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Swarm ASM burst-mode L1b data and the L2 whistler product they allow to derive

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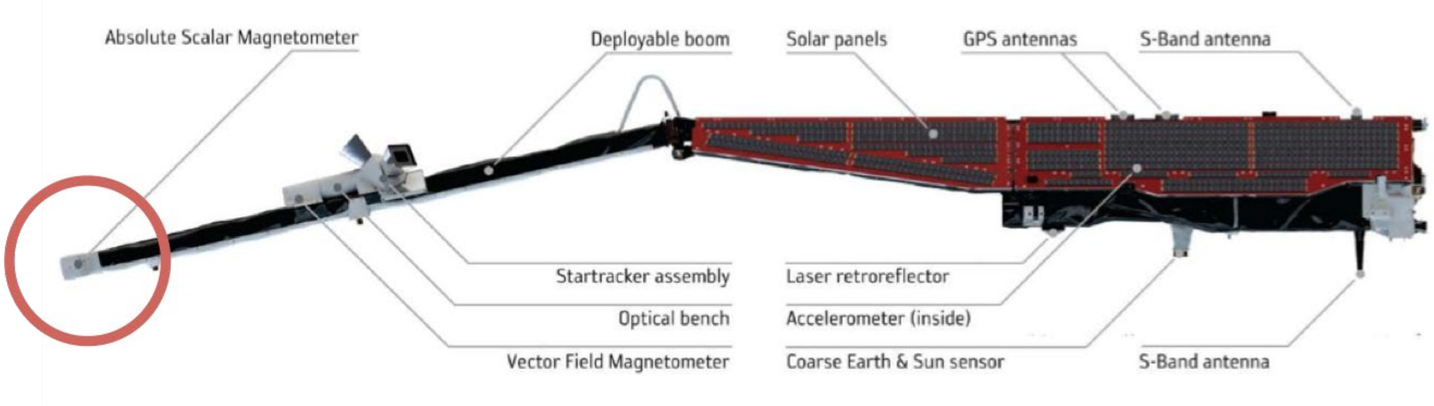
Session B2.05: Swarm - ESA's Extremely Versatile Magnetic Field and Geospace Explorer, 26/05/2022

ASM instrument modes on Swarm satellites



ASM instruments are absolute magnetometers that can be run in two (exclusive) modes

- An **ASM vector mode** producing **1 Hz absolute scalar and synchronous self-calibrated vector data** (see poster "Self-calibrated absolute vector data produced by the ASM absolute magnetometers on board the Swarm satellites: results, availability and prospect" in this session)
- An **ASM Burst mode** producing **250 Hz absolute scalar data**

The ASM nominal mode is the vector mode, the Burst mode being only run during dedicated sessions

ASM Burst mode L1b data history

- **Not originally meant to be used as a Science mode**
- **Early short sessions during Cal/Val in 2014 for instrument performance validation,** on the three Alpha, Bravo and Charlie satellites.
- **Detailed analysis revealed that Burst mode could detect natural signals worthy of scientific analysis** (in particular whistler signals, see later)
- **Perturbations and issues that can affect ASM Burst mode data have been investigated, as well as how to correct and flag them**, targeting production of a new Swarm L1b product.
- **Coordination with ESA ensured running ASM in Burst mode would not affect nominal production of other Swarm data**
- **Dedicated processing chain derived by IPGP and CEA-Léti, was tested on new short test sessions in 2018**.
- ESA approved **regular one week Burst mode sessions and L1b data production started in 2019**
- **Burst mode L1b data are now available to the Swarm Mission Users through ESA**

ASM Burst mode session decision process

- **Burst mode sessions must be kept shorter than one week** (as this mode was not intended to be a science mode, absolute time is only known at onset of each session and if relative time is lost for too long, accurate timing cannot be recovered)
- **One session per month on each Alpha and Bravo satellites** (Charlie can no longer provide any such data since November 5, 2014), to ensure ASM vector mode are also produced for global field modelling purposes.
- **Control of** when to start and end **sessions is under IPGP responsibility**.
- **Timing of sessions** (currently) **driven by Science needs associated with Whistler investigations**:

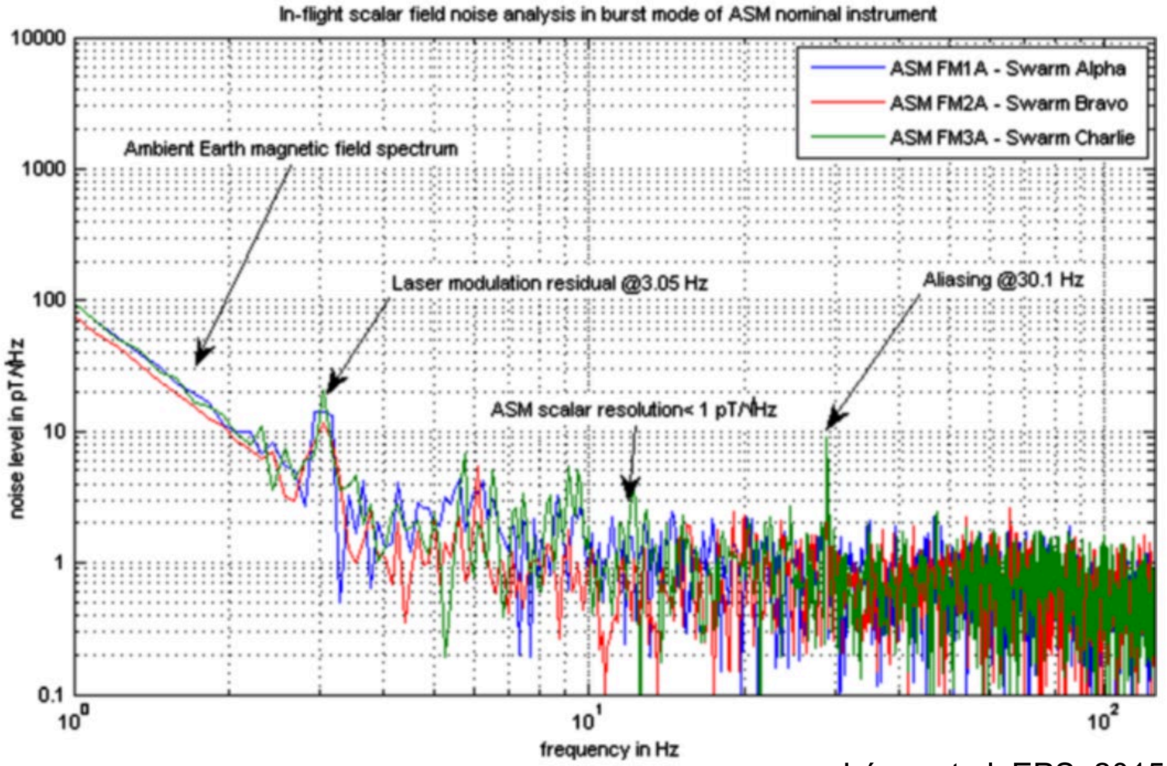
  - targeting **coverage of all Local Times**

  - running **simultaneous sessions on Alpha and Bravo when orbits are close enough** (e.g., recent counter-rotating orbits)

  - taking advantage of **close encounters with relevant other satellites**, such as the CSES Chinese satellite (also capable of detecting whistlers)

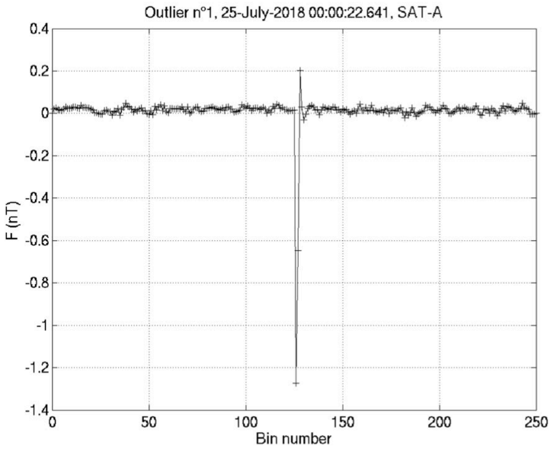
ASM Burst mode data noise characteristics

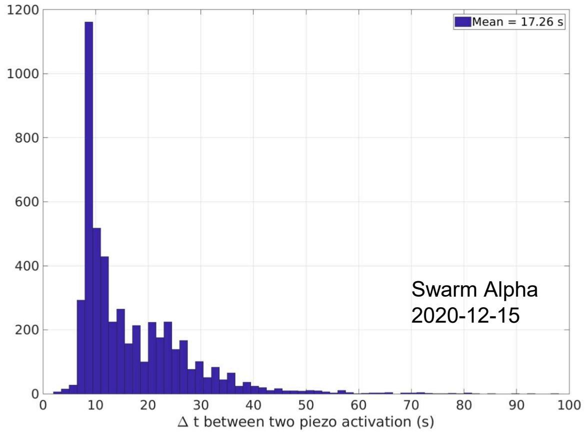
- **Absolute data (65 pT accuracy at instrument level)**
- **1pT/(Hz)$^{1/2}$ scalar resolution**
- **100 Hz low pass filtered**
- **Instrument related small signals at 3.05 Hz and 30.1 Hz**

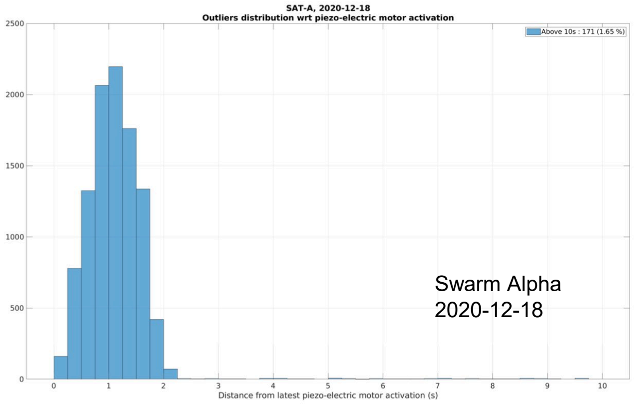


Léger et al, EPS, 2015

Flagged ASM Burst mode data perturbations



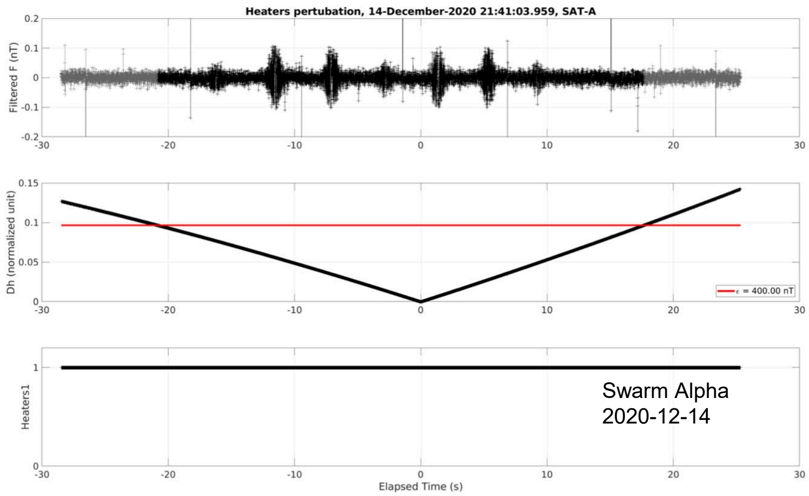




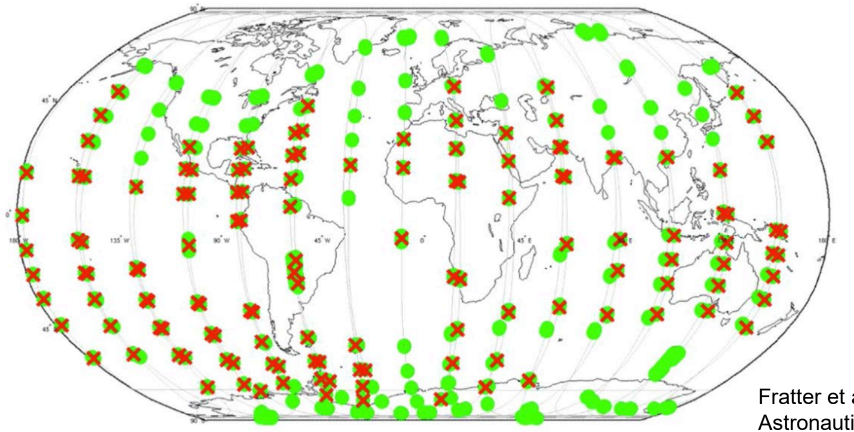
(See *ASM Burst Product Definition for Operational Release of Data*, SW-ASMV-DD-IPGP-0008, 2A, 2021-07-05)

- **All outliers** (only limited consecutive data values, up to a few nT) **are flagged**
- **Most occur within 3s of instrument's piezo-electric motor activation** (regularly activated to maintain isotropic performance of the instrument)
- **Timing of motor activation** is **provided.**

Flagged ASM Burst mode data perturbations



Heater perturbations on Swarm Alpha, 2014-01-07



Fratter et al, Acta Astronautica, 2016

(See *ASM Burst Product Definition for Operational Release of Data*, SW-ASMV-DD-IPGP-0008, 2A, 2021-07-05)

- **Longer lasting characteristic perturbations** are produced **when** the instrument's **heater is on and the magnitude of the field has known quantified values**
- **Due to** (unforeseen) **interferences between** harmonics of the **power line of the heater and the Larmor frequency used by the instrument**
- **Flags** for heater activation and for magnetic conditions met **are provided**

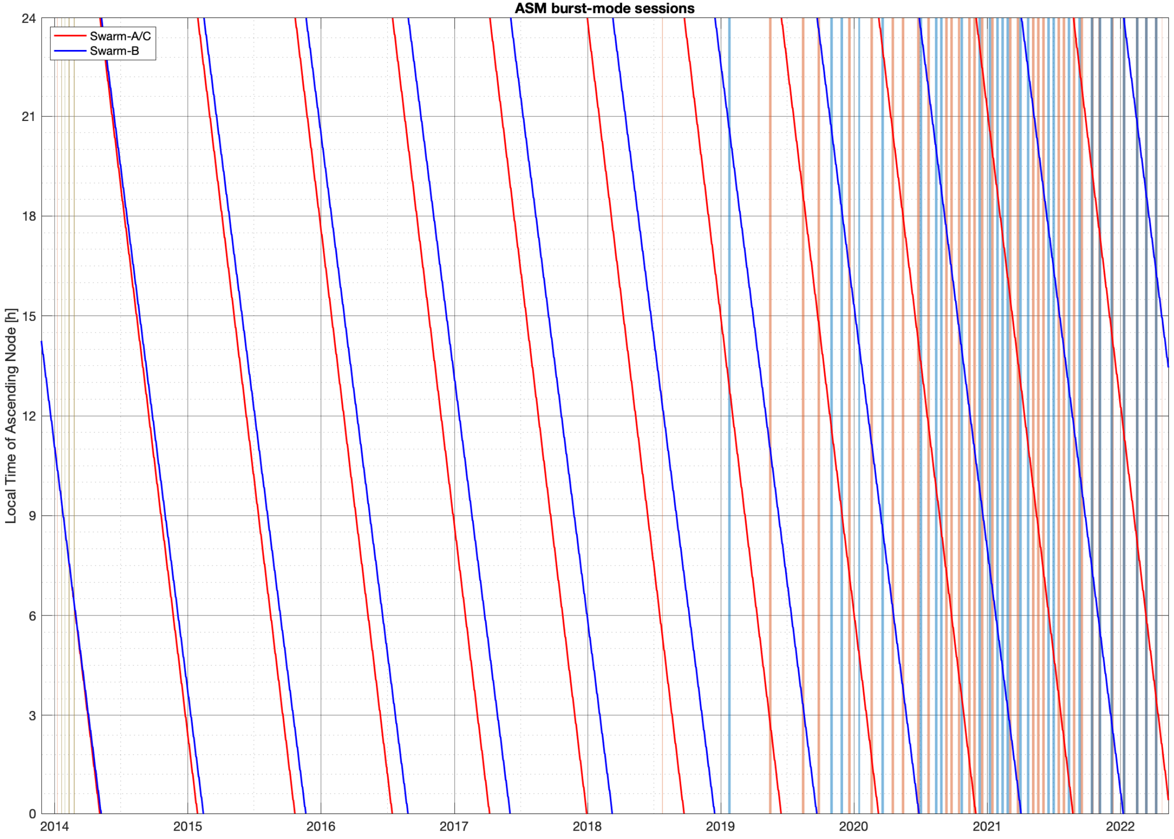
ASM Burst mode L1b data summary

- **Available to the Swarm Mission Users through ESA as an official Swarm L1b data**
- **Regular one week sessions per month on Swarm Alpha and Bravo since 2019**
- **Provided as daily files (like other Swarm L1b products) for each satellite when a burst mode session was running**
- **Product definition provided in *ASM Burst Product Definition for Operational Release of Data*, SW-ASMV-DD-IPGP-0008, 2A, 2021-07-05.**
- **More background information in:**

Léger, J.M., Jager, T., Bertrand, F., Hulot G., Brocco, L., Vigneron, P., Lalanne, X., Chulliat, A., Fratter, I., In-flight performance of the Absolute Scalar Magnetometer vector mode on board the Swarm satellites, *Earth Planets Space,* 67 : 57, doi: 10.1186/s40623-015-0231-1, 2015.

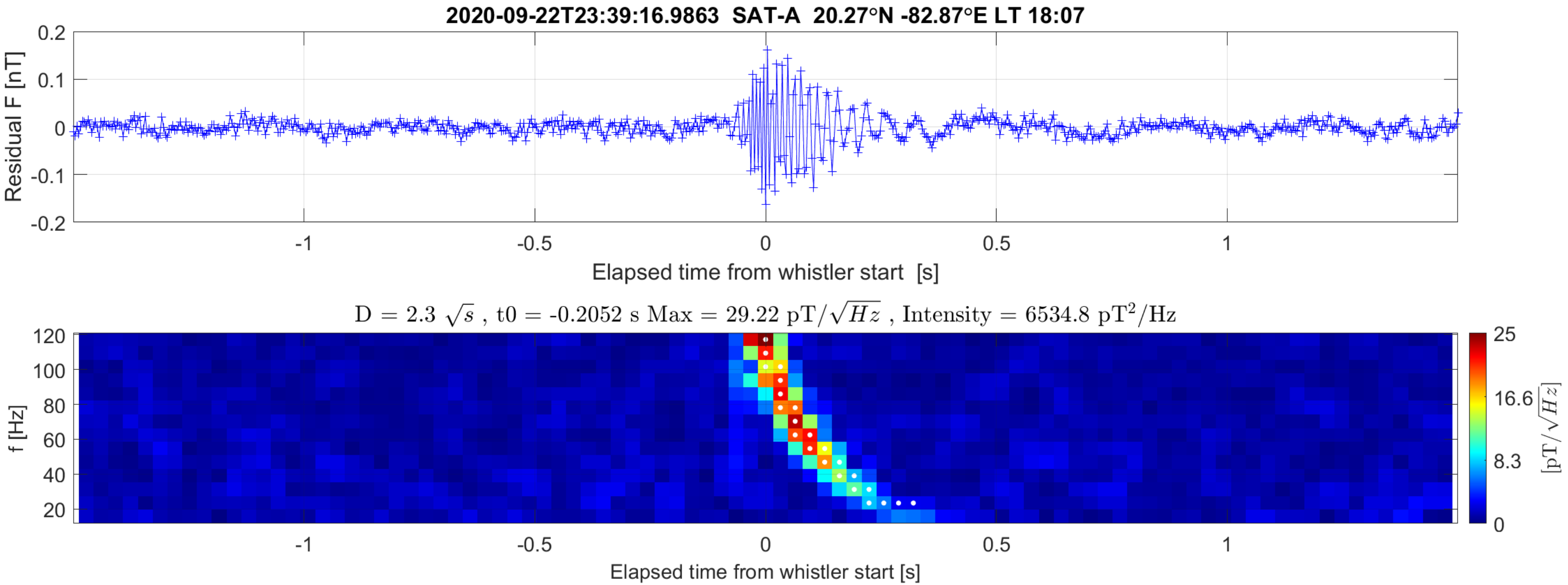
Fratter, I., Léger, J.M., Bertrand, F., Jager, T., Hulot, G., Brocco, L., Vigneron, P., Swarm Absolute Scalar Magnetometers first in−orbit results, *Acta Astronautica*, 121, 76-87, doi: 10.1016/j.actaastro.2015.12.025, 2016.

ASM Burst mode L1b data sessions



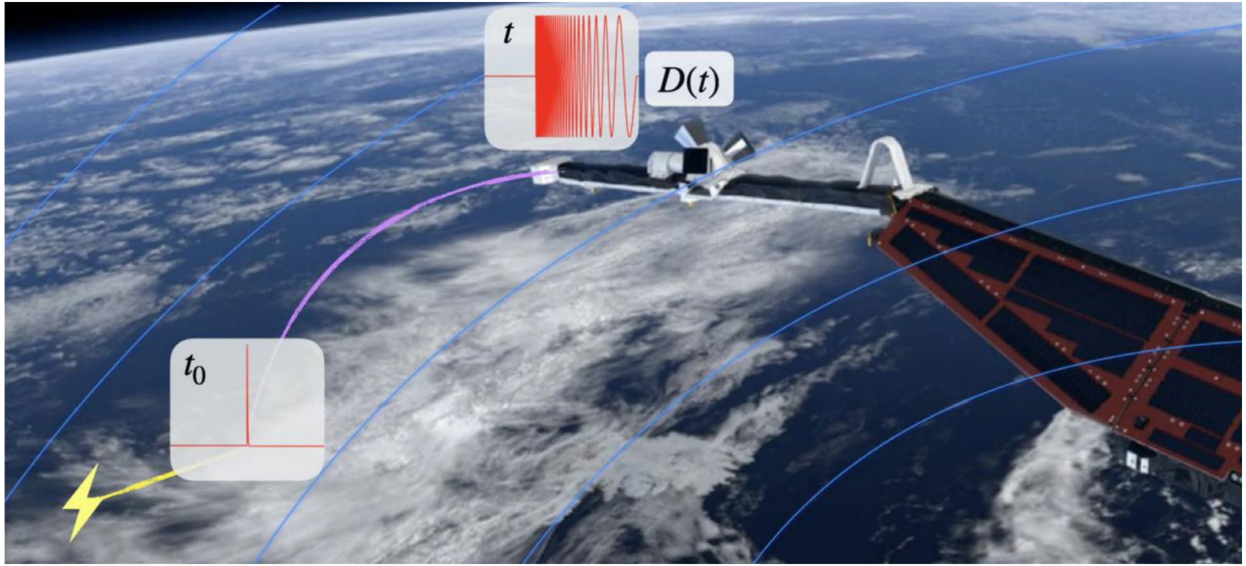
- ASM burst on Swarm A
- ASM burst on Swarm B
- ASM burst A+B
- ASM burst A+B+C

ASM Burst mode L1b data reveal ELF whistlers



- **Characteristic signature with high frequencies arriving first, followed by lower frequencies** (descending tone).
- **Unambiguously confirmed to be associated with lightning strikes, using e.g. the WWLLN ground network (University of Washington).**

Whistlers are sensing the state of the ionosphere



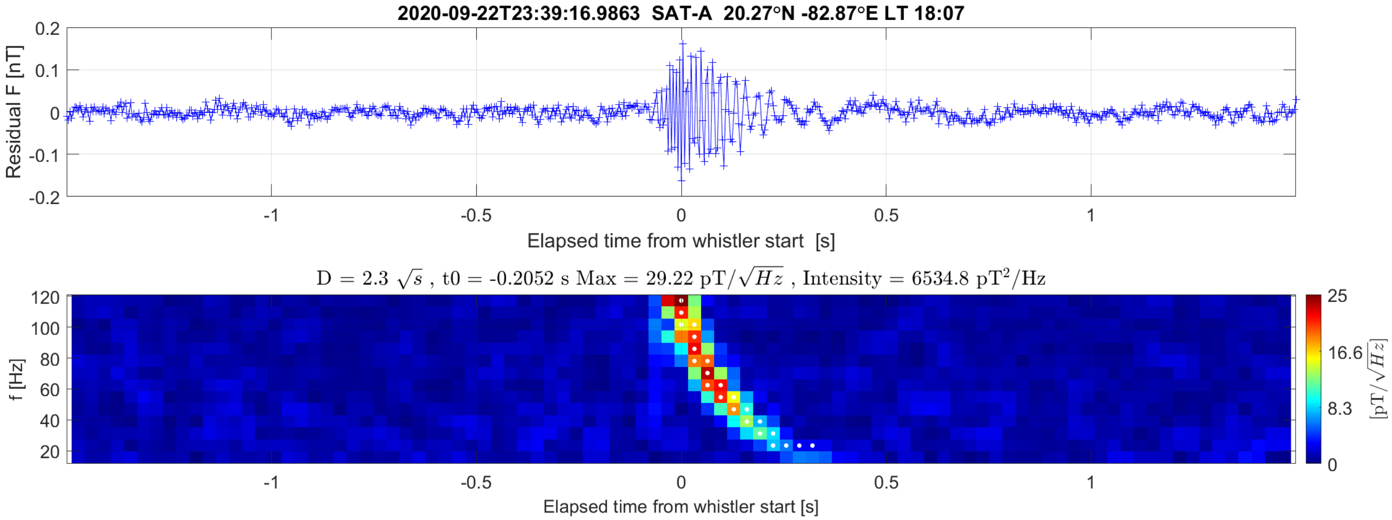
- **Pulse produced by a lightning strike** in the neutral atmosphere.
- **Propagates in the neutral atmosphere** at close to the speed of light.
- **Part of the signal leaks in the ionosphere,** slows down and **gets dispersed** along its path to the satellite.
- **Path and dispersion controlled by** the magnetic field and **state of the ionosphere**

Prompted the production of a Swarm L2 Whistler

Three key parameters can be recovered by best fitting the Eckersley (1935) formula to the DSP:

- **Dispersion D,**
- **Origin time t_0**
- **Intensity**

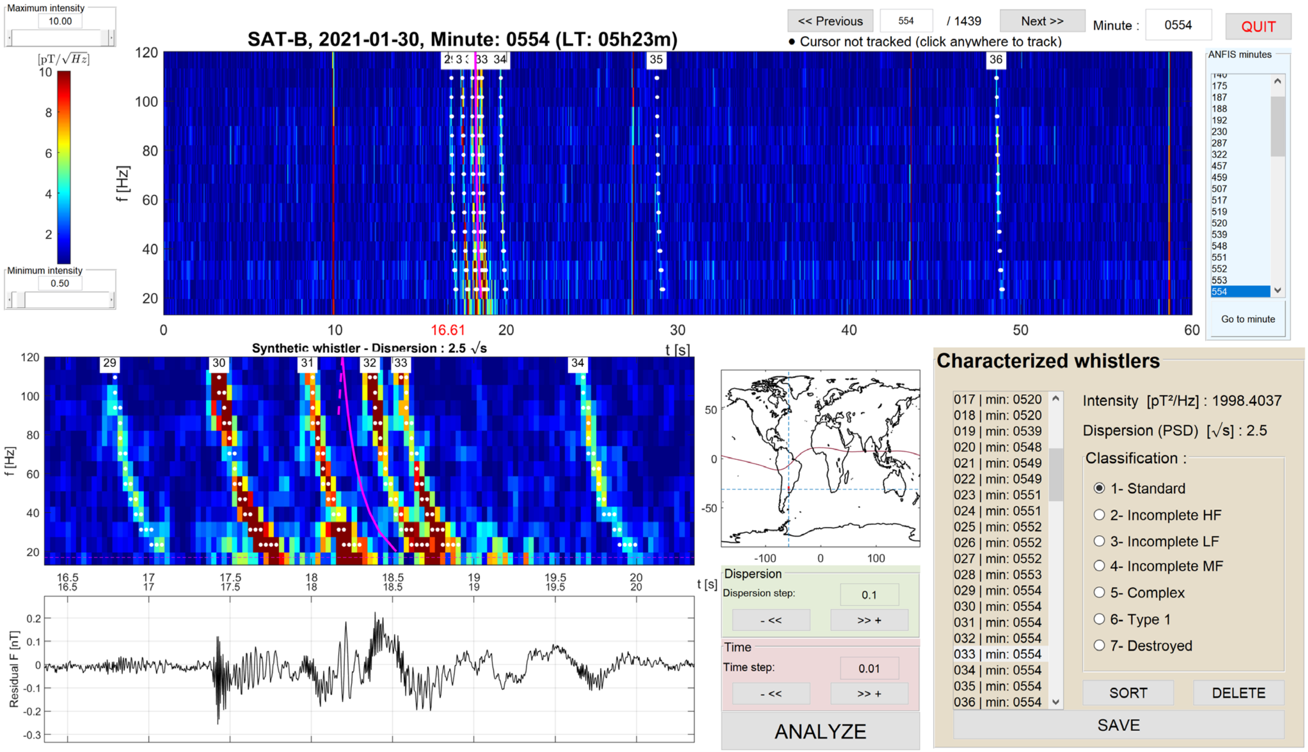
$$D = \sqrt{f(t)}(t - t_0)$$



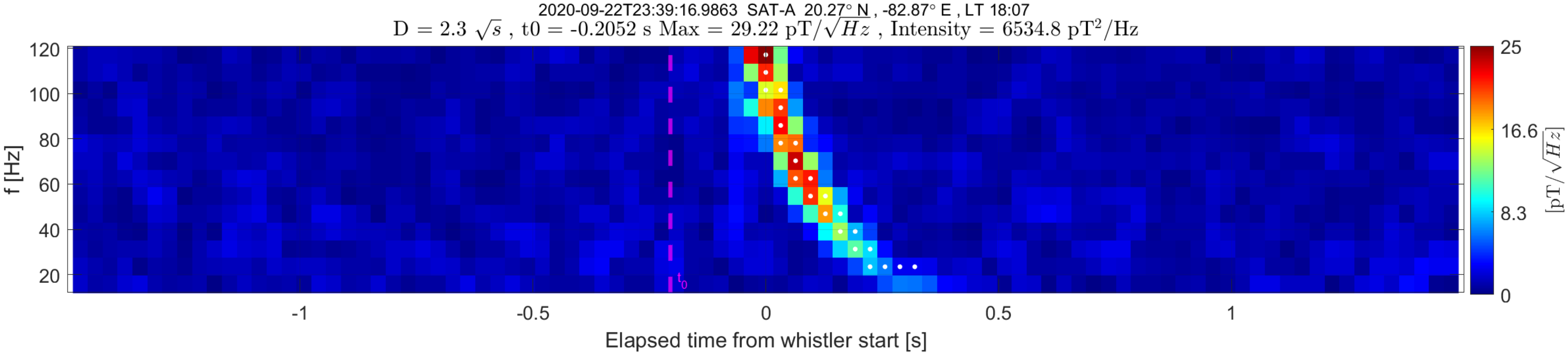
Whistler detection and characterization

Four steps process:

- **High-pass filter** L1b Burst mode data
- **Produce a DSP** with high temporal resolution
- **Scan all DSP using AI (Neural Network)** searching for Whistler type of behaviour
- **Manually validate and characterize** the Dispersion, Origin time, Intensity



Whistler dispersion, origin time and intensity



$$D = \sqrt{f(t)}(t - t_0)$$

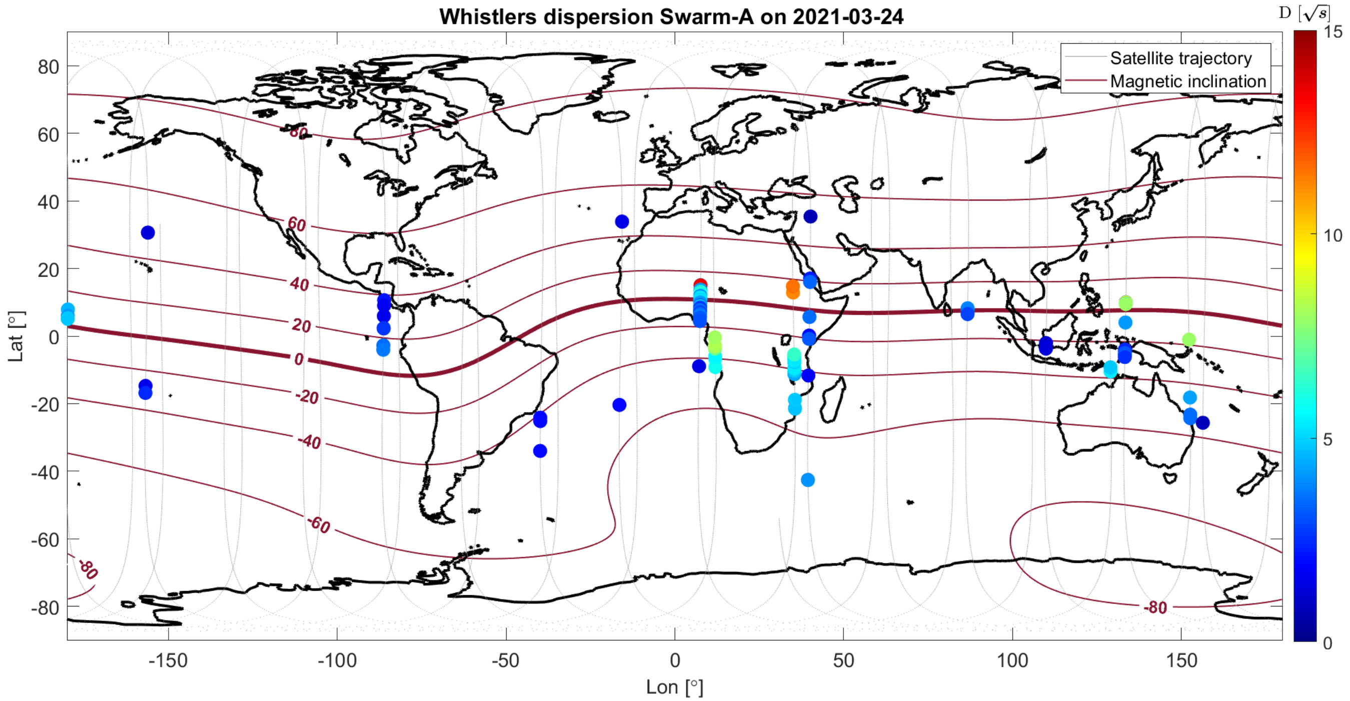
$$I = \sum_{j=1}^{N} p_j^2$$

- **Best fitting the DSP leads to D and t_0** (red vertical mark)
- **Adding the observed square value of the DSP intensity** p_j in each of the N tiles crossed by the best fitting curve (white points) **leads to the intensity I** (in pT^2/Hz)
- Note that this is the intensity of the vector whistler signal along the direction of the main field

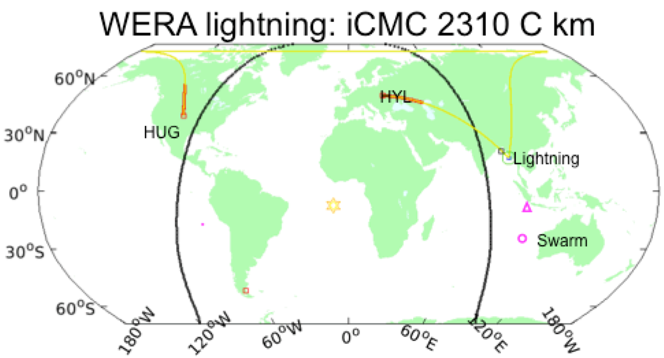
Swarm Whistler L2 product summary

- **Available to the Swarm Mission Users through ESA as an official Swarm L2 product**
- **Produced as daily files whenever L1b Burst mode data are available**
- **Each daily file lists all whistlers detected and characterized during the day**
- **For each whistler, the following is provided:**
  - **- the 3s of high-pass L1b data used for detection**
  - **- original L1b outlier flags**
  - **- the corresponding DSP sequence**
  - **- Dispersion, Time of Origin, and Intensity**
- **Product definition to be found in *ASM Whistler Product Definition for Operational Release of Data*, SW-ASMV-DD-IPGP-0012, 1D, 2022-01-31.**

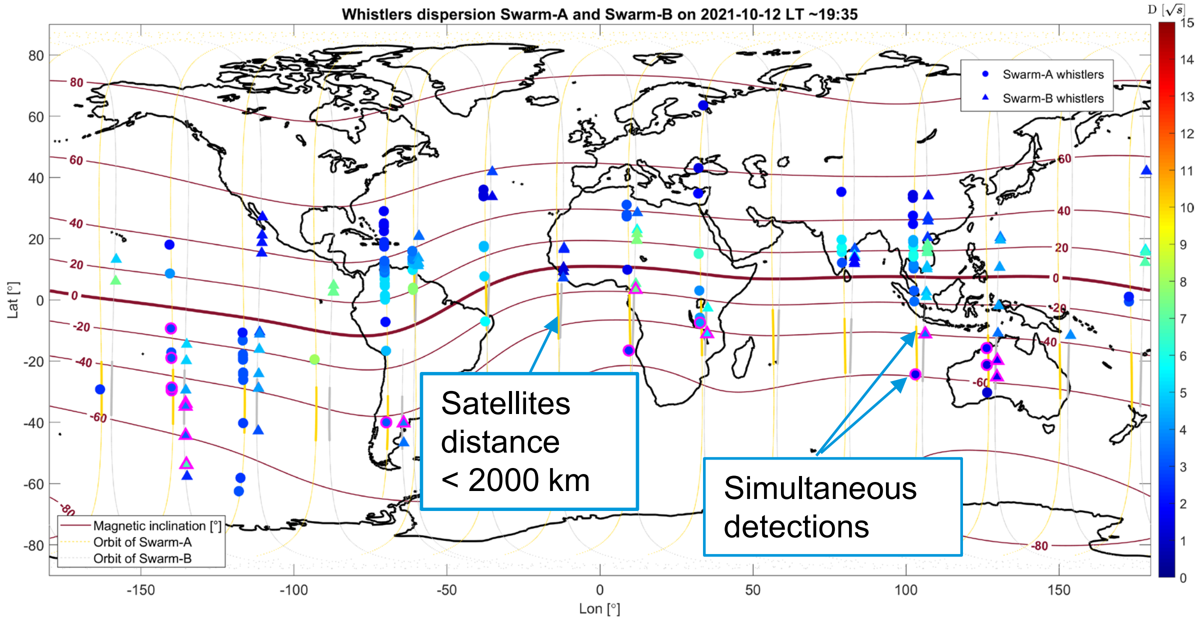
One day example of (189) whistlers detected on Swarm Alpha



Example simultaneous detection by Swarm Alpha and Bravo

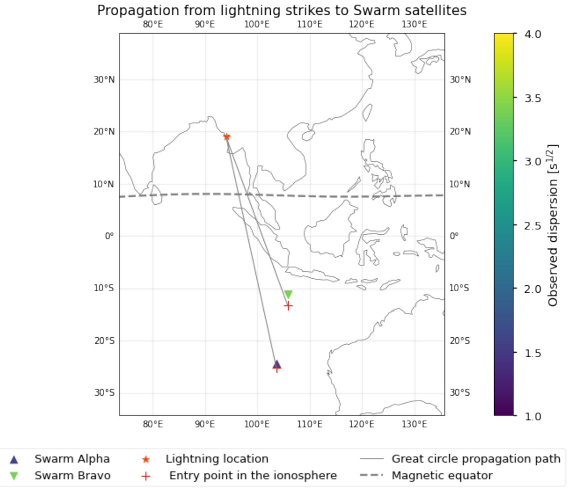


Identification of originating lightning using WERA (also WWLLN) confirms common origin of powerful discharge.

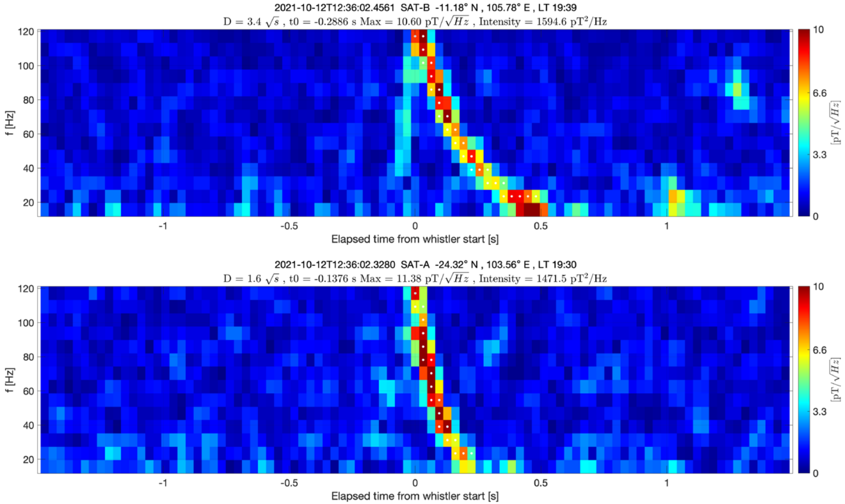


When Alpha and Bravo were counter-rotating in similar orbital planes in October 2021, closest distance was reached every 4 hours, providing opportunities of simultaneous detection (more frequent when distance was less than 3000 km)

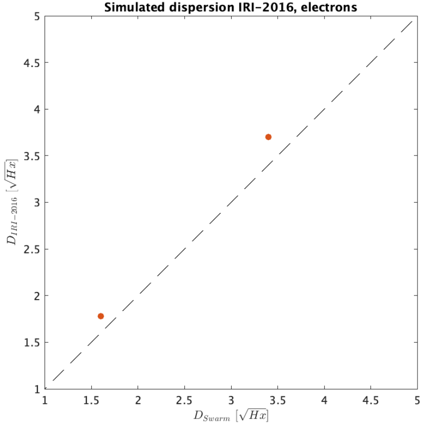
Example simultaneous detection by Swarm Alpha and Bravo



Lightning and satellie locations



Detected on both satellites, with different dispersions



Properly predicted using IRI and ray tracing

Whistlers can be used to test and improve ionospheric models, as well as understand conditions for whistlers to penetrate into the ionosphere.

For more about the Science that can be done with such whistlers

Talk by P. Coisson et al.

Today 26/05/22, Session A6.02, 14:15

"Whistler in ELF detected from LEO: lightning detection and ionospheric monitoring using Swarm satellites and the future NanoMagSat mission"