IXO Observations of Supernova Remnants

- from my personal point of view -

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0. Supernova Remnants in the Universe

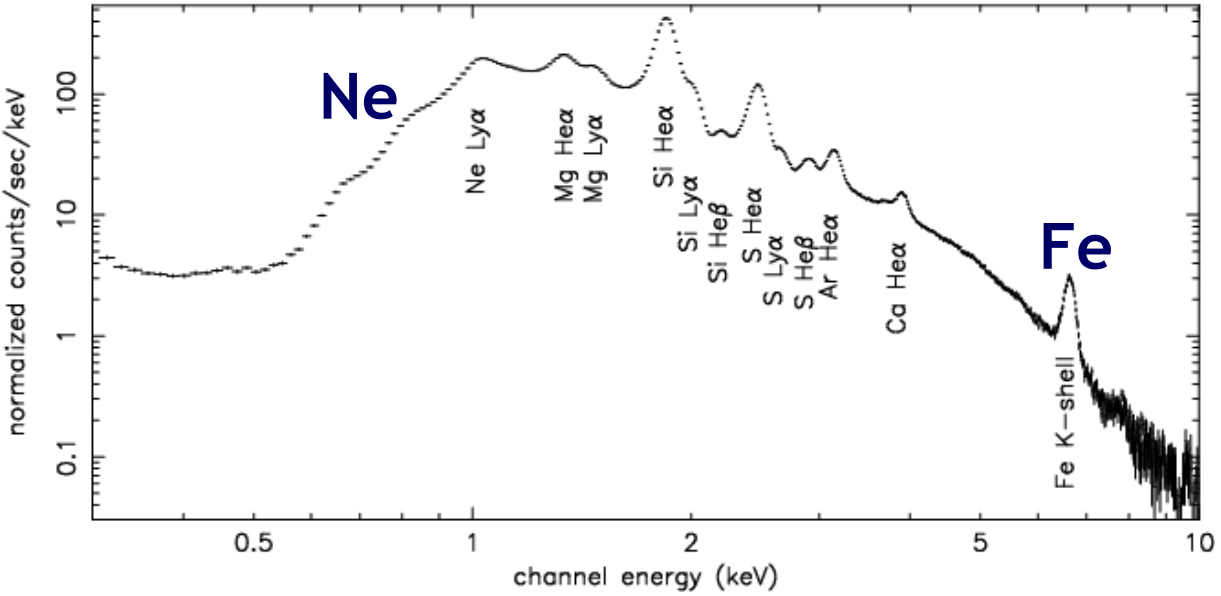
SNRs are main suppliers of { energy, heavy elements, cosmic rays }

SNRs make diversity in the Universe !

What we know	How to know
amount of some elements (O, Ne, Mg, Si, Fe …)	thin thermal plasma with kT of ~keV
2D image of them	emission lines size of ~arcmin - deg.
CR is accelerating in SNRs	sync. X-rays

We know main elements and position

Cas A spectrum (Chandra)

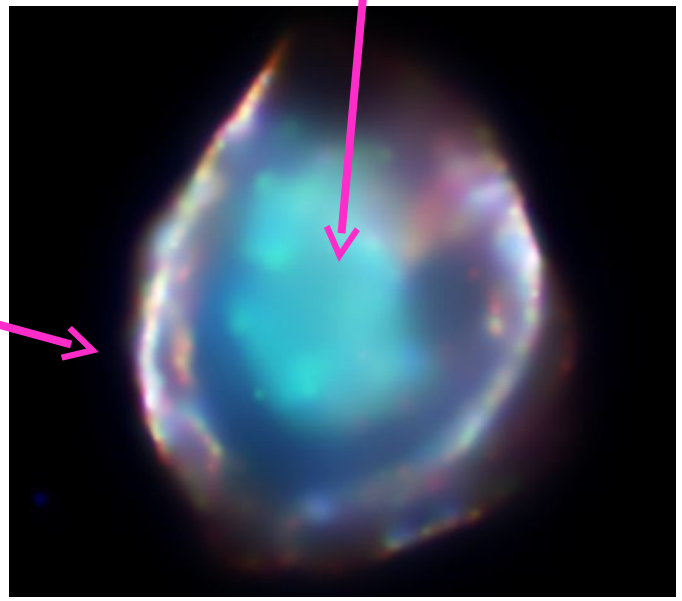


temperature,
ionization timescale,
abundance …

rough 2D position of elements

Fe

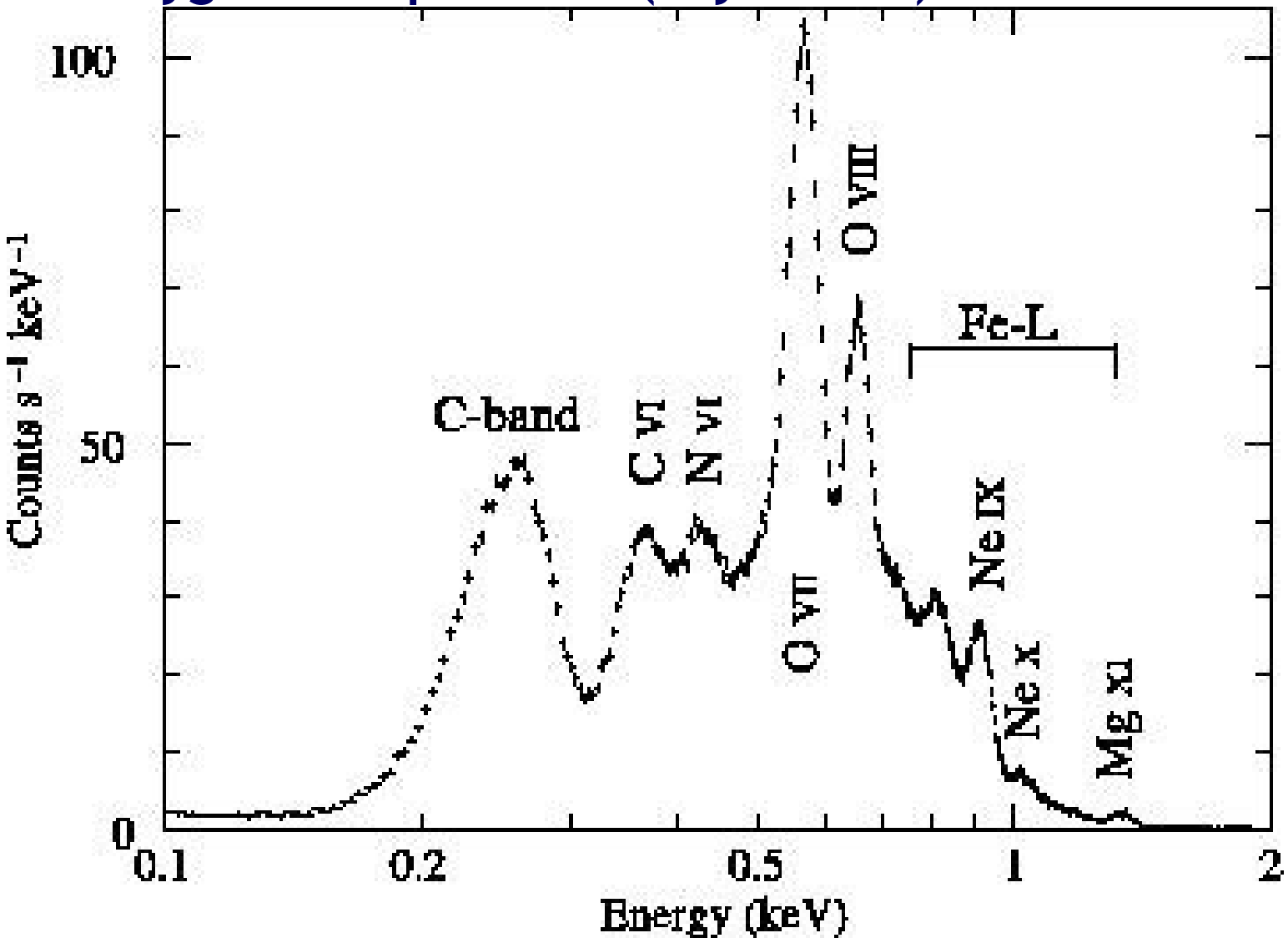
lighter elements



DEM L71 (Chandra)

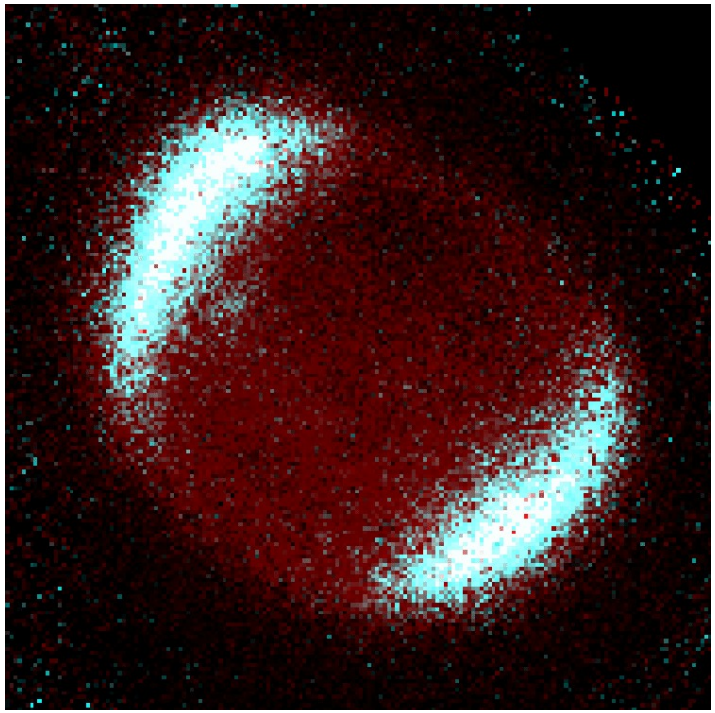
Suzaku detected C/N/O

Cygnus Loop NE rim (Miyata+07)



elements are scattered via SNRs

Cosmic rays are accelerated in SNR shocks!



Koyama+95:

discovered synchrotron X-rays
from the shells of SN1006

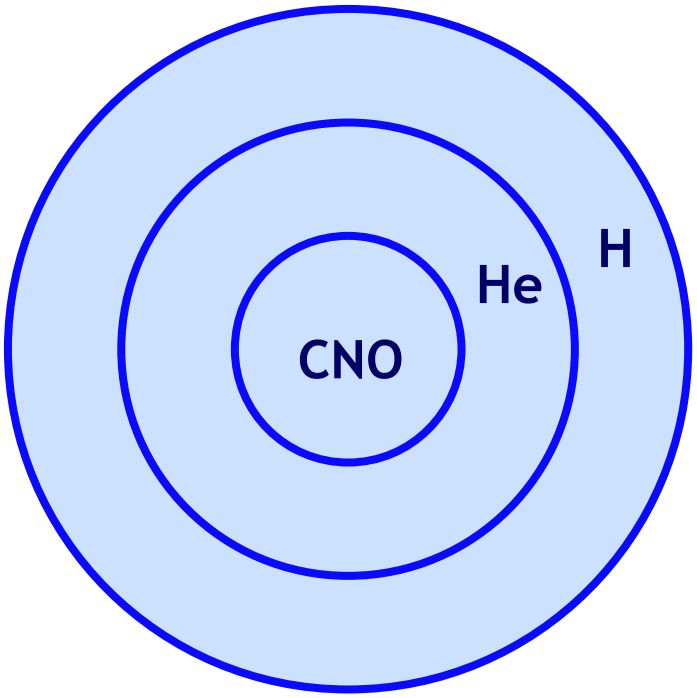
-> CR electrons are accelerated
up to ~TeV
the first evidence of CR acc.
on shocks of SNRs

Now:

several SNRs are synchrotron X-ray emitters !
RXJ1713-3946, RCW86, Vela Jr., ….
acceleration is very efficient ?

Straight-forward further study with IXO can be ….

- more precise kT, nt, abundance, …
- more precise structure of SNRs, …
  - 3D “onion-structure”
    - determined from expansion velocity
- more detailed study on acceleration



In this talk,
I would like to discuss
topics with new idea

0. Supernova Remnants in the Universe

SNRs are main suppliers of
- energy
- heavy elements
- cosmic rays

SNRs make diversity in the Universe !

What we know

amount of some elements
(O, Ne, Mg, Si, Fe …)
2D image of them

CR is accelerating in SNRs

What we don't know

(1) amount of "rare metal"
lighter than iron (Cr, Mn, …)

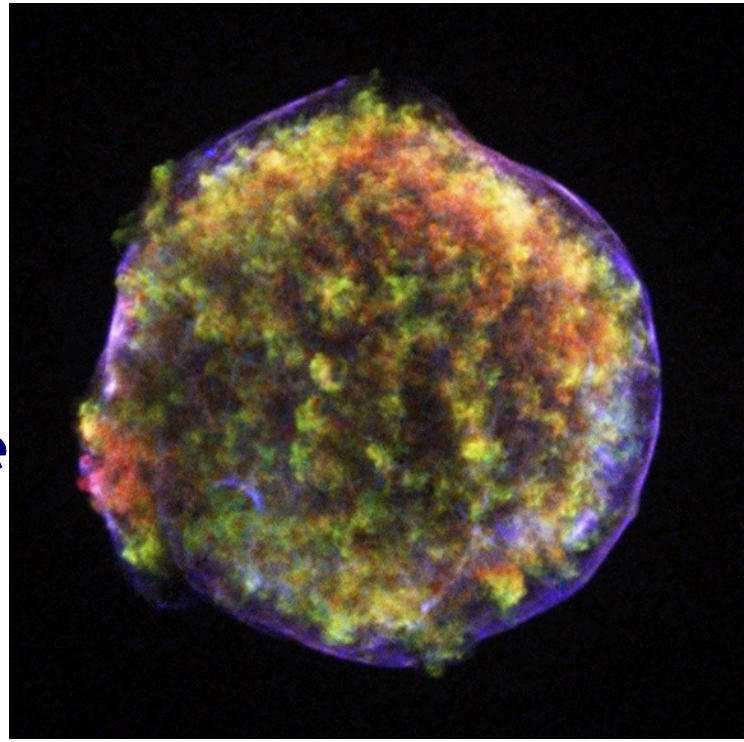
(2) elements beyond iron
(Au, Pt, U, …)

(3) Acceleration efficiency
in SNRs

1. Elements lighter than Fe

Elements lighter than Fe

produced in stars before their death
scattered when the stars explode



Tycho w. Chandra
(size=8arcmin)

Question

Which kind of light stars can be Ia SNe
and scatter elements ?
key parameter: metallicity

important to understand
elements near iron
(produced in imcomplete Si burning)

chromium manganese

11 Na 22.99	12 Mg 24.31	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr	25 Mn	26 Fe	27 Co 58.93	28 Ni 58.69	29 Cu 63.55
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag

Prove of metallicity of progenitors

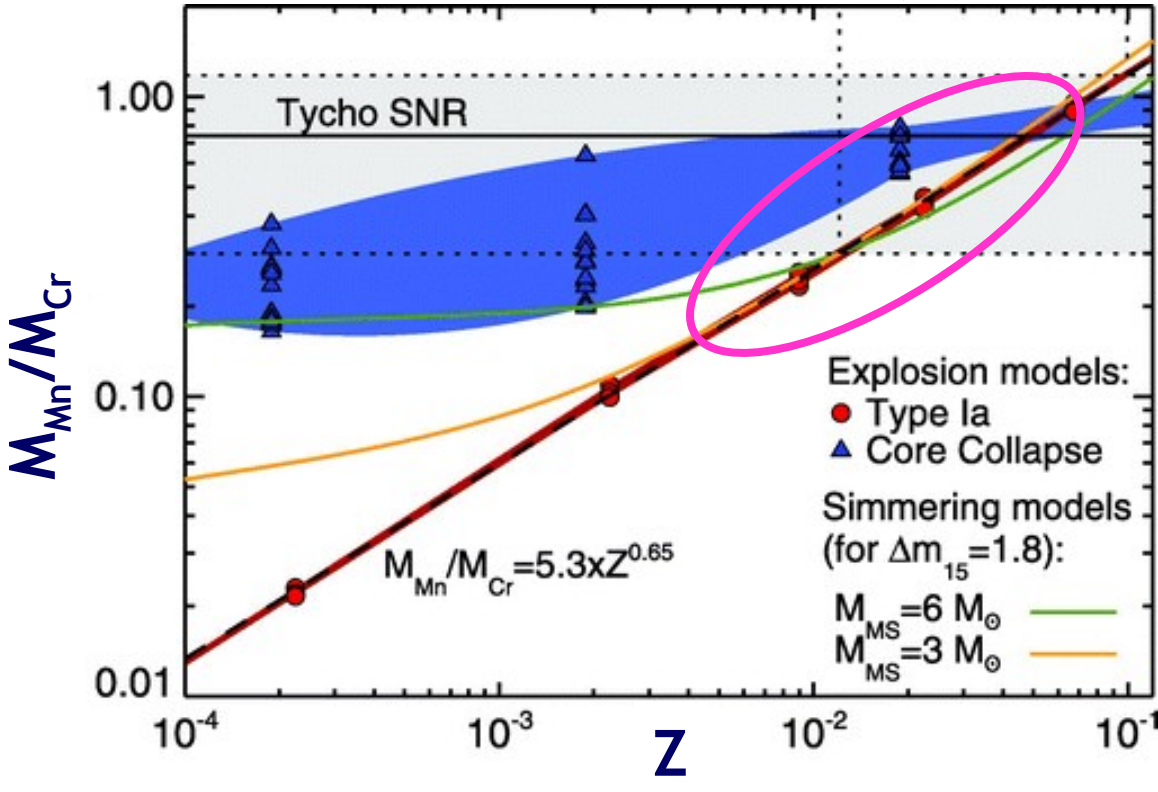
metallicity of progenitors has tight correlation with M_{Mn}/M_{cr}

$M_{Mn}/M_{cr} = 5.3 \times Z^{0.65}$ (Badenes+08)

very good indicator !

Optical observations cannot detect Mn
due to the strong emission line from ^{55}Fe
(2.7 yr half-life decay chain $^{55}Co \rightarrow ^{55}Fe \rightarrow ^{55}Mn$)

X-rays are
the ideal tool
to know
the metallicity of
progenitors !



Suzaku detection of Cr and Mn emission lines from Tycho

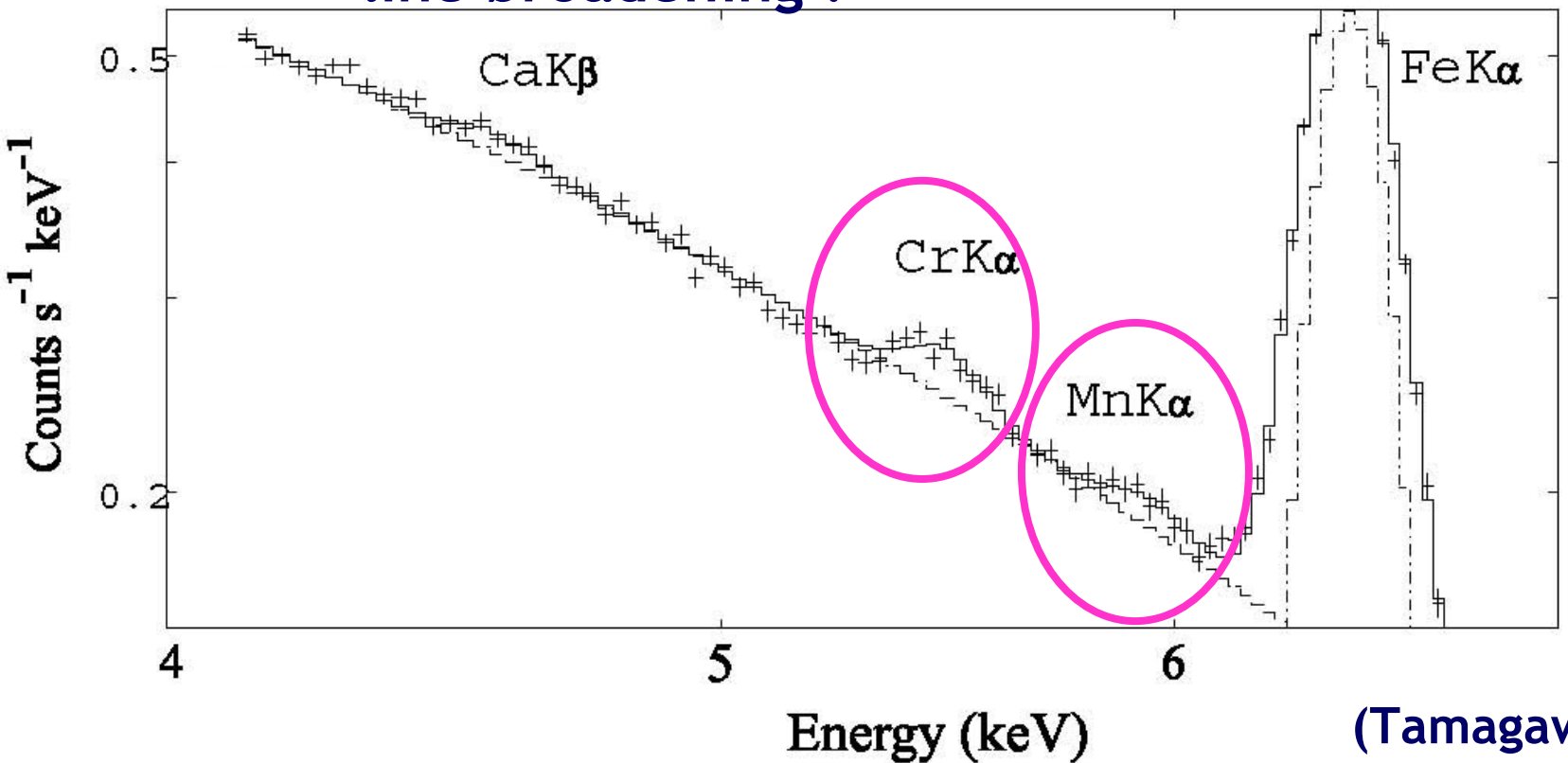
Suzaku 100ks observation -> detection of Cr and Mn lines !

M_{Mn}/M_{Cr} = 0.5 (0.2-0.7)

We need precise measurements of these lines

precise ratio ?

line broadening ?



(Tamagawa+08)

IXO observation of Tycho remnant

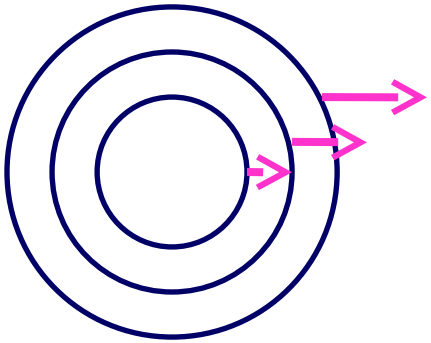
TES, 100ks observation (assumption: v_{exp} = 3000km/s)

Error of line intensity 5% -> error of M_{Mn}/M_{Cr} ~ 7%

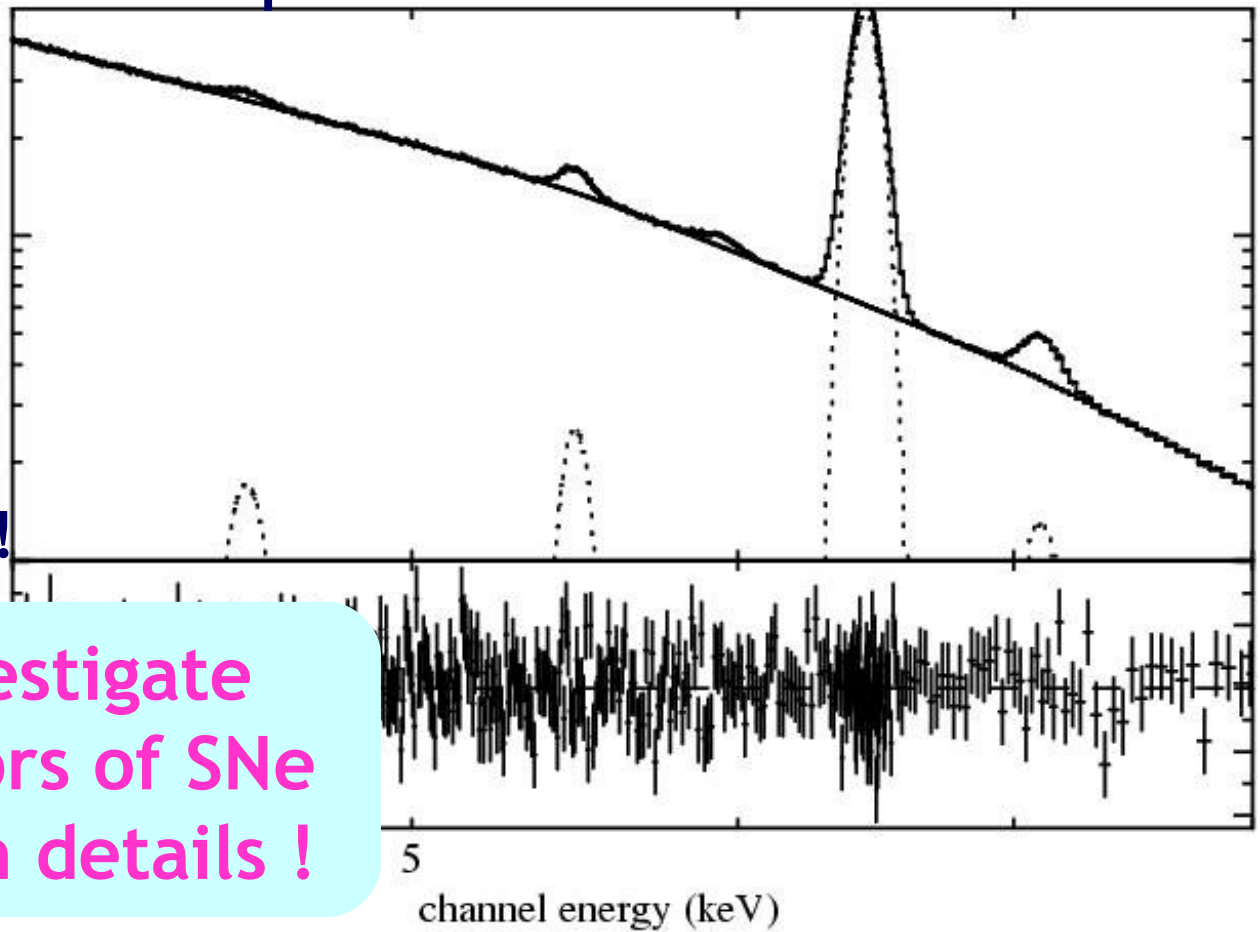
-> good estimation of the progenitor !

Error of line broadening 7% -> error of v_{exp} ~ 200km/s

-> the position of these elements !



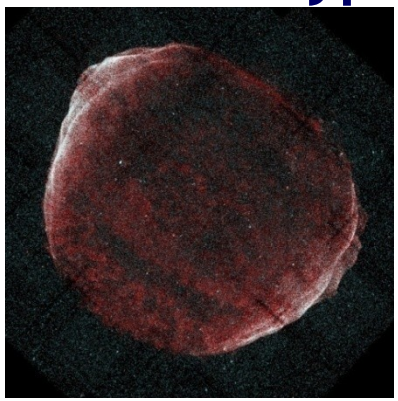
3D image of elements distribution!

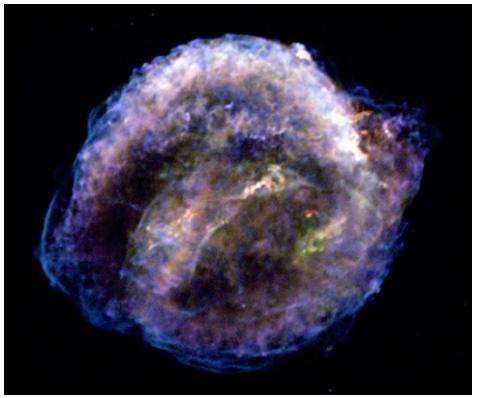


We can investigate the progenitors of SNe and explosion details !

Other targets ??

With IXO, we can detect Cr and Mn lines
from all of Galactic and LMC/SMC Type Ia SNRs !





Galactic SNRs

Kepler, SN1006,W49B? ….

determining
the progenitors
the 3D structure of every elements

LMC/SMC SNRs … ~8sigma detection of these lines

DEML71, N103B, 0509-675, 0519-690, DEML316A, …
dozen of samples

IXO will determine
Which stars can explode
and
How they explode

2. Elements beyond Fe

Elements beyond iron

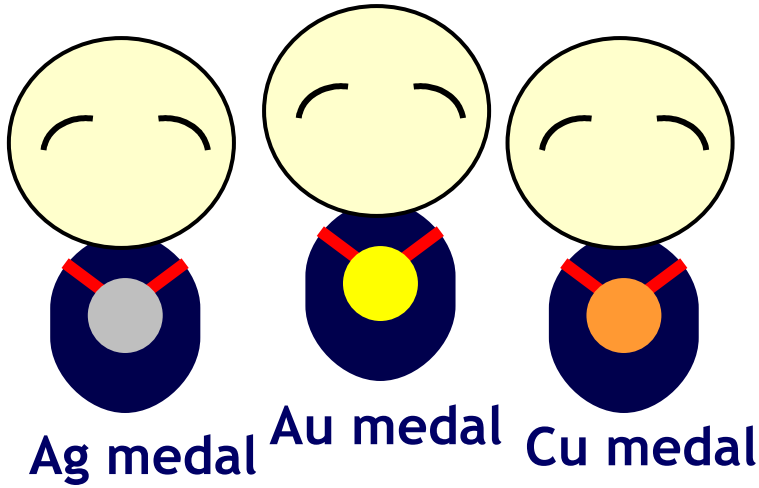
Elements beyond iron can be produced
only with Supernova explosion

key process: neutron capture in high density medium

s-process (slow process)

$$^{A}_{Z}X + n \rightarrow {}^{A+1}_{Z}X \rightarrow {}^{A+1}_{Z+1}Y$$

slower than beta-decay
-> # neutron ~ # proton
only smaller than ^{209}Bi



Olympic medalist !

r-process (rapid process)

$$^{A}_{Z}X + n + n + n + \ldots \rightarrow {}^{A+b}_{Z}X \rightarrow \ldots \rightarrow {}^{A+b}_{Z+b}Y$$

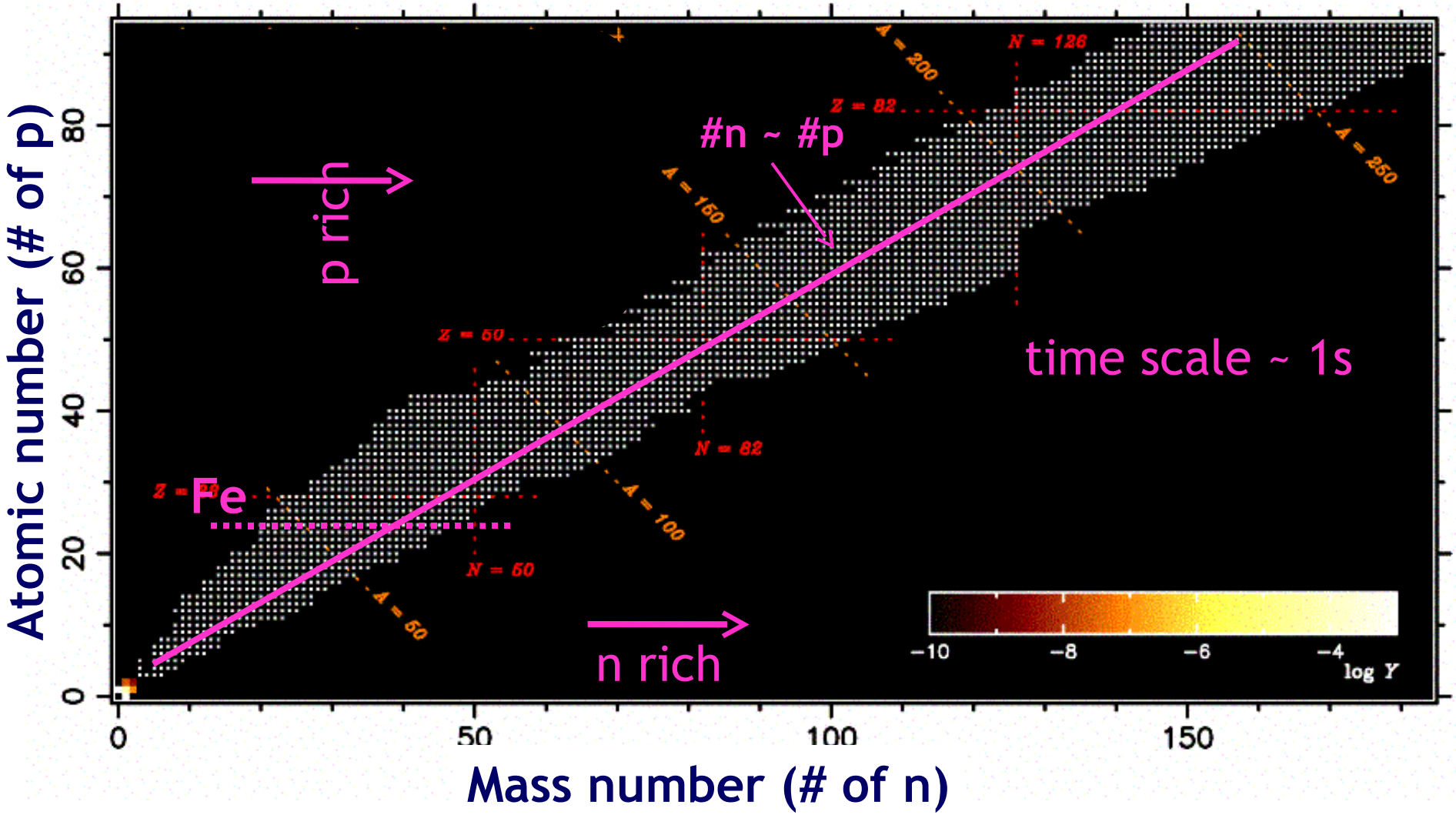
faster than beta-decay
-> # neutron >> # proton

s and r-processes
crucial to understand
the elements beyond iron !

It should be
one of the key program
in the COSMIC VISION
“Life Cycle of Matter”

r-process procedure

(Courtesy of Dr.Wanajo)



n-rich elements are all radio-active

emission line on their decay is the direct evidence of such processes (independent from kT, n, …)

Can IXO detect lines from decay chains of r-process nucleus ?

Too many decay chains of r-process nuclei !

stable nuclei: ~300

unstable nuclei: ~ 6000-8000 ??

Line energy:

~ 10 keV - a few MeV

we can select lines detectable with IXO HXI

Lifetime:

<1s - ~stable

we can select decay series depending on our targets

Line flux:

1Ms obs., E.A.=$10^3 cm^2$, bgd = almost free

detectable if $F_\gamma > 10^{-8}$ ph $cm^{-2}s^{-1}$

(10 cnts @ 1Ms)

Target candidates

(1) young and near SNRs

Cas A	(t=320 yrs	d=3kpc	size=3arcmin)	
Vela Jr.	(t=1000yrs	d=1kpc?	size=2deg.)	} too large
Vela	(t=old	d=250pc	size=4deg.)	} too large
Cyg Loop	(t=old	d=440pc	size=4deg.)	} too large
G1.9+0.3	(t=140yrs	d=8kpc	size=arcmin)	} too far
SN1987A	(t=21yrs	d=60kpc	size=point)	} too far

(2) Galactic SNe

1 event per every 30 years in our Galaxy ?

Major decay chains of r-process nuclei (1)

Best lifetime is between 100 - 10000 years for SNRs

Best target: Cas A (320 yrs, 3kpc) (Qian+99)

r-process nucleus	life (10^3yr)	E (keV)	F_γ for Cas A (10^{-8} γ cm^{-2}s^{-1})
^{226}Ra -> ... -> ^{214}Bi	2.31	242	8.9×10^{-3}
		295	2.2×10^{-2}
		352	4.2×10^{-2}
... -> ^{214}Po		609	5.2×10^{-2}
^{229}Th -> ... -> ^{225}Ac	10.6	40.0	8.3×10^{-2}
... -> ^{213}Po		440	7.4×10^{-2}
^{241}Am -> ... -> ^{237}Np	0.624	59.5	9.7×10^{-2}
^{243}Am -> ... -> ^{239}Np	10.6	74.7	1.8×10^{-2}
... -> ^{239}Pu		106	7.4×10^{-2}
^{249}Cf -> ... -> ^{245}Cm	0.506	333	4.3x
		388	1.2x
^{251}Cf -> ... -> ^{247}Cm	1.3	177	3.0x
		227	1.1×10^{-2}

too faint for IXO ...

Major decay chains of r-process nuclei (2)

Best lifetime is between 1 - 100 years for SNe

(lines w. lifetime < 1yrs cannot go out due to dense material)

Considering SNe at 10 kpc

r-process nuclei	life (yr)	E (keV)	F_γ ($10^{-8}\gamma$ $cm^{-2}s^{-1}$)
^{125}Sb -> ^{125}Te	3.98	35.5	7
		176	11
		.....	
^{137}Cs -> ^{137}Ba	43.4	662	3.5
^{144}Ce -> ^{144}Pr -> ^{144}Nd	1.12		80.1 3.5
		134	29
		.....	
^{155}Eu -> ^{155}Gd	6.87		86.5 5.0
^{194}Os -> ^{194}Ir -> ^{194}Pt	8.66	43.1	6.5
		294	3.1
		328	16
		.....	

detectable with IXO !
press release:
“fingerprint of alchemists”

(Qian+98, Tanaka+ in prep.)

Detecting fingerprint of r-process

difficult with young SNRs even with IXO HXI
larger effective area or larger FOV is needed

possible with galactic SNe !

It is very challenging,
but hard X-ray study is the ONLY way
to untangle this problem

We are now searching for more decay chains
which can be detected with IXO

3. CR acceleration in SNRs

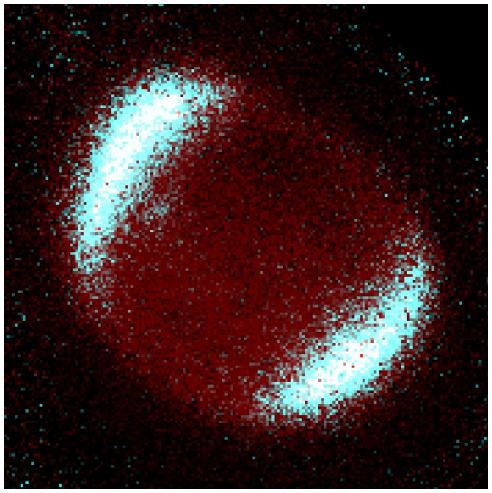
CR acceleration sites

Cosmic Rays (CR): one of the main component of our Galaxy

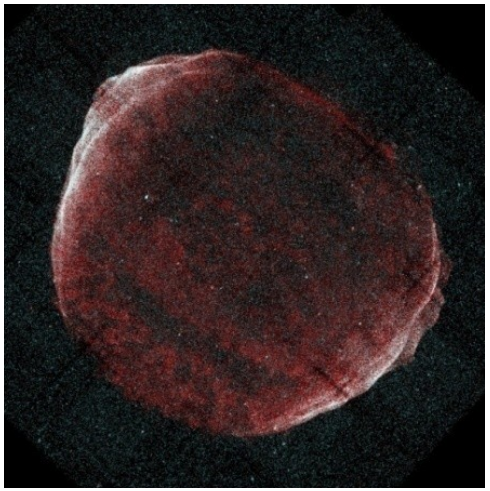
cosmic rays	~ 1 eV/cc
stellar light	< 0.3 eV/cc
magnetic field	0.3 eV/cc
turbulence	0.3 eV/cc
thermal energy	0.01 eV/cc

shocks of SNRs: CR acceleration site
sync. X-rays: the firm probe of TeV e

(Koyama+95)



acceleration efficiency: very efficient !?
thin filaments -> B amplified?
(Bamba+03,05; Vink+03; Uchiyama+07; ….)



Direct evidence of rapid acceleration ??

year scale time variability of nonthermal filaments in RXJ1713-3946

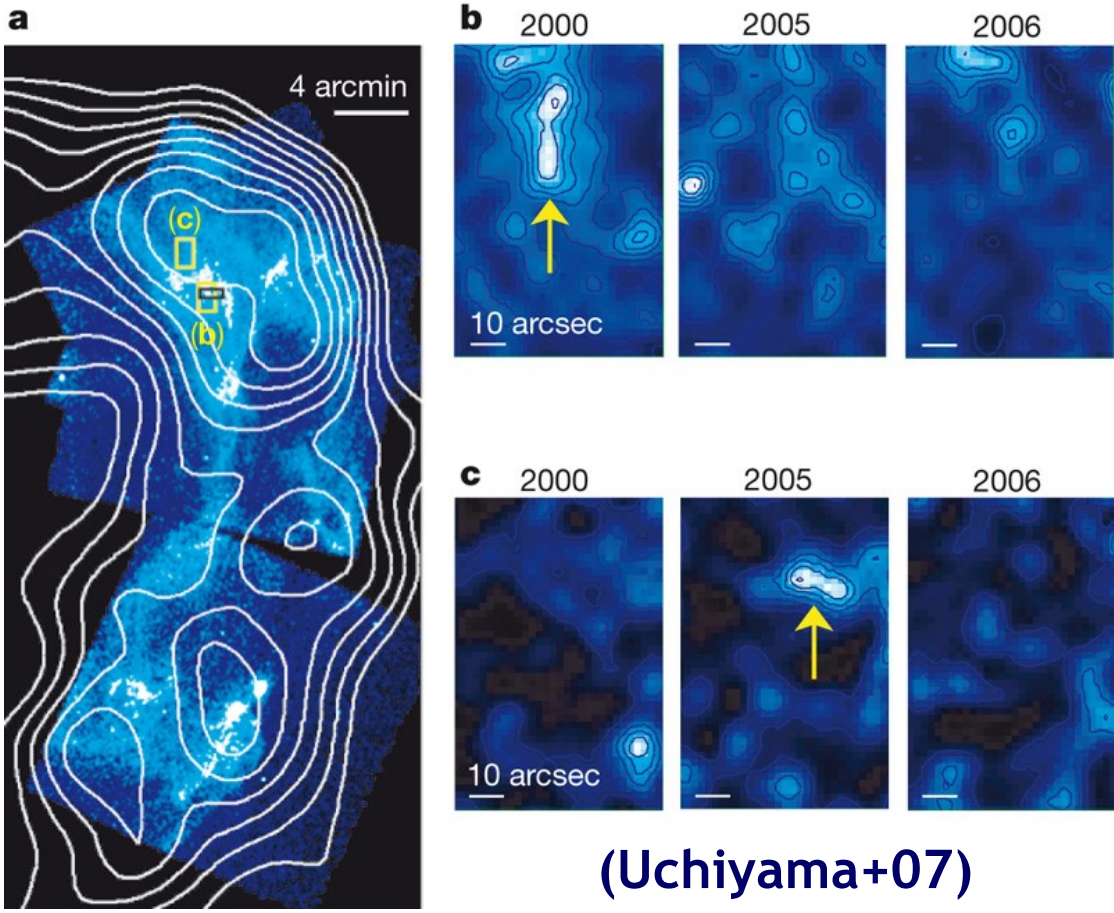
synchrotron loss ~ 1yr -> B >= 1mG !!

acc.time-scale ~ 1yr -> very very efficient !!

How about total emission?

Only a few % of emission is time variable

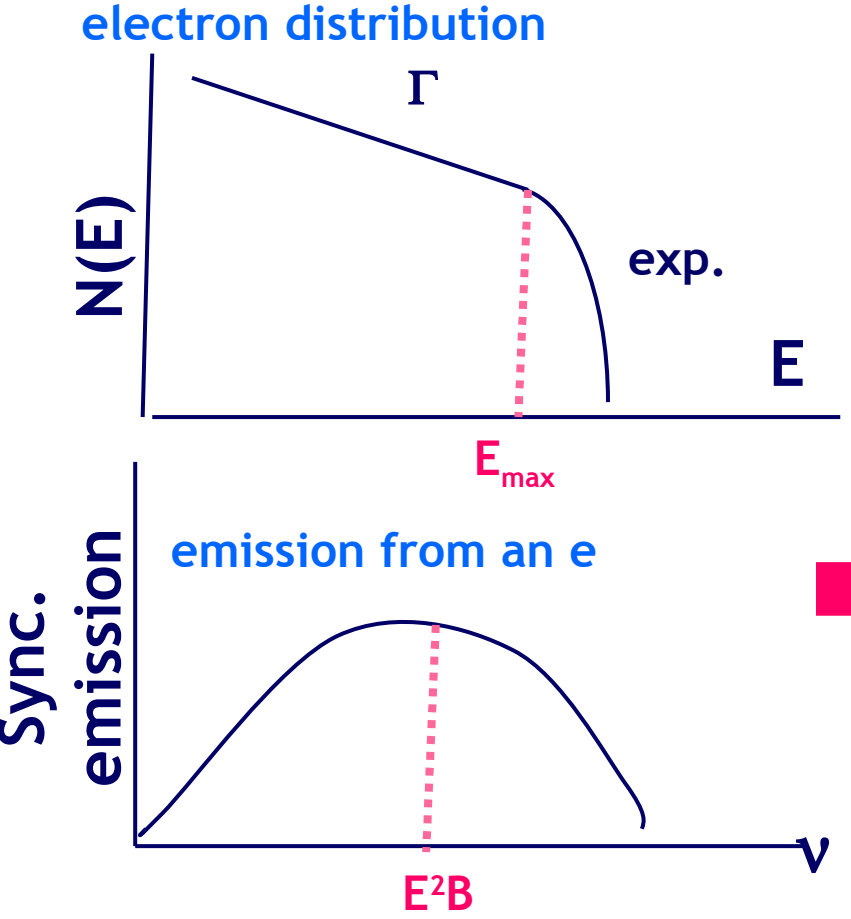
The acc. is efficient in total ??

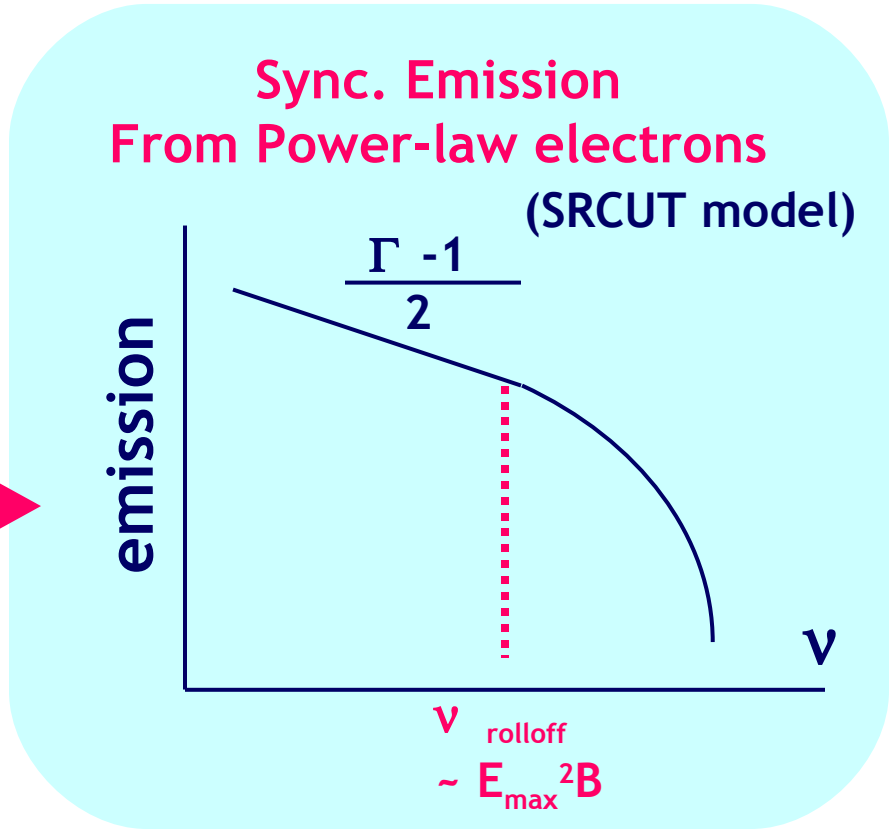


(Uchiyama+07)

How to search for efficient acceleration ?

synchrotron X-rays have roll-off



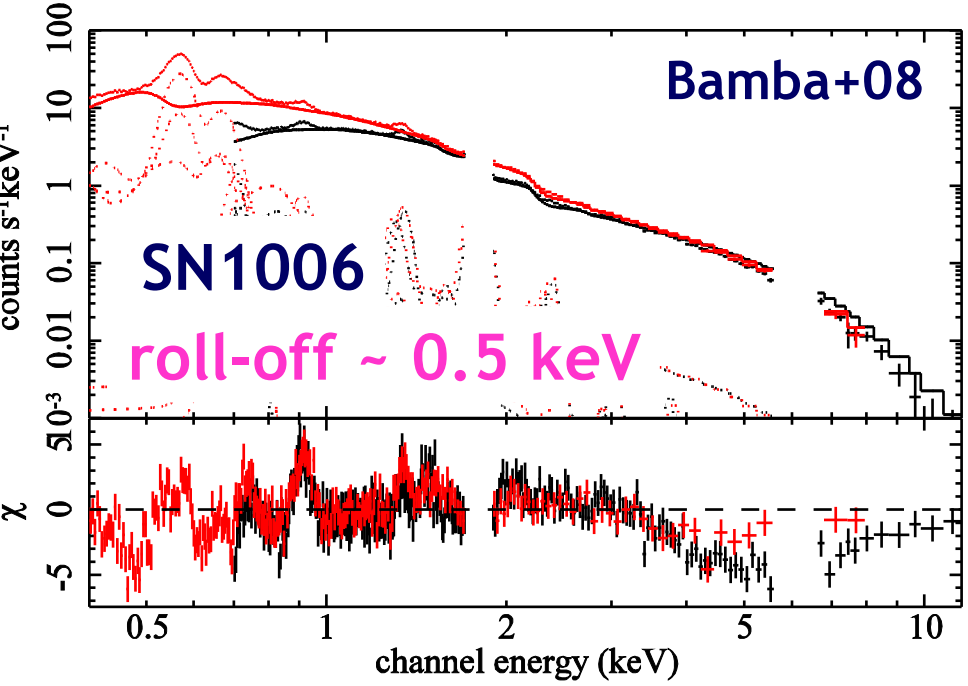


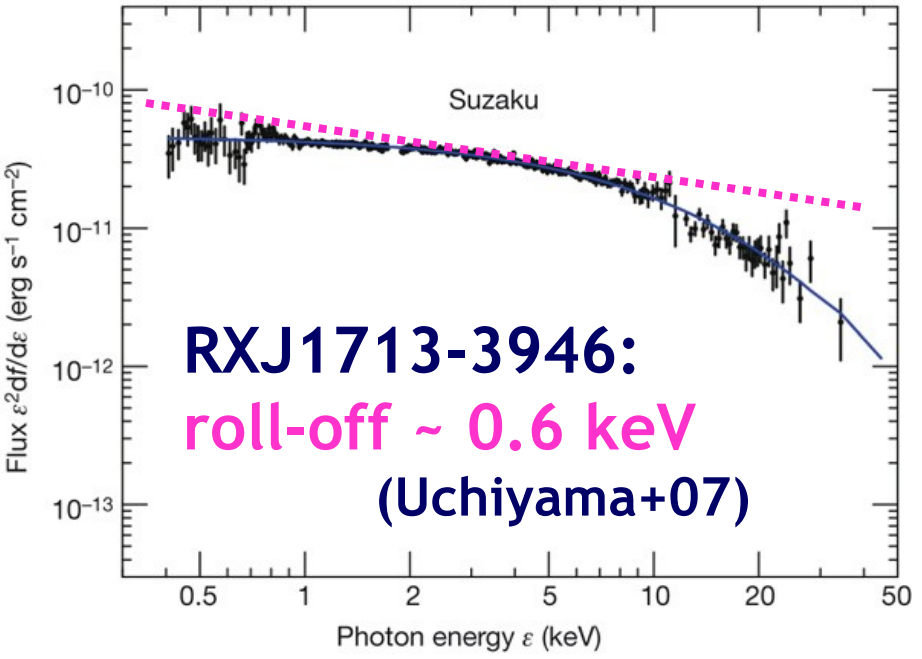
$$\text{roll-off freq.} = 1.6\times10^{16}\left(\frac{B}{10\,\mu\,G}\right)\left(\frac{E_{max}}{10\text{TeV}}\right)^2 \quad [\text{Hz}]$$

(Reynolds 1998)

B: magnetic field E_{max}: the maxmimum E of e

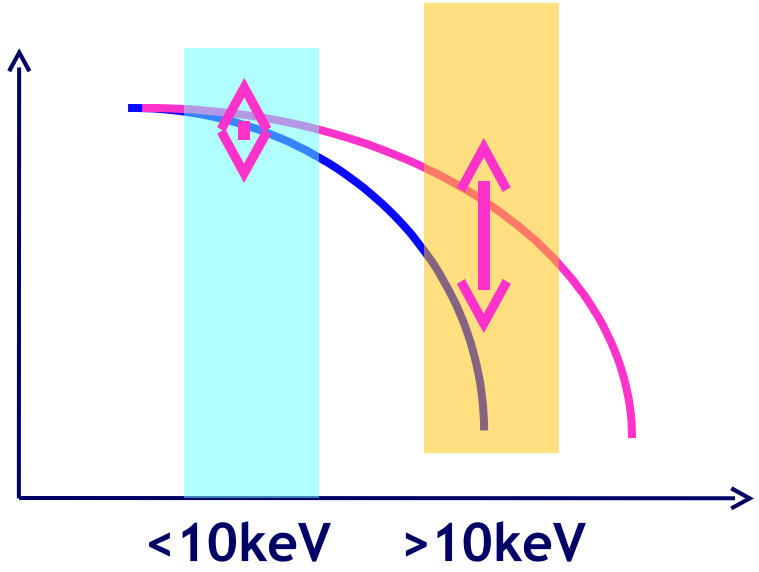
The roll-off is around a few keV





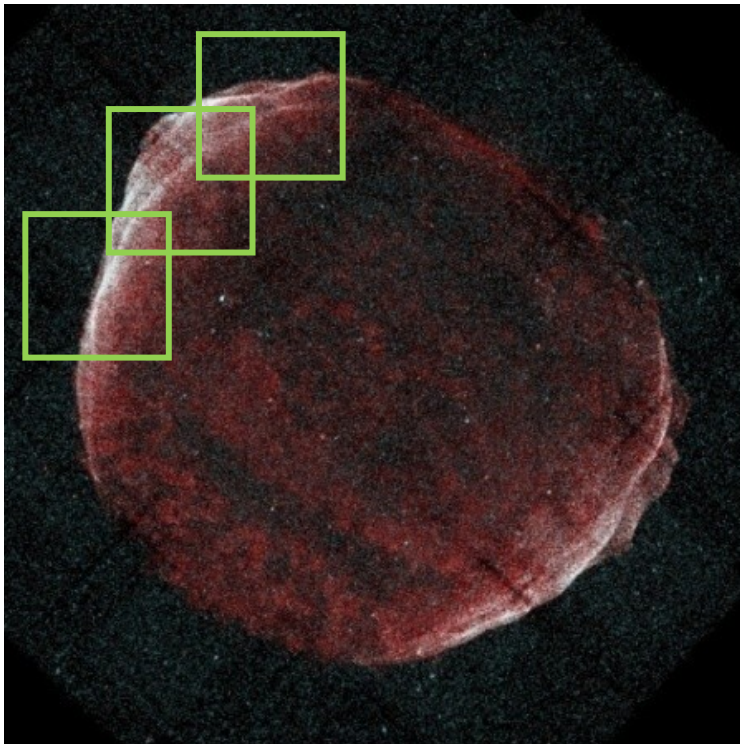
efficient acc.
-> roll-off changes with BxE^2

The change can be seen much easier in higher energy wider energy range help it.



SN1006 with IXO

NE rim can be covered with HXI
with 3 pointings



100ks observations

90 src photons in 5”x5”
(PSF and filament width)
-> ~10 % variability can be
resolved

The roll-off freq. is determined
within the errors of 10^{16}Hz (0.1 keV) in every 5”x5”
Condition is better combining data of WFI

The short-time-scale acc. is common or not ??
-> efficient acceleration is common or not ??

Summary

- SNRs makes the variety in the universe

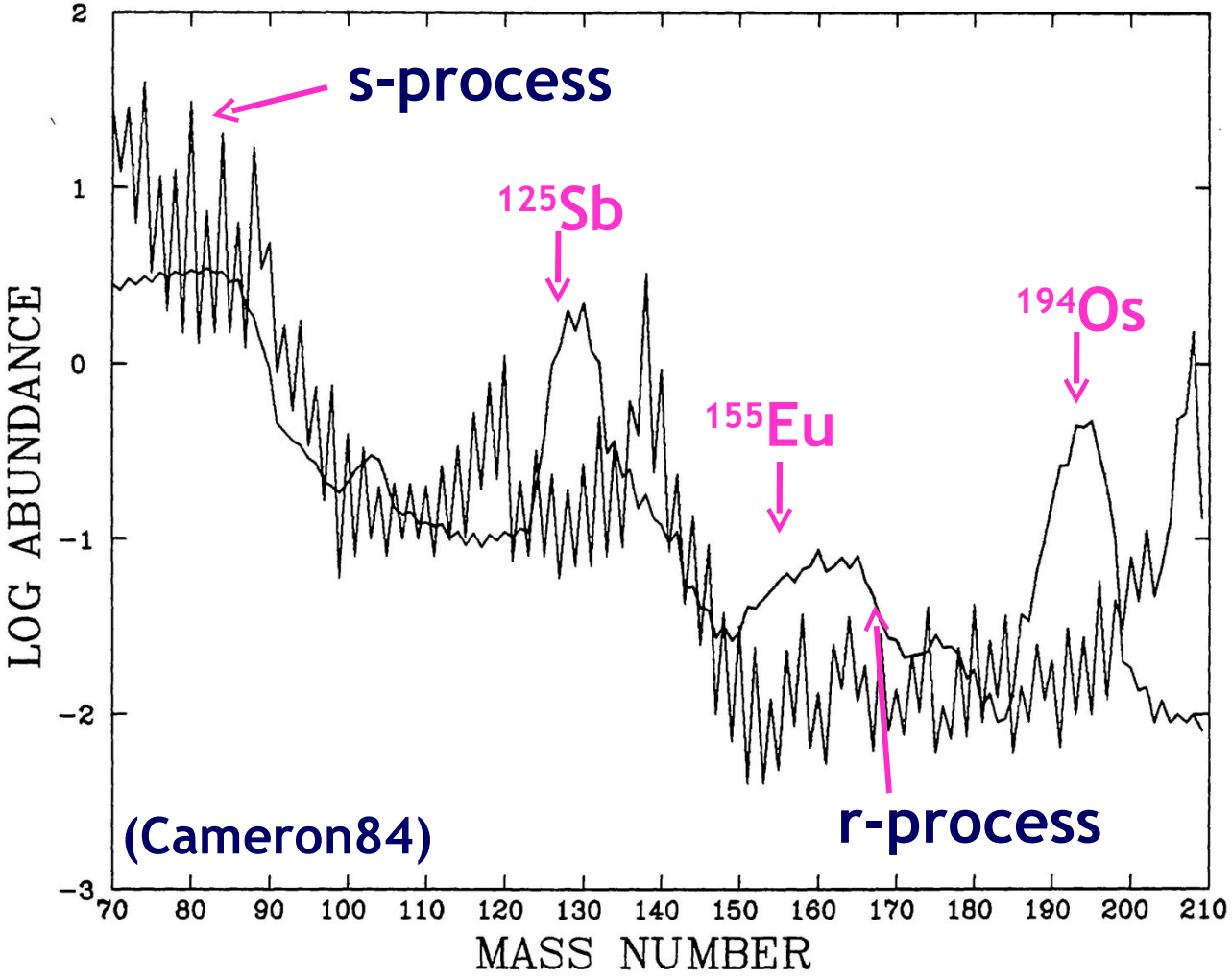
- IXO TES will detect rare-metals in SNRs like Cr and Mn
  and determine the explosion mechanism of SNe.

- Elements heavier than iron can be made
  only through s- and r-processes. Only IXO can detect them.
  We need large E.A. and larger energy band for HXI.

- IXO WFI/HXI can distinguish
  whether the acceleration on the shocks of the remnants
  are efficient or not.

Lighter elements ?

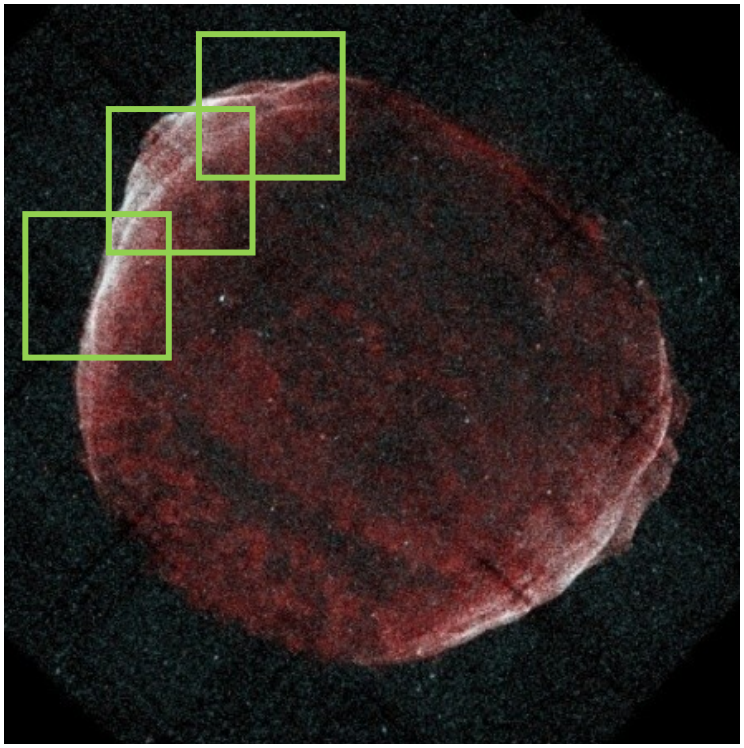
We cannot distinguish slow and rapid processes but ..



We can select elements made in r-process mainly.

SN1006 with IXO

NE rim can be covered with HXI with 3 pointings



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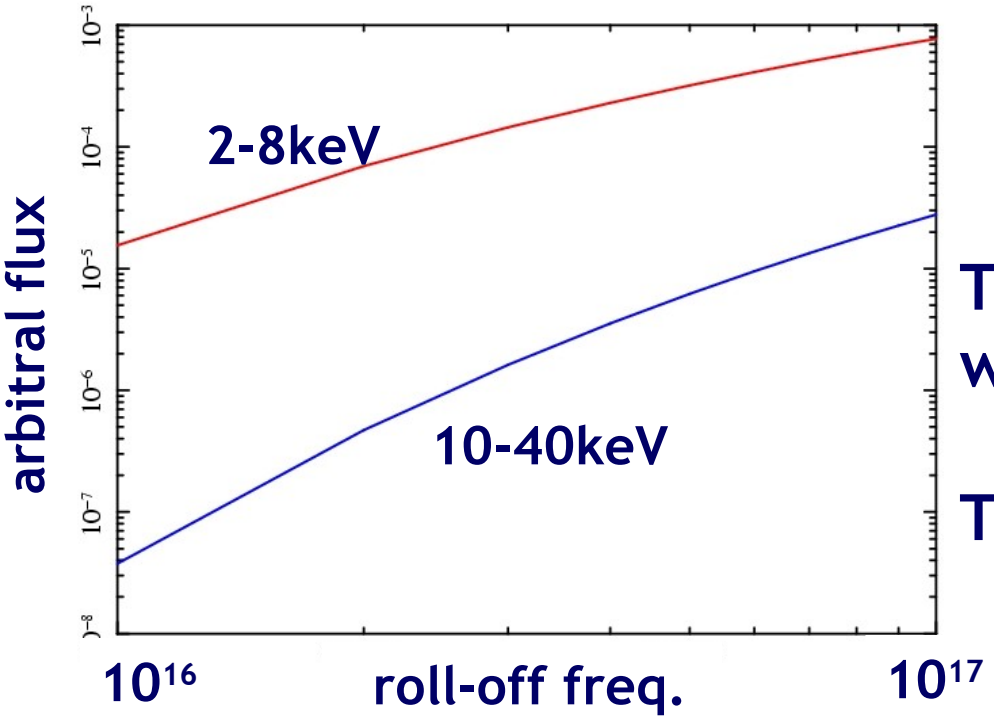

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