SWA-EAS Electron 3D VDFs

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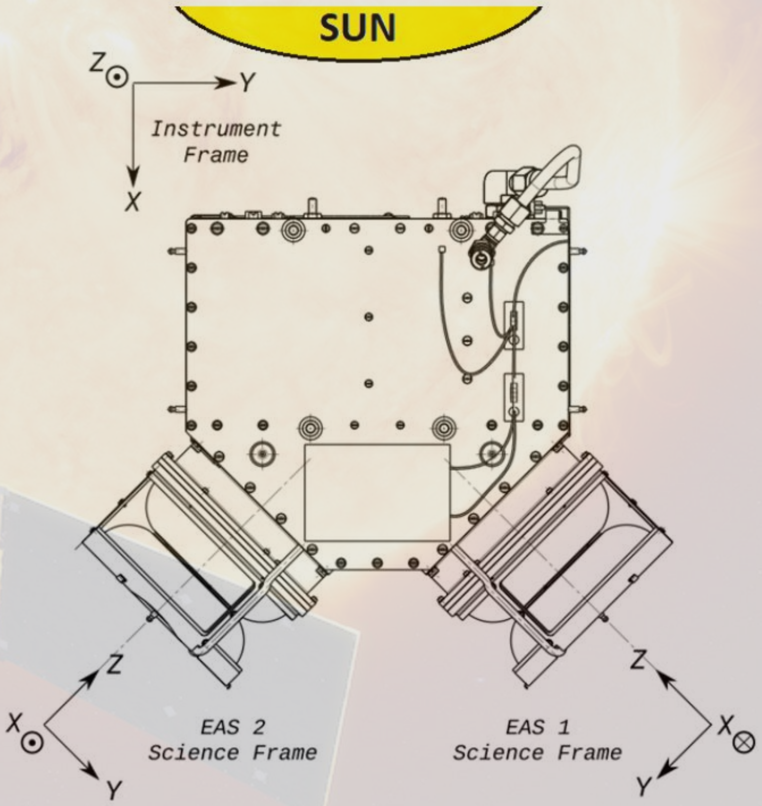
3D VDFs

- Distribution of particle velocity components;
- Plasma bulk properties;

  (e.g., density, velocity, temperature);
- Plasma dynamics;
- Heating/acceleration;
- Anisotropies.

3D VDFs by SWA-EAS

- Full sky coverage;
- Frame transformation required;
- Cross -calibration between two heads;
- Deal with other typical challenges (e.g, s/c charging).



Forward modeling (simulation)

- Maxwellian distribution function for the plasma on instrument frame

$$f(\boldsymbol{u}) = n(\pi v_{\text{th}}^2)^{-\frac{3}{2}} \exp\left[-\frac{(\boldsymbol{u}-\boldsymbol{v})^2}{v_{\text{th}}^2}\right]$$

n : density

$\boldsymbol{u}$: particle velocity

$\boldsymbol{v}$: bulk velocity

v_{th} : thermal speed

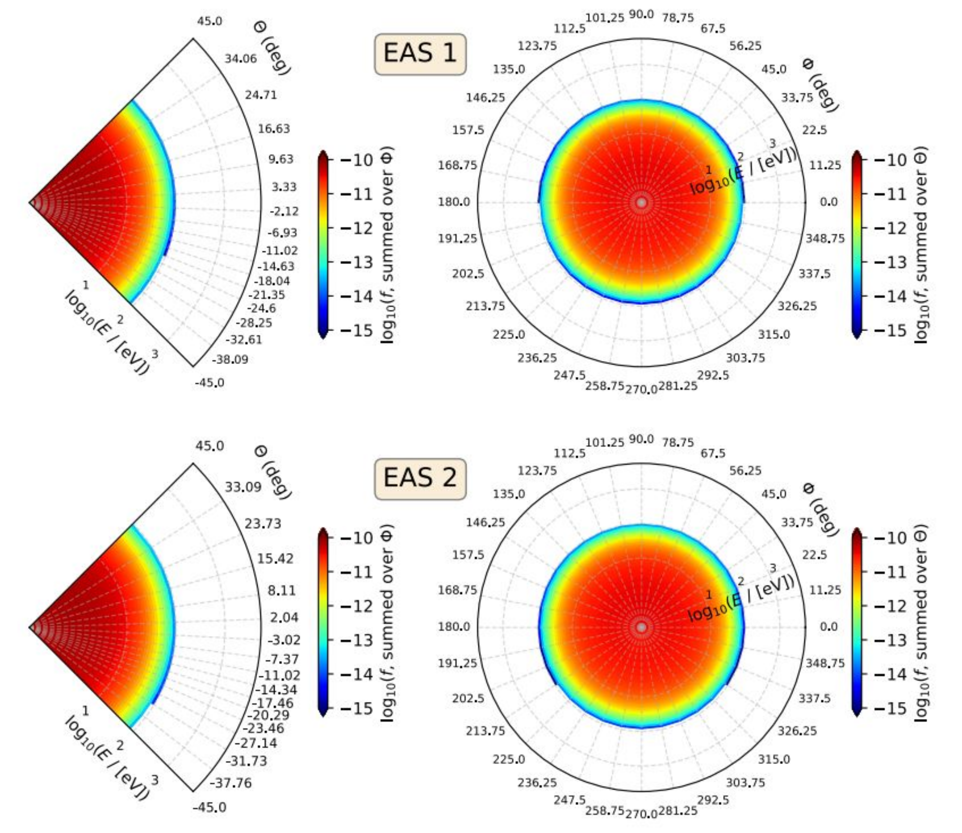
- Project to each SWA-EAS head

$$\begin{bmatrix} v_{\text{x,EAS1}} \\ v_{\text{y,EAS1}} \\ v_{\text{z,EAS1}} \end{bmatrix} = \begin{bmatrix} 0 & 0 & -1 \\ \sin(45^\circ) & -\cos(45^\circ) & 0 \\ -\cos(45^\circ) & -\sin(45^\circ) & 0 \end{bmatrix} \begin{bmatrix} v_{\text{x}} \\ v_{\text{y}} \\ v_{\text{z}} \end{bmatrix}$$

$$\begin{bmatrix} v_{\text{x,EAS2}} \\ v_{\text{y,EAS2}} \\ v_{\text{z,EAS2}} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 \\ \sin(45^\circ) & \cos(45^\circ) & 0 \\ -\cos(45^\circ) & \sin(45^\circ) & 0 \end{bmatrix} \begin{bmatrix} v_{\text{x}} \\ v_{\text{y}} \\ v_{\text{z}} \end{bmatrix}$$

Creating measurements

An ideal Maxwellian as would be observed by SWA-EAS 1 and SWA-EAS 2.

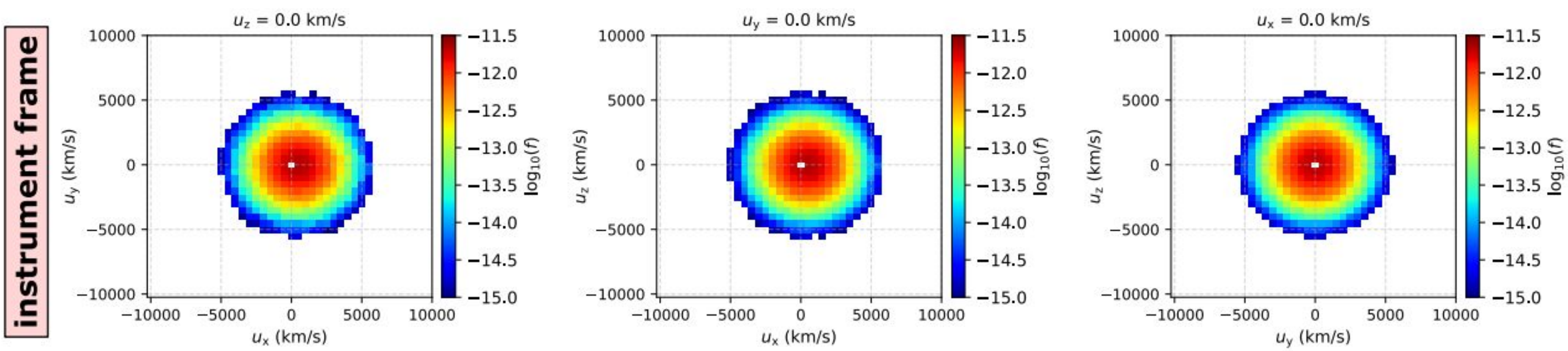


Nicolaou et al., 2021, A&A

From EAS heads to instrument frame

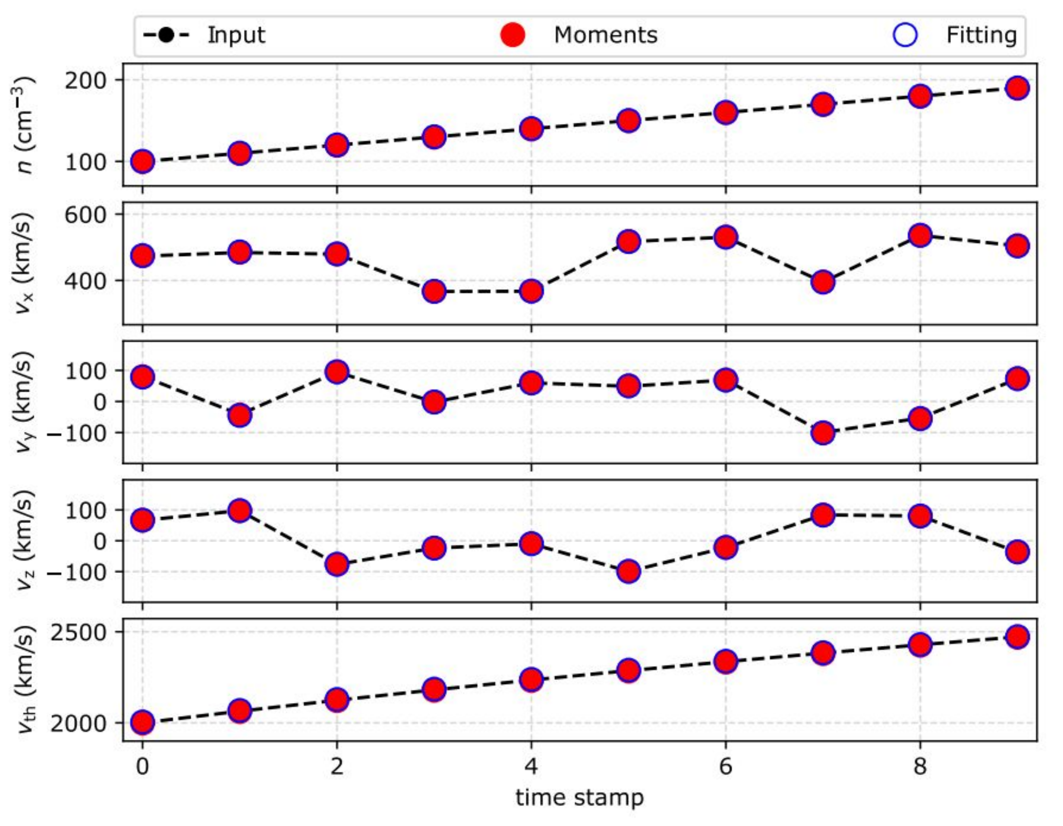
- We create a grid in the instrument frame;
- We project the grid to EAS heads;
- We assign to each grid pixel the corresponding VDF value.

Nicolaou et al., 2021, A&A



3D VDF analysis

- Numerical calculation of the statistical moments;
- Fitting the constructed distribution with an analytical function (e.g., Maxwellian);
- Almost identical parameters.



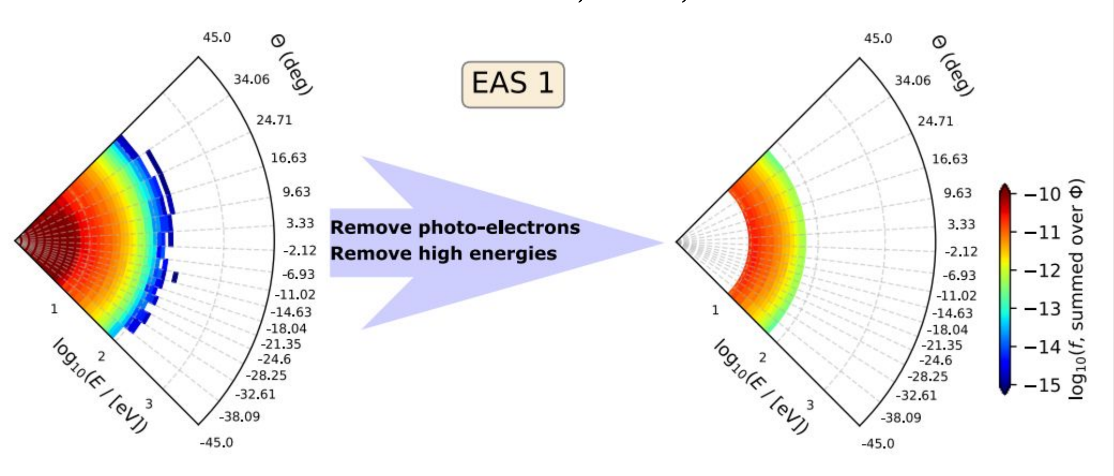
Nicolaou et al., 2021, A&A

Application to flight data

- Convert counts to VDF
- Exclude low energies < 10 eV due to photo-electron contamination;
- Exclude energies > “strahl” energy ~68 eV;
- Apply a constant factor to SWA-EAS 2 scaling them to SWA-EAS 1.

$$f(E,\Theta,\Phi) = \frac{m_e^2 C(E,\Theta,\Phi)}{2E^2 G_f(\Theta,\Phi) Q_e(E)\Delta\tau},$$

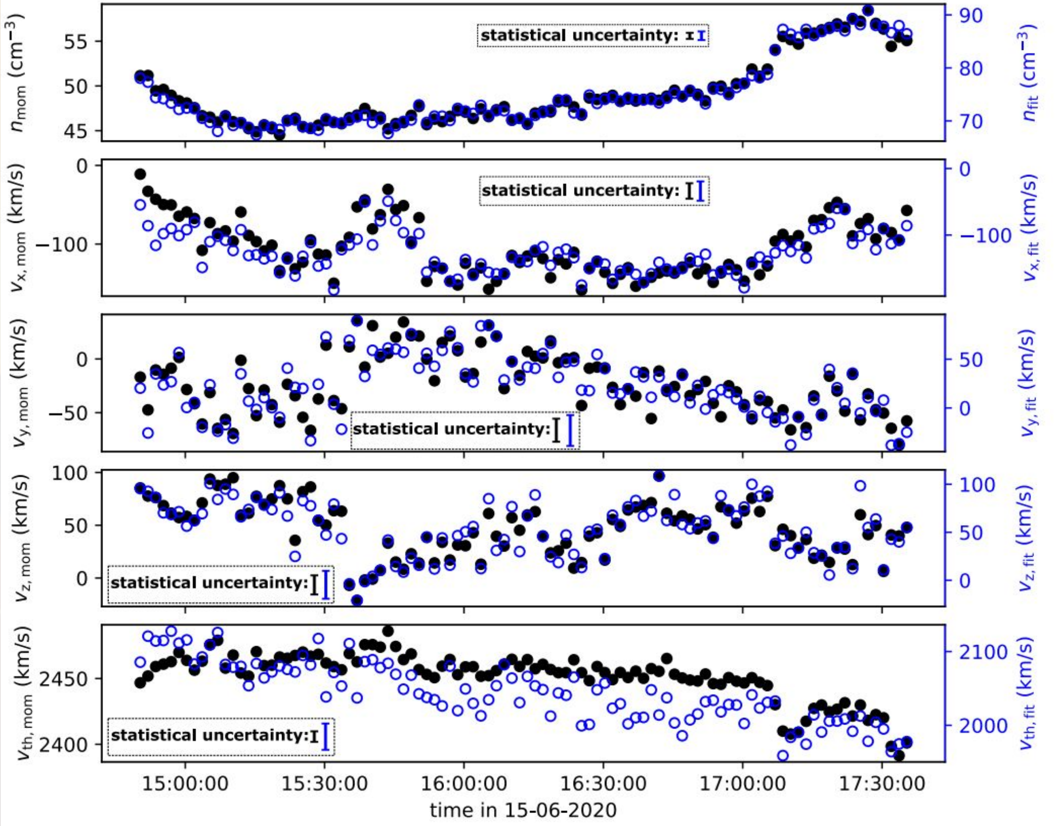
Nicolaou et al., 2021, A&A



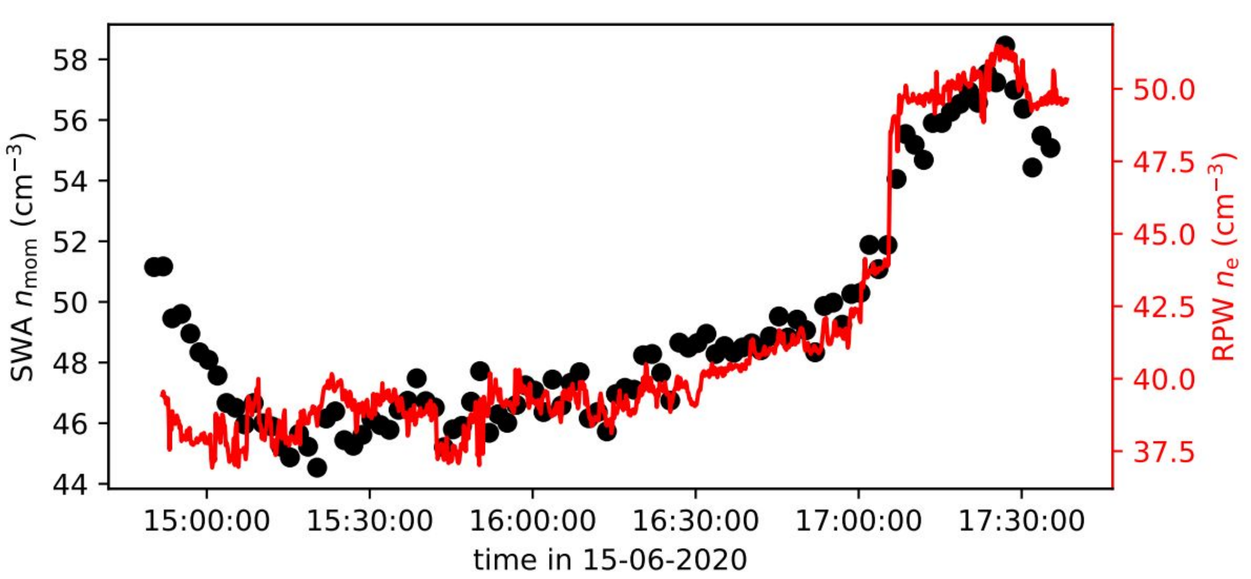
Application to real data

- First data application to nominal solar wind
- Moments vs fits: expected differences
- The velocity vector is not as expected: contamination issues, not complete calibration

Nicolaou et al., 2021, A&A



Compare to RPW densities

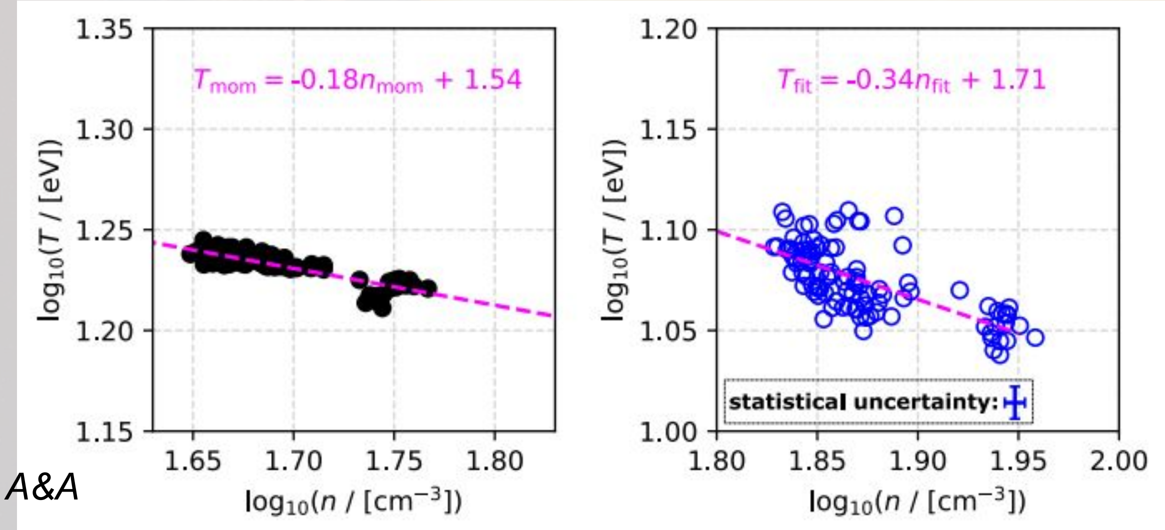


Nicolaou et al., 2021, A&A

Although there is an offset, the density variation captured by both instruments is similar

Preliminary studies of solar wind thermodynamics

- Polytropic index: indicating the heat transfer;;
- Determined from the logT vs logN curve.

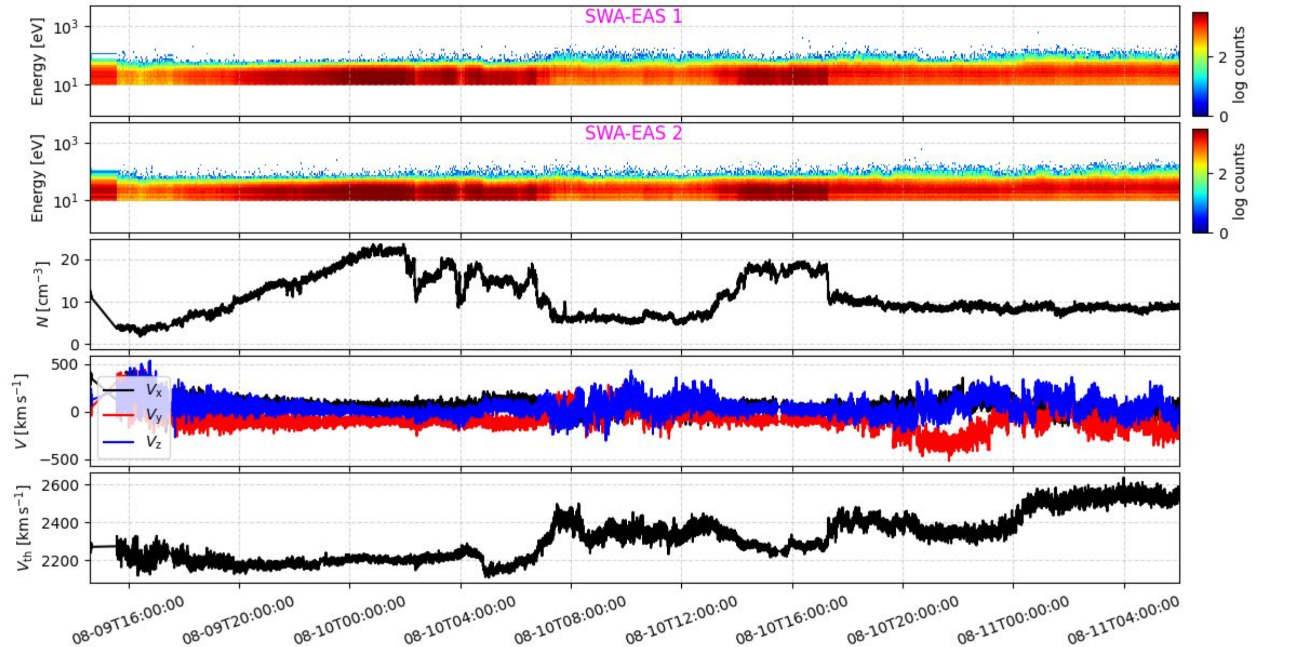


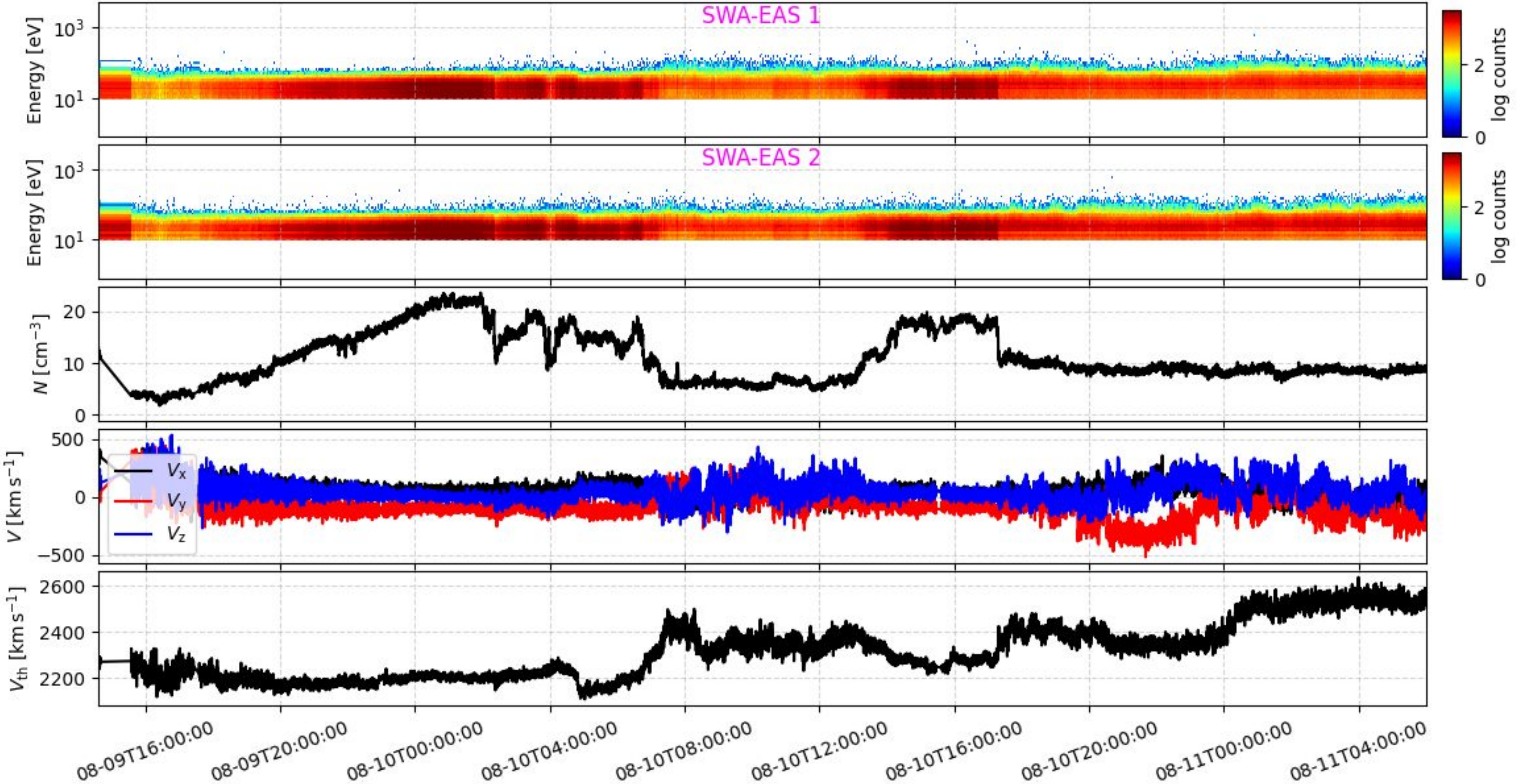
Nicolaou et al., 2021, A&A

Venus flyby

Our 3D VDF analysis shows:

- Density increment;
- Temperature variations;
- No clear velocity changes



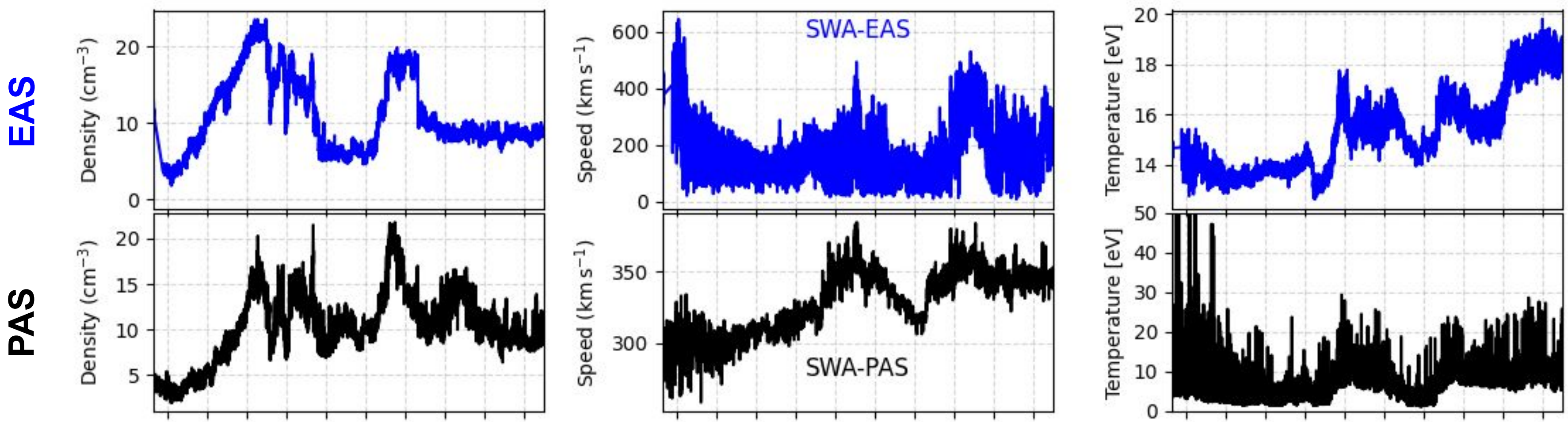


SWA-EAS 1
SWA-EAS 2
Energy [eV]
log counts
$N\,[\mathrm{cm}^{-3}]$
$V\,[\mathrm{km\,s}^{-1}]$
V_x
V_y
V_z
$V_{th}\,[\mathrm{km\,s}^{-1}]$
08-09T16:00:00
08-09T20:00:00
08-10T00:00:00
08-10T04:00:00
08-10T08:00:00
08-10T12:00:00
08-10T16:00:00
08-10T20:00:00
08-11T00:00:00
08-11T04:00:00

Venus flyby

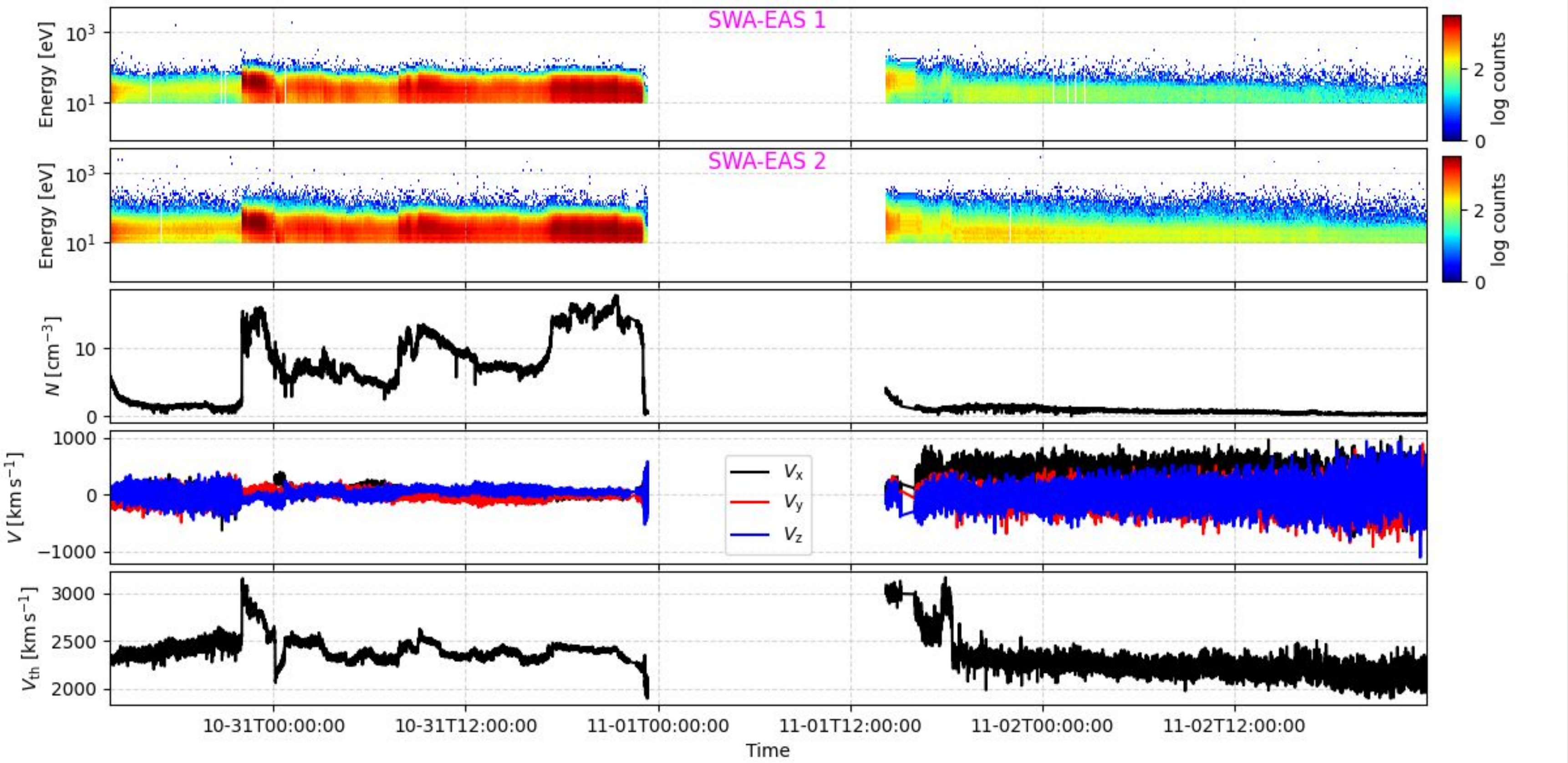
SWA-EAS / SWA-PAS comparison:

- Similar density trend
- Some of the temperature variations are similarly captured



Discontinuities

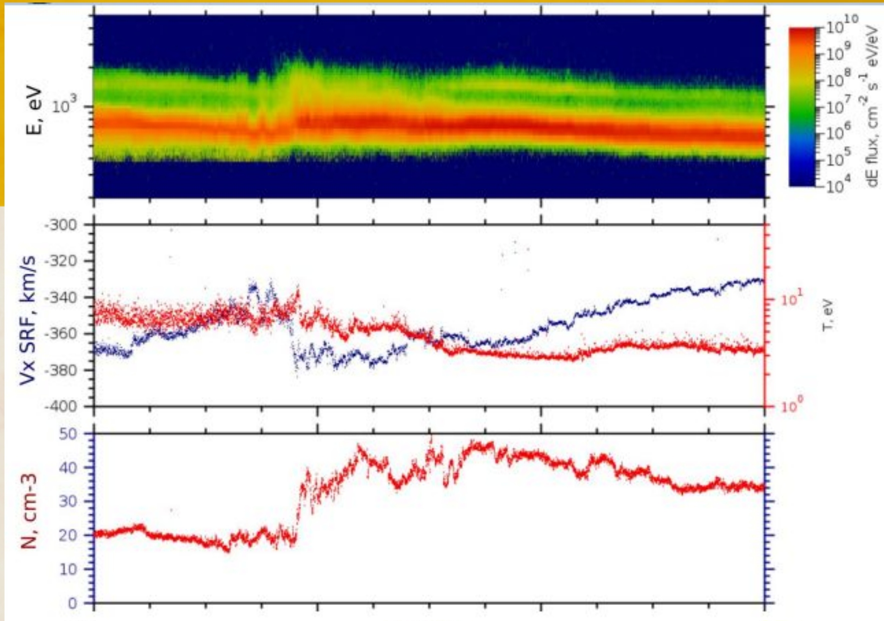
Halloween period

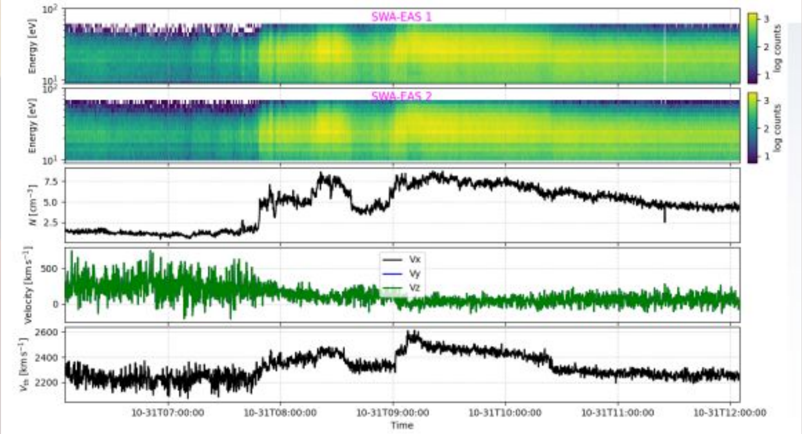


Discontinuities

Our 3D VDF analysis shows:

- Density and temperature jumps across shocks;
- The velocity cannot be accurately resolved yet;
- Similar trend to SWA-PAS densities





SWA-PAS parameters provided by A. Fedorov

Future tasks:

- A more sophisticated cross calibration between EAS 1 and EAS 2
- Careful comparison with RPW
- Careful comparison with PAS
- Analyse more data

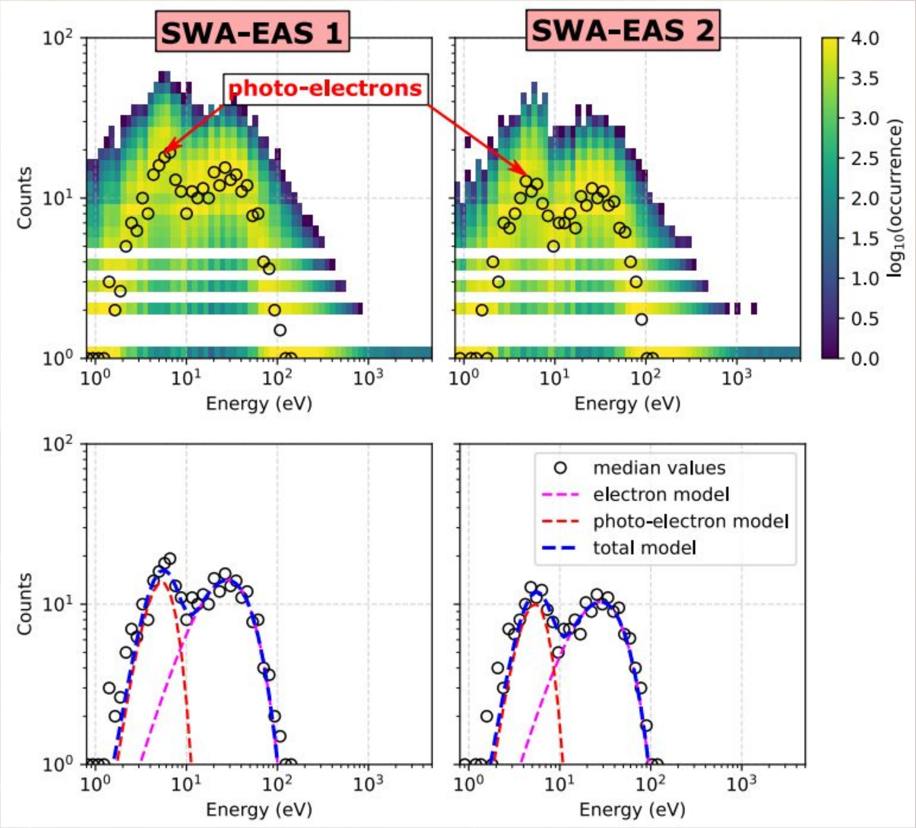
Thank you

Extra details

Photo-electron contamination

Attempt to describe photo-electrons with a Maxwellian

10 eV seems to be the energy at which photo-electrons and solar wind electrons are well separated

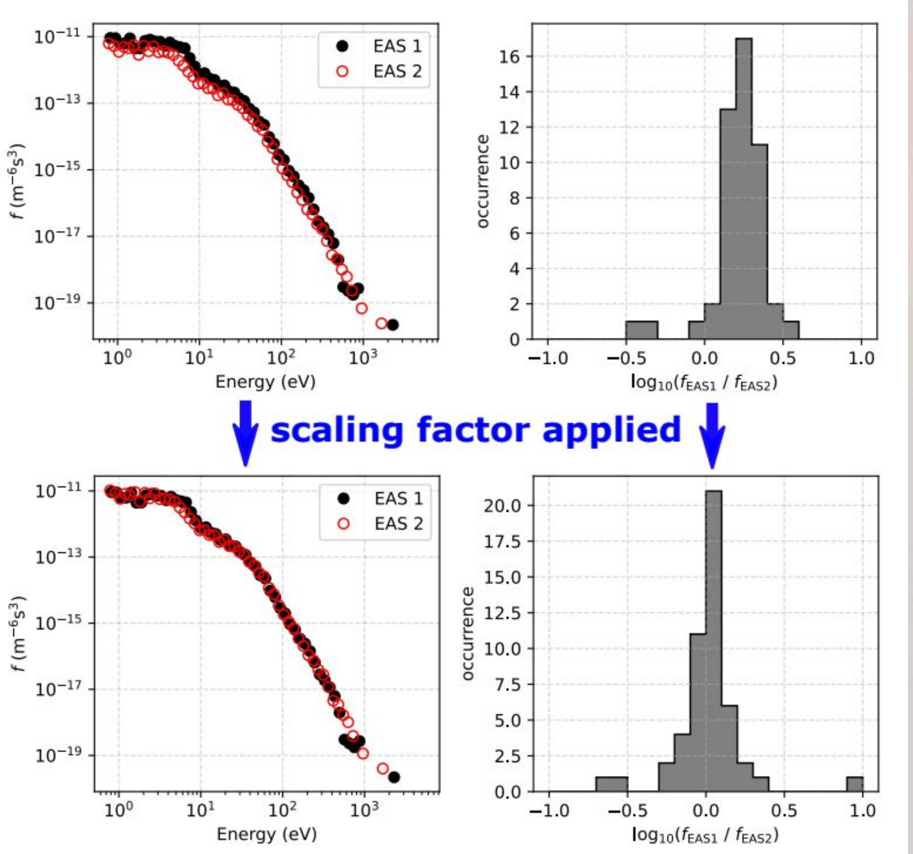


Extra details

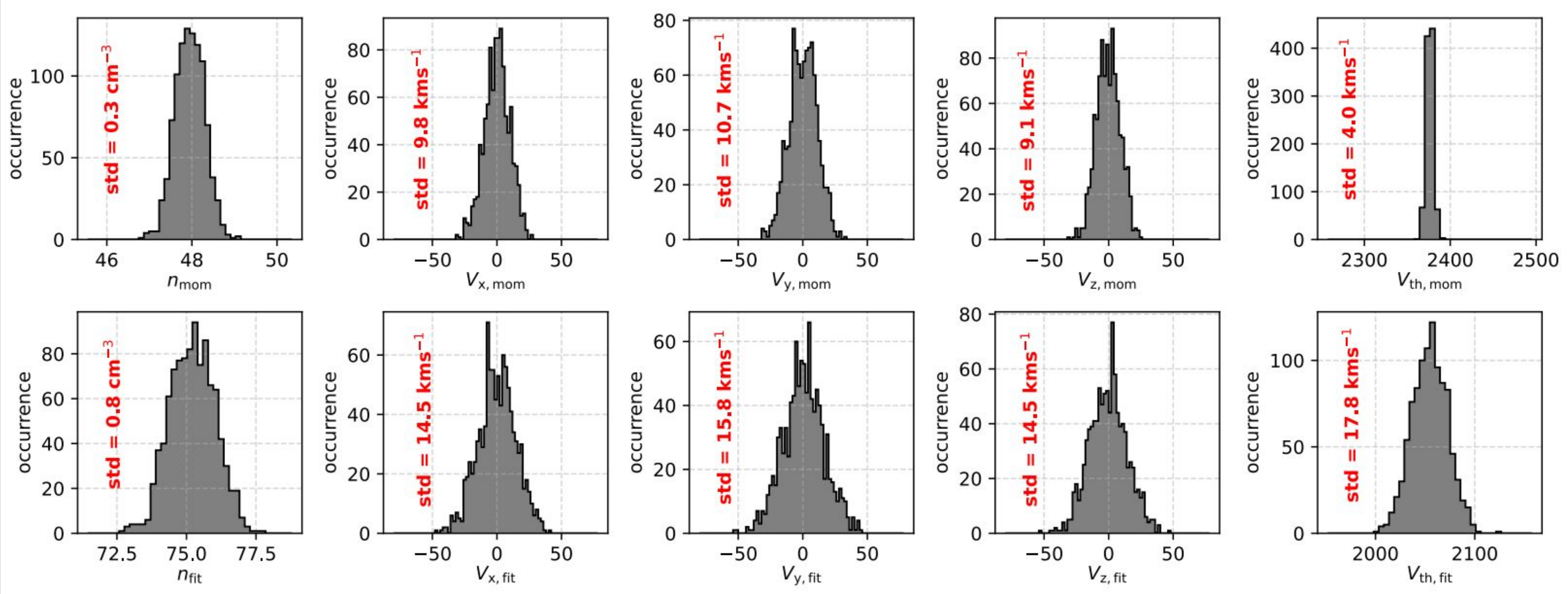
Preliminary “cross-calibration”

SWA-EAS 2 consistently measures a smaller number of counts for the same “look” directions as SWA-EAS 1.

For now, we apply a constant multiplication factor to SWA-EAS 2 measurements.



Extra details



Typical uncertainty

We use the forward model for typical plasma parameters.

We sample thousands of measurements following the Poisson statistics and we calculated the derived bulk parameters and their standard deviation