SM31C-2379

Van Allen Probes
Radiation Belt Storm Probes

The Electric Fields and Waves Instrument (EFW) on the NASA Van Allen Probes: Science Operations Center, Operational Modes, and Data Products and Access

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Abstract

The Electric Field and Waves (EFW) instrument on the NASA Van Allen Probes (previously RBSP) provides measurement of 3D DC and AC E-fields, as well as 3D AC magnetic fields as provided on board from the EMFISIS tri-axial searchcoil magnetometer (MSC).

Two 100-m tip-to-tip spin plane and 12 to 14-m tip-to-tip axial E-field antennas are deployed on each of the two observatories, with all instrument operations controlled on board via the EFW Instrument Data Processing Unit (IDPU). Both continuous waveform and spectral data products from DC up to 8 kHz, as well as high-rate burst waveforms (E-field and interferometric modes) are produced on-board through a highly-configurable digital signal processing system.

A large-capacity waveform burst memory (32 GB) with human-in-the-loop playback selection is also included in the EFW instrument, allowing for days to tens of days of lookback and playback of selected time intervals of burst data.

EFW also provides higher-frequency 3D E-field signals to the EMFISIS suite, providing waveform coverage up to 12 kHz and spectral coverage to over 400 kHz.

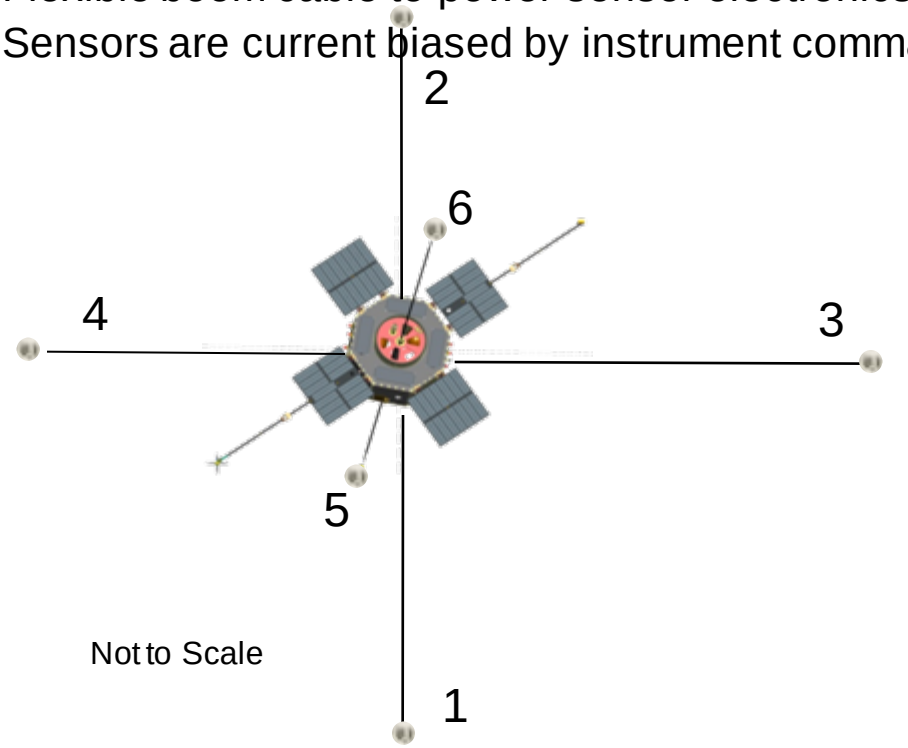
A description of all the EFW operational modes and data products is presented. Access to the ISTP-Compliant CDF datasets served from the primary EFW Science Operations Center (SOC) at the University of California, Berkeley is shown, along with support for data acquisition and analysis under the IDL THEMIS Data Analysis Software (TDAS) and Science Data Tool (SDT) packages.

EFW
Instrument Overview

"A High-Impedance, Low-Noise, Three-Axis Digital Voltmeter in Space"

Booms and Sensors:

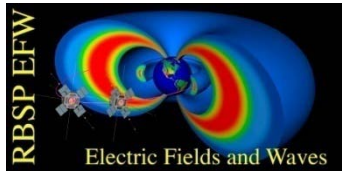
- Four spin plane booms (2 x 100-m tip-to-tip)
- Two spin axis stacer booms (12-14 m tip-to-tip; length trimable on-orbit)
- Spherical sensors and preamplifiers near outboard tip of boom (400-kHz response)
- Flexible boom cable to power sensor electronics & return signals back to SC
- Sensors are current biased by instrument command to optimize DC and AC response.



Instrument Data Processing Unit (IDPU):
Main electronic box, controlling sensor bias, A-D conversion, digital filtering, burst memory, diagnostics, mode commanding, TM formatting).
Provides analog interface between EFW and EMFISIS instruments (shared E- and B-field measurement capabilities).
Provides Space Weather quantities (spin fit E; SC_POT) to "beacon" and std. TM.

Note: EFW E-field and EMFISIS MAG and MSC sensor axes roughly aligned (w/in few degrees) to ease initial data analysis.

EFW
SOC and Science Team Organization



Dr. John Wygant
EFW PI (UMN)

EFW Science Team
(UMN, UCB, LASP,
Dartmouth, Millstone Hill,
AFRL, UCLA)

Duty Scientist
"TOHBAN"

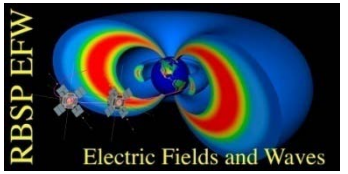
Dr. John Bonnell
EFW SOC Lead (UCB)

Will Rachelson
EFW GSE Lead (UCB)

Peter Schroeder
EFW SDC Lead (UCB)

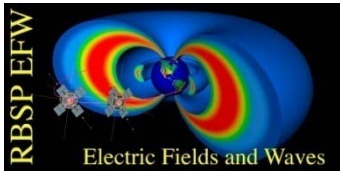
EFW Instrument Operators
(UCB, UMN)

EFW
Team and Operations Summary



- **EFW efforts are lead by Dr. John Wygant (wygant@fields.space.umn.edu) from the PI institution, Univ. of Minnesota (UMN).**
- **Nominal science operations provided by SOC Team at Univ. of California, Berkeley (UCB).**
- **Pre- and Post-Launch scientific input, testing and guidance provided by EFW PI and Science team.**
- **EFW PI and Tohban (Duty Scientist) provide a single point of contact between the Science Team and the SOC (Operations) team post-launch.**
- **Bi-weekly Science team and weekly SciSOC provide venues for team members and others to discuss science, operations, and instrument modes.**

Who is the TOHBAN, and what does he or she do?



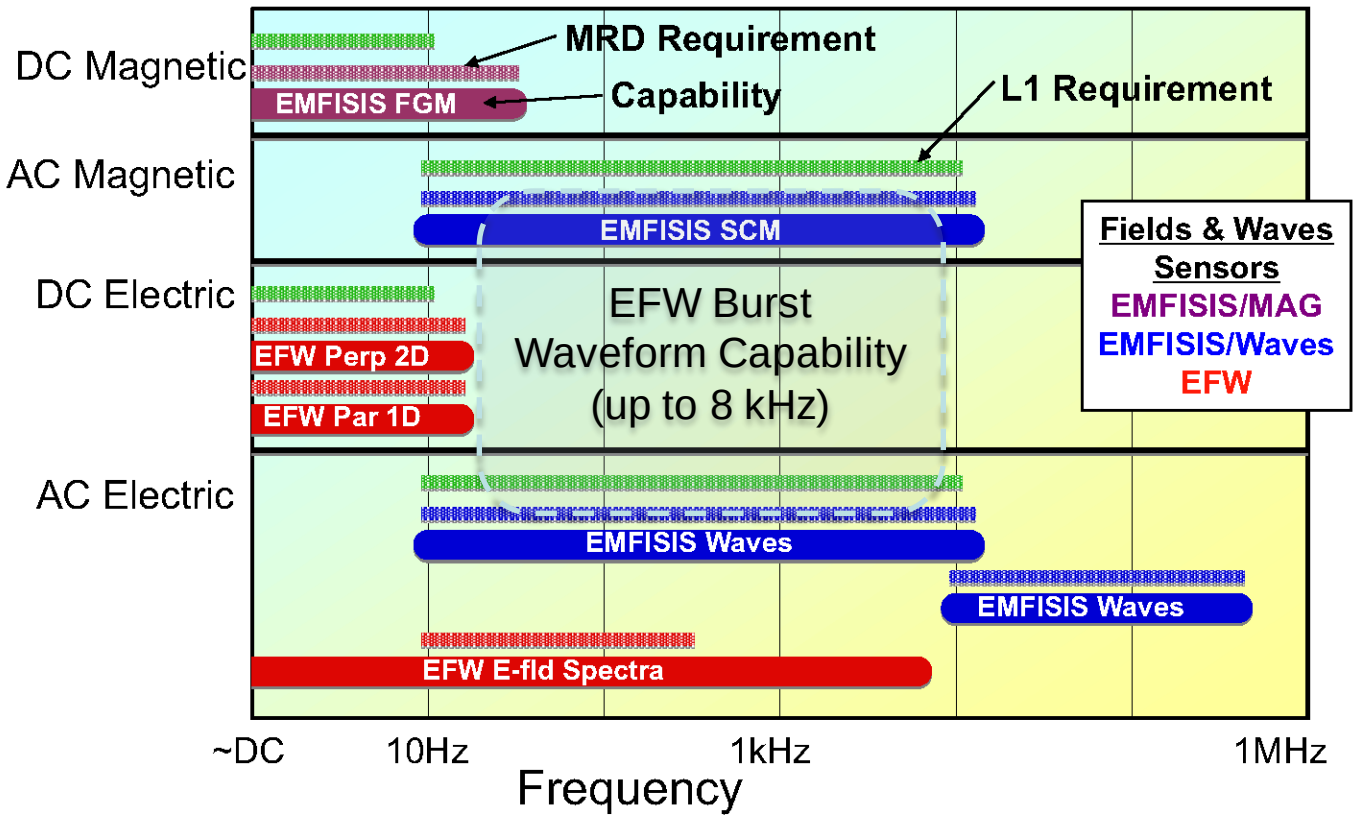
"Ask not what EFW can do for you, but what you can do for EFW…"

- **"Scientist on Duty" (TOHBAN = Duty Officer or Officer of the Day).**
- **2-4 week stints providing:**
- **PI Support (planning, analysis, discussion).**
- **Data Validation.**
- **Burst Playback Selection.**
- **Liaison between EFW Science Team SOC Team:**
  - Implementation of science measurement goals and requirements.
  - Coordination between EFW and other RBSP Instrument teams.
- **What's in it for you?**
  - Deeper understanding and appreciation of EFW dataset.
  - First cut at data fresh off the satellite.
  - Larger role in burst selection planning.
  - Enduring appreciation of EFW technical and ops staff.

Contact Dr. John Wygant
(wygant@fields.space.umn.edu)
and sign up today!

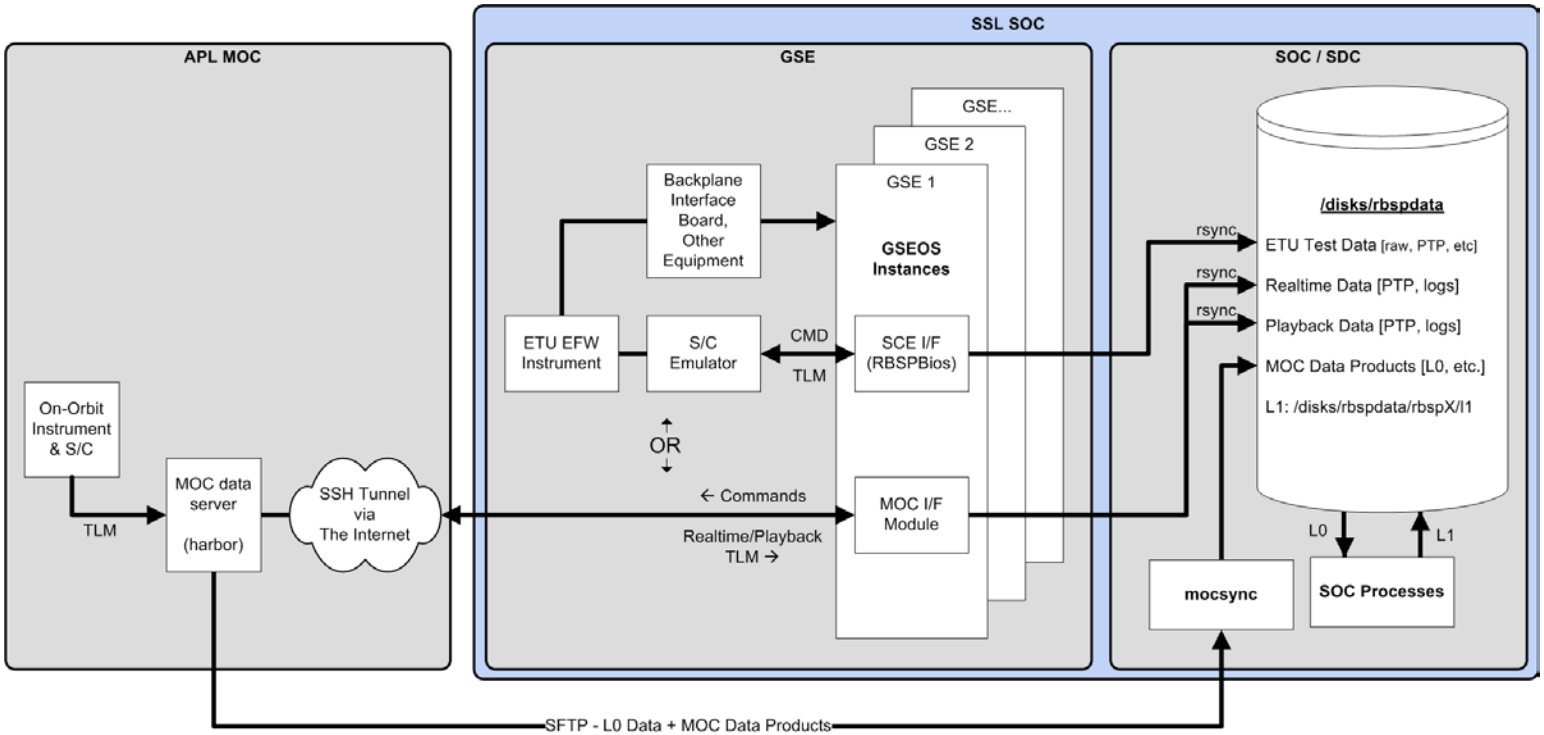
EFW and EMFISIS
EM Field Data Coverage

Fields Instruments capabilities meet / exceed MRD Allocations of L1 required measurements



From RBSP M-CDR, p.4.1-10.

EFW
SOC Data Flow



Mission Overview – Instruments Data Products

EFW
ISTP-Compliant CDFs
Accessed via IDL/TDAS or SDT

Data Level	ECT	EFW	EMFISIS	RBSPICE	RPS
L0	Raw Telemetry (Raw de-commutated telemetry received from MOC)	Raw Telemetry (Raw de-commutated telemetry received from MOC)	Raw Telemetry (Raw de-commutated telemetry received from MOC)	Raw Telemetry (Raw de-commutated telemetry received from MOC)	Raw Telemetry (Raw de-commutated telemetry received from MOC)
L1	Count Rates (Sorted time tagged instrument separated counts per second)	Time Tagged Raw waveform and spectral data (Expressed in spinning spacecraft coordinate system)	Time series and spectra (relative amplitudes); burst data Calibrated Magnetic Field values (Calibrated and corrected physical units)	Count Rates (Sorted time tagged instrument separated counts per second)	Energy/Photon deposits, singles and coincidence rates (Time tagged in UTC, magnetic field vector, minimal magnetic coordinates)
L2	Calibrated Flux (Calibrated and corrected physical units)	Calibrated Waveform and Spectral Data (In despun spacecraft coordinate system and other relevant geophysical Systems)	Spectral Quantities (Calibrated and corrected physical units); Includes low frequency spectra from MAG	Calibrated Flux (Calibrated and corrected physical units)	Flux versus Energy Spectrum
L3	Pitch Angle and Moments (Pitch angle distributions and moments of the plasma distribution)	Calibrated Waveform and Spectral Data (with VxB subtraction for DC E-field estimate)	Magnetic wave parameters	Pitch Angle and Moments (Pitch angle distributions and moments of the plasma distribution)	Energy-pitch angle spectrum and magnetic coordinates
L4	Phase Space Density (PSD units in adiabatic coordinate space)	Global Electric Field Pattern	Wave propagation parameters (Spectral matrices, WNA, polarization, Poynting flux, etc) Electron densities	Phase Space Density (PSD units in adiabatic coordinate space) (PSD will be calculated for specific ring current relevant observations)	Global Maps (flux vs E/K/Phi and PSD versus M/K/Phi)

Table 4.2. Mission Level Data Products

QuickLook Summary Plots
ISTP-Compliant CDFs

From RBSP SDMP, p.38.

EFW Data Access
ISTP-Compliant CDFs

- **ISTP-Compliant L1+ CDFs of EFW data available (or will be available) via this URL via UCB: http://themis.ssl.berkeley.edu/data/rbsp/rbsp{a,b}/l{1,2,3}.**
- **Mirror/Transfer of data to CDAWeb, UMN and other sites in the works (Jan 2013).**
- **Data is processed from L0->L1 within 1-2 days of acquisition for survey waveform and spectral data.**
- **QL Summary Plots (quasi-L2) processed using predicted attitude and ephemerides.**
- **Full access to L1->L2 processing for general uses is dependent upon public attitude and ephemerides data, which comes available about 1 week after data acquisition.**

EFW
L1/2 Directory Structure

- http://themis.ssl.berkeley.edu/data/rbsp/
  - rbspa
    - l1
      - eb1
        - 2012
        - 2013
          - rbsp{a,b}_l{1,2}_{dqd}_YYYYMMDD_vNN.cdf
          - …
        - 2014
      - eb2
      - esvy
      - fbk
      - …
    - l2 (Coming soon – Jan 2013!)
      - …
  - rbspb
    - …

EFW
Data Products

Data Product ("dqd", or data quantity descriptor)	Notes (Nominal Rates and Config)	Coverage
ESVY	32 samp/s; EDC12, EDC34, EDC56 (U,V, W)	Continuous
VSVY	16 samp/s; V1..V6.	Continuous
MAGSVY	64 samp/s; MAG U, V, W (disabled).	Contingency for EMFISIS-MAG
FBK	Filter Bank; 1 channel, 13 bins, pk and avg, 1/8-s cadence; E12DC (U).	Continuous
SPEC	FFT Power Spec; 7 channels, 8-s cadence; 10% df/f (64 bins); E12AC (U), E56AC (U), SCM U,V,W	Continuous.
XSPEC	FFT Cross Spec; 2 channels, 8-s cadence.	Continuous.
E, B Spin Fit (FIT)	10.9-s (spin period) cadence; E12DC (U), MAGU.	Continuous.
Burst1: EB1, VB1, MSCB1	512 samp/s: EDC, V1..V6, SCM.	7.5% (~1.8 hr/day, or 40 min/orbit)
Burst2: EB2, VB2, MSCB2	16384 samp/s: V1AC..V6AC.	0.1% (~80 s/day, or ~30 s/orbit).
Housekeeping (HSK)	Various rates; Instrument SOH, Burst Memory Parameters, etc.	Continuous

EFW QuickLook Summary Plots Access

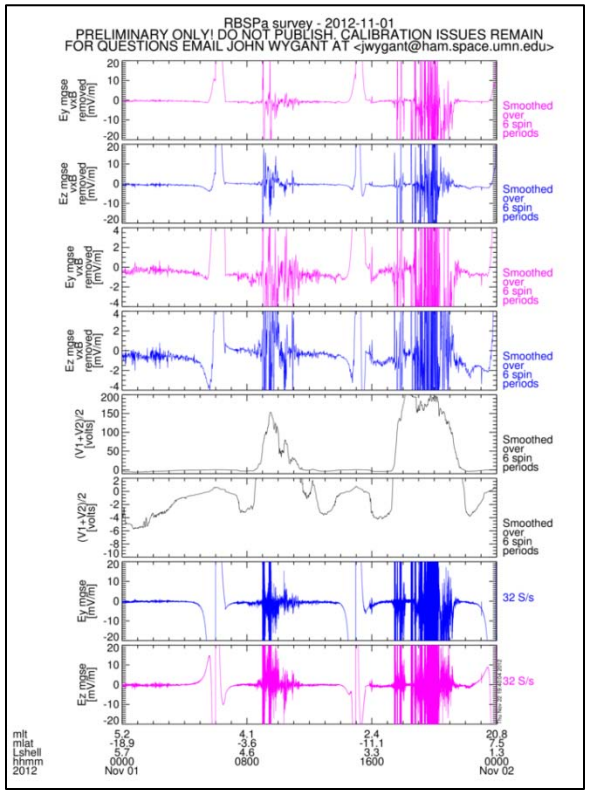
- **EFW QuickLook (QL) Summary Plots available via the following URL:**
  - http://tetra.space.umn.edu/rbsp/survey/

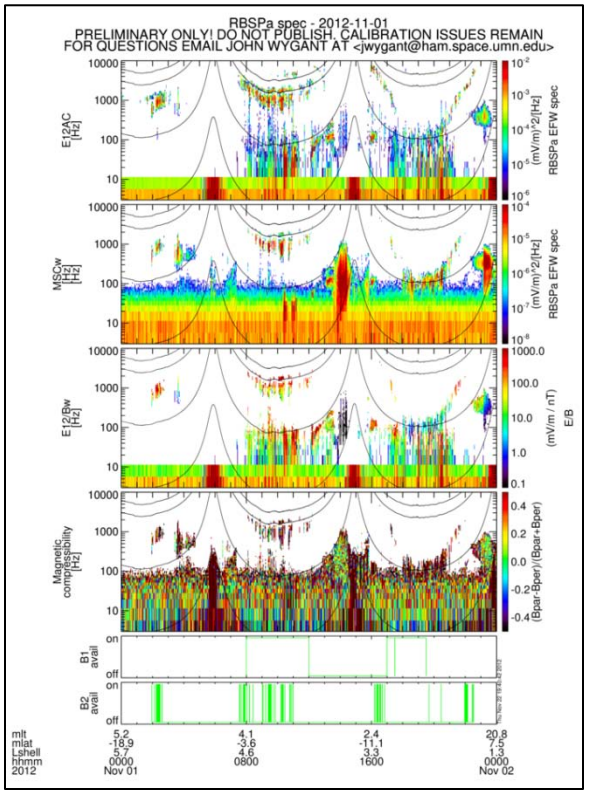
- **Caveats:**
  - The QL Summary plots represent PRELIMINARY L2 data products.
  - The data depicted in the plots may contain known and unknown systematic errors which include: saturation during charging events or eclipse; inappropriate sensor bias; spin phase errors during or around eclipse; offsets and scale factor errors due to variations in plasma conditions from nominal; etc.

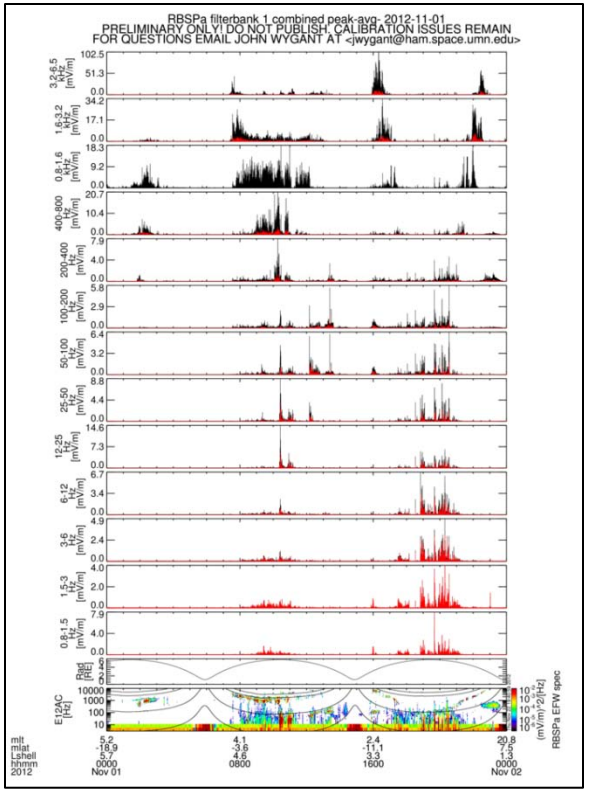
- **Suggested Rules of the Road for use of EFW QL Summary Plots:**
  - They should not be used in publications.
  - They should not be used in talks or other presentations until vetted by the EFW PI (John Wygant, jwygant@fields.space.umn.edu) or his designate.
  - It is suggested that one contact the EFW PI prior to starting any significant analysis utilizing the QL Summary Plots so that the data can be vetted, and one can collaborate with any members of the EFW team that are working along the same or similar lines of investigation.
  - It is also suggested that one acknowledge of the EFW PI (Wygant) in any talk or presentation that utilizes the QL Summary plots.

EFW QuickLook Summary Plots Examples

- **Live Demo Here… daily plot examples from RBSP-A, 1 Nov 2012:**

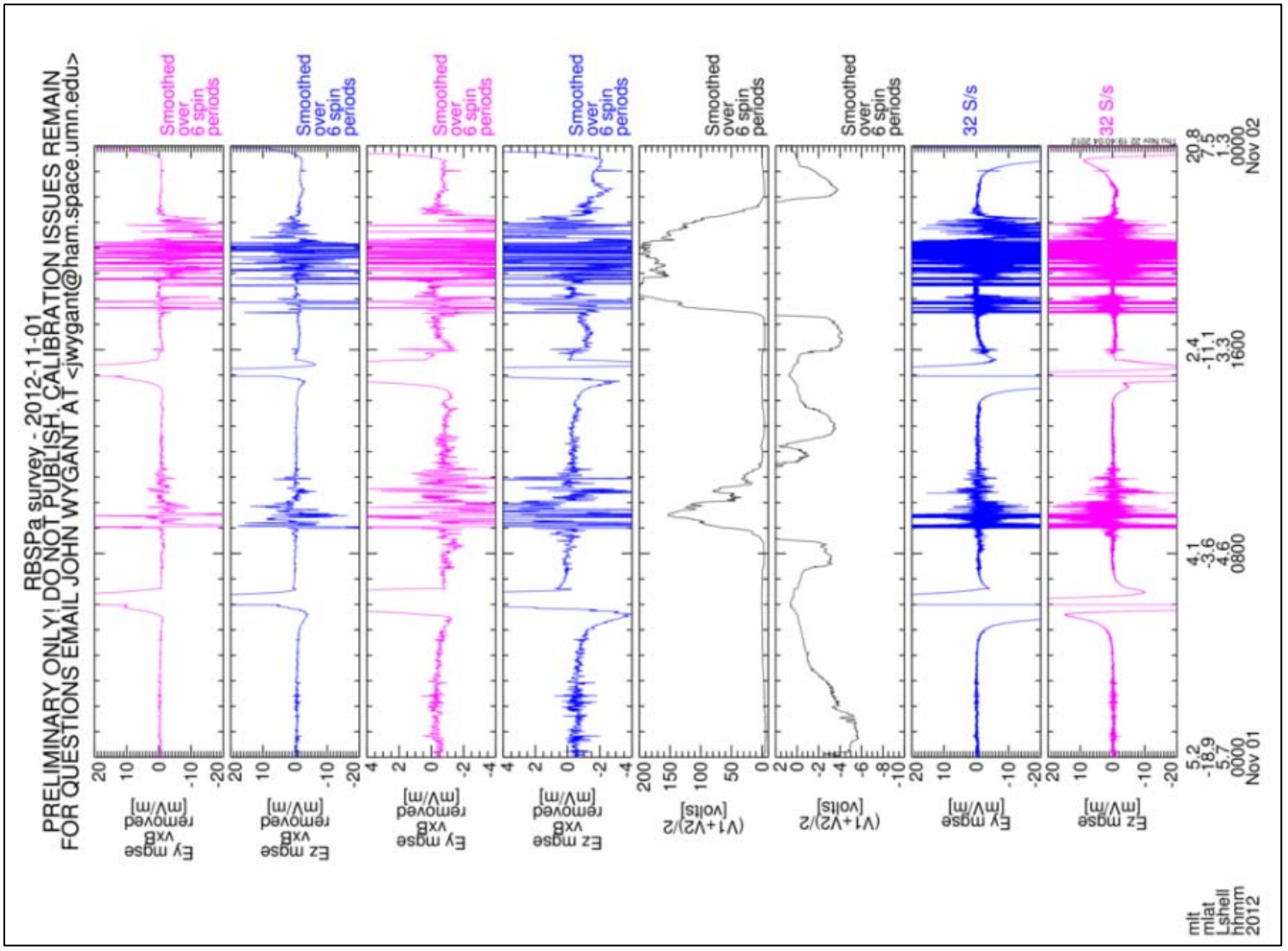






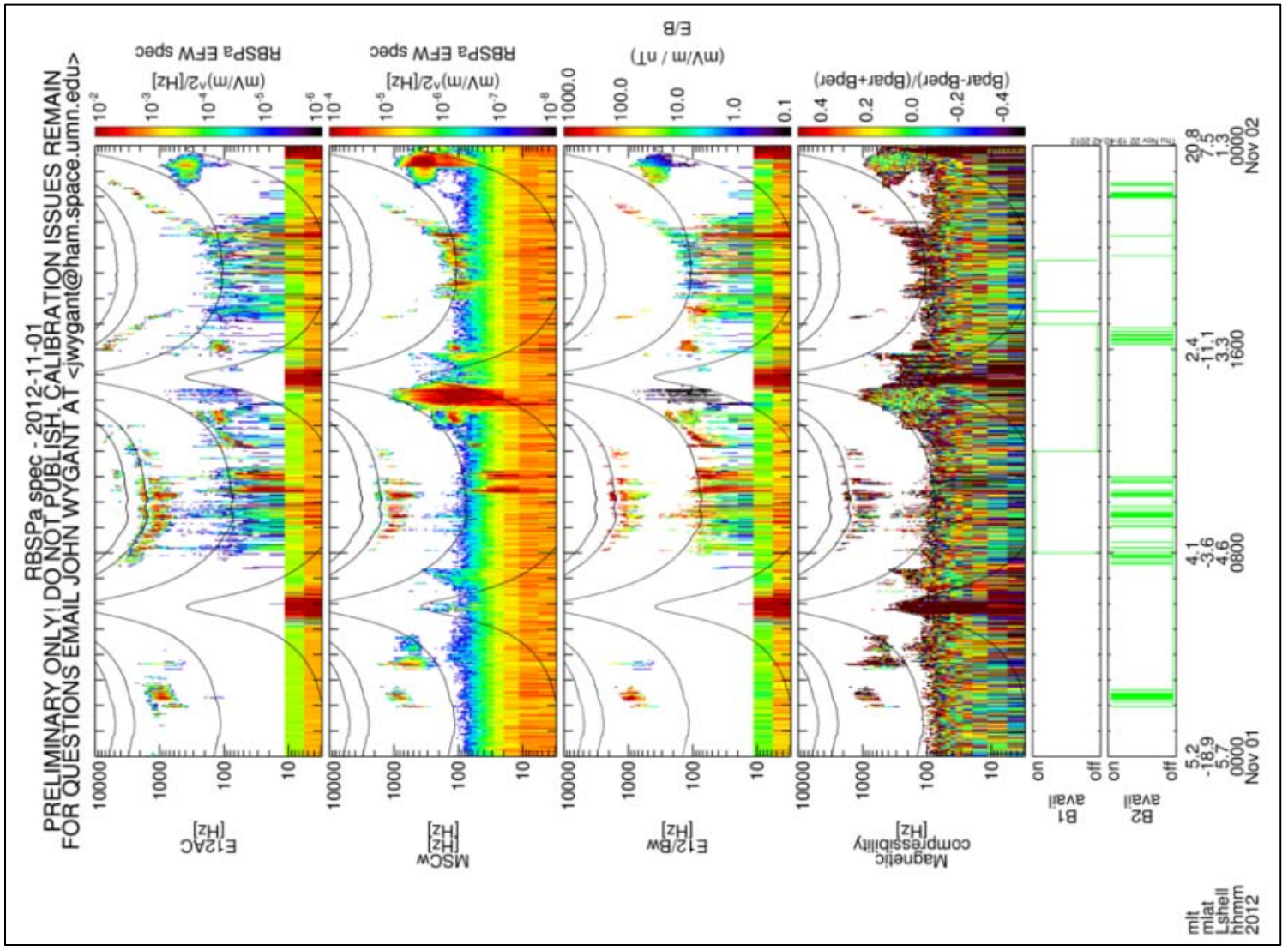
- **Features to come: zoomed time scales; orbit-by-orbit plots; more data quantities.**

EFW QuickLook Summary Plots
Example: Waveform E and Vsc



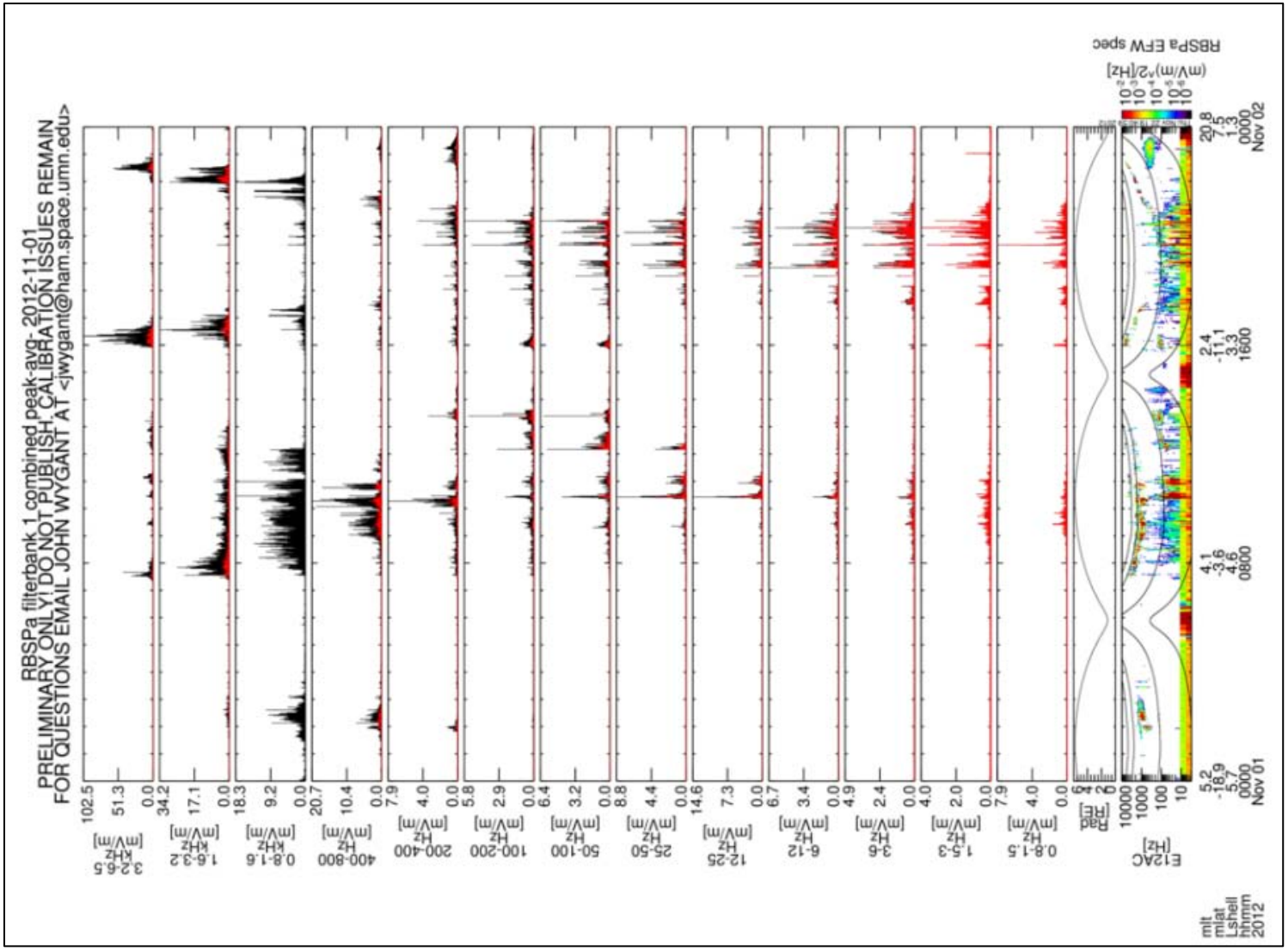
Bonnell et al., SM31C-2379, Fall 2012 AGU

EFW QuickLook Summary Plots
Example: SPEC data and B1/2 Availability



Bonnell et al., SM31C-2379, Fall 2012 AGU

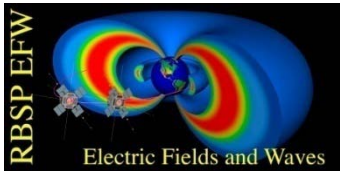
EFW QuickLook Summary Plots
Example: Filter Banks



EFW
Data Access

Direct From CDF	EFW/TDAS (IDL)	SDT
Roll your own browse or analysis access via L2 CDF data (Autoplot, etc.)	Direct access to calibrated L1+ CDF data in IDL environment.	Direct access to calibrated L1+ CDF data.

EFW via TDAS
Acquiring and Setting Up TDAS



- **Eventually (mid 2013), the EFW routines will be part of the normal TDAS distribution available via this URL: http://themis.ssl.berkeley.edu/software.shtml.**
- **Now, the EFW package is available via the latest "bleeding edge" TDAS software release via this URL: http://themis/ssl.berkeley.edu/socware/bleeding_edge/thmsw_latest.zip.**
- **CAVEAT: Bleeding edge is a nightly build, and has not been fully QA tested. There will be bugs and feature changes over time.**

- **TDAS is a package built to run in IDL; it is tested against IDL 6.4-7.1, and makes extensive use of the TPLOT libraries in IDL developed and refined over many past missions (WIND, FAST, STEREO, Cluster, THEMIS/ARTEMIS, etc.). TDAS team actively working on support under 8.x, but buggy IDL 8.0, 8.1 versions have hampered this.**

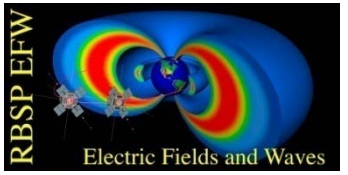
- **To support the TDAS and EFW packages, patches a/o supporting libraries (dlm/dll or .so) for CDF, SPICE and GEOPACK are required:**
  - http://cdf.gsfc.nasa.gov/
  - http://naif.jpl.nasa.gov/naif/toolkit_IDL.html
  - http://dysprosium.jhuapl.edu/idl_geopack/ or http://themis.ssl.berkeley.edu/beta/software.shtml.

- **The process required to add the SPICE and GEOPACK support is described in README.txt files in the "external/IDL_GEOPACK" and "external/IDL_ICY" directories of the TDAS distribution, copies of which are included in the Backup Slides to this presentation.**

- **Initial contact points for issues/questions:**
  - TDAS: Lewis (jwl@ssl.berkeley.edu).
  - EFW TDAS: Bonnell (jbonnell@ssl.berkeley.edu), Schroeder (peters@ssl.berkeley.edu).

- **Acknowledgments to TDAS development team for support and guidance:**
  - **UCB: D King (ret), J Lewis, J McTiernan, B Sadeghi.**
  - **UCLA: P. Cruce, C. Russell, A. Flores, L. Philpott, V Angelopoulos.**

EFW via TDAS
Running TDAS



- **The relevant ISTP-Compliant CDFs are fetched from remote sites or from local directories (this demo uses pre-loaded data).**
- **The contents are converted to TPLOT variables, which can then be plotted on a common time axis, various plotting options manipulated, the time series waveforms or spectra extracted, manipulated, combined, and new TPLOT variables generated (this is how the preliminary L1->L2 processing is done for the QL Summary Plots, for example).**

EFW TDAS Data Access

Access Routine	Quantities Accessed	Analogous THEMIS Access Routine
RBSP_EFW_LOAD_WAVEFORM	E_SVY, V_SVY, MAG_SVY; EB1, VB1, MSCB1; EB2, VB2, MSCB2.	THM_LOAD_EFI
RBSP_EFW_LOAD_FBK	FBK.	THM_LOAD_FBK
RBSP_EFW_LOAD_SPEC	SPEC.	THM_LOAD_FFT
RBSP_EFW_LOAD_XSPEC	XSPEC.	n/a.
RBSP_EFW_LOAD_FIT	E, B Spin Fit.	THM_LOAD_FIT.
RBSP_EFW_LOAD_HSK	Housekeeping.	THM_LOAD_HSK (EFI only).
RBSP_EFW_LOAD_STATE	SPICE-based attitude and ephemerides (vehicle position and velocity)	THM_LOAD_STATE
RBSP_LOAD_EMFISIS	EMFISIS L2 MAG, WFR, and HFR data products.	THM_LOAD_FGM
RBSP_LOAD_{other instruments}	Public L2 data from other instruments (RBSPICE, HOPE, MagEIS, REPT, RPS) (not yet implemented)	

EFW Access via SDT

The EFW waveform data products and supporting data at L1 and greater can also be accessed and analyzed via the legacy analysis package Science Data Tool (SDT). SDT can be installed from the website:

http://sprg.ssl.berkeley.edu/~sdt/SdtReleases.html

Five platforms are currently supported:

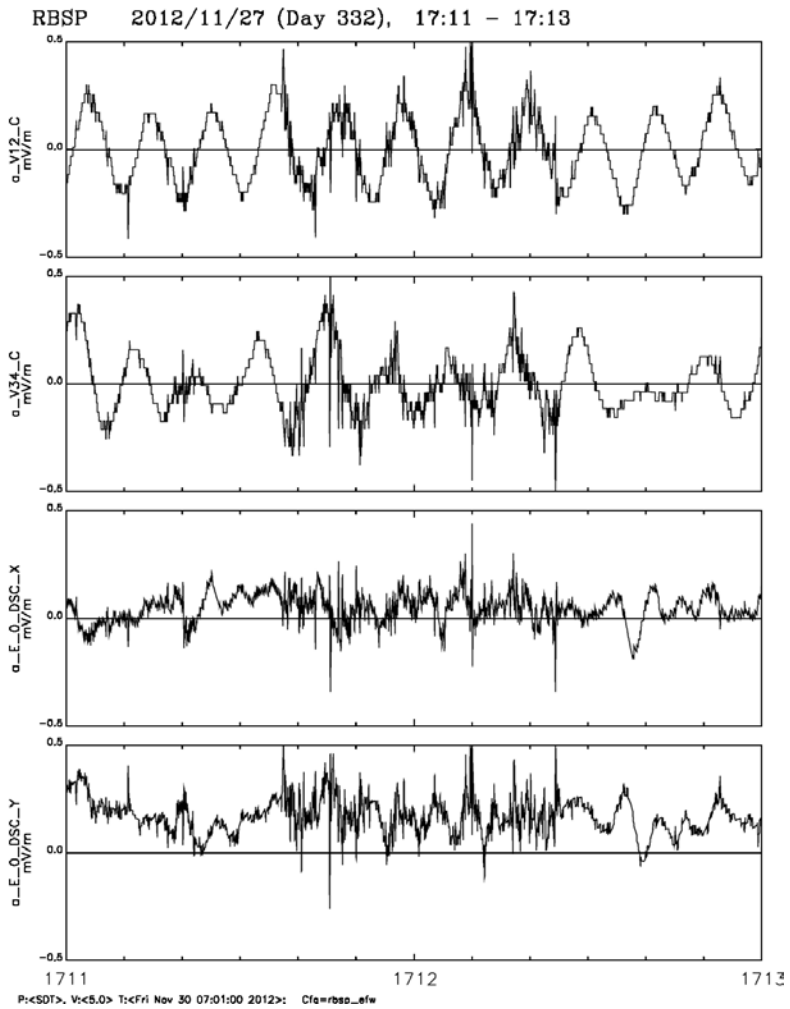
Solaris/SPARC; Linux, 32- and 64-bit); MacOSX, 32-bit (Leopard or above); MacOSX, 64-bit (Lion or above).

Corresponding to each platform is an "INSTRUCTIONS" guide on the webpage, which indicate how to install SDT and set up for various supported projects: FAST, POLAR-EFI, CLUSTER-EFW, THEMIS-EFI, RBSP-EFW. Once installed, instructions on how to get started using SDT are in the text document:

sdt_installation_directory/docs/SdtUse

Jack Vernetti (jackv@ssl.berkeley.edu) and Forrest Mozer (fmozer@ssl.berkeley.edu) are the primary points of contact for questions of SDT support and applications.

Example of SDT Analysis and Output



(analysis courtesy F. Mozer):

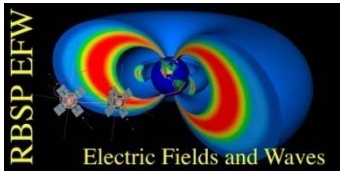
- Amplitude scale is 0.5 mV/m!
- Top two plots are raw electric field data showing quasi-sinusoidal variation due to rotation of sensors in the quasi-static external E-field.
- Fine steps in raw data are one bit steps of 16 bit A-D converter. From smoothness of the steps, there is no noise at this level.
- Bottom two plots are despun data. They show quasi-static fields and waves with amplitudes of ~0.1 mV/m.

What is M-GSE?

- **M-GSE stands for Modified GSE.**
- **It is a coordinate system tied to the nearly Sun-pointing attitude of the Van Allen Probes spacecraft that is nominally within 18 deg of the actual GSE coordinate system:**
  - **X_MGSE** is parallel to the spacecraft spin axis, **W**, which is within about 20 deg of **X_GSE**.
  - **Y_MGSE** is along –(**WxZ_GSE**), and points roughly duskward, close to **Y_GSE**.
  - **Z_MGSE** is along (**WxY_MGSE**), and points roughly ecliptic normal, close to **Z_GSE**.

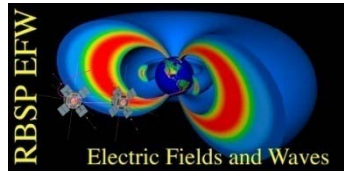
- **It is a useful intermediate coordinate system for the E-field data which only uses the spin plane (higher accuracy) E-field measurements.**

What are E, E_0 and E_dot0?



- **The generally poorer accuracy of the axial vs. radial E-field estimates from any double probe instrument has led to the development of several ways to generate a 3D vector E-field estimate for transformation from spacecraft to geophysically-relevant coordinate systems:**
  - "**E**": this version treats the radial and axial components of the E-field in the spacecraft frame on an equal footing, and coordinate system and frame (i.e.. **VxB** subtractions) are done using the axial component "as is".
  - "**E_0**": this version sets the axial component to zero in the spacecraft frame before applying and coordinate system or frame transformations. Comparison of it to the E and E_dot0 versions allows one to see what contribution the axial component has to the total vector E.
  - '**E_dot0**": this version sets the axial component to the value which makes **E**·**B** = 0 in the spacecraft frame, and allows one to estimate the total vector $\mathbf{E}_{perp}$ under the assumption that $\mathbf{E}_{para}$ = 0; note that this has the best accuracy when **B** is well away from the spin plane.
- **The EFW science software packages (TDAS and SDT) can generate these different versions on-the fly from L1 CDFs to allow one to compare and contrast and understand the quality of the vector E-field estimate.**
- **The L2 CDFs will contain despun E in all three versions, and at least the E_dot0 versions in relevant geophysical coordinates.**

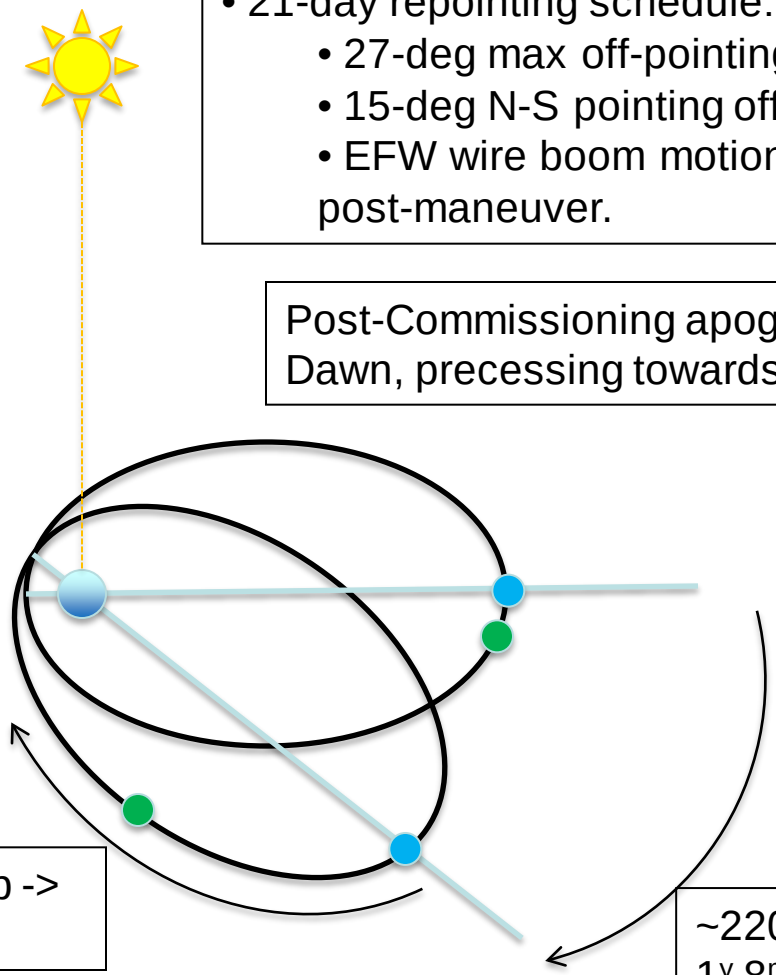
Mission Overview – Orbits and Attitude



- SC spin axis points near the Sun.
- 21-day repointing schedule:
  - 27-deg max off-pointing.
  - 15-deg N-S pointing offset.
  - EFW wire boom motion < 0.5-deg, post-maneuver.

Post-Commissioning apogee is near Dawn, precessing towards Midnight …

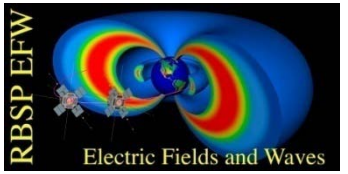
- ~ 600 km alt. perigee
- ~ 5.8 Re radius apogee
- ~ 9-hr period.
- 10-deg inclination (to equator)



~70 days/lap -> 5 laps/yr

~220 deg/yr -> $1^{y}\ 8^{m}$ precession

EFW Burst System Motivation



- **Why Burst?**
  - Past experience (rockets, Freja, FAST, Polar, Cluster, STEREO, THEMIS, etc.) shows that sporadic micro-scale events of short duration can have a significant impact on macro-scale physics of acceleration and scattering.
  - TM rates to ground do not support continuous high-rate TM, and so some form of burst collection, selection, and playback is required to support observation and characterization of such events.

- **What Instruments Can "Burst" on RBSP?**
  - EFW and EMFISIS:
    - high-rate waveforms (both).
    - On-board spectral products (EMFISIS).
  - ECT-HOPE (limited to variable energy sweep modes).

  - RBSP ≠ (Sounding Rocket, FAST):
    - Particle pitch angle imaging on spin period (12-s) time scales.
    - Multiple spins required for significant counts of higher energies.
    - Long delays (2-3 s each way) in on-board inter-instrument communication.

EFW Burst System Description

- **EFW supports two kinds of Burst waveform data:**
  - BURST1 (B1):
    - Medium-Rate (512-samp/s nominal) E, V, and MSC (searchcoil) waveforms.
    - Banked continuously into SDRAM and then into 32-Gbyte FLASH array.
    - ≈25-days storage under nominal configuration.
    - Allows for "person in the loop" selection of burst playback from ground.
    - Used already to support after-the-fact selection of data during storm/injection periods, HAARP conjunctions, instrument diagnostics, etc.

...	B1_00345	B1_00346	B1_00347	B1_00348	B1_00349	B1_00350	B1_00351	B1_00352	...
...	145	230	004	250	245	230	120	032	...
	playback			playback	playback	playback			

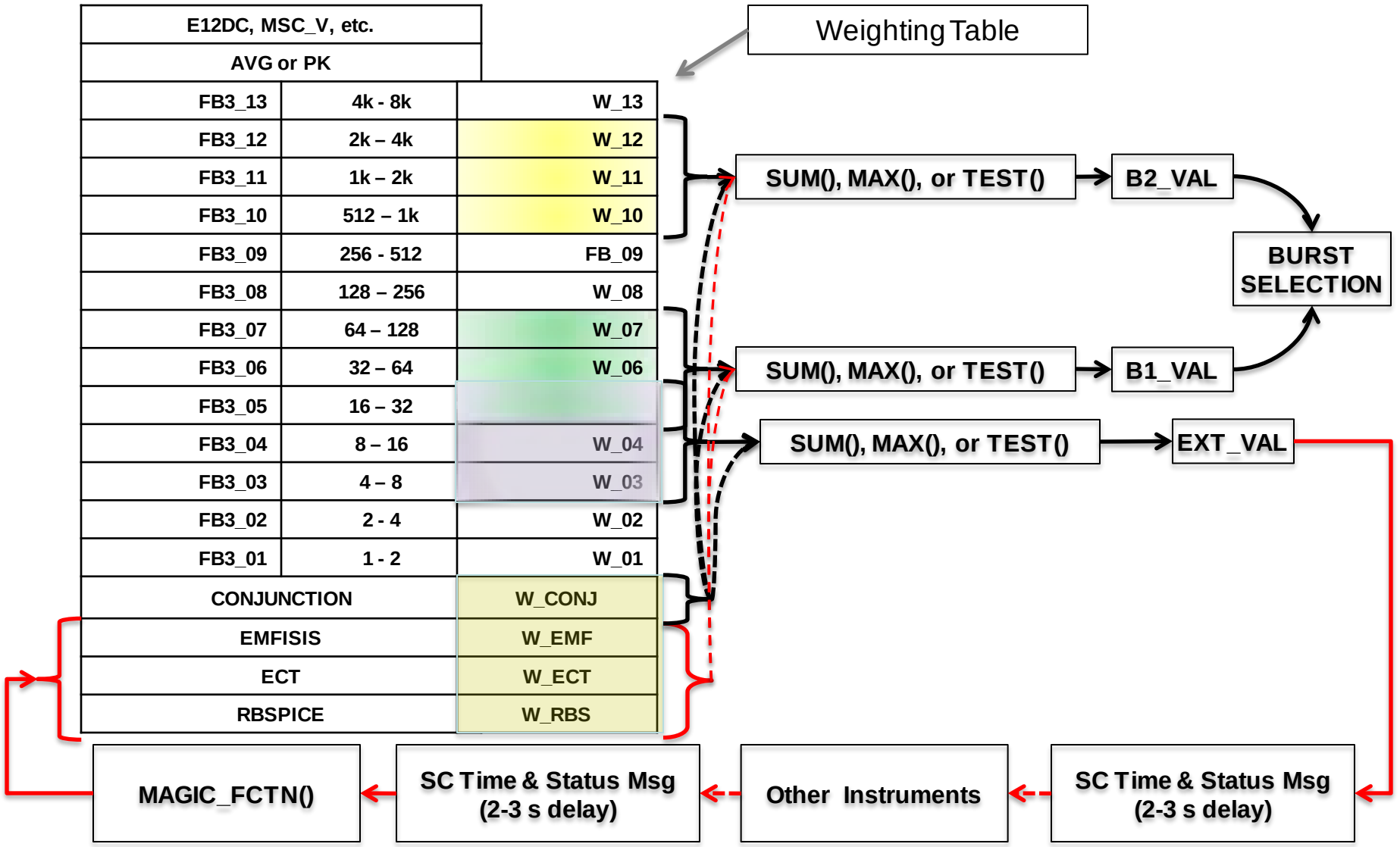
  - BURST2 (B2):
    - Higher-rate (16-ksamp/s nominal) V_AC waveforms (interferometric mode).
    - Collected continuously into commandable (128 nominal) number of B2 segments (few seconds each; many minutes total).
    - Survival and playback of B2 based on BURST QUALITY.
    - Segment write allows for "pre-/post-trigger" data collection:

B2_VAL	080

B2_014	128	pre	post

B2_032	103	pre	post

EFW Burst Valuation, aka. “Trigger Functions”



Bonnell et al., SM31C-2379, Fall 2012 AGU