How the area of coronal holes affects the properties of high-speed streams near Earth

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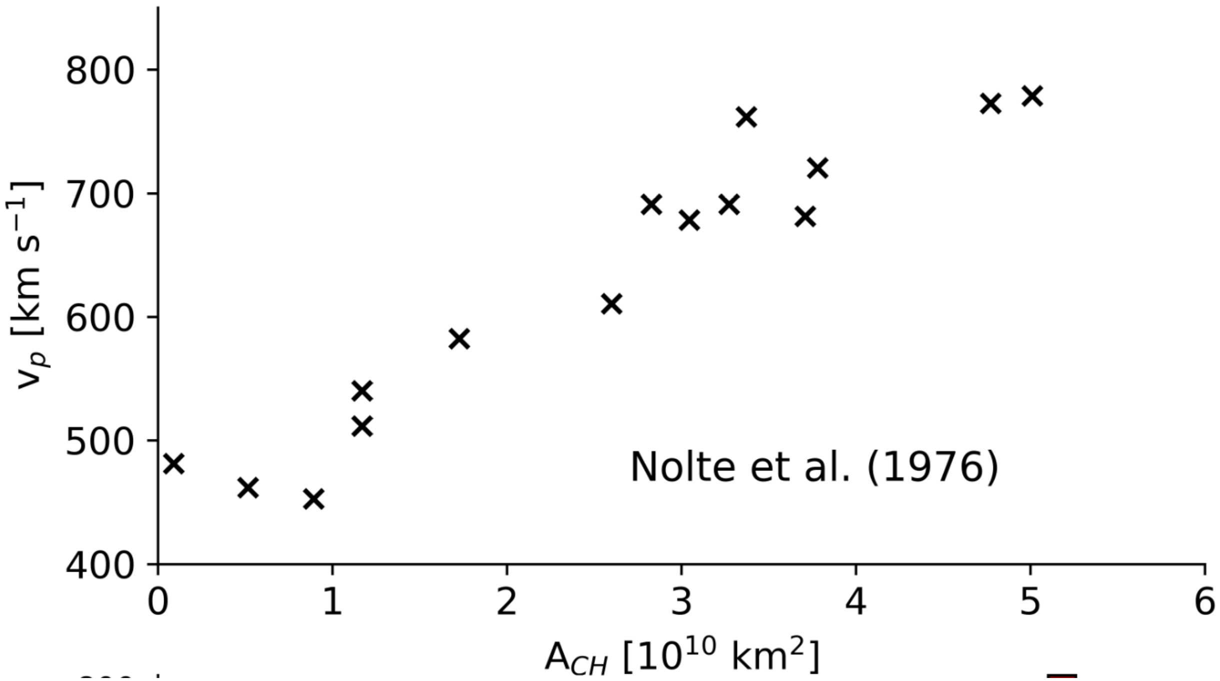
Introduction

- Since the 1970s, it is known that the peak velocity of high-speed streams is (anti-)correlated to

  1) the area of coronal holes <- Why?

  2) the flux tube expansion factor



Overview

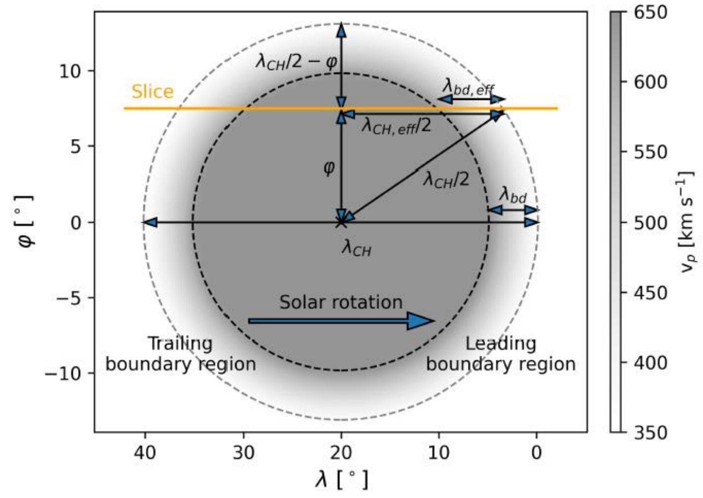
1. Freely propagating high-speed solar wind streams
    - Presume no interactions or heating -> dispersion of its initial temporal velocity distribution function

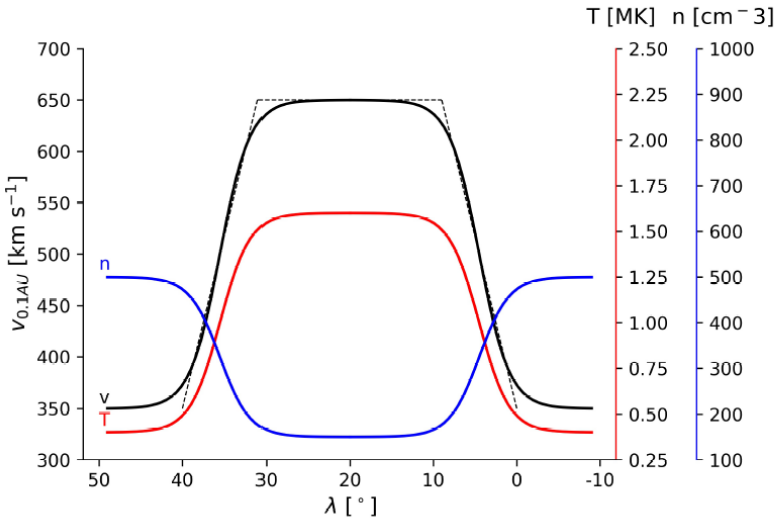
2. Kinematics of the stream interface
    - Conservation of momentum

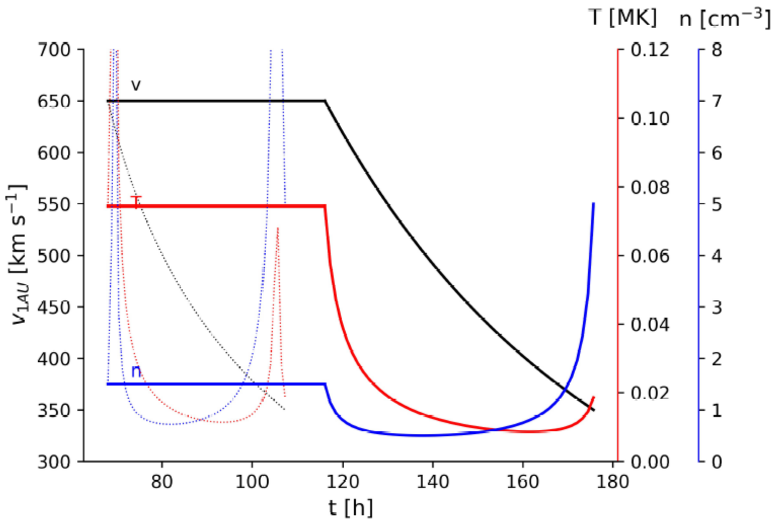
3. Properties of high-speed streams near Earth
    - Properties of freely propagating high-speed streams evaluated at the arrival time of the stream interface at Earth

2) Freely propagating high speed streams

Let’s neglect any boundary effects in interplanetary space, and any local heating.
I.e., let’s describe the propagation as a simple dispersion of its initial temporal velocity distribution

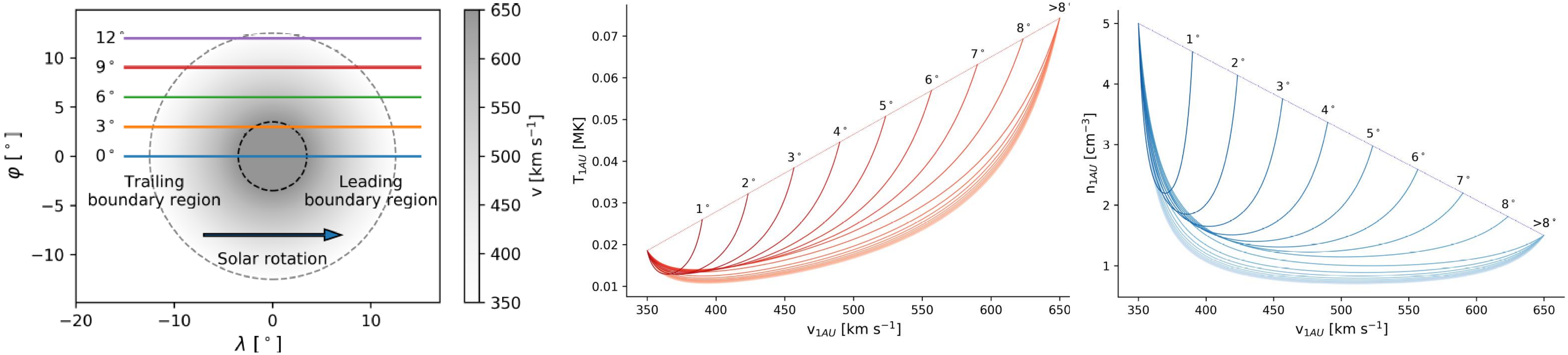






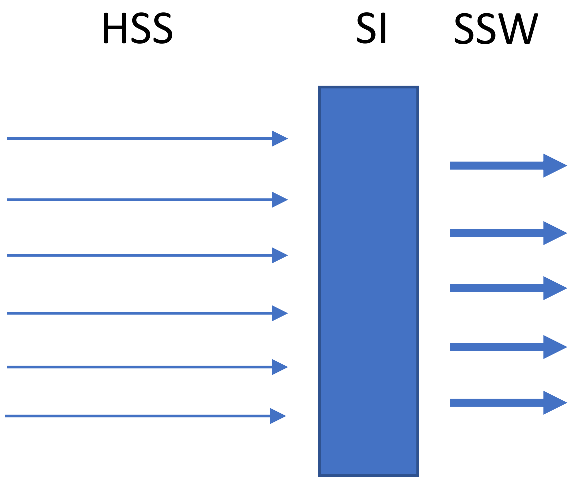
2) Freely propagating high speed streams
- temperature and density

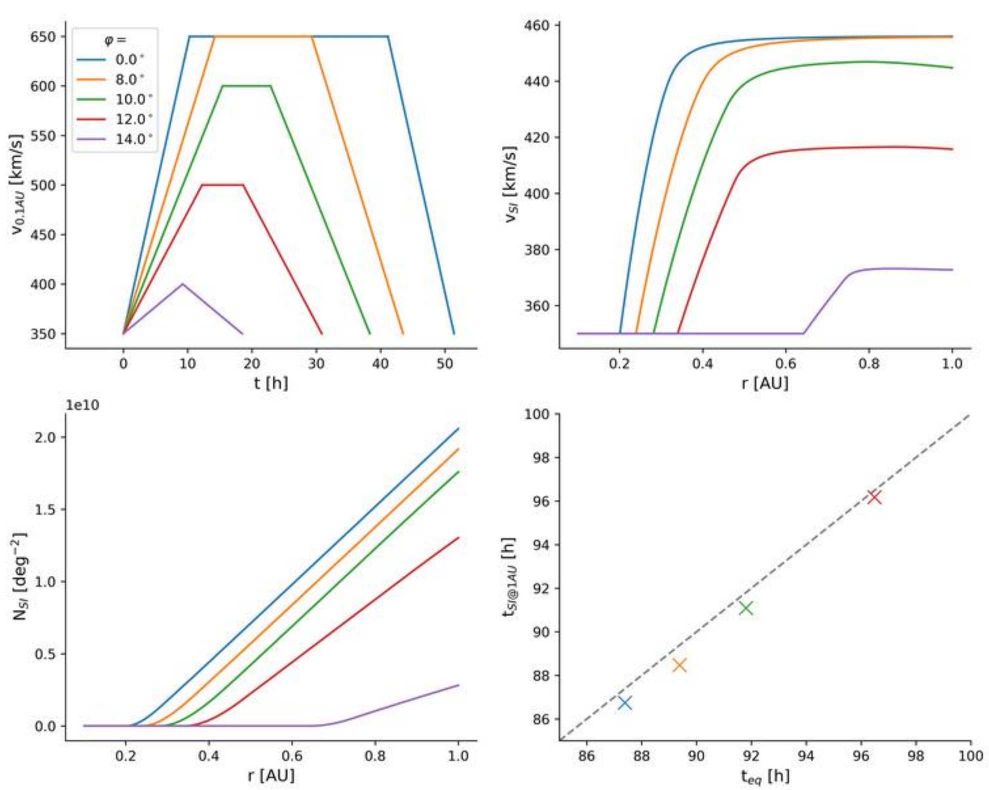
$$\frac{V_{0.1\,\mathrm{AU}}(t)}{V_r(\breve{t})} = \frac{r_0^2}{r^2}\cdot\left(\left|1-\frac{5\ \omega\ (r-0.1\,\mathrm{AU})(v_{0.1\,\mathrm{AU}}(t)-v_s)(v_{sl,max}-v_{0.1\,\mathrm{AU}}(t))}{\lambda_{bd,eff}\ v_{0.1\,\mathrm{AU}}(t)^2\ (v_{sl,max}-v_s)}\right|\right)^{-1}$$



2) Kinematics of the stream interface

3-body conservation of momentum





$$\frac{dv_{SI}(t)}{dt} = \frac{1}{N_{SI}} \left(n_r \, (v_r - v_{SI})^2 - n_s \, (v_s - v_{SI})^2 \right)$$

$$\frac{dN_{SI}(t)}{dt} = n_s \, (v_{SI} - v_s) + n_r \, (v_r - v_{SI}),$$

Properties of HSSs at Earth

- Plasma parcels of freely propagating HSSs that did not impinge into the stream interface yet

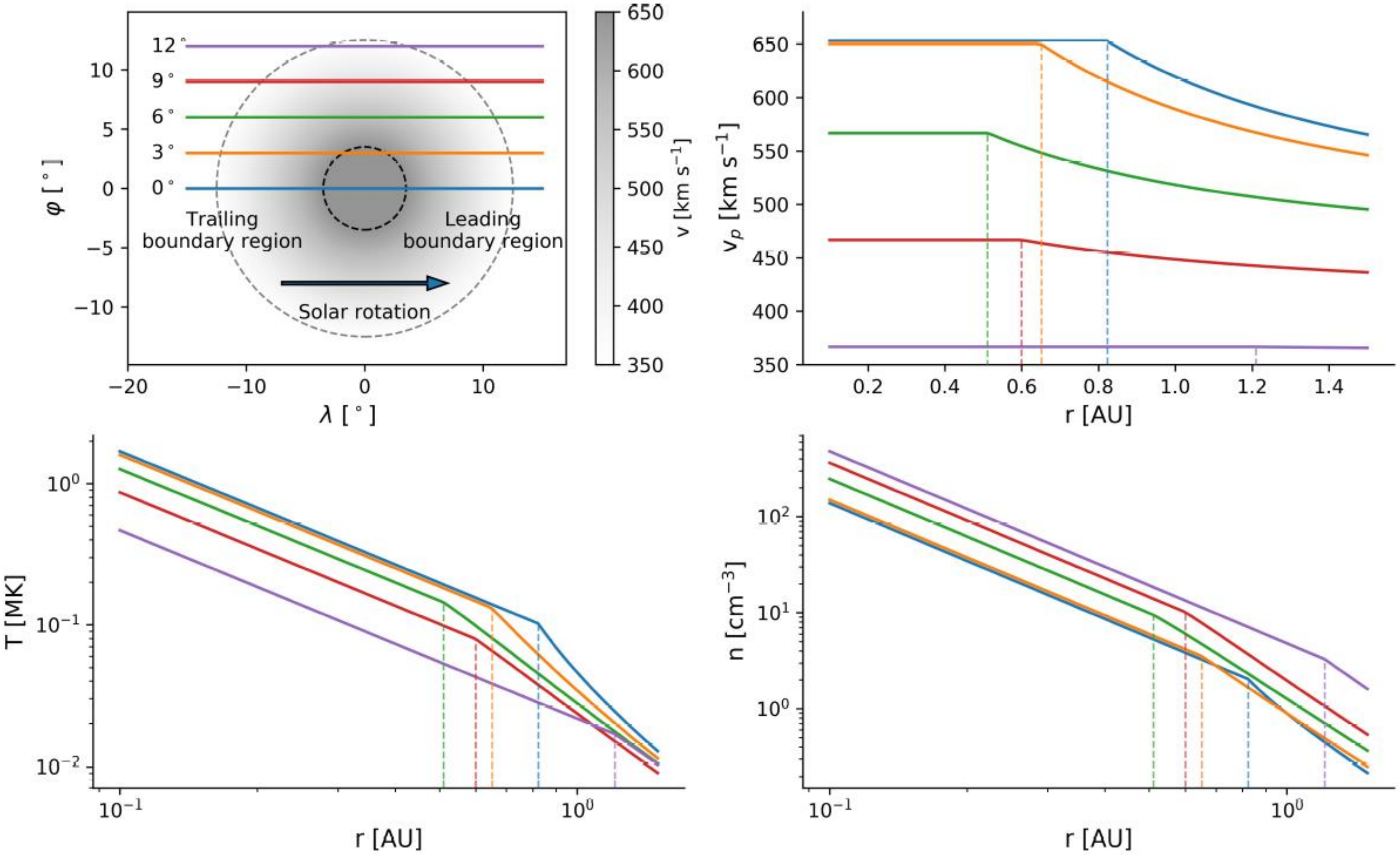
  -> Peak velocity = velocity of freely propagating HSSs evaluated at the arrival time of the stream interface

$$v_p(r) = \begin{cases} v_{sl,max} & \text{for } t_{SI} \leq \frac{\lambda_{CH,eff} - \lambda_{bd,eff}}{\omega} + \frac{r}{v_{sl,max}}, \\ 0.5 \left(v_s - v_{sl,max} + \frac{v_{sl,max}\ v_s}{v_{SI}} - \frac{r\ \omega}{v_{SI}}\ \frac{dv}{d\lambda} + \lambda_{CH,eff}\ \frac{dv}{d\lambda} + \right. & \\ \left. + \sqrt{\left(v_s - v_{sl,max} + \frac{v_{sl,max}\ v_s}{v_{SI}} - \frac{r\ \omega}{v_{SI}}\ \frac{dv}{d\lambda} + \lambda_{CH,eff}\ \frac{dv}{d\lambda} \right)^2 + 4\ r\ \omega\ \frac{dv}{d\lambda}} \right) & \text{for } t_{SI} > \frac{\lambda_{CH,eff} - \lambda_{bd,eff}}{\omega} + \frac{r}{v_{sl,max}} \end{cases}$$

- Density and temperature can be derived by the volume expansion of this plasma parcel (see slides before)

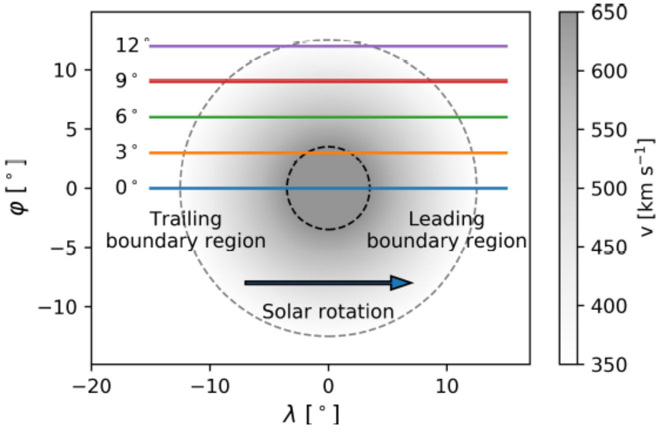
Properties of HSSs at Earth

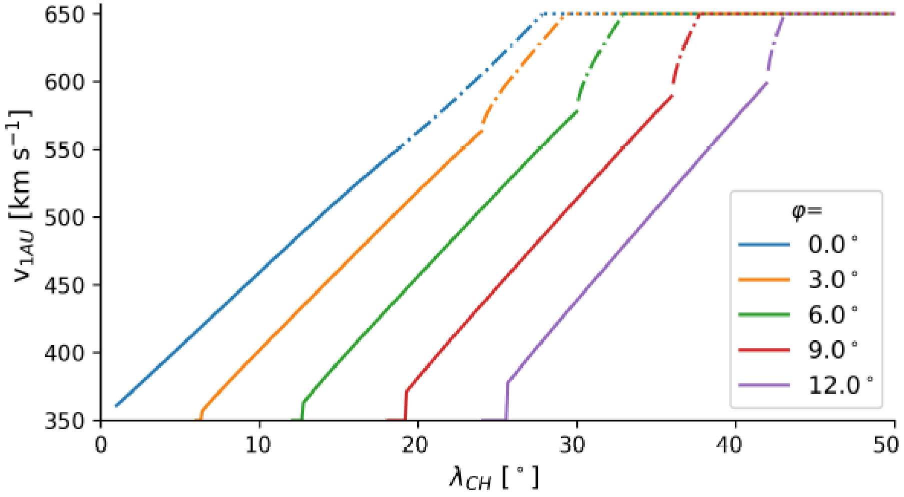
- radial behavior of the peak velocity, temperature, and density

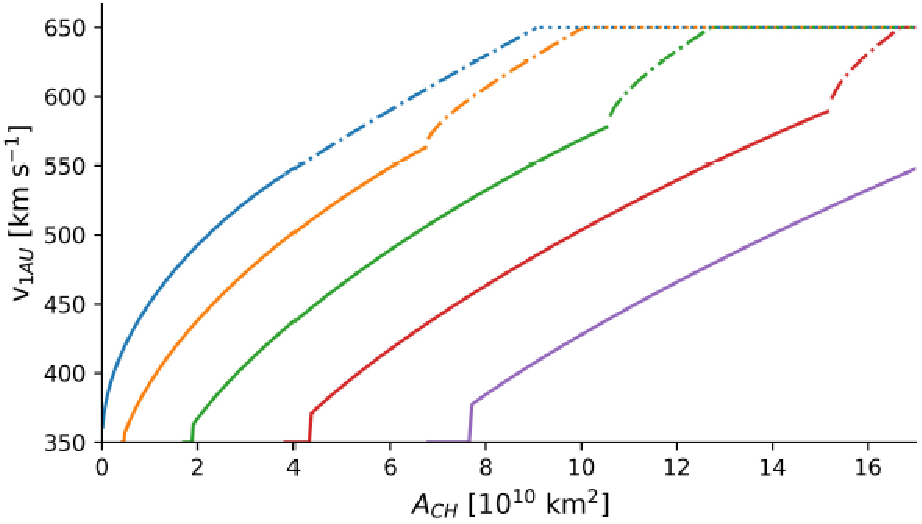


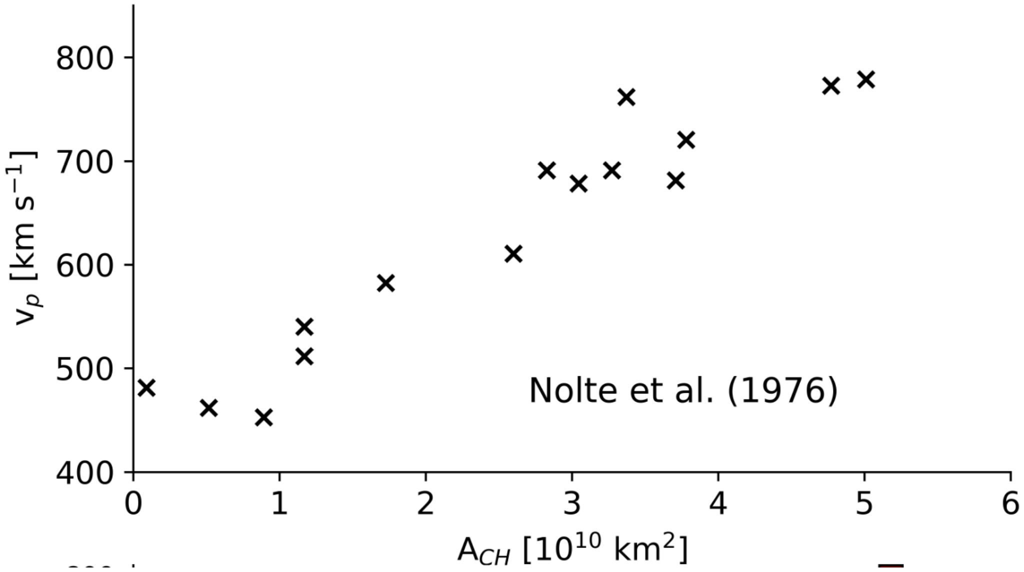
Properties of HSSs at Earth

- Peak velocity vs. longitudinal extension / area



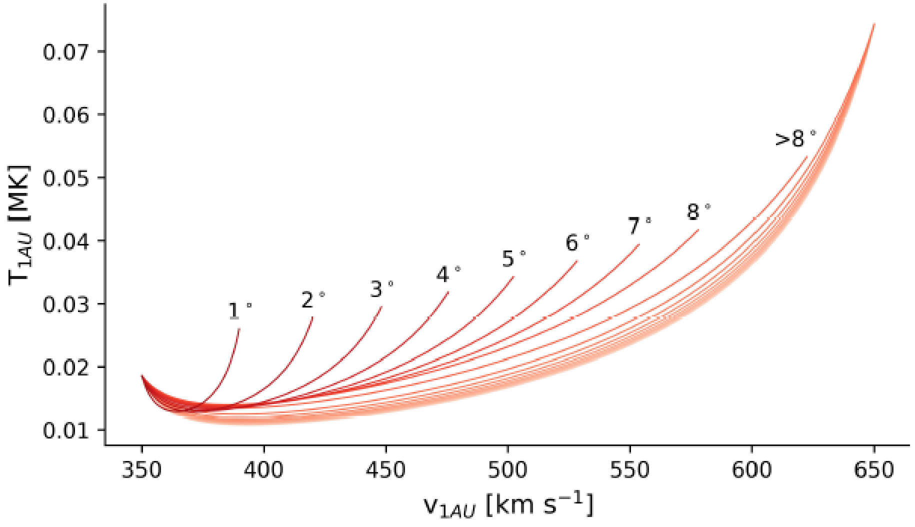


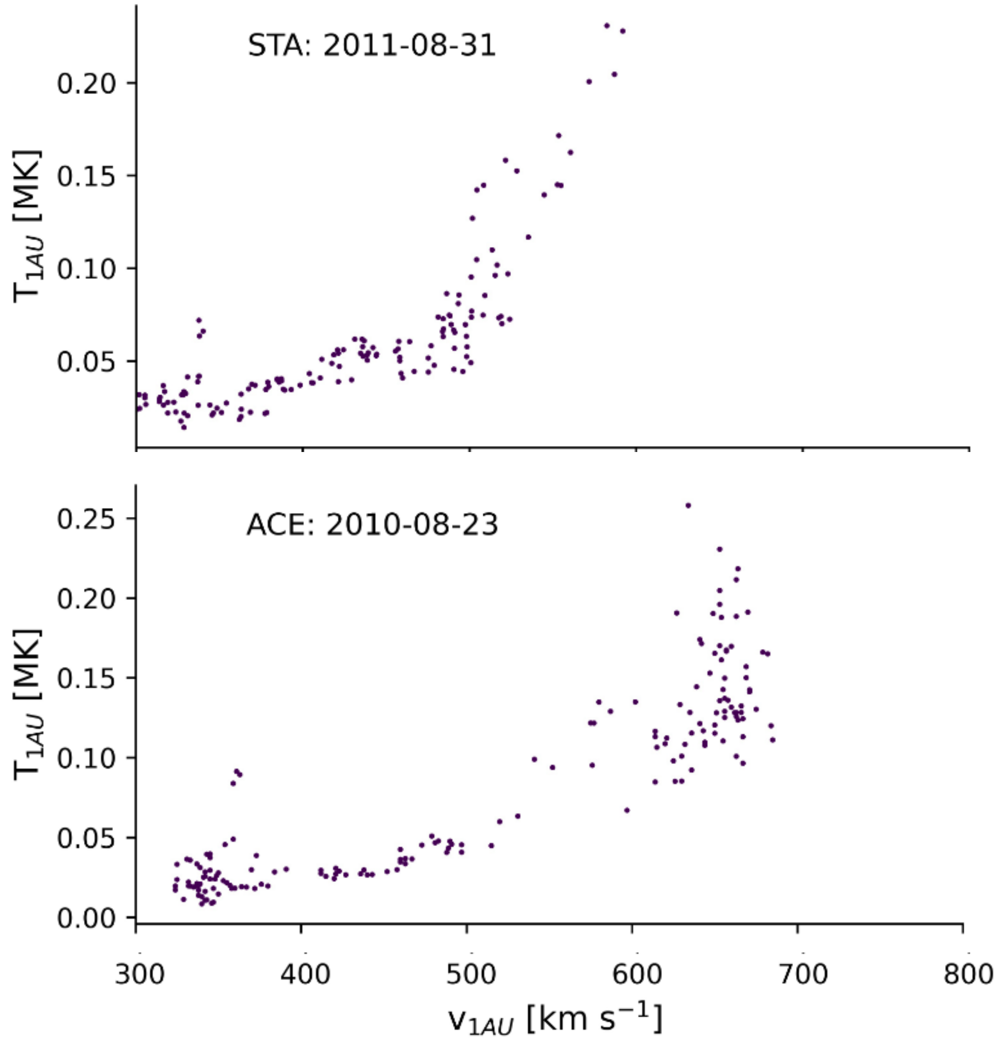




Properties of HSSs at Earth

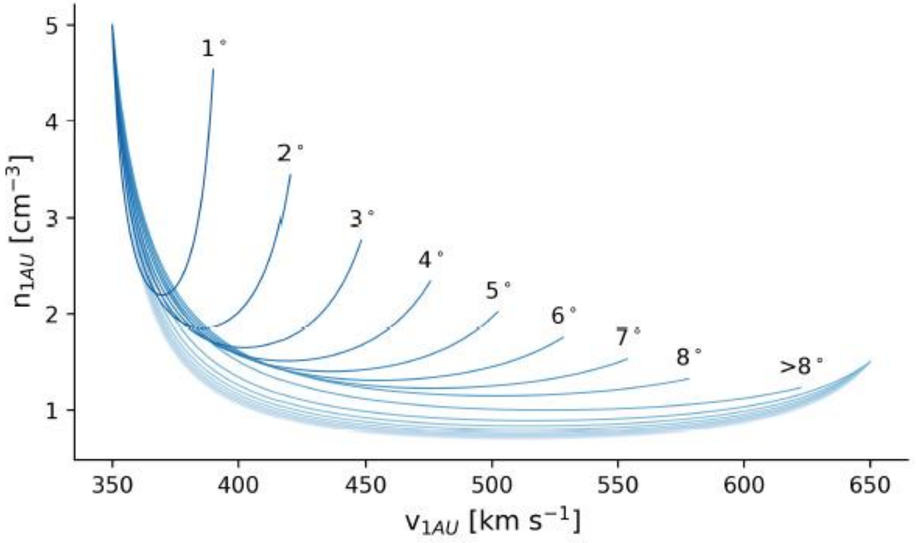
- temperate and density vs. velocity: individual HSSs

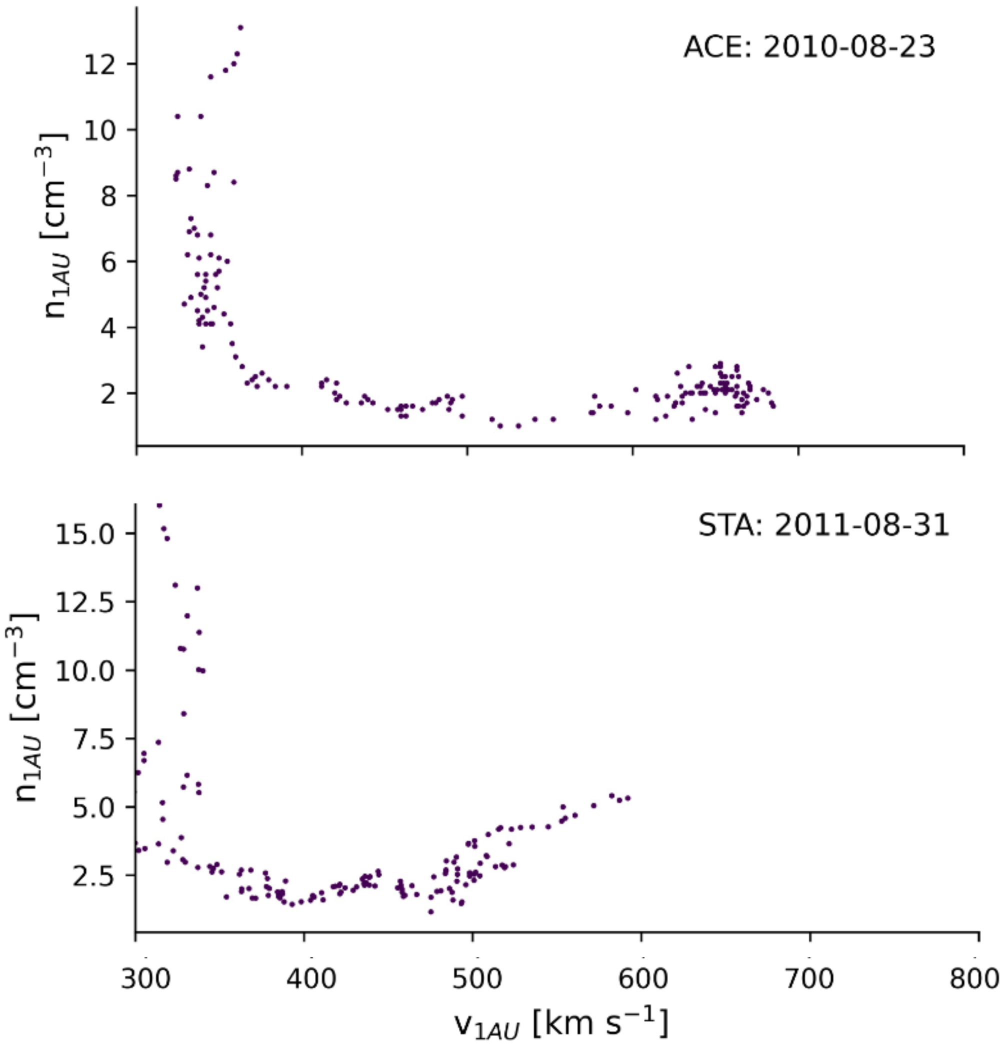




Properties of HSSs at Earth

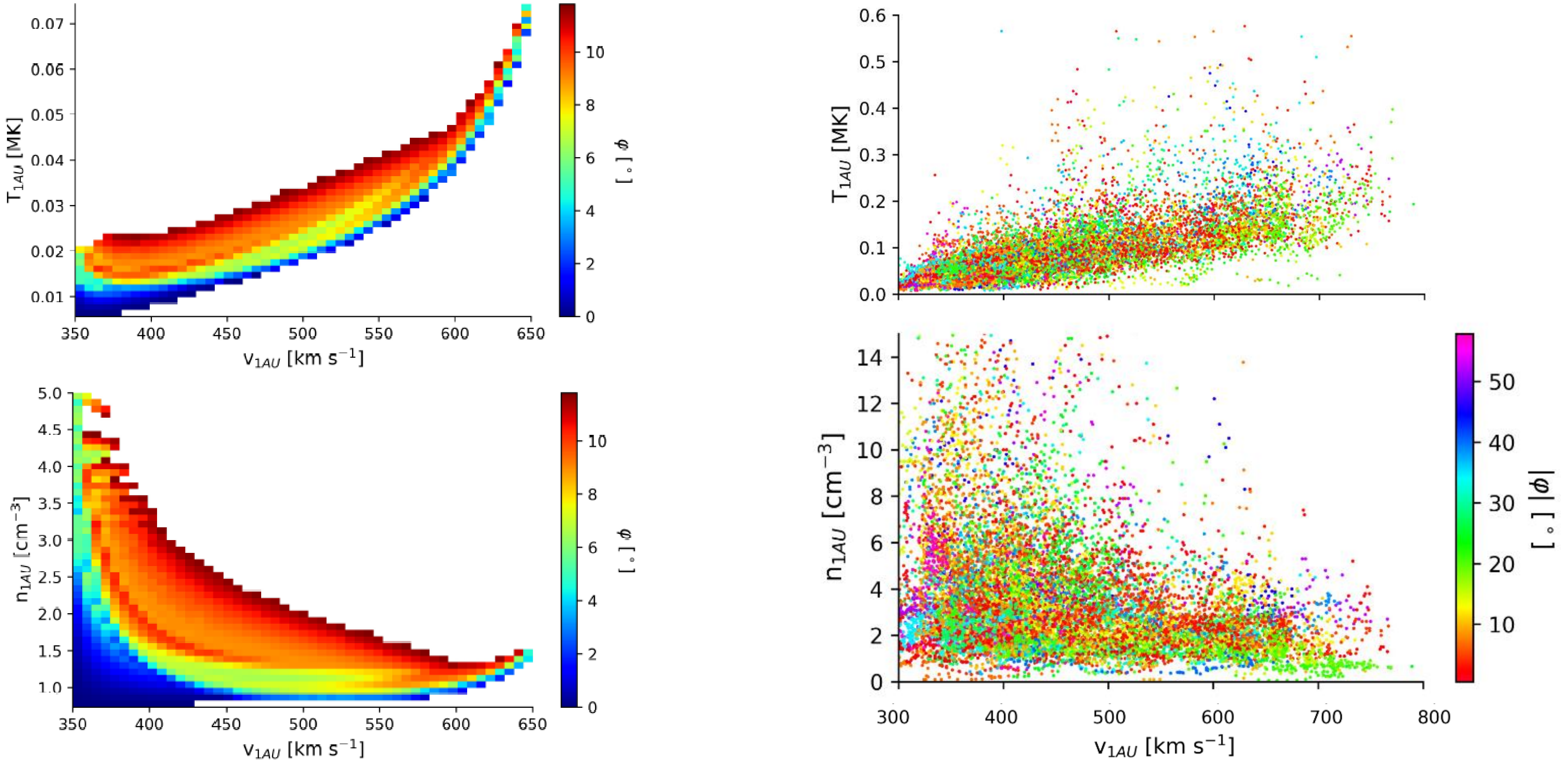
- temperate and density vs. velocity: individual HSSs





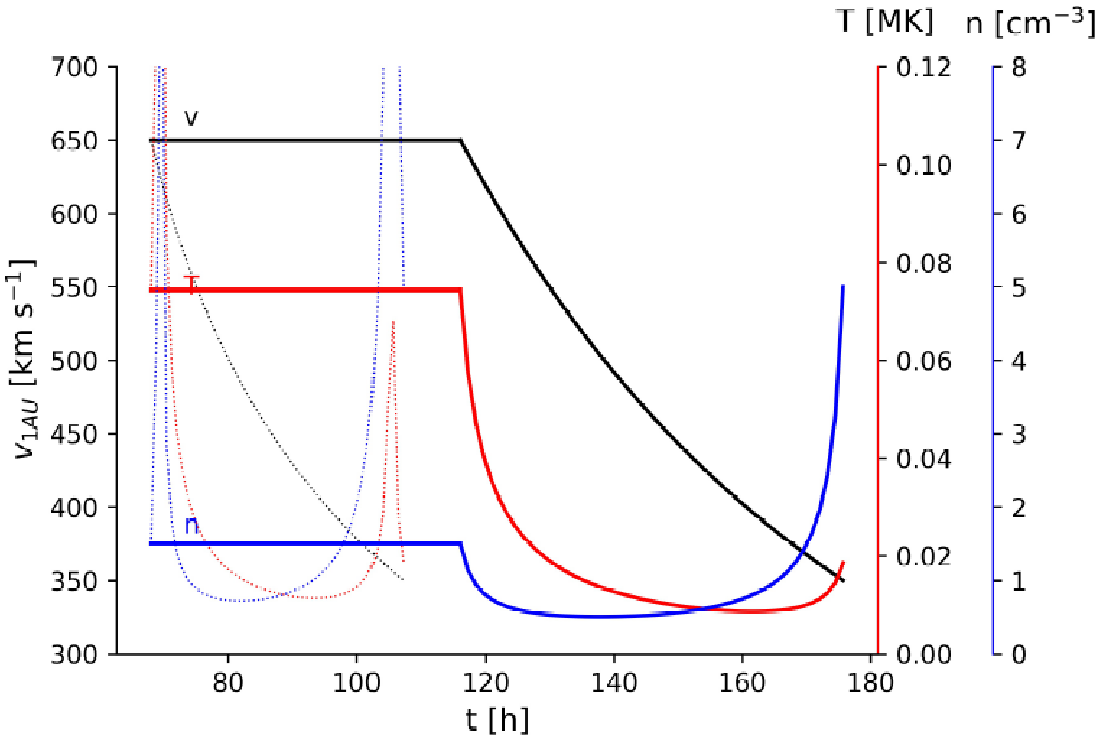
Properties of HSSs at Earth

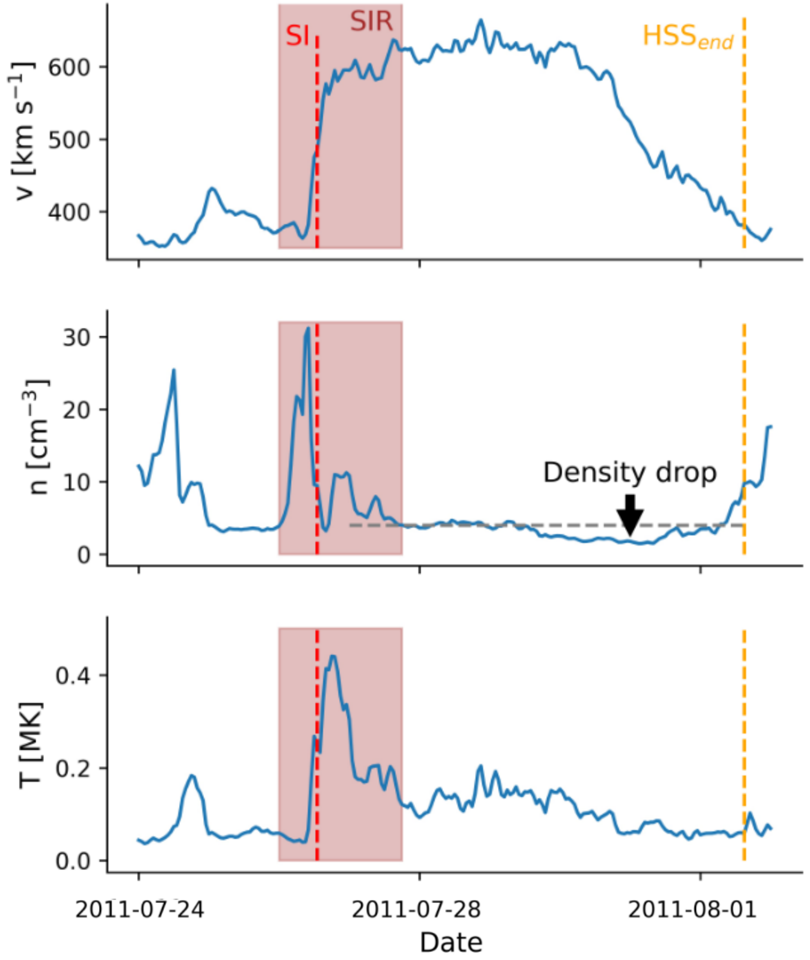
- temperate and density vs. velocity: all HSSs



Properties of HSSs at Earth

- density time line





Summary of the results

- The **propagation phase** of HSSs from the Sun to Earth has a strong effect on the properties we see at Earth.

- The **widths of the HSS boundary region** is an important parameter.

- The **peak velocity of HSSs at Earth depend on the effective longitudinal widths** of HSSs at 0.1 AU, or the longitudinal widths of their coronal holes, respectively. This also explains the empirical relationship between coronal hole areas and HSS peak velocities at Earth.

- The **density and temperature of HSS plasma parcels near Earth depend on their radial expansion** on their way from Sun to Earth, giving the temperature-velocity and density-velocity relationships their specific shape.

- This radial expansion **weakens the correlation between HSS temperatures and velocities** at large statistical datasets at Earth distance. However, it **completely destroys the HSS density to velocity correlation** at Earth distance.