Nuclear Physics in Stars

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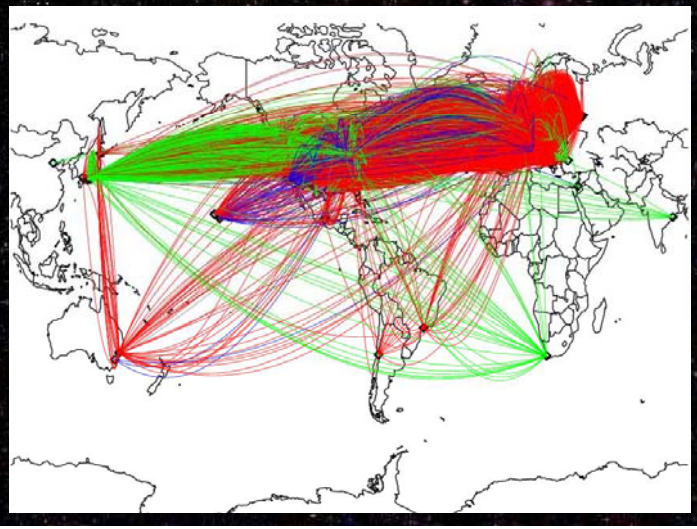
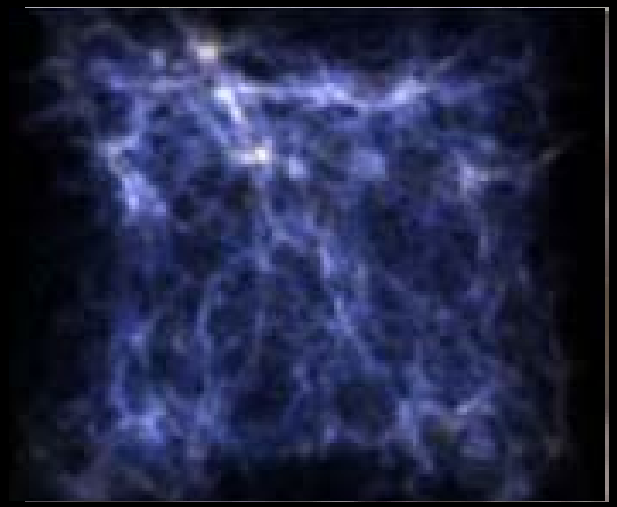
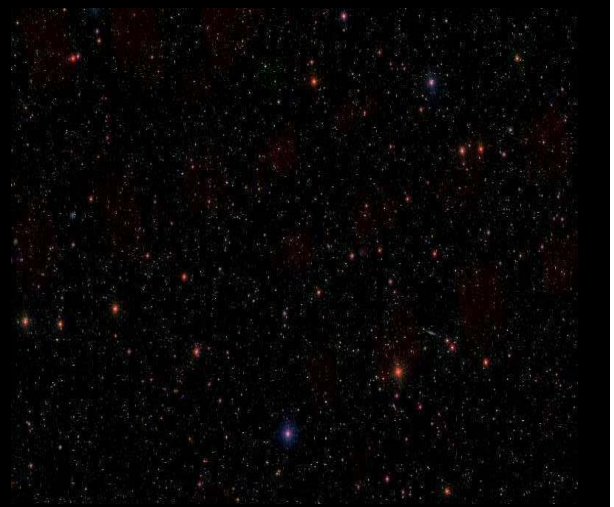
Scientific goal in Nuclear Astrophysics is to explore:

- Nuclear Signature in the Cosmos
- The Nuclear Engine of Stellar Evolution & Stellar Explosion
- The Origin of the Elements
- The Origin of Life ?

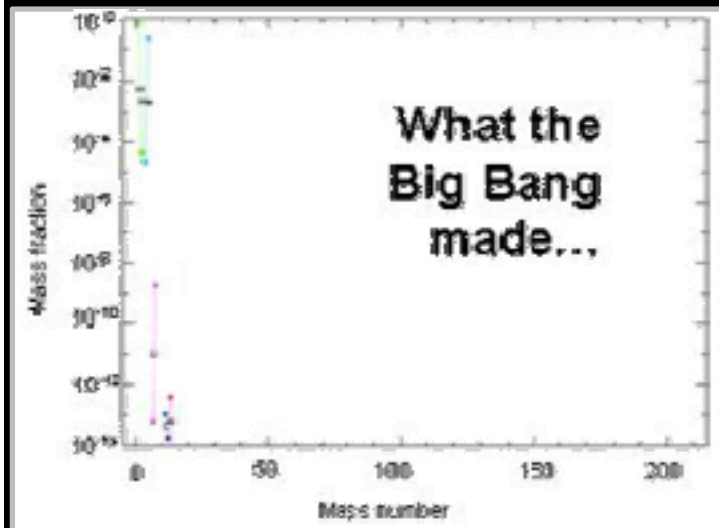
A network of international JINA collaborations for achieving this goal



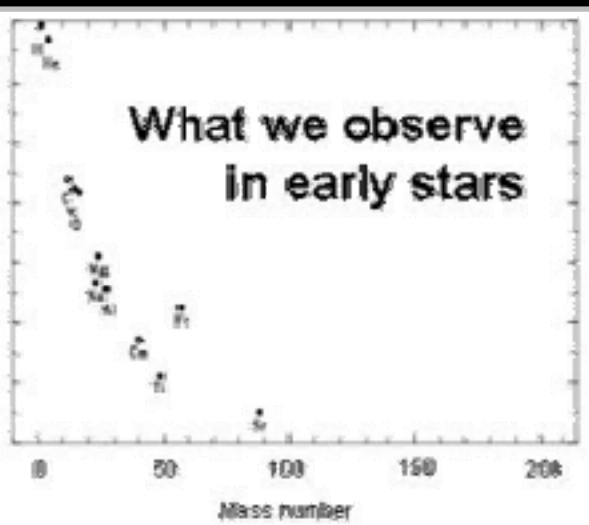




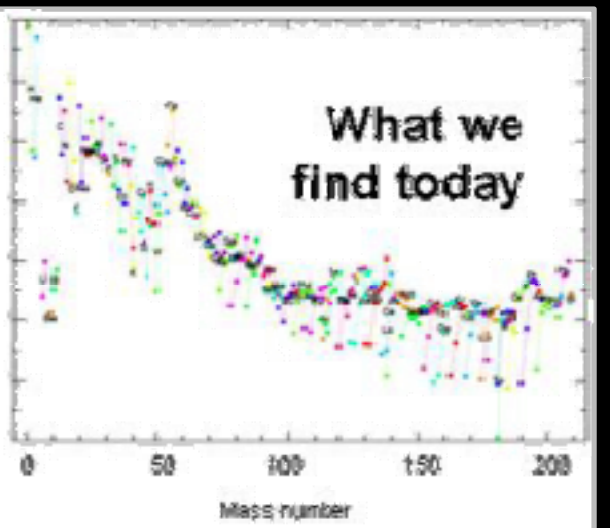
Nucleosynthesis History



(The primordial abundance pattern)
Brian Fields (2002)



(The abundance pattern in the oldest observed stars He1017 & HH1327)
Anna Frebel (2006)



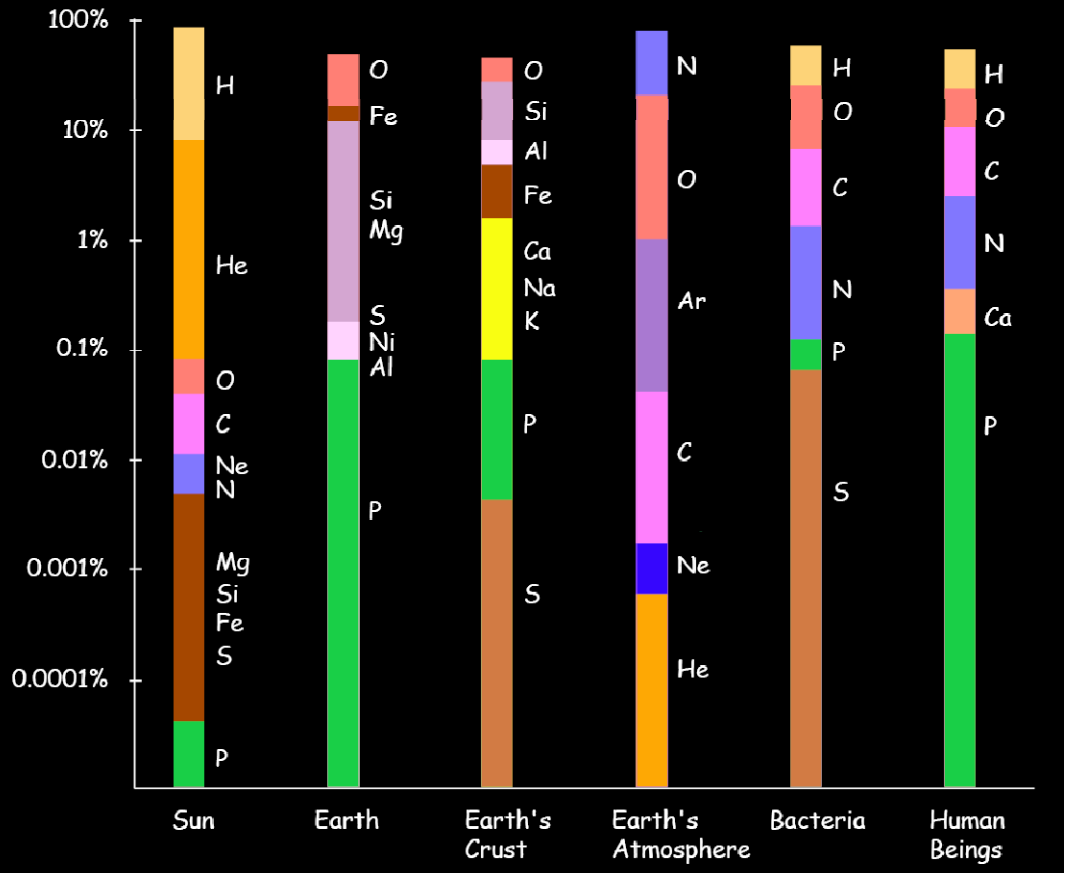
(The solar abundance pattern)
Grevesse & Noels (1995)

Signatures of Nucleosynthesis

The origin and formation of the elements is the main signature for nuclear physics in the Universe!

The light emission of stars and stellar explosions reflects the role of stars as nuclear power plants!

galactic abundance distribution



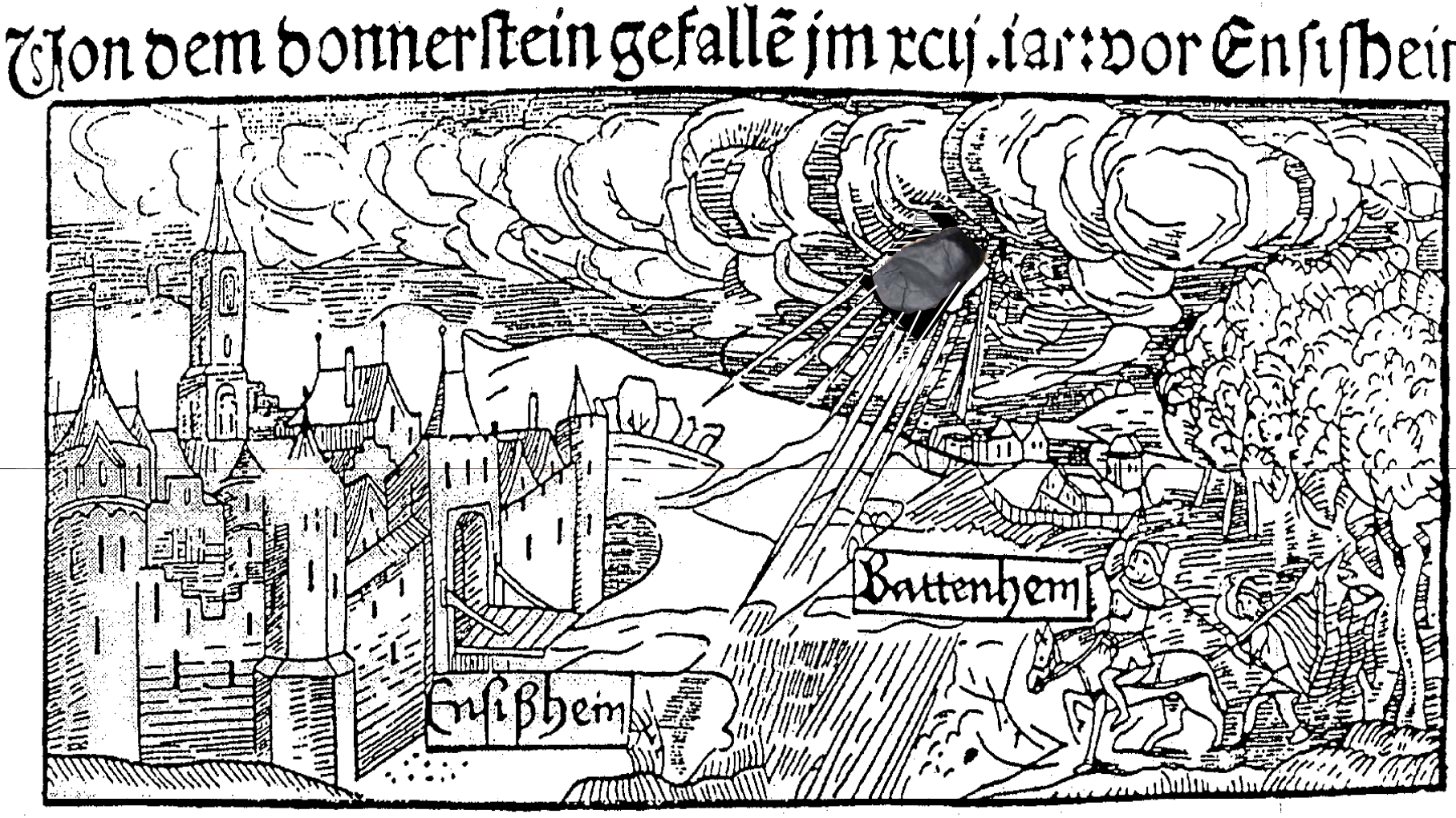
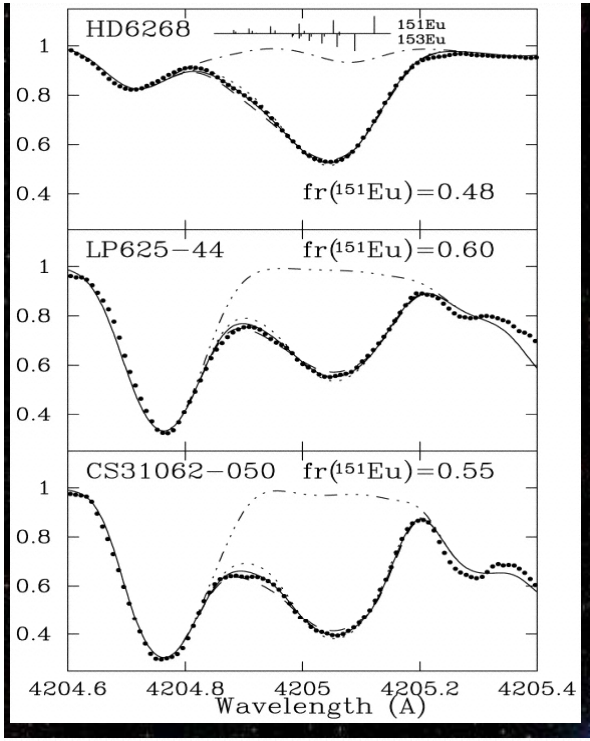
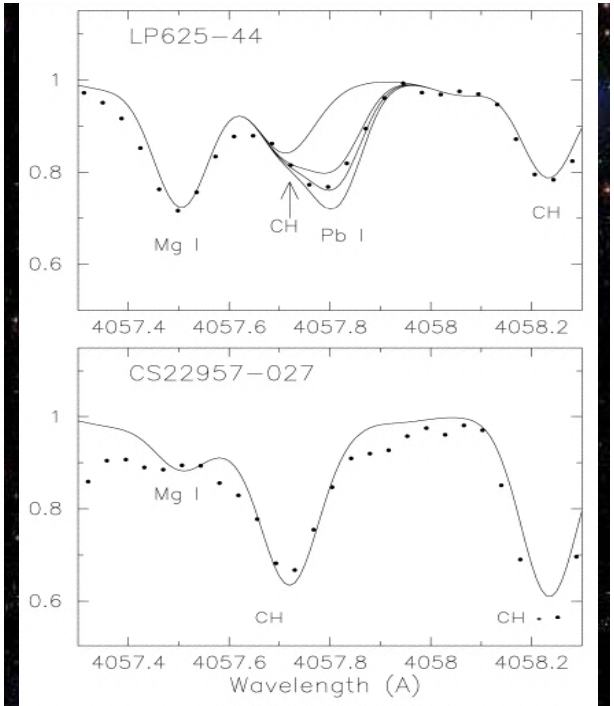
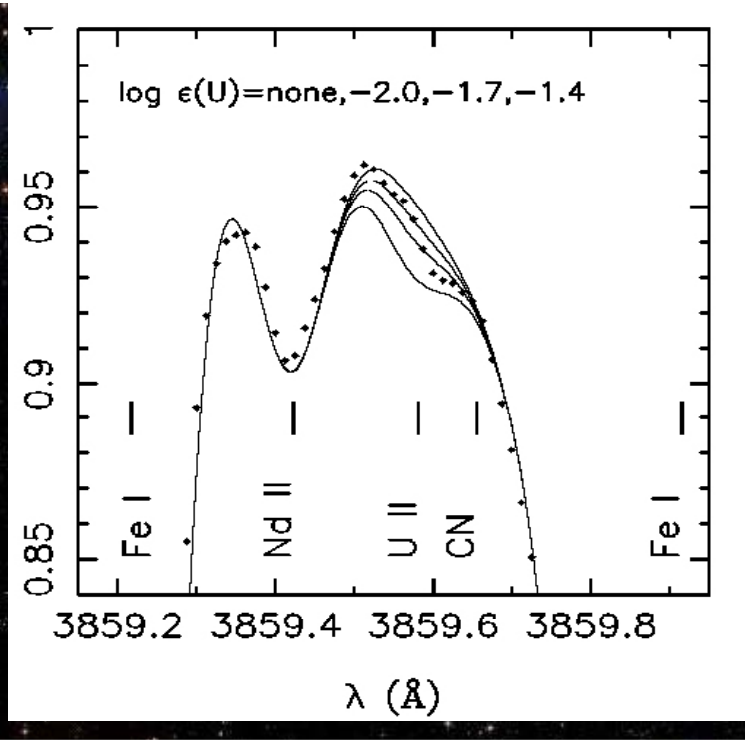
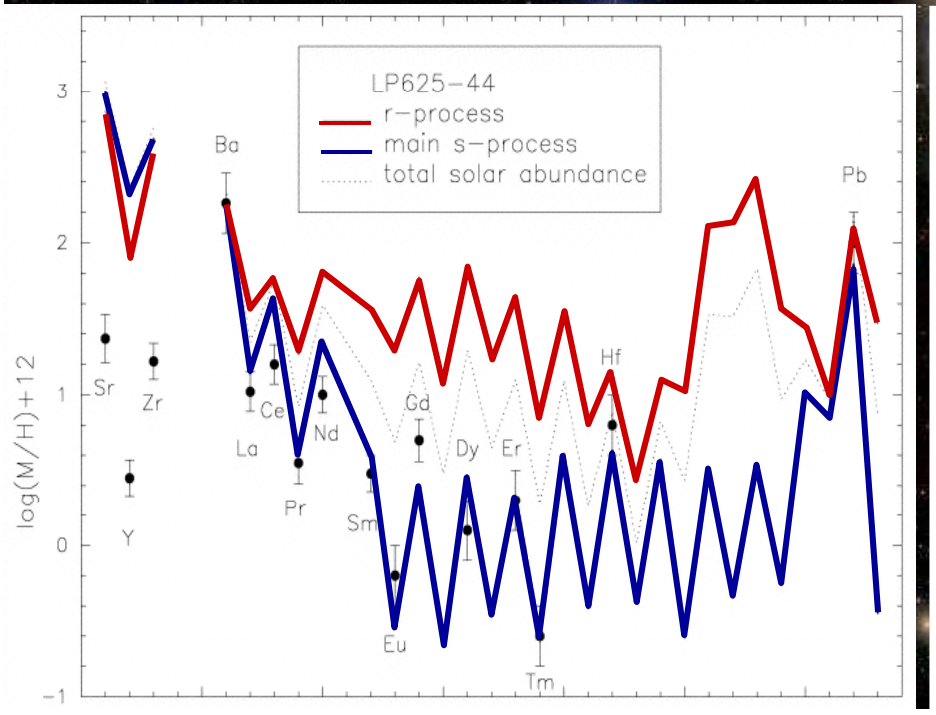


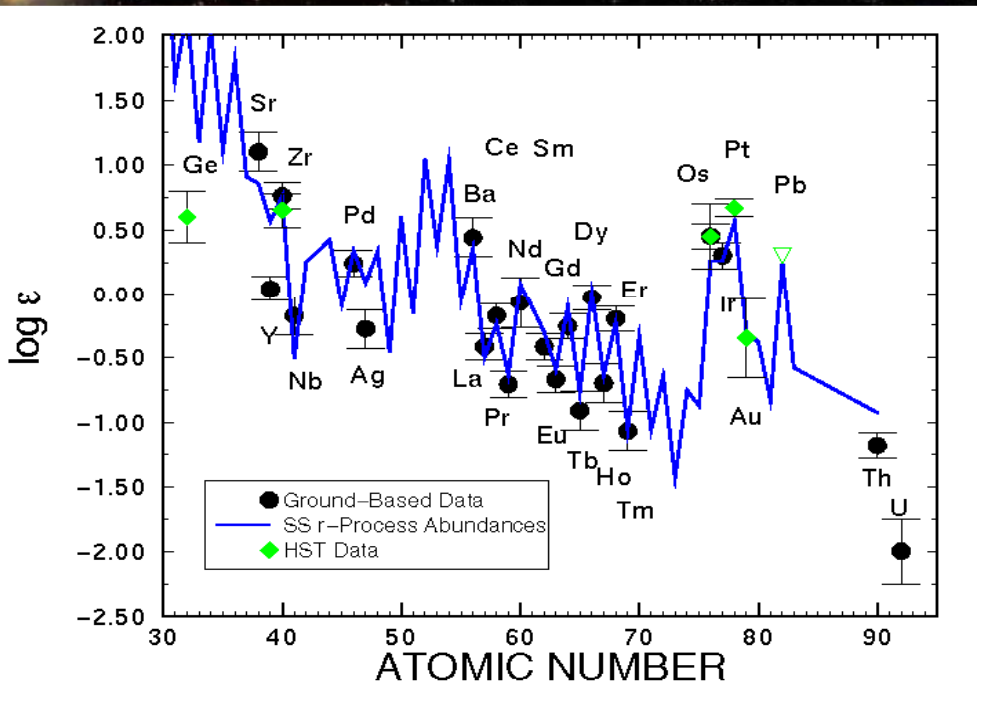
Figure I-2. Woodcut depicting the fall of the Ensisheim LL chondrite on 7 November 1492. A literal translation of the German caption (by Sebastian Brant) is "of the thunder-stone (that) fell in xcii (92) year outside of Ensisheim." This meteorite, which is preserved in the city hall of Ensisheim, Alsace, is the oldest recorded fall from which material is still available.


HD6268
151Eu
153Eu
fr(151Eu)=0.48
LP625−44
fr(151Eu)=0.60
CS31062−050
fr(151Eu)=0.55
Wavelength (A)


LP625−44
Mg I
CH
Pb I
CH
CS22957−027
Mg I
CH
CH
Wavelength (A)

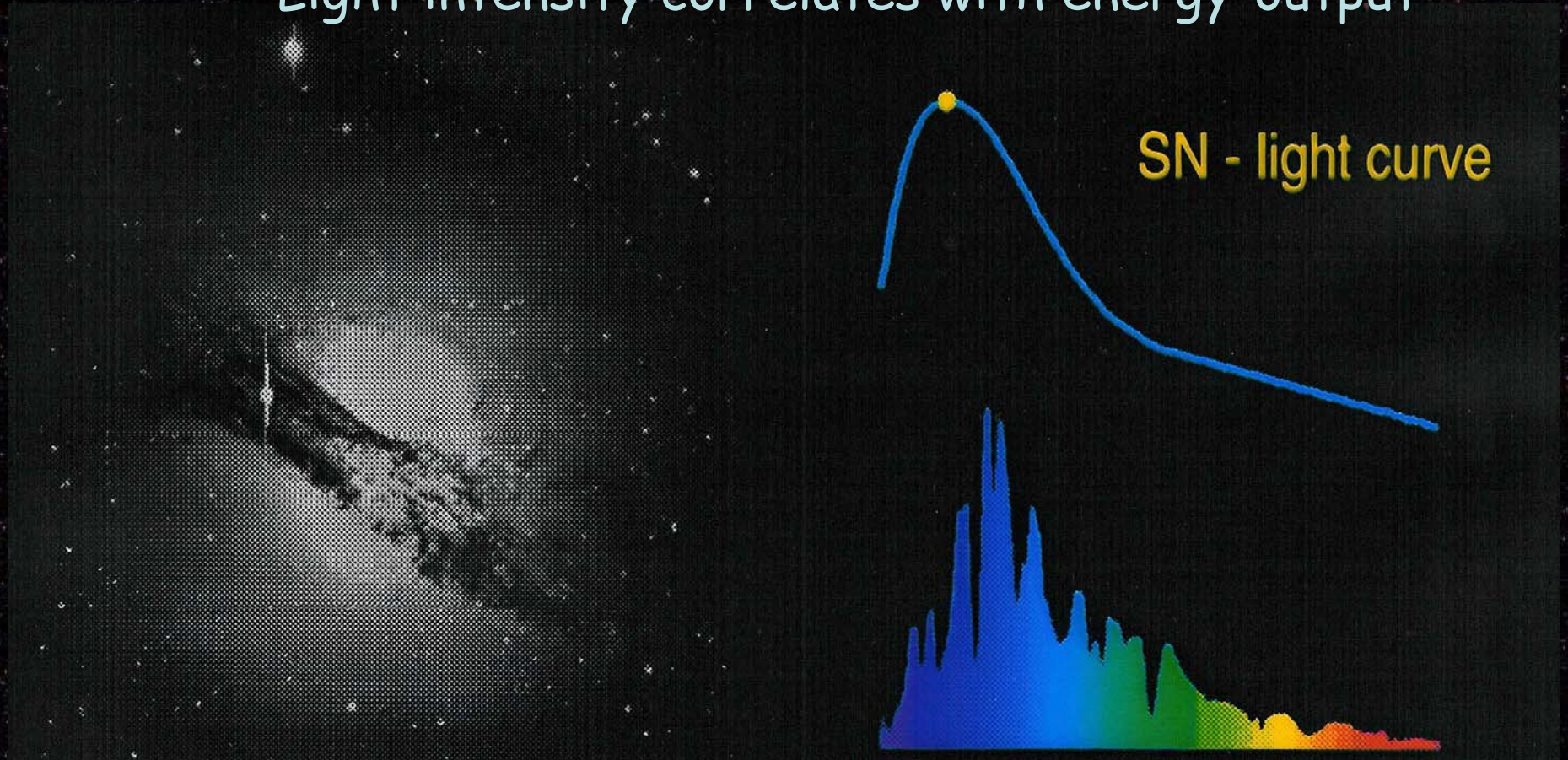

log ε(U)=none,−2.0,−1.7,−1.4
Fe I
Nd II
U II
CN
Fe I
λ (Å)


LP625−44
r−process
main s−process
total solar abundance
log(M/H)+12


log ε
Ground−Based Data
SS r−Process Abundances
HST Data
ATOMIC NUMBER

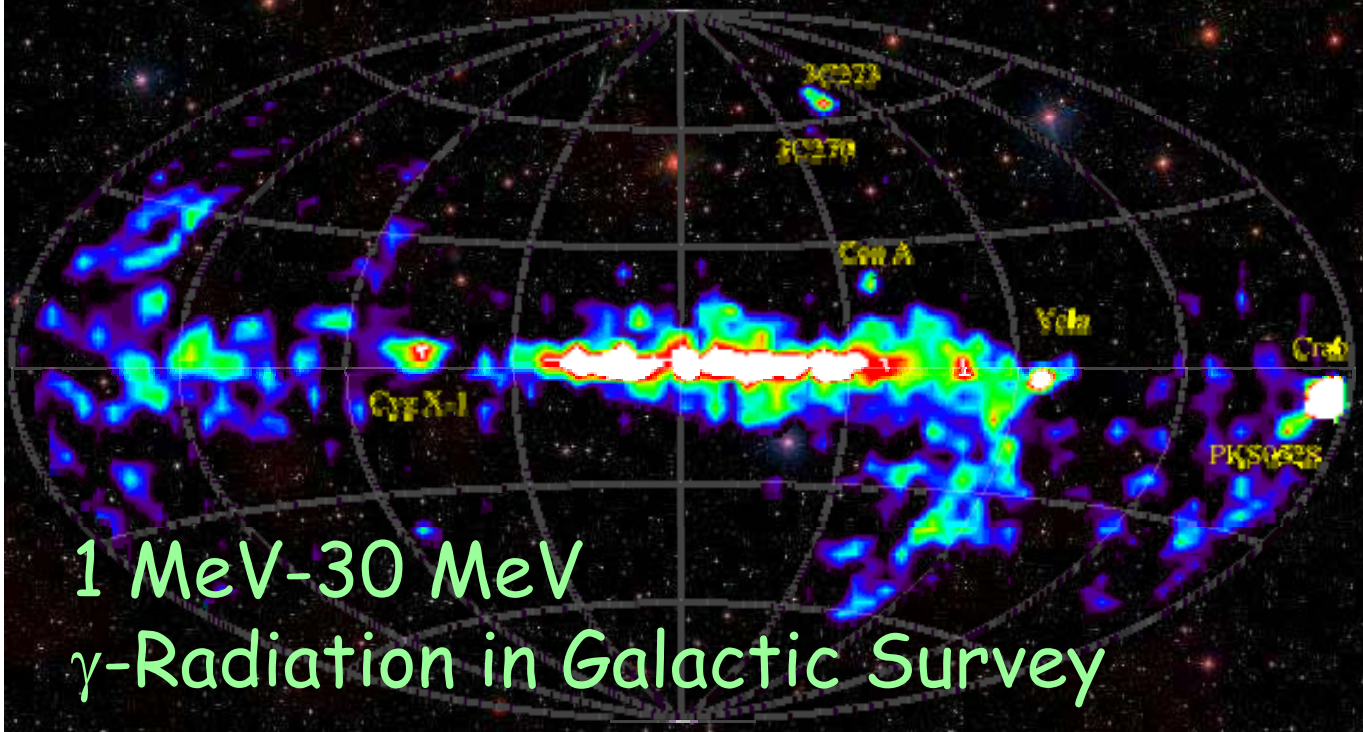
Light and Light-Curves

Light intensity correlates with energy-output



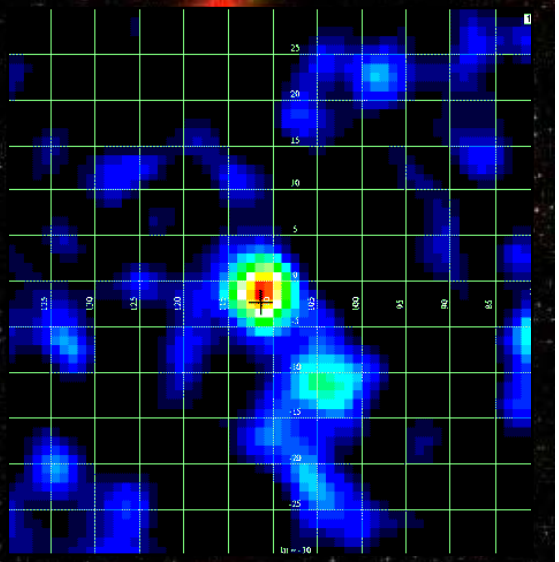
Light curve follows the radioactive decay law ^{56}Ni, ^{56}Co, ^{44}Ti

The (radio) active Universe



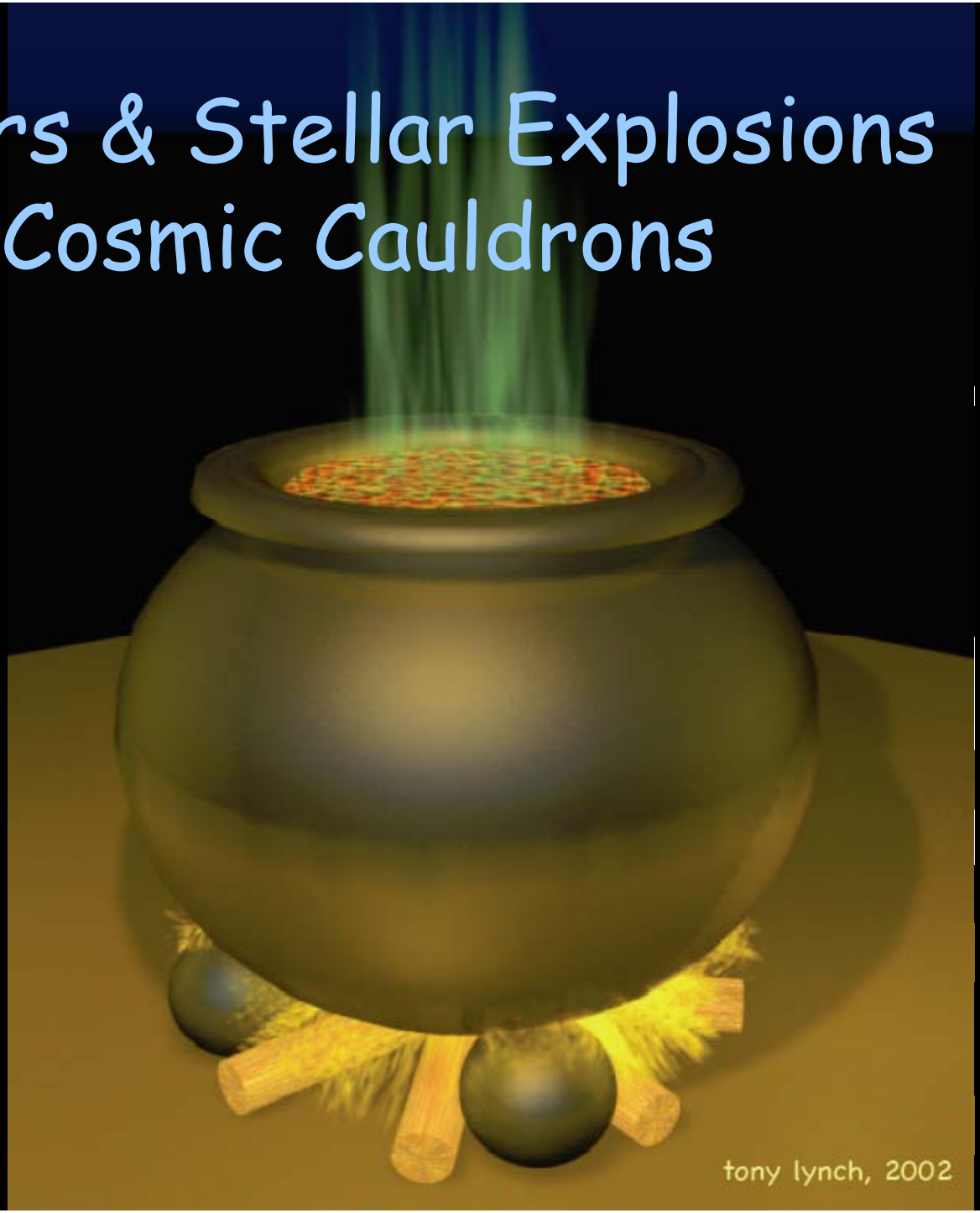
COMPTEL
INTEGRAL

1 MeV-30 MeV
γ-Radiation in Galactic Survey



^{44}Ti in Supernova Cas-A Location

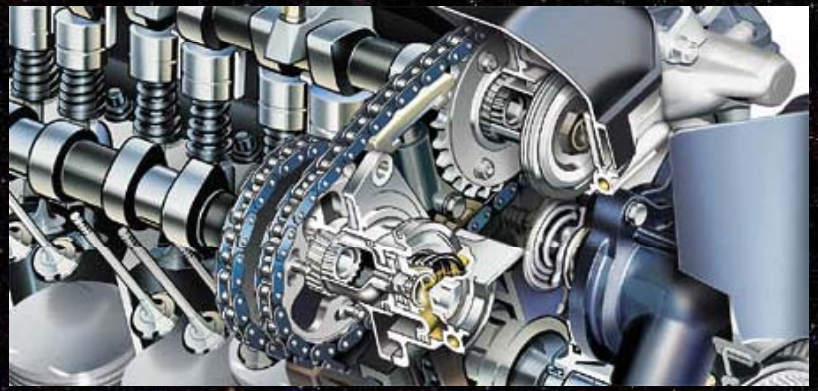
Stars & Stellar Explosions are Cosmic Cauldrons

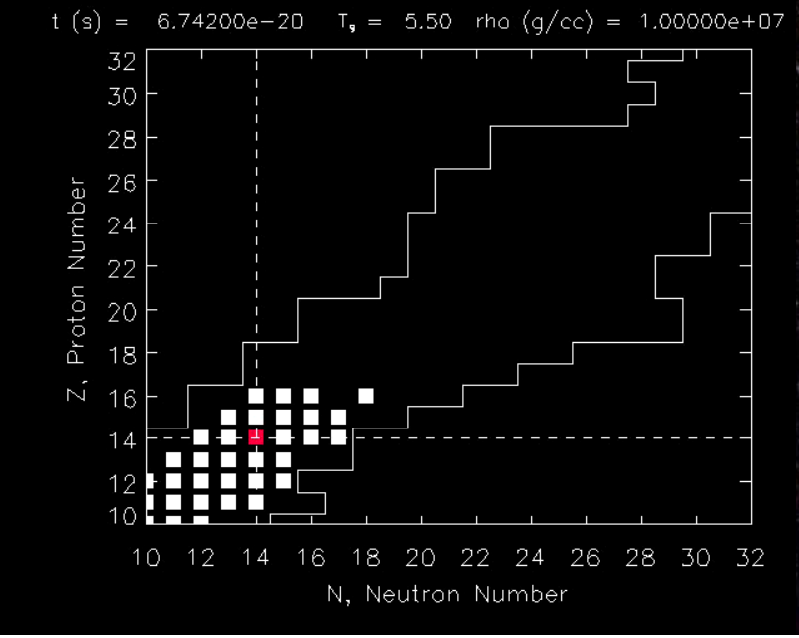


Nuclear processes are the engine of the Universe !

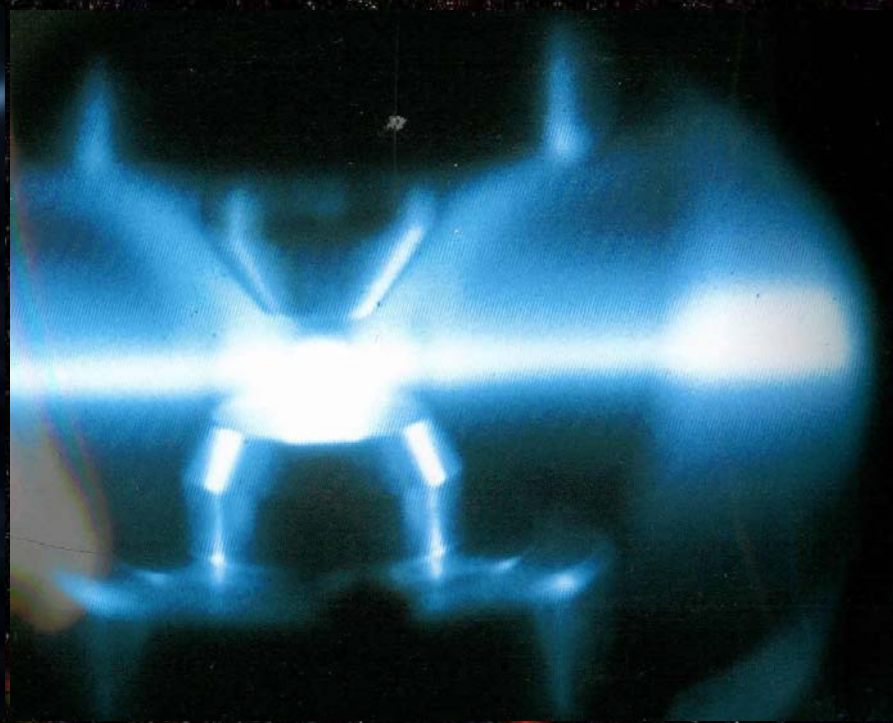
the looks

and the engine





Simulation of stellar processes in laboratory environment



Comparison with observational results and interpretation through computer modeling

Nuclear Reactions in Stars

- generate energy
- create new isotopes and elements

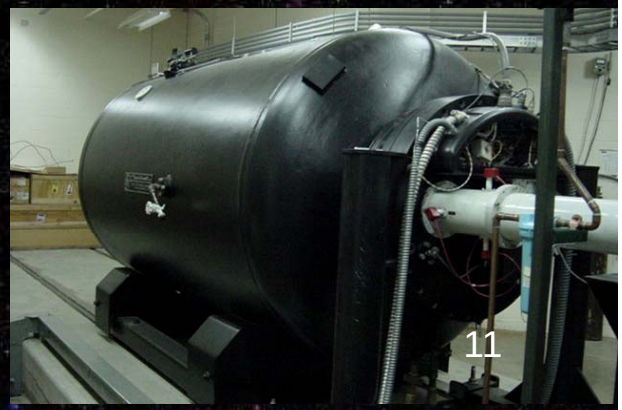
p

^{12}C

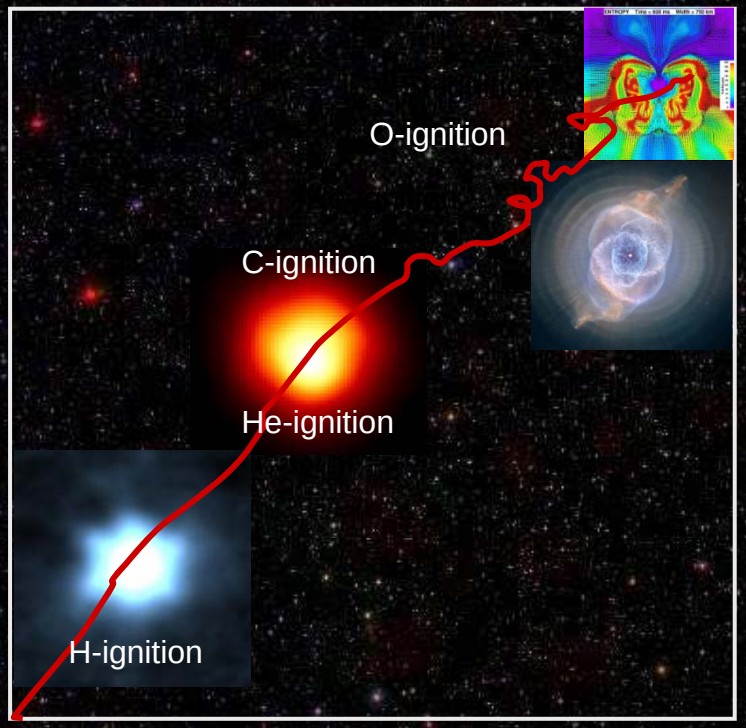
γ

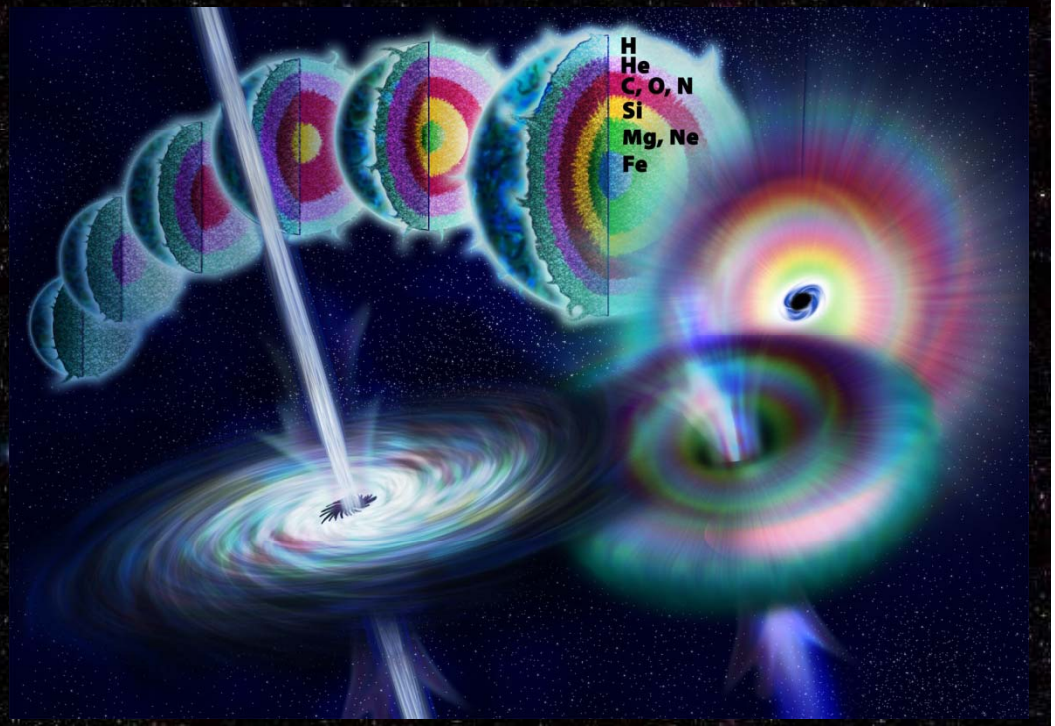
$^{12}C(p,\gamma)^{13}N$

reaction probability $\Rightarrow$
σ: reaction cross section
(in unit barns=$10^{-24}cm^2$)



Nuclear burning & stellar evolution



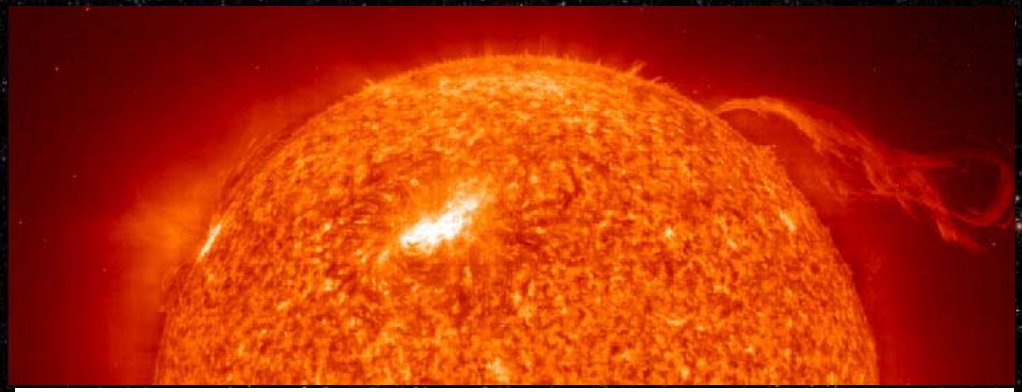


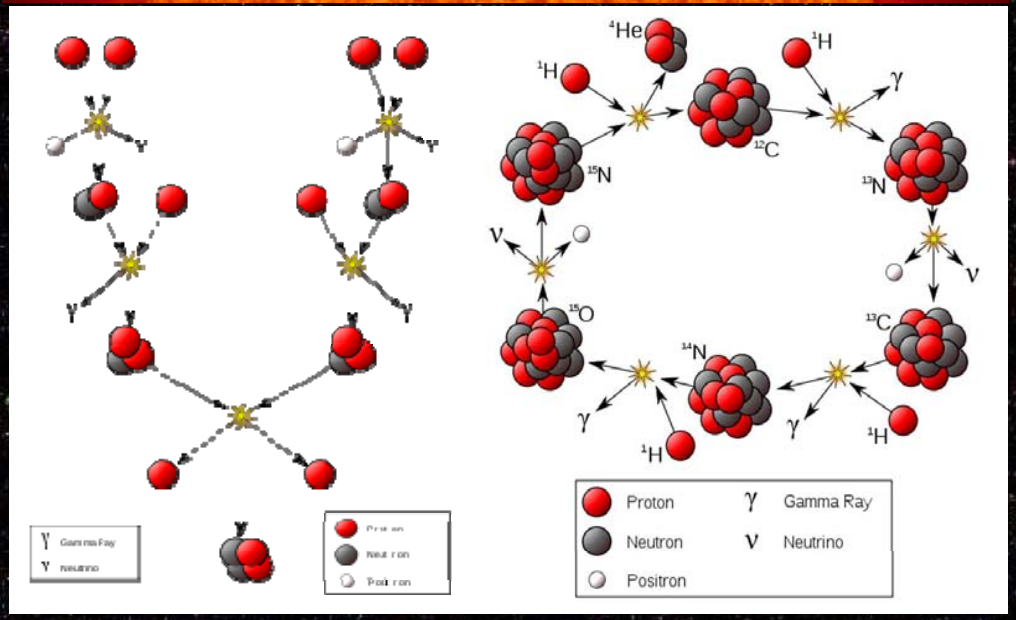
Each burning phase is determined by nuclear reactions in terms of

- energy generation,
- time scale
- nucleosynthesis

JINA

Neutrinos from the Sun





Neutrino Sources in the Sun:

$^1H(p,e^-\nu)^2H$	(total)
$^3He(3He,2p)^4He$	(pp-I)
$^3He(\alpha,\gamma)^7Be$	(pp-II
$^7Be(p,\gamma)^8B$	(pp-III)
$^{14}N(p,\gamma)^{15}O$	(CNO)

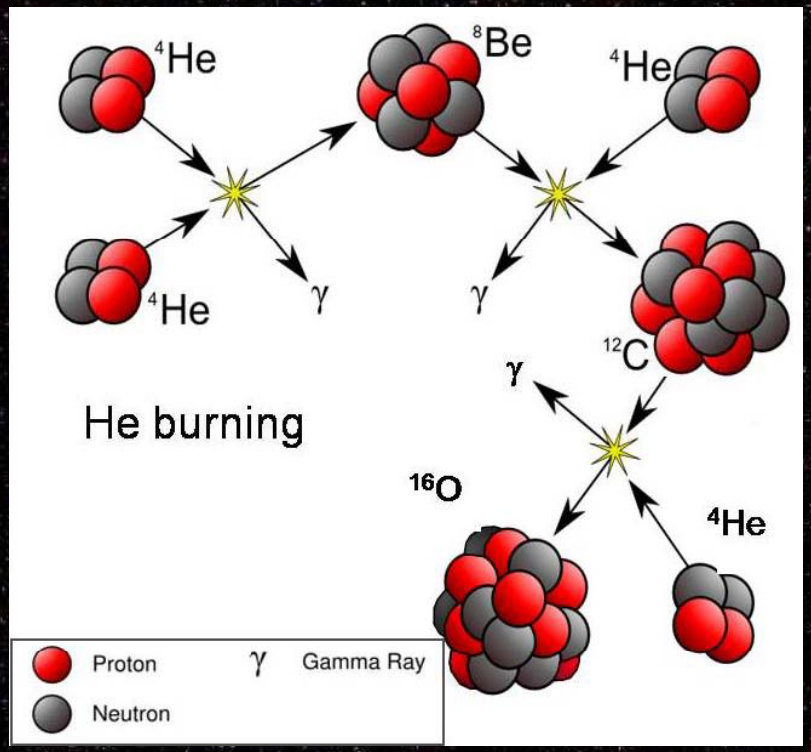
Neutrino detectors

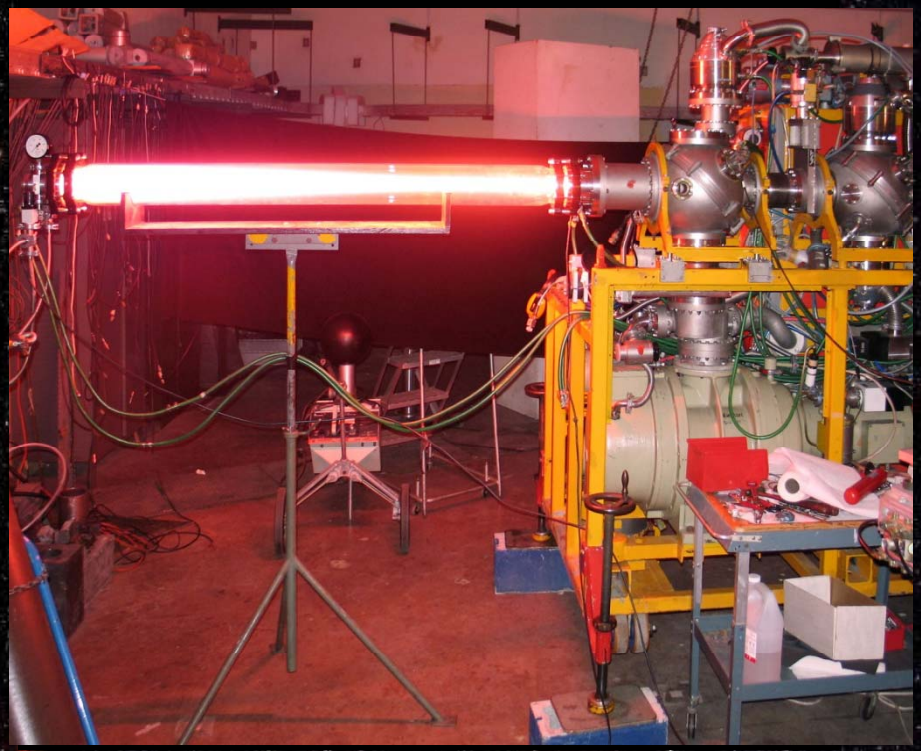
Borexino, Gran Sasso, Italy

SNO, Canada, and

Superkamiokande, Japan

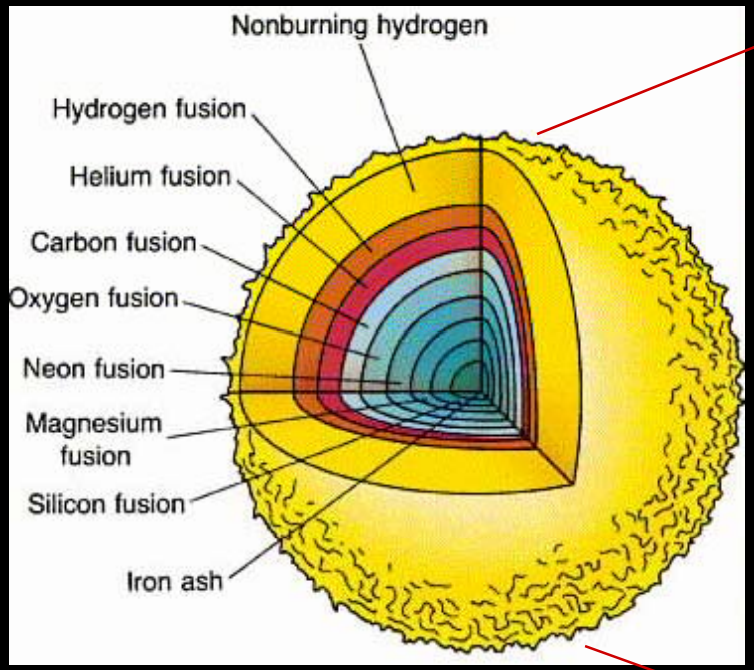
Reactions in red Giant Stars

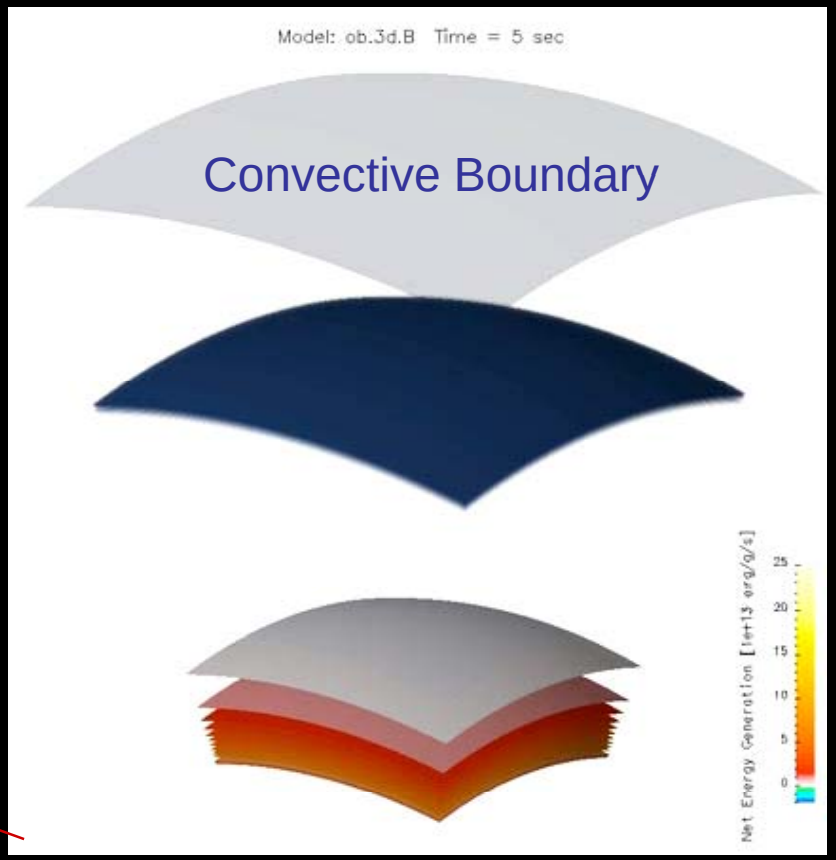




The last Days of Stellar Burning

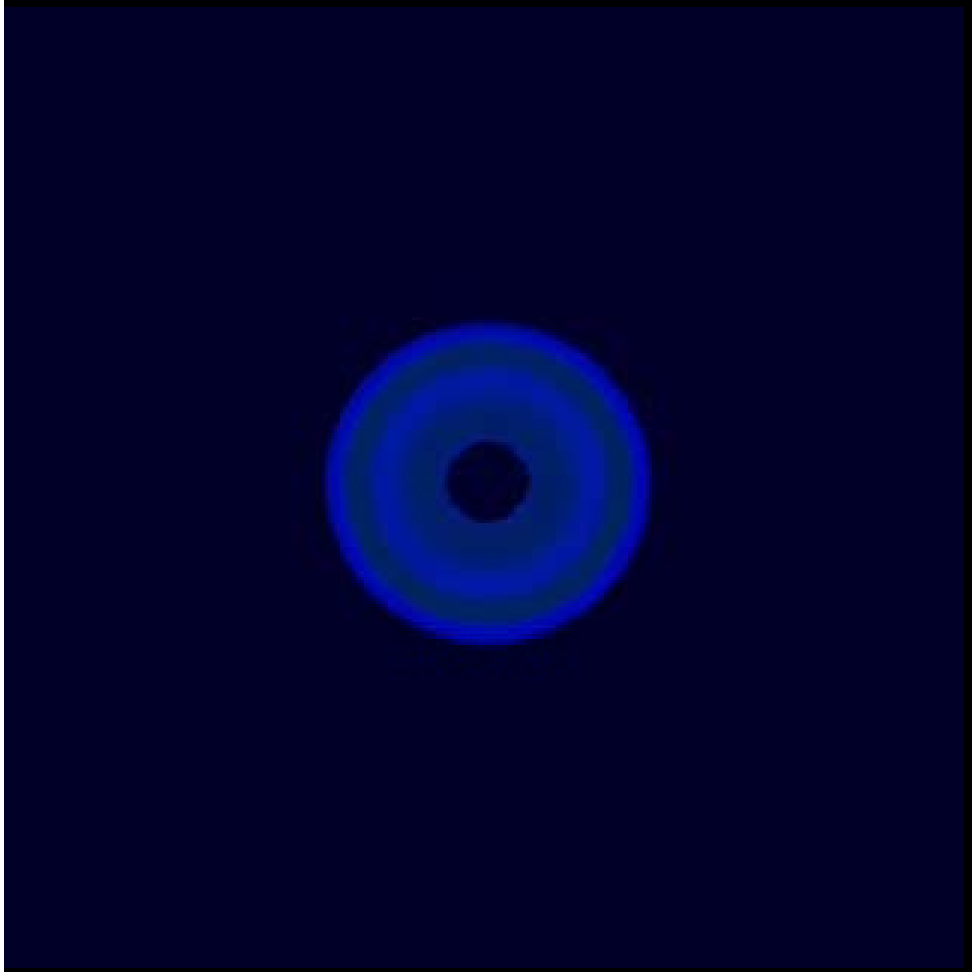
dissolution of burning shells and mixing of matter with as yet unforeseeable consequences!

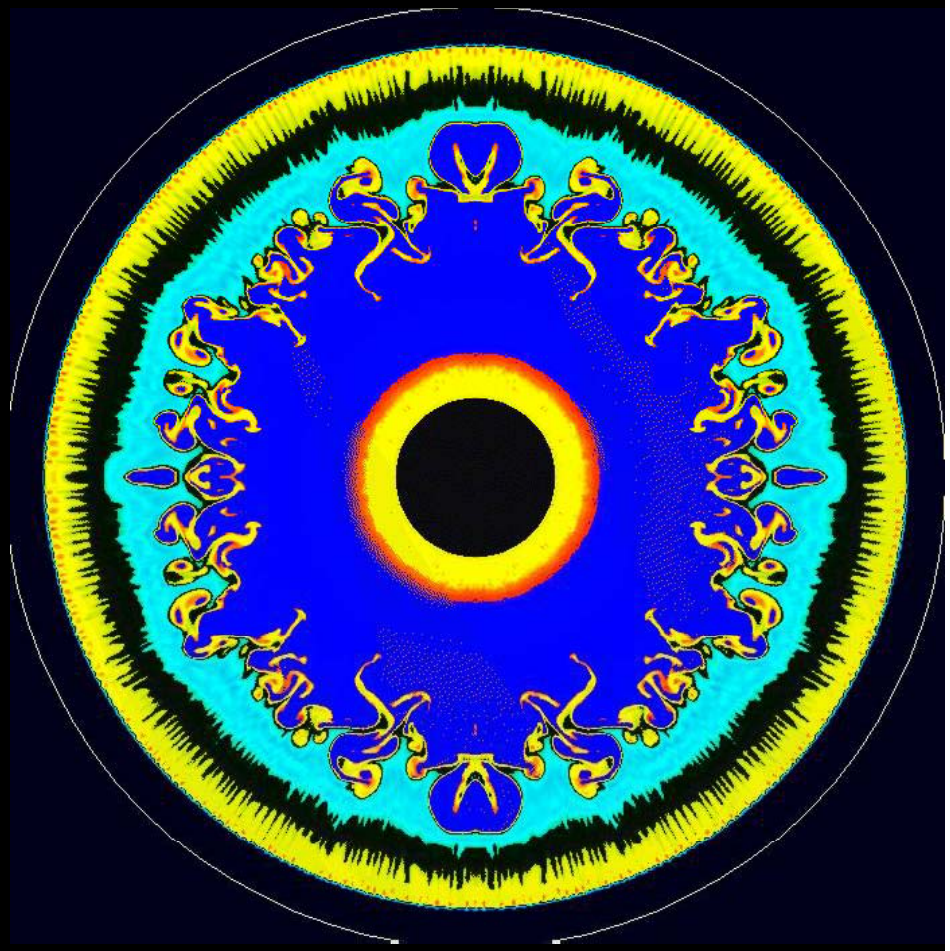




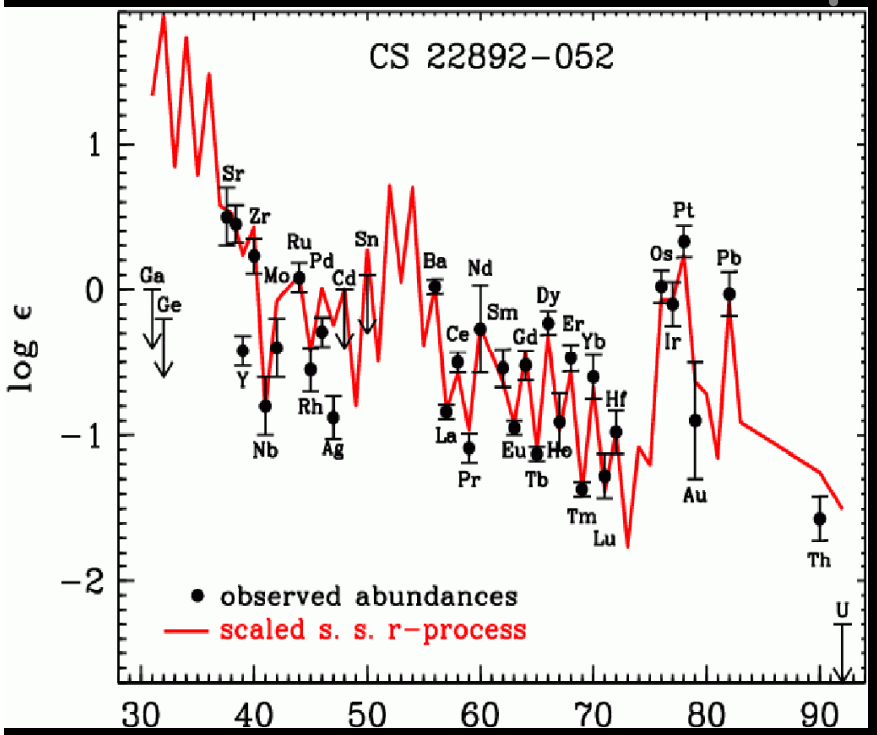
Dave Arnett; Santa Barbara, "The last Days of Burning"
http://www.jinaweb.org/events/ucsb06/talks_SB06.html

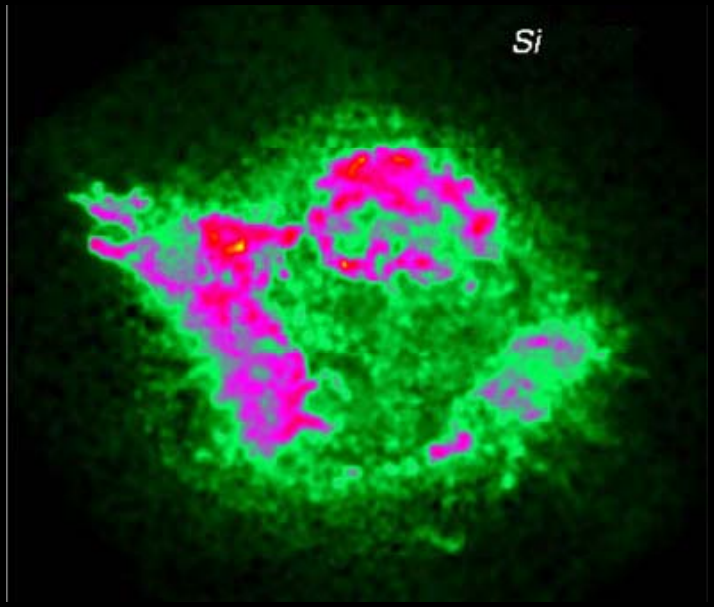
Massive Stars Collapse re-bounce and shock driven by neutrino wind pressure

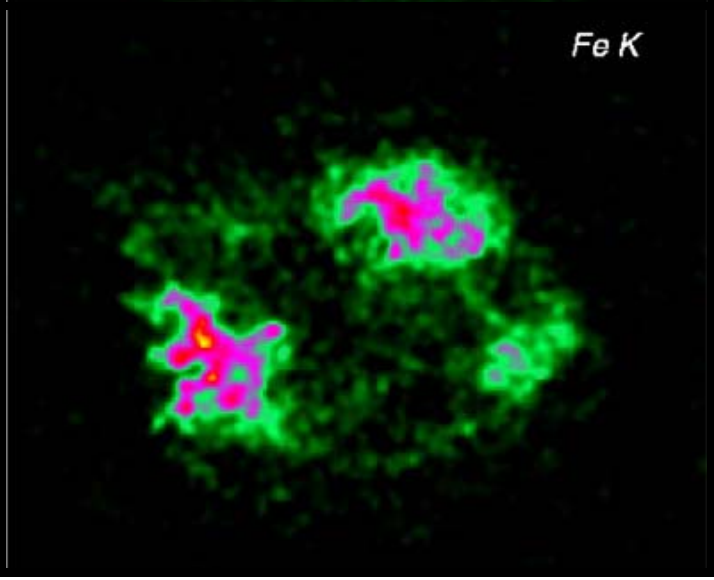




r-process production of heavy elements in supernova shock







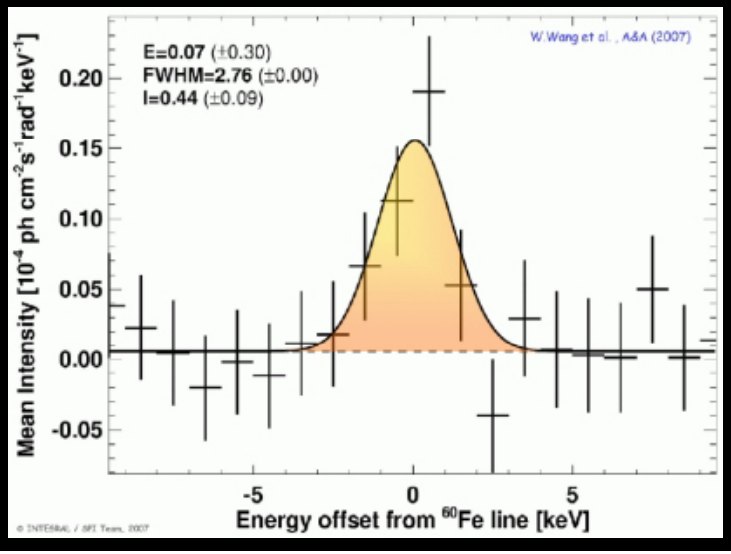
Abundance distribution in metal-poor (old) galactic halo stars matches solar r-process abundances!

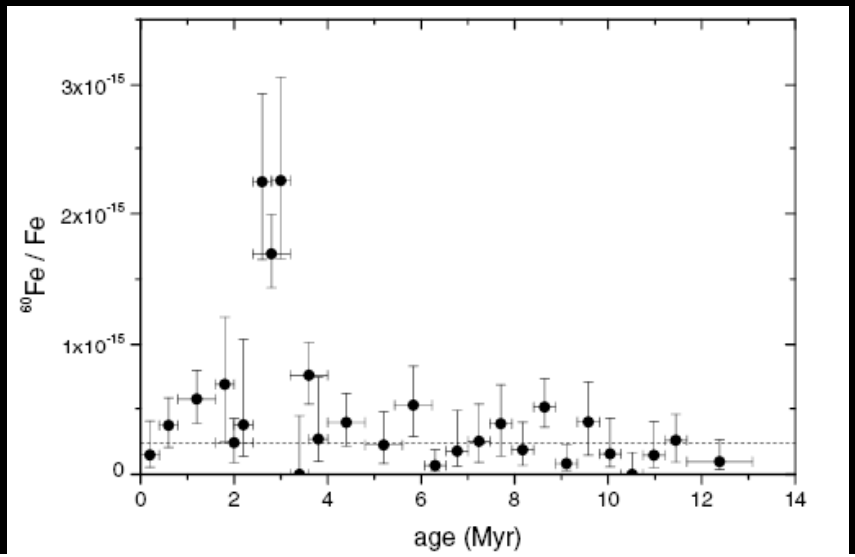
⇨ unique r-process site!

Detection of ^{60}Fe with INTEGRAL

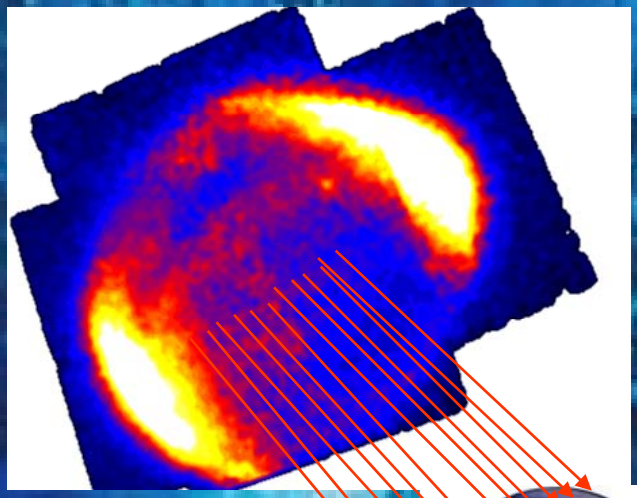
^{60}Fe enrichment in deep sea iron manganese sediments

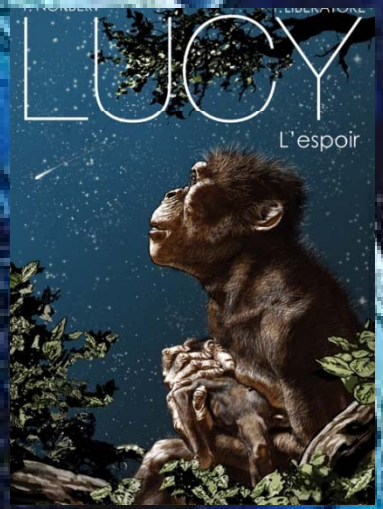
Observation of ^{60}Fe by radioactive decay





Observational evidence for a nearby Supernova 2.8 Myr ago at a distance of ~10pc!

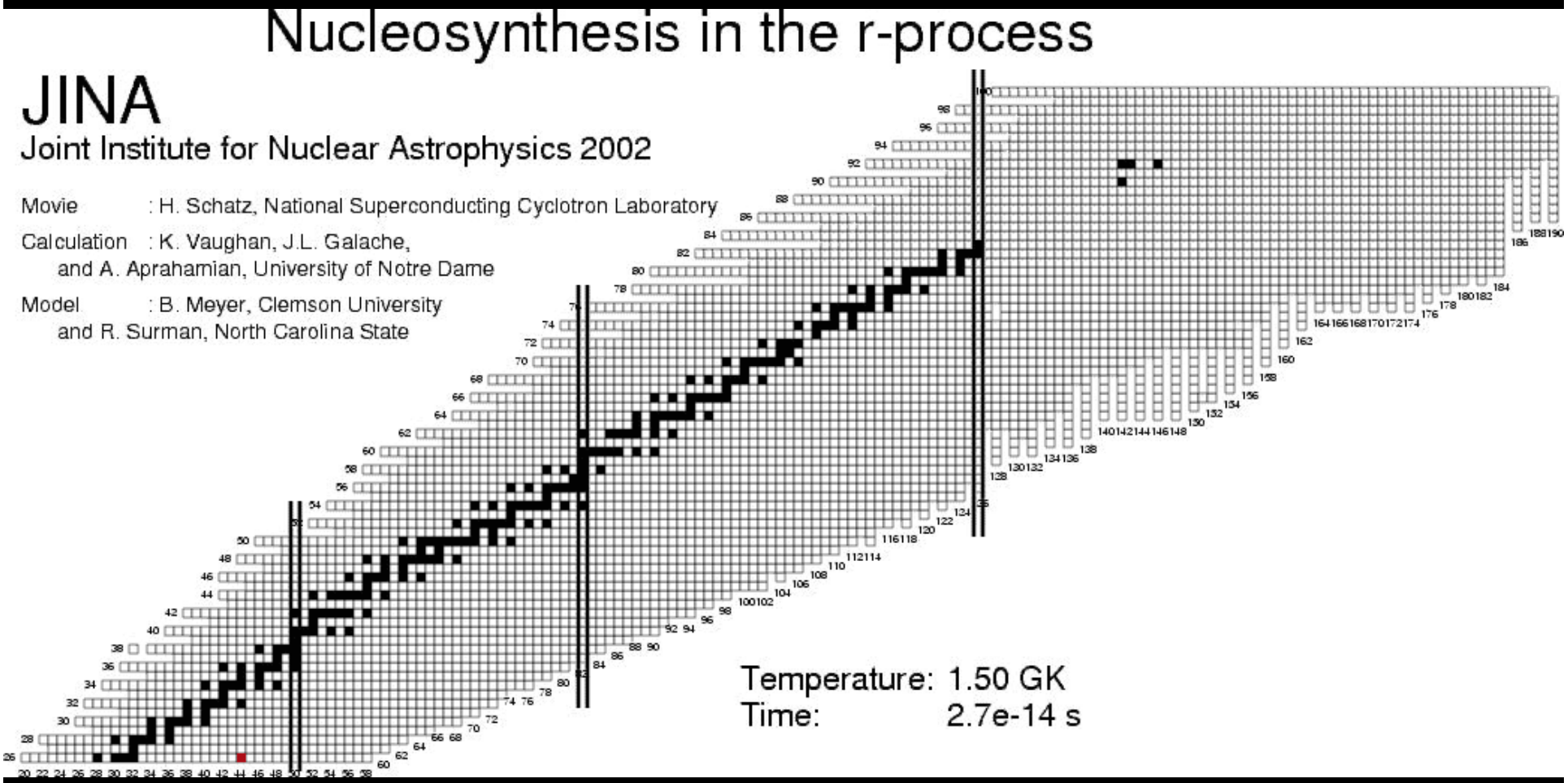




The oldest "walking" human ancestor
Australopithecus afarensis

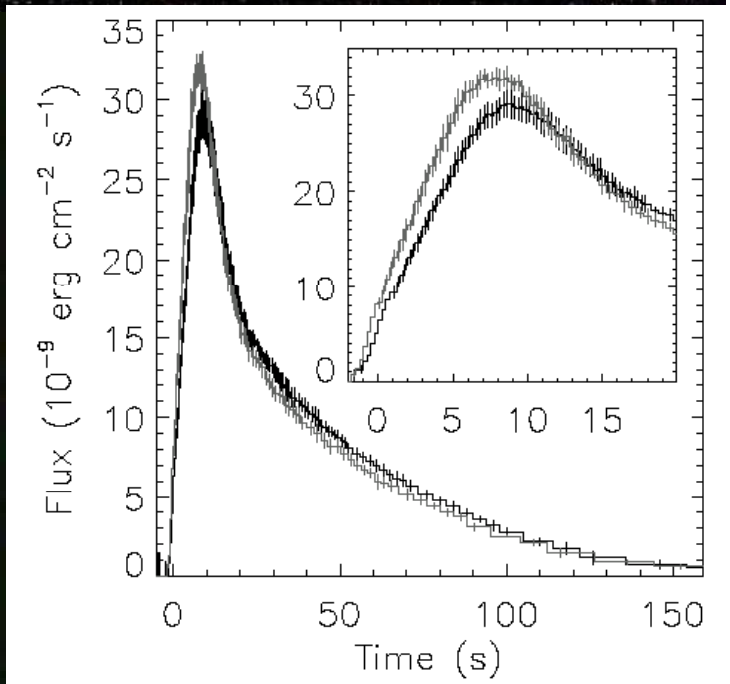
Nucleosynthesis in supernova shock

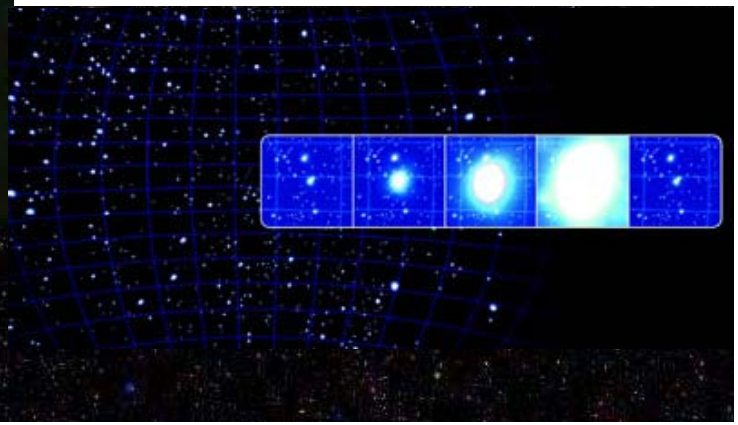
Important model parameter for abundance predictions
masses, shell closures $T_{1/2}$, P_n, (n,γ) & ν-processes!



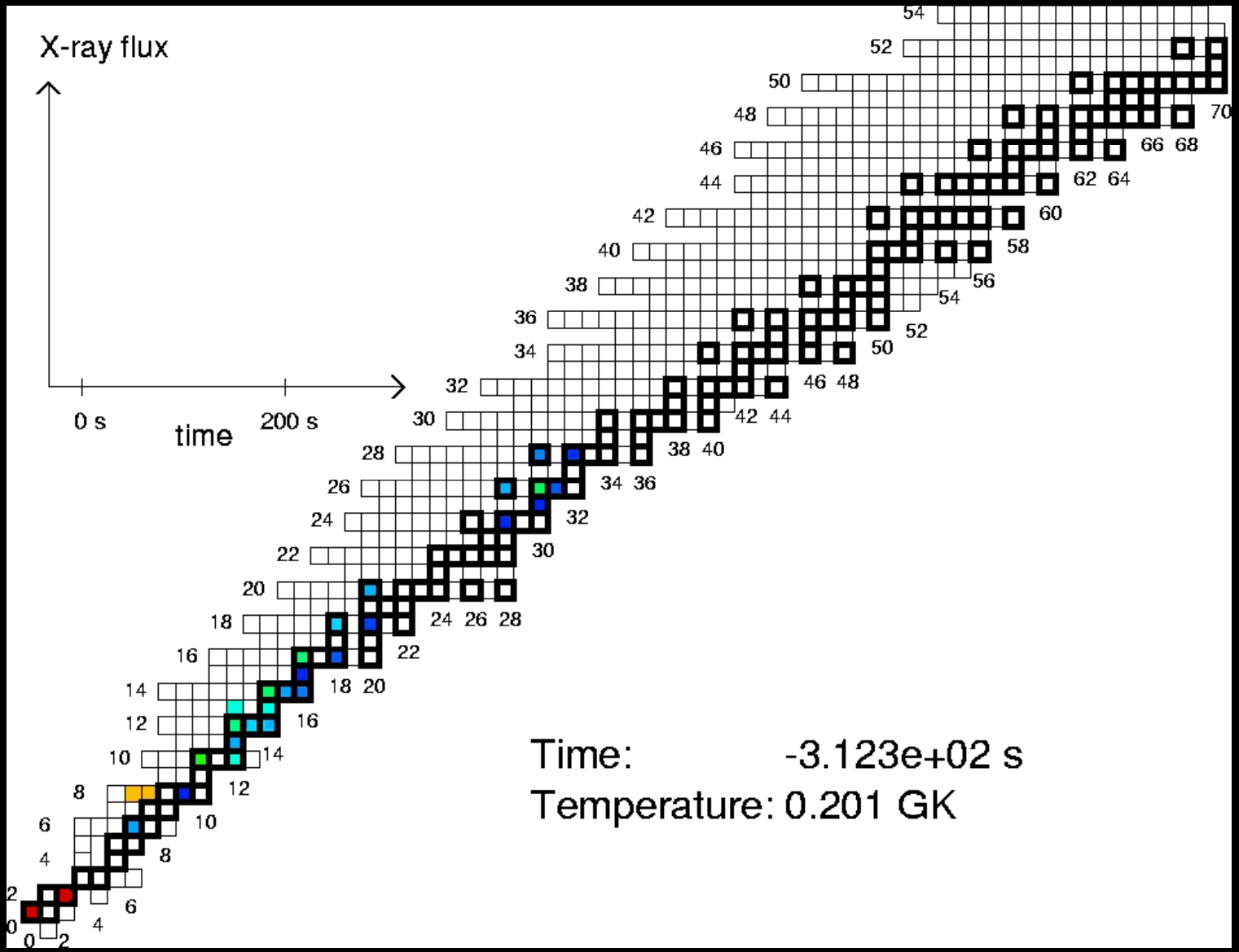
Production of ~50% of heavy elements

X-Ray Bursts as Nuclear Laboratory

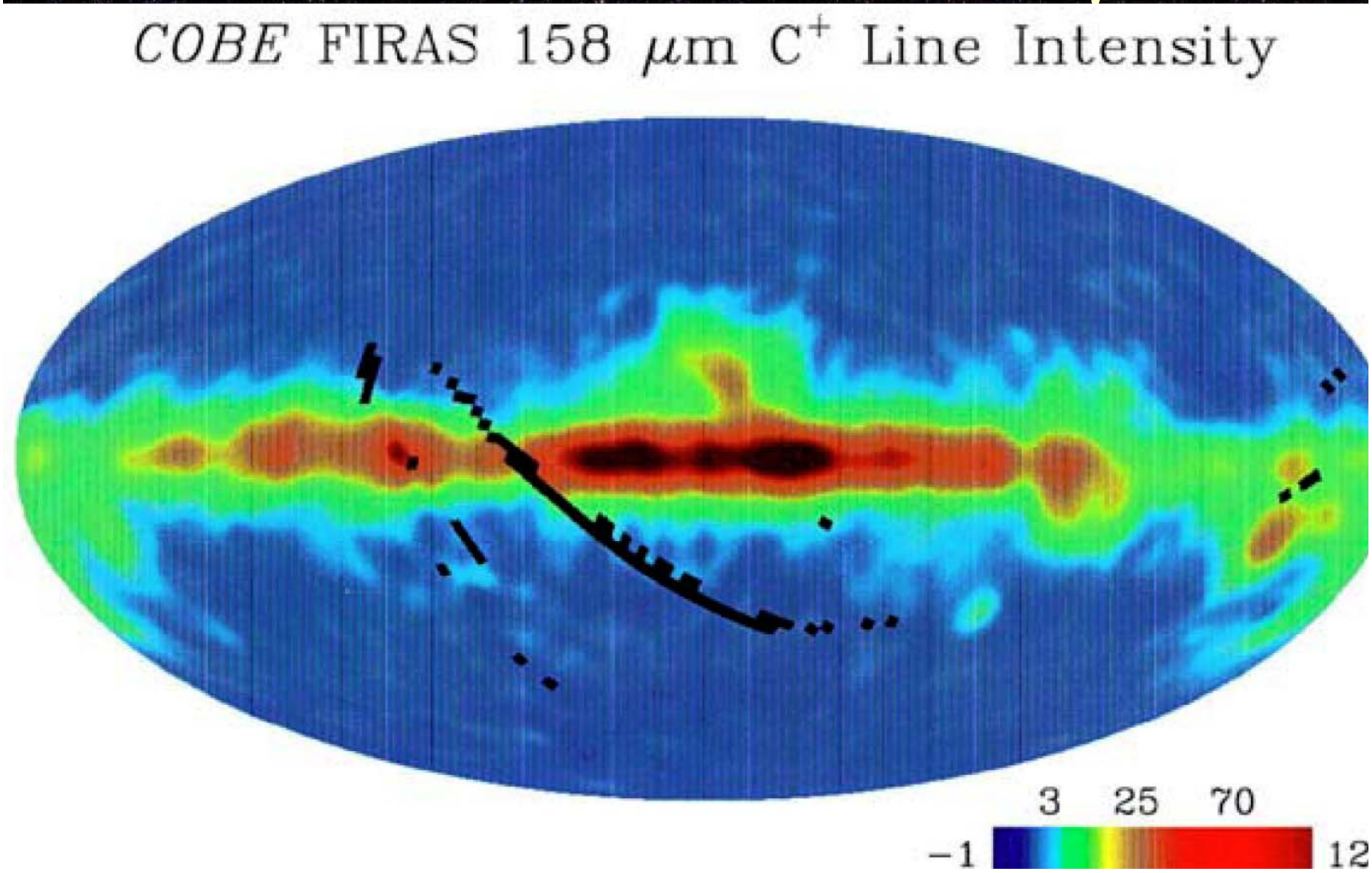


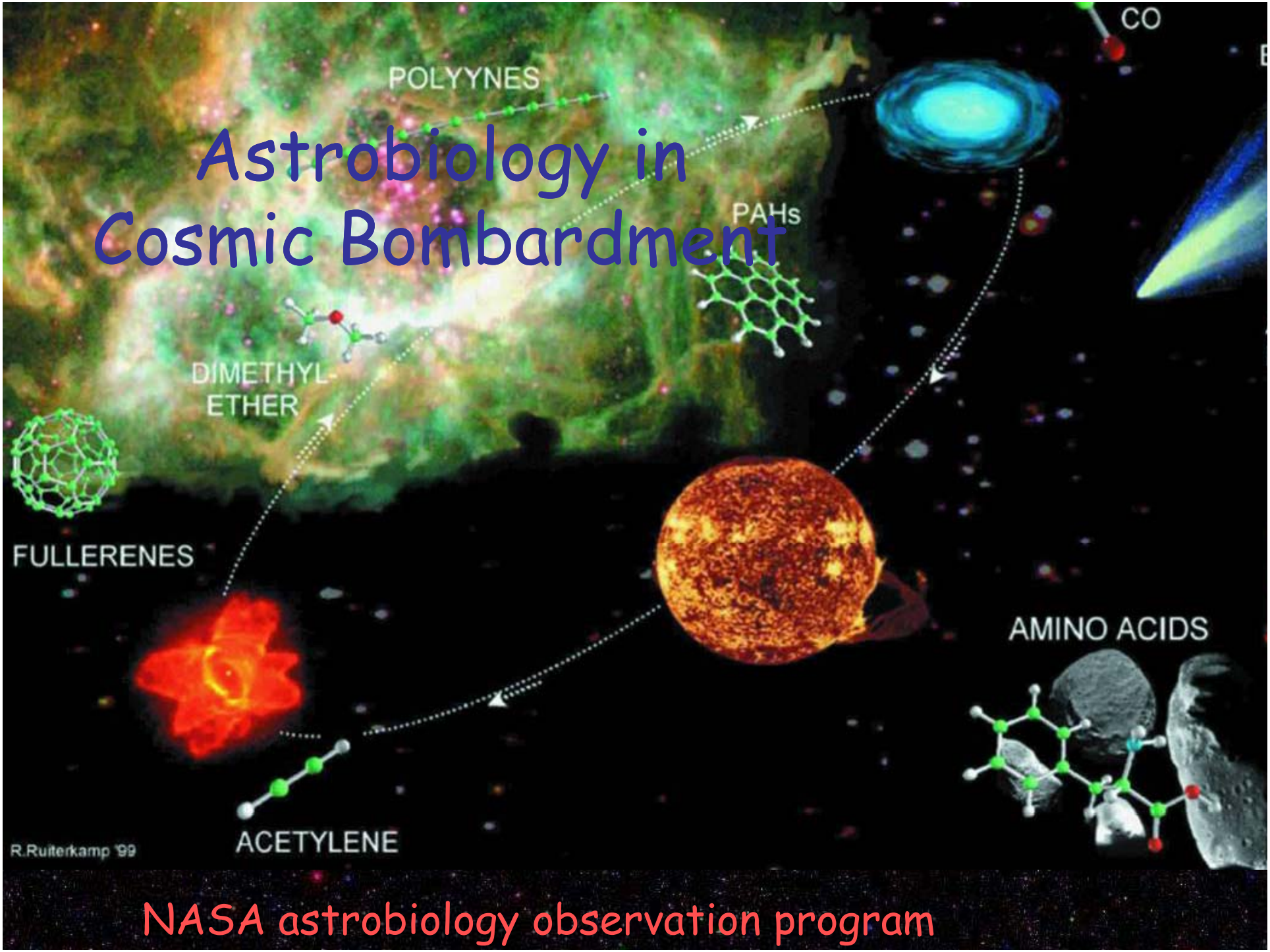


HCNO & rp-Process



Elements in our Galaxy

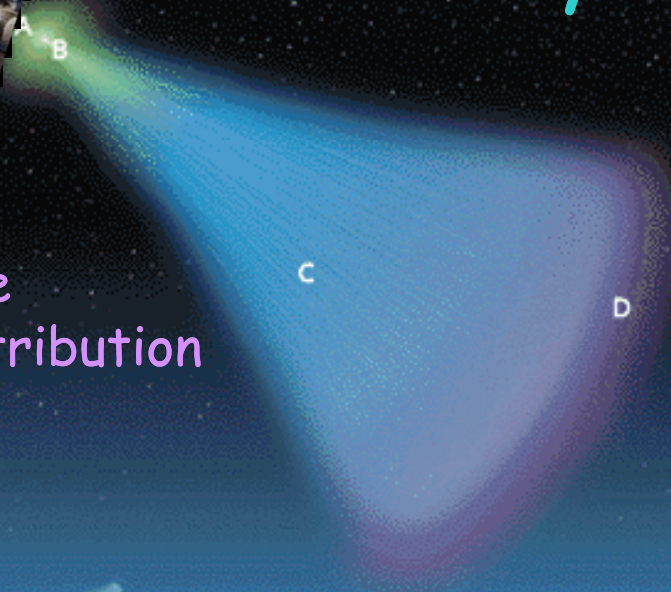


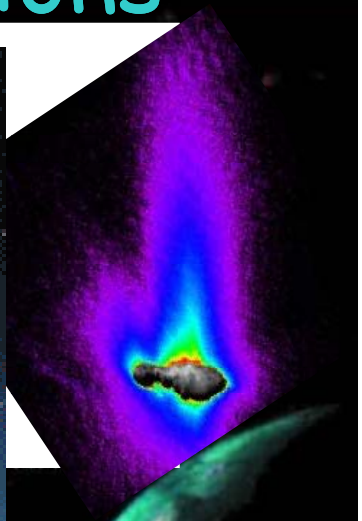

Astrobiology in
Cosmic Bombardment
CO
POLYYNES
PAHs
DIMETHYL-
ETHER
FULLERENES
AMINO ACIDS
ACETYLENE
R.Ruiterkamp '99
NASA astrobiology observation program

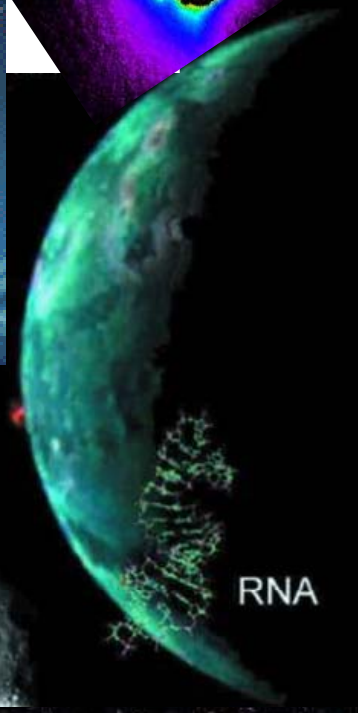
New Initiatives: Cosmic Ray Simulations

JINA

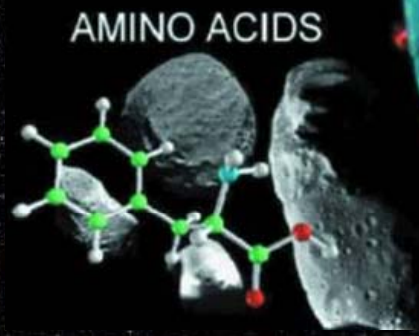
Accelerators provide
5 MeV Radiation distribution





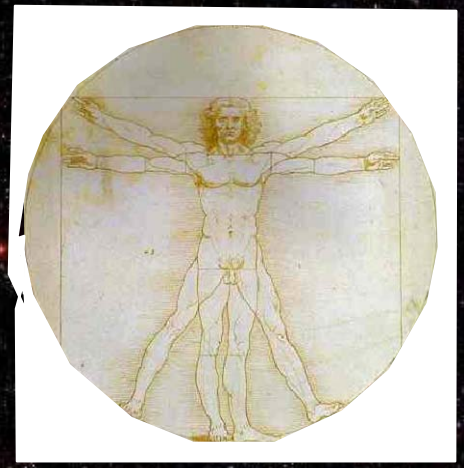


Bombardment of asteroid material leads to the formation of complex "organic" molecules, the first step to LIFE - Astrobiology



RNA

Each heavy atom in our body was build and processed through ~40 supernova explosions since the beginning of time!



We are made of star stuff

Carl Sagan