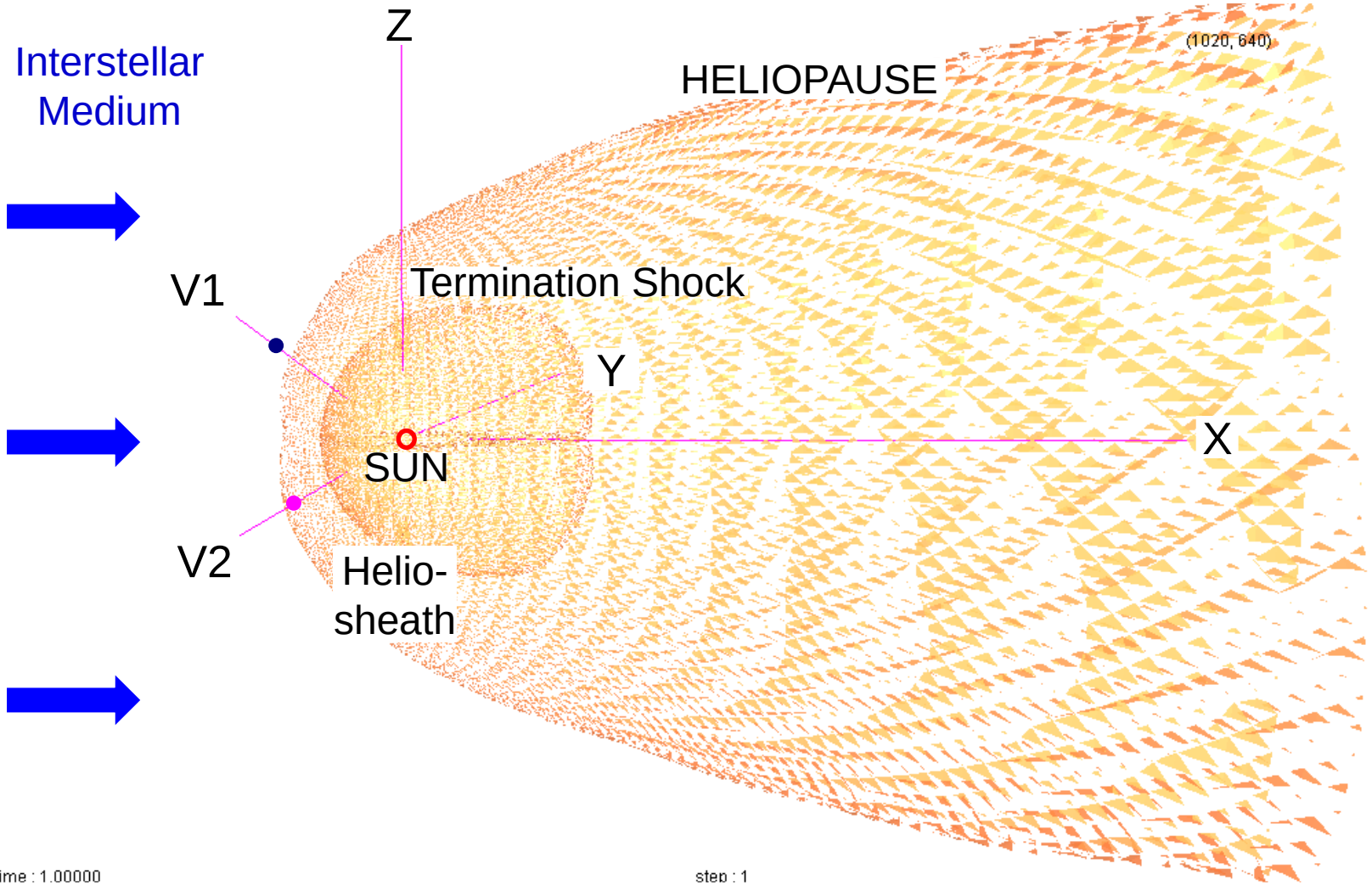
STEシミュレーション研究会　2017年9月6日　神戸大学

太陽圏外圏構造の長期及び短期変動

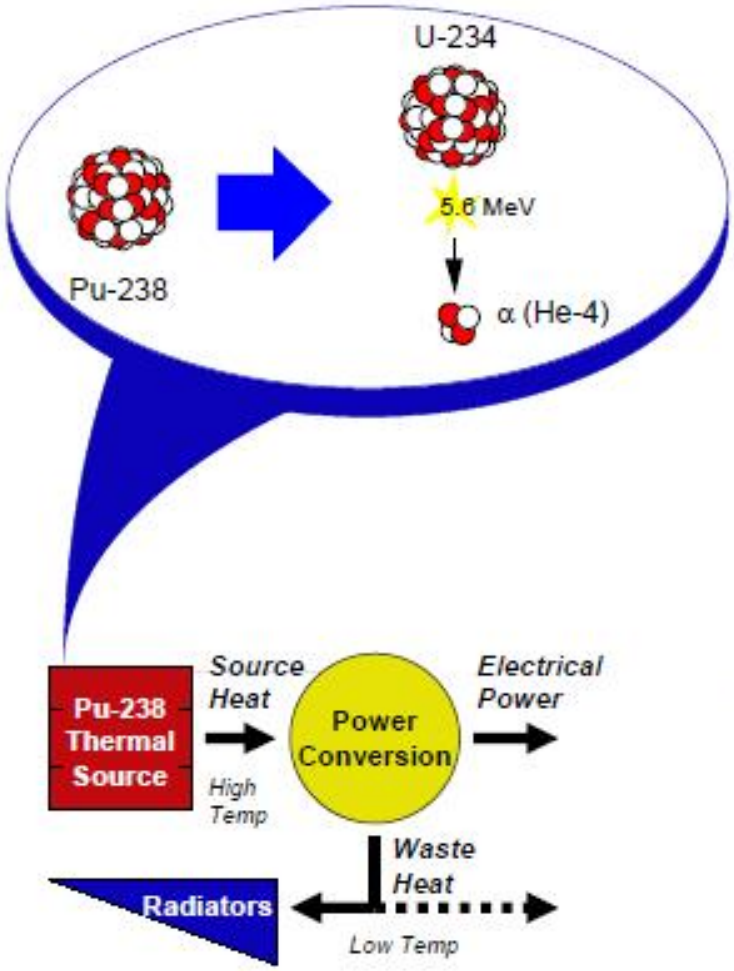
鷲見治一　九大国際宇宙天気科学研究教育センター
共同研究者: 田中高史、Gary Zank



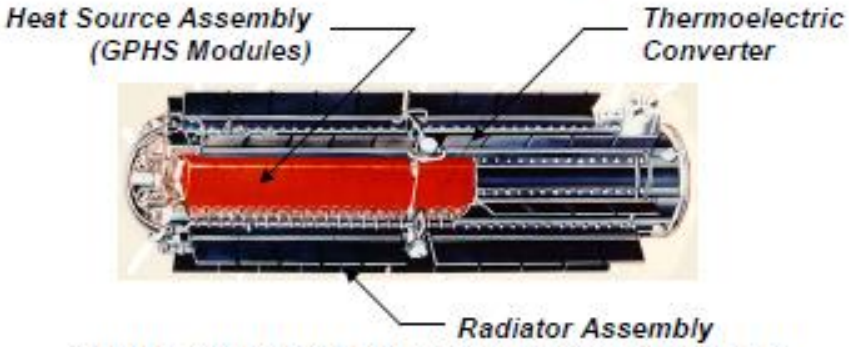
太陽圏外圏及び銀河系ガス直接探査の歴史

1957年　初の人工衛星（スプートニク1号）
1964年　NASAにて　Galaxy Probe 計画案
1971-72年　Pioneer　10号、11号　打ち上げ
1971年　Outer　Heliosphere　の研究開始
1977年　Voyager　1号、2号　打ち上げ
2004年　V1　Termination Shock 通過
2007年　V2　Termination Shock 通過
2008-9年　IBEX 探査機打ち上げ, 中性粒子リボン状分布観測
2012年　V1　Heliopause 通過、星間空間に入る

The Basis: A Nuclear Heat Source

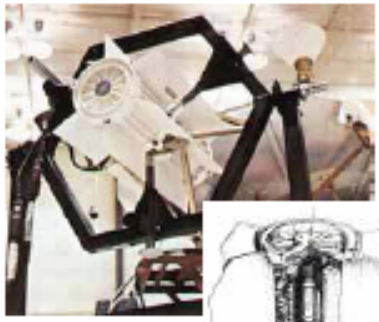


- **Heat produced from natural alpha (α) particle decay of Plutonium (Pu-238)**
  - 87.7-year half-life
- **Small portion of heat energy (6%-30%) converted to electricity via passive or dynamic processes**
  - Thermoelectric (existing & under development)
  - Stirling (under development)
  - Brayton, TPV, etc. (future candidates)
- **Waste heat rejected through radiators – portion can be used for thermal control of spacecraft subsystems**



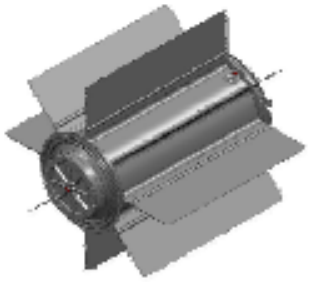
GPHS-Radioisotope Thermoelectric Generator (RTG)

Recent and Planned RPS Units

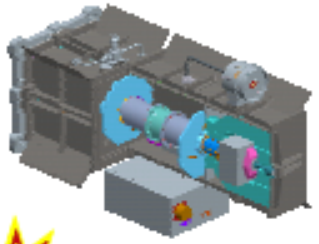


SNAP-19
- Pb-Te/TAGS thermoelectrics
- 40.3 Watts (BOM)
- 6.2 % eff; 3 We/kg

- Nimbus B-1/III
- Pioneer 10 & 11
- Viking 1 & 2



Multi-Mission RTG (MMRTG)



Advanced Stirling Radioisotope Generator (ASRG)

- *Mars Science Lab (MSL)*
- *Other missions*

1970 **1980** **1990** **2000** **2010**

Multi-Hundred Watt (MHW) RTG
- Si-Ge thermoelectrics
- 39.7 dia x 58.4 long (cm)
- 158 We (BOM)
- 6.6 % eff; 4.2 We/kg

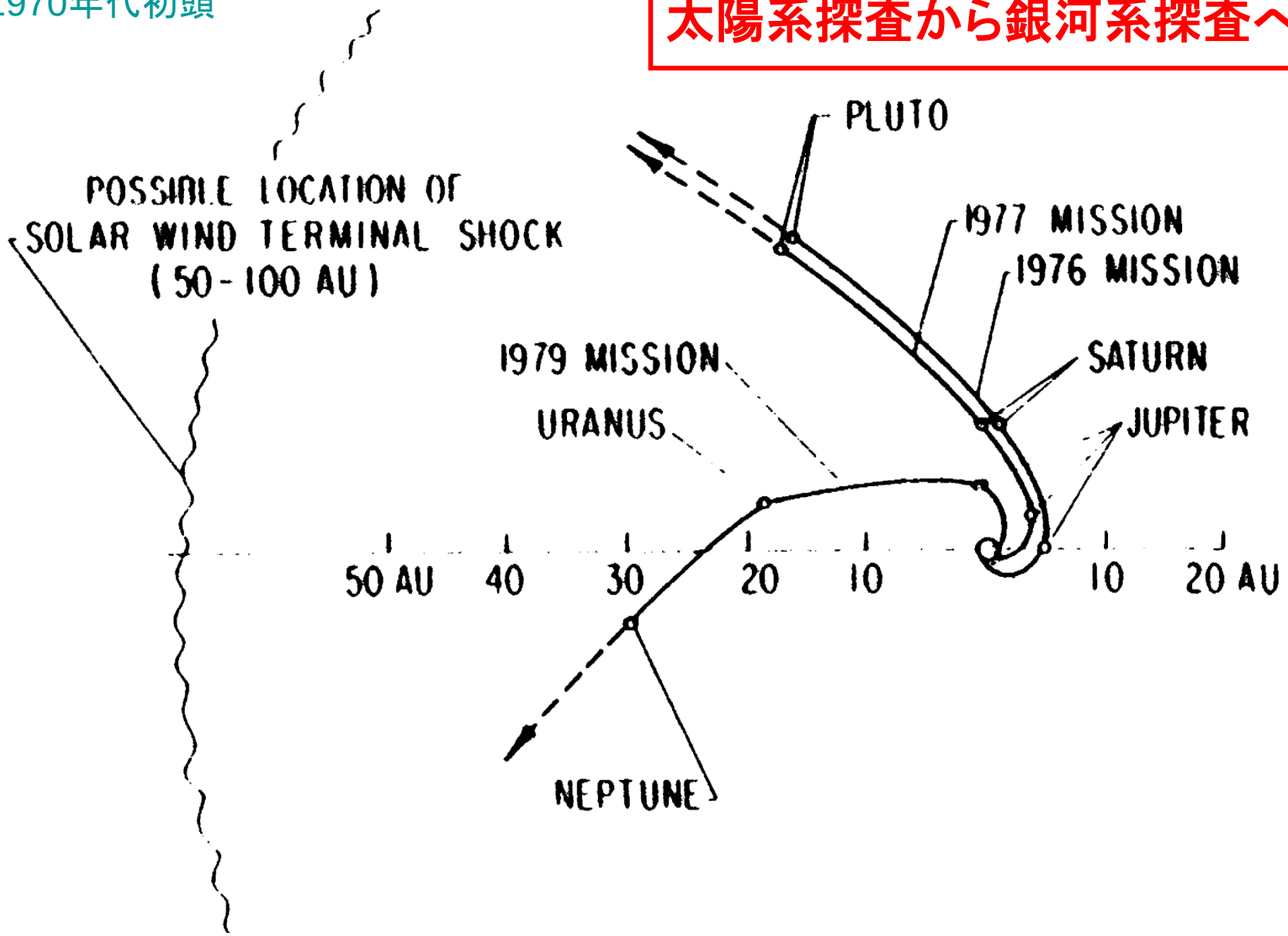
- LES 8 & 9
- Voyager 1 & 2

GPHS RTG
- Si-Ge thermoelectrics
- 42.7 dia x 44.9 long (cm)
- 292 We (BOM)
- 6.8% eff; 5.2 We/kg

- Galileo
- Ulysses
- Cassini
- New Horizons

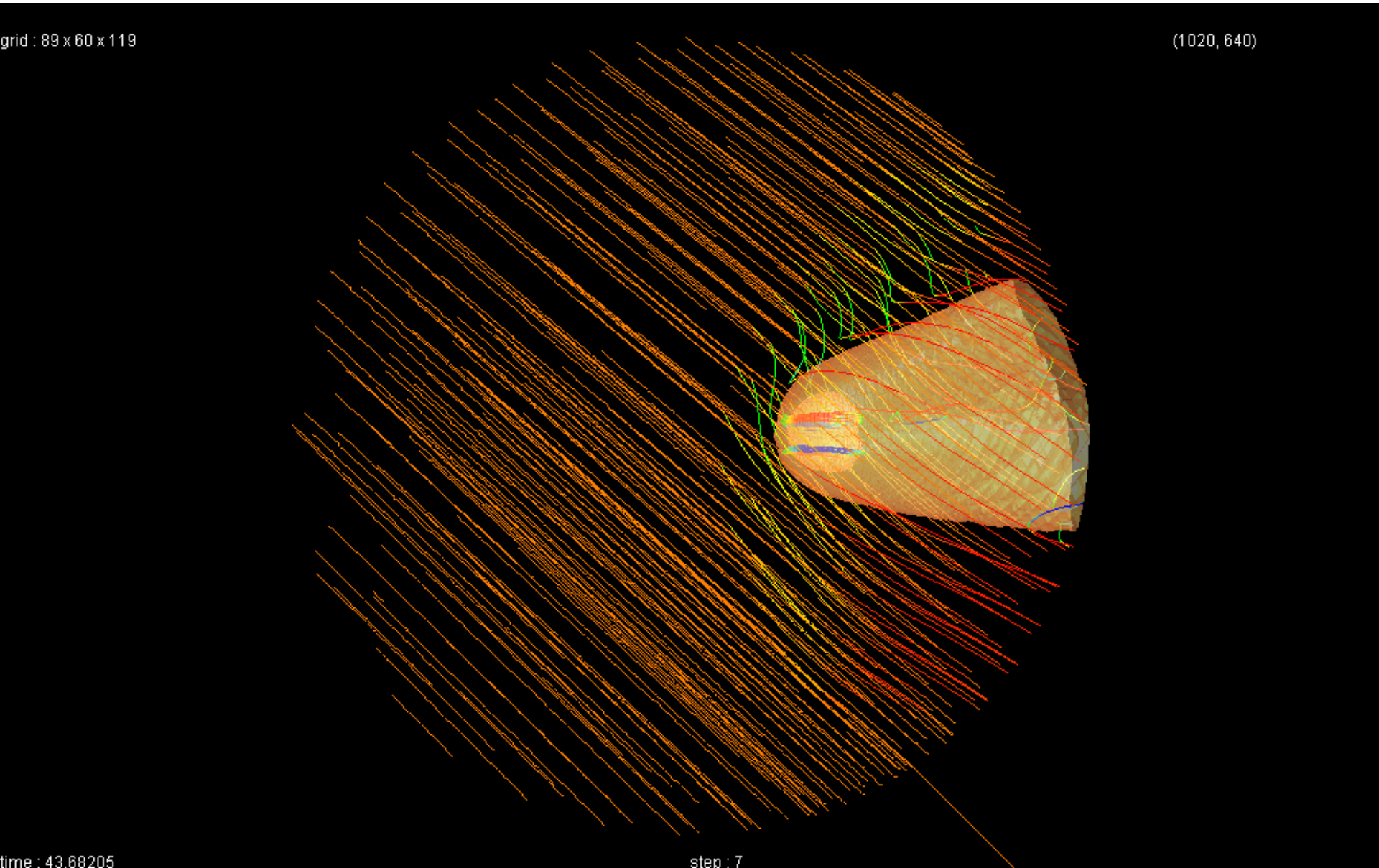
1970年代初頭

太陽系探査から銀河系探査へ！



“Grand Tour” missions to the outer region of solar system.
These missions were launched in 1977 and named “Voyager 1/2”

North-South asymmetric structure of the Heliosphere

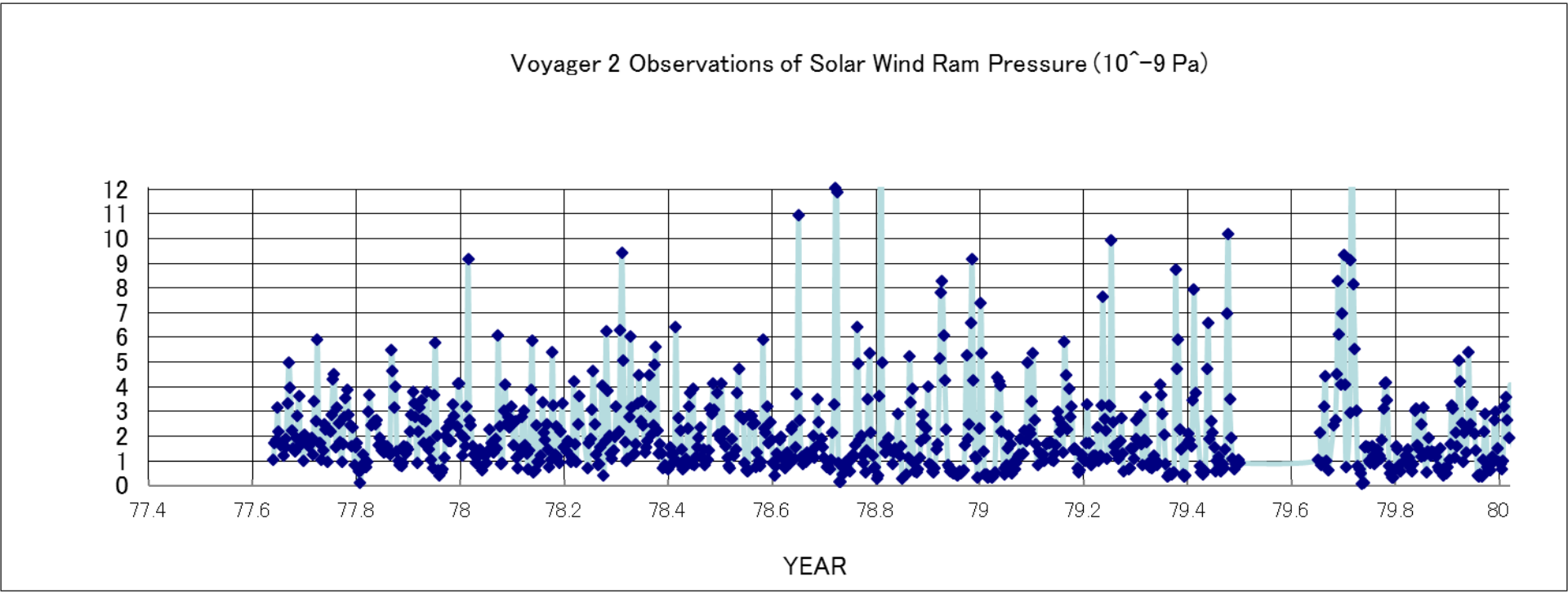


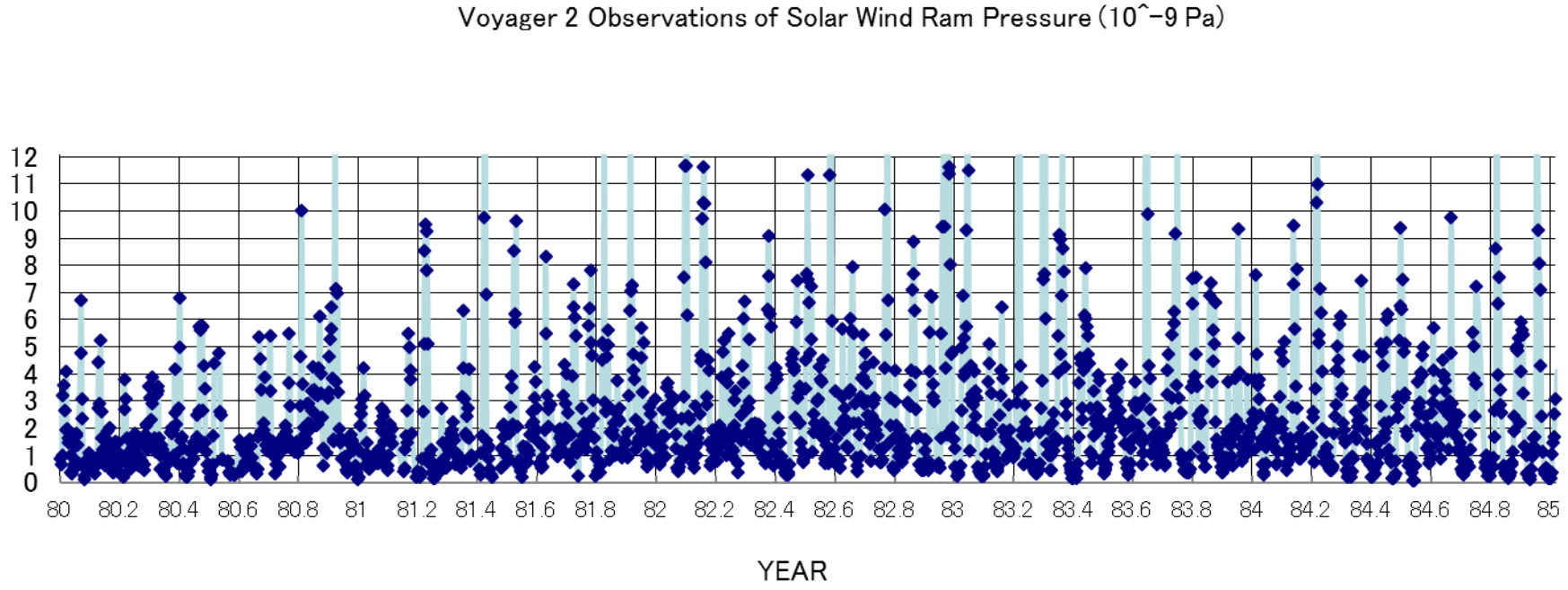
1977年　Voyager　1号、2号　打ち上げ

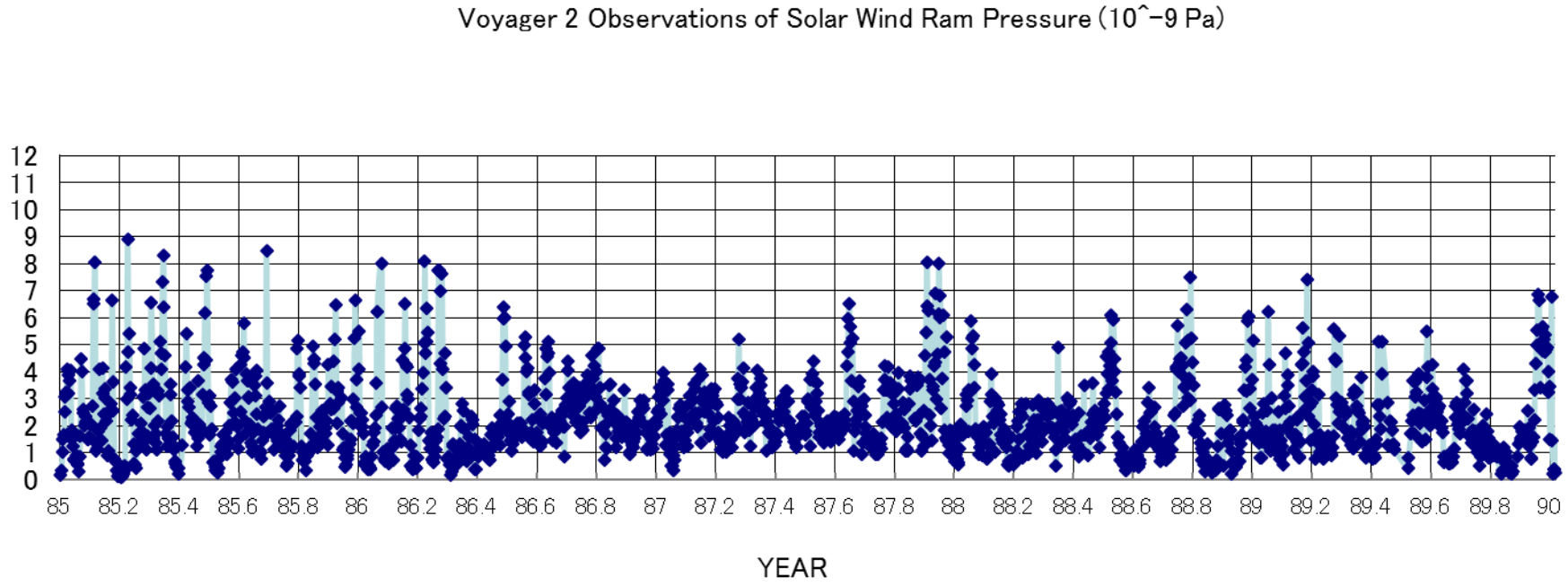
2004年　V1　Termination Shock 通過

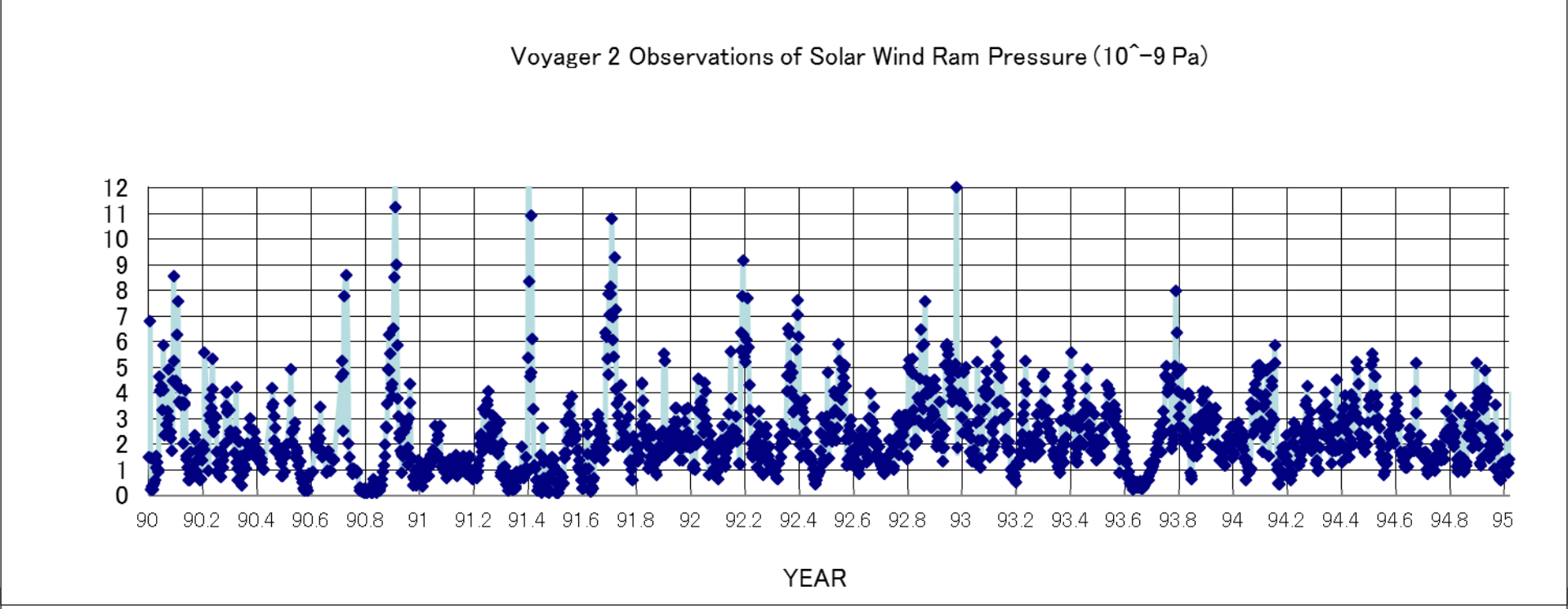
2007年　V2　Termination Shock 通過

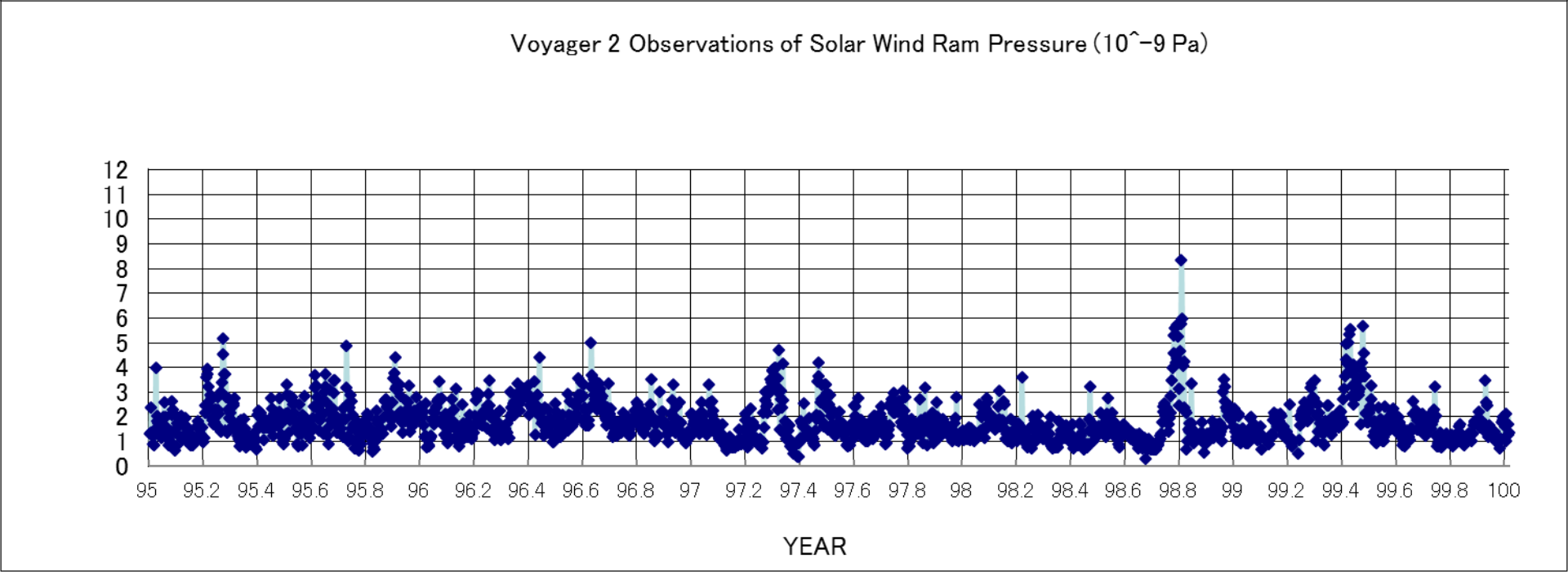
2012年　V1　Heliopause 通過、星間空間に入る

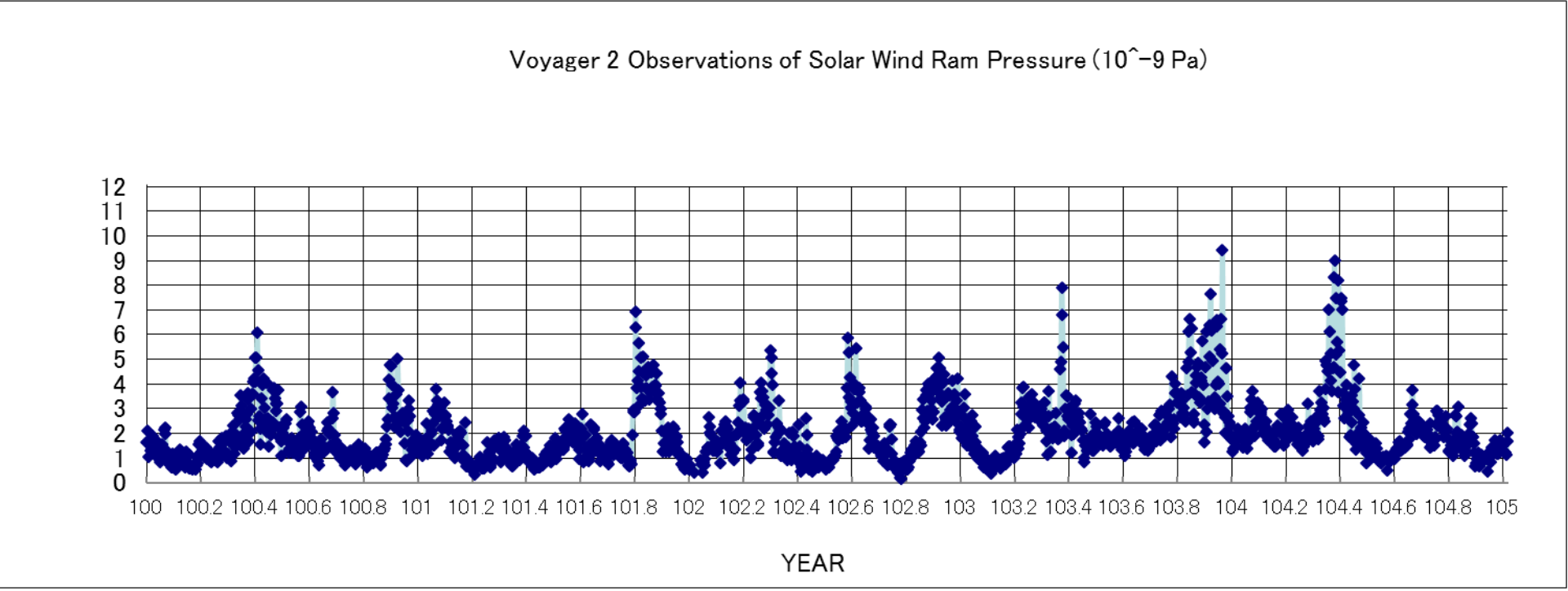

Voyager 2 Observations of Solar Wind Ram Pressure (10^-9 Pa)
12
11
10
9
8
7
6
5
4
3
2
1
0
77.4
77.6
77.8
78
78.2
78.4
78.6
78.8
79
79.2
79.4
79.6
79.8
80
YEAR

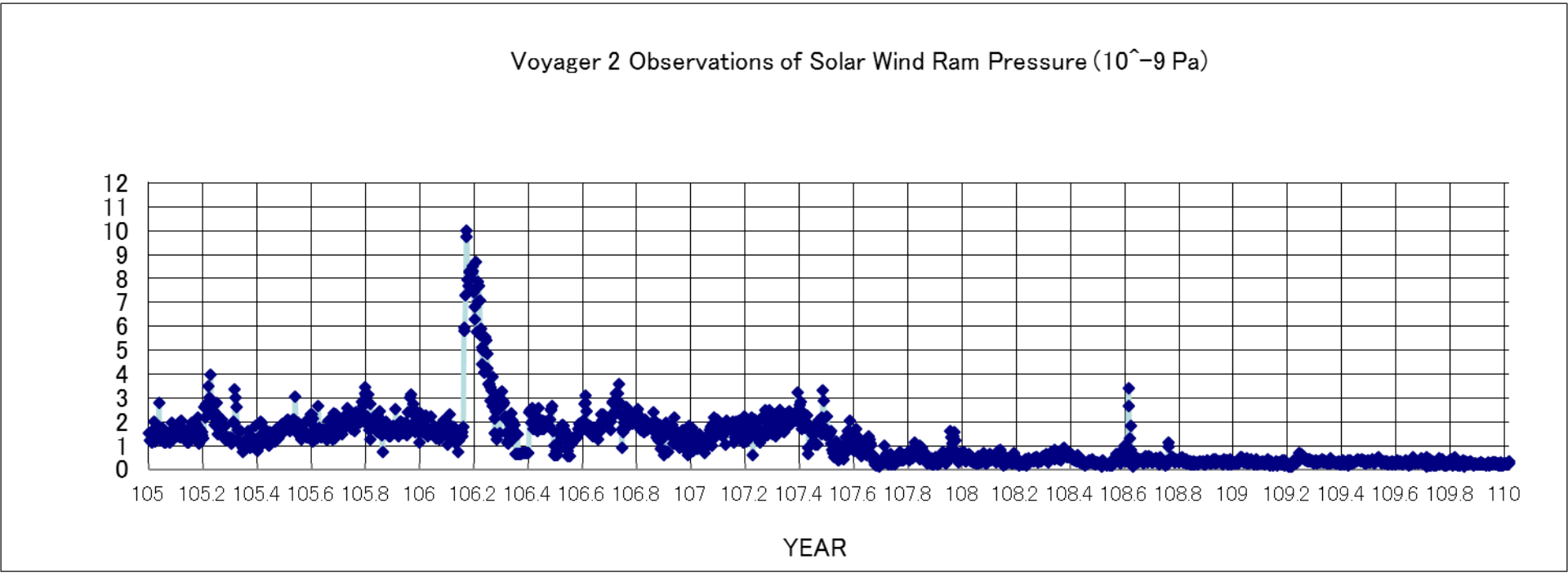

Voyager 2 Observations of Solar Wind Ram Pressure (10^-9 Pa)
12
11
10
9
8
7
6
5
4
3
2
1
0
80 80.2 80.4 80.6 80.8 81 81.2 81.4 81.6 81.8 82 82.2 82.4 82.6 82.8 83 83.2 83.4 83.6 83.8 84 84.2 84.4 84.6 84.8 85
YEAR

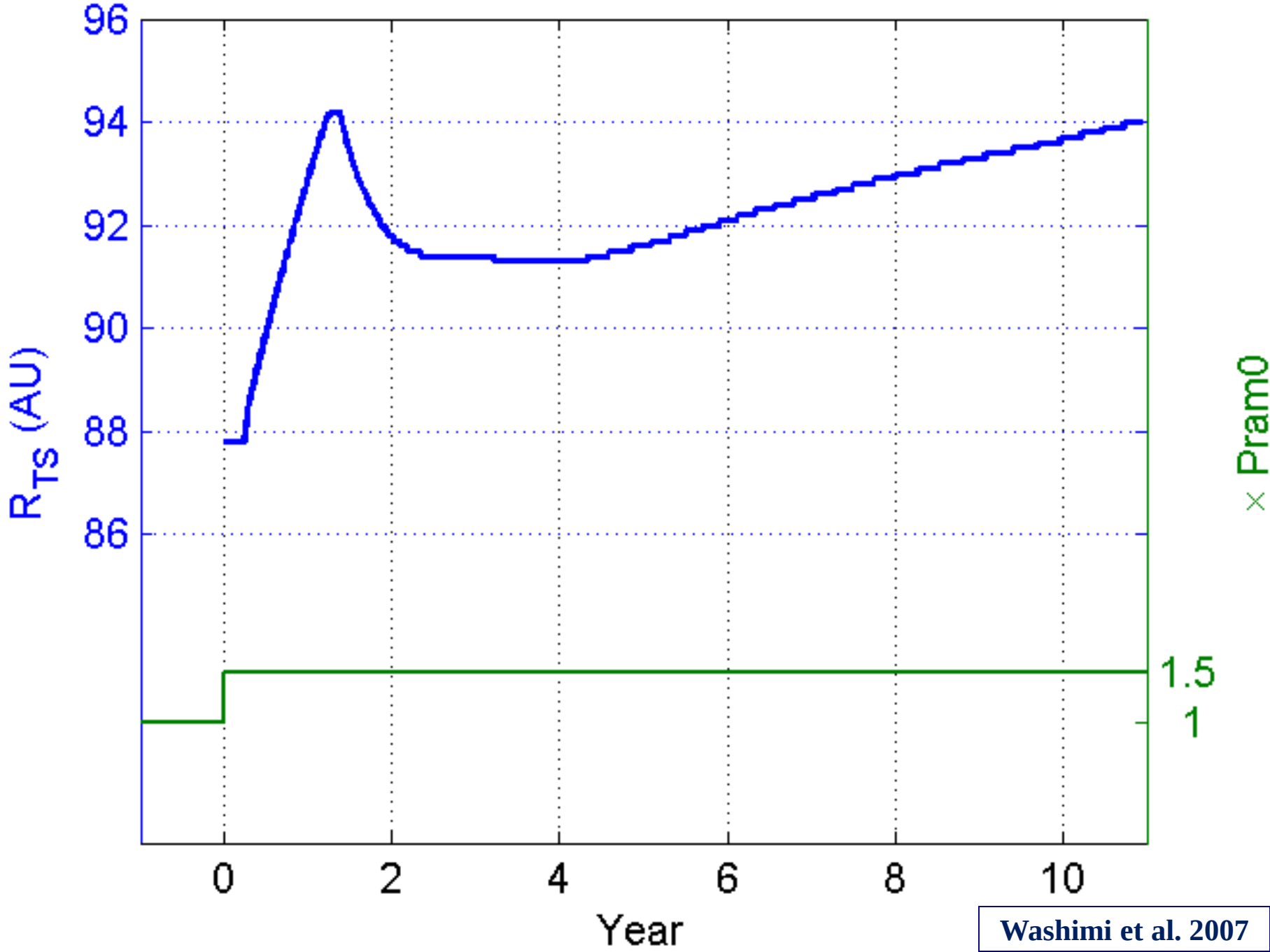

Voyager 2 Observations of Solar Wind Ram Pressure (10^-9 Pa)
12
11
10
9
8
7
6
5
4
3
2
1
0
85 85.2 85.4 85.6 85.8 86 86.2 86.4 86.6 86.8 87 87.2 87.4 87.6 87.8 88 88.2 88.4 88.6 88.8 89 89.2 89.4 89.6 89.8 90
YEAR


Voyager 2 Observations of Solar Wind Ram Pressure (10^-9 Pa)
12
11
10
9
8
7
6
5
4
3
2
1
0
90 90.2 90.4 90.6 90.8 91 91.2 91.4 91.6 91.8 92 92.2 92.4 92.6 92.8 93 93.2 93.4 93.6 93.8 94 94.2 94.4 94.6 94.8 95
YEAR

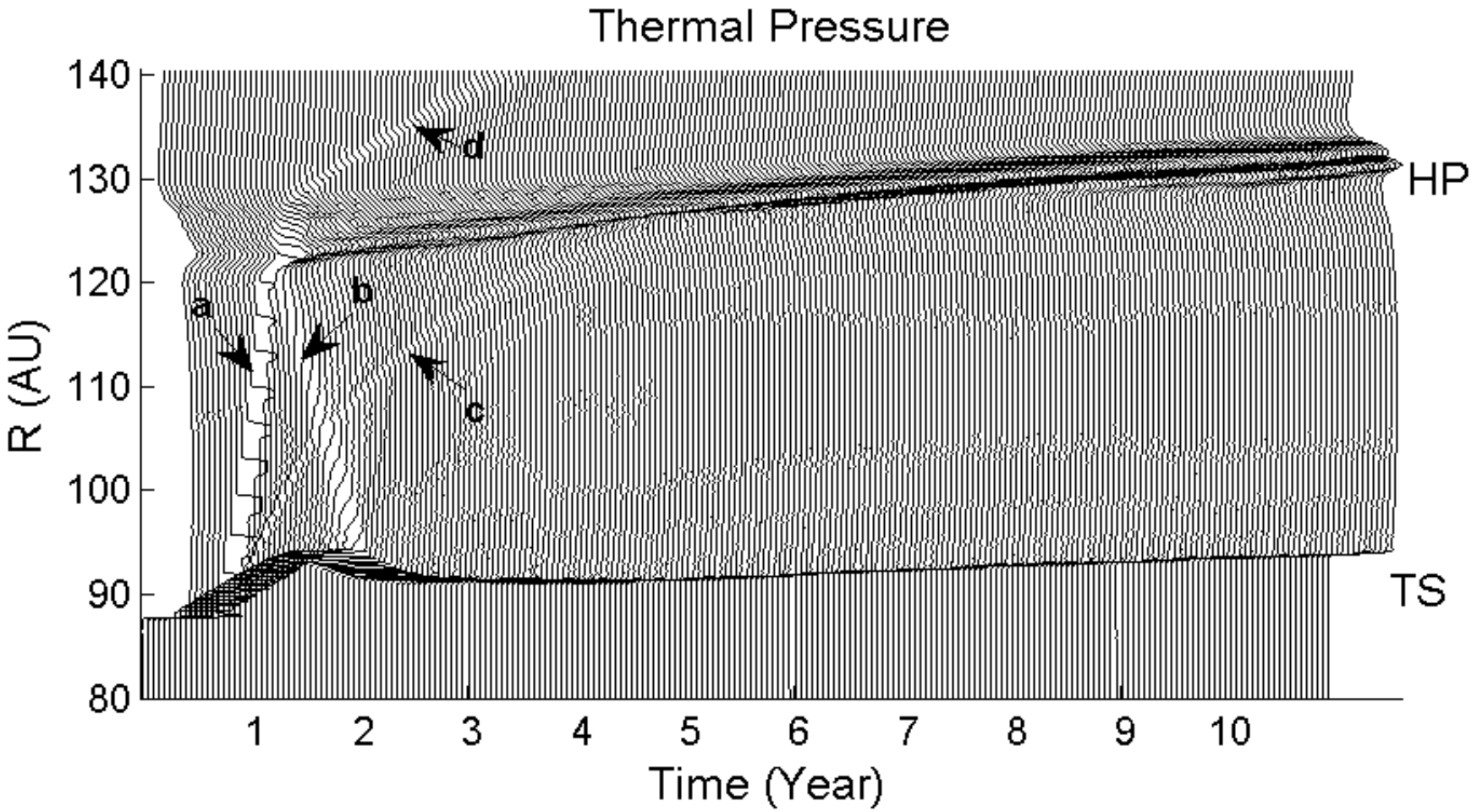

Voyager 2 Observations of Solar Wind Ram Pressure (10^-9 Pa)
12
11
10
9
8
7
6
5
4
3
2
1
0
95 95.2 95.4 95.6 95.8 96 96.2 96.4 96.6 96.8 97 97.2 97.4 97.6 97.8 98 98.2 98.4 98.6 98.8 99 99.2 99.4 99.6 99.8 100
YEAR


Voyager 2 Observations of Solar Wind Ram Pressure (10^-9 Pa)
12
11
10
9
8
7
6
5
4
3
2
1
0
100 100.2 100.4 100.6 100.8 101 101.2 101.4 101.6 101.8 102 102.2 102.4 102.6 102.8 103 103.2 103.4 103.6 103.8 104 104.2 104.4 104.6 104.8 105
YEAR


Voyager 2 Observations of Solar Wind Ram Pressure (10^-9 Pa)
12
11
10
9
8
7
6
5
4
3
2
1
0
105 105.2 105.4 105.6 105.8 106 106.2 106.4 106.6 106.8 107 107.2 107.4 107.6 107.8 108 108.2 108.4 108.6 108.8 109 109.2 109.4 109.6 109.8 110
YEAR

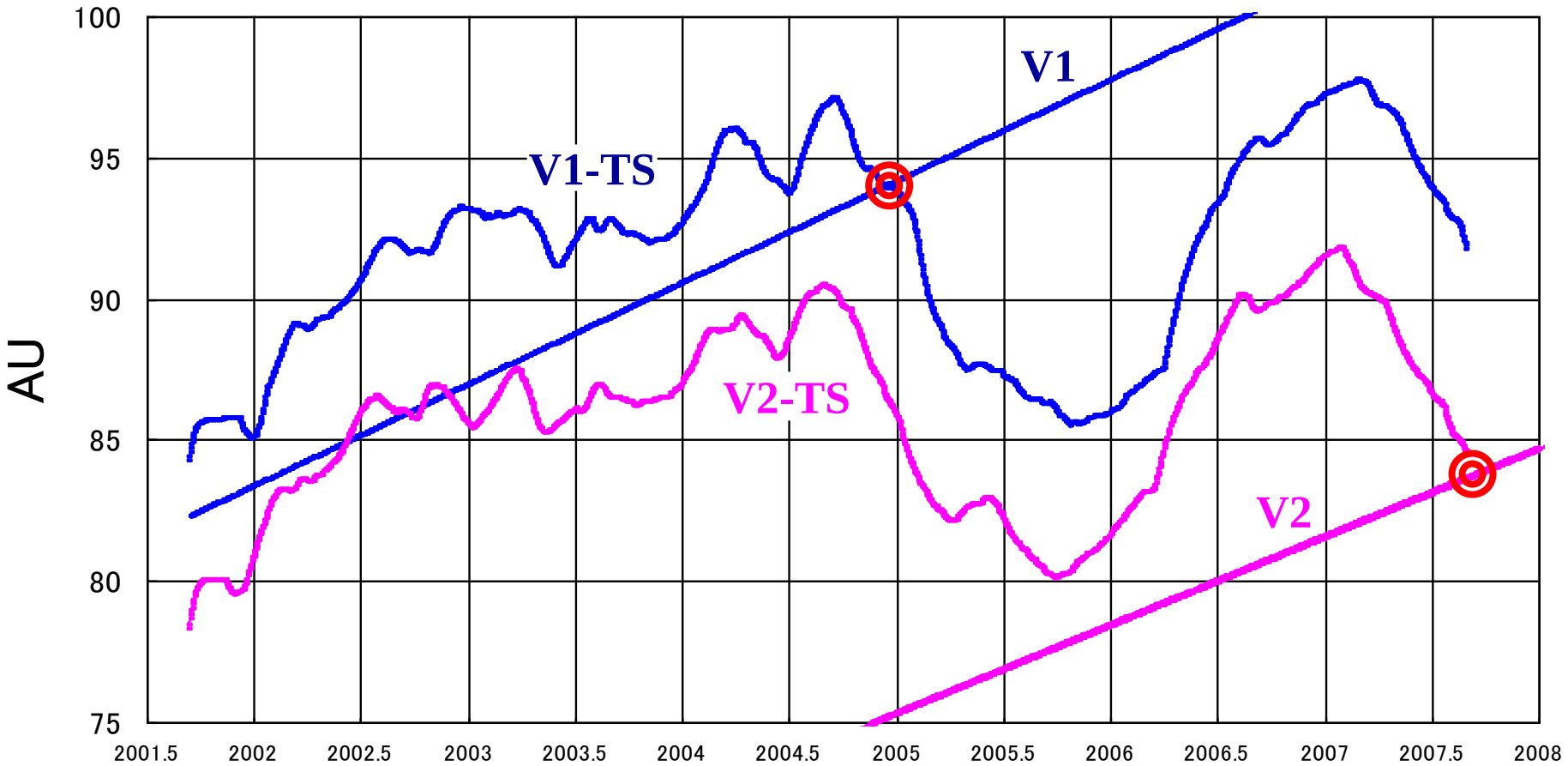


Washimi et al. 2007

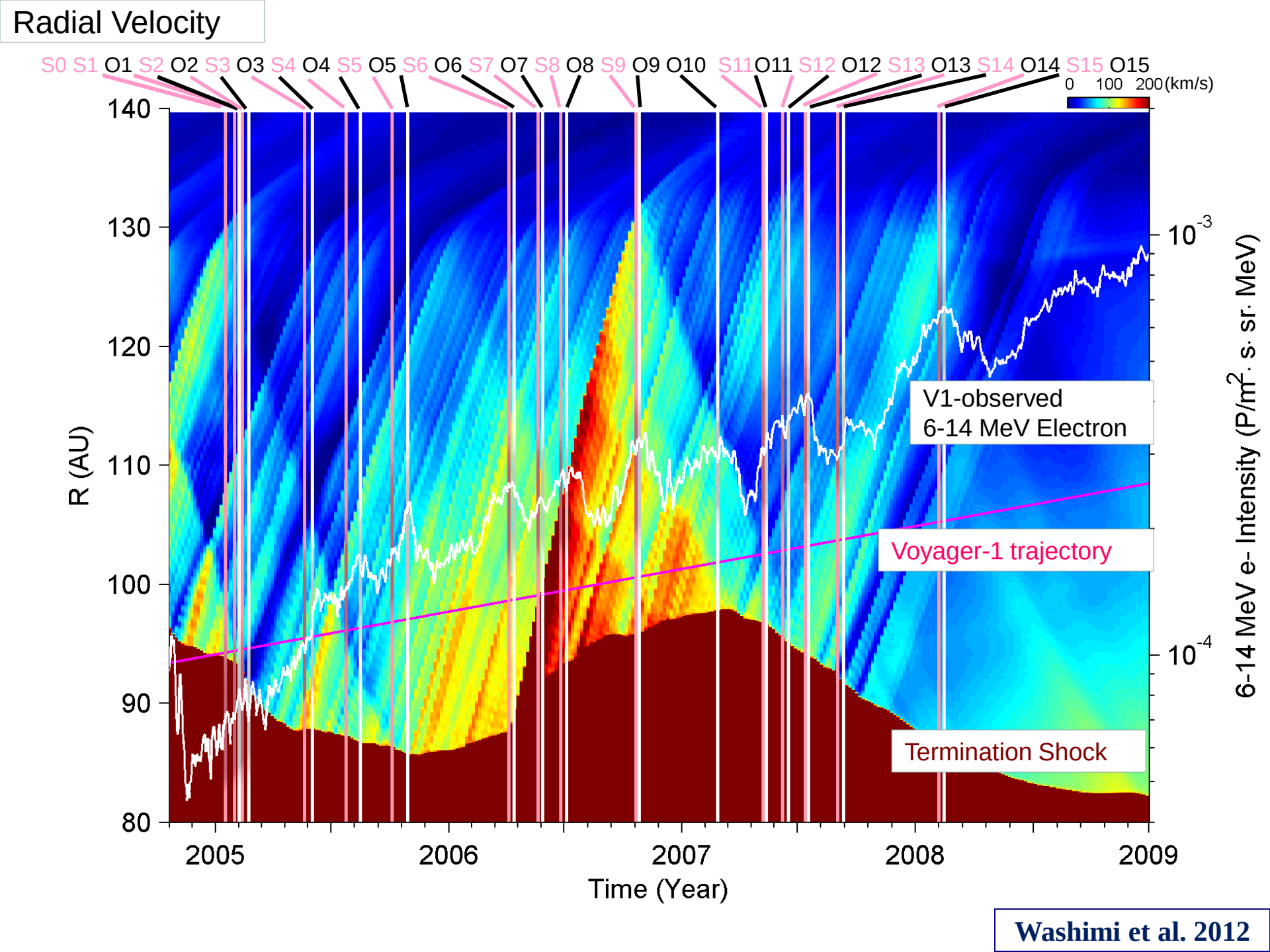


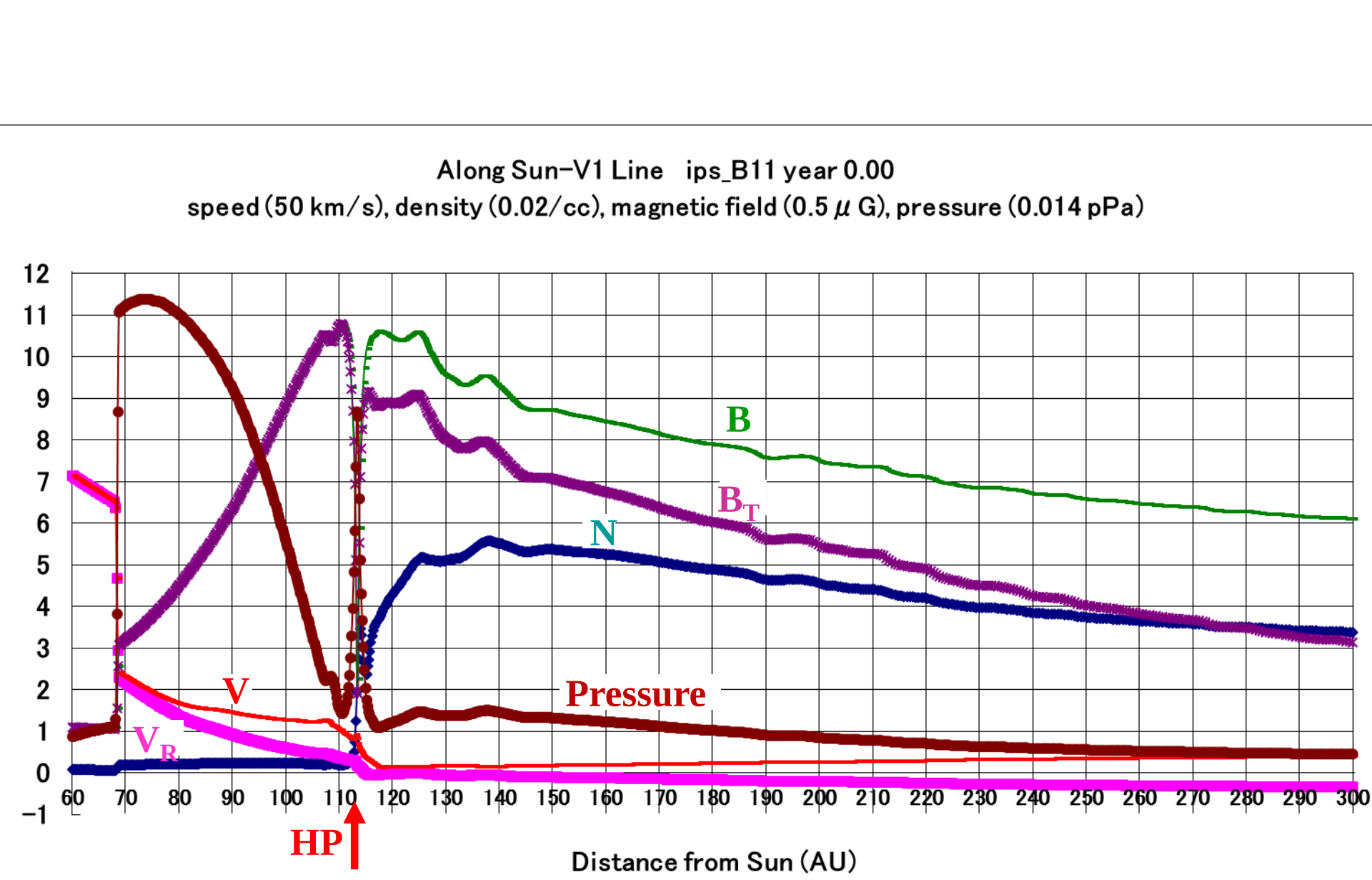
Washimi et al. 2007

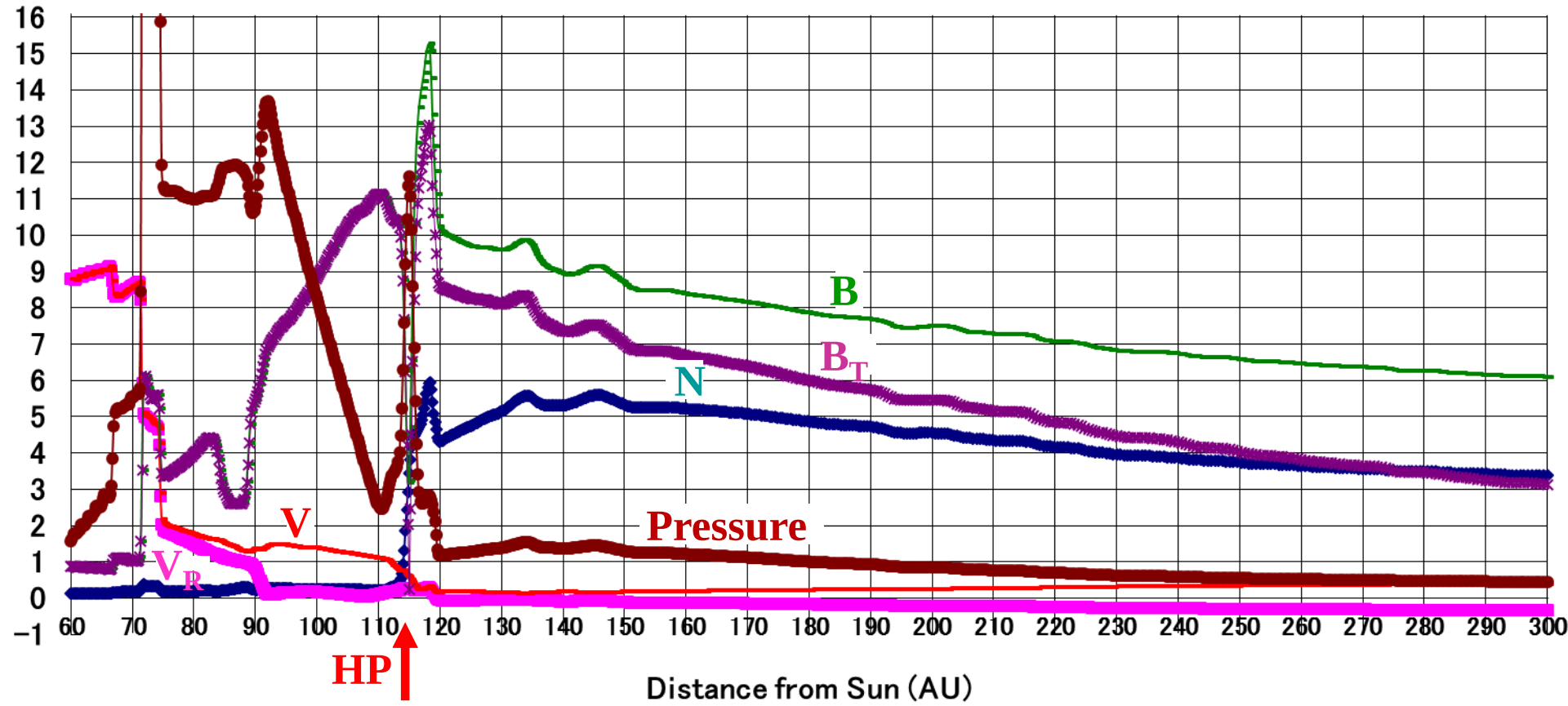
TS Positions along Sun–V1 and Sun–V2 Lines

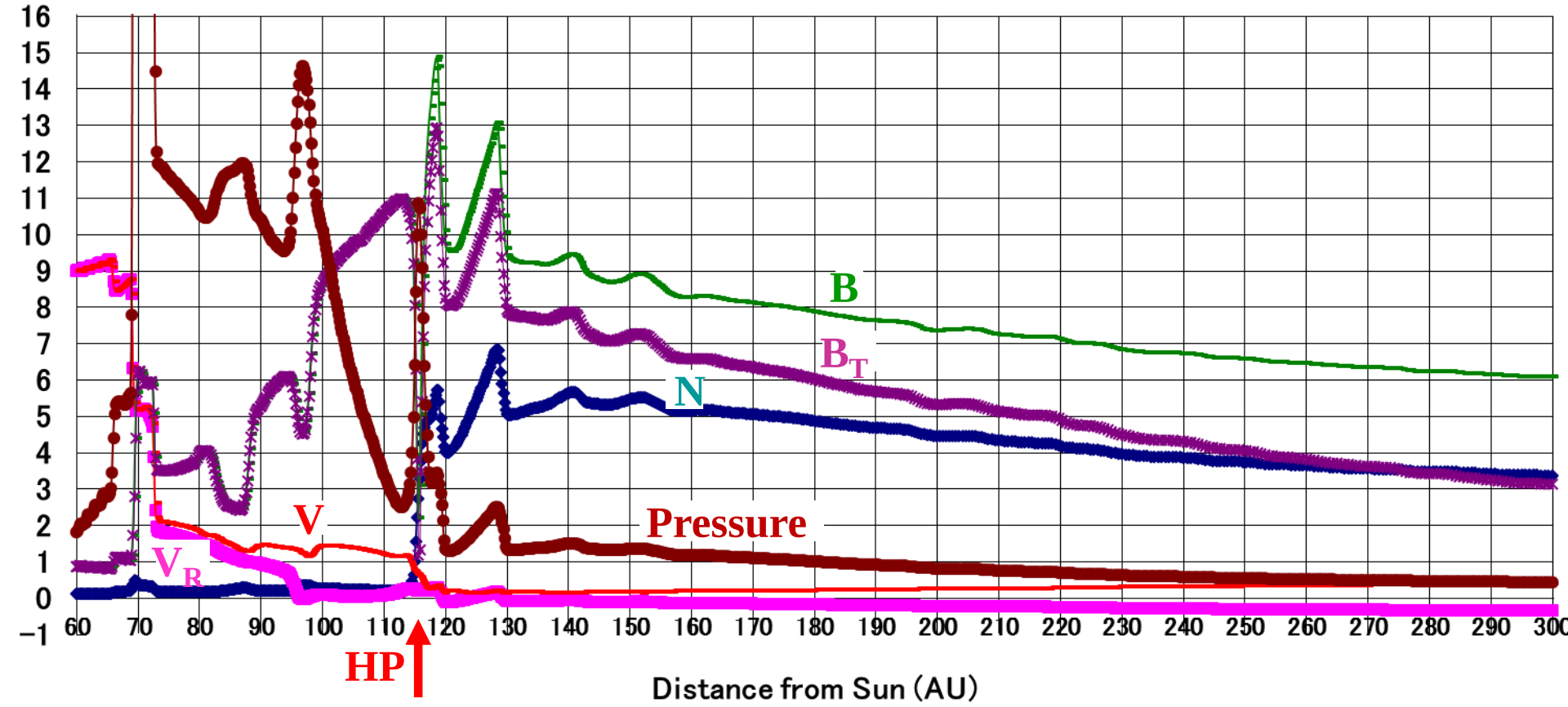


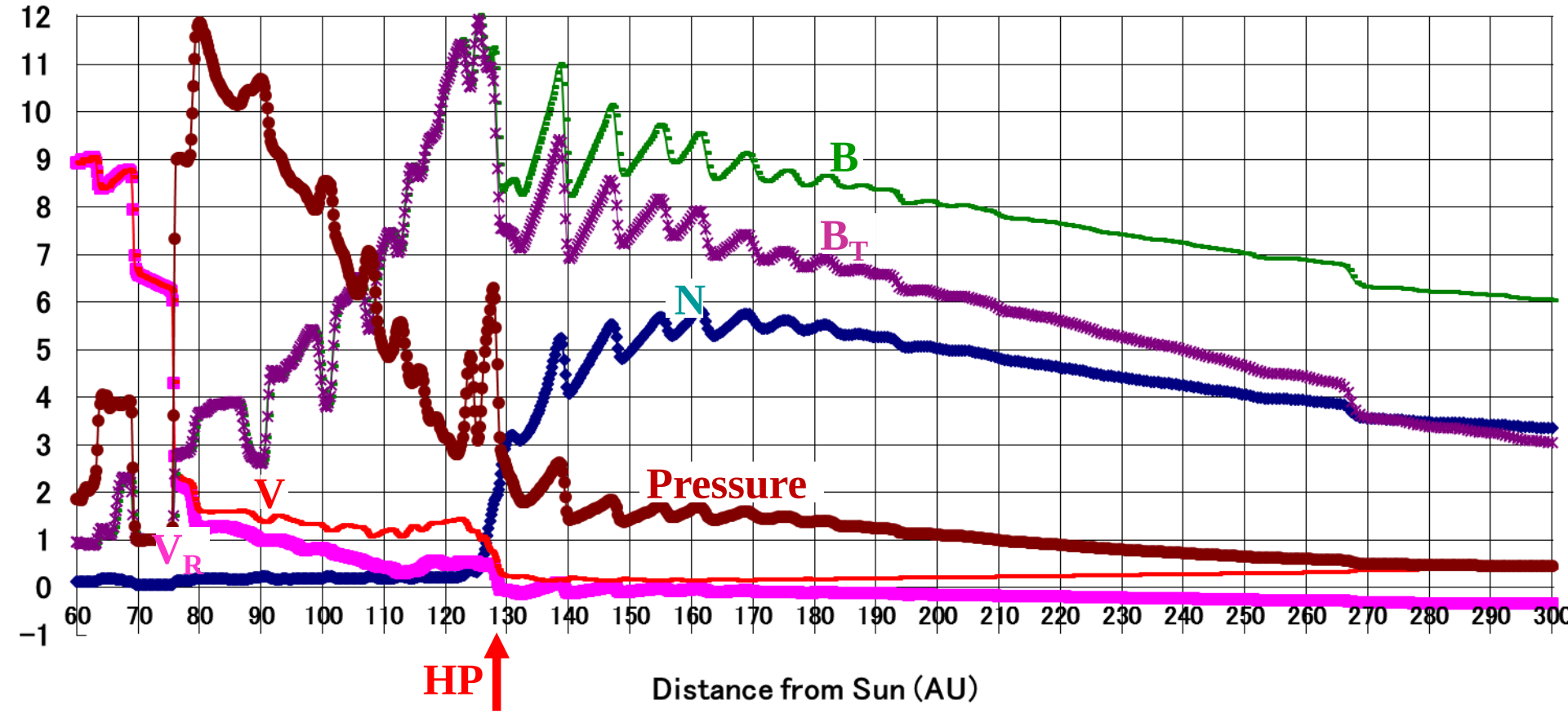
Washimi et al. 2012

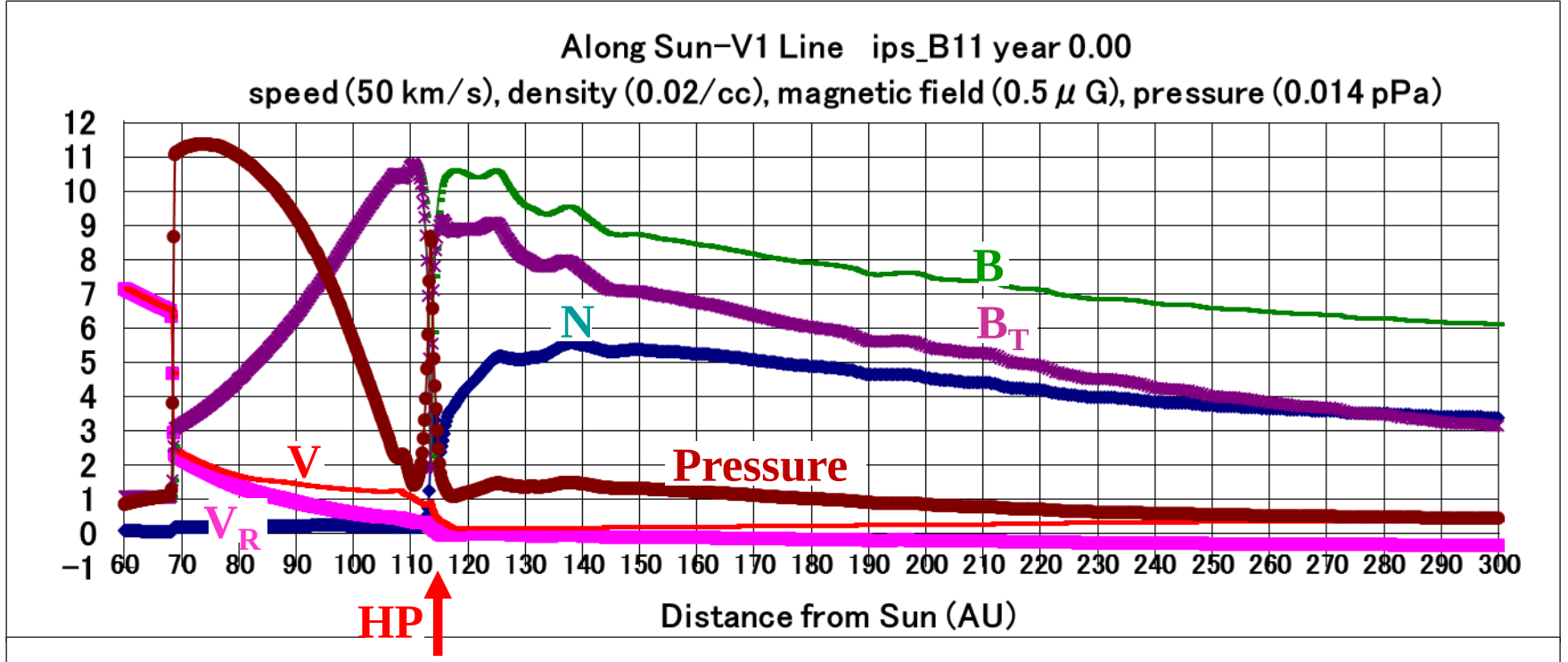

Radial Velocity
S0 S1 O1 S2 O2 S3 O3 S4 O4 S5 O5 S6 O6 S7 O7 S8 O8 S9 O9 O10 S11 O11 S12 O12 S13 O13 S14 O14 S15 O15
0 100 200 (km/s)
140
130
120
110
100
90
80
R (AU)
2005
2006
2007
2008
2009
Time (Year)
10^{-3}
10^{-4}
6-14 MeV e- Intensity (P/m^2· s· sr· MeV)
V1-observed
6-14 MeV Electron
Voyager-1 trajectory
Termination Shock
Washimi et al. 2012

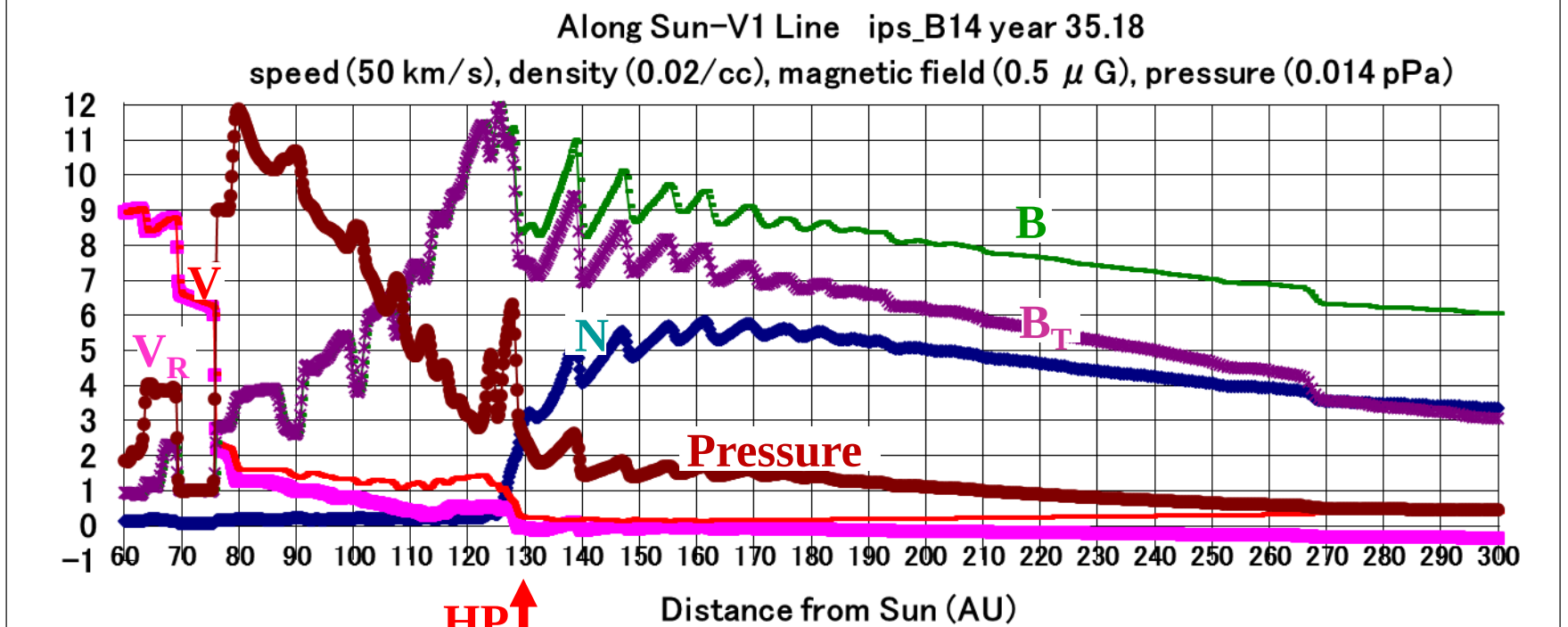

Along Sun−V1 Line ips_B11 year 0.00
speed (50 km/s), density (0.02/cc), magnetic field (0.5 μ G), pressure (0.014 pPa)
12
11
10
9
8
7
6
5
4
3
2
1
0
−1
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
B
B_T
N
V
V_R
Pressure
HP
Distance from Sun (AU)

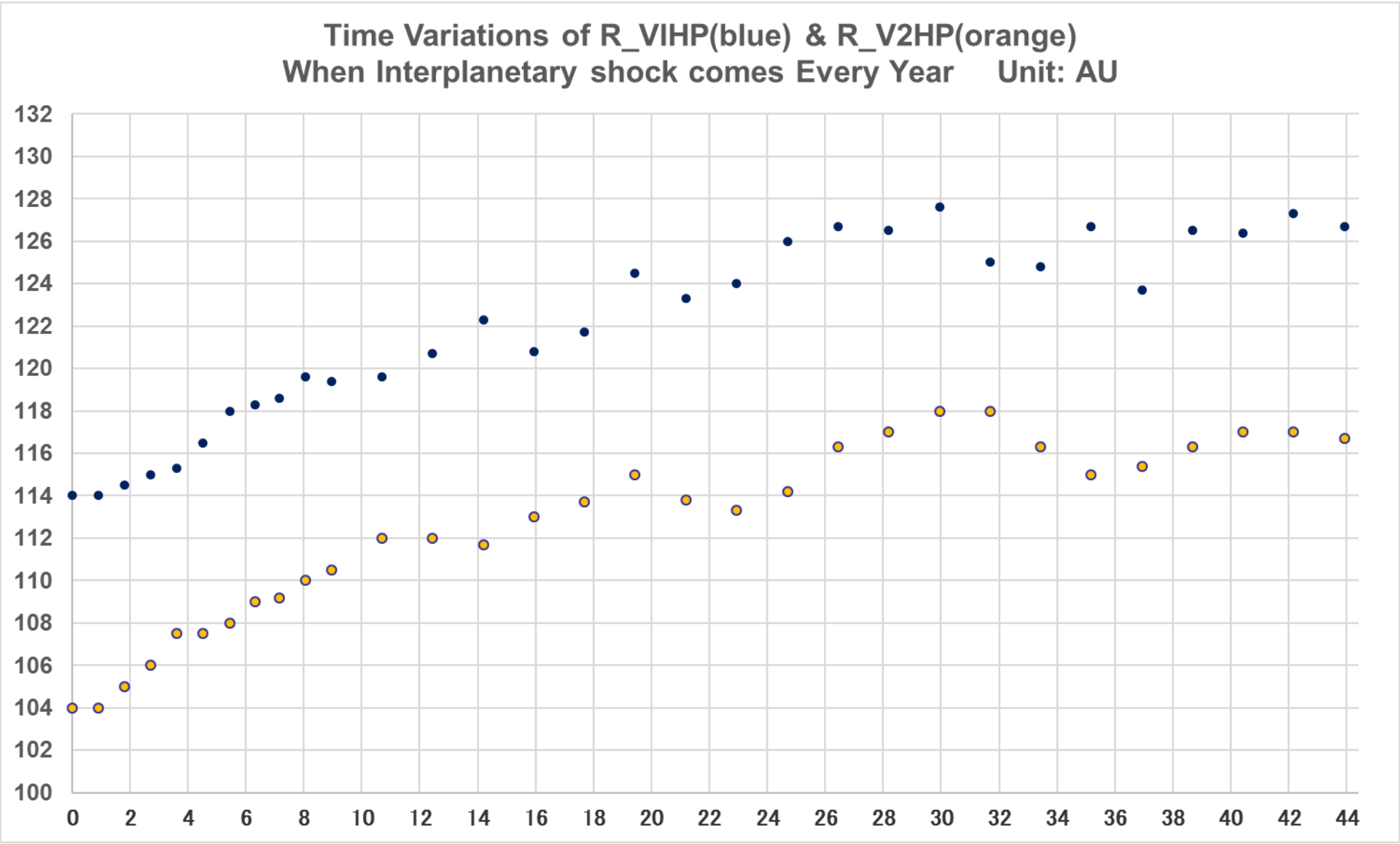

Along Sun−V1 Line C10 year 1.22
speed (50 km/s), density (0.02/cc), magnetic field (0.5 μ G), pressure (0.014 pPa)
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
−1
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
B
B_T
N
V
Pressure
V_R
HP
Distance from Sun (AU)

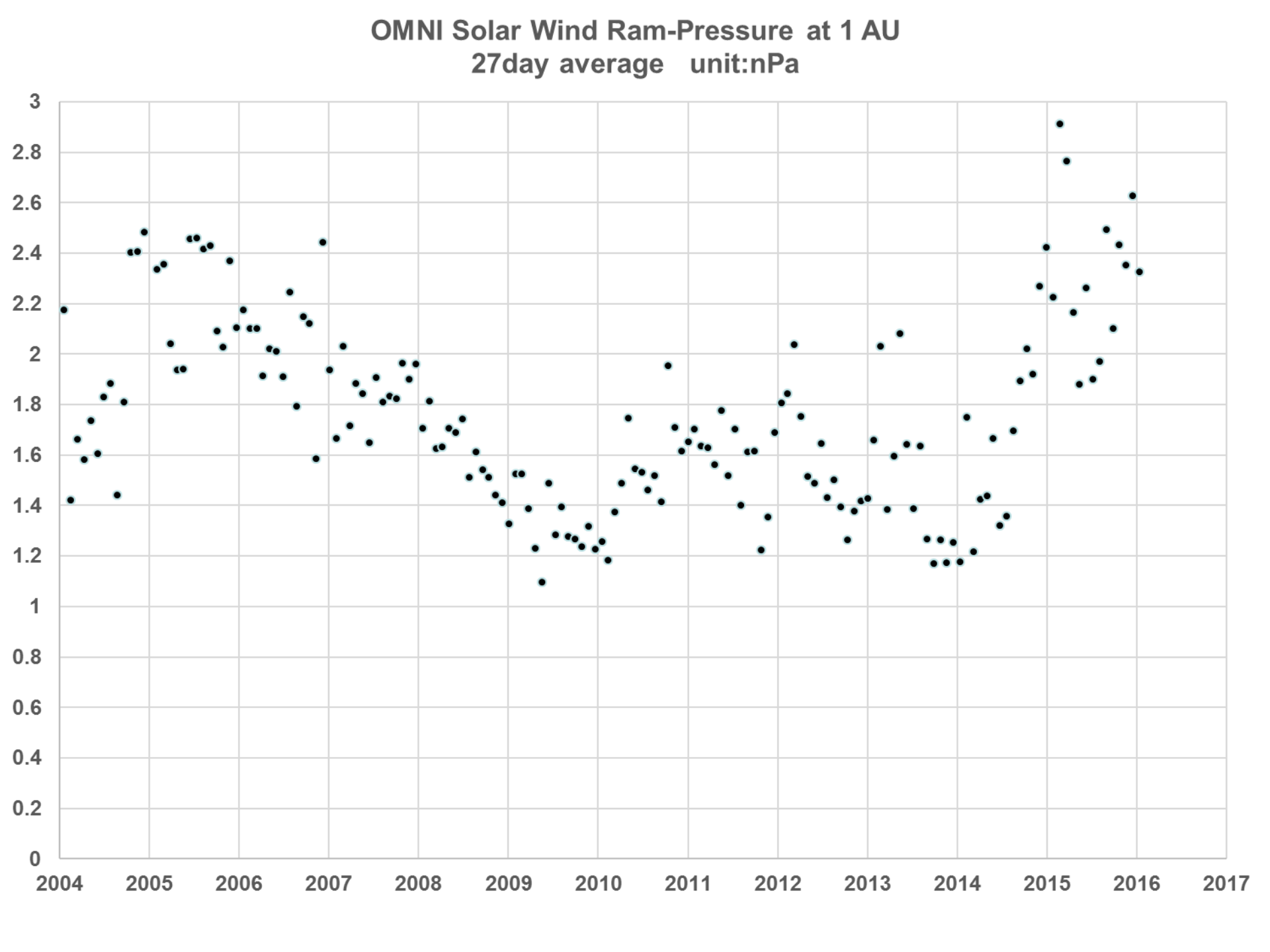

Along Sun–V1 Line ips_C11 year 2.21
speed (50 km/s), density (0.02/cc), magnetic field (0.5 μ G), pressure (0.014 pPa)
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
−1
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
B
B_T
N
V
Pressure
V_R
HP
Distance from Sun (AU)

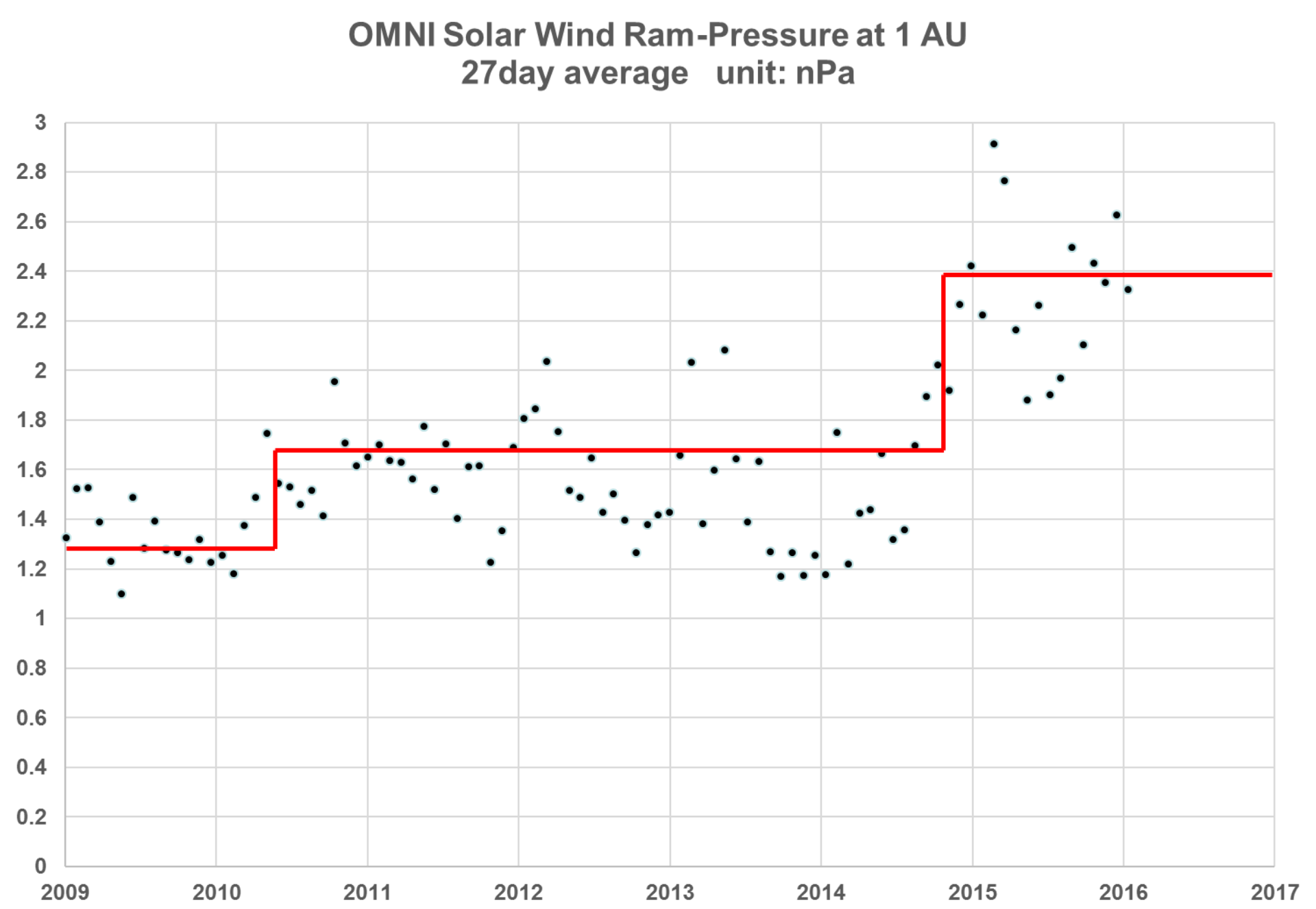

Along Sun−V1 Line ips_B14 year 35.18
speed (50 km/s), density (0.02/cc), magnetic field (0.5 μ G), pressure (0.014 pPa)
12
11
10
9
8
7
6
5
4
3
2
1
0
−1
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
B
B_T
N
Pressure
V
V_R
HP
Distance from Sun (AU)

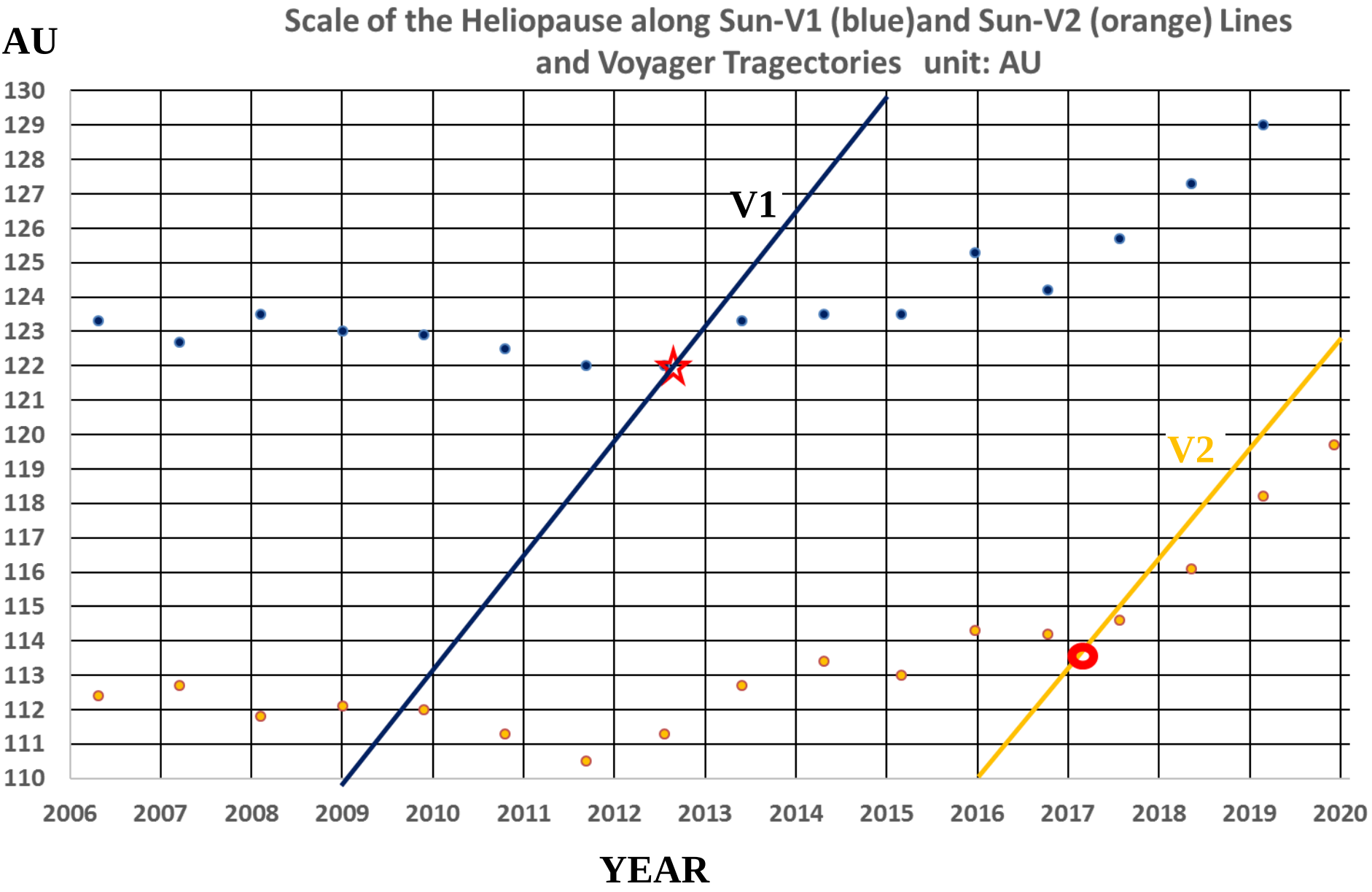

Along Sun-V1 Line ips_B11 year 0.00
speed (50 km/s), density (0.02/cc), magnetic field (0.5 μ G), pressure (0.014 pPa)
B
N
B_T
V
Pressure
V_R
HP
Distance from Sun (AU)

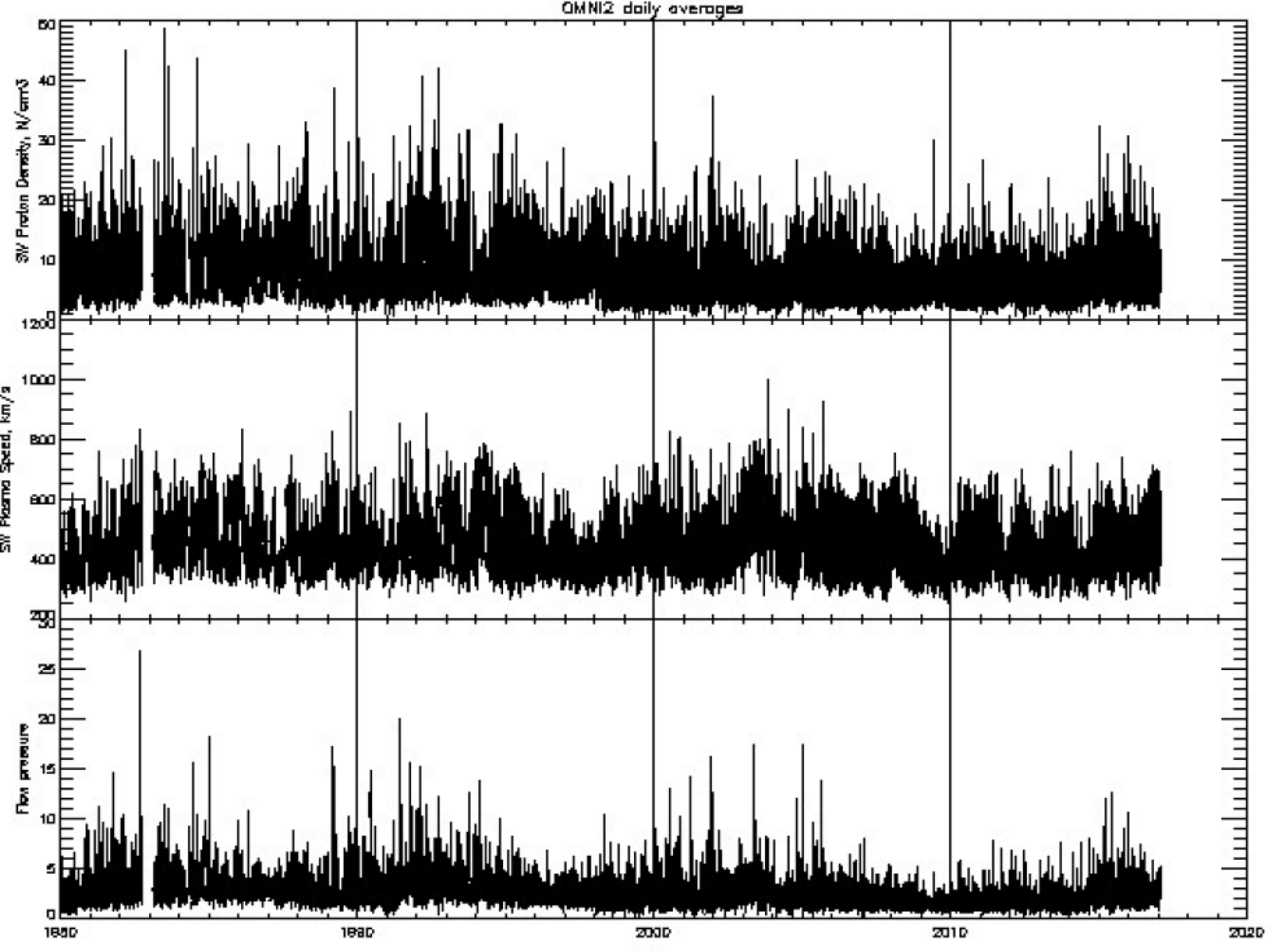

Along Sun-V1 Line ips_B14 year 35.18
speed (50 km/s), density (0.02/cc), magnetic field (0.5 μ G), pressure (0.014 pPa)
B
V
V_R
N
B_T
Pressure
HP
Distance from Sun (AU)

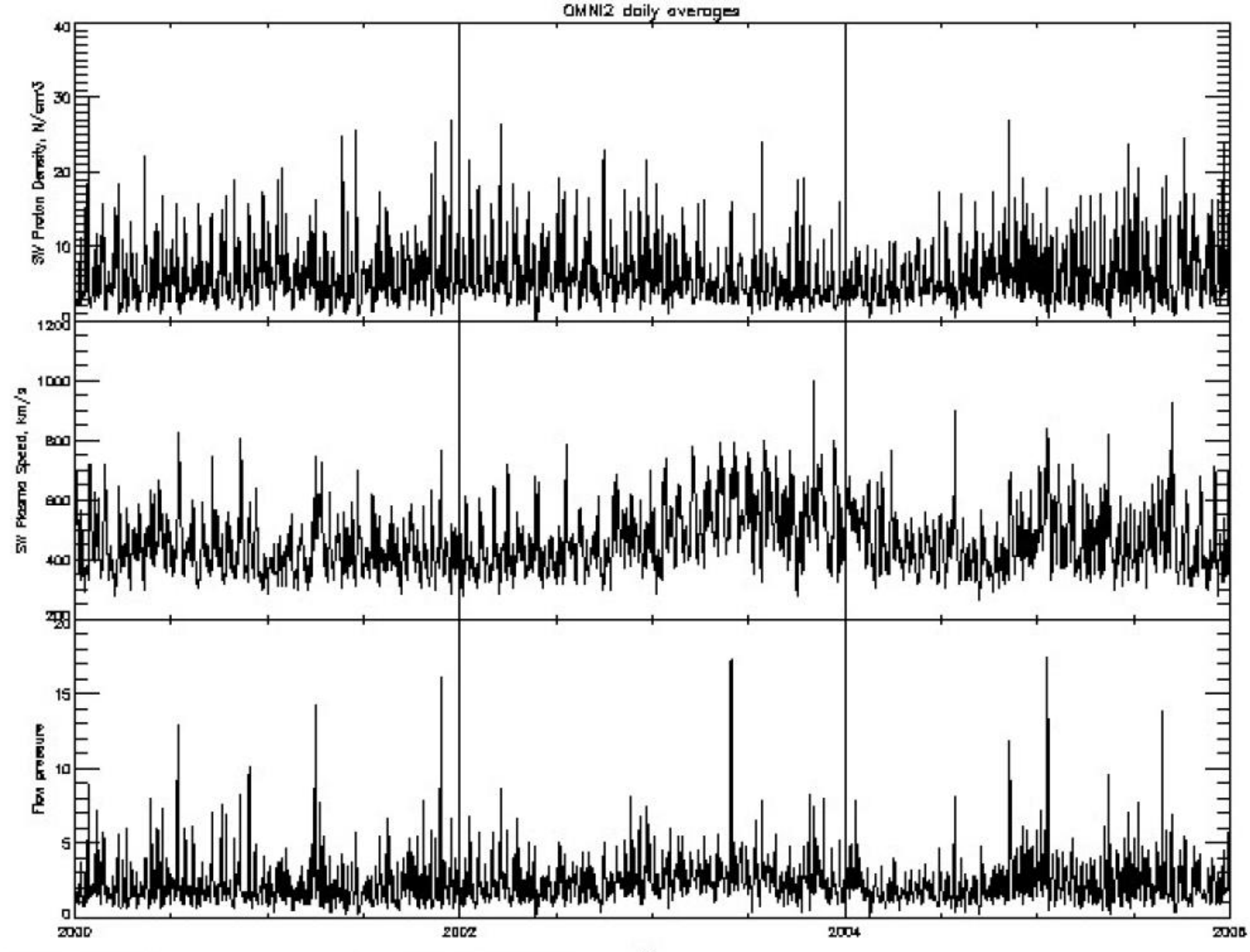

Time Variations of R_VIHP(blue) & R_V2HP(orange)
When Interplanetary shock comes Every Year Unit: AU
132
130
128
126
124
122
120
118
116
114
112
110
108
106
104
102
100
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44


OMNI Solar Wind Ram-Pressure at 1 AU
27day average unit:nPa
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017


OMNI Solar Wind Ram-Pressure at 1 AU
27day average unit: nPa
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2009
2010
2011
2012
2013
2014
2015
2016
2017


Scale of the Heliopause along Sun-V1 (blue)and Sun-V2 (orange) Lines
and Voyager Tragectories unit: AU
AU
130
129
128
127
126
125
124
123
122
121
120
119
118
117
116
115
114
113
112
111
110
V1
V2
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
YEAR


OMNI2 daily averages
SW Proton Density, N/cm^3
SW Plasma Speed, km/s
Flow pressure
1990
2000
2010
2020


OMNI2 daily averages
SW Proton Density, N/cm^3
SW Plasma Speed, km/s
Flow pressure
2000
2002
2004
2006