The RadMap Telescope

Updates, Early Results, and Next Steps

Martin J. Losekamm * | Technical University of Munich 3 September 2024





U.S. NATIONAL LABORATORY

DLR



*For the RadMap Telescope team: Thomas Berger, Peter Hinderberger, Moritz Kaseman, Thomas Kendelbacher, Carl Kuehnel, Karel Marsalek, Daniel Matthiä, Luise Meyer-Hetling, Stephan Paul, Thomas Pöschl, Bartos Przybyla, Markus Rohde, Sebastian Rückerl, Michael Wirtz, Hans J. Zachrau

The Space Radiation Environment

Composition and Dosimetry

- Cosmic-ray nuclei
 - Small fluxes
 - Large dose contribution
- Charge-dependence of quality factor and relative biological effectiveness

$$Q_{\text{NASA}} = (1 - P(Z, E)) + \frac{6.24(\Sigma_o / \alpha_\gamma)}{\text{LET}} P(Z, E)$$
$$P(Z, E) = \left(1 - e^{\frac{-(Z^*/\beta)^2}{k}}\right)^m (1 - e^{-(E/0.2)})$$



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The RadMap Telescope

Instrument Overview





The RadMap Telescope

Instrument Overview





Secondary Sensor: M-42 Dosimeter Real-time dosimetry using 300-µm silicon diode

Energy Dep. Range:	60 keV to 17.7 MeV
Resolution:	1004 channels, 17.6 keV width
Coverage:	Full solid angle

Primary Sensor: Active Detection Unit Real-time radiation monitoring using tracking calorimeter

Energy Range: Energy Resolution:

Angular Resolution:

Coverage:

>~70 MeV/n 1% for <90 MeV (protons) *non-isotropic 7% for <200 MeV (protons) *isotropic < 2°

Full solid angle Geom. Acceptance: 1013 cm²sr (detection) 925 cm²sr (reconstruction)

On-Orbit Operations

Operational Concept

- Deployment in various locations throughout the USOS
 - Node 3 \rightarrow May 2023 •
 - Japanese Experiment Module \rightarrow June 2023
 - US Lab \rightarrow October 2023 •
 - European Columbus Orbital Facility
- ¹⁶⁺ months (planned) Rotation through these locations in ~6 months
- Easy relocation (seat track mounting interface)
- Co-location with operational sensors for cross-validation of measurements (e.g., ISS-Rad and DOSTEL)









Primary Sensor

Active Detection Unit (ADU)

- 1024 sensor channels in four 256-channel modules (8 layers with 32 fibers each per module)
 - Kuraray SCSF-78 scintillating-plastic fibers
 - KETEK PM3325-WB-D0 silicon photomultipliers (SiPMs)
- Active tracking volume of ~ 8 x 8 x 8 cm³
- Custom SiPM arrays
- Individual bias-voltage filtering for each channel
- Calibration at piM1 beamline of Paul Scherrer Institute







Uncalibrated



15

16







 \succ

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#

Layer

3

4

5

6

7

8

9

10

11

12

13

14

15

16

2 4

6

Uncalibrated



Fiber # (even layers) / Z

2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32



Fiber # (even layers) / X

8 10 12 14 16 18 20 22 24 26 28 30 32

 \succ

#

Layer

Energy deposition (ADC code)

Uncalibrated



Energy sum:

13

14

15

16

2680.69 ADC code

3 4 5 6 7 8 9 10 11 12 13 13 13 . . . 14 14 14 . . . 15 15 15 16 16 16 8 10 12 14 16 18 20 22 24 26 28 30 32 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 2 4 6 Fiber # (even layers) / X Fiber # (even layers) / Z Event ID: 974661669 Baseline / cut threshold: 5/20 100 200 300 400 0 500 Fibers hit: 19/19 Event type: SXXX

Timestamp:

2023-11-23 06:59:15

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#

Layer

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13

14

15

16

2 4

6

Uncalibrated



Fiber # (even layers) / X



8 10 12 14 16 18 20 22 24 26 28 30 32



Baseline / cut threshold: 5/20 77 / 59 4355.44 ADC code Energy sum:

Fiber # (even layers) / Z

2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32

Fibers hit:

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Layer

3

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12

Uncalibrated



13 14 15 16 8 10 12 14 16 18 20 22 24 26 28 30 32 2 4 6

400

500

200

300

Energy deposition (ADC code)

100

0

Fiber # (even layers) / X

Event ID: 974661925 Event type: SXXX 2023-11-23 06:59:15 Timestamp:

16

Baseline / cut threshold: 5/20 31/26 2976.13 ADC code Energy sum:

Fiber # (even layers) / Z

2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32

Fibers hit:

16

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#

Layer

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16

0

Uncalibrated



UP / YX-Projection





15

16

Baseline / cut threshold: 5/20 Fibers hit: 46 / 40 8009.55 ADC code Energy sum:

Fiber # (even layers) / Z

2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32

15

16



Projected Performance

ADU Working Principle

Bragg Curve Spectroscopy

•







ADU Working Principle

Challenges

- 1. Energy-loss straggling
- 2. Fragmentation
- 3. Ionization quenching





Track Angles

• Geant4 simulation data, fully isotropic distribution from H to Fe, 70 MeV to 5 TeV, 10⁷ events



 $\sigma_{\theta} = 1.15 \deg$



Track Angles

• Geant4 simulation data, fully isotropic distribution from H to Fe, 70 MeV to 5 TeV, 10⁷ events



 $\sigma_{oldsymbol{\Phi}}=1.\,02$ deg



Particle / Ion Identification

 Geant4 simulation data, fully isotropic distribution from H to Co, 70 MeV to 5 TeV, 10⁷ events

									True	identity	
	Н	He	Li	Be	В	C	N	0	F	Ne-Fe	- 0
Т	99.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
He	0.2	98.8	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.1	
:	0.0	0.7	98.0	0.8	0.1	0.0	0.0	0.0	0.0	0.1	20
Be	- 0.0	0.2	1.1	97.1	1.2	0.0	0.0	0.0	0.0	0.2	40
В	0.0	0.0	0.1	1.4	96.2	1.3	0.1	0.0	0.1	0.3	40
O	0.0	0.0	0.1	0.2	1.7	95 <u>.</u> 9	1 <u>.</u> 4	0.1	0.1	0.5	- 60
ш Z	0.0	0.1	0.2	0.3	0.7	2.6	95.9	3.0	0.8	1.0	
leconst O	0.0	0.0	0.0	0.0	0.0	0.1	2.1	93.7	2.9	1.3	80
ructed F	0.0	0.0	0.0	0.0	0.0	0.0	0.3	2.9	95.3	5.2 -	00
identity Ne-Fe	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	1.0	91.2	100

H to F



F to Co

WORK IN PROGRESS

tity	8	- 0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.3	0.4	0.6	1.0	1.5	2.8	6.5	21.1	53.7		100
dent	-e (- 0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.3	0.3	0.5	0.5	0.7	1.0	1.4	2.3	5.1	17.2	38.0	25.9-		
ed i	∕In F	- 0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.9	1.7	3.5	13.4	32.6	20.9	7.5 -	-	
ruct	Cr	- 0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.3	0.4	0.5	0.7	1.4	2.8	7.8	26.6	49.3	29.0	10.3	5.0 -	-	00
nsti	٧a	- 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.6	2.2	11.4	27.2	11.4	2.9	0.9	0.5 -		80
Jeco	Ţ	- 0.1	0.2	0.2	0.3	0.3	0.4	0.6	0.7	1.0	1.5	2.5	5.9	21.1	41.5	24 <u>.</u> 1	8.8	4.8	3.3	2.5 -		
ш.	Sc	- 1.1	1.2	1.5	1.6	1.7	1.8	2.3	2.5	3.0	4.3	7.8	21.2	39.8	21.5	8.0	4.6	3.3	2.8	2.4 -	_	
	Ca	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.6	1.2	3.5	15.2	35.7	17.4	5.4	1.9	1.1	0.8	0.5	0.4 -	_	60
	X	- 0.0	0.1	0.1	0.1	0.2	0.4	0.8	1.8	5.1	19.2	43 . 1	21.4	6.6	2.7	1.2	0.6	0.4	0.3	0.2 -	_	
	Ar	- 0.7	0.7	0.9	1.0	1.2	1.5	2.1	3.9	15.4	36.8	16.6	5.3	2.9	2.2	1.5	1.2	1.0	0.8	0.8 -	-	
	Ū	0.2	0.2	0.4	0.6	0.9	1.8	4.7	19.5	45.6	22.4	6.9	3.1	1.8	1.1	0.6	0.4	0.3	0.2	0.2 -	-	
	S	- 0.0	0.0	0.1	0.3	0.7	3.2	19.5	45 . 4	17 <u>.</u> 7	4.4	1.7	0.8	0.4	0.3	0.2	0.1	0.1	0.1	0.1 -	_	40
	٩	- 0.8	1.2	1.7	2.5	5.0	21.1	47 . 2	16.9	5.5	3.1	2.0	1.4	1.1	0.8	0.6	0.5	0.4	0.3	0.3 -	-	
	Si	- 0.3	0.5	0.9	2.4	13.9	44.2	13.8	3.6	1.5	0.8	0.4	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1 -	-	
	A	- 0.3	0.8	2.5	15.7	53.8	18.1	4.0	1.6	0.8	0.5	0.3	0.3	0.2	0.1	0.1	0.1	0.0	0.1	0.1 -	-	
	Mg	- 1.2	2.4	11.9	52 . 3	15.3	3.4	1.7	1.0	0.7	0.5	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1 -	-	20
	Na	- 3.5	15.5	64 . 3	18.9	4.3	2.1	1.3	0.9	0.7	0.6	0.4	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1 -	-	
	Ne	-13.4	63.8	12.0	2.4	1.0	0.5	0.4	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0 -	-	
	ш	78.2	13.0	3.0	1.6	1.0	0.8	0.6	0.5	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.1	0.2	-	0
	I	F	Ne	Na	Ма	AI	Si	Р	S	CI	Ar	K	Са	Sc	Ti	Va	Cr	Mn	Fe	Со		U

%

True identity

Page 19

%

Particle / Ion Identification

• Geant4 simulation data, fully isotropic distribution from H to Fe, 70 MeV to 5 TeV, 10⁷ events





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Nuclear charge, Z

Energy

- Geant4 simulation data, fully isotropic distribution, 70 MeV to 1 GeV, 10⁷ events
- NN- vs. MC-selected particles





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Energy

- Geant4 simulation data, fully isotropic distribution, 70 MeV to 1 GeV, 10⁷ events
- NN- vs. MC-selected particles





Technica

University



On-Orbit Data

Count Rates

Comparison Between ADU & M-42

- Scaling of ADU and M-42 count rates with $\label{eq:FADU} GF_{ADU} = 1013 \ cm^2 sr \\ GF_{M-42} = 7.61 \ cm^2 sr$





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Count Rates

Comparison Between ADU & M-42

- Scaling of ADU and M-42 count rates with $GF_{ADU} = 1013 \text{ cm}^2\text{sr}$ $GF_{M-42} = 7.61 \text{ cm}^2\text{sr}$





Date



GCR-SAA Separation

Based on Count Rates





00:00

11-24

21:00

Energy Deposition

Single Channels vs. Full Detector (Uncalibrated)

Page 27 Counts 23 November 2023 GCR: 14670628 SAA: 5492240 10⁵ 10⁴ 10³ 10² 10¹ 10⁰ 10-Diff (%) 100 0 -100 10⁻³ 10⁻² 10² 10⁻¹ 10⁰ 10¹ 10³ Total energy deposition (a.u.)

10⁶ Counts GCR x-projection [13,13]: 298598 10⁵ yx-projection [5,6]: 242153 yx-projection [7,15]: 270452 yx-projection [8,22]: 80871 10⁴ yx-projection [5,5]: 86106 10³ 10² 10¹ 10⁰ 10⁻¹ 10⁶ Counts SAA yx-projection [13,13]: 129031 10⁵ yx-projection [5,6]: 98081 yx-projection [7,15]: 115380 yx-projection [8,22]: 55504 10⁴ yx-projection [5,5]: 41665 10³ 10² 10¹ 10⁰ 10⁻¹ 1000 3000 3500 4000 0 500 1500 2000 2500 Signal amplitude (ADC code)



Orbit Correlation

JEM vs. USL

- Raw count rates, no • cleanup whatsoever
- 1 x 1 deg bins

0°

30°S







Count rate (1/s)

Secondary Sensor

M-42 Dosimeter



• Planar silicon detector

- 300 µm thickness, 1.23 cm² area
- E_{dep}: 60 keV 17.7 MeV in Si
- 1004 channels, 17.6 keV width
- Interfaces: power, data (UART)



Berger, T., Marsalek, K., Aeckerlein, J., Hauslage, J., Matthiä, D., Przybyla, B., Rohde, M., Wirtz, M. (2019). The German Aerospace Center M-42 radiation detector – a new development for applications in mixed radiation fields. Review of Scientific Instruments, 90, 125115. https://doi.org/10.1063/1.5122301

M-42 Dosimeter

Daily Dose





M-42 Dosimeter

Energy-Deposition Spectra



NODE 3



JEM





Summary & Outlook



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- RadMap Telescope deployed to ISS in April 2023; measurements in
 - Node 3 \rightarrow May 2023
 - Japanese Experiment Module \rightarrow June 2023
 - US Lab \rightarrow October 2023
- Co-location with ISS-Rad in US Lab \rightarrow data comparison pending
- Analysis of ADU data ongoing
 - Clearly identifiable track candidates in ~30% of events \rightarrow identify nature of rest
 - Baseline subtraction, crosstalk identification, and noise suppression work
 - Tracking works, automatic correction of position-dependent light yield in verification
 - Energy / gain calibration ongoing
 - Start `physics' analysis

Unfortunately: Communication problems with the instrument

- On-orbit troubleshooting not successful
- Return & re-flight in planning

Outlook

- Quality issues during RadMap ADU production
- New approach: pot fibers in epoxy
- Insensitive material, MC correction required to reconstruct particle energies
- > Total suppression of optical cross-talk; more robust













Thank you for listening!

For questions, contact

Martin J. Losekamm m.losekamm@tum.de

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