Initial Results from the Radiation Dosimetry Experiment (RaD-X) Balloon Flight Mission

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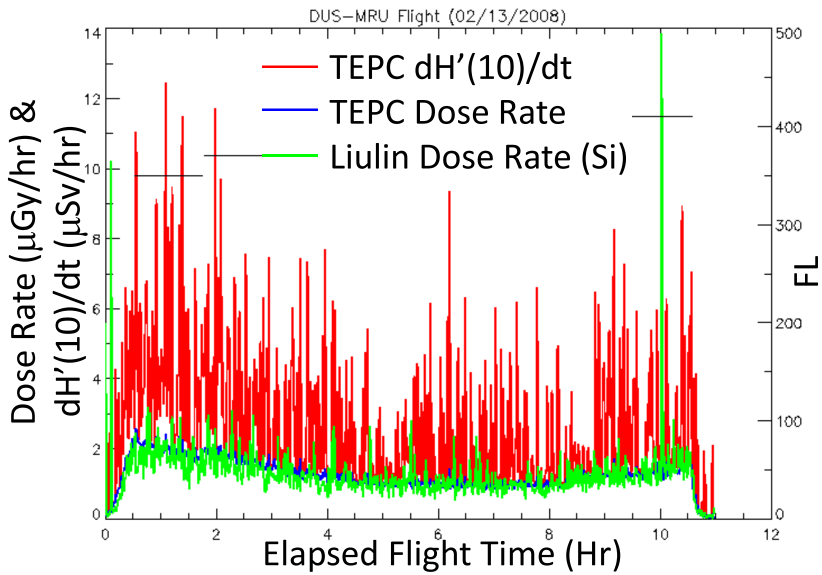
Outline

- **Research Motivation**
  - Aviation Radiation Health Effects
  - Aviation Radiation Avionic Effects
  - NAIRAS Model Development
- **Cosmic Ray Basics**
  - Sources
  - Energy and Composition
  - Atmospheric Interactions
  - Biological Interactions
- **Dosimetric Quantities**
  - Definitions
  - Range of Values @ Flight Altitude
- **NAIRAS Model**
  - Representative Data Products
  - Variation With Solar Cycle and Geomagnetic Cutoff Rigidity
  - Solar and Geomagnetic Storm Effects
- **RaD-X Science**
  - Motivation (in more detail)
  - Science Goals and Objectives
  - Instrument Selection

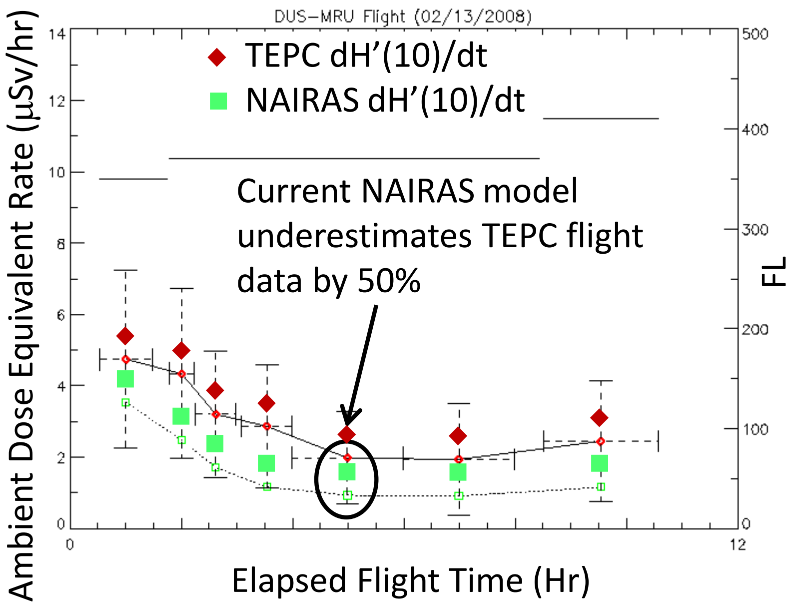
NAIRAS Comparisons to Aircraft Dose

The NAIRAS model currently underestimates actual data.
This performance is quantified by comparisons with recent DLR-TEPC/Liulin measurements from 2008 [*Mertens et al.*, 2013]

- **These results are consistent with the large volume of data reported by *Lindborg et al.* [2004] and tabulated by the International Commission on Radiation Units and Measurements: *ICRU Report 84* [2010]**
- **The NAIRAS/DLR/ICRU comparisons in publication [*Mertens et al., 2013*]**

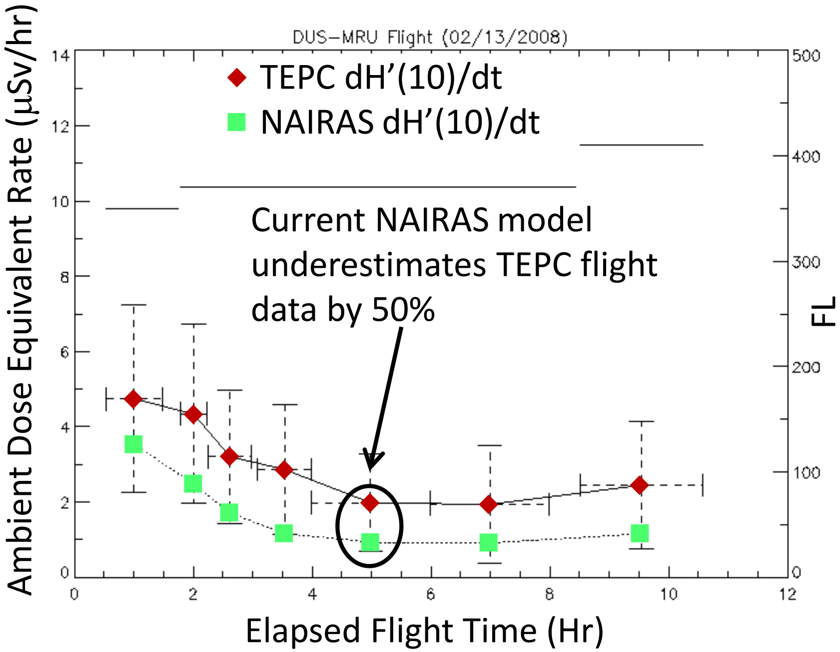


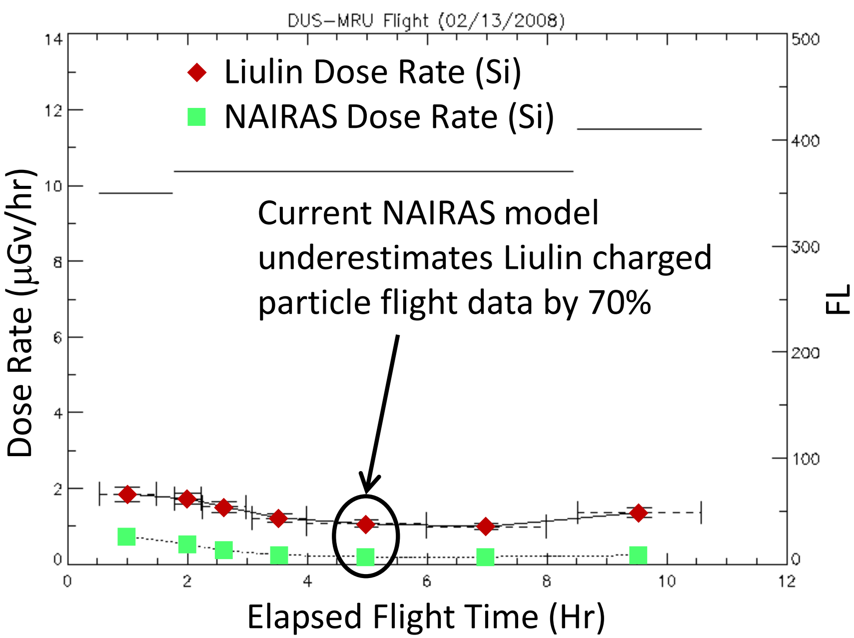
Large statistical variations experienced at flight level illustrate the need for RaD-X TOA measurements



NAIRAS Comparisons to Existing Measurements

- **NAIRAS comparisons with existing TEPC/Liulin measurements shows much larger discrepancies in silicon absorbed dose**
  - **Suggests larger uncertainty in NAIRAS charged-particle source/transport/interactions**
  - **TOA measurements characterize charged-particle source (i.e., cosmic ray primaries)**



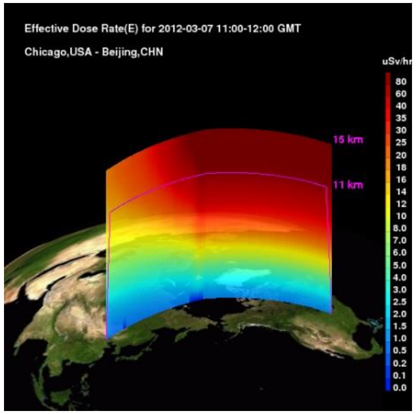


RaD-X : Radiation Dosimetry Experiment

Science Goals and Objectives

- Improve tools that predict energy deposition characteristics of penetrating cosmic radiation in Earth's atmosphere
  - Measure radiation dosimetry in upper atmos
  - Separate cosmic ray primary contributions
- Identify and characterize low-cost radiation measurement solutions
  - Characterize relationship between solid state radiation instruments and biological response

RaD-X Measures Radiobiological Dose and CR Primary Proton and HZE Contributions



Mission and Instrument Parameters

- Platform: High-Altitude Balloon
- Launch Site: Fort Sumner, NM (34N, 104W)
- Mission Duration: 20+ hours of science data
- Temporal Sampling: 1-5 minutes
- Launch Date: September 25-26, 2015
- Instruments: (1) TEPC, (2) TID detector, (3) LET spectrometer, and (4) microdosimeter emulator
- All instrument components at TRL 6 or higher

Science Team and Partners

NASA Langley
NASA ARC
NASA GSFC/WFF
Prairie View A & M University (PVAMU)
Center for Radiation Engineering and Science for Space Exploration (CRESSE)
Oklahoma State University
University of Virginia
Space Environment Technologies, Inc.

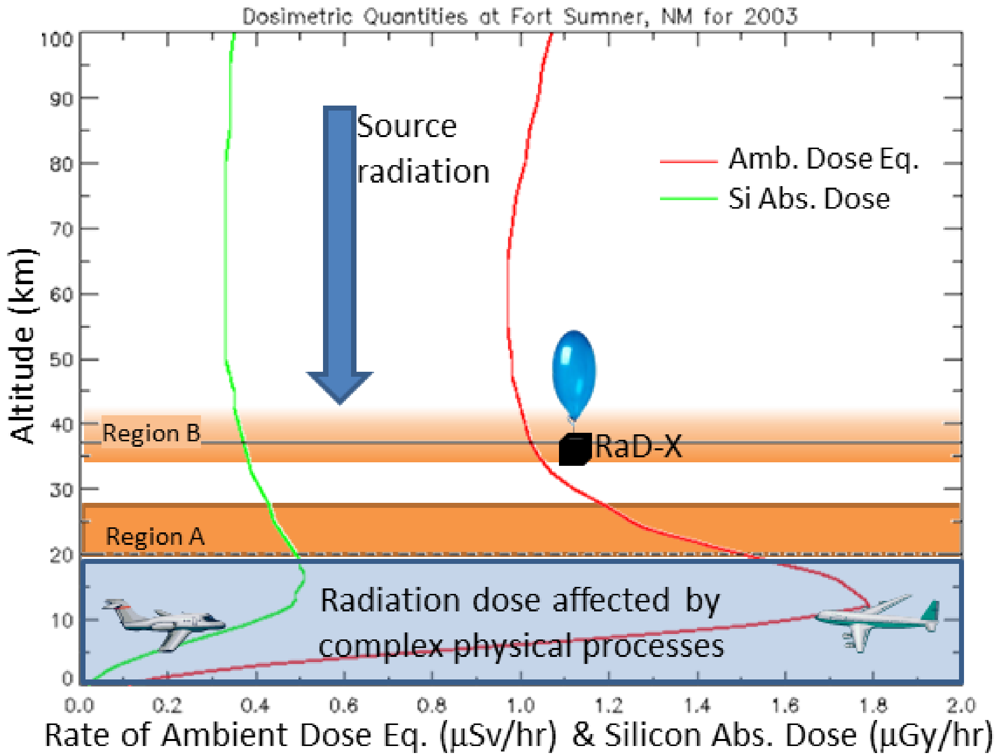
RaD-X Science Goals

High-altitude balloon flight (> 20 km) out of **Fort Sumner, NM** with dosimeter measurements utilized to improve cosmic radiation dose assessment and characterize the energy deposition from CR primaries

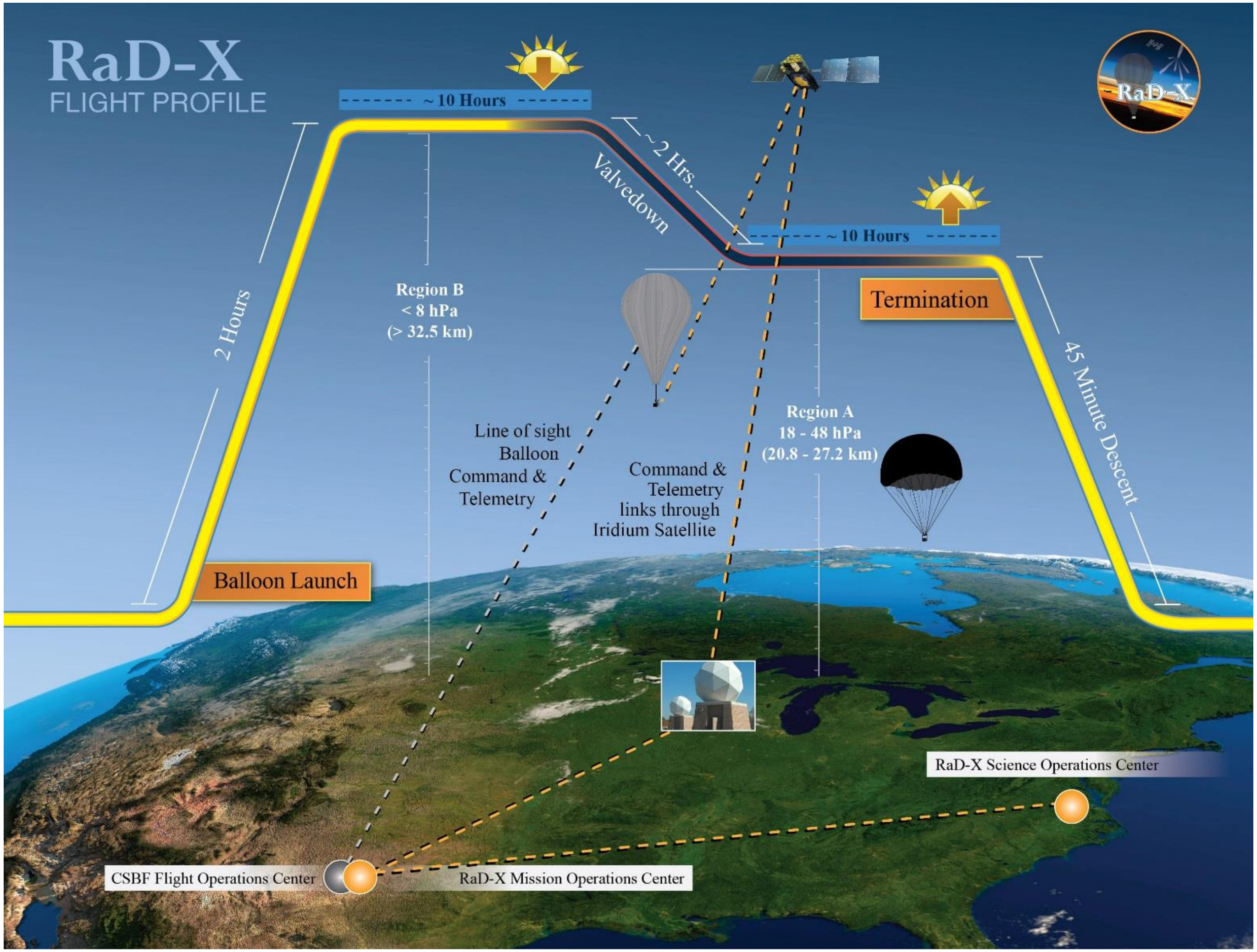
- **NAIRAS** underestimates effective body dose by 50% at lower latitudes (≤ 50°), the region of largest model error [*Mertens et al., Space Weather, 2013*]. Uncertainty must be ≤ 30% for latitudes ≥ 30° for reliable dose assessments [*ICRU Report 84, 2010*]
- Measurements > 20 km next step needed to understand source of uncertainty and guide model improvement

GOALS

1. **Improve tools that predict energy deposition characteristics of penetrating CR in Earth's atmosphere**
   - Combine different dosimeter measurements and two flight altitudes to assess model uncertainty in CR primaries
2. **Identify and characterize low-cost radiation measurement solutions**
   - Continuous, global measurements for real-time data assimilative modeling

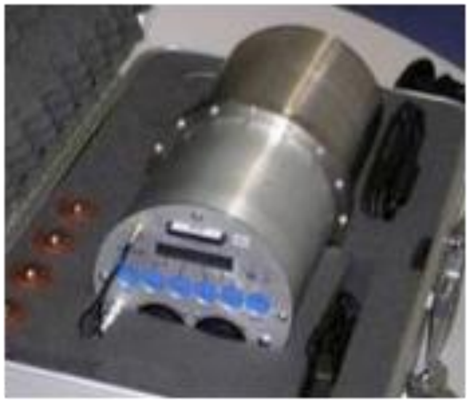


RaD-X Flight Profile



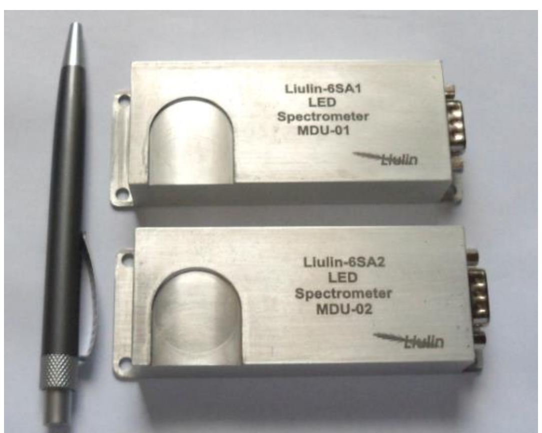
RaD-X Science Instruments

TEPC: Tissue Equivalent Proportional Counter
Far West Technology, Inc.



Total Ionizing Dose (TID) Detector
Teledyne Microelectronic Technologies

Liulin LET Spectrometer
Prof. Dachev SRTI-BAS



RaySure Detector
QinetiQ & Univ. of Surrey, UK

RaD-X Payload @ LaRC Pre-Ship

Drs. John Grunsfeld & Paul Hertz

Preparing for Launch at Fort Sumner

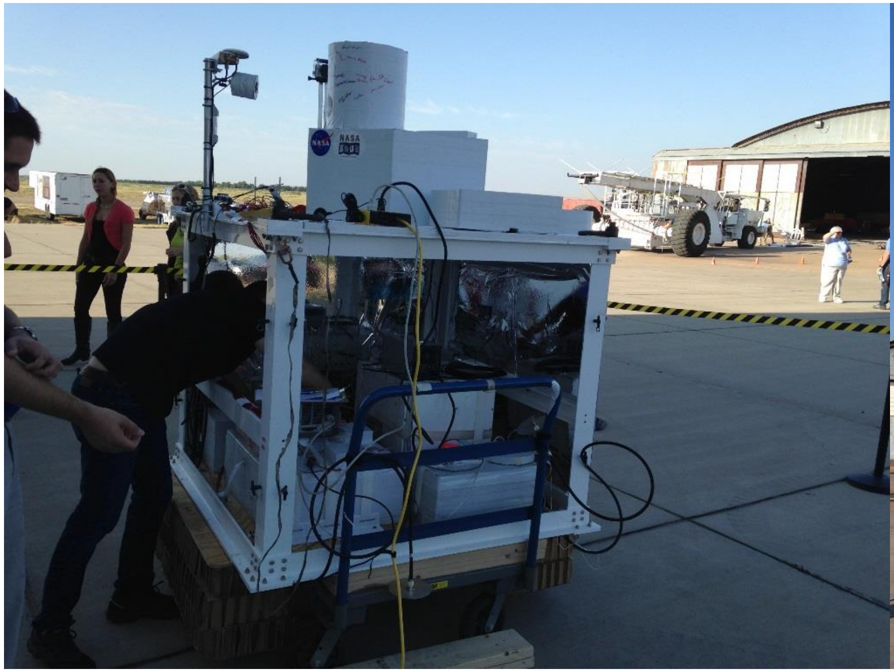
Dr. Grunsfeld, NASA SMD Associate Administrator
Dr. Hertz, NASA SMD Astrophysics Division Director

RaD-X PI at Fort Sumner

Waiting for Launch at Fort Sumner

RaD-X Payload Ready for Launch

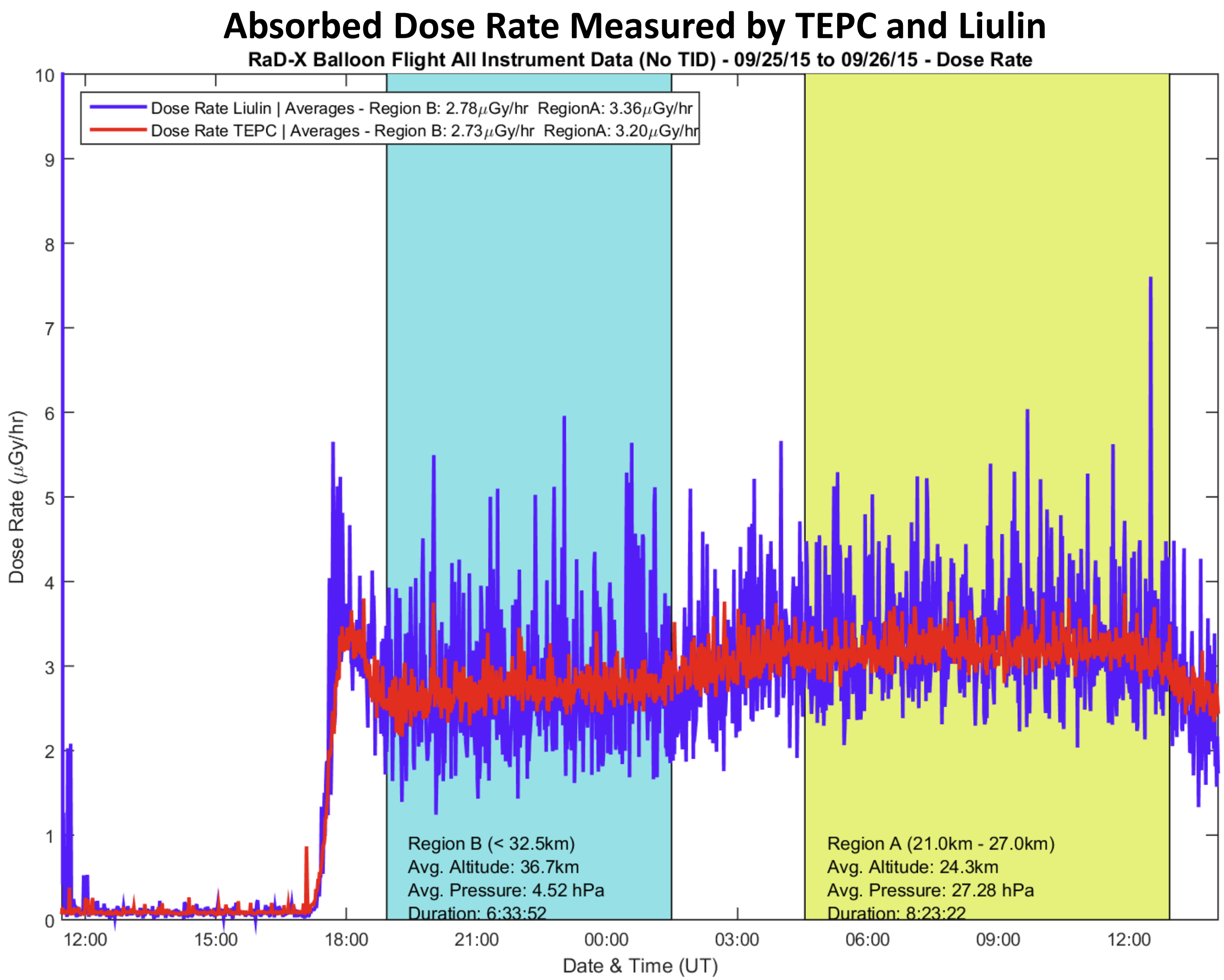
Payload integrated to balloon gondola



"Big Bill" transporting payload to launch site

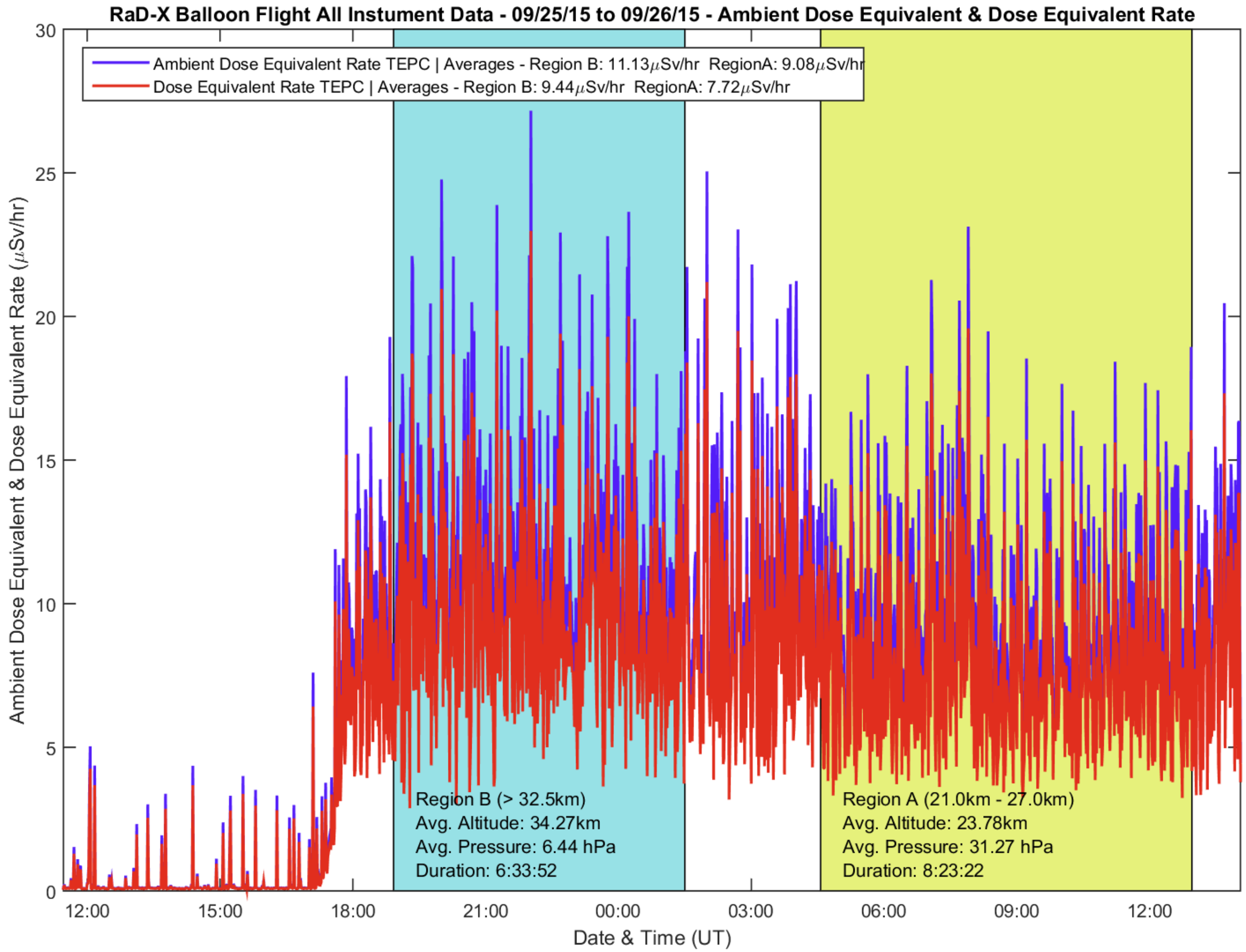
RaD-X Launches Sep 25, 2015

RaD-X Absorbed Dose Rate



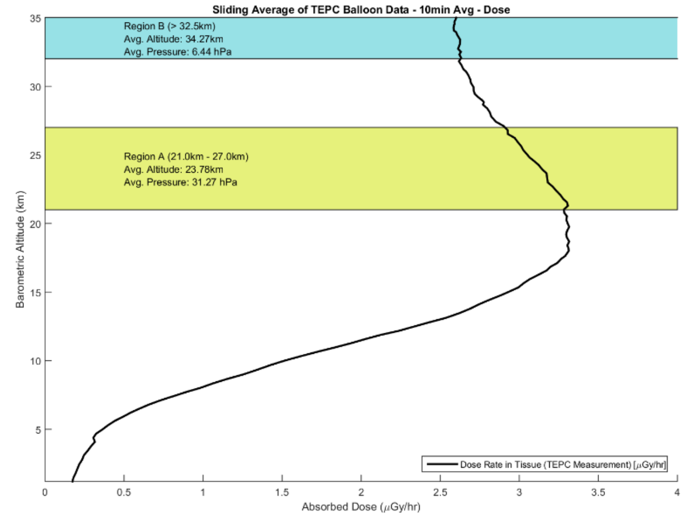
RaD-X Radiobiological Dose Rate

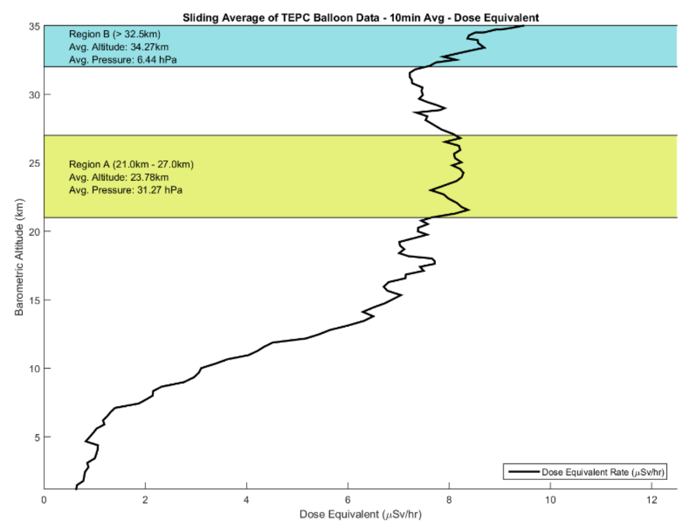
TEPC Measurements of Dose Equivalent and Ambient Dose Equivalent Rates



RaD-X TEPC Dose Rate Profiles

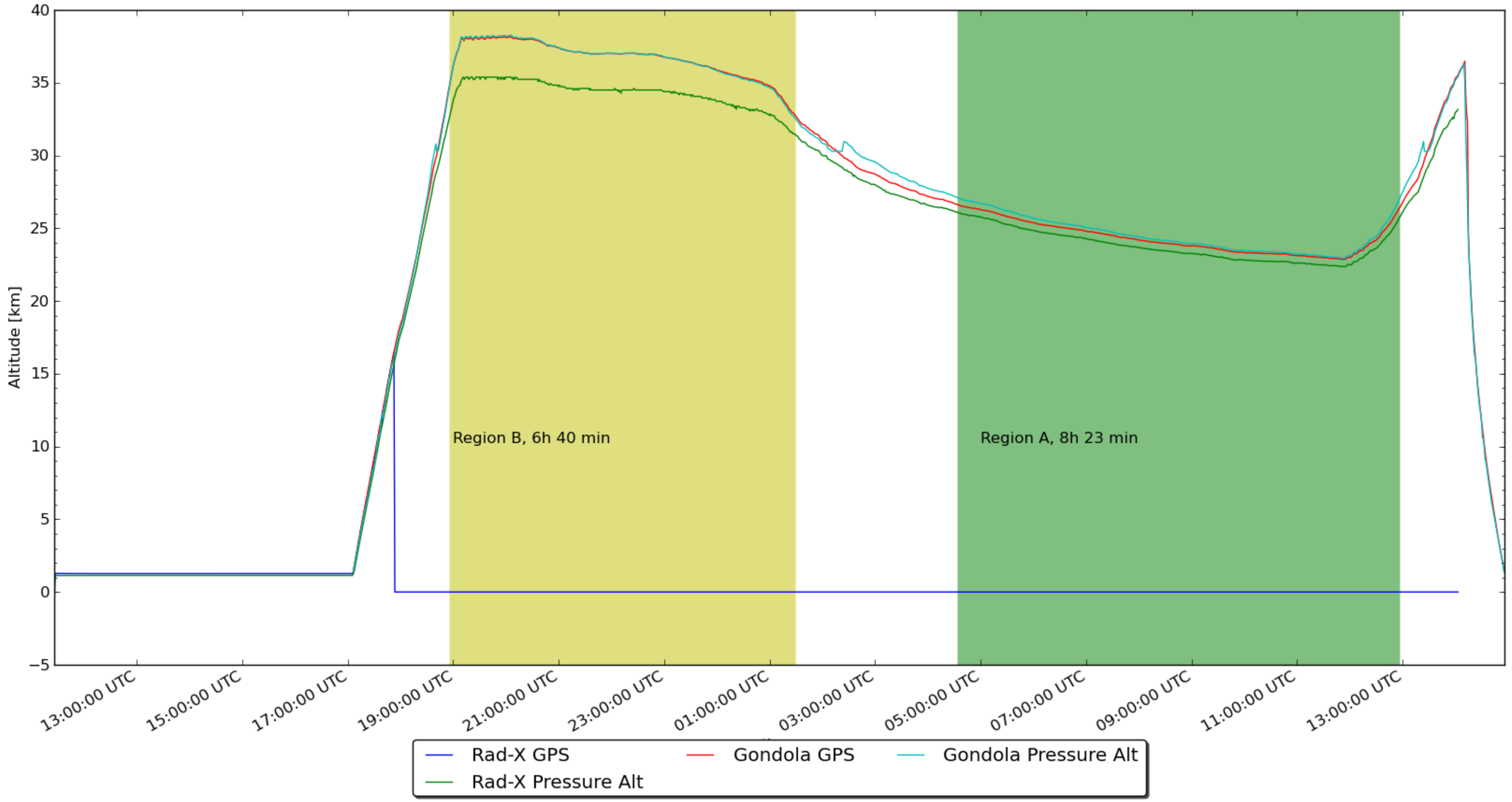
- **TEPC Dose Rate Profiles**
  - Constructed from +/- 10 minute widow average of measured dose rates
  - Absorbed Dose Rate (**Dose**) Profile (**Top Right**)
  - Dose Equivalent (**DoseE**) Rate (**Bottom Right**)
- **Dose** Profile Features
  - Very broad Pfotzer maximum corresponding to the peak in the dose rate
- **DoseE** Profile Features
  - **Key Finding**: No Pfotzer maximum in DoseE
  - Lack of low-LET secondary particles above ionization peak is compensated by high-LET albedo neutrons and cosmic ray primary particles
  - Increase in DoseE in Region B due to HZE particles





RaD-X/CSBF Flight Altitudes

RaD-X Payload versus CSBF Altitudes During Balloon Flight

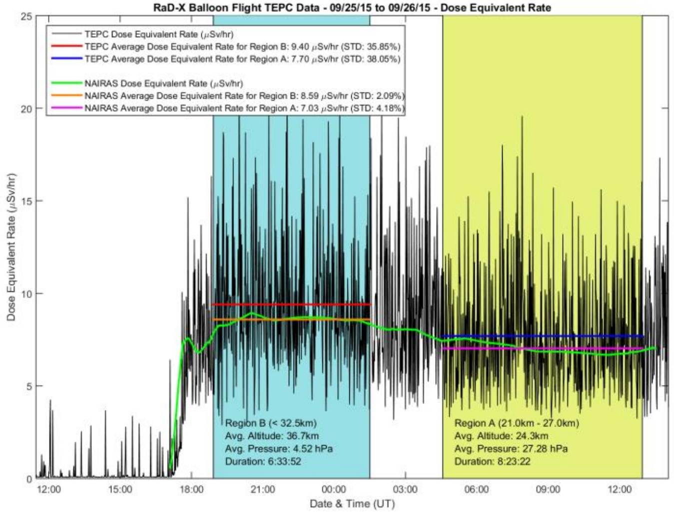


Note: RaD-X/NAIRAS comparisons preliminary until barometric pressure differences resolved

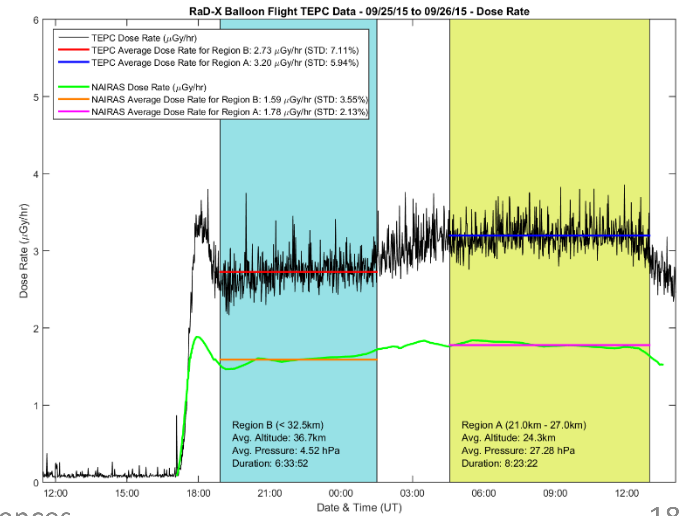
RaD-X / NAIRAS Comparisons

- **RaD-X TEPC /NAIRAS Comparisons**
  - Dose Equivalent Rate (DoseE):
    - DoseE includes radiobiological weighting of neutrons and other high-LET particles
    - NAIRAS underestimate by less than 10%
  - Absorbed Dose Rate (Dose):
    - Dose insensitive to neutrons
    - NAIRAS underestimate by > 50%
- **Trend in NAIRAS Comparisons to the Other Measurements** (RaD-X Liulin, ER-2 TEPC, King Air C90 TEPC/Liulin)
  - NAIRAS underestimate measurement data
  - Differences largest near Pfotzer maximum (peak in absorbed dose rate)
- **Preliminary Inferences**
  - NAIRAS underestimates pion-initiated electromagnetic (π-EM) cascade processes
    - Underestimate charged particle (low-LET) contributions to Dose/DoseE
    - Overestimate neutron (high-LET) contributions to DoseE
  - π-EM backscatter appears to be important (Region A in particular)
  - NAIRAS may underestimate cosmic ray primary protons

TEPC / NAIRAS Dose Equivalent



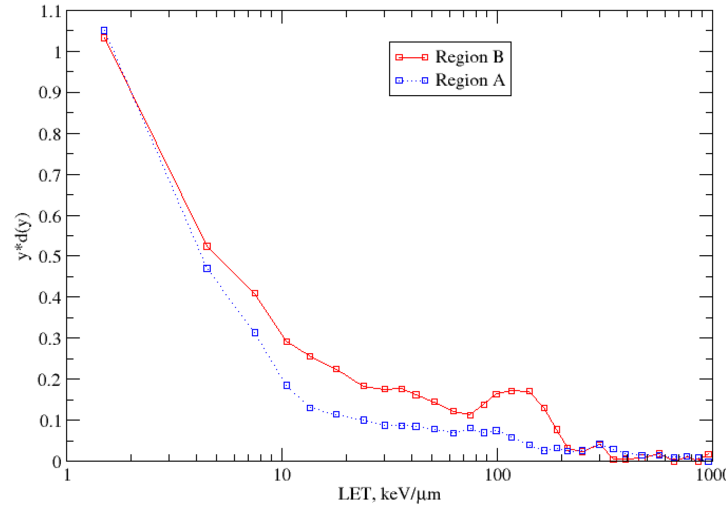
TEPC / NAIRAS Absorbed Dose



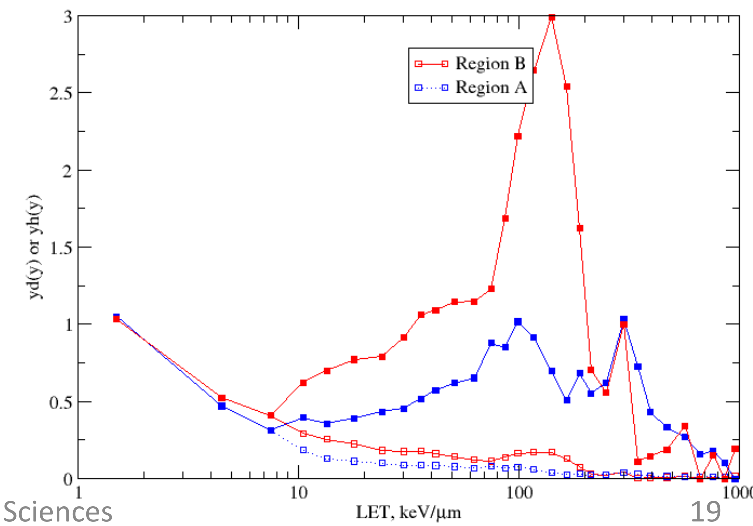
RaD-X TEPC Dose-LET Spectra

- The **TEPC Dose-LET spectra** show the different particle content in Regions A and B
  - Compare relative contributions from High-LET events
  - **High-LET** event **> 10 keV/um**
- **Region B**: evidence of **HZE particles**
  - Larger contributions from high-LET events in Region B
- **Region A**: Cosmic ray primary protons and albedo neutrons
  - High-LET events but much smaller contributions to dose in Region A compared to Region B
- Peak in Region B Dose-LET spectrum interesting and needs further investigation
- **RaD-X ConOps** design of the two float altitudes (Regions A and B) succeeded in isolating HZE cosmic ray primary particle contributions to dose

RaD-X TEPC Relative Dose-LET Spectra



RaD-X TEPC Relative DoseE-LET Spectra



Average Dose: RaD-X + Aircraft

Altitude km	Pressure hPa	Platform	Liulin	TEPC	TEPC	TEPC
			Dose Rate uGy/hr	Dose Rate uGy/hr	Dose Equiv uSy/hr	H*(10) uSy/hr
8	444.9	King Air C90	0.94 ± 0.02	0.90 ± 0.01	2.44 ± 0.11	N/A
17	92.0	ER-2	N/A	4.63 ± 0.02	8.95 ± 0.22	N/A
20	85.6	ER-2	N/A	5.00 ± 0.03	10.26 ± 0.34	N/A
24.3	27.3	RaD-X	3.34 ± 0.03	3.20 ± 0.01	7.70 ± 0.13	9.05 ± 0.15
36.7	4.5	RaD-X	2.77 ± 0.04	2.73 ± 0.01	9.40 ± 0.17	11.09 ± 0.20

RaD-X Science Summary (Prelim)

- All instrument flight data recovered and suitable for scientific investigation
- TEPC absorbed dose rate profile shows very broad Pfotzer maximum,
- TEPC dose equivalent profile shows no Pfotzer maximum at all
  - Indicative of high-LET albedo neutrons and cosmic ray primaries
- Assessment of NAIRAS
  - Qualitatively captures the essential features of the atmospheric ionizing radiation field
    - Adequately defined the science objectives and Flight ConOps to achieve science goals
  - Quantitatively, its underestimation of the measurements point to the following deficiencies
    - Inadequate production of π-EM particles (i.e., the complex region), highlighting the role of backscatter contributions
    - Possibly underestimation of cosmic ray primary protons