# Current State of Reduced Solar Activity: Space Weather Events in the Inner Heliosphere

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The decade after the International Heliophysical Year 2007
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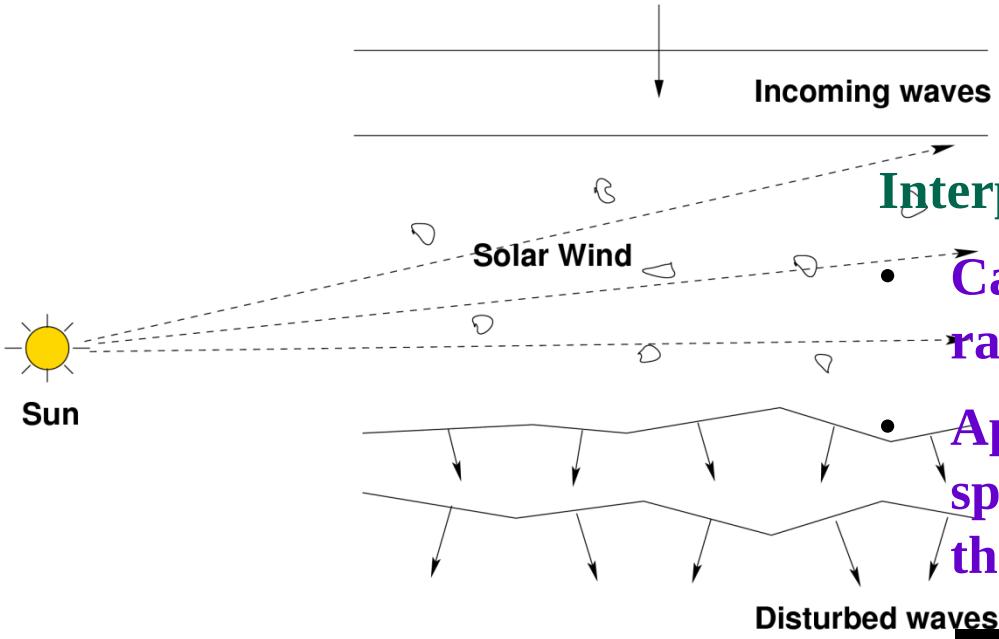
# Remote sensing the inner heliosphere

## Interplanetary scintillation (IPS)

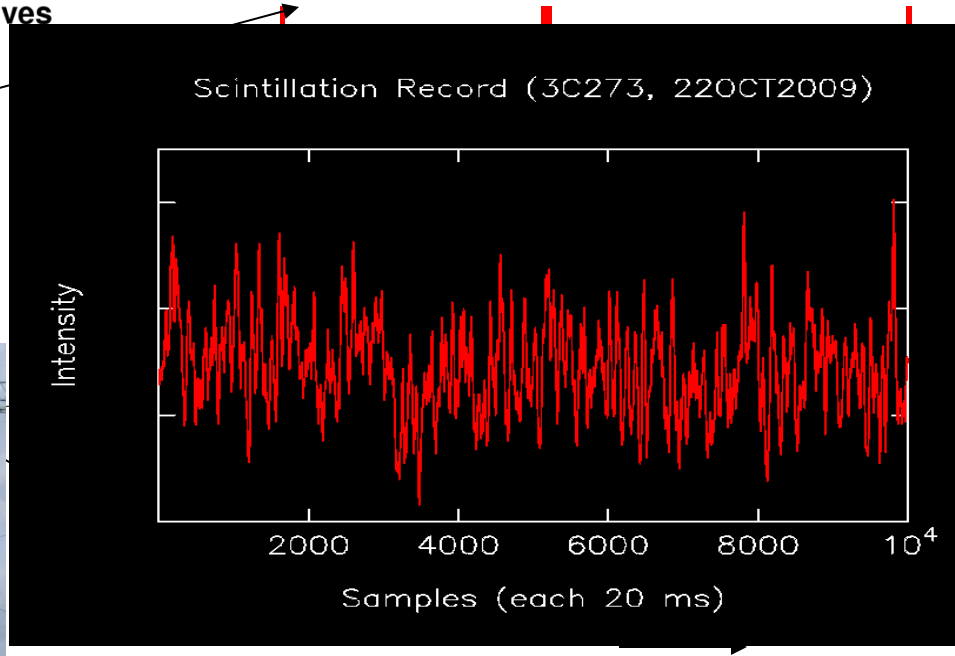
**In the Sun-Earth distance**

**Full range of helio latitudes**




## Interplanetary Scintillations (IPS)

- Caused by density irregularities moving radially outward from the Sun
- Appropriate inversion of IPS provides speed and level of density turbulence in the solar wind



# Introduction

**Coronal mass ejections (CMEs) are responsible for most of large magnetic disturbances at the Earth.**

- **CME speed ranges between ~100 – 3000 km/s**
- **Evolution of magnetic field, size, speed, direction – important to predict the impact on the Earth**
- **Plus evolution of shock associated a CME**

**IPS technique is useful to track CMEs in the Sun-Earth distance**

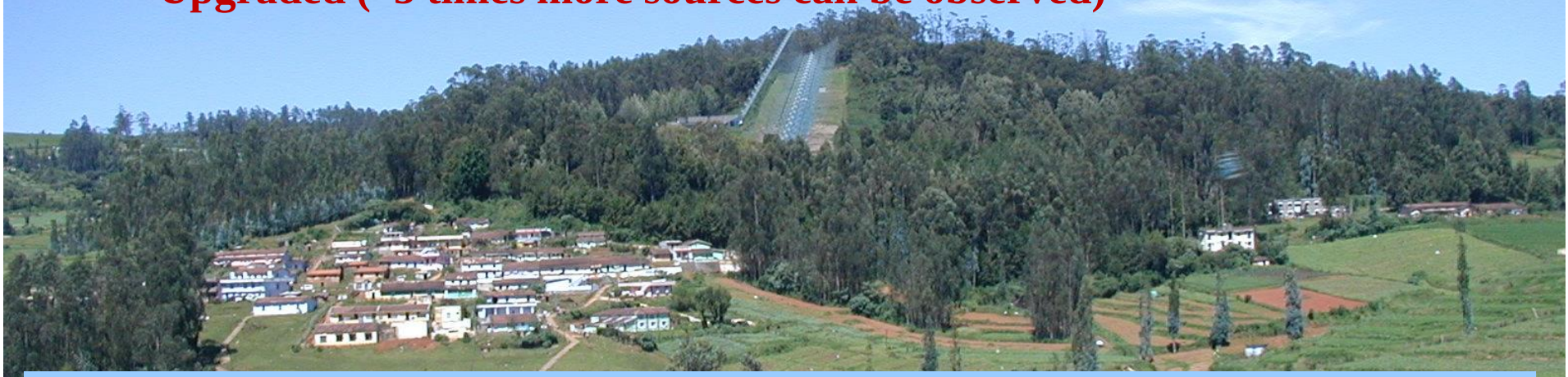
- **Each day IPS can provide snapshot images**
- **Routine monitoring of IPS on a large number of sources and the tomography reconstruction can provide the 3-D evolution of heliosphere**

# IPS – Radio Arrays

- Several radio telescopes are employed in IPS studies
  - Ooty Radio Telescope (327 MHz)
  - Solar-Terrestrial Environment Laboratory (327 MHz)
  - MEXART (140 MHz)
  - MWA
  - LOFAR
  - BSA (Russian) array ~110 MHz
  - EISCAT
  - Korea Space Weather Center (327 MHz)
  - Urumqi (NAOC) + Kunming 40m Radio Telescope
    - Solar wind speed
    - Density turbulence level - efforts to combine data

# Ooty Radio Telescope

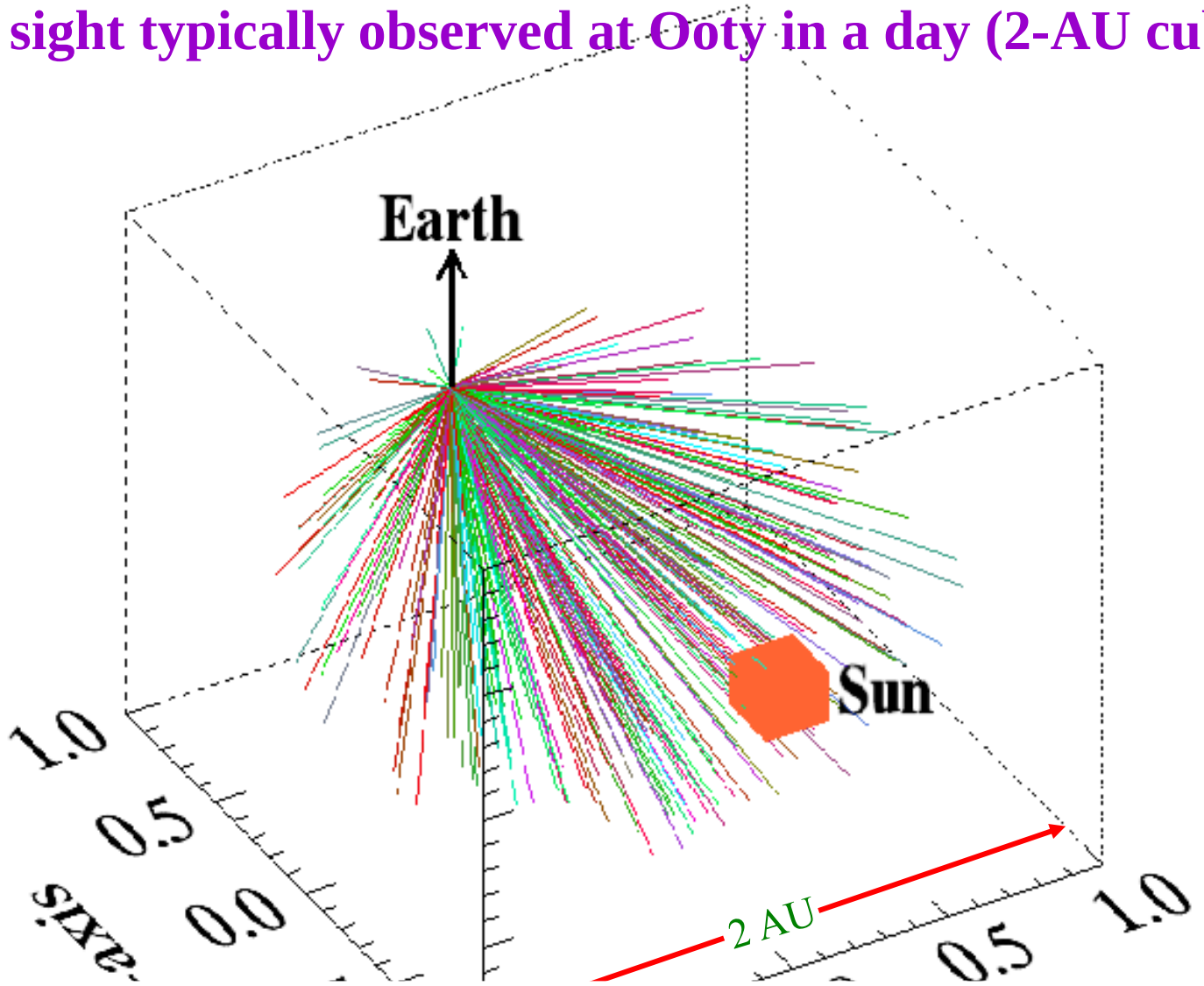
- 327 MHz
- 530m (N-S) x 30m (E-W) – equatorially mounted – (E-W) tracking ~9.5 hours
- North-South beam steering (± 65 deg. declination)
  - Sensitive telescope – observes ~1000 radio sources per day
  - Upgraded (~5 times more sources can be observed)



**Ooty IPS measurements provide estimates of**

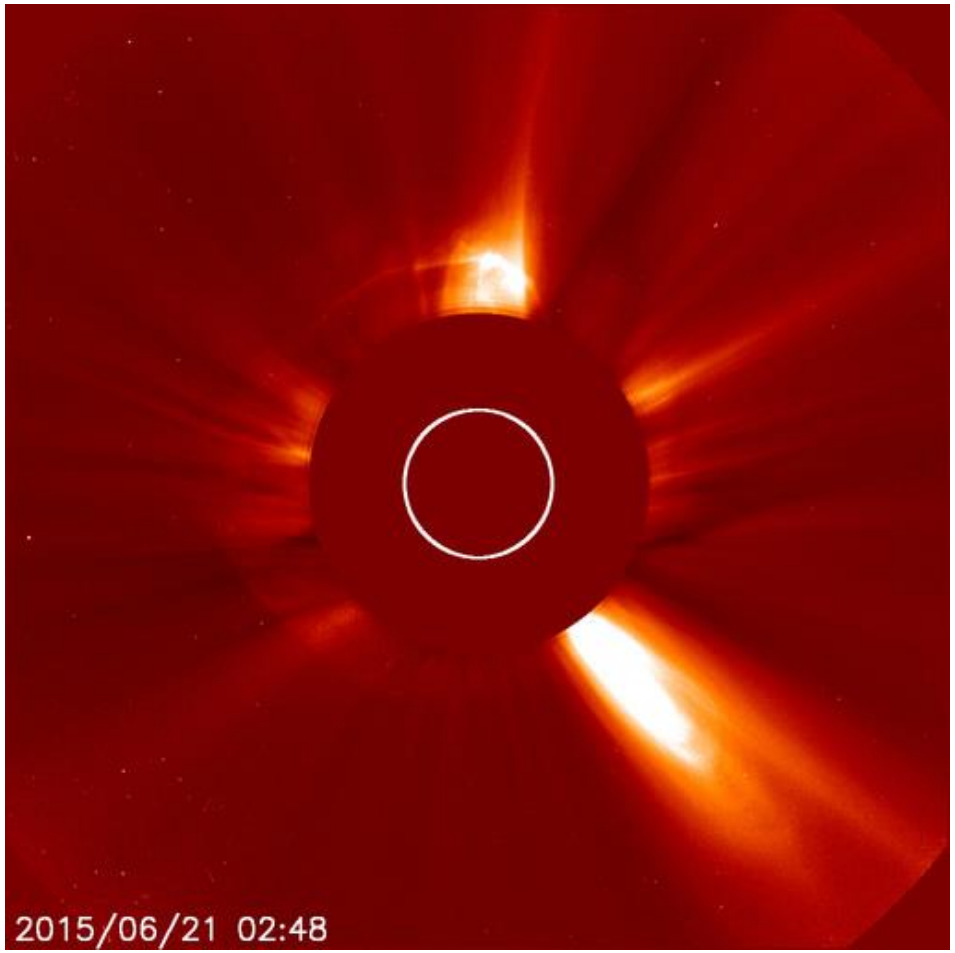
- solar wind velocity
- δNe level (g-value)
- at a heliocentric distance range of 10 – 250 $R_{\odot}$
- at all helio latitudes

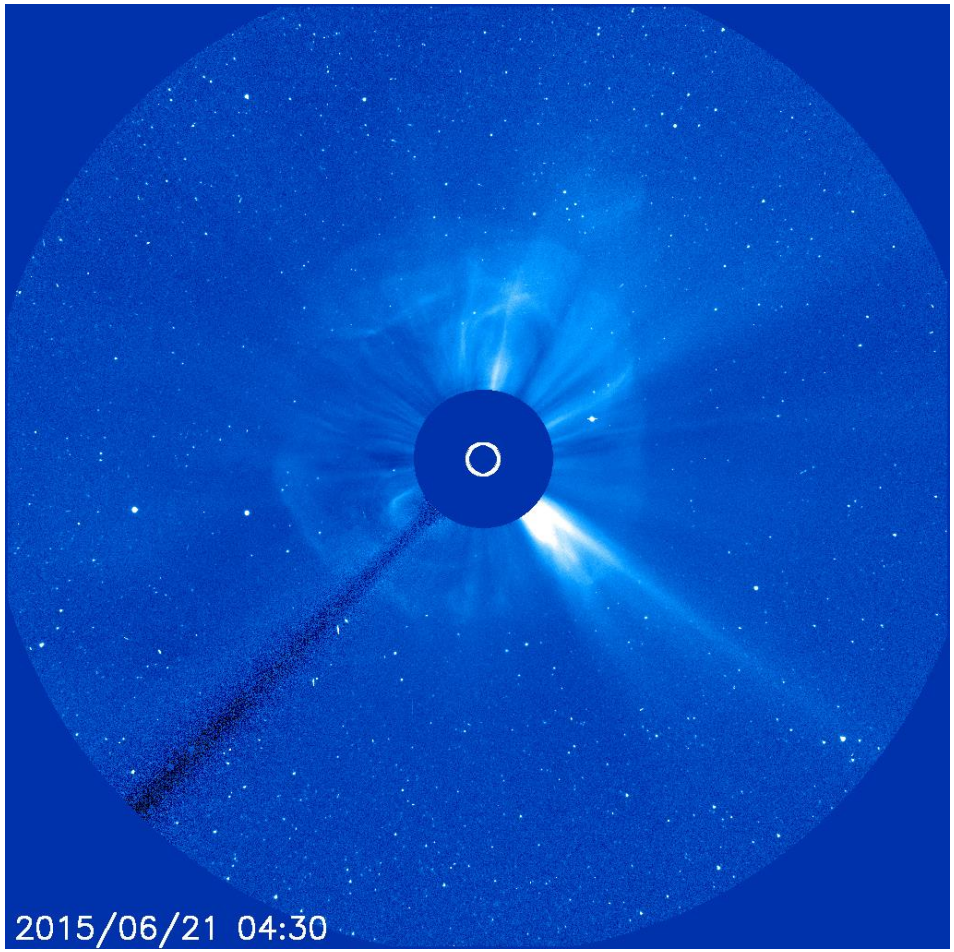
# Lines of sight typically observed at Ooty in a day (2-AU cube)




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

# Evolution of CMEs (Sun to 1 AU distance)

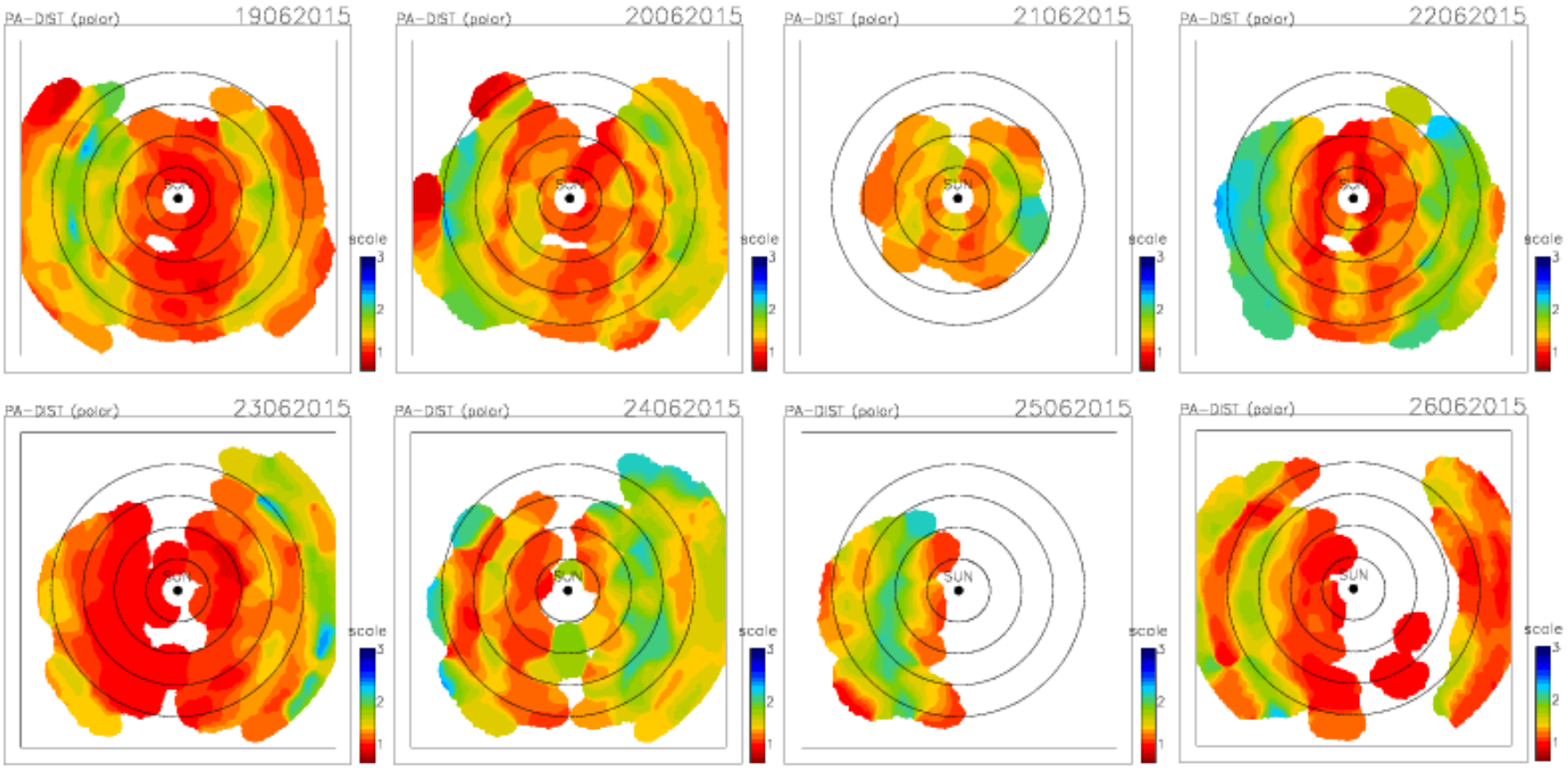


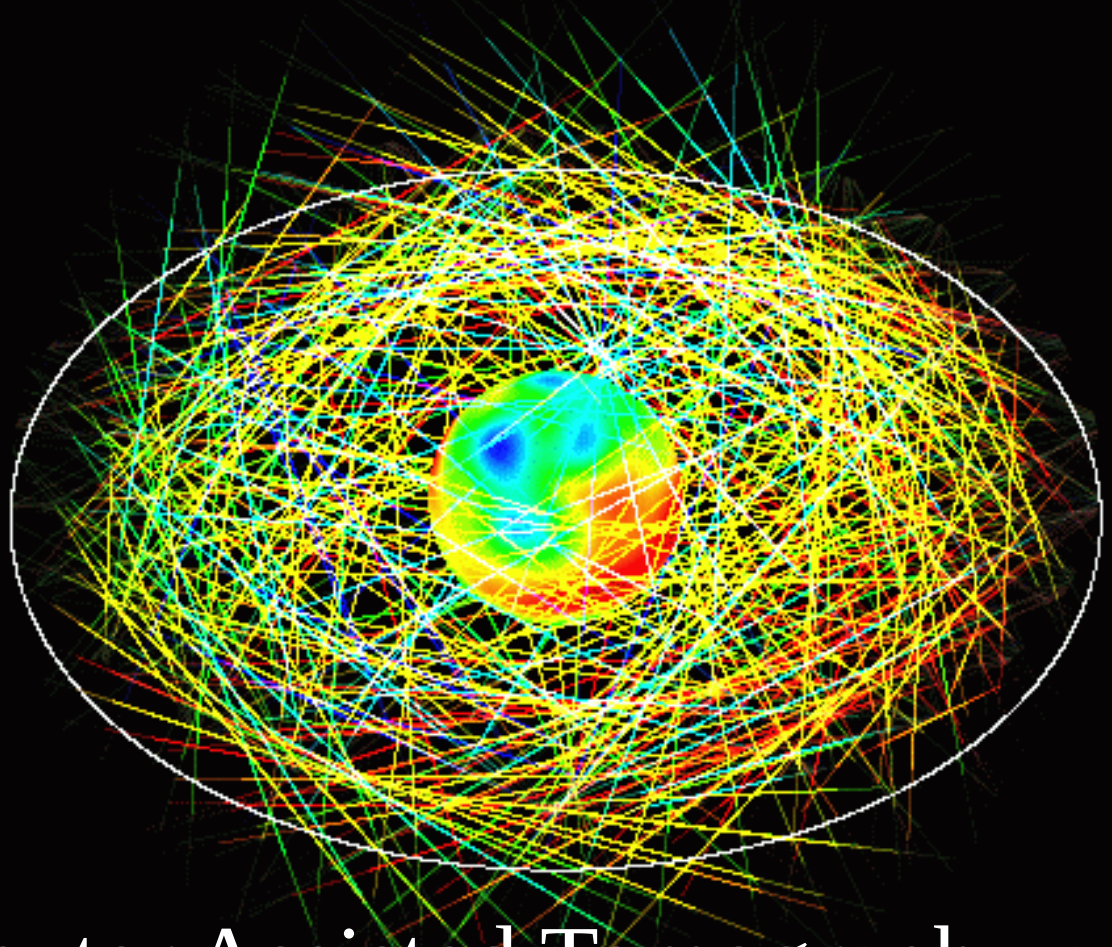

## Fast and wide CMEs

## June 21 – 24, 2015

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

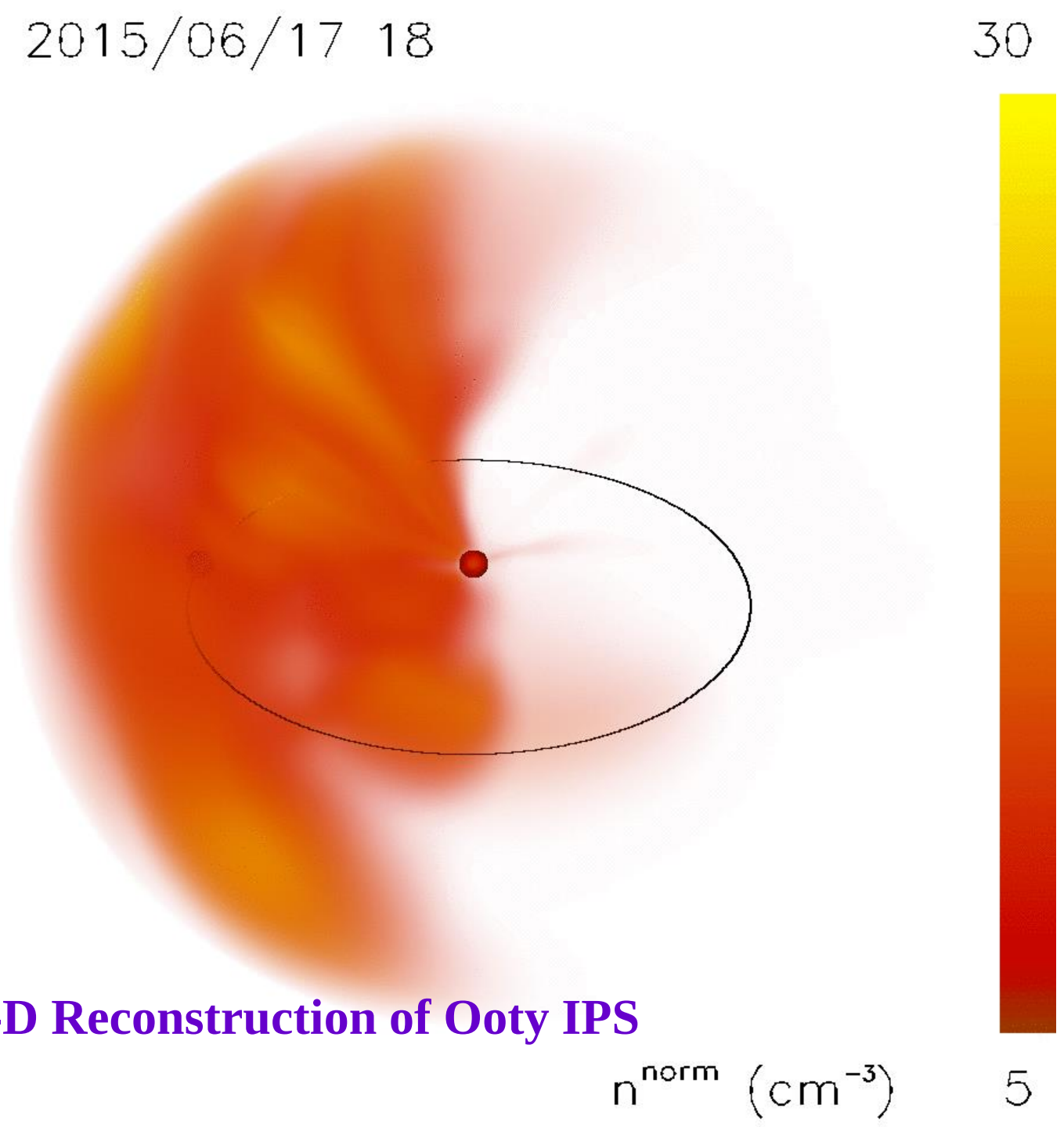


Solar rotation and radial outward flow of the solar wind provide the 3-d structure of th
solar wind at different view angles

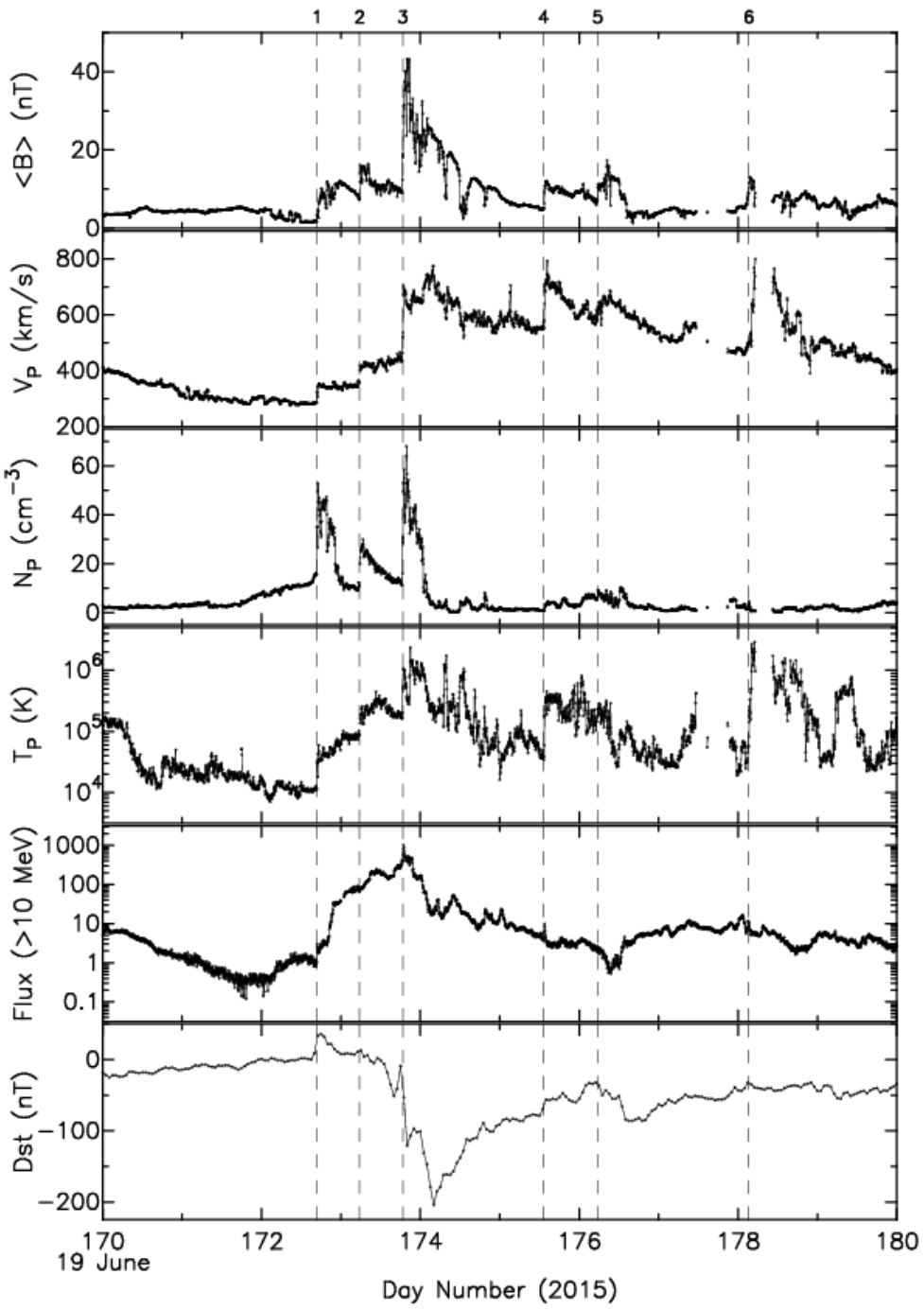


# Computer Assisted Tomography analysis

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



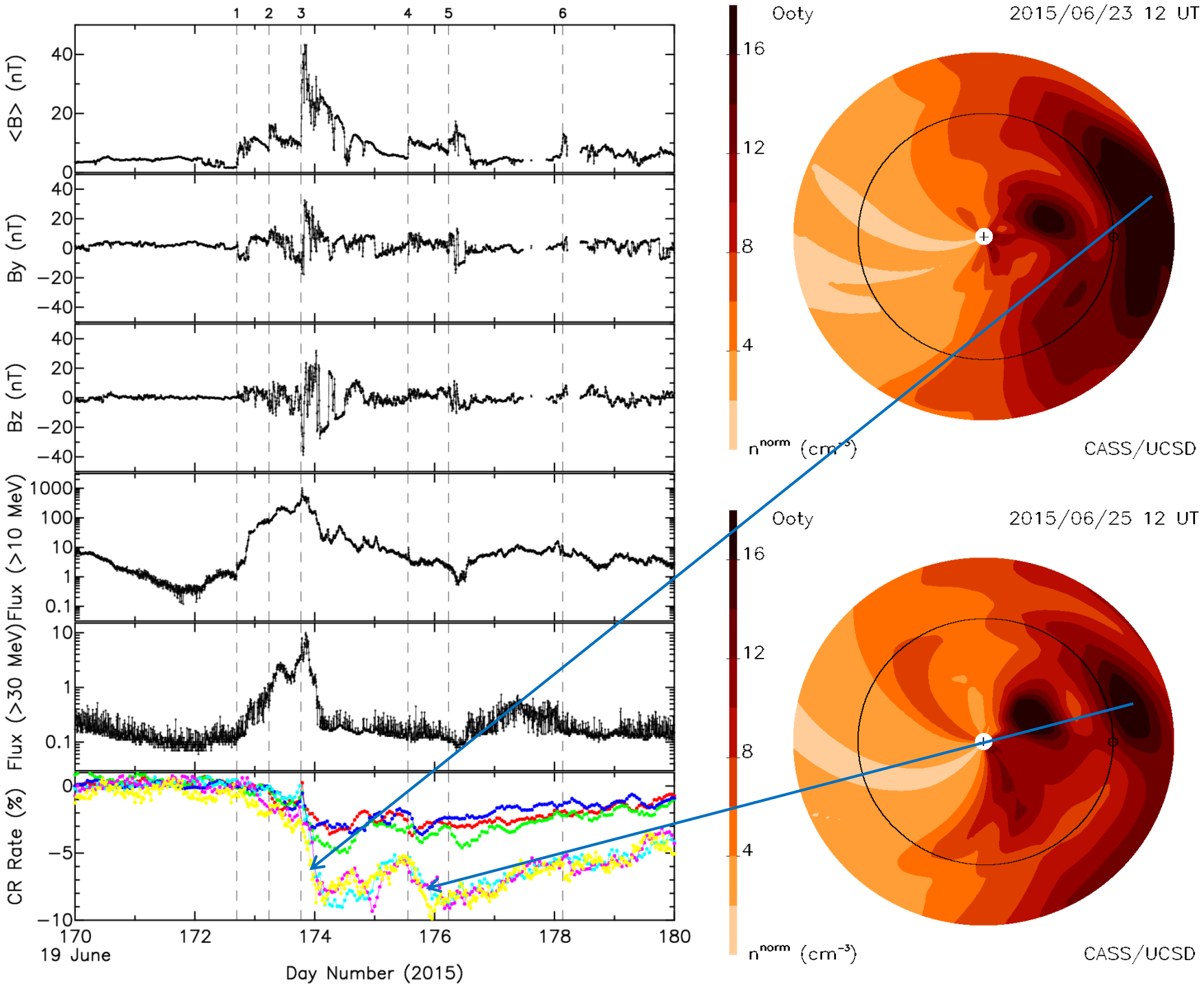

**UCSD 3-D Reconstruction of Ooty IPS**



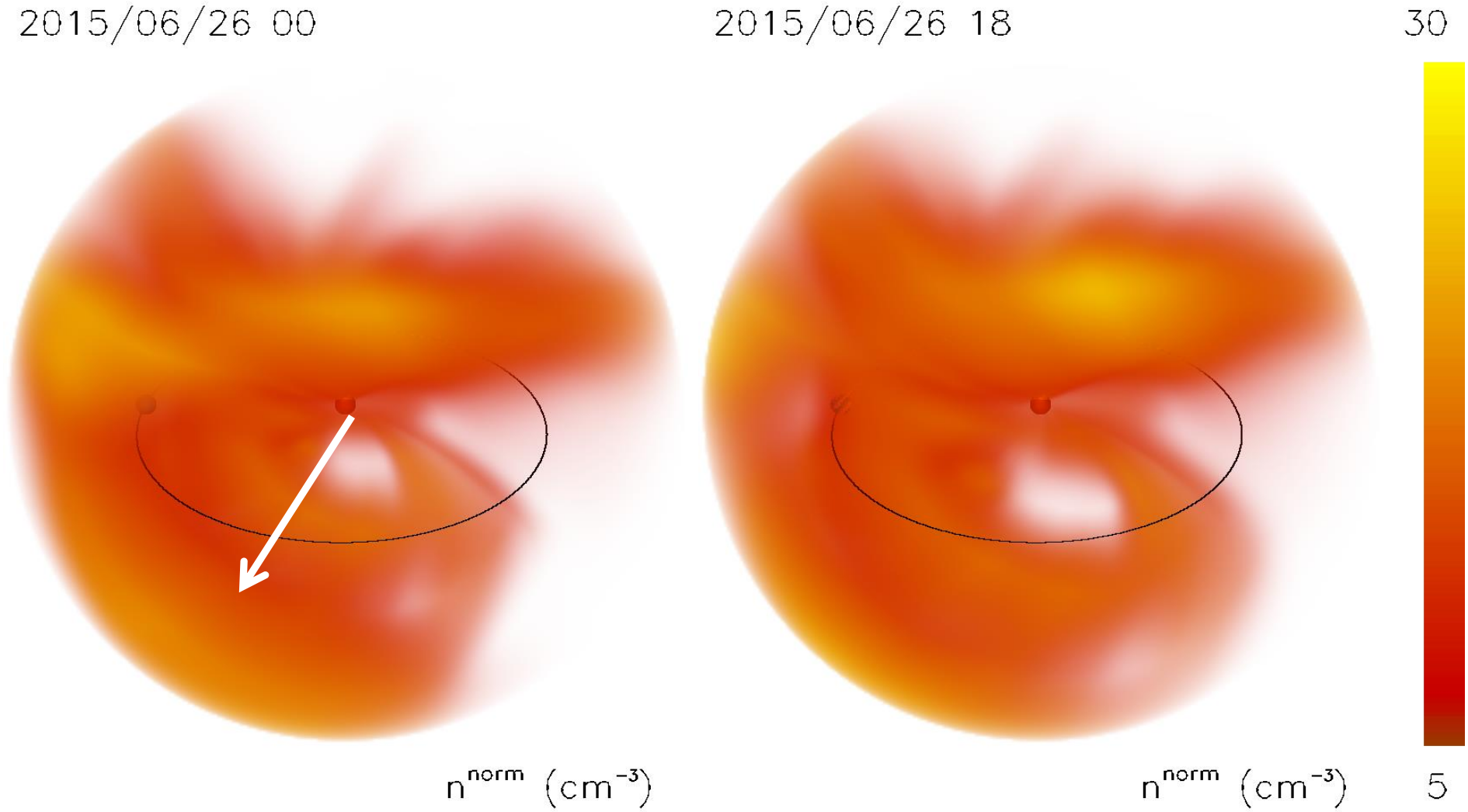

**21 – 27 June 2015 CMEs**

**SEP Events**

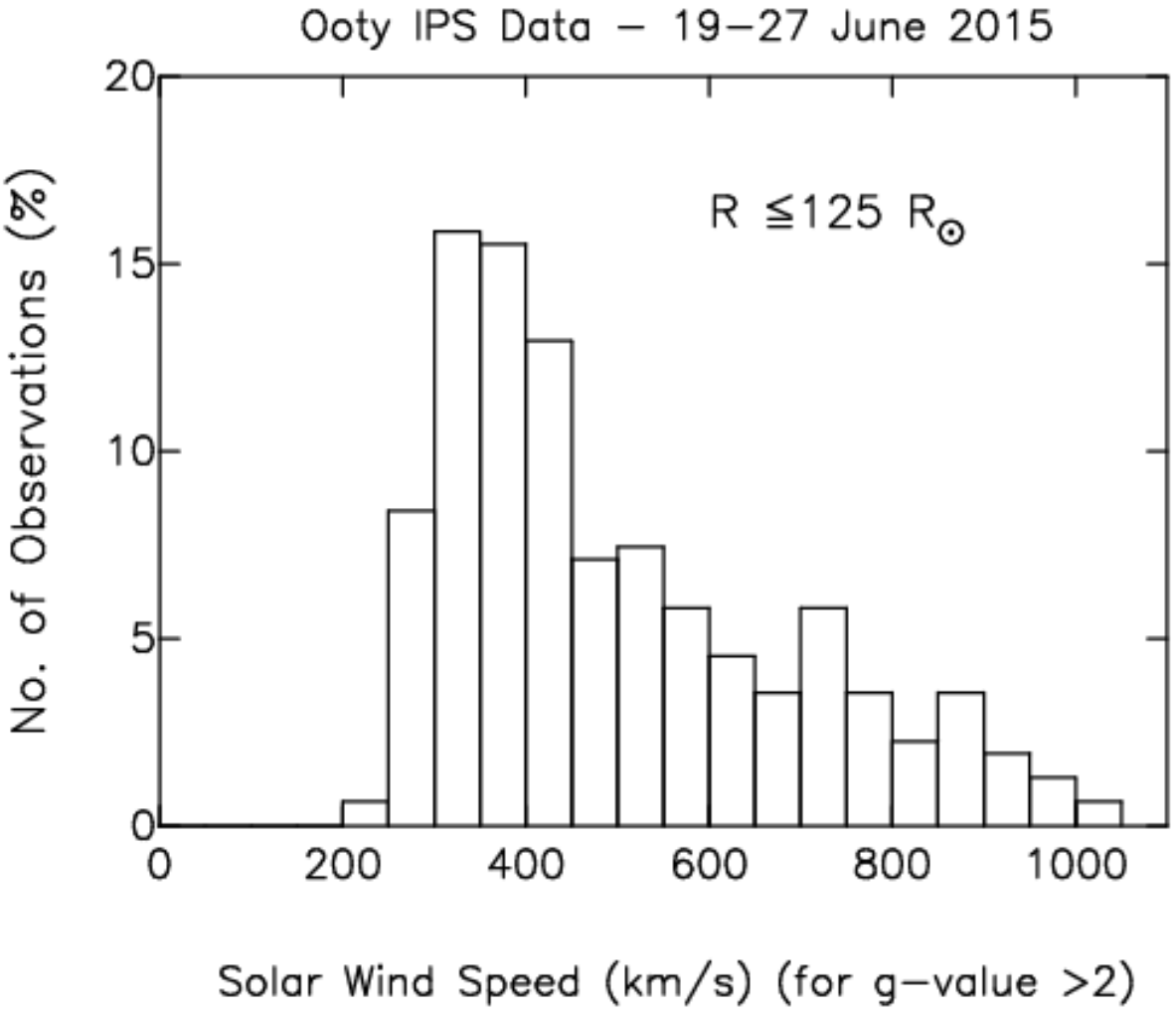
**Five IP Shocks at 1 AU**
**+**
**intense and moderate geo-magnetic storms**


1
2
3
4
5
6
<B> (nT)
By (nT)
Bz (nT)
Flux (>10 MeV)
Flux (>30 MeV)
CR Rate (%)
19 June
Day Number (2015)
Ooty
2015/06/23 12 UT
n^norm (cm^-3)
CASS/UCSD
Ooty
2015/06/25 12 UT
n^norm (cm^-3)
CASS/UCSD

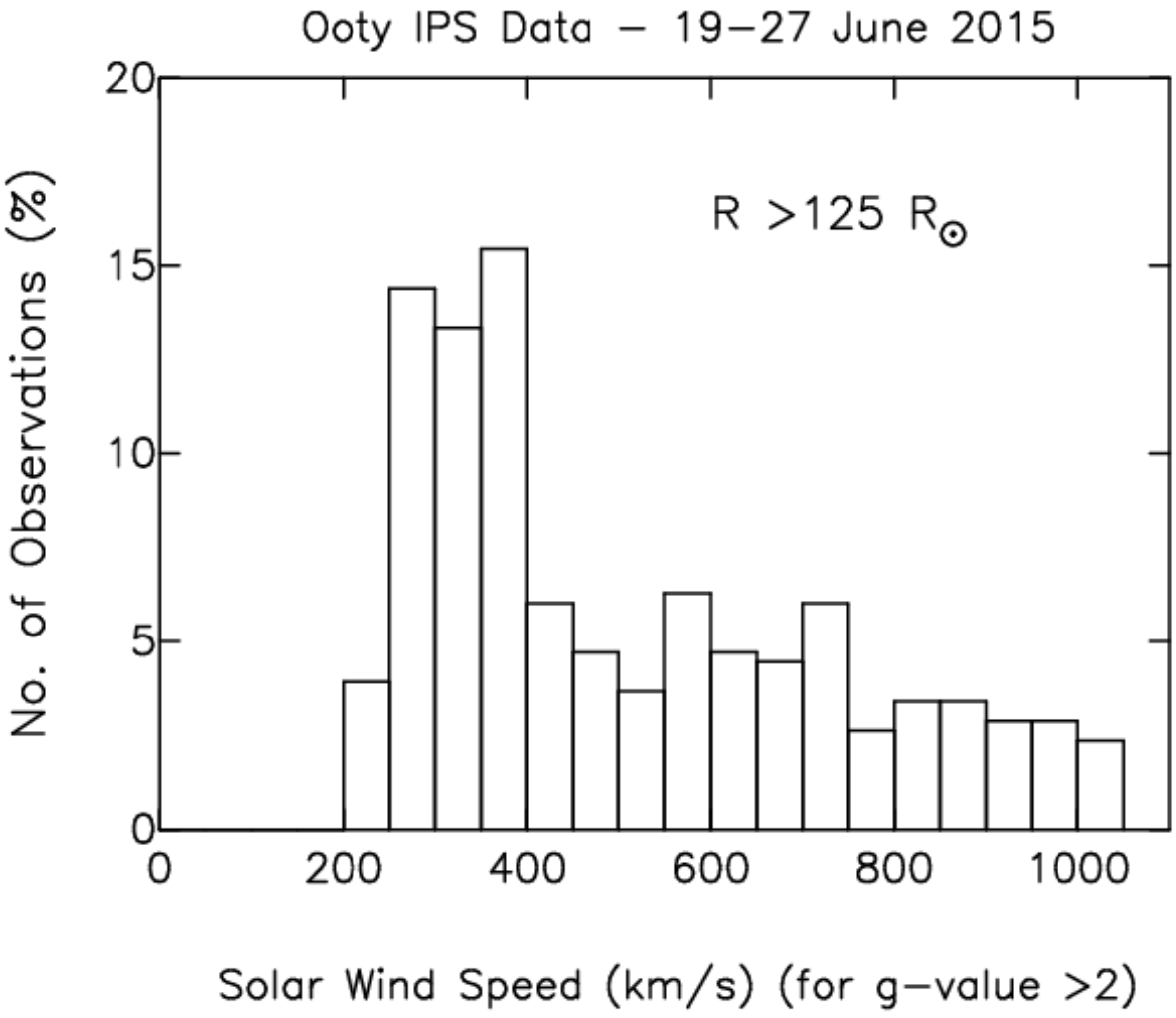
# UCSD 3-D Reconstruction of Ooty IPS




Manoharan et al. (2016)




**IPS observations provide a global view of the heliosphere**

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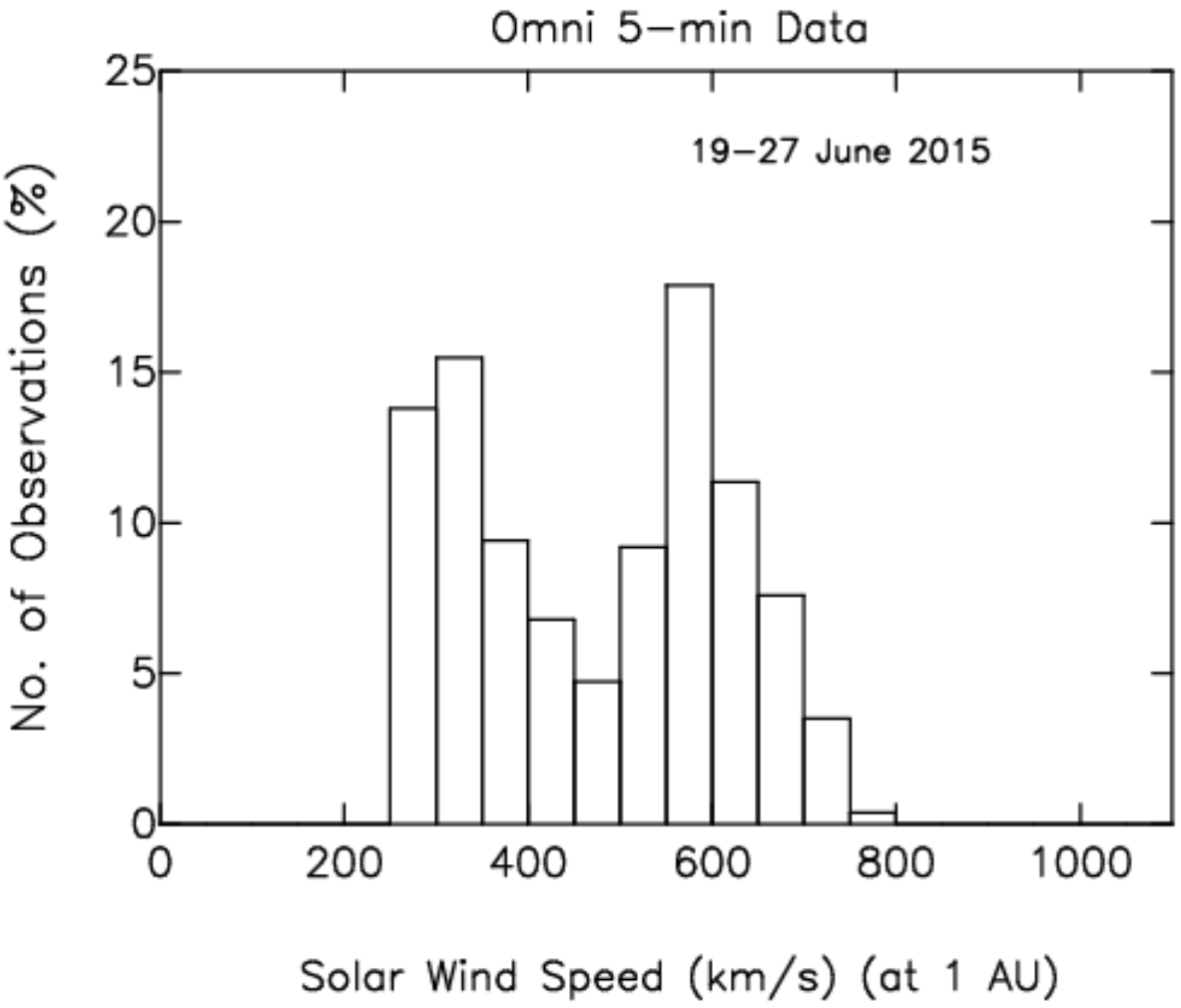
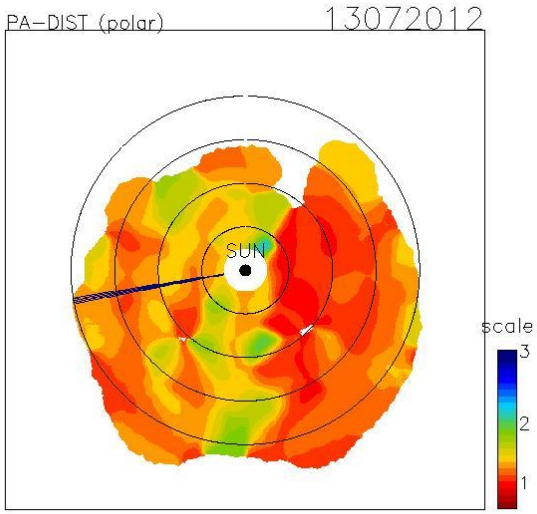
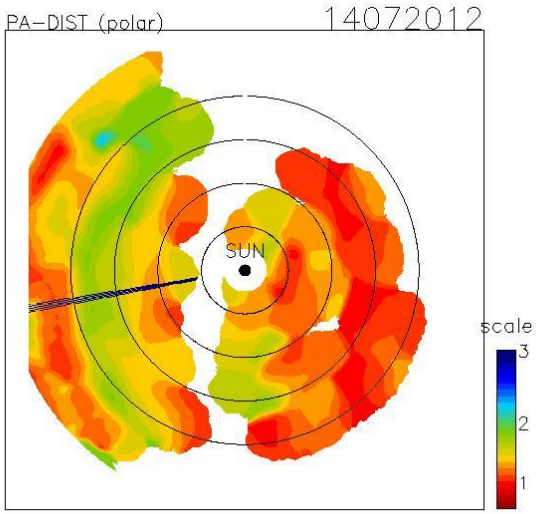
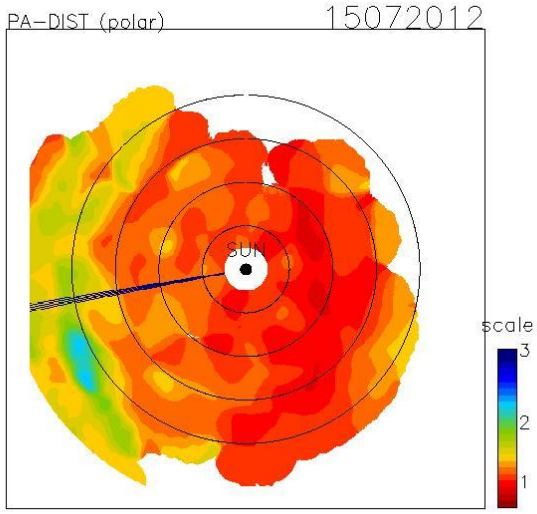



**“in-situ” measurements close to Earth’s orbit**


PA–DIST (polar)
13072012
SUN
scale
3
2
1


PA–DIST (polar)
14072012
SUN
scale
3
2
1


PA–DIST (polar)
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SUN
scale
3
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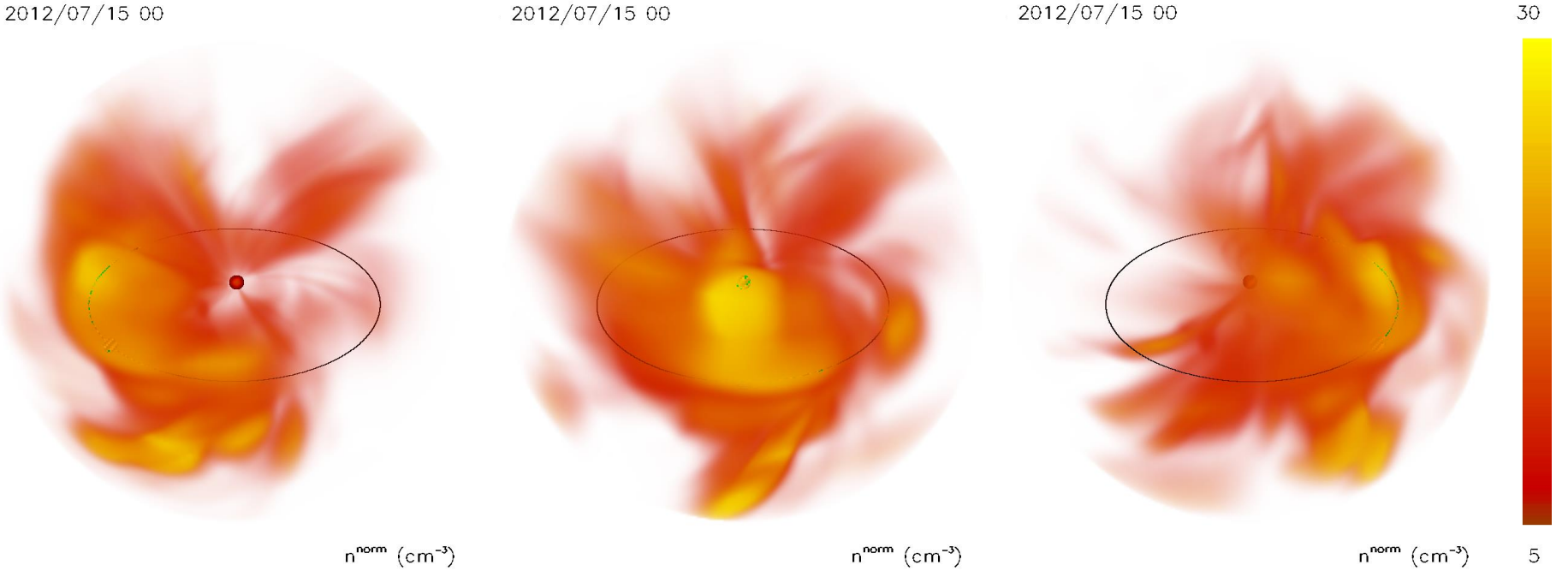
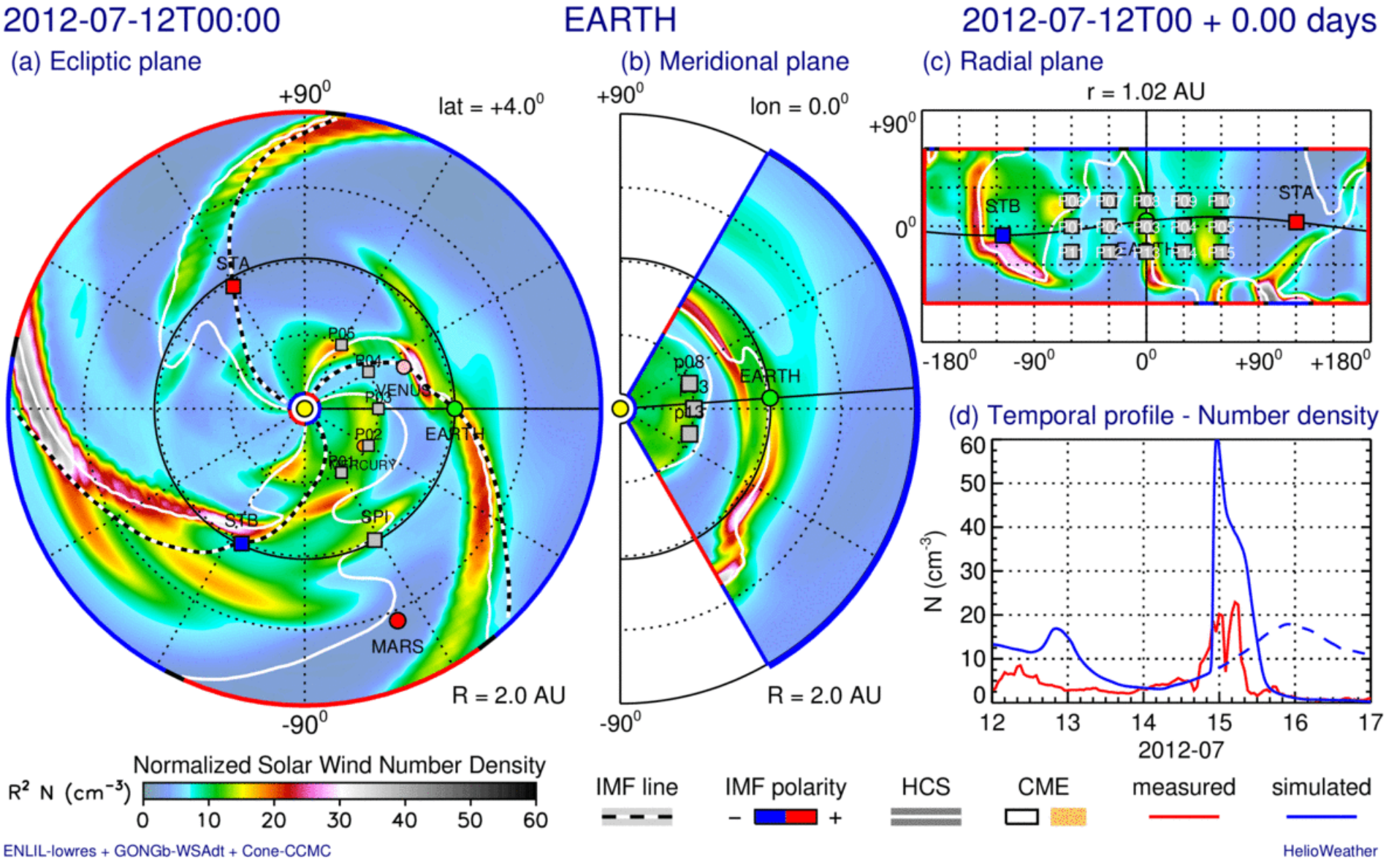

2012/07/15 00
2012/07/15 00
2012/07/15 00
30
n^norm (cm^-3)
n^norm (cm^-3)
n^norm (cm^-3)
5


2012-07-12T00:00
EARTH
2012-07-12T00 + 0.00 days
(a) Ecliptic plane
(b) Meridional plane
(c) Radial plane
(d) Temporal profile - Number density
+90⁰
lat = +4.0⁰
-90⁰
R = 2.0 AU
lon = 0.0⁰
r = 1.02 AU
0⁰
-180⁰
-90⁰
+90⁰
+180⁰
STA
STB
EARTH
VENUS
MERCURY
MARS
SPI
P01
P02
P03
P04
P05
P06
P07
P08
P09
P10
P11
P12
P13
N (cm⁻³)
2012-07
Normalized Solar Wind Number Density
R² N (cm⁻³)
IMF line
IMF polarity
HCS
CME
measured
simulated
ENLIL-lowres + GONGb-WSAdt + Cone-CCMC
HelioWeather

# Thank You