Observations directly linking relativistic electron microbursts to whistler mode chorus:

Van Allen Probes and FIREBIRD II

Breneman A. et al., (2017), Observations directly linking relativistic electron microbursts to whistler mode chorus: Van Allen Probes and FIREBIRD II, Geophys. Res. Lett., 44, doi:10.1002/2017GL075001.

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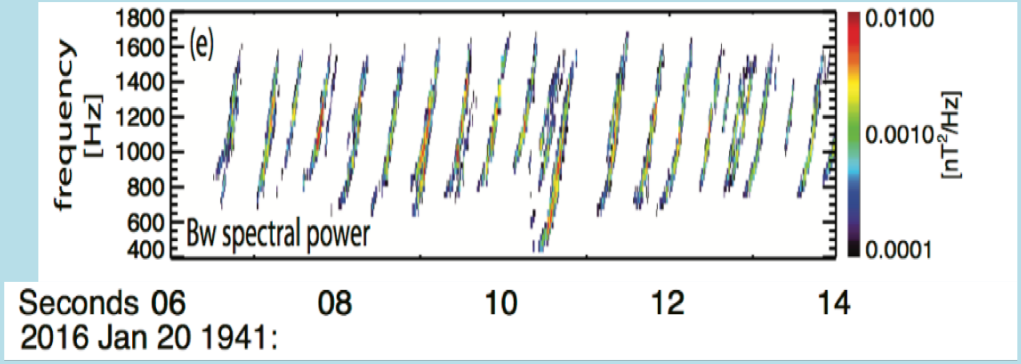
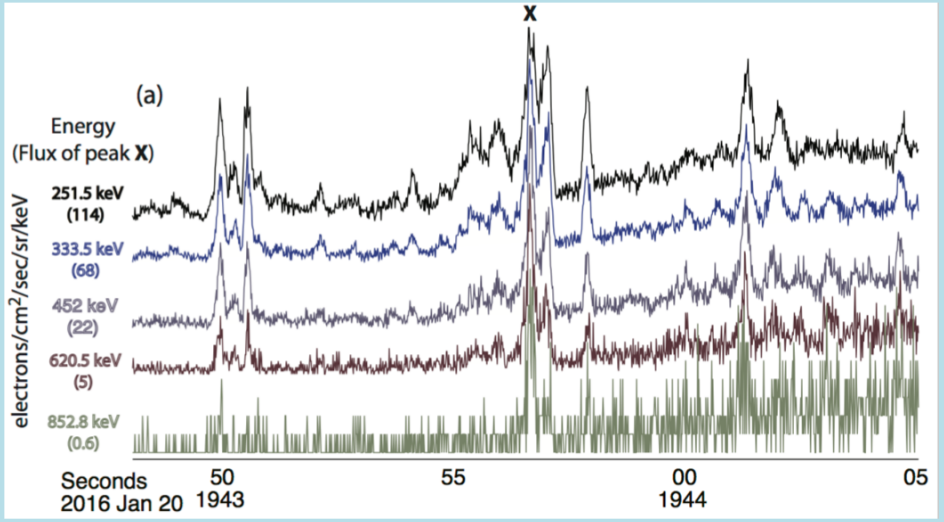
Chorus and microbursts?

- Chorus waves
  - whistler mode plasma wave
  - Outside of plasmasphere, dawn/morning MLT, typically
  - right-hand circularly/elliptically polarized
  - 0.1fce < f < fce
  - Cause scattering loss of e- (e.g. diffuse aurora, microbursts) as well as prompt, localized acceleration of e- to MeV energies.

- Microbursts
  - Impulsive e- injections (few msec) into atmosphere
  - Energies from 10s keV to >MeV
  - May be a significant source of e- loss in storm recovery phase



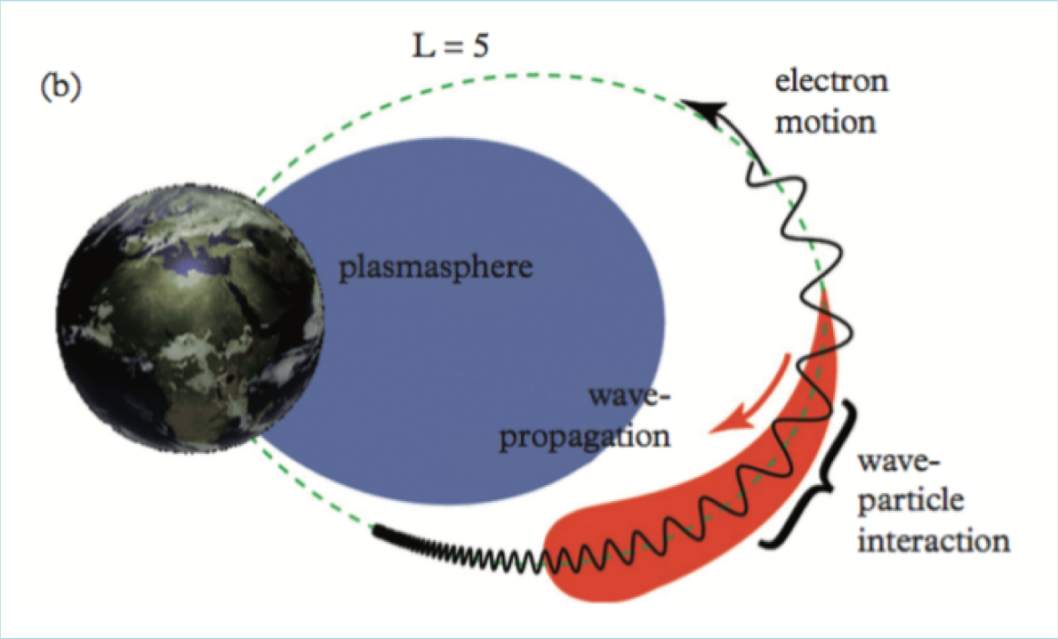


How and where are uB thought to be created?

- Chorus waves, emitted near equator, have cyclotron resonance with energetic electrons
- Resonance energy increases away from equator

Doppler-shifted cyclotron Resonance condition

$$\omega - \mathbf{k} \cdot \mathbf{V} = n\Omega$$



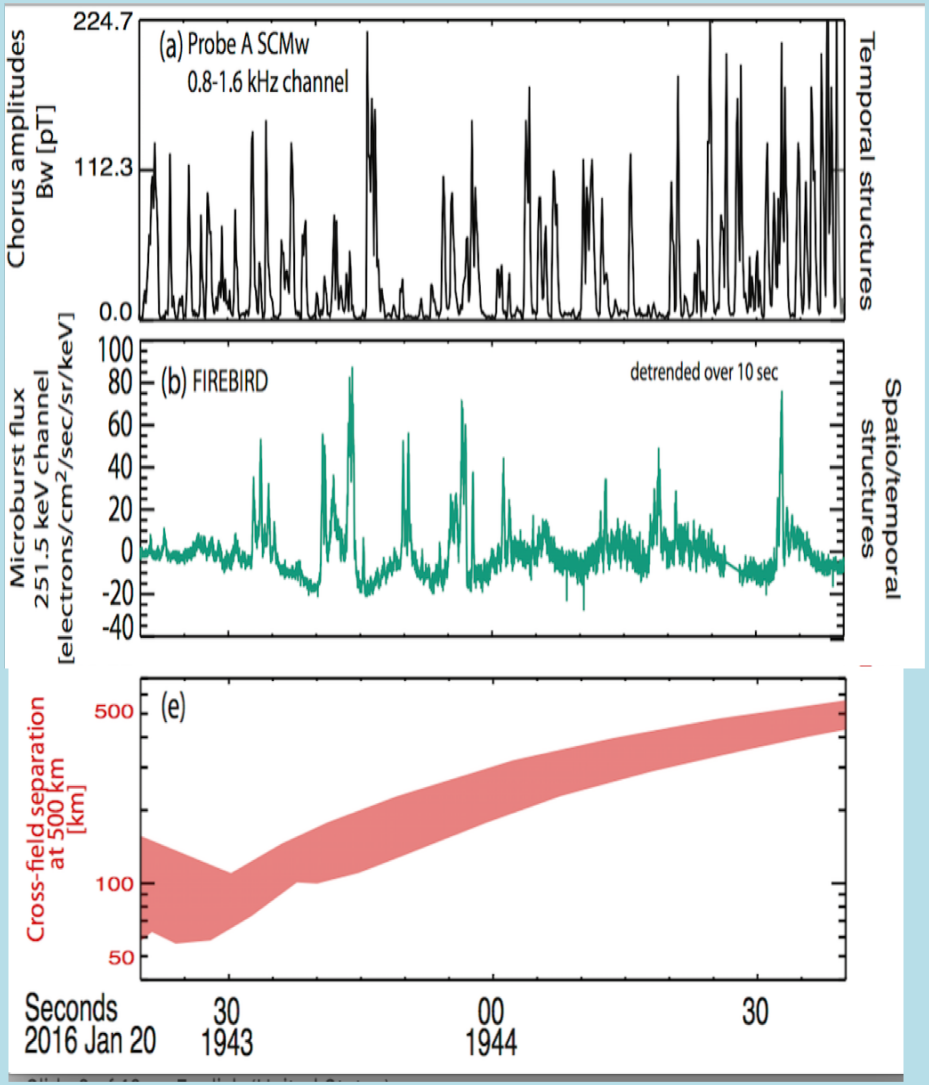
History and Previous studies

- **No direct causal link b/t chorus and relativistic μB has been observed**
- Closest previous comparison [Kersten et al., 2011], ΔMLT=1.5 hrs. Data either sparse (short burst waveforms), or low resolution
- Combination of Van Allen Probes and FIREBIRD provides the first real opportunity to observe simultaneous chorus and μB. *This is about as good as you can do without specifically designing a mission for this measurement!*

[Klumpar et al., 2015, Crew et al., 2016]

Results!

- First observations of simultaneous chorus and μB on same magnetic flux tube. Order of magnitude closer than previous studies
- Single, nonlinear/coherent interaction at 20-30^{o} latitude with chorus creates μB from 200 keV to 1 MeV
- The observed time-averaged μB flux may be a significant source of relativistic e- loss from outer belt



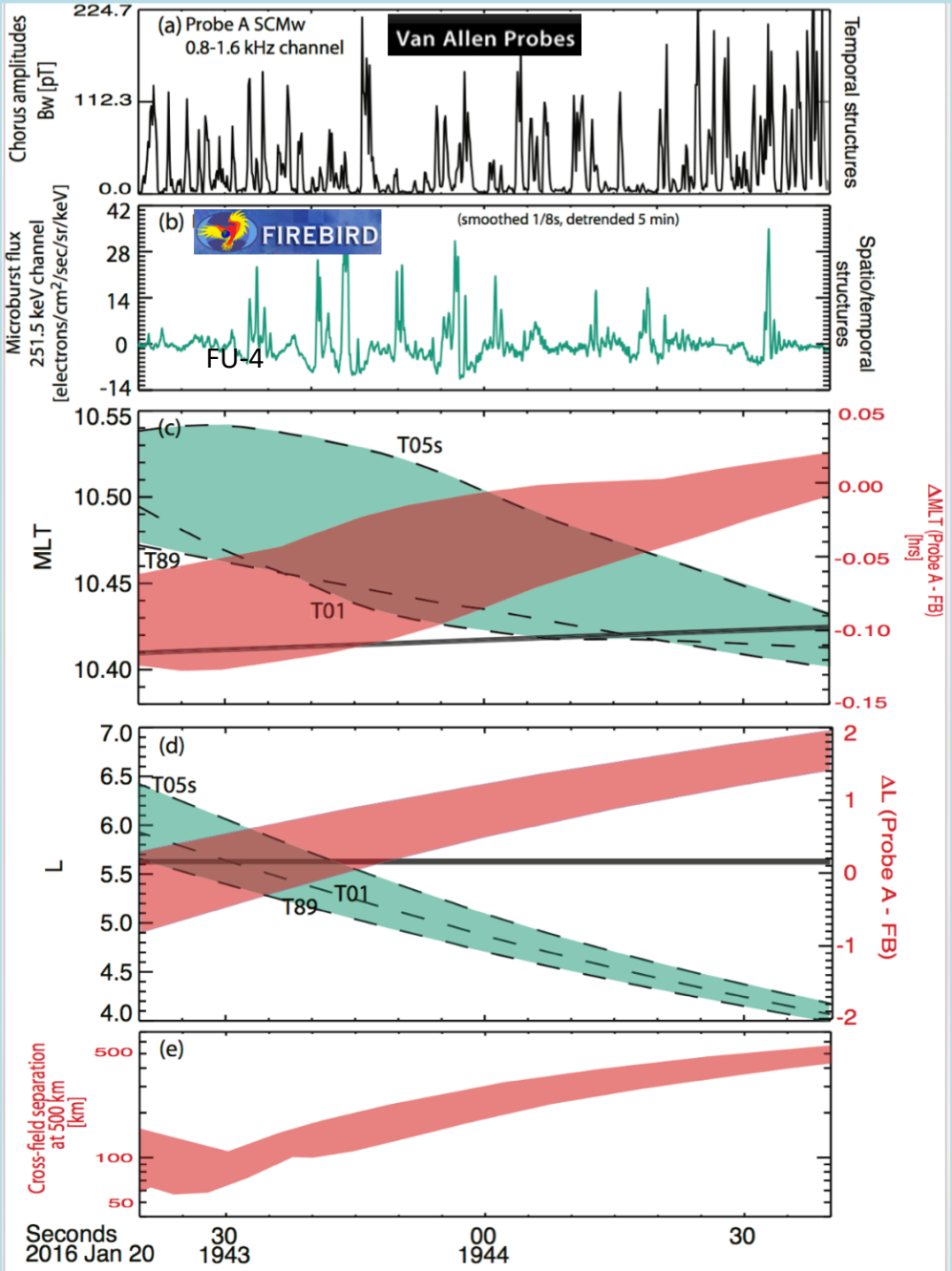
**Flux tube defined as transverse packet size of chorus (100-2000 km) [Santolik et al., 2003, Agapitov et al., 2011; Aryan et al., 2016]

How conjunction is determined

Map position of FIREBIRD from low altitude to magnetic equator using three dayside-applicable Tsyganenko magnetic field models (T89, T01, T05)

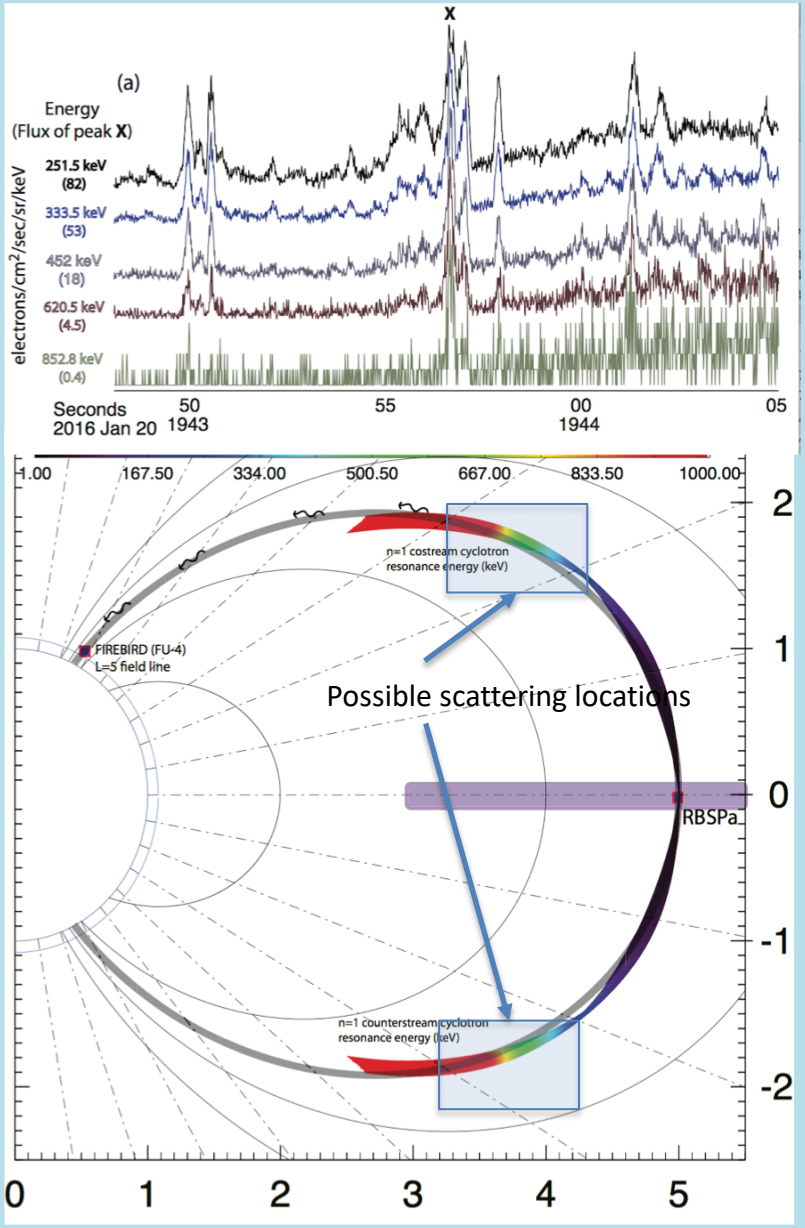
Compare to position of Probe A, which is already near equator

Probe A and FIREBIRD **on same magnetic flux tube**, defined as transverse packet size of chorus (100-2000 km)
[Santolik et al., 2003, Agapitov et al., 2011; Aryan et al., 2016]



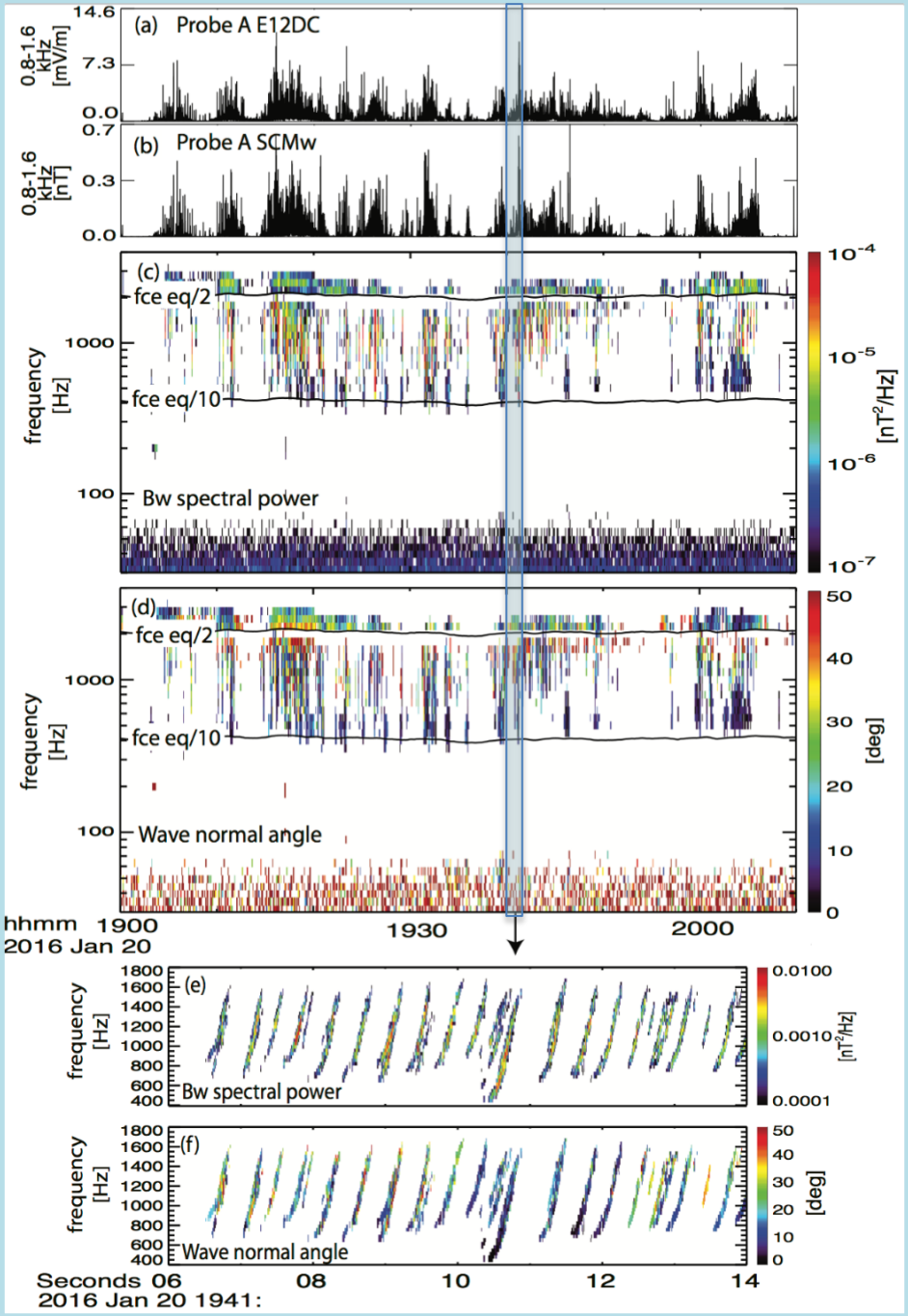
Where/how are these uB created?

- **NOT likely Landau resonance** - occurs at >50 mlat. Rays should be strongly damped by this point
- **NOT likely Higher order |n|>1 cyclotron resonance near equator** - This requires highly oblique chorus, which we do not observe
- **Most likely first order cyclotron resonance which occurs at off-equatorial locations**



Global context 1: Conjunction is only a small glimpse into larger precipitation region

- Size of ΔMLT = 1 hr, contains strong chorus (<=1 nT) with similar properties
- Chorus relatively field-aligned ($\theta_{kb} < 30^{o}$)
- Burst data indicates rising tone chorus
- **No waves other than chorus – these must be causing the uB!**



Global context 2: are these uB a significant source of e- loss?

Method: Compare time-averaged uB flux to total flux tube content

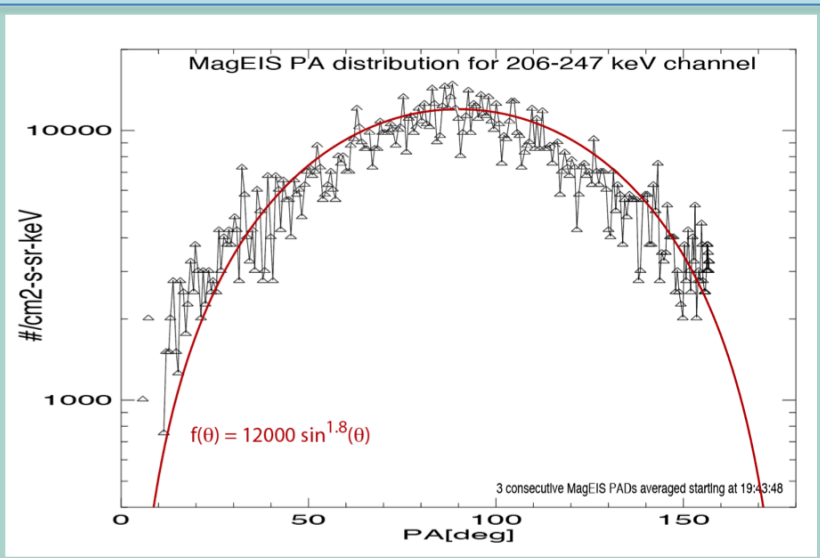
Calculate time-averaged uB flux by fitting 25 largest uB in the ~80 sec conjunction to Gaussians.

$$\langle \text{flux uB} \rangle = \left(0.235 \frac{\text{sec}}{\text{uB}}\right)\left(0.36 \frac{\text{uB}}{\text{sec}}\right)\left(69 \frac{e-}{\text{cm}^2\ \text{s sr keV}}\right) = 5.8 \frac{e-}{\text{cm}^2\ \text{s sr keV}}$$

<duration> Occurrence frequency <flux>

Total flux in single flux tube

$$\text{flux Total} \approx 20{,}000 \frac{e-}{\text{cm}^2\ \text{s sr keV}}$$



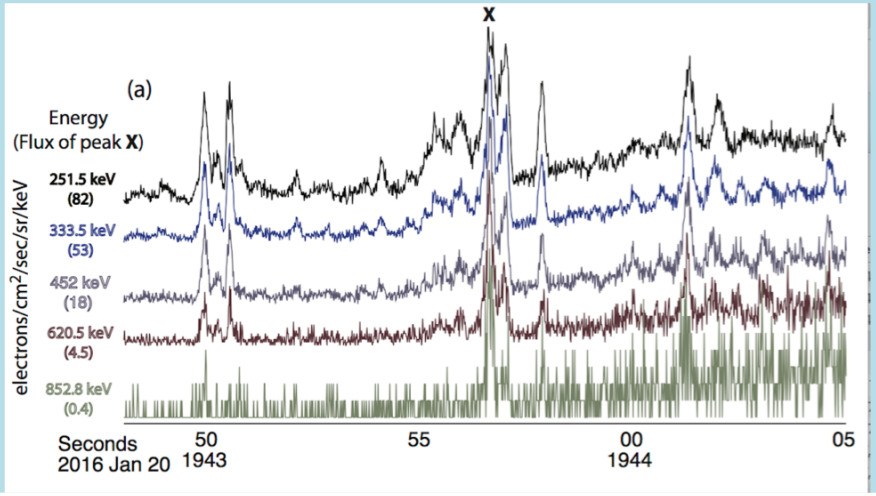
Global context 3: are these uB a significant source of e- loss?

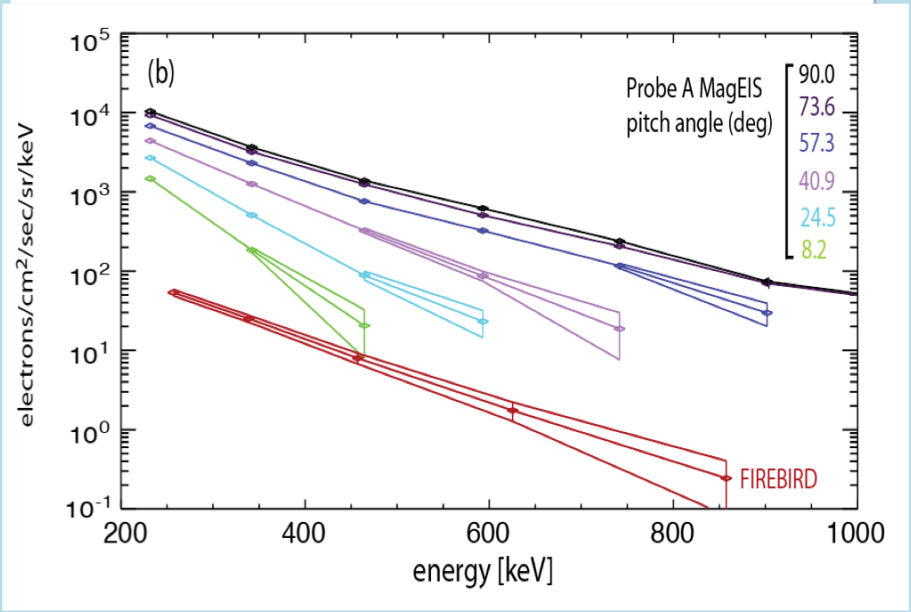
- To clear out a single flux tube would take 160 min and 3400 uB
- The time to clear an entire drift shell depends on the MLT extent of the precipitation region. From Van Allen Probes we observe:
  - ΔMLT = 1 hr → 60 hours
    - (size of local chorus region observed on Probe A)
  - ΔMLT = 3-5 hr → 10-20 hours
    - (size of chorus region observed on Probe A + Probe B). This is consistent with size of long-duration (9 hr) uB region (9-13 MLT, L=5-10) observed by Anderson et al., 2017 using BARREL and AeroCube 6

If the precipitation region is extended and long-lasting (consistent with previous observations) then **YES!**

Global context 4: loss at higher energies?

- A spectral comparison indicates that any loss timescale estimated for 250 keV also applies to energies up to (possibly) 1 MeV
- Loss timescales consistent with past SAMPEX studies by Lorentzen et al, 2001b and O'Brien et al., 2004





Conclusions

- **Closest ever simultaneous measurements of chorus and μB show unequivocally that chorus creates μB from sub-relativistic to relativistic energies!**

- Scattering likely occurs at 20-30 deg latitude via first order cyclotron resonance

- Observed time-averaged μB flux may represent a major source of e- loss in outer belt!