Developing an Independent Source of Space Weather Data for Aircrew Radiation Dose Assessment

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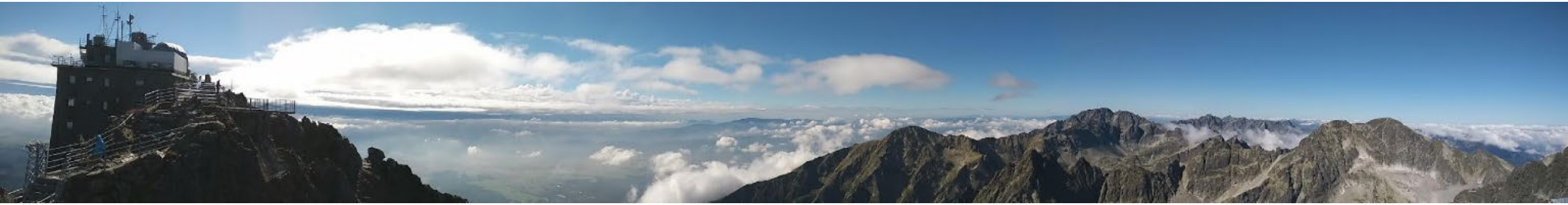
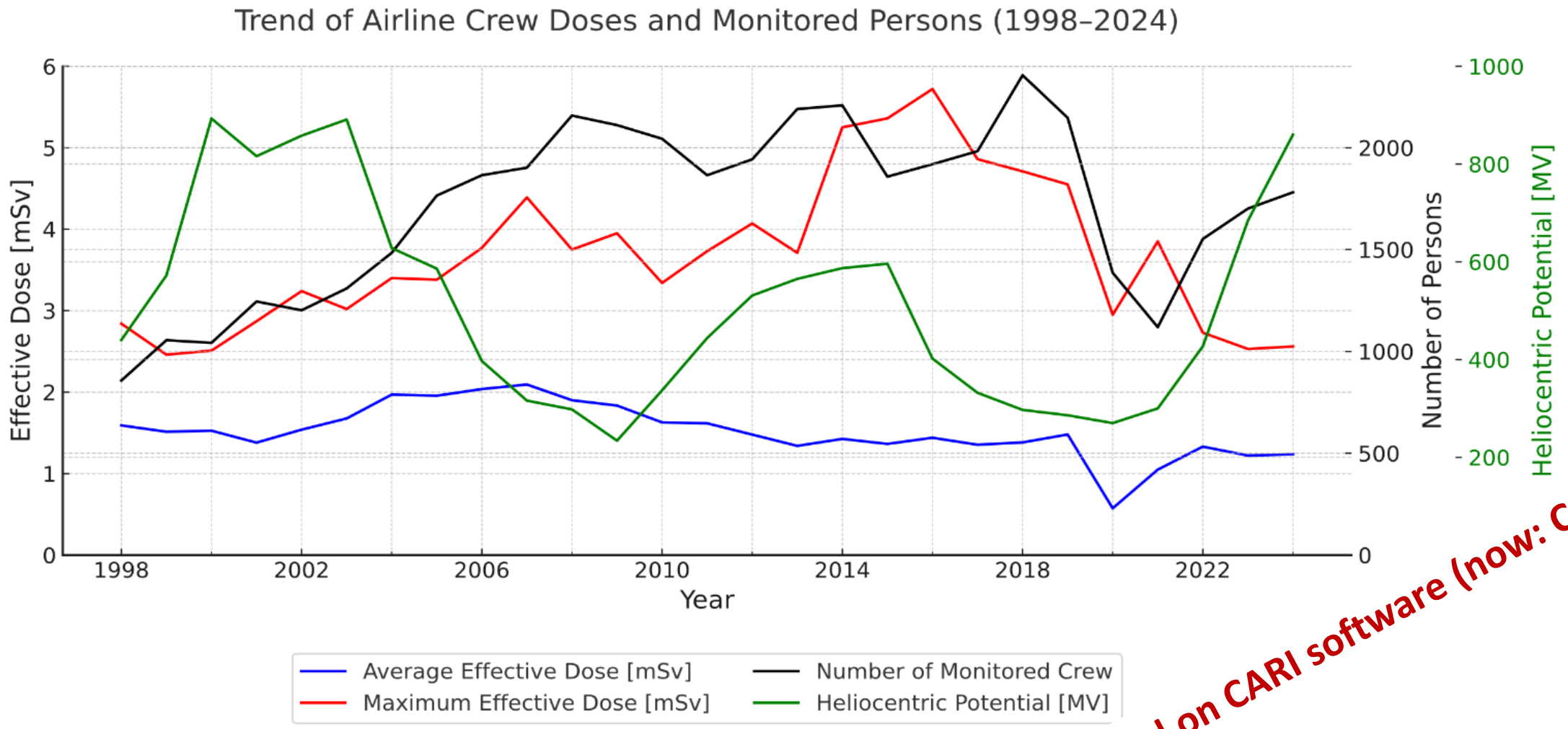
Outline

- Background: Aircrew dosimetry at NPI CAS since 1998
- Motivation for the ESADOS project
- The Lomnický Štít neutron monitor
- Methodology: Deriving heliocentric potential from NM data
- Radiation measurements on board aircraft for model validation
- Summary and future work



Czech Aircrew Dosimetry – 27 Years



Based on CARI software (now: CARI-7A)

Established at NPI by Prof. František Spurný
FAA HP calculated based on Apatity neutron monitor (NM) measurements
Average annual effective doses of aircrew belong to highest professional doses in Czechia

Motivation for the ESADOS Project

- Aircrew dosimetry with CARI-7
- Limitation: single-source heliocentric potential from FAA
- Goal: Independent European space weather data input
- ESA-funded project

In collaboration with IEP SAS

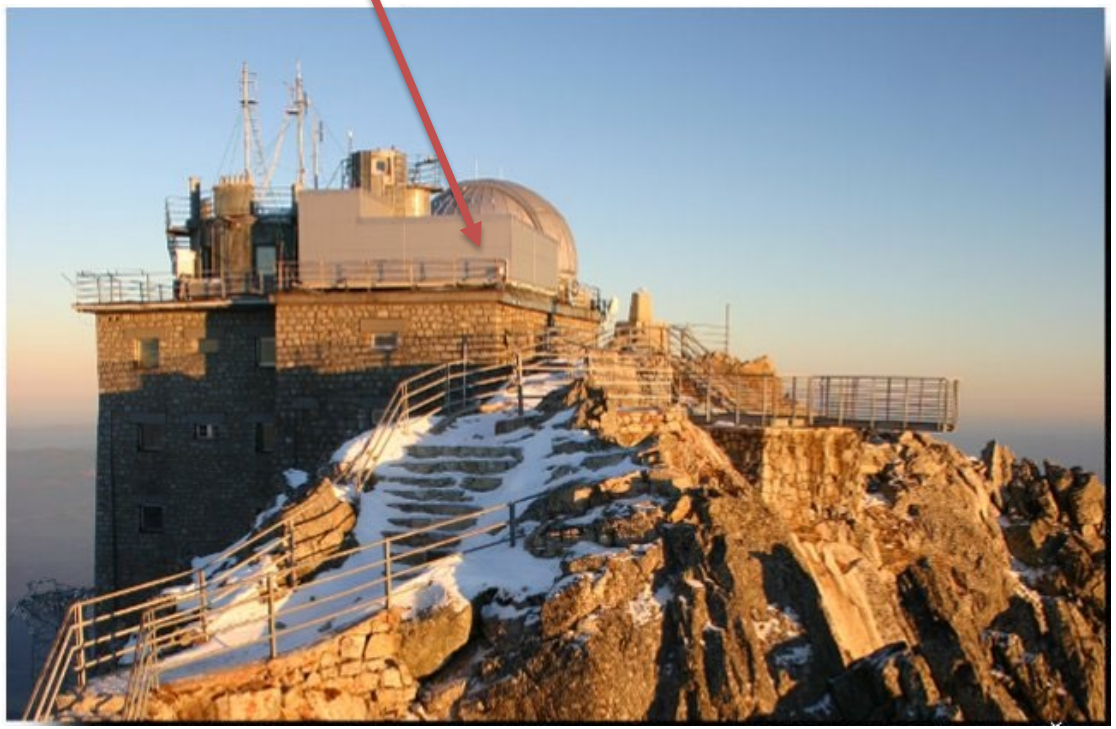
ESADOS Method of HP evaluation

- Author: **Jan Kubančák**
- Model uses Neutron Monitor LMKS
  - FAA website
  - paper by Usoskin et al. [2]
  - Lomnický štít neutron monitor data (ZENODO)
  - Lomnický štít, Oulu, Jungfraujoch, Moscow and Apatity NM stations data (www.nmdb.eu)
- R-based data processing and regression
- Fitted to historical FAA data
- Deliverable: open-source scripts and model

Neutron monitor at Lomnický štít observatory

- Altitude: 2638 m a.s.l.
- Type: NM64, 8 tubes
- Counter gas: 7x $^{10}BF_3$ + 1x ^{3}He
- Producer: lead
- Moderator: polyethylen
- Reflector: polyethylen

- In operation: from 1981
- Reliable and high count rates



Basic parameters of neutron monitor data

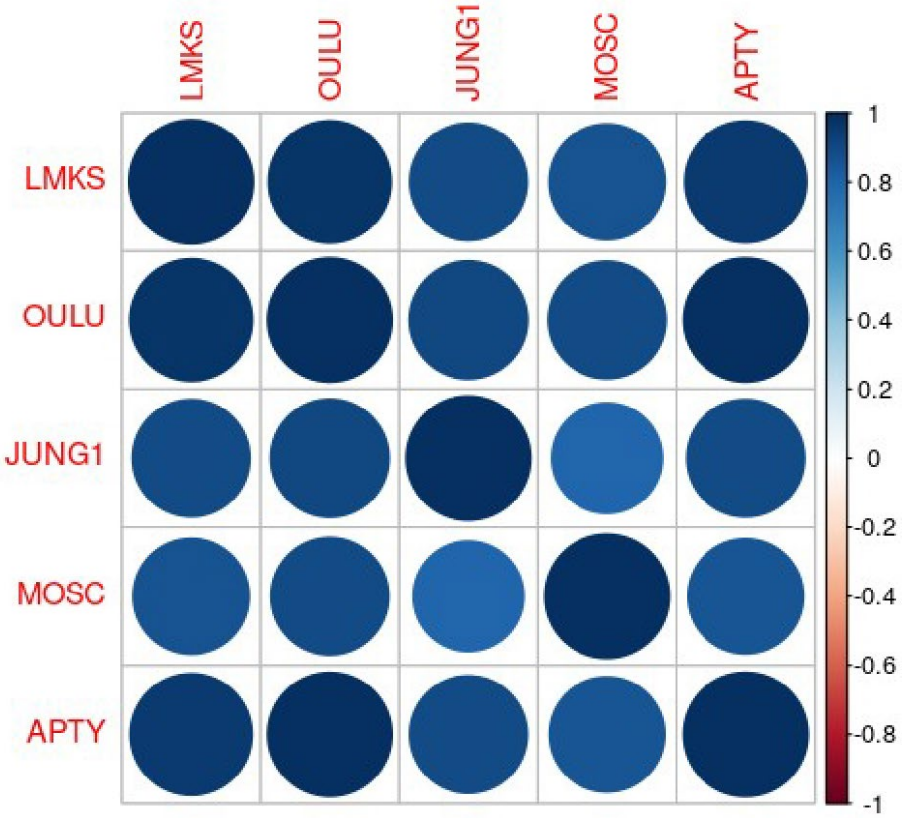
	Location	Vertical cut-off rigidity [GV]	Altitude [m a.s.l.]	NM type	Since
LMKS	near Poprad, Slovakia	3.84	2 634	8NM64	1981
OULU	Oulu, Finland	0.8	15	9NM64	1964
JUNG1	near Interlaken, Switzerland	4.5	3 475	3NM64	1986
MOSC	Troitsk, Russia	2.43	200	24NM64	1966
APTY	Apatity, Russia	0.65	181	18NM64	1961

LMKS data are shifted against the OULU and APTY data in particular in periods close to solar minimum in cycles 22 and 23. Very good agreement since 2012. Relative deviations from mean value are lower than 1%.

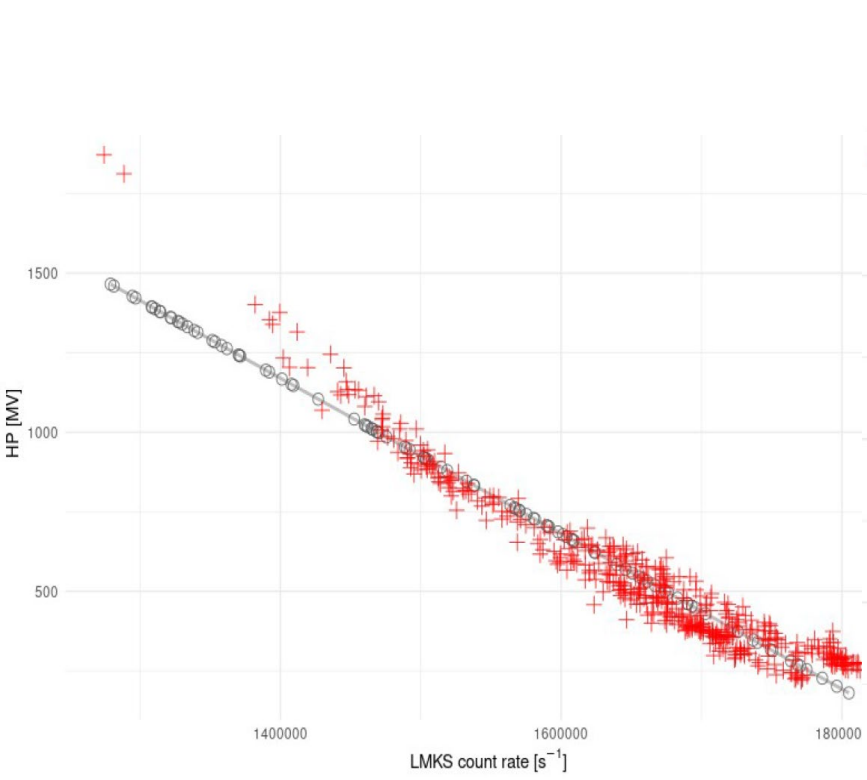
Lomnický štít reconstruction in 2012

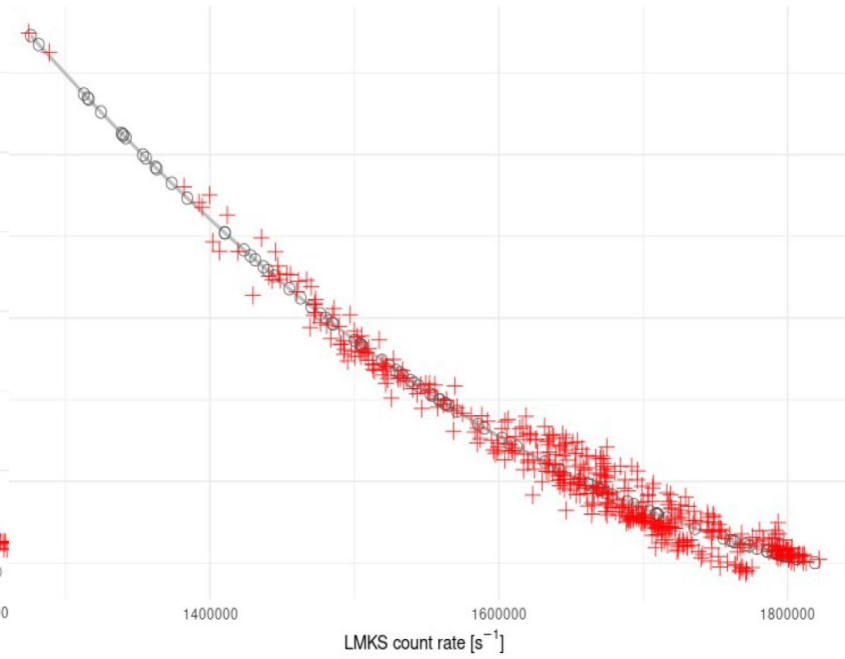
Cross correlation analysis

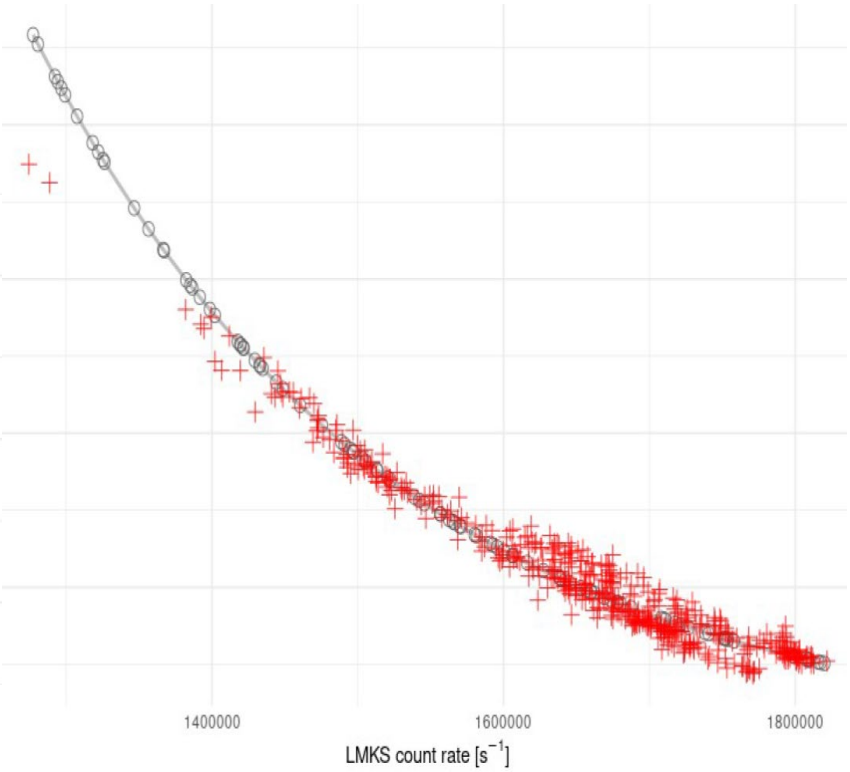
- LMKS data correlates at best with the OULU and APTY data; correlation with the JUNG1 and MOSC is lower
- excellent correlation is between Oulu and LMKS - better than 99% for data from 2013



Selection of the best fit function

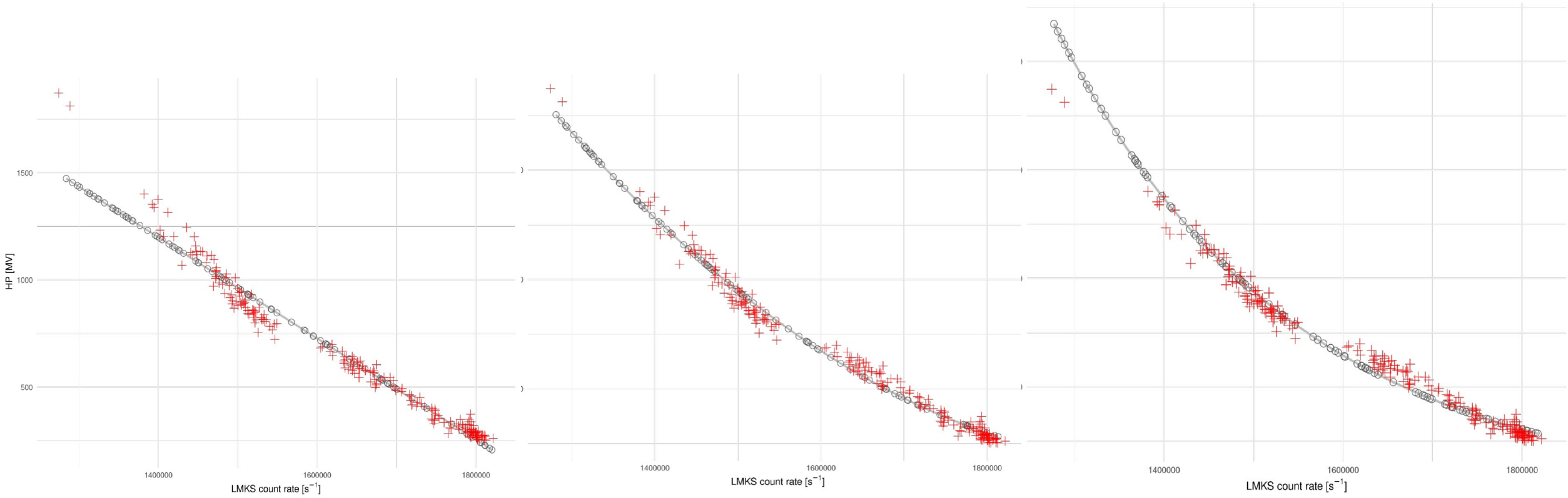






Linear Quadratic Exponencial

Selection of the best fit function



Linear

Quadratic

Exponencial

second tail removed

Selection of the best fit function

	Neutron monitor station				
	LMKS	**LMKS** (tail removed)	**APTY**	**OULU**	**LMKS-OULU AVG**
Linear $f(x) = ax + b$ R^2	a = -2.443e-03 b = 4.590e03	a = -2.359e-03 b =4.502e03	a = -23.16 b =4.490e03	a = 0.3813 b =39.8939	a = -14.5608 b =4653.2441
	0.9294	0.9738	0.9841	0.9611	0.9434
Quadratic $f(x) = ax^2 + bx + c$ R^2	a =3.725e-09 b =-1.450e-02 c = 1.430e04	a = 2.911e-09 b =-1.177e-02 c = 1.205e04	a = 1.314e04 b =-1.249e-02 c = 1.314e04	a = 7.927e-01 b =-2.014e02 c = 1.292e04	a = 1.232e-01 b =-8.244e01 c = 1.396e4
	0.9661	0.9837	0.997	0.9853	0.9758
Exponential $f(x) = e^{ax+b}$ R^2	a = -4.058e-06 b =1.292e01	a = -3.758e-06 b =1.248e01	a =-0.0453979 b =13.9492157	a =-0.0671271 b =13.2057830	a =-0.0242098 b =13.0319807
	0.9321	0.9738	0.9892	0.9731	0.9478

$$HP[MV] = 2.911\text{e-}09 * CPS_{LMKS}{}^2 - 1.177\text{e-}02 * CPS_{LMKS} + 1.205\text{e}04$$

Radiation measurements onboard aircraft

- From April 2001
- Liulin MDU spectrometer (Si, 256-channel)
- Measurements started in 2000 (130 flights)
- GLE 60 – 15th April 2001

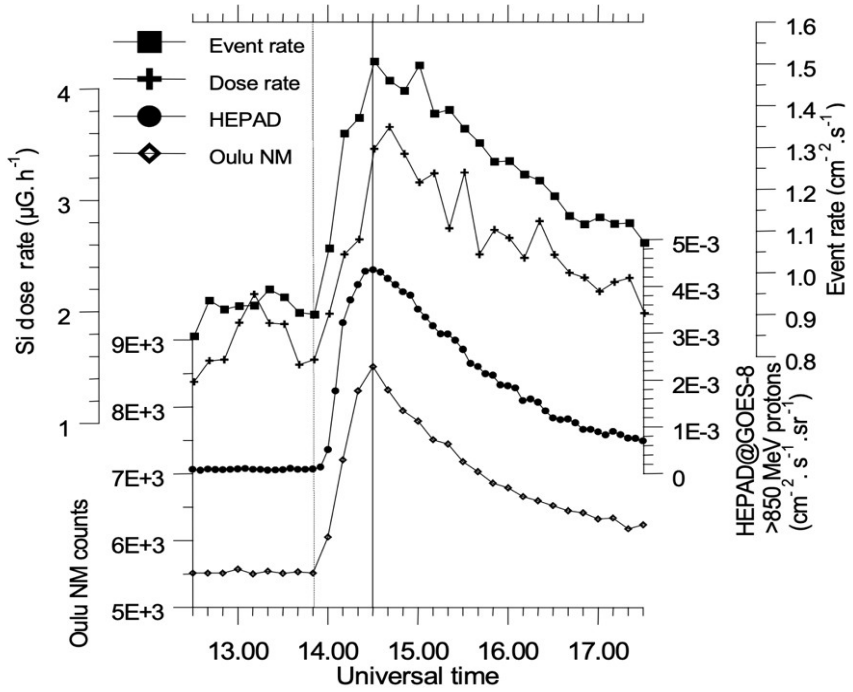


Figure 1. Comparison of on-board measured results with the data of the cosmic ray monitor (Oulu) and the GOESS high-energy proton fluxes.

F. Spurný and Ts. Dachev

10.1093/oxfordjournals.rpd.a006552

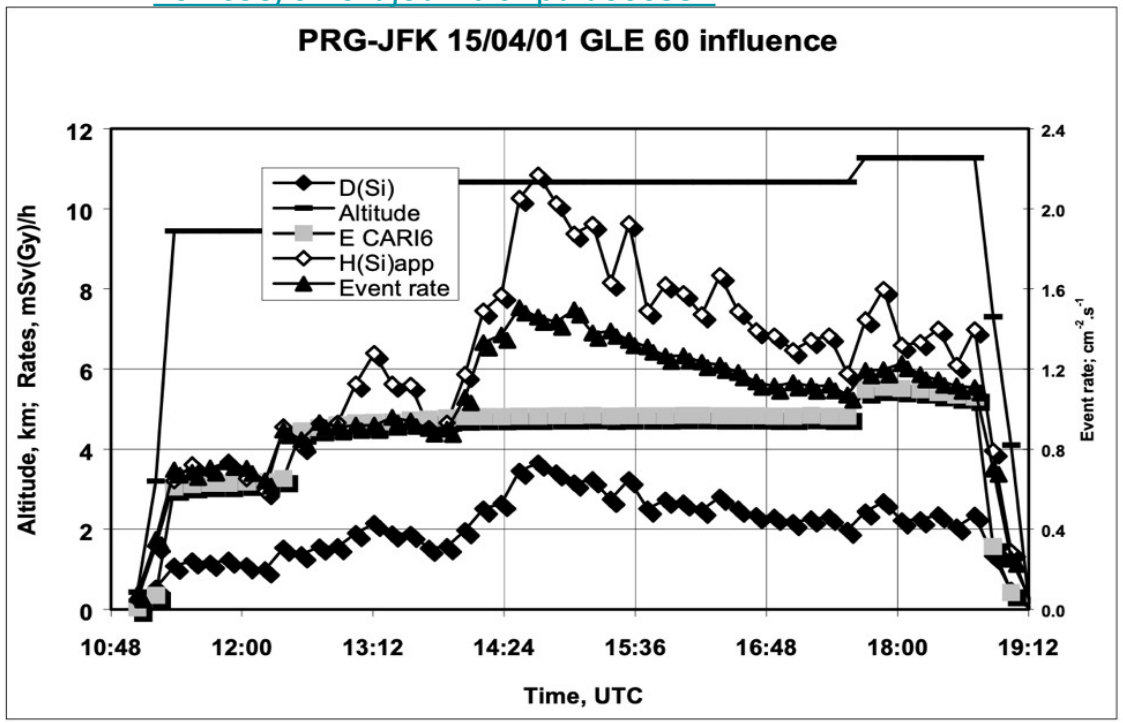


Figure 2. Flight data and experimental results from the Prague-New York flight on April 15, 2001.

Radiation measurements onboard aircraft

- Long-term installation
  - civilian aircraft of Smartwings, business jets of ABS Jets
- Individual flights: e.g. Egypt, Madeira, Antarctica, …
- Campaigns: REFLECT Oct2017, Dec2020, Feb2021, 2022
- Czech Army Aircraft in frame of NATO MILSWx (Military Space Weather Panel) - from Sept 2025

REsearch FLight of EURADOS and CRREAT

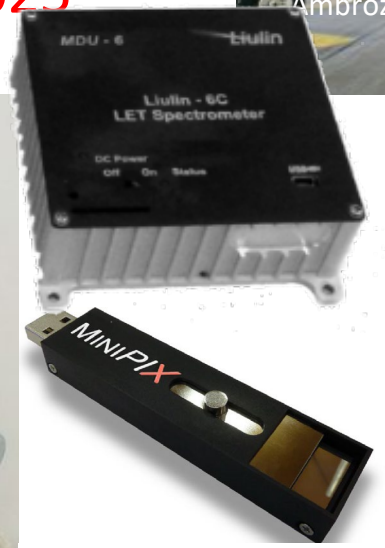
Ambrožová, I, et al. (2020) REFLECT: intercomparison of various radiation dosimeters onboard aircraft." Radiat Meas 137.

HAWK TEPC

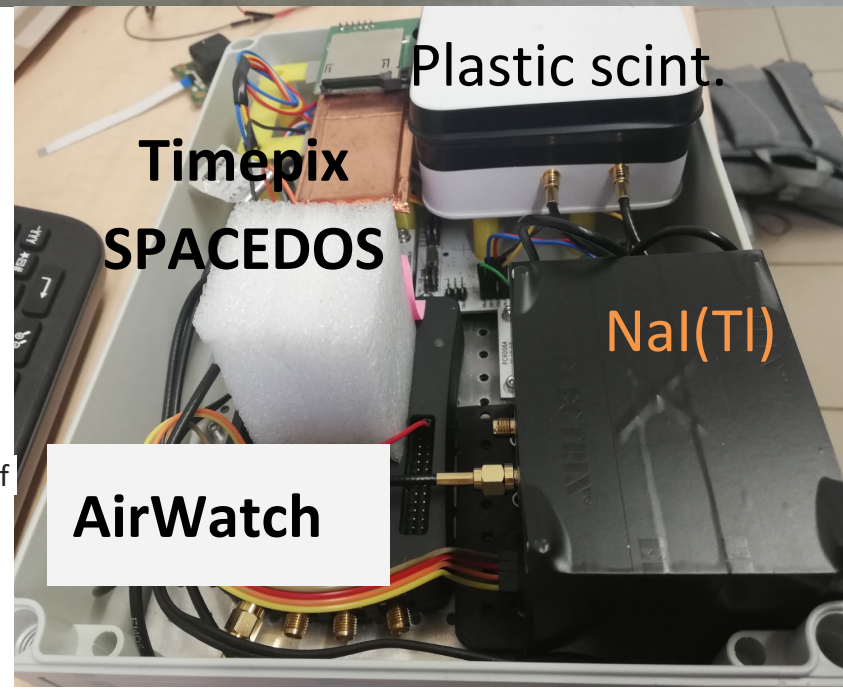
Standard
ISO/TC85/SC2/WG21

CERTIFIED for use on aircraft

Kákona, M. et al. AIRDOS—open-source PIN diode airborne dosimeter. *Journal of Instrumentation* 16.03 (2021): T03006.



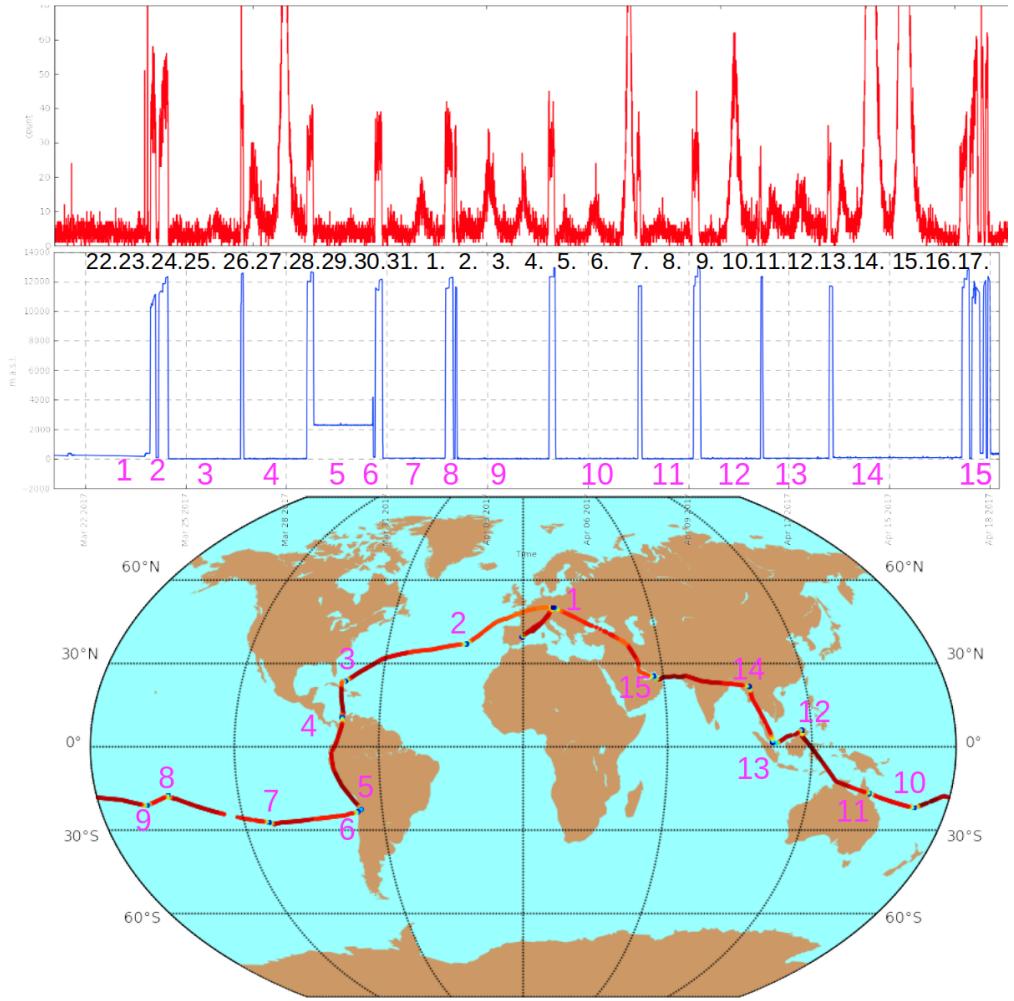
Sommer, M, et al. Calibration of silicon detectors Liulin and AIRDOS using cosmic rays and timepix for use at flight altitudes. *Radiat Prot Dosim* 198.9-11 (2022): 597-603.



Flights around the world

Interesting due to different cut-off rigidities

Liulin, Airdos and TLDs on board



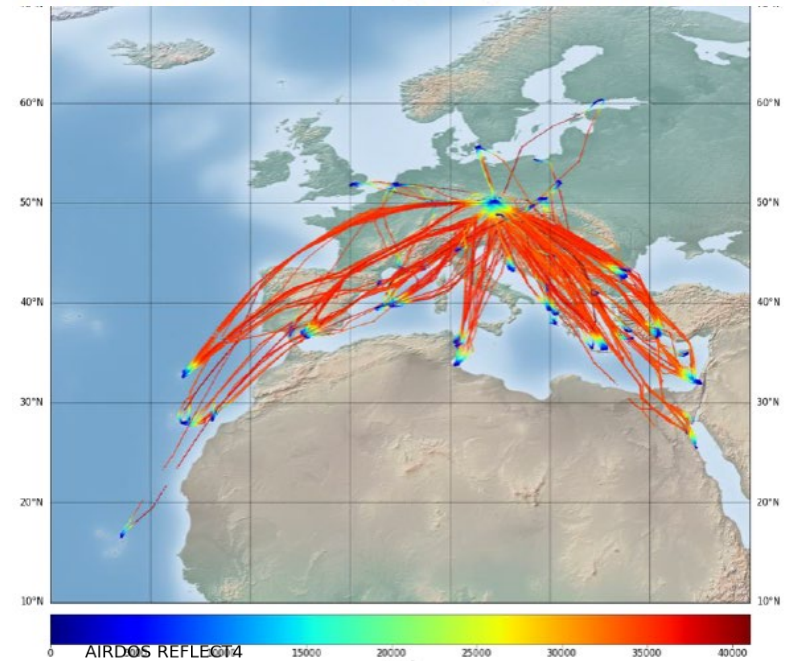
REFLECT-P (Intercomparison of passive detectors onboard aircraft)

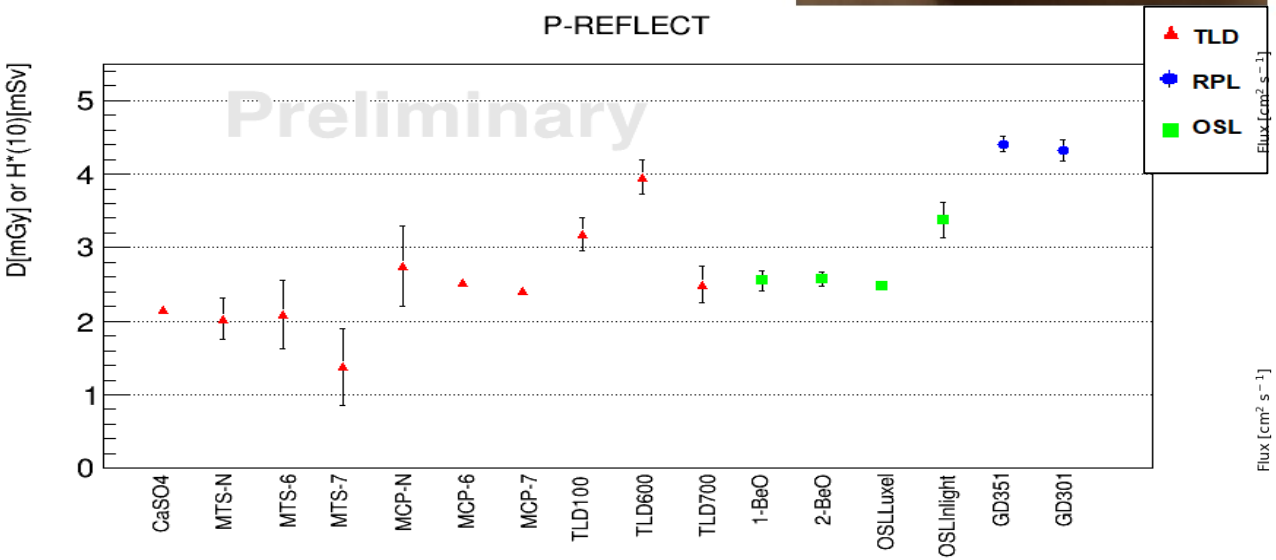
- Various passive detectors (TLD, OSL, RPL, D-shuttle, CR-39) + AIRDOS
- NPI, PoliMi, PSI, IRSN, DLR, ELI, NCBJ, Hiroshima University
- onboard aircraft (2022)
- CERF (June 2022, position CS3)

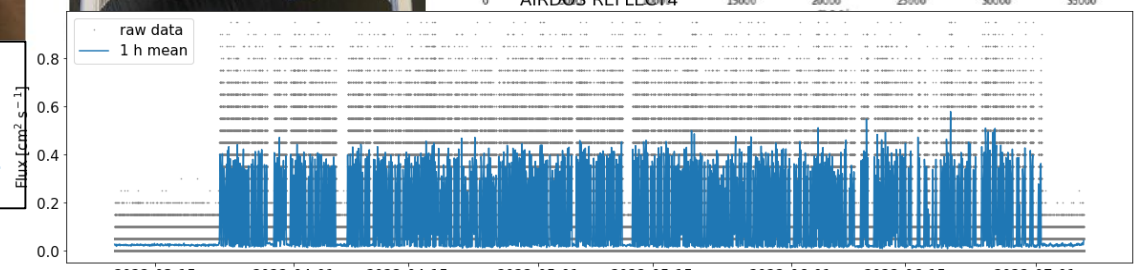
EURADOS

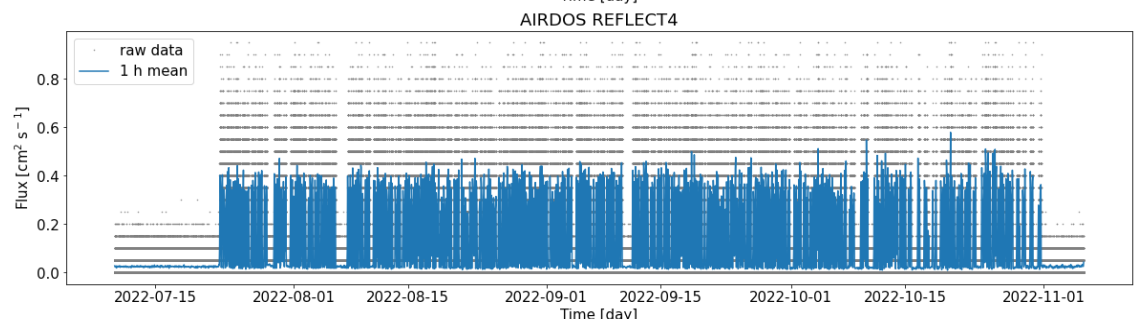
Long-term (Mar – Oct 2022) continuous measurement onboard aircraft (OK-TSI, Smartwings)

> 800 individual flights, ~ 2000 hours



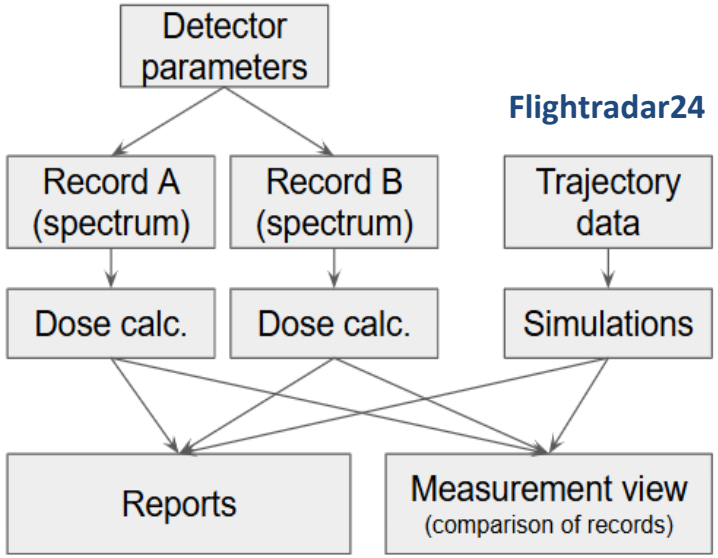






DOSPORTAL

Web-based tool for data management and handling of records from particle detectors



Flightradar24

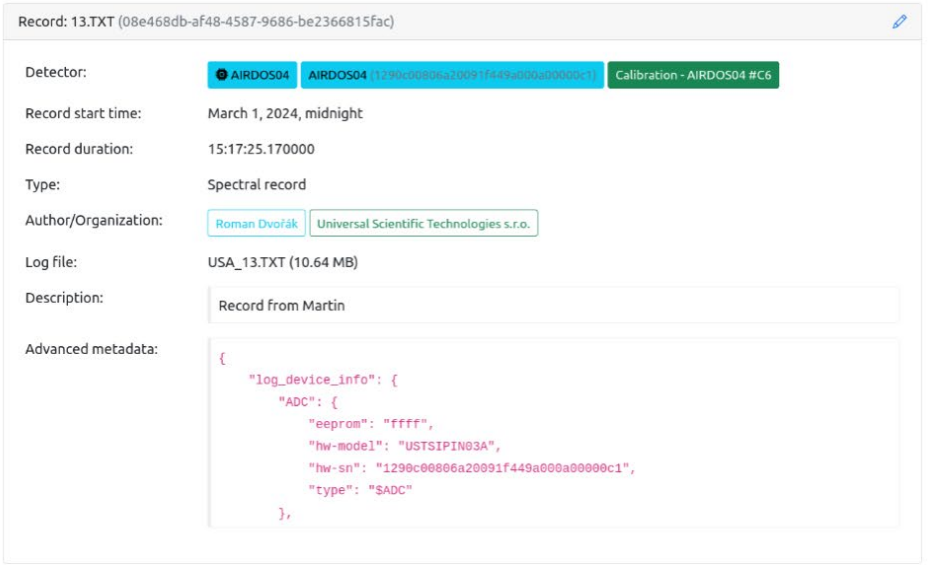
Currently supported detectors:

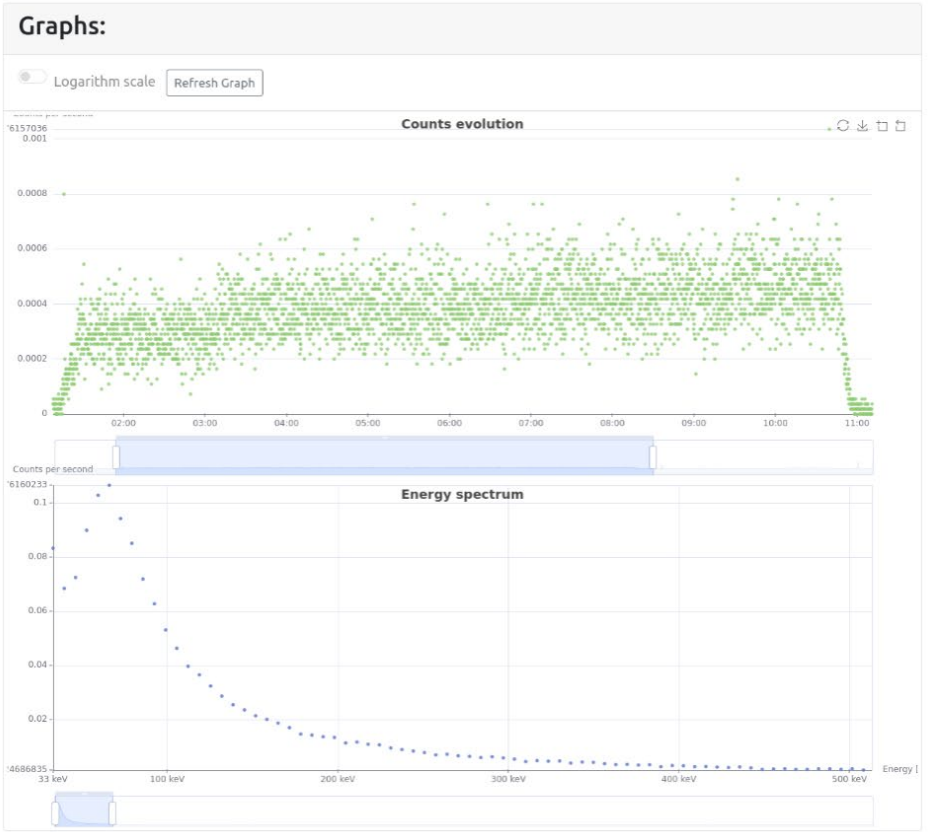
- AIRDOS04
- LABDOS01
- AIRDOS02

Current status:

- Single log view that have its system time aligned to absolute time.
- Display of radiation intensity progres graph
- Display of the energy spectrum
- Cross-filtering by energy/time
- Display of telemetry data (temperature, pressure...)

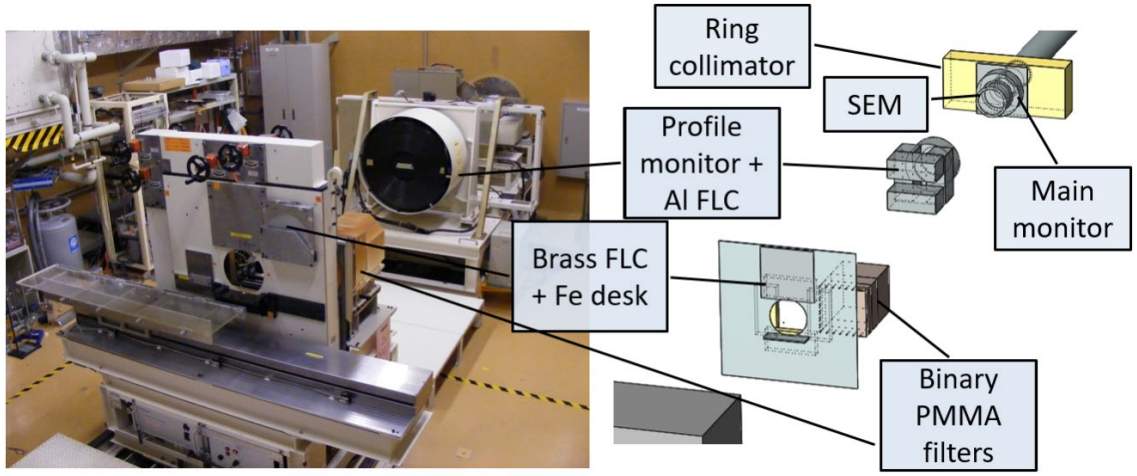
Vernetto, S. et al. (2025). Performance of the LABDOS01 spectrometer in dosimetric measurements. *Radiation Physics and Chemistry*, 113031.

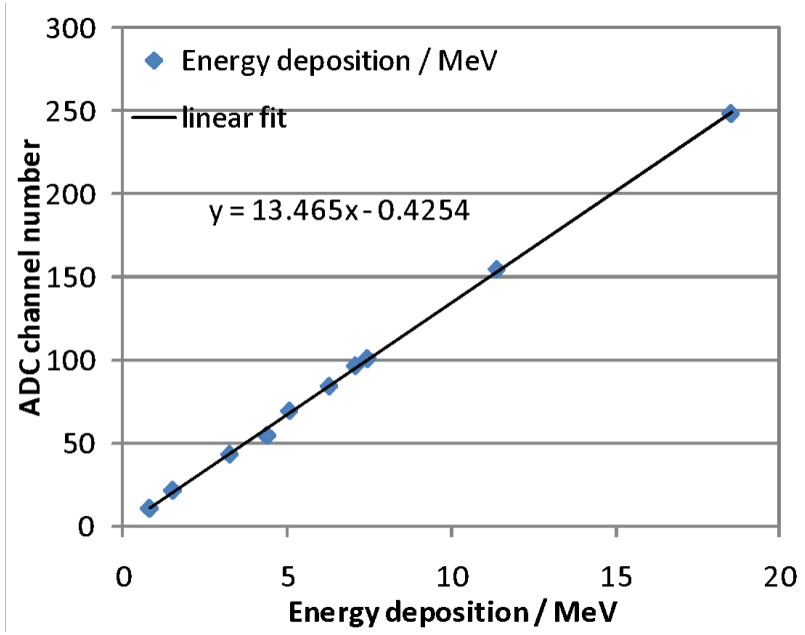


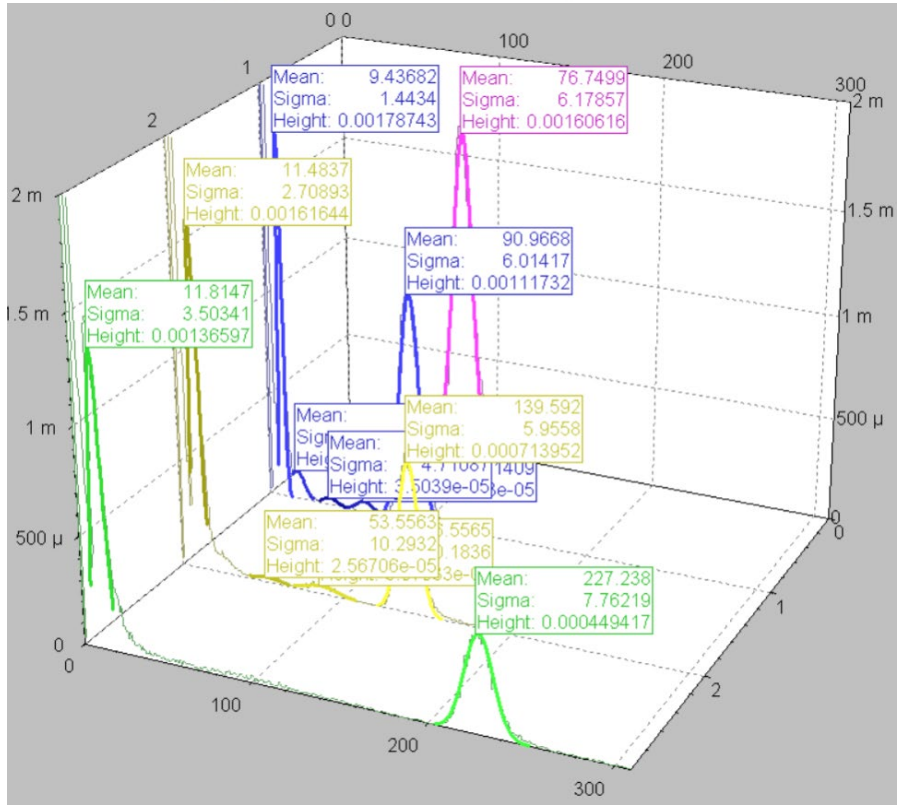


Calibration of Liulin detector at HIMAC BIO

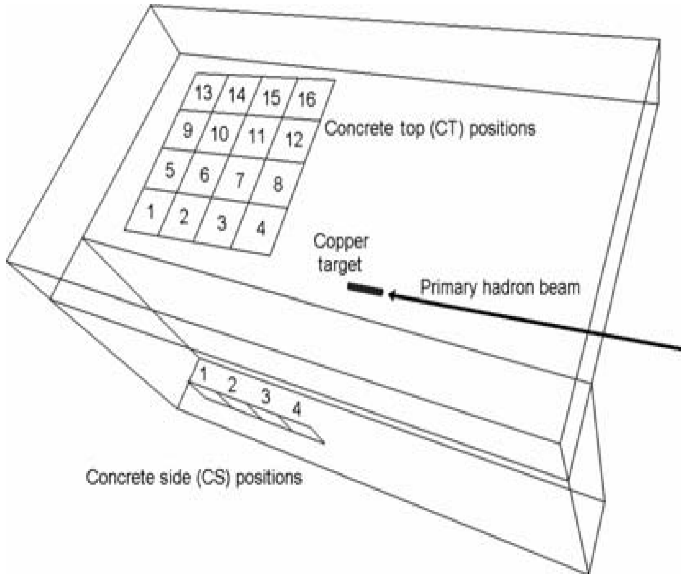
Energy deposition spectrum shows several due to fragmentations in the beam-line.

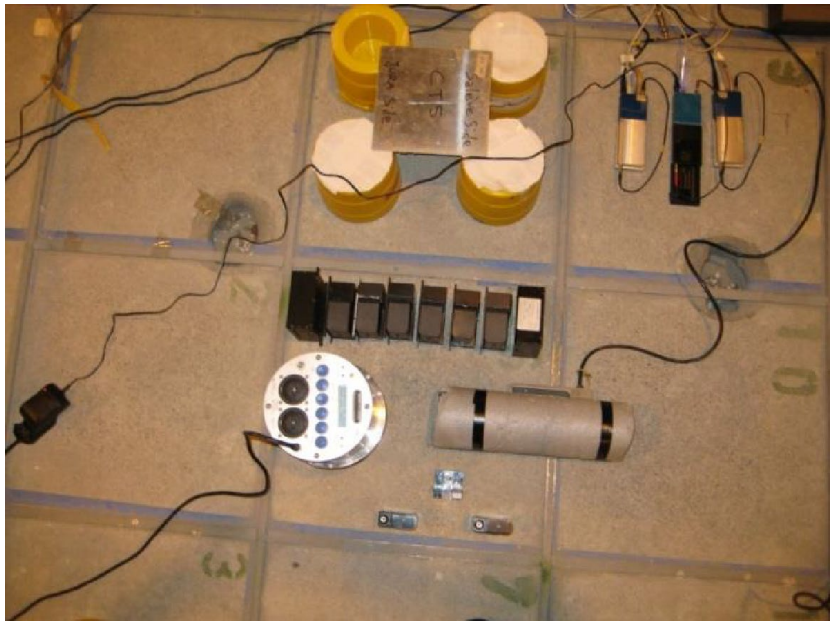






Calibrations at CERF



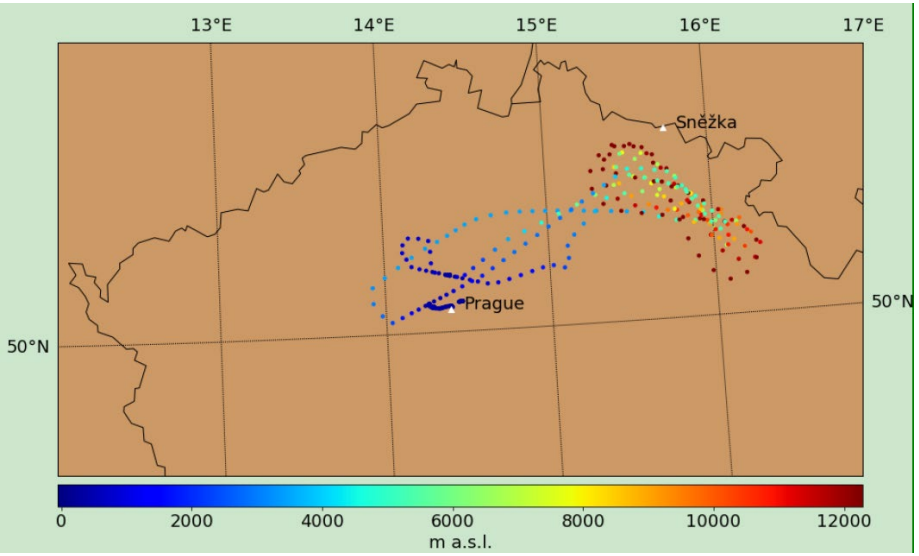


$H^*(10) = D_{low}*K_1 + D_{high}*K_2$

K_1, K_2 – established in CERF fields and through onboard comparison with TEPC results

REFLECT2 – December 2020

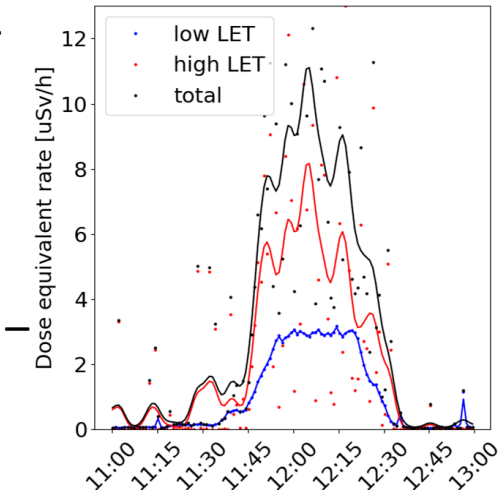
Research Flight of EURADOS and CRREAT, small aircraft (Embraer Legacy)

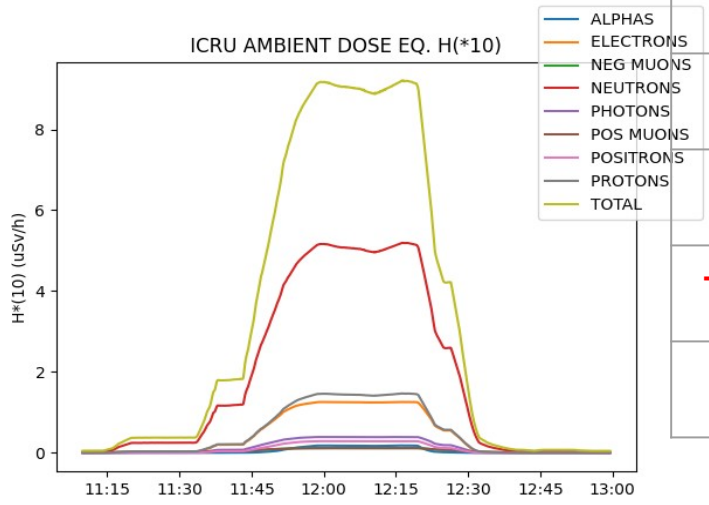


Method	D_{Si} [µGy/h]	H*(10) [µSv/h]
CARI-7	3.0	9.0
TEPC HAWK	--	8.8 ± 0.3
Liulin 14	2.9 ± 0.2	
Liulin 15	3.1 ± 0.2	
Liulin 10	2.2 ± 0.2	
Airdos dd	2.0 ± 0.2	
Airdos 98	2.7 ± 0.4	
Timepix H08	2.2 ± 0.3	
Timepix I08	2.6 ± 0.4	

TEPC represents standard for radiation measurements on board aircraft but limited number of flights were done

Liulin and Airdos calibrations – connected to TEPC Hawk





Conclusions

- Method of HP calculation using LMKS data was introduced
- NPI's Long-term radaition mesurements onboard aircraft provide basis for validation
- Validation using TEPC and/or Liulin/Airdos calibrated with TEPC

Future work

- Validate on independent datasets
- Goal: Web portal with current and forecasted HP
- Export-ready data for CARI-7 use

- Test our newly installed NM from Kiel University on Milesovka