Designing Masterclasses in Nuclear Astrophysics

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Overview

- **Project Framework**
- **Nuclear Astrophysics** as Seen by a **Teacher**
- Didactic **Challenges** & **Solutions** in Reconstructing Nuclear Astrophysics
- General **Design Aspects** of the Masterclasses
- Insight into the **Content and Materials**
- **Lookout**

Project Framework

- Development of two Nuclear Astrophysics Masterclasses (Work in Progress!)
- Support by
  - Uta Bilow, Kai Zuber & Lana Ivanjek (TU Dresden)
  - Daniel Bemmerer & Simon Rümmler (HZDR)
- Currently designing the **first draft** of the first Masterclass
- Starting the **evaluation** in May 2022
- **Translation** in 11 different languages
  (English, German, Spanish, Italian, Romanian, Swedish, Hungarian, Lithuanian, Catalan, Hebrew)
- Available to multipliers in **October 2022** & October 2023

Project Framework

Structure of the Masterclass

- Masterclass for **two days**, aiming for 2x 4h
- **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
  - Conveying the basic idea of this science field
  - Depicting how physical knowledge develops
    Dynamics, evolution & open questions of nuclear astrophyiscs

Nuclear Astrophysics as Seen by a Teacher

Nuclear Astrophysics as Seen by a Teacher

Fundamentals of Nuclear Physics
- Nuclei structure
- Binding energy, Valley of Stability
- Nuclear reactions and radioactivity
- Nuclear fusion
- Table of nuclides

Theoretical Astrophysics

Nuclear Astrophysics
- Structure of stars
- Evolution of stars
- Nucleosynthesis
  - Primordial NS
  - Stellar NS
  - S- und R-Process
  - Explosive NS
- Planetology

Gaining information about …

Cosmologic Questions
- Emergence and evolution of the universe
- Big Bang models

Nuclear physics Experiments
- Nuclear Reactions
- Cross sections, Reaction rates
- Ion accelerators & Detectors

Observables
- Spectra
- Lightcurves
- Abundances

Observational Astronomy
- Herzsprung-Russell diagram
- Spectroscopy
- Structure of the universe

Nuclear Astrophysics as Seen by a Teacher

The science field Nuclear Astrophyics

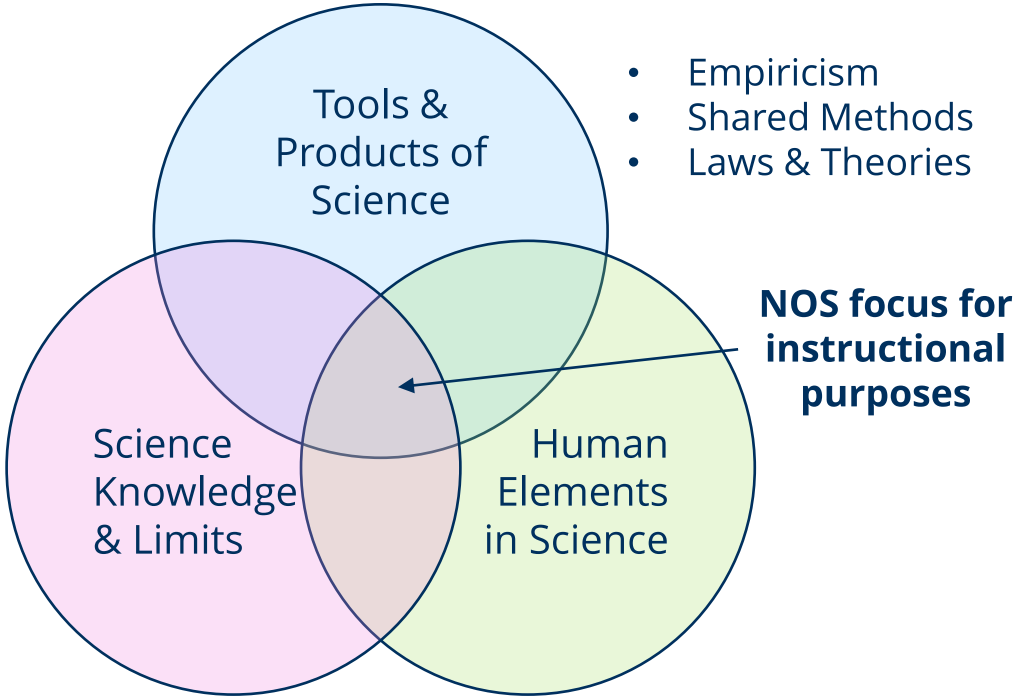
- Complex structure
  → Necessity, to understand the basics of paired scientific fields
  → Necessity of complexy reduction

- Very representative to approach **Nature-of-Science-Aspects** of physics

Nuclear Astrophysics as Seen by a Teacher

Nature of Science (NoS)

- *How does Science work? What are the characteristics of Science?*
- Goal in teaching NoS:
  enhancing the understanding of science concepts, to enable the students to make informed decisions about scientifically-based issues.



- Empiricism
- Shared Methods
- Laws & Theories

- Science vs. Technology
- Tentative vs. Durable
- Science has Limits

- Creativity
- Subjectivity
- Cultural Influence

Mccomas & Kampourakis, 2015

Nuclear Astrophysics as Seen by a Teacher

Nature of Science in Nuclear Astrophysics

- Evolutionary and revolutionary developments in the History of Science
  → Historical development of the Concept of **Elements** and their formation
- Process of knowledge aquisition
  → How can we reconstruct the physical processes in distant stars?
  → Limits of Modelling those processes
- Technical and physical limits and their impact on research methods

Didactic **Challenges & Solutions** in Reconstructing Nuclear Astrophysics

Didactic Challenges & Solutions

1. Challenge: Complexity

Solution:

- Access to nuclear astrophyics with different Points of View

DIDACTIC CHALLENGES & SOLUTIONS

1. Challenge: Complexity

2. Challenge: Accessability & Translatability

Solutions:

- Masterclass available in both online and live formats
- Previous knowledge in astrophysics and nuclear physics helpful but not mandatory
- Reducing the content to everything thats necessary, to understand the analysis and conclusion of the experiment

Didactic Challenges & Solutions

1. Challenge: Complexity

2. Challenge: Accessabiliy & Translatabiliy

3. Challenge: High level of abstraction

Solutions:

- Question-driven learning
- Research oriented: Building around one experiment and its results

Didactic Challenges & Solutions

1. Challenge: Complexity
2. Challenge: Accessabiliy & Translatabiliy
3. Challenge: High level of abstraction
4. **Challenge: Capturing the Bigger Picture**

Solutions:

- oriented at Nature-of Science-Aspects of nuclear astrophysics
- Gaining insight into working methods and the process of knowledge aquisition

General **Design Aspects** of the Masterclasses

General Design Aspects: Structure

Phase	Content	Method
Beginning & Motivation	Historical Insight	lecture
	Insight in modern Research	short video
Basics of nuclear physics	Nuclear Reactions	Group Puzzle
	Binding Energy + (In)stability	lecture
Basics of Stellar evolution	Building a Hertzsprung-Russell-Diagram	Group project
	Story of the evolution of a Star	„tale lecture“
Basics of stellar nucleosynthesis	Hydrogen & helium burning	lecture
Analysis & Evaluation of a nuclear physics experiment	Basics of Gamma spectroscopy	Partner work
	Data Analysis	
	Evaluation & Discussion	Plenum
Emergence of higher elements	Neutron sources and their meaning	lecture
	S- and R-Processes: Nuclei Domino	Game
Outlook	Cosmological & open Questions	Plenum

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General Design Aspects

Question driven Learning

- Every learning phase has the task, to **answer a question** and **create new questions**!

What is a Element?

Where are Elements coming from?

What's the connection between stars and chemical elements?

How can we create new Elements?

Why do we need neutron sources?

How can we create Elements beyond iron?

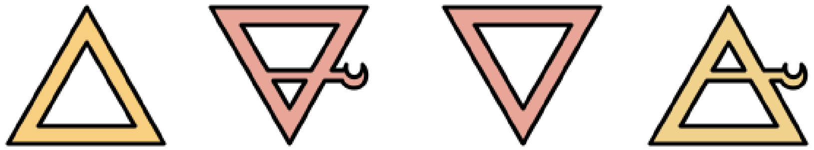
Insight into the **Content and Materials**

Insight in the Content & Materials

Beginning & Motivation

- Historical Insights:
  Reconstruction of the concept of chemical elements in history

1. Four Elements in the antiquity



Fire Earth Water Air

2. Alchemy as natural philosohy in the 2. century
   Transmutation as early (obsolete) precursor of nucleosynthesis
3. Developement of the periodic table
4. Measurement of modern element abundances

Insight in the Content & Materials

Beginning & Motivation

Insight in modern research:

- Taking a Look at the Felsenkeller laboratory in Dresden in a short video
- Basic idea: Making the participants curious

How can underground nuclear physics experiments help us to understand the development of stars and the emergence of elements?

Foto: André Wirsig / HZDR
https://www.hzdr.de/db/Cms?pOid=50674&pNid=614

Insight in the Content & Materials

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Insight in the Content & Materials

Building a Hertzsprung-Russell-Diagram

- Every participant gets the key datas of multiple stars and has to locate his stars into a shared diagram
- Creating a HRD together

Building a Hertzsprung-Russell-Diagram

Aldebaran

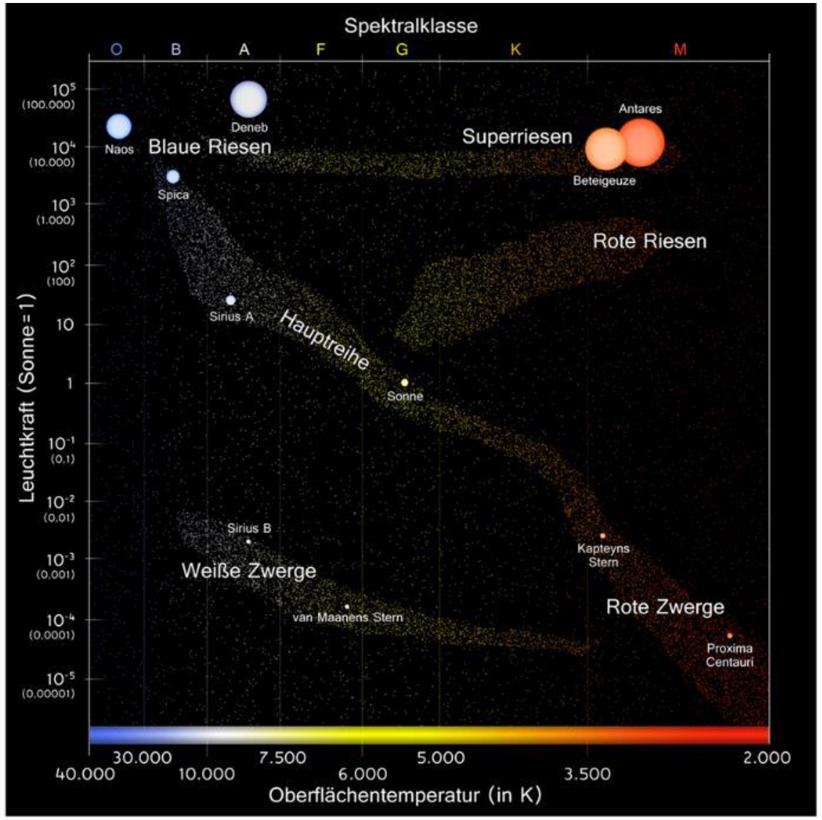
Eckdaten

Scheinbare Helligkeit	0,87 mag
Leuchtkraft	150 $L_\odot$
Effektive Temperatur	3850 K
Spektralklasse	K
Masse	1,16 $M_\odot$
Radius	44,2 $R_\odot$
Entfernung	66,6 Lj
Sternbild	Stier

Aldebaran hebt sich durch seine rote Farbe von den benachbarten Plejaden ab

Eigenschaften

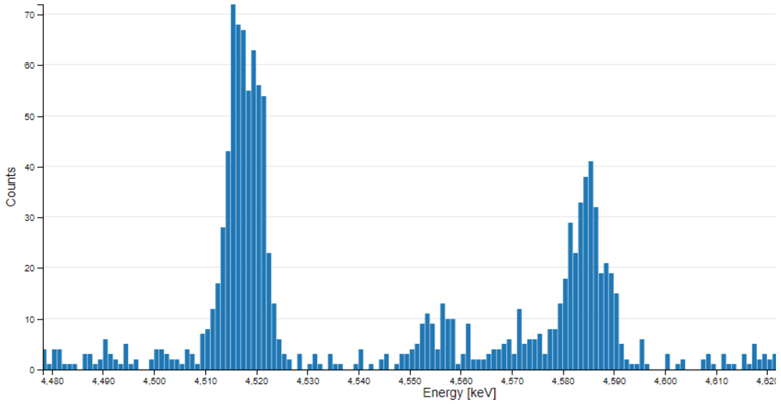
Aldebaran ist ein Doppelsternsystem im Sternenbild Stier. Der Name bedeutet *Der Folgende,* da Aldebaran von der Erde aus gesehen den Plejaden folgt. Es handelt sich um einen roten Riesen, dessen auffällig rote Farbe freiäugig am Nachthimmel gut erkennbar ist. Aldebaran hat ungefähr die Masse der Sonne, allerdings den 44-fachen Radius und die 150-fache Leuchtkraft.



Insight in the Content & Materials

Data-Analysis of a nuclear physics experiment

- Measurements of the ${}^{14}_{7}N(\alpha,\gamma){}^{18}_{9}F$ reaction
- Analysing the data in partner work
  Peak measurement, calculating the cross section and the reaction rate)
  - Driven by Small step work orders
- Understanding the importance of the reaction as possible neutron source



Insight in the Content & Materials

Teaching S- and R-Processes in a Board Game

- Table of Nuclides as a board
- Neutron captures & radioactive decays as possible steps in the board game
- Throwing of a dice determines the possible steps
- Goal:
  - Creating higher elements
  - Analyzing the influence of higher neutron fluxes
  - Highly stochastic process !

Insight in the Content & Materials

Entstehung schwerer Elemente

Nuklid-Domino

CHETEC INFRA

Protonenanzahl Z

	31n	32n	33n	34n	35n	36n	37n	38n
32p	Ge-63 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Ge-64 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Ge-65 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Ge-66 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Ge-67 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Ge-68 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Ge-69 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Ziel Ge-70 stabil
31p	Ga-62 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Ga-63 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Ga-64 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Ga-65 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Ga-66 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Ga-67 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Ga-68 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Ga-69 stabil
30p	Zn-61 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Zn-62 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Zn-63 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Zn-64 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Zn-65 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Zn-66 stabil	Zn-67 stabil	Zn-68 stabil
29p	Cu-60 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Cu-61 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Cu-62 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Cu-63 stabil	Cu-64 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Cu-65 stabil	Cu-66 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Cu-67 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$
28p	Ni-59 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Ni-60 stabil	Ni-61 stabil	Ni-62 stabil	Ni-63 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Ni-64 stabil	Ni-65 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Ni-66 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$
27p	Co-58 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Co-59 stabil	Co-60 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Co-61 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Co-62 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Co-63 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Co-64 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Co-65 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$
26p	Fe-57 stabil	Start Fe-58 stabil	Fe-59 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Fe-60 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Fe-61 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Fe-62 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Fe-63 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Fe-64 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$
25p	Mn-56 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Mn-57 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Mn-58 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Mn-59 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Mn-60 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Mn-61 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Mn-62 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$	Mn-63 $\lambda = 1{,}1 \cdot 10^{-7} \frac{1}{s}$

Neutronenanzahl N

Ziel des Spiels

Die Aufgabe besteht darin, mithilfe von Neutroneneinfang das Zielnuklid zu synthetisieren, es also mit deiner Spielfigur zu erreichen. Versuche dabei, in weniger Schritten als dein Gegenspieler ins Ziel zu kommen.

Spielregeln

Um die Nukleosynthese voranzutreiben, musst du versuchen, in der Nuklidkarte nach oben rechts zu klettern. Dabei hilft dir der Neutroneneinfang. Allerdings findet der Neutroneneinfang nur mit einer gewissen Wahrscheinlichkeit statt. Instabile Nuklide können auch zerfallen, bevor ein Neutroneneinfang erfolgt.

Wenn du am Zug bist:

1. Berechne das Verzweigungsverhältnis für das Nuklid, auf dem du gerade stehst (gibt an, wie wahrscheinlich ein Neutroneneinfang im Vergleich zum Kernzerfall ist).
2. Entnehme der Tabelle, welche Zahl du würfeln musst, damit ein Neutroneneinfang gelingt. Je höher das Verzweigungsverhältnis, desto höher ist deine Chance für einen Neutroneneinfang.
3. Wenn deine Würfelzahl hoch genug ist, kannst du die Neutroneneinfangbewegung auf dem Spielbrett vornehmen (n erhöht sich um 1) und weiterspielen. Du darfst also auf dem neuen Feld wieder bei Schritt 1 beginnen.
   Wenn deine Würfelzahl zu niedrig ist, zerfällt das Nuklid, auf dem du gerade stehst. Du musst also deine Spielfigur entsprechend der Regeln des Kernzerfalles bewegen (Beta-Minus, Beta-Plus oder doppelter Elektroneneinfang). Damit ist dein Zug beendet und dein Gegenspieler ist am Zug.

Verzweigungsverhältnis b	Benötigte Zahl
0,05 – 0,20	6
0,21 – 0,40	5 oder 6
041 – 0,60	4,5 oder 6
0,61 – 0,80	3,4,5 oder 6
0,81 – 0,95	2,3,4,5 oder 6
0,95 - 1	1,2,3,4,5 oder 6

Thank you for your attention.