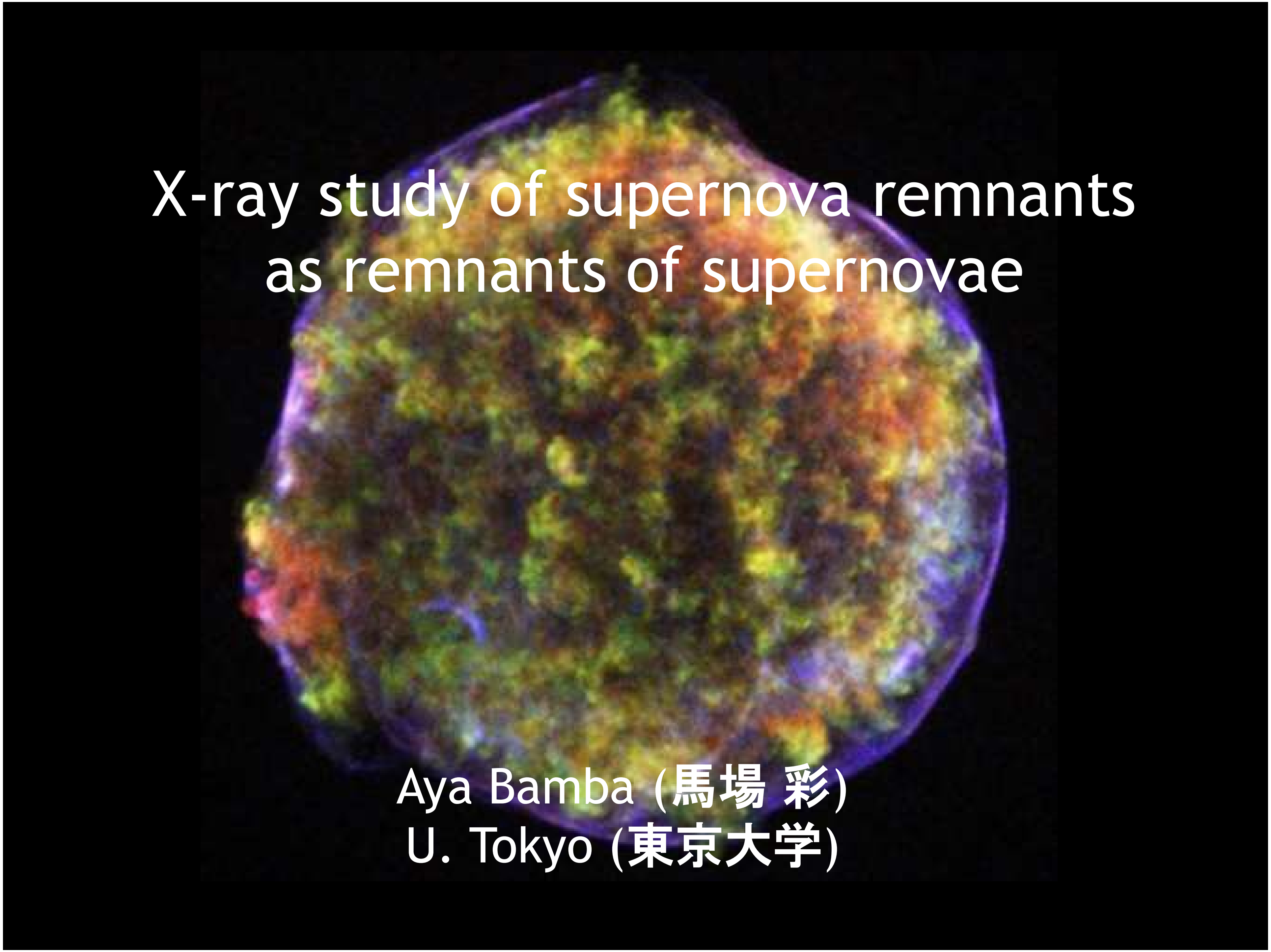
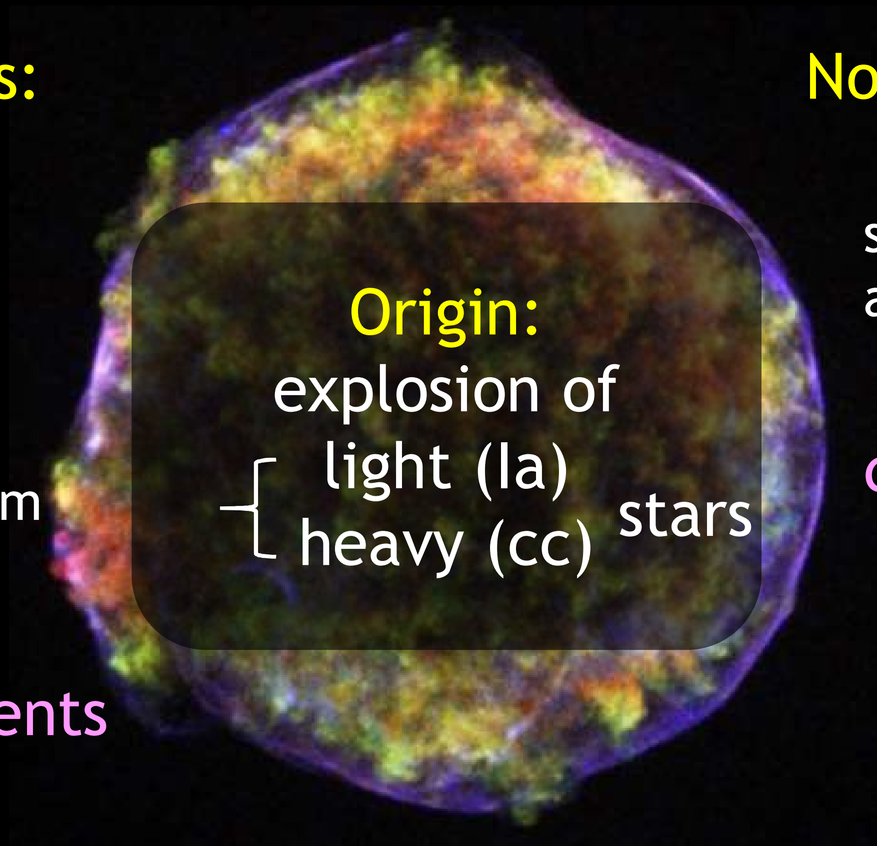
X-ray study of supernova remnants as remnants of supernovae



Aya Bamba (馬場 彩)
U. Tokyo (東京大学)

1.1. Role of supernova remnants in the universe



Thermal aspects:

thin plasma
with $kT \sim$ keV
time scale
$<\sim 10^4$ yrs
in non-equilibrium

distribute
heavy elements

Origin:

explosion of
light (Ia)
heavy (cc)
stars

Nonthermal aspects:

shock $v \sim 10^{3\text{-}4}$ km/s
accelerate particles
efficiently

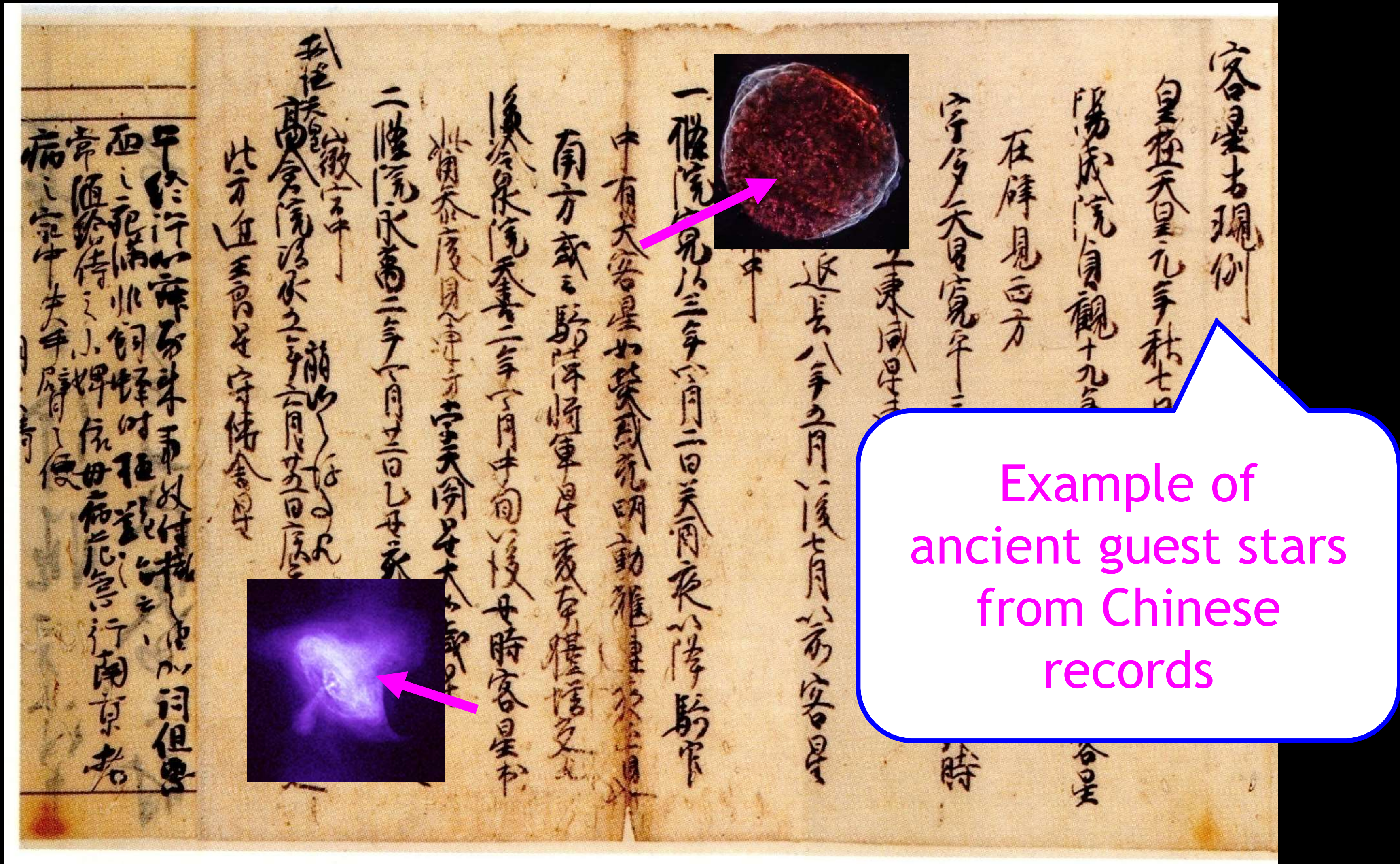
distribute
cosmic rays

distribute
thermal/kinetic E
compact stars

SNRs makes the diversity of the universe !

We kept optical observations of SNe long time !

明月記 (Teika Fujiwara)



the number is limited

How energetic the explosions are ?

Total energy: 10^{53} erg

99% of the energy escape via neutrino

Kinetic energy: 10^{51} erg

<-> 1 yr electricity usage in China

2.5e26 erg

total emission of the Sun in its life

~10^{51} erg

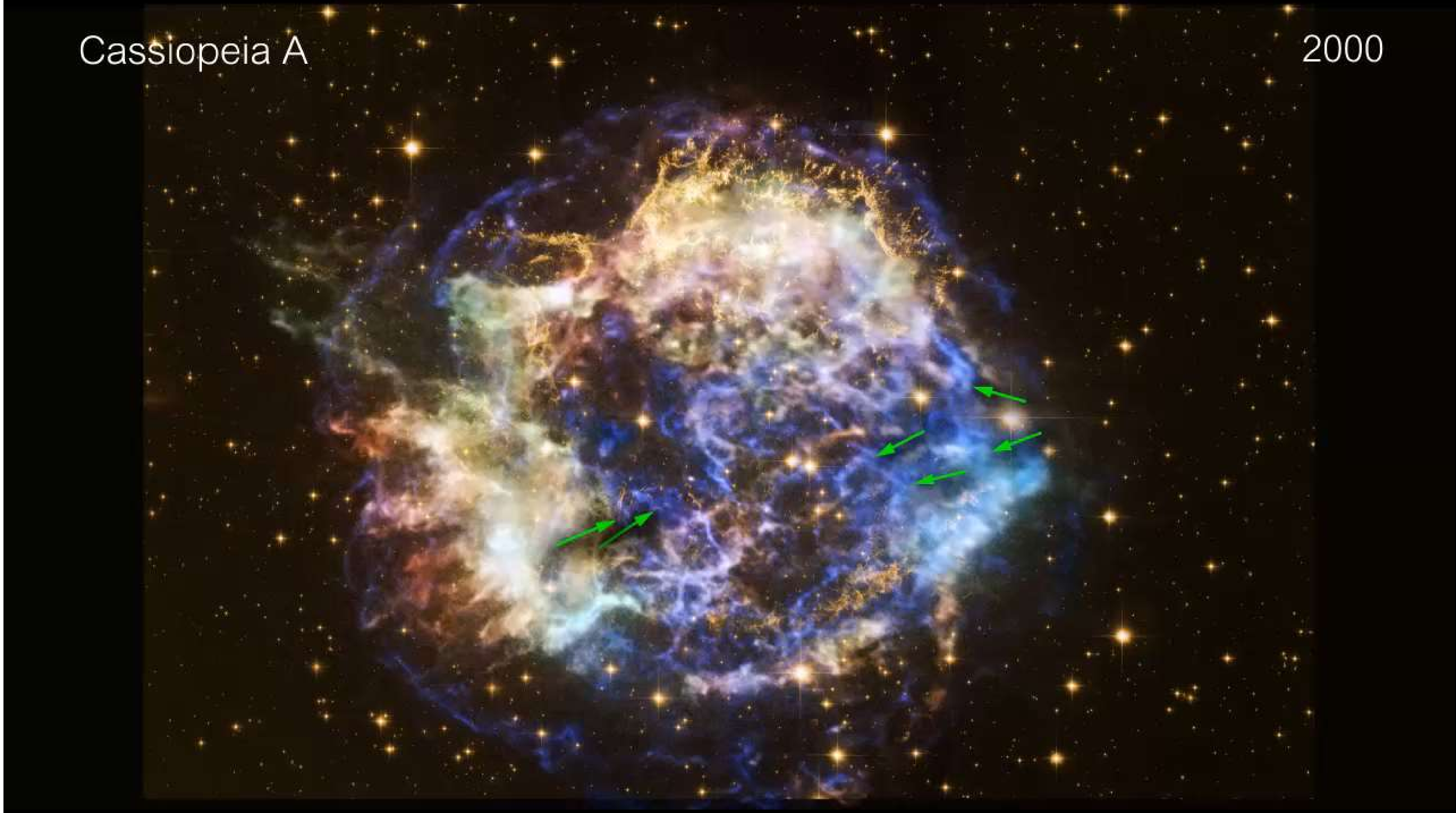
total mass ~ 1 Mo

$E = \frac{1}{2}$ Mo v^2

-> initial velocity: 1e4 km/s

3% of light speed

Chandra movie of Cas A (SN1682) expansion



https://chandra.harvard.edu/photo/2019/firstlight/

1.2. Why X-ray observations are strong to understand SNRs?

shock velocity: $10^{3\text{-}4}$ km s^{-1}

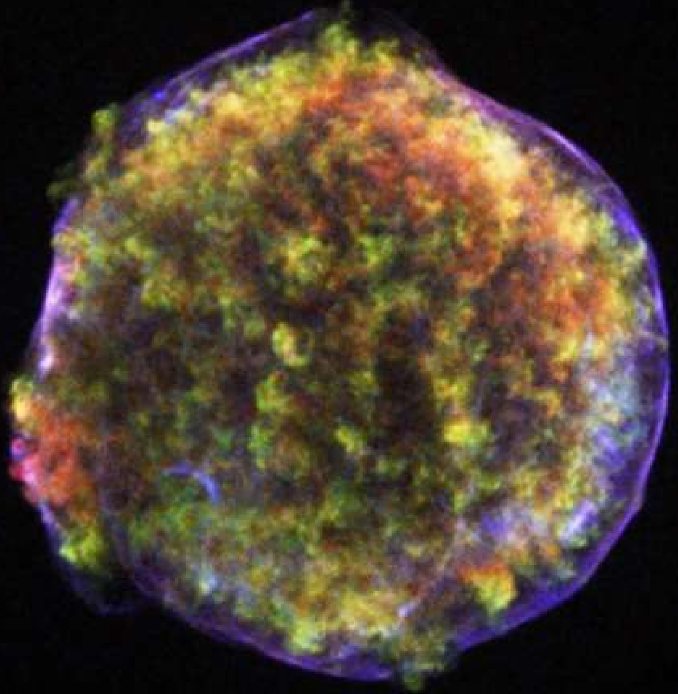
-> ejecta and interstellar medium heat up to ~1 MK or 0.1 keV

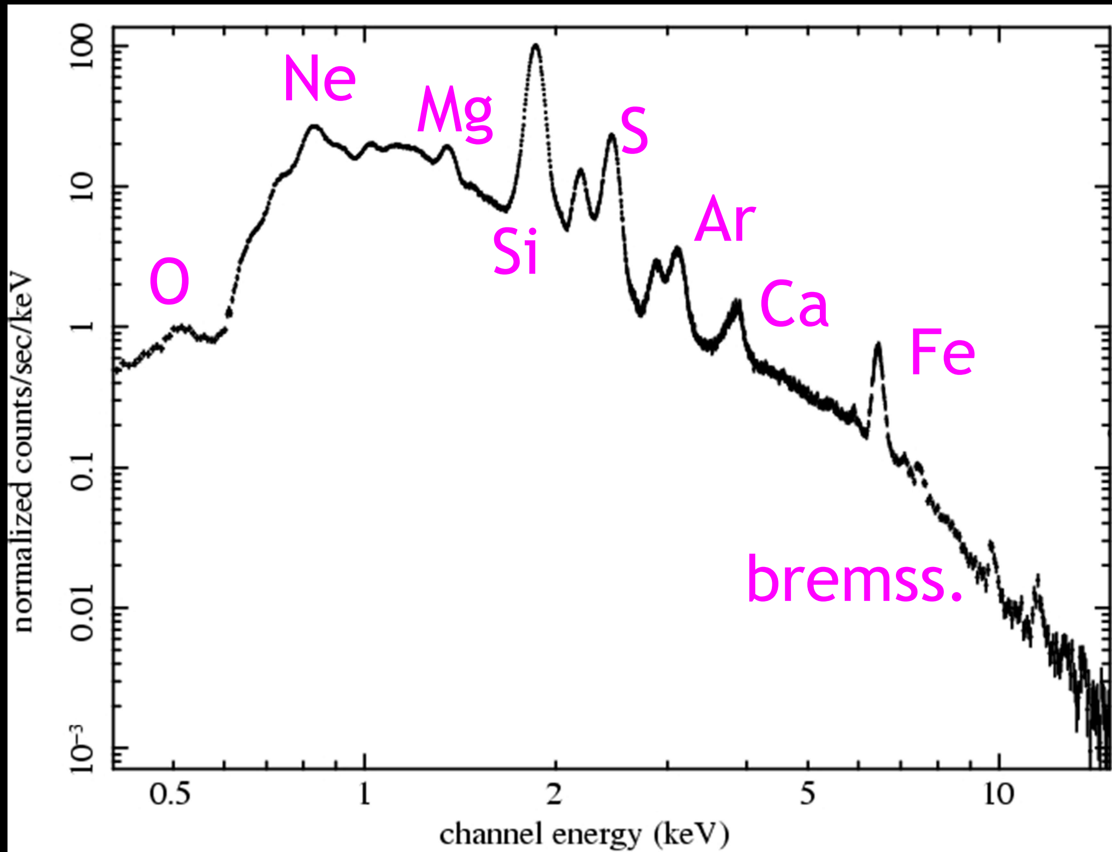
-> ionized thin thermal plasma (n ~ 1 cm^{-3})

-> thermal bremsstrahlung in X-ray band

+ characteristic X-rays from ionized heavy ions

Image & spectrum of Tycho remnant (SN1572)





1.3. Types of Supernova remnants

Type Ia

End-point of
mass accretion to WD
up to M_{ch} (SD)
or
WD-WD merger (DD)

A lot of Fe, Ni, Cr, Mn
Isotropic explosion ?

"Standard candle"

Core-collapsed (CC)

End-point of
heavy stars (>~ 10 M_{O})

A lot of lighter elements
O, Ne, Mg, Si, S, ...

Neutron stars, black holes

Questions:

Can we distinguish Ia/cc for SNRs with X-ray observations ?
Do they have diversity more than types ?
SD/DD progenitor mass of CCs ?
Important to understand how the universe became such enriched world.

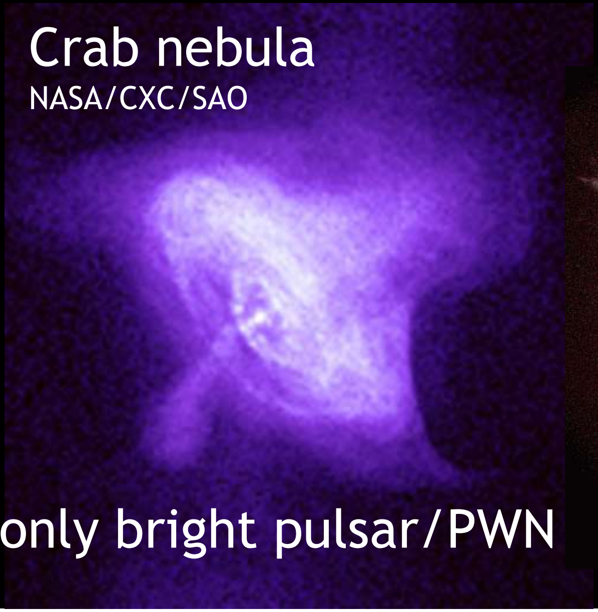
1.4. Conventional method of type diagnostics

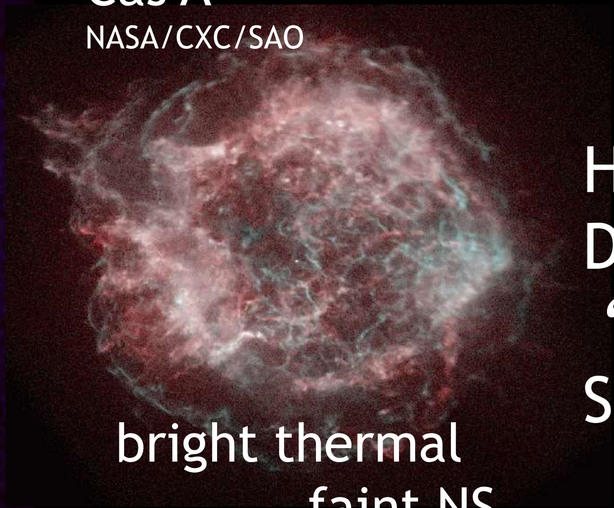
(1) Searching for compact sources

Some of CC SNe: remain neutron stars
Ia SNe: remain nothing

Young neutron stars:
emit blackbody emission with kT ~ keV
forms pulsar wind nebulae with bright synchrotron X-rays

They are CC SNRs !



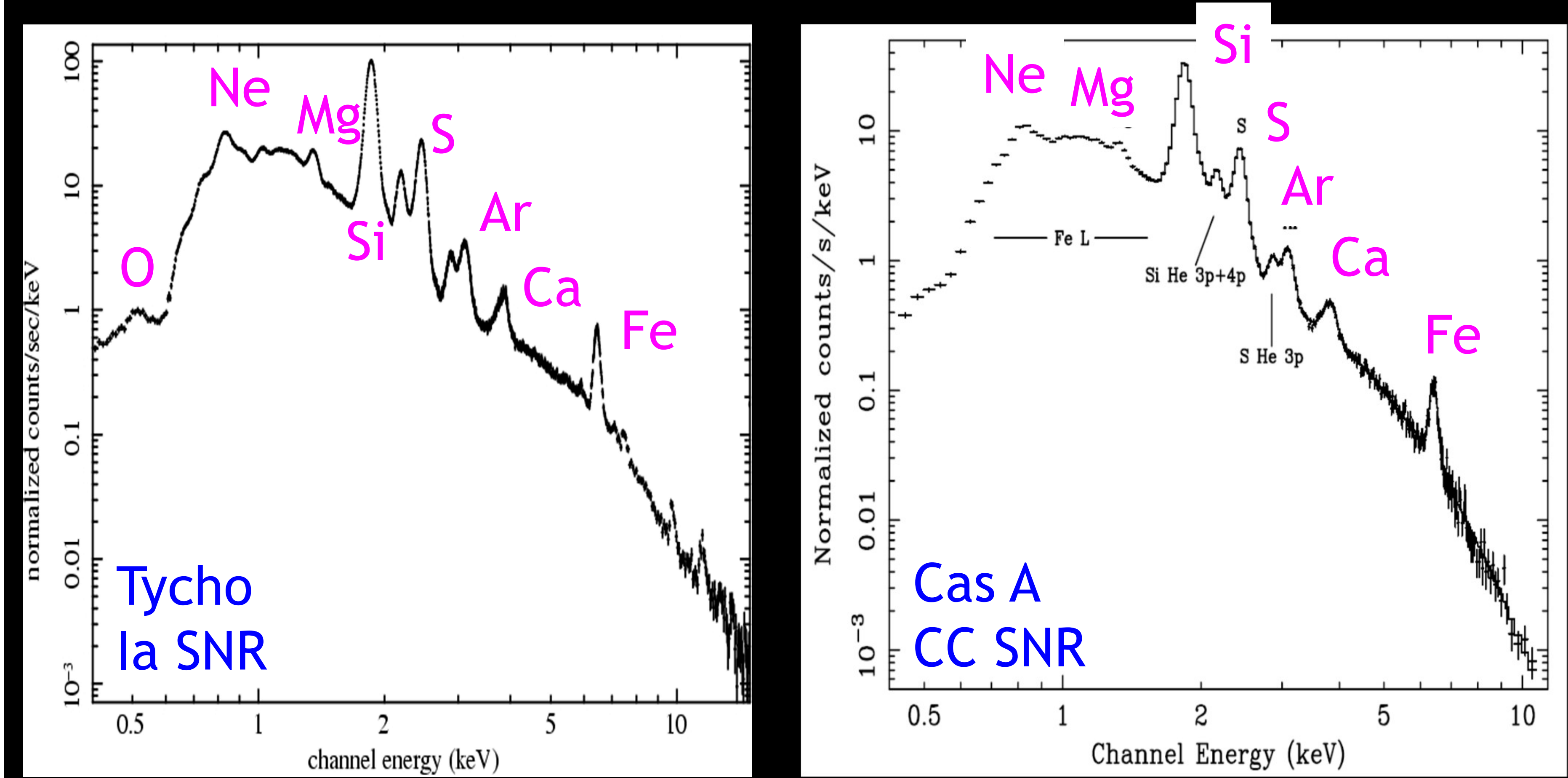


However ...
Difficult to say
"they do not have a NS".
Some CC do not remain
NSs.

(2) Abundance pattern of heated ejecta

Ia SNRs have abundant Fe / Fe group

CC SNRs have abundant lighter alpha-elements (Si, S, Mg, ...)



cannot see unheated ejecta -> cannot be used for very young SNRs

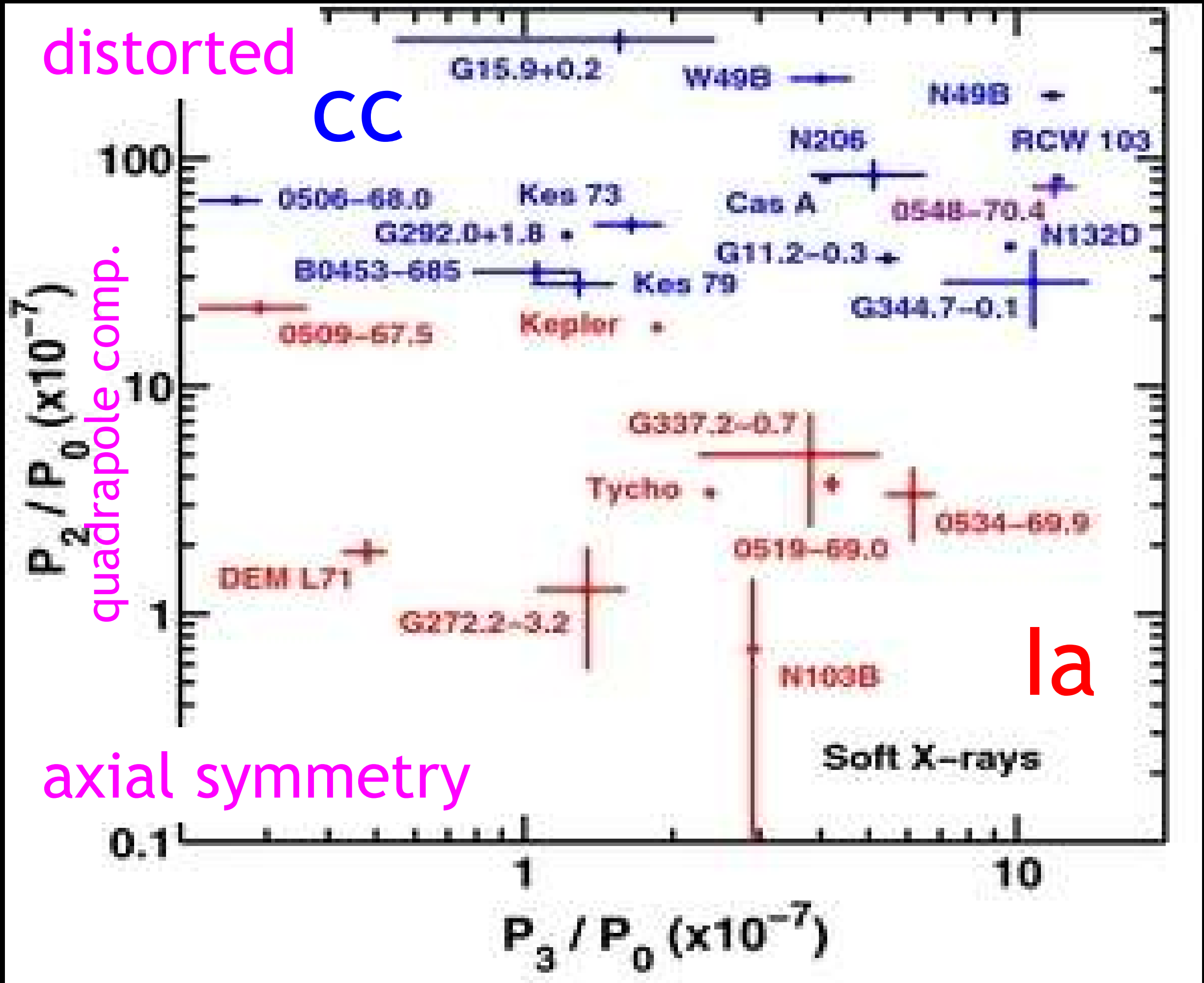
contamination of heated ISM -> cannot be used for old SNRs

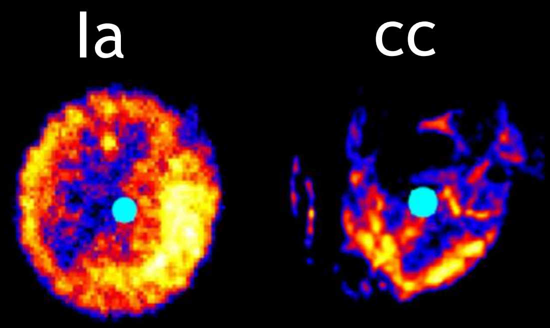
2. Diversity of progenitor explosion

2.1. Type estimation from X-ray morphology (Lopez+11)

Ia: isotropic explosion → circular SNR ?
cc: anisotropic explosion → more complicated SNR ?

Lopez+11: wavelet analysis of Chandra image of many SNRs



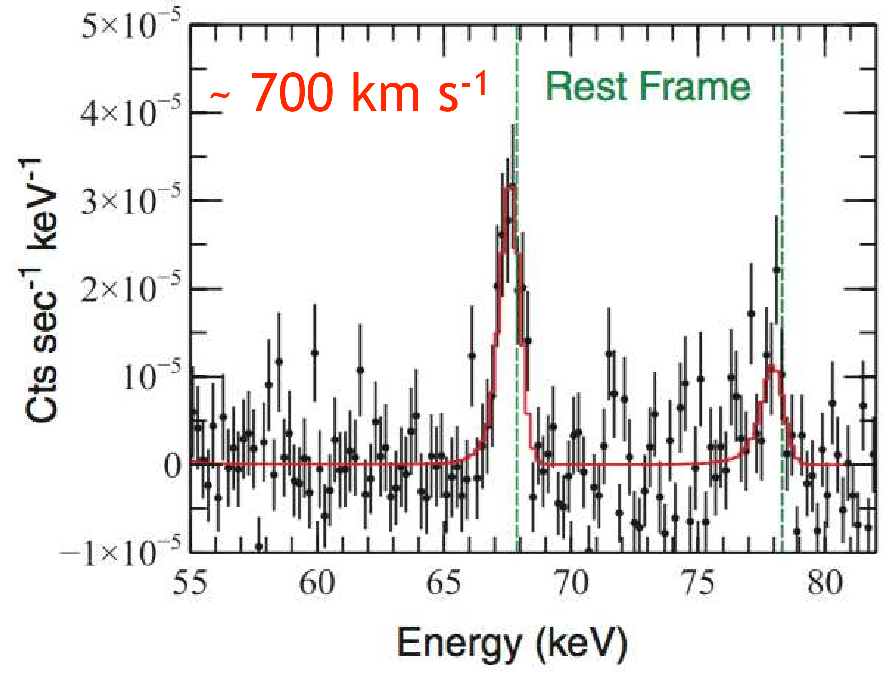


CC SNRs has more distorted morphology !

NuSTAR: ^{44}Ti enables us to access unheated ejecta

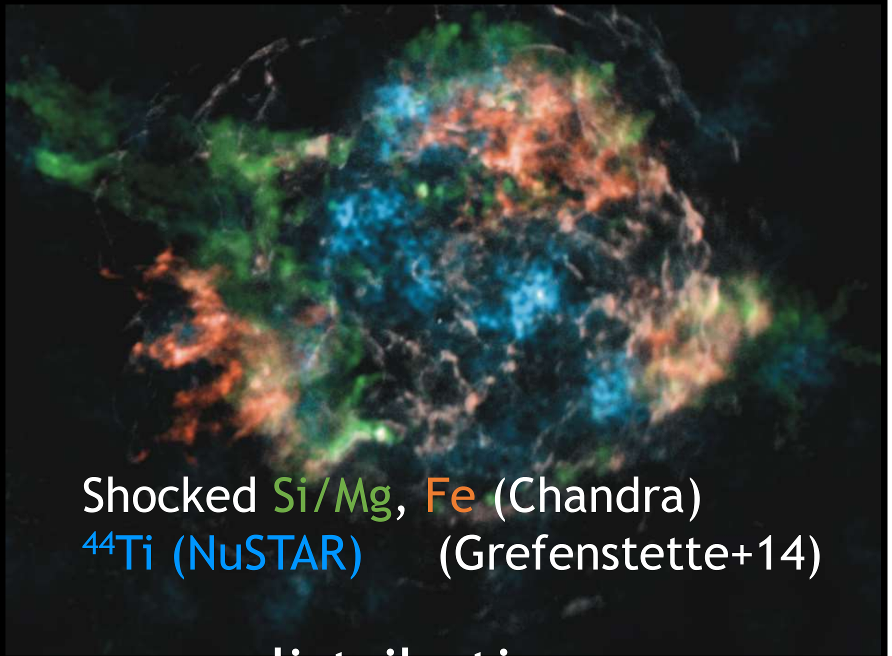
CC SNR expansion with ^{44}Ti

SN 1987A (~30 yrs)



Only red-shift ^{44}Ti line
-> asym. expansion of ejecta

Cas A (~330 yrs)

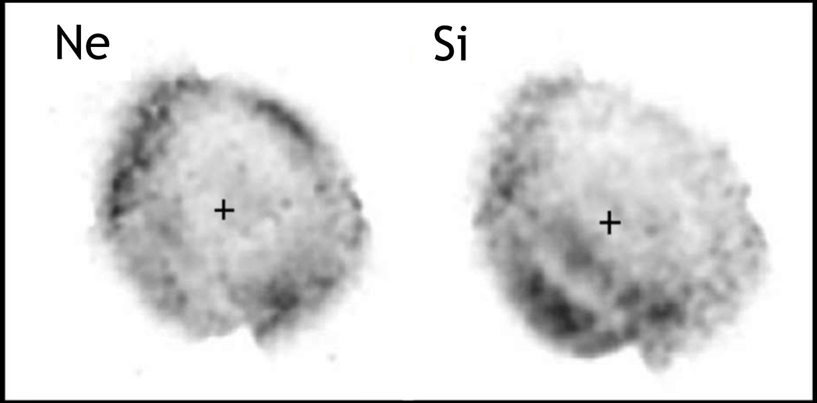


asym. distribution
Neither isotropic
nor axial symmetric
expansion

CC SNRs show highly asymmetric expansion

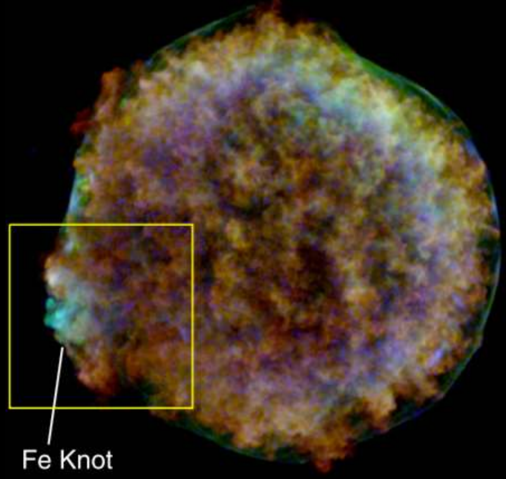
Does Ia expand isotopically ?

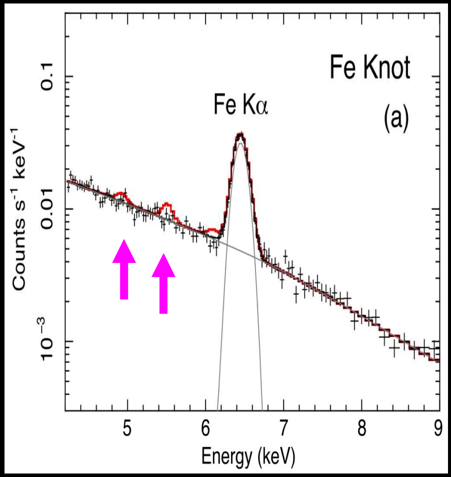
SN1006 (Uchida+13)



Si, S, Fe are abundant
in south eastern region

Tycho (Yamaguchi+17)





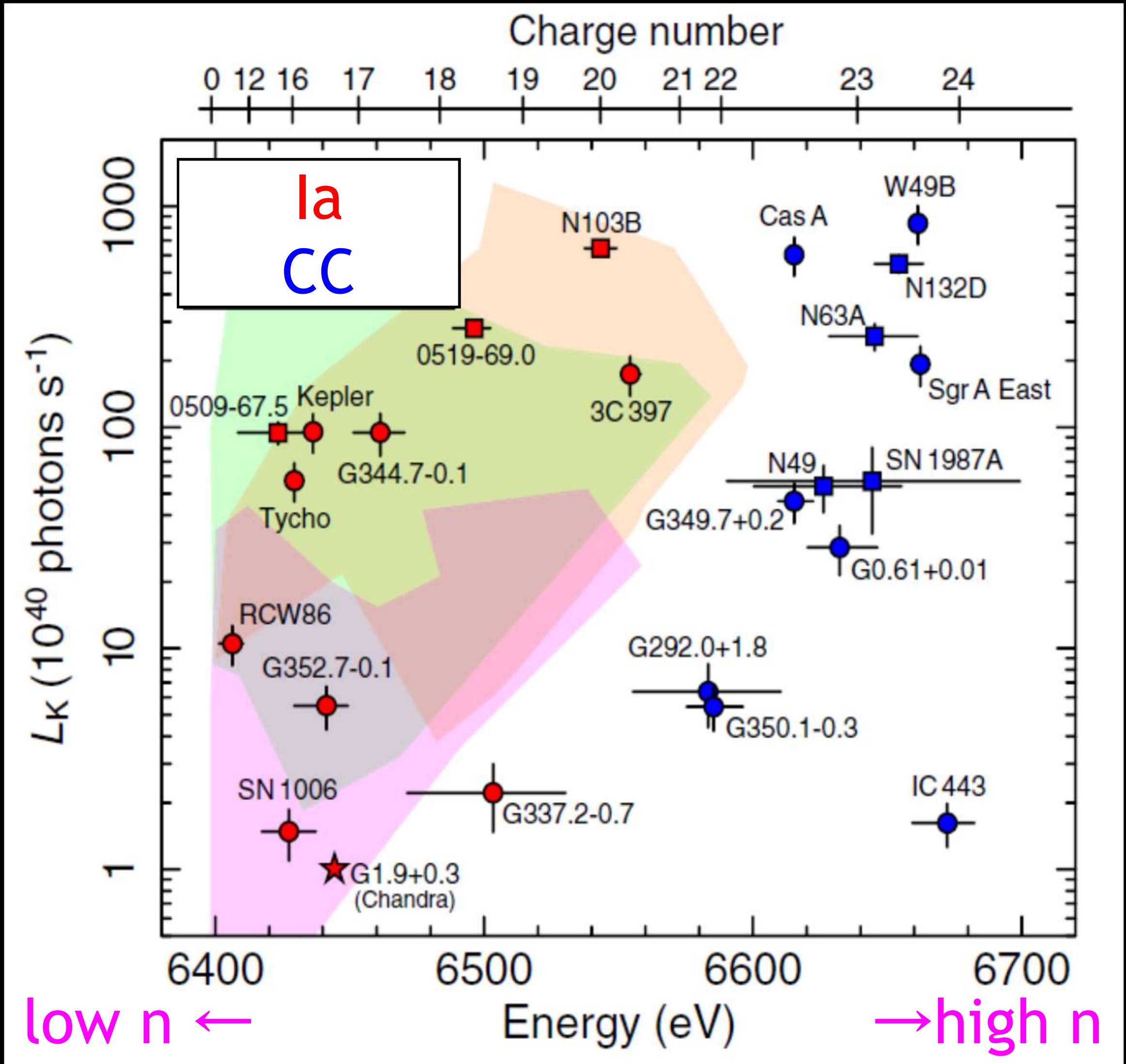
pure iron ejecta (no Cr, Mn)

Several "text-book" Ia remnants show anisotropy.
It is still an open issue
how isotropic Ia explosions are.

important on heavy element distribution in the universe,
maximum luminosity of SNe (amount of Ni), etc.

2.2. Type estimation from Iron K line center (Yamaguchi+14)

low density medium for Ia → low ionization state
high density (CSM or ISM) for cc → high ionization state

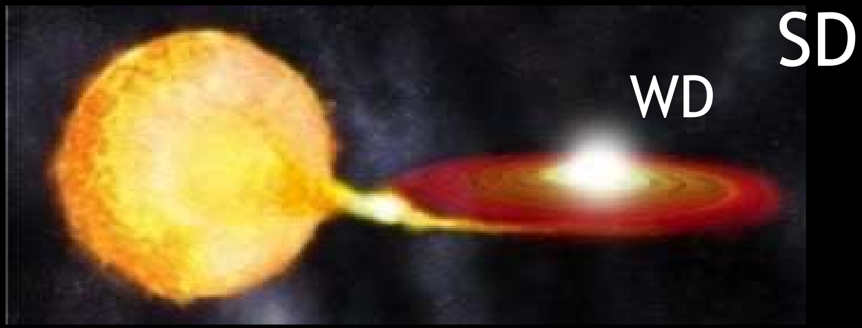


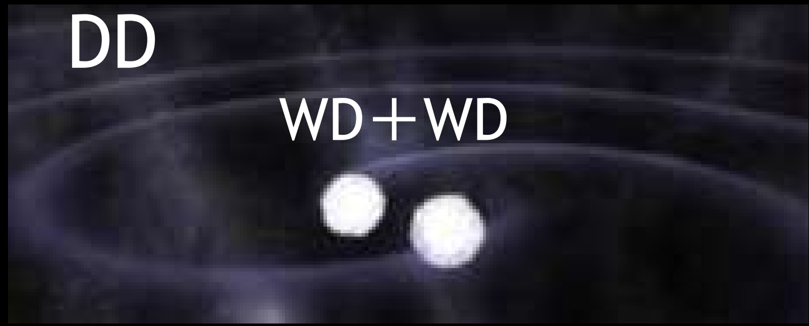
Ia has lower E iron-K

Ia is really
in the low density ISM

More classification
from spectral info.?

2.3. Origin of Ia ?

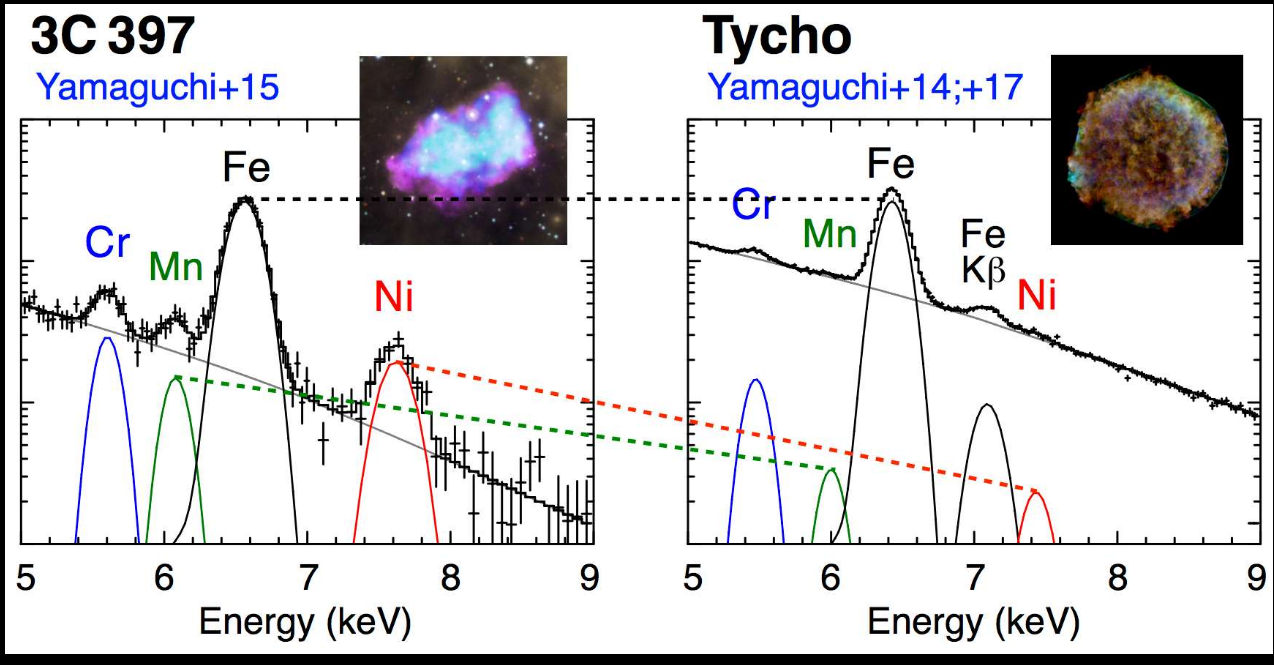




~M_{ch}, dense core ($\rho \geq$ 2e8 g/cm^3)

sub M_{ch}, less dense core

high ρ in SD core makes more Ni, Mn due to more electron capture



3C397 needs M_{ch}

Strong diagnostics to distinguish SD and DD

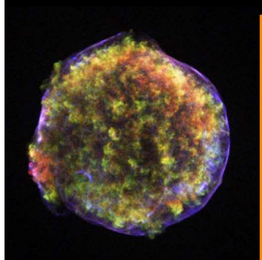
Related to abundance of CGs

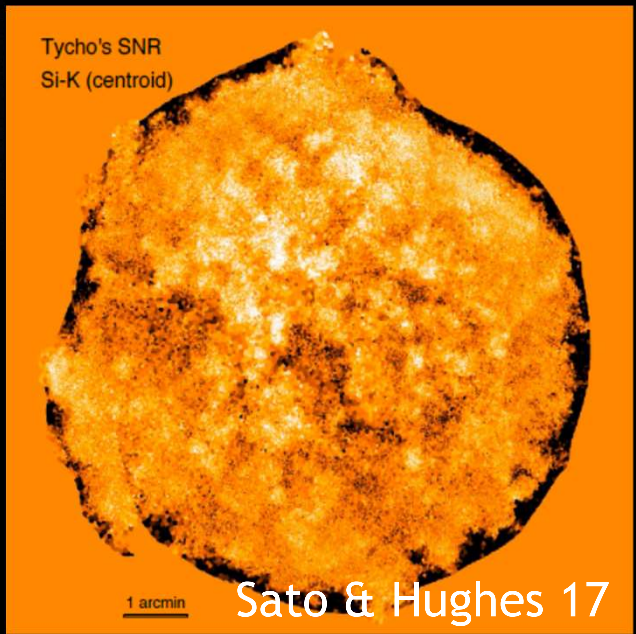
2.4. Expansion structure of Ia SNRs

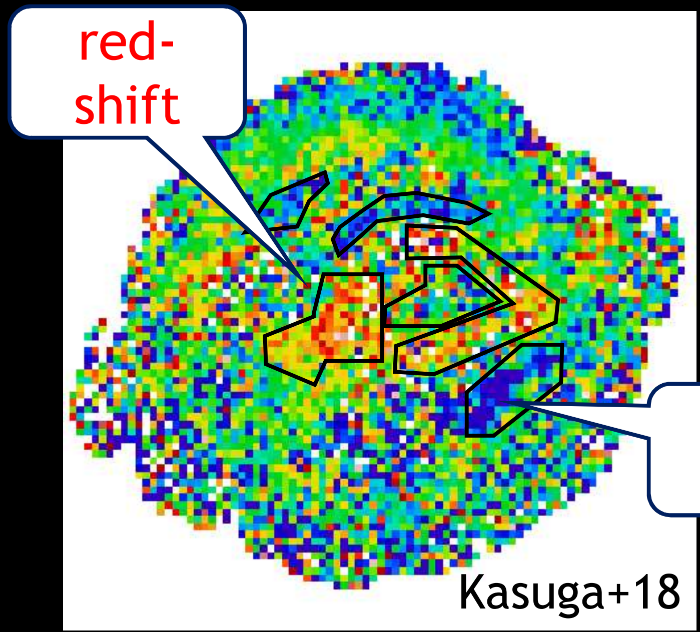
DD -> more symmetric   SD -> more asymmetric ??

Doppler mapping show us the ejecta expansion structure of young SNRs.

Tycho Si Doppler map   Kepler Fe Doppler map





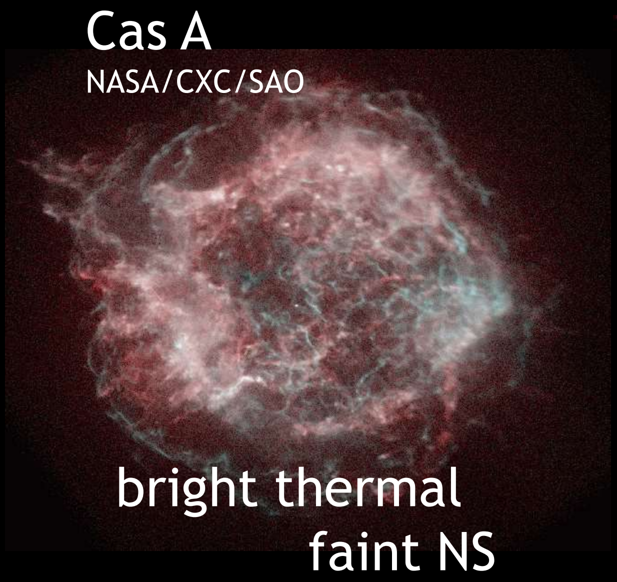


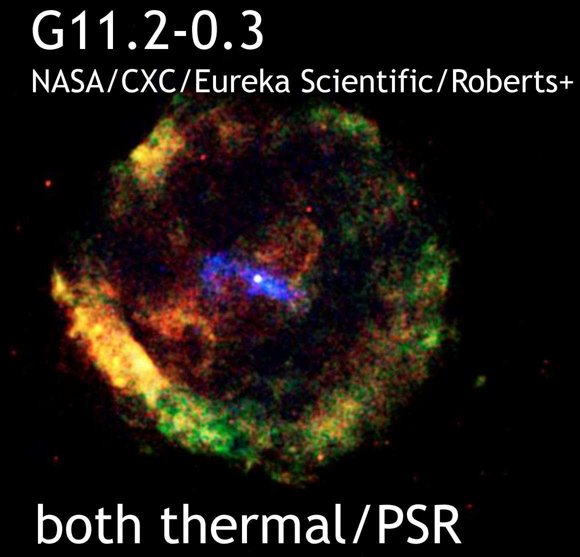
almost symmetric

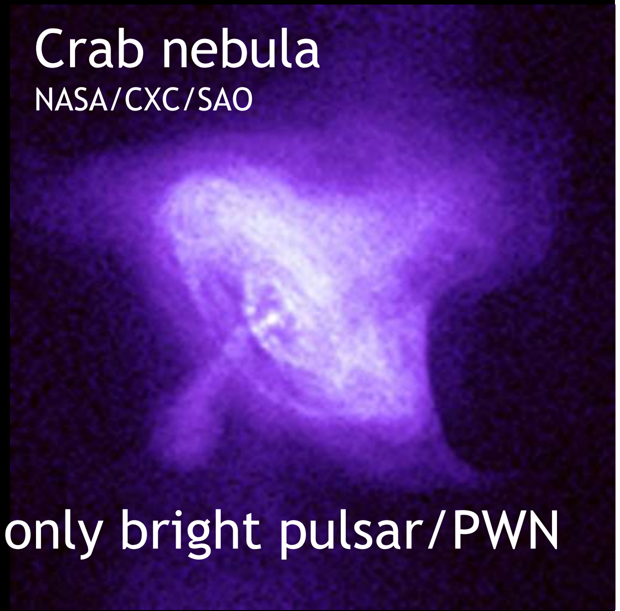
red and blue-shifet components
asymmetric expansion

SNRs of Ia SNe have diversity.
Diversity of explosion mechanism ?

2.5. Variety of CC SNRs



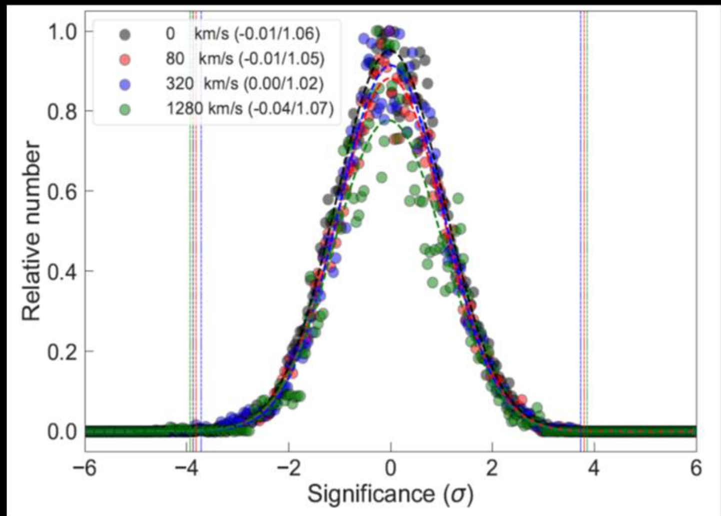




What makes such difference ?

Thermal line search from Crab
w. Hitomi/micro-calorimeter
-> blind search could not detect
any emission/absorption line

-> SN with less explosion E ?
(Hitomi coll.+17)

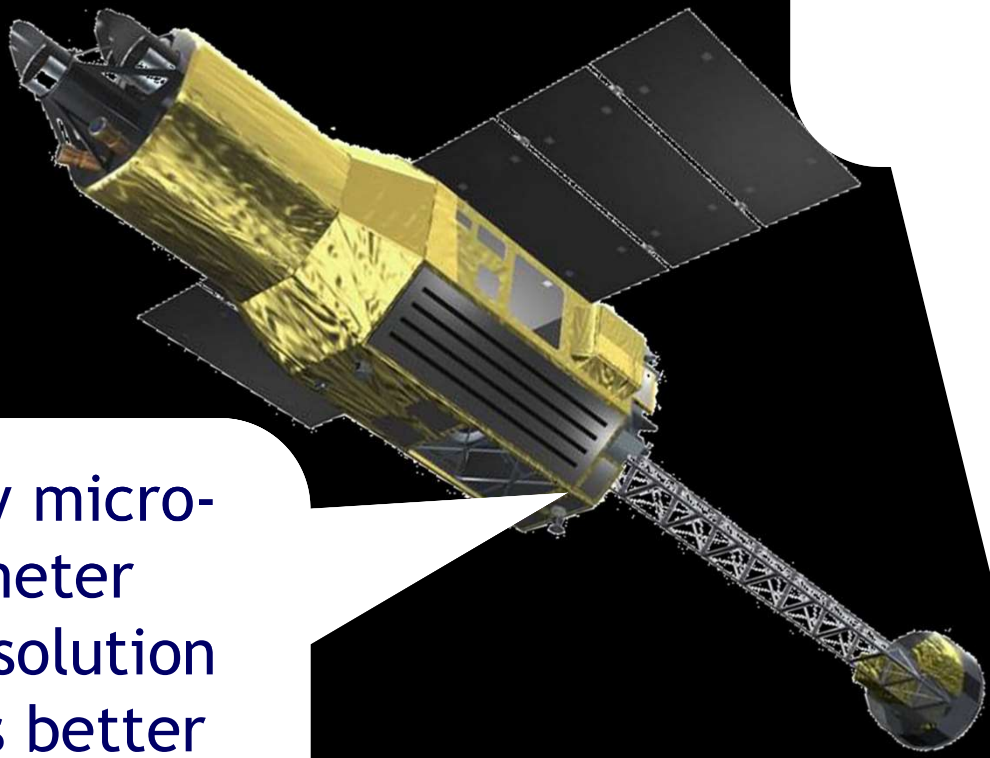


3. Future plan: Micro-calorimeter science

3.1. Hitomi mission

Hitomi mission: (2016)
JS-US X-ray mission
https://heasarc.gsfc.nasa.gov/docs/hitomi/

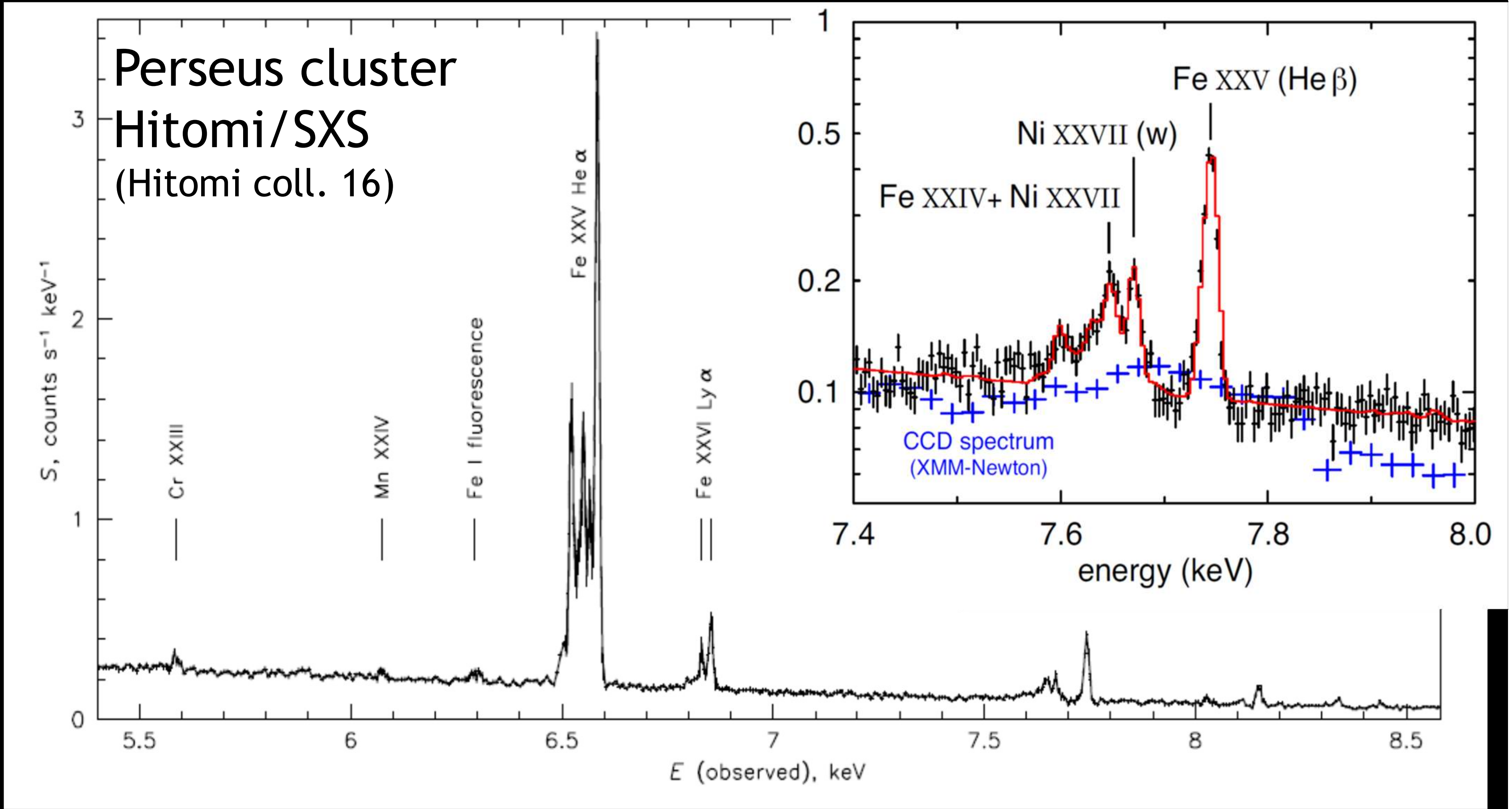
Wide energy range
0.2 – 600 keV



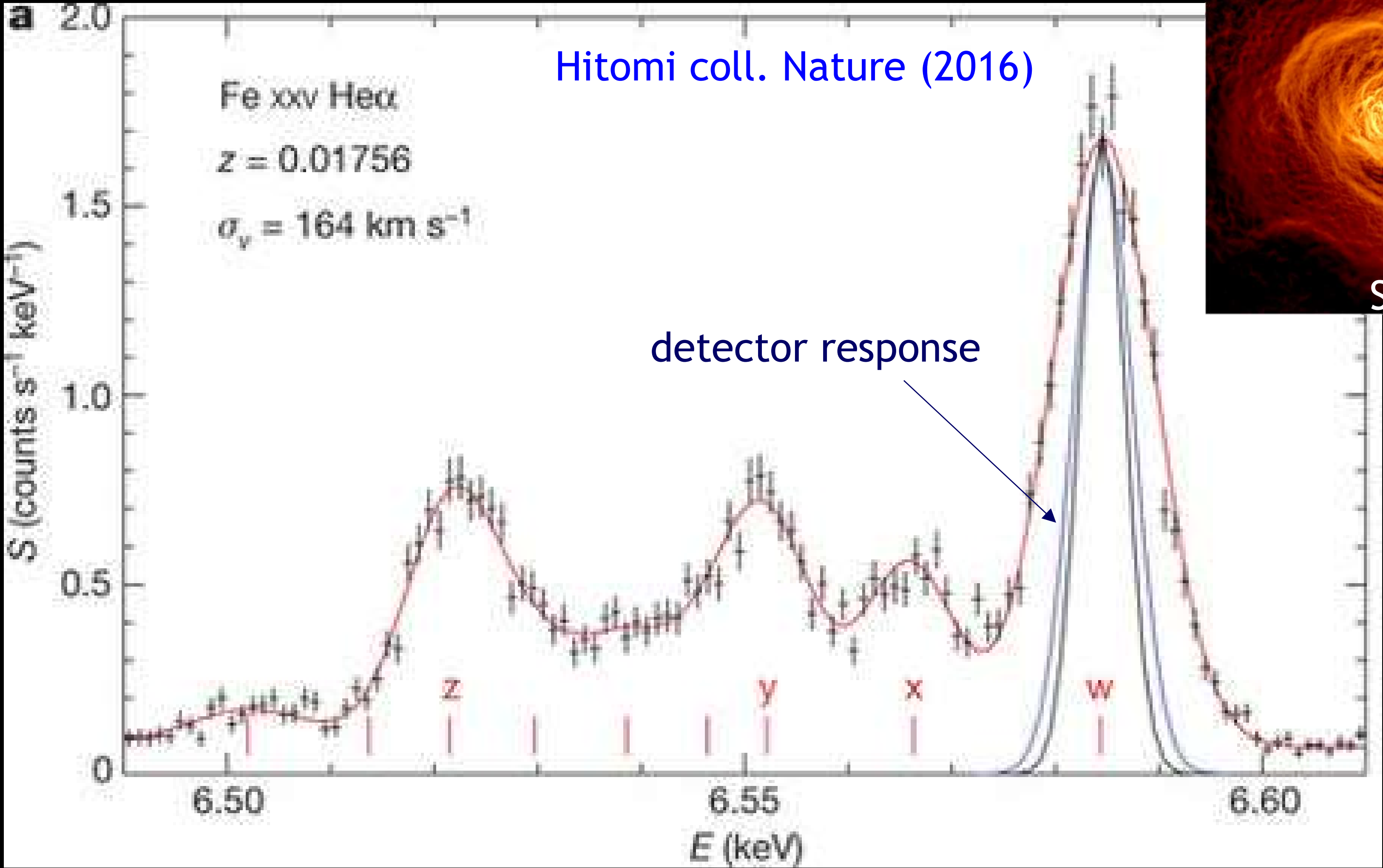
First X-ray micro-calorimeter
energy resolution
~30 times better than
X-ray CCDs

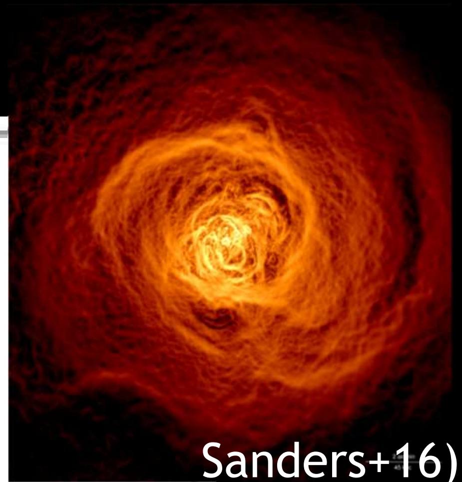
Unfortunately, the satellite was lost only 1 month after the launch.

But Hitomi left heritages.



Perseus cluster is “quiet”.





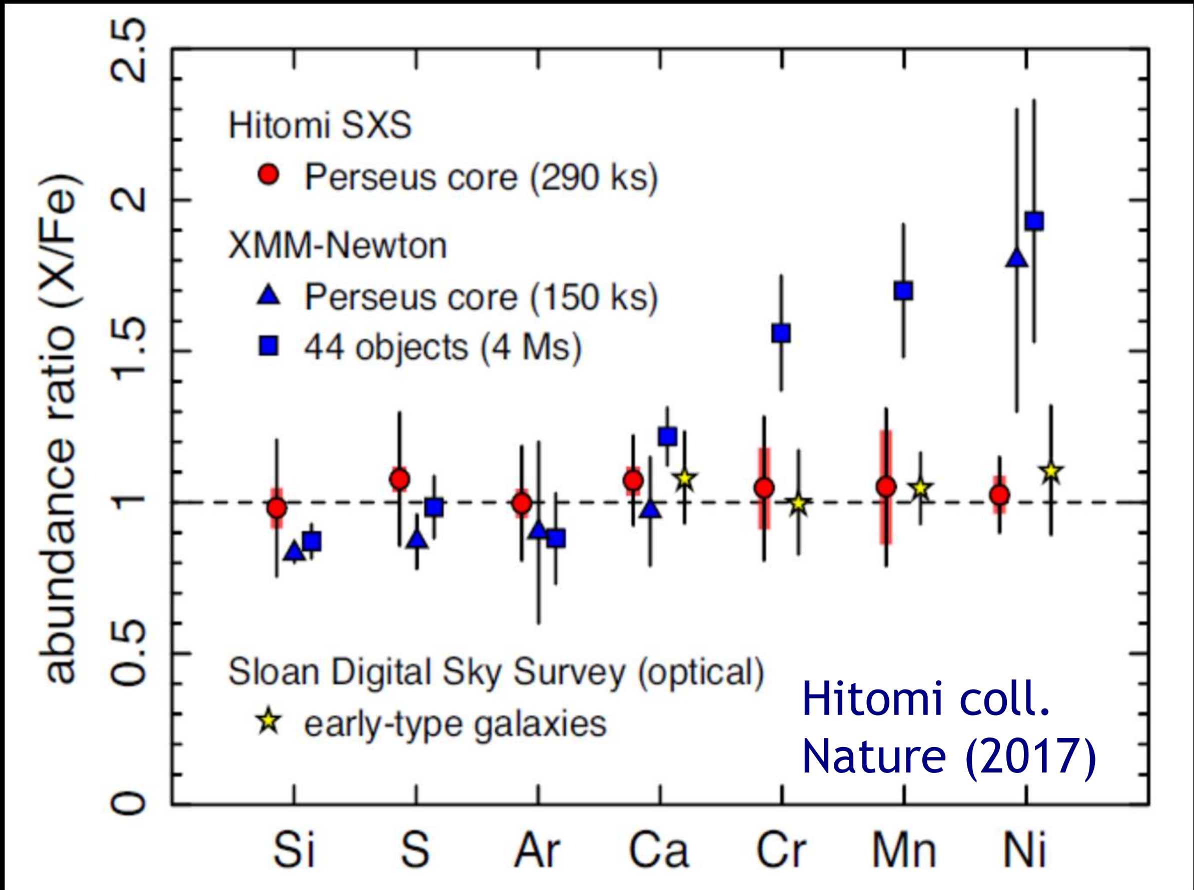
Sanders+16)

Lines do not Doppler broadened (turbulent velocity ~ 164 km/s)
Hitomi arised a new question:
“Why gas in clusters are “quiet” although there are a lot of shock and heat sources ?”

Where Fe and Ni came from ?

Heavy ions produced by star nucleosynthesis are distributed into clusters of galaxies.

Fe/Ni ratio is an important parameter to understand which kinds of stars are born in the clusters.



Same abundance pattern between Perseus and our solar system !

-> Recipe of galaxies can be common.

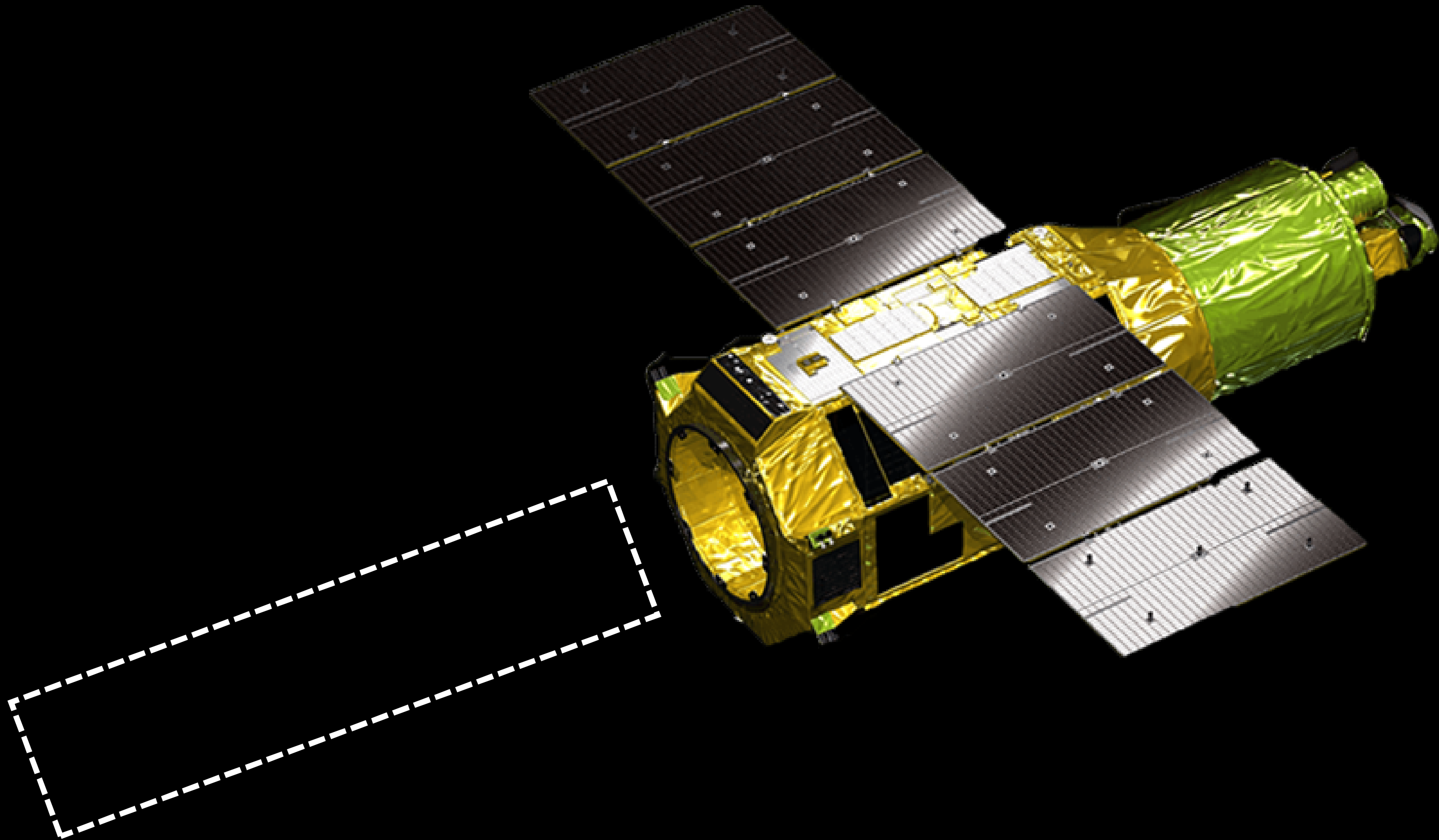
Hitomi papers and more:

16 papers including 2 Nature papers.
We believe the data still have unpublished new results.

You can find Hitomi archive via:
https://heasarc.gsfc.nasa.gov/docs/hitomi/

3.2. XRISM mission

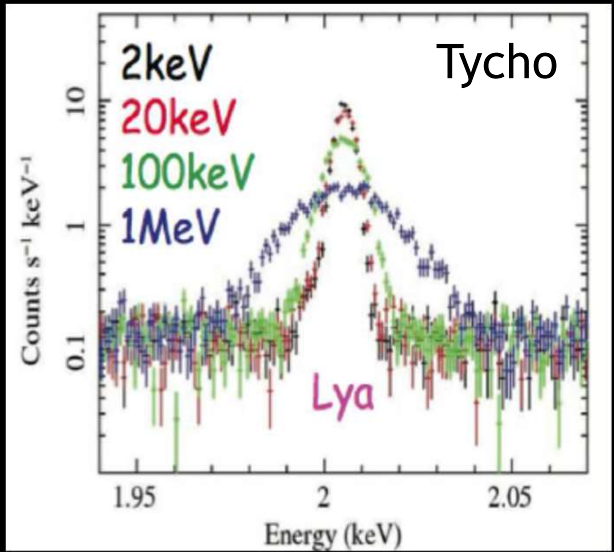
X-Ray Imaging Spectroscopy Mission
to be launched on JFY2021



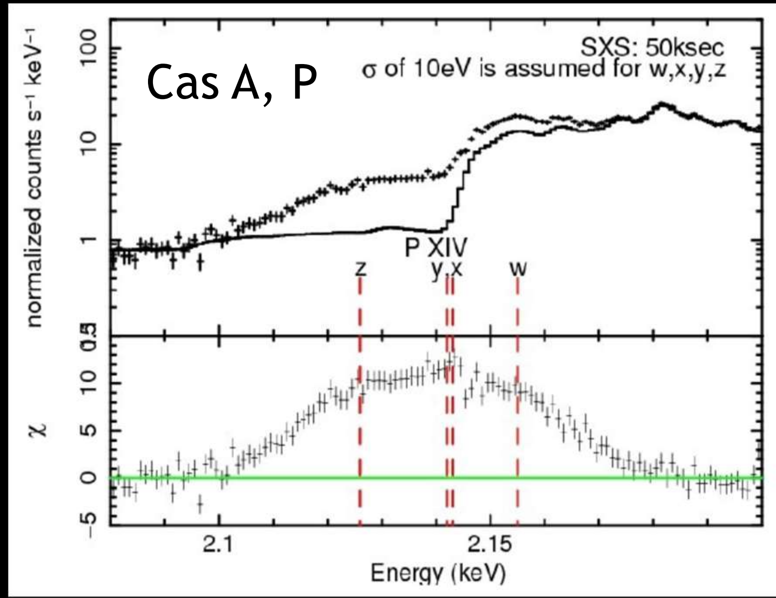
Only micro-calorimeter and CCD

Expected science with XRISM

Ion kT measurement from Doppler



Minor element search

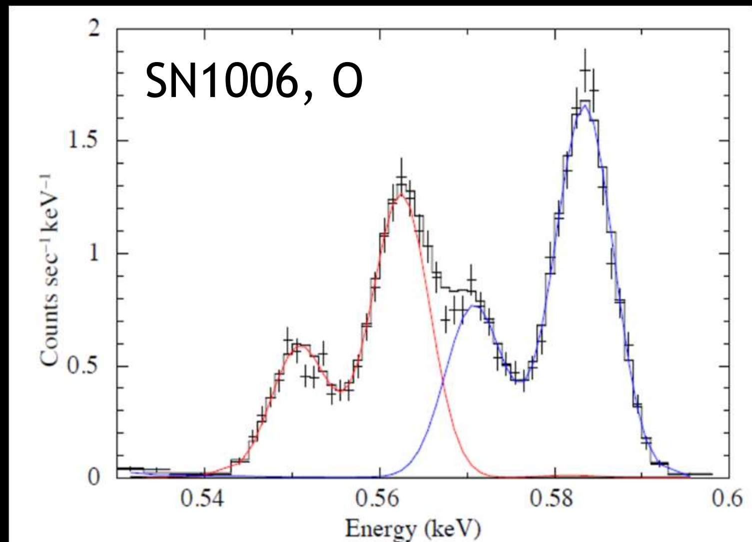


Available at:
ASTRO-H White papers
arxiv:1412.1169
arxiv: 1412.1170

Simulation tools will be available in this month.

https://xrism.isas.jaxa.jp/

expansion measurement



4. Summary

- Supernova remnants make diversity of the universe in thermal and nonthermal aspects.

- X-ray observations are strong tool of SNR study.

- We can resolve Type of progenitor SNe.
- Both Ia and CC have variety.

- Near future missions such as XRISM will resolve many unsolved problems.