



### A NEW NUCLEAR ASTROPHYSICS MASTERCLASS

A Journey through the Elements

Hannes Nitsche (TU Dresden)

Uta Bilow, Lana Ivanjek, Kai Zuber (TU Dresden), Daniel Bemmerer (HZDR)





This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008324

### WHAT ARE WE WORKING ON?

- Development of two Nuclear Astrophysics Masterclasses
  - First Masterclass available in German & English since last year • @mc.chetec-infra.eu/de
  - Second Masterclass coming End of 2023
- Languages
  - German, English, Spanish, French, Italian, Romanian, Swedish, Hungarian, Lithuanian, Catalan, Hebrew, Czech, Bulgarian, Welsh and Sorbian
- Unusual Masterclass for Netzwerk Teilchenwelt
  - Hadron Physics, hardly contact with particle physics
  - Hands-on Data Analysis comparatively small part







# INSIGHT INTO THE CONTENT AND MATERIALS







- **Centerpiece** of the Masterclasses: Analysis & evaluation of a **physical experiment** 
  - > Current Measurements carried out by nuclear physicists / Astrophysicists
- Learning Goals
  - Teaching the basic principles of nuclear physics & astrophysics Nuclei Structure, Nuclear Reactions, Nucleosynthesis, Stellar Evolution, Cross Sections etc.
  - Conveying the basic idea of this science field What questions does nuclear astrophysics ask itself and how does it work to answer them?
  - Depicting how physical knowledge develops Dynamics, evolution & open questions of nuclear astrophyiscs
  - Insight into the work of nuclear astrophysicists
  - Create interest in Nuclear Astrophysics





	PHASE	CONTENT	Метнор	
	<b>Part I</b> Ancient & Modern	Historical Insight: The Development of the Periodic Table	Lecture	
Lectures	Research	Insight in Modern Research	Short Video	
	Part II	Basics of Nuclear Reactions	Group Puzzle	
	Atomic nuclei and their peculiarities	Binding Energy & (In)stability	Lecture	
Activities !	Part III	Building a Hertzsprung-Russell-Diagram	Group project	
	The Evolution of a Star	The Story of the evolution of a Star	Lecture	
	Part IV	Neutron sources and their Meaning	Lecture	
More Details:	On To Higher Elements!	S- and R-Processes: Nuclei Race	Game	
	Part V	What does the photon tell us? Basics of Gamma spectroscopy	Partner work	
Guide		Data Analysis: The Search for Neutrons		





NFR/

- Centerpiece of the Masterclass: Analysis & evaluation of a nuclear physics experiment
- Measurement carried out at the Felsenkeller Laboratory Underground ion accelerator lab in Dresden
- Research Question:
   Where do the Neutrons come from?
- Data Analysis of  $^{14}N(\alpha,\gamma)^{18}F$ 
  - Start of a Reaction Chain taking place in red giant stars towards the end of helium burning
  - One of the main neutron sources for s-processes







- Centerpiece of the Masterclass: Analysis & evaluation of a nuclear physics experiment
- **Tasks** of the Learners:
  - Gamma Spectroscopy & Peak Measurements
  - Usage of a Term Diagram
  - Consideration of the underground
  - Determination of the cross section & reaction rate
- Goals:
  - Working as a Nuclear Physicist for one day
  - Gain an Insight into the Laboratory and the working methods of a Nuclear Physicist



Data Analysis Work Sheets







- Centerpiece of the Masterclass: Analysis & evaluation of a nuclear physics experiment
- **Tasks** of the Learners:
  - Gamma Spectroscopy & Peak Measurements
  - Usage of a Term Diagram
  - Consideration of the underground
  - Determination of the cross section & reaction rate
- Goals:
  - Working as a Nuclear Physicist for one day
  - Gain an Insight into the Laboratory and the working methods of a Nuclear Physicist

#### Data Analysis

Following, you can analyze the measurement date of an nuclear reaction. The series of measurements were taken in 2021 in the Felsenkeller laboratory in Dresden. In the experiment, an N-14 (Nirrogen) target was irradiated with helium nuclei. The gamma spectrum of the resulting F-18 nucleus (Fluorine) can be viewed here.

Photon energies from 0 to 16300 keV were measured. Choose the energy range in which

#### 1. Choose the interval

Sereveral series of Measurements were carried out. Here you can choose between for

2. Choose the Measurement series



Data Analysis Webtool







- Various Lectures linking the activities e.g. ...
  - Development of the understanding of • chemical elements over history



The Aristotelian Cosmos



The modern Periodic Table







> Various Lectures linking the activities e.g. ...

- Development of the understanding of chemical elements over history
- The life story of our sun from protostar to white dwarf









- Various Lectures linking the  $\succ$ activities
- **Videos & Visualizations**  $\succ$ 
  - Camera tour through the ٠ Felsenkeller underground laboratory
  - Astronuclear Nibbles Video series



Felsenkeller Laboratory







- Various Lectures linking the activities
- Videos & Visualizations
- Multiple Activities with Gamification Elements, e.g. ...
  - Building a Hertzsprung–Russell diagram together









- Various Lectures linking the activities
- Videos & Visualizations
- Multiple Activities with Gamification Elements, e.g. ...
  - Building a Hertzsprung–Russell diagram together







- Various Lectures linking the activities
- Videos & Visualizations
- Multiple Activities with Gamification Elements, e.g. ...
  - Building a Hertzsprung–Russell diagram together
  - The Nuclei Race: Recreating s- and r-processes in a board game

33p	As-63 unbekannt	$As-64$ $\lambda = 3,8\frac{1}{s}$	$As-65$ $\lambda = 5, 4\frac{1}{s}$	As-66 $\lambda = 7, 2\frac{1}{s}$	$As-67$ $\lambda = 1, 6 \cdot 10^{-2} \frac{1}{s}$	As-68 $\lambda = 4, 6 \cdot 10^{-3} \frac{1}{s}$	As-69 $\lambda = 7, 6 \cdot 10^{-4} \frac{1}{s}$	$As-70$ $\lambda = 2, 2 \cdot 10^{-4} \frac{1}{s}$	$As-71$ $\lambda = 2,9 \cdot 10^{-6} \frac{1}{s}$	$As-72$ $\lambda = 7, 4 \cdot 10^{-6} \frac{1}{s}$	$As-73$ $\lambda = 1.0 \cdot 10^{-7} \frac{1}{s}$	As-74 ک
32p	Ge-62 unbekannt	$\frac{\text{Ge-63}}{\lambda = 4,9\frac{1}{s}}$	$\frac{\text{Ge-64}}{\lambda = 1.1 \cdot 10^{-2} \frac{1}{s}}$	$\frac{\text{Ge-65}}{\lambda = 2, 2 \cdot 10^{-2} \frac{1}{s}}$	$\frac{\text{Ge-66}}{\lambda = 8,5 \cdot 10^{-5} \frac{1}{s}}$	$Ge-67$ $\lambda = 6, 1 \cdot 10^{-4} \frac{1}{s}$	$Ge-68$ $\lambda = 3, 0 \cdot 10^{-8} \frac{1}{s}$	$\frac{\text{Ge-69}}{\lambda = 4,9 \cdot 10^{-6} \frac{1}{s}}$	Ge-70 stabil	$Ge-71$ $\lambda = 7,0 \cdot 10^{-7} \frac{1}{s}$	Ge-72 stabil	= 4, 5 · 10 <sup>-7</sup> - 5 Ge-73 stabil
31p	Ga-61 $\lambda = 4, 1\frac{1}{s}$	Ga-62 $\lambda = 6,0\frac{1}{s}$	$Ga-63$ $\lambda = 2, 1 \cdot 10^{-2} \frac{1}{s}$	$Ga-64$ $\lambda = 4, 4 \cdot 10^{-3} \frac{1}{s}$	$Ga-65$ $\lambda = 7, 6 \cdot 10^{-4} \frac{1}{s}$	$Ga-66$ $\lambda = 2, 0 \cdot 10^{-5} \frac{1}{s}$	$Ga-67$ $\lambda = 2, 5 \cdot 10^{-6} \frac{1}{s}$	$Ga-68$ $\lambda = 1,7 \cdot 10^{-4} \frac{1}{s}$	Ga-69 stabil	<b>Ga-70</b> λ = 5.5, 10 <sup>-4</sup>	<b>Ga-71</b> stabil	$Ga-72$ $\lambda = 1.4 \cdot 10^{-5} \frac{1}{s}$
30p	$\frac{\text{Zn-60}}{\lambda = 4,8 \cdot 10^{-3} \frac{1}{s}}$	$\frac{\textbf{Zn-61}}{\lambda = 7,8 \cdot 10^{-3} \frac{1}{s}}$	$\frac{\text{Zn-62}}{\lambda = 2, 1 \cdot 10^{-5} \frac{1}{s}}$	$\frac{\text{Zn-63}}{\lambda = 3, 0 \cdot 10^{-4} \frac{1}{s}}$	$\frac{\mathbf{Zn-64}}{\lambda = 7,8 \cdot 10^{-25} \frac{1}{s}}$	$\frac{\text{Zn-65}}{\lambda = 3, 3 \cdot 10^{-8} \frac{1}{s}}$	Zn-66 stabil	Zn-67 stabil	Zn-68 stabil	$\frac{2n-69}{\lambda = 2,0 \cdot 10^{-4} \frac{1}{s}}$	$\frac{\mathbf{Zn-70}}{\lambda = 1.7 \cdot 10^{-24} \frac{1}{g}}$	$\frac{\text{Zn-71}}{\lambda = 4,7 \cdot 10^{-3} \frac{1}{s}}$
29p	Cu-59 $\lambda = 8, 5 \cdot 10^{-3} \frac{1}{s}$	$\frac{\text{Cu-60}}{\lambda = 4,9 \cdot 10^{-4} \frac{1}{s}}$	$\frac{\text{Cu-61}}{\lambda = 5,8 \cdot 10^{-5} \frac{1}{s}}$	$\frac{\text{Cu-62}}{\lambda = 1, 2 \cdot 10^{-3} \frac{1}{s}}$	Cu-63 stabil	$\frac{Cu-64}{\lambda} = 1.5 \cdot 10^{-5}$	Cu-65 stabil	$\frac{\text{Cu-66}}{\lambda = 2,3 \cdot 10^{-3} \frac{1}{s}}$	$\frac{\text{Cu-67}}{\lambda = 3, 1 \cdot 10^{-6} \frac{1}{s}}$	$\frac{\text{Cu-68}}{\lambda = 2, 2 \cdot 10^{-2} \frac{1}{s}}$	$\frac{\text{Cu-69}}{\lambda = 4, 1 \cdot 10^{-3} \frac{1}{s}}$	$\frac{\text{Cu-70}}{\lambda = 1.6 \cdot 10^{-2} \frac{1}{s}}$
28p	Ni-58 $\lambda = 5, 5 \cdot 10^{-23} \frac{1}{s}$	$\frac{Ni-59}{\lambda = 2,9 \cdot 10^{-13} \frac{1}{s}}$	Ni-60 stabil	Ni-61 stabil	Ni-62 stabil	$\frac{1}{\lambda} = 2, 2 \cdot 10^{-10} \frac{1}{s}$	Ni-64 stabil	Ni-65 $\lambda = 7, 6 \cdot 10^{-5} \frac{1}{s}$	Ni-66 $\lambda = 3, 5 \cdot 10^{-6} \frac{1}{s}$	Ni-67 $\lambda = 3, 3 \cdot 10^{-2} \frac{1}{s}$	$Ni-68$ $\lambda = 2, 4 \cdot 10^{-2} \frac{1}{s}$	$Ni-69$ $\lambda = 6, 1 \cdot 10^{-2} \frac{1}{s}$
27p	$\frac{\text{Co-57}}{\lambda = 2,9 \cdot 10^{-8} \frac{1}{s}}$	$\frac{\text{Co-58}}{\lambda = 1, 1 \cdot 10^{-7} \frac{1}{s}}$	Co-59 stabil	$\frac{\text{Co-60}}{\lambda = 4, 2 \cdot 10^{-9} \frac{1}{s}}$	$\frac{\text{Co-61}}{\lambda = 1, 2 \cdot 10^{-4} \frac{1}{s}}$	$co-62$ $\lambda = 7, 7 \cdot 10^{-3} \frac{1}{s}$	$\frac{\text{Co-63}}{\lambda = 2,5 \cdot 10^{-2} \frac{1}{s}}$	$\frac{\textbf{Co-64}}{\lambda = 2, 3\frac{1}{s}}$	$\frac{\text{Co-65}}{\lambda = 5,8 \cdot 10^{-1} \frac{1}{s}}$	$\frac{\textbf{Co-66}}{\lambda = 3,8\frac{1}{s}}$	$\frac{\text{Co-67}}{\lambda = 1, 6\frac{1}{s}}$	$\frac{\textbf{Co-68}}{\lambda = 3, 5\frac{1}{s}}$
26p	Fe-56 stabil	Fe-57 stabil	Fe-58 stabil	$Fe-59$ $\lambda = 1.8 \cdot 10^{-7} \frac{1}{s}$	$Fe-60$ $\lambda = 8.4 \cdot 10^{-15} \frac{1}{s}$	$Fe-61$ $\lambda = 1,9 \cdot 10^{-3} \frac{1}{s}$	$Fe-62$ $\lambda = 1.0 \cdot 10^{-2} \frac{1}{s}$	$Fe-63$ $\lambda = 1, 1 \cdot 10^{-1} \frac{1}{s}$	$Fe-64$ $\lambda = 3, 5 \cdot 10^{-1} \frac{1}{s}$	$Fe-65$ $\lambda = 5,3 \cdot 10^{-1} \frac{1}{s}$	$Fe-66$ $\lambda = 1, 6\frac{1}{s}$	$Fe-67$ $\lambda = 1, 2\frac{1}{s}$
25p	Mn-55 stabil	$\frac{\text{Mn-56}}{\lambda = 7,5 \cdot 10^{-5} \frac{1}{s}}$	$\frac{\mathbf{Mn-57}}{\lambda = 8,1 \cdot 10^{-3} \frac{1}{s}}$	$\frac{\mathbf{Mn-58}}{\lambda = 2, 3 \cdot 10^{-1} \frac{1}{s}}$	$\frac{\text{Mn-59}}{\lambda = 151 \cdot 10^{-1} \frac{1}{s}}$	$\frac{\text{Mn-60}}{\lambda = 1, 4 \cdot 10^{-2} \frac{1}{s}}$	$Mn-61$ $\lambda = 1, 0\frac{1}{s}$	$\frac{\mathbf{Mn-62}}{\lambda = 7,9 \cdot 10^{-1} \frac{1}{s}}$	$\frac{\text{Mn-63}}{\lambda = 2, 4\frac{1}{s}}$	$\frac{\mathbf{Mn-64}}{\lambda = 1, 1 \cdot 10^{-7} \frac{1}{s}}$	$\frac{\text{Mn-65}}{\lambda = 7, 7\frac{1}{s}}$	$\frac{Mn-66}{\lambda = 1.4 \cdot 10^3 \frac{1}{s}}$
25p	Mn-55 stabil	$\frac{\text{Mn-56}}{\lambda = 7,5 \cdot 10^{-5} \frac{1}{s}}$	$\frac{\text{Mn-57}}{\lambda = 8, 1 \cdot 10^{-3} \frac{1}{s}}$	$\mathbf{Mn-58}$ $\lambda = 2, 3 \cdot 10^{-1} \frac{1}{s}$	$\frac{\text{Mn-59}}{\lambda = 151 \cdot 10^{-1} \frac{1}{s}}$	$\frac{\text{Mn-60}}{\lambda = 1, 4 \cdot 10^{-2} \frac{1}{s}}$	$\frac{\text{Mn-61}}{\lambda = 1, 0\frac{1}{s}}$	$\mathbf{Mn-62}$ $\lambda = 7, 9 \cdot 10^{-1} \frac{1}{s}$	$\frac{\text{Mn-63}}{\lambda = 2, 4\frac{1}{s}}$	$\mathbf{Mn-64}\\\lambda = 1, 1 \cdot 10^{-7} \frac{1}{s}$	$\frac{\text{Mn-65}}{\lambda = 7,7\frac{1}{s}}$	Μι λ = 1







- Various Lectures linking the activities
- Videos & Visualizations
- Multiple Activities with Gamification Elements, e.g. ...
  - Building a Hertzsprung–Russell diagram together
  - The Nuclei Race: Recreating s- and r-processes in a board game









### **R-PROCESS IN ACTION**







INFRA

# GENERAL **DESIGN ASPECTS** OF THE MASTERCLASSES







### 1. Low Threshold

- Previous knowledge in astrophysics and nuclear physics not mandatory
- Target Group: Age 15+







### 1. Low Threshold

#### 2. Accessability

- Masterclass available in both online and live formats
- Open Access to all materials online
- No software installations necessary
- Analog materials can be recreated easily







- 1. Low Threshold
- 2. Accessability
- 3. Reproducibility
- Complete materials & instructions for educators open access
- Making it as easy as possible, to be a Nuclear Astrophysics Facilitator







- 1. Low Threshold
- 2. Accessability
- 3. Reproducibility
- 4. Two different Masterclasses
- Access to nuclear astrophysics with different Points of View
- No Necessity to visit the first Masterclass to understand the second
- Two independent Masterclasses
  - Each Scientist can choose their preferred topic





















#### First Masterclass Run Through

- @ the Delta-X Student Lab (Helmholz-Zentrum Dresden Rossendorf)
- with 13 students (14-16 Yrs o.)







- First Masterclass Run Through
- Masterclass Training Day
  - @ the NPA-X Summer School
  - 1 week PhD School on Nuclear Astrophysics @ the CERN











- First Masterclass Run Through
- Masterclass Training Day
  - @ the NPA-X Summer School
  - 1 week PhD School on Nuclear Astrophysics @ the CERN
  - 1 whole Day for Outreach Activities
  - Using the Masterclass to
    - Train Facilitators
    - Discuss about how to communicate Nuclear Astrophysics







- First Masterclass Run Through
- > Masterclass Training Day
- Second Masterclass Run Through
  - School in Spremberg
  - With 20 Students 11th & 12th Grade
- Third Masterclass Run Through in February 2023
  - School in Berlin
  - With 16 Students 10th Grade





### **O**UTLOOK







### Ουτιοοκ

#### We are aiming for...

- Creating a Network of Nuclear Astrophysics Facilitators
- Giving every Physicist the opportunity to be a Educator
- Mediate Nuclear Astrophysics around the Globe











### Ουτιοοκ

#### We are looking for...

**Science Communicators** who want to give Nuclear Astrophysics Masterclasses

- Anyone who works in this field, can be an Educator & Facilitator
- Open Access Teaching Materials including
  - Presentation
  - Guide for the whole Masterclass
  - Guided Masterclass Run Through

If you're interested, get in touch:

hannes.nitsche@tu-dresden.de









# Thank you for your attention.







