TECHNISCHE UNIVERSITÄT DRESDEN

DRESDEN concept

IKTP Institute seminar

From the interior of stars and tunnels

Nuclear astrophysics in a nutshell

Steffen Turkat

07.01.2021

<u>In preparation for this talk:</u>
Please visit Slido.com (mobile phone) and enter with #1444
→ Leave it like that, the rest will appear automatically

INSTITUTE OF NUCLEAR AND PARTICLE PHYSICS

HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Konrad Adenauer Stiftung


Copyright: ESA/Hubble/NASA/M.Kornmesser

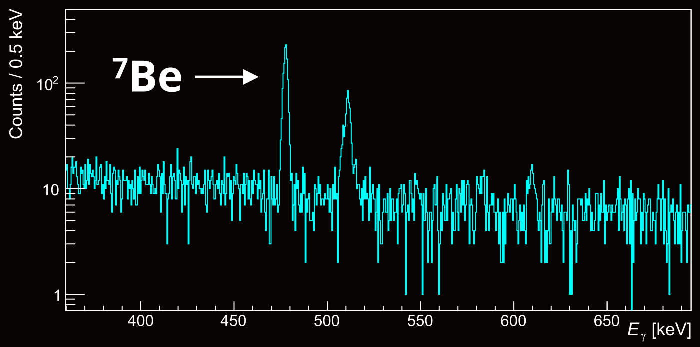
Nuclear astrophysics

→ The origin of the elements


Copyright: André Wirsig (HZDR)

The new underground facility at Felsenkeller

→ How to study the universe from underground

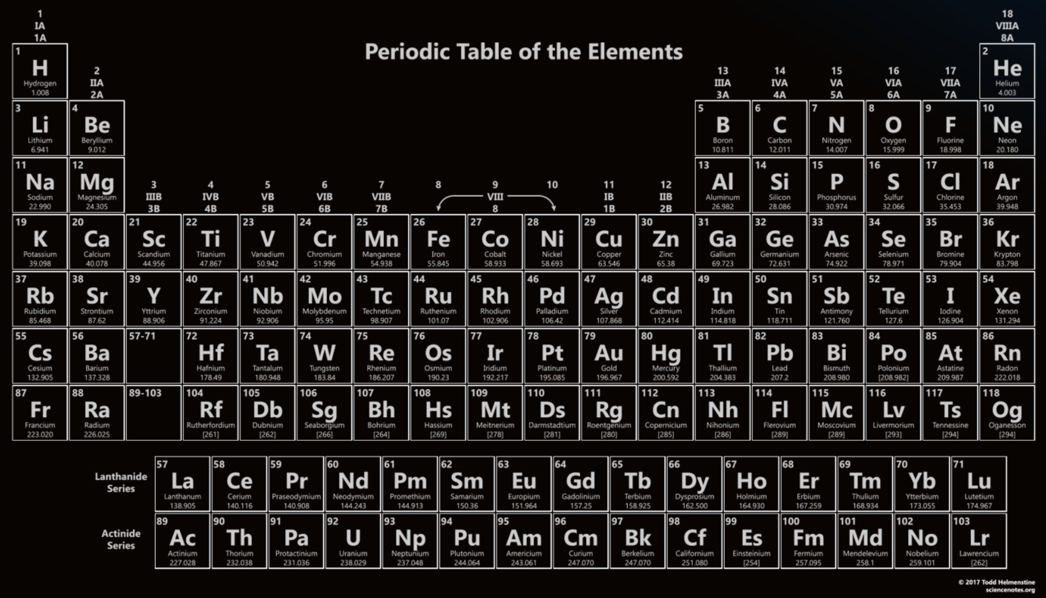


Recent achievements and outlook

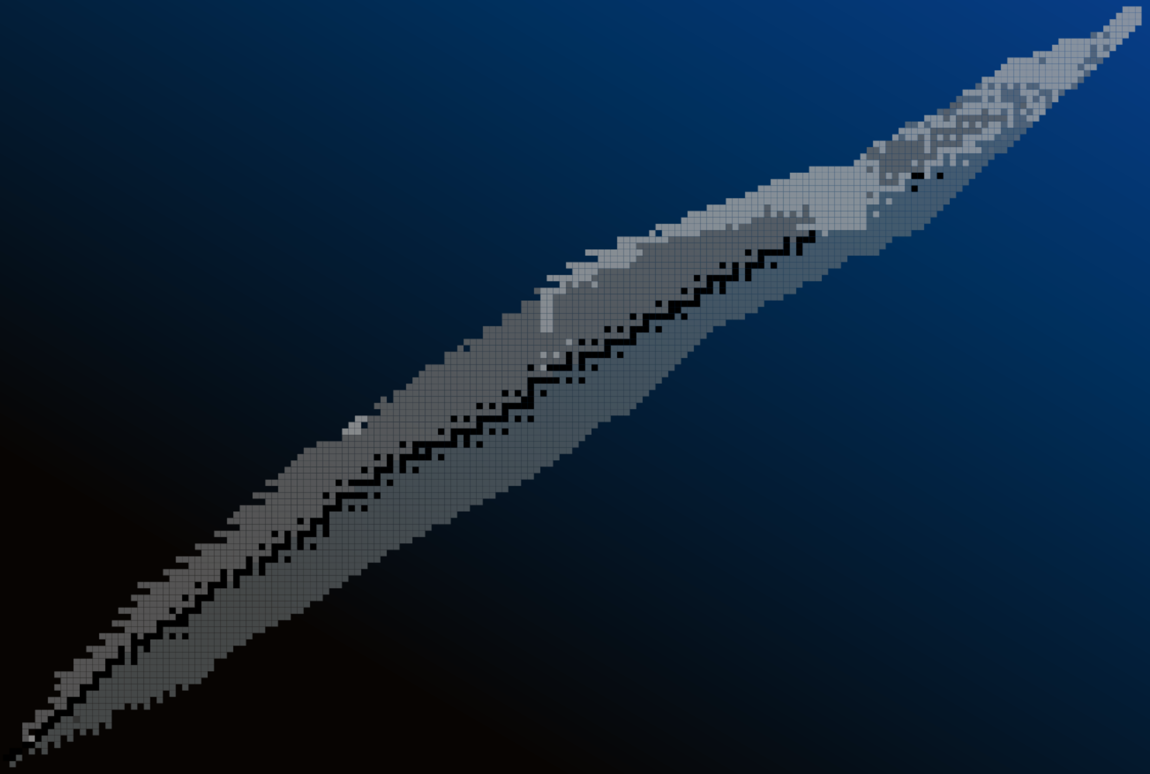
→ Experimental campaign on ^{3}He$(\alpha,\gamma)^{7}$Be

Chemical evolution of the universe

➢ **How, when & in which amounts were all the elements in our universe formed?**



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



Elemental abundance of our earth

What are the four most abundant elements of our earth?
→ Please visit Slido.com & enter **#1444**
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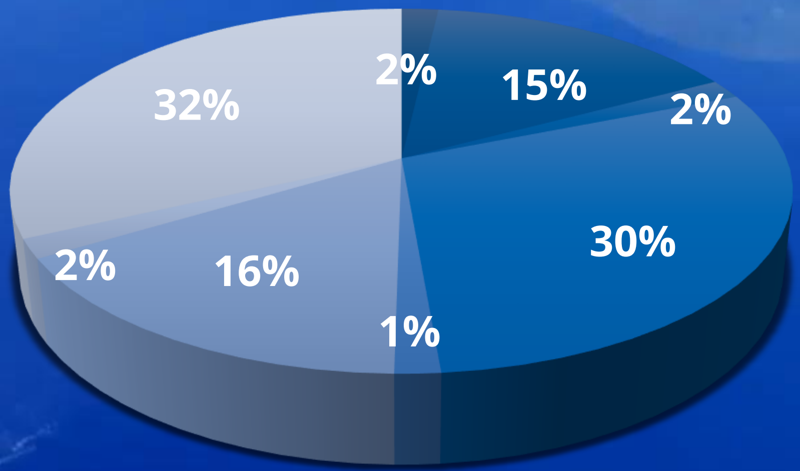


Source: NASA

Active poll

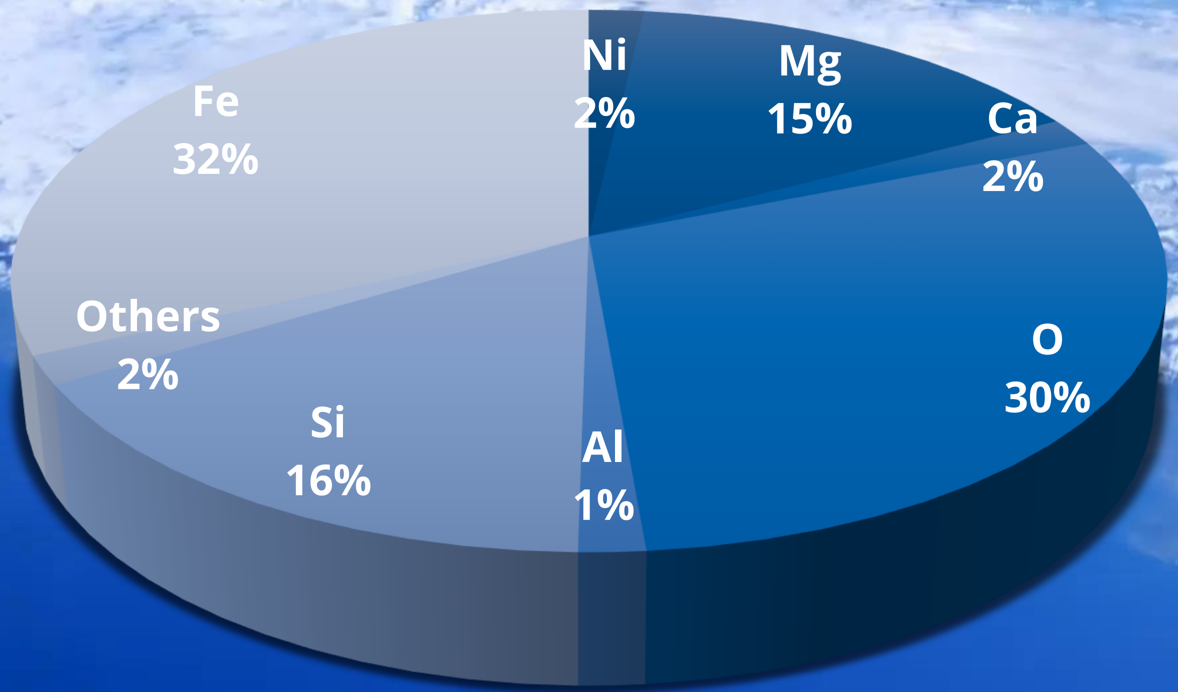
Join at
slido.com
#1444

What are the four most abundant elements on our earth?

0 0 0

- H
- He
- C
- N
- O
- Na
- Mg
- Al
- Si
- K
- Ca

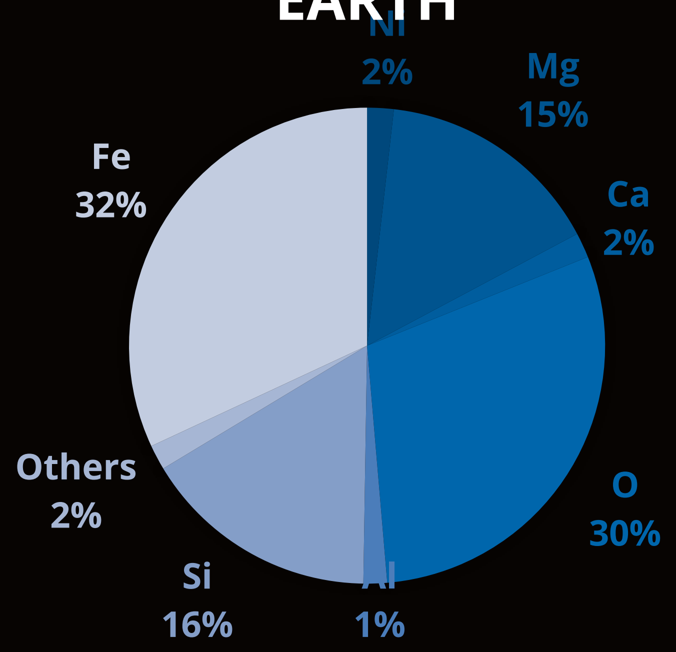
Elemental abundance of our earth



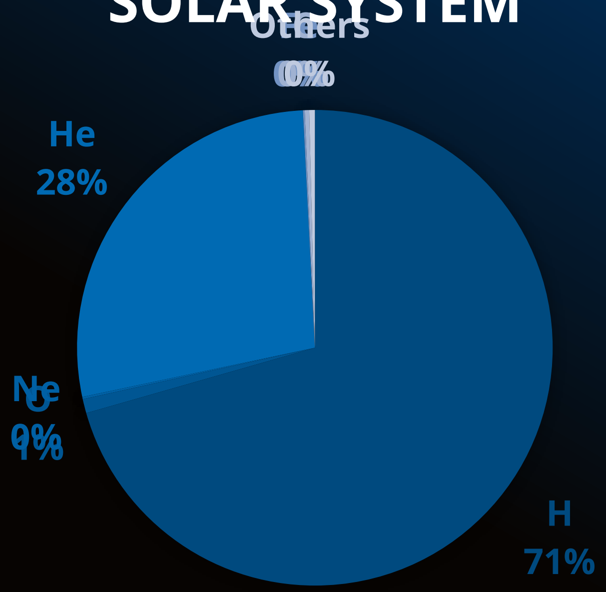
Source: NASA

The composition of the universe

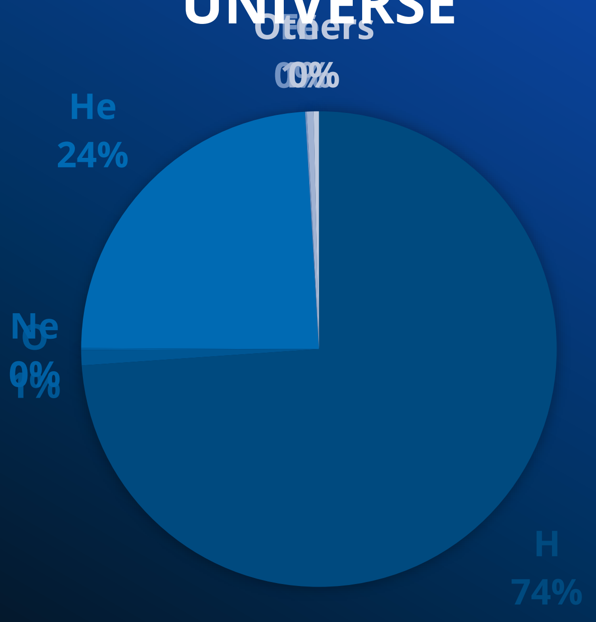
EARTH



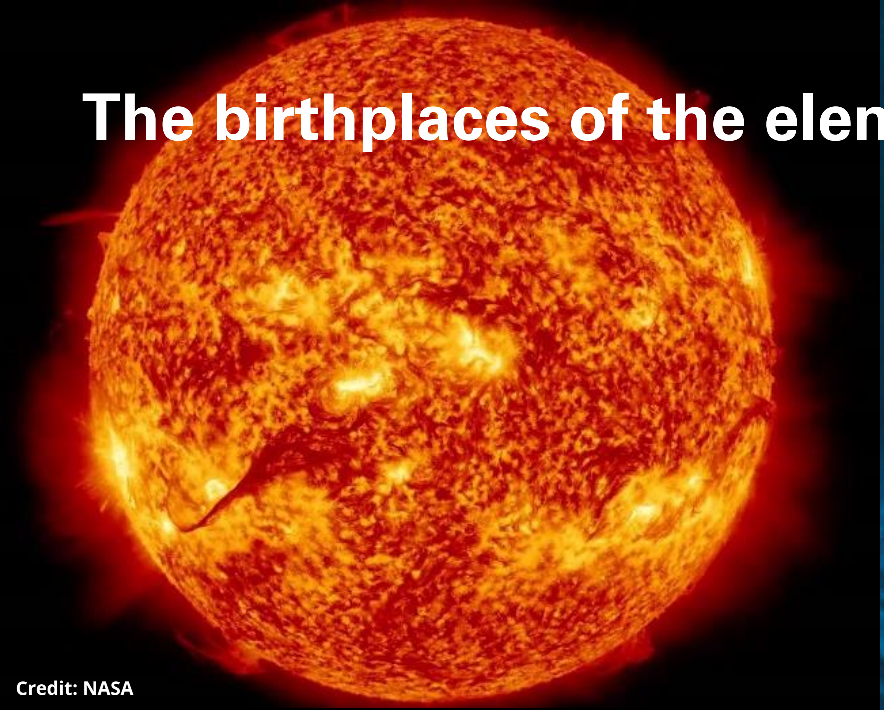
SOLAR SYSTEM



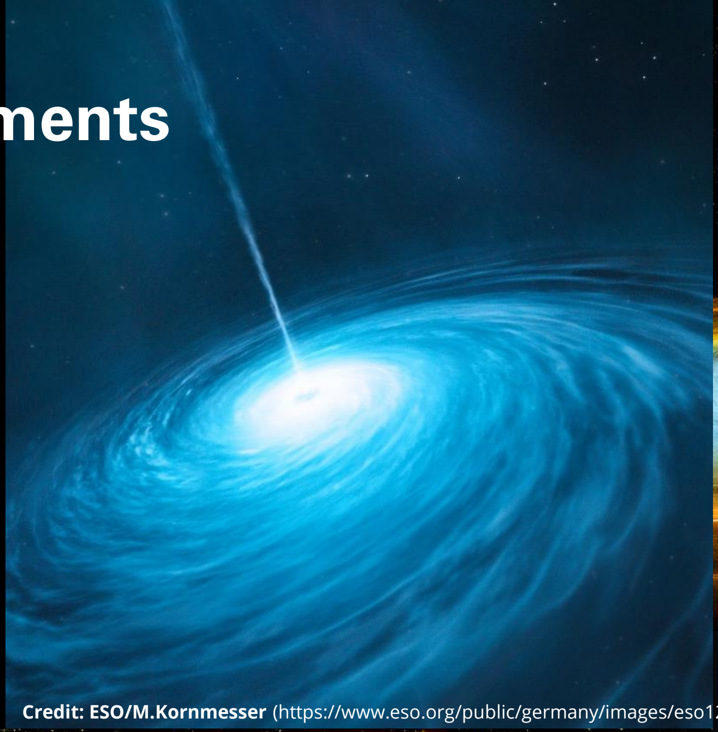
UNIVERSE



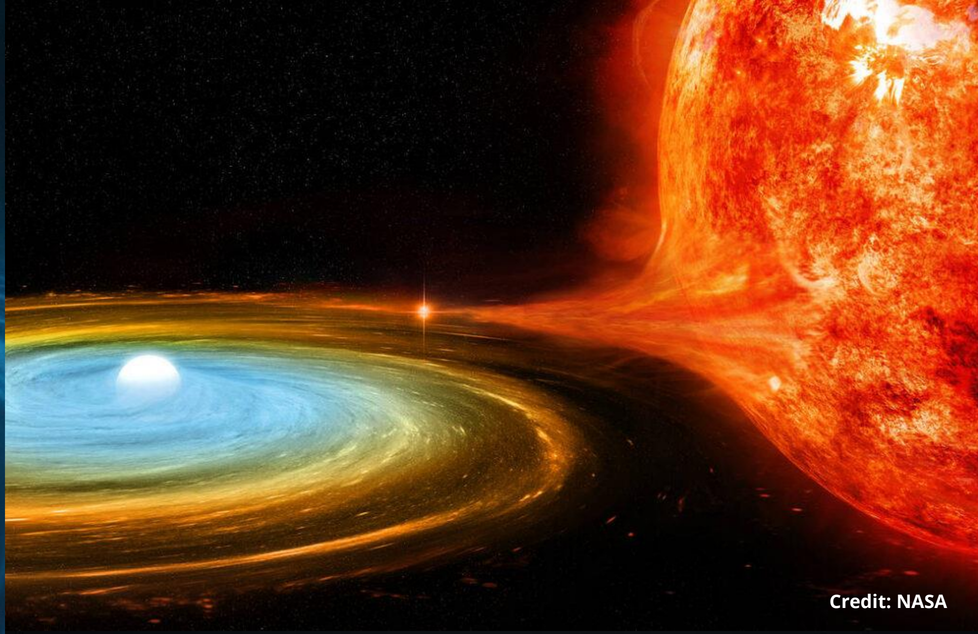
The birthplaces of the elements



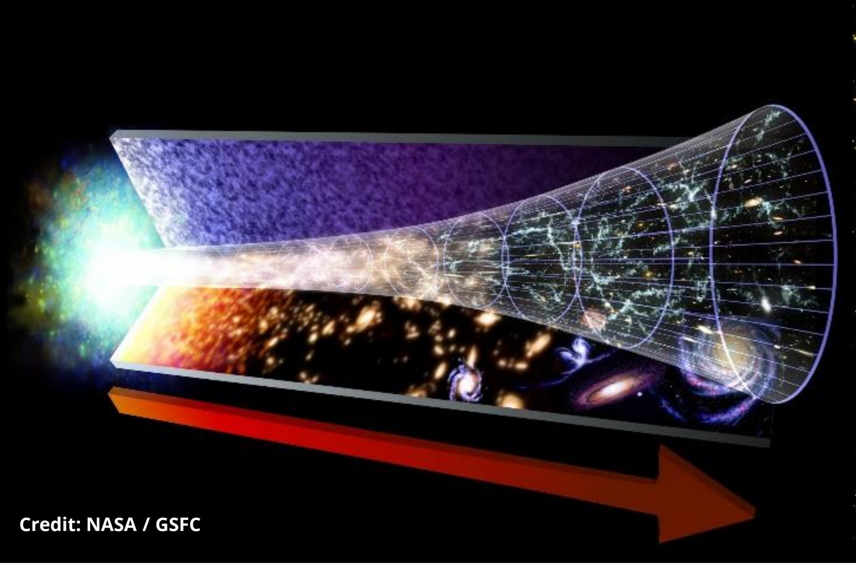
Credit: NASA



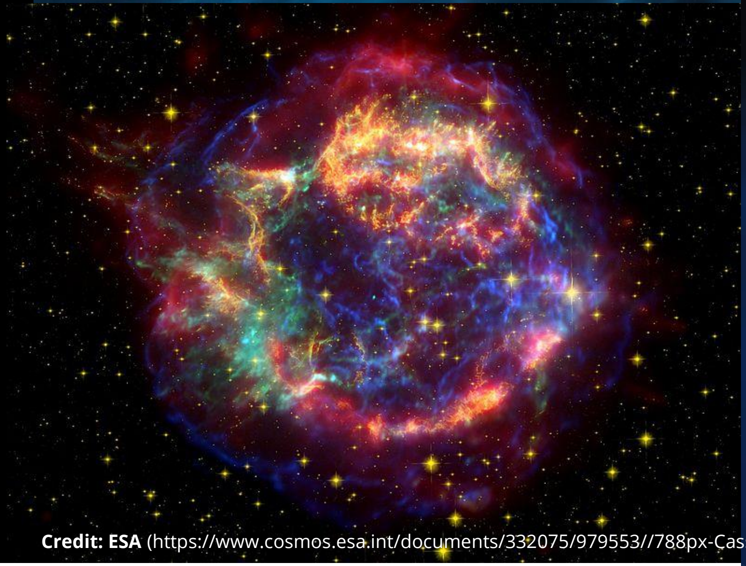
Credit: ESO/M.Kornmesser (https://www.eso.org/public/germany/images/eso1229a/)



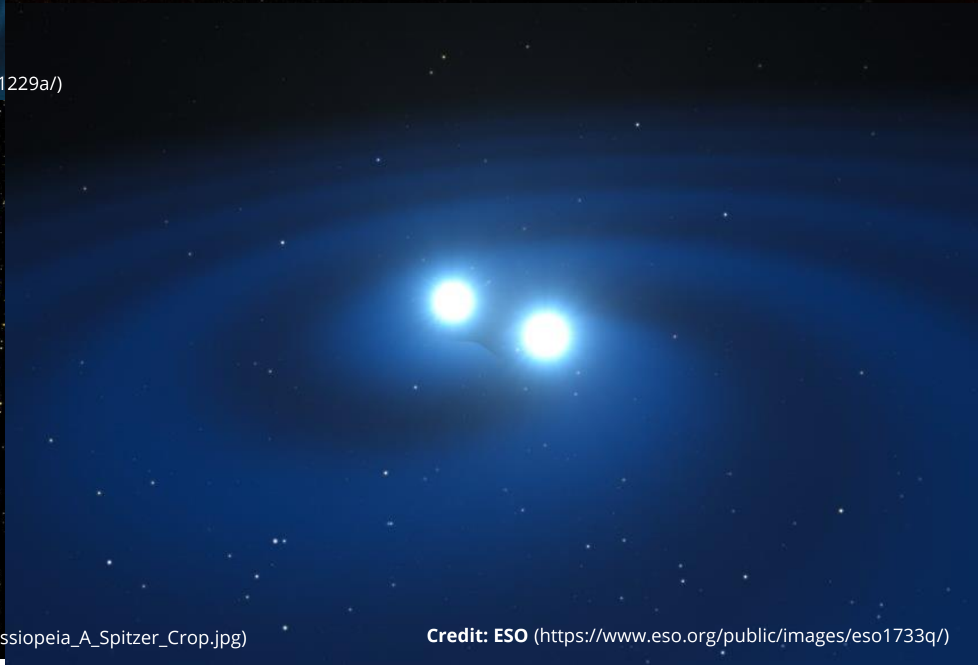
Credit: NASA



Credit: NASA / GSFC

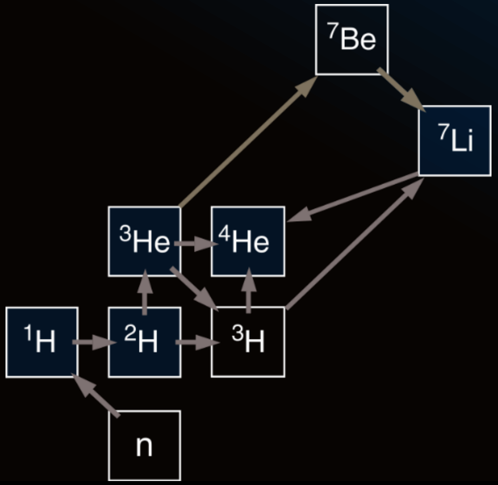


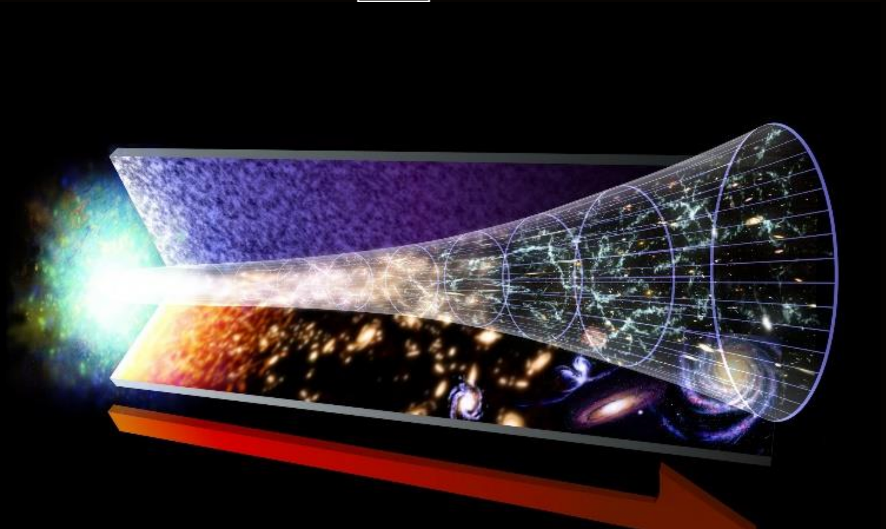
Credit: ESA (https://www.cosmos.esa.int/documents/332075/979553//788px-Cassiopeia_A_Spitzer_Crop.jpg)



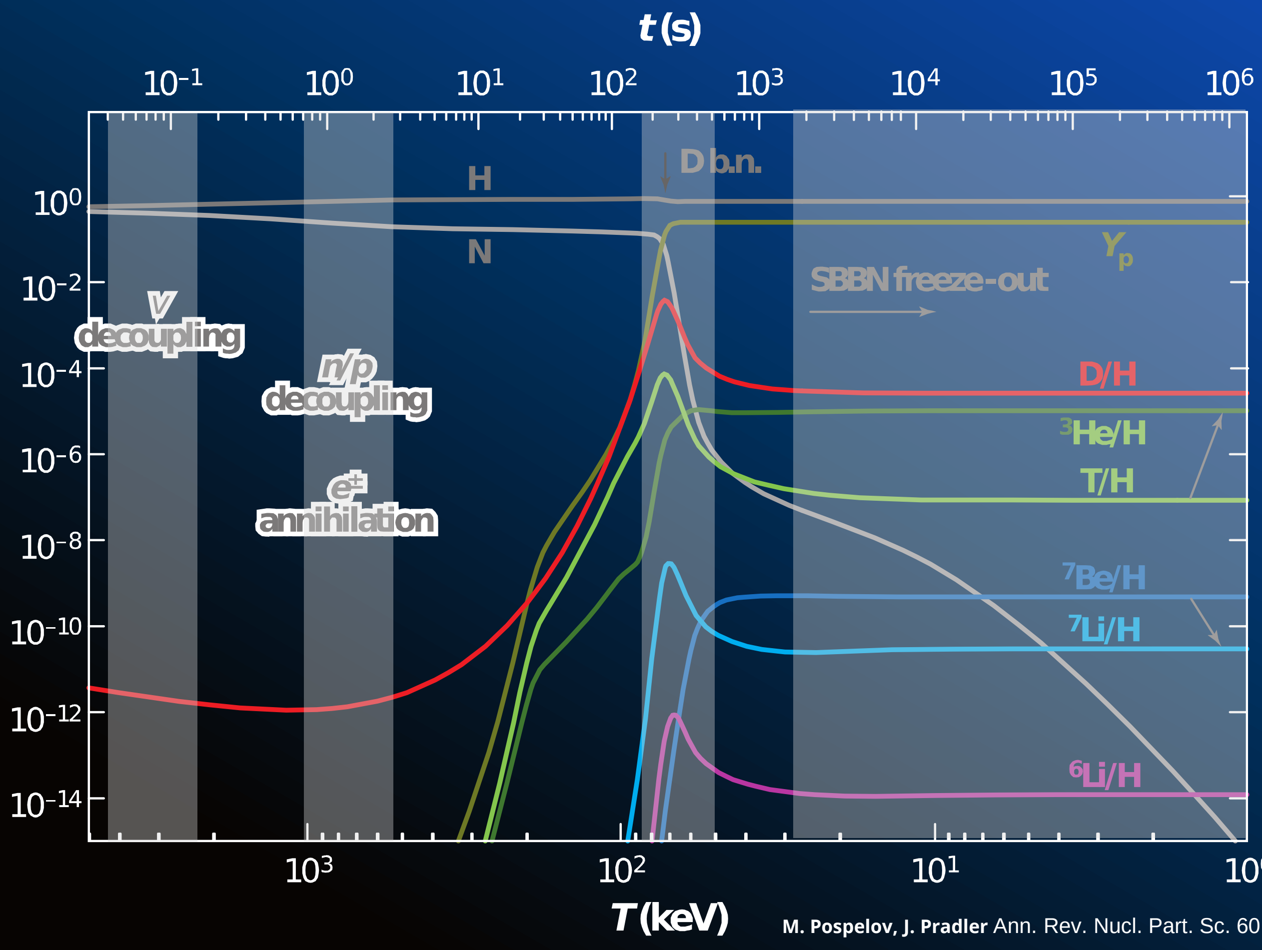
Credit: ESO (https://www.eso.org/public/images/eso1733q/)

The Big Bang Nucleosynthesis





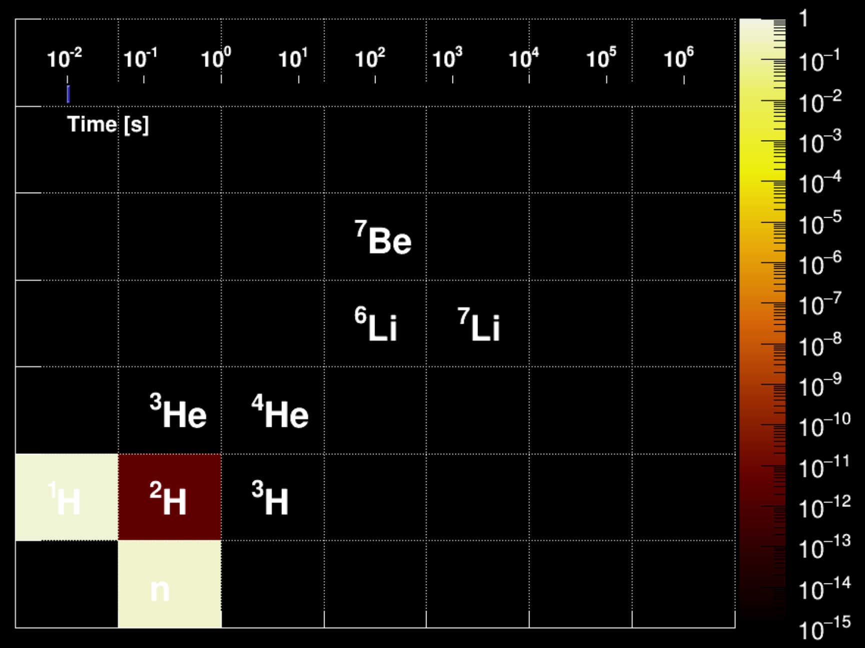
Credit: NASA / GSFC

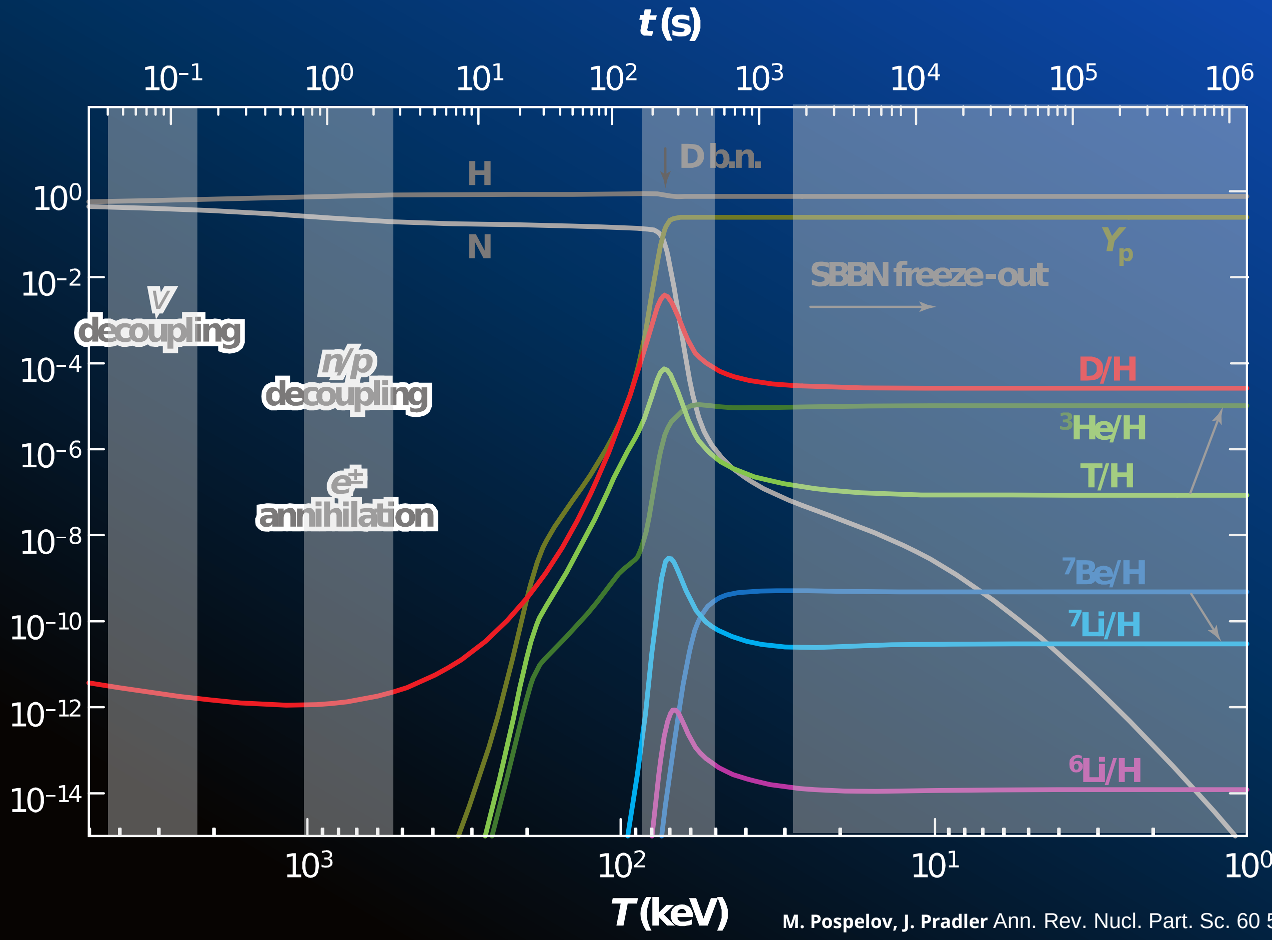


M. Pospelov, J. Pradler Ann. Rev. Nucl. Part. Sc. 60 539 (2010)

- **Chromodynamic binding energy p/n:** ~1 GeV
- **^{2}H bottle neck:** Literally the whole universe had to wait for ^{2}H
- **Spoiler:** Upcoming paper on **^{2}H(p,γ) ^{3}He** in Phys. Rev. C (*Turkat et al.)*

The Big Bang Nucleosynthesis





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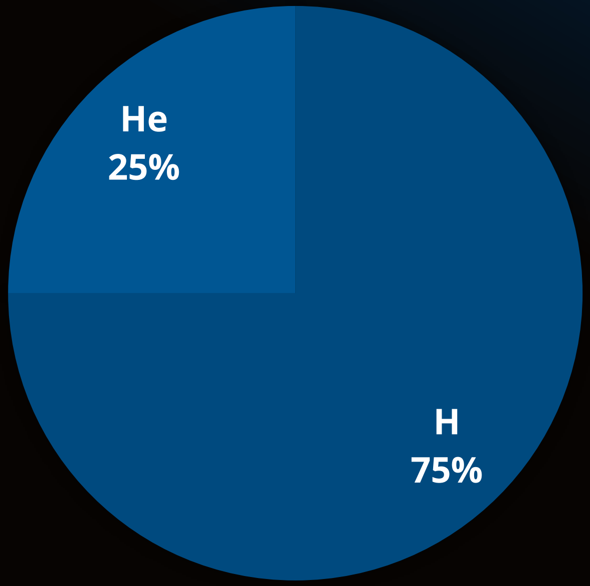
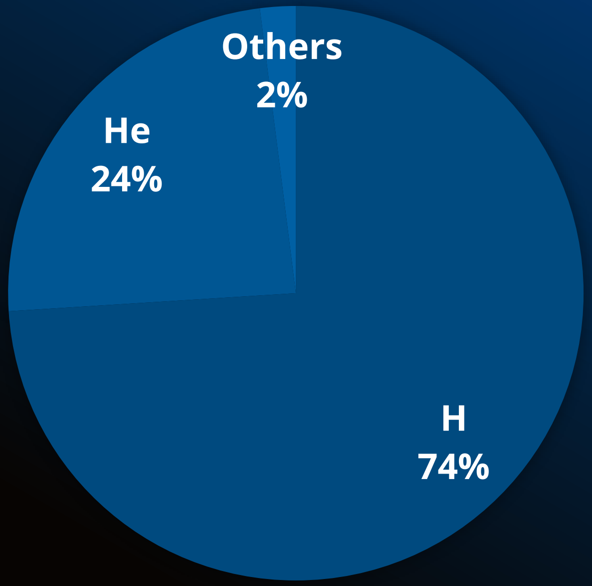
The origin of the elements

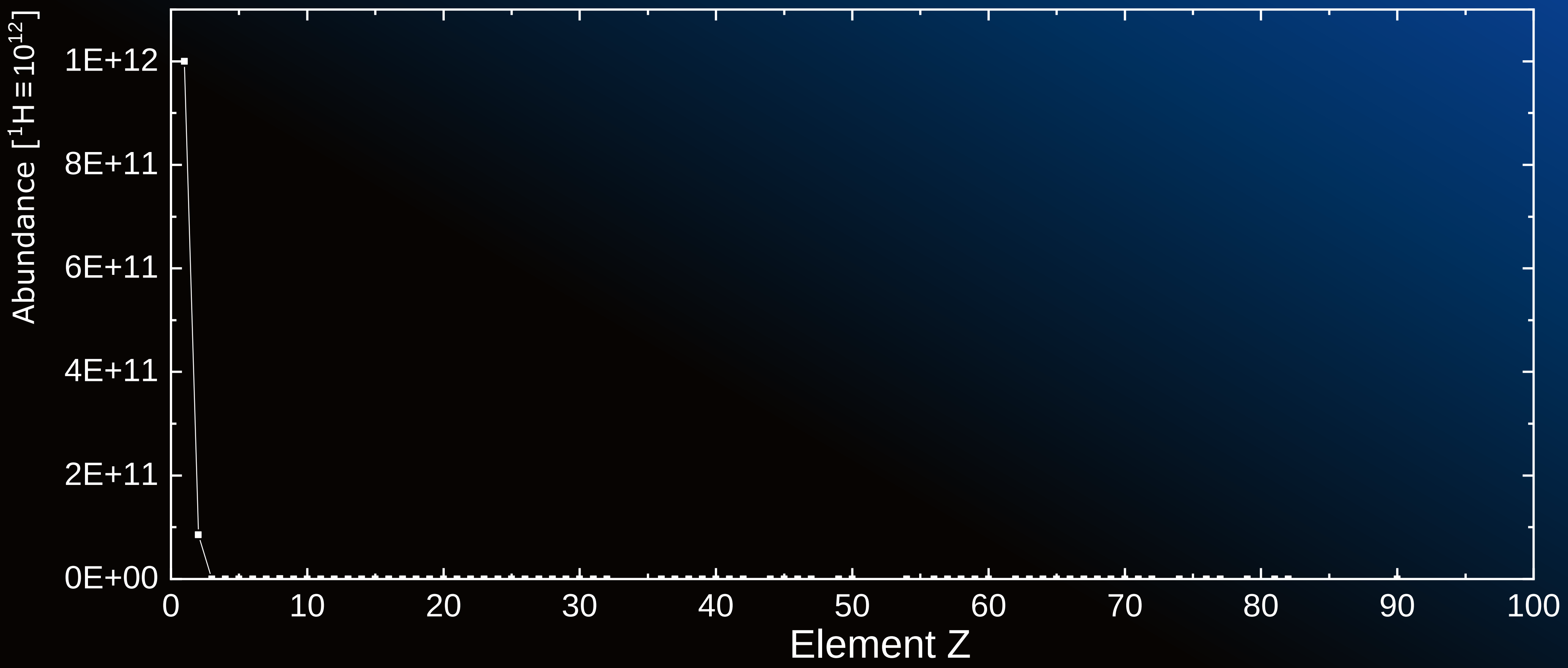
BIG BANG NUCLEOSYNTHESIS



CURRENT UNIVERSE

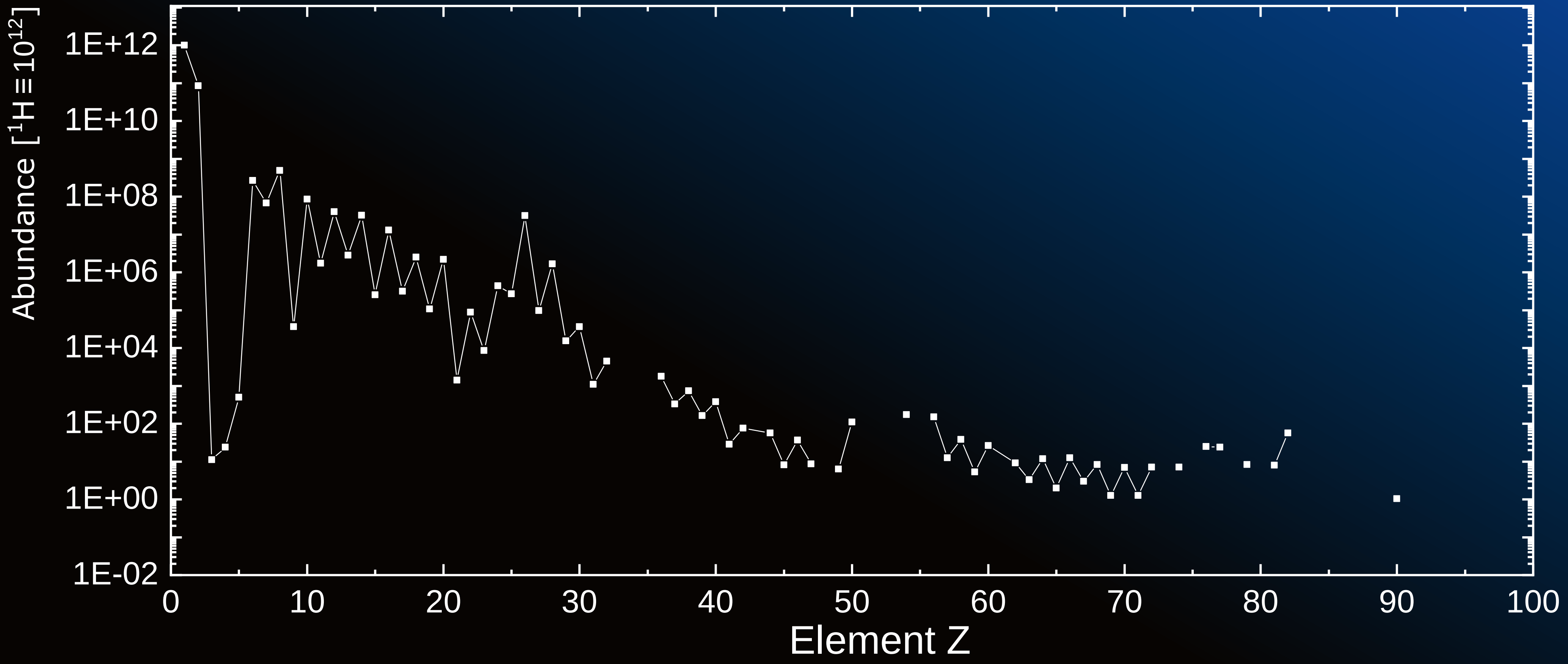


Elemental abundance of the solar photosphere



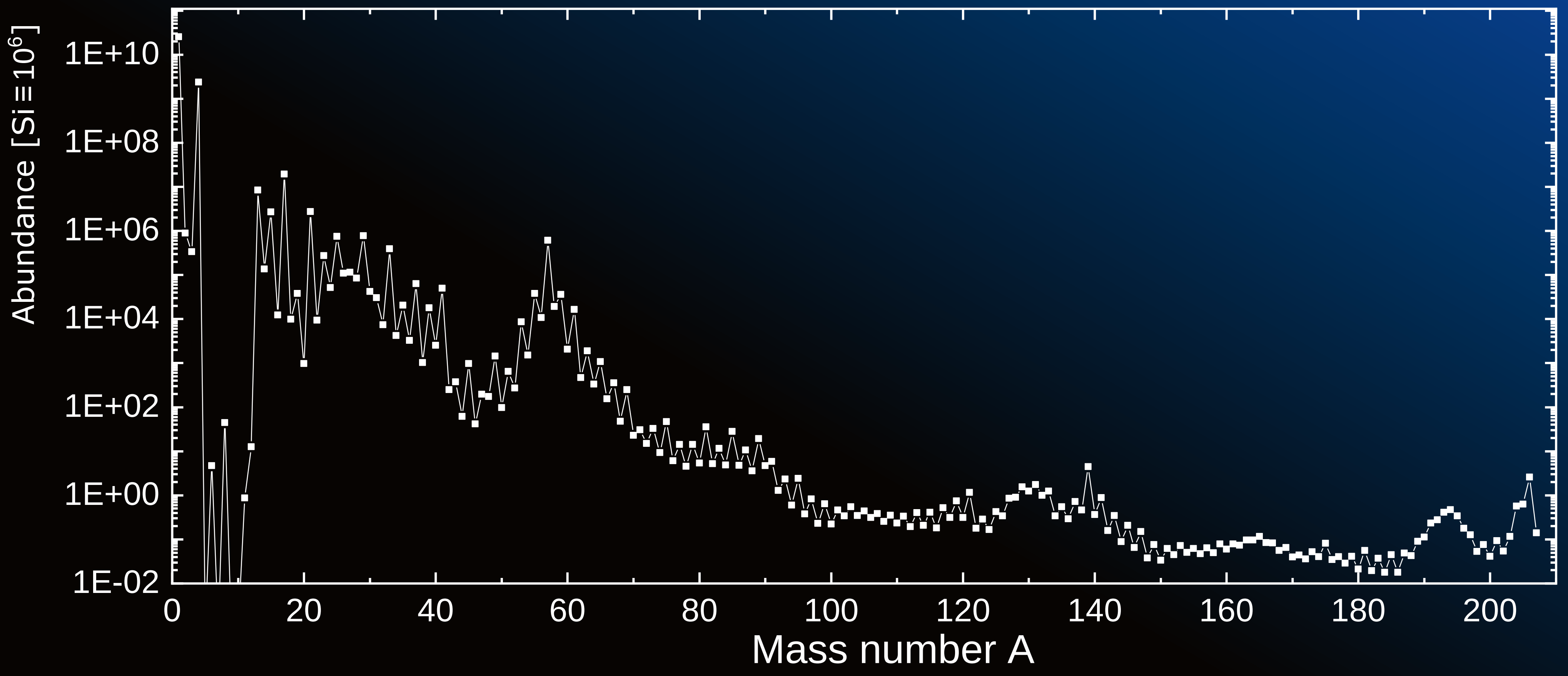
Data from: M. Asplund *et al.* Annual Reviews of Astronomy and Astropysics, Vol. 47, 481 (2009)

Elemental abundance of the solar photosphere



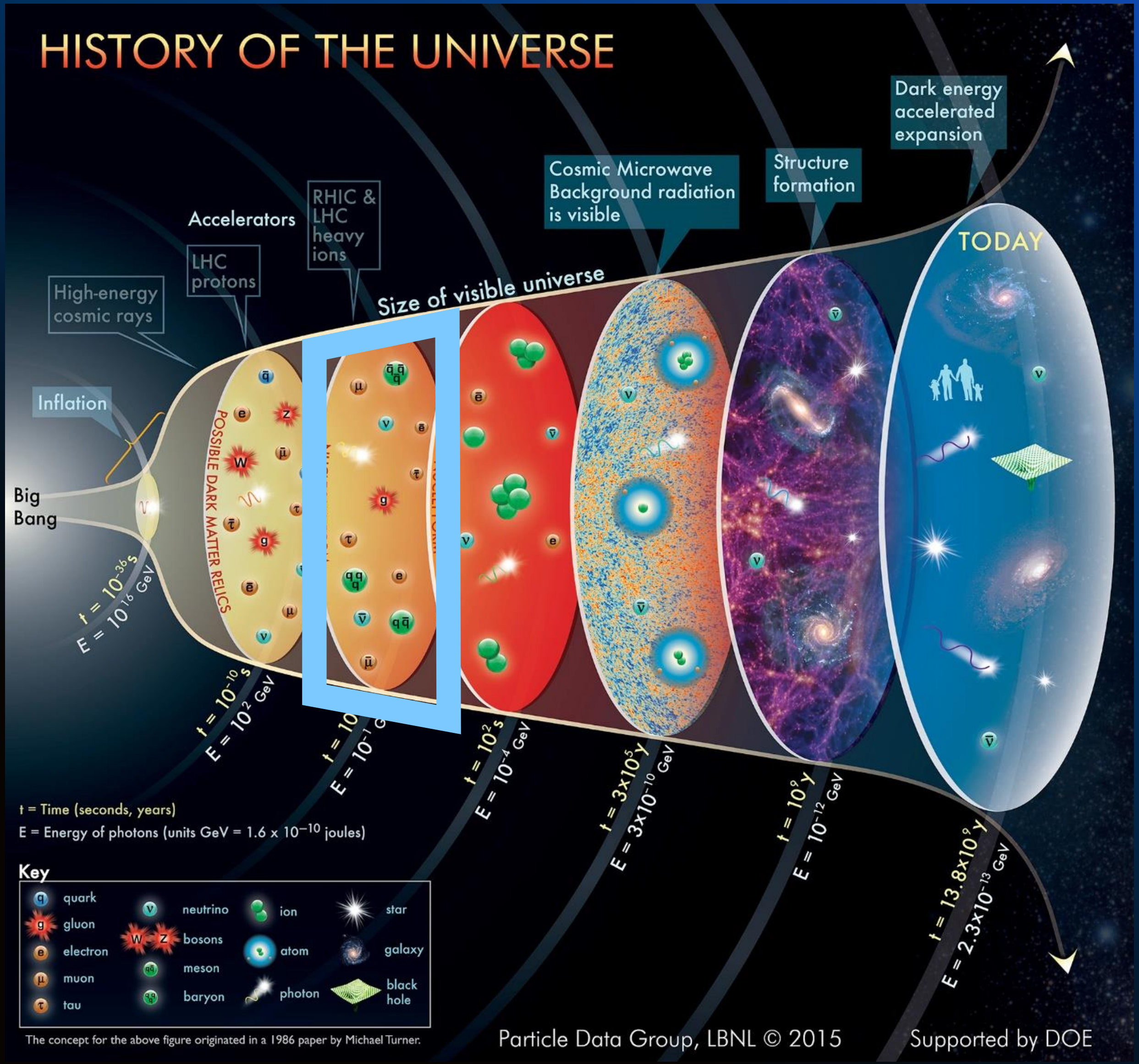
Data from: M. Asplund *et al.* Annual Reviews of Astronomy and Astropysics, Vol. 47, 481 (2009)

Isobaric abundance of the solar system



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

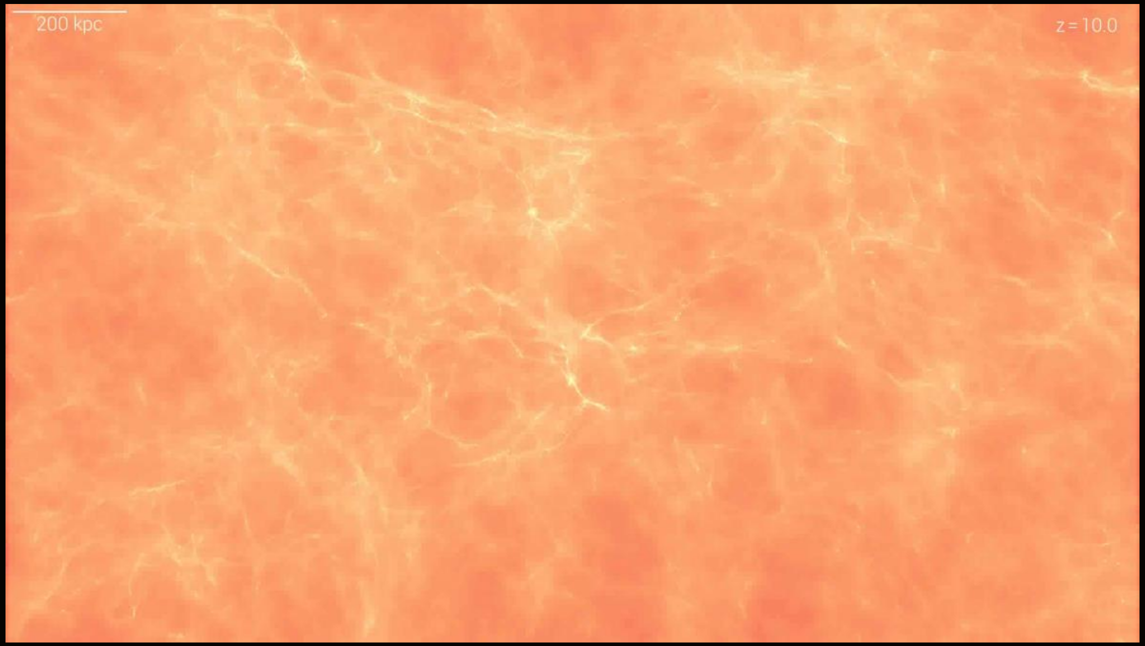
During the last 13.6Gyr…



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

Recreating nucleosynthesis environments

→ Large scale simulation ~$\mathcal{O}$(Mpc)
→ Simulation of galaxy supercluster



→ “Small” scale simulation ~$\mathcal{O}$(kpc)
→ Simulation of a single galaxy

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

→ Osmium
→ density: ~22 g/cm^3
→ densest material on earth

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

Active poll

How much more dense does the center of a protostar need to get in order to finally start nucleosynthesis?

0 0 0

- 5 times more than Os
- 300 times more than Os
- 8000 times more than Os

Join at

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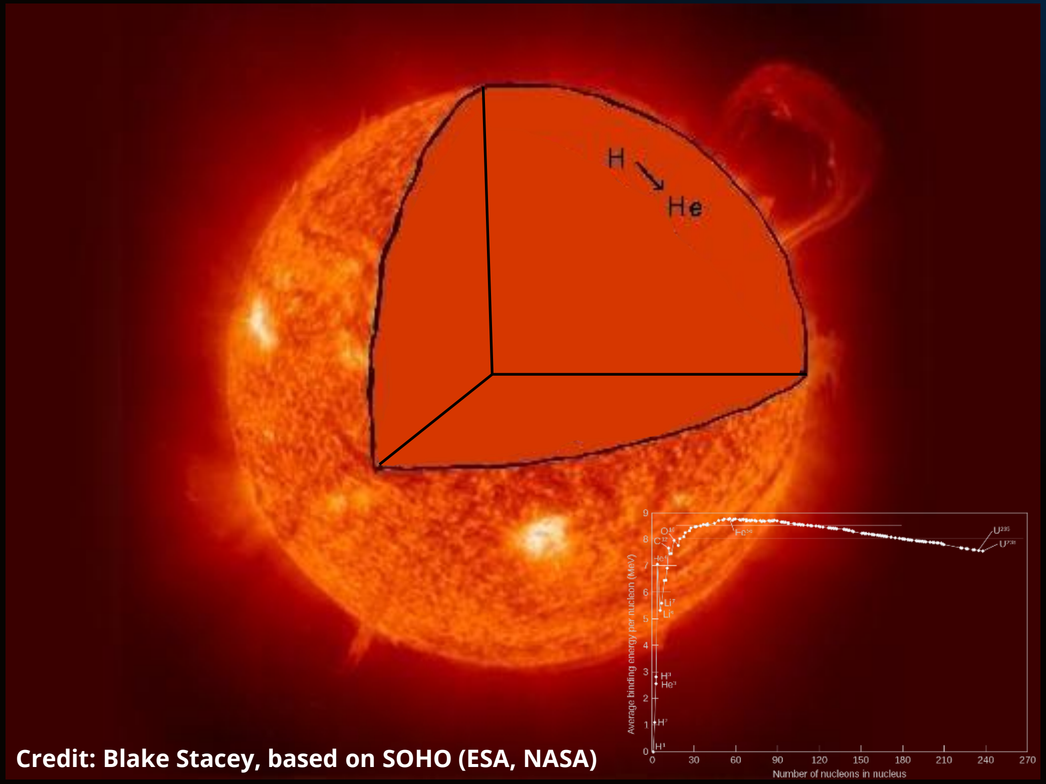
Protostar formation + stellar nucleosynthesis

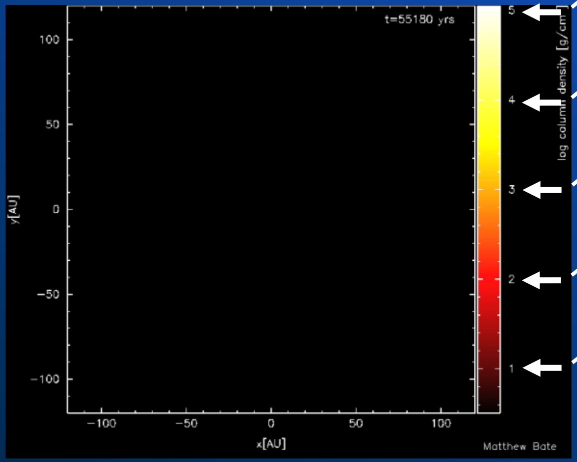


Credit: Blake Stacey, based on SOHO (ESA, NASA)

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

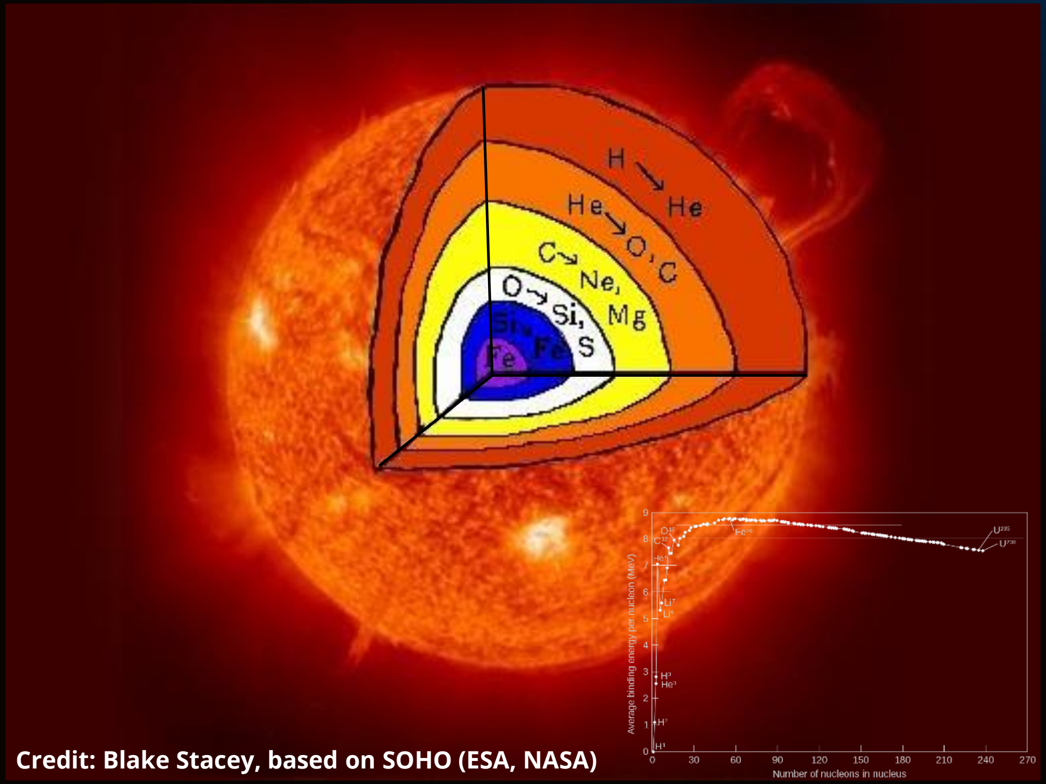
Density /[g/cm³]



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

Courtesy: Matthew Bate (University of Exeter)

Stellar nucleosynthesis

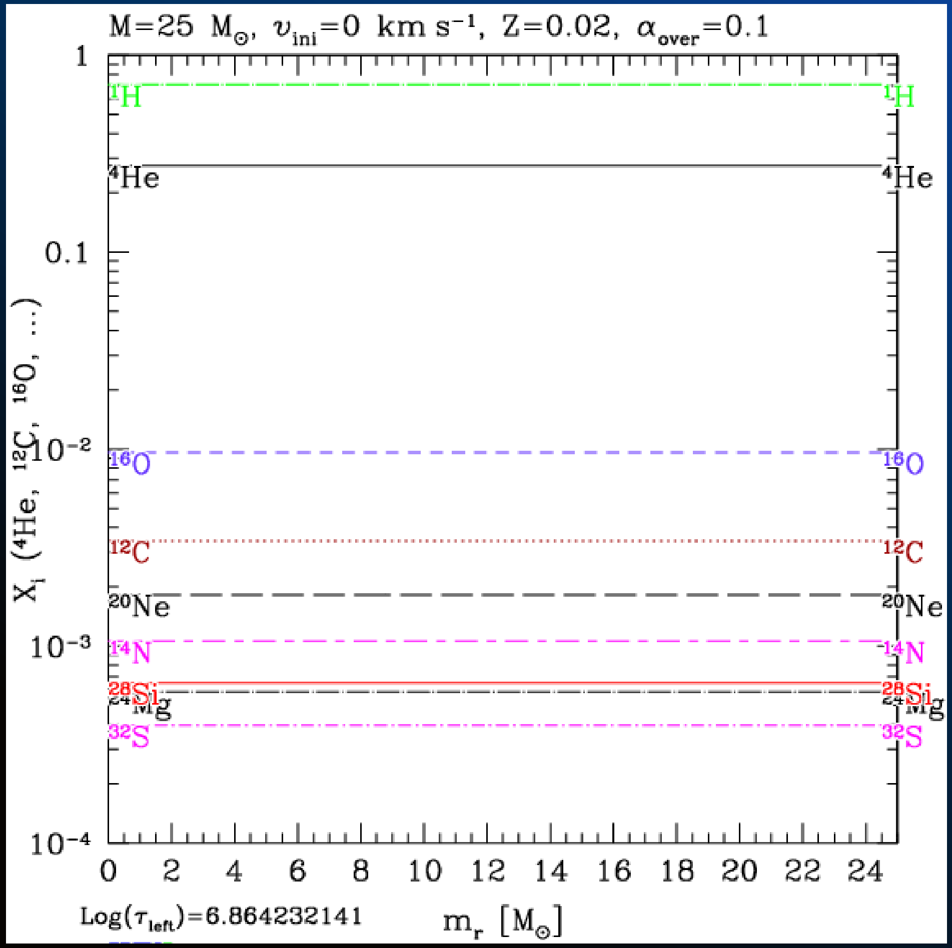


Credit: Blake Stacey, based on SOHO (ESA, NASA)

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

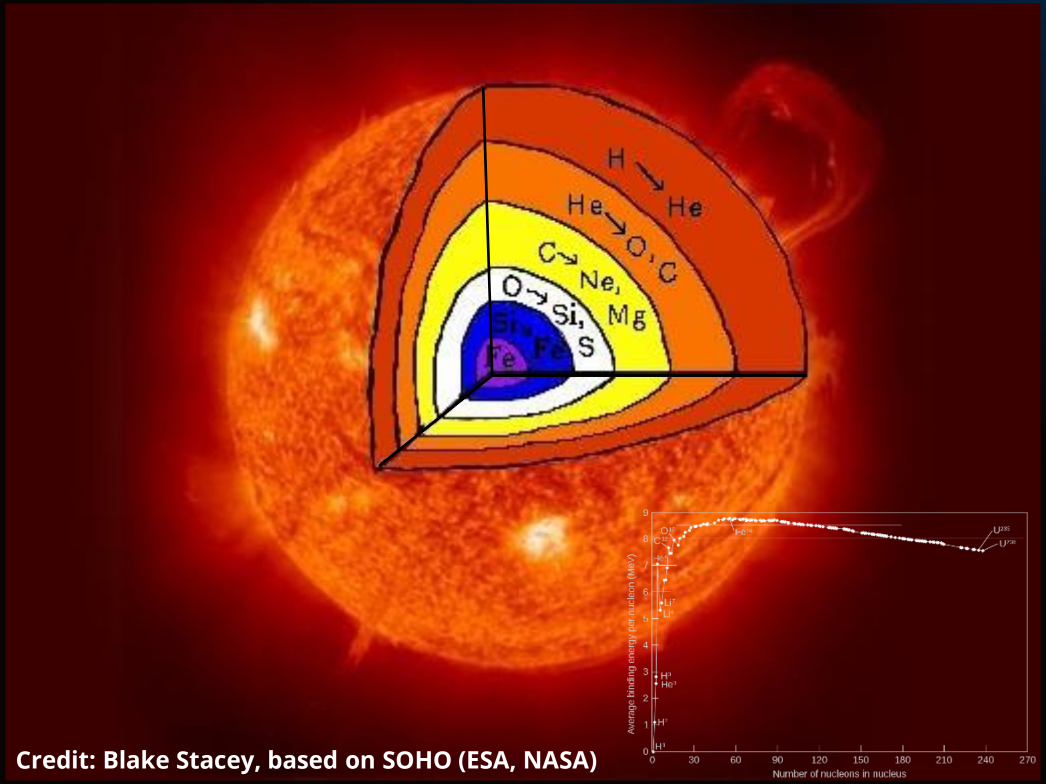
Core ↓

Surface ↓



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

Stellar nucleosynthesis

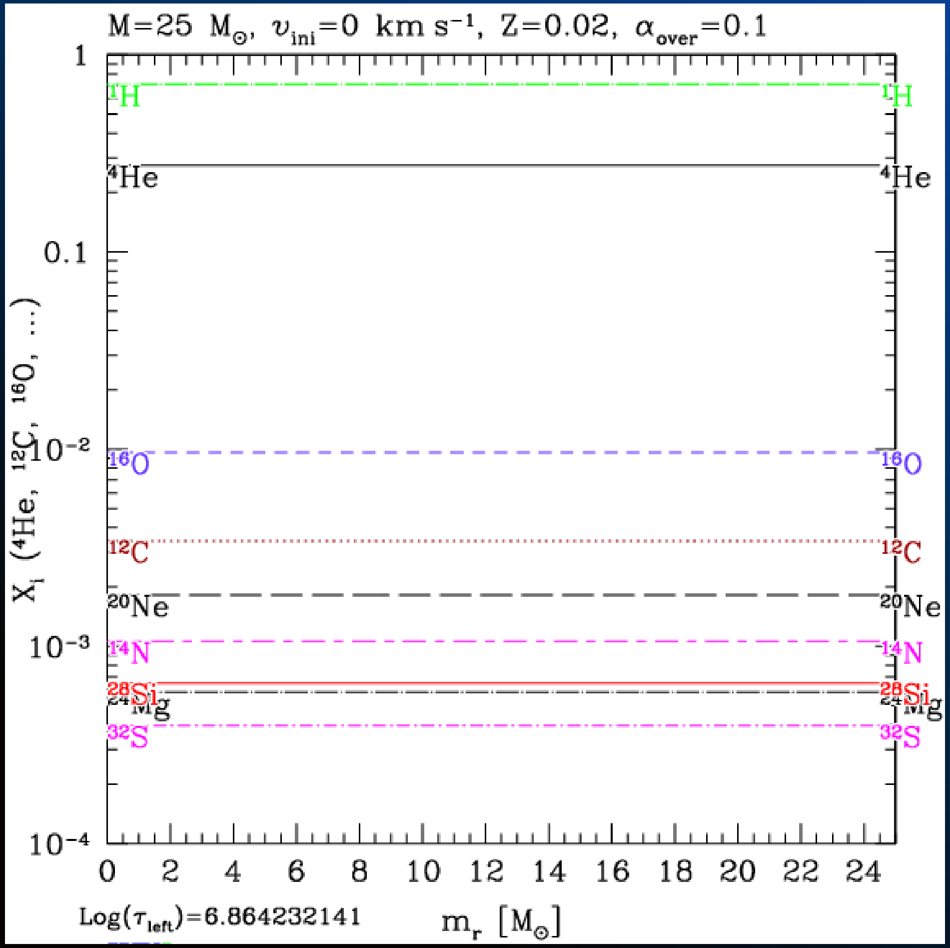


Credit: Blake Stacey, based on SOHO (ESA, NASA)

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

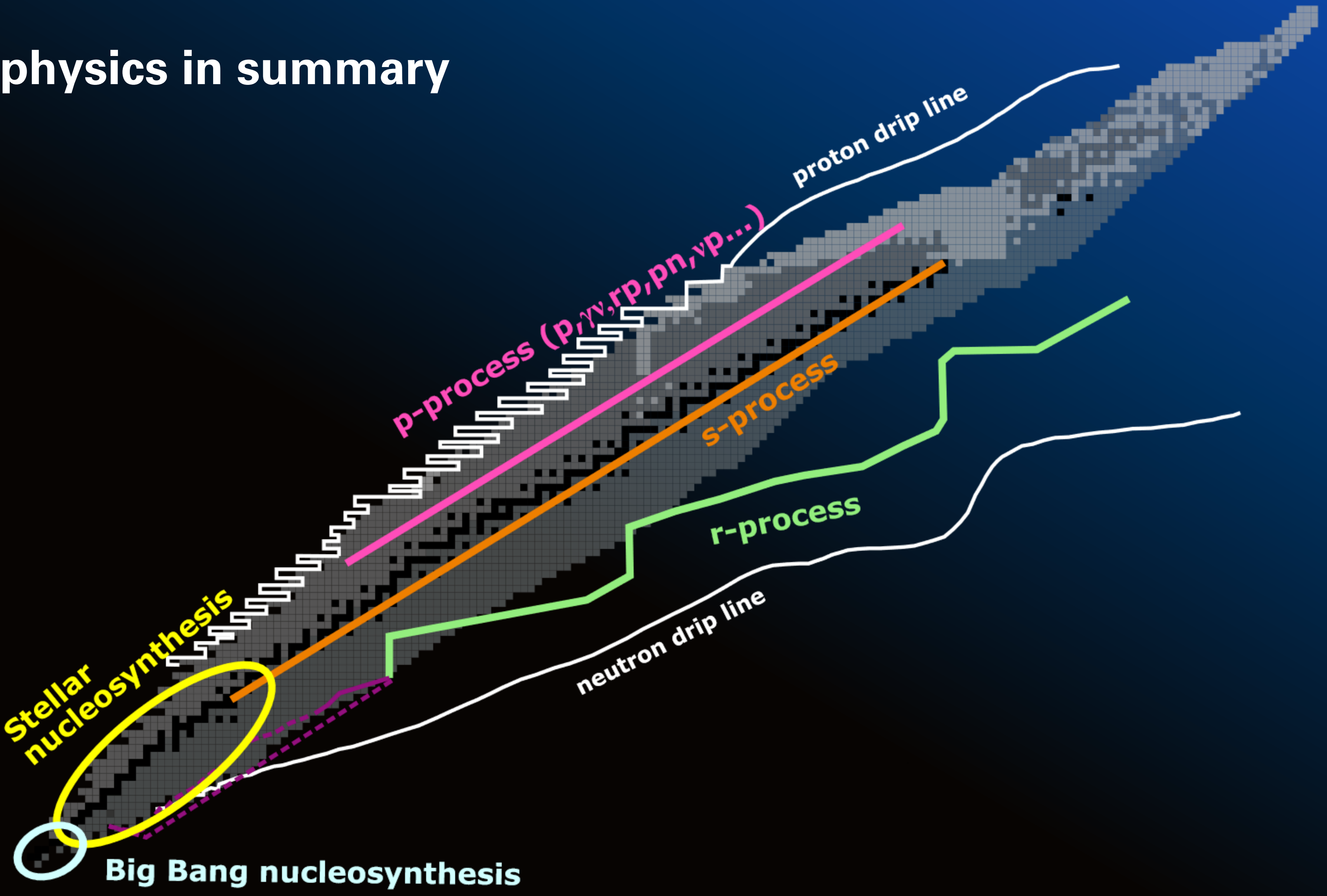
Core

Surface

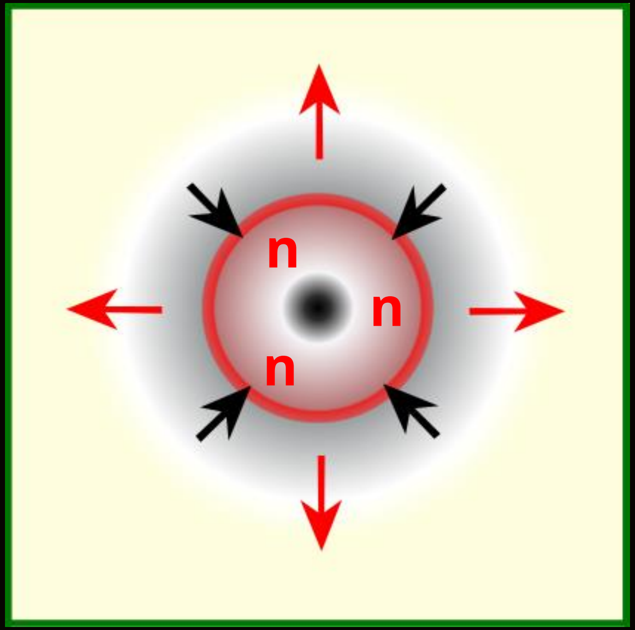


https://www.astro.keele.ac.uk/~hirschi/animation/anim.html

Nuclear astrophysics in summary

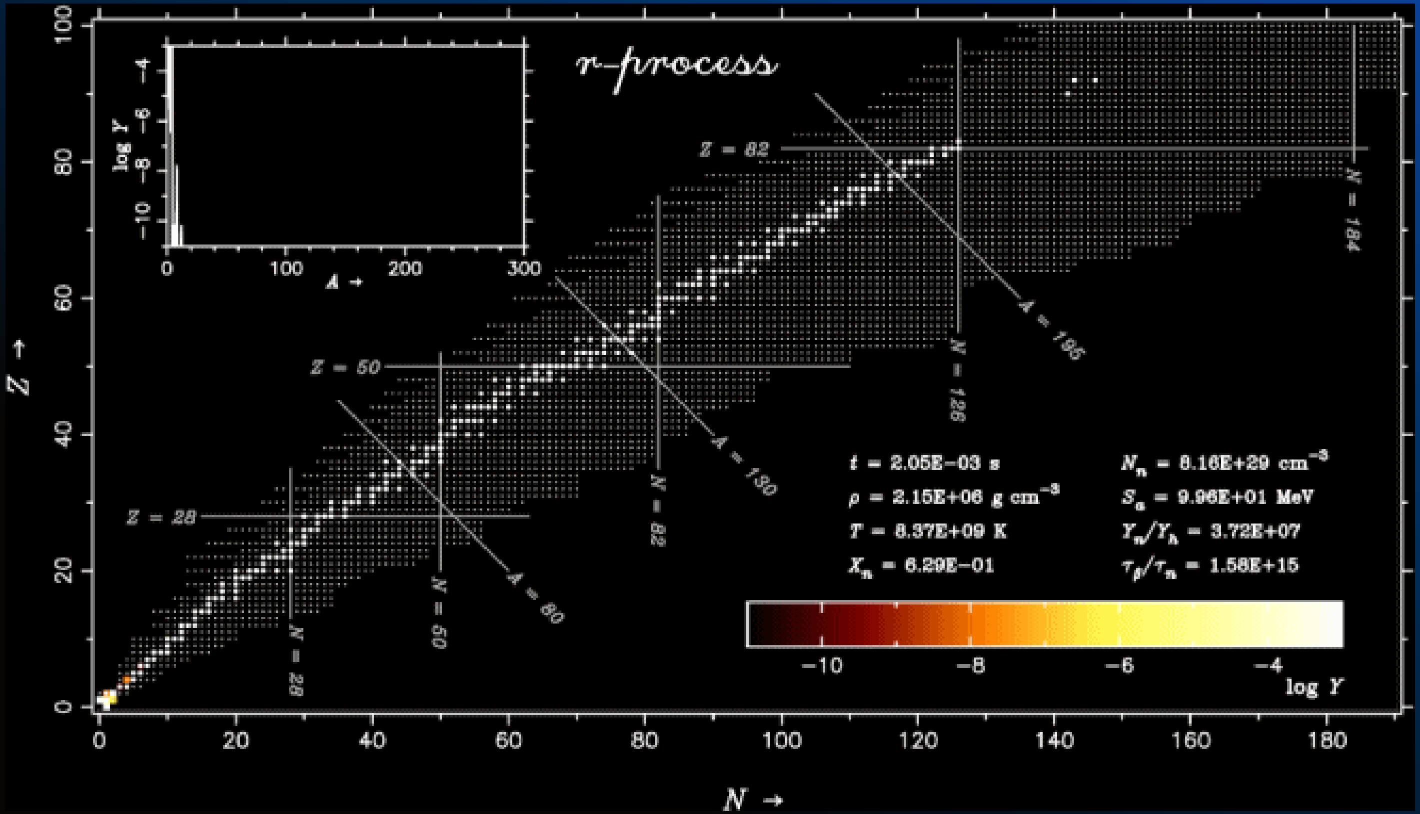


Explosive nucleosynthesis



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

Explosive nucleosynthesis

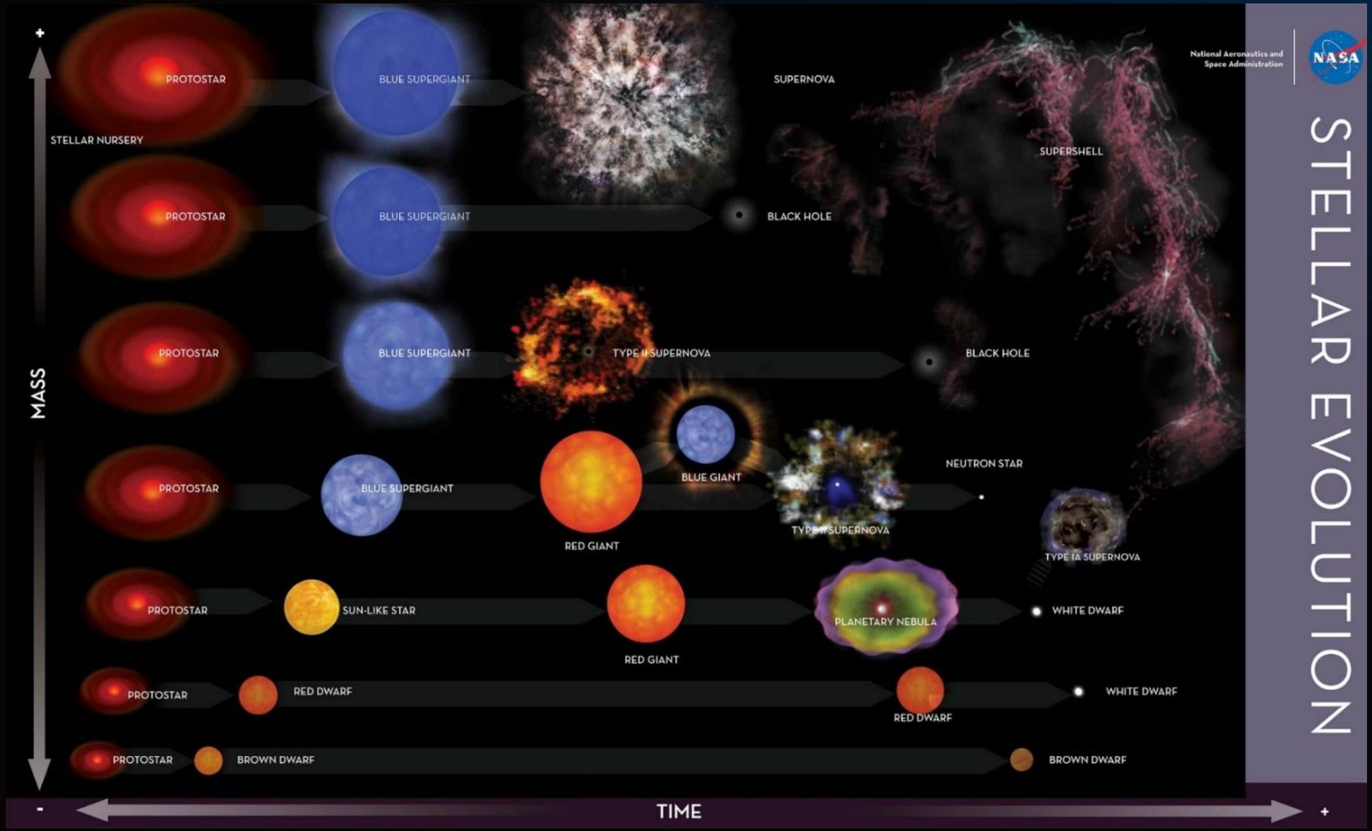


http://www.ph.sophia.ac.jp/~shinya/research/research.html

https://en.wikipedia.org/wiki/Type_II_supernova# … A_Spitzer_Crop.jpg)

Credit: ESA (https://www.esa.int/ESA_Multimedia/ …)

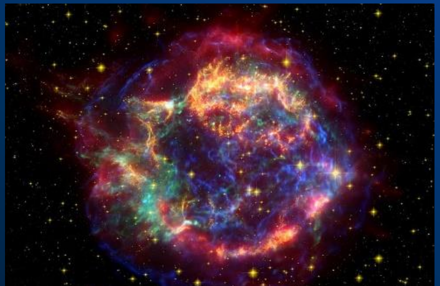
Nuclear astrophysics during stellar evolution



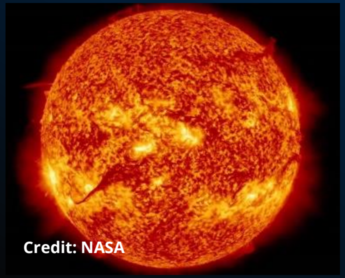
Credit: NASA (https://www.accessscience.com/media/EST/media/654000FG0010.jpg)

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

Credit: NASA



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



Credit: NASA

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

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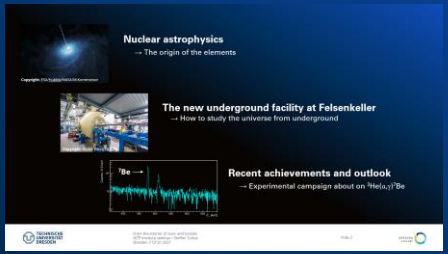
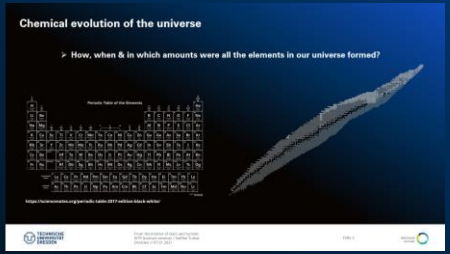
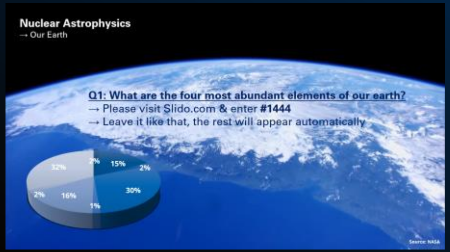
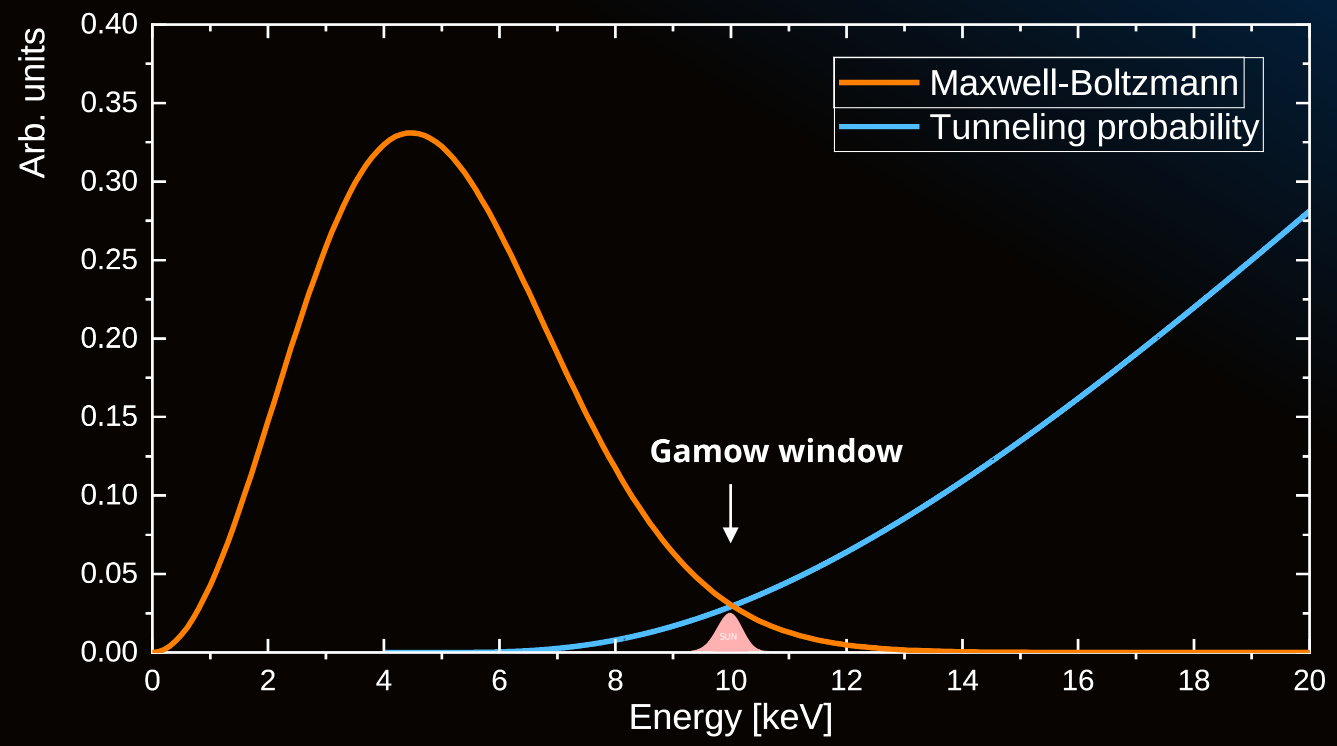
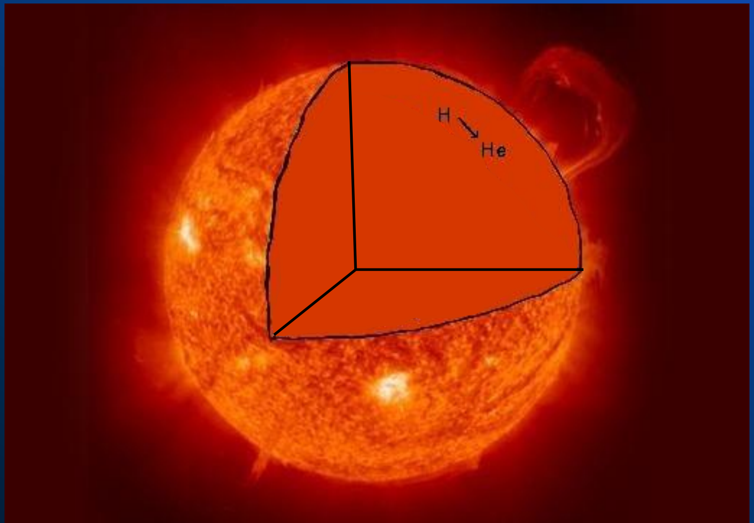




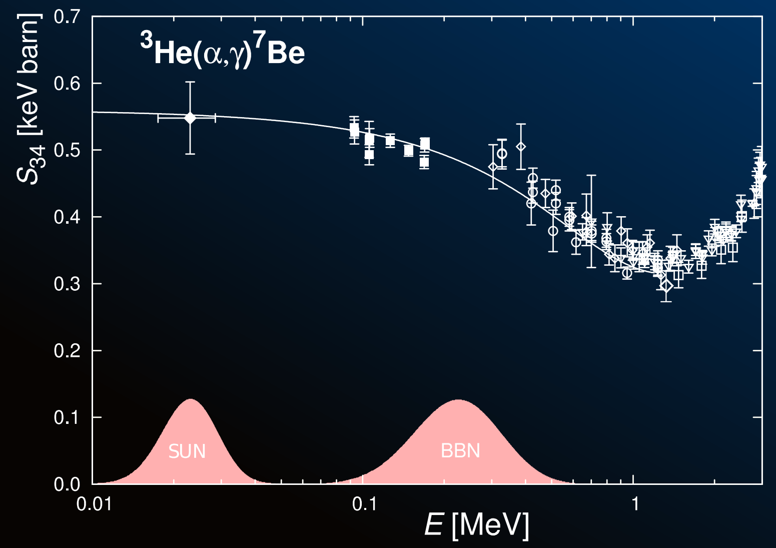


From the interior of stars to the interior of tunnels





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



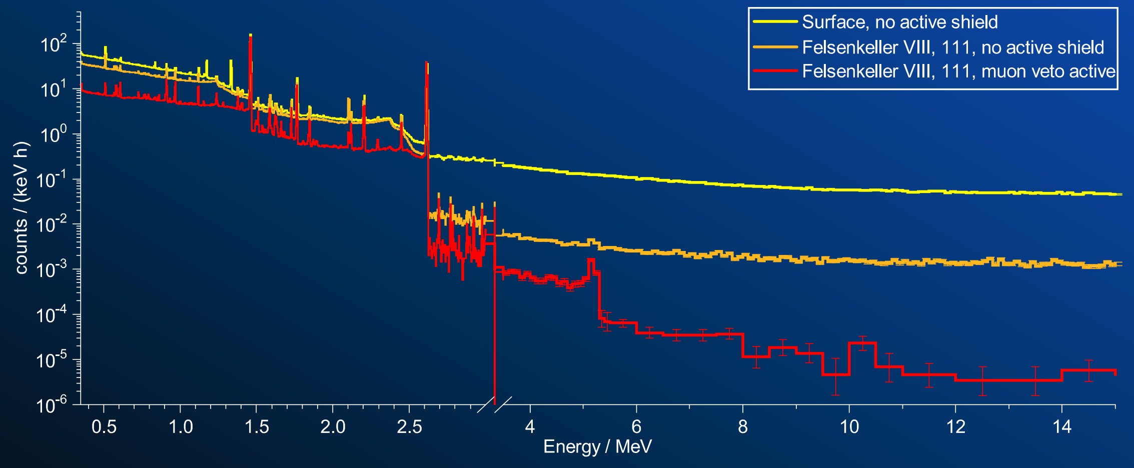
The new Felsenkeller laboratory

Technical leader
D. Bemmerer

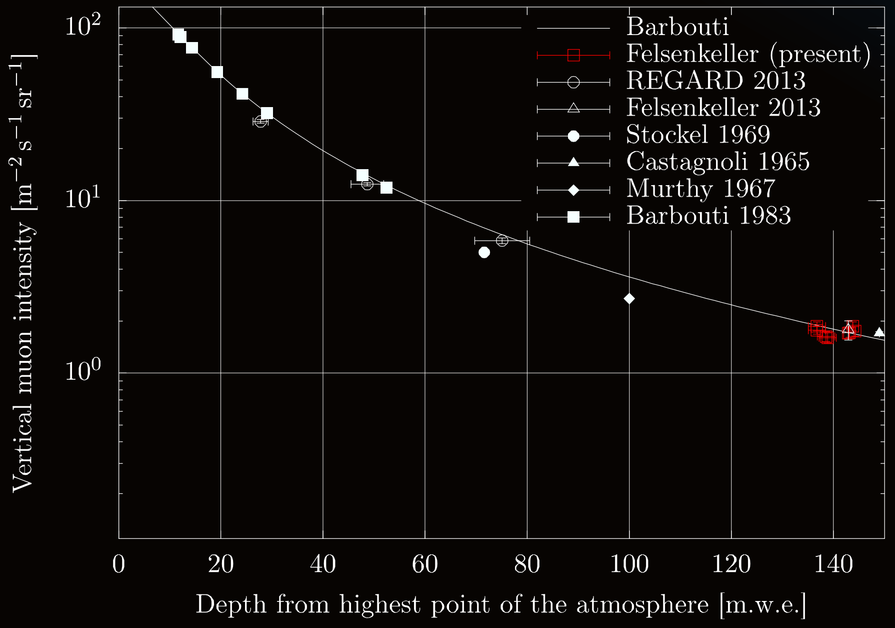
Scientific leader
K. Zuber

The benefit of going underground

- Protection from cosmic muons (reduce background)
- Investigate rare processes in nuclear astrophysics
  - Measure close to Gamow window

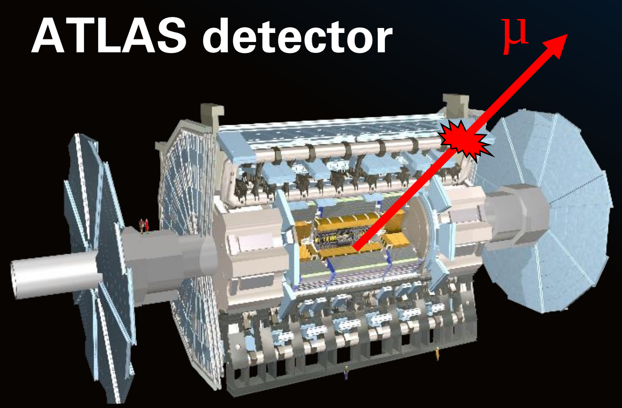


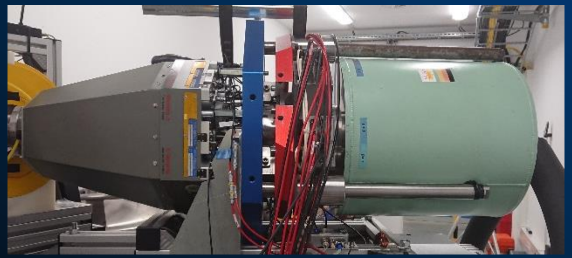
Adapted from: ***T. Szücs et al.*** **European Physics Journal A 55, 174**

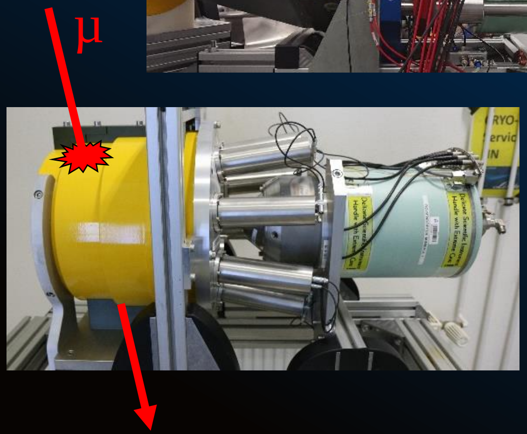


F. Ludwig et al. **Astroparticle Physics 112 (2019) 24-34**

ATLAS detector

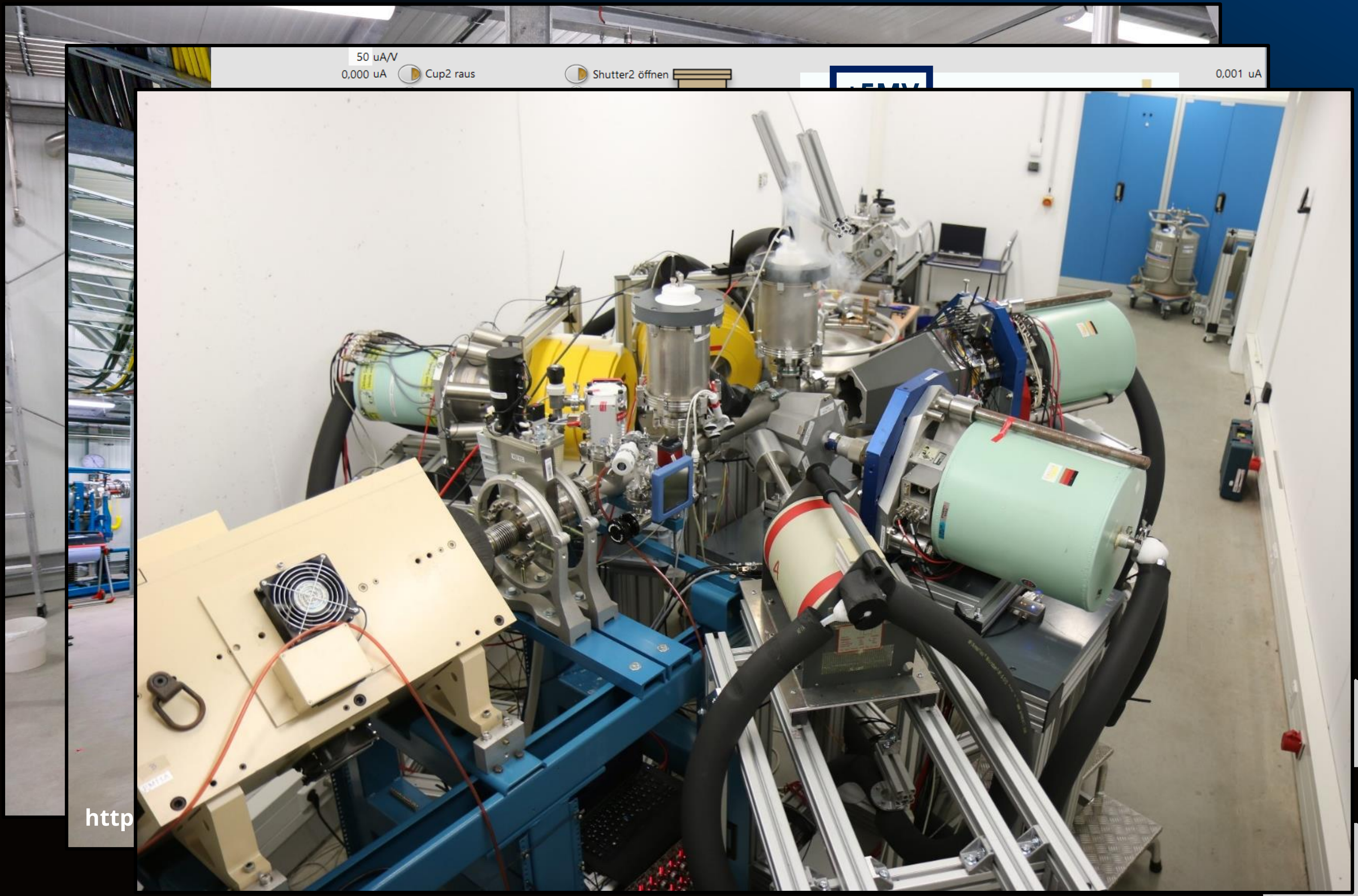




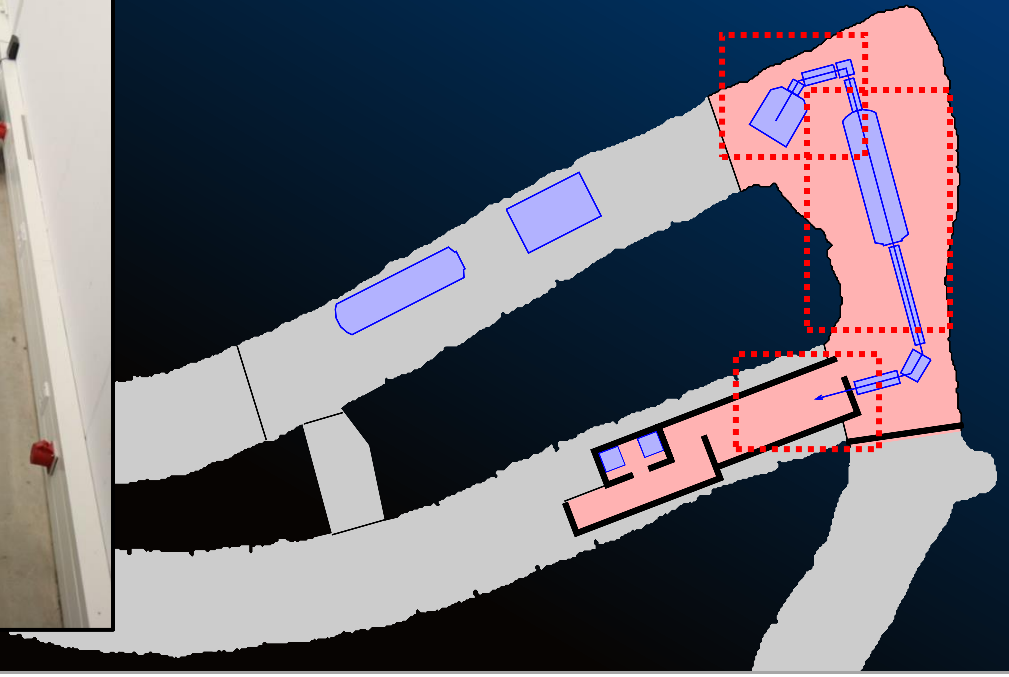


http://opendata.atlas.cern/books/current/get-started/_book/GLOSSARY.html

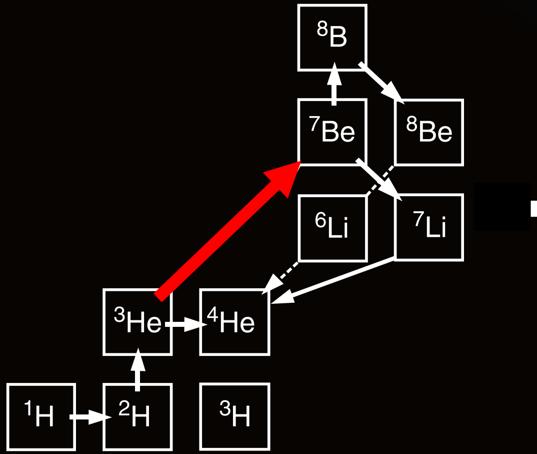
The new Felsenkeller underground laboratory

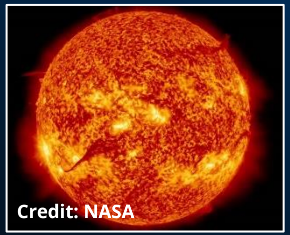


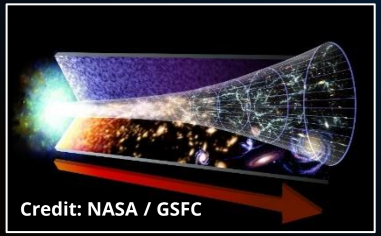
- → **External ion source**
  - → Carbon beam ($^{12}C^{-}$) in tandem mode
- → 5MV **Pelletron accelerator**
  - → Carbon beam in tandem mode
- → **Interal ion source**
  - → H & He beam in single end mode
- → **Current experimental setup**
  - → $^{3}He(\alpha,\gamma)^{7}Be$ campaign

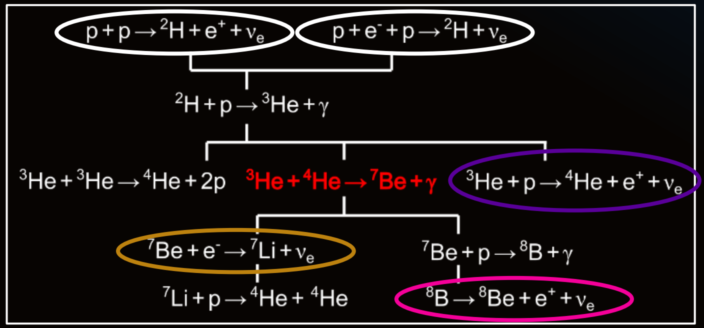


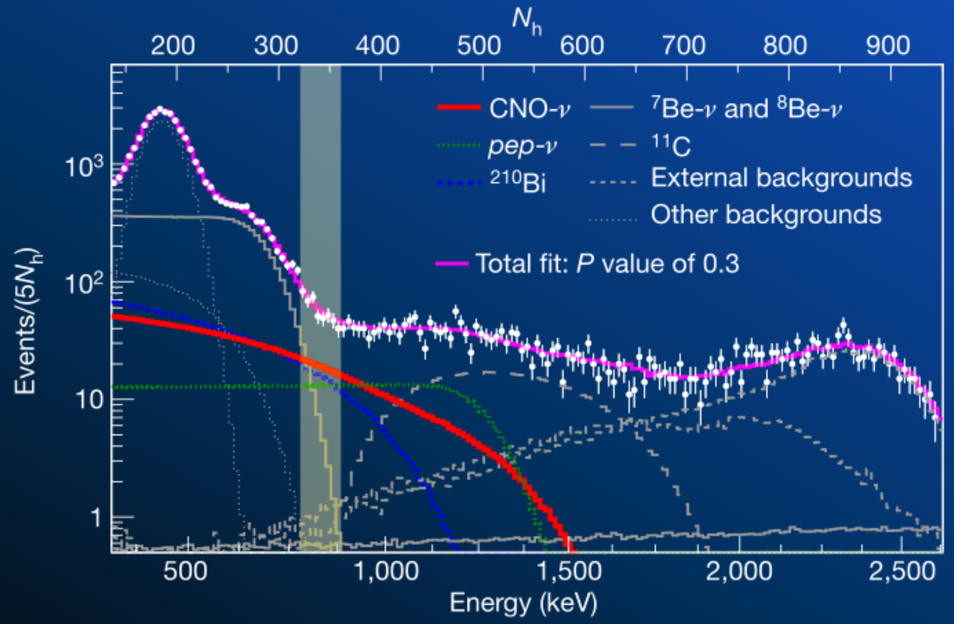
The $^3He(\alpha,\gamma)^7Be$ reaction



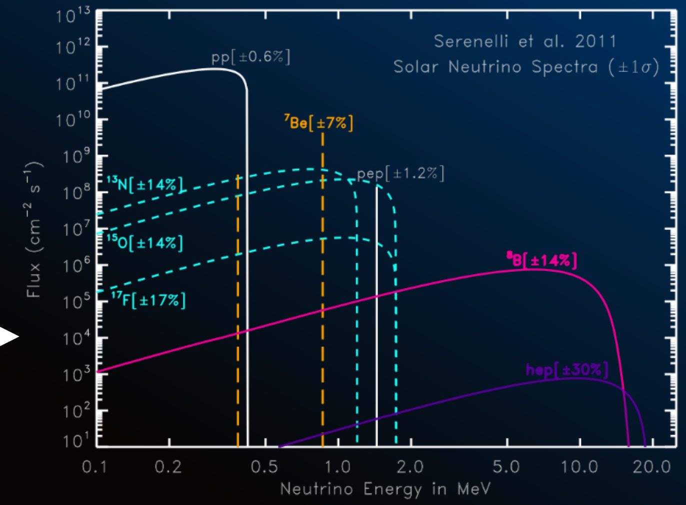

Credit: NASA


Credit: NASA / GSFC





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

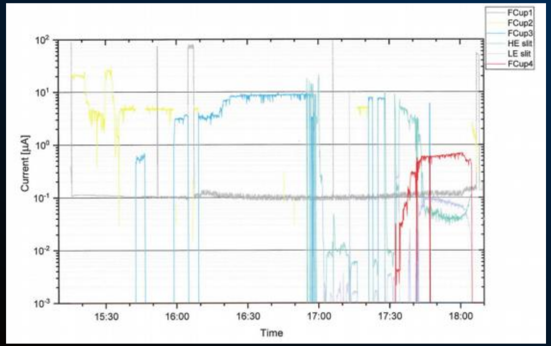


Haxton et al. **Annu. Rev. Astron. Astrophys. 51 1 (2013)**

Timeline of the last three years

Credit: Philipp Lindenau (TU Dresden)

28.06.2017: Topping out ceremony



03.07.2019: First light at FK (external ion source)

09.11.2020: Stable beam (internal ion source)

26.11.2020: Beam quality improvements

13.08.2018: Last beam line component underground

04.07.2019: Inauguration

Credit: André Wirsig (HZDR)

16.11.2020: First $^{3}He(\alpha,\gamma)^{7}Be$ reaction