

# *Exploring Geospace Using NASA Sounding Rockets*

## Canadian Space Agency Workshop

Robert F. Pfaff, Jr.

Project Scientist, NASA Sounding Rocket Program  
Goddard Space Flight Center  
Greenbelt, MD, USA

Boucherville, QC, Canada

April 15, 2010

## *Outline of Presentation*

- General Features of NASA's Sounding Rocket Program
- Science Discipline Requirements and Examples of Accomplishments
  - Astronomy / Planetary / Solar
  - Geophysics
  - Microgravity
  - Special Projects (e.g., Re-entry tests, Aerobraking, etc.)
- SR Technology Roadmap -- Future Prospects
  - Small Mesospheric Payloads
  - High Altitude Sounding Rocket
- Summary

## *NASA Rocket Program -- General Remarks*

- For over 4 decades, NASA's Sounding Rocket Program has provided an essential ingredient of the agency's exploration and science initiatives.
- Sounding Rocket Program rests solidly on 3 critical elements:
  - Unique, **cutting-edge science** missions
  - Platform for development and **test of new technology**
  - **Education and training** of students, young researchers, and engineers
- Two important features of the program:
  - **Low Cost**
  - **Rapid, quick response**

## *NASA Rocket Program -- General Remarks (cont.)*

- Success of NASA Sounding Rocket Program *implementation* rests on a strong three-way partnership:

**P.I. • Sounding Rocket Program Office (Wallops) • NASA HQ**

- An important aspect of the program is that **the P.I. is firmly in charge of the mission** -- from proposal to payload design to making the launch decision to the data analysis and publication of results.
  - Very appealing aspect of SR program to scientists.
  - P.I. must work within an agreed-upon science budget with no contingency.
  - Scope of project must stay within “envelope” outlined in proposal approved by both HQ and SRPO.
  - Excellent, “real world” training for P.I., particularly with respect to managing a scientific investigation.

## *NASA Rocket Program -- General Remarks (cont.)*

Program serves numerous scientific disciplines at NASA:

- **Astronomy**

  - UV Astrophysics

  - High Energy Astrophysics

- **Planetary**

- **Solar**

- **Geospace**

  - Magnetosphere (Auroral Acceleration and other Plasma Physics)

  - Ionosphere/Thermosphere/Mesosphere

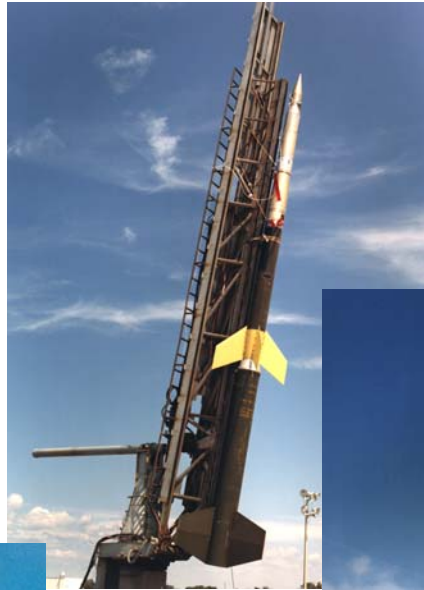
- **Microgravity**

- **Special Projects** (e.g., Aero-braking and Re-entry Studies)

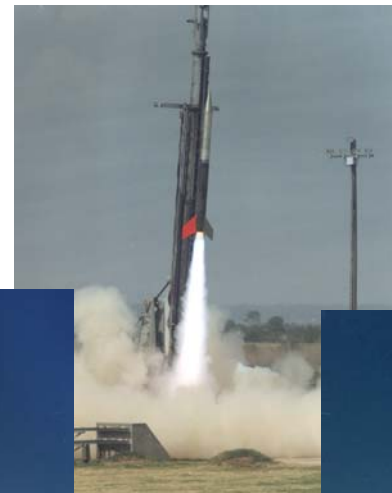
# *Sounding Rocket Vehicles*



*Terrier Malemute*



*Nike Orion*



*Orion*



*Black Brant XII*

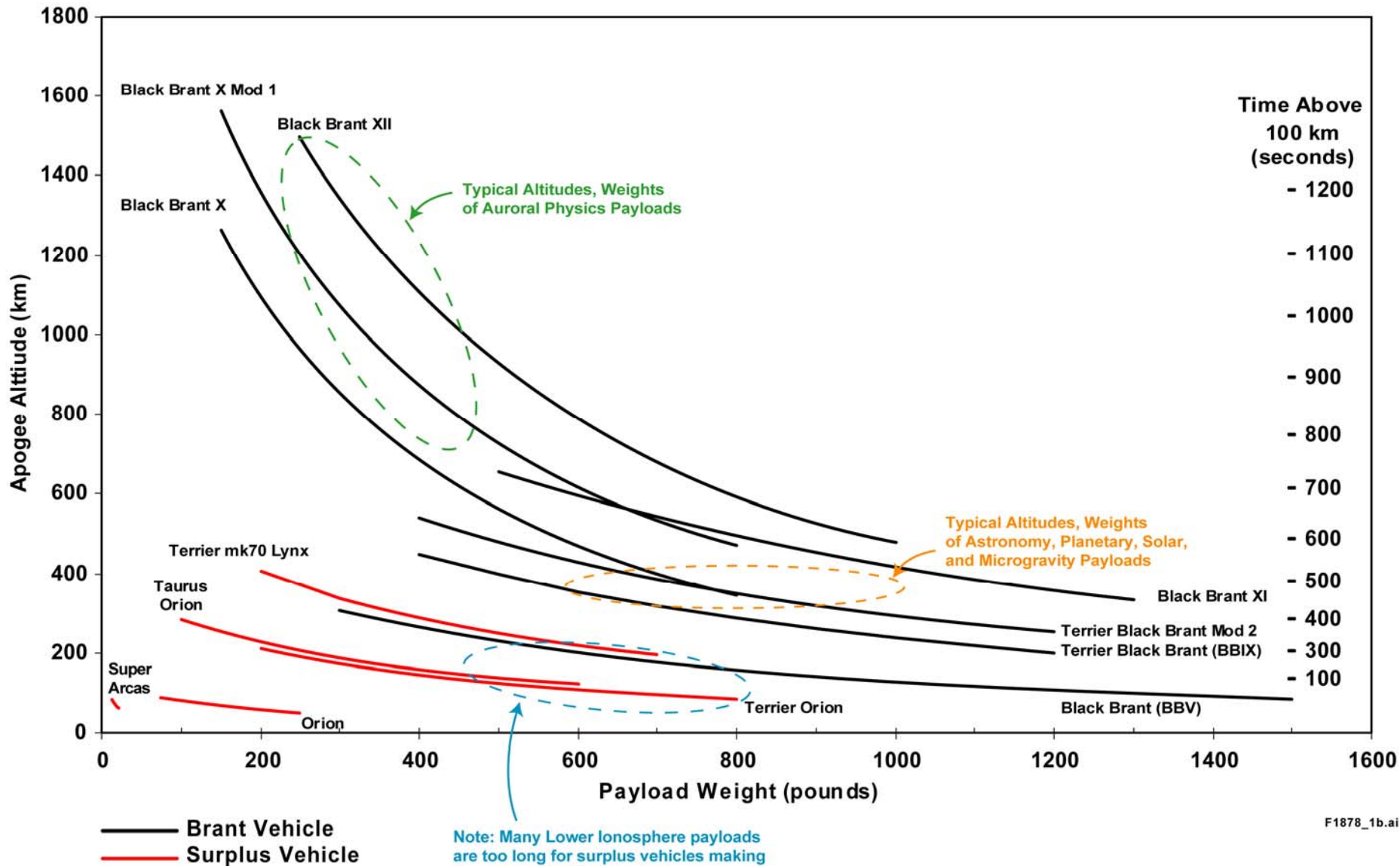


*Terrier Orion*



*Black Brant IX*

# NASA Sounding Rocket Vehicle Performance



# *Payload Design and Sub-systems -- Provided by Wallops Flight Facility*

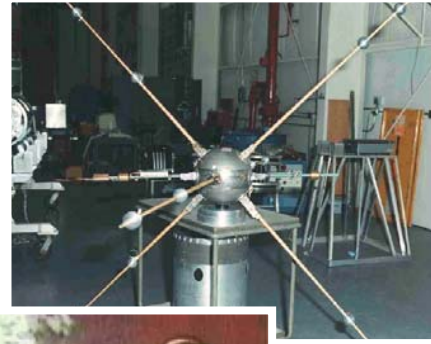
## Mechanical

Nosecones

Diameters range from 4 to 22 inches

Deployments

Sub-payloads



## Power

+28 V,  $\pm 18$  V, + 9 V typical

10-100 Watts typical (from batteries)

## Telemetry, Timers, Commands

Multiple links up to 10 Mbps typical

Serial, parallel, analog data accepted

GSP provides trajectory

Uplink command for events, joy-stick control

Timing typically with  $< 0.1$  sec accuracy

## Attitude Control and Knowledge

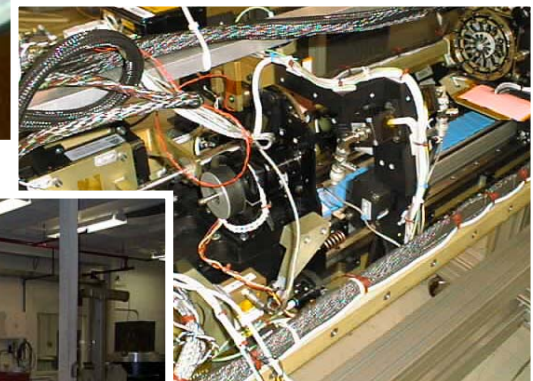
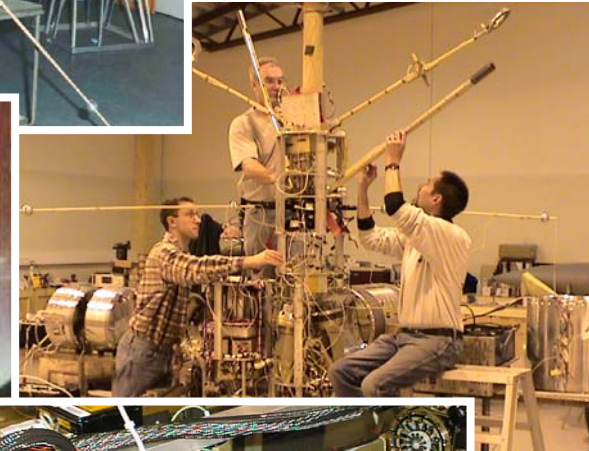
Coarse pointing along or perp to B or V

Fine pointing to  $\sim 0.1$  arcsec

## Recovery sub-systems

Land, Water, Air

## Trajectory and Performance Analysis



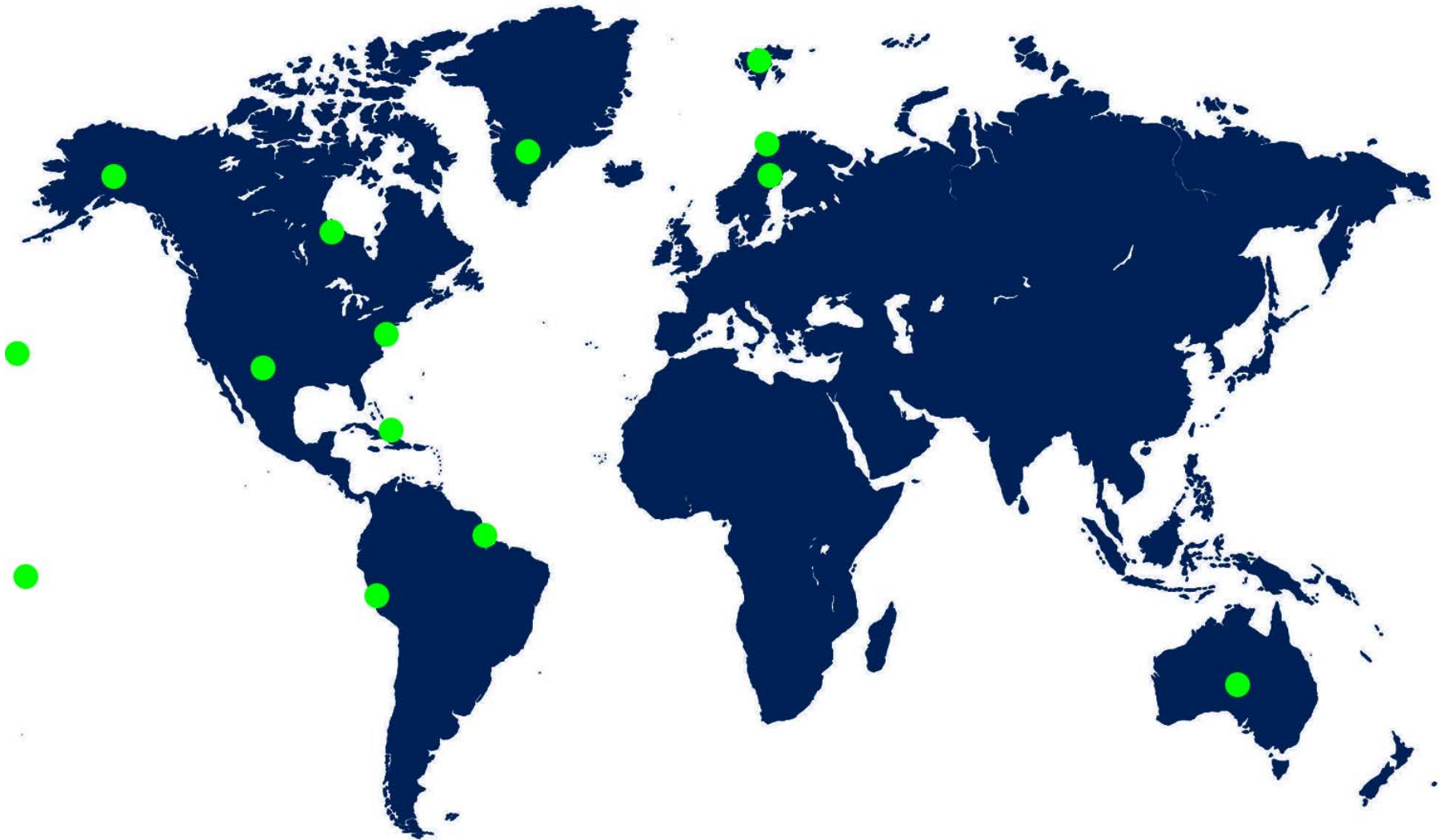


## *Sounding Rocket Launch Sites Used by NASA in last 25 years*

- US Fixed
  - Wallops Flight Facility
  - White Sands Missile Range
  - Poker Flat Research Range
- Foreign Fixed
  - Sweden
  - Norway (Andoya & Svalbard)
  - Canada (Churchill)\*
- Mobile
  - Australia
  - Brazil
  - Puerto Rico
  - Greenland
  - Peru
  - Kwajalein
  - Hawaii



\* No Longer Routinely accessible



Sounding Rocket Launch Sites Used by NASA in the Last 25 Years

# *Sounding Rocket Mission Categories*

Requirements

Examples of Accomplishments

1. Astronomy -- Planetary -- Solar
2. Geospace

## *Sounding Rocket Mission Categories*

Disciplines: UV Astronomy, X-Ray, Planetary, Solar

### Remote sensing (Telescopes)

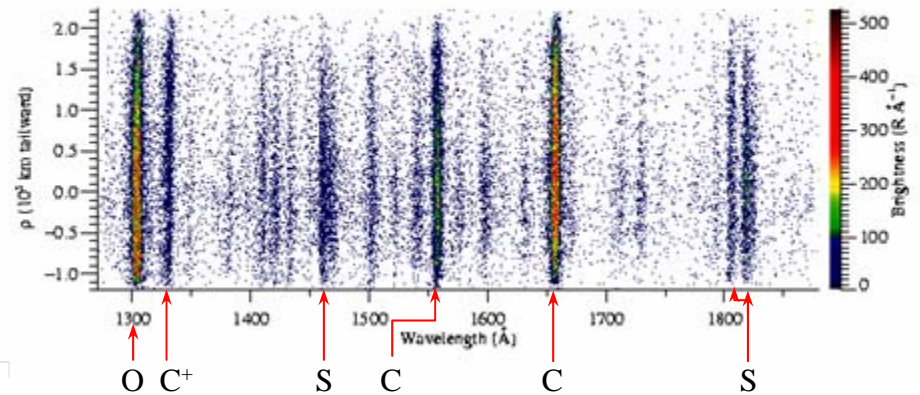
- Main requirements:
  1. Observing platform above earth's atmosphere
  2. Fine pointing of payloads (sub-arc second usually required)
  
- Features:
  3. Real-time, joy stick uplink command positioning available
  4. Payload recovery/re-flights are routine (launches are at White Sands)
  5. Southern Hemisphere launch location (Australia) used on campaign basis
  6. Ability to observe sources close to the sun (e.g., comets, Mercury, Venus)

# Strongest Ever Carbon Monoxide Production Discovered in Coma of Comet Hale-Bopp



Image of Comet Hale-Bopp, courtesy W. Johnsson.

Comet Hale-Bopp -- 6 April 1997  
JHU-NASA Sounding Rocket 36.156 UG

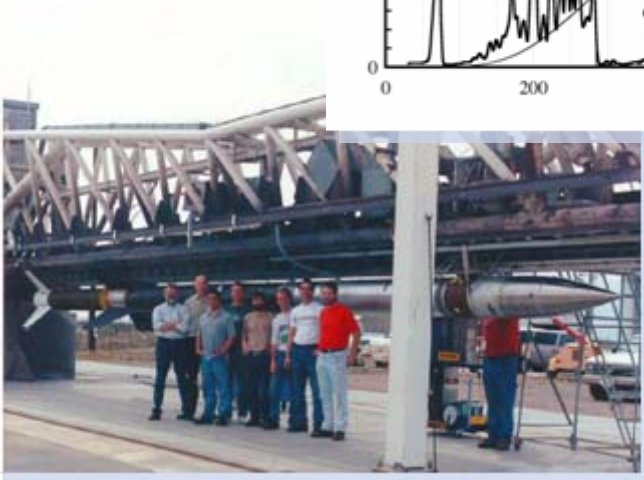
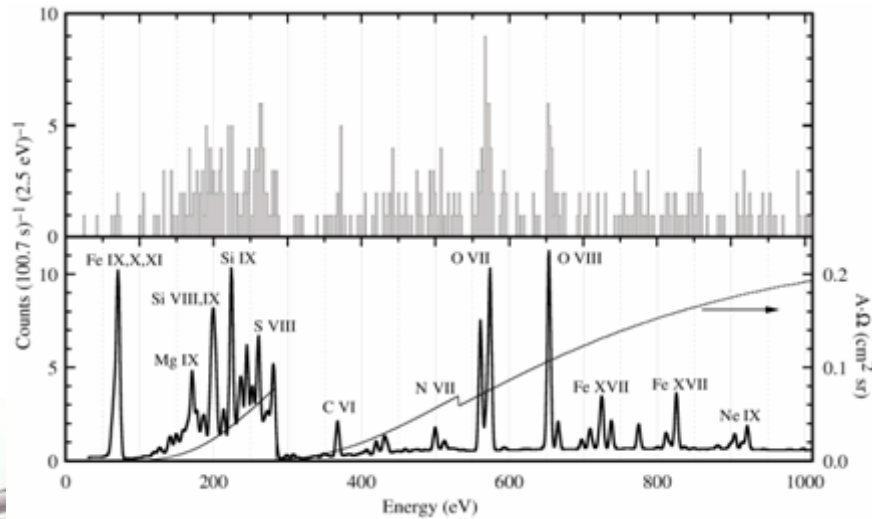


- Remaining emissions are bands of the carbon monoxide Fourth Positive system.

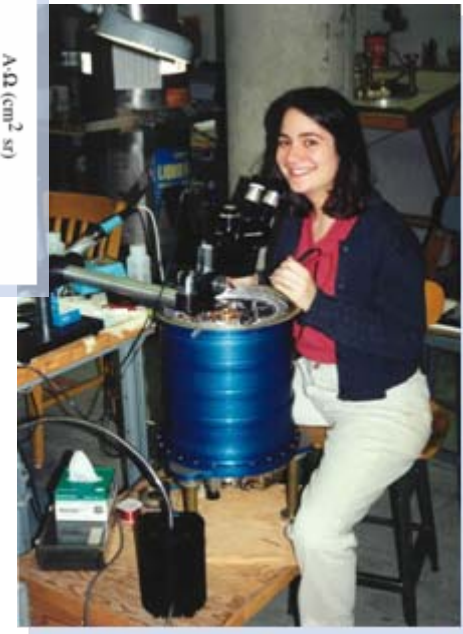
- Carbon abundances may simply result from photodissociation of CO.
- Observations gathered very close to perihelion; Comet was very active.

[Data: P. Feldman, Johns Hopkins Univ.; See also J. McPhate, *Ap. J.*, 521, 920, 1999.]

# New X-Ray Detector Developed on Sounding Rockets



Scientists at the launch pad



Graduate student checks instrument

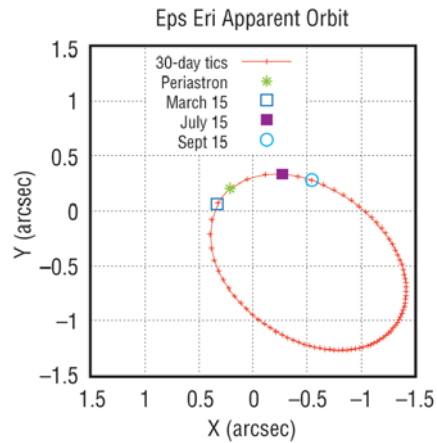
- **1st Detection of diffuse emission in 172 Å Fe lines**
- **Observations demonstrate soft X-ray background is thermally produced.**
- **Detector to be deployed on Astro-E2, Constellation-X, XEUS**

# Planet Imaging Concept Testbed Using a Rocket Experiment

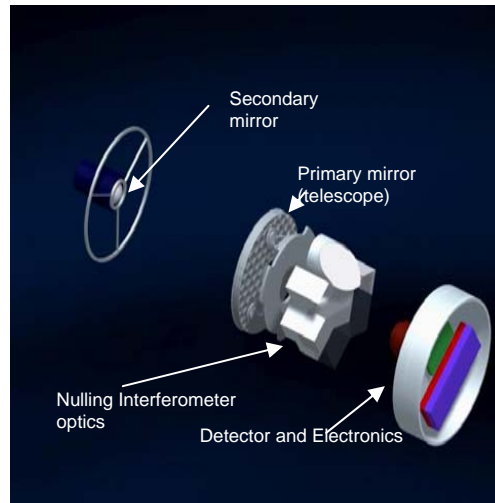
**Goal 1:** Directly image an extrasolar planet using telescope flown on a sounding rocket

**Goal 2:** Demonstrate nulling interferometer technology for future NASA missions

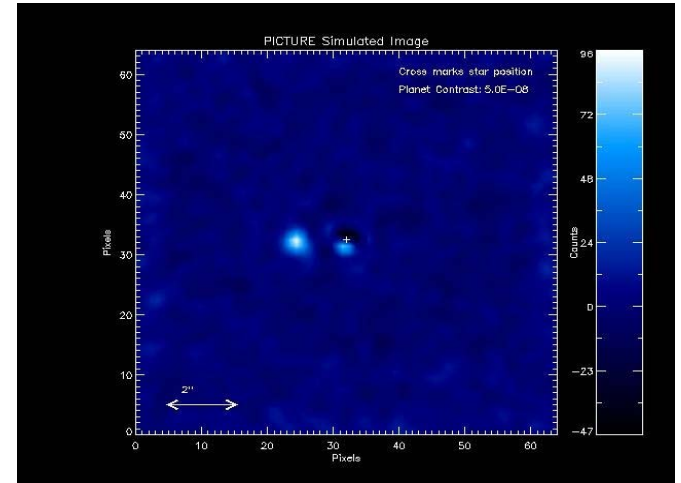
**Status:** In Development; first launch in summer '07



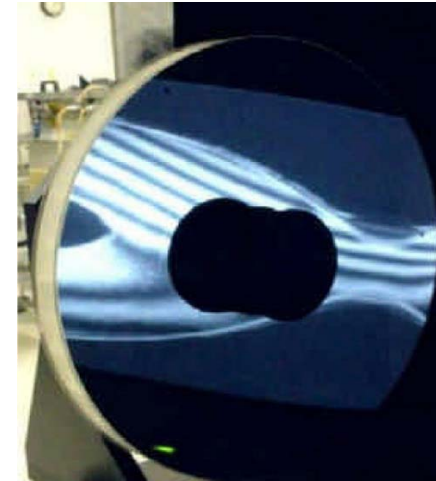
Accurate pointing  
( $<0.1$  arc sec) needed.



Experiment concept



Expected Image, Planet Contrast:  $5 \times 10^{-8}$



Lightweight primary mirror;  
0.5m dia, 4.5 kg



Carbon fiber  
telescope  
structure

*S. Chakrabarti, Boston University, P.I.*

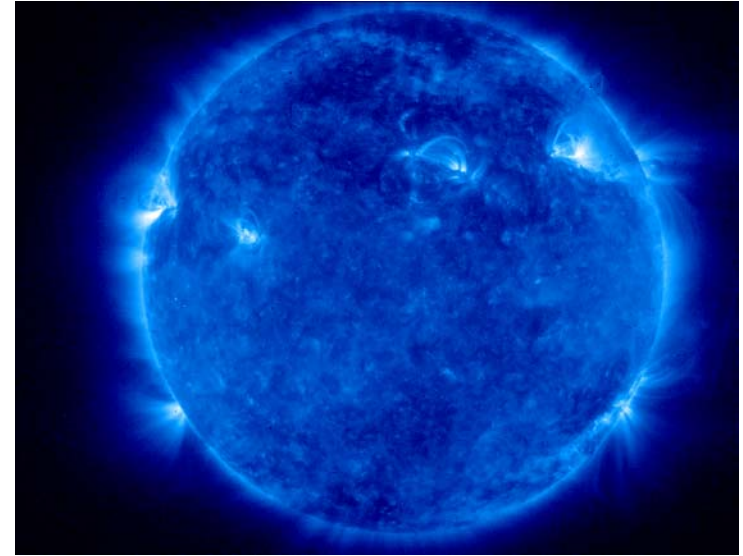
<http://newsroom.spie.org/x3847.xml>

# High Time and Spatial Resolution Reveal New Features of Solar Physics



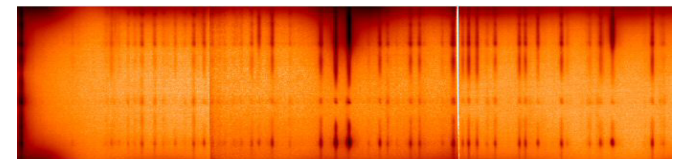
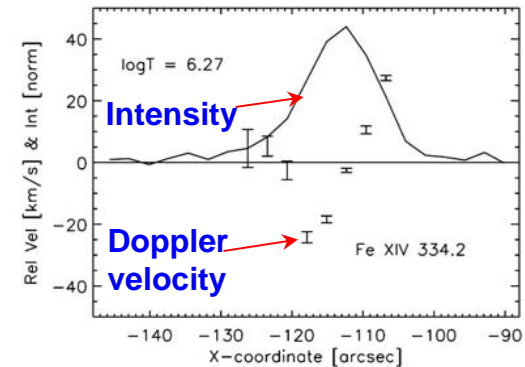
Images of sun using normal incidence, multi-layer optics revolutionized high resolution studies of the corona and paved the way for EIT on SOHO.

Image: Moses, NRL



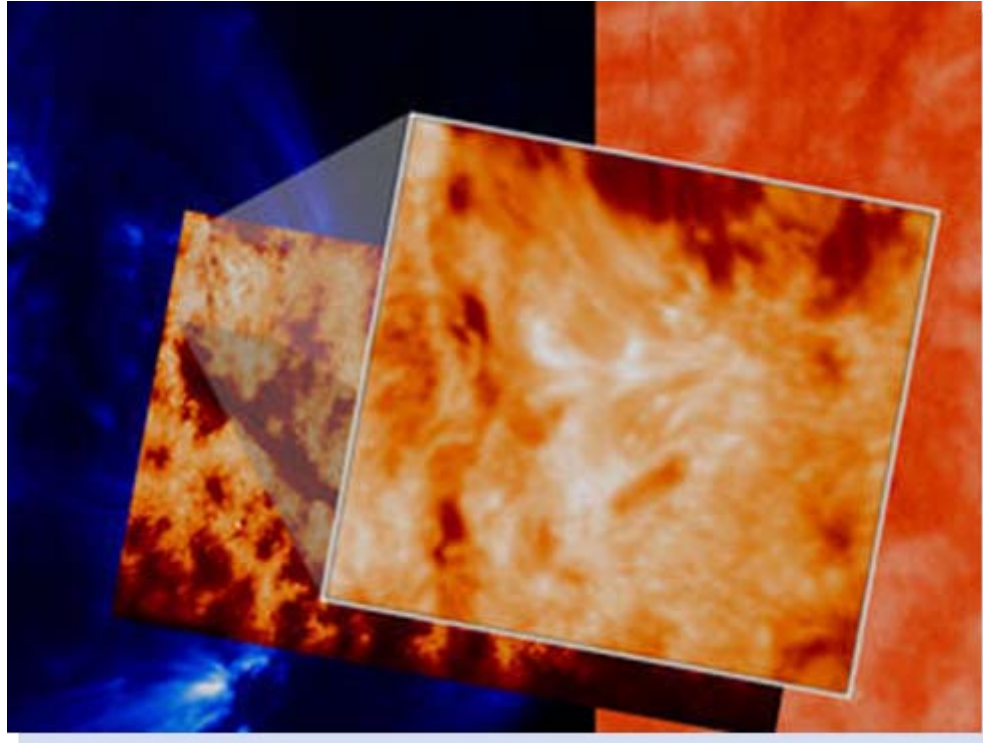
Sounding rocket measurements of the solar corona in/outflow that formed the basis for Rottman et al. 1982 *Ap J*. article was a primary motivation for the SOHO mission.

EUNIS [Rabin et al., 2006] measured both upflows and downflows of up to 40 km s<sup>-1</sup> in a coronal bright point at temperatures in excess of 2 x 10<sup>6</sup> K, **the highest temperatures at which flows have been reported in a bright point and a challenge to existing models.**





## *High Time and Spatial Resolution in Lyman $\alpha$ Reveal New Features of Solar Chromosphere*



- **Highest Spatial resolution achieved to date (<0.3 arc sec)**
- **Simultaneous measurements with SoHo, TRACE enable different layers of the sun to be observed of the same region**

Very high Angular resolutions ULtraviolet Telescope (VAULT), Naval Research Lab

# *Solar Physics Experiments on Sounding Rockets*

## *Instruments that contributed significantly to Orbital Missions*

**Bruner, Walker, Golub, Moses, Rabin:** EUV Multilayer Normal Incidence Optics  
for High Resolution

SOHO EIT, TRACE, STEREO EUVI, SDO AIA, Hinode

**Davis, Moses:** Soft X-ray Grazing Incidence and CCD detectors

Yohkoh, Hinode X-ray telescopes

**Neupert, Davila:** EUV Spectroscopy

SOHO CDS, Hinode EIS

**Brueckner, Bruner, Korendyke:** VUV Spectroscopy

SOHO SUMER, TRACE

**Cole:** UV Spectroscopy of the Corona

SOHO UVCS

**Woods, Judge:** EUV Irradiance Monitor

SOHO, SDO EUV instrument

## *Sounding Rocket Mission Categories*

### Geospace (Magnetosphere, Ionosphere, Thermosphere, Mesosphere)

#### *In situ measurements (general)*

- Main requirements/features:
  1. Access to altitudes too low for satellite *in situ* sampling (25-125 km region)
  2. *Vertical* profiles of measured phenomena (cf. satellite *horizontal* profiles).
  3. Slow vehicle speeds enable new phenomena to be studied; payloads “dwell” in regions of interest
  4. Launches are frequently in geophysical “Targets” (e.g., aurora, cusp, thunderstorms, ionospheric turbulence at equator, noctilucent clouds, electrojets, ionospheric metallic layers, etc.)
  5. SR Portability provides access to remote geophysical sites (high, middle, low latitudes)
  6. Launches in conjunction with ground observations (e.g., radars, lidars, etc.)

(Continued)

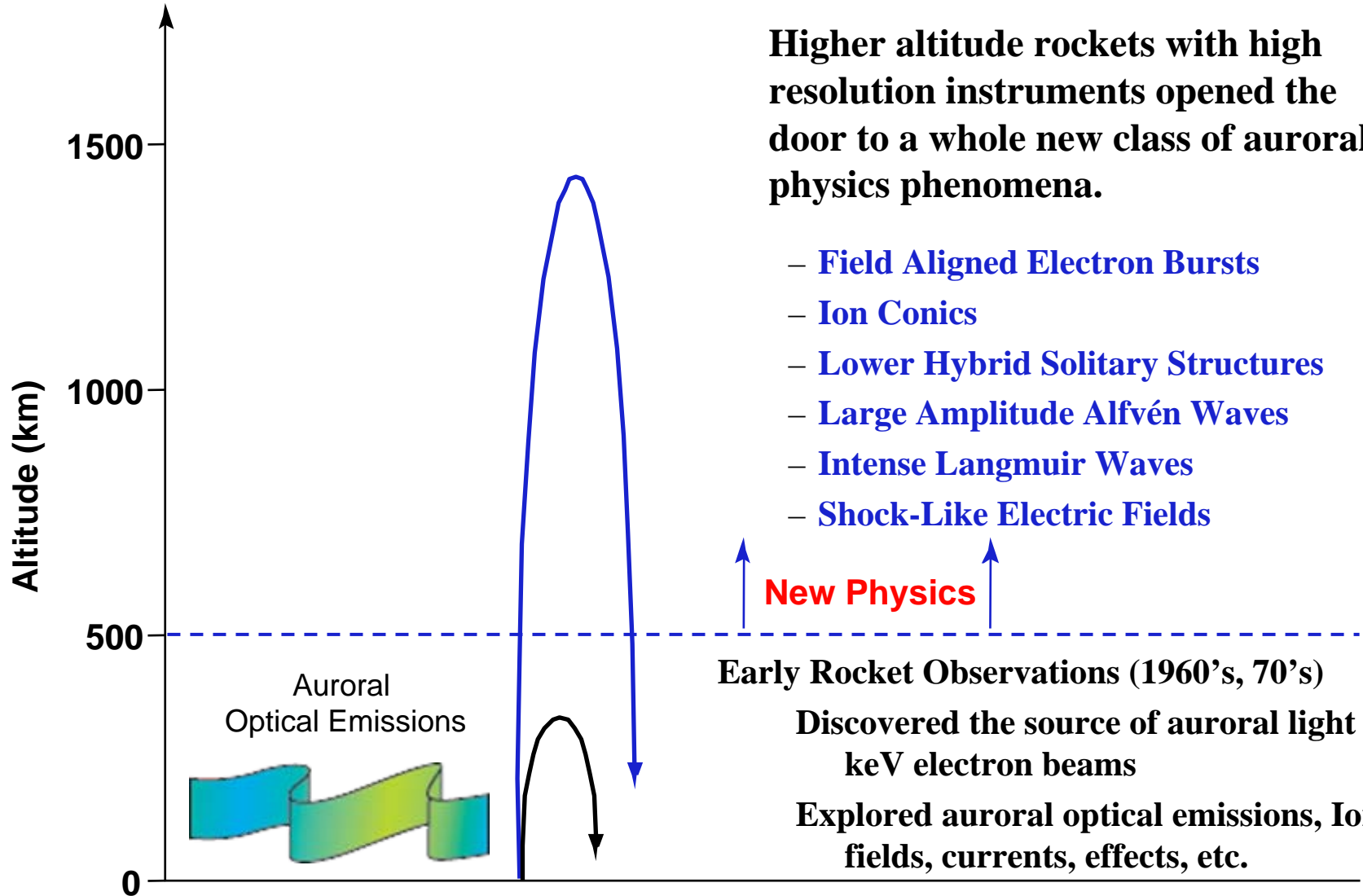
## *Sounding Rocket Mission Categories*

### Geospace (Magnetosphere, Ionosphere, Thermosphere, Mesosphere)

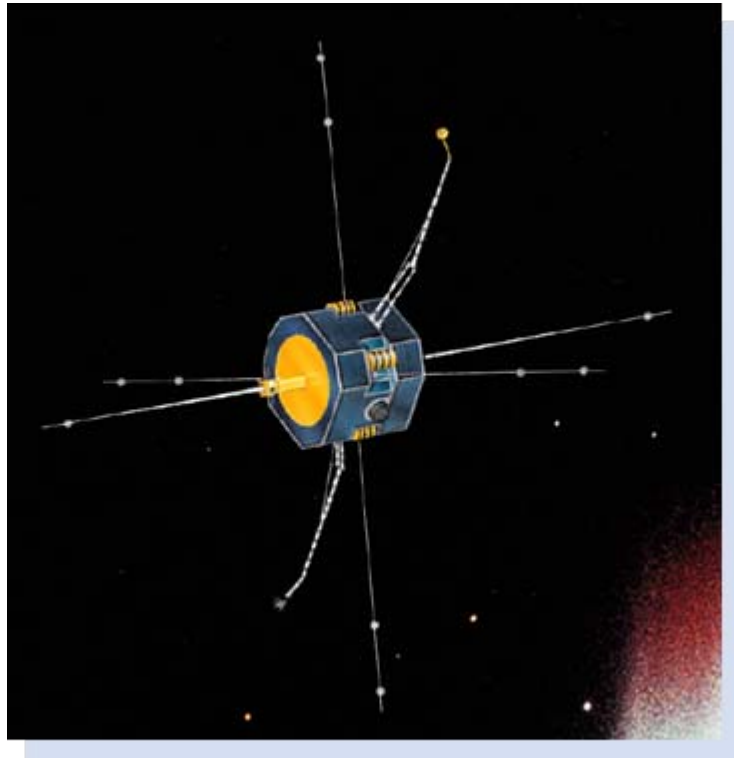
#### *In situ measurements (general)*

- Main requirements/features (continued):
  7. Multiple payloads (clusters) launched on single rocket
  8. Multiple, simultaneous launches (high and low apogees, different azimuths, etc.)
  9. Luminous trails to serve as tracers of geophysical parameters such as winds
  10. Flights in conjunction with orbital missions (e.g., Dynamics Explorer, TIMED)
  11. Tether capabilities (e.g., 2 km tethers between payloads have been flown)
  12. Collection of stratosphere/mesosphere samples (e.g., 24 underflights of UARS)

# *Auroral Physics on Sounding Rockets: Understanding Particle Acceleration in Nature*

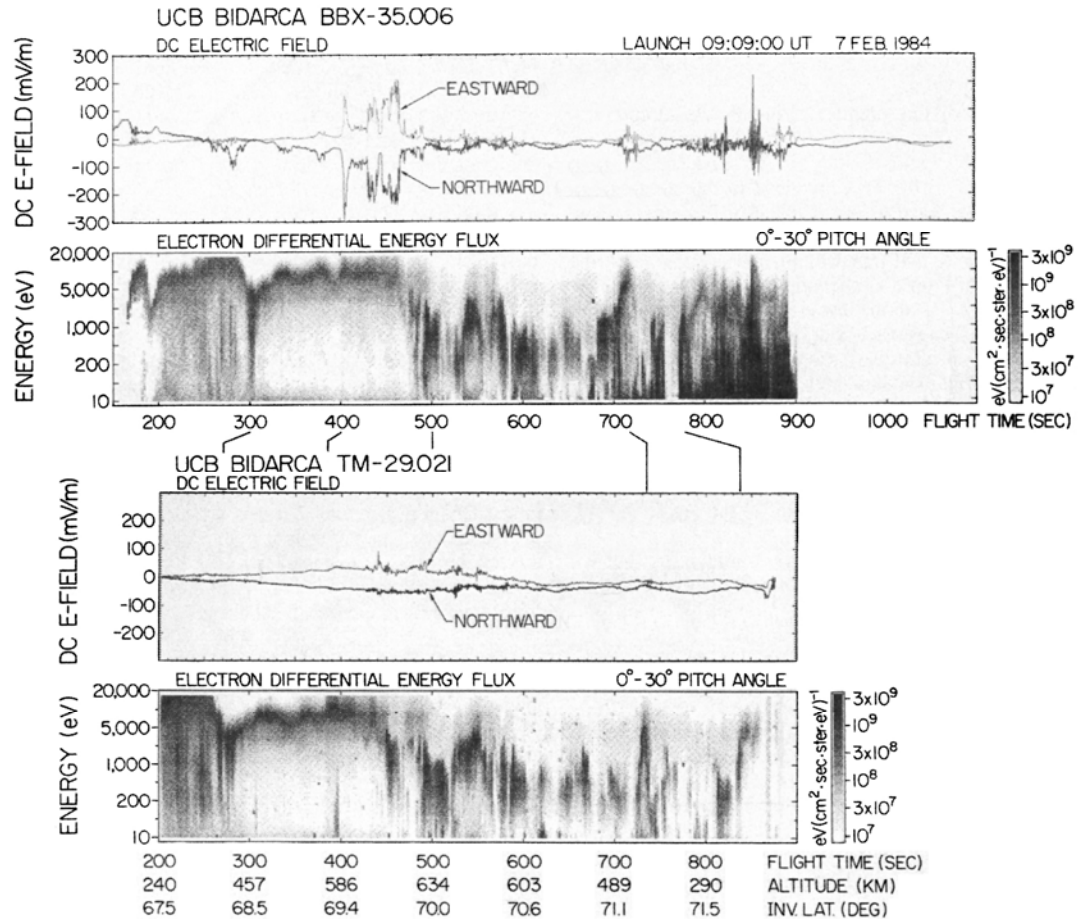
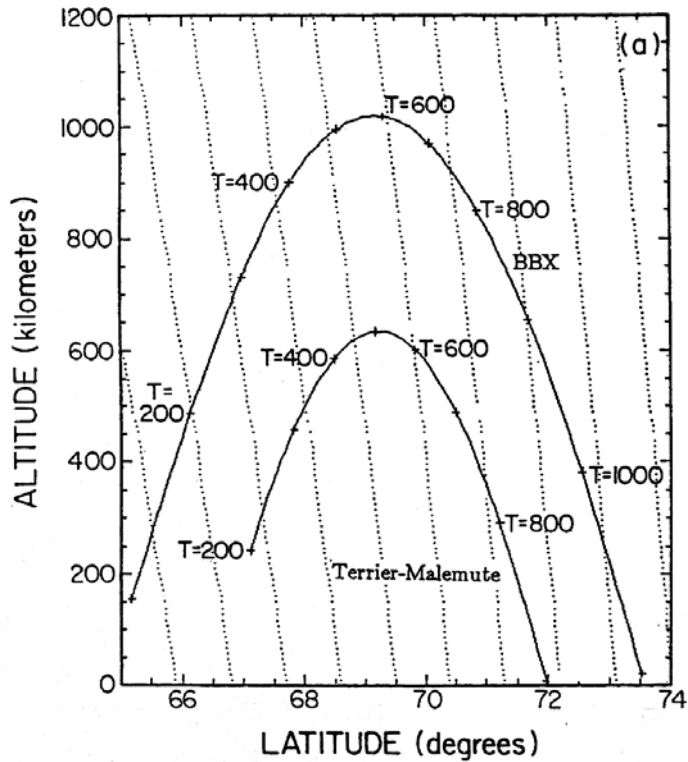


## *Auroral Zone Rocket Discoveries Formed the Springboard for NASA's FAST Satellite*



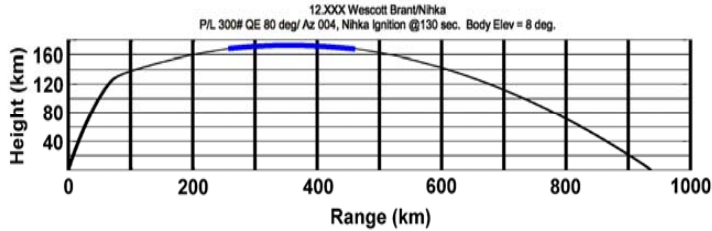
- **Auroral physics discovered on sounding rockets formed the basis of FAST Small Explorer Satellite**
- **FAST in-situ instruments were developed on rockets (e.g., “Top Hat” electrostatic detectors, plasma wave Interferometers)**
- **FAST experimenters, including P.I., had extensive prior experience with sounding rockets**

# Dual-Rocket Observations of Electrostatic Shocks in the Auroral Zone

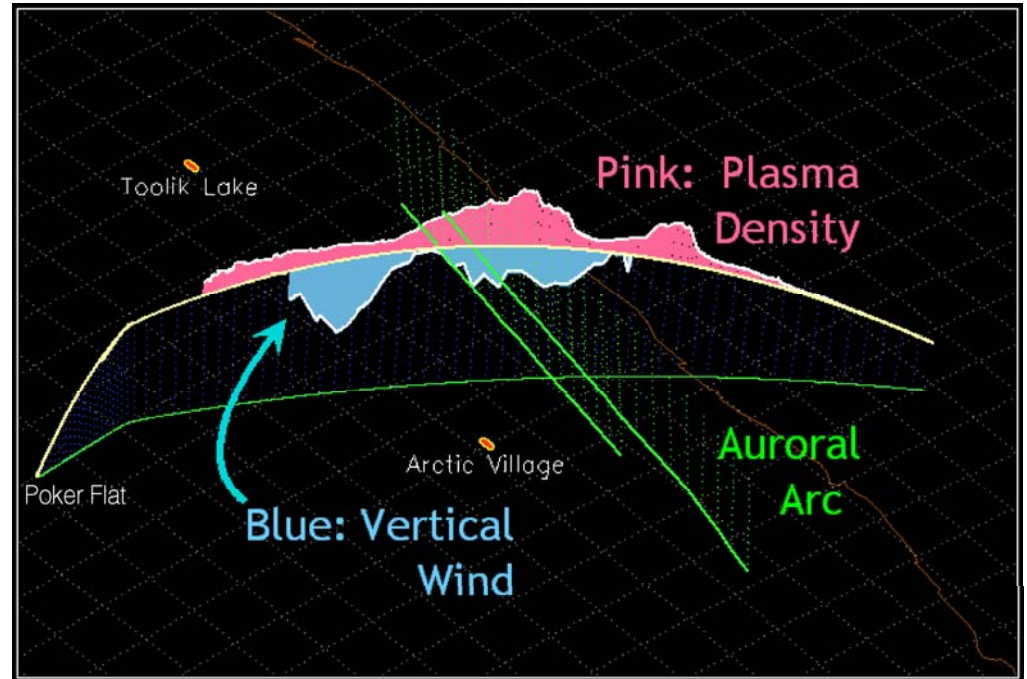


[Boehm et al., JGR, 1990]

# NASA's first "Tailored" Trajectory Reveals Vertical, Horizontal Winds over Auroral Arc



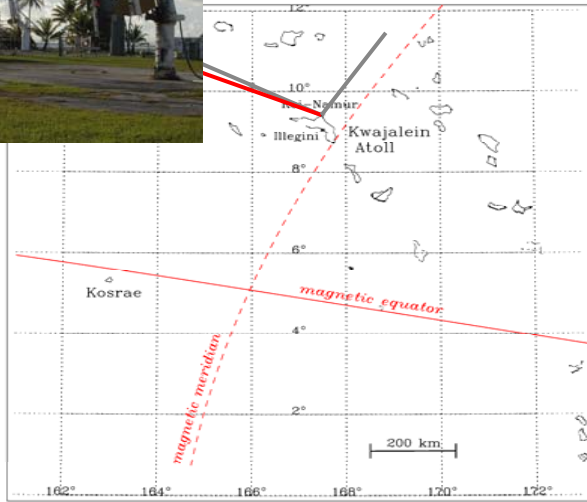
Puffed chemical release "trail"



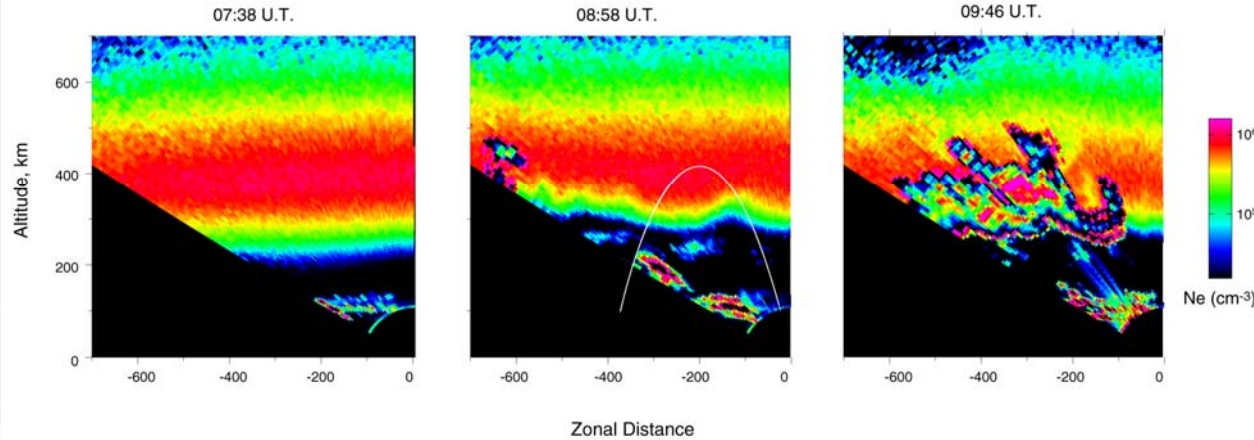
- HEX project (Univ. Alaska) measured *vertical* winds by deploying a *near-horizontal* chemical trail over a large horizontal trajectory that traversed a stable auroral arc.
- This required actively re-orienting the rocket prior to 3<sup>rd</sup>-stage ignition. (First for NASA.)
- Results revealed *downward* winds in the vicinity of the arc, defying the usual presumption that Joule heating would drive neutral upwelling near arcs. Downward wind was also accompanied by an unexpectedly large divergent velocity gradient in the zonal direction.
- Results a **complete surprise**, suggest upper atmosphere gravity waves dominate physics.



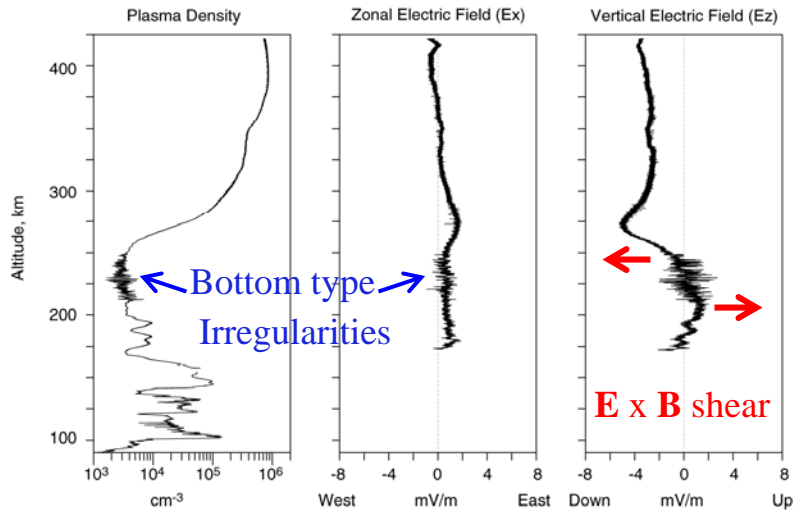
# Vertical Profiles of Electrodynamics at Onset of Equatorial Spread-F Reveals $E \times B$ Shear, Bottomside Waves believed to “Trigger” instability



Altair Radar — 158 MHz  
Kwajalein Atoll — 7 August 2004



Kwajalein Atoll — 29.037  
7 August 2004  
Upleg

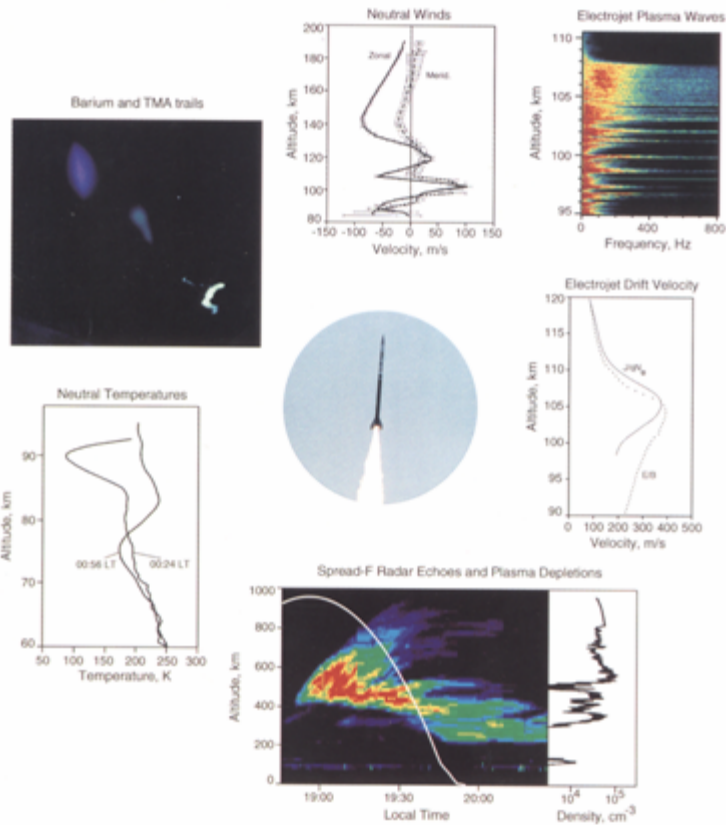


- Vertical electric fields prove the existence of strong shear flow and retrograde drifts in the bottomside F-region prior to onset of ESF.
- Rocket data show that bottom-type irregularities reside in valley region, below where the density gradient is steepest.
- Bottom-type irregularities shown to be viable “seeds” of equatorial spread-F.
- Dave Hysell, Cornell University, P.I.

# NASA Guar Campaign

## 13 Rocket Launches at the Magnetic Equator in Brazil

### Geophysical Research Letters



JULY 1, 1997

Volume 24 Number 13

AMERICAN GEOPHYSICAL UNION

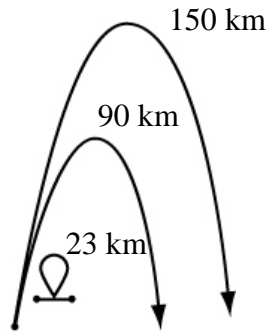
### Observations include several significant “Firsts”:

- Polarization DC electric field that drives the equatorial electrojet
- High altitude (>800 km) DC and wave electric fields gathered in a Spread-F plume
- Neutral wind gradients associated with enhanced E-fields at sunset
- Gravity wave breaking in the equatorial mesosphere
- Primary two-stream wave spectra and phase velocities in electrojet.

# Direct Penetration of Lightning Electric Fields in the Ionosphere, High T/M Reveals new Wave Physics

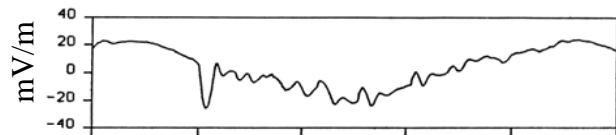
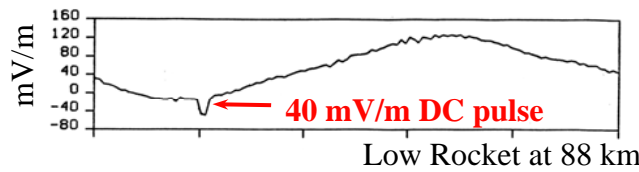


Ground Receiver, WFF

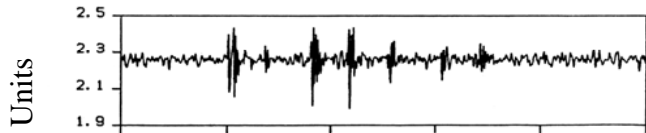


High Rocket at 142km

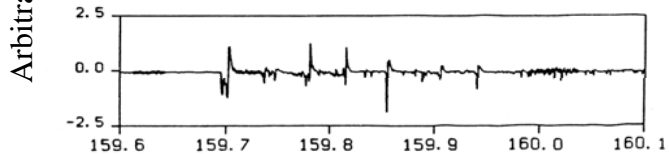
Thunderstorm Electric Fields



Balloon at 23 km

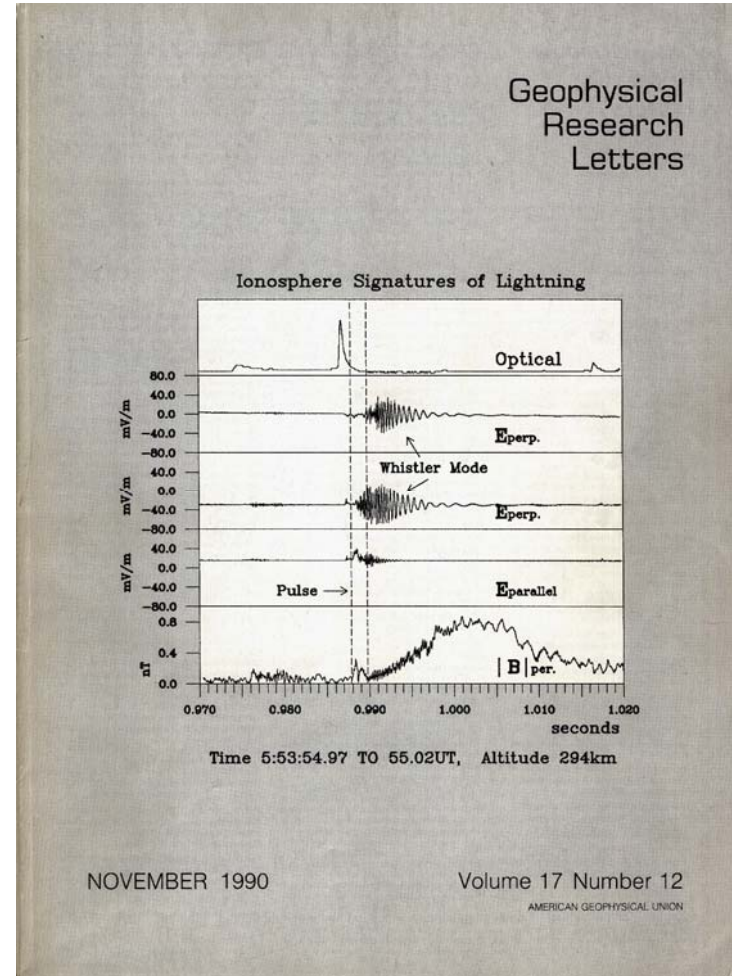


Ground Receiver



Seconds After Launch

[Kelley et al., JGR, 1985]



NOVEMBER 1990

Volume 17 Number 12

AMERICAN GEOPHYSICAL UNION

Detailed wave measurements show how sferics with parallel E-fields convert to whistler mode.

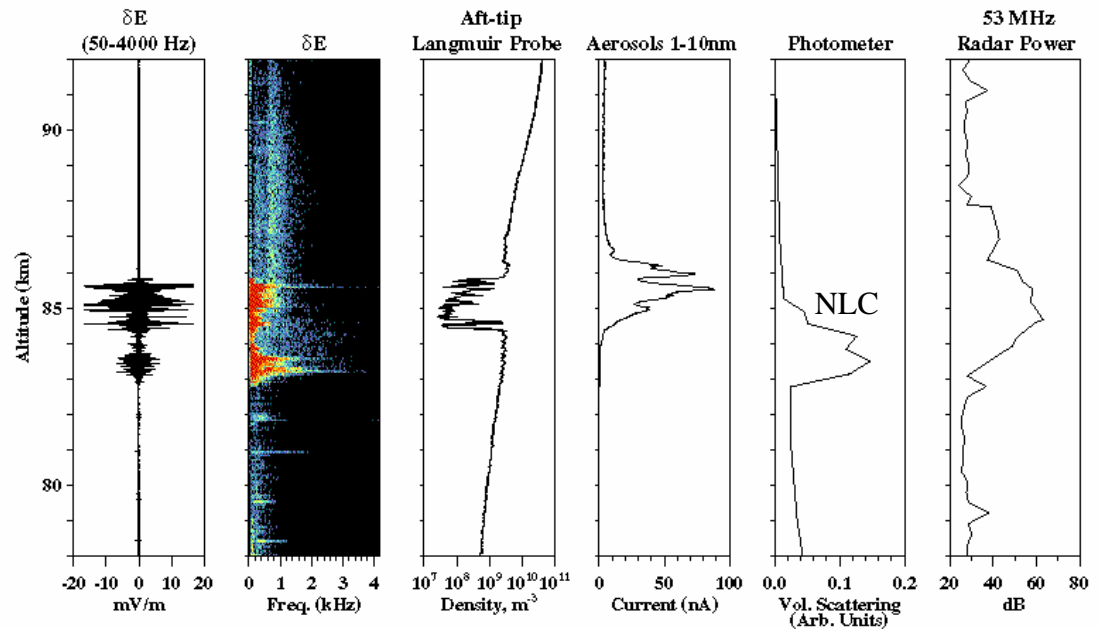
High T/M rates (~10 Mbps) make this possible

# Rocket Measurements of Noctilucent Clouds (NLC): A Near-Earth Icy, Dusty Plasma



- NLC located in high latitude summer mesosphere.
- Lowest neutral temperatures in atmosphere.
- Possible indicators of anthropogenic change
- Region of very intense radar echoes
- Complex aerosol chemistry, dynamics, electrical charge distributions.

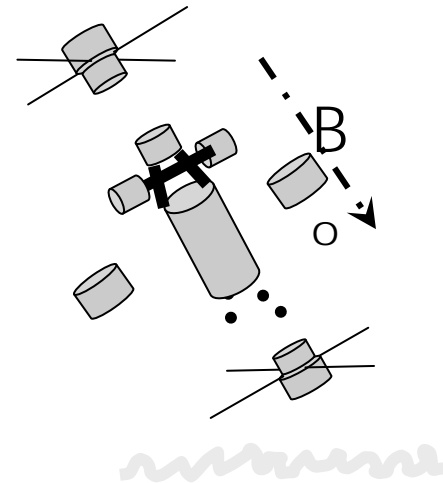
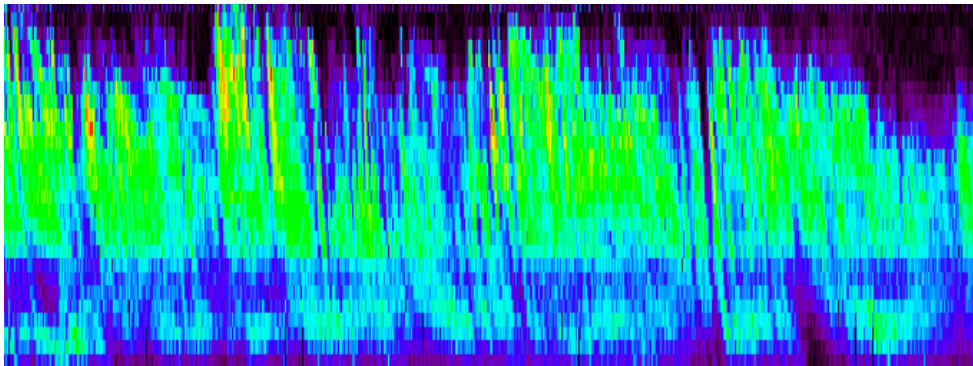
Data from rocket flight into NLC  
with intense radar echoes from  
Andoya, Norway



[see Goldberg et al., [GRL](#), 2001.]

## *Multiple Payloads on Single Rocket*

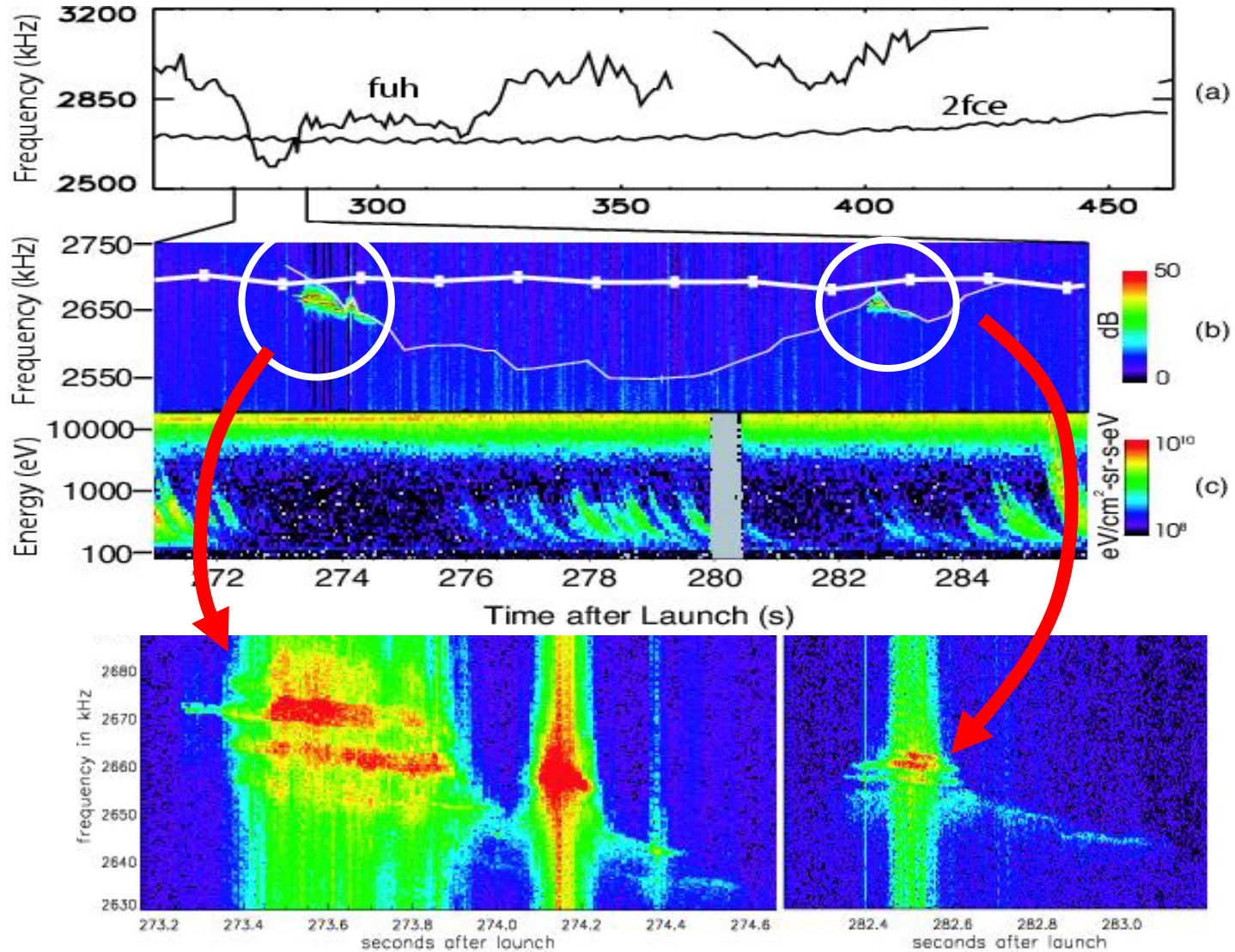
- Increasingly used for Auroral Studies where revealing spatial and temporal variations is important to understand physics
- 4-5 small “daughter” or sub-payloads have been flown (Lynch).
- Sub-payloads can be fired on small “rockets” to increase separation (Lessard)
- Multiple chemical releases on sub-payloads separated with high velocities reveal new wind information



CASCADES-2 Rocket (K.Lynch) includes 4 sub-payloads to examine arc structures, shears, Alfvén waves

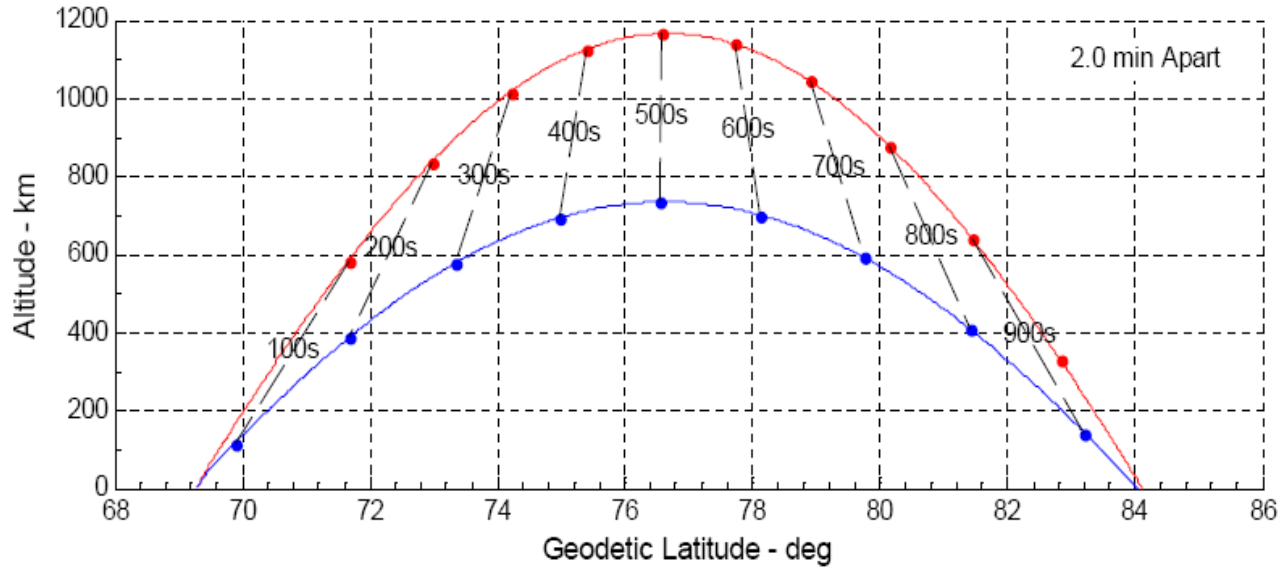
# Very High Telemetry reveals new phenomena

(Note: 180 Mbps flown from Poker in Feb. 2010 by LaBelle)

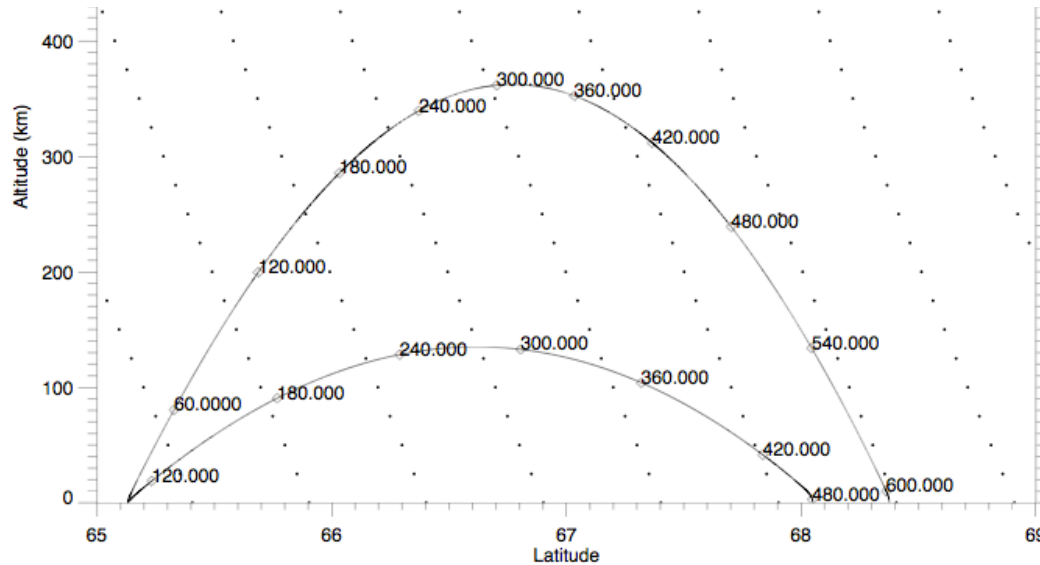


(expanded view)

# Dual Rockets Launched on Same Azimuth, different apogees



TRICE  
Kletzing, 2007



ACES,  
Bounds, 2008

# Rocket Underflights of Satellite Missions provide critical calibrations and correlative measurements

## TIMED Calibration (Univ. Colorado, Woods) -- 5 Flights, Also anticipated for SDO

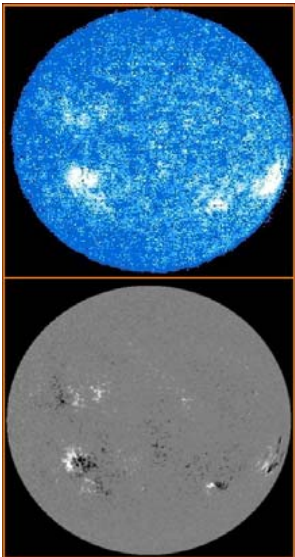
Primary Objective:

Provide an underflight calibration for the Solar EUV Experiment on TIMED

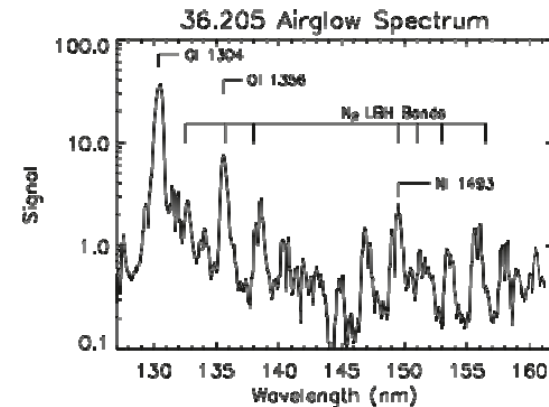
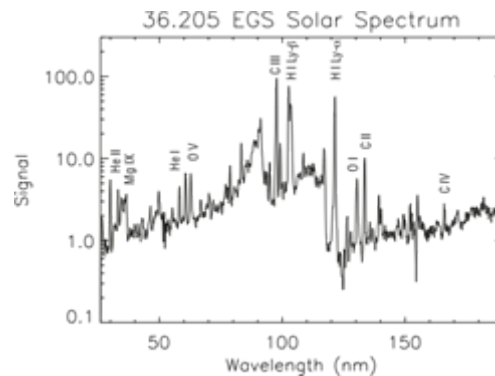
Secondary Objectives

- Provide an underflight validation for the TIMED GUVI measurements of the FUV airglow
- Provide validation for the TIMED measurements of the neutral densities (O, O<sub>2</sub>, N<sub>2</sub>)

Rocket Ly- $\alpha$  Image



SOHO  
Magnetogram



- EGS degradation determined with these rocket results
  - 10-20% changes observed
- XPS degradation
  - < 1% degradation for most XUV photometers
- Long-term accuracy for the SEE solar irradiances is improved by about a factor of 2 because of the rocket results



## *Sounding Rocket Mission Categories*

### Microgravity

- Main requirements/features:
  1. Long periods of “zero-G” relative to airplanes, drop towers
  2. Recovery usually required (launches are at White Sands)
  3. Rockets provide very low acceleration, disturbance rates relative to STS, ISS

### Special projects

- Aerobraking tests, re-entry technology testing, etc.

Large descent velocities (afforded by high apogee) usually sought to simulate re-entry tests.

## *Technology Roadmap*

Technology Roadmap developed jointly by WFF  
and the Sounding Rocket Working Group

- Small Mesospheric “Dart” payload
- High Altitude Sounding Rocket
- Recovery of high altitude sounding rocket payloads

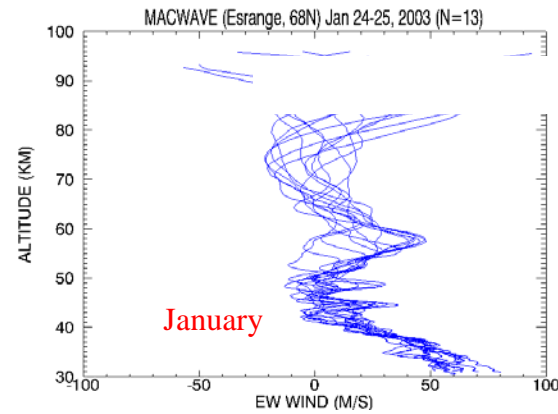
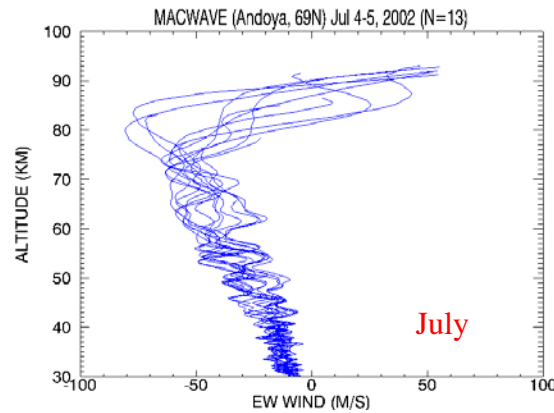


# New Technology Initiative --

## Wallops Small Rocket Will Enable Systematic Sampling of Mesosphere

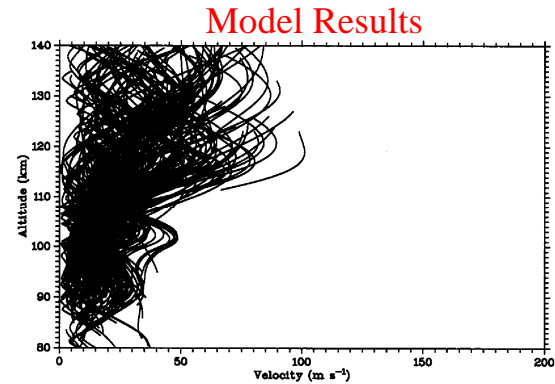
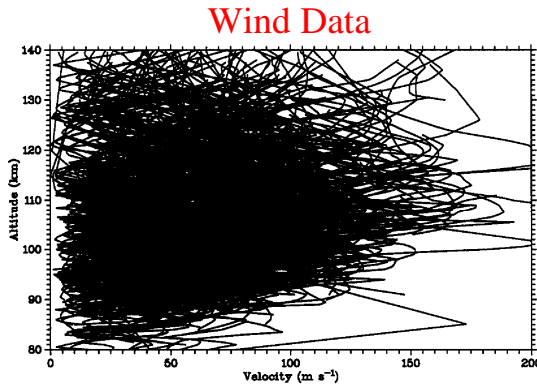
Example: Falling Spheres on Small Rockets

This is the *only* reliable technique to observe winds from 50-80 km



[Courtesy, F. Schmidlin, R. Goldberg, GSFC]

Neutral Winds (80-140 km) -- Large, variable, *not* understood



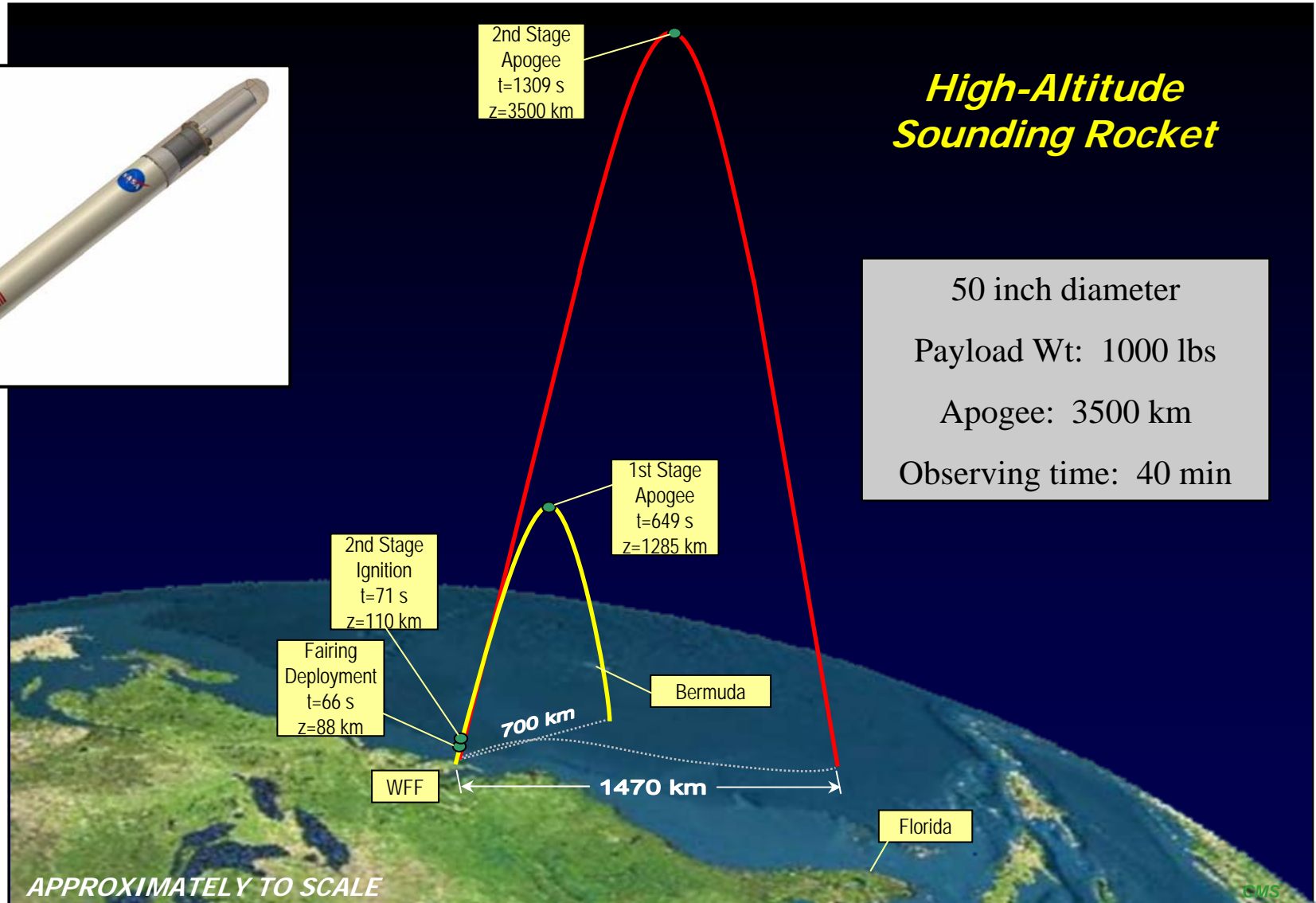
[Larsen et al., 2000]

# High Altitude Sounding Rocket



## *High-Altitude Sounding Rocket*

50 inch diameter  
Payload Wt: 1000 lbs  
Apogee: 3500 km  
Observing time: 40 min



# *High Altitude Sounding Rocket Science Applications*

- **Astronomy / Planetary / Solar**
  - Increased “hang time” and sensitivity -- observe for ~ 40 minutes with larger diameter (~ 1m) telescopes
  - Near-Sun observations of comets, inner planets
  - Observe temporal evolution of solar phenomena
  - IR observations (payload has time to cool down)
  - Observation of faint targets including “near-sun” observations of comets, inner planets
- **Geospace Science**
  - Penetrate the auroral and cusp acceleration region (> 3000 km)
  - Observe high altitude regions with constellations of well-instrumented sub-payloads
  - Observe M-I coupling resonances and wave interactions with periods of 10’s of minutes
  - Study inner radiation belt and slot region from Wallops
- **Mission to Planet Earth**
  - Hurricane Observations with New Imaging Technology
- **Microgravity**
  - Combustion experiments for considerably longer periods in “ideal microgravity”
- **Exploration**
  - 6-7 km/sec entry velocity available for planetary probe testing
  - Entry, Descent, and Landing Technology Demonstrations

# Summary

- NASA Sounding Rocket Program provides a wide range of technical capabilities including unique launch vehicles, payload capabilities, and range operations.
- Commonality building on previous designs keep costs low.
- Missions are tailored to meet scientific needs of experiment.
- Program has served space science exceedingly well.
- Sounding rockets look forward to continued innovation and show great promise for the future.

*Back up Slides*

Sounding Rocket User Web Site --

<http://rscience.gsfc.nasa.gov>