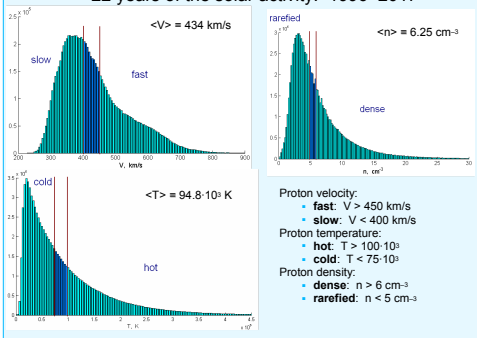
Classification scheme for the solar wind based on the main MHD parameters

A. Lukashenko[1], K. Kaportseva[2], I. Veselovsky[1,3]

[1]SINP MSU, Moscow, Russia, a_lu@mail.ru
[2]Faculty of Physics, MSU, Moscow, Russia
[3]Space Research Institute of RAS, Moscow, Russia

Hydrodynamic classification

22 years of the solar activity: 1996–2017



Proton velocity:
- **fast**: V > 450 km/s
- **slow**: V < 400 km/s

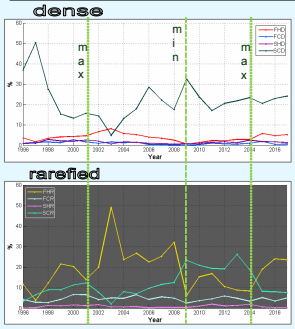
Proton temperature:
- **hot**: T > 100·10³
- **cold**: T < 75·10³

Proton density:
- **dense**: n > 6 cm⁻³
- **rarefied**: n < 5 cm⁻³

1-min. data from the portal https://omniweb.gsfc.nasa.gov/ for 1996–2017 (23rd & 24th cycles)

9 hydrodynamic types of the solar wind

№	Type	Abbreviation	Abundance
1	fast-hot-dense	FHD	4.0%
2	fast-hot-rarefied	FHR	19.1%
3	fast-cold-dense	FCD	1.1%
4	fast-cold-rarefied	FCR	4.6%
5	slow-hot-dense	SHD	1.5%
6	slow-hot-rarefied	SHR	0.9%
7	slow-cold-dense	SCD	21.9%
8	slow-cold-rarefied	SCR	11.8%
0	indeterminate type	—	35.2%

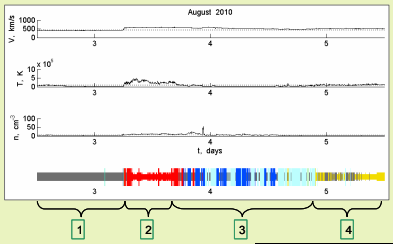


The hydrodynamic solar wind (SW) types arise from various manifestations of the solar activity and occur with different frequencies at different phases of the solar cycle

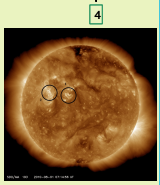
Veselovsky I.S., Lukashenko A.T., Kaportseva K.B. Classification scheme for solar wind // Physics of Atomic Nuclei, 2018 (*in print*)

Solar wind stream interaction

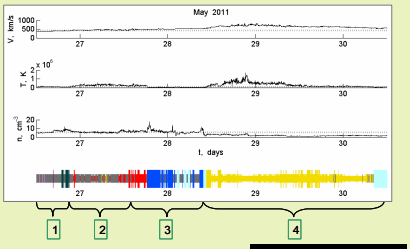
3–5 August, 2010 — **CME–CME interaction**



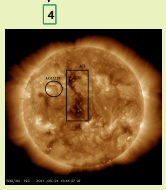
1. 0–18 h. 3.VIII.2010 — tail of stream from a coronal hole
2. 18 h. 3.VIII.2010–4 h. 4.VIII.2010 — shock wave formed by the arrival of the 1st CME, followed by the compression region (sheath)
3. 4 h. 4.VIII.2010–8 h. 5.VIII.2010 — region of interaction between the 1st and 2nd CMEs
4. 8 h. 5.VIII.2010–0 h. 6.VIII.2010 — unidentified high-speed stream



27–30 May, 2011 — **CME–high speed stream interaction**



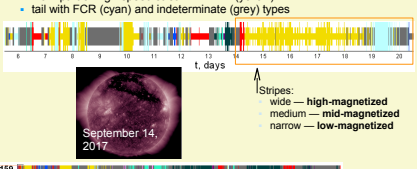
1. 0–9 h. 27.V.2011 — part of the heliospheric current sheet (on May 26 at 11 h. sectors of the magnetic field changed)
2. 9 h. 27.V.2011–6 h. 28.V.2011 — the 1st part of the high-speed stream from the coronal hole
3. 6 h. 28.V.2011–23 h. 28.V.2011 — CME
4. 23 h. 28.V.2011–0 h. 30.V.2011 — the 2nd part of the high-speed stream from the coronal hole

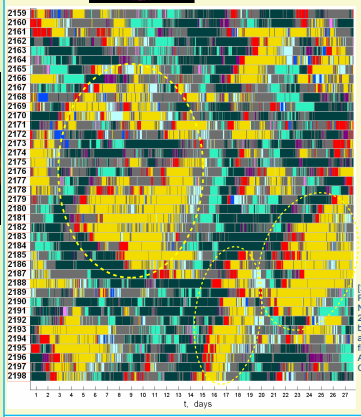


Rodkin D.G., Kaportseva K.B., Lukashenko A.T., Slemzin V.A., Veselovsky I.S., Shugay Yu.S. // Cosmic Research, 2018 (*in print*)

Coronal holes — sources of FHR wind

Typical structure of a high-speed stream from a coronal hole:
- compression region — FHD (red)
- main part of high-speed stream — FHR (yellow)
- tail with FCR (cyan) and indeterminate (grey) types





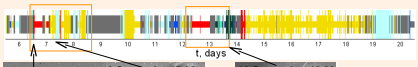
Carrington rotations 2159–2198 (years 2015–17)

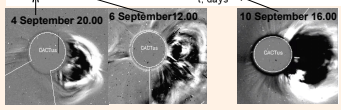
Large yellow spots correspond to the solar wind from coronal holes

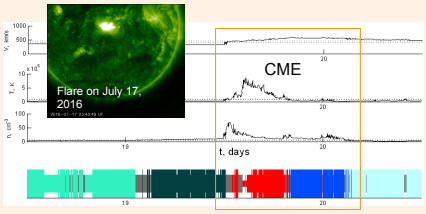
The biggest elliptic contour — a giant coronal hole of 2015–17[2]

[2] Akhtemov Z.S., Perebeynos V.A., Shtertser N.I. Giant coronal hole of 2015–2017: II. Relation between magnetic field, active solar regions and flares // Izvestiya Krymskoi Astrofizicheskoi Observatorii. V. 114, №1

CMEs — sources of FHD and FCD wind







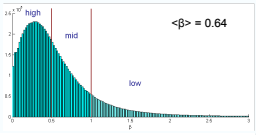
MHD classification

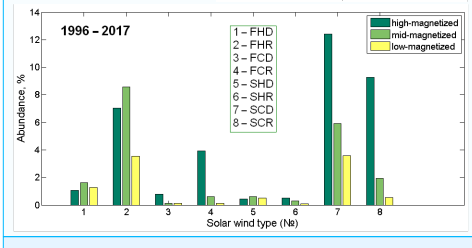
MHD subtypes of the solar wind

Proton beta:

$$\beta = \frac{8\pi n k_B T}{B^2}$$

Magnetization:
- **high-magnetized**: β < 0.5
- **mid-magnetized**: 0.5 < β < 1
- **low-magnetized**: β > 1





Common and rare SW types

SCD — common type, usually dominates in the minimum of the solar activity

FHR — common type, typical for the decline phase of the solar activity

FCD is one of two rarest solar wind types. It associates with some CMEs, such as on July, 2016, and complex events

The most common type usually is the indeterminate ("zero") type

Indeterminate type

Abundance in 1996–2017	35.2%		
Only one parameter is close to the typical[1] values	28.6%	Velocity	14.1%
		Temperature	7.0%
		Density	7.5%
Two parameters are close to the typical values	6.0%		
Three parameters are close to the typical values	0.5%		

[1] Dmitriev A.V., Suvorova A.V., Veselovsky I.S. // Handbook on solar wind: effects, dynamics and interactions / Ed. Johannson H.E. New York: Nova Science Publishers. 2009. P. 81–144

Probable sources for the different solar wind types

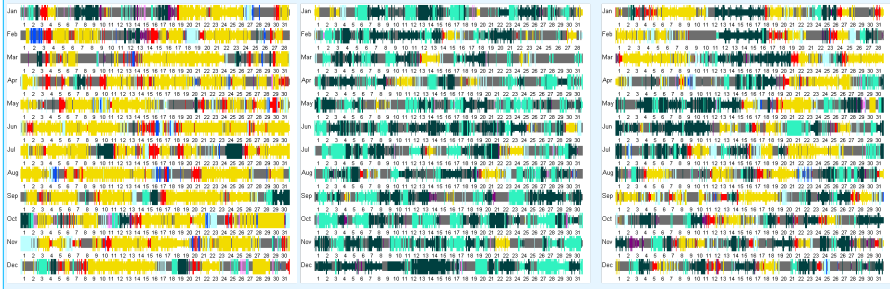
fast-hot-dense	CMEs after strong flares, shock waves, compressive regions in CIR
fast-hot-rarefied	High-speed streams from the coronal holes
fast-cold-dense	Some CMEs (maybe prominences)
fast-cold-rarefied	Tails of the high-speed streams from the coronal holes and CMEs
slow-hot-dense	In the nonstationary streams
slow-hot-rarefied	In the expanding hot remnants of eruptive plasma clouds
slow-cold-dense	Streams from the streamer belt, HSE regions
slow-cold-rarefied	Streams from the streamer belt
indeterminate type	Sources are usually unidentified

SW types for some years of the 23rd and 24th solar activity cycles

2003 – decline in solar activity		
fast-hot-rarefied	FHR	49.1%
fast-hot-dense	FHD	8.2%
fast-cold-rarefied	FCR	5.0%

2009 – solar minimum		
slow-cold-dense	SCD	32.5%
slow-cold-rarefied	SCR	23.4%
fast-hot-rarefied	FHR	6.1%

2017		
slow-cold-dense	SCD	24.1%
fast-hot-rarefied	FHR	23.6%
slow-cold-rarefied	SCR	7.6%



Wide stripes — **high-magnetized** SW streams, medium stripes — **mid-magnetized**, narrow stripes — **low-magnetized**

CONCLUSION

- The classification of solar wind (SW) streams according to the main hydrodynamic parameters — the combination of the velocity (fast or slow), temperature (hot or cold) or density (dense or rarefied) of protons — is considered. According to this approach, we specify eight types of SW: fast-hot-dense (FHD), fast-hot-rarefied (FHR), fast-cold-dense (FCD), etc. As an additional parameter, the proton plasma beta is taken into account for description of the magnetic state of the SW streams. The listed types of SW occur with different frequencies, depending on the phases of the solar activity cycles
- It is convinient to use this classification in studies of such events as CMEs and high-speed streams from coronal holes, and also more complicated events, for example CME–CME interactions

IRIS-9, Göttingen, 25-29 June 2018

Poster

5. Opportunities and challenges

Classification scheme for the solar wind based on the main MHD parameters

A. Lukashenko[1], K. Kaportseva[2], I. Veselovsky[1,3]

[1] *Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University*
[2] *Faculty of Physics, Lomonosov Moscow State University*
[3] *Space Research Institute of the Russian Academy of Sciences*

A new magnetohydrodynamic (MHD) classification of the solar wind is presented and discussed. This classification is based on four main MHD parameters: proton speed V, temperature T, density n and dimensionless plasma parameter β for protons. In the space of these parameters the boundaries for fast (f) and slow (s), hot (h) and cold (c), dense (d) and rarefied (r), magnetized (m) and nonmagnetized (n) wind are set. In total, we obtain 16 solar wind types: fhdm, fhdn, fhrm, etc. We also add a zero type, which corresponds to the solar wind streams, where value of at least one parameter is close to the statistical average.

We analyzed 1-minute OMNIWeb data for 23^{rd} and 24^{th} solar cycles and tried to find a correspondence of common and rare types with their sources at the Sun. All of the above types occur due to different solar activity phenomena and appear with various frequency at different phases of the solar cycles.

We also propose that there is only a little sense to search localized coronal sources of the solar wind with average properties. It is due to nonlocality of the phenomenon.