New Frontiers in Big Bang Nucleosynthesis
Catching Up with Cosmology and Astronomy

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Nuclear Physics in Astrophysics XII
Cluj-Napoca

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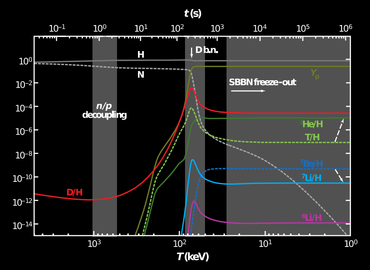
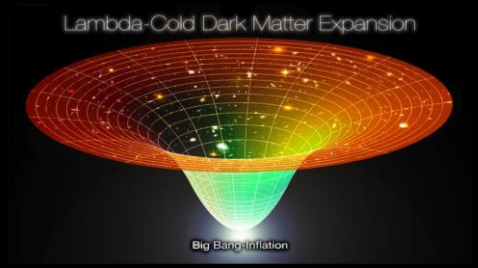
Technische Universität Dresden
INSTITUTE OF NUCLEAR AND PARTICLE PHYSICS
HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF
erc
LUNA NOVA



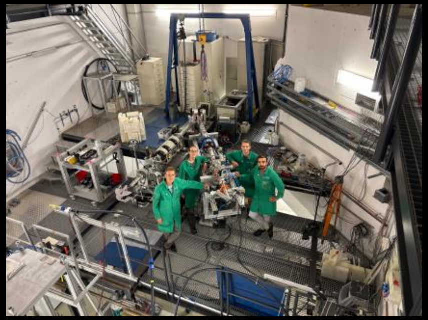
The Big Bang Nucleosynthesis

→ Nuclear astrophysics during the first minutes of our universe



Cosmic concordance

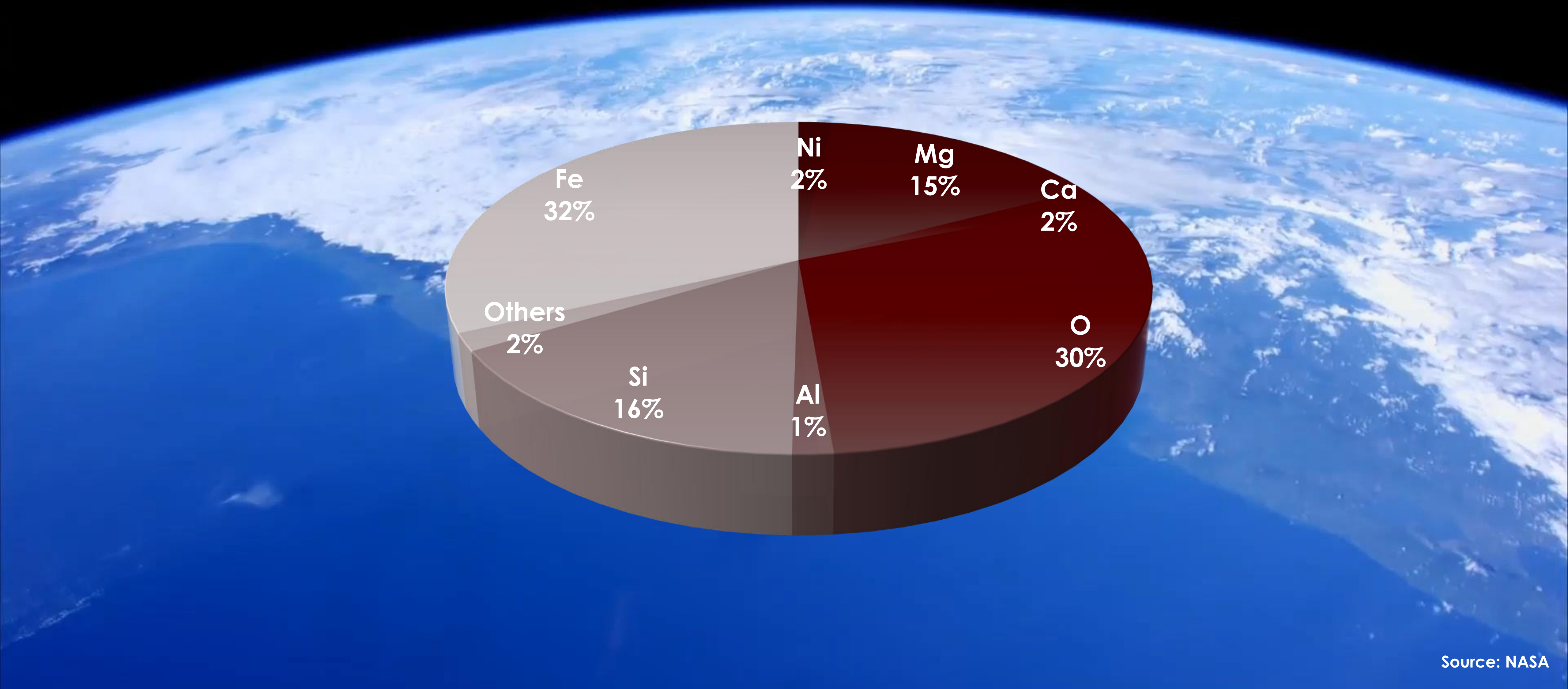
→ Connection to cosmology and astrophysics



Catching Up with Cosmology and Astronomy

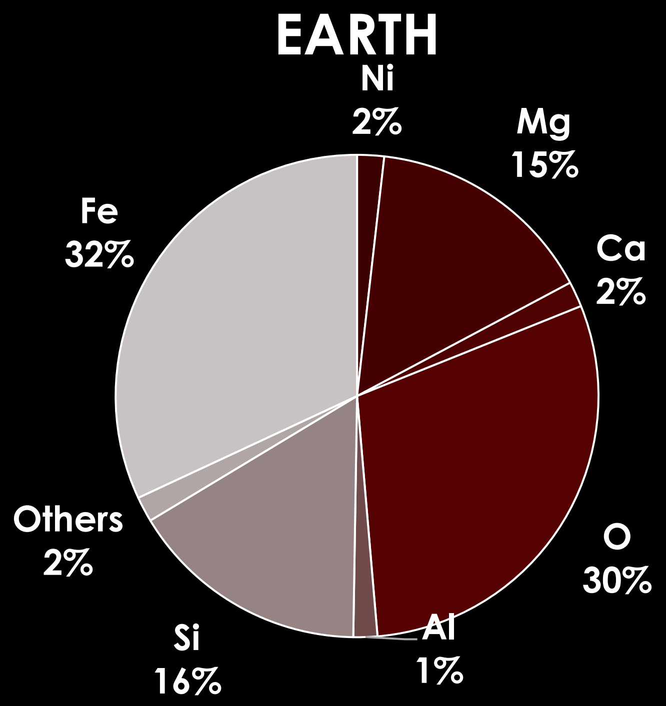
→ ^{2}H(^{2}H,p)^{3}H and ^{2}H(^{2}H,n)^{3}He at the DT generator of TU Dresden

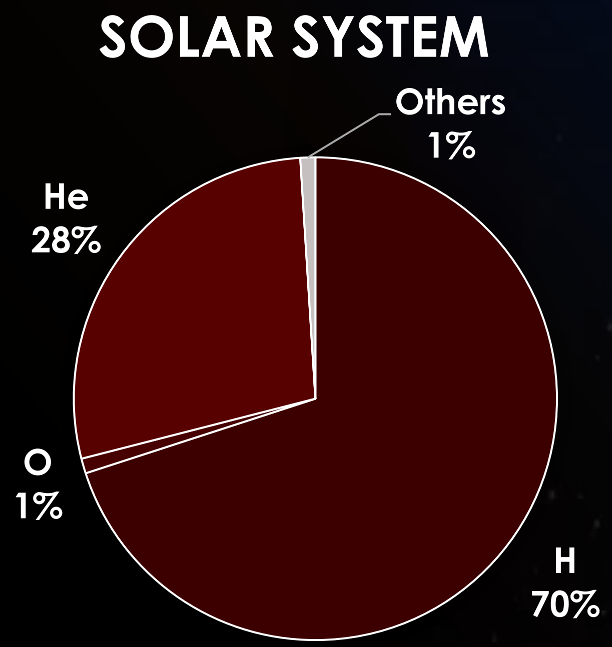
Elemental composition of our earth

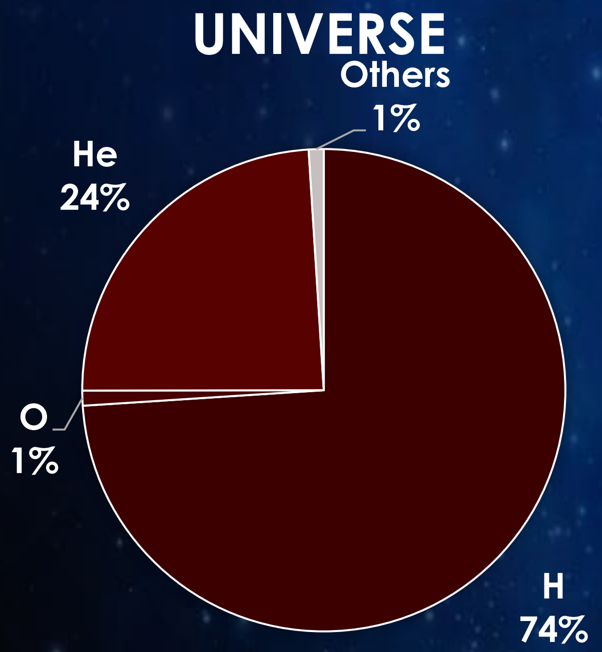


Source: NASA

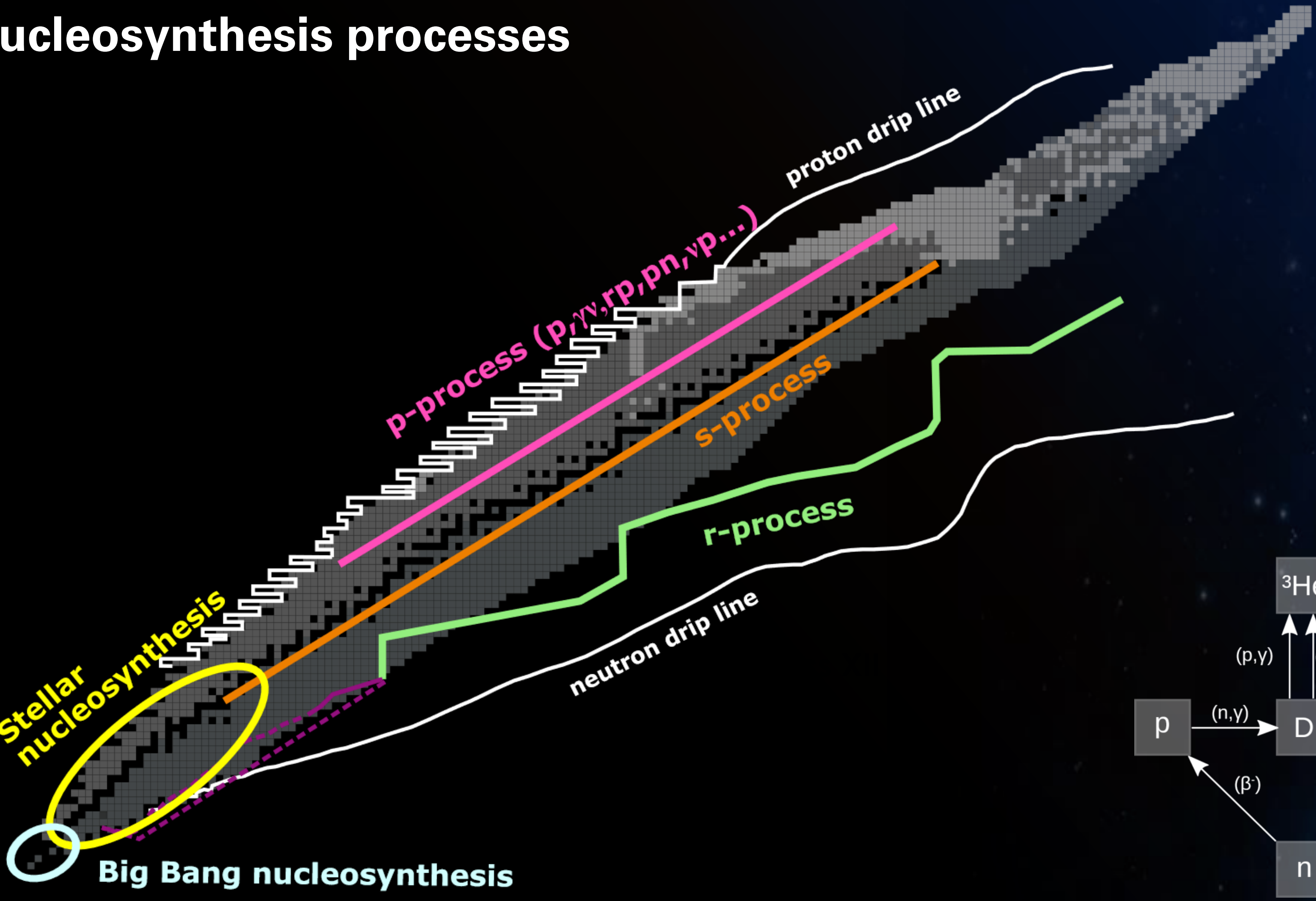
The chemical composition of our universe

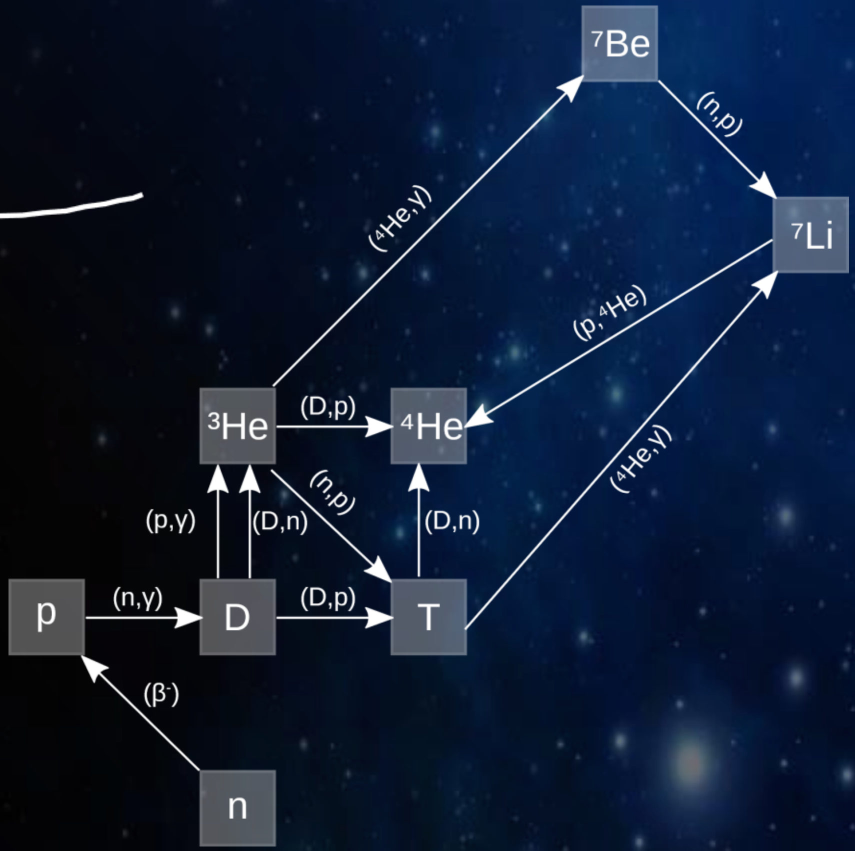




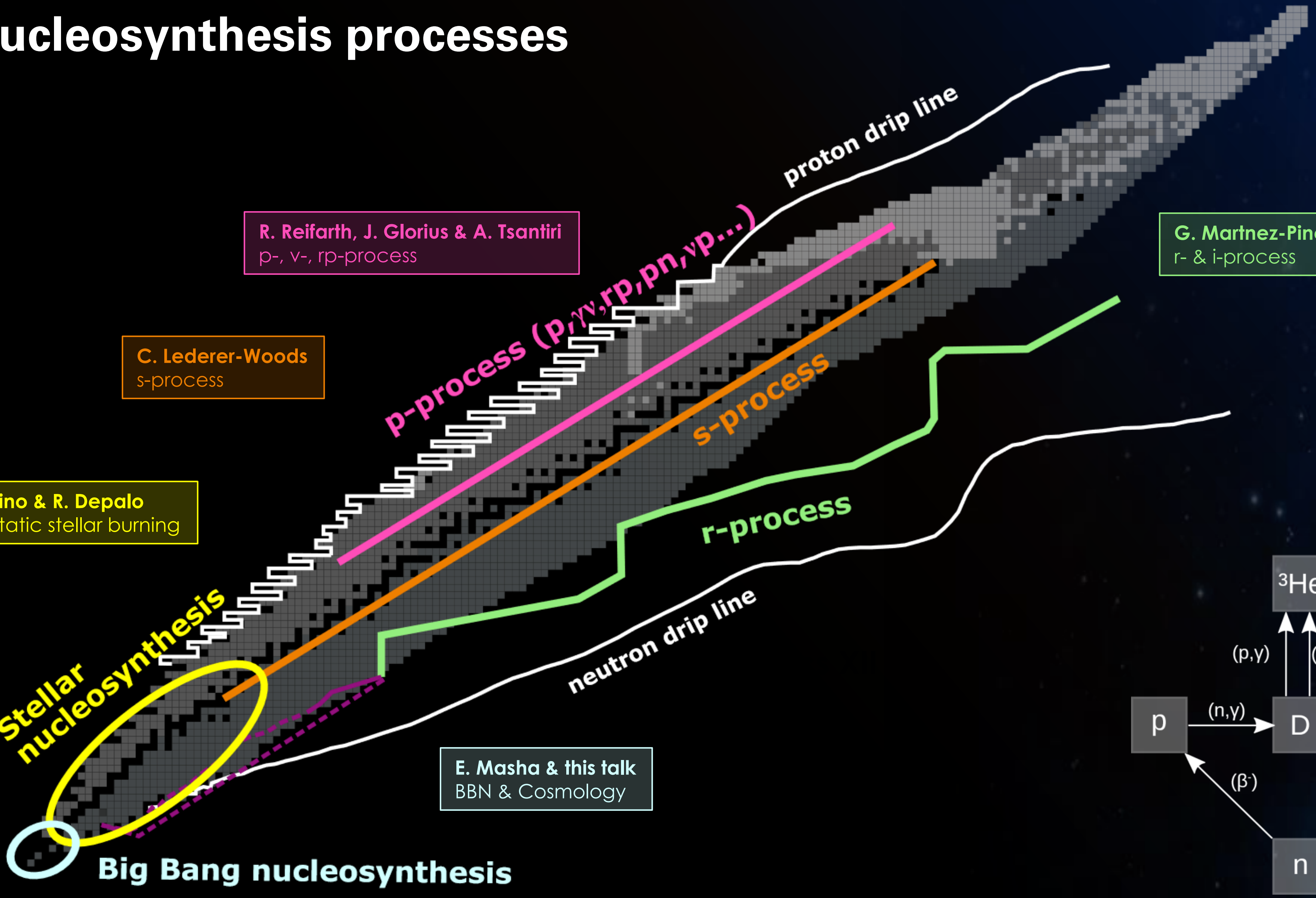


Nucleosynthesis processes





Nucleosynthesis processes



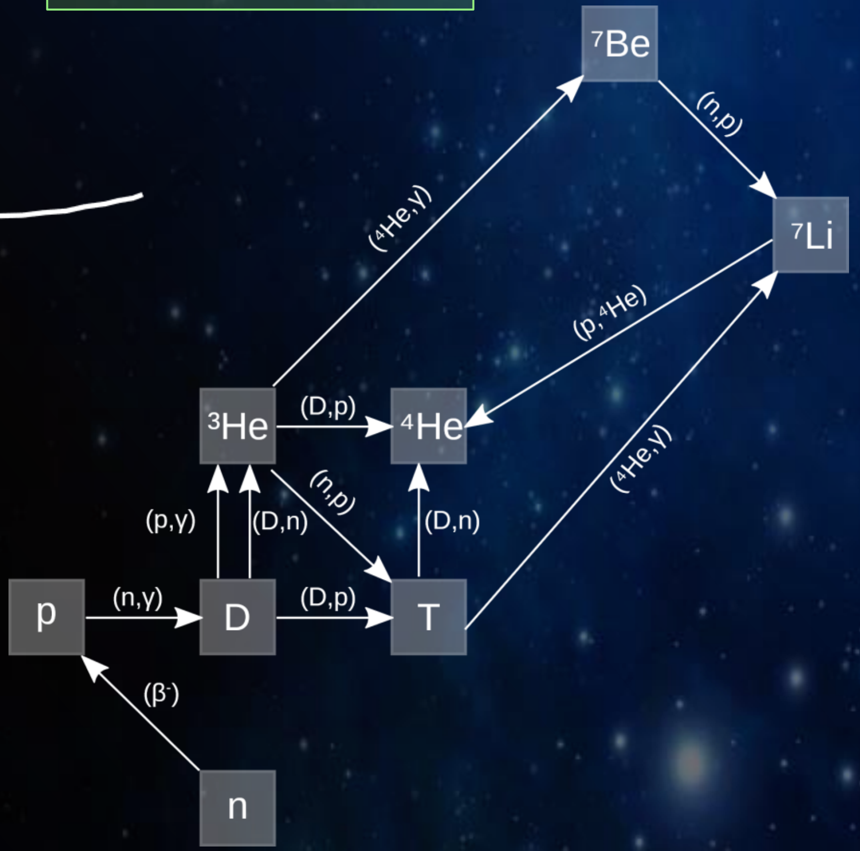
R. Reifarth, J. Glorius & A. Tsantiri
p-, ν-, rp-process

C. Lederer-Woods
s-process

A. Tumino & R. Depalo
Hydrostatic stellar burning

E. Masha & this talk
BBN & Cosmology

G. Martnez-Pinedo & N. Vassh
r- & i-process



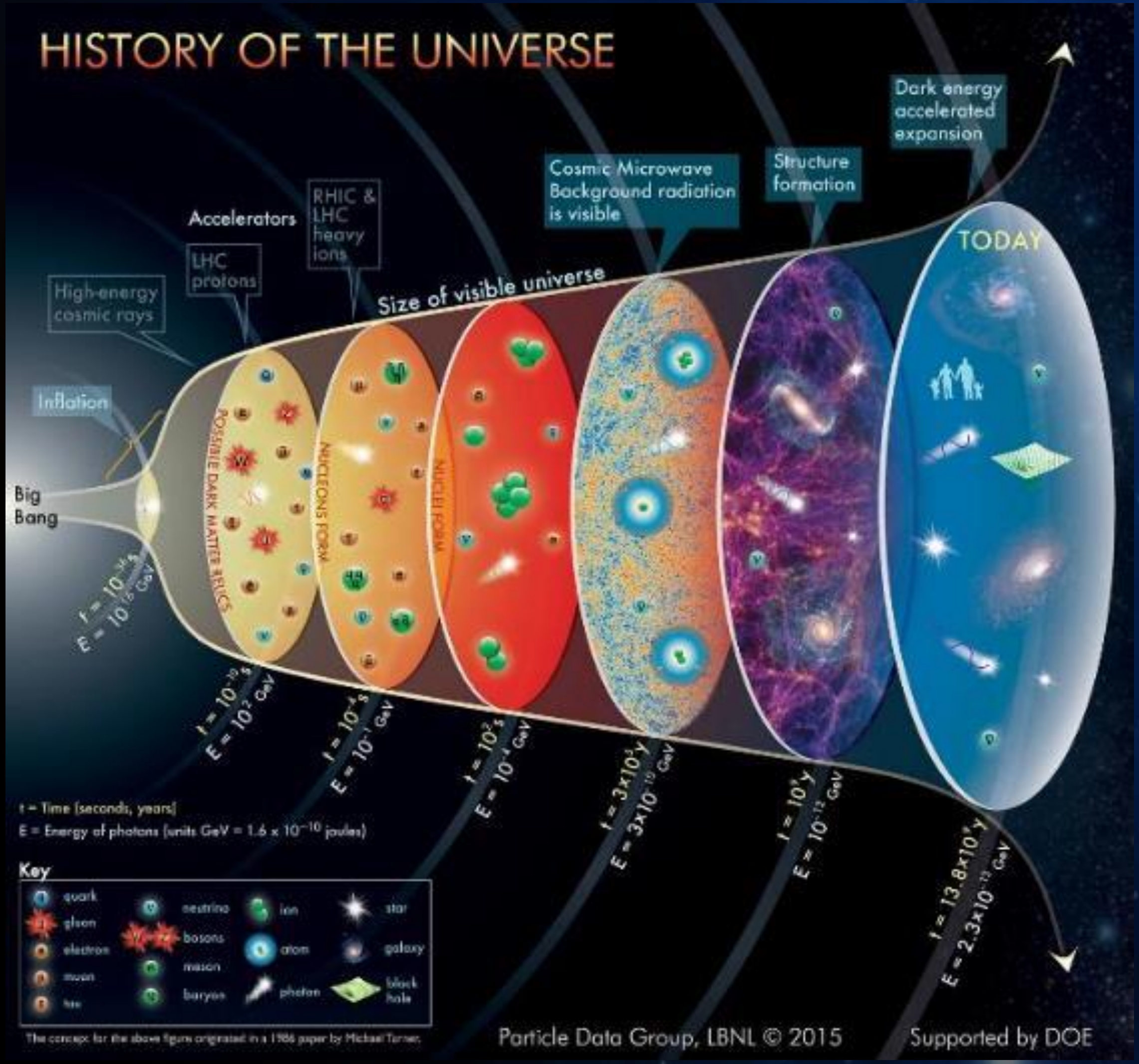
Big Bang Nucleosynthesis

The birth of the nucleons (E ~ 150MeV)

- Protons and neutrons condense from QGP

What information do we need for BBN?

- **What do we start with?**
  - **t≪1s: Neutron to proton ratio n/p = 1**
  - Weak interaction preserves equilibrium



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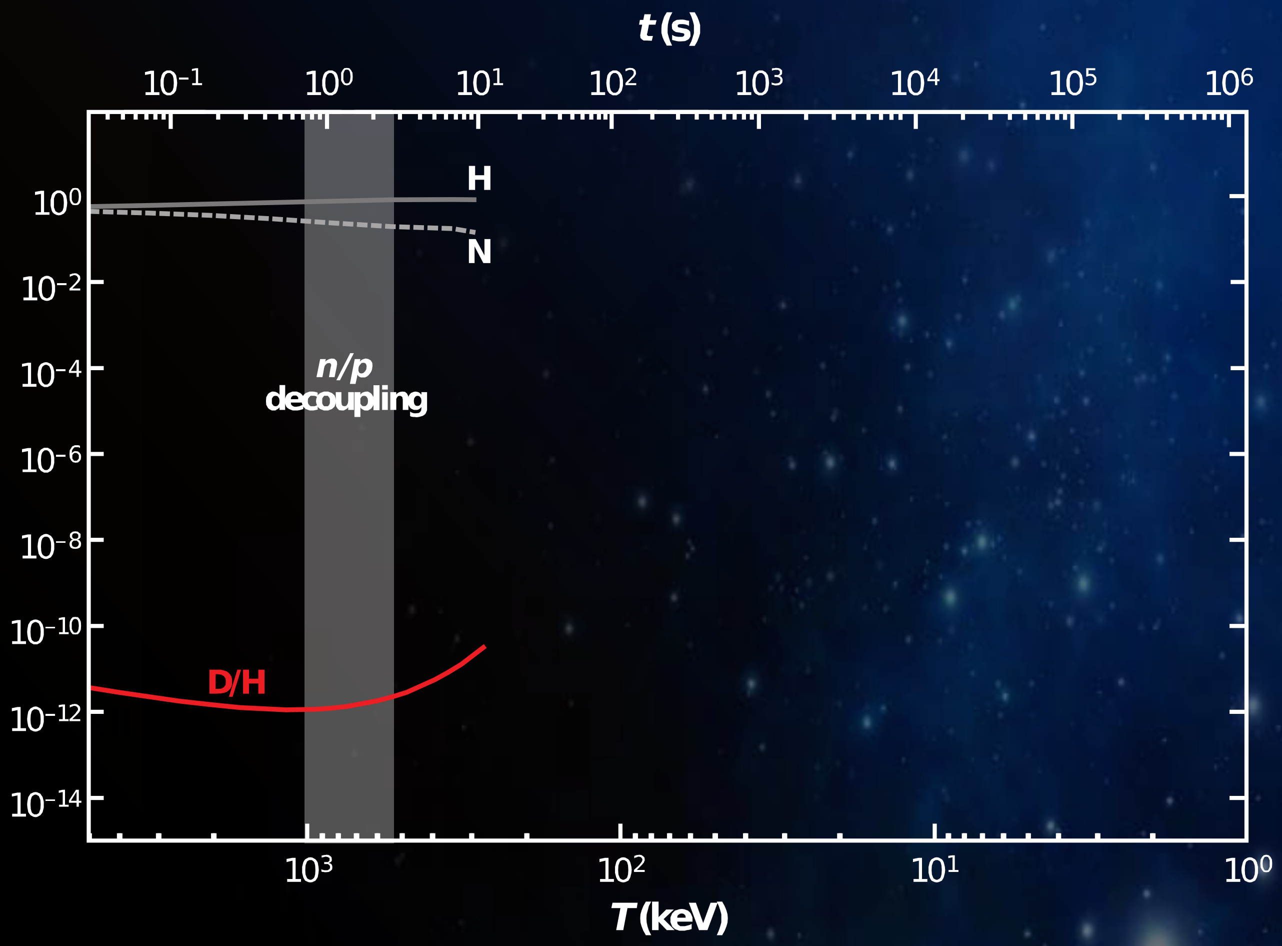

Adapted from: M. Pospelov, J. Pradler Ann. Rev. Nucl. Part. Sc. 60 539 (2010)

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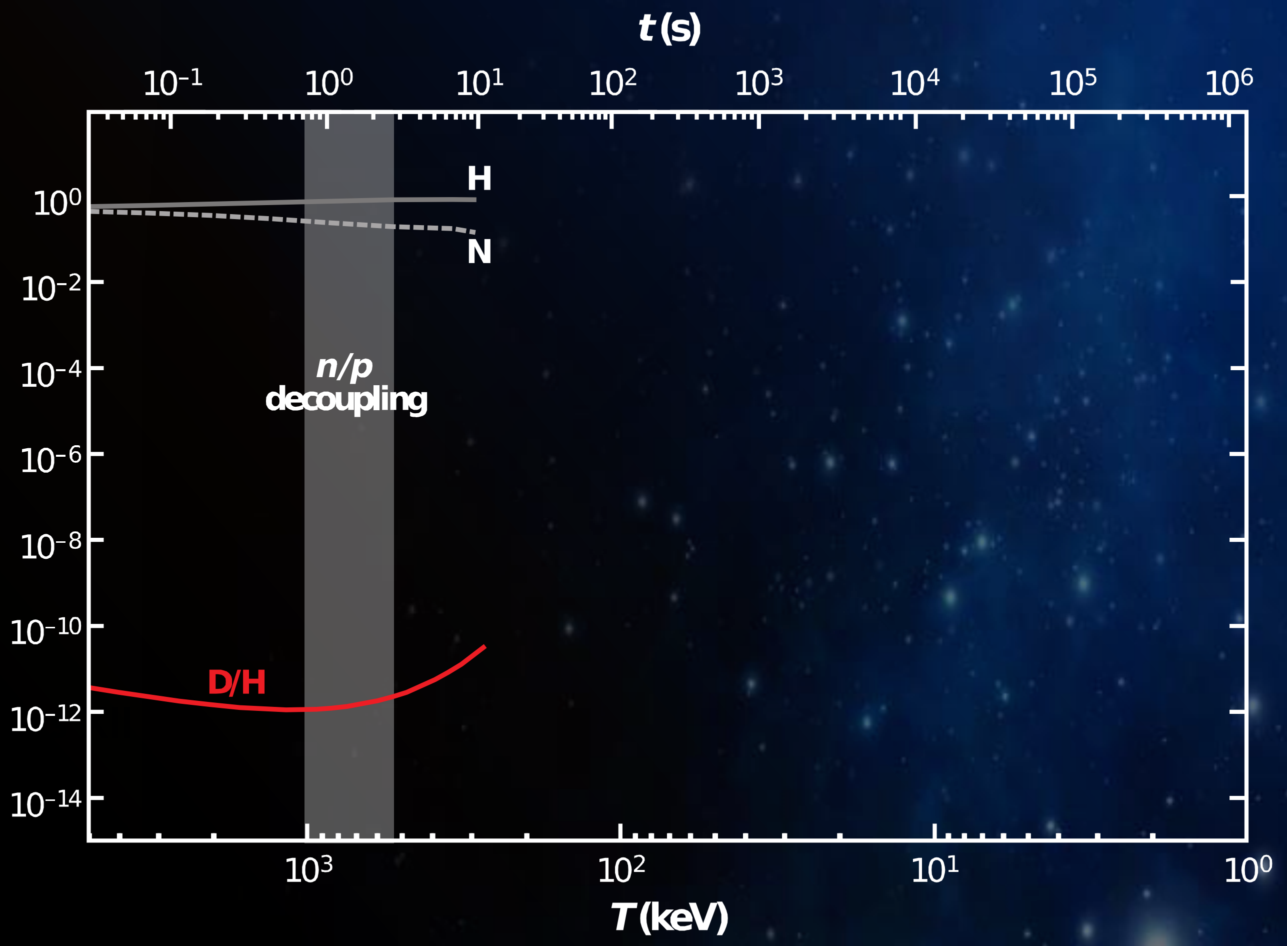
- **Does this change over time?**
  - **Mass ratio** leads to deviations
    At ~2s: n/p freeze-out with n/p ~ 1/6

$$\frac{n_\mathrm{n}}{n_\mathrm{p}} = \left(\frac{m_\mathrm{n}}{m_\mathrm{p}}\right)^{3/2} \exp\left(-\frac{Q}{k_\mathrm{B}T}\right) \approx \exp\left(-\frac{Q}{k_\mathrm{B}T}\right)$$

  - **Neutron life time** is crucial
    Until 270s: n/p ratio mainly influenced by $T_{1/2}(n)$
    At this point: n/p ~ 1/7
- **What is creating new elements?**
  - **Reaction cross sections**
- **What can potentially dissociate elements?**
  - **Baryon/Photon ratio**



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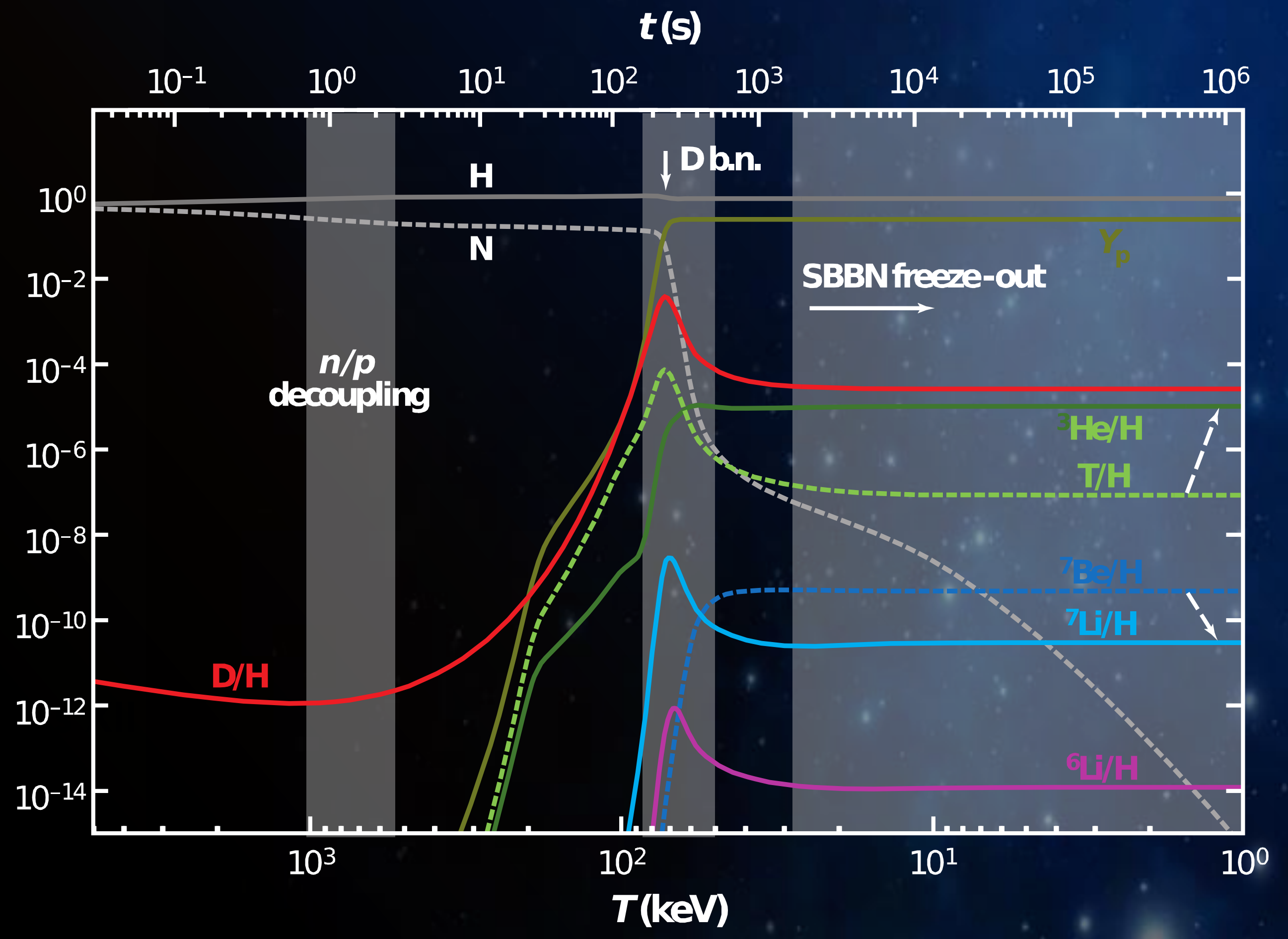

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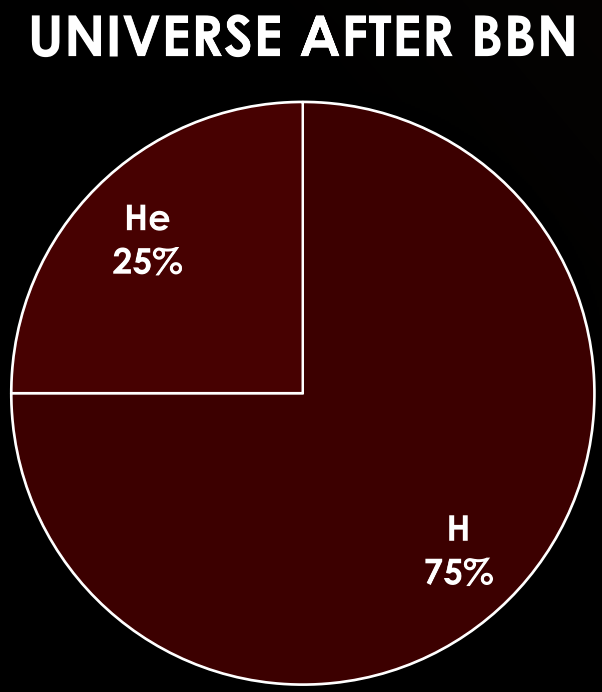
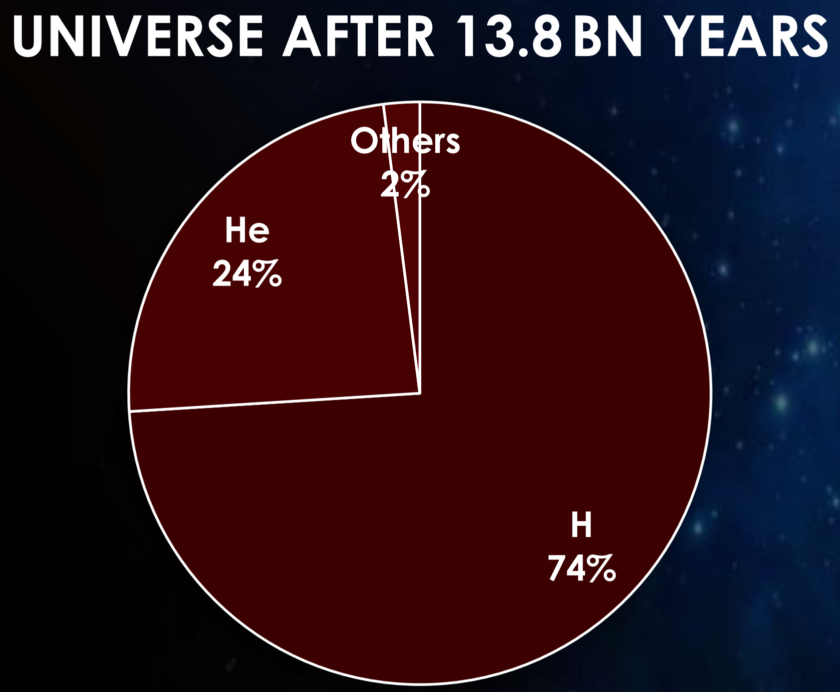
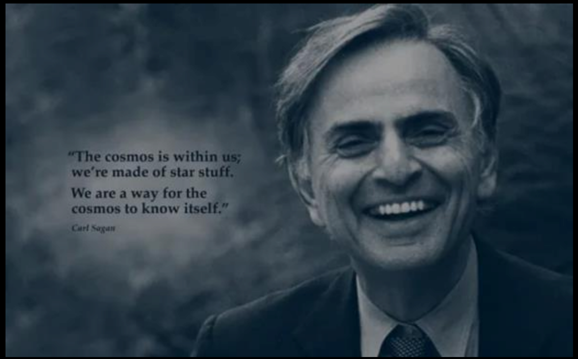
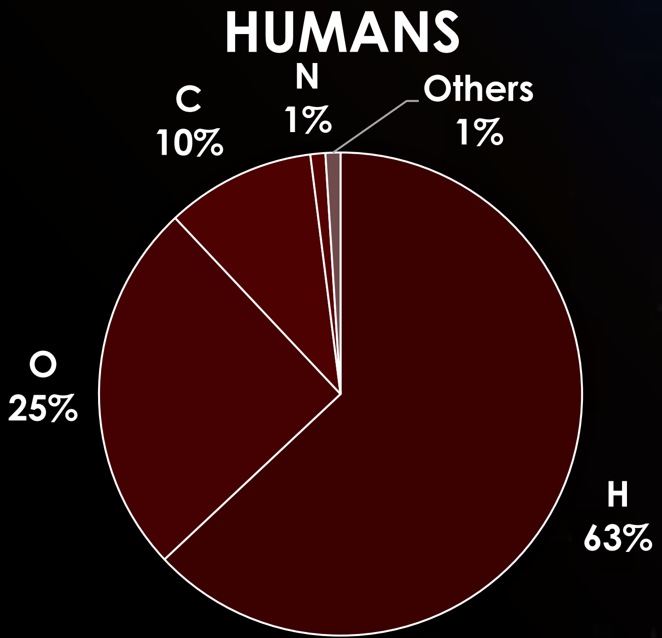
The evolution of chemical elements

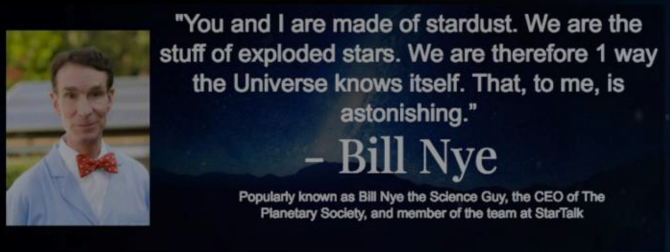


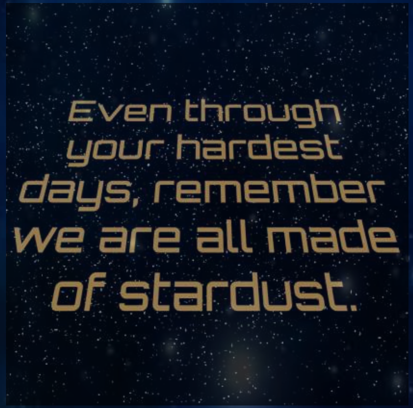


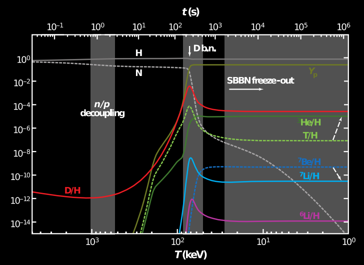
We are made of star dust





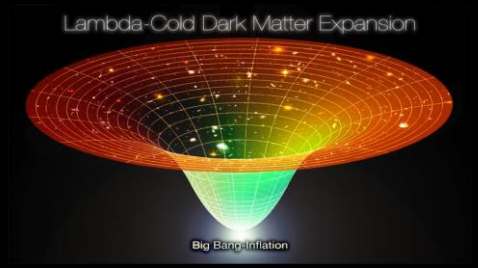






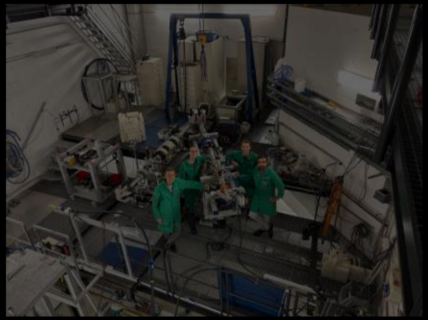
The Big Bang Nucleosynthesis

→ Nuclear astrophysics during the first minutes of our universe



Cosmic concordance

→ Connection to cosmology and astrophysics



Catching Up with Cosmology and Astronomy

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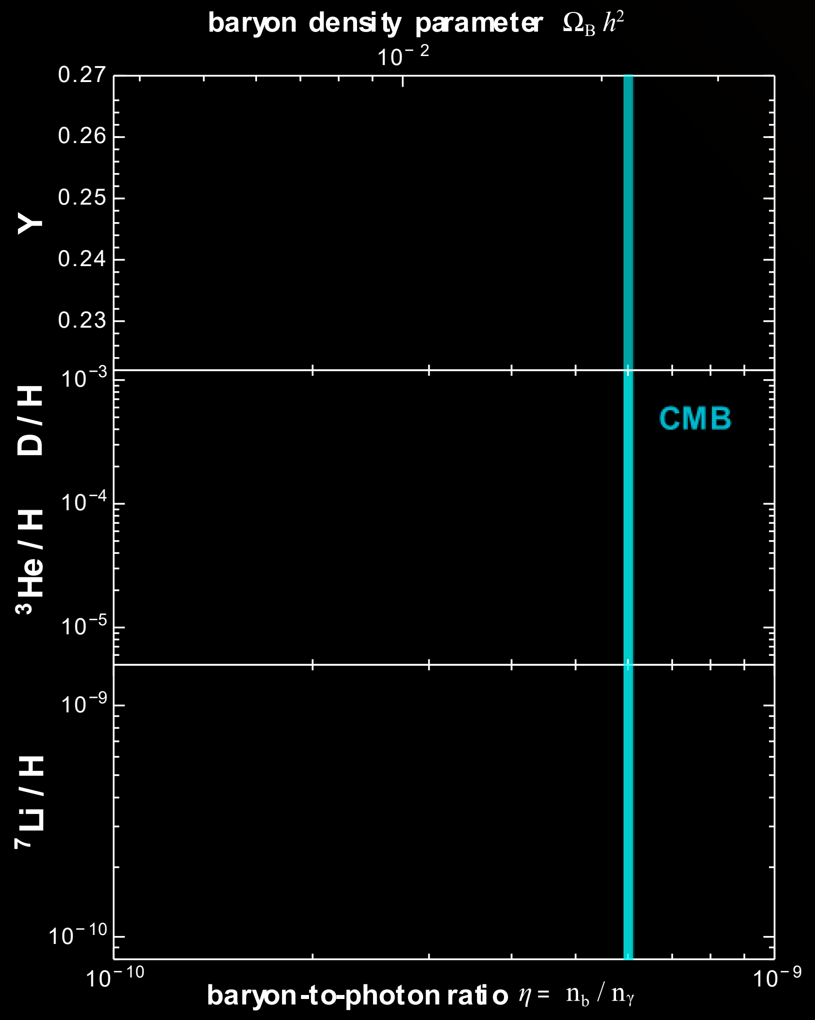
The cosmic concordance



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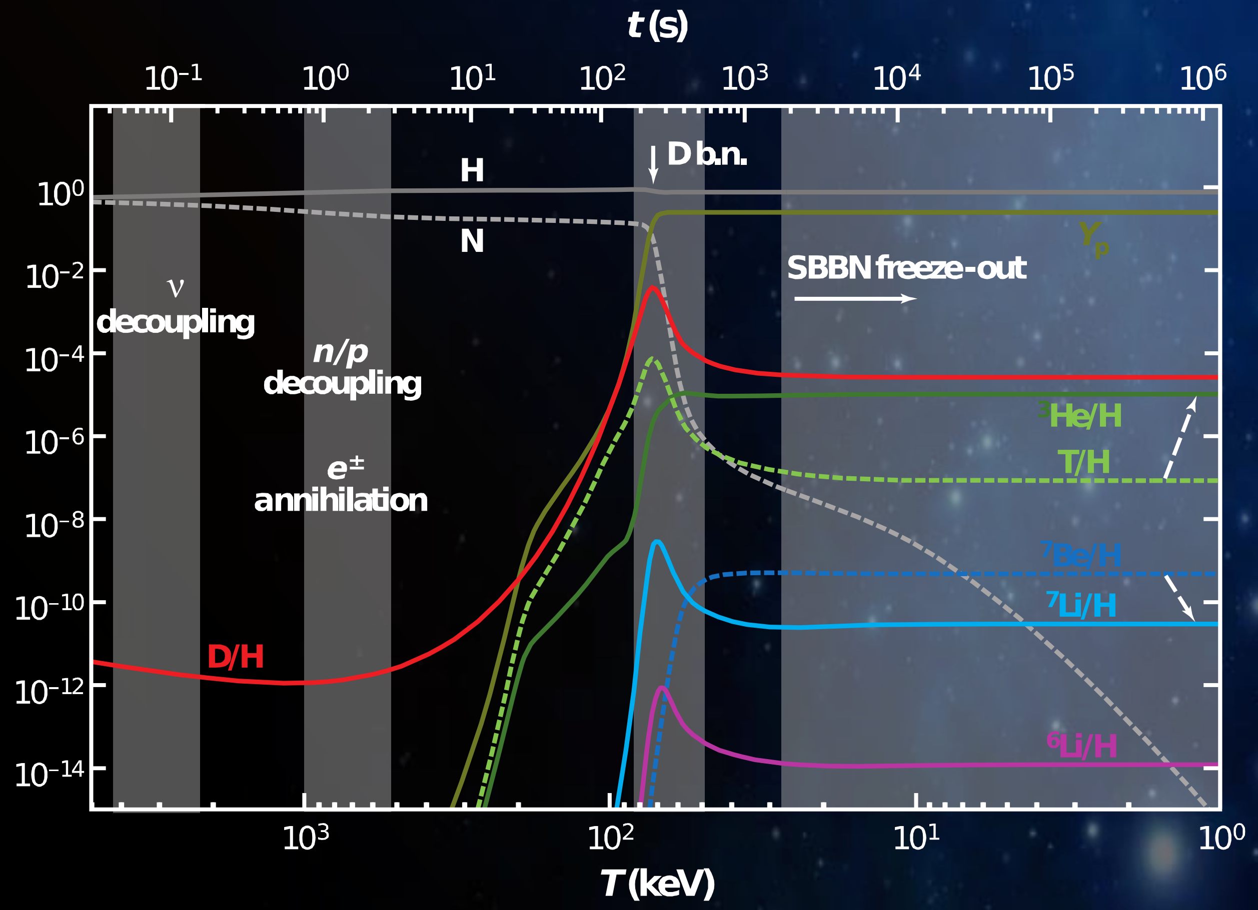

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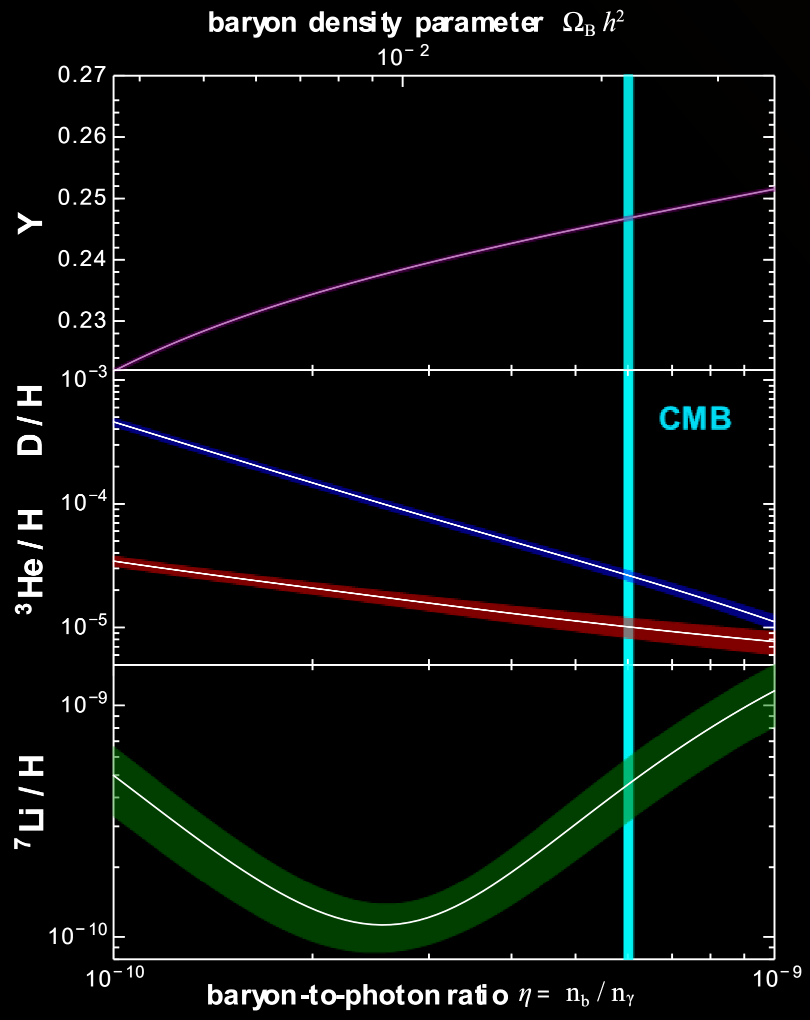

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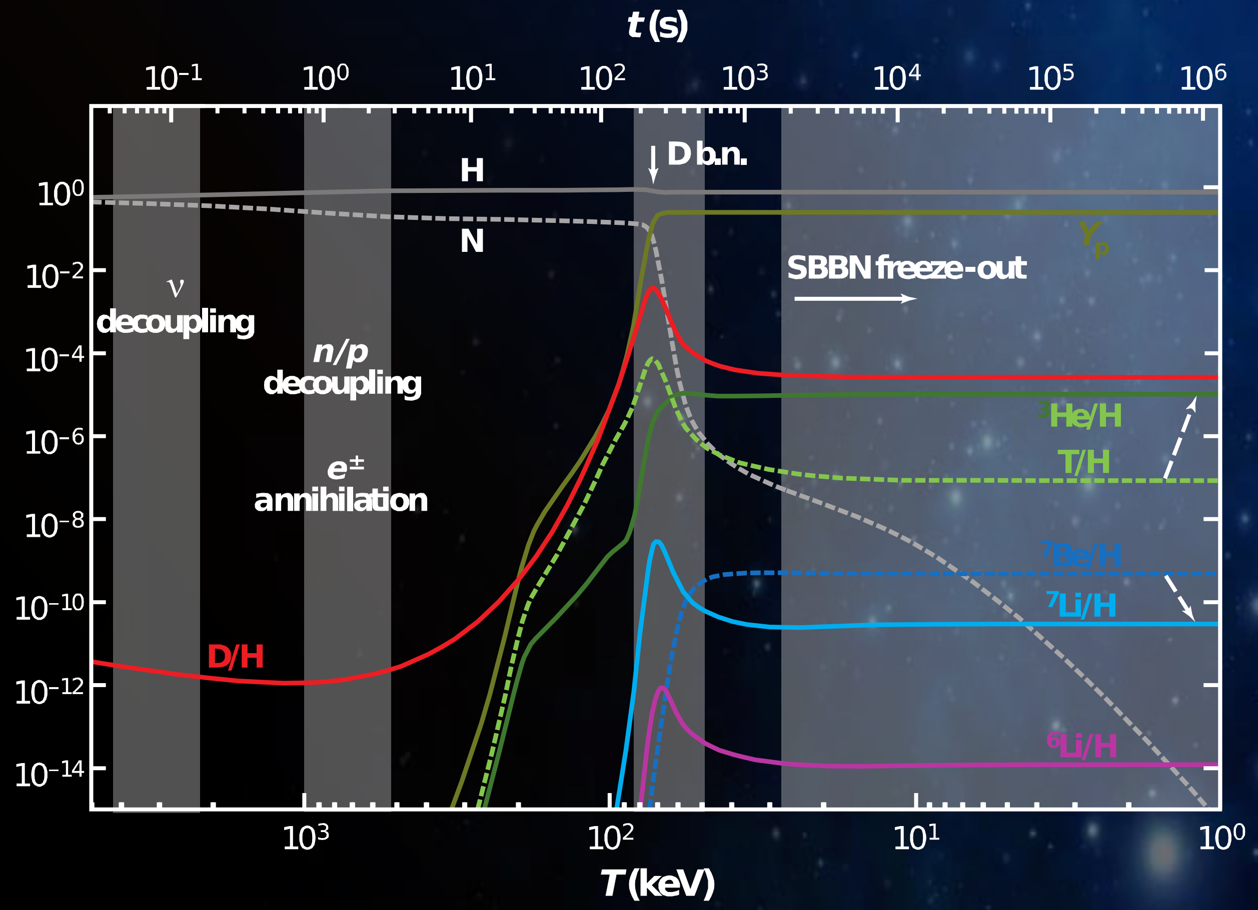

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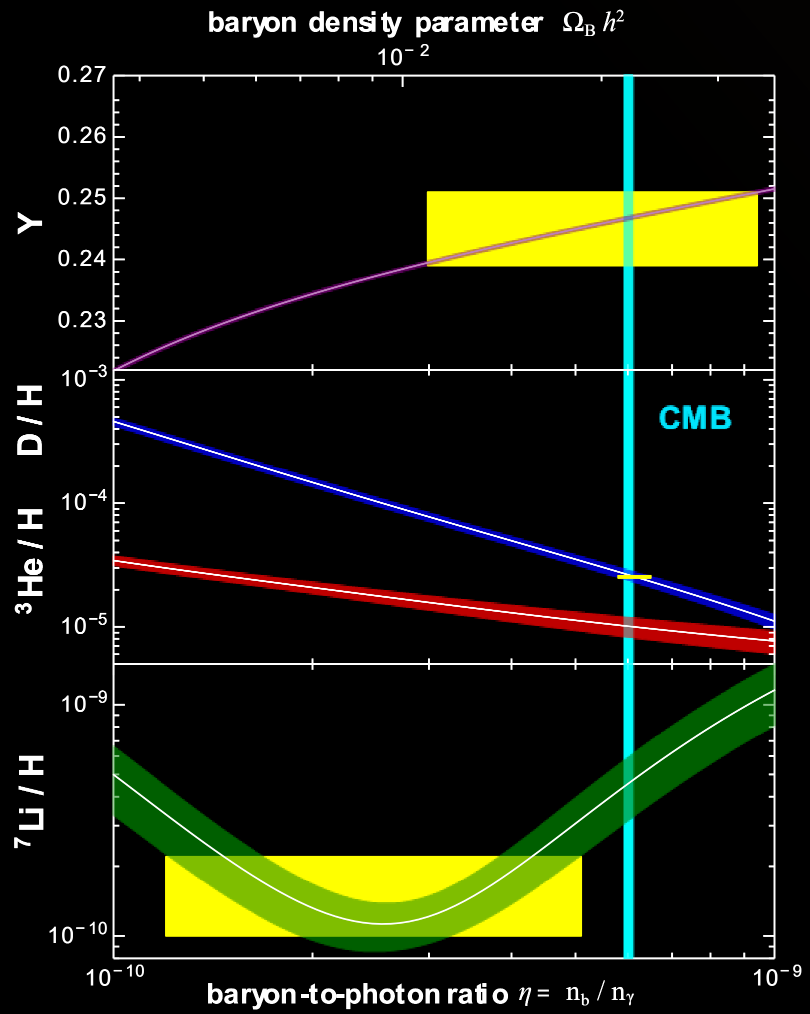

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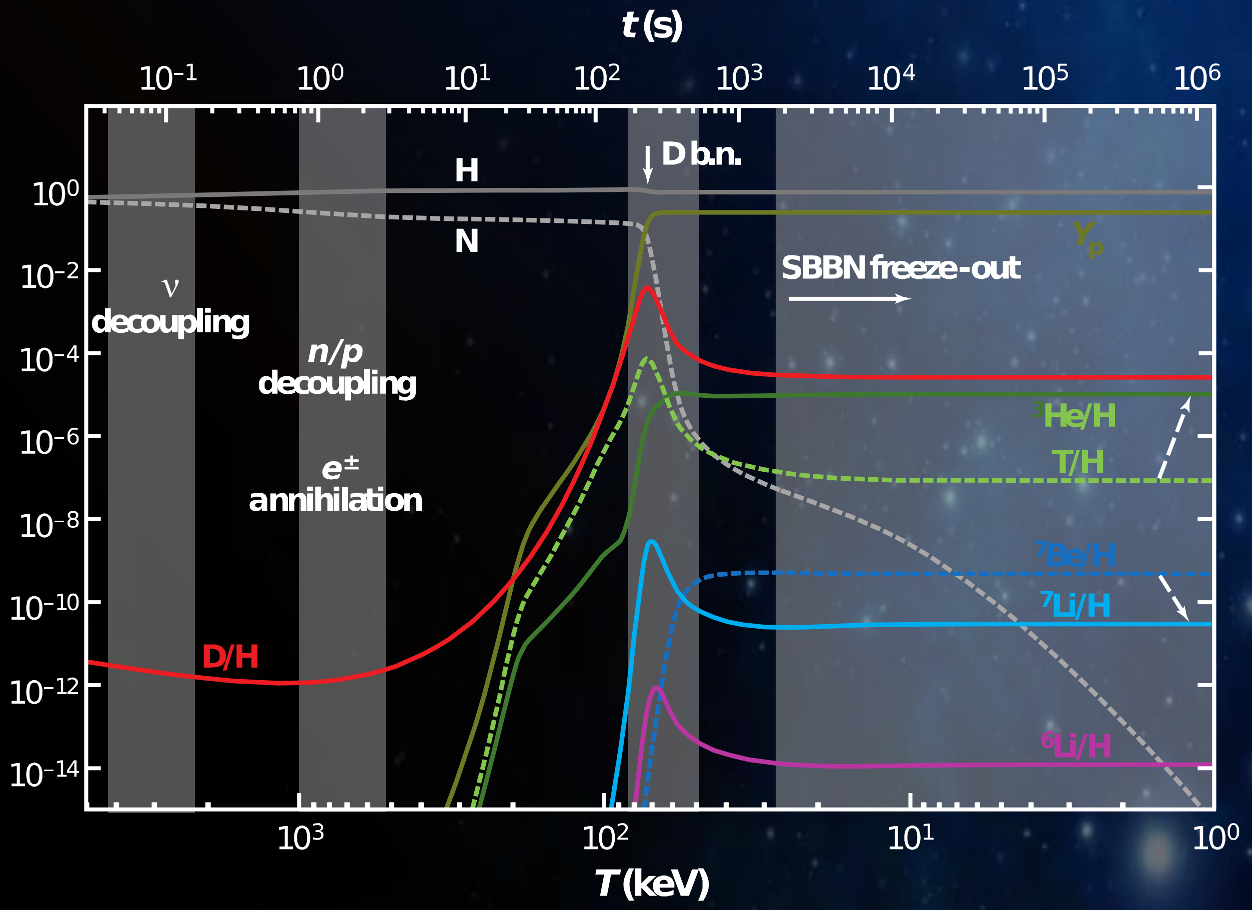

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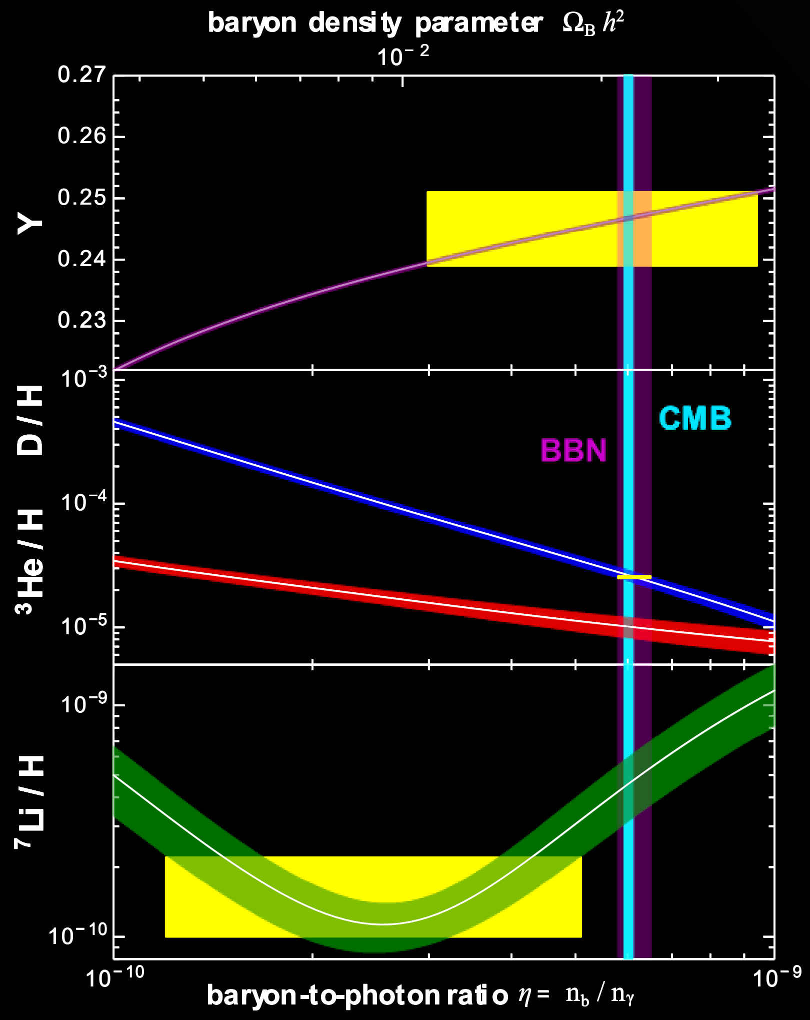
The cosmic concordance until 2020

Eliana Masha – Today @11:30, Stay tuned!!!
New measurements for Big Bang and stellar nucleosynthesis at Felsenkeller



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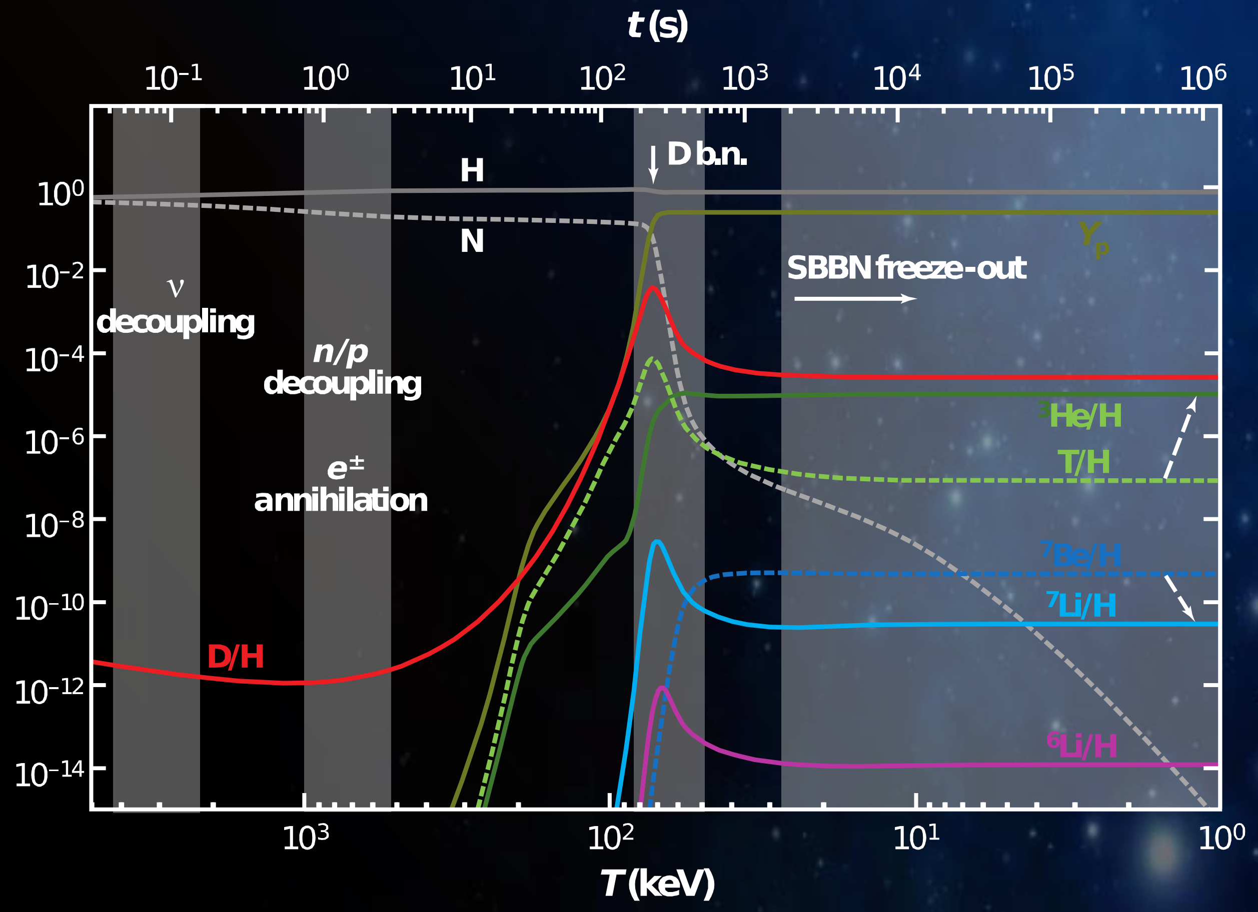

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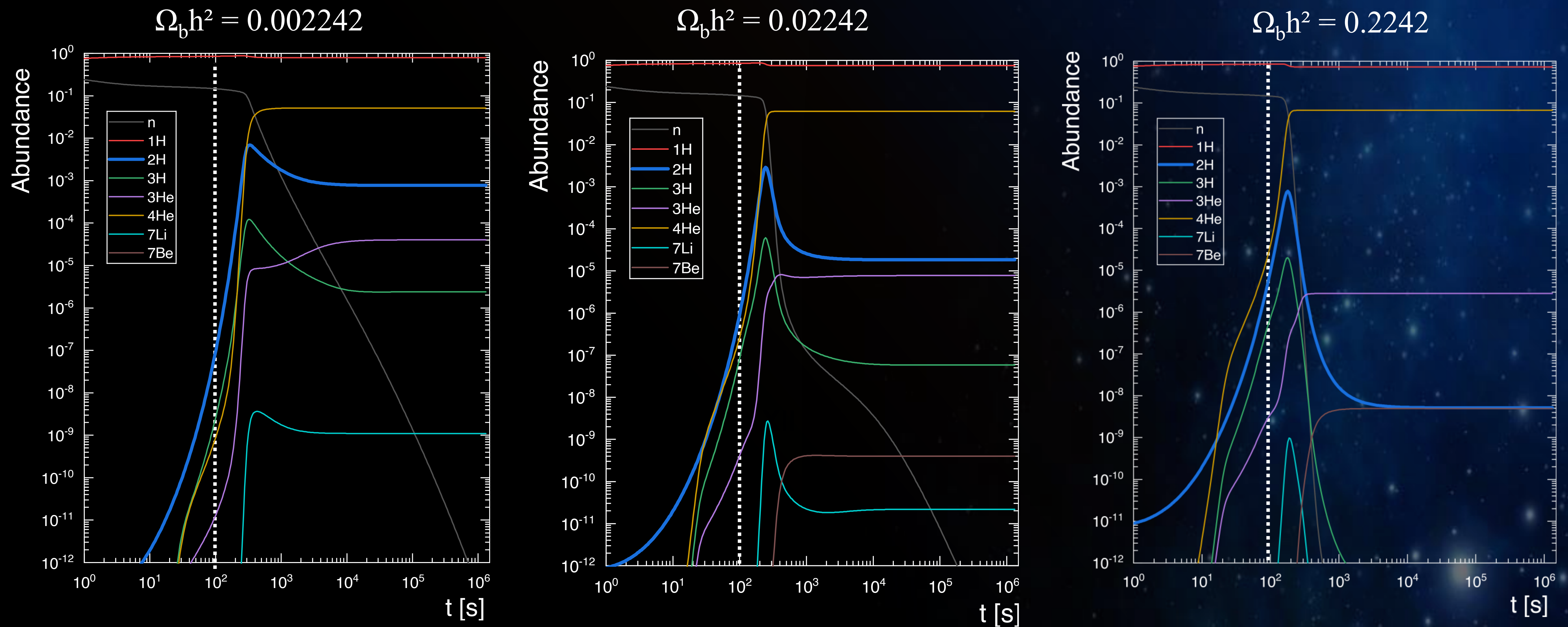
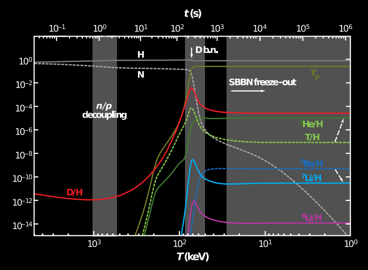
Finetuning the primordial deuterium abundance

Check out PRIMAT from Cyril Pitrou!!
https://primat.streamlit.app/





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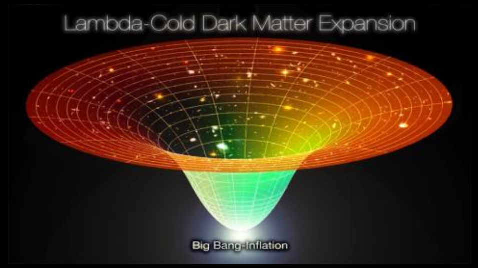

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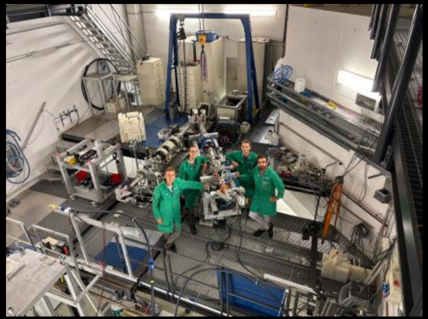
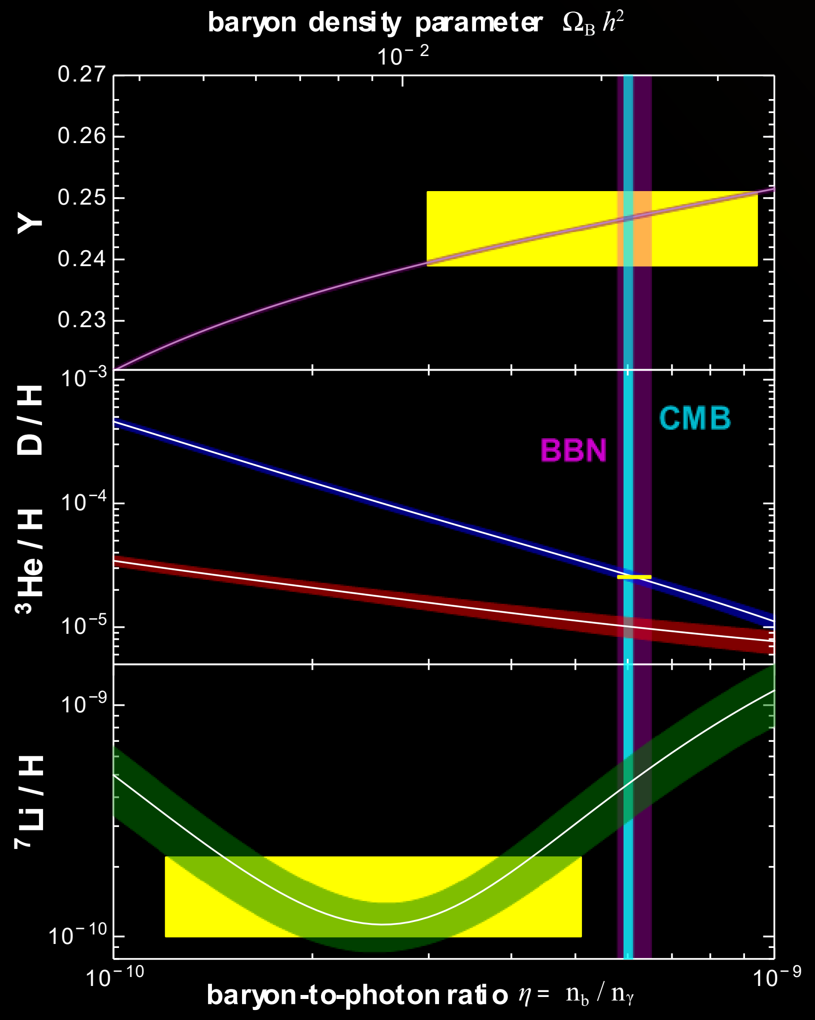


Catching Up with Cosmology and Astronomy

→ $^{2}H(^{2}H,p)^{3}H$ and $^{2}H(^{2}H,n)^{3}He$ at the DT generator of TU Dresden

Nuclear physics is still lacking behind?



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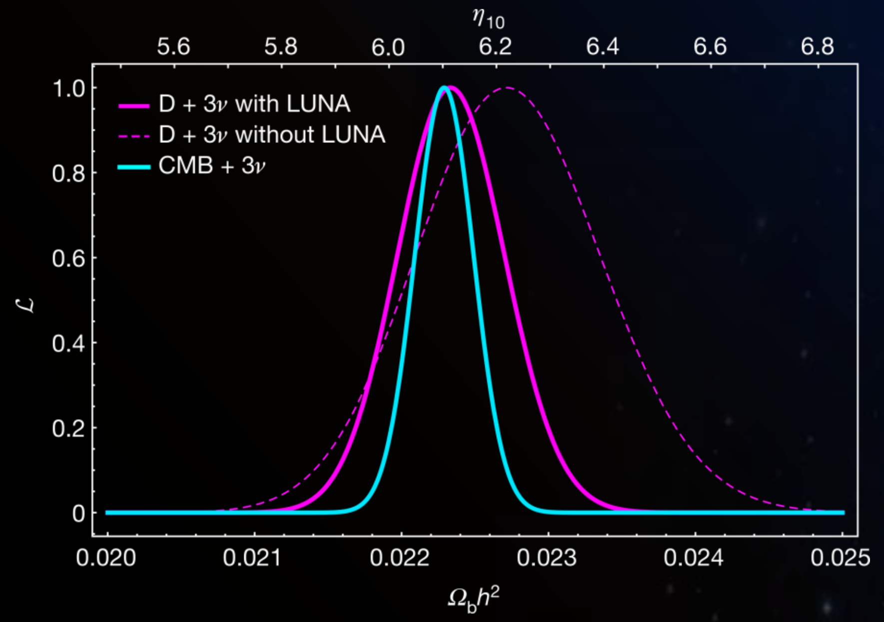
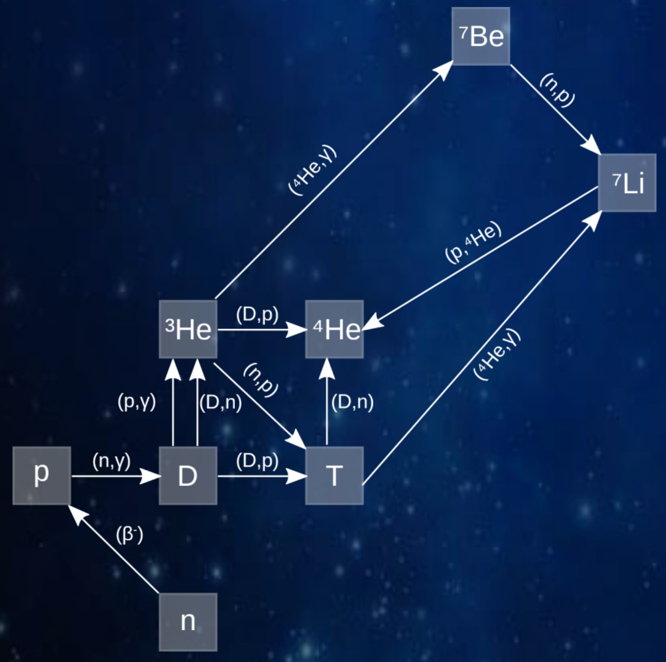


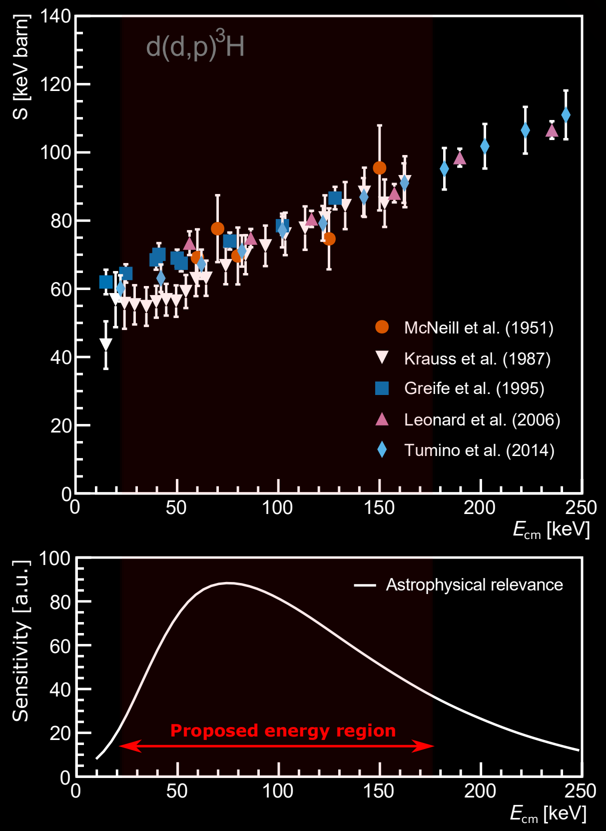


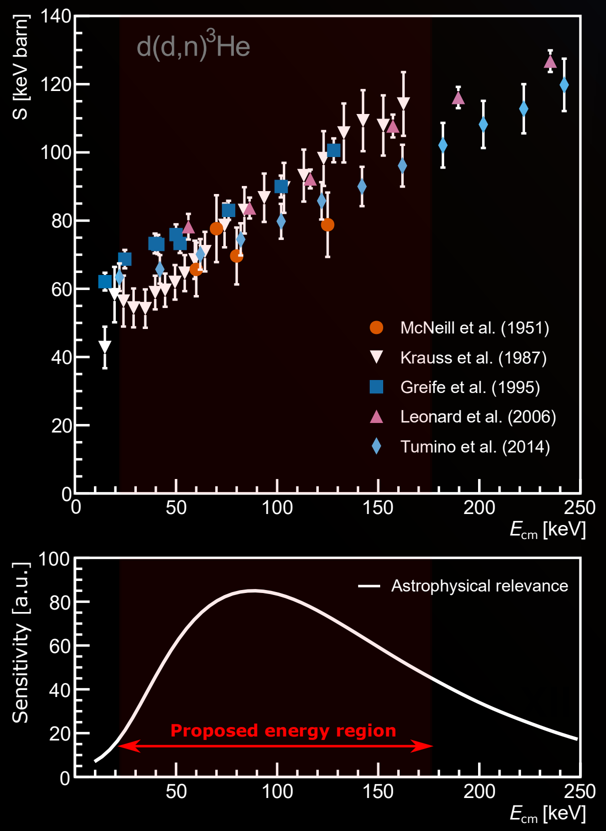
Reaction	d(d,n)^{3}He	d(d,p)^{3}H	d(p,γ)^{3}He	^{3}He(d,p)^{4}He	p(n,γ)d	3He(n,p)t
Contrib. to D/H unc.	61%	27%	12%	<0.05%	<0.05%	<0.05%

Tsung-Han Yeh et al., JCAP03, 046 (2021)

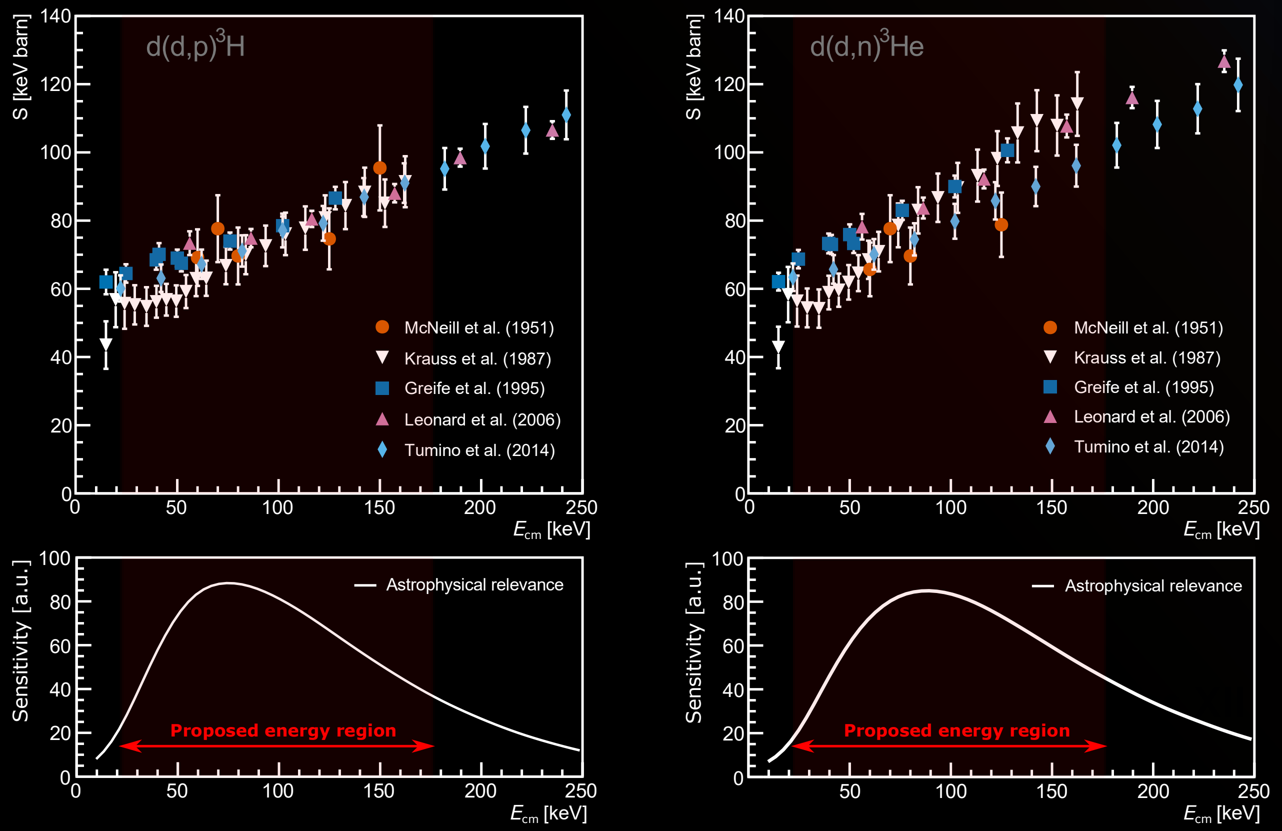
NUCLEAR PHYSICS in Astrophysics XII

The d(d,p)^{3}H & d(d,n)^{3}He reactions



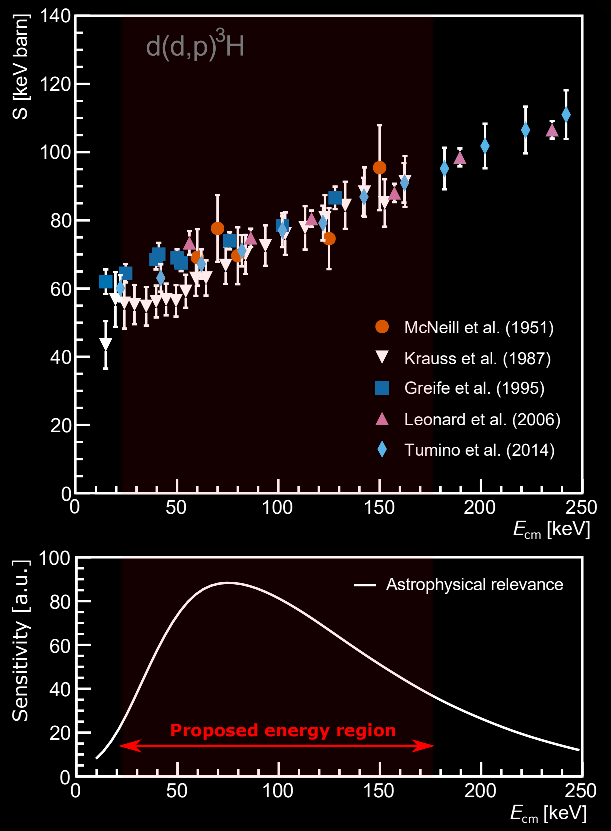


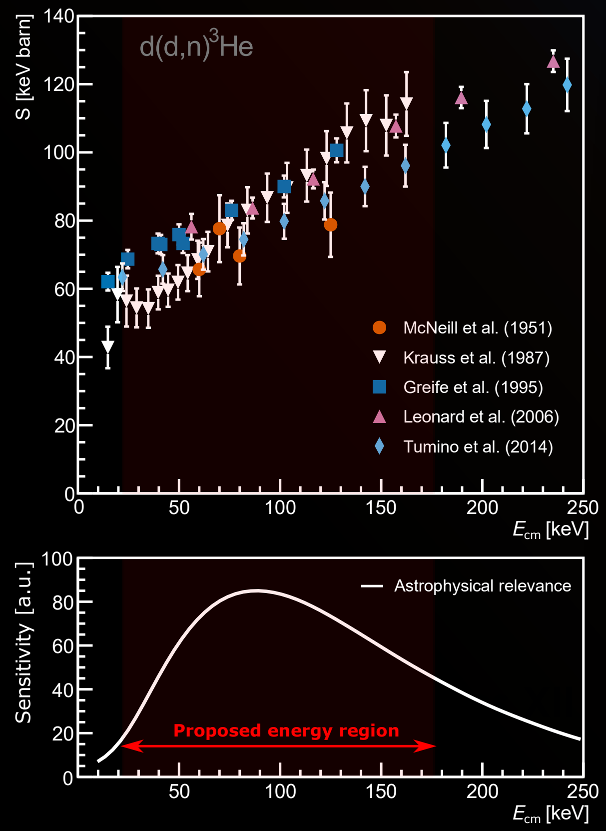
The d(d,p)³H & d(d,n)³He reactions



- **New data set from Sun et al. In 2026**
  - Acta Phys. Sin. Vol. 75, No. 9 (2026) 090103
  - 6 new data points for d(d,p)
  - 5 new data points for d(d,n)
  - Legendre coefficients for A_0, A_2 & A_4

The d(d,p)^{3}H & d(d,n)^{3}He reactions





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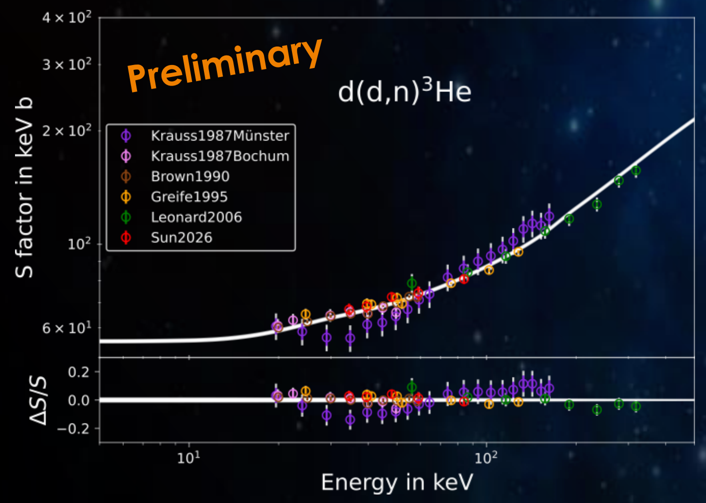
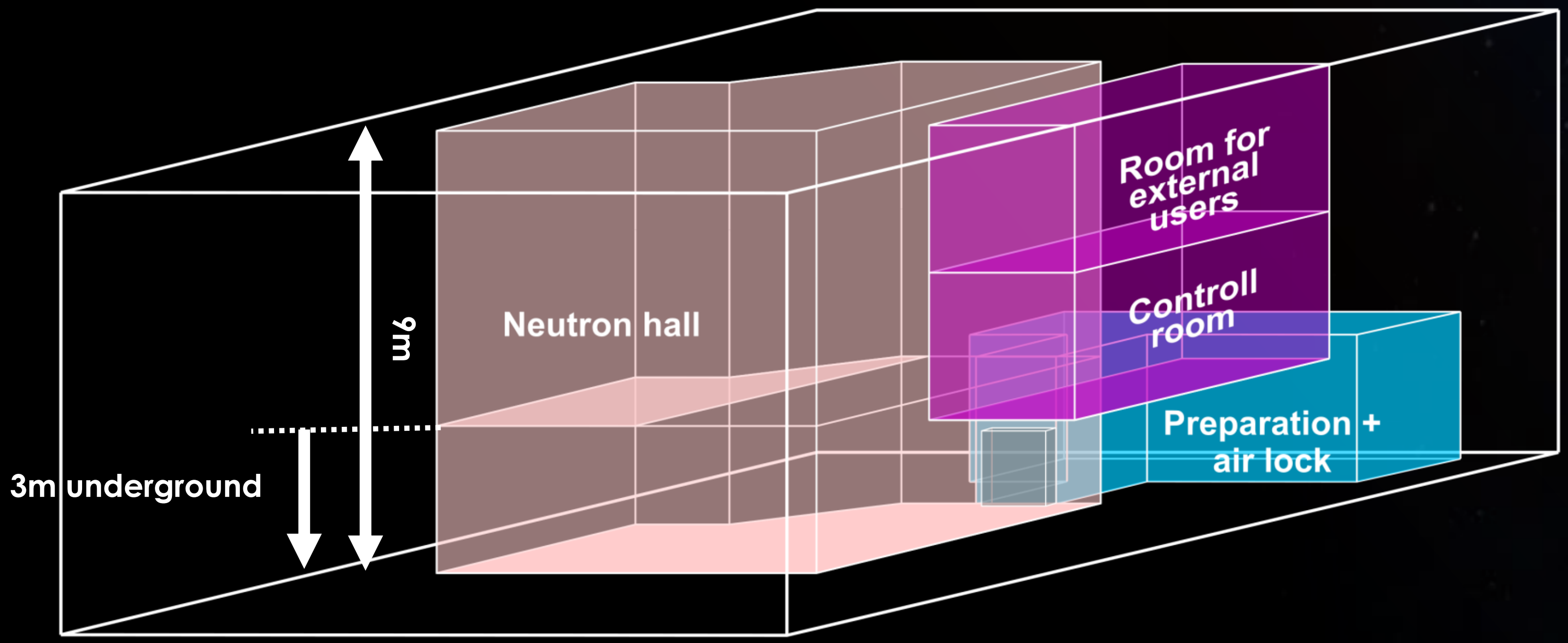
- **Astrophysical impact under investigation**
  - Master student: Vincent Schulz (Felsenkeller)
  - Bayesian analysis with theory from Viviani et al. (2023)



Stay tuned!!

The DT neutron generator of TU Dresden

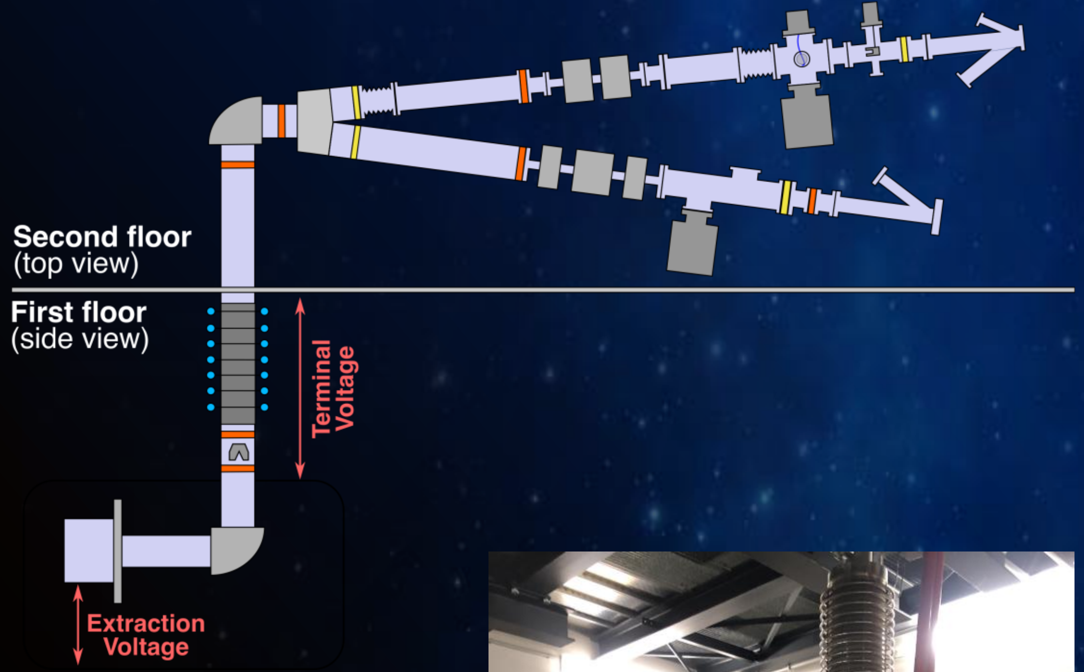
- **Located in Dresden (Germany)**
  - **Operated by**: Institute for Nuclear and Particle Physics of TU Dresden
  - **Located at:** Helmholtz-Zentrum Dresden-Rossendorf



The DT neutron generator of TU Dresden

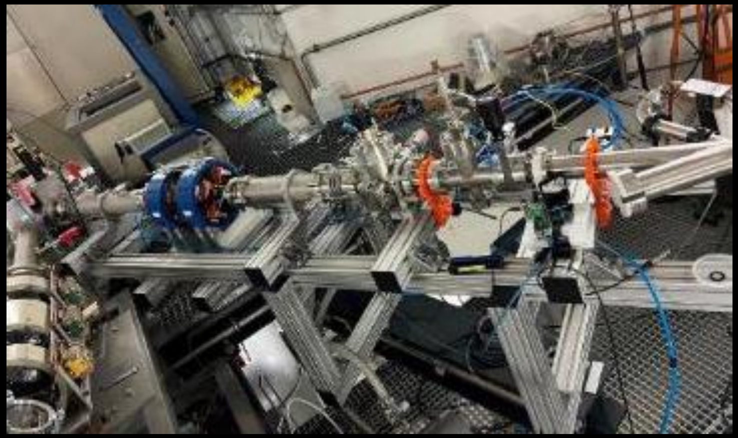
Duoplasmatron + Cockcroft-Walton HV

- Extraction of intense ^{1}H and ^{2}H beams up to 10 mA
- E_{lab} = 10 - 350 keV
- Main purpose:
  - Fusion research & neutron activation analysis
  - Up to 10^{12} neutrons per second via $^{2}H(^{3}H,n)^{4}He$



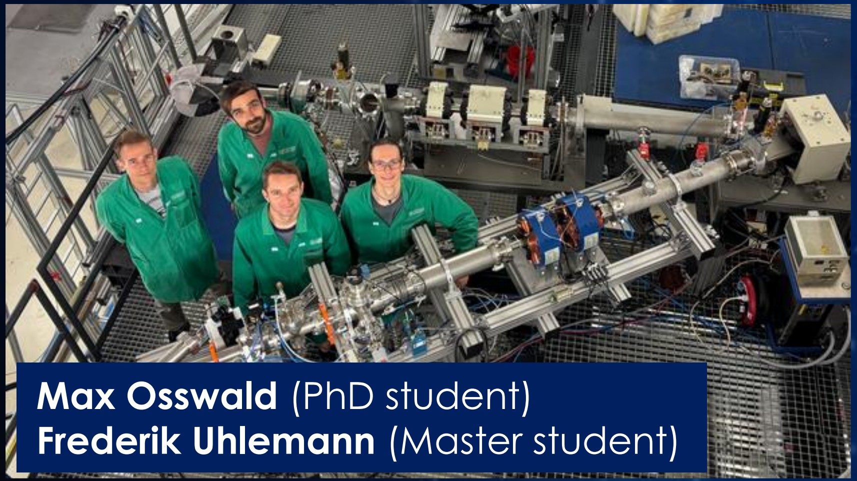
Until March 2026

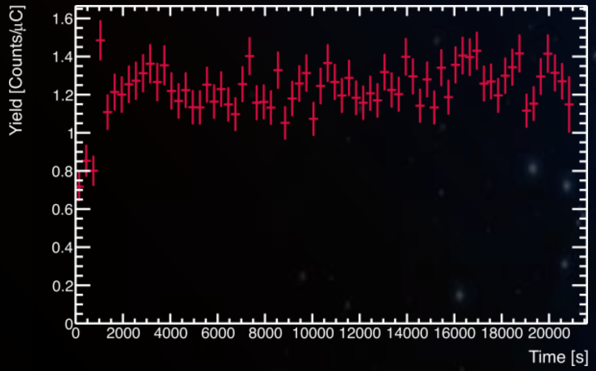
Astro beam line finished in June 2026

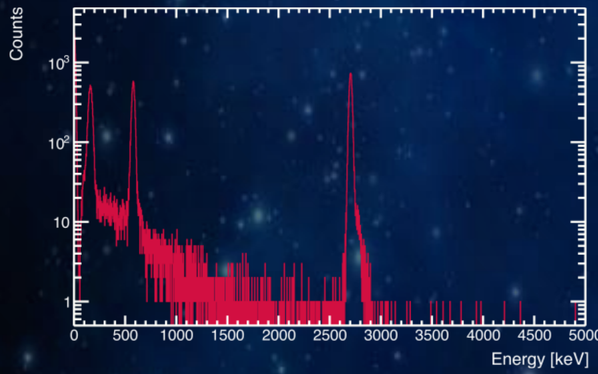


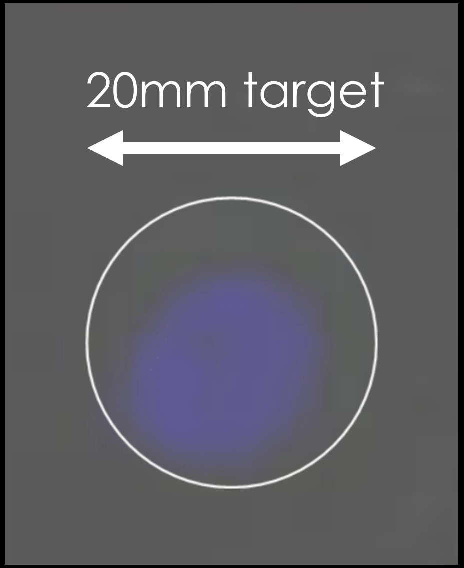
Current status of $d(d,p)^3H$ & $d(d,n)^3He$ at the DT

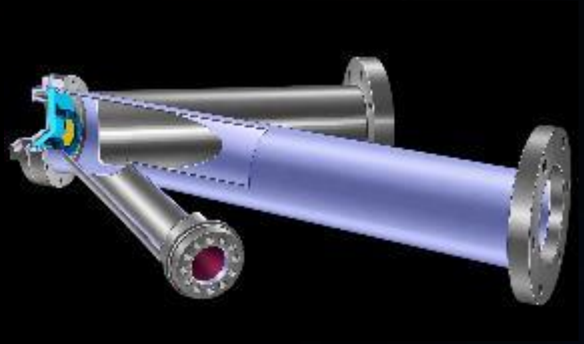
- ✓ Accelerator is characterized
- ✓ New, dedicated beamline is commishioned
- ✓ Preliminary setup with planar Si detector under fixed angle
- ✓ First tests using transmissive targets promising
  - ✓ No significant degradation within hours of irradiation

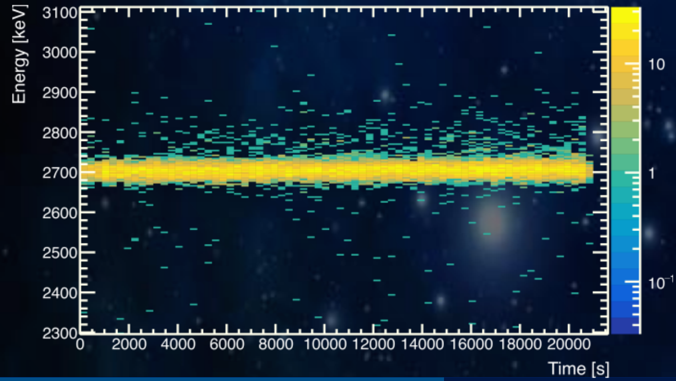




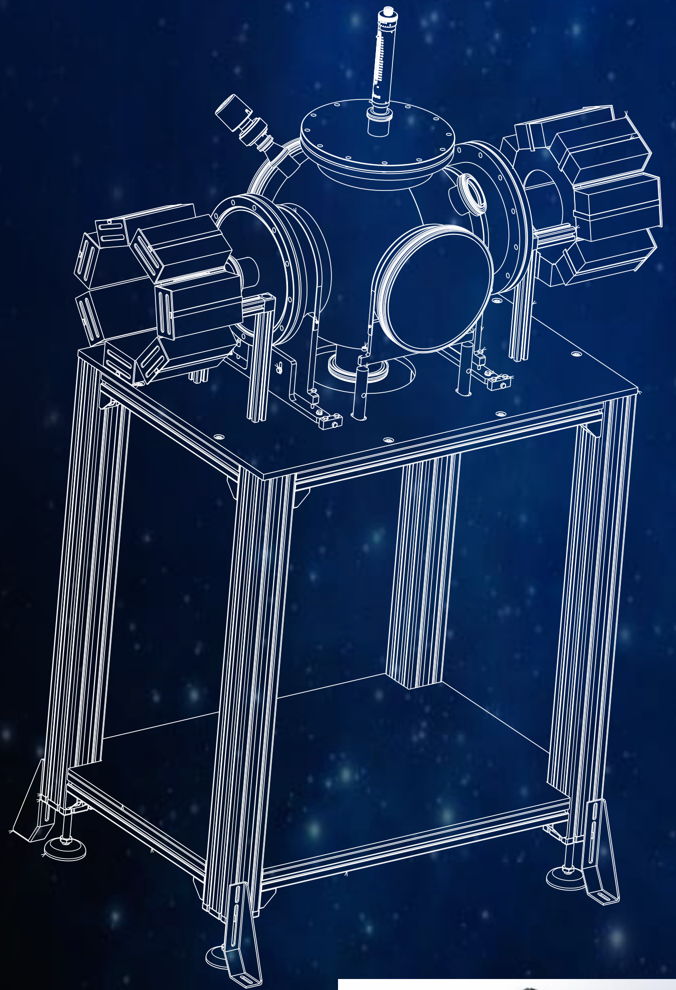








Bringing expertise together



Current issue of BBN

➢ d(d,p)^{3}H & d(d,n)^{3}He are limiting our understanding of BBN & baryon density

Our aim

➢ Measurement of both reactions within E_{lab} = 10 - 350 keV

➢ Precision data set for cross section and angular distribution

Combination of

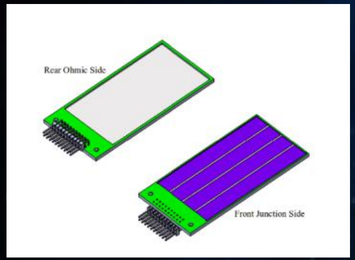
➢ **DT neutron generator of TU Dresden**

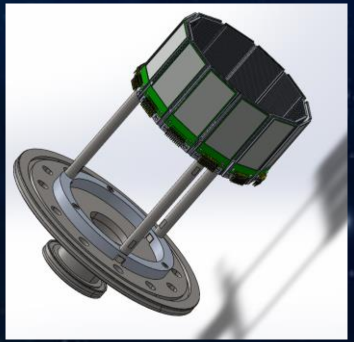
➢ **The ELISSA array**

Haridas Pai – Today @12:30
Kabita Kundalia – Tomorrow @10:00
Ana Lupoae - Poster

The ELISSA array

- Collaboration of ELI-NP & INFN-LNS Catania
- 4π double-sided silicon strip detector array





Summary and outlook

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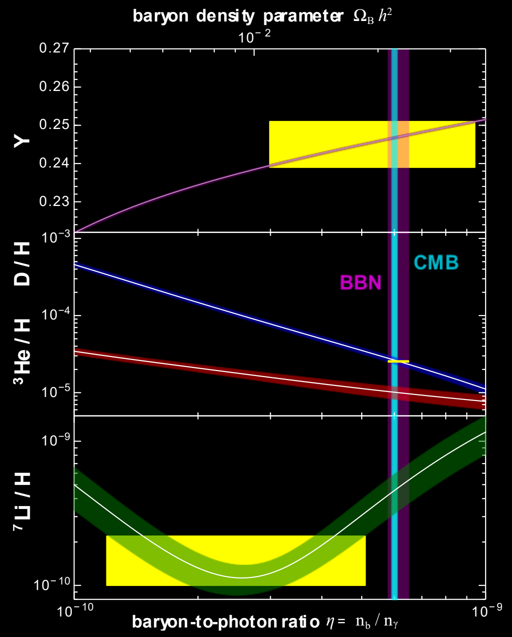
- Determination of η_B is stunning success for the alignment of cosmology, astronomy, theoretical physics & nuclear astrophysics
- **Take home message:** Nuclear astrophysics is awesome!
- However…



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T.-H. Yeh et al JCAP03(2021)04600

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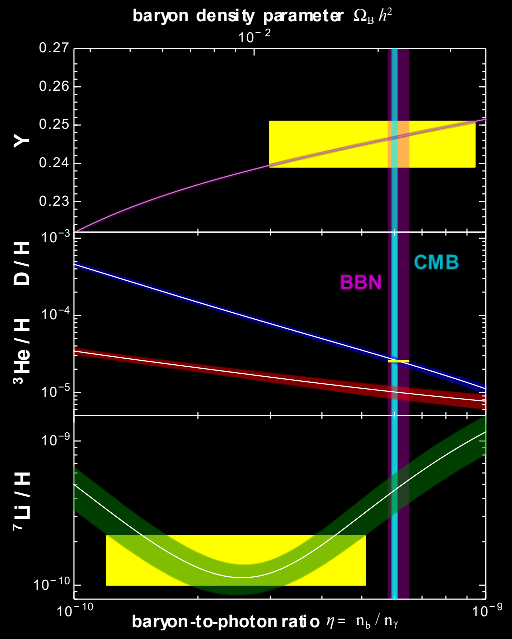

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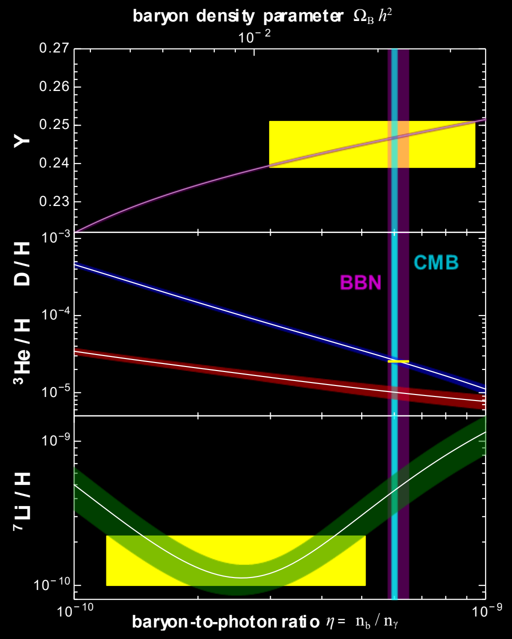

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We think that a closer collaboration among different groups in assessing a common understanding and quantifying the theoretical primordial D/H uncertainty would be quite important and desirable.

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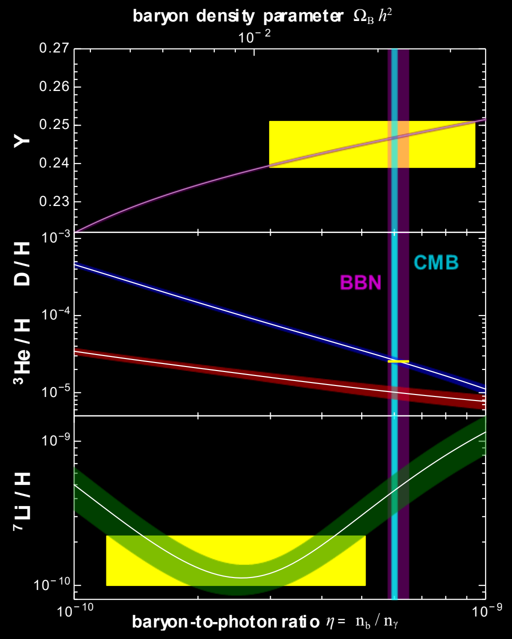

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Just read the entire summary!
Free interpretation: We need to urge for correctness, not precision

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