Influence of solar wind parameters on unsupervised solar wind classification

S. Teichmann [1], V. Heidrich-Meisner [2] , R. Wimmer-Schweingruber [2]
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ML Helio
23.03.2022

Solar wind and solar wind classification

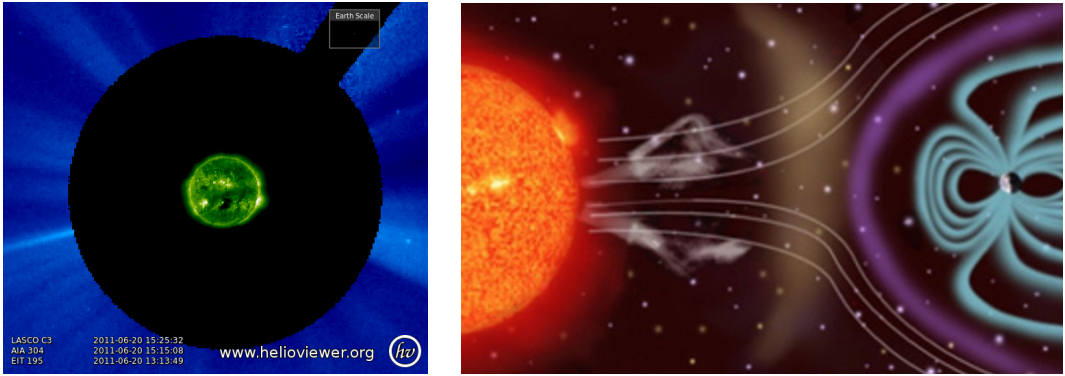


Figure: Left: Instruments on SOHO (Solar and Heliospheric Observatory): LASCO (Large Angle and Spectrometric Coronagraph) and EIT (Extreme ultraviolet Imaging Telescope), Right: Schematic display of the Sun, solar wind and Earth by ESA [2]. Visualisation of the 3 motivation for solar wind classification: understanding the origin, transport effects and space weather.

Solar wind classification - transport effects

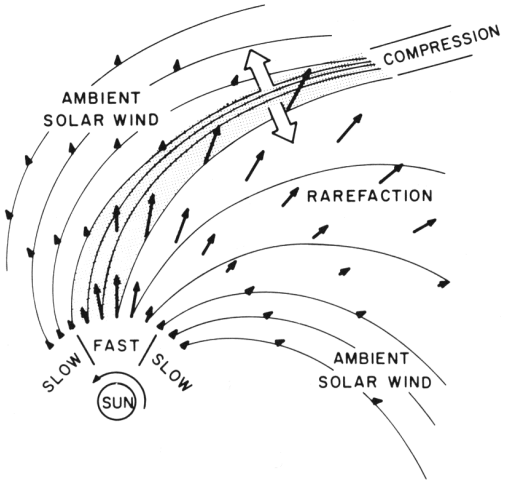


Figure: Visualisation of Stream interaction regions by Jian [3]

Parameters

density (n_{sw}) mean density of protons in the solar wind

velocity (v_{sw}) mean velocity of protons in the solar wind

temperature(T_{sw}) mean temperature of protons in the solar wind

magnetic field (B) absolute value of the magnetic field

collisional age (a_{col}) number of collisions in the plasma

oxygen ions ($n_{O^{7+}}/n_{O^{6+}}$) ratio between the densities O^{7+} and O^{6+}

Iron ions (q_{Fe}) mean charge state of iron

instruments on ACE:

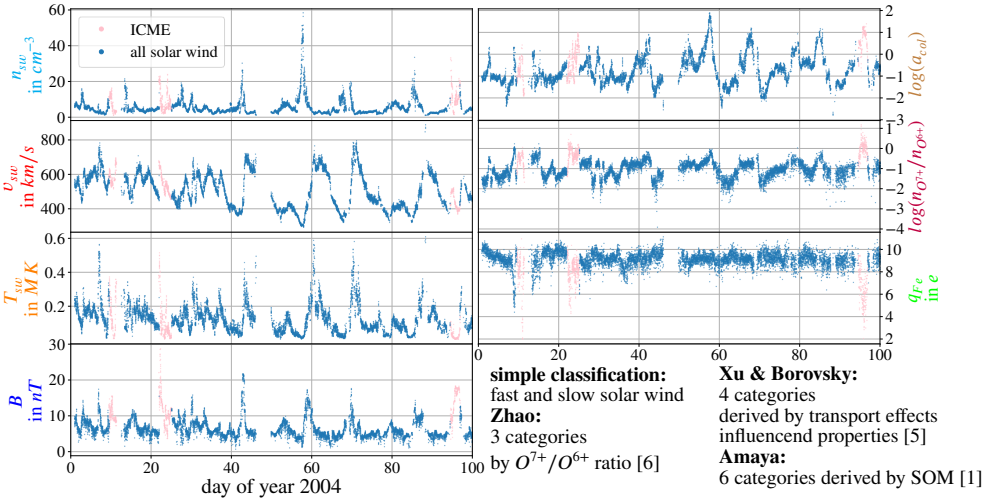
- Solar Wind Electron Proton and Alpha Monitor (SWEPAM)
- Solar Wind Ion Composition Spectrometer (SWICS)
- Magnetometer (MAG)

timeframe : 2001-2011

number of points in dataframe: 258574 (with ICME: 282231)

Figure: Logo of the Ace Mission [4]

Existing classifications



simple classification:
fast and slow solar wind
Zhao:
3 categories
by O^{7+}/O^{6+} ratio [6]

Xu & Borovsky:
4 categories
derived by transport effects
influencend properties [5]
Amaya:
6 categories derived by SOM [1]

⇒ transport effect vs. origin based classifications

How it's done: k-means clustering

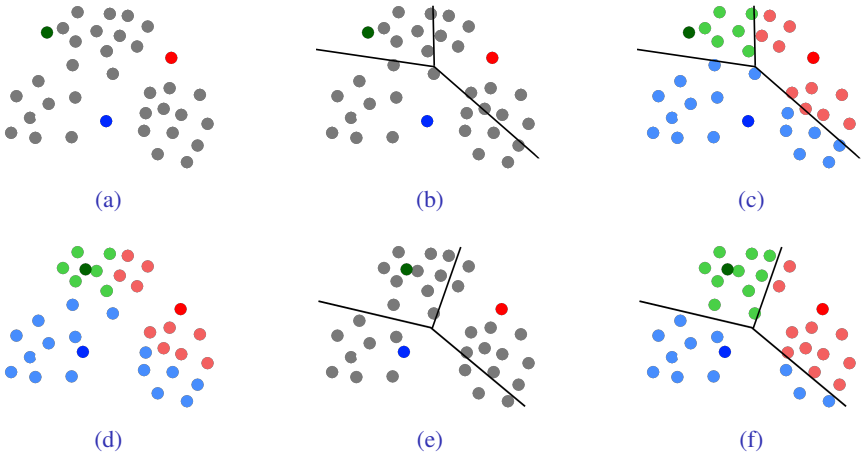
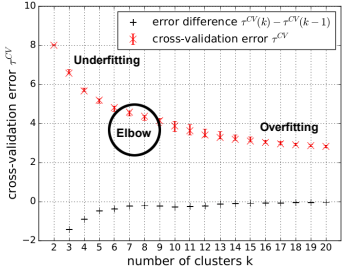


Figure: Visualisation of k-means clustering by Heidrich-Meisner. Implementation: sklearn version 0.23.2 in python version 3.9.2

How to choose k or on the number of solar wind types



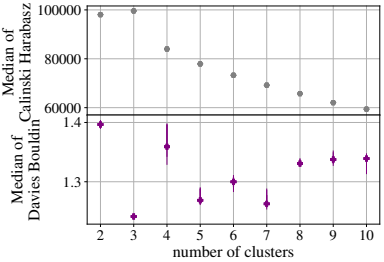


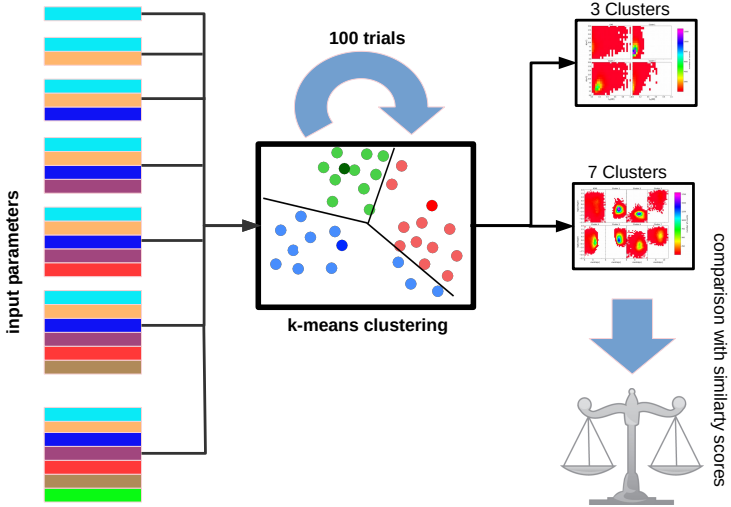
Figure: Left: Elbow plot by Heidrich-Meisner on the same dataset. Right: Elbow plot based on the experimental settings

⇒ resulting cluster are not convex

⇒ **k=3** and **k=7**

- **Cross validation error:** inner cluster distance
- **Calinski Harabasz score:** sum of between-clusters dispersion and of within-cluster dispersion
- **Davies Bouldin score:** average similarity between clusters

The experiment: variation of input parameters



How to evaluate the results

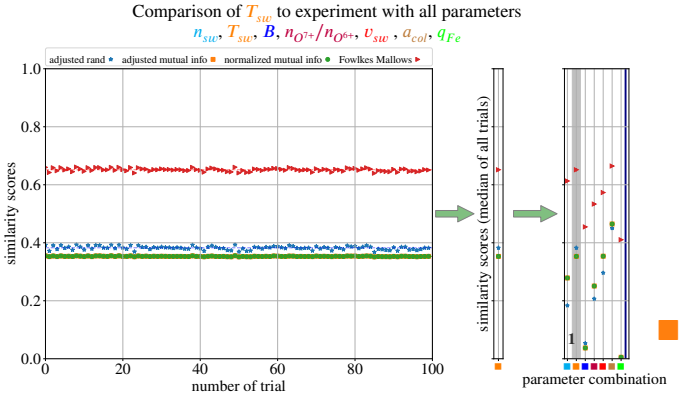
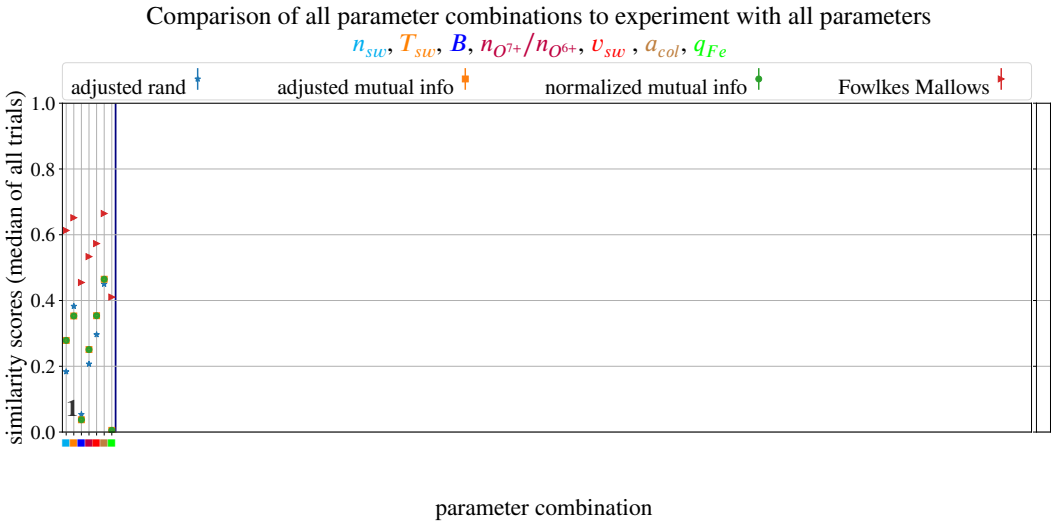


Figure: Schematic demonstration how the results for each parameter combination is evaluated on the example of T_{sw} .

- **Fowlkes Mallows score:** ranges from 0 to 1 based on statistical errors (true positive ...)
- **Adjusted rand score:** ranges from -1 to 1 counting pairs that are the same and differently labelled
- **Mutal information score:** **adjusted** and **normalized**, ranges from 0 to 1, shared information of two clusterings & if adjusted for chance effects

3 Clusters - overview of the results



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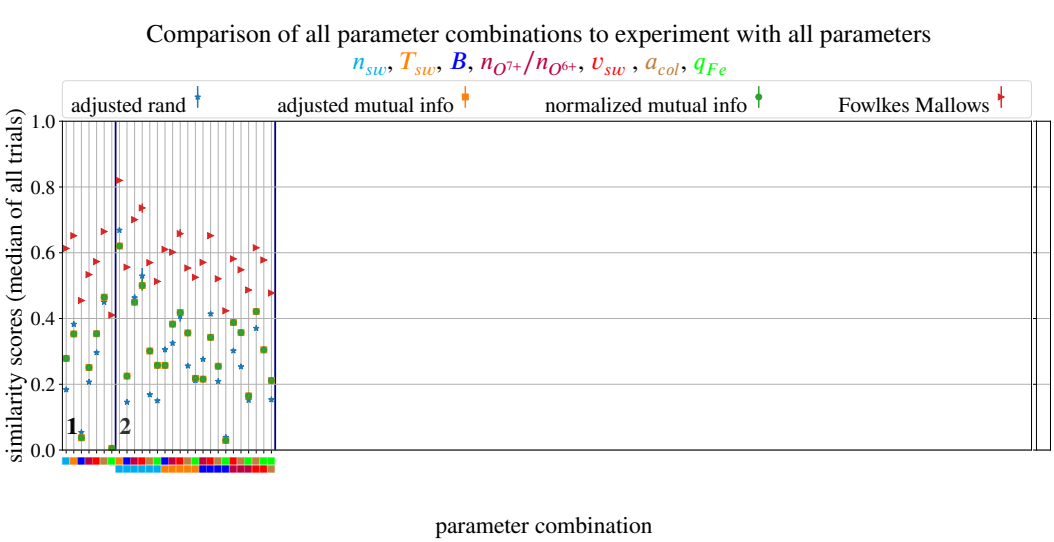

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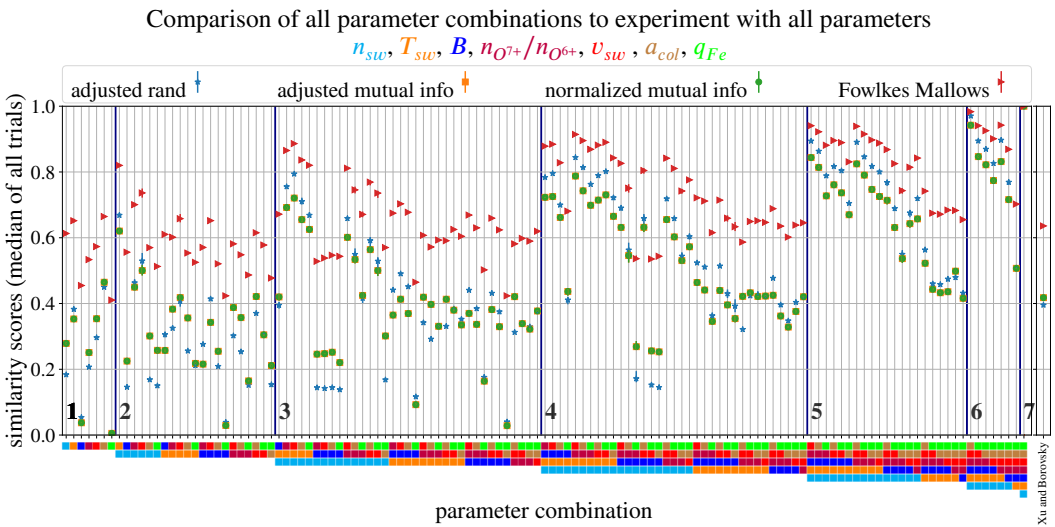

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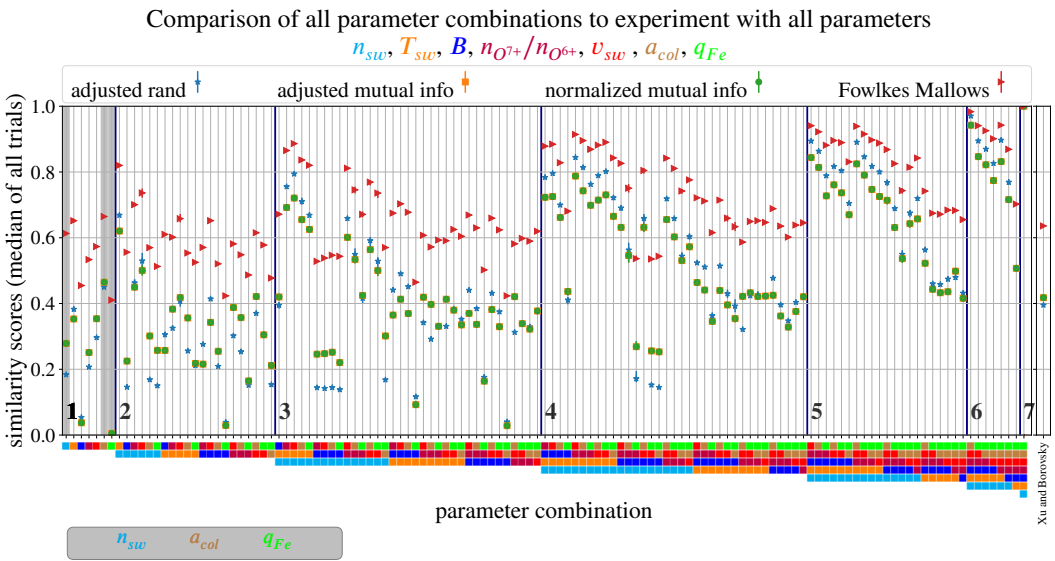
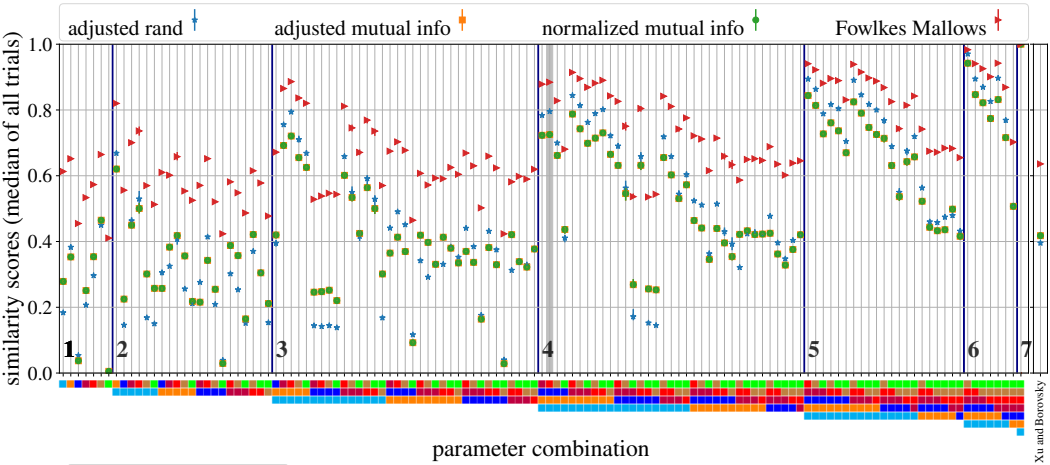


3 Clusters - overview of the results

Comparison of all parameter combinations to experiment with all parameters

n_{sw}, T_{sw}, $\boldsymbol{B}$, $n_{O^{7+}}/n_{O^{6+}}$, v_{sw} , a_{col}, q_{Fe}



n_{sw},T_{sw},$\boldsymbol{B}$,v_{sw}

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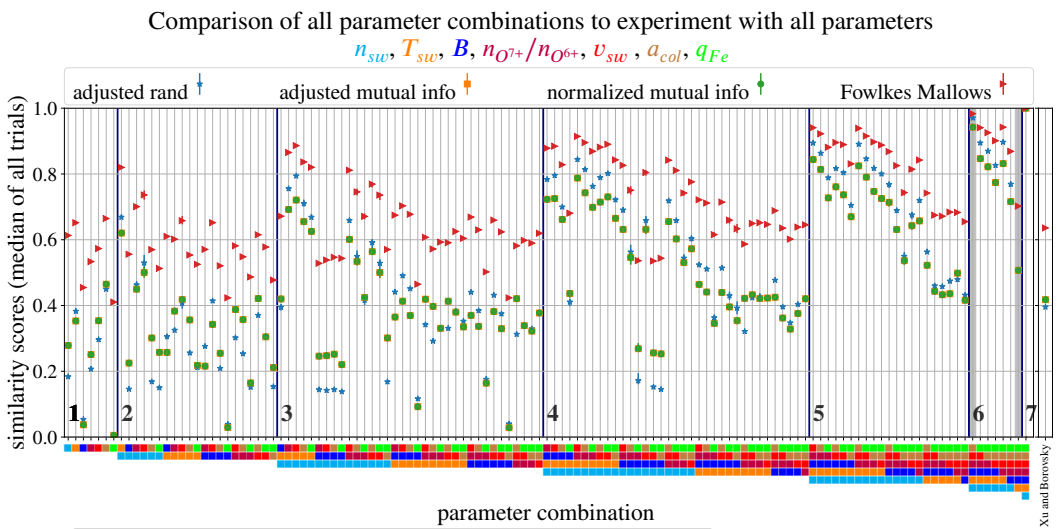

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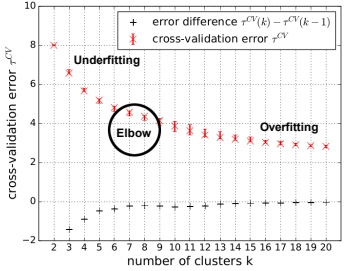

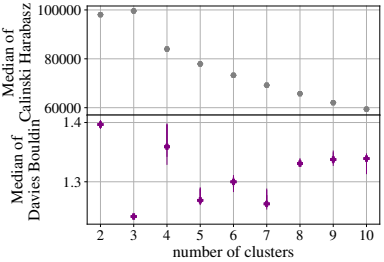

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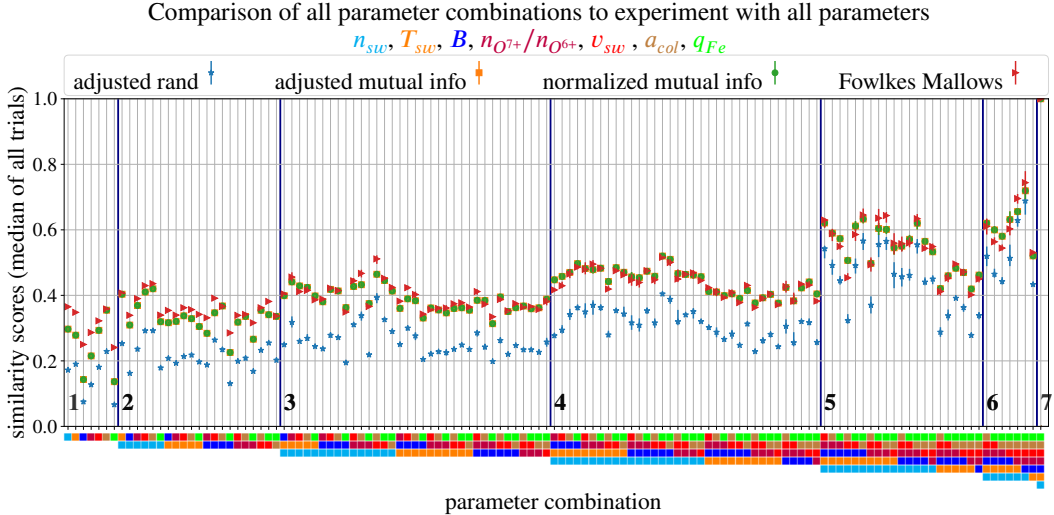

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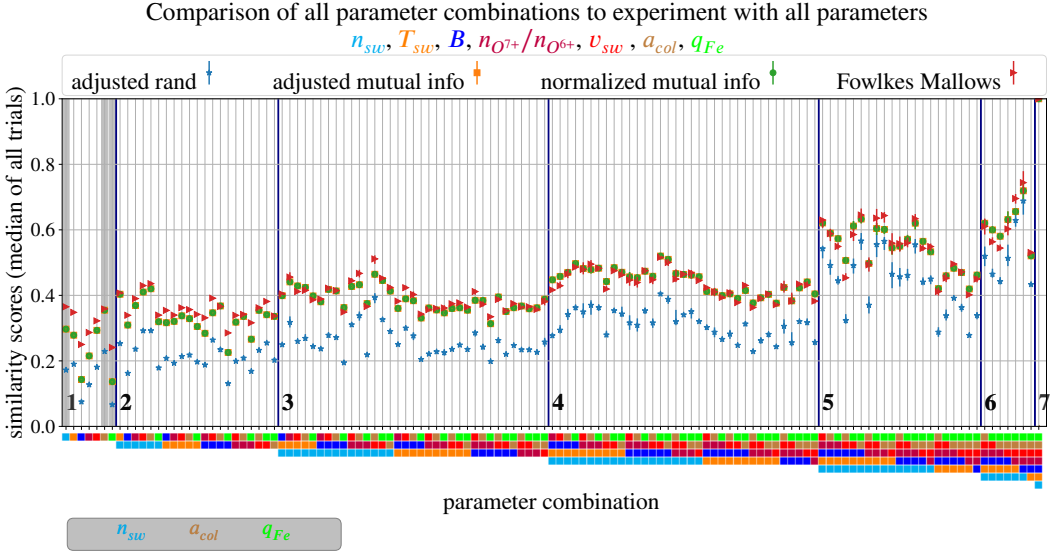

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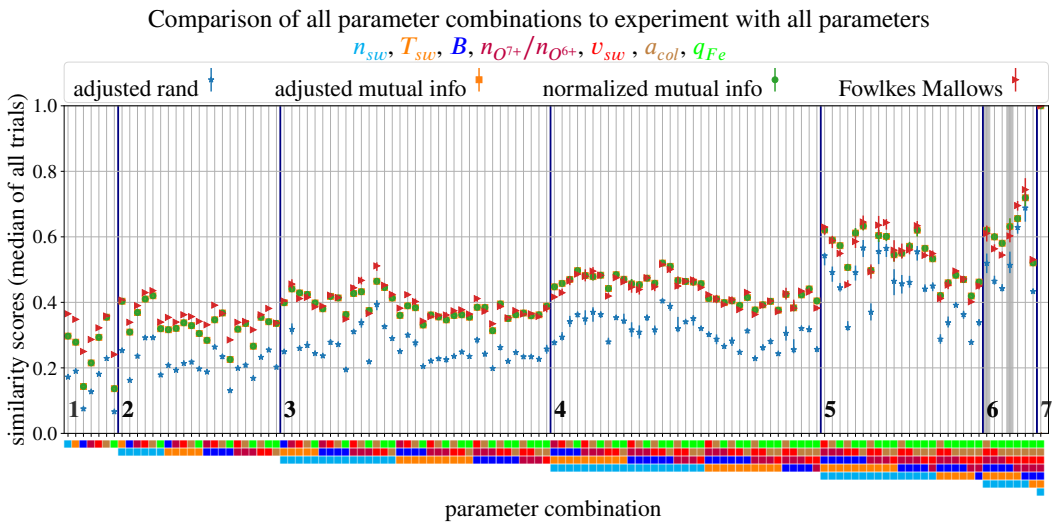

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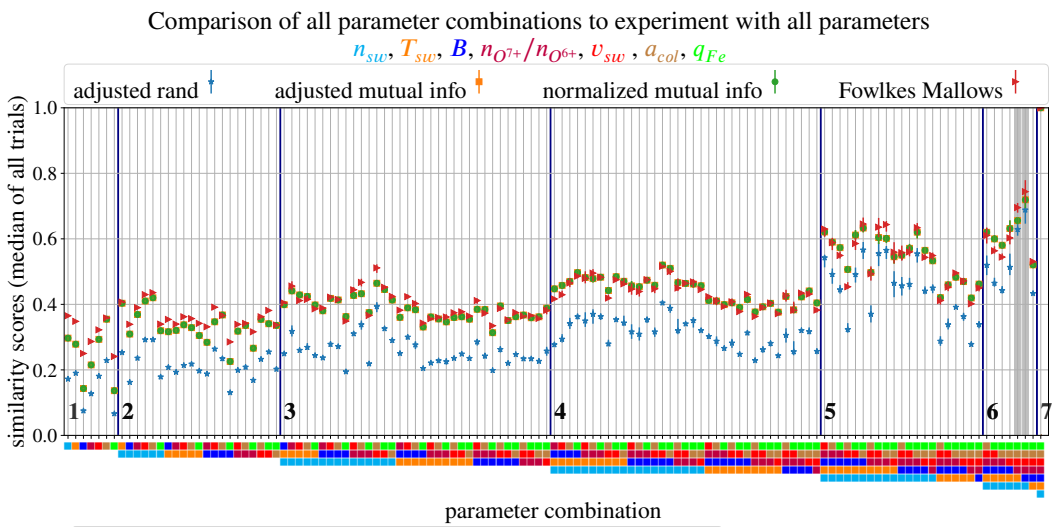
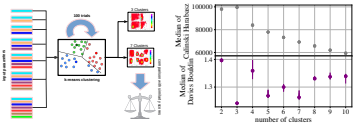


Summary of the results

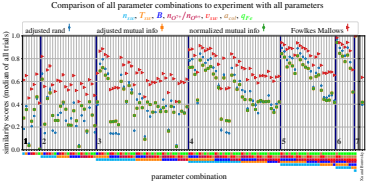
General results from k-means

- more than 3 different types are needed to differentiate between origin based and transport effects
- for 3 Clusters slow solar wind, fast solar wind and compression regions are identified



Conclusion

- n_{sw} is the most important parameter for classification
- charge states (especially q_{Fe}) are needed for detailed classification



⇒ transport effects should be considered for detailed clustering!

Thank you for your attention & please ask questions !

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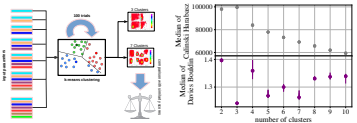

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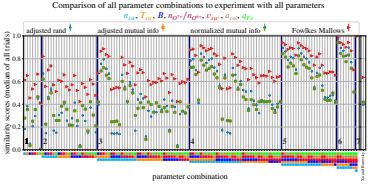

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References I

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Visualizing and interpreting unsupervised solar wind classifications.
Frontiers in Astronomy and Space Sciences, 7:66, 2020.

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space.
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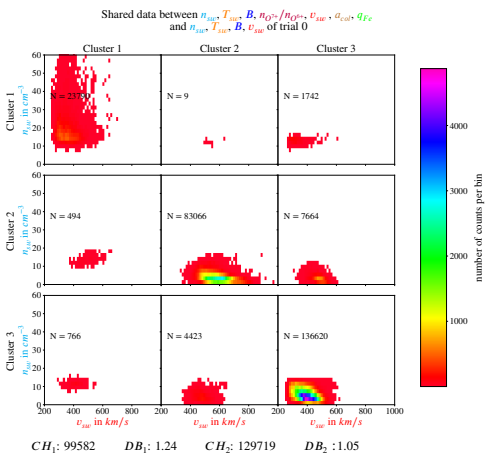
A new four-plasma categorization scheme for the solar wind.
Journal of Geophysical Research: Space Physics, 120(1):70–100, 2015.

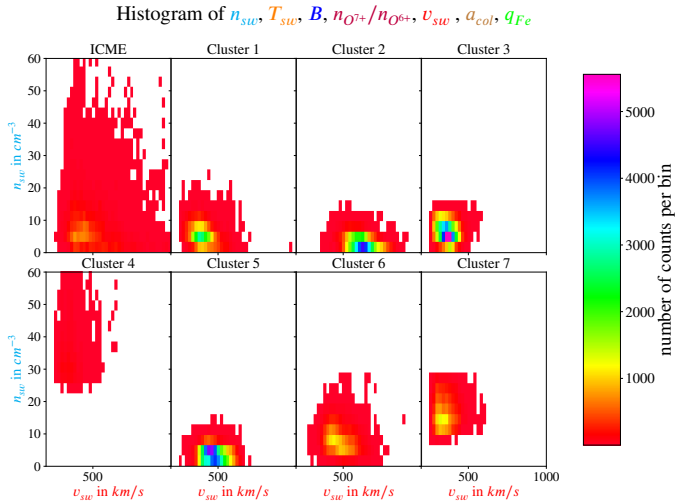
L. Zhao, T. Zurbuchen, and L. Fisk.
Global distribution of the solar wind during solar cycle 23: Ace observations.
Geophysical Research Letters, 36(14), 2009.

3 Cluster - First results

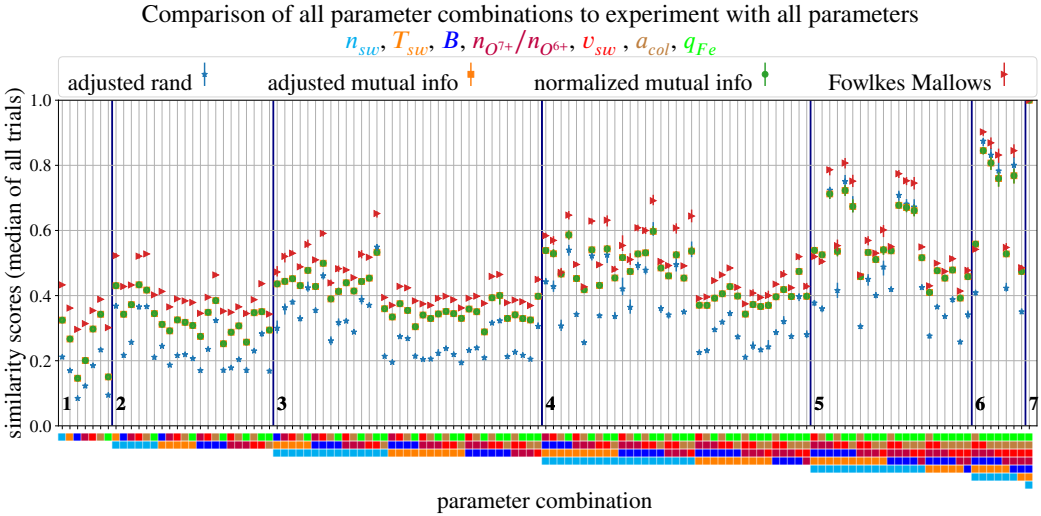


CH_1: 99582 DB_1: 1.24 CH_2: 129719 DB_2 : 1.05

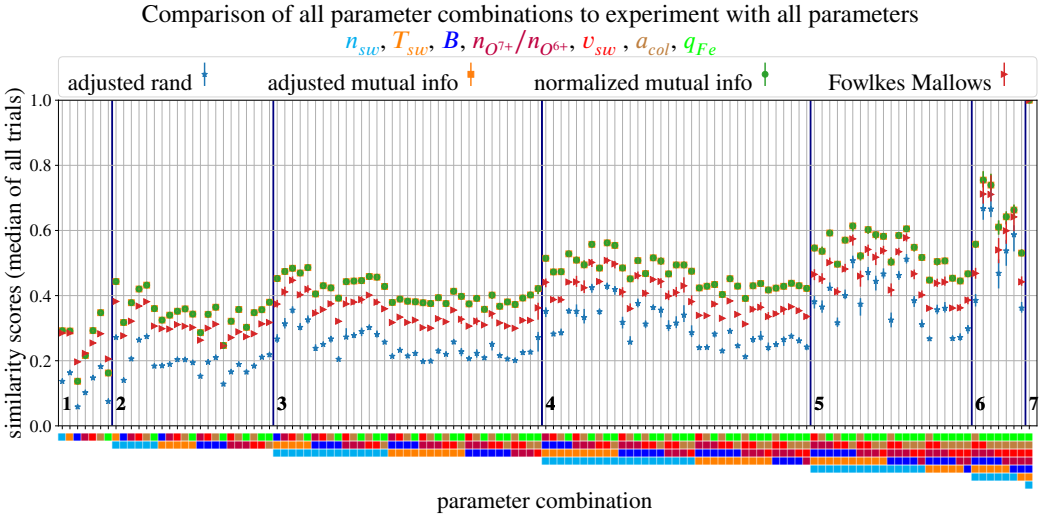
7 Cluster


Histogram of n_{sw}, T_{sw}, B, $n_{O^{7+}}/n_{O^{6+}}$, v_{sw} , a_{col}, q_{Fe}
ICME
Cluster 1
Cluster 2
Cluster 3
Cluster 4
Cluster 5
Cluster 6
Cluster 7
n_{sw} in cm^{-3}
v_{sw} in km/s
number of counts per bin
CH: 69196
DB: 1.26

6 Cluster


Comparison of all parameter combinations to experiment with all parameters
n_{sw}, T_{sw}, B, $n_{O^{7+}}/n_{O^{6+}}$, v_{sw} , a_{col}, q_{Fe}
adjusted rand
adjusted mutual info
normalized mutual info
Fowlkes Mallows
similarity scores (median of all trials)
1.0
0.8
0.6
0.4
0.2
0.0
1
2
3
4
5
6
7
parameter combination

10 Cluster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