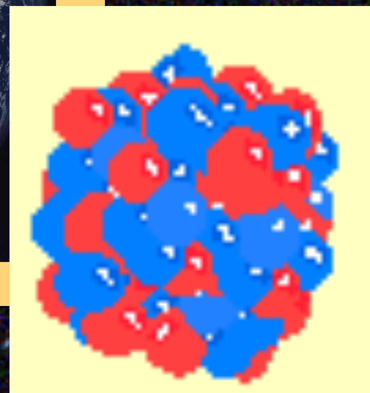
A Cosmic Connection:
Properties of Nuclei and Properties of the Cosmos



Nuclear Physics in Naples

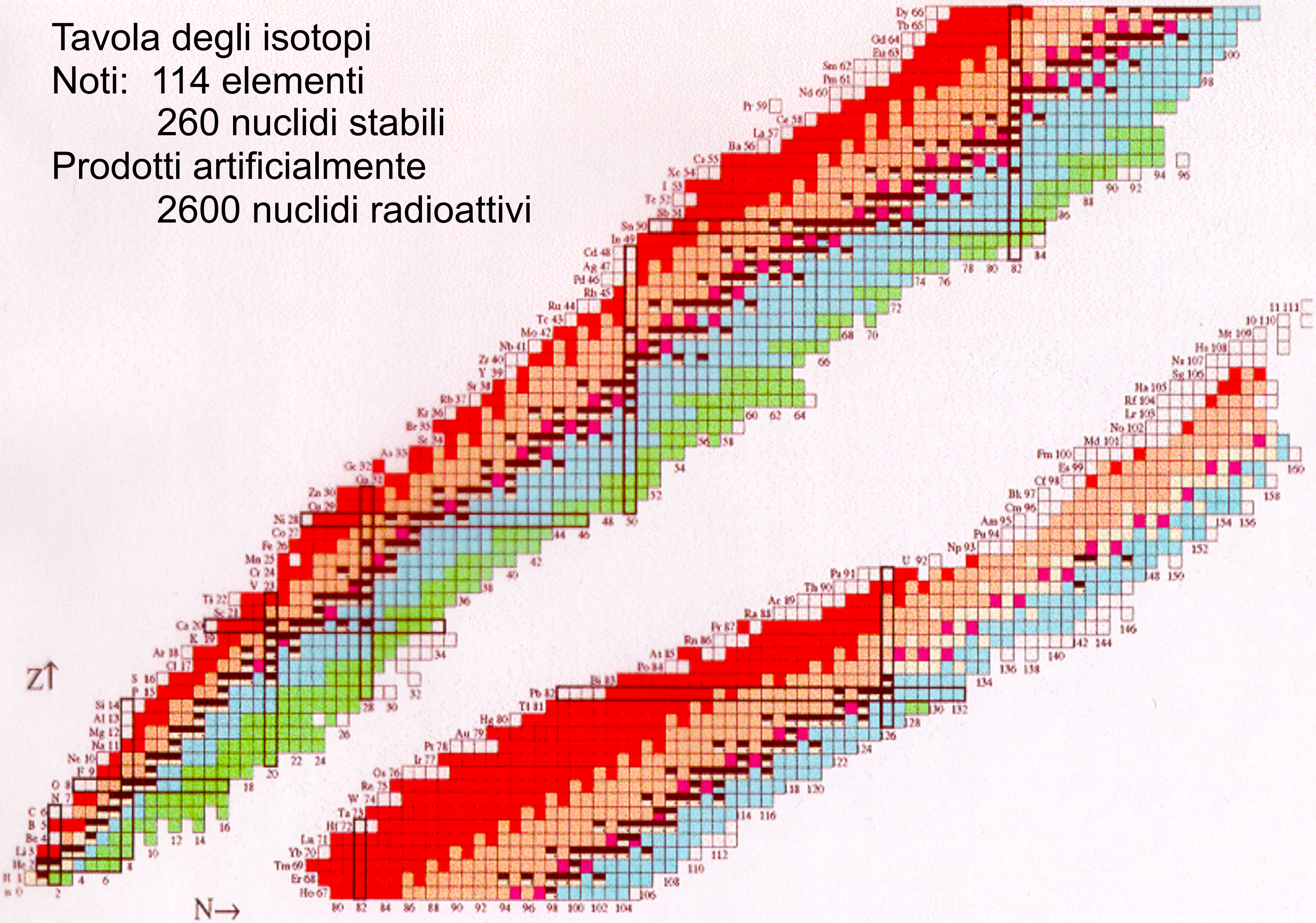
Tavola degli isotopi

Noti: 114 elementi

260 nuclidi stabili

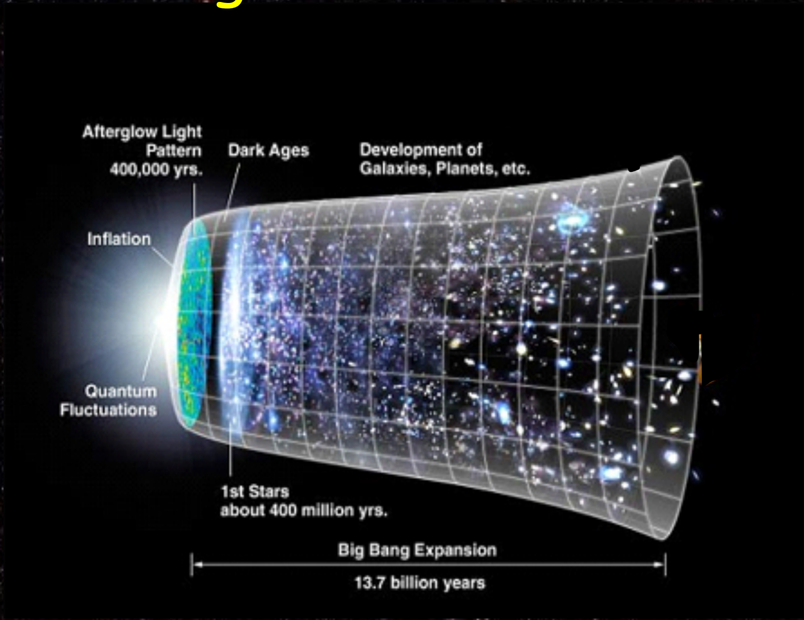
Prodotti artificialmente

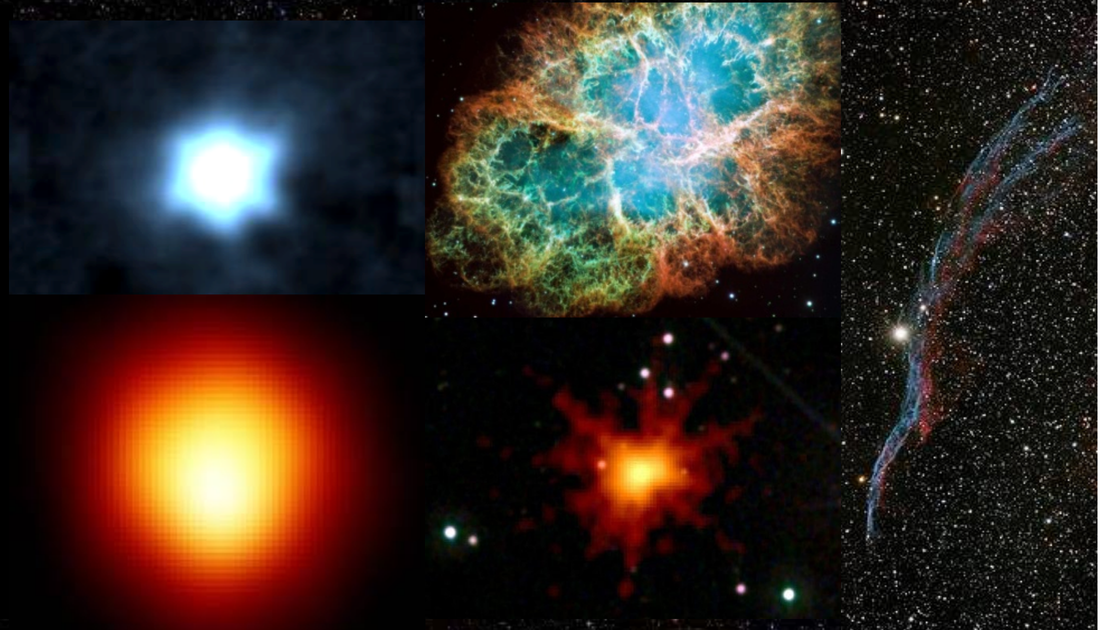
2600 nuclidi radioattivi

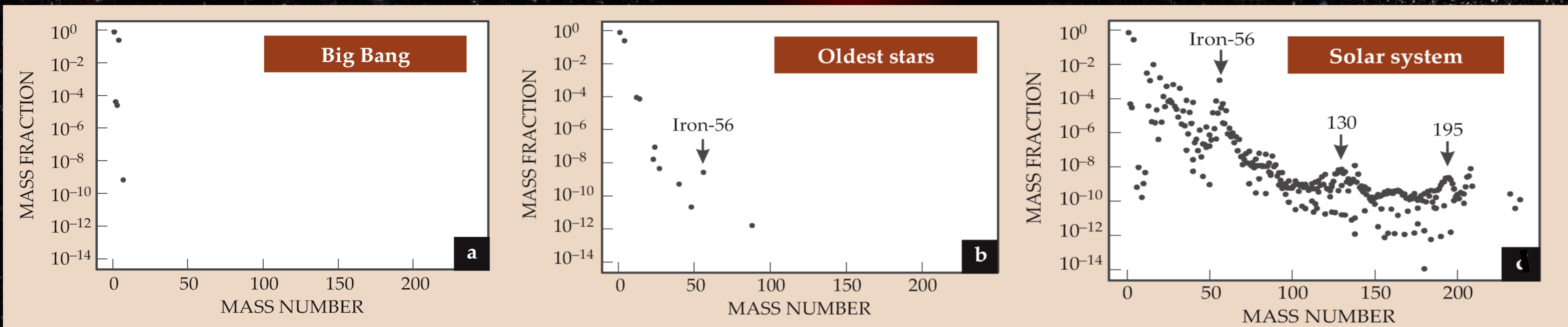


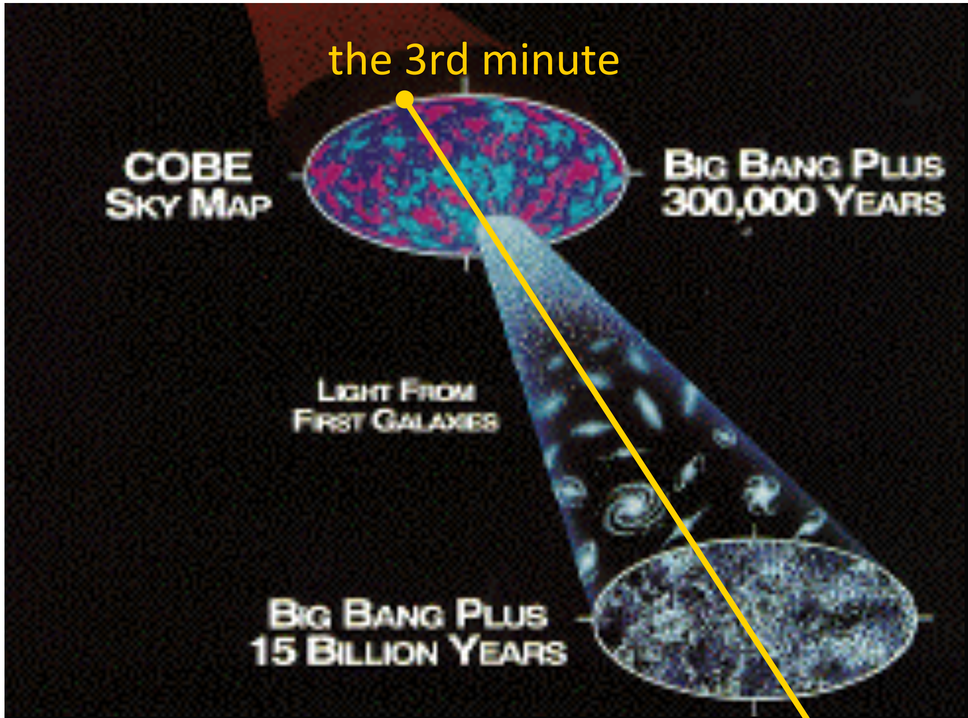
Science Questions in Nuclear Physics

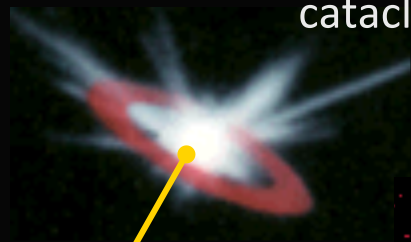
The origin of elements & the chemical evolution of our universe

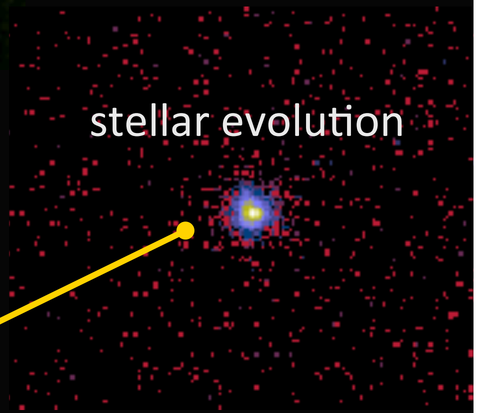


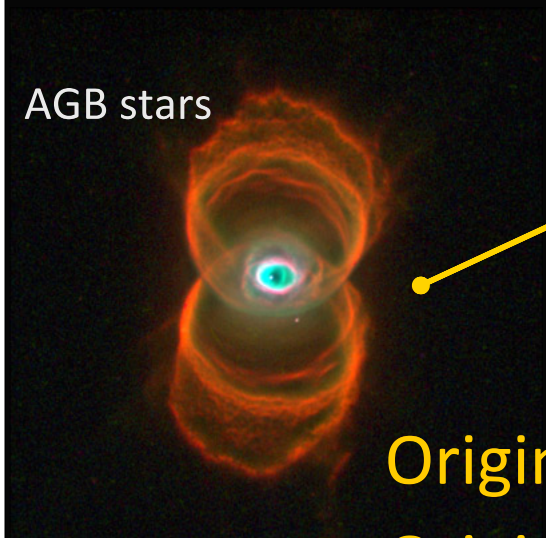




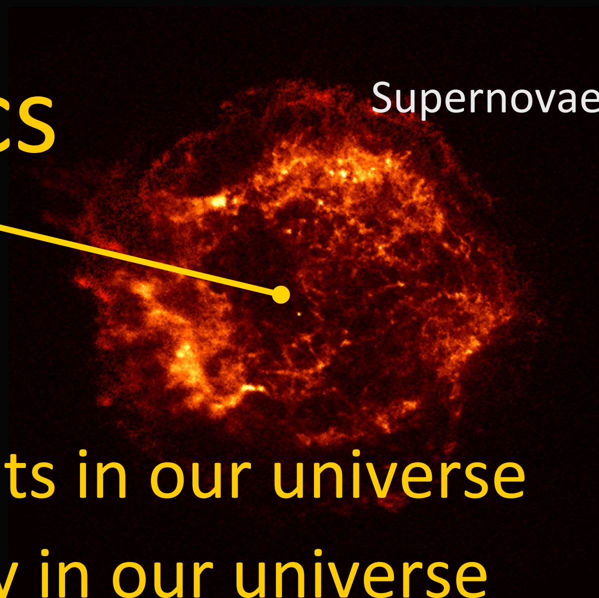








Nuclear Physics

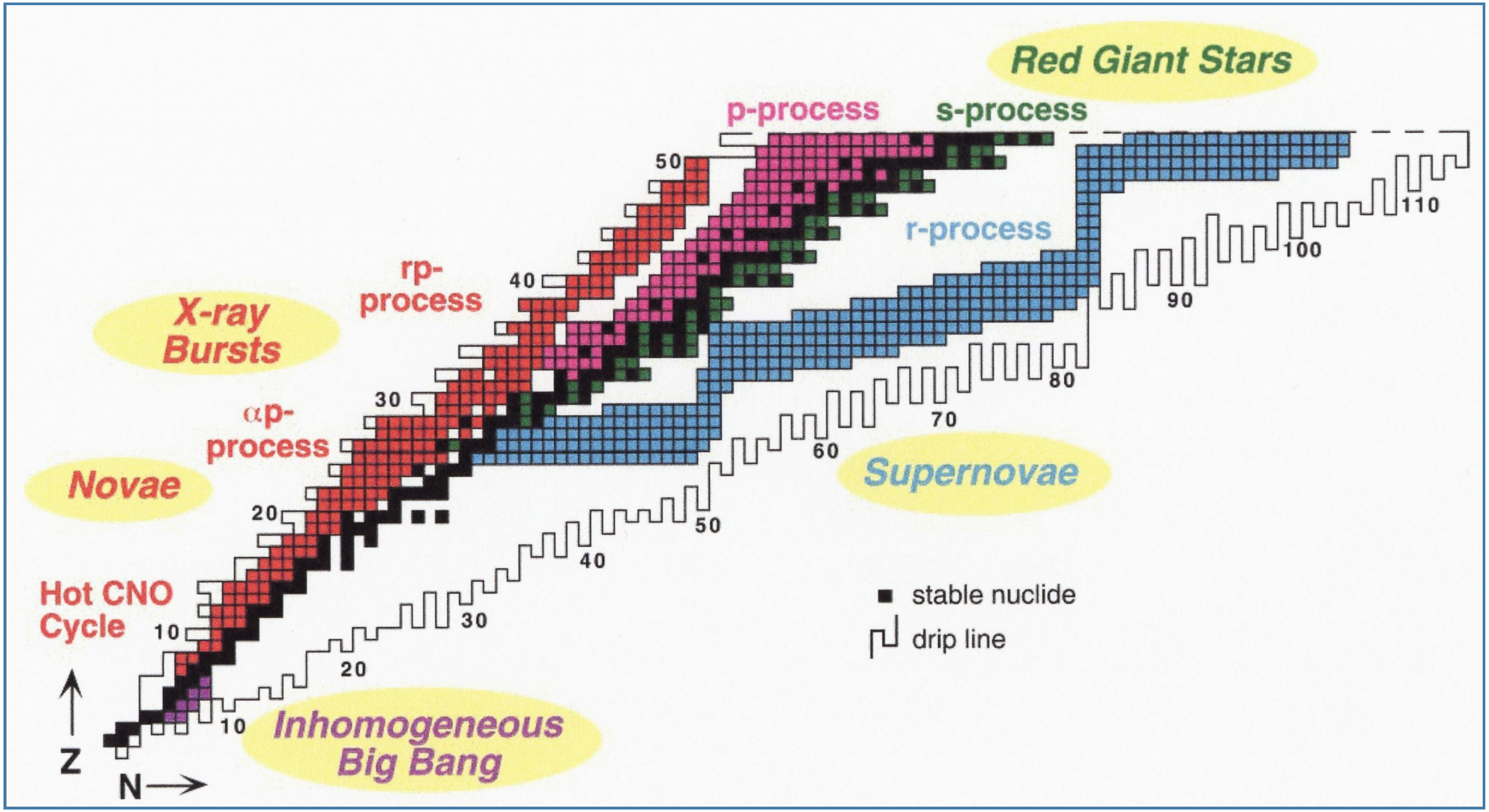


Origin and fate of the elements in our universe

Origin of radiation and energy in our universe

Physics under extreme conditions

How were Elements from Iron to Uranium made?

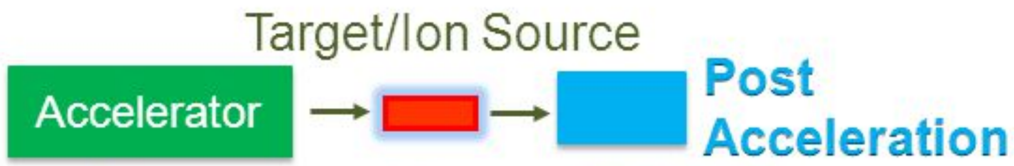


"The 11 Greatest Unanswered Questions of Physics", 3rd in the list
http://discovermagazine.com/2002/feb/cover
From: National Academy of Science Report, 2002

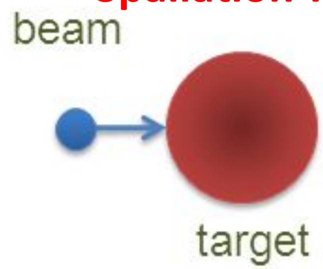
RIB: Radioactive Ion Beam Facilities for Explosive Nucleosynthesis

Production of radioactive isotopes

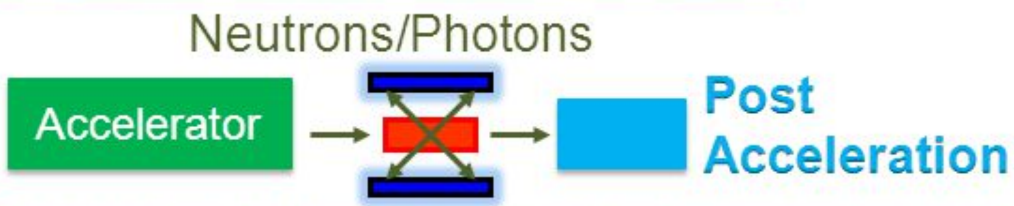
- Target spallation and fragmentation by light ions (Used by TRIUMF, HRIBF)



Spallation-ISOL

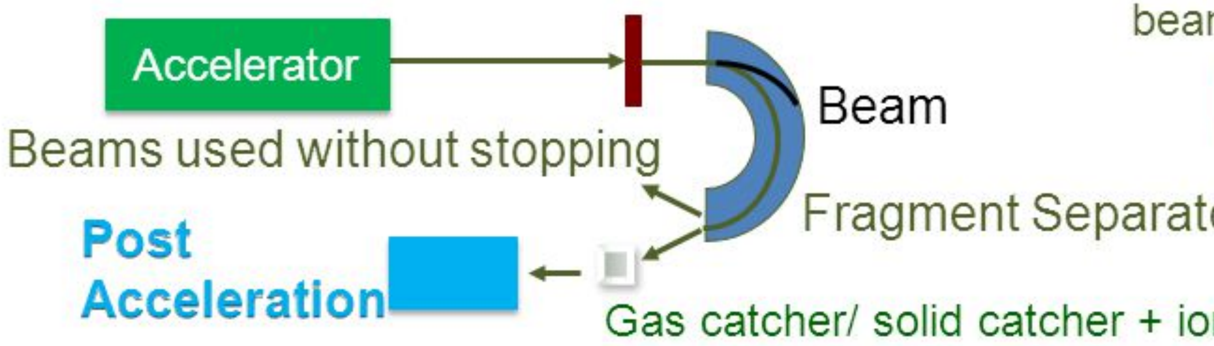


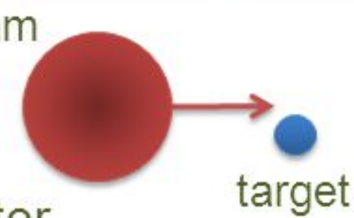
- Neutron or photon induced fission (TRIUMF)



FISSION-ISOL

- In-flight Separation following projectile fragmentation/fission (Used by FRIB)

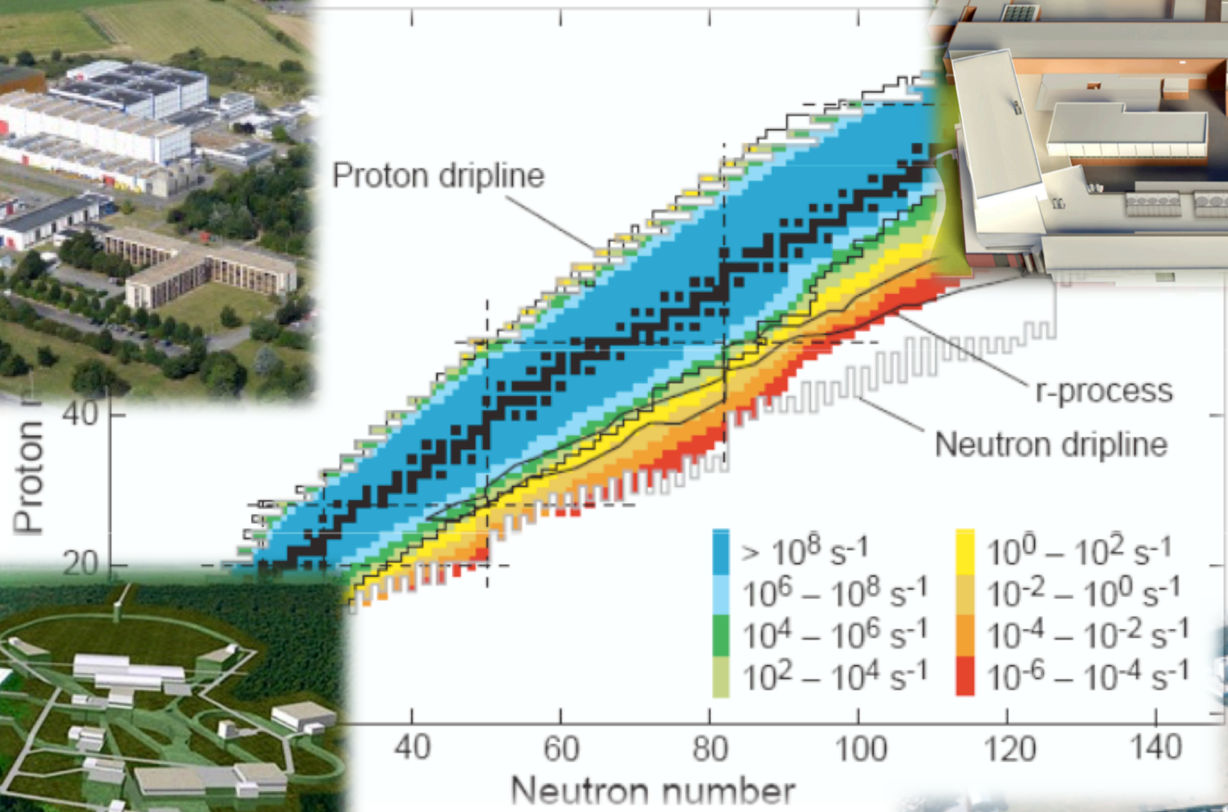




Fragmentation in flight

Facilities for Explosive Nucleosynthesis

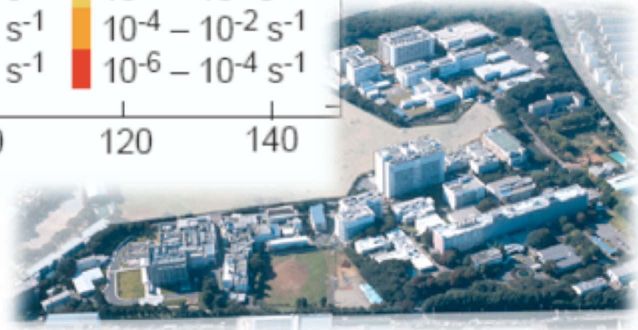
SPIRAL2/GANIL



FRIB/MSU

FAIR/GSI

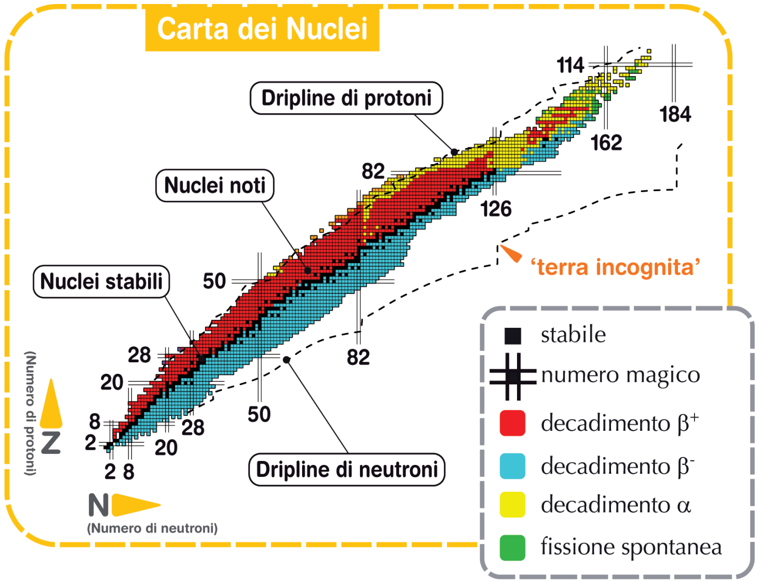
RIBF/RIKEN



Providing high intensity radioactive beams for studying nuclear reaction and decay processes associated with explosive stellar burning far from stability!

Others are CARIBU/ANL, ISAC/TRIUMF, REX/ISOLDE, TwinSol/Notre Dame

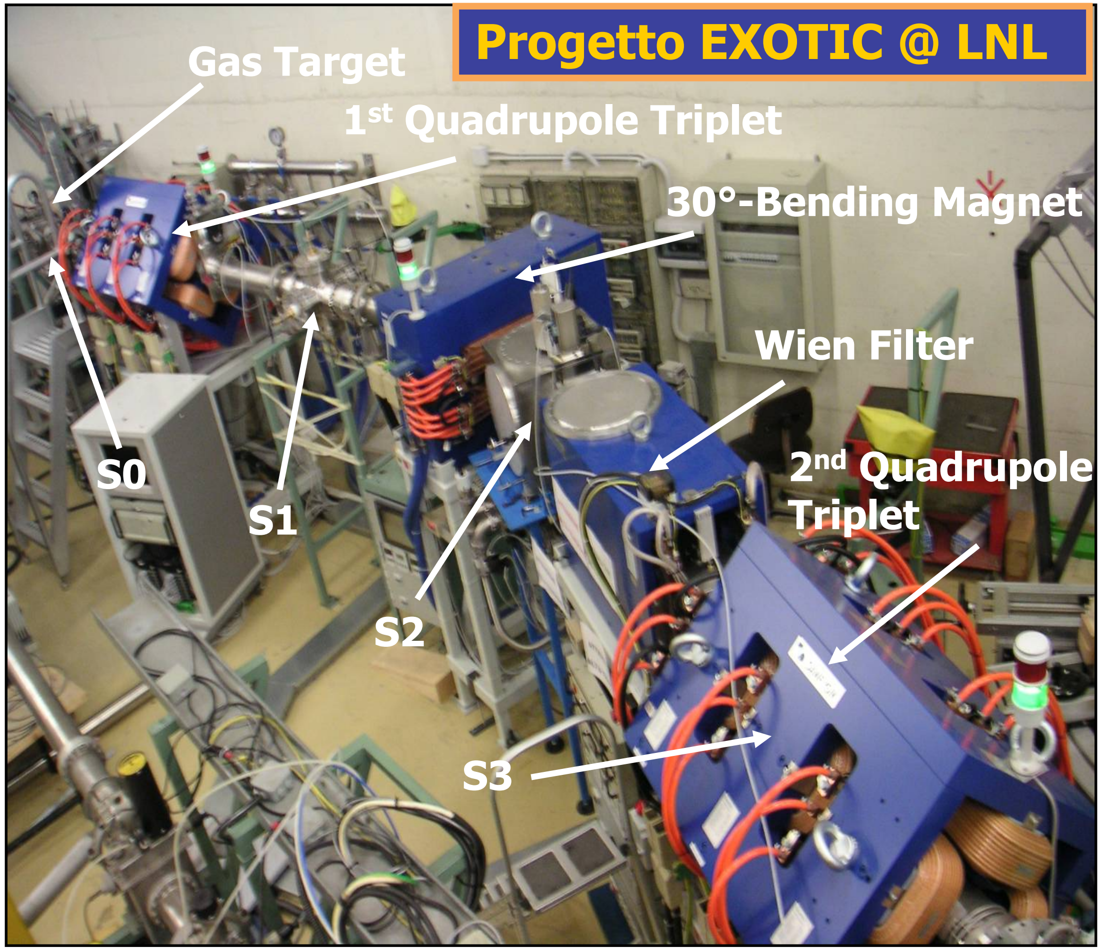
Fasci radioattivi: Progetto EXOTIC at LNL



284 nuclei "stabili"
3600 nuclei radioattivi noti
6000 nuclei di "possibile" esistenza

Fasci radioattivi permettono studi di

Struttura, Astrofisica, Dinamica



EXOTIC @ LNL: produzione di fasci di nuclei leggeri radioattivi tramite reazioni di cinematica inversa di fasci primari di nuclei stabili su bersagli gassosi → studio della dinamica di reazione e di struttura nucleare a $E_{lab} \sim V_C$

Fasci prodotti: ^{17}F, ^{8}B, ^{7}Be, ^{8}Li, ^{10}C, ^{11}C **Fasci futuri:** ^{18}Ne, ^{18}F, ^{14}O

Moti collettivi del nucleo atomico
Risonanze Giganti
un comportamento organizzato di un sistema complesso

Risonanza Dipolare Gigante (GDR) → oscillazione collettiva di protoni in opposizione di fase ai neutroni del nucleo atomico: emissione γ dipolari
Dipolo Dinamico (DD) → eccitazione di una **GDR** di **pre-equilibrio** in reazioni tra ioni pesanti asimmetrici in carica: emissione γ dipolari pronti

Studio del Dipolo Dinamico importante per:
Dinamica dell'equilibrazione di carica
Informazioni su $E_{sym}(\rho)$ a $\rho<\rho_0$: nuclei radioattivi con alone, stelle di neutroni …
Raffreddamento in reazioni di fusione → formazione di SHE

Highlights

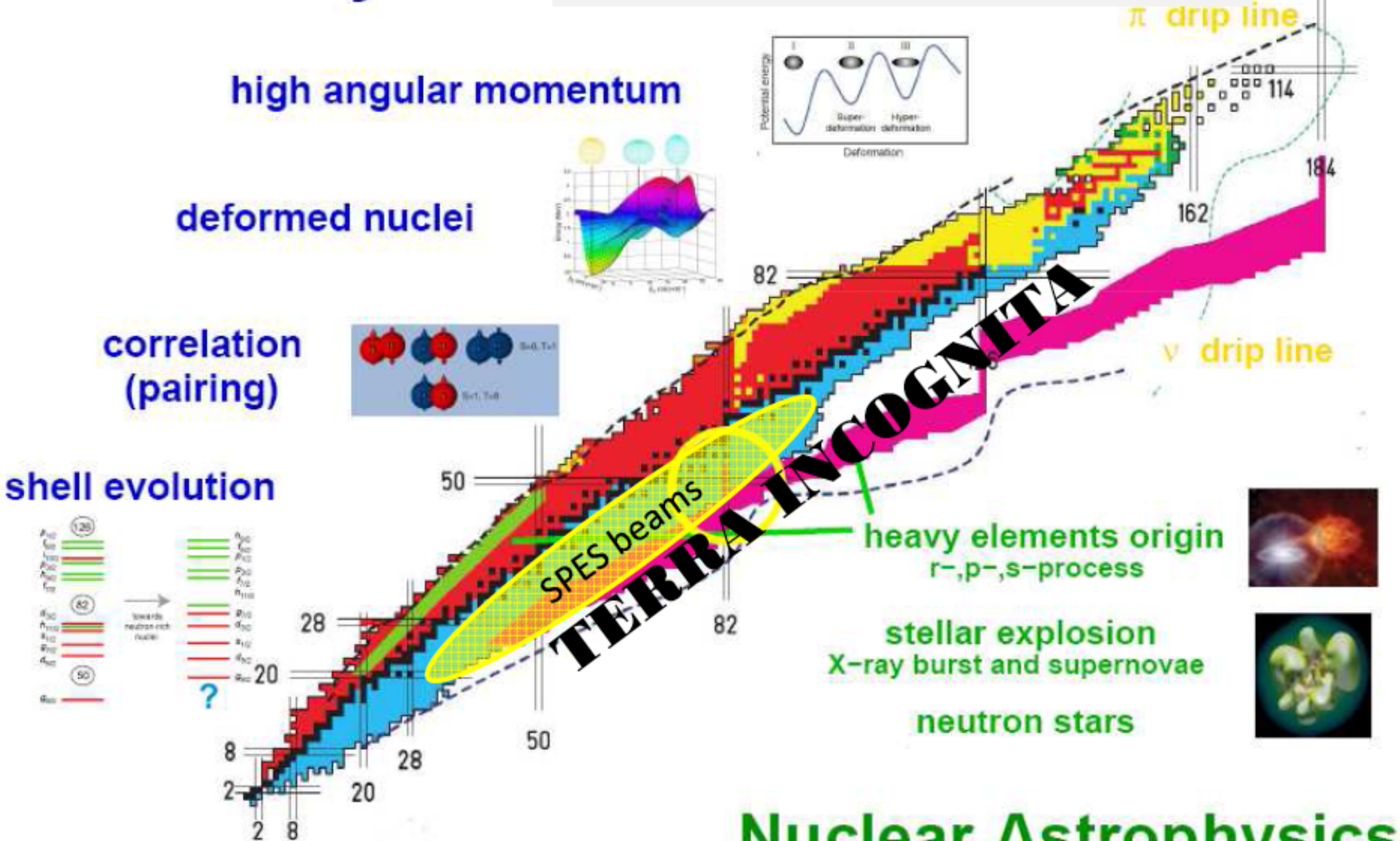
Primo studio sistematico del Dipolo Dinamico in reazioni centrali e periferiche usando un metodo sperimentale indipendente dal modello

SPES α & β

Selective Production (and reacceleration) of Exotic Species

Fission process is the prefered way to produce neutron-rich beams

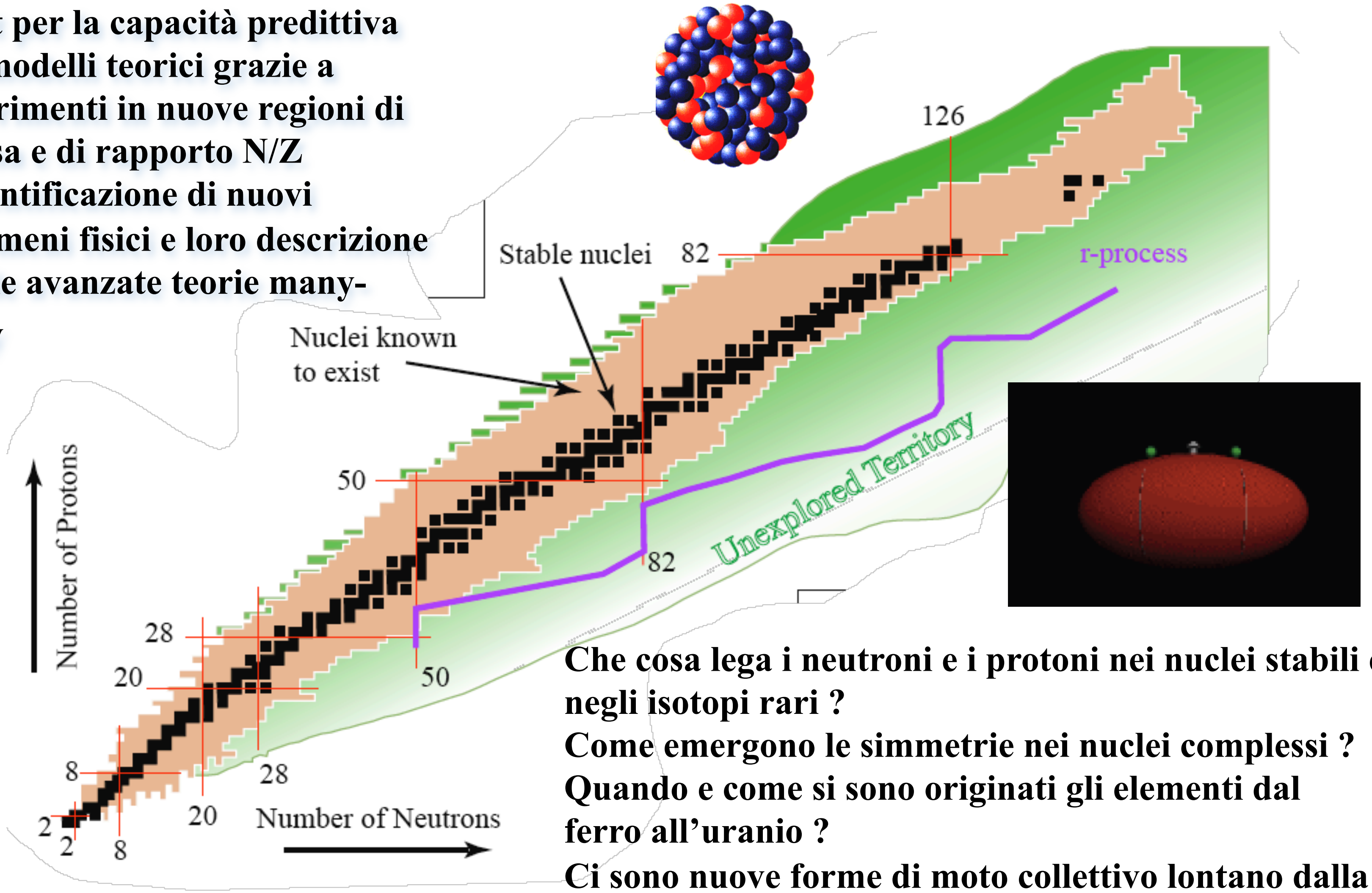
Nuclear Physics



Nuclear Astrophysics

Struttura Nucleare Teorica

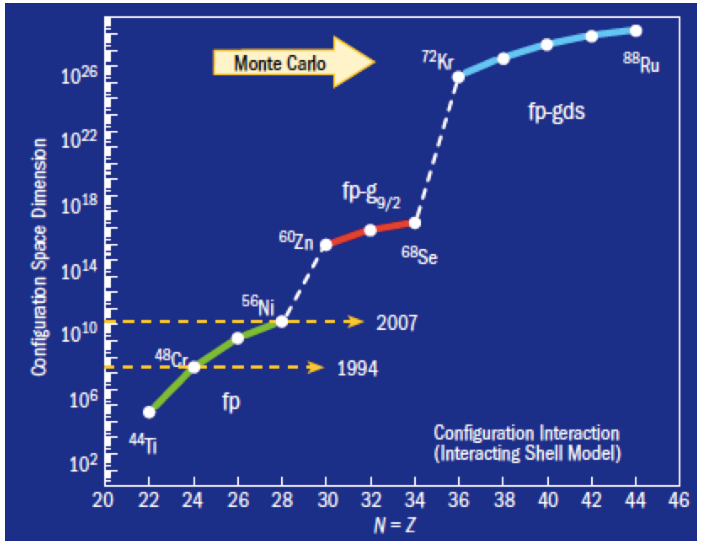
- Test per la capacità predittiva dei modelli teorici grazie a esperimenti in nuove regioni di massa e di rapporto N/Z
- Identificazione di nuovi fenomeni fisici e loro descrizione con le avanzate teorie many-body

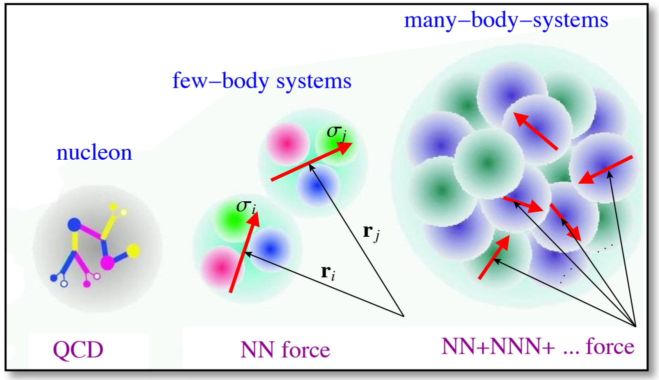


Che cosa lega i neutroni e i protoni nei nuclei stabili e negli isotopi rari ?
Come emergono le simmetrie nei nuclei complessi ?
Quando e come si sono originati gli elementi dal ferro all’uranio ?
Ci sono nuove forme di moto collettivo lontano dalla regione di stabilità?

Calcoli microscopici di struttura nucleare

Studiamo le proprietà dei nuclei partendo da un'interazione NN che soddisfa le simmetrie della QCD



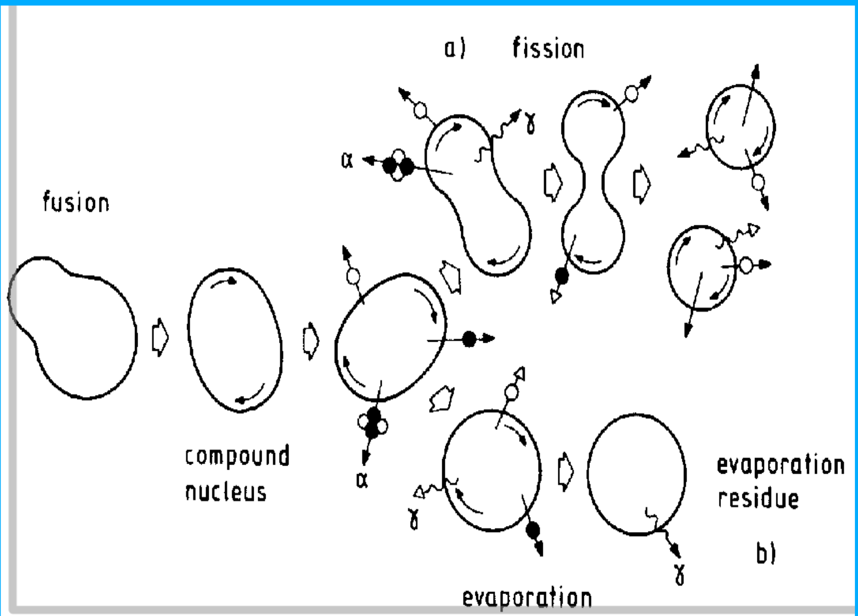


Ricorso a HPC (High Performance Computing)

Supercalcolatore MARCONI 20 PetaFlops

Possibilita' di tesi per laurea magistrale presso il Consorzio Interuniversitario per il Calcolo Automatico (CINECA)

Studio della Fusione-Fissione indotta da ioni pesanti



Collaborazioni:
- Flerov Laboratory Nuclear Reaction, Dubna
- Department of Physics, Jyvaskyla
- Omsk State University, Russia

Nuclei di massa media (A~100-150 amu)
elevata Energia di Eccitazione (~100 MeV)
alti Momenti Angolari (fino a 80$\hbar$)

Tempi caratteristici dei processi di fissione (Particle clock)

Viscosità della materia nucleare

Modelli dinamici e modello statistico

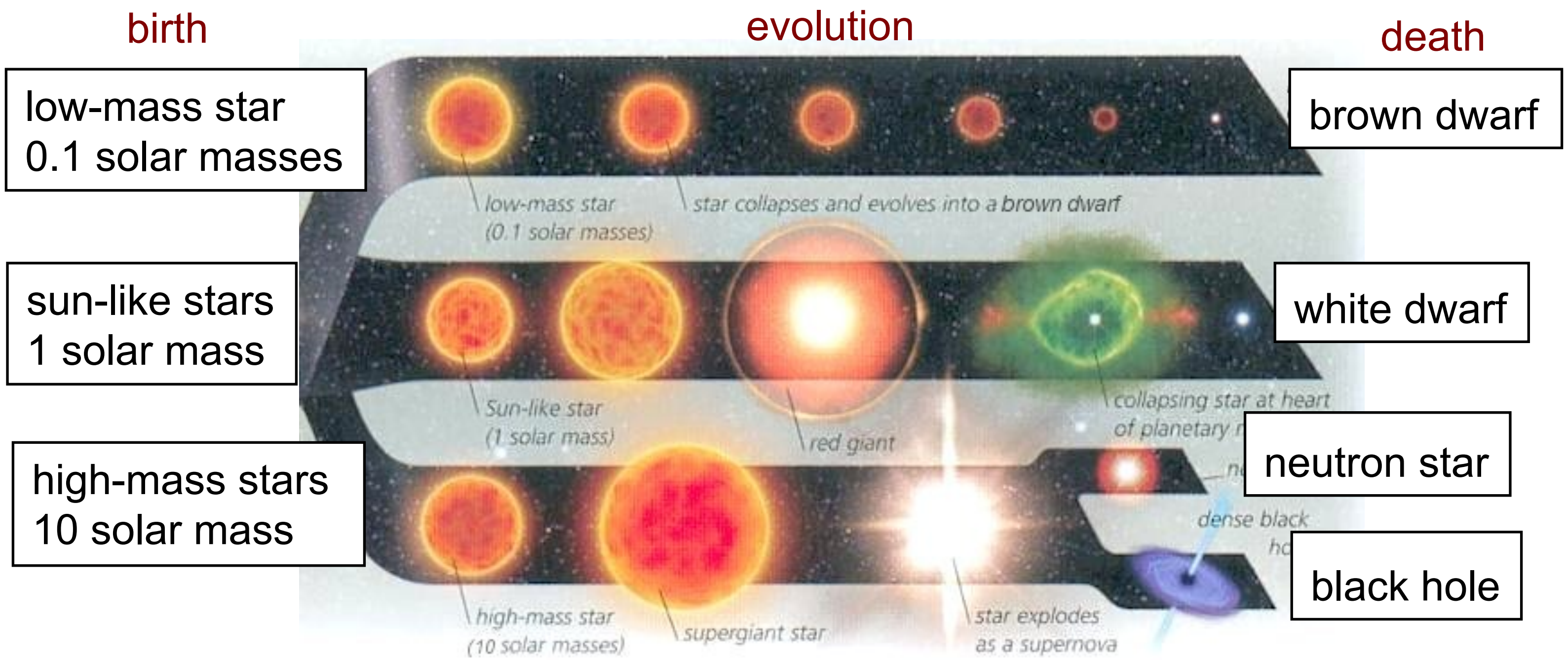
Osservabili: Frammenti di fissione, Particelle Cariche, Residui di Evaporazione

Docenti coinvolti

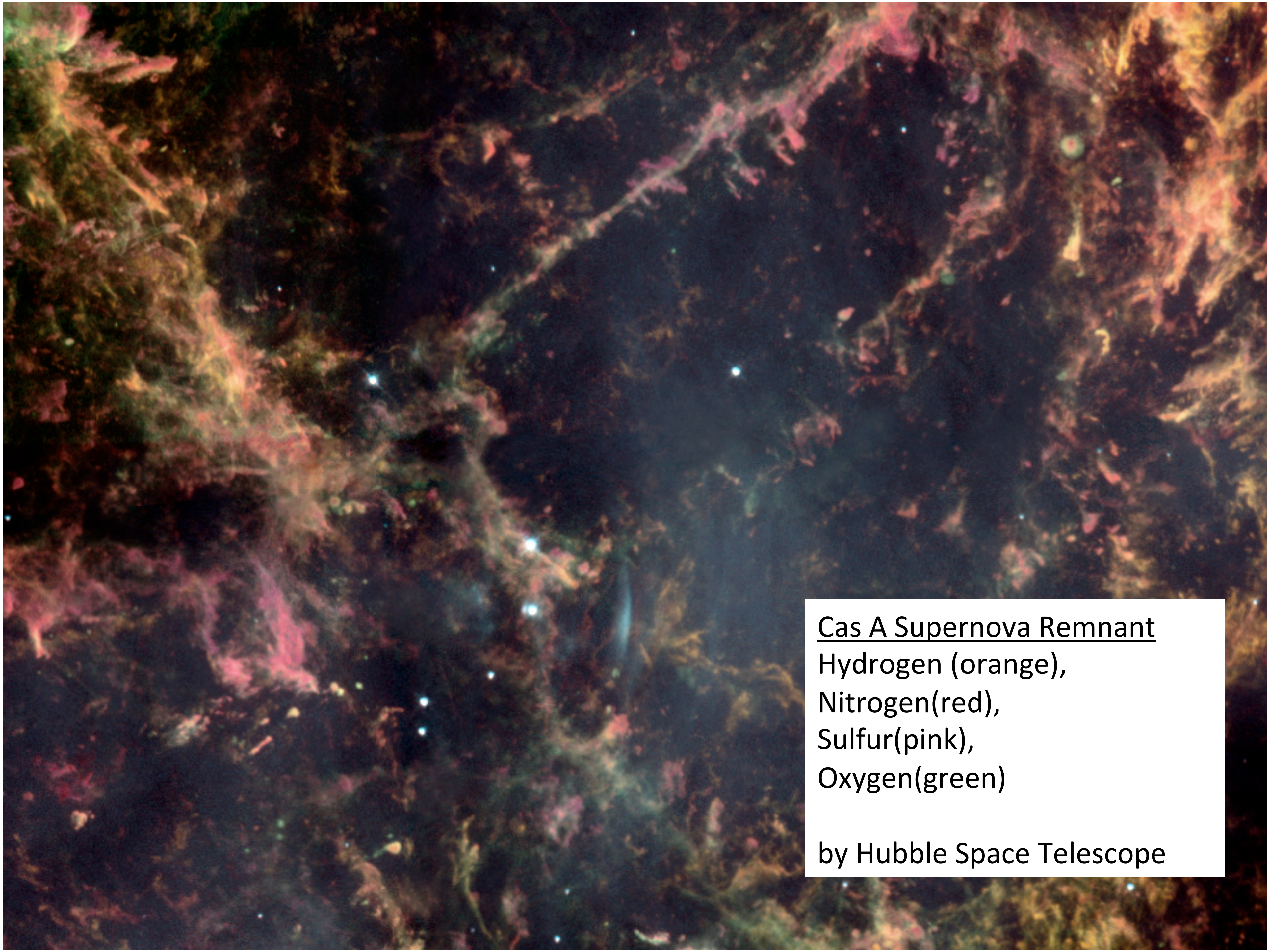
Dipartimento	INFN
Francesco Andreozzi	Luigi Coraggio
Giovanni La Rana	Angela Garano
Marco La Commara	Dimitra Pierroutsakou
Antonio Porrino	
Mariano Vigilante	
Emanuele Vardaci	

Quiescent stellar nucleosynthesis

Stellar evolution and nucleosithesys

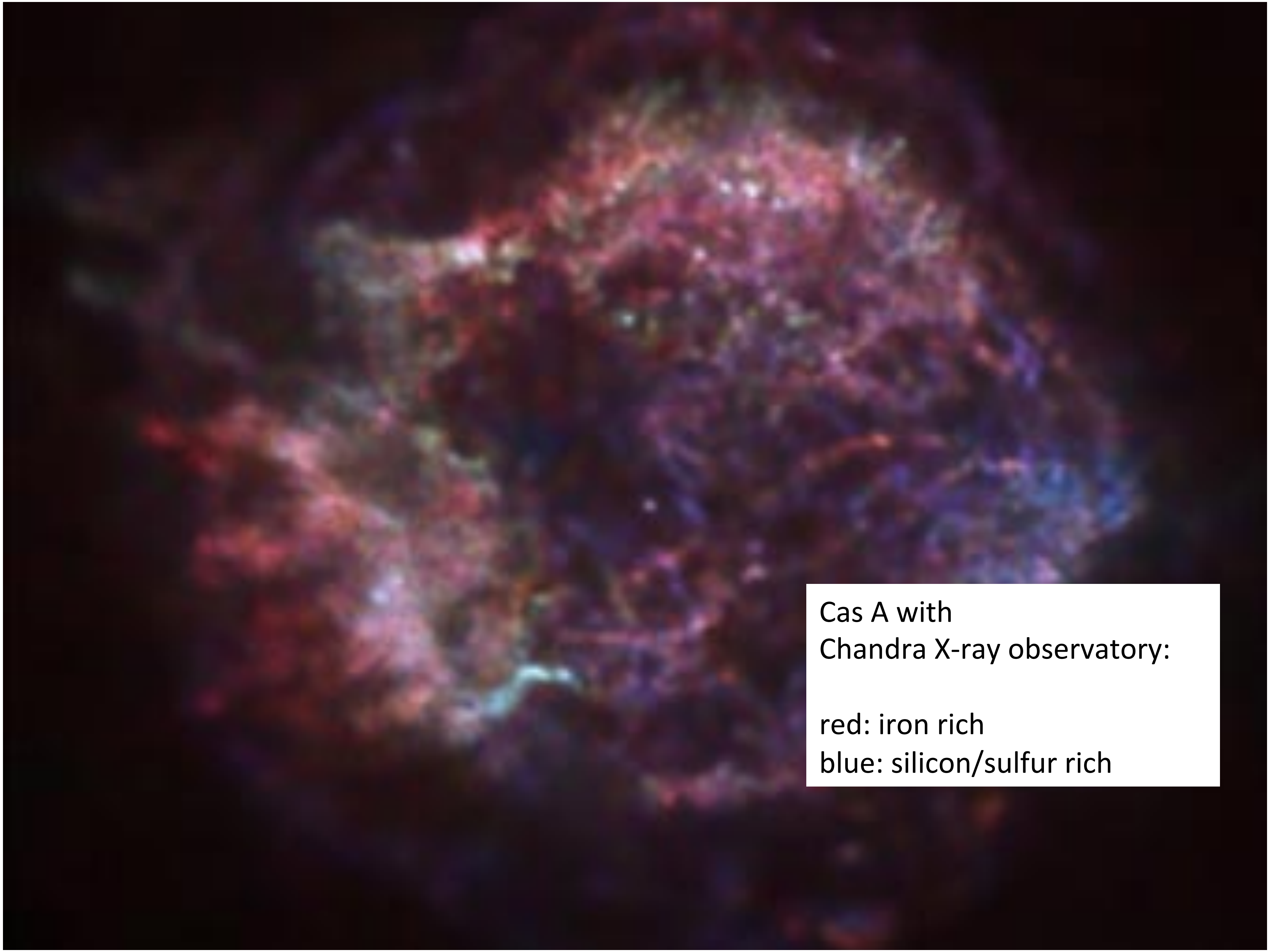


Reactions	Products	Temperature (K)	Timescale for Sun (yr)	Timescale for 20 $M_{\odot}$ star (yr)
Hydrogen burning	He	$1 - 4 \times 10^7$	10^{10}	10^7
Helium burning	C, O	$1 - 2 \times 10^8$	10^9	10^6
Carbon burning	Ne, Na, Mg	8×10^8	--	300
Neon burning	Mg, Si	1.7×10^9	--	< 1
Oxygen burning	Si, S	2.1×10^9	--	< 1
Silicon burning	Ti to Zn	4×10^9	--	2 days

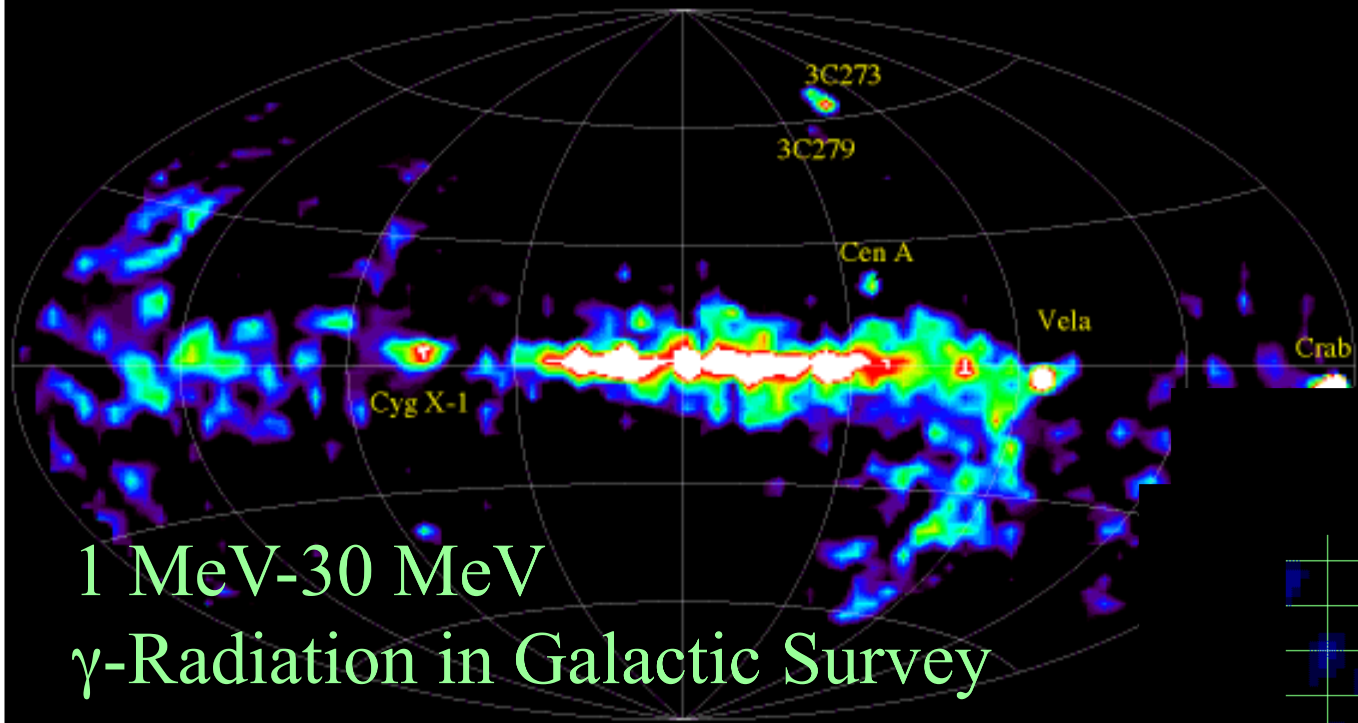


<u>Cas A Supernova Remnant</u>
Hydrogen (orange),
Nitrogen(red),
Sulfur(pink),
Oxygen(green)

by Hubble Space Telescope


Cas A with
Chandra X-ray observatory:
red: iron rich
blue: silicon/sulfur rich

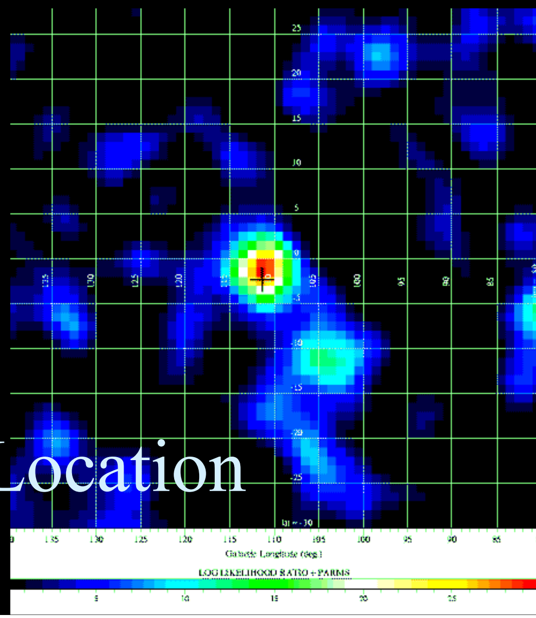
Galactic Radioactivity - detected by γ-radiation



1 MeV-30 MeV

γ-Radiation in Galactic Survey

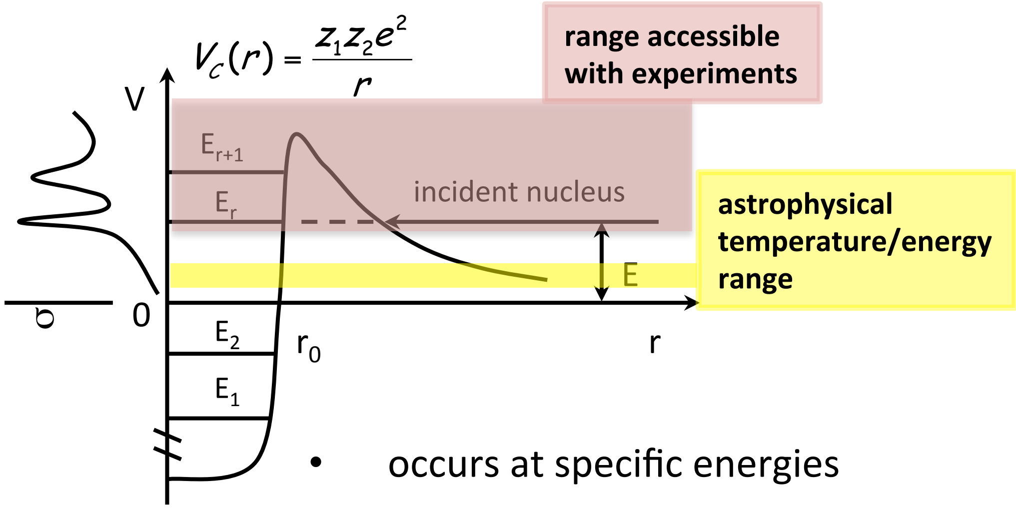
(^{26}Al Half life: 700,0000 years)



^{44}Ti in Supernova Cas-A Location

(Half life: 60 years)

Nuclear reactions at astrophysical energies



Example

z_1=p and z_2=p (e.g. in the Sun)

T ~ 15×10^6 K $\Rightarrow$ E = kT ~ 1 keV

E_C = 550 keV

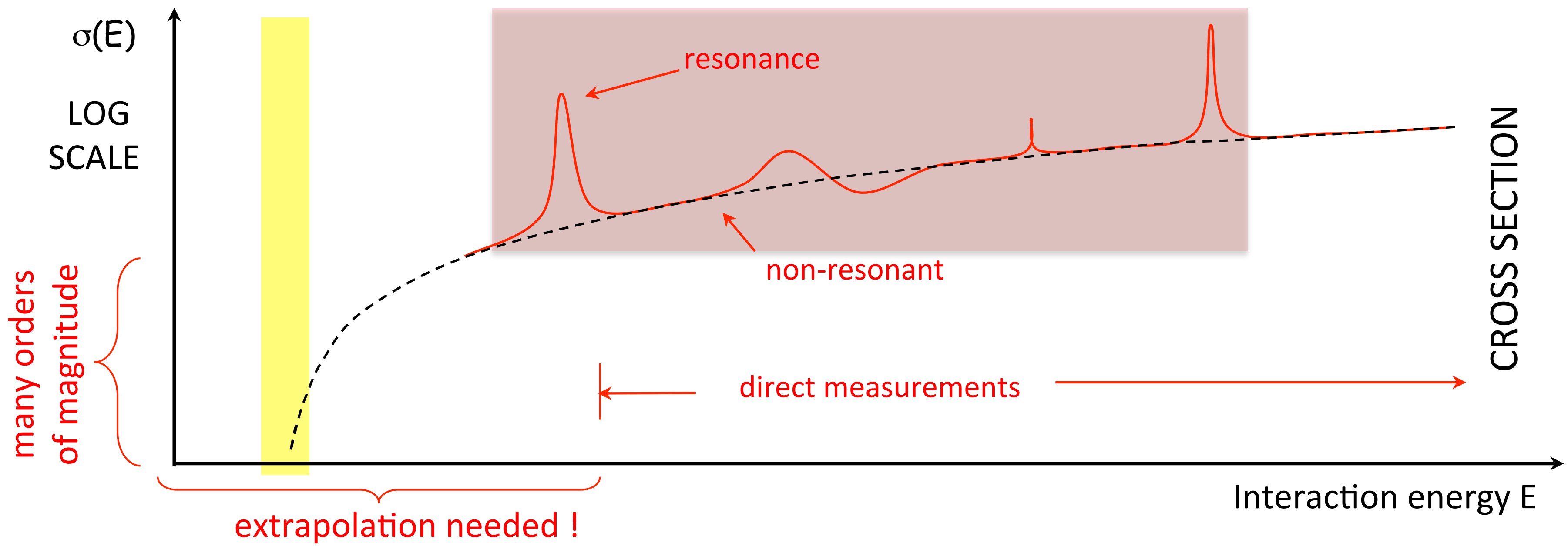
during quiescent burnings:

$kT \ll E_c$

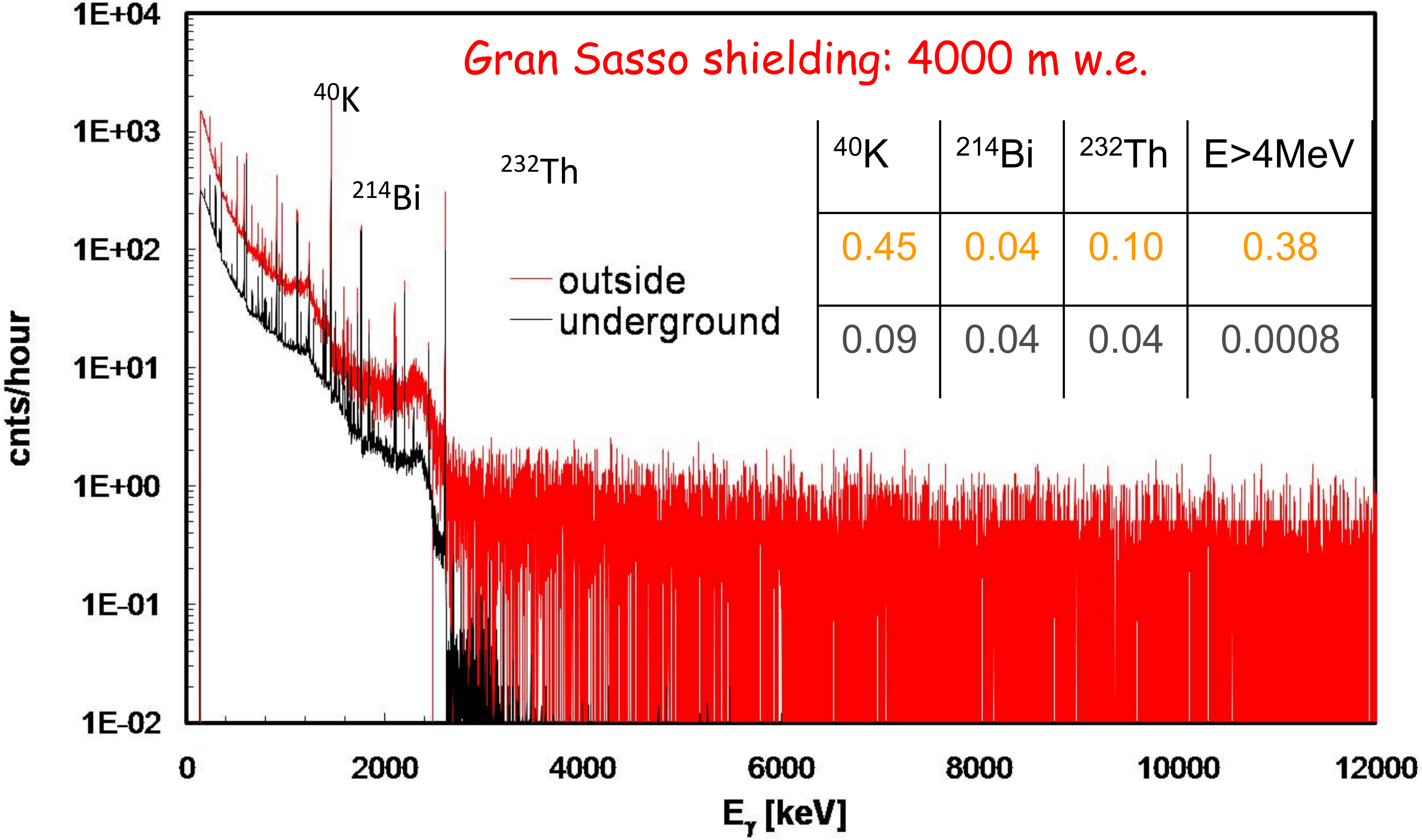
reactions occur through

TUNNEL EFFECT

- occurs at specific energies
- cross section has STRONG energy dependence



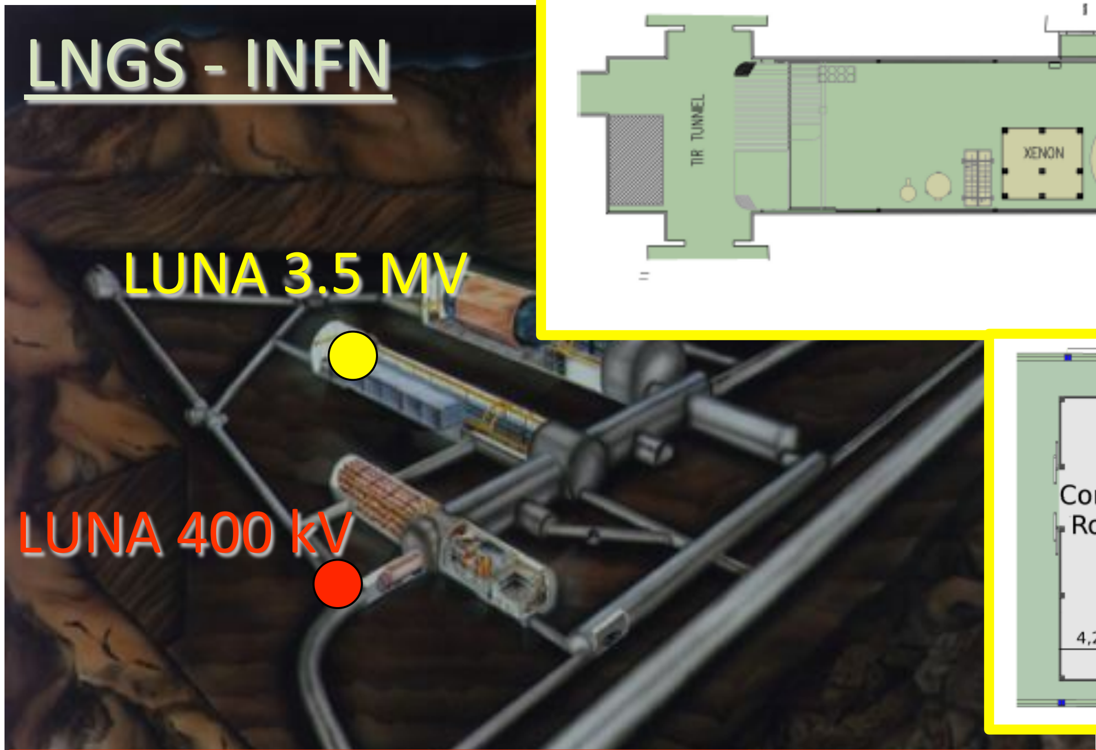
Why going underground

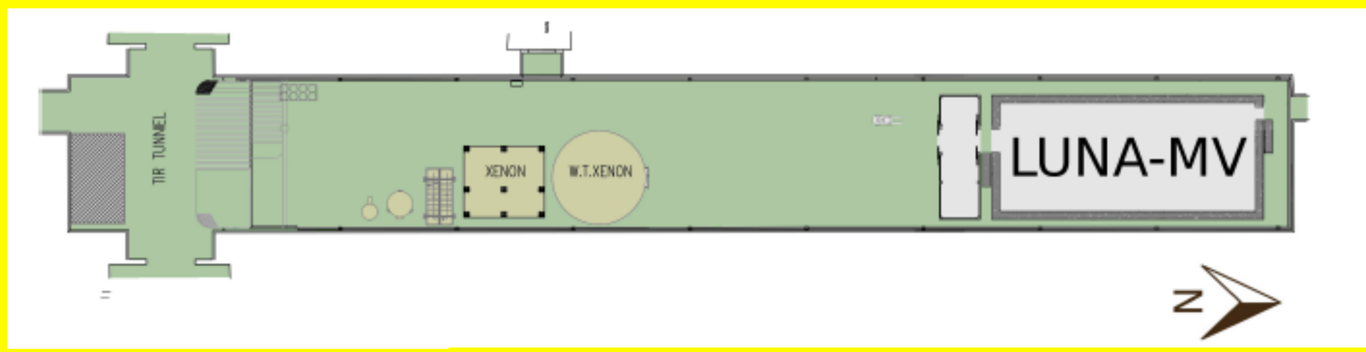


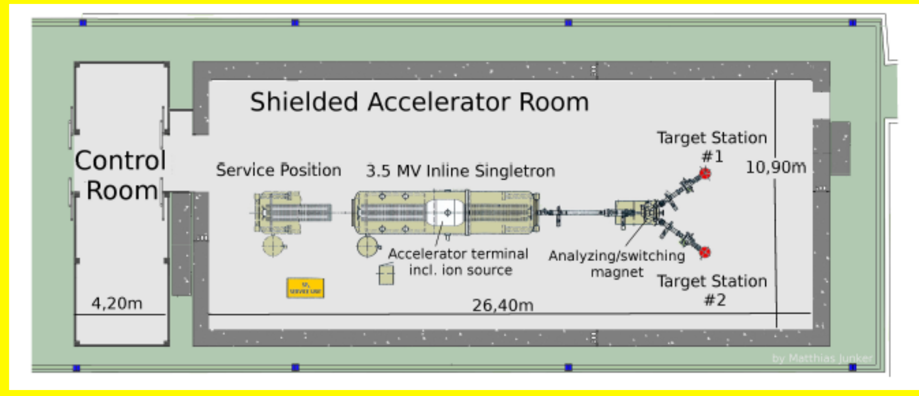
Therefore, the advantage of an underground environment is evident for high Q-value reactions such as **$^{14}N(p,\gamma)^{15}O$, $^{15}N(p,\gamma)^{16}O$, $^{25}Mg(p,\gamma)^{26}Al$**......

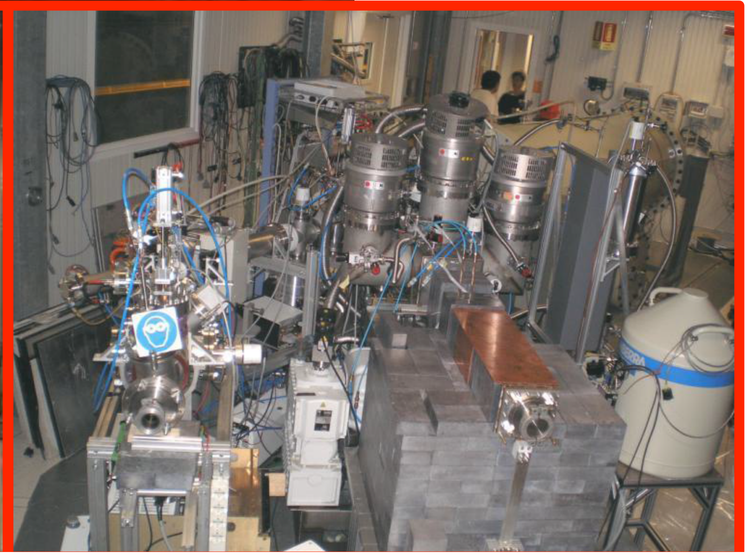
Radiation	LNGS/out
muons	10^{-6}
neutrons	10^{-3}

Laboratory for Underground Nuclear Astrophysics









Some examples

- **H-burning in the Sun and solar neutrinos**:

  $p+p \rightarrow D+e^+ +\nu$, $^3He(^3He, 2p)^4He$, $^3He(\alpha,\gamma)^7Be$, $^7Be(p,\gamma)^8B$ and $^{14}N(p,\gamma)^{15}O$

- **Age of Globular Clusters and C production in AGB:**

  $^{14}N(p,\gamma)^{15}O$

- **AGB nucleosynthesis - $^{17}O/^{18}O$ abundaces, ^{19}F origin, ^{26}Mg excess....:**

  $^{14}N(p,\gamma)^{15}O$, $^{14}C(\alpha,\gamma)^{18}O$, $^{14}N(\alpha,\gamma)^{18}F$, $^{15}N(\alpha,\gamma)^{19}F$, $^{15}N(p,\gamma)^{16}O$, $^{15}N(p,\alpha)^{12}C$, $^{17}O(p,\gamma)^{18}F(\beta^+)^{18}O$, $^{18}O(p,\gamma)^{19}F$, $^{18}O(\alpha,\gamma)^{22}Ne$, $^{18}O(p,\alpha)^{15}N$, $^{18}F(\alpha,p)^{21}Ne$, $^{19}F(\alpha,p)^{22}Ne$, $^{22}Ne(p,\gamma)^{23}Na$, $^{23}Na(p,\gamma)^{24}Mg$, $^{24}Mg(p,\gamma)^{25}Al(\beta^+)^{25}Mg$, $^{25}Mg(p,\gamma)^{26}Al(\beta^+)^{26}Mg$, $^{26}Mg(p,\gamma)^{27}Al$

- **Main neutron sources:**

  $^{13}C(\alpha,n)^{16}O$, $^{22}Ne(\alpha,n)^{25}Mg$

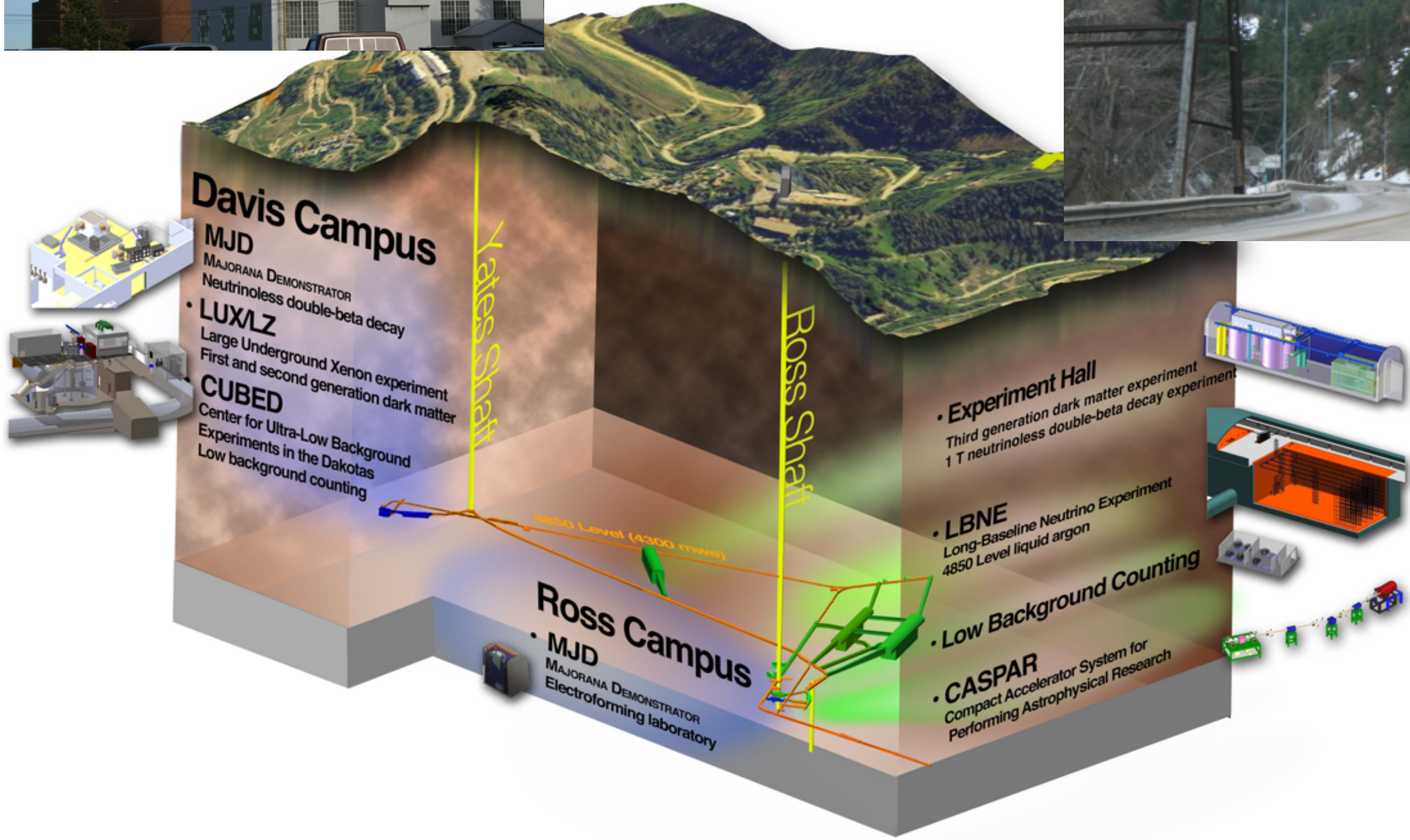
- **Explovive CNO burning:**

  $^{15}O(\alpha,\gamma)^{19}Ne$, $^{14}O(\alpha,\gamma)^{18}Ne$, $^{18}Ne(\alpha,p)^{21}Na$

- **He and advaced burnings:**

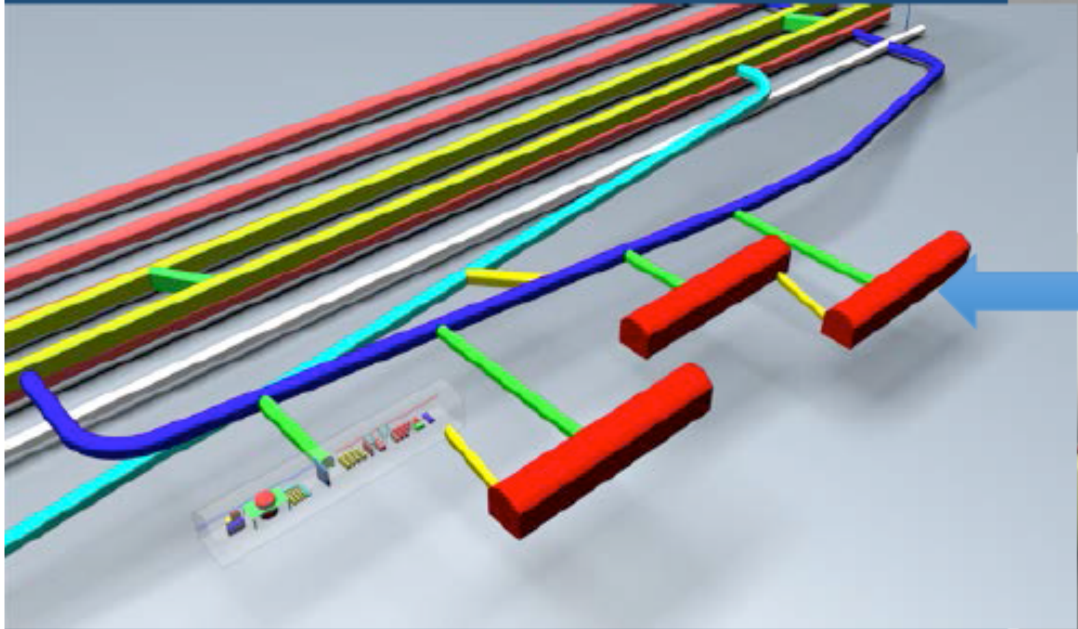
  $^{12}C(\alpha,\gamma)^{16}O$, $^{12}C(^{12}C, p)^{23}Na$, $^{12}C(^{12}C,\alpha)^{20}Ne$, $^{16}O(\alpha,\gamma)^{20}Ne$

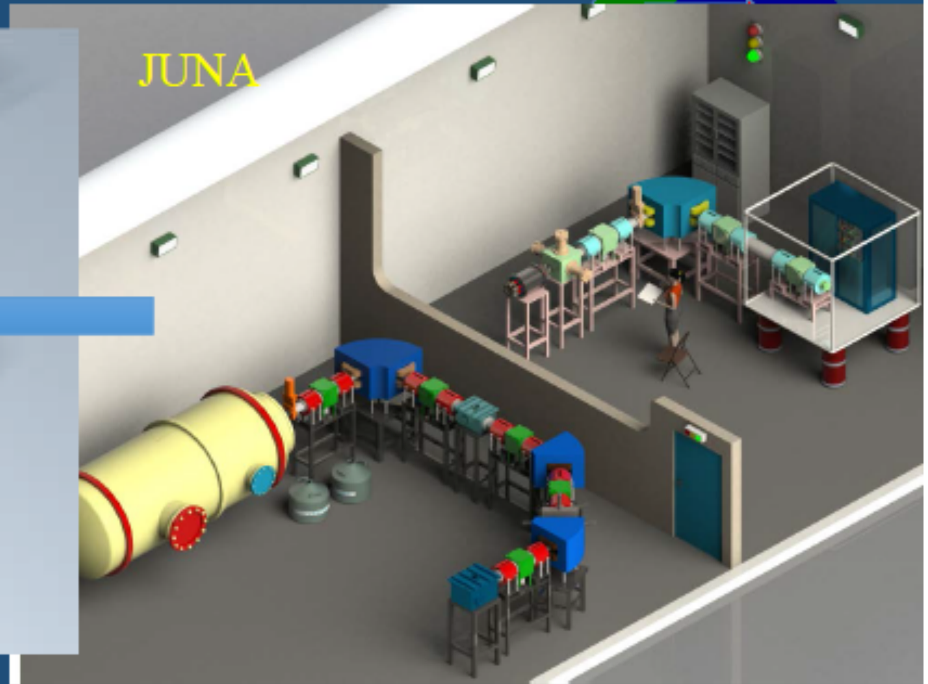
Sanford Underground Research Facility



CJPL 中国锦屏地下实验室
China Jinping Underground Laboratory

JUNA





JUNA

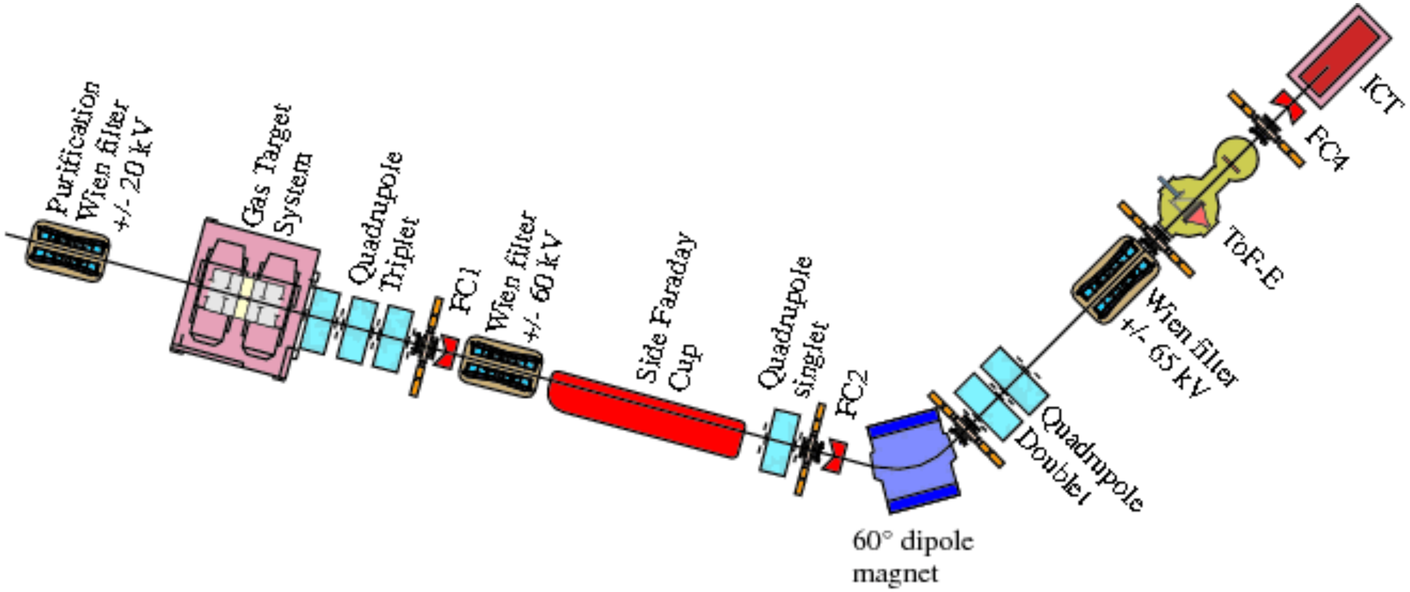
Jinping Underground Nuclear Astrophysics

An alternative approach: Recoil Mass Separator

Center for **I**sotopic **R**esearch on **C**ultural and **E**nvironmental heritage

European **R**ecoil separator

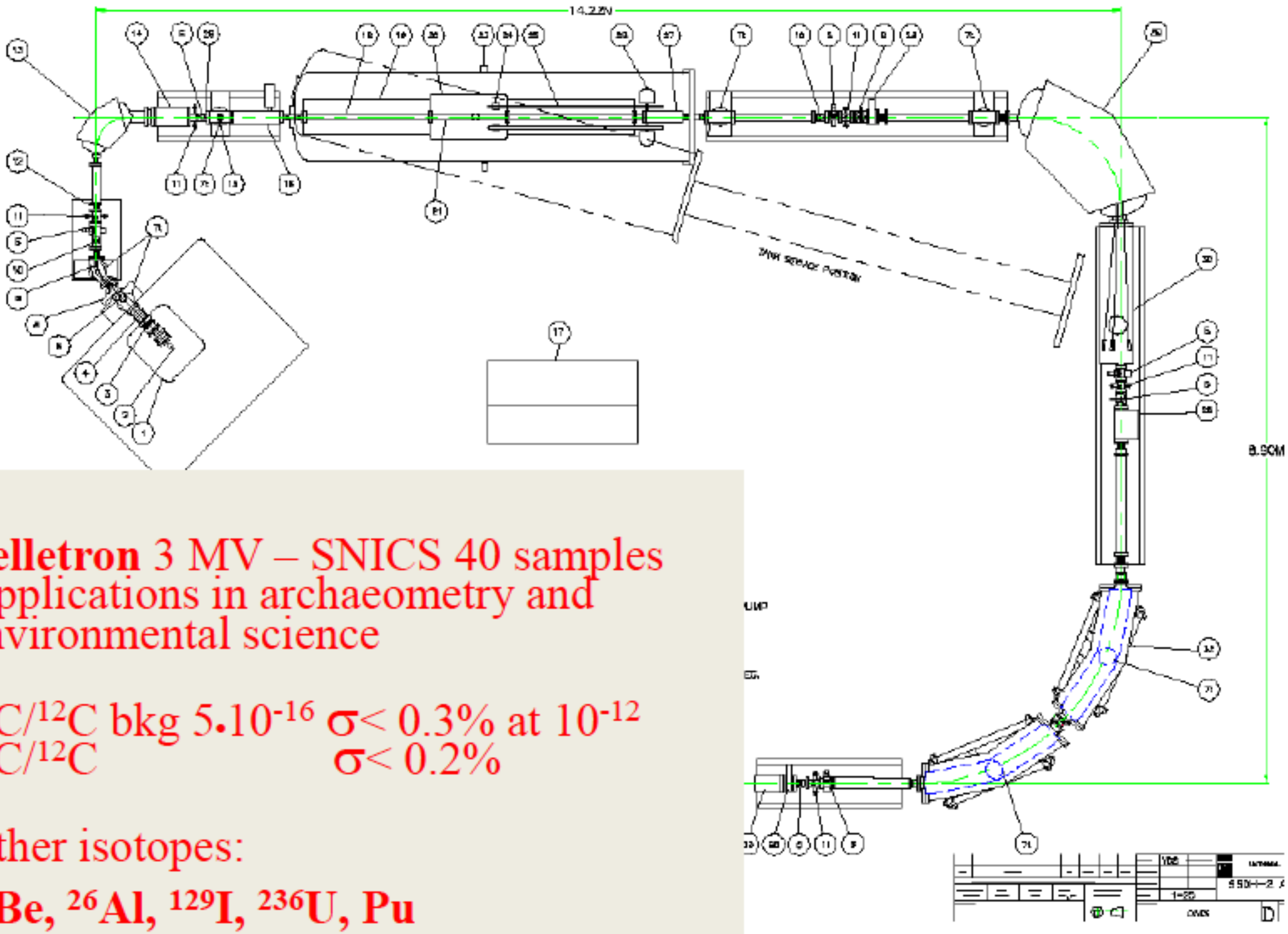
for Nuclear **A**strophysics



Other Applications of Low energy Nuclear Physics

- Radioactive Dating
  - C^{14}/C^{12} gives ages for dead plants/animals/ people.
  - Rb/Sr gives age of earth as 4.5 Gigayear (1 Gigayear= 1×10^9 years).
- Environmental radioactivity.
- Element analysis
  - Forenesic (eg date As in hair, C^{14}/C^{12} bomb spike).
  - Biology (eg elements in blood cells)
  - Archaeology (eg provenance via isotope ratios).

The AMS system CIRCE



Pelletron 3 MV – SNICS 40 samples
Applications in archaeometry and environmental science

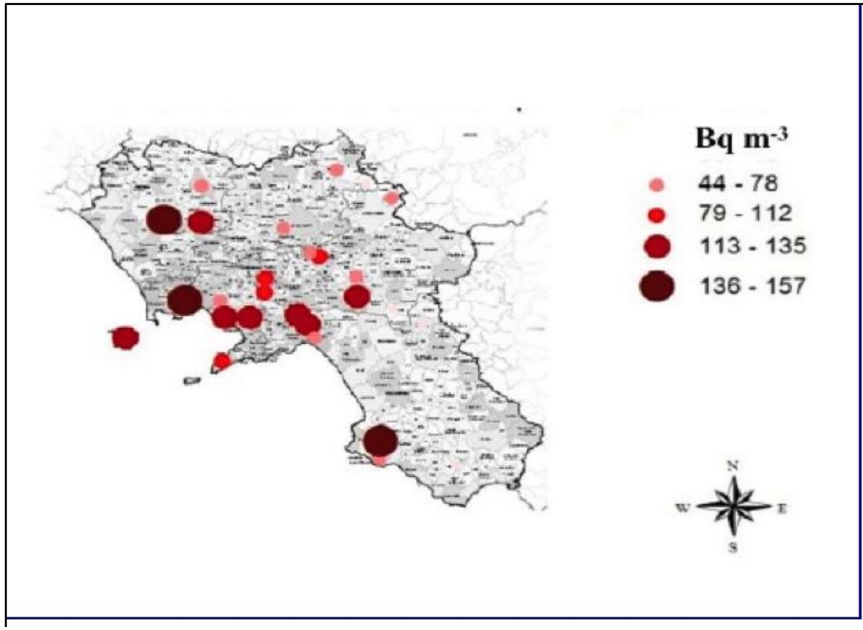
$^{14}C/^{12}C$ bkg $5 \cdot 10^{-16}$ $\sigma < 0.3\%$ at 10^{-12}
$^{13}C/^{12}C$ $\sigma < 0.2\%$

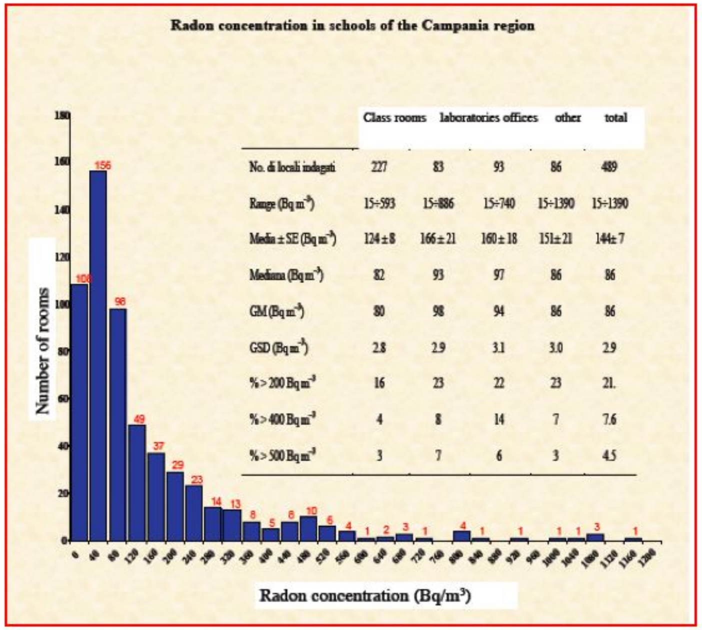
Other isotopes:

^{10}Be, ^{26}Al, ^{129}I, ^{236}U, Pu

Radioattività Ambientale

Nell'ambito delle attività del laboratorio continua la mappatura della radioattività in varie tipologie di ambienti della Campania. In questa attività giocano un ruolo di primo piano le scuole, che da ambienti da controllare sono diventate veri centri di coordinamento delle campagne di misura e di approfondimento, da parte degli studenti, delle tematiche relative alla radioattività.





Docenti coinvolti

Dipartimento	INFN
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Antonino Di Leva	
Gianluca Imbriani	
Giovanni Paternoster	
Enzo Roca	

Curriculum Nucleare

Insegnamenti I anno	Insegnamenti II anno
Elettrodinamica Classica	Laboratorio di Fisica Nucleare
Meccanica Quantistica	*Insegnamento affine*
Laboratorio di Fisica	*Insegnamento a scelta autonoma*
Fisica Nucleare	
Reazioni Nucleari	
Insegnamento affine	

Insegnamenti affini	Insegnamenti affini
Fisica Computazionale	Metodologie Nucleari per la Fisica Sanitaria e il Controllo Ambientale
Fisica dei Nuclei Esotici	Fisica Nucleare per i Beni Culturali e Ambientali
Astrofisica Nucleare	