Wave instrument for Distributed Space Weather Sensor System

János Lichtenberger [1,2], Balázs Heilig[3], Péter Szegedi[4], Fabrice Ciprianil[5] and Balázs Zábori[6]

1Eötvös University, Budapest, Hungary
[2]Geodetic and Geophysical Institute, RCAES, Hungarian Academy of Sciences, Sopron, Hungary
[3]Mining and Geological Survey of Hungary
[4]BL Electronics Ltd, Hungary
[5]TEC-EPS, ESTEC, ESA
[5]Centre for Energy Research, Space Research Laboratory, Budapest, Hungary

Measurement requirements for SWE

Table 1. A summary of the different observational requirements for the magnetosphere and radiation belts.

Data for Earth Magnetosphere & Radiation Belt	**Measurement range**
High energy protons	>10MeV
High energy ions	>10MeV/nuc
Protons	1 to 10MeV
High energy ions	1 to 10 MeV/nuc
Ions	30 keV/nuc to 1 MeV/nuc
Electrons	30 keV - 8 MeV
Thermal and Supra-thermal Electron	0 to 30 keV
Magnetospheric Radiowave Spectra	1 kHz - 500 kHz
Thermal Ions Density and Temperature	0.1 eV - 30 keV
Local Magnetospheric Magnetic Field in Orbit	~1 - 50000 nT
Plasma Drift Velocity	0.1 eV - 30 keV

But no wave instrument is proposed in D3S!

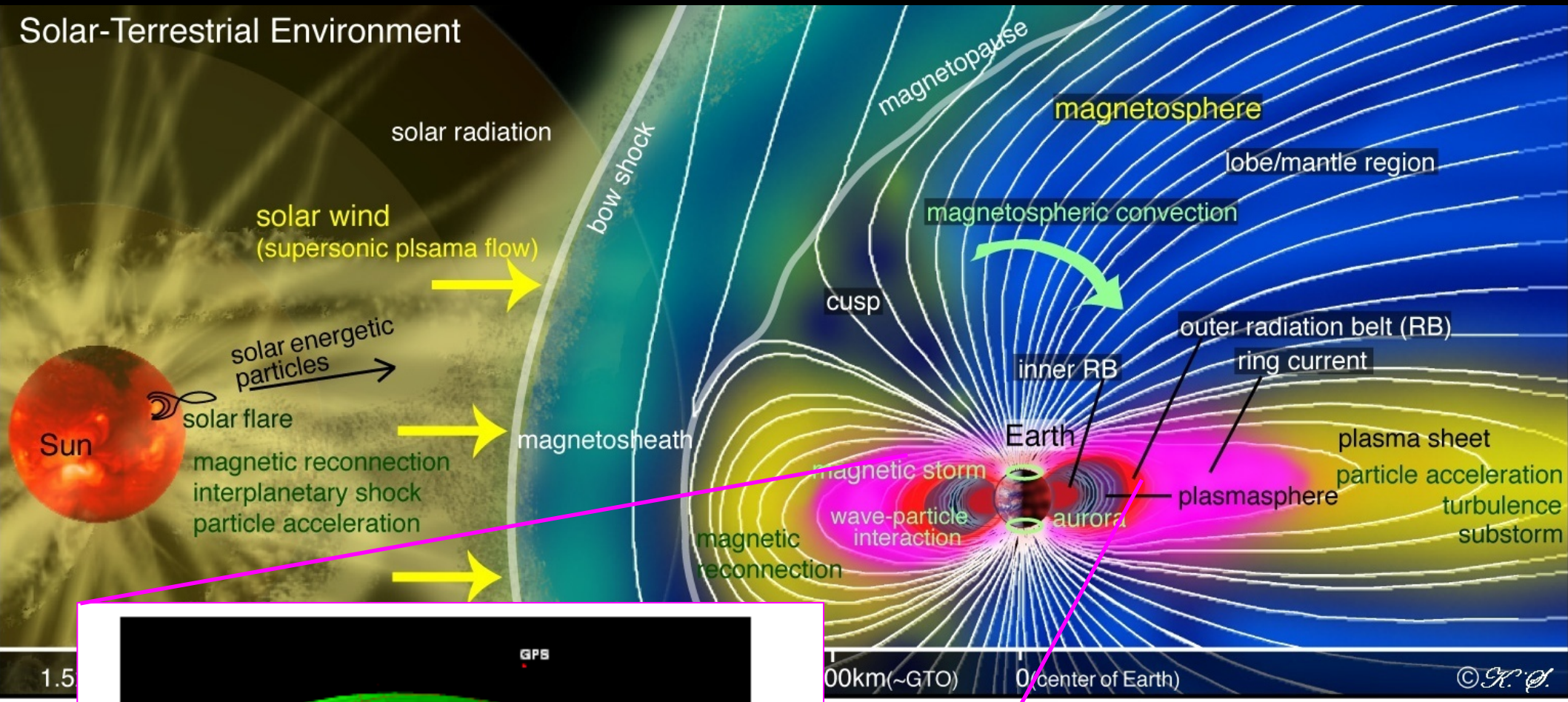
Kraft et al., AA, 2018

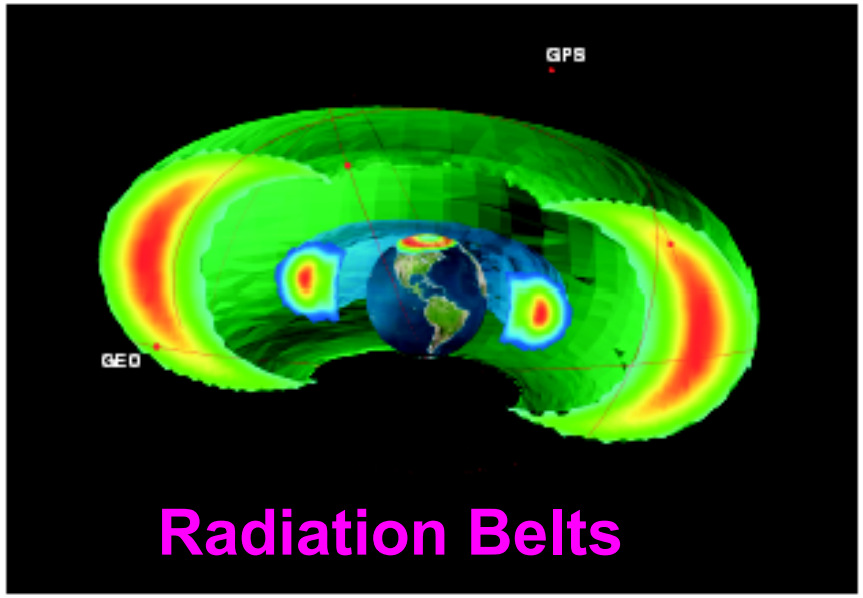
Update: a question

Melanie mentioned yesterday a plan of “electron density” measurements on MEO/HEO Small Sat Study:

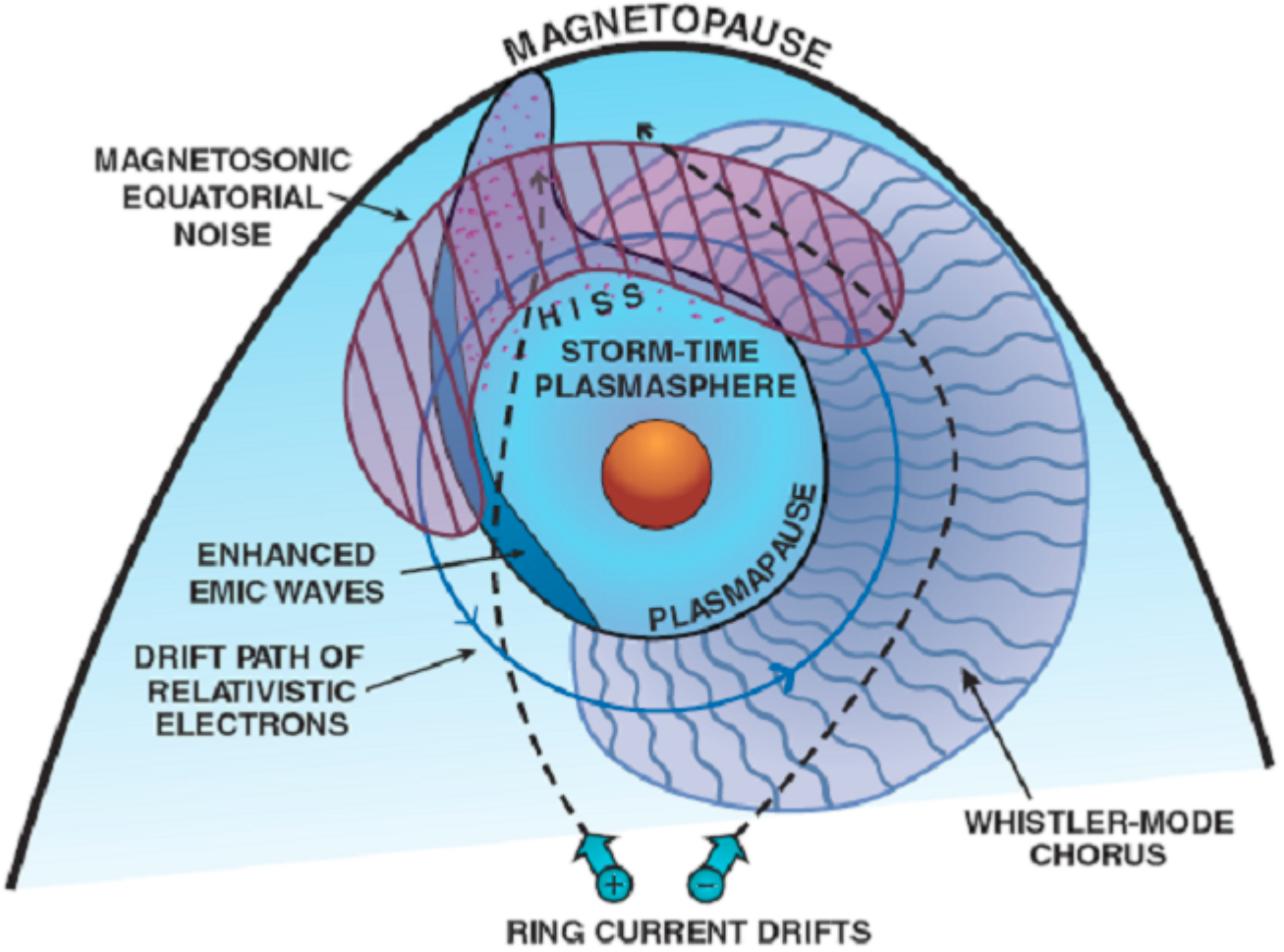
How can you measure electron density in magnetosphere without wave instrument?

Geospace


Solar-Terrestrial Environment
solar radiation
solar wind
(supersonic plsama flow)
bow shock
magnetopause
magnetosphere
lobe/mantle region
magnetospheric convection
cusp
solar energetic particles
solar flare
Sun
magnetosheath
magnetic reconnection
interplanetary shock
particle acceleration
outer radiation belt (RB)
ring current
inner RB
Earth
plasma sheet
particle acceleration
turbulence
substorm
magnetic storm
wave-particle interaction
aurora
plasmasphere
magnetic reconnection
1.5
00km(~GTO)
0 (center of Earth)
©K.O.


GPS
GEO
Radiation Belts

Waves in Geospace



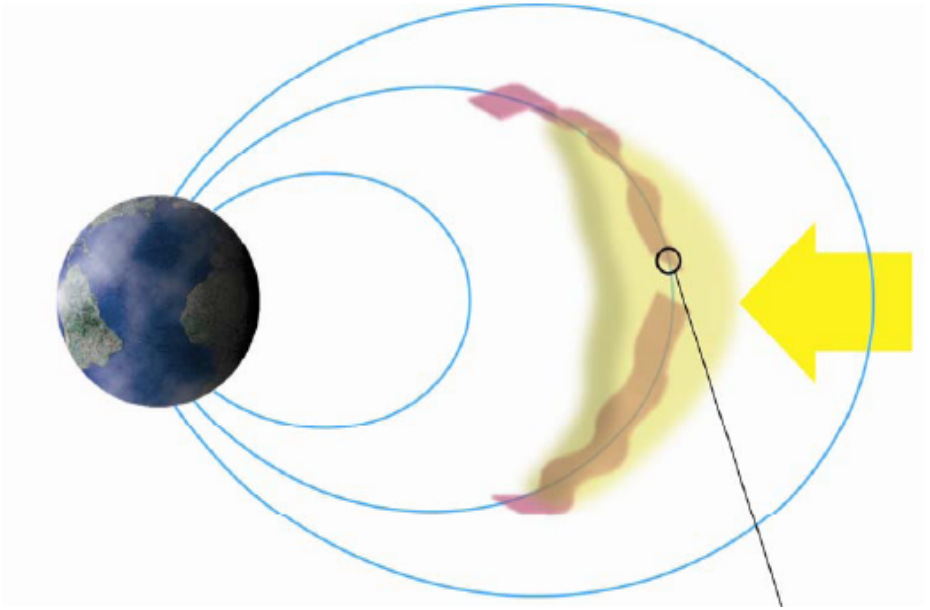
[Thorne *JGR, 2010*]

Why wave measurements are important?

Wave-particle interactions:

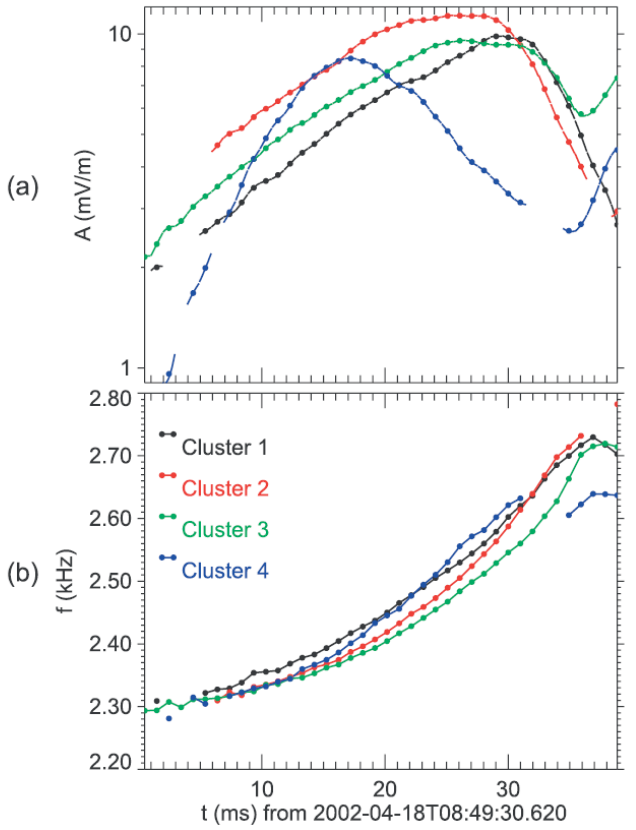
1. Waves are generated by particles

Chorus Emission due to Injection of Energetic Electrons

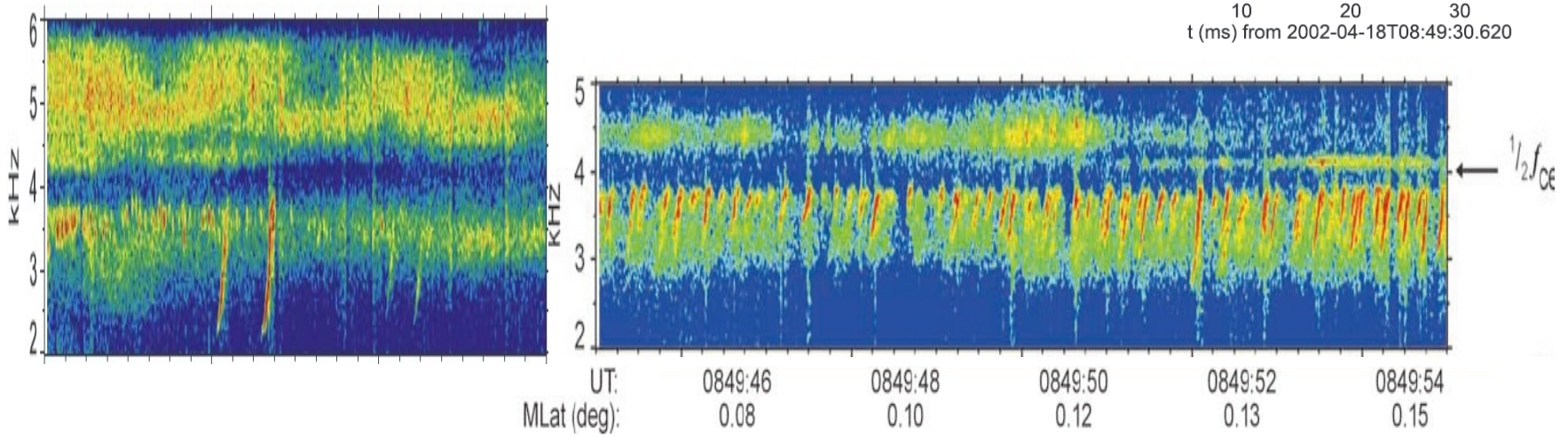


10 – 100 keV

$$\frac{T_\perp}{T_\parallel} > 1$$



Cluster observation



[*Santolik, Gurnett, Pickett, Parrot, Cornilleau-Wehrlin, JGR*, 2003]

Why wave measurements are important?

Wave-particle interactions:

1. Waves are generated by particles

2. Particles are **accelerated** and **scattered** (precipitated) by waves

3. Waves related to SWE dynamics can also be measured **far** from the active regions (LEO/GEO orbit)

Waves:

- Whistlers and whistler mode hiss and chorus waves (ELF-VLF)
- Electromagnetic Ion Cyclotron Waves (ULF)
- Magnetosonic Waves (ELF)

Why wave n

Wave-particle inte

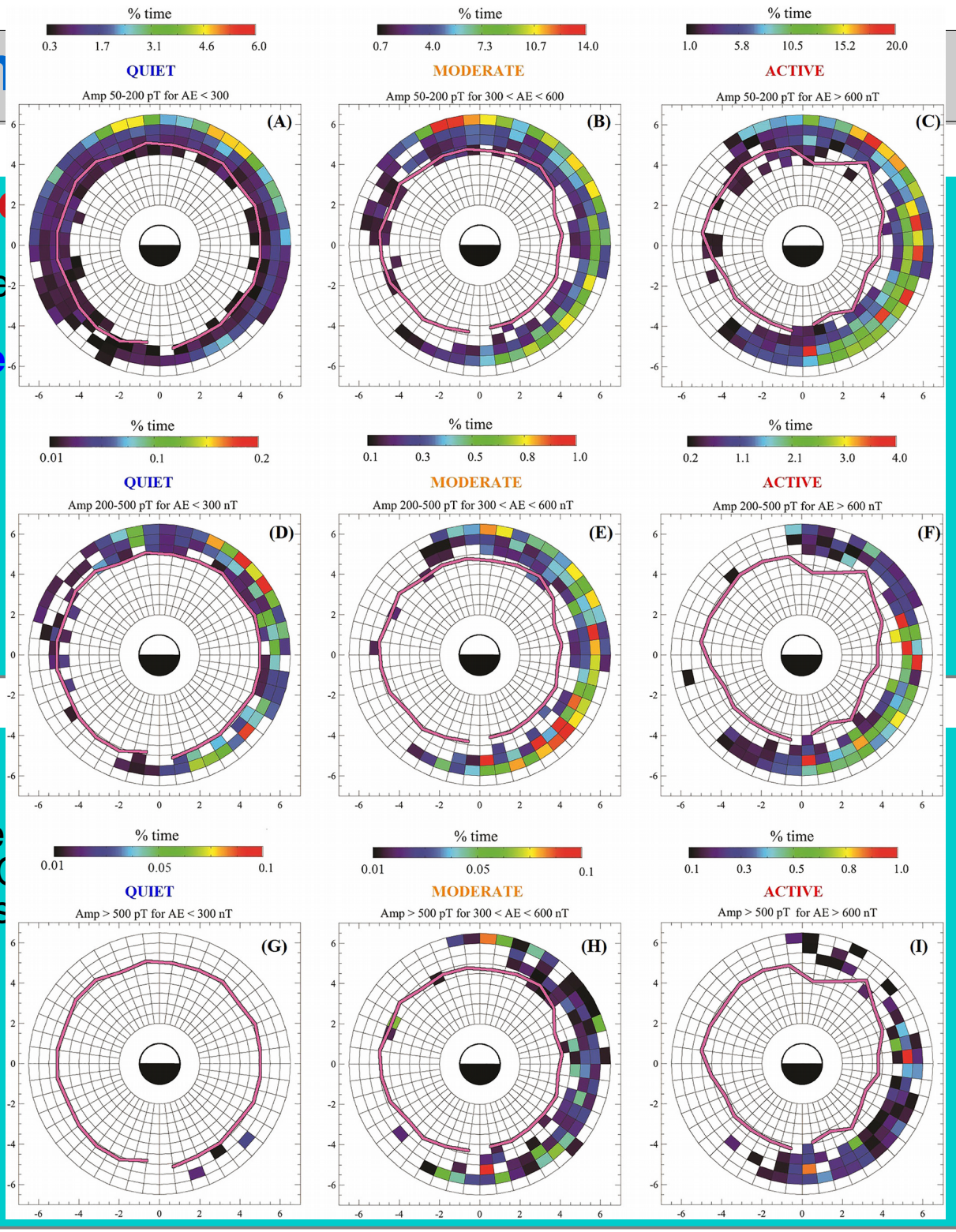
1. Waves are generate

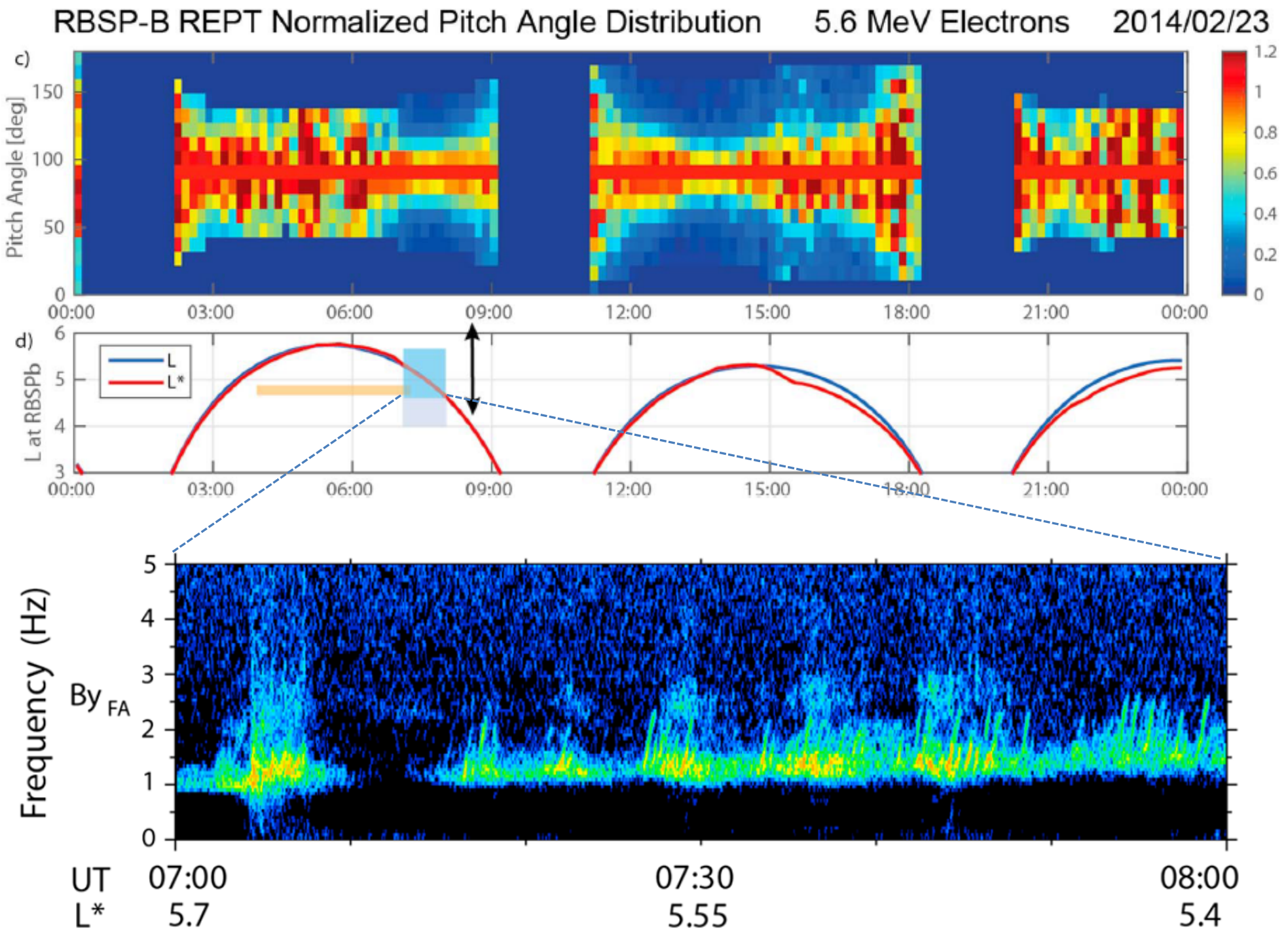
2. Particles are **accele**

Waves:

- Whistlers and whistle
- Electromagnetic Ion C
- Magnetosonic Waves

Tyler et al., JGR 2019





[*Engebretson et al., JGR*, 2015]

Why wave measurements are important?

Fokker-Planck Equation:

$$\frac{\partial f}{\partial t} = L^2 \frac{\partial}{\partial L}\left(\frac{D_{LL}}{L^2} \frac{\partial f}{\partial L} \right)\Bigg|_{\mu J} + \frac{1}{g(\alpha)} \frac{\partial}{\partial \alpha}\left(g(\alpha) D_{\alpha\alpha} \frac{\partial f}{\partial \alpha} \right)\Bigg|_{EL} + \frac{1}{A(E)} \frac{\partial}{\partial E}\left(A(E) D_{EE} \frac{\partial f}{\partial E} \right)\Bigg|_{\alpha L} - \frac{f}{\tau(\alpha, E)}$$

Radial transport | Pitch angle diffusion | Energy diffusion | Losses

Diffusion coefficients:

$$\mathcal{D} = \lim_{V \to \infty} \sum_n \frac{q^2}{m^2} \int \frac{d^3k}{(2\pi)^3 V} \frac{i}{\omega_{\mathbf{k}} - k_{\|} v_{\|} - n\omega_c} (\mathbf{a}_{n,\mathbf{k}})^* (\mathbf{a}_{n,\mathbf{k}})$$

wave amplitude and polarization critical (RH, LH, X, O, and their combinations)

Wave specification in SWE

3.3.41 MR-013-M: Magnetospheric Radiowave Spectra - Measurement

PRODUCT	Magnetospheric Radiowave Spectra - Measurement
Product Code	MR-013-M
Input Data required	
Data to be provided and associated units	Magnetospheric radio wave spectra
Dynamic Range	TBD
Physical Range	(1 kHz, 500 kHz)
Spatial range	400 km - 60,000 km altitude, long: 0 - 360, lat: -90, 90
Spatial resolution	2 observation points on polar LEO, 2 observation points on MEO and 2 observation points on GEO.
Time Range	current date
Time resolution	10 s
Timeliness/Latency	The data shall be available with a maximum delay of 60 min. This requirement can be downgraded to 100 min subject to Customer approval.
Accuracy	0,2
Other Specific	AKR shall be measured from non-occulted location
Related CRD Requirement	SWE-CRD-GEN-1728
Justification of the requirements	For incorporation into end-to-end space weather simulation
Comment	Sensors should remain in two separate hemispheres (i.e. the phasing should roughly be 180 degrees). for MEO, Galileo altitudes are adequate (threshold), a greater range of altitudes is desirable (goal).

Proposed Wave Instrument Specification

PRODUCT	Magnetospheric Radiowave Measurement: I. Monitoring mode II. Survey mode III. Burst mode IV. Event detector mode
Product Code	
Input Data required	Magnetic sensor: 1 search coil input Electric field: 2 electric probes input
Sensor booms	Magnetic field: 4m long deployable boom, sensor folded at the tip Electric field: 2.5m long boom deployed in a same line as the search coil boom, but opposite direction
Sensor orientation	3 axis stabilized platform: horizontal plane spin stabilized platform: spin plane
Magnetic sensor noise level	10Hz: 500fT/√Hz 100Hz: 50fT/√Hz 1kHz: 10fT/√Hz 10kHz: 10fT/√Hz 40kHz: 12fT/√Hz
Magnetic field signal dynamic range	1-10000 pT/√Hz (80dB)
Electric sensor noise level	DC-100Hz: 400nV/m/√Hz; 100Hz-500kHz: 50nV/m/√Hz
Electric field signal dynamic range	1-10000 μV/m/√Hz (80dB)
Data to be provided and associated units	Magnetospheric radio wave spectra
Physical Range	10Hz-40kHz (magnetic component); DC-500kHz (electric component)
Spatial range	400 km - 60,000 km altitude, long: 0 - 360, lat: -90, 90
Spatial resolution	2 observation points on polar LEO, 2 observation points on MEO and 2 observation points on GEO.
Time Range	current date
Time resolution	I. Monitoring mode: FFT spectrum of 16384 data points/1 min of all 2 field components II. Survey mode: FFT spectrum of 16384 data points/1 sec of all 2 field components III. Burst mode: raw data samples of 6 (10) sec of all the magnetic field component; raw data samples of 1 sec of 1 electric field component at predefined time epochs (“on demand”) IV. Event detector mode: 32 byte/sec

Proposed Wave Instrument : SAS-D3S

Operating modes:

I. Monitoring mode: FFT spectrum of 16384 data points/1 min of all 4 field components

II. Survey mode: FFT spectrum of 16384 data points/1 sec of all 4 field components

III. Burst mode: raw data samples of 6 (10) sec of all the 3 magnetic field components; raw data samples of 1 sec of 1 electric field component at predefined time epochs (“on demand”)

IV. Event detector mode: number of events in all categories per minutes (32 bytes/min)

SAS-D3S: Heritage

Signal Analyzer and Sampler (SAS) instruments on:

I. past/present:

1) Active satellite (1989-1992): SAS-1
2) COMPAS2 satellite (2005-2006): SAS2-K2
3) Chibis-M satellite (2012-2013): SAS3-Ch
4) Within Obstanovka experiment on ISS (2013-): SAS3-O1
5) RELEK-Vernov satellite (2014): SAS3-R

And

Intelligent Signal Detector Module in Plasma Wave Instrument, MMO, BepiColombo (ESA Contract No. 4000100050)

II. under development:

1) ELTESAT – based on a concept of 'full featured' wave measurements in an ESA project (Contract No. 4000120693),
2) Trabant mission (2 satellites, 2023): 2xSAS3-T
3) Obstanovka Phase 2 on ISS (2023-2024): 4xSAS3-O2

SAS-D3S: Heritage

Signal Analyzer and Sampler (SAS) instrument specification

Input bandwidth: 1Hz – 40kHz
Sampling rate: 80kSps
Sensors power supply / input voltage range: ±5V
Input supply voltage: +28V
TM/TC interface: MIL-1553
Data interface: serial LVDS interface with data clock and strobe.
Typical power consumption: 5W
Operating temperature range: -30 – +60◦C
Mechanical size: 100x100x30mm
Mass: 500g

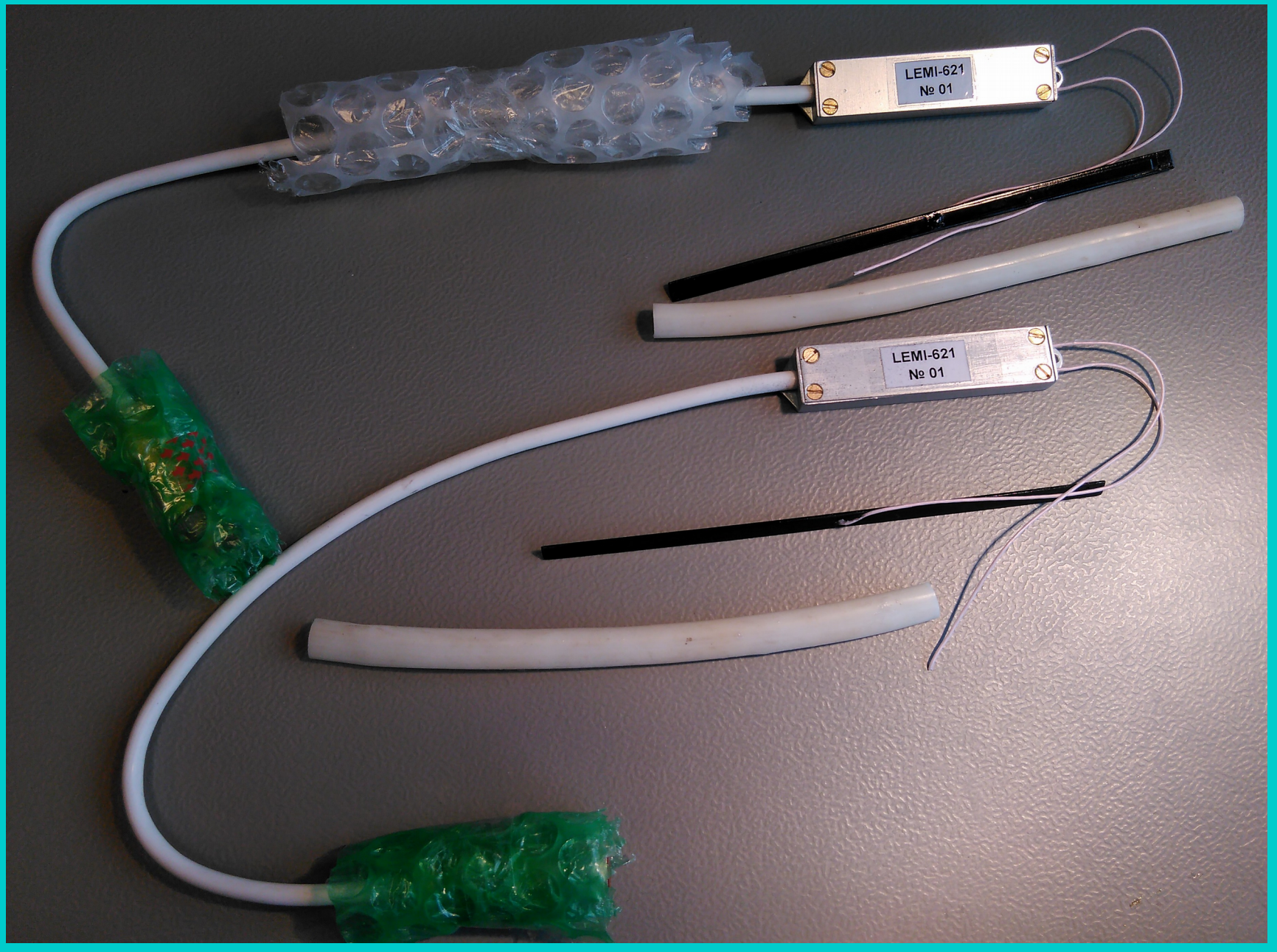
TRL= 9-10

SAS-D3S: Heritage

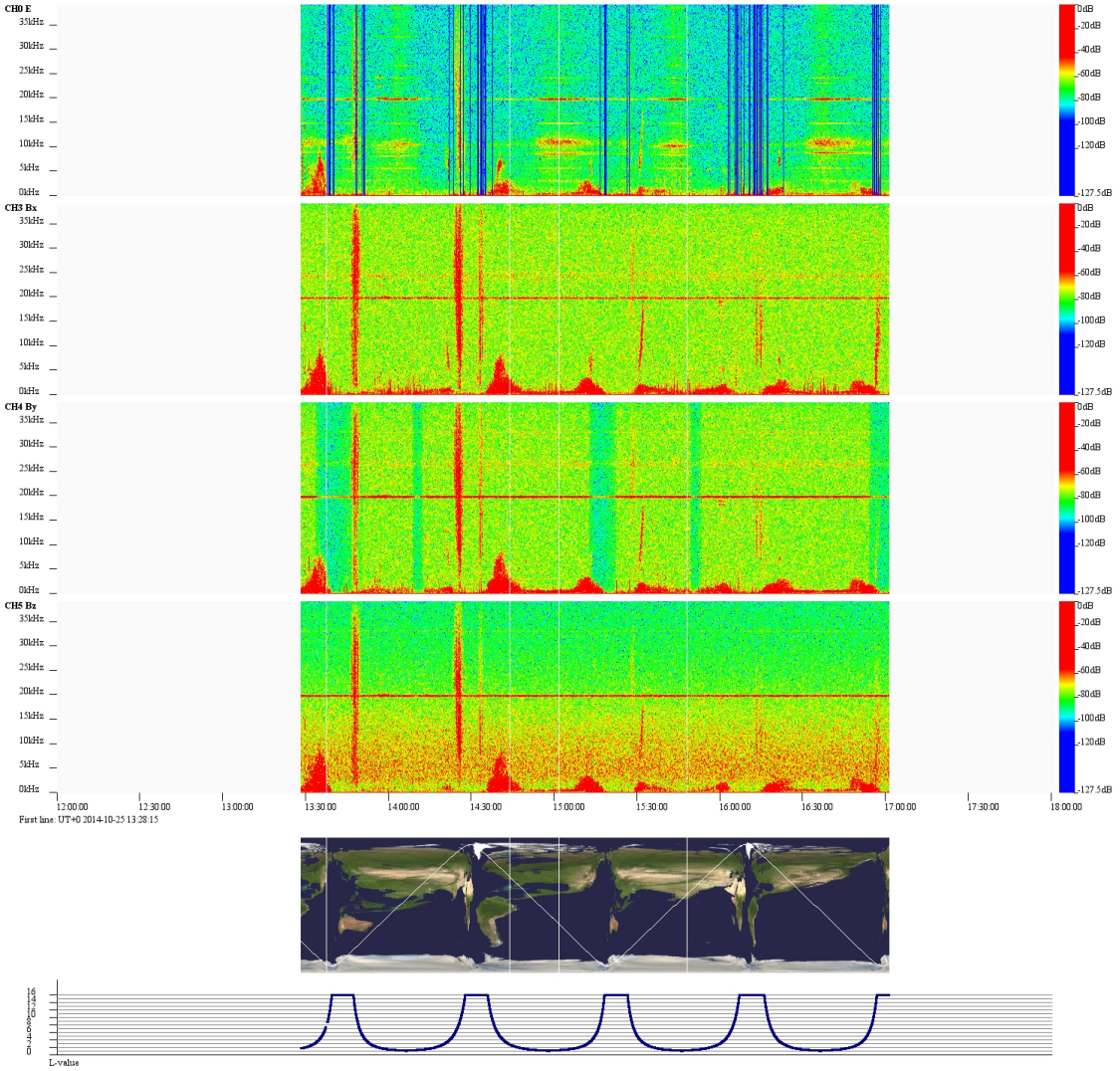
Signal Analyzer and Sampler (SAS) instrument sensors: search coil

SAS-D3S: Heritage

Signal Analyzer and Sampler (SAS) instrument sensors: electric probes

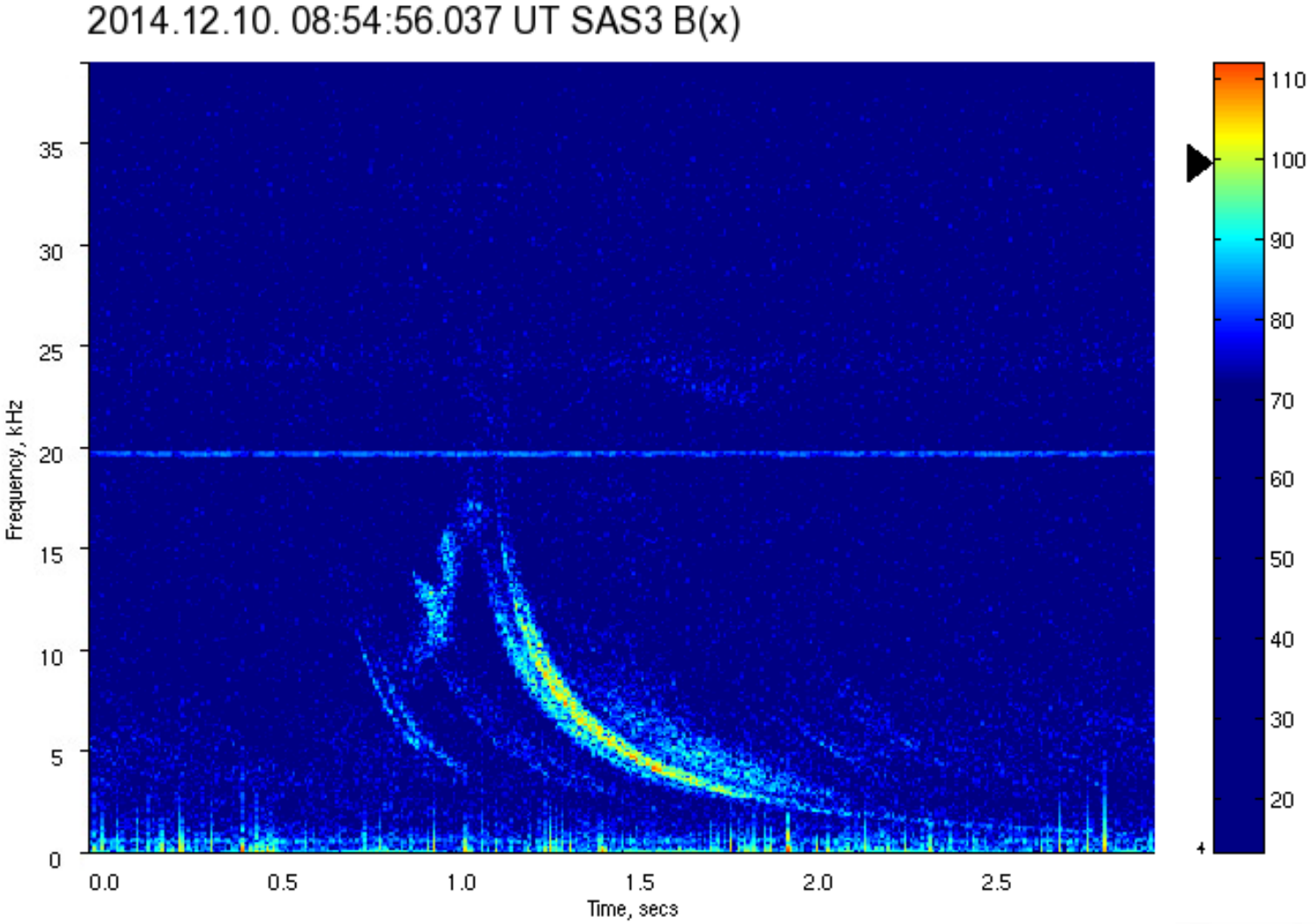


SAS-D3S: Heritage

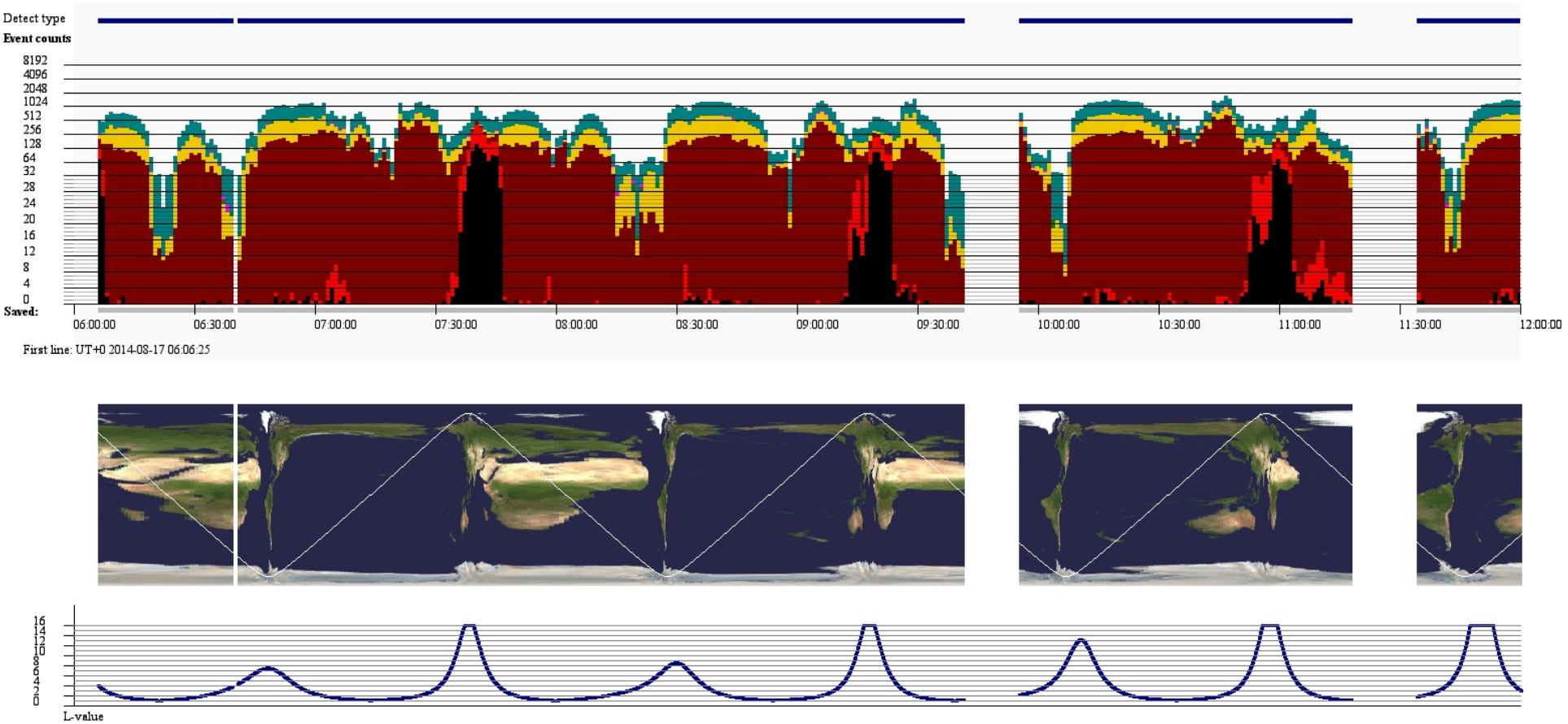


RELEK SAS3-R Monitoring mode
25 October 2014

SAS-D3S: Heritage

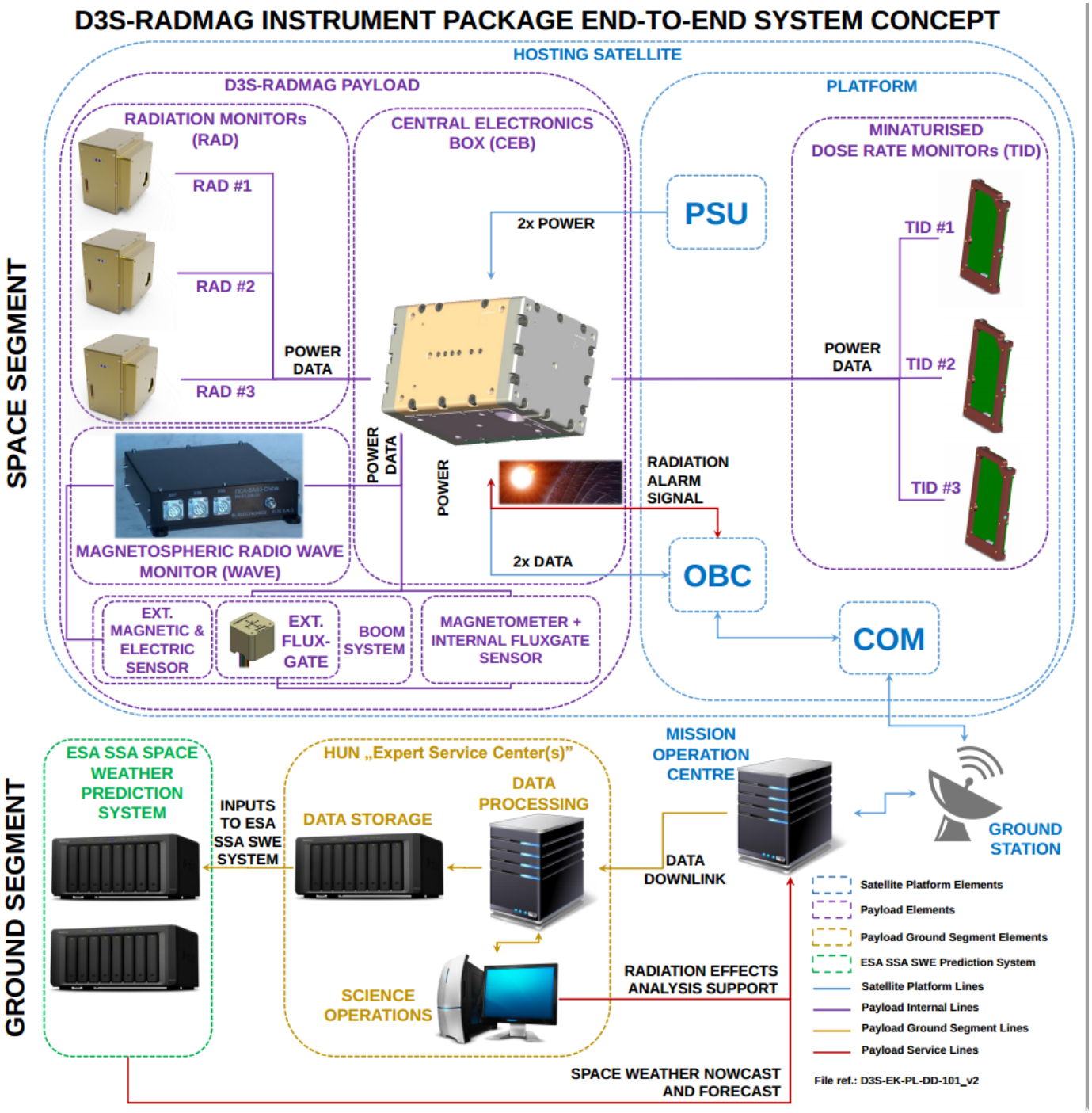


RELEK SAS3-R Burst mode
12 December 2014



RELEK SAS3-R Event detector mode
17 August 2014

D3S-RADMAG (Zábori et al.)

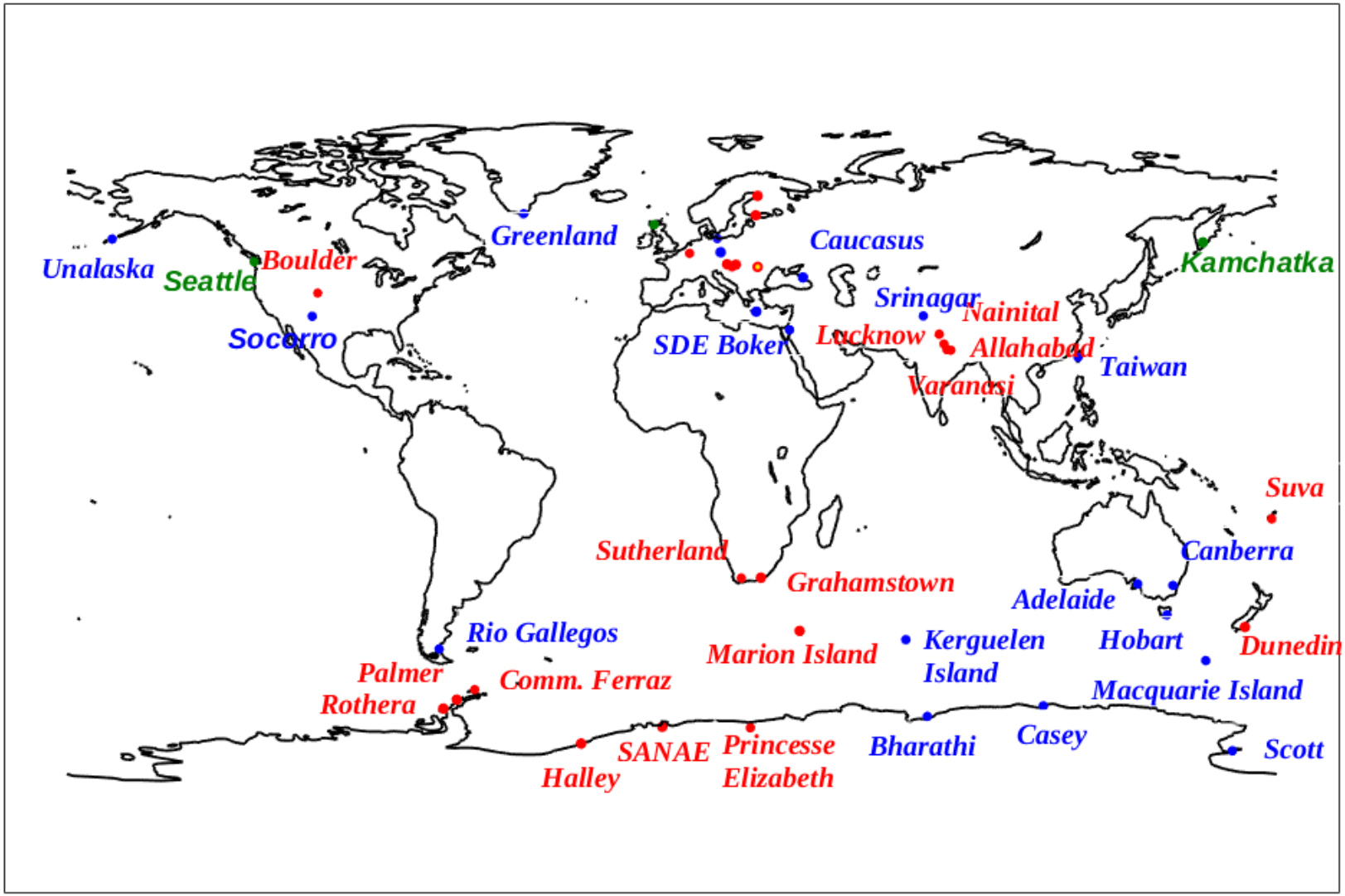


AWDANet: a unique, complementing network to SAS-D3S

Automatic Whistler Detector and Analyzer Network
AWDANet - Europe

AWDANet: a unique, complementing network to SAS-D3S

Automatic Whistler Detector and Analyzer Network
AWDANet - World



Summary

I. Wave data are inevitable for any SWE application/model/forecast

II. SAS wave instruments have a long and successful heritage

III. SAS-D3S wave instrument: an straightforward and important extension to D3S-RADMAG