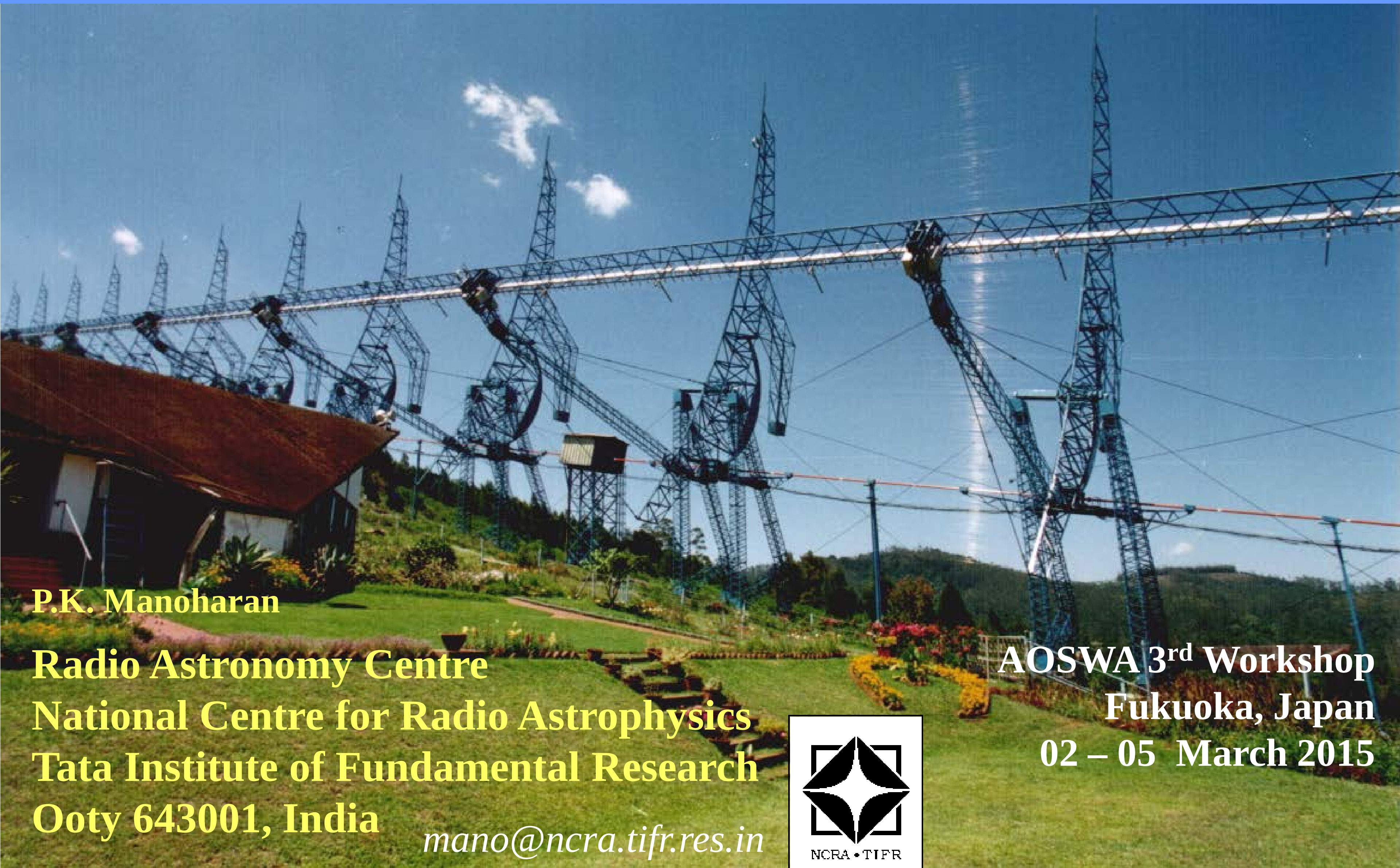
Space Weather Effects of Solar Wind Transients in the Sun - Earth Distance – IPS Studies



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National Centre for Radio Astrophysics
Tata Institute of Fundamental Research

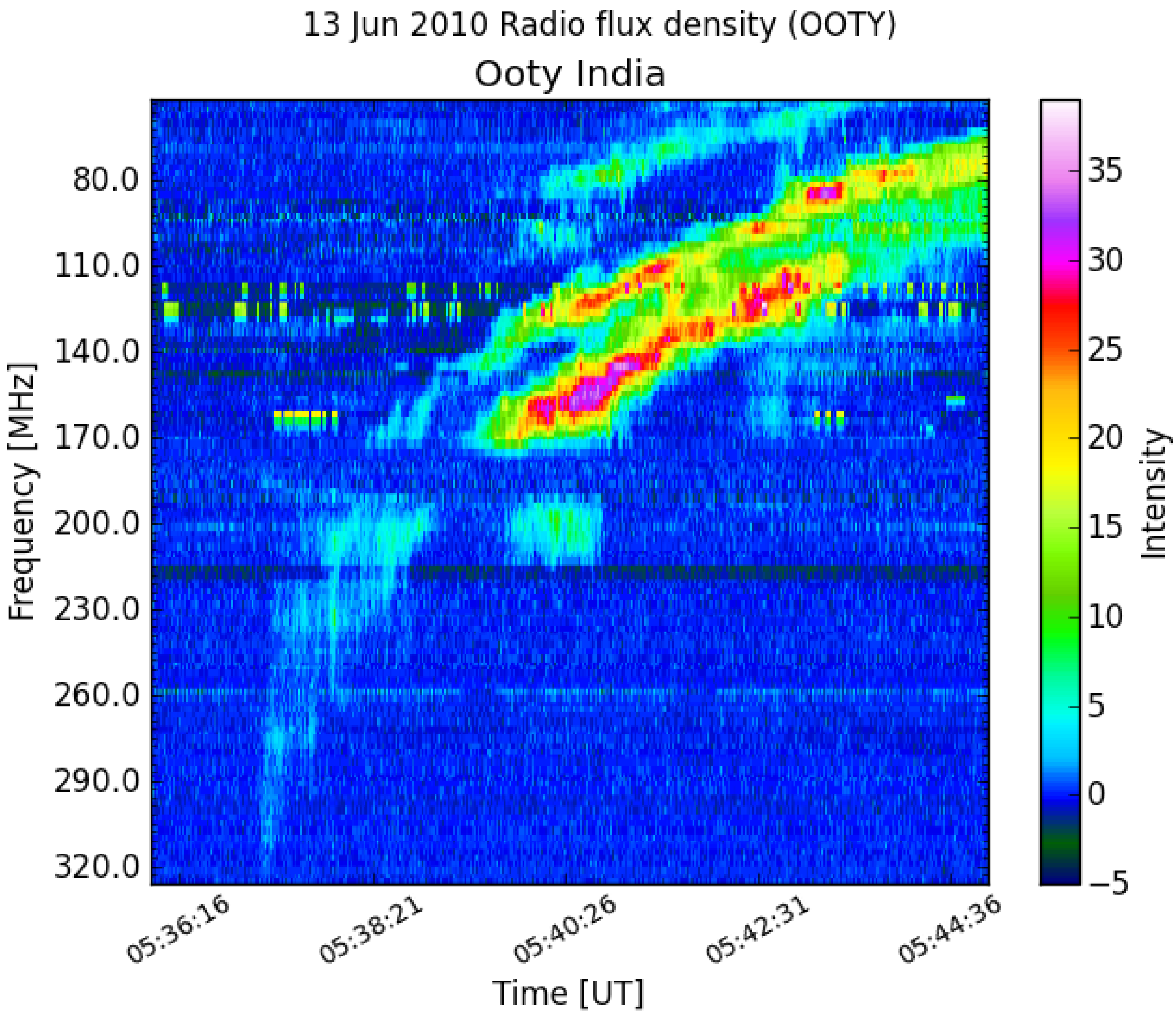
Major Observing Facilities

Giant Metrewave Radio Telescope
(multi-frequency synthesis imaging system)

Ooty Radio Telescope
(solar spectrograph)

- **530m (N-S) x 30m (E-W) – east-west tracking of ~9.5 hours**
- **North-South beam steering (± 65 deg. declination)**
- **High sensitivity, S/N ~ 25 (1s integration, BW 4 MHz)**
  - **Observes ~1000 radio sources per day**
- **Ooty Radio Telescope is upgraded (BW ~40 MHz, 27 deg coverage)**

Ooty Callisto – Part of Worldwide Radio Network



Space Weather Forecasts: Required Solar, IPM Measurements and Models

Magnetic Field Imprint & Spatial Geometry

Photospheric & H-alpha Measurements

Source Region Identification

Full Disk EUV Observations

CME Spatial Structure, Propagation & Interaction with Ambient Corona

Coronagraph and IPS (essential) Observations

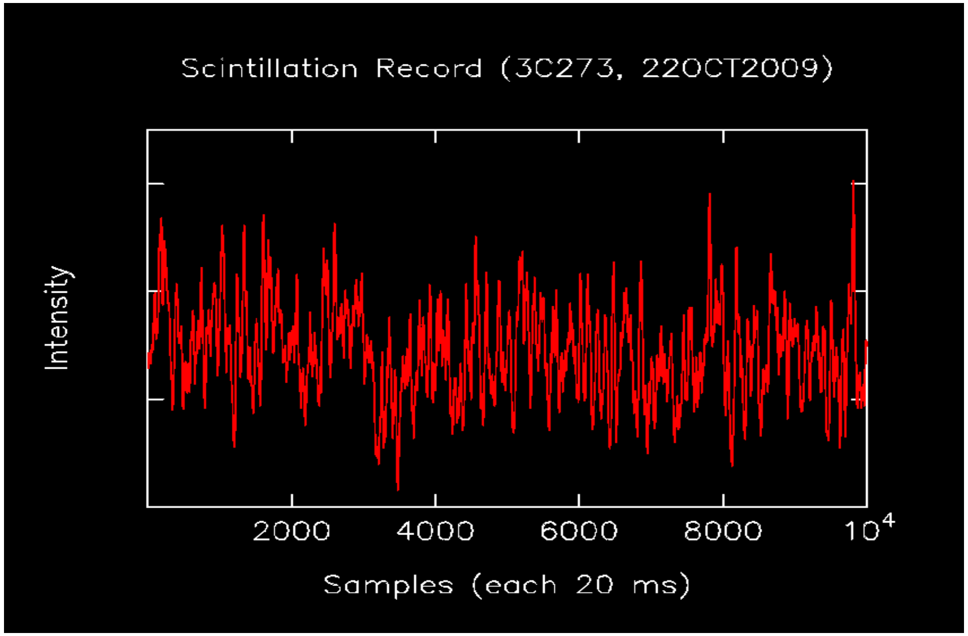
Elliptical Cone Model & Expansion/Propagation Models

Space Weather Consequences

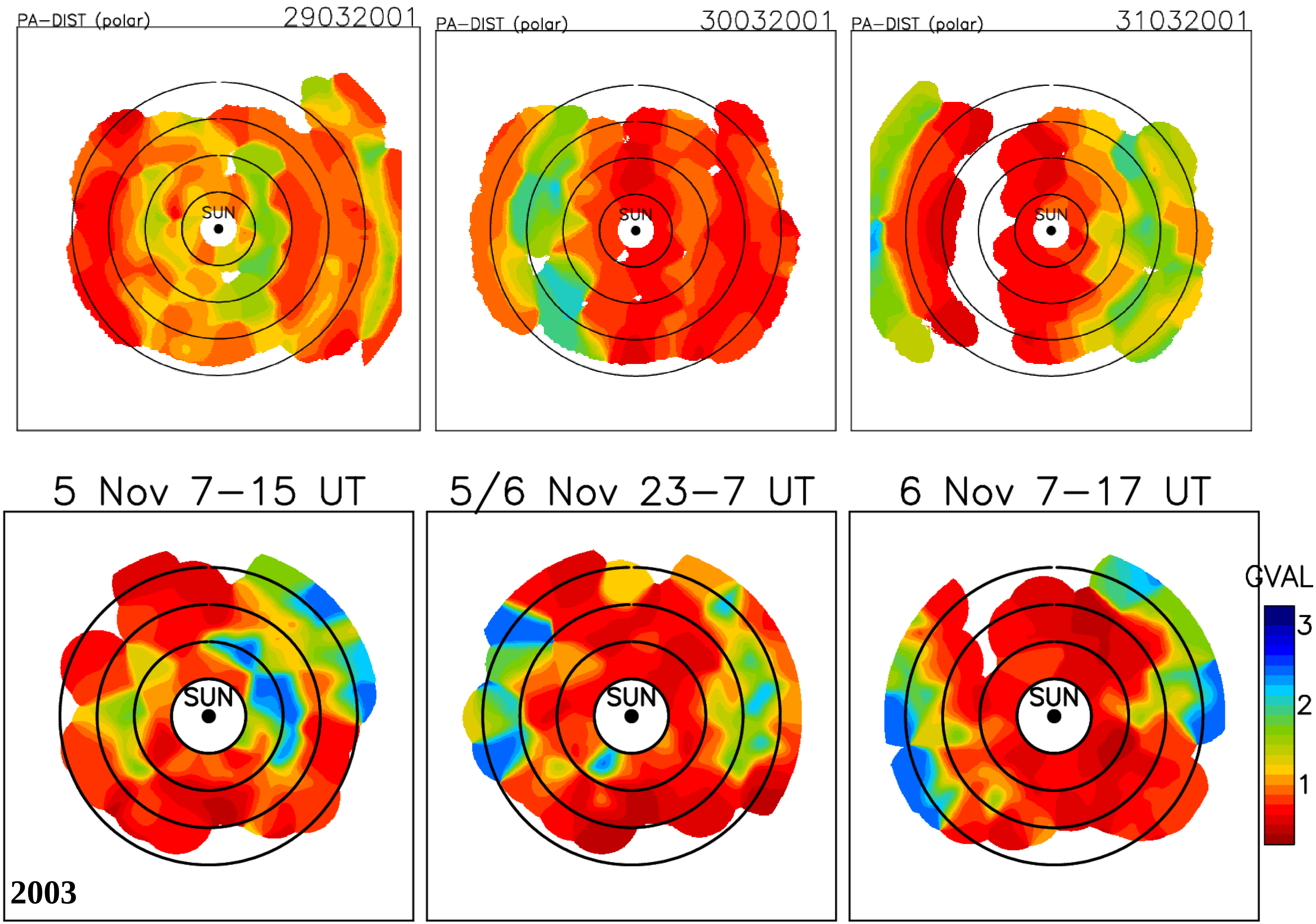
Models for Interplanetary Evolution (Expansion and Interaction)

Interplanetary scintillation

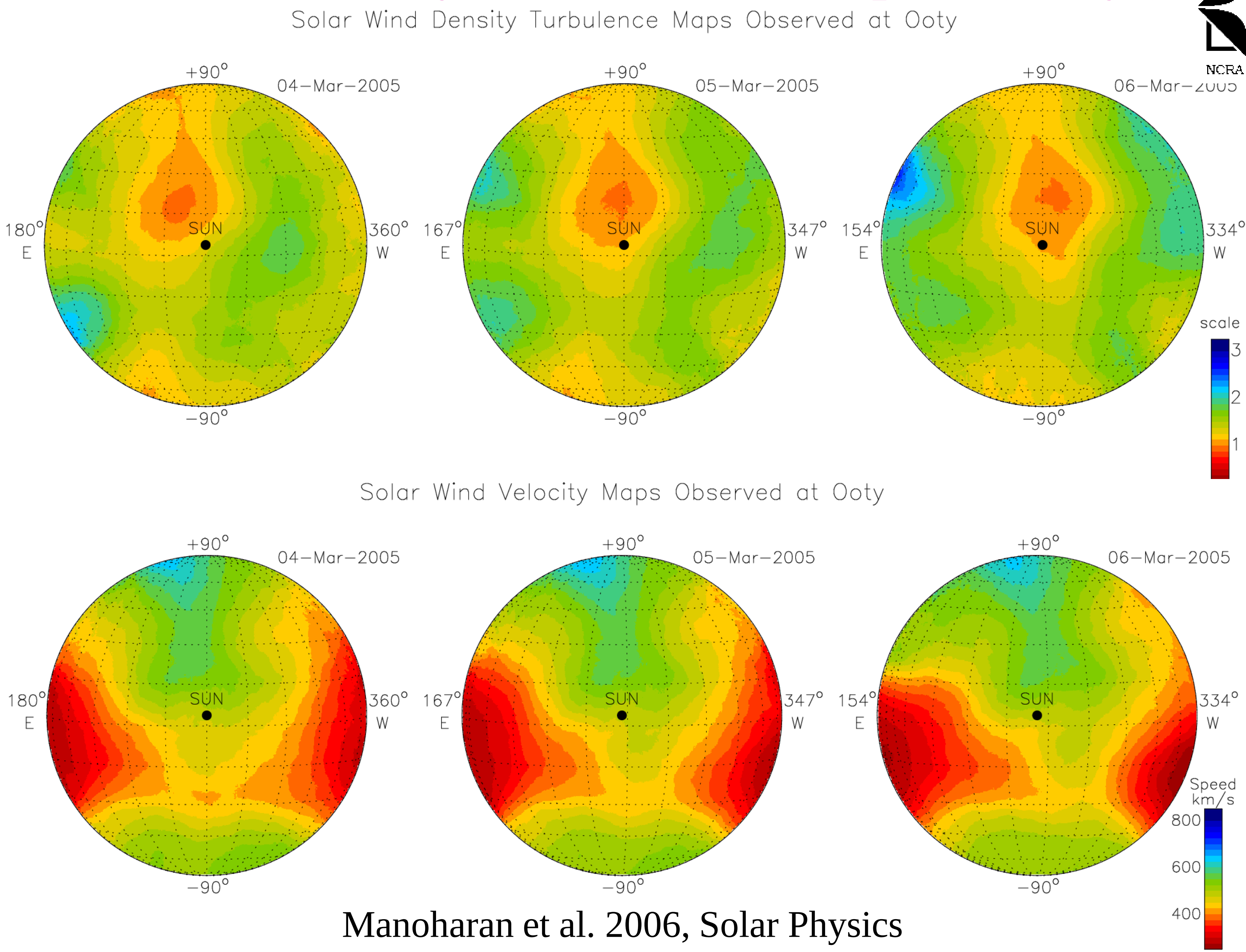
Ooty IPS Observations



- **Measurements on a large number of radio sources in a day (different line-of-sight cuts in 3D heliosphere) – allow speed and Δne estimates – provide couple of snap shot images of the inner heliosphere per day.**
- **At Ooty more than 1000 radio sources are observed per day**
  - **Computer assisted tomography (CAT) developed by Bernie Jackson and his group at UCSD can provide line of sight integral corrected solar wind**
  - **The time-dependent CAT (e.g., Jackson et al. 2009) can been employed to reconstruct the solar wind density and velocity structures.**

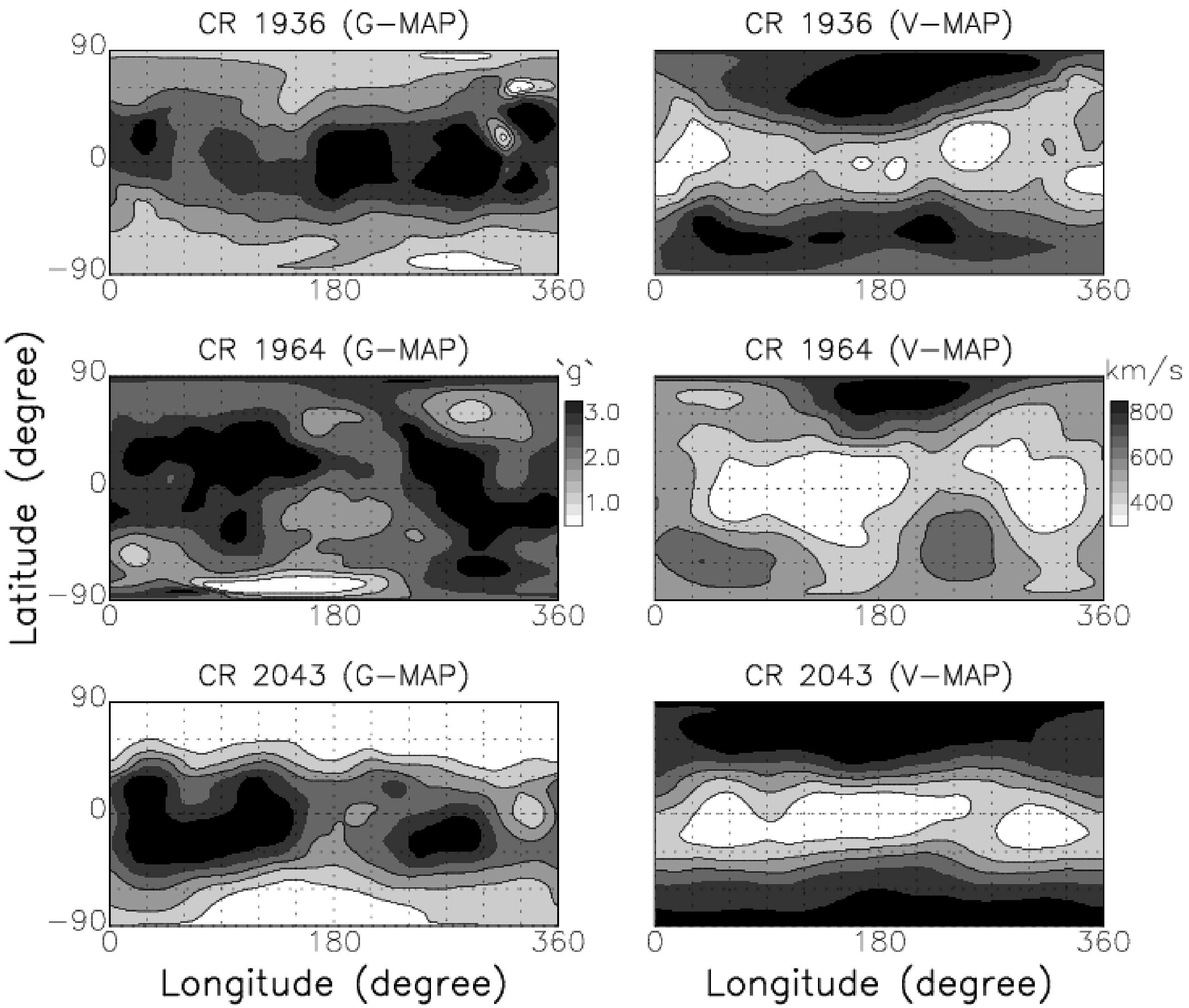

PA–DIST (polar)
29032001
SUN
PA–DIST (polar)
30032001
SUN
PA–DIST (polar)
31032001
SUN
5 Nov 7–15 UT
SUN
2003
5/6 Nov 23–7 UT
SUN
6 Nov 7–17 UT
SUN
GVAL
3
2
1

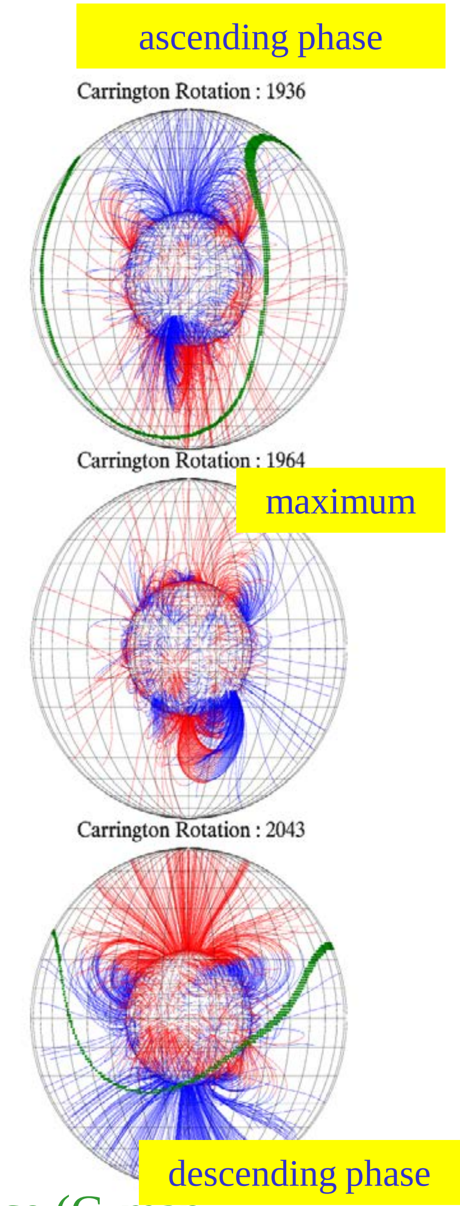
Solar Wind Density Turbulence and Speed (3 days)



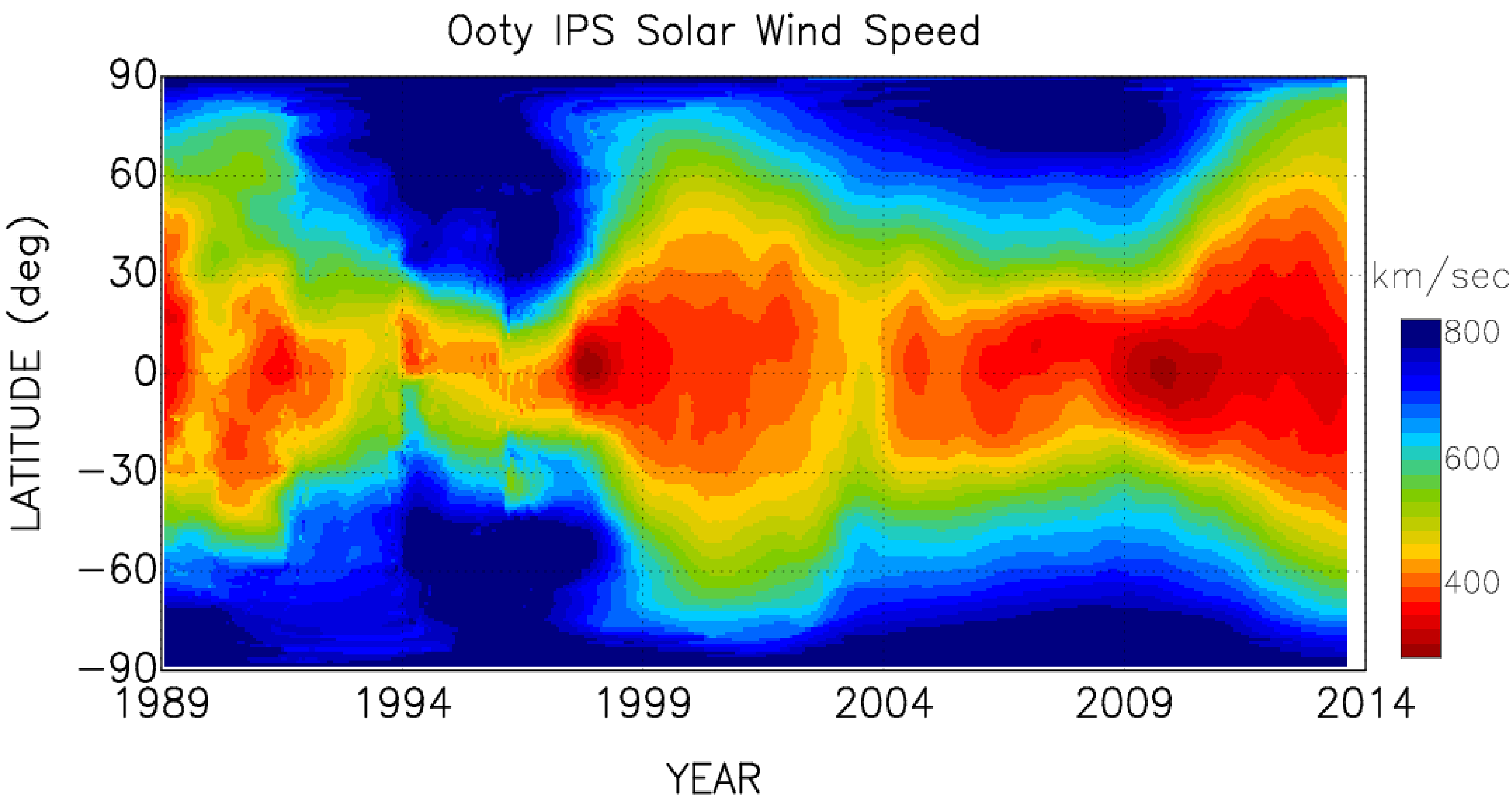
Manoharan et al. 2006, Solar Physics

Ooty IPS Synoptic Maps – Density Turbulence and Speed





Representative synoptic images of solar wind normalized density turbulence (G-map, left) and speed (v-map, middle) from Ooty IPS measurements for Carrington Rotations 1936, 1964, and 2043, respectively for ascending, maximum, and minimum phases of the solar cycle #23. At the right, extrapolated magnetic field images are shown.

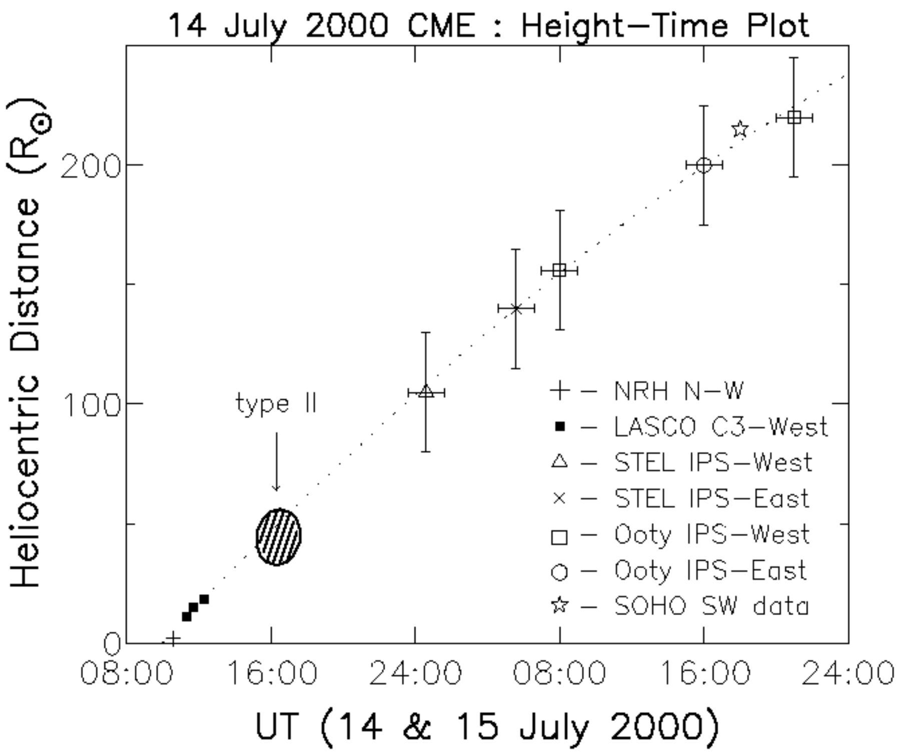


Ooty IPS Solar Wind Speed
90
60
30
0
−30
−60
−90
LATITUDE (deg)
1989
1994
1999
2004
2009
2014
YEAR
km/sec
800
600
400

Evolution of Coronal Mass Ejections
(Sun to 1 AU distance)

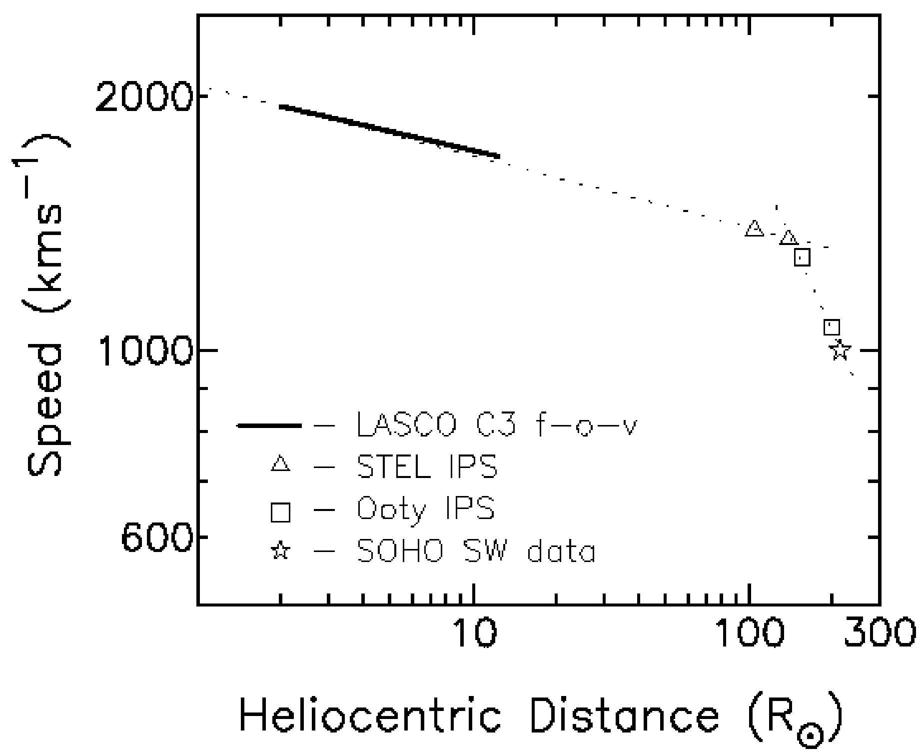
CME Propagation Speed (from Sun to Earth)

Height – Time plot



K.E. lost/dissipated within <100Rsun
~10^{32} erg

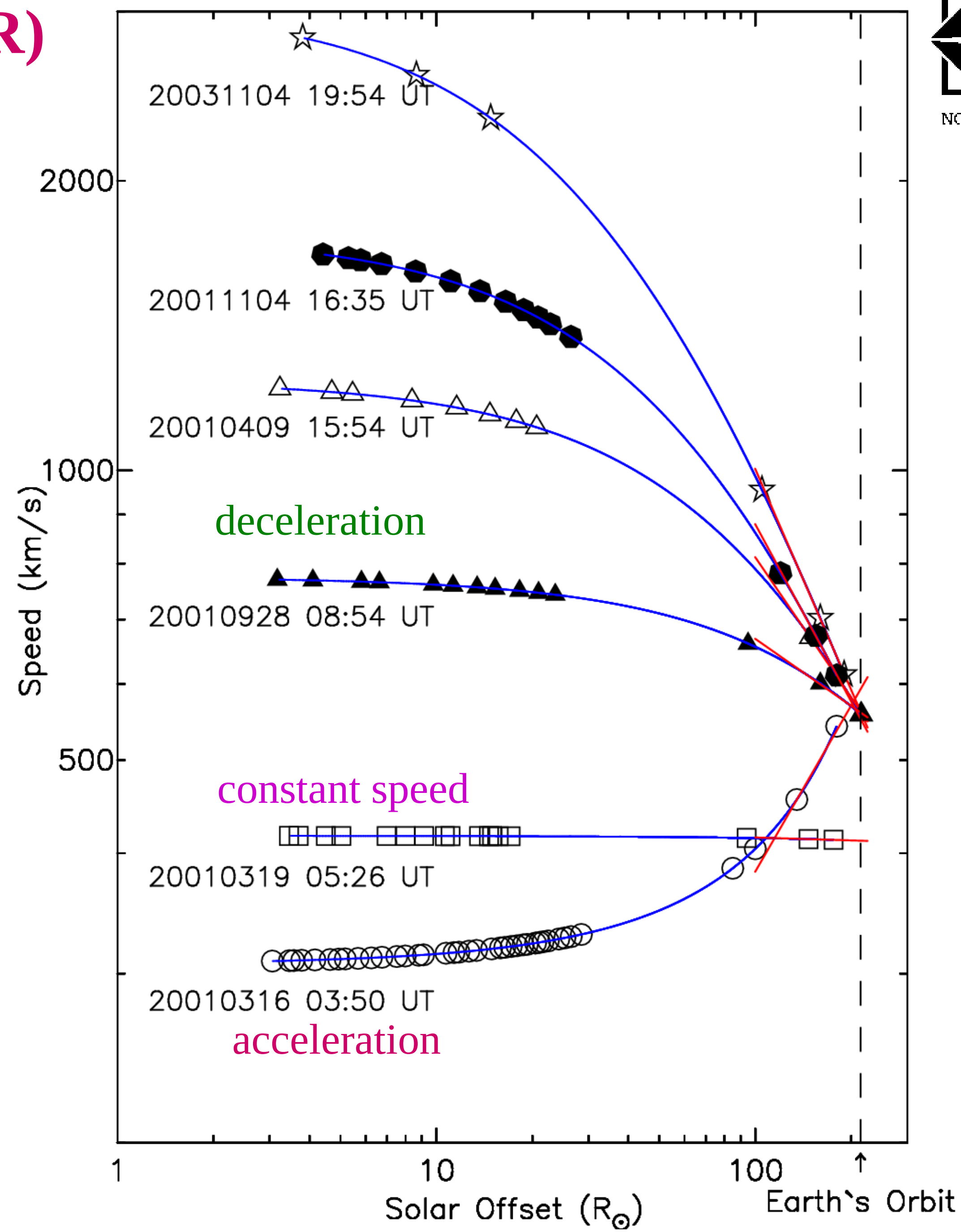
Radial Evolution of Speed



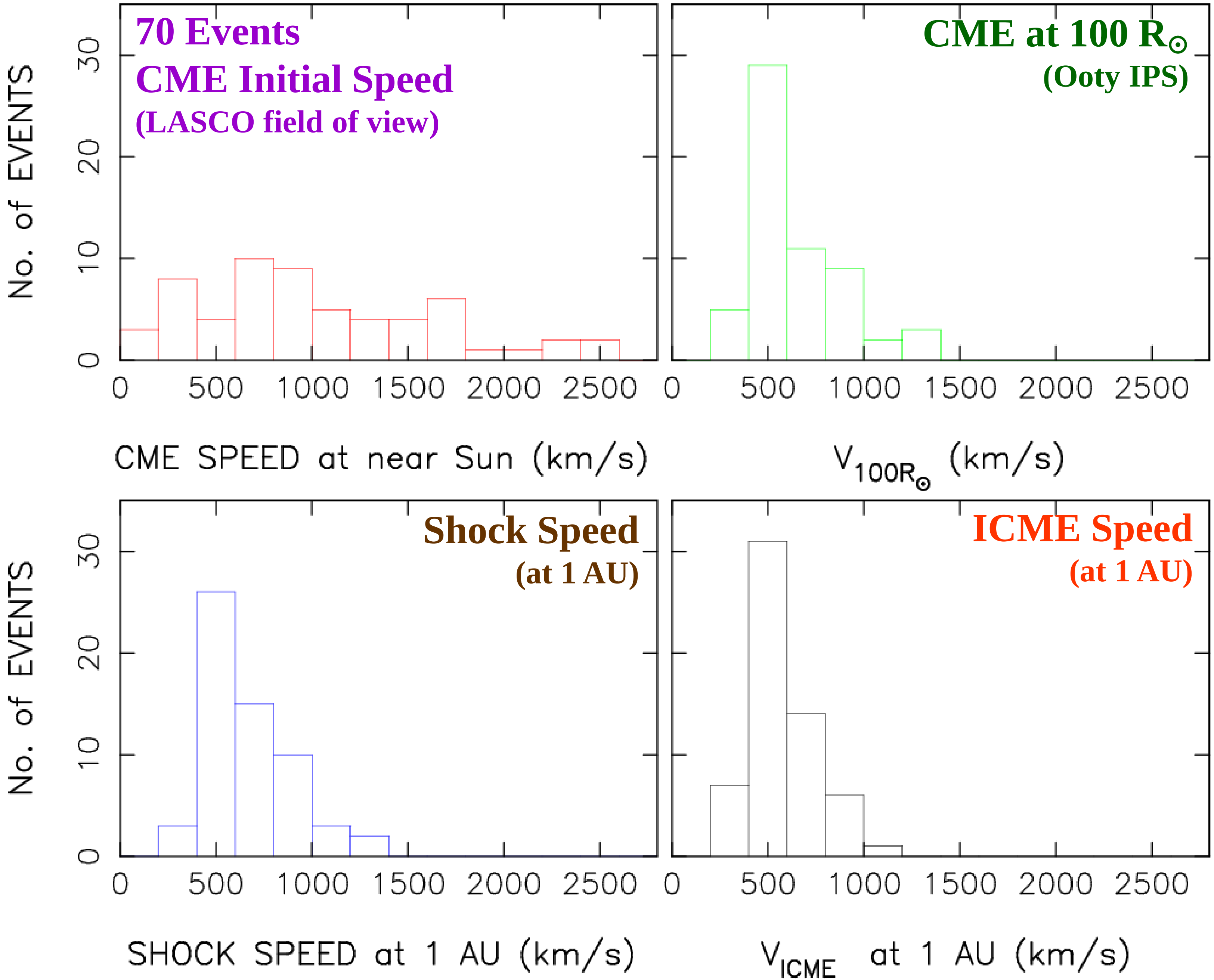
$V_{CME} \sim R^{-0.08}$ at R < 100 Rsun

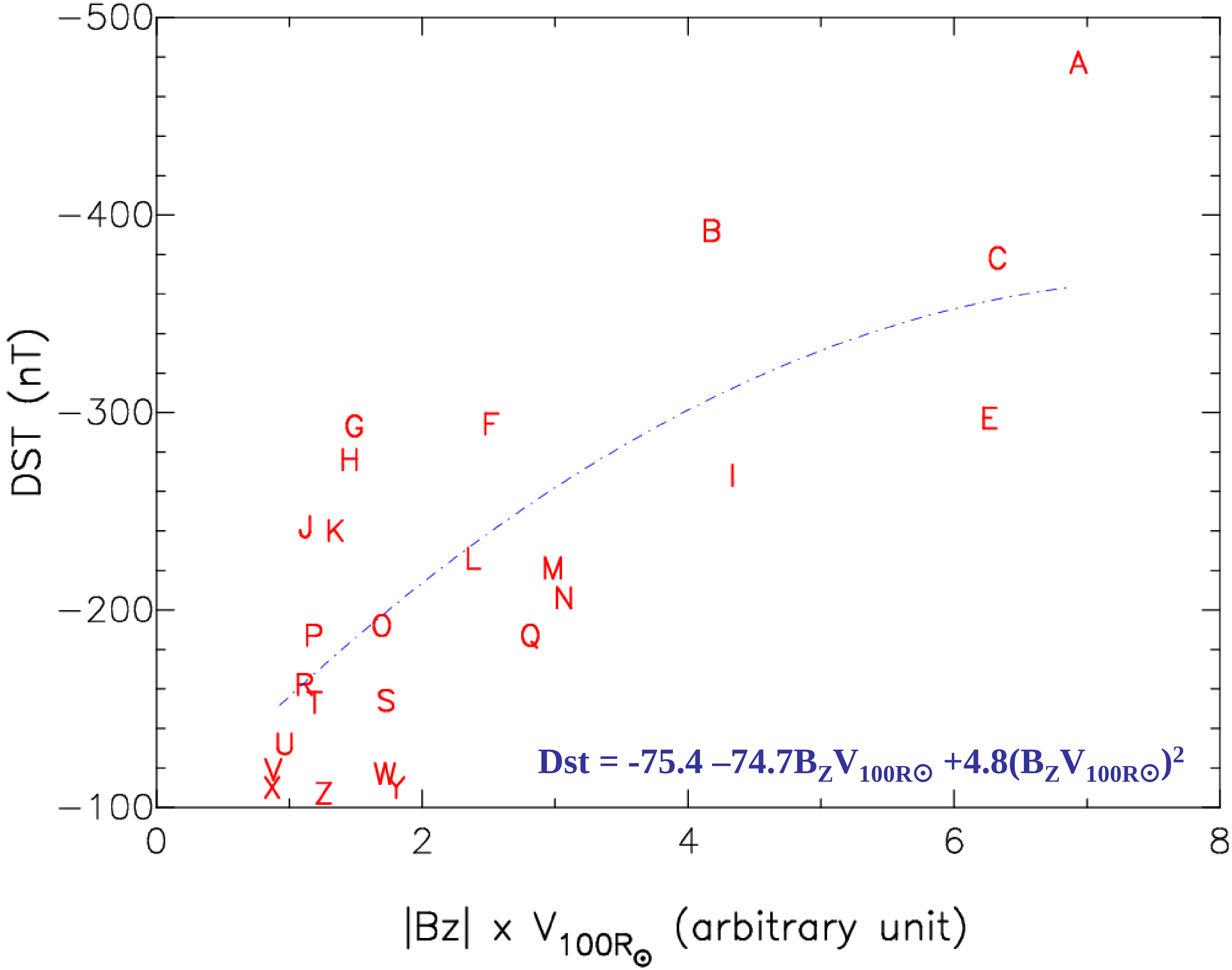
$V_{CME} \sim R^{-0.72}$ at R > 100 Rsun

Speed Profiles: $V_{CME}(R)$

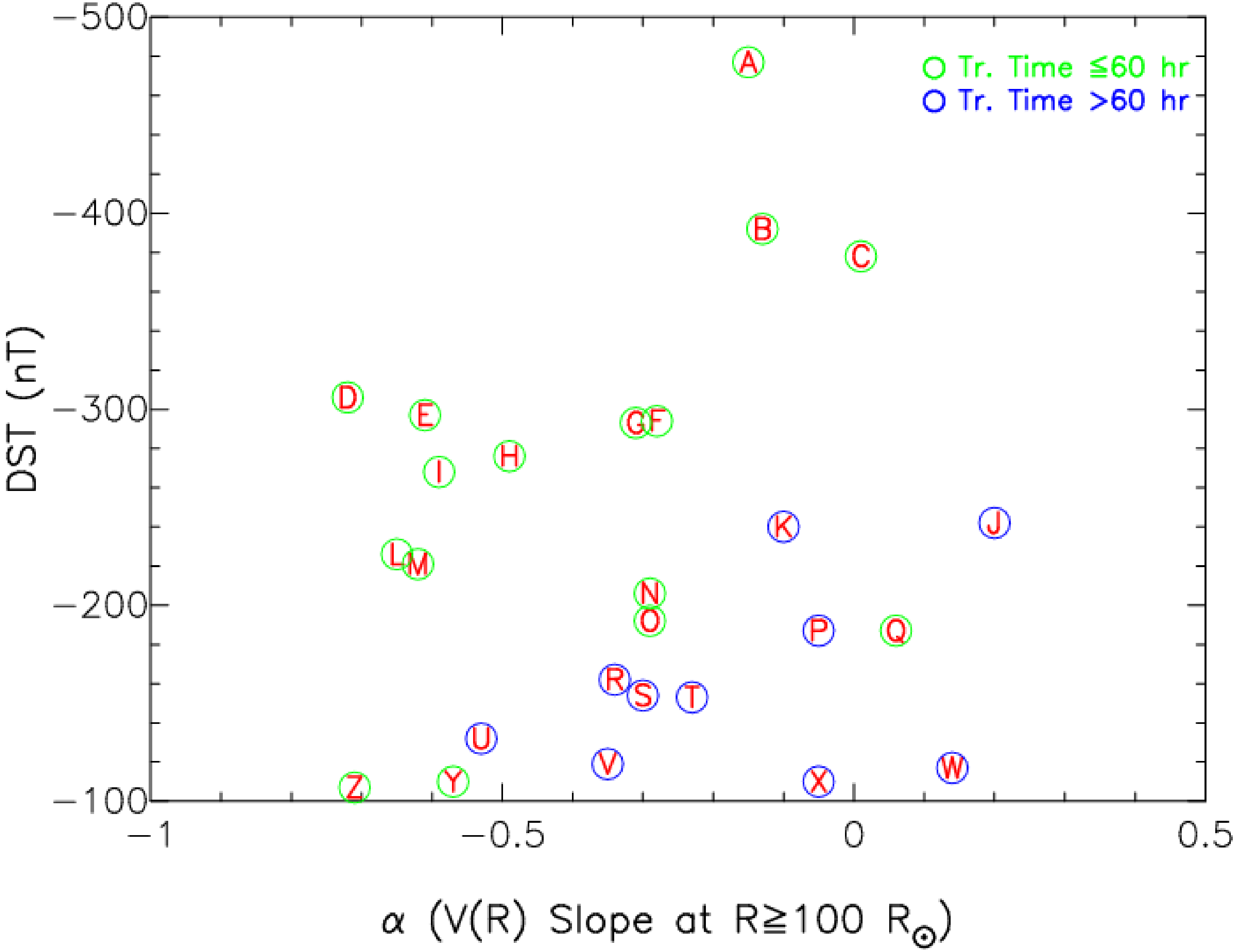


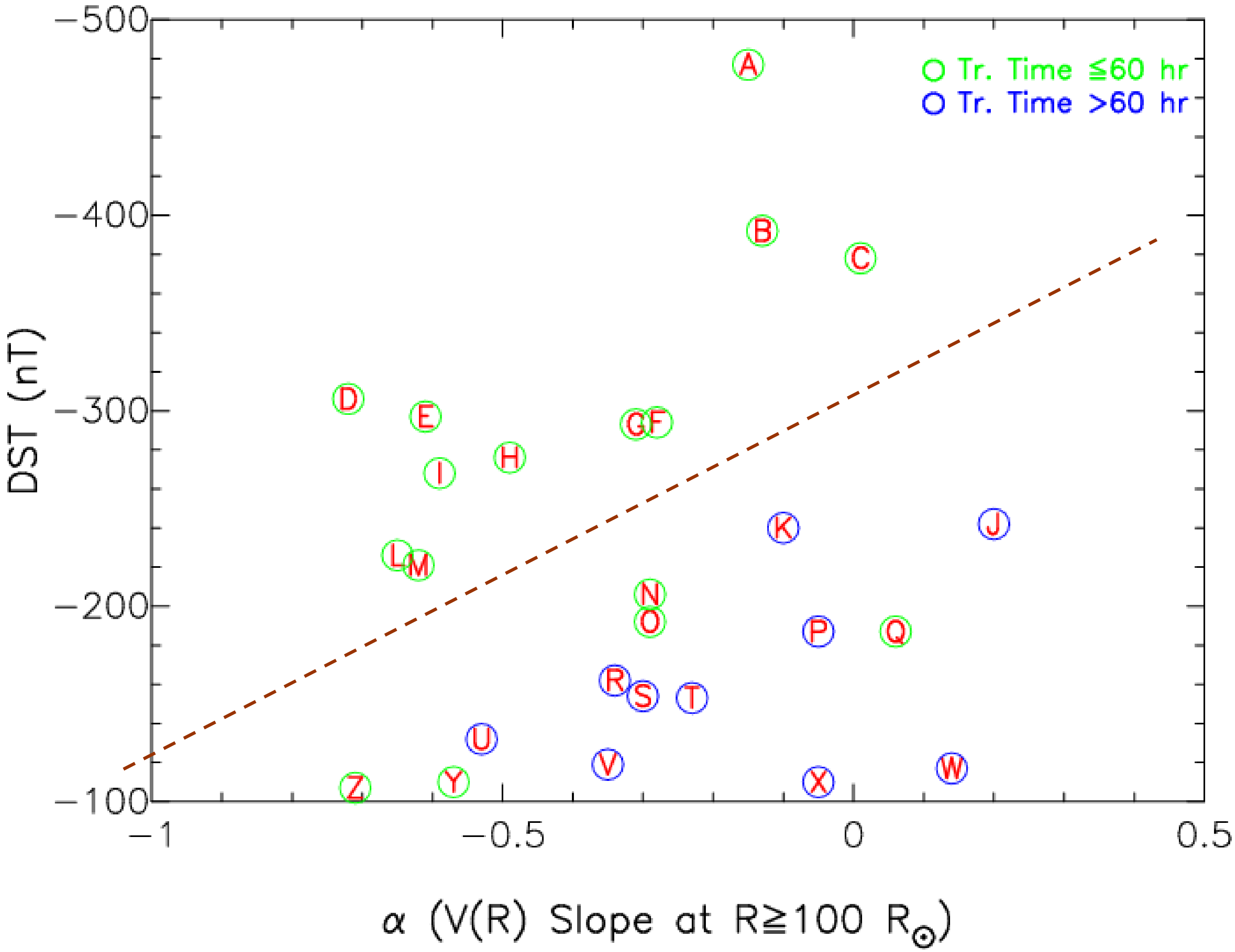
Which CMEs can cause most intense geo-magnetic storms?


70 Events
CME Initial Speed
(LASCO field of view)
CME at 100 R⊙
(Ooty IPS)
Shock Speed
(at 1 AU)
ICME Speed
(at 1 AU)
No. of EVENTS
0
10
20
30
0
500
1000
1500
2000
2500
CME SPEED at near Sun (km/s)
V100R⊙ (km/s)
SHOCK SPEED at 1 AU (km/s)
VICME at 1 AU (km/s)

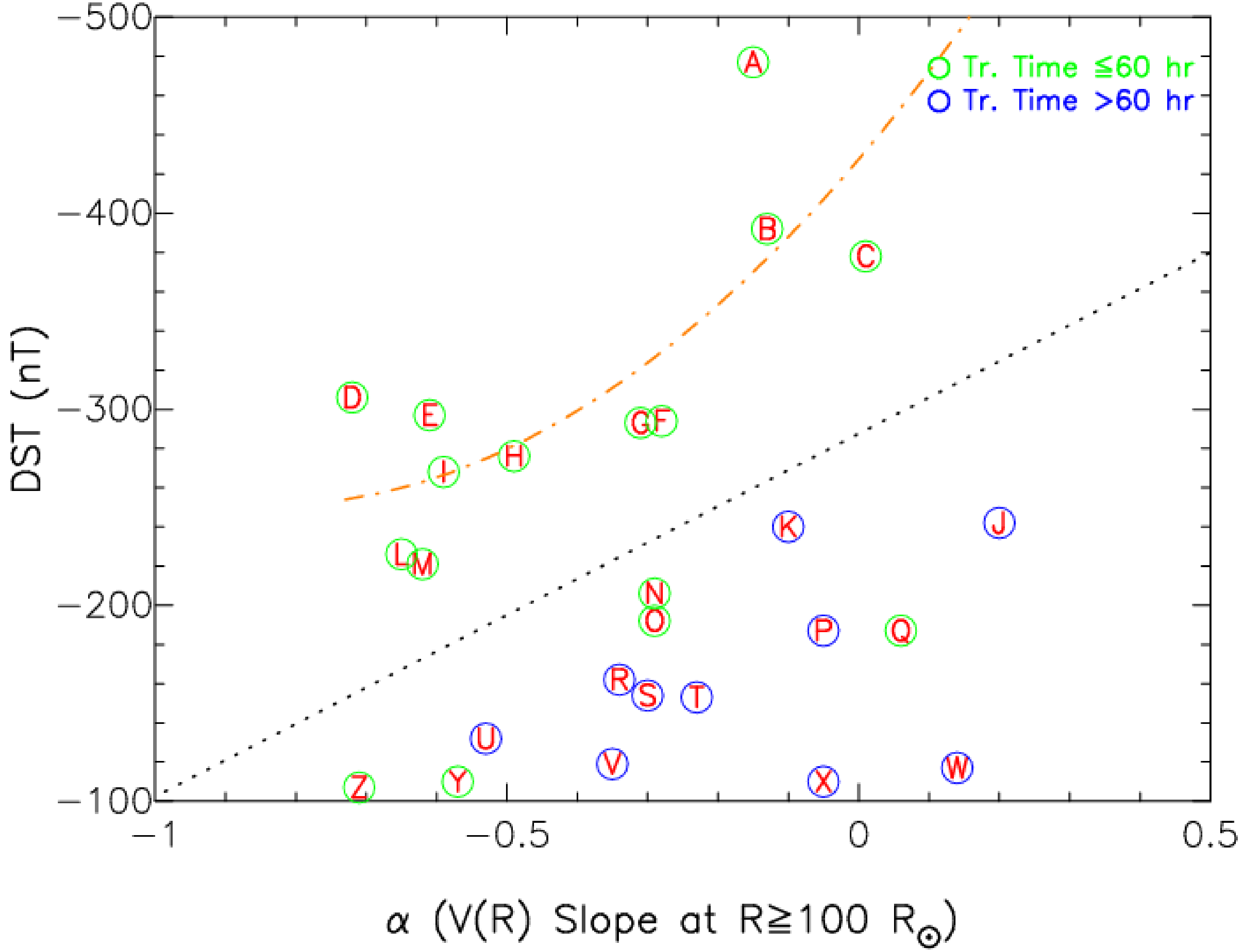


DST (nT)
−500
−400
−300
−200
−100
0
2
4
6
8
|Bz| x V100R⊙ (arbitrary unit)
A
B
C
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
Dst = -75.4 –74.7BZV100R⊙ +4.8(BZV100R⊙)²

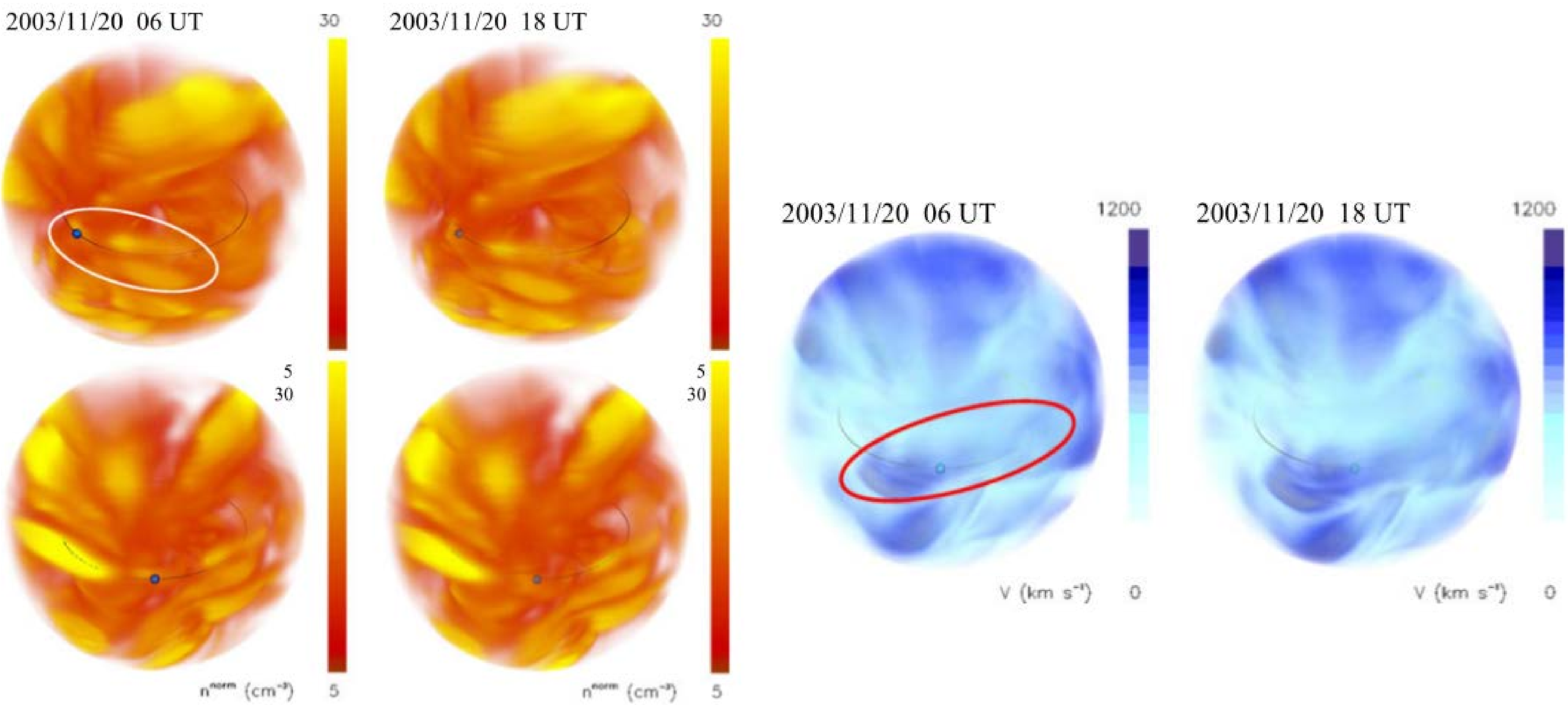

Tr. Time ≤60 hr
Tr. Time >60 hr
A
B
C
D
E
G
F
H
I
K
J
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
−500
−400
−300
−200
−100
−1
−0.5
0
0.5
DST (nT)
α (V(R) Slope at R≧100 R⊙)



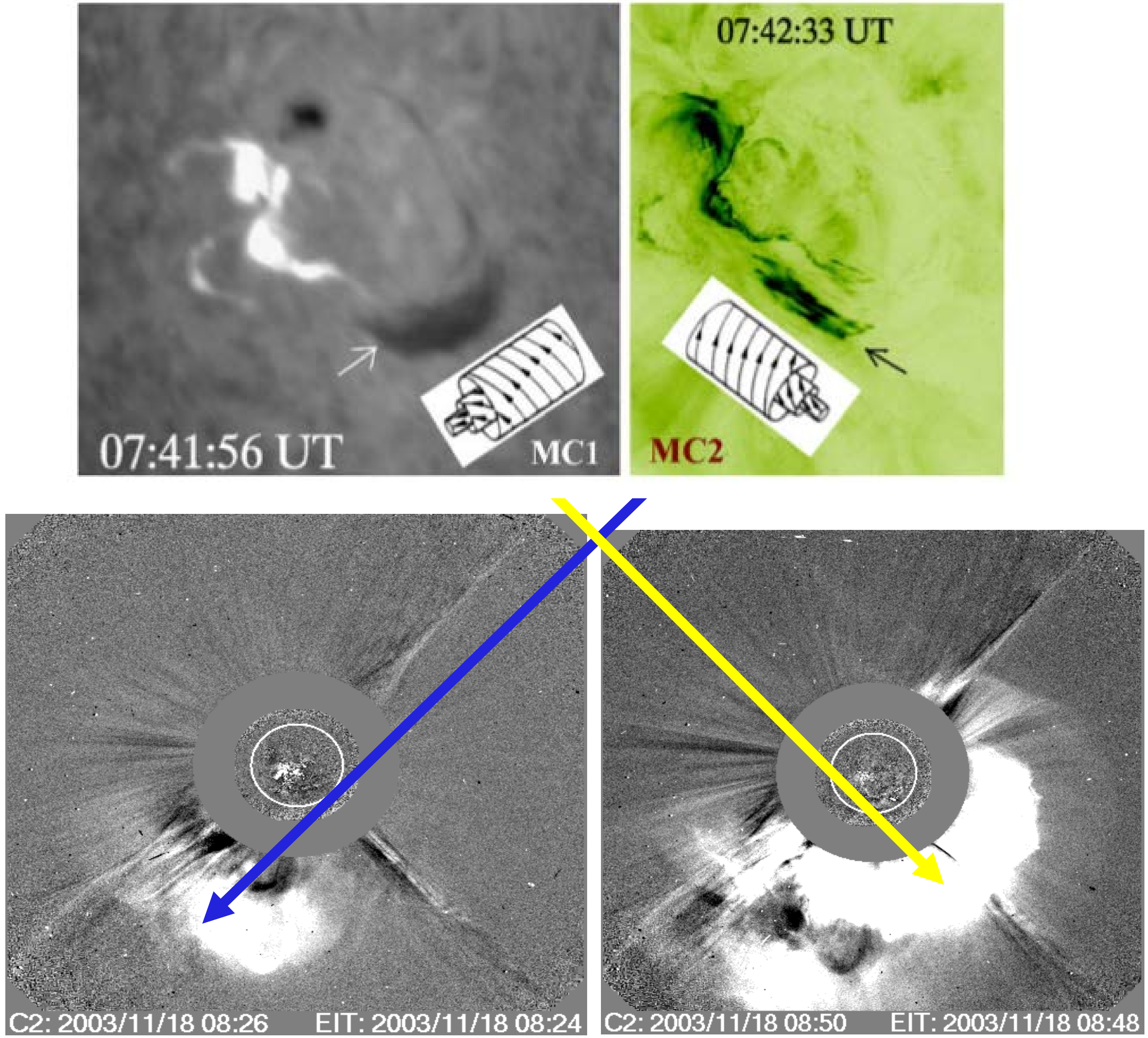
Tr. Time ≦60 hr
Tr. Time >60 hr
DST (nT)
−500
−400
−300
−200
−100
−1
−0.5
0
0.5
α (V(R) Slope at R≧100 R⊙)
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z



−500
−400
−300
−200
−100
−1
−0.5
0
0.5
DST (nT)
α (V(R) Slope at R≧100 R⊙)
Tr. Time ≦60 hr
Tr. Time >60 hr
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z

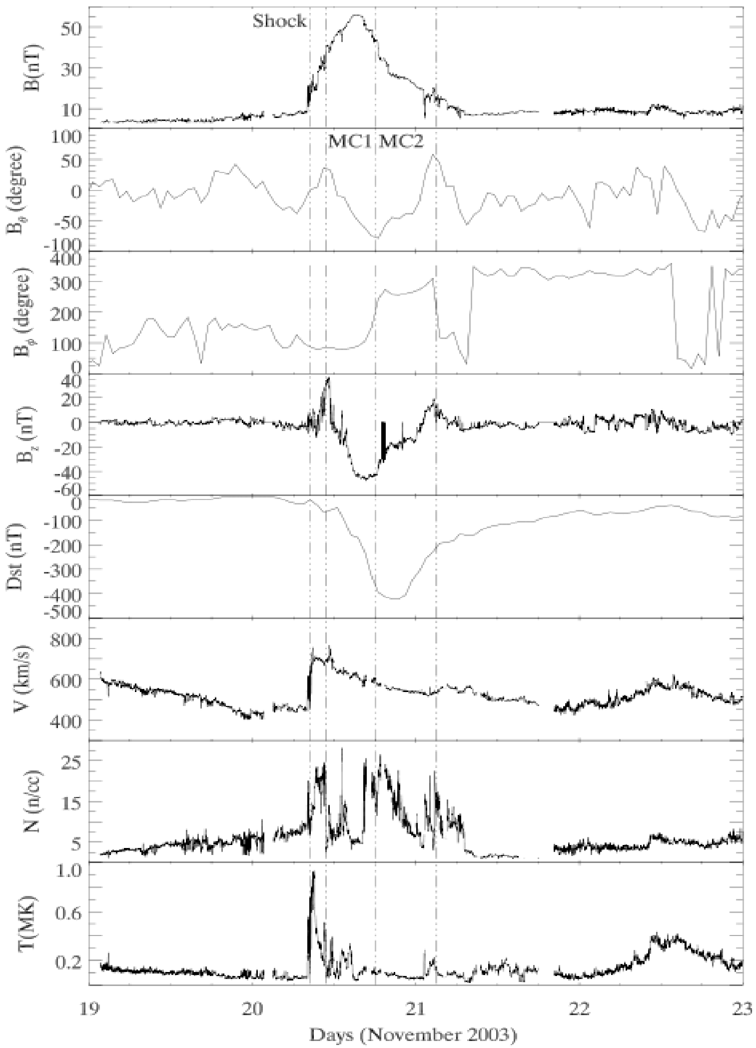


Three-dimensional density (left panels) and velocity (right panel) images of the solar wind reconstructed from Ooty IPS observations, showing the merged structure of two CMEs (shown inside the ellipse) hitting the Earth on 20 November 2003, at around 6 UT.



Two merged magnetic clouds in the interplanetary medium with the solar sources.

Near-Earth Observations



Merged CMEs cause intense storm

Shock travel time T=47.5 hours

Solar wind speed~430 to 750 km/s

Bz ~-45.58 nT

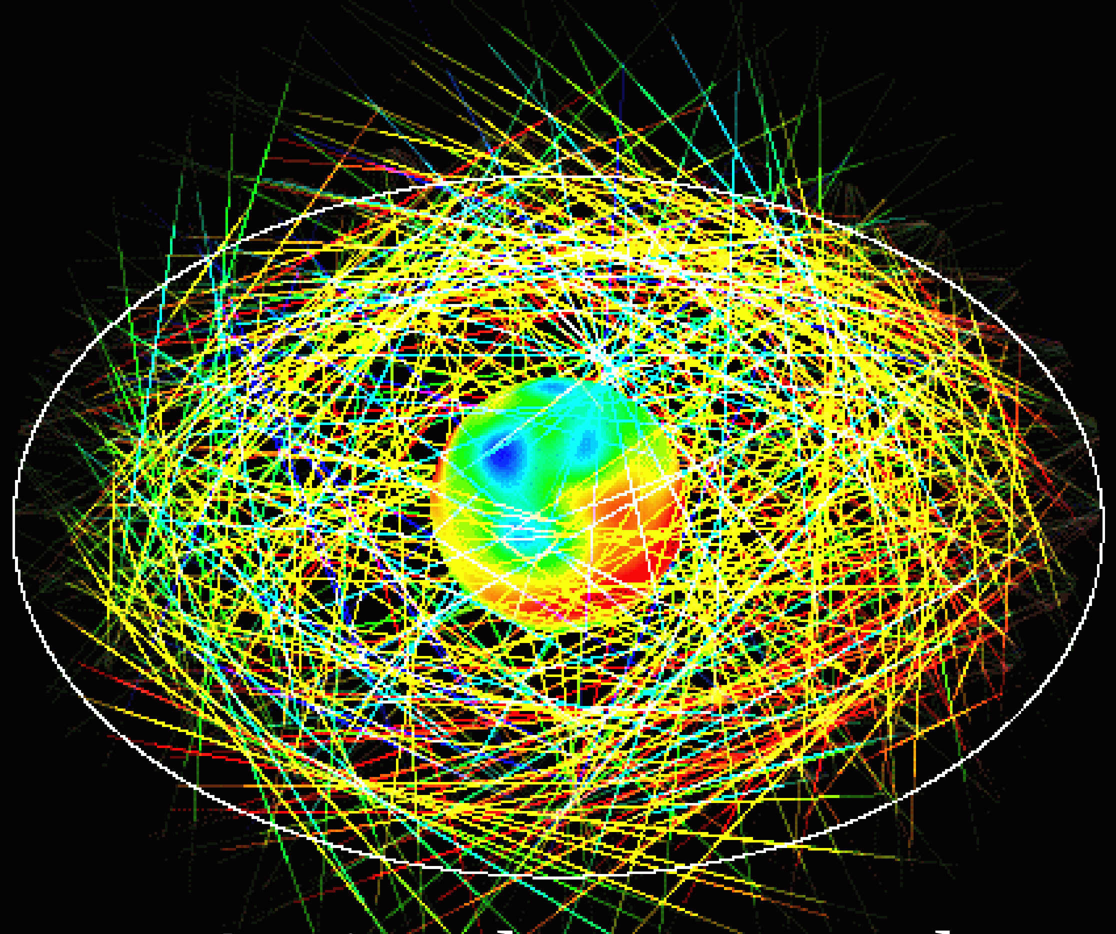
Duration southward Bz ~13.5 hrs

Dst index~-472 nT

Interplanetary medium plasma parameters at 1 AU during 19-23 November 2003

Tomography reconstruction of Ooty IPS Data

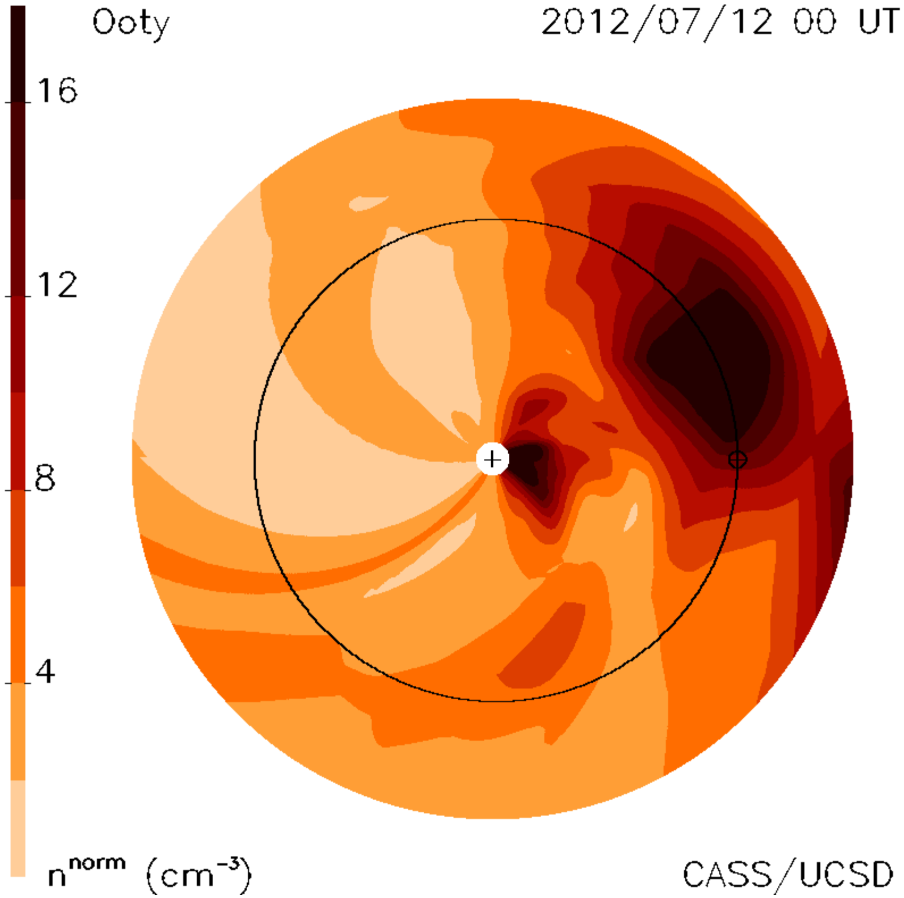
Solar rotation and radial outward flow of the solar wind provide the 3-d structure of the solar wind at different view angles

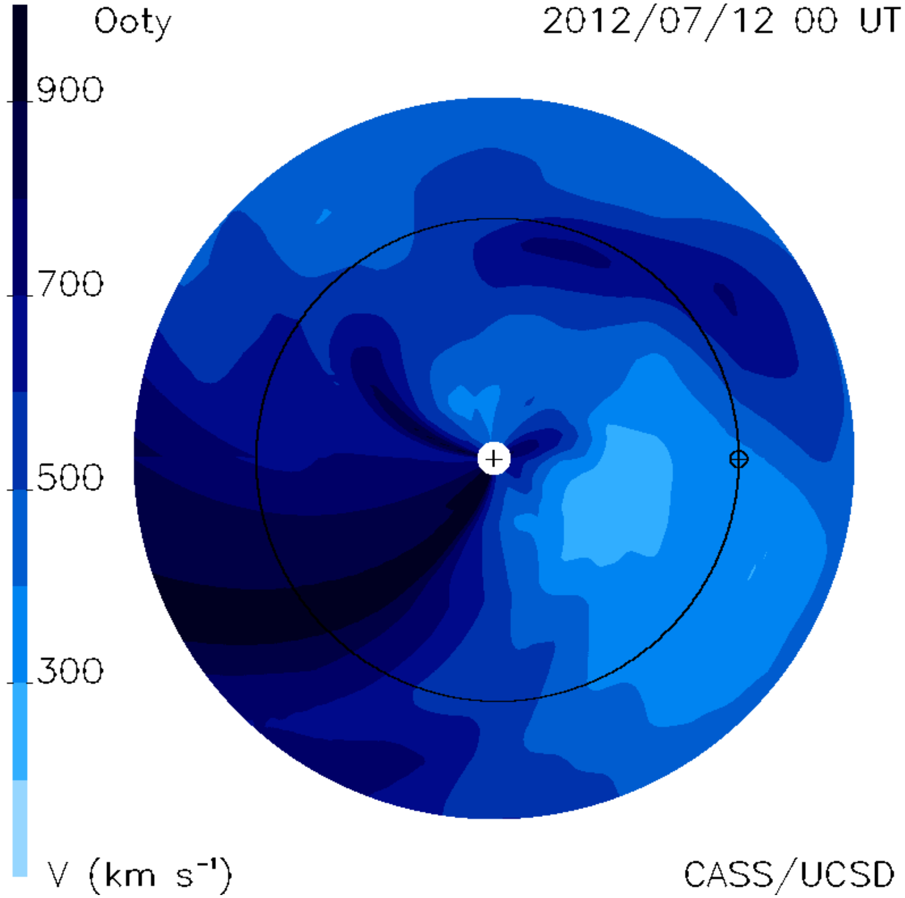


Computer Assisted Tomography analysis

can remove the line-of-sight integration imposed on the solar wind parameters also provides high spatial resolution

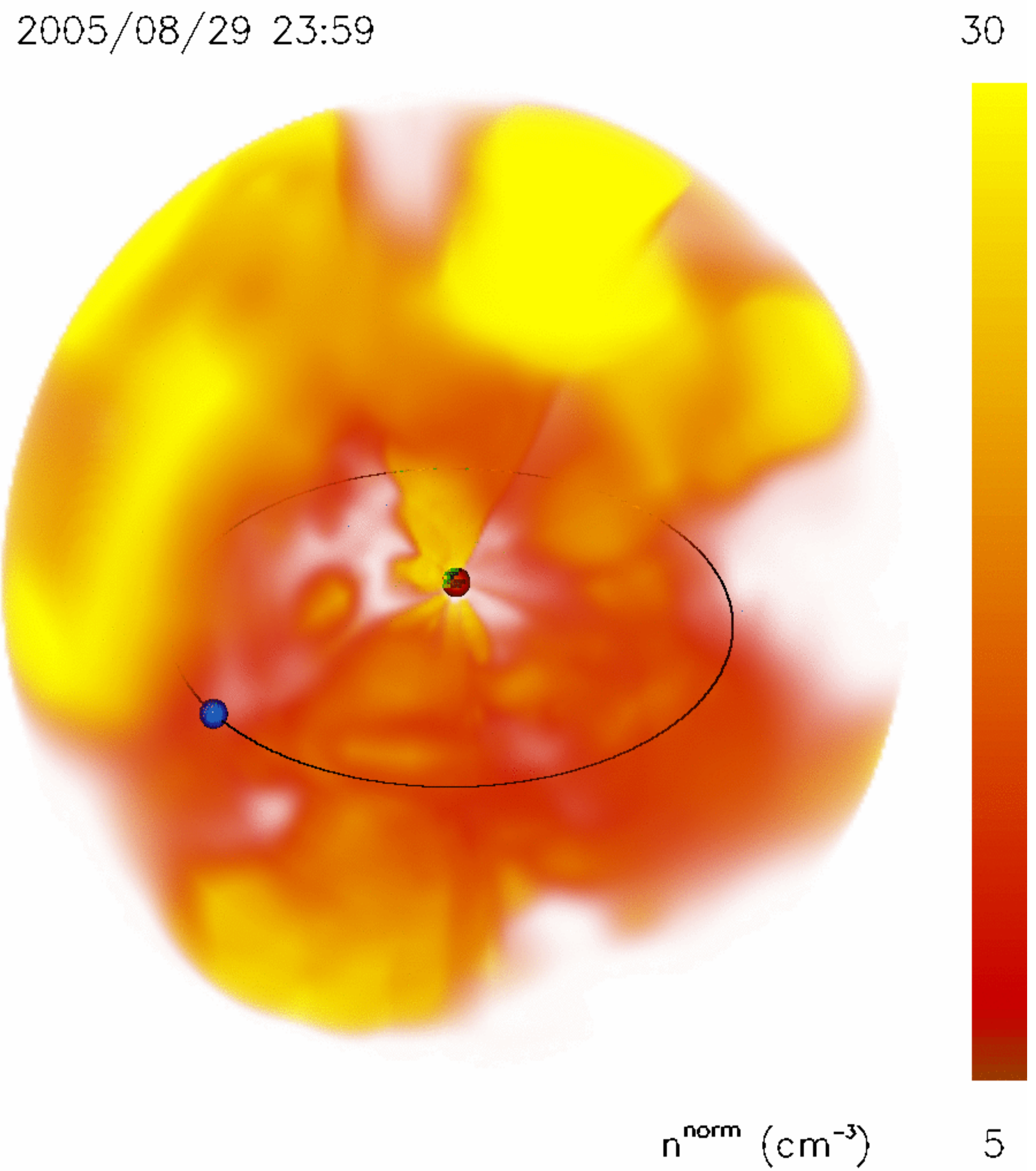
3D Ooty Density and Speed Reconstructions





Ecliptic cuts through the 3D Ooty IPS reconstruction

(density and speed)



NCRA • TIFR

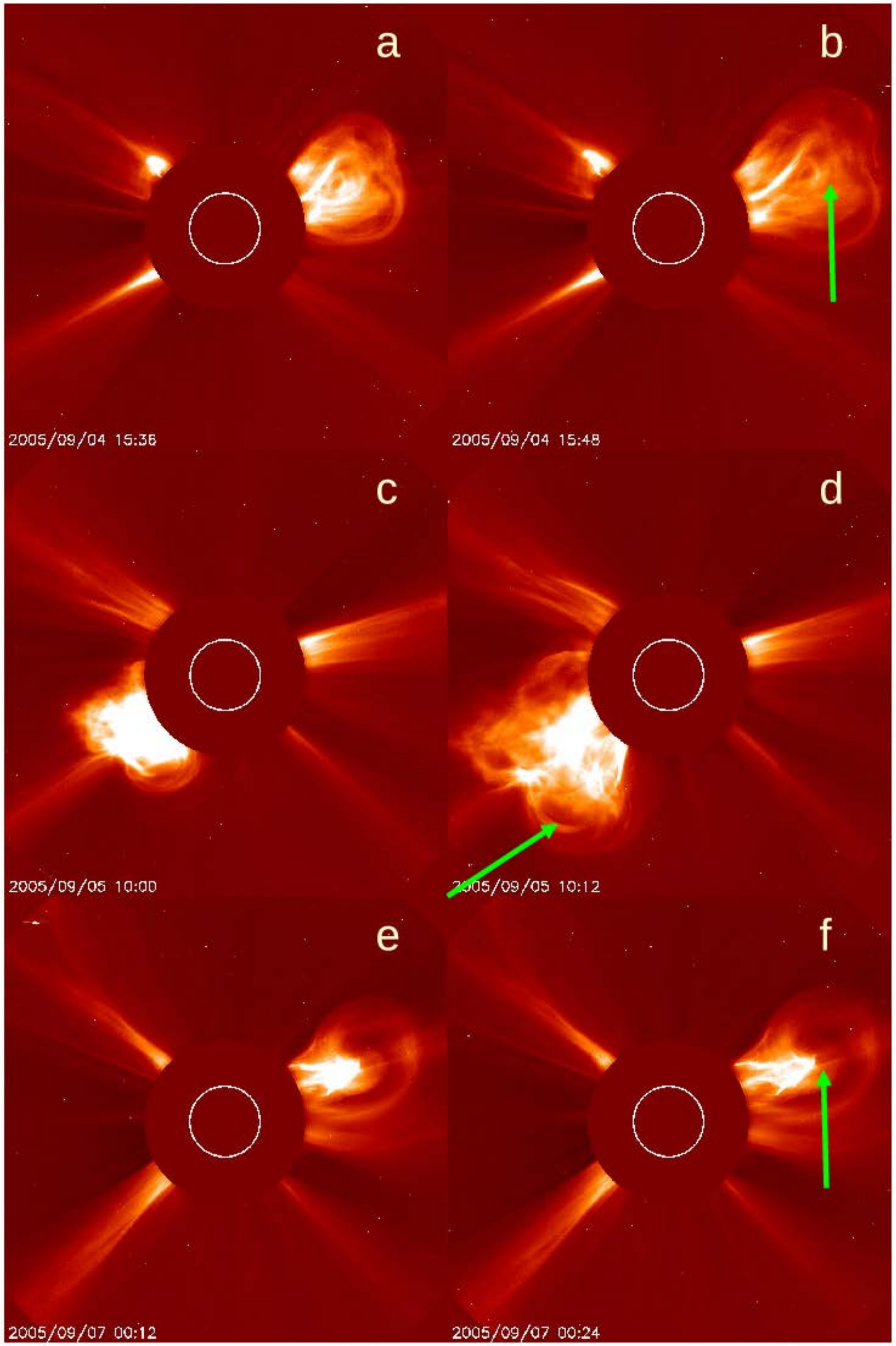
3-D reconstruction of heliosphere

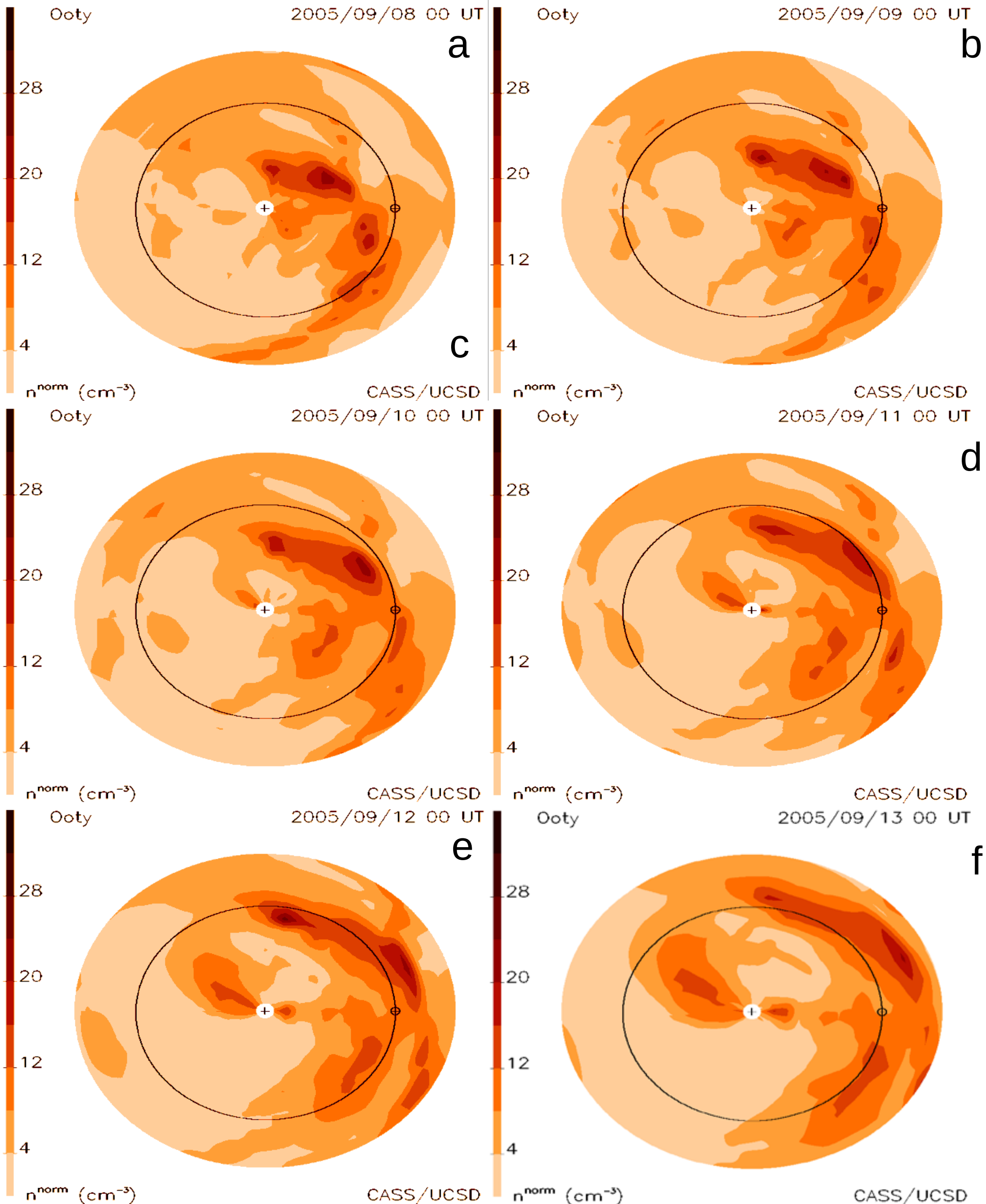
Solar Events during September 4 – 13, 2005

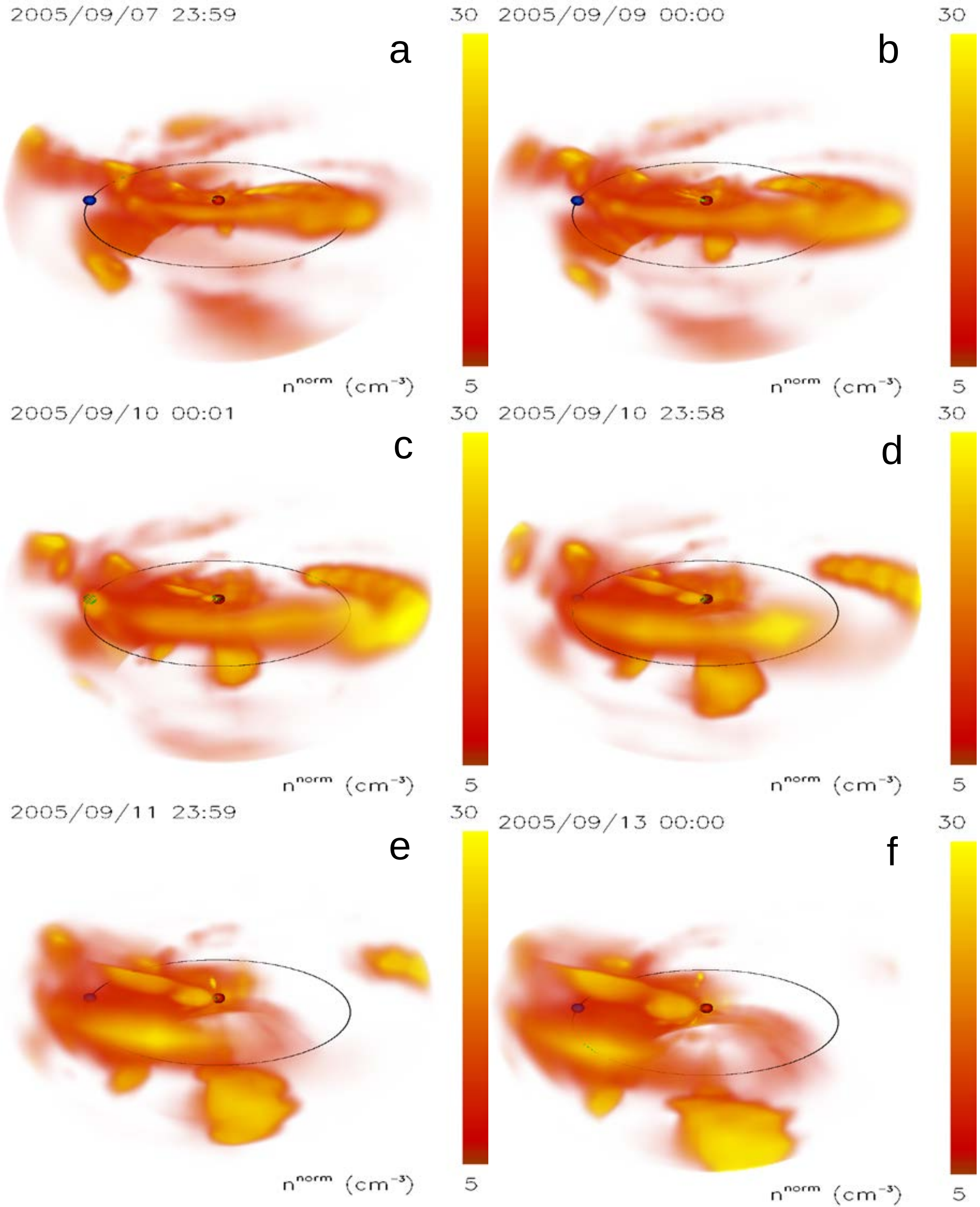
No.	Date	Flare Class	Flare Loc.	CME Time (UT)	CME Type	CME Speed kms^{-1}	PA	Type-II Speed kms^{-1}
1	04/09	C2.0	W Limb	14:48	PHalo	1000-1500	N-W	
2	05/09	C2.7	E Limb	09:48	Halo	2350	S-E	
3	06/09	M1.4	W Limb	21:12	PHalo	200–1000	N-W	
4	07/09	X17.0	S11E77	17:40	Halo?		S-E	$\geq$1900

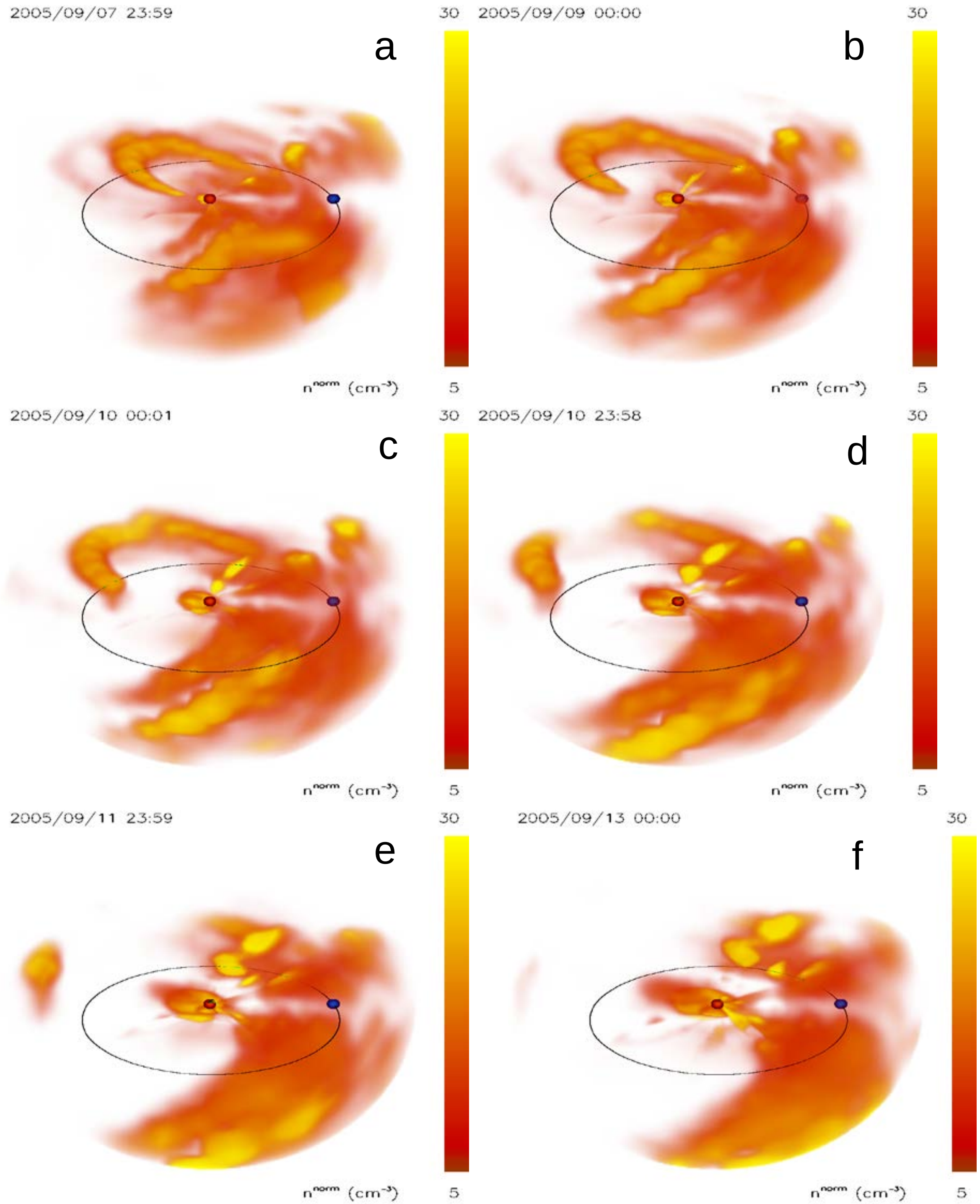
Corresponding ARs #803 and #808 - These events were responsible for spectacular and orderly flux-rope type of ejections, as illustrated following by the Ooty IPS analyses.

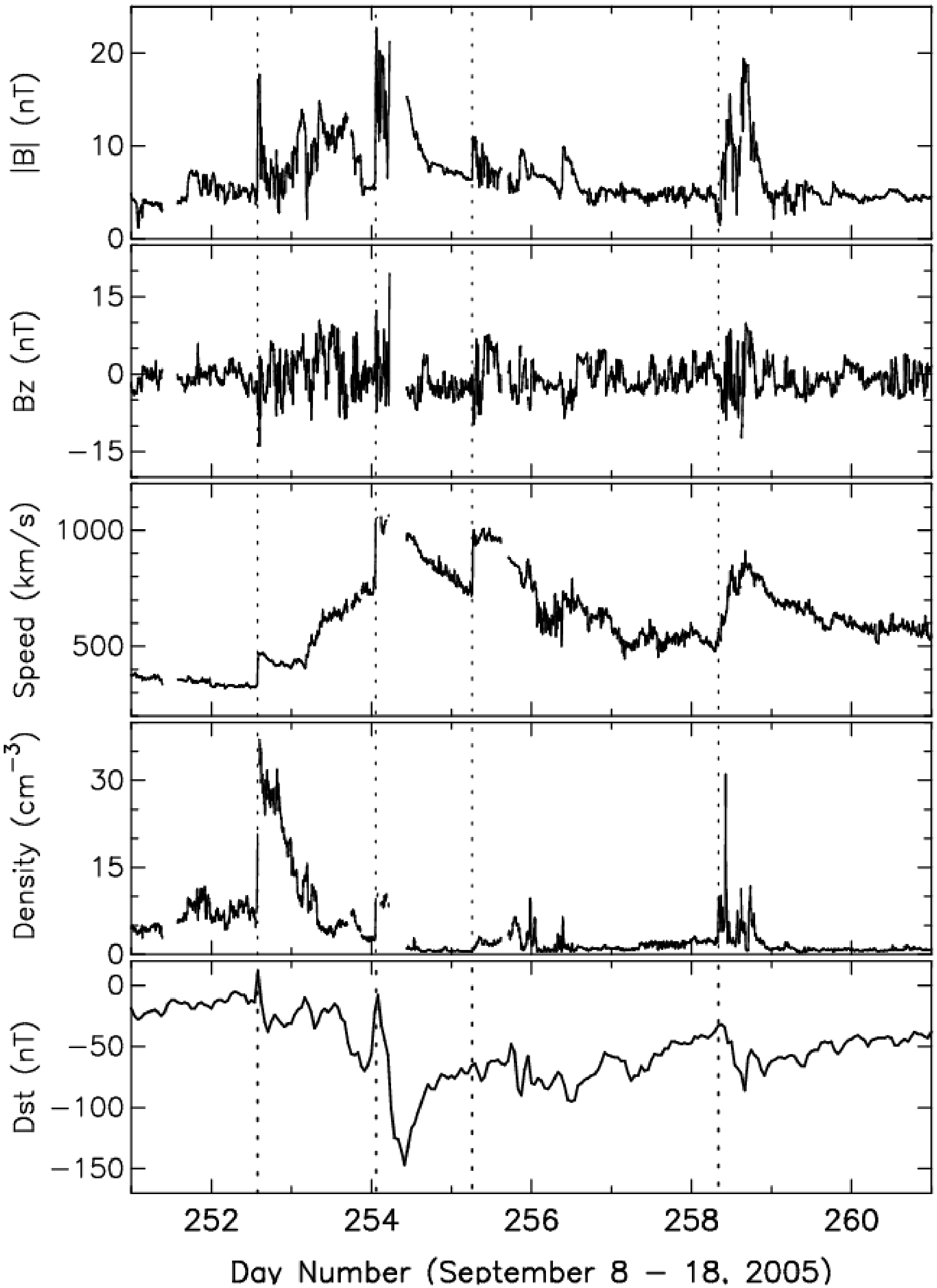
LASCO C2 images




Ooty
2005/09/08 00 UT
a
28
20
12
4
n^{norm} (cm^{-3})
CASS/UCSD
Ooty
2005/09/09 00 UT
b
28
20
12
4
n^{norm} (cm^{-3})
CASS/UCSD
c
Ooty
2005/09/10 00 UT
28
20
12
4
n^{norm} (cm^{-3})
CASS/UCSD
Ooty
2005/09/11 00 UT
d
28
20
12
4
n^{norm} (cm^{-3})
CASS/UCSD
Ooty
2005/09/12 00 UT
e
28
20
12
4
n^{norm} (cm^{-3})
CASS/UCSD
Ooty
2005/09/13 00 UT
f
28
20
12
4
n^{norm} (cm^{-3})
CASS/UCSD

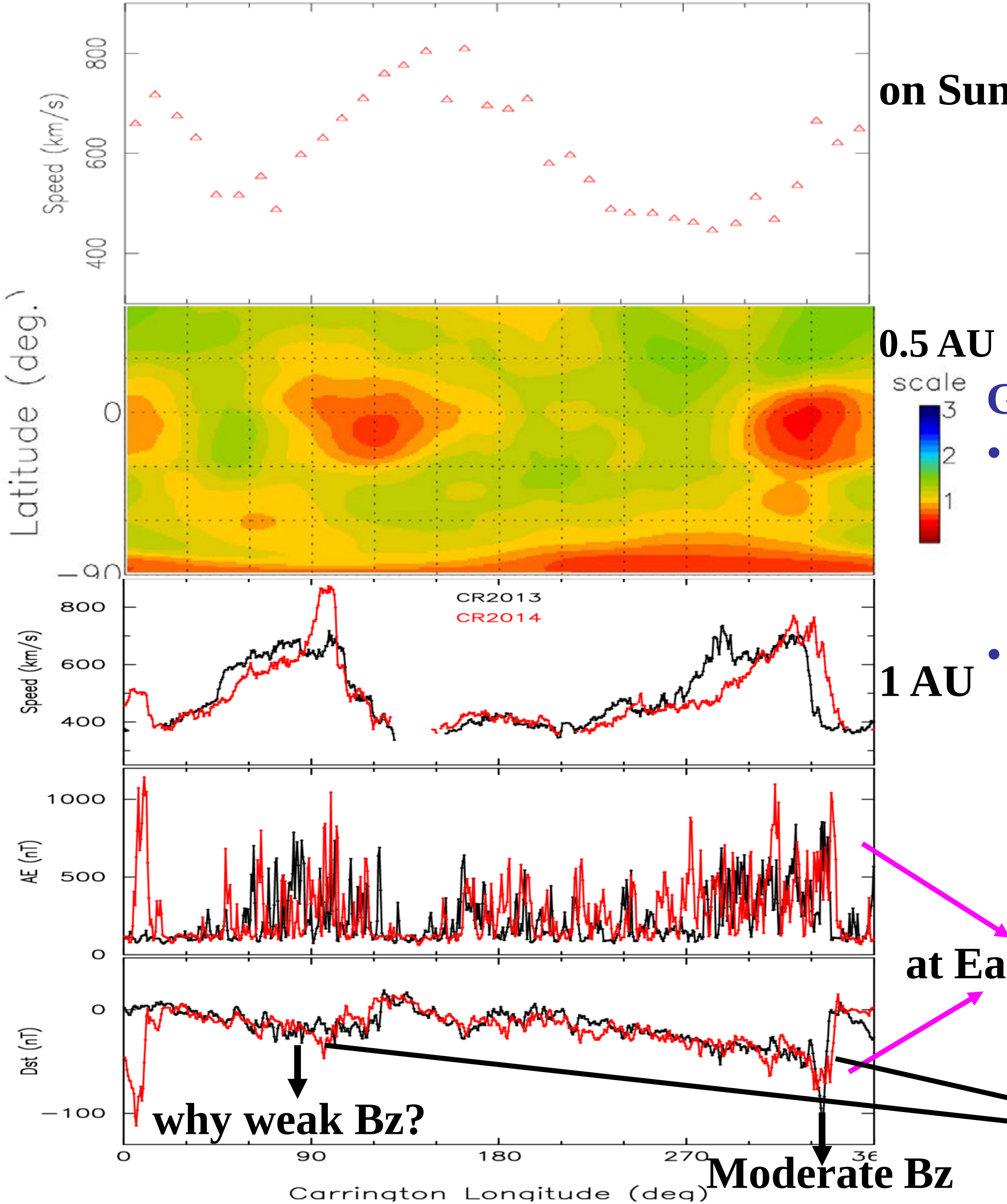

2005/09/07 23:59
a
2005/09/09 00:00
b
2005/09/10 00:01
c
2005/09/10 23:58
d
2005/09/11 23:59
e
2005/09/13 00:00
f
30
5
n^{norm} (cm^{-3})


2005/09/07 23:59
a
30
5
n^{norm} (cm^{-3})
2005/09/09 00:00
b
30
5
n^{norm} (cm^{-3})
2005/09/10 00:01
c
30
5
n^{norm} (cm^{-3})
2005/09/10 23:58
d
30
5
n^{norm} (cm^{-3})
2005/09/11 23:59
e
30
5
n^{norm} (cm^{-3})
2005/09/13 00:00
f
30
5
n^{norm} (cm^{-3})



|B| (nT)
Bz (nT)
Speed (km/s)
Density (cm^{-3})
Dst (nT)
Day Number (September 8 – 18, 2005)

Co-rotating Interaction Regions (CIRs)



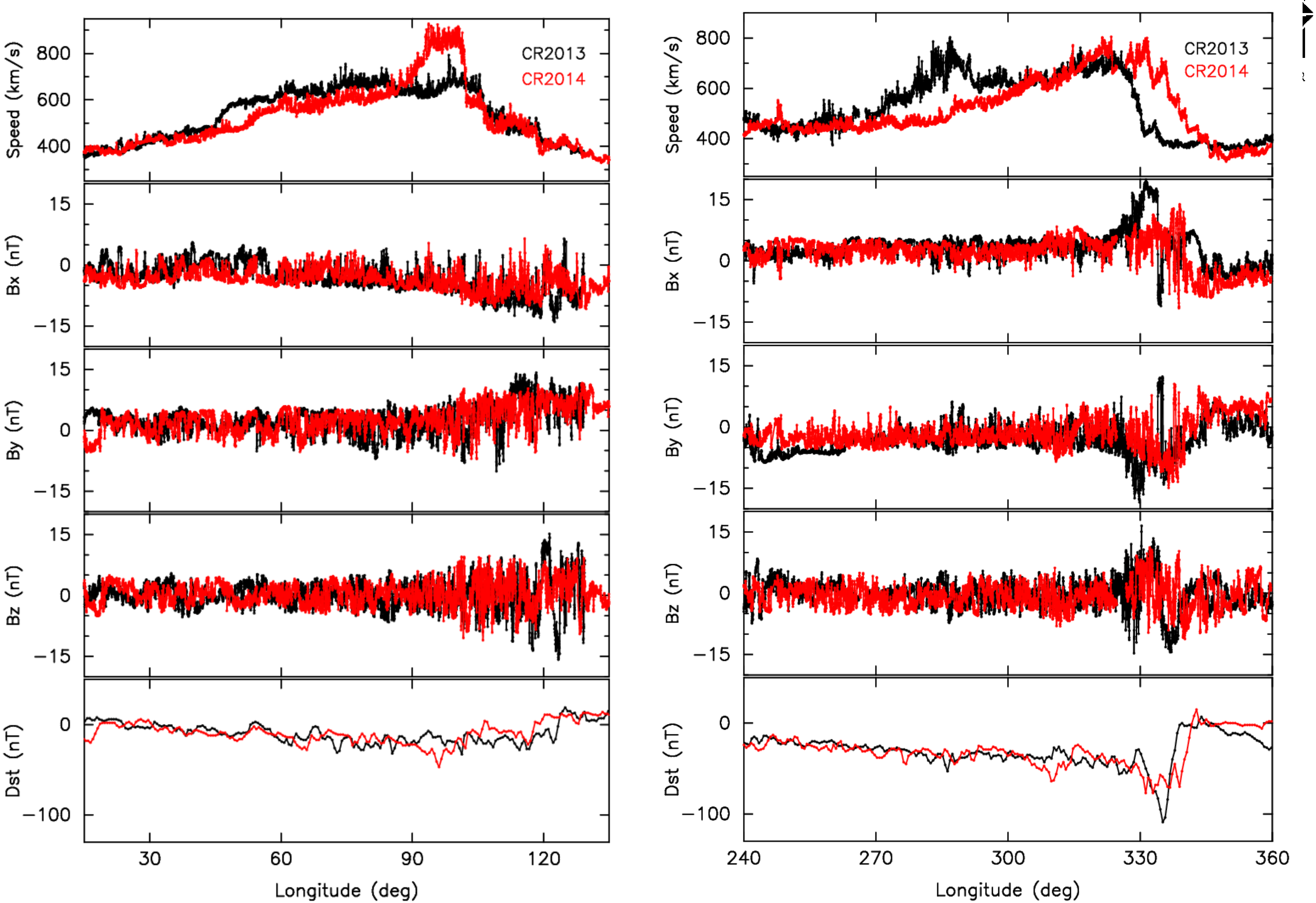
Geo-Storms:

- coronal hole (~100º longitude) does not produce significant storms
- where as CH at ~330º causes moderate storms at the Earth (AE & Dst).

IMF geometry and CH Magnetic field play key role

But, nearly equal |B|

CR2013 **CR2014**



Interested in IPS data, welcome to collaborate

Thank You