HELCATS WP7:

Assessing the complementary nature of radio measurements of solar wind transients – Interplanetary Scintillation (IPS)

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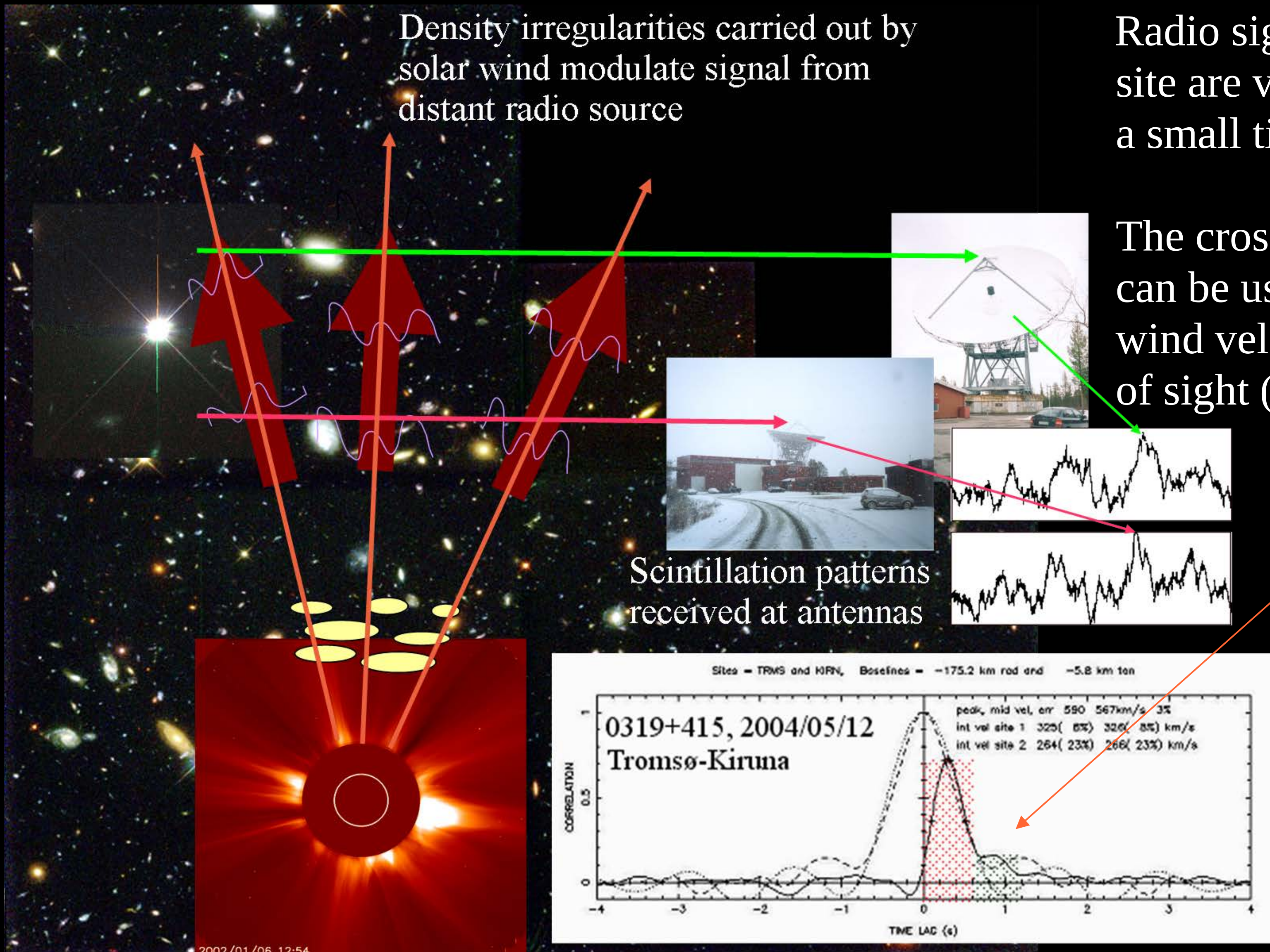
Outline

- An Introduction to Interplanetary Scintillation (IPS).
- IPS Telescopes/Arrays.
- Brief Introduction to the UCSD 3-D Time-Dependent Tomography.
- Example Work That We Will Build Upon.
- A Brief Overview of the IPS Work Plan (Task 7.1).

An Introduction to Interplanetary Scintillation (IPS)

An Introduction to IPS (1)



Hubble Deep Field – HST (WFPC2) 15/01/96 – Courtesy of R. Williams and the HDF Team and NASA

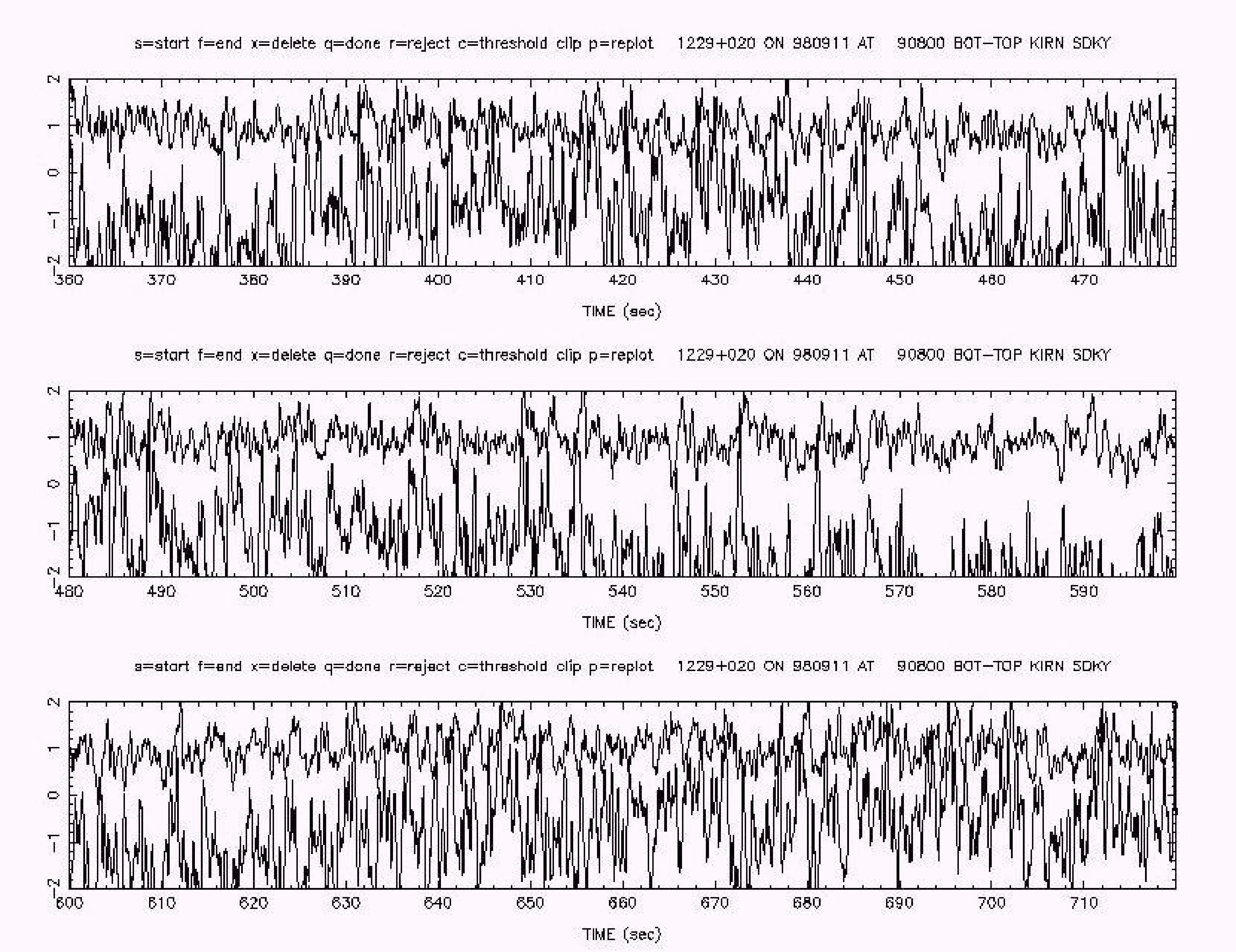
Radio signals received at each site are very similar except for a small time-lag.

The cross-correlation function can be used to infer the solar wind velocity(s) across the line of sight (LOS).

(Not to scale)

IPS is most-sensitive at and around the P-Point of the LOS to the Sun and is only sensitive to the component of flow that is perpendicular to the LOS; it is variation in intensity of astronomical radio sources on timescales of ~0.1s to ~10s that is observed.

An Introduction to IPS (2)

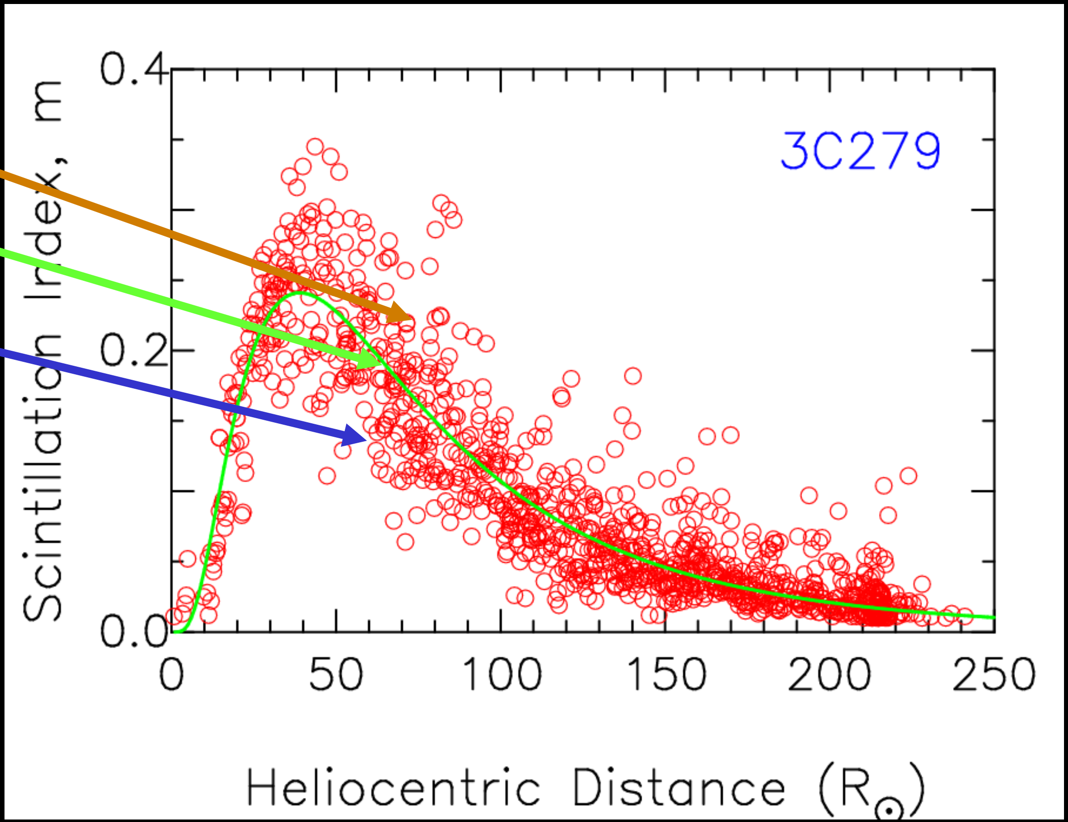


An Introduction to IPS (3)

Density Turbulence

- Scintillation index, m, is a measure of level of turbulence.
- Normalized Scintillation index, g = m(R) / <m(R)>.

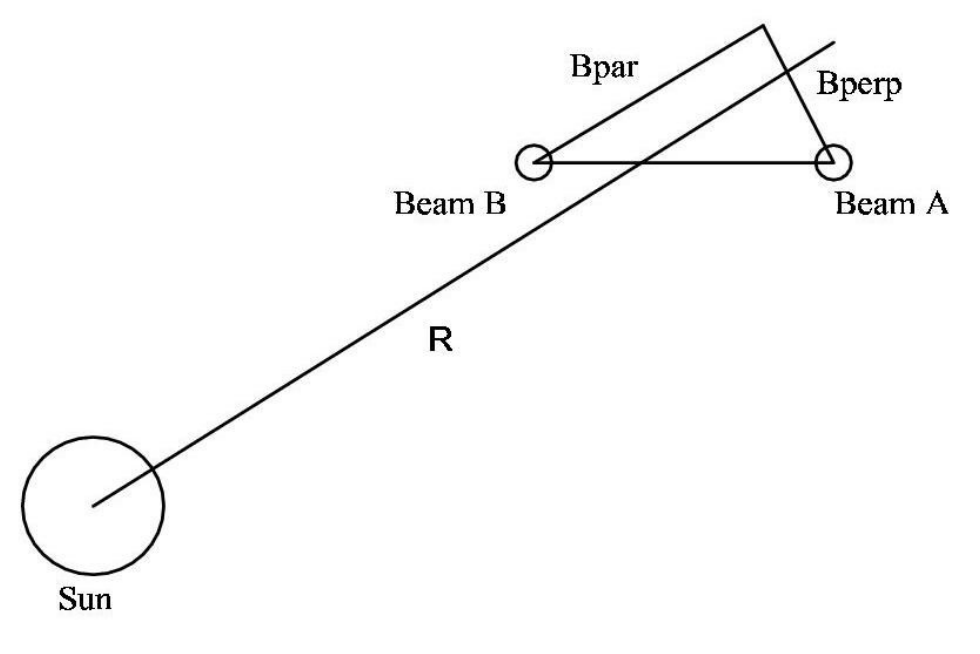
- **g > 1 → enhancement in δNe.**
- **g ≈ 1 → ambient level of δNe.**
- **g < 1 → rarefaction in δNe.**



(Courtesy of
Prof. P.K. Manoharan.)

Scintillation enhancement with respect to the ambient wind identifies the presence of a region of increased turbulence/density and possible CME along the line-of-sight to the radio source.

An Introduction to IPS (4)



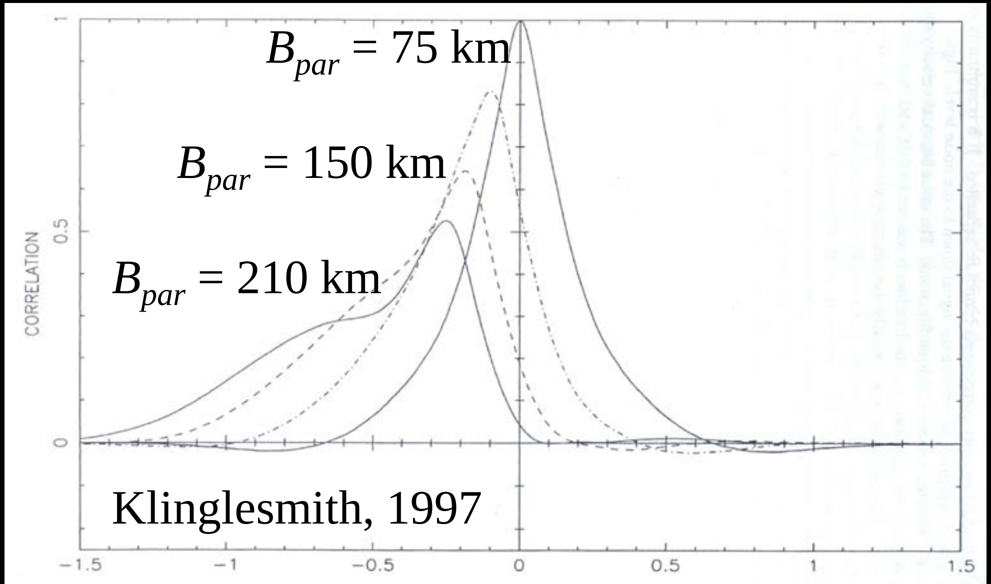


Figure 3.3. Effect of baseline length on resolving velocities. Solid, dashed, and dash dot lines are calculated for baselines of 210, 150, and 75 km. respectively.

- The ability to distinguish between streams of different velocity improves as the parallel baseline length (B_{par}) increases between two observing sites; if (B_{par}) is long enough, streams with different velocities appear as widely-separated peaks in the (temporal) cross-correlation function.
- The height of the maximum cross correlation decreases as parallel baseline length increases since density pattern changes with time.

IPS Telescopes/Arrays

EISCAT, ESR, and MERLIN (224 MHz-~6GHz)




*Above: The European Incoherent SCATter radar (EISCAT) and EISCAT Svalbard Radar (ESR) radio telescopes from left-to-right: Tromsø, Norway (M.M. Bisi, October 2003); Kiruna, Sweden (M.M. Bisi, May 2003); Sodankylä, Finland (*http://www.eiscat.com/sodan.html*); and the ESR 42m in the foreground and steerable 32m in the background (M.M. Bisi, May 2005).*

Left: The Multi-Element Radio-Linked Interferometer Network (MERLIN) MkIa (Lovell) radio telescope at Jodrell Bank (near Manchester, England); and Right: The MERLIN MkII radio telescope also at Jodrell Bank (M.M. Bisi, May 2004).

The LOw Frequency ARray (LOFAR) (1)

LOFAR Core High-Band Antenna (top) and LOFAR Core Low-Band Antenna (bottom); both with Dr. Richard A. Fallows (~ 5’ 5½” tall) in for size comparison.

LOFAR superterp (top) and LOFAR Chilbolton (bottom).

LOFAR (2)

LOFAR core in The Netherlands with stations around The Netherlands and International Stations in Germany (5), France (1), Sweden (1) and in the UK (1). The stations shown in green are complete and operational while yellow depicts stations that are under construction as of March 2013.

Japan, India, and other IPS Arrays/Telescopes

The Solar Terrestrial Environment Laboratory (STELab) antennas of Fuji (top left), Sugadaira (top middle), (new) Toyokawa (top right), (old) Toyokawa (bottom left), and Kiso (bottom middle); and the Ootacamund (Ooty) Radio Telescope (ORT) (bottom right)

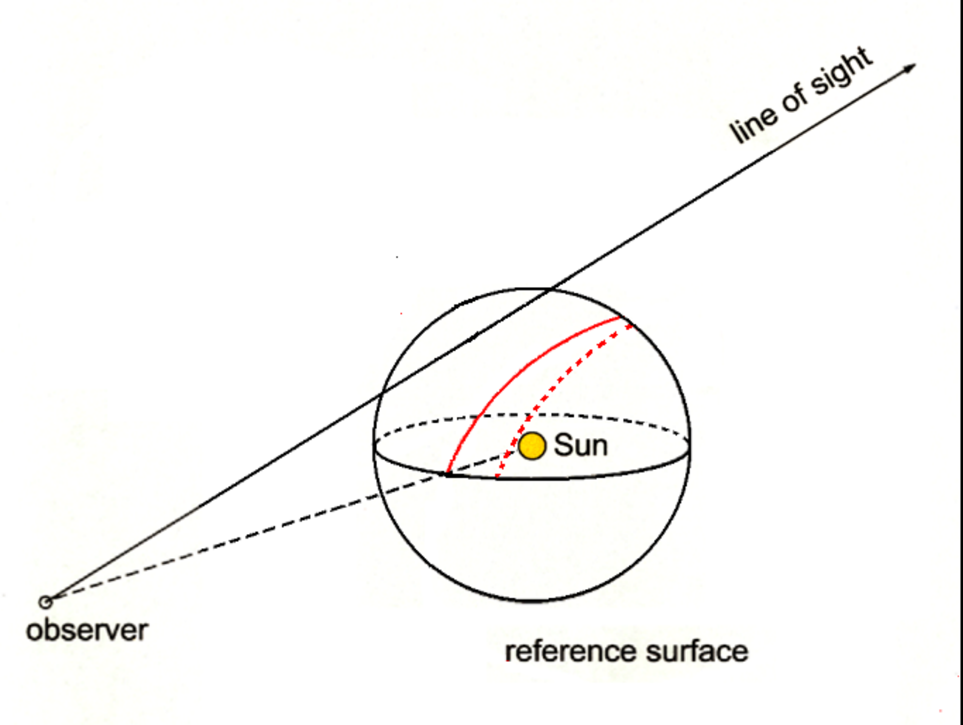
(Courtesy of http://stesun5.stelab.nagoya-u.ac.jp/uhf_ant-e.html, B.V. Jackson, and P.K. Manoharan).

Others also include: MEXART, Mexico; Pushchino, Russia; UTR-2, Ukraine; and the Murchison Widefield Array (MWA), Australia.

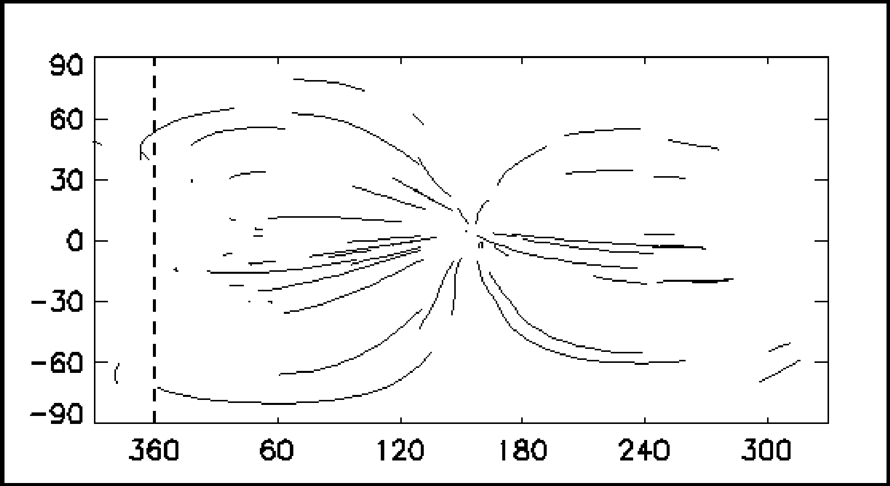
Brief Introduction to the UCSD 3-D Time-Dependent Tomography

UCSD 3-D Tomography (1)

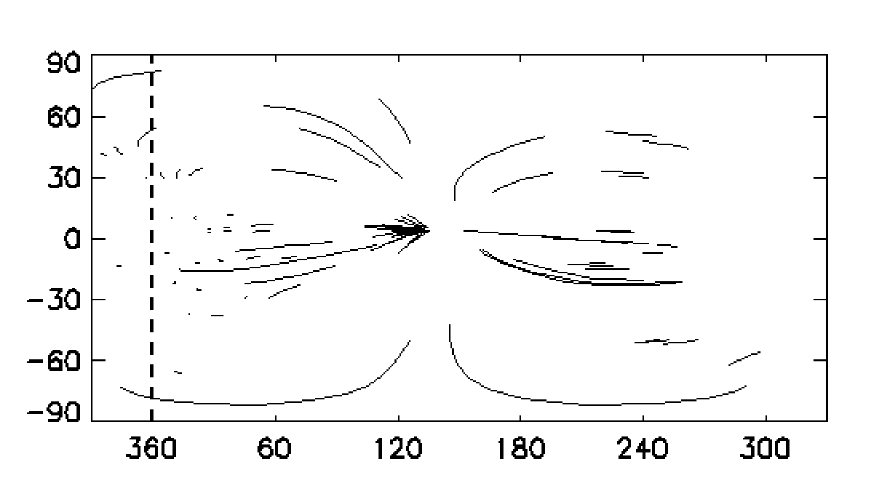
Heliospheric C.A.T. Analyses: example line-of-sight distribution for each sky location to form the source surface of the 3D reconstruction.



STELab IPS

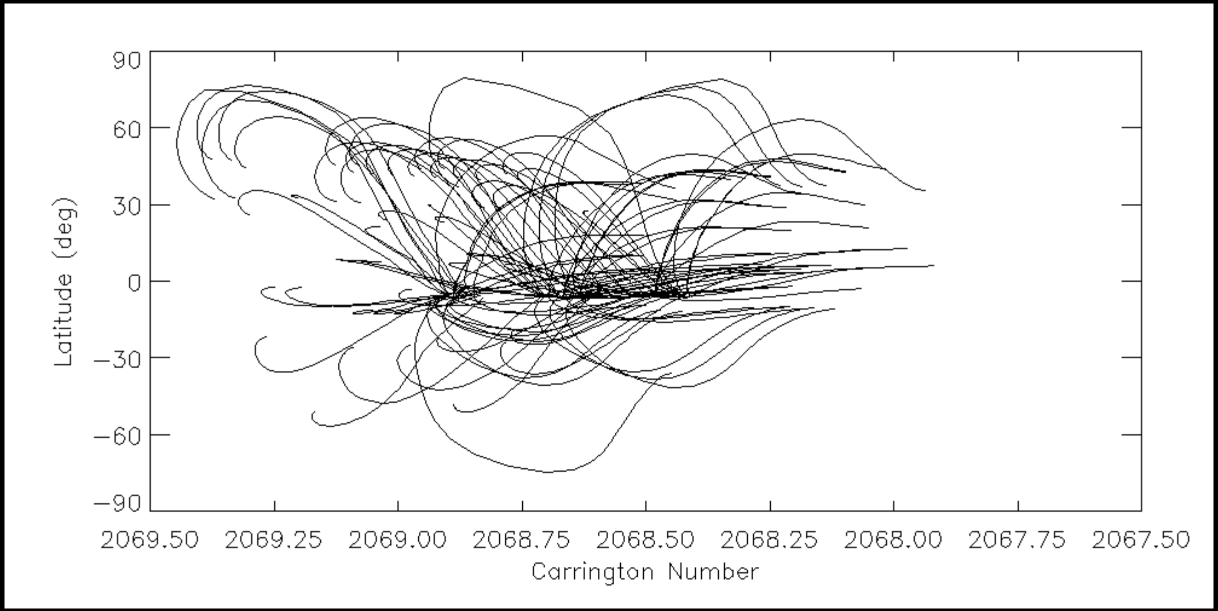


13 July 2000



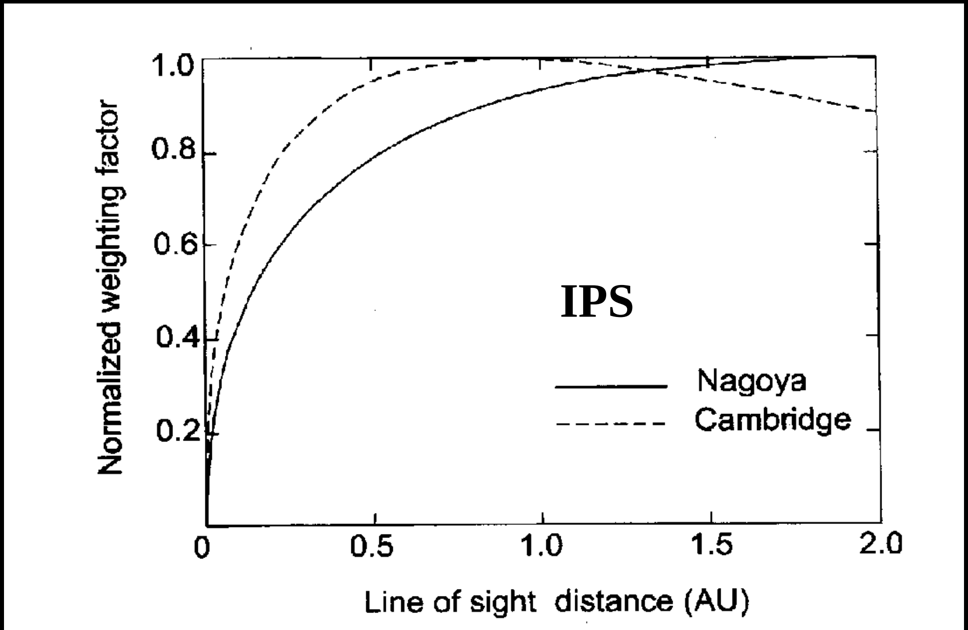
14 July 2000

UCSD 3-D Tomography (2)



Heliospheric C.A.T. Analyses: velocity IPS line-of-sight distribution during CR2068 for each sky location plotted onto a Carrington source-surface map (left).

Heliospheric C.A.T. Analyses: line-of-sight weighting values for each sky location (right).

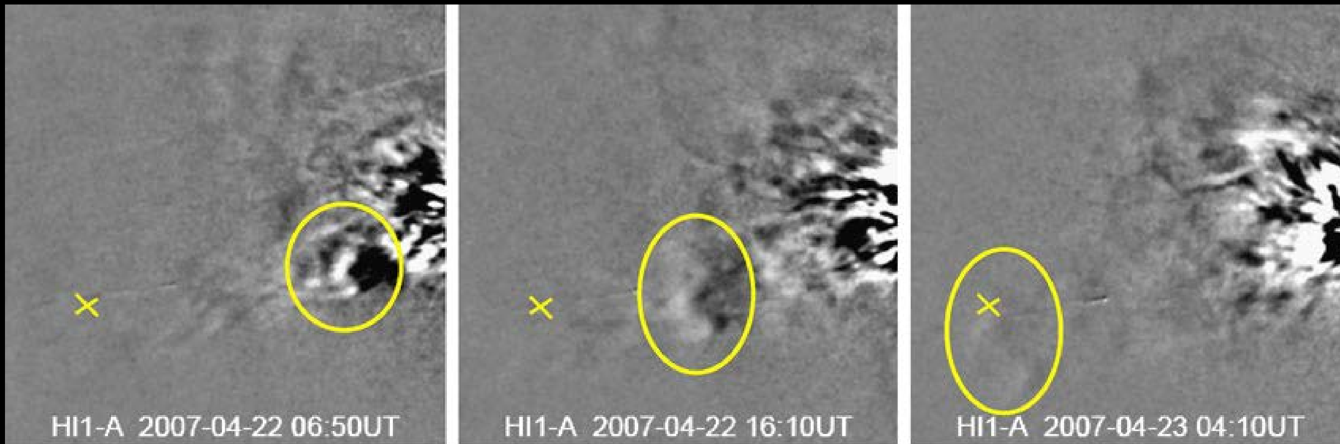


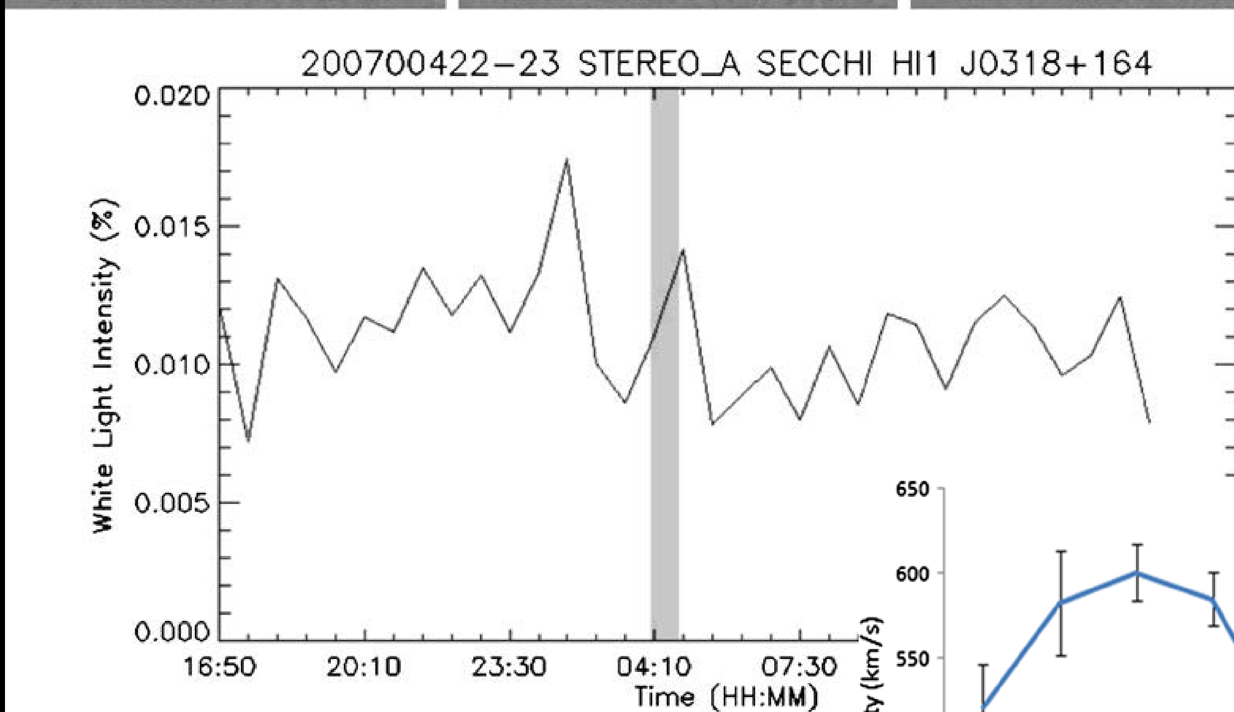
Example Work That We Will Build Upon

Comparison Between IPS and STEREO HIs

- S.A. Hardwick, M.M. Bisi, J.A. Davies, A.R. Breen, R.A. Fallows, R.A. Harrison, and C.J. Davis, "Observations of Rapid Velocity Variations in the Slow Solar Wind", Solar Physics "Observations and Modelling of the Inner Heliosphere" Topical Issue (Guest Editors M.M. Bisi, R.A. Harrison, and N. Lugaz), 285 (1-2), 111-126, 2013.

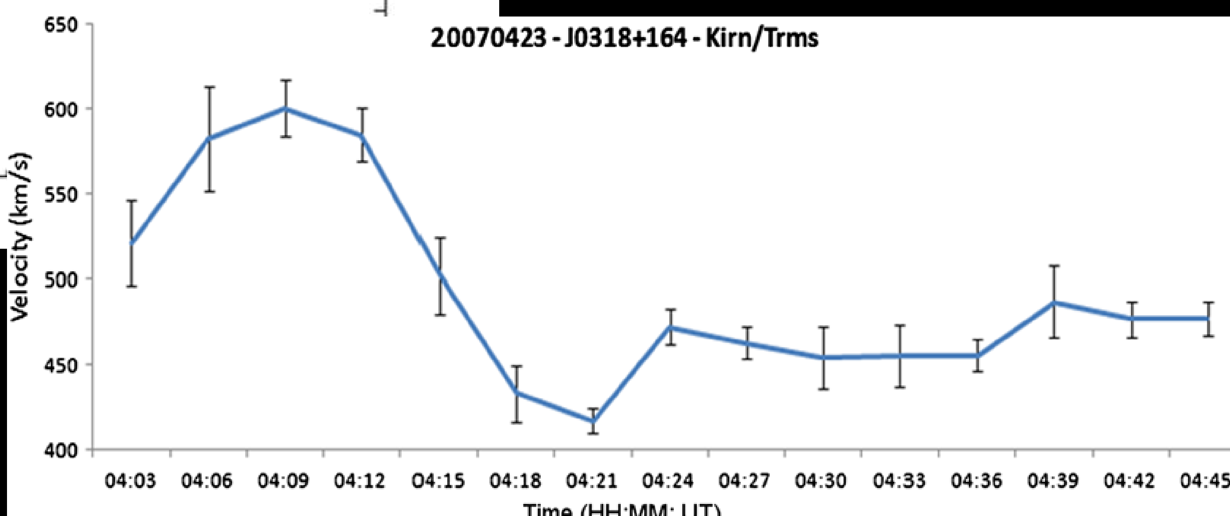
EISCAT IPS and STEREO HI1-A Comparisons





- Sequence of STEREO HI1-A images of a CME with the IPS P-Point superimposed; the grey area on the intensity plot represents the overlap in time with the IPS.

- Variation in velocity as determined from the IPS.



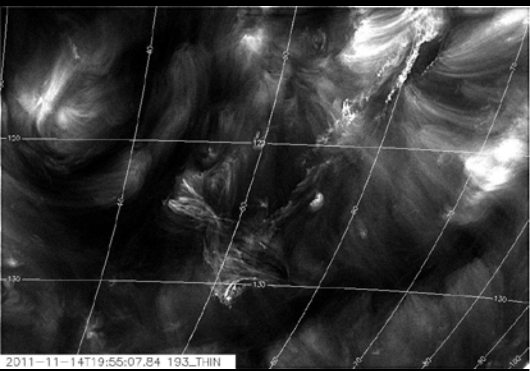
IPS with LOFAR: The First CME Detection

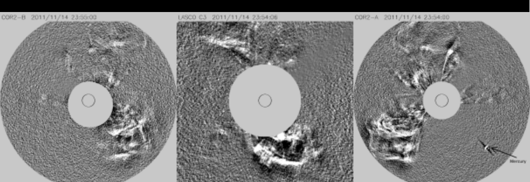
- R.A. Fallows, A. Asgekar, M.M. Bisi, A.R. Breen, S. ter-Veen, and on behalf of the LOFAR Collaboration, "The Dynamic Spectrum of Interplanetary Scintillation: First Solar Wind Observations on LOFAR", Solar Physics "Observations and Modelling of the Inner Heliosphere" Topical Issue (Guest Editors M.M. Bisi, R.A. Harrison, and N. Lugaz), 285 (1-2), 127-139, 2013.

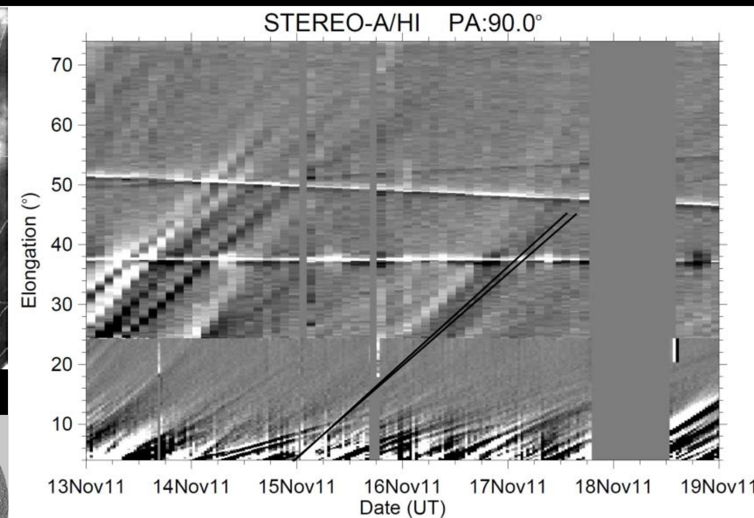
- Bisi, M.M., S.A. Hardwick, R.A. Fallows, J.A. Davies, R.A. Harrison, E.A. Jensen, H. Morgan, C.-C. Wu, A. Asgekar, M. Xiong, E. Carley, G. Mann, P.T. Gallagher, A. Kerdraon, A.A. Konovalenko, A. MacKinnon, J. Magdalenić, H.O. Rucker, B. Thide, C. Vocks, *et al.*, "The First Coronal Mass Ejection Observed with the LOw Frequency ARray (LOFAR)", To be submitted to The Astrophysical Journal Supplementary Series, May 2014 (and references therein).

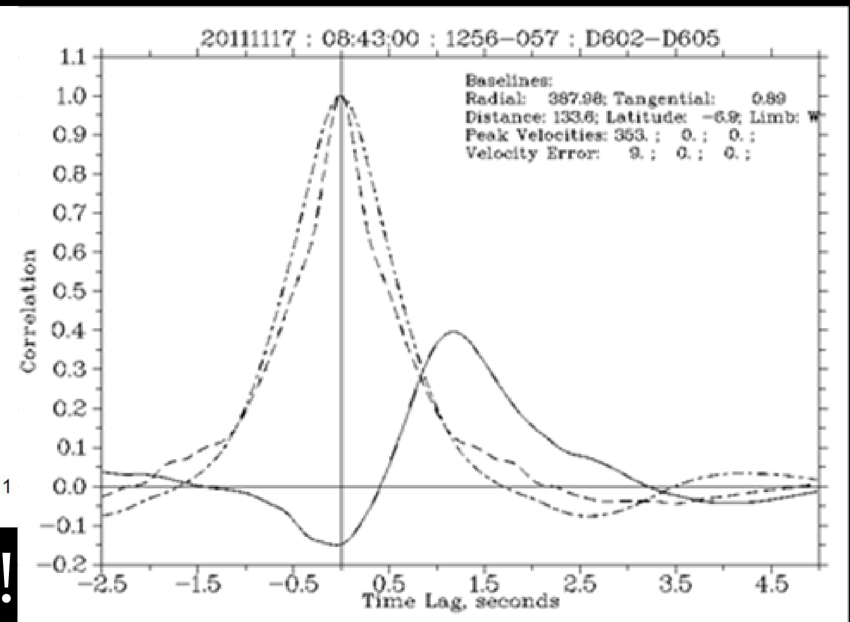
The First CME with LOFAR…

- Observations of J1256-057 (3C279) detecting a CME with LOFAR on 17 November 2011 and (briefly) its comparison so far with other remote-sensing observations and modelling.

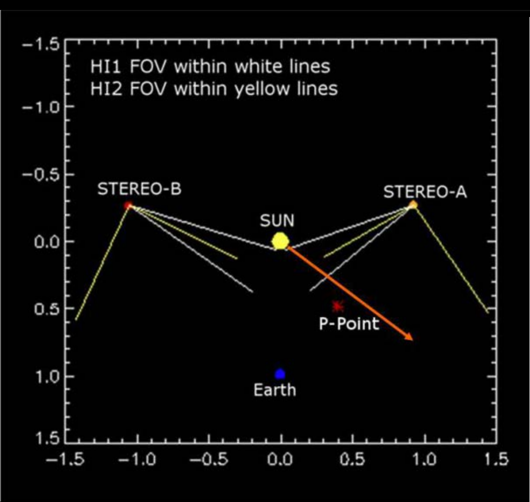




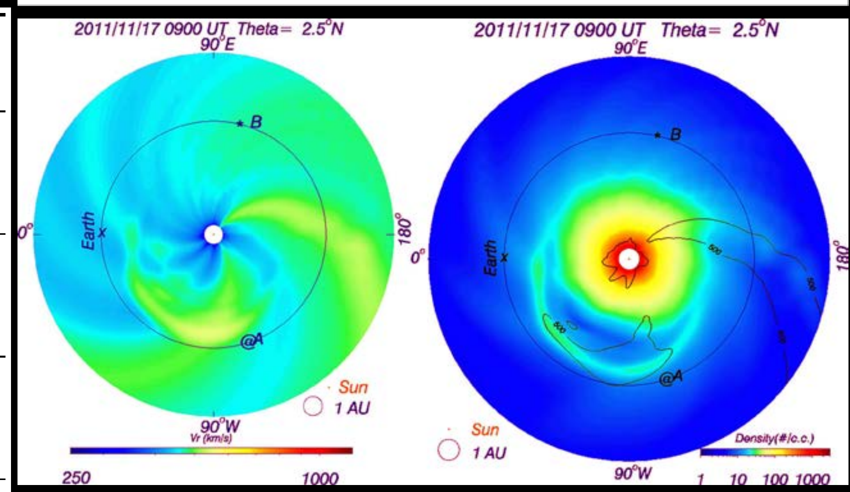




Fully-consistent Results!



Model Used:	Best Fit in Radial Velocity ($km\,s^{-1}$):	Error in Radial Velocity ($km\,s^{-1}$):
Front:		
Fixed Phi	342.22	12.00
SSEF (30°)	348.83	12.00
Harmonic Mean	352.35	11.00
Middle:		
Fixed Phi	338.36	10.00
SSEF (30°)	343.61	10.00
Harmonic Mean	346.11	9.00
Rear:		
Fixed Phi	335.83	9.00
SSEF (30°)	343.53	8.00
Harmonic Mean	348.37	8.00

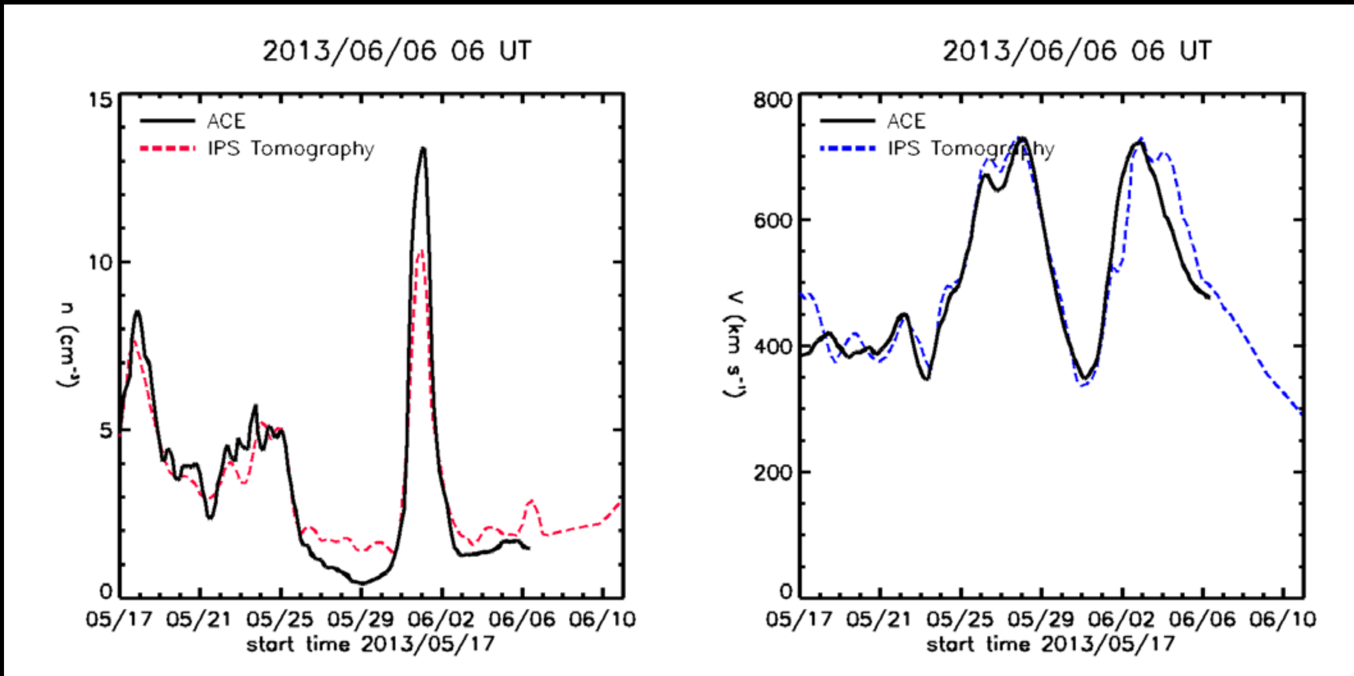


Forecast of a Combined CME and SIR Event at Earth with the Inclusion of *in-situ* data

- Publications in preparation.

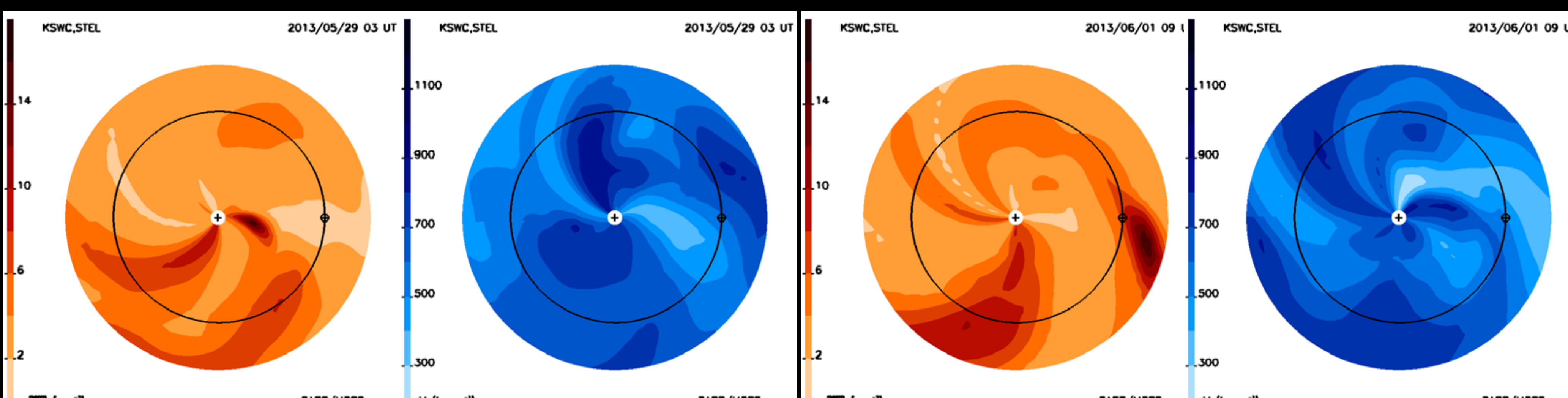
- Real-time forecasting using STELab IPS data at UCSD for the Earth, at several other planets, and at several interplanetary spacecraft: http://ips.ucsd.edu/.

UCSD Tomography at the Korean Space Weather Center



The set of interaction events of interest reached Earth early on 01 June 2013 resulting in a geomagnetic storm and was mostly missed by other forecasting methods.

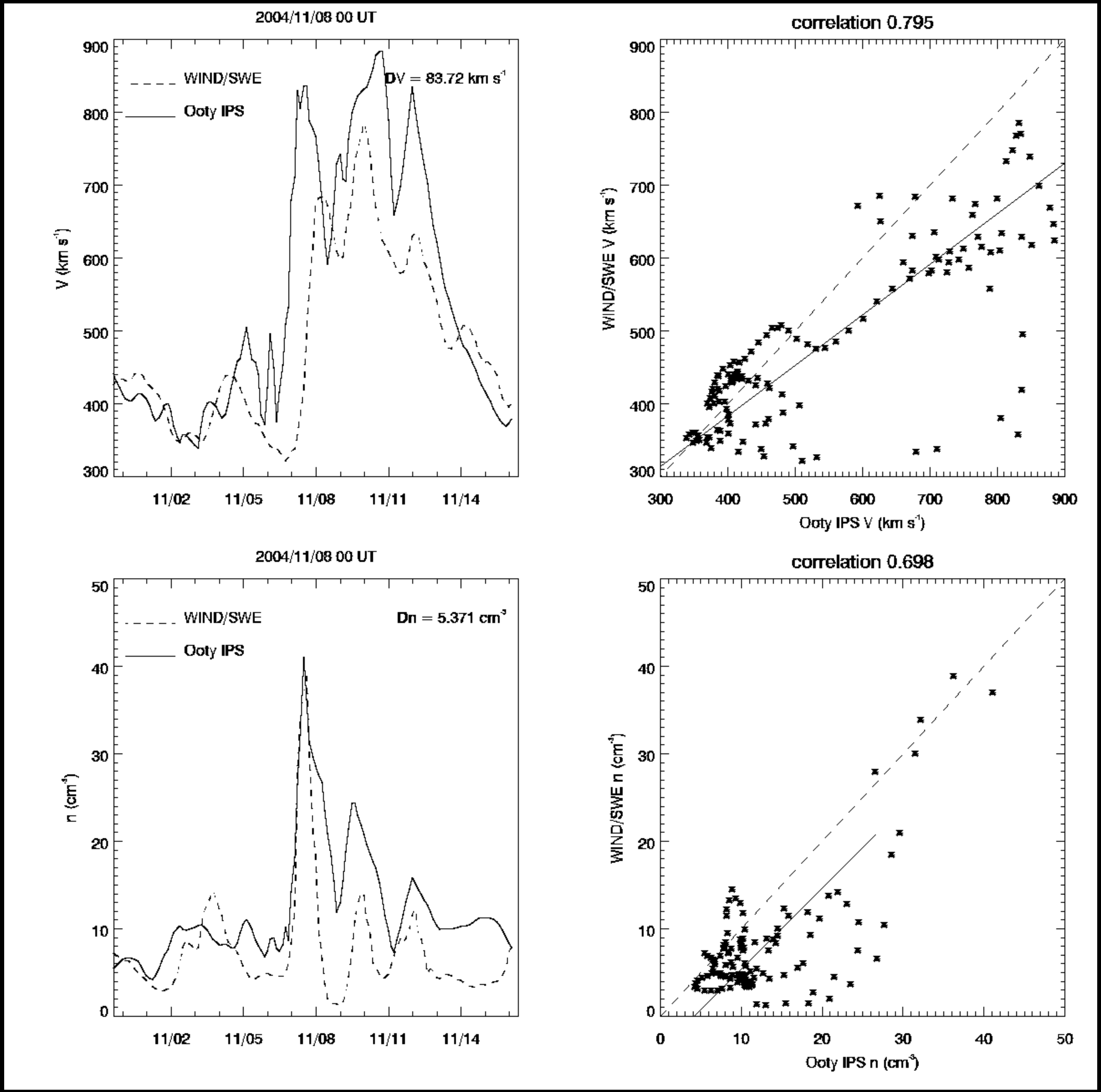
As forecast on: http://www.spaceweather.go.kr/models/ips.



The early November 2004 events with Ooty: 2004/11/04-2004/11/08 SOHO|LASCO CME and Halo/Partial-Halo CME-events at and near the Earth (ICMEs/MCs) resulting in Two Intense Geomagnetic Storms

- Bisi, M.M., B.V. Jackson, J.M. Clover, P.K. Manoharan, M. Tokumaru, P.P. Hick, and A. Buffington, "3-D reconstructions of the early-November 2004 CDAW geomagnetic storms: analysis of Ooty IPS speed and density data", Annales Geophysicae, 27, pp.4479-4489, 2009.

Comparisons with Wind *in situ* Data (not in Tomography)



A Brief Overview of the IPS Work Plan (Task 7.1)

Task 7.1 Objectives

- Start at month 10 (February 2015) for 19.5 months effort.
- Development of a catalogue of CMEs observed using IPS during the STEREO mission time line and comparison with observations from STEREO/HI and COR as well as SOHO|LASCO, where appropriate, and where the geometry allows.
- As above but for CIRs/SIRs.
- Interaction(s) with the solar wind and resulting structure(s).
- Explore how IPS can aid to the investigations of interacting CMEs seen in the STEREO HIs.
- Radio telescopes/antennas to be used: EISCAT/ESR, LOFAR, KAIRA/EISCAT_3D, plus, where feasible/possible and data are available, STELab and Ooty/ORT.