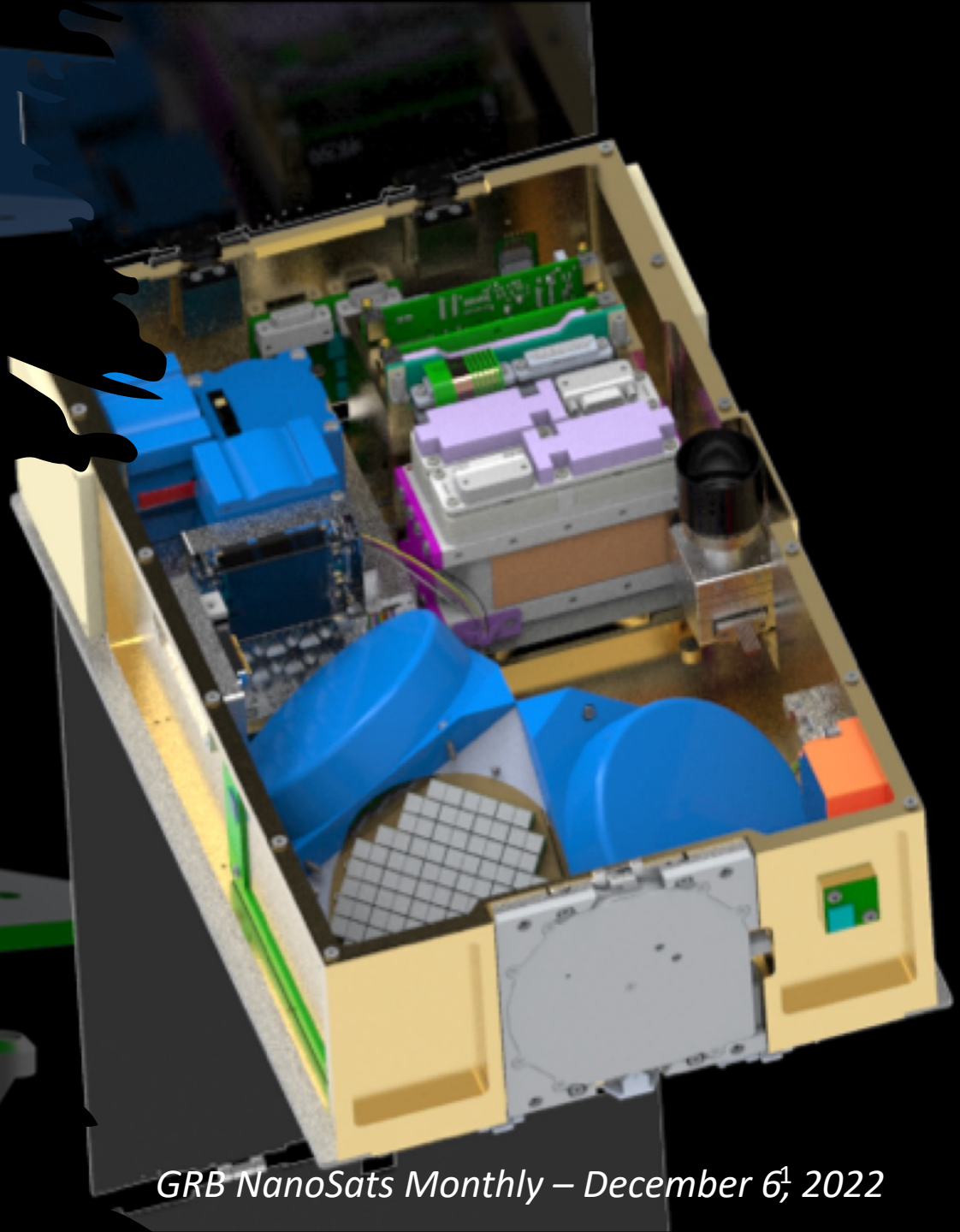
Data Formats and Archive

(BurstCube as an example for wide-field gamma-ray GRB NanoSats, and still in development)

Judy Racusin (NASA/GSFC)
on behalf of the
BurstCube Team



BurstCube Team

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Action Item from Brno Panel Discussion

Action 11 - Data formats and sharing (where (HEASARC/Zenodo) - keep formats as common as possible

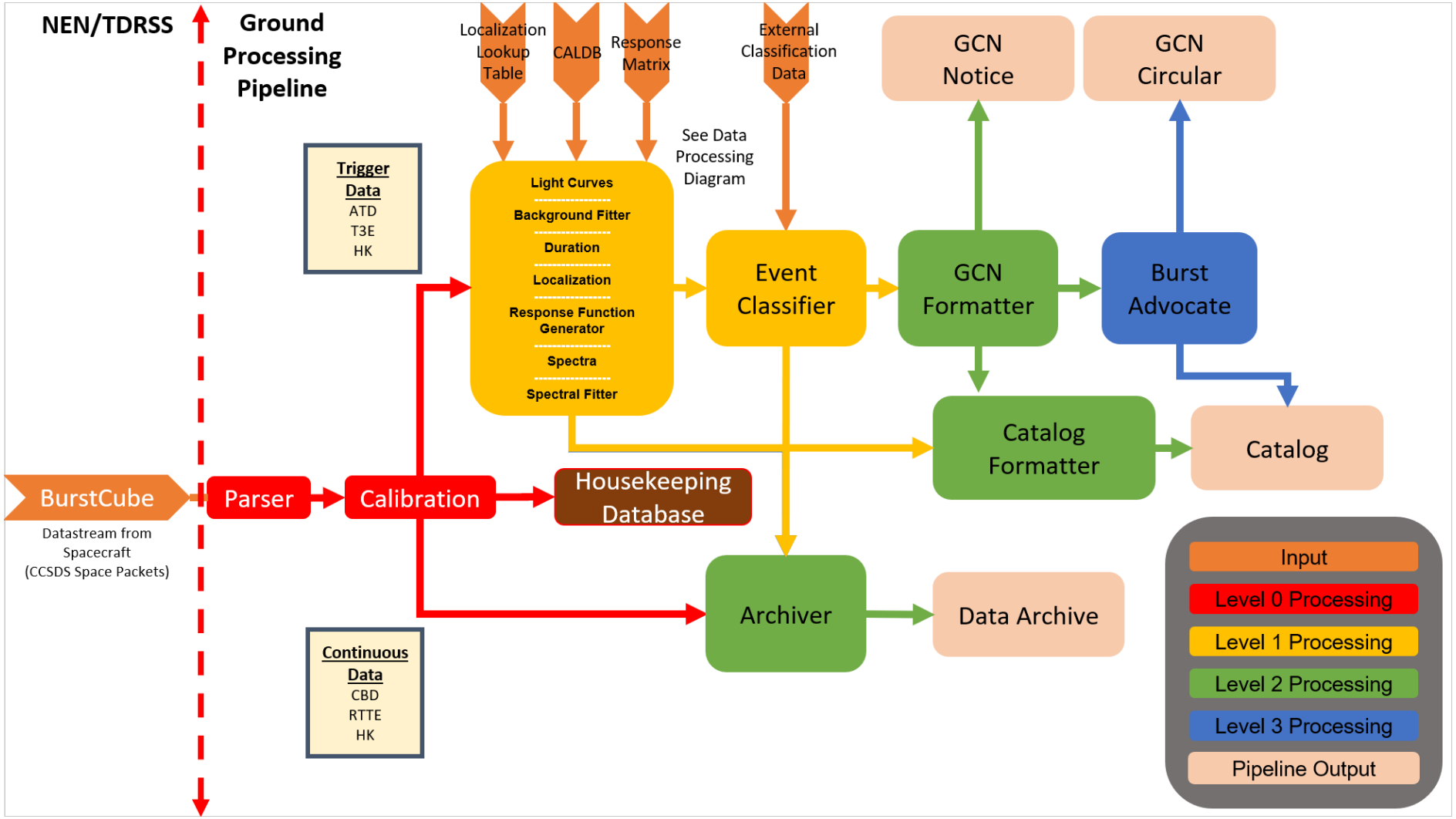
Why do we care about BurstCube-specific formats and archive?

- Maybe this will prevent your team from reinventing the wheel
- Uniformity in file formats will make it easier to reuse software and pipelines
- It'll be easier to combine datasets from different instruments for science analyses and joint localizations or sub-threshold searches

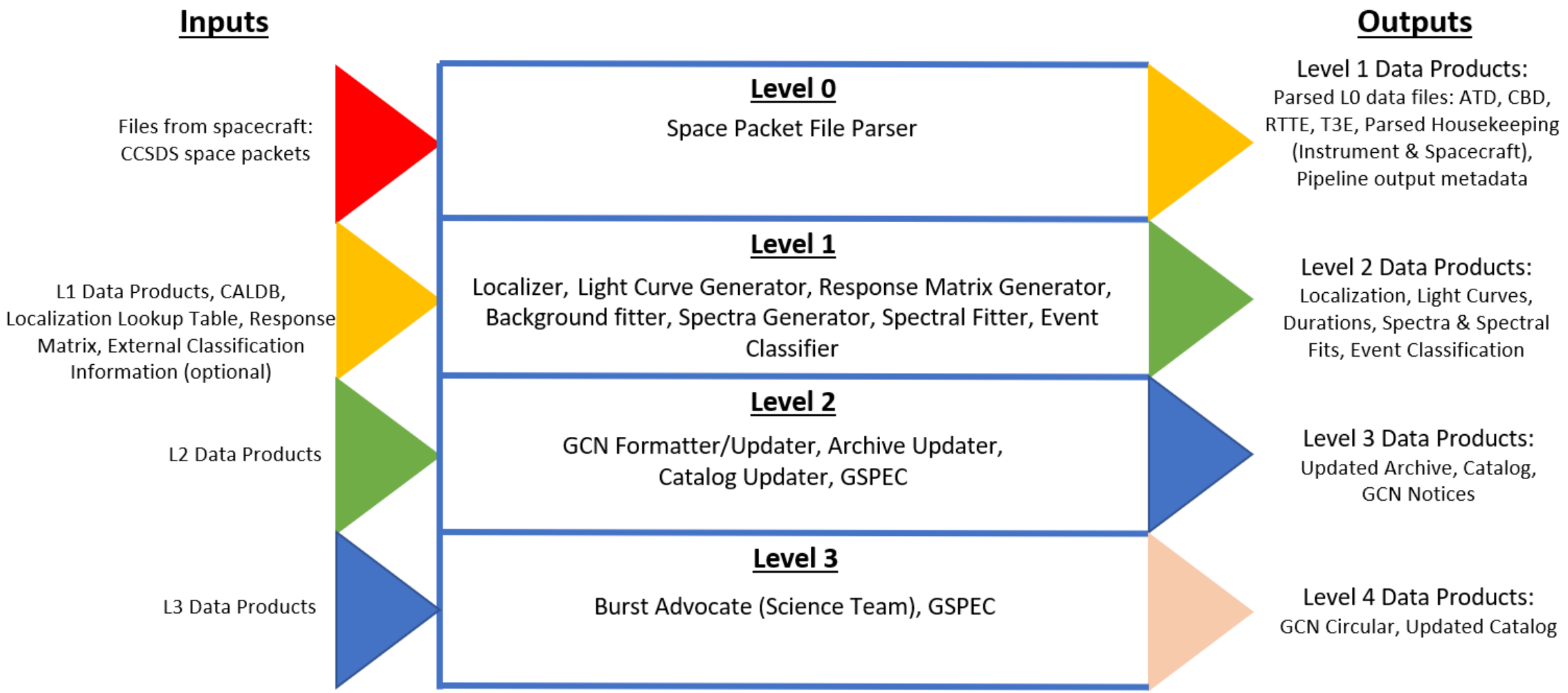
BurstCube-Specific Limitations/Restrictions

- HEASARC compliance (designed for pointed X-ray instruments)
  - FITS standards
  - CALDB
  - FTOOLs compatibility
  - https://heasarc.gsfc.nasa.gov/docs/heasarc/heasarc_req.html
- All data public immediately upon processing (except for most spacecraft housekeeping)
- Fast processing for generating GCN Notices
- Bandwidth
  - Direct to Earth (DTE): s-band, once daily pass, 2 Mbit/s
  - TDRSS (space network): s-band, as needed, 1 kbit/s

BurstCube Pipeline

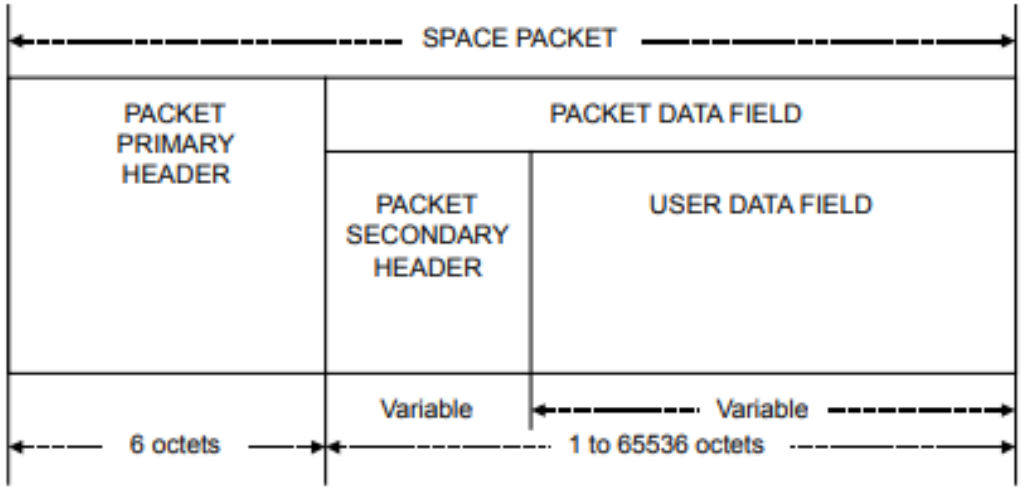


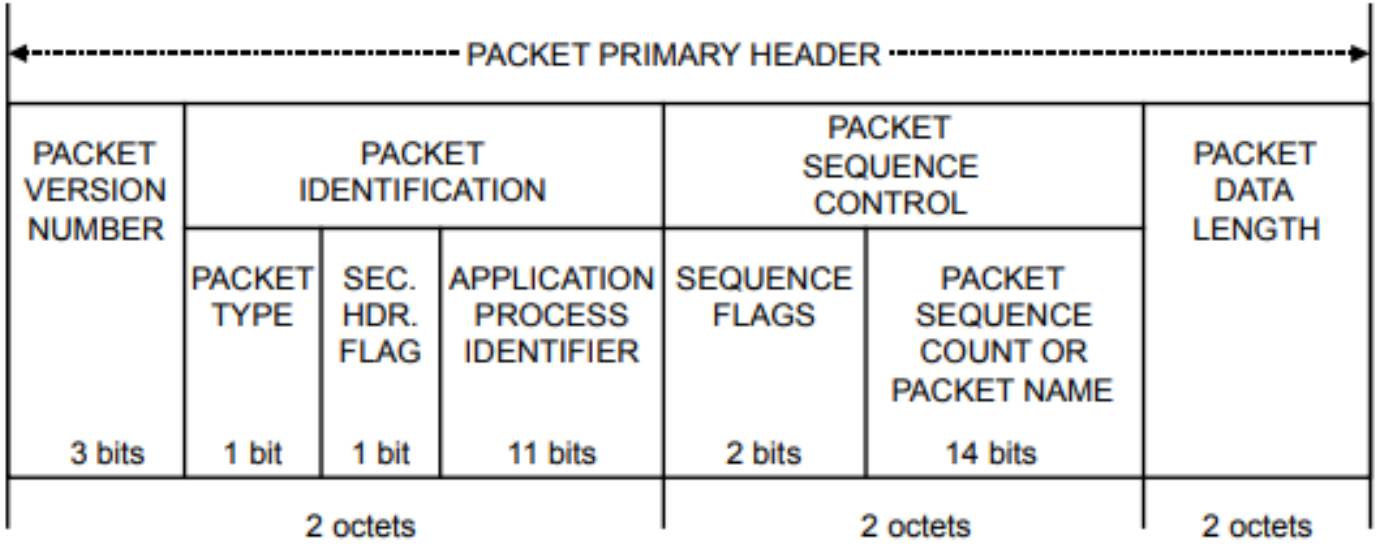
BurstCube Data Products



BurstCube Data Products (Level 0)

- Raw Space packets -> FITS
- Packet handling
  - packet sorting
  - gaps





https://public.ccsds.org/Pubs/133x0b2e1.pdf

BurstCube Data Products (Level 1)

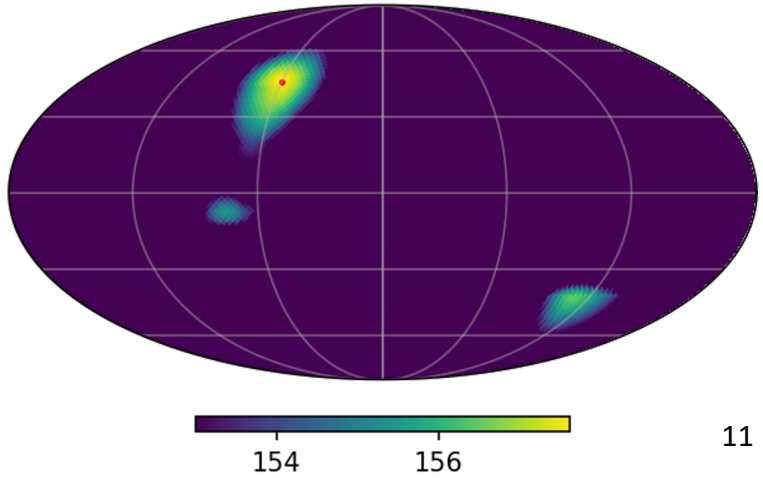
Datatype	Latency	Type	Energy Channels	Time Resolution	Time Coverage
Alert Trigger Data (ATD)	≲15 min	Trigger	16	50 ms to 2 s	-60 to +60 s
Triggered Time Tagged Event (T^3E)	≲1 day	Trigger	1024	10 µs	-30 to 100 s
Requested TTE (RTTE)	≲1 day	Requested	1024	10 µs	requested
Continuous Binned Data (CBD)	≲1 day	Continuous (excluding SAA)	16	256 ms	Continuous (excluding SAA)
Instrument Housekeeping (IHK)	≲1 day	housekeeping	N/A	1 s, 60 s	continuous
Orbit/Attitude Spacecraft Files	≲1 day	housekeeping	N/A	60 s	continuous

Requested Time Tagged Event Data (RTTE)

- Onboard buffer holds ~48 hours of TTE data
  - Passes insufficient to downlink all
  - Can downlink <1 hour/day
- Onboard file system setup such that we can downlink upon request
  - community request via a webform
  - requests generated via GCN Notices on detections by other instruments
- Prioritization based upon likelihood of subthreshold counterparts and astrophysical interestingness
- Window of data around time of interest will be downlinked at daily pass on a best effort basis
- Same format at T^3E

BurstCube Data Products (Level 2)

- Triggers Only
- Light Curves (FITS and images)
  - 1 file per detector
    - 50-100, 100-300, 300-1000 keV at 64 ms (TTE) and 1 s resolution (ATD + TTE)
  - 1 file with summed detectors
    - 50-100, 100-300, 300-1000 keV at 64 ms (TTE) and 1 s resolution (ATD + TTE)
- Spectra
  - source PHA2 files
  - response functions
  - background spectra
- Duration
  - Includes automated background estimation
  - Probability that a GRB is short or long
- Spectral Modeling
  - PL, CPL, Band, SBPL fits
- Localization
  - 2D image with WCS coordinates
  - Healpix probability map
  - image of localization map
- Trigger Classification
  - GCN Notice
  - Catalog



BurstCube Data Products (Level 3)

- GCN Notices
  - Standard parameters
    - trigger details (time, trig algorithm, timescale, etc.)
    - localization (RA/Dec circular approximation radius, HEALPIX map)
    - classification (GRB, solar flare, TGF, particles, galactic transient)
  - Automated analysis parameters
    - fluxes, fluences
    - spectral fits
- Trigger Catalog
  - summary of details in notices and more characterization (spectral fits, duration, etc.)
  - based upon Fermi-GBM trigger/GRB catalogs

BurstCube Data Products (Level 4)

- GCN Circulars
  - descriptions of triggers based upon data in notices
- Updated Catalog
  - From science team improved background and spectral fits

TITLE: GCN CIRCULAR
NUMBER: 40234
SUBJECT: GRB 231206A: BurstCube Detection
DATE: Judith Racusin at NASA/GSFC (judith.racusin@nasa.gov)

J. L. Racusin (NASA/GSFC) reports on behalf of the BurstCube Team:

At 22:09:04.72 UT on 6 December 2023, BurstCube triggered and located GRB 231206A (trigger 193492323/20231206923).

The on-ground calculated location, using the BurstCube trigger data is:

RA/Dec = 234.3, -47.3 (J2000)
with a circular equivalent statistical error of 10.4 deg (radius, 90% confidence).

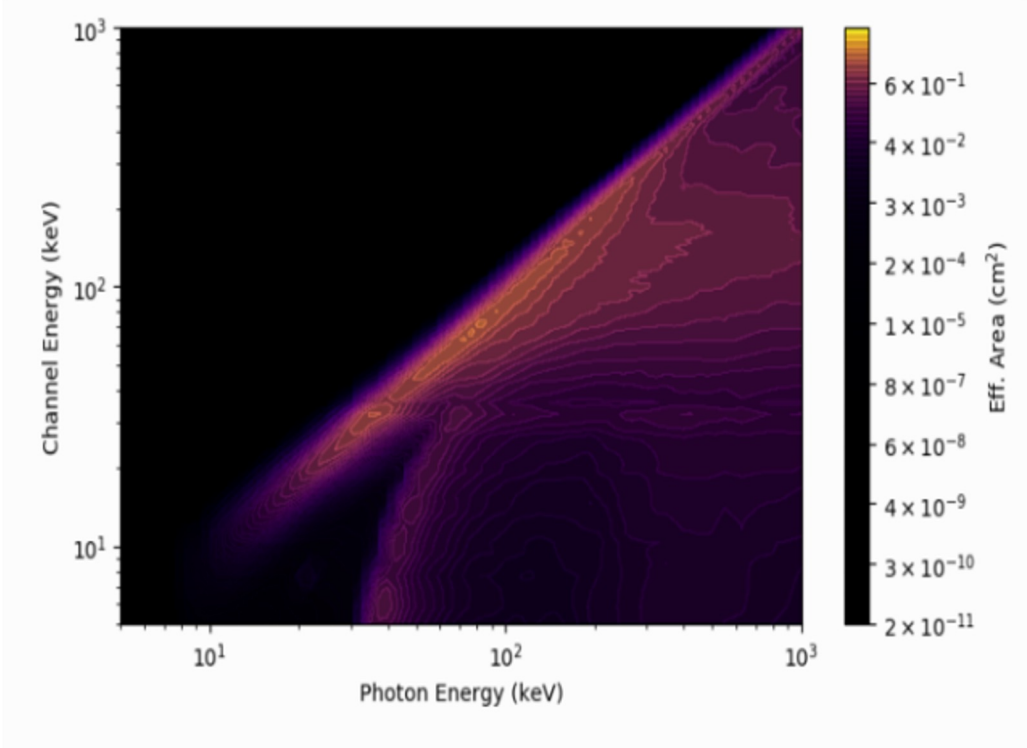
The skymap and HEALPix FITS file can be found here:
https://heasarc.gsfc.nasa.gov/FTP/burstcube/data/transient/2023/bn231206923/quicklook/bc231206923csa_atdloc.fits

The light curve can be found here:
https://heasarc.gsfc.nasa.gov/FTP/burstcube/data/transient/2023/bn231206923/quicklook/bc231206923csa_atdlc.fits

Totally made-up example based on GBM

Calibration Database (CALDB)

- Alignment file
  - describes detector orientations and relative coordinate systems
- SAA polygon definition
- Energy bounds
  - 16 energy channels (ATD, CBD)
  - 1024 energy channels (TTE)
- Full set of Response functions
  - 3072 per detector (NSIDE=16)
- Not actually used in analyses, but for reference



See also talks by Israel Martinez

/burstcube

/csa

/ bcf /…

/cpf /…

/index file1 file2

BurstCube Archive Structure

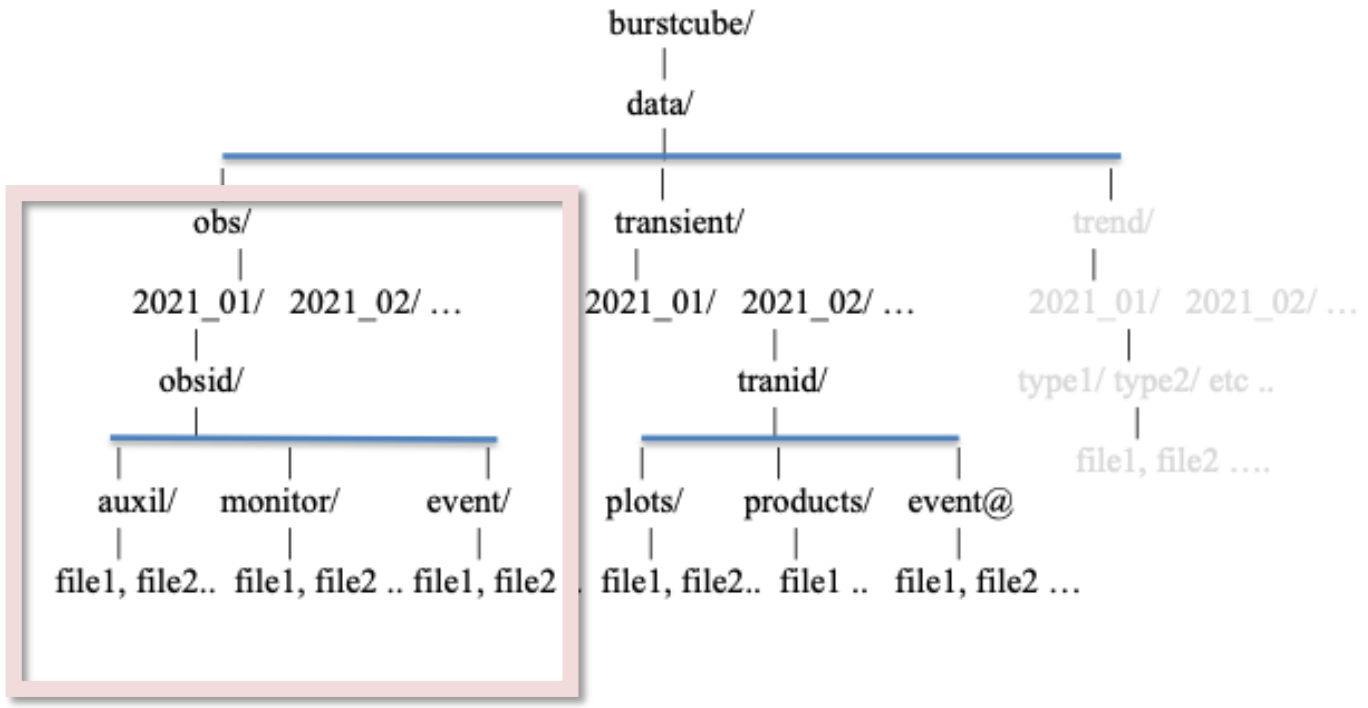
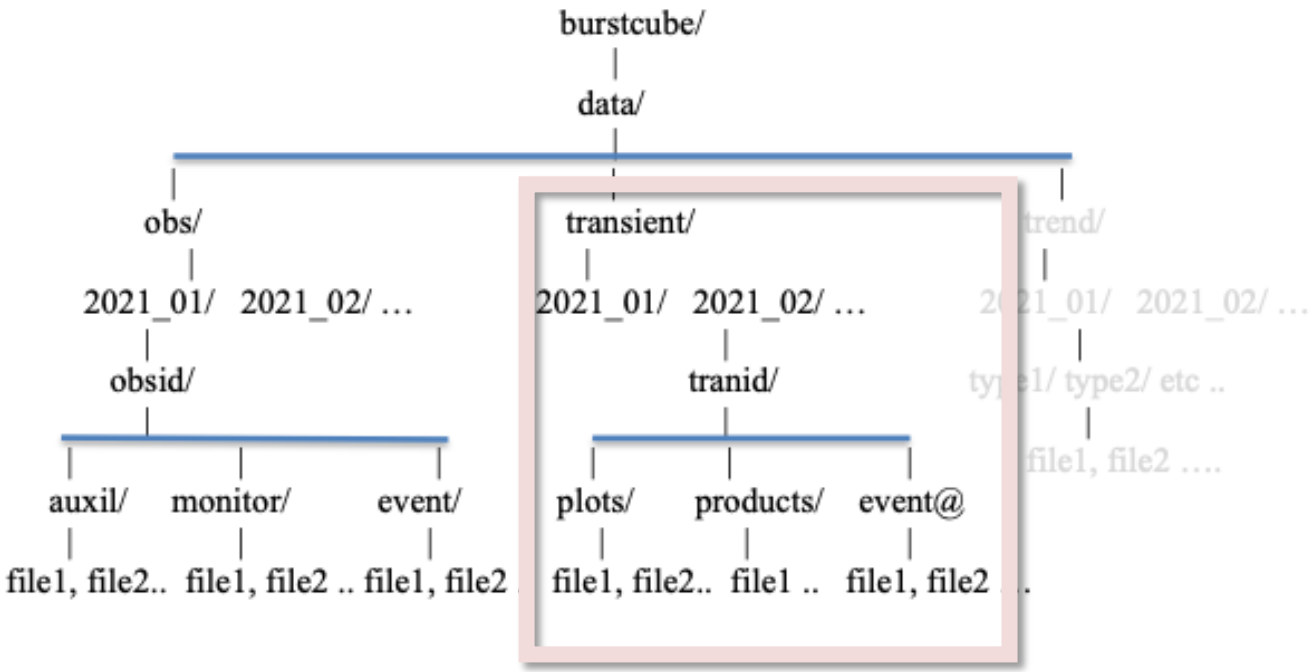


Table 3.4	
a)1st data set : daily observation data	
obs/	
Auxiliary filename	**Description**
auxil/	
bcYYMMDDcsa.hk	HK for the parameters of the detectors
bcYYMMDD.hk	HK for spacecraft including attitude and orbit
bcYYMMDD.cat	Catalog file
bcYYMMDD_joblog.html	Log file of the processing
Science Data	**Description**
monitor/	
bcYYMMDDcs0_Xcbd.fits	Binned 16 chan spectra NNN s detector CS0
bcYYMMDDcs1_Xcbd.fits	Binned 16 chan spectra NNN s detector CS1
bcYYMMDDcs2_Xcbd.fits	Binned 16 chan spectra NNN s detector CS2
bcYYMMDDcs3_Xcbd.fits	Binned 16 chan spectra NNN s detector CS3
	*NNN is one of the selectable integration time
events/	
bcYYMMDDcs0_ atdYYMMDDXXX.fits	Alert trigger cs0 YYMMDDXXX
bcYYMMDDcs1_ atdYYMMDDXXX.fits	Alert trigger cs1 YYMMDDXXX
bcYYMMDDcs2_ atdYYMMDDXXX.fits	Alert trigger cs2 YYMMDDXXX
bcYYMMDDcs3_ atdYYMMDDXXX.fits	Alert trigger cs3 tYYMMDDXXX
bcYYMMDDcs0_ tteYYMMDDXXX_uf.evt	T3E/RTTE det cs0 trig YYMMDDXXX
bcYYMMDDcs1_ tteYYMMDDXXX_uf.evt	T3E/RTTE det cs1 trig YYMMDDXXX
bcYYMMDDcs2_ tteYYMMDDXXX_uf.evt	T3E/RTTE det cs2 trig YYMMDDXXX
bcYYMMDDcs3_tteYYMMDDXXX_uf.evt	T3E/RTTE det cs3 trig YYMMDDXXX

BurstCube Archive Structure



b)2nd data set : transient data	
transient/	
Science Data	**Description**
products/	
bcYYMMDDXXXcs0_ttelc	Lighcurves several extensions per cs0
bcYYMMDDXXXcs1_tte.lc	Lighcurves several extensions per cs1
bcYYMMDDXXXcs2_tte.lc	Lighcurves several extensions per cs2
bcYYMMDDXXXcs3_tte.lc	Lighcurves several extensions per cs3
bcYYMMDDXXXcsa_tte.lc	Lighcurves several extensions per all csa
bcYYMMDDXXXcs0_tte.pha	PHA2 Spectra per cs0
bcYYMMDDXXXcs1_tte.pha	PHA2 Spectra per cs1
bcYYMMDDXXXcs2_tte.pha	PHA2 Spectra per cs2
bcYYMMDDXXXcs3_tte.pha	PHA2 spectra per cs3
bcYYMMDDXXXcs0_bg.pha	Background spectrum for cs0
bcYYMMDDXXXcs1_bg.pha	Background spectrum for cs1
bcYYMMDDXXXcs2_bg.pha	Background spectrum for cs2
bcYYMMDDXXXcs3_bg.pha	Background spectrum for cs3
bcYYMMDDXXXcs0.rsp	Response per cs0
bcYYMMDDXXXcs1.rsp	Response per cs1
bcYYMMDDXXXcs2.rsp	Response per cs2
bcYYMMDDXXXcs3.rsp	Response per cs3
bcYYMMDDXXXcsa.fits	Localization for the trigger YYMMDDXXX: 2d image primary plus keywords for trigger information, healpix representation in 1st extension
bcYYMMDDXXX.cat	Catalog file
bcYYMMDDXXX_joblog.html	Log file of the processing
plot/	
bcYYMMDDXXXcs0_atdlc.gif [png]	Plot lightcurve cs0
bcYYMMDDXXXcs1_atdlc. gif [png]	Plot lightcurve cs1
bcYYMMDDXXXcs2_atdlc. gif [png]	Plot lightcurve cs2
bcYYMMDDXXXcs3_atdlc. gif [png]	Plot lightcurve cs3
bcYYMMDDXXXcs0_atdpha. gif [png]	Plot spectra cs0
bcYYMMDDXXXcs1_atdpha. gif [png]	Plot spectra cs1
bcYYMMDDXXXcs2_atdpha. gif [png]	Plot spectra cs2
bcYYMMDDXXXcs3_atdpha. gif [png]	Plot spectra cs3
bcYYMMDDXXXcs0_ttelc.gif [png]	Plot lightcurve cs0
bcYYMMDDXXXcs1_ttelc. gif [png]	Plot lightcurve cs1
bcYYMMDDXXXcs2_ttelc. gif [png]	Plot lightcurve cs2
bcYYMMDDXXXcs3_ttelc. gif [png]	Plot lightcurve cs3
bcYYMMDDXXXcs0_ttepha. gif [png]	Plot spectra cs0
bcYYMMDDXXXcs1_ttepha. gif [png]	Plot spectra cs1
bcYYMMDDXXXcs2_ttepha. gif [png]	Plot spectra cs2
bcYYMMDDXXXcs3_ttepha. gif [png]	Plot spectra cs3
bcYYMMDDXXXcsa. gif [png]	Plot image of the localization

What are practical archive solutions for other missions?

- HEASARC does host some non-NASA missions
  - Significant cost/effort in implementation
  - Community familiarity with interfaces
  - Easy access to data products and tools
- Common formats make that easier
  - compatibility with analysis tools even better
- Public data has lots of benefits, but requires community support, which is difficult for small missions
- Public alerts for transient missions are even more important
- Long-term archive adds to scientific output of missions

Data Analysis Tools

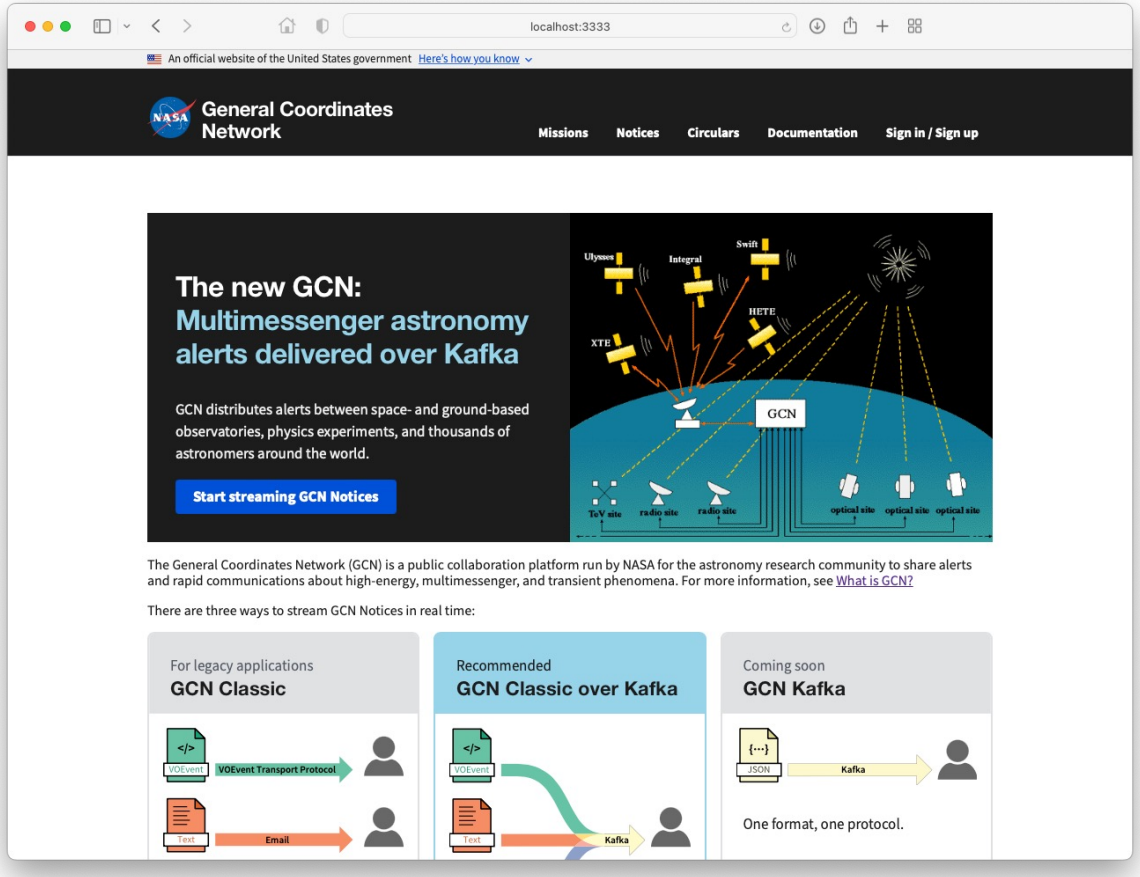
- GBM Data Tools
  - Fermi-GBM python analysis package
    - https://fermi.gsfc.nasa.gov/ssc/data/analysis/gbm/gbm_data_tools/gdt-docs/index.html
- bc-tools
  - BurstCube specific tools built upon GBM Data Tools
  - https://gitlab.com/burstcube/bc-tools/
  - Towards an effort to make detector-agnostic programming interface for count-based gamma-ray instruments

GCN Modernization on behalf of GCN Team:

- General Coordinates Network (https://gcn.nasa.gov)
- Phasing out legacy GCN system (GCN Classic) over next couple of years

Why switch to the new GCN?

	GCN Classic	GCN Classic over Kafka
Self-service	**NO.** Users need to contact administrator in order to make account and subscription changes	**YES.** Manage your own account and subscription settings through the web site
Open standards	**NO.** Notices are sent using three custom protocols	**YES.** Notices are sent using one standard protocol, Apache Kafka
Open source	**NO.** Custom software needed to receive notices	**YES.** Receive notices using open-source software
Highly available	**NO.** Notices are broadcast by a single server	**YES.** Notices are broadcast by a cluster of highly-available Kafka brokers in the cloud
Secure	**NO.** Notices are sent as plaintext	**YES.** Notices are protected with SSL/TLS



New GCN web portal

GCN Notices

- Producer Instruments
  - All new notice types will go thru the new GCN not legacy system (GCN Classic)
  - Unifying schema between instruments (as much as possible) - available soon
- Consumers – Switch now!
  - Self-managed GCN Notice subscriptions via email
  - Self-managed GCN Notices over Kafka (replaces socket & VOEvent transport protocol)
  - Still available in all 3 legacy formats (text, 160-byte binary, VOEvent)
- More Details
  - https://nasa-gcn.github.io/gcn-presentation/

GCN Circulars (Coming Soon)

- Modernization of GCN Circulars
  - Self-service subscription management
  - Self-service submitter registration using peer endorsement system
    - automatic onboarding of existing subscribers and submitters
  - Webform submission with Astro-flavored Markdown (email submission still accepted)
    - Correct handling of Unicode
    - Contextual parsing of links
- Migrate archive
- Smooth transition of subscribers
- Future enhancements
  - Automatically minted DOIs and BiBTeX entries
  - Link ORCIDs to GCN Circulars
  - Filtering by source type
  - Erratum