



RADIATION EFFECTS TESTING AT RADEF

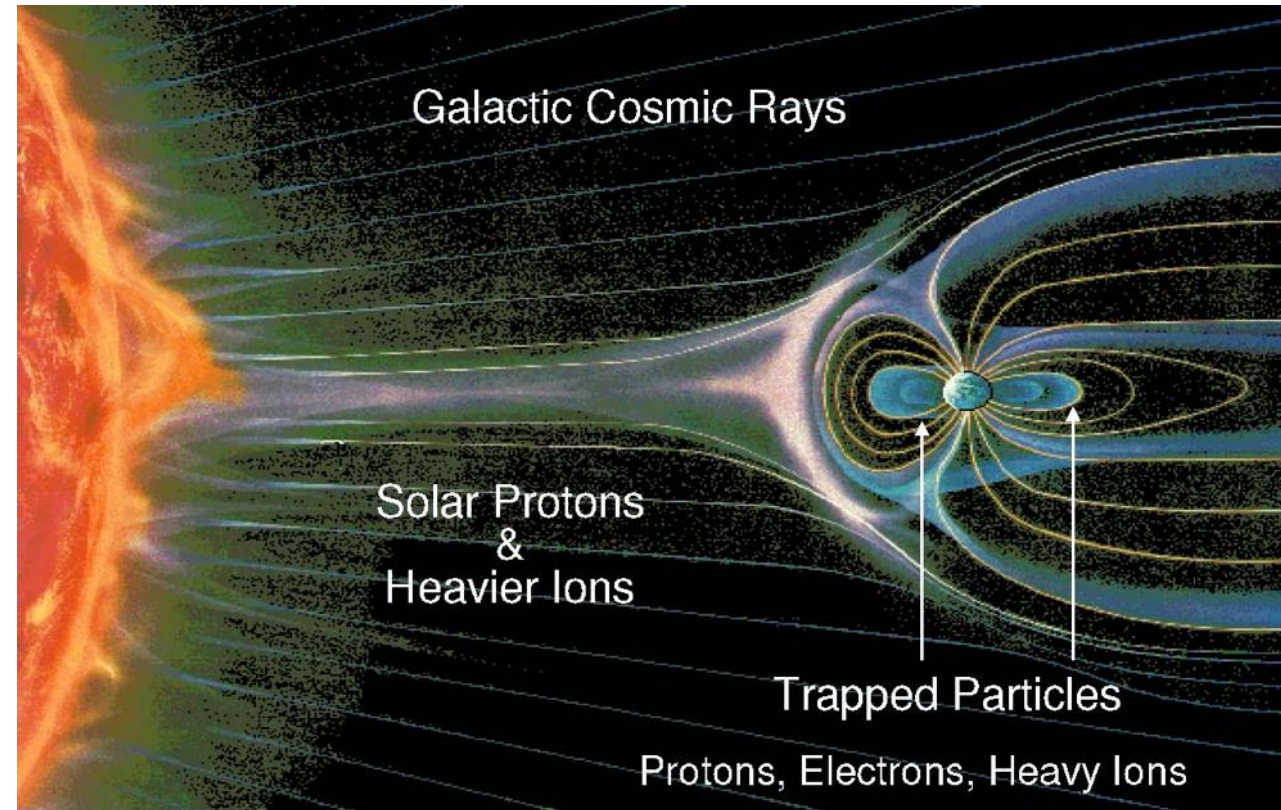
Arto Javanainen
University of Jyväskylä
Accelerator Laboratory

Finnish Satellite Workshop
January 18th 2018



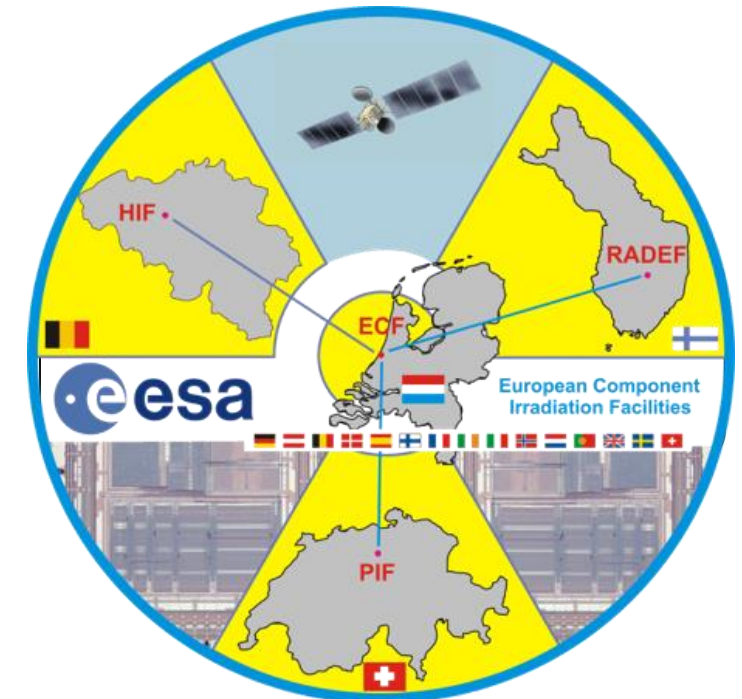
Radiation Environments

- Radiation can cause a myriad of problems in space systems
 - Single Event Effects
 - Cumulative effects
 - Total Ionizing Dose
 - Displacement Damage
- Modern technologies
 - SEEs can occur at **ground level** due to neutrons and even muons



RADiation Effect Facility - RADEF

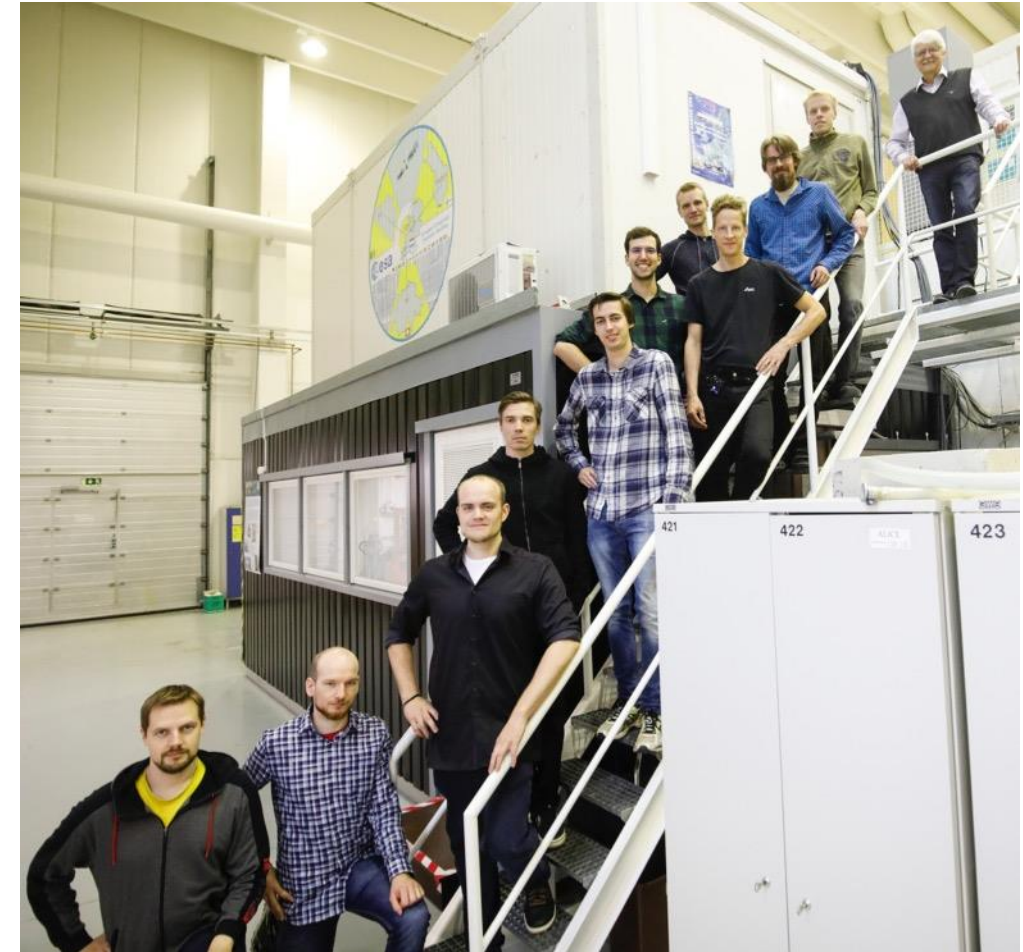
- <https://www.jyu.fi/accelerator/radiation-effects-facility>
- Accelerator Laboratory at University of Jyväskylä (JYFL)
- First commercial irradiation tests by Daimler Benz in 1998
- ESA supported facility since 2005
 - **1/3 ESA's external test sites**
 - 1/2 Heavy ion test sites



RADEF GROUP

Ari Virtanen, **professor**
Arto Javanainen, **senior researcher**
Heikki Kettunen, **laboratory engineer**,
Mikko Rossi, **laboratory engineer**
Jukka Jaatinen, **laboratory engineer**
Alexandre Bosser, **post doctoral researcher**(- 30.6.2018)
Maris Tali, **graduate student**
(ESA-NPI project, hosted by CERN, 1.12.2015-)
Corinna Martinella, **graduate student**
(hosted by CERN, 1.1.2017 -)
Sascha Luedeke, **graduate student**
(RADSAGA EU- MSCA project, 1.10.2017 -)
Daniel Söderström, **graduate student**
(RADSAGA EU- MSCA project, 1.10.2017 -)
Andrea Coronetti, **graduate student**
(RADSAGA EU-MSCA-project 1.12.2017-)
Jaakko Tuominen, **MSc. Student**
Juhani Lepistö, **MSc. Student**
Orvokki Eerola, **MSc. Student**
Davide Giurisato, **MSc. Student**
(ERASMUS from University of Padova)

18.1.2018



RADEF BEAMS

■ Heavy ions at 9.3 MeV/u (upgrade up to 16 MeV/u in progress)

■ Protons

- 500 keV – 6 MeV (low)
- 6 MeV – 55 MeV (high)

■ Electrons

- 6 / 9 / 12 / 16 / 20 MeV
- X-rays continuous spectra:
 - 0 – 6 MeV (peak @ 1 MeV)
 - 0 – 15 MeV (peak @ 2 MeV)

Table 1. 9.3 MeV/amu cocktails ($M/Q \approx 3.7$, $^{\dagger}M/Q \approx 3.3$).

Ion	Energy [MeV]	LET ^{MEAS} @surface [MeV/mg/cm ²]	LET ^{MEAS} @Bragg peak [MeV/mg/cm ²]	LET ^{SRIM} @surface [MeV/mg/cm ²]	Range ^{SRIM} [microns]	LET ^{SRIM} @Bragg peak [MeV/mg/cm ²]
¹⁵ N ⁺⁴	139	1.87	5.92 (@191 um)	1.83	202	5.9 (@198 um)
²⁰ Ne ^{+6[†]}	186	3.59	9.41 (@138 um)	3.63	146	9.0 (@139 um)
³⁰ Si ⁺⁸	278	6.53	13.7 (@114 um)	6.40	130	14.0 (@120 um)
⁴⁰ Ar ^{+12[†]}	372	10.07	18.9 (@100 um)	10.2	118	19.6 (@105 um)
⁵⁶ Fe ⁺¹⁵	523	18.59	29.7 (@75 um)	18.5	97	29.3 (@77 um)
⁸² Kr ⁺²²	768	31.21	41.7 (@68 um)	32.2	94	41.0 (@69 um)
¹³¹ Xe ⁺³⁵	1217	57.36	67.9 (@57 um)	60.0*	89*	69.2 (@48 um)

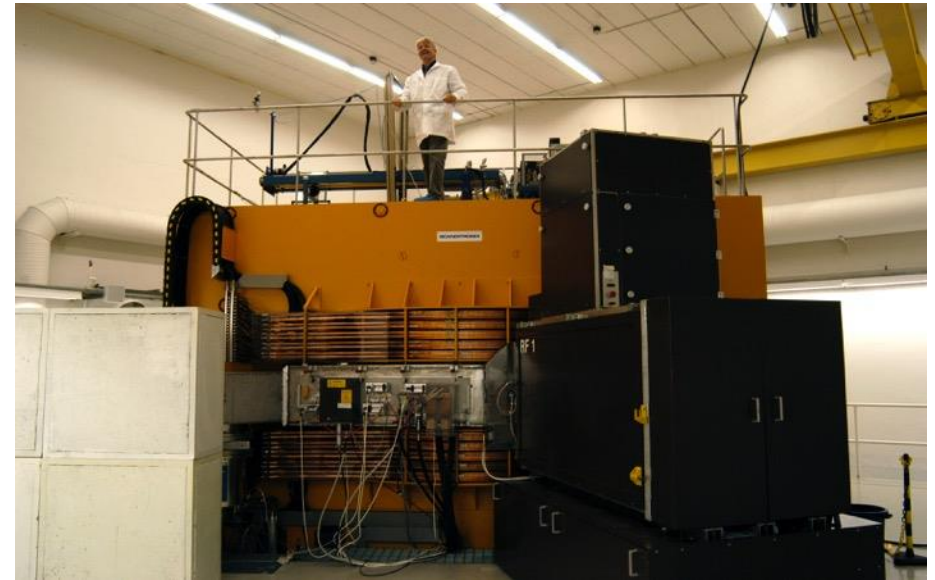


EQUIPMENT FOR TESTING

Heavy ions and protons



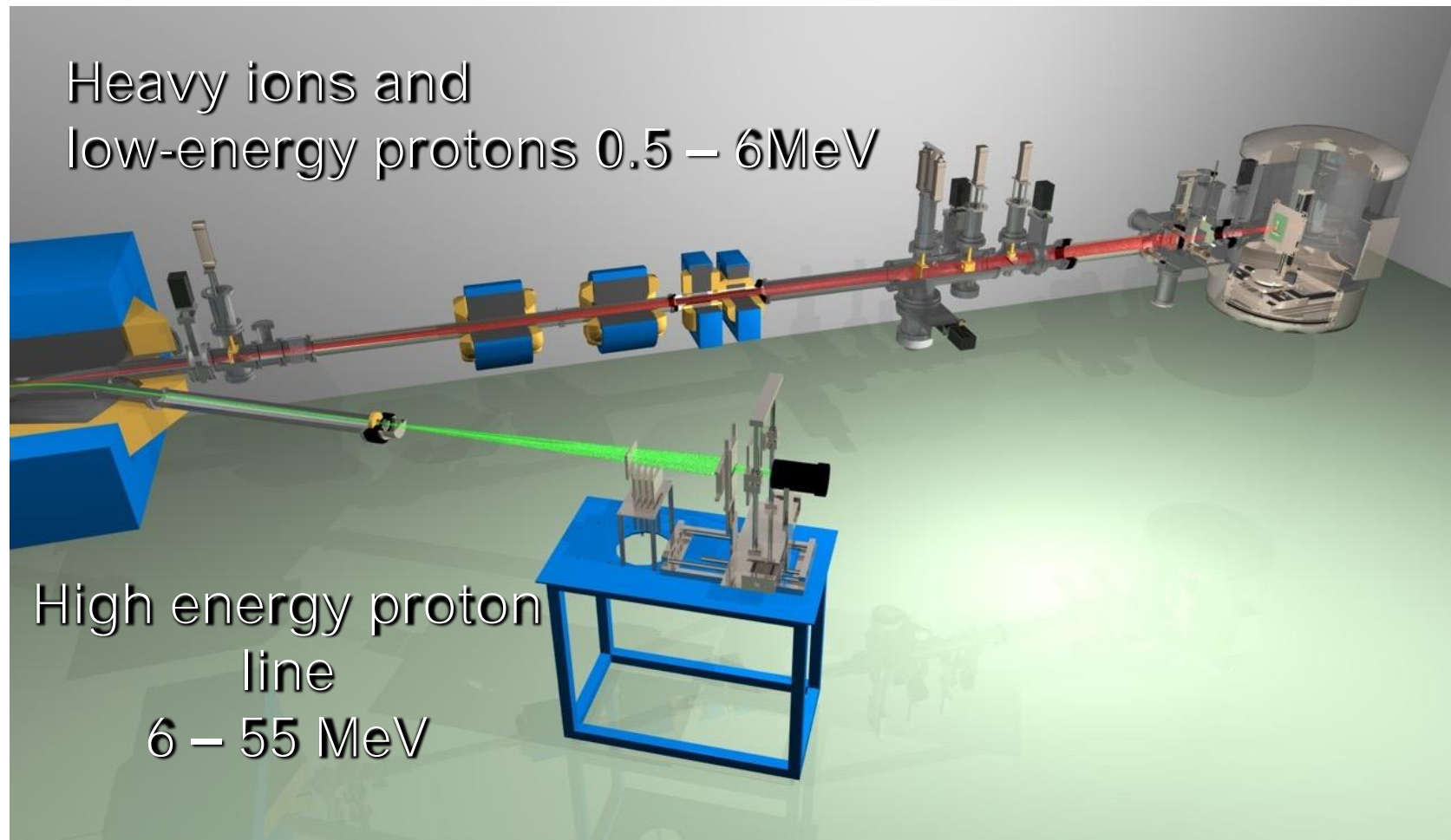
ECR ION SOURCE



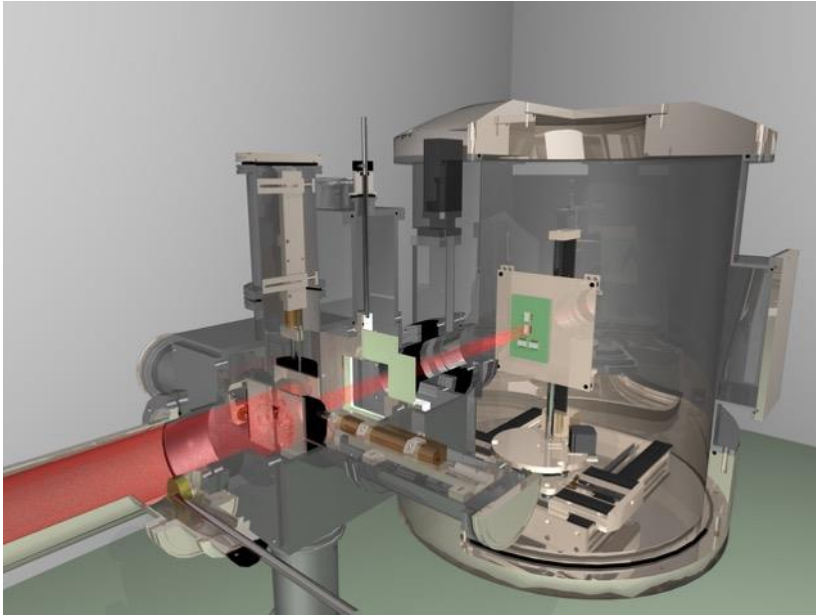
K-130 CYCLOTRON



EQUIPMENT FOR TESTING



EQUIPMENT FOR TESTING



- Heavy ions and low-energy protons typically in vacuum
 - 1-2 minutes to ventilate
 - ~ 5 minutes to pump down
- Device positioning and dosimetry remotely controlled.
 - Typically ~ 2x2cm² beam area
 - X-Y and tilting
- **Cabling for user's equipment on request**
- Possible to test in air (limited)
 - Sensitive volume has to be on surface
 - Faster device change
 - Limited ion range



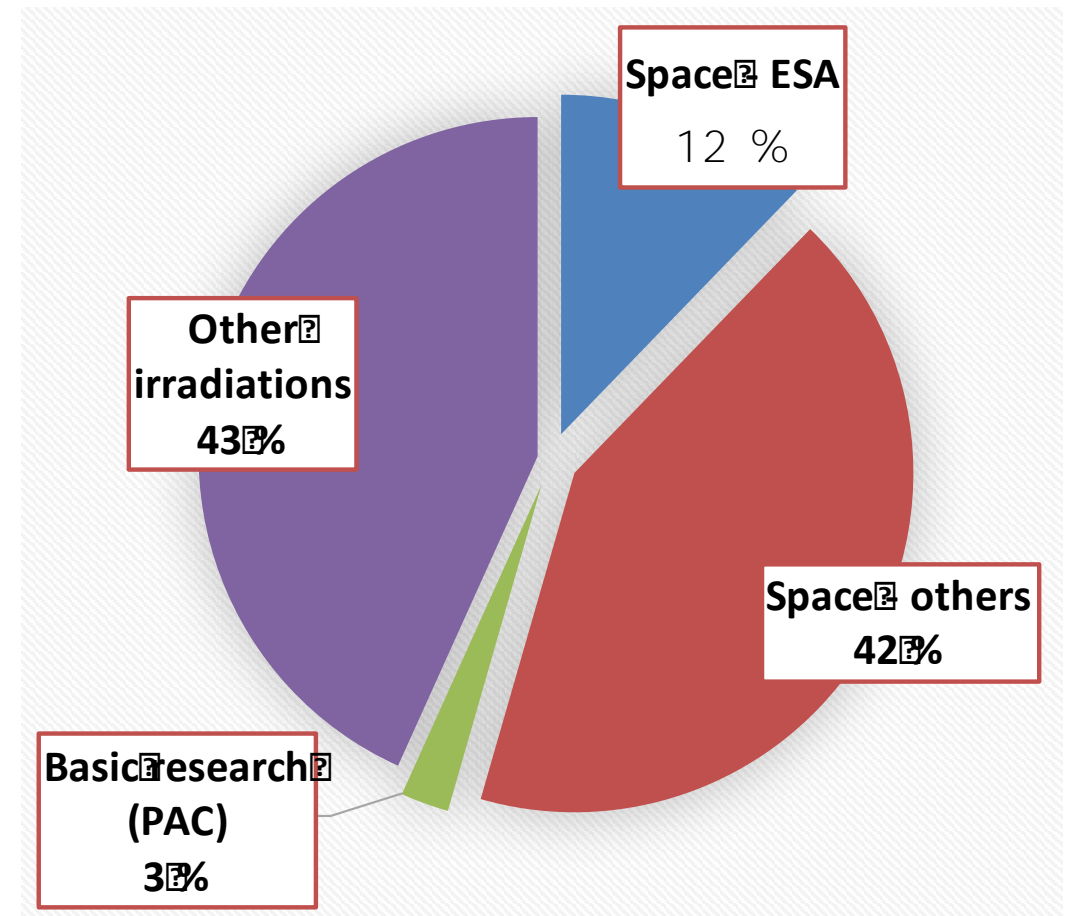
Electron Linear Accelerator

- Recommissioned Varian Clinac® medical accelerator
- 6 / 9 / 12 / 16 / 20 MeV
- X-rays continuous spectra:
 - 0 – 6 MeV (peak @ 1 MeV)
 - 0 – 15 MeV (peak @ 2 MeV)
- Typical beam area is about 25x25 cm²
- Remote controlled from user barrack
- **Cabling for user's equipment on request**
- For harsh electron environments
 - Jupiter Icy Moon Explorer mission
 - MEO satellites (e.g. navigation)

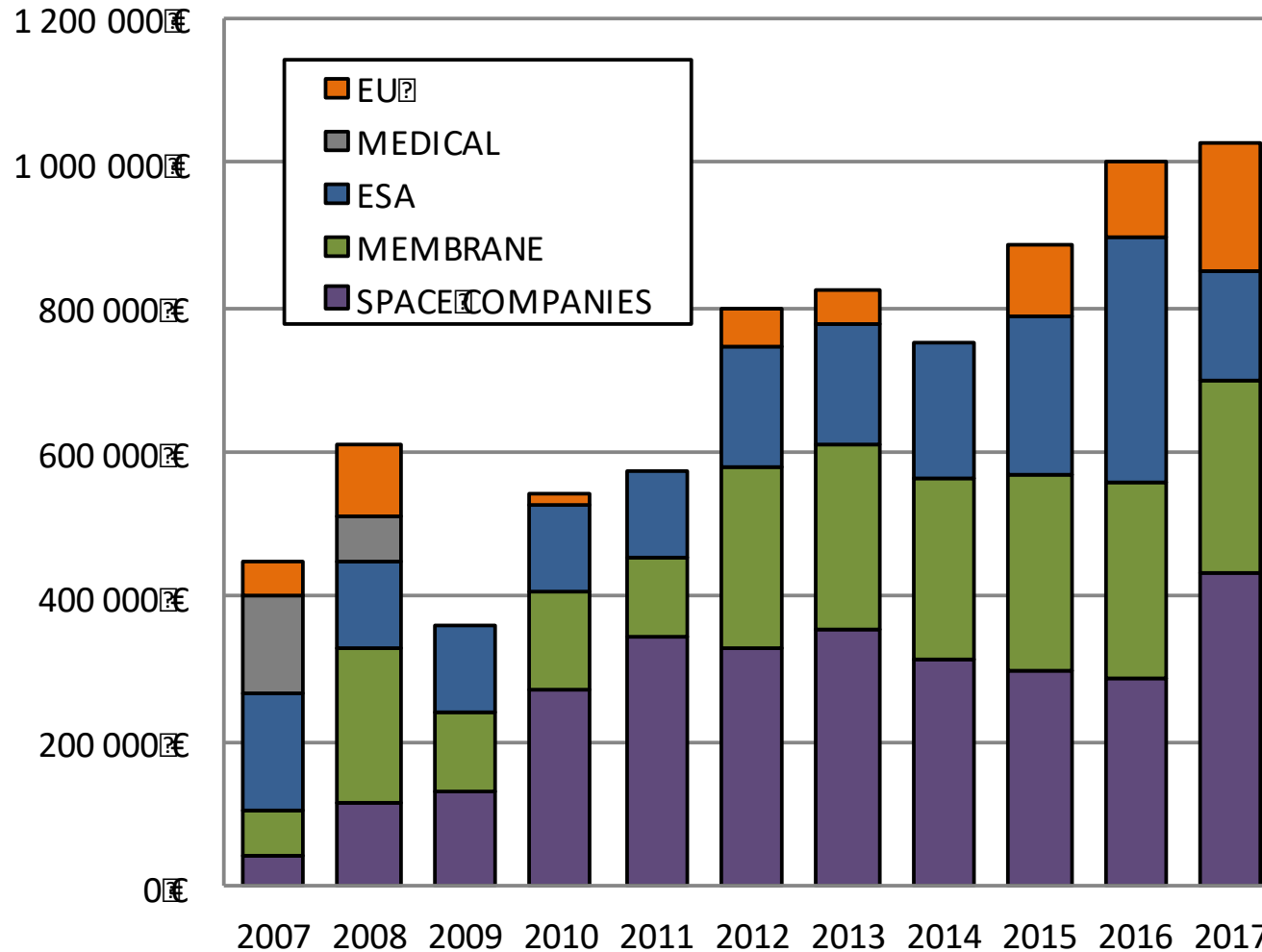


Beam time usage at RADEF facility

- in 2017
 - 45 irradiation campaigns
 - 26 individual users
 - ~1400 hours
 - ~1/4 of total beam time at JYFL



Annual revenue – last 10 years



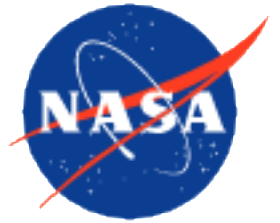
Recent RADEF projects

Membrane prod.	2012-17	1 560 k€
ESA/GSTP	2015-18	400 k€
CCN for ESA TRP	2016-17	840 k€
ESA/NPI	2016-18	90 k€
EU-MARIE-CURIE ITN	2017-20	538 k€
	TOT.	3 428 k€

Incipient projects

- **Membrane production**
 - contract **2.2 M€/5yrs** 2018->
- **ESA**
 - contract **600 k€/5yrs** 2018->
 - Promise to space industry **>2M€/5yrs**

Collaborators ~70 over the years



How to apply for beam time

- 1st option: Contact Heikki Kettunen (heikki.i.kettunen@jyu.fi)
 - High demand → recommended months in advance
 - 800 eur/hour for heavy-ions and protons
 - 400 eur/hour for electrons

- 2nd option: Scientific proposal to PAC
 - Deadlines: March 15th and September 15th
 - Submitted to Mikael Sandzelius (mikael.sandzelius@jyu.fi)
 - Free of charge, but requires solid scientific basis
 - Testing COTS for scientific Cubesat may not be sufficient ;)





RADSAGA EU-MSCA-ITN



- RADiation and Reliability Challenges for Electronics used in Space, Aviation, Ground and Accelerators
- “Brings together industry, universities, laboratories and test-facilities in order to innovate and train young scientists and engineers in all aspects related to electronics exposed to radiation.”
- <https://radsaga.web.cern.ch/>
- Started 2017
- 15 PhD projects
 - 3 PhD students at RADEF
- Total budget 3.9 M€ (~ 0.5 M€ for RADEF)
- CERN as coordinator



FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG
TECHNISCHE FAKULTÄT



Other recent activities

- SkyFlash (262890 EU-FP7 Project) <http://www.skyflash.eu/>
 - development of a RadHard by design (RHBD) methodology for non-volatile flash memories
- R2RAM (640073, H2020-COMPET-2014 RIA)
 - Development of Radiation Hard Resistive Random-Access Memory
- Airbus D&S GmbH, sub-contract
 - Radiation tests of the PHY transceiver electronics with heavy ions and protons
- SENSROVER (Proposal H2020-MSCA-ITN-2018)
 - SENSors for RObots in Various EnviRonments
- VIRTUOSA (Proposal, H2020-SPACE-2018-2020 RIA)
 - Very Integrated Rf Technology solution for frequency Up-conversion and amplitude-phase Operation setting dedicated to next generation Smart Antenna array systems
- Radiation effects in SiC power devices
 - Vanderbilt, NASA, Silvaco Inc., ESA, CERN, ETH, STMicroelectronics
 - Ongoing



Recent publications (~ 100 since 2012)

- **Microbeam SEE Analysis of MIM Capacitors for GaN Amplifiers**, P. Kupsc et al. IEEE TNS, (2018), in print
- **Single Event Burnout of SiC Junction Barrier Schottky Diode High-Voltage Power Devices**, A. F. Witulski et al., IEEE TNS, (2018) in print
- **Single-Event Effects in the Peripheral Circuitry of a Commercial Ferroelectric Random-Access Memory**, A.L. Bosser et al., IEEE TNS, (2018), in print
- **Application and development of ion-source technology for radiation-effects testing of electronics**, T. Kalvas et al., NIM B, vol. 406, (2017), pp. 205-209
- **Heavy-Ion Induced Degradation in SiC Schottky Diodes: Incident Angle and Energy Deposition Dependence**, A. Javanainen et al. IEEE TNS, 2017, Vol. 64, no. 8, (2017) pp. 2031 - 2037
- **High-Energy Electron-Induced SEUs and Jovian Environment Impact**, M. Tali et al. IEEE TNS, Vol. 64, no. 8, (2017), pp. 2016 – 2022
- **Single-Event Upsets Induced by Direct Ionization from Low-Energy Protons in Floating Gate Cells**, M. Bagatin et al., IEEE TNS, vol. 64, no. 1, (2017), pp. 464 – 470
- **Heavy Ion Induced Degradation in SiC Schottky Diodes: Bias and Energy Deposition Dependence**, A. Javanainen et al. , IEEE TNS, vol. 64, no. 1, (2017), pp. 415-420
- **Energy loss and straggling of MeV Si ions in gases**, C. Vockenhuber et al., NIM B, vol. 391, (2017), pp. 20-26
- **Determination of electronic stopping powers of 0.05–1MeV/u ^{131}Xe ions in C-, Ni- and Au-absorbers with calorimetric low temperature detectors**, A. Echler et al., NIM B, vol. 391, (2017), pp. 38-51

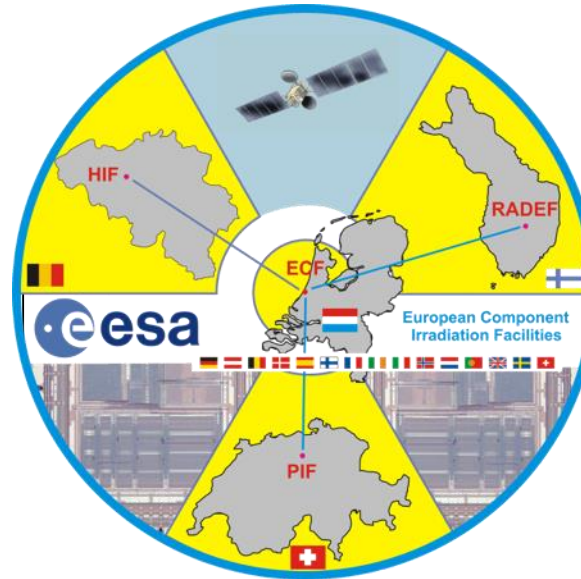


Conclusions

- **RADEF's activities growing steadily**
 - Solid customer base (space industry and membrane production)
 - Annual total revenue about 1Meur (~ 60% space related)
 - 10-20 scientific publications annually
 - 5 PhD students
- Strong support from ESA both scientifically and economically
 - 300 keur for HIISI + 100 keur for high energy electrons
 - continuing basic contract 600 keur for 2018-23
- International collaboration
 - ESA, NASA, JAXA, CNES, RADSAGA, Vanderbilt, Montpellier, ETH, STMicroelectronics, etc.
- Partnering in EU projects and proposals (EU-FP7 and H2020)



Thank you for your attention



Need to test your components? Welcome!

<https://www.jyu.fi/accelerator/radiation-effects-facility>

