Active Experiments using Pulsed Electron Beams on Rockets and Satellites

Geoffrey Reeves, LANL
Beams have been used, successfully, for many active space experiments

- **Spacecraft Charging**: e.g. Mullen et al., 1986; Sasaki et al., 1986; 1988; Banks et al., 1990

- **Beam-Plasma Interaction Physics**: e.g. Gendrin, 1974; Cambou et al., 1978; Cambou et al., 1980

- **Magnetic Bounce and Drift Physics**: e.g. Hendrickson et al., 1975; Winckler et al., 1975; Hendrickson et al., 1976

- **VLF Wave Generation**: e.g. Monson et al., 1976; Dechambre et al., 1980; Obayashi et al., 1982; Farrell et al., 1988; Reeves et al., 1988; Reeves et al., 1990a; Reeves et al., 1990b

- **National Security Applications**: e.g. the BEAR Rocket
CONNEX
Magnetosphere-Ionosphere Connections Explorer

Beam PIE
Beam-Plasma Interactions Experiment
Relativistic Electron Accelerator Technologies

John Lewellen
Spaceborne Electron Accelerators

Jeff Neilson
Design of a Field-Emission X-Band Gun
Driven by Solid-State RF Source
Spacecraft Charging Mitigation

Grant Miars
Ion Emission Experiments Enabling Electron Beam Emission in Tenuous Plasmas
Beam Propagation & Beam Stability

Ennio Sanchez
Propagation properties of Relativistic Electron Beams for Active Experiments in the Magnetosphere
Beam Detection & Footpoint Identification

Bob Marshall
Diagnostic of Relativistic Electron Beam Injection in the Upper Atmosphere

Liz MacDonald
Active Experiment Science Enhancement through Citizen Science
The ultimate objective of CONNEX is not to operate an electron beam.

CONNEX will enable resolution of important, long-standing problems in understanding magnetosphere-ionosphere coupling.
What are the magnetospheric processes and conditions that drive various types of auroral & ionospheric activity?
“Quiet” & “Normal” Conditions

- Quiet time Auroral Arcs
- Growth Phase Arcs
- Onset Arc
- Auroral Beading
- Proton Arcs
- Poleward expansion & Westward traveling surge
- Rays & Folding
- ETC!
Active and Storm Conditions

- Storm-time Double Oval
- PBIs, Streamers
- Re-activation of the equatorward arc system
- Omega Bands
- Giant Pulsations
- Torches Structures
- ETC!
What are the ionospheric signatures of magnetospheric regions and processes?
What are the ionospheric signatures of magnetospheric regions and processes?

- Electron & Ion plasma sheets
- Substorm injection, dipolarization fronts, BBFs
- Sawtooth Events
- SAPS and SAID
- Ring current pressure peak
- Plasmapause
- Isotropic Boundary
- PSBL
- Open/Closed Boundary
Why do we need to know the magnetic connection?

In this example, field models map MMS to red or black points – or anywhere in between. That’s a HUGE difference, with no way to tell which is correct.

No way to link in situ measurements to aurora -> **and no way to know what creates the aurora**.

Furthermore the picture is **dynamic** and changes on time scales of minutes.
Measurements of magnetospheric boundaries, processes, & conditions

- Slightly Elliptical GEO
  e.g. ~ 5 x 8 Re
- Plasma fluxes
- Moments
  - temperature
  - density
  - pressure
- Plasma Gradients
- Magnetic fields, Gradients, & Curl
- Electric Fields and Flow Velocities
- 5 x 8 RE 24 hour orbital period keeps the entire orbit in the auroral / transition region 24 x 7 x 365
- Max/Min Latitude set by apogee/perigee (we can optimize the orbit)
- The entire footpoint loop can be precessed East-West
- Winter -> Canada Optical | Summer -> Alaska Radar
- One year of foot points shown below
- Up to 50 hrs in a 1°x1° bin
- Thousands of hours over any single ASI field of view
- East - West drift of the footpoint is fuel-cheap
TREx

Target Region

Slice

01 Greenline ASI
02 Blueline ASI
03 Imaging Riometer
04 Spectrograph
05 GNSS
06 Existing Infrastructure
  (SuperDARN, Redline Aurora, Magnetometers, etc.)

Derived Quantities
  (precipitating electron and proton energy flux, etc.)
Beam $\pi$

Beam Plasma Interactions Experiment

LCAS Proposal
Beam PIE
The Beam Plasma Interactions Experiment

- Quantitatively test theories of how energetic electron beams couple to plasmas to stimulate whistler mode radiation

- Discover and characterize how energetic electron beams couple to plasmas to stimulate propagating X-mode radiation

- Measure and quantify the resonant wave-particle scattering of ambient ionospheric electrons by X-mode electromagnetic waves

- Demonstrate advanced linear electron accelerator technologies for CONNEX and other future space experiments
• Mother-Daughter Configuration

• Accelerator payload with a 0-60 keV pulsed beam

• Receiver payload with fields, waves, plasma spectrometer, Langmuir probe & attitude control

• Launch from Poker to ~450 km in dark skies but Quiet conditions
• Generate whistler and X-mode waves using various pulsed electron beam patterns
• Detect and characterize the waves at the receiver payload
• Measure the ambient electron pitch angle distribution near the bounce loss cone
• Look for an increase in upward-going electrons when the beam is generating waves
Collaborative Ground Instrumentation (as available)

- **Purpose:**
  - To remotely sense whistler and X-mode waves
  - Beam propagation
  - Demonstrate detectability

- **Wave Receivers**
- **AMISR radar**
- **Optical Detectors**
- **Riometers**
Both whistler and X-mode waves will be generated (at different frequencies).

Chart (wave power at 50 kHz, 5% duty cycle) shows X-mode actually dominates.
Predicted whistler and X-mode wave power as a function of modulation frequency.

- All plots are for a 5 keV - 5% duty cycle beam.
- Note the relative wave powers and discrete harmonic structure.
Whistler mode wave power is a function of beam energy and pitch angle.
X-mode wave generation by electron beams has not previously been studied.

Upper hybrid frequency: $\omega_{uh} = 2.3 \omega_{ce}$
Beam Operations

Almost Infinitely Configurable

Electron gun with variable voltage (nominally 3 to 20 kV)

6-GHz accelerator cavity with up to 40 keV energy gain

3 keV to 60 keV electron beam (10-20 mA)

Multiple 5-GHz, 500-W HEMT RF drivers

Coupling from RF drive to cavity

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<table>
<thead>
<tr>
<th>Beam Firing</th>
<th>Beam Energy</th>
<th>Modulation Frequency</th>
<th>Mini Pulse</th>
<th>Duty Cycle</th>
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<td>1</td>
<td>5 keV</td>
<td>50 kHz</td>
<td>1 μs</td>
<td>5%</td>
</tr>
<tr>
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<td>11</td>
<td>60 keV</td>
<td>5 kHz</td>
<td>10 μs</td>
<td>5%</td>
</tr>
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</table>

T_pulse = 0.5 sec

T_mini = 100 μs

each vertical line is a burst of electrons, spaced at 5.1 GHz
The final pitch angle distribution of test electrons with energy 39 keV and initial pitch angle 69° evolving in the field of an X-mode wave with $\omega = 2.1 \omega_{ce}$ for 0.4 ms.
Beam PIE Team

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- Geoff Reeves
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Thank You