

# Heliospheric Tomography used to Provide Velocities, Densities, and Vector Magnetic Fields

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and

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<http://smei.ucsd.edu/>

<http://ips.ucsd.edu/>

CASS/UCSD CCMC 2014

# Heliospheric Tomography

## Introduction:

### **Motive:**

**Current progress in heliospheric tomography.**

### **Data Set/Analysis:**

**Interplanetary scintillation (IPS) mainly from STELab, Japan.**

### **Heliospheric Tomography:**

**3-D Heliospheric Tomography (a fit to data – a time-dependent heliospheric view from a single observer location)**

**Speeds and densities from the IPS, vector fields from solar surface magnetic field maps.**

### **Current Applications:**

**Accurate and continuously verifiable forecasts, analysis using 3D-MHD models including ENLIL, Faraday Rotation**

# Heliospheric Tomography

## Interplanetary Scintillation (IPS) Analysis

# Heliospheric Tomography

## DATA

### IPS Heliospheric Analyses (STELab)



STELab IPS array near Mt. Fuji



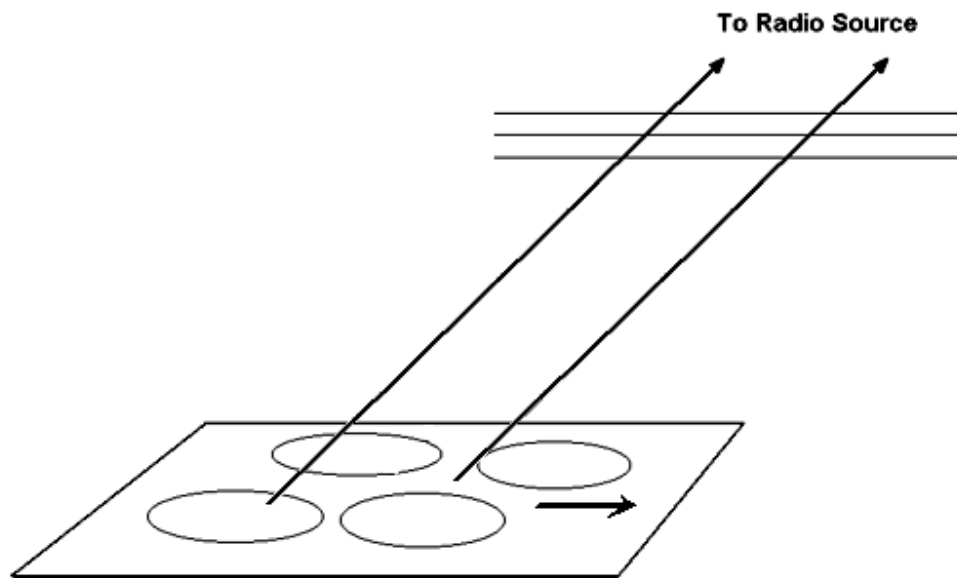
STELab IPS array systems



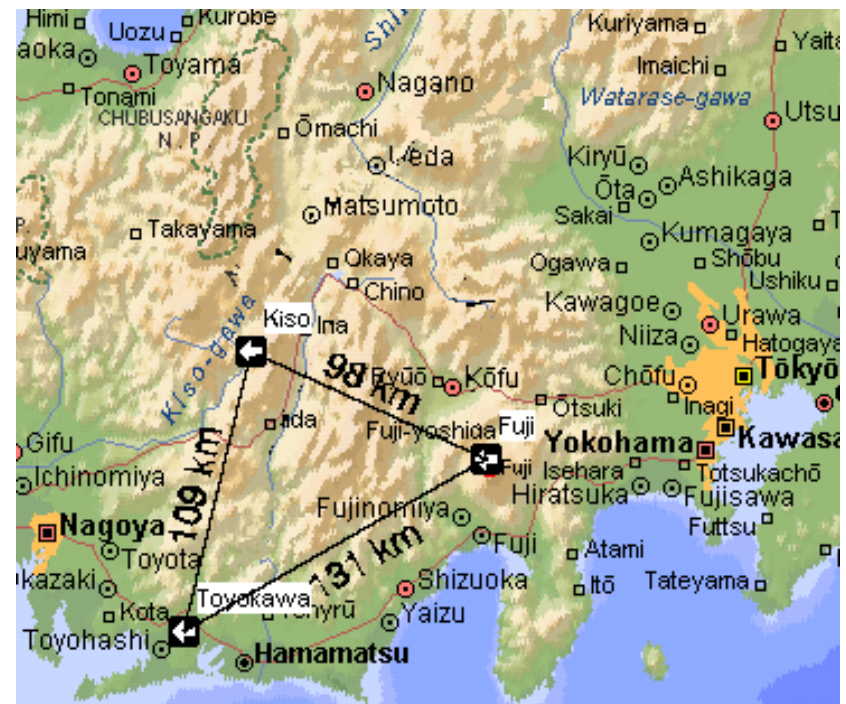
# Heliospheric Tomography

## DATA

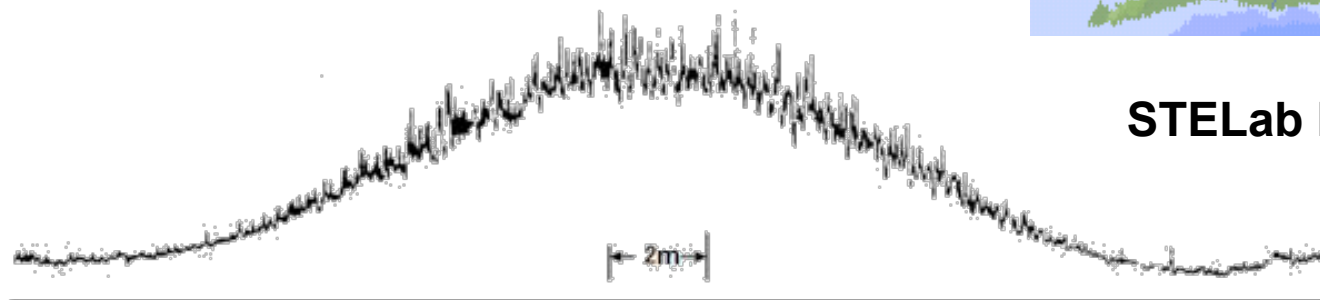
### IPS Heliospheric Analyses (STELab)



IPS line-of-sight response



STELab IPS array systems



# Heliospheric Tomography

## Current STELab Toyokawa IPS System



**New STELab IPS array in Toyokawa  
(3,432 m<sup>2</sup> array now operates well – year-round operation began in 2011)**



# Heliospheric Tomography

## Other Current Operating IPS Radio Systems



**The Pushchino Radio Observatory 70,000 m<sup>2</sup>  
110 MHz array, Russia (summer 2006)  
Now named the “Big Scanning Array of the  
Lebedev Physical Institute” (BSA LPI).**

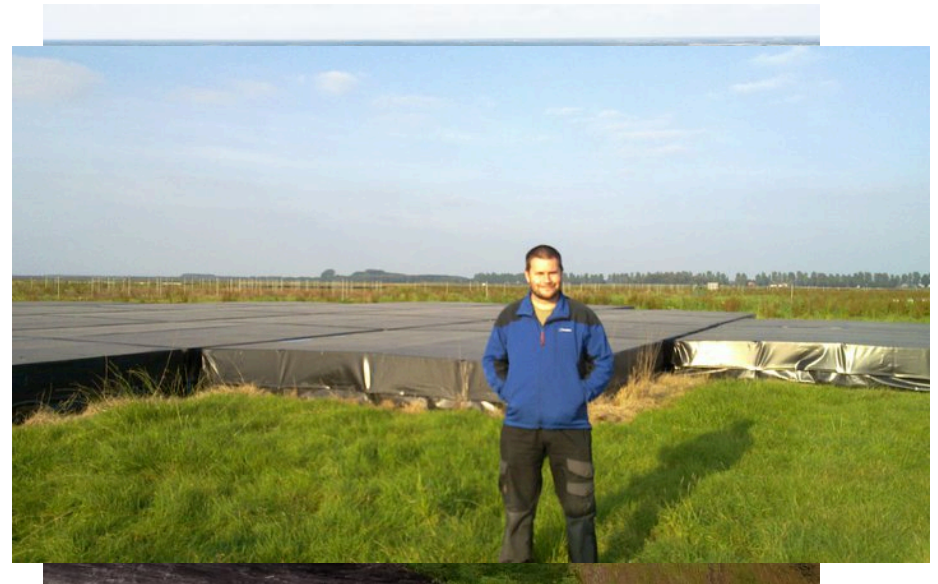


**The Ootacamund (Ooty), India  
off-axis parabolic cylinder 530 m  
long and 30 m wide (15,900 m<sup>2</sup>)  
operating at a nominal frequency  
of 326.5 MHz.**



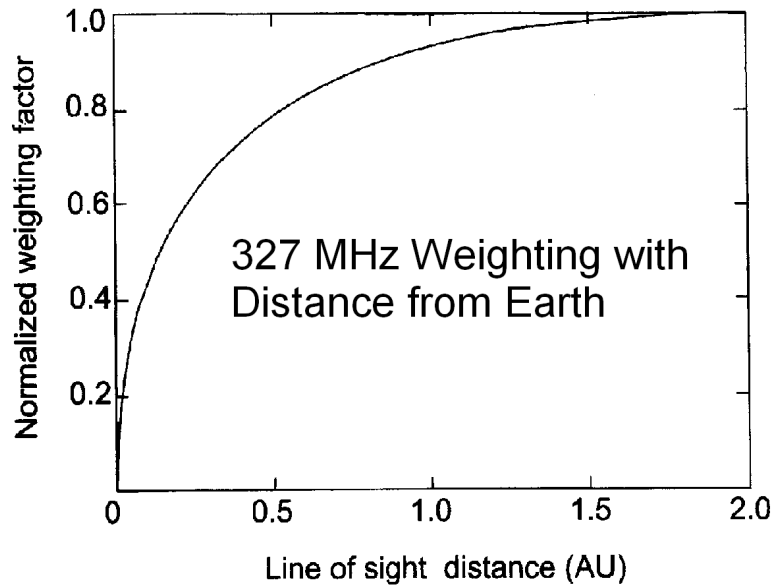
# Heliospheric Tomography

## Other and Potential Future IPS systems



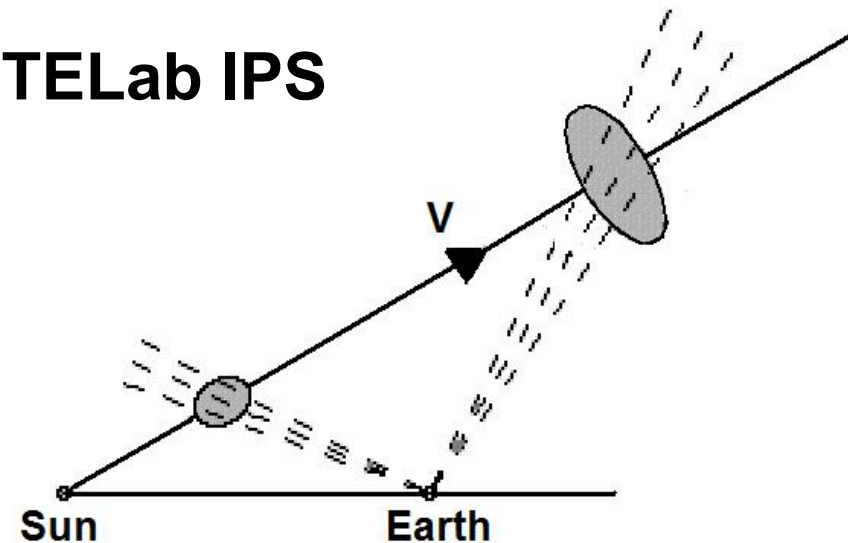
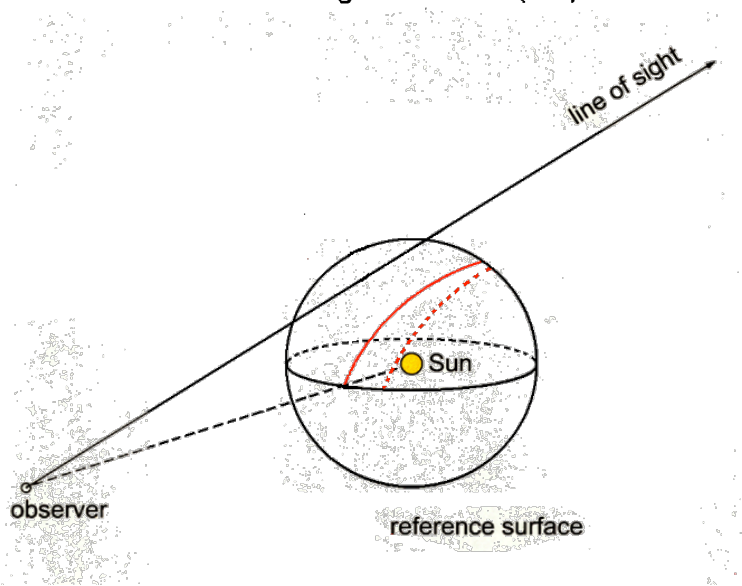
# Heliospheric Tomography

**IPS line-of-sight response** Jackson, B.V., et al., 2008, *Adv. in Geosciences*, 21, 339-360.



**Heliospheric C.A.T. analyses:**  
example line-of-sight distribution  
for each sky location to form the  
source surface of the 3D  
reconstruction.

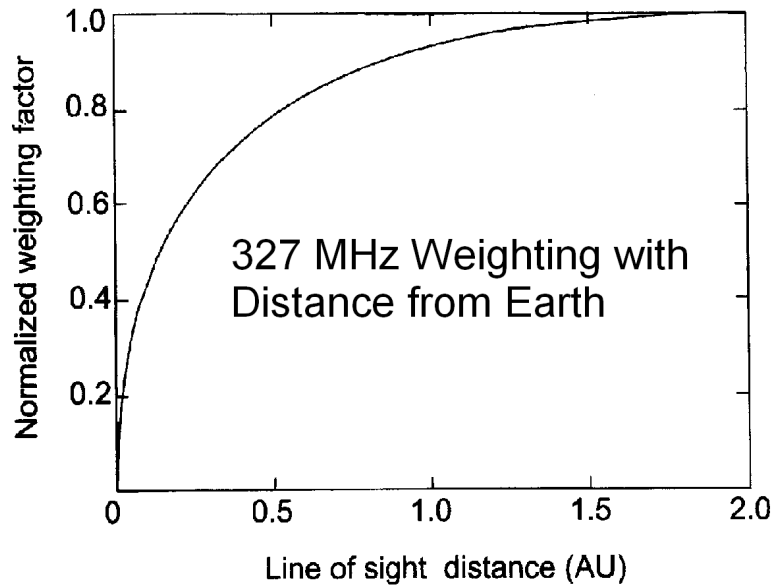
## STELab IPS



**Sample outward motion  
over time**

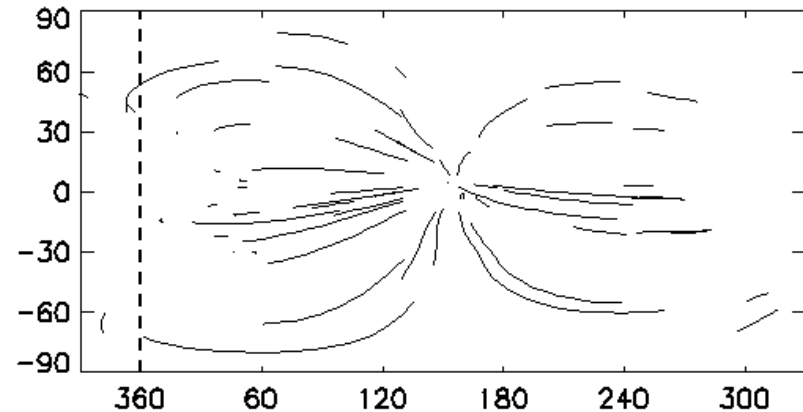
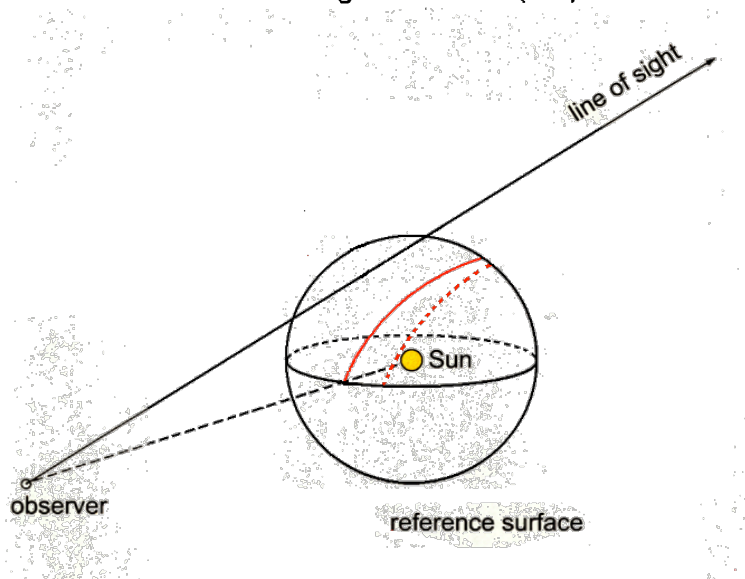
# Heliospheric Tomography

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## STELab IPS



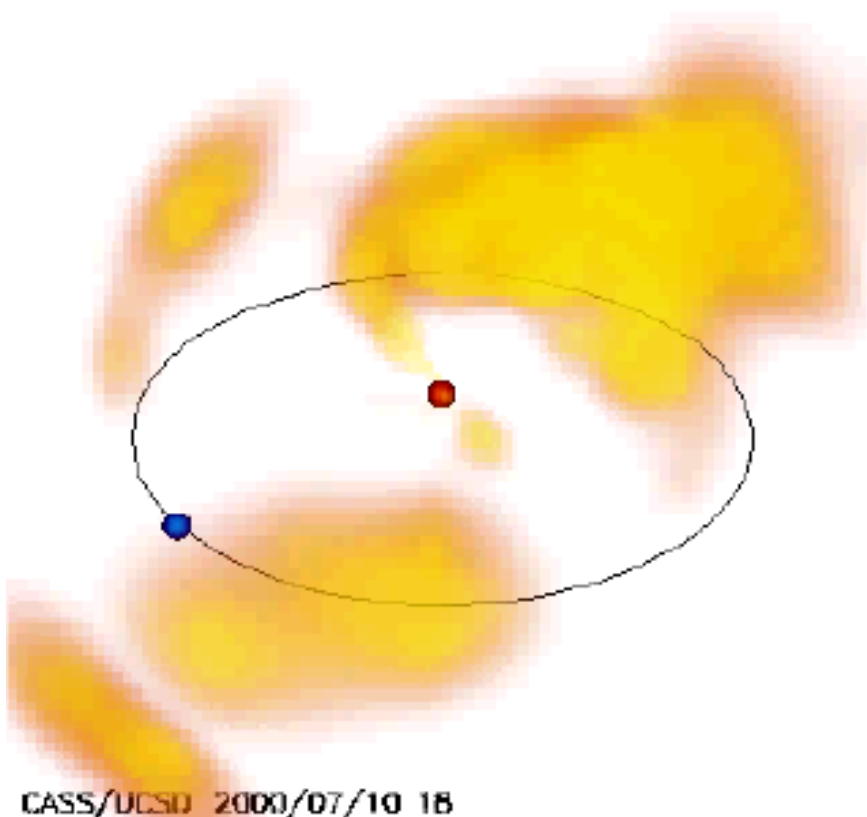
13 July 2000



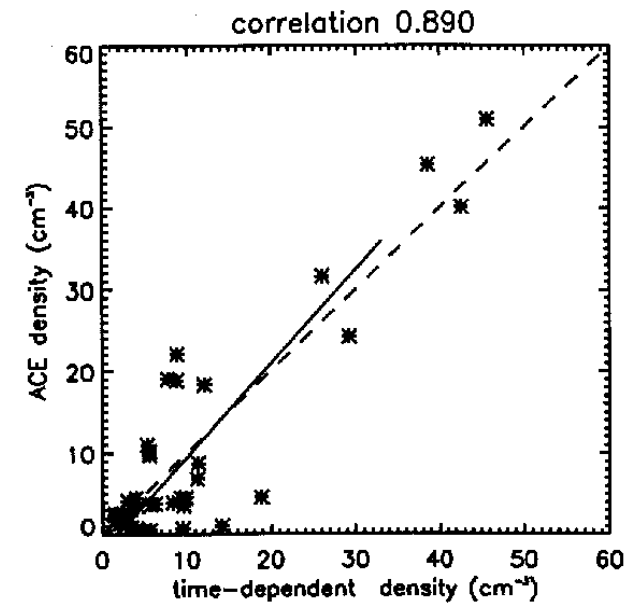
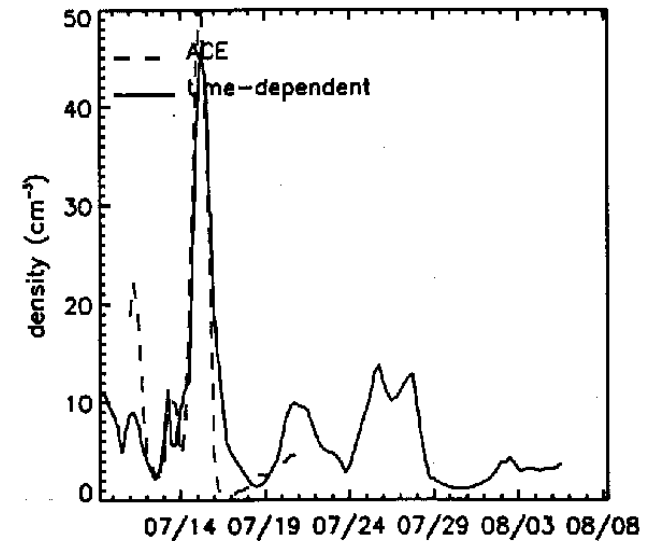
# Heliospheric Tomography

Jackson, B.V., et al., 2002, *Solar Wind* 10, 31

## IPS C.A.T. Analysis Bastille Day Event 14 July 2000



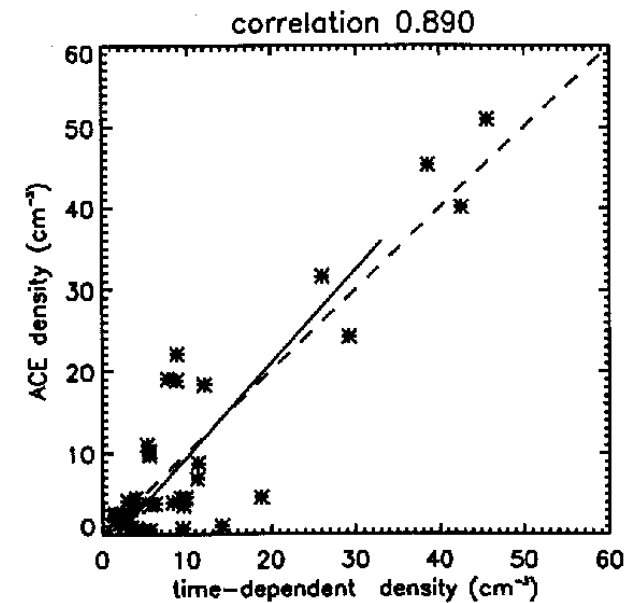
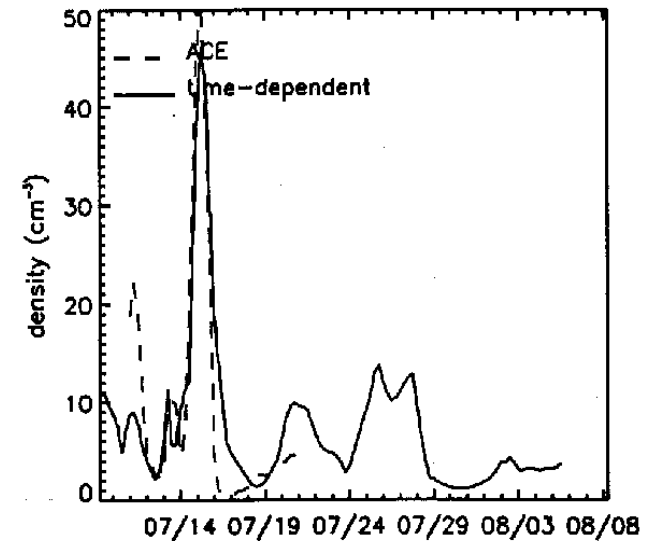
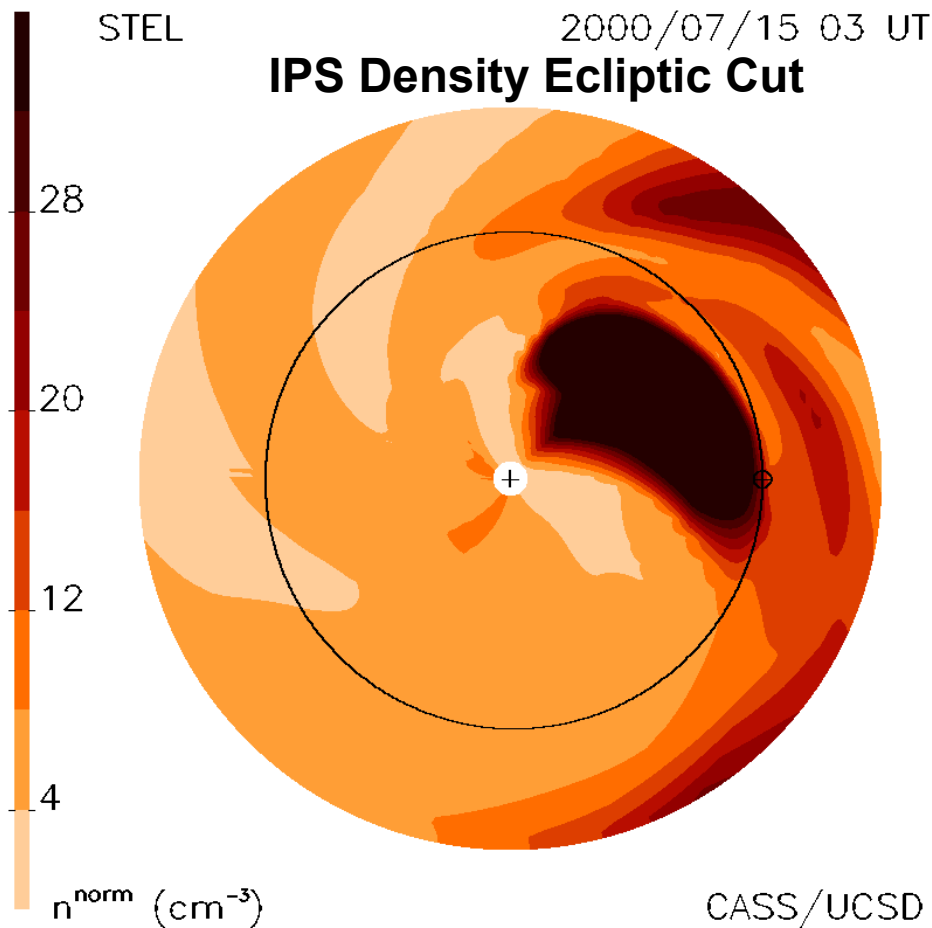
IPS Density Remote View



# Heliospheric Tomography

Jackson, B.V., et al., 2002, *Solar Wind 10*, 31

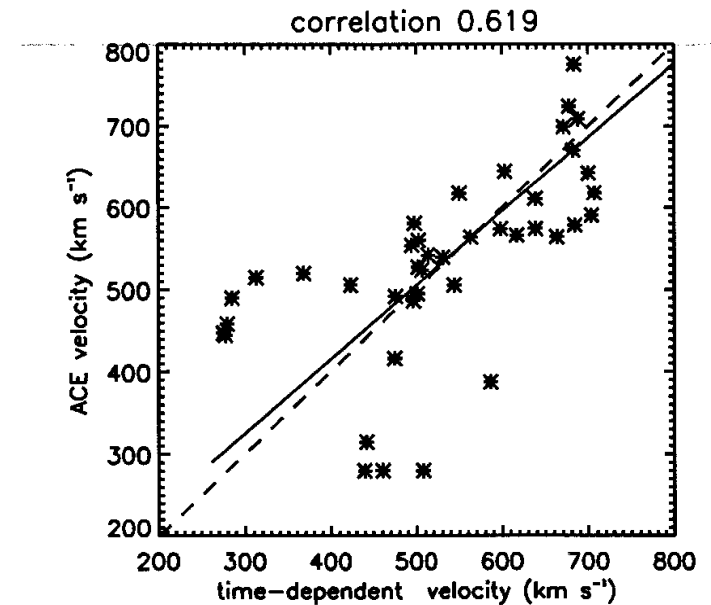
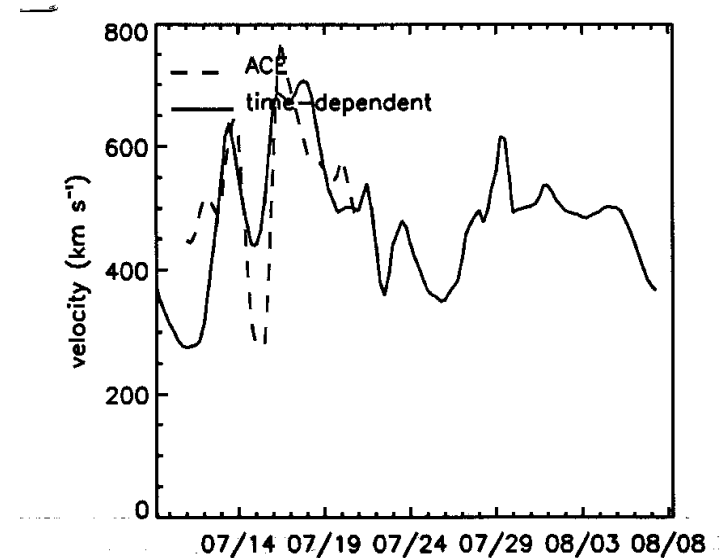
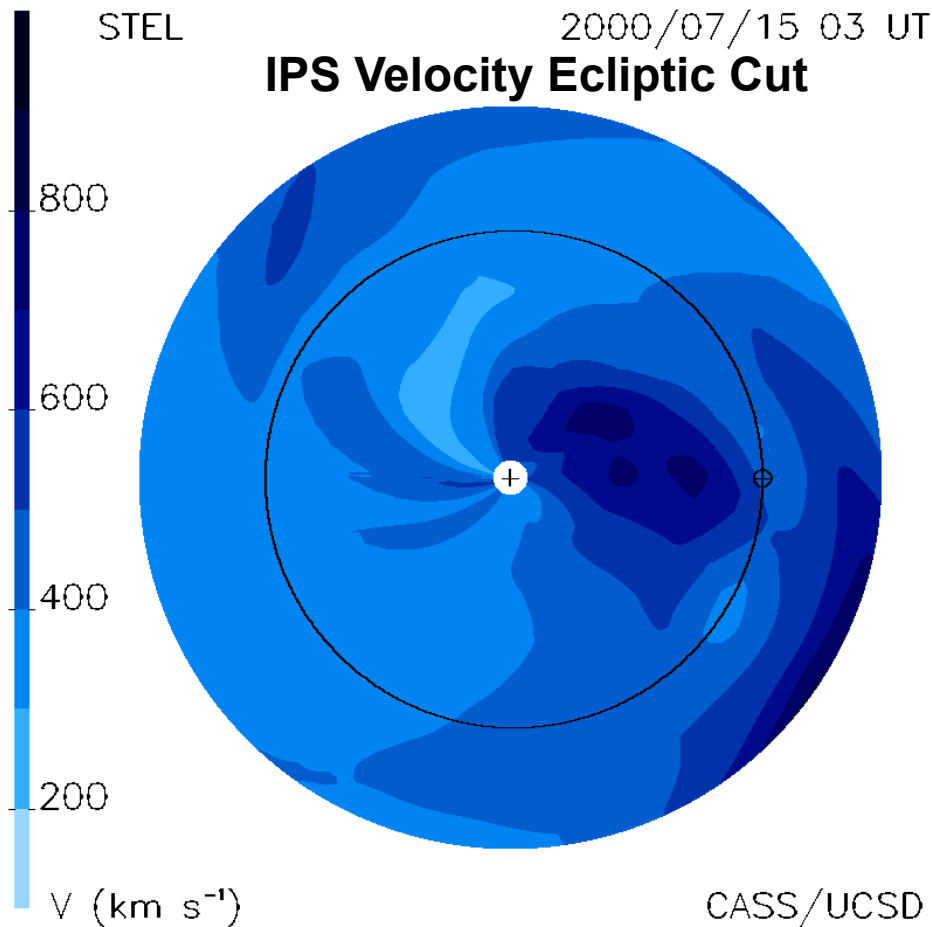
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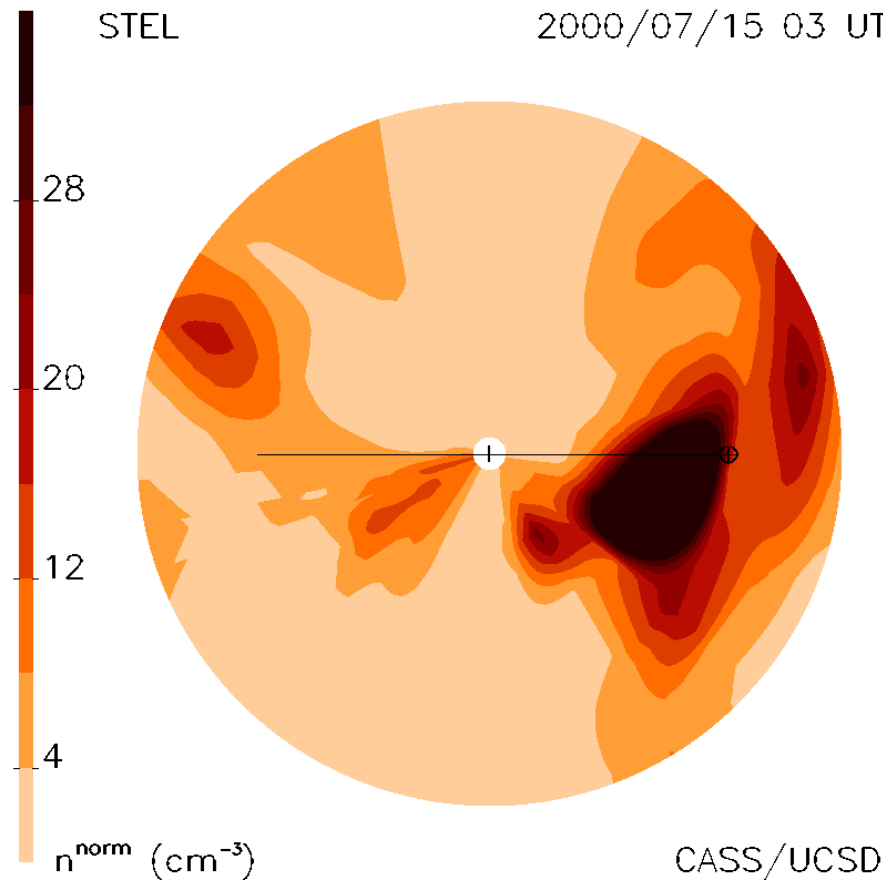
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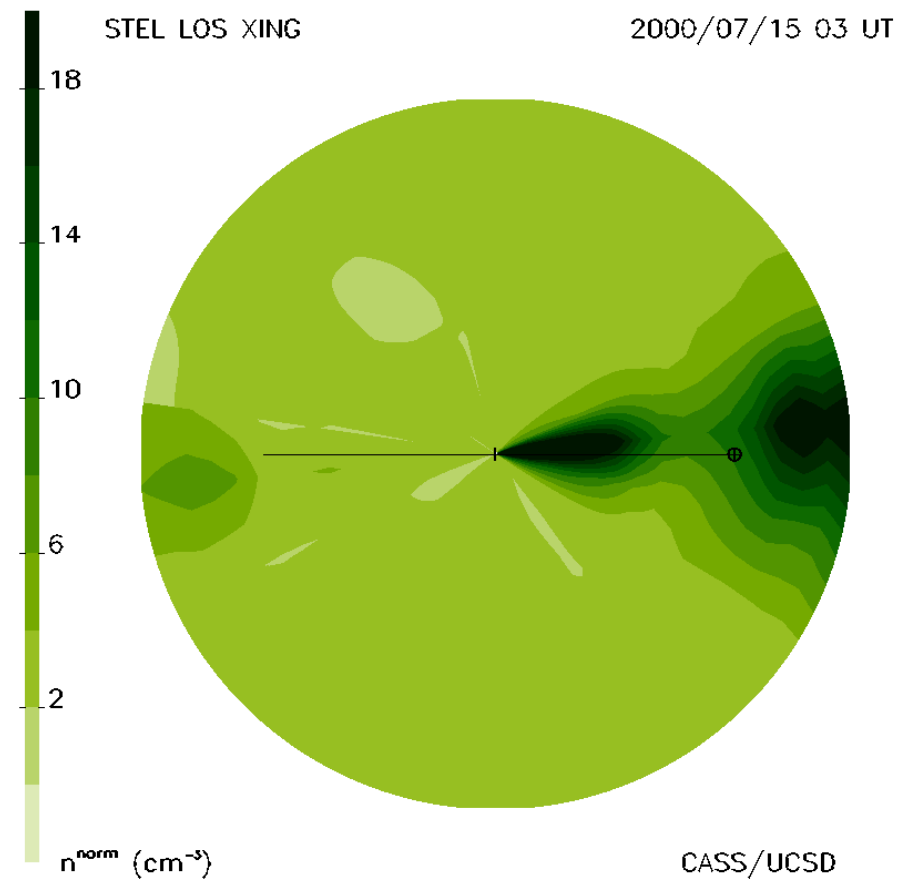
# Heliospheric Tomography

Jackson, B.V., et al., 2002, *Solar Wind* 10, 31

## IPS C.A.T. Analysis Bastille Day Event 14 July 2000



IPS Density Meridional Cut



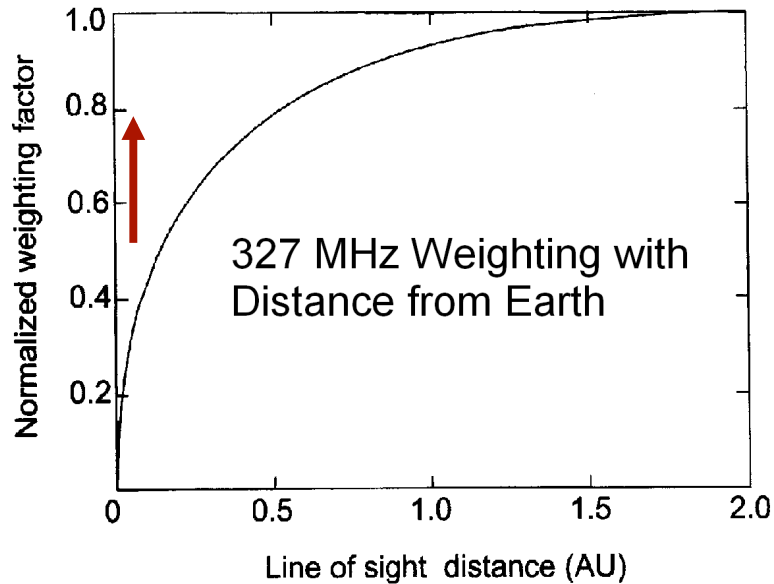
IPS Density LOS X-ing Meridional Cut

# Heliospheric Tomography

Jackson, B.V., et al., 2010, *Solar Phys.*, 265, 245-256.

Jackson, B.V., et al., 2008, *Adv. in Geosciences*, 21, 339.

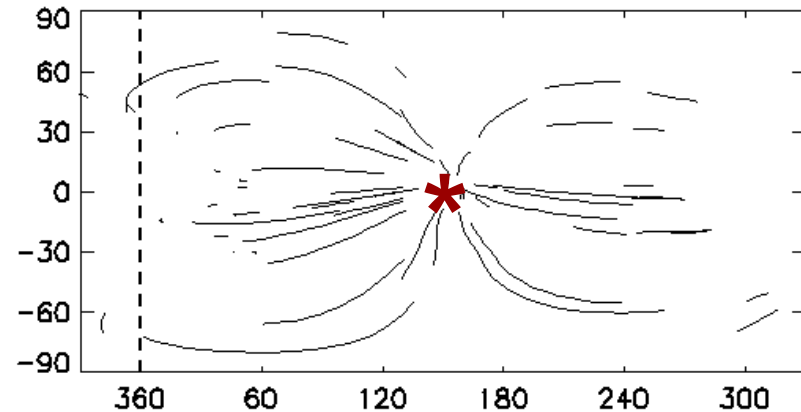
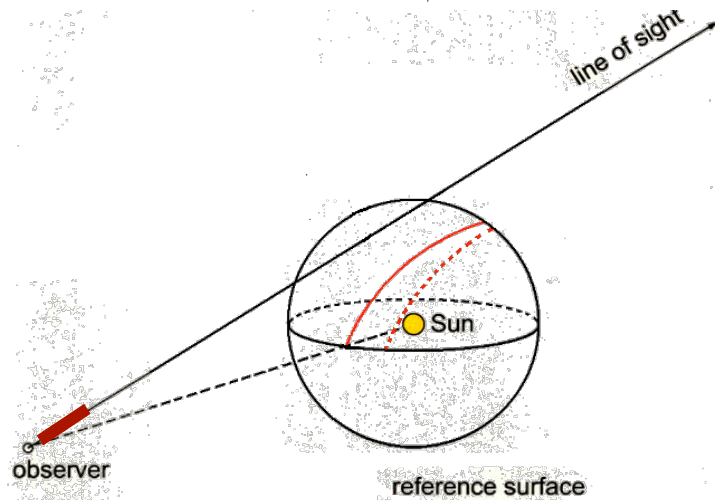
## IPS line-of-sight response



**Heliospheric C.A.T. Analyses:**  
example line-of-sight distribution  
for each sky location to form the  
source surface of the 3D  
reconstruction.

## STELab IPS

## Innovation



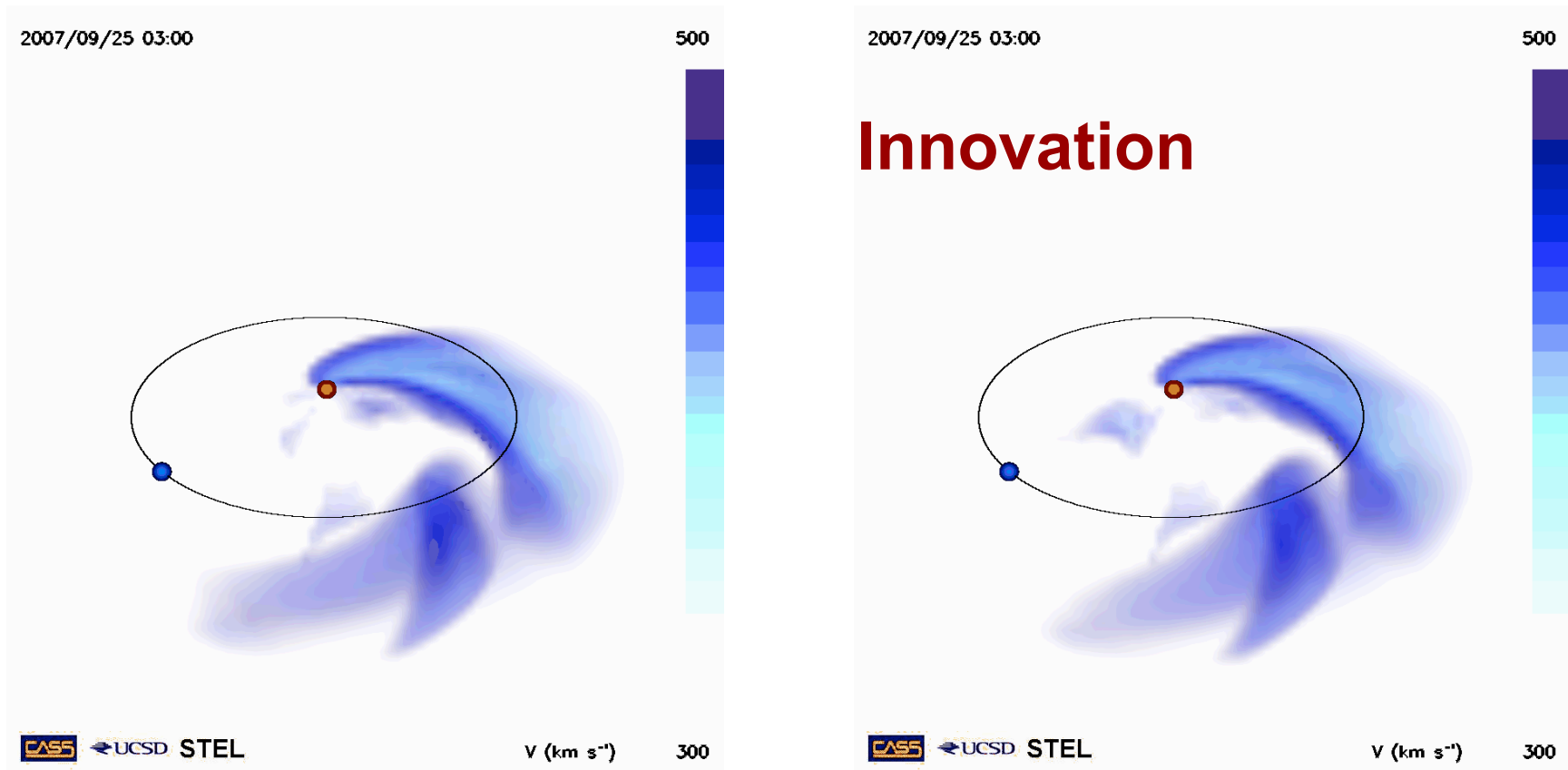
13 July 2000

**Inclusion of in-situ measurements into the 3D-reconstructions**

# Heliospheric Tomography

Jackson, B.V., et al., 2010, *Solar Phys.*, 265, 245-256.

## Heliospheric 3D-reconstructions



### Inclusion of in-situ measurements into the 3D-reconstructions

Jackson, B.V., et al., 2011, *Adv. in Geosciences*, 30, 93-115.

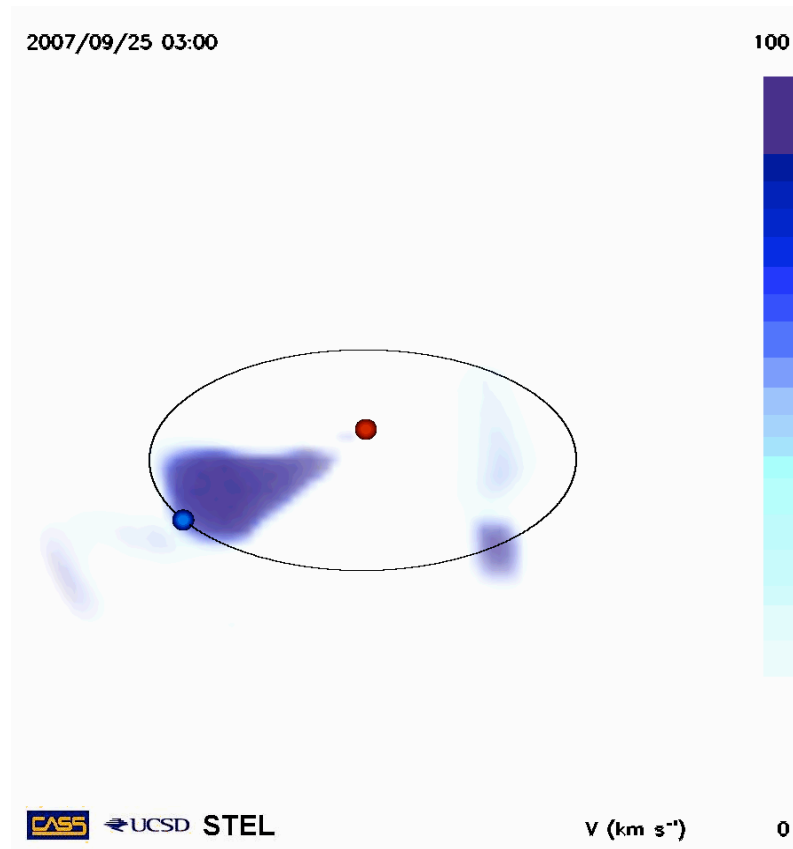


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Jackson, B.V., et al., 2010, *Solar Phys.*, 265, 245-256.

## Heliospheric 3D-reconstructions

**Innovation**



**Inclusion of in-situ measurements into the 3D-reconstructions**

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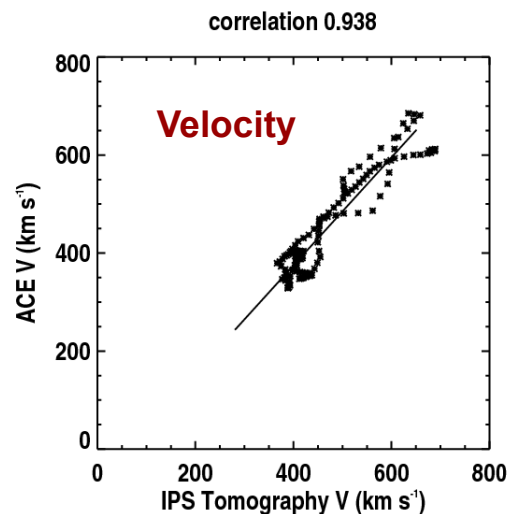
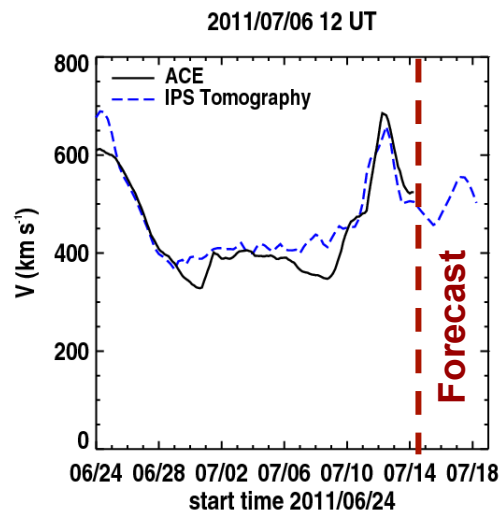
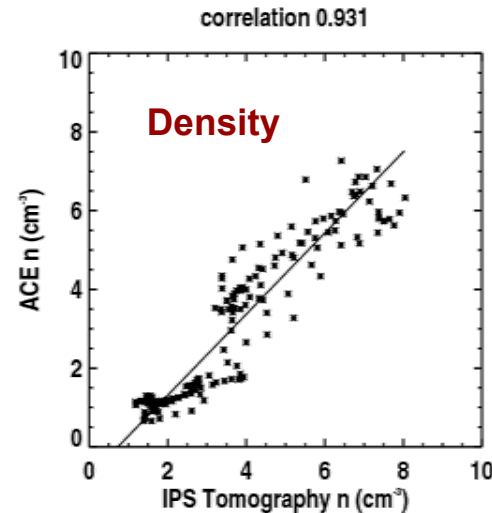
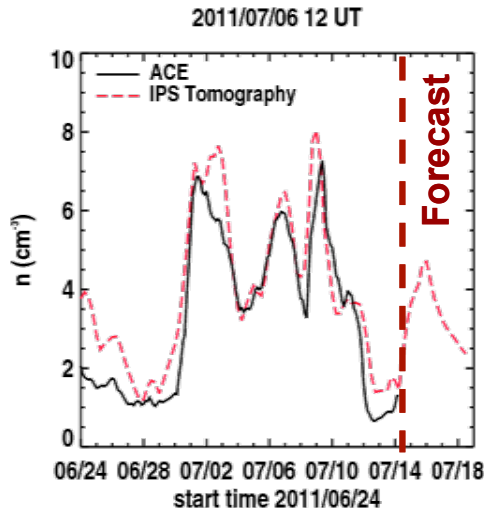
Used at the CCMC  
and the KSWC

Forecast

## Heliospheric 3D-reconstructions

Inclusion of in-situ  
measurements into the  
3D-reconstructions

Forecasts work  
better if the values  
match up to the  
present.



# Heliospheric Tomography

Jackson, B.V., et al., 2010, *Solar Phys.*, 265, 245-256.

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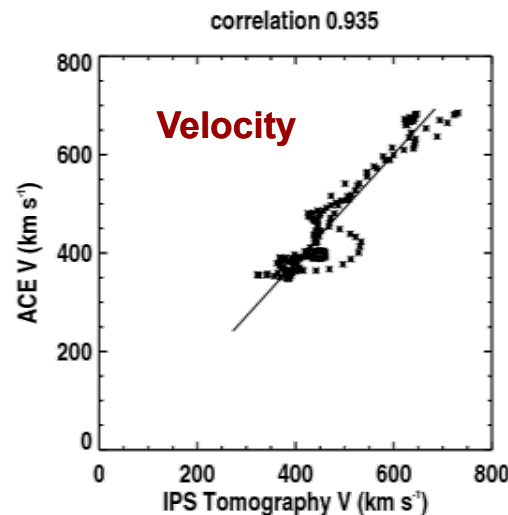
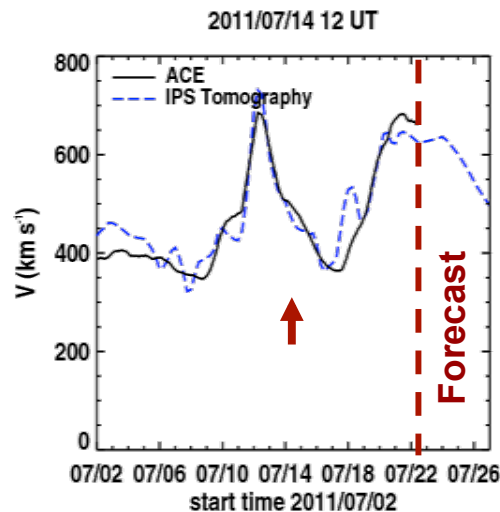
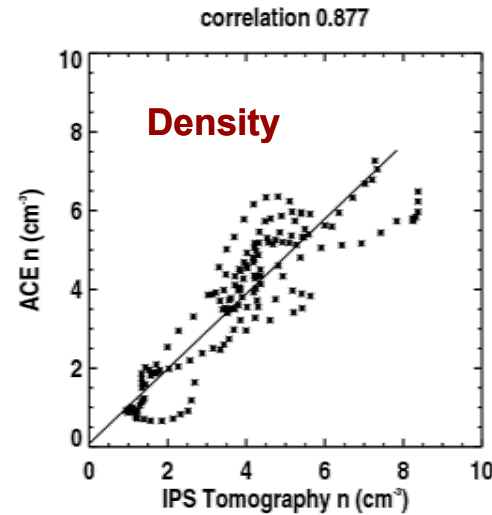
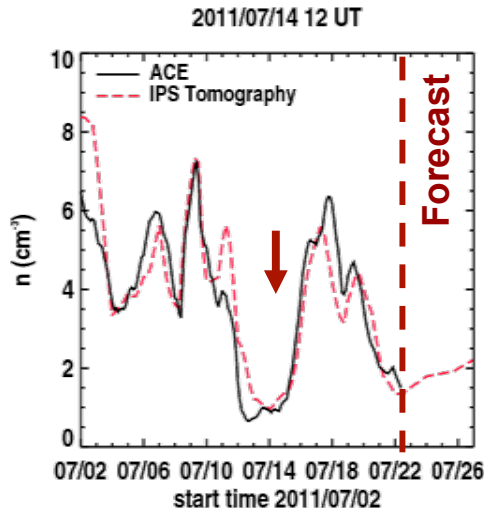
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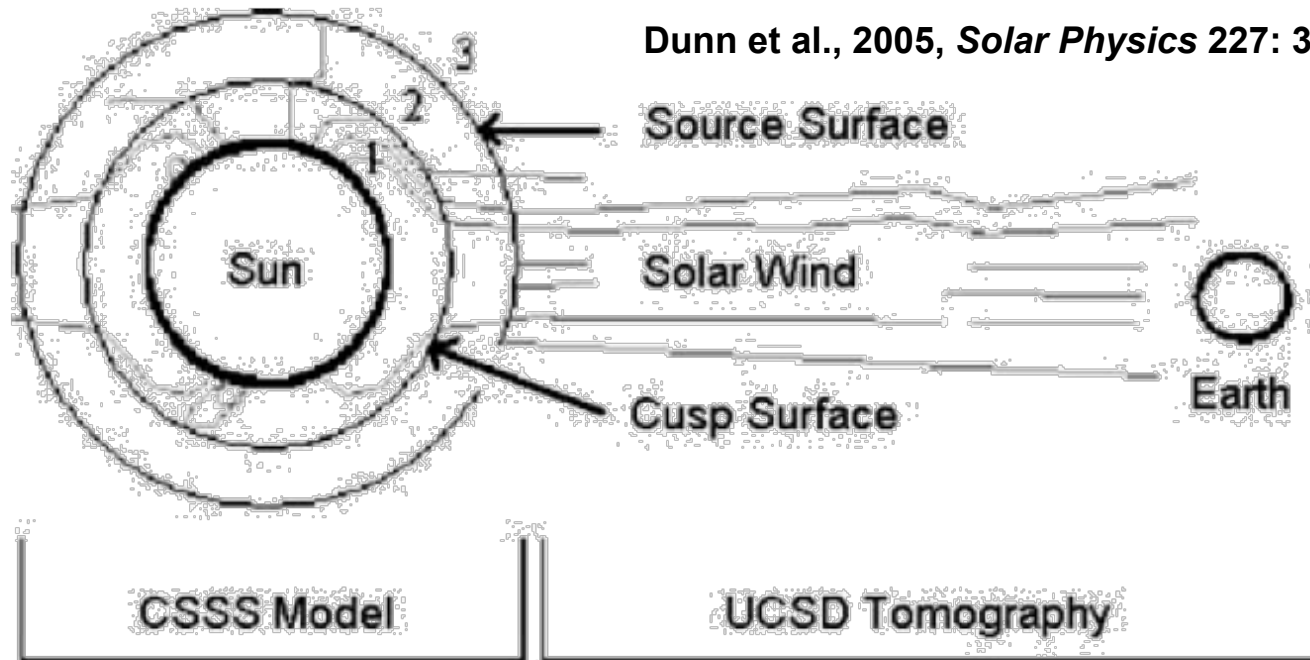


# Heliospheric Tomography

Zhao, X. P. and Hoeksema, J. T., 1995, *J. Geophys. Res.*, 100 (A1), 19.

<http://ips.ucsd.edu/>

## Magnetic Field Extrapolation



1. Inner region: the CSSS model calculates the magnetic field using photospheric measurements and a horizontal current model.
2. Middle region: the CSSS model opens the field lines. In the outer region.
3. Outer region: the UCSD tomography convects the magnetic field along velocity flow lines.

Jackson, B.V., et al., 2012, *Adv. in Geosciences*, 30, 93-115.

# Heliospheric Tomography

## IPS Forecasts

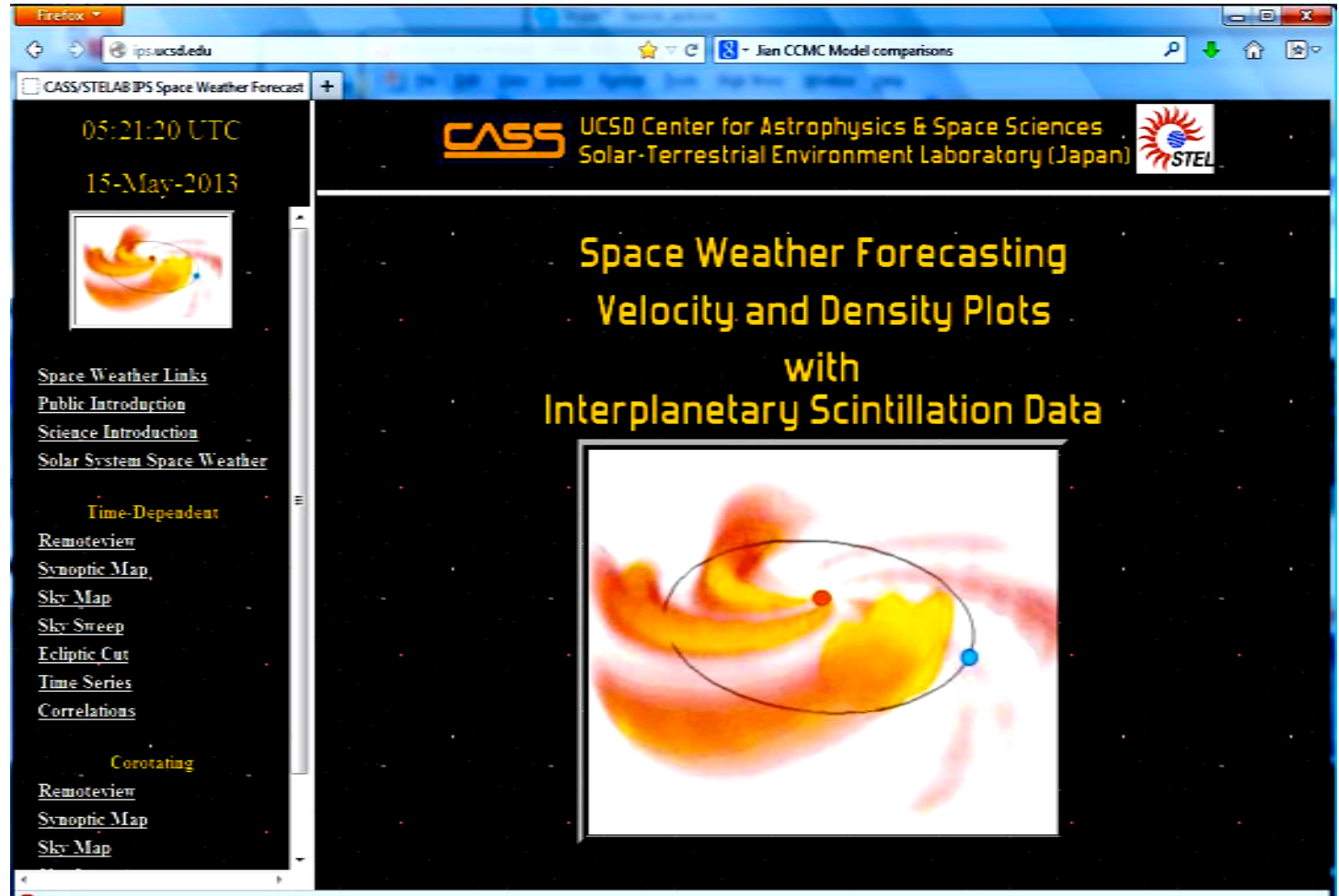
# Heliospheric Tomography

Jackson, B.V., et al., 2011, *Adv. in Geosciences*, 30, 93-115.

<http://ips.ucsd.edu/> **Real-Time Forecasts**

**UCSD IPS  
analysis**

**UCSD  
Web  
pages**



The screenshot shows a Firefox browser window displaying the UCSD IPS Space Weather Forecast website. The browser's address bar shows the URL <http://ips.ucsd.edu/>. The website header includes the CASS logo and the text "UCSD Center for Astrophysics & Space Sciences Solar-Terrestrial Environment Laboratory (Japan)" along with the STEL logo. The main content area features the title "Space Weather Forecasting Velocity and Density Plots with Interplanetary Scintillation Data" and a large image of a heliospheric tomography plot. The left sidebar contains a navigation menu with sections for "Space Weather Links" (Public Introduction, Science Introduction, Solar System Space Weather), "Time-Dependent" (Remoteview, Synoptic Map, Sky Map, Sky Sweep, Ecliptic Cut, Time Series, Correlations), and "Corotating" (Remoteview, Synoptic Map, Sky Map). The browser's status bar at the bottom indicates the page title "CASS/STELAB IPS Space Weather Forecast".

**Web Analysis Runs Automatically Using Linux on a P.C.**



# Heliospheric Tomography

<http://ips.ucsd.edu/>

Skymap view

Jackson, B.V., et al., 2011, *Adv. in Geosciences*, 30, 93-115.

CASS/STELAB IPS Space Weather Forecast - Mozilla Firefox

File Edit View History Bookmarks Tools Help


http://ips.ucsd.edu/

Most Visited American Astronomic... Getting Started Latest Headlines

CASS/STELAB IPS Space Weather For...

## UCSD IPS forecast

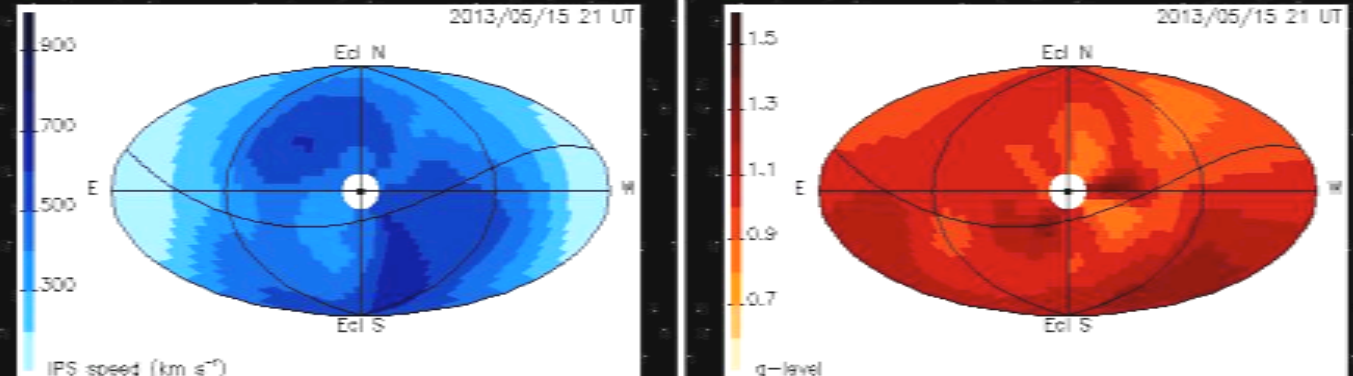
05:21:20 UTC  
15-May-2013



[Space Weather Links](#)  
[Public Introduction](#)  
[Science Introduction](#)  
[Solar System Space Weather](#)

**Time-Dependent**  
[Remoteview](#)  
[Synoptic Map](#)  
[Sky Map](#)  
[Sky Sweep](#)  
[Time Series](#)  
[Correlations](#)

**CASS** UCSD Center for Astrophysics & Space Sciences  
Solar-Terrestrial Environment Laboratory (Japan) **STEL**



2013/05/15 21 UT

IPS speed ( $\text{km s}^{-1}$ )

g-level

[Go to movie](#)

**Time-Dependent Model: Current IPS distribution across the sky**

The display shows [Hammer-Aitoff](#) map (an equal area projection of the entire sky) or ["Fisbeve"](#) map (a polar projection of solar elongation angles up to 70 degrees) of the sky as observed from Earth. The Sun is centered with the ecliptic plane along the horizontal axis. In the Hammer-Aitoff map the curved line indicates the celestial equator. The map shows the interplanetary scintillation (IPS) derived speed (left) and g-level (right) at the time indicated above the skymap by an IPS radio array pointing at any location in the sky. Areas where data coverage is poor are left blank. The display is updated hourly, most recently at 2013/05/15 21 UT. The model is updated every time new data are received from [STELab, Japan](#), most recently at 2013/05/15 21 UT. The animations run in 6.0-hour steps from 6.0 days before, to 1.0 days after the last time data were received.

Web analysis runs automatically using Linux on a P.C.

# Heliospheric Tomography

<http://ips.ucsd.edu/>

Skysweep view

Jackson, B.V., et al., 2011, *Adv. in Geosciences*, 30, 93-115.

**UCSD IPS forecast**

**CASS UCSD Center for Astrophysics & Space Sciences Solar-Terrestrial Environment Laboratory (Japan)**

05:21:20 UTC  
15-May-2013

Space Weather Links  
Public Introduction  
Science Introduction  
Solar System Space Weather

Time-Dependent  
Remoteview  
Synoptic Map  
Sky Map  
Sky Sweep  
Time Series  
Correlations

2013/05/15 03 UT  
Ecl N  
Ecl S  
E W  
IPS speed (km s<sup>-1</sup>)  
Go to movie

2013/05/15 03 UT  
Ecl N  
Ecl S  
E W  
g-level  
Go to movie

**Time-Dependent Model: Last observed IPS sources**  
The display presents a [Hammer-Aitoff](#) (an equal area projection of the entire sky) or ["Fisheye"](#) (equal distances for equal solar elongation angles) projection of the sky as observed from Earth. The map represents a 'sweep of the sky' view of the meridian over Japan in a 24-hour period centered on local noon at 2013/05/15 03 UT, about 18.3 hours ago, as indicated at the top. The horizontal axis is the ecliptic plane. In the Hammer-Aitoff projection, the celestial equator is marked by a curved line. The position of the Sun is centered in the image. The circles indicate the location of the last IPS observations obtained. The color of each circle indicates its observed value. The size reflects the difference of the observations with the time-dependent, solar wind model last run at 2013/05/15 21 UT. Areas where coverage is poor are left blank. The animations run in 6.0-hour steps from 6.0 days before, to 1.0 days after the last time data were received.

Web analysis runs automatically using Linux on a P.C.



# Heliospheric Tomography

<http://ips.ucsd.edu/>

Skymap view

Jackson, B.V., et al., 2011, *Adv. in Geosciences*, 30, 93-115.

The screenshot shows a web browser window displaying the UCSD IPS Space Weather Forecast page. The page features a navigation menu on the left with links for 'Space Weather Links', 'Public Introduction', 'Science Introduction', 'Solar System Space Weather', 'Time-Dependent', 'Remoteview', 'Synoptic Map', 'Sky Map', 'Sky Sweep', 'Time Series', and 'Correlations'. The main content area displays two circular skymaps for the date 2013/05/15 21 UT. The left skymap shows 'IPS speed (km s<sup>-1</sup>)' with a color scale from 0.300 to 0.900. The right skymap shows 'g-level' with a color scale from 0.7 to 1.5. Both maps are labeled with 'Ecl N', 'Ecl S', 'E', and 'W' and include a 'Go to movie' link. The page header includes the CASS logo and the text 'UCSD Center for Astrophysics & Space Sciences Solar-Terrestrial Environment Laboratory (Japan)'. A large white box with the text 'UCSD IPS forecast' is overlaid on the top right of the browser window.

Web analysis runs automatically using Linux on a P.C.

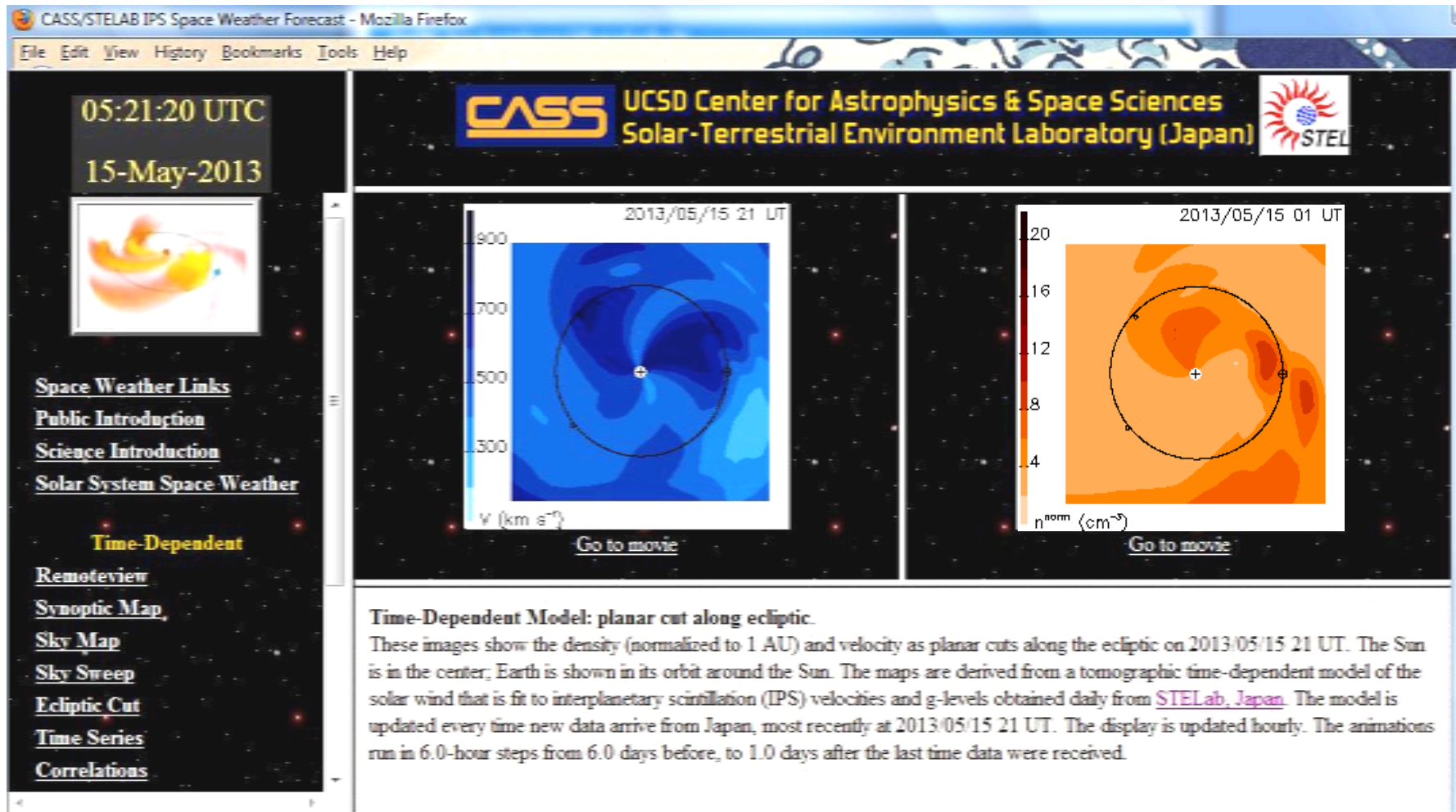
# Heliospheric Tomography

<http://ips.ucsd.edu/>

Jackson, B.V., et al., 2011, *Adv. in Geosciences*, 30, 93-115.

Forecast

Fit to CELIAS data



One CME just passed 2013/05/14 4-6 UT increase by ~8 Np/cc

Web Analysis Runs Automatically Using Linux on a P.C.

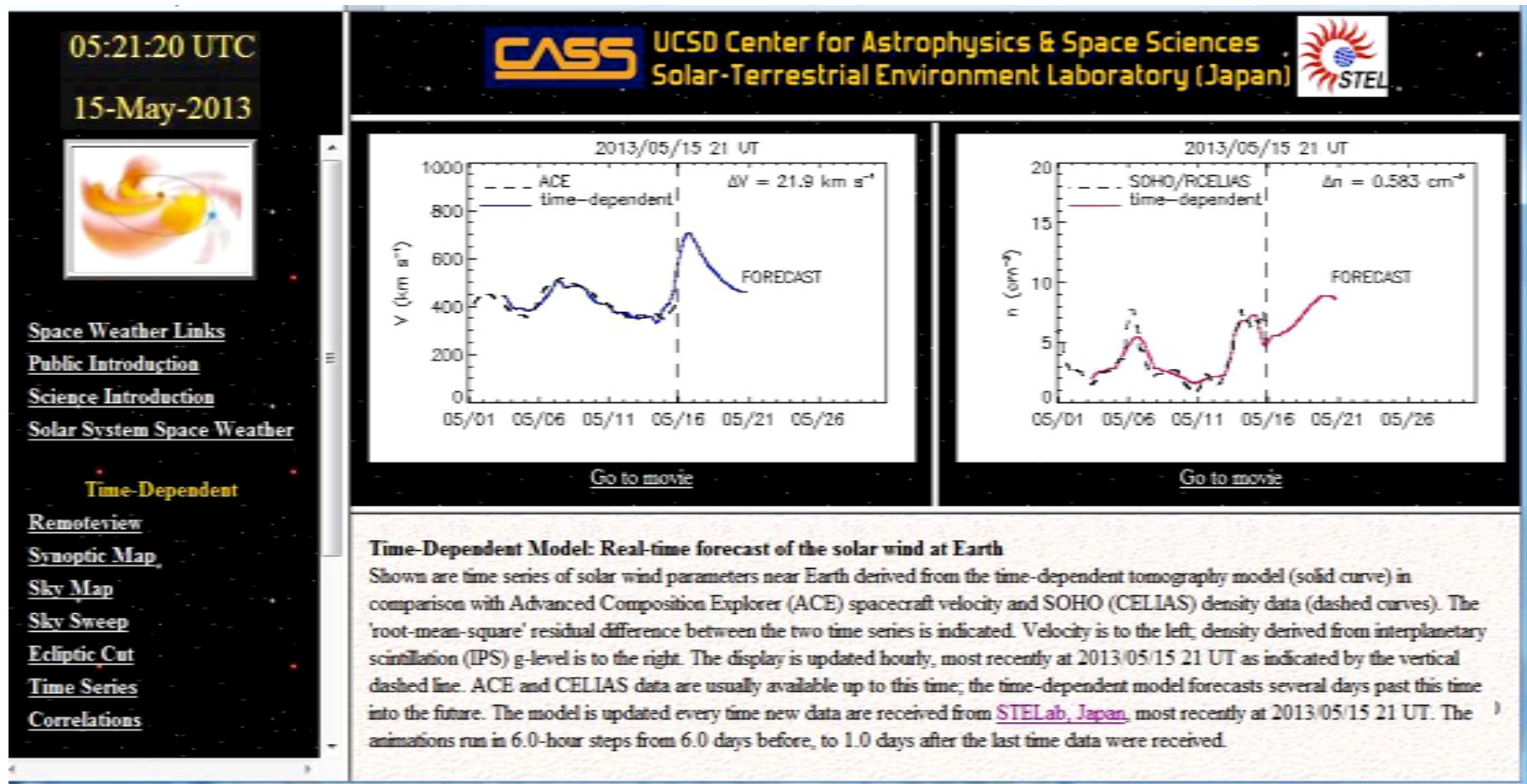
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## Forecast

## Fit to CELIAS data



One CME just passed 2013/05/14 4-6 UT increase by ~8 Np/cc

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# Heliospheric Tomography

Jackson, B.V., et al., 2010, *Solar Phys.*, 265, 245-256.

Jackson, B.V., et al., 2011, *Adv. in Geosciences*, 30, 93-115.

## Correlations (from UCSD forecast)

Pearson's  $r$  correlation coefficient, day to day forecast verification

Five day behind forecast

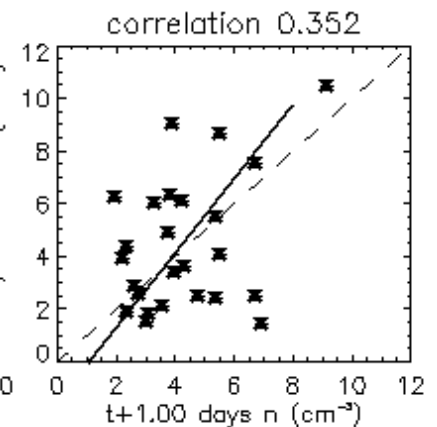
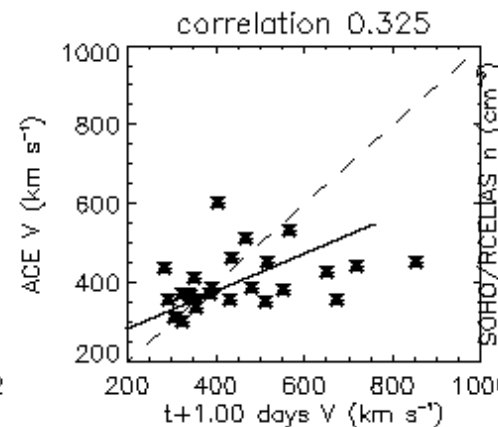
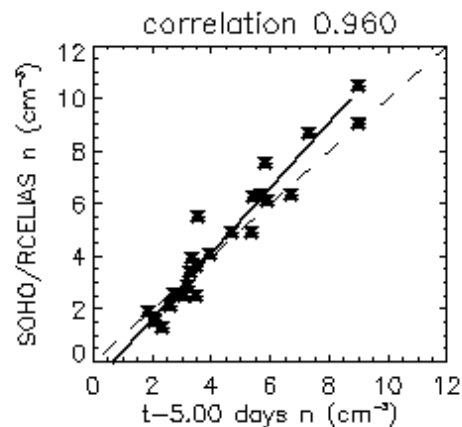
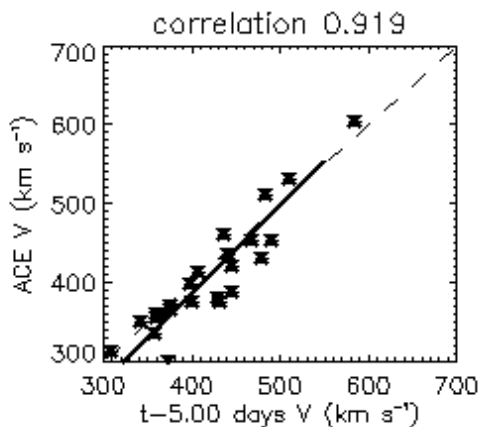
One day ahead forecast

Velocity

Density

Velocity

Density



Velocity matched to ACE, density matched to CELIAS

Remote velocity from  
STELab IPS three-site

Remote density from  
STELab IPS g-level

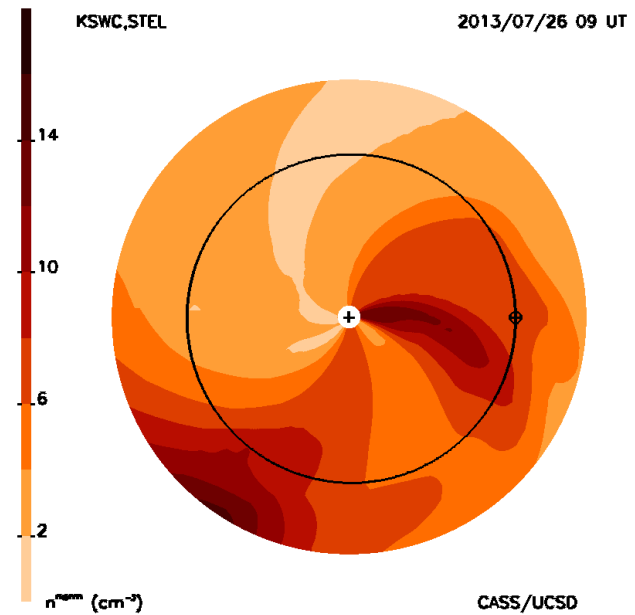
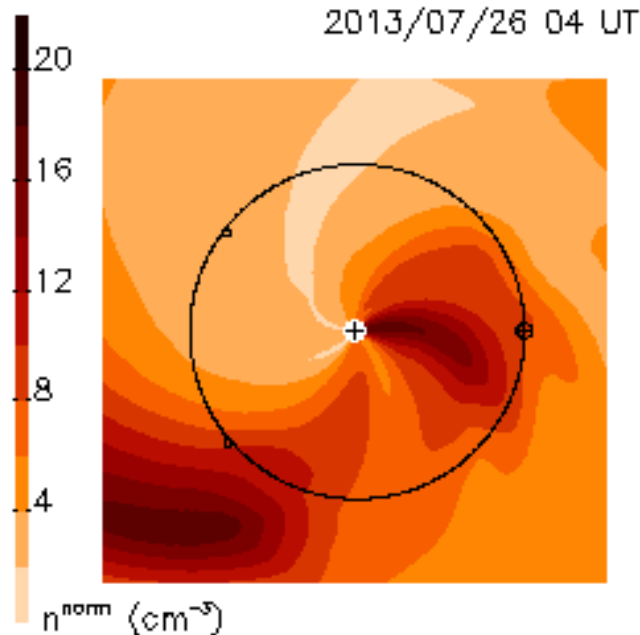


# Heliospheric Tomography

Fit to CELIAS  
UCSD

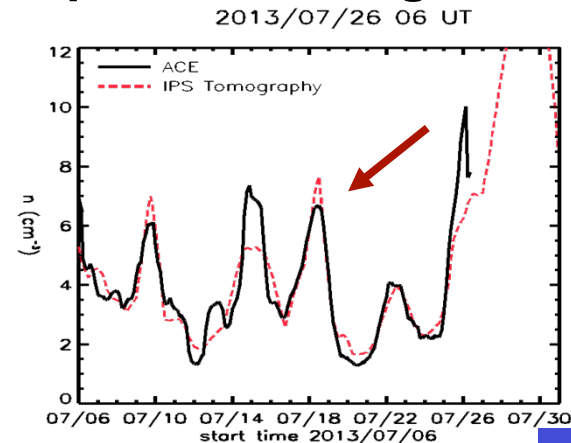
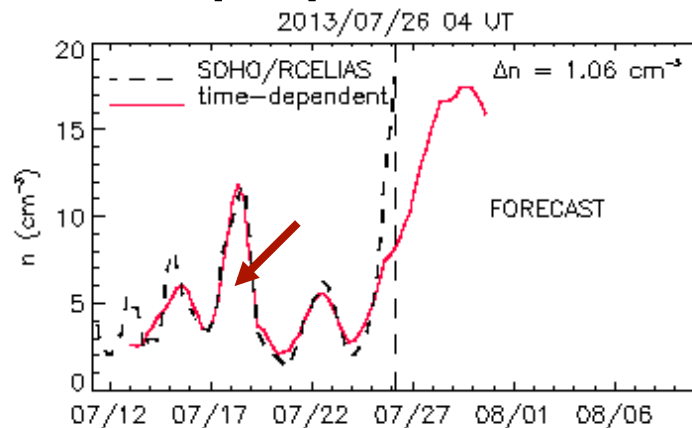
Current Forecasts

Fit to ACE L0  
KSWC



<http://ips.ucsd.edu/>

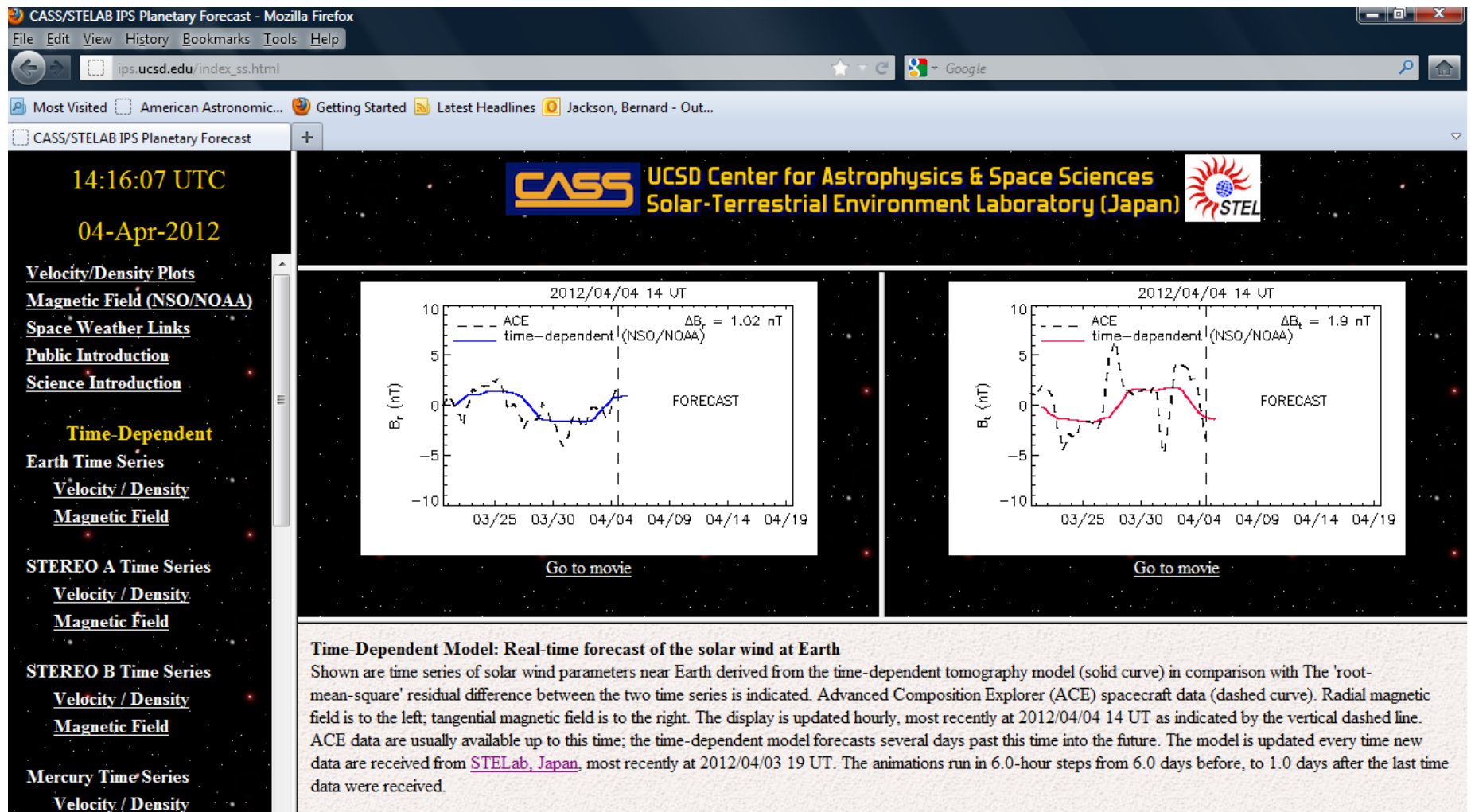
<http://www.spaceweather.go.kr/models/ips>



# Heliospheric Tomography

Jackson, B.V., et al., 2012, *Adv. in Geosciences*, (in press).

<http://ips.ucsd.edu/> **Earth** Radial and Tangential Magnetic Field



Web Analysis Runs Automatically Using Linux on a P.C.

# Heliospheric Tomography

Jackson, B.V., et al., 2011, *Adv. in Geosciences*, 30, 93-115.

## Correlations (from UCSD forecast)

Pearson's  $r$  correlation coefficient, day to day forecast verification

Five day behind forecast

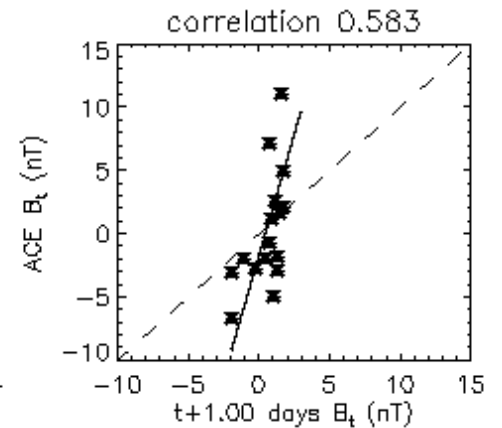
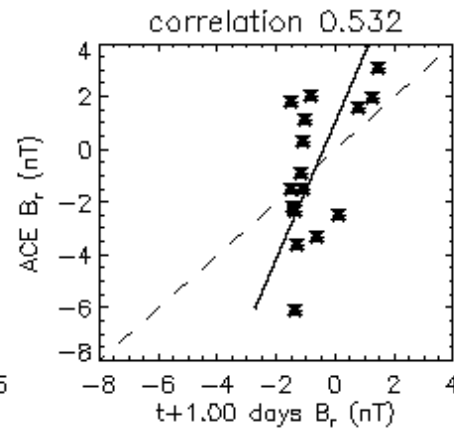
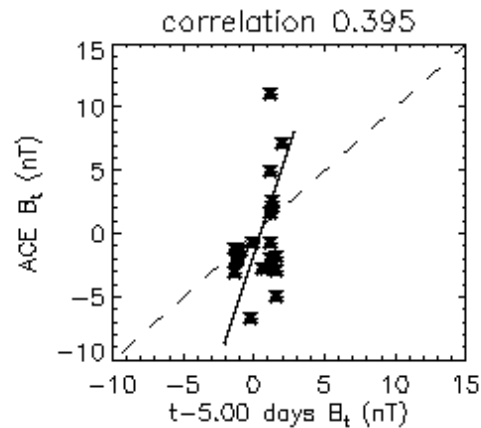
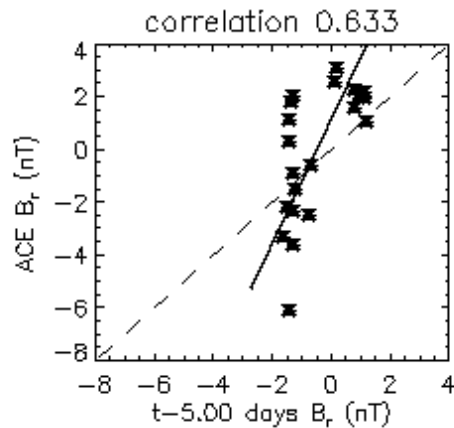
One day ahead forecast

$B_{\text{radial}}$

$B_{\text{tangential}}$

$B_{\text{radial}}$

$B_{\text{tangential}}$



RTN coordinates

# Heliospheric Tomography

Jackson, B.V., et al., 2011, *Adv. in Geosciences*, 30, 93-115.

## Correlations (from UCSD forecast)

Pearson's  $r$  correlation coefficient, day to day forecast verification

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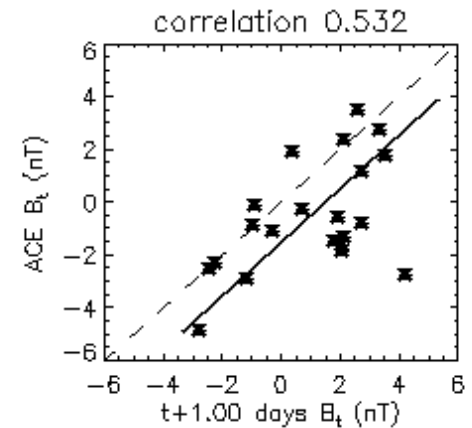
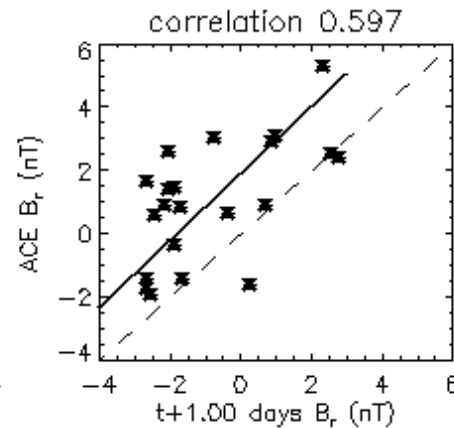
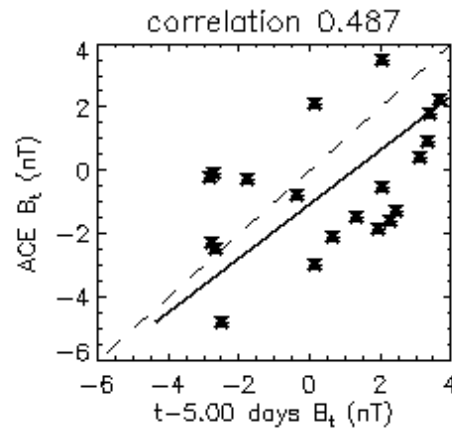
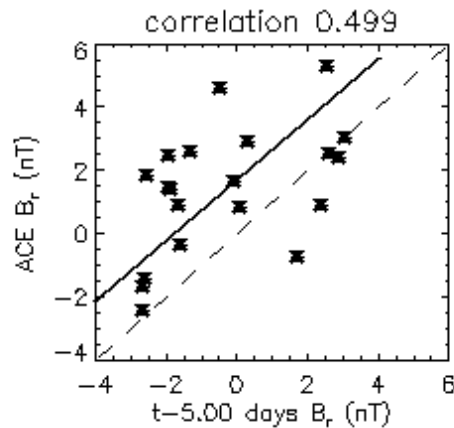
One day ahead forecast

$B_{\text{radial}}$

$B_{\text{tangential}}$

$B_{\text{radial}}$

$B_{\text{tangential}}$

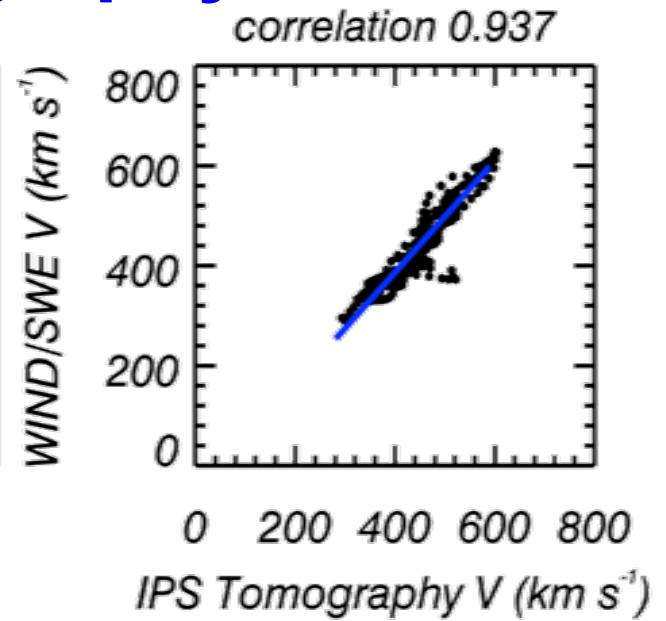
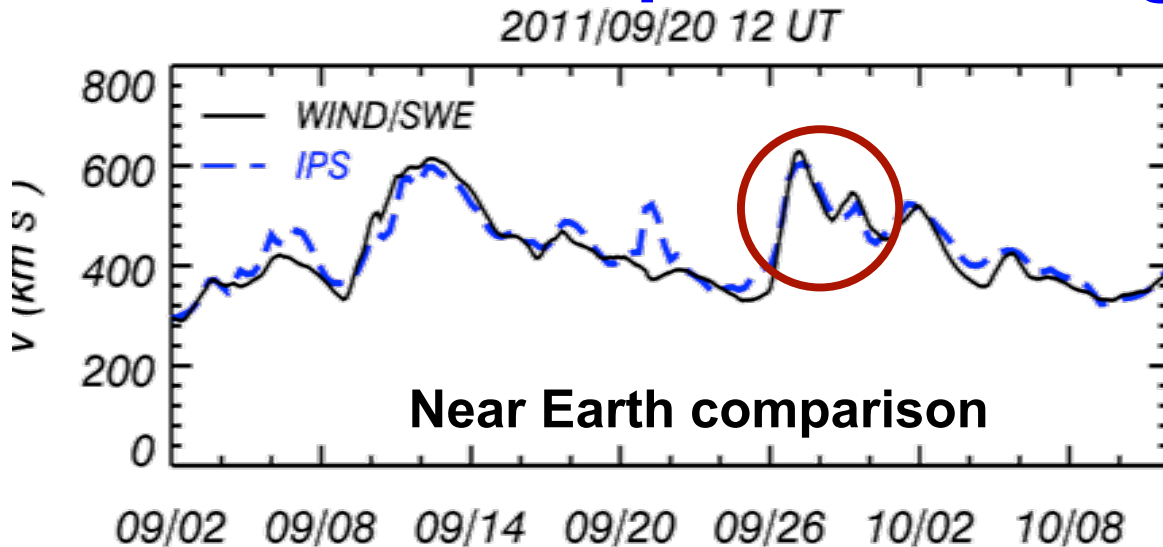


RTN coordinates

# Heliospheric Tomography

**Towards  
a Comprehensive Model  
that Includes 3D-MHD**

# UCSD Heliospheric Tomography

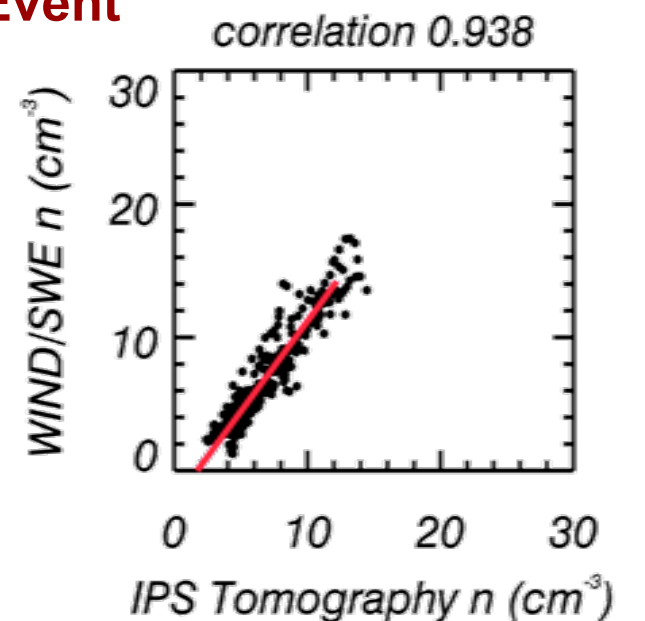
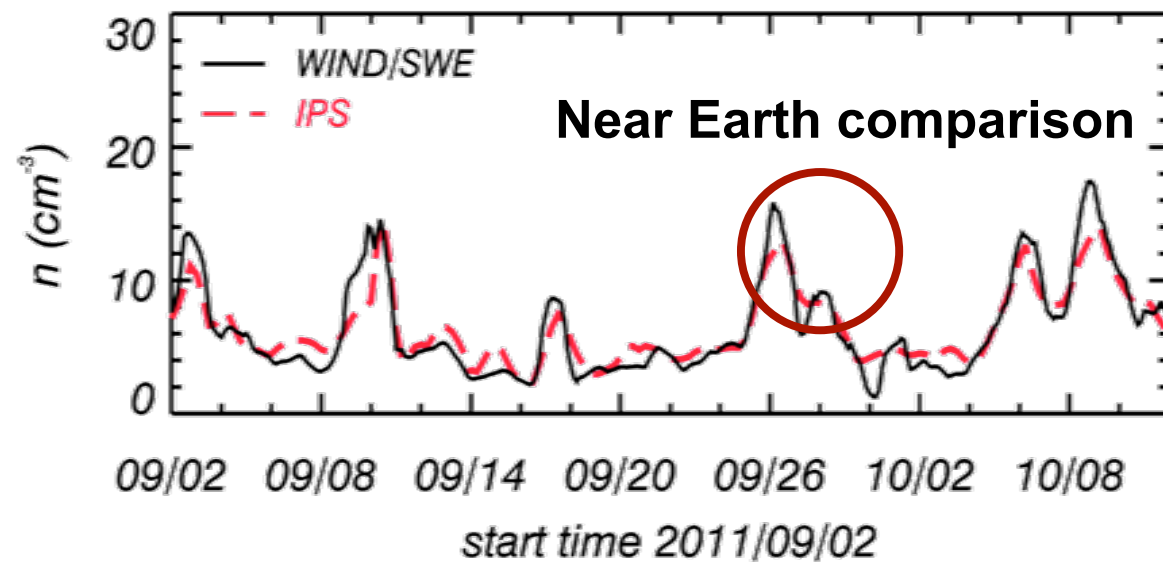


**Kinematic Model  
Iterative Data Fit**

start time 2011/09/02

**Interesting Event**

2011/09/20 12 UT



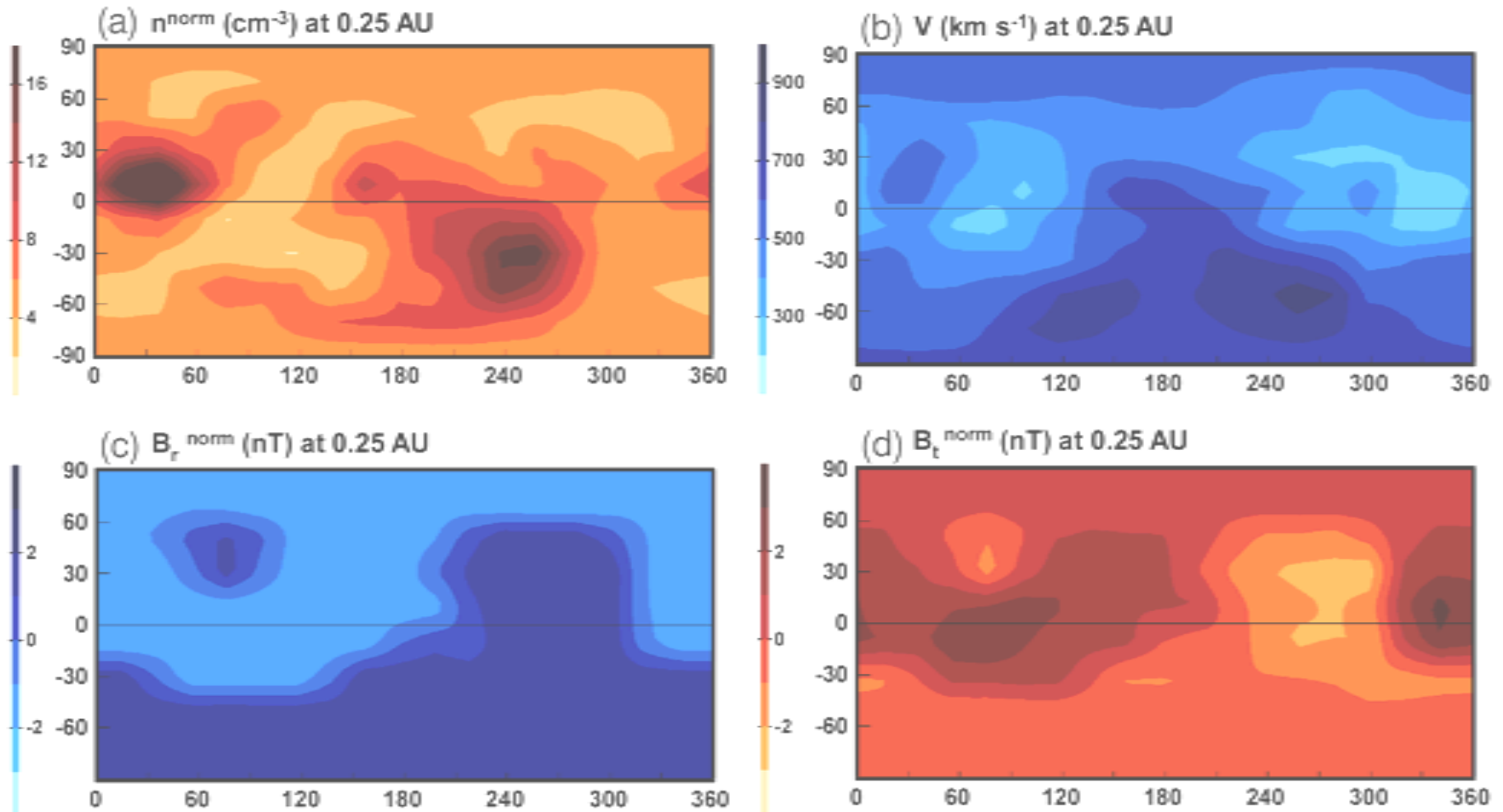


# Heliospheric Tomography

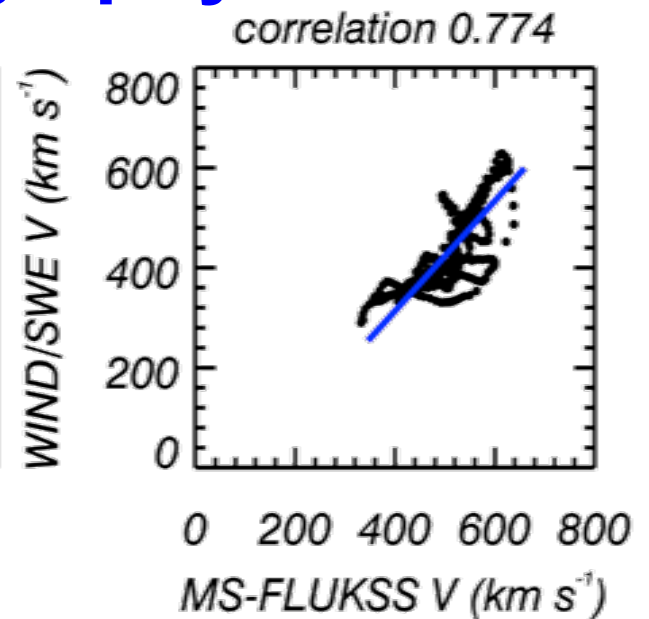
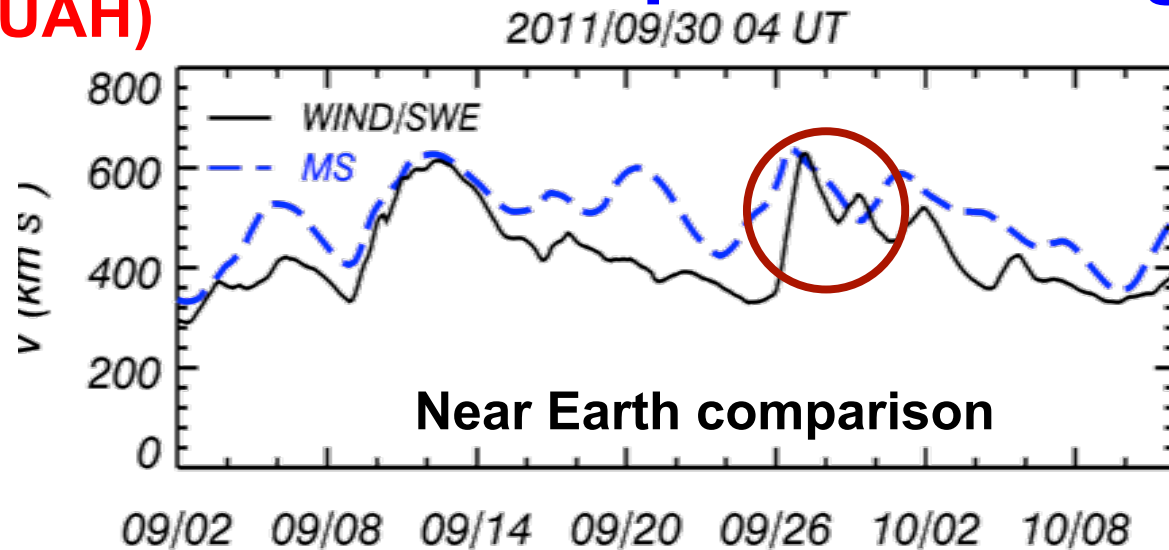
(Yu, H-S., et al., 2012, *AIP Conference Proc.* 1500, pp. 147-152.)

## IPS-Derived 3D-MHD Model Boundaries

2011 September 01 03:00UT at 0.25AU Boundary

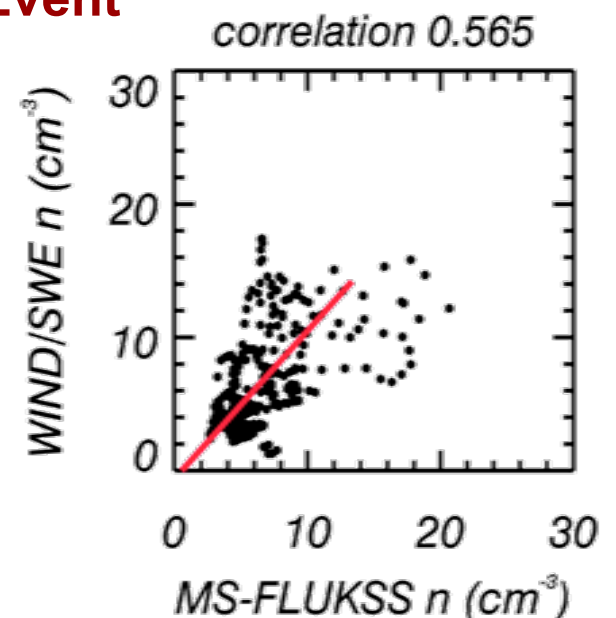
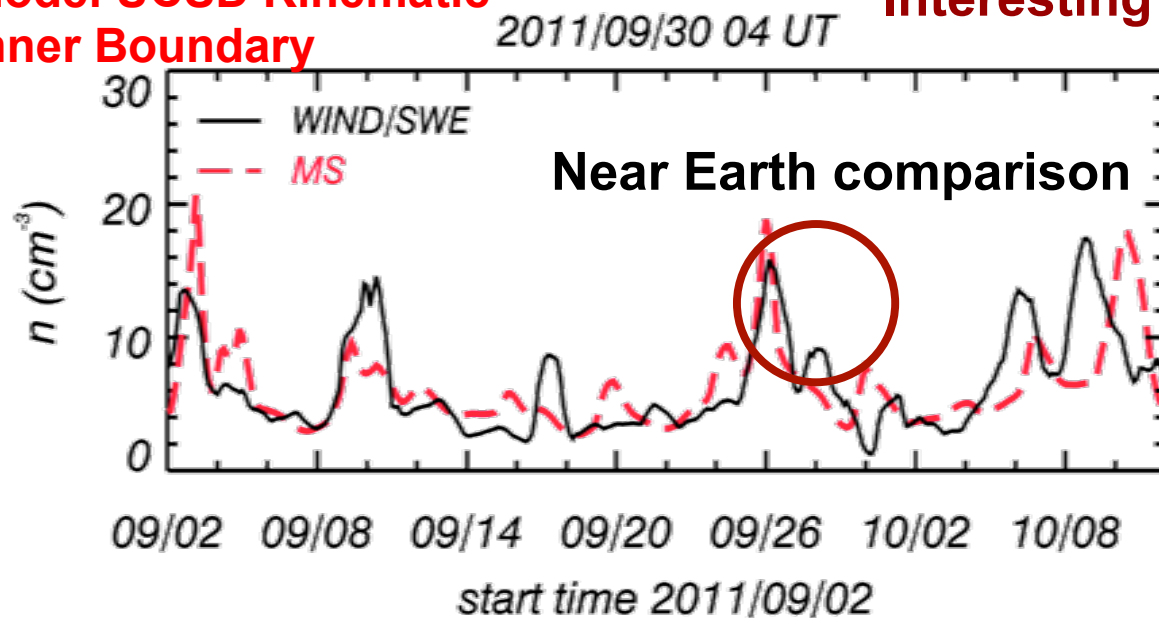


# MS-FLUKSS Heliospheric Tomography (UAH)



Forward 3D-MHD  
Model UCSD Kinematic  
Inner Boundary

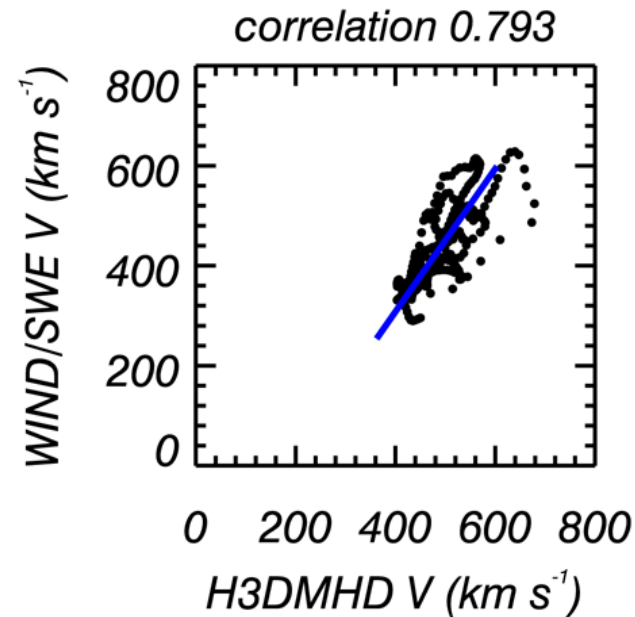
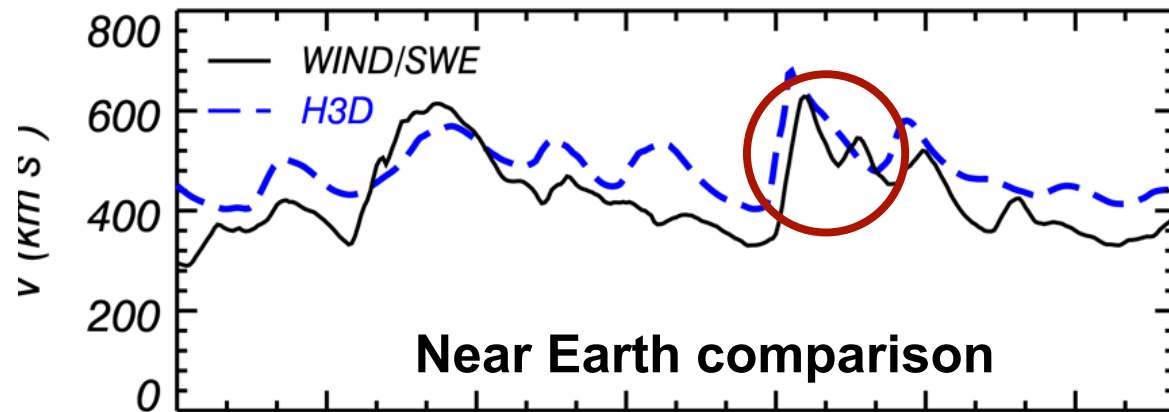
Interesting Event



# H-3D-MHD (NRL)

# Heliospheric Tomography

2011/09/21 17 UT

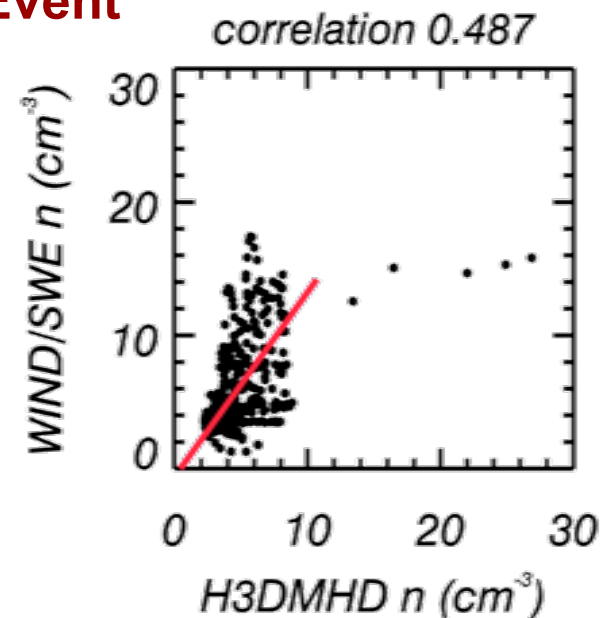
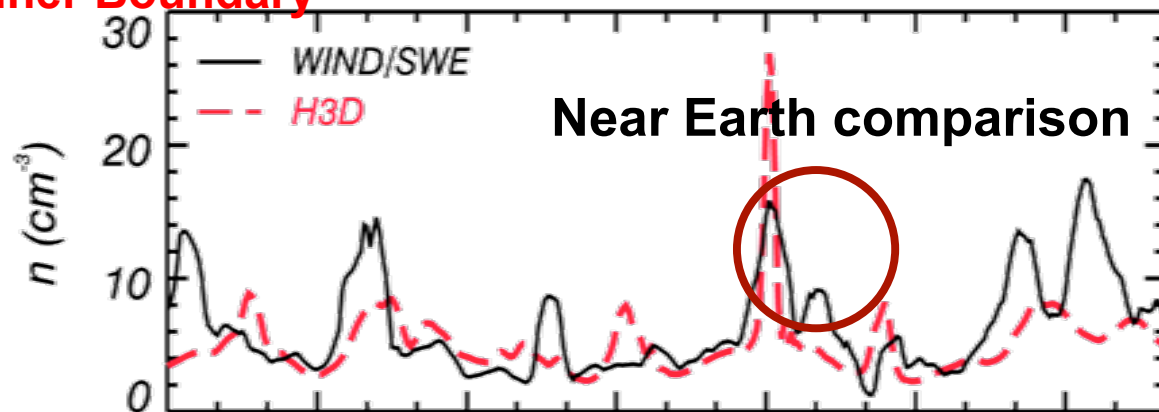


# Forward 3D-MHD Model UCSD Kinematic Inner Boundary

start time 2011/09/02

# Interesting Event

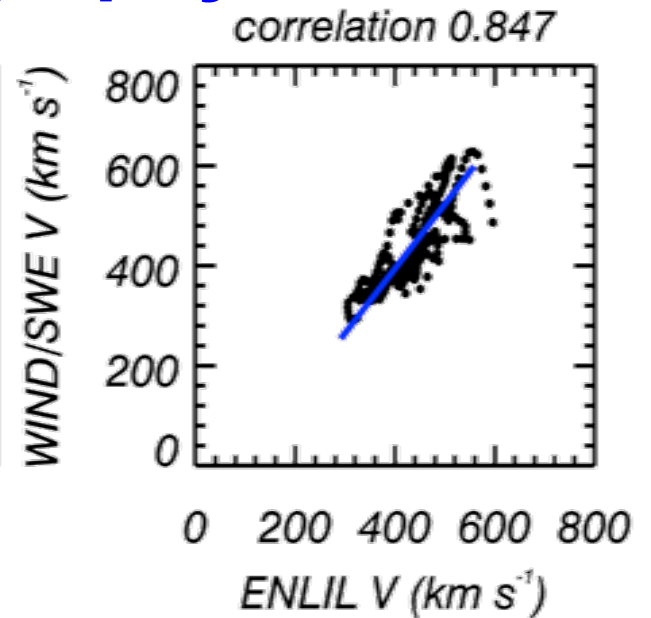
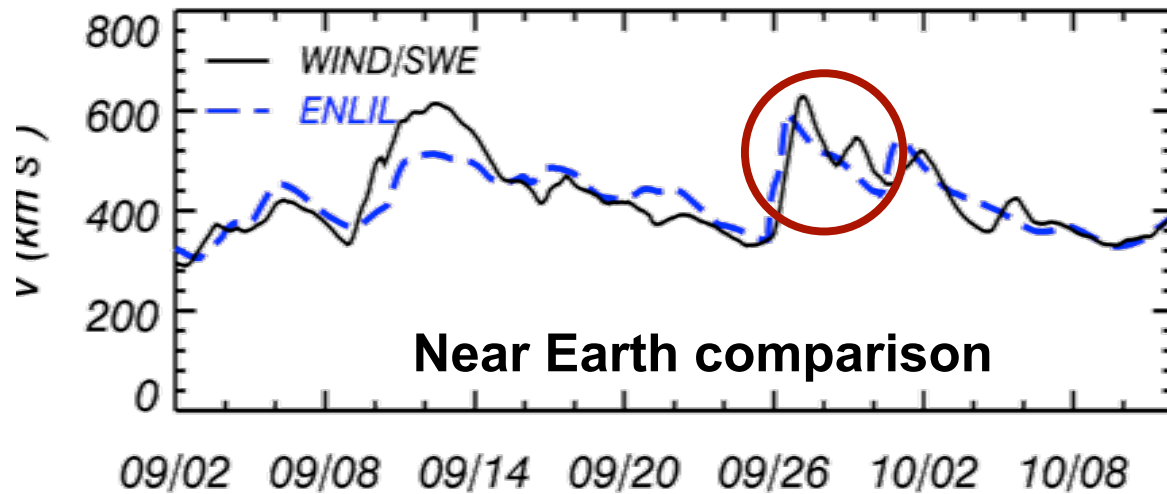
2011/09/21 17 UT



**ENLIL**  
(D. Odstrcil)

# Heliospheric Tomography

2011/09/26 12 UT

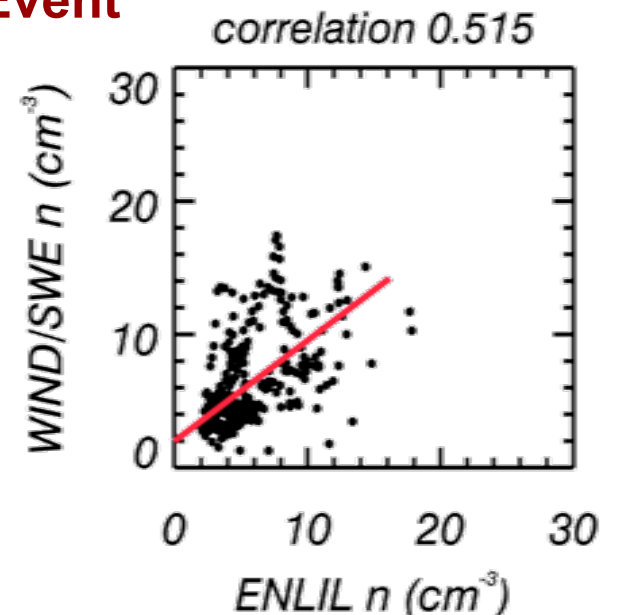
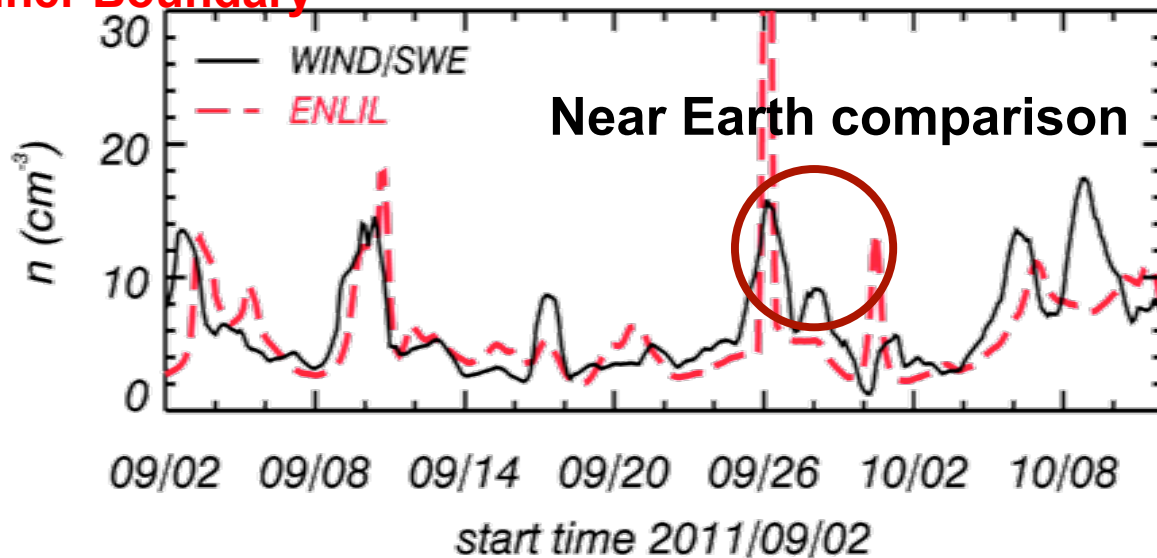


**Forward 3D-MHD**  
**Model UCSD Kinematic**  
**Inner Boundary**

start time 2011/09/02

**Interesting Event**

2011/09/26 12 UT



# Kinematic Model Iterative Data Fit

# Heliospheric Tomography

## UCSD IPS Data Fit Model

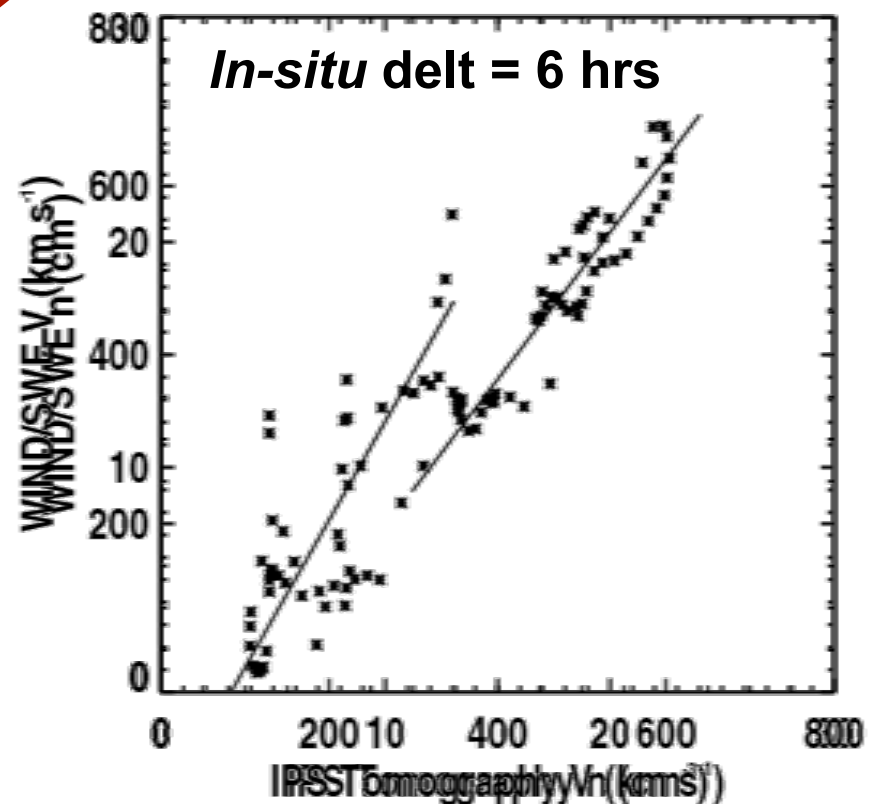
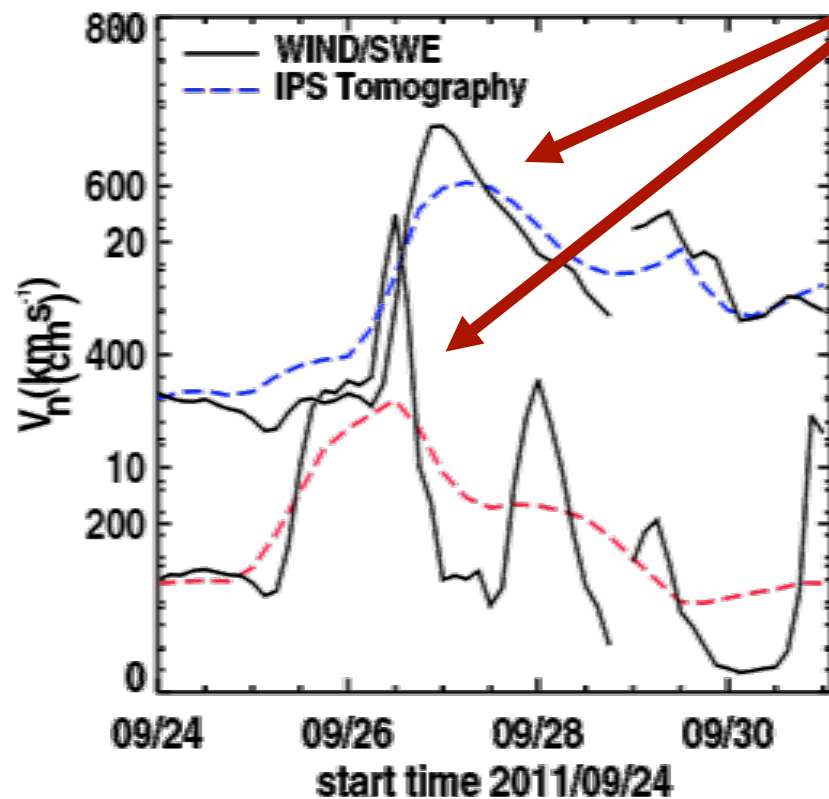
UCSD kinematic modeling from a 15.0 Rs  
3D time-dependent IPS tomography boundary.

(Yu, H-S., et al., 2014, NOAA Space Weather Week, poster.)

2011/09/20 12 UT

Interesting Event

correlation 0.942



ENLIL  
(D. Odstrcil)

# Heliospheric Tomography

## UCSD IPS Data Fit Model

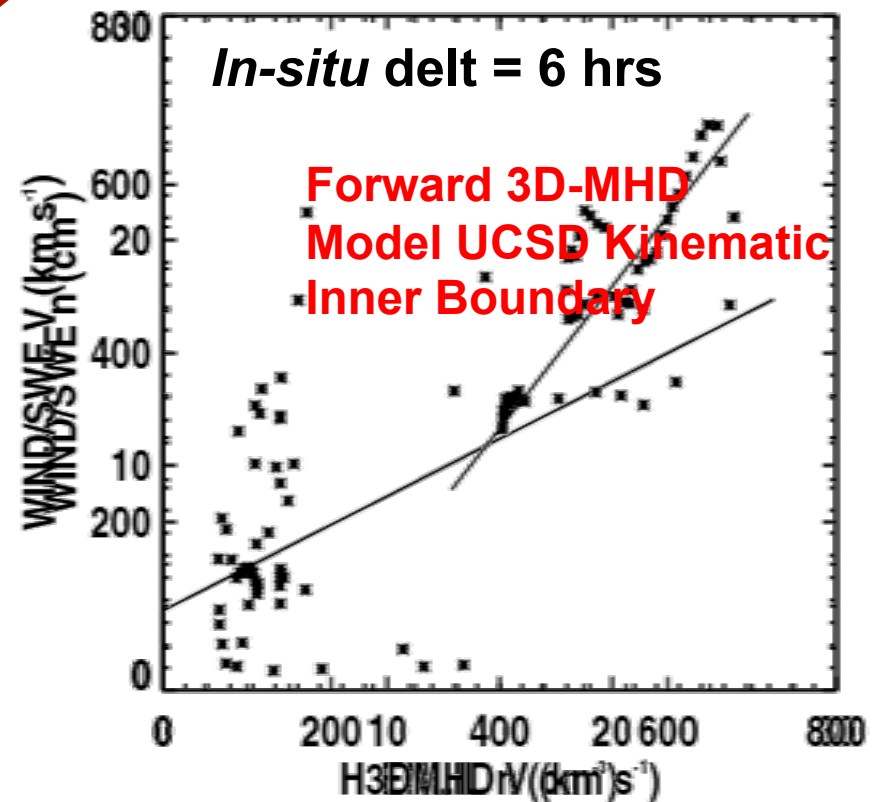
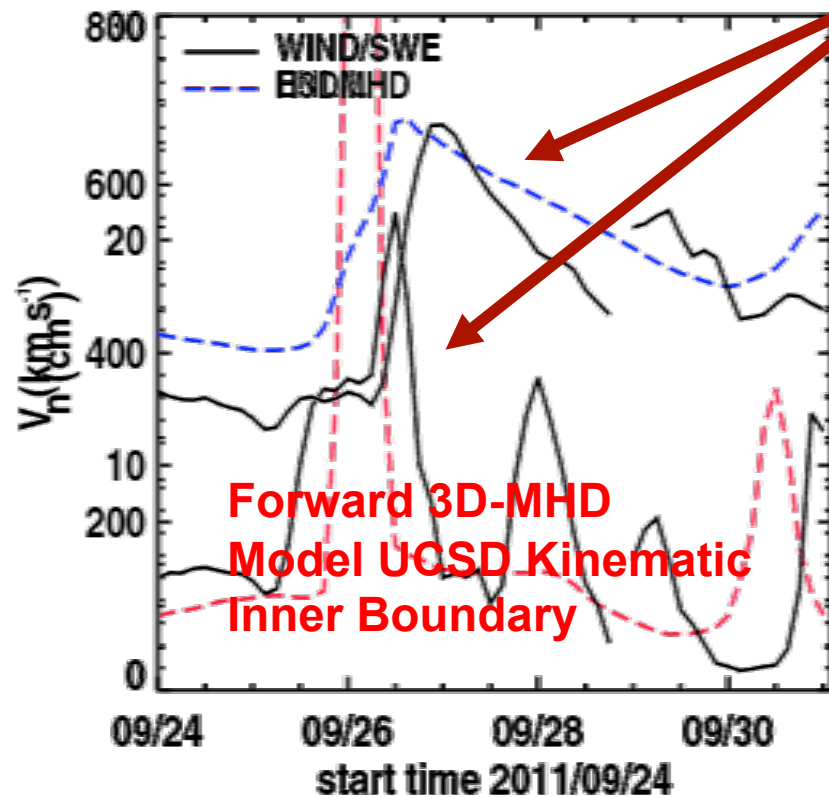
ENLIL forward modeling from a 21.0 Rs  
3D time-dependent IPS tomography boundary.

(Yu, H-S., et al., 2014, NOAA Space Weather Week, poster.)

2011/09/26 12 UT

Interesting Event

correlation 0.388



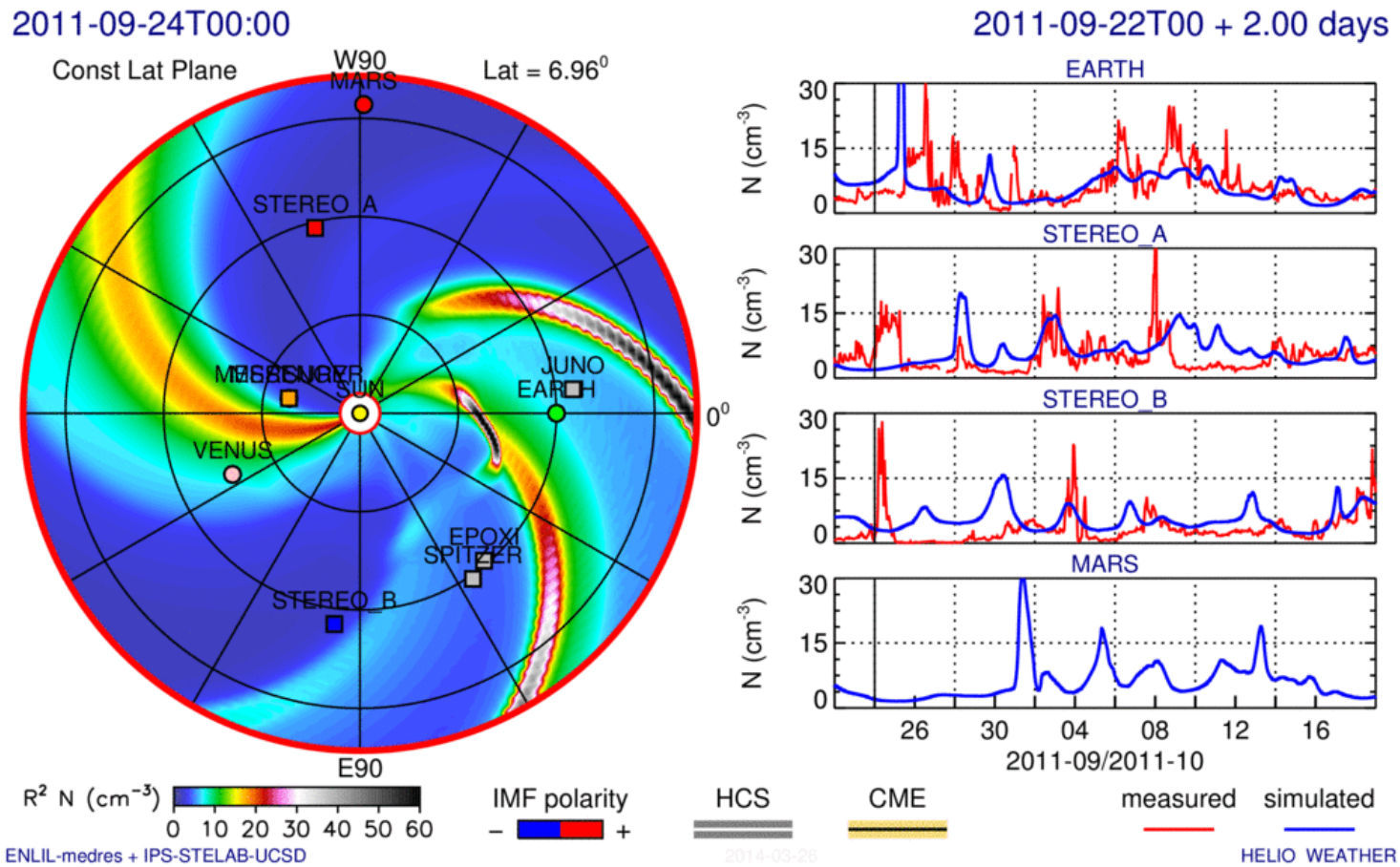


**Kinematic Model**  
**Iterative Data Fit**

# Heliospheric Tomography

## UCSD IPS Data Fit Model

**ENLIL forward modeling from a 21.0 Rs  
 3D time-dependent IPS tomography boundary.**



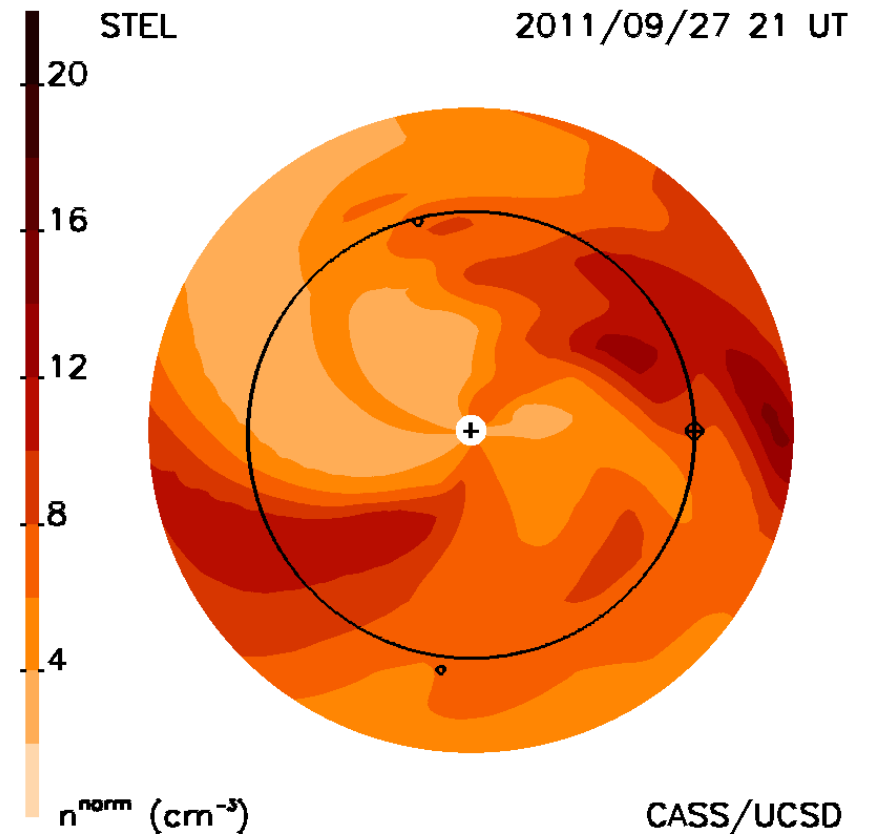
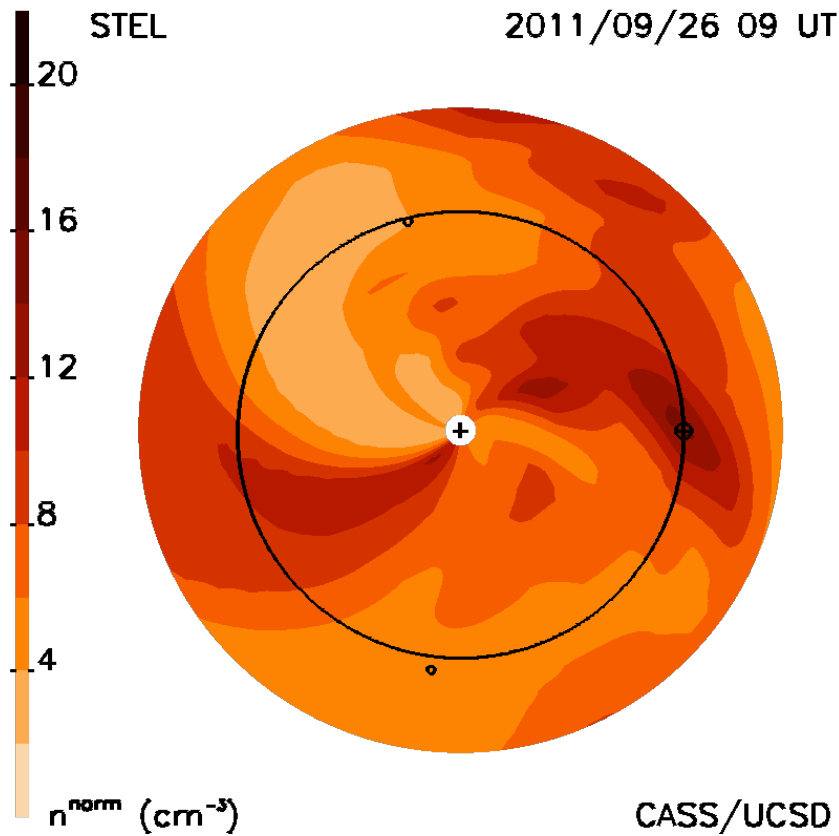
# Density

**Kinematic Model**  
**Iterative Data Fit**

# Heliospheric Tomography

## UCSD IPS Data Fit Model

### Ecliptic Cuts

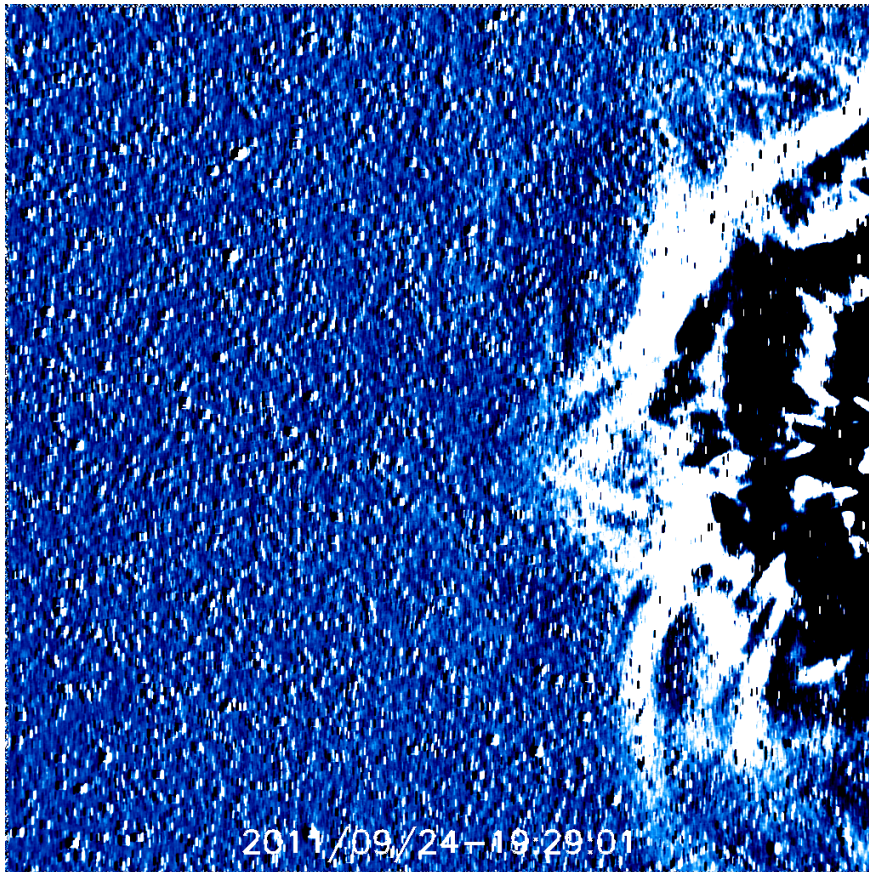


# Density

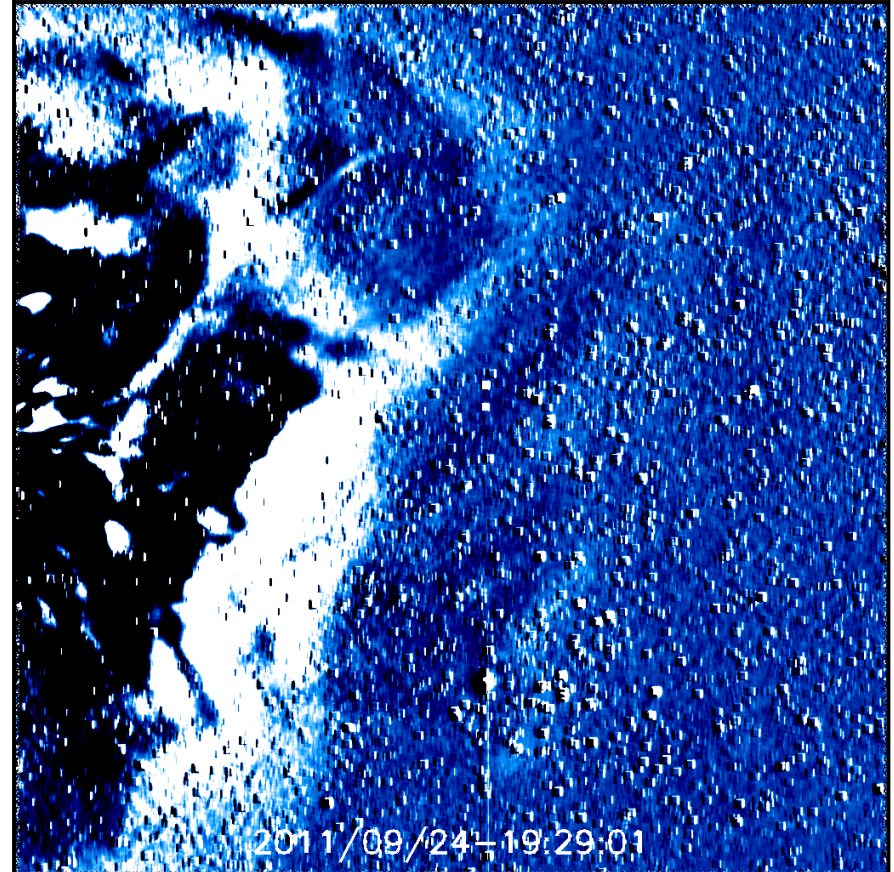
# Heliospheric Tomography

## Observations

### CMEs Observed by C2 STEREO HI-A,B



HI-A



CME 1

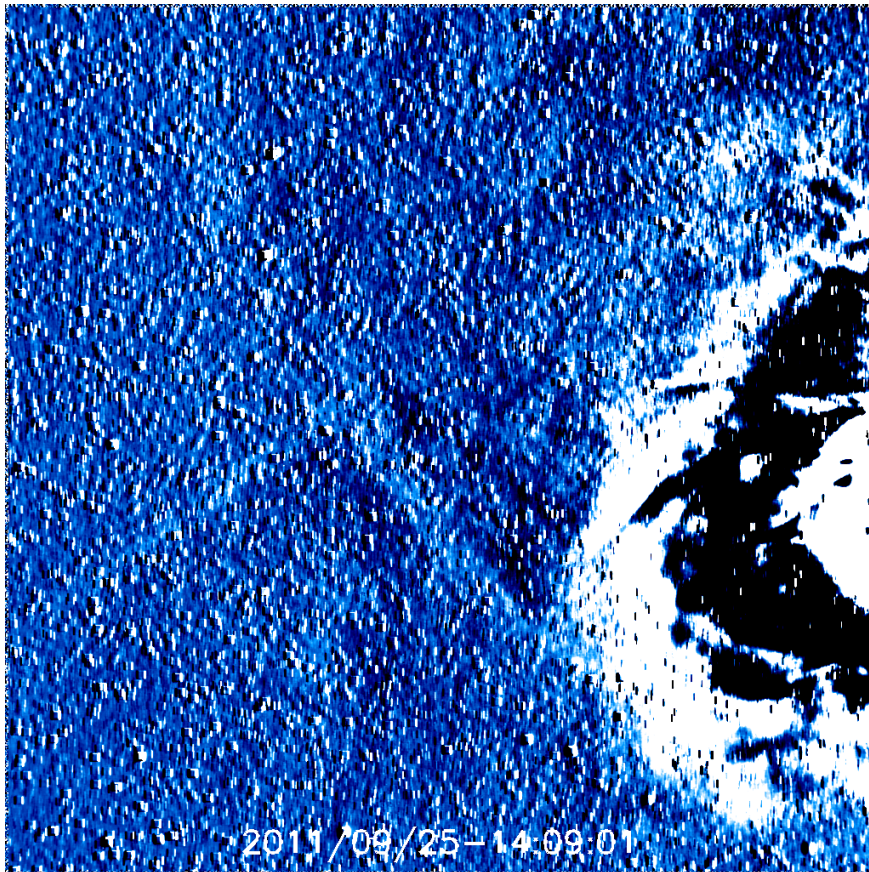
HI-B



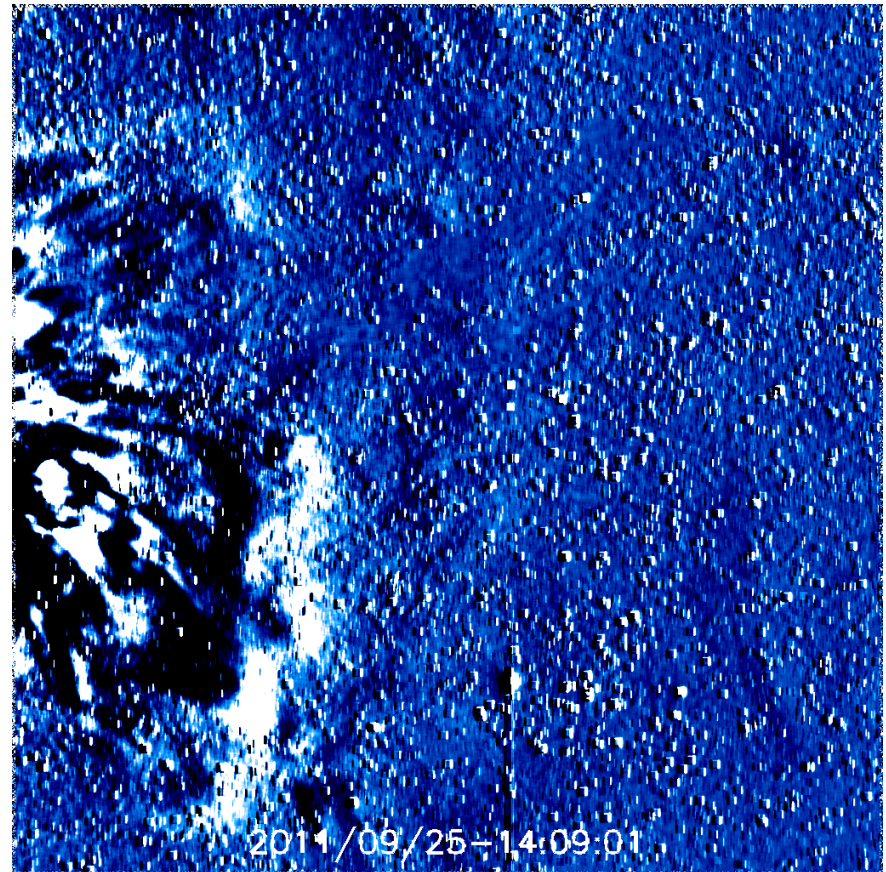
# Heliospheric Tomography

## Observations

### CMEs Observed by C2 STEREO HI-A,B



HI-A



CME 2

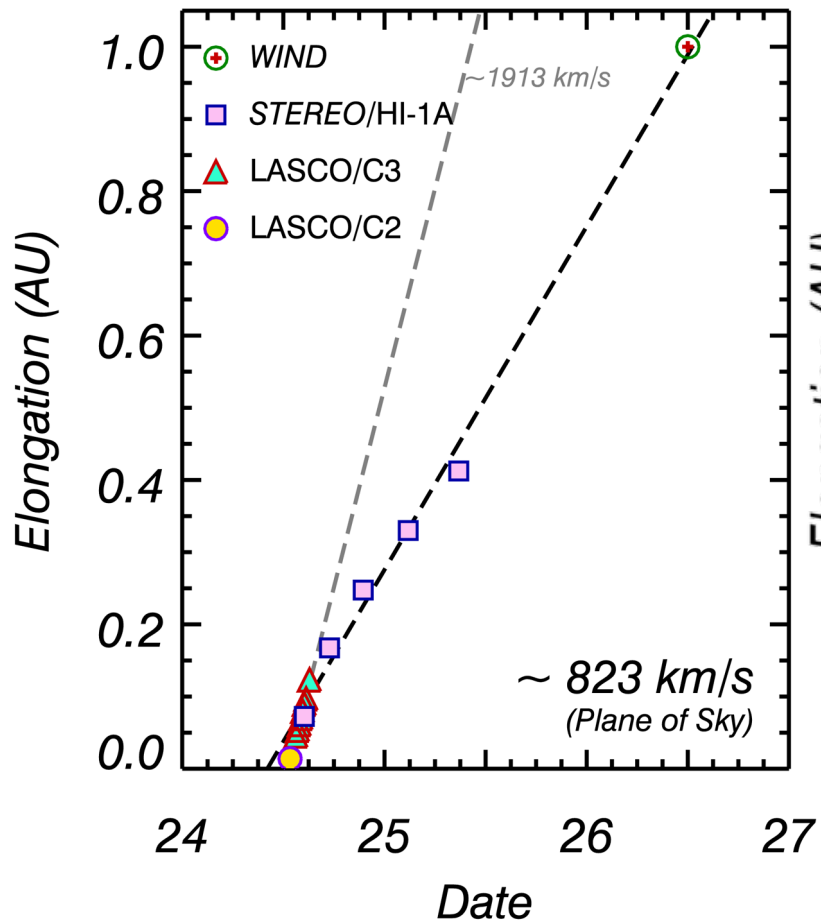
HI-B

# Heliospheric Tomography

## Observations

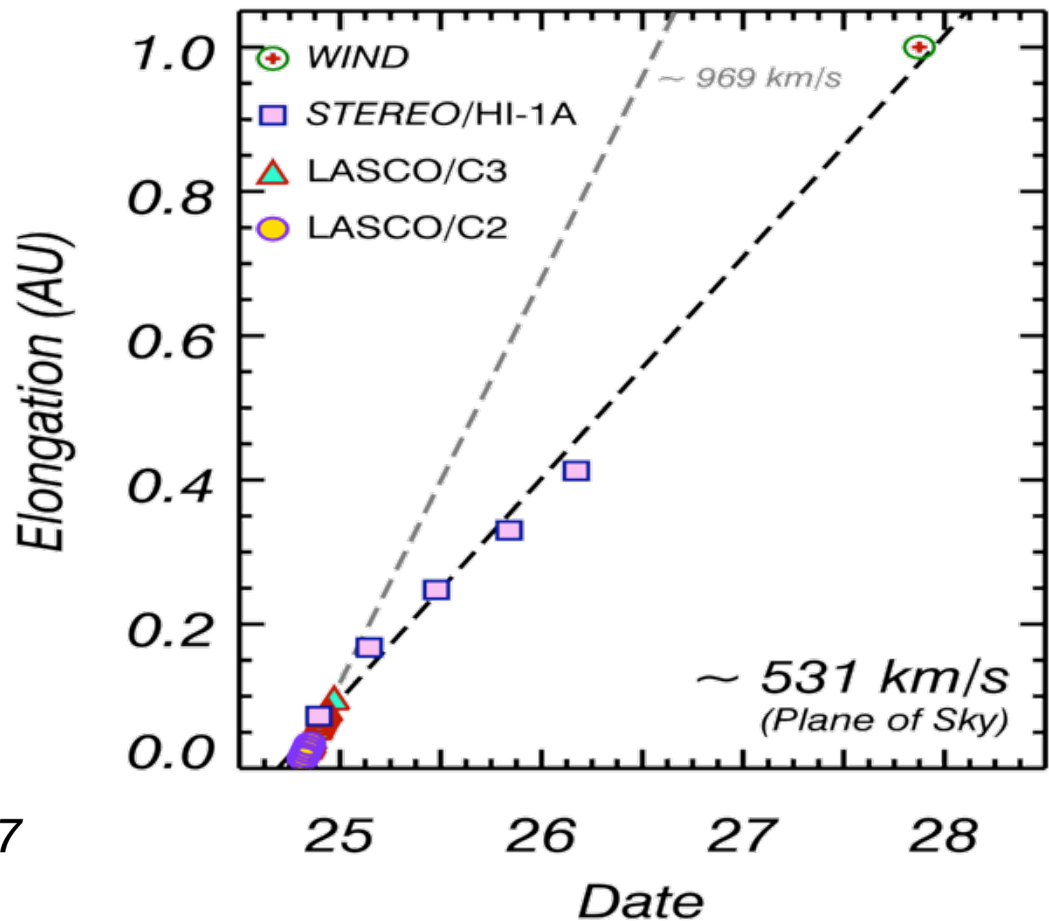
### CMEs Observed by C2 STEREO HI-A,B

2011 Sep 24



**CME 1**

2011 Sep 24



**CME 2**



ENLIL  
(D. Odstrcil)

# Heliospheric Tomography

## UCSD IPS Data Fit Model

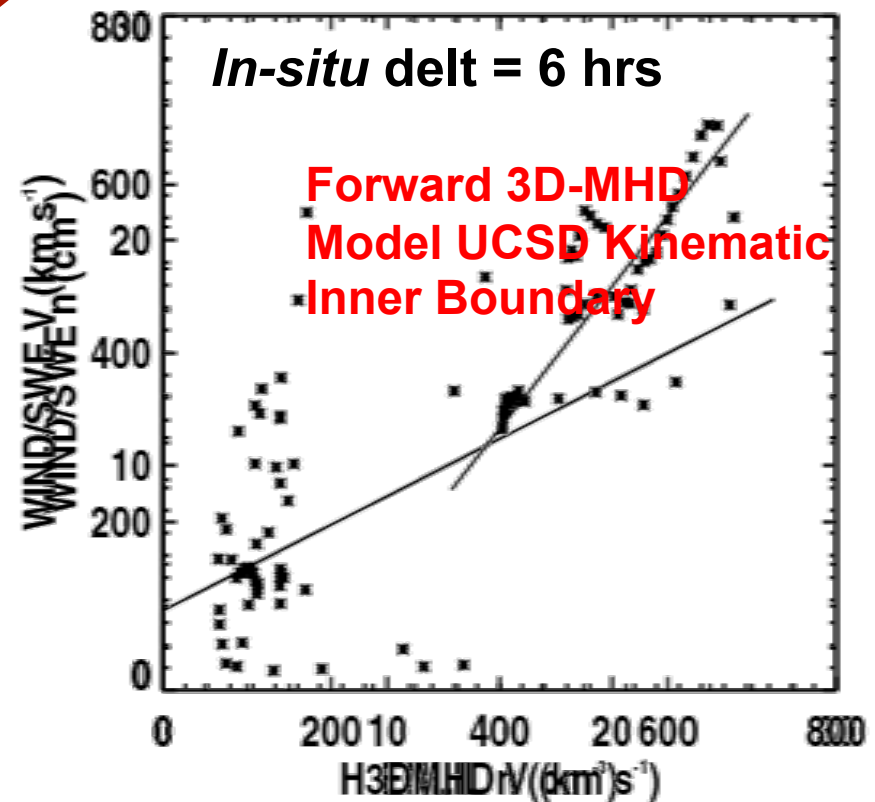
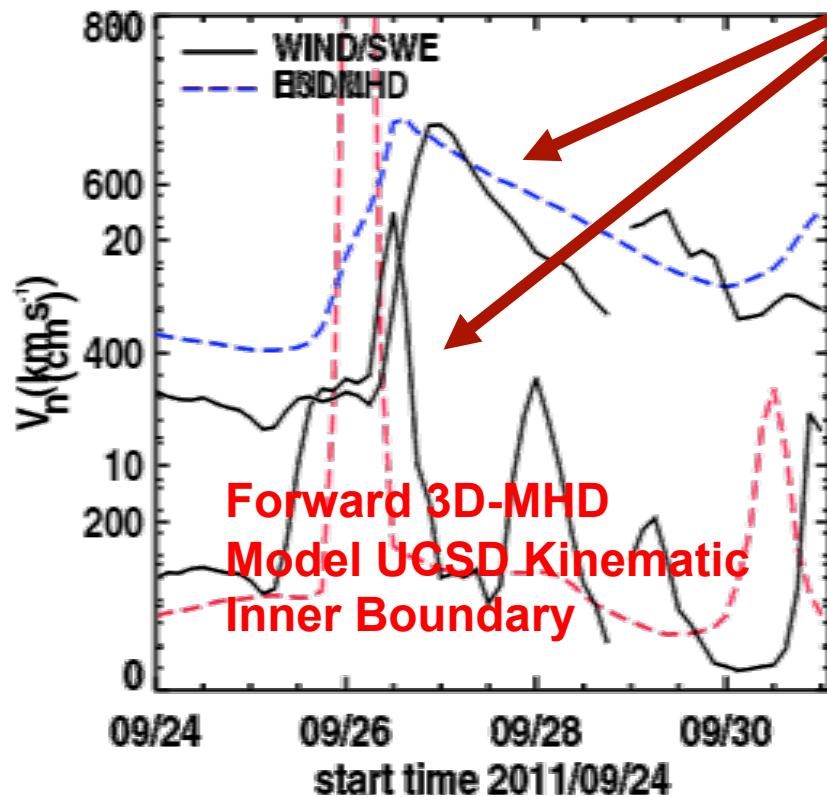
ENLIL forward modeling from a 21.0 Rs  
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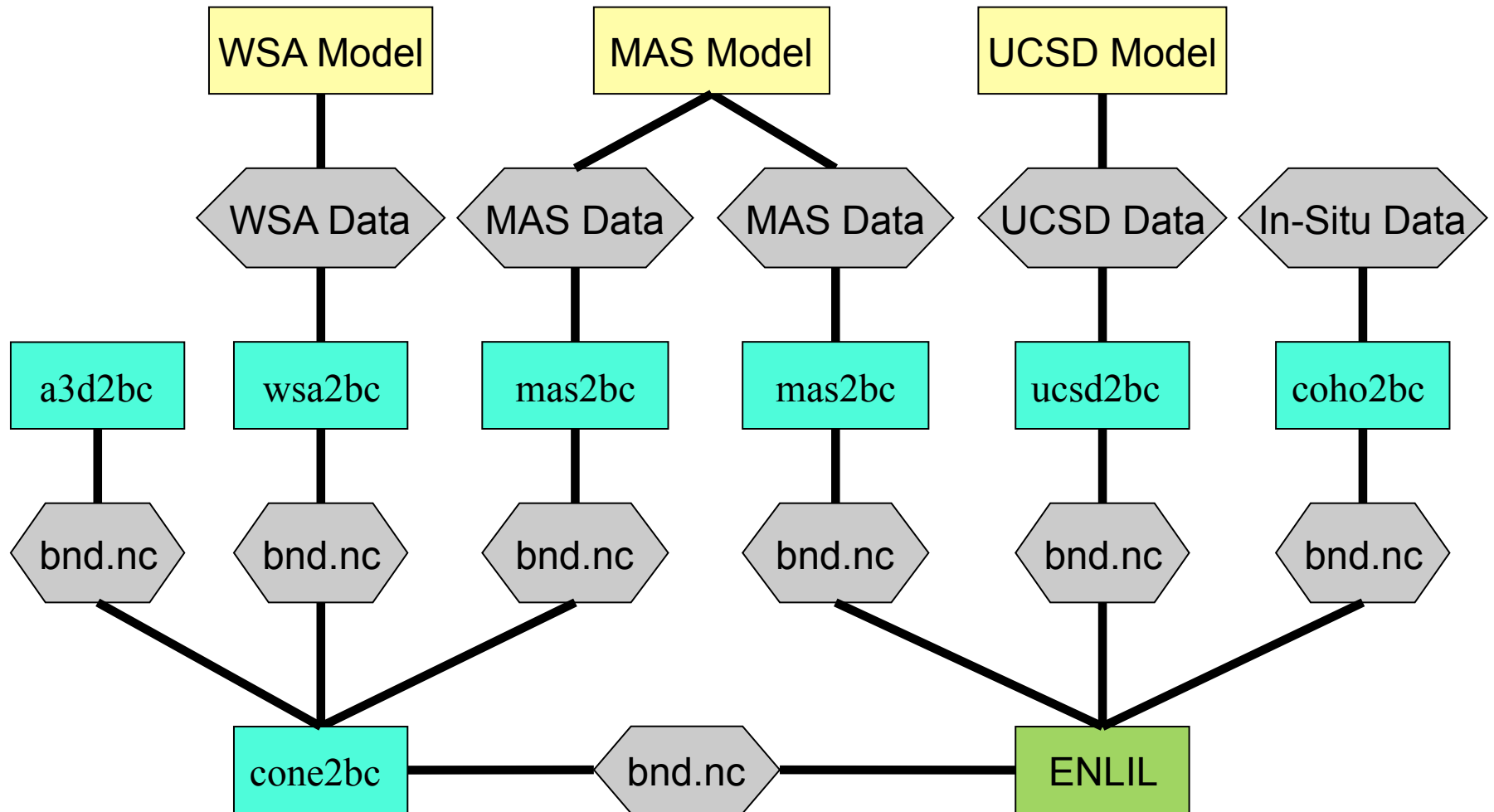
2011/09/26 12 UT

Interesting Event

correlation 0.388



# Heliospheric Tomography ENLIL Model Drivers



- Currently, there are three models (yellow) that can be used to drive ENLIL (green)
- Computational system shares data sets (grey) and uses couplers (blue)

# Heliospheric Tomography

## Summary:

### **IPS analysis:**

**A ground-based technique. Can provide low-resolution velocity and density analysis, and accurate forecasts of time-variable heliospheric structure.**

**The IPS analysis can provide input to 3D-MHD models. Better, and more abundant IPS data, should be available in the near future.**

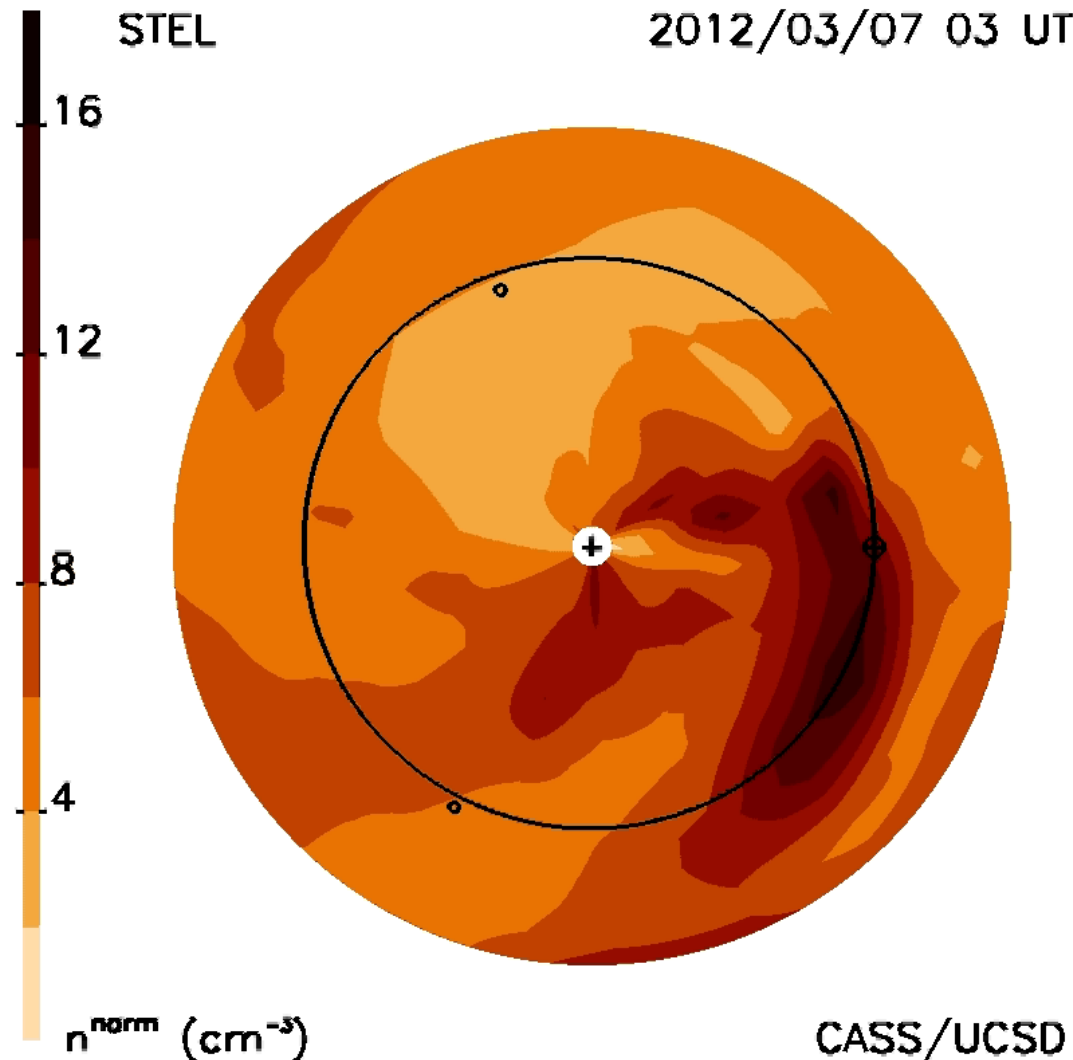
# Heliospheric Tomography

## More Details

### Faraday Rotation

# Heliospheric Tomography

$$\Phi = \lambda^2 \int n_e \bar{\mathbf{B}} \cdot d\bar{\mathbf{s}}$$

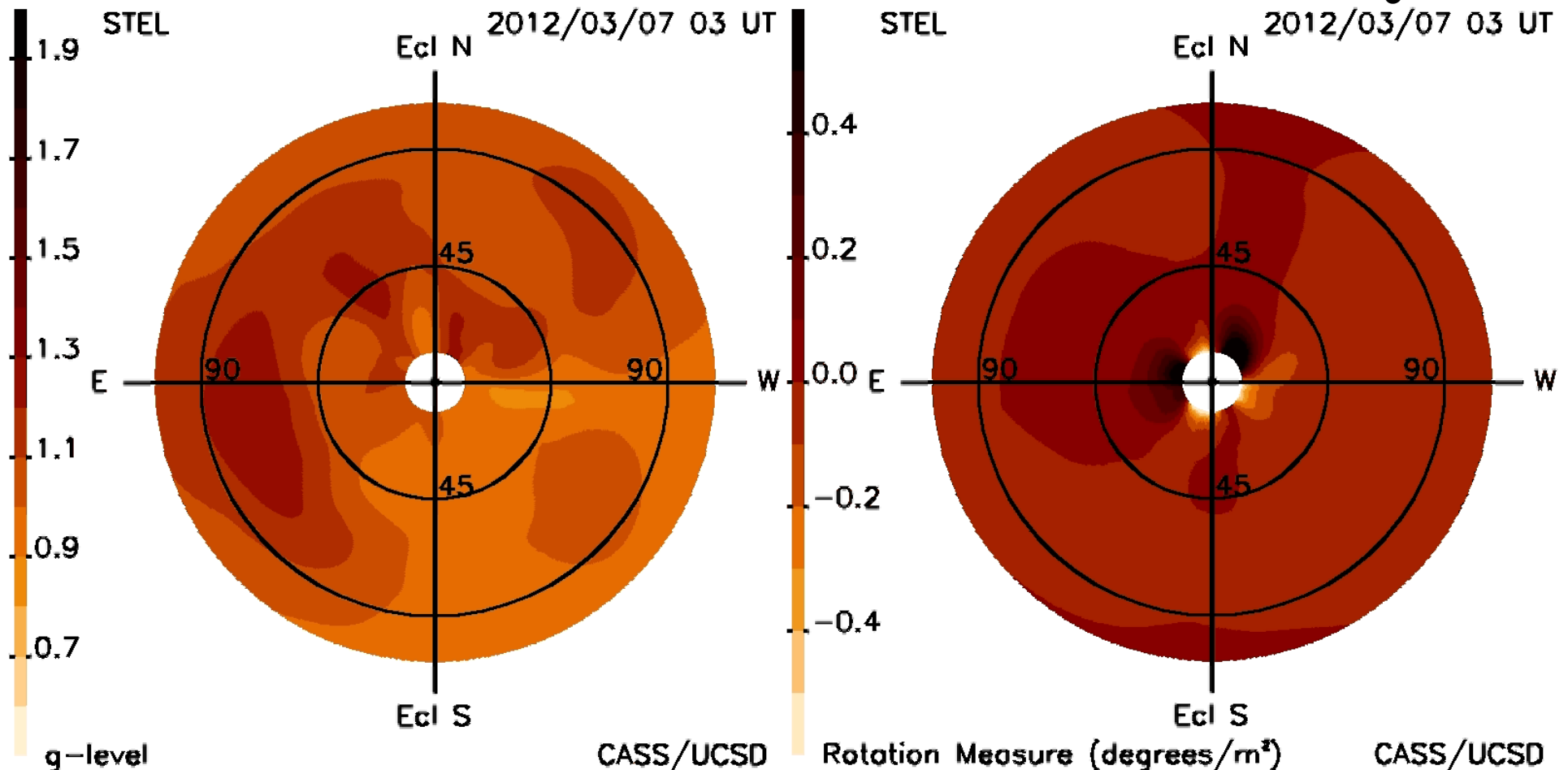


3-D reconstructions of Carrington rotation (CR) 2121 showing a CME of interest from 07 March 2012 launched around 01:00UT.



# Heliospheric Tomography

$$\Phi = \lambda^2 \int n_e \bar{\mathbf{B}} \cdot \bar{\mathbf{d}\mathbf{s}}$$



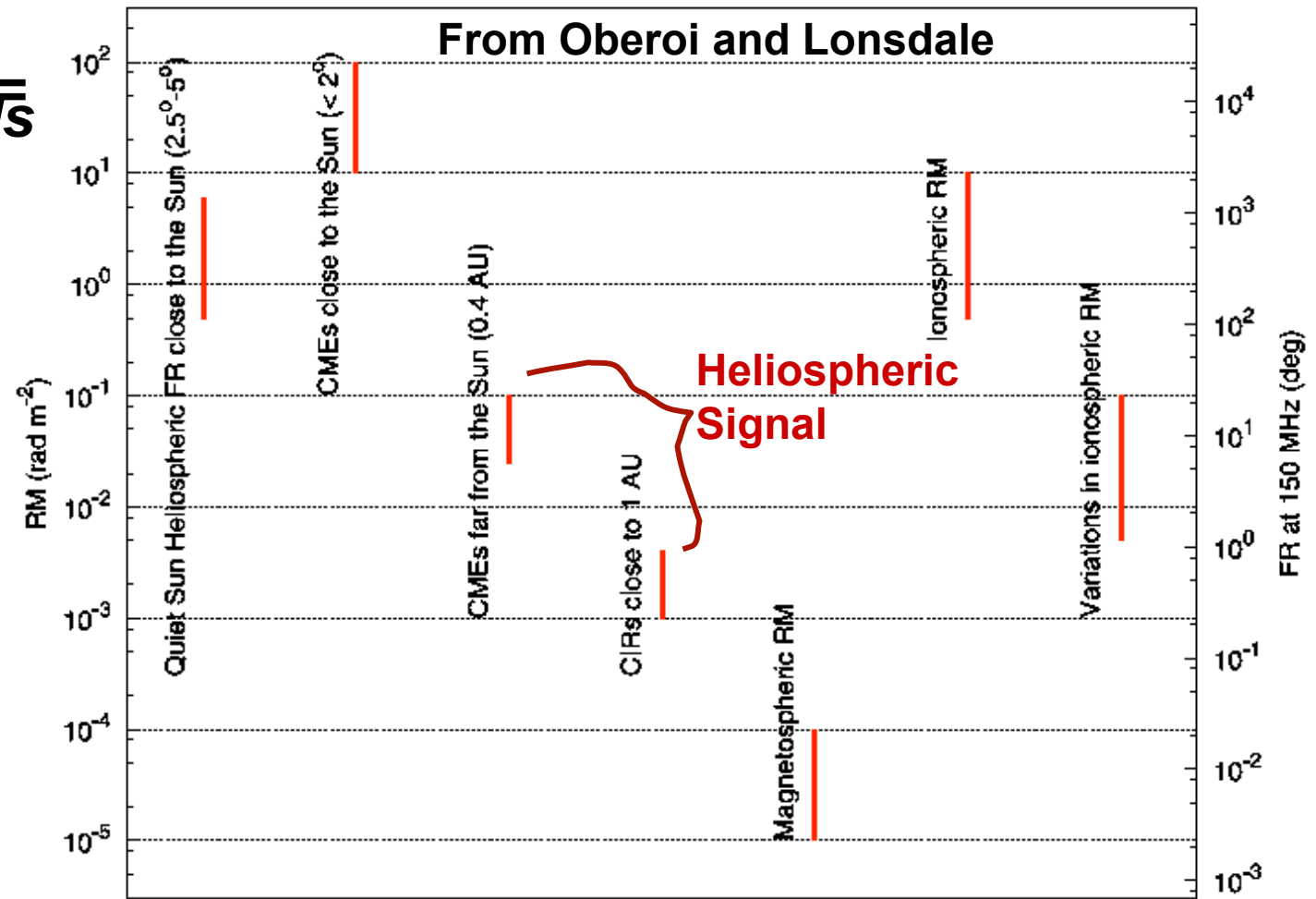
The same period extracted from CR2121 comparing IPS *g*-level fisheye sky map (left) with that of reconstructed RM from ambient magnetic fields (right) perturbed by the CME.

# Heliospheric Tomography

Oberoi and Lonsdale, 2012, *Radio Science*, 47, RS0K08, doi:10.1029/2012RS004992.

## Faraday rotation signals at low frequency

$$\Phi = \lambda^2 \int n_e \bar{\mathbf{B}} \cdot d\bar{\mathbf{s}}$$



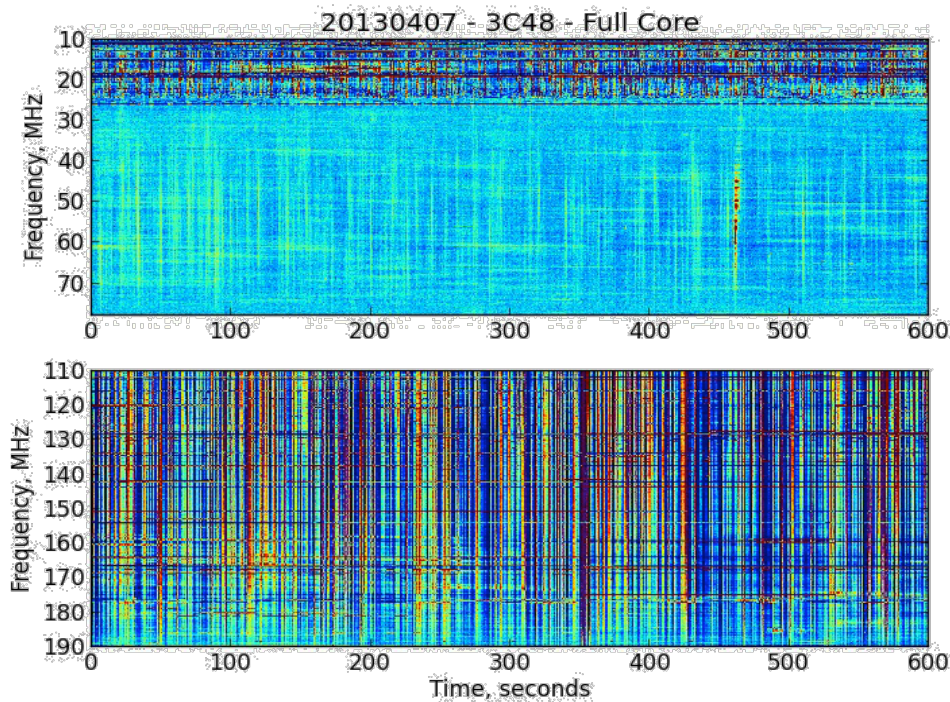
# Heliospheric Tomography

**Better IPS data**

# Heliospheric Tomography

## Future Potential – Better IPS Data

### LOFAR (Western Europe)



### LOFAR IPS 3C48 Signal



(Some parts of the LOFAR system are now operating - Richard Fallows, Mario Bisi are involved. IPS tests are ongoing.)



# Heliospheric Tomography

## KSWC and IPS array





# Heliospheric Tomography

## IPS Workshop 2013

(November 23-24, 2013, STELab, Japan following CAWSES II)

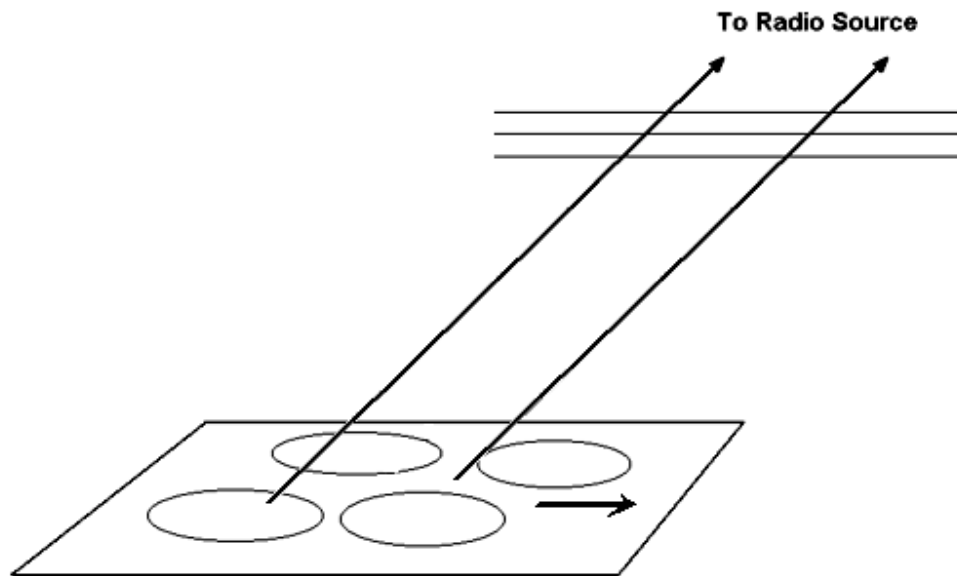
### Objectives:

- 1) Standardize the IPS measurement output for external use.
- 2) Discuss the best way to provide IPS velocities and g-level from a single site IPS system
- 3) Discuss current progress on heliospheric Faraday rotation measurement.

# Heliospheric Tomography

## DATA

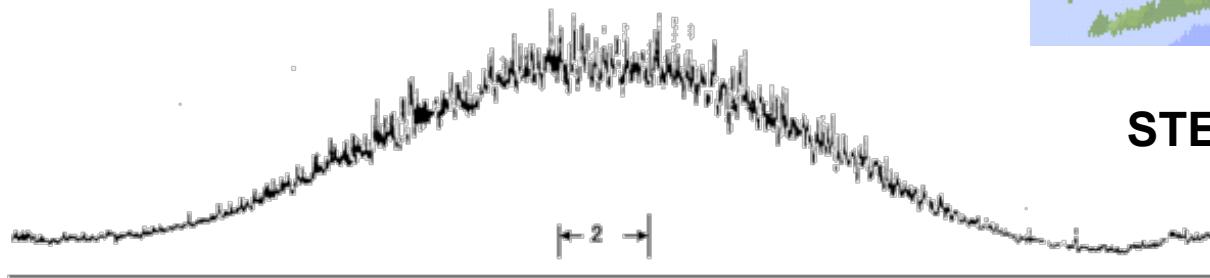
### IPS Heliospheric Analyses (STELab)



IPS line-of-sight response



STELab IPS array systems



# Heliospheric Tomography

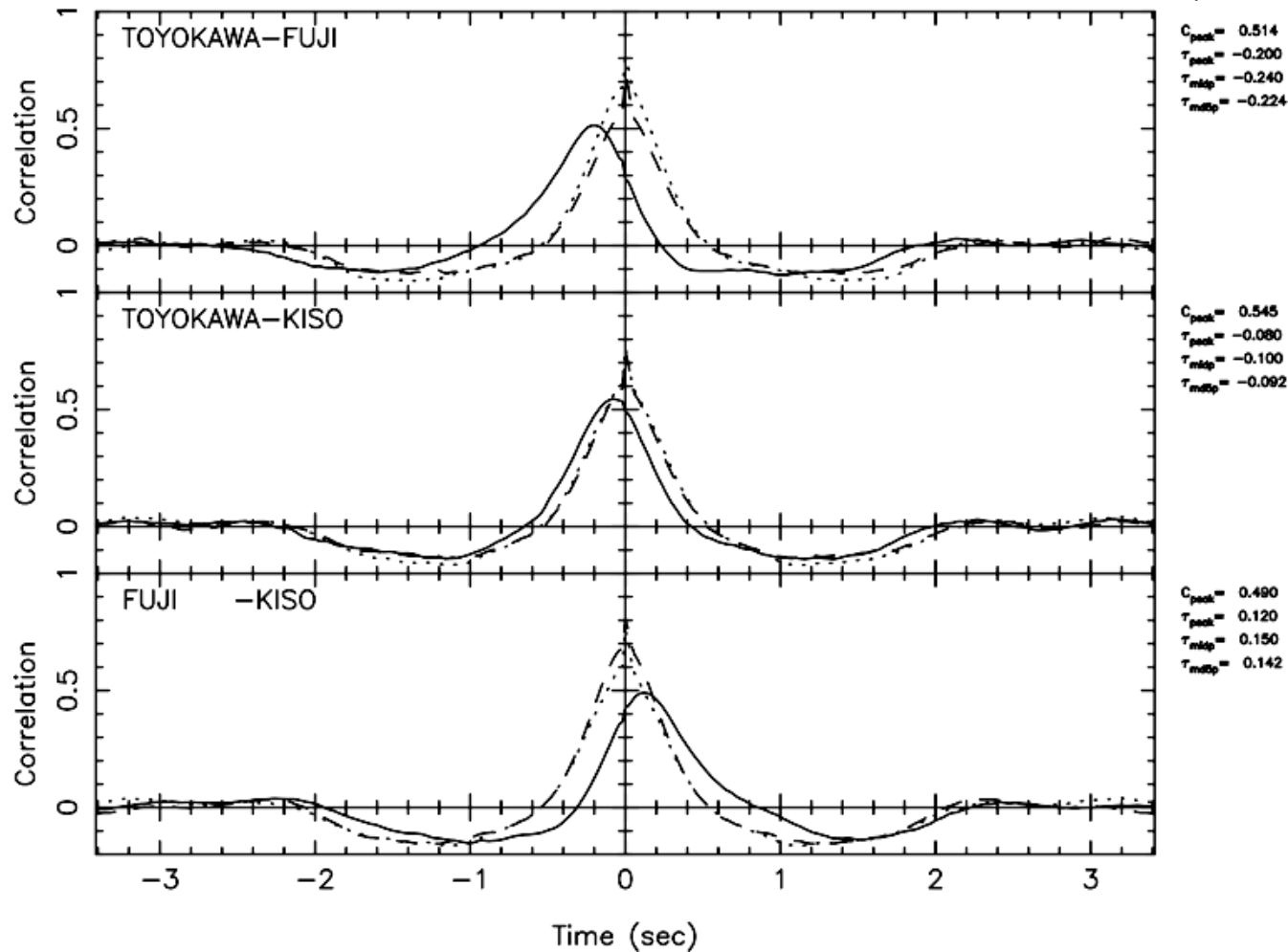
## Cross Correlation Analysis with

(Courtesy of  
M. Tokumaru)

## Upgraded STEL IPS System

3C283 2010/10/29 1.56UT

Tokumaru, M., et al., 2013, AOGS 2013  
Presentation, June, Brisbane, Australia.



Solid lines: Cross  
Correlation  
Dashed/Dotted  
lines: Auto  
Correlation

Taking account of  
the baseline  
geometry, we  
determine the  
solar wind speed.  
For this case, we  
obtain  
 **$V=522\pm 3$  km/s.**  
Here, we assume  
radial flow and the  
anisotropy.

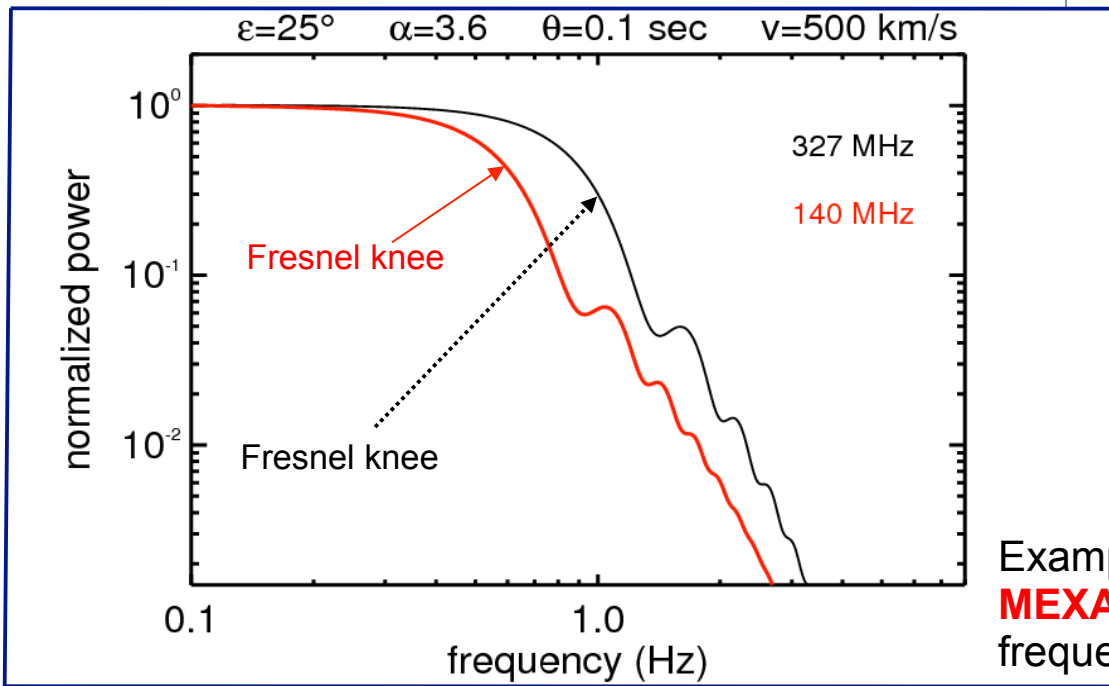
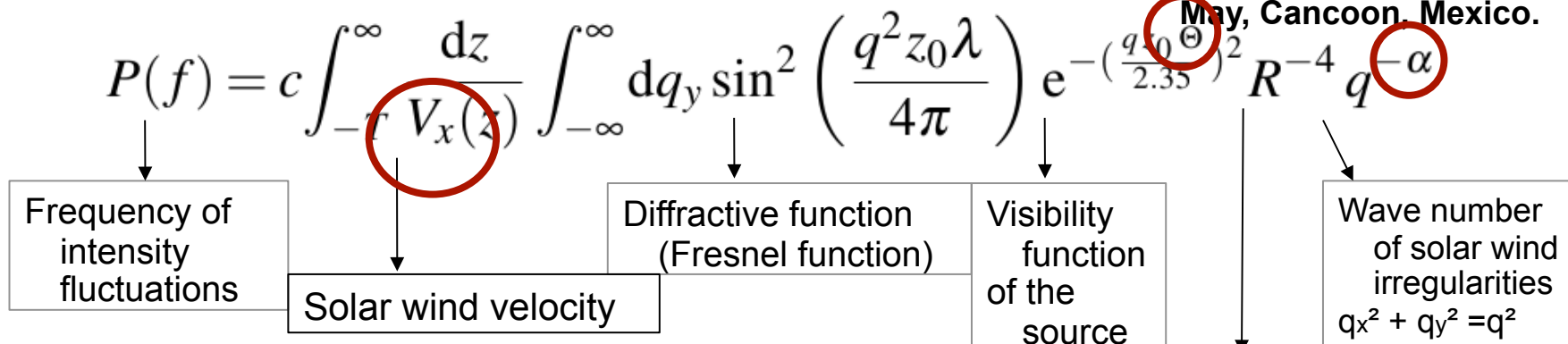
# Heliospheric Tomography

## A model of the power spectra of density fluctuations

To calculate solar wind velocities using a single IPS station, we use a theoretical power spectrum: an integration of scattering layers along the line of sight ( $z$ ).

The spectrum depends on:  $\lambda$ ,  $\epsilon$ ,  $v$ ,  $\Theta$ ,  $\alpha$  (isotropic medium).

Mejia-Ambroz, J., et al., 2013,  
AGU 2013 Presentation,  
May, Cancun, Mexico.



Heliocentric distance at the region of IPS (point P)

$\alpha \approx 3.5 \pm 0.5$   
Turbulence spectrum follows a potential law

Example of the model (log-log):  
**MEXART** and **STEL** observing frequencies.

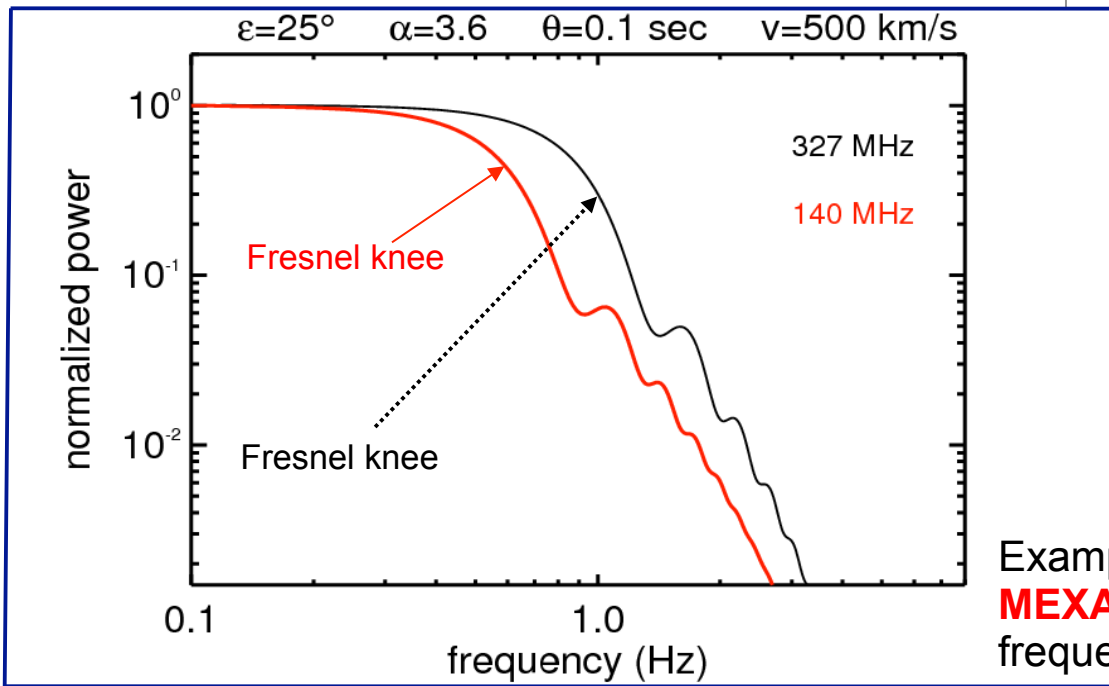
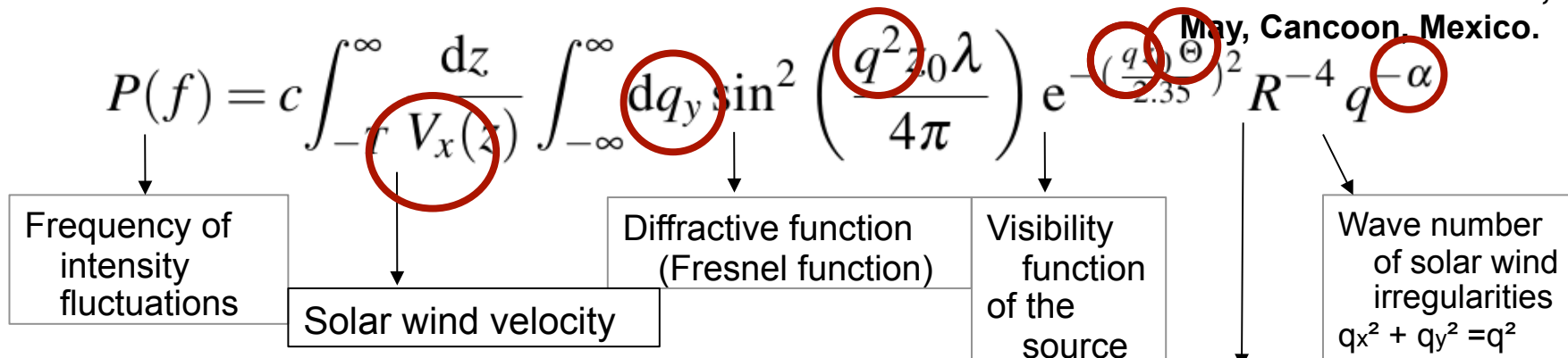
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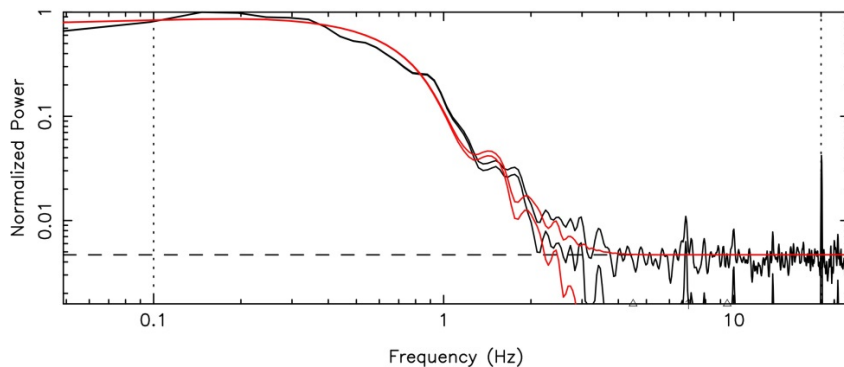
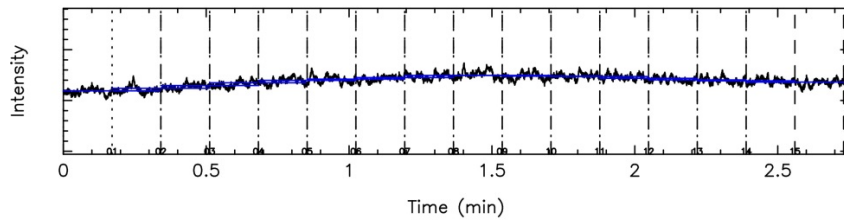


# Heliospheric Tomography

## Comparison between Spectrum Fitting and Cross Correlation Methods

3C273 2012/9/3

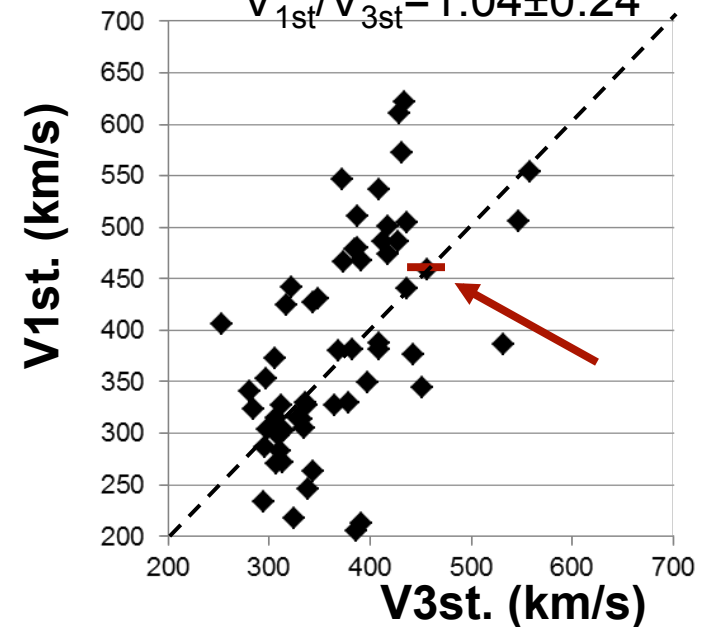
TOYOKAWA 3C273 2012/09/03(247)13:28:02-13:30:47JST 95Rs



from IPS obs. for 3C273 in 2012

Correlation  $\sim 0.47$

$$V_{1st}/V_{3st} = 1.04 \pm 0.24$$



Spectrum Fitting Method  
(Single-station meas.)

Speed  $V_{1st} = 459$  km/s

Axial Ratio = 1.07

Spectral Index = 3.8



Cross Correlation Method  
(3-station meas.)

Speed  $V_{3st} = 457 \pm 13$  km/s

(Courtesy of  
M. Tokumaru)

Tokumaru, M., et al., 2013, AOGS 2013  
Presentation, June, Brisbane, Australia.

# Heliospheric Tomography

## Summary:

### **IPS analysis:**

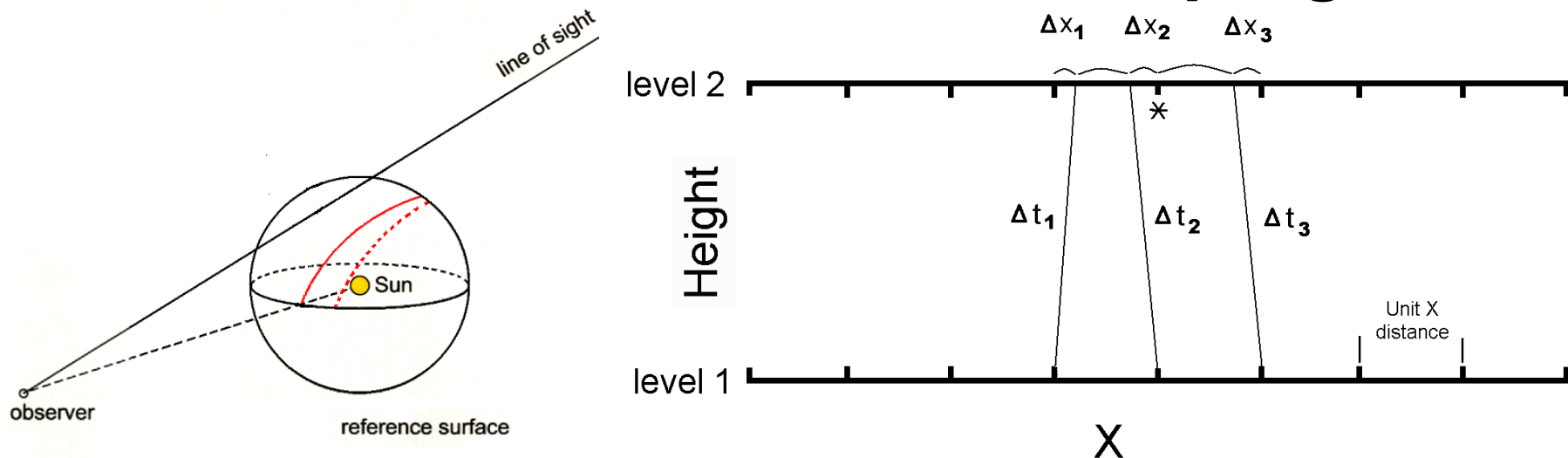
**A ground-based technique. Can provide low-resolution velocity and density analysis, and accurate forecasts of time-variable heliospheric structure.**

**Other ground-based analyses such as heliospheric Faraday rotation can possibly be provided from the same radio systems. The IPS analysis can provide input to 3D-MHD models. Better, and more abundant IPS data, should be available in the near future.**

# Heliospheric Tomography

Jackson, B.V., et al., 2008, *Adv. in Geosciences*, 21, 339-360.

## The UCSD 3D-reconstruction program



The “**traceback matrix**” (any solar wind model works)  
In the traceback matrix the location of the upper level data point (starred) is an interpolation in x of  $\Delta x_2$  and the unit x distance –  $\Delta x_3$  distance or  $(1 - \Delta x_3)$ . Similarly, the value of  $\Delta t$  at the starred point is interpolated by the same *spatial* distance. Each 3D traceback matrix contains a regular grid of values  $\Sigma \Delta x$ ,  $\Sigma \Delta y$ ,  $\Sigma \Delta t$ ,  $\Sigma \Delta v$ , and  $\Sigma \Delta m$  that locates the origin of each point in the grid at each time and its change in velocity and density from the heliospheric model.

# Heliospheric Tomography used to Provide Velocities, Densities, and Vector Magnetic Fields



**B.V. Jackson**  
and

**H.-S. Yu, P.P. Hick, A. Buffington, D. Odstrcil**  
*Center for Astrophysics and Space Sciences,  
University of California at San Diego, LaJolla, CA, USA*

<http://smei.ucsd.edu/>

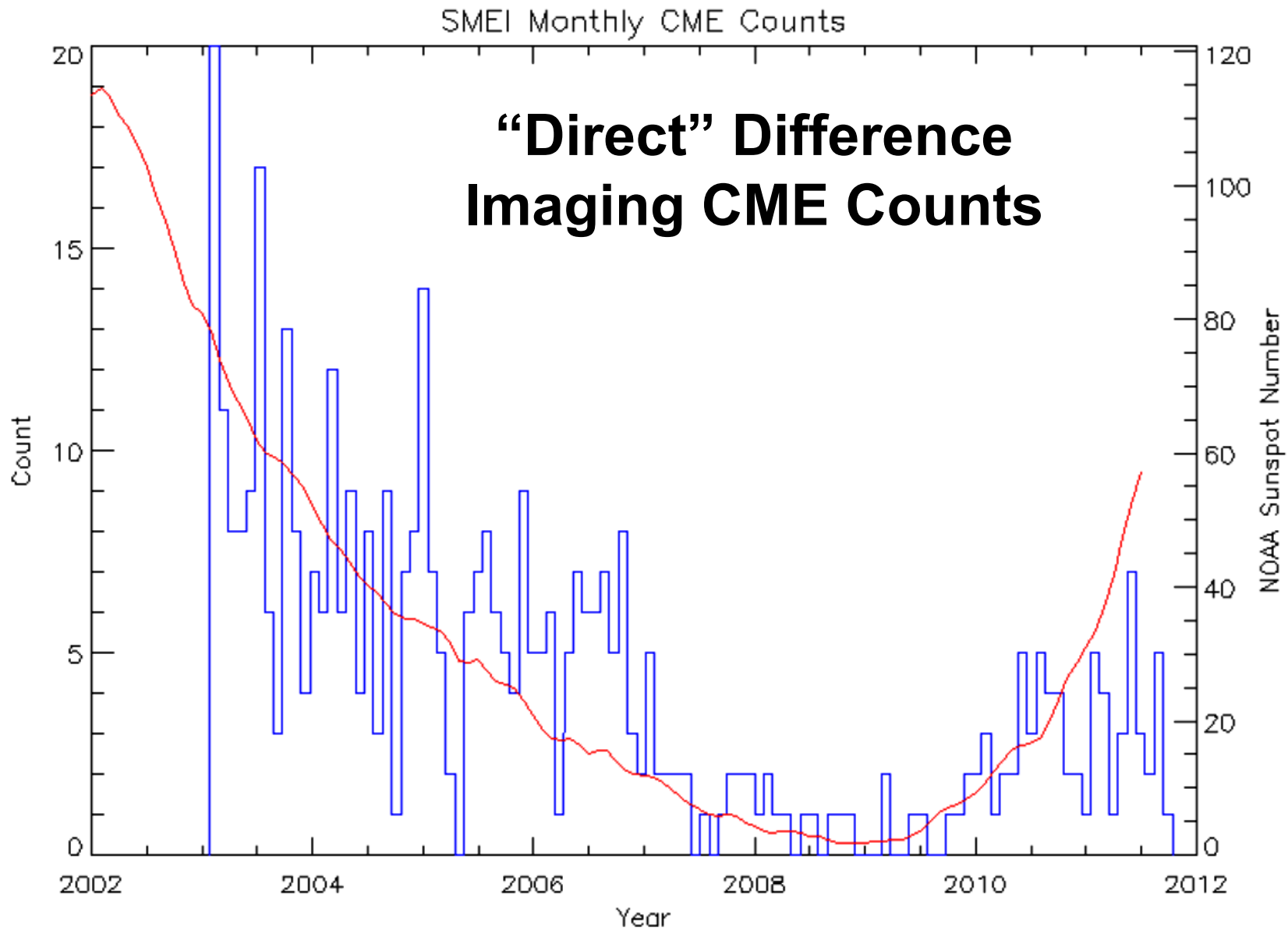
<http://ips.ucsd.edu/>

# Heliospheric Tomography

## Solar Mass Ejection Imager (SMEI) Analysis



# Heliospheric Tomography

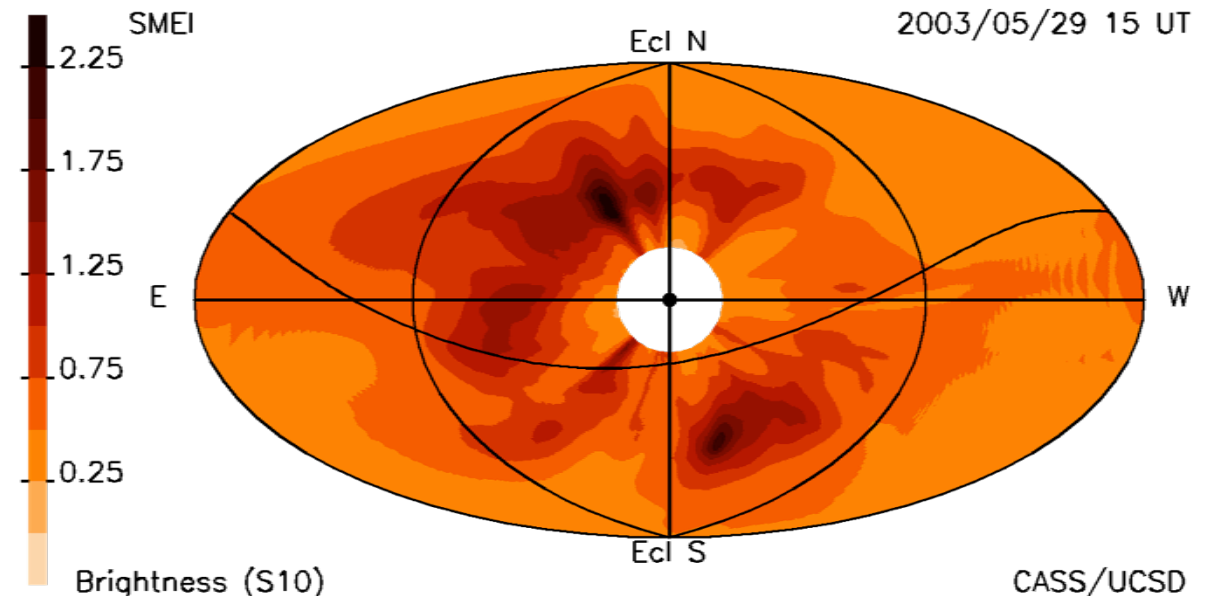
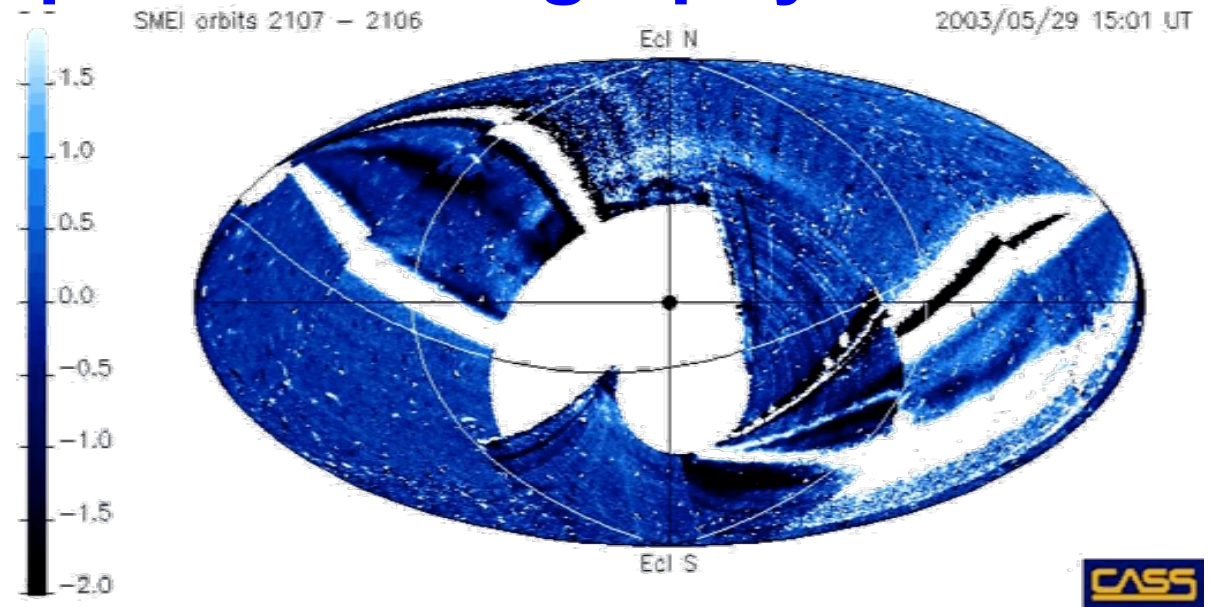


# Heliospheric Tomography

## SMEI

### 2003 May 27-28 CMEs

Brightness from the 28  
May 2003 halo CMEs:  
Direct difference (top),  
3D-reconstruction  
(bottom).

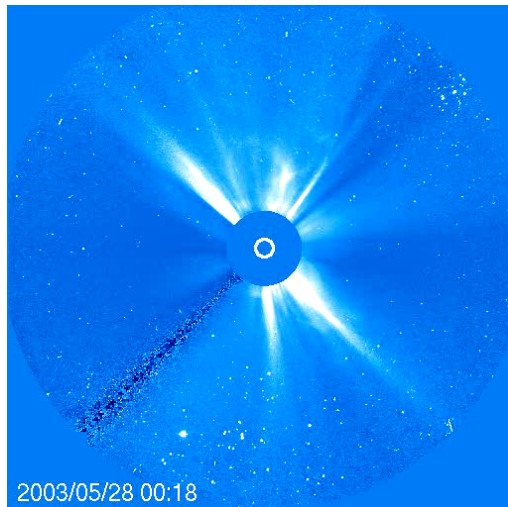


# Heliospheric Tomography

Jackson, B.V., et al., 2008, *J. Geophys Res.*, 113, A00A15, doi:10.1029/2008JA013224

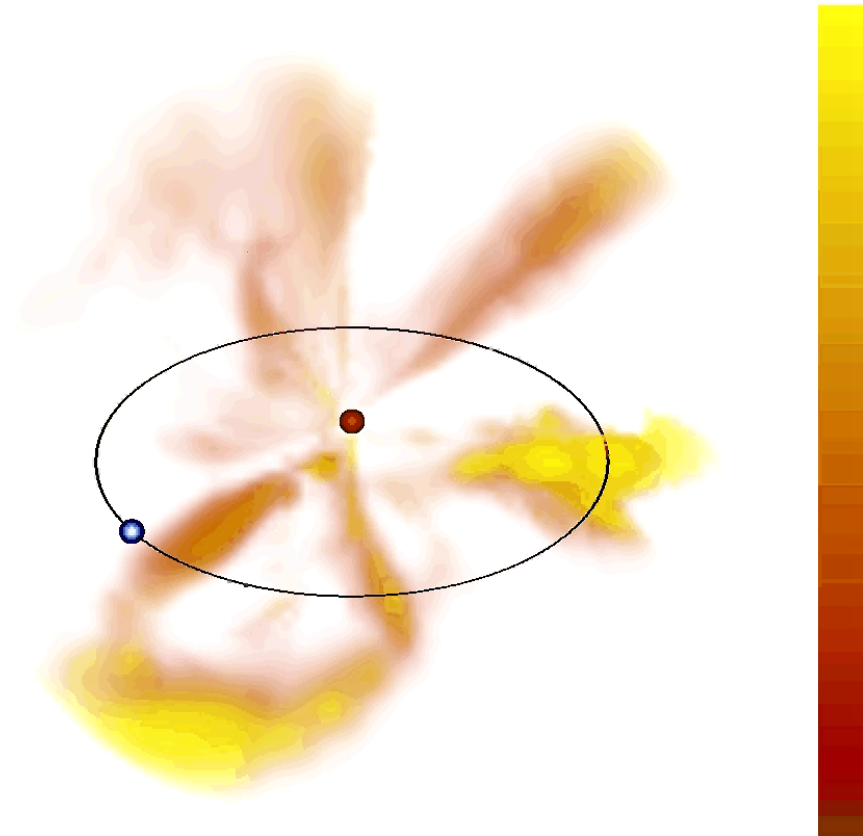
## 2003 May 27-28 CME events

SMEI density 3D reconstruction of the 27-28 May 2003 halo → CMEs as viewed from 30° above the ecliptic plane about 30° west of the Sun-Earth line.



LASCO C3

2003/05/27 00



CASS ← UCSD SMEI

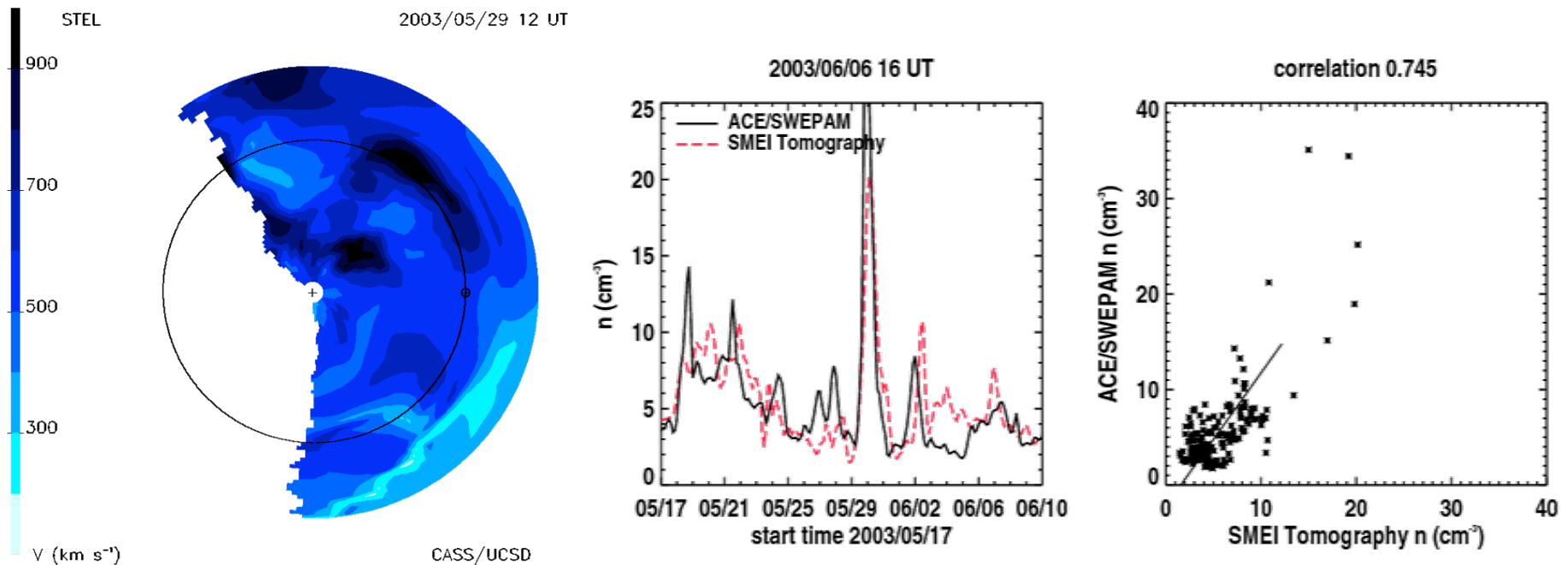
$n^{\text{norm}}$  ( $\text{cm}^{-3}$ ) 5

SMEI density (remote observer view) of the 27-28 May 2003 halo CMEs

# Heliospheric Tomography

Jackson, B.V., et al., 2008, *J. Geophys Res.*, 113, A00A15, doi:10.1029/2008JA013224

## 27-28 May 2003 CME event period



Full SMEI data set, 6-hour cadence, 3° x 3° lat, long

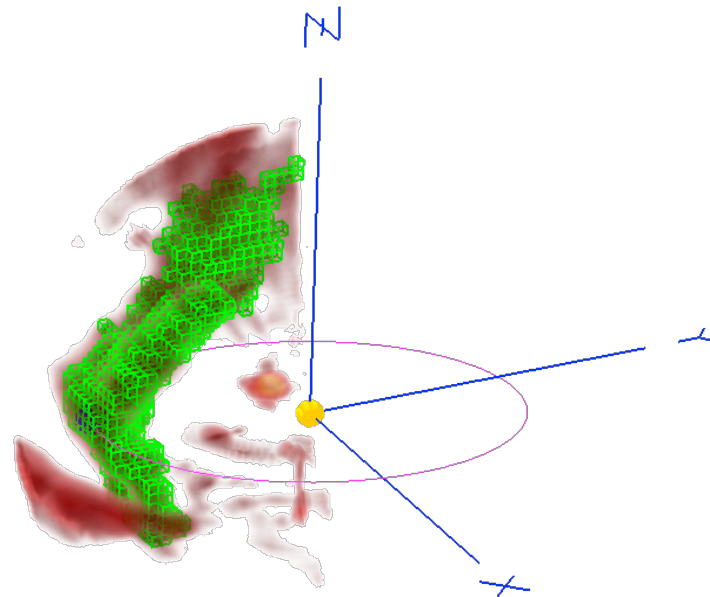
**SMEI proton density reconstruction for the 27-28 May 2003 halo CME sequence. Reconstructed and ACE L2 *in-situ* densities are compared over one Carrington rotation.**

# Heliospheric Tomography

Jackson, B.V., et al., 2008, *J. Geophys Res.*, 113, A00A15, doi:10.1029/2008JA013224

## 2003 May 27-28 CME events

### CME mass



Excess Mass(g): 1.844E+016  
Total Mass(g): 2.491E+016  
Ambient (g): 6.470E+015  
Energy (ergs): 3.448E+031

2003/05/30 00:00 UT

Volume: 0.144 AU<sup>3</sup>



# Heliospheric Tomography

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smei.ucsd.edu/new\_smei/data&images/data&images.html

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**Available Data**

- Daily Averages
- 3D Reconstructions**
  - Fisheye
  - Hammer-Aitoff
  - Ecliptic Cuts
  - Meridional Cuts
  - Remote View
  - Error Cuts
- Boston College CME Lists
  - CME Summary List
  - AICMED Summary List
- Volumetric Data
- Comet Studies
- Stellar Time Series

Carrington Rotations vs. GMT:

Enter a C.R. Number.

Enter a date (y/m/d).

**Ecliptic Cut**

**Density**

SMEI 2003/05/30 00 UT

$n^{\text{norm}}$  (cm<sup>-3</sup>)

CASS/UCSD

**Velocity**

STEL 2003/05/30 00 UT

V (km s<sup>-1</sup>)

CASS/UCSD

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2003		<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>
2004	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>
2005	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>
2006	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>	<a href="#">Den.</a> <a href="#">Vel.</a>

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