Impact of CME on the 3D coronal electron density

$$\text{M.Kramar}^1, \text{J.Davila}^2, \text{H.Xie}^1$$

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

[2] NASA-Goddard Space Flight Center

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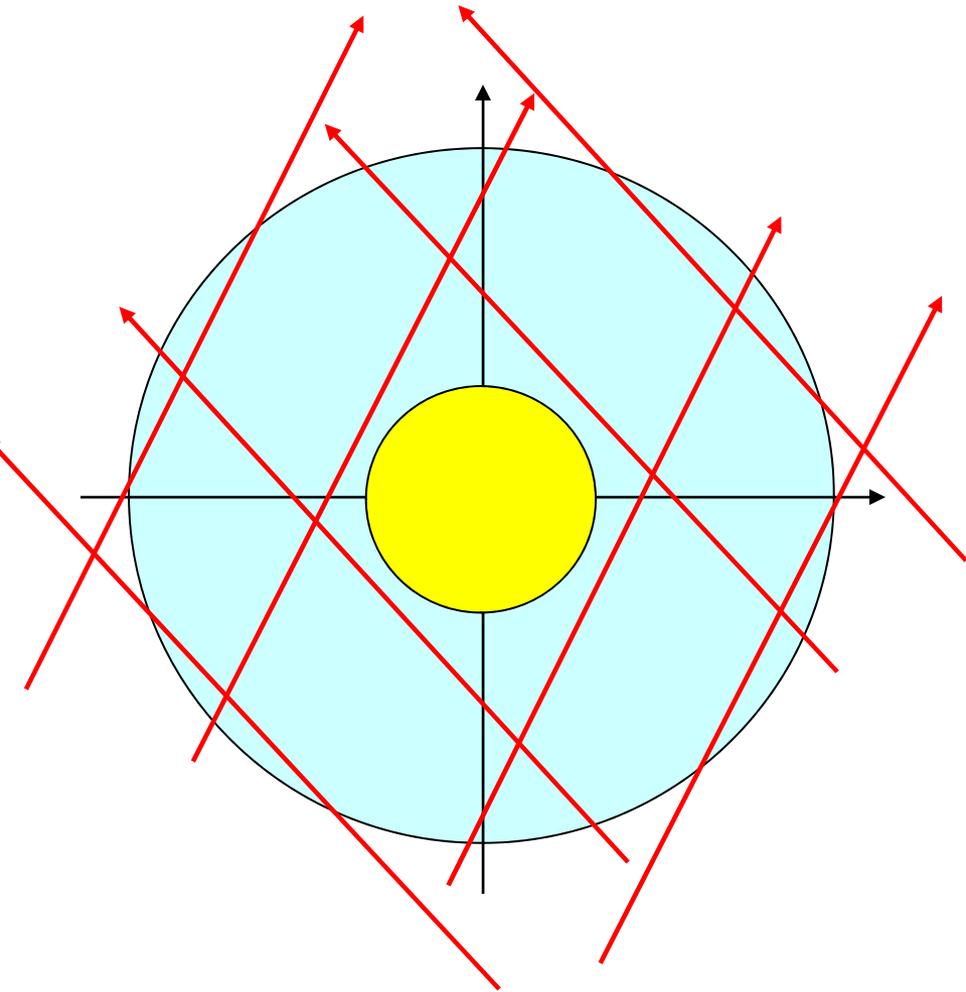
- Problem is badly conditioned, e.g. number of unknown variables exceeds the number of equations
- Random noise in the data

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.
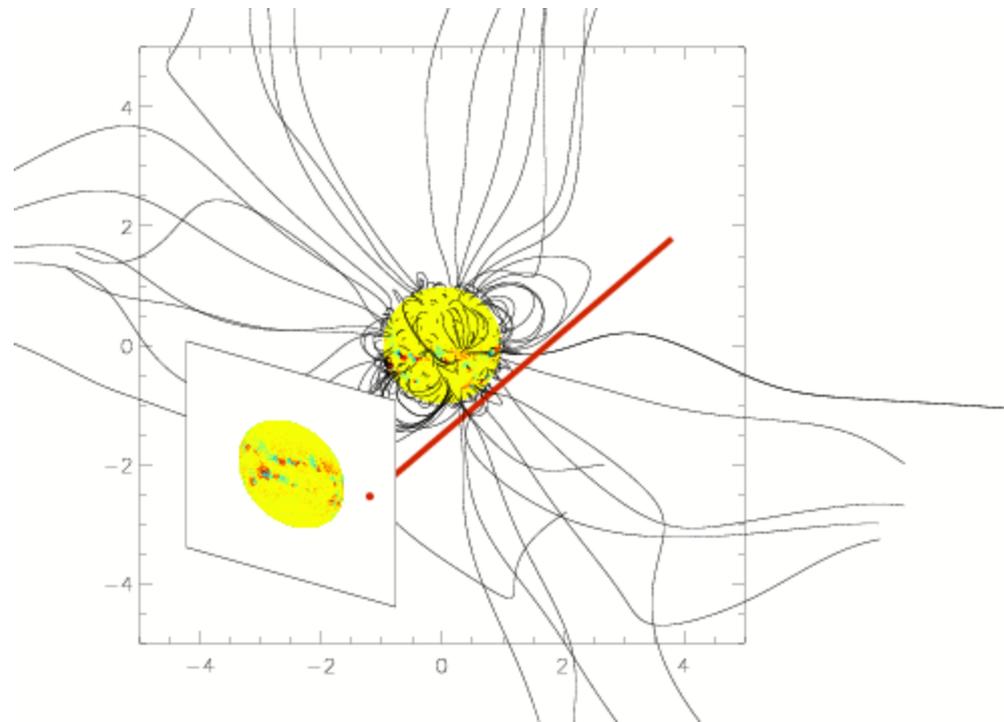
Tomographic Reconstruction for the Solar Corona

Input:

- COR1 observations: pB images, 341x341 pixels

- Two weeks, ~ twice per day

- Roll minimum background subtracted

- Starting point for the iterations is flat field (constant density)

Output:

- 3D Electron Density Distribution: 128x128x128 pixels

Reconstruction of the Electron Density

Reconstruction: CAR 2058
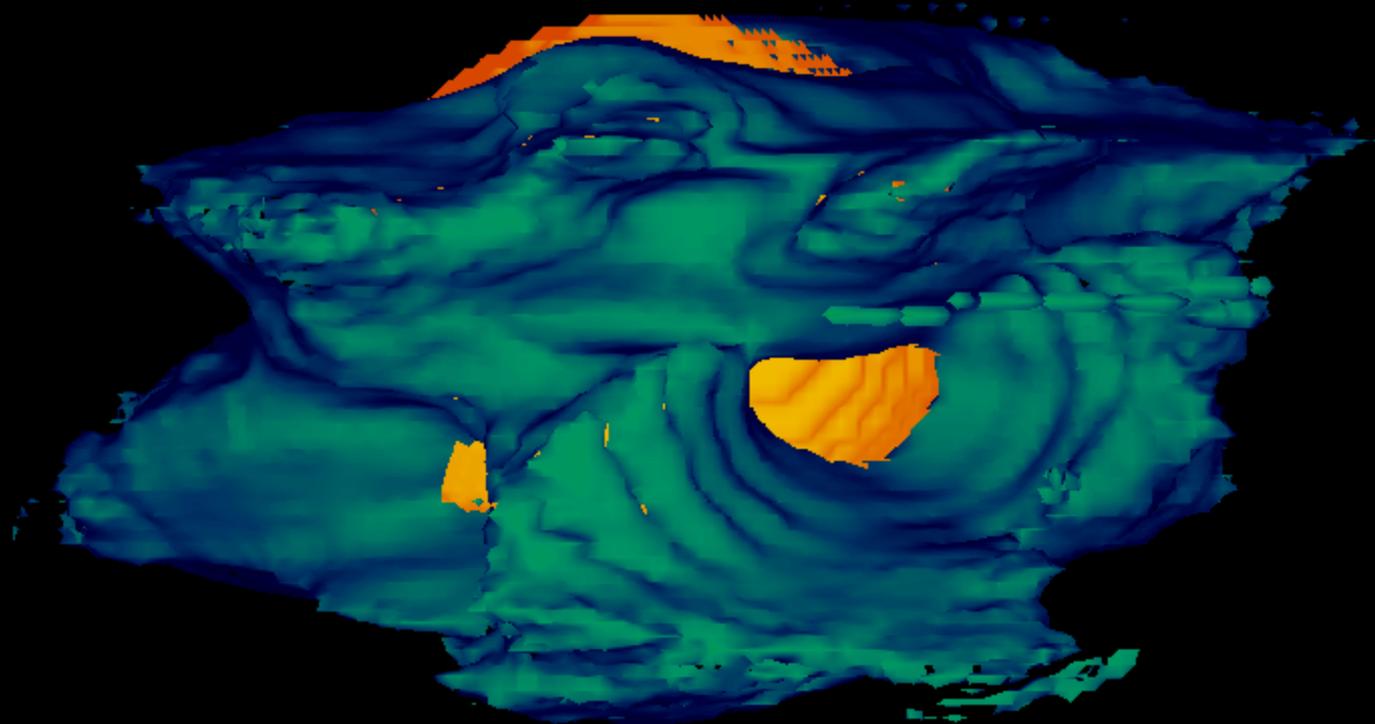
$\theta = 90.00°$
$\phi = 340.00°$

Isosurface: Ne=3.6e+10 m^{-3}

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

Inner spherical boundary is at 1.5 Rsun

Reconstruction of the Electron Density

Reconstruction: CAR 2058
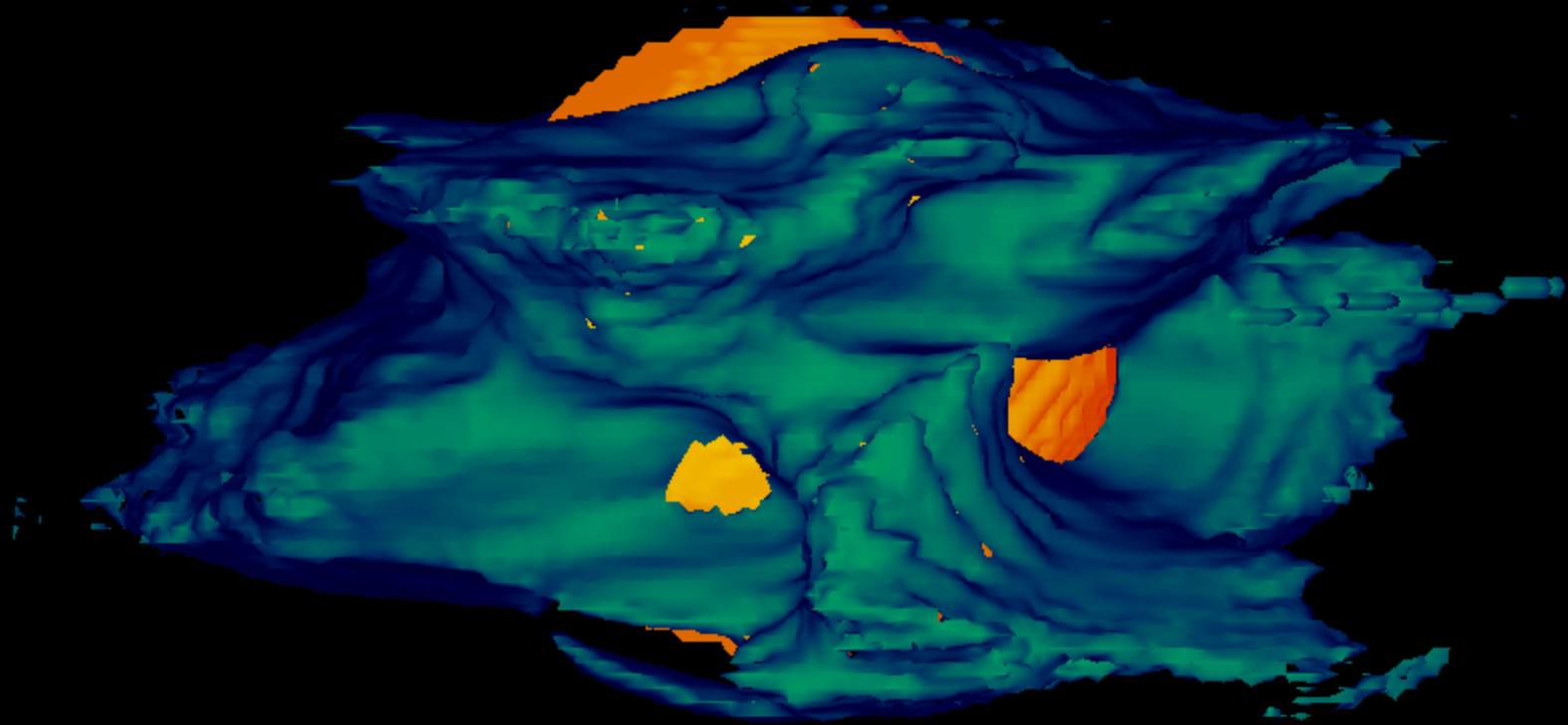
$\theta = 90.00°$
$\phi = 320.00°$

Isosurface: Ne=3.6e+10 m^{-3}

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

Inner spherical boundary is at $1.5\ R$sun

Reconstruction of the Electron Density

Reconstruction: CAR 2058
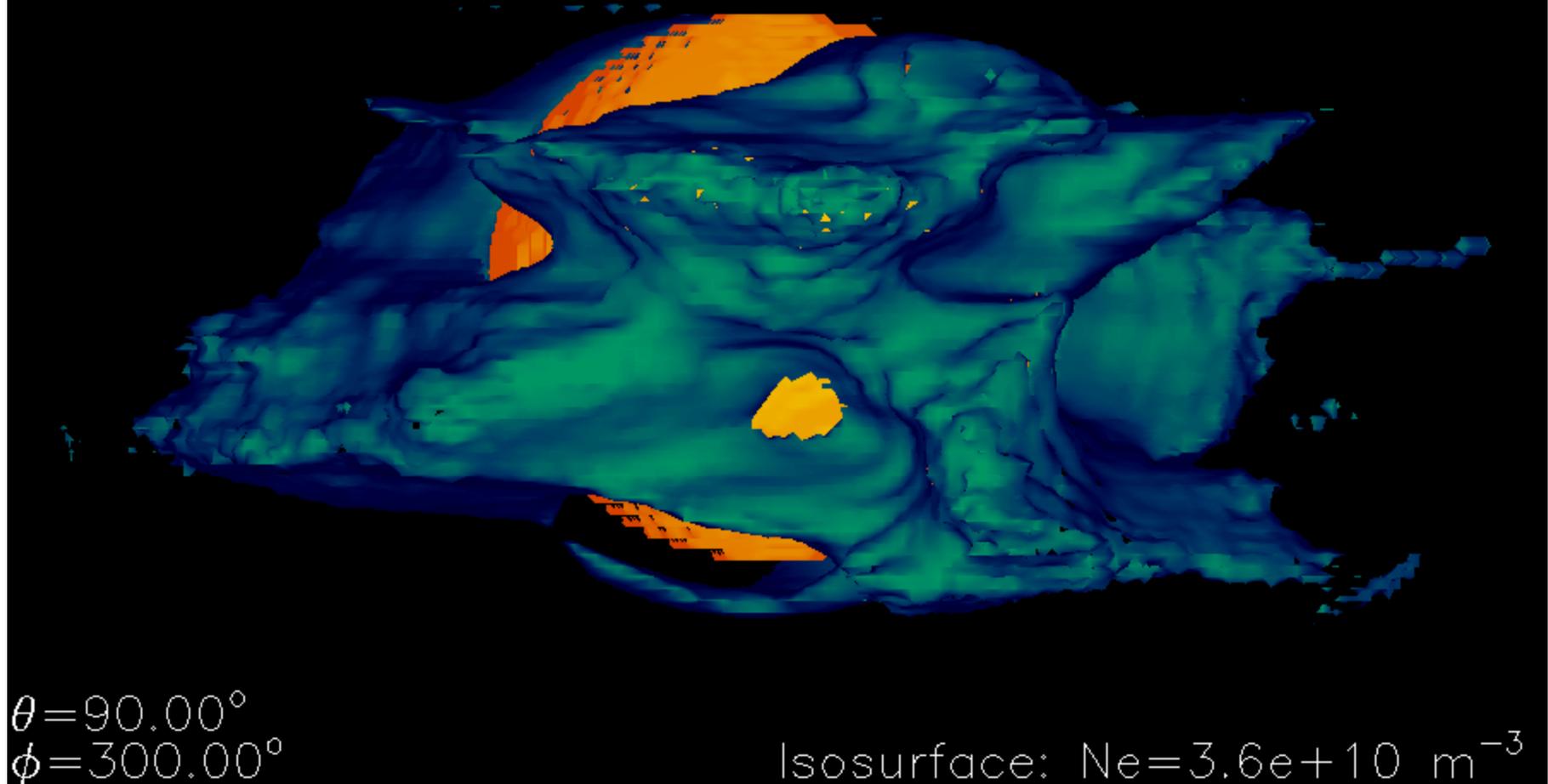
$\theta=90.00°$
$\phi=300.00°$

Isosurface: Ne=3.6e+10 m^{-3}

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

Inner spherical boundary is at $1.5\,R$sun
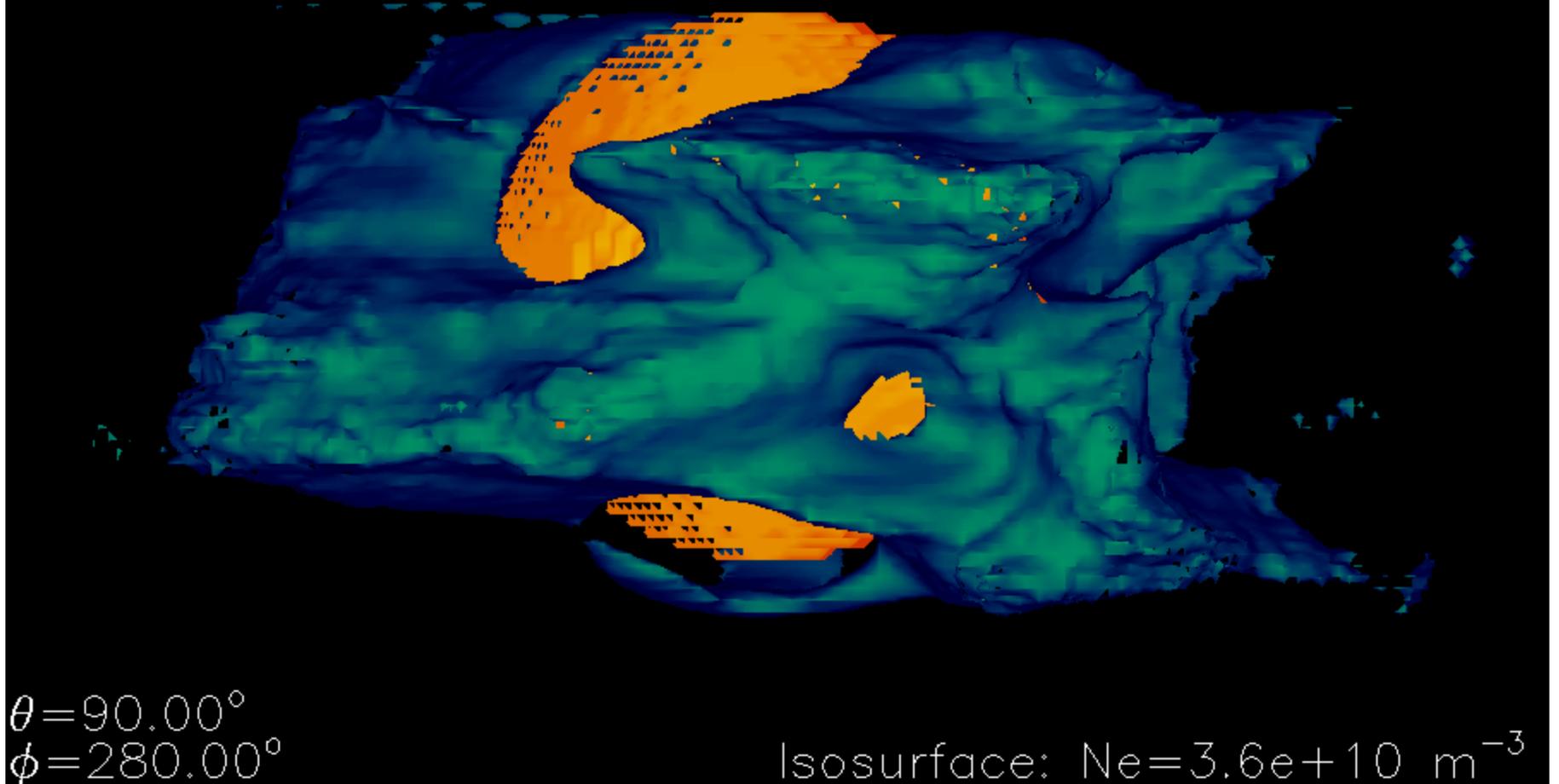
Reconstruction of the Electron Density

Reconstruction: CAR 2058

$\theta = 90.00°$
$\phi = 280.00°$

Isosurface: Ne=3.6e+10 m^{-3}

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

Inner spherical boundary is at 1.5 Rsun
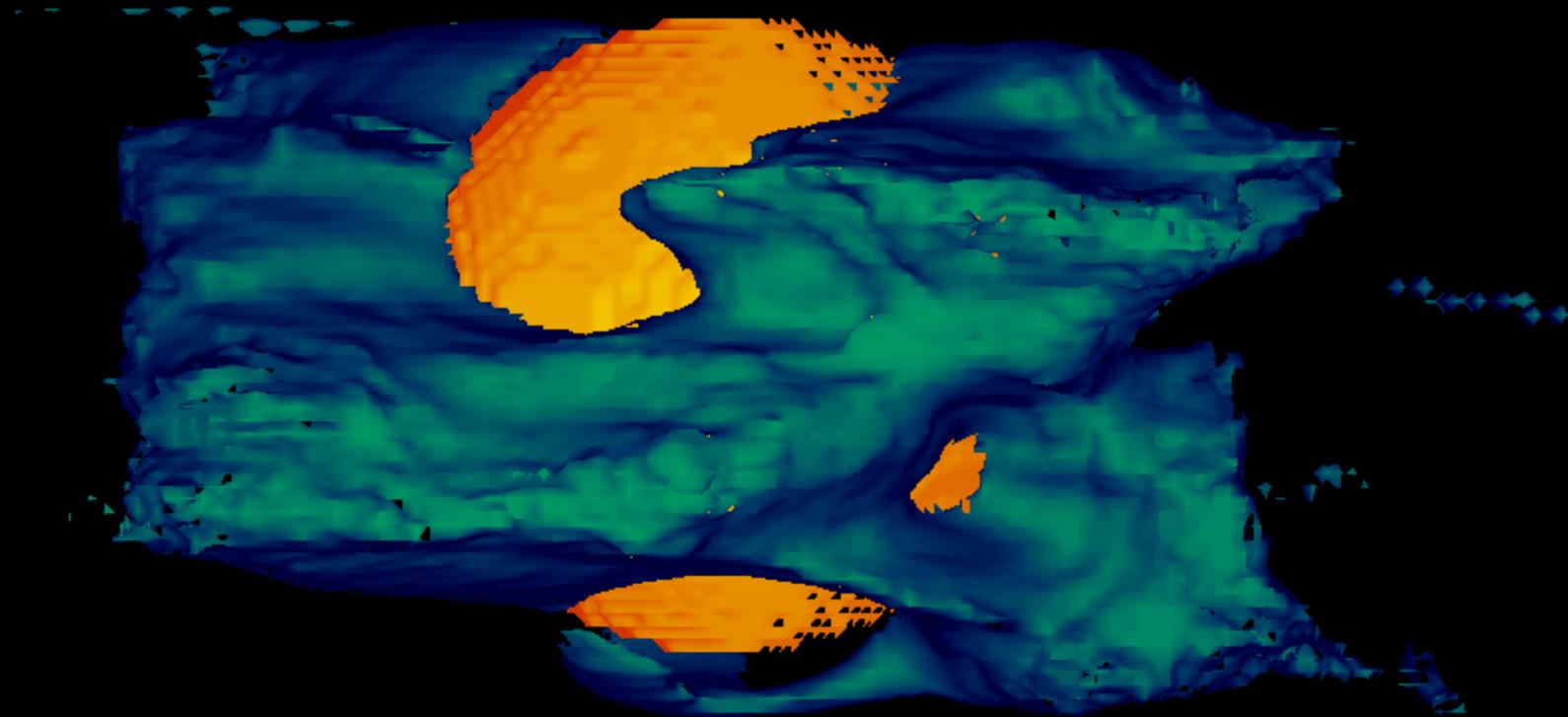
Reconstruction of the Electron Density

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

Inner spherical boundary is at 1.5 Rsun

Reconstruction of the Electron Density

Reconstruction: CAR 2058
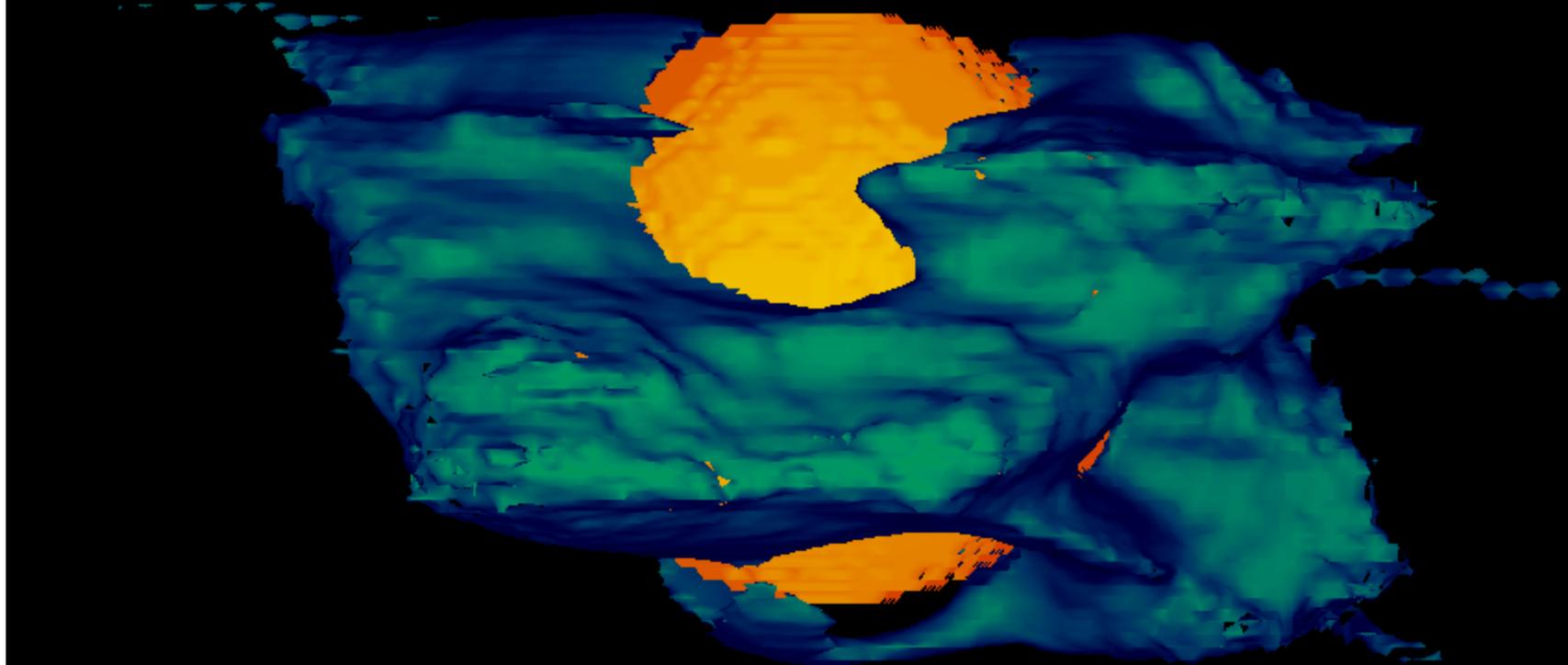
$\theta = 90.00°$
$\phi = 240.00°$

Isosurface: Ne=3.6e+10 m^{-3}

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

Inner spherical boundary is at 1.5 Rsun
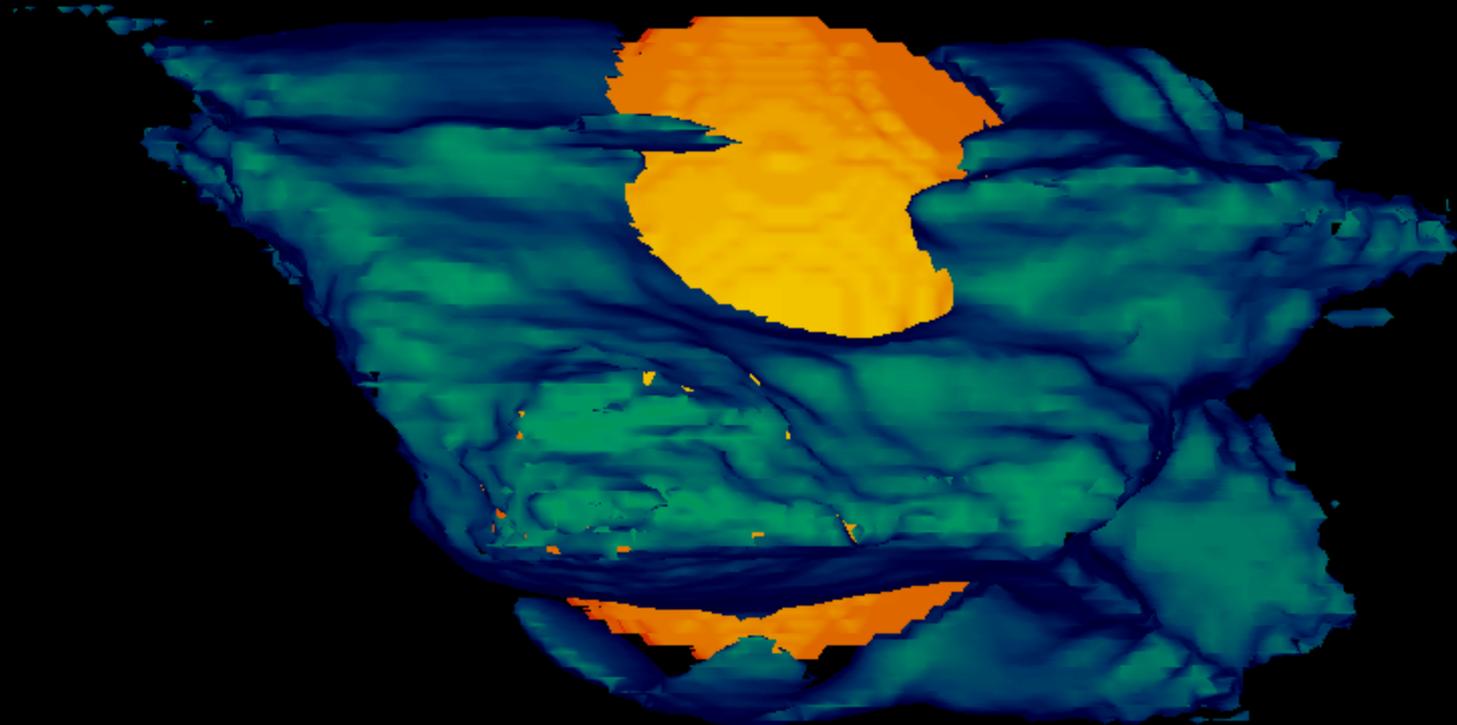
Reconstruction of the Electron Density

Reconstruction: CAR 2058

$\theta = 90.00°$
$\phi = 220.00°$

Isosurface: Ne=3.6e+10 m^{-3}

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

Inner spherical boundary is at 1.5 Rsun
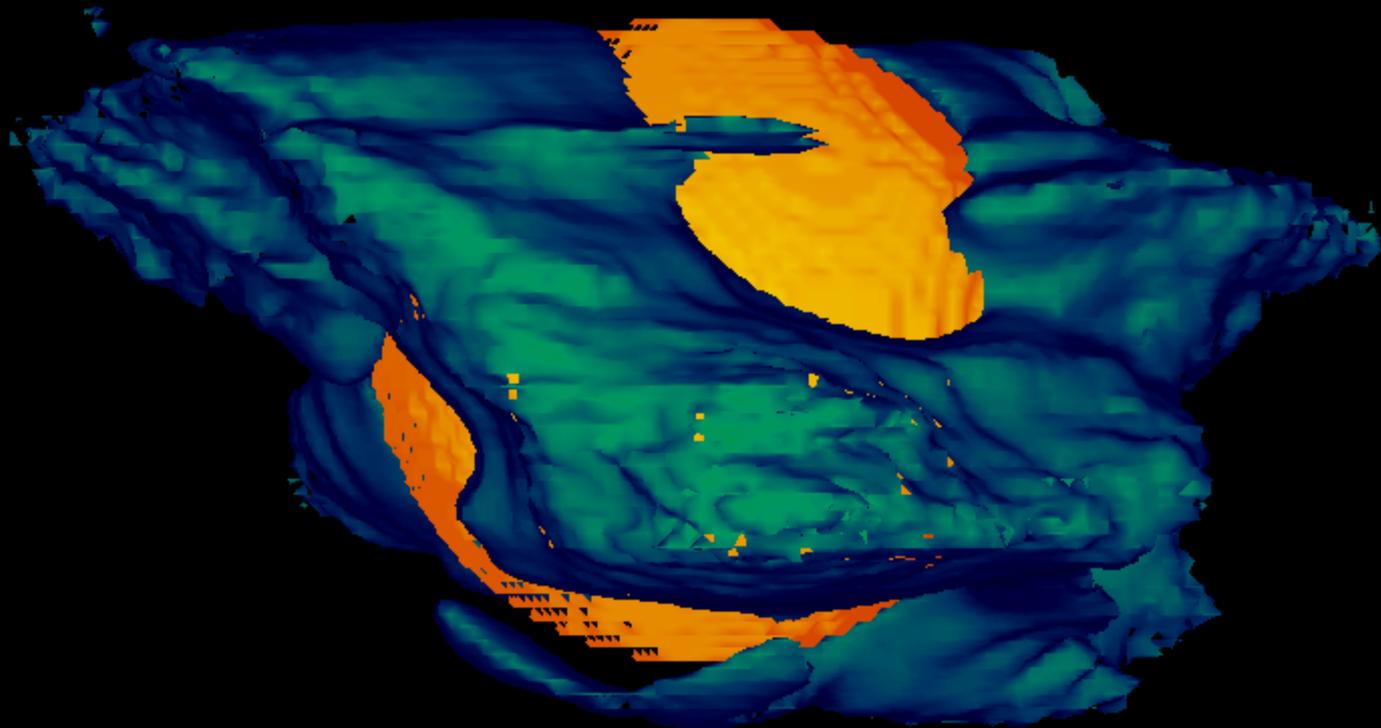
Reconstruction of the Electron Density

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

Inner spherical boundary is at 1.5 Rsun

Reconstruction of the Electron Density

Reconstruction: CAR 2058

$\theta=90.00°$
$\phi=180.00°$

Isosurface: Ne=3.6e+10 m^{-3}

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

Inner spherical boundary is at $1.5\ R$sun

$\varphi_{\mathrm{LOS}}=0°$
$\theta_{\mathrm{LOS}}=90°$

STEREO−B EUVI 195   Ln(img+1)

$\phi_{\mathrm{Los}}=0.05°$
$\theta_{\mathrm{Los}}=86.48°$ 2007−07−17T18:56
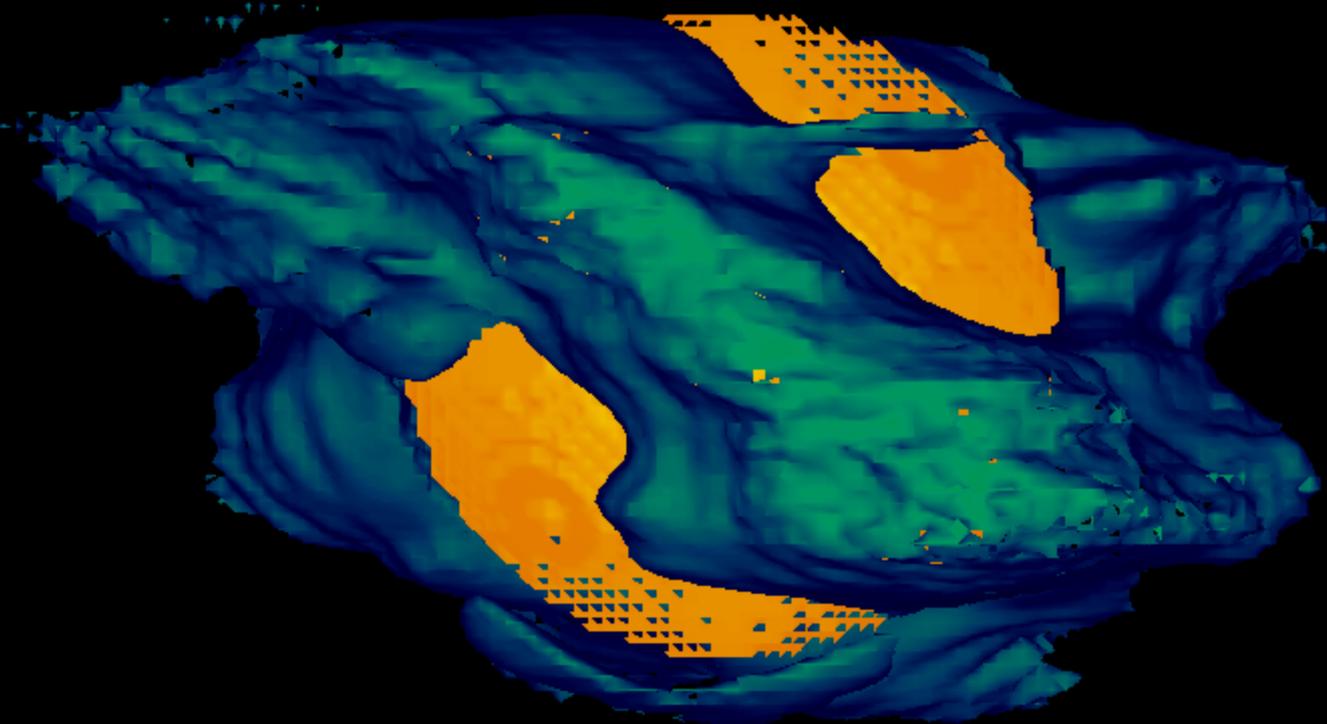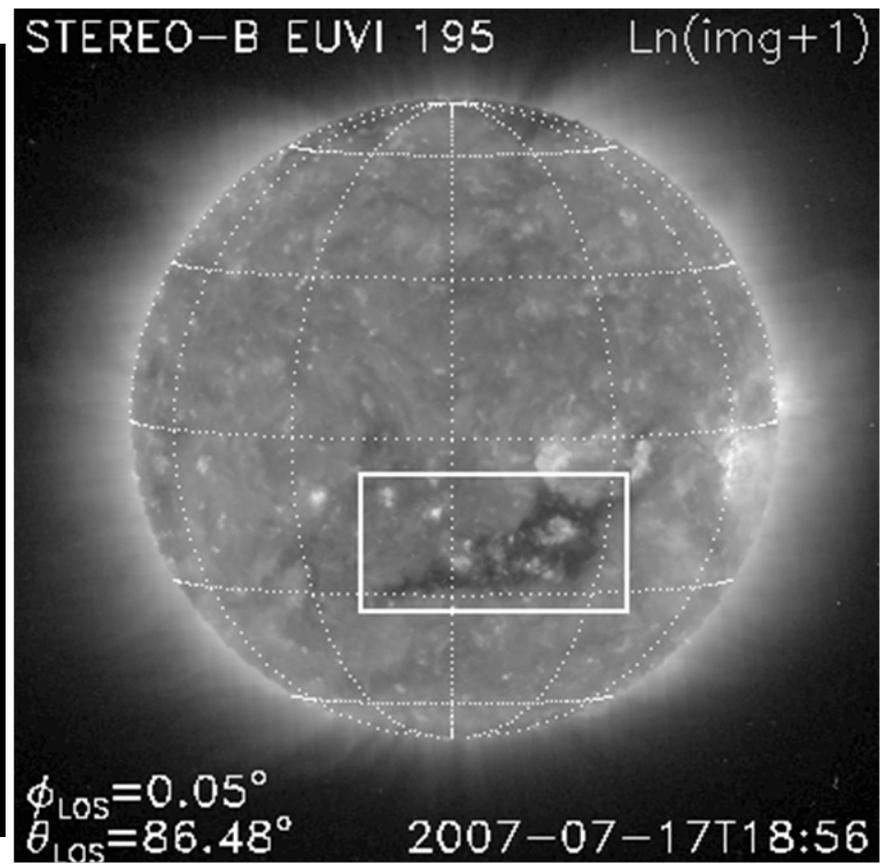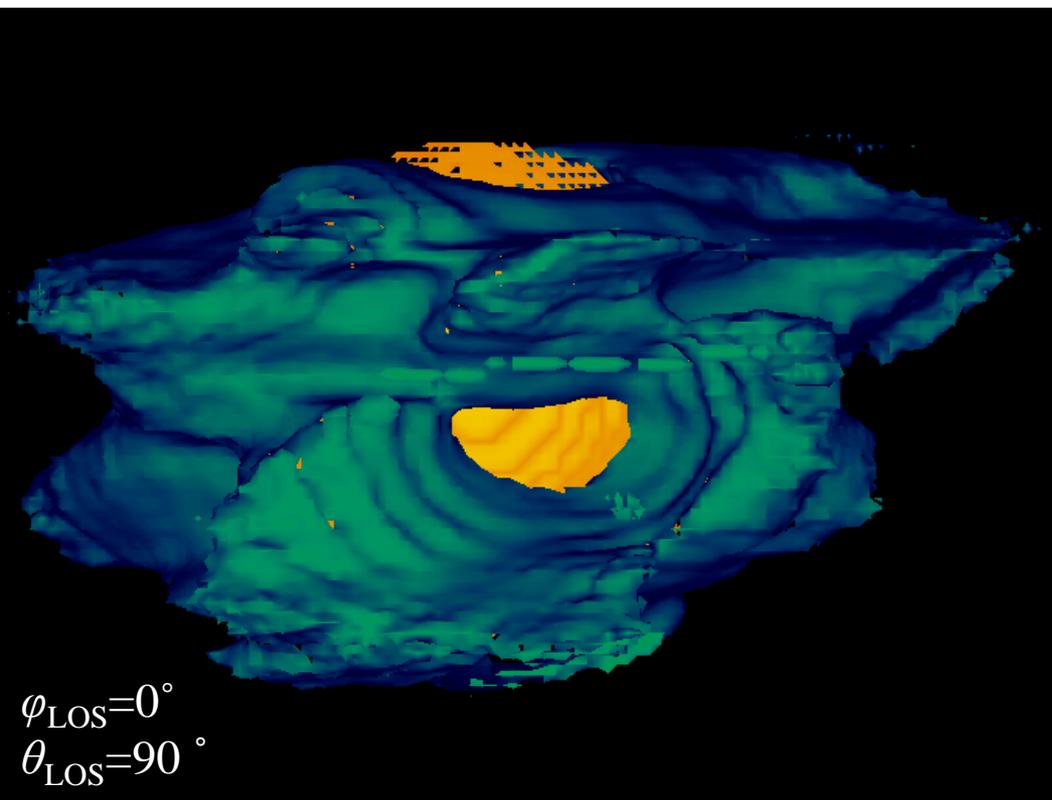
Spherical cross-section at $2\,R_{\mathrm{sun}}$

Reconstruction

2.0$R_\odot$

Carrington latitude [deg]

CAR2058 NSO

Carrington longitude [deg]

100   200   300   400   500   600 [cm$^{-3/2}$]

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

MHD simulation (http://iMHD.net/stereo)

2.0$R_\odot$

Carrington latitude [deg]

CAR2058 MHD

Carrington longitude [deg]

2   3   4   5 [10^6 cm^{-3}]

STEREO-B EUVI 195   Ln(img+1)

ϕ_{LOS}=0.05°
θ_{LOS}=86.48°   2007-07-17T18:56
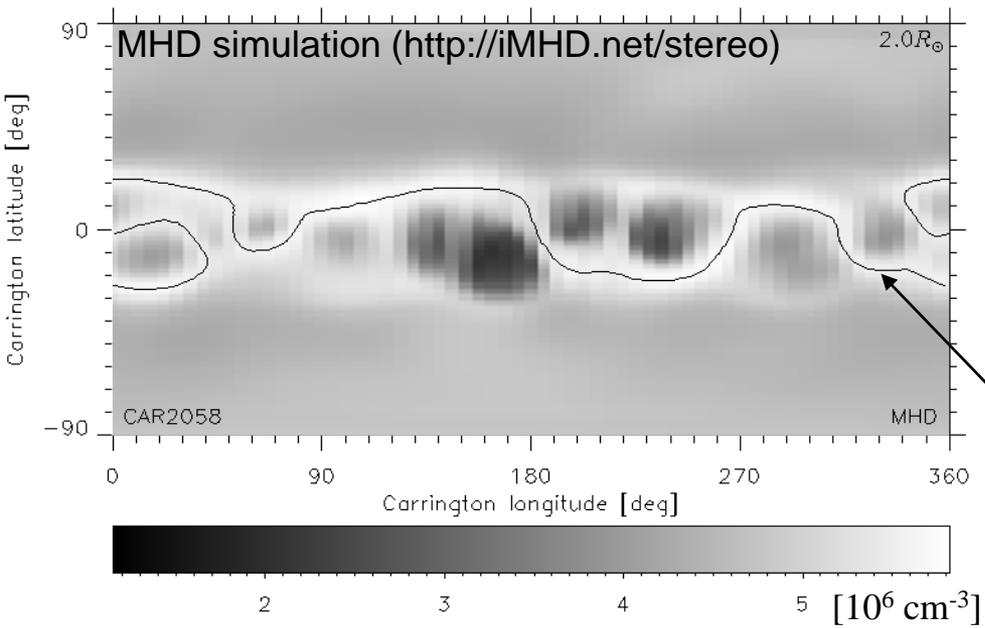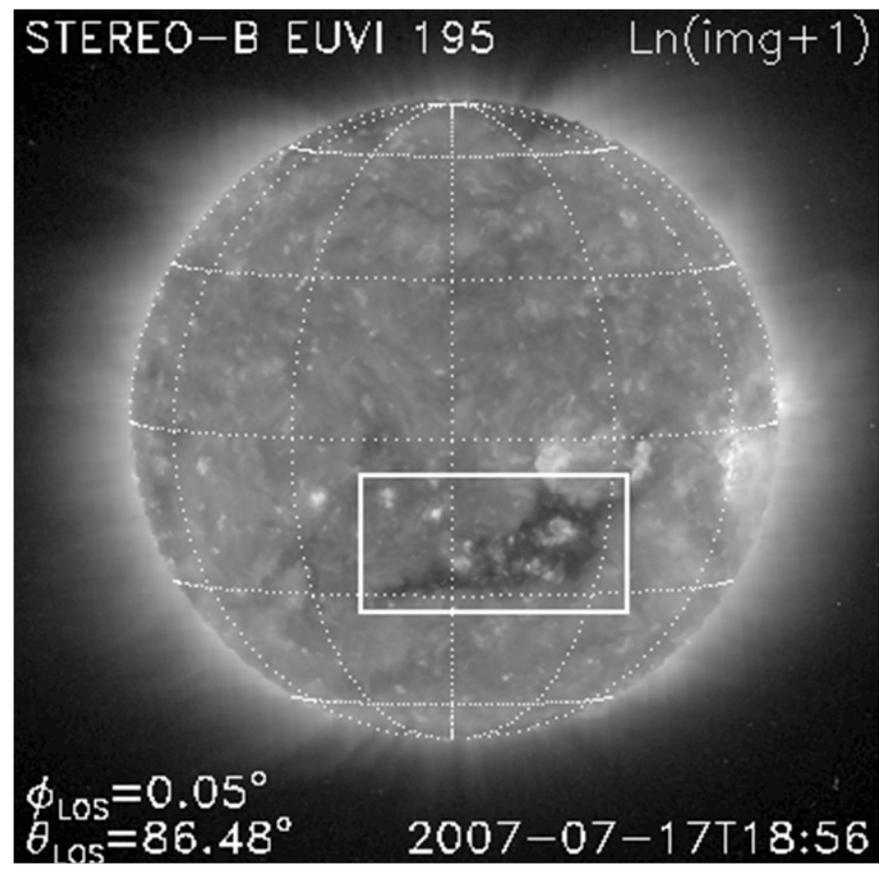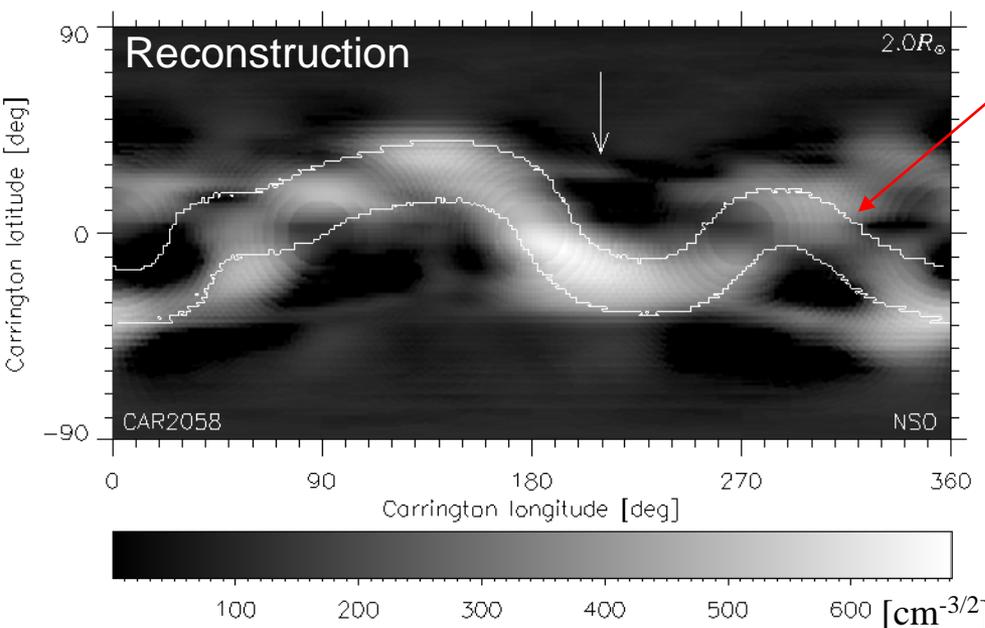
Black contour line is the magnetic neutral line

3D Electron Density: Streamer

Total Brightness
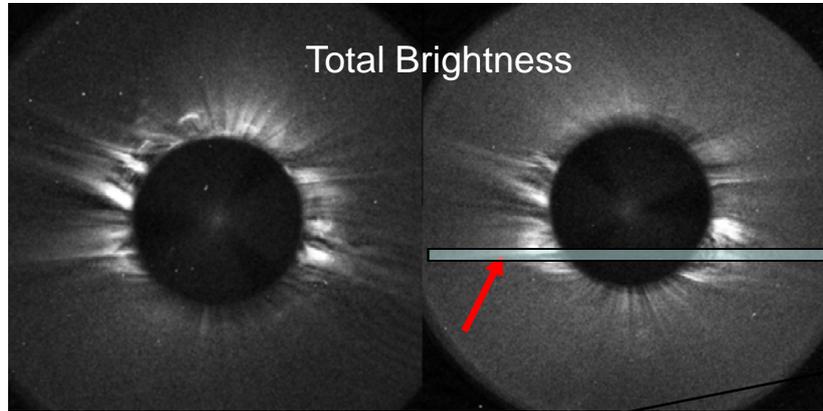
Red lines on pictures below
are the streamer's positions
found by triangulation method

Cross-section by plane
perpendicular to z-axis
(carrington system)

Reconstruction: av. μ_{reg}=0.10E−21

is=46
z=−1.16R$_\odot$

cut_off: 4

Reconstruction: av. μ_{reg}=0.10E−21

is=47
z=−1.09R$_\odot$

cut_off: 4
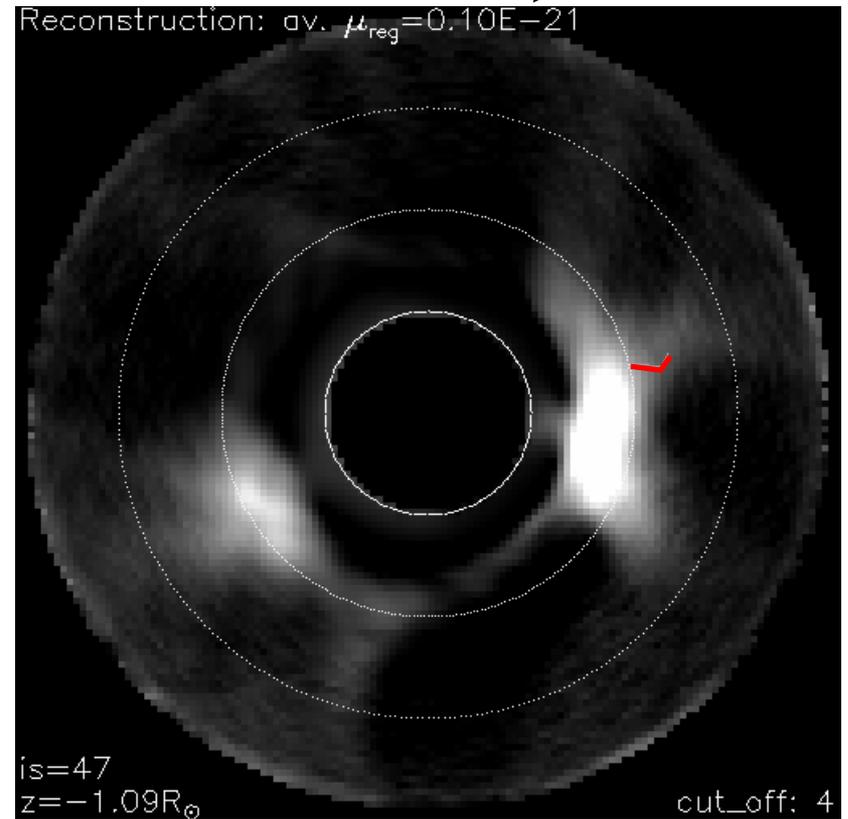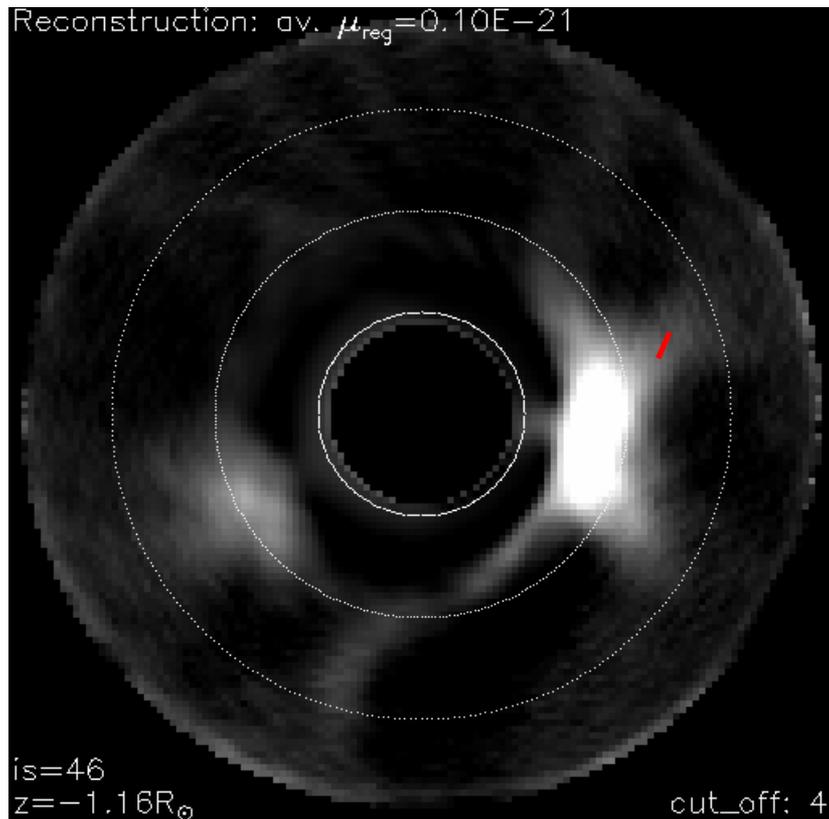
Reconstruction of the electron density for the Solar Corona: pre- and post-CME corona

CME: June 1st, 2008

CME: Dec 31st, 2007
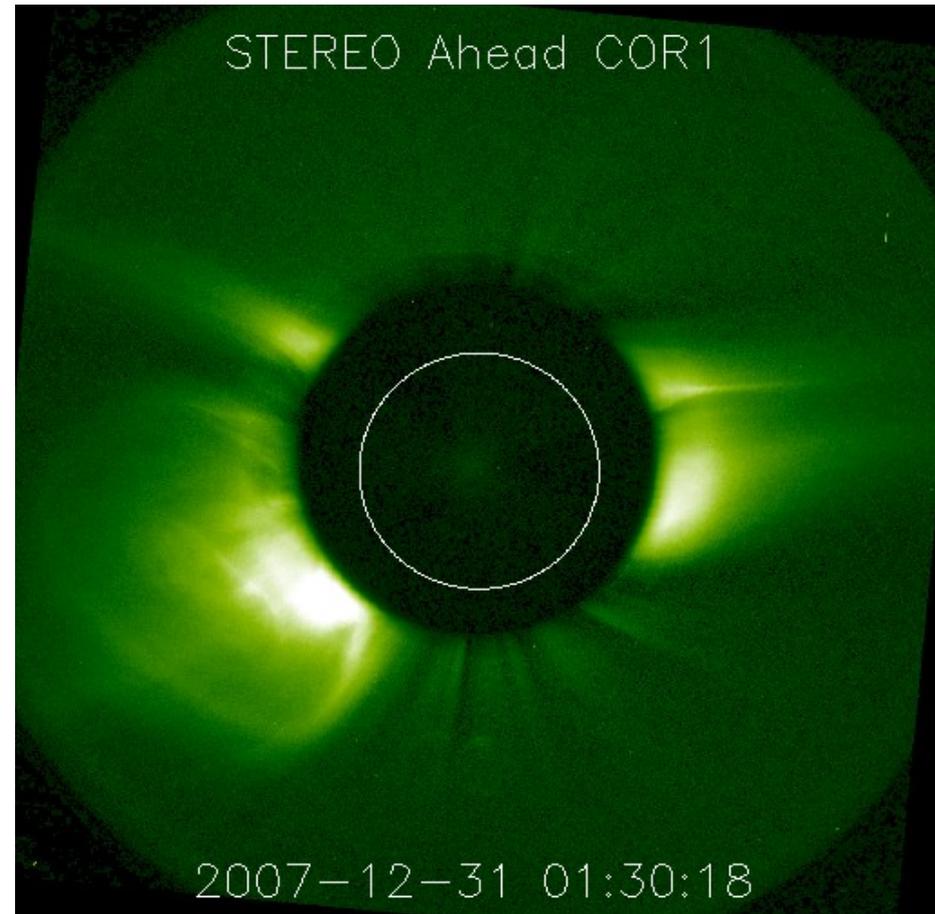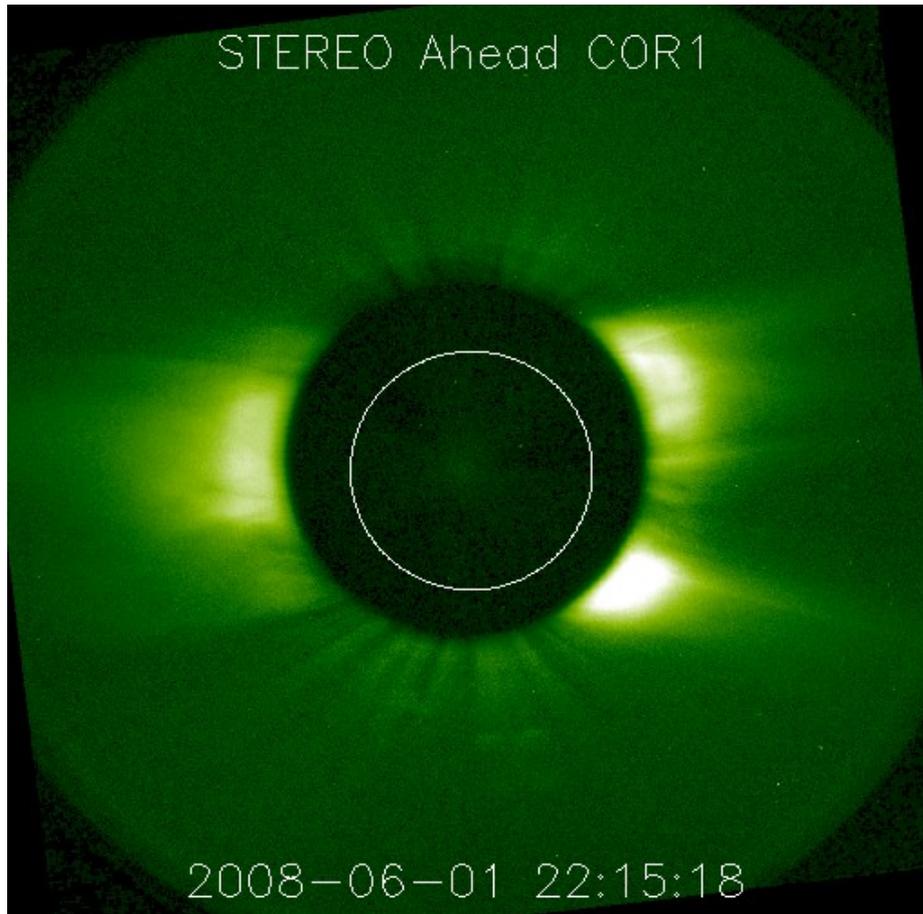
CME: June 1st, 2008

Before the CME
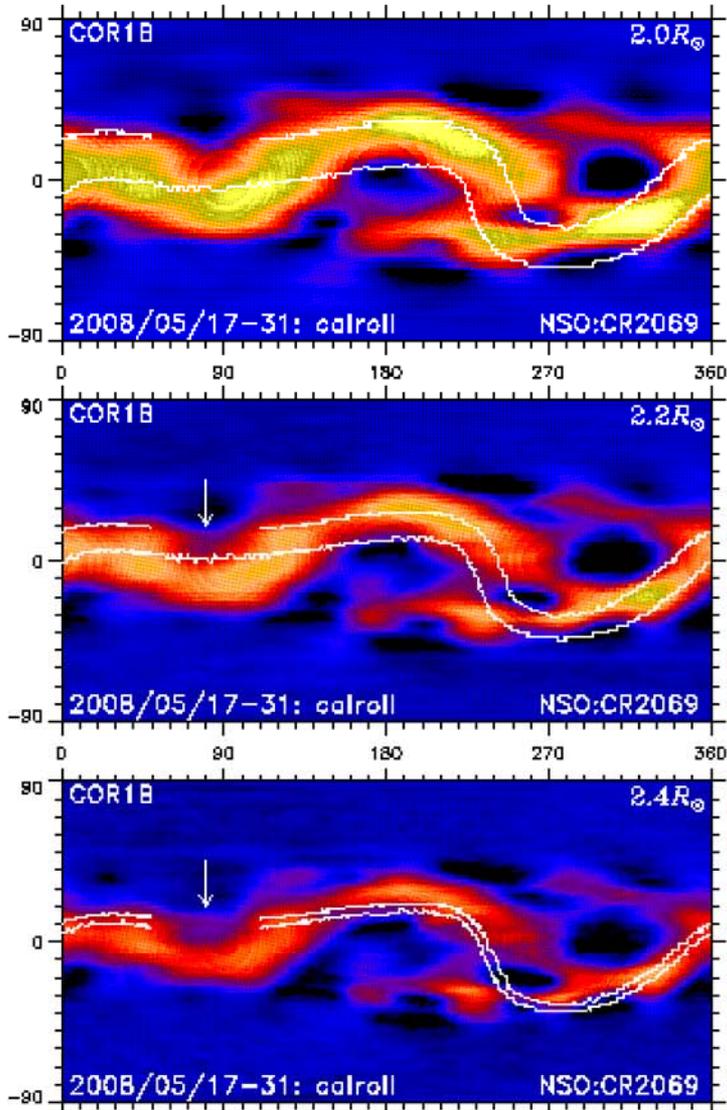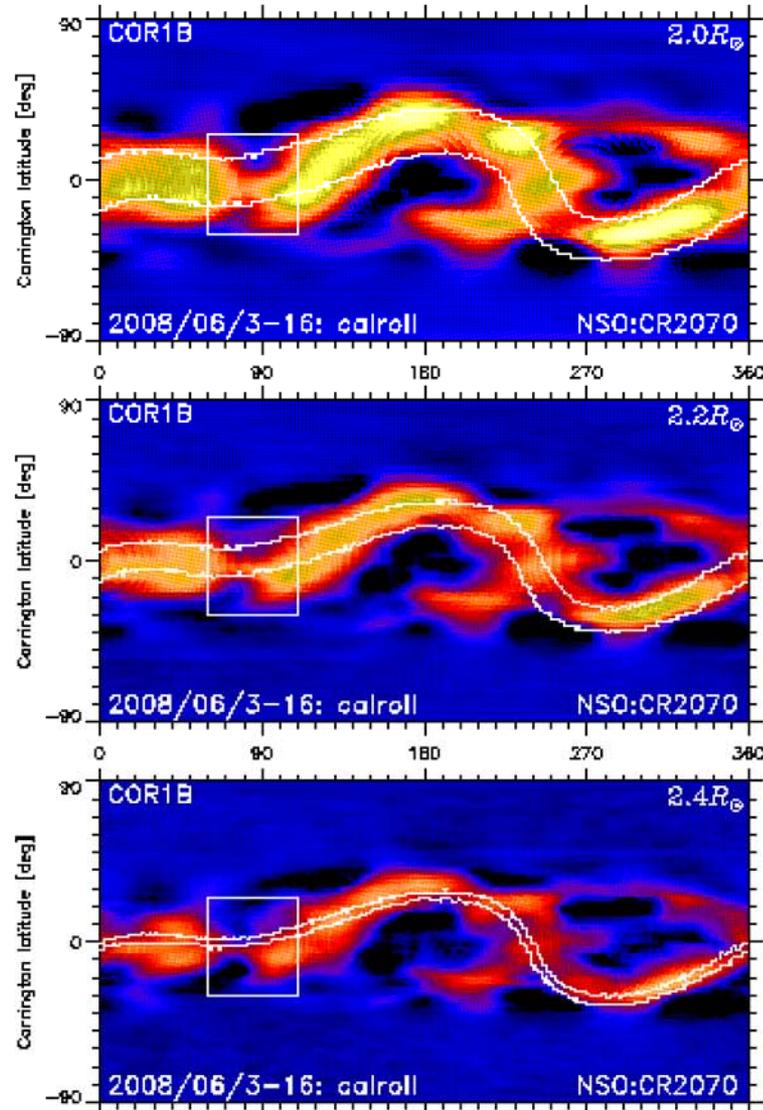
After the CME

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

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

(Robbrech et al 2009)

CME: June 1st, 2008

Before the CME   After the CME
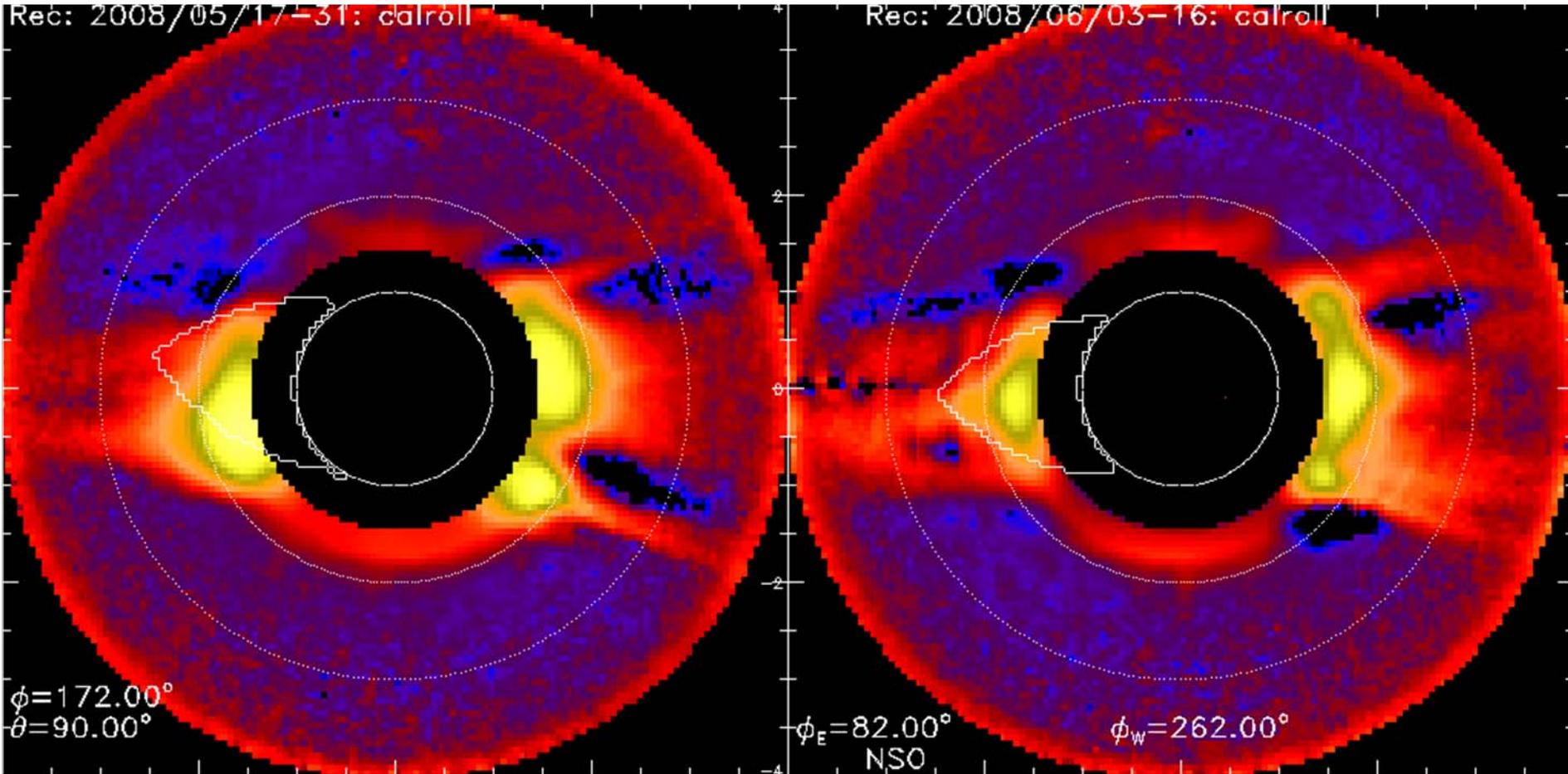
CME: Dec 31st, 2007 & Jan 2, 2008

Before the CME

After the CMEs
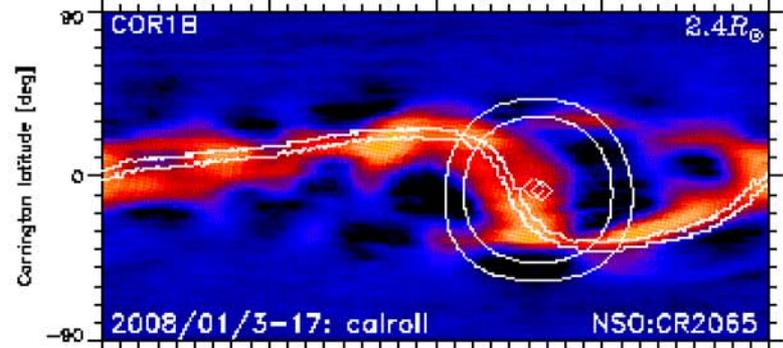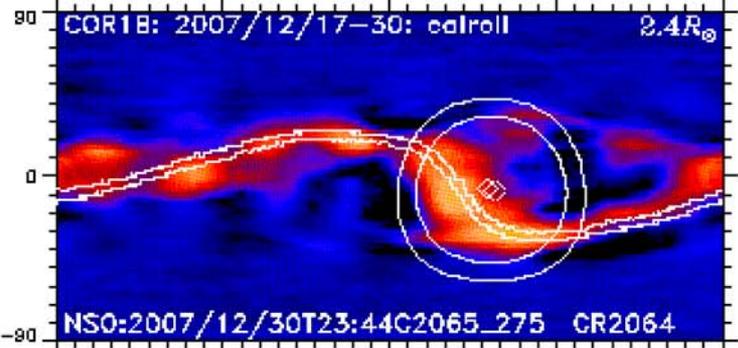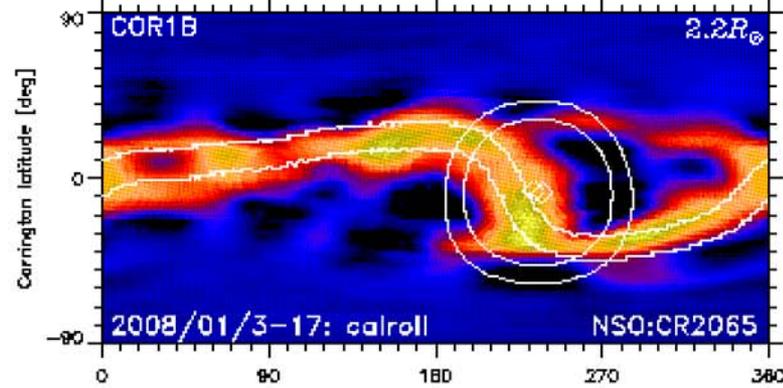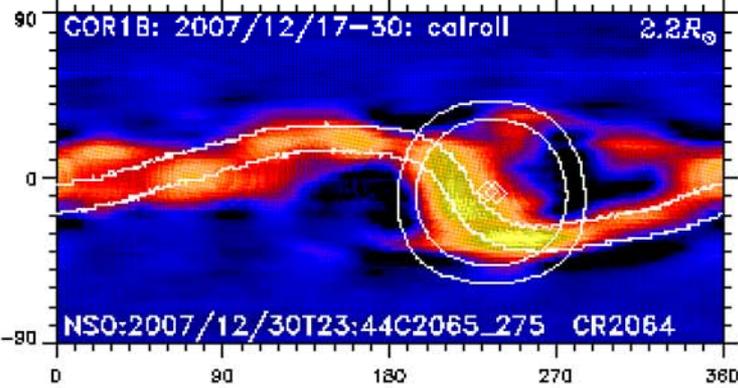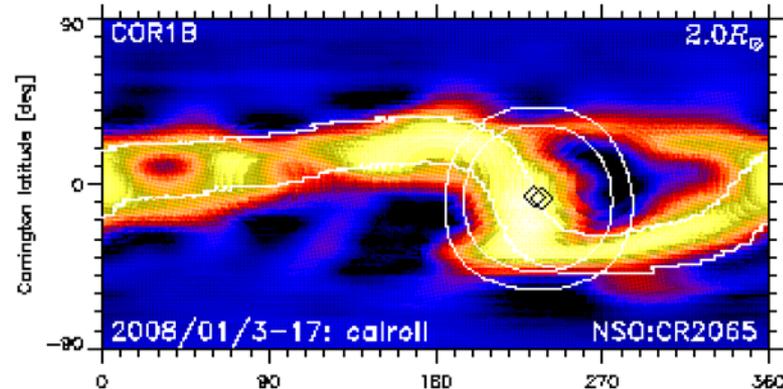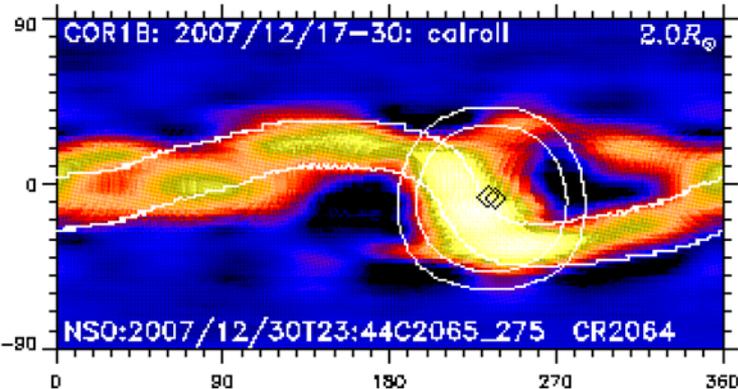
Mass lost:
1.1*10^15 g

CME masses:
4.3*10^15 g
1.1*10^15 g

Reconstructions for the whole year of 2008
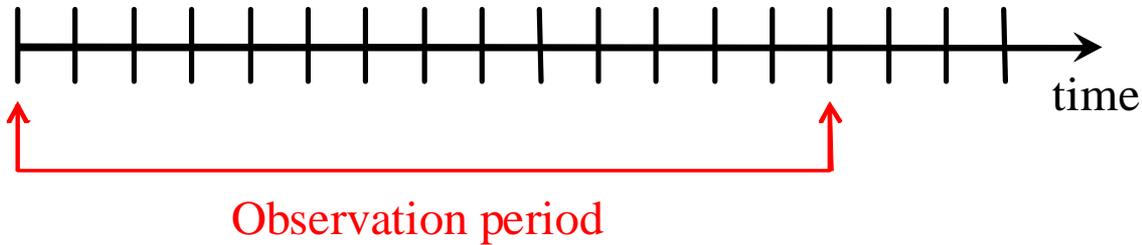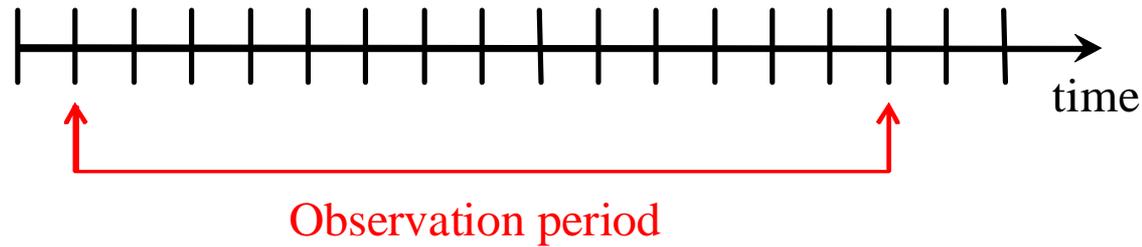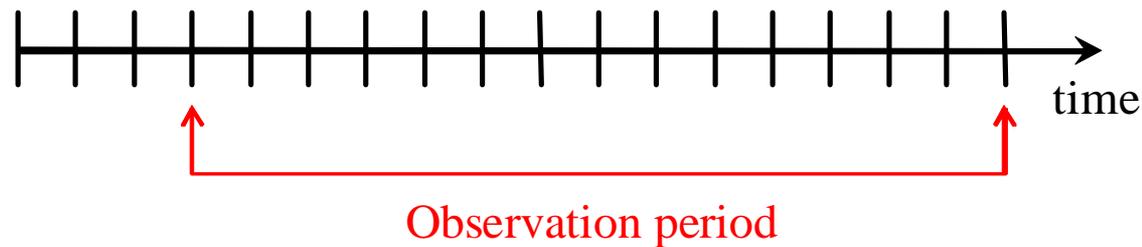
Reconstructions for the whole year of 2008
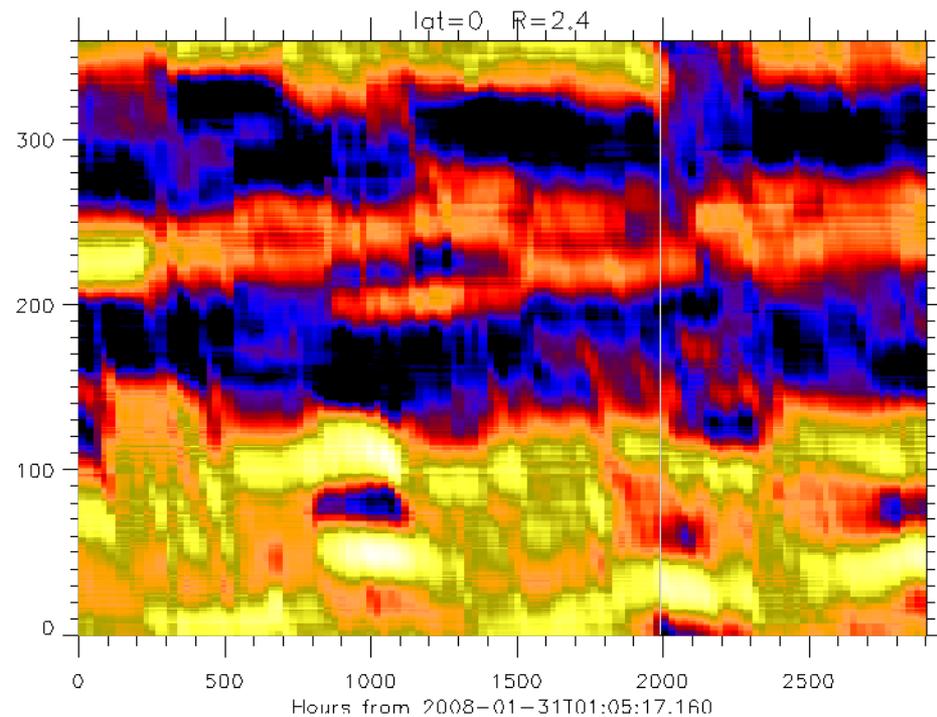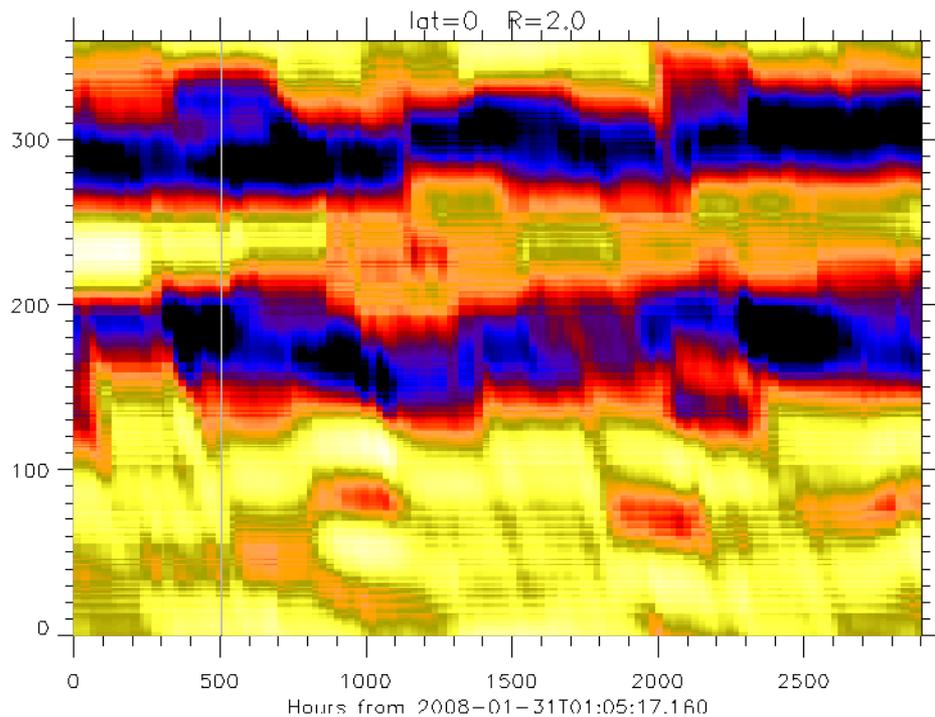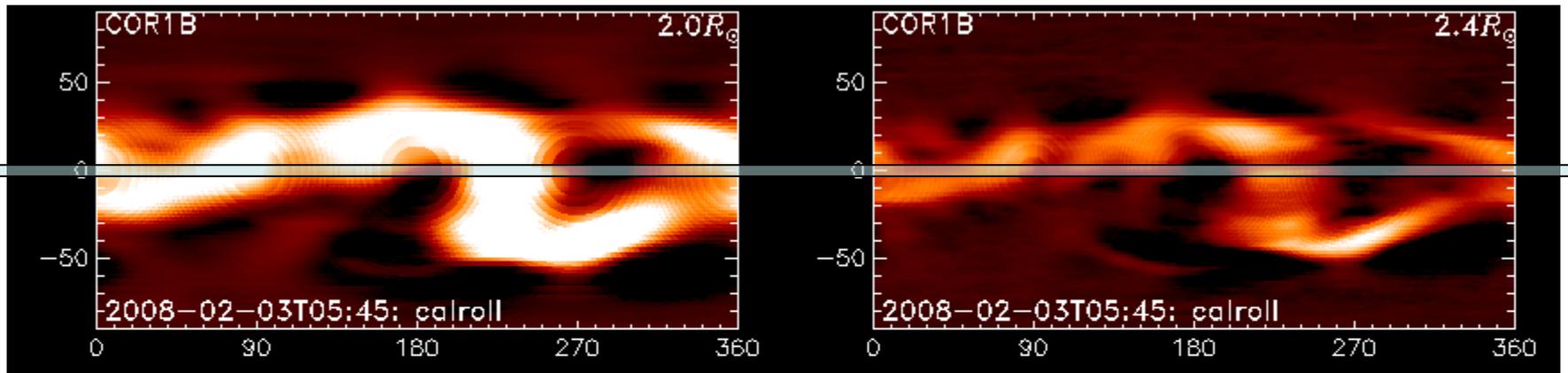
Reconstructions for the whole year of 2008
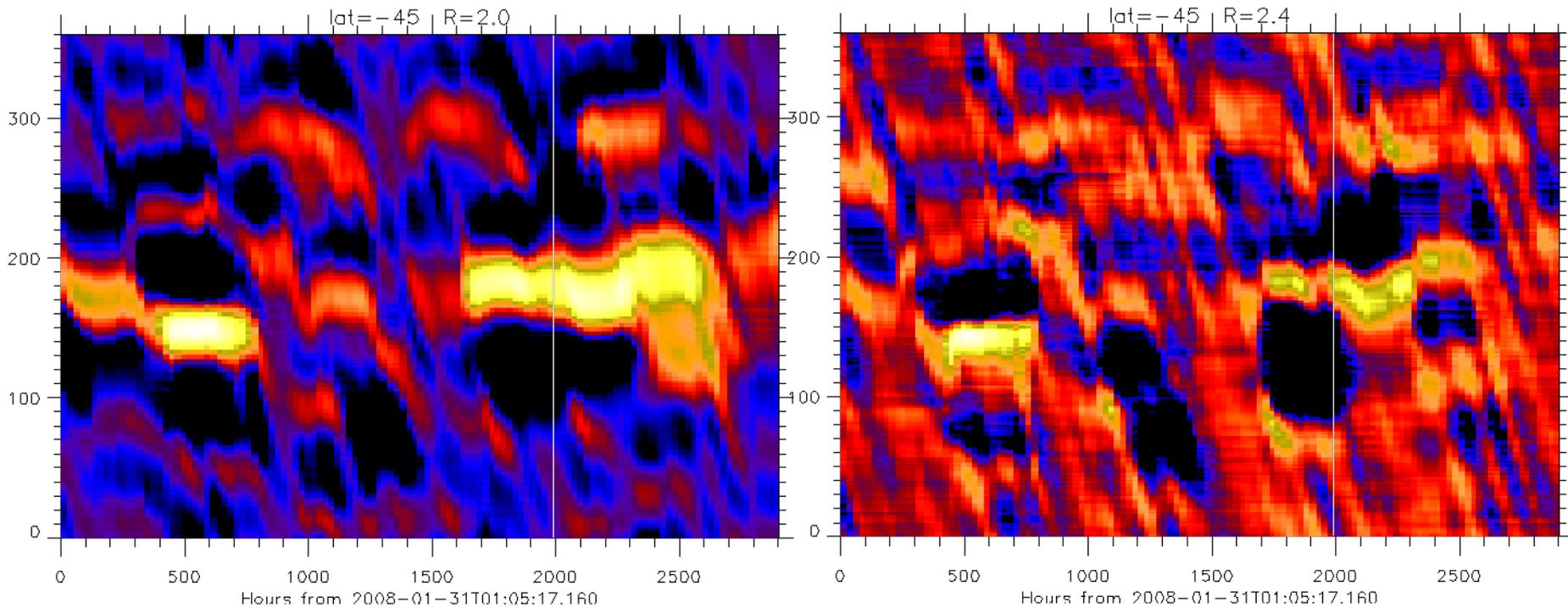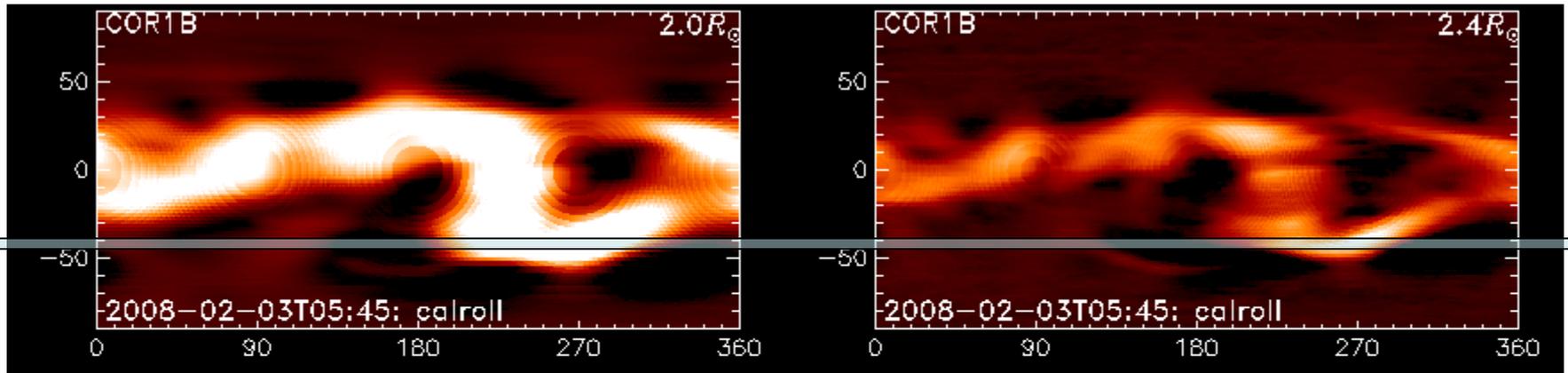
Conclusion

- It was found evidence of streamer blow out during CME event on June 1st 2008 – it is not LOS effect.

- Streamer mass loss for slow CME on 1st June 2008 is $9*10^{14}$ gram which is comparible with the CME mass in COR1 field of view

- After CME the coronal magnetic field comes to the nearly potential configuration.

- We can produce 3D tomographic reconstruction almost for any period of COR1 observations in routine way. So, more statistical study is in progress.