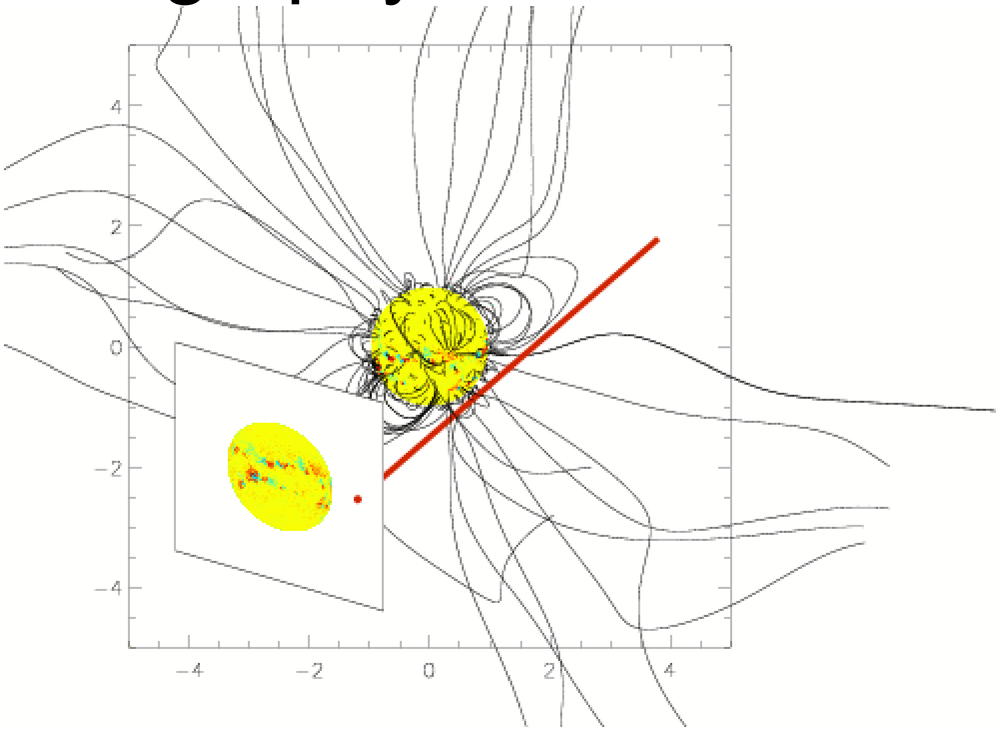
3D tomography for the solar corona



M.Kramar[1], J.Davila[2], H.Xie[1] , D.Lamb[1] , B.Inhester[3] , H.Lin[4]

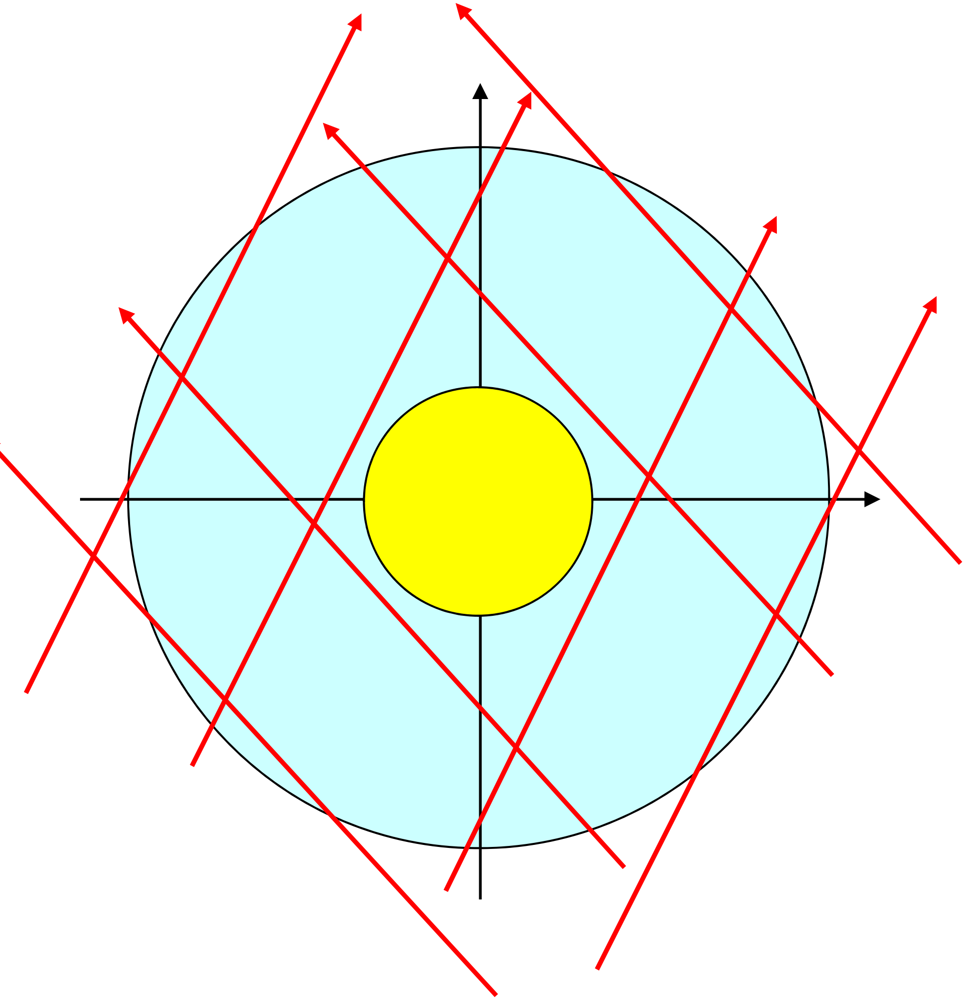
[1] *The Catholic University of America, NASA-Goddard Space Flight Center*

[2] *NASA-Goddard Space Flight Center*

[3] *Max-Planck-Institut fuer Sonnensystemforschung*

[4] *University of Hawaii*

Scalar Field Tomography: Regularization



- Problem is badly conditioned, e.g. number of unknown variables exceeds the number of equations
- Random noise in the data

In result, there is possible no unique reconstruction. Problem is ill-conditioned.

$$F = \sum_{i=1}^{\text{Number of Rays}} \left(I_i^{\text{sim}} - I_i^{\text{obs}}\right)^2 + \mu \cdot F_{\text{reg}} =$$

$$= \left|\mathbf{A} \cdot \mathbf{X} - \mathbf{Y}\right|^2 + \mu \cdot \left|\mathbf{L} \cdot \mathbf{X}\right|^2$$

Tomography for the Solar Corona

- Problem is badly conditioned, e.g. number of unknown variables exceeds the number of equations
- Noise in the data

⇒ Regularization should be applied

- Stationarity of the corona during the observations must be assumed. Coronal observations are restricted to only one-three view direction in ecliptic plane.

Tomographic Reconstruction for the Solar Corona

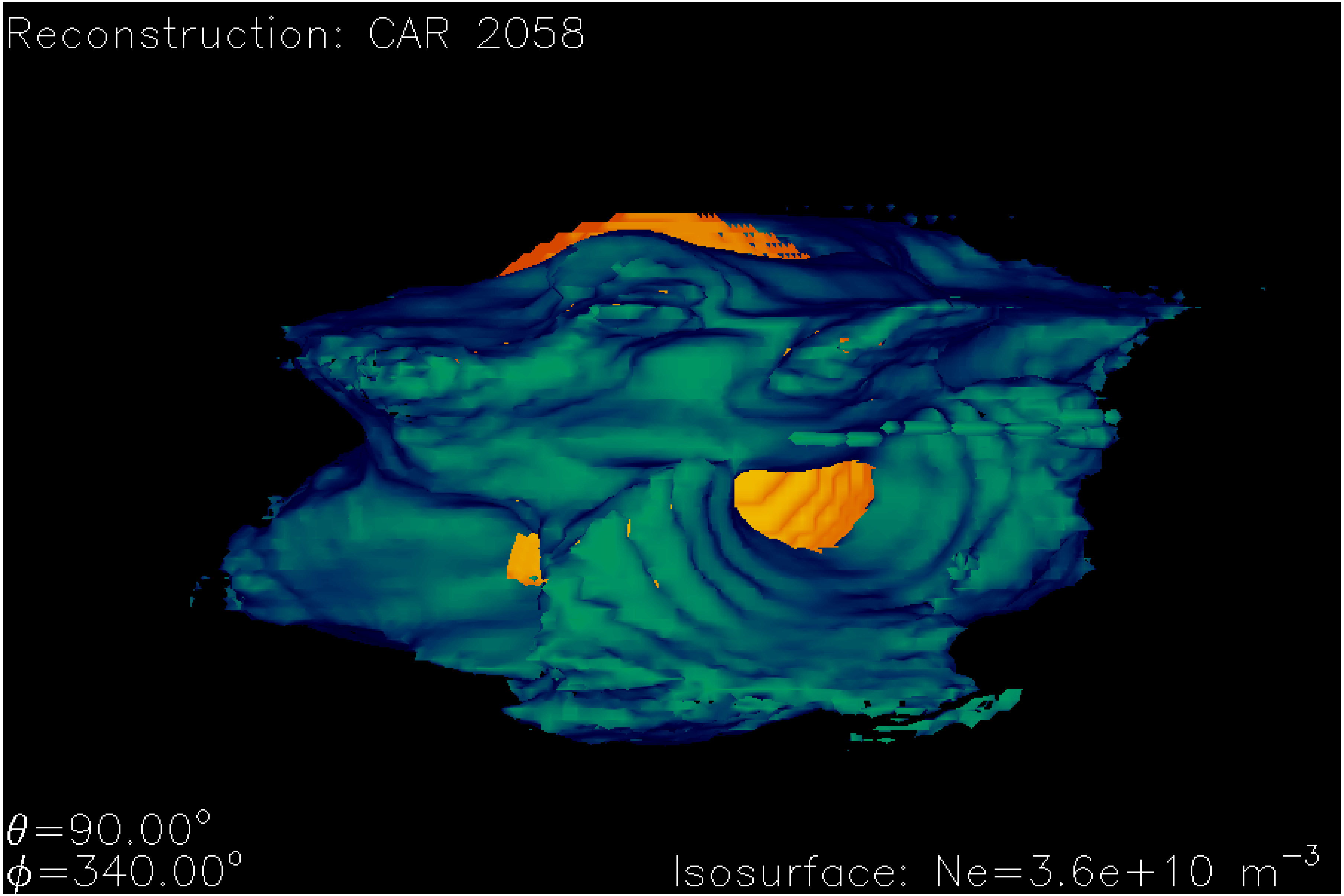
Input:

- COR1 observations: pB images
- Observations during a half of solar rotation, 2-4 obs per day
- Roll minimum background subtracted
- Starting point for the iterations is flat field (constant density)
- Weighting factor is applied for low intensity pixels

Output:

- 3D Electron Density Distribution: 128x128x128 pixels

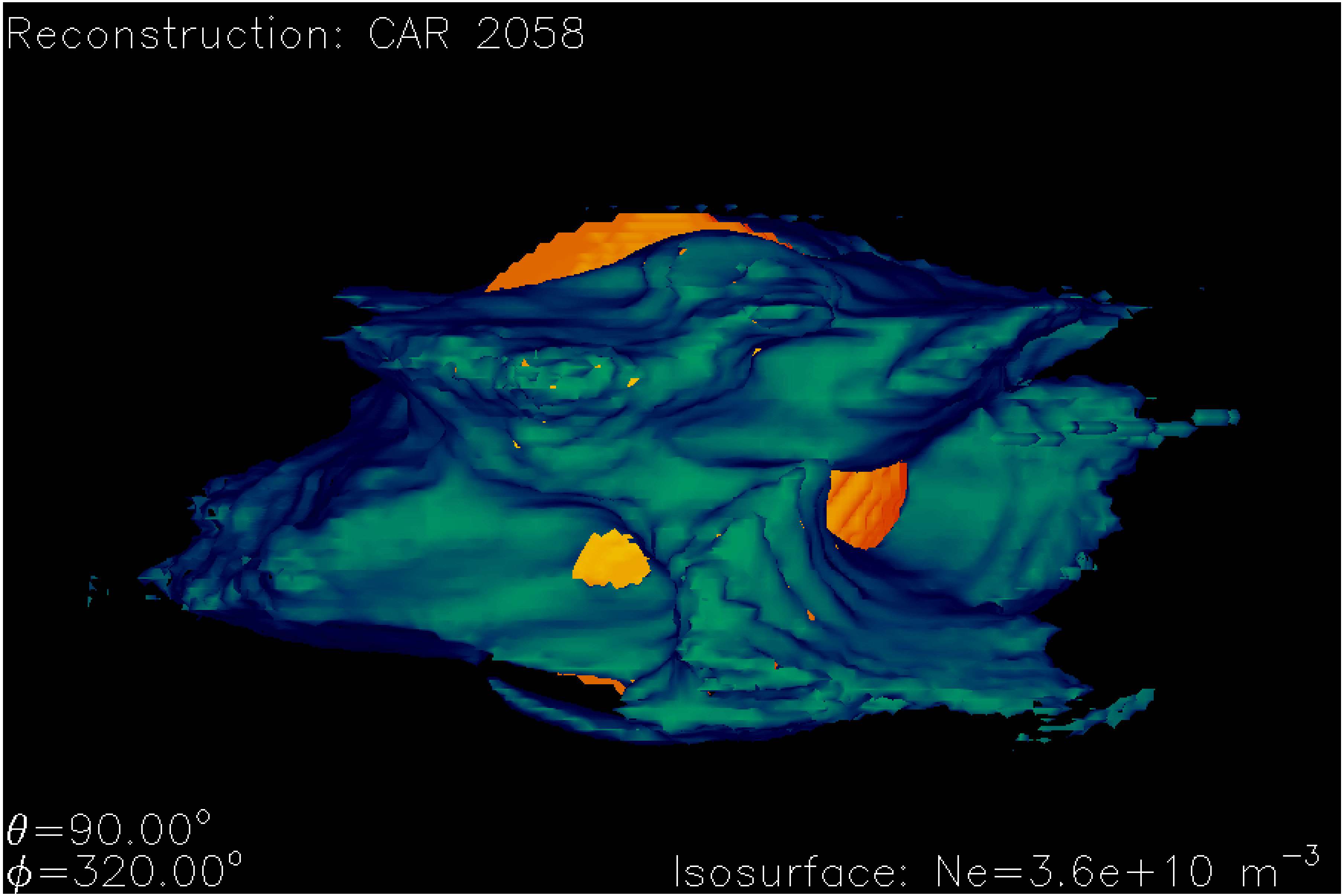
Reconstruction of the Electron Density



Isosurface: N_e=3.6*10^{10} m^{-3}

Inner spherical boundary is at 1.5 Rsun

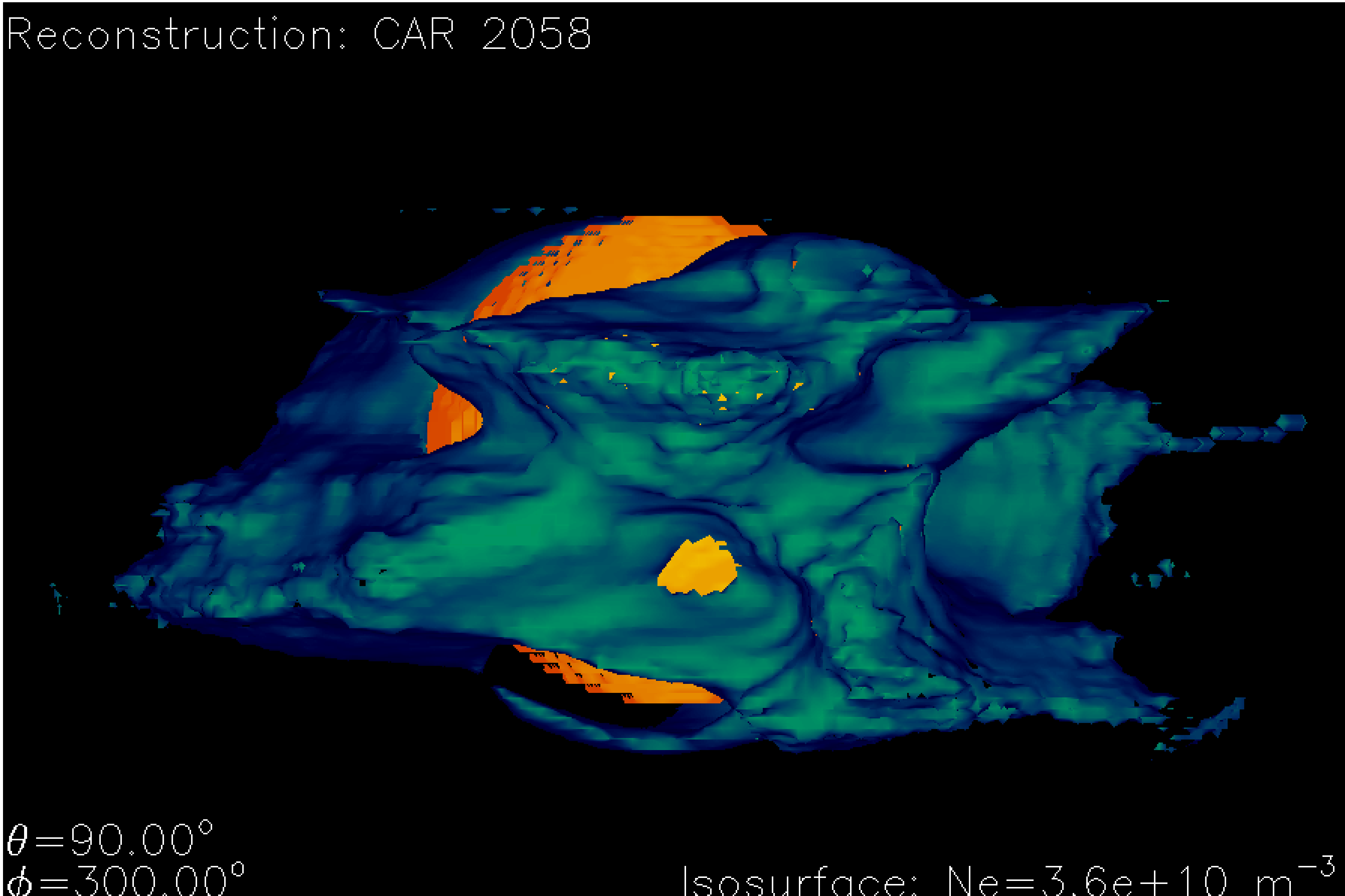
Reconstruction of the Electron Density



Isosurface: $N_e = 3.6 * 10^{10}$ m^{-3}

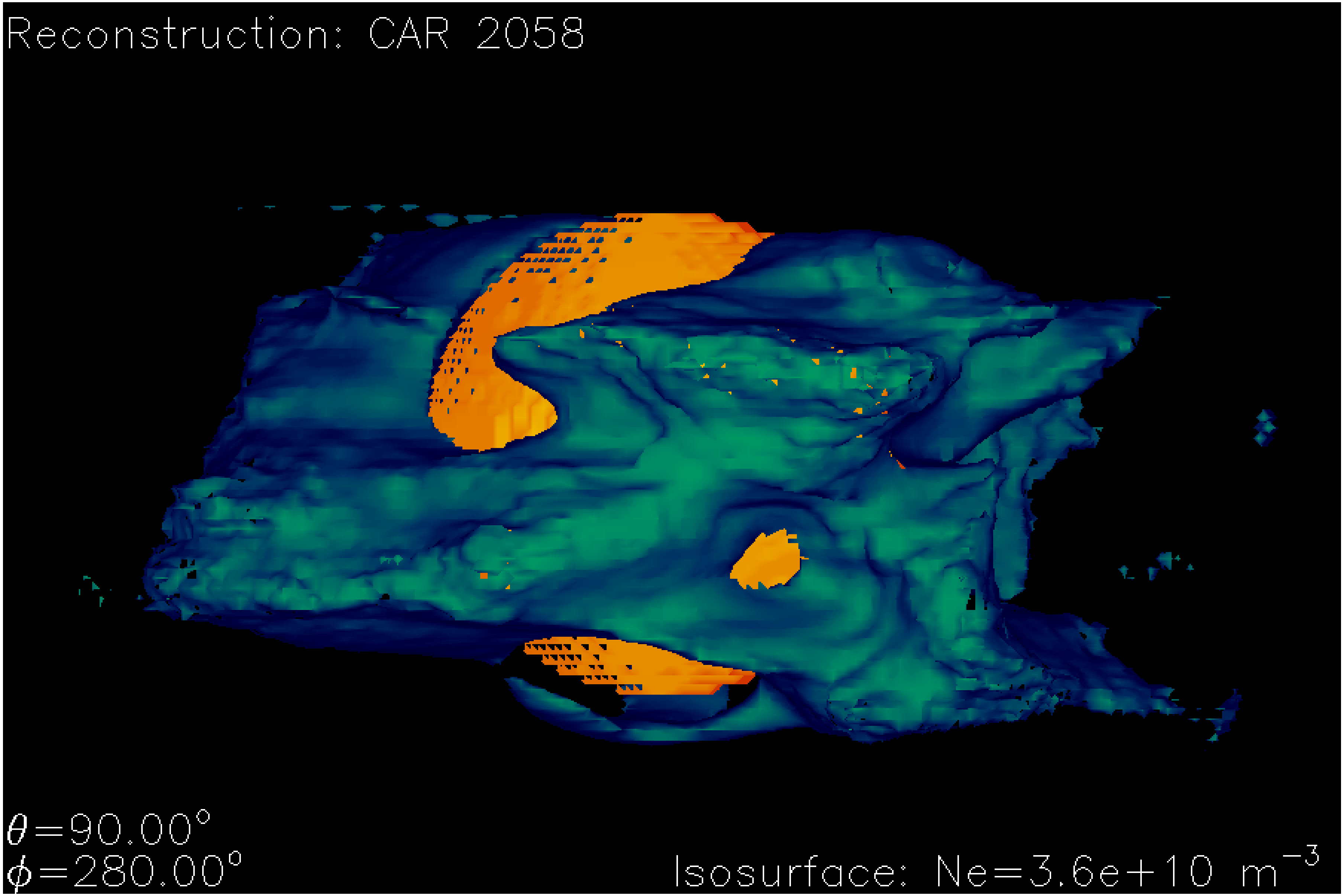
Inner spherical boundary is at 1.5 *R*sun

Reconstruction of the Electron Density



Isosurface: N_e=3.6*10^{10} m^{-3} Inner spherical boundary is at 1.5 Rsun

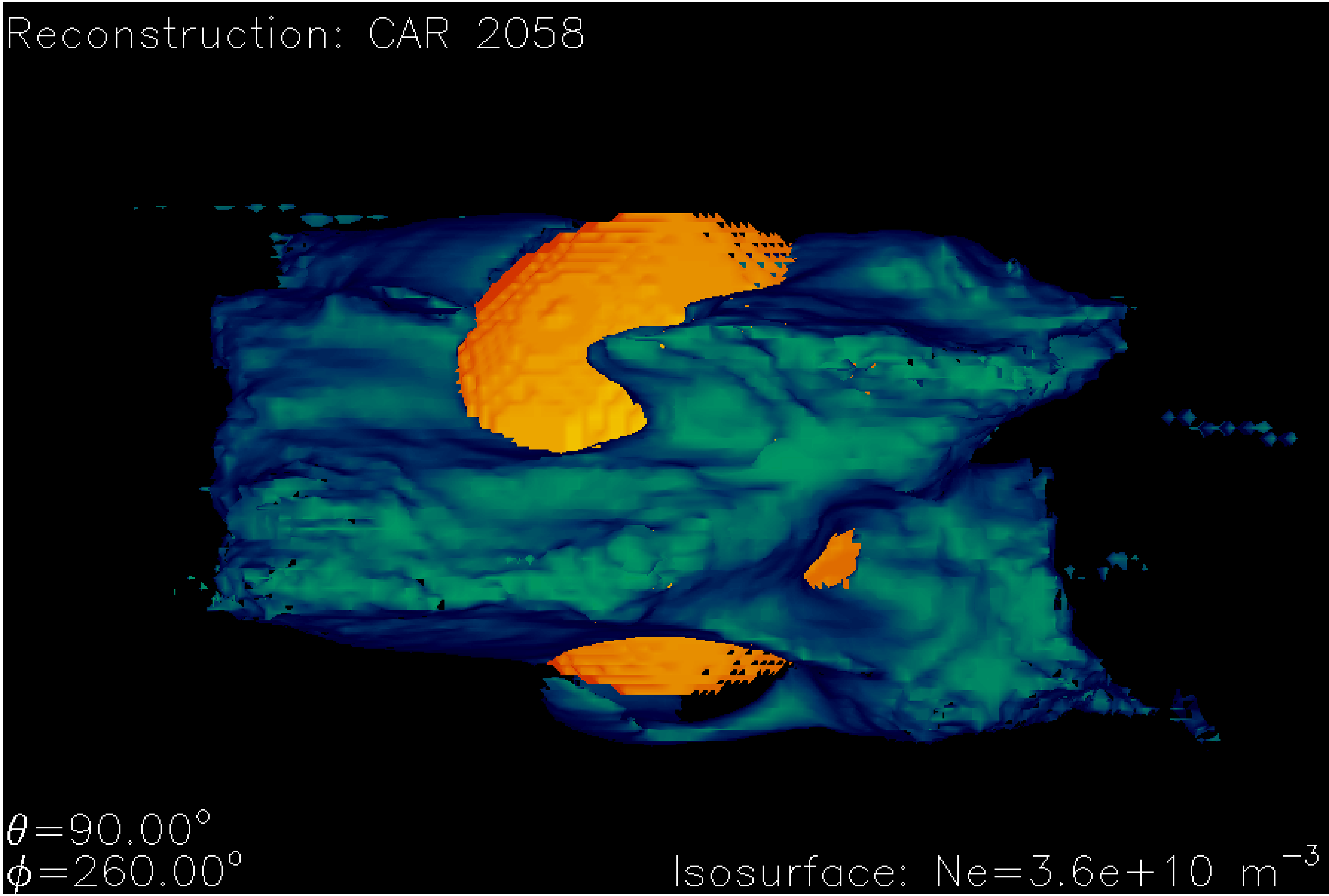
Reconstruction of the Electron Density



Isosurface: N_e=3.6*10^{10} m^{-3}

Inner spherical boundary is at 1.5 Rsun

Reconstruction of the Electron Density



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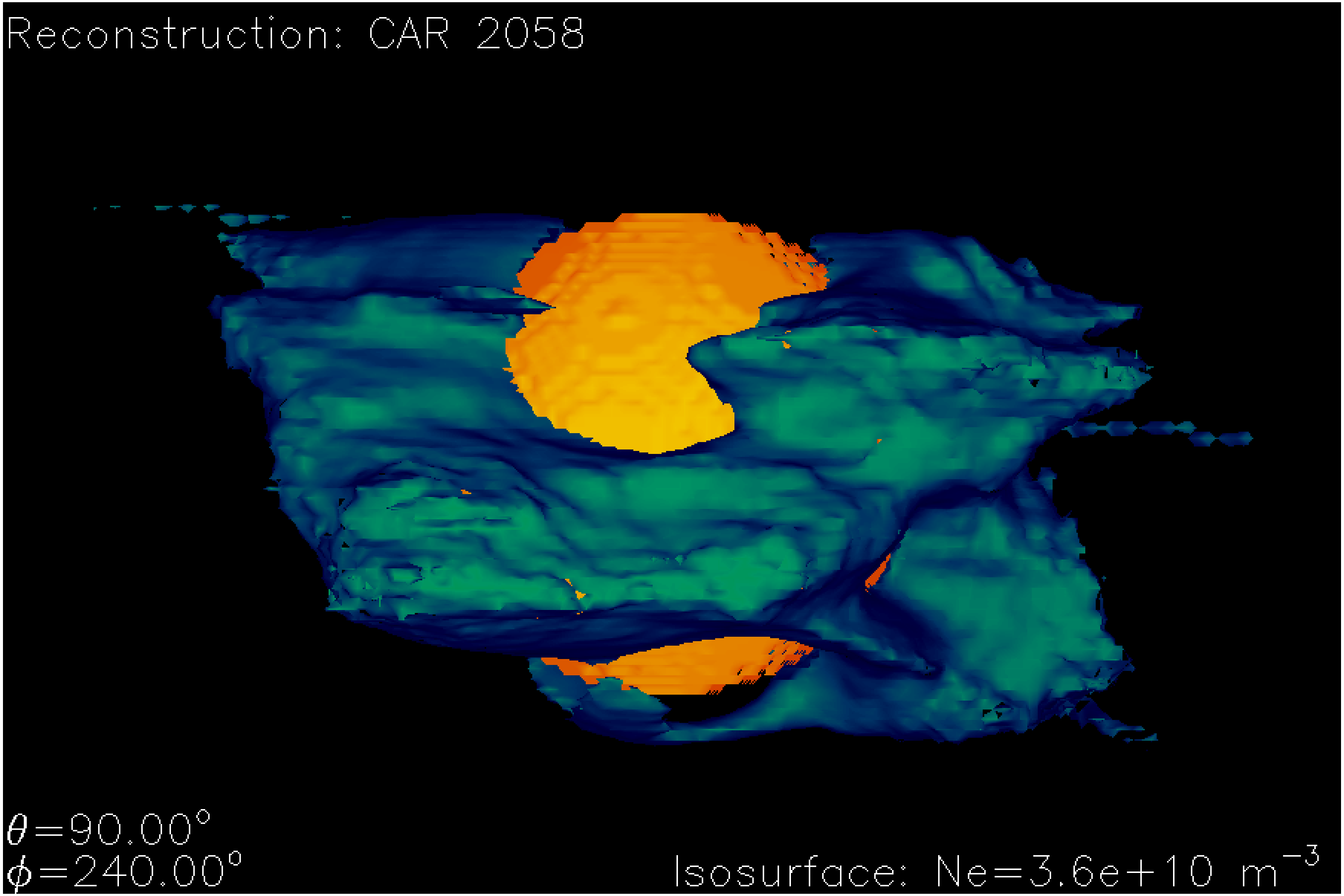

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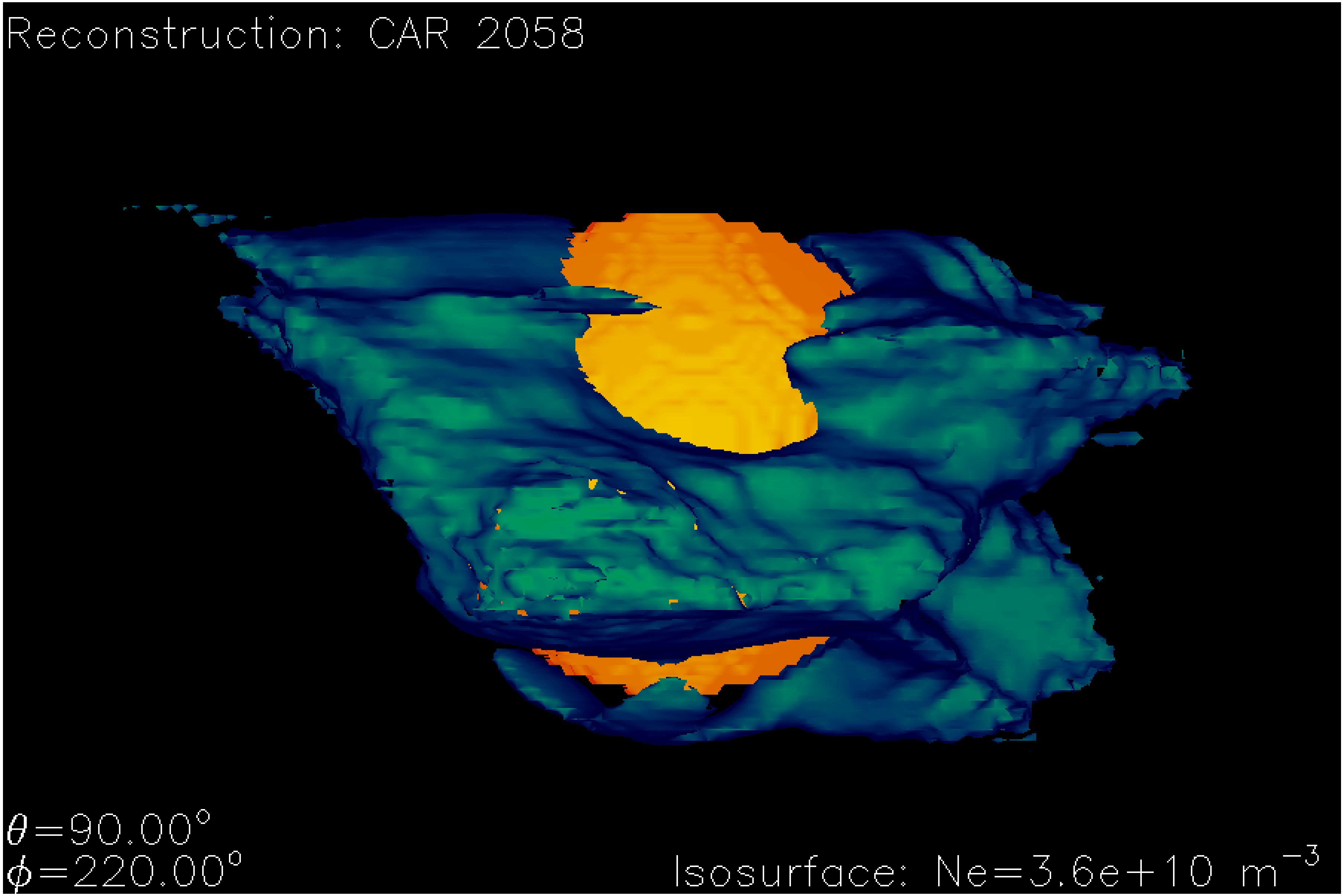

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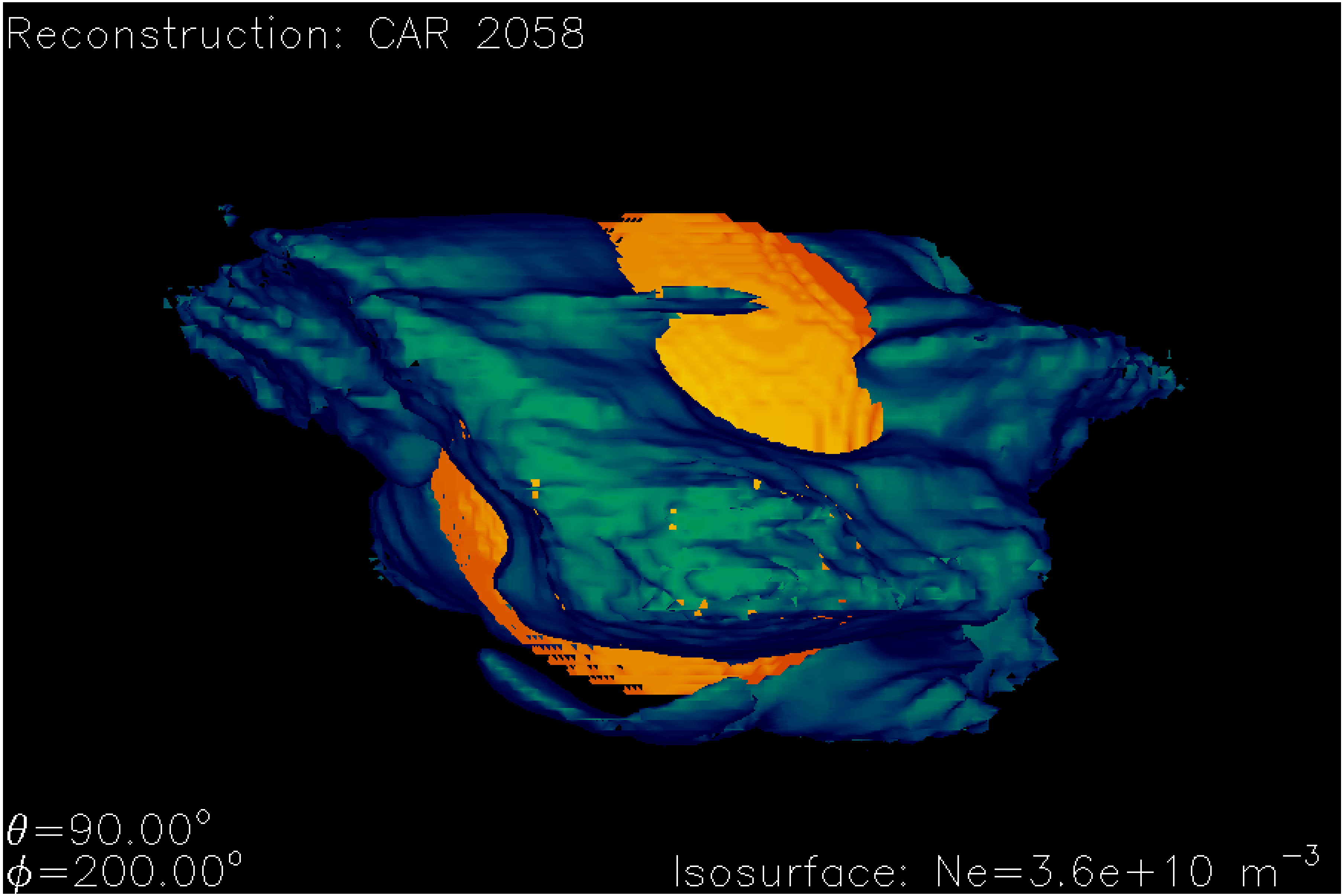
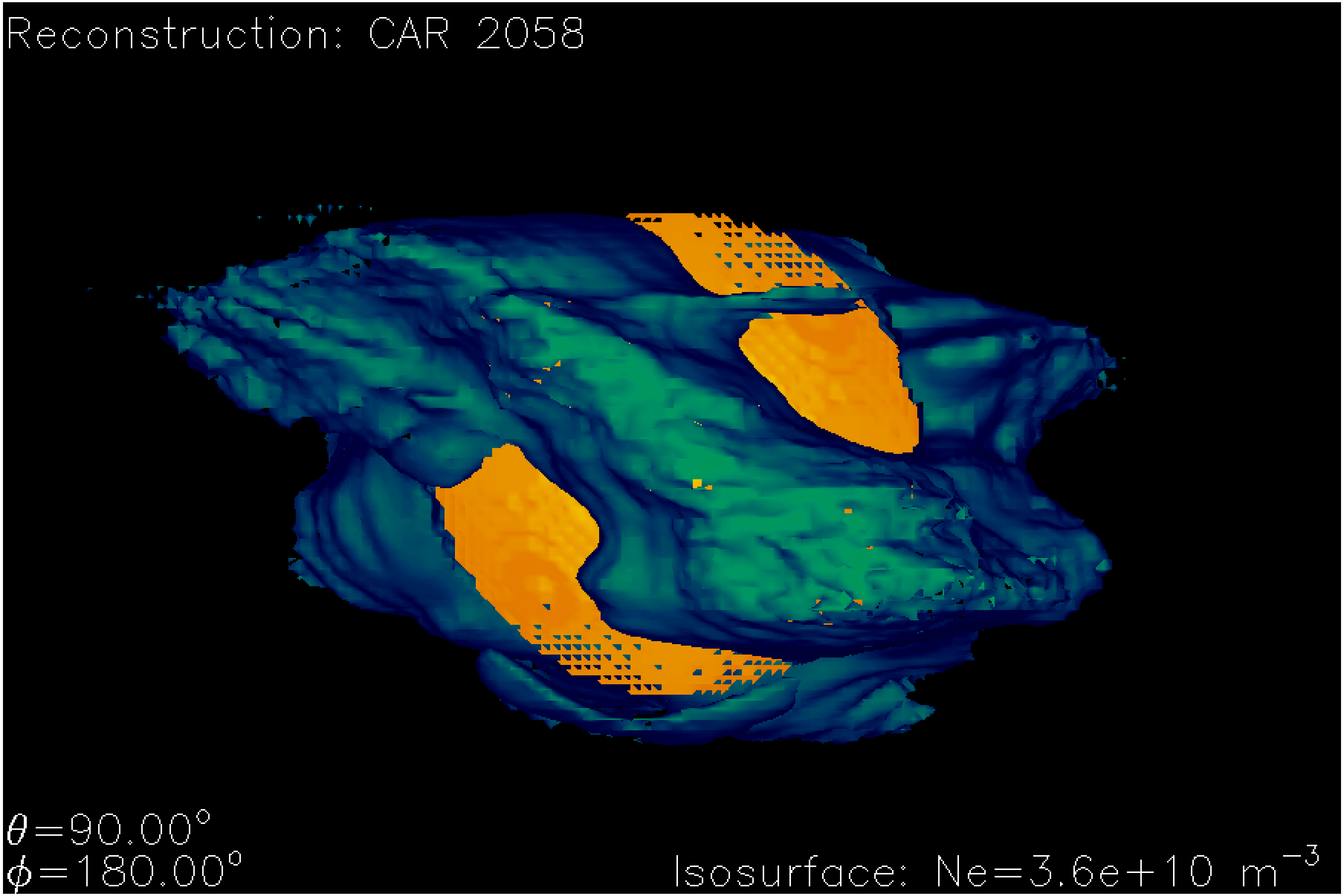
Reconstruction of the Electron Density



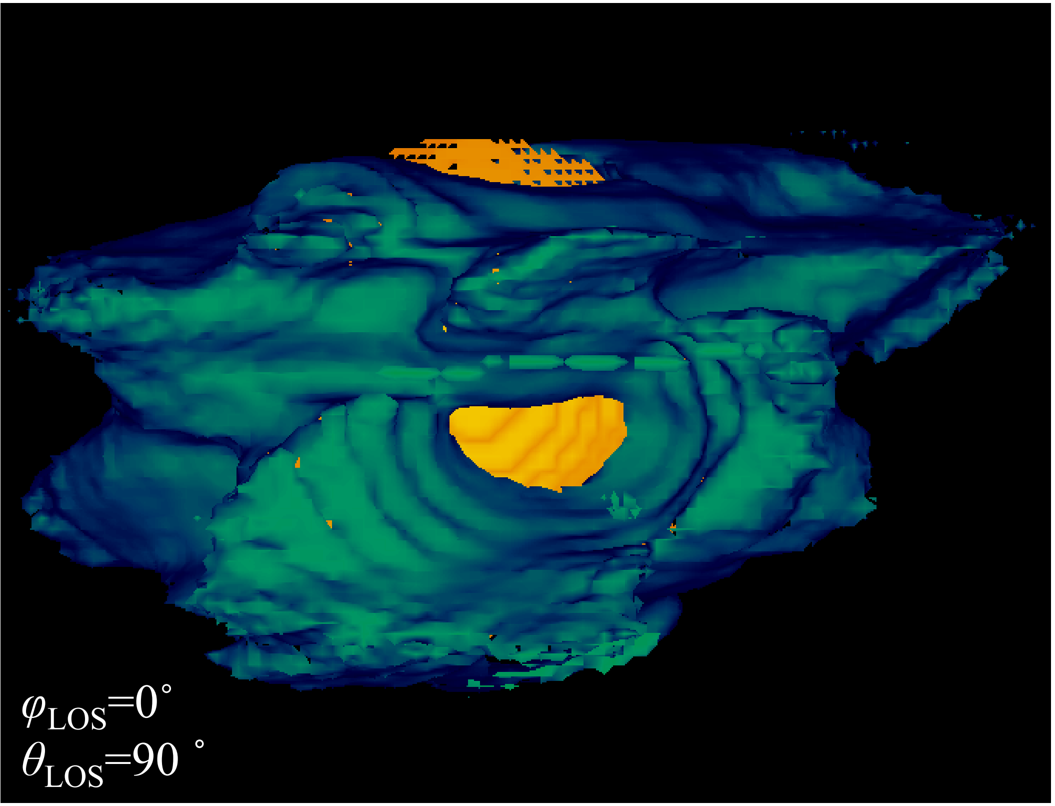
Isosurface: N_e=3.6*10^{10} m^{-3} Inner spherical boundary is at 1.5 Rsun

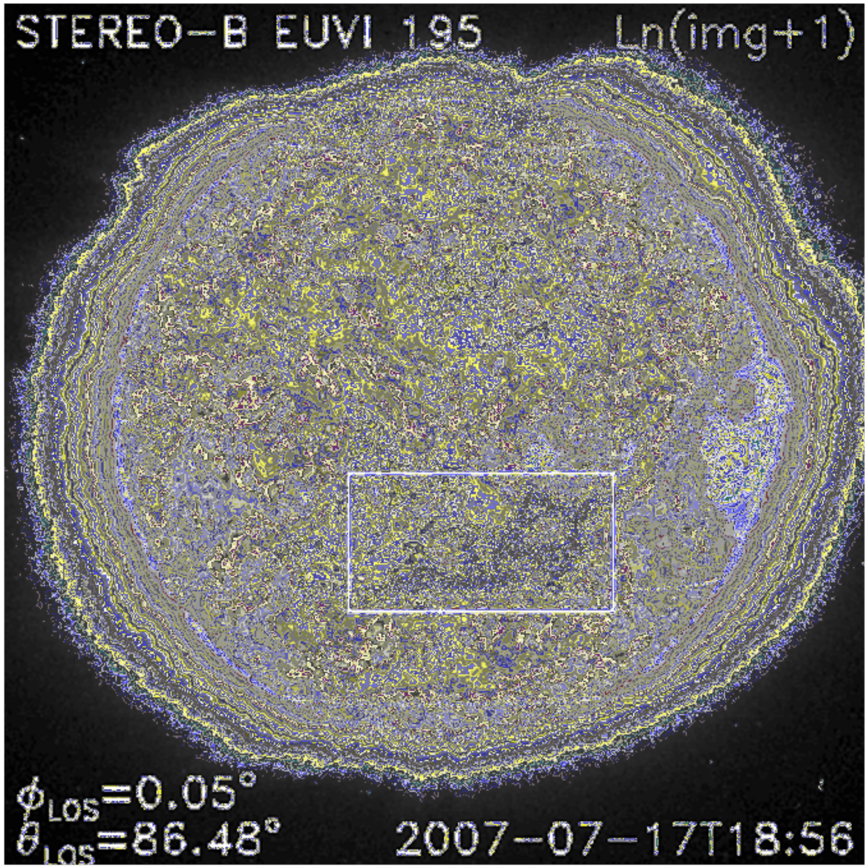
Reconstruction of the Electron Density



Isosurface: N_e=3.6*10^{10} m^{-3}

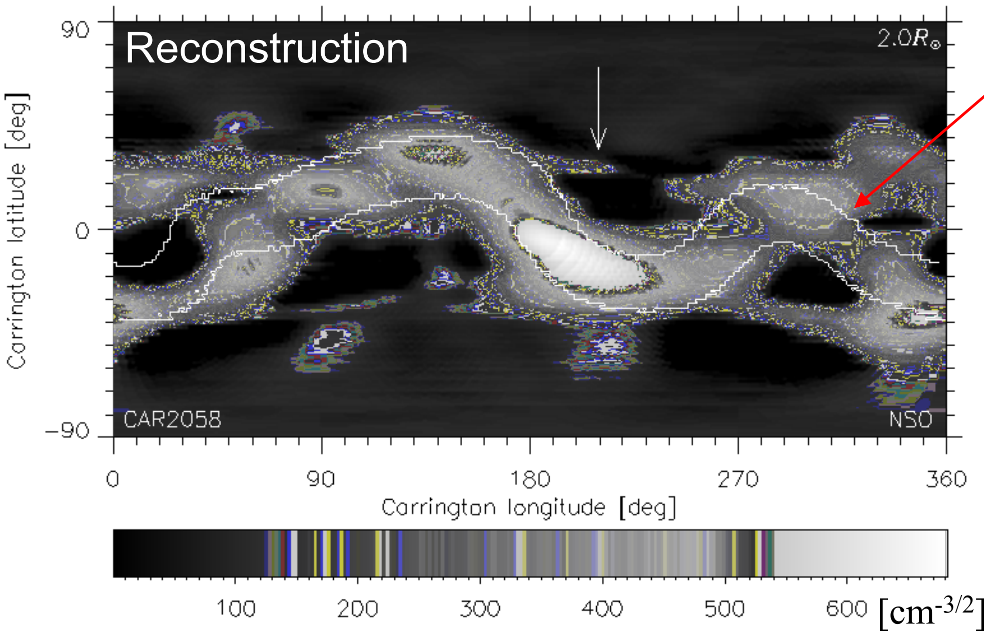
Inner spherical boundary is at 1.5 Rsun

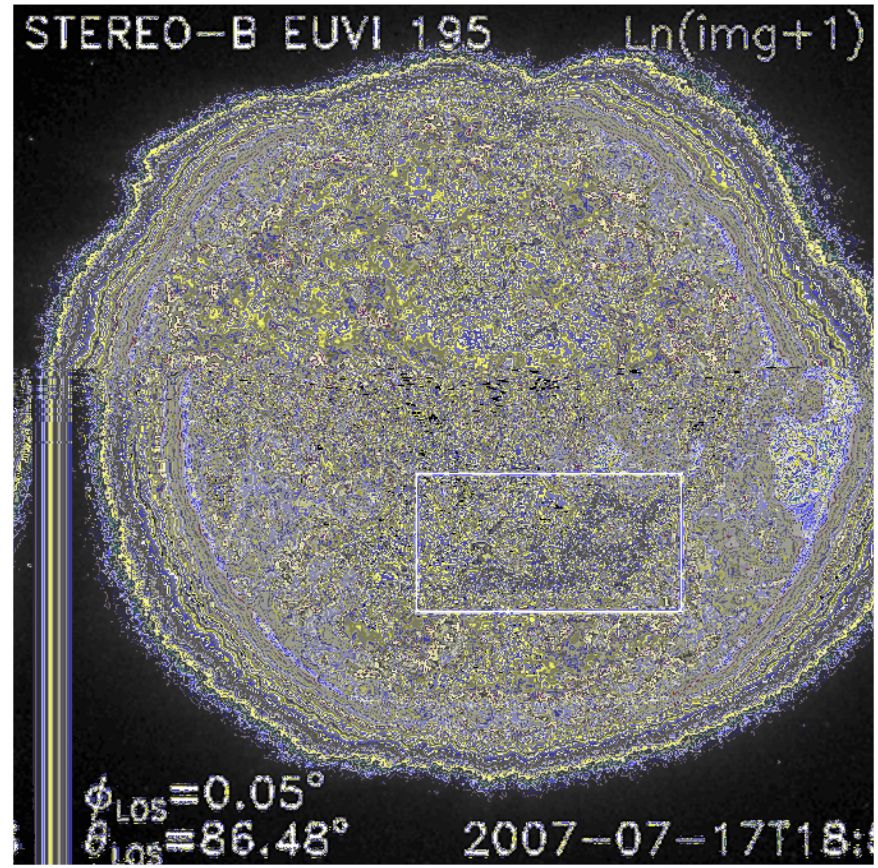

φLOS=0°
θLOS=90 °

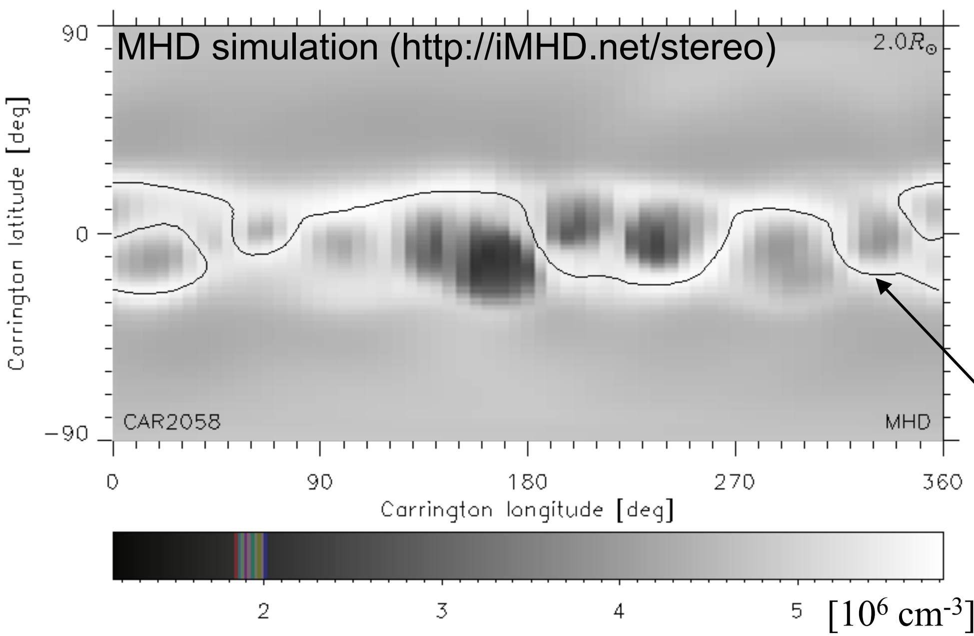

STEREO-B EUVI 195
Ln(img+1)
φLOS=0.05°
θLOS=86.48°
2007-07-17T18:56

Spherical cross-section at 2 R_{sun}

White contour lines are boundary between open and closed magnetic field lines in potential field reconstruction with SS=2.5Rsun



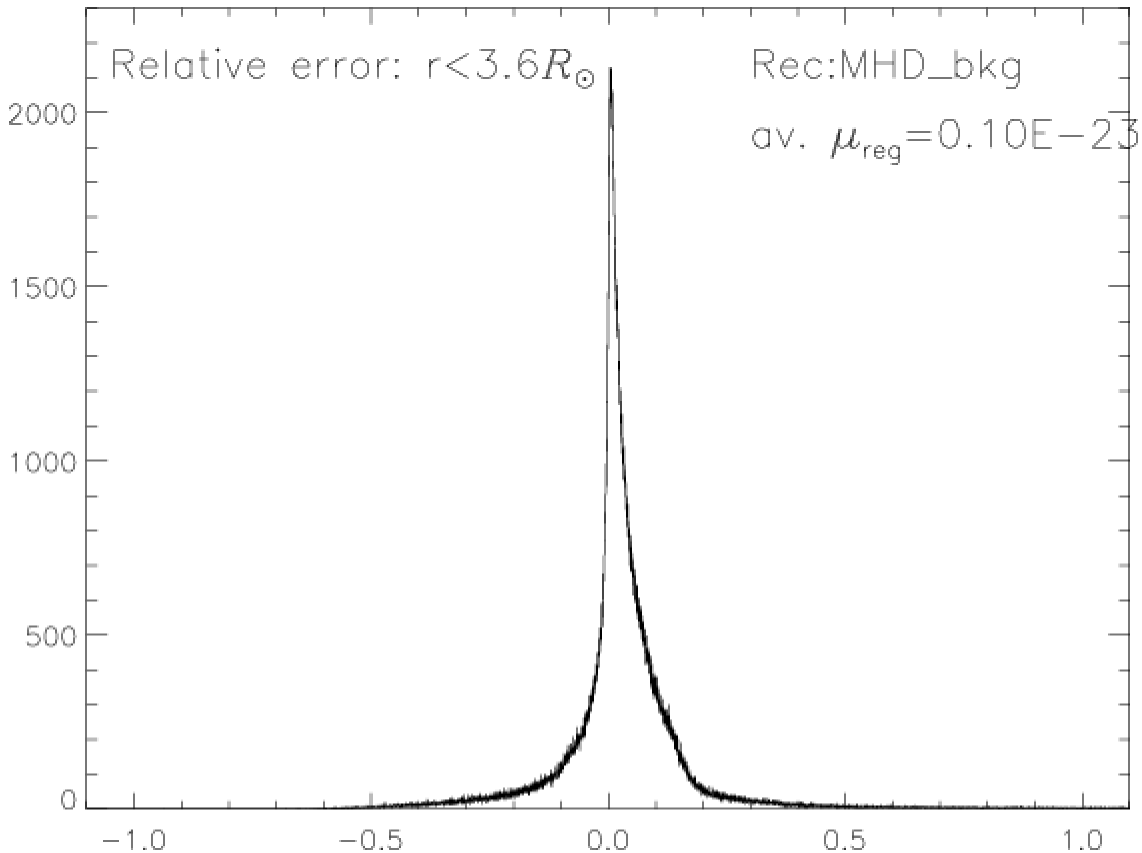




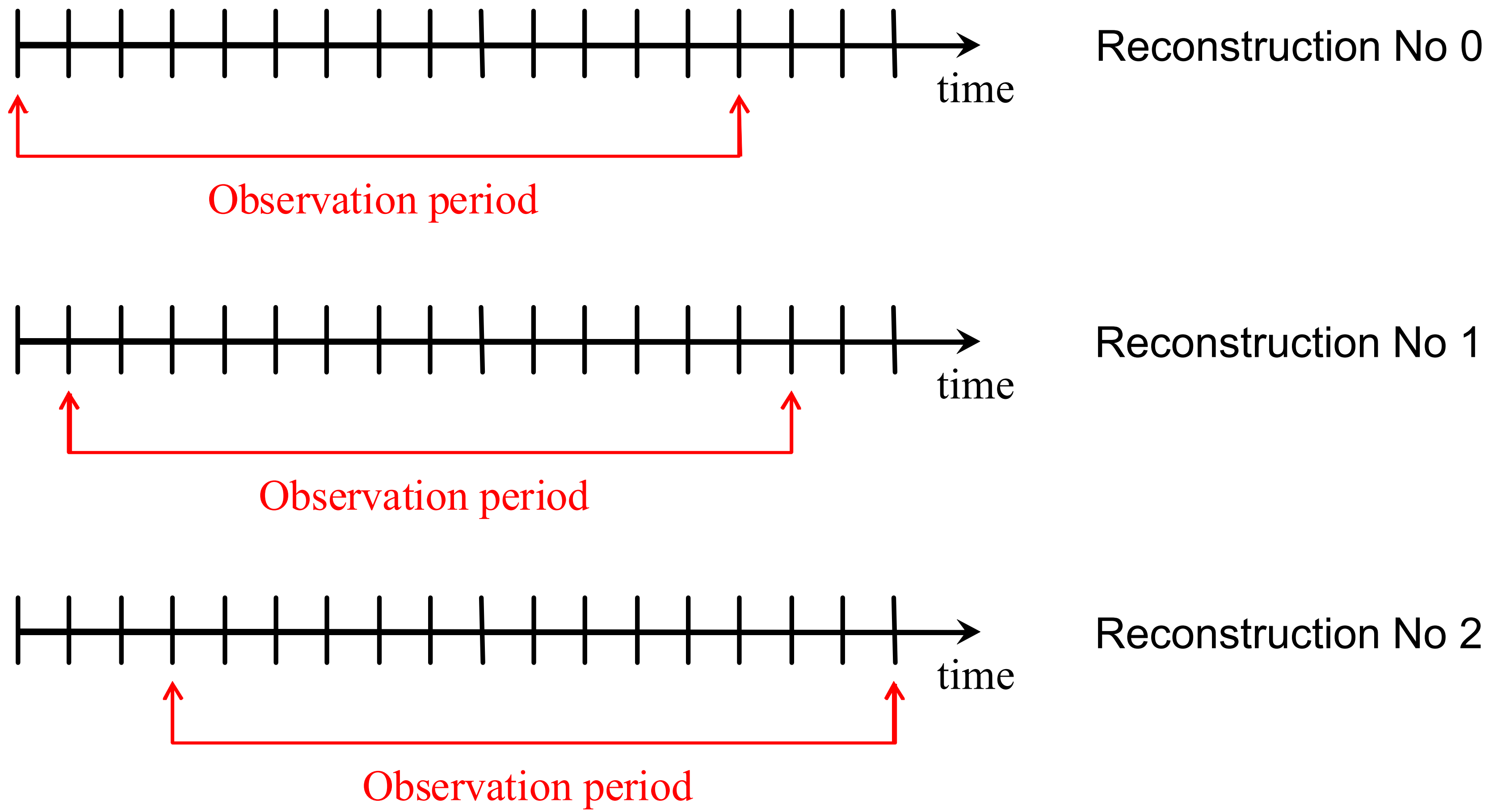
Black contour line is the magnetic neutral line

Tomography for the Solar Corona: Errors

Relative Error for the Inversion only



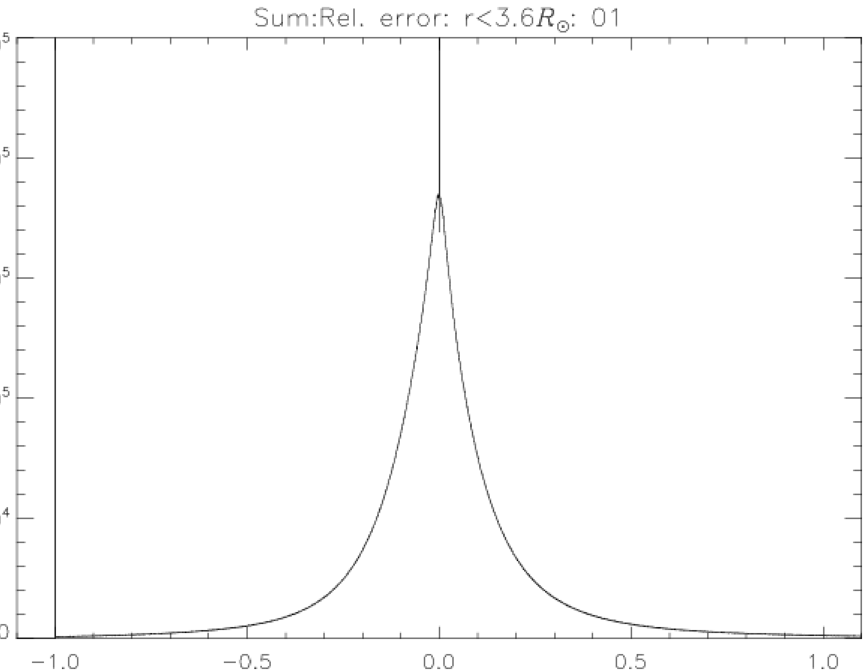
Reconstructions for the whole year of 2008



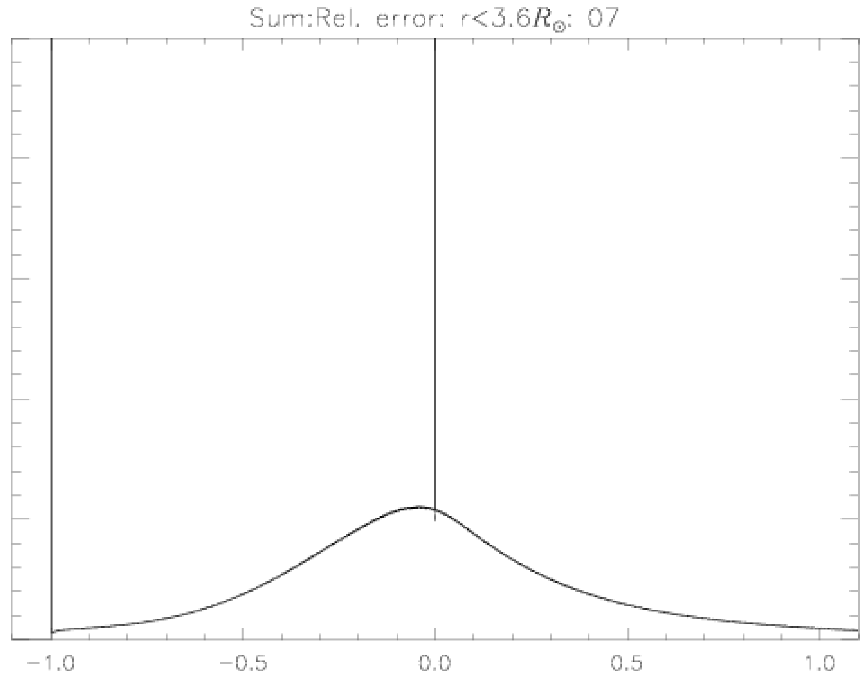
Tomography for the Solar Corona: Errors

Relative Error due to non-stationarity of the corona

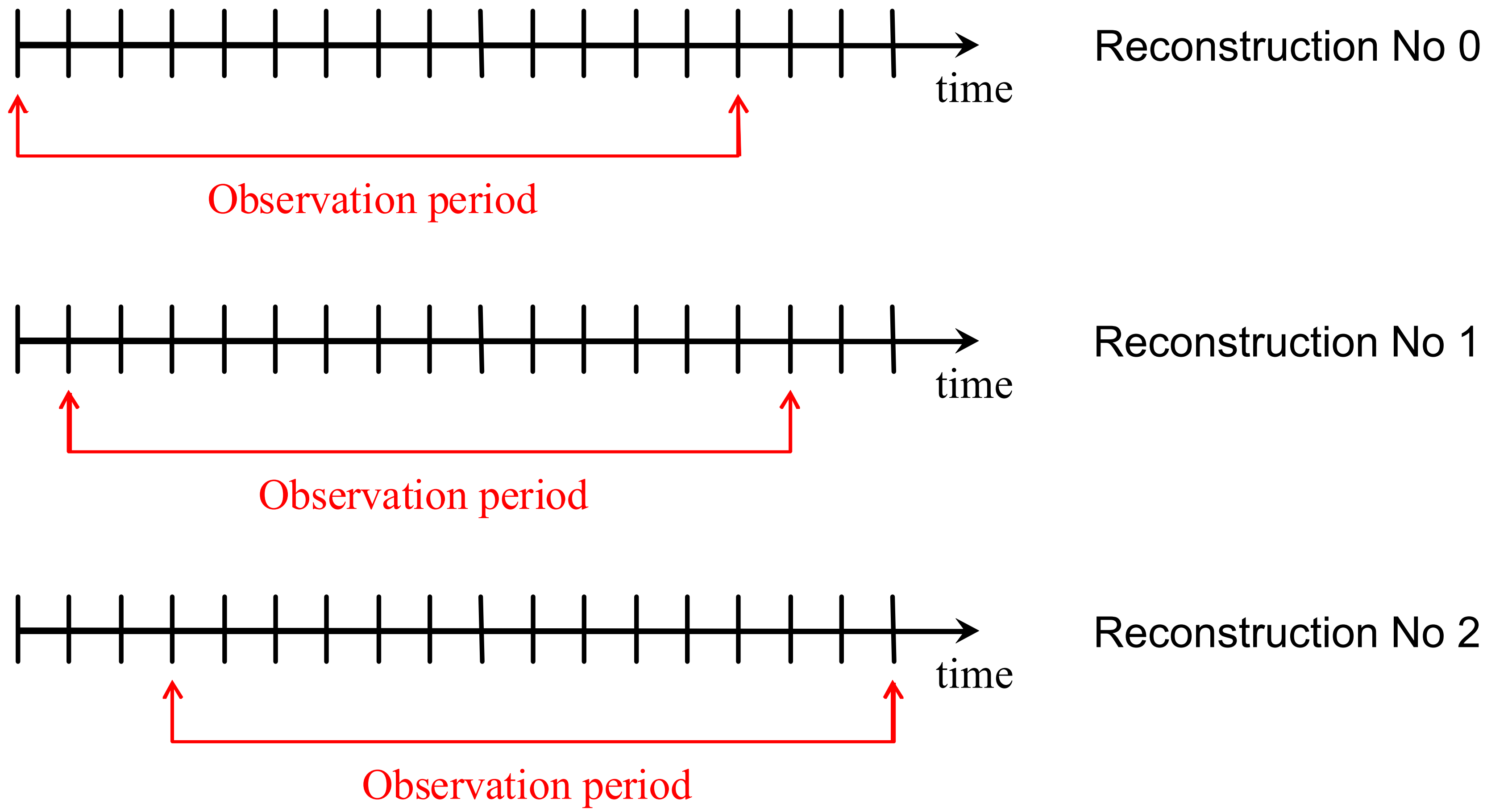
One day difference



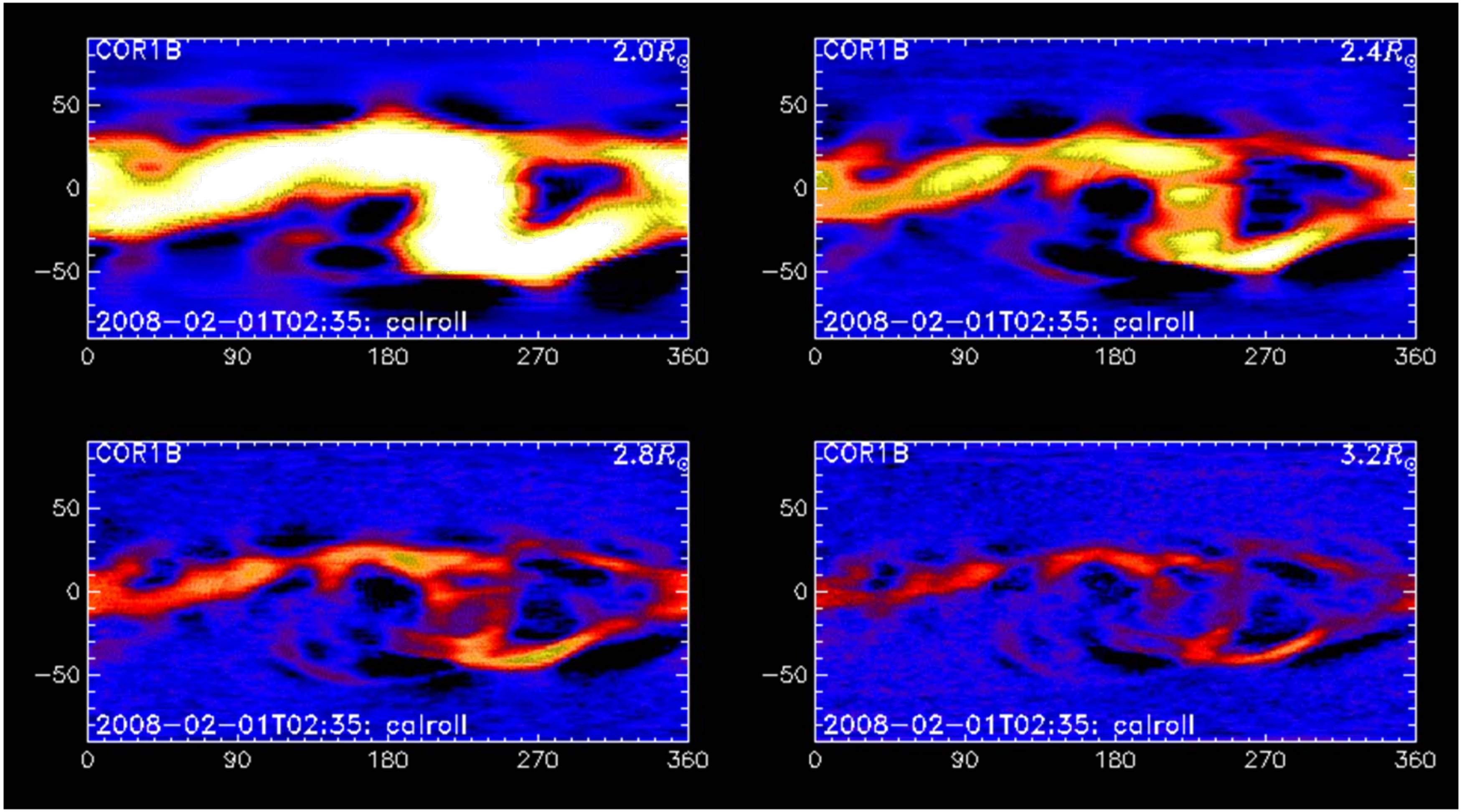
Seven days difference



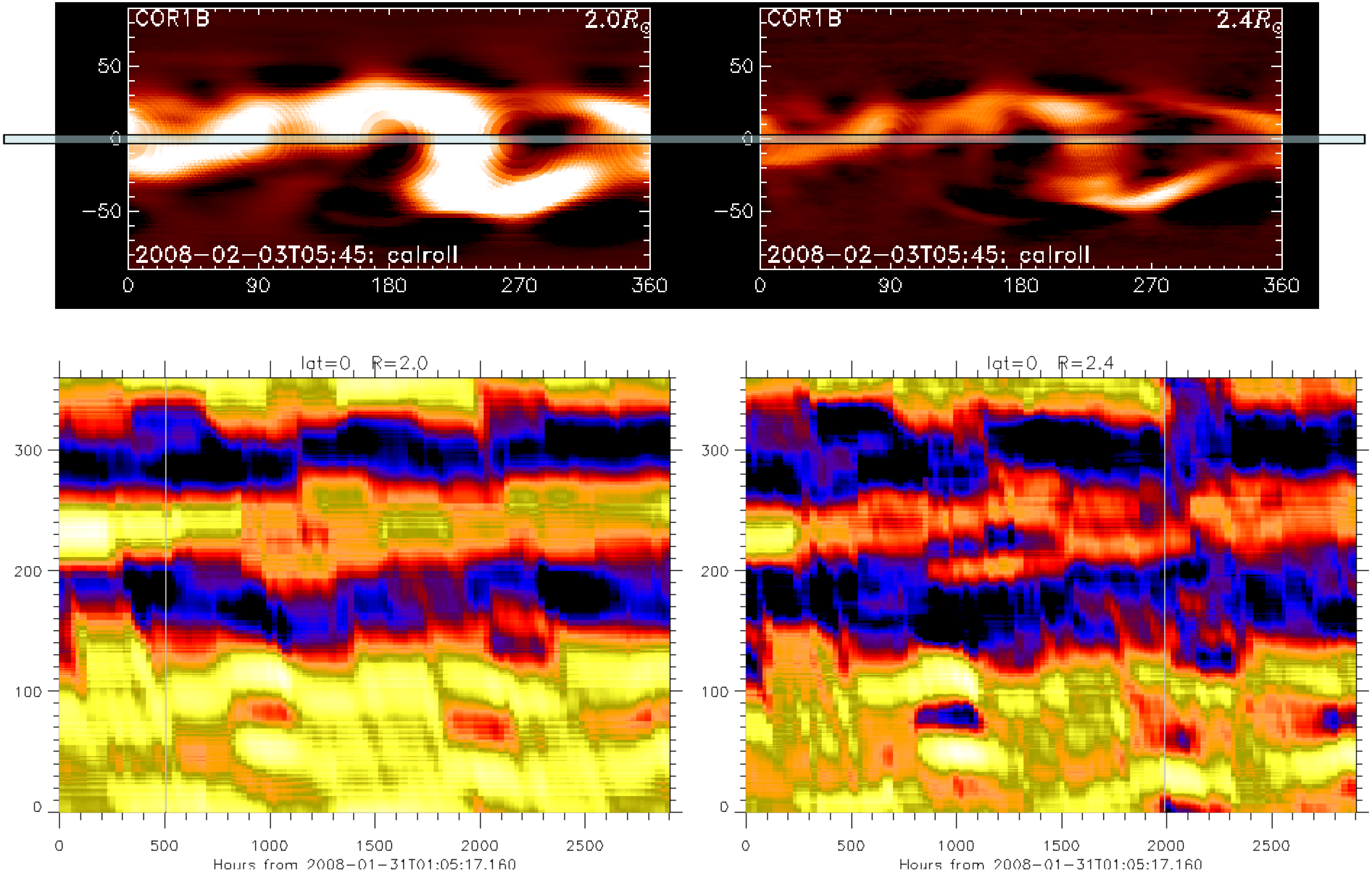
Reconstructions for the whole year of 2008



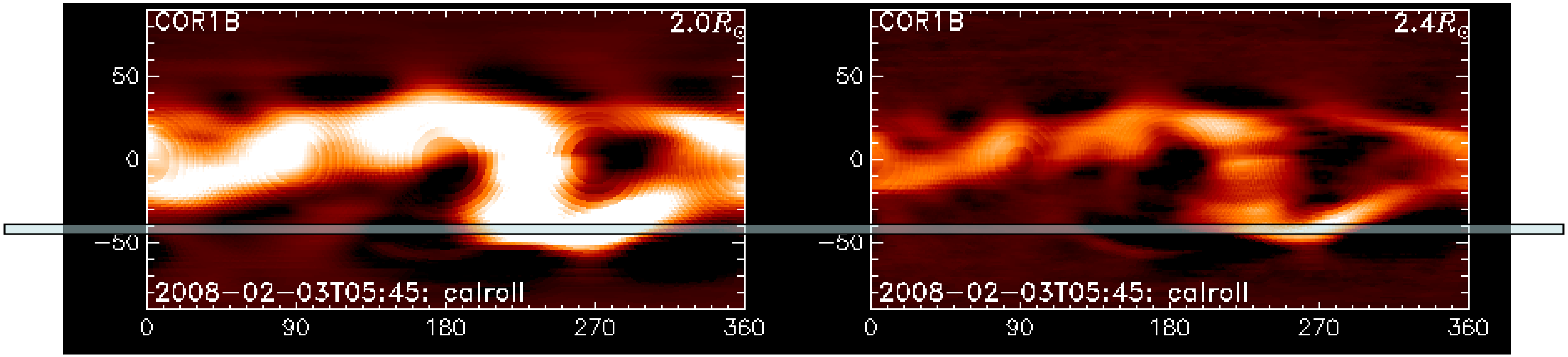
Reconstructions for the whole year of 2008

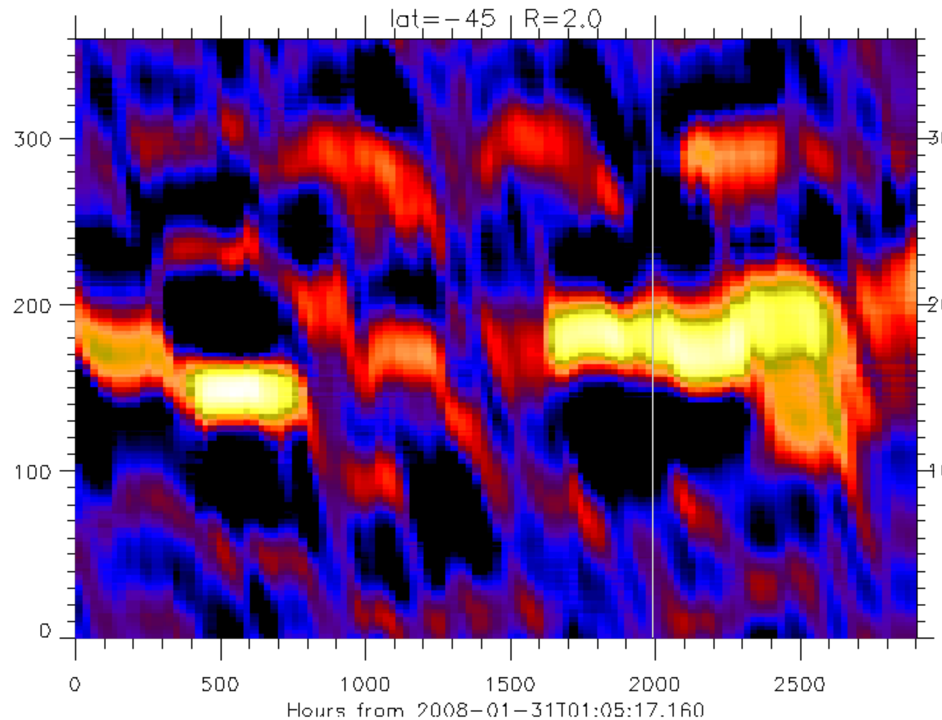


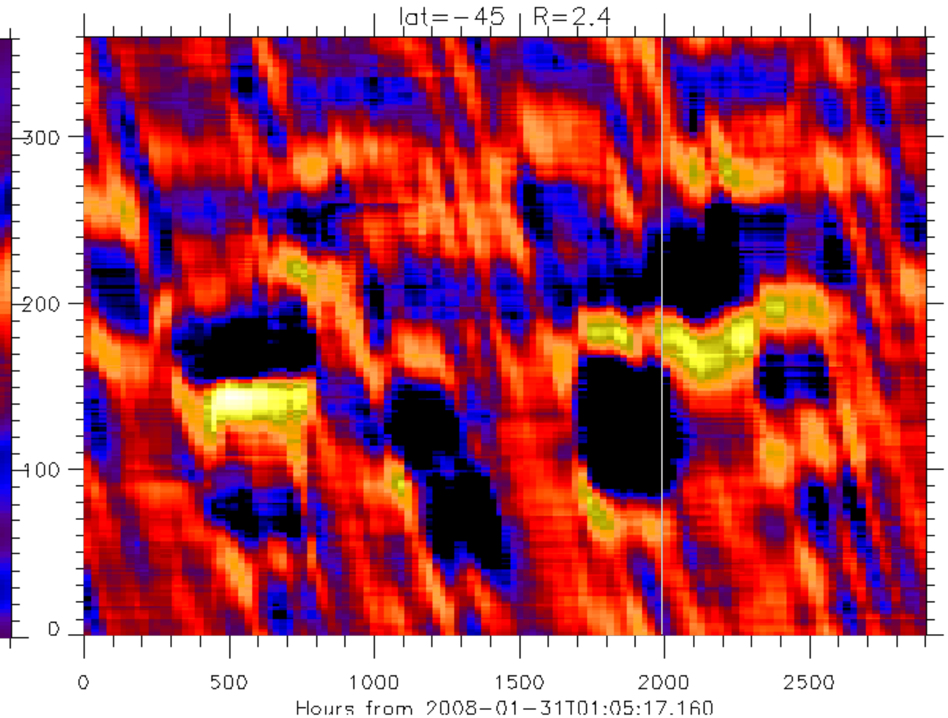
Reconstructions for the whole year of 2008



Reconstructions for the whole year of 2008

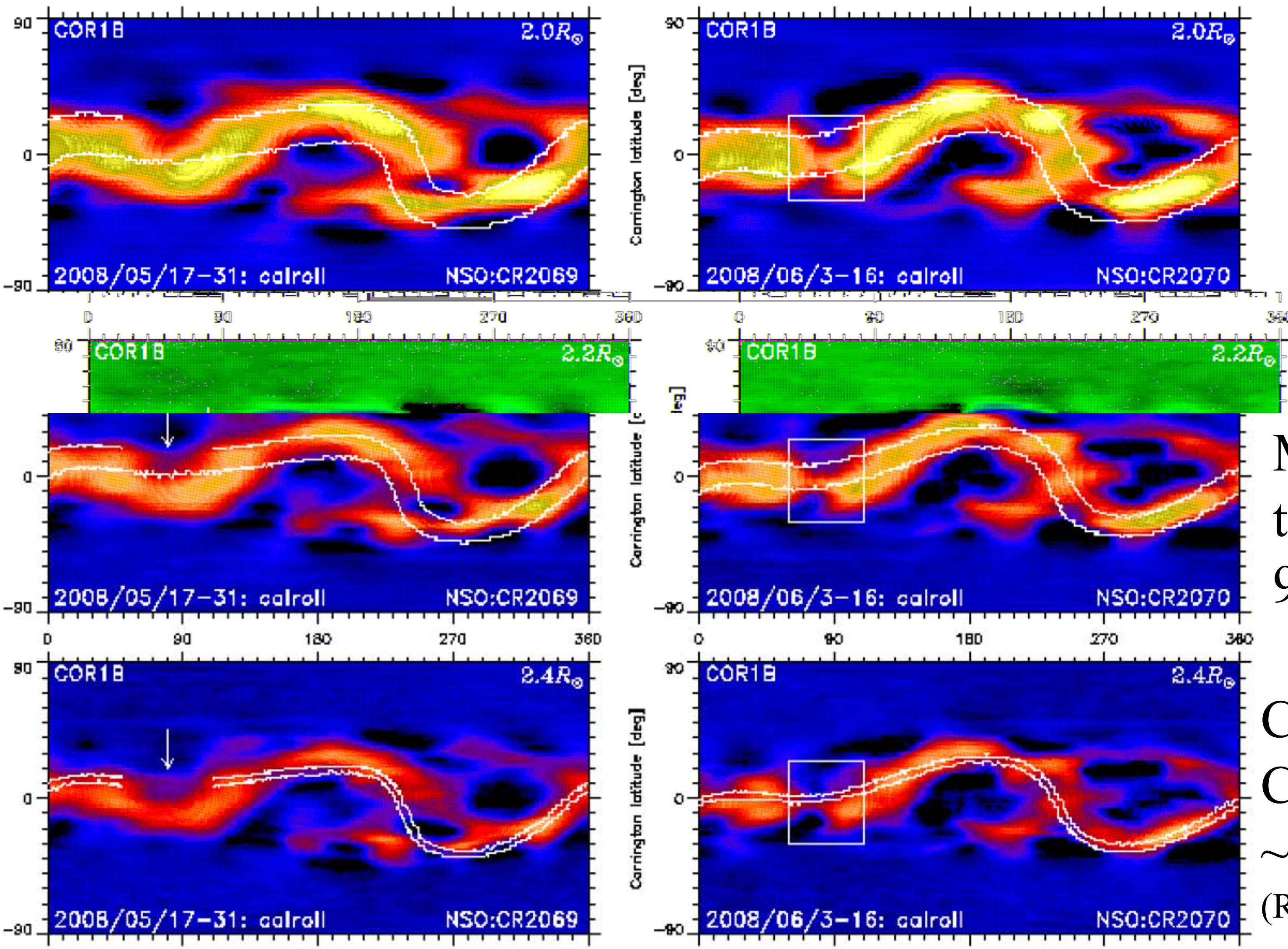






CME: June 1st, 2008

Before the CME | After the CME



Mass lost by the streamer: $9*10^{14}$ g

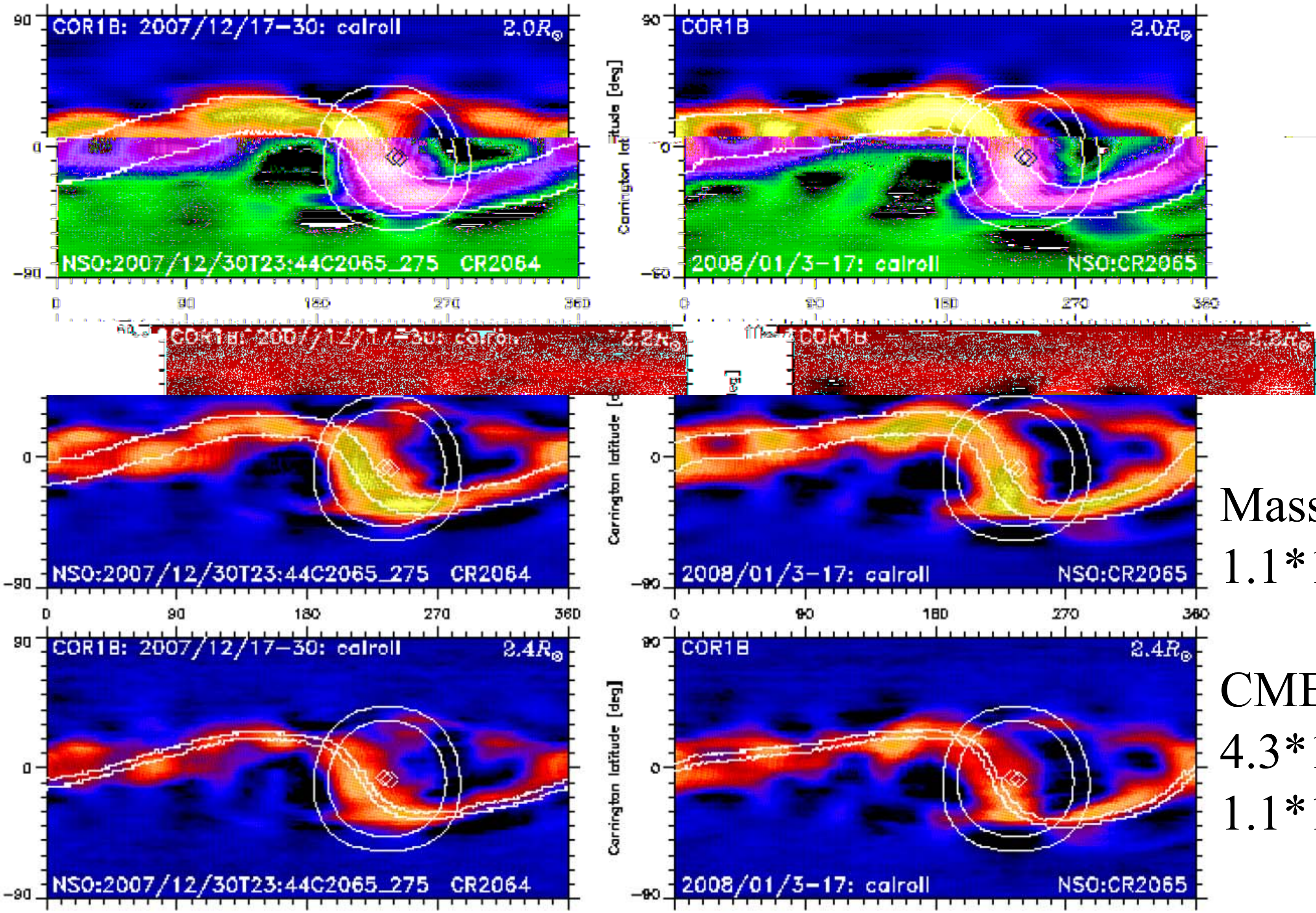
CME mass in COR1 FOV: $\sim 9*10^{14}$ g

(Robbrech et al 2009)

CME: Dec 31st, 2007 & Jan 2, 2008

Before the CME

After the CMEs

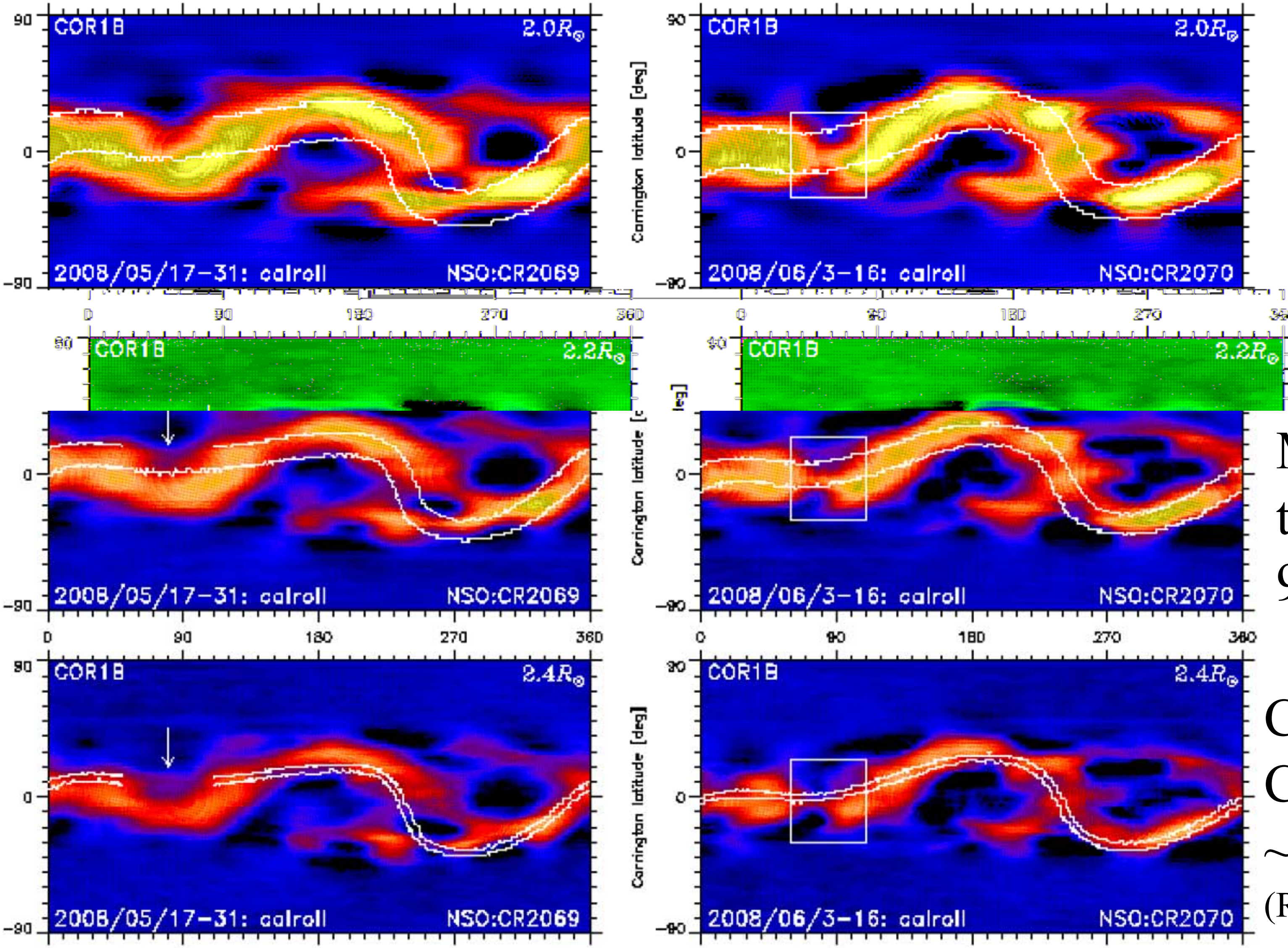


Mass lost:
$1.1*10^{15}$ g

CME masses:
$4.3*10^{15}$ g
$1.1*10^{15}$ g

CME: June 1st, 2008

Before the CME | After the CME



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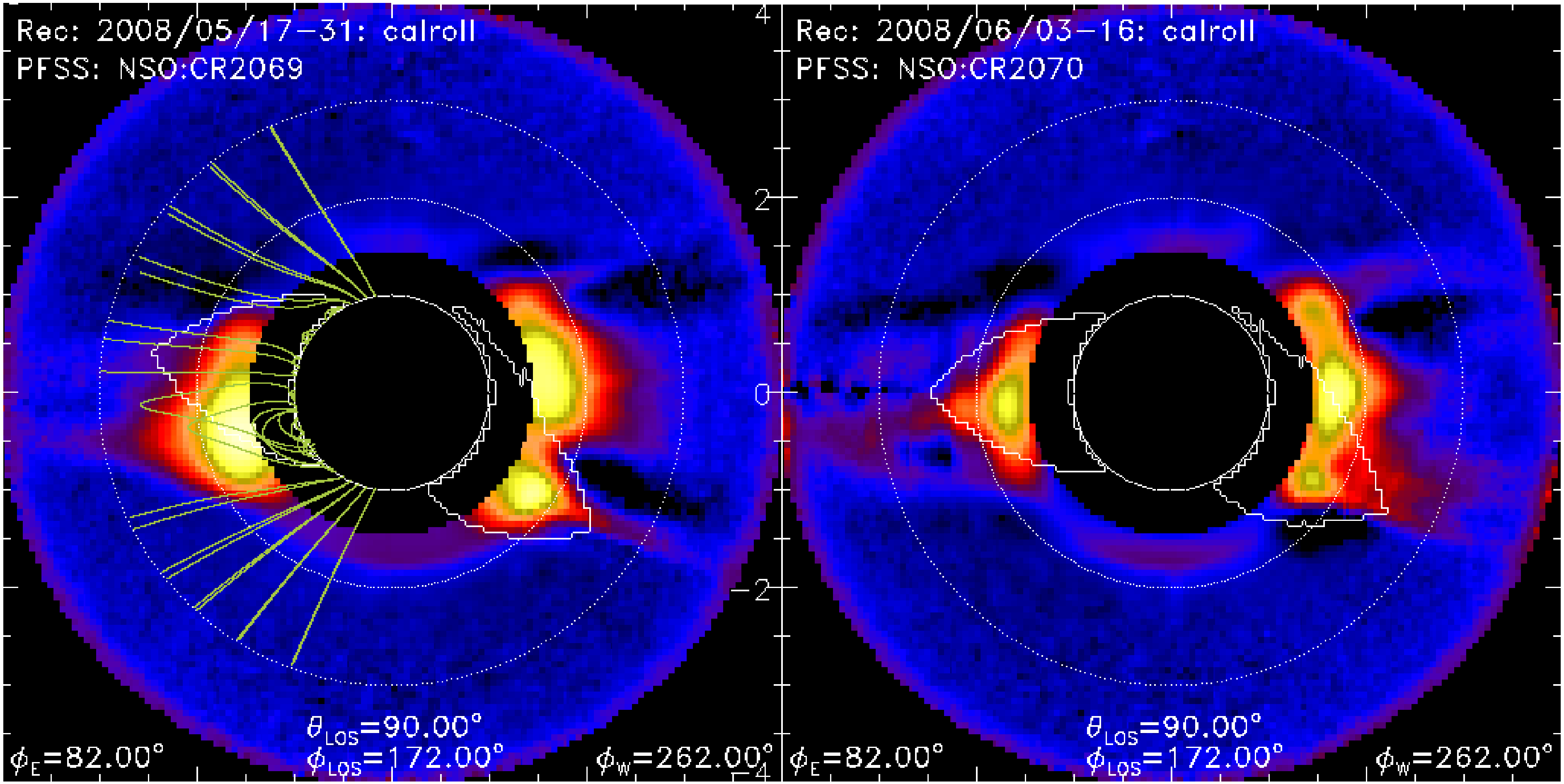
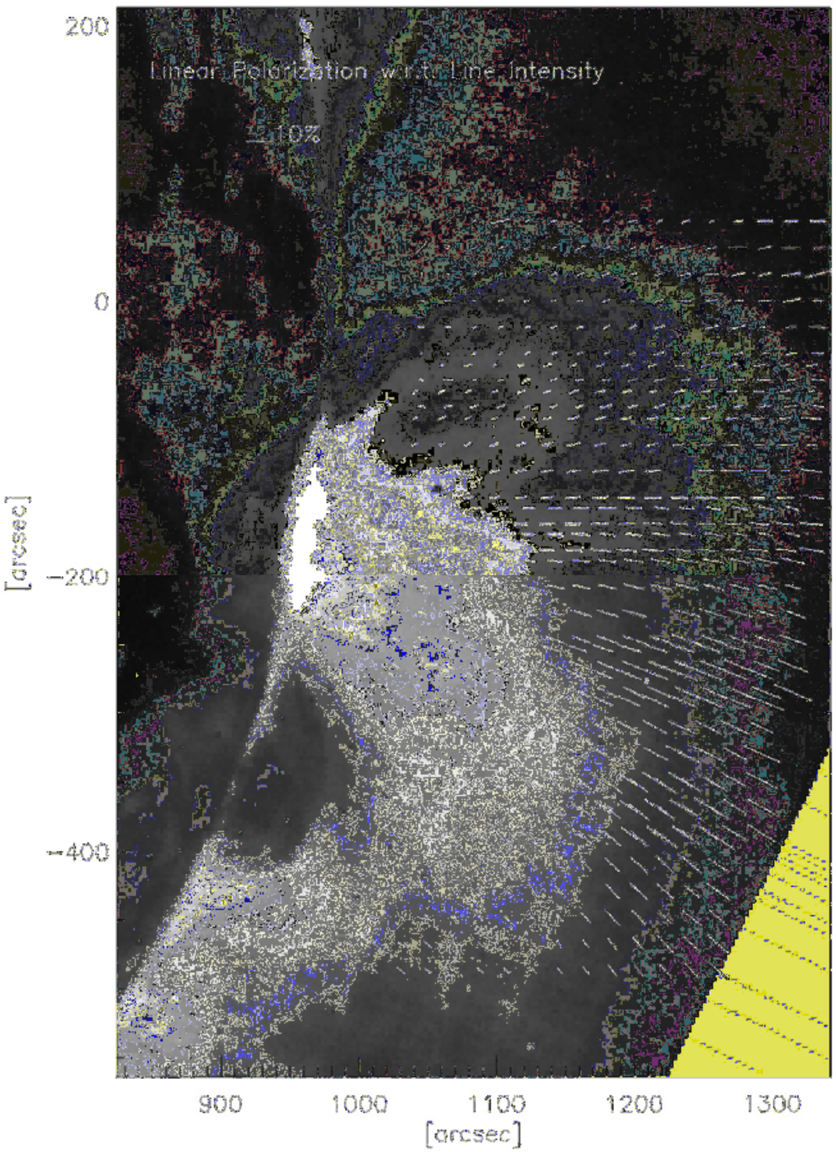
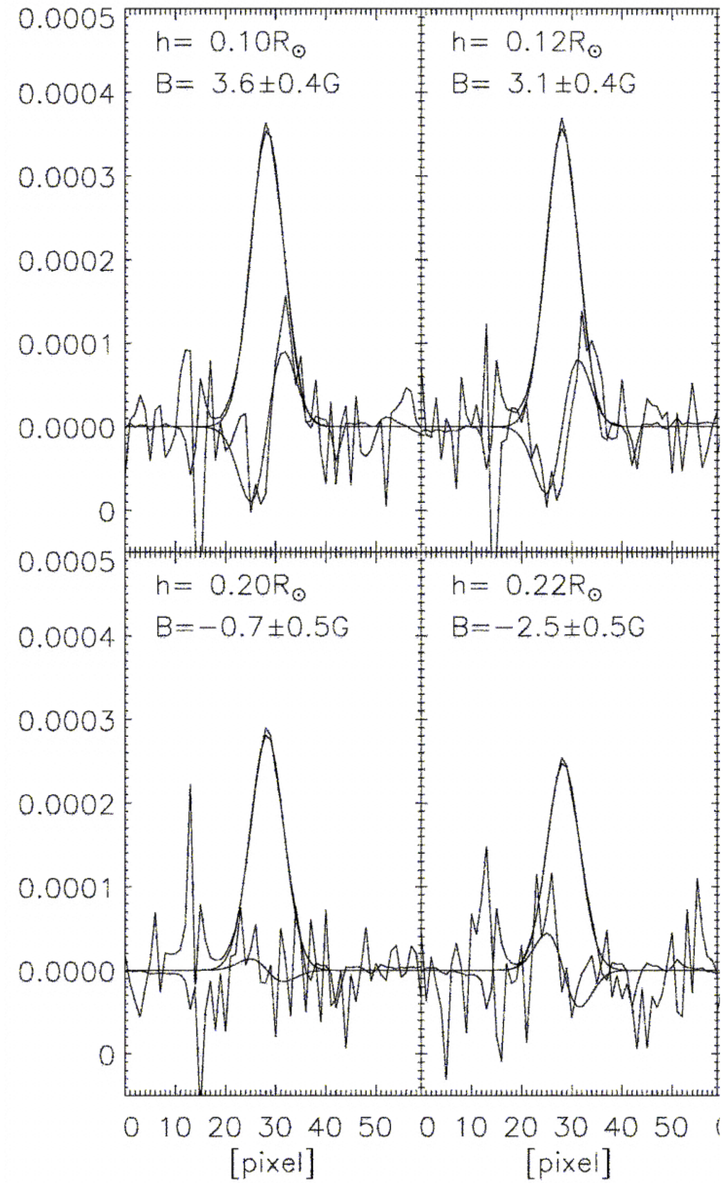


Next: Vector Field Tomography for the Coronal Magnetic Field

Zeeman/Hanle-effect in the Corona:Observations of Fe XIII

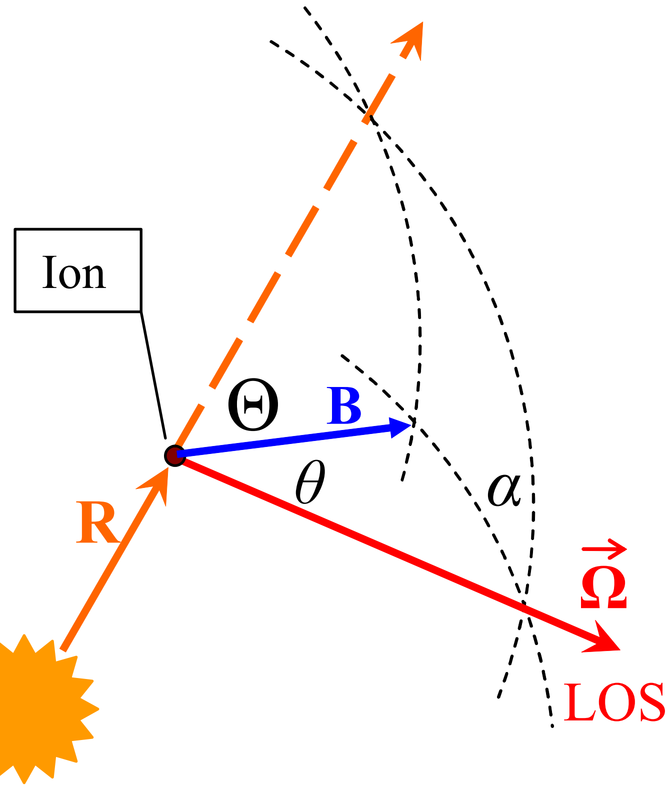




Lin et al. 2004

Hanle – effect: Emission coefficients

$$I = \int_{LOS} \varepsilon(r)\, dl$$



FeXIII and FeXIV ions (Querfeld 1982)

$$\begin{bmatrix} \varepsilon_I \\ \varepsilon_Q \\ \varepsilon_U \\ \varepsilon_V \end{bmatrix} \propto \begin{bmatrix} 4\Sigma + \Delta(3\cos^2\theta - 1)(3\cos^2\Theta - 1) \\ \Delta(3\cos^2\Theta - 1)\sin^2\theta\cos 2\alpha \\ \Delta(3\cos^2\Theta - 1)\sin^2\theta\sin 2\alpha \\ 0 \end{bmatrix}$$

θ is the angle between the magnetic field direction and the LOS to the observer;

α is the angle between the local radius and the observed polarization projected on the POS;

Θ is the angle between local radius and magnetic field direction;

Σ and Δ are proportional to the Zeeman sublevel populations (depends on the properties of incident light, T, N);

$V(\Theta) = 3\cos^2\Theta - 1$ is the van Vleck factor

There is no information about magnetic field strength!

Vector Field Tomography: Regularization

We need additional information about field:

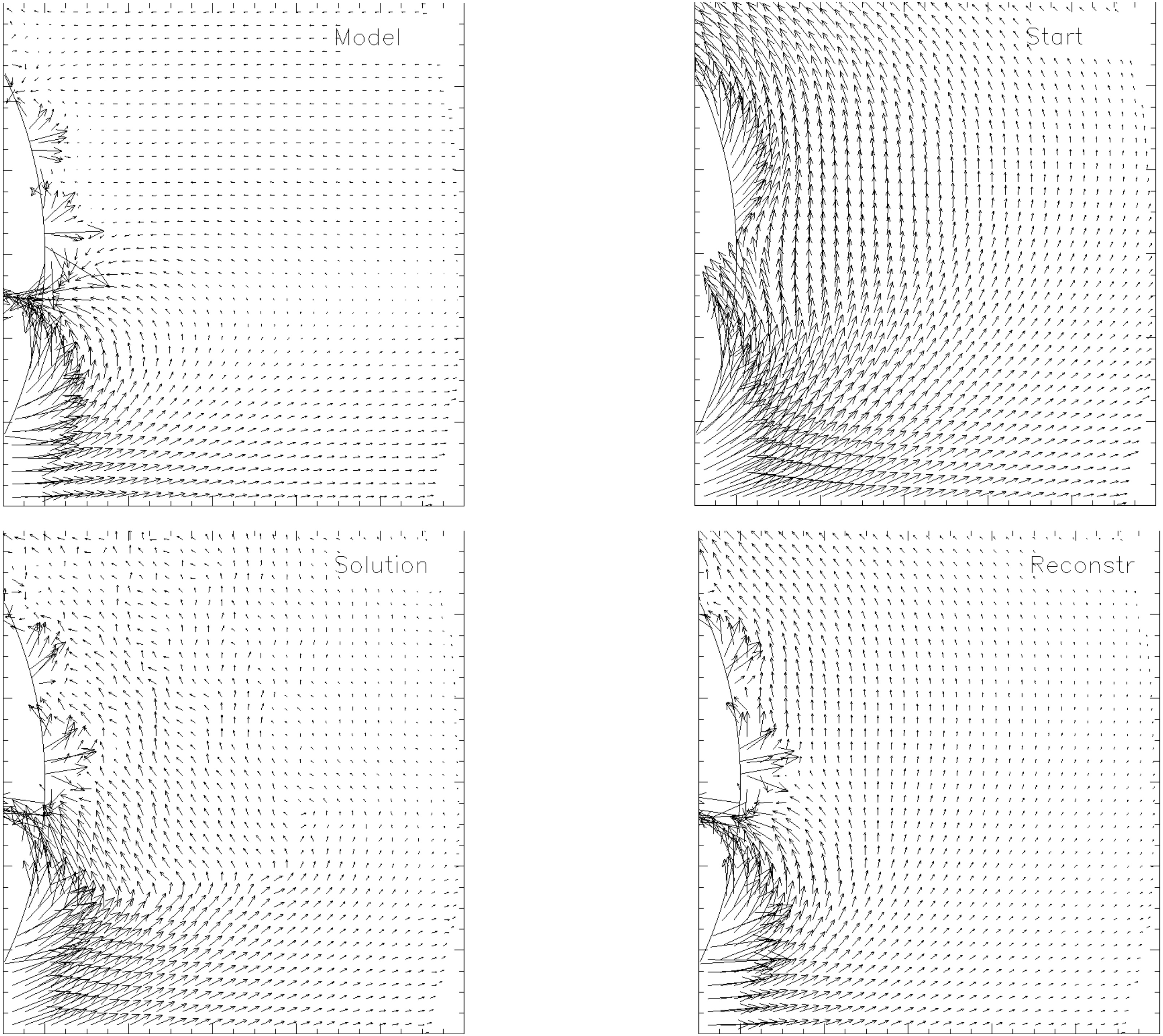
Magnetic field is divergence-free: $\nabla \cdot \vec{B} = 0$

$$F = \sum_{i=1}^{\text{Number of Rays}} \left(D_i^{\text{sim}} - D_i^{\text{obs}} \right)^2 + \mu \int_{Corona} \left| \nabla \cdot \vec{B} \right|^2 dV$$

Should be minimized

Nice properties of this regularization:

- makes the use of photospheric ***B*** observation as boundary condition
- reproduces standard potential ***B*** if *div*-term alone is minimized


Model
Start
Solution
Reconstr

Conclusion

- We can produce 3D reconstruction of electron density almost for any period of COR1 observations in routine way.
- It was found evidence of streamer blow out during CME event on June 1^{st} 2008 – it is not LOS effect.
- Streamer mass loss for slow CME on 1^{st} June 2008 is $9*10^{14}$ gram which is comparible with the CME mass in COR1 field of view
- After the CME the coronal magnetic field came to the nearly potential configuration.
- Vector tomography based on spectropolarimetric observations has a possibility to reconstruct the non-potential field that could lead to CME eruption.