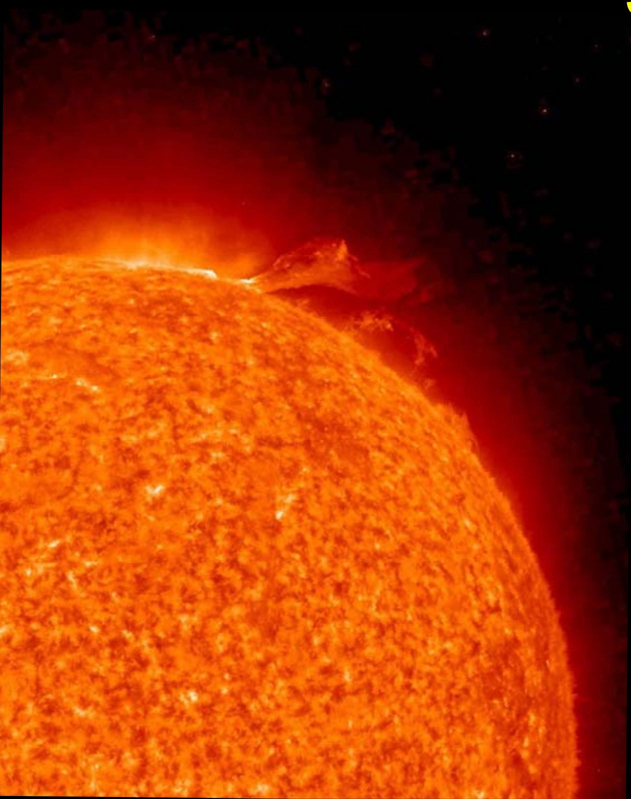
STEREO SWG: PLASTIC Science Snipits

Toni Galvin (UNH)
for the PLASTIC Team

Special thanks to K. Simunac, B. Klecker

STEREO PLASTIC Institutions:
UNH, U Bern, MPE, U Kiel, NASA/GSFC
IDPU/LVC provided by UCB (IMPACT)



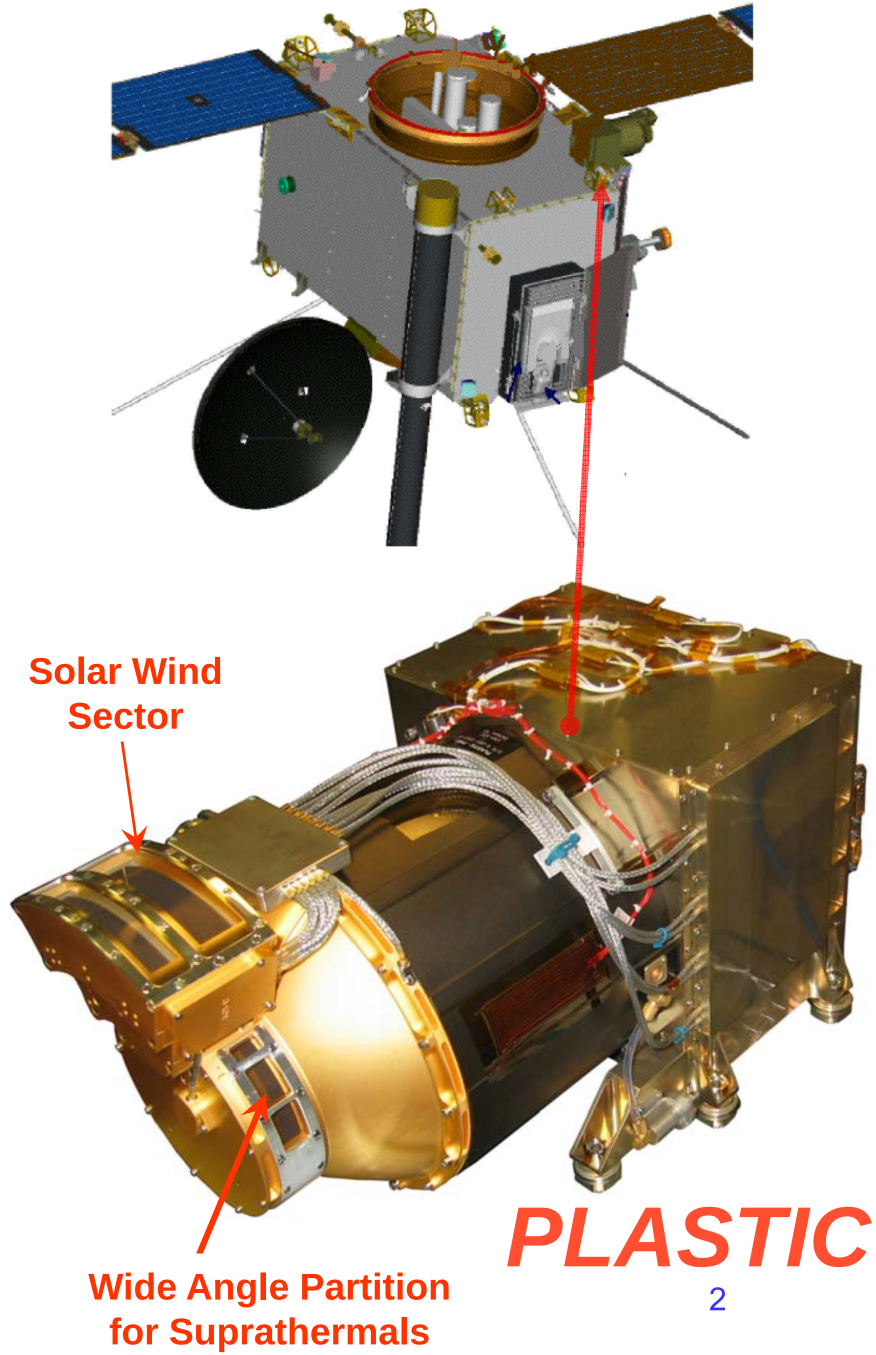
The Sun in EUV courtesy STEREO/SECCHI/NRL

PLASMA AND SUPRATHERMAL ION COMPOSTION INSTRUMENT

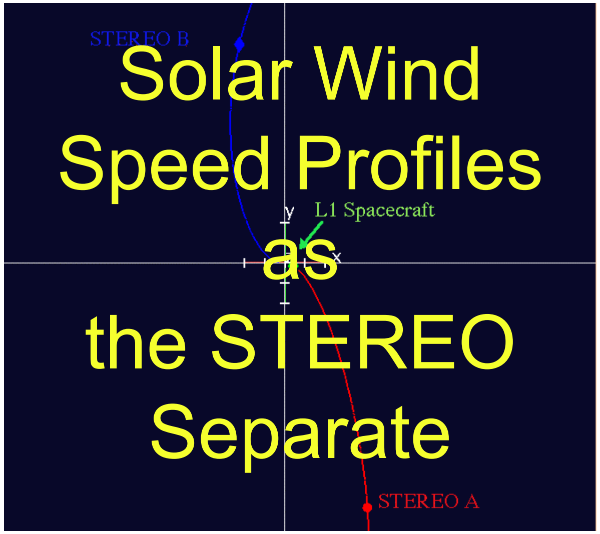
- ***Solar Wind Sector* (SWS) Small (Proton) Channel** measures the distribution functions of **solar wind protons (H+)** and **alphas (He^{+2})**, providing proton density (*n*), speed (*Vsw*), thermal speed (*Vth*).

- ***Solar Wind Sector* (SWS) Main (Composition) Channel** measures the elemental composition, charge state distribution, and speed of the more abundant **solar wind heavy ions** (e.g., C, O, Mg, Si, and Fe).

- ***Wide-Angle Partition* (WAP)** measures distribution functions of **suprathermal ions**, including interplanetary shock-accelerated (IPS) particles associated with CME-related SEP events, recurrent particle events associated with Co-rotating Interaction Regions (CIRs), and heliospheric pickup ions.



Solar Wind Speed Profiles as the STEREO Separate



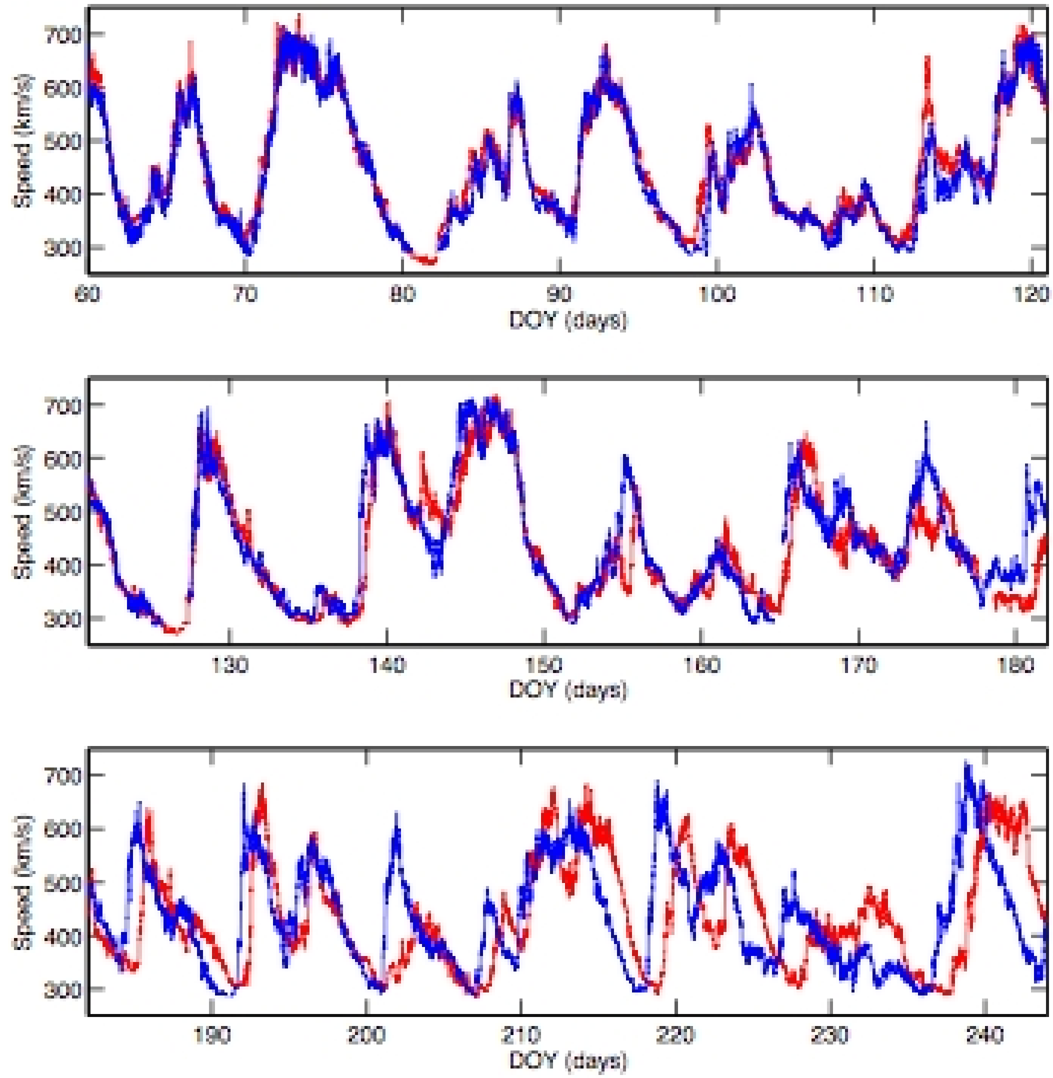
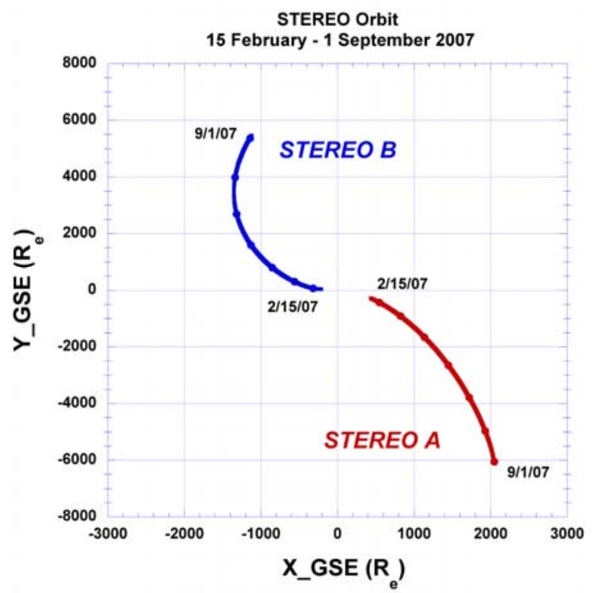


Figure 2 Solar wind speed measured by Stereo A (red) and Stereo B (blue) from 2007 March 1 (DOY 60) through 2007 August 31 (DOY 243).

Podesta et al 2007



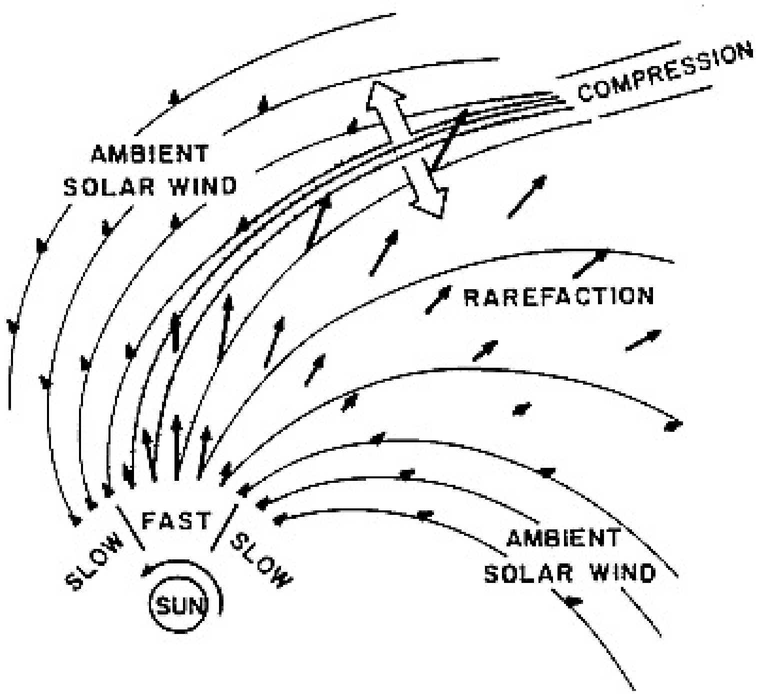
Work in Progress (PLASTIC)

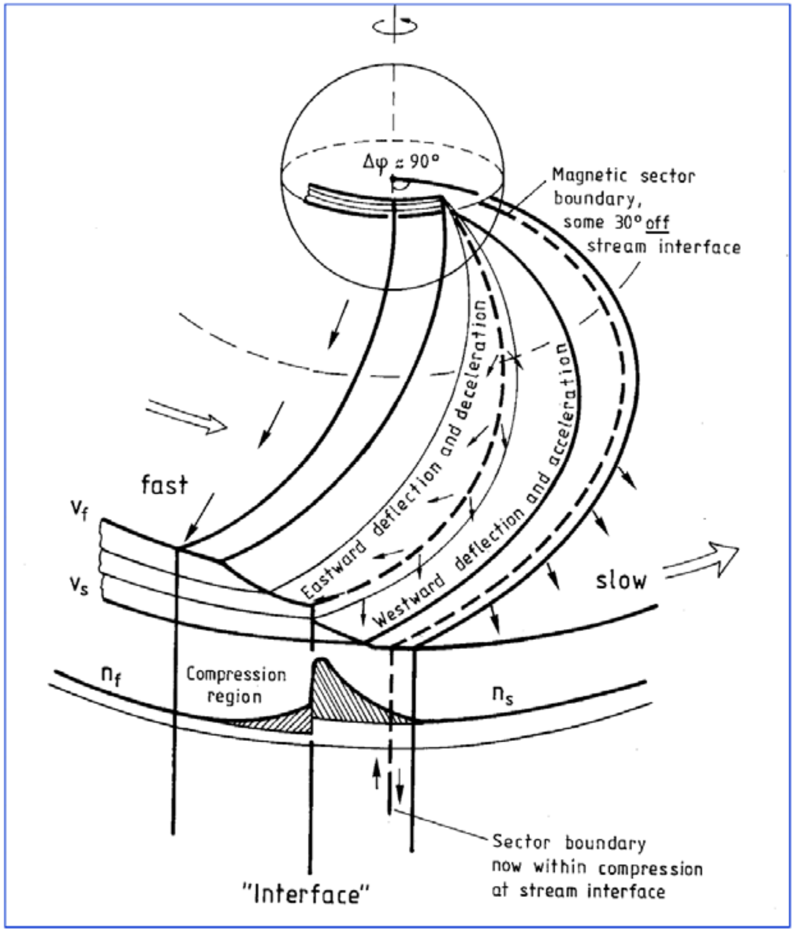
- Solar wind and suprathermal processes and composition at (CIR) stream interfaces (PLASTIC, IMPACT/MAG; Galvin, Popecki, Barry, et al.)
- Variability of suprathermal He^+, correlations with SOHO STOF (Klecker et al).
- Extended X-line reconnection (exhaust events) (IMPACT with PLASTIC,Gosling et al., Eriksson et al, with Simunac, Blush).
- Solar wind helium and minor ion velocity distributions (Karrer, Bochsler, Popecki, Walker et al)
- Bulk parameter determinations and multi-spacecraft comparisons of solar wind CIR structure and spatial geometry - STEREO, Wind, ACE, SOHO (Simunac et al.)
- Reconstruction of magnetic clouds using observations from two spacecraft (Farrugia, Möstl, Leitner et al.) Case Study: the May 22 2007 Flux Rope Event (study led by Huttunen, with contributions by Farrugia and Möstl:)
- Composition in the slow and fast solar wind (Daoudi, Popecki, Galvin, Karrer , et al.)
- Deep magnetotail observations by STEREO B - Energetic O^+ (PLASTIC with IMPACT/MAG and SWEA, Kistler et al.)
- Correlation lengths in the solar wind tangent to the earth's orbit (Podesta et al., Opitz et al.)

Snip-it Outline

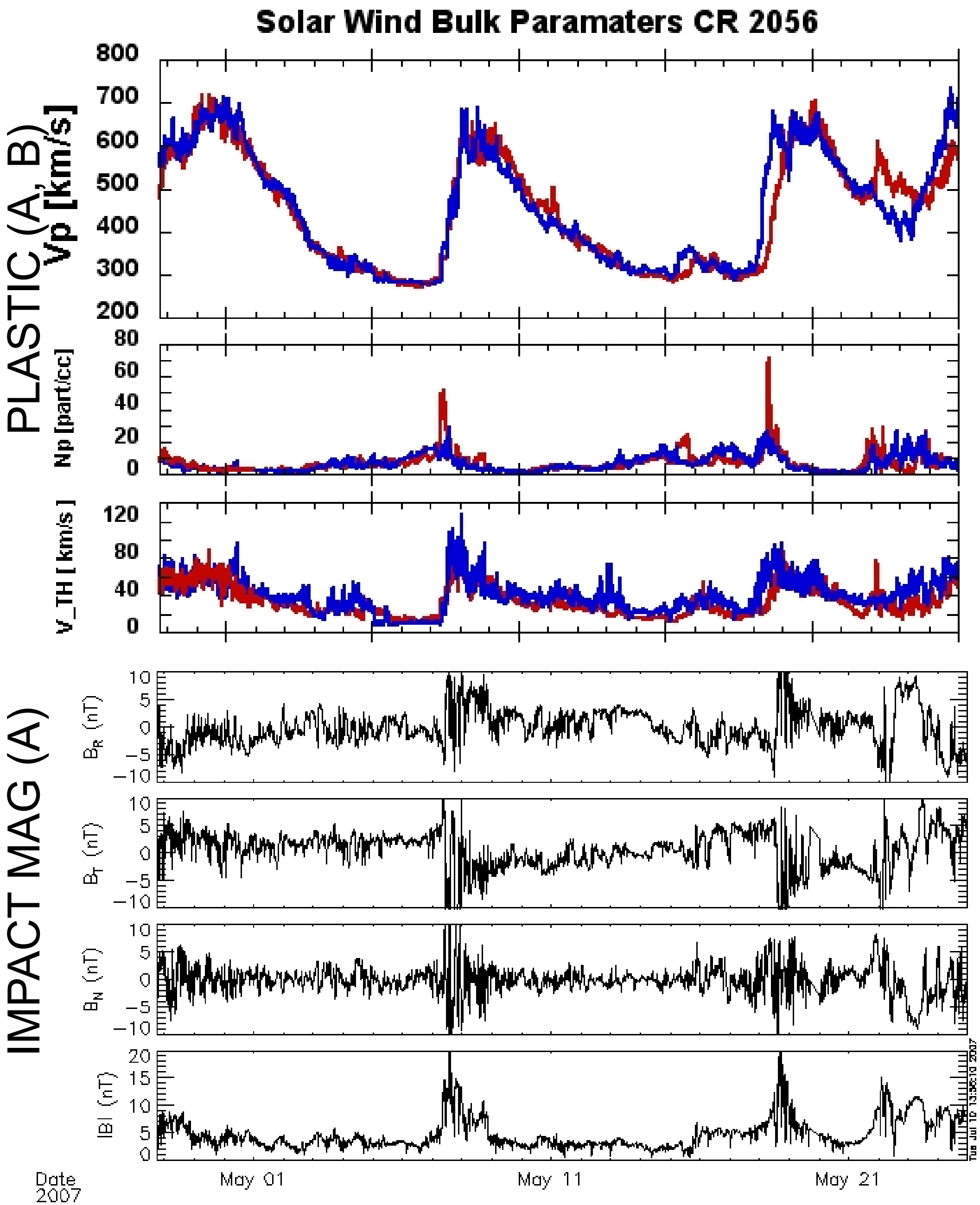
- Some science snip-its at CIRs
  - Geometry of the Structure (predicting or mapping back)
  - Compression region
  - Pickup ion energy distribution

Fast Wind and Slow Wind Interact and Evolve into Corotating Interaction Regions





Pizzo, V. (1978), A three-dimensional model of corotating streams in the solar wind: 1. Theoretical foundations, J. Geophys. Res., 83, 5563–5572.



High speed and low speed interaction regions:

Regions are are seen in both solar wind proton and magnetic field bulk parameters.

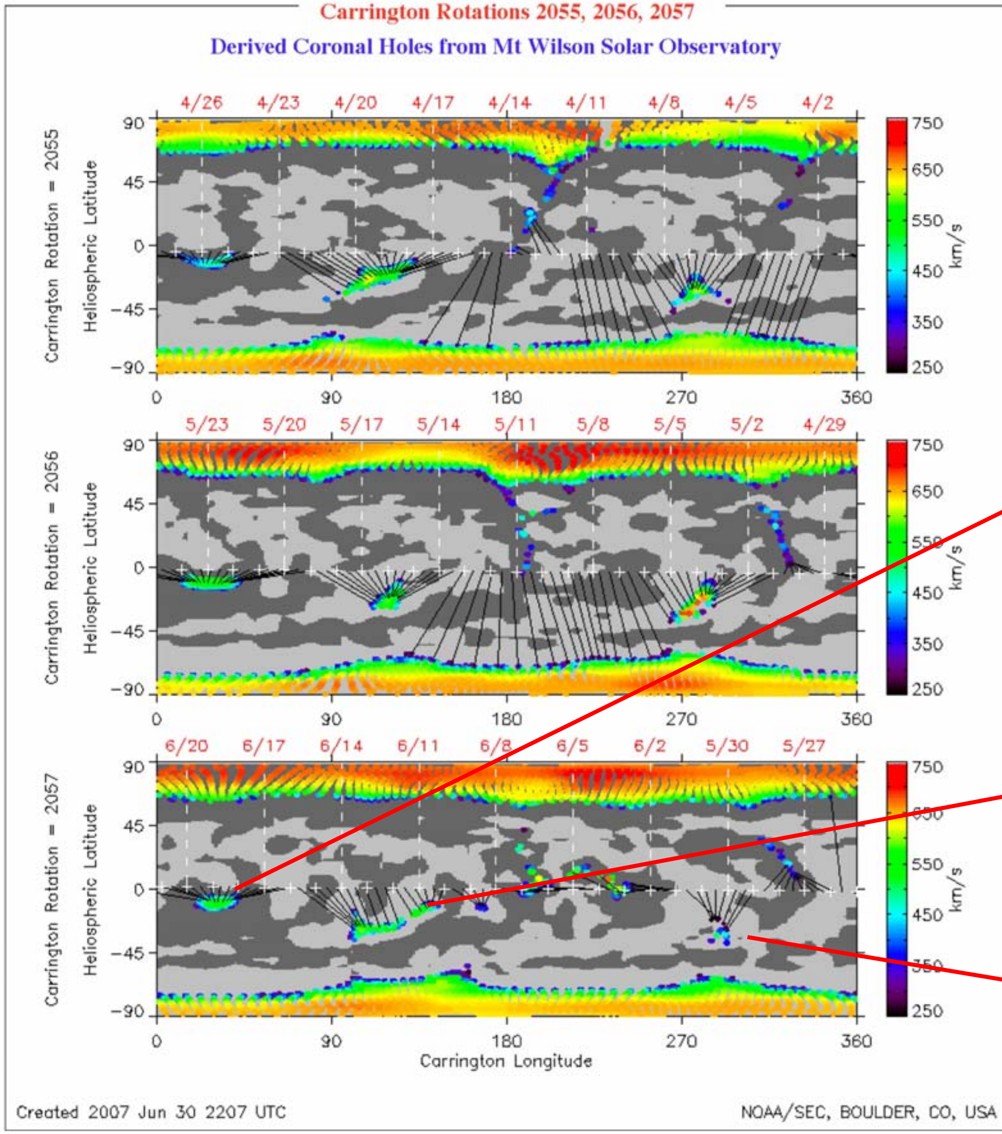
STEREO Observations of the 2-D Geometry of Co-rotating Solar Wind Streams (Simunac et al.)

Some Motivation

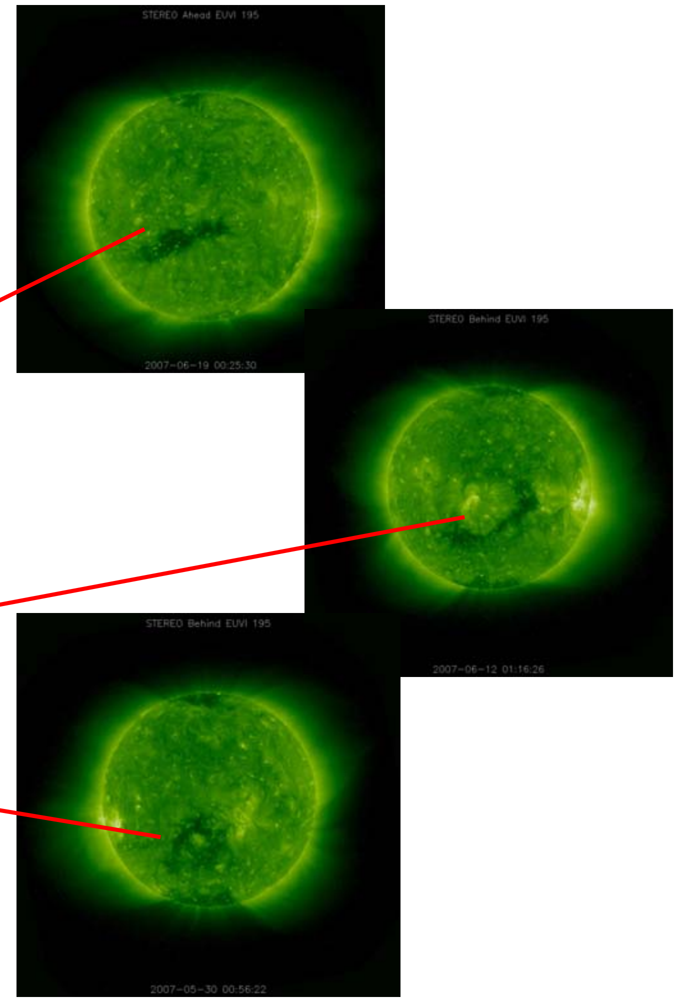
Mapping large-scale solar wind structures back to the Sun:

Science: identification of coronal source region for correlation studies with in-situ

Application: prediction of arrival of CIR structure to Earth or other spacecraft using "early warning" from s/c located at other longitudes



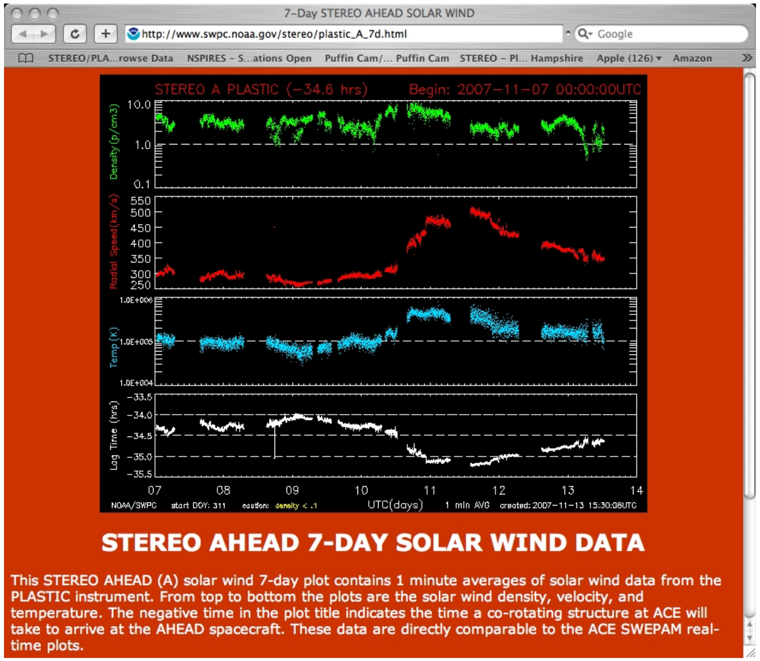
Solar sources for the high speed solar wind - long lived polar and equatorial coronal holes - observed by SECCHI EUVI (B).

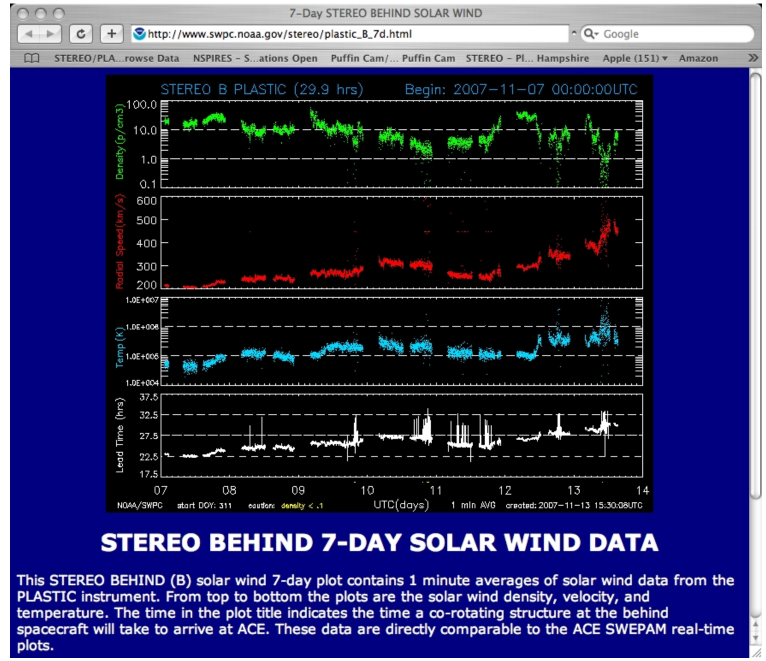


Science:

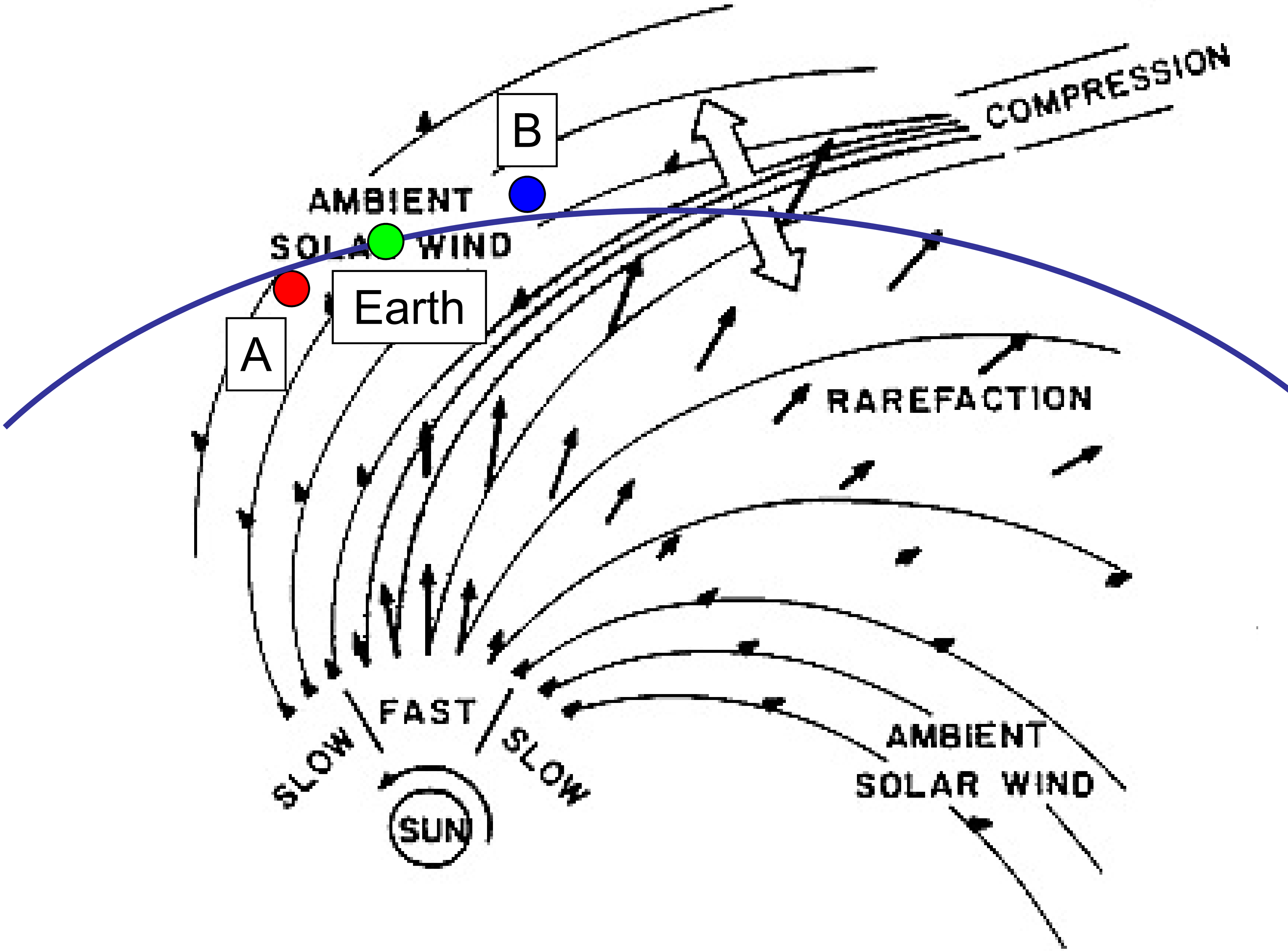
Fast: from CH   Slow: More than one source?

Application (NOAA SEL)





- Using s/c at different solar longitudes to predict arrival of large scale structures at other locations (L1, Earth, …)

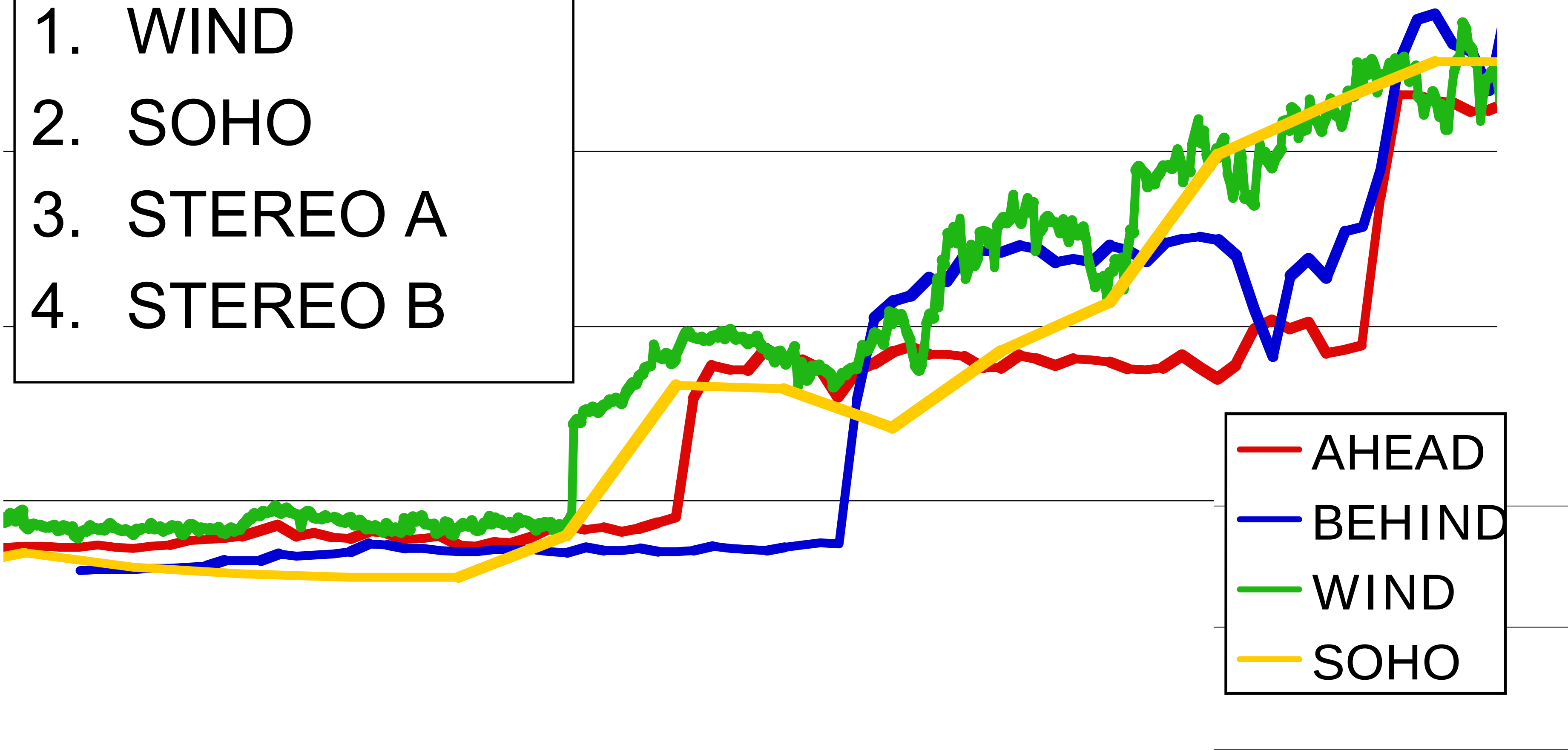


COMPRESSION
B
AMBIENT
SOLAR WIND
Earth
A
RAREFACTION
FAST
SLOW
SLOW
SUN
AMBIENT
SOLAR WIND

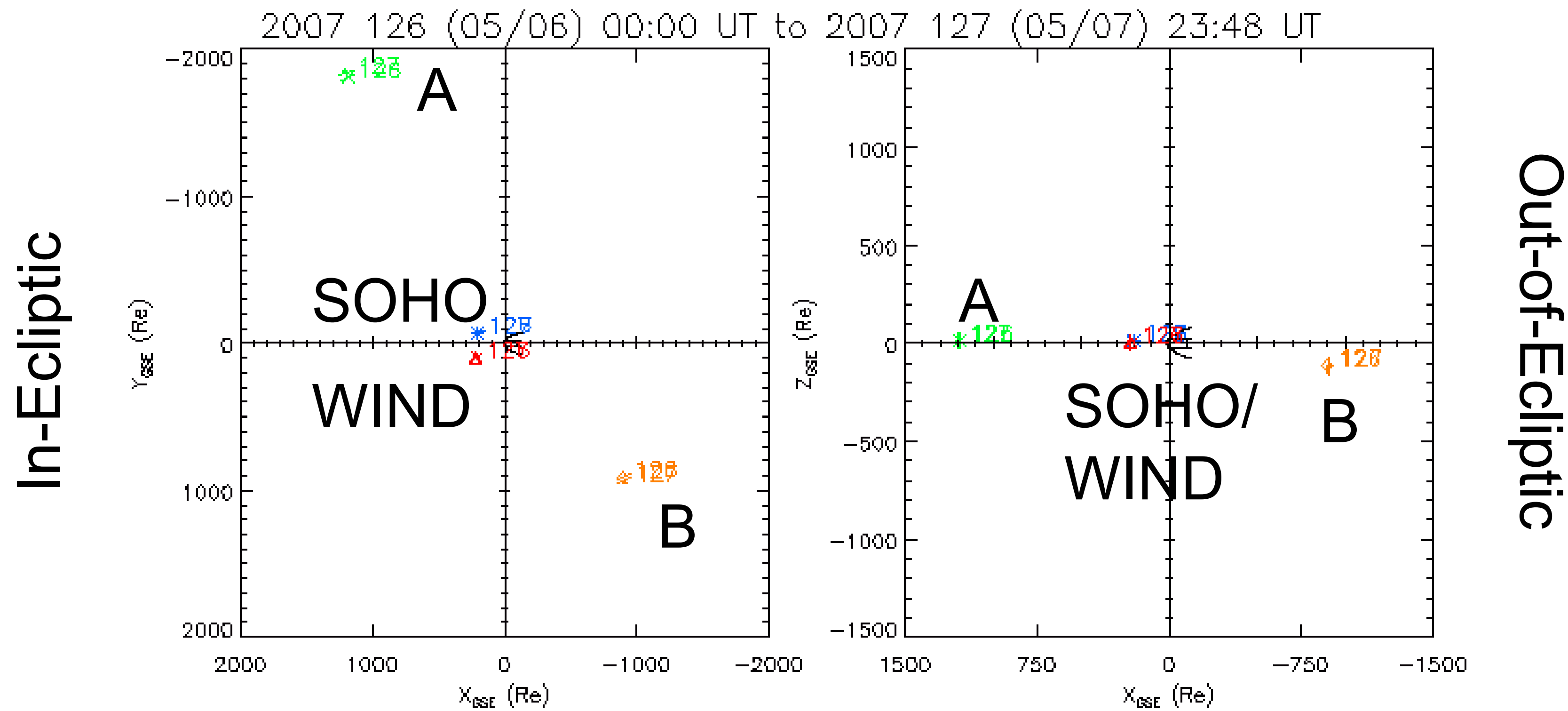
Not always obvious: Note Arrival Order of CIR Forward Shock in the March 7, 2007 Event

Arrival Order:

1. WIND
2. SOHO
3. STEREO A
4. STEREO B

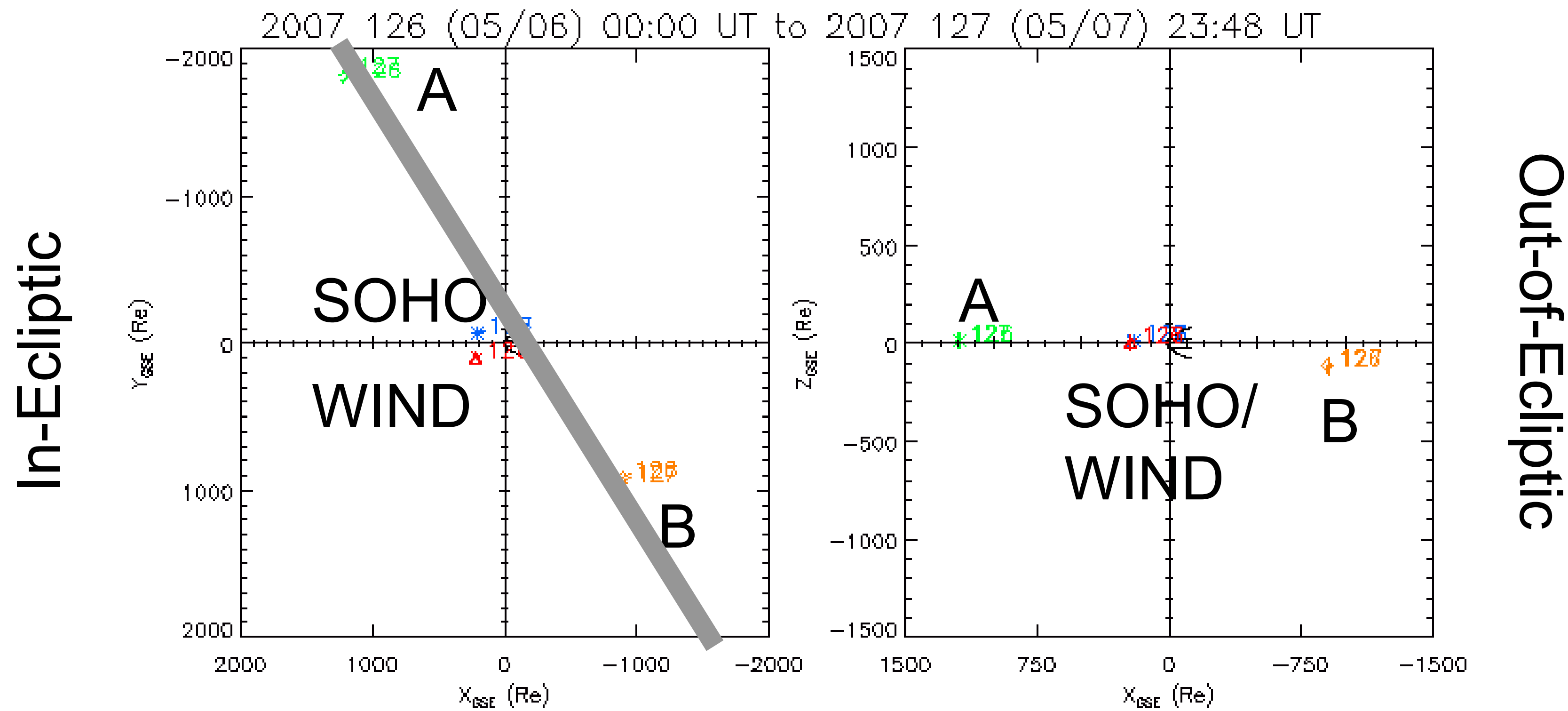


7 May, 2007
spacecraft locations



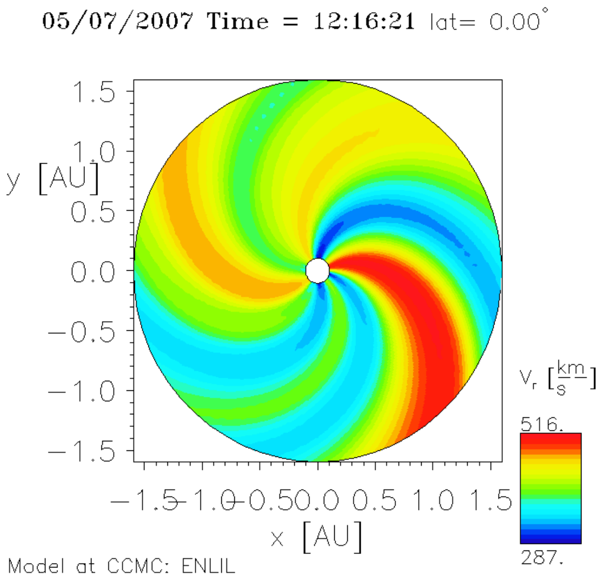
http://sscweb.gsfc.nasa.gov/cgi-bin/sscweb/Locator_graphics.cgi

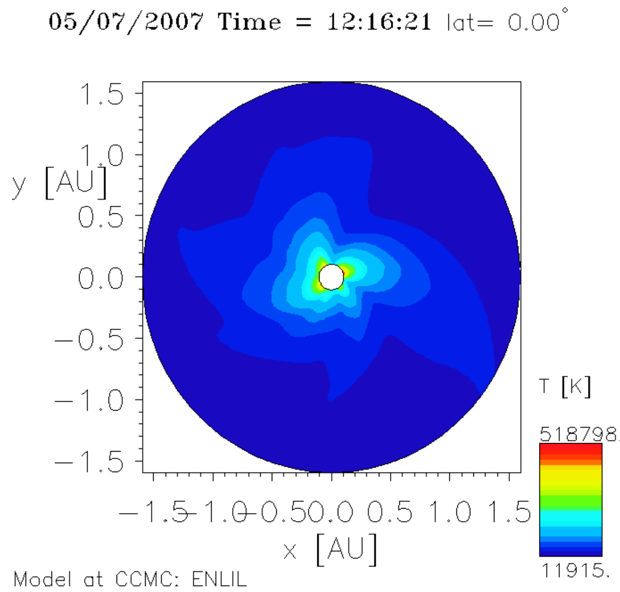
7 May, 2007
spacecraft locations

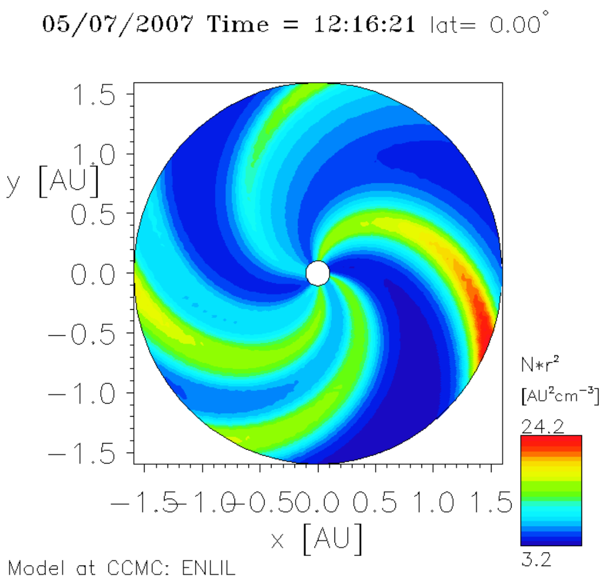


http://sscweb.gsfc.nasa.gov/cgi-bin/sscweb/Locator_graphics.cgi

Sophisticated model predictions are available:





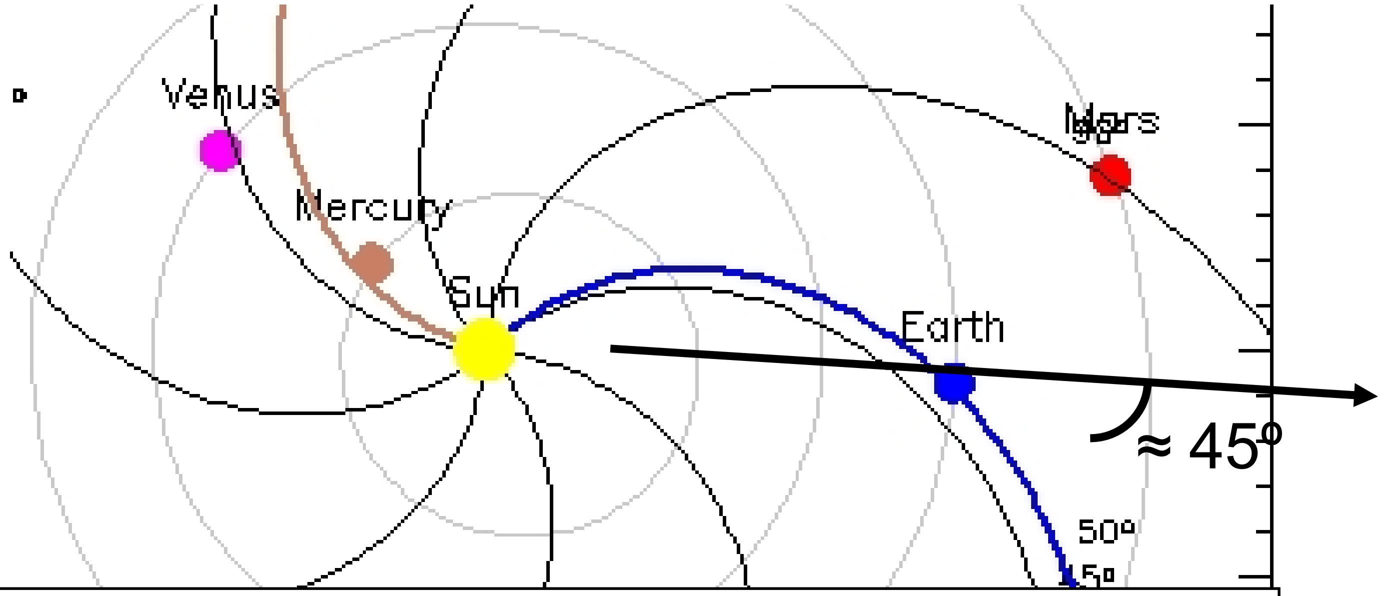


Modeled solar wind for May 7 2007 by CCMC using ENLIL code

‘Back of envelope’ simple methods :

- The simplified constant velocity approximation is usually reasonably good for the CIR trailing edge
- For CIR leading edge, testing use of “traveling interface technique” (Schwenn, 1990). Structure takes shape of “Parker-type” spiral with curvature expressed from “effective propagation speed”.

“Parker Spiral Angle”



$$\tan\alpha = \frac{\Omega_{sun} R}{V_{sw}}$$

$\alpha = 45°$ at 1 AU when $V_{sw} = 400\ km/s$

Effective Propagation Speed

Schwenn (1990) defines an effective propagation speed based on two simultaneous observations of a stream interface.

$$v = \frac{\Omega_{sun}(R_1 - R_2)}{(\phi_1 - \phi_2)}$$

(This is simply based on the geometric definition of an Archimedes spiral.)

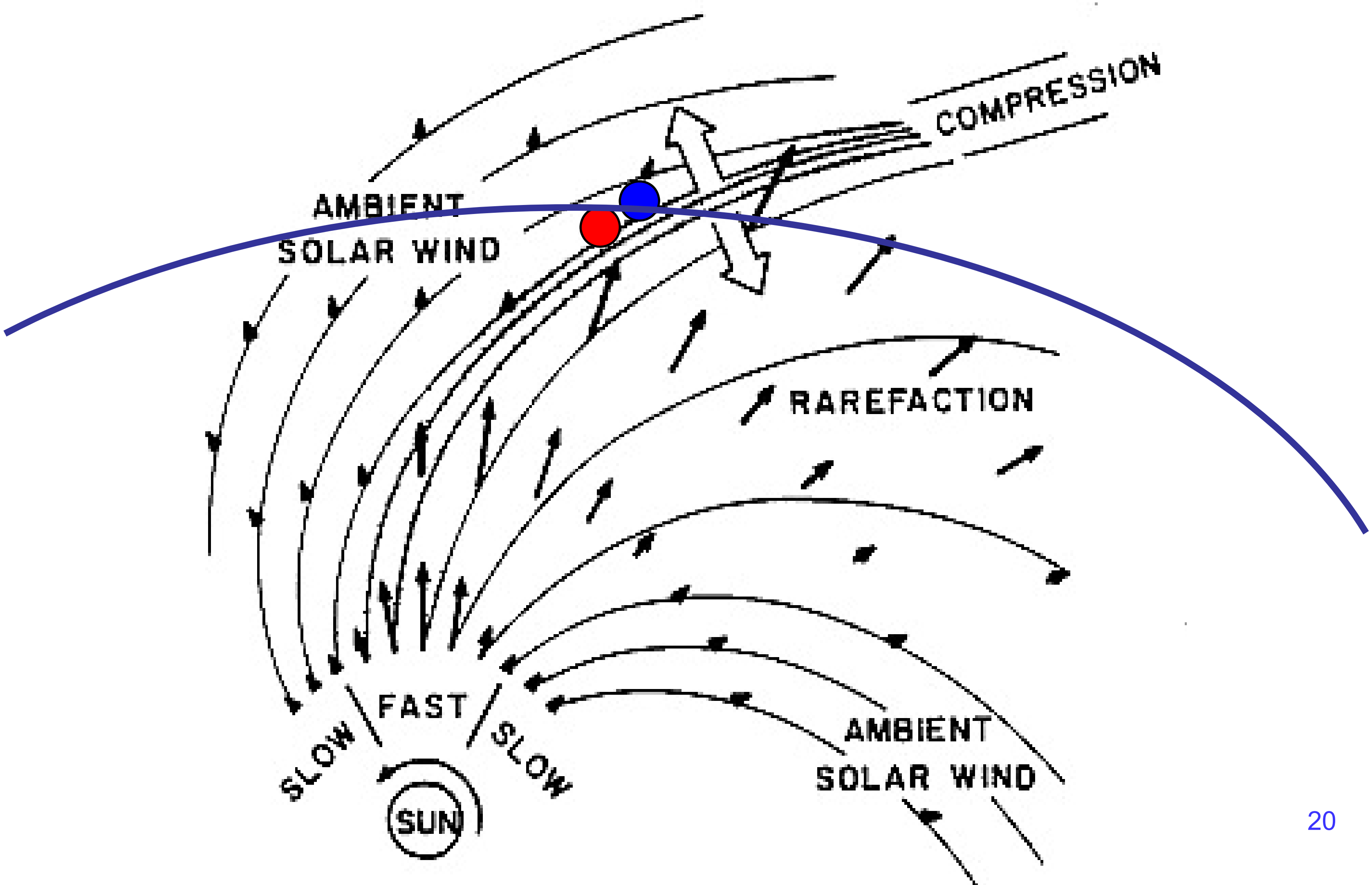
Effective Propagation Speed

Adapting for non-simultaneous observations on A and B:

$$v = \frac{\Omega_{sun}(R_B - R_A)}{(\phi_A - \phi_B - \Omega_{sun} t)}$$

Example Case Study

Radial and Longitudinal Separation are Similar

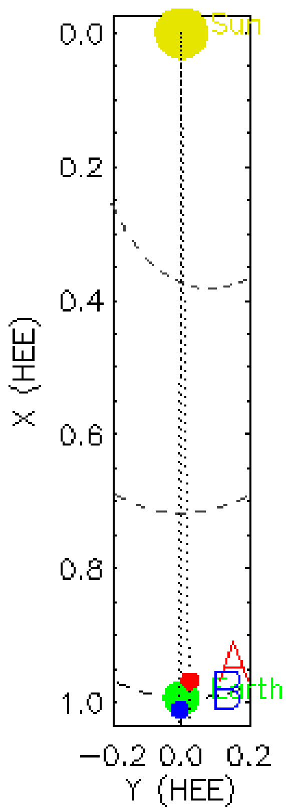


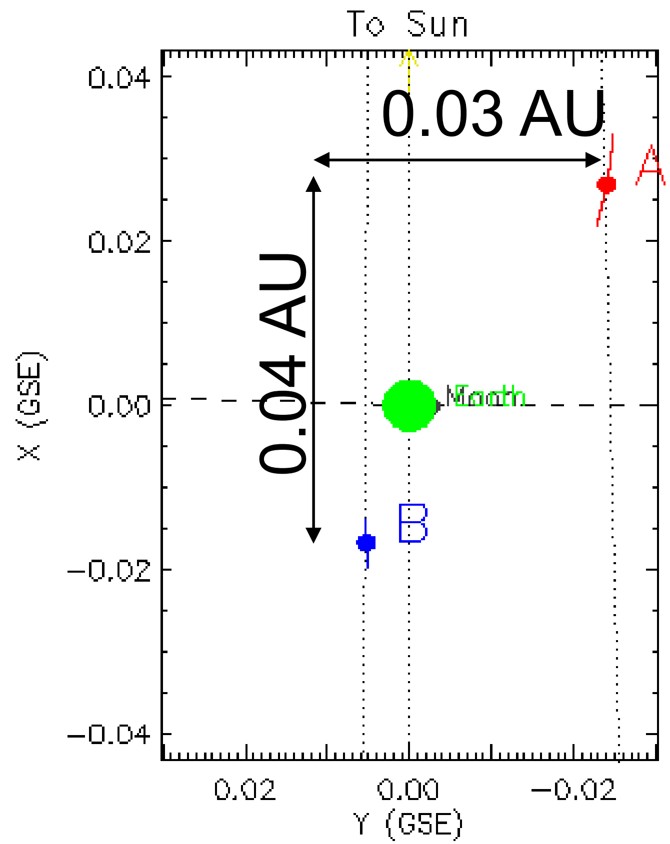
12 March, 2007

Separation Angle with Earth

A: 1.444º
B: 0.312º

Angle between A and B: 1.746º





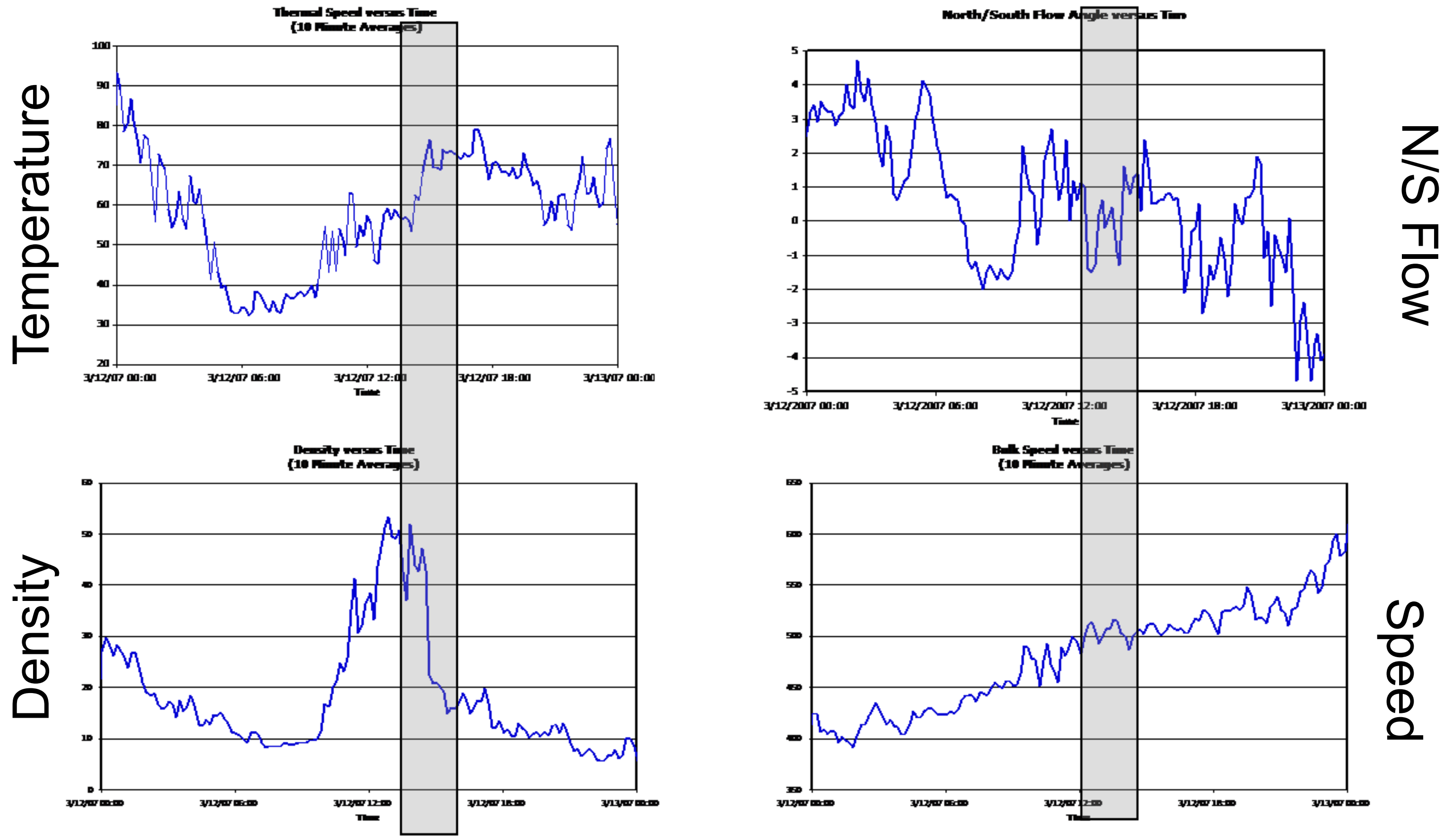
Distance from Sun (AU)

A: 0.967
B: 1.010

Earth: 0.994

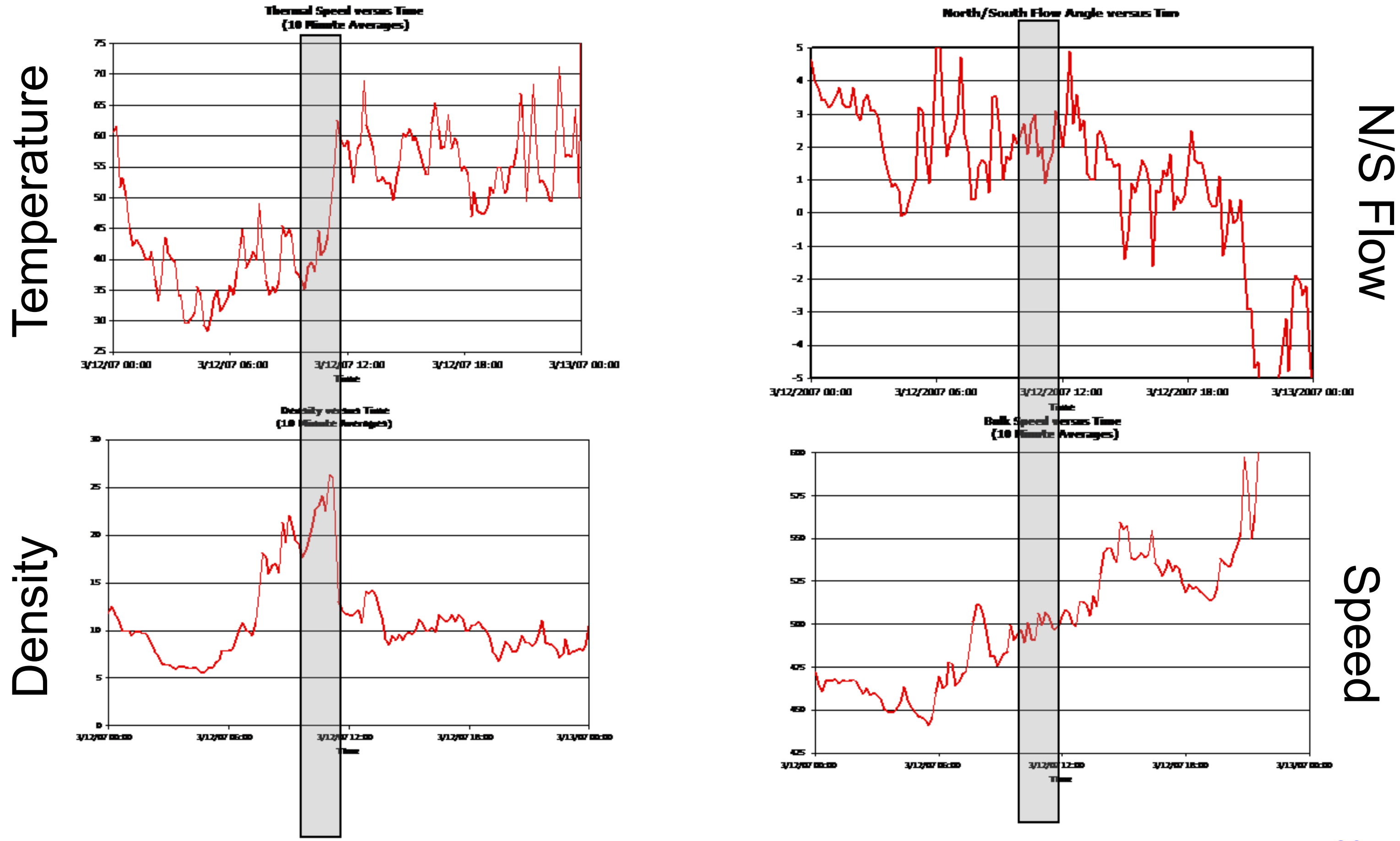
STEREO B: Stream Interface

14:40 UT 12 March, 2007

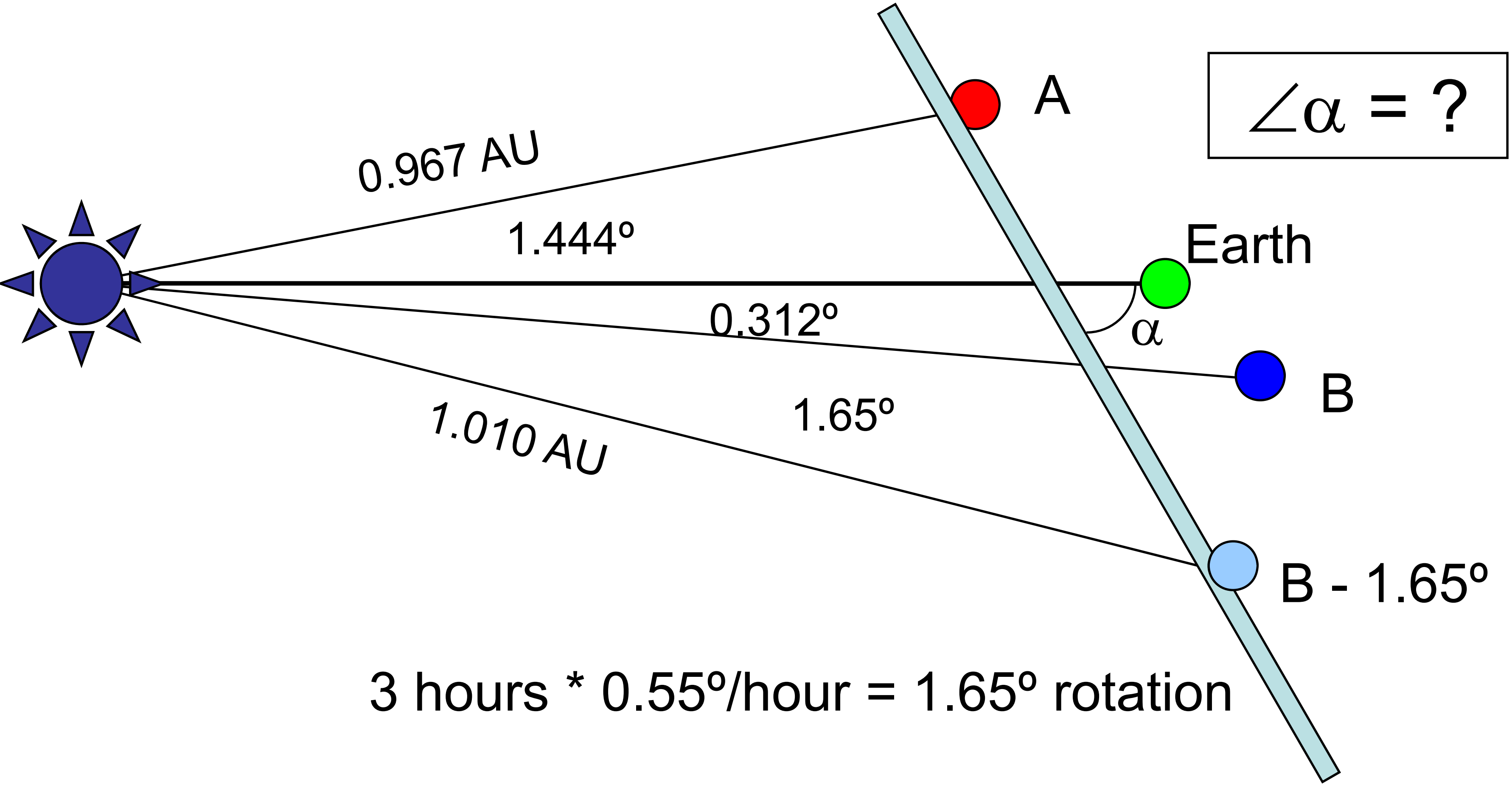


STEREO A: Stream Interface

11:40 UT 12 March, 2007 (3 hour **earlier** than B)



A Geometry Exercise

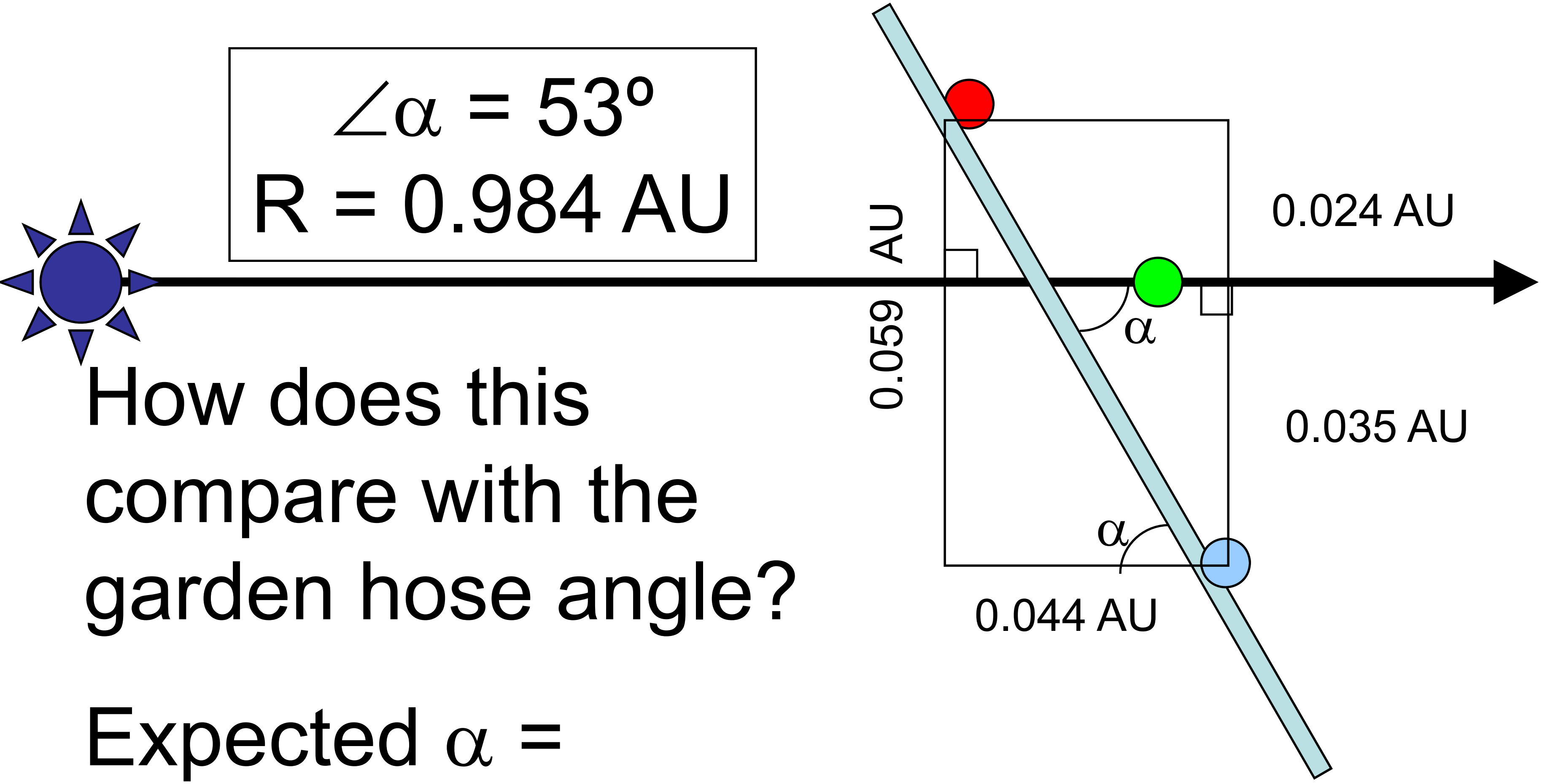


3 hours * 0.55°/hour = 1.65° rotation

CARTOON IS NOT TO SCALE!

Parallel Lines and Similar Triangles

$\angle\alpha = 53°$
R = 0.984 AU

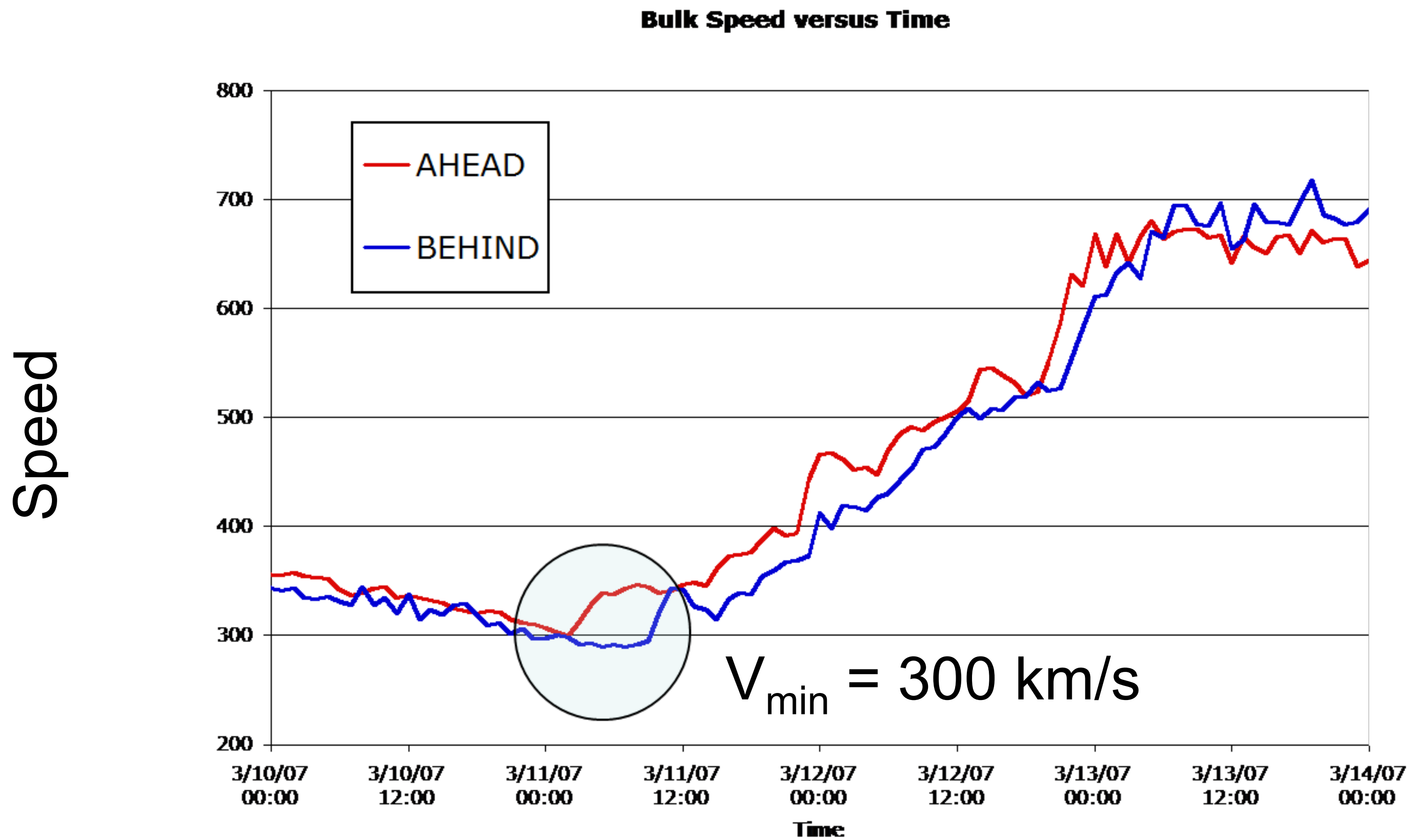


How does this compare with the garden hose angle?

Expected α = Arctan $(\Omega_{sun}R/V_{sw})$

Solar Wind Speed

Minimum Speed Prior to Interface



Time

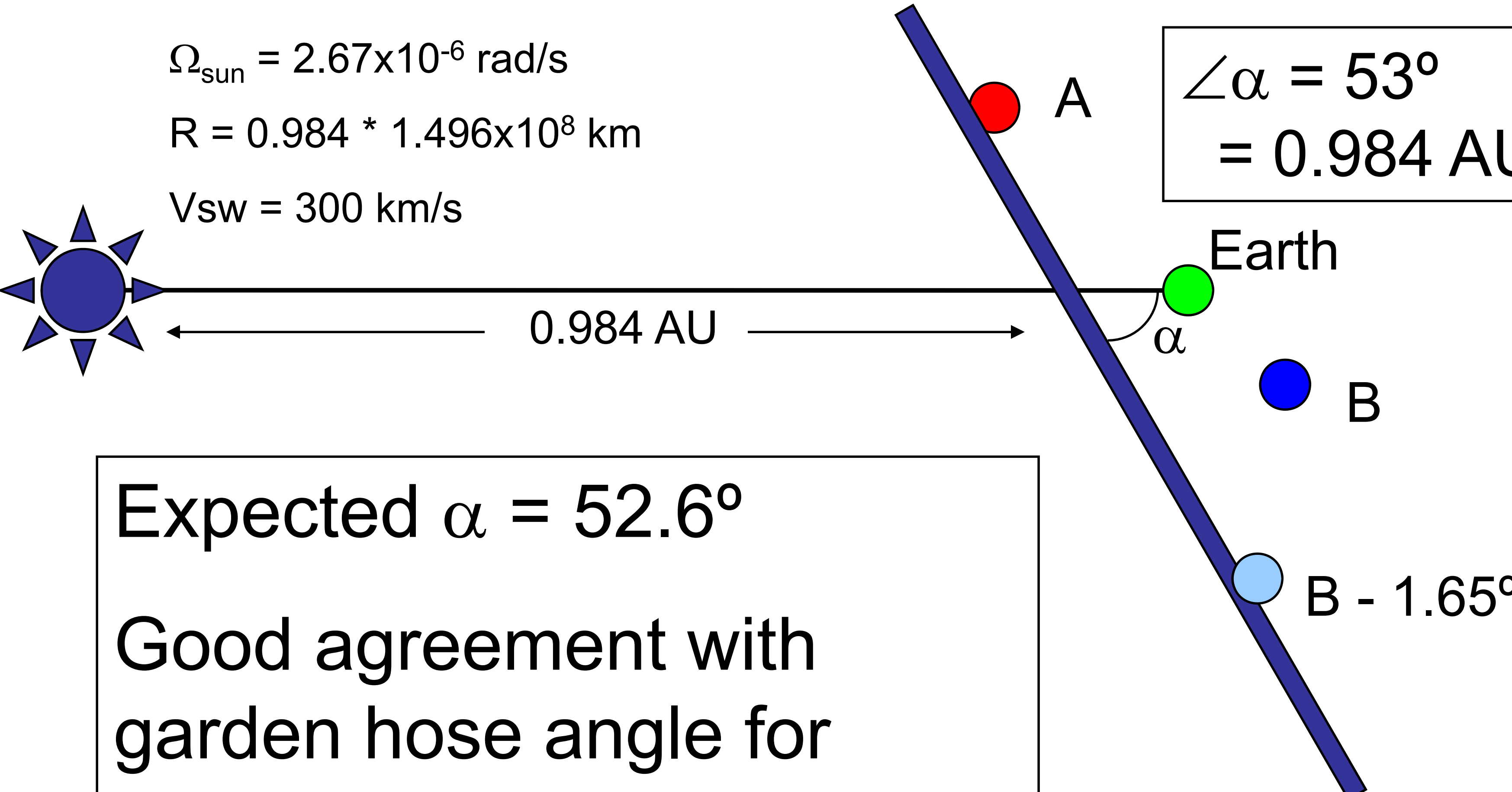
Agreement

Ω_{sun} = 2.67x10^{-6} rad/s

R = 0.984 * 1.496x10^{8} km

Vsw = 300 km/s

∠α = 53º R = 0.984 AU



Expected α = 52.6º

Good agreement with garden hose angle for minimum solar wind speed.

Effective Propagation Speed

Inserting values into the propagation speed calculation:

$$v = \frac{\Omega_{sun}(R_B - R_A)}{(\phi_A - \phi_B - \Omega_{sun} t)}$$

$$v = \frac{(1.53x10^{-4}{}^\circ/s)(1.010AU - 0.967AU)}{\left(1.444^\circ + 0.312^\circ + \dfrac{0.55^\circ/hour}{3\ hours}\right)}$$

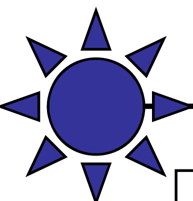
$$v = 290\ km/s$$

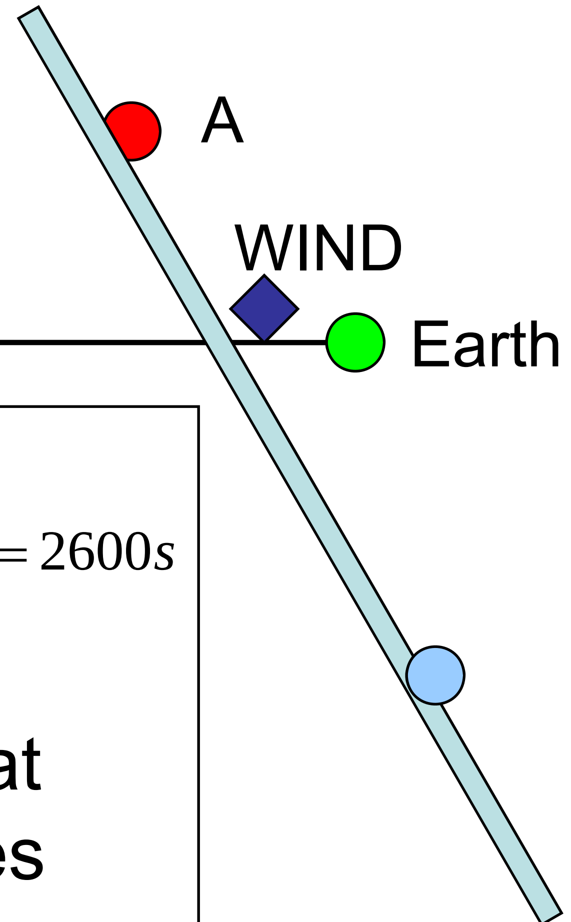
When do we expect WIND to see the stream interface?

WIND coordinates (GSE)

$X = 200\ R_E = 0.009\ AU$

$Y = -52\ R_E = -0.002\ AU$



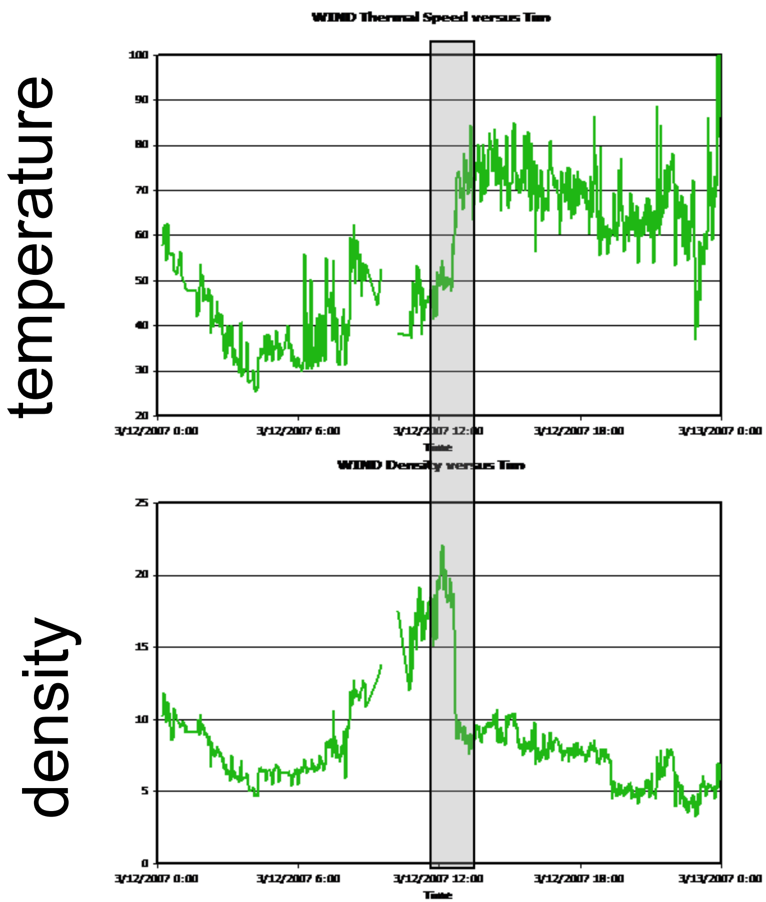


$$0.005AU\left(\frac{1.496x10^{8}km}{AU}\right)\Big/\left(\frac{290km}{s}\right) = 2600s$$

Expected time of arrival at WIND is about 45 minutes after arrival at A

WIND data courtesy of K.W. Ogilvie (NASA GSFC), A.J. Lazarus (MIT), and M. R. Aellig (MIT)

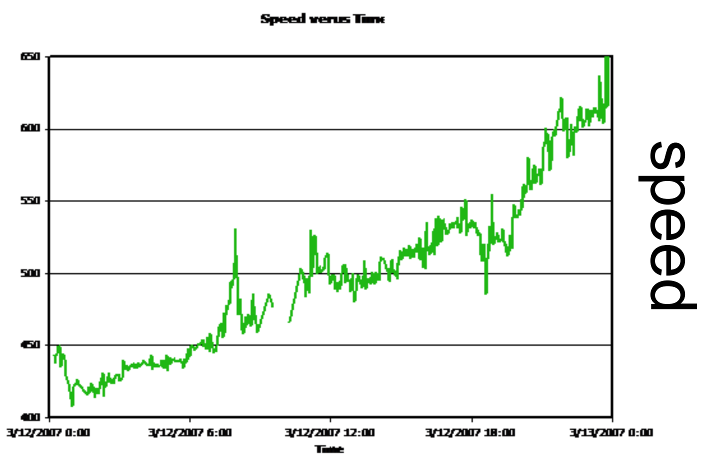
WIND Stream Interface

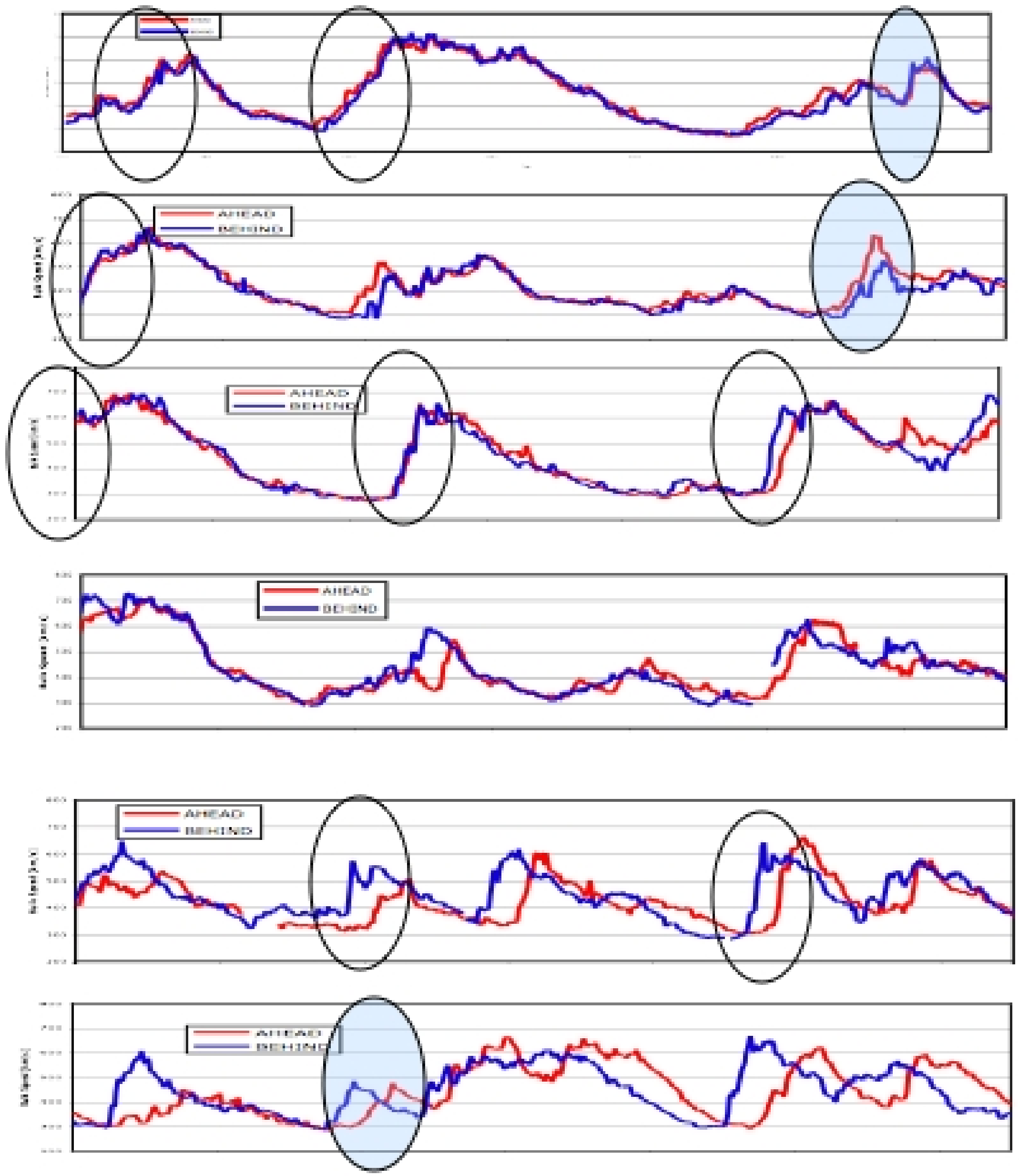


12 March, 2007

12:30 UT

(about 50 minutes after arrival at A)





2054
3/4 to 3/31

2055
3/31 to 4/27

2056
4/27 to 5/24

2057
5/24 to 6/21

2058
6/21 to 7/18

2059
7/18 to 8/14

Based on minimum Vsw

Summary of Analysis

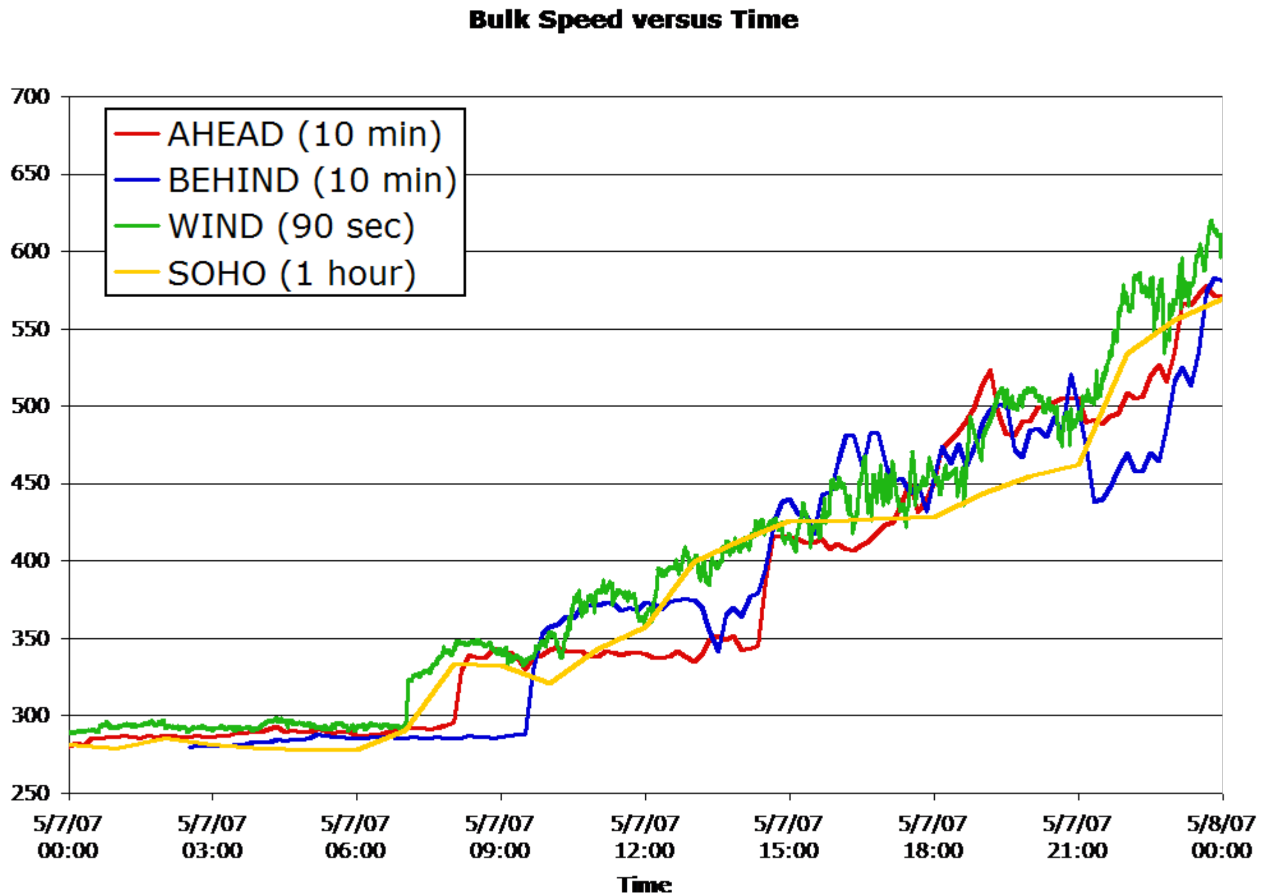
Date 2007	Angle between A and B [deg]	Expected α [deg]	Observed α [deg]	Effective Propagation Speed [km/s]	Observed Minimum Speed [km/s] STA/STB
6 March	1.5	50 - 52	50	336	310/340
12 March	1.8	53 - 54	54	294	300/290
25 March	2.5	55 - 56	66	175	270*/275*
1 April	3.1	50 - 52	49	348	330/315
23 April	5.2	53 - 54	62	210	300/290
27 April	5.7	45 - 46	46	389	400/385
7 May	6.9	55 - 56	57	262	270*/280
18 May	8.5	54	54	294	290/290
29 June	15.8	49 - 51	46	392	325/350
10 July	18.0	53 - 54	52	309	305/285
26 July	21.1	54	60	235	285/285

Composition at CIRs

SOHO data courtesy of CELIAS/MTOF
(F. Ipavich and J. Paquette, Maryland)

CIR Compression Region
May 7, 2007

speed



time

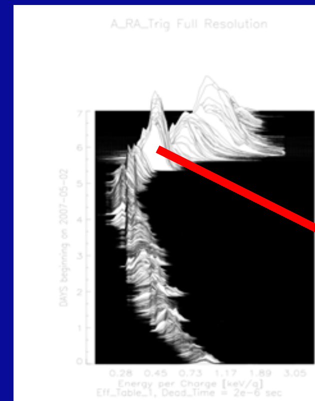
CIR compressions - How it looks to the Solar Wind

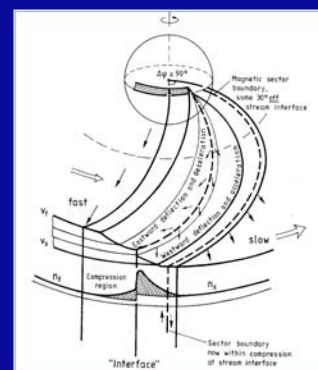
Polar Deflection

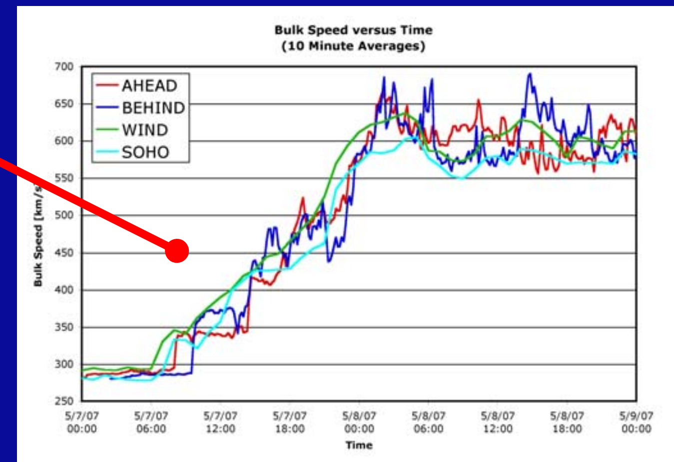
STEREO A PLASTIC

QuickTime™ and a Cinepak decompressor are needed to see this picture.

Energy per charge



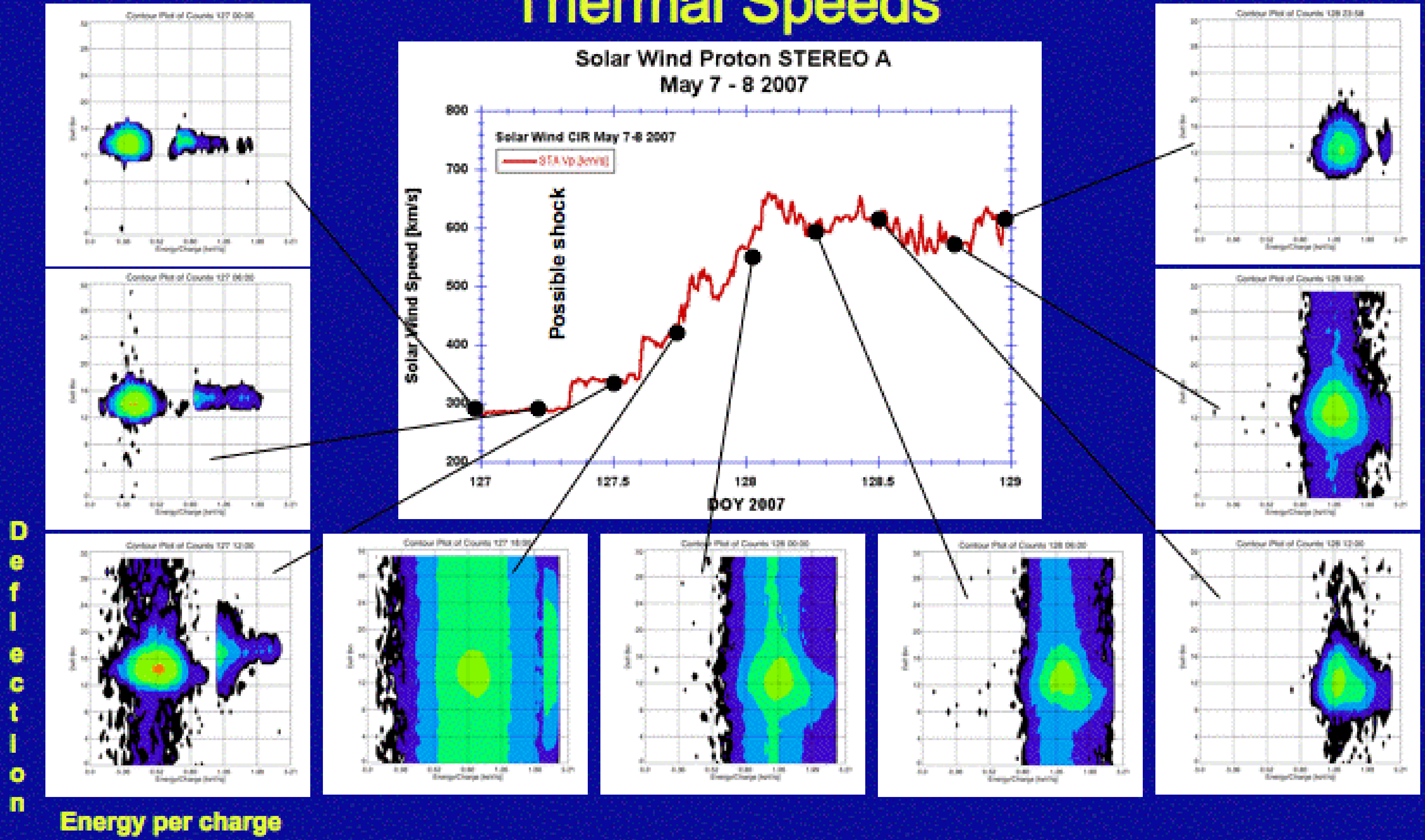




Multiple spacecraft observations - all near 1 AU, but at different longitudes

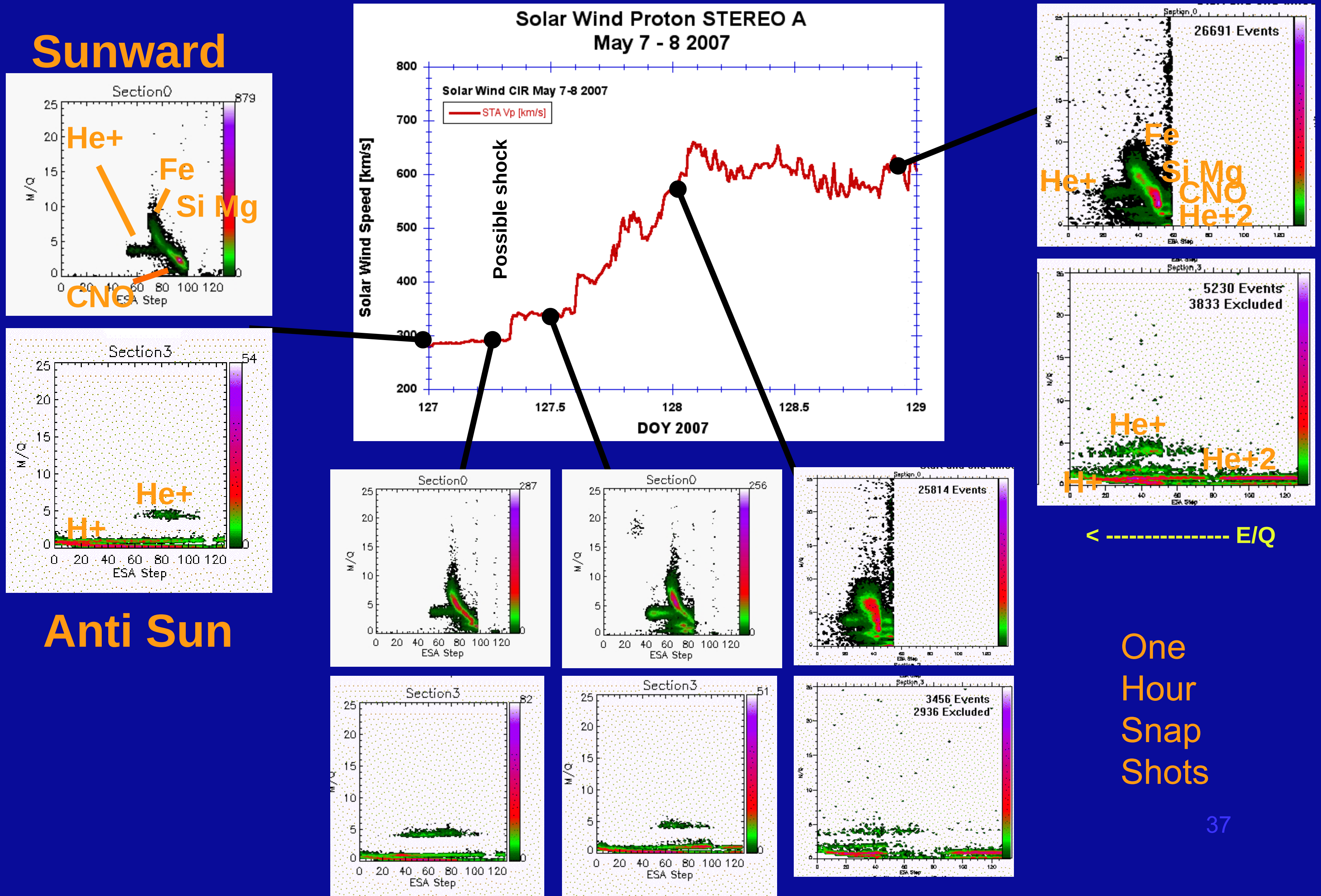
Interaction regions are of specific interest … to solar wind … suprathermals … and energetic particles

CIR compressions - Changes in Solar Wind Bulk and Thermal Speeds



One minute Snap Shots

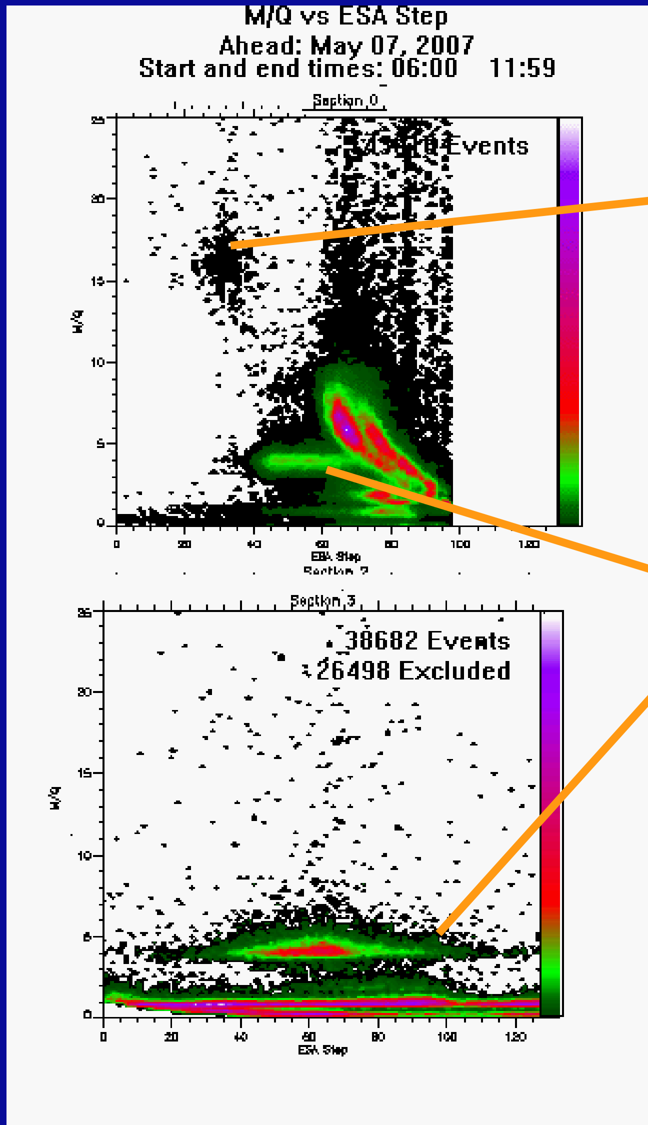
CIR compressions - Changes in Composition



One Hour Snap Shots

Sunward

AntiSun



O+

He+

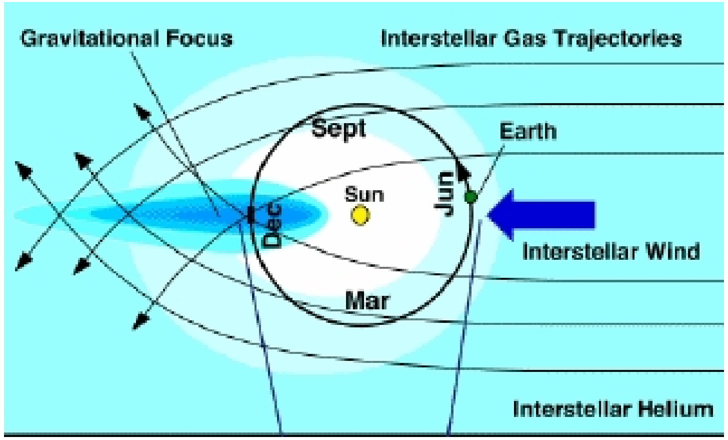
Six Hour Snap Shot

80 keV/e < ---- E/Q 0.3 keV/e

In addition to the ubiquitous He^{+} pickup ions, small amounts of O^{+} may be observed at CIRs

Also note presence of suprathermal H^{+}, He^{+2}, and extended energy He^{+}

Historical Review - Pickup He^+



Interstellar Origin

First Direct Measurements

Möbius et al., 1985 (pickup He^+)

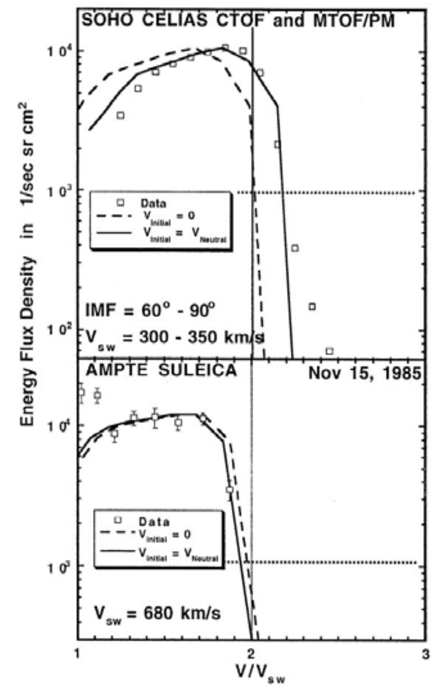
Gloeckler et al., 1993 (pickup H^+)

Geiss et al., 1994 (pickup N^+, O^+, Ne^+)

Energy Spectra of Pickup Ions

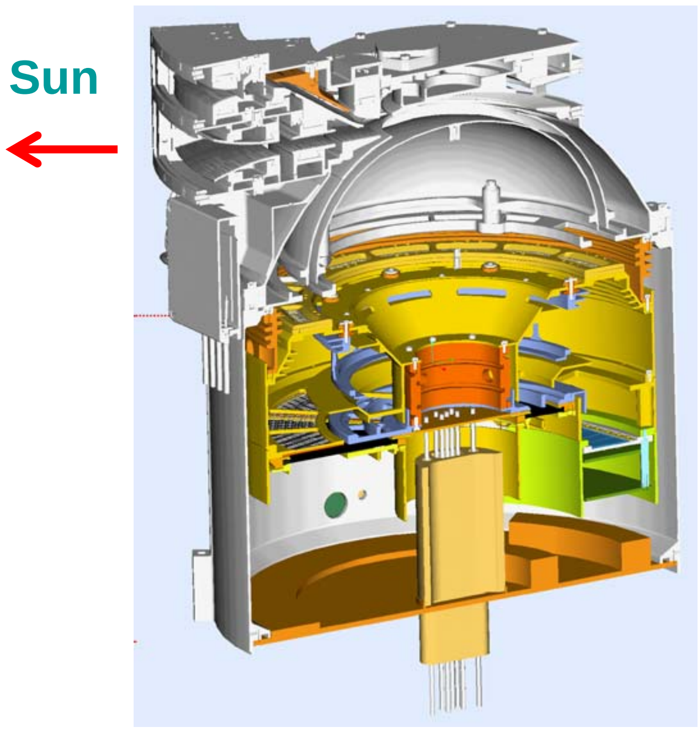
Variation of the Cutoff Energy E_{cutoff}

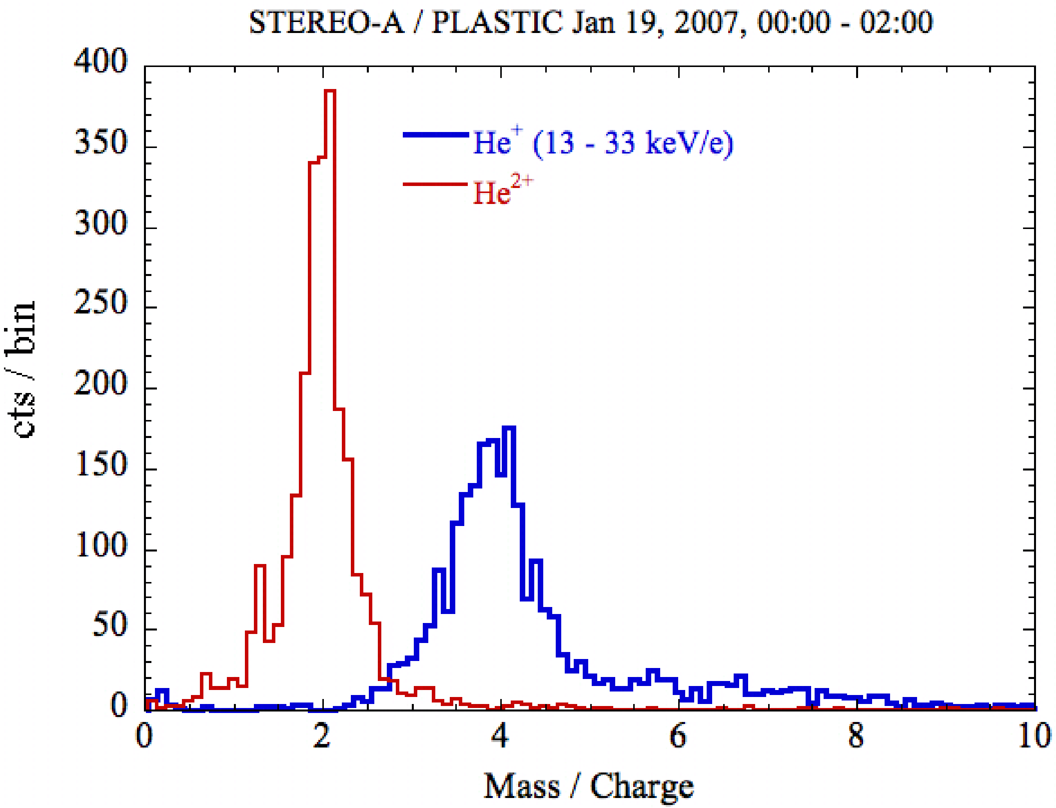
- **To Zeroth Order: $V_{cutoff} = 2 * V_{SW}$**
- **But: Relative Speed between neutral He and V_{SW} has to be taken into account**



Möbius et al., 1999

STEREO / PLASTIC - FIRST RESULTS (courtesy B. Klecker)



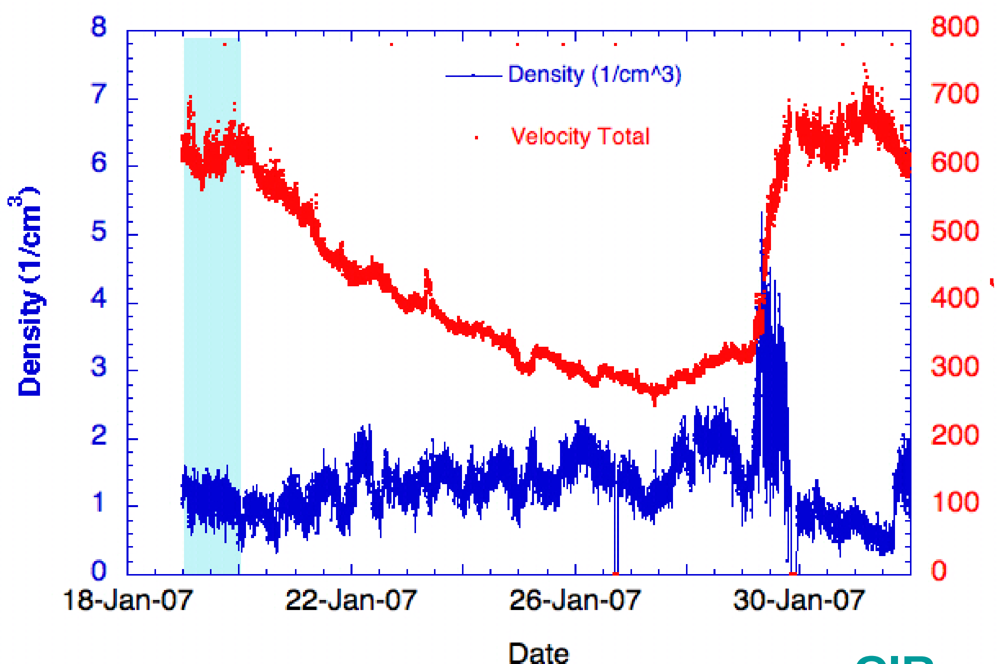


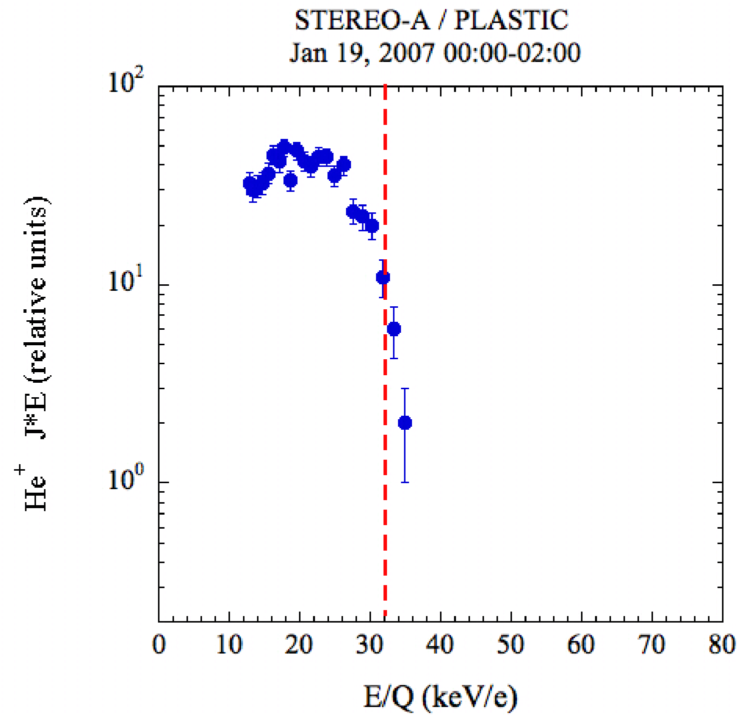
Separation of He^+ by M/Q Analysis

STEREO / PLASTIC - FIRST RESULTS

He+ Pickup Ions in the Solar Wind

Solar Wind Parameters for January 2007





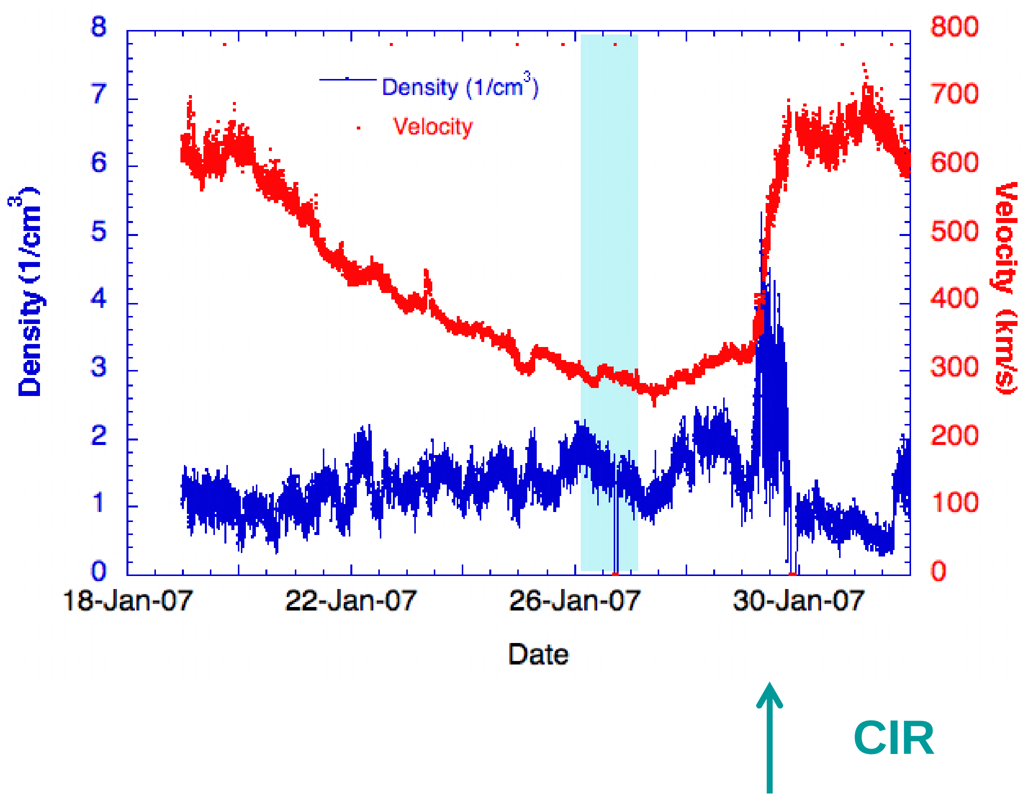
CIR

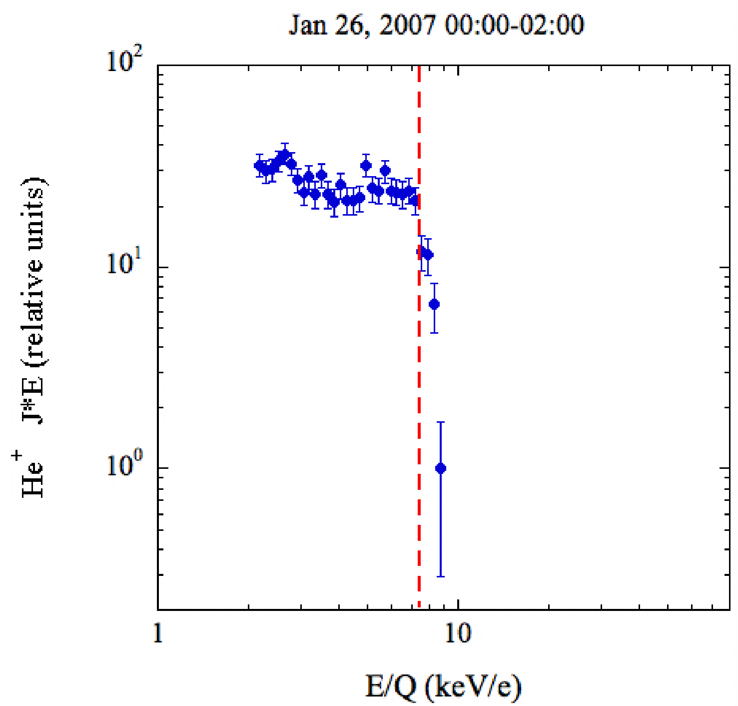
Several CIRs have been observed by STEREO in the time period January - March 2007

STEREO / PLASTIC - FIRST RESULTS

He^+ Pickup Ions in the Solar Wind

Solar Wind Parameters for January 2007

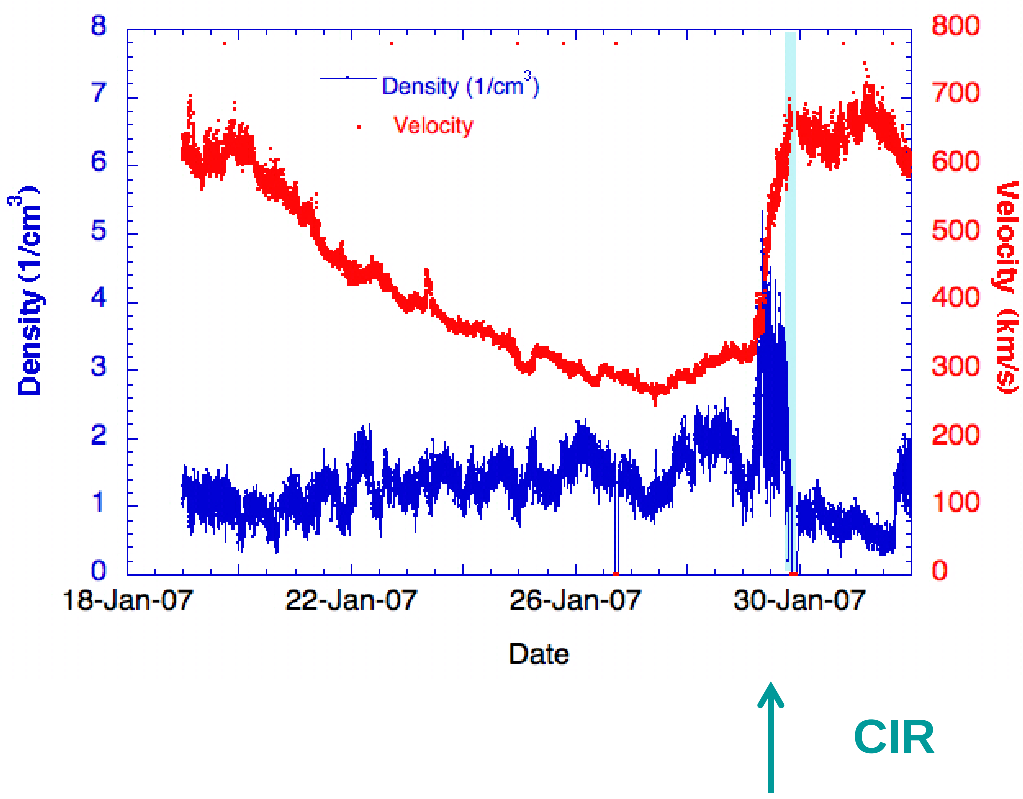


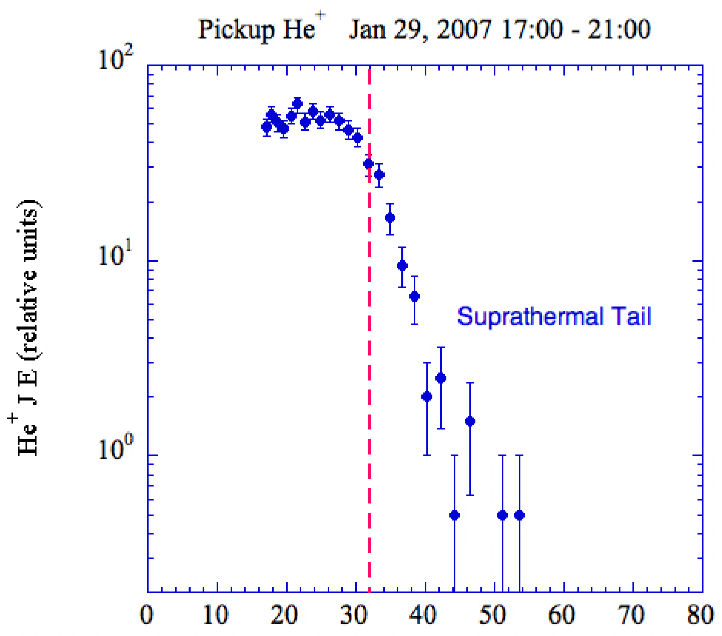


STEREO / PLASTIC - FIRST RESULTS

He$^+$ Pickup Ions in the Solar Wind

Solar Wind Parameters for January 2007

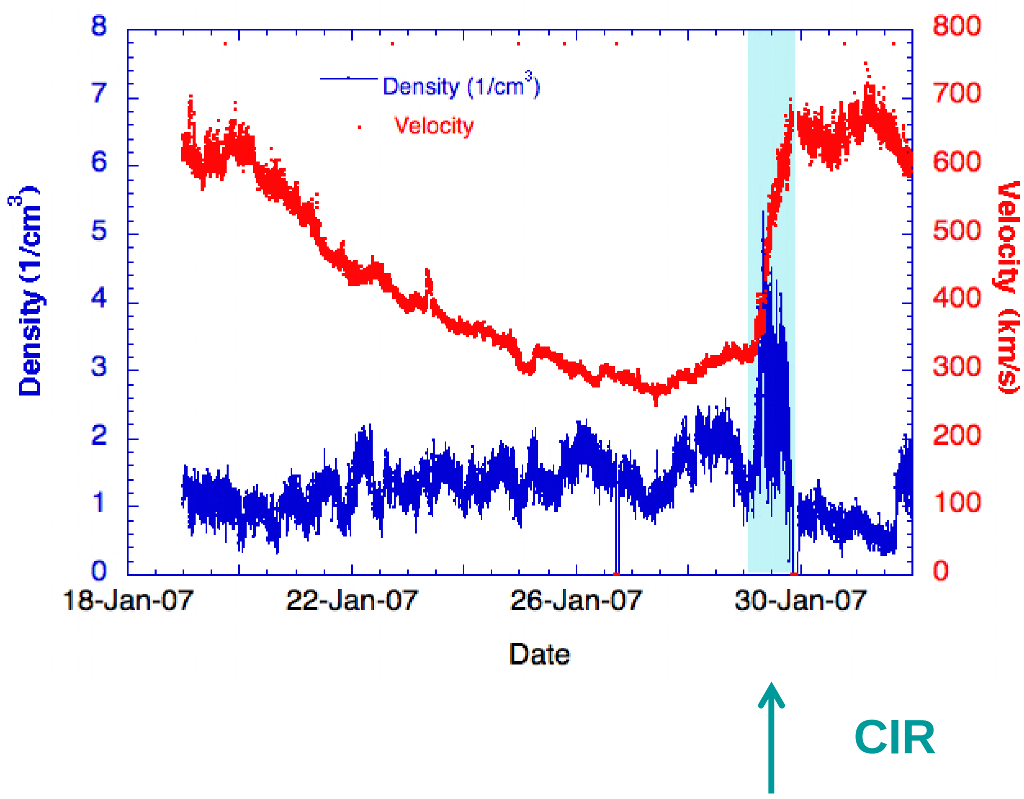


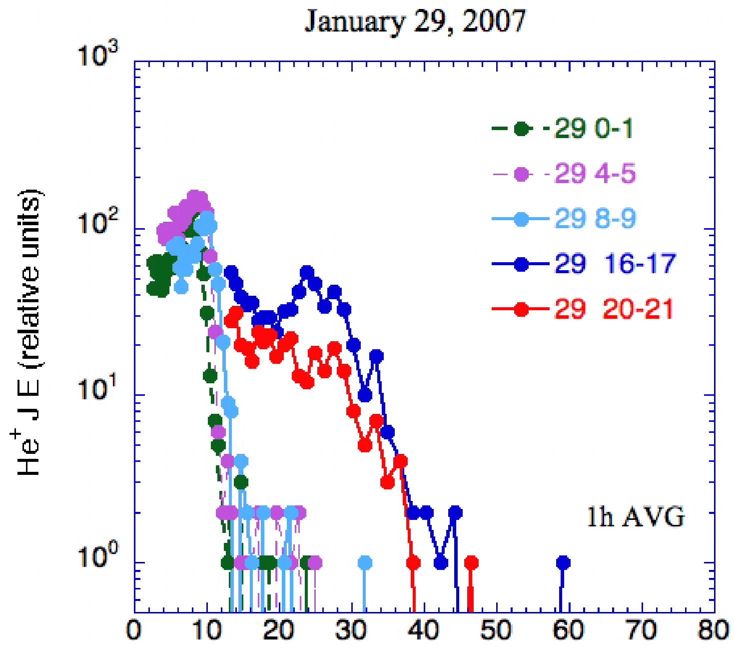


STEREO / PLASTIC - FIRST RESULTS

He^+ Pickup Ions in the Solar Wind

Solar Wind Parameters for January 2007





CIR Stream Interface - it's work in progress

Solar wind at CIRs

- **In situ signatures with STEREO HI observaions**
- **Multi-spacecraft observations (longitudinal variations, CIR geometry)**
- **Rarefaction regions**
- **Compositional signatures at higher resolution**

Suprathermals in CIRs

- **Measurement of He^+ with high time resolution during CIR**
- **Development of suprathermal tails - directional information**