

National Aeronautics and Space Administration



RaD-X Radiation Dosimetry Experiment

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Principal Investigator

Micro Dosimeter Users Meeting
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RaD-X : Radiation Dosimetry Experiment



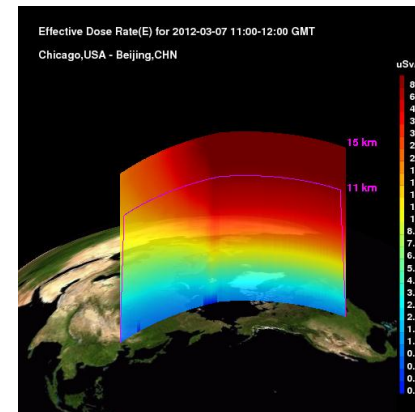
Science Goals and Objectives

- Improve predictive atmos. ionizing dose tools by characterizing energy deposition by cosmic ray primaries
 - Measure dosimetric quantities in upper atmos
 - Separate cosmic ray primary contributions
- Identify and characterize low-cost atmos. radiation dose measurement solutions for continuous, global monitoring

Mission and Instrument Parameters

- Platform: High-Altitude Balloon
- Launch Site: Fort Sumner, NM
- Mission Duration: 24-hours
- Temporal Sampling: 1-5 minutes
- Launch Readiness Date: September 2015
- Instruments: (1) TEPC, (2) TID detector (**Teledyne**), (3) LET spectrometer, and (4) microdosimeter emulator
- Measurement uncertainty: < 30 %
- All instrument components at TRL 6 or higher

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

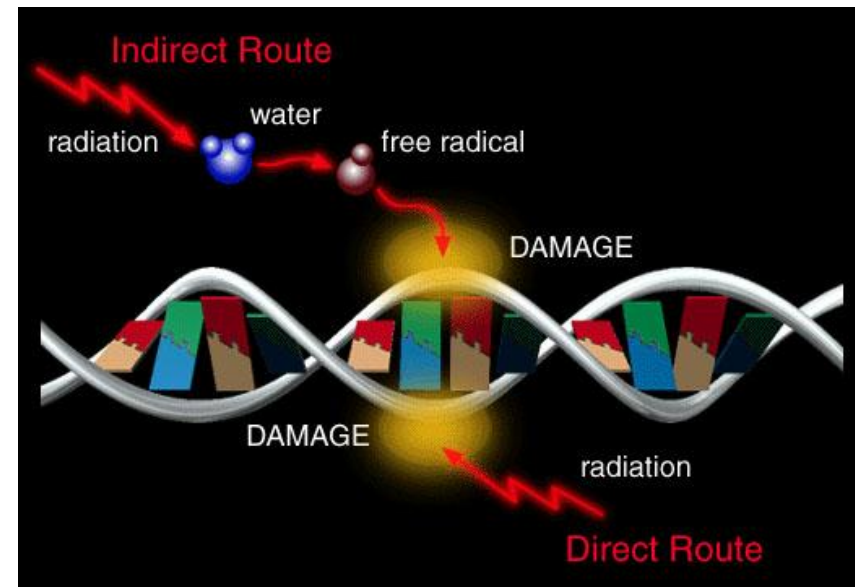
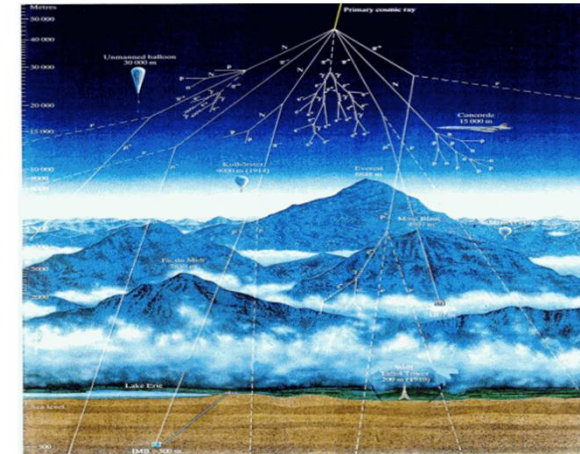


Science Team and Partners

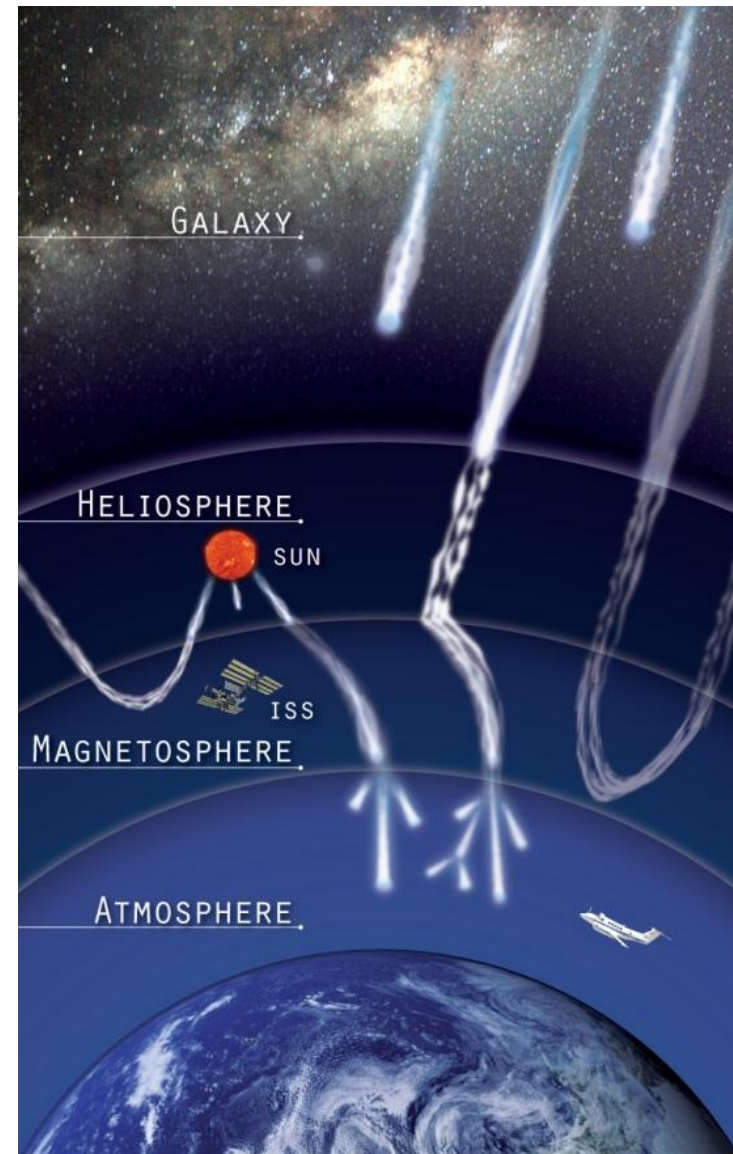
NASA Langley
NASA ARC
NASA GSFC/WFF
Prairie View A & M University (PVAMU)
Center for Radiation Engineering
and Science for Space Exploration (CRESSE)
University of Virginia
Space Environment Technologies, Inc.

- The Earth is continuously bombarded by high-energy cosmic rays (**CR**) that penetrate deep within the atmosphere
- **CRs** are the primary source of ionizing radiation that increases risk of fatal cancer or other adverse health effects to air travelers
 - Need to know how **CRs** cascade down to where aircraft fly
 - Dosimetric quantities (measured/model) are accepted way to gauge risk to exposure
- Commercial aircrews are classified as radiation workers (ICRP, 1990)
 - Most exposed occupational group
 - Individual career and storm exposures unquantified and undocumented
- Maximum public and prenatal exposure easily exceeded (ICRP recommendations)
 - One high-latitude solar storm event
 - Frequent use of high-latitude routes (~5-10 round-trips)
- Equivalent Flight Exposures
 - Round-trip international ~ 2 chest x-rays
 - 100k mile flyer ~ 20 chest x-rays

Cosmic Ray Interactions



- **LaRC's Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS) Model**
 - Prototype development funded by NASA Applied Sciences (ROSES)
 - Running in real-time at the LaRC/DAAC since April 2011
- **Distinguishing Features**
 - First real-time physics-based, global model
 - First real-time inclusion of SEP radiation
 - First real-time solar-magnetospheric effects on radiation
 - First real-time meteorological data used





NAIRAS Model: 2012 Storm



Effective Dose Rate¹(E) for 2012-03-07 11:00-12:00 GMT

5km (16,000 feet) Radiative Dose Rate (uSv/hr)								
lat	90S-60S	60S-40S	40S-20S	20S-0	0-20N	20N-40N	40N-60N	60-90N
avg	12.01	8.51	3.77	1.06	0.88	2.58	8.21	11.74
max	13.67	12.35	8.81	3.03	3.64	8.71	12.45	13.61
11km (35,000 feet) Radiative Dose Rate (uSv/hr)								
lat	90S-60S	60S-40S	40S-20S	20S-0	0-20N	20N-40N	40N-60N	60-90N
avg	63.79	43.36	15.16	2.69	2.14	9.45	41.37	66.03
max	69.41	66.18	47.22	10.15	13.08	45.58	67.98	72.08
15km (49,000 feet) Radiative Dose Rate (uSv/hr)								
lat	90S-60S	60S-40S	40S-20S	20S-0	0-20N	20N-40N	40N-60N	60-90N
avg	133.91	84.70	22.91	3.21	2.51	13.33	76.84	142.45
max	144.86	140.66	94.98	13.45	17.59	90.36	147.34	152.19

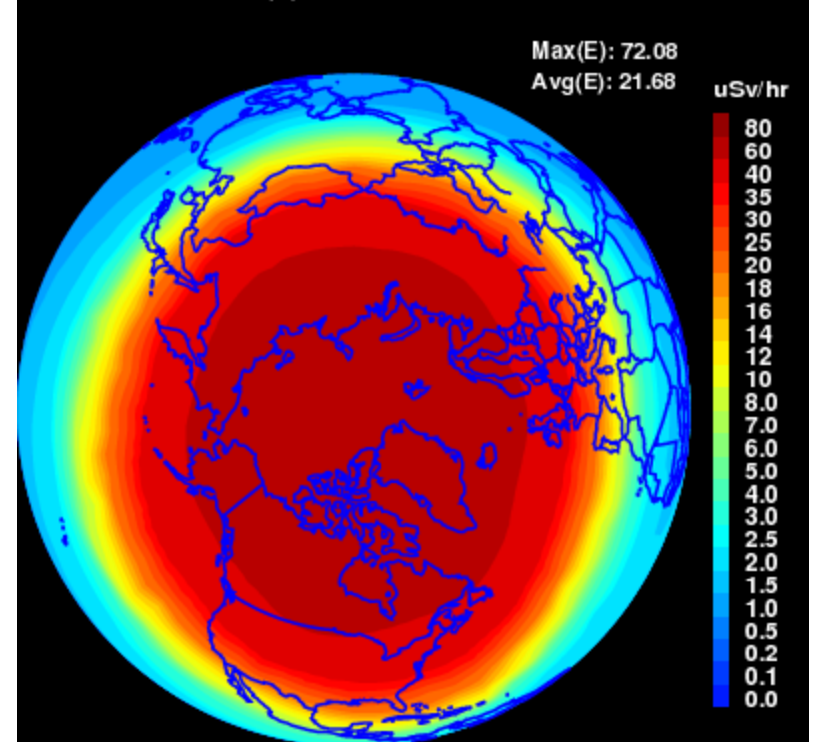
Representative High-Latitude Flights

2012-03-07 11:00-12:00 GMT

Flight Name	Time hours	Rate ¹ uSv/hr	Dose ¹ mSv	Safety Signal		
				Aircrew ²	Public ³	Prenatal ⁴
London,GBR - New York,USA	5.50	51.52	0.283	Yellow	Green	Yellow
Chicago,USA - Stockholm,SWE	8.50	63.09	0.536	Yellow	Yellow	Red
Chicago,USA - Munich,DEU	8.50	56.35	0.479	Yellow	Yellow	Red
Chicago,USA - Beijing,CHN	13.50	60.34	0.815	Yellow	Red	Red

Signal	Aircrew ⁵ Max_Annual(800hrs)	Public ⁶ one_trip	Prenatal ⁶ one_trip
Green	0-6.0mSv	0-0.330mSv	0-0.167mSv
Yellow	6.0-12.0mSv	0.330-0.670mSv	0.167-0.333mSv
Red	>12.0mSv	>0.670mSv	>0.333mSv

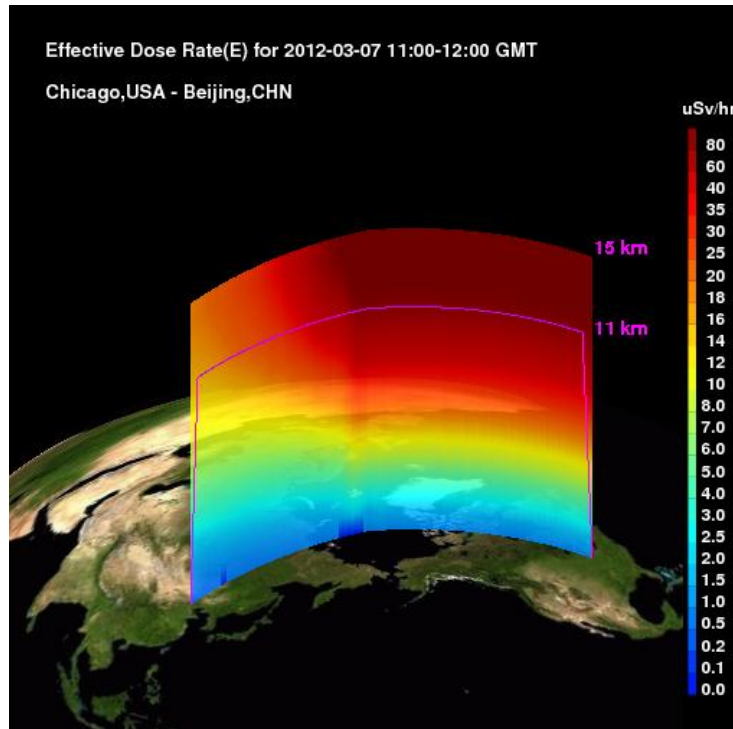
Effective Dose Rate(E) at 11km for 2012-03-07 11:00-12:00 GMT



Public Web site: <http://sol.spacenvironment.net/~nairas/> (or google NAIRAS)



NAIRAS Model: 2012 Storm

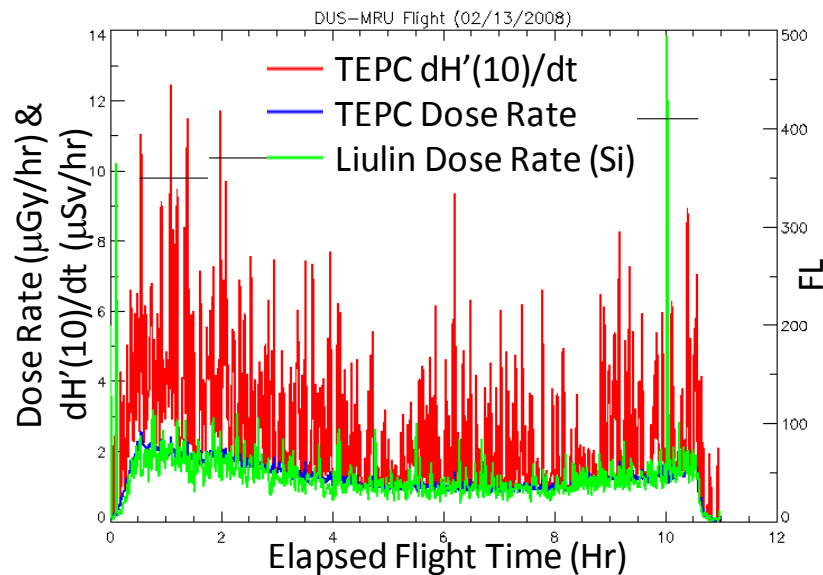


Public Web site: <http://sol.spacenvironment.net/~nairas/> (or google NAIRAS)

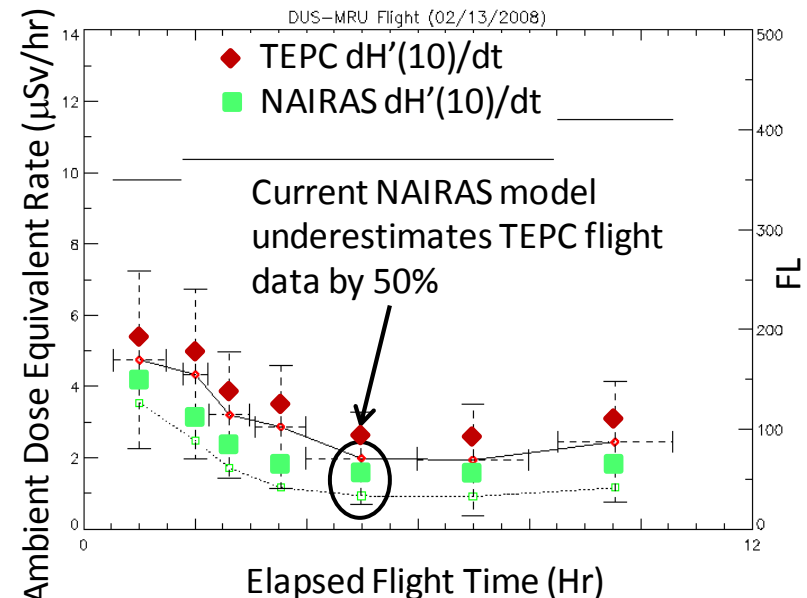
The NAIRAS model currently underestimates actual data.

This performance is quantified by comparisons with recent DLR-TEPC/Liulin measurements from 2008 [Mertens *et al.*, 2012]

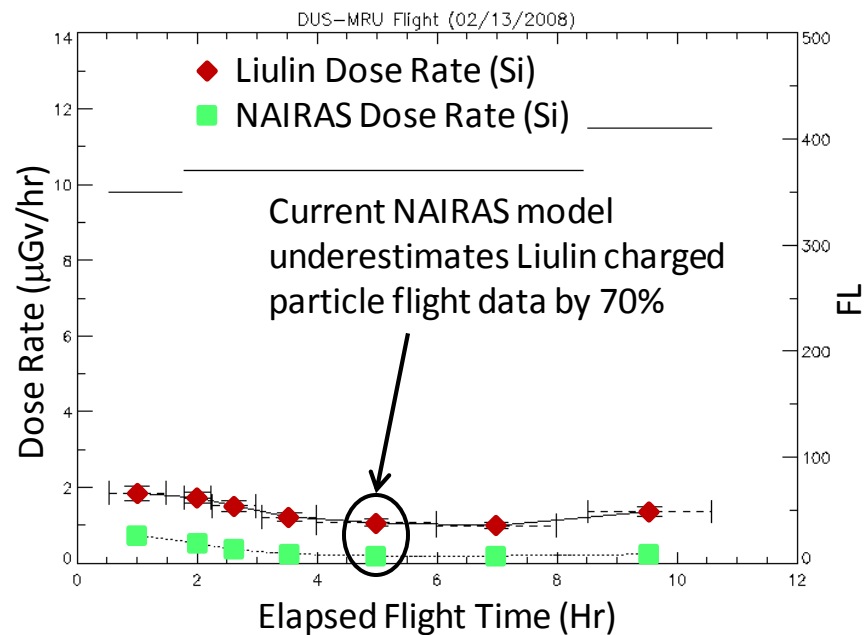
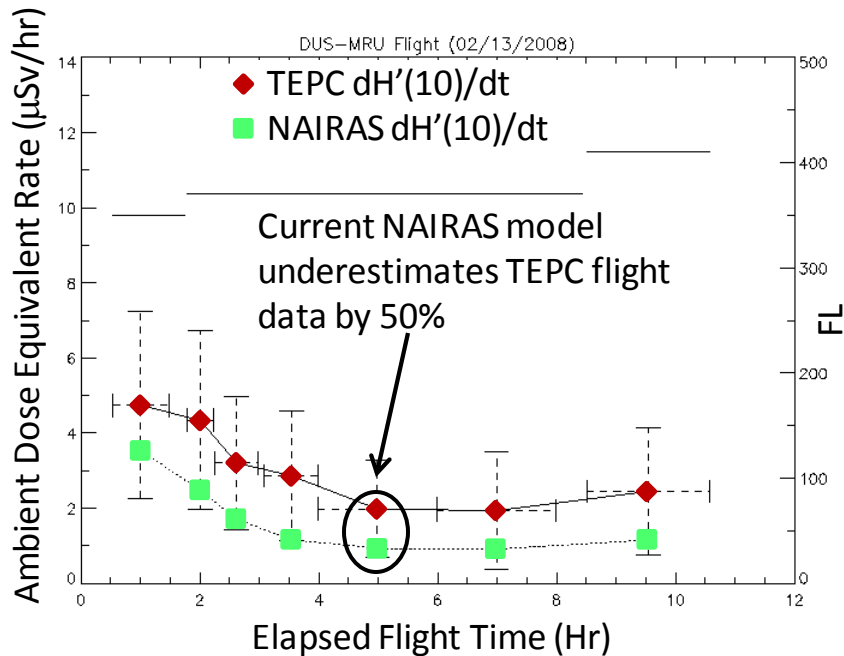
- These results are consistent with the large volume of data reported by Lindborg *et al.* [2004] and tabulated by the International Commission on Radiation Units and Measurements: *ICRU Report 84* [2010]
- The NAIRAS/DLR/ICRU comparisons in publication [Space Weather, 2013]



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





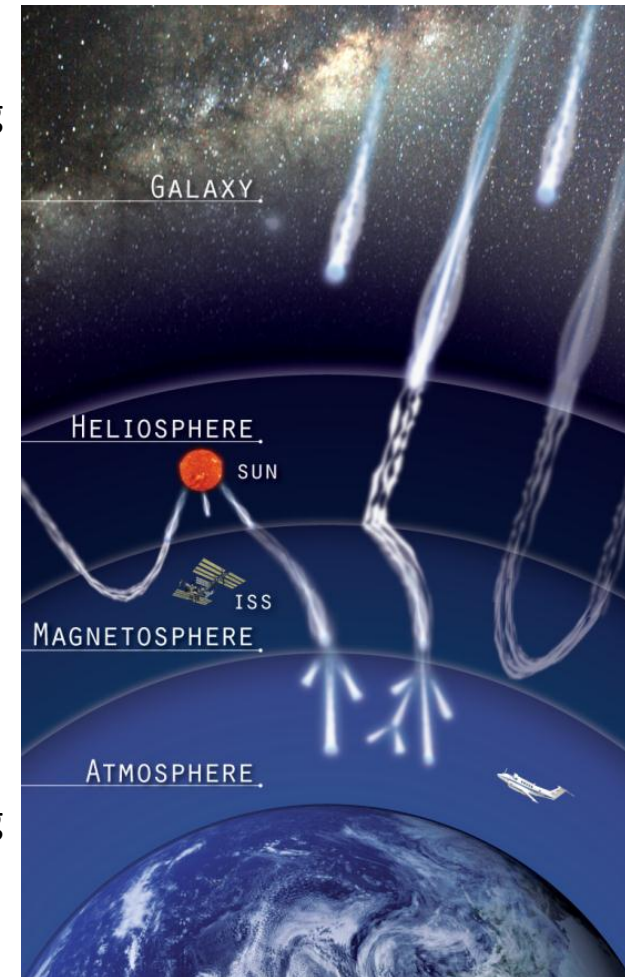
RaD-X Science Motivation



RaD-X contributes to the NASA Heliophysics Division Living With A Star (LWS) Program's Strategic Goal #1: improve prediction of biologically harmful radiation exposure to air travelers by enhancing the understanding of cosmic ray transport processes and interactions with the atmosphere

NASA LaRC has made significant advances in quantifying and documenting aircraft radiation exposure by developing the Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS) model: the first real-time, global, physics-based model that includes both galactic cosmic ray and solar energetic particle sources of radiation exposure.

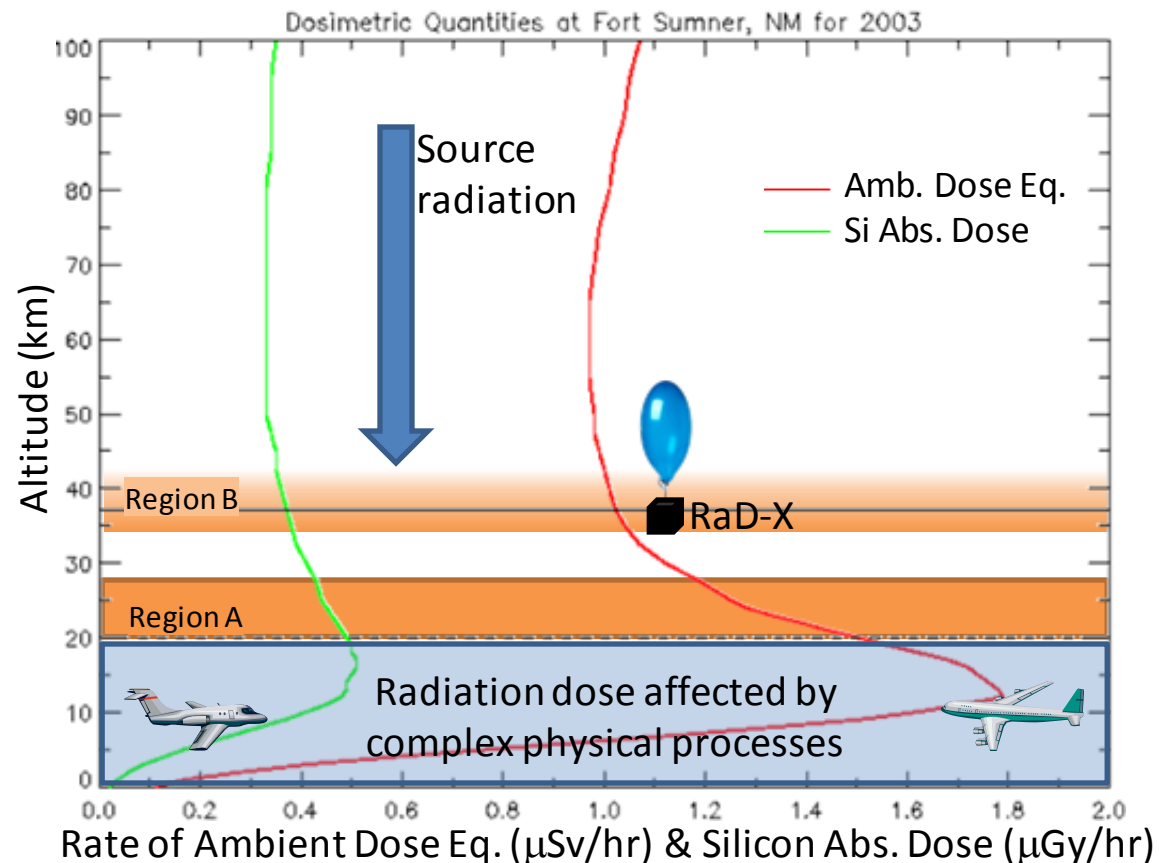
- **A critical step remains** before NAIRAS can transition to operations at the NOAA National Weather Service: It must be verified & validated
- **RaD-X** is an important **next** step in the V&V process -- collecting and processing data from the top of the atmosphere (TOA) that will constrain the model



LWS Strategic Goal #1: "Penetrating particle radiation adversely affects aircraft avionics and potentially the health of airline crews and passengers... The [LWS] program needs to deliver the understanding and modeling required for useful prediction of the variable solar particulate and radiation environment at Earth..."

Taking data at TOA provides a direct measurement of the primary cosmic rays, permitting the separation of discrepancies due to source uncertainties from discrepancies caused by the ensemble of complex physical processes at aircraft altitudes

- TOA radiation is a large source of uncertainty for radiation exposure [*Lindborg et al., 2004*]
- Model/measurement comparisons at aircraft altitudes point out discrepancies, but do little to reveal a causal source of discrepancy due to the variation in composition and energy of the radiation environment with atmospheric depth



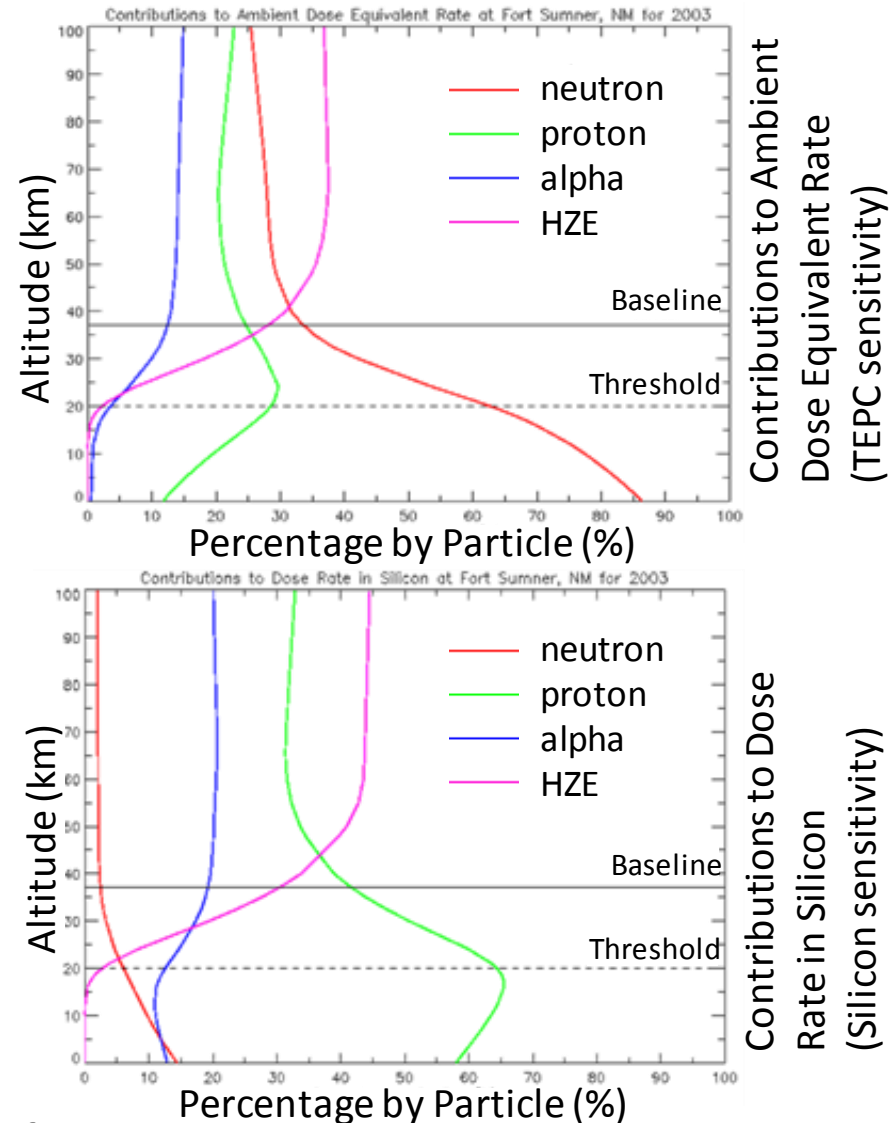


RaD-X Instrument Selection

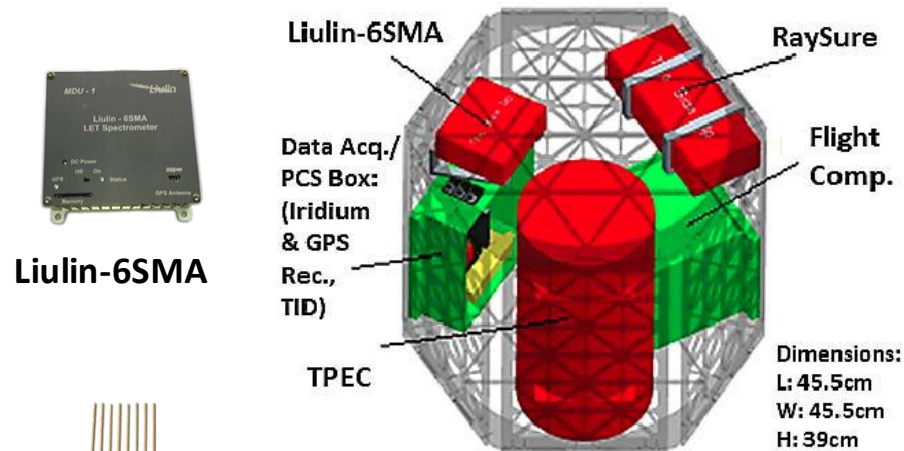
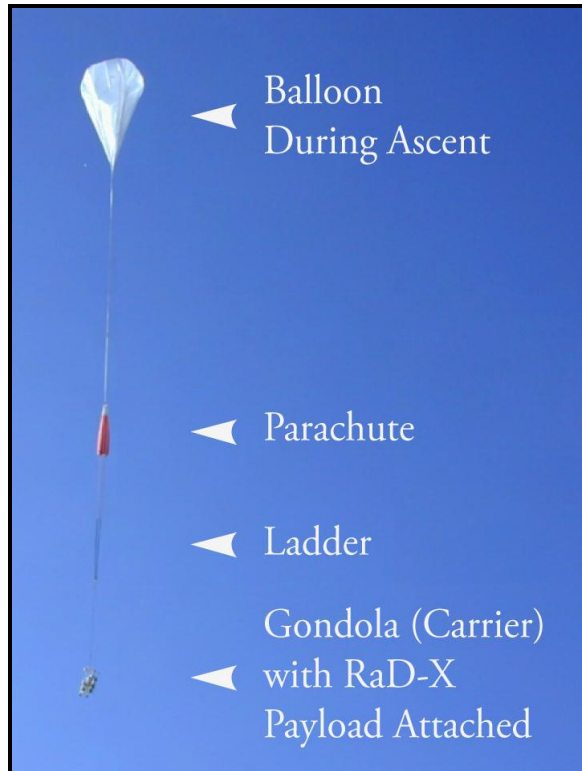


The choice of detectors was motivated by the ability to separate cosmic ray primaries at the threshold/baseline levels

- **TEPC:** Industry standard microdosimeter provides radiation protection (operational) dose measurement, which is defined as the ambient dose equivalent [ICRU, 2010; ISO, 2012]
- **TID:** When combined with TEPC, permits separation of neutron and charged particle contributions, with protons being the most abundant [Mazur et al., 2011]
- **Liulin:** When combined with TEPC, permits separation of heavy particles at the baseline altitude [Dachev et al., 2009]
- **RaySure:** Viable silicon-based microdosimeter “emulator” which is easy to manufacture



- Balloon/Gondola assembly provided by BPO
 - Gondola provides power and back up communication capability



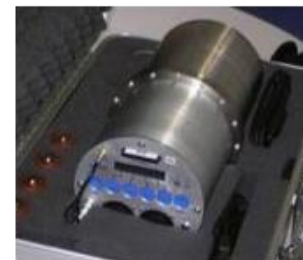
RaySure



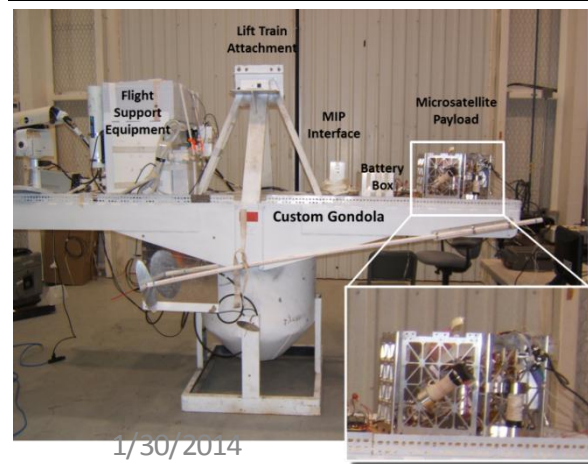
Liulin-6SMA



Teledyne TID

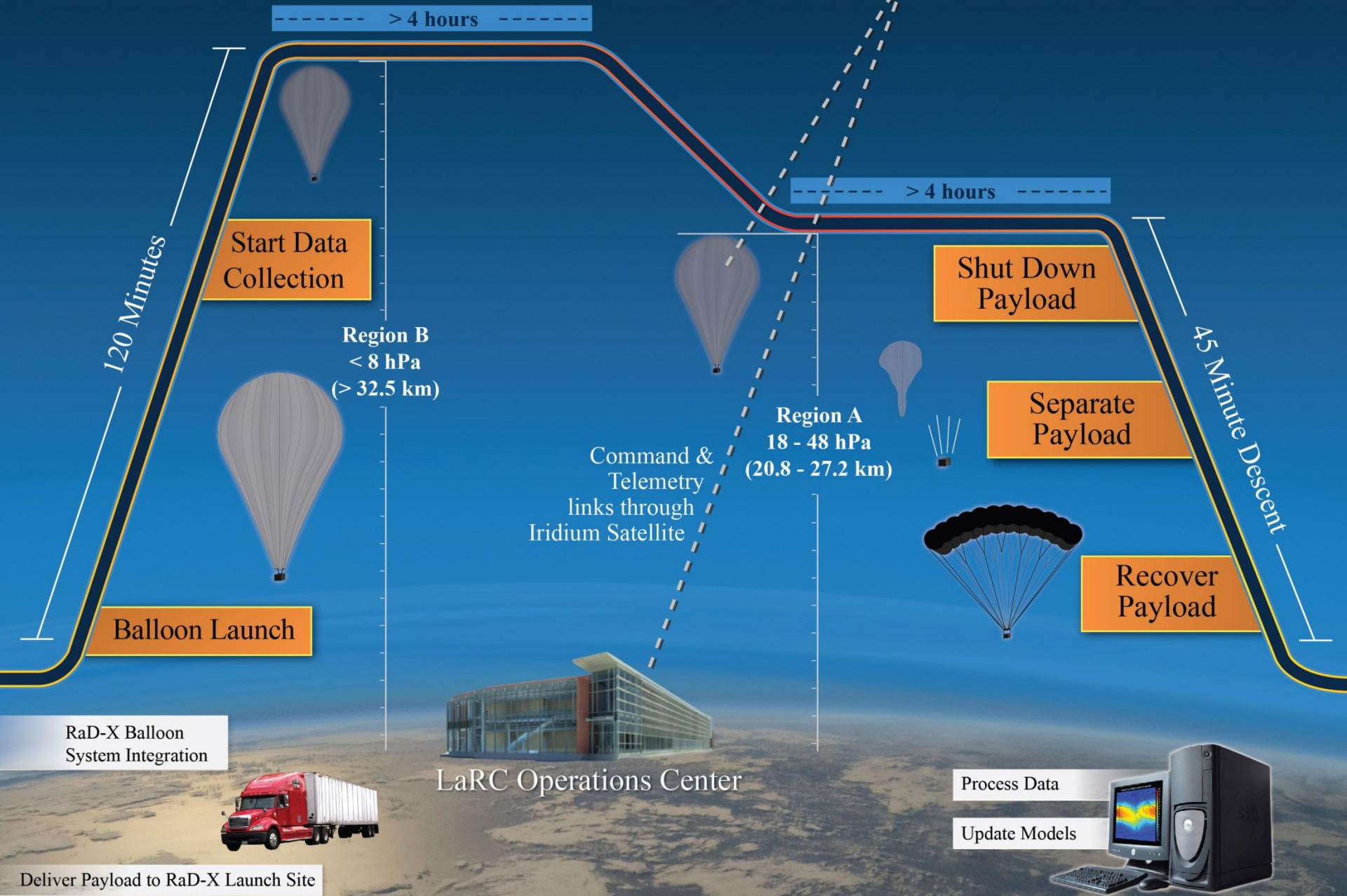


Tissue Equivalent Proportional Counter
TEPC



RaD-X

CONOPS





Wrap-Up



- Project Milestones
 - Selection Conference (08/20/2013)
 - Project Initiation Conference with ESSPO (10/25/2013)
 - Kickoff (10/31/2013)
 - 60-Day Review (12/11/2013)
 - SRR: System Requirements Review (02/19/2014) – **Passed!!!**
- Near-Term Science Activities
 - Modeling of instrument and radiation shielding environment using Monte Carlo transport code
 - Dosimeter Beam Calibration Plan and Analysis Software
 - PDR: Preliminary Design Review (05/16/2014)
 - Beam Exposure (08/2014)
 - Lawrence Livermore National Laboratory
 - Loma Linda Medical University Proton Therapy Center



BACKUP SLIDES

Absorbed Dose

$D_j(\mathbf{x})$: Energy deposited in a target medium (e.g., tissue, silicon) by the radiation field of particle j

Unit: Gray (Gy) = Joules per kilogram

Equivalent Dose in Tissue

Unit: Sievert (Sv) = Joules per kilogram x radiation weighting factor

$$H_{j,T} = w_j D_{j,T}$$

← Absorbed dose from particle j averaged over the tissue volume

↙ Radiation weighting factor (radiobiological effectiveness)

Effective Dose

Unit: Sievert (Sv) = Joules per kilogram x radiation weighting factor x tissue weighting factor

$$E = \sum_T \sum_j w_T H_{j,T}$$

Tissue weighting factor

Effective dose is full-body averaged dose proportional to the total biological detriment

All ICRP recommended radiation exposure limits are expressed in terms of effective dose

Dose Equivalent in Tissue

Unit: Sievert (Sv) = Joules per kilogram x radiation quality factor

$$H_{j,T}(\mathbf{x}) = \int_L Q(L) D_{j,T}(\mathbf{x}, L) dL$$

LET: Linear energy transfer
(keV/μm)

LET-dependent quality
Factor $Q(L)$

Absorbed dose LET-spectrum from particle j at
point $\mathbf{x}$ in tissue

Ambient Dose Equivalent Unit: Sievert (Sv)

$$H^*(10) = \sum_j H_{j,T}^*(10)$$

Dose equivalent produced by an expanded and aligned field at 10-mm depth along the radius of a 300-mm diameter spherical tissue phantom

Operational proxy for effective (body) dose



Aircraft Radiation Exposure

Typical Dose Values



- Unit of radiation dose related to health risk = Sievert (Sv)
 - Chest x-ray = 0.1 millisievert (mSv)
 - Instant death > 3 Sv
- ICRP recommended limits
 - Public annual limit < 1 mSv
 - Prenatal limit < 1 mSv total; < 0.5 mSv any month
 - Radiation worker annual limit < 20 mSv
 - ☐ Pilots are classified as radiation workers
- Typical passenger exposure
 - One round-trip international = 0.2 mSv (2 chest x-rays)
 - 100k mile flyer = 2 mSv (20 chest x-rays)
- Solar storm exposures at high-latitude
 - January 2005 = 1 mSv
 - February 1956 = 5 mSv
 - Carrington 1859 = 20 mSv (average)