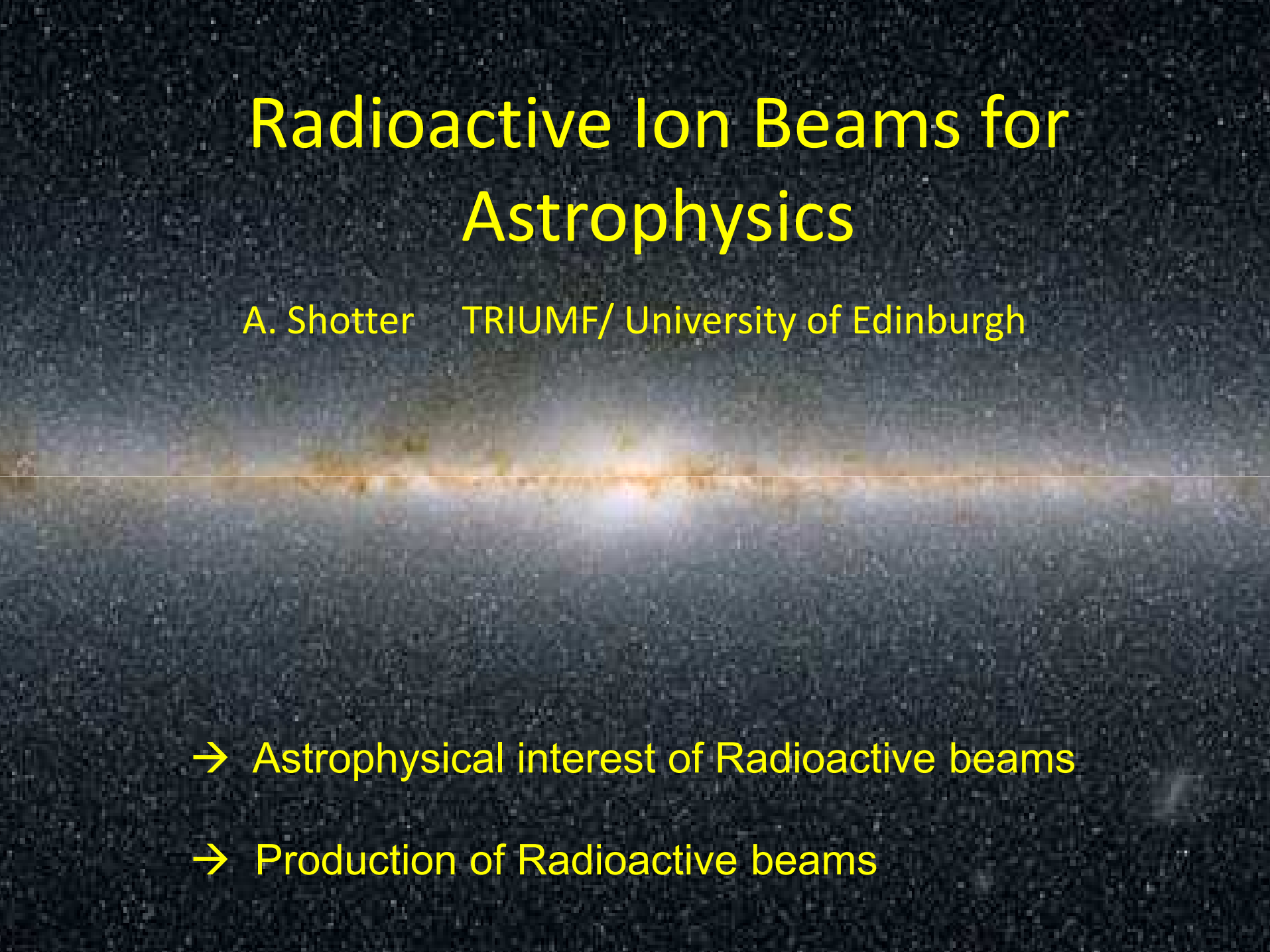
Radioactive Ion Beams for Astrophysics

A. Shotter TRIUMF/ University of Edinburgh



→ Astrophysical interest of Radioactive beams

→ Production of Radioactive beams

2

Internatio

Kepler's First

That the planets move i
elliptical orbits with the
one focus.

Kepler's Second

That the speed of the p
changes at each mome
that the time between t
positions is always prop
to the area swept out o
orbit between these pos

Kepler's Third La

That the ratio of the len
semi-major axis of each
orbit (cubed), to the tim
orbital period (squared), is the
same for all planets.

On the
Jupiter

On the

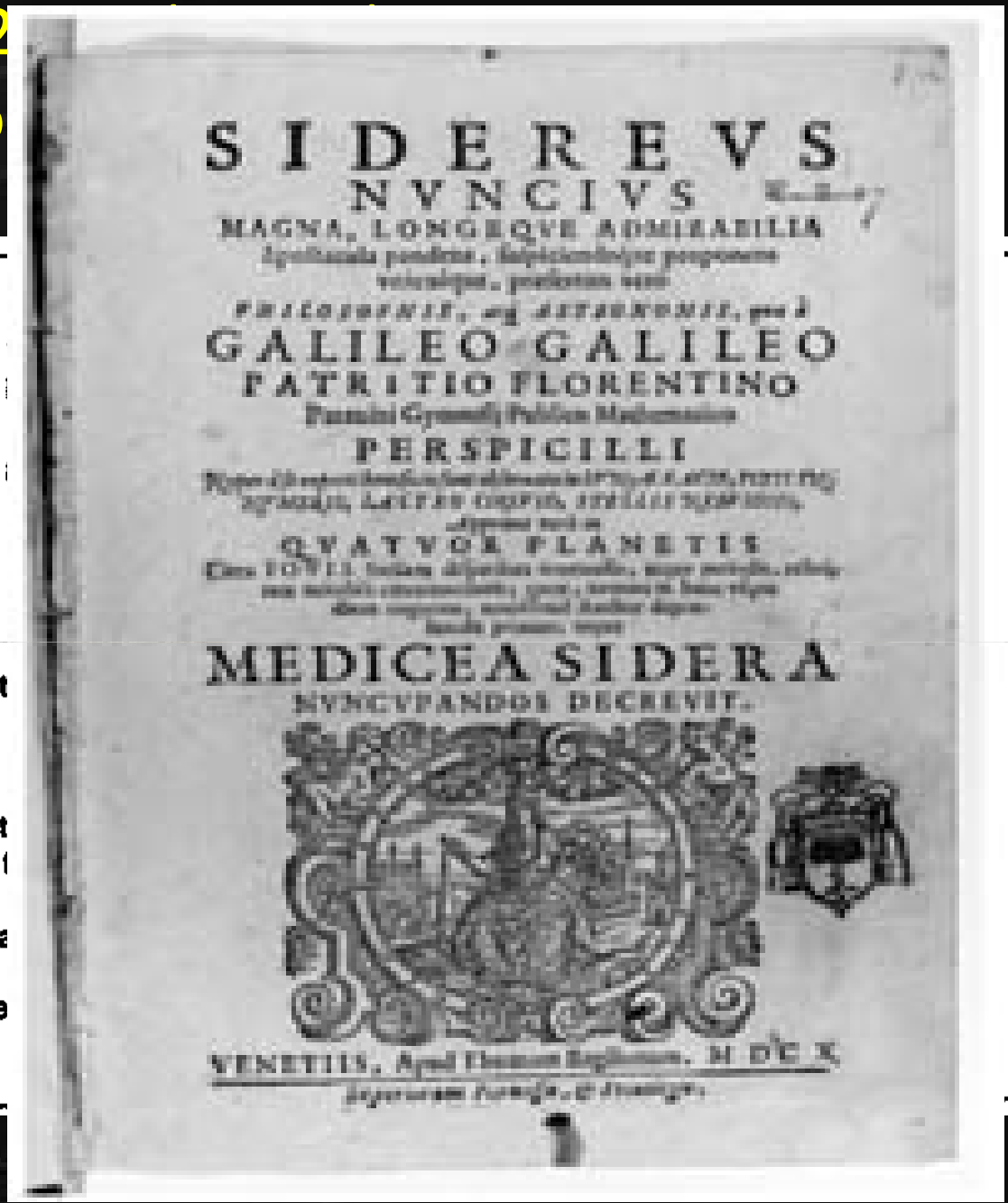
On the

The 13t

On the

The 15t
distant

The spa
greater
they we


SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
GALILEO GALILEO
PATRITIO FLORENTINO
PERSPICILLI
QVATVOR PLANETIS
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.
VENETIIS,

Published 1610

Pre Kepler / Galileo

↓

Observations

↓

Aristotelian Natural philosophy

↓

Truth

Kepler / Galileo

↓

Observations
Quantitative measurements

↓

Deduction of logical Quantitative interdependence of Physical quantities

↓

Truth

A most important modern question: what is the composition of matter and energy in the Universe?

- What is dark matter?
- What is dark energy?
- How and where are the heavy elements from iron to uranium made?

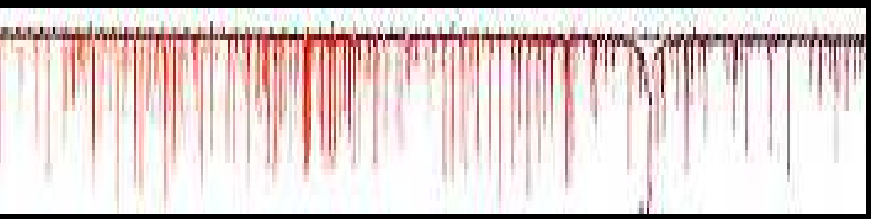
What is the distribution of elements in the Universe?

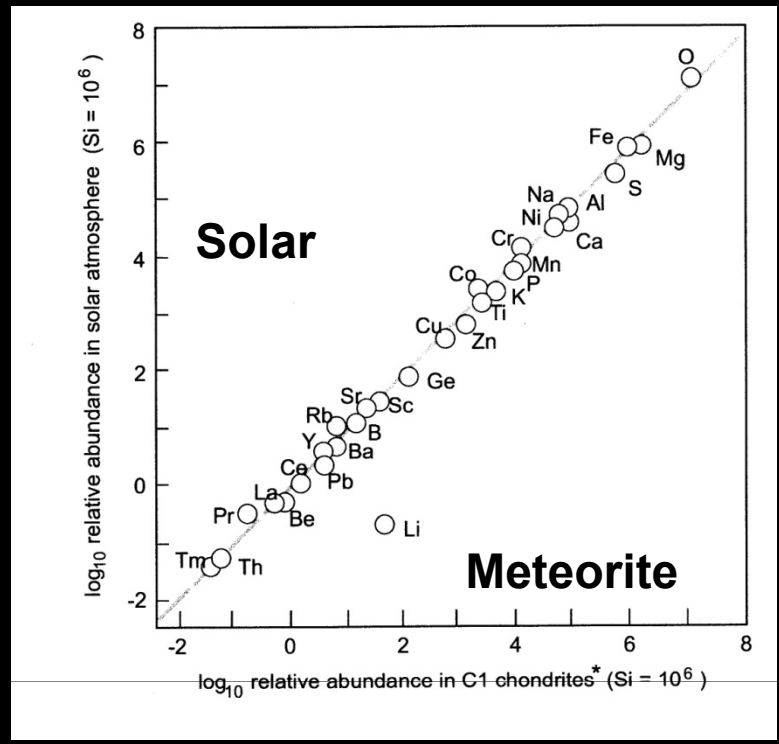
How did this distribution evolve?

Telescopes/ Spectrometers

Particle accelerators: RIB

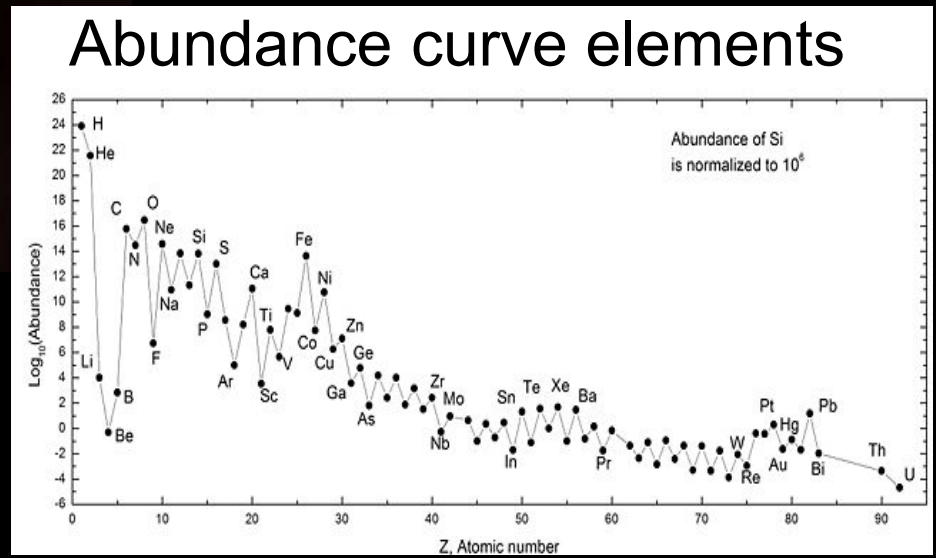
Element abundance in the solar system

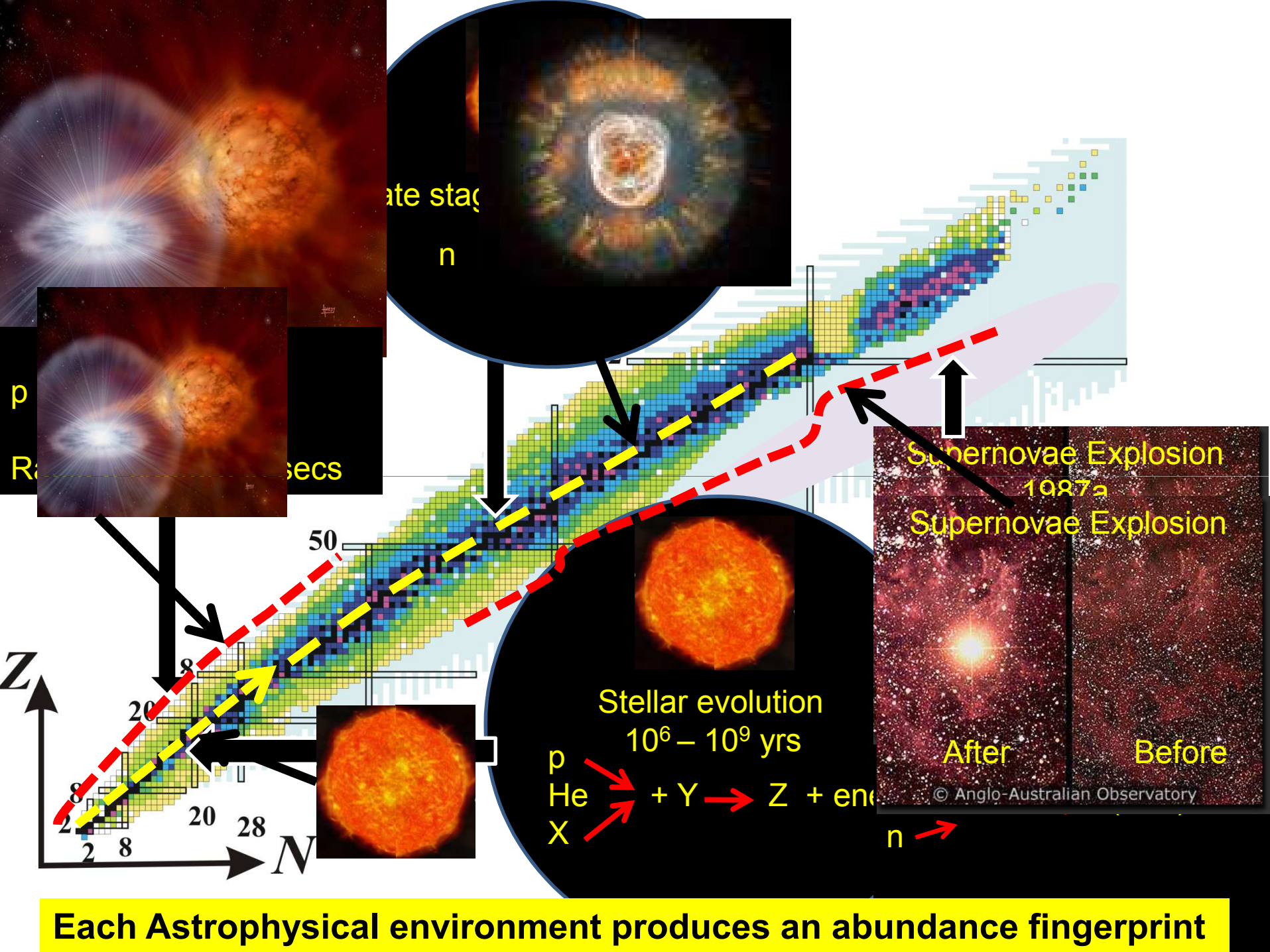




Revelstoke Meteorite

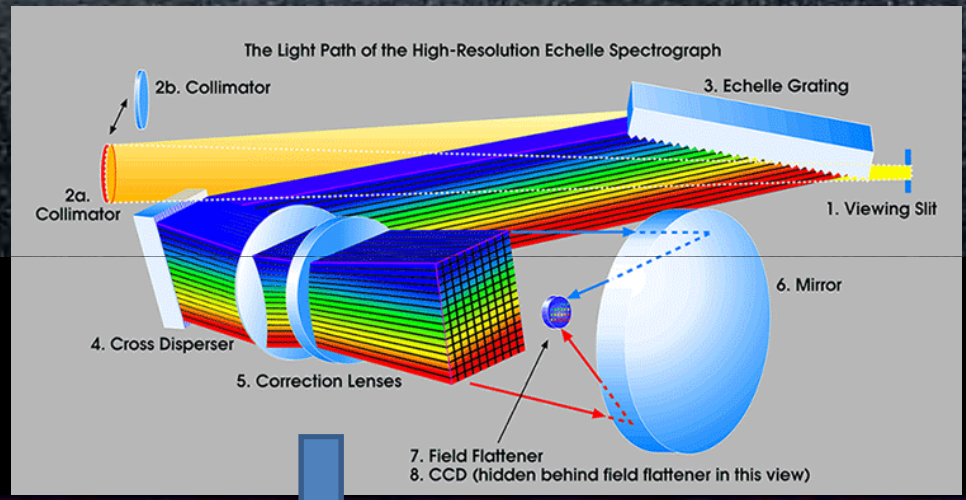
Abundance curve elements

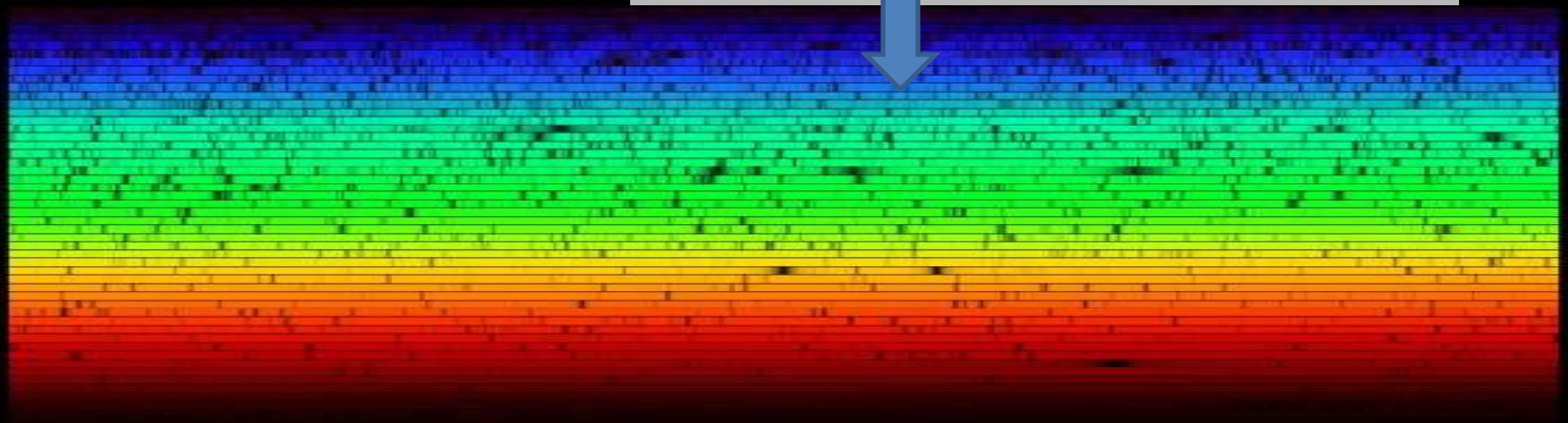


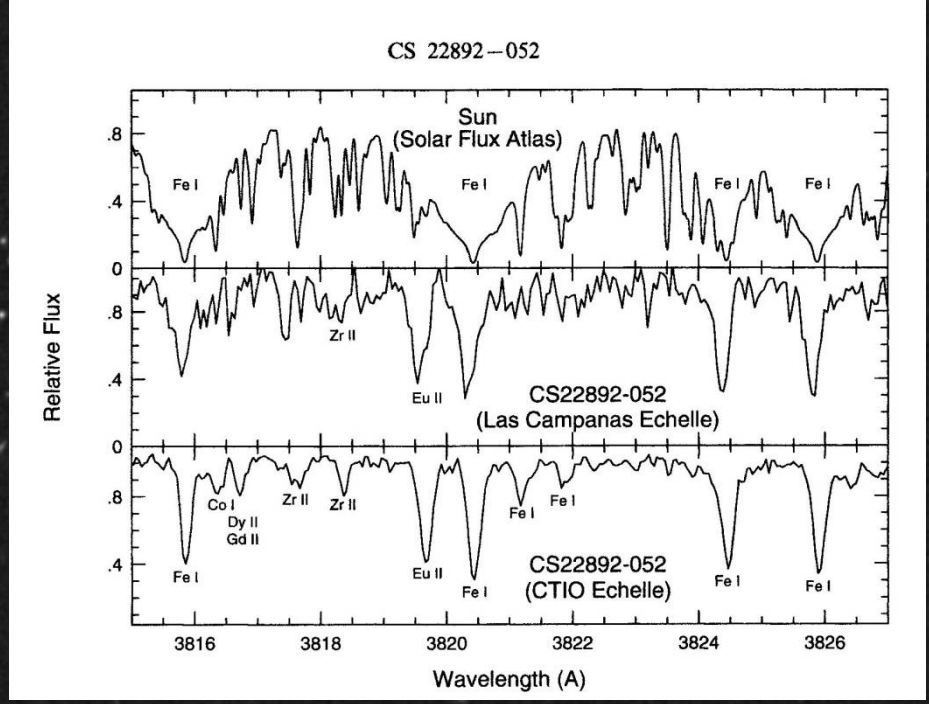


Each Astrophysical environment produces an abundance fingerprint

Element abundance in other stellar systems



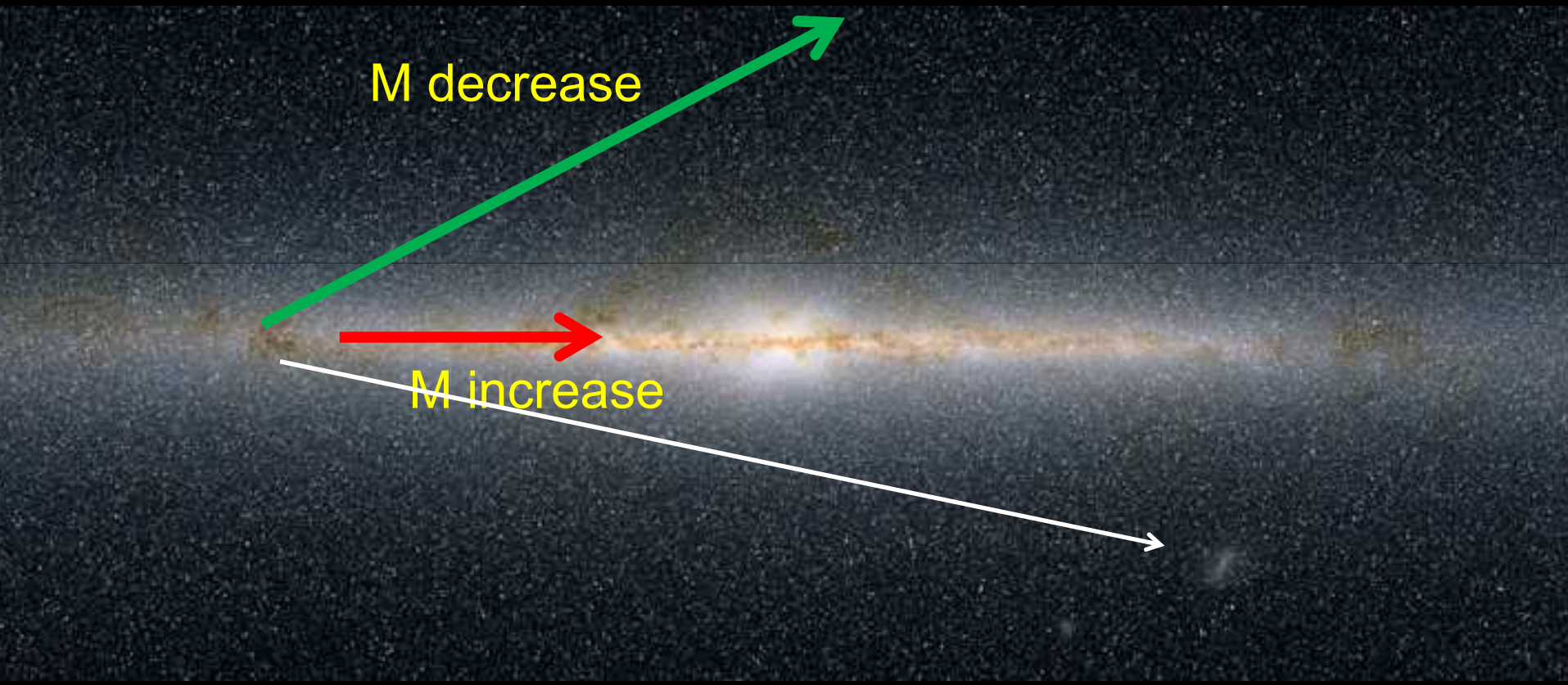




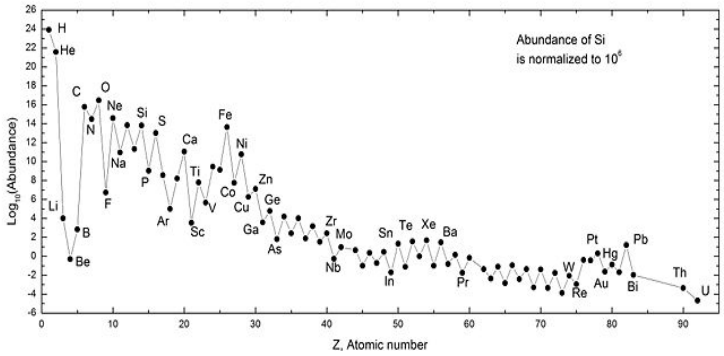
Over 50 element abundances determined for CS22892-52

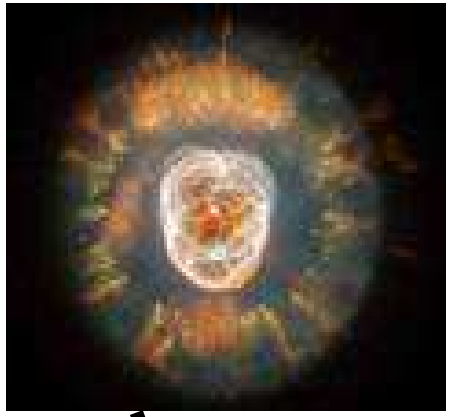
$$M=[Fe/H] = \log(Fe/H)_{star} - \log(Fe/H)_{sun}$$

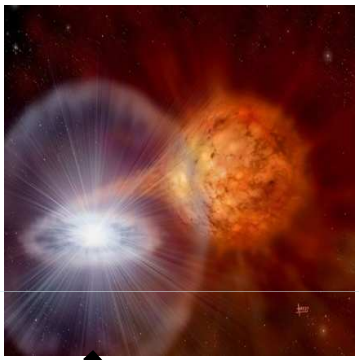
$$M=[Fe/H] = \log(Fe/H)_{star} - \log(Fe/H)_{sun}$$



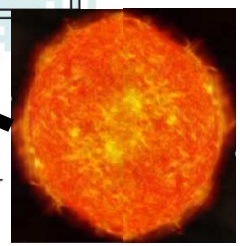
Advances in telescopes/ spectrometers → greater surveying capability


Abundance of Si
is normalized to 10^6
Log_{10}(Abundance)
Z, Atomic number
H
He
Li
Be
B
C
N
O
F
Ne
Na
Si
P
S
Ar
Ca
Sc
Ti
V
Co
Cu
Fe
Ni
Zn
Ga
Ge
As
Zr
Mo
Nb
Sn
In
Te
Xe
Ba
Pr
Pt
Hg
W
Re
Au
Pb
Bi
Th
U

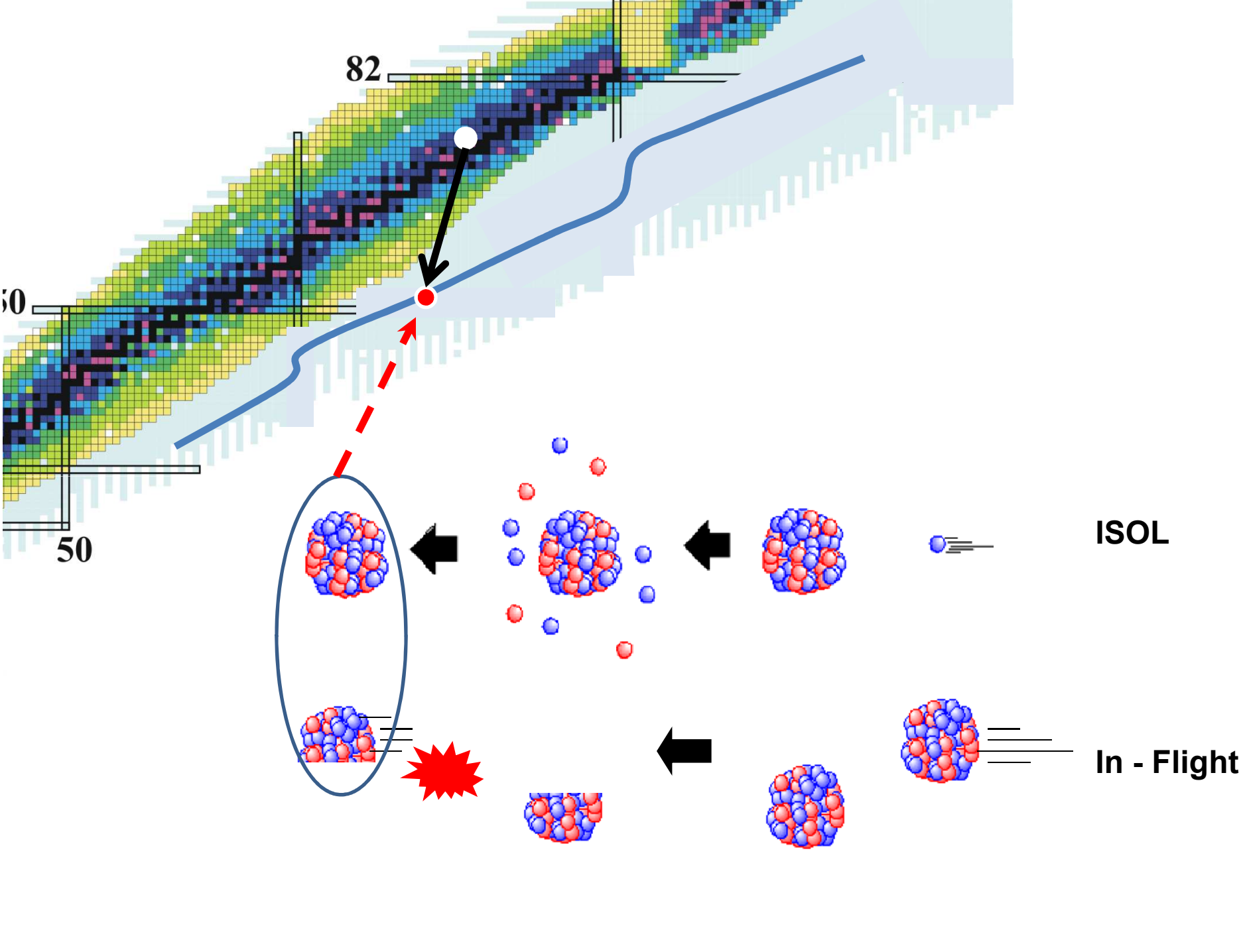


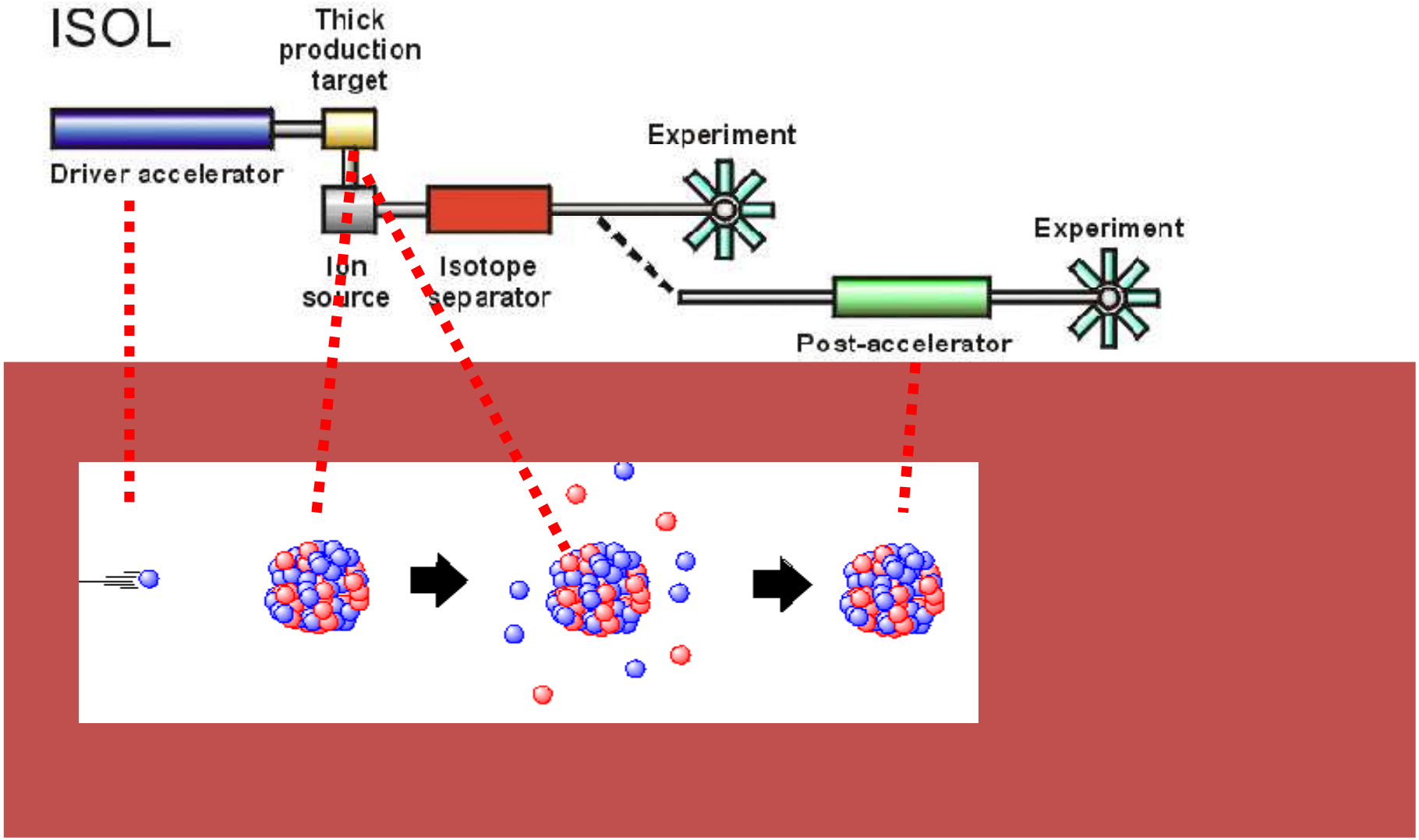


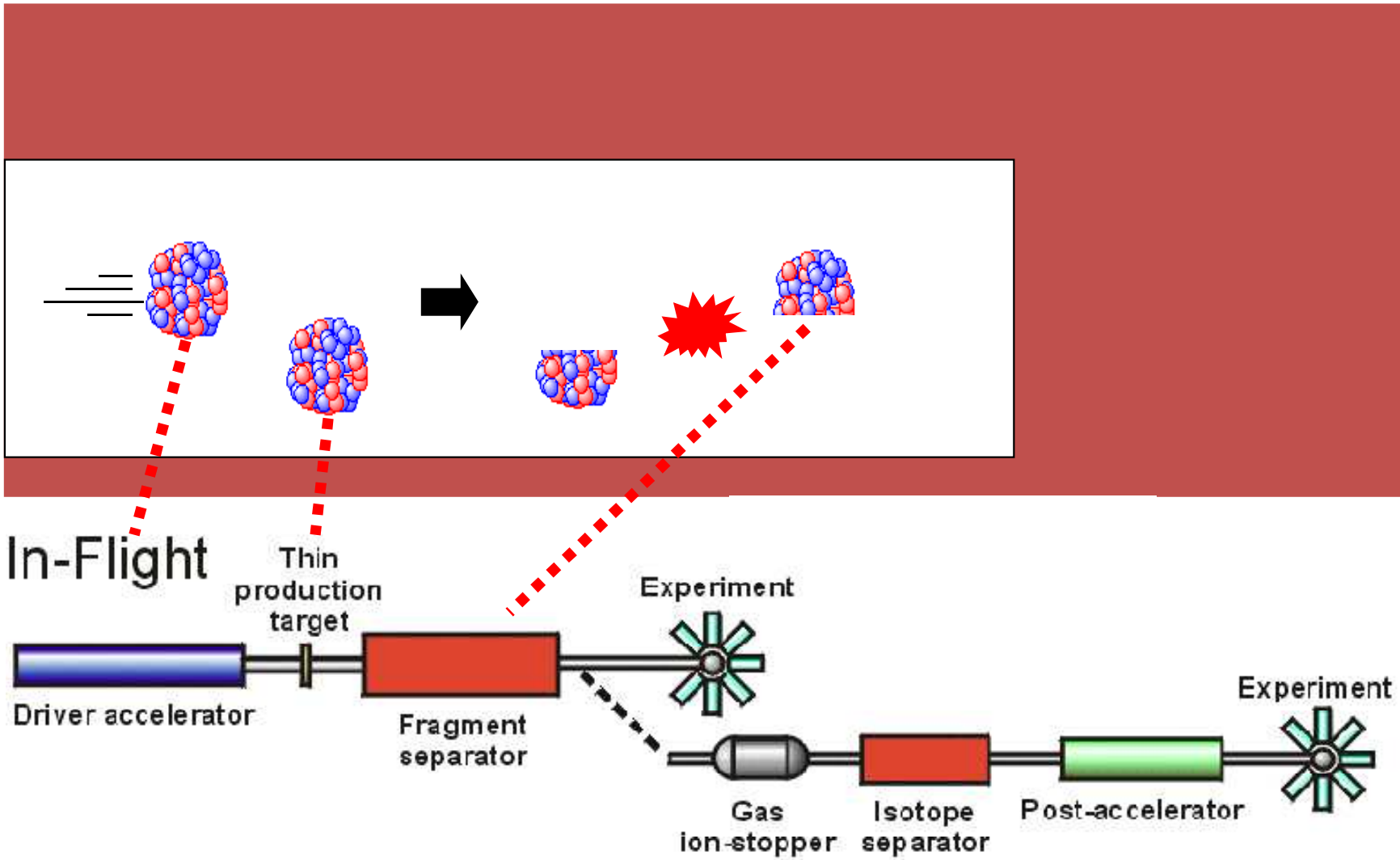

© Anglo-Australi

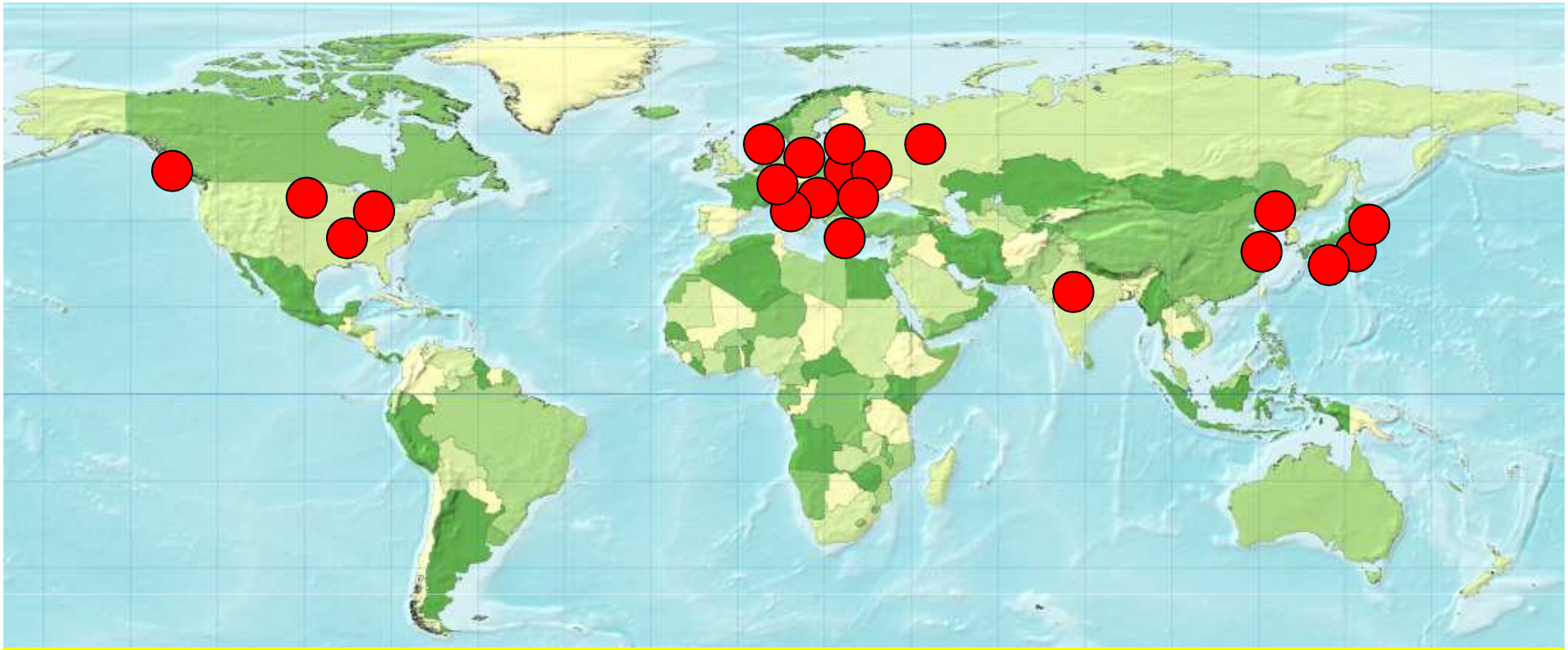


UNEXPLORED
82
50
126
82
28
20
8
2
2
8
20
28
Z
N


82
50
ISOL
In - Flight


ISOL
Thick production target
Driver accelerator
Experiment
Ion source
Isotope separator
Experiment
Post-accelerator


In-Flight
Thin production target
Experiment
Driver accelerator
Fragment separator
Experiment
Gas ion-stopper
Isotope separator
Post-accelerator



China:- BFRIB, HIRFL

Japan:- RIBF, RARF, TRIAC

India:- VEC-RIB

Belgium:- CRC

Russia:- DRIBS

E.U.:- ISOLDE, EURISOL

Italy:- EXCYT, SPES

Germany:- GSI, FAIR, MAFF

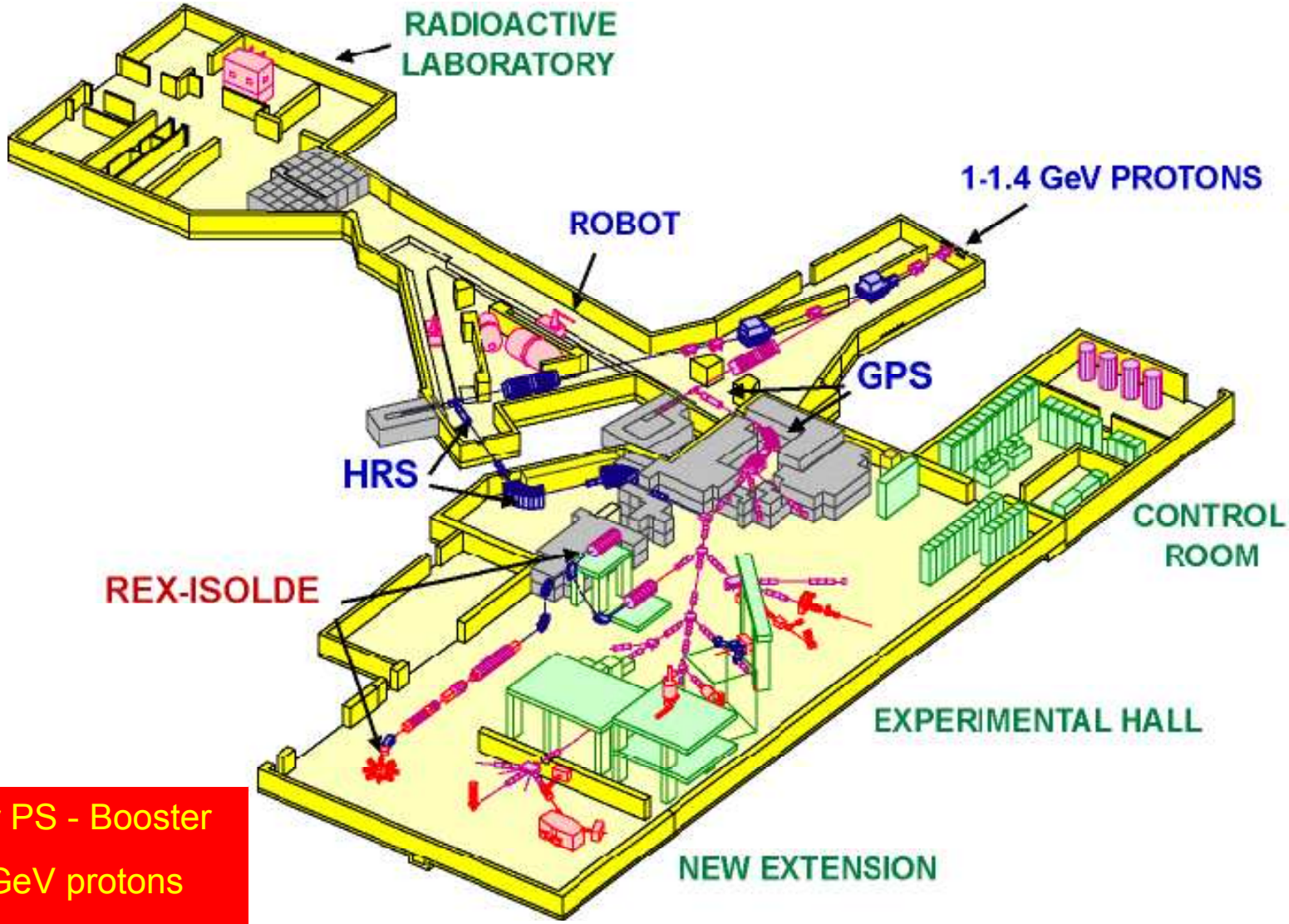
France:- SPIRAL, SPIRAL2

United States:- HRIBF, MSU(FRIB)

Canada:- ISAC

ISOL

CERN



Driver Accelerator PS - Booster

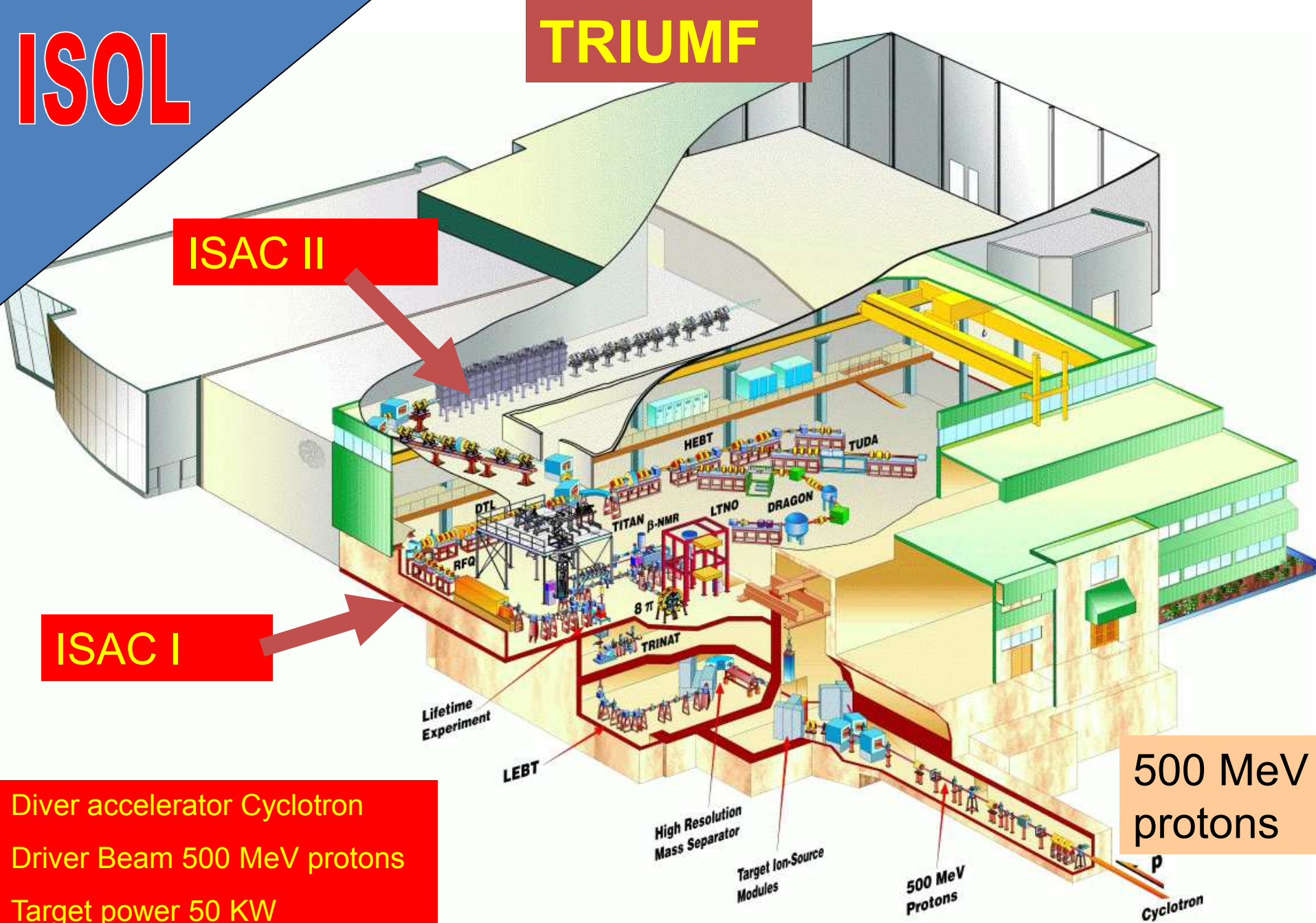
Driver Beam 1.4 GeV protons

Target power ~ 2 KW

Post Accelerator ~ Linear

ISOL

TRIUMF



500 MeV protons

Diver accelerator Cyclotron

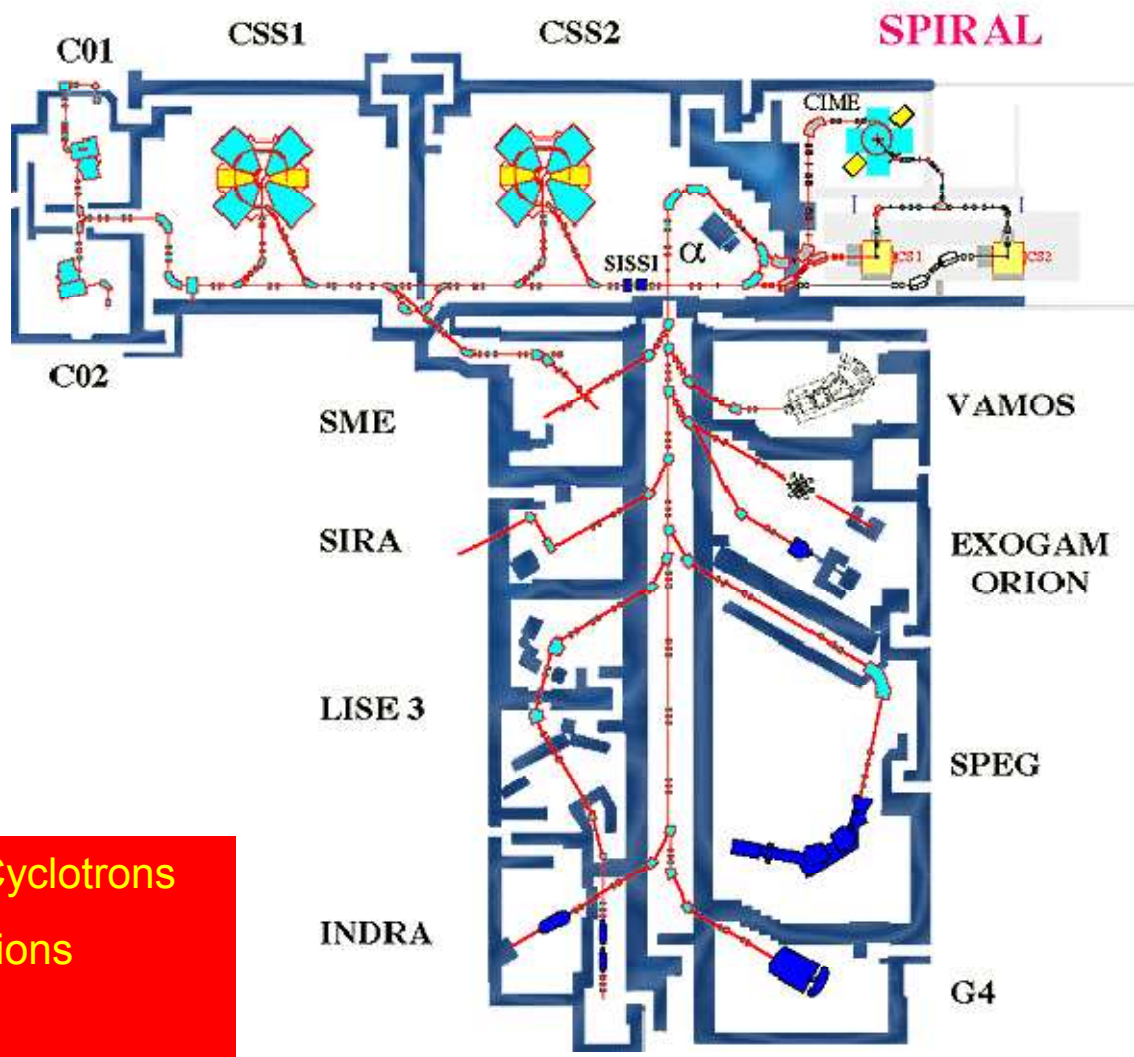
Driver Beam 500 MeV protons

Target power 50 KW

Post Accelerator ~ Linear

ISOL +
In flight

GANIL - SPIRAL



Diver accelerator Coupled Cyclotrons

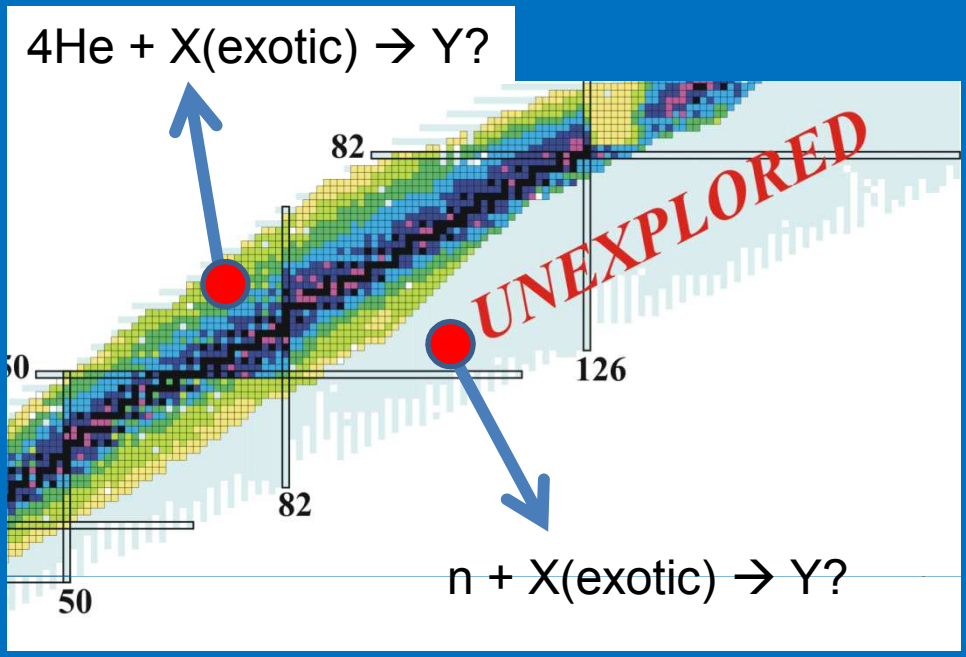
Driver Beam light to heavy ions

For ISOL:-

Target power 2 KW

Post Accelerator ~ Cyclotron

The Nuclear Astrophysics Challenge



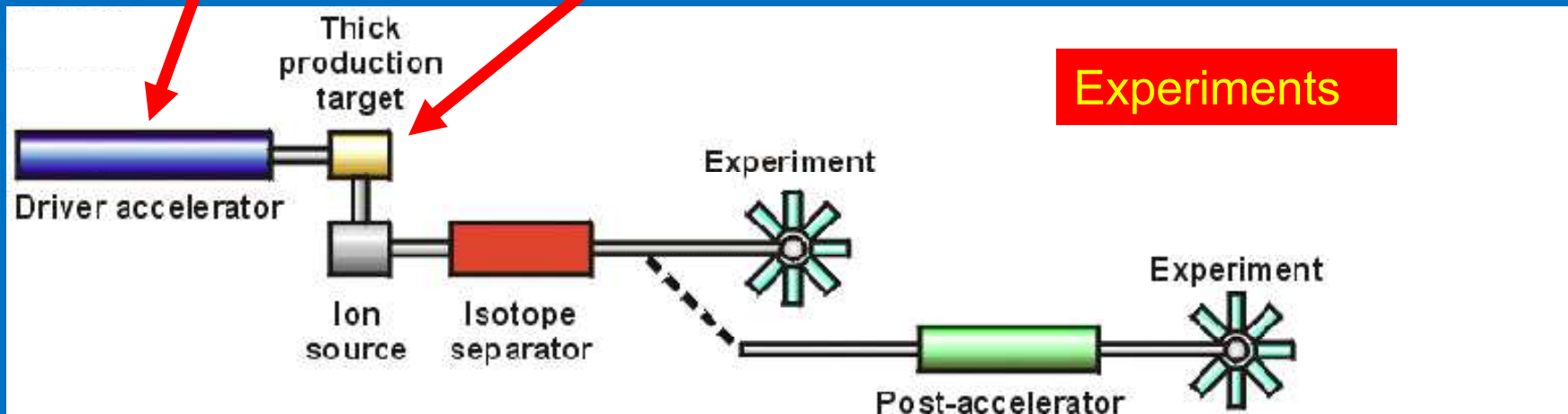
	Stable Beam pps	RIB . X pps
Beam pps	10^9 - 10^{12}	1- 10^9
Event rate	OK	low
background	low	high
Sig./noise	good	poor

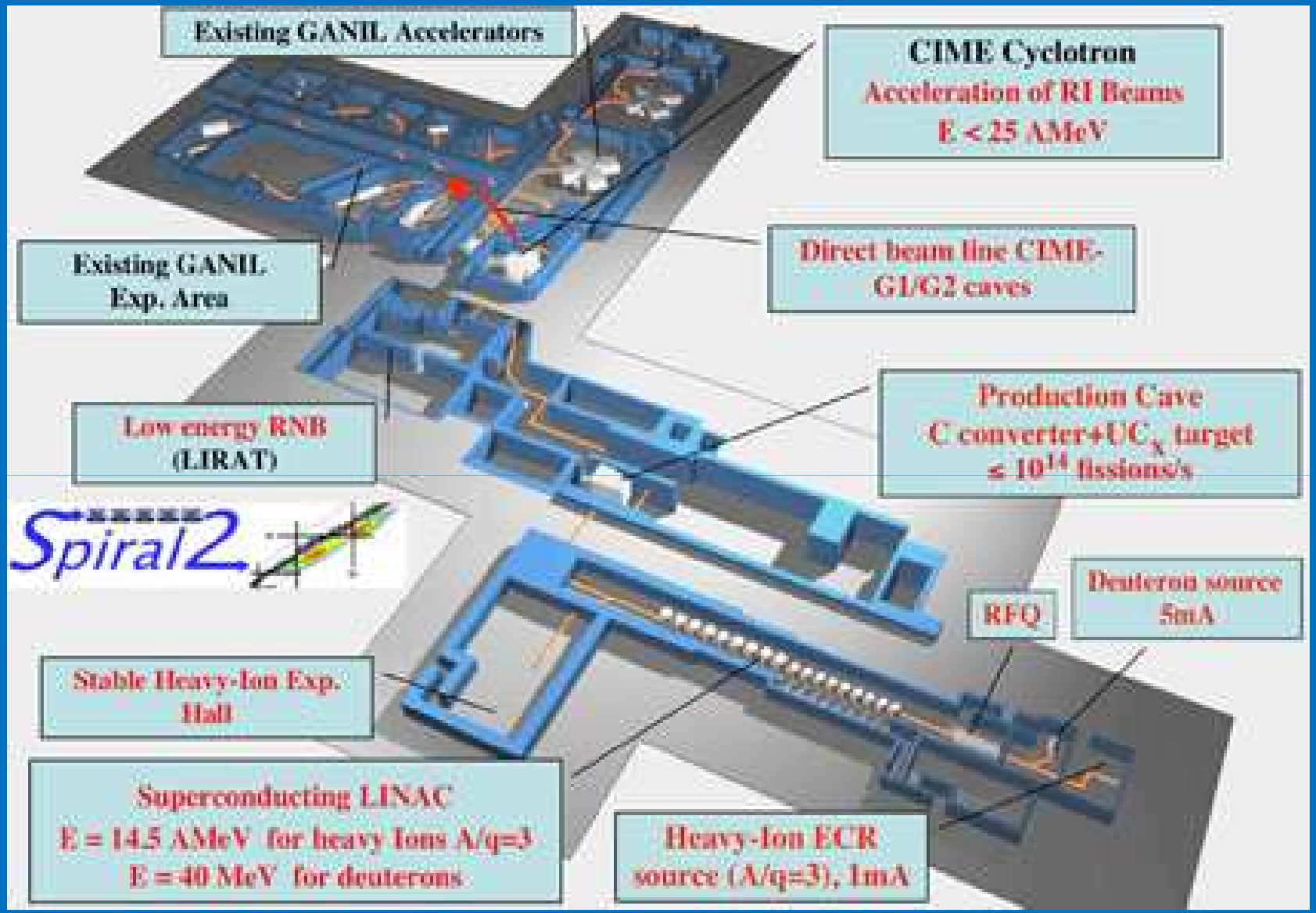
Innovation needed in all areas

Accelerators

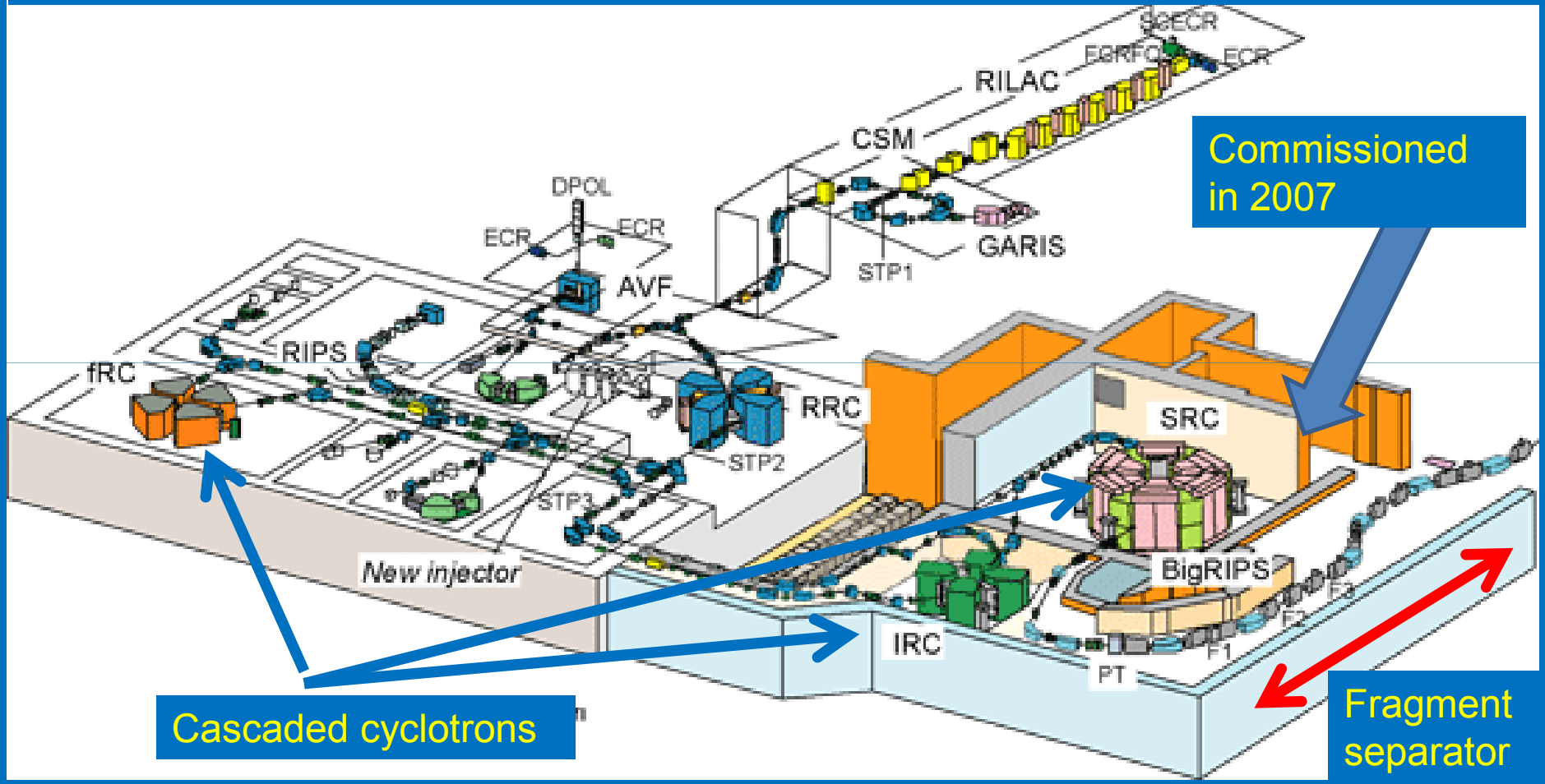
Targets

Experiments



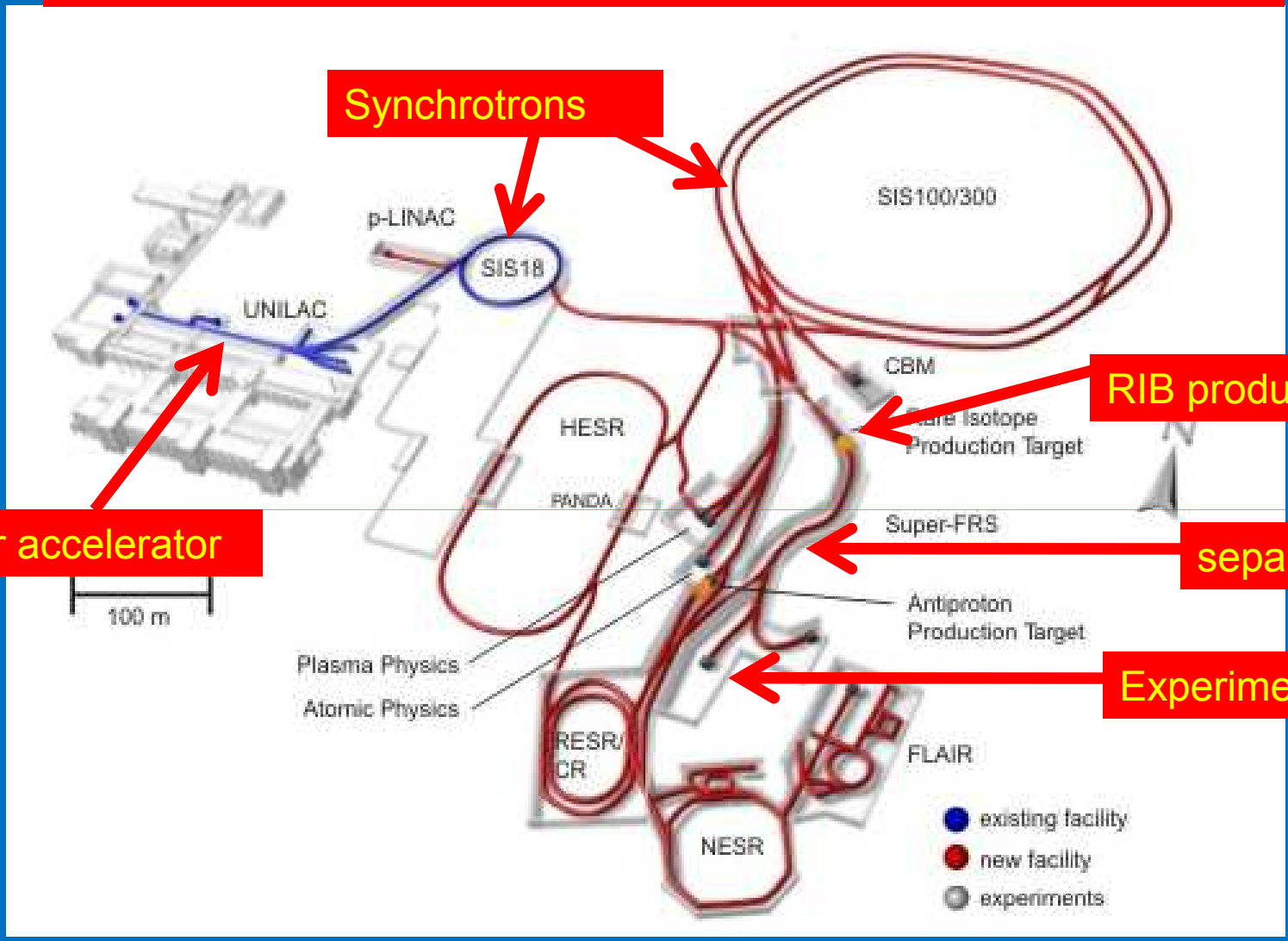

Existing GANIL Accelerators
CIME Cyclotron
Acceleration of RI Beams
E < 25 AMeV
Existing GANIL
Exp. Area
Direct beam line CIME-
G1/G2 caves
Low energy RNB
(LIRAT)
Production Cave
C converter+UC$_x$ target
≤ 10^{14} fissions/s
Spiral2
RFQ
Deuteron source
5mA
Stable Heavy-Ion Exp.
Hall
Superconducting LINAC
E = 14.5 AMeV for heavy ions A/q=3
E = 40 MeV for deuterons
Heavy-Ion ECR
source (A/q=3), 1mA

Radioactive Ion Beam Factory
RIKEN



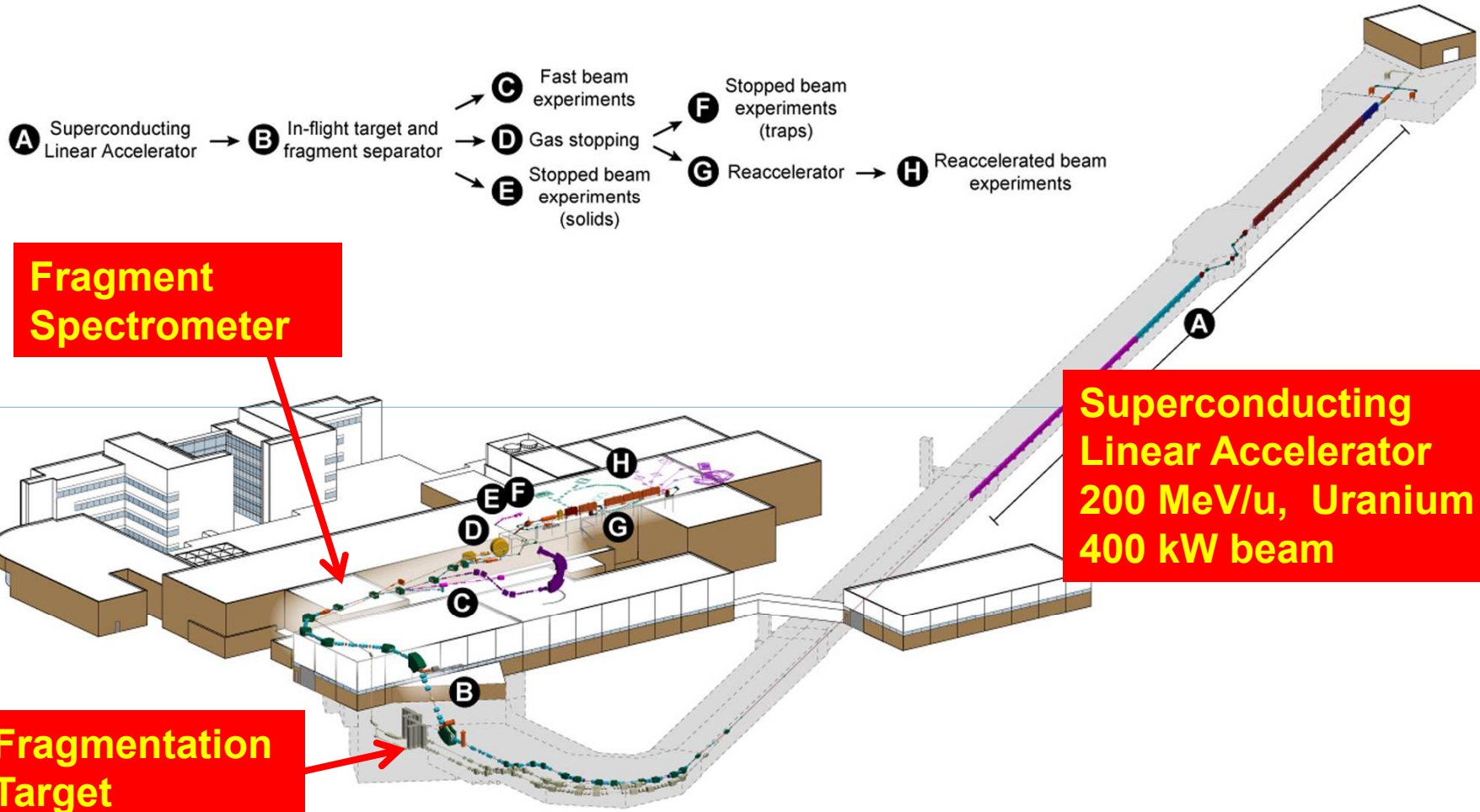
Facility design goal 350MeV/A Uranium ions up to ~ 10^{13} pps → 80kW
Current ~ 3* 10^{9} pps (soon *10)

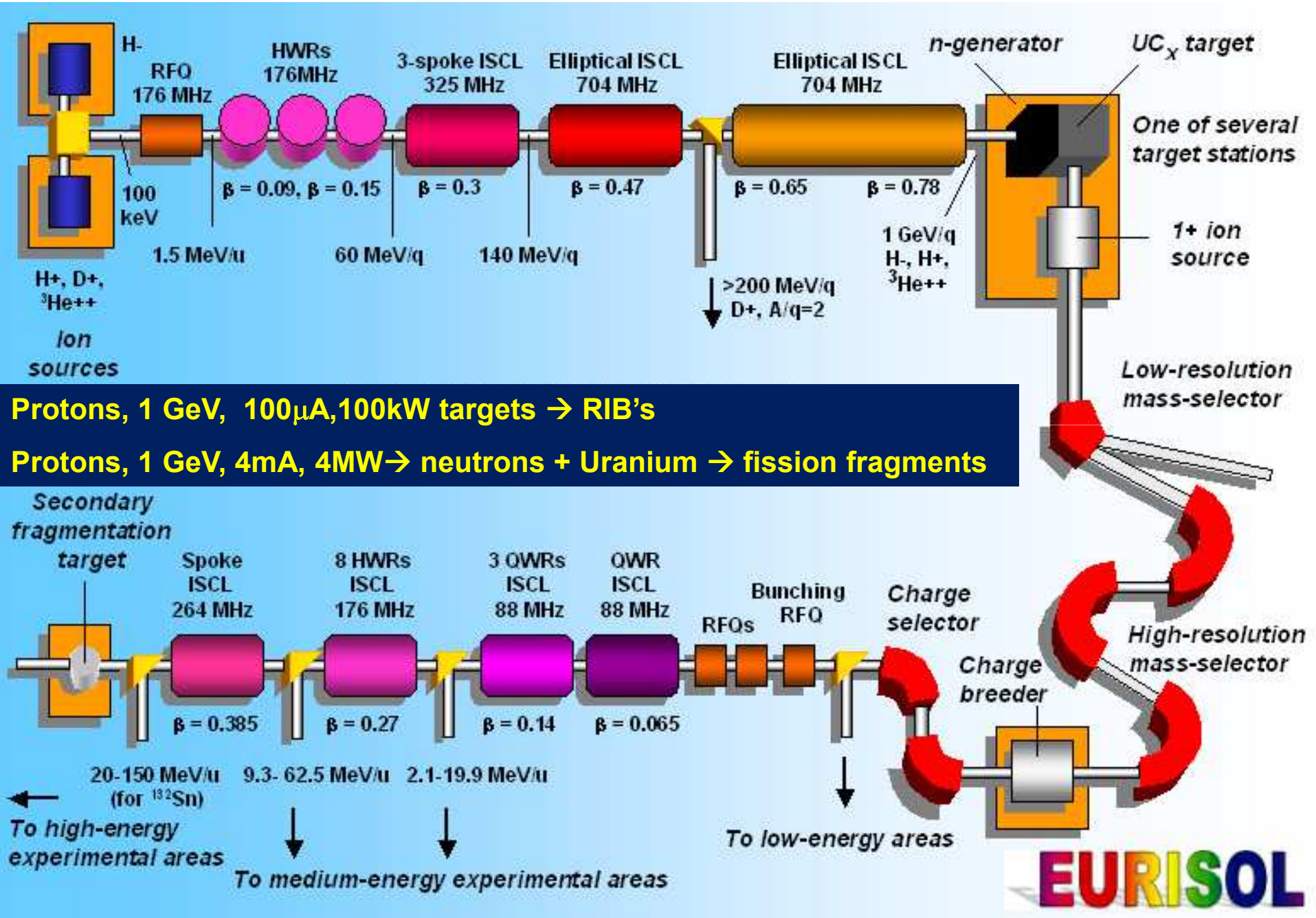
FAIR at GSI
Fragmentation of high intensity heavy ions



Aim : RIB fragmentation of heavy ions/ fission of U up to 1.5 GeV/u 10^{12} pps
→ up to10,000 increase in intensity over current values
Under Construction

FRIB at Michigan State University

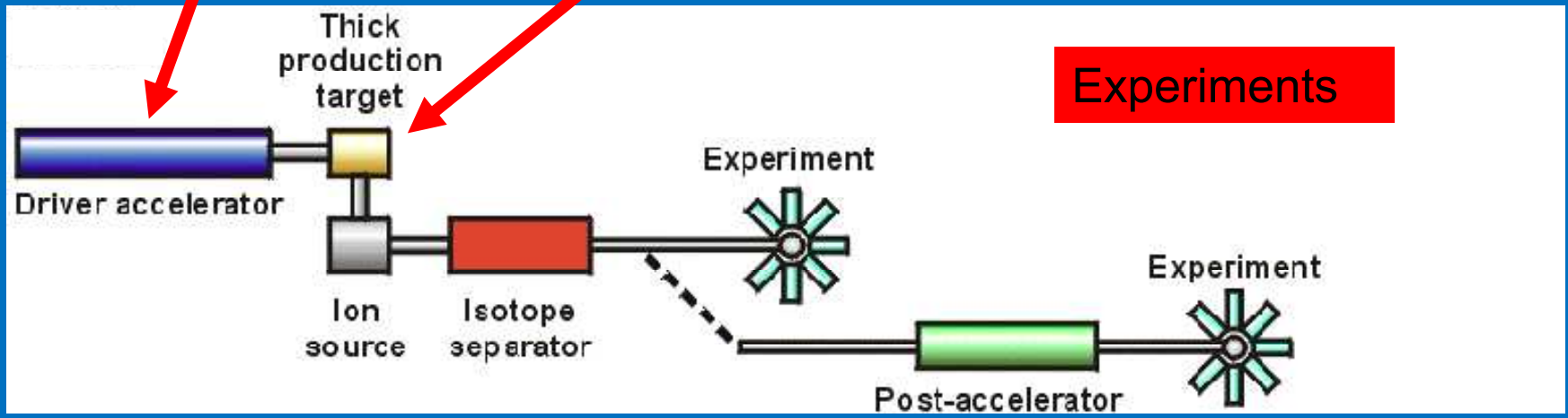



H-
RFQ
176 MHz
HWRs
176MHz
3-spoke ISCL
325 MHz
Elliptical ISCL
704 MHz
Elliptical ISCL
704 MHz
n-generator
UCx target
One of several
target stations
100
keV
β = 0.09, β = 0.15
β = 0.3
β = 0.47
β = 0.65
β = 0.78
1 GeV/q
H-, H+,
3He++
1+ ion
source
1.5 MeV/u
60 MeV/q
140 MeV/q
>200 MeV/q
D+, A/q=2
H+, D+,
3He++
Ion
sources
Low-resolution
mass-selector
Protons, 1 GeV, 100μA,100kW targets → RIB's
Protons, 1 GeV, 4mA, 4MW→ neutrons + Uranium → fission fragments
Secondary
fragmentation
target
Spoke
ISCL
264 MHz
8 HWRs
ISCL
176 MHz
3 QWRs
ISCL
88 MHz
QWR
ISCL
88 MHz
RFQs
Bunching
RFQ
Charge
selector
High-resolution
mass-selector
Charge
breeder
β = 0.385
β = 0.27
β = 0.14
β = 0.065
20-150 MeV/u
(for 132Sn)
9.3- 62.5 MeV/u
2.1-19.9 MeV/u
To high-energy
experimental areas
To low-energy areas
To medium-energy experimental areas
EURISOL

Accelerators

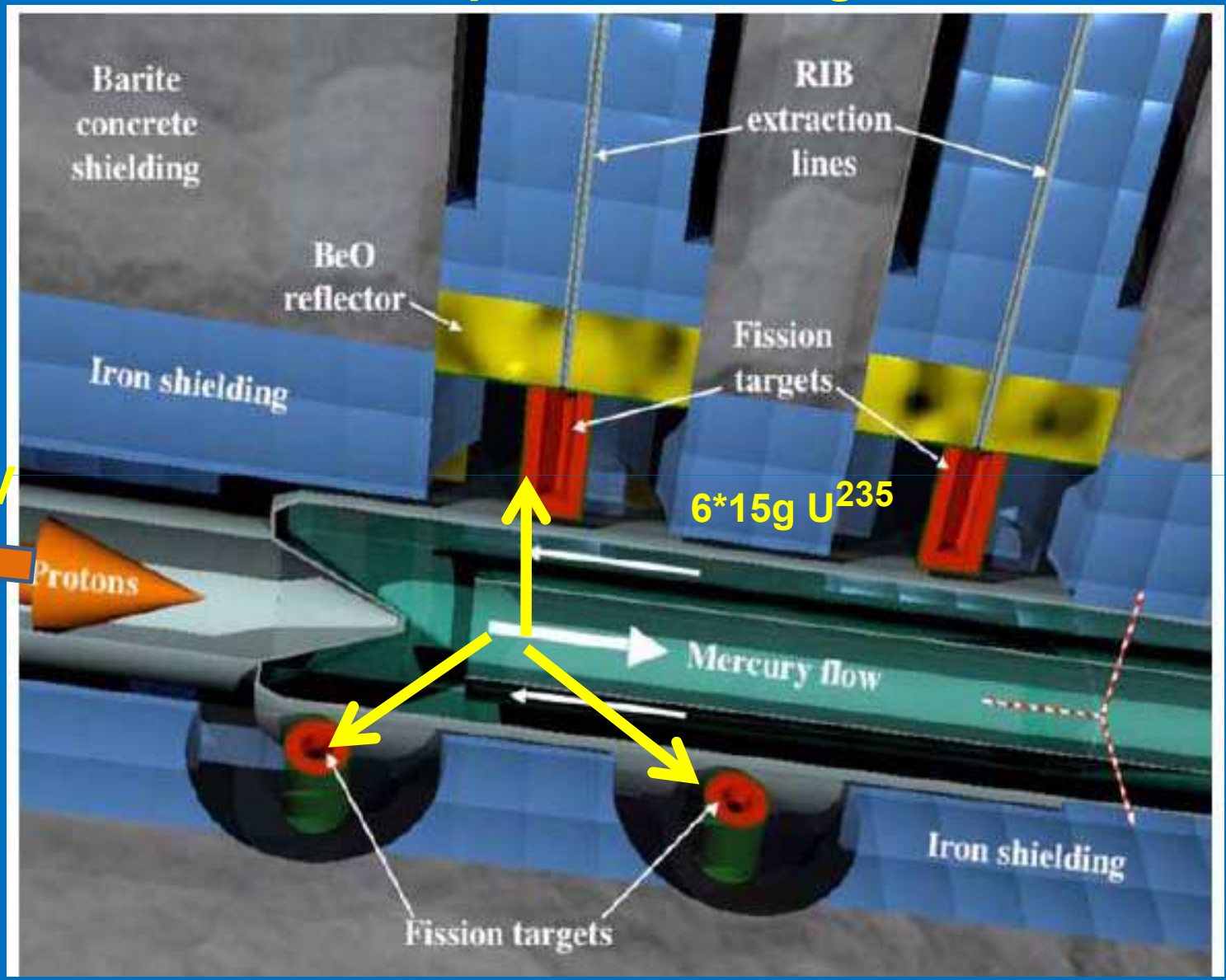
Targets

Innovation needed in all areas



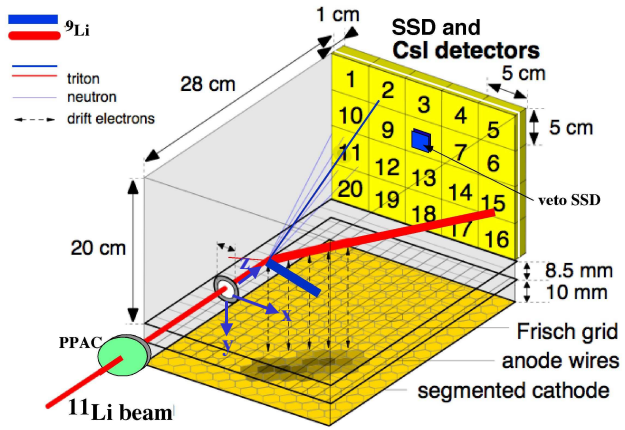
Experiments

EURISOL RIB production target



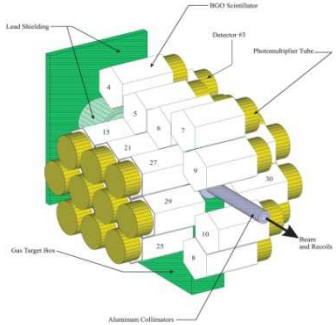
4mA, I GeV

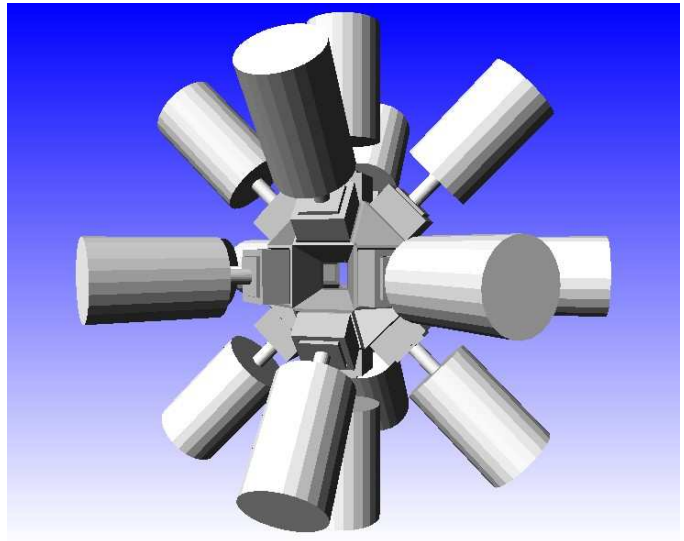
~ $5*10^{15}$ fissons/s → ~200kW + 4MW from primary beam



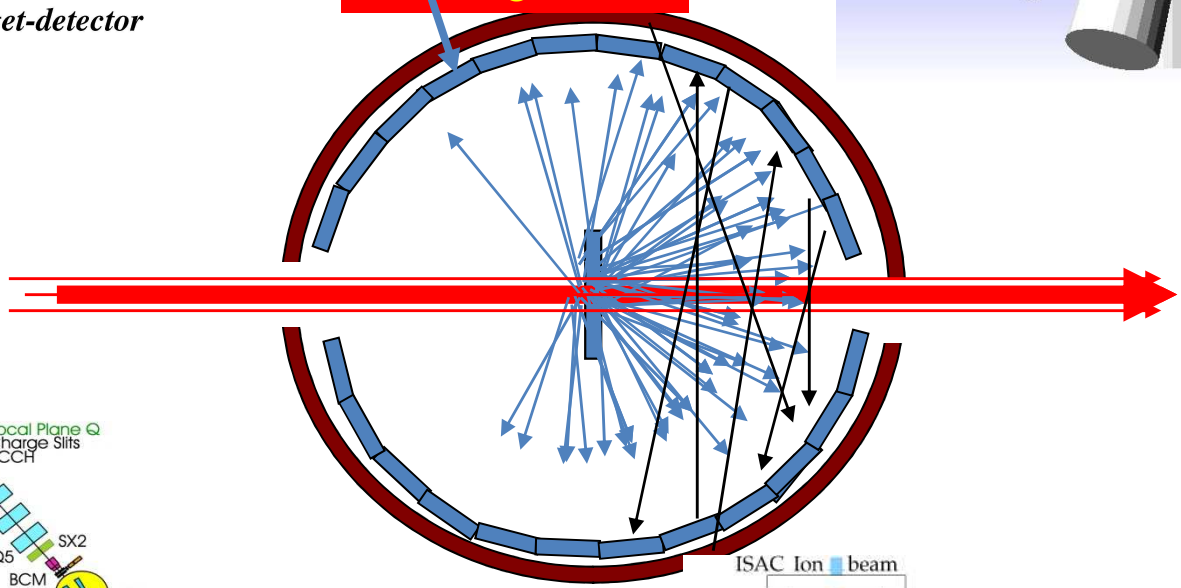
39MeV, (2 - 4)* 10^3 pps

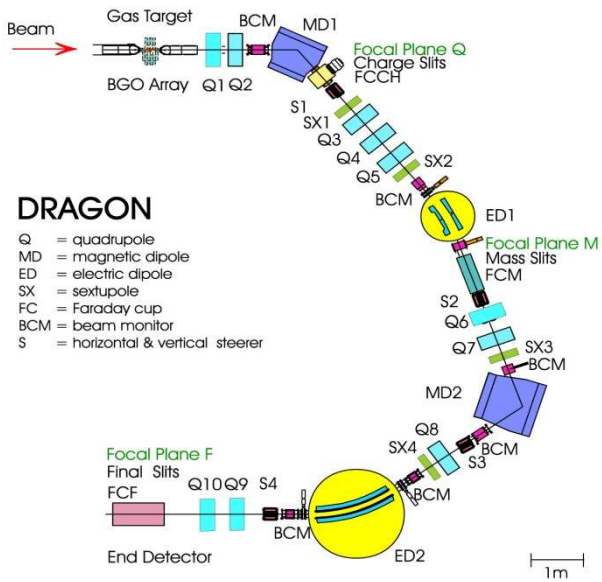
MAYA target-detector





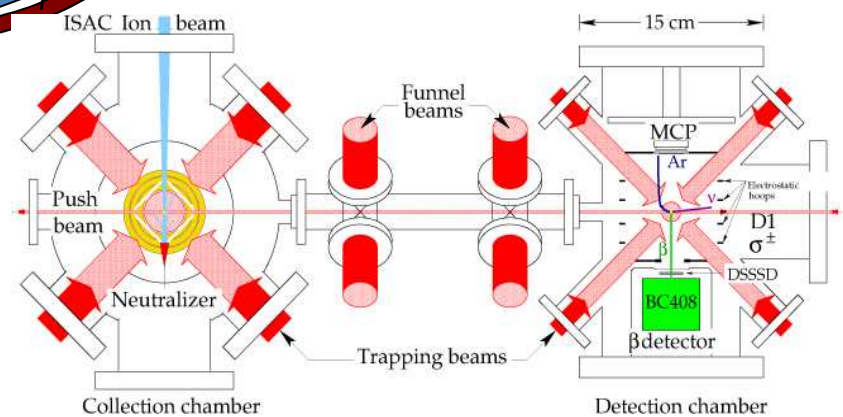
4π Detector coverage





DRAGON

Q = quadrupole
MD = magnetic dipole
ED = electric dipole
SX = sextupole
FC = Faraday cup
BCM = beam monitor
S = horizontal & vertical steerer

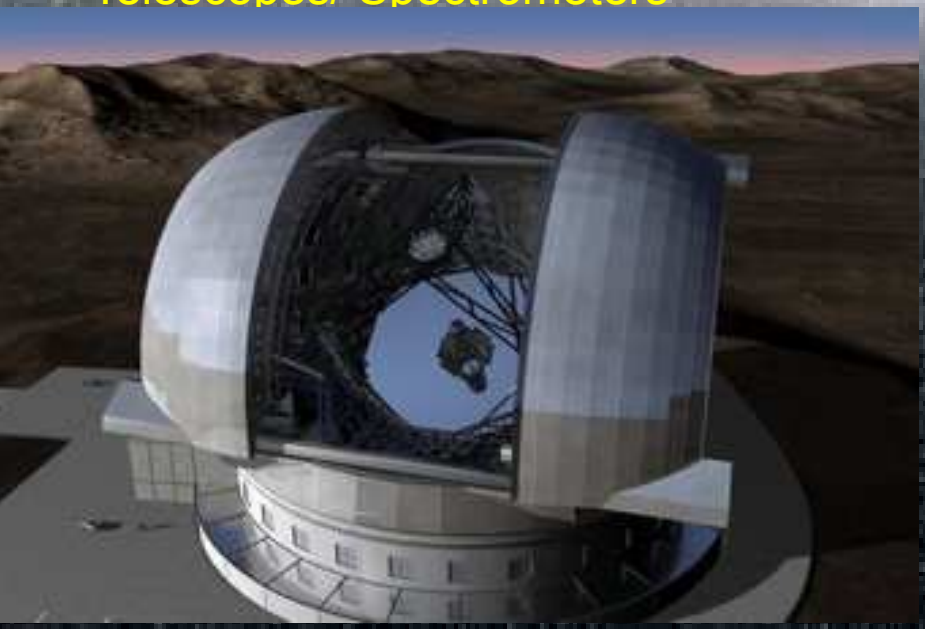


How and where are the heavy elements from iron to uranium made?

What is the distribution of elements in the Universe?

Instruments

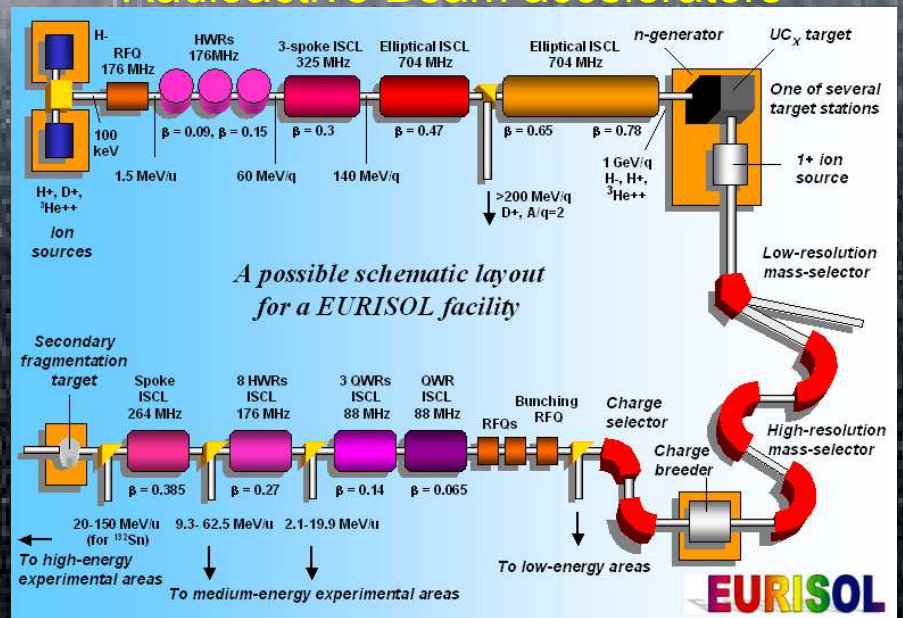
Telescopes/ Spectrometers



How did this distribution evolve?

Instruments

Radioactive Beam accelerators



Scientific instruments

Scientific TRUTH

Sine nobis scientia languet


Thank You