Nuclear Physics in Stars

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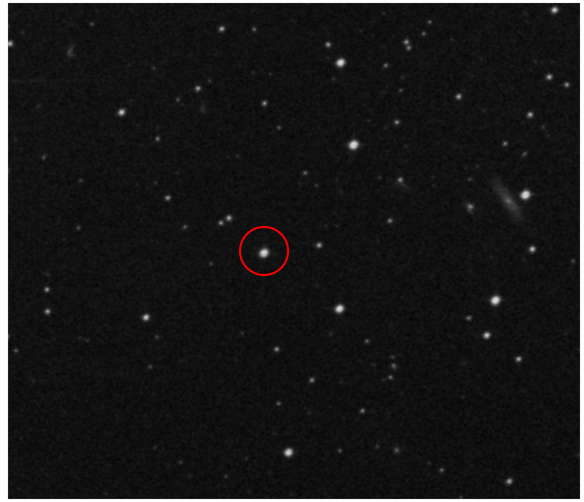
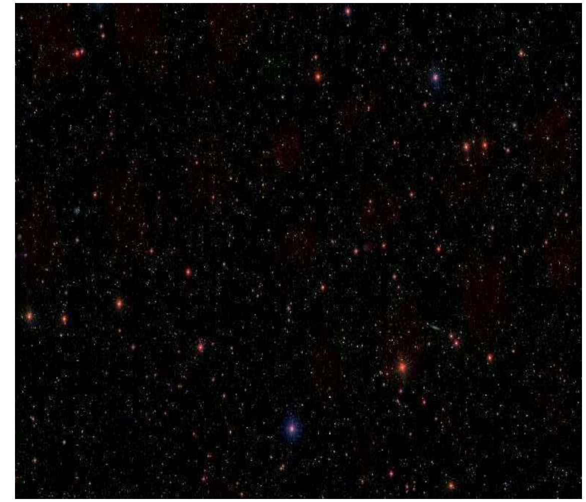
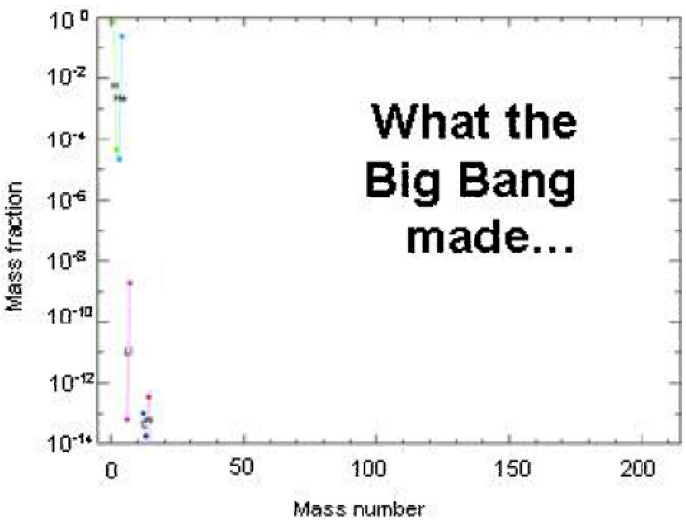
Scientific goal in Nuclear Astrophysics is to explore:

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

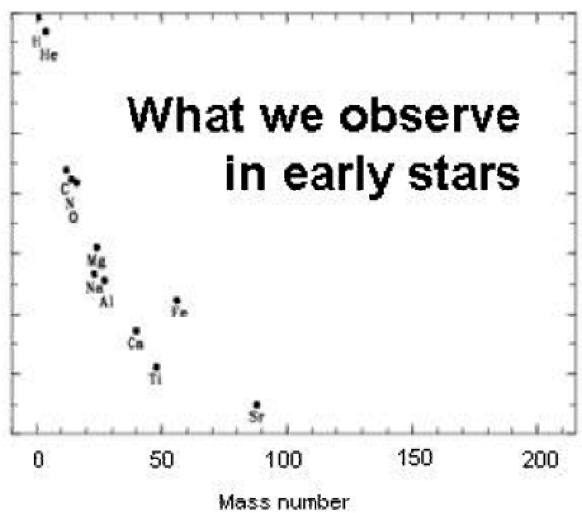




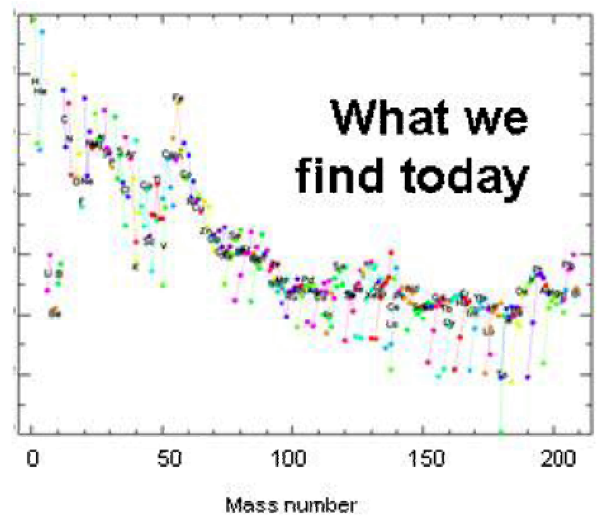
Nucleosynthesis History



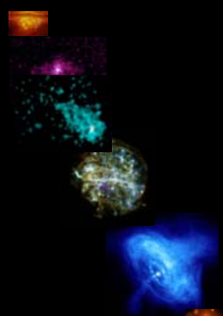
(The primordial abundance pattern)
Brian Fields (2002)



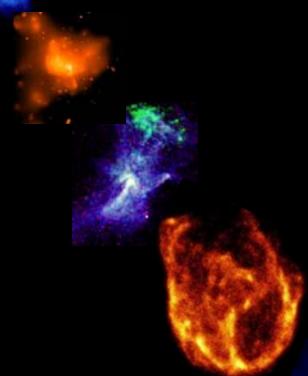
(The abundance pattern in the oldest observed stars He1017 & HH1327)
Anna Frebel (2006)

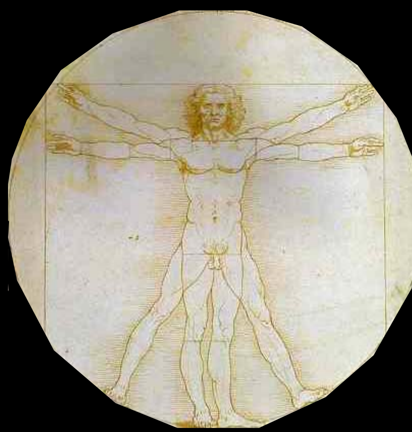


(The solar abundance pattern)
Grevesse & Noels (1995)



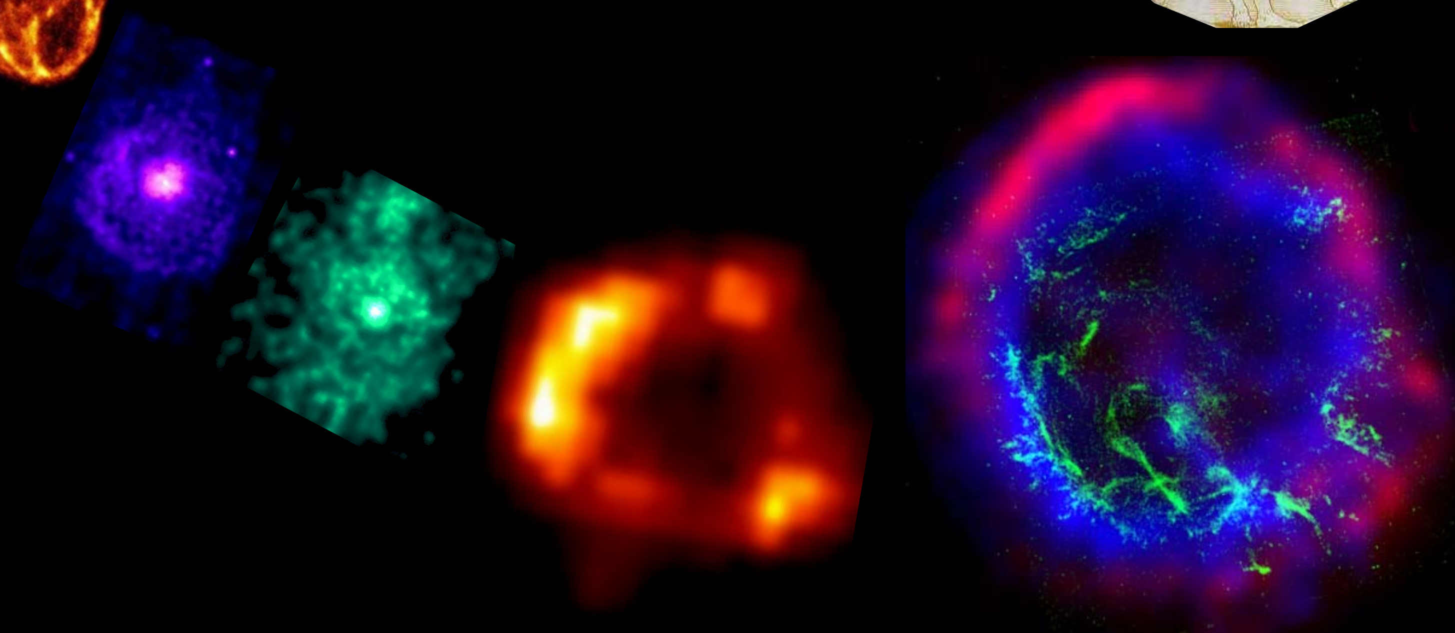
Each heavy atom in our body was build and processed through ~40 supernova explosions since the beginning of time!





We are made of star stuff

Carl Sagan

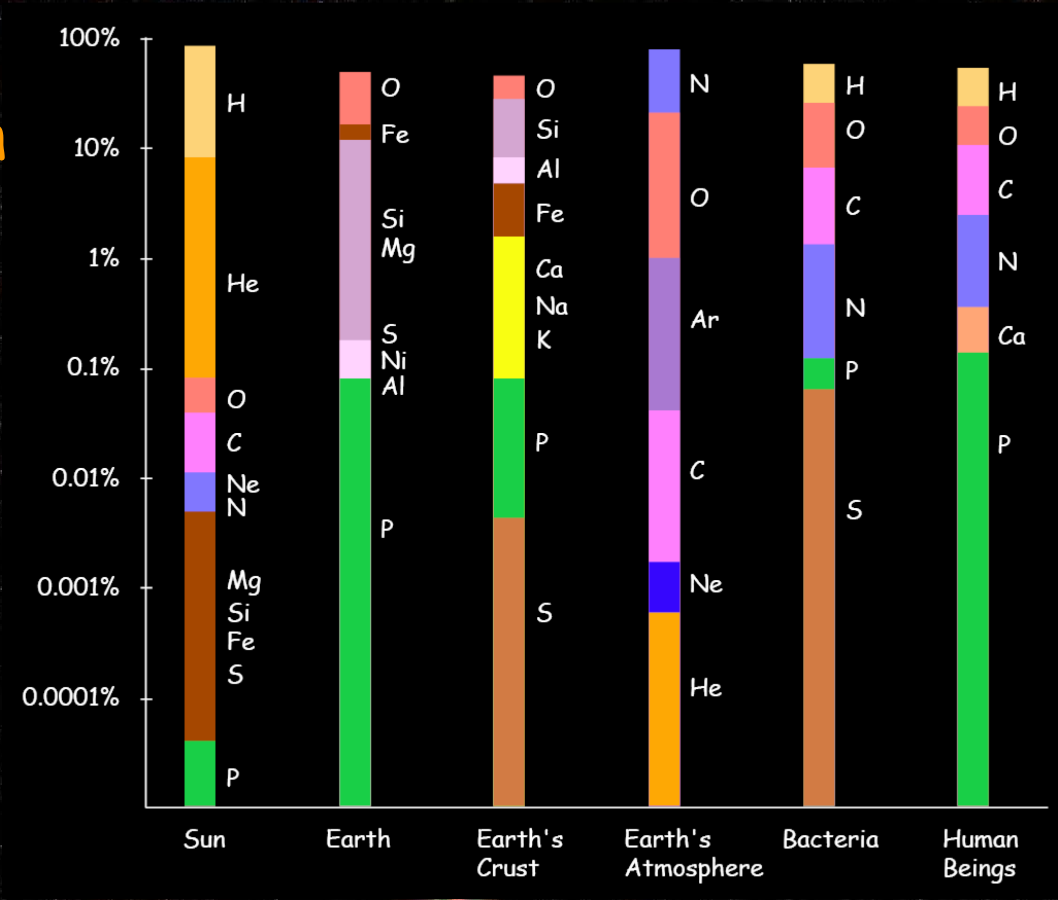


Signatures of Nucleosynthesis

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



Von dem donnerstein gefallẽ jm xcij .iar: vor Ensisheim.

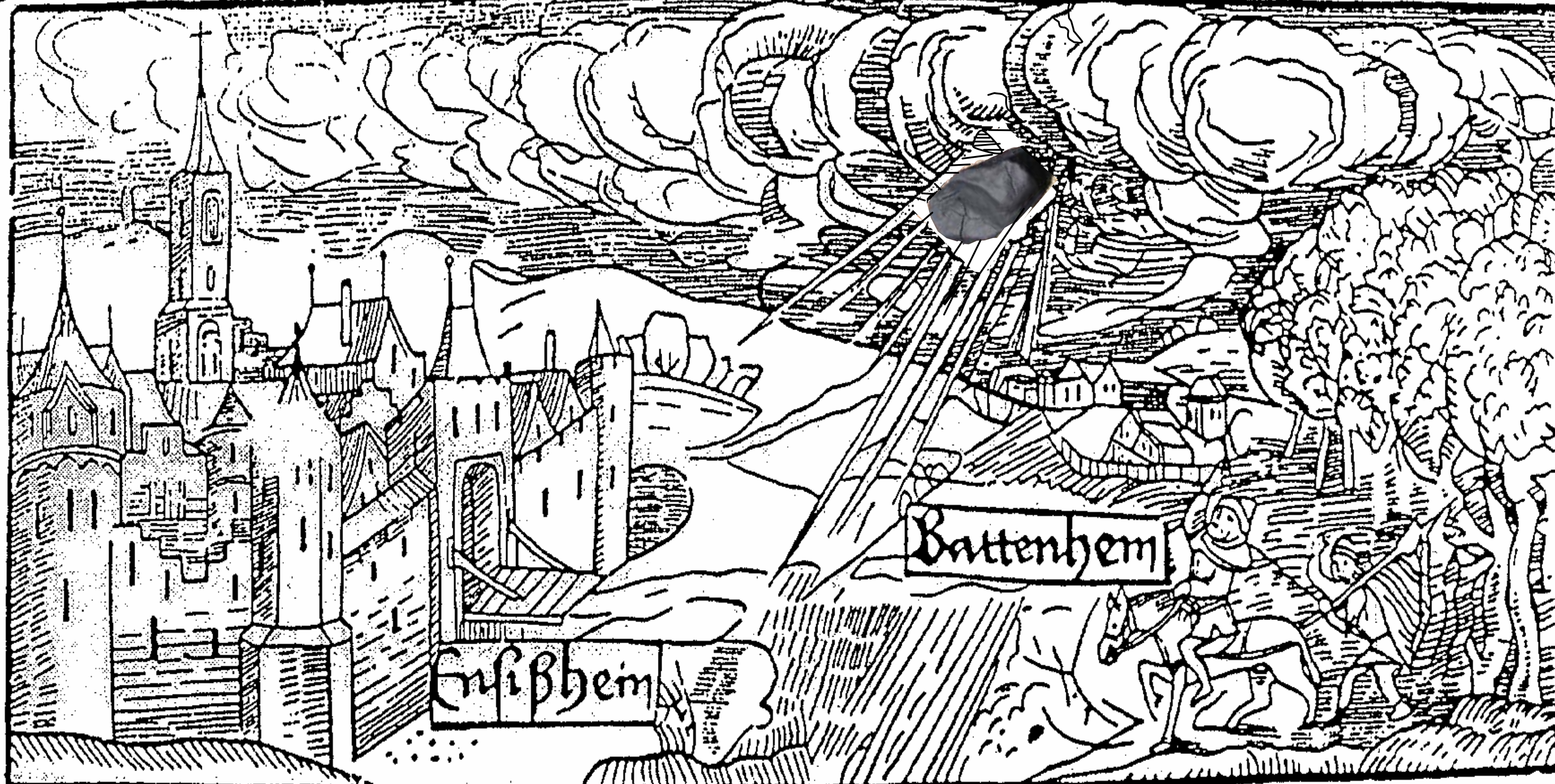
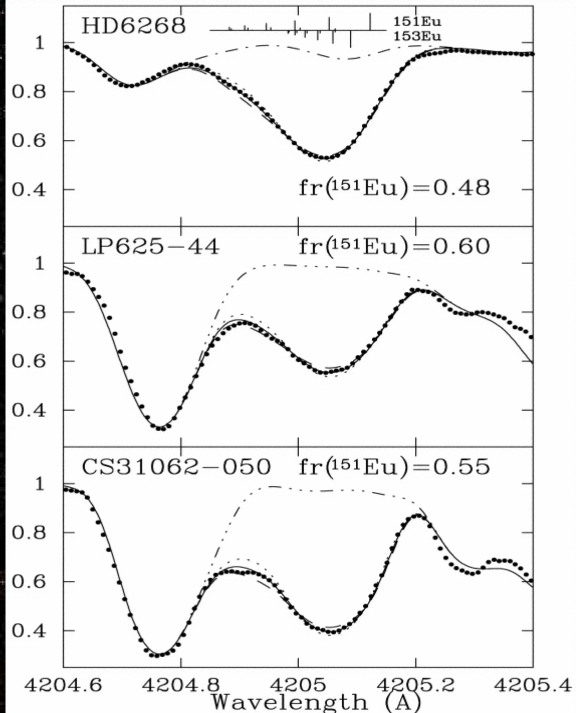
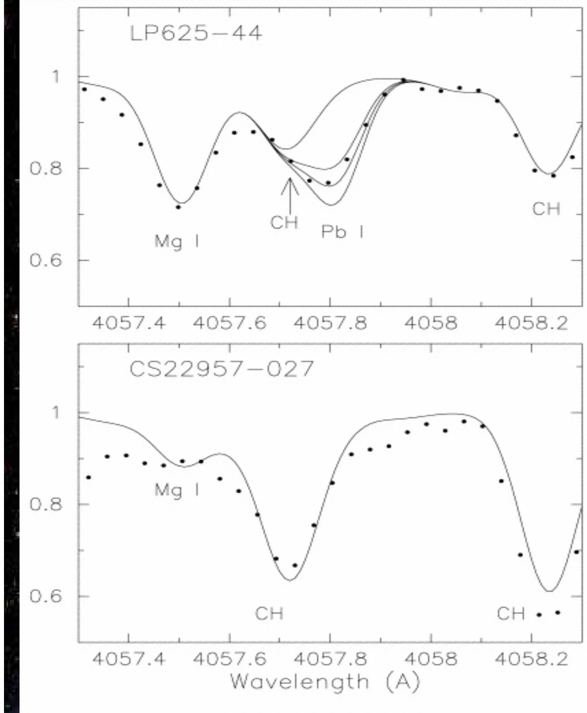
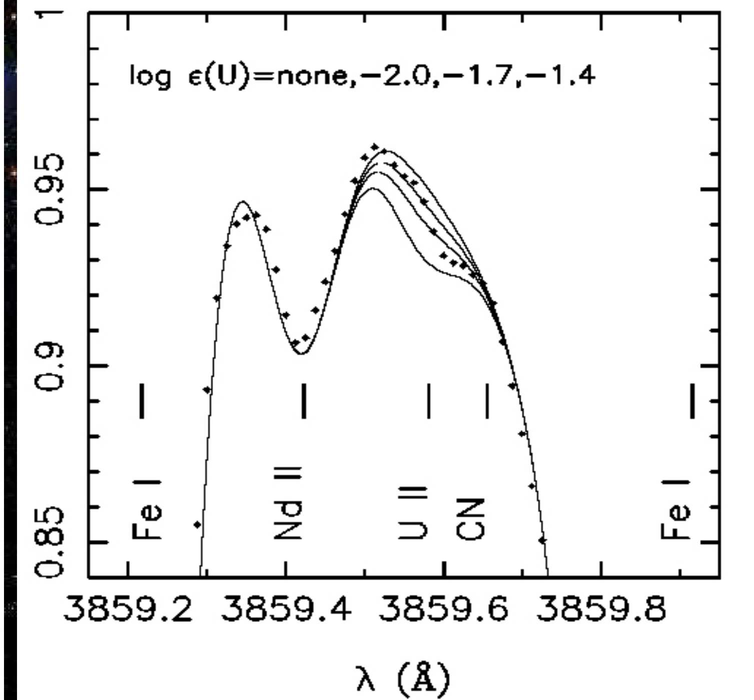
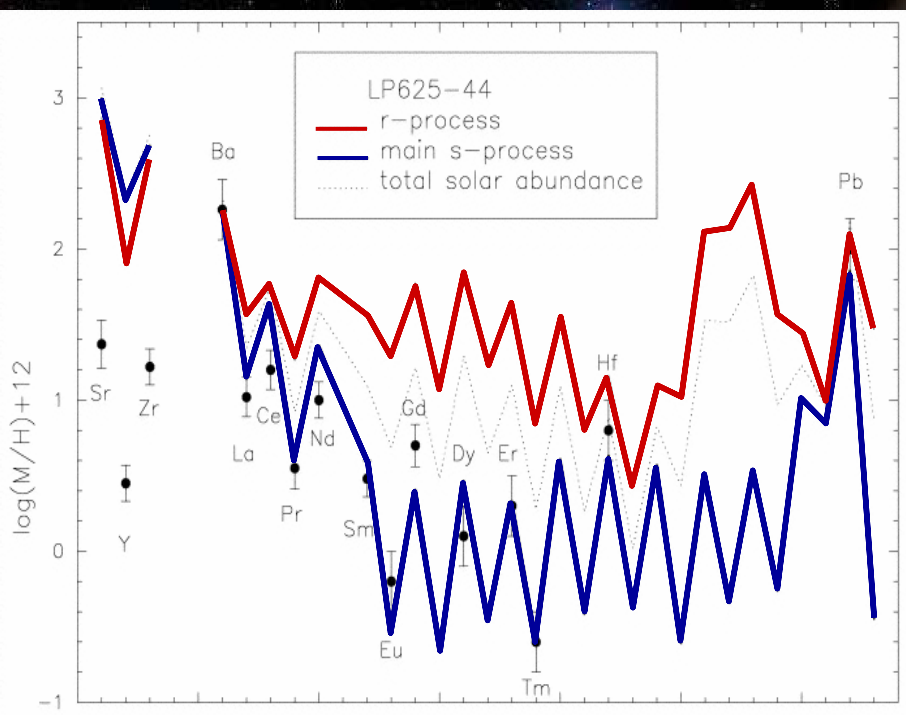


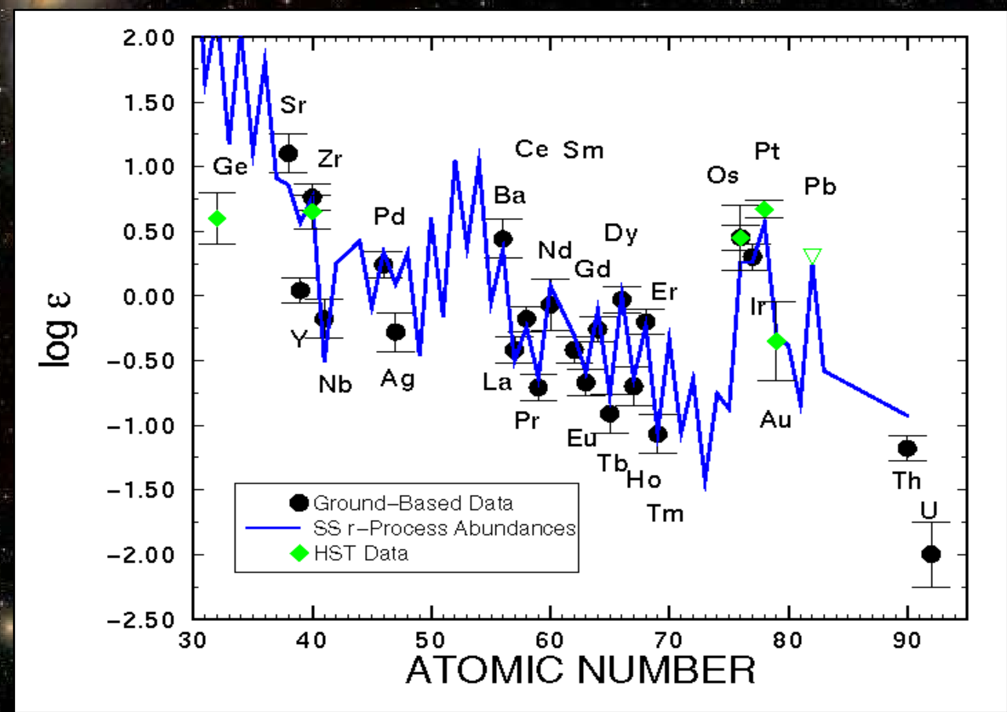
Figure I-2. Woodcut depicting the fall of the Ensisheim LL chondrite on 7 November 1492. A literal translation of the German caption (by Sebastian Brant) is "of the thunder-stone (that) fell in xcii (92) year outside of Ensisheim." This meteorite, which is preserved in the city hall of Ensisheim, Alsace, 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
4204.6
4204.8
4205
4205.2
4205.4
Wavelength (A)


LP625−44
Mg I
CH
Pb I
CH
4057.4
4057.6
4057.8
4058
4058.2
CS22957−027
Mg I
CH
CH
Wavelength (A)

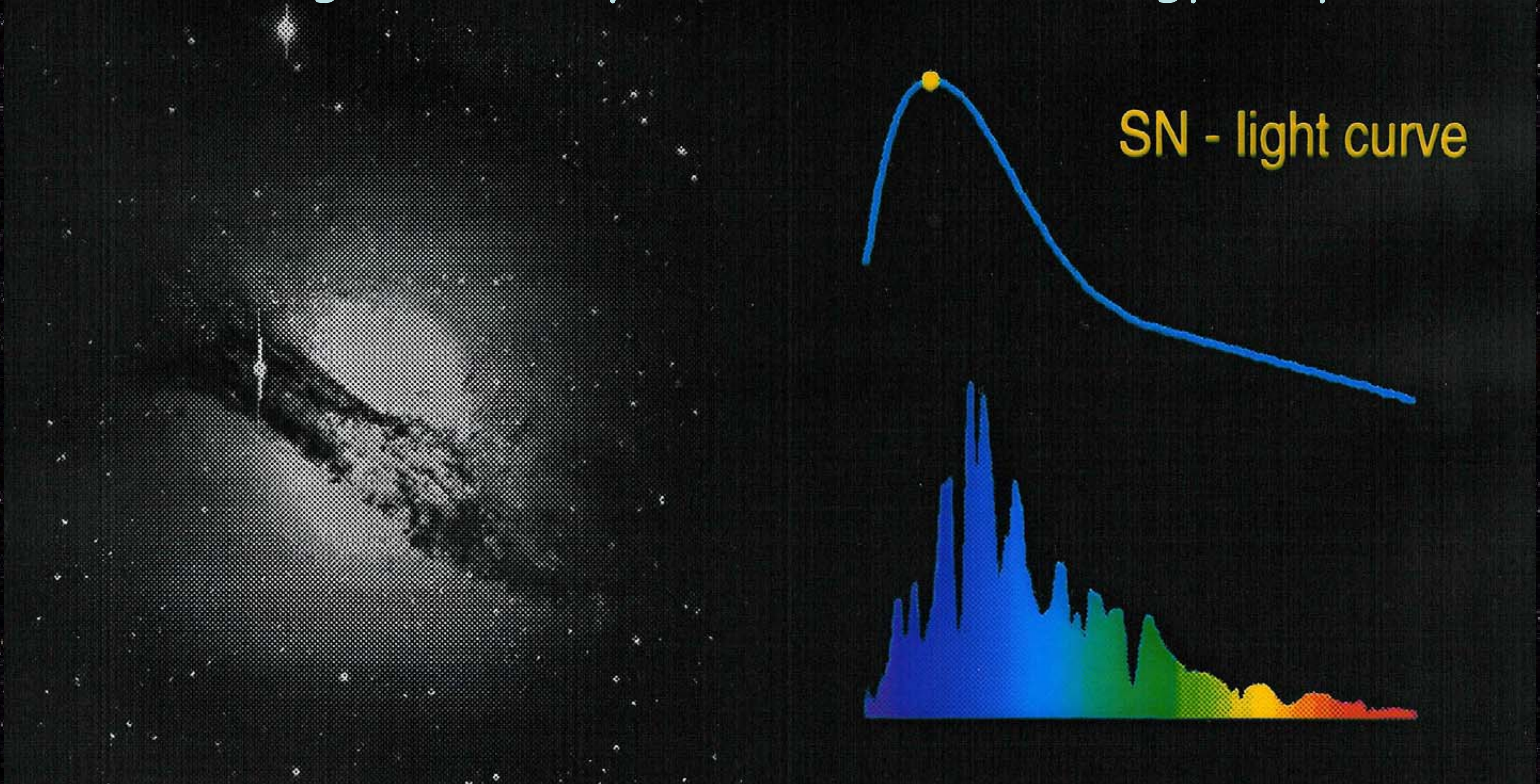

log ε(U)=none,−2.0,−1.7,−1.4
0.95
0.9
0.85
Fe I
Nd II
U II
CN
Fe I
3859.2
3859.4
3859.6
3859.8
λ (Å)


LP625−44
r−process
main s−process
total solar abundance
log(M/H)+12
Sr
Y
Zr
Ba
La
Ce
Pr
Nd
Sm
Eu
Gd
Dy
Er
Tm
Hf
Pb


log ε
ATOMIC NUMBER
Ground−Based Data
SS r−Process Abundances
HST Data
Ge
Sr
Y
Zr
Nb
Pd
Ag
Ba
La
Ce
Sm
Pr
Nd
Eu
Gd
Tb
Dy
Ho
Er
Tm
Os
Ir
Pt
Au
Pb
Th
U

Light and Light-Curves

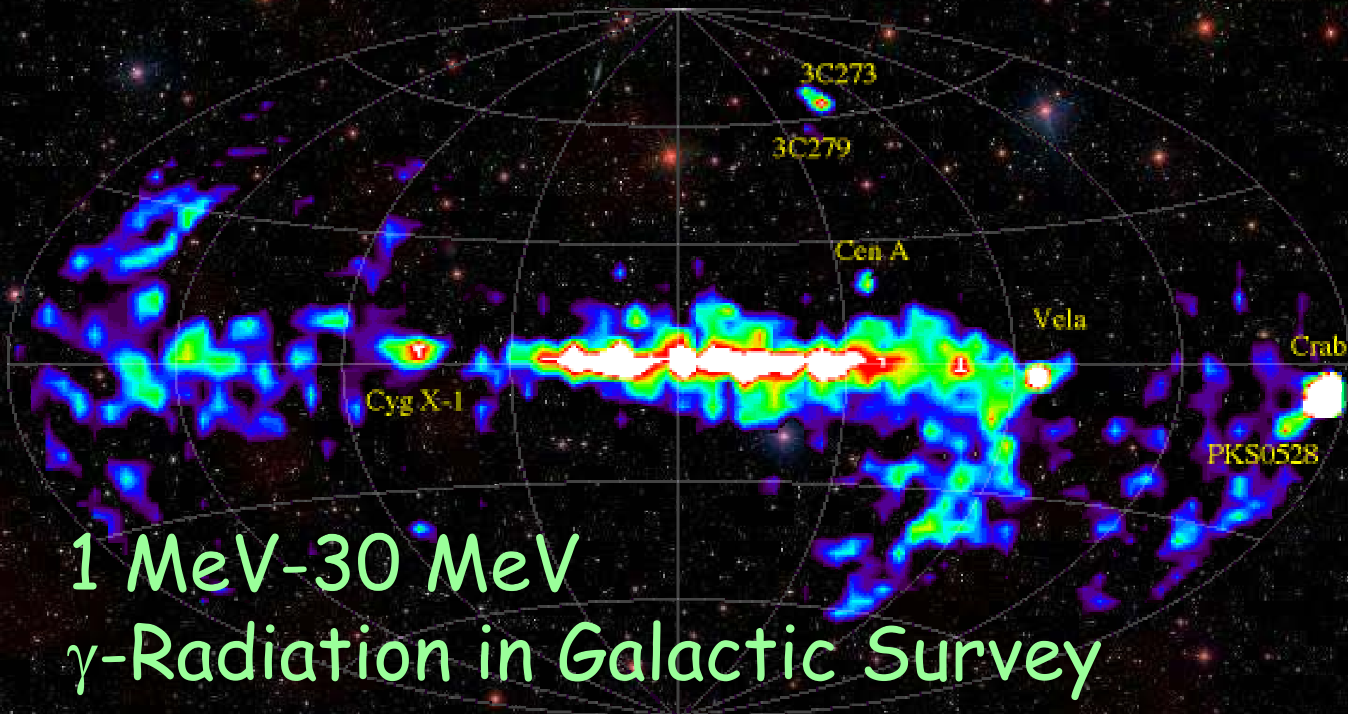
Light intensity correlates with energy-output



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

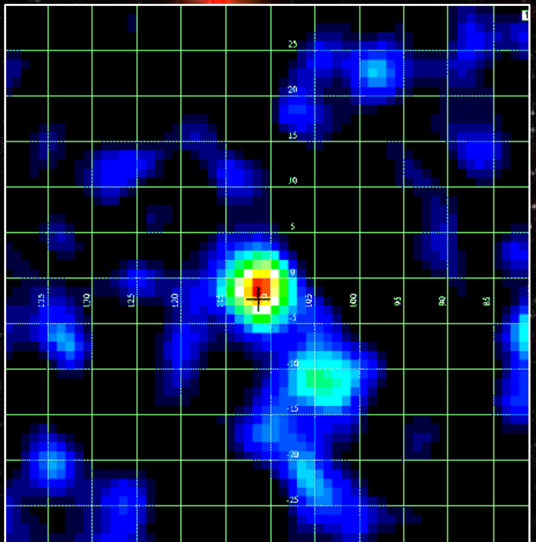
The (radio) active Universe

COMPTEL
INTEGRAL



1 MeV-30 MeV
γ-Radiation in Galactic Survey

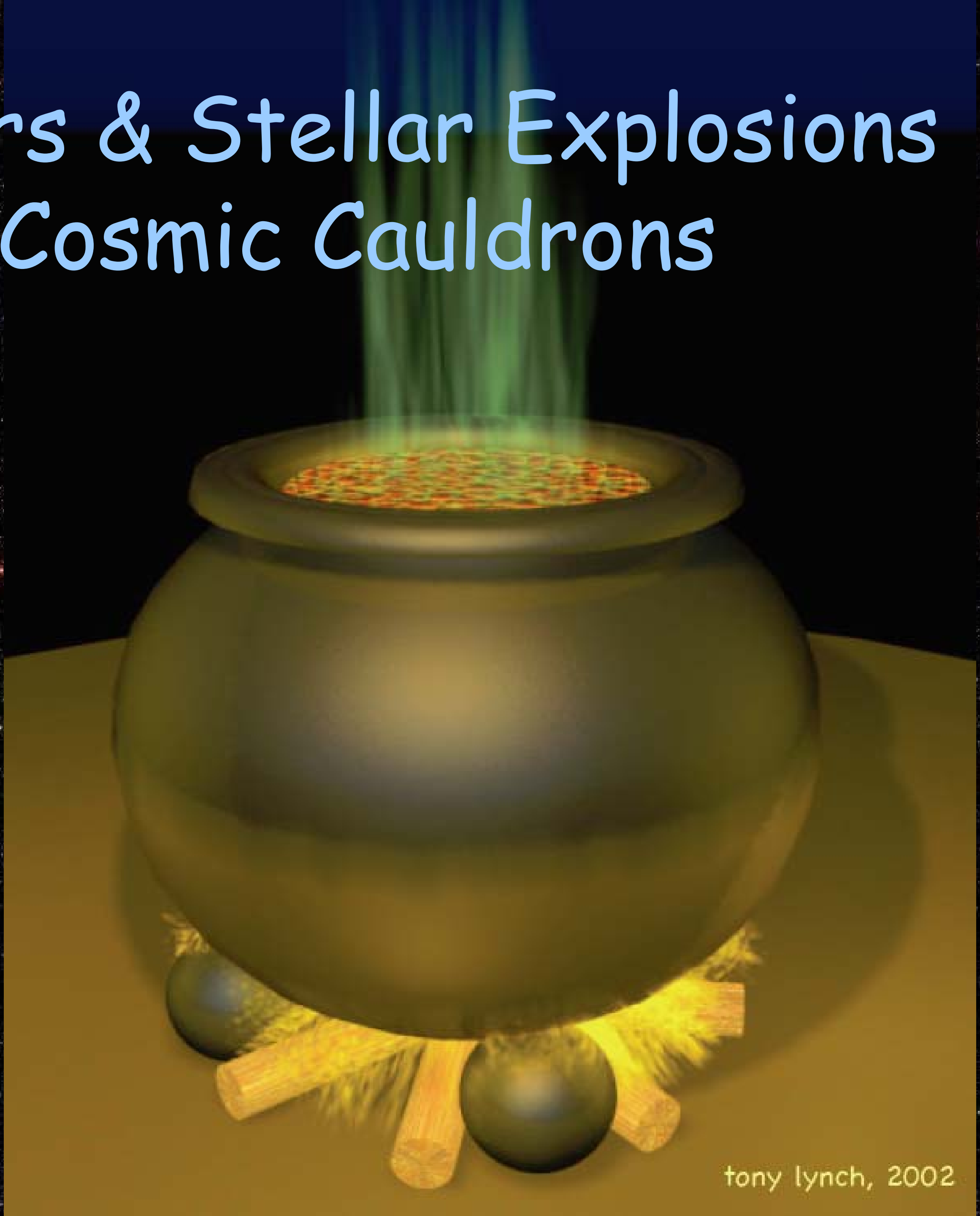
(^{26}Al Half life: 700,0000 years)



^{44}Ti in Supernova Cas-A Location

(Half life: 60 years)

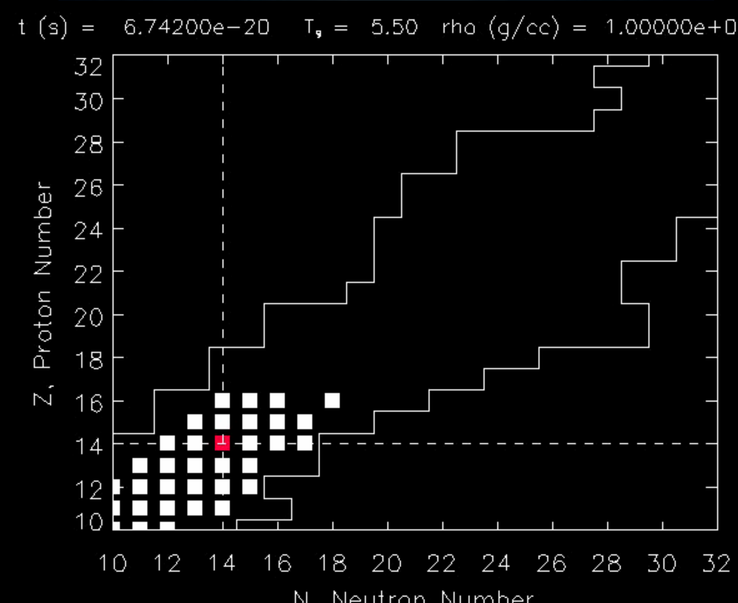
Stars & Stellar Explosions are Cosmic Cauldrons



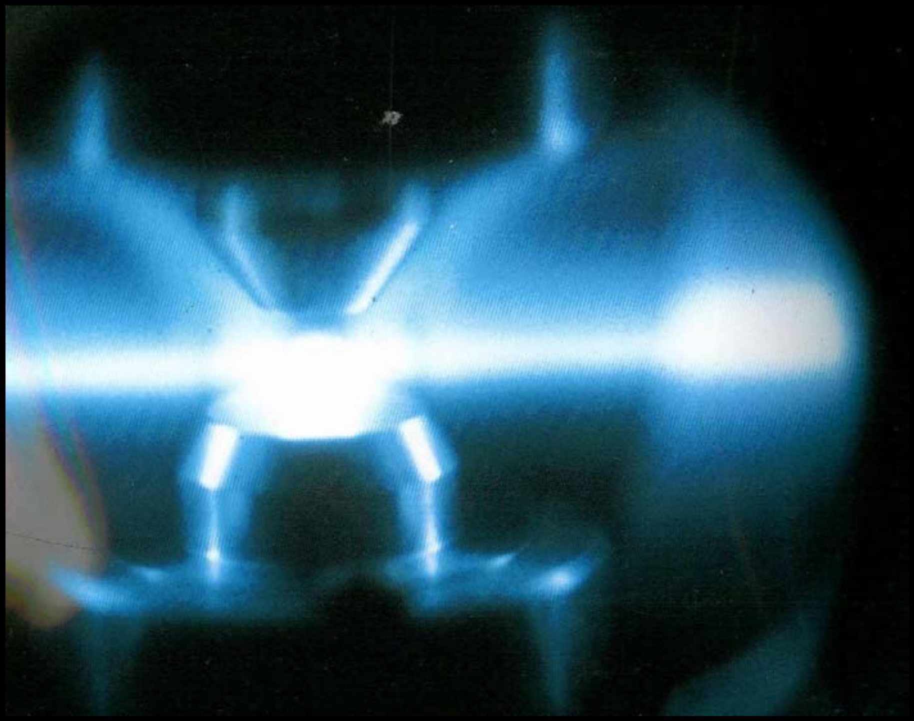
Nuclear processes are the engine of the Universe !

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

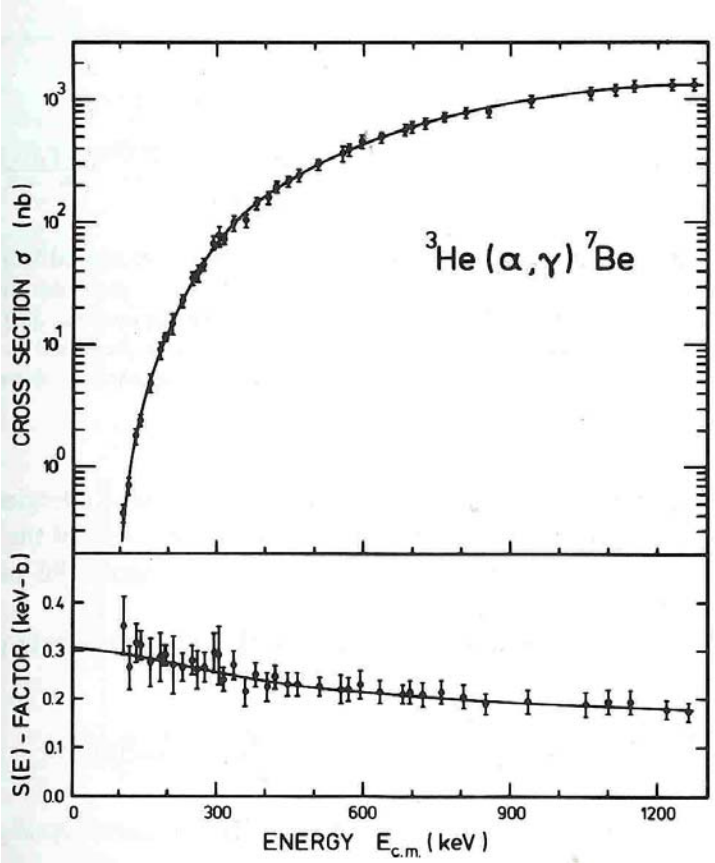
- generate energy
- create new isotopes and elements

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

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

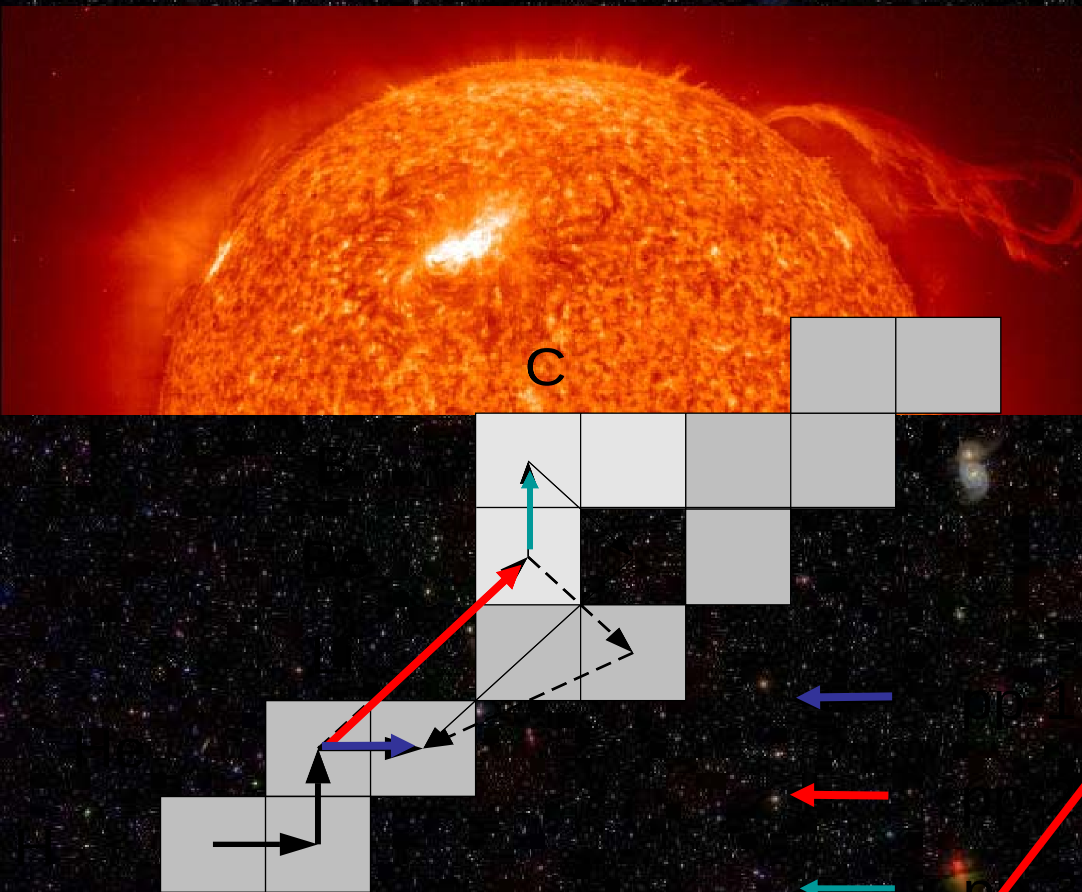
Problem: low energy measurement

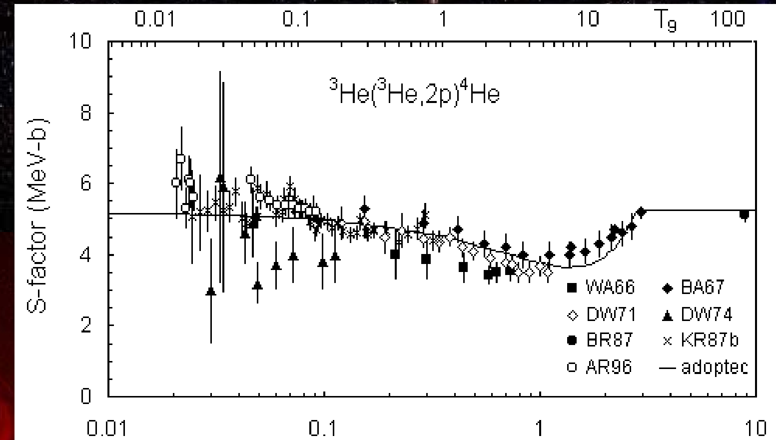
Cross section drops exponentially towards lower energies!

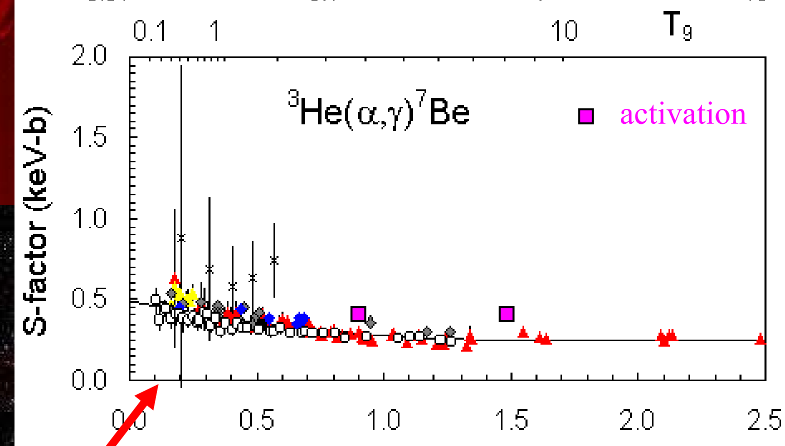


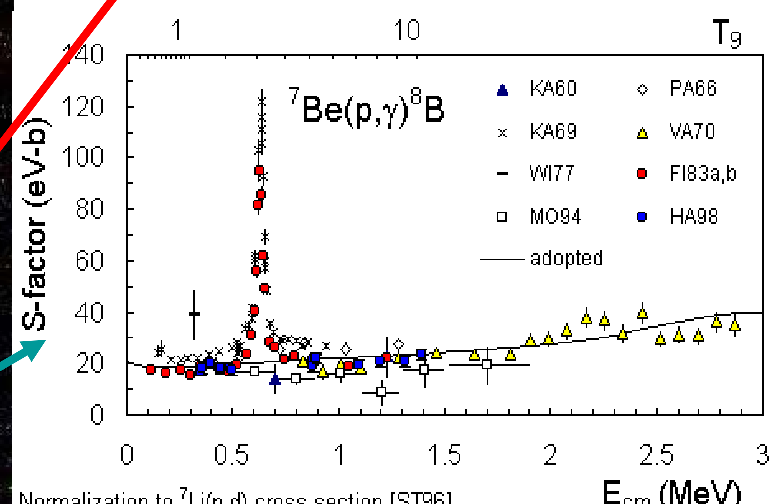
Low energy experiments last for many months to obtain one single data point, studies are handicapped by cosmic ray and beam induced background

pp-chains in the sun







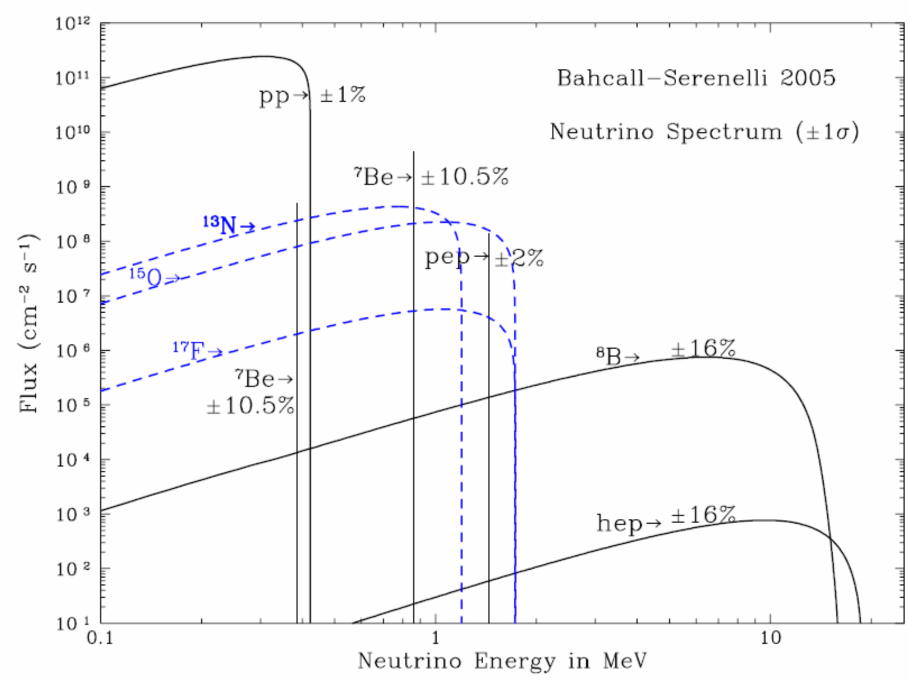


Impact on solar neutrino detectors

Borexino

SNO & Superkamiokande

Solar Neutrinos from the pp-chains and CNO cycles

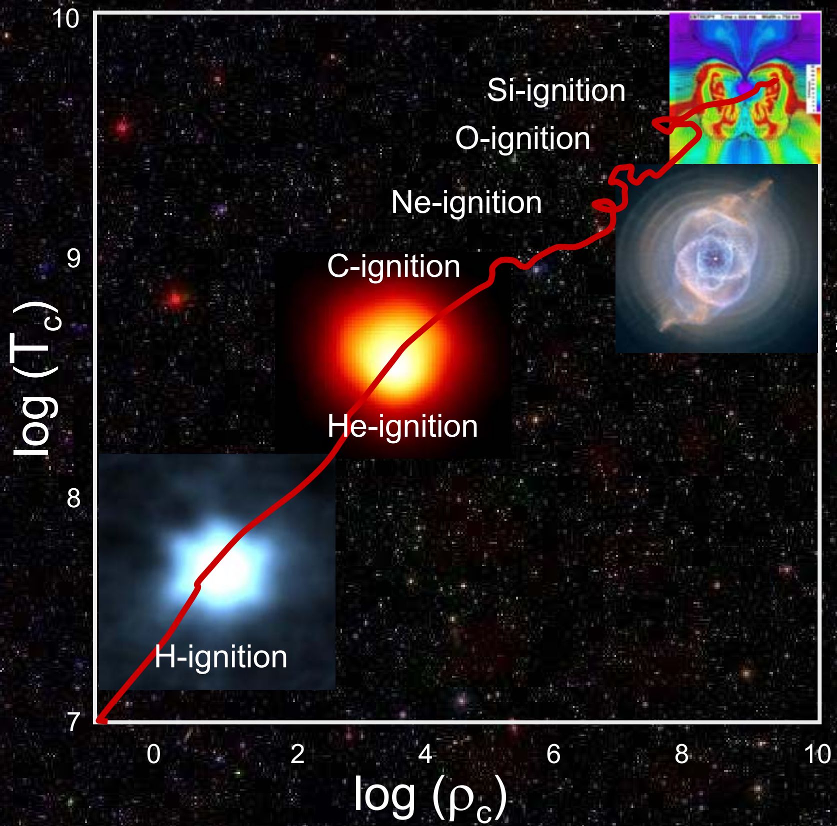


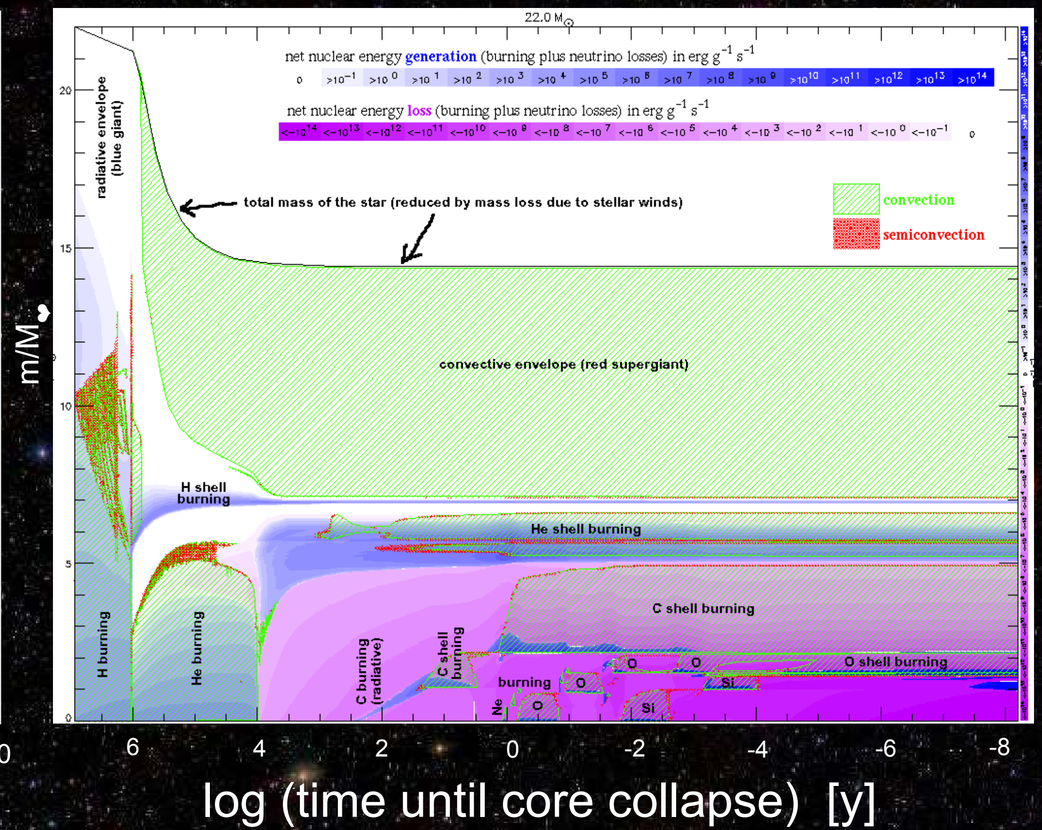
High accuracy in measurement of:

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

Provides better flux predictions for comparison with observations. Data provide information and check on standard solar model and on solar neutrino oscillation characteristics.

Nuclear burning & stellar evolution





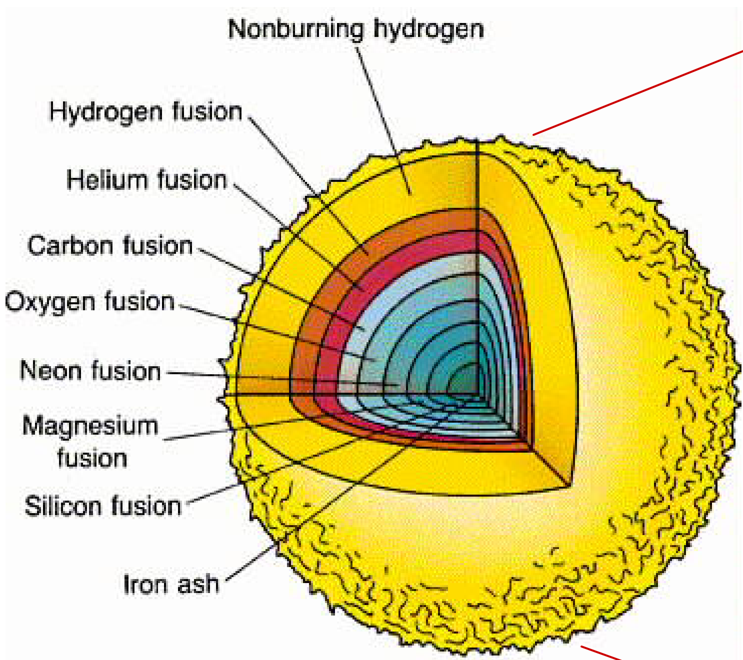
Each burning phase is determined by nuclear reactions in terms of

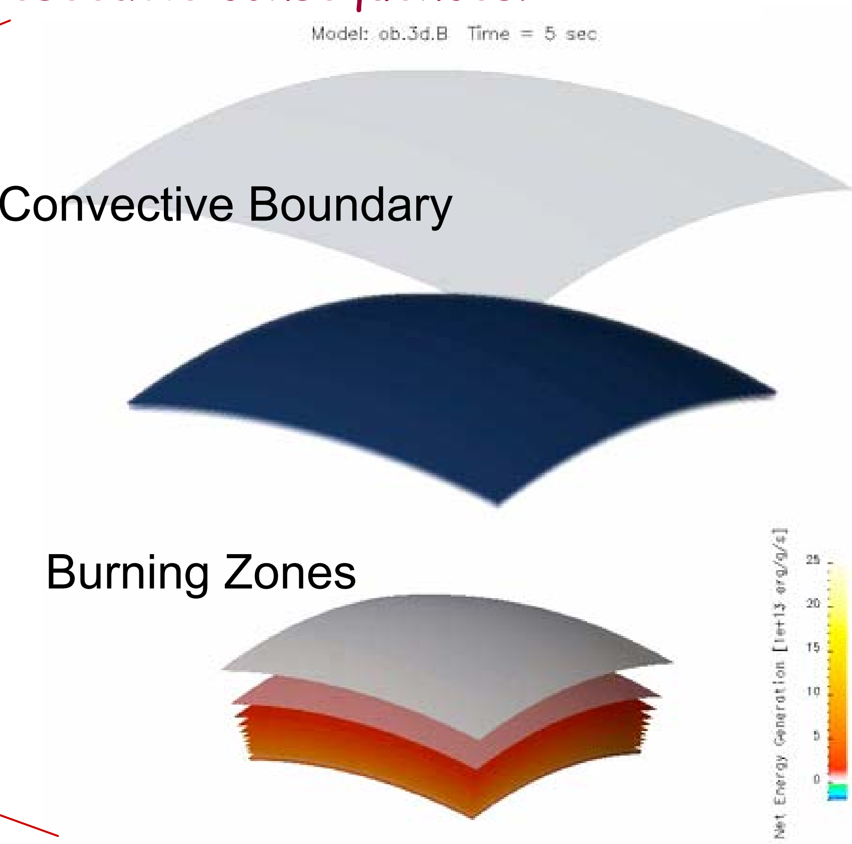
- energy generation,
- time scale
- nucleosynthesis

J I N A

The last Days of Stellar Burning

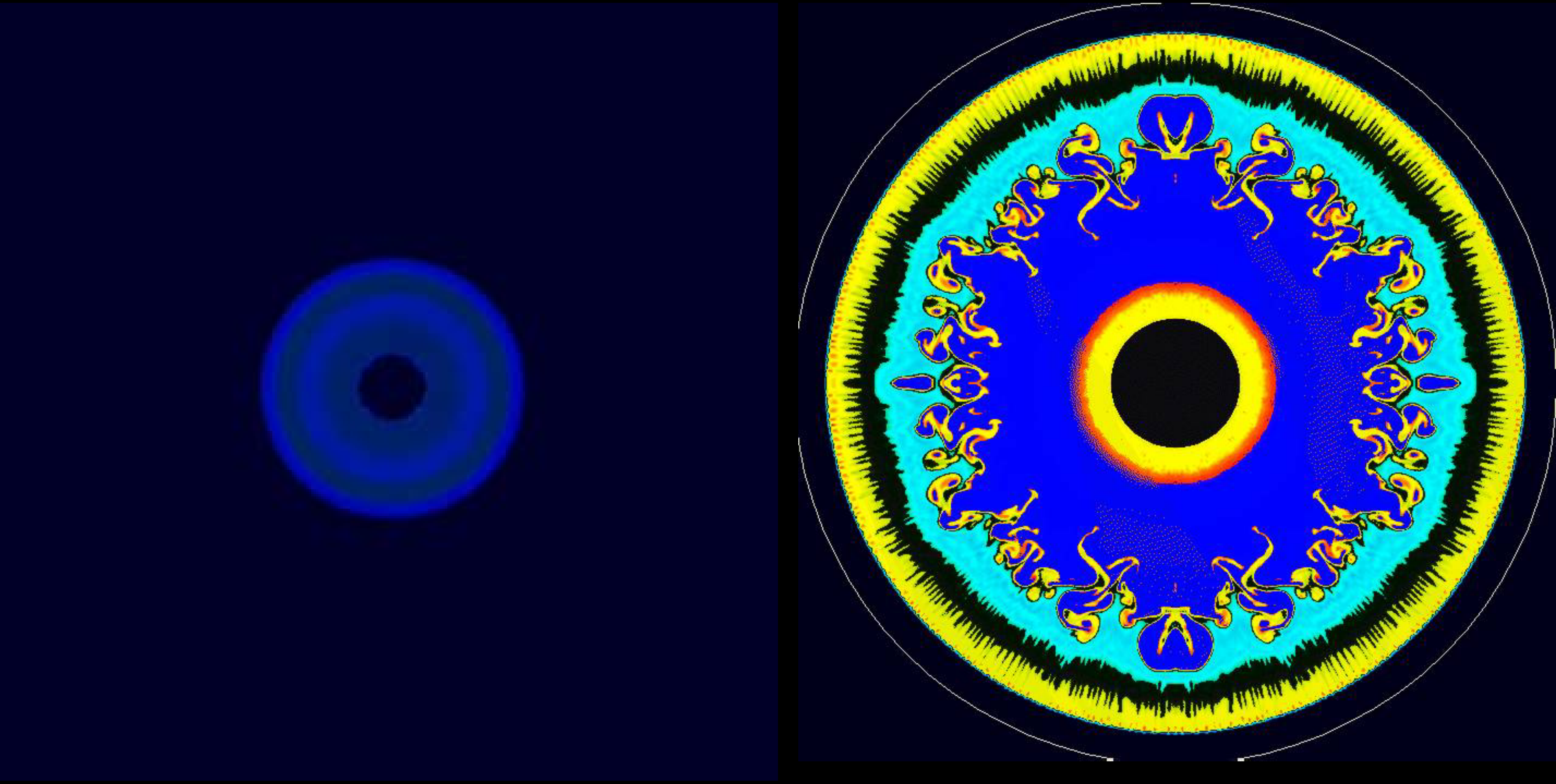
dissolution of burning shells and mixing of matter with as yet unforeseeable consequences!



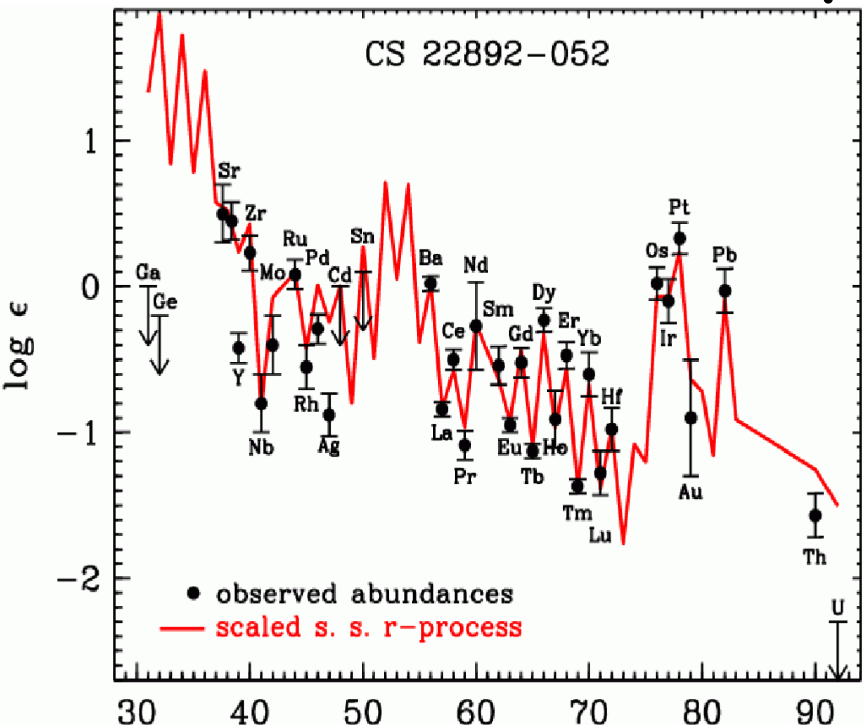


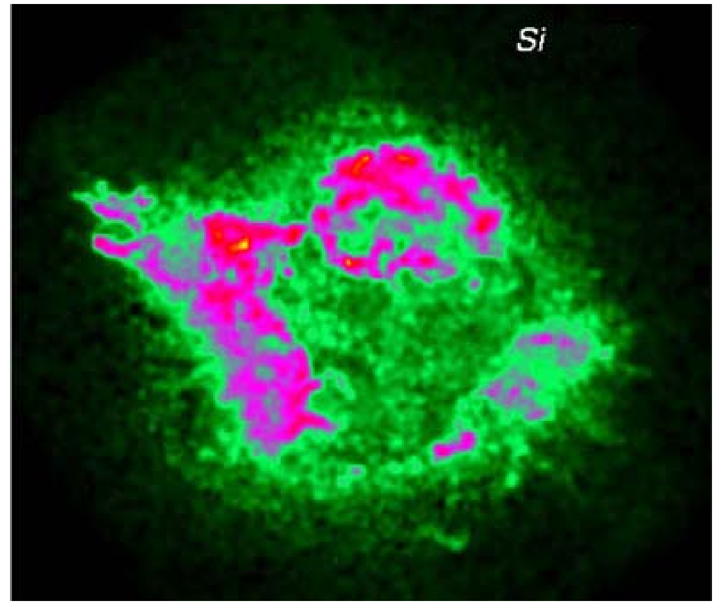
Dave Arnett; Santa Barbara, “The last Days of Burning”
http://www.jinaweb.org/events/ucsb06/talks_SB06.html

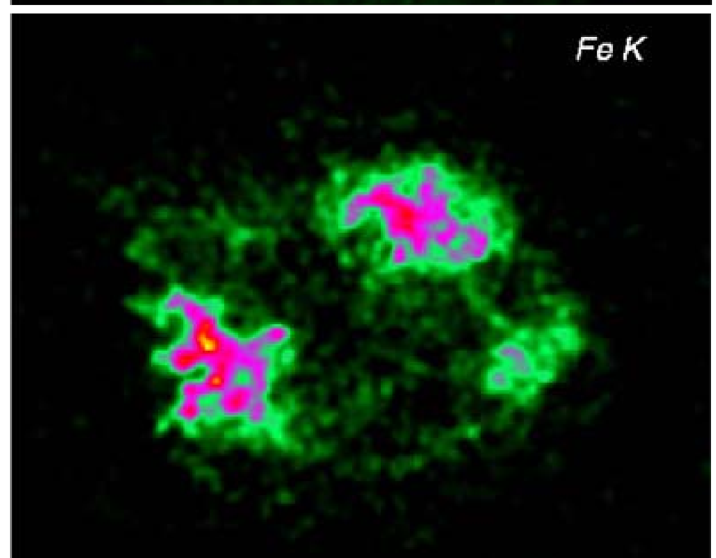
Massive Stars Collapse re-bounce and shock driven by neutrino wind pressure



r-process production of heavy elements in supernova shock



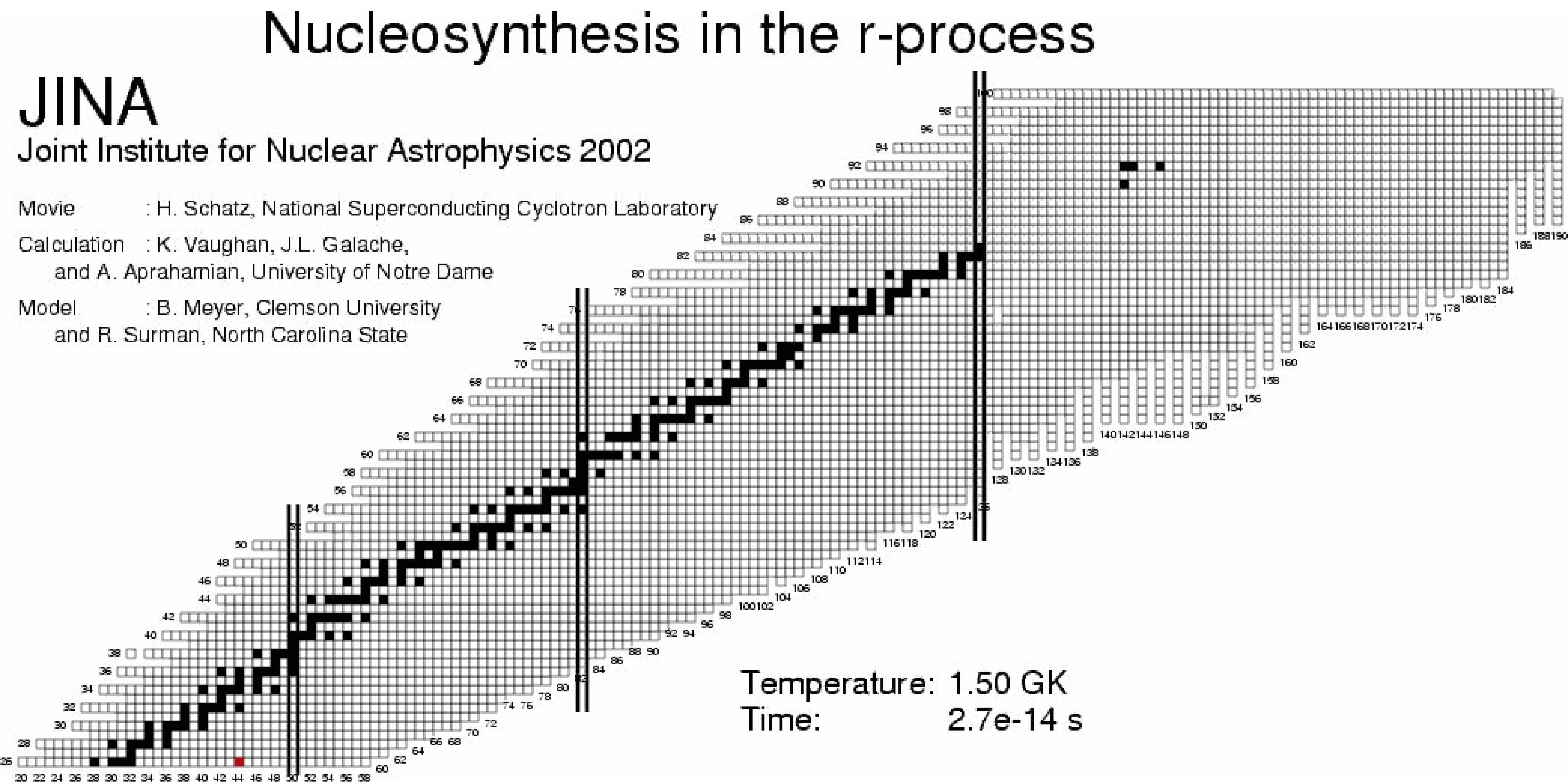




Abundance distribution in metal-poor (old) galactic halo stars matches solar r-process abundances!
⇨ unique r-process site!

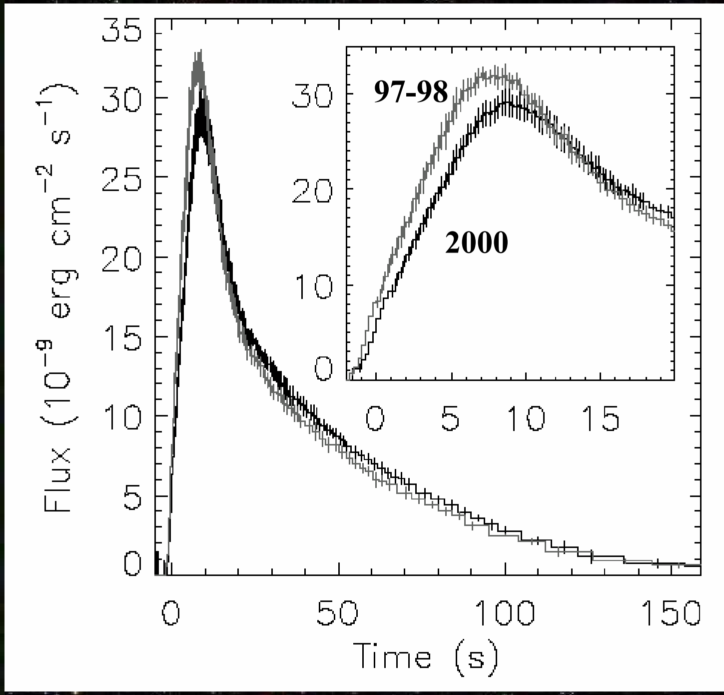
Nucleosynthesis in supernova shock

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

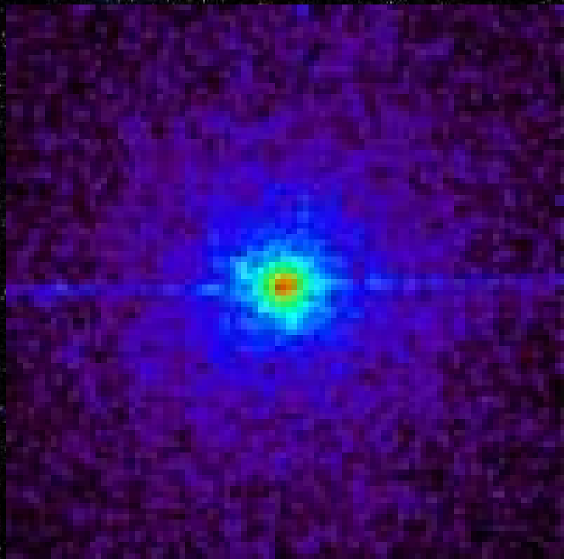


Production of ~50% of heavy elements

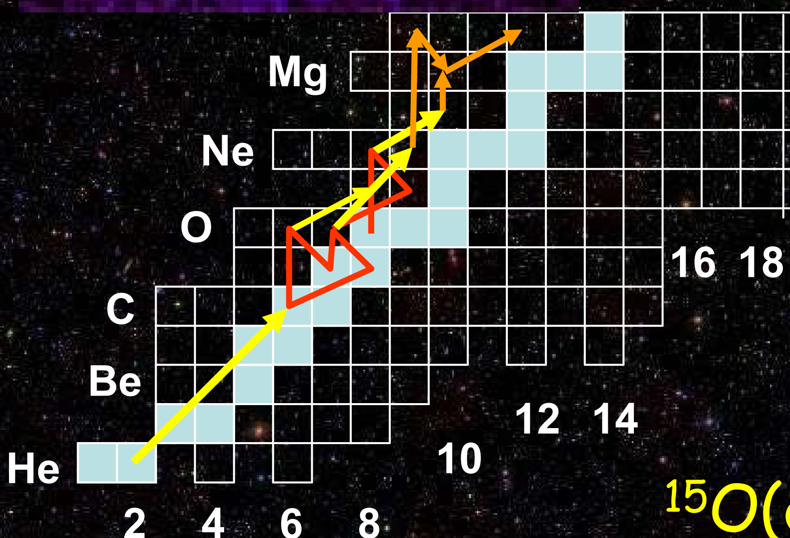
X-Ray Bursts as Nuclear Laboratory

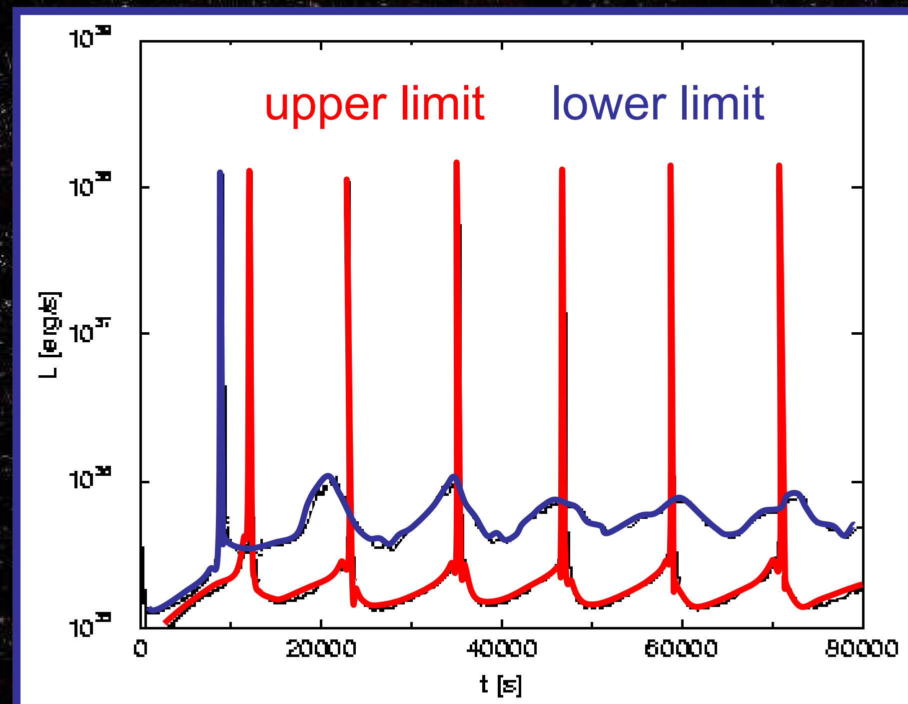


The nuclear trigger of X-ray Bursts



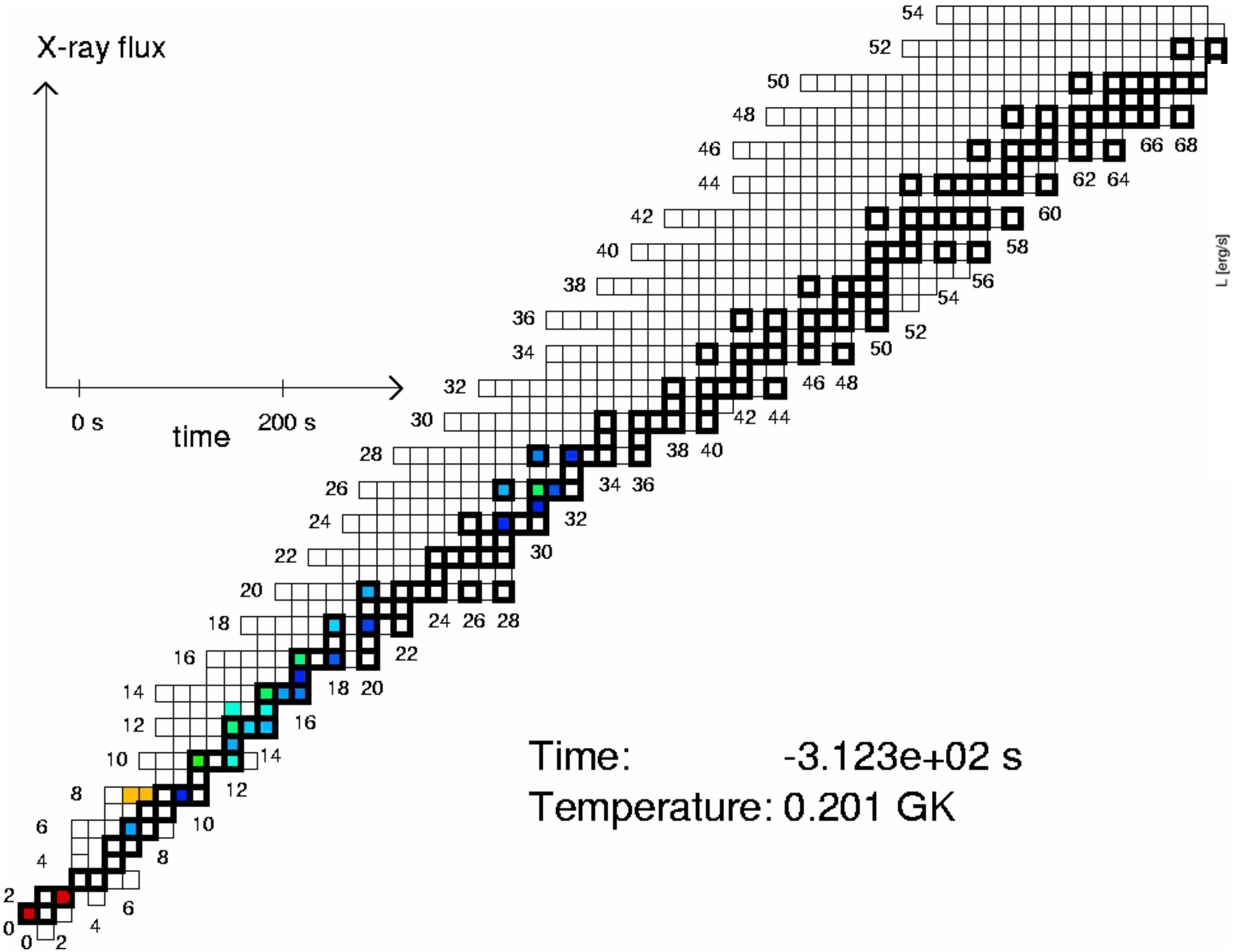
$^{15}O(\alpha,\gamma)^{19}Ne$ $^{18}Ne(\alpha,p)^{21}Na$



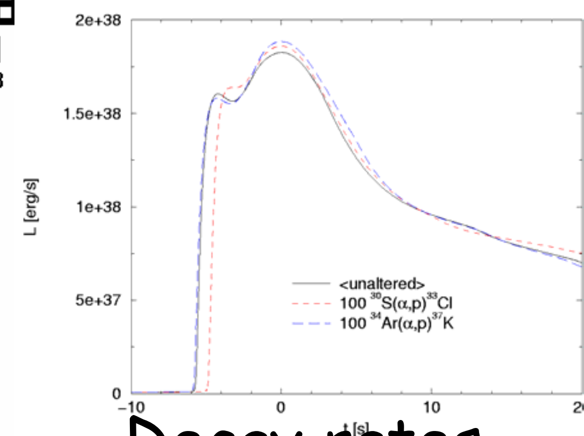


$^{15}O(\alpha,\gamma)^{19}Ne$ as switch for XRB pattern

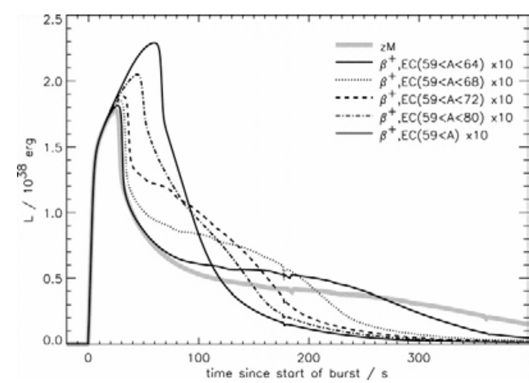
HCNO & rp-Process



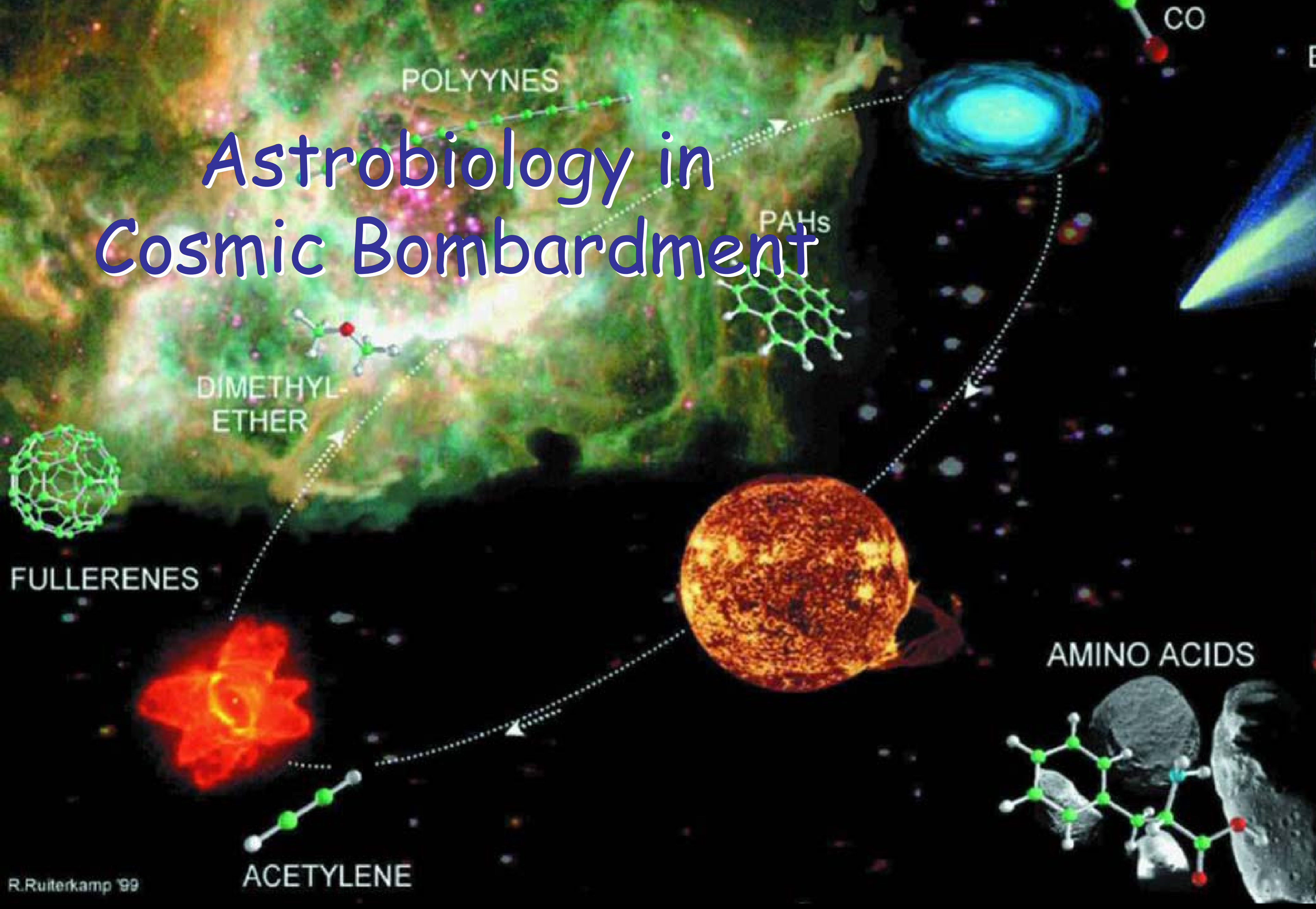
Reaction rates



Decay rates & masses

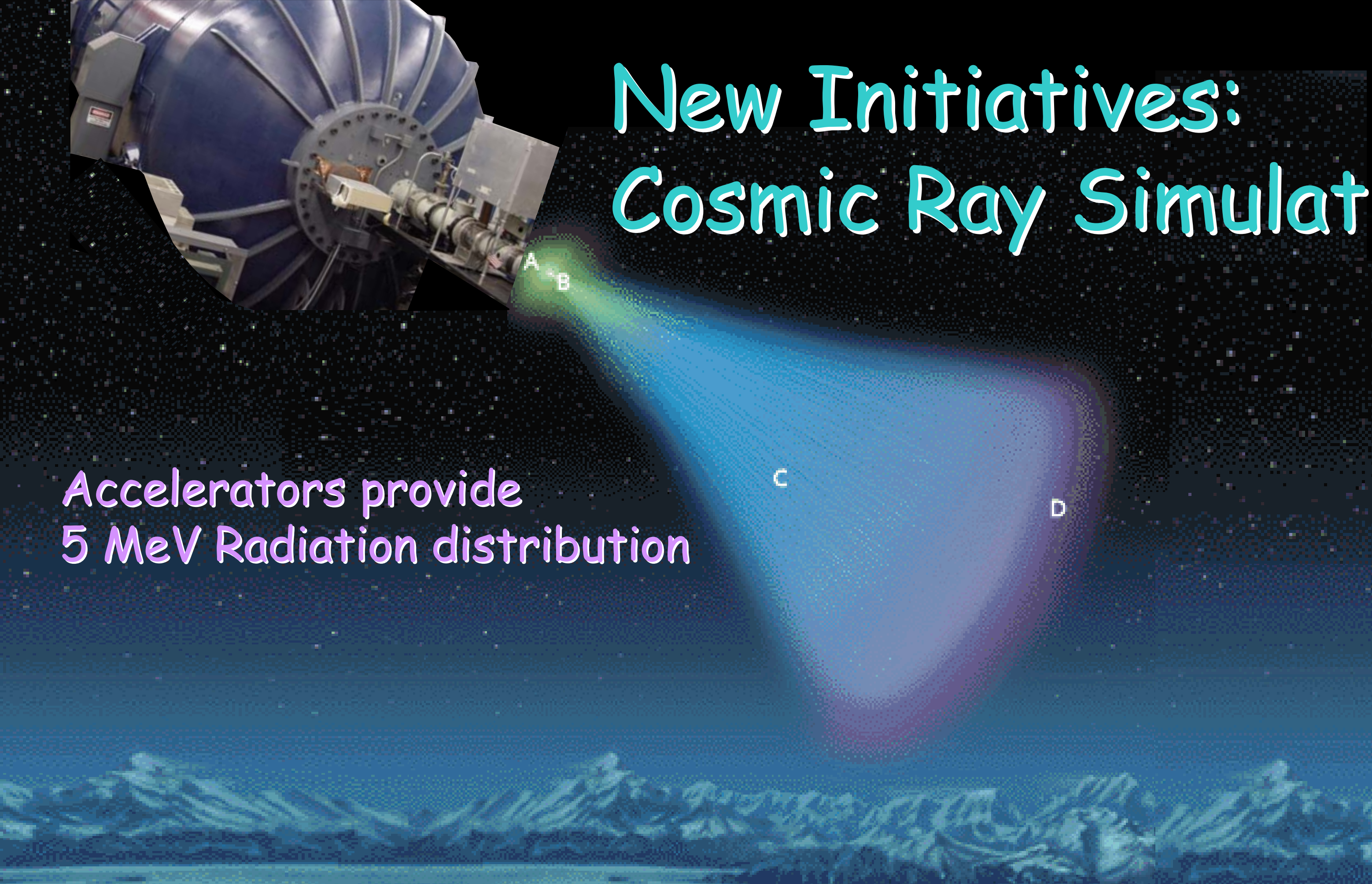


Astrobiology in Cosmic Bombardment

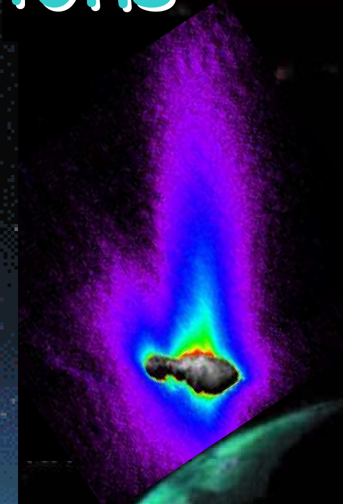


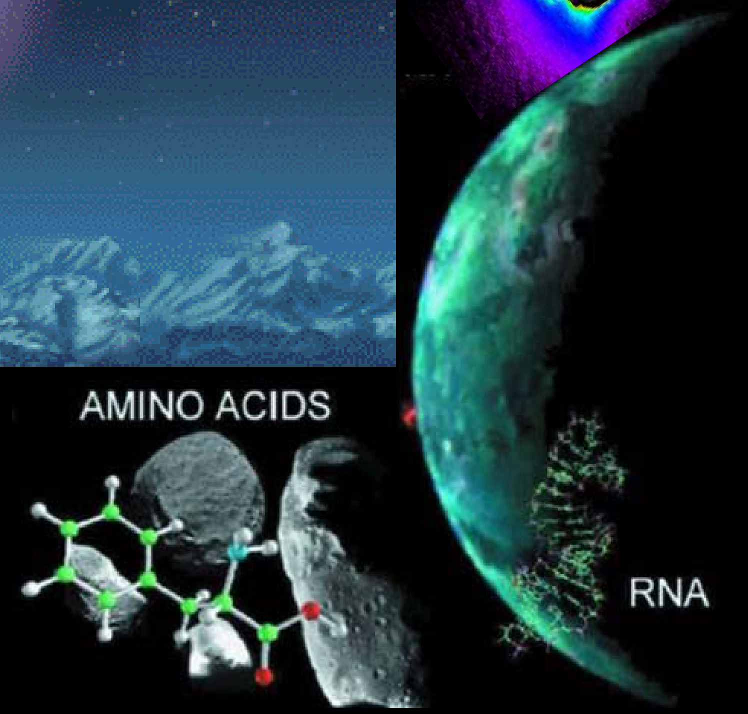
NASA astrobiology observation program

New Initiatives: Cosmic Ray Simulations



Accelerators provide
5 MeV Radiation distribution

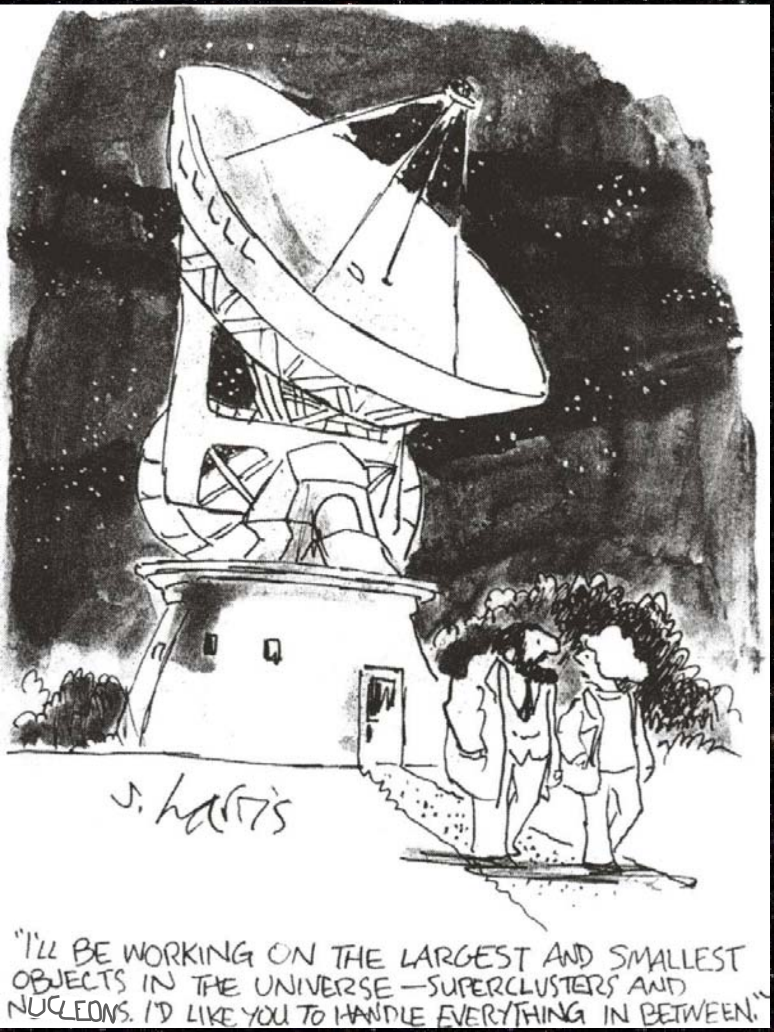




Bombardment of asteroid material leads to the formation of complex "organic" molecules, the first step to LIFE - Astrobiology

Summary & Conclusion

"everything in between" is a broad field
– impossible to cover within 45 minutes …



- SIB nucleosynthesis in stellar evolution
- RIB nucleosynthesis in novae & XRBs
- RIB-neutron nucleosynthesis for r-process
- pycnonuclear processes in neutron stars
- biochemical processes induced by Cosmic Radiation

But, simulating the multitude of stellar nucleosynthesis processes needs nuclear accelerator facilities from 1keV-100GeV