Variations of alpha particle parameters across corotating rarefaction regions

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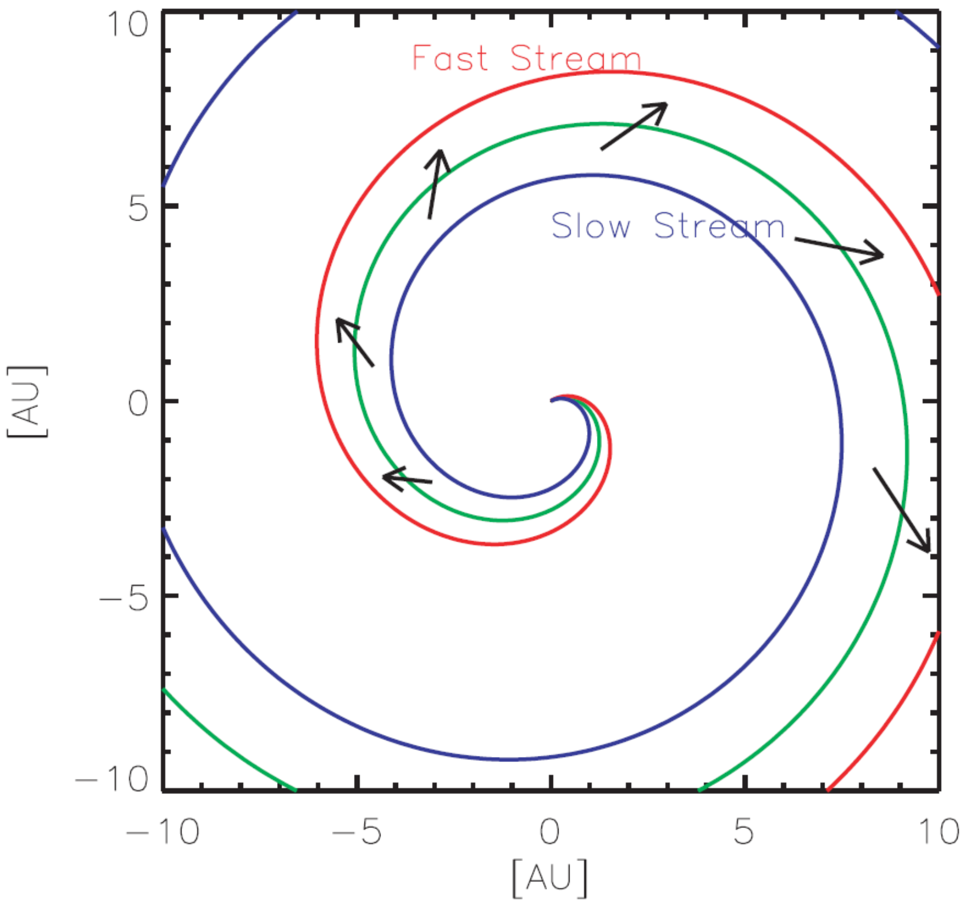
Space Physics Lab

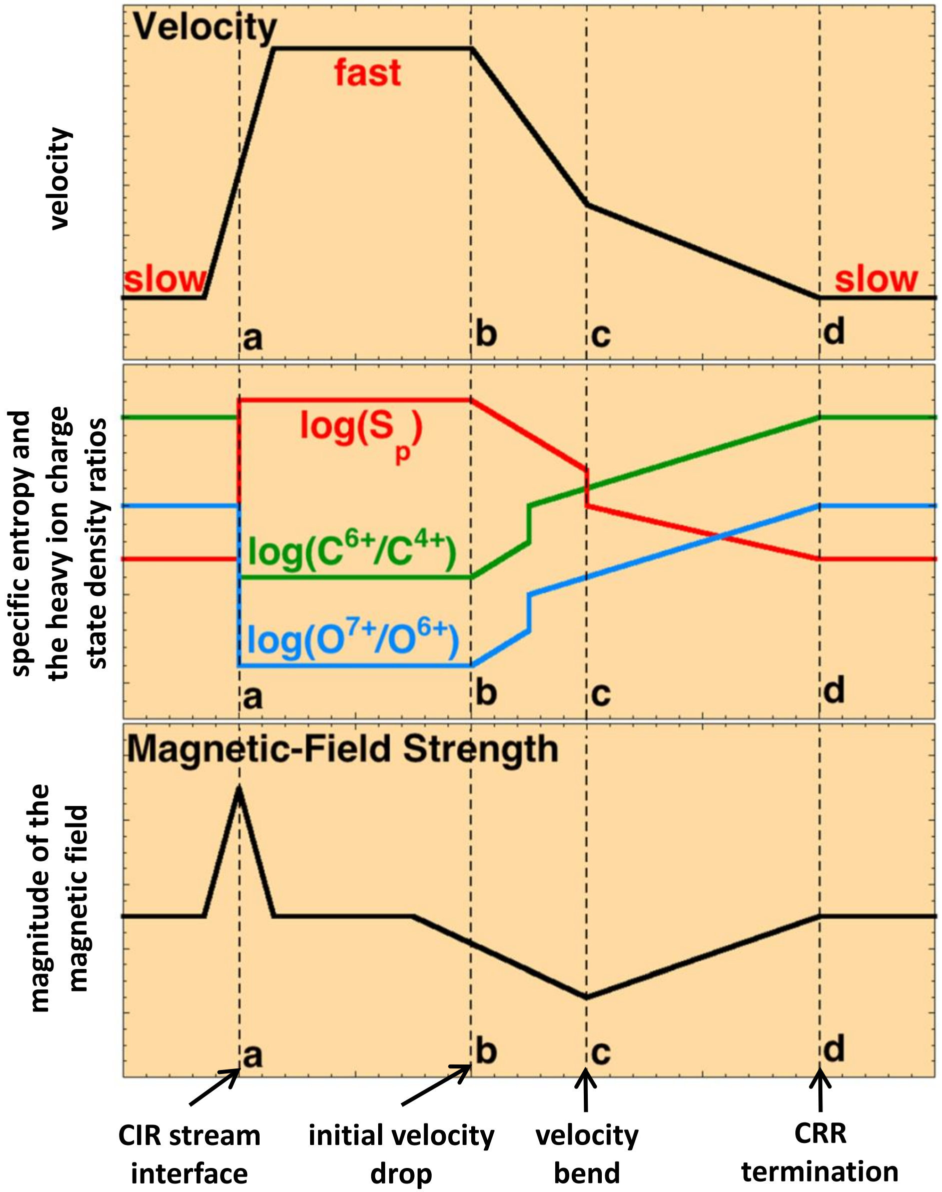
Corotating rarefaction region (CRR)



(Murphy et al., 2002)

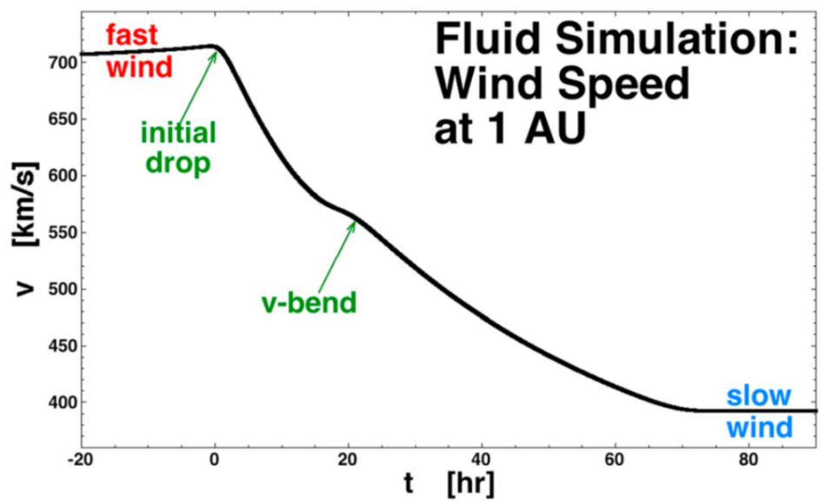
- When the high-speed stream outruns the slow solar wind, the region of rarefacted solar wind is formed
- CRRs are characterized by:
  - Low density and weak magnetic field
  - Monotonic decrease in solar wind speed
  - Magnetic field orientation more radial then predicted by Parker model
- When the solar wind within CRR is mapped back to the Sun along streamlines, it is associated with the regions of small longitudinal extent on the Sun

CRR structure



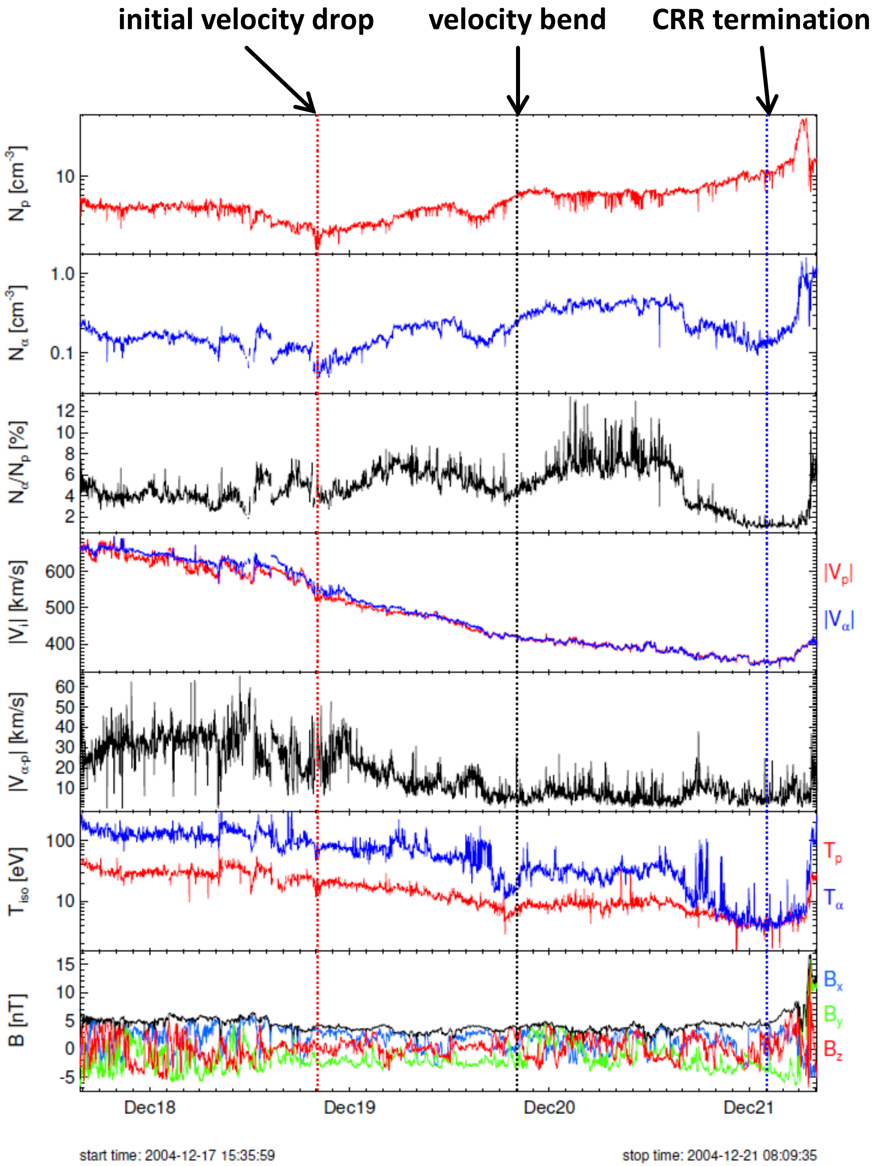
Borovsky et al. (2016) prepared a sketch illustrating chronology of the major signatures in the fast stream and its surrounding at 1 AU.

1D numerical simulations indicate that the velocity bend is the collision point of the pressure-driven expansions of the slow stream and the fast stream in CRR:



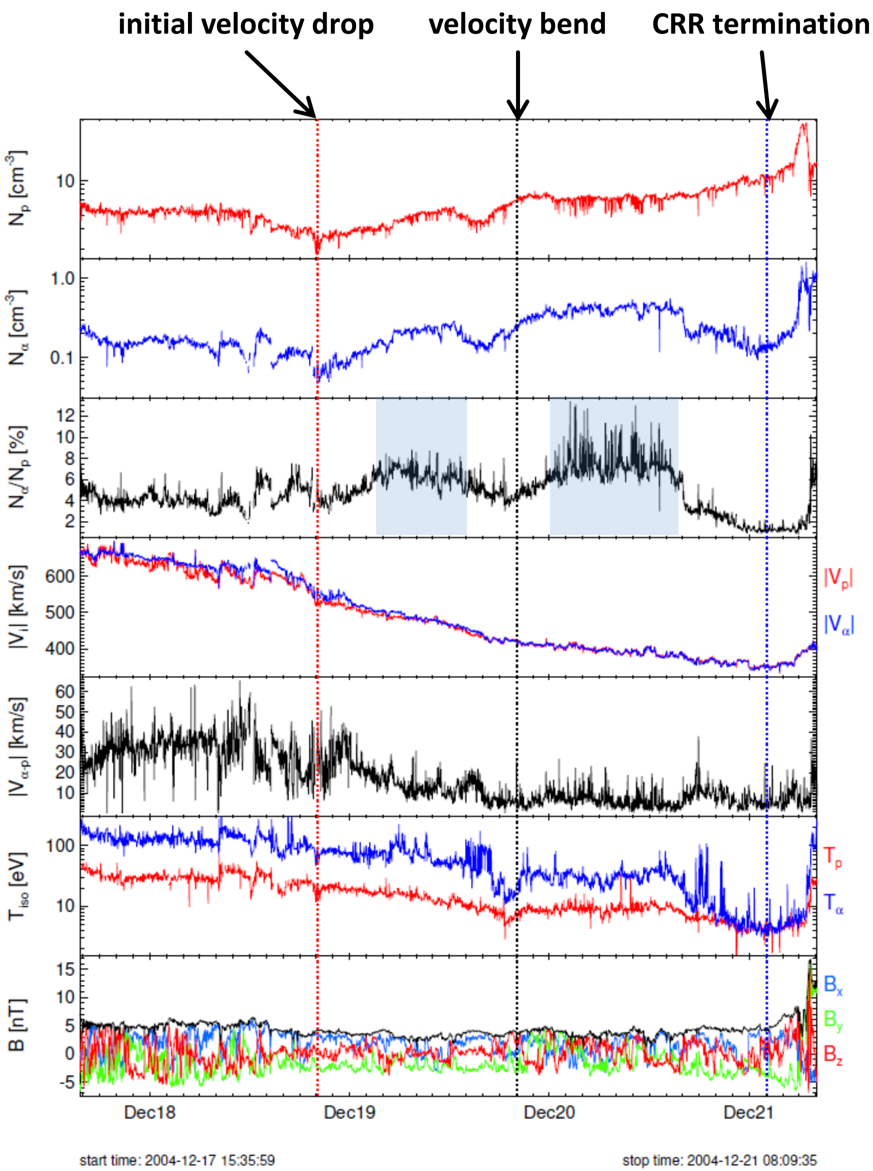
(Borovsky et al., 2016)

Motivation - Example of CRRs



- CRR is usually a large region observed for several days
- It is filled with the intermediate solar wind with mixed characteristics, the origin of which is still not understood
- The content of alpha particles can be even higher in the CRR than in the pristine fast solar wind
- The parameters of alpha particles corresponding to the typical slow solar wind occur at different locations

Motivation - Example of CRRs



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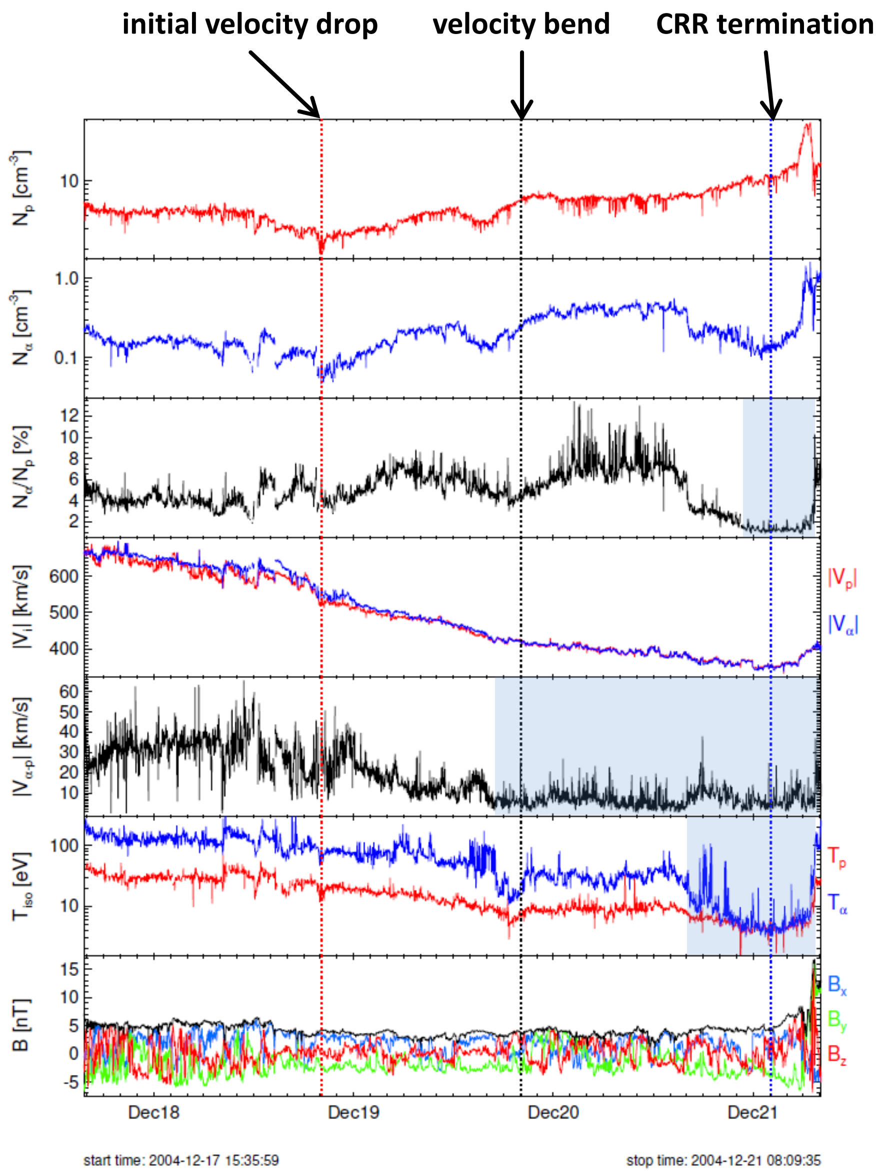

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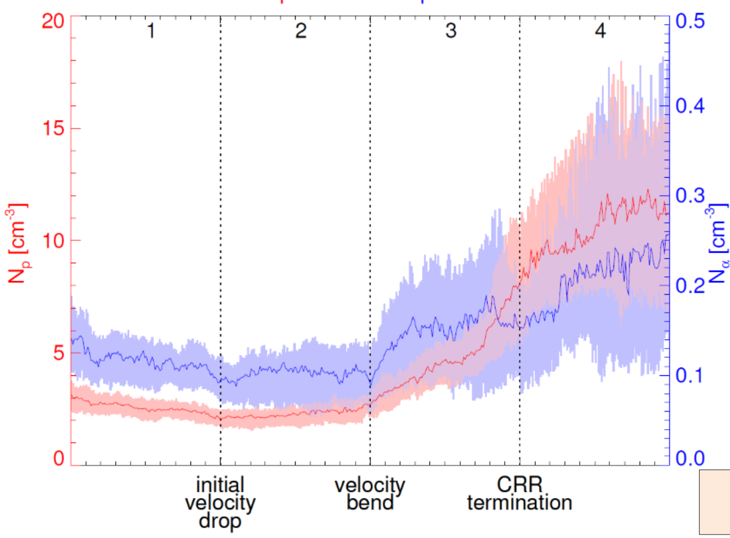
Superposed epoch analysis – basic parameters

How does the global profile of proton and alpha parameters look like across the CRR?

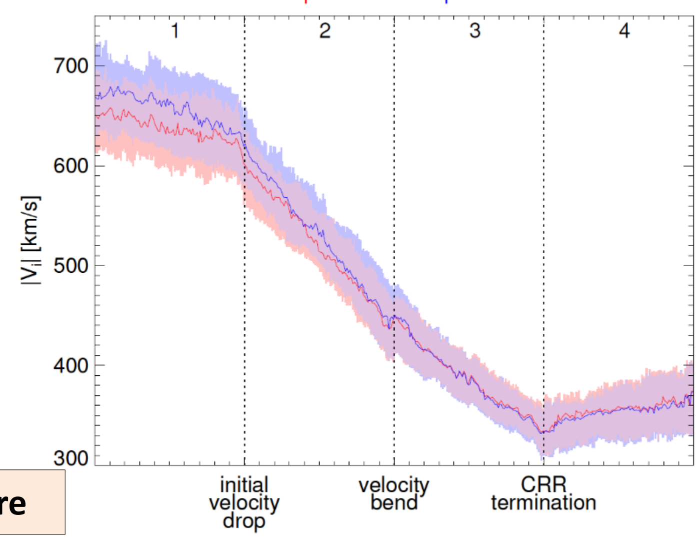
density

proton alpha



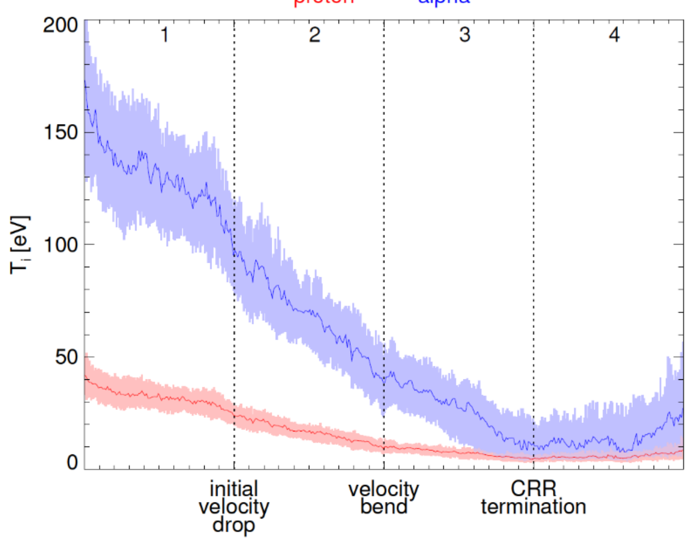
velocity

proton alpha



temperature

proton alpha



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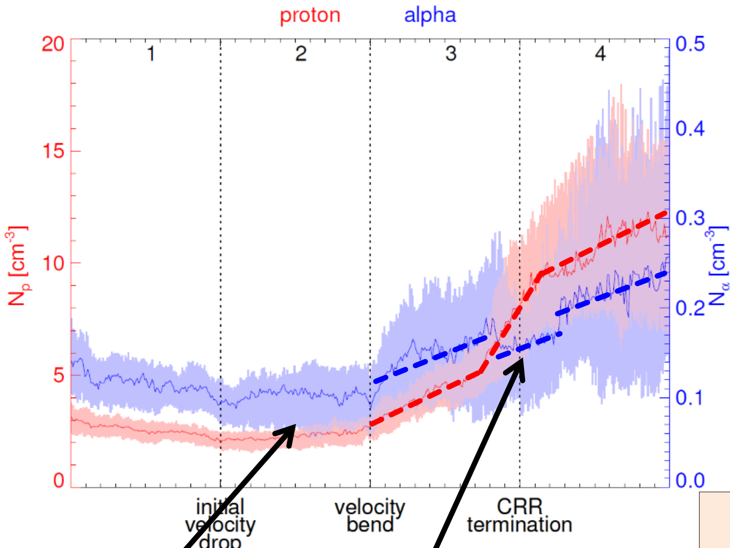
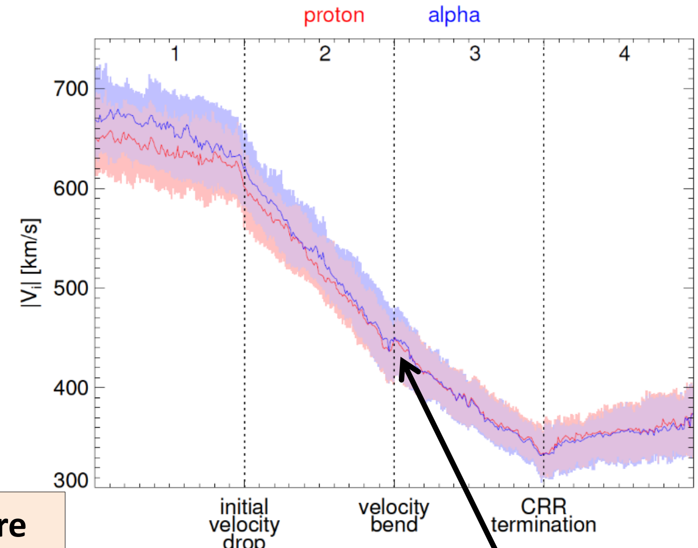


velocity



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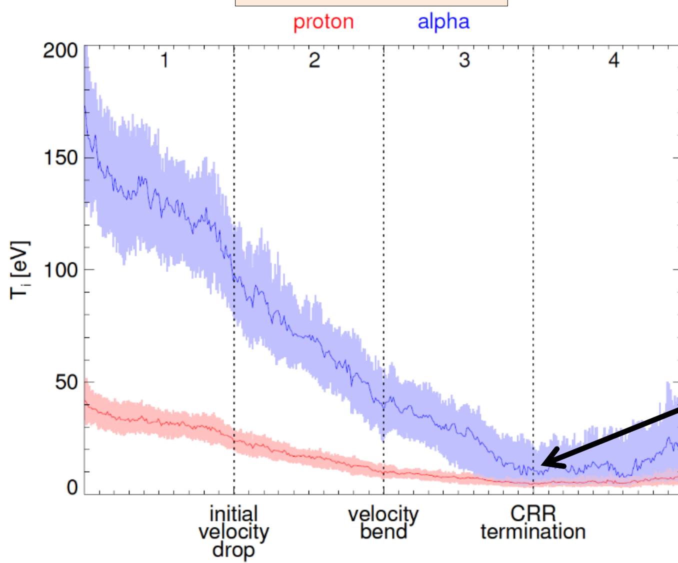


Only a small decrease of density is observed

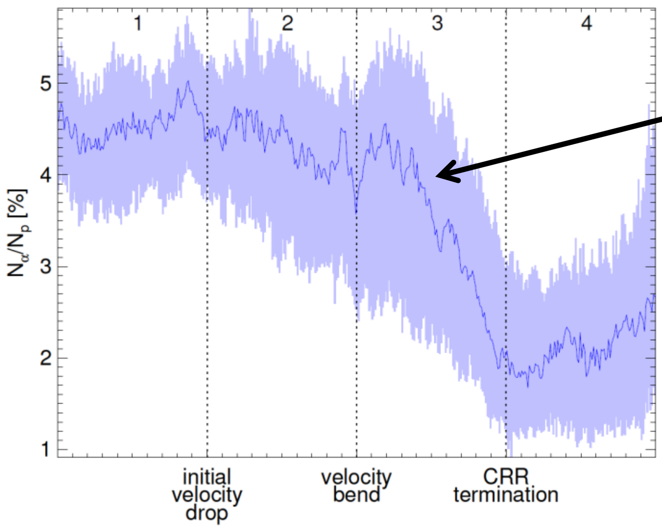
Profiles of the proton and alpha densities differ

Both components reach almost the same speed already near the velocity bend

Both temperatures are nearly balanced

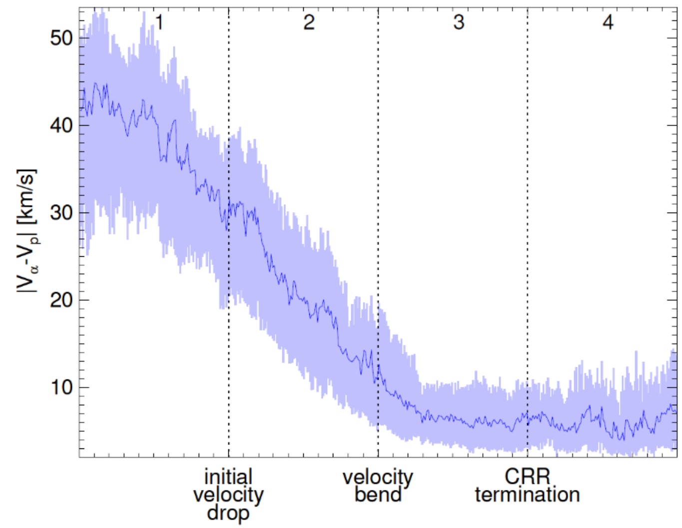
Superposed epoch analysis – mutual relations

relative abundance of alpha particles

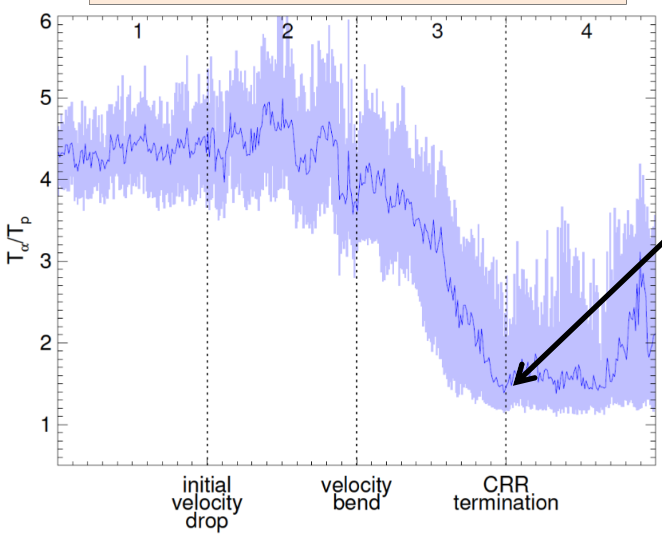


The abundance increases near the velocity bend and then decreases sharply

alpha-proton relative drift



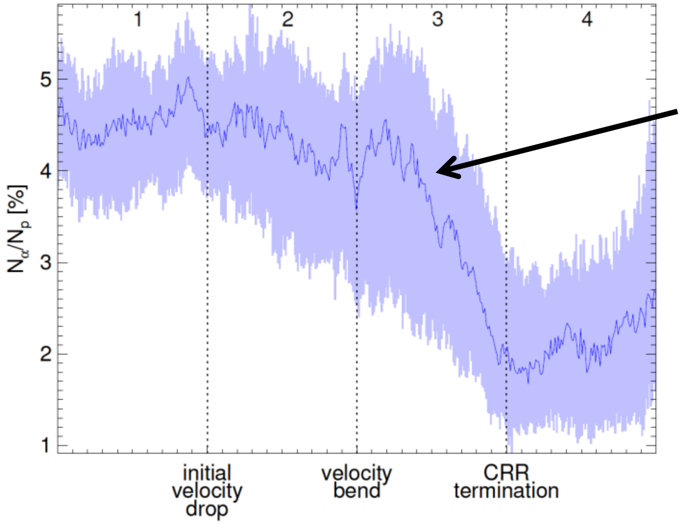
alpha-proton temperature ratio



When the abundance reaches values typical for the slow streams, both temperatures are nearly equal

Superposed epoch analysis – mutual relations

relative abundance of alpha particles



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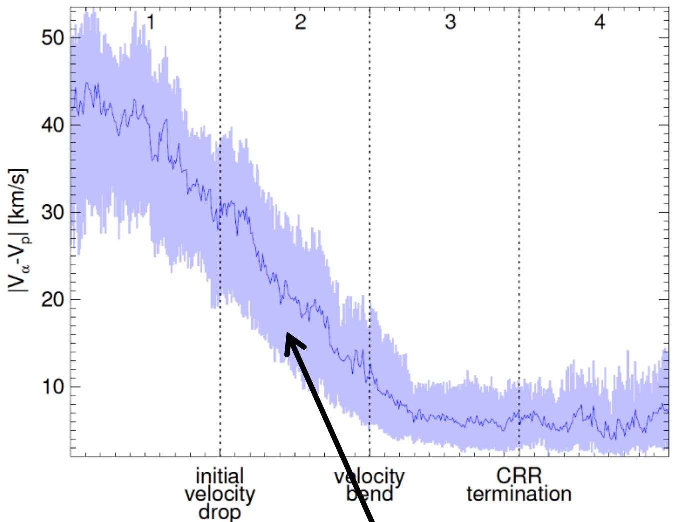
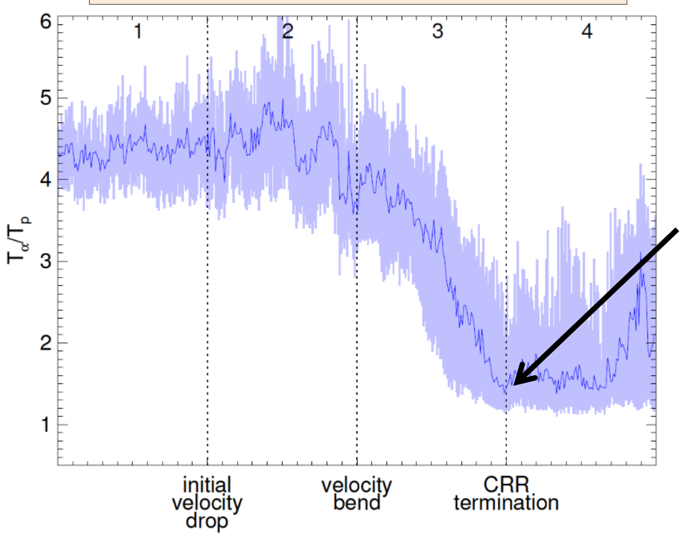


The relative drift decreases from the beginning of the CRR and remains close to 0 after the velocity bend

alpha-proton temperature ratio



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Reduction of the alpha-proton relative drift

Verscharen et al. (2015) proposed two collisionless mechanisms for limiting the alpha-proton relative drift:

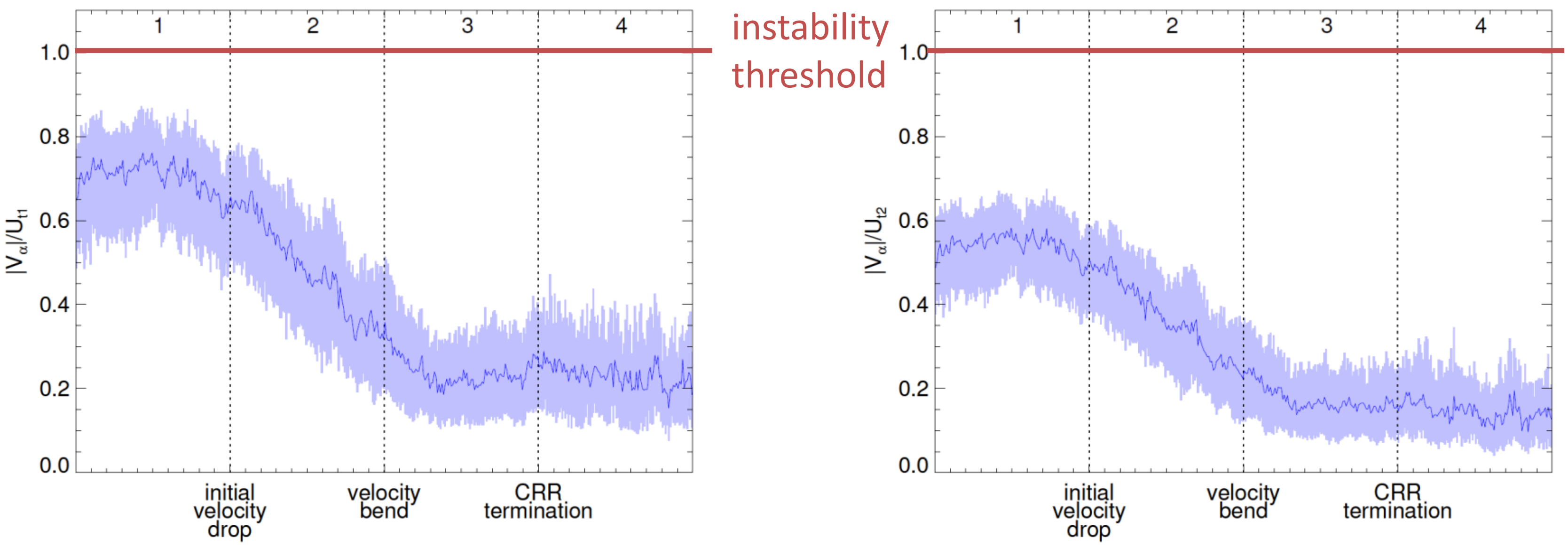
1. **Plasma instabilities**
   The authors found the minimum value of the relative drift needed to excite the following instabilities:

the Alfvén/ion-cyclotron (A/IC) instability

$$U_{t1} = v_A - \sigma_1\left(\frac{T_{\perp\alpha}}{T_{\parallel\alpha}} - 1\right)w_{\parallel\alpha} - \frac{v_A^2 T_{\parallel\alpha}}{4\sigma_1 w_{\parallel\alpha} T_{\perp\alpha}}$$

the fast-magnetosonic/whistler (FM/W) instability

$$U_{t2} = v_A - \sigma_2\left(1 - \frac{T_{\perp\alpha}}{T_{\parallel\alpha}}\right)w_{\parallel\alpha} + \frac{v_A^2 T_{\parallel\alpha}}{4\sigma_2 w_{\parallel\alpha} T_{\perp\alpha}}$$



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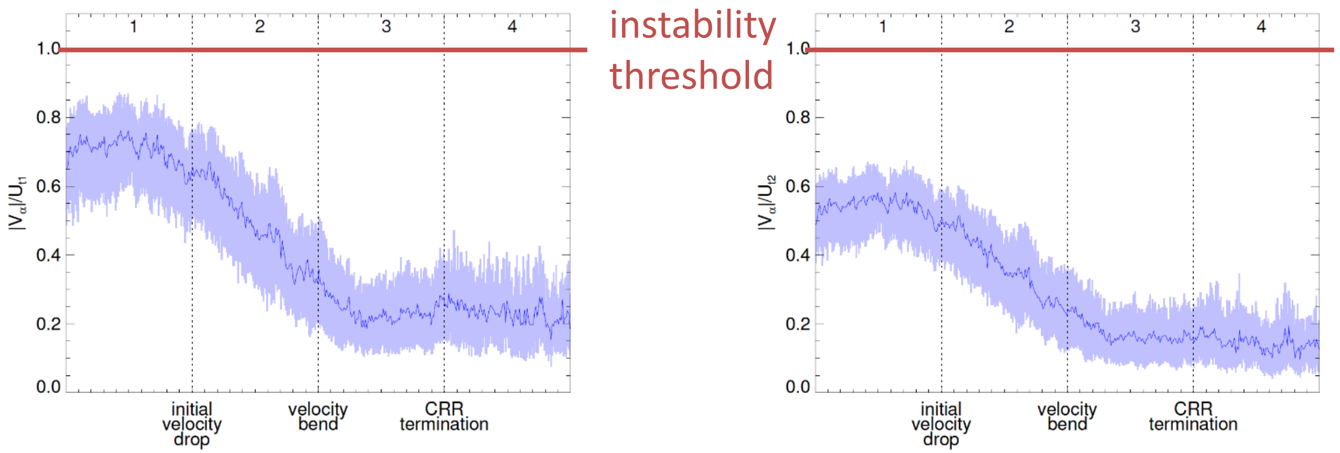
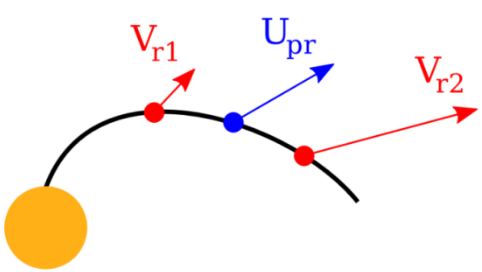


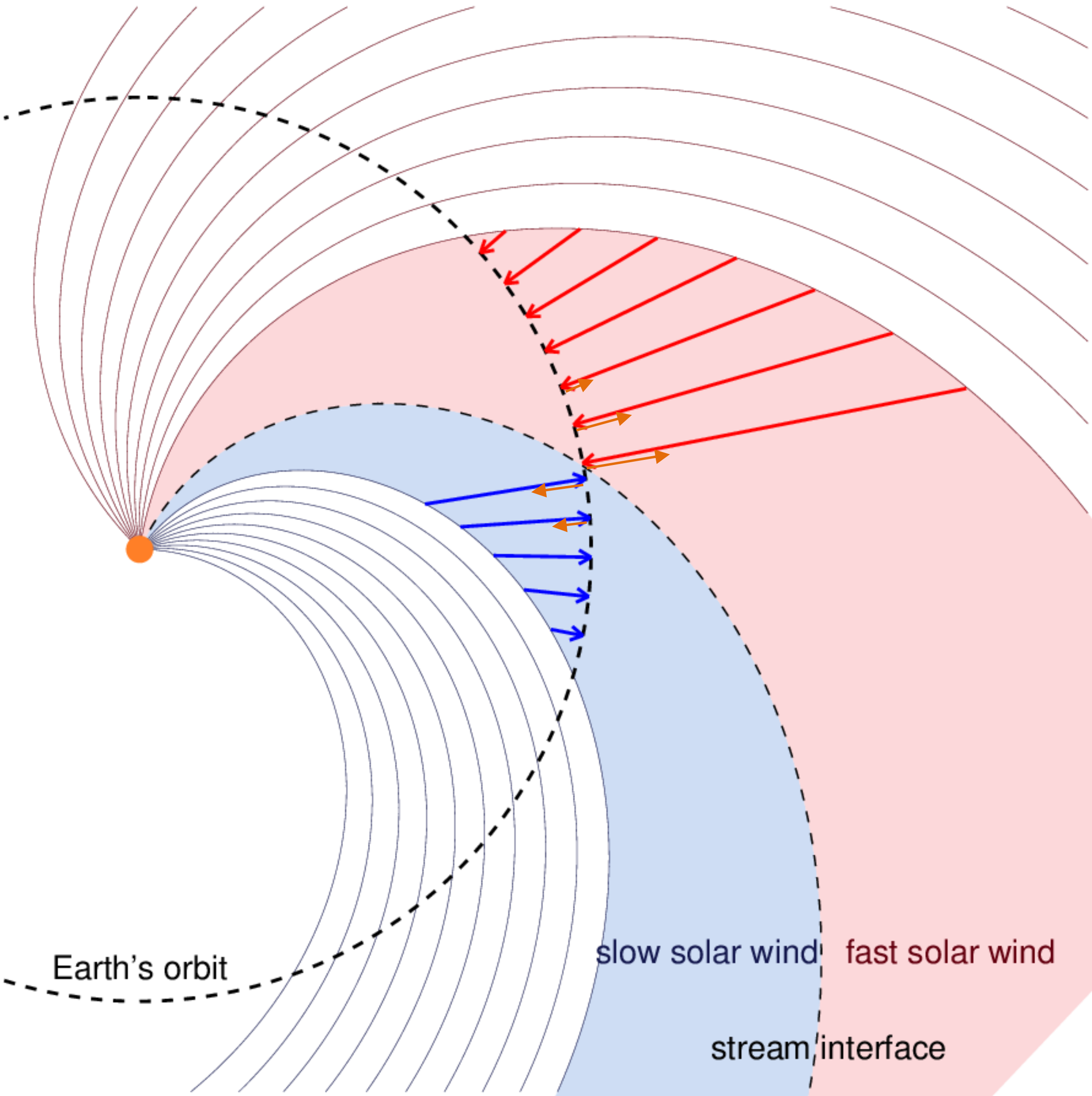
All observations made at 1 AU across the CRRs are below both thresholds for A/IC and FM/W instabilities. As the distance from the CRR leading edge increases, the alpha-proton relative drift decreases even more.

2. Rotational force



- Alpha particles can be viewed as beads sliding on a wire, where the wire is the spiral interplanetary magnetic field, which is anchored to and rotates with the Sun
- It controls the deceleration of alphas at radial distances greater than 2.5 AU

Reduction of the alpha-proton relative drift



- Another mechanism leading to the reduction of the relative drift and to the abundance changes is based on the mirroring of the multicomponent solar wind in a converging magnetic field
- Such a magnetic field configuration may arise in CRR during the sunward expansion of the fast solar wind stream
- Mirrored are particles moving toward the Sun in the "solar wind frame"

(Ďurovcová et al., 2019)

Summary and conclusions

- Using the CRR collection by Borovsky et al. (2016) we found global profiles of alpha parameters across CRR and compared them with those of protons

- We found that changes of different alpha parameters are temporally separated:
  - Behind the initial velocity drop, the velocities of alphas and protons gradually decrease. Both components reach almost the same speed already near the velocity bend
  - Around the velocity bend, the alpha relative abundance increases. Thereafter, it decreases sharply until the CRR termination is reached
  - The alpha and proton temperature ratio begins to decrease at the velocity bend. When the alpha relative abundance reaches values typical for the slow streams, both temperatures are nearly equal

- Our observations suggest that an additional process occurs in CRR. It changes the alpha parameters in the intermediate wind around the velocity bend like mirroring in CIRs

Thank you for your attention

Acknowledgement

This project was supported by the Grant Agency of the Charles University under the project number 264220. We would also like to thank professor Vítek for his continuous support and valuable insight.