SWAP Capabilities

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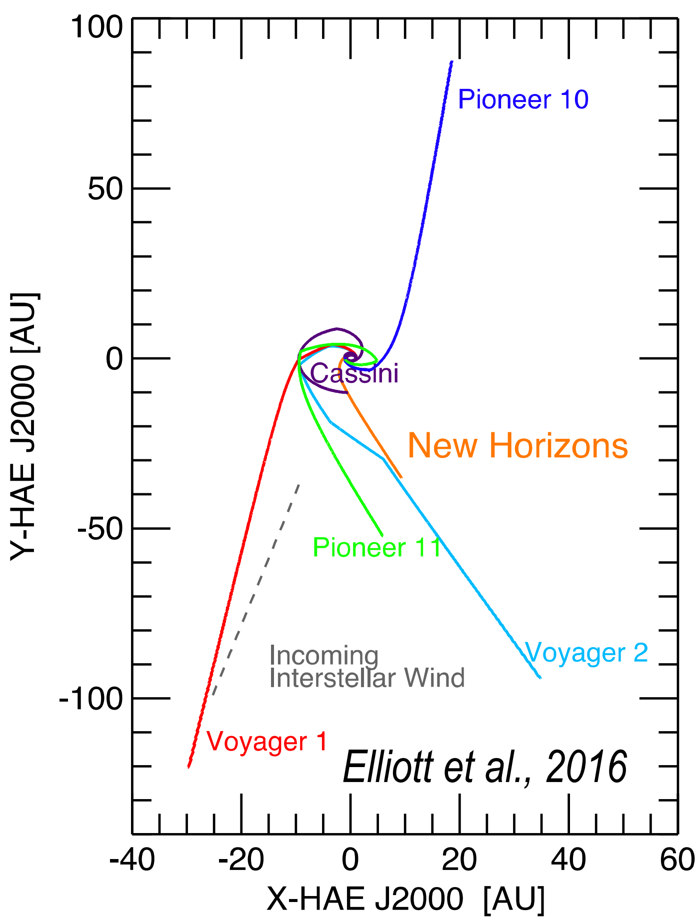
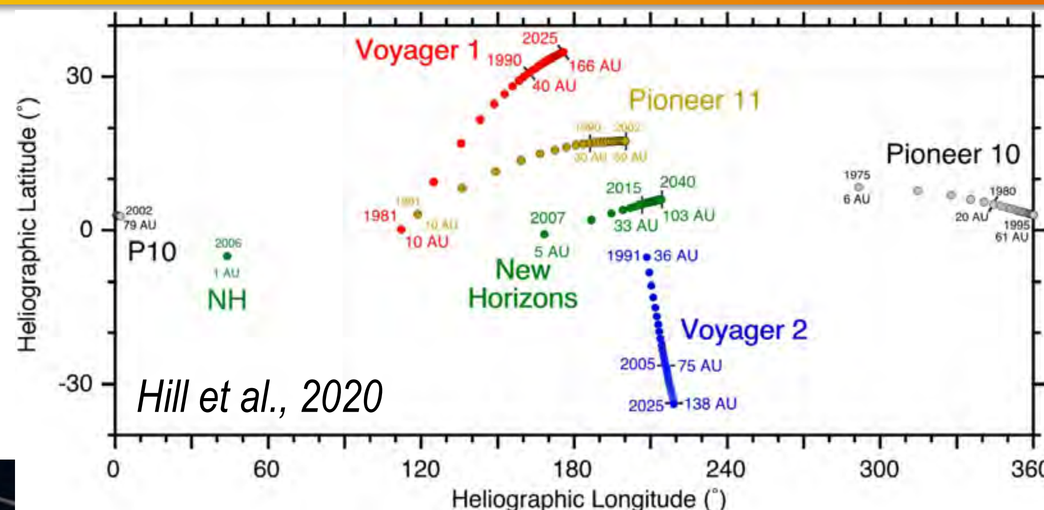
Introduction

- New Horizons (NH) trajectory
- Brief description of the Solar Wind Around Pluto (SWAP) instrument
- Examples of SWAP measurements
- Types of Science Studies
  - Radial Trends
    - Radial profiles of the solar wind parameters
    - Radial profiles of interstellar pickup ions
    - Slowing of the solar wind relative to the inner heliosphere.
    - Radial variation of T-n relationship (polytropic index).
  - Pickup Ion interplanetary shock modification
- NH will be the 1st mission to measure interstellar pickup ions and the solar wind when crossing the termination shock.

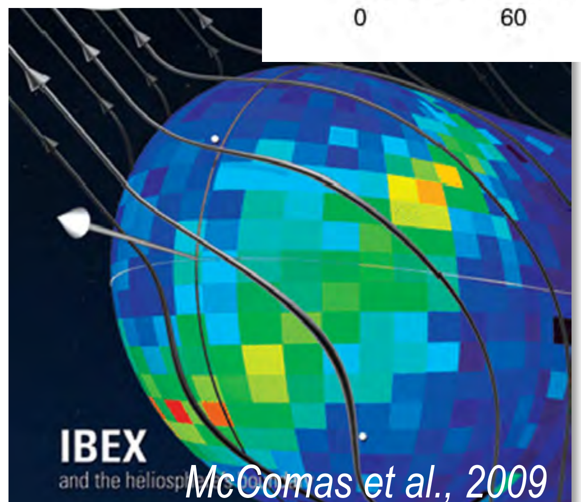
Few Missions Have Explored the Outer Heliosphere



Elliott et al., 2016



Hill et al., 2020

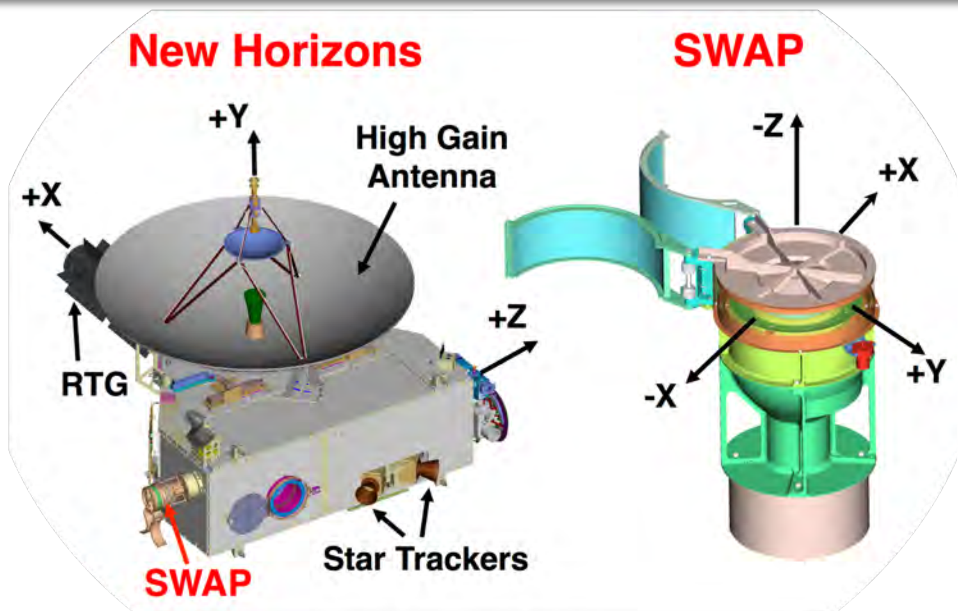


McComas et al., 2009

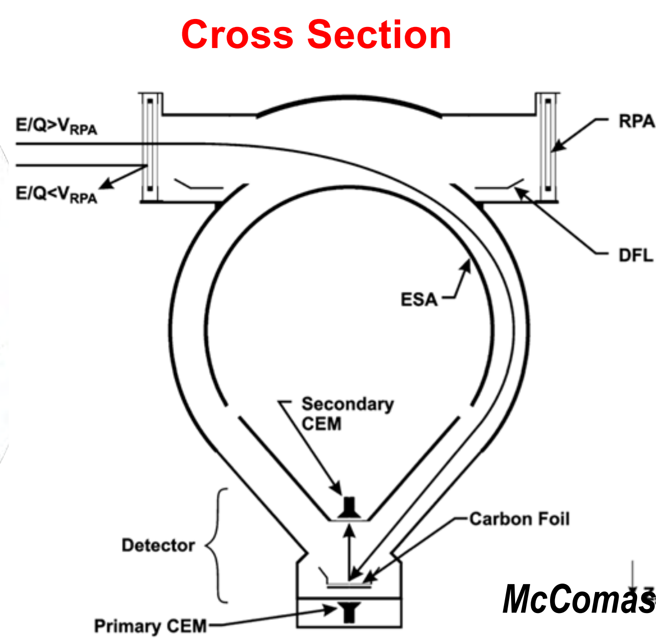
New Horizons is currently the only spacecraft exploring the outer heliosphere and Kuiper Belt.

NH headed towards the ENA Ribbon.

Instrument Overview :
NH Solar Wind Around Pluto (SWAP)



Elliott et al., 2016



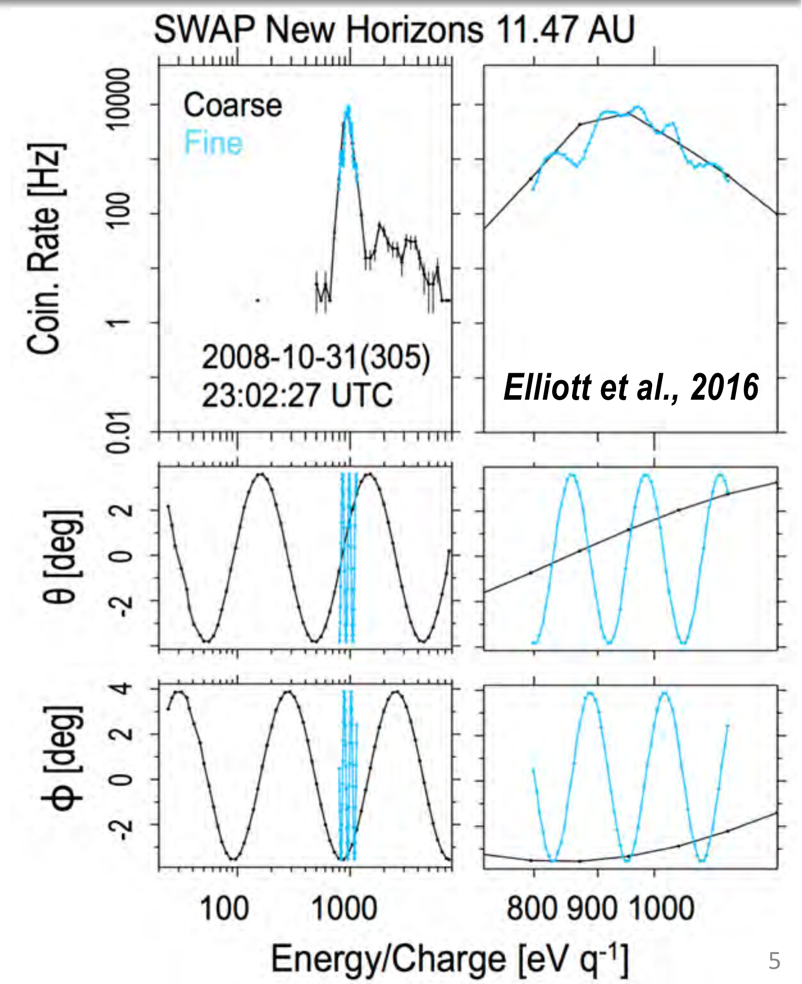
McComas et al., 2008

- Tophat electrostatic analyzer.
- The SWAP field of view is 276º by 10º
- Coincidence measurements based on timing between primary and secondary CEM detector signals.

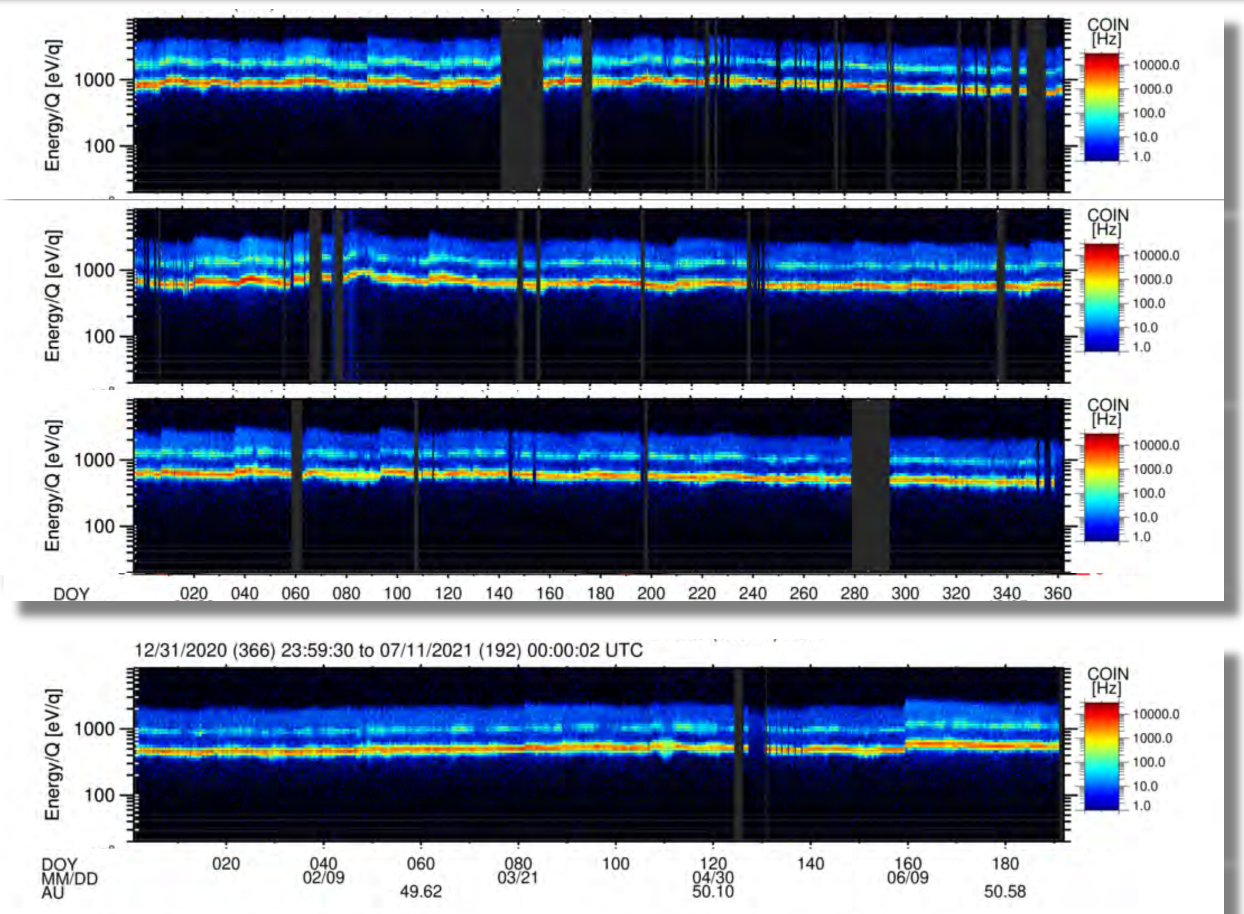
- The ratio of the SCEM to PCEM rate can be used to separate heavy and light ions.

Individual SWAP Energy Sweeps

- The accumulation time for each measurement is 0.39 sec.
- Both the coarse and fine sweeps are 32 sec each.
- A 64 step coarse energy sweep spanning the full energy range (~21-7800 eV) is followed by a 64 step fine sweep centered on the peak count rate in the coarse scan.
- The time between sweeps is variable.
  - Based on resources: 5 min, 10 min, 20 min, 30 min, 1hr, or 2hr
  - 64 sec continuous near Pluto and MU69, and Pluto rehearsal.



SWAP Spectrograms



2018
40.31 to 43.27 au

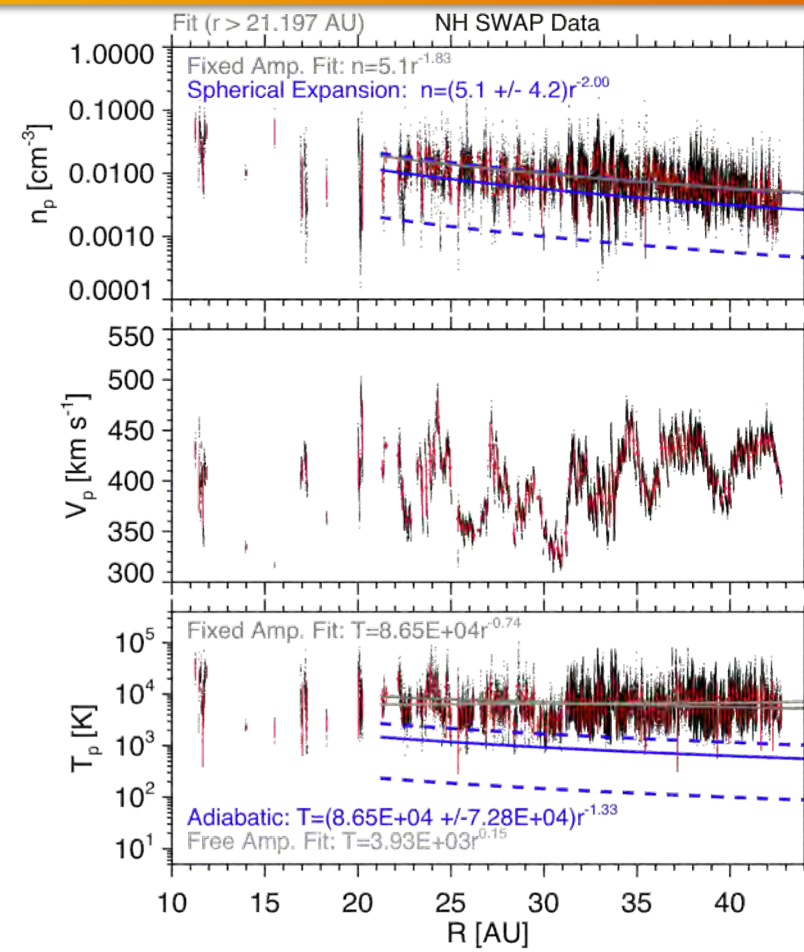
2019
43.27 to 46.22 au

2020
46.22 to 49.16 au

2021
49.16 to ~51 au

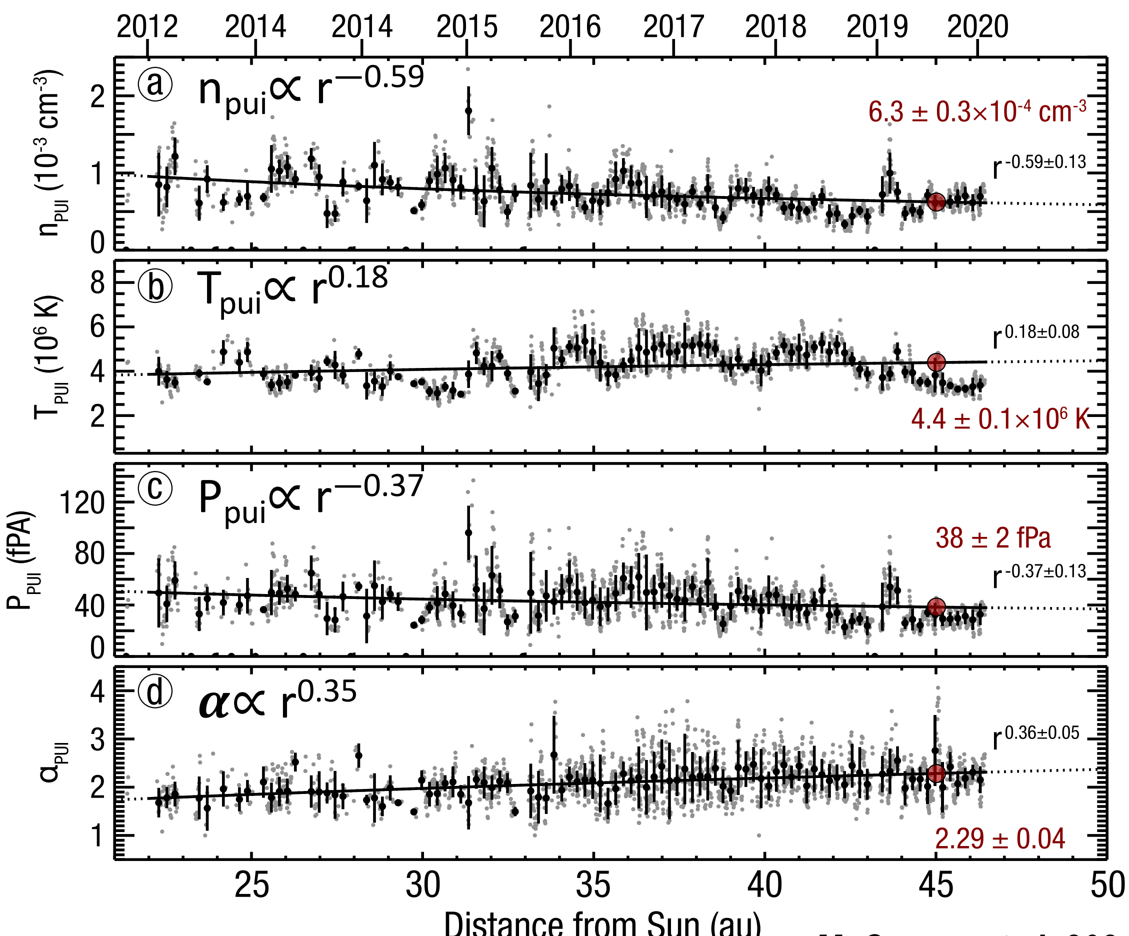
Radial Profiles of New Horizons Solar Wind Parameters

- Density profile drops off slightly less ($r^{-1.83}$) than spherical expansion (r^{-2}).
- Temperature profile ($r^{-0.71}$) decrease a lot less than what would be expected for adiabatic cooling ($r^{-1.33}$) implying heat must be added in the outer heliosphere.
- Based on the NH speed profile alone we see no clear radial trend.



Elliott et al., 2016; 2019

Radial Trends in PUI Parameters

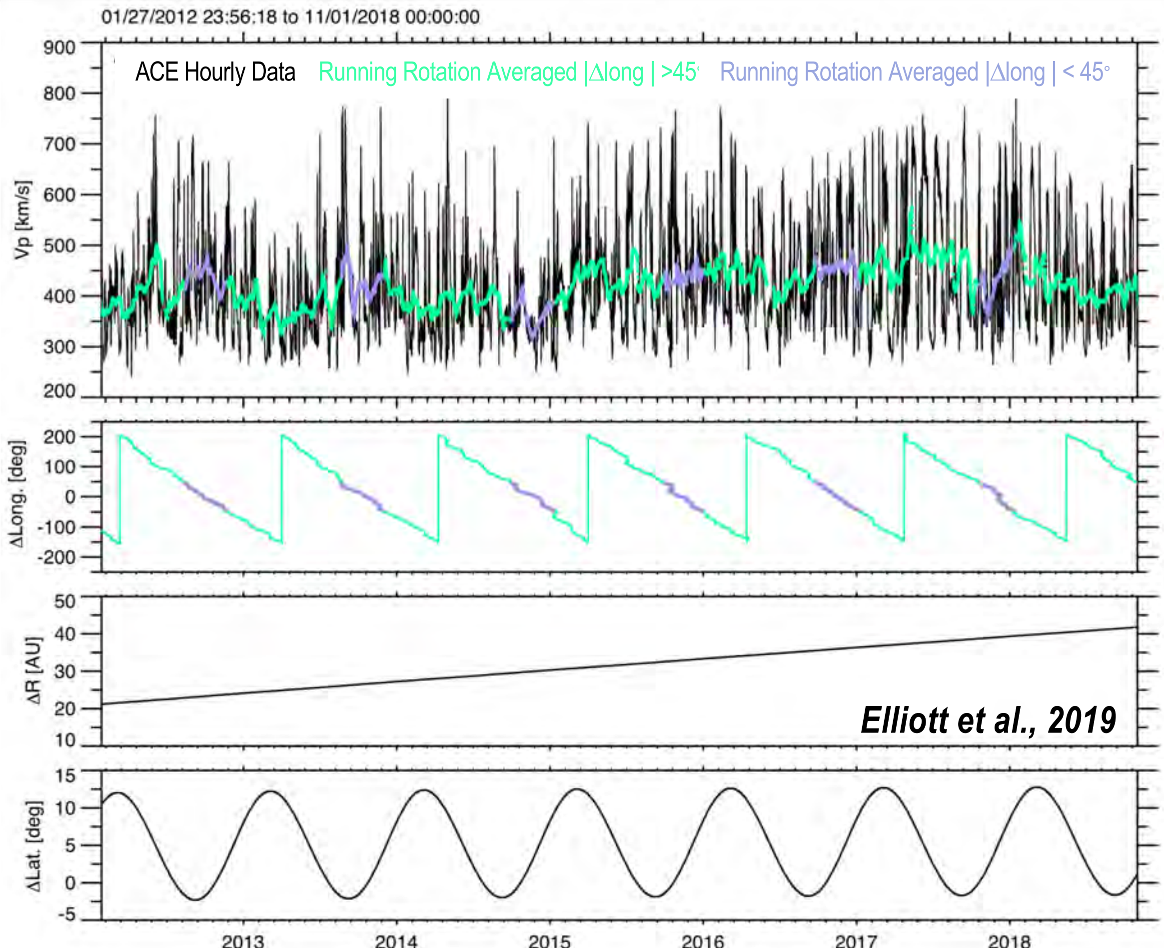


McComas et al. 2021

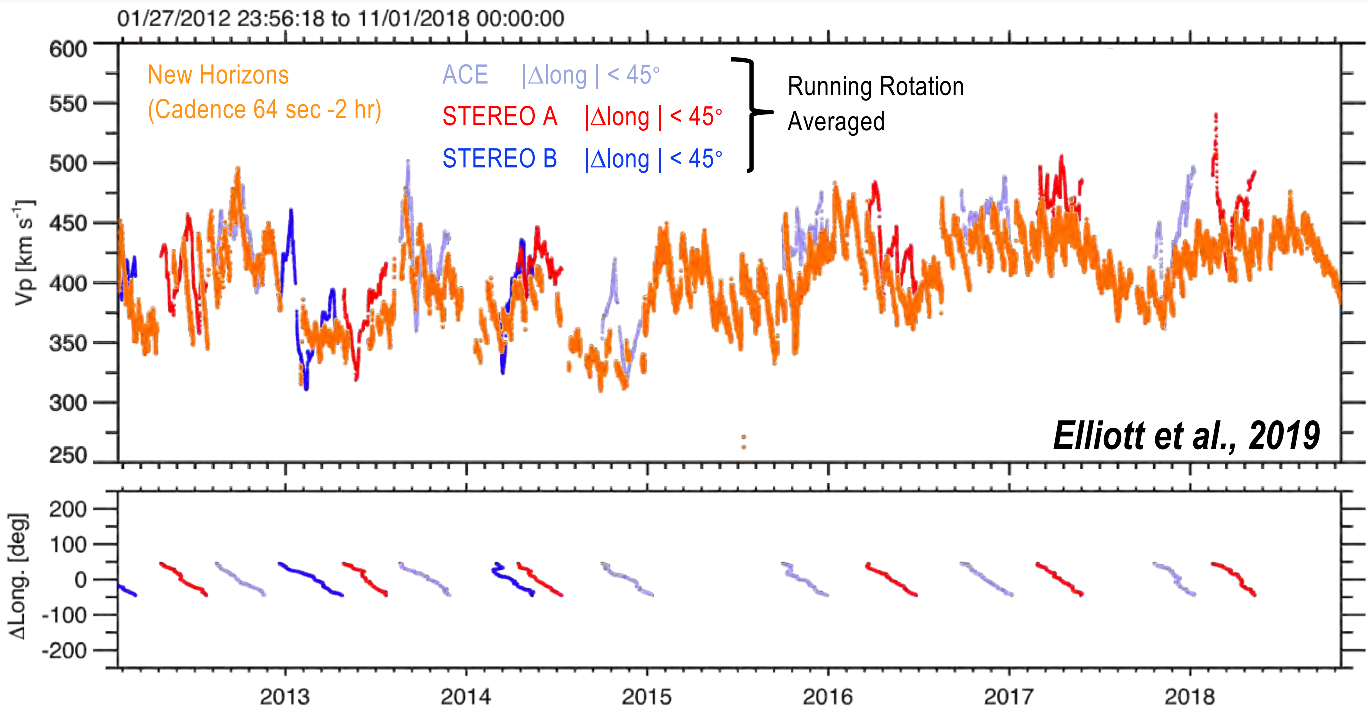
- Solar wind density decreases more steeply ($r^{-1.83}$) than the interstellar pickup ion density does ($r^{-0.59}$).
- Solar wind temperature is slightly decreases ($r^{-0.71}$) in the outer heliosphere, but the interstellar pickup ion temperature increases with distance ($r^{+0.18}$).
- Solar wind thermal pressure decreases rapidly ($r^{-2.5}$), but the thermal pressure for the interstellar PUI decreases less rapidly ($r^{-0.327}$).

Average 1 AU Wind Speeds and Propagate Out to NH

- Amplitude of solar wind structures is much larger at 1 au.
- Many structures at 1 au merge and/or are worn down prior to reaching NH.

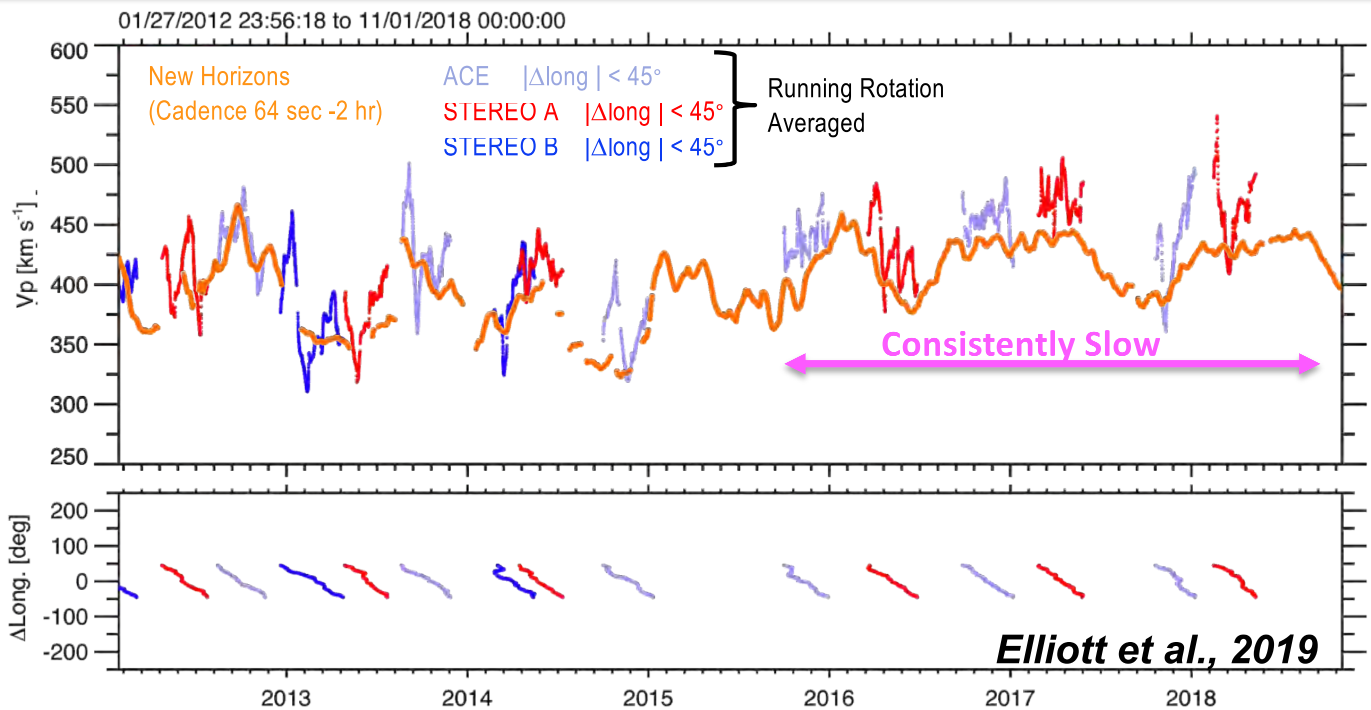


Direct Comparison of NH (No Averaging) and Solar Rotation Averaged 1 AU Data



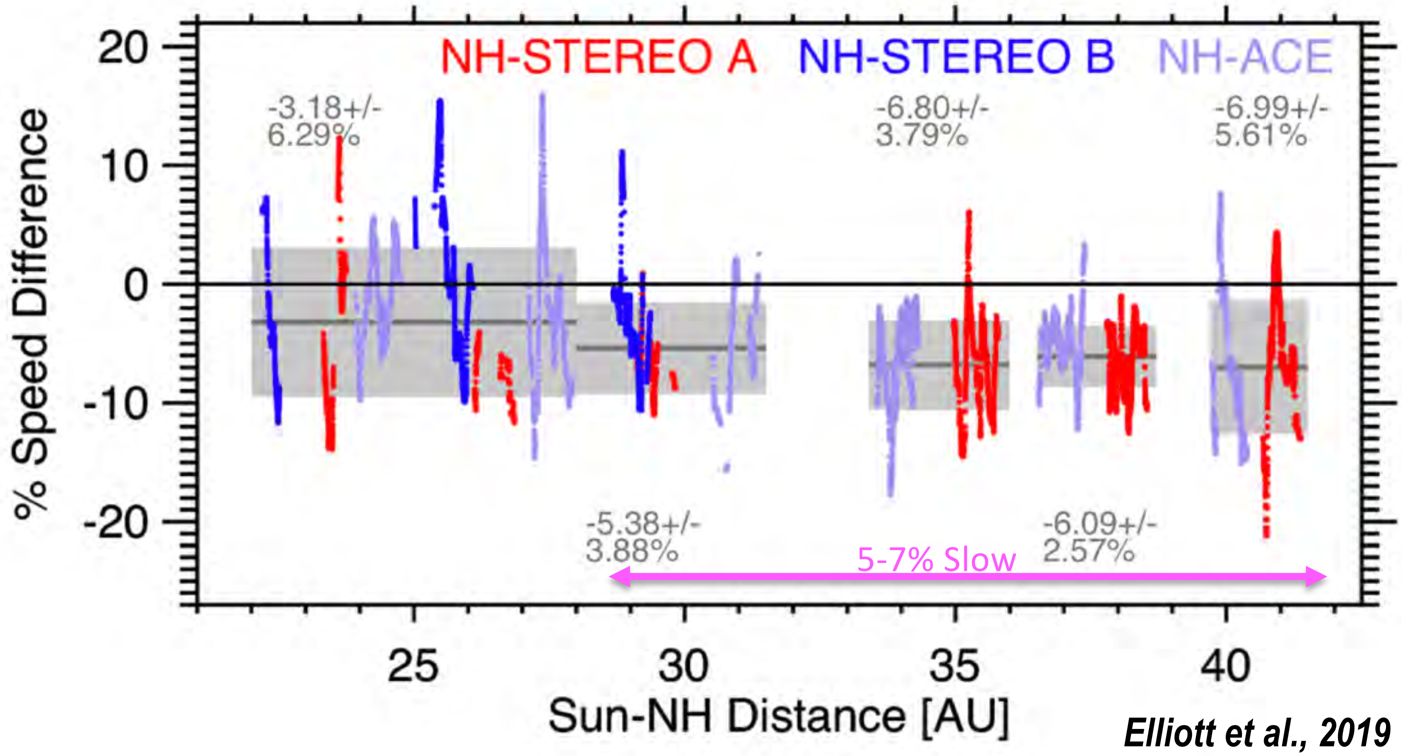
- SWAP data NOT averaged.
- 1 au data propagated and 25 day running average.
- Many structures at 1 au merge and/or are worn down prior to reaching NH.

Direct Comparison of Solar Rotation Averaged NH and 1 AU data



- Same format as previous plot with running solar rotation averages for the New Horizons data.
- Beyond late 2015 the speed at New Horizons is consistently lower than the 1 au speeds.

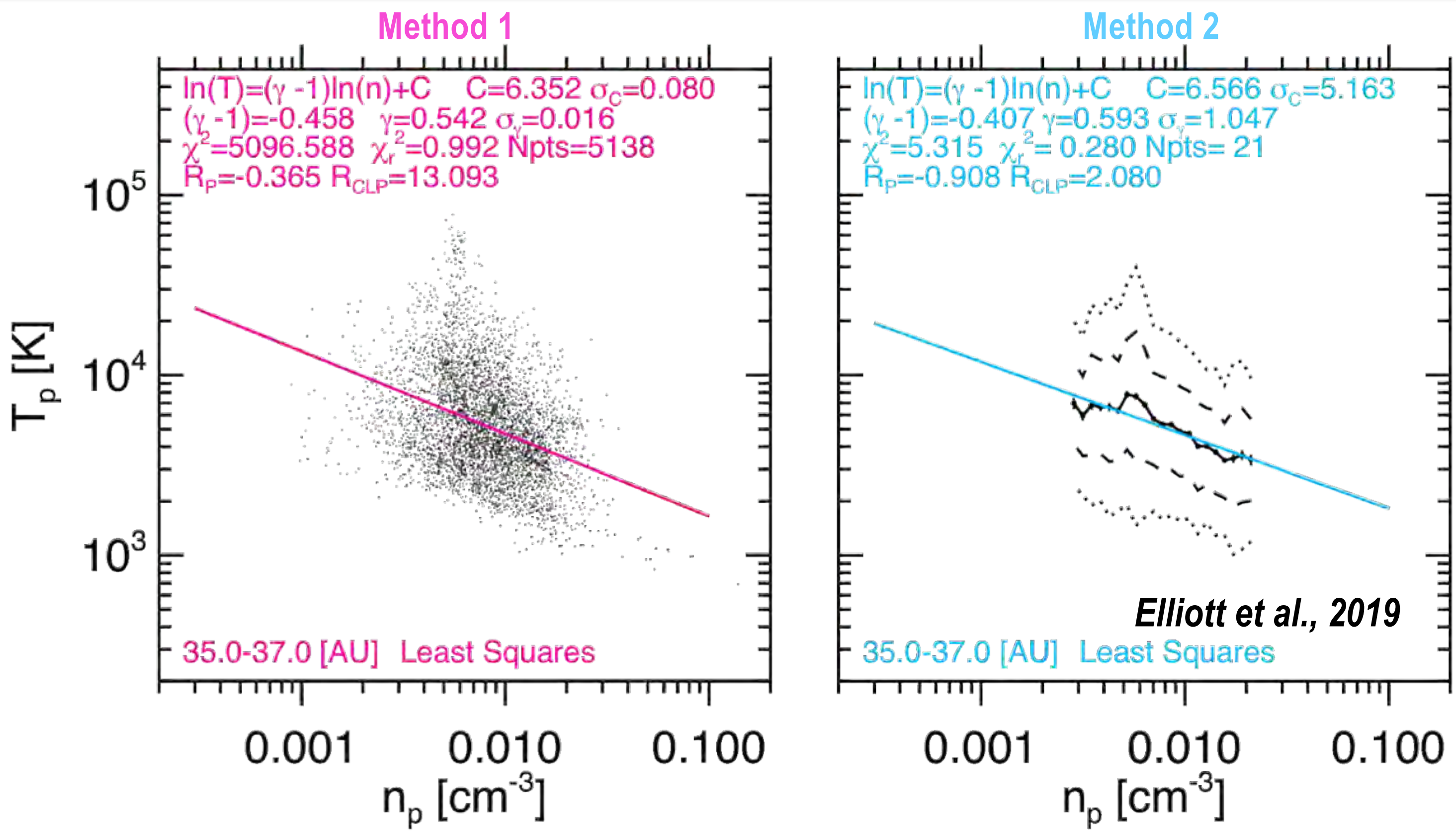
Radial Variation of Percent Slowing of the Solar Wind



Elliott et al., 2019

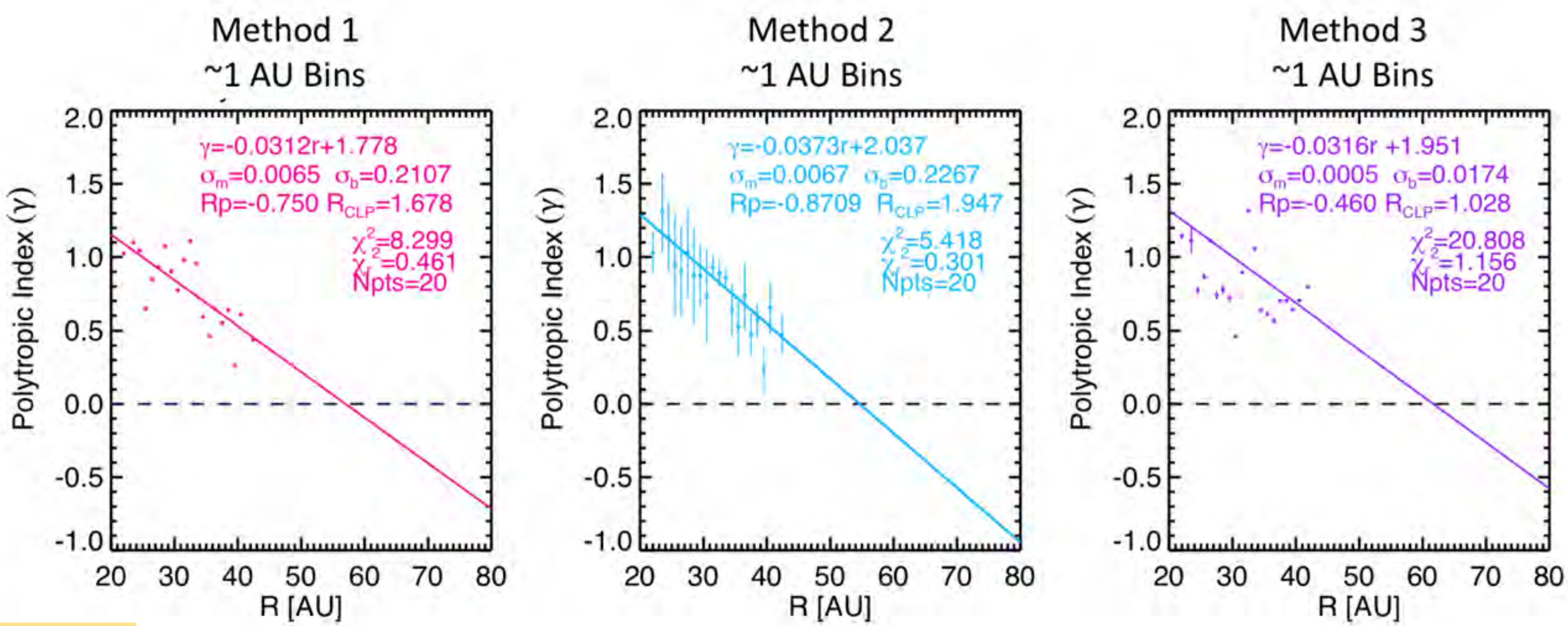
- Between 30 and 43 au New Horizons observes an averaging slowing of the solar wind ranging between 5 to 7% compared to 1 au speeds.

Determining the Polytropic Index (γ): Method 1 & 2



$$T = cn^{\gamma-1} \qquad \ln T = (\gamma - 1) \ln n + c \qquad \gamma = m + 1$$

Fitting the Solar Wind Polytropic Index (γ) Radial Profile

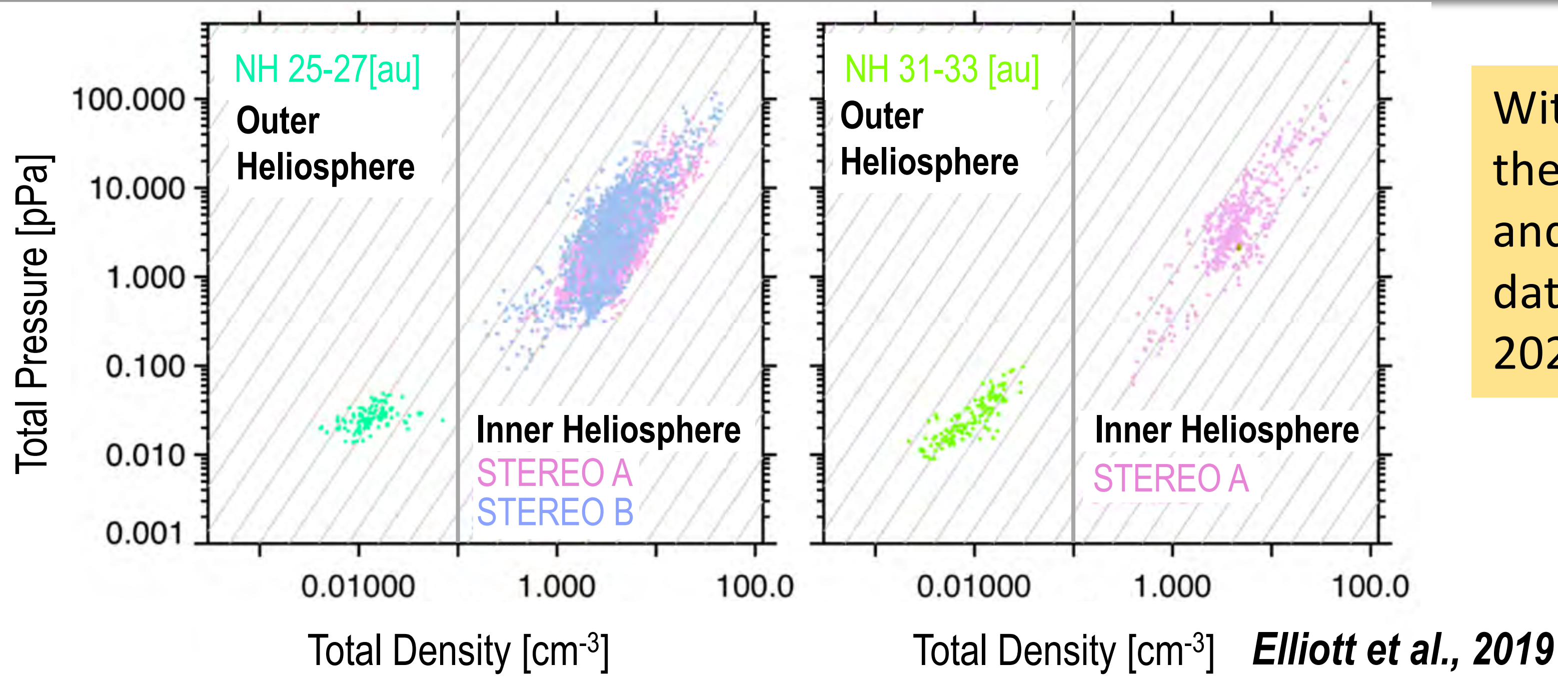


$$T = cn^{\gamma-1}$$

Elliott et al., 2019

- The solar wind polytropic index decreases towards 0 in the outer heliosphere.
- IBEX results indicate the plasma polytropic index is ~0 in the inner heliosheath.

Total (SW +PUI) Pressure Vs Density



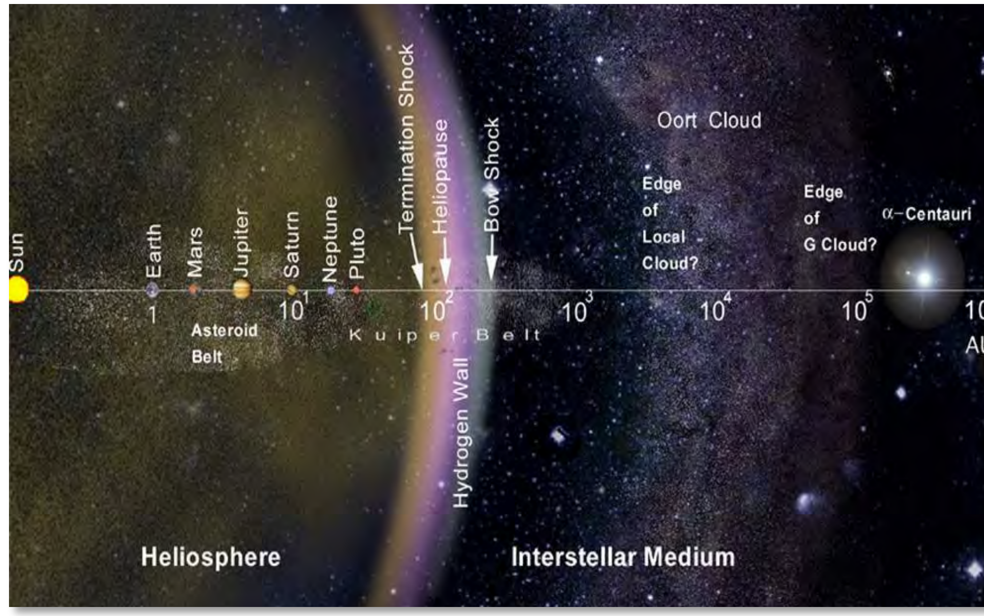
With SWAPI on IMAP there will be solar wind and interstellar pickup data at 1 au starting in 2025.

- Assume at 1 au no pickup.
- Used SW and PU at NH.
- The gray lines indicate adiabatic lines.

- The inner heliospheric data is close to adiabatic.
- The outer heliosphere data departs from adiabatic.
- The inner and outer heliosphere do not line along a common adiabatic line.

When Will New Horizons Reach the Termination Shock?

- New Horizons moves at ~14 km/s which corresponds to about 3 au/year.
- The Voyagers crossed the TS at 94 and 84 au during a very active solar cycle.
- NH is at ~49 au, and will reach 80 au in about 10.3 years and 95 au in ~15.3 years.
- Our current polytropic index estimate of a TS crossing at ~62 au provides a minimum time to reach the TS of ~4.3 years, since that was based on measurements from a less active cycle and the activity level is increasing.
- Based on these estimates depending on the solar cycle activity the time for NH to reach the TS could range from about 4 to 16 years.



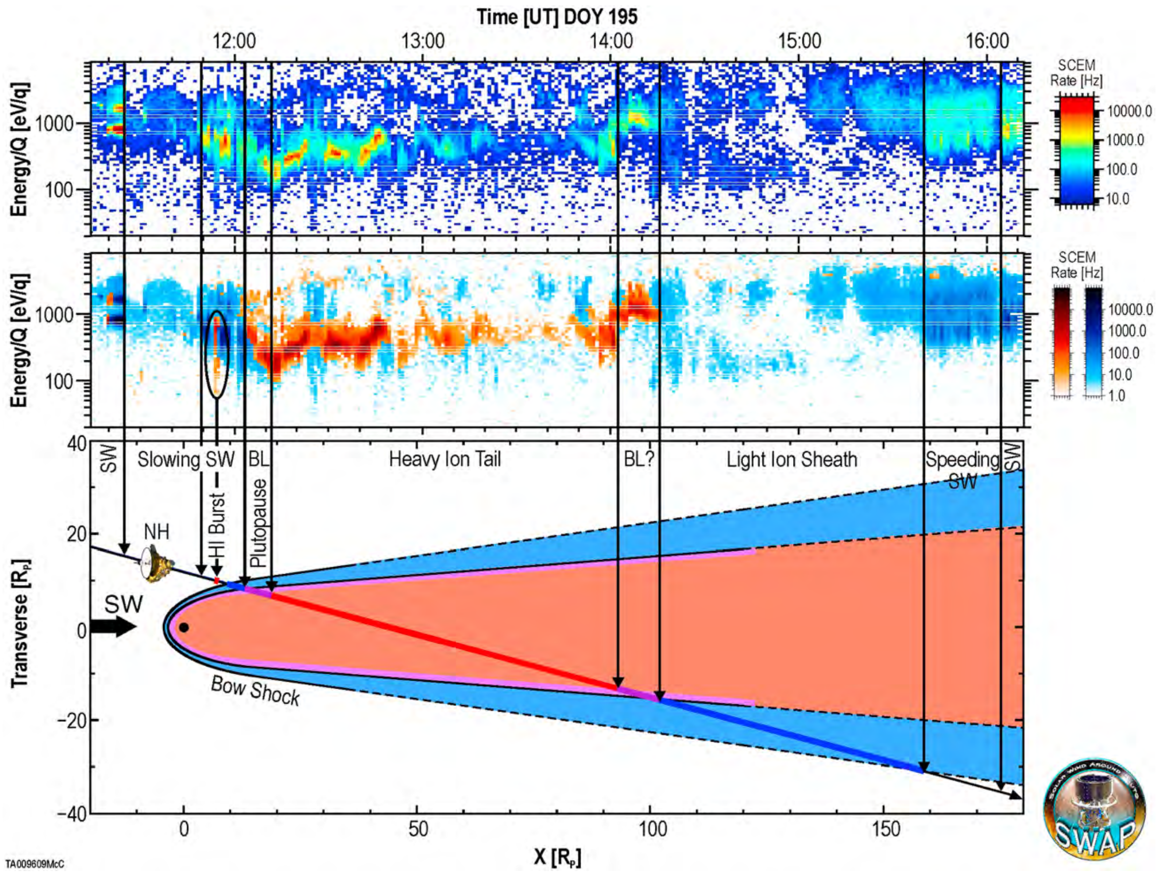
- Based on **initial** power estimates NH will have sufficient power to be on and operating until somewhere in the 90 to 110 au range (Stern et al. 2018, SSR).
- Therefore, it is highly likely NH will have power when it crosses the termination shock.

Summary and Conclusions

1. New Horizons is the only spacecraft in the solar wind.
2. It is headed towards the ribbon.
3. It can be used to study the solar wind and interstellar pickup ions in the outer heliosphere.
4. Provides valuable constraints for simulations.
5. NH will be the 1st mission to measure interstellar pickup ions and the solar wind when crossing the termination shock.

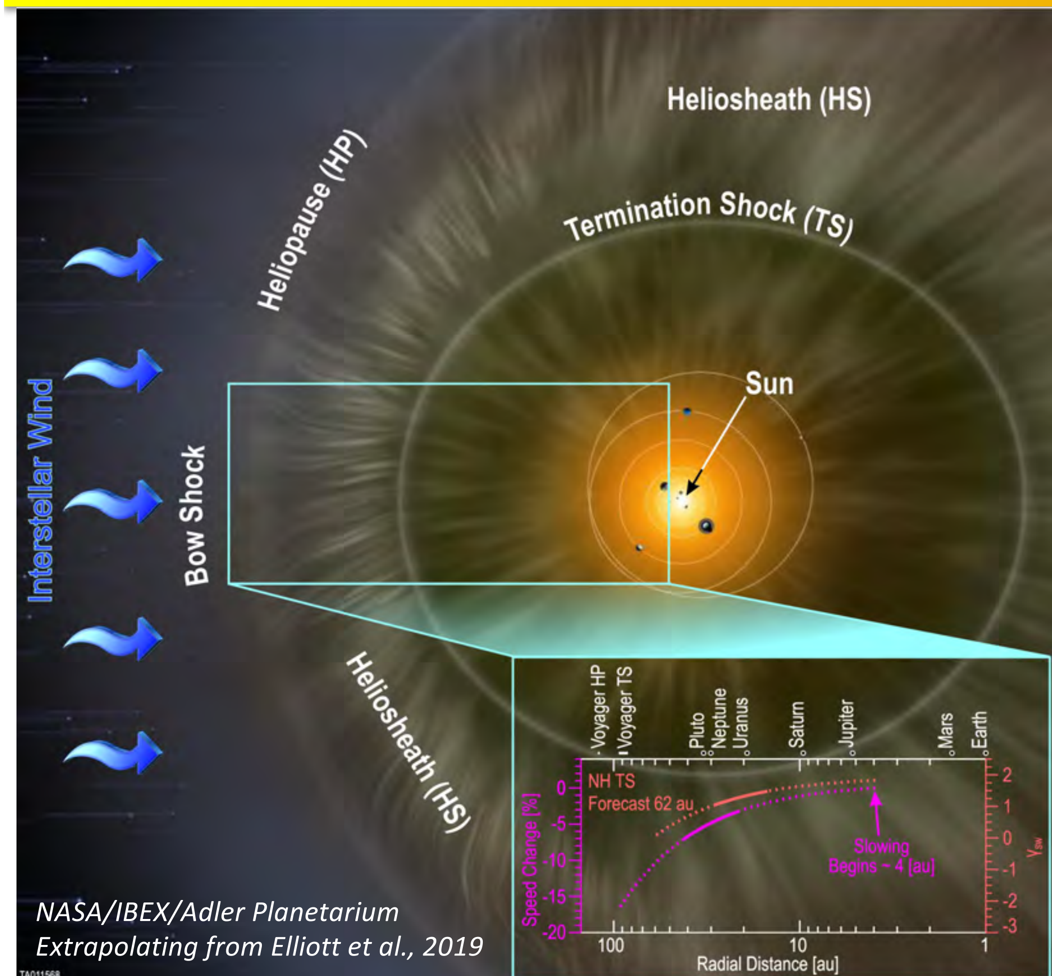
BACKUP

Pluto's Heavy Ion Tail



McComas et al. 2016

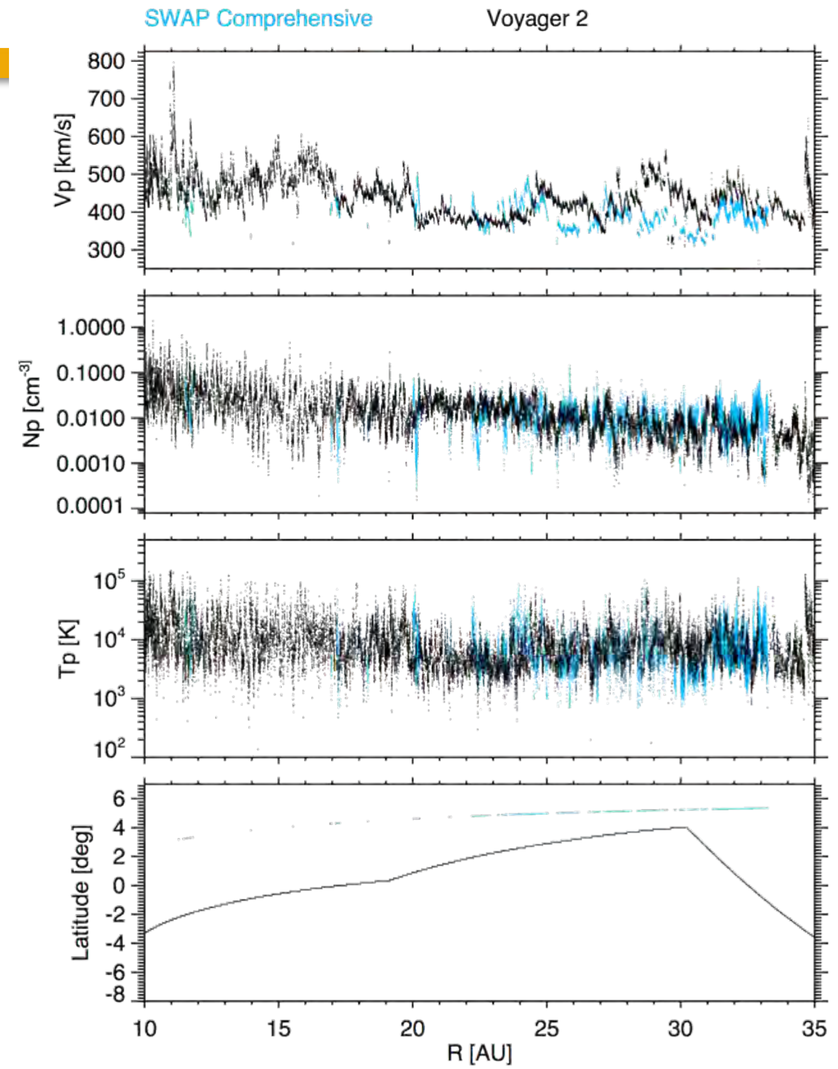
Implications



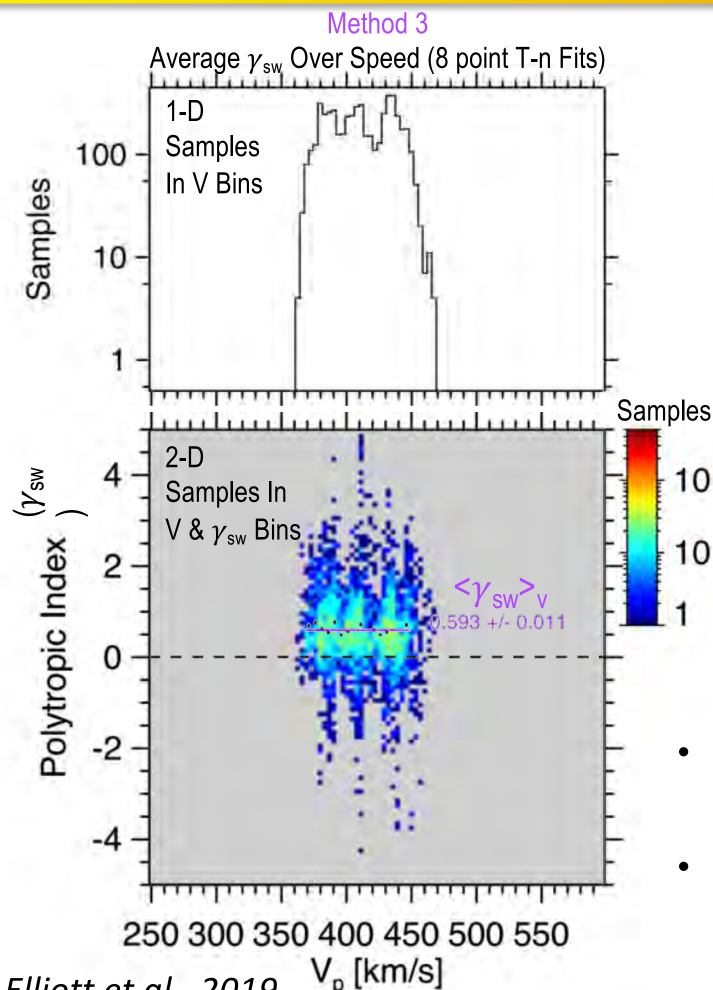
- Extrapolating the amount of slowing to the inner heliosphere we find the slowing begins around 4au.
- IBEX observations indicate the polytropic index goes to zero in the heliosheath.
- Extrapolating the solar wind polytropic index to find when it goes to 0 produces termination shock at ~62 au.
- However, the solar activity is increasing so New Horizons may cross the termination shock at a distance closer to the 84 to 94 au Voyager crossing distances.

Solar Activity Level

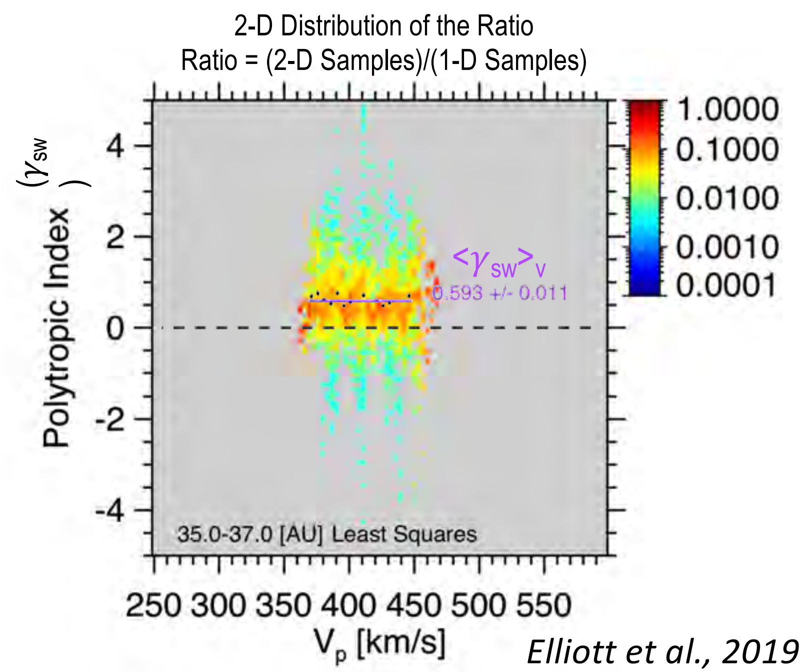
- Voyager 2 observed more variability in the outer heliosphere because that solar cycle was more active.
- Speeds at NH not as variable owing to lower activity levels



Determining the Polytropic Index (γ): Method 3s



Elliott et al., 2019



Elliott et al., 2019

- Fit 8 pairs of T & n measurements at a time using an running 8 point window for the entire data set.
- For a given radial distance range we average the polytropic index γ over speed.

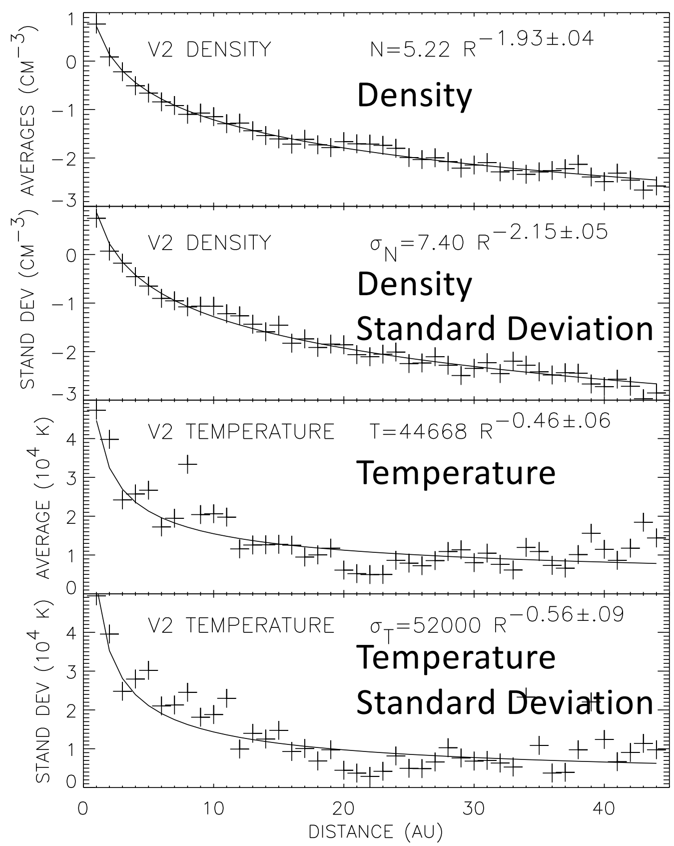
Amount of Slowing Depends on the Interstellar Material Picked Up

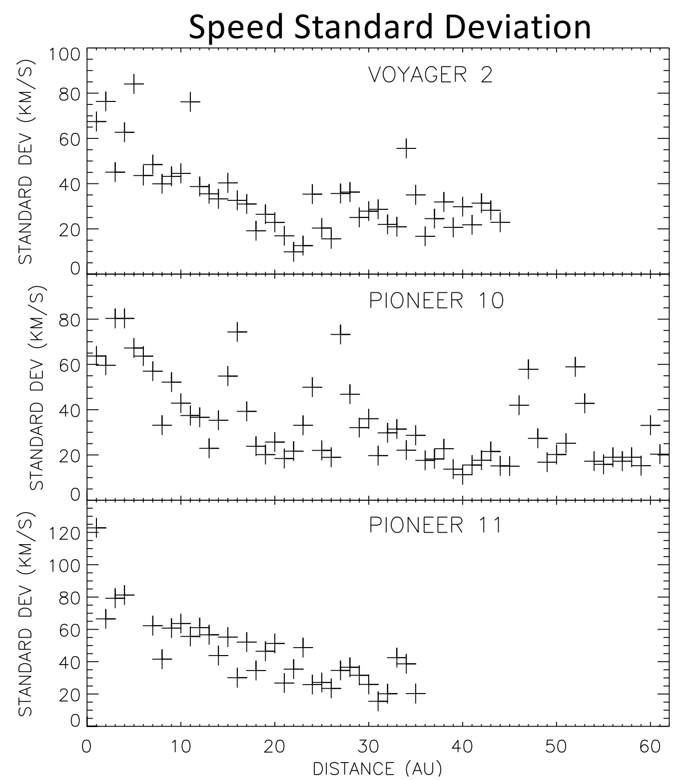
$$\frac{n_{pui}}{n_{sw}} = -\frac{\delta v}{v_{sw}}\left(\frac{2(2\gamma_{sw}-1)}{(3\gamma_{sw}-1)}\right)$$

Richardson et al., 1995

- Richardson et al. (1995) assumed an adiabatic heating profile and let $\gamma_{\mathrm{sw}} = 5/3$.
- This equation is derived by solving the continuity, and momentum equations.
- Includes photoionization, charge exchange, and constant interstellar neutral density in the outer heliosphere.
- Spherically expanding solar wind density profile.
- Here, we let γ_{sw} depend on distance (γ_{sw}(r)).
- The polytropic index is weakly dependent on radial distance.

Radial Trends from Voyager 2





Richardson et al., 1996