COOKING WITH THE STARS

What are we made of?

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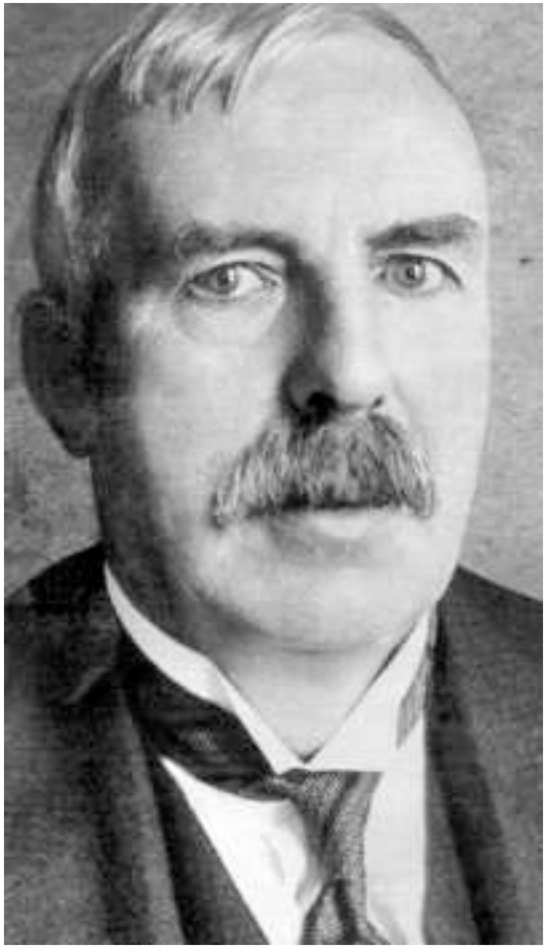
Element	% (no. of atoms)	How they were made
Hydrogen	61.6	Big Bang
Oxygen	26.3	?
Carbon	9.99	?
Nitrogen	1.48	?
Calcium	0.24	?
Phosphorus	0.20	?
Sulphur	0.06	?
Sodium	0.06	?
Chlorine	0.04	?
Magnesium	0.03	?

Nuclei



Rutherford

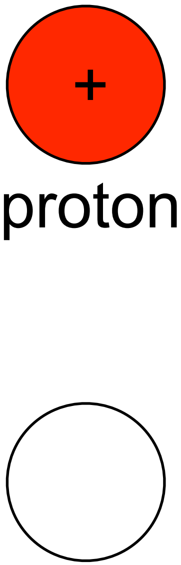
Nuclear Safety Officer

Rutherford's Discovery - 1911

Nucleus

If an atom were as large as the McGill campus, the nucleus would be the size of a dime

Basic Ingredients

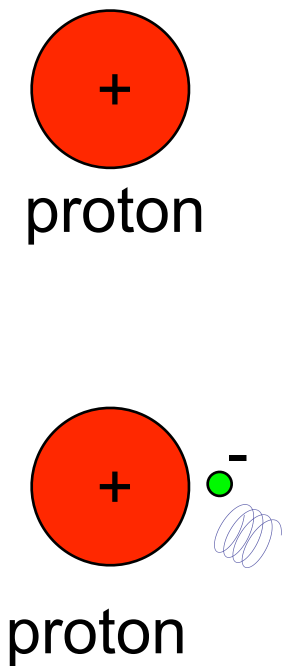


proton

neutron

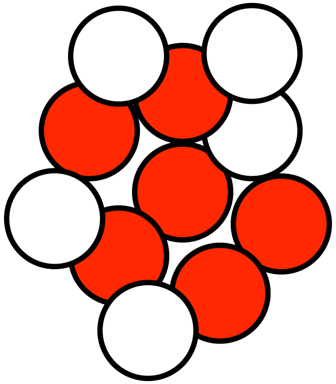
free protons live forever, but neutrons decay in about 10 minutes

Basic Ingredients

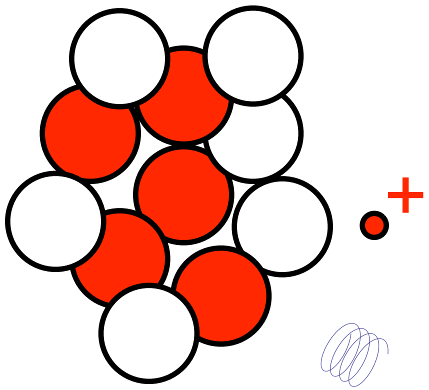


Beta decay of the neutron

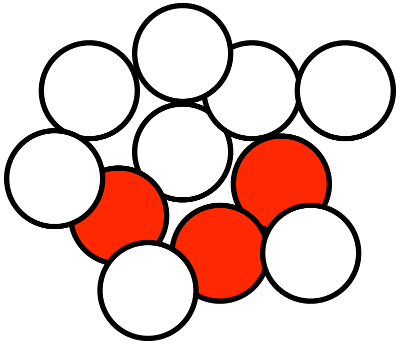
Carbon-11 with too many protons



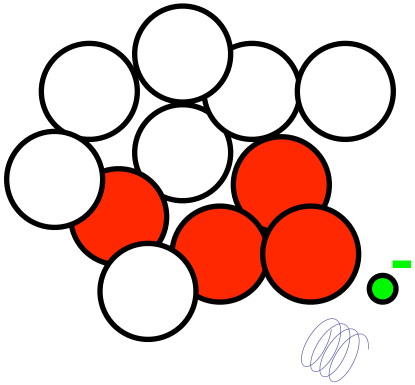
changes to boron-11 by emitting a positron

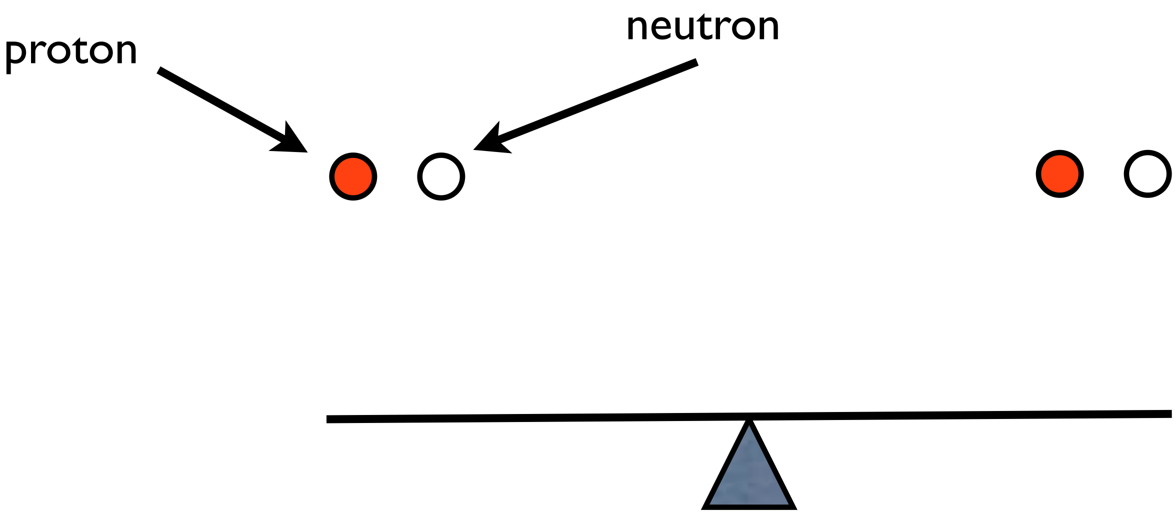


Lithium-11 with too many neutrons

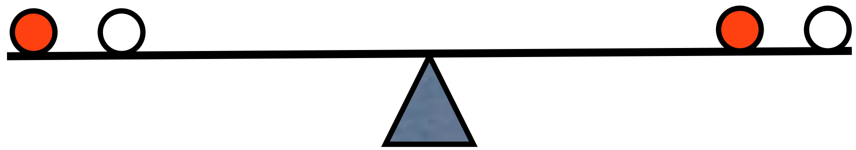


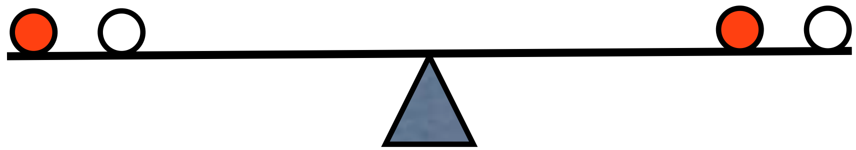
Changes to beryllium - 11 by emitting an electron



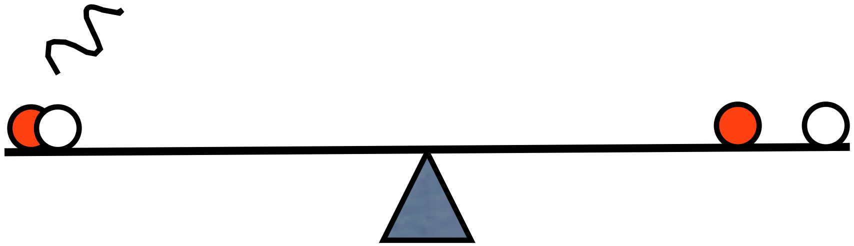


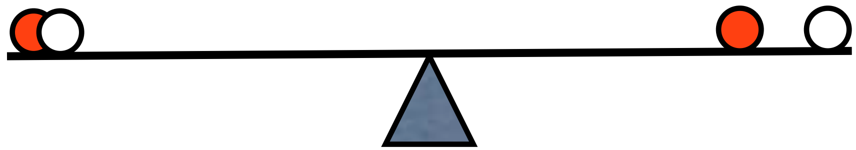
The simplest nuclear reaction: a proton meets a neutron





$$E = mc^2$$





If we could weigh nuclear particles
we could calculate the energy released

J.J. Thompson - 1897
-discovery and mass of the electron-

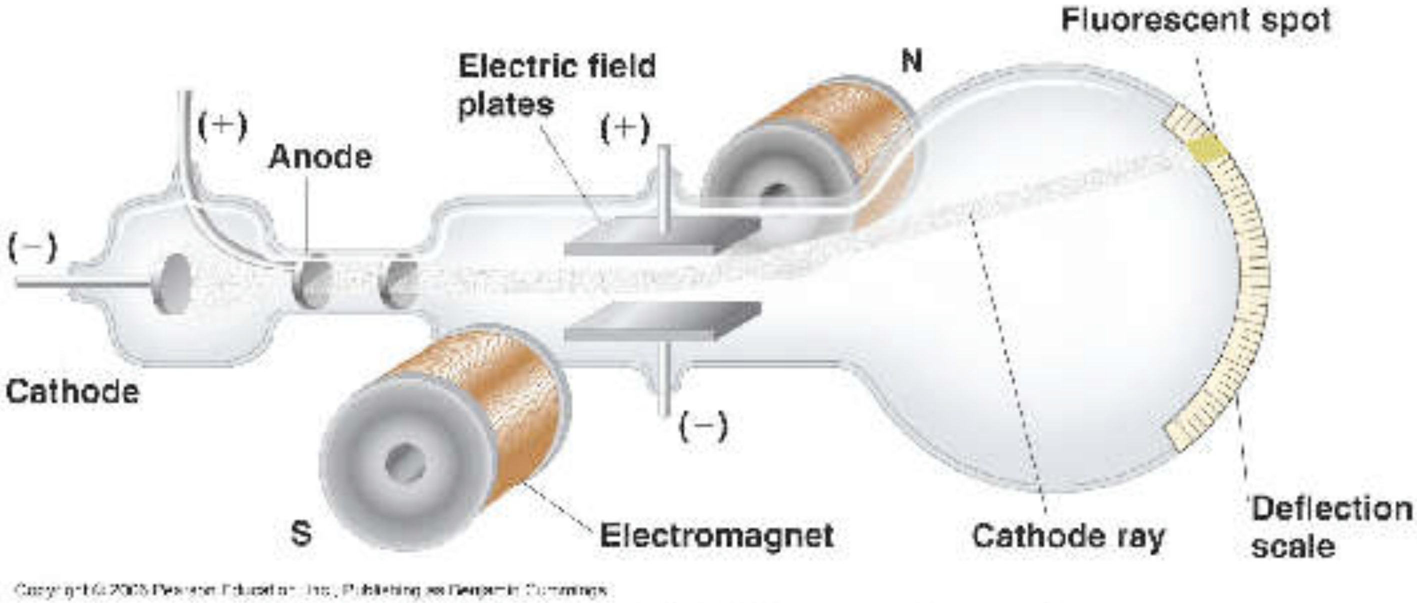
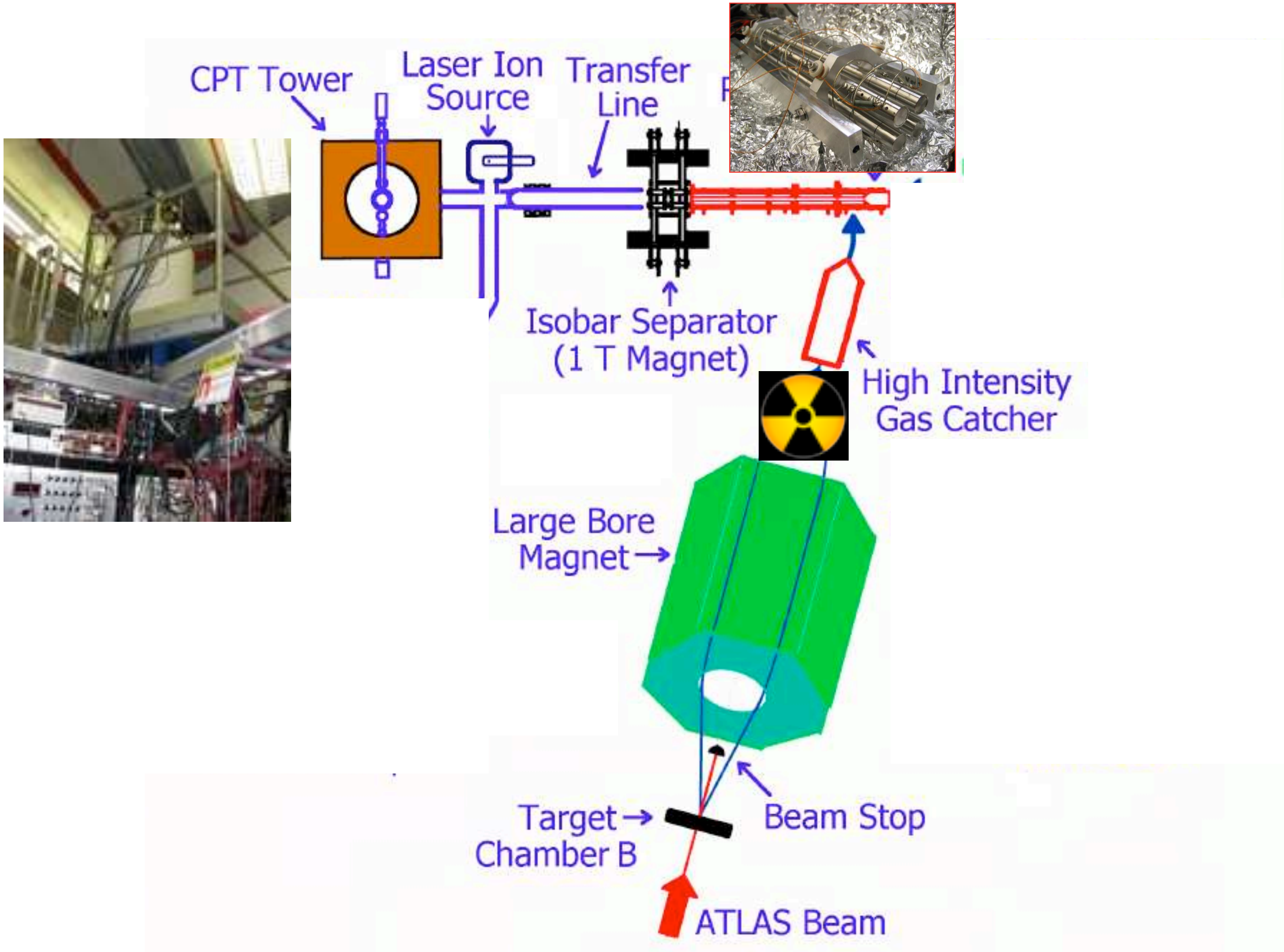


Figure 1: Schematic of J.J. Thompson's experiment.

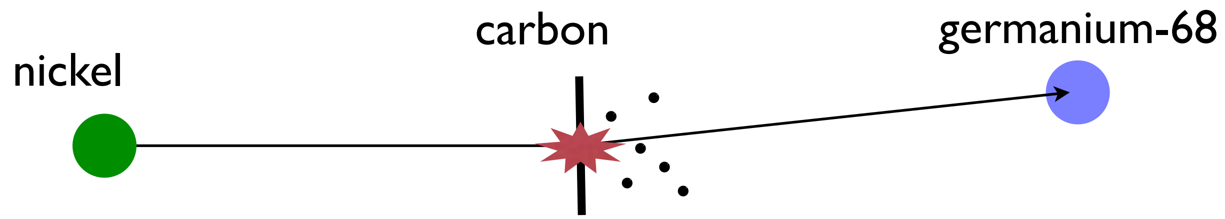
This was the first mass spectrometer


Argonne National Laboratory

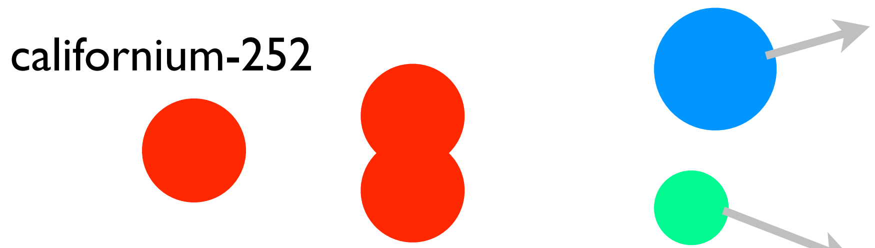
The Canadian Penning Trap



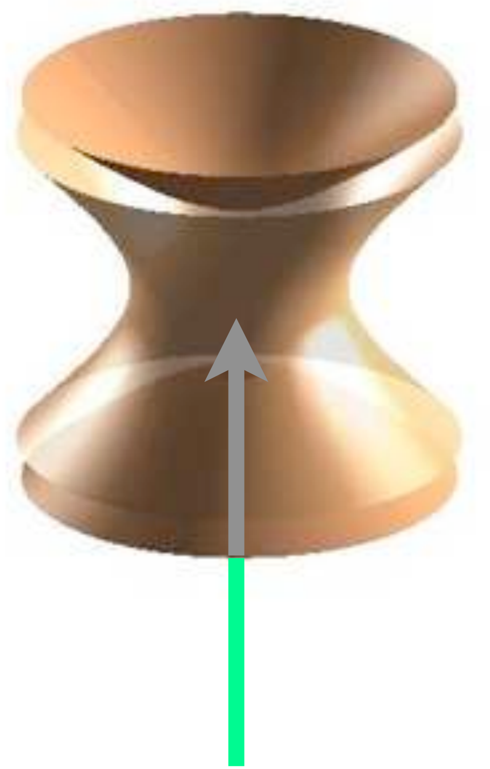
Making proton-rich isotopes by collisions from ATLAS



Making neutron-rich isotopes by californium fission

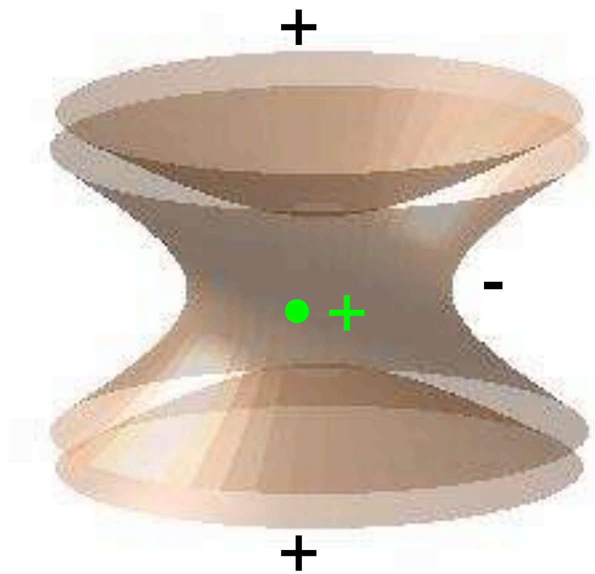


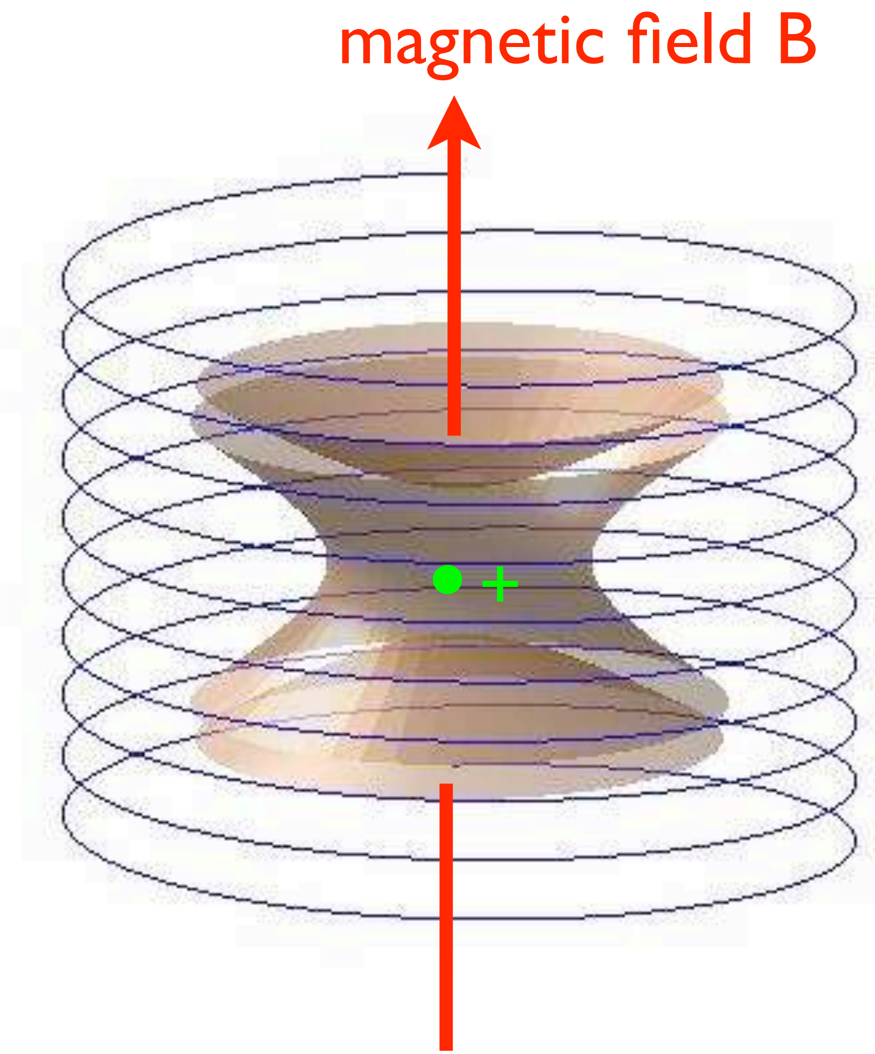
Ion Trap



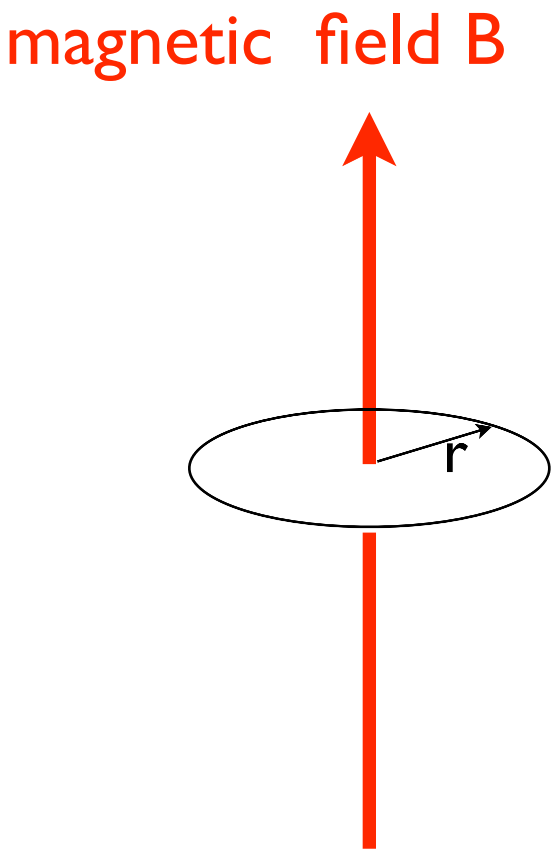
from ion guide

+ve caps keep the ion from escaping axially



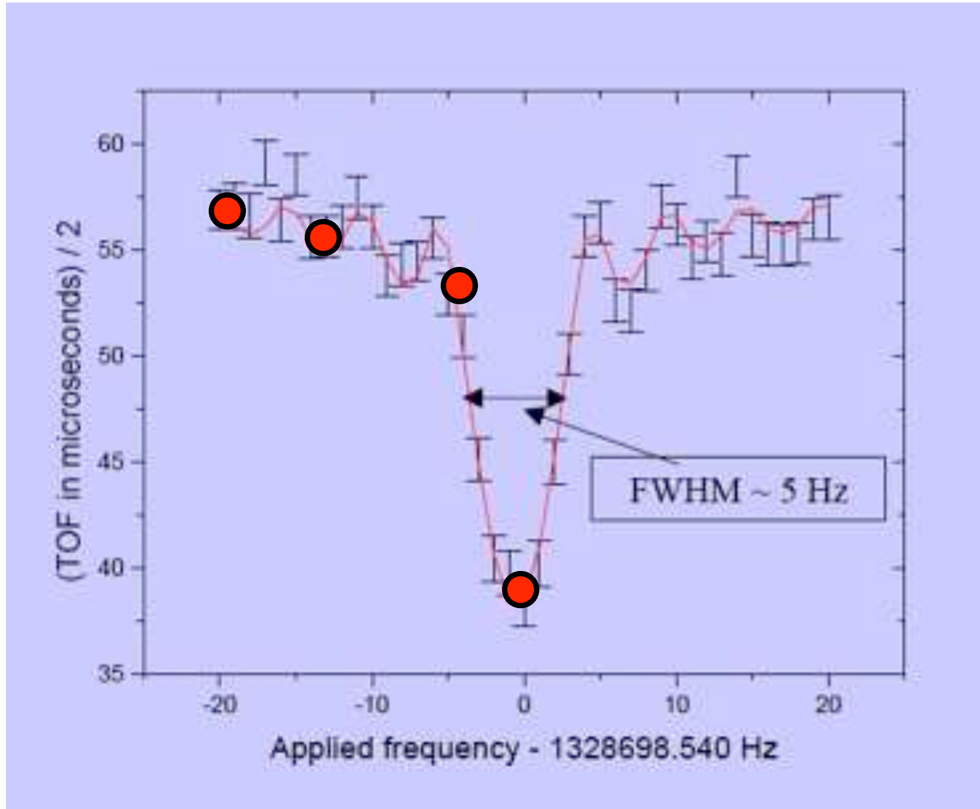


- magnetic field keeps the ion from escaping radially



rotation speed = constant x qB/m

Measuring the frequency



-kick the ions out of the trap

-the ones that have spun in the field arrive first

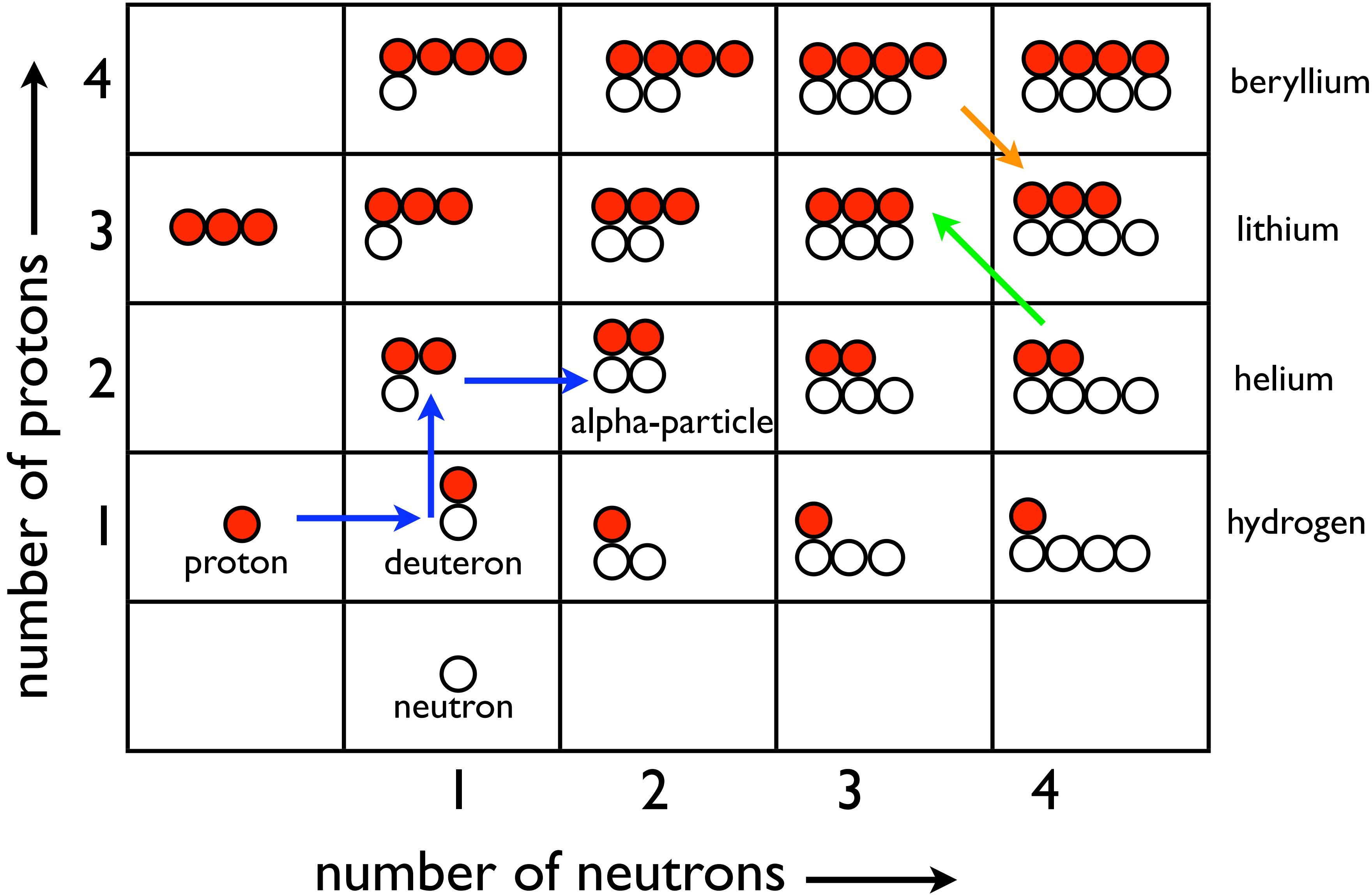
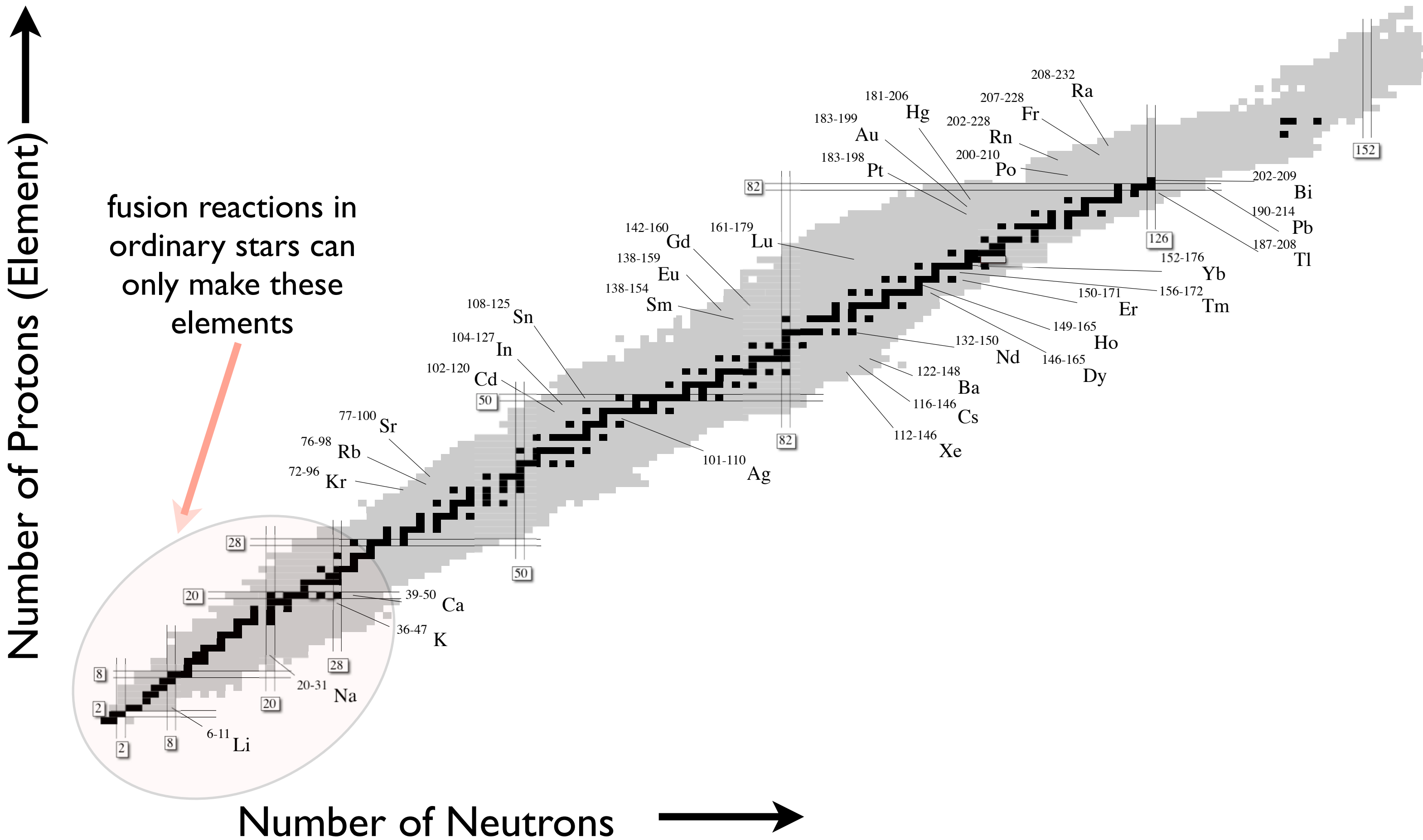
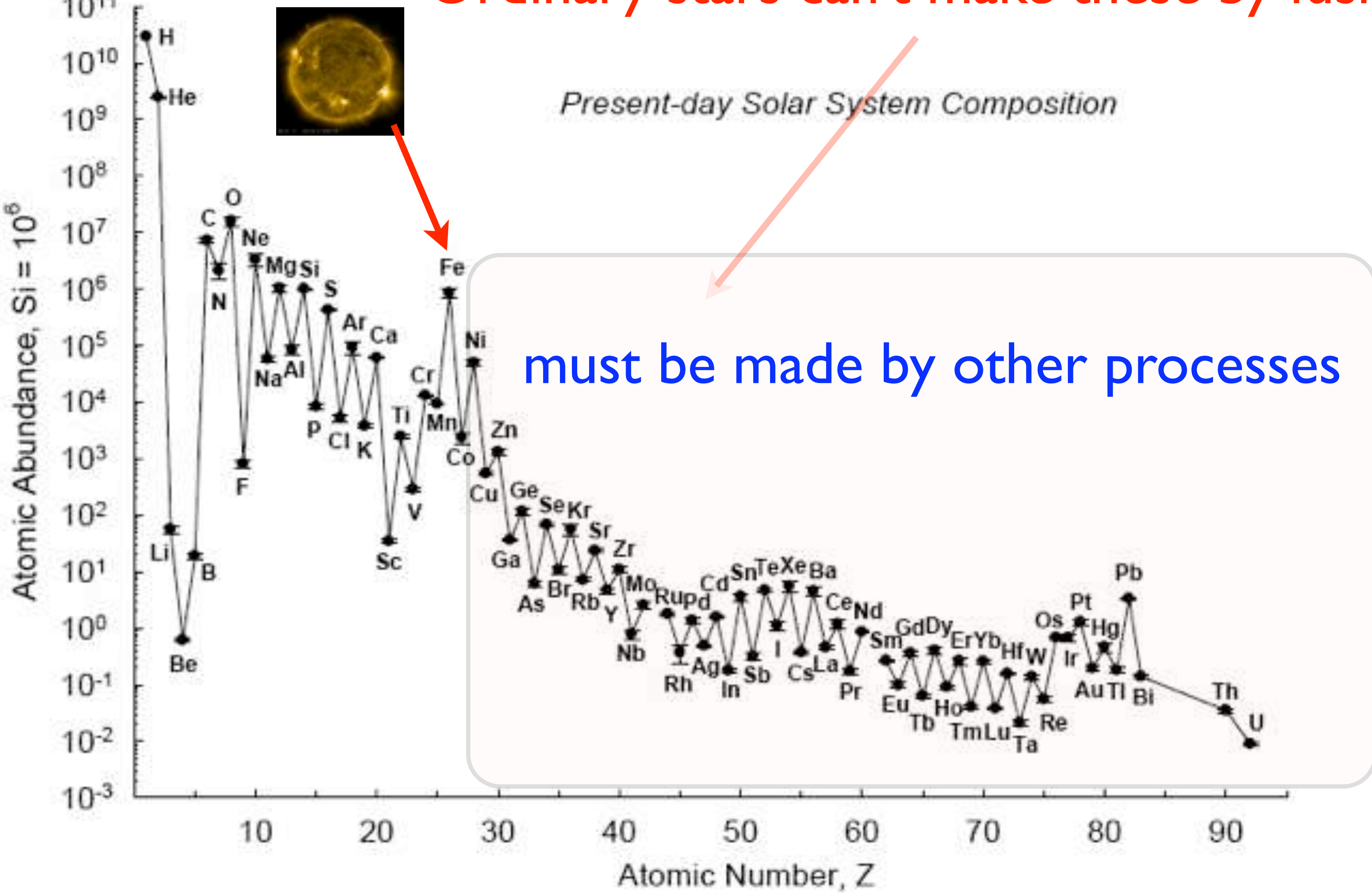
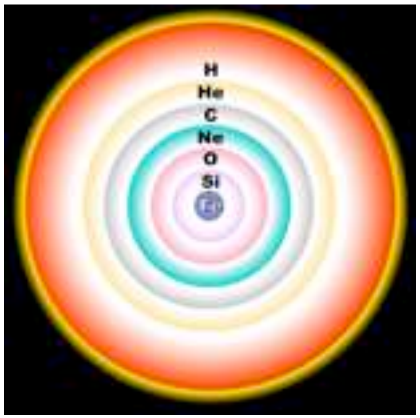

4
3
2
1
number of protons
proton
deuteron
neutron
alpha-particle
beryllium
lithium
helium
hydrogen
1
2
3
4
number of neutrons

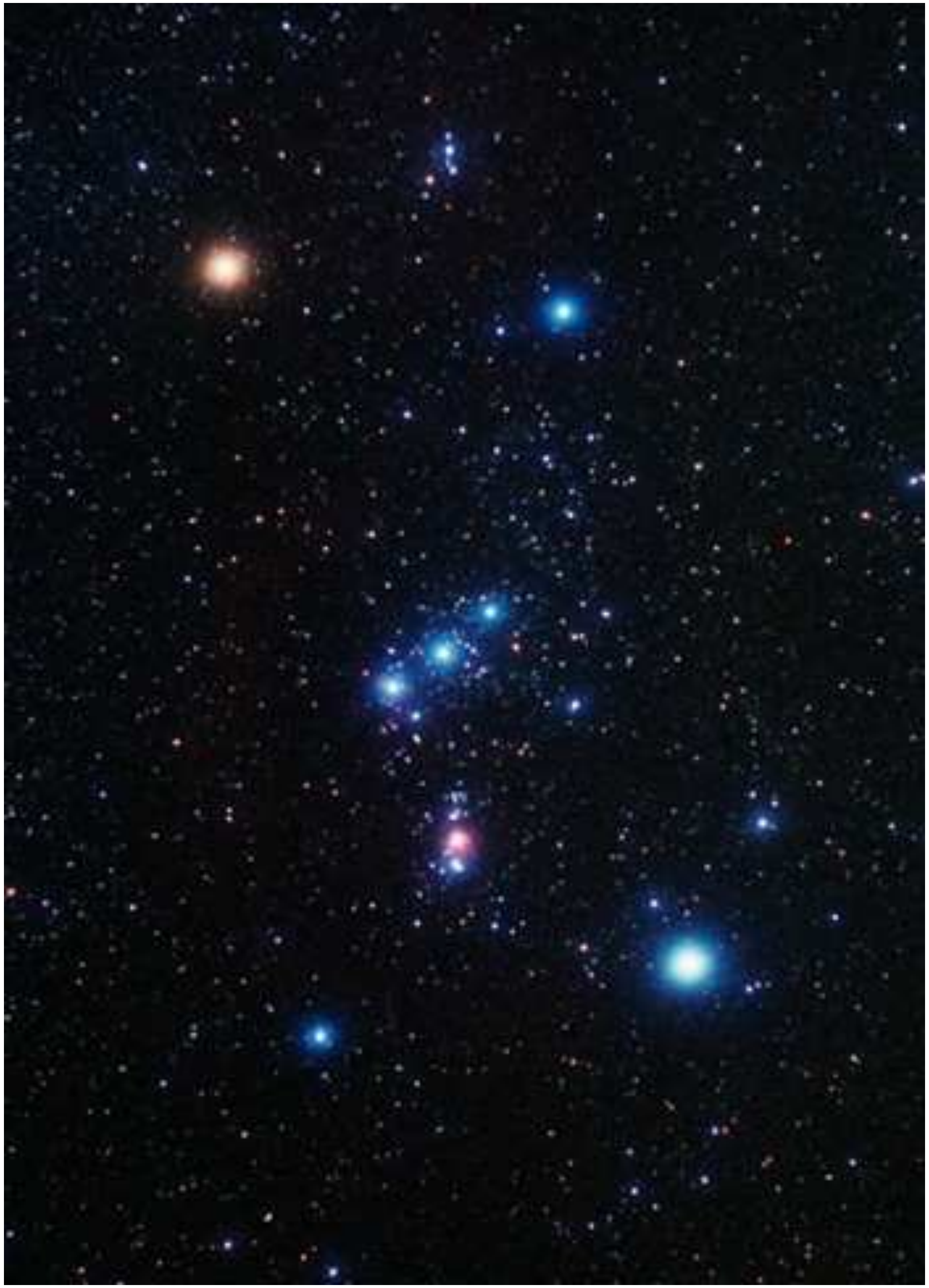
Chart of Nuclides



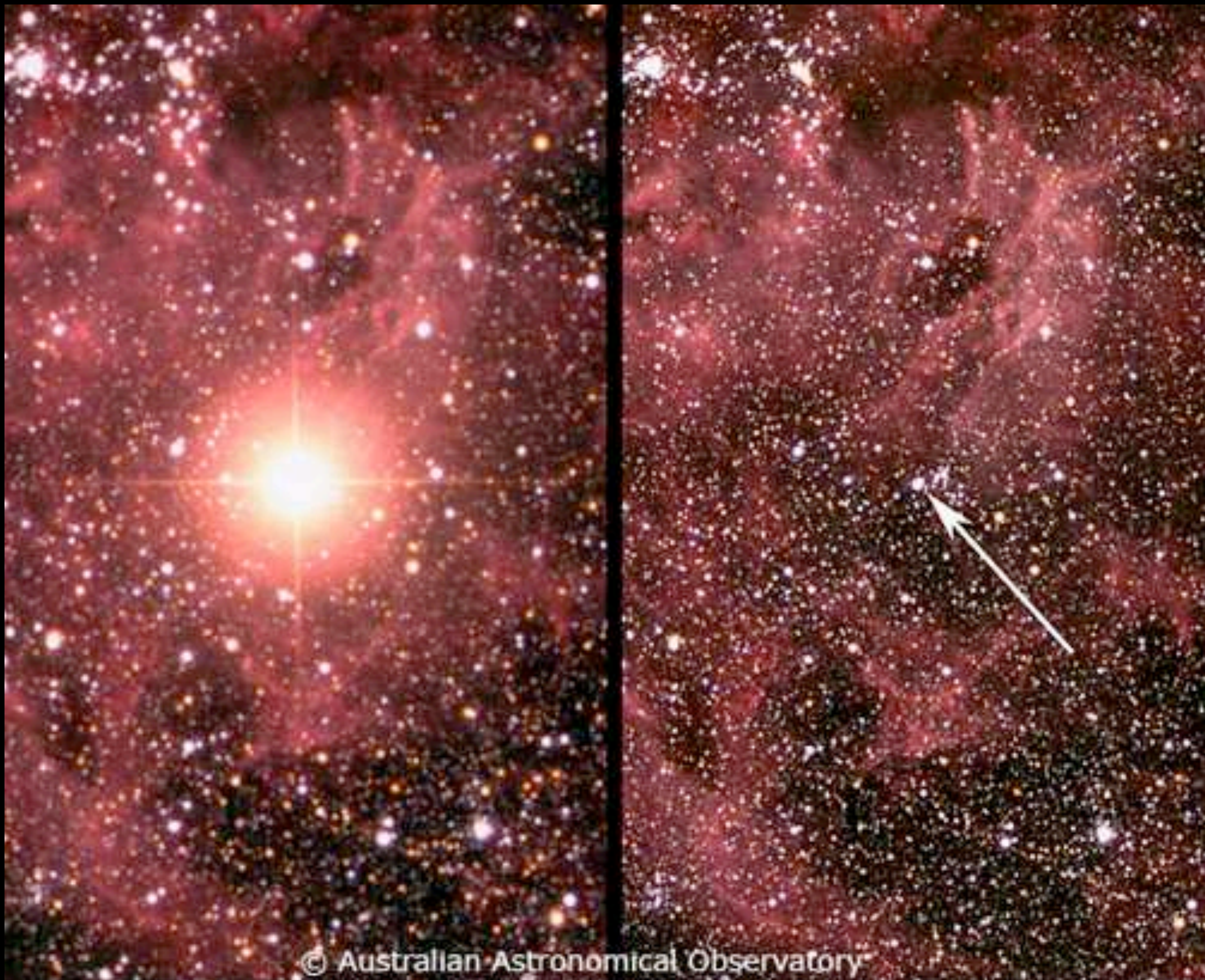
Ordinary stars can't make these by fusion




H
He
C
Ne
O
Si



Supernova 1987a - before and after



Top left is NE. Width of each image is about 8 arc min
Roll mouse over picture to see arrow (image AAT 50a)
Image and text © 1989-2010, Australian Astronomical Observatory, photograph by David Malin.

Nucleosynthesis in the r-process

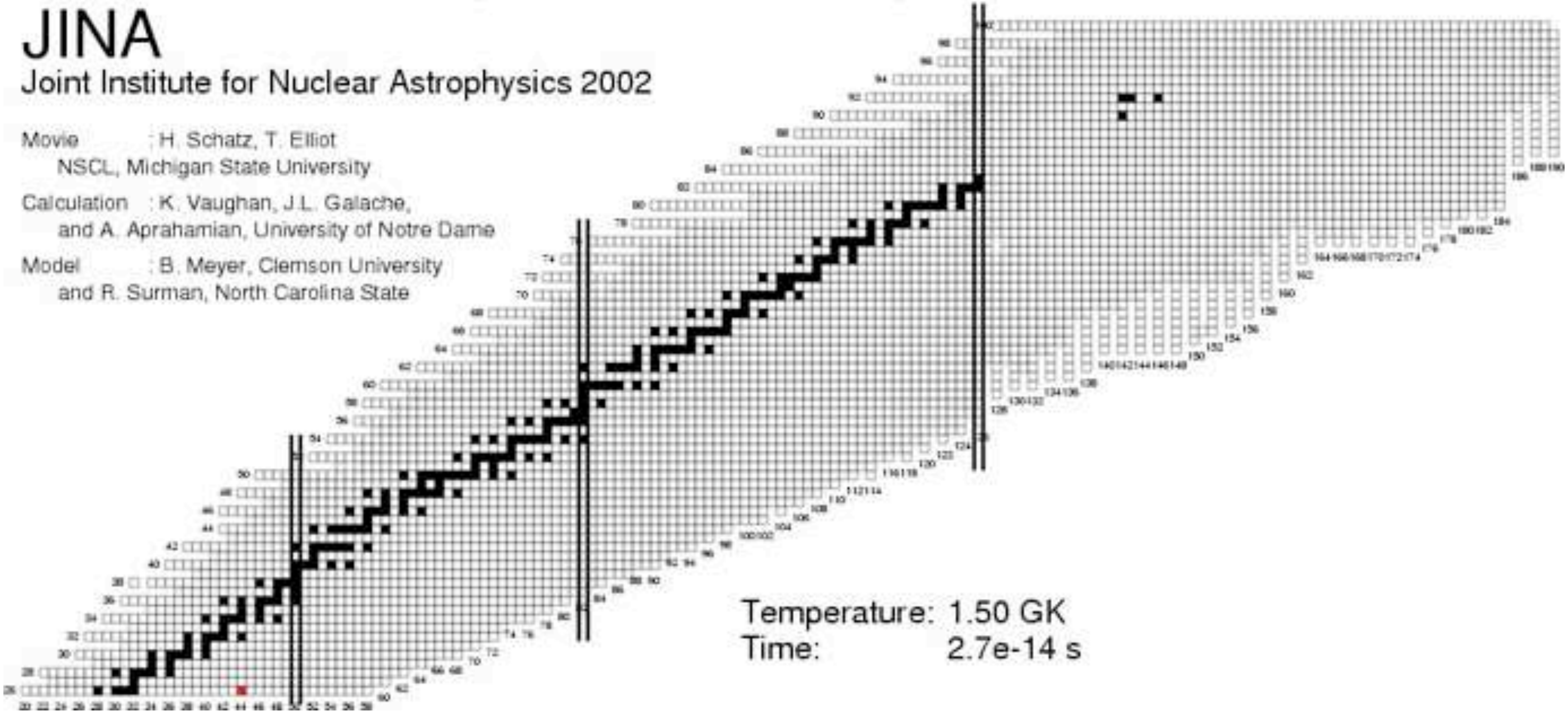
JINA

Joint Institute for Nuclear Astrophysics 2002

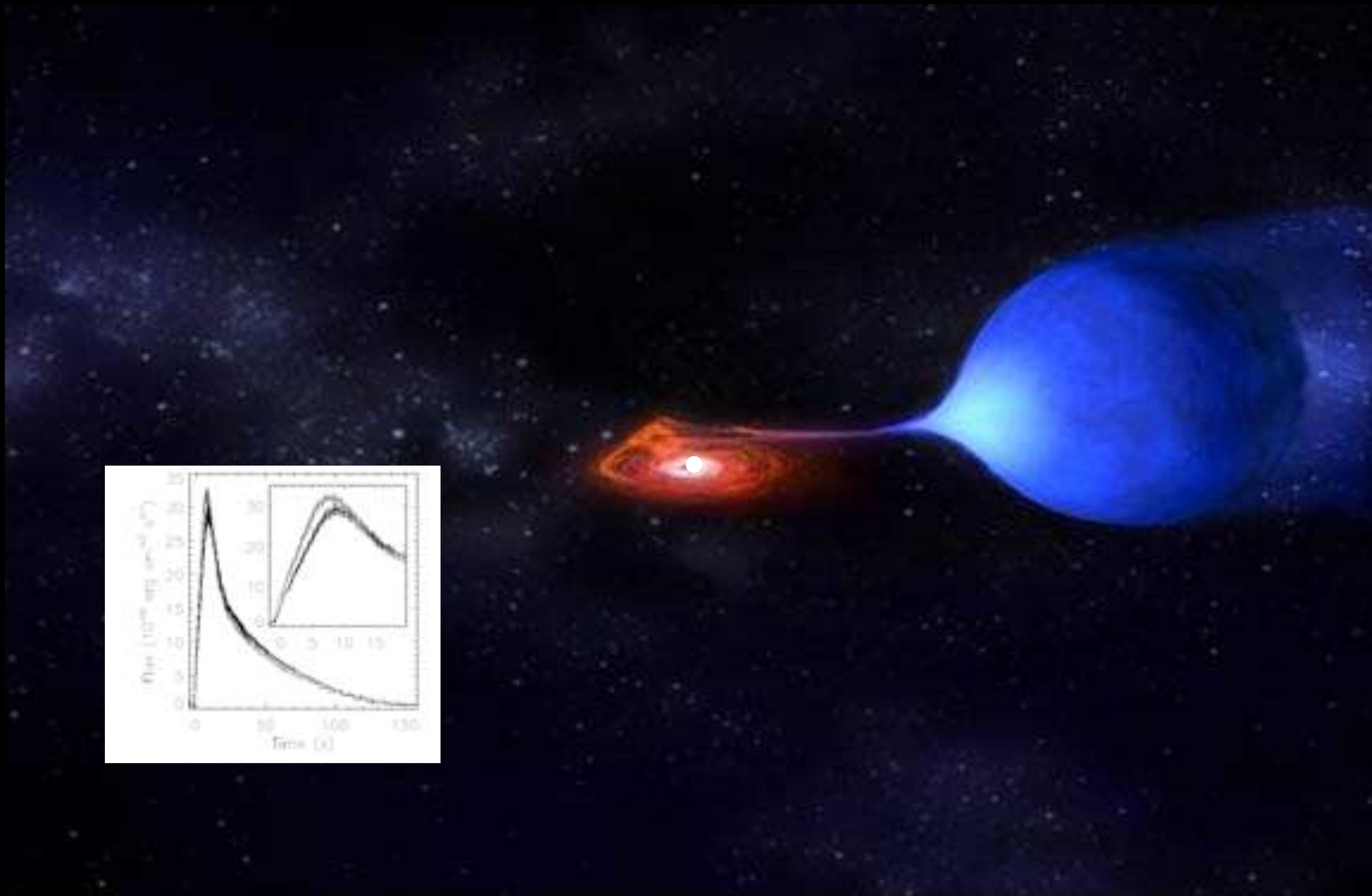
Movie : H. Schatz, T. Elliot
NSCL, Michigan State University

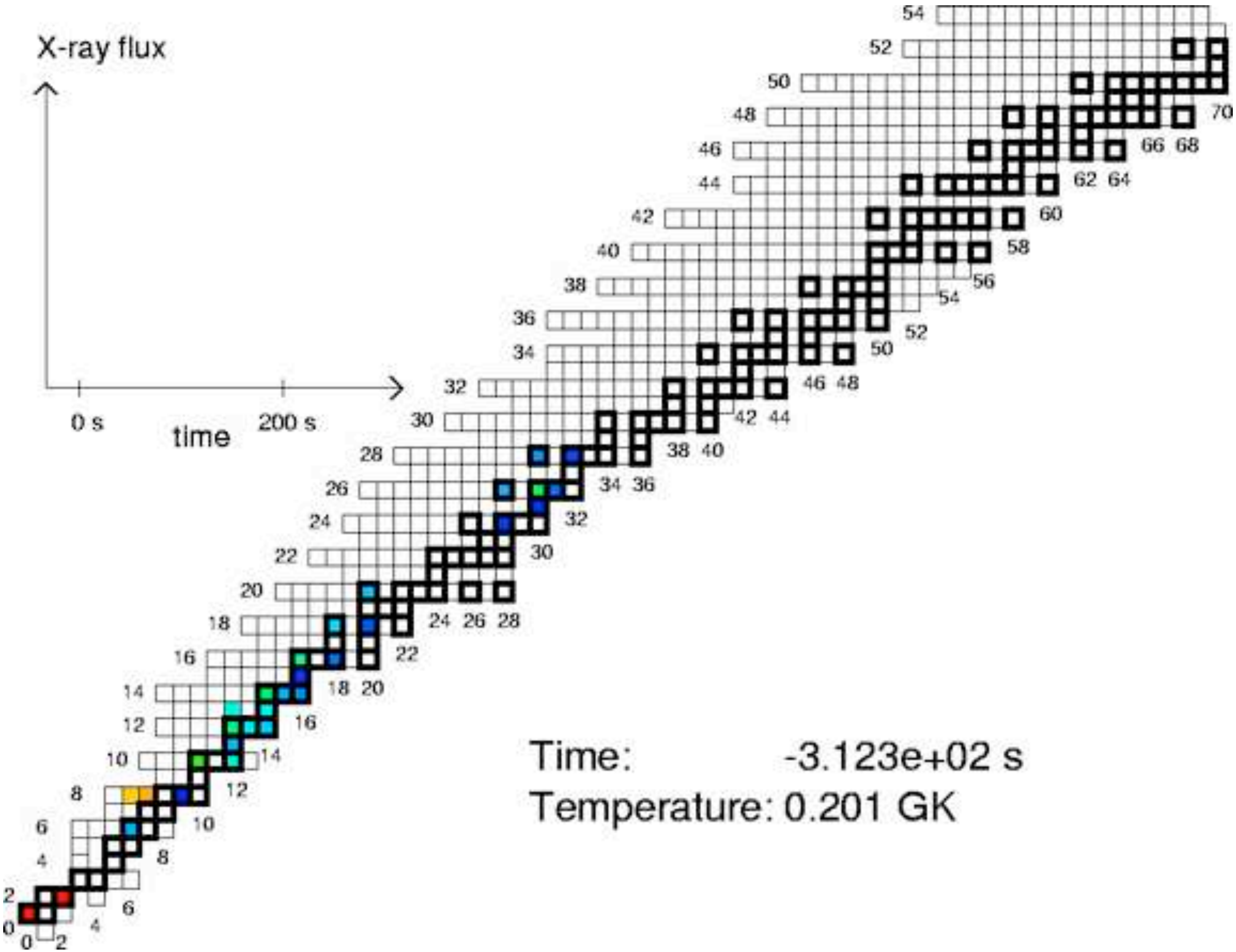
Calculation : K. Vaughan, J.L. Galache,
and A. Aprahamian, University of Notre Dame

Model : B. Meyer, Clemson University
and R. Surman, North Carolina State



X-ray bursts on a neutron star

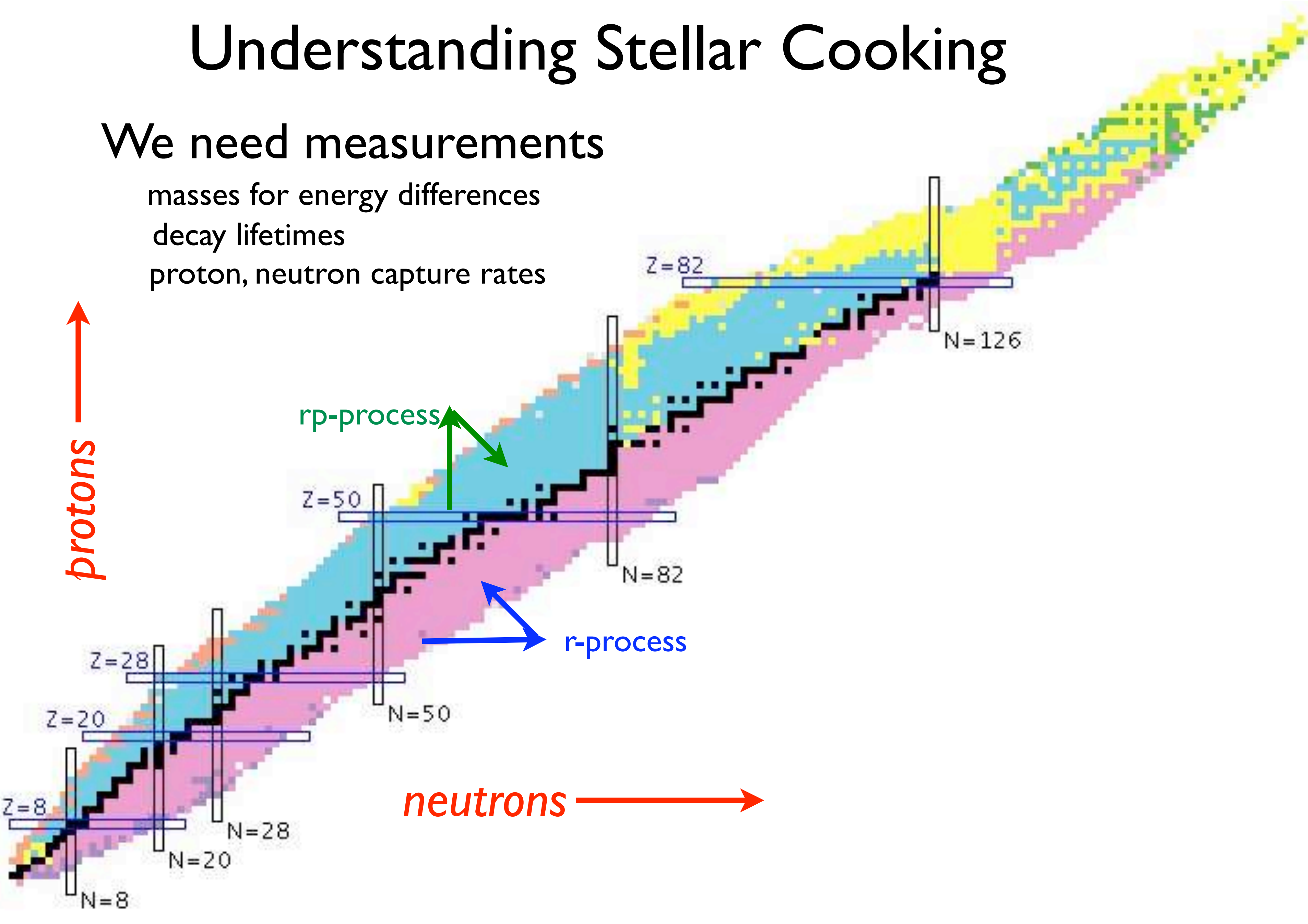



X-ray flux
0 s
time
200 s
Time: -3.123e+02 s
Temperature: 0.201 GK

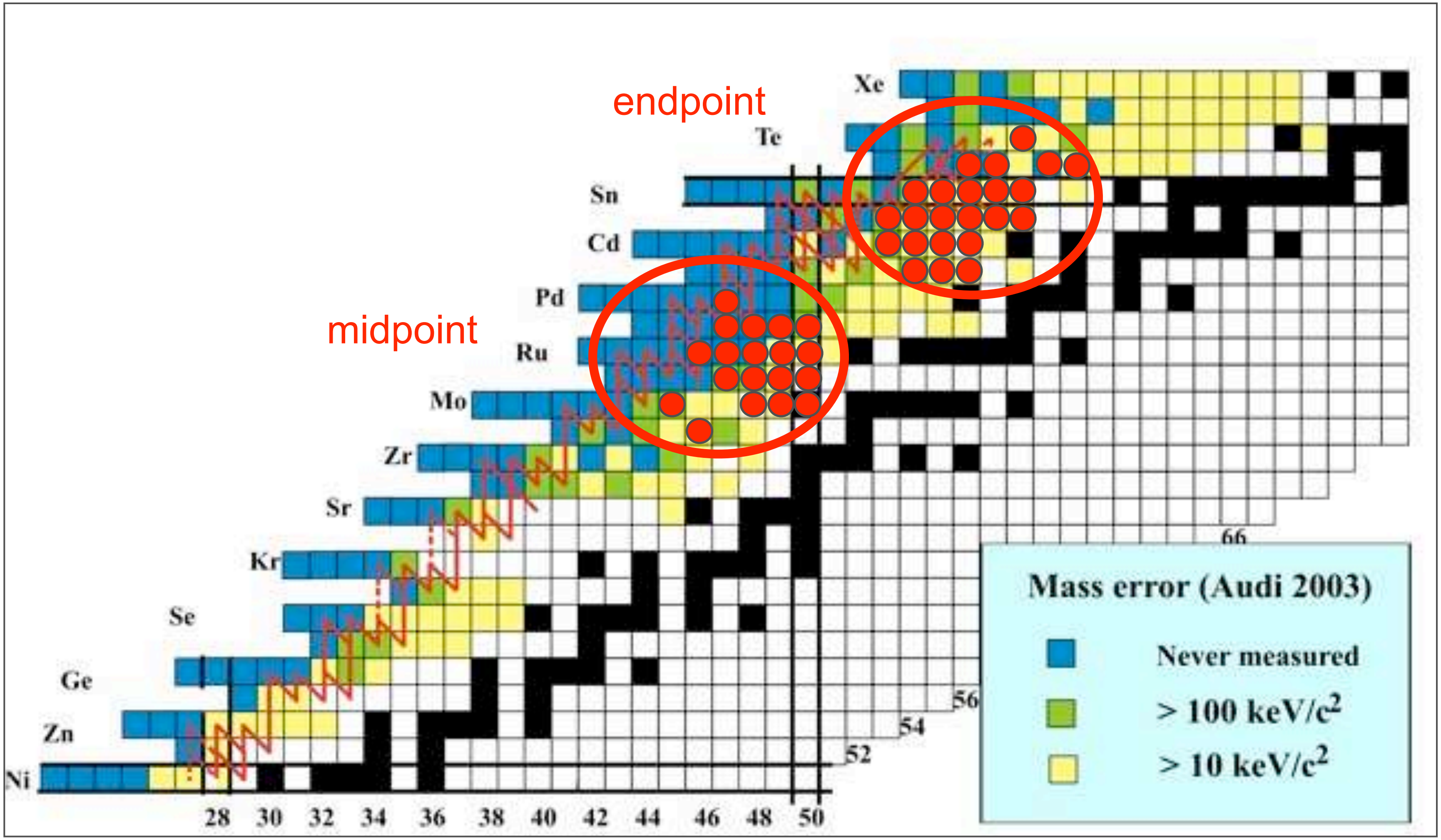
Understanding Stellar Cooking

We need measurements

masses for energy differences
decay lifetimes
proton, neutron capture rates



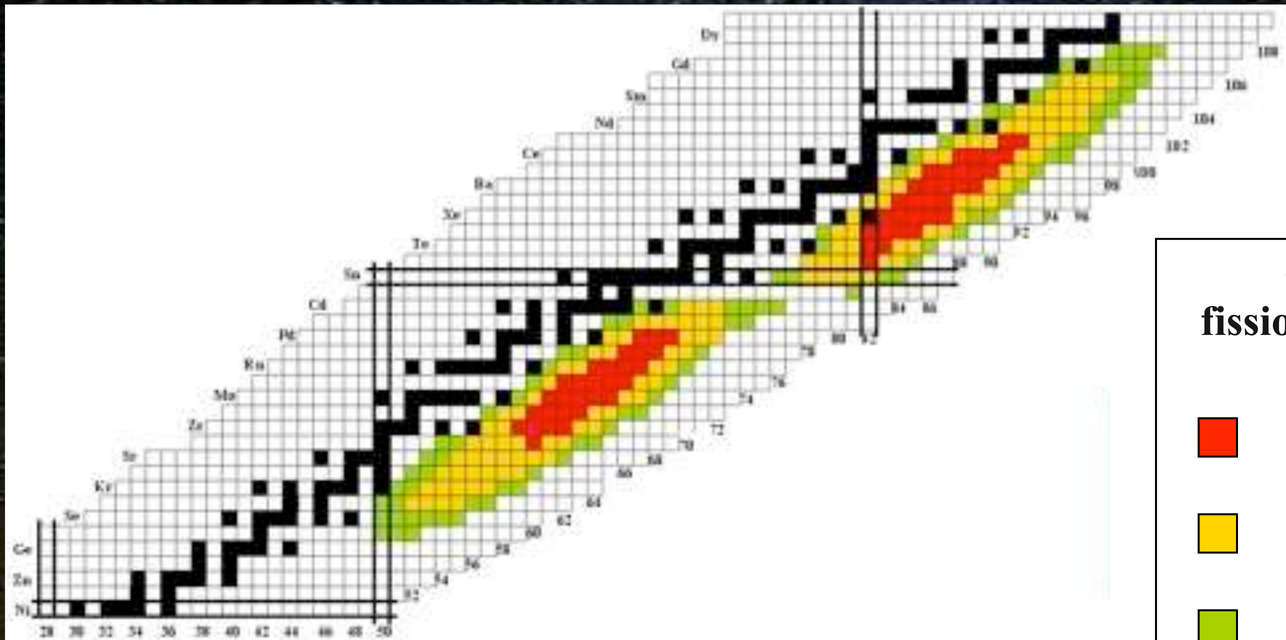
rp-process measurements using the ATLAS beam



- More than 40 proton-rich nuclides measured over the past few years
- Most masses were determined to better than 10 keV/c^2

G. Audi et al., Nucl. Phys. A 729, 337 (2003).

Californium Fission

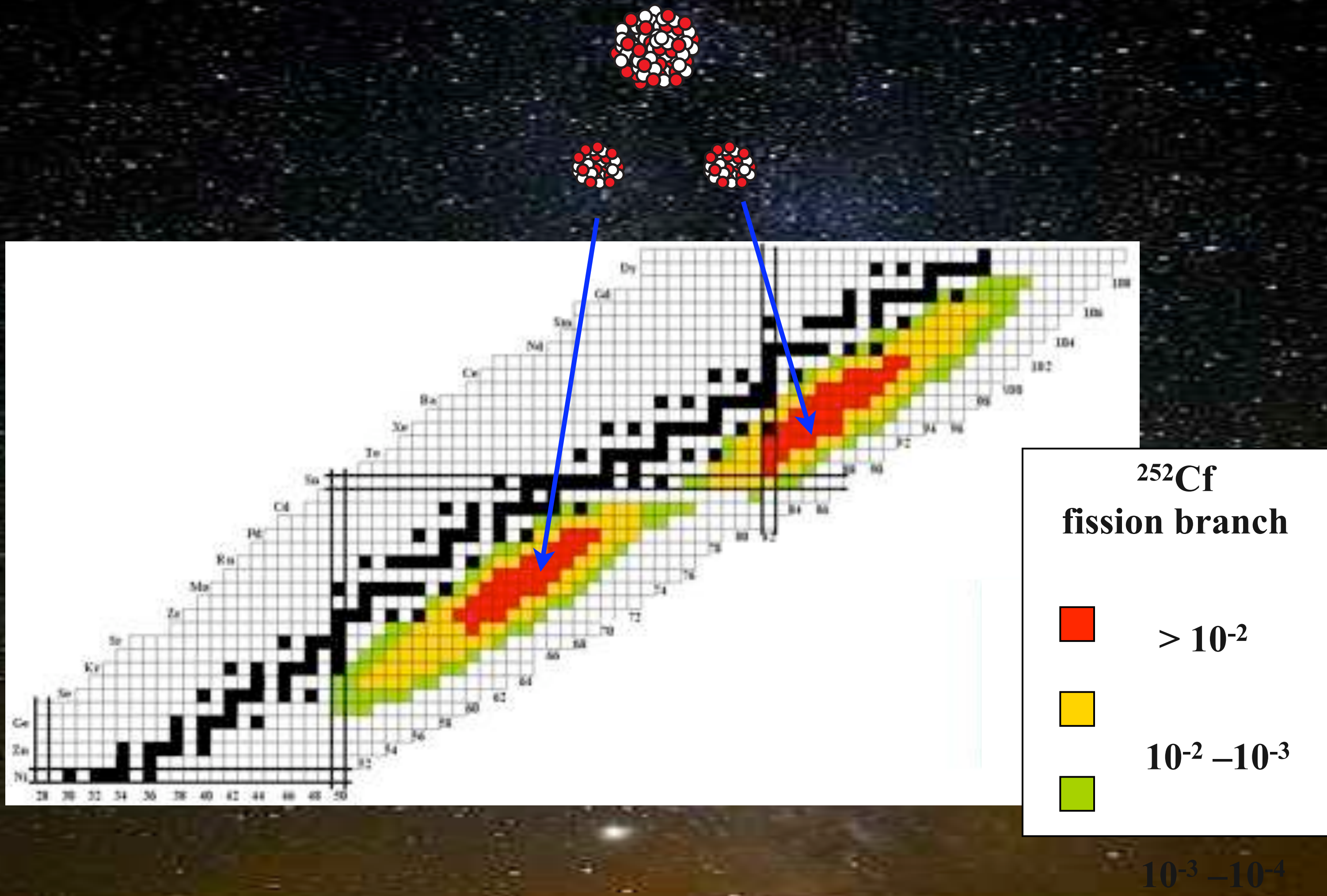


^{252}Cf fission branch

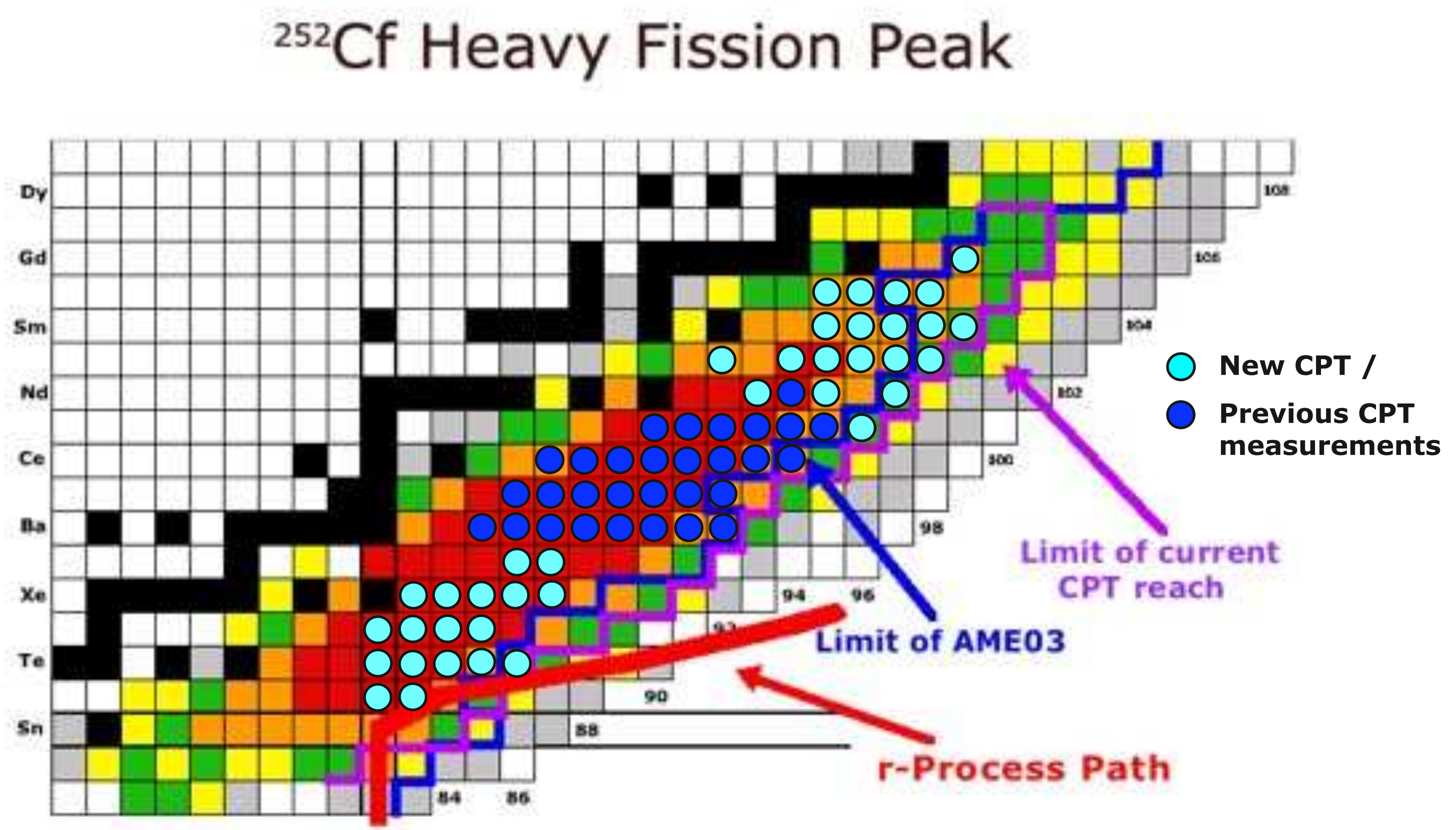
$> 10^{-2}$

$10^{-2} - 10^{-3}$

$10^{-3} - 10^{-4}$


^{252}Cf
fission branch
$> 10^{-2}$
$10^{-2} – 10^{-3}$
$10^{-3} – 10^{-4}$

r-process measurements using the californium source

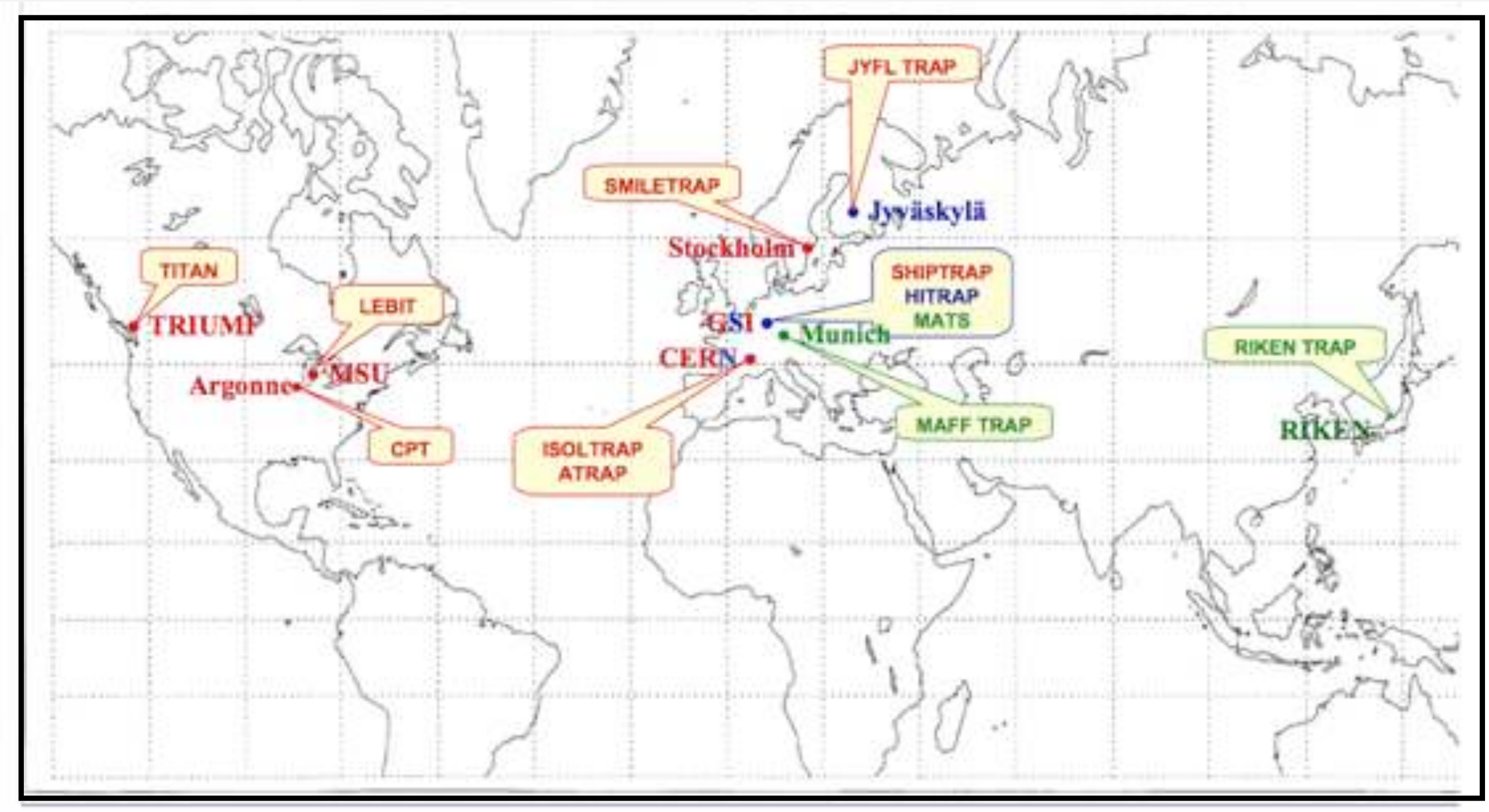


- Ongoing program of measurements since March 2008, target 15 keV uncertainty
- 40 species, 5 have never been previously measured by any means, most others improved by a typical factor of 5
- Adds to 30 measurements taken at CPT in past years with small gas catcher


CARIBU
Californium-252 one curie source


HYSTER

Mass Measurement Penning Trap Facilities



Operating Under Construction Planned