Lexington Computer/Technology Group

Voyager Spacecraft Update
Lessons Learned

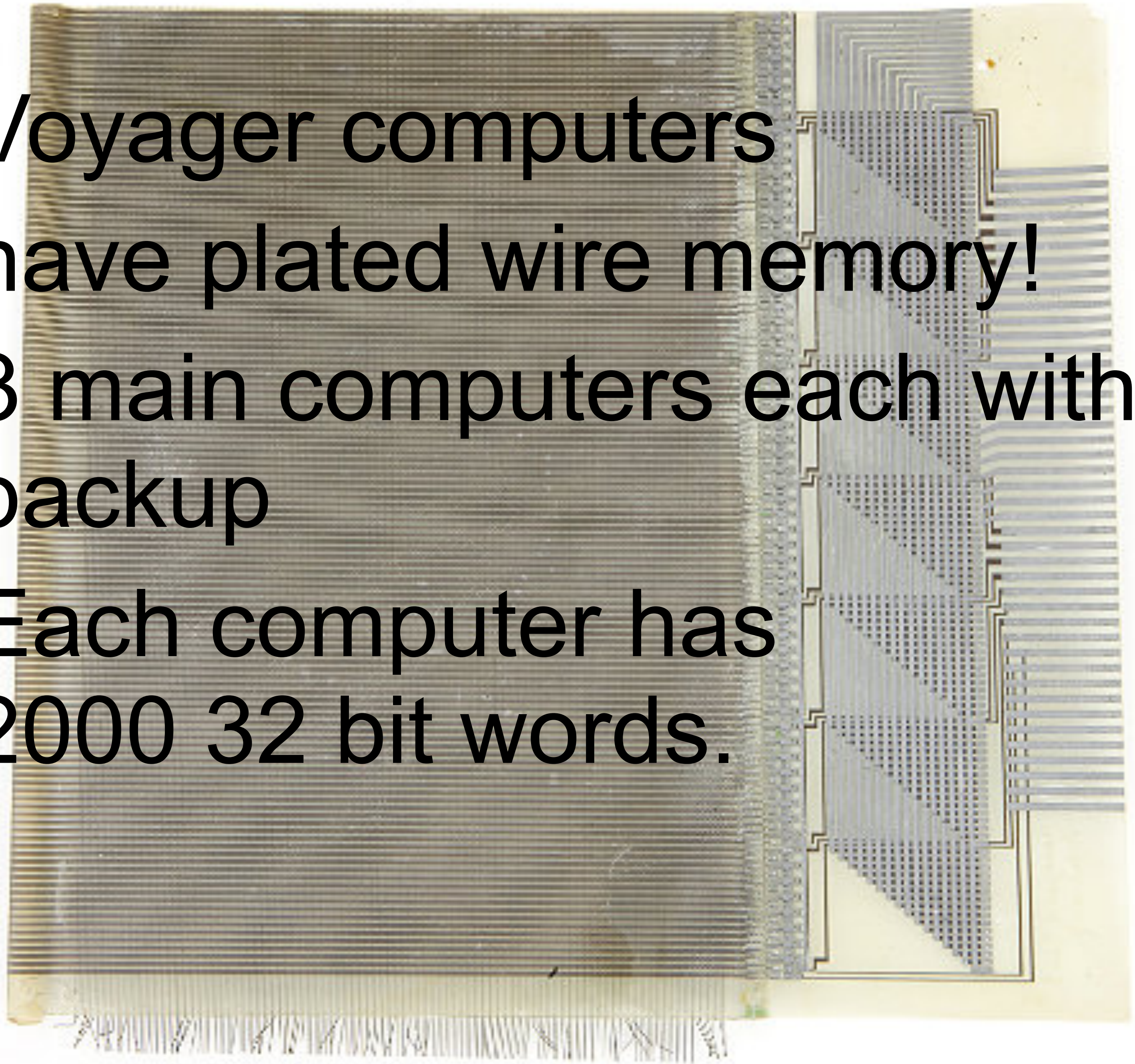
November 16, 2022

John W. Belcher

Voyager 1 & 2 launched on Aug/Sept 1977, 45 years ago.

MIT Plasma Science Instrument (PLS)

PI’s: Herb Bridge, John Belcher, John Richardson



Voyager computers

have plated wire memory!

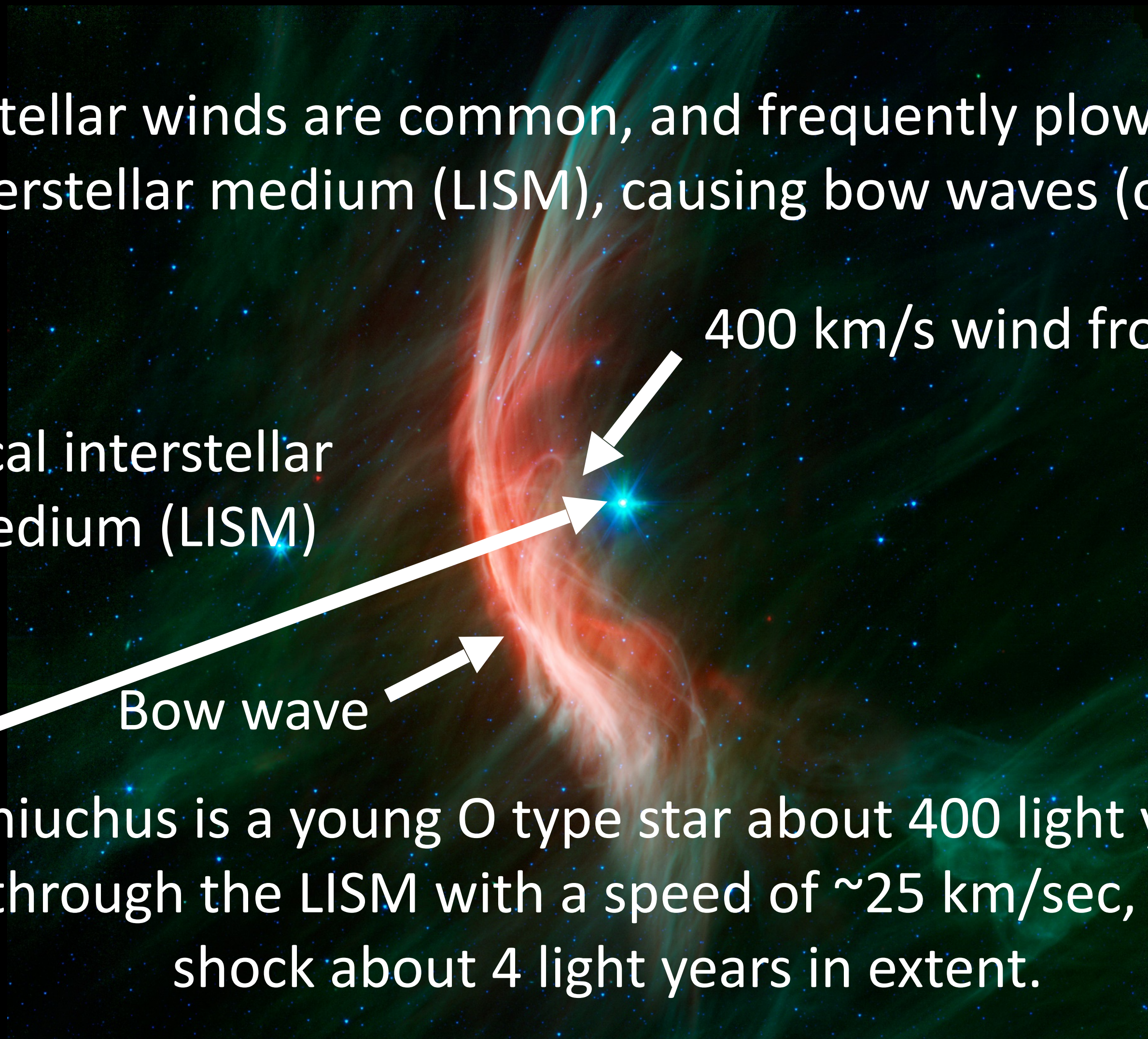
3 main computers each with a backup

Each computer has 2000 32 bit words.

Outline of Talk

- Some history of the concept of winds and the cavities they evacuate in the surrounding interstellar medium
- Some history of the Voyager Mission
- Voyager 2 crossing the termination shock in 2007
- Voyager 2 crossing into the interstellar medium 11/2018

Stars with stellar winds are common, and frequently plow through the local interstellar medium (LISM), causing bow waves (or shocks)



Zeta Ophiuchus is a young O type star about 400 light years away, moving through the LISM with a speed of ~25 km/sec, with a bow shock about 4 light years in extent.

The prediction of the solar wind and the heliosphere

- Eugene Parker in the 1950's predicted that a solar wind blows from the hot solar corona, reaching terminal speeds of around 400 km/s
- The solar wind blows a bubble in the local interstellar medium
- Distance to the boundary set by the balance between the solar wind ram pressure ρV^2 (decreasing as inverse radius squared) and the interstellar thermal and magnetic field pressure
- In 1955 Leverett Davis Jr. (Parker's thesis advisor at Cal Tech) estimated this distance to be 200 AU
- This was 6 years *before* the solar wind plasma energy spectra was directly measured in 1961 by Herb Bridge and Al Lazarus of MIT with Explorer 10

The Interstellar Medium (ISM)

Local Bubble: The Sun is located inside of a ring of massive hot OB stars known as Gould's Belt. These stars create a vast low density hot void 1000 light years in extent in the interstellar medium around the Sun. This void is known as the Local Bubble

$T \sim 10^6$ K; ionized H $\sim 0.005\ cm^{-3}$; neutral H$<0.0005\ cm^{-3}$

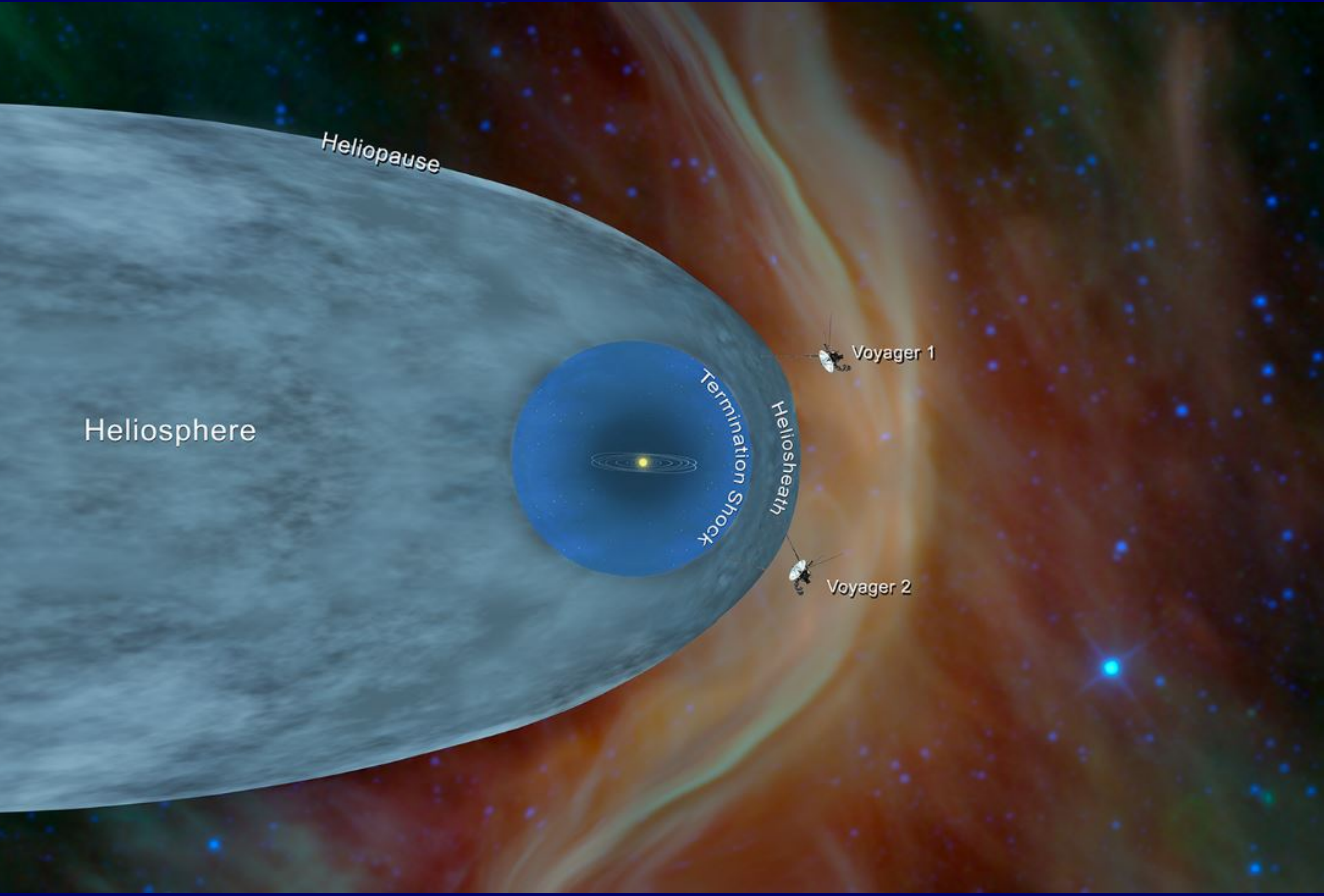
Local Fluff: Embedded in the vast Local Bubble is a much smaller feature (a few light years across) of higher density and lower temperature. The sun at present sits in this warm partially ionized medium, the Local Fluff, and will exit it in about 10,000 years to return to the Local Bubble

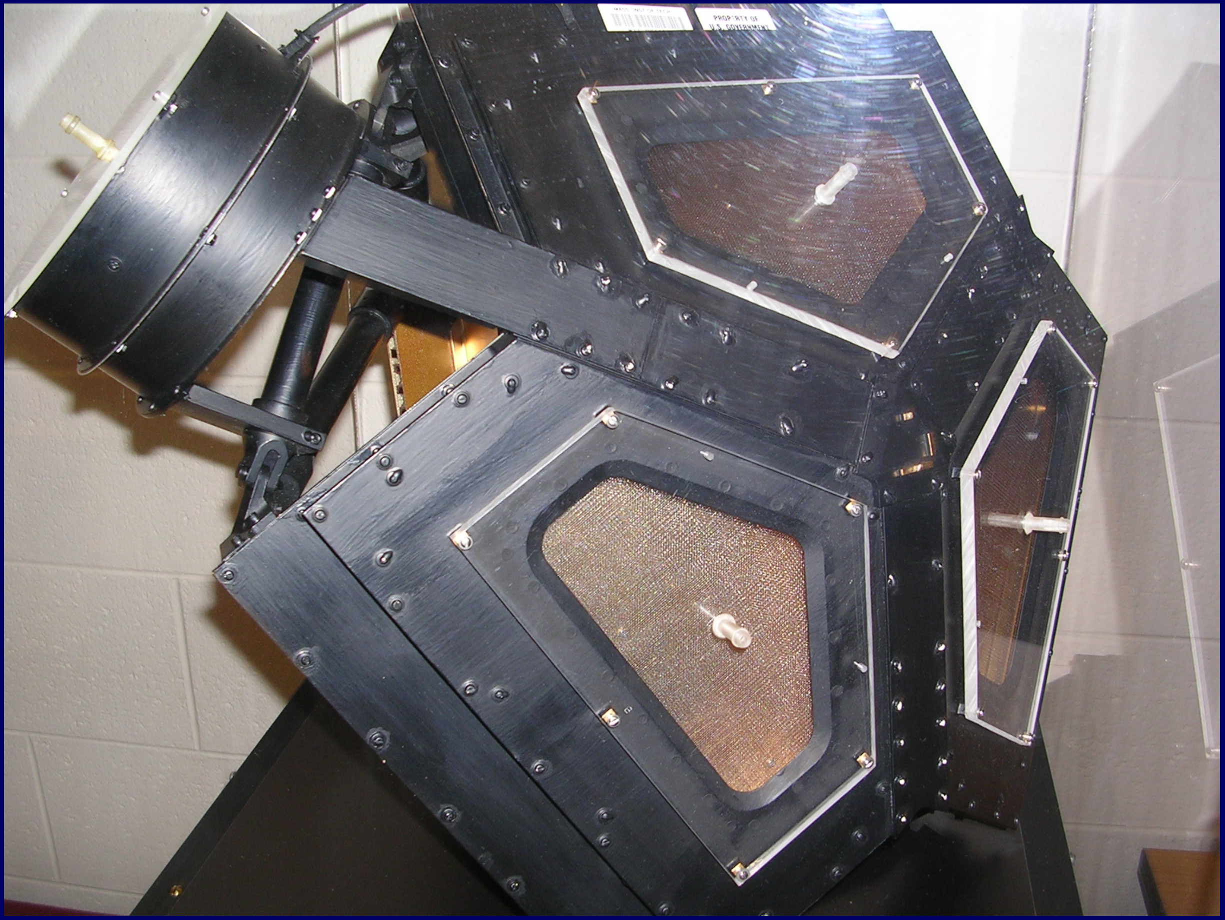
$T=6500$ K; ionized H $0.11\ cm^{-3}$; neutral H$=0.22\ cm^{-3}$

$V_{\text{with respect to sun}} = 26$ km/s

History

- Voyager 1 crossed the termination shock in December 2004 at 94 AU
- The MIT plasma instrument on Voyager 1 has been dead since 1981, but the plasma instrument on Voyager 2 is alive and well.
- Voyager 2 crossed the termination shock in Aug 2007 at 84 AU
- Voyager 1 crossed the heliopause into interstellar space on August 25, 2012
- Voyager 2 to crossed into interstellar space in 2018, and made the first direct measurements of the interstellar plasma


Heliopause
Heliosphere
Termination Shock
Heliosheath
Voyager 1
Voyager 2

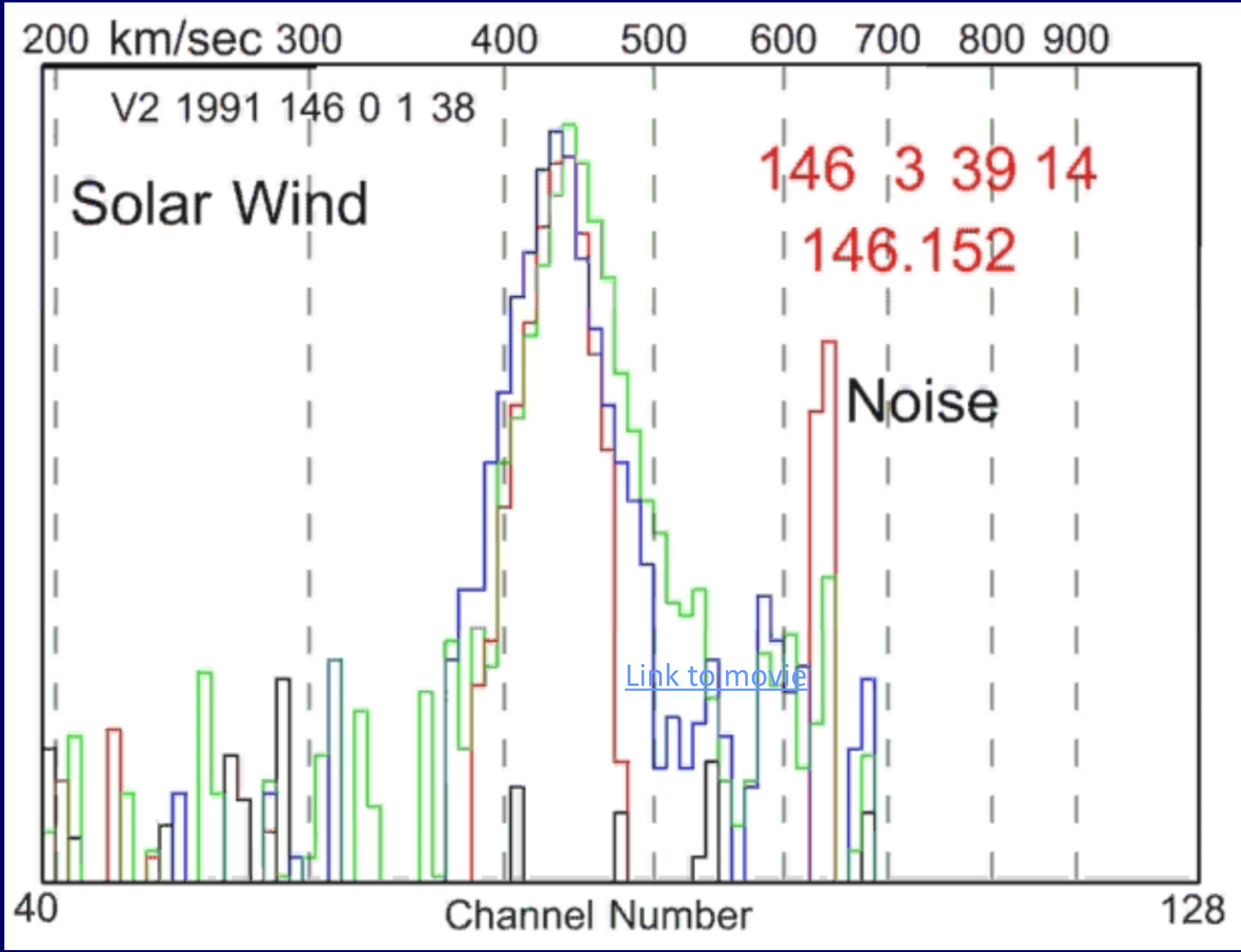


Four detectors open to space, with biasing wire grids over the apertures

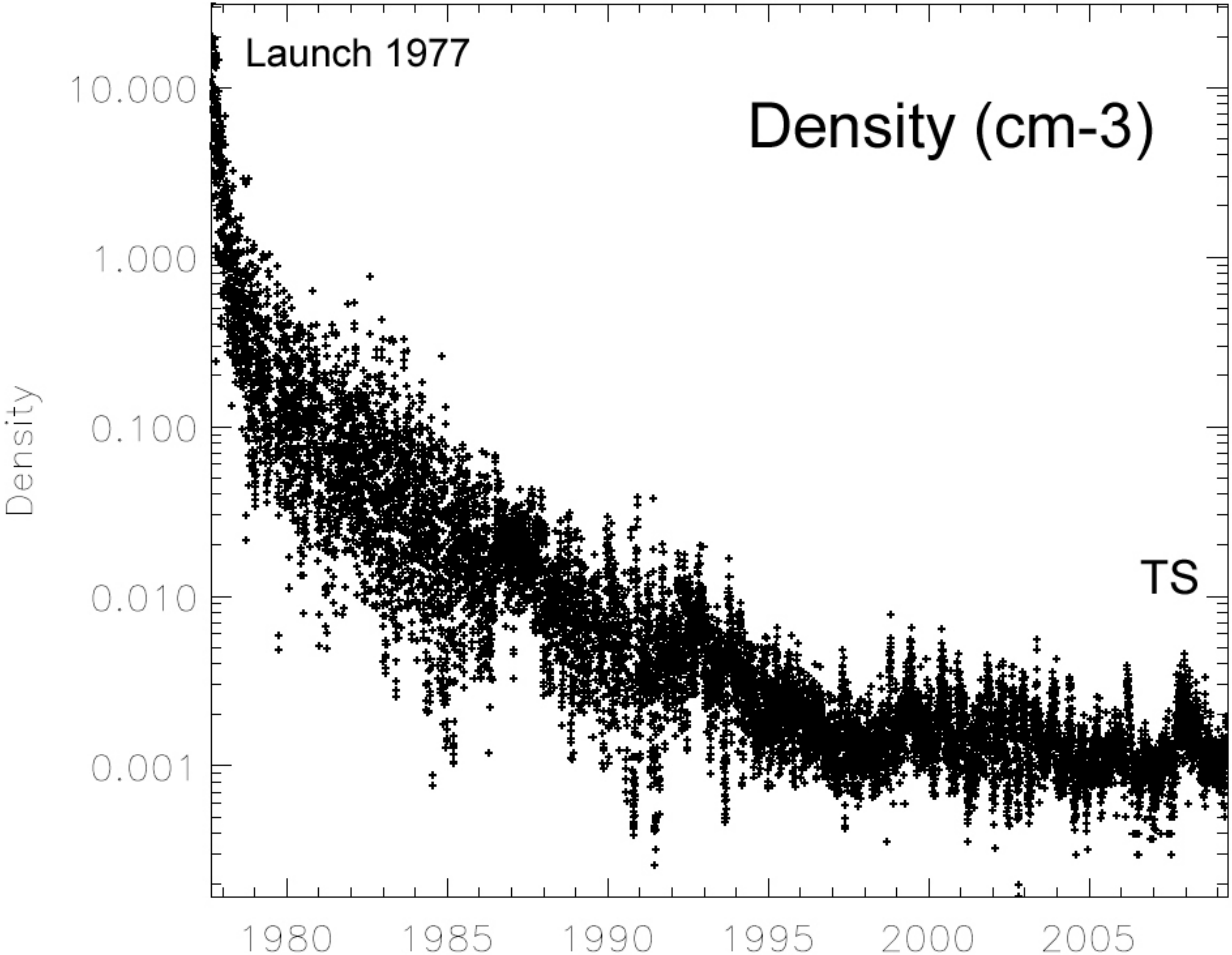
Data from the Voyager 2 Plasma Instrument at 30 AU

1 AU = distance from Sun to Earth = 215 $R_{☉}$

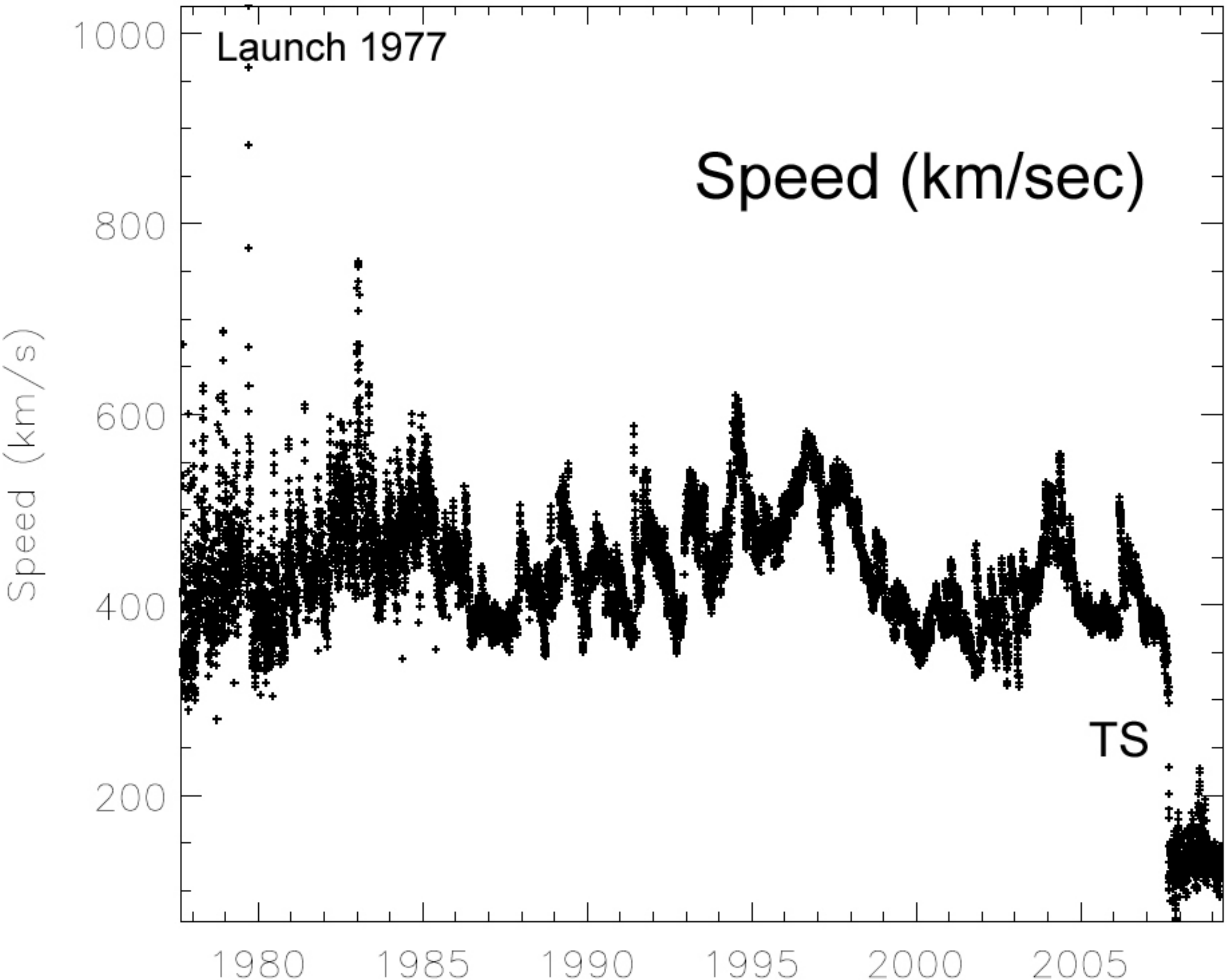
30 AU = 6450 $R_{☉}$

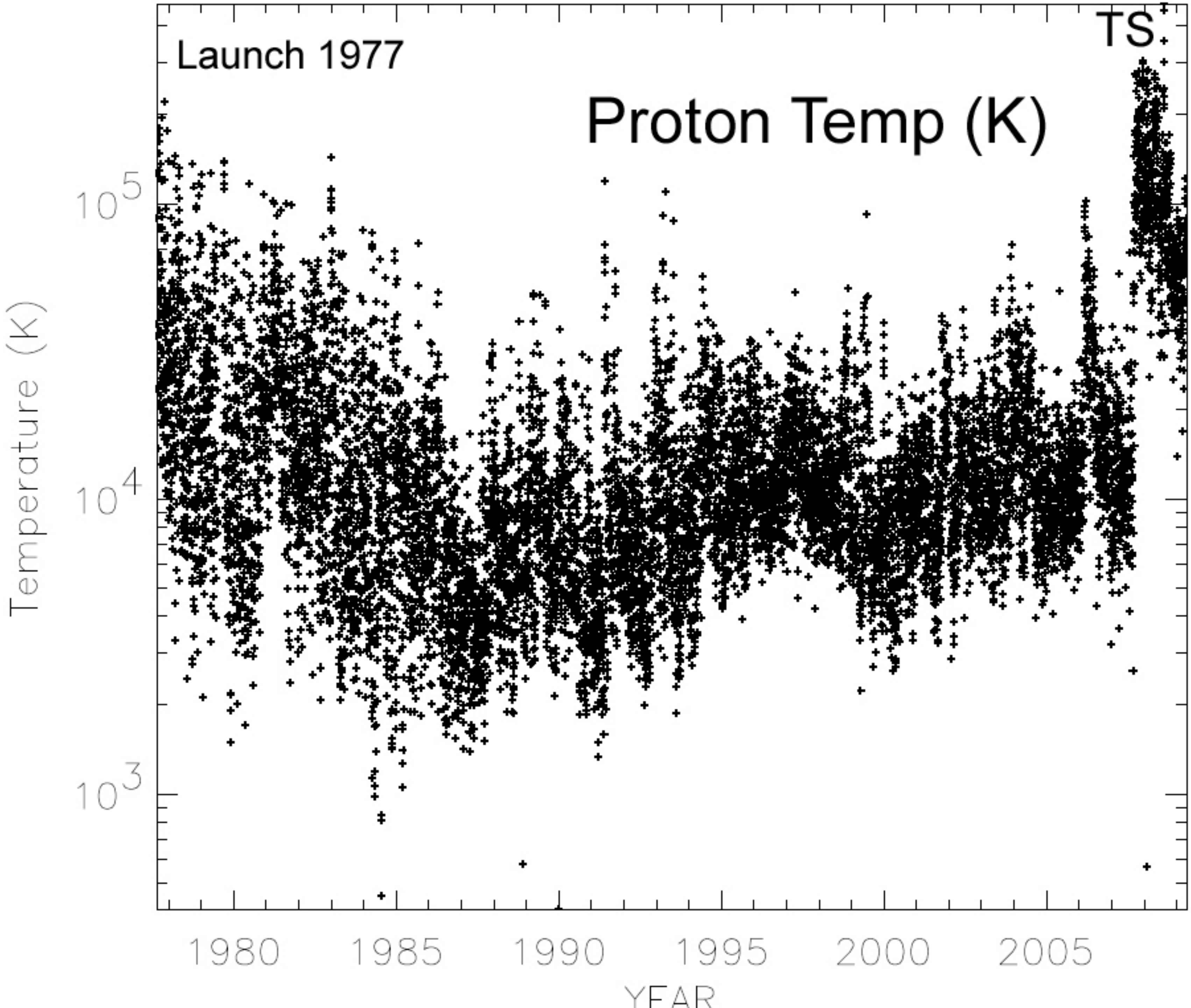


Link to movie



Launch 1977
Density (cm-3)
TS
Density
10.000
1.000
0.100
0.010
0.001
1980
1985
1990
1995
2000
2005

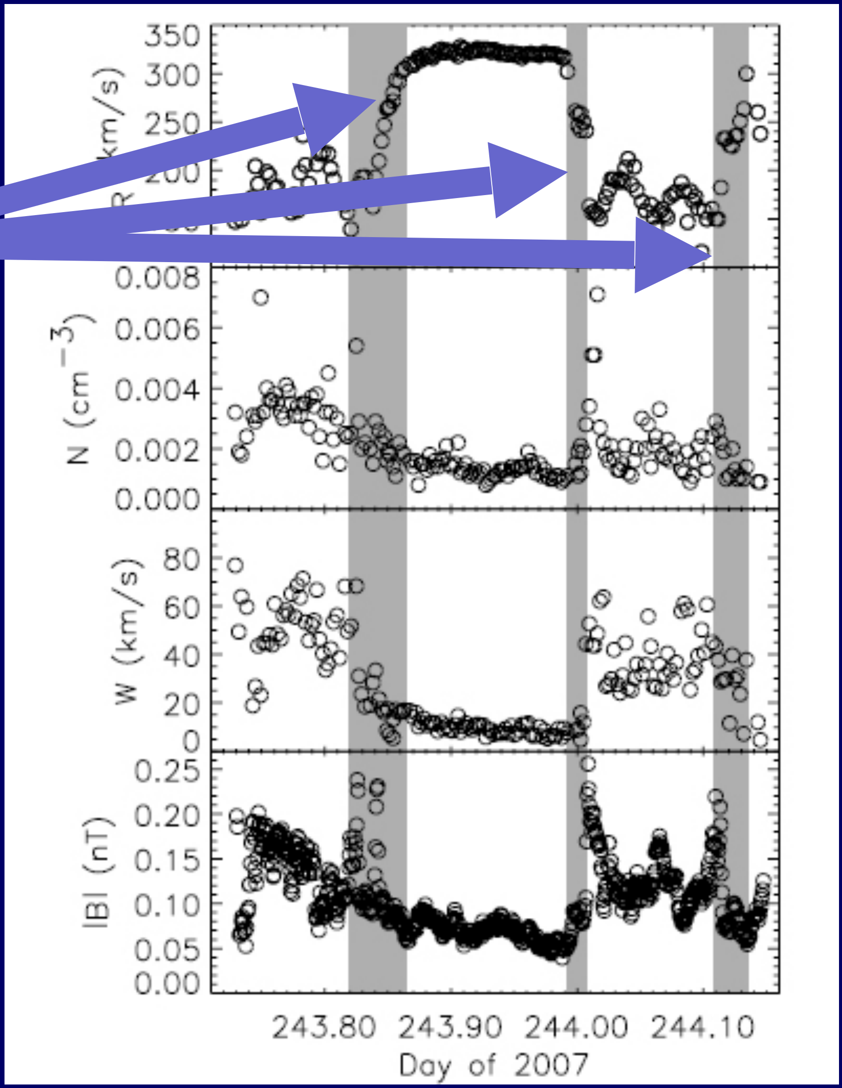

Launch 1977
Speed (km/sec)
TS
Speed (km/s)
1000
800
600
400
200
1980
1985
1990
1995
2000
2005

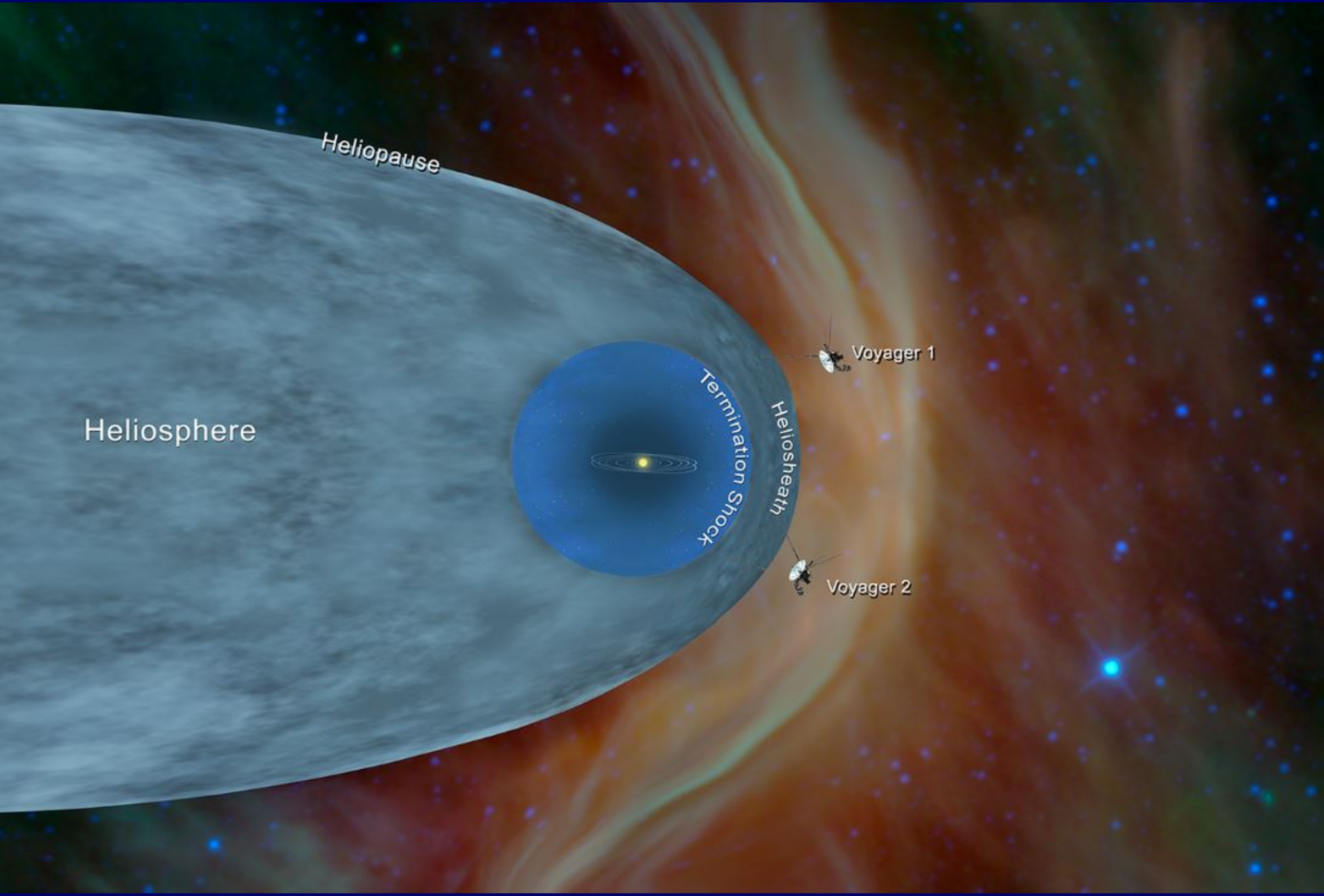


Launch 1977
TS
Proton Temp (K)
Temperature (K)
10^5
10^4
10^3
1980
1985
1990
1995
2000
2005
YEAR

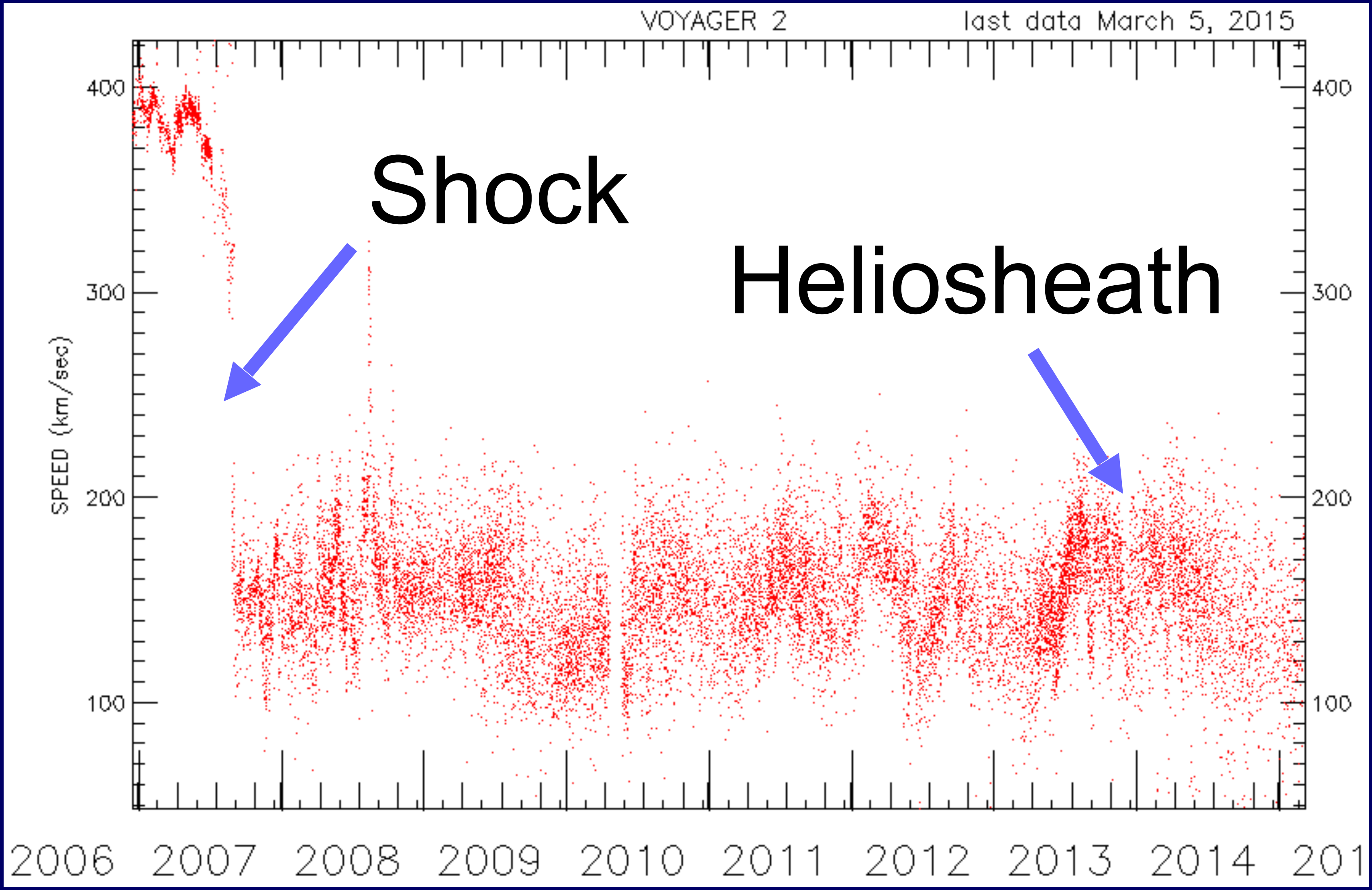
2 1/2 Termination shock crossings!

Thickness is about the Alfven speed times the proton cyclotron period




Heliopause
Heliosphere
Termination Shock
Heliosheath
Voyager 1
Voyager 2

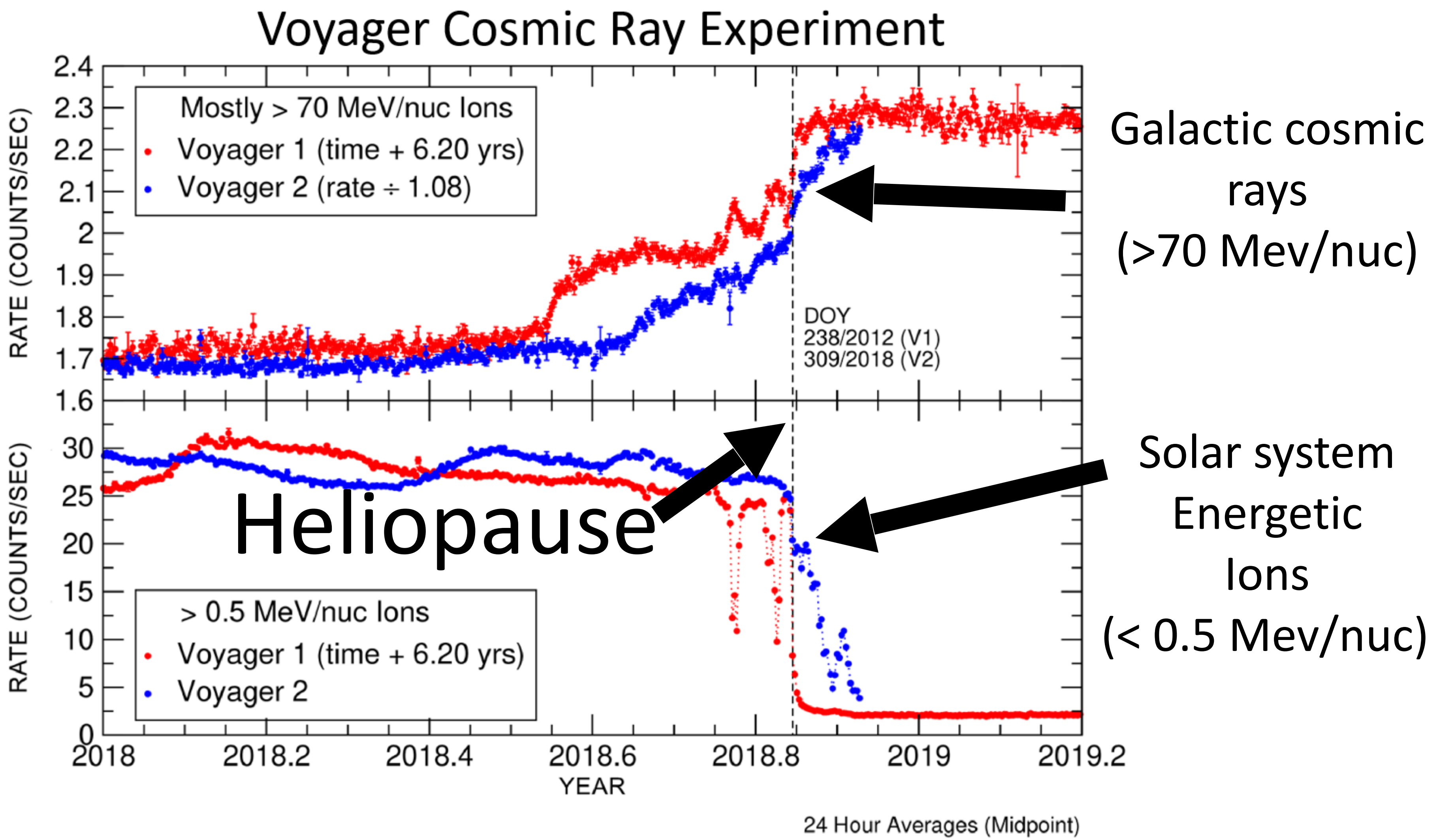
MIT Voyager 2 Plasma Data Through March 5, 2015



For the 11 years after the termination shock but before crossing into interstellar space, we were asking "Will we see *anything* in interstellar space?"

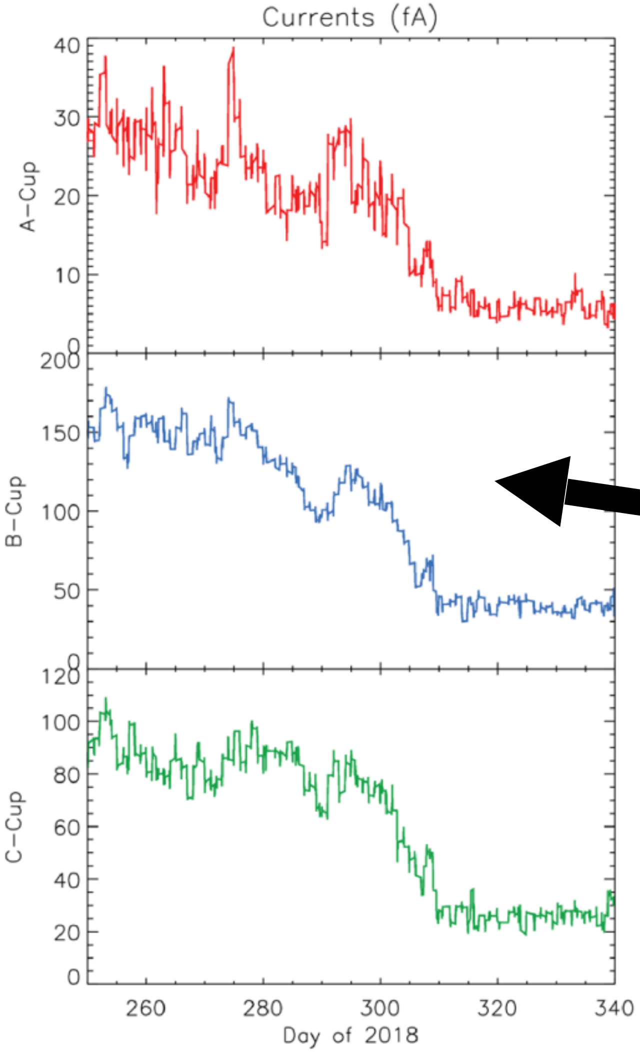
The speed and thermal speed of the interstellar plasma were both estimated to be about 20 km/sec, and the lowest energy channel starts at 44 km/sec

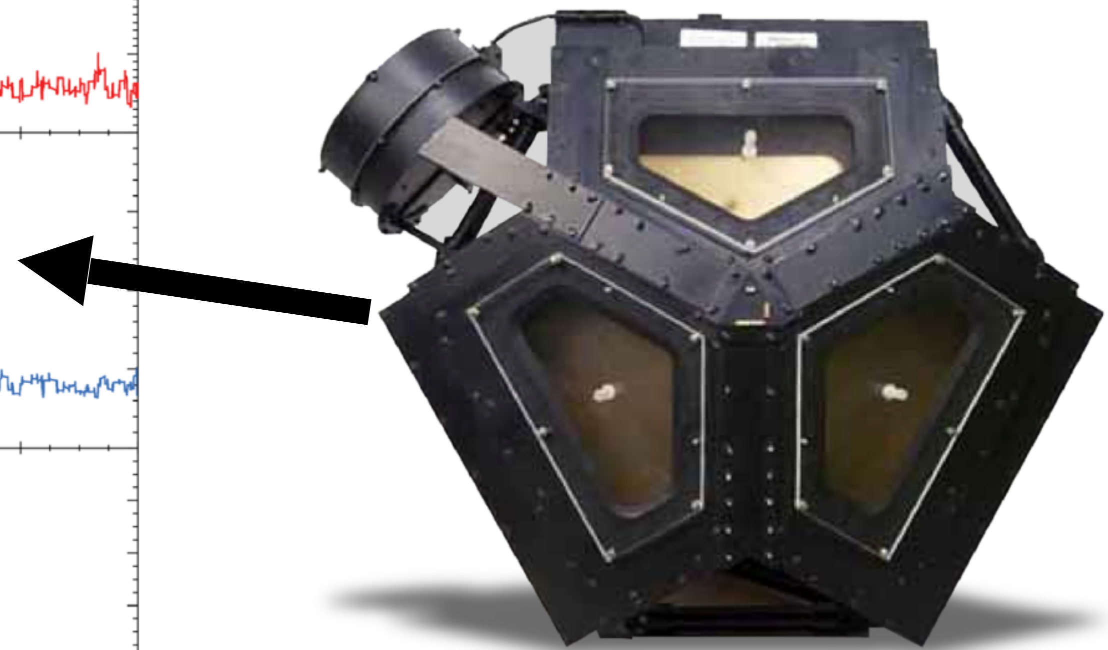
The main sensor is looking perpendicular to the expected interstellar wind flow direction, and the side sensor is about 50 degrees away from its expected flow direction when Voyager is on Vela as a lock star


Voyager Cosmic Ray Experiment
Mostly > 70 MeV/nuc Ions
Voyager 1 (time + 6.20 yrs)
Voyager 2 (rate ÷ 1.08)
RATE (COUNTS/SEC)
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
DOY
238/2012 (V1)
309/2018 (V2)
Galactic cosmic rays
(>70 Mev/nuc)
Heliopause
Solar system Energetic Ions
(< 0.5 Mev/nuc)
> 0.5 MeV/nuc Ions
Voyager 1 (time + 6.20 yrs)
Voyager 2
RATE (COUNTS/SEC)
30
25
20
15
10
5
0
2018
2018.2
2018.4
2018.6
2018.8
2019
2019.2
YEAR
24 Hour Averages (Midpoint)

Currents in Main Sensors

femtoamps



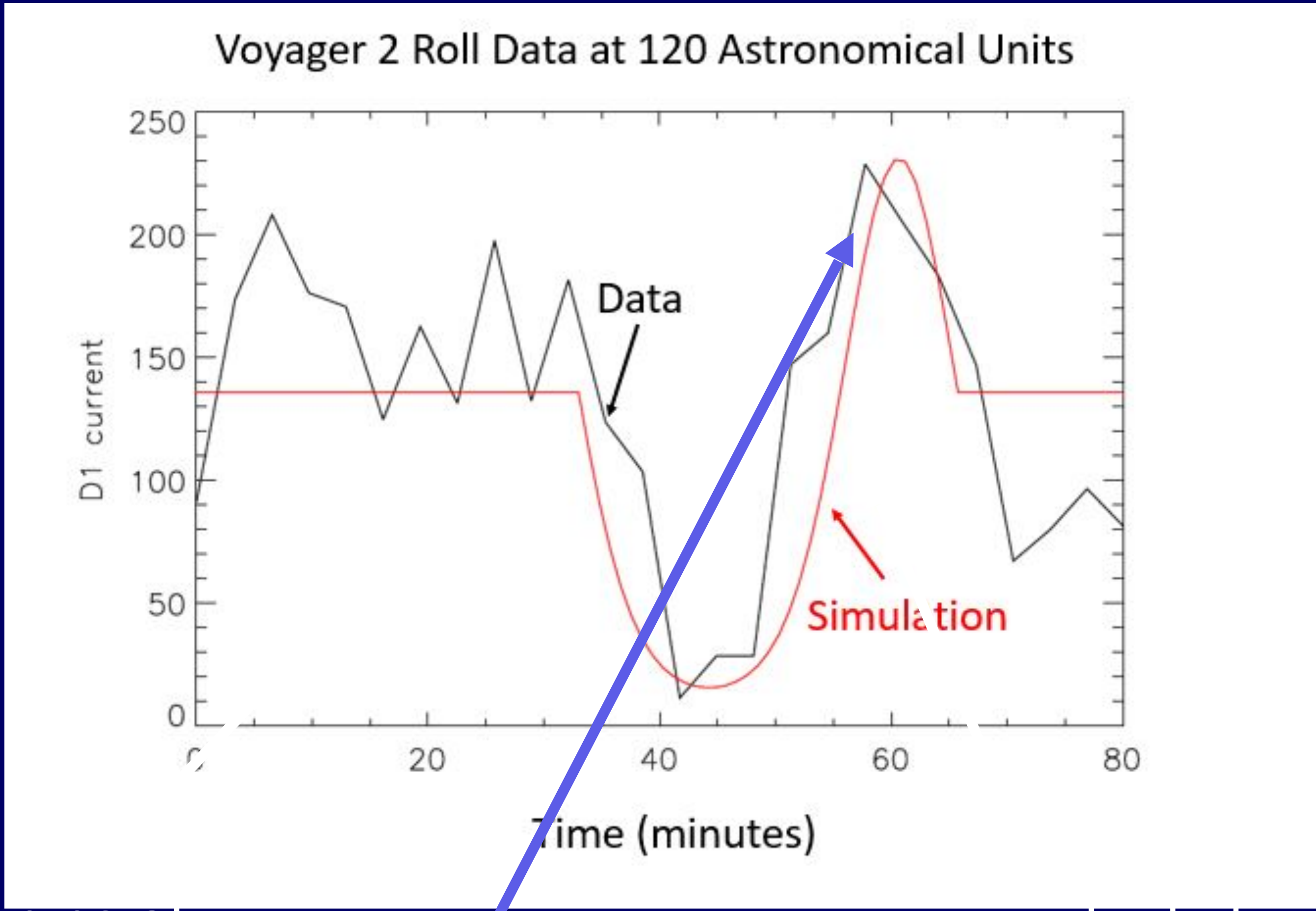


We saw the hot (W ~ 200 km/s) heliosheath plasma disappear from the main sensor at the heliopause, as we expected would happen

After the heliopause we saw significant currents only in the lowest channel of the side looking cup, which scans from from 10-30 V, or 44-76 km/s

The current in this channel give us lots of information about the LISM (onset of interstellar shocks, for example), but we can also determine interstellar plasma parameters from measurements in 1st channel


To Earth
Side Looking Sensor
Wind
Direction
Interstellar wind direction

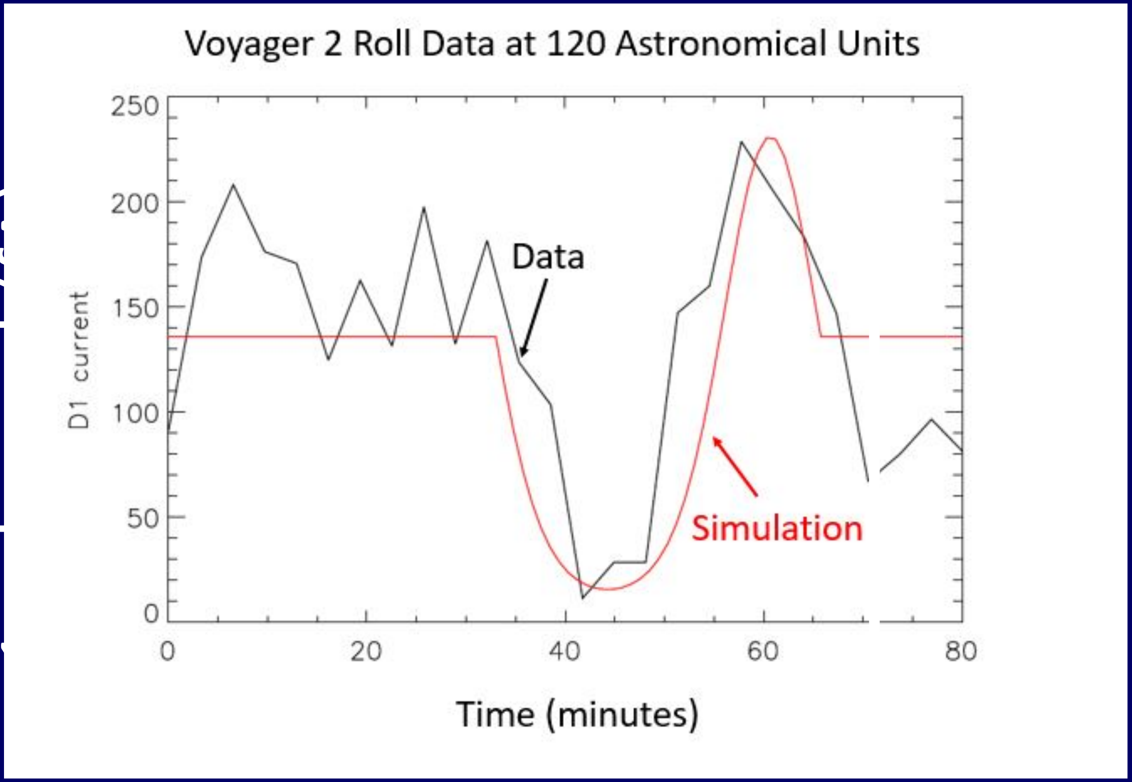


1st channel (fA)

Beginning of roll

End of roll

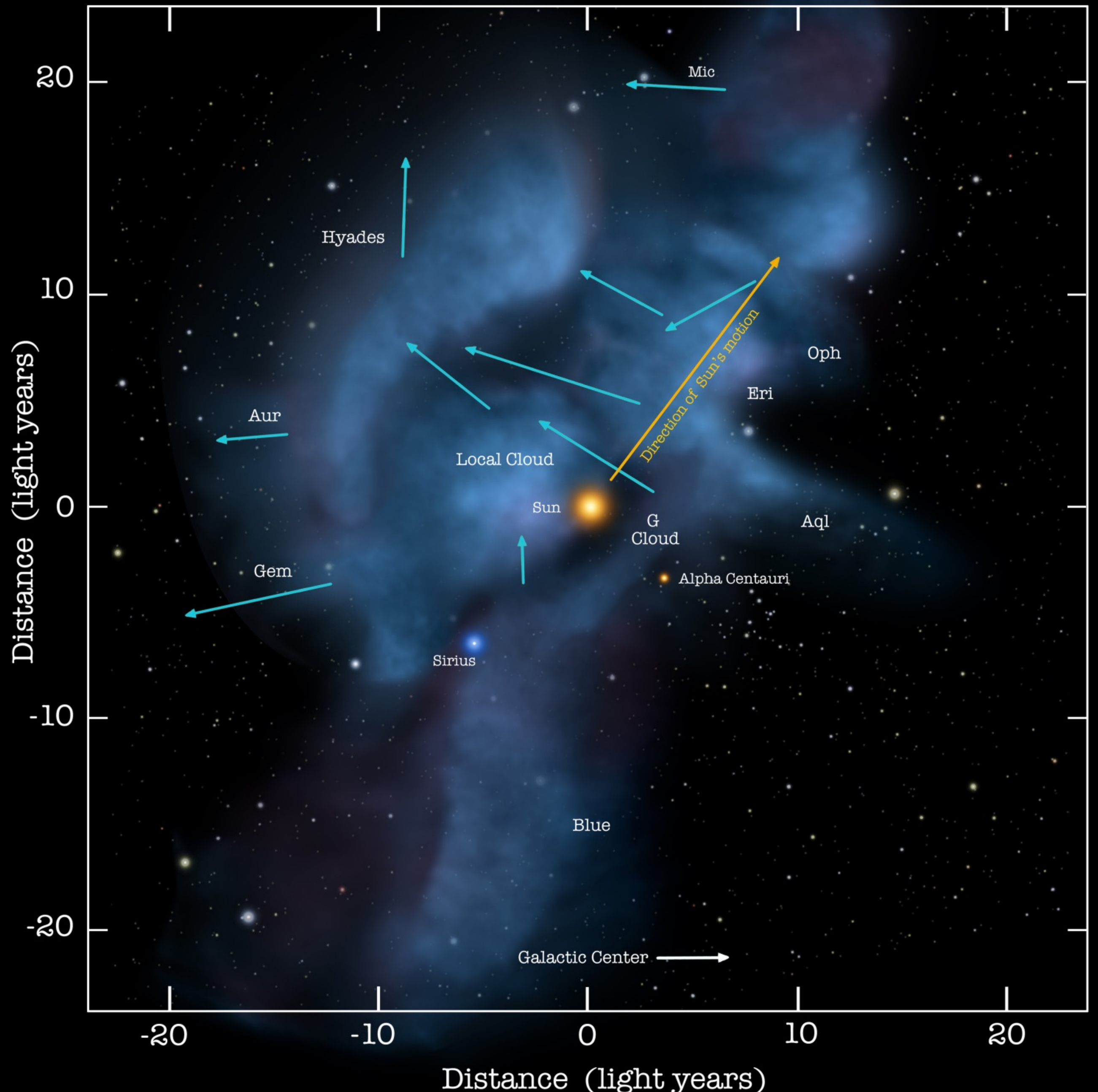
Looking directly into interstellar flow direction

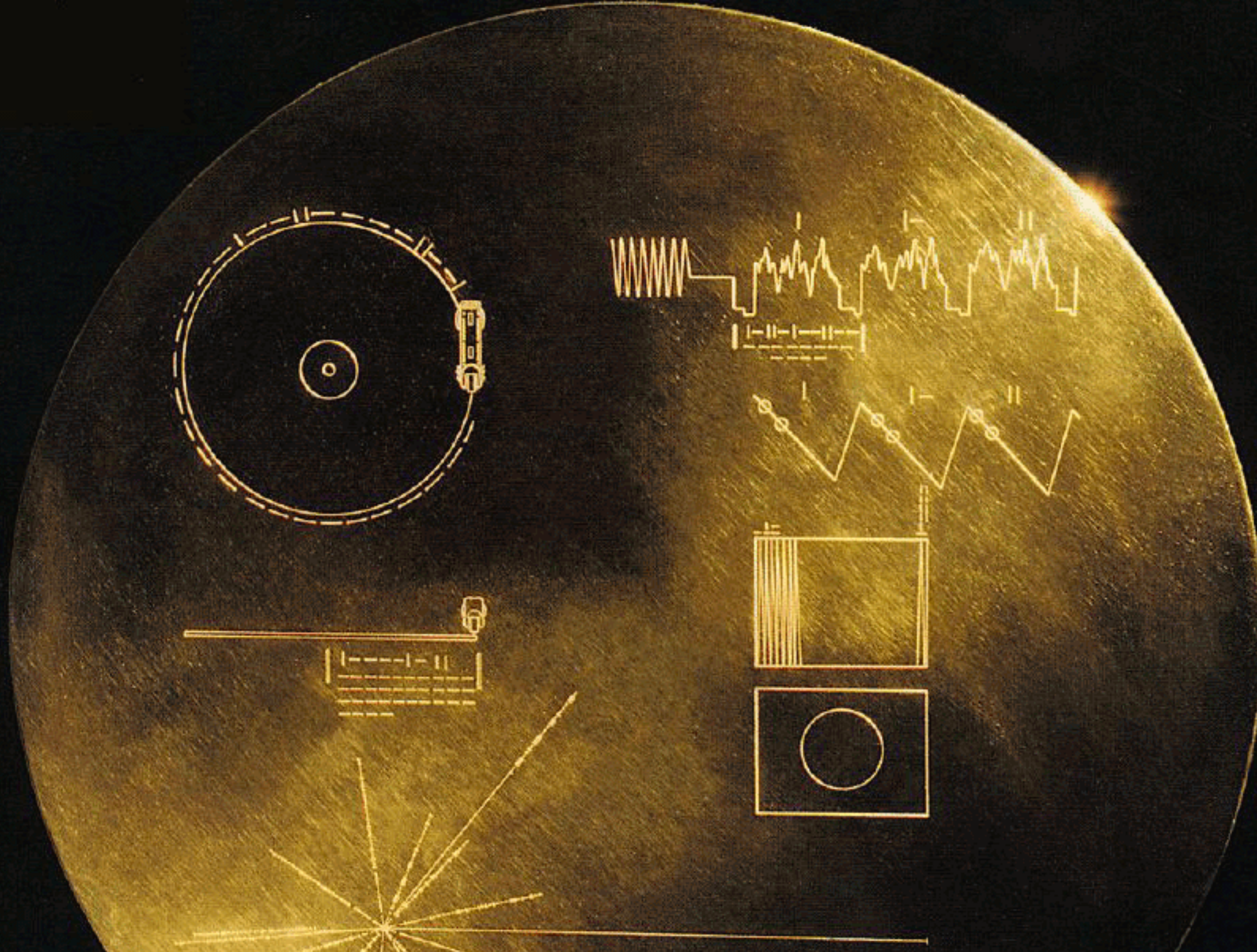


From this data we get good estimates of the plasma properties of the ionized component of the Local Fluff: density, thermal speed, and velocity

Forward/backward asymmetry is a measure of the Mach number of the flow

The very local interstellar medium





Professor Herbert Bridge
(1919-1995)
Director Center for Space Research
1978-1984

John Richardson, John Belcher, and Ralph McNutt at the Voyager 2 Uranus encounter in 1986