# Decommutation and Processing of Particle Measurements

- On board collection and processing (particles only)
  - Collection of counts, count rate
  - Sectoring, Angle maps, Square-root compression
  - Burst strategy and compression by averaging in energy/angle
  - Compression by moment and pitch angle spectra computation
  - Corrections (scpot) and pitfalls (cold ions, sun/moon/neutrals)
- Transmission (all products)
  - Packets, headers, time series compression, lossy compression
  - Encoding (CCSDS, Viderbi, convolutional)
  - Ground decommutation and processing
- Ground processing (particles only)
  - Loading and viewing on-board data
  - Higher level products and visualization
  - Corrections and pitfalls
- Examples
  - Potential subtraction, Cold plasma detection, Magnetopause sounding

http://www.igpp.ucla.edu/public/vassilis/ESS265/20080428

# Further reading
## (in class web site unless otherwise specified)

- Curtis et al., On board analysis techniques for space plasma particle instruments, Rev. Sci. Instrum., 60, 372, 1989.
- Abiad, R., The ESA and SST (ETC) board requirements specification, 2005. thm_sys_105a_etc_req.1.7.pdf
- Carlson, C. W., The square-root compression algorithm, 1993. FAST_ESA_SQRT_compression.doc
- Fast-Floating Point:
  - Description: thm_fsw_221_Floating_Point.doc (by Harvey, P. R.)
  - Converter: thm_fsw_221_ffp.xls (by Harvey, P. R.)
- Huffman, Differencing in:
  - thm_fsw_900_Compression_Options.doc; thm_fsw_901A_Compression_Huffman.doc
- THEMIS analysis software
  - User's Guide: ftp://apollo.ssl.berkeley.edu/pub/THEMIS/3%20Ground%20Systems/3.2%20Science%20Operations/Science%20Operations%20Documents/Software%20Users%20Guides/THEMIS_Science_Data_Analysis_Software_Users_Guide.pdf
  - GEM'07 Tutorial: ftp://apollo.ssl.berkeley.edu/pub/THEMIS/3%20Ground%20Systems/3.2%20Science%20Operations/Science%20Operations%20Documents/Science%20Software%20Data%20Analysis%20Software%20Presentation%20-%20GEM%20Dec%202007/Themis_Science_Software_Demo_Software_GEM_Dec_2007_Rev%20A.ppt

# On board collection/processing

- Collection of counts, count rates
- Sectoring, Angle maps, Square-root compression
  - See modes, energy, sector maps in:
    - class_materials/energy_angle_maps/etcmap_*.xls
- Burst strategy and compression by averaging in energy/angle
- Compression by moment and pitch angle spectra computation
  - See: Curtis et al. Rev. Sci. Instr. And
  - Abiad, technical memo: thm_sys_105a_etc_req1.7.pdf
- Corrections (scpot) and pitfalls (cold ions, sun/moon/neutrals)

# Transmission

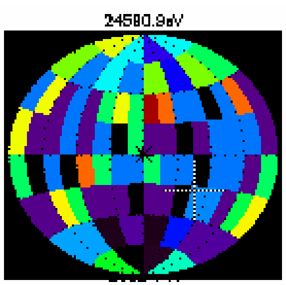
- Packets, headers, time series compression, lossy compression
- Encoding (CCSDS, Viterbi, convolutional)
- On-board data: Ground decommutation and processing
  - Moments
    - L0 (.pkt) and L1 (.cdf) contain same (raw) data in DSL coordinates
    - L2 (.cdf) contain calibrated data in other coordinates (GSE, GSM)
  - Particle distributions
    - L0 packet files
      - Raw, sqrt-compressed counts (efficient for loading)
      - Files organized by APID, but transparent to user
    - L1 CDF files
      - Raw, uncompressed counts
      - All quantities in one file
    - L2 CDF files
      - Omni-directional spectra (will eventually contain DF’s)
      - Derived, ground-processed moments in useful coordinates

# Ground processing (particles only)

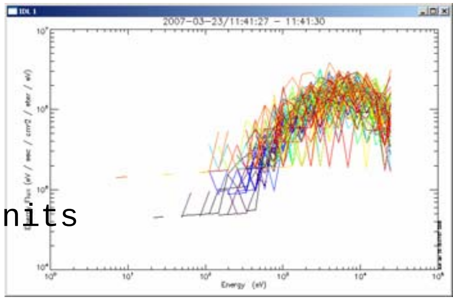
- Loading and viewing on-board processed data
  - There is a single routine for loading on-board moments
    - thm_load_mom, level=1 (loads L1 or L2 data)
      - Products introduced (in either case)
        - » 1 thb_p[e,s,t][i,e]m_density x 6
        - » 2 thb_peim_flux (particle flux in #/cm$^2$/s)
        - » 3 thb_peim_mftens (momentum flux in eV/ cm$^3$)
        - » 4 thb_peim_eflux (particle flux in #/cm$^2$/s)
        - » 5 thb_peim_velocity (km/s)
        - » 6 thb_peim_ptens (eV/cm$^3$)
        - » 7 thb_peim_ptot (trace of pressure tensor)
        - » …
        - » 43 thb_pxxm_pot (probe potential subtracted, in Volts)
        - » 44 thb_pxxm_qf
        - » 45 thb_pxxm_shft
      - Note: [e,s,t] correspond to ESA, SST, Total; [i,e] to ions, electrons
      - E.g., thb_ptim_velocity is the total velocity from the ESA and SST combined
  - There are two routines for introducing ESA distributions
    - thm_load_esa_pkt (loads L0 data)
    - thm_load_esa, level=… (loads L1 and L2 data, will become prime in future)
  - There is a single routine for introducing SST distributions
    - thm_load_sst (loads SST L1 data)

# Ground processing (particles only)

- Loading and viewing on-board processed data
  - There is a single routine for loading on-board moments
    - thm_load_mom, level=1 (loads L1 or L2 data)
  - There are two routines for introducing ESA distributions
    - thm_load_esa_pkt (loads all L0 data, introduces spectra)
      - Products introduced (12 total): omnidirectional spectra
        - » 46 thb_pe[i,e][r,f,b]_en_counts x 6 (spectra)
        - » 47 thb_pe [i,e][r,f,b]_mode x 6 (energy/angle modes)
      - Note: [i,e] is ions, electrons; [r,f,b] is reduced, full, burst mode
    - thm_load_esa, level=… (now loads L2 spectra, in the future L1 data as well)
  - There is a single routine for introducing SST distributions
    - thm_load_sst (loads SST L1 data)
  - Generic routines
    - To "get" any distribution function type:




```
» dat=thm_part_dist('thb_peif',gettime(/c))
» ;or: ctime,t & dat=thm_part_dist('thb_peif',t)
» ;or: ctime,t & dat=get_tha_peif(t)
» wset,1 & spec3d,dat
» wset,2 & plot3d,dat,units='counts' ; convert units
» ; other types: eflux,flux,df,rate
```



- To obtain moments type (e.g. n, v, t):
  - » thm_part_spec_calc,probe='b',moments=['density','flux'],instrument=['peif','psif']
- Unit Conversions:
  - To copy/convert to/from units (eflux,flux,df,counts,rate), use function conv_units:
    - » `dat_new=conv_units(dat,'df')`

# Ground processing (particles only)

- Loading and viewing on-board processed data
  - There is a single routine for loading on-board moments: thm_load_mom, level=1
  - There is a main routine for introducing ESA distributions: thm_load_esa_pkt
  - There is a single routine for introducing SST distributions: thm_load_sst
  - Generic routines
    - To "view" distribution function contents type:
      - » dat=thm_part_dist('thb_peif',gettime(/c))
      - » help, dat, /str
      - » print, dat.energy, dat.theta, dat.phi ; to view energy/angle bin centers

```
** Structure &lt;13c28790&gt;, 35 tags, length=140952, ….:
  PROJECT_NAME    STRING    'THEMIS'
  SPACECRAFT      STRING    'b'
  DATA_NAME       STRING    'IESA 3D Full'
  APID            INT            454
  UNITS_NAME      STRING    'counts'
  UNITS_PROCEDURE STRING    'thm_convert_esa_units'
  VALID           BYTE        1
  TIME            DOUBLE      1.1746494e+009 ; seconds since 1970
  DELTA_T         DOUBLE           3.0899630
  INTEG_T         DOUBLE       0.0030175420
  DT_ARR          FLOAT     Array[32, 88]
  CONFIG1         BYTE         2
  CONFIG2         BYTE         1
  AN_IND          INT            1
  EN_IND          INT            1
  MODE            INT            2
  NENERGY         INT            32
  ENERGY          FLOAT     Array[32, 88]
  DENERGY         FLOAT     Array[32, 88]
  EFF             DOUBLE    Array[32, 88]
  BINS            INT       Array[32, 88]
  NBINS           INT             88
  THETA           FLOAT     Array[32, 88]
  DTHETA          FLOAT     Array[32, 88]
  PHI             FLOAT     Array[32, 88]
  DPHI            FLOAT     Array[32, 88]
  DOMEGA          FLOAT     Array[32, 88]
  GF              FLOAT     Array[32, 88]
  GEOM_FACTOR     FLOAT
0.00153000
  DEAD            FLOAT      1.70000e-007
  MASS            FLOAT        0.0104389
  CHARGE          FLOAT          1.00000
  SC_POT          FLOAT         0.000000
  MAGF            FLOAT     Array[3]
  DATA            FLOAT     Array[32, 88]
```

# Ground processing (particles only)

- Loading and viewing on-board processed data
  - ….
  - Generic routines
    - To introduce s/c potential and magnetic field type:
      - » ctime,t & dat=thm_part_dist(‘thb_peif’,t)
      - » get_data,’thb_pxxm_pot’,data=thb_pxxm_pot_str
      - » it=where((thb_pxxm_pot_str.x gt t(0)-3.) and (thb_pxxm_pot_str.x lt t(0)+3.))
      - » dat.sc_pot=median(thb_pxxm_pot_str.y(it))
      - » get_data,’thb_fgs_dsl’,data=thb_fgs_dsl_str
      - » jt=where((thb_fgs_dsl_str.x gt t(0)-1.5) and (thb_fgs_dsl_str.x lt t(0)+1.5))
      - » dat.magf(*)=thb_fgs_dsl_str.y(jt,*)
    - If sc_pot not available, use a guess (e.g., sc_pot=15V)
      - » dat.sc_pot=-10. ; Volts
    - Compute the density, temperature for that instant
      - » `print,'ion density  1/cc  = ',n_3d(dat)`
      - » `print,'ion temperature eV = ',t_3d(dat)`
    - Another way is to use generic tool to introduce scpot and mag:
      - » thm_part_spec_calc,probe='b',scpot_suffix=‘_pxxm_pot’,mag_suffix=‘_fgs_dsl’,
      - » moments=['density',‘velocity‘,’t3’,’magt3’],instrument=['peif','psif']

# Ground processing (particles only)

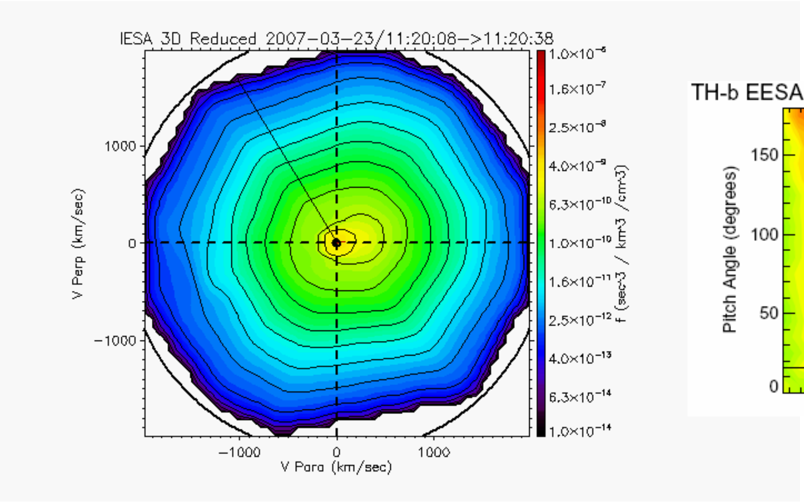
- Loading and viewing on-board processed data
  - Viewing Cuts
    - Use (crib themis_cut_crib provided in class material: idl/dfcuts):

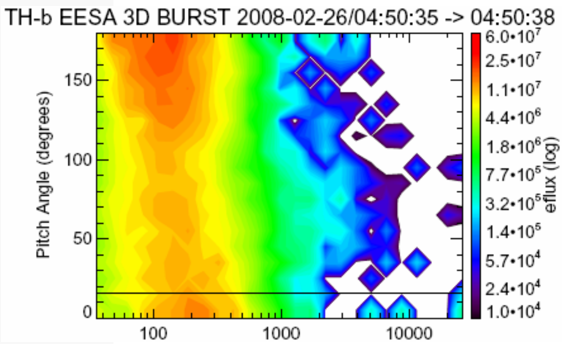
```
slice2d_themis_longer_esa,sc,typ,current_time,timeinterval,thebdata='th'+sc
+'_fgs_dsl',species=species,range=range,rotation=rotation,angle=angle,file
type=filetype,outputfile=outputfile;,nosmooth=1
```

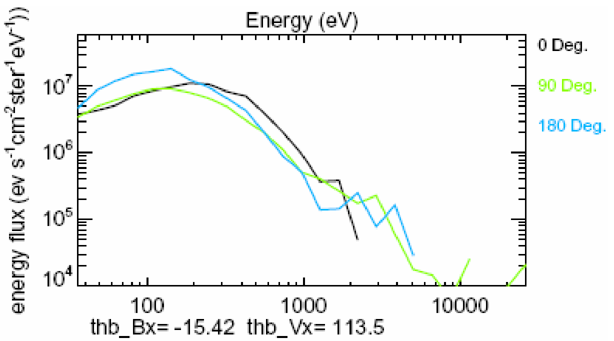
    - Note, rotations:

```
– ; 'BV': x = V_para and the bulk velocity in the x-y plane. (DEFAULT)
– ; 'BE': x = V_para and the VxB in the x-y plane.
– ; 'xy': x = V_x and y = V_y.
– ; 'xz': x = V_x and y = V_z.
– ; 'yz': x = V_y and y = V_z.
– ; 'perp': x-y plane is perp. to B, x is velocity projection on plane.
– ; 'perp_xy': x-y plane is perp. to B, x is x-axis projection on plane.
– ; 'perp_xz': x-z plane is perp. to B, y is z-axis projection on plane.
– ; 'perp_yz': x-y plane is perp. to B, x is y-axis projection on plane.
```

    - Other options (PA vs E)



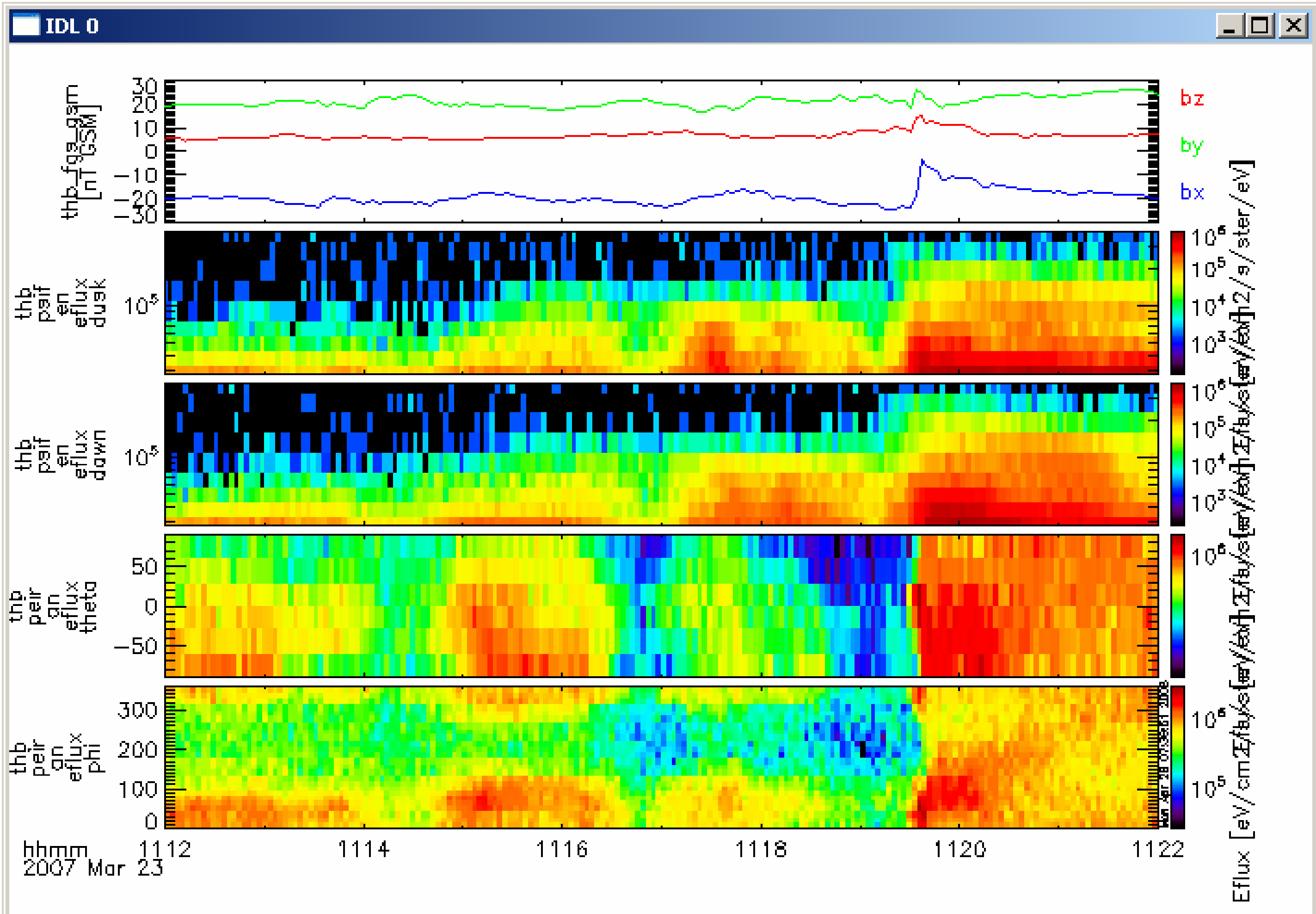



# Ground processing (particles only)

- Higher level products and visualization
  - Particle spectrograms in various coordinates
    - DSL coordinates
      - Energy, theta/phi angle spectrograms
      - ;DSL coordinates
      - ; energy spectrogram
      - thm_part_getspec, probe=['b'], trange=['07-03-23/11:10','07-03-23/11:30'], $
      - data_type=['psif'],/energy, $
      - phi=[-135,-45], theta=[-45,45], erange=[25000,500000],suff='_dusk'
      - thm_part_getspec, probe=['b'], trange=['07-03-23/11:10','07-03-23/11:30'], $
      - data_type=['psif'],/energy, $
      - phi=[45,135], theta=[-45,45], erange=[25000,500000],suff='_dawn'
      - ; phi spectrogram
      - thm_part_getspec, probe=['b'], trange=['07-03-23/11:10','07-03-23/11:30'], $
      - data_type=['peir'],angle='phi', $
      - phi=[0,360], theta=[-90,90], erange=[1.5e4,2.5e4]
      - ; theta spectrogram
      - thm_part_getspec, probe=['b'], trange=['07-03-23/11:10','07-03-23/11:30'], $
      - data_type=['peir'],angle='theta', $
      - phi=[0,360], theta=[-90,90], erange=[1.5e4,2.5e4]
      - tplot,'thb_fgs_gsm thb_psif_en_eflux_dusk thb_peir_an_eflux_*'
      - tlimit,['07-03-23/11:12','07-03-23/11:22']

# Ground processing (particles only)

- DSL coordinates
  - Energy, theta/phi angle spectrograms
  - ;DSL coordinates (results)

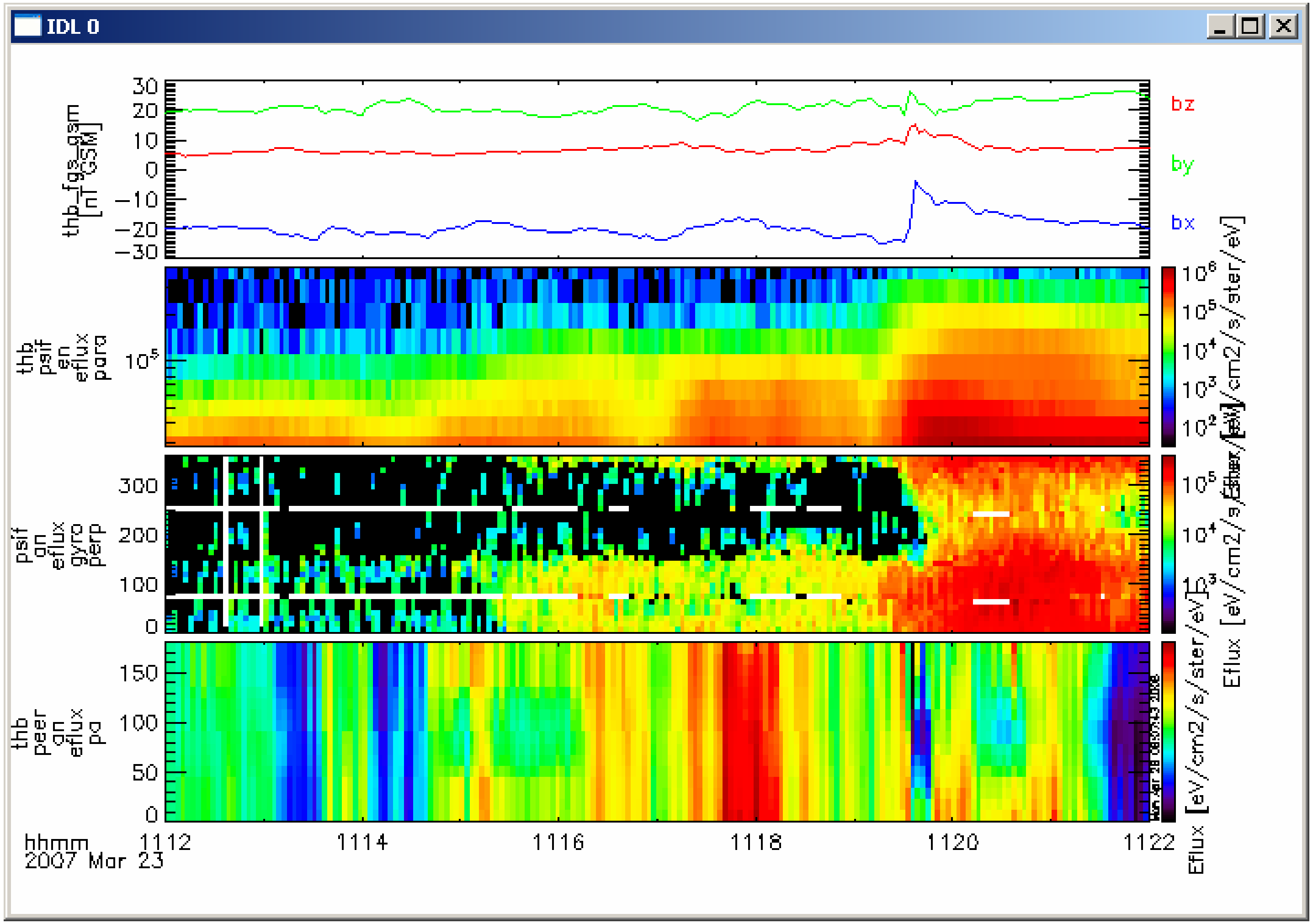


# Ground processing (particles only)

- Higher level products and visualization
  - Particle spectrograms in various coordinates
    - FAC coordinates (field aligned)
      - Energy, pitch angle (pa) / gyro(velocity)phase angle spectrograms
      - ; Energy spectrogram
      - thm_part_getspec, probe=['b'], trange=['07-03-23/11:10','07-03-23/11:30'],$
      - data_type=['psif'], /energy, $
      - pitch=[0,45], suff='_para', $
      - erange=[25000,500000],regrid=[32,16]
      - ; Gyro(velocity)phase spectrogram
      - thm_part_getspec, probe=['b'], trange=['07-03-23/11:10','07-03-23/11:30'],$
      - data_type=['psif'], angle='gyro', $
      - pitch=[45,135], other_dim='ygsm', suff='_perp', $
      - erange=[100000,150000],regrid=[32,16]
      - ; Pitch angle spectrogram
      - thm_part_getspec, probe=['b'], trange=['07-03-23/11:10','07-03-23/11:30'],$
      - data_type=['peer'], angle='pa', $
      - erange=[15000,25000],regrid=[32,16]
      - tplot,'thb_fgs_gsm thb_psif_en_eflux_para  thb_psif_an_eflux_gyro_perp thb_peer_an_eflux_pa'
      - tlimit,['07-03-23/11:12','07-03-23/11:22']

# Ground processing (particles only)

- FAC coordinates (field aligned)
  - Energy, pitch angle (pa) / gyro(velocity)phase angle spectrograms (results)



# Ground processing (particles only)

- Higher level products and visualization
  - Particle spectrograms in various coordinates
    - FAC coordinates (field aligned) (Look in: `thm_fac_matrix_make`)
      - other_dimension:
        - ; 'Xgse', (DEFAULT) translates from gse or gsm into FAC
        - ; Definition(works on GSE, or GSM): X Axis = on plane defined by Xgse - Z
        - ; Second coordinate definition: Y = Z x X_gse
        - ; Third coordinate, X completes orthogonal RHS
        - ; 'Rgeo',translate from geo into FAC using radial position vector
        - ; Rgeo is radial position vector, positive radialy outwards.
        - ; Second coordinate definition: Y = Z x Rgeo (westward)
        - ; Third coordinate, X completes orthogonal RHS XYZ.
        - ; 'mRgeo', opposite to above
        - ; mRgeo is radial position vector, positive radially inwards.
        - ; 'Phigeo', translate into FAC using azimuthal position vector
        - ; Phigeo is the azimuthal geo position vector, positive Eastward
        - ; First coordinate definition: X = Phigeo x Z (positive outwards)
        - ; Second coordinate, Y ~ Phigeo (eastward) completes orthogonal RHS XYZ
        - ; 'mPhigeo', opposite to above
        - ; Second coordinate, Y ~ mPhigeo (Westward) completes orthogonal RHS XYZ
        - ; 'Phism', translate into FAC using azimuthal Solar Magnetospheric vector.
        - ; Phism is "phi" vector of satellite position in SM coordinates.
        - ; Y Axis = on plane defined by Phism-Z, normal to Z
        - ; Second coordinate definition: X = Phism x Z; Third completes orthogonal RHS;
        
          ; 'mPhism', opposite to above
        - ; mPhism is minus "phi" vector of satellite position in SM coordinates.
        - ; 'Ygsm', translate into FAC using cartesian Ygsm position as other dimension.
        - ; Y Axis on plane defined by Ygsm and Z
        - ; First coordinate definition: X = Ygsm x Z
        - ; Third completes orthogonal RHS XYZ

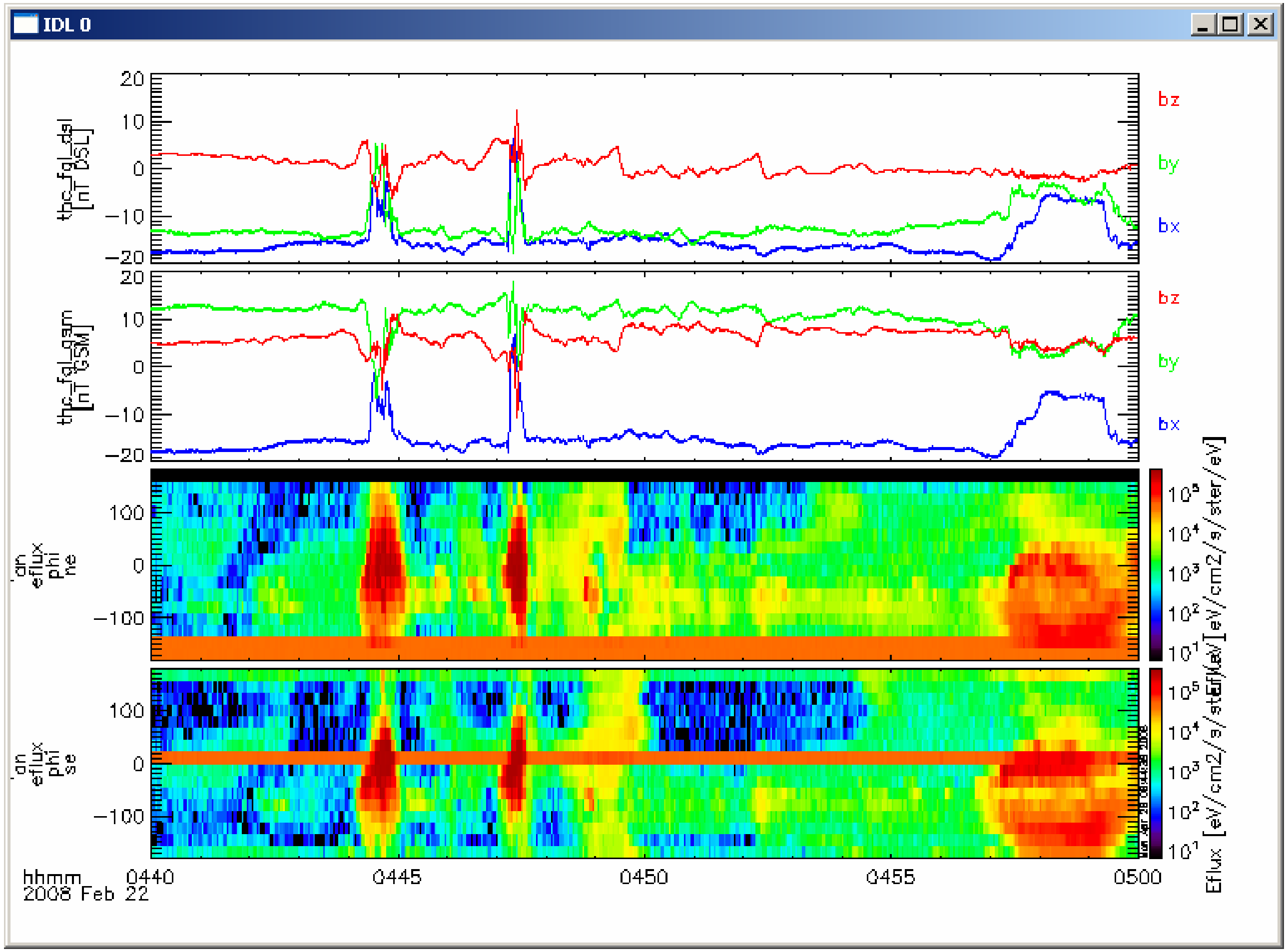
# Ground processing (particles only)

- Pitfalls
  - Sun contamination

```
» ; Sun contamination
» ;
» trange=['08-02-22/04:40','08-02-22/05:00']
» timespan,'08-02-22/04:00',1,/hours
» sc='c‘
» thm_load_fgm,probe=sc,data='fgl',coord='dsl gsm'
» thm_part_getspec, probe=sc,trange=trange, $
»               theta=[0,45], phi=[0,360], start_angle=-180., $
»               erange=[25000,40000], data_type=['psif'], $
»               suffix='_ne',angle=phi
» thm_part_getspec, probe=sc,trange=trange, $
»               theta=[-45,0], phi=[0,360], start_angle=-180., $
»               erange=[25000,40000], data_type=['psif'], $
»               suffix='_se',angle=phi
» tplot,'thc_fgl_dsl thc_fgl_gsm thc_psif_an_eflux_phi_ne
  thc_psif_an_eflux_phi_se'
» tlimit,['08-02-22/04:40','08-02-22/05:00']
```

# Ground processing (particles only)

- Pitfalls
  - Sun contamination
    - » ; Sun contamination



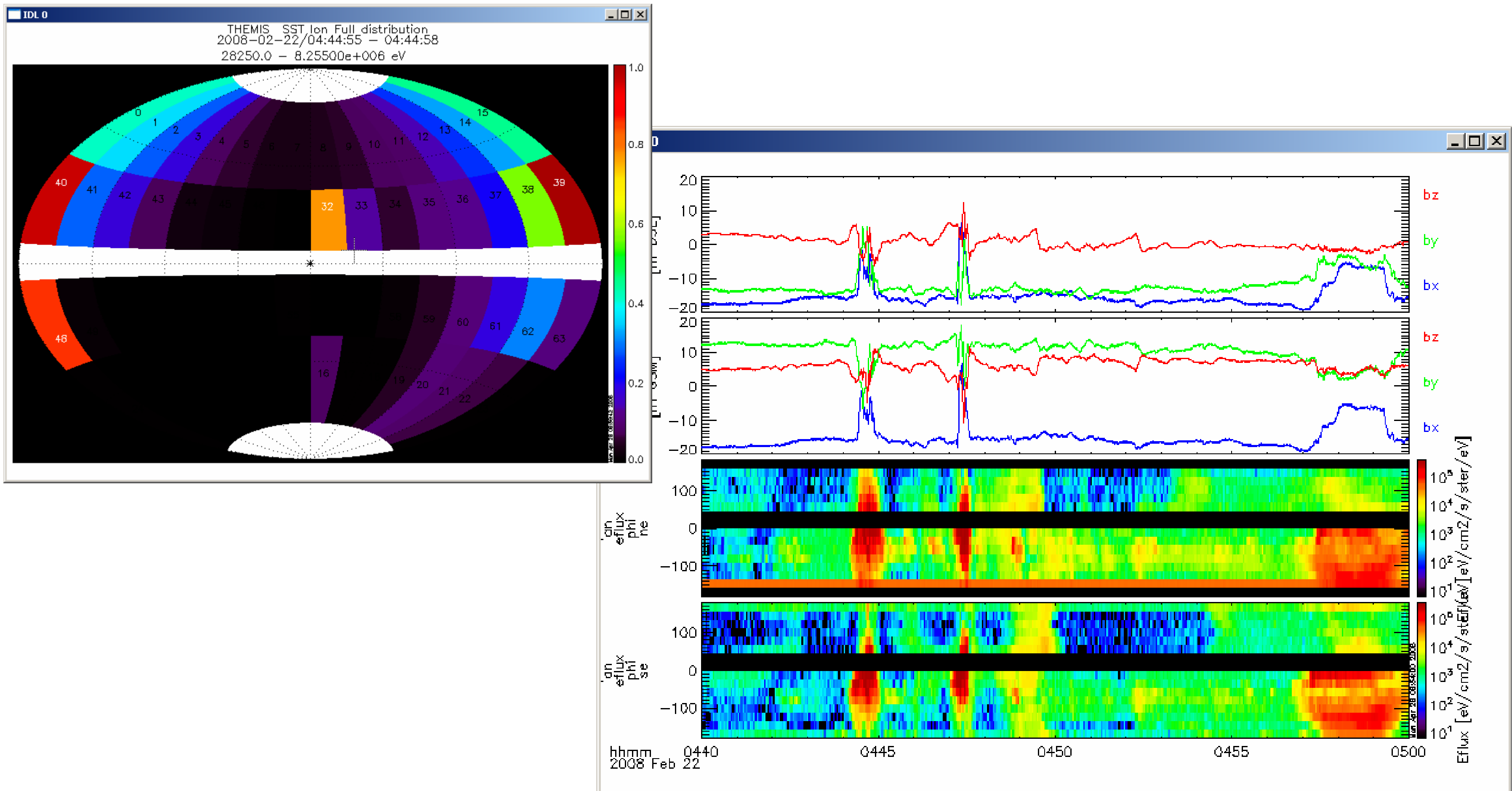
# Ground processing (particles only)

- Pitfalls
  - Sun contamination: Bin removal

```
;
edit3dbins,thm_sst_psif(probe=sc, gettime(/c)), bins2mask
; ON: Button1;    OFF: Button2;   QUIT: Button3
bins2mask = where(bins2mask eq 0)
print,bins2mask
thm_part_getspec, probe=sc,trange=trange, $
        theta=[0,45], phi=[0,360], start_angle=-180., $
        erange=[25000,40000], data_type=['psif'], $
        suffix='_ne',angle=phi,bins2mask=bins2mask
;
thm_part_getspec, probe=sc,trange=trange, $
        theta=[-45,0], phi=[0,360], start_angle=-180., $
        erange=[25000,40000], data_type=['psif'], $
        suffix='_se',angle=phi,bins2mask=bins2mask
;
tplot
```

# Ground processing (particles only)

- Pitfalls
  - Sun contamination: Bin removal
    - » ;



# Homework

- Find a THEMIS interval of interest to your research
- Plot one energy, phi, theta spectrogram from ESA and SST
- Plot one pitch, gyrophase spectrogram from ESA and SST
- Plot ESA ion and electron distribution functions in
  - Vpar, perp and in XY coordinates
  - Cold plasma detection

# Topics for May 14/May 19 class

- Potential subtraction
- Cold plasma detection
- Magnetopause sounding