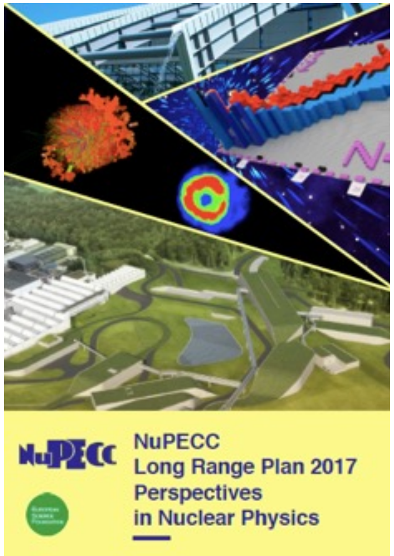
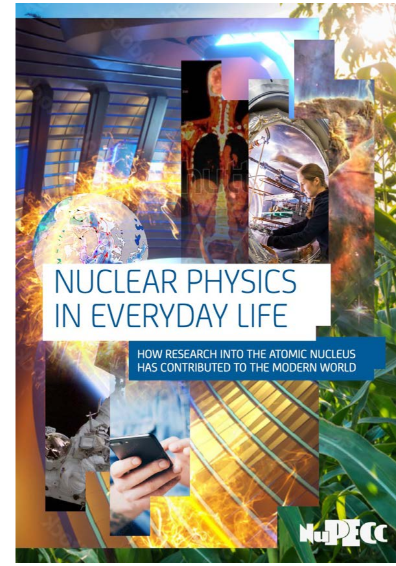


Nowa Era Fizyki Jądrowej



Marek Lewitowicz

Grand Accélérateur National d'Ions Lourds (GANIL), Francja

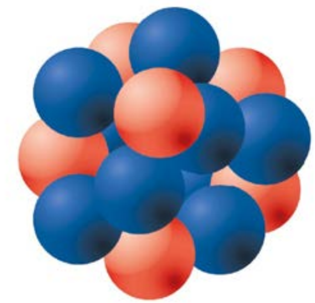
&

Nuclear Physics European Collaboration Committee (NuPECC)

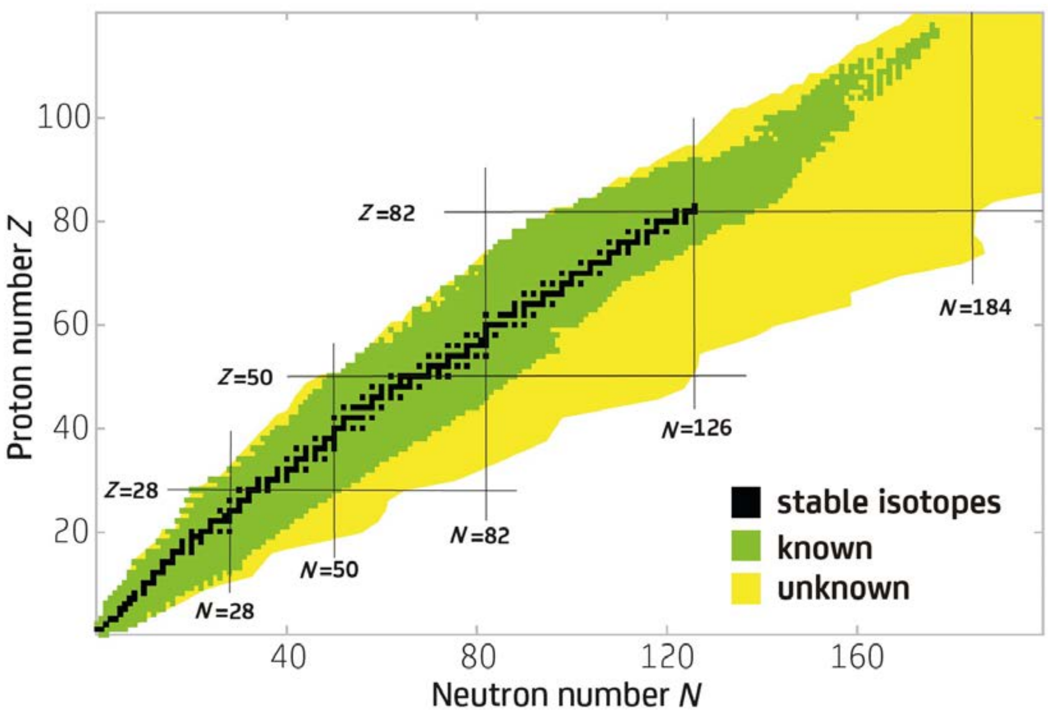
- **Fizyka jądrowa (FJ) w życiu codziennym**
- **FJ w Europie i na świecie - przykłady**
- **Quo Vadis, czyli plany na najbliższe 10 lat – infrastruktury FJ**

Nuclear Physics

NUCLEAR PHYSICS IS THE STUDY OF THE ATOMIC NUCLEUS, ITS CONSTITUENTS, STRUCTURE AND BEHAVIOUR. IT IS A KEY BASIC SCIENTIFIC FIELD THAT INVESTIGATES THE PROPERTIES OF MATTER AT THE SUBATOMIC LEVEL.



Diameter of a nucleus
1.7×10^{-15} - 11.7×10^{-15} m

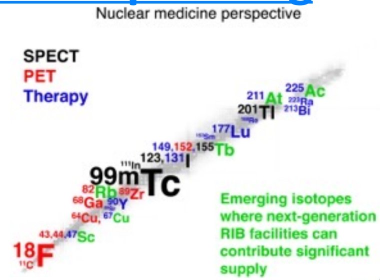


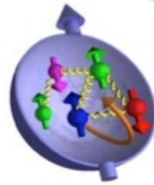
Strong force binding a nucleus

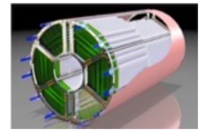
254 stable isotopes
3500 known isotopes
> 8000 unknown

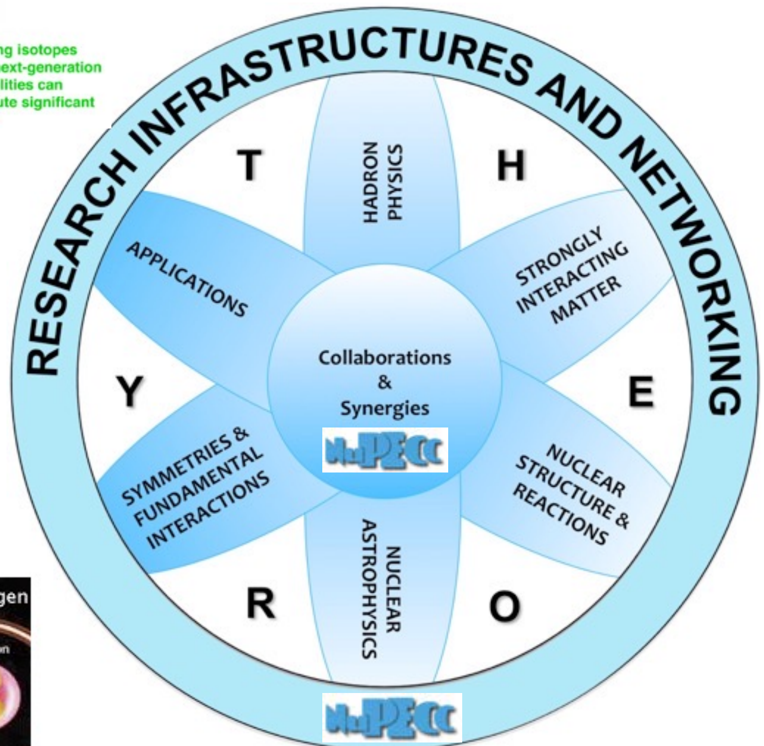
Nuclear Physics in Europe

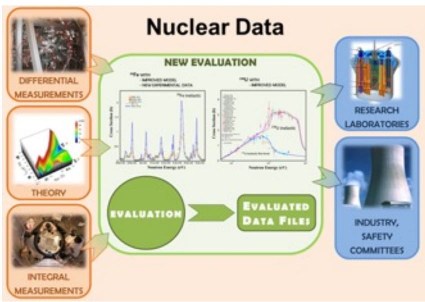
http://www.nupecc.org

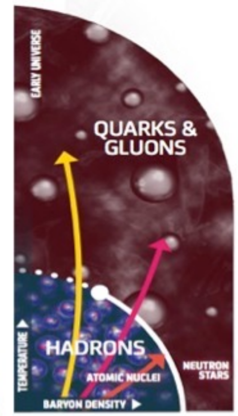


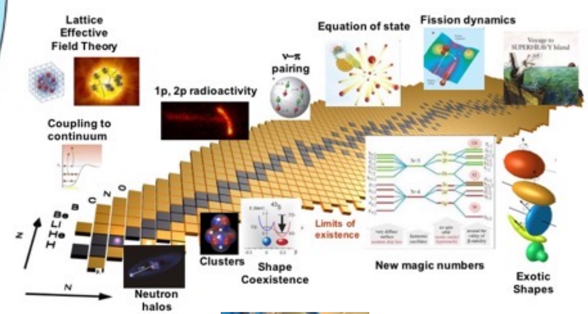


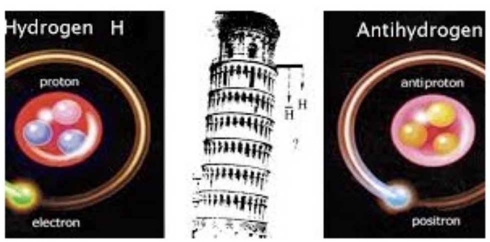


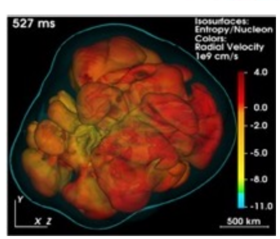


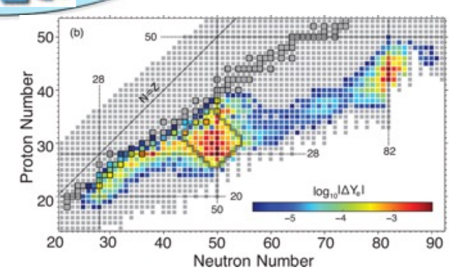


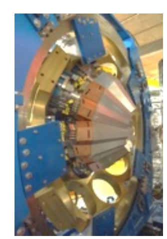


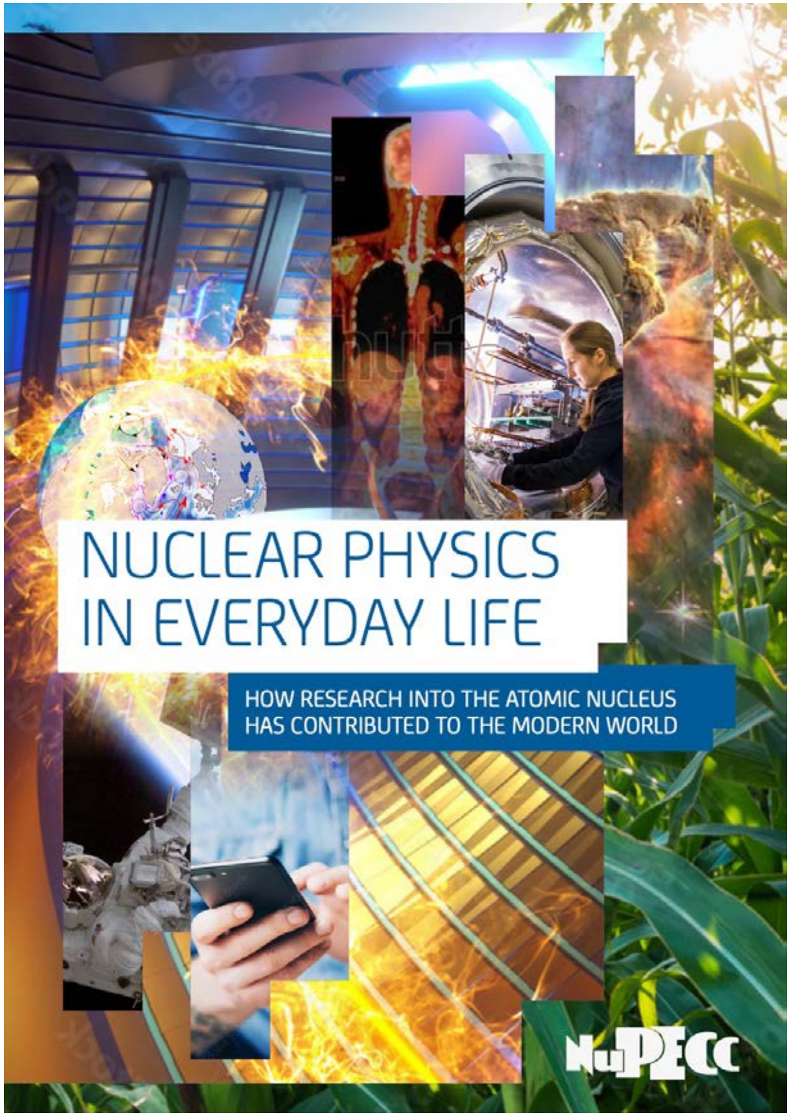












NuPECC report on

Nuclear Physics in Everyday Life

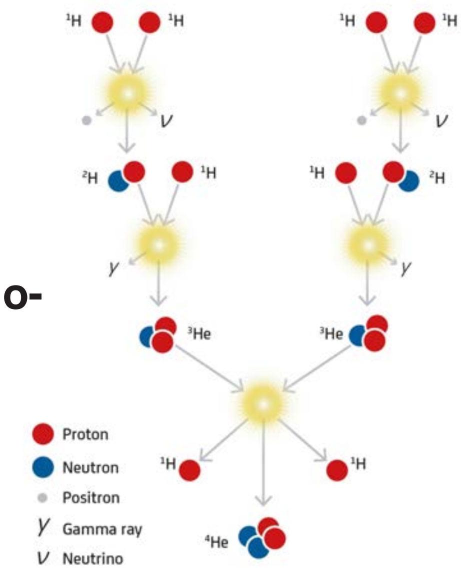
(100 pages, open access on-line and printed version available at)

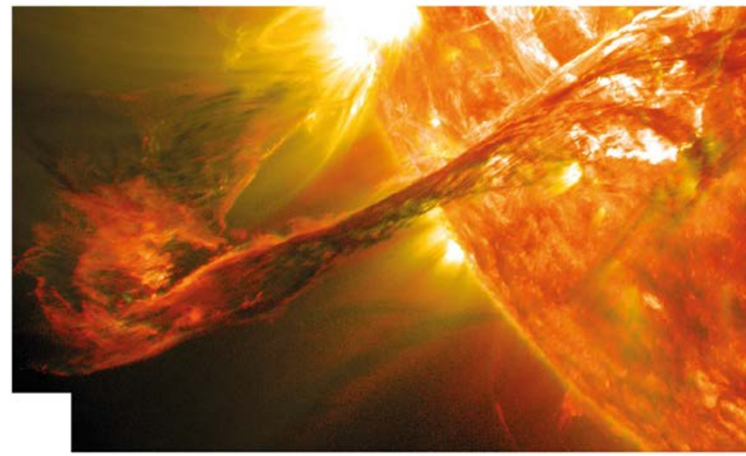
https://nupecc.org/pub/np_life_print.pdf

- **Climate & Environment** (Sun activity, heat in the Earth interior, ocean monitoring, wastewater treatment, mapping of groundwater resources, ...)

THE SUN

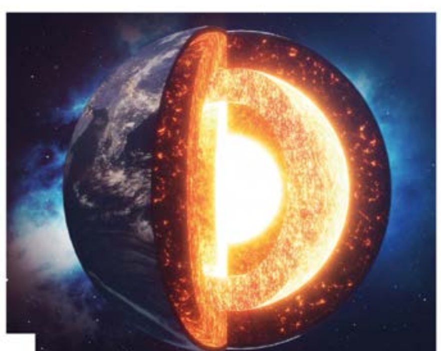
Energy from thermo-nuclear reactions



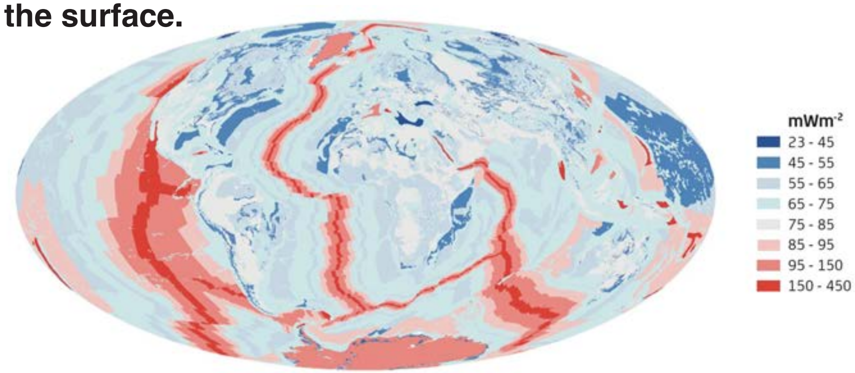


THE EARTH

Approximately half of the geothermal energy comes from radioactivity (decay of U, Th and ^{40}K)

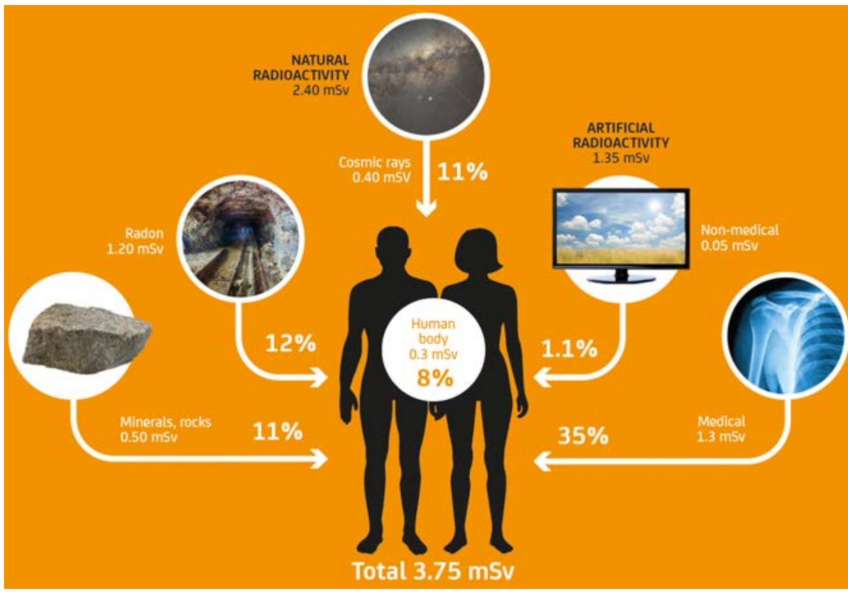


A map of heat output from the Earth's interior to the surface.



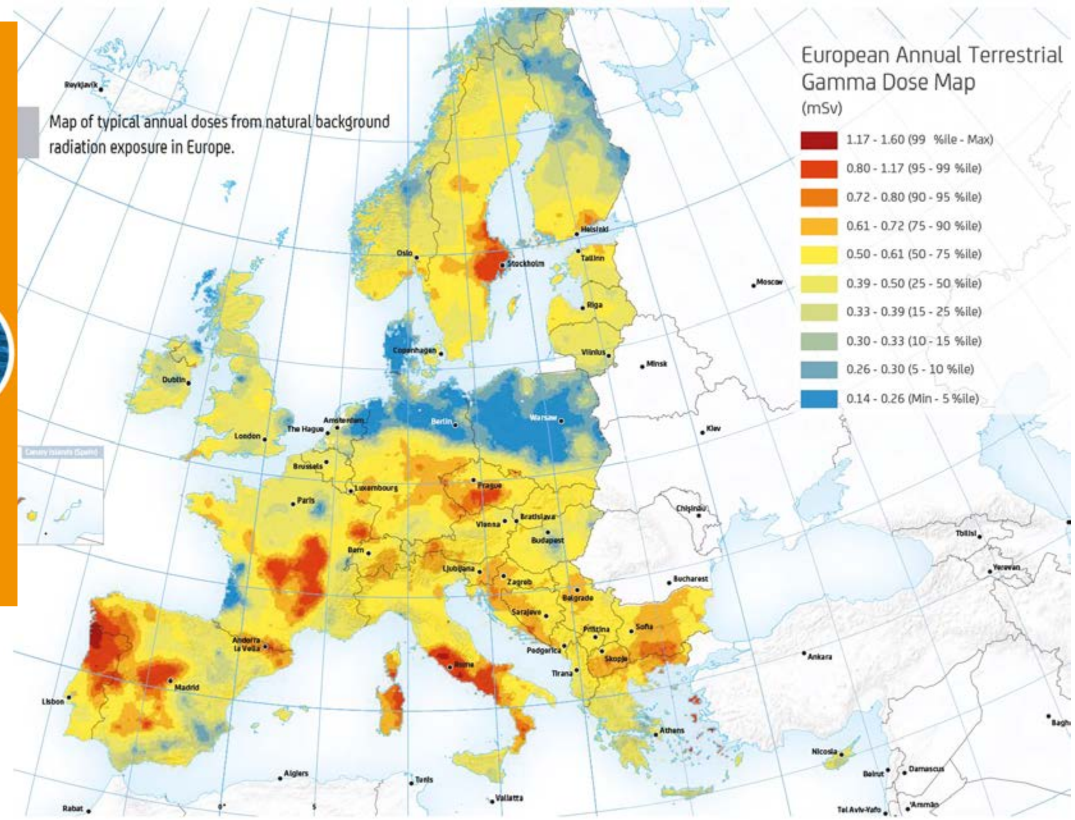
- **Radioactivity & Radiation**

Sources of radiation contributing to an adult average annual dose in Europe (mSv).

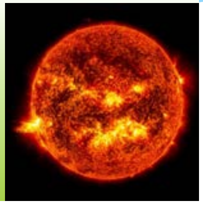


In a 70-kg person 5,000 atoms of natural radioactive isotope ^{40}K undergo radioactive decay each second.

Map of typical annual doses from natural background radiation exposure in Europe.



- **Climate & Environment** (Sun activity, heat in the Earth interior, ocean monitoring, wastewater treatment, mapping of groundwater resources, ...)

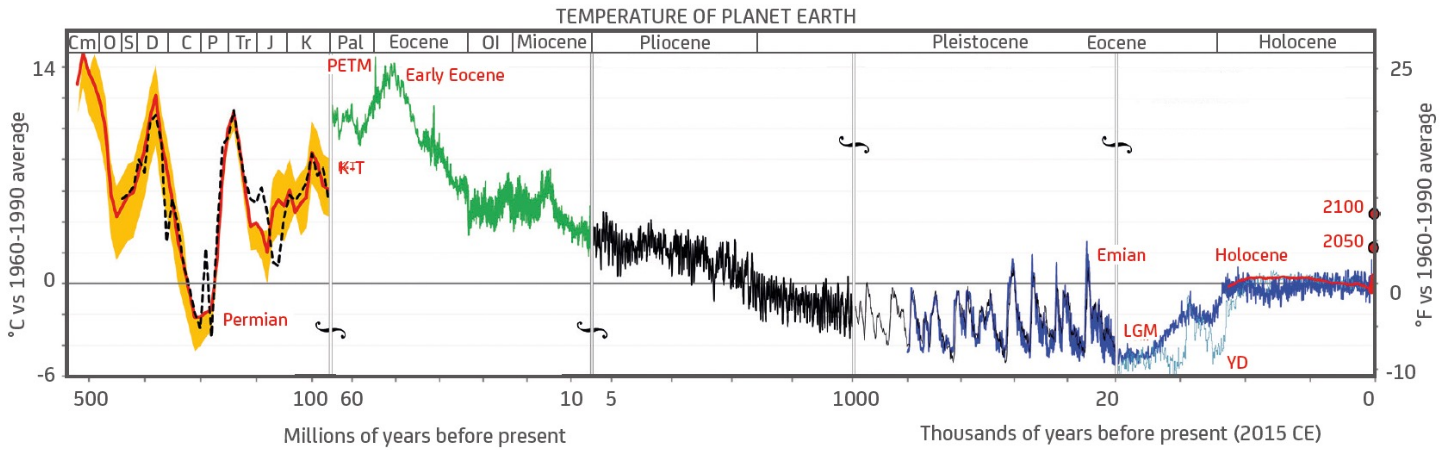


How to measure the global average surface air temperature in the past ?

$\delta^{18}O$ is a measure of the temperature of precipitation, a measure of groundwater/mineral interactions, and an indicator of processes that show isotopic fractionation. In paleosciences, ^{18}O to ^{16}O ratio from corals, foraminifera and ice cores is used as a proxy for temperature.

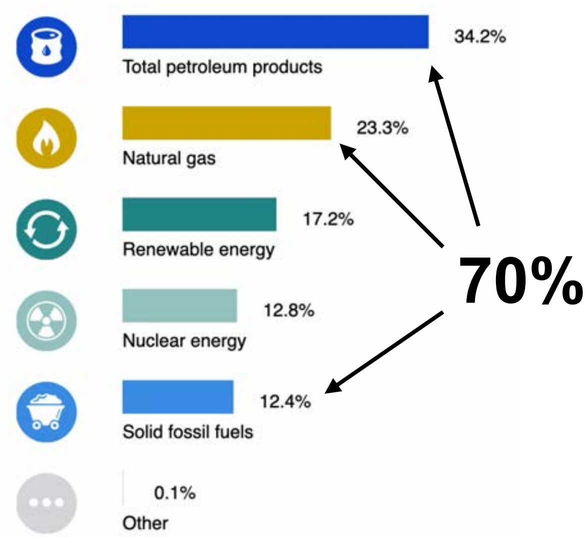
$$\delta^{18}O = \left(\frac{\left(\frac{^{18}O}{^{16}O}\right)_{sample}}{\left(\frac{^{18}O}{^{16}O}\right)_{standard}} - 1 \right) \times 1000\ ‰$$

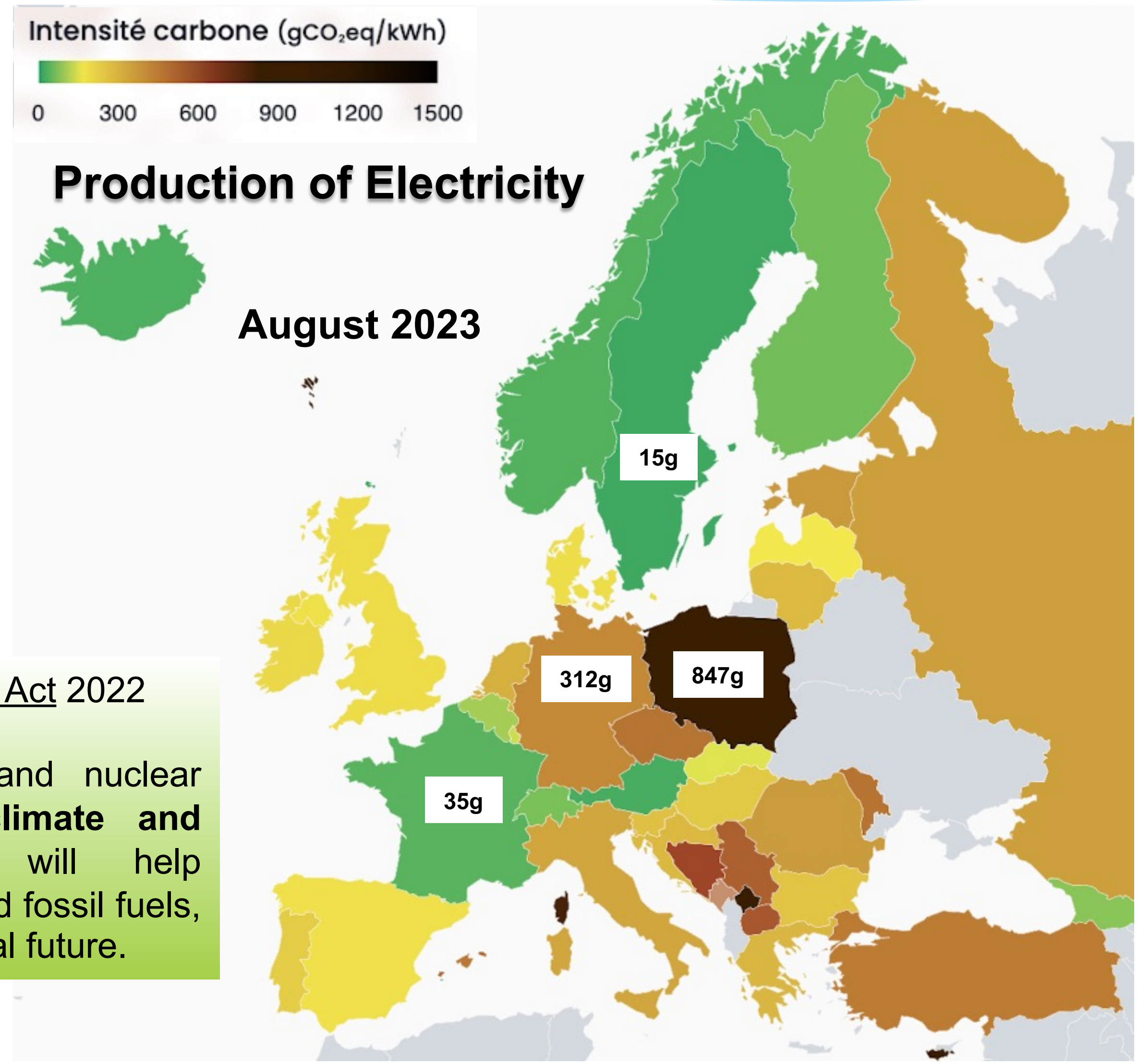
Mass spectrometry!



Production of Electricity
Impact on the Environment

Energy mix for EU





EU Complementary Climate Delegated Act 2022

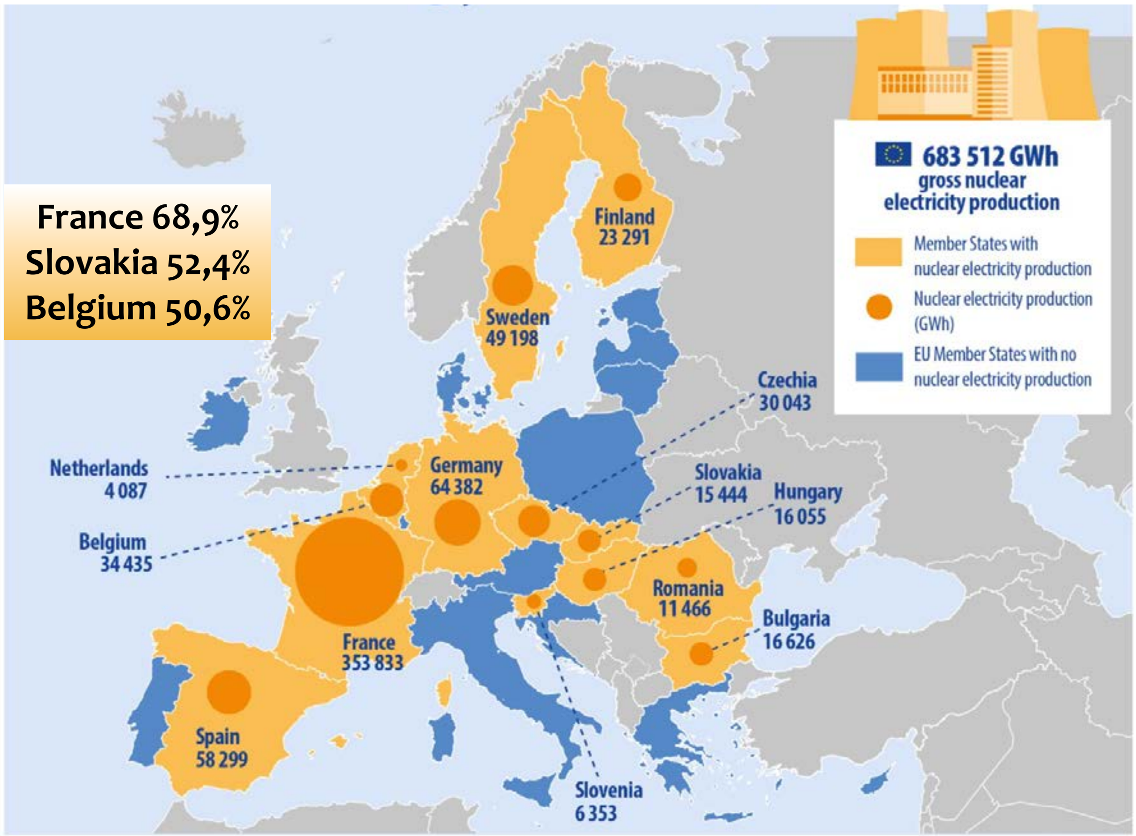
The criteria for the specific gas and nuclear activities are **in line with EU climate and environmental objectives** and will help accelerating the shift from solid or liquid fossil fuels, including coal, towards a climate-neutral future.

Sources: Electricity Maps

Energy applications

Nuclear Energy in EU (2021)

France 68,9%
Slovakia 52,4%
Belgium 50,6%



In 2022, nuclear plants generated 22 % of the electricity produced in the European Union, with nuclear reactors operating in 12 Member States

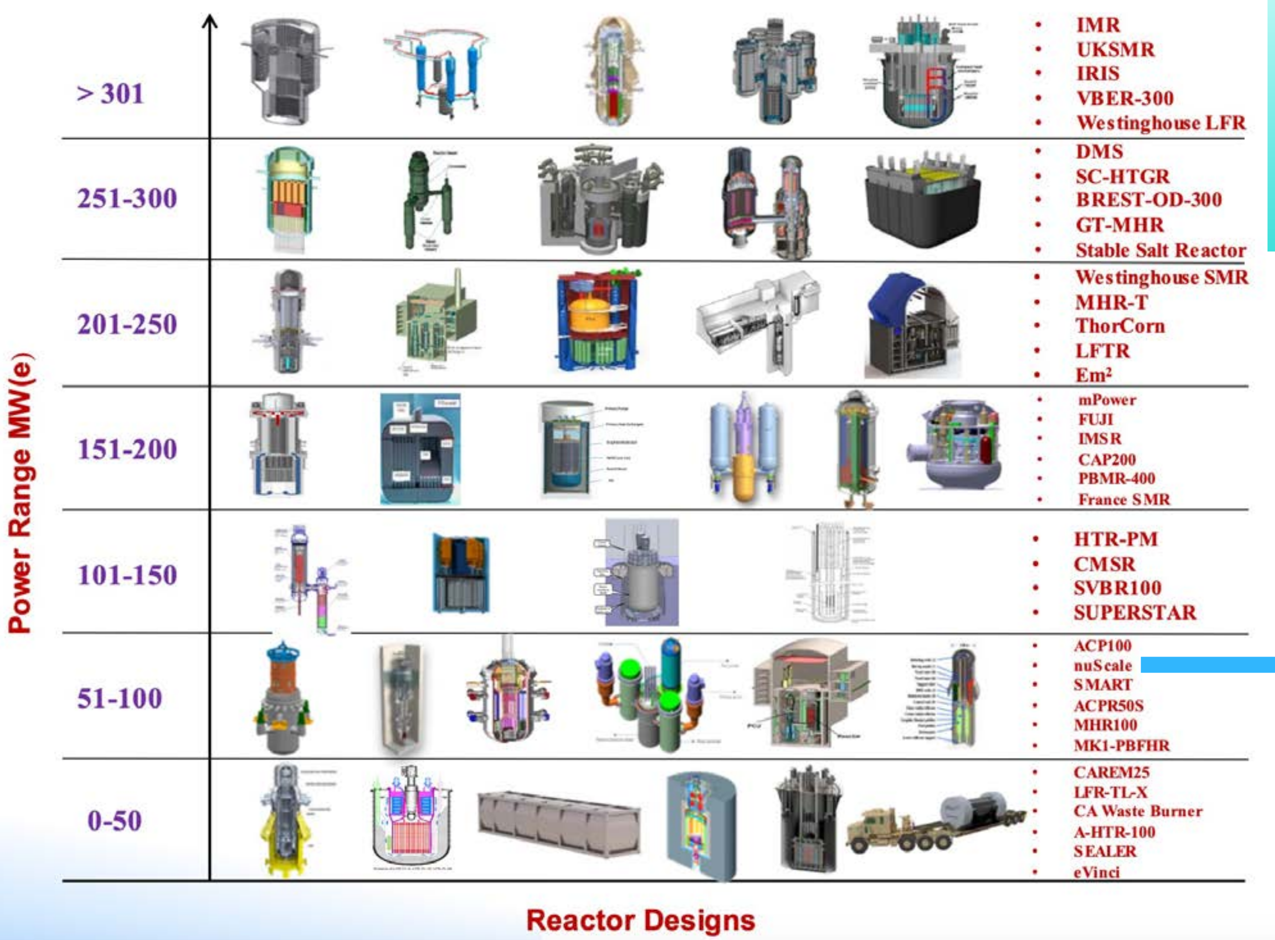
In Europe (2023):
164 nuclear power reactors
(107,7 GWe)
Under construction:
4 reactors in EU & UK
(5 in Russia and Ukraine)

New reactors will be constructed in Bulgaria, France (14), Poland and UK

Sources: EUROSTAT, EC, WORLD NUCLEAR ASSOCIATION

Energy applications

Small Modular Reactors (SMR)



SMRs - advanced nuclear reactors, ≤300 MW(e) (1/3 of standard reactors)

Small – size
Modular – easy to transport and assemble
Reactors – fission

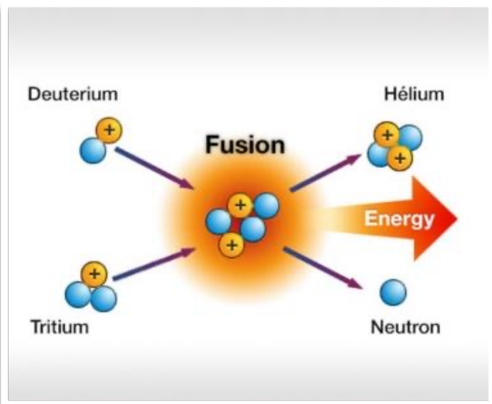
Licencing process in US

- Who: NuScale Power, LLC (NuScale)
- What: Application for a Standard Design Approval for a small modular reactor (US460) 77MWe/reactor
- When: By letter dated December 31, 2022 NuScale completed its staged SDA application submittal.

Sources: IAEA, NRC

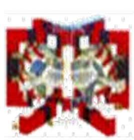
Energy applications

ITER – Bringing the power of the sun to earth



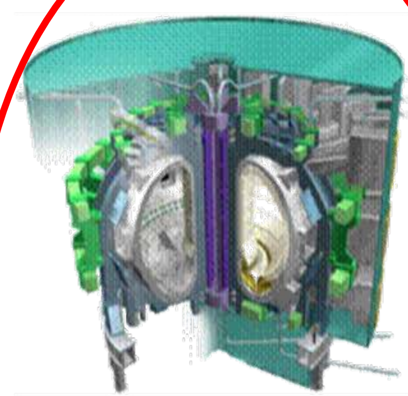
Fusion on earth needs temperatures of 100-150 million ° C

Many experiments in Europe and the rest of the world

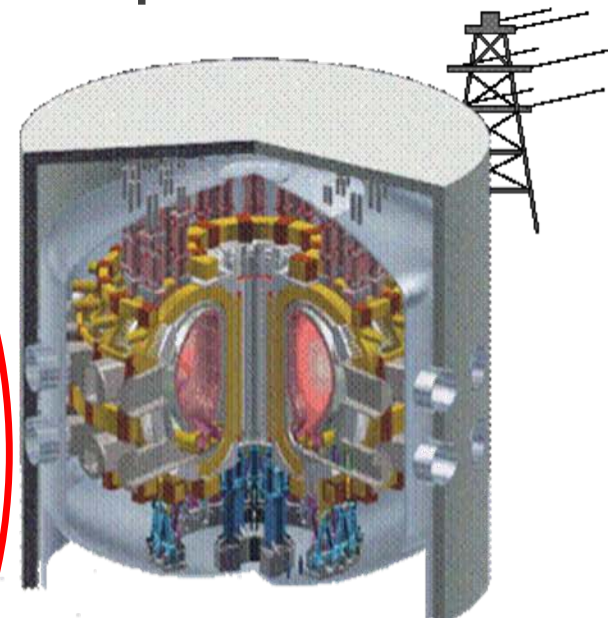


Tore Supra
25 m³
~ 0 MW_{th}

JET
80 m³
~16 MW_{th}



ITER
800 m³
~ 500 MW_{th}

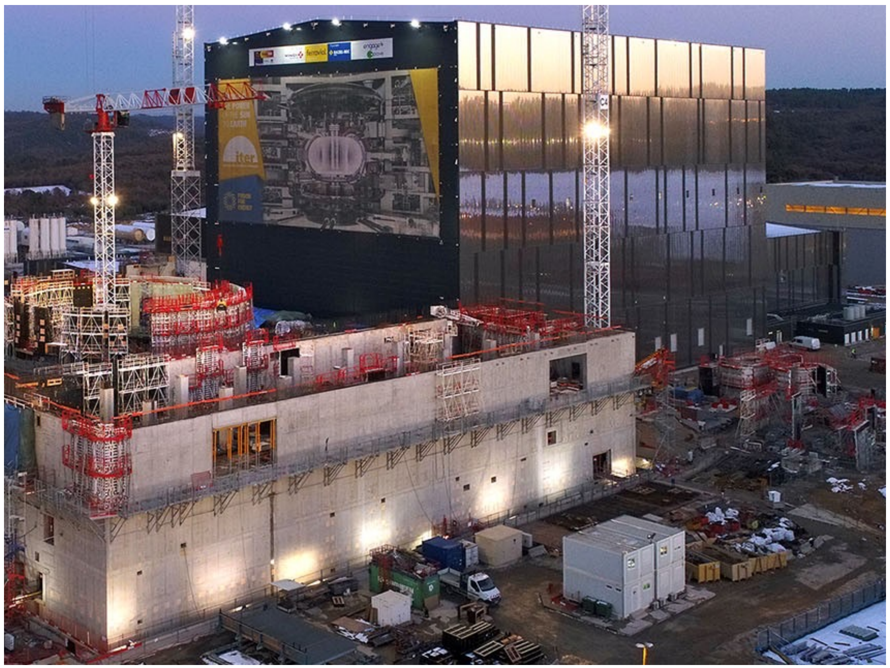


DEMO
~ 1000 - 3500 m³
~ 2000 - 4000 MW_{th}

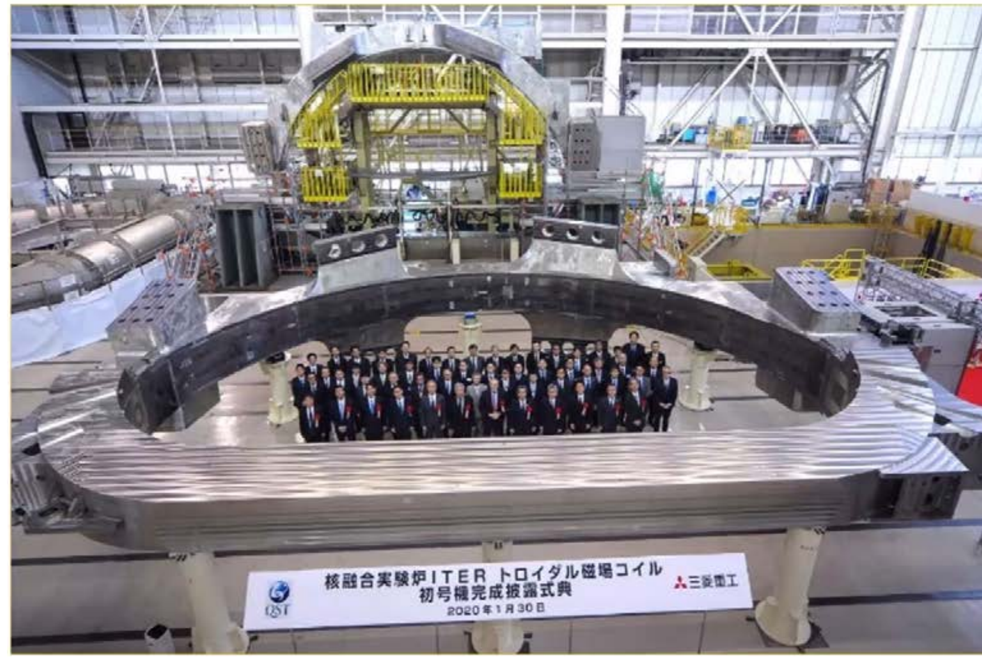
Energy applications

ITER – Bringing the power of the sun to earth

Construction site at Cadarache, France



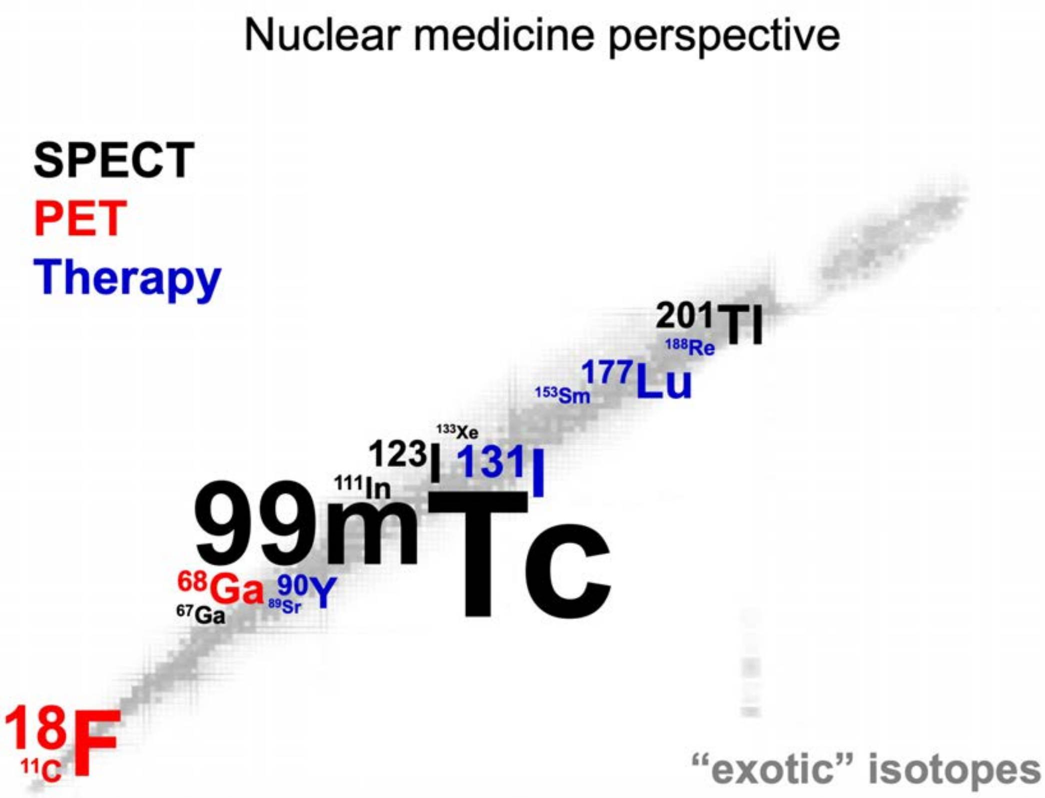
Completed Superconducting TF Coil



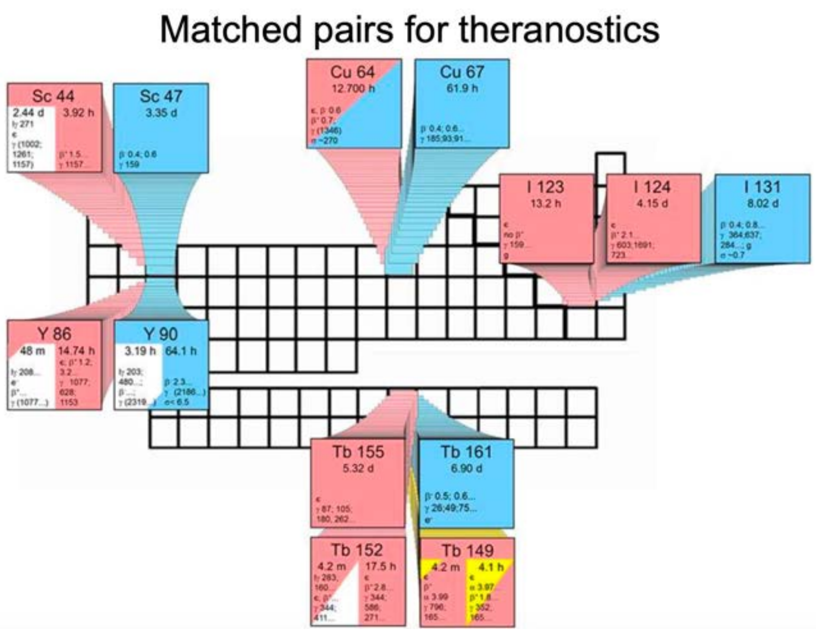
First plasma ≥ 2025
Full power by 2035

- **Health** (radioisotopes for therapy and diagnosis, hadrontherapy)

New isotopes for medicine and theranostics



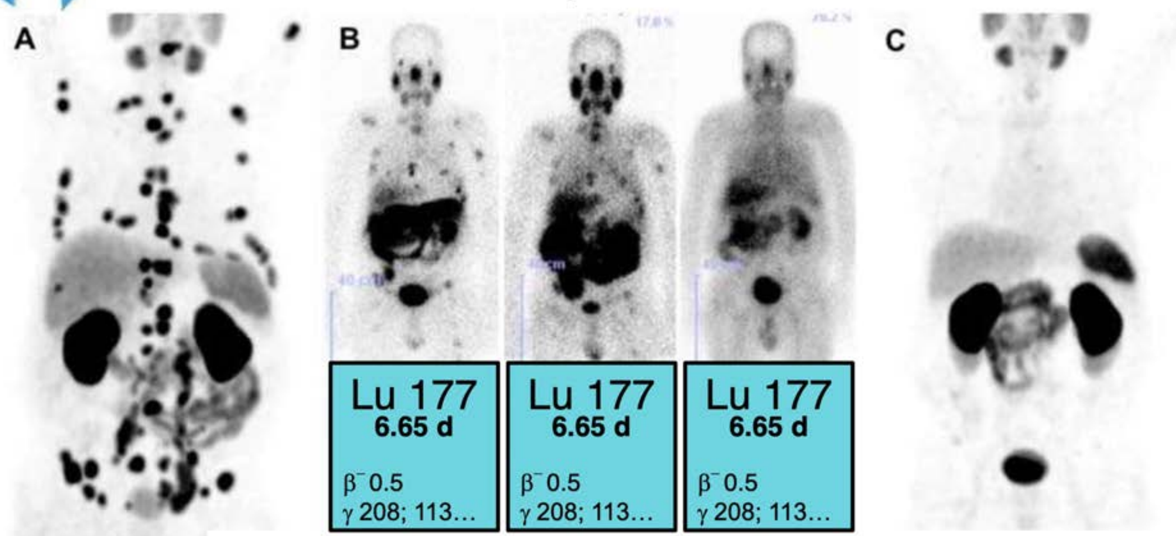
Theranostics in Nuclear Medicine: Integrated Imaging and Therapies in the Era of Precision Oncology



Curtesy of U. Koester

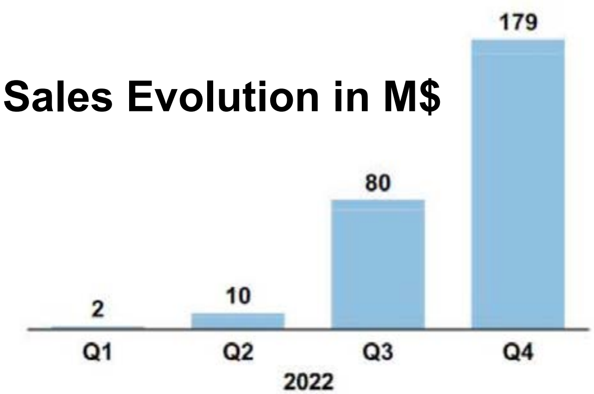
- **Health** (radioisotopes for therapy and diagnosis)

^{177}Lu-radioligand therapy of advanced prostate cancer

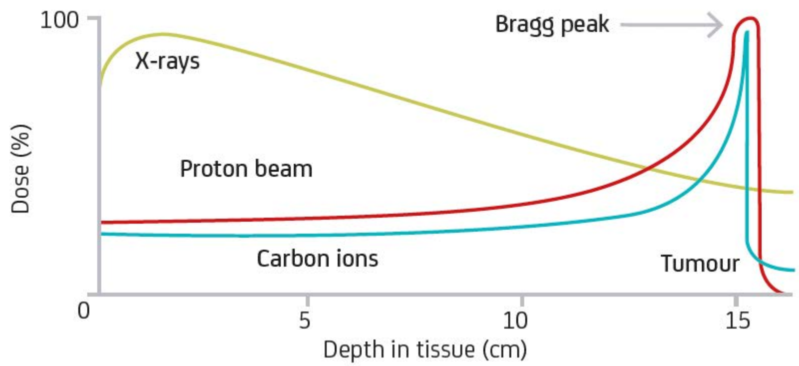


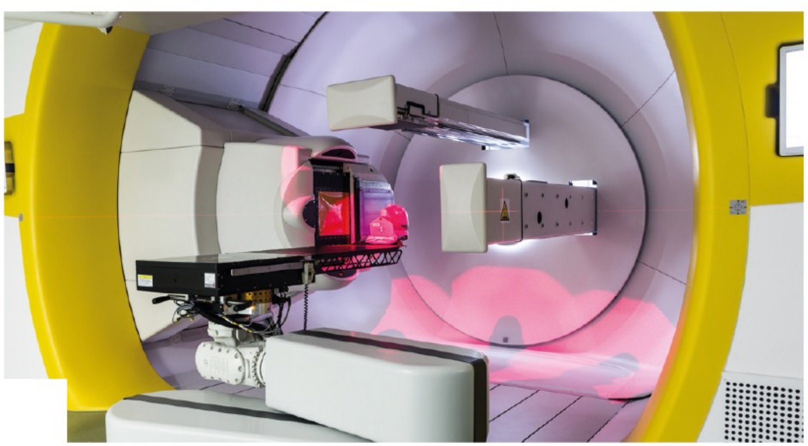
^{177}Lu-PSMA-617
PLUVICTO

Sales Evolution in M$

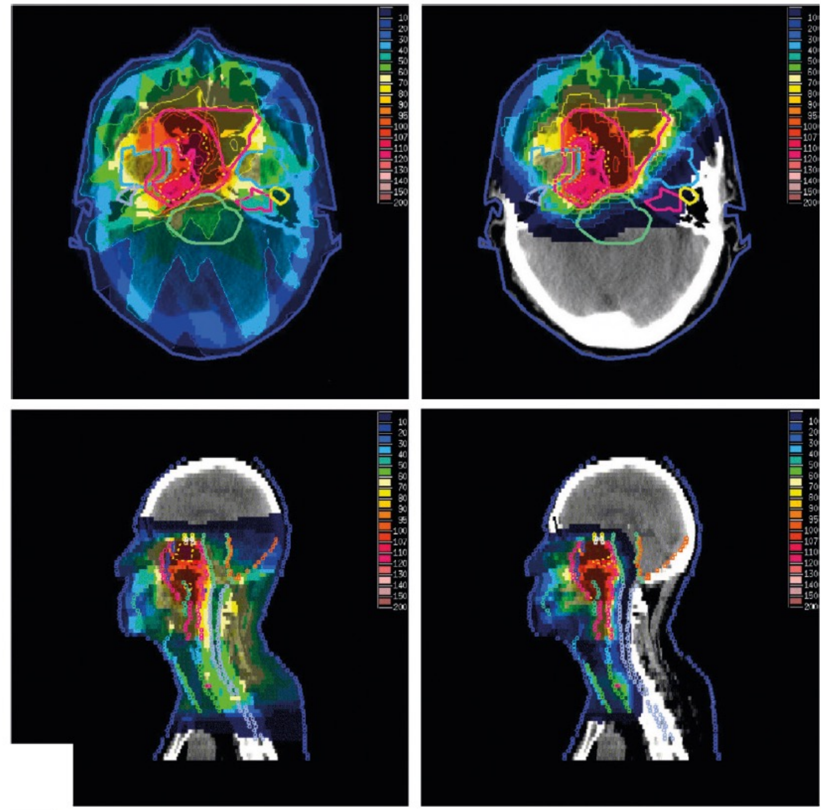


- **Health** (hadrontherapy)



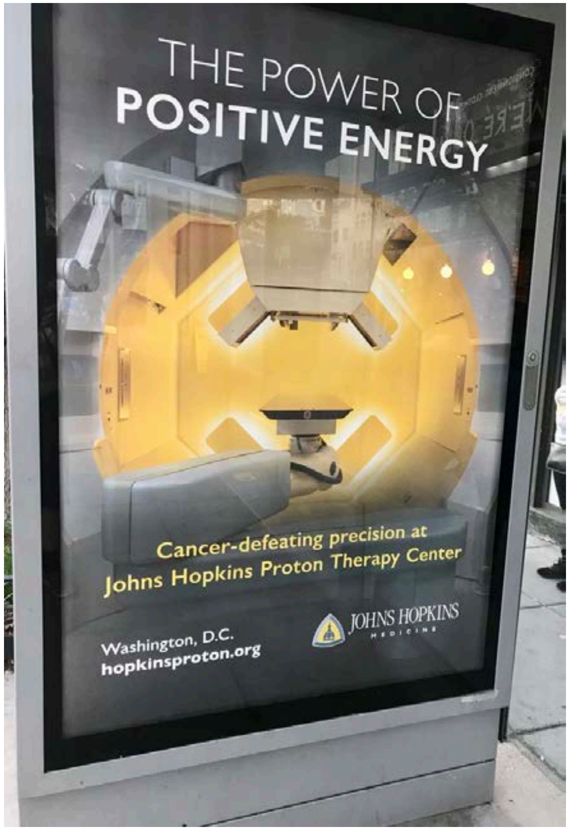


Proton therapy with a movable gantry at CCB/Institute of Nuclear Physics in Kraków Poland.



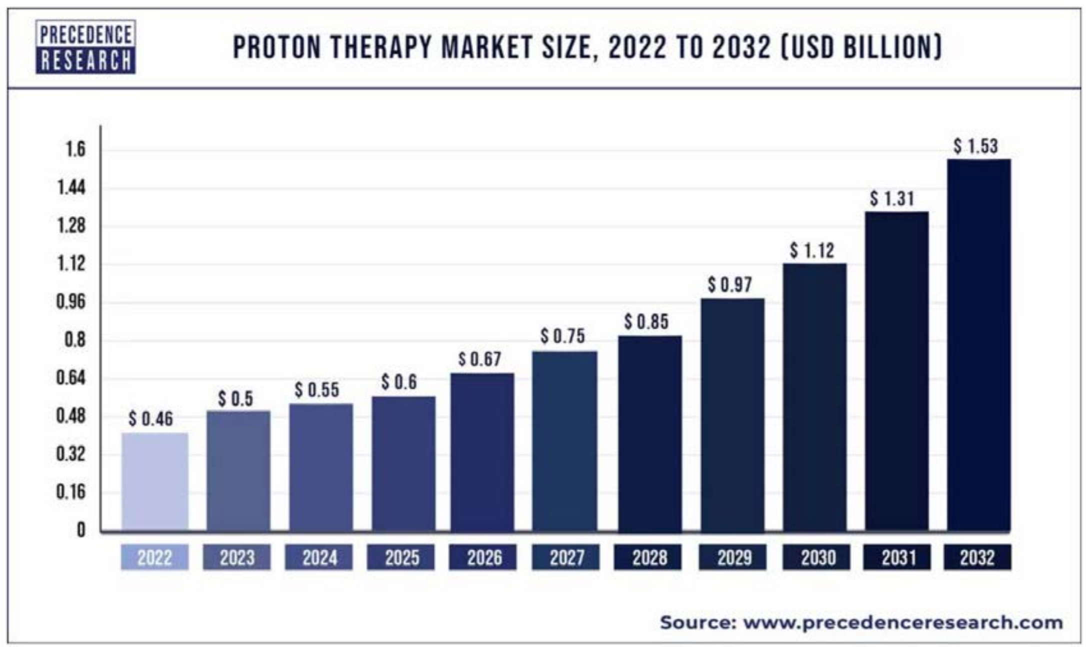
Proton therapy (right) is more accurate that X-rays (left) in delivering the optimum therapeutic radiation dose.

- **Health** (hadrontherapy)



Proton Therapy Market Share, By Region, 2022 (%)

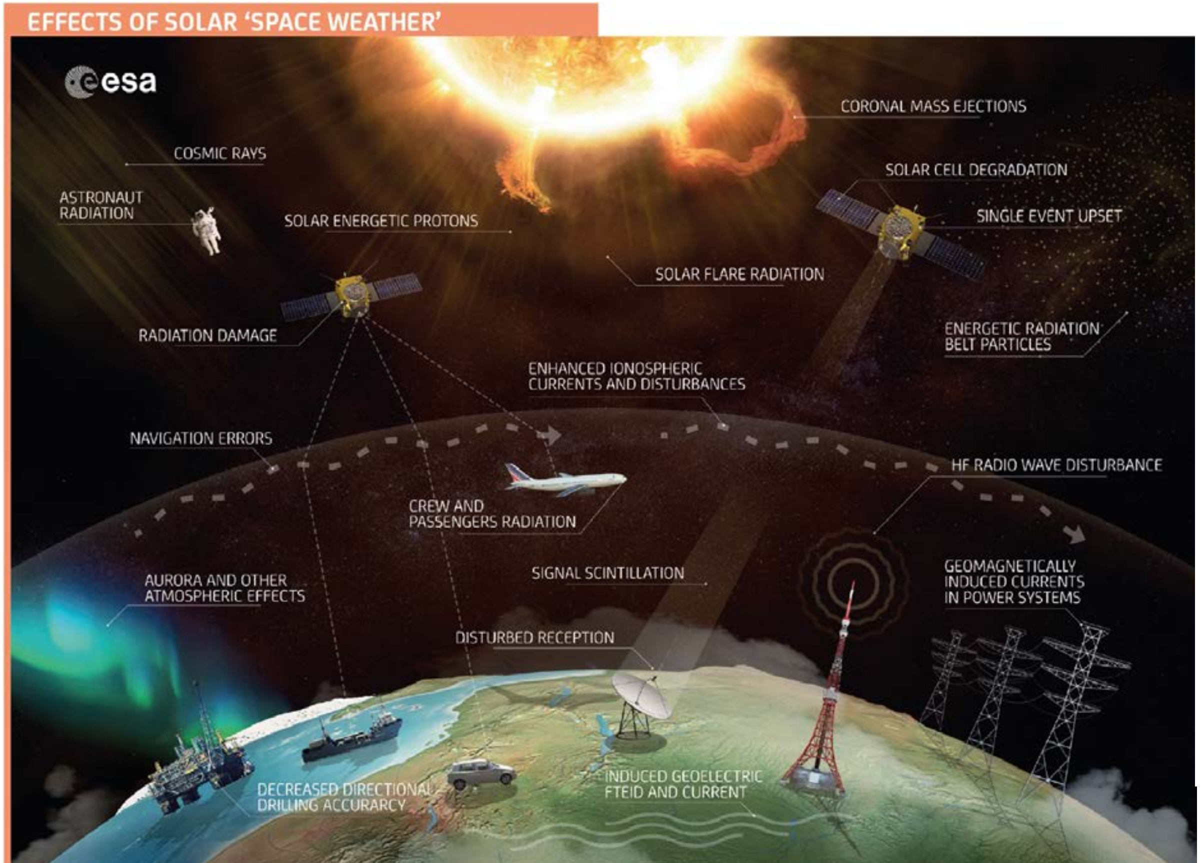
Regions	Revenue Share in 2022 (%)
North America	43%
Asia Pacific	20%
Europe	28%
Latin America	6%
MEA	3%



- **100 proton therapy centres in the world**
- **35 under construction**

• Space technology & exploration

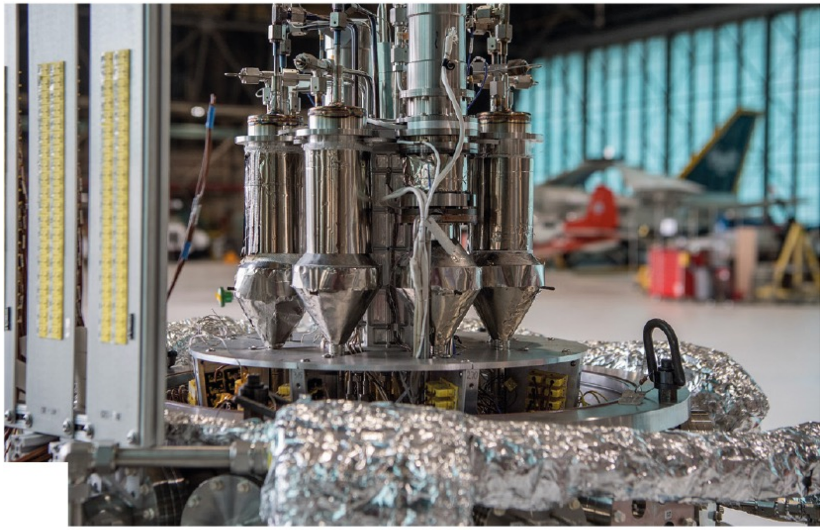
High demand for hardening and tests of electronics with ion beams



RADNEXT
EU H2020 Project

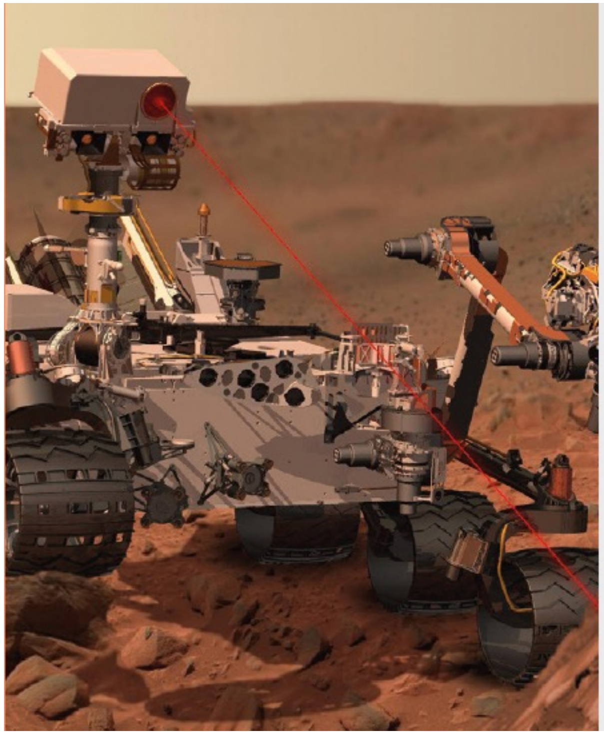
Partners & Associates

- **Space technology & exploration**



The prototype NASA nuclear reactor, Kilopower, designed for space travel - 1 to 10 kilowatts for at least 10 years.

Future habitats on Mars would rely on nuclear power.



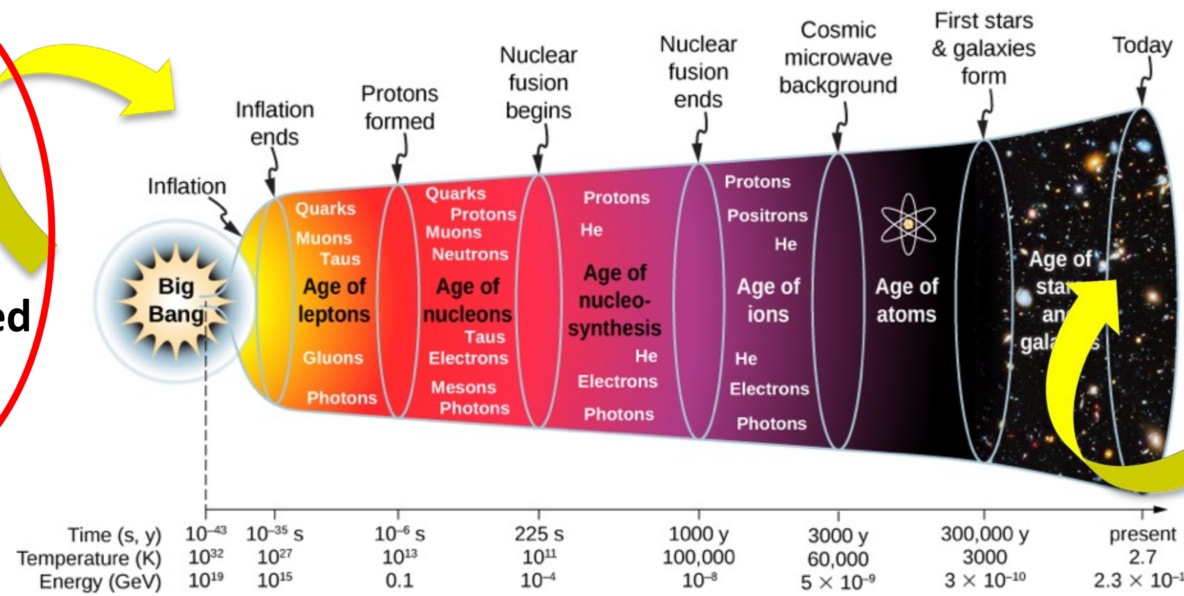
The Mars Perseverance rover successfully landed in the Jezero crater in February 2021 requires a nuclear battery (110W, 14 year lifetime) to operate.

Nuclear physics and the evolution of the Universe

- **What are the properties of nuclei and strong-interaction matter as encountered shortly after the Big Bang, in catastrophic cosmic events, and in compact stellar objects?**
- **How and where in the universe are the chemical elements produced?**

QCD

QCD in hot compressed matter



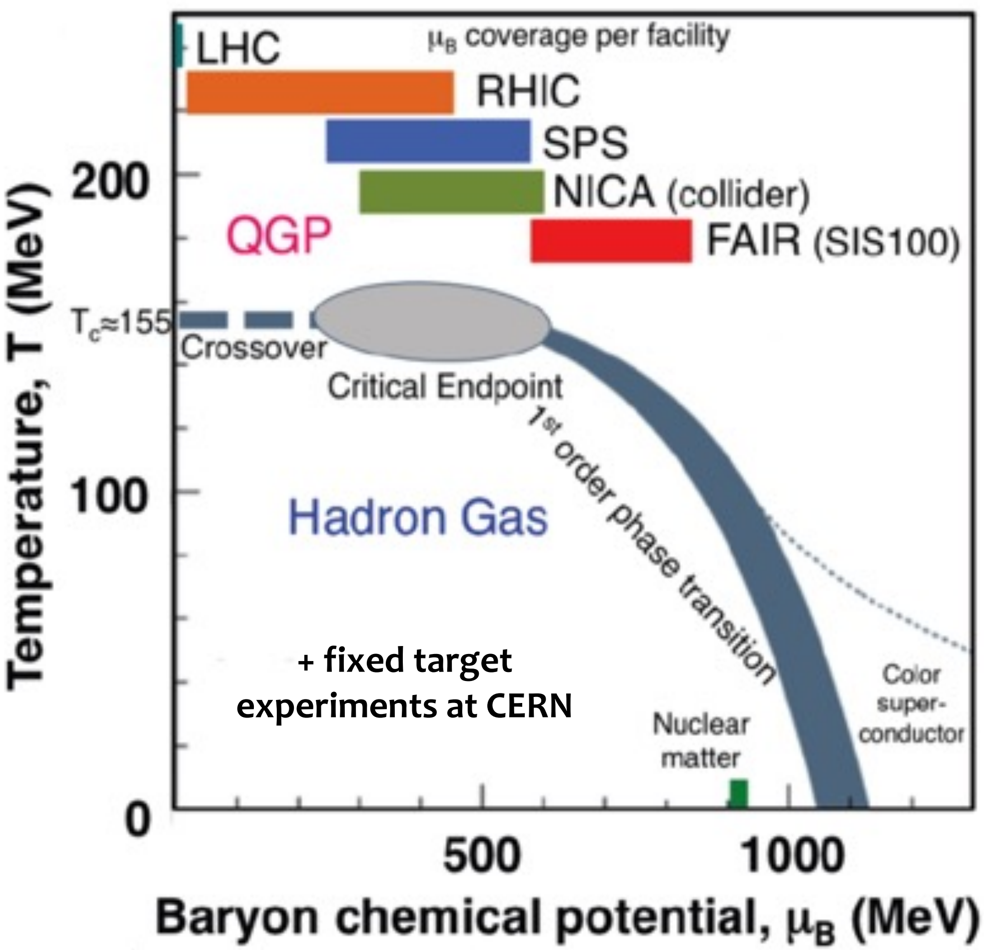
Nuclear structure
Nucleosynthesis

Reactions for astrophysics

Compressed nuclear matter

Hadronic Matter at the very extremes

- **What are the properties of nuclei and strong-interaction matter as encountered shortly after the Big Bang, in catastrophic cosmic events, and in compact stellar objects?**

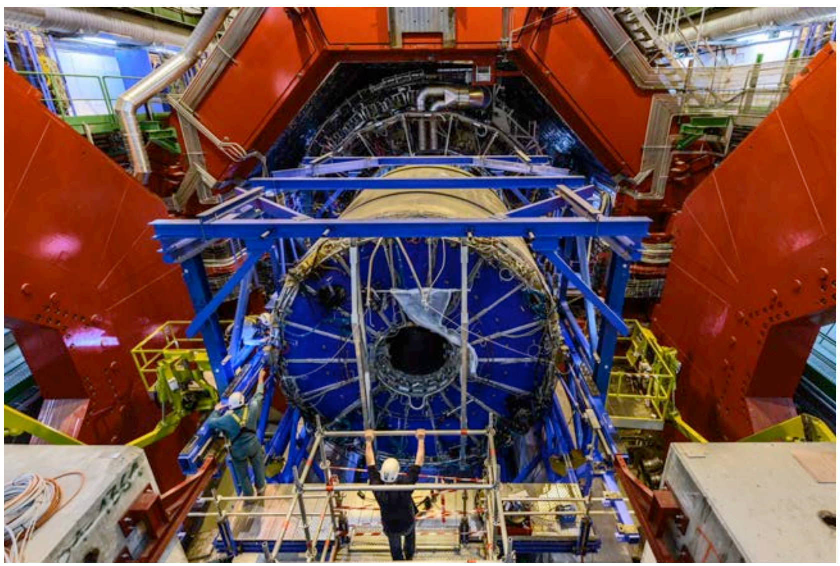


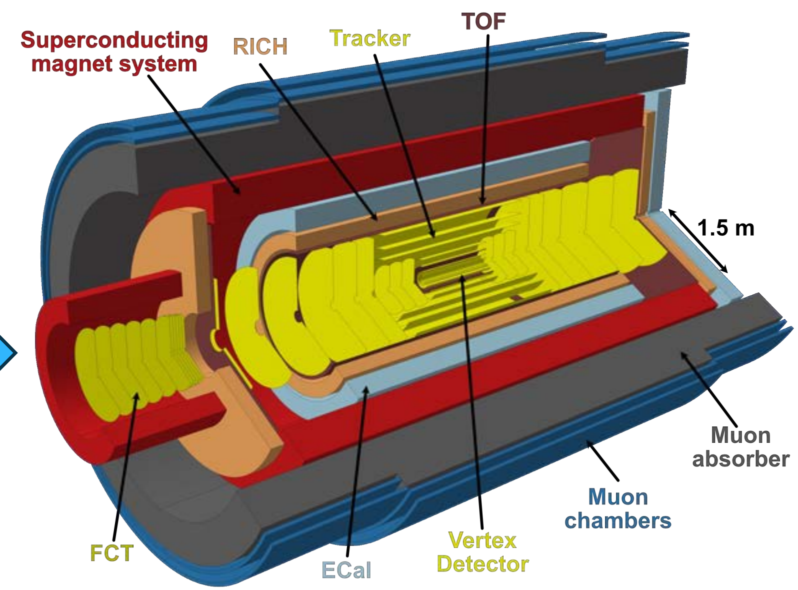
CERN/LHC ALICE ➡ ALICE3

High luminosity for ions
HL-LHC
Higher luminosities for ions

Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
2009 - 2013	2015 - 2018	2022 - 2025	2029 - 2032		

ALICE 1	ALICE 2 upgrade	ALICE 2.1 upgrade	ALICE 3 upgrade





Letter of Intent: CERN-LHCC-2022-009
LHCC minutes: LHCC-149

Curtesy of B. Erazmus

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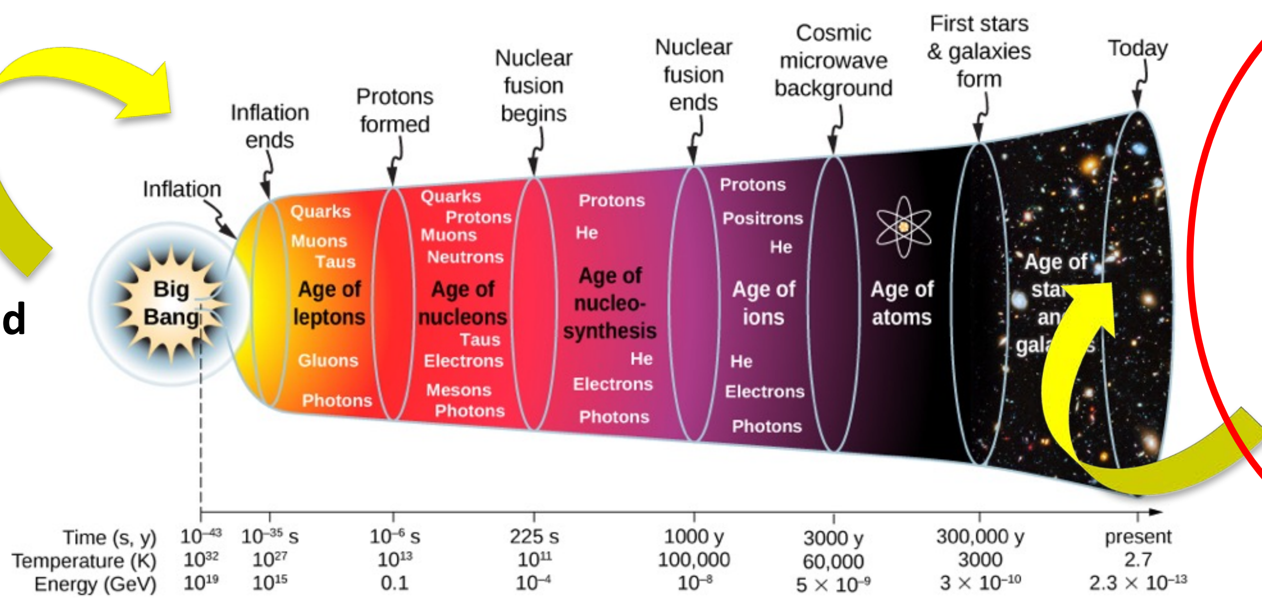
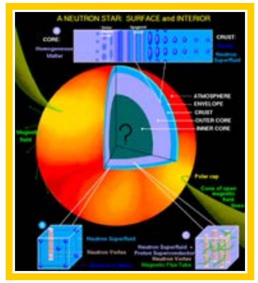


Nuclear structure
Nucleosynthesis

Reactions for astrophysics

Compressed nuclear matter

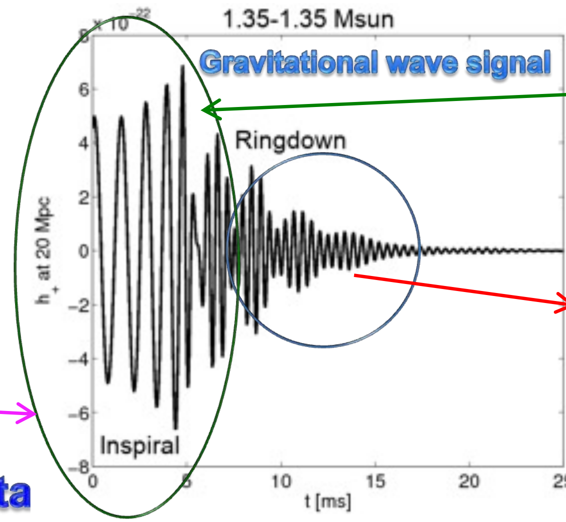
Neutron star mergers
Truly interdisciplinary research



The messengers from neutron star mergers :

- **Gravitational waves**
- **Electromagnetic signals characterizing the nuclei in the ejecta**
- **neutrinos**

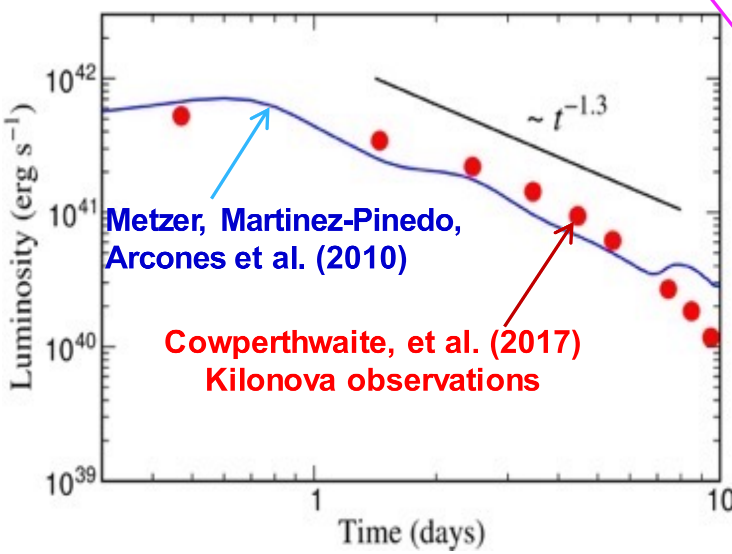
GW170817

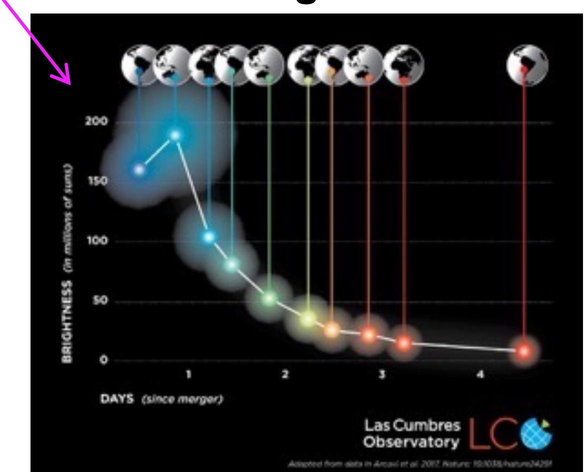


Neutron star mass

Ringdown depends on the Nuclear Equation of state

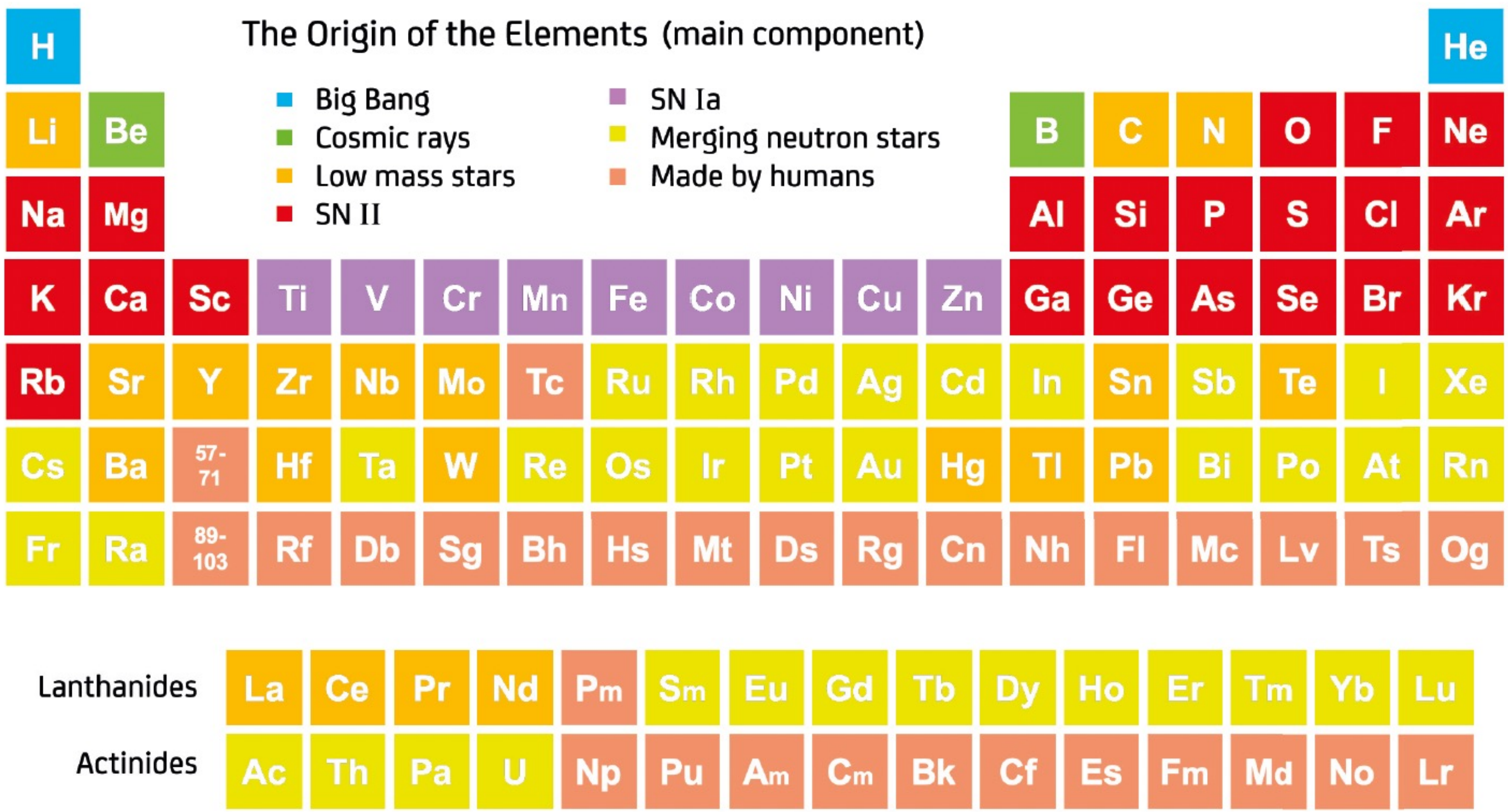
Gravitational wave emission seen together with electromagnetic signals





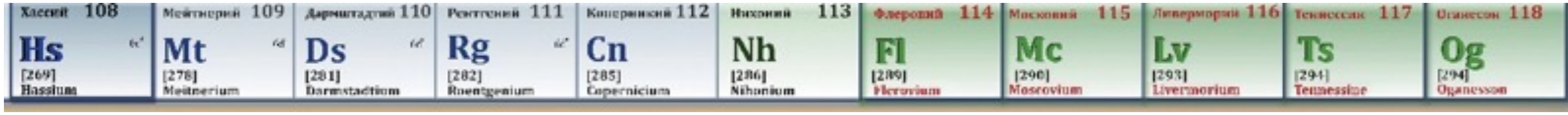
Time evolution determined by the radioactive decay of r-process nuclei (science drive of facilities with Radioactive Ion Beams)

New Periodic Table of Elements

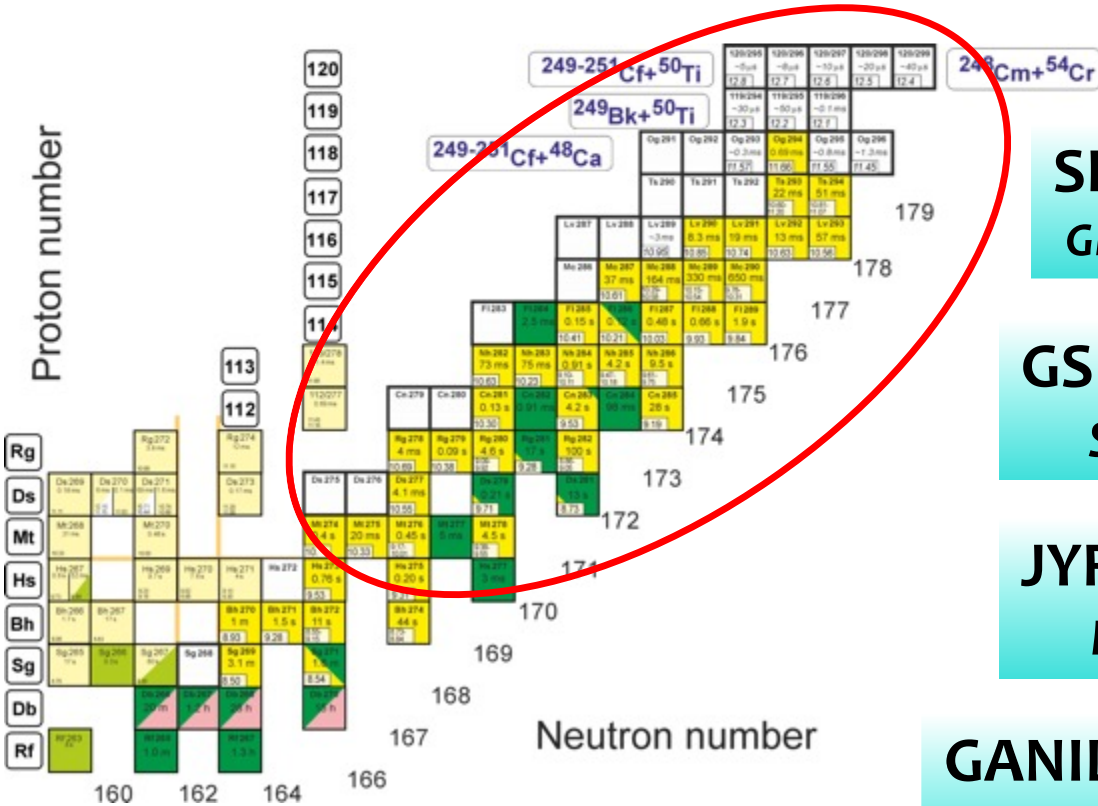


Definitely not the final version!

Quest for Limits
Study of Heavy and SH nuclei



10 out of 11 elements discovered at GSI and JINR



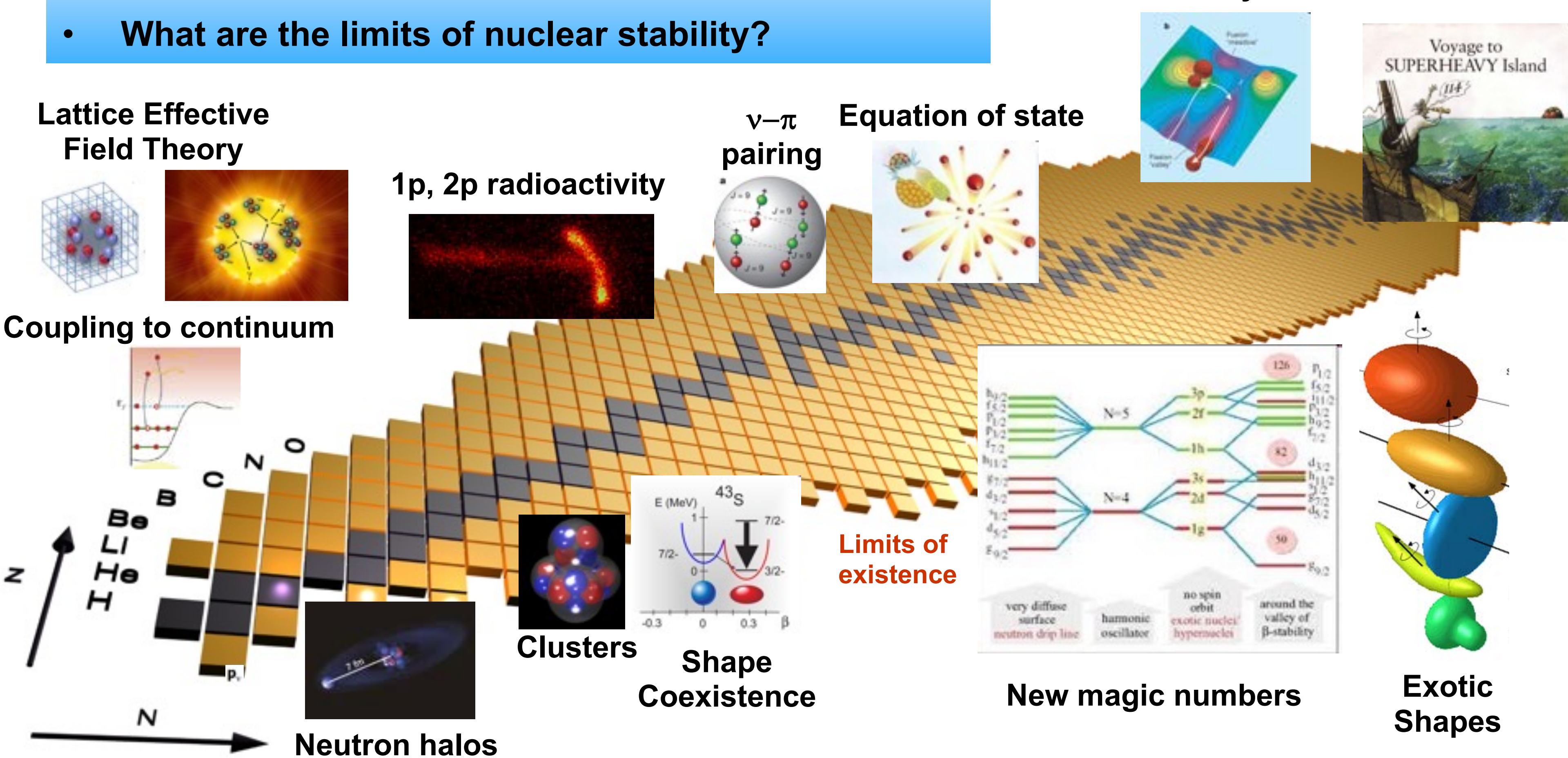
Search for new elements Z=119 and 120

Scientific programs at:

SHEF – Dubna *GFS II & III, SHELS*	*Taking data*
GSI – Darmstadt *SHIP & TASCA*	*Taking data*
JYFL – Jyväskylä *RITU & MARA*	*Taking data*
GANIL/SPIRAL2 – Caen *S3 & VAMOS GFS*	*Commissioning of LINAC & S3*

Structure of complex nuclei

- How does the complexity of nuclear structure arise from the interaction between nucleons?
- What are the limits of nuclear stability?

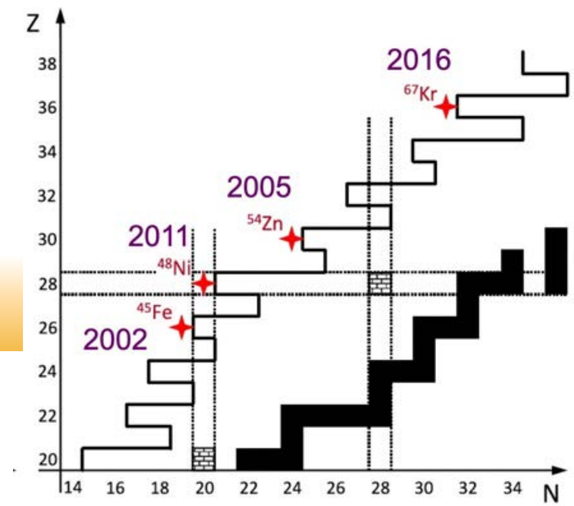


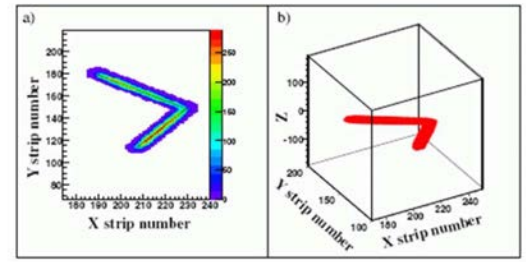
-> SR4A: dr Maria Kmiecik & dr Katarzyna Hadyńska-Klęk

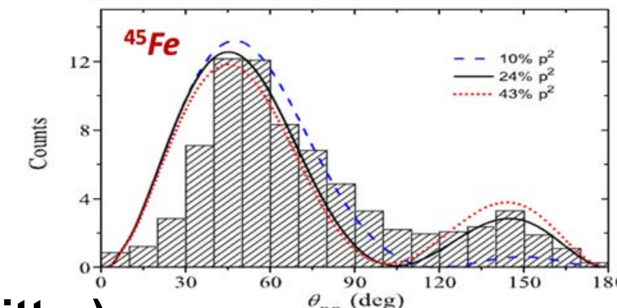
Structure of complex nuclei

New modes of radioactivity

2-proton radioactivity







Ex. ^{58}Ni (lightest isotope in nature) -> ^{48}Ni (2-proton emitter)

experimental status

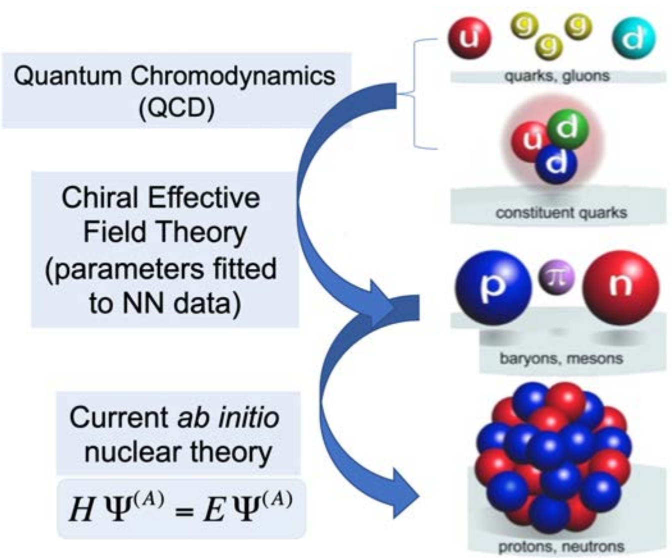
4 known cases (long-lived)

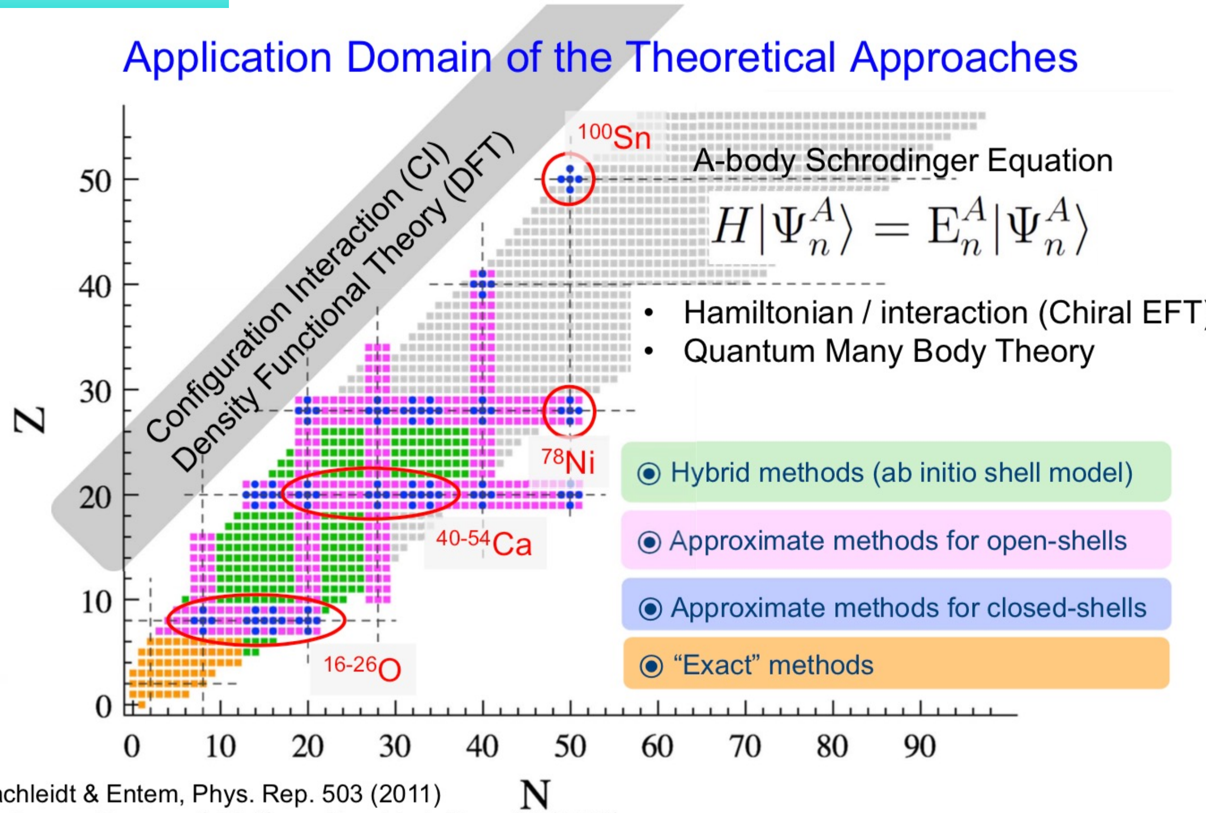
- **^{45}Fe**: first **indirect** evidence (J. Giovinazzo *et al.*, M. Pfützner *et al.*, 2002)
  first **direct** observation of 2 protons (J. Giovinazzo et al., 2007)
  angular distribution (K. Miernik et al., 2009)
- **^{54}Zn**: first **indirect** observation (B. Blank *et al.*, 2005)
  first **direct** observation, few p-p correlations (P. Ascher et al., 2011)
- **^{48}Ni**: **indirect** observation of one 2p event (C. Dossat *et al.*, 2005)
  direct observation, few p-p correlations (M. Pomorski et al., 2011)
- **^{67}Kr**: **indirect** observation (T. Goigoux *et al.*, 2015) → **half-life problem…**

Courtesy of B. Blank

Structure of complex nuclei
New Era of Nuclear Theory

-> SR4A: prof. Elżbieta Stephan





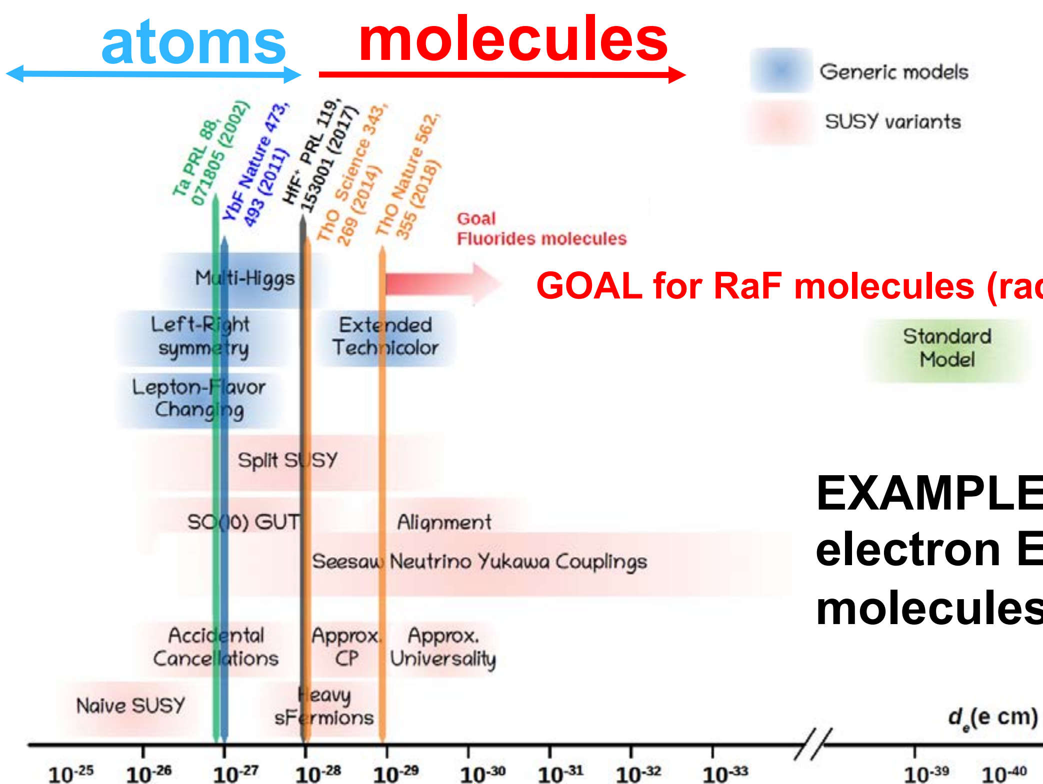
Machleidt & Entem, Phys. Rep. 503 (2011)
Epelbaum, Hammer & Meißner, Rev. Mod. Phys. 81 (2009)
Hagen,- Rept. Prog. Phys. 77 (2014)
Hergert,- Phys. Rep. 621 (2016)

-> SR4A: dr Michał Kowal

Courtesy T. Duguet & P. Navratil

Where is New Physics?

- **High precision measurements at low energies**
- **Complementary to experiments at the highest energies and offering sensitivities to new effects beyond the Standard Model**



GOAL for RaF molecules (radioactive only!)

EXAMPLE: best limit on the electron EDM comes from molecules

100 TeV Collider

See SR8C & SR9D

Courtesy R.F. Garcia Ruiz

What is NuPECC ?

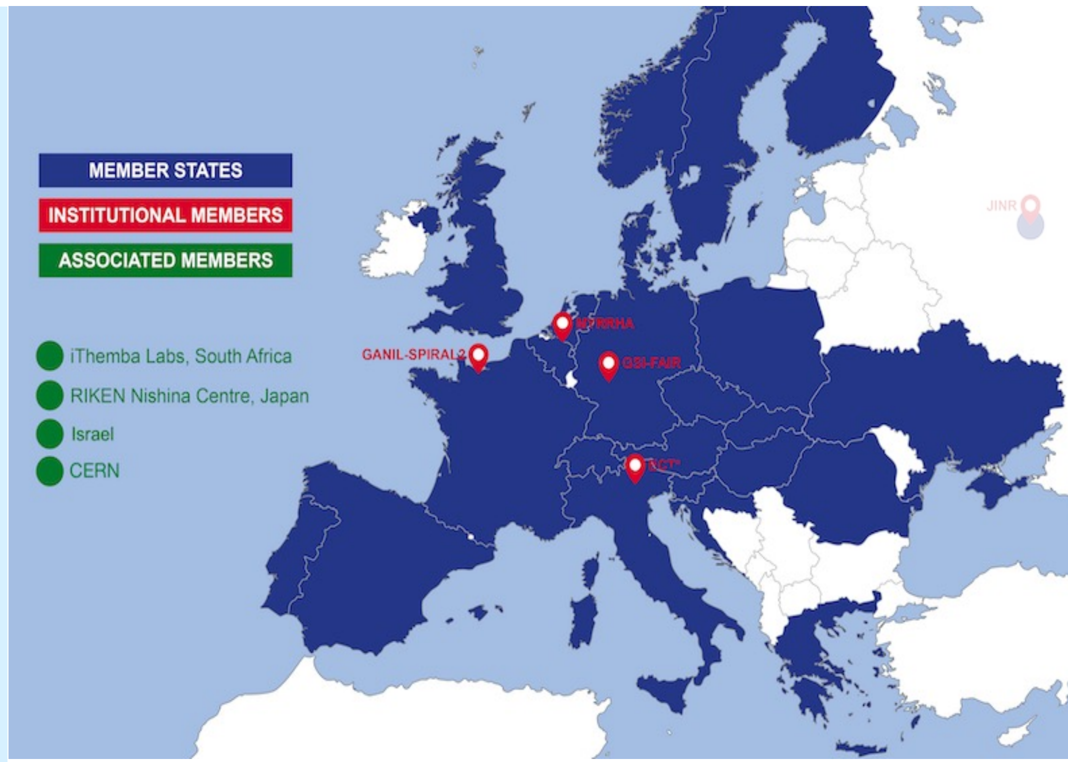
Nuclear Physics European Collaboration Committee (NuPECC)
Is the European Expert Board for Nuclear Physics
hosted by European Science Foundation

Representing

6000 scientists

Composition:

- 35 representatives from 23 countries (new member Ukraine), 3 ESFRI NP Infrastructures & ECT*
  JINR Dubna – suspended in March 2022
- 4 associated members
  - CERN
  - Israel
  - iThemba Labs
  - Nishina Center
- 9 observers (ALAFNA, ANPhA, APPEC, CINP, ECFA, ESF, IAEA, NPD/EPS, NSAC)

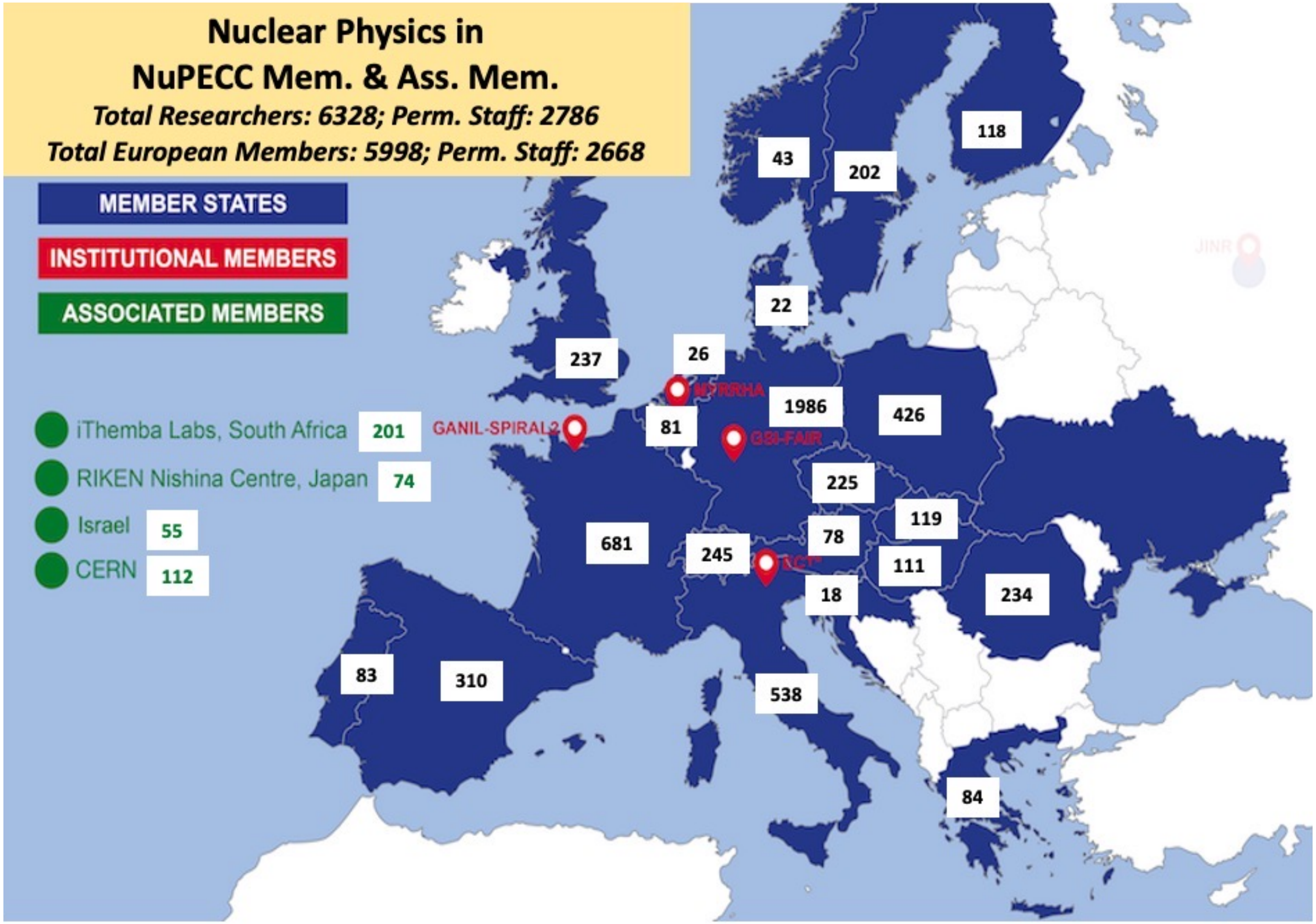


3 regular Committee meetings/y

34 Years of NuPECC activities

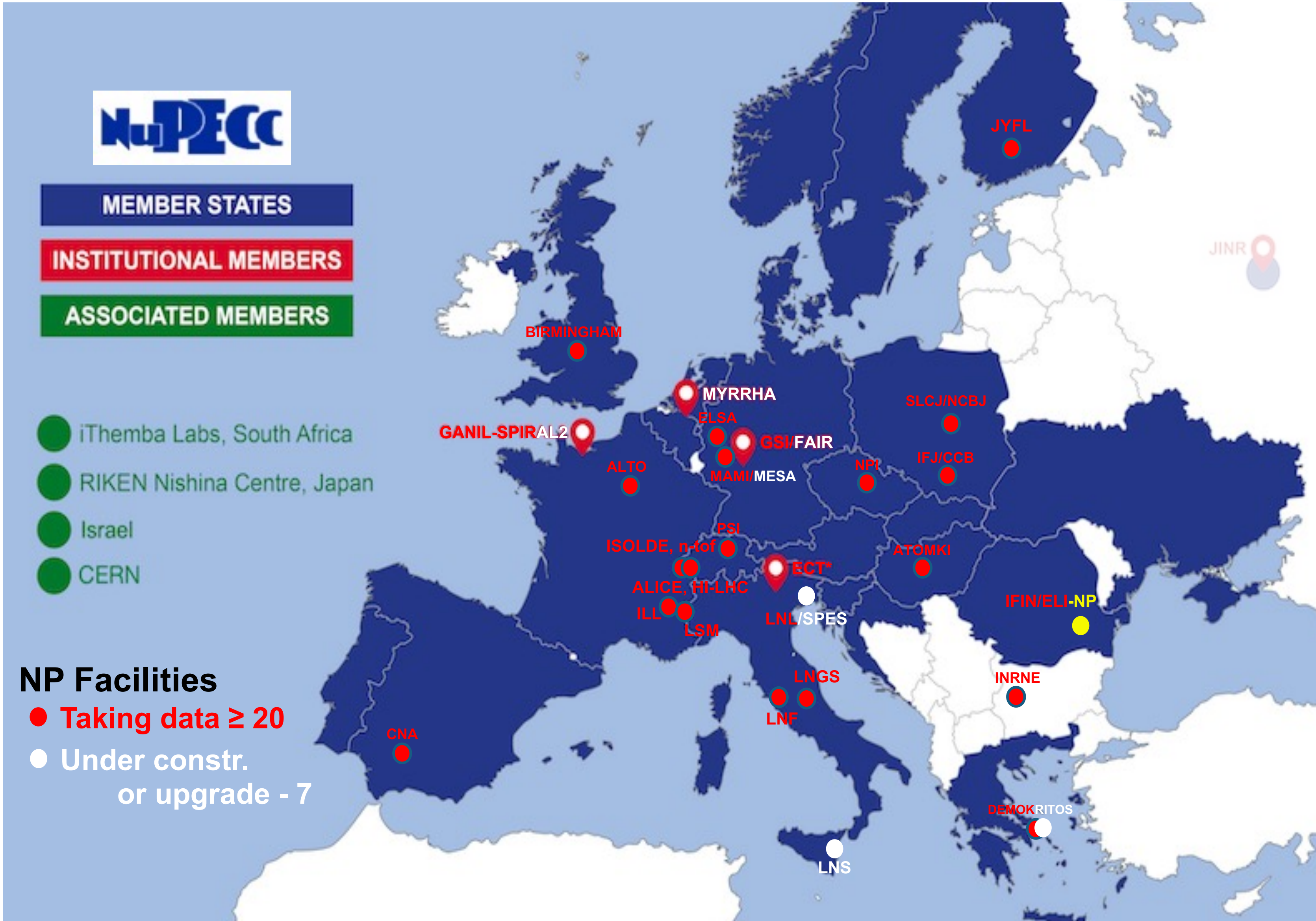
https://nupecc.org

NuPECC Survey of Nuclear Physics in Europe



J. J. Gomez Camacho, Ulf-G. Meißner et al.

European Landscape of major NP infrastructures



Darmstadt, Germany

FAIR by 2028

ESFRI

Finland	France	Germany	India	Poland	Romania	Russia	Slovenia	Sweden	United Kingdom	Czech Republic

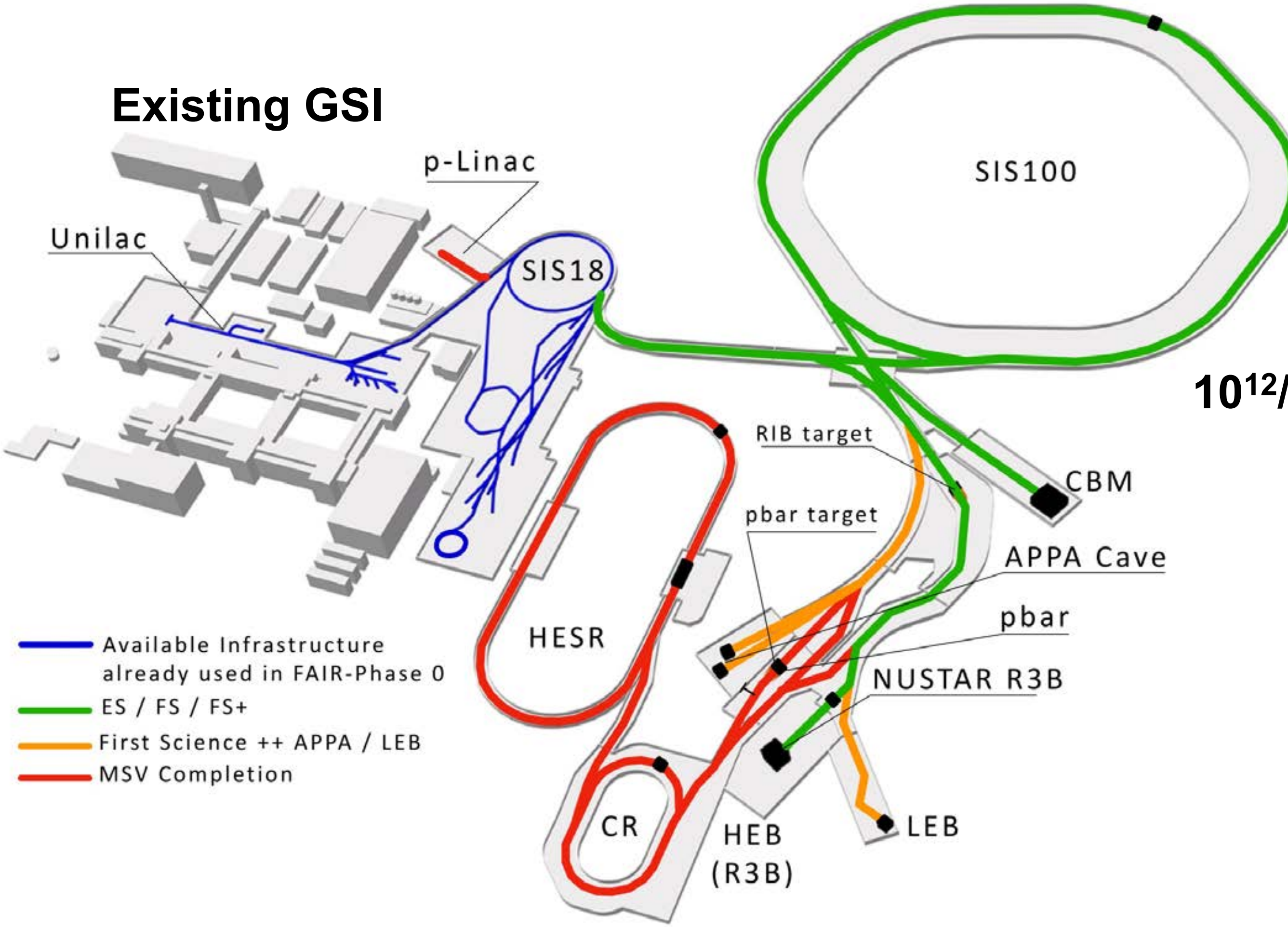
> 3B€

until 2028

>3.3 B€ investment

10^{12}/s; 1.5-2 GeV/u; $^{238}U^{28+}$

after 2028



-> SR4A: prof. Piotr Salabura

Curtesy of P. Giubellino

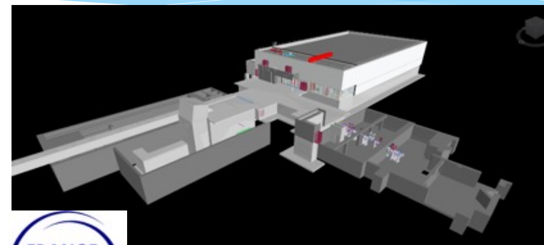
SPIRAL2 at GANIL, Caen, France

Experimental program in full swing

EXPERIMENTAL ROOM NFS (NEUTRONS FOR SCIENCE) **NFS**

Convertor room

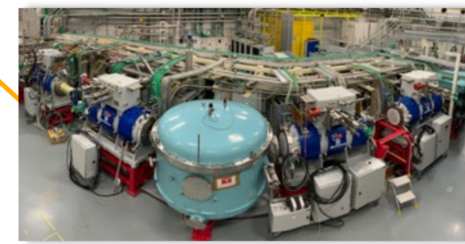
Time of Flight room



EXPERIMENTAL ROOM DESIR (Desintegration, Excitation and Storage of Radioactive Ions)

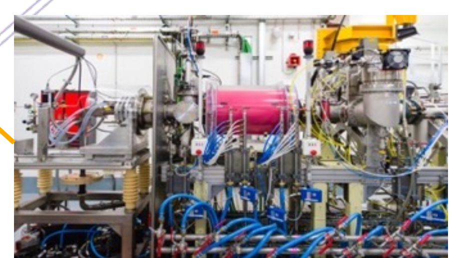
Civil construction 2023- 2024

Commissioning Planned end 2024



EXPERIMENTAL ROOM S3 (SUPER SEPARATOR SPECTROMETER)

LINEAR accelerator (LINAC)



ION SOURCE

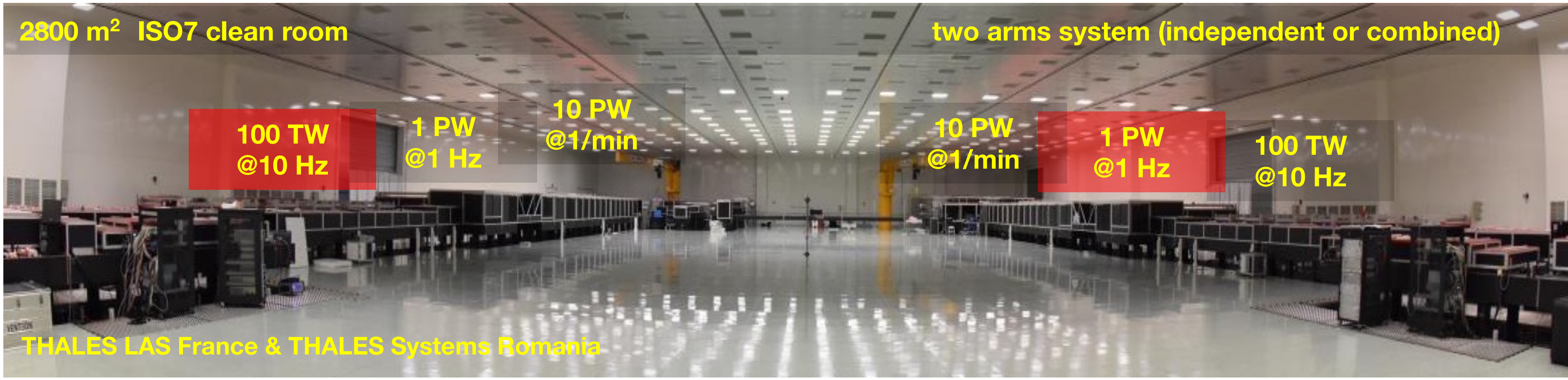
Project started

NEWGAIN NEW GANIL INJECTOR

High intensity beams :
5 mA, 33 MeV protons
5 mA, 40 MeV deuterons
1 mA, <14,5 MeV/A heavy ions

Curtesy of P. Chomaz

Roadmap NP facilities



ELI-NP Magurele, Romania

Operational since 2020

The highest power (10PW) operational laser system in the world

- **100 TW : *ongoing***
  - Four-wave mixing in vacuum, in search of dark matter candidates
  - X ray production through betatron emission
- **1 PW : *ongoing***
  - Benchmark TNSA proton acceleration
  - Benchmark LWFA electron acceleration
- **10 PW solid target : *starte in 2022***
  - Demonstrate extreme focal intensity through laser-γ conversion ("γ-flash")
  - Demonstrate over 200 MeV proton acceleration
  - Dense heavy ion beams for nuclear physics
- **10 PW gas target : *start in 2023***
  - 10 PW laser wakefield acceleration of multi-GeV electron beams

Courtesy of N. Marginean and C. Ur

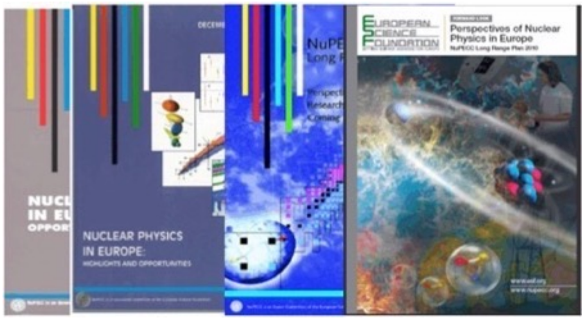
MYRRHA/MINERVA, SCK/CEN, Belgium

- **Accelerator Driven System (ADS) MYRRHA/MINERVA broke the ground in 2023**
- **Construction of ISOL@MYRRHA systems based on 100MeV 0.5mA proton linac started**
- **First ISOL beams by 2031**

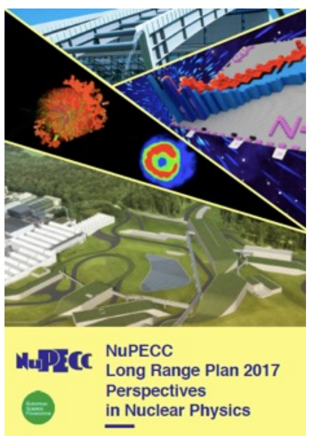
Courtesy of L. Popescu

Towards NuPECC Long Range Plan 2024

1991 1997 2004 2010



- The LRP identifies opportunities and priorities for the nuclear science in Europe
- The LRP provides national funding agencies, ESFRI and European Commission with a framework for coordinated advances in nuclear science in Europe



NuPECC LRP 2017

NuPECC LRP 2024

https://www.nupecc.org/lrp2016/Documents/lrp2017.pdf

Launched in May 2022 to be published in 2024

Modern Nuclear Physics in Europe

Strategy Pillars

- **Science: Interplay between strong Theory & ambitious Experiments**
- **Applications - huge societal impact**
- **Facilities – in Europe (FAIR, SPIRAL2, ELI-NP, ISOLDE, SPES,…) and at other continents (RIBF, TRIUMF, iThemba, EIC, FRIB)**
- **Detectors - ex. ALICE3 , AGATA,…**
- **Data, Open Science, AI/ML – ex. ESCAPE H2020 program**
- **Synergies with neighbouring fields – Dark Matter, Gravitational Waves, neutrinos, EDMs, detectors,…**

Strategy Development

- The 2017 NuPECC Long Range Plan defined an ambitious strategy for European Nuclear Physics
- **Next NuPECC LRP 2024 in a full swing!**

https://nupecc.org