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Eight types of the solar wind and their origins

9th Workshop "Solar Influences on the Magnetosphere, Ionosphere and Atmosphere"

Sunny Beach, Bulgaria
May 30 – June 3, 2017

Introduction

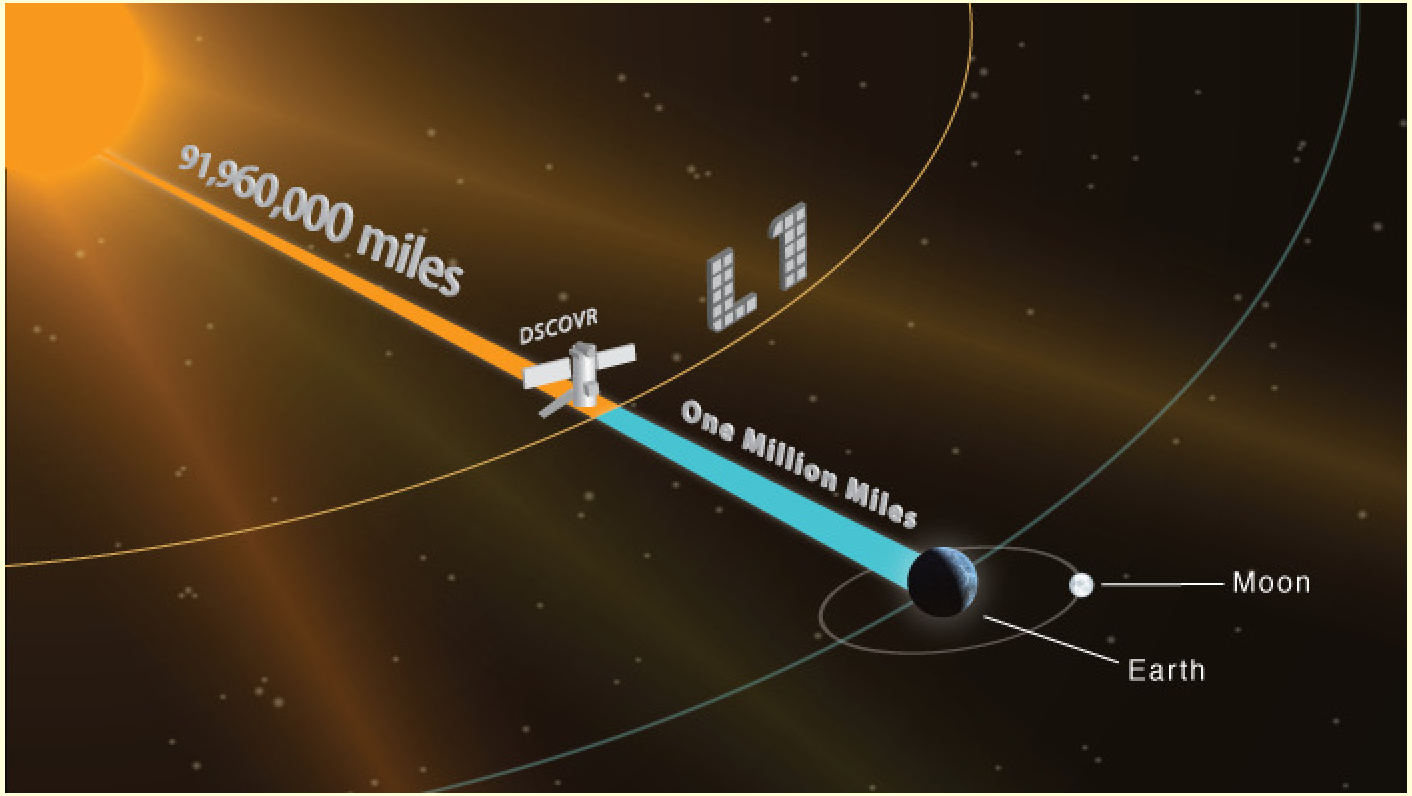
- In July 2016 high cadence data from the new DSCOVR satellite launched at the Lagrange point in February 2015 became available

- On the basis of these data a binary (large-small) three-parameter classification of solar wind types according to the main hydrodynamic parameters (speed, temperature, density) is presented, and examples of the determination of different types of solar wind in real time are given

DSCOVR satellite

The Deep Space Climate ObserVatoRy (DSCOVR) satellite is a NOAA operated asset at the first Lagrange (L1) point. The spacecraft was launched on February 11, 2016. Data are available from July 26, 2016

1. **Fluxgate magnetometer (MAG) measures the local magnetic field**
2. **Faraday Cup (FC) measures the solar wind bulk properties (wind speed, temperature and density)**



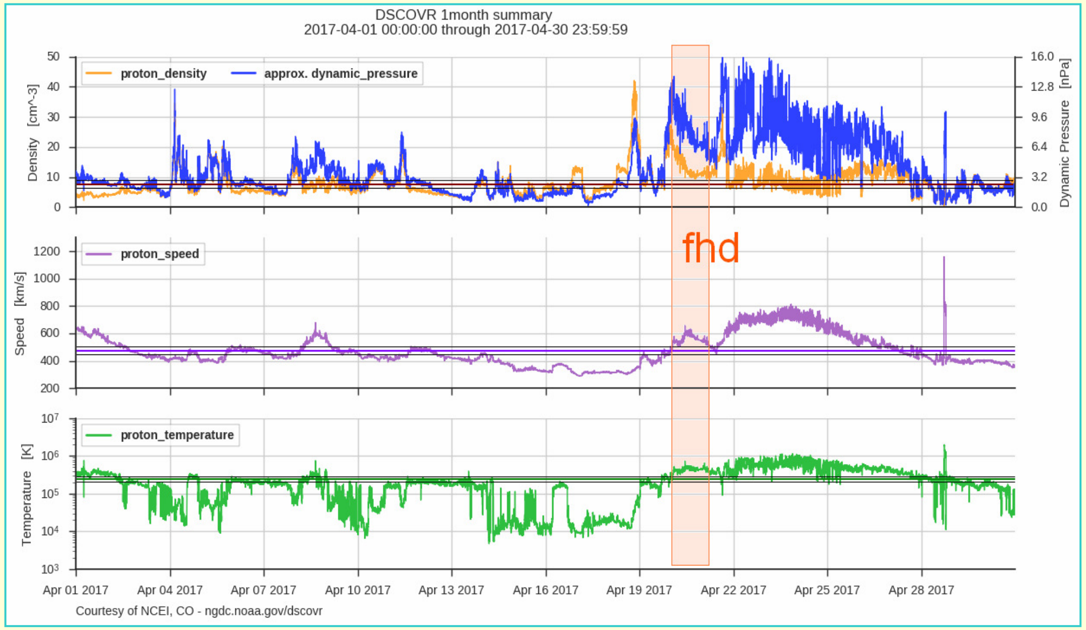
- From the Sun to the Earth the solar wind reaches about 3–4 days
- From point L1 to the Earth — about 1 hour

Eight types of solar wind

Binary classification based on the three main hydrodynamic parameters:

- **velocity**
  - fast
  - slow
- **temperature**
  - hot
  - cold
- **concentration**
  - dense
  - rarefied

№	Type	Abbreviation
1	fast-hot-dense	fhd
2	fast-hot-rarefied	fhr
3	fast-cold-dense	fcd
4	fast-cold-rarefied	fcr
5	slow-hot-dense	shd
6	slow-hot-rarefied	shr
7	slow-cold-dense	scd
8	slow-cold-rarefied	scr
	none of them	—

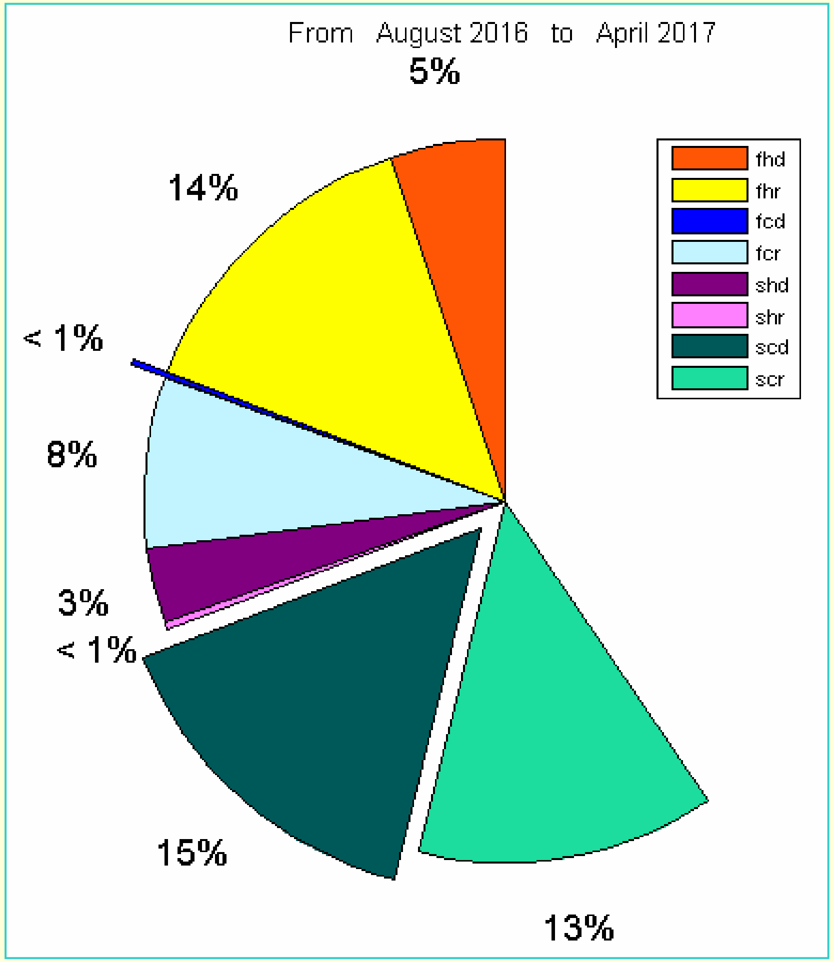


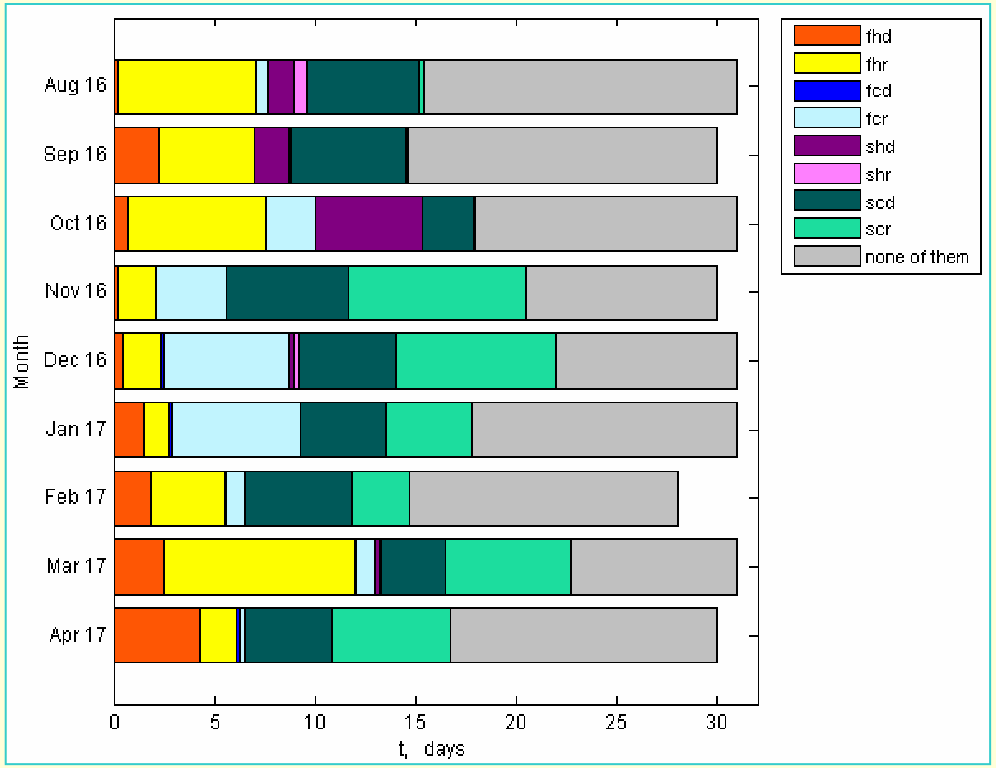
We will assume that the wind belongs to one or another type if the parameters deviate from the averaged values by more than a certain threshold (10% for example)

← Sample of visual solar wind classification

All time: August 2016 – April 2017

- $\langle V \rangle$ = 479 km/s, $\langle T \rangle = 2.56 \cdot 10^5$ K, $\langle n \rangle$ = 7.13 cm^{-3} (values averaged over the period from Aug. 2016 to Apr. 2017)
- threshold = 10%
- non-smoothed f3s data (Faraday Cup 3 second resolution)



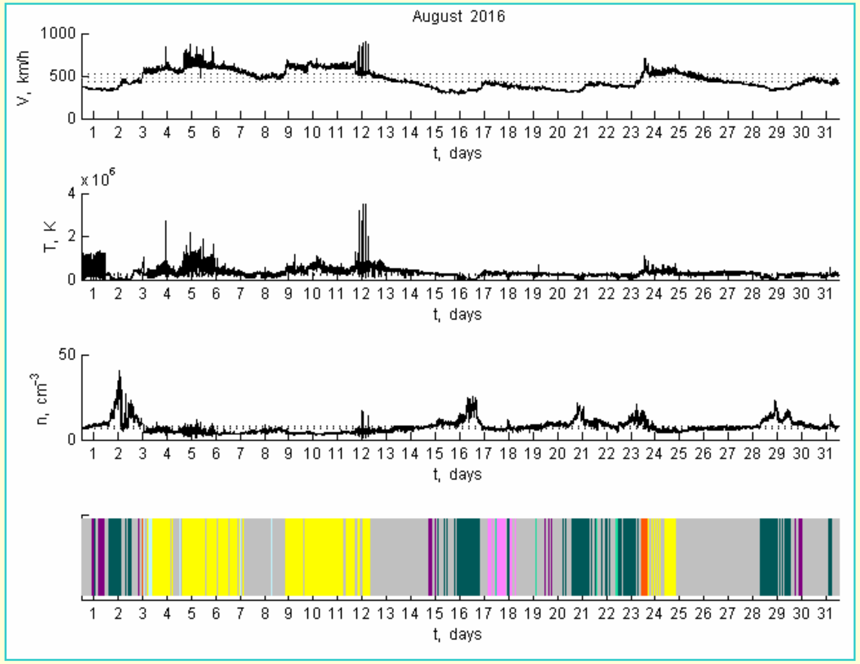


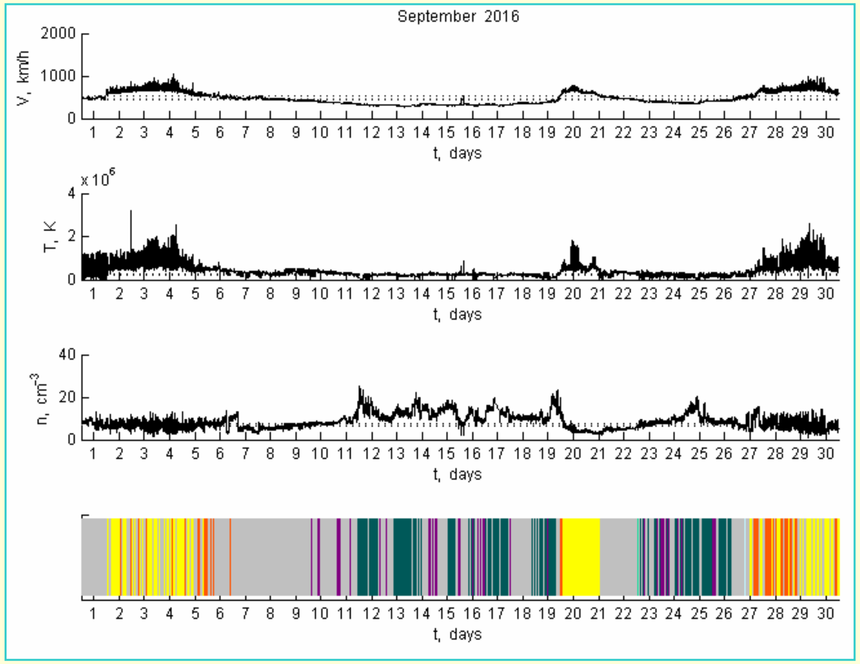
1. August – October 2016

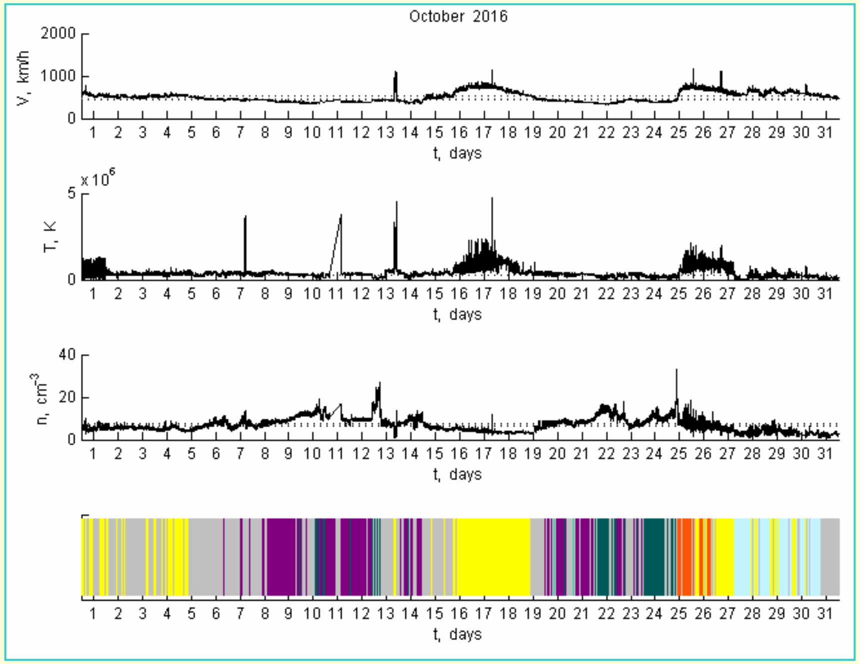
Automatic classification, threshold = 10%,
reference averages: ⟨V⟩, ⟨T⟩, ⟨n⟩

For these three months:

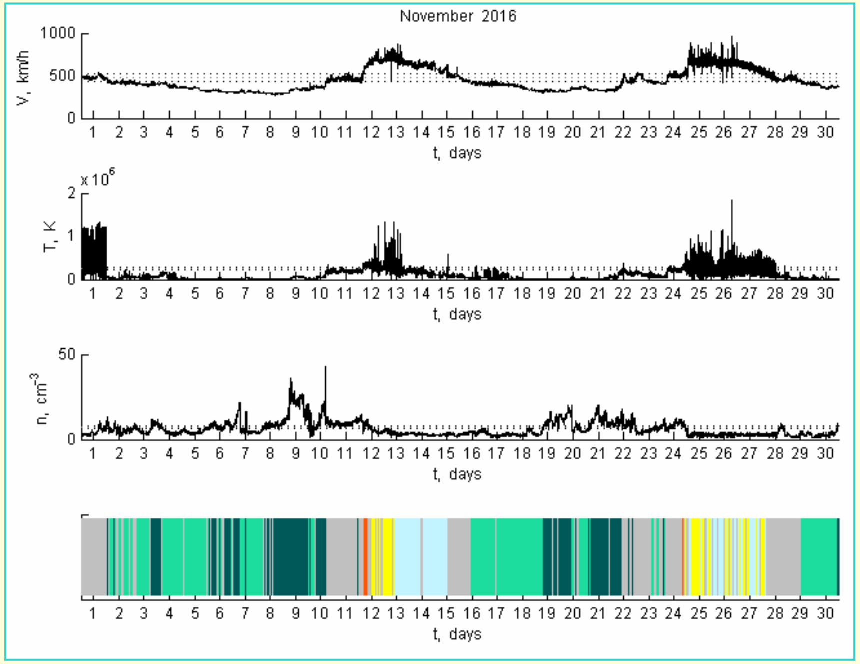
- $\langle V \rangle_1$ = 479 km/s
- $\langle T \rangle_1 = 3.86 \cdot 10^5$ K
- $\langle n \rangle_1$ = 7.69 cm^{-3}







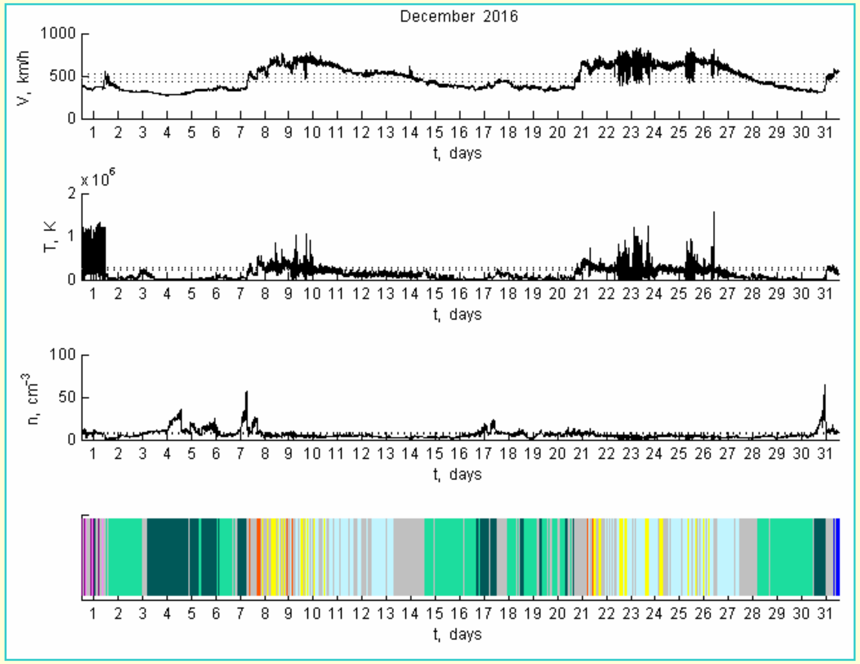
2. November 2016 – January 2017

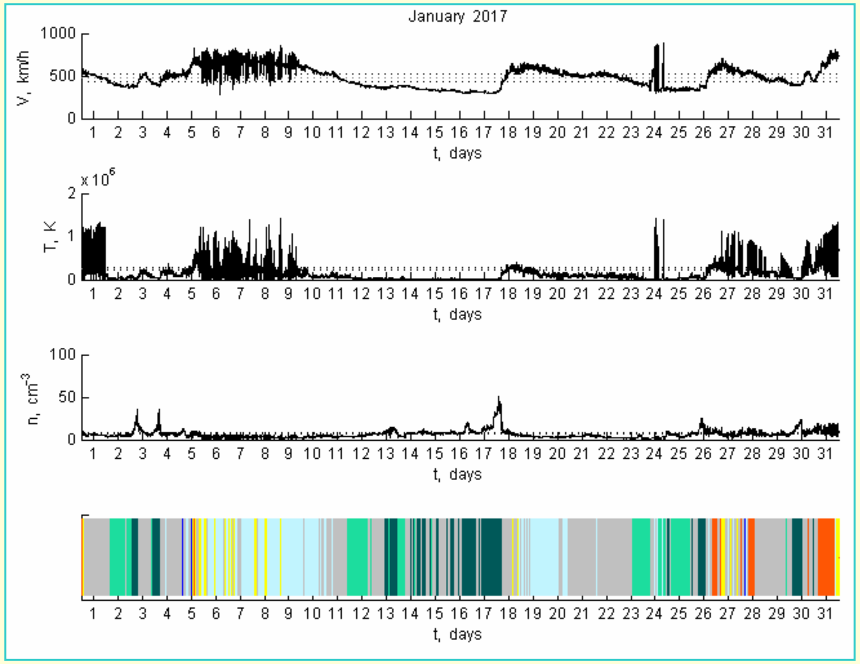


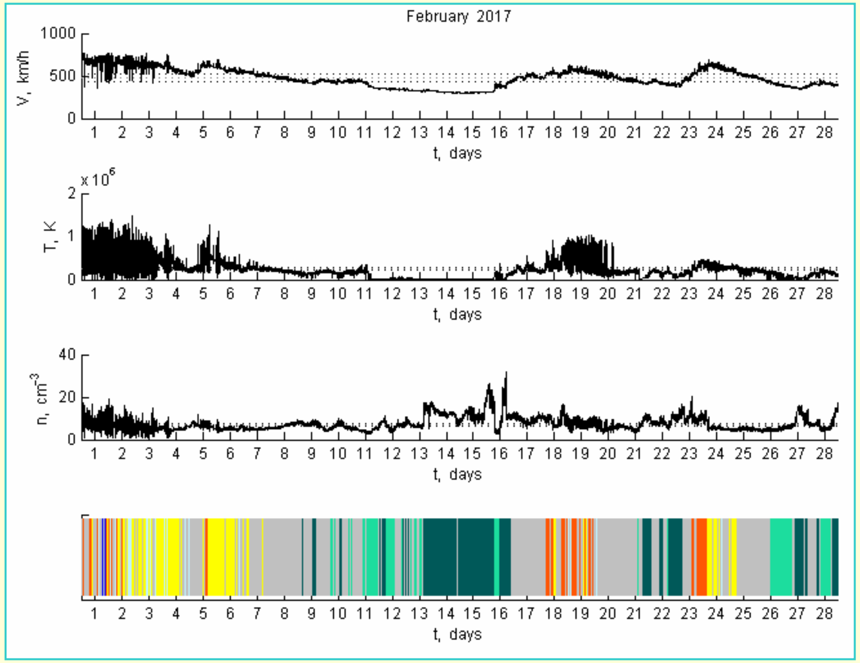
Automatic classification, threshold = 10%, reference averages: ⟨V⟩, ⟨T⟩, ⟨n⟩

For these three months:

- $\langle V \rangle_2$ = 468 km/s
- $\langle T \rangle_2 = 1.35{\cdot}10^5$ K
- $\langle n \rangle_2 = 6.27$ cm^{-3}





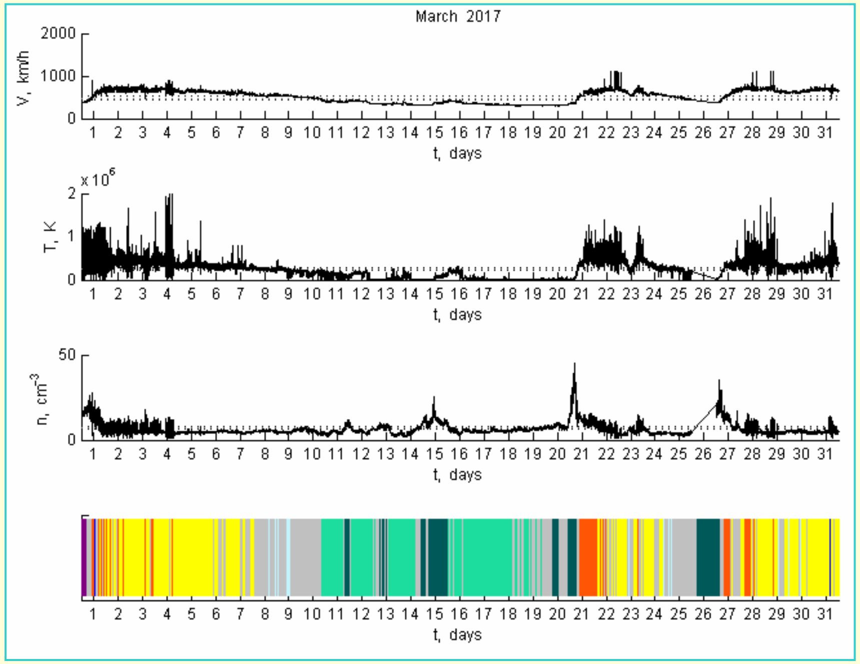


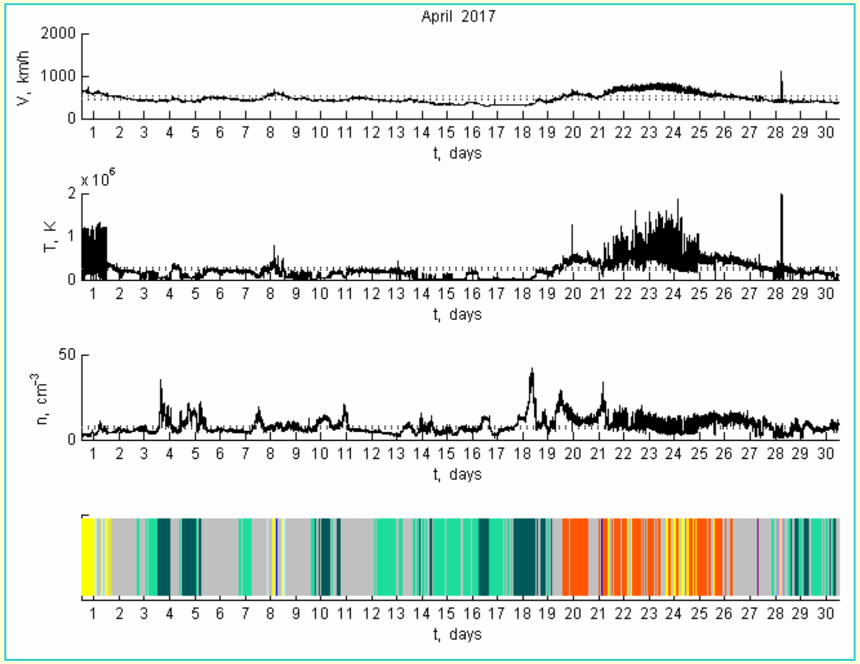
3. February – April 2017

Automatic classification, threshold = 10%, reference averages: ⟨V⟩, ⟨T⟩, ⟨n⟩

For these three months:

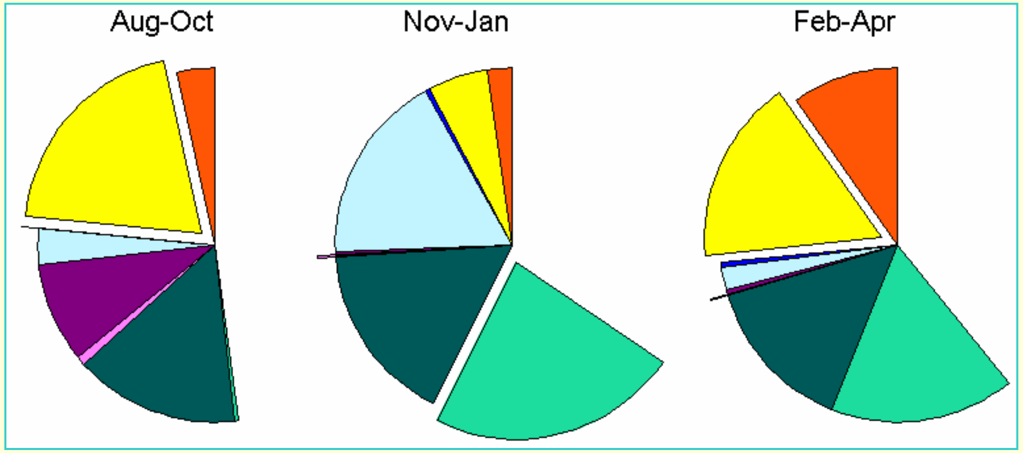
- $\langle V\rangle_3$ = 489 km/s
- $\langle T\rangle_3$ = $2.46{\cdot}10^5$ K
- $\langle n\rangle_3$ = 7.42 cm^{-3}





Subperiods

1. **August–October:**
   - hot wind
   - dense wind
2. **November–January:**
   - cold & rarefied wind
3. **February–April:**
   - fast hot wind
   - slow cold wind

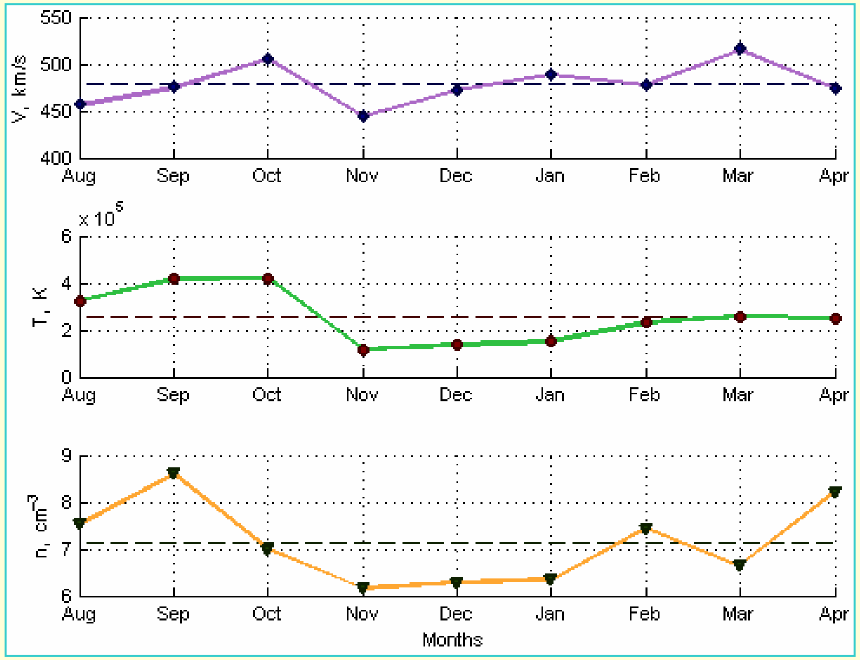


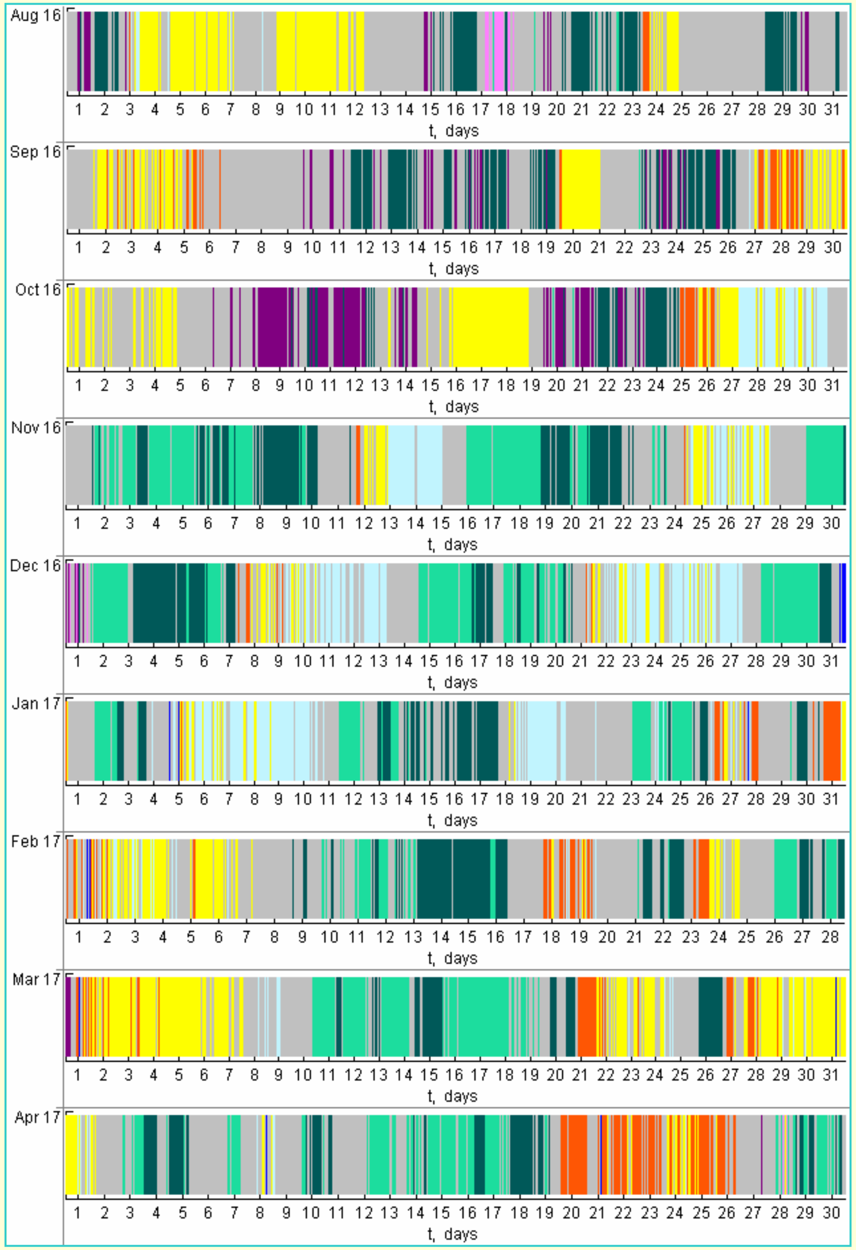
№	Type	Frequency, %			
		Aug–Oct	Nov–Jan	Feb–Apr	All time
1	fhd	3.49	2.27	9.73	5.11
2	fhr	20.0	5.54	16.9	14.1
3	fcd	$2.26 \cdot 10^{-3}$	0.370	0.412	0.260
4	fcr	3.29	17.4	2.13	7.66
5	shd	9.07	0.335	0.370	3.29
6	shr	0.870	0.202	0.0916	0.391
7	scd	15.0	16.5	14.4	15.3
8	scr	0.376	22.8	16.8	13.3
9	none of them	47.9	34.5	39.2	40.5

August 2016 – April 2017 (1)

- Solar wind types classification for nine months in the case of
  - threshold = 10%
  - reference averages: ⟨V⟩, ⟨T⟩, ⟨n⟩
  - non-smoothed f3s data

Average per month values of speed, temperature and density

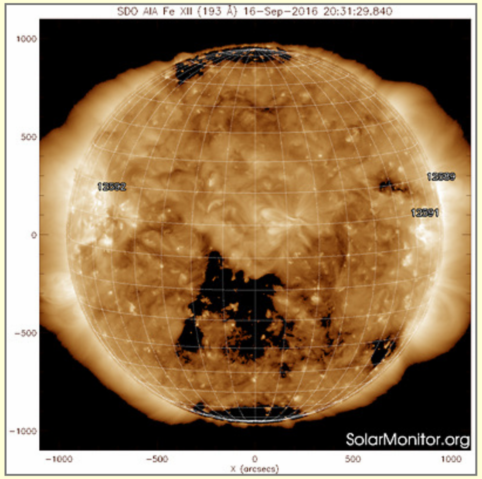




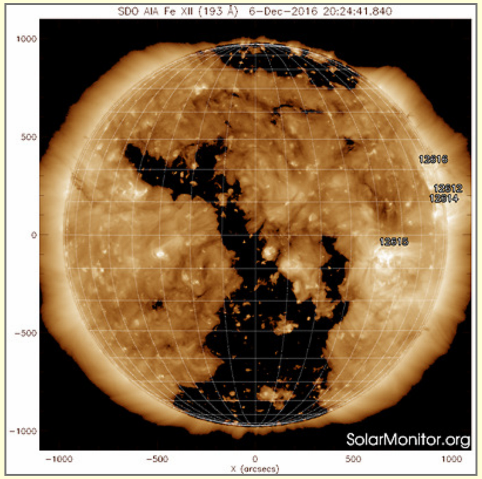
Carrington rotations

- Recurrent disturbances from long-living coronal hole.

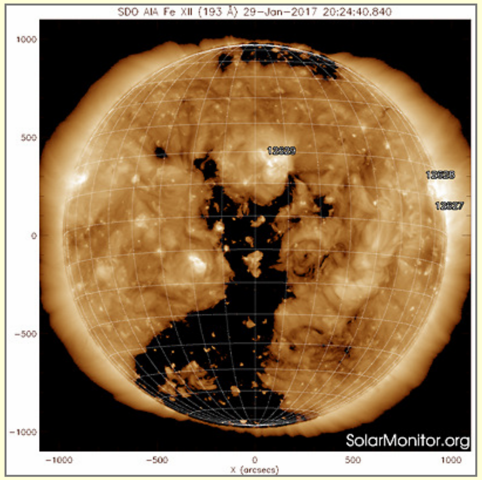
16.09.2016



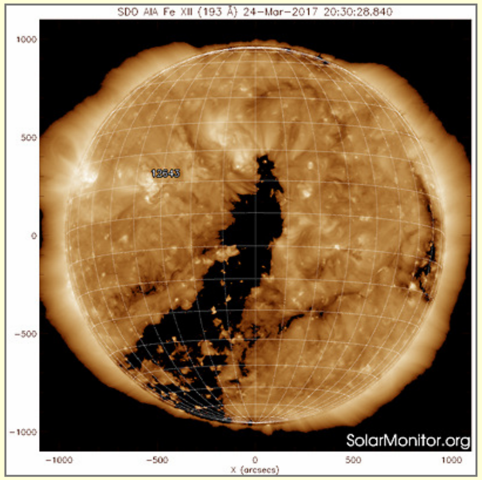
06.12.2016

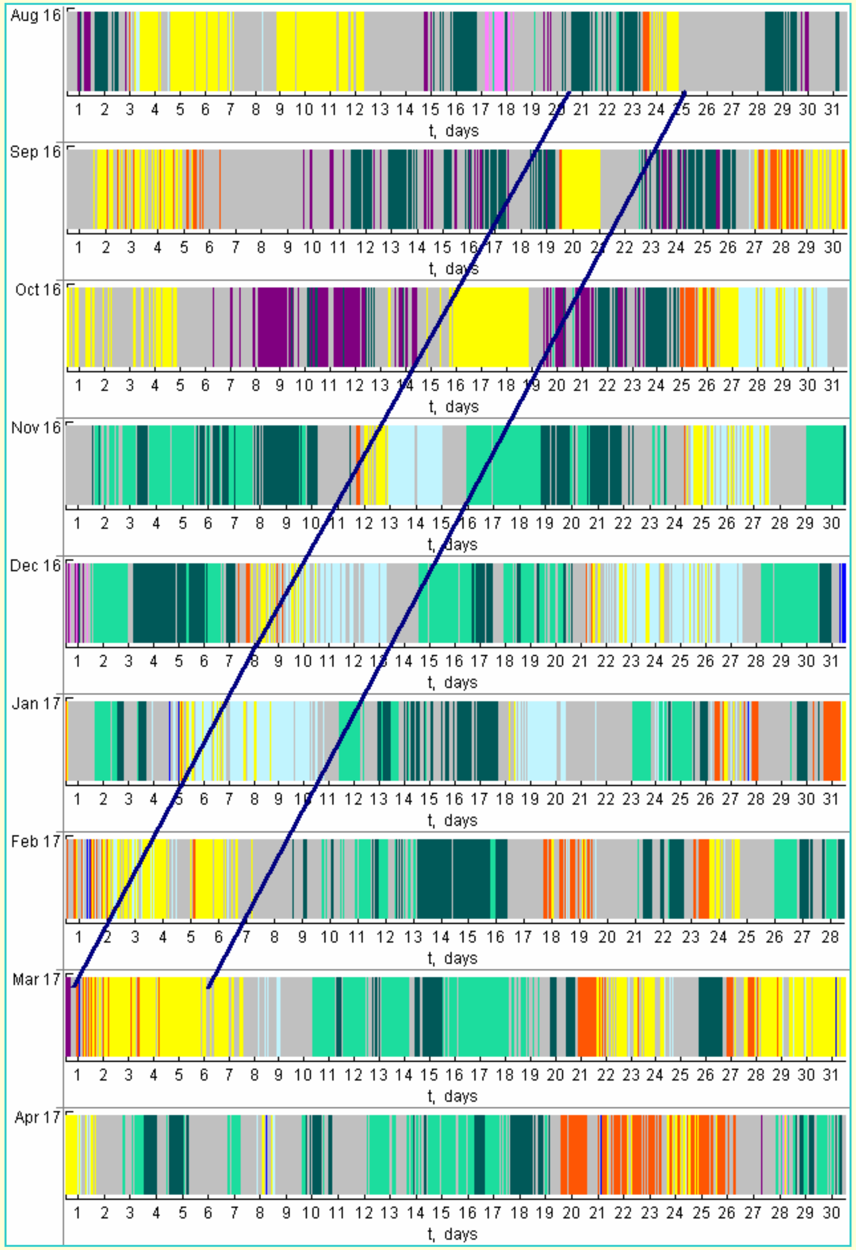


29.01.2017



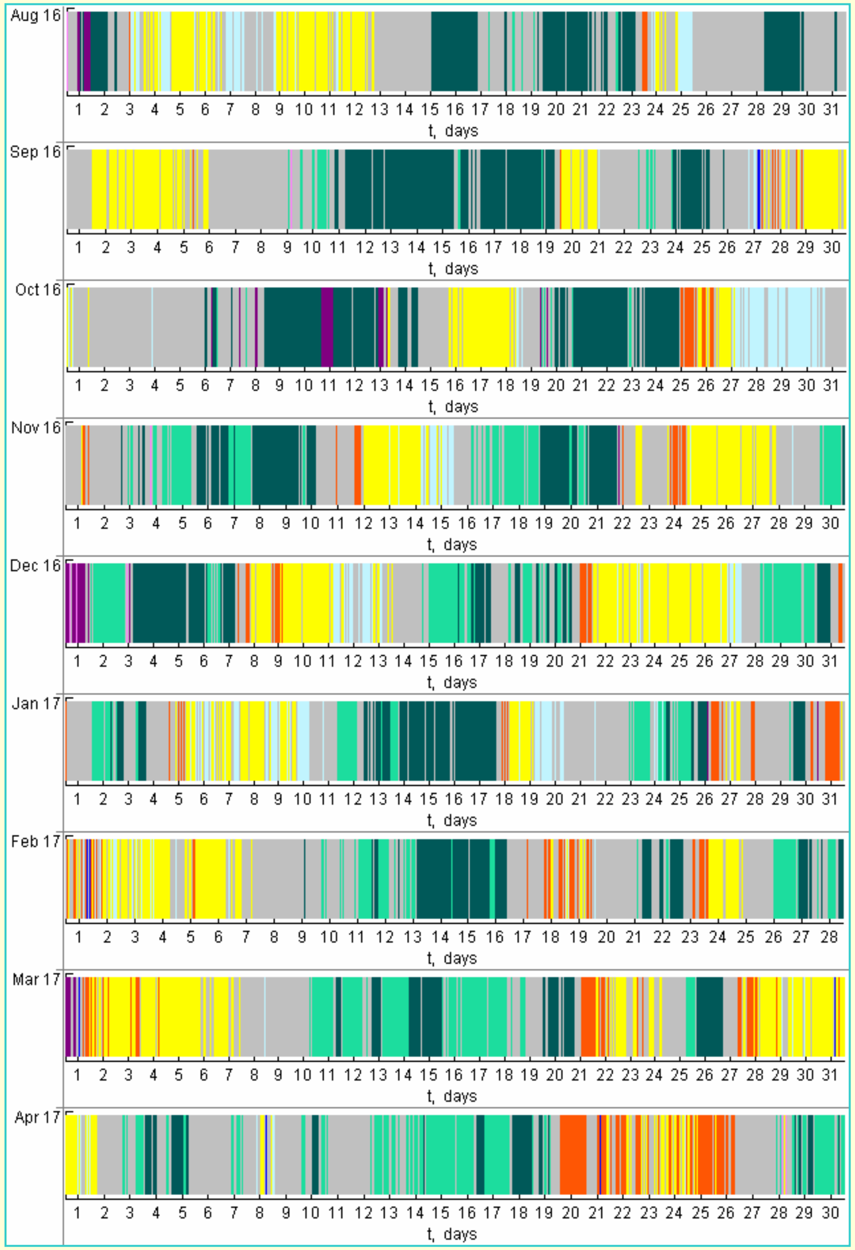
24.03.2017





August 2016 – April 2017 (2)

- Solar wind types classification for nine months in the case of
  - threshold = 10%
  - reference averages: $\langle V \rangle_{month}$, $\langle T \rangle_{month}$, $\langle n \rangle_{month}$ for each month
  - non-smoothed f3s data



With a smaller value of the threshold zones of the each type of the solar wind expand. With more rigid value they narrow down and vanish

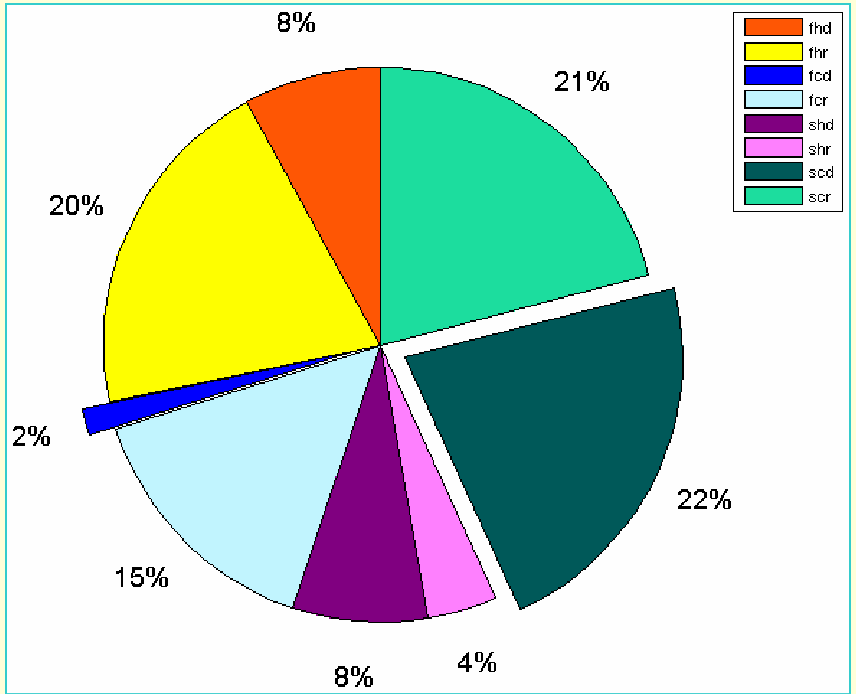
The attribution of the solar wind to a particular type also depends on the period for which the reference average values of the parameters are calculated, as well as the nature of the data smoothing or its absence

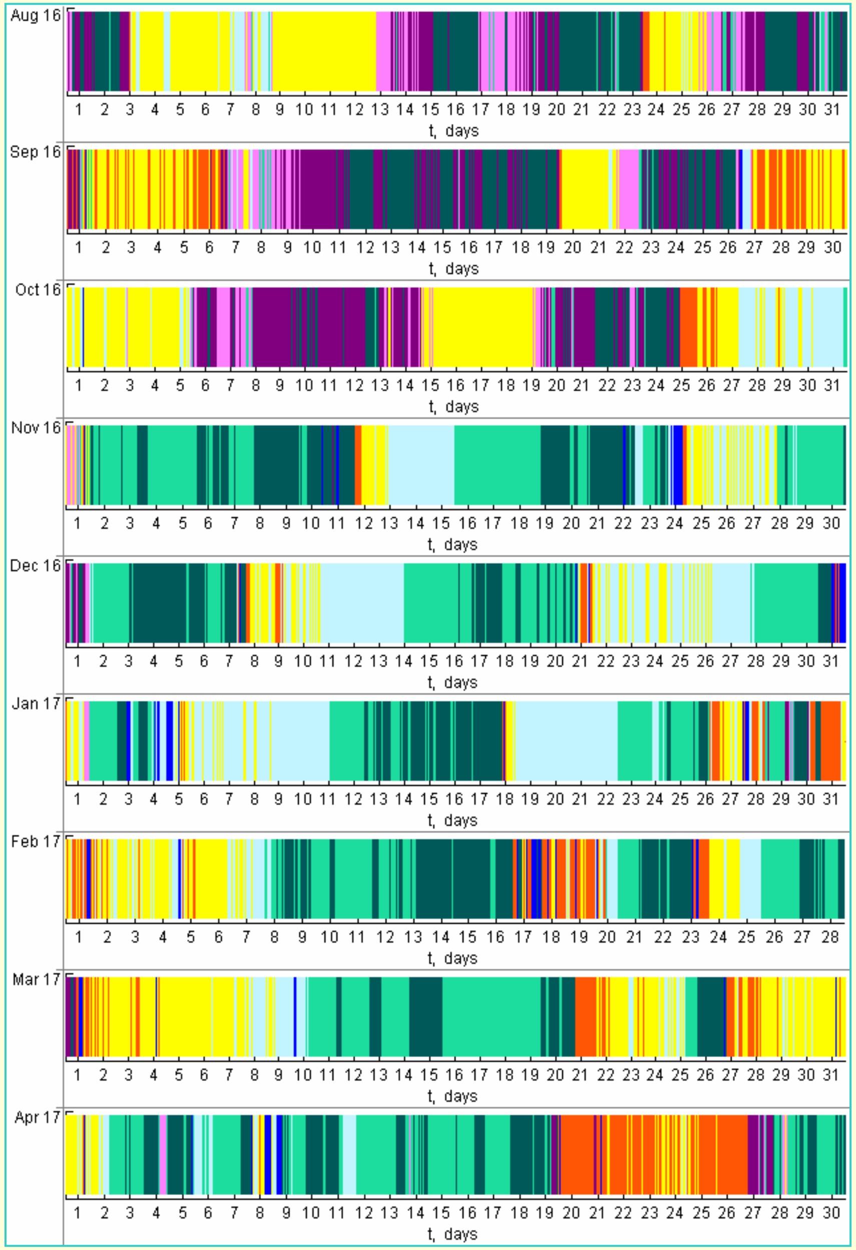
August 2016 – April 2017 (3)

- Solar wind types classification for nine months in the case of
  - <u>zero threshold</u>
  - reference averages: ⟨V⟩, ⟨T⟩, ⟨n⟩
  - non-smoothed f3s data

Frequent: fhr, scd, scr

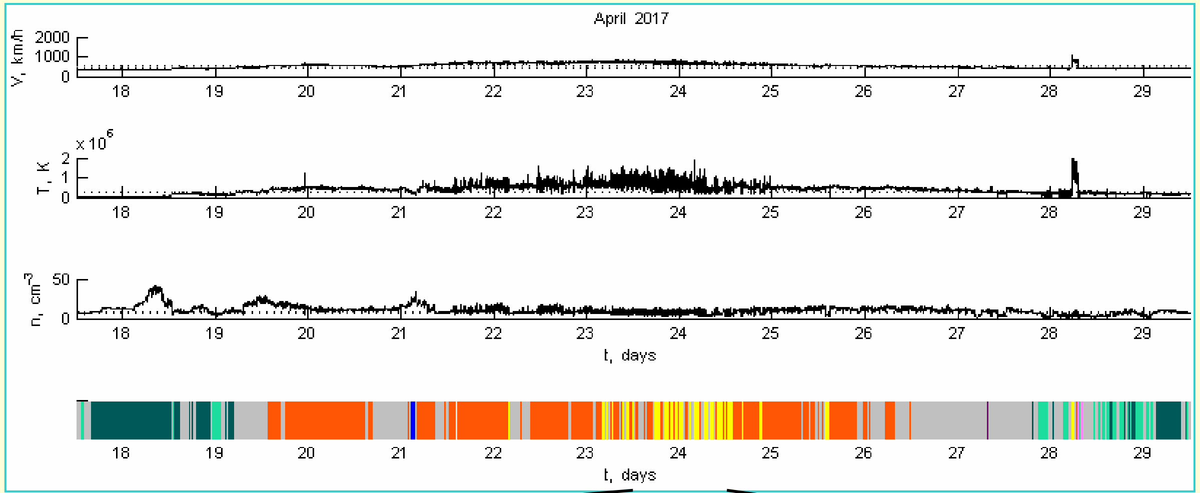
Rare: fcd, shr





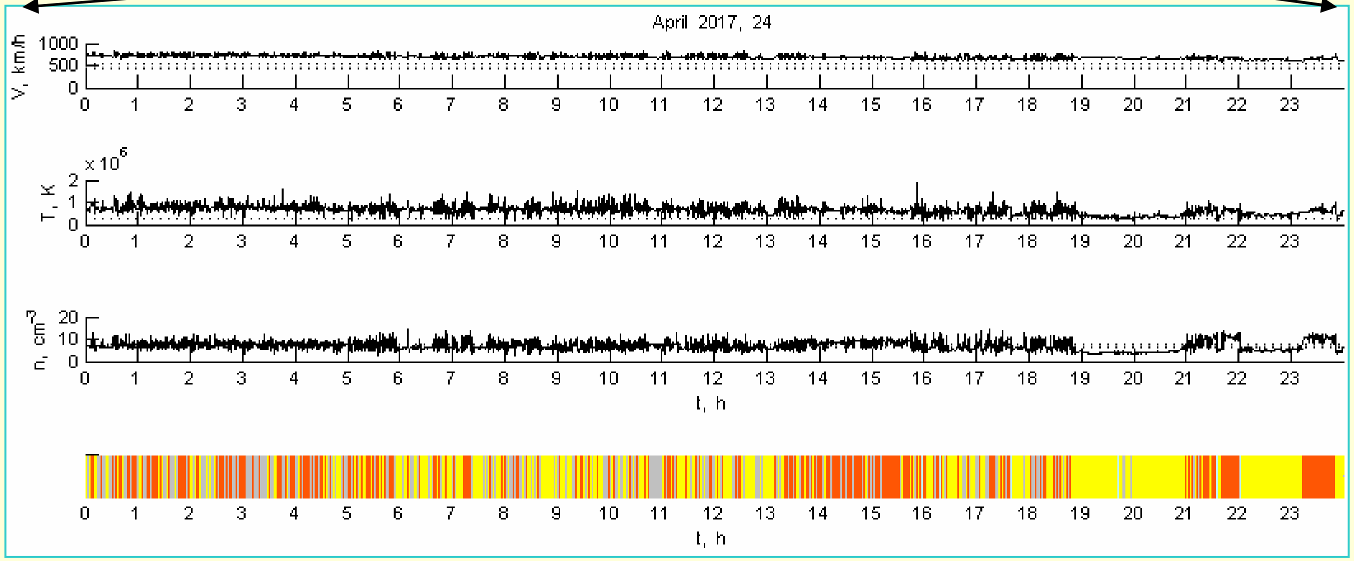
Fine structure

- Solar wind types classification for 12 days and 1 day in April 2017 in the case of
  - threshold = 10%
  - reference averages: ⟨V⟩, ⟨T⟩, ⟨n⟩
  - non-smoothed f3s data



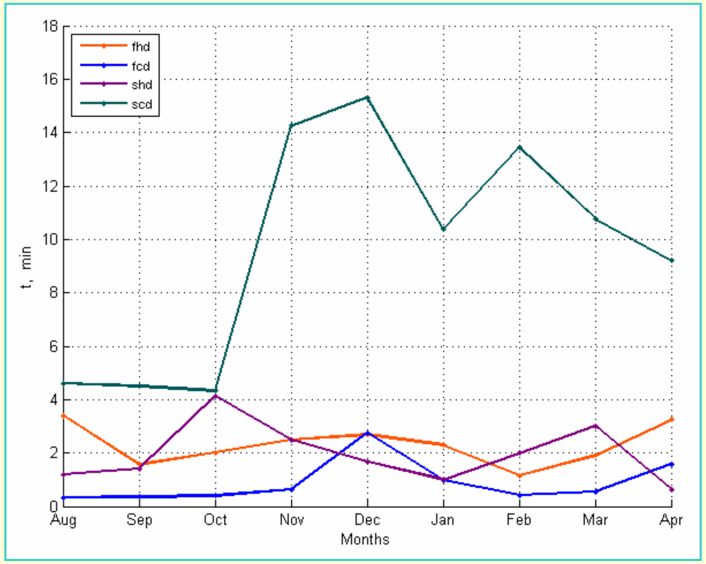
Sometimes homogeneous areas belonging to one or another solar wind type are observed

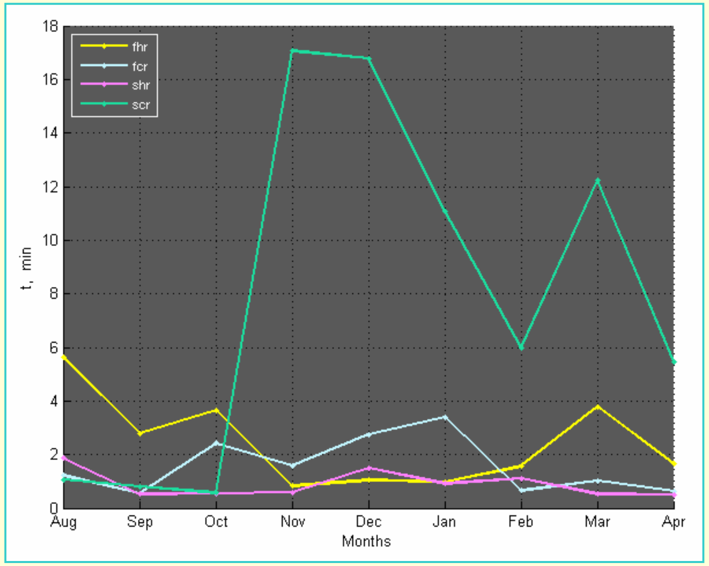
Sometimes we can see frequent switching between types



Duration

- Shortest in time: fcd, shr
- Longest in time: scd, scr





№	Type	Mean duration, min.			
		Aug–Oct	Nov–Jan	Feb–Apr	All time
1	fhd	1.73	2.38	2.05	2.00
2	fhr	3.86	0.937	2.52	2.38
3	fcd	0.375	1.38	0.719	0.934
4	fcr	2.03	2.53	0.778	2.04
5	shd	2.31	1.68	2.37	2.28
6	shr	1.54	1.46	0.720	1.40
7	scd	4.50	13.15	11.05	7.77
8	scr	0.892	15.30	7.24	9.49

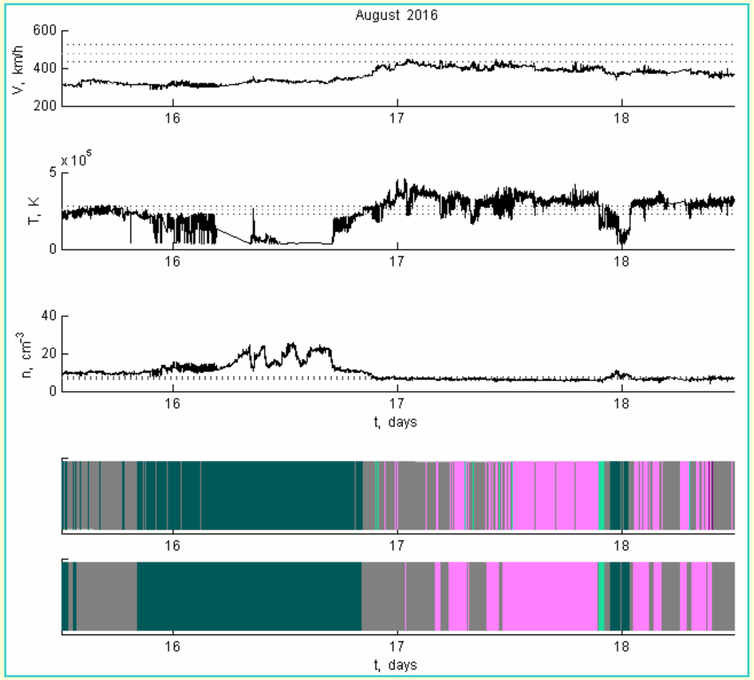
Effects of smoothing

№	Type	Frequency, %		
		Non-smoothed data	One-minute smoothing	Half-hour smoothing
1	fhd	5.11	5.08	4.83
2	fhr	14.1	14.3	14.2
3	fcd	0.260	0.204	0.178
4	fcr	7.66	7.26	6.88
5	shd	3.29	3.25	2.91
6	shr	0.391	0.402	0.422
7	scd	15.3	15.3	15.5
8	scr	13.3	13.3	13.2

- The effect of smoothing is greatest for rare and short-term solar wind types

Non-smoothed data →

Half-hour smoothing →



Characterization

№	Type	Properties and possible sources
1	**fhd**	This type is most often found in maximums of the solar activity and is most noticeable in the shock waves after powerful eruptive solar flares. However, it is also formed in the region of interaction of corotating fast flows at a sufficiently large distance from the Sun, including beyond the Earth’s orbit
2	**fhr**	A very common type. Long time flows from coronal holes. On the Earth's orbit it is most often encountered when the Sun is reversed to the solar cycle decline and is responsible for recurrent geomagnetic disturbances
3	**fcd**	This rare and short-lived type arises from the release of a cold prominence (protuberance). It can contain an anomalously large amount of helium, leading to strong compression of the magnetosphere and unusual geomagnetic storms
4	**fcr**	Cold magnetic clouds in a fast wind. Empty “bubbles”. Remains of expanded and cooled eruptions. Recall that within the coronal holes are often visible small evolving ephemeral active regions
5	**shd**	Like Type 1, this type also sometimes occurs in non-stationary flows after eruptive flares and coronal mass ejections
6	**shr**	This type occurs in the expanding remnants of hot eruptive clouds of plasma, picked up by the general flow
7	**scd**	Conventional representatives of this type are flows from coronal streamers and pseudostrimers. Heliospheric plasma layers near magnetic sectors also may belong to this type. And so uncompressed density enhancements
8	**scr**	Areas of rarefaction in the tail part of high-speed flows from coronal holes. Expanded, cooled and delayed emissions

Conclusion

1. There are eight types of solar wind in introduced binary classification: fast-hot-dense, fast-hot-rarefied, fast-cold-dense, fast-cold-rarefied, slow-hot-dense, slow-hot-rarefied, slow-cold-dense, slow-cold-rarefied comparing to average values for given time intervals

2. These types occur at different frequencies and are consequences of different solar activity sorts. The most interesting situations correspond to extreme values because of magnetospheric effects

3. To improve the quality of these results, it is desirable to add an account the degree of plasma magnetization (ratio of the plasma pressure to the magnetic pressure $\beta > 1$ or $\beta < 1$) and, possibly, another characteristics based on dimensionless analysis

Thank you for your attention!