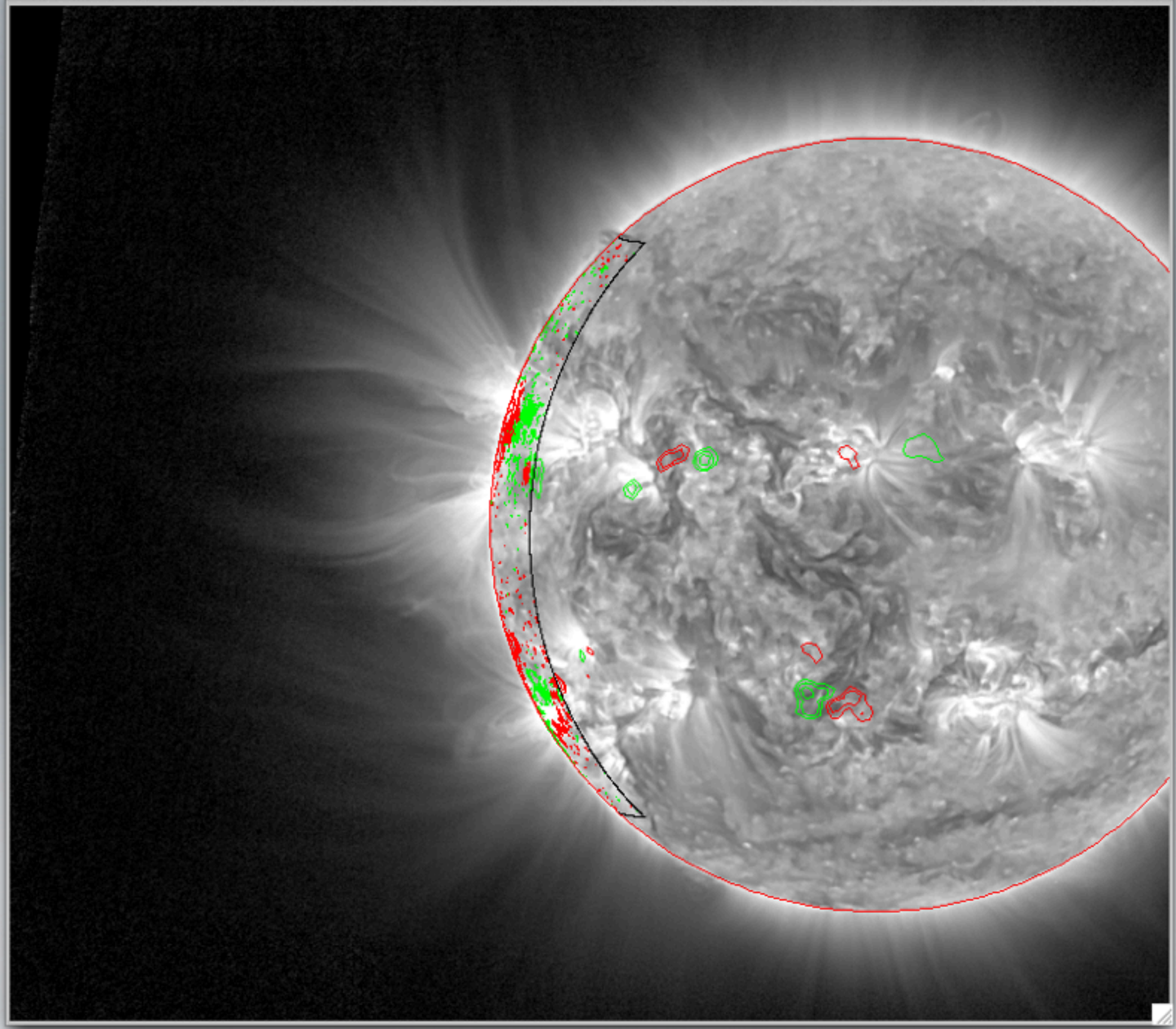
3D Display #0



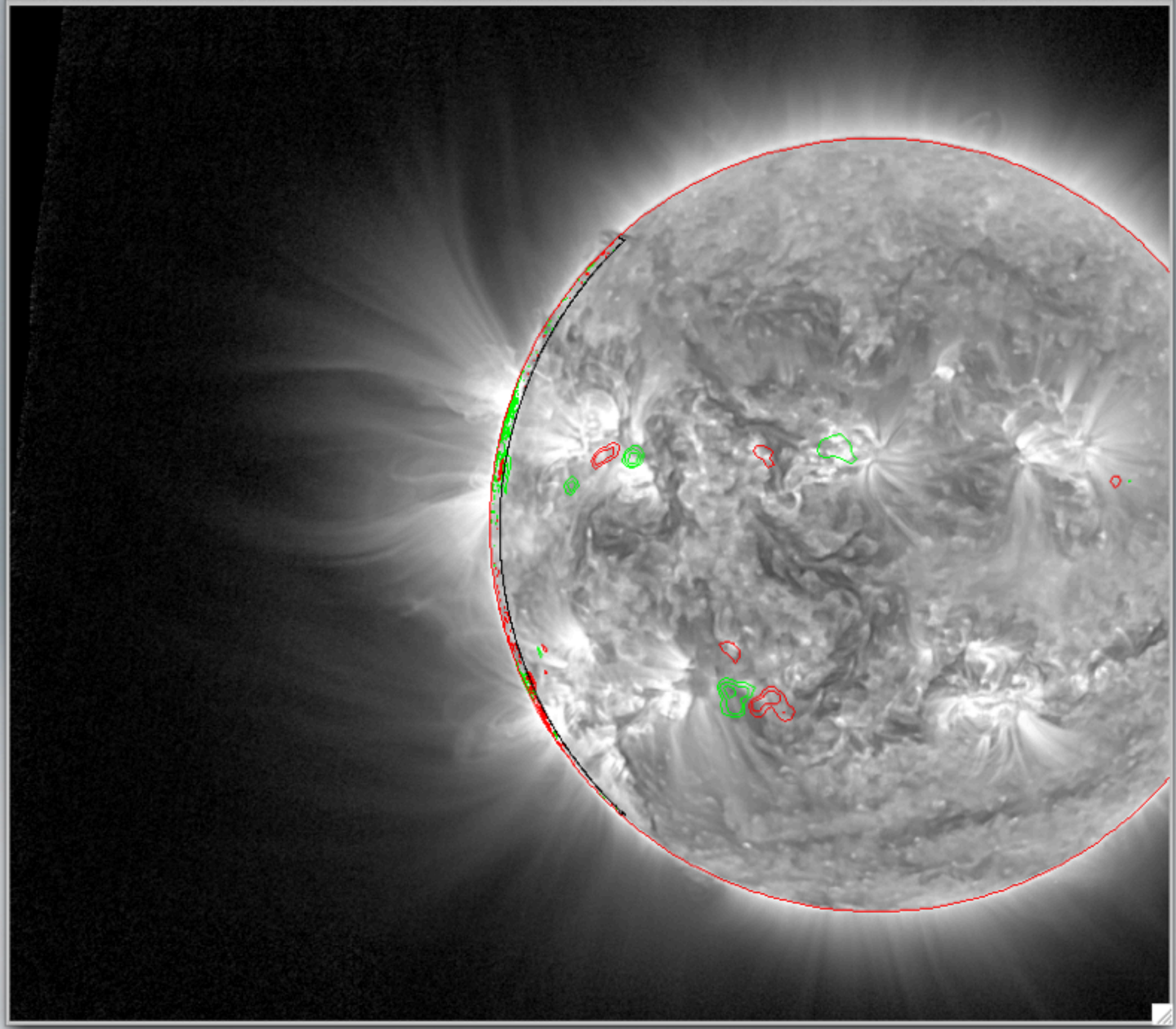
3D Display #0



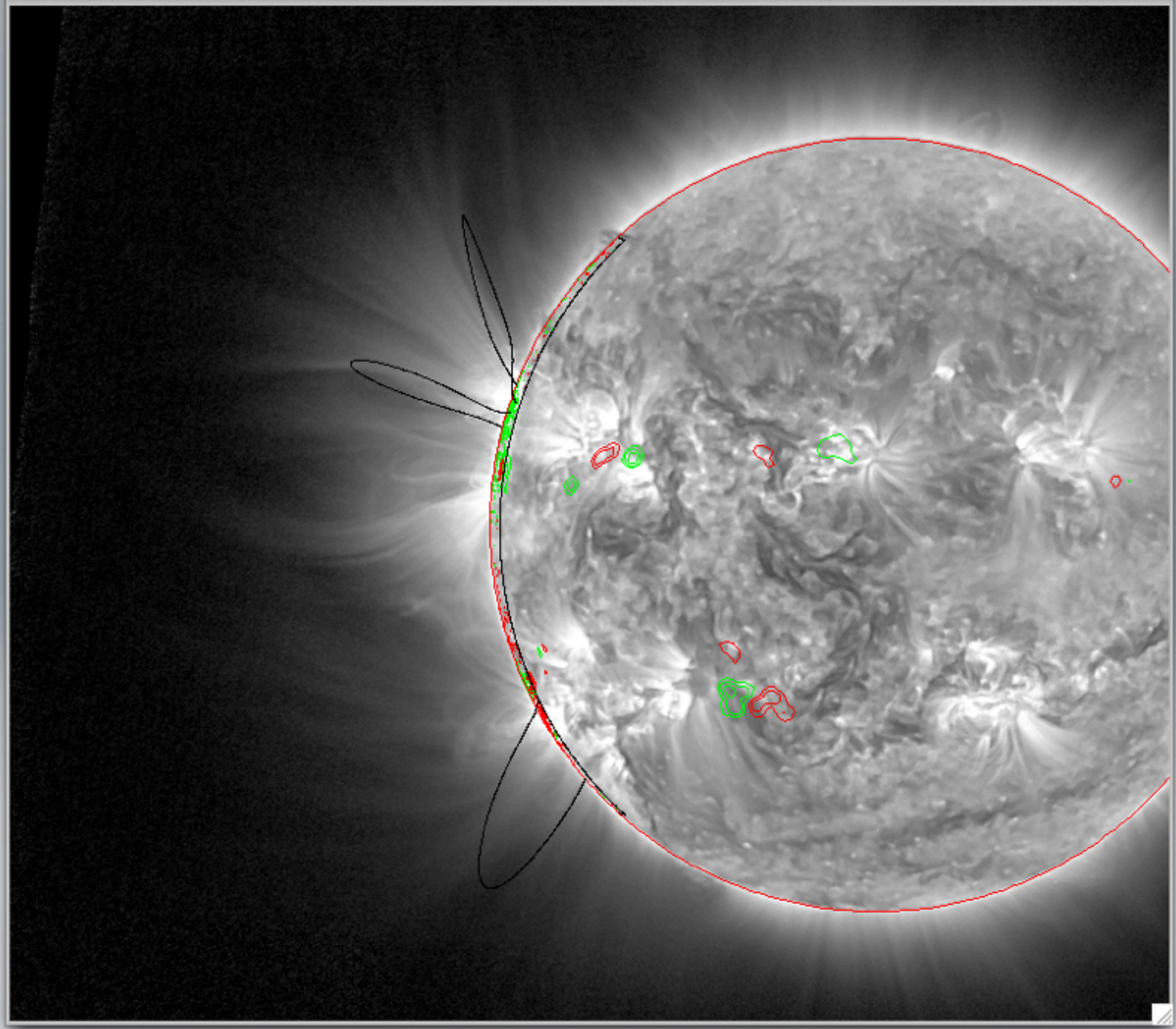
3D Display #0



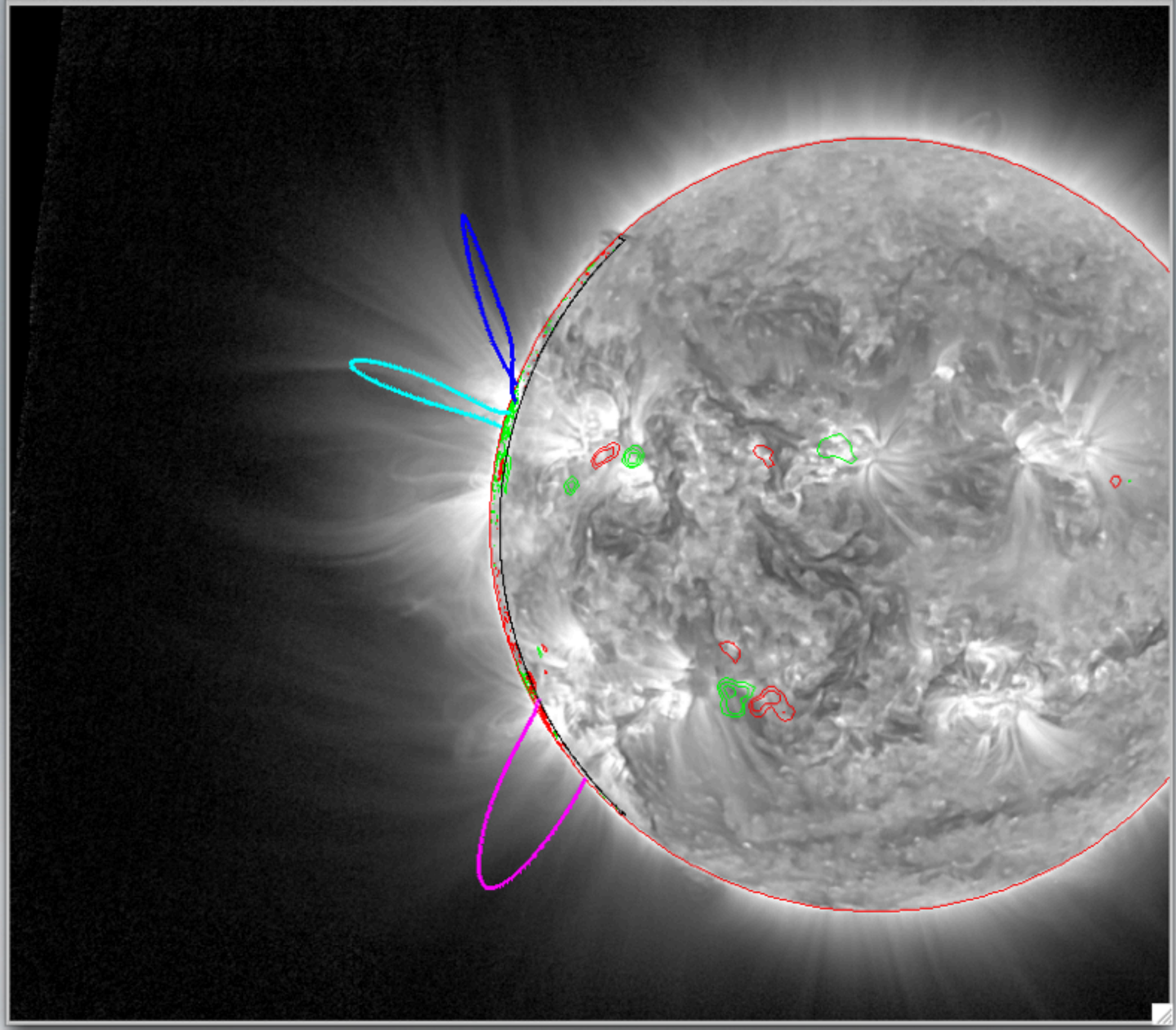
3D Display #0



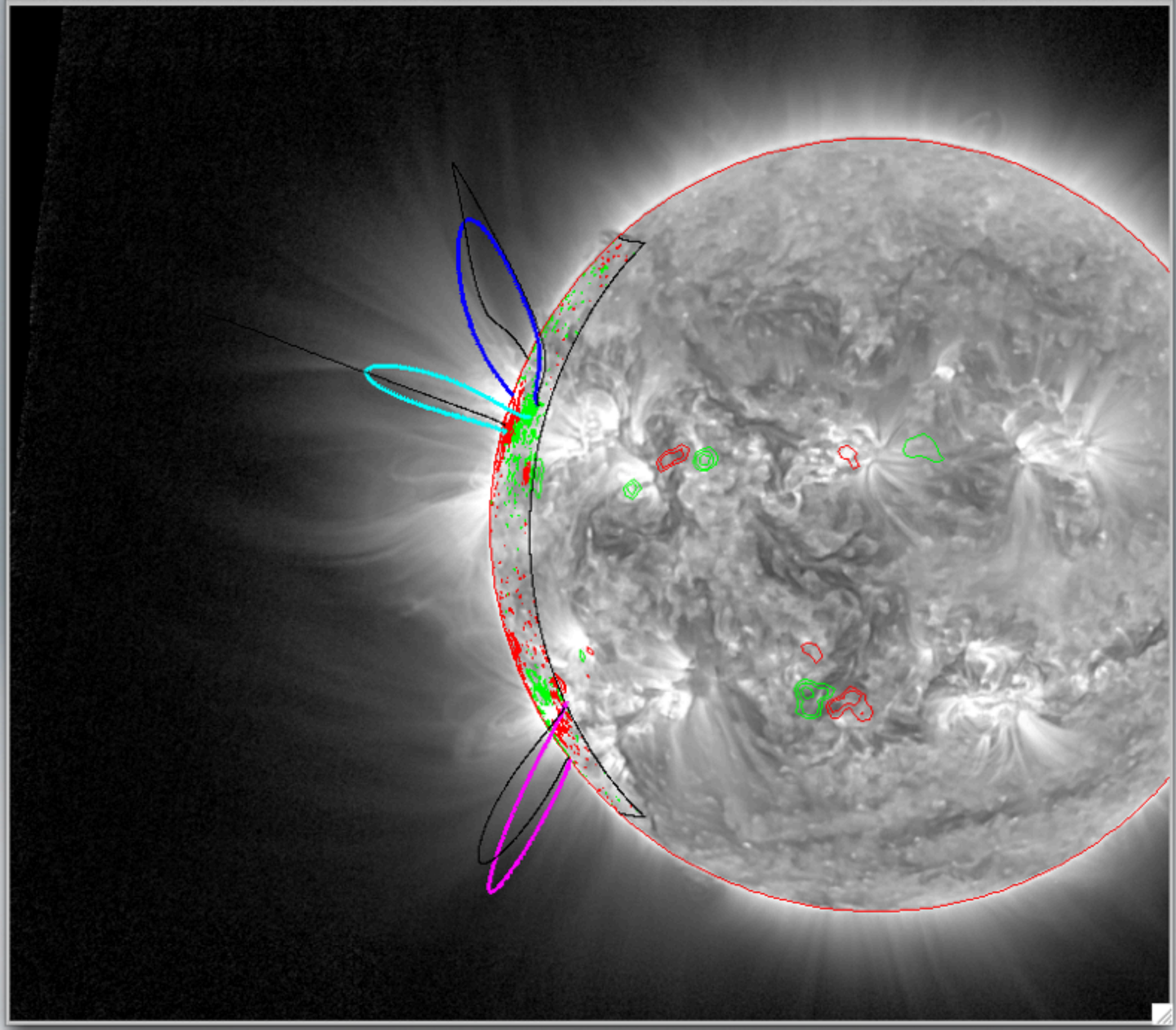
3D Display #0



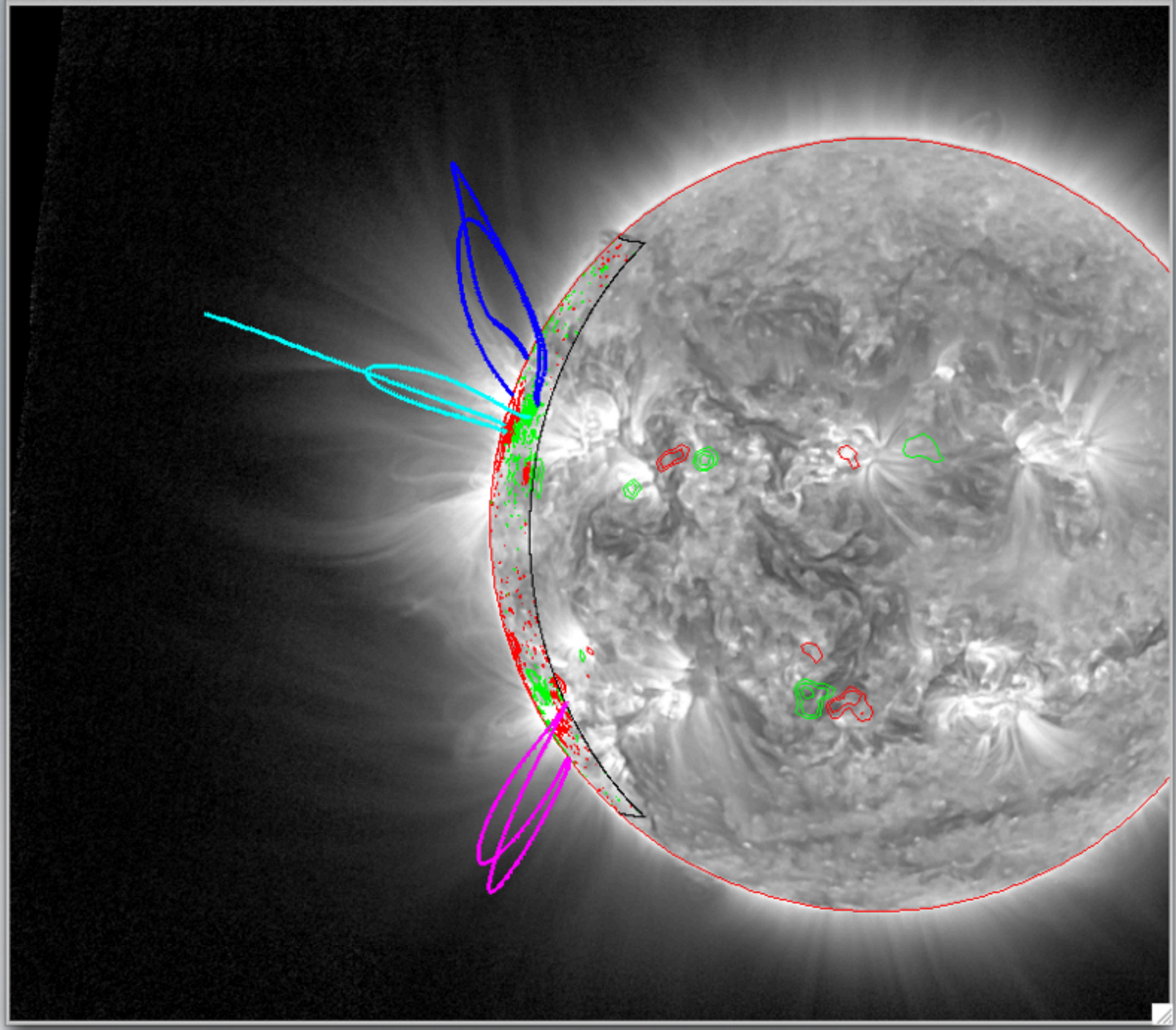
3D Display #0



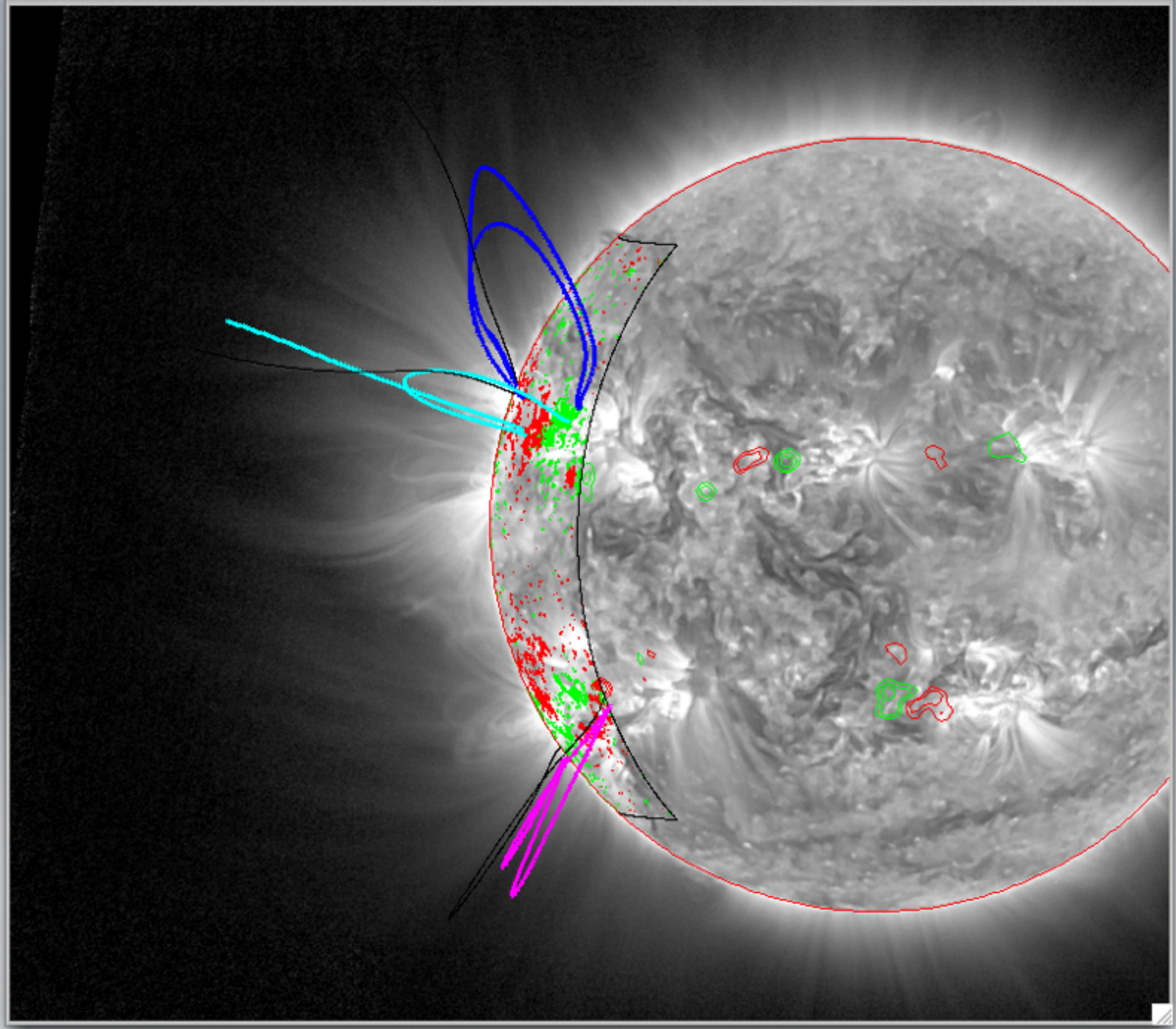
3D Display #0



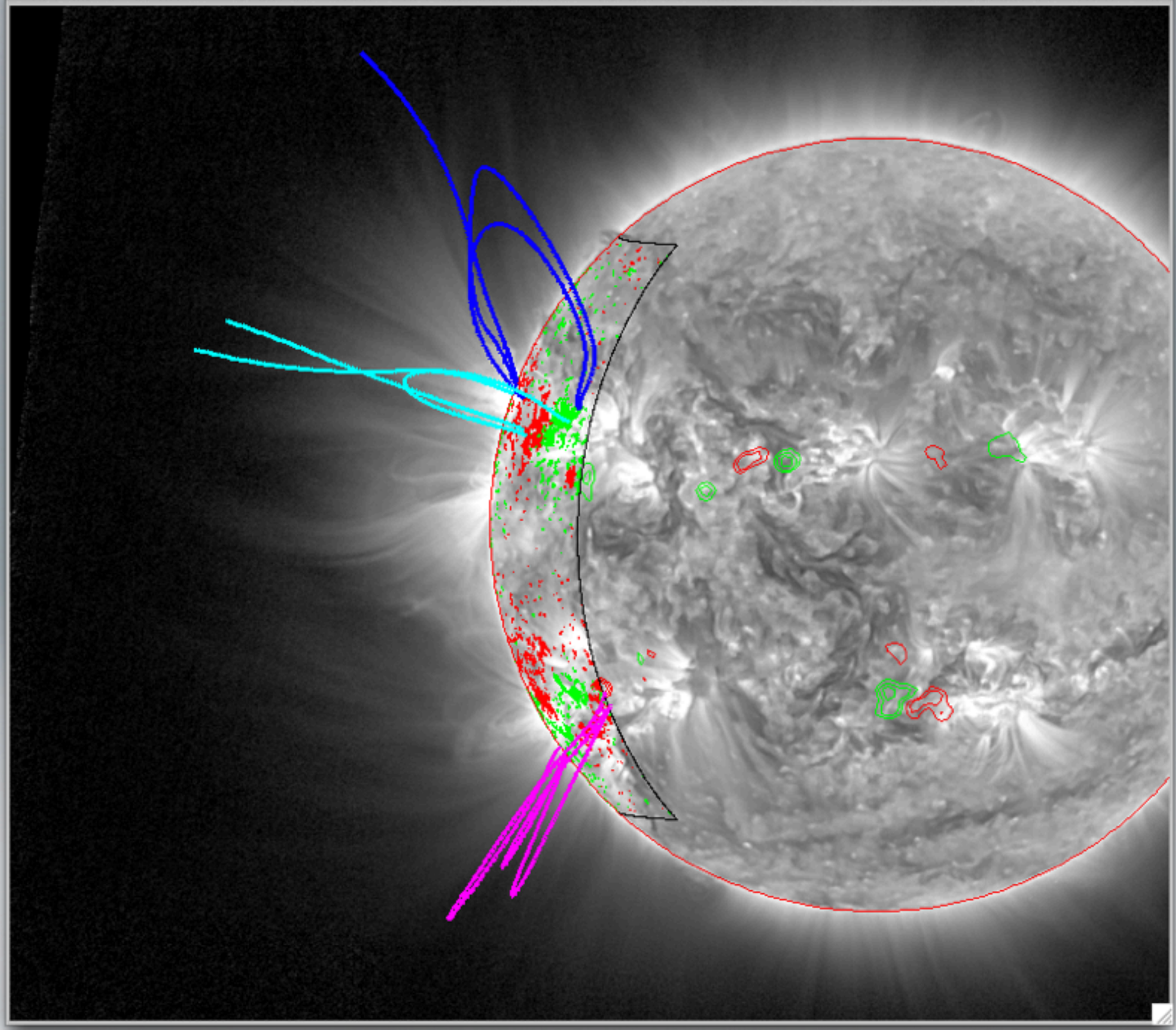
3D Display #0



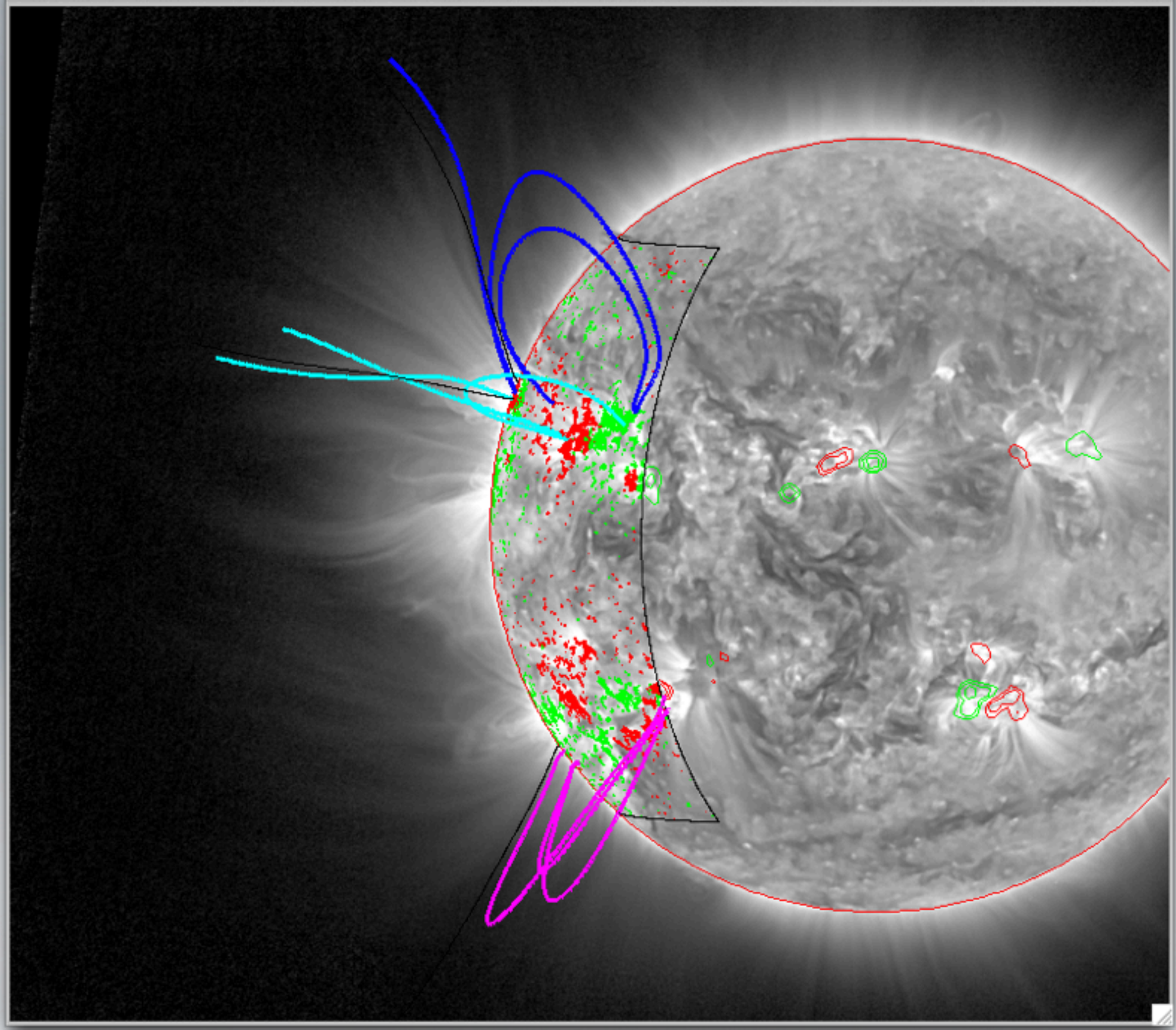
3D Display #0



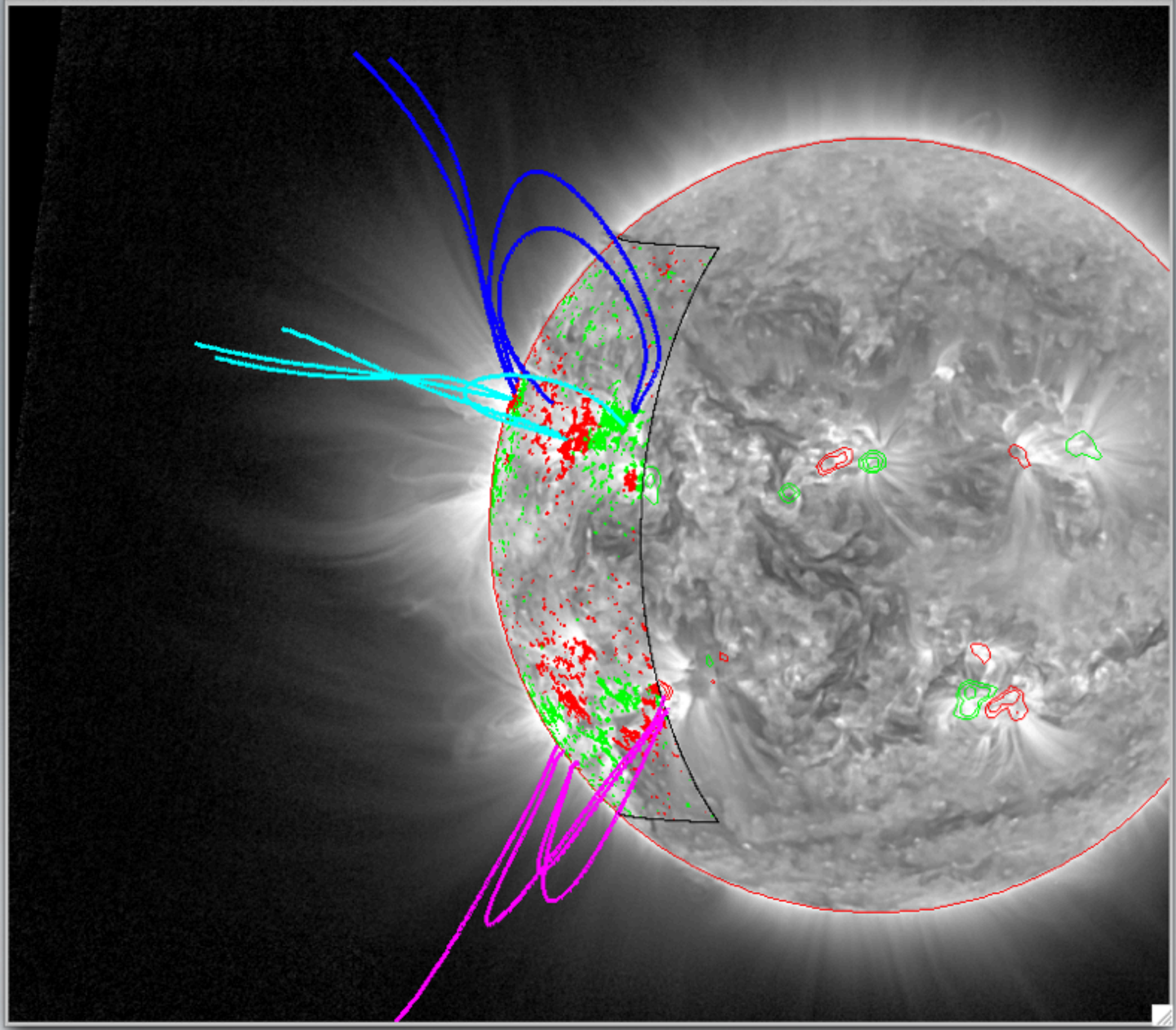
3D Display #0



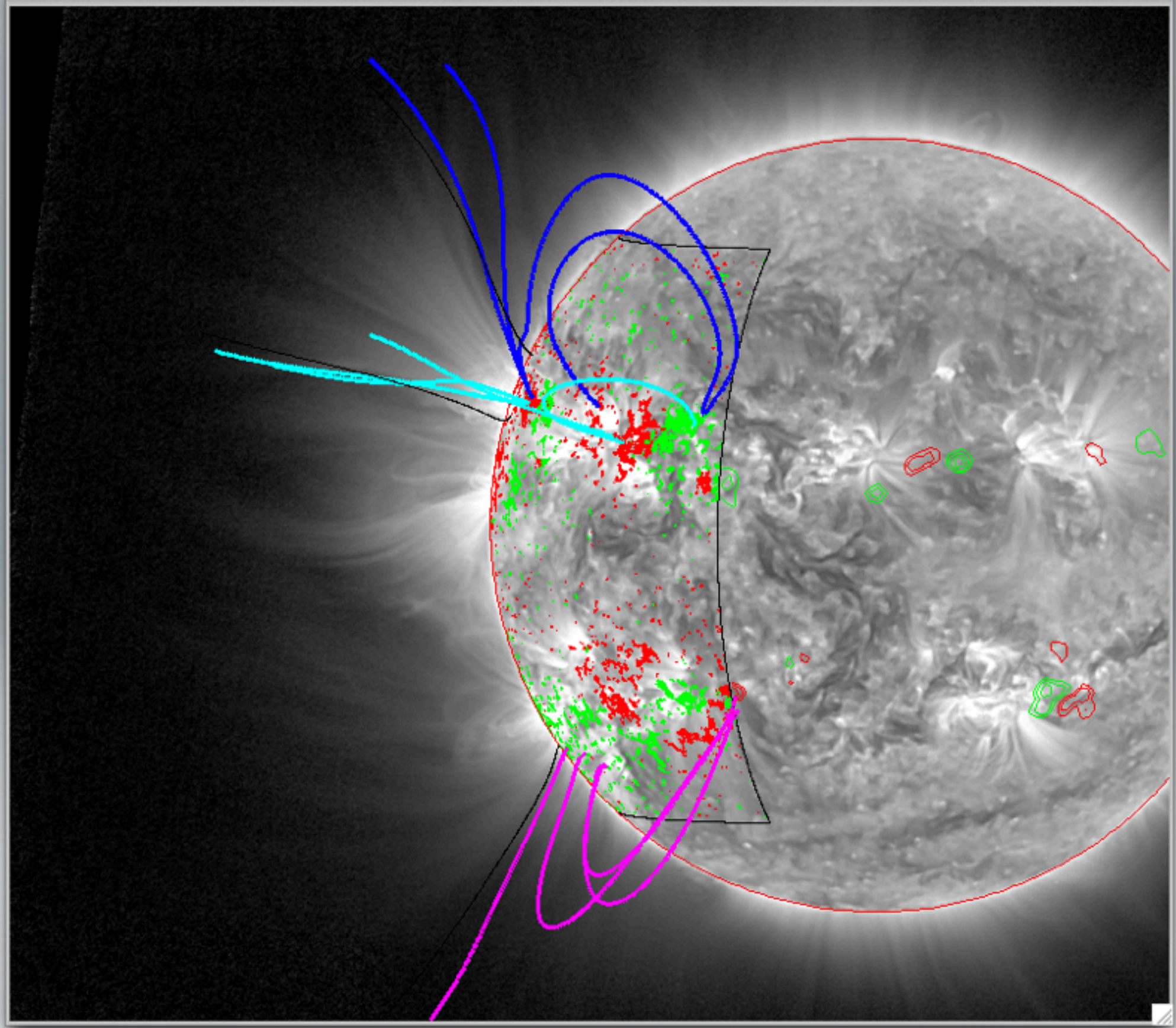
3D Display #0



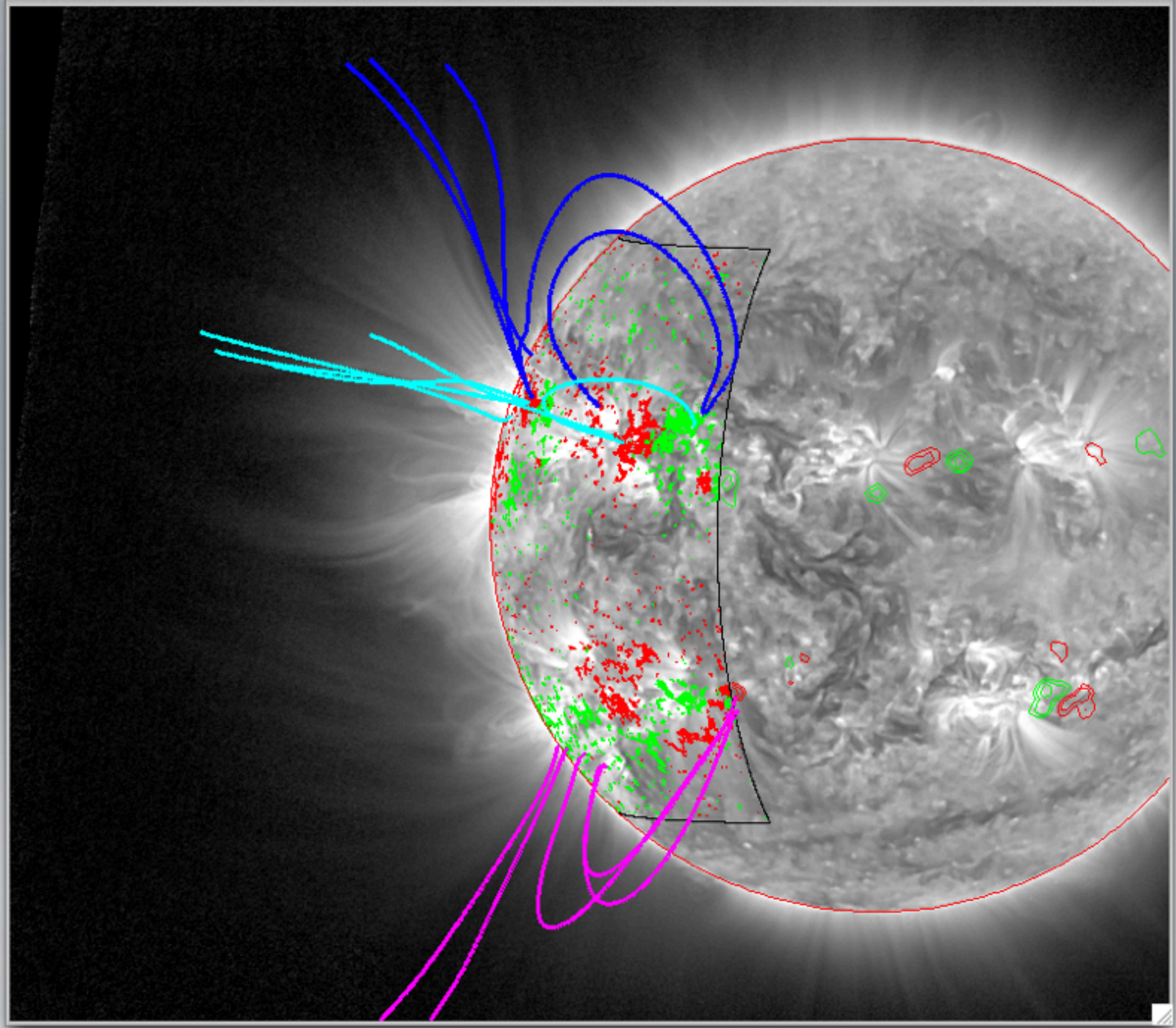
3D Display #0



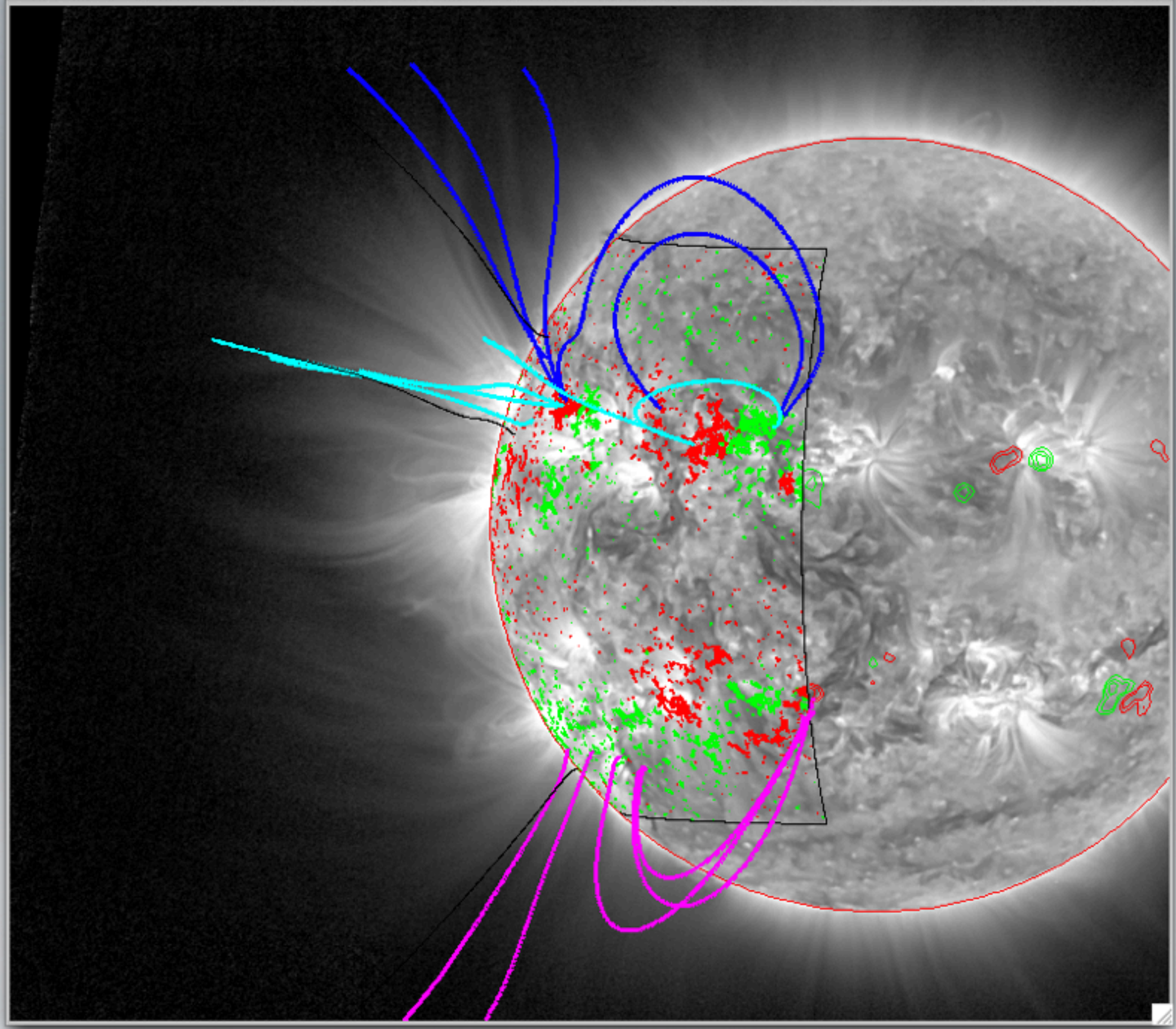
3D Display #0



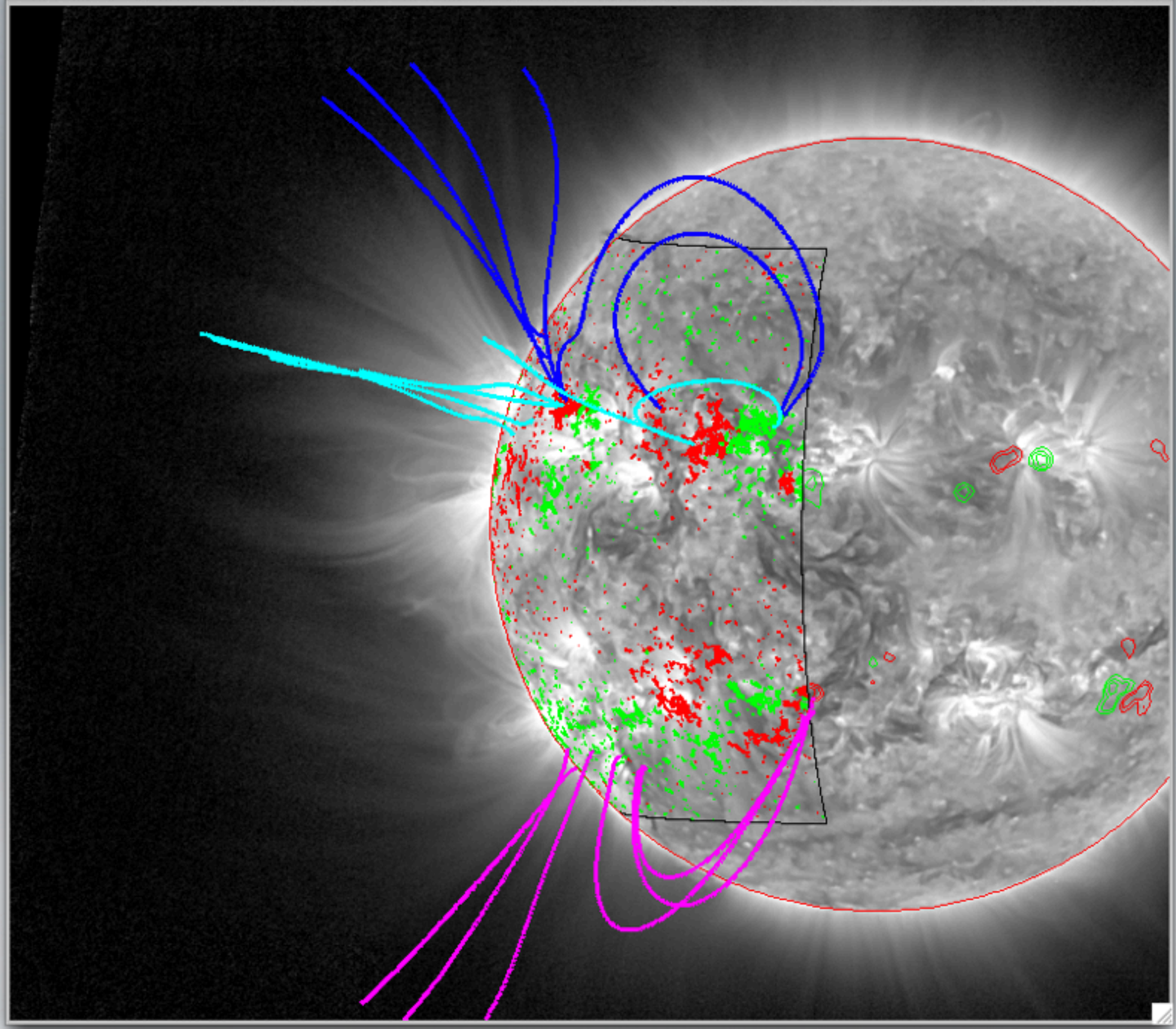
3D Display #0



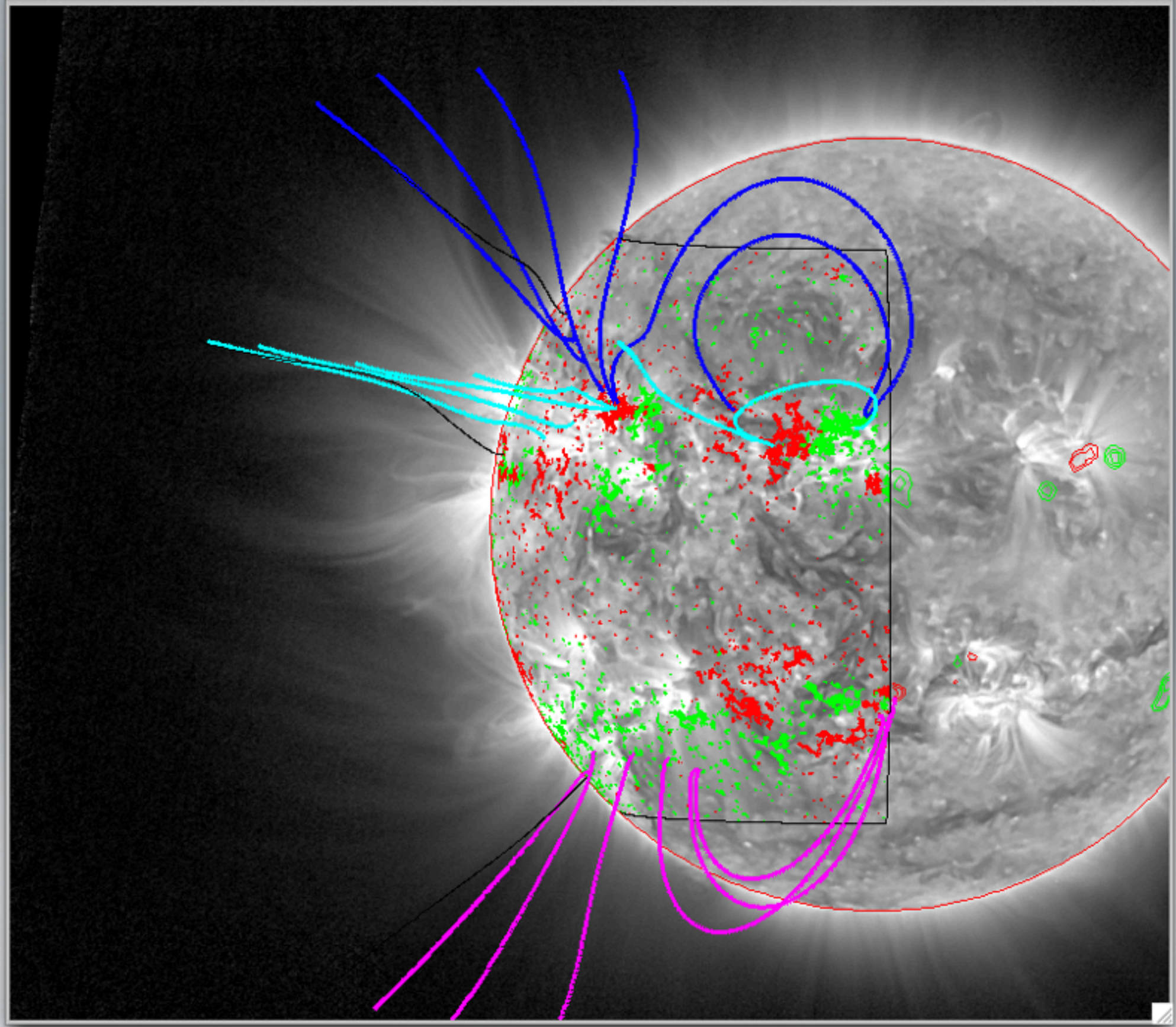
3D Display #0



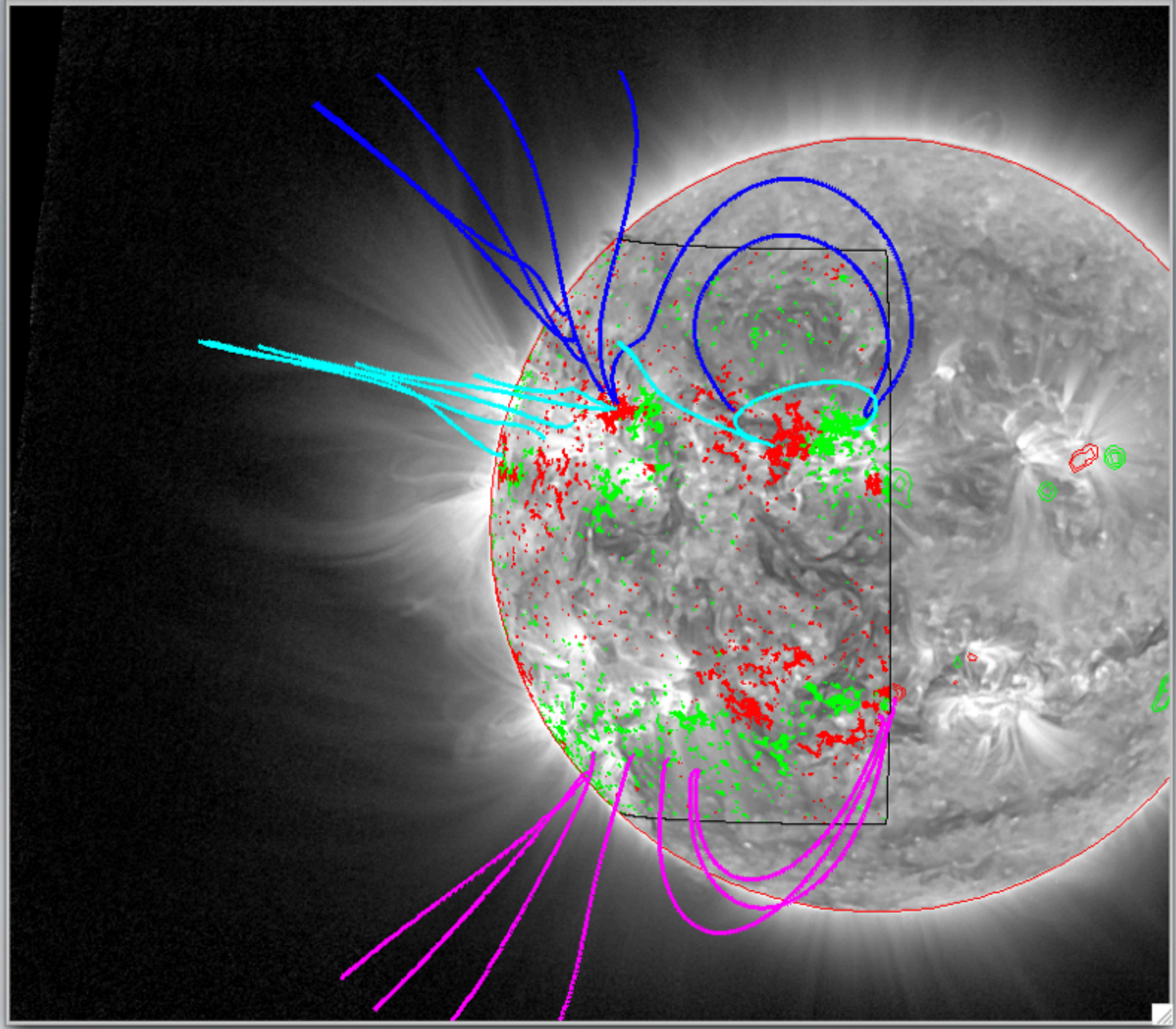
3D Display #0



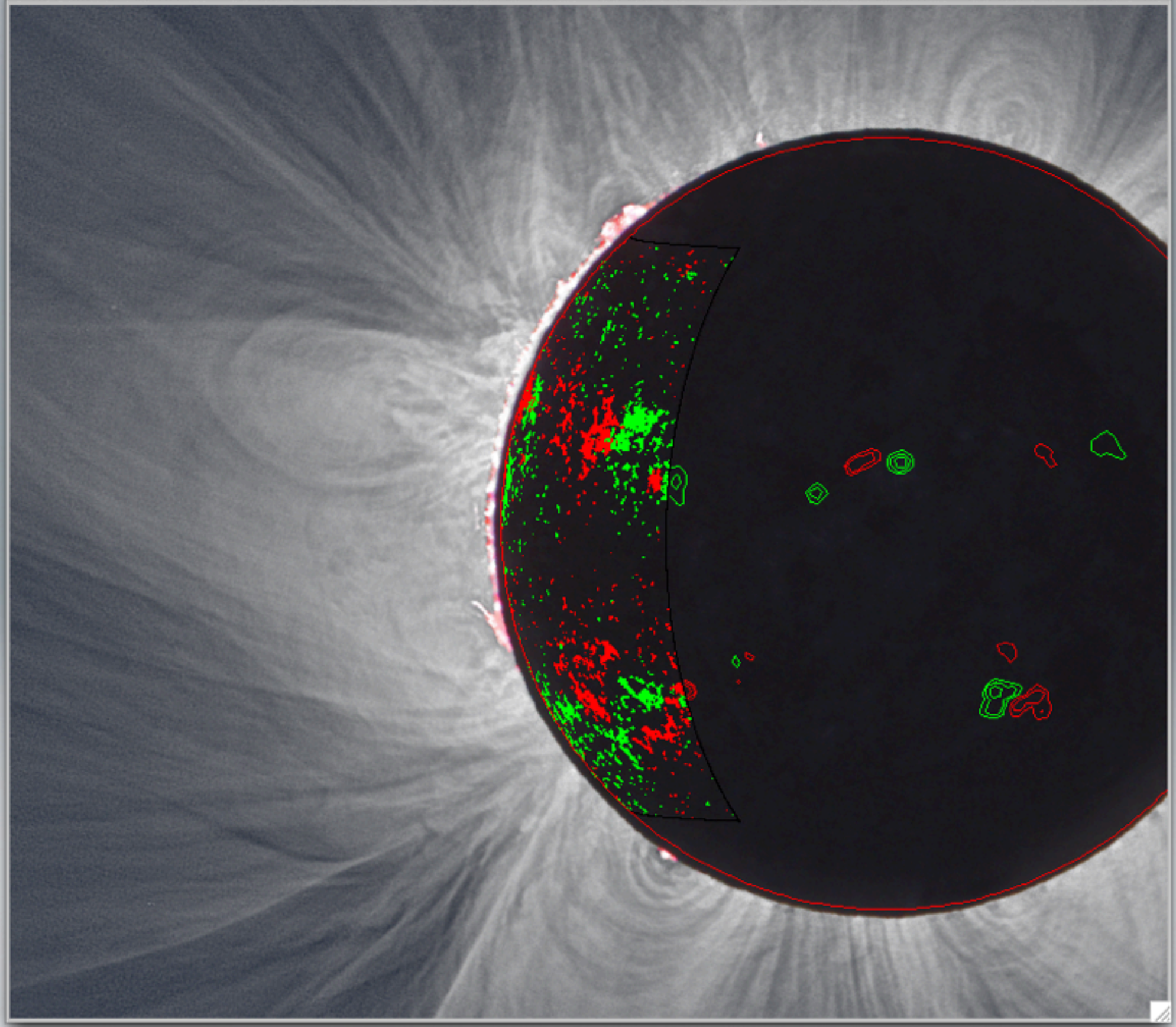
3D Display #0



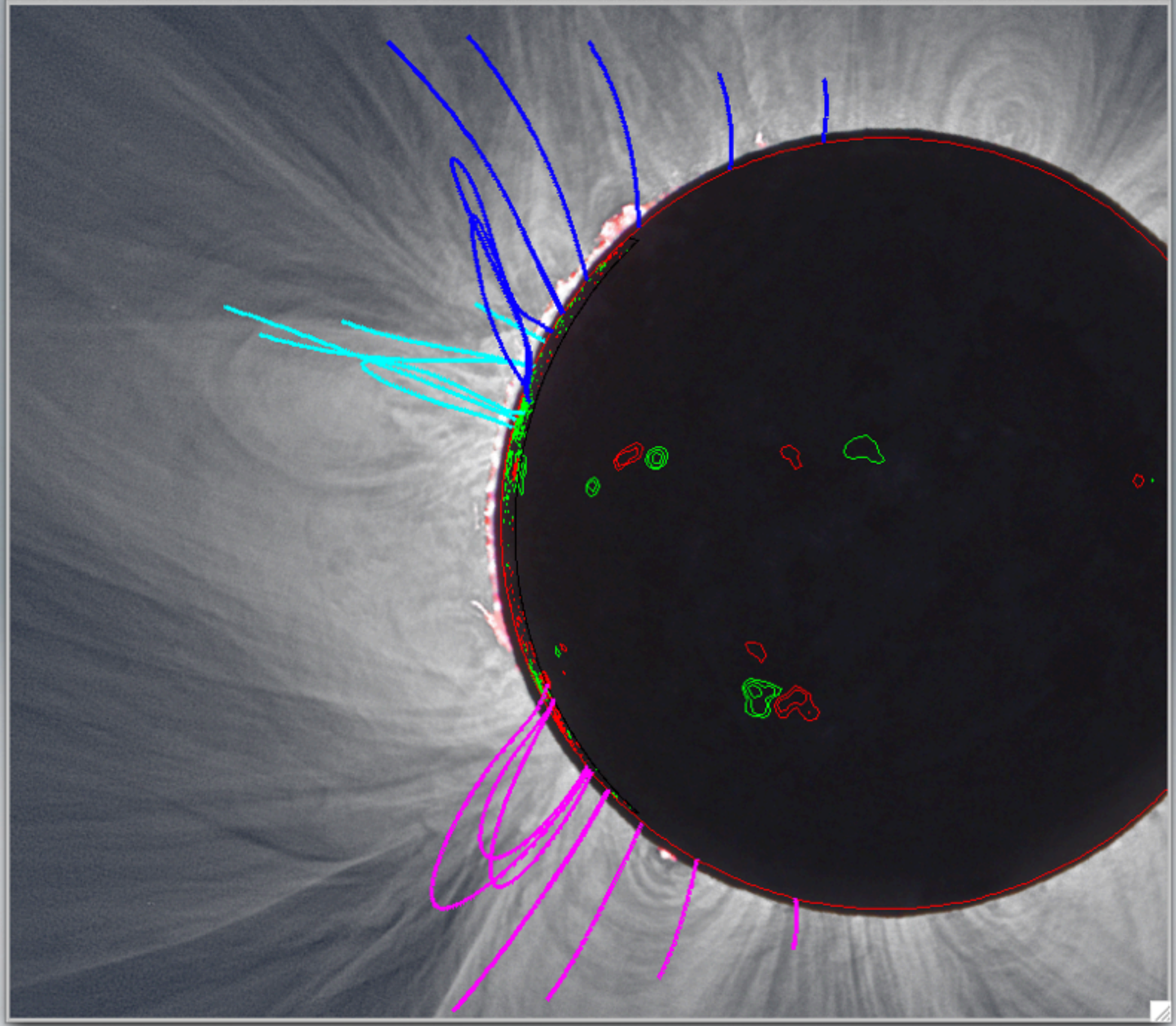
3D Display #0



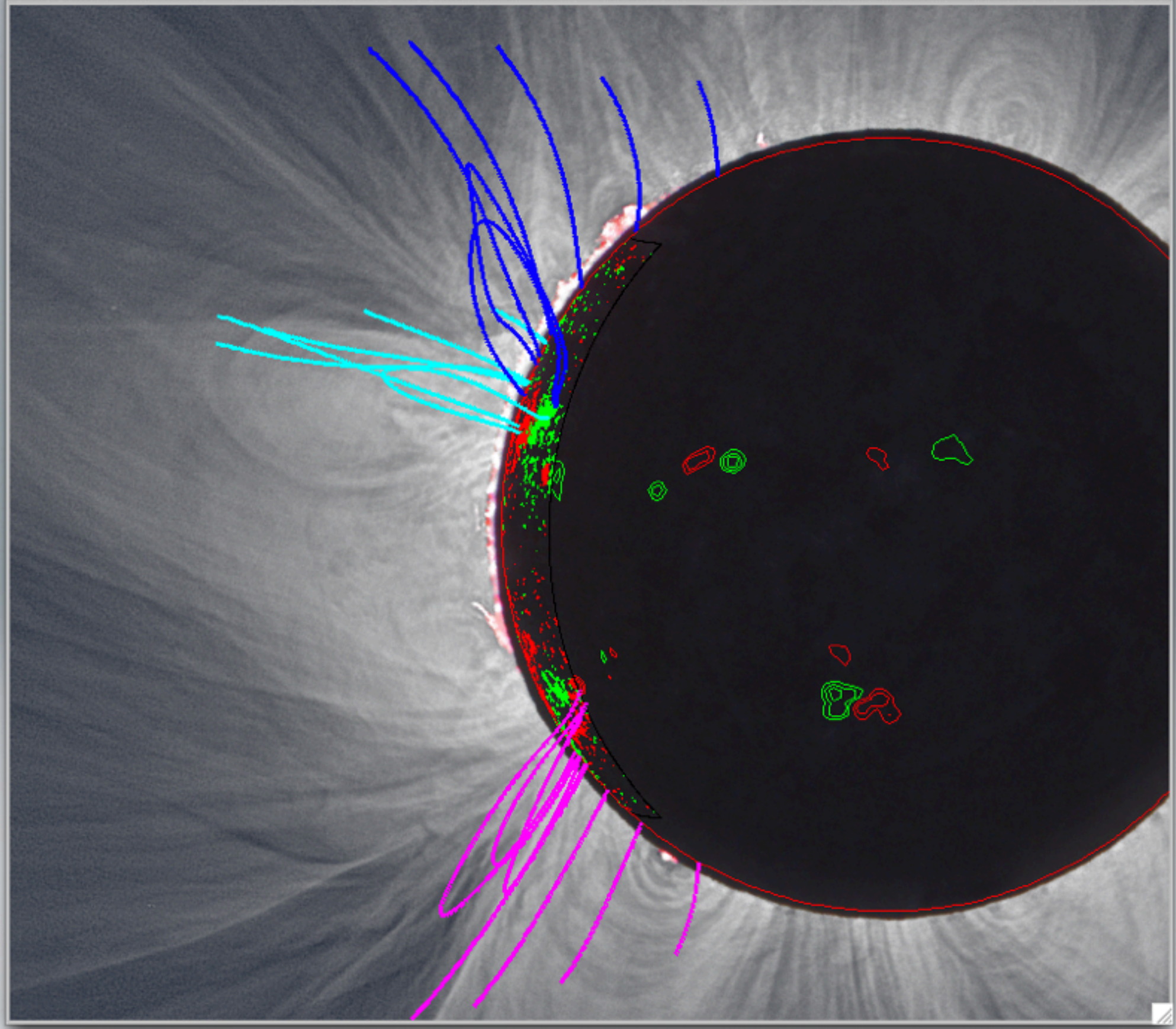
3D Display #0



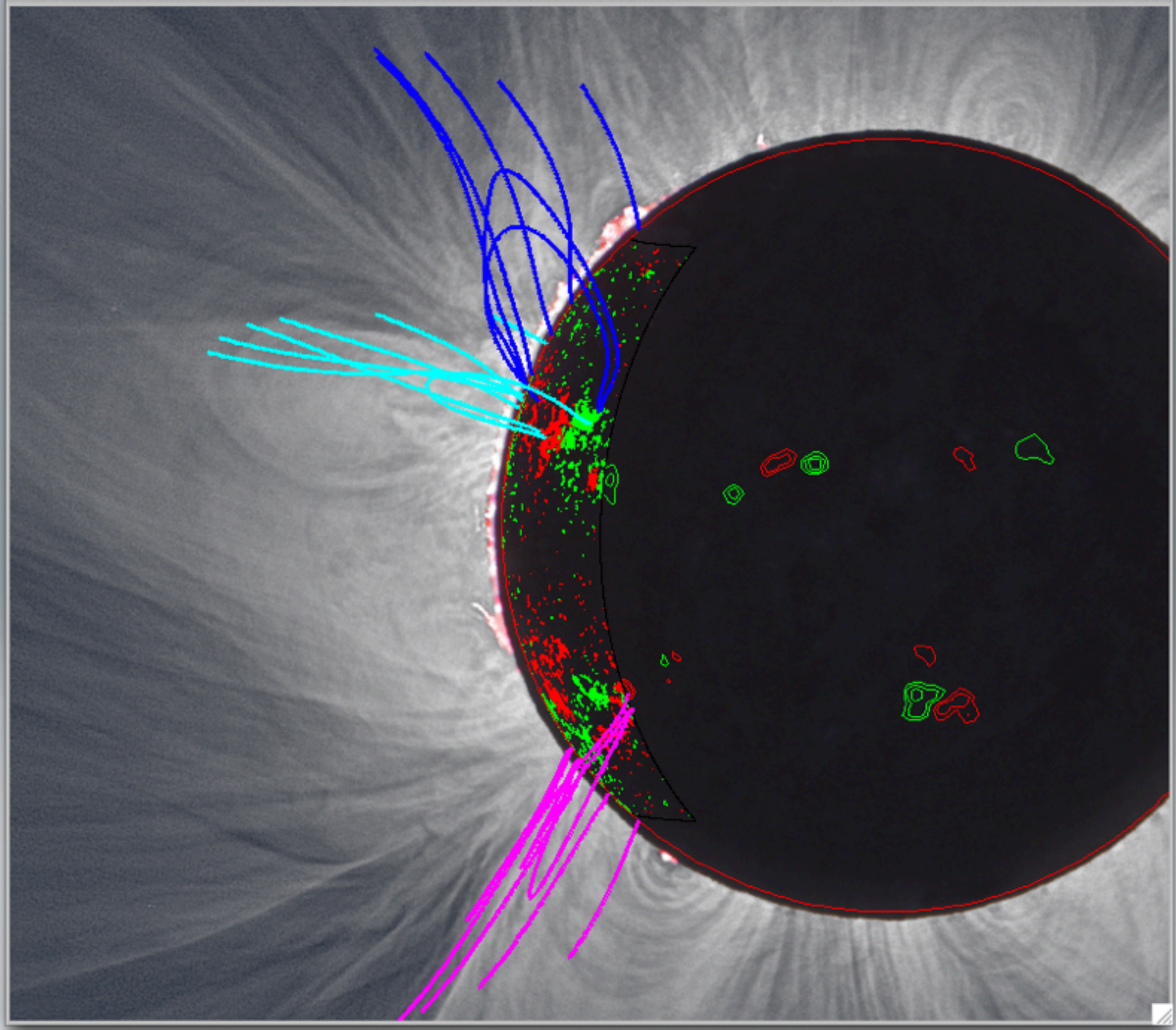
3D Display #0



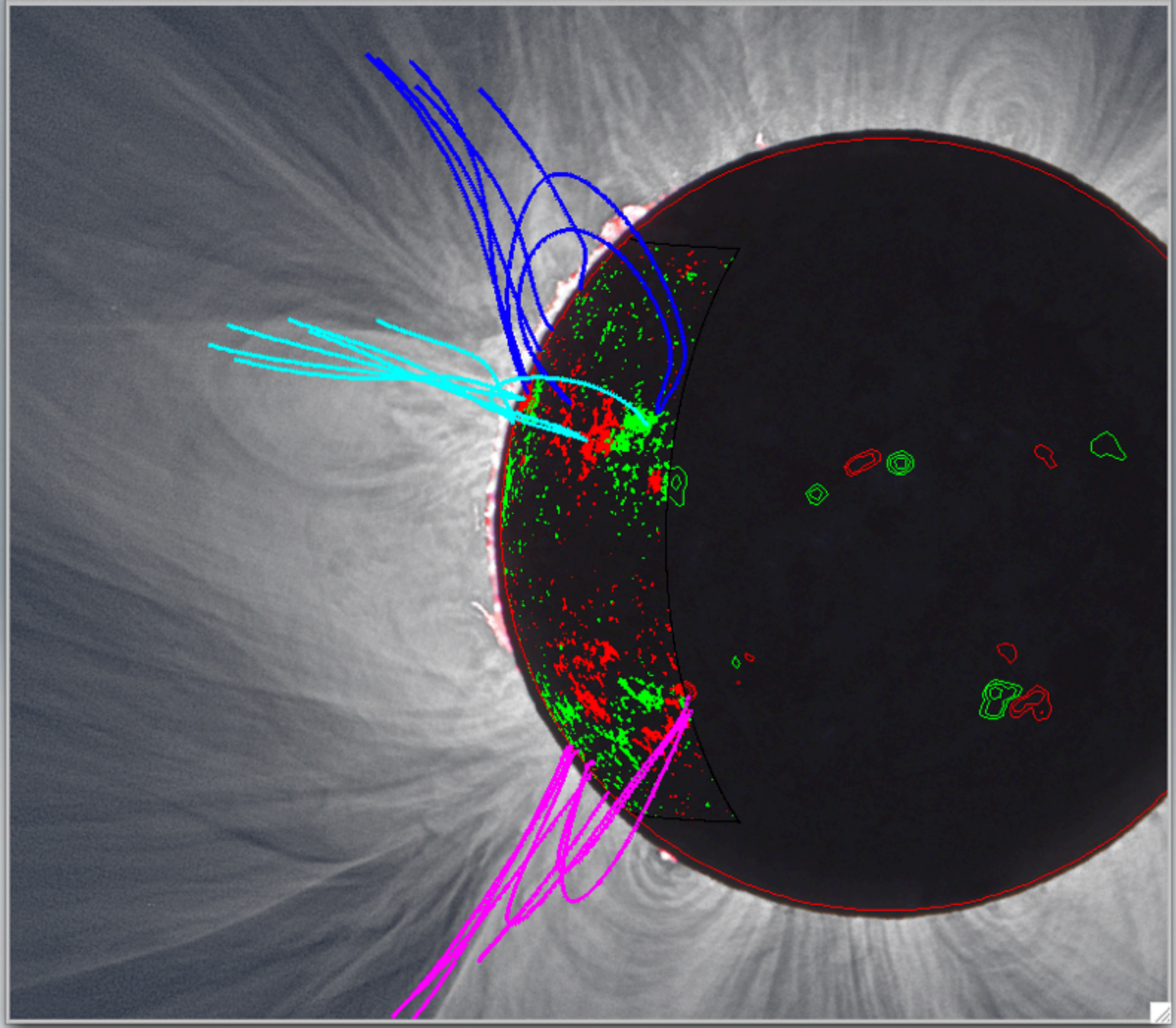
3D Display #0



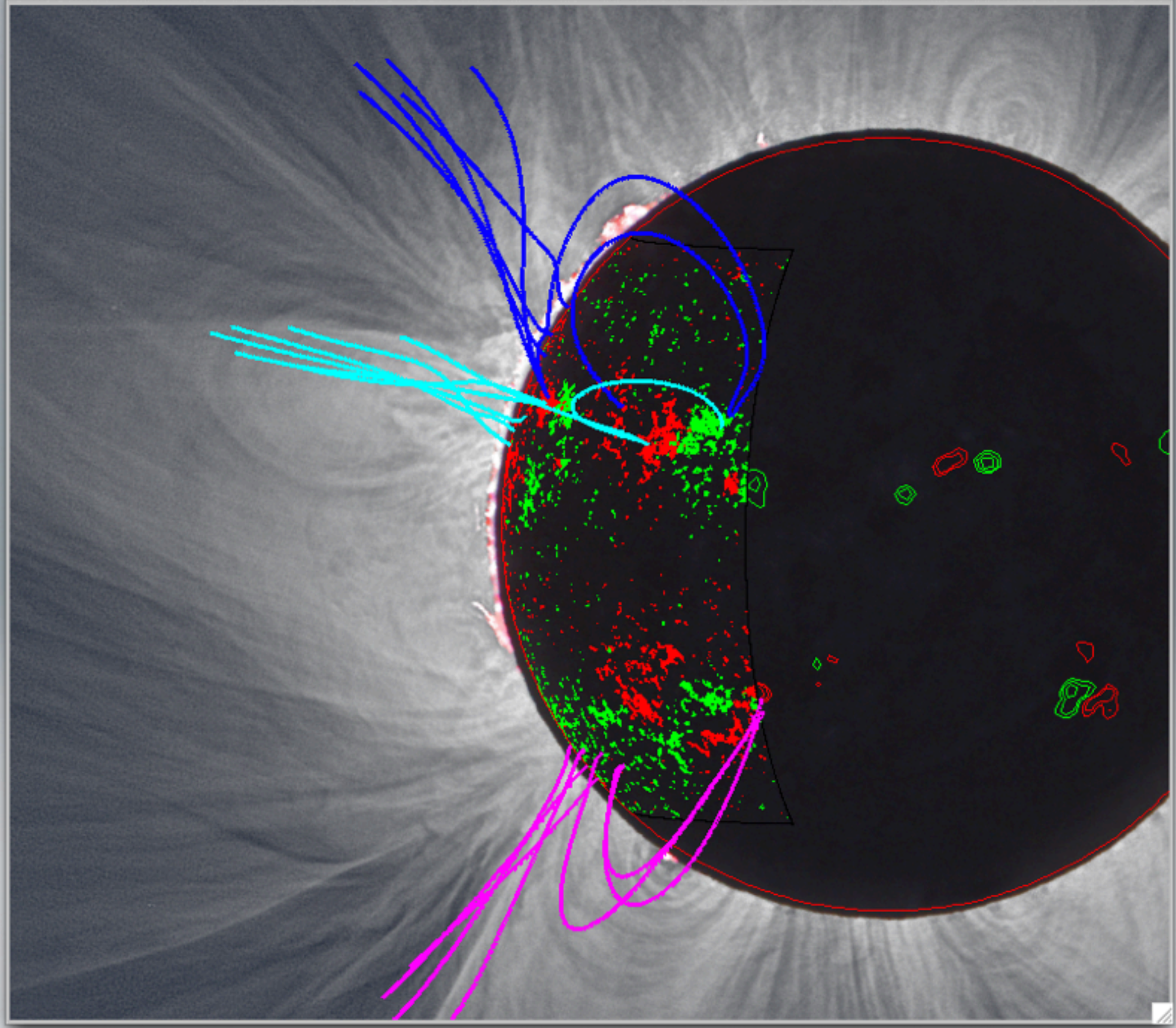
3D Display #0



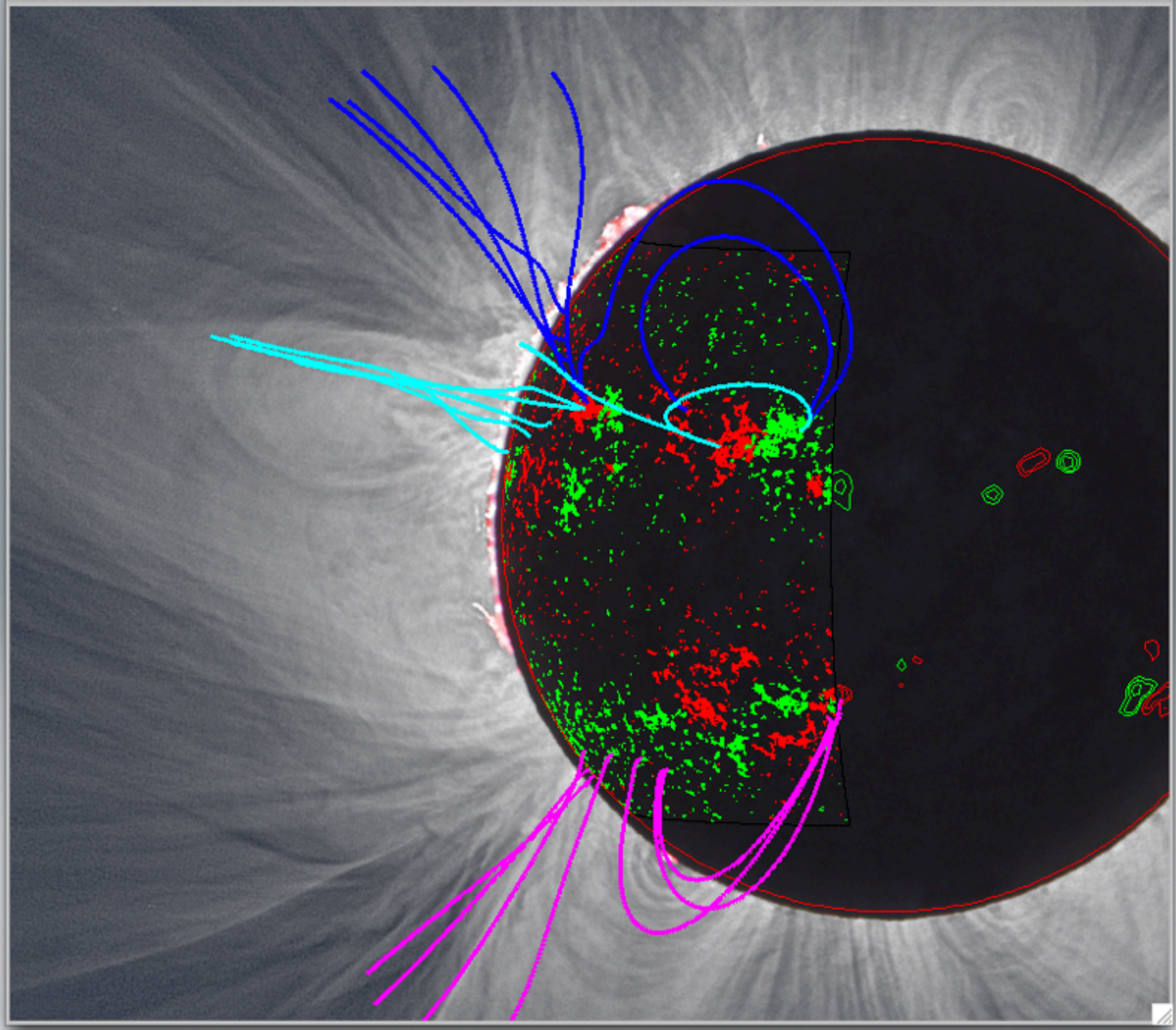
3D Display #0



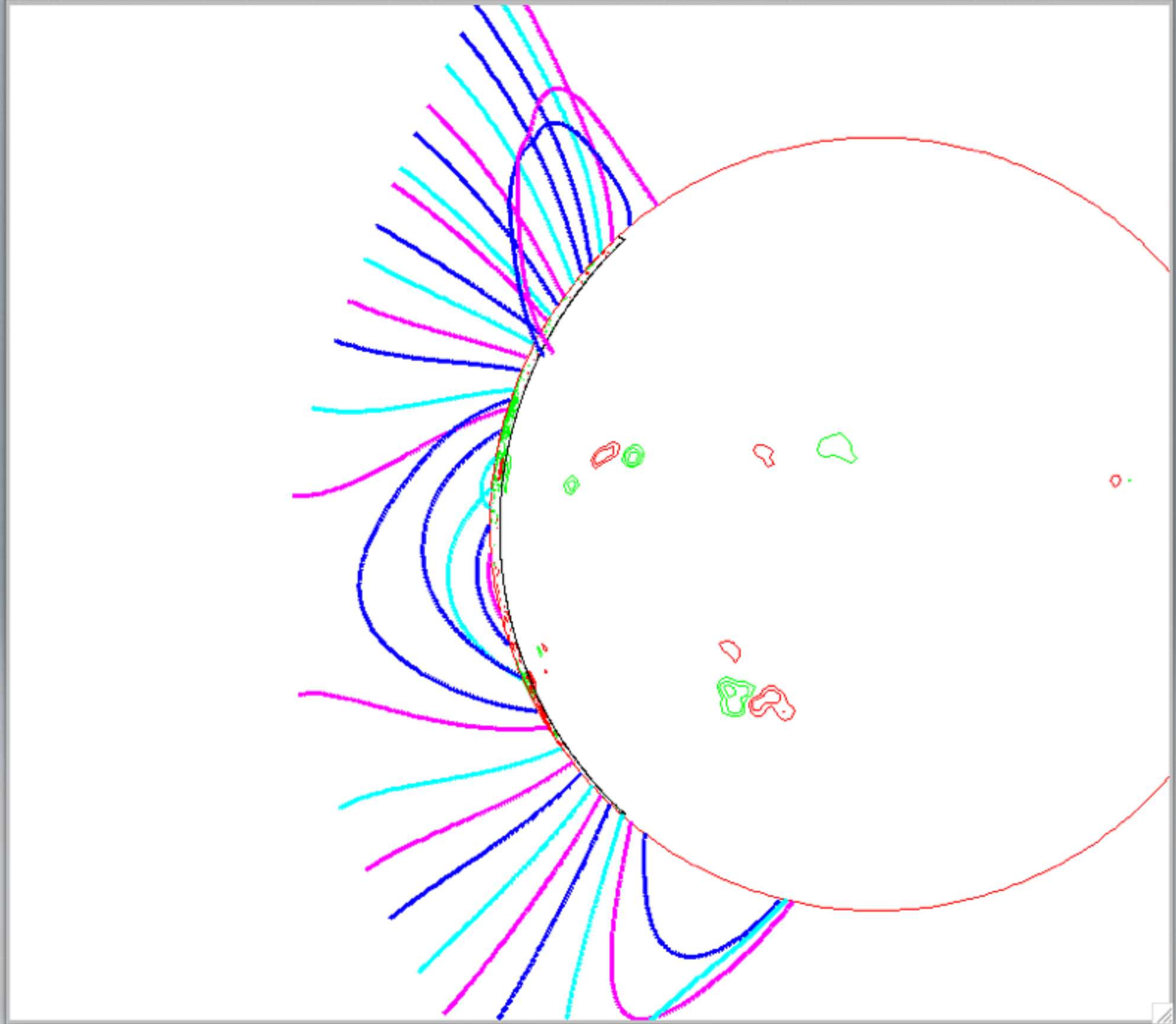
3D Display #0



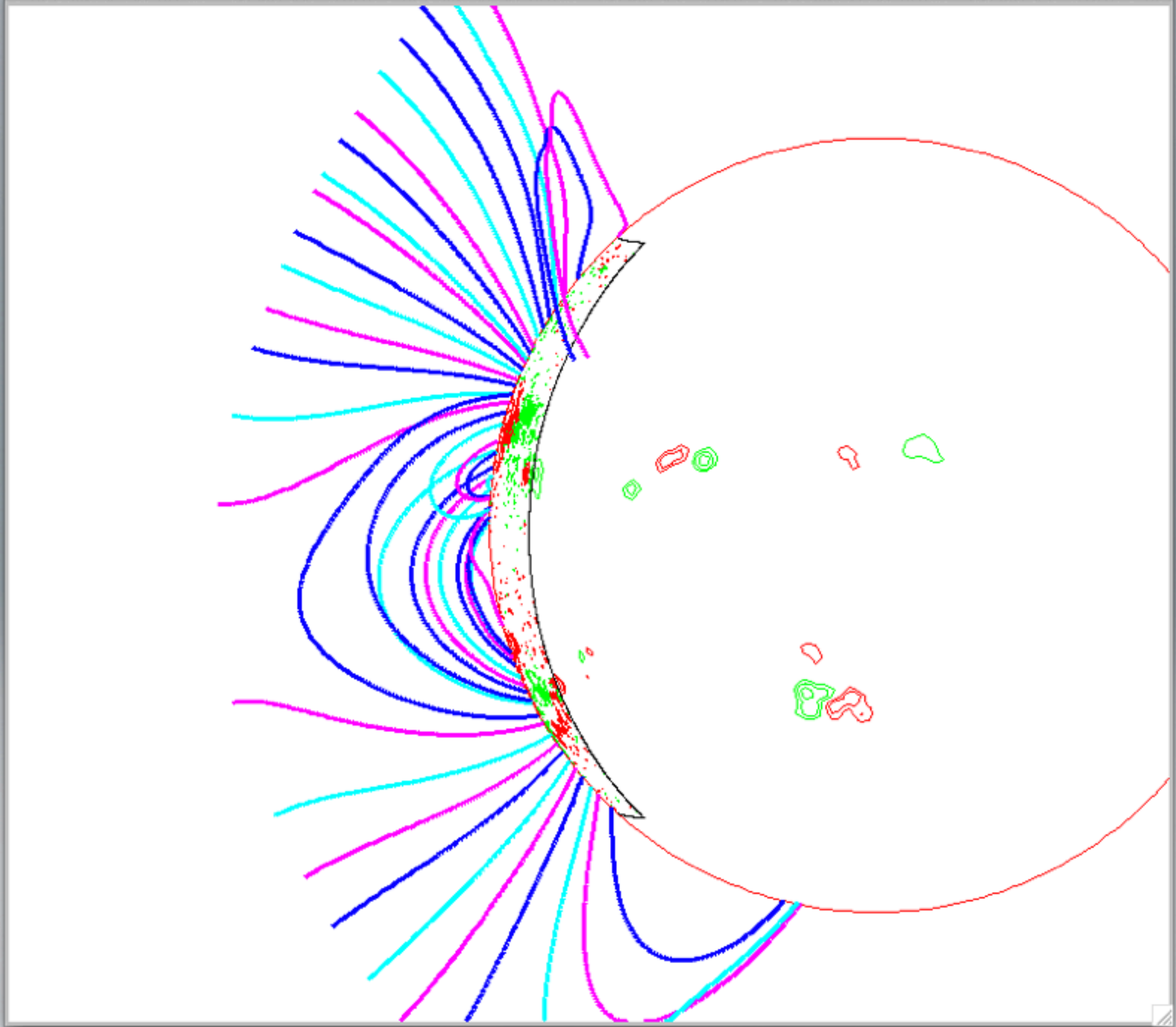
3D Display #0



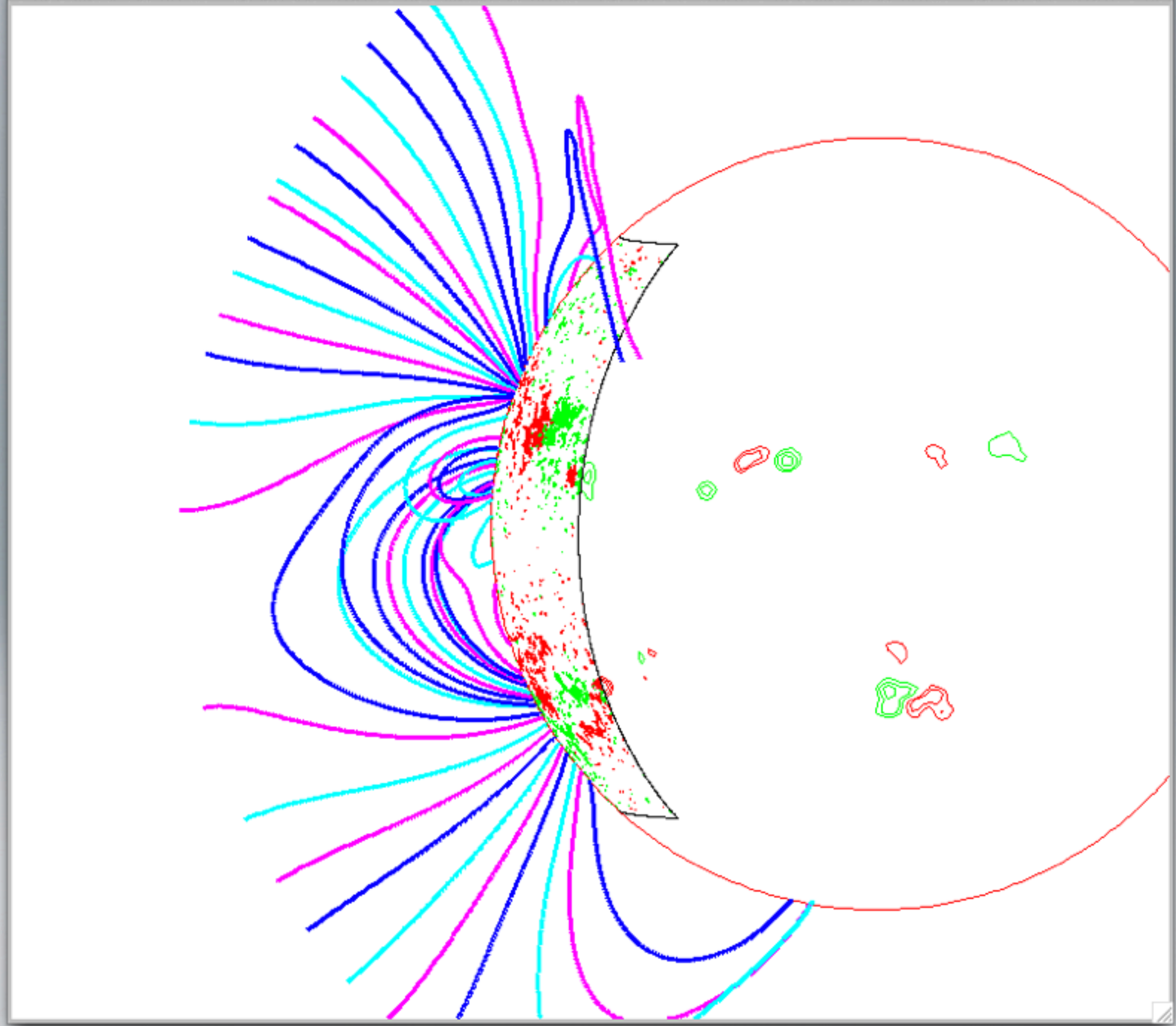
3D Display #0



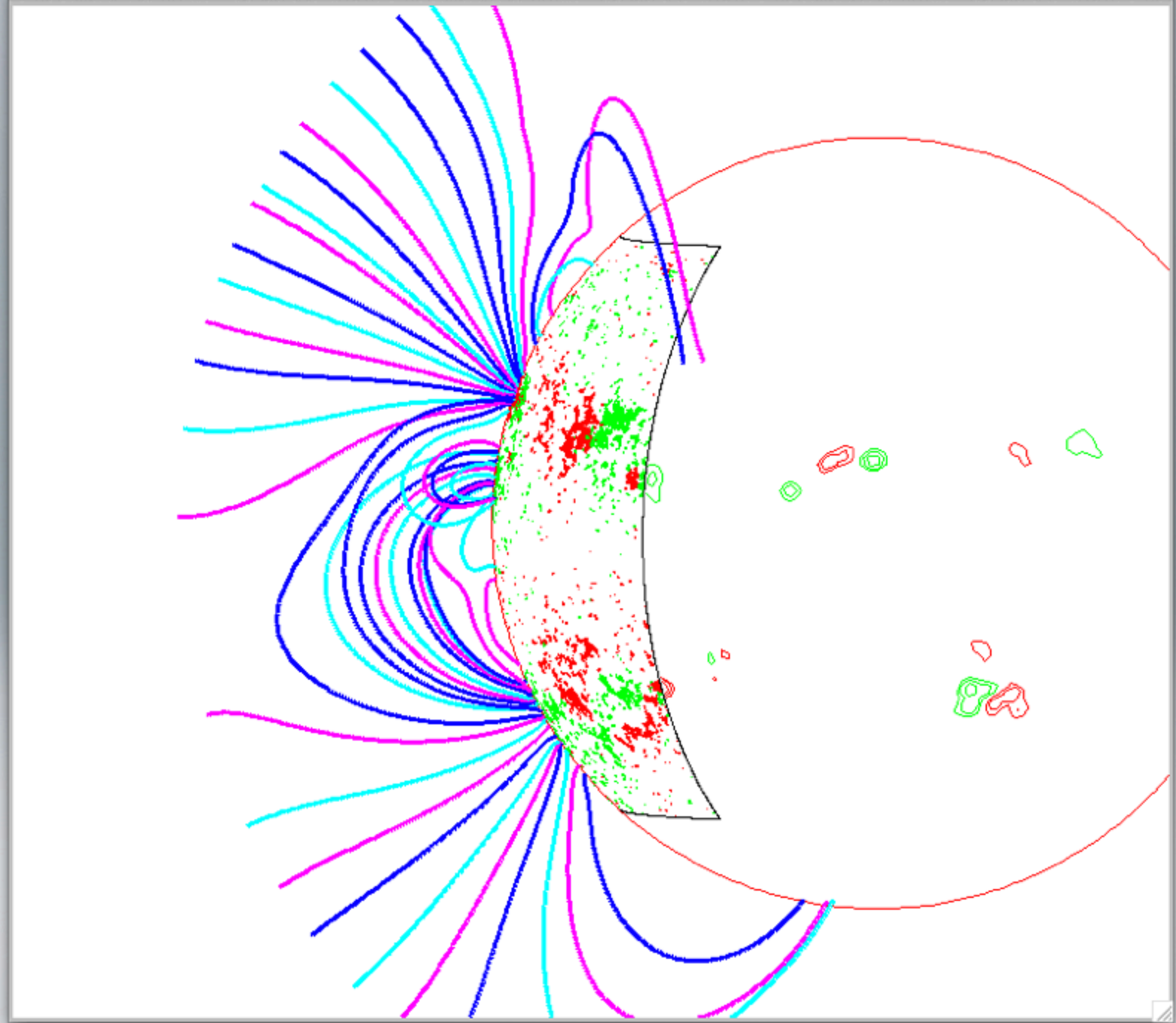
3D Display #0



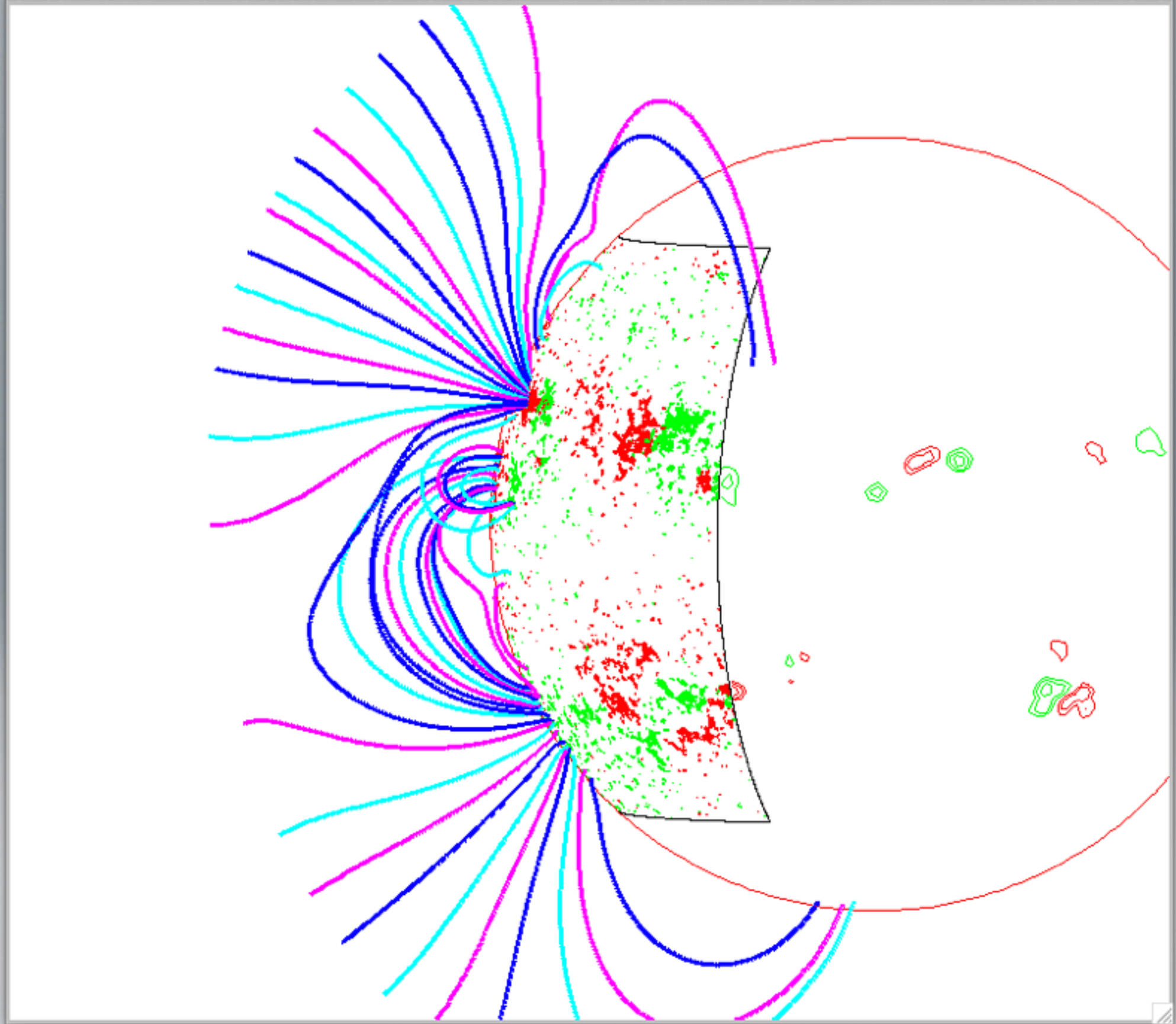
3D Display #0



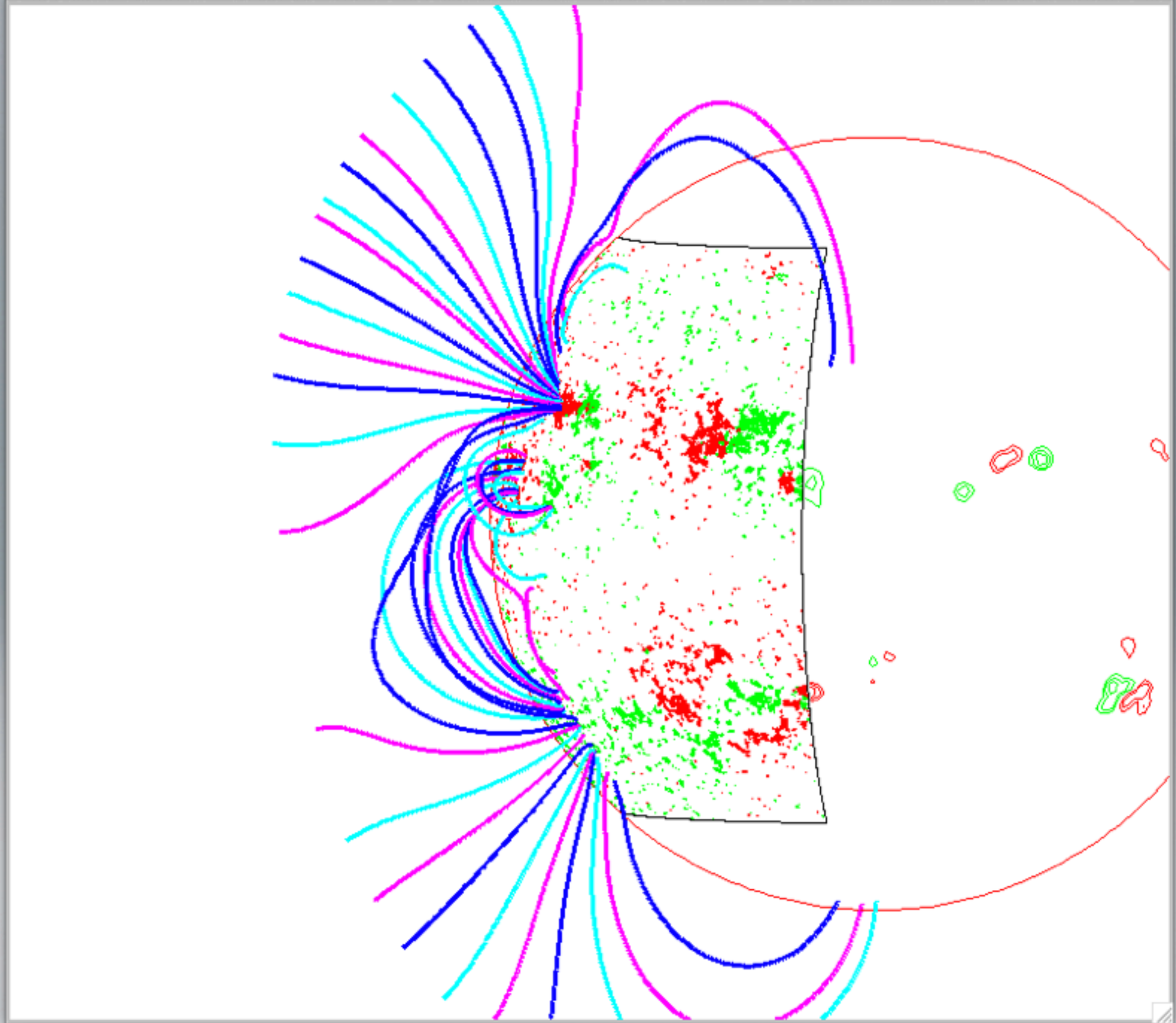
3D Display #0



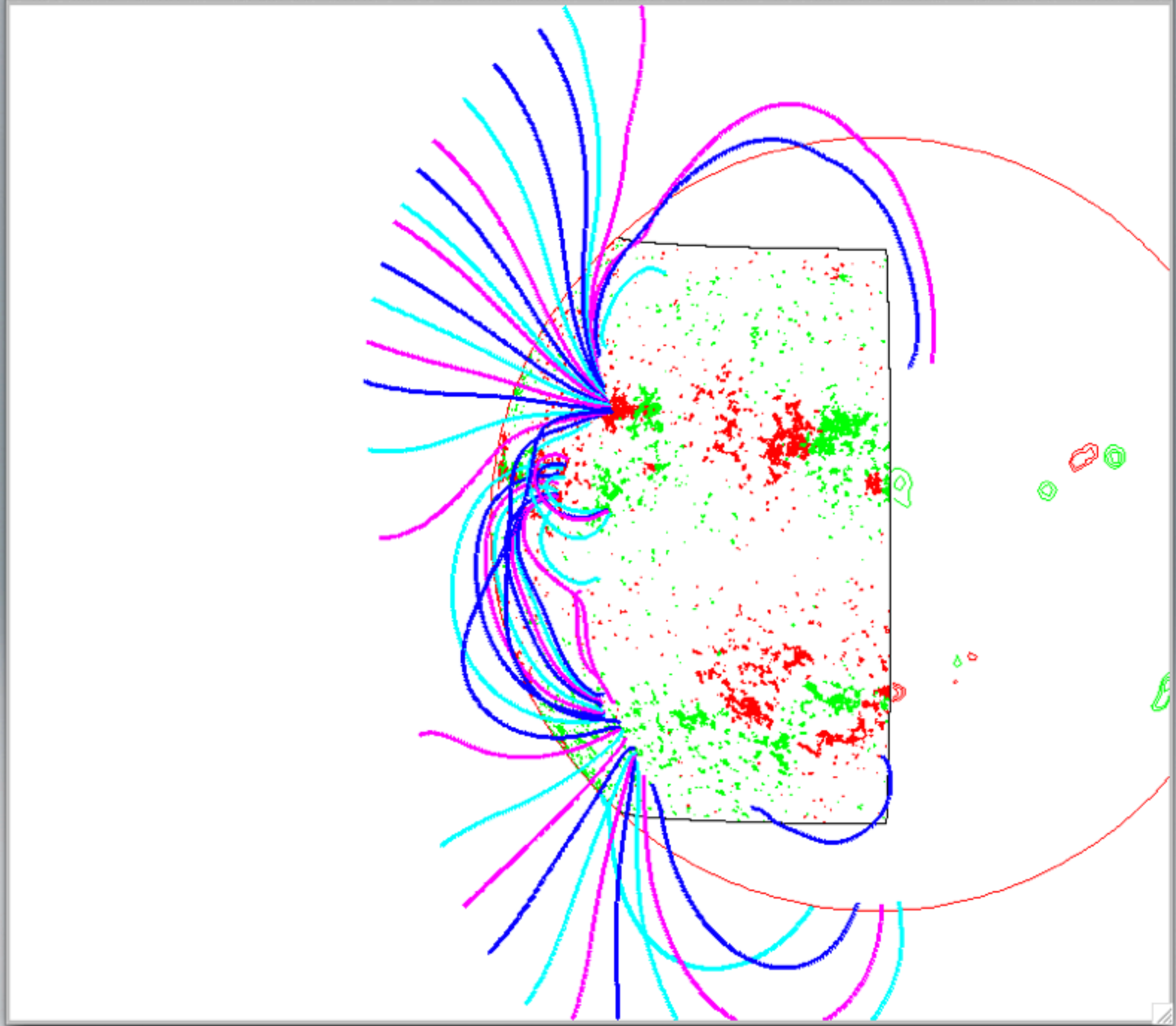
3D Display #0



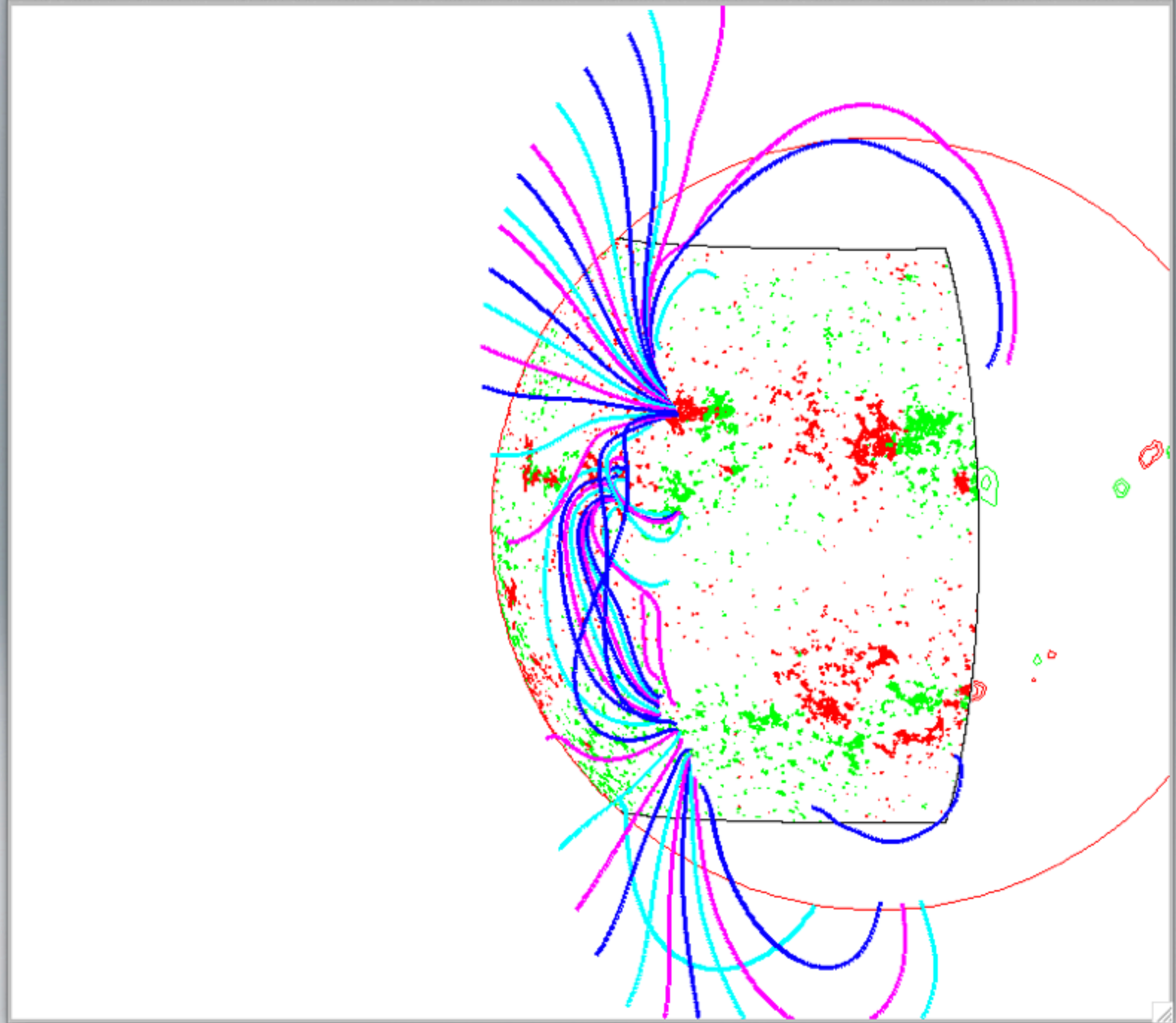
3D Display #0



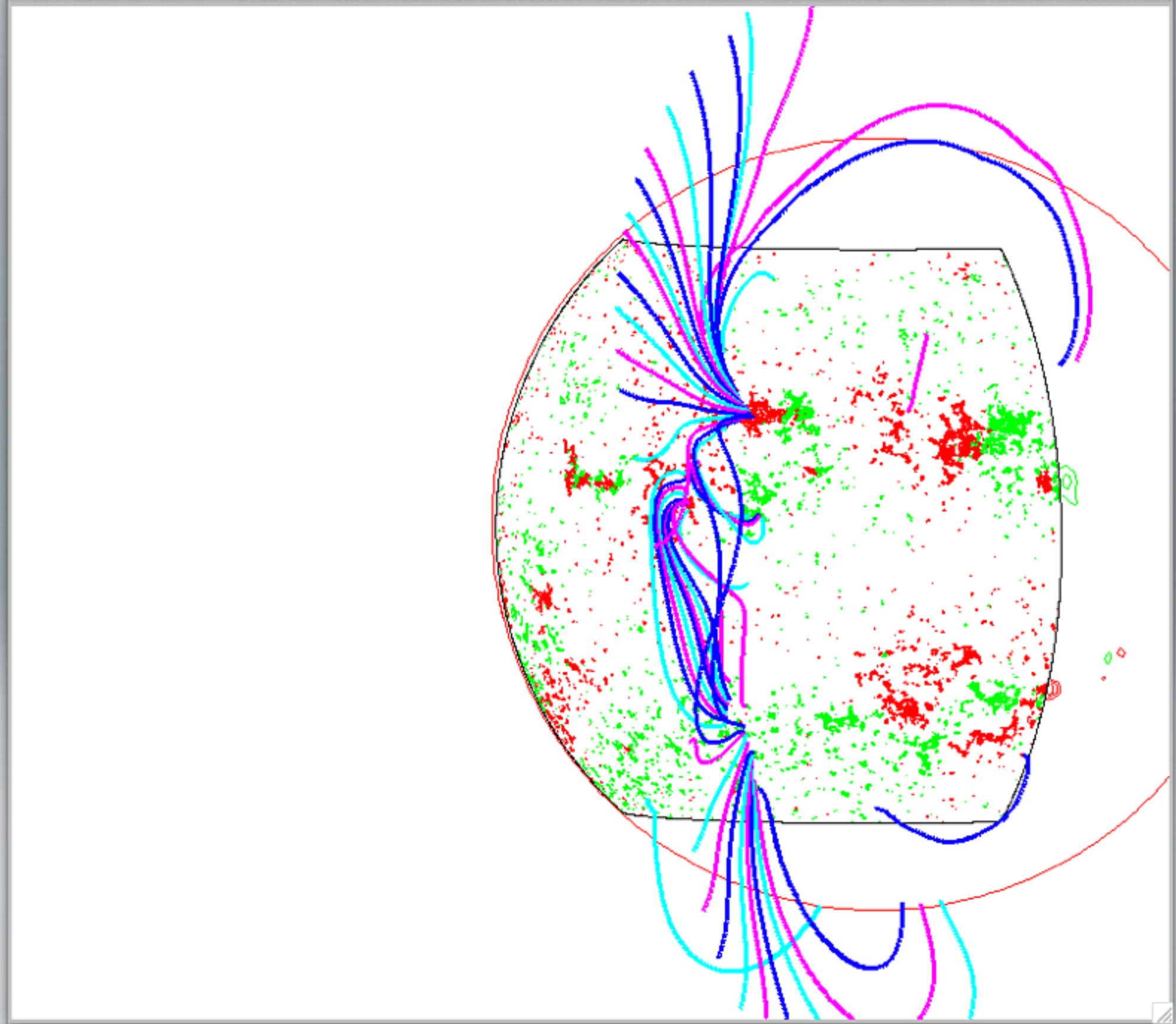
3D Display #0



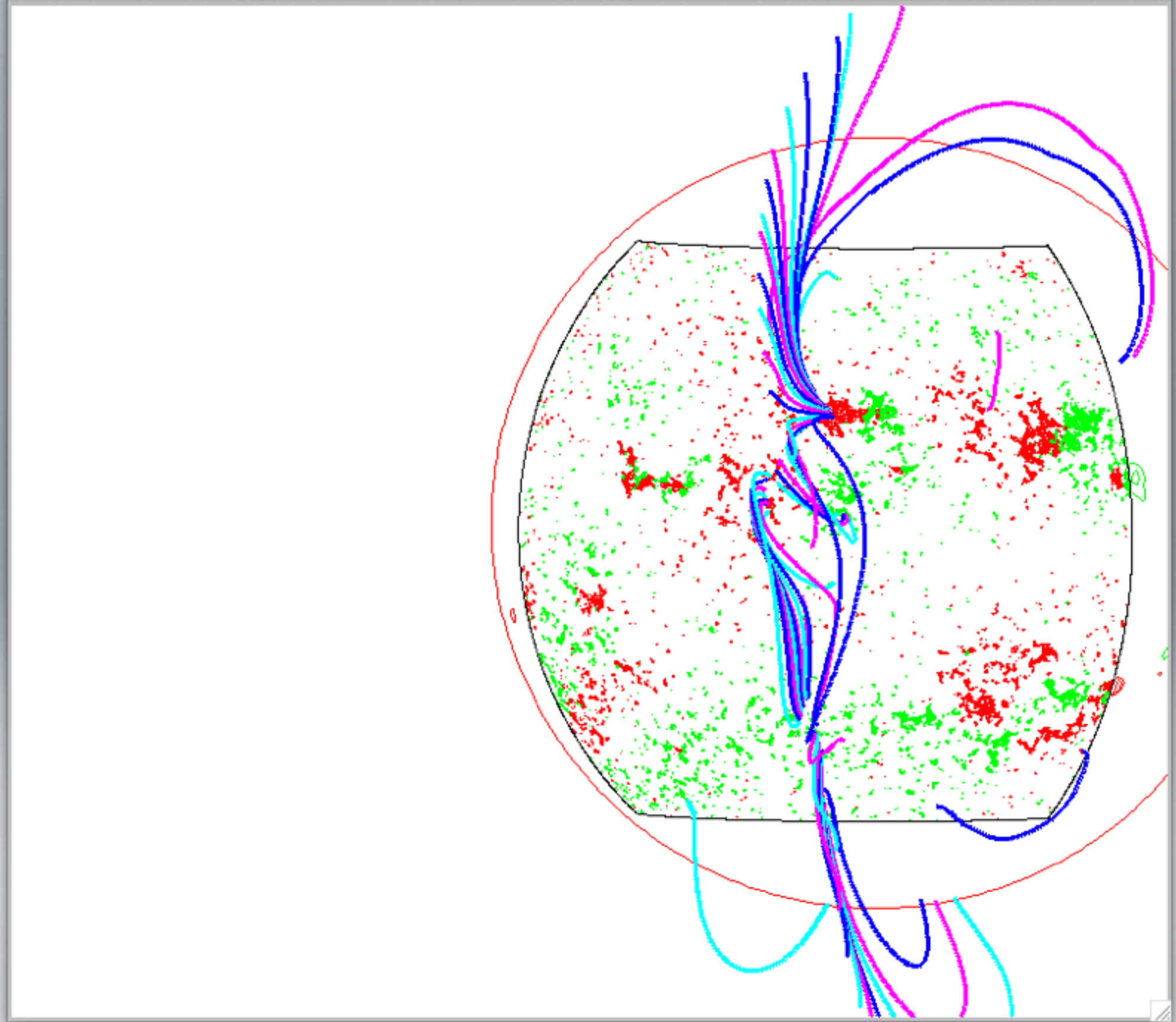
3D Display #0

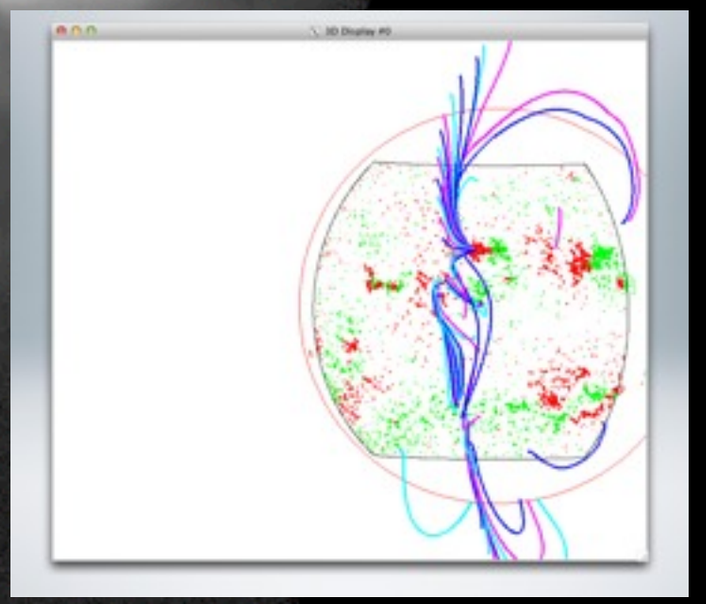


3D Display #0



3D Display #0




3D Display #0

FUTURE WORK

FUTURE WORK

- Improve Coronal Modeling System

- Study 2010 Total Solar Eclipse
  - Source Surface Height
  - Radial features in ‘quiet Sun’

- Study the bright features in SWAP that are dark in white light

ACKNOWLEDGMENT

Prof. Jay Pasachoff
Dr. Yingna Su
Dr. Adrian van Ballegooijen
Dr. Daniel Seaton

Royal Observatory of Belgium

All members of SIDC, including:
Matthew West
David Berghmans
Koen Stegen

My research is supported, in part, by a *Grant-In-Aid of Research* from the National Academy of Sciences, administered by Sigma Xi, The Scientific Research Society (Grant ID: G20120315159311) and by the Williams College Summer Science Research Program and the Williams College Astronomy Department. SWAP project is supported a grant from the Guest Investigator Program from the Solar Influences and Data Analysis Center, Royal Observatory of Belgium. Our research at Williams College about the eclipses of 2012 is supported by NSF Atmospheric and Geospace Sciences Division grant AGS-1047726