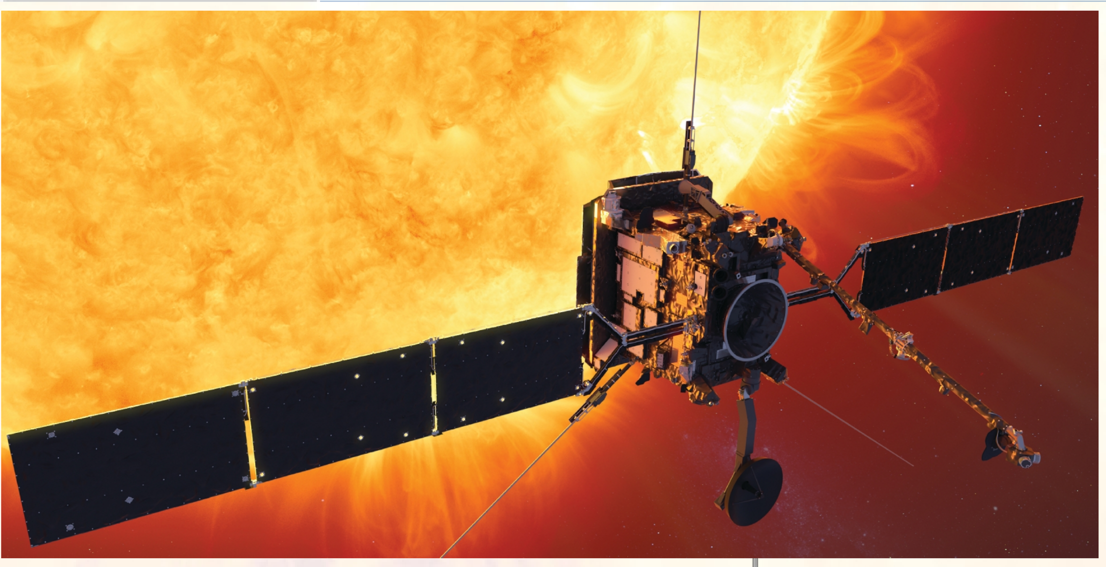
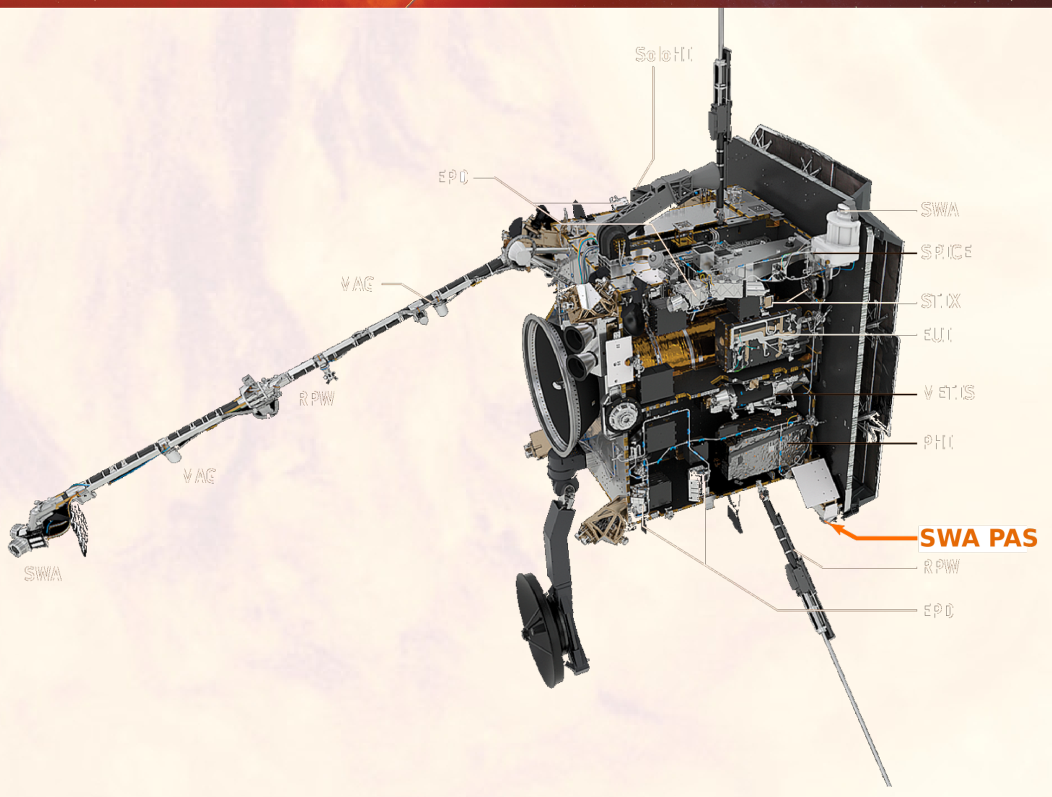
# The Proton and Alpha Sensor (PAS) for the Solar Orbiter Mission:
## motivations, design, operation principle, and expected scientific return

A. Fedorov (1), P. Louarn (1), B. Lavraud (1) and PAS Team






### ESA Solar Orbiter:

- Mission to sample inner heliosphere inside 60 RS
- Equipped with enhanced remote-sensing and *in-situ* instruments.
- Orbit design to co-rotate with Sun and remain in a single solar wind outflow for periods of several days

### Proton-Alpha ion spectrometer PAS:

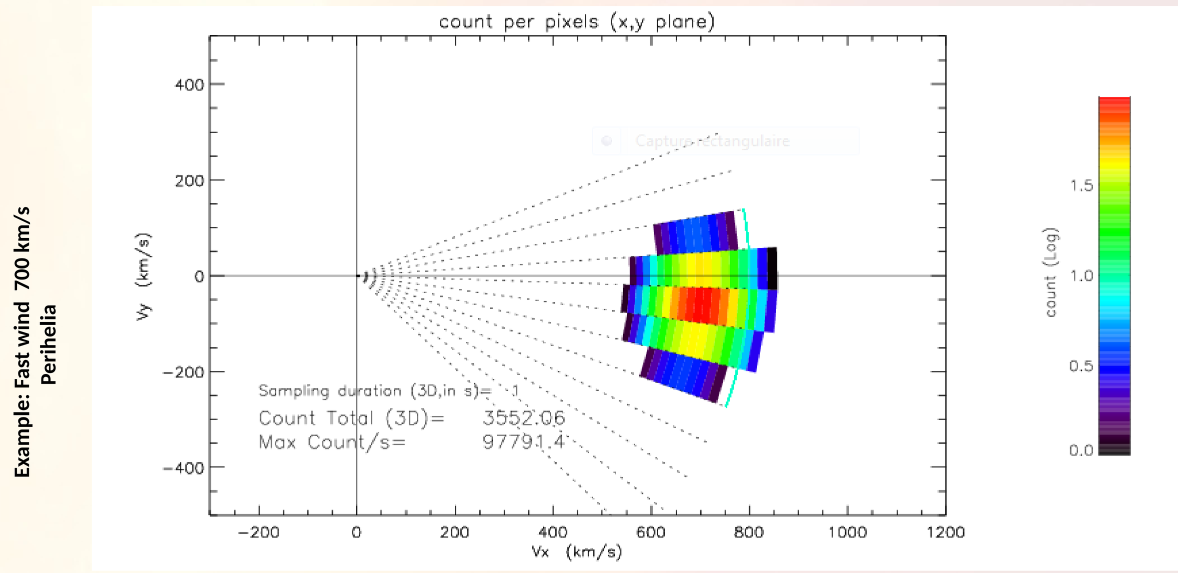
is designed, developed, manufactured, tested, calibrated, and managed by **IRAP, Toulouse, France**
It is a part of **Solar Wind Analyzer (SWA)** plasma package

### PAS Scientific Requirements

PAS shall determine the SW ion properties both at kinetic f(v,Ψ,Ω) and fluid (n,V,T) levels up to time cadence ~ 0.1 s.

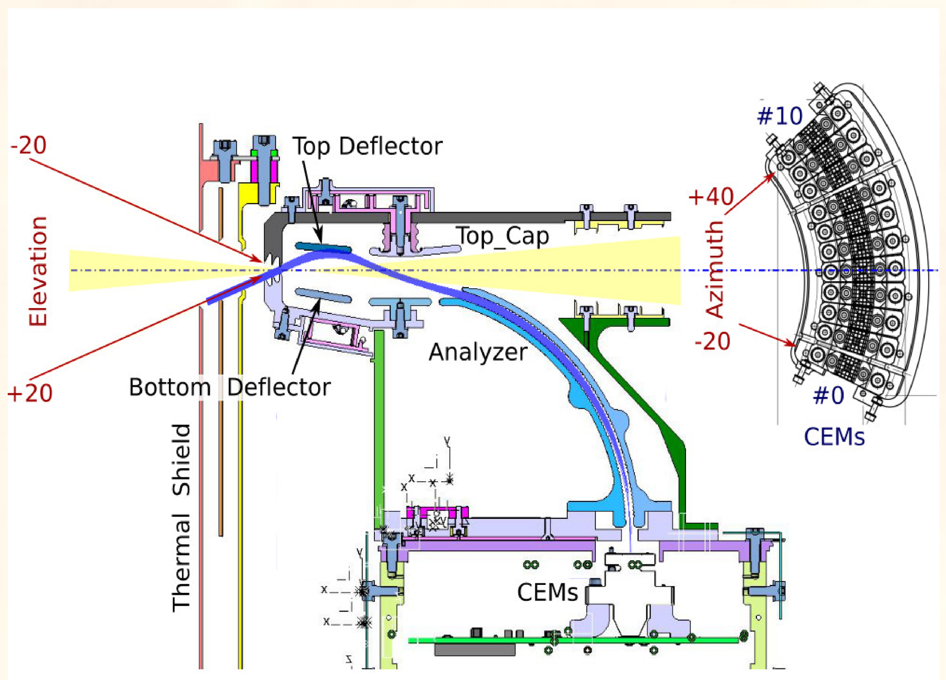
To measure the full distribution function at all distances from Sun PAS field-of-view shall be of 45° in elevation and 66° in azimuth, and its energy range 200 eV – 20 keV

PAS resolutions shall be 0.08 eV/eV in energy and 6° in elevation/azimuth



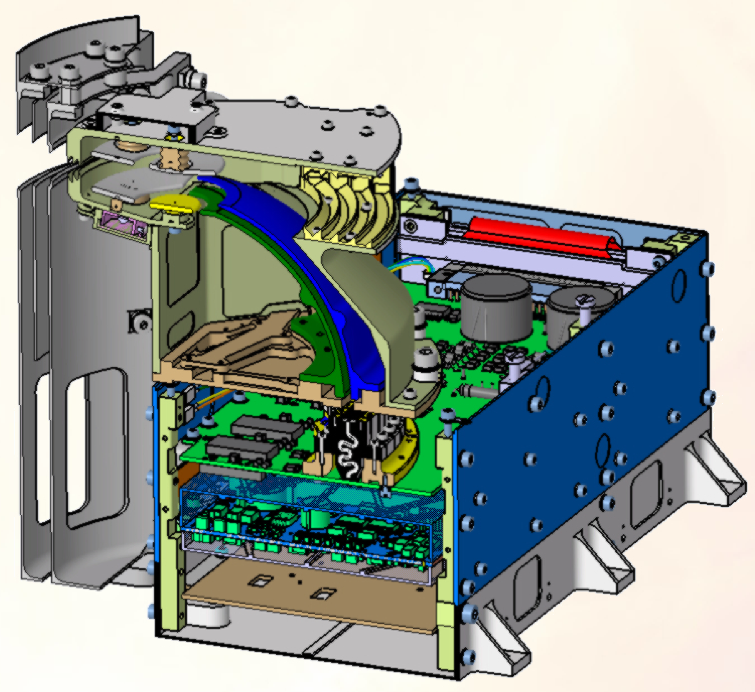

Expected 2D instant sampling (ion velocity distribution) of PAS

## PAS Design

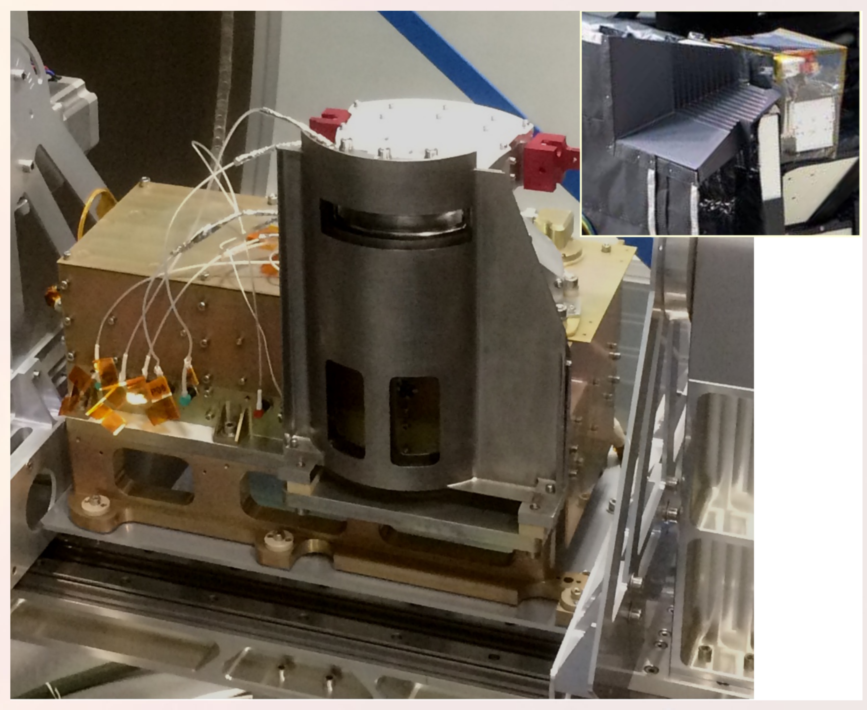



Cut-away representation of the PAS analyser head. The yellow triangles represent the direct solar light and the blue curves show the extreme ion trajectories. The right insert shows the top view of the CEMs array detector and its angular range.

PAS sensor head is comprised of the electrostatic analyzer and an array of conventional channel electron multipliers (CEM) used to detect the solar wind ions. Since the instrument line-of-sight points to the Sun, the main driver of the sensor design was to provide reasonable defence against direct sunlight and heat radiation. In order to protect the sensor, it has a narrow aperture slit in front of the optical surfaces located outside of the solar light path through the sensor. This geometry avoids any interaction of the light beam with the internal elements of the sensor. The rear of the PAS analyzer head is open to allow sunlight to pass straight through the head. In addition, the sensor has its own heat-shield system to locally protect the analyser. Figure on the right shows the three mechanical sections of PAS: the titanium multi-layer heatshield, the sensor head, and the electronics box. The CEM detectors are located inside the electronics box.

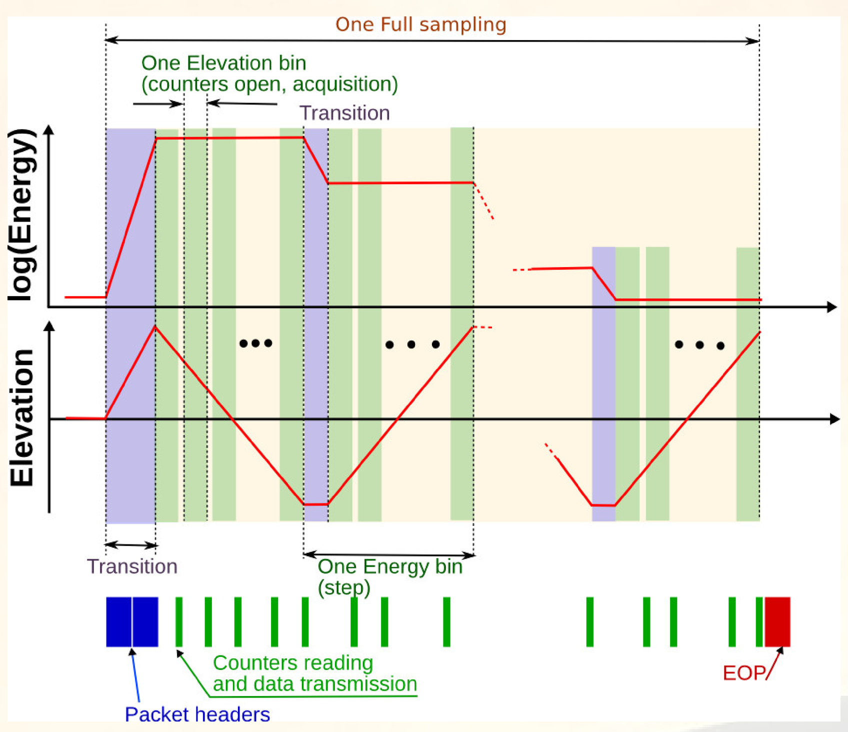


The 3D cut of the full SWA-PAS instrument. You can see three main elements of SWA-PAS design: 1) The analyser (sensor head). 2) The electronics box containing the CEM detectors, HV sources and other electronics boards. 3) The the front thermal shield.



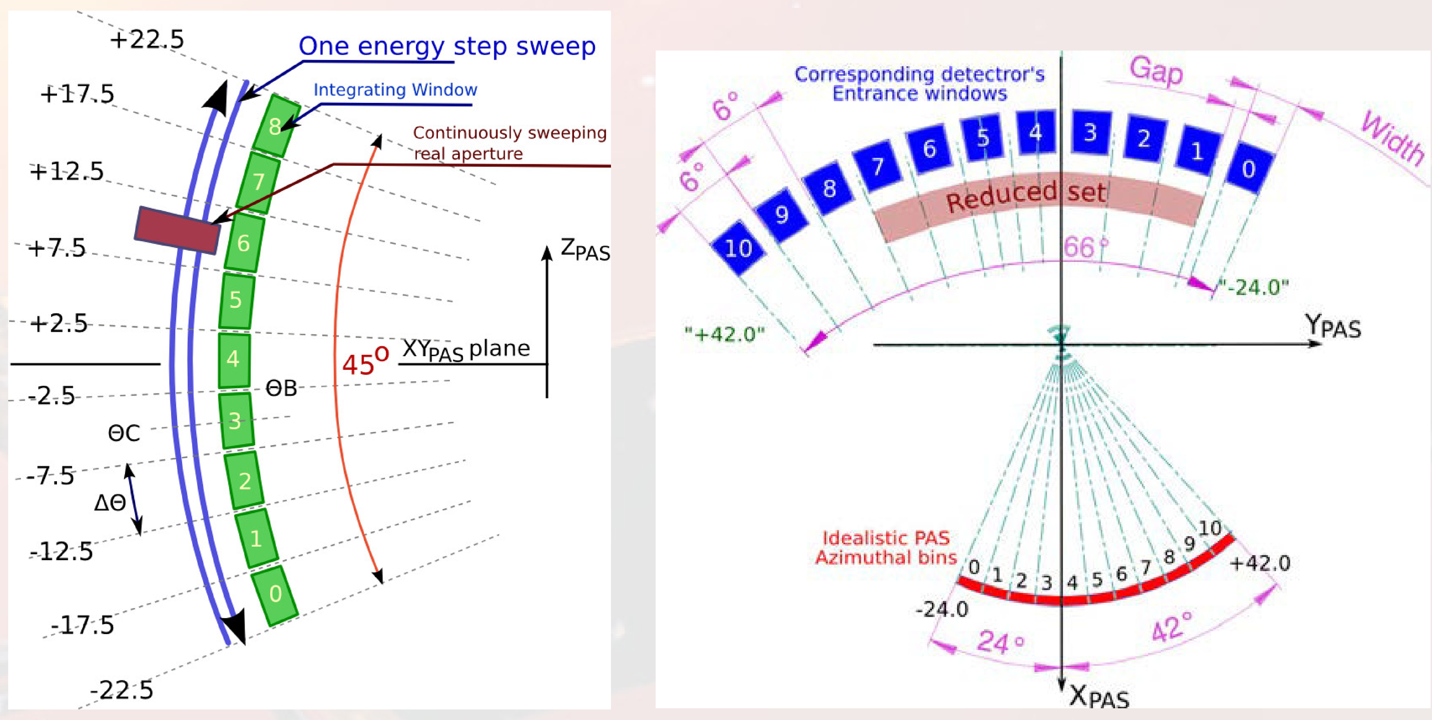
Flight model of the PAS unit in the vacuum chamber during its calibration. The white analyzer head is mounted on the top of the electronics box. Both are located behind the PAS-specific heatshield. The upper right insert show the PAS installed on the spacecraft. PAS looks toward Sun through a specific feedthrough with a stepping profile helping to reduce the stray light.

## PAS Measurement Principle

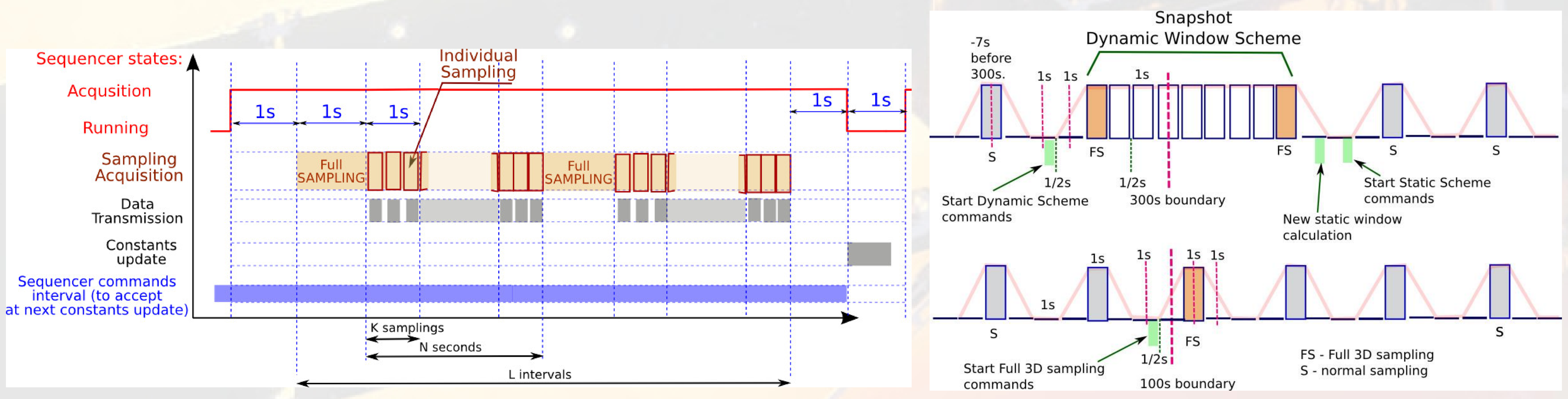



PAS Energy - Elevation sampling waveform

A complete 3D measurement of an ion distribution function is a matrix of (96, 9, 11) elements (energy, elevation, azimuth). Each bin of this matrix corresponds to the counts measured during a defined elementary time period of 1 ms by a specific channeltron, for a given energy and elevation angle bin. PAS accumulates counts in all azimuth bins simultaneously, but to cover all elevation and energy bins, PAS performs elevation sweeping and energy stepping. For a given energy, PAS makes a continuous sweep over the elevation range. The width of the instant elevation response is 3°. To fill one bin PAS opens the corresponding counter when the elevation scan enters the corresponding elevation bin, and stops the counter when the scan leaves the elevation bin. As soon as one elevation sweep is completed, PAS transfers to another energy step. The duration the full 3D sampling consisting of (96, 9, 11) elements is exactly 1 sec.
The PAS design allows for the reduction of the number of energy steps and elevation angles, and also the use of 7 rather than 11. Reduced distribution functions are then obtained: for example, samples of (48, 9, 7) or (24, 3, 7), etc. If the duration of the reduced sampling factor is less than the full sampling duration, PAS can perform several samplings per second. This fundamental advantage of the PAS burst mode allows taking of short-duration high-cadence snapshots.

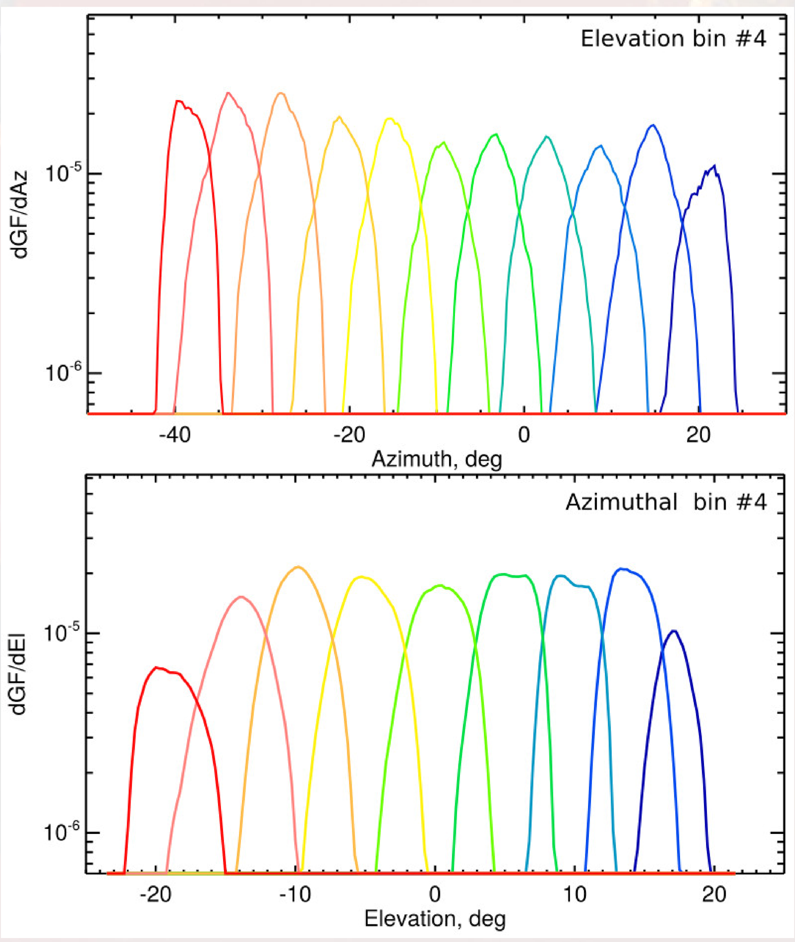



PAS detector angular bins defined by the sensor geometry for the azimuth bins (left panel) and by deflector sweep for the elevation bins (right panel)



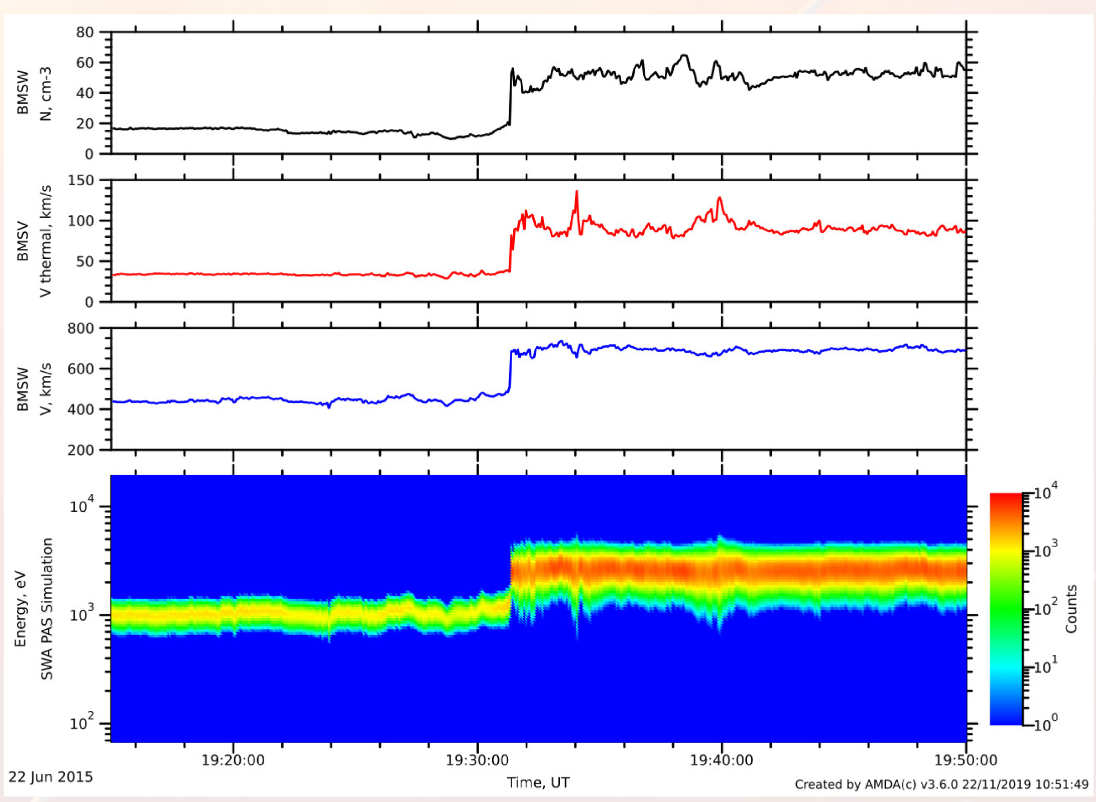

Schematic illustration of the PAS cyclogram for data capture. For the very fast measurements PAS puts several reduced samplings in one sec. (left panel). To find the right position of the reduced window we do the maximal sampling before the fast cadence. The normal PAS operation consists in large sampling every 4 sec and a short fast 8 sec snap-shot.

## PAS Calibration and Data simulation




Top: PAS azimuth responses for the elevation bin #4. Bottom: PAS elevation responses for Azimuth bin #4

The PAS performance is close to that expected on the basis of the design numerical simulations with minor exceptions. The energy resolution varies between 3 and 12%, a range that brackets the target resolution of 5.5%. This deviation is related to the generic property of the slit aperture deflector and was identified with the first numerical simulation. The elevation range is slightly asymmetric.
The averaged geometrical factor of one bin is $5 \cdot 10^{-6}$ $cm^2$ sr eV/eV.




An example of the expected output from the SWA-PAS sensor is show in the left. We used the PAS calibration data to simulate the PAS response, together with very high sampling rate solar wind data from the Faraday cup instrument BMSW onboard of RadioAstron mission as an input for the simulation. The resulting E-T color coded spectrogram in the lower panel of the figure illustrates to the expected output in the PAS normal mode when the instrument takes a full 3D ion velocity distribution function every 4s.

(1) IRAP-UPS-CNRS, Toulouse, France

**PAS Team**: Carine Amoros, Alain Barthe, Rituparna Baruah, Sandra Bordon, Wilfried Marty, Matieu Petiot, Emmanuel Penou, Jean Rubiella, Henry-Claude Seran, Gaelle Terrier

Poster 496302, SH21D-3312