Tracking CMEs with Ooty IPS data and Possible Collaboration with CCMC

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Outline

Interplanetary Scintillation (IPS) Technique

- Remotely probes solar wind speed and density turbulence (δNe) in the inner heliosphere

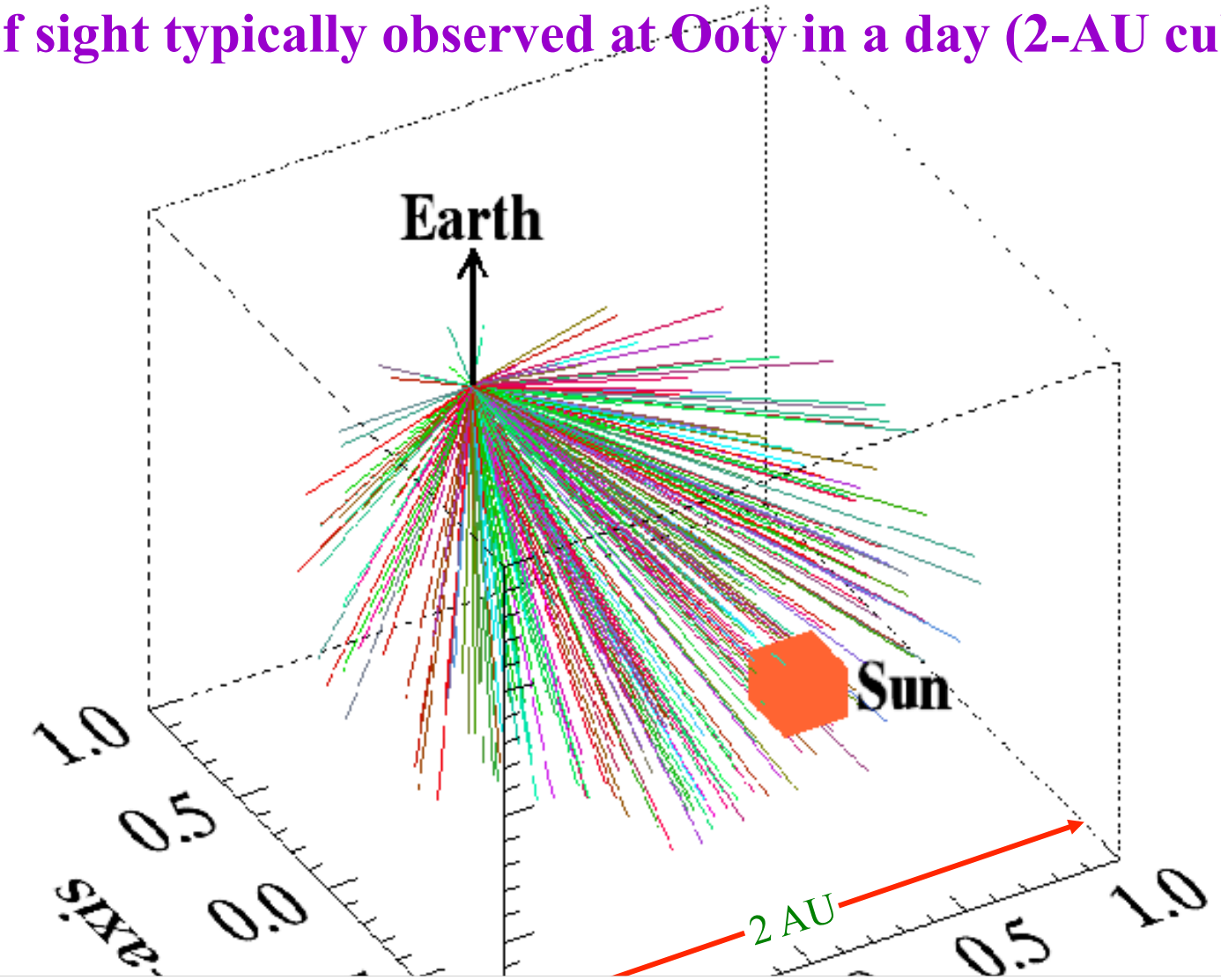
IPS with the Ooty Radio Telescope

- I present solar wind images of the inner heliosphere
- Snapshot images/tracking of CMEs
- Examples of UCSD Tomography reconstruction of Ooty IPS

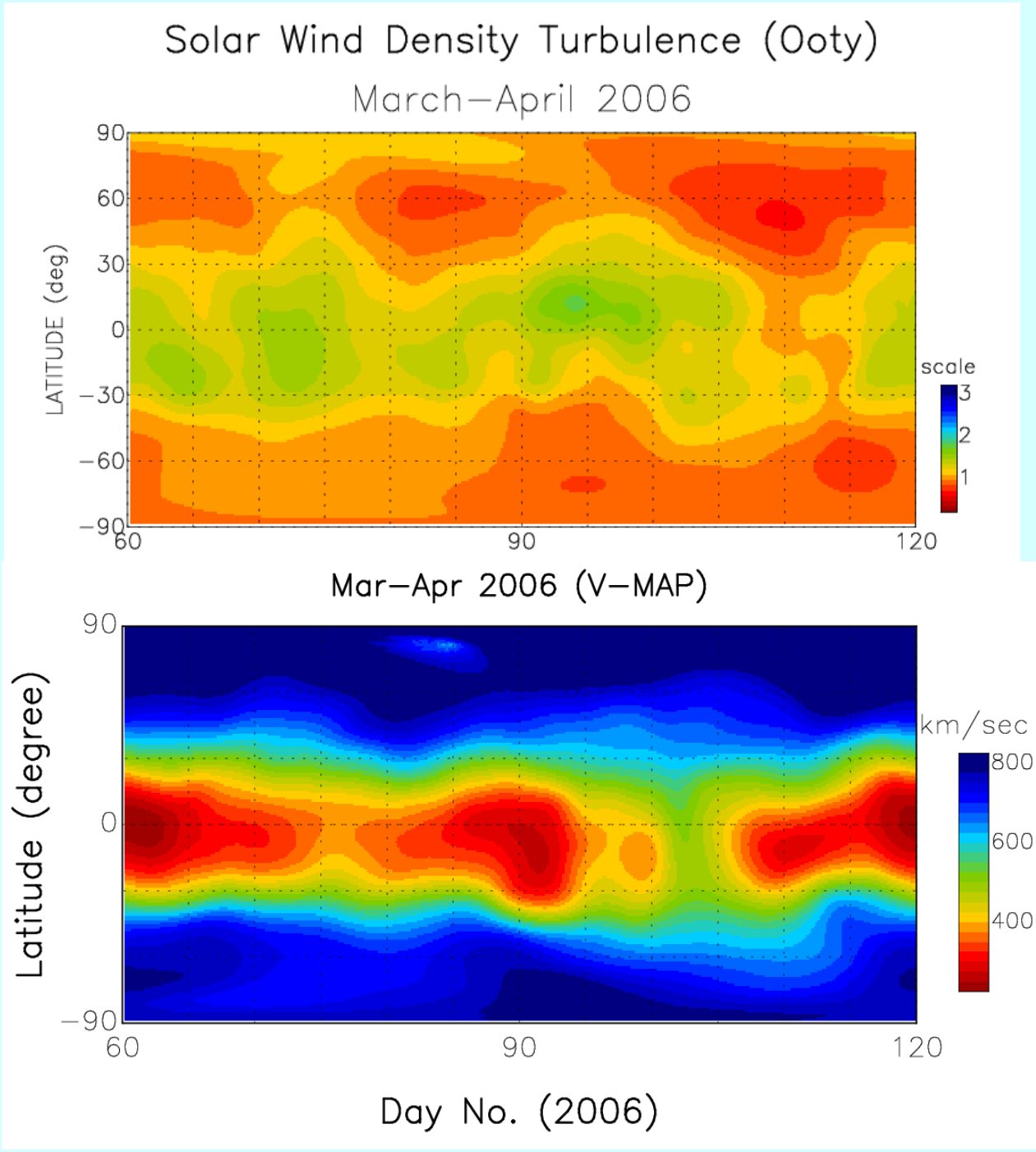
Usefulness of IPS measurements to the CCMC

- 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)

Lines of sight typically observed at Ooty in a day (2-AU cube)



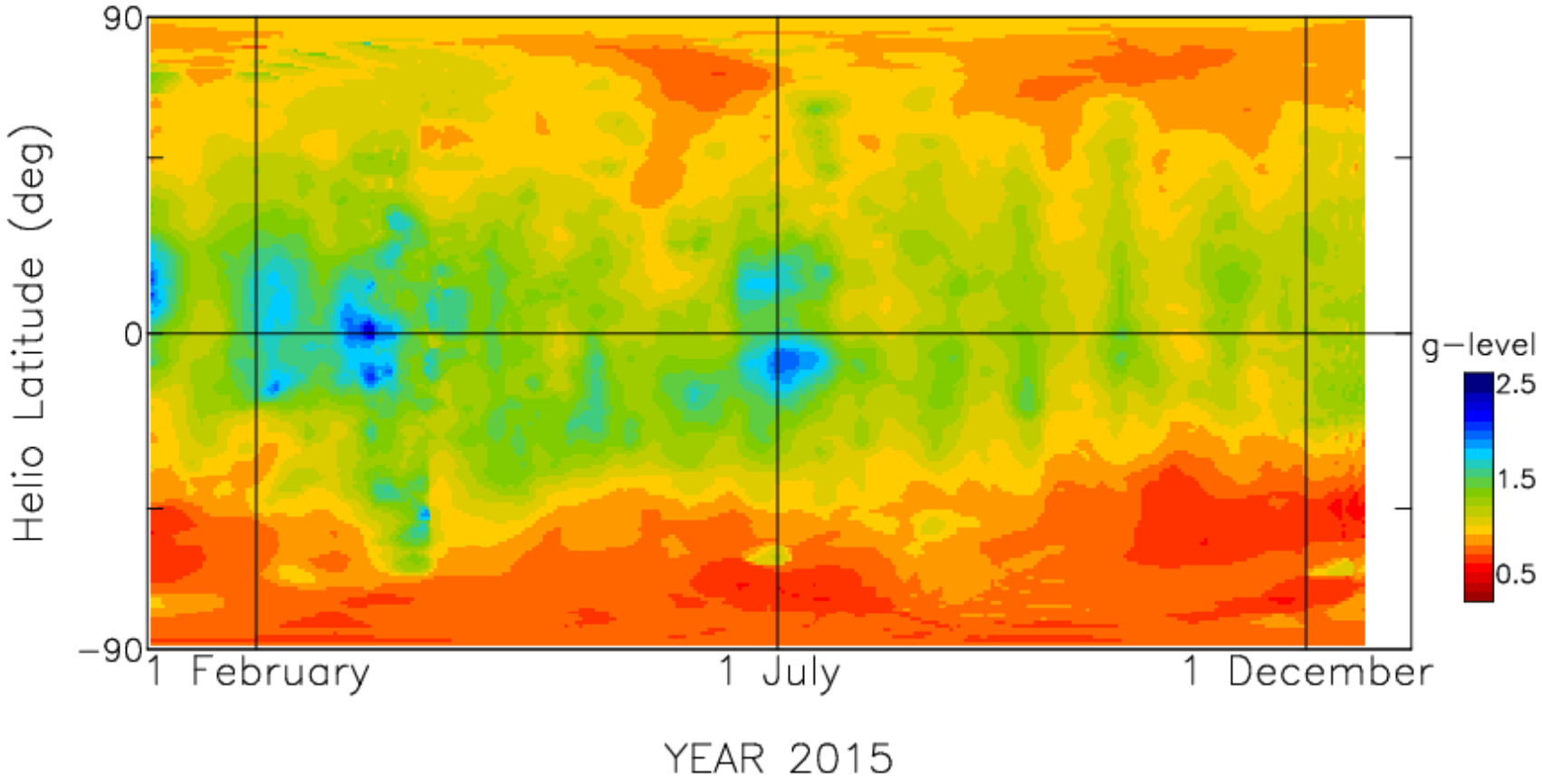
These measurements can provide 3-D view of solar wind speed, and density turbulence of scale size 10 – 500 km

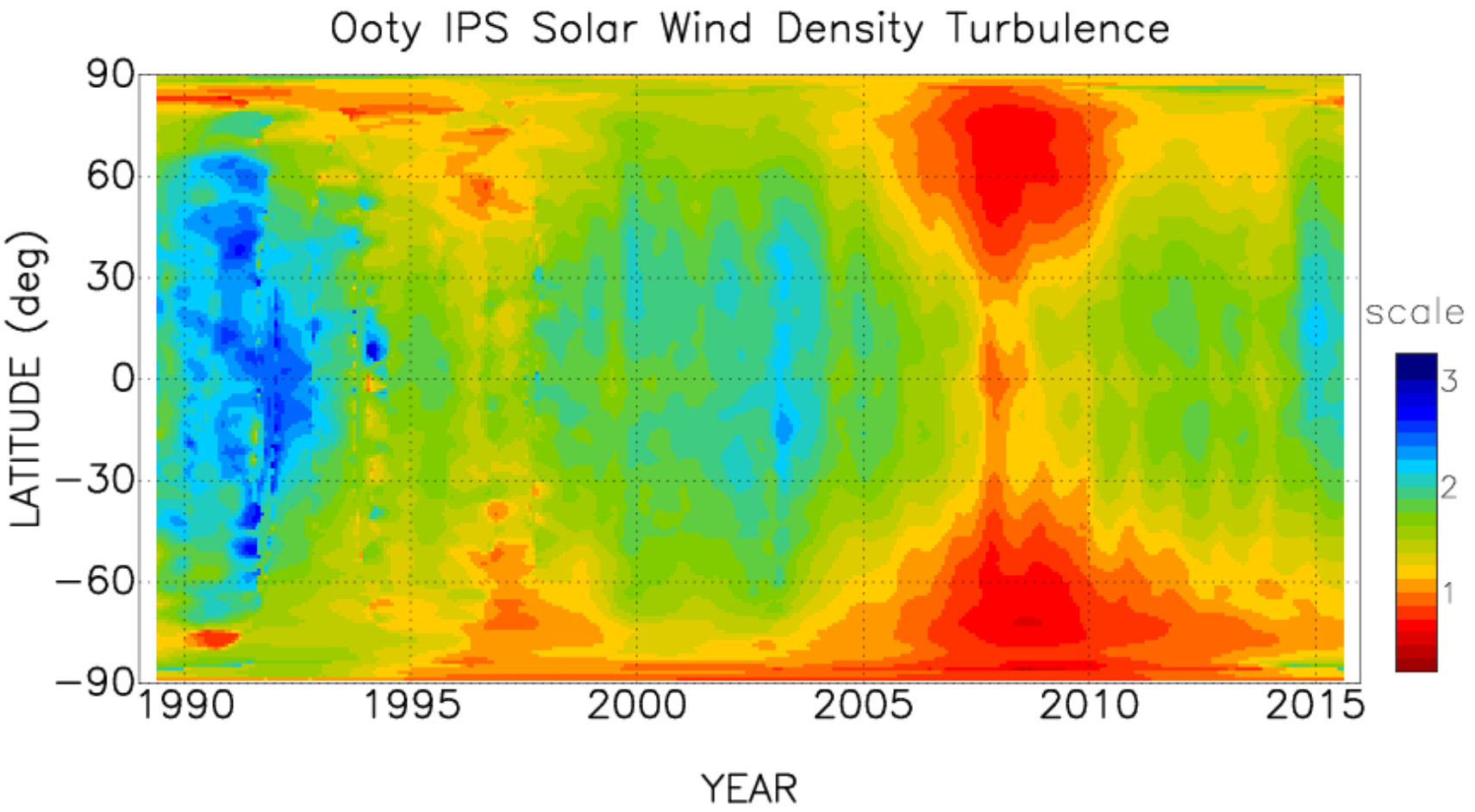

Solar Wind Density Turbulence (Ooty)
March–April 2006
LATITUDE (deg)
90
60
30
0
−30
−60
−90
60
90
120
scale
3
2
1
Mar–Apr 2006 (V–MAP)
Latitude (degree)
90
0
−90
60
90
120
km/sec
800
600
400
Day No. (2006)

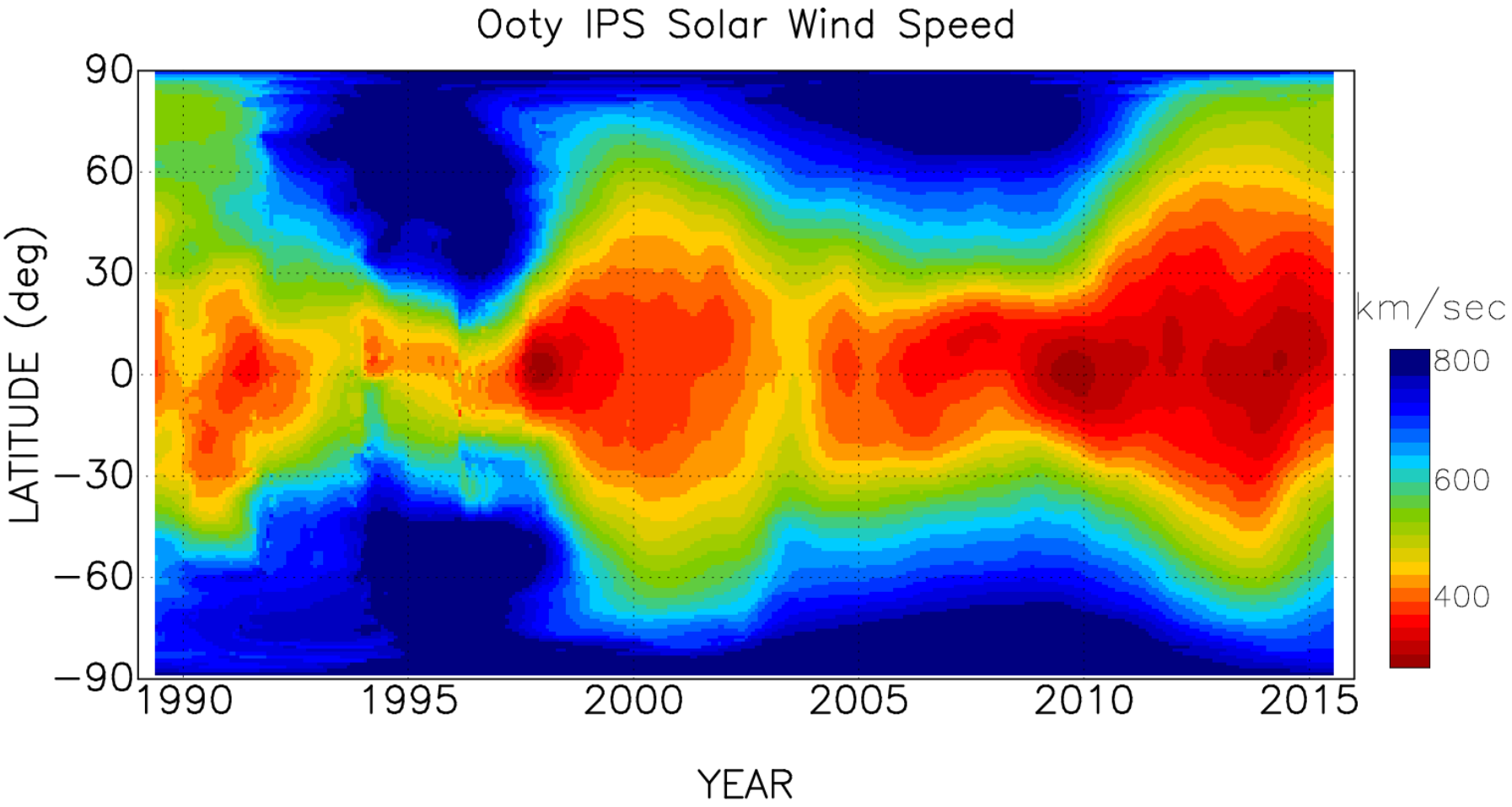
NCRA • TIFR

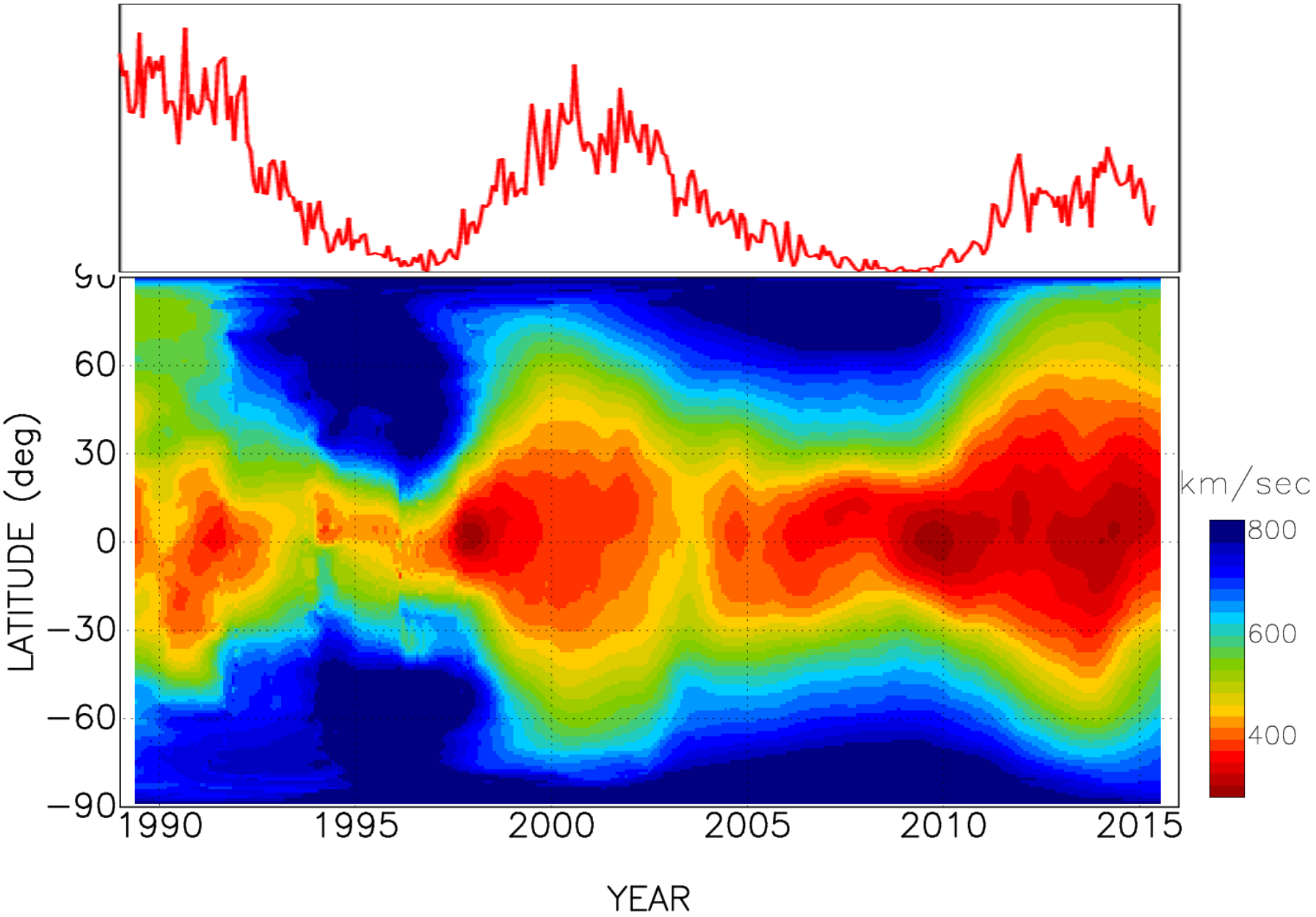
NCRA • TIFR

Level of Density Turbulence in Solar Wind (g–map)
Ooty IPS Measurements (2015)




Ooty IPS Solar Wind Density Turbulence
LATITUDE (deg)
90
60
30
0
−30
−60
−90
1990
1995
2000
2005
2010
2015
YEAR
scale
3
2
1


Ooty IPS Solar Wind Speed
LATITUDE (deg)
90
60
30
0
−30
−60
−90
1990
1995
2000
2005
2010
2015
YEAR
km/sec
800
600
400


90
60
30
0
−30
−60
−90
LATITUDE (deg)
1990
1995
2000
2005
2010
2015
YEAR
km/sec
800
600
400

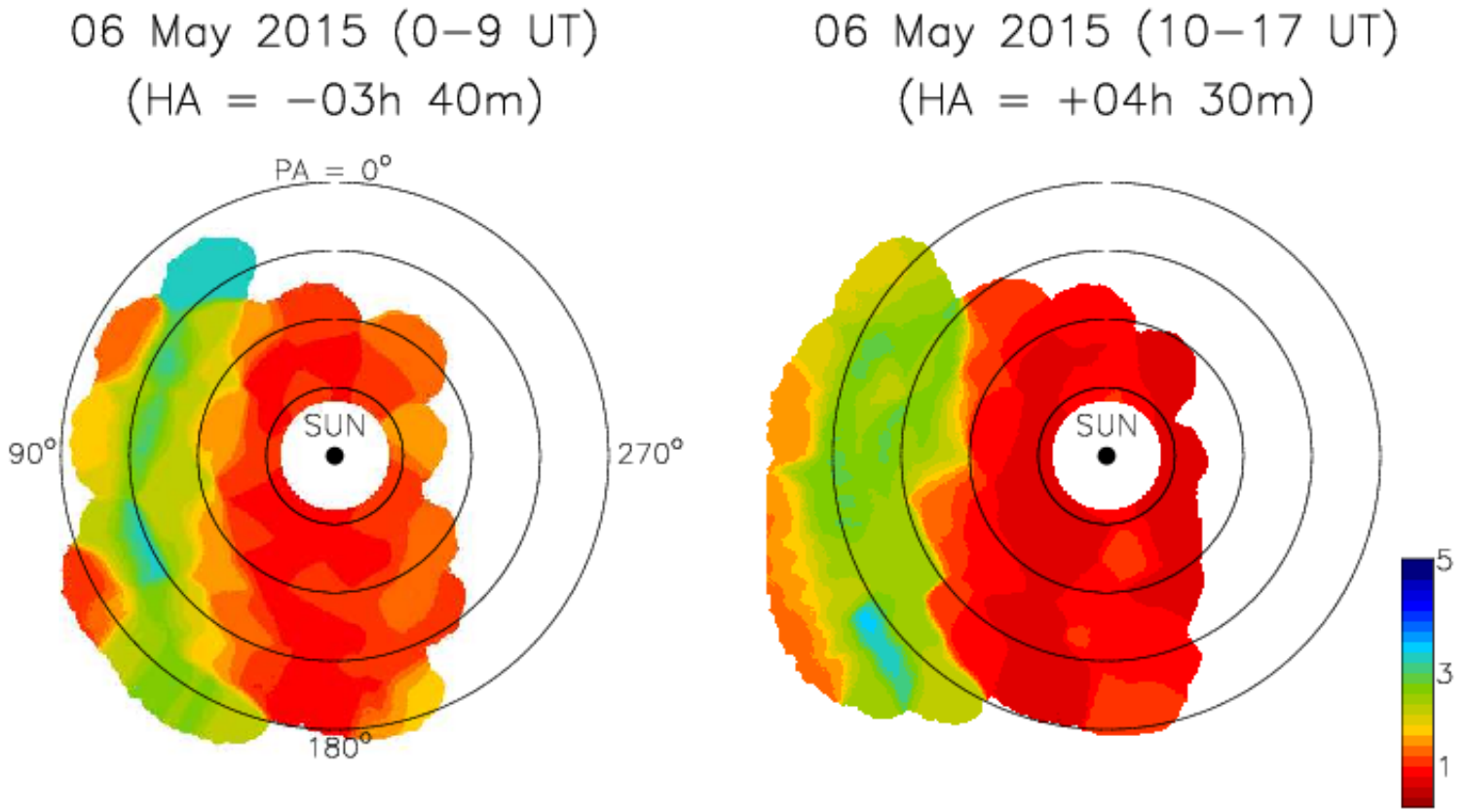
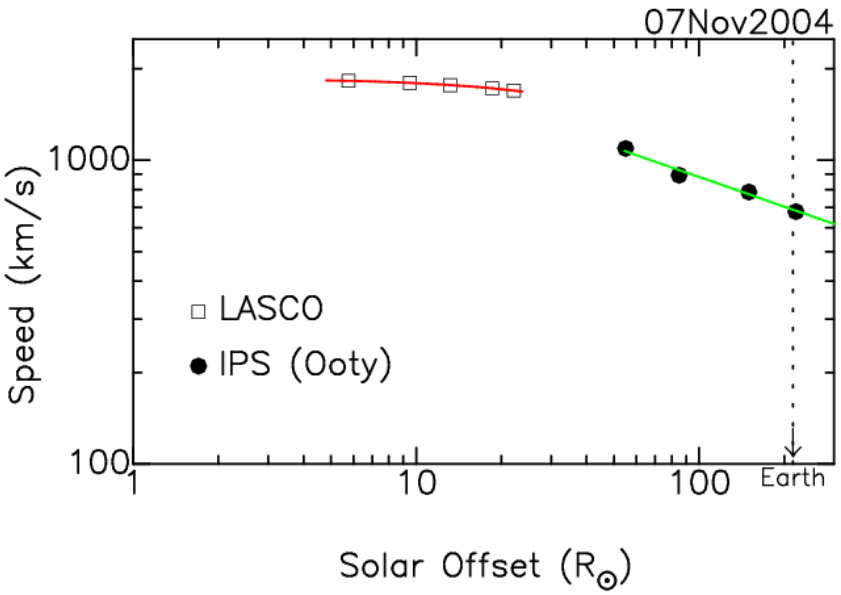
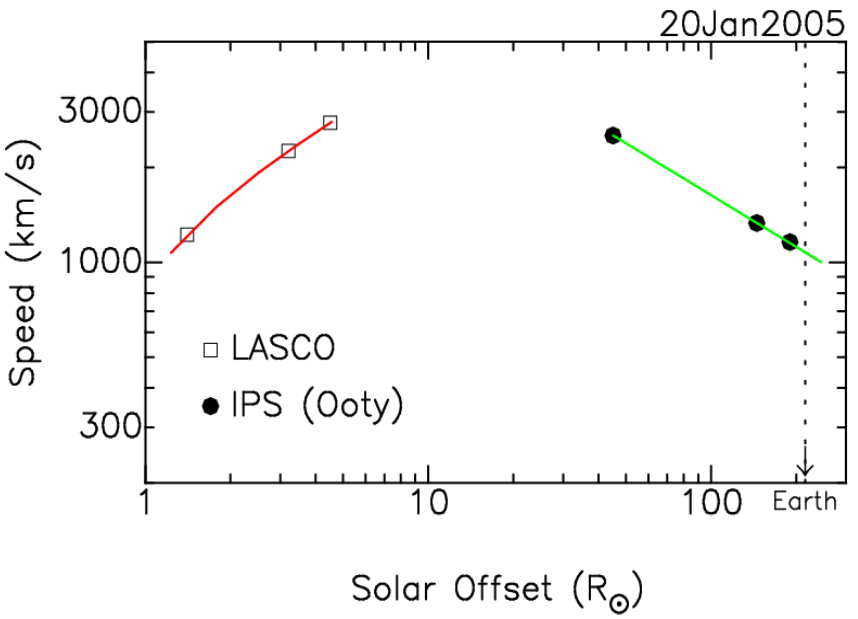


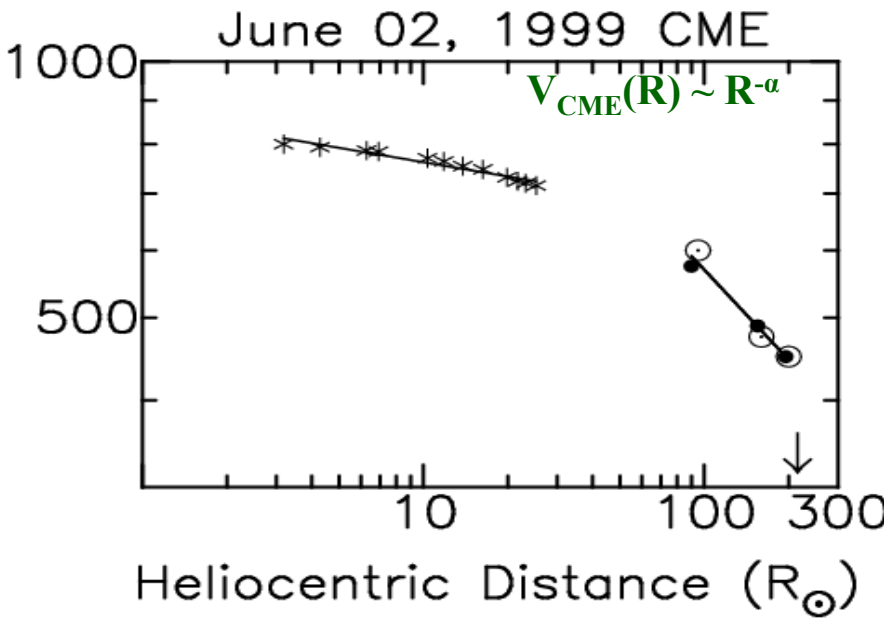
Figure 8. Interplanetary scintillation images observed with the ORT on 06 May 2015. In these "position angle–distance" diagrams, Sun is at the centre and concentric circles are of radii 50, 100, 150, 200 $R_\odot$. The colour scale shows the normalised scintillation index (g-value). Time increases from the right-hand side of the image to the left-hand side of the image. The indicated hour angle (HA) positions correspond to the ORT pointing directions. The position angles (PAs), 0°, 90°, 180°, and 270°, respectively, correspond to north, east, south, and west of the Sun.

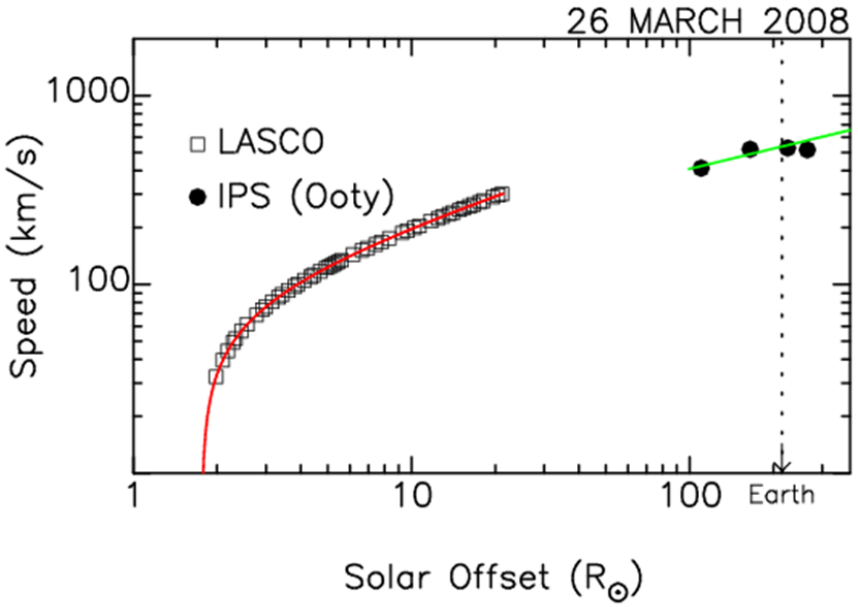
the internal magnetic energy associated with the filament (or flux rope) supports to propel the CME structure out into the solar-wind (*e.g.* Chen *et al.*, 1997;

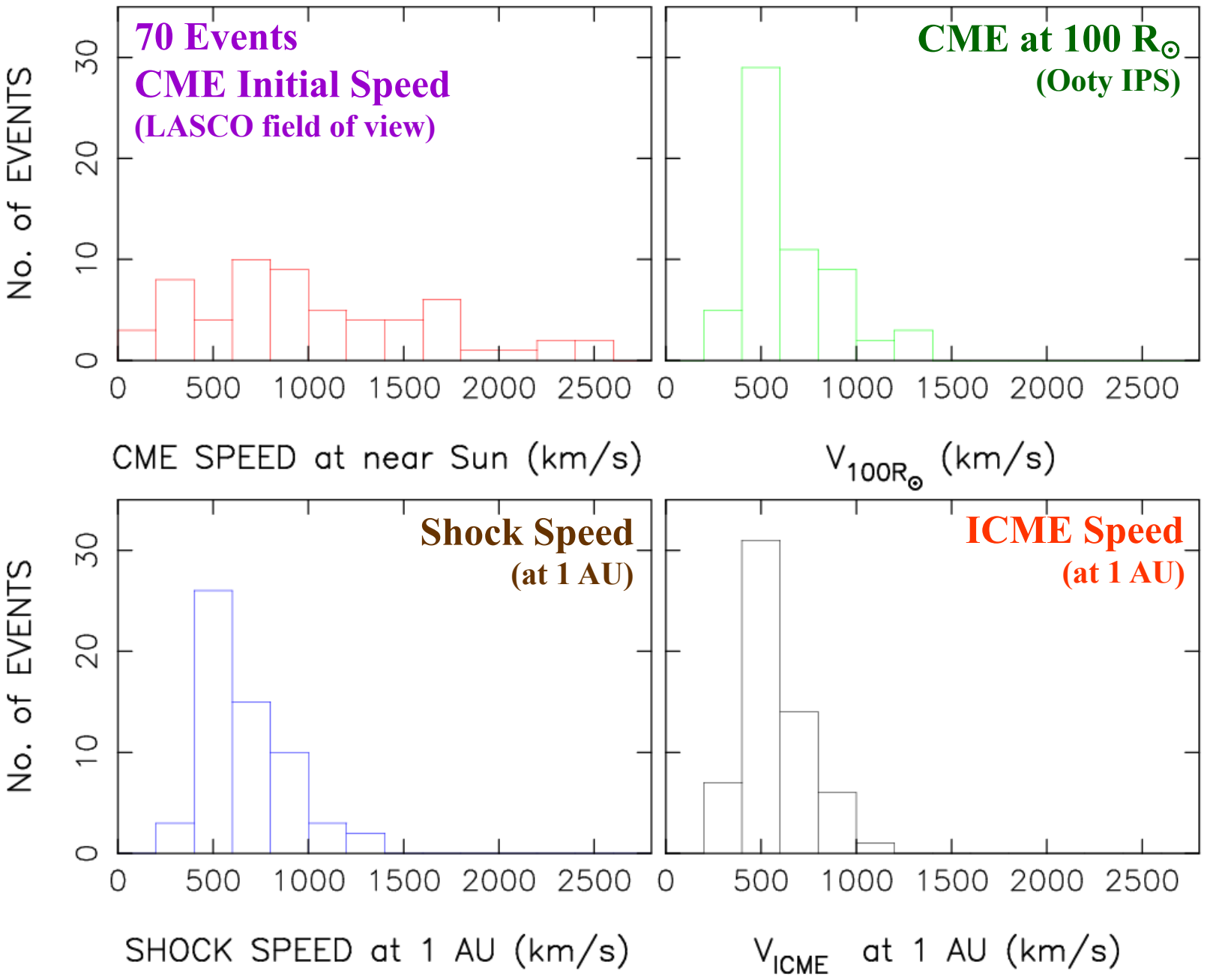
Speed-Distance Plots









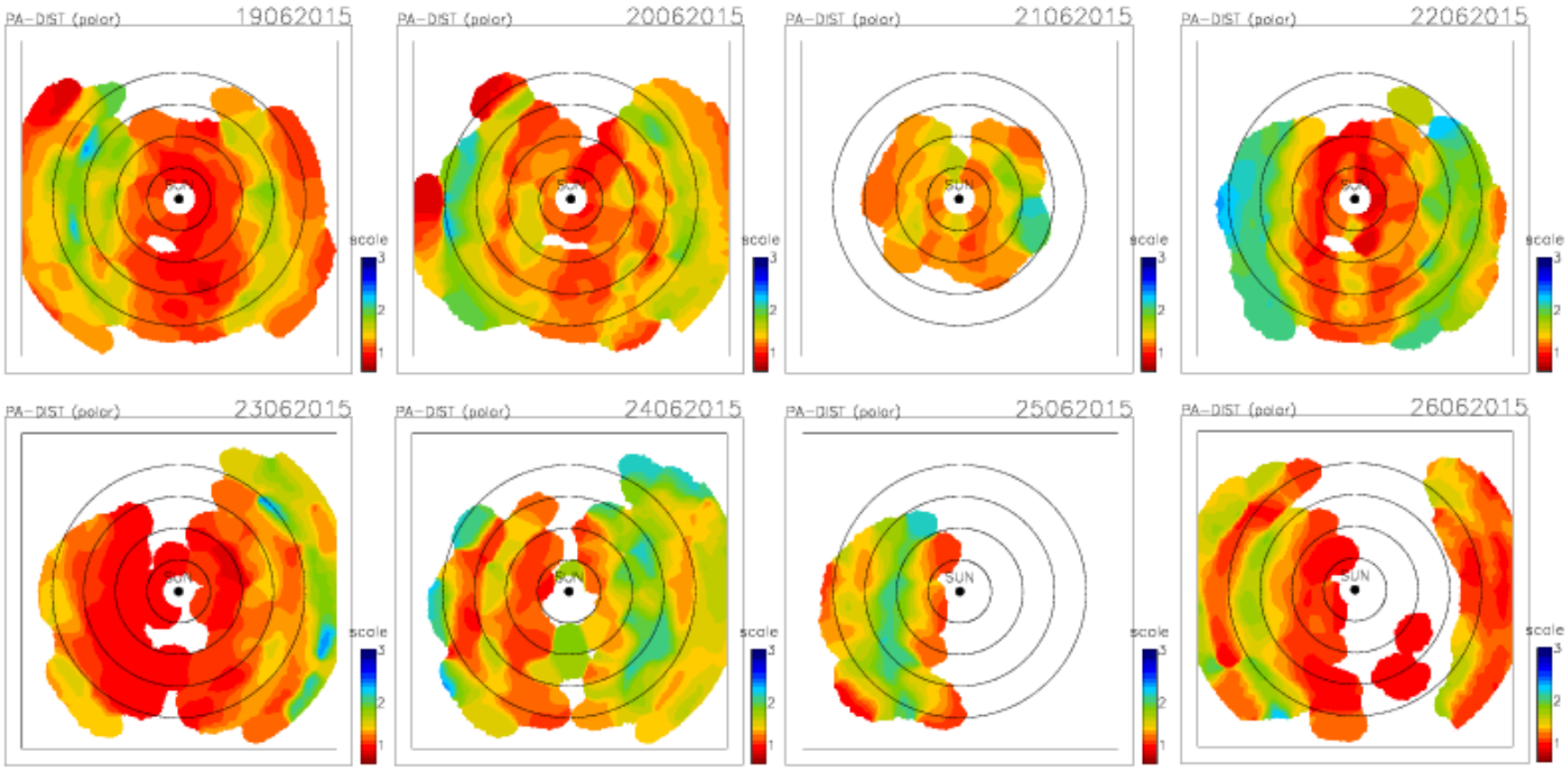

70 Events
CME Initial Speed
(LASCO field of view)
CME at 100 R⊙
(Ooty IPS)
Shock Speed
(at 1 AU)
ICME Speed
(at 1 AU)
No. of EVENTS
No. of EVENTS
0
10
20
30
0
500
1000
1500
2000
2500
CME SPEED at near Sun (km/s)
V100R⊙ (km/s)
SHOCK SPEED at 1 AU (km/s)
VICME at 1 AU (km/s)

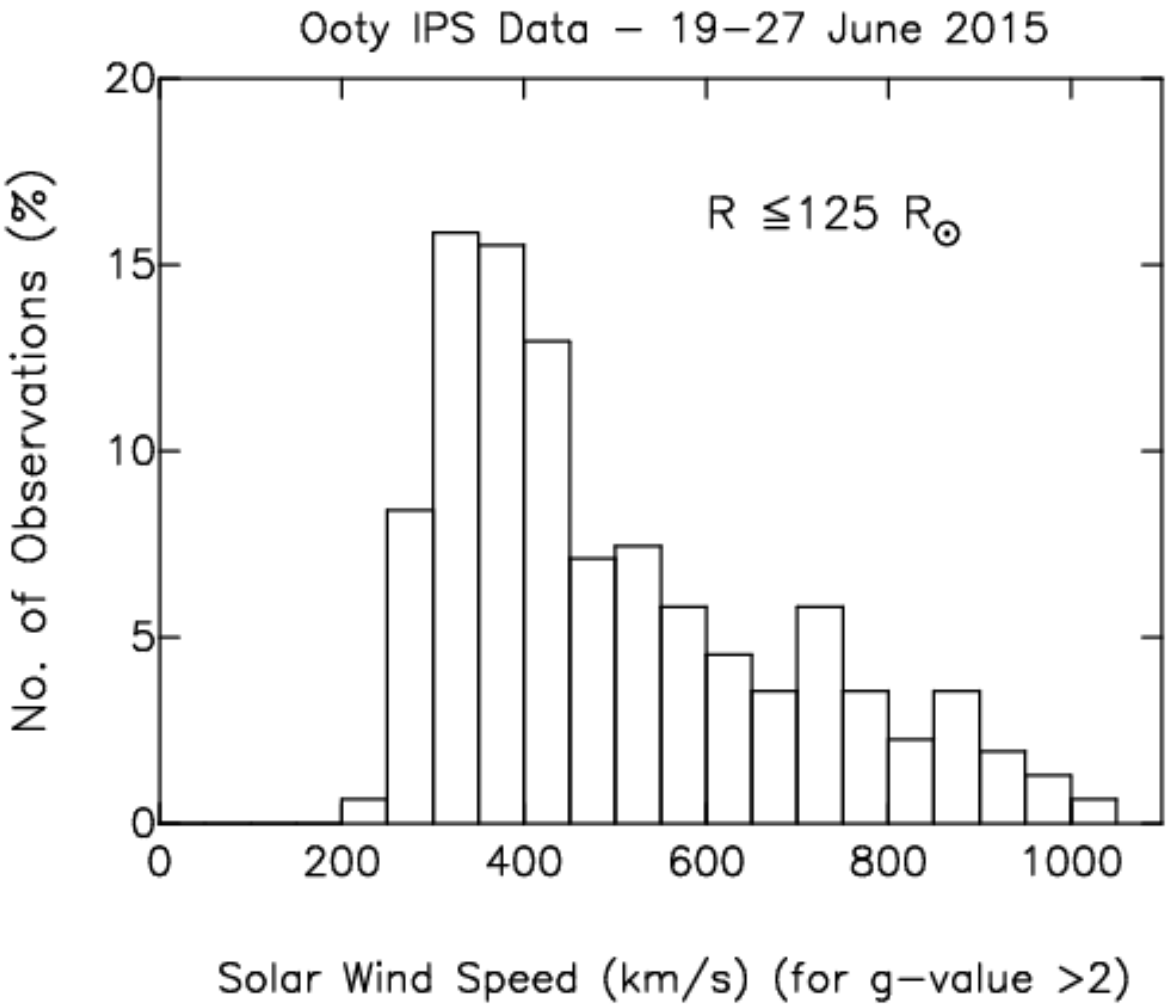
CMEs during 18 – 25 June 2015

No.	Date (2015)	Flare Class	Flare Loc.	CME Time (UT)	CME Type	CME Speed (kms^{-1})	Type-II Speed (kms^{-1})	Active Region #
1	18 June	M3.0/1N	N15E50	17:24	Halo	~1100		2371
2	19 June		S21W27	06:42	PHalo	~300		2367
3	21 June	M2.6	N12E13	02:48	Halo	~1200	>700	2371
4	22 June	M6.5	N12W08	18:36	Halo	1250	~1400	2371
5	25 June	M7.9/3B	N10W42	08:36	Halo	1500	~1700	2371

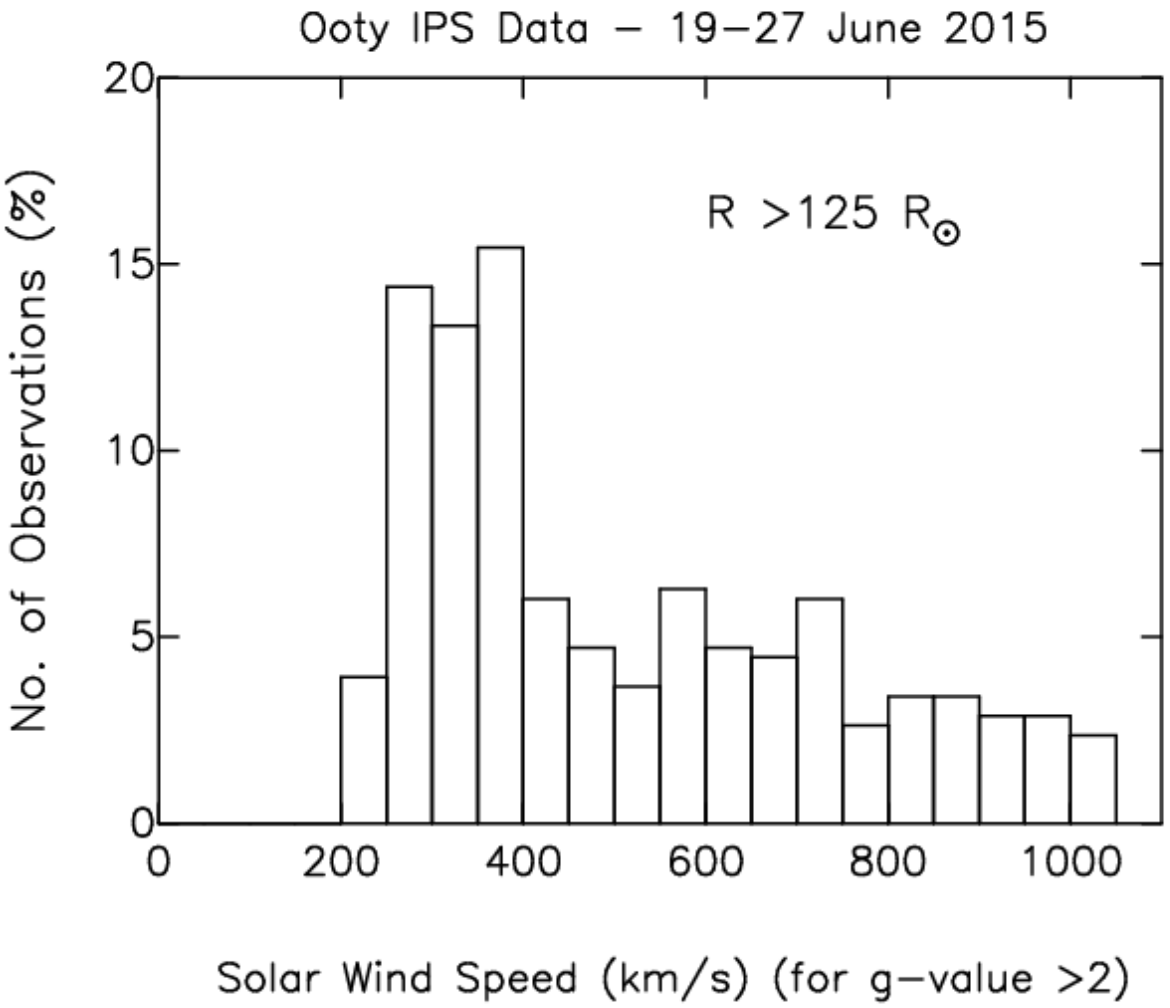
[†]The solar radio spectral data sets, available at `ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA`, are from US Air Force Radio Solar Telescope Network (RSTN).

CMEs in the inner heliosphere
IPS images during 19 – 26 June 2015

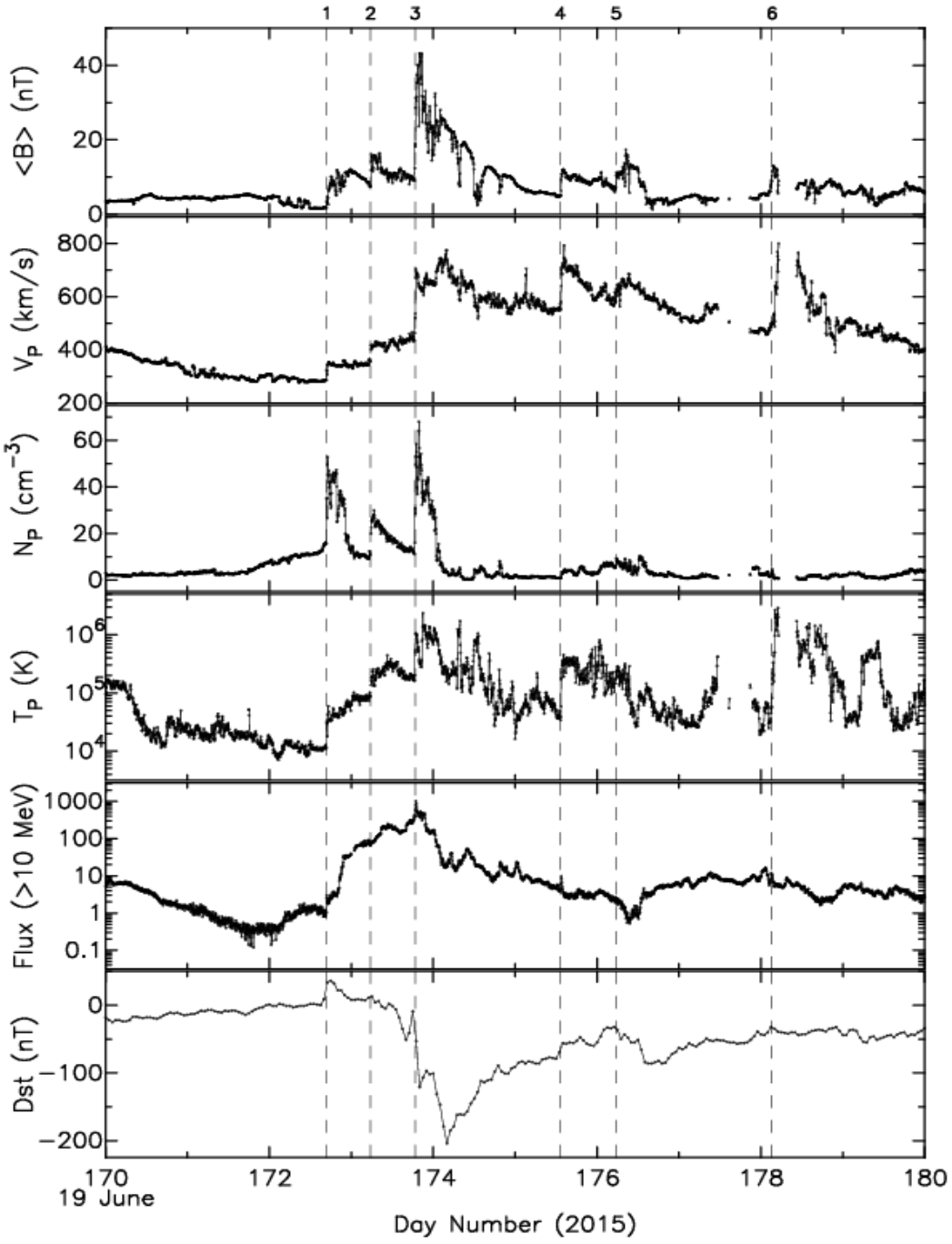




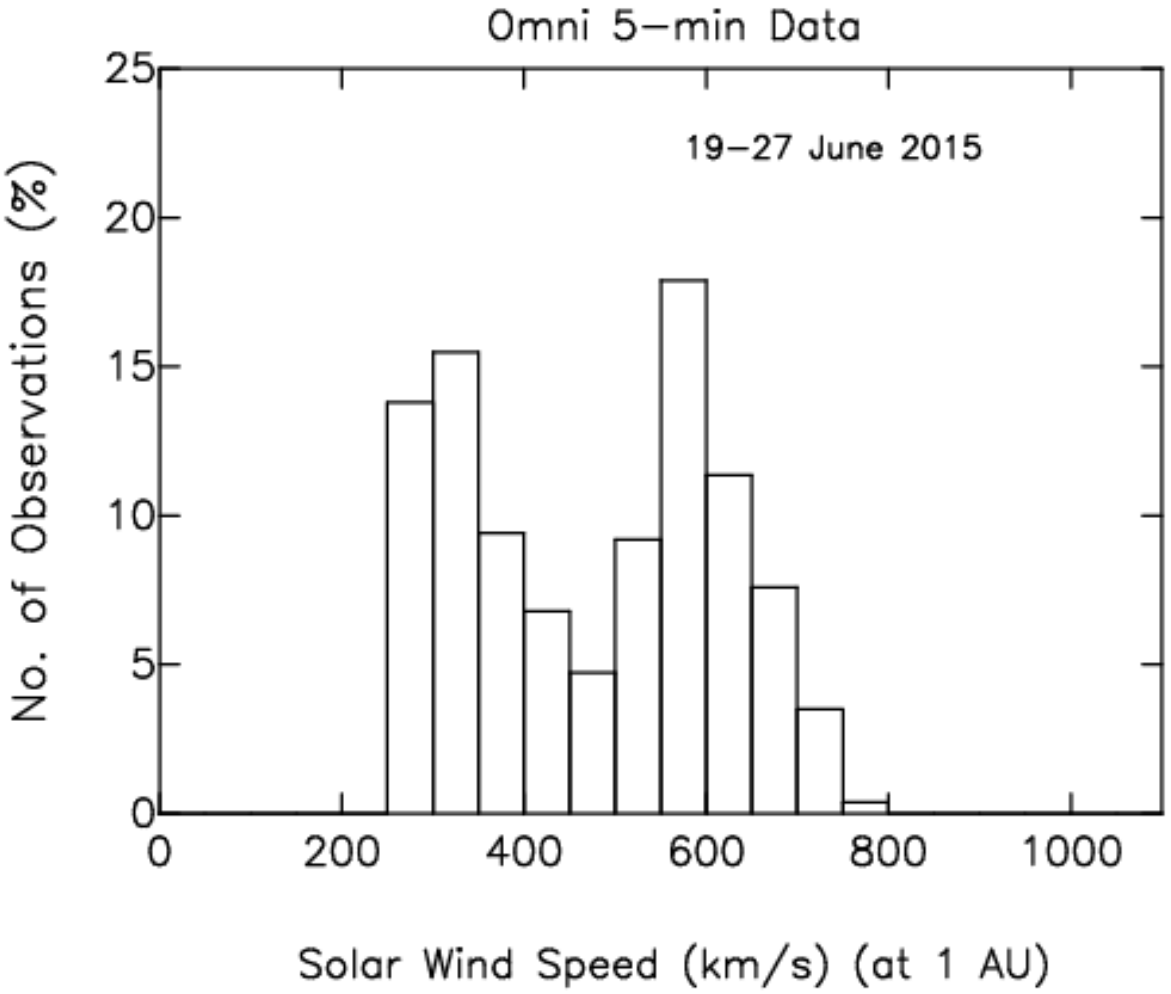
IPS observations provide a global view of the heliosphere



IPS observations provide a global view of the heliosphere



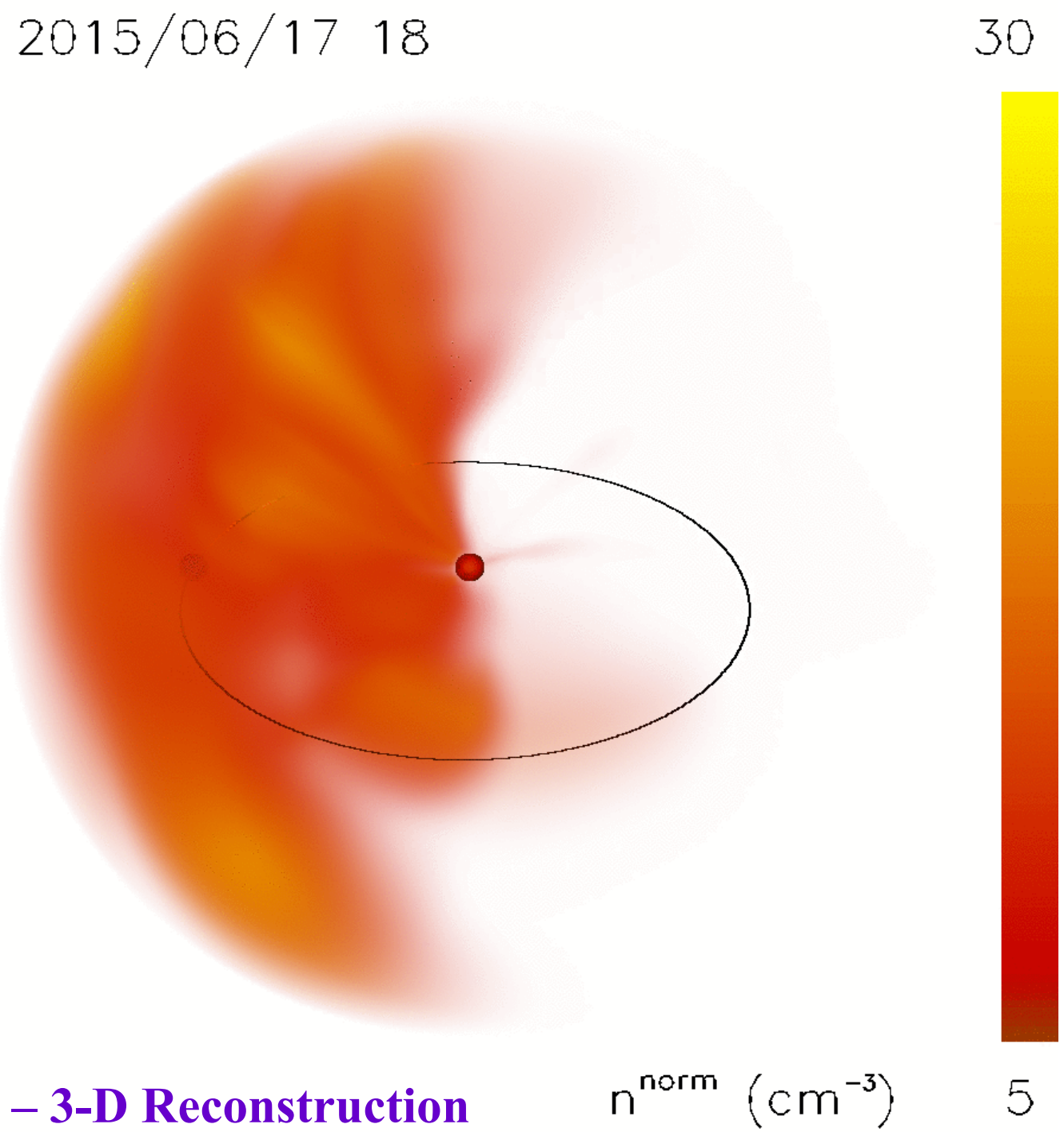
21 – 27 June 2015
Five IP Shocks at 1 AU
+
an intense geo-magnetic storm



“in-situ” measurements close to Earth’s orbit

Ooty Radio Telescope can observe a large number of radio sources per day

- **Speed and Density turbulence estimates as functions of**
  - **Time, latitude, and longitude, heliocentric distance**
- **Computer assisted tomography (CAT) analysis, developed by Bernie Jackson and his team at UCSD, allows the correction of line of sight integration and reconstruction of 3-D heliosphere (e.g., Jackson et al. 2009)**



Ooty IPS – 3-D Reconstruction

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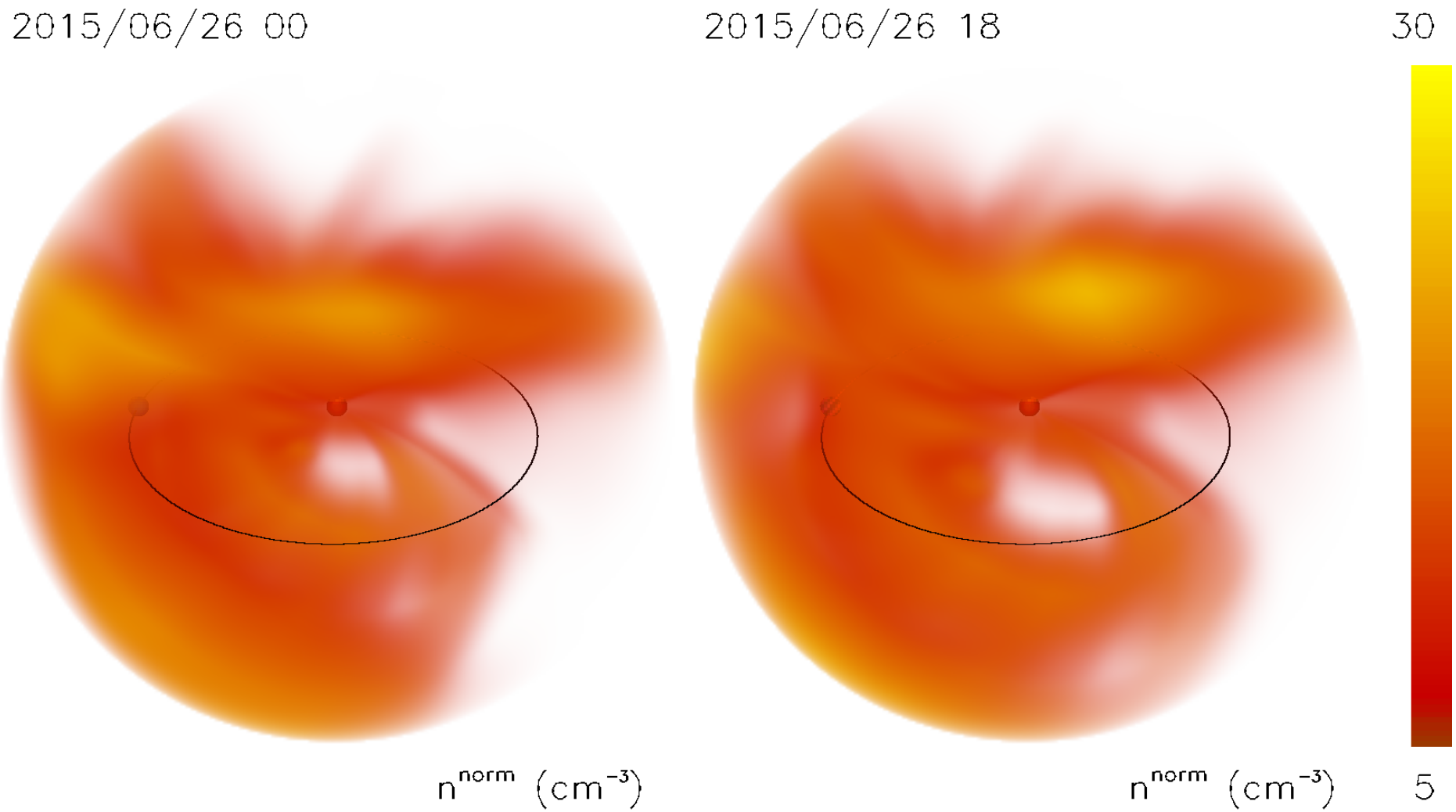
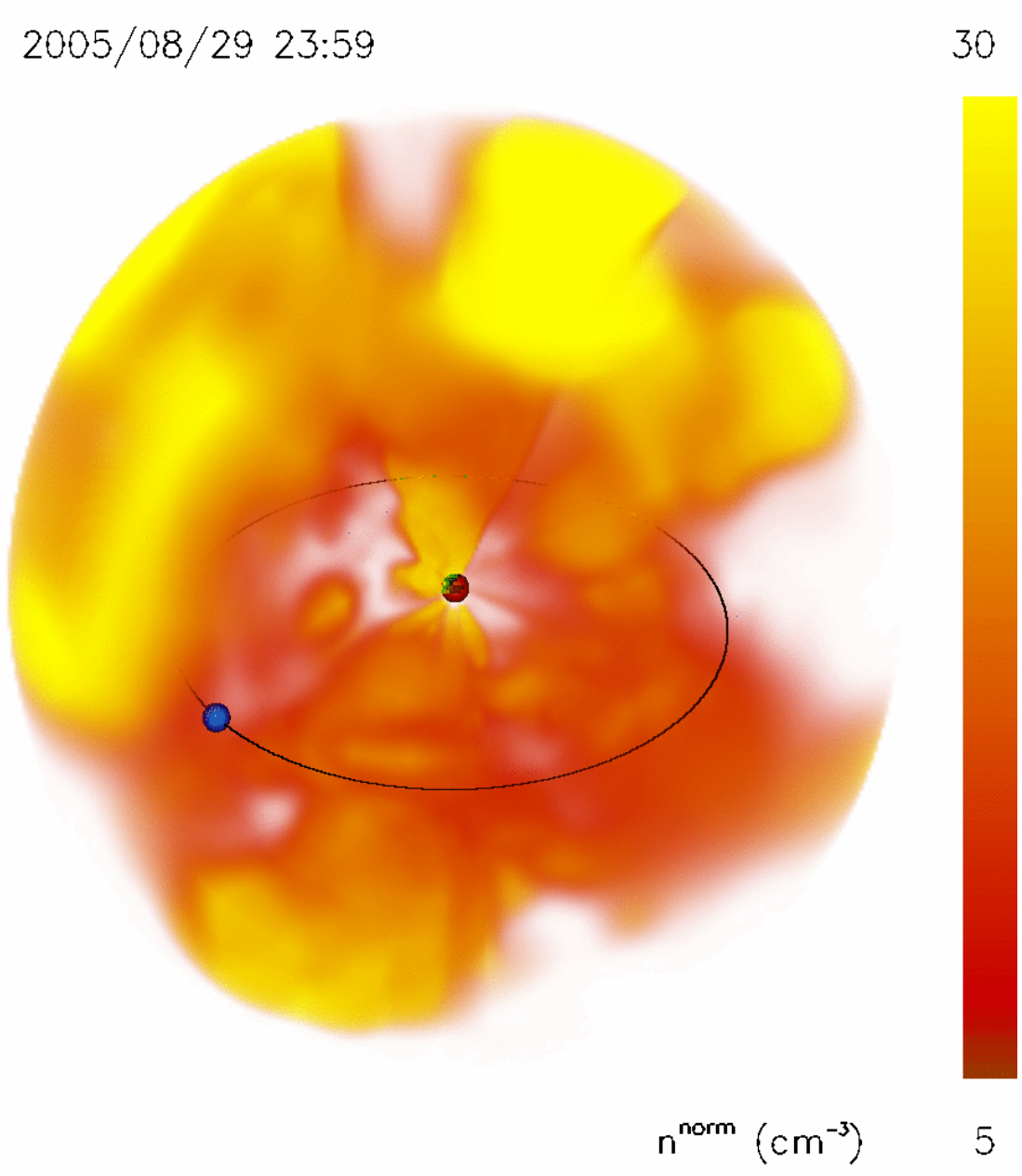


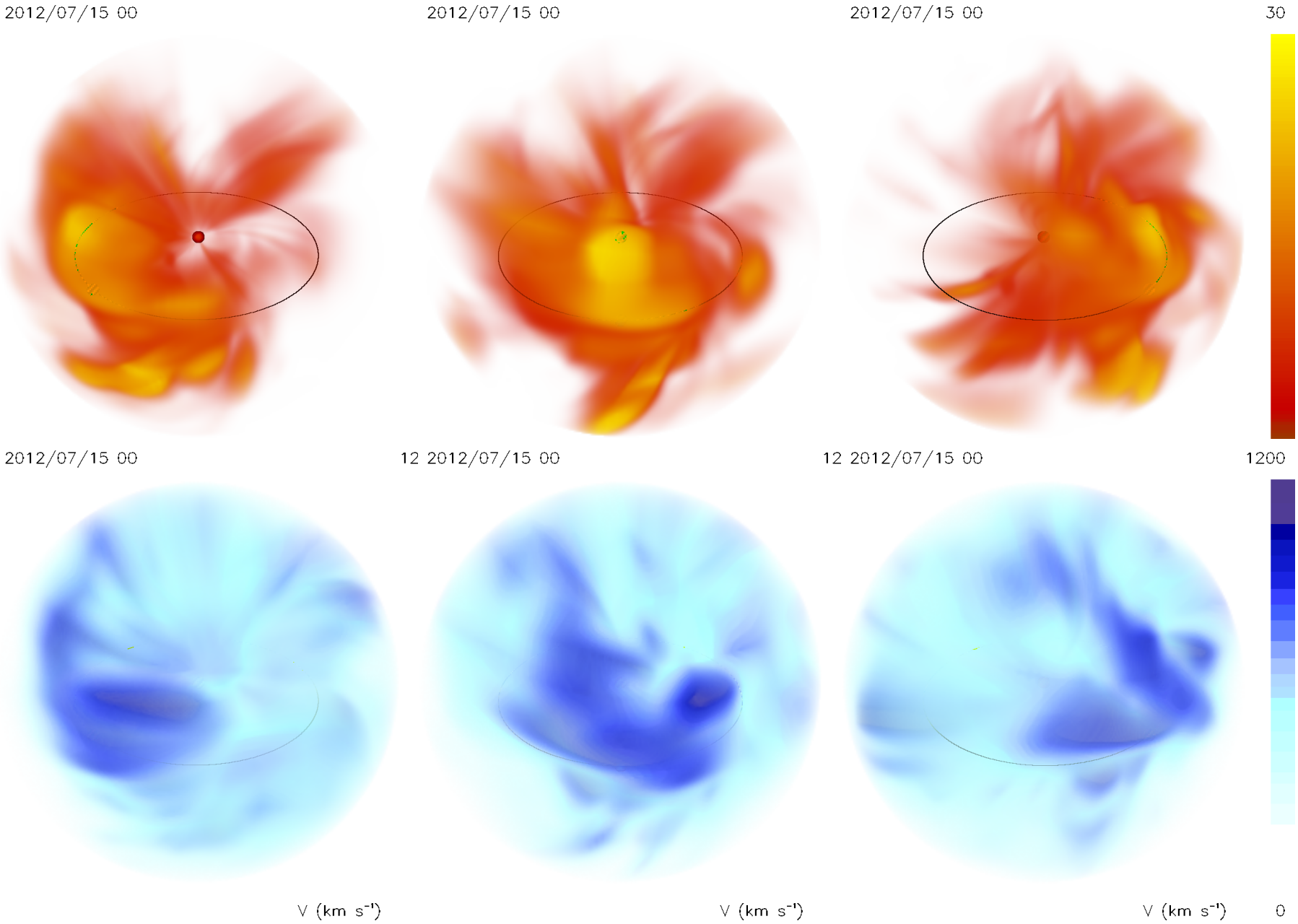

2005/08/29 23:59
30
n^{norm} (cm^{-3})
5

July 2012 Events

AR 1520 produced several flares and associated CMEs

- **12 July 2012 – close to the disk center disk X1.4 S17W08; H CME at 16:48 UT – LASCO speed at 10 Run ~1050 km/s;**
- **17 July 2012 – M1.7 at S28W65; PH CME at 13:48 UT 958 km/s**
- **18 July 2012 – S14W88; H CME 873 km/s nearly constant speed**
- **19 July 2012 – M7.7 S13W88; H CME at 05:24 UT 1631 km/s**
- **23 July 2012 – associated with an estimate of M8 – X2.5 flare event; location ~W133 degree; SRA located at 121 degree reasonably well located to observed the CME**

Density and Speed – 3D Reconstructions



Each CME seems to have different radial evolution!

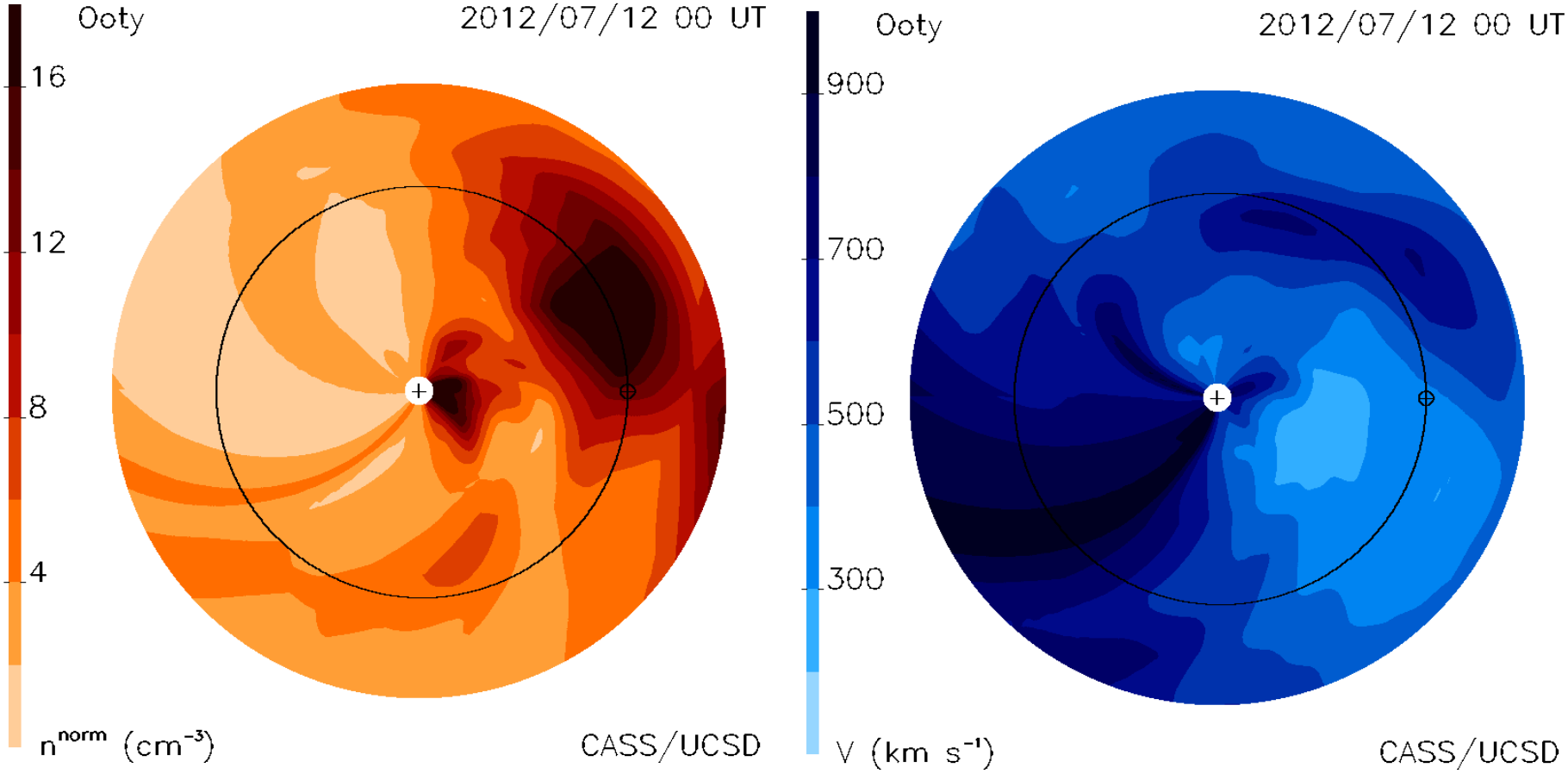
- Understanding of CME propagation requires observations of background and speed profile of the CME
- CME propagation effects can be tried out and tested with the available Ooty IPS data
- Results of Ooty IPS at ~0.5 AU can be useful to CCMC modeling to predict the arrival time of a CME

Thank You

IPS 3-D reconstruction of heliosphere

is it consistent with in-situ measurement?

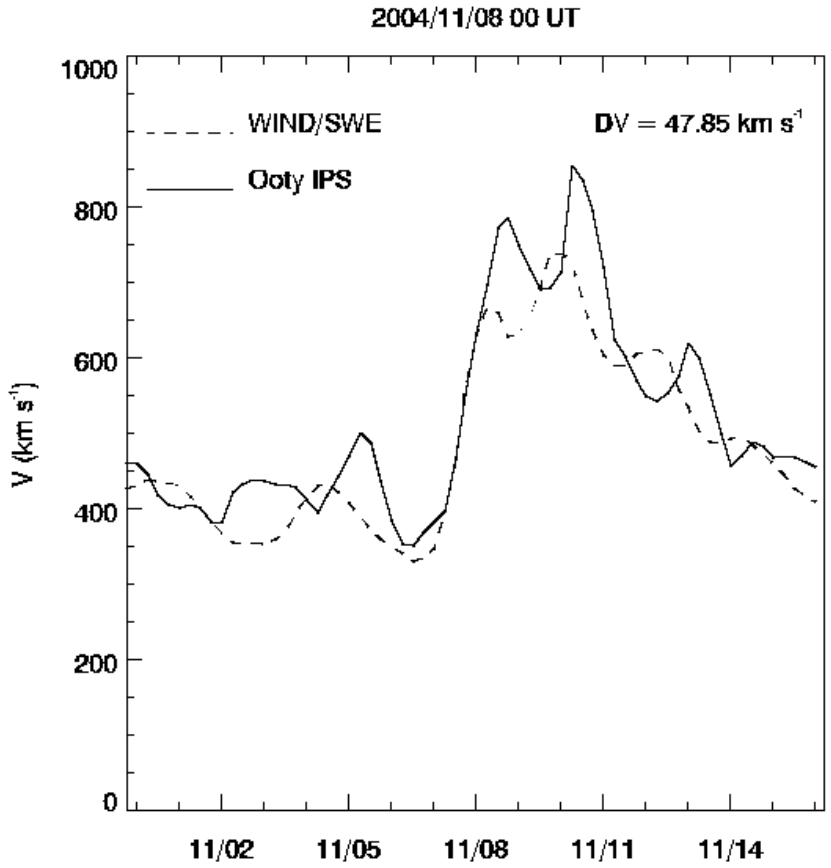
3D Ooty Density and Speed Reconstructions

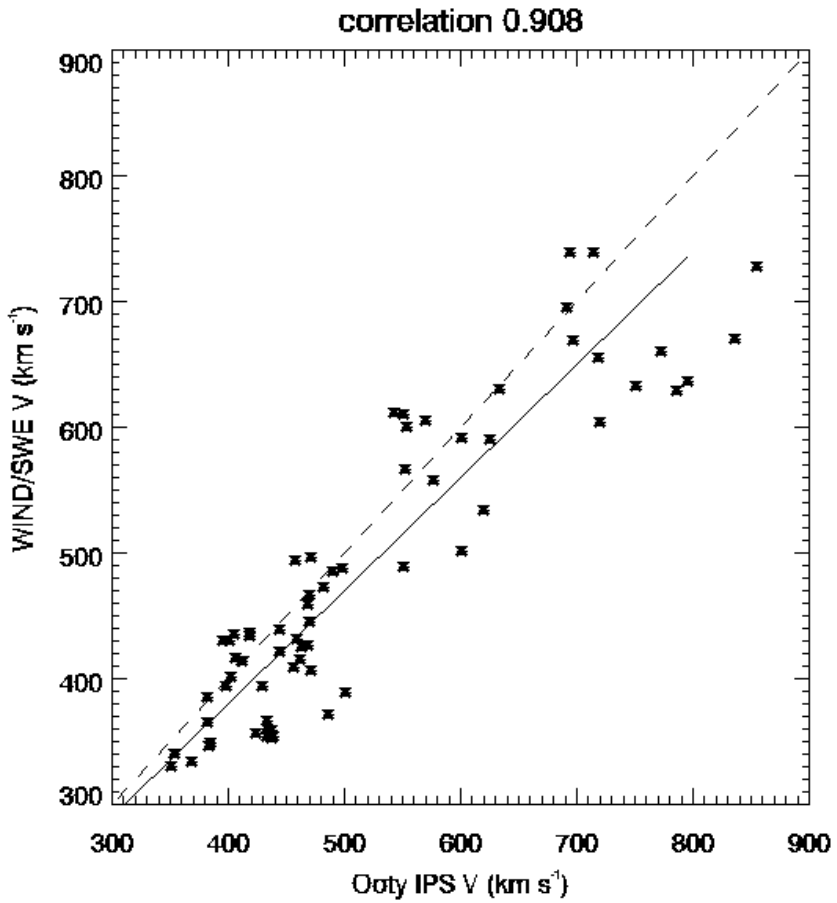


Ecliptic cuts through the 3D Ooty IPS reconstruction

(density and speed)

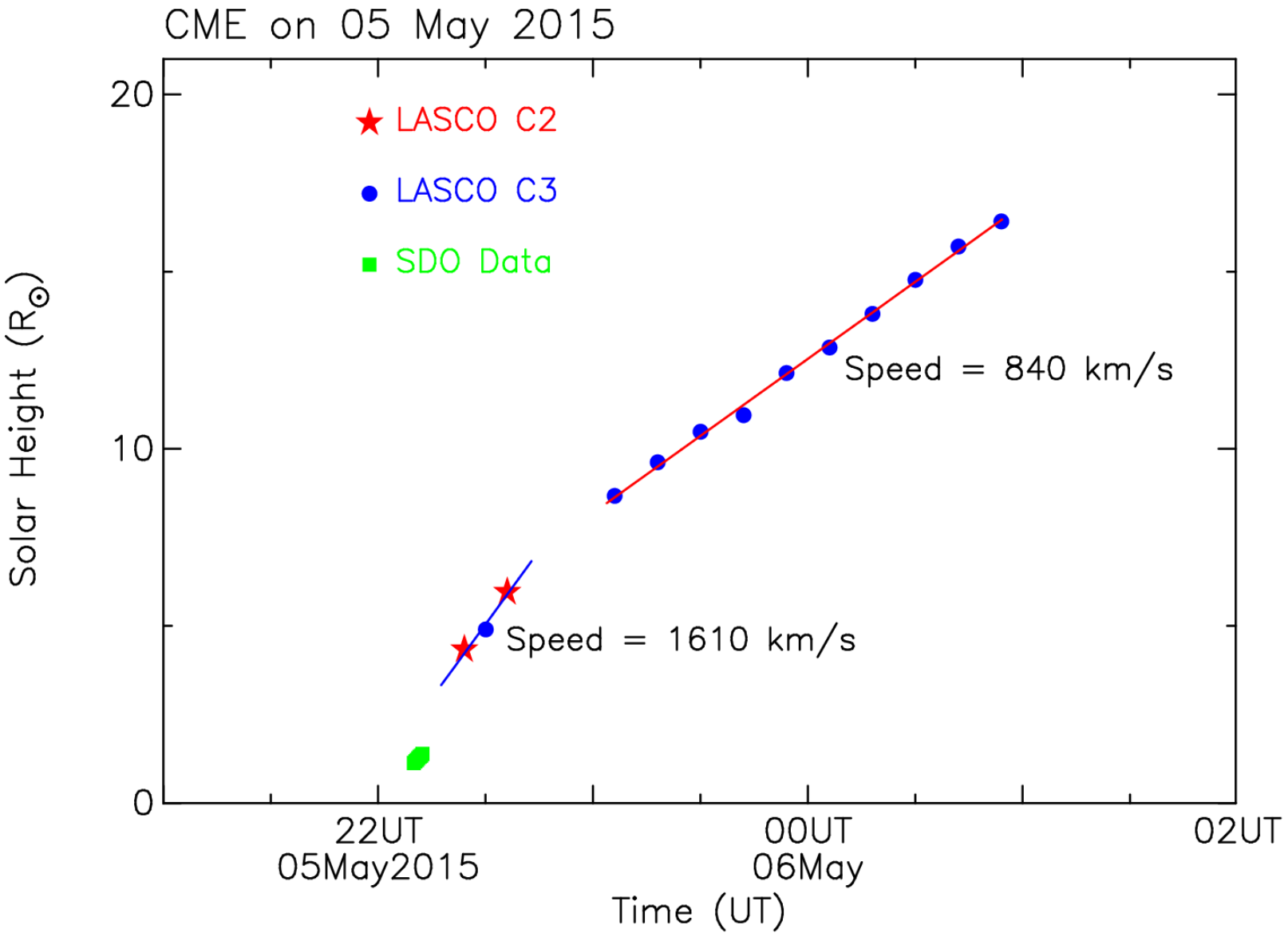
Speed Comparisons with Wind *in situ* Data





Thank You

CME Event on 05 May 2015



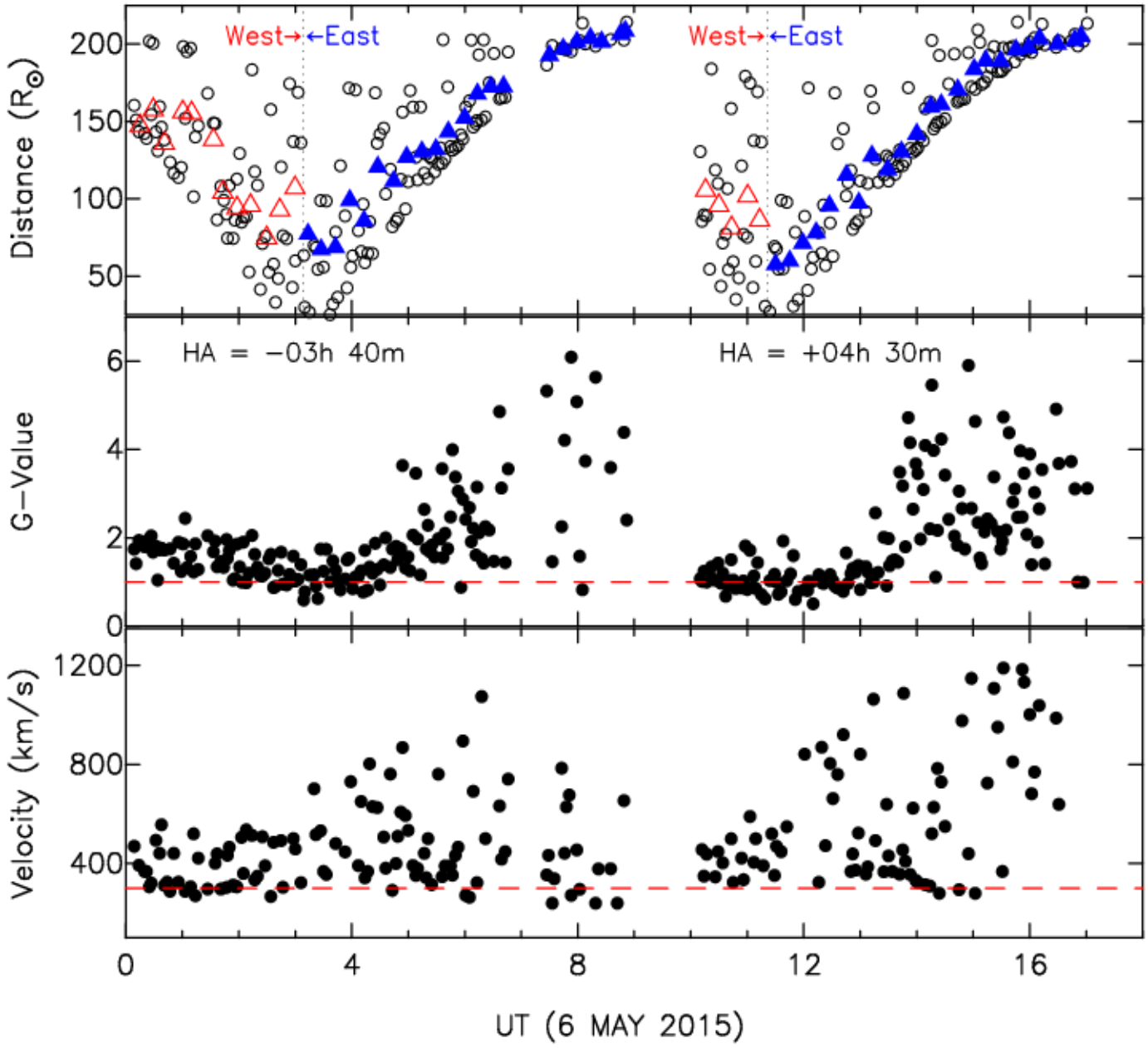
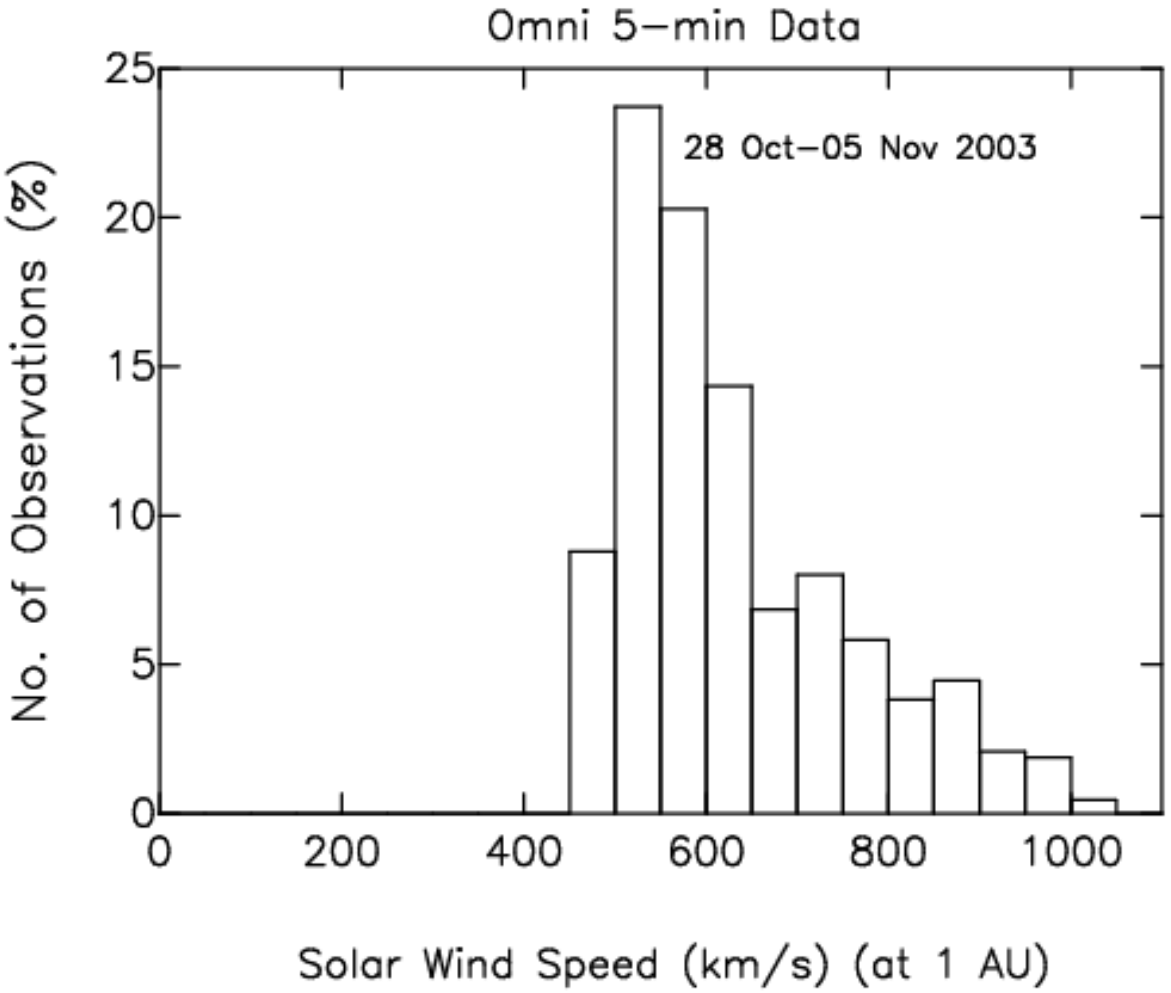


Figure 7. Time series of IPS observations on 06 May 2015. The bottom and middle panels


Omni 5−min Data
28 Oct−05 Nov 2003
No. of Observations (%)
Solar Wind Speed (km/s) (at 1 AU)
0
5
10
15
20
25
0
200
400
600
800
1000

CME event on July 12, 2012