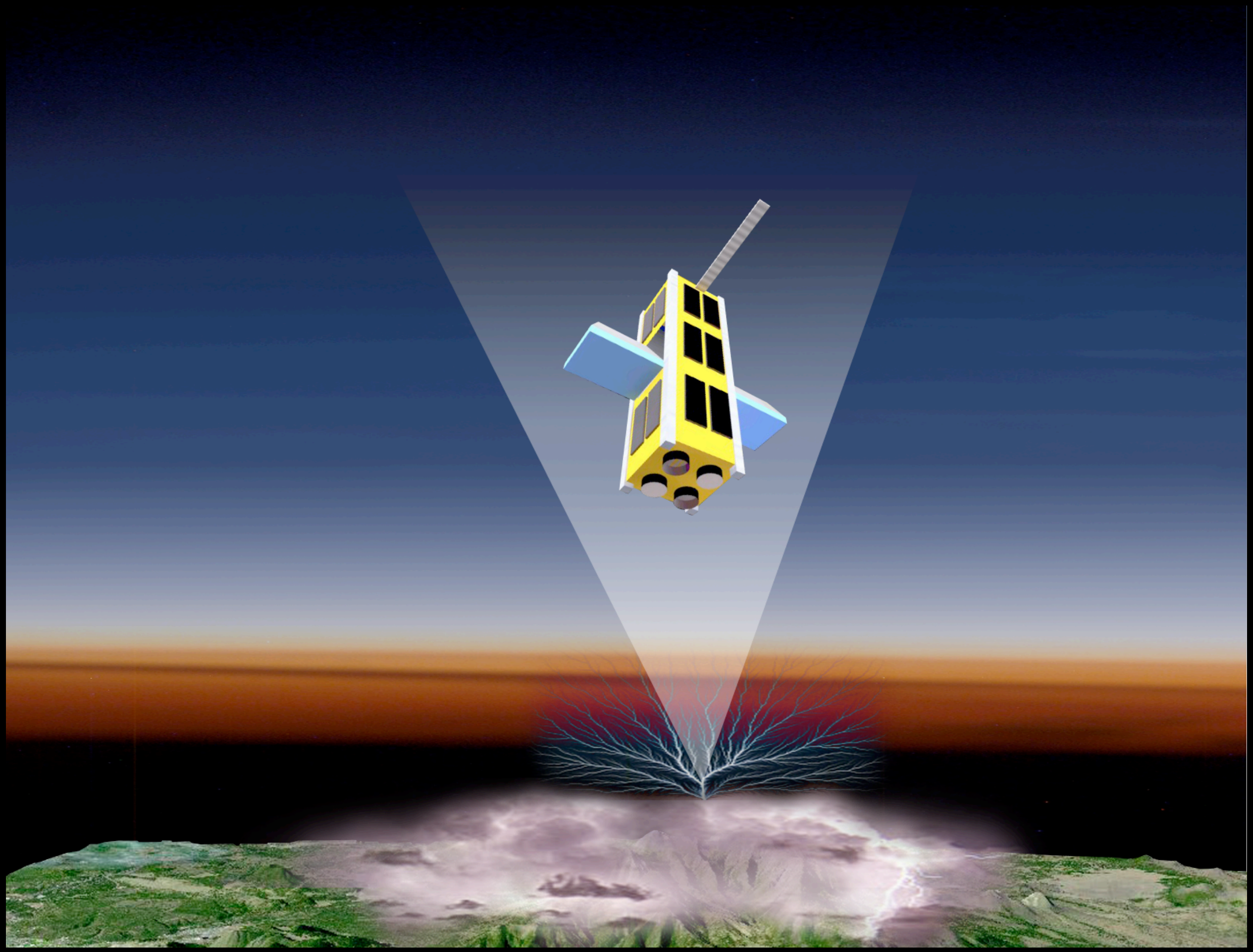
The Firefly Mission

Understanding Earth's most powerful natural particle accelerator



D. Rowland

CubeSat Developers' Workshop

April 22, 2009

The Firefly Team









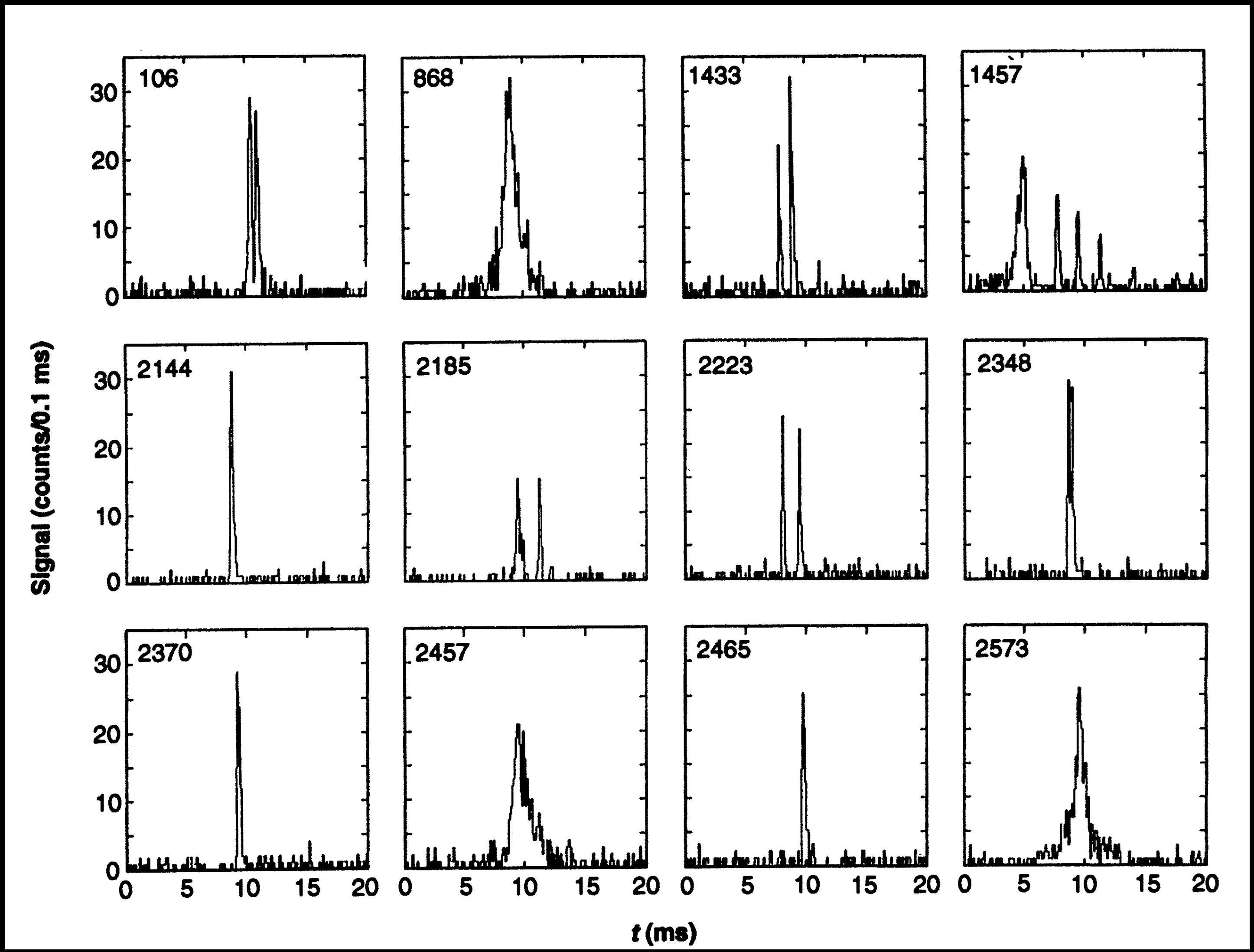


Mysterious TGFs

- The Earth as a source of gamma rays?
- Lightning as an antimatter factory
- Lightning source for inner belt electrons?
- Why and how does lightning occur?
- Does all lightning produce energetic radiation?
- What about other planets?
- How does activity in the troposphere affect the chemistry and plasma populations at 80-100 km?

Terrestrial Gamma ray Flashes (TGFs)

Initial Observation by BATSE / CGRO (Fishman et al., *Science*, 1994)



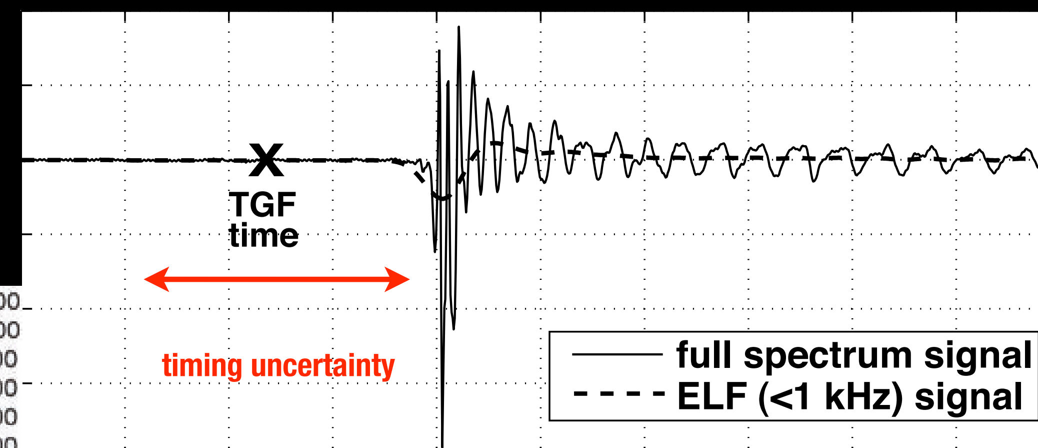
- **Coming from nadir (Earth source)**
- **Much shorter than cosmic Gamma-Ray Bursts (~1 ms vs. 1-100 s)**
- **Much harder spectrum than cosmic GRB's (break at 30 MeV vs. 250 keV, power law slope -1 vs. -2)**
- **Momentarily brighter than solar flares**
- **Suggestive evidence for thunderstorm source**
- **Bremsstrahlung radiation from energetic electrons - accelerated from thermal energies to tens of MeV in ~1 ms**
- **fundamental process that may be implicated in all lightning discharges**
- **may provide weak but continuous source of energetic electrons for Earth's radiation belt**

TGF / lightning relationship

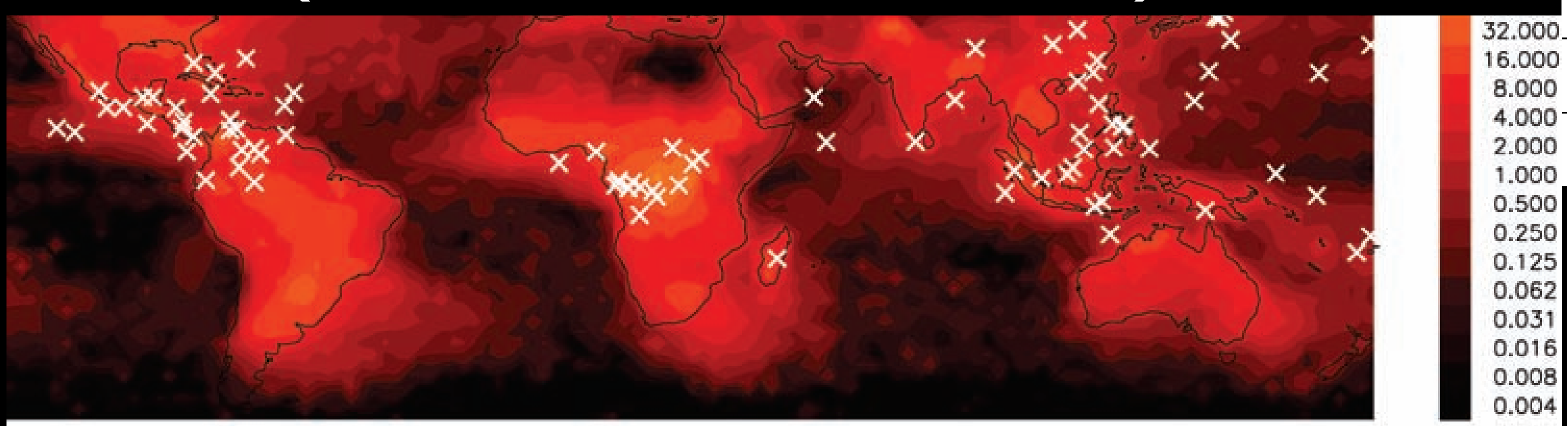
- **RHESSI has revolutionized our understanding of TGFs:**
  - **Much more common than previously thought**
  - **Evidence for 35 MeV electron source at 15-20 km altitude**
  - **Approximately 15/month detected (better triggering / detection algorithm)**
  - **RHESSI has 20 MeV stopping power, and sees TGF gammas of this energy**
  - **976 events detected to date (7 years)**

Lightning detected remotely, associated with a RHESSI TGF (Cummer et al., *JGR*, 2005)

- **Ground-based VLF receivers detect sferic from lightning within a few ms of one of the RHESSI TGFs**
- **Several ms uncertainty in relative timing**
- **Many TGFs occur "out of sight" of ground-based arrays**



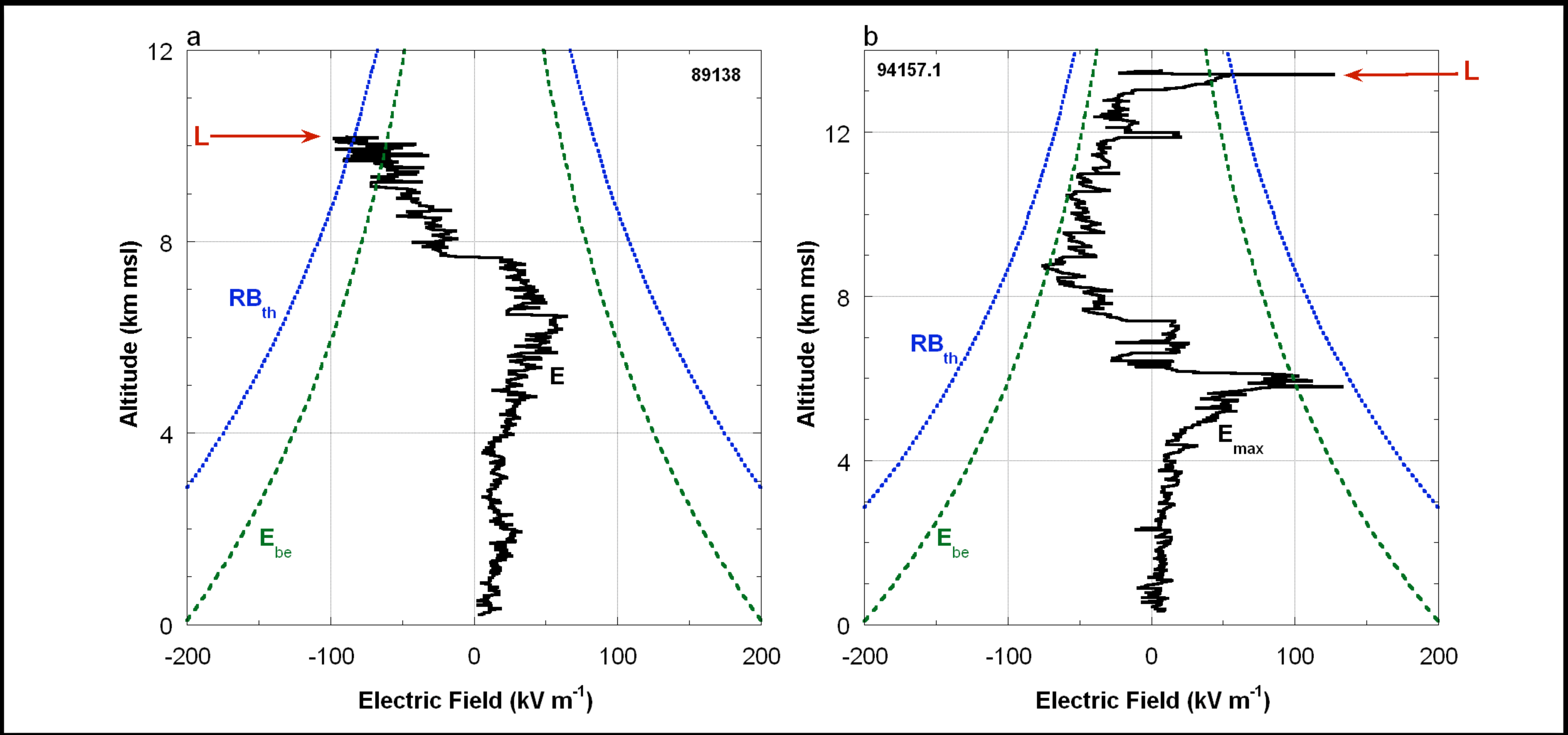
Association with lightning-producing regions (Smith et al., *Science*, 2005)



- **Low-mid latitudes, suggestive of a need for thunderstorm activity and high tropopause height**
- **Most common near thunderstorm production areas**

Electric fields in thunderclouds: consistent with Runaway Breakdown

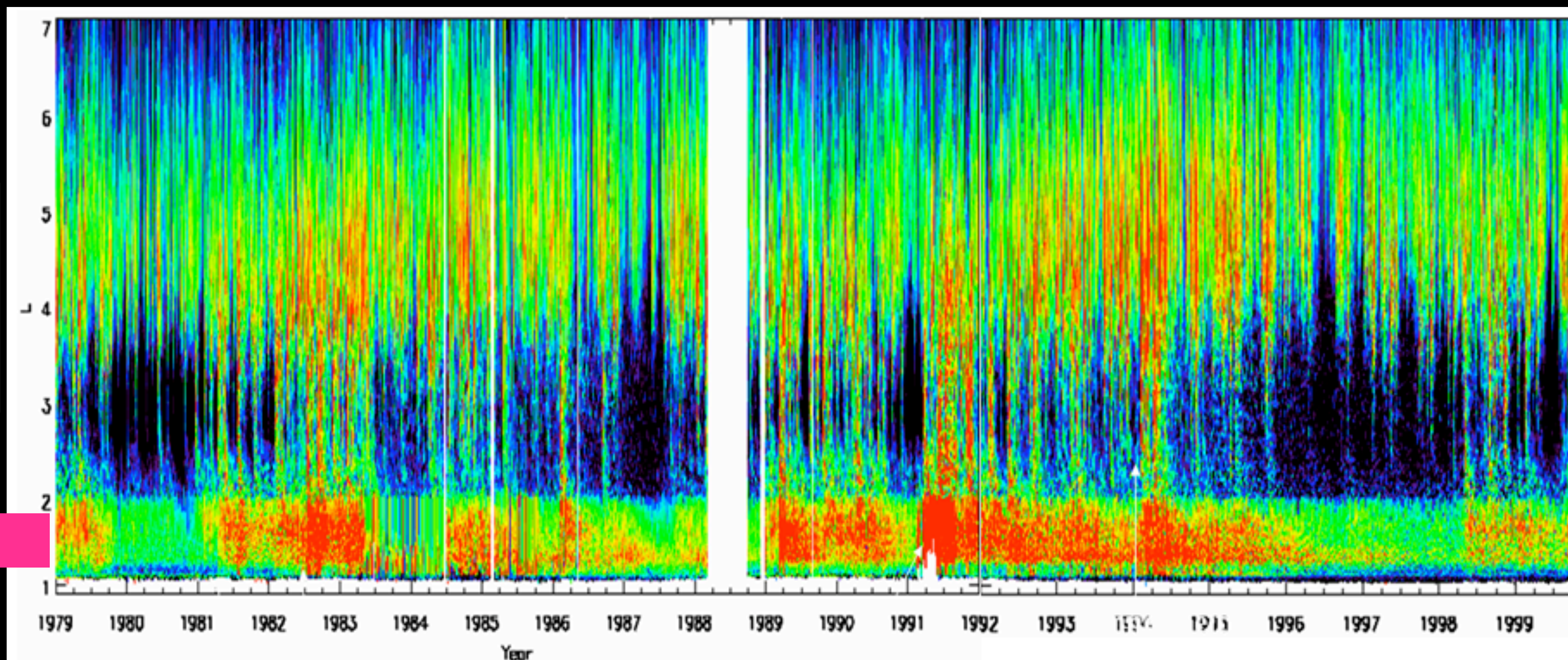
(positron / gamma feedback and MeV electron avalanche)



M. Stolzenburg et al. , GEOPHYSICAL RESEARCH LETTERS, VOL. 34, L04804

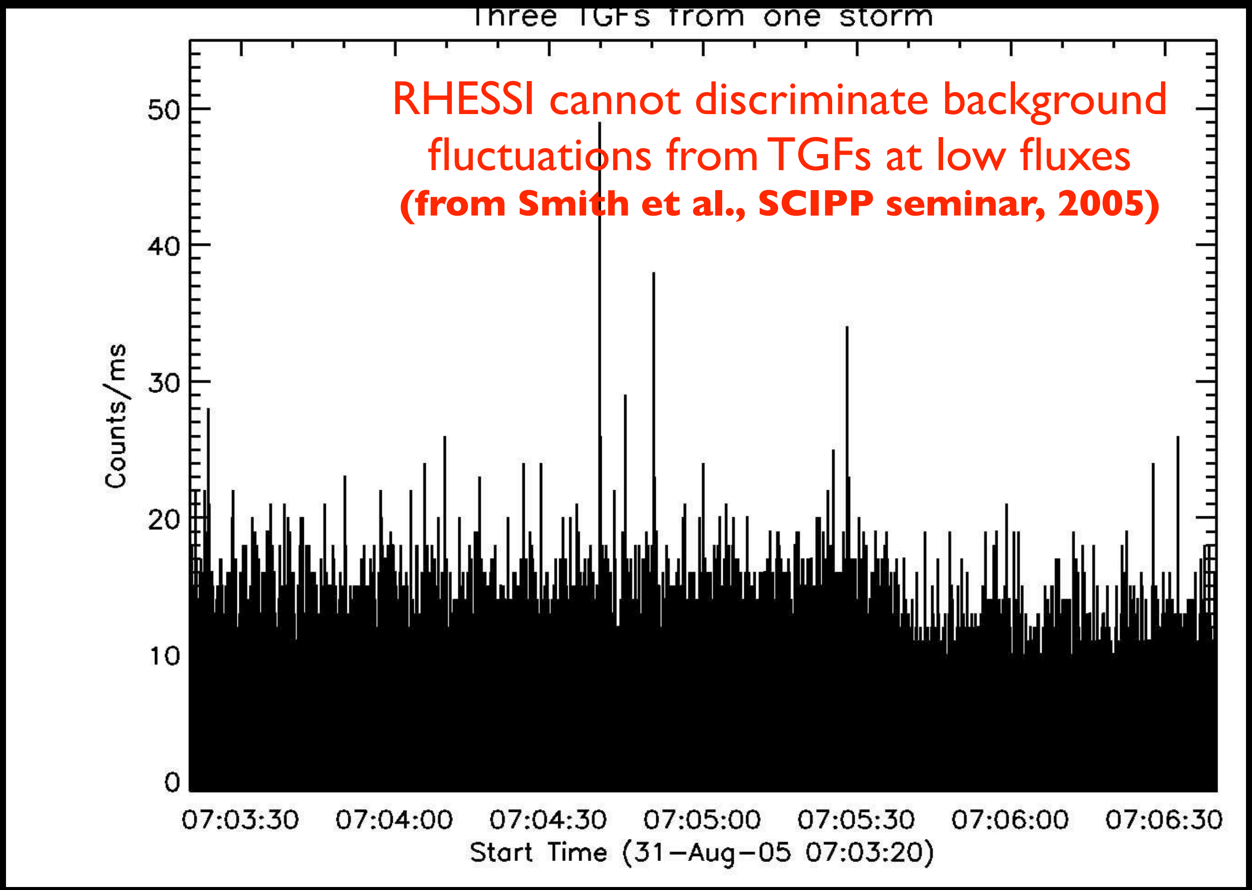
Radiation Belt Access

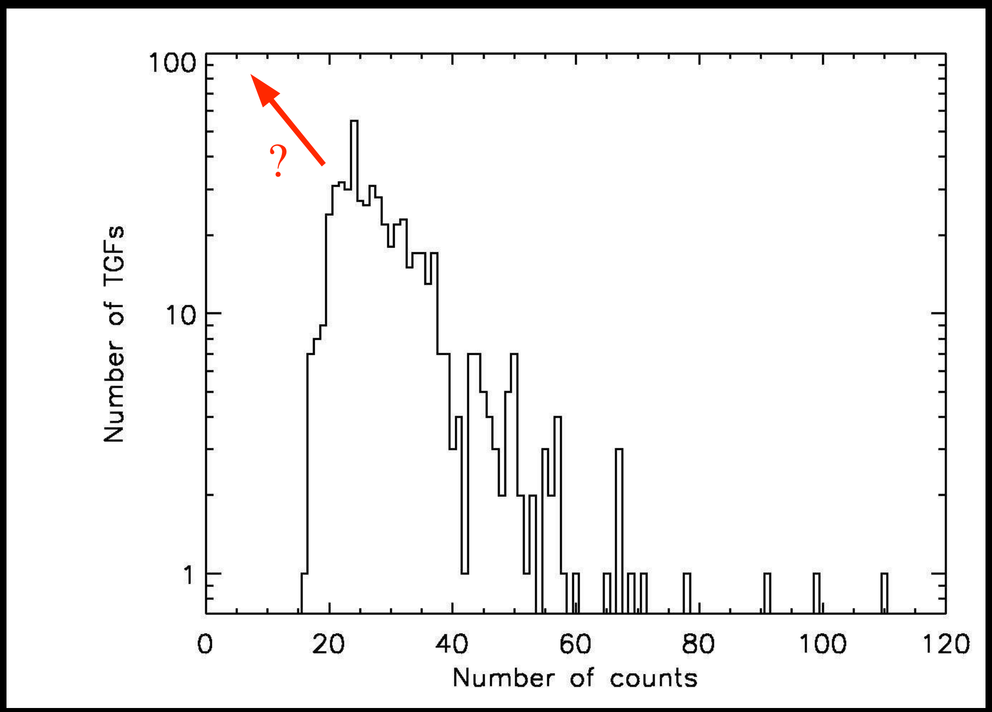
Region of significant TGF occurrence

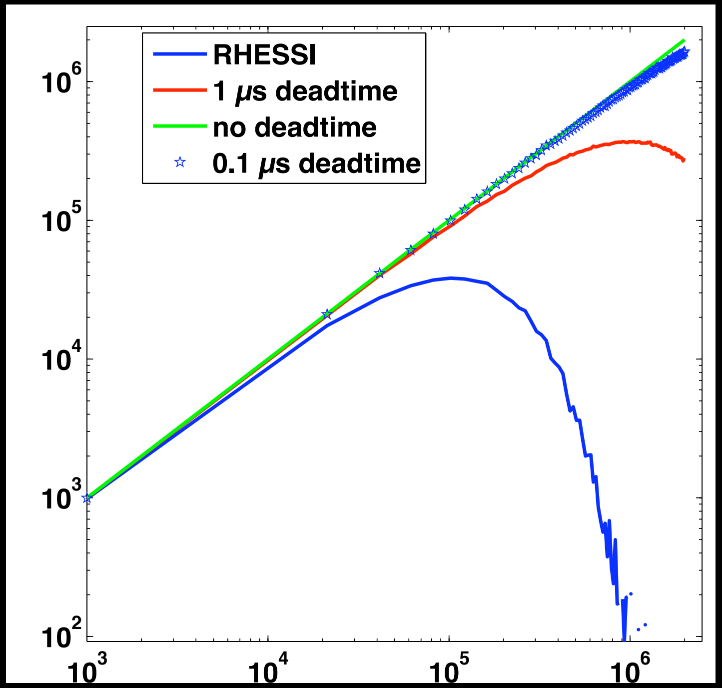


X. Shao

How bright are they?







RHESSI Instrument saturates at high count rates.
Possibly underestimating TGF fluxes by 2-5.

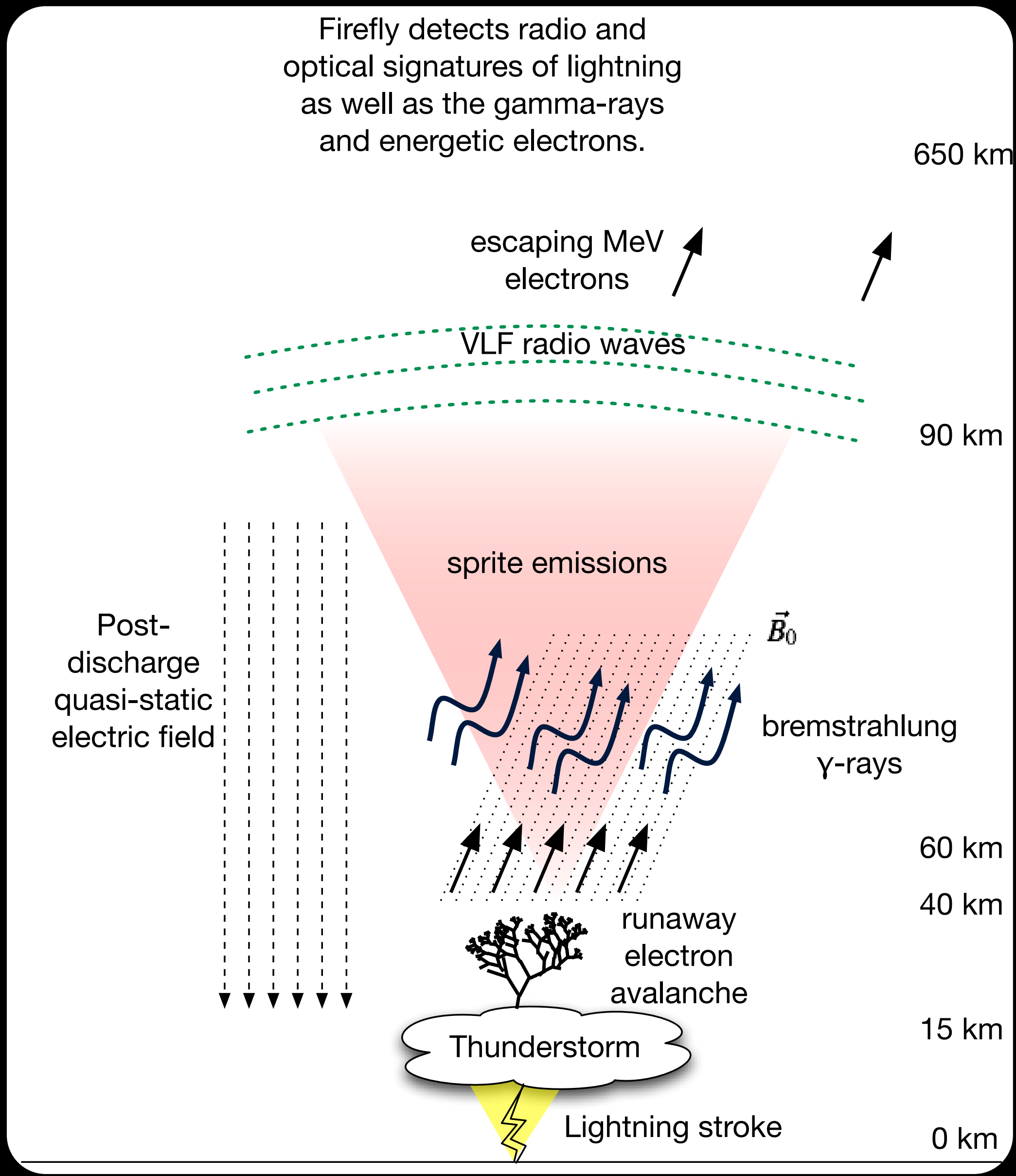
What do we need?

- Single platform that measures gamma rays, electrons, and lightning signatures
  - provides accurate relative timing
  - discriminates electron from gamma ray counts
  - uses VLF and optical signatures to discriminate weak TGFs from statistical fluctuations
- Accurate relative timing (1 μs)
- Accurate absolute timing to UTC (better than 1 ms)
- Fast detector: 1 MHz or (preferably) better
- Overflights of ground-based receivers for lightning characterization

Instruments

Gamma Ray Detector (GRD) measures:

photons from 20 keV to 20 MeV, at count rates up to 1 MHz
electrons from 100 keV to 10 MeV, at count rates up to 300 kHz
“counts” up to 10 MHz
snapshots, spectra, and count rate histograms



VLF wave receiver (VLF) measures:

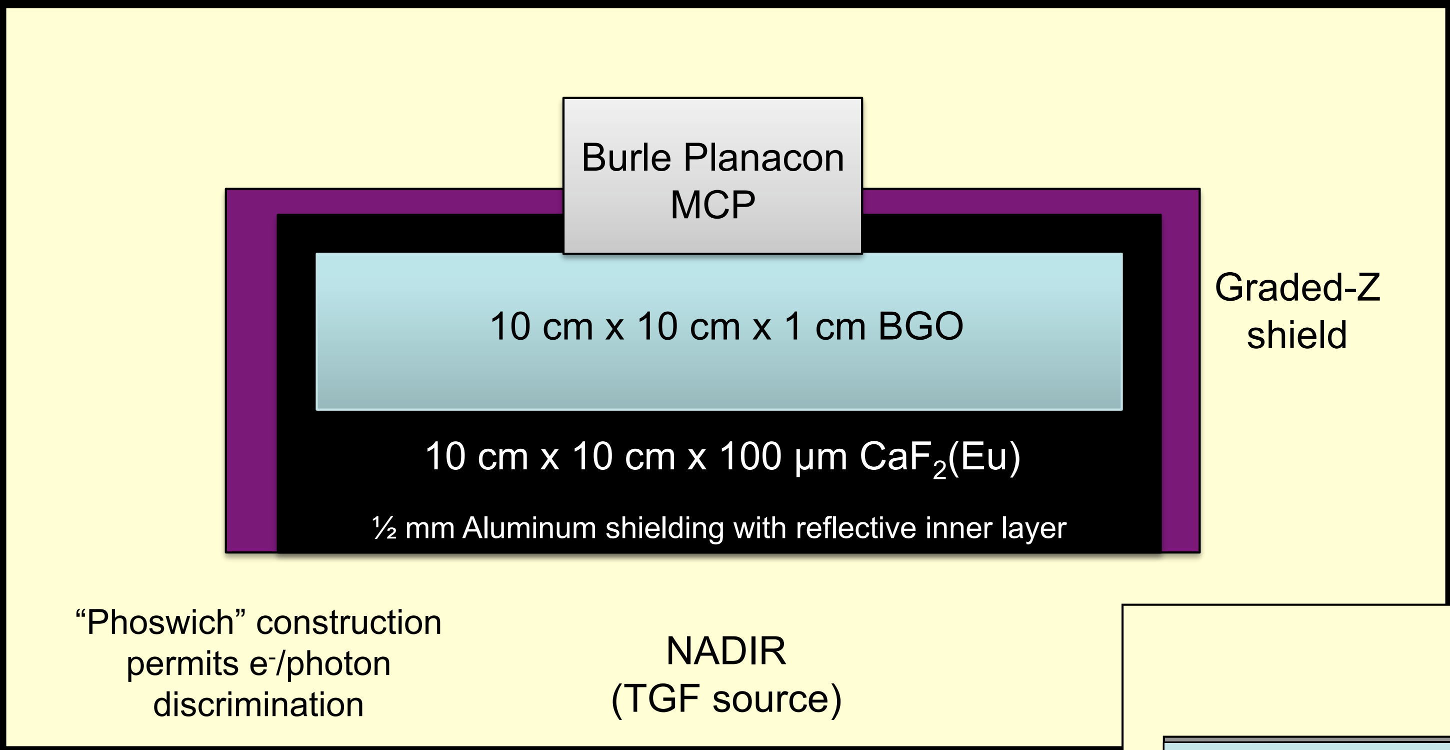
single-axis electric fields 100 Hz to 20 kHz, up to 10 mV/m

Optical photodiode (OPD) measures:

four FOV light levels 100 Hz to 20 kHz, saturates above 98 %ile lightning
provides localization of lightning to one of twelve regions (overlap of FOVs)
can see lightning within about 400 km horizontal distance
designed to work day and night

Gamma Ray Detector

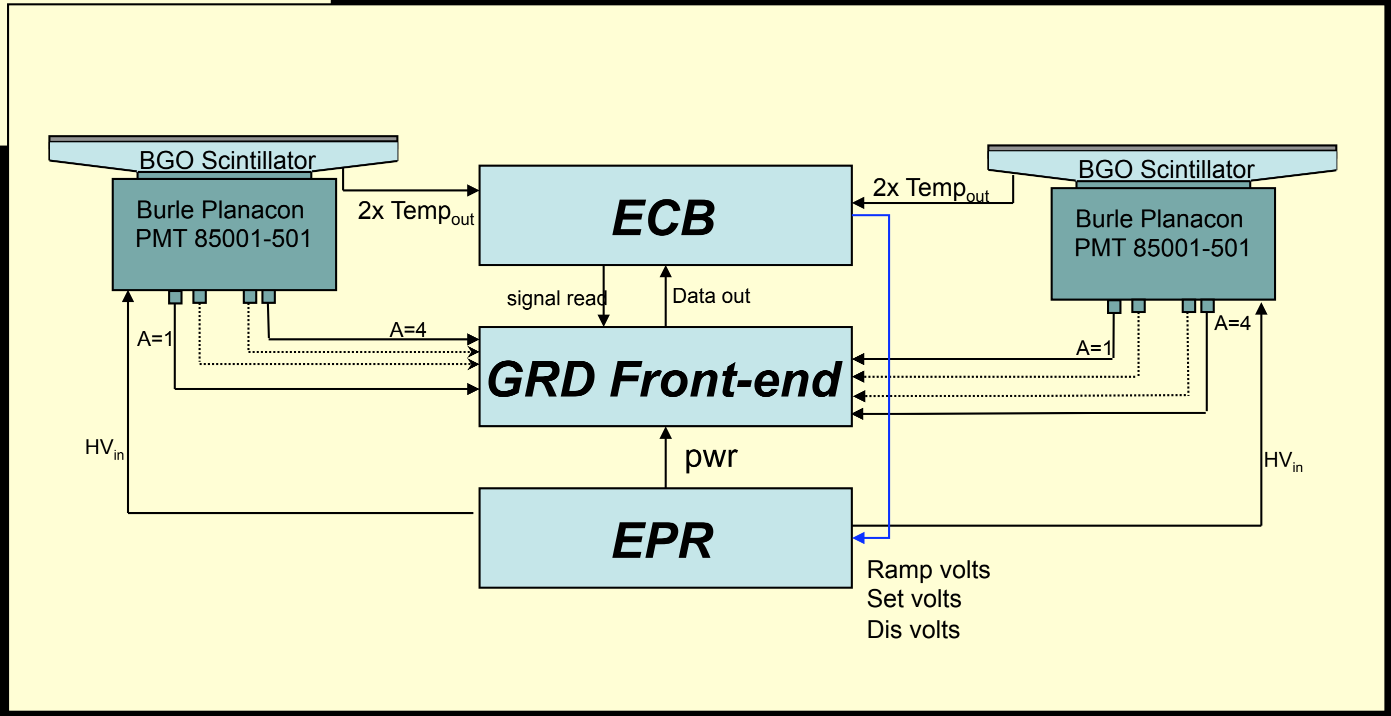
Development at NASA GSFC



200 cm^2 x 1 cm thick scintillator

Electrons <= 1 MeV interact in CaF2(Eu)
Photons interact in BGO
Electrons > 1 MeV interact in both

BGO and CaF2(Eu) have different light decay times (300 ns, 900 ns). By integrating the resulting charge signal with two different shaping amplifiers, the nature of the incoming radiation can be determined, and the energy can be measured by standard pulse-height analysis.



VLF receiver

Development at Siena College

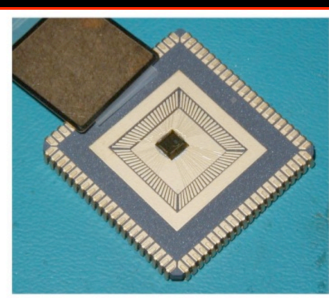
Measure electric field signatures in the range of 100 Hz to 1 MHz

User selectable anti-aliasing filter of 30 kHz, 180 kHz, and 1080 kHz.

1.6 m tip-to-tip electric dipole antenna

Dual, multiplexed 6 MHz Stanford ADCs for all science instruments

We gratefully acknowledge collaboration with Stanford University.



12.25 mm^2 die area

- Features
  - Self-calibration algorithm for enhanced fidelity
- Physical characteristics
  - Commercial 0.25-µm BiCMOS technology (only CMOS layers used)
  - 2.5 V supply, 1.0 V_{PP} differential input range

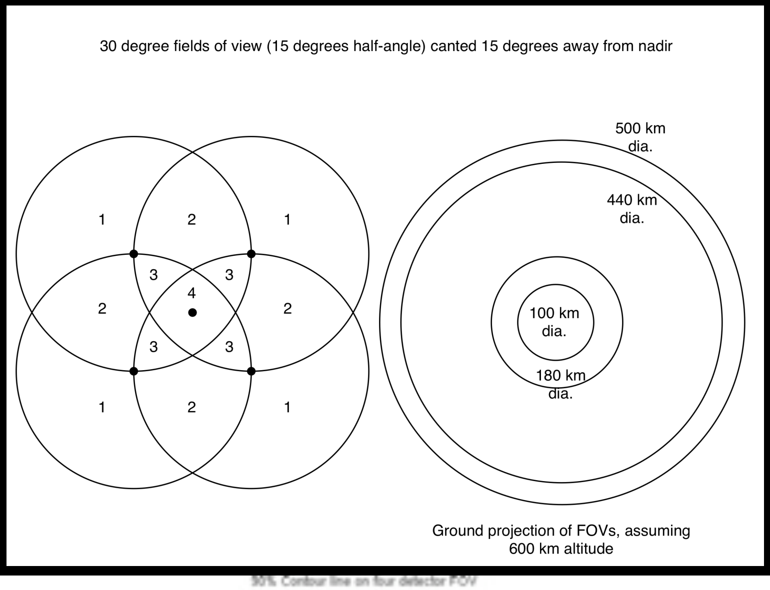
Time-tag VLF events for ground-based VLF correlation

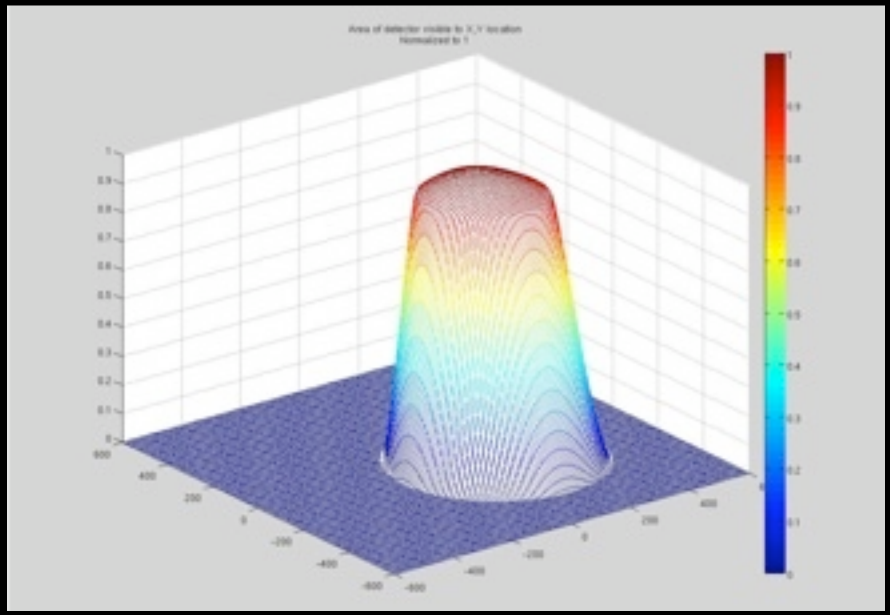
Primary goal is 1ms timing accuracy to UTC.

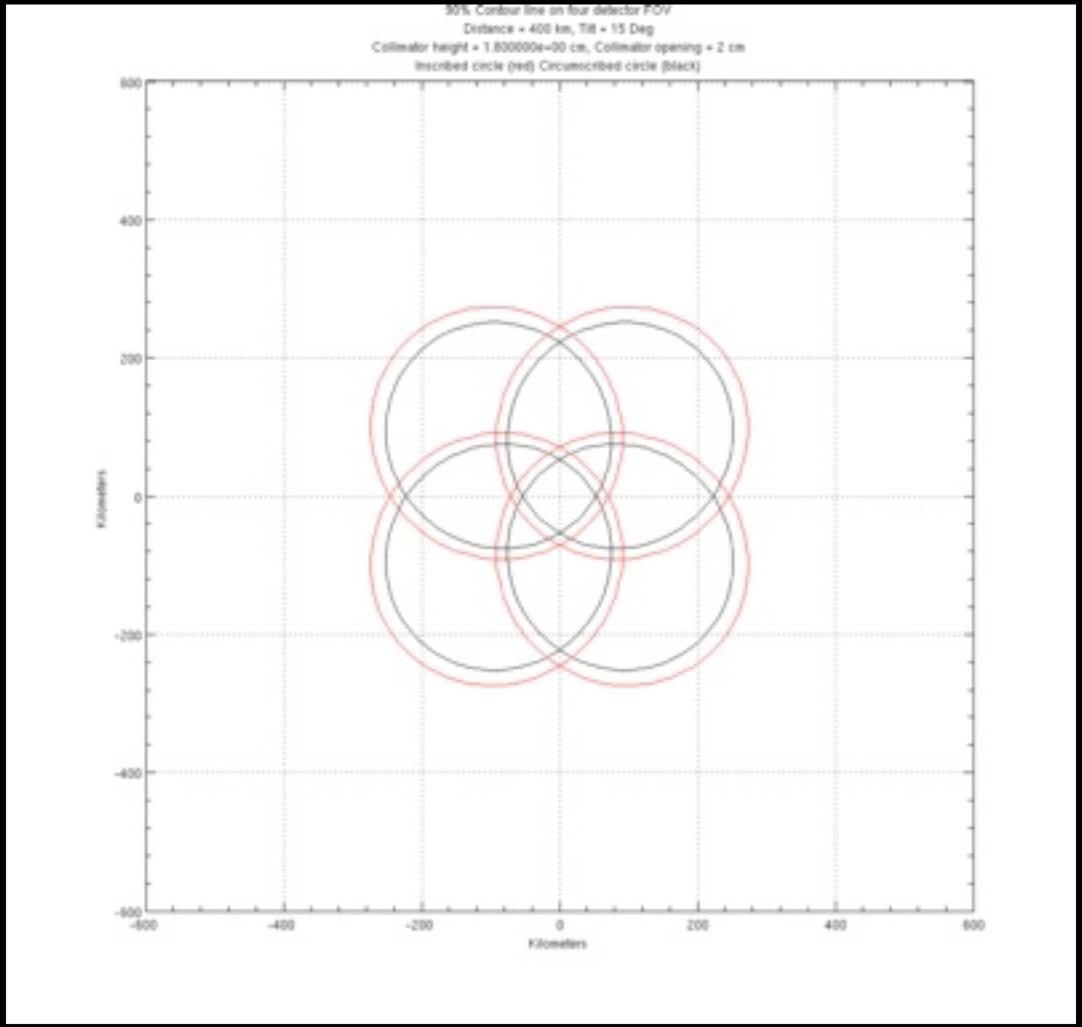
Secondary goal is 1us timing accuracy to UTC.

Optical Photodiodes

- Development at Siena College
- Bobby Carroll, John DeMatteo, Jennifer Williams
- Al Weatherwax, Joe Kujawski, Michele McColgan
- FOV Calculations
  - Minimum and maximum field of view were calculated based on the geometry of the photo detector and collimator
  - The square photodetector was modeled as two circles:
    - inscribed (min)
    - circumscribed (max)
  - Equations developed using geometric models and implemented in Matlab







The spacecraft

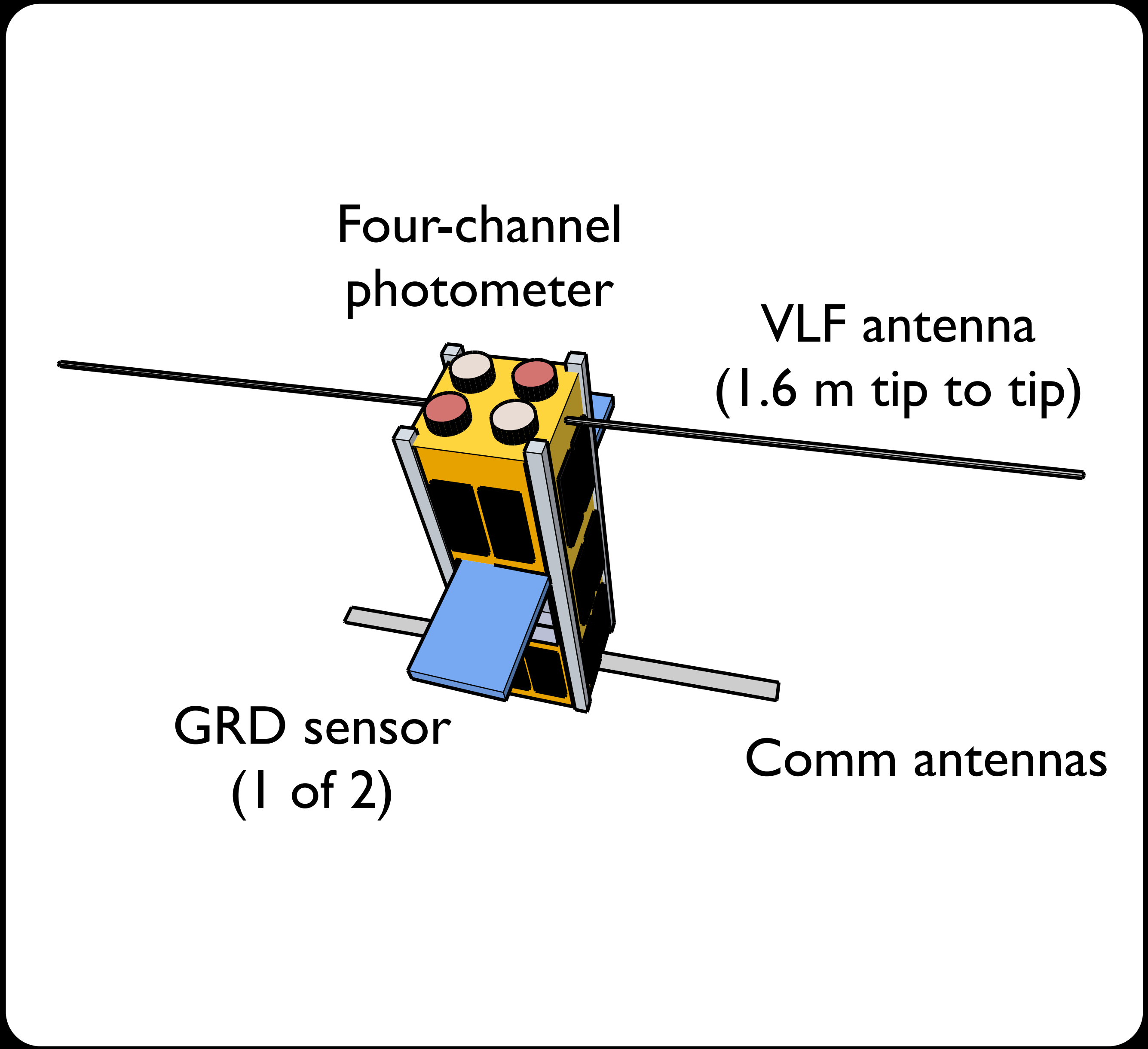
Development at the Hawk Institute for Space Sciences

- Mass: 4.5 kg
- Power: 3 W orbit-averaged
- Comm: 425 MHz
- 19.2 kbps downlink
- GPS for accurate timing to UTC

- Gravity gradient boom and magnetotorquers for attitude control

- 3-axis attitude magnetometer and solar cell measurements for attitude determination

- points within 30 degrees of nadir
- attitude knowledge requirement 10 degrees
- 1 μs accuracy to UTC
- 2 GB onboard storage



Operations concept

- Prime data are 100 ms "snapshots" triggered by increase in gamma ray counts, electron counts, VLF signal, or optical signal
- trigger levels adjustable from ground
- expect ~50 snapshots per day
- expect 1-5 weak TGFs / day, 1 strong TGF every 2-3 days
- Duty cycle of about 50% to save power (on during eclipse)
- ground contacts only 8x5, during business hours
- Ramp down HV in South Atlantic Anomaly

Student involvement - Siena

J. Williams, J. DeMatteo, R. Carroll
working with A. Weatherwax, J. Kujawski, M. McColgan, E. Breimer, R. Yoder

AWESOME VLF Receiver
- Ground-based VLF support.
- Already in progress.

GSE
- *MATLAB Instrument* Control Toolbox

Instrument modeling
- Optical photodiode collimator optimization

Data Processing and Analysis
- *MATLAB*

LEGO Firefly Mission

Experiment Expansion Modules
- FFT, Filter bank, advanced triggering

Geographic Information System
- Worldwide lightning network

Student involvement - UMCP

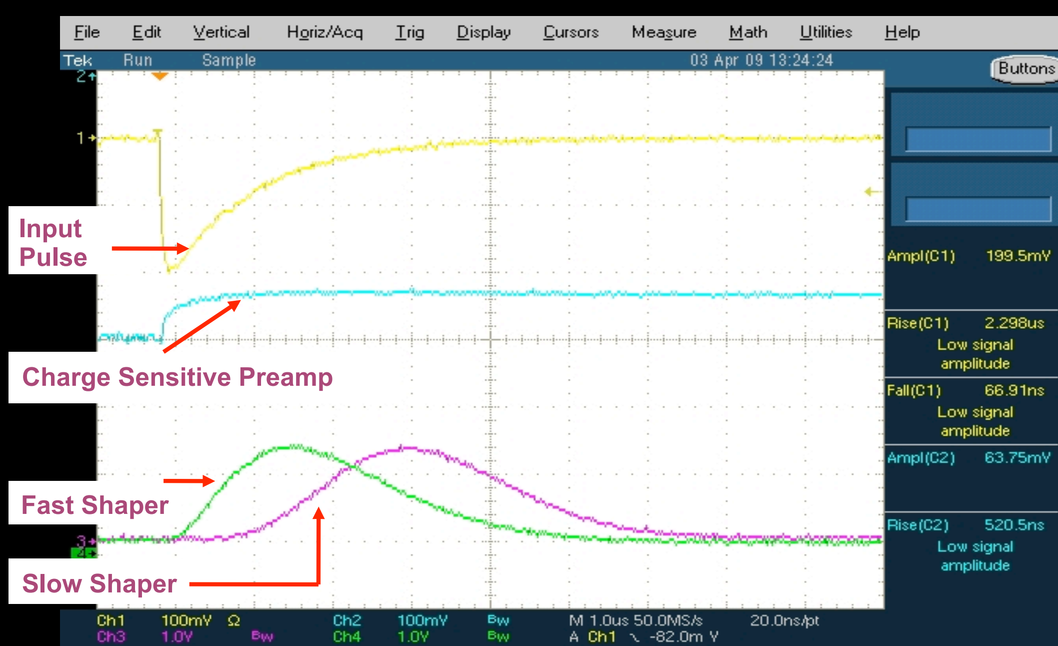
S. Kholdebarin, L. Ramsey

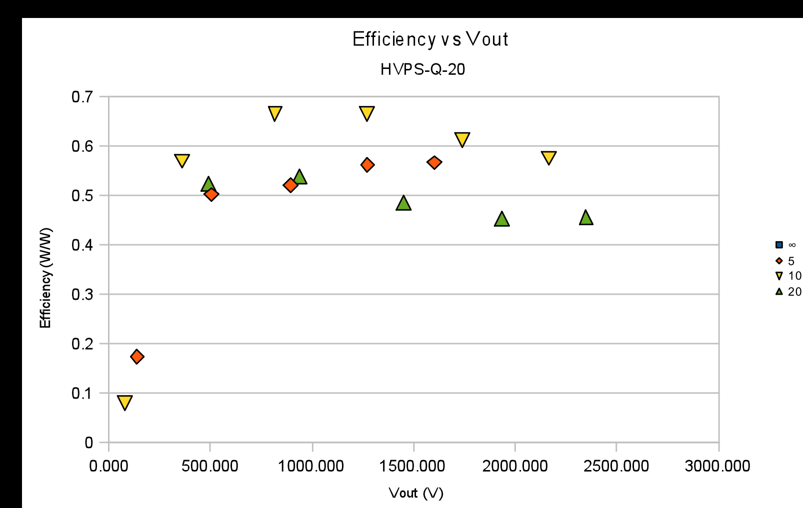
Prototyping the detection electronics

Testing the GRD front-end electronics

GSE SW for configuring instrument

Characterizing High Voltage Power Supply





Student involvement - UMES

- UMES students are taking a class in spacecraft systems taught by Hawk personnel.
- 1-3 UMES students will intern at Hawk over the next year, assisting with the spacecraft design and integration, and flight software and ground station testing
- UMES students will mentor Pocomoke High students in operating the ground station

Schedule

- Project start: Sept 18, 2008
- Mission Requirements Review: Jan 12, 2009
- Design Review: June, 2009
- Experiment Integration: January 2010
- Spacecraft level environmental testing: Feb / March 2010
- PPOD environmental testing: April 2010
- Launch: August 2010

Status

- Successful Mission Requirements Review in Jan 2009
- Prototyping instruments
- Flight software and mechanical design underway
- Procurements for commercial subsystems underway
- Attitude Control System design underway

http://firefly.gsfc.nasa.gov