RADIATION EFFECTS TESTING AT RADEF

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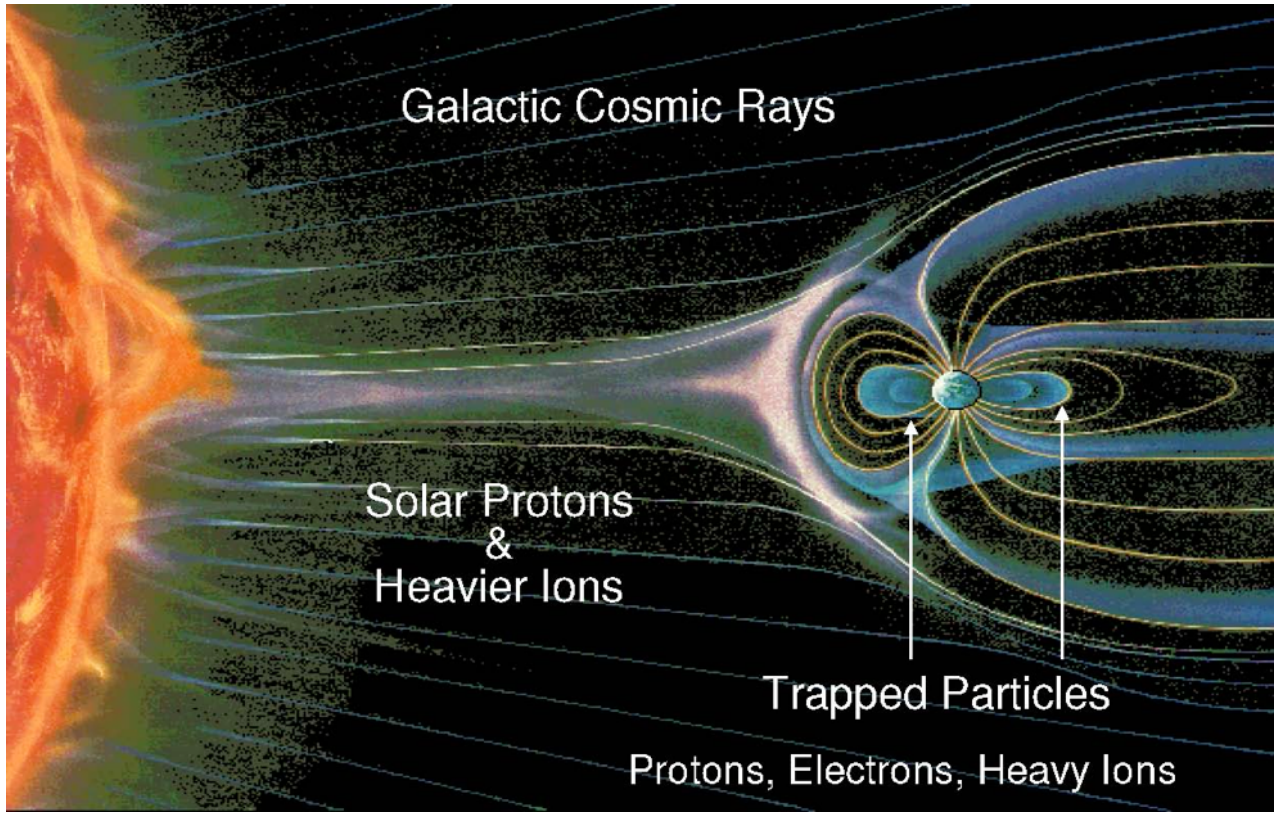
Finnish Satellite Workshop
January 18th 2018

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

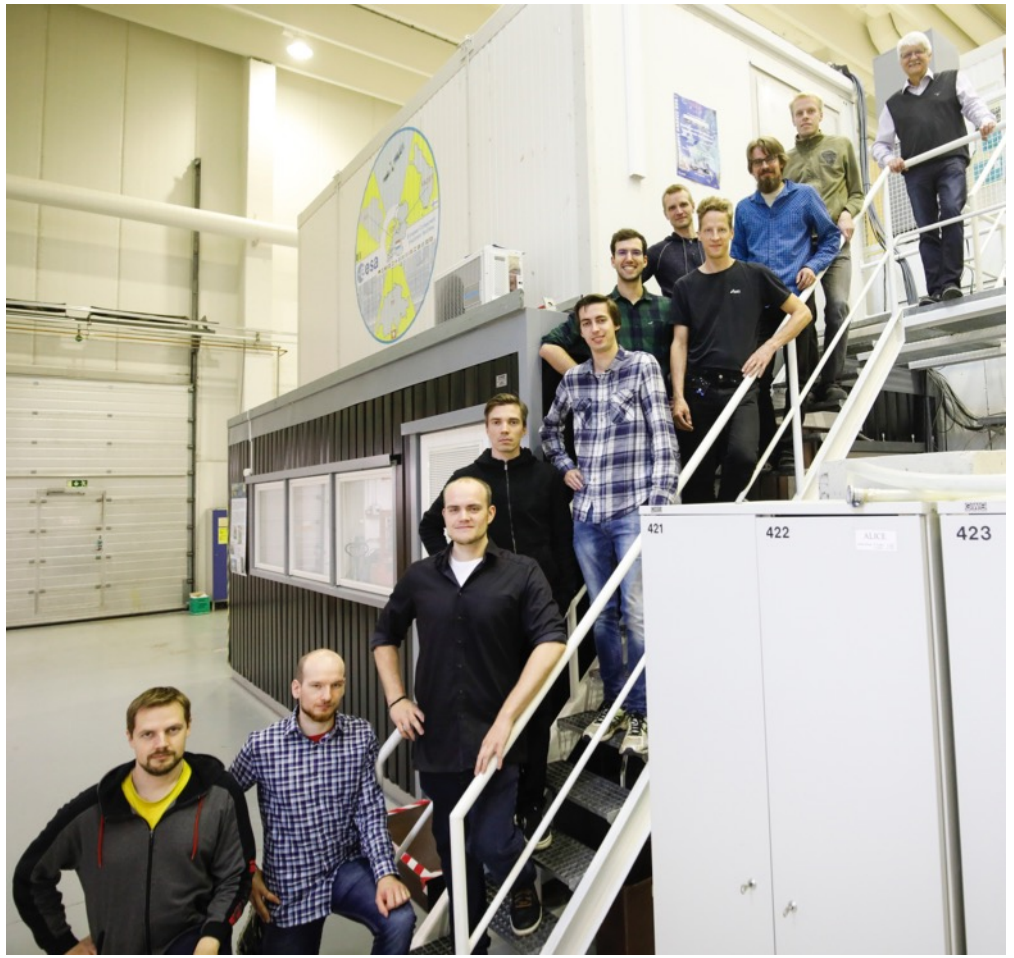


RADiation Effect Facility - RADEF

- 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)



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 @ 1MeV)
    - 0 – 15 MeV (peak @ 2MeV)

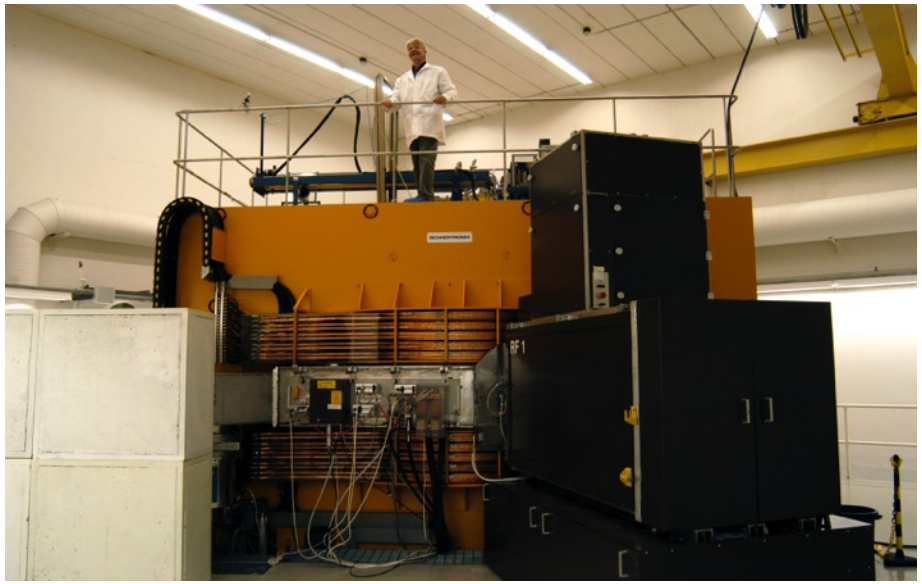
Table 1. 9.3 MeV/amu cocktails (M/Q≈3.7, ‡M/Q≈3.3).

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

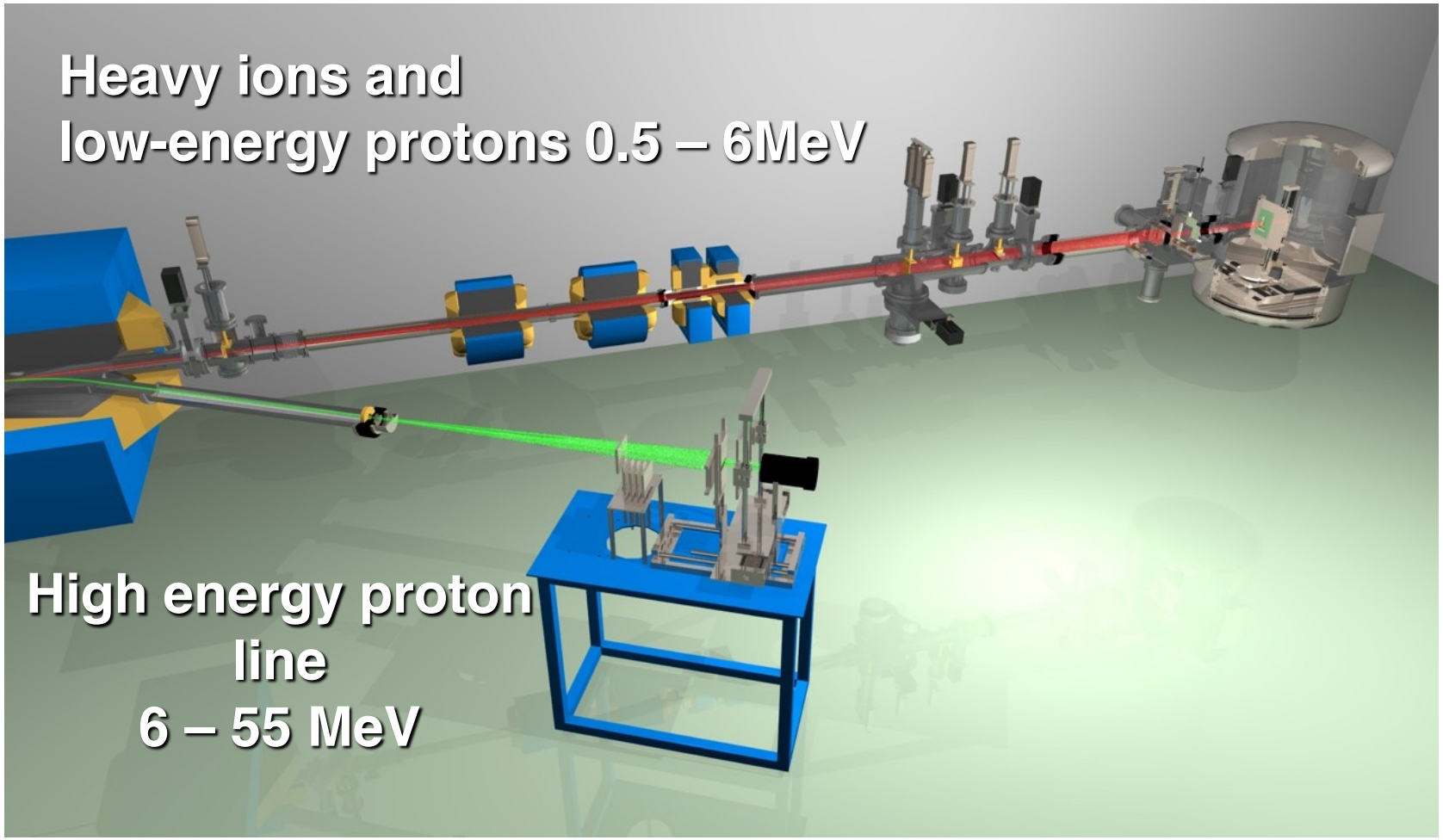
Heavy ions and protons

ECR ION SOURCE

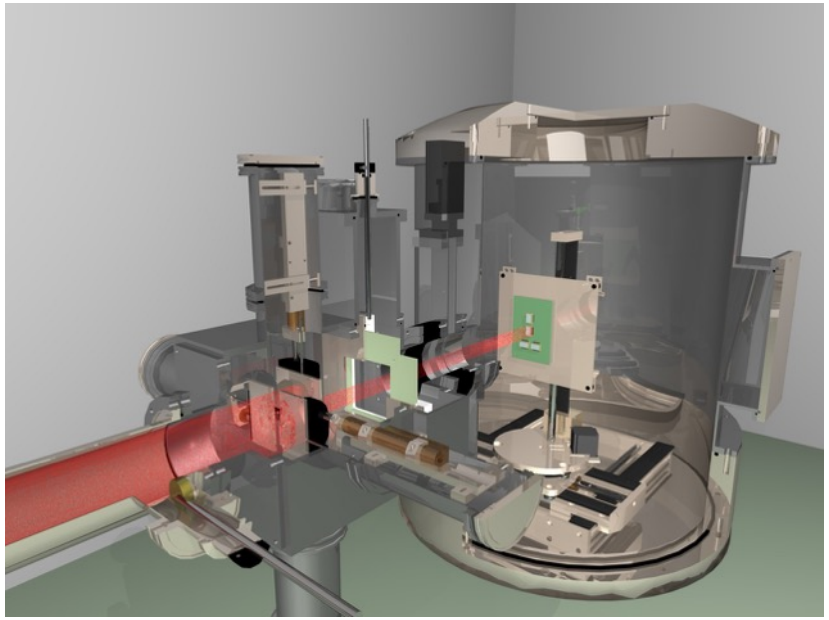


K-130 CYCLOTRON

EQUIPMENT FOR TESTING



EQUIPMENT FOR TESTING



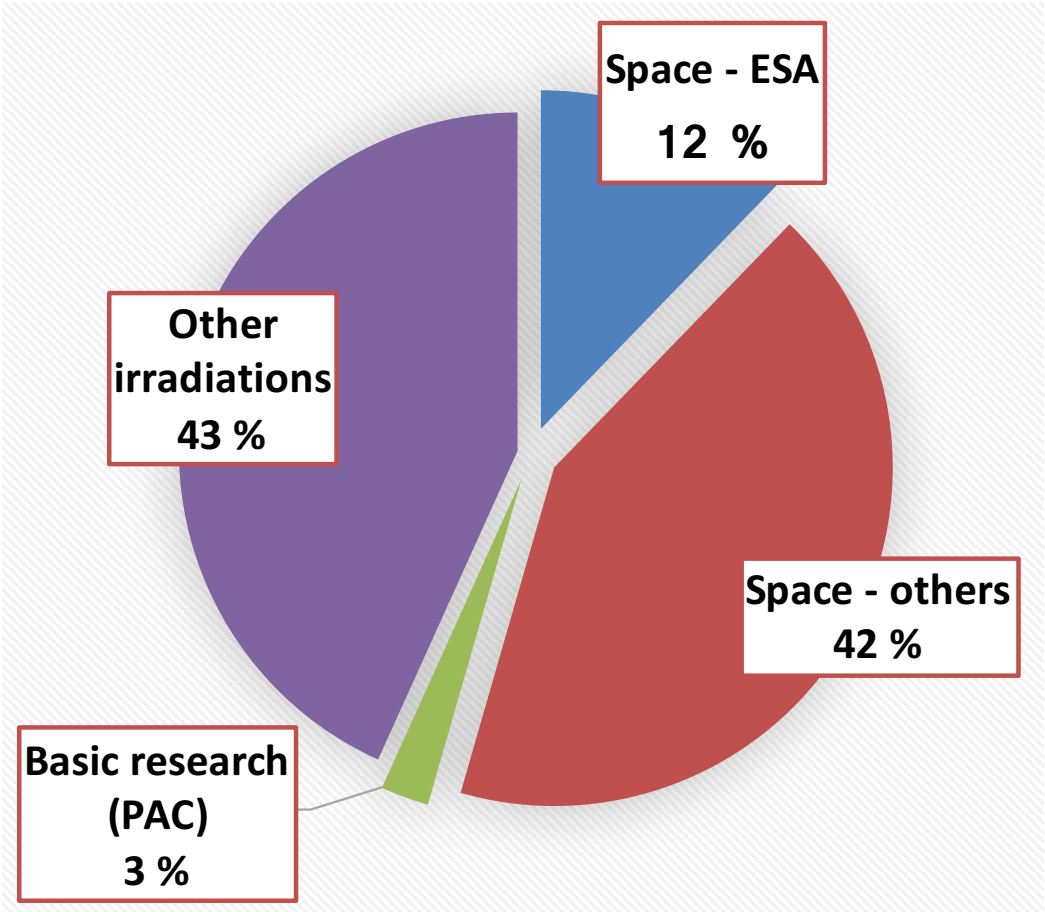
- Heavy ions and low-energy protons typically in vacuum
  - 1-2 minutes to ventilate
  - ~ 5 minutes to pump down
- Device positioning and dosimetry remotely controlled.
  - Typically ~ 2x2cm^2 beam area
  - X-Y and tilting
- Cabling for user's equipment on request
- Possible to test in air (limited)
  - 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 continous spectra:
  - 0 – 6 MeV(peak @ 1 MeV)
  - 0 – 15 MeV (peak @ 2 MeV)
- Typical beam area is about 25x25 cm^2
- 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



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

- **RAD**iation and Reliability Challenges for Electronics used in **S**pace, **A**viation, **G**round and **A**ccelerators
- "*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

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)
  - **SENS**ors for **RO**bots in **V**arious **E**nvi**R**onments
- VIRTUOSA (Proposal, H2020-SPACE-2018-2020 RIA)
  - **V**ery **I**ntegrated **R**f **T**echnology solution for frequency **U**p-conversion and amplitude-phase **O**peration setting dedicated to next generation **S**mart **A**ntenna 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