A clustering technique to separate alpha particles from protons in solar wind measurements: application to observations

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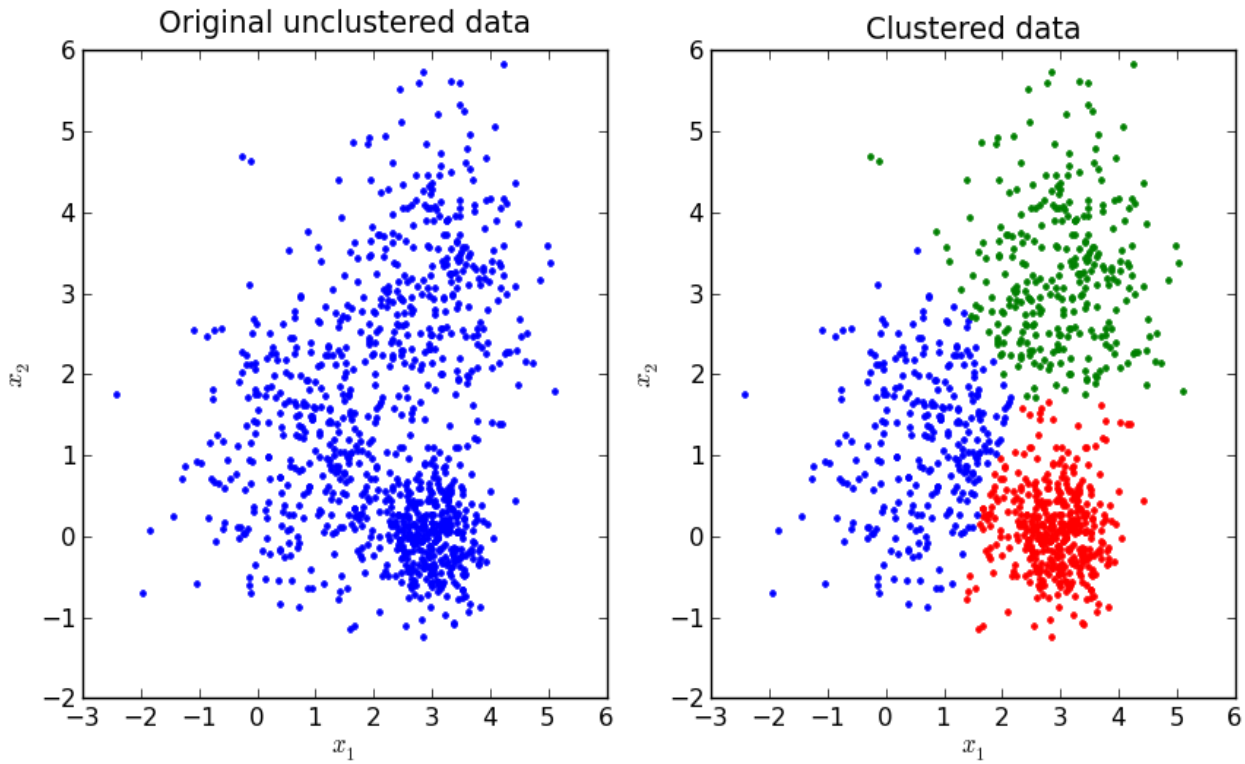
INAF-IAPS

Solar Orbiter SWA Team Meeting – Firenze, March 28-29, 2019

Clustering
Introduction

Clustering is the assignment of a set of observations into subsets so that observations in the same cluster are similar in "some sense"

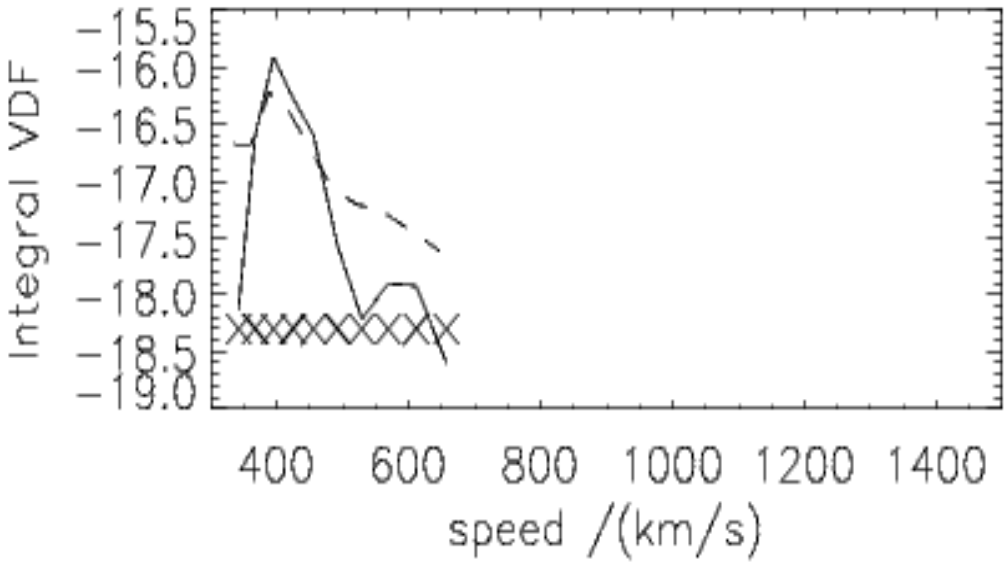


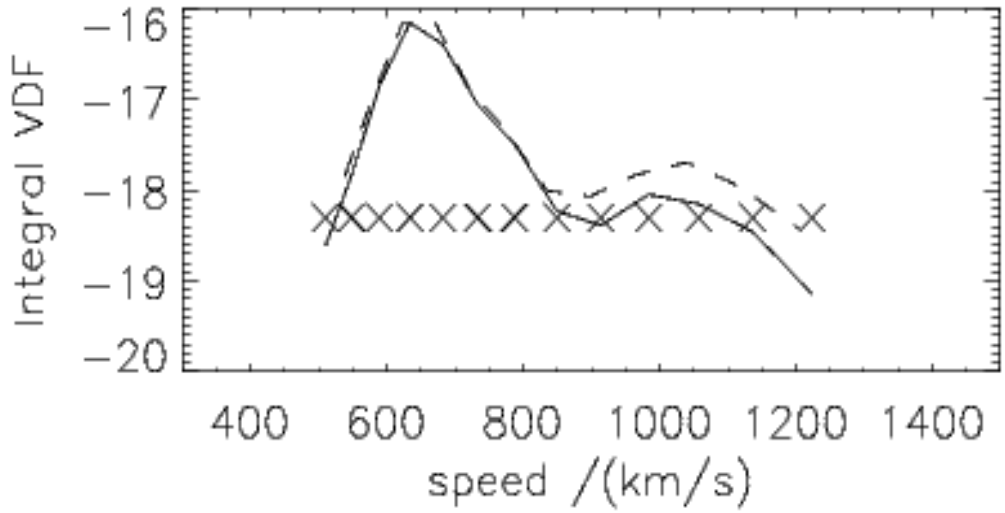
Solar wind measurements
Energy spectra

Since $m_\alpha = 4m_p$ and $q_\alpha = 2q_p$

$$\left(\frac{E}{q}\right)_\alpha = 2\left(\frac{E}{q}\right)_p$$

In solar wind measurements, energy distributions of different particles appear as different peaks in the same energy-per-charge spectrum





Gaussian mixture model
Introduction

We assume that solar wind measurements are distributed as a weighted linear combination of a finite number of multivariate normal distributions.

The Gaussian Mixture Model (GMM) is defined as the weighted sum of Gaussians.

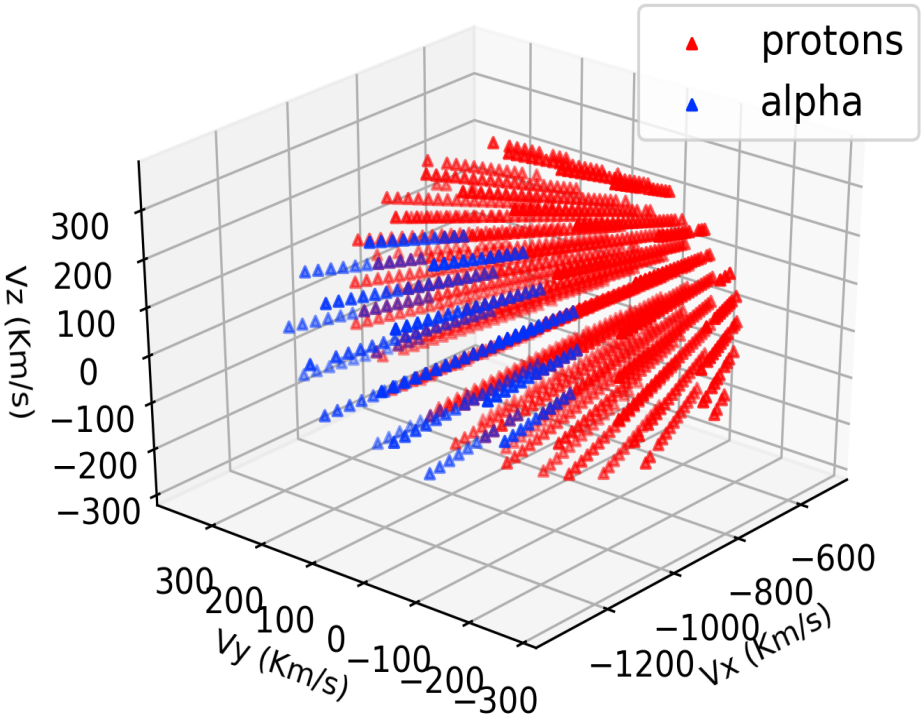
$$P(\vec{v}_i) = \sum_j w_j N(v_i | \vec{\mu}_j, \Sigma_j)$$

where $\sum_i w_1 = 1$

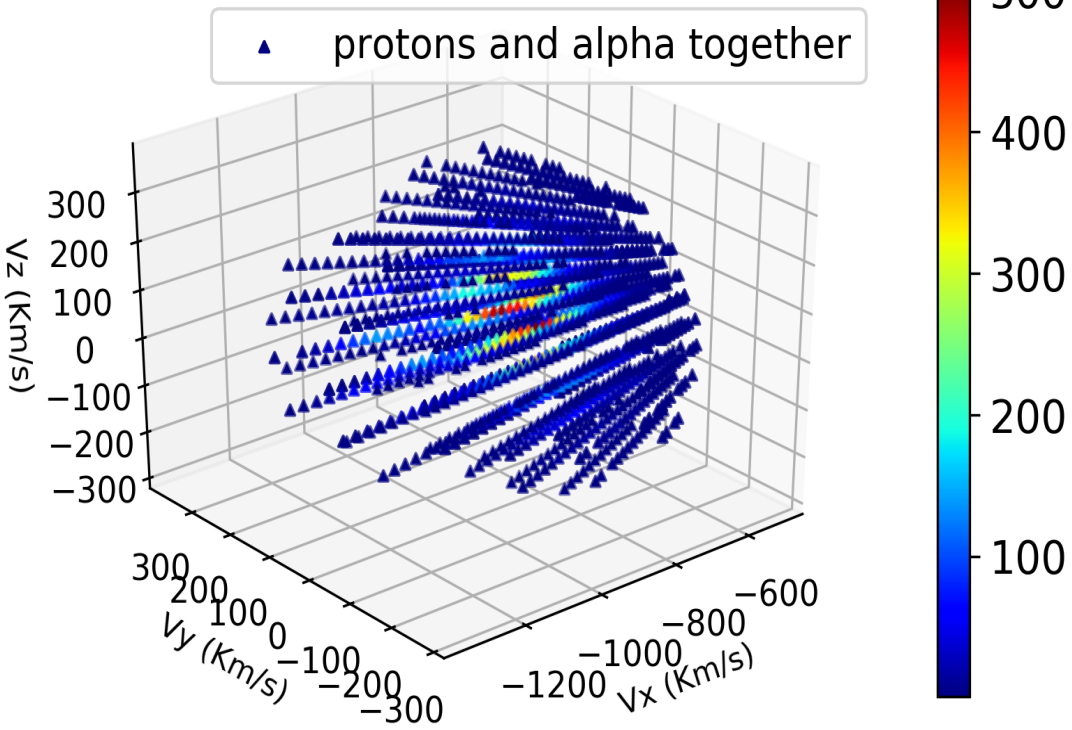
Example of particle indentification
using PAS simulator

given moments → simulate observations → separate particles

How they are



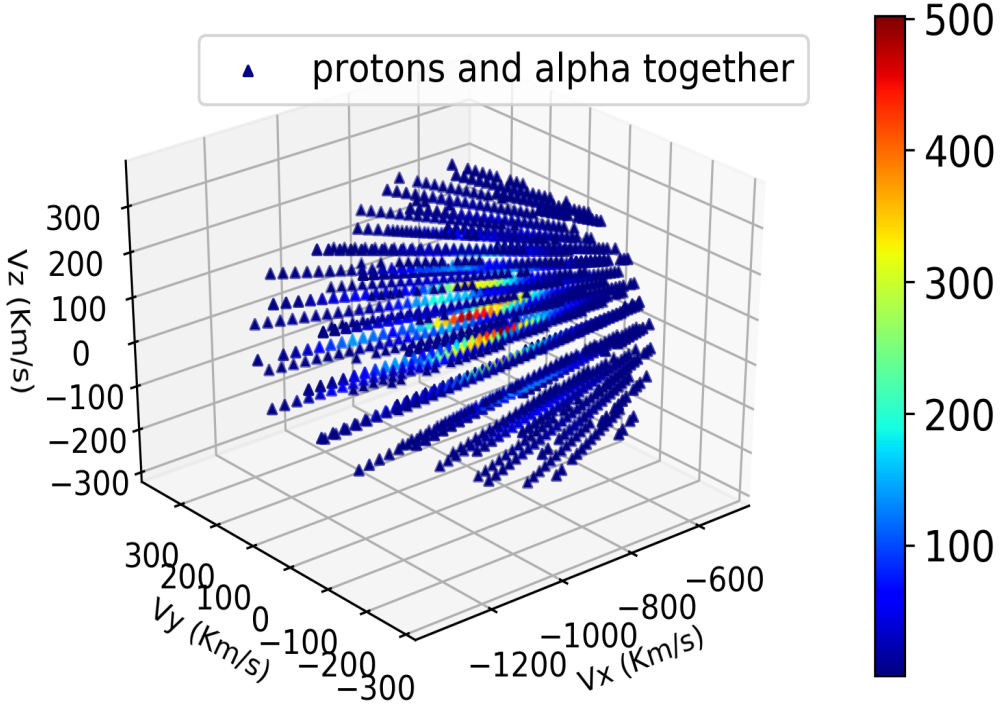
How they appear



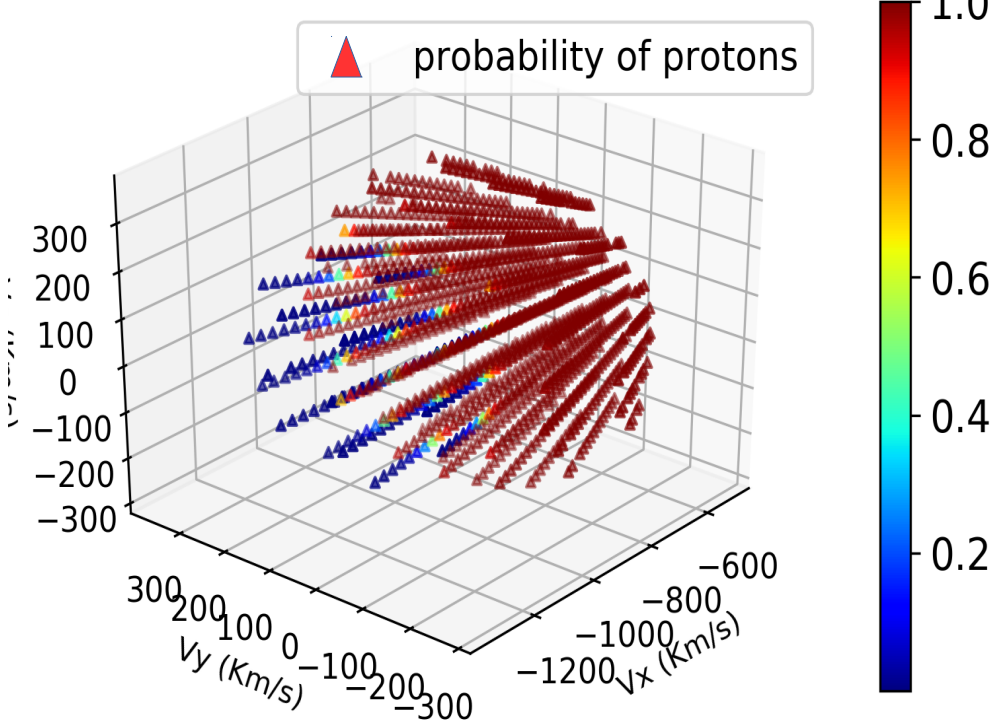
Example of particle indentification
using PAS simulator

given moments → simulate observations → separate particles

Input



Output



But what about real data?

Example of particle indentification
Real data

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 87, NO. A1, PAGES 35–51, JANUARY 1, 1982

Solar Wind Helium Ions: Observations of the Helios Solar Probes Between 0.3 and 1 AU

E. MARSCH,[1] K.-H. MÜHLHÄUSER,[2] H. ROSENBAUER,[1]
R. SCHWENN,[1] AND F. M. NEUBAUER[3]

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 87, NO. A1, PAGES 52–72, JANUARY 1, 1982

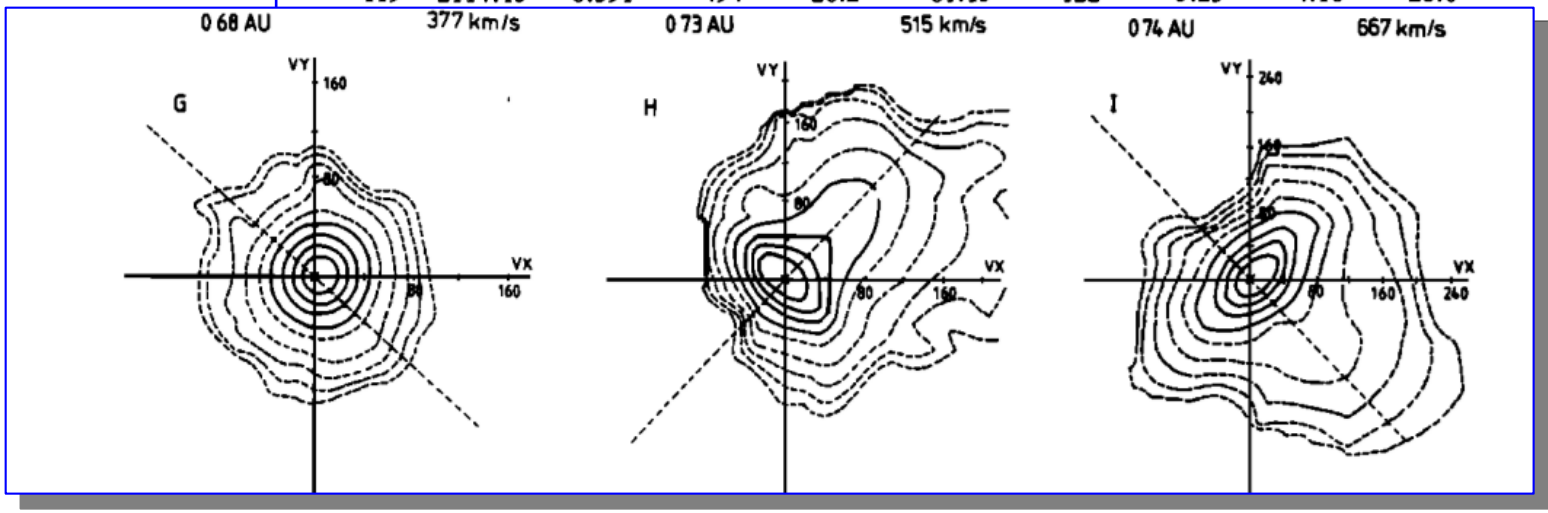
Solar Wind Protons: Three-Dimensional Velocity Distributions and Derived Plasma Parameters Measured Between 0.3 and 1 AU

E. MARSCH[1], K.-H. MÜHLHÄUSER[2], R. SCHWENN[1],
H. ROSENBAUER[1], W. PILIPP[2], AND F. M. NEUBAUER[3]

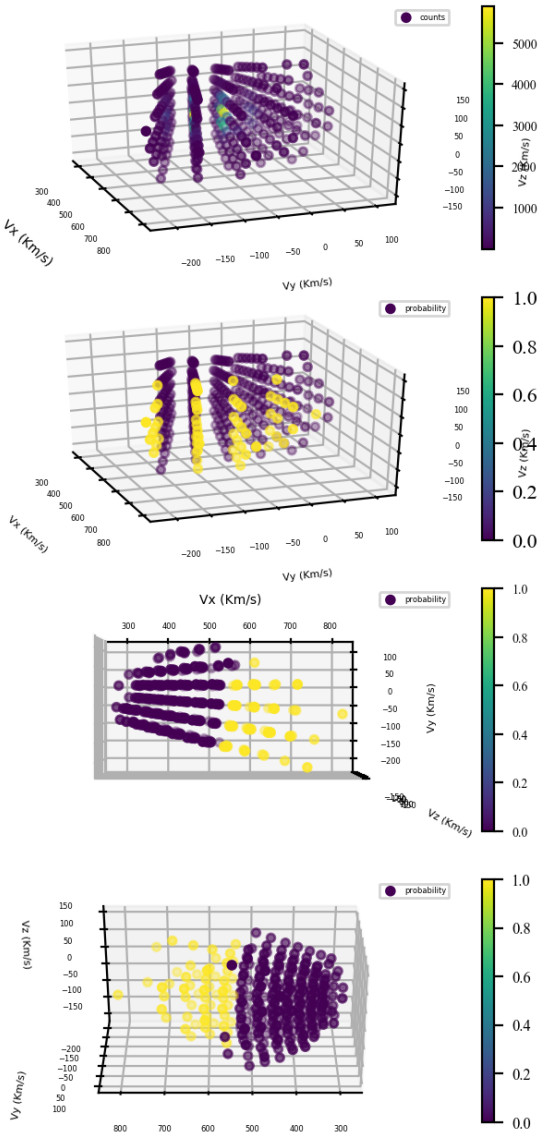
Example of particle indentification
Real data

TABLE 1. Solar Wind Parameters for Figure 4

Day 1976	Time, UT	R, AU	$\lvert v_P \rvert$, km/s	n_P, cm^{-3}	$\lvert Q_P \rvert$, 10^{-4} erg/cm^{2}s	v_D, km/s	$T_{\lVert P}$, 10^5 °K	$T_{\perp P}$, 10^5 °K	B, 10^{-5} G	α_B, deg	ε_B, deg	$f(v_M)$, 10^{-20}cm^{-6} s^3	Letter
30	1634:21	0.964	360	17.3	0.20	···	0.48	0.39	8.2	71.7	7.2	18.93	A
35	1021:43	0.949	479	6.7	1.83	67.7	1.81	1.12	6.8	−67.6	21.1	1.33	B
23	1150:54	0.978	717	2.1	5.17	···	3.43	2.62	4.7	134.3	45.3	0.34	C
73	2134:54	0.681	377	20.6	5.08	···	0.94	0.36	12.7	124.3	6.8	22.80	D
71	1952:25	0.703	515	4.4	4.15	···	2.84	0.81	9.4	−39.9	−2.8	1.87	E
67	2232:33	0.742	667	5.6	9.35	···	3.13	3.30	9.4	−80.5	44.2	0.30	F
122	0157:09	0.421	359	139.6	2.08	···	0.75	0.80	17.6	145.8	34.4	59.43	G
88	0351:25	0.504	463	21.2	45.15	···	4.15	1.92	17.8	36.3	17.2	2.57	H
85	1132:18	0.546	618	10.4	15.00	···	2.67	2.88	17.2	−16.5	38.8	0.96	I
102	0933:49	0.319	360	129.0	111.90	···	2.23	0.88	33.5	156.1	−15.9	70.92	J
119	2114:15	0.391	494	26.2	81.15	122	5.23	4.10	28.0	−166.5	27.6	0.97	K
										141.5	−21.0	0.43	L

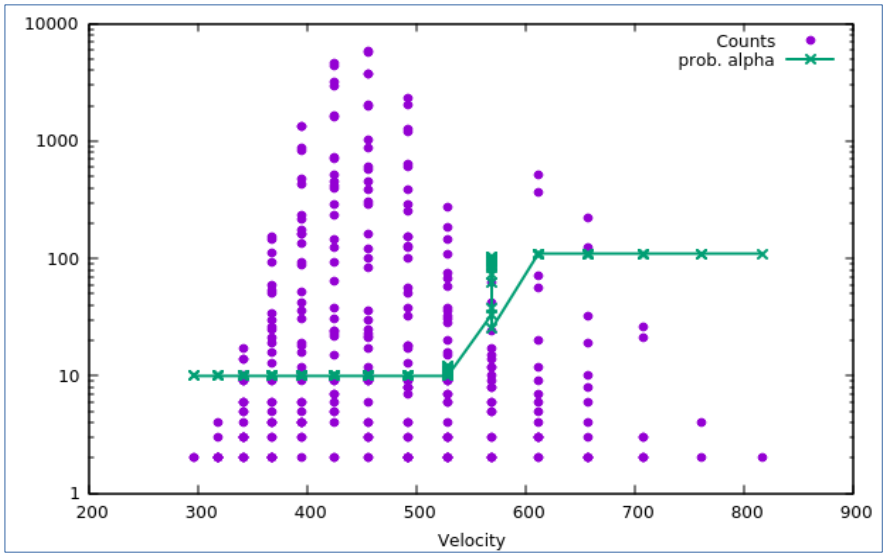


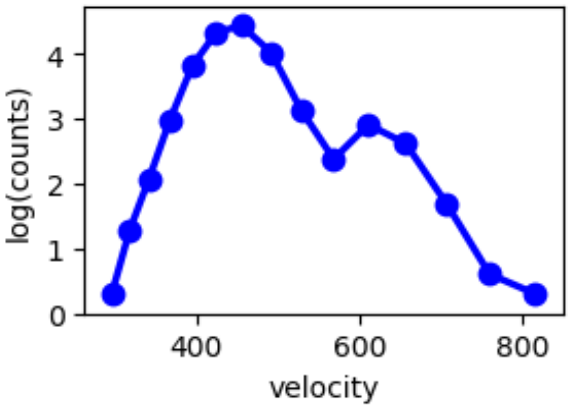
Example of particle indentification
using observations: slow wind



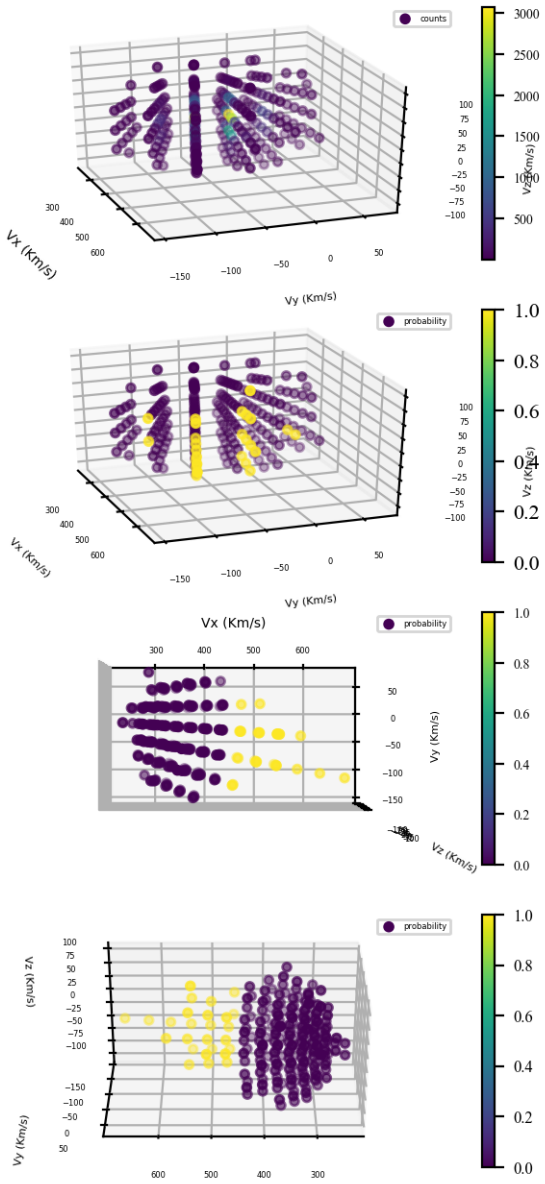
	CDAWEB	Marsch et al.	Clustering
density alpha	6.48	5.67	7.7
velocity alpha	418.3	441	435.7
Temp. alpha (x10^5 K)	2.016	2.19/1.86	2.86/2.7
density protons	279.19	--	208.31
Velocity protons	423.9	--	440.1
Temp. protons (x10^5 K)	0.98	--	1.25

d102h18m40s51



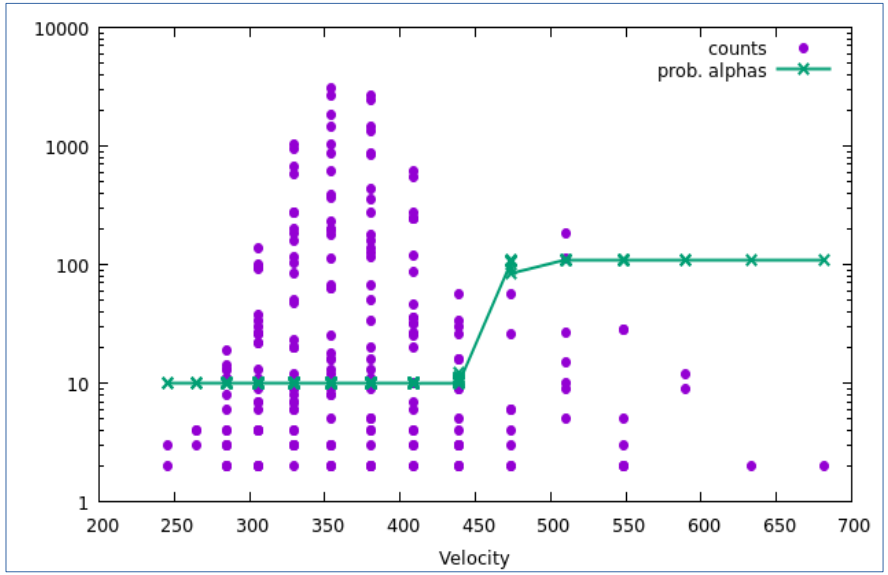


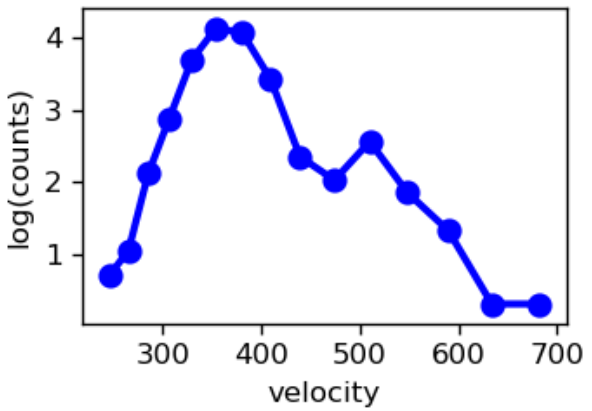
Example of particle indentification
using real observation: slow wind



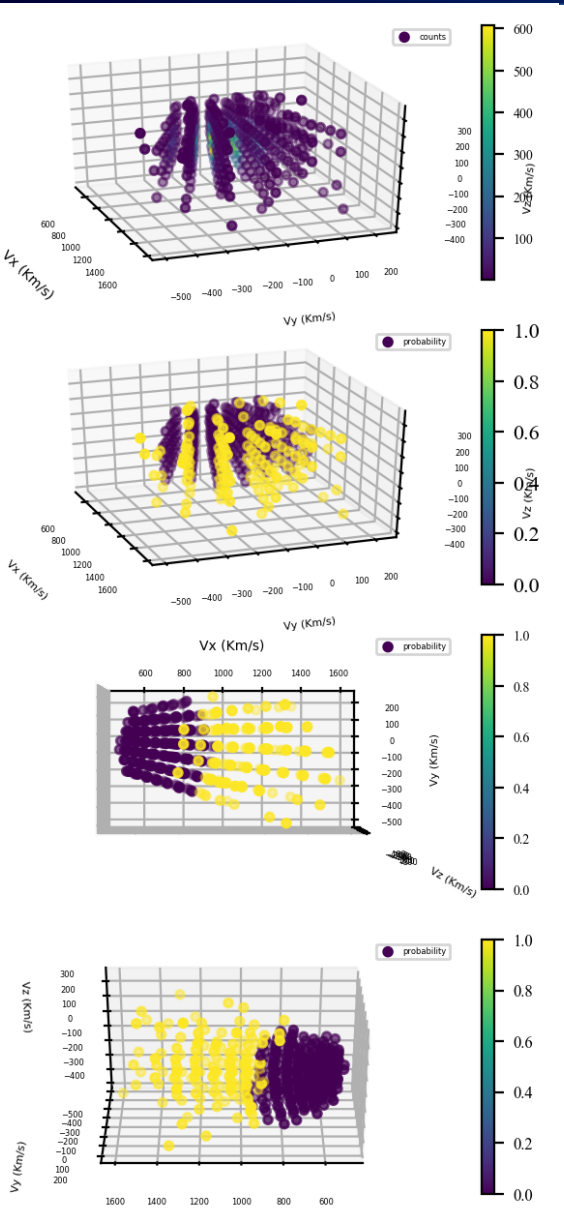
	CDAWEB	Marsch et al.	Clustering
density alpha	2.4	--	2.86
velocity alpha	382.9	--	360
Temp. alpha (x10^5 K)	1.36	--	1.52/1.96
density protons	151.66	139.6	123
Velocity protons	383.9	359	359.5
Temp. protons (x10^5 K)	0.61	0.75/0.80	0.74/0.84

d122h01m57s09



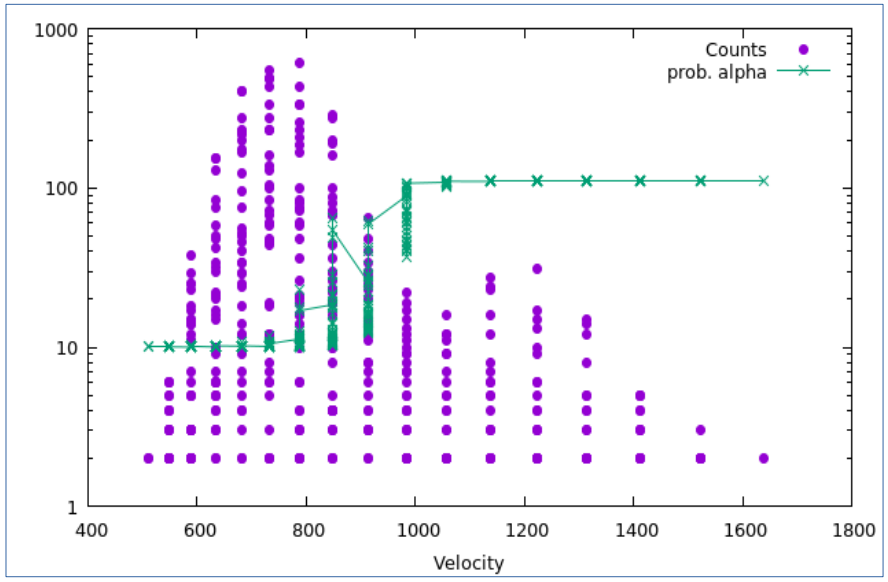


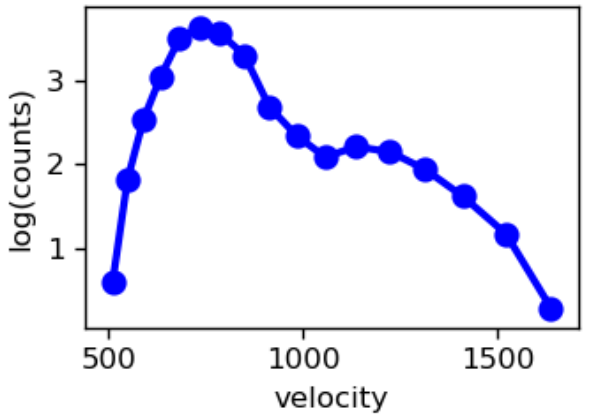
Example of particle indentification
using observations: fast wind



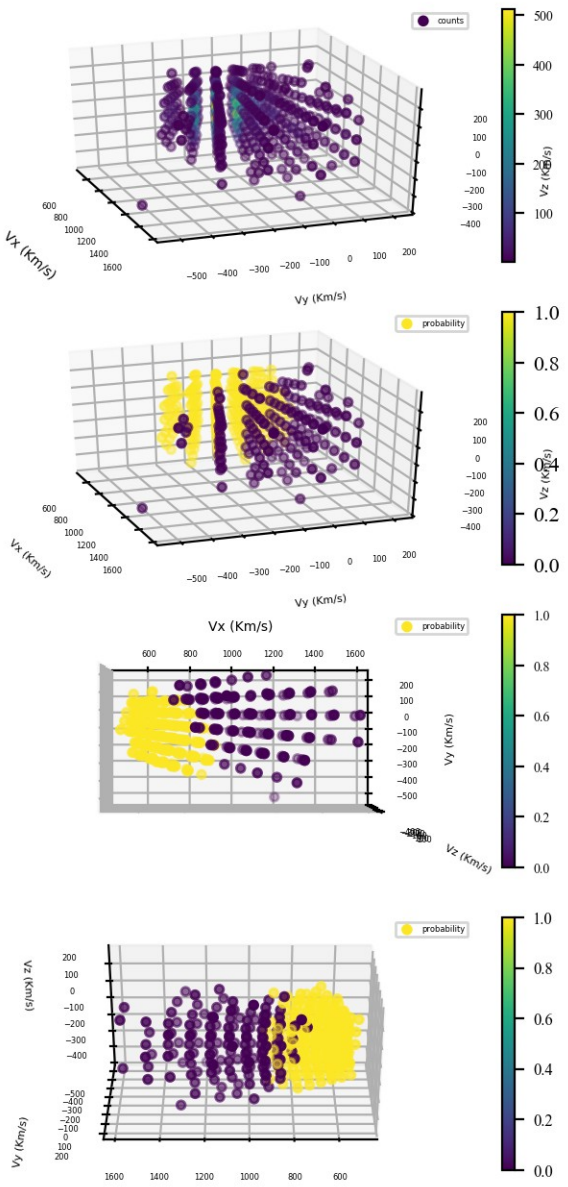
	CDAWEB	Marsch et al.	Clustering
density alpha	0.92	0.88	1.76
velocity alpha	816	867	781
Temp. alpha (x10^5 K)	13.8	45.44/36.47	60.26/37.41
density protons	30.37	--	27.8
Velocity protons	734.5	--	732.3
Temp. protons (x10^5 K)	5.54	--	7.03

d108h01m01s14





Example of particle indentification
using observations: fast wind



	CDAWEB	Clustering
density alpha	-1.000E+31	1.64
velocity alpha	-1.000E+31	786
Temp. alpha (x10^5 K)	-1.000E+31	44.87/35.06
density protons	28.1	24.46
Velocity protons	723.3	727
Temp. protons (x10^5 K)	5.51	6.95

d107h07m50s13