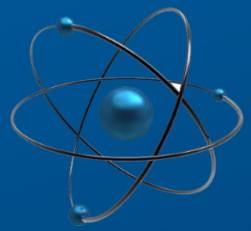
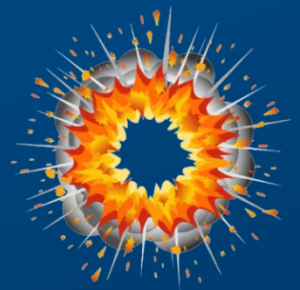
TECHNISCHE UNIVERSITÄT DRESDEN

NETZWERK TEILCHENWELT

DRESDEN concept





Forschung trifft Schule

Das Leben, das Universum & der ganze Rest

Eine Einführung in die nukleare Astrophysik

Steffen Turkat

27.09.2022

In Vorbereitung für das Seminar:
Bitte besuchen Sie Slido.com und geben Sie den Pin #7654 ein
→ Einfach so lassen, der Rest erscheint später automatisch!

INSTITUTE OF NUCLEAR AND PARTICLE PHYSICS

HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Konrad Adenauer Stiftung

Universum & Kosmologie

→ Was ist in den letzten 14 Mrd. Jahren im Universum passiert?

→ Wie sieht die Zukunft unseres Universums aus?

Nukleare Astrophysik

→ Auf der Suche nach dem Ursprung aller Elemente

Kurzer Einblick in eigene Forschung

→ Das Felsenkeller-Untertagelabor in Dresden

→ Virtuelle Tour durch die Stollenanlage

Kern- und Teilchenphysik

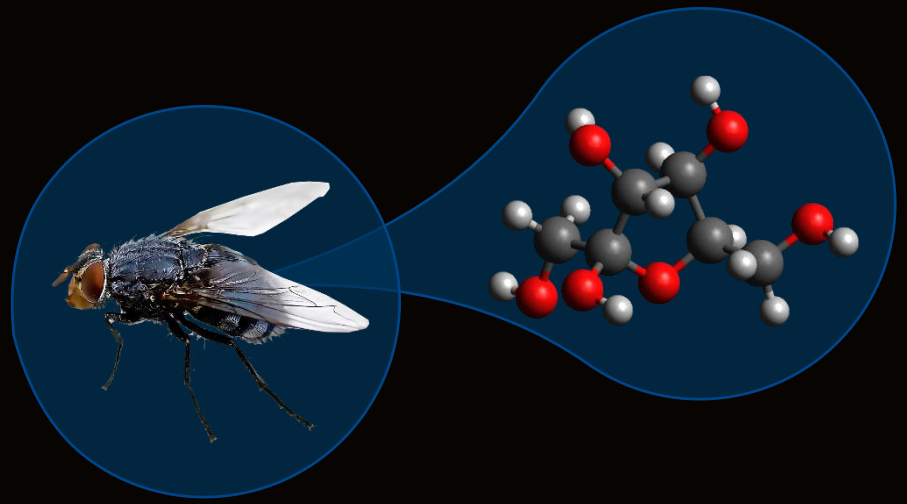
Was die Welt im Innersten zusammenhält

- **Größenskalen im Universum**

Biologie
~ 10^{-2} m

Was die Welt im Innersten zusammenhält

- **Größenskalen im Universum**

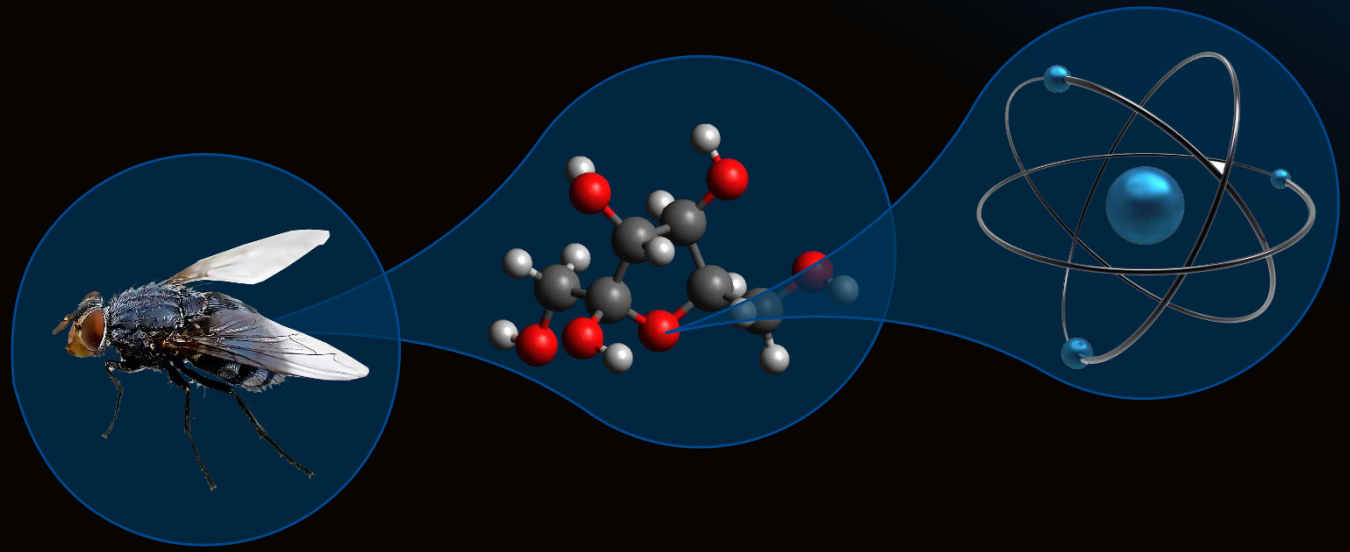


Biologie
~ 10^{-2} m

Chemie
~ 10^{-9} m

Was die Welt im Innersten zusammenhält

- **Größenskalen im Universum**



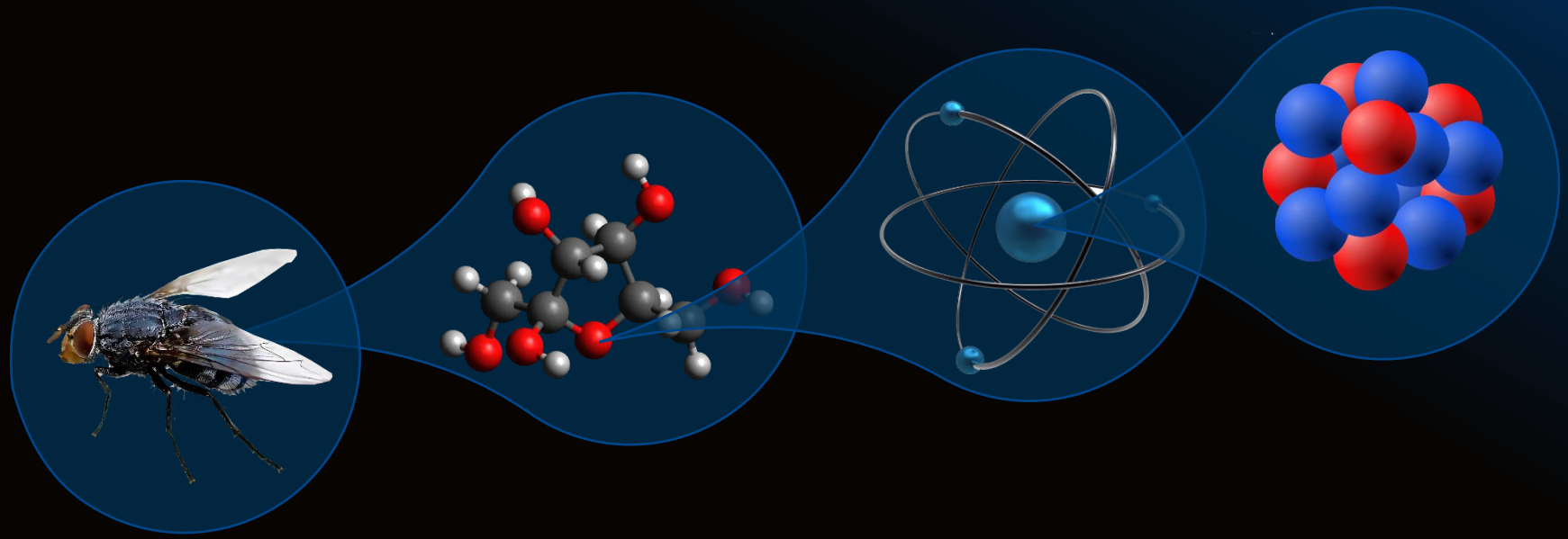
Biologie
~ 10^{-2} m

Chemie
~ 10^{-9} m

Atomphysik
~ 10^{-10} m

Was die Welt im Innersten zusammenhält

- **Größenskalen im Universum**



Biologie
~ 10^{-2} m

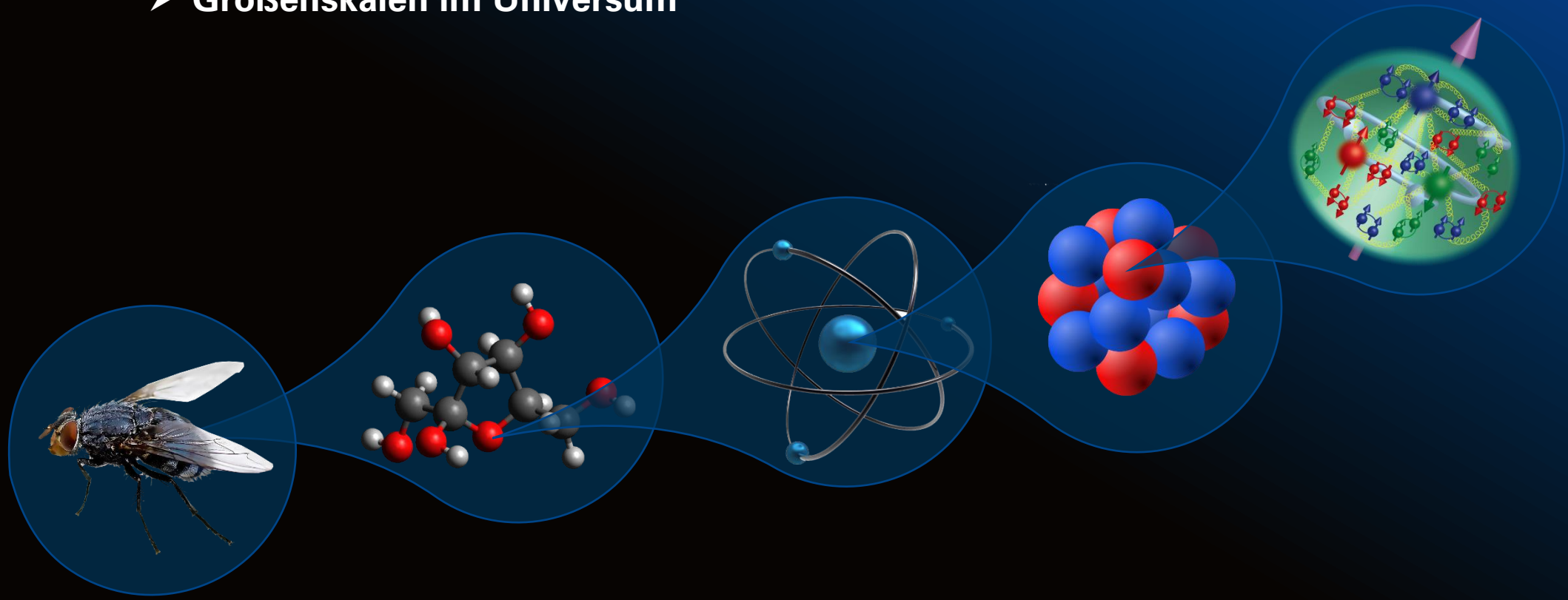
Chemie
~ 10^{-9} m

Atomphysik
~ 10^{-10} m

Kernphysik
~ 10^{-14} m

Was die Welt im Innersten zusammenhält

- **Größenskalen im Universum**



Biologie
~ 10^{-2} m

Chemie
~ 10^{-9} m

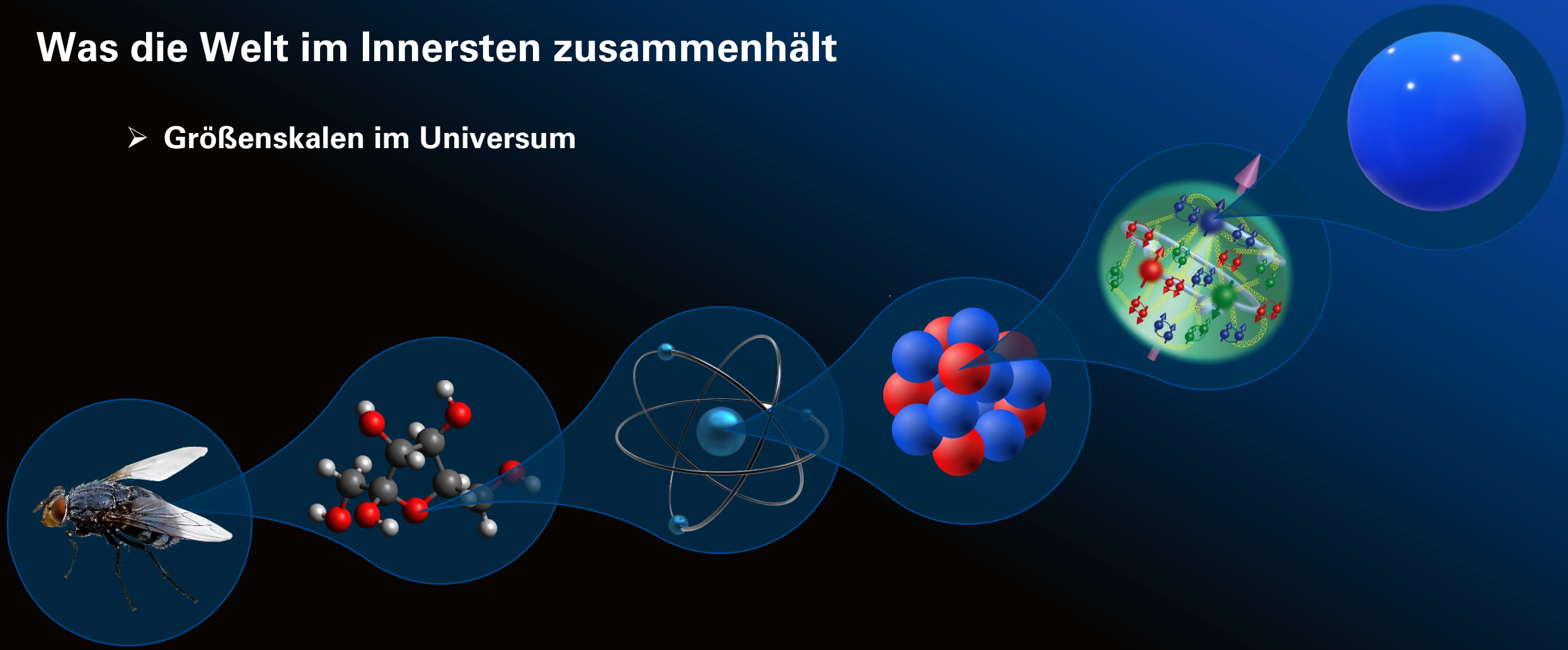
Atomphysik
~ 10^{-10} m

Kernphysik
~ 10^{-14} m

Teilchenphysik
~ 10^{-15} m

Was die Welt im Innersten zusammenhält

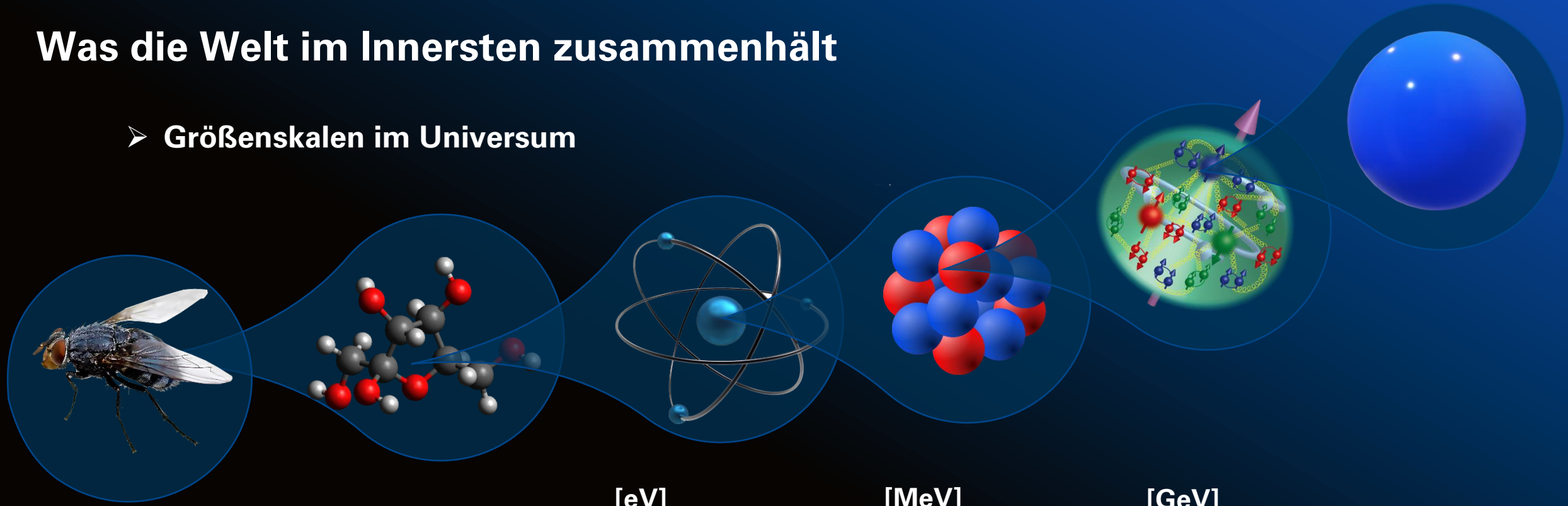
- **Größenskalen im Universum**



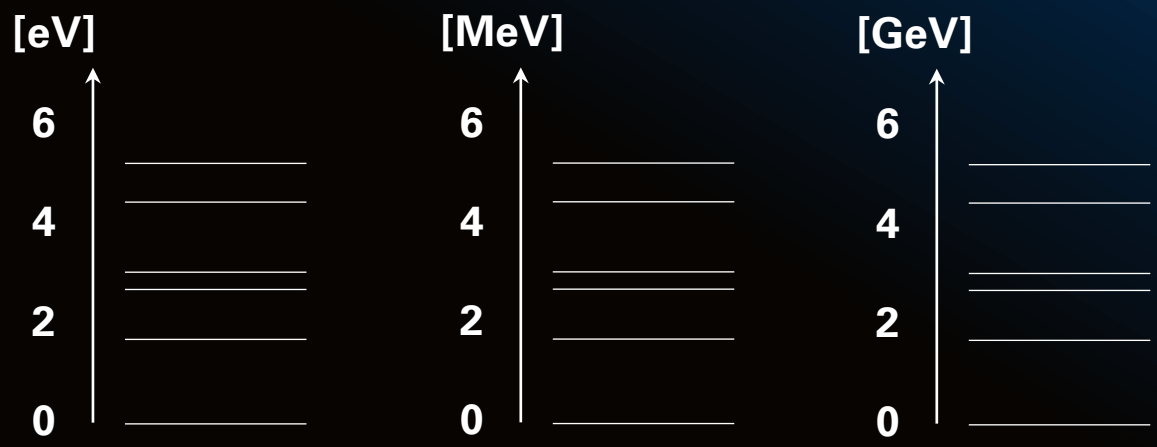
Biologie	Chemie	Atomphysik	Kernphysik	Teilchenphysik	→ ???
~ 10^{-2} m	~ 10^{-9} m	~ 10^{-10} m	~ 10^{-14} m	~ 10^{-15} m	< 10^{-18} m

Was die Welt im Innersten zusammenhält

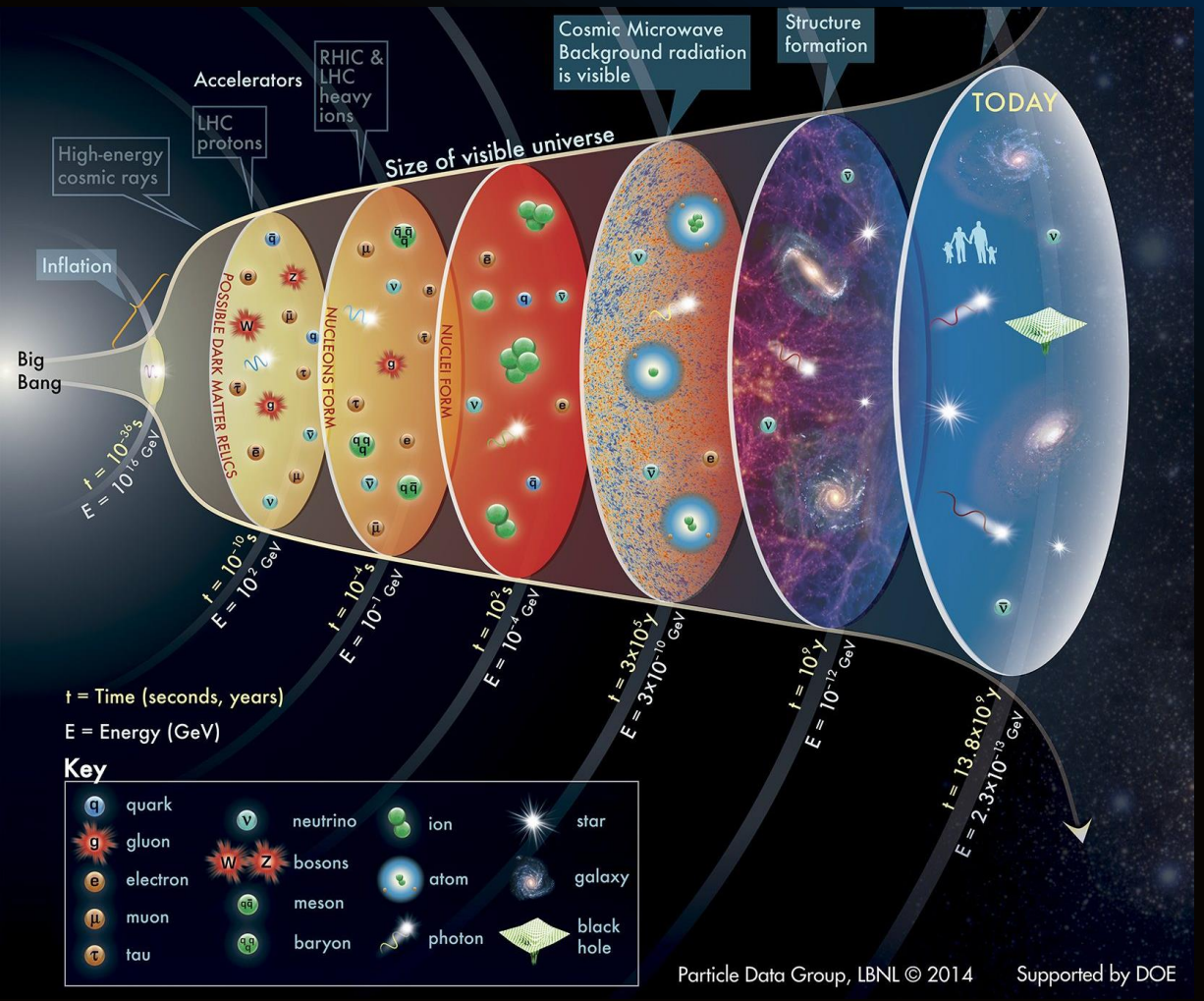
- Größenskalen im Universum



- Energieskalen im Universum

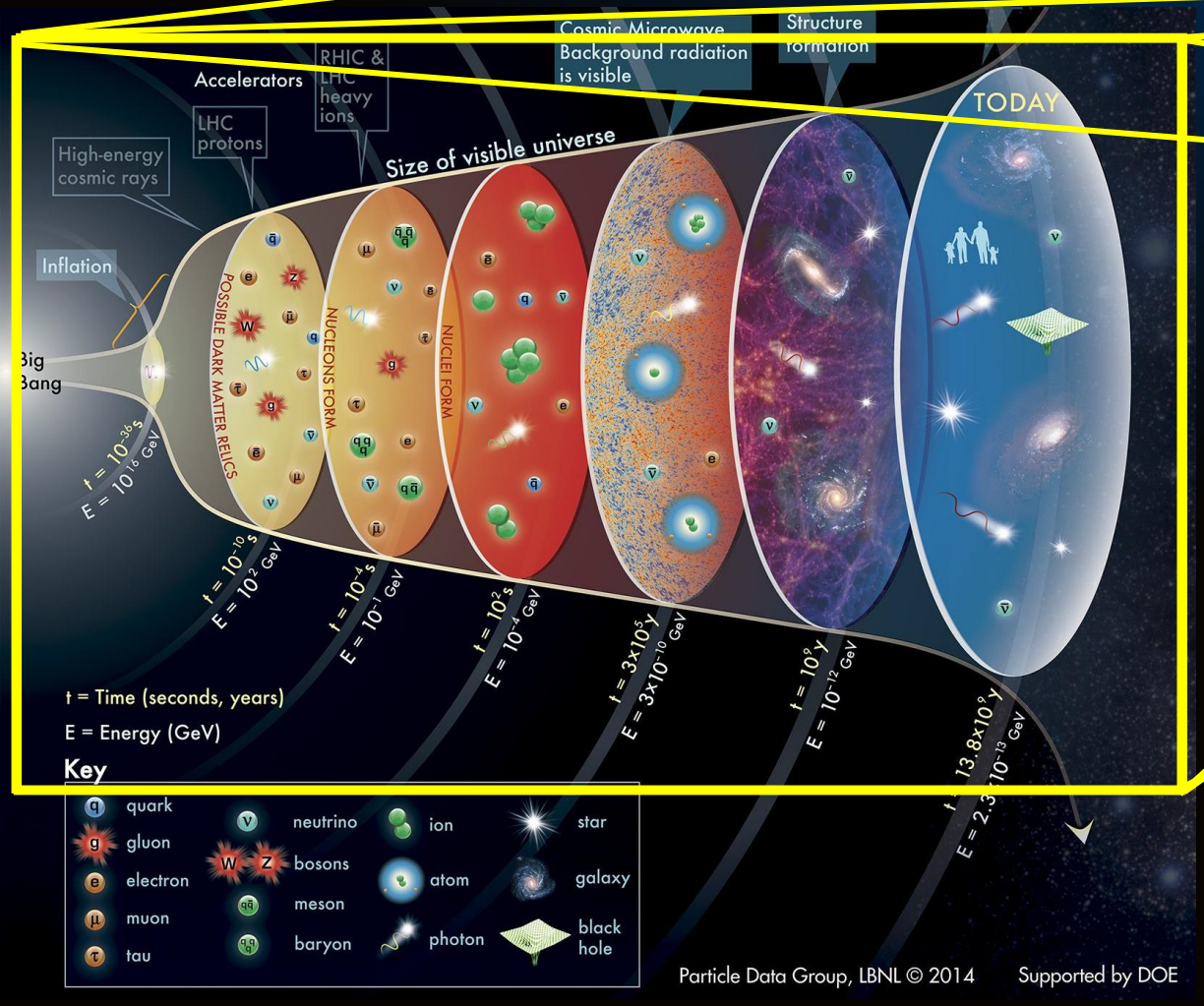


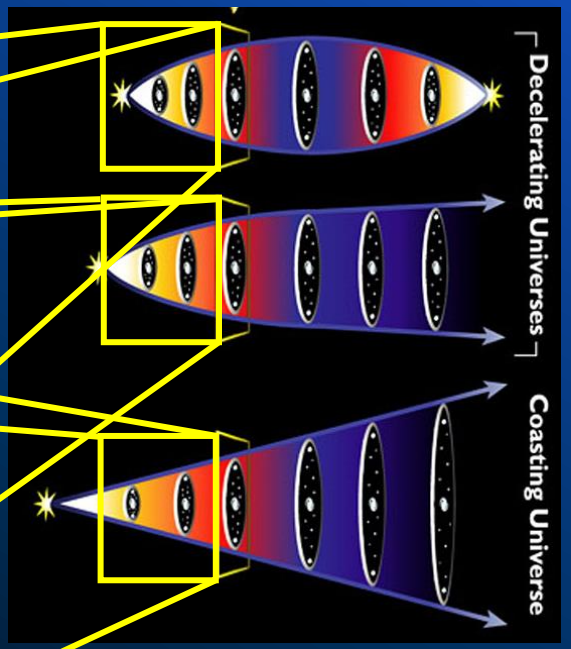
Was ist in den letzten 13.8 Milliarden Jahren so passiert?



- 0s — Big Bang
- 10^{-44} s — Planck-Zeit
- 10^{-32} s — Inflation
- 10^{-6} s — Bildungen von Proton & Neutron
- 10^{0} s — Urknall-Nukleosynthese
- 380000 y — Mikrowellen-Hintergrundstrahlung
- 10^{8} y — Erste Sterne
- $1.38 \cdot 10^{10}$ y — Heute

Was ist in den letzten 13.8 Milliarden Jahren so passiert?





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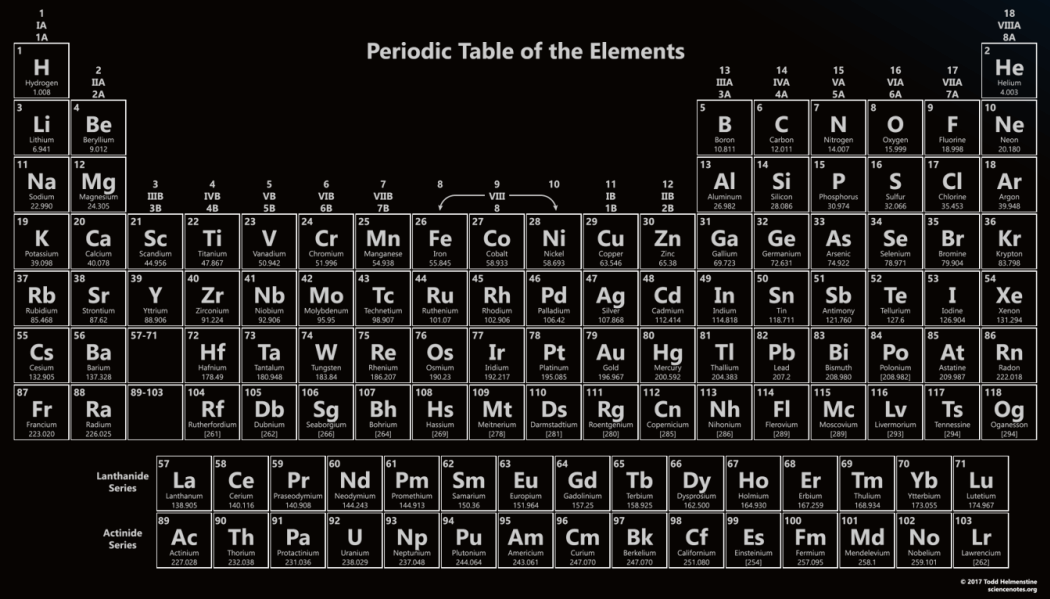
- 10^{8} y — Erste Sterne
- $1.38 \cdot 10^{10}$ y — Heute

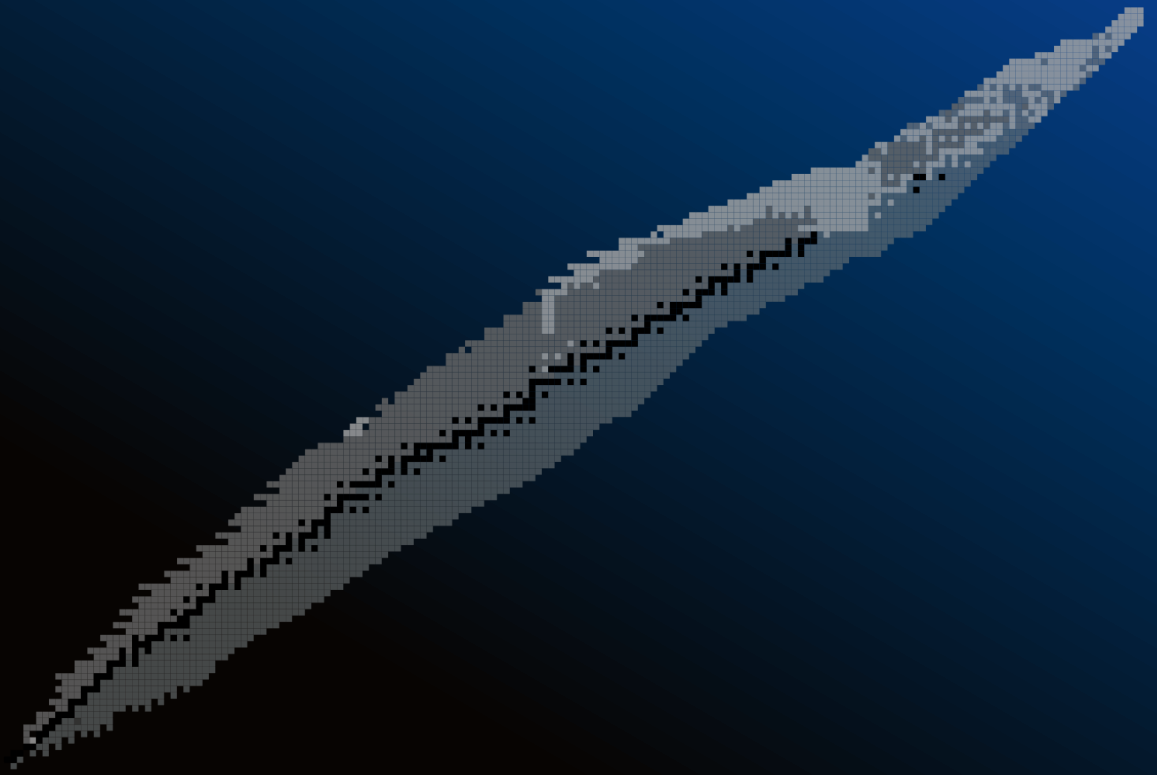
Nukleare Astrophysik

Chemische Zusammensetzung des Universums

- **Wie, wann und in welchen Mengen wurden die Elemente unseres Universums gebildet?**



https://sciencenotes.org/periodic-table-2017-edition-black-white/

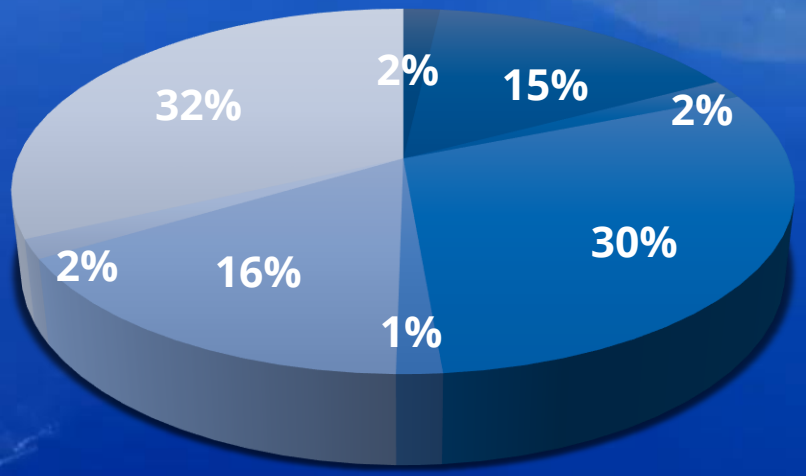


Chemische Zusammensetzung unserer Erde

Was sind die vier häufigsten Elemente unserer Erde?

→ Bitte besuchen Sie Slido.com & geben Sie den Pin **#7654** ein

→ Alles einfach so lassen, der Rest erscheint automatisch



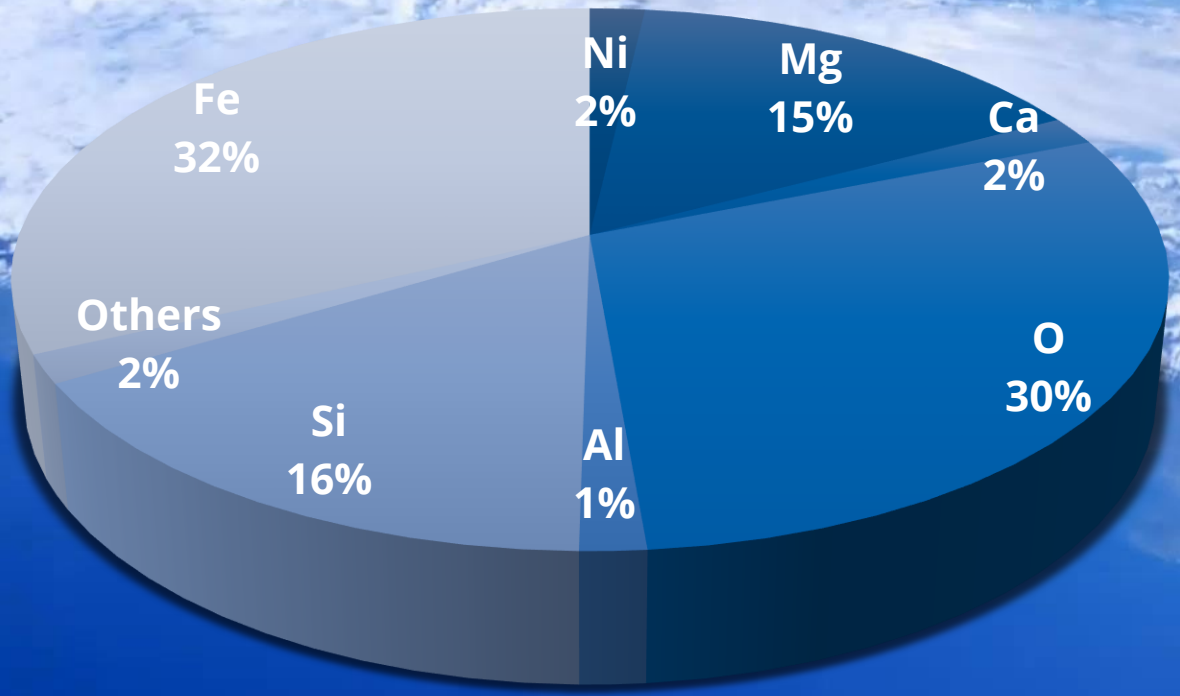
Source: NASA

slido

Was sind die vier häufigsten Elemente unserer Erde?

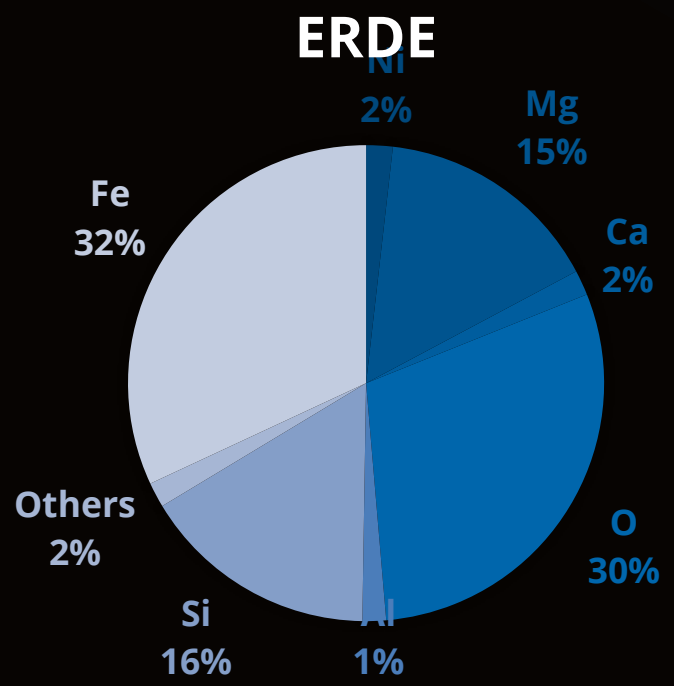
ⓘ Start presenting to display the poll results on this slide.

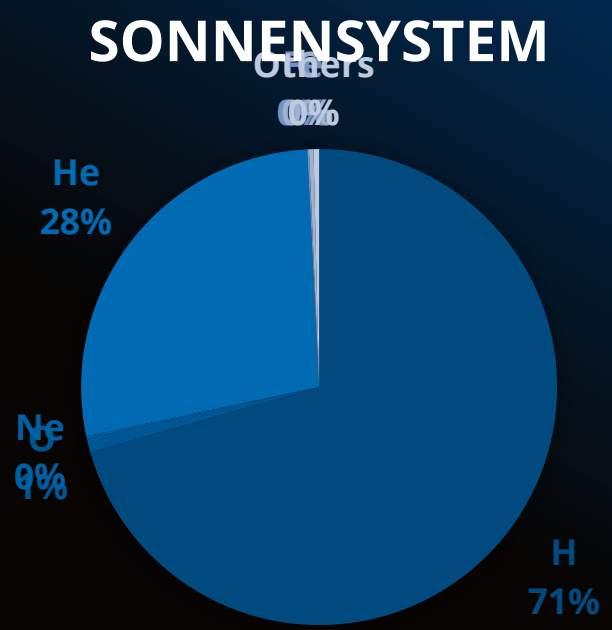
Chemische Zusammensetzung unserer Erde

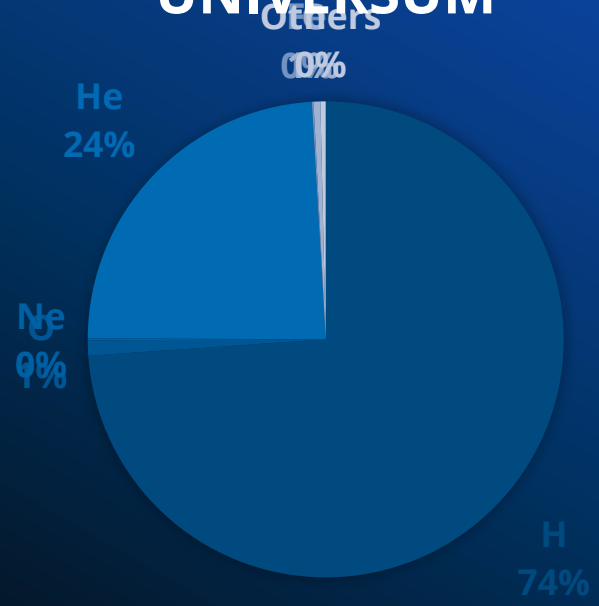


Source: NASA

Die Zusammensetzung unserer Erde



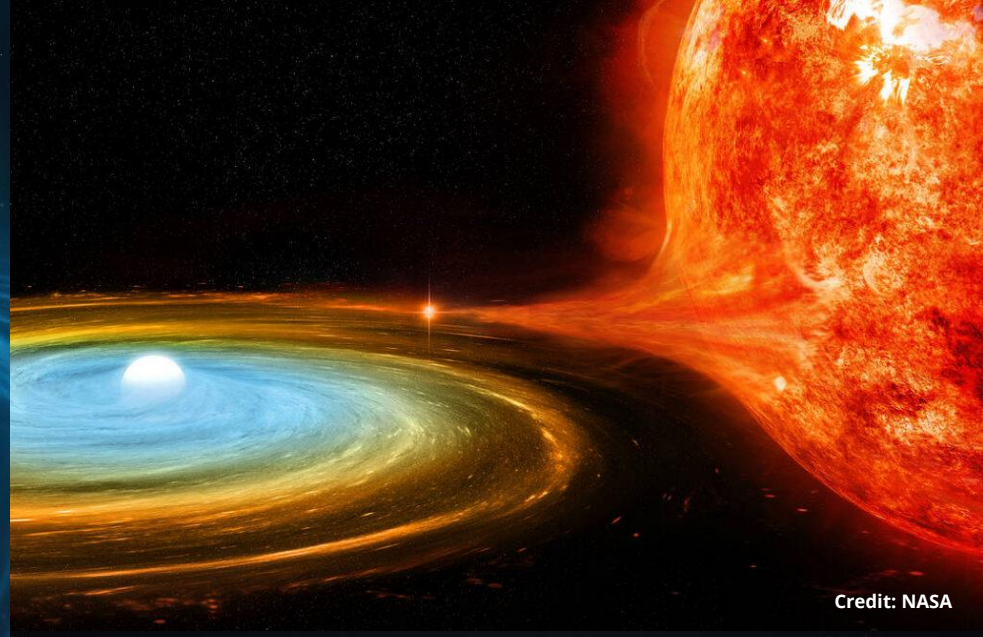




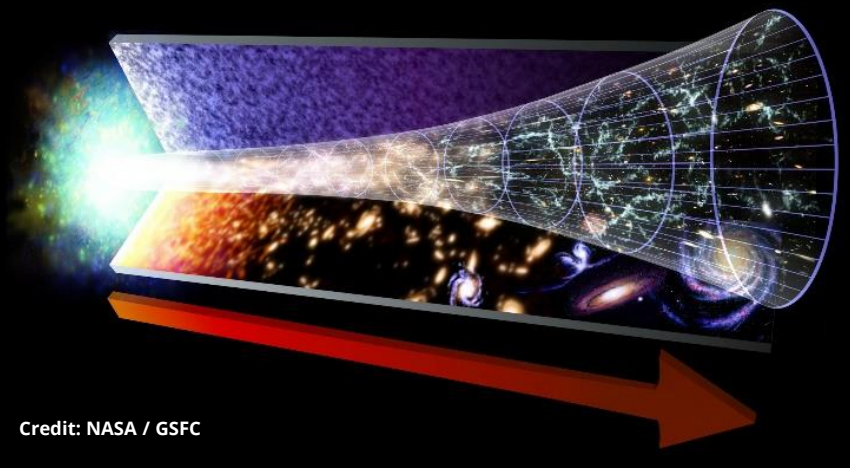
Die Geburtsstätten des Universums

Credit: NASA

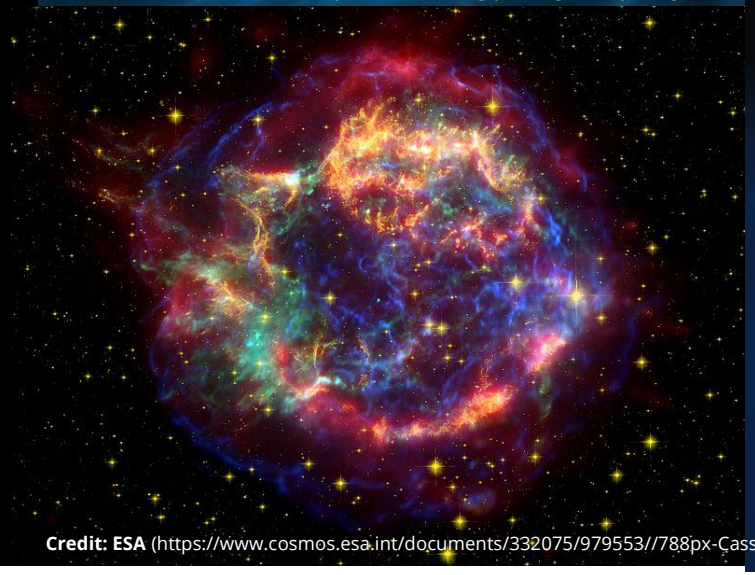
Credit: ESO/M.Kornmesser (https://www.eso.org/public/germany/images/eso1229a/)



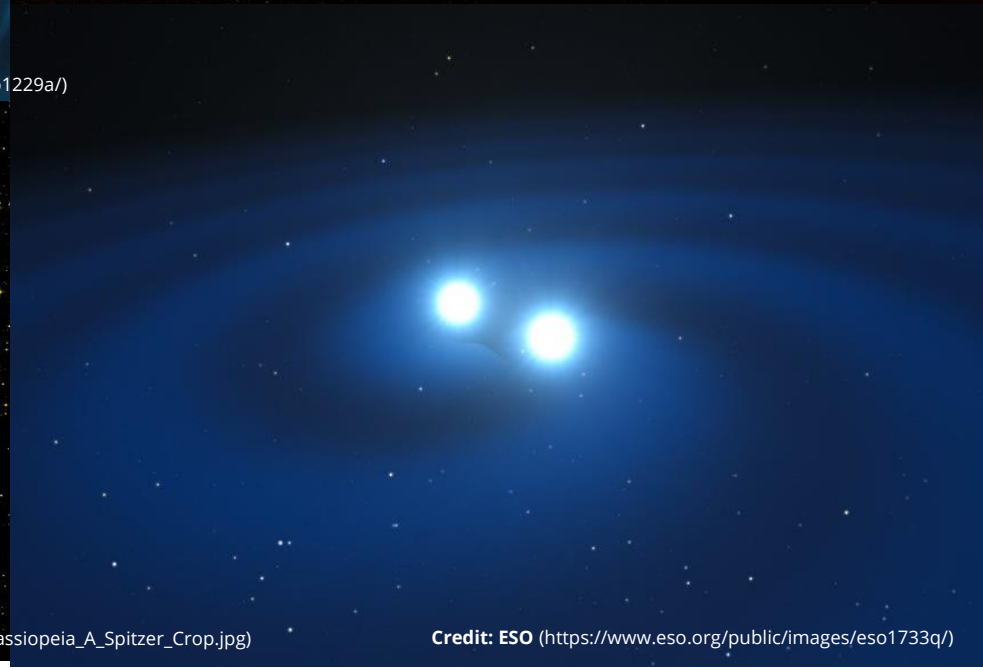
Credit: NASA



Credit: NASA / GSFC

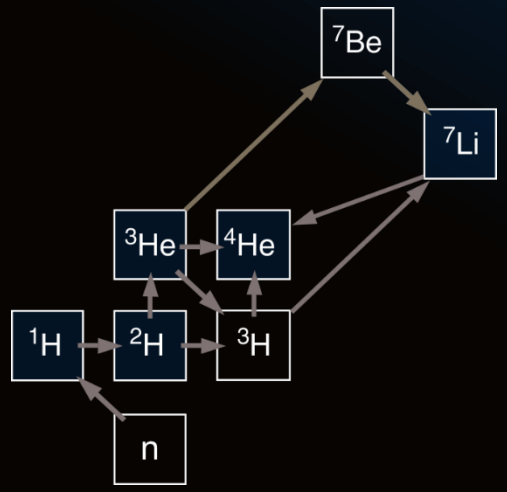


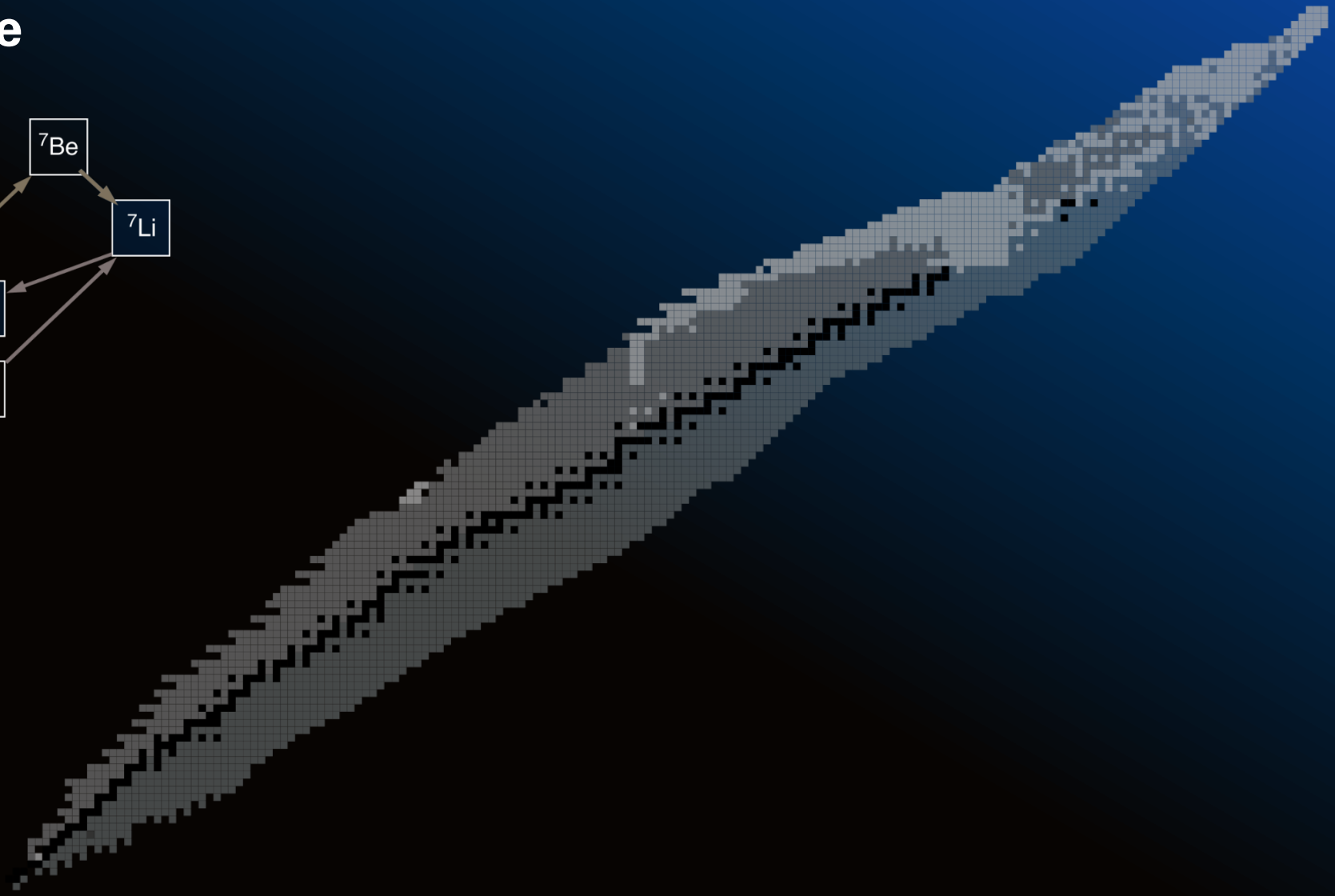
Credit: ESA (https://www.cosmos.esa.int/documents/332075/979553//788px-Cassiopeia_A_Spitzer_Crop.jpg)



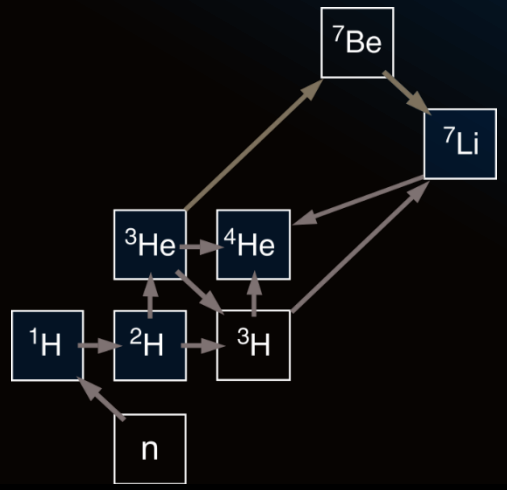
Credit: ESO (https://www.eso.org/public/images/eso1733q/)

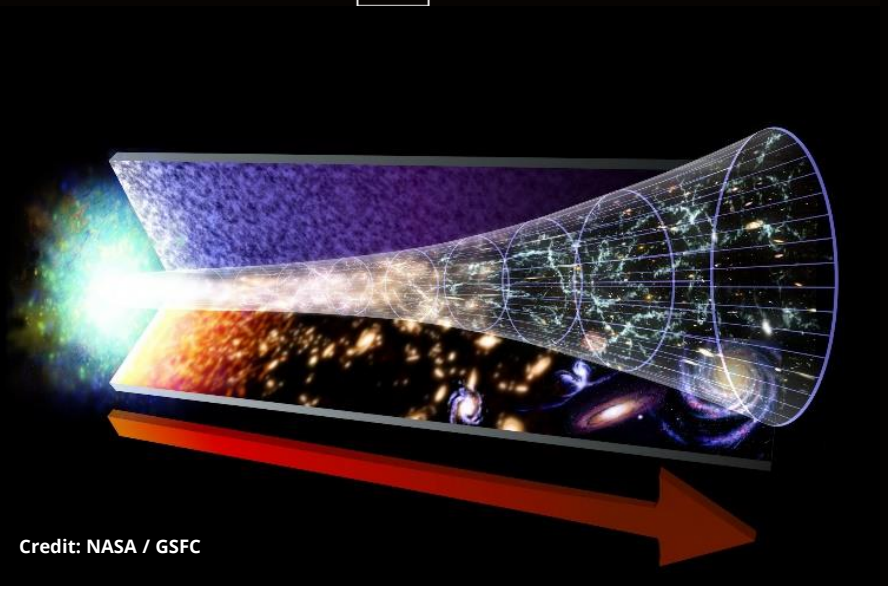
Die Nuklidkarte

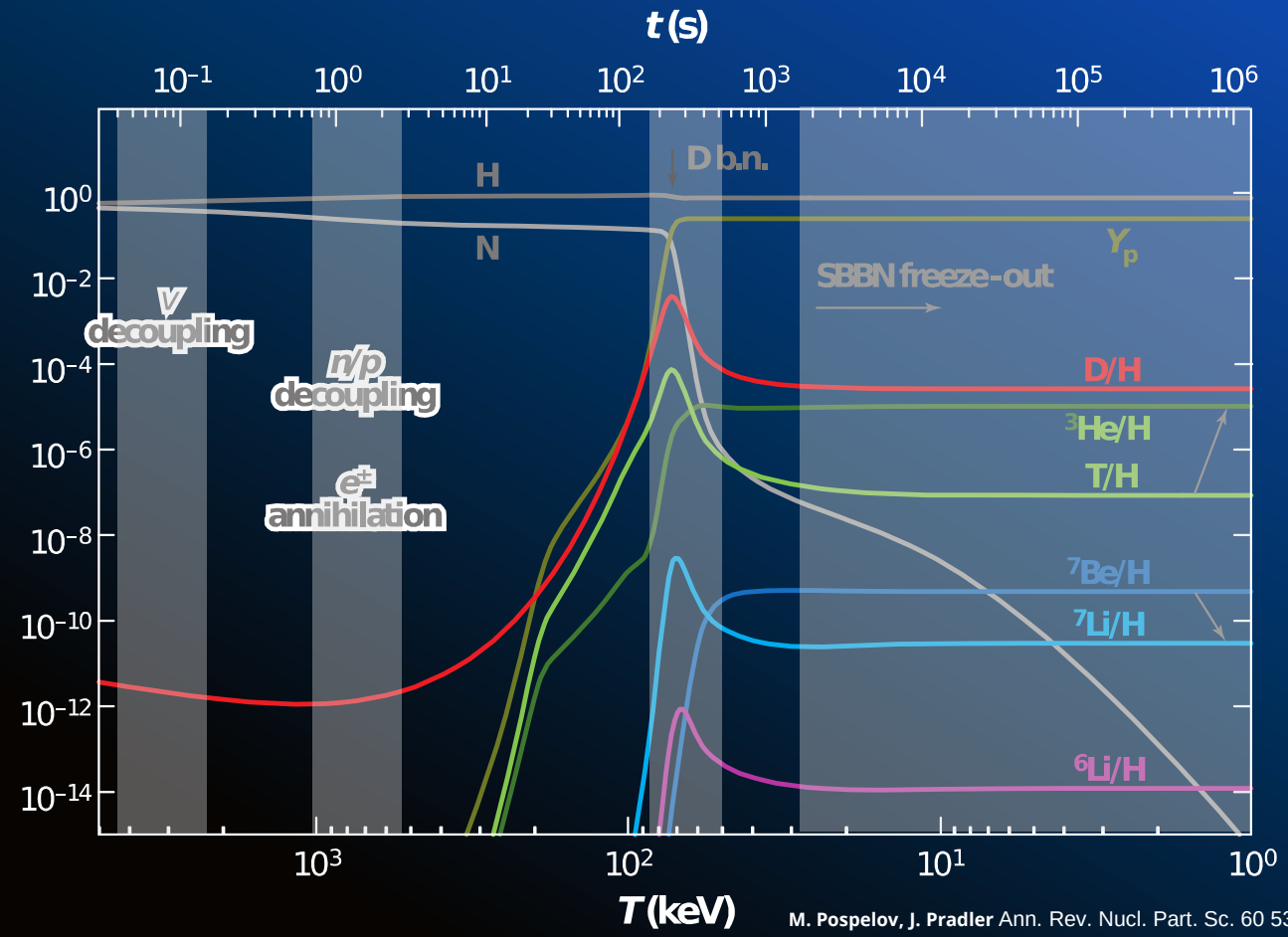




Die Urknall-Nukleosynthese



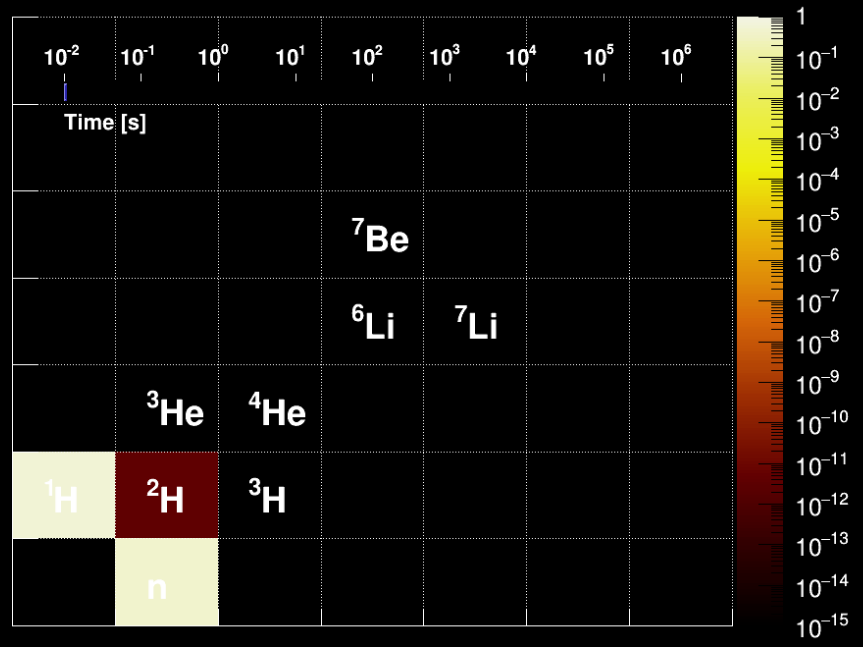

Credit: NASA / GSFC

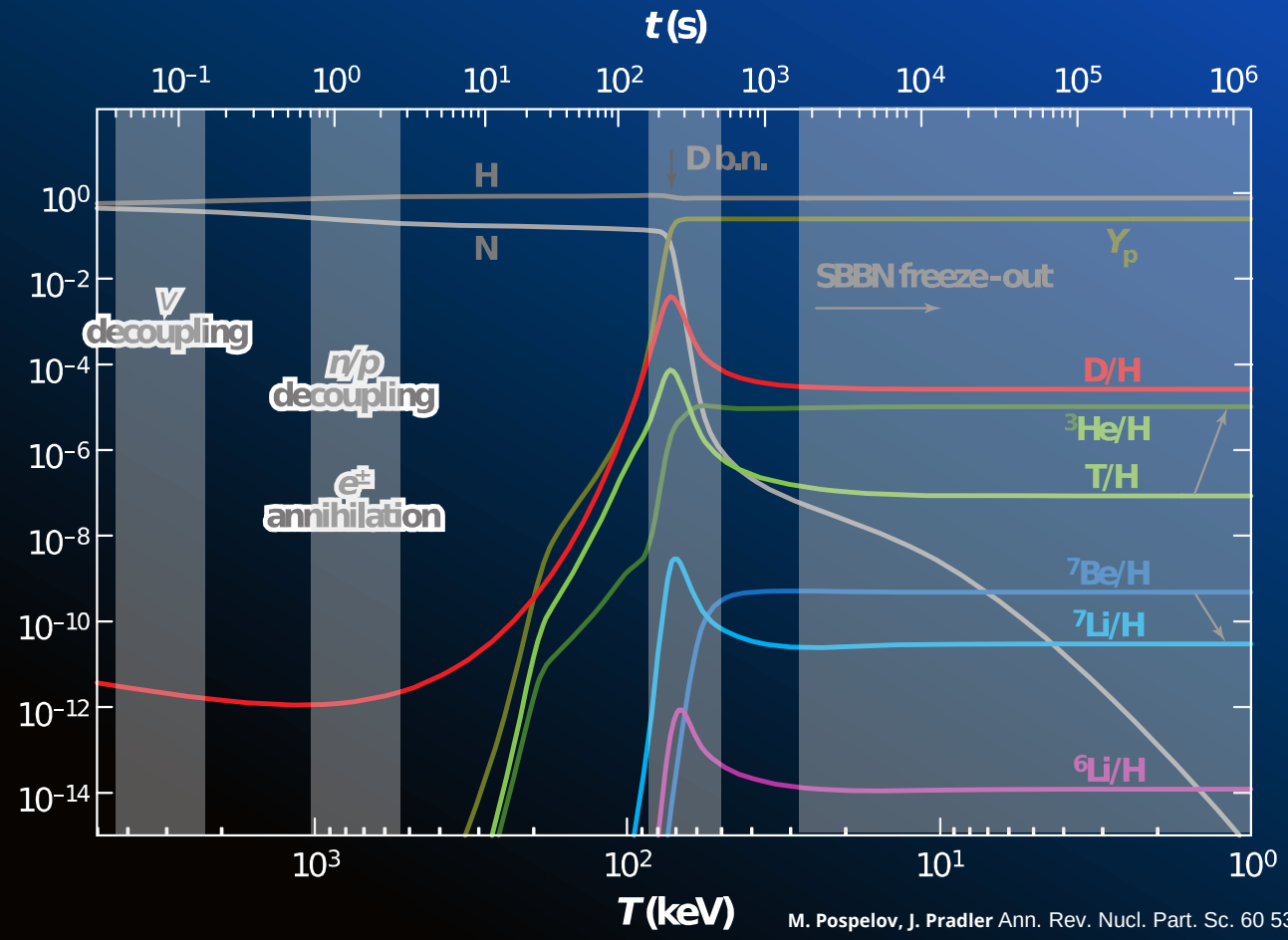


M. Pospelov, J. Pradler Ann. Rev. Nucl. Part. Sc. 60 539 (2010)

- **Chromodynamische Bindungsenergie p/n:** ~1 GeV
- **^{2}H Flaschenhals:** Das ganze Universums musste auf Deuterium warten

Die Urknall-Nukleosynthese





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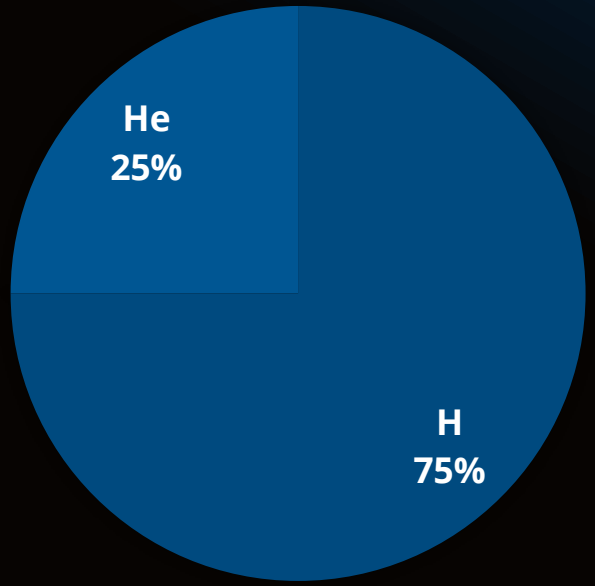
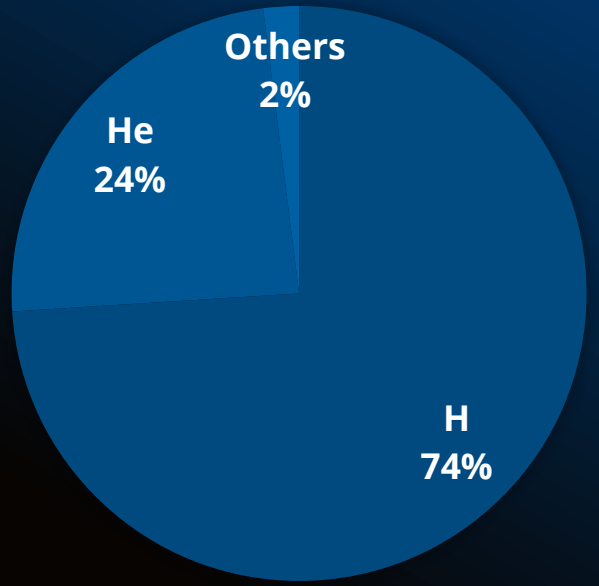
- **^{2}H Flaschenhals:** Das ganze Universums musste auf Deuterium warten

Der Ursprung der Elemente

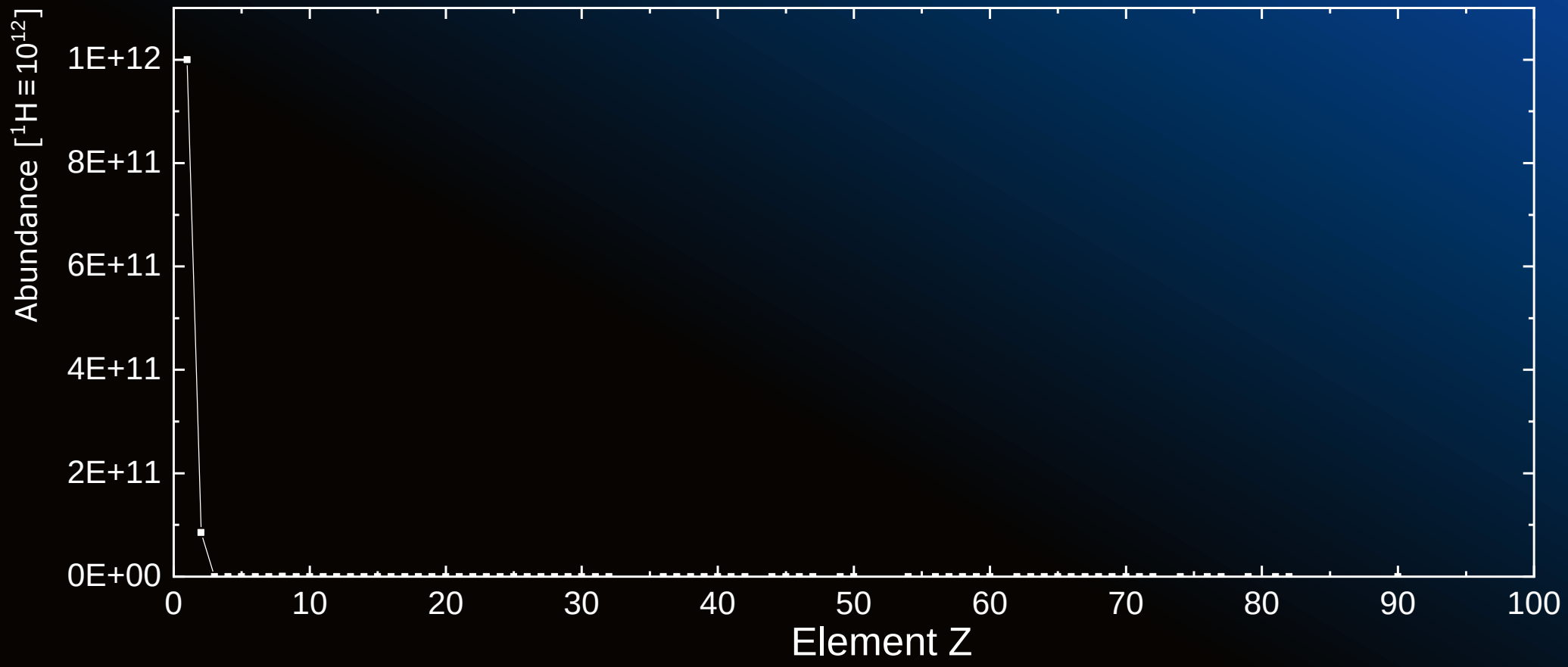
URKNALL-NUKLEOSYNTHESE



DERZEITIGES UNIVERSUM

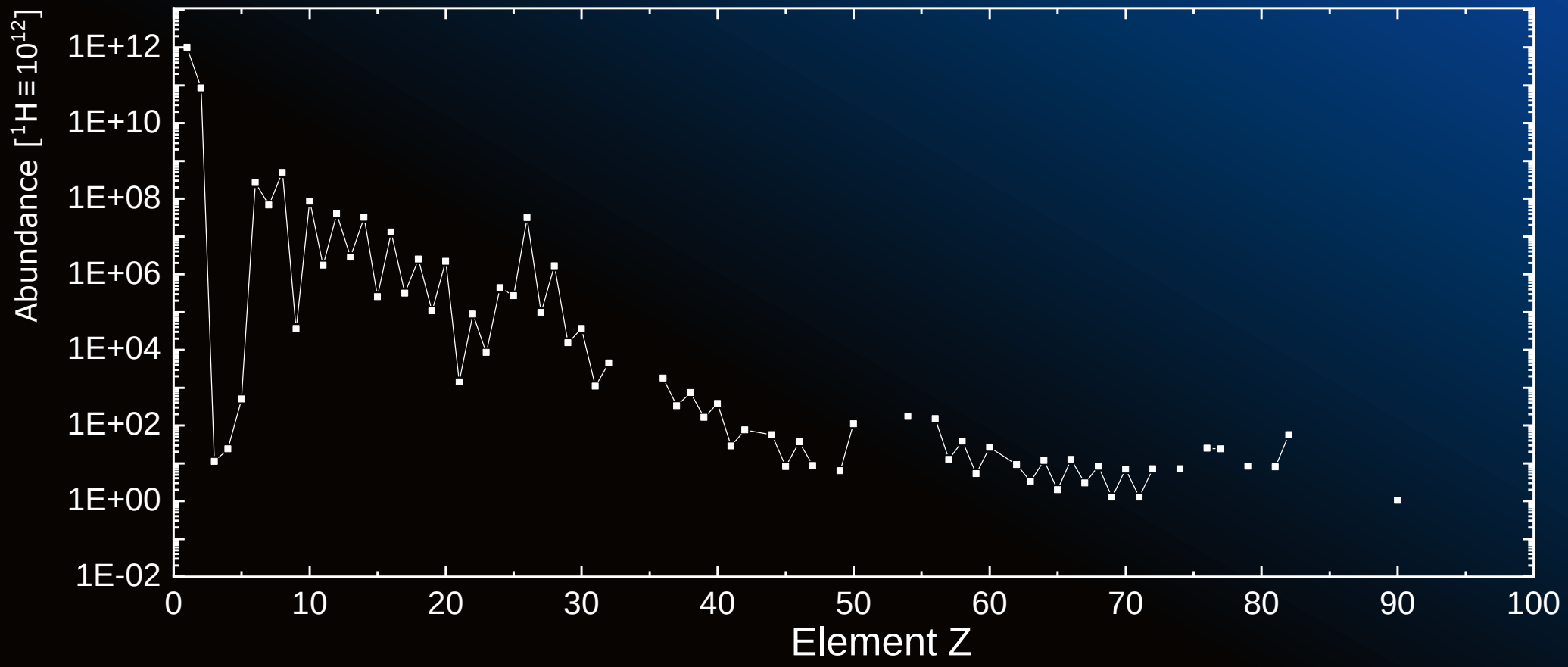


Chemische Zusammensetzung der solaren Photosphäre



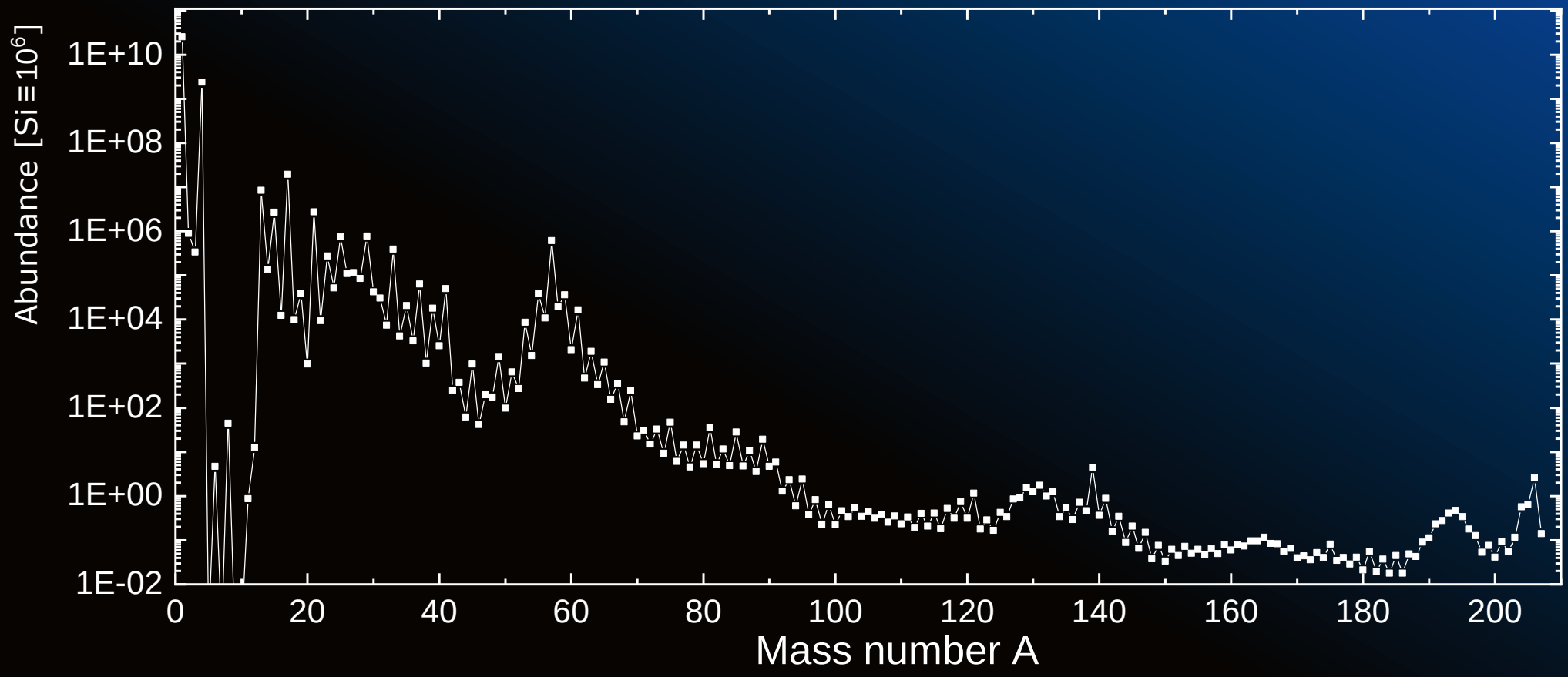
Data from: M. Asplund *et al.* Annual Reviews of Astronomy and Astropysics, Vol. 47, 481 (2009)

Elemental abundance of the solar photosphere



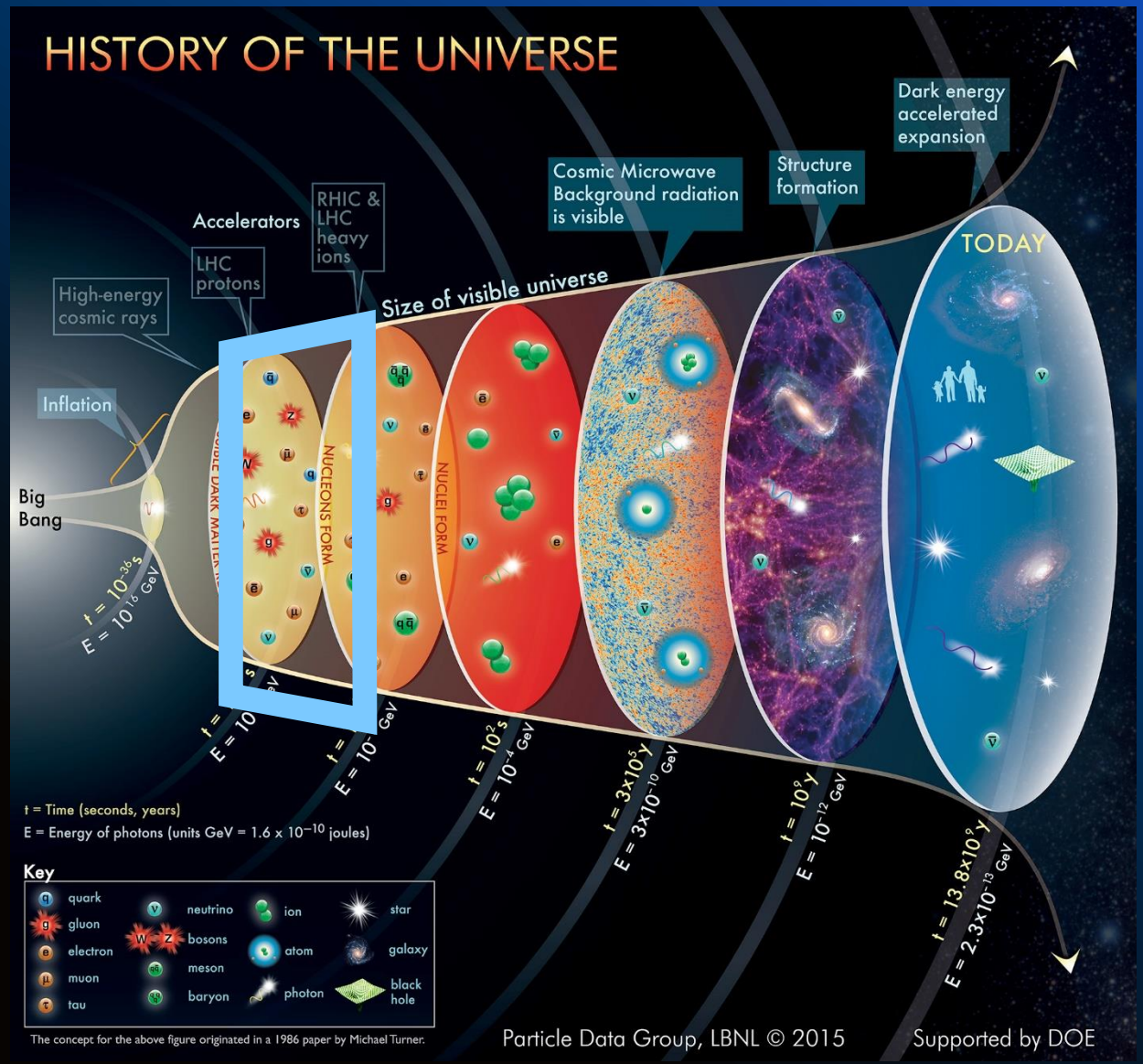
Data from: M. Asplund *et al.* Annual Reviews of Astronomy and Astropysics, Vol. 47, 481 (2009)

Chemische Zusammensetzung der solaren Photosphäre



Data from: E. Anders & N. Grevesse, Geochimica et Cosmochimica Acta, Vol. 53, 197 (1989)

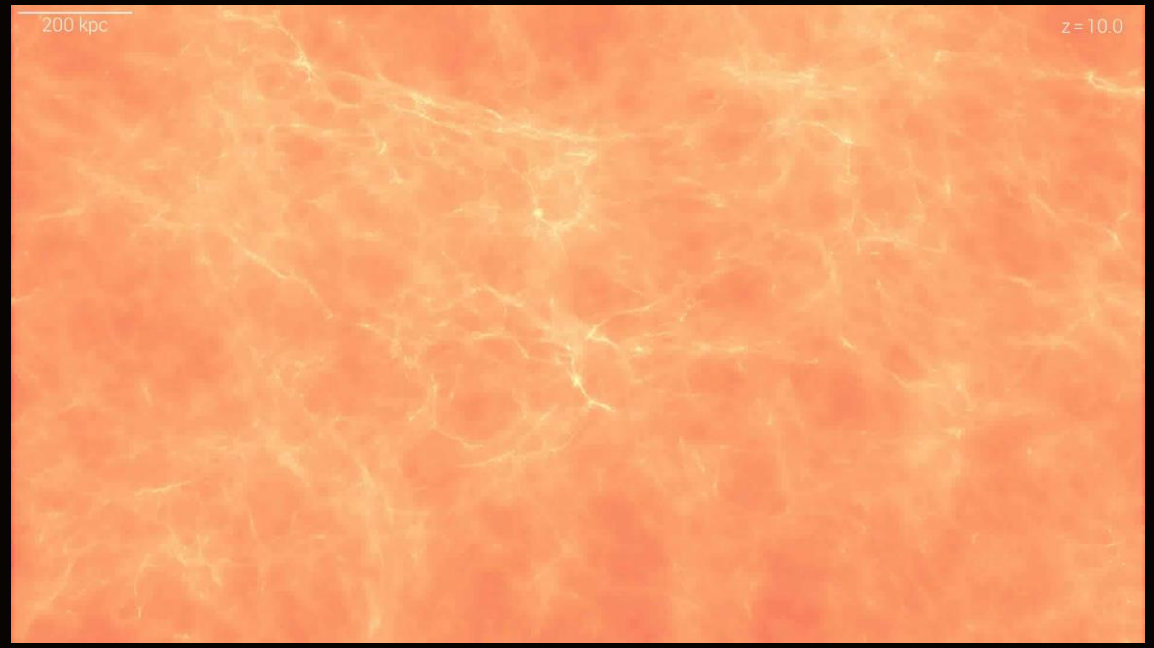
Während der letzten 13.6Mrd Jahre…



https://particleadventure.org/images/history-of-the-universe-2015.jpg

Widerherstellung von Nukleosynthese-Mileus

→ **Große Simulation ~ $\mathcal{O}$(Mpc)**
→ **Simulation von Galaxie-Superclustern**



→ **Kleinskalige Simulation ~ $\mathcal{O}$(kpc)**
→ **Simulation einer einzelnen Galaxie**

https://en.wikipedia.org/wiki/Osmium

→ **Osmium**
→ Dichte: **~ 22 g/cm³**
→ Dichtestes Material der Erde

Credit: The TNG Project (https://www.tng-project.org/media/)

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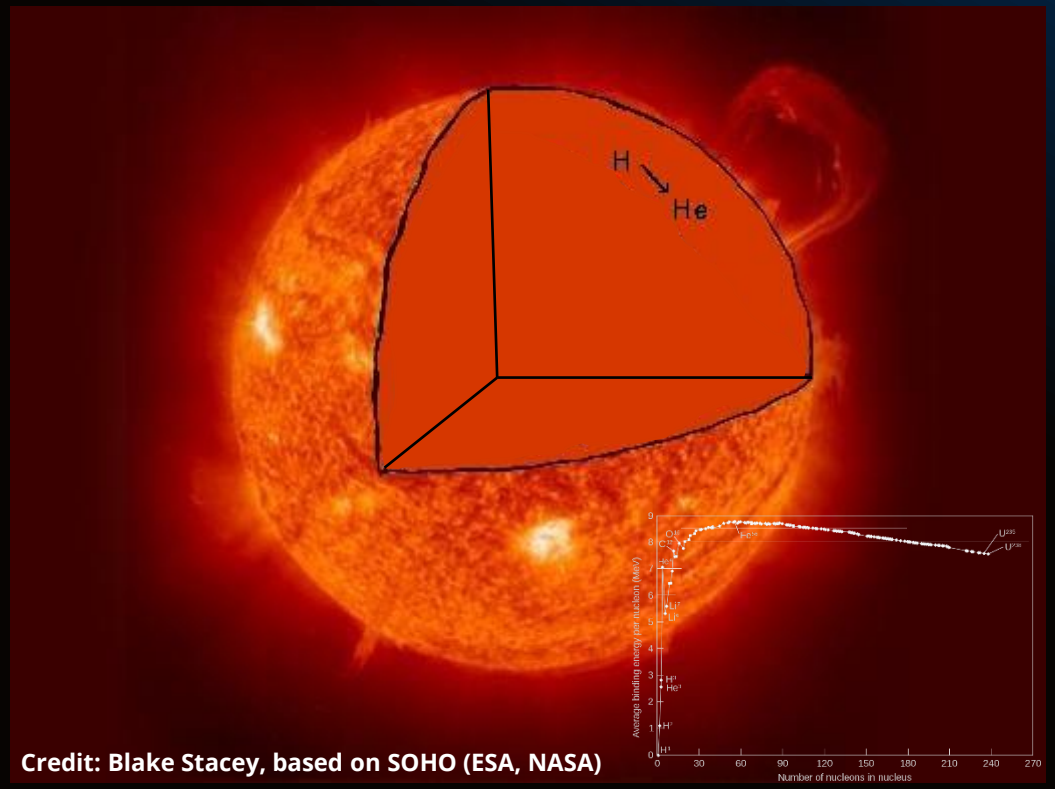
Wieviel dichter als Osmium muss das Zentrum eines Protostern sein, um wieder Kernfusion betreiben zu können?

ⓘ Start presenting to display the poll results on this slide.

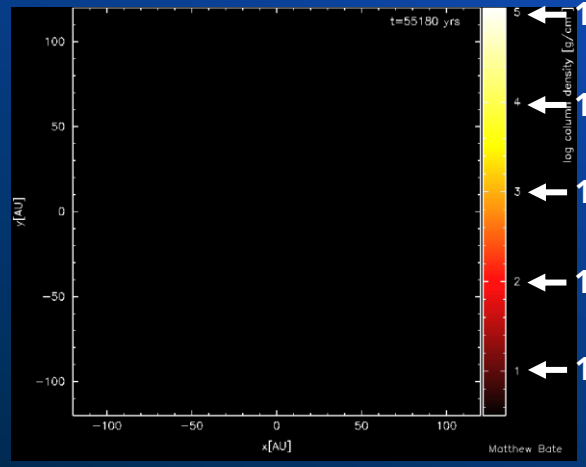
Protostern-Formation + Stellare Nukleosynthese



Credit: Blake Stacey, based on SOHO (ESA, NASA)

https://en.wikipedia.org/wiki/Nuclear_binding_energy

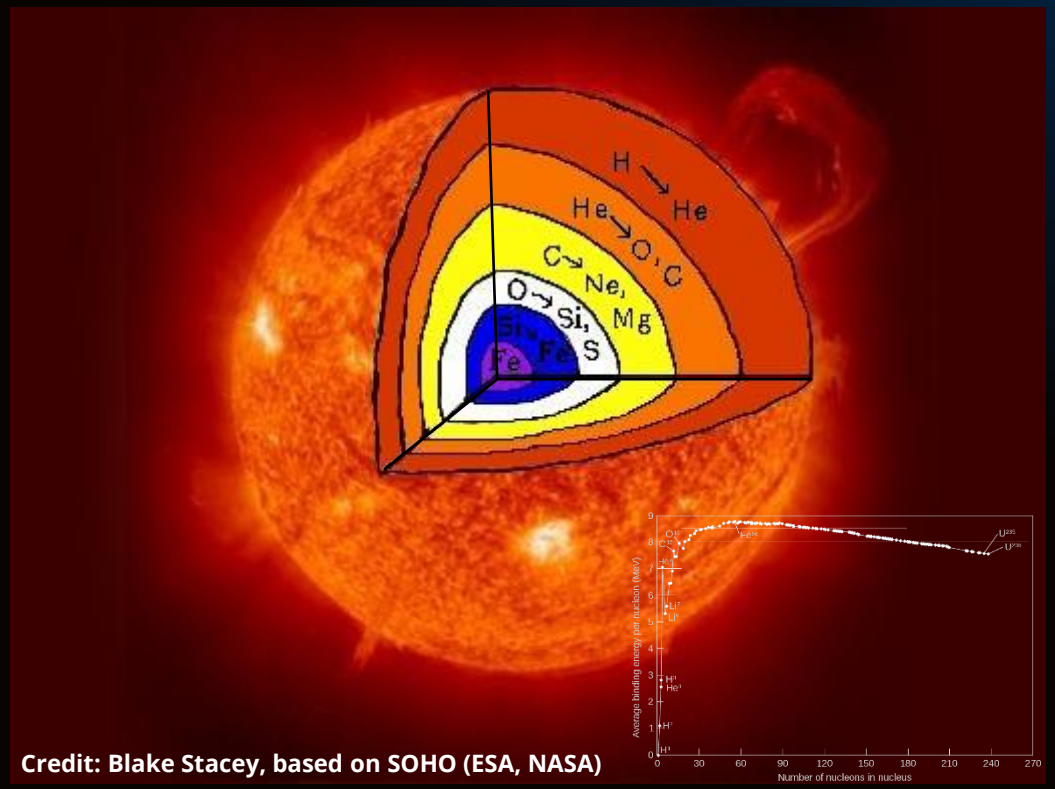
	T_{min} [K]	ρ_{min} [g/cm³]
H ➔ He	13 E+6	100 E+0
He ➔ C,O	100 E+6	100 E+3
C ➔ O, Ne, Mg, Na	500 E+6	200 E+3
Ne ➔ O, Mg	1.2 E+9	4 E+6
O ➔ Mg, Si, S, P	1.5 E+9	10 E+6
Si ➔ Ti, Fe, Ni …	~ 3.0 E+9	30 E+6



https://www.astro.ex.ac.uk/people/mbate/Animations/Beta0_01_RT_1M_DensSplash.mov

Courtesy: Matthew Bate (University of Exeter)

Stellare Nukleosynthese

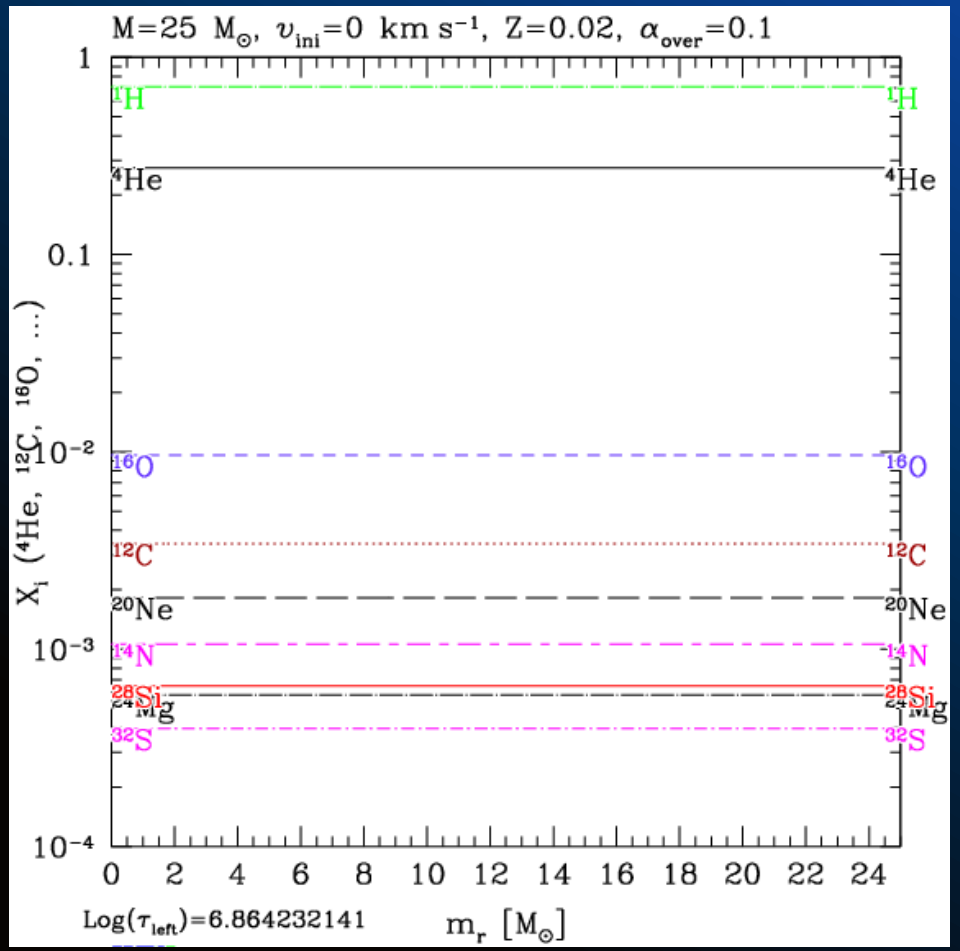


Credit: Blake Stacey, based on SOHO (ESA, NASA)

https://en.wikipedia.org/wiki/Nuclear_binding_energy

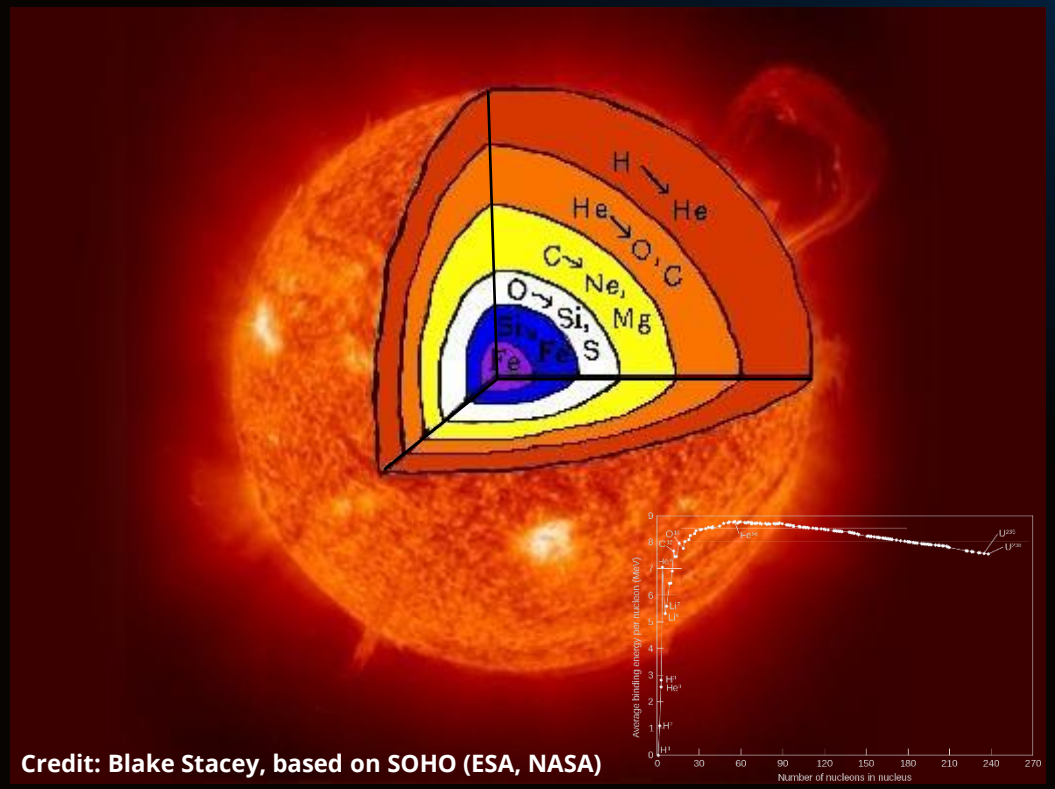
Zentrum

Oberfläche



https://www.astro.keele.ac.uk/~hirschi/animation/anim.html

Stellare Nukleosynthese

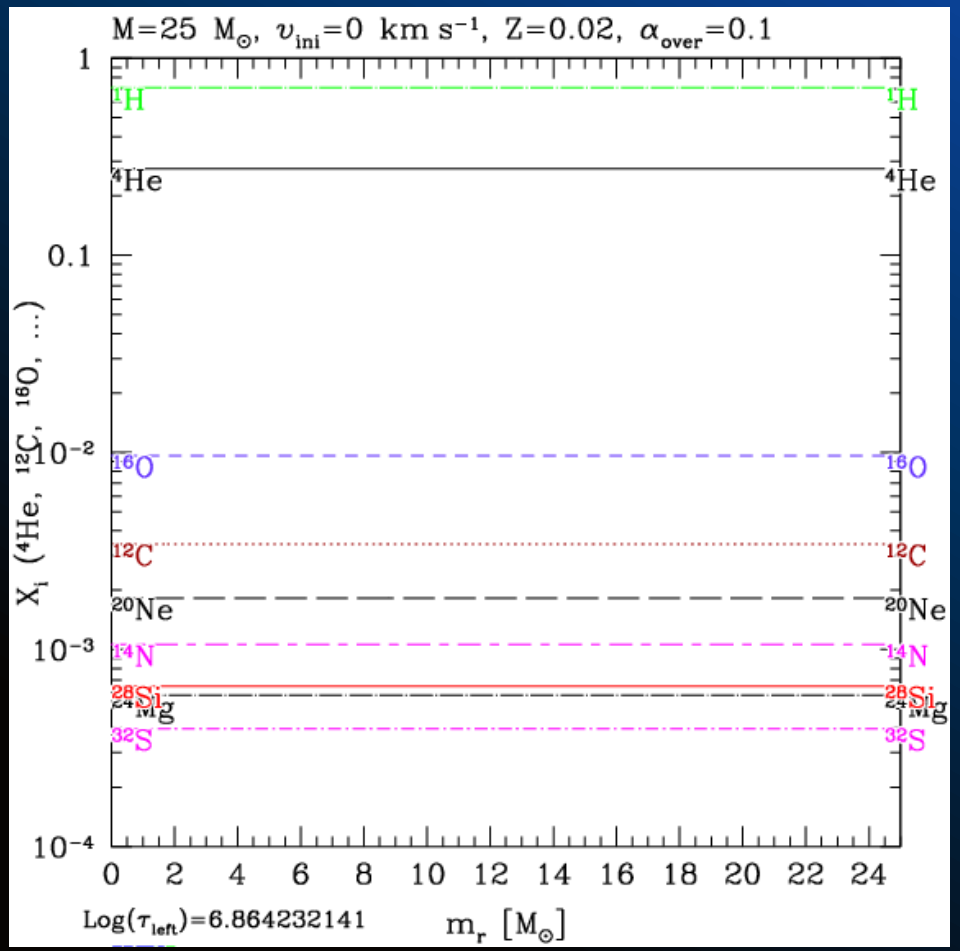


Credit: Blake Stacey, based on SOHO (ESA, NASA)

https://en.wikipedia.org/wiki/Nuclear_binding_energy

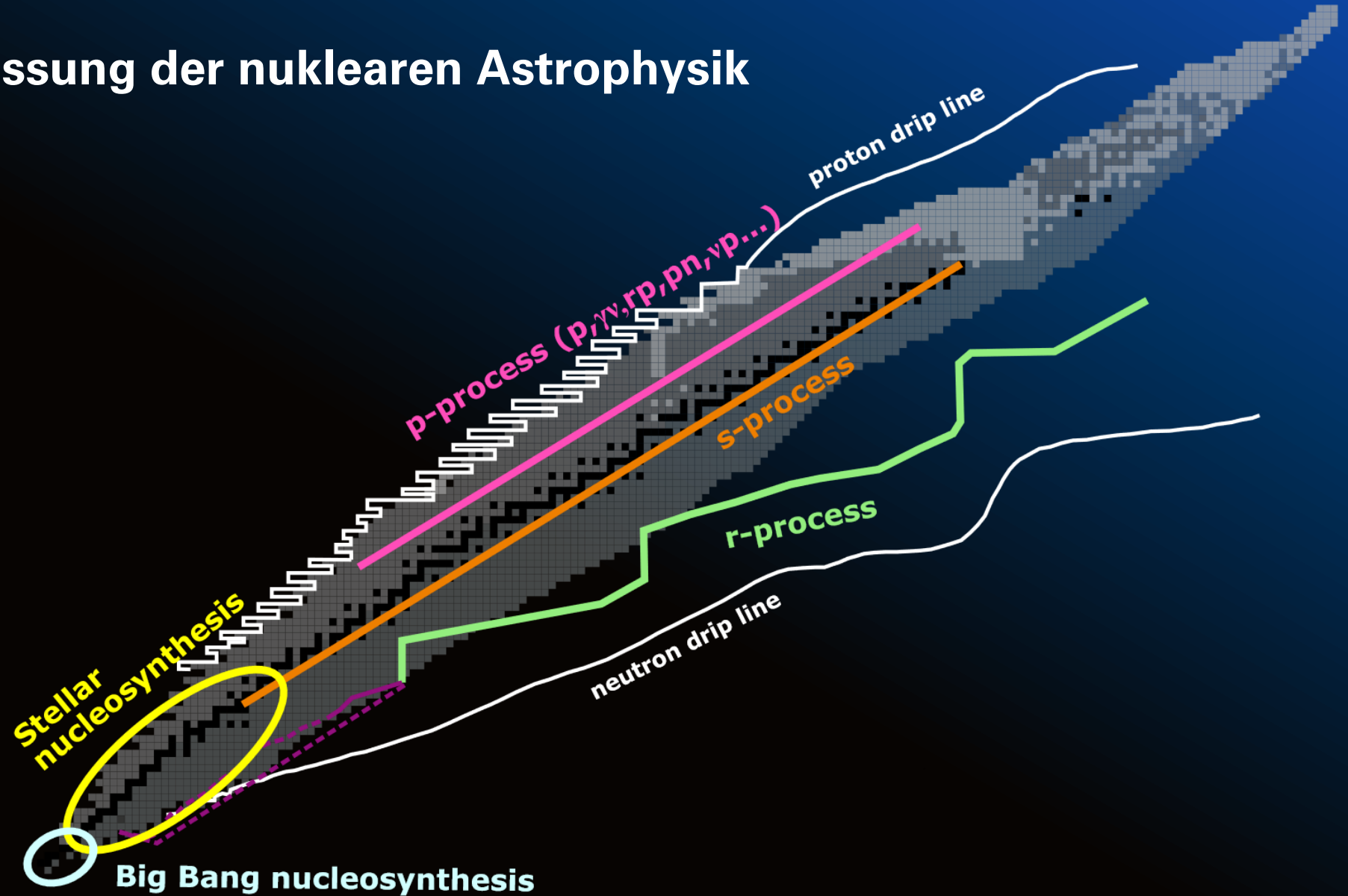
Zentrum

Oberfläche

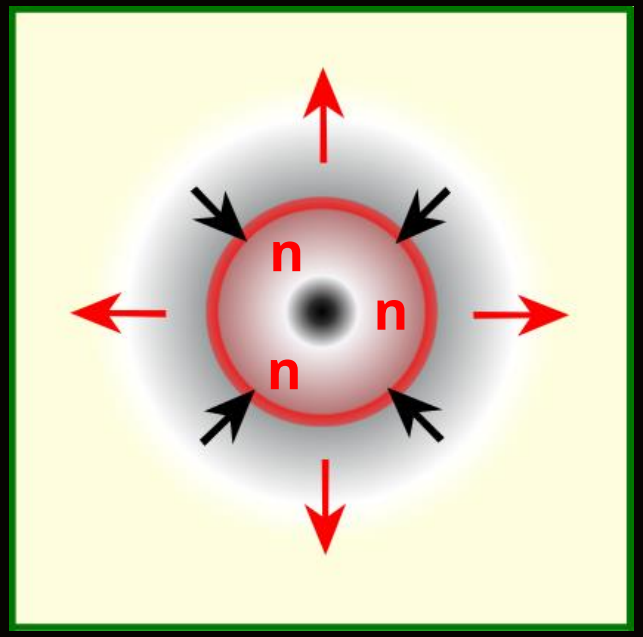


https://www.astro.keele.ac.uk/~hirschi/animation/anim.html

Zusammenfassung der nuklearen Astrophysik

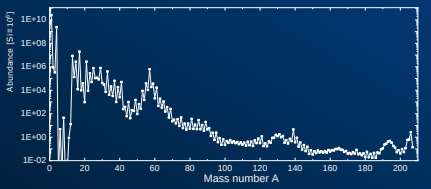


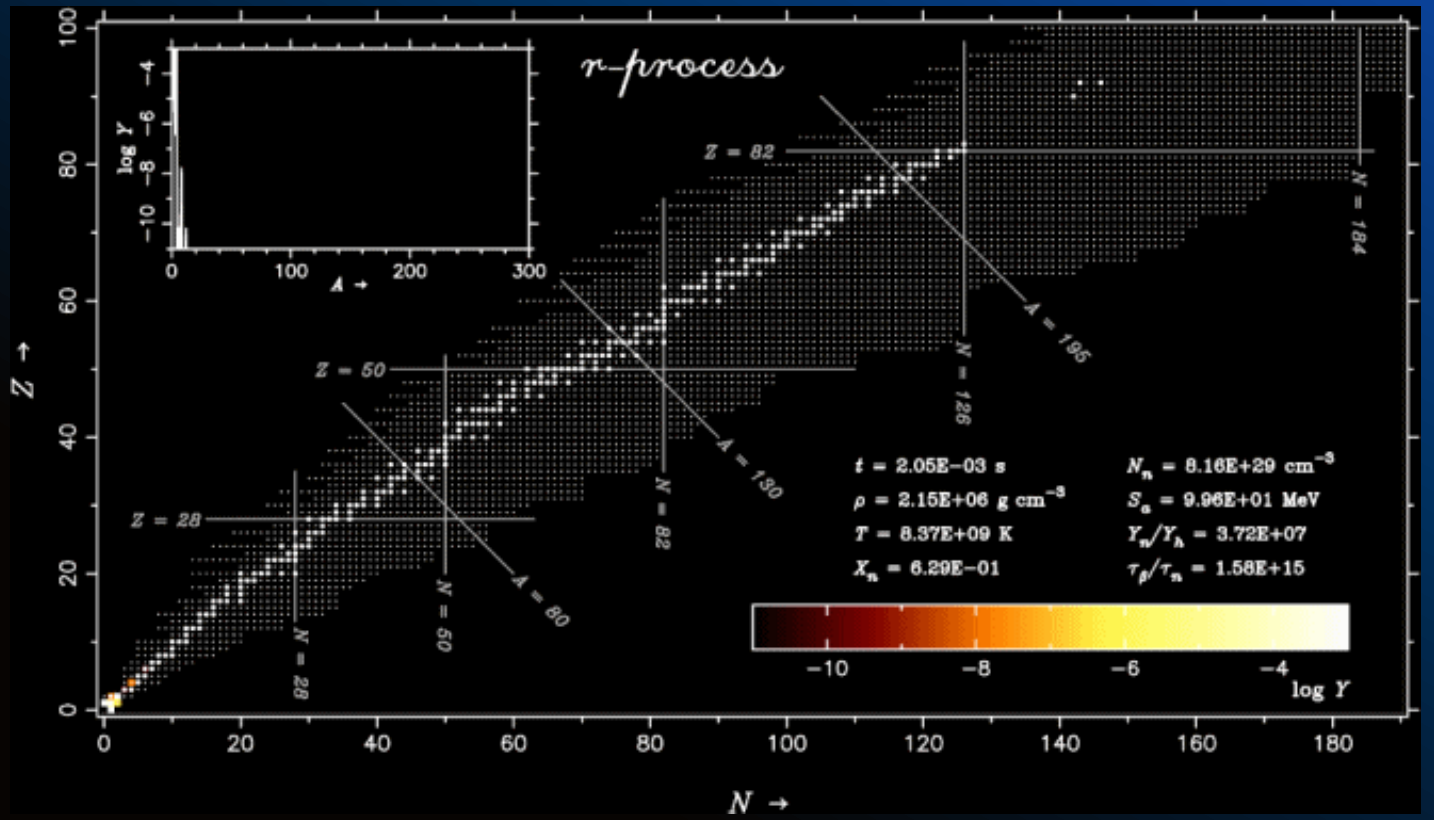
Explosive Nukleosynthese



https://en.wikipedia.org/wiki/Type_II_supernova#

Explosive Nukleosynthese

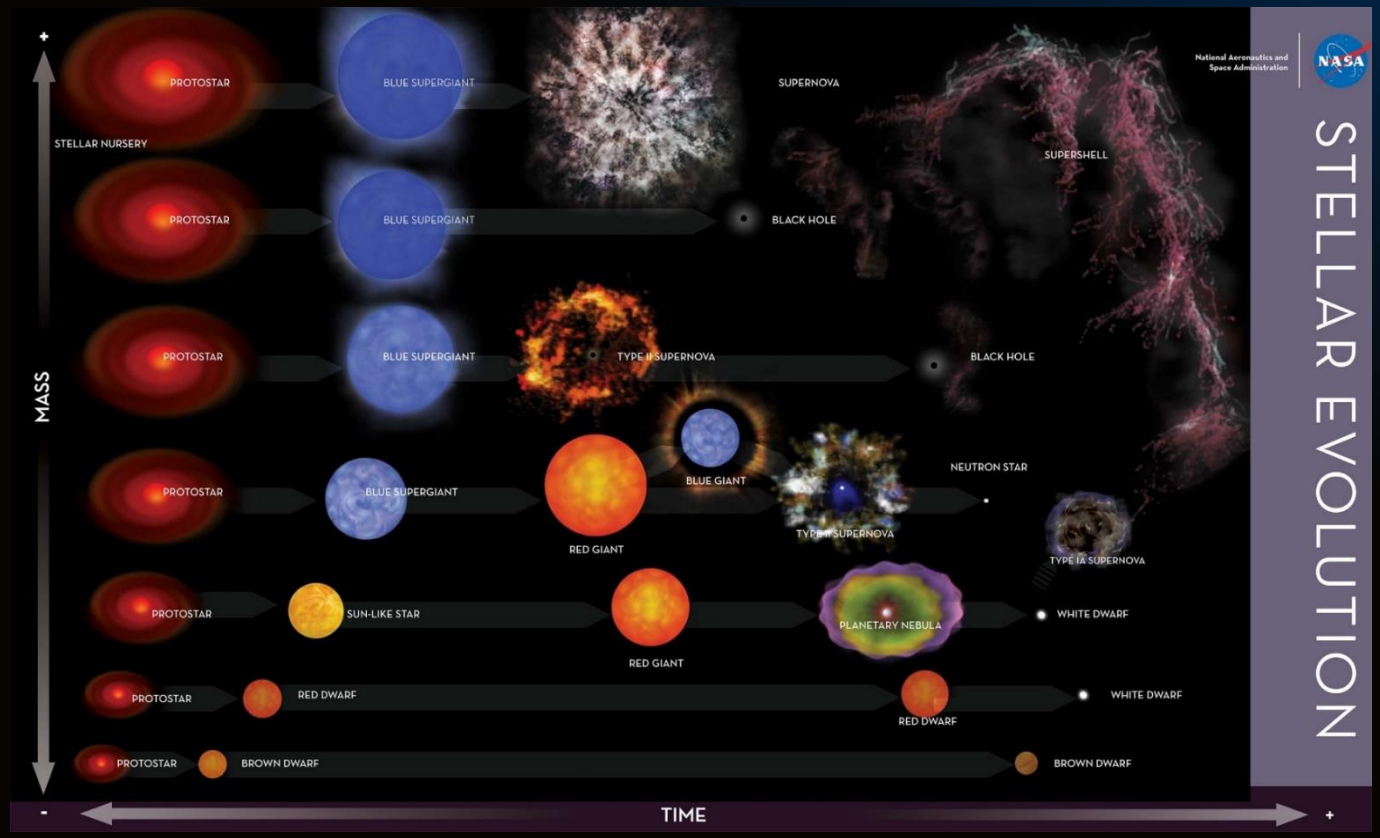




http://www.ph.sophia.ac.jp/~shinya/research/research.html

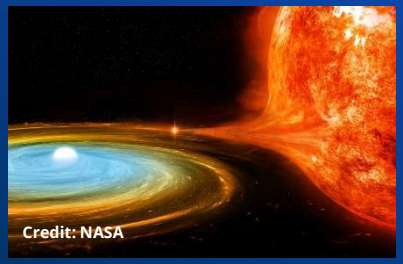
Credit: ESA (https://www.esa.int/ESA_Multimedia/Images/2013/07/Type_Ia_supernova#/media/ESA/Hubble/Type_Ia_supernova_A_Spitzer_Crop.jpg)

Nukleare Astrophysik in der Sternentwicklung

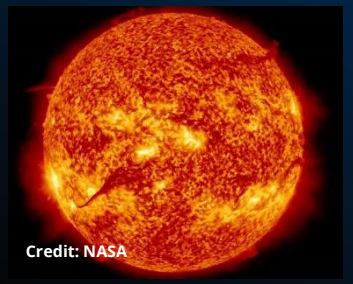


Credit: NASA (https://www.accessscience.com/media/EST/media/654000FG0010.jpg)

Credit: ESO/M.Kornmesser (https://www.eso.org/public/germany/images/eso1229a/)



Credit: NASA



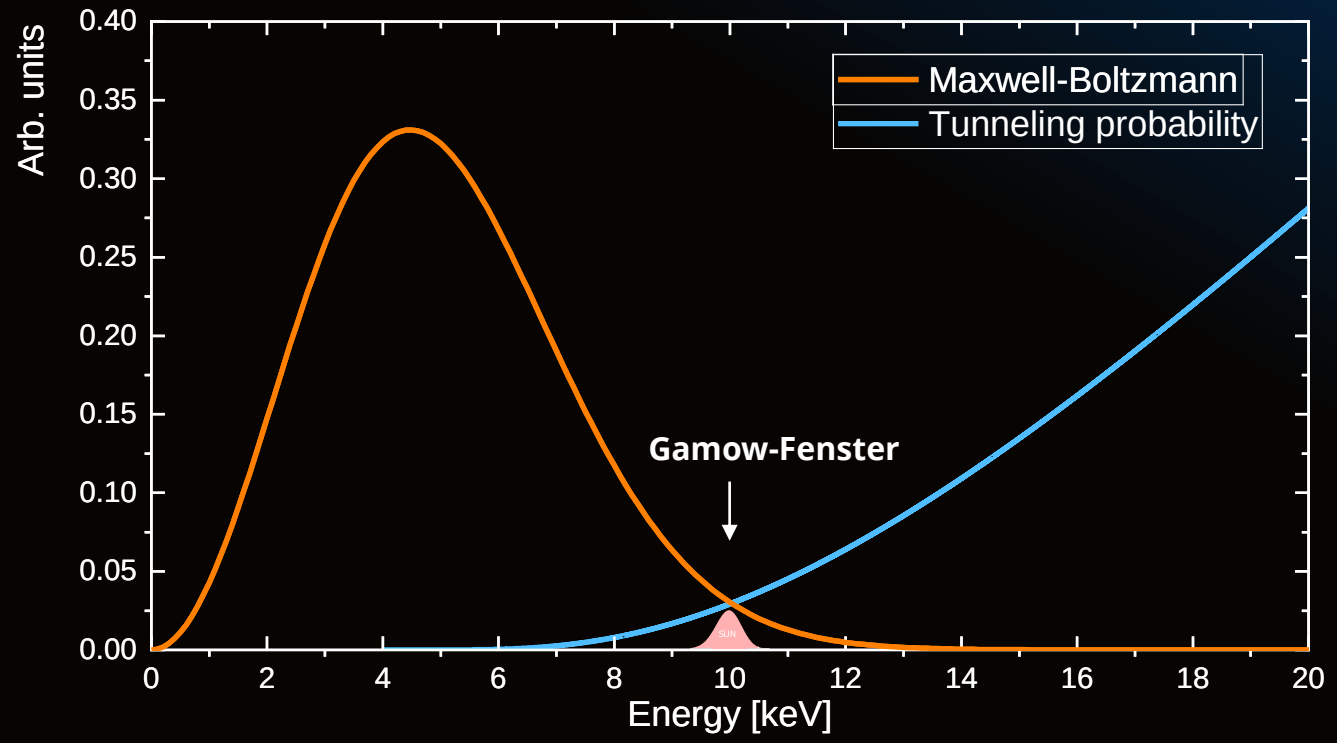
Credit: NASA

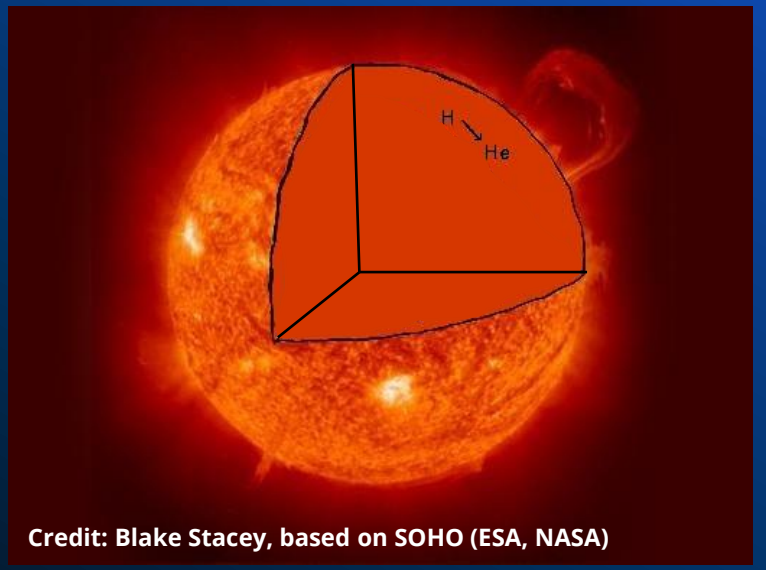
Credit: ESA (https://www.cosmos.esa.int/documents/332075/979553//788px-Cassiopeia_A_Spitzer_Crop.jpg)

Credit: ESO (https://www.eso.org/public/images/eso1733q/)

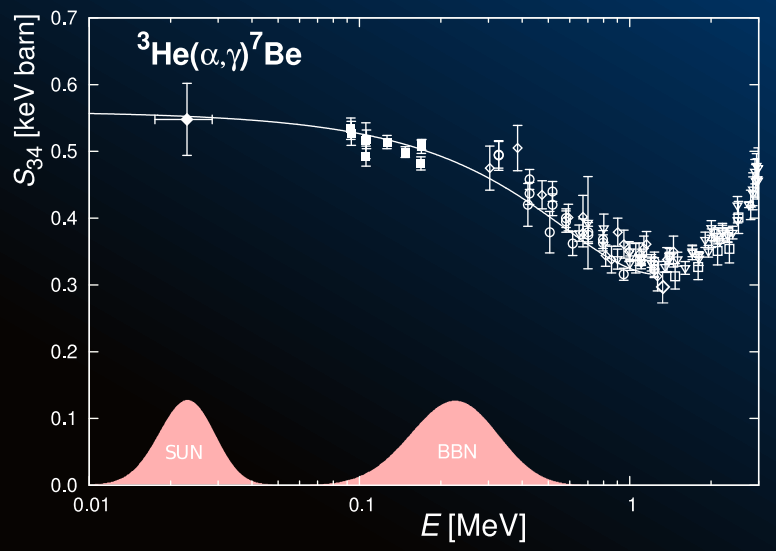
Das Felsenkeller-Untertagelabor

Vom Inneren der Sterne zum Inneren von Tunneln





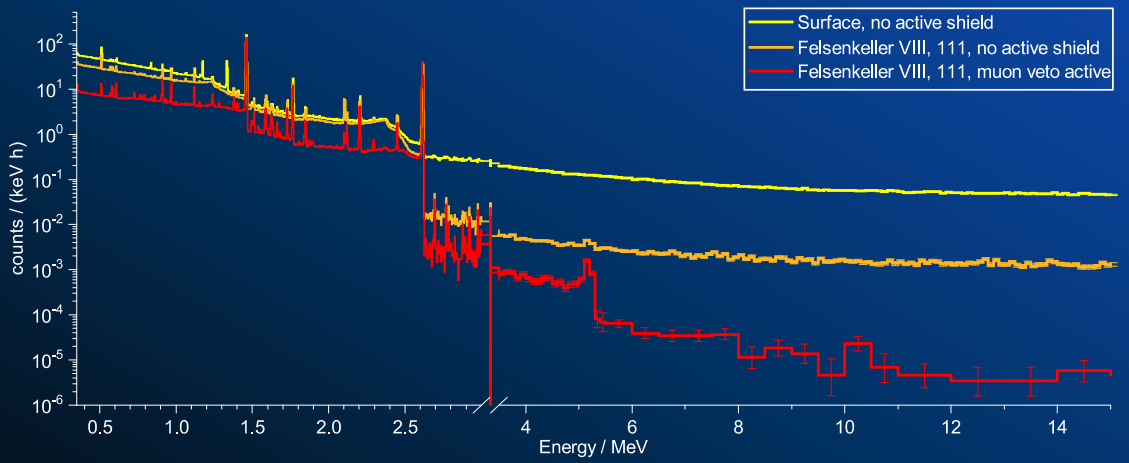
Credit: Blake Stacey, based on SOHO (ESA, NASA)



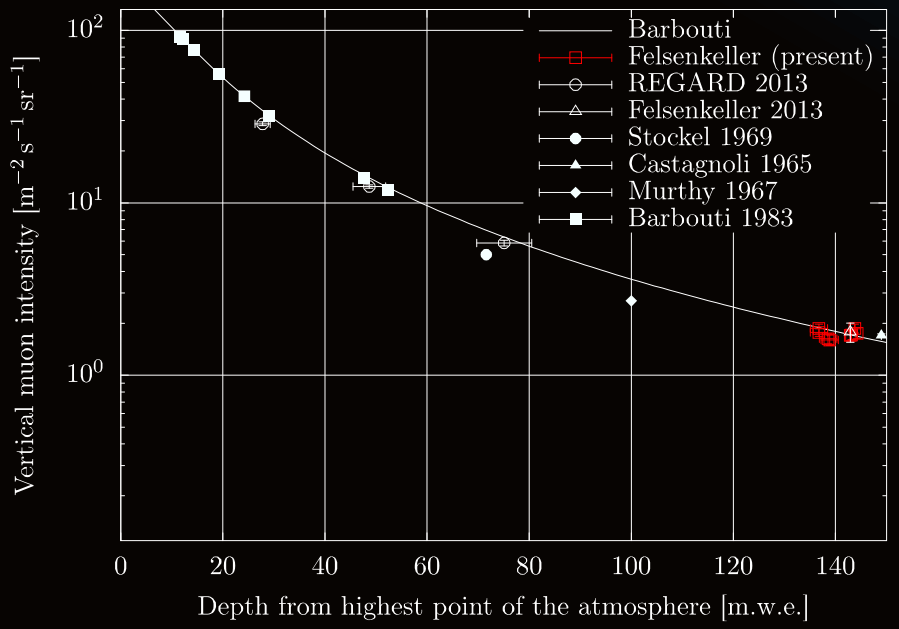
Das neue Felsenkeller-Labor

Warum untertage?

- Schutz vor kosmischen Myonen (Untergrund reduzieren)
- Erforschung sehr seltener Prozesse
  - Messungen im Bereich des Gamow-Fensters

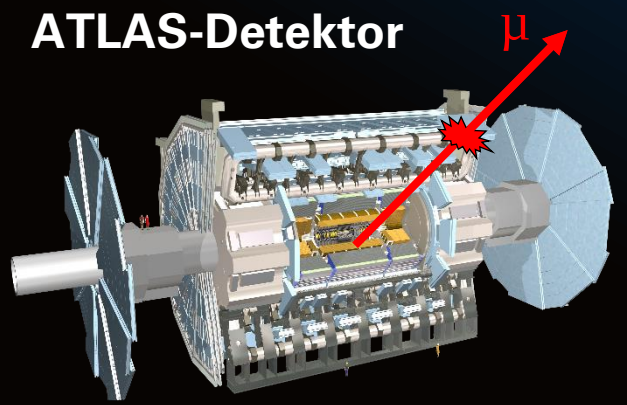


Adapted from: ***T. Szücs et al.*** **European Physics Journal A 55, 174**

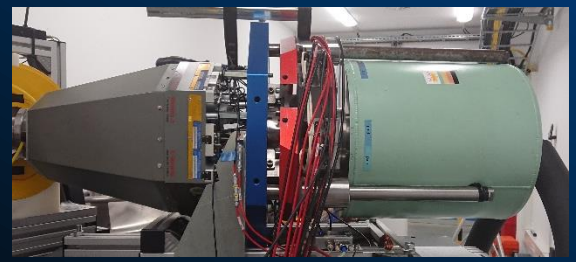


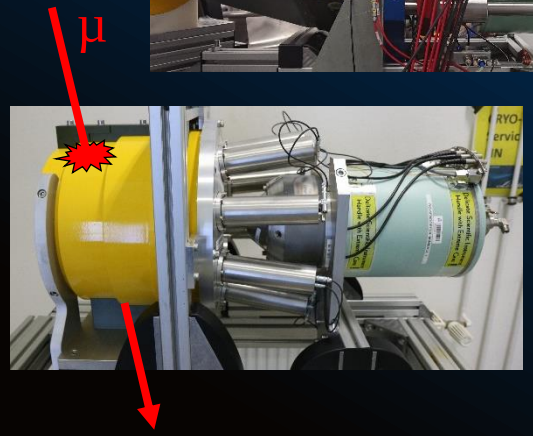
F. Ludwig et al. **Astroparticle Physics 112 (2019) 24-34**

ATLAS-Detektor

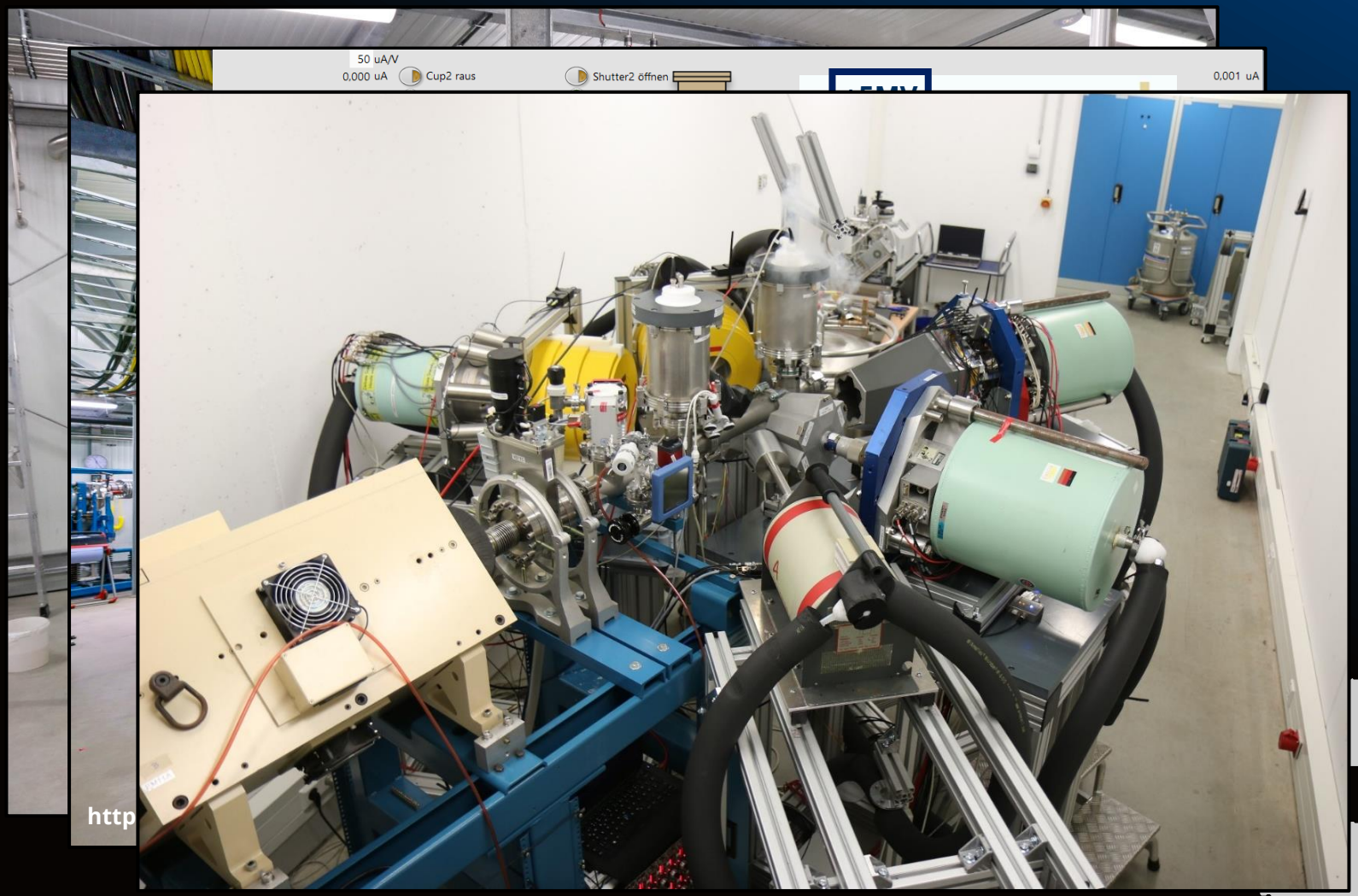


http://opendata.atlas.cern/books/current/get-started/_book/GLOSSARY.html

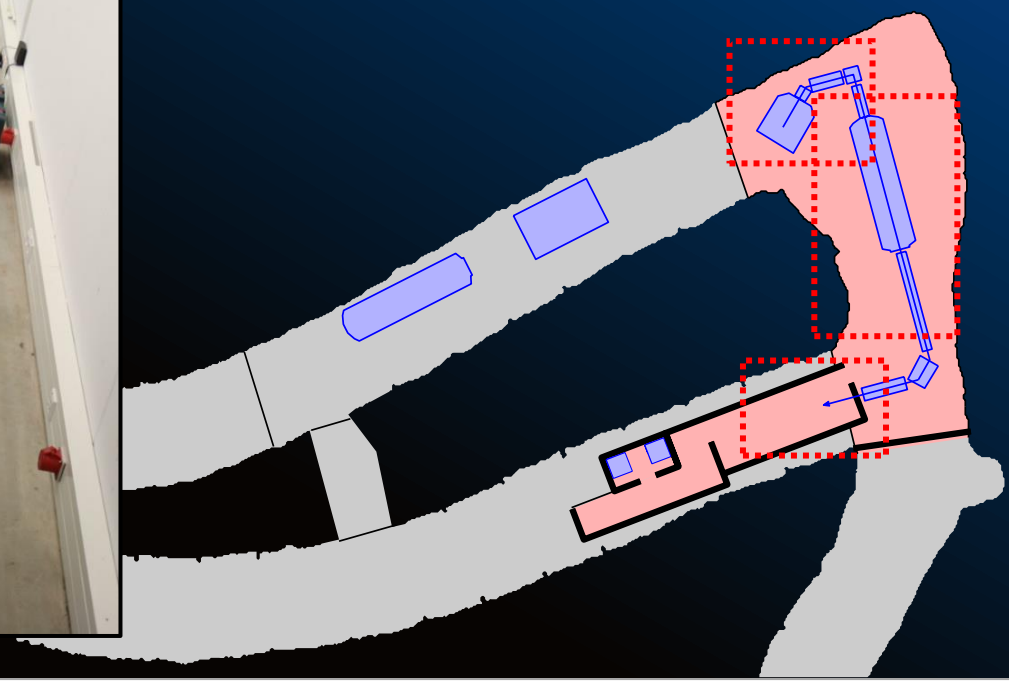




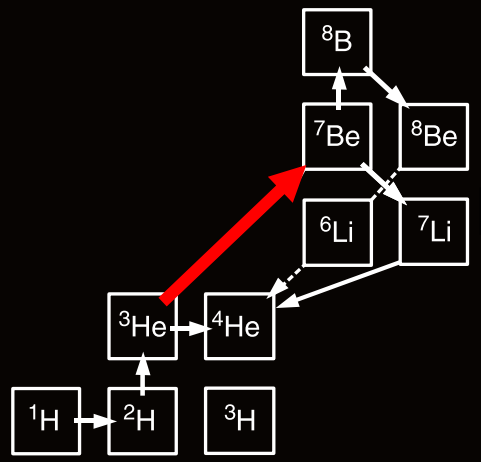
Das neue Felsenkeller Untertage-Labor

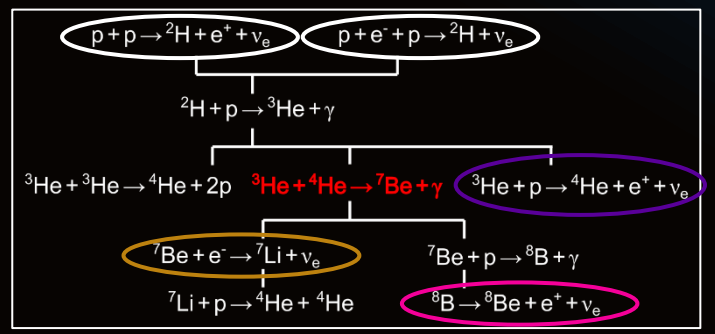


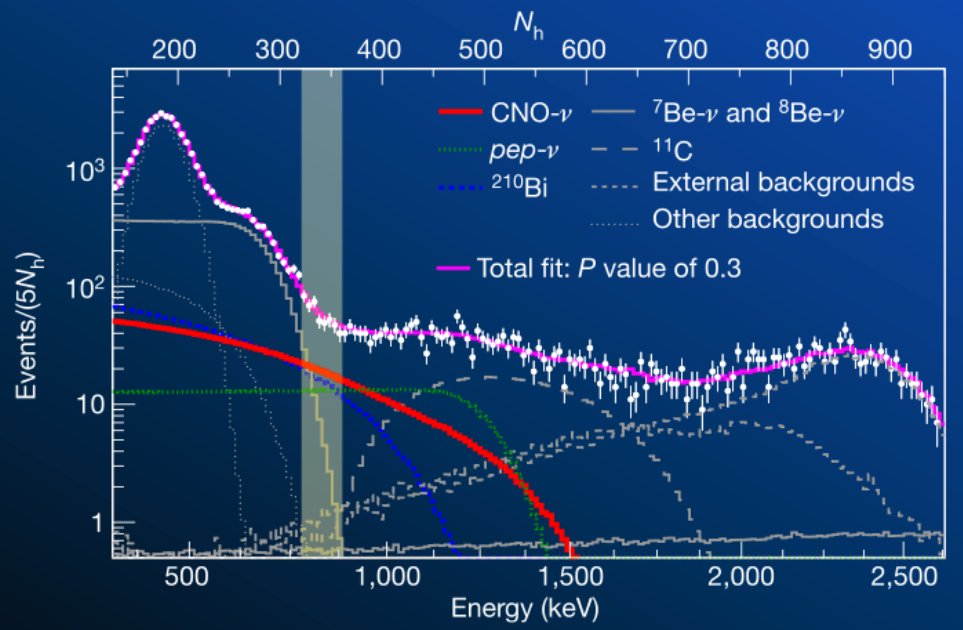
→ **Externe Ionenquelle**
→ Kohlenstoffstrahl ($^{12}C^-$)
→ 5MV **Pelletron Beschleuniger**
→ **Interne Ionenquelle**
→ H & He-Strahl
→ **Derzeitiger Experimentier-Aufbau**
→ $^3He(\alpha,\gamma)^7Be$-Kampagne



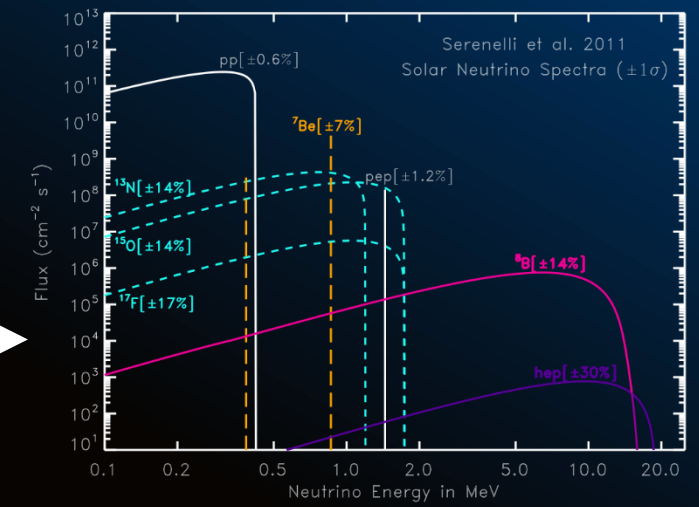
Die $^3He(\alpha,\gamma)^7Be$ Reaktion







The Borexino collaboration, **Nature volume 587, 577–582 (2020)**



Haxton et al. **Annu. Rev. Astron. Astrophys. 51 1 (2013)**