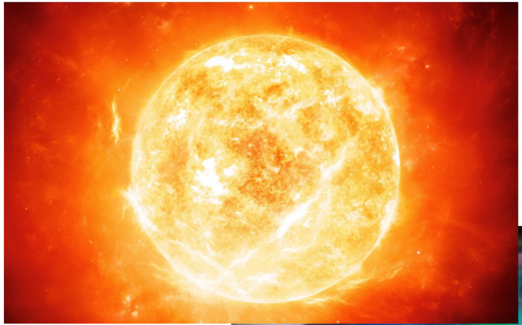
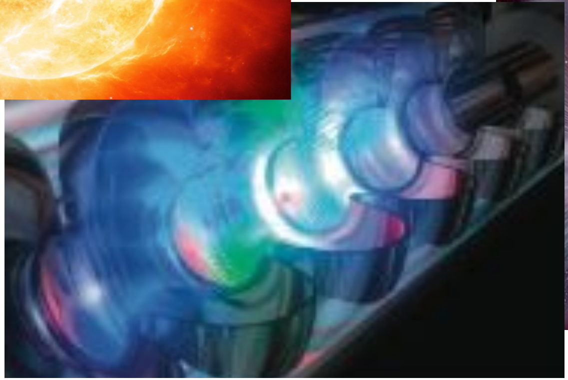
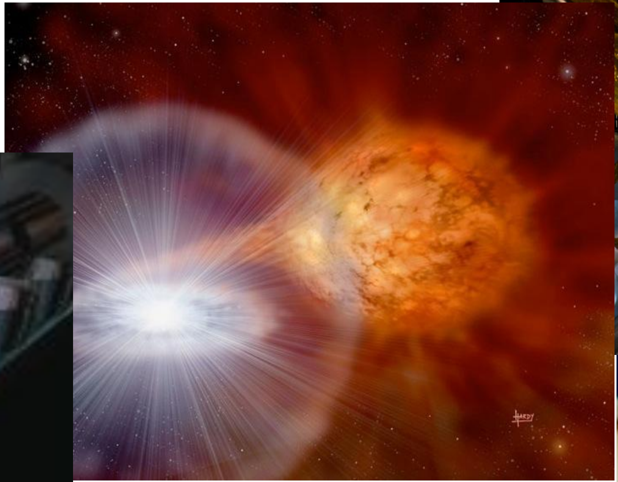
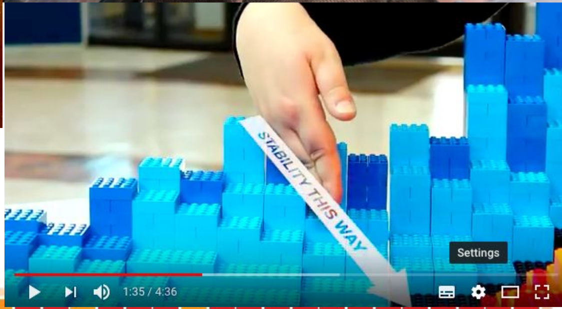
# Binding Blocks UK

A National, Inclusive Programme For Nuclear Physics Education





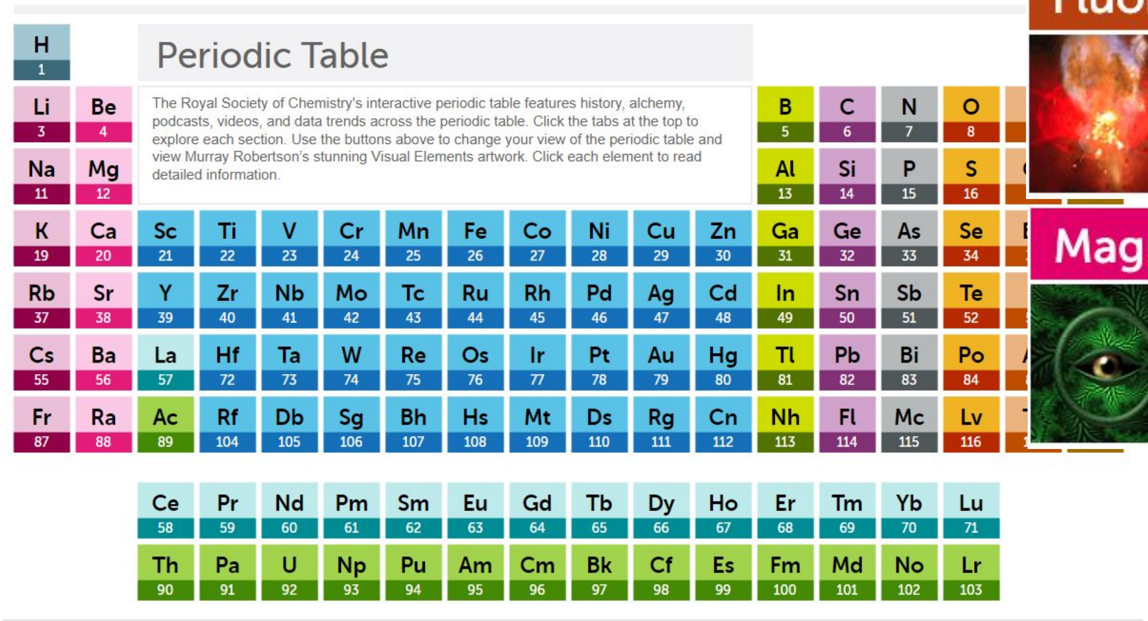


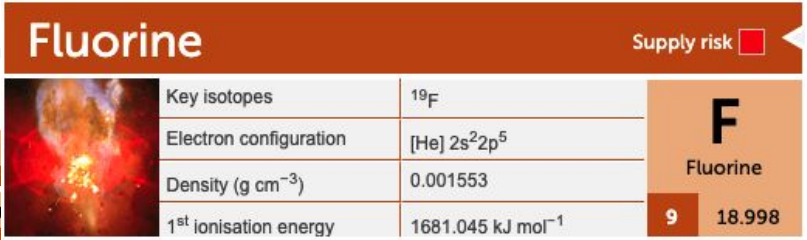



*Christian Aa. Diget @ York*

# Elements and Isotopes

## Nucleons (A), protons (Z), and neutrons (N)

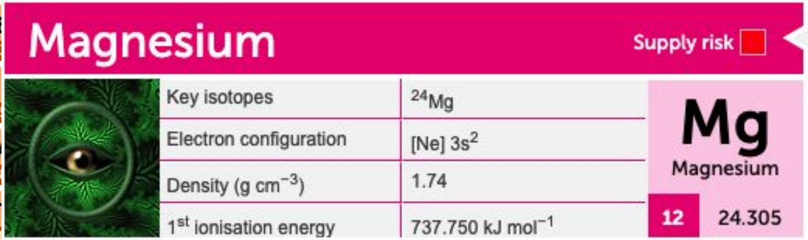


**Fluorine** Supply risk

| | |
|---|---|
| Key isotopes | $^{19}F$ |
| Electron configuration | [He] $2s^2 2p^5$ |
| Density (g $cm^{-3}$) | 0.001553 |
| 1st ionisation energy | 1681.045 kJ $mol^{-1}$ |

F Fluorine 9 18.998



**Magnesium** Supply risk

| | |
|---|---|
| Key isotopes | $^{24}Mg$ |
| Electron configuration | [Ne] $3s^2$ |
| Density (g $cm^{-3}$) | 1.74 |
| 1st ionisation energy | 737.750 kJ $mol^{-1}$ |

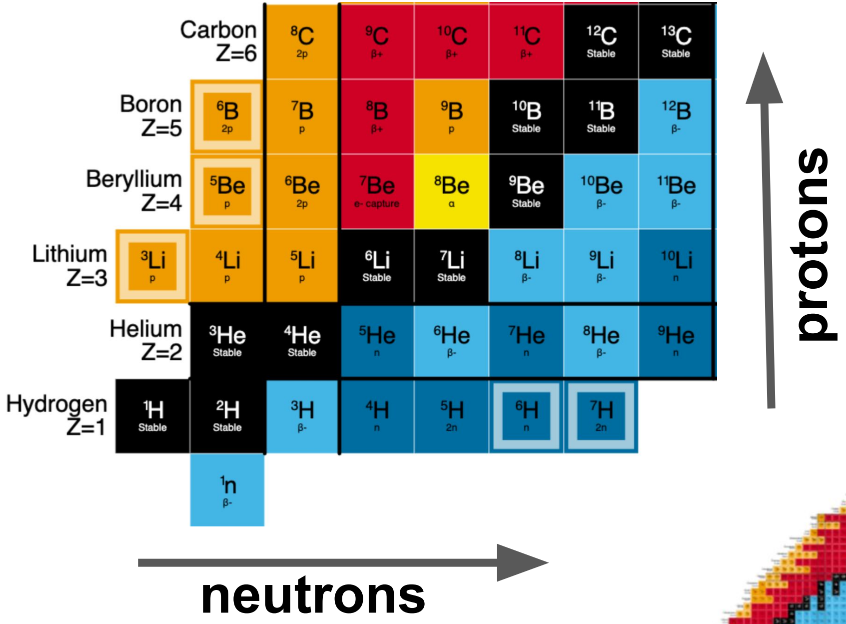
Mg Magnesium 12 24.305

Some elements only have a single naturally occurring isotope, some have several.

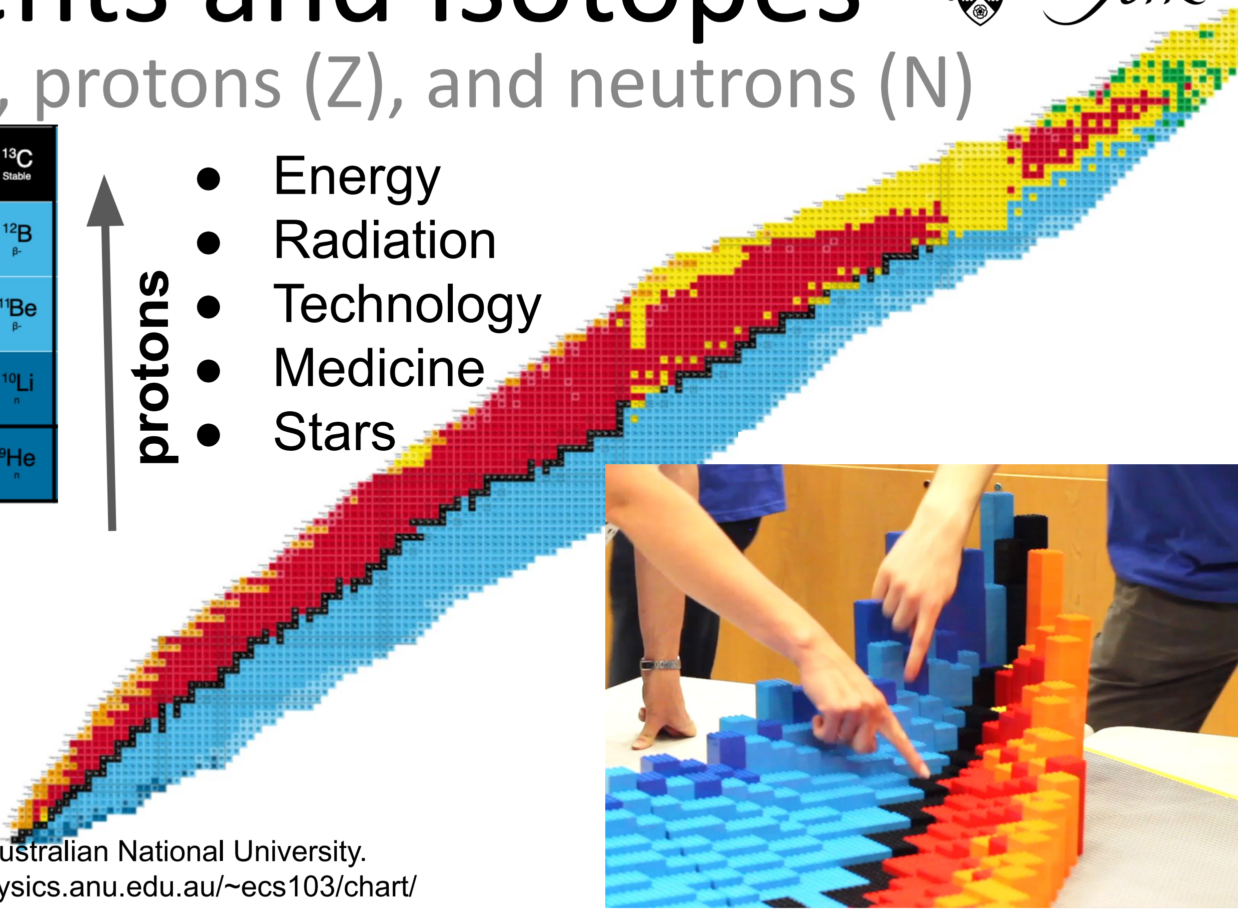
Periodic table taken from Royal Society of Chemistry. Interactive version available at: https://www.rsc.org/periodic-table

# Elements and Isotopes

## Nucleons (A), protons (Z), and neutrons (N)




- Energy
- Radiation
- Technology
- Medicine
- Stars



Colorful Nuclide Chart by Dr. Ed Simpson, The Australian National University.
Interactive version available at: https://people.physics.anu.edu.au/~ecs103/chart/

# We are all made of stars

## Stellar fusion and energy

Binding Blocks
Building the Universe one nucleus at a time

UNIVERSITY of York


Energy is from $E = mc^2$
c = 299,792,458 m/s
So $c^2$ is huge!

m = 1 kg   (kg * m/s * m/s = J)
$mc^2$ = 90,~~000~~,~~000~~,000,000,000 J
You use (electr.): 19,000,000,000 J/year
Incredible energies even if only 0.1% of one gram is converted to energy.

Helium has a lower mass than the sum of the four nucleons

# We are all made of stars

## Stellar fusion and energy


Deuterium ($^2H$) fusion ( $E = mc^2$ ):

$^2H + {}^2H \rightarrow {}^4He + E$

$M_{2H} = 2.0141$ amu ; $M_{4He} = 4.00026$ amu

(amu = m($^{12}C$) /12 = $1.661 \cdot 10^{-27}$ kg)

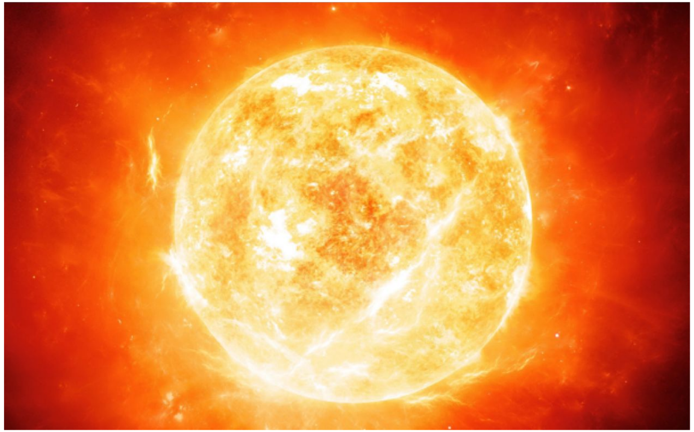
0.0312% deuterium abundance (by H mass)

m = 1 kg (kg * m/s * m/s = J)

$mc^2$ = 90,000,000,000,000,000 J

You use (electr.): 19,000,000,000 J/year

Incredible energies even if only 0.1% of one gram is converted to energy.



# Online Nuclear Masterclass

Binding Blocks
Building the Universe one nucleus at a time

UNIVERSITY of York

## Binding Blocks 2022/23

FREE, flexible, nuclear physics learning through live webinars; videos; quizzes; calculations; simulations; and games. Now with additional modules and a brand new GCSE nuclear masterclass. Ready for in-school delivery.

**GCSE**

- **Week 1: Building Blocks of the Universe**
- **Week 2: Radiation**
- **Week 3: Fission & Fusion**
- **Week 4: Medical Physics**

**A-Level**

- **Week 1: Energy and Decay**
- **Week 2: Experimental Nuclear Physics**
- **Weeks 3 and 4: Optional Modules**
  **Nuclear Astrophysics**
  **Fusion Technology**
  **Medical Physics**
  **Particle Physics meets Nuclear Physics**

# School Kit

## Loan scheme for teachers - supported by researchers

**Funded and supported mentoring opportunities for Early Career Researchers:** a) support first steps into Public and Schools Engagement; b) include their own (your!) research; c) build a foundation for their own PE funding

- **Binding Blocks Chart of Nuclides**
- **Scattering experiment**
- **Hot-CNO decay and reaction activity**

- **Kromek D3S scintillator and 'radiation sources'**

- **15-cm Diffusion Cloud Chamber**

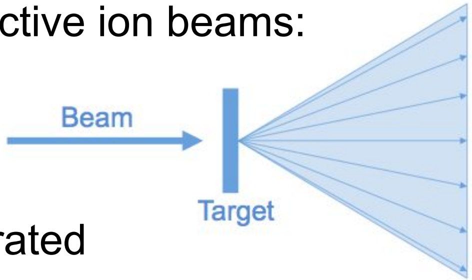
# The Hot CNO-Cycle

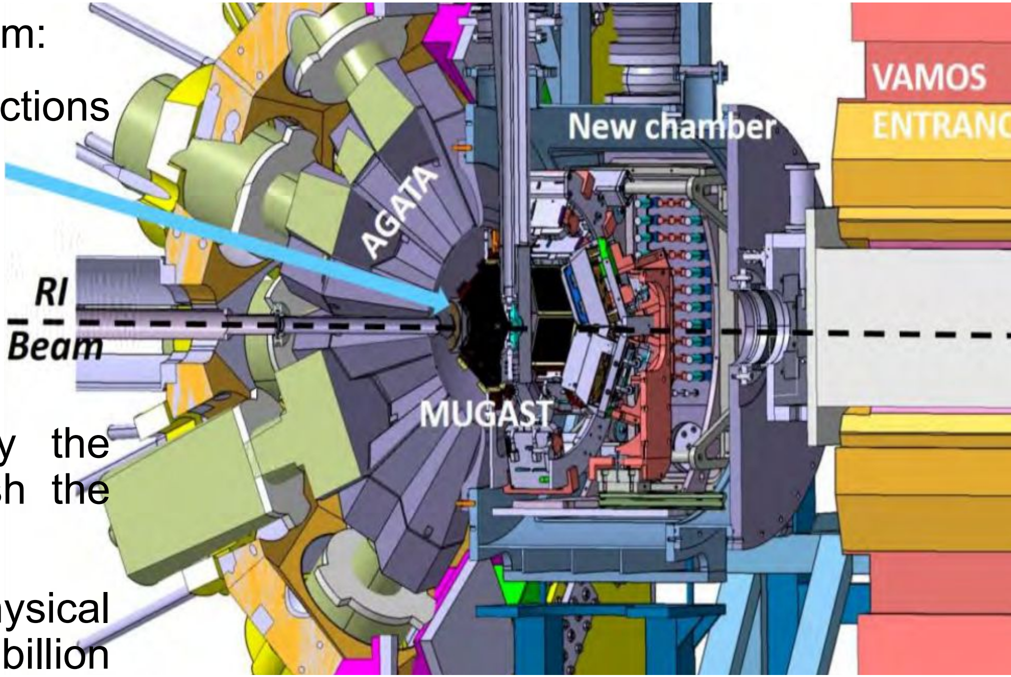
## Down-to-Earth Astrophysics (in practice)

Challenging to fuse oxygen-15 with helium:

Measurement of key nuclear reactions using radioactive ion beams:

- Intense
- Pure
- Accelerated




2019 experiment in France to study the reactions that happen when we smash the beam into the target

3 events observed for the astrophysical reaction channel (from among one billion events and 20 TB of data...)

# Working with schools

## Mentoring and workshop development opportunities

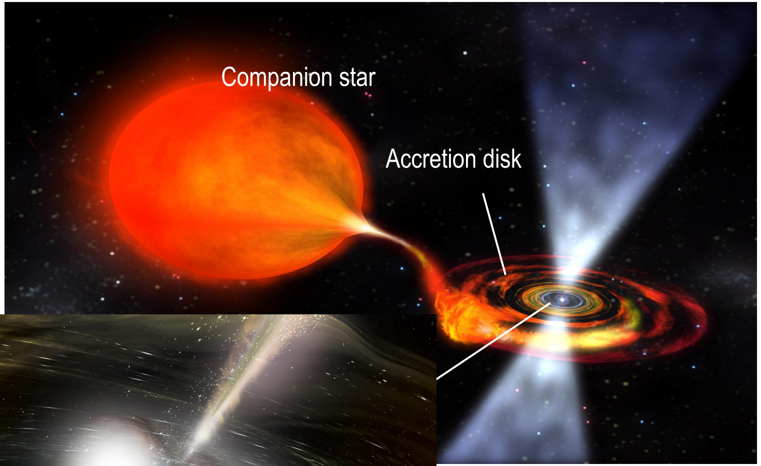
https://sites.google.com/york.ac.uk/bindingblocks/pre-16
https://sites.google.com/york.ac.uk/bindingblocks/post-16
https://tinyurl.com/npecr2022

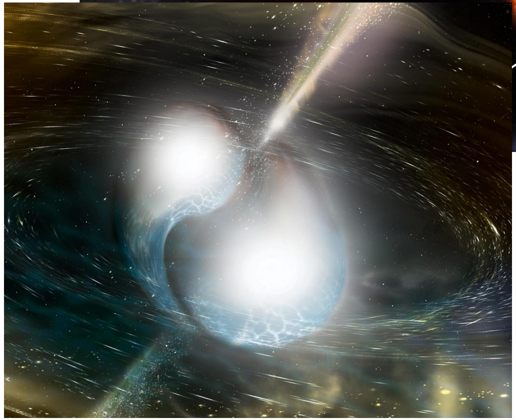
# The Hot CNO-Cycle

## X-ray bursts and neutron stars

- Neutron star in binary system
- “Steals” hydrogen
- H fused to He through catalytic fusion on for example carbon:

1) Add four protons (Hydrogen)
2) Let two protons beta-decay to neutrons
3) Let the final nucleus alpha decay (Helium)



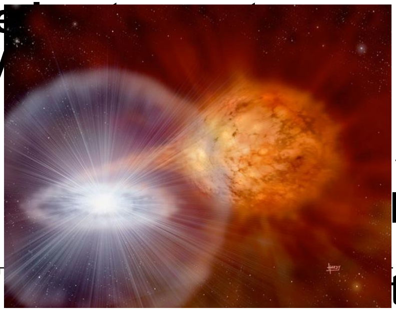
[Image credit: ESA]
[Image credit: National Science Foundation/LIGO/Sonoma State University/A. Simonnet]
[J Keegans et al., MNRAS 485:620 (2019)]

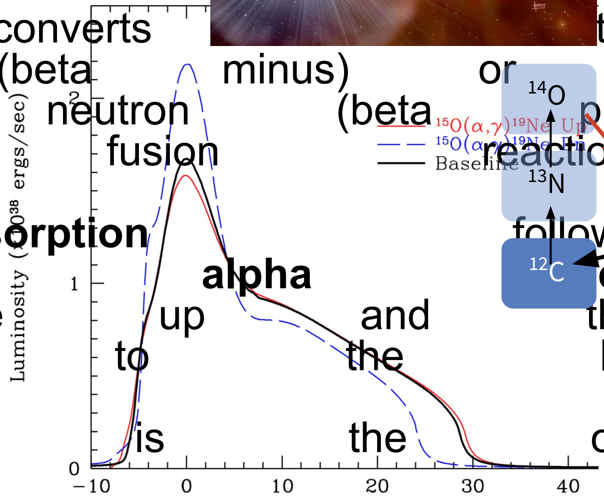
# The Hot CNO-Cycle

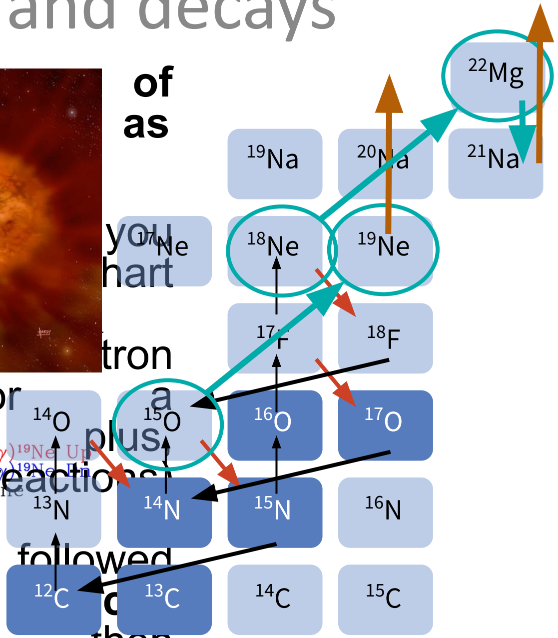
## Catalytic fusion through reactions and decays

**In the hot CNO cycle we nee[...] of decay: alpha and beta decay[...] as proton absorption (or fusion)**

- **Proton absorption** [...] you one nuclide up in [...]hart
- **Beta decay** converts [...]tron to a proton (beta minus) or a proton to a neutron (beta plus) in proton fusion reactions
- **Proton absorption** followed (immediately) by **alpha** [...] moves you one up and then diagonally down to the left.
- **Alpha absorption** is the only escape route





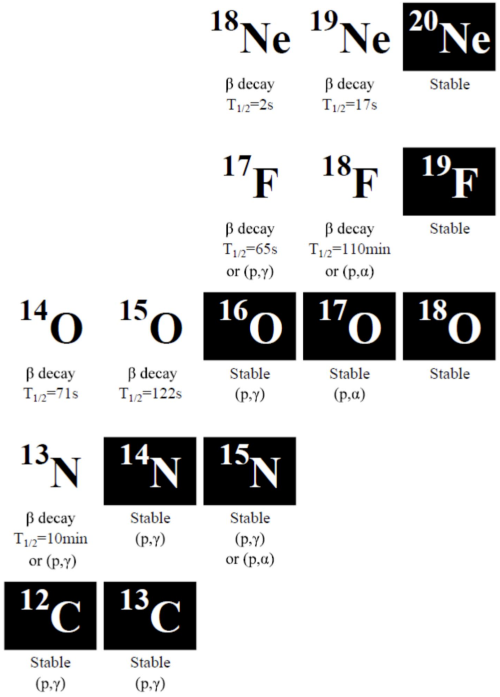



# The Hot CNO-Cycle

## Let's play the Hot-CNO game

**Fast Catalytic Fusion of Hydrogen**

- Fuels Nova explosions and the initial phase of X-ray bursts
- Limited of key isotopes
- Waiting $^{14}O$, $^{15}O$, $^{18}Ne$
- Driving explosions



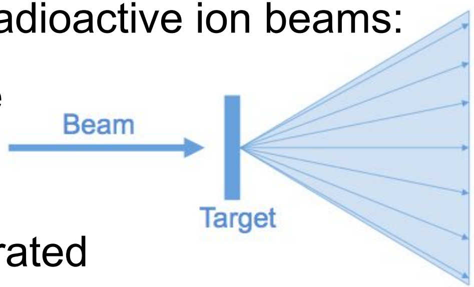

(See worksheet from nuclear masterclass)

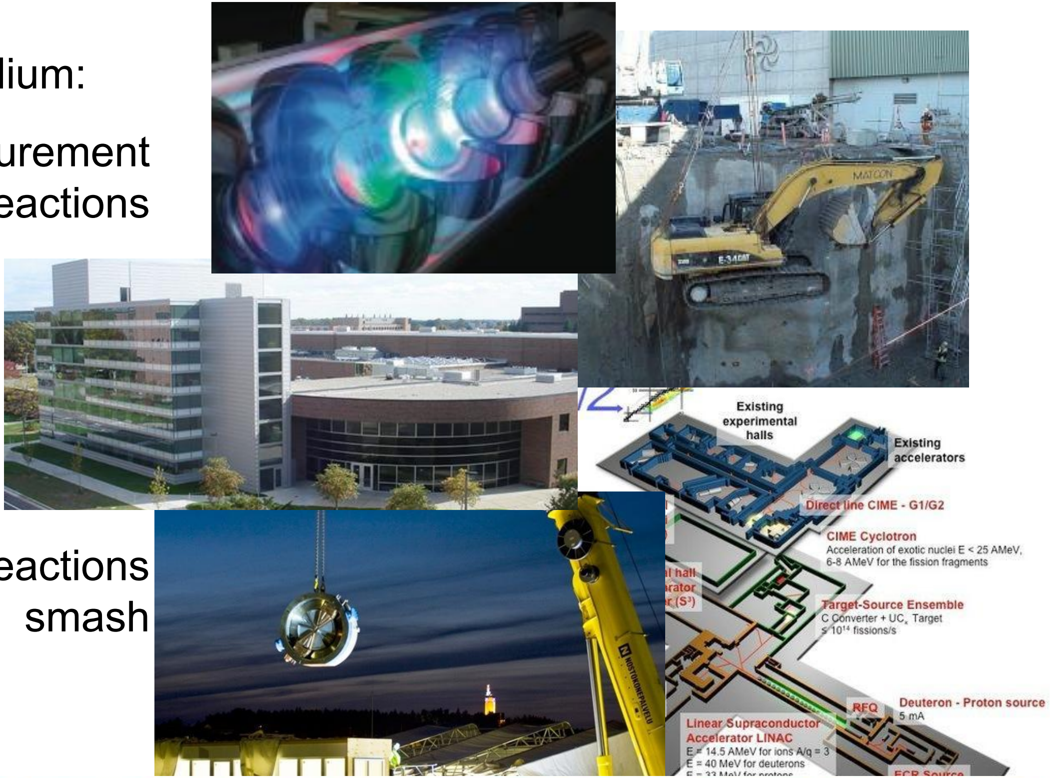
# The Hot CNO-Cycle

## Down-to-Earth Astrophysics (in practice)

Challenging to fuse oxygen-15 with helium:

- New facilities for measurement of key nuclear reactions using radioactive ion beams:
- Intense
- Pure
- Accelerated




Setup for studying the reactions that happen when we smash the beam into the target

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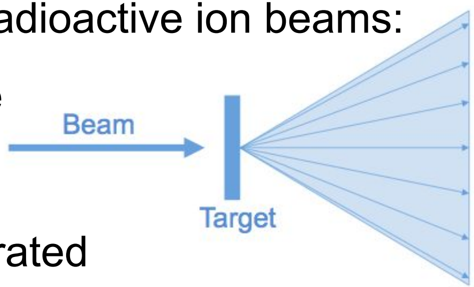
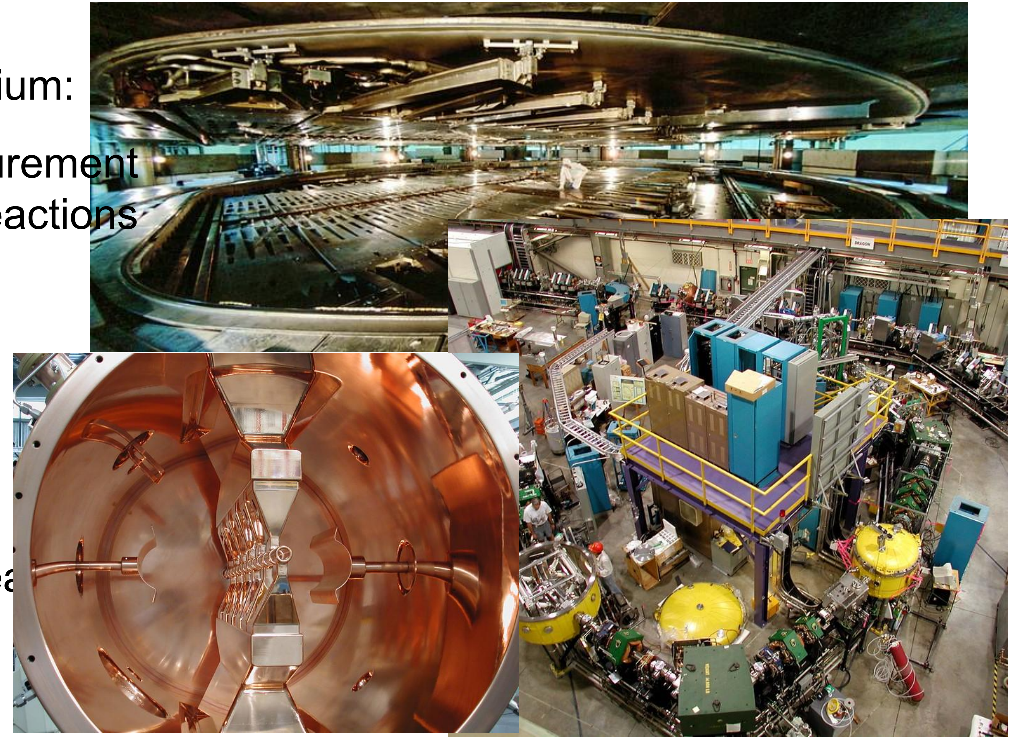



Setup for studying the rea that happen when we the beam into the target



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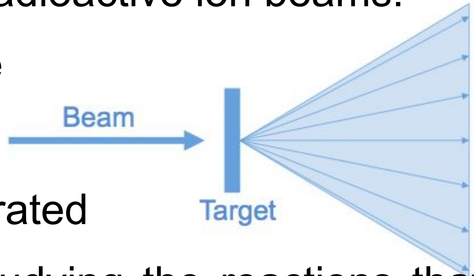
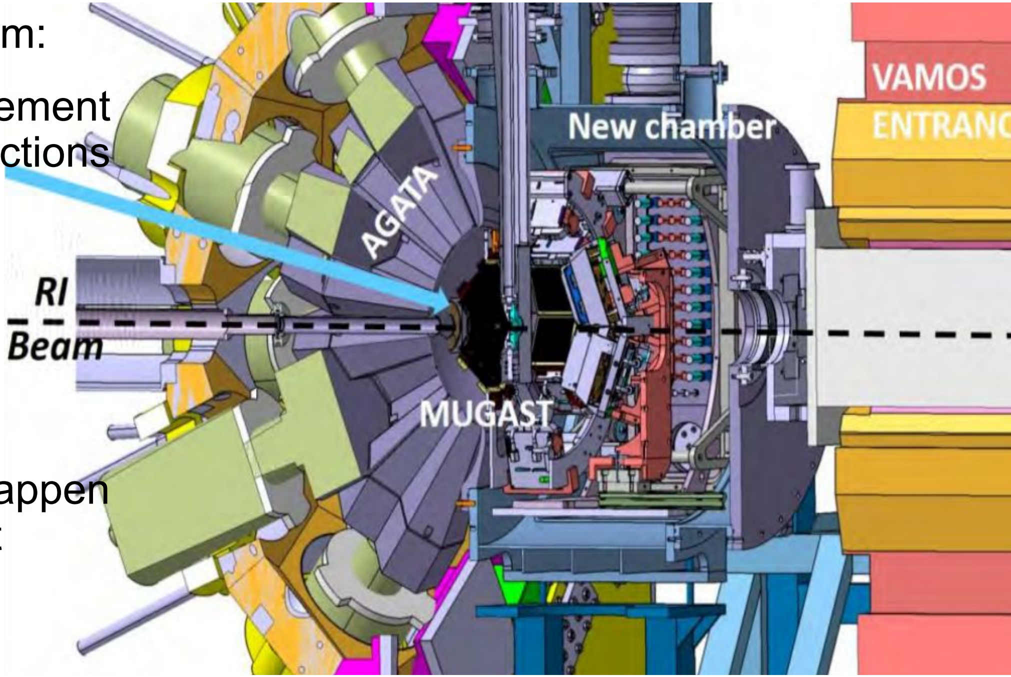
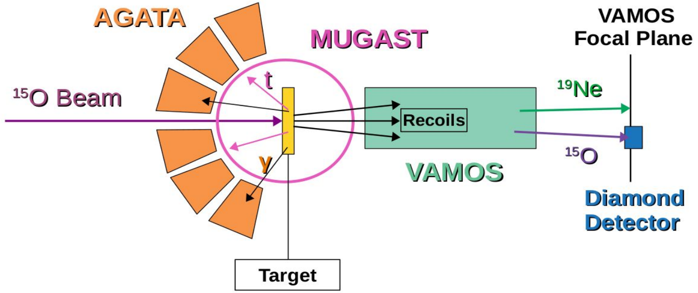


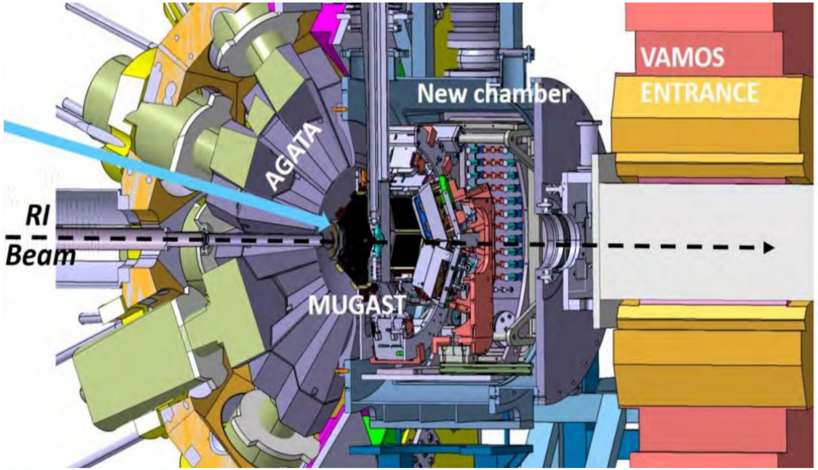




Setup for studying the reactions that happen when we smash the beam into the target

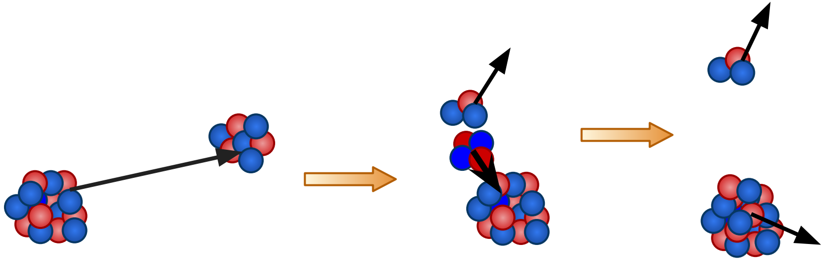
# The Hot CNO-Cycle

## Down-to-Earth Astrophysics (in practice)




$$^{15}\mathrm{O} + {}^{7}\mathrm{Li} \longrightarrow t + {}^{19}\mathrm{Ne}^{*} \longrightarrow t + {}^{19}\mathrm{Ne} + \gamma$$



- ★ July 2019 @GANIL, France
- ★ RIB $^{15}$O @ 4.7 MeV/u
- ★ Beam Intensity $\sim 10^7$ pps
- ★ Triple coincidence using:
  - ○ AGATA - HPGe: prompt-γ
  - ○ MUGAST - DSSDE: light particle t
  - ○ VAMOS: $^{19}$Ne recoil

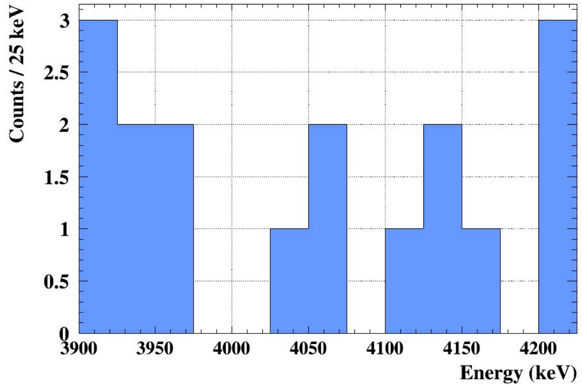
[https://www.ganil-spiral2.eu/]
[**M Assiè**, et al. NIMA]
[**J.S. Rojo**, et al. J Phys.]

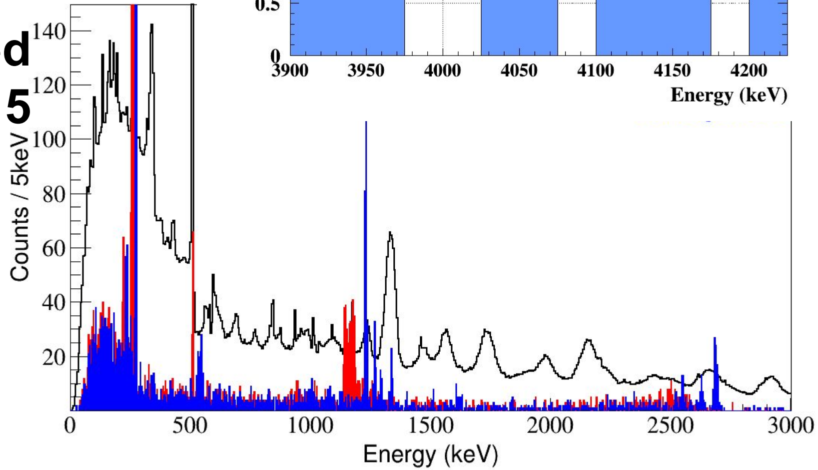
# The Hot CNO-Cycle

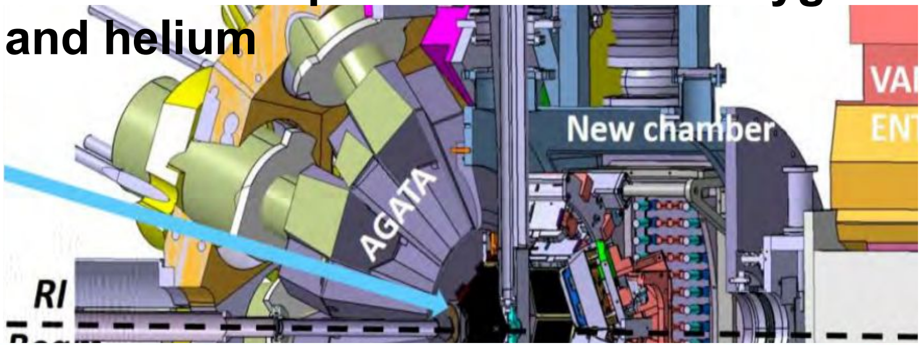
## Finding a needle in a hay stack

- Final coincidence-gated γ-ray spectrum
- 3 events (from among one billion events and 20 TB of data...)
- Extremely challenging experiment!

**Even more challenging than expected for stellar explosions to fuse oxygen-15 and helium**



# Down-to-Earth Astrophysics

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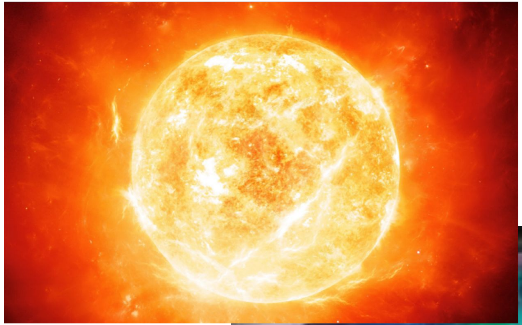
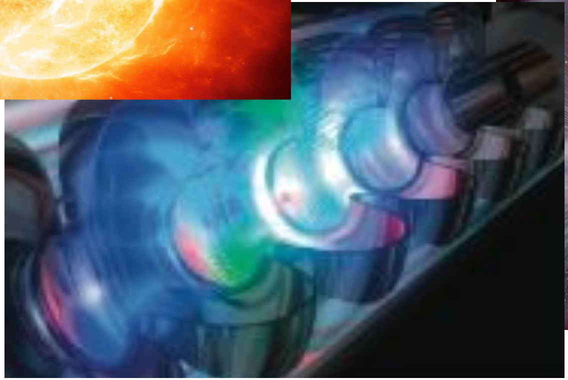
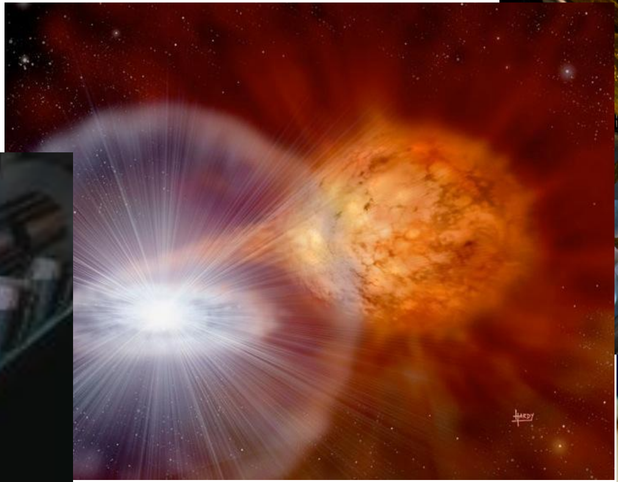
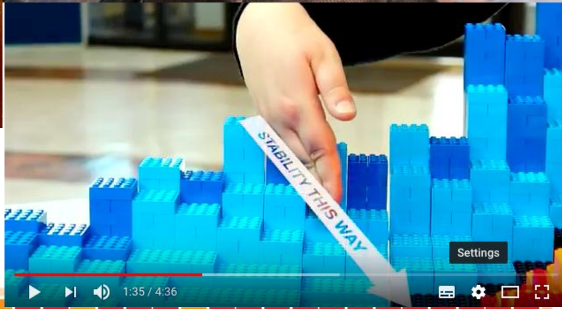
## How are we made of Stars? - How can we know what they make?










*Christian Aa. Diget, 19th July 2022, @ York*