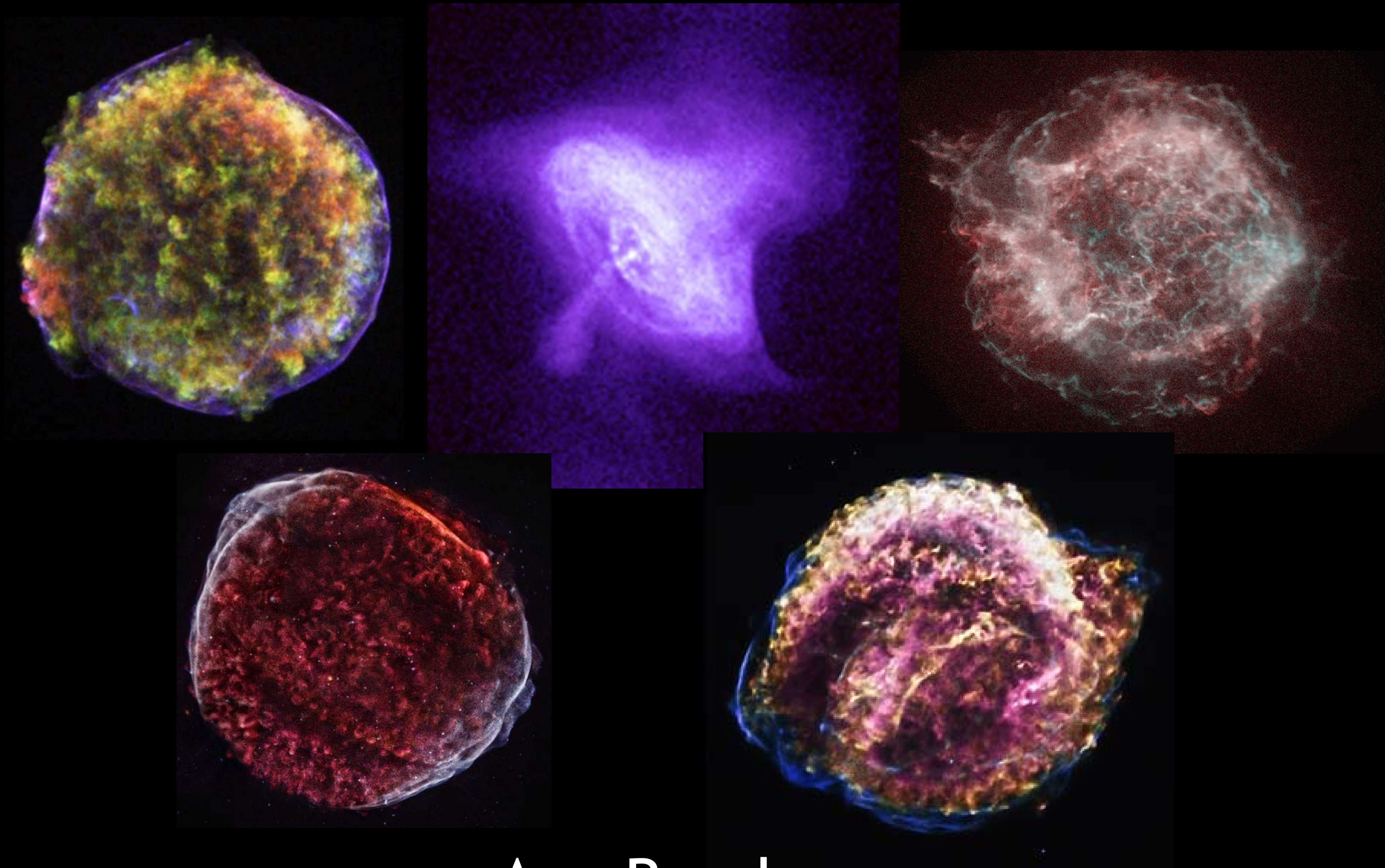
X-ray Observations of Supernova Remnants



Aya Bamba
(U. of Tokyo, Japan)

0. Contents of this talk

1. Introduction of SNRs
2. Recent Progress of X-ray study of SNRs
3. SNRs with future X-ray missions

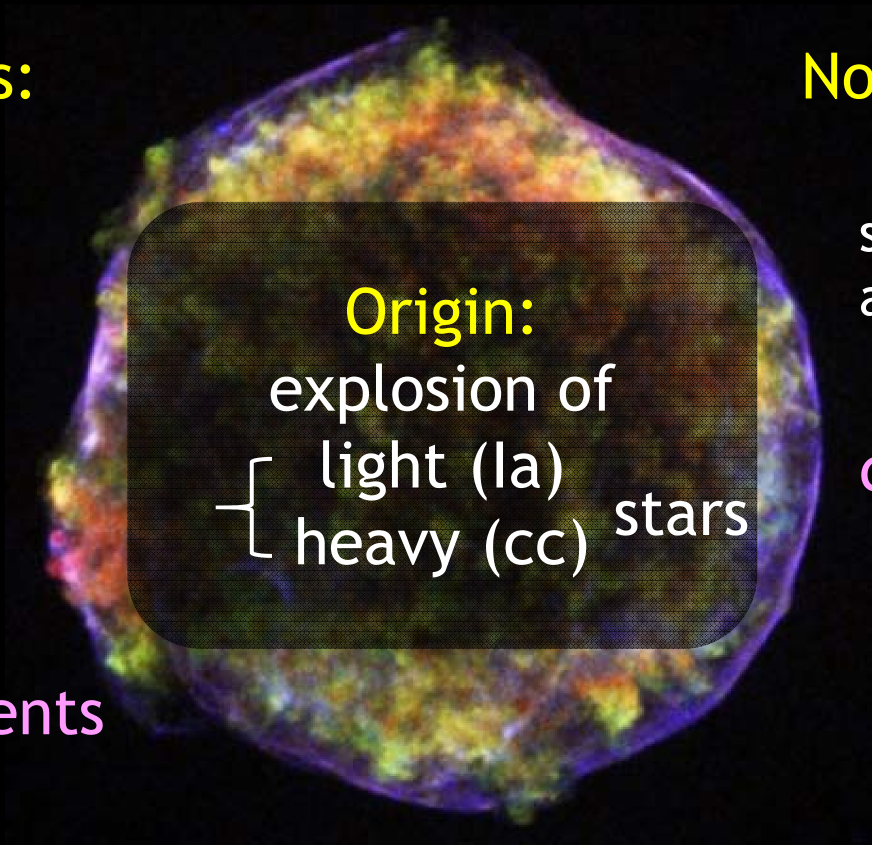
1. Introduction of SNRs

1.1. Role of supernova remnants in the universe

Thermal aspects:

thin plasma
with kT ~ keV
time scale
<~ 10^4 yrs

distribute
heavy elements



Origin:
explosion of
{ light (Ia) / heavy (cc) } stars

Nonthermal aspects:

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

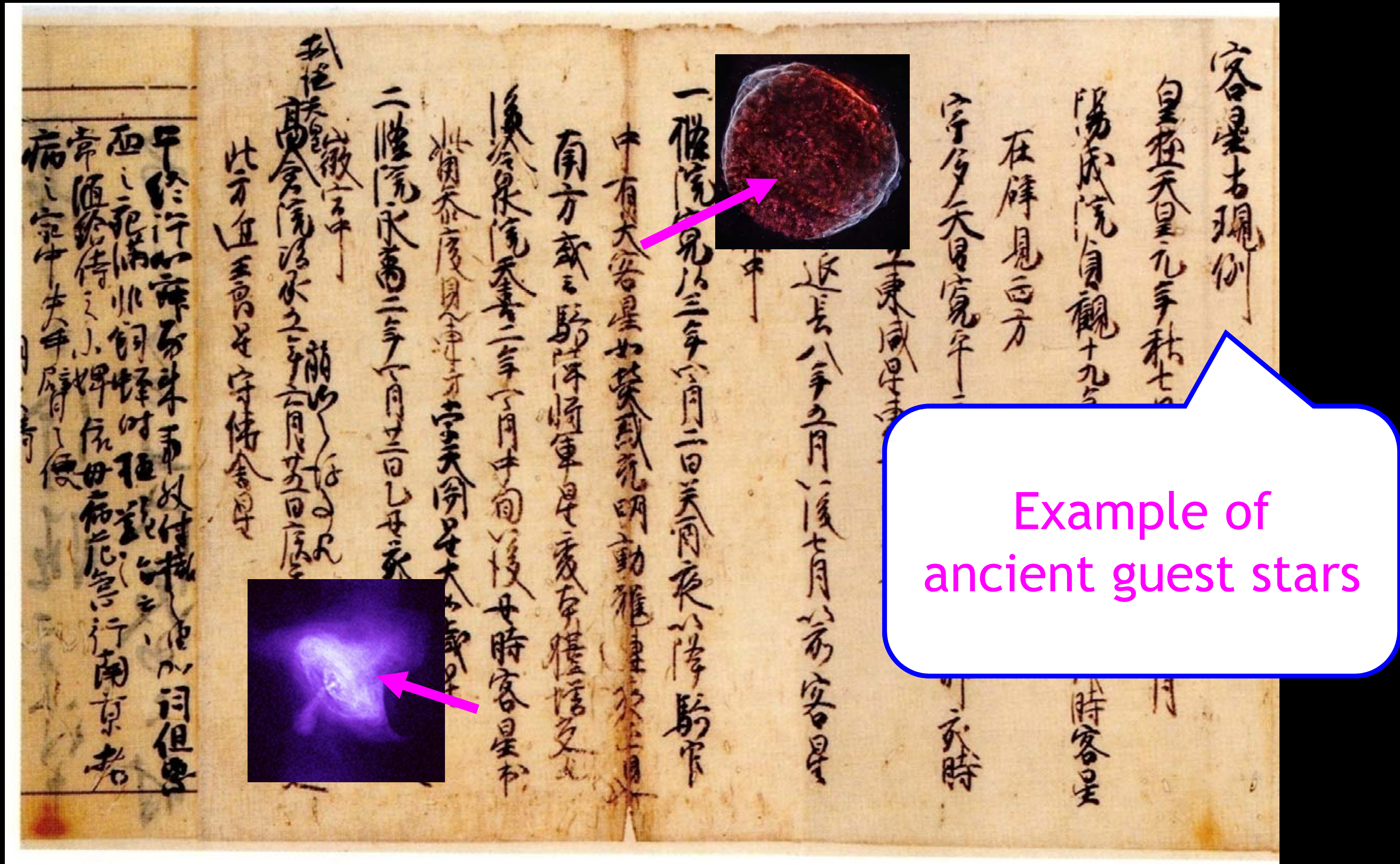
distribute
cosmic rays

distribute
thermal/kinetic E
compact stars

SNRs make the diversity of the universe !

We kept optical observations of SNe long time !

Japanese record of guest stars



the number is limited

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

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

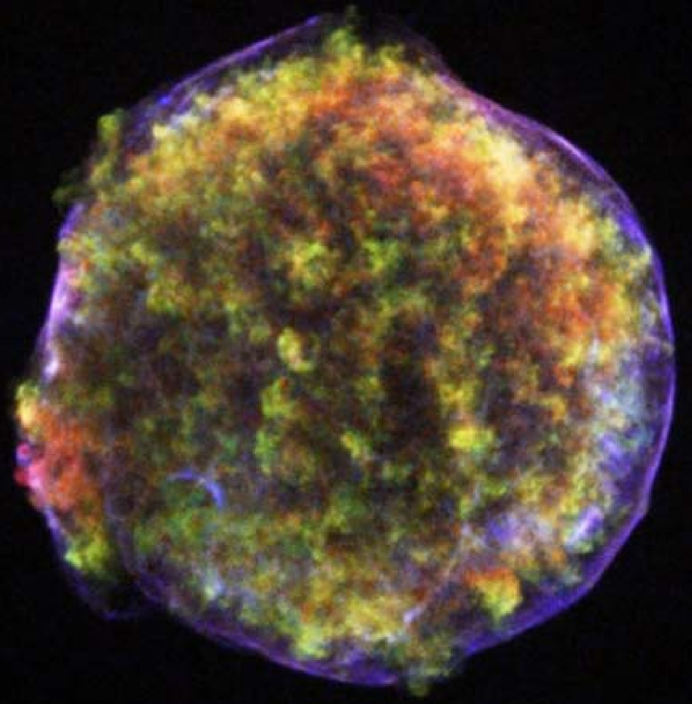
-> ejecta and interstellar medium heat up to ~1 MK or 0.1 keV

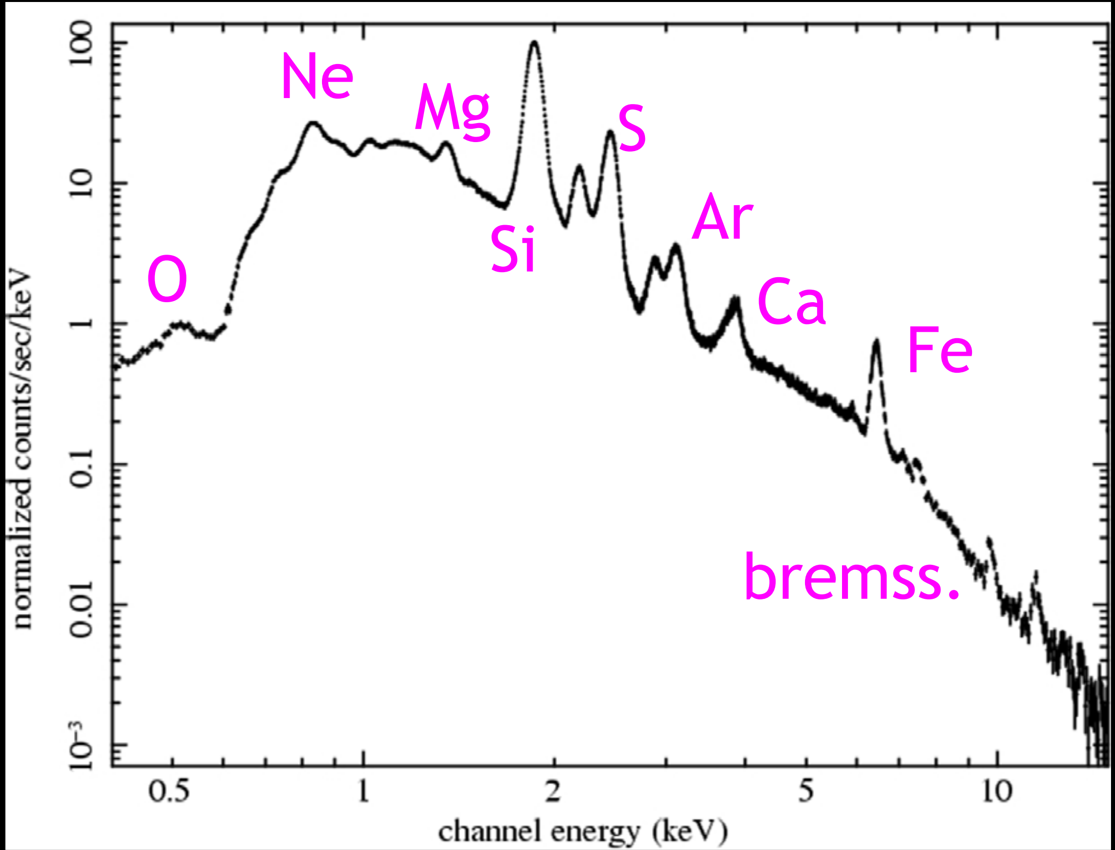
-> ionized thin thermal plasma (n ~ 1 cm^{-3})

-> 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	Core-collapsed (CC)
End-point of mass accretion to WD up to M_{ch} (SD) or WD-WD merger (DD)	End-point of heavy stars (>~ 10 M_{O})
A lot of Fe, Ni, Cr, Mn Isotropic explosion ?	A lot of lighter elements O, Ne, Mg, Si, S, ...
"Standard candle"	Neutron stars, black holes

Questions:

Can we distinguish Ia/cc for SNRs with X-ray observations ?

Do they have diversity more than types ?

ratio of SD/DD ? progenitor mass of CCs ?

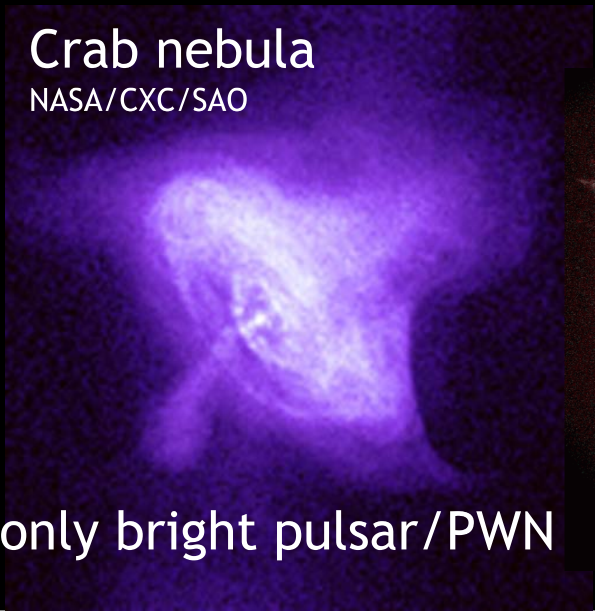
1.4. Conventional method of type diagnostics

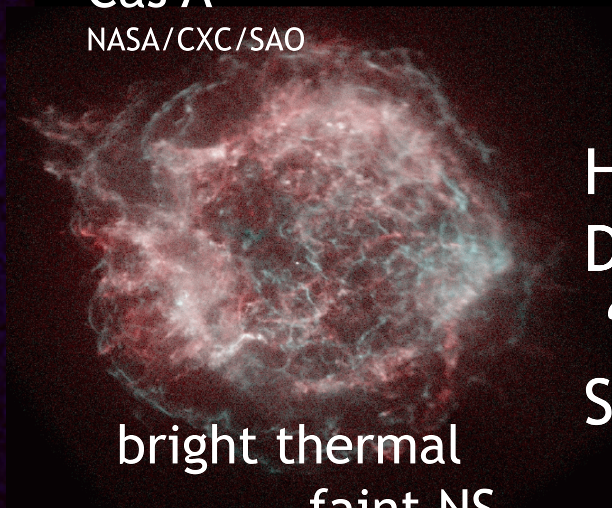
(1) Searching for compact sources

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 !

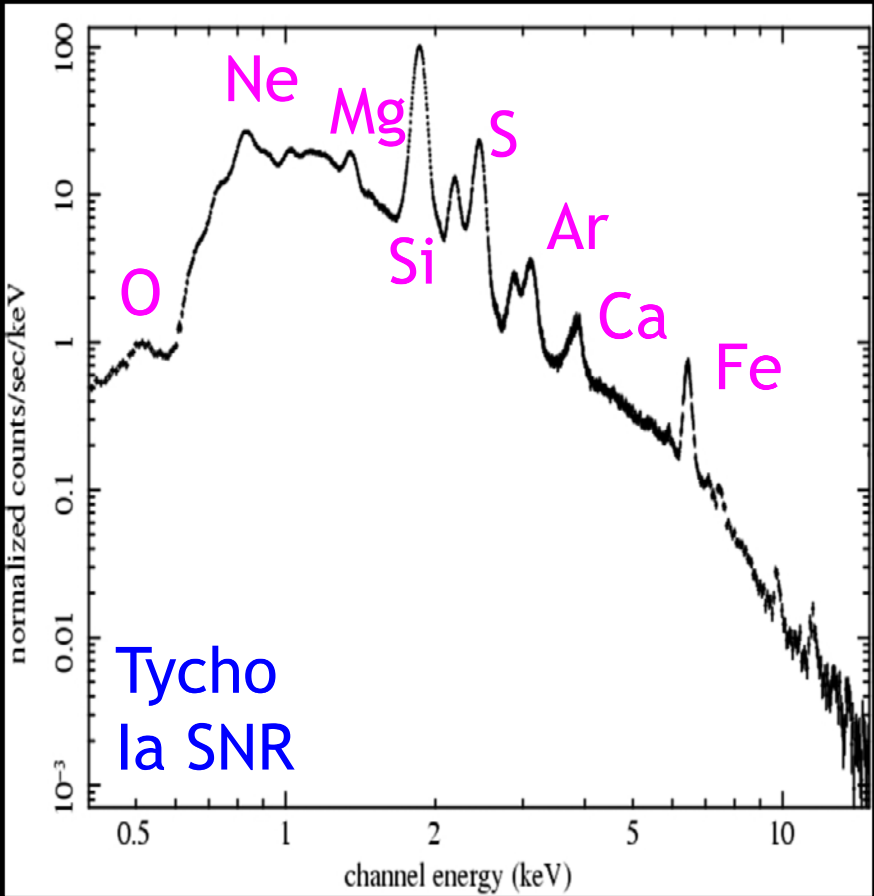


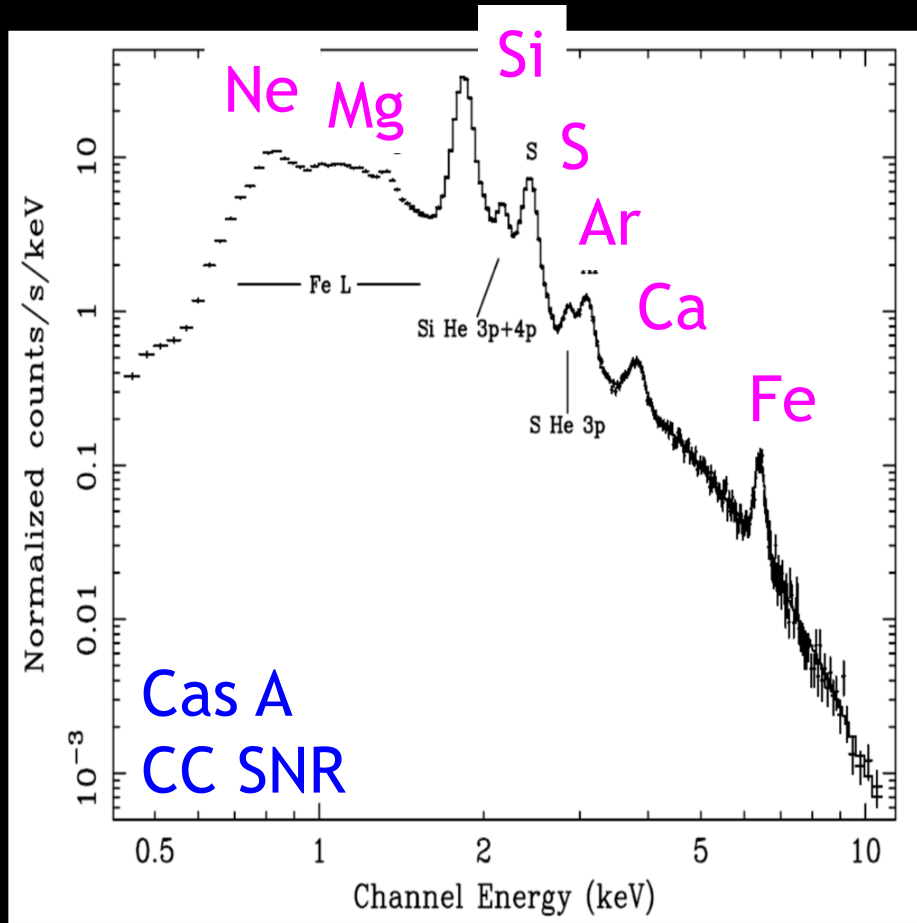


However ...
Difficult to say
"they do not have a NS".
Some CC do not remain NSs.

(2) Abundance pattern of heated ejecta

Ia SNRs have abundant Fe / Fe group
CC SNRs have abundant lighter alpha-elements (Si, S, Mg, ...)





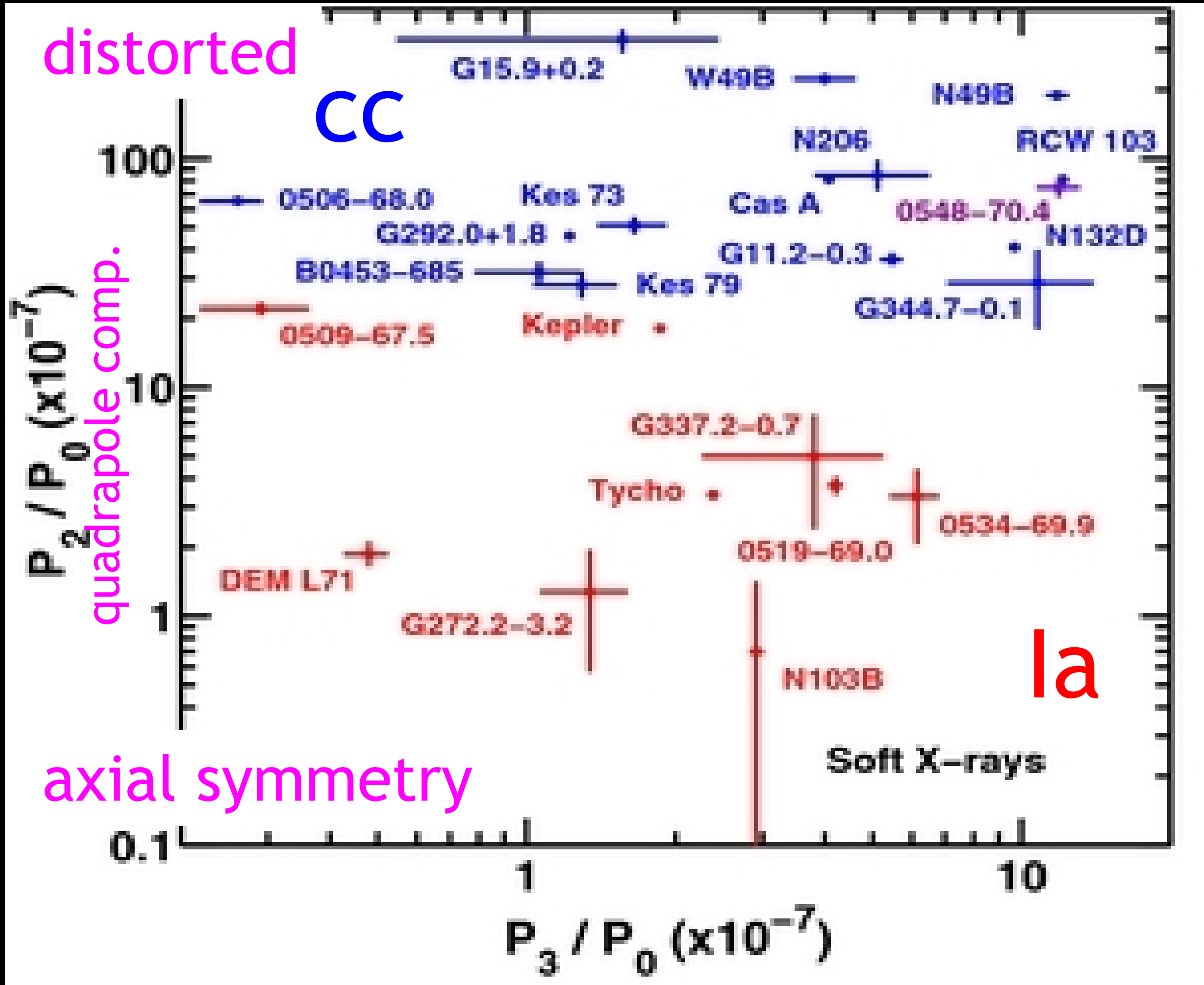
cannot see unheated ejecta -> cannot be used for very young SNRs
contamination of heated ISM -> cannot be used for old SNRs

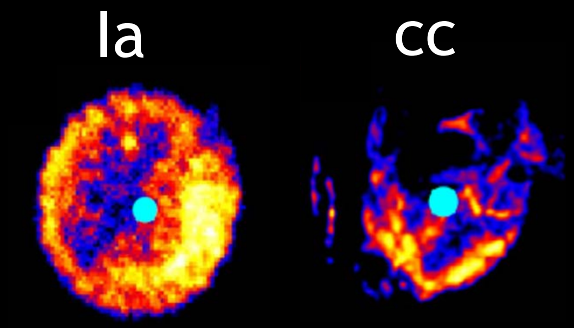
2. Recent Progress of X-ray study of SNRs

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



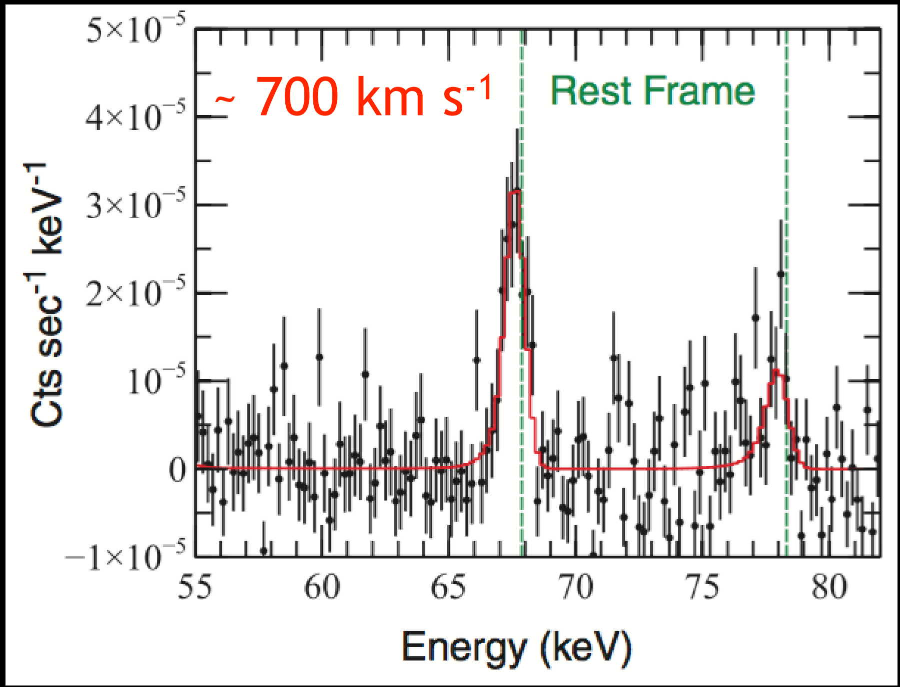


CC SNRs has more distorted morphology !

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

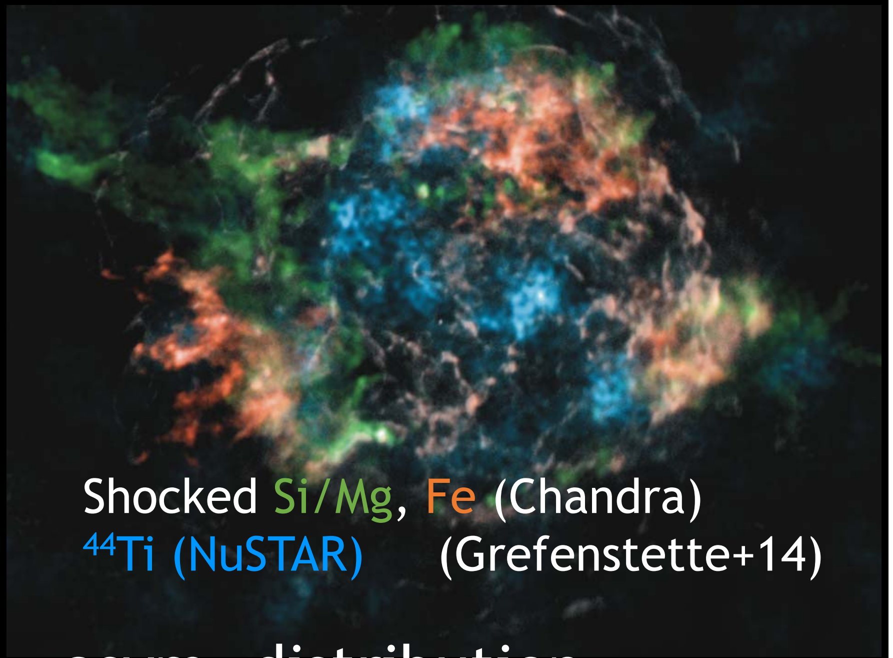
CC SNR expansion with ^{44}Ti

SN 1987A (~30 yrs)



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

Cas A (~330 yrs)

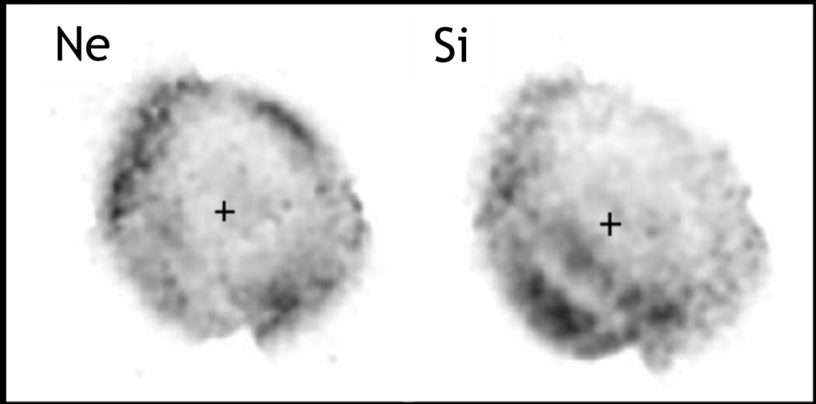


asym. distribution
Neither isotropic
nor axial symmetric
expansion

CC SNRs show highly asymmetric expansion

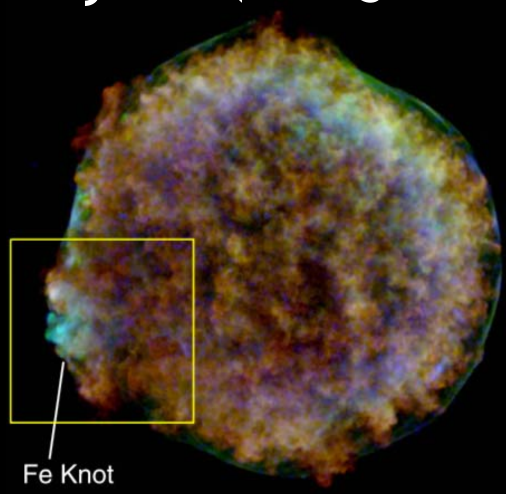
Does Ia expand isotopically ?

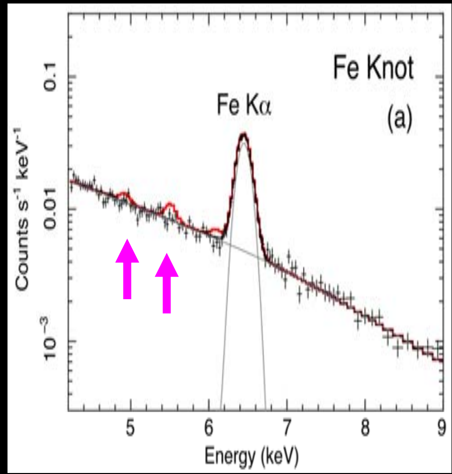
SN1006 (Uchida+13)



Si, S, Fe are abundant
in south eastern region

Tycho (Yamaguchi+17)





pure iron ejecta (no Cr, Mn)

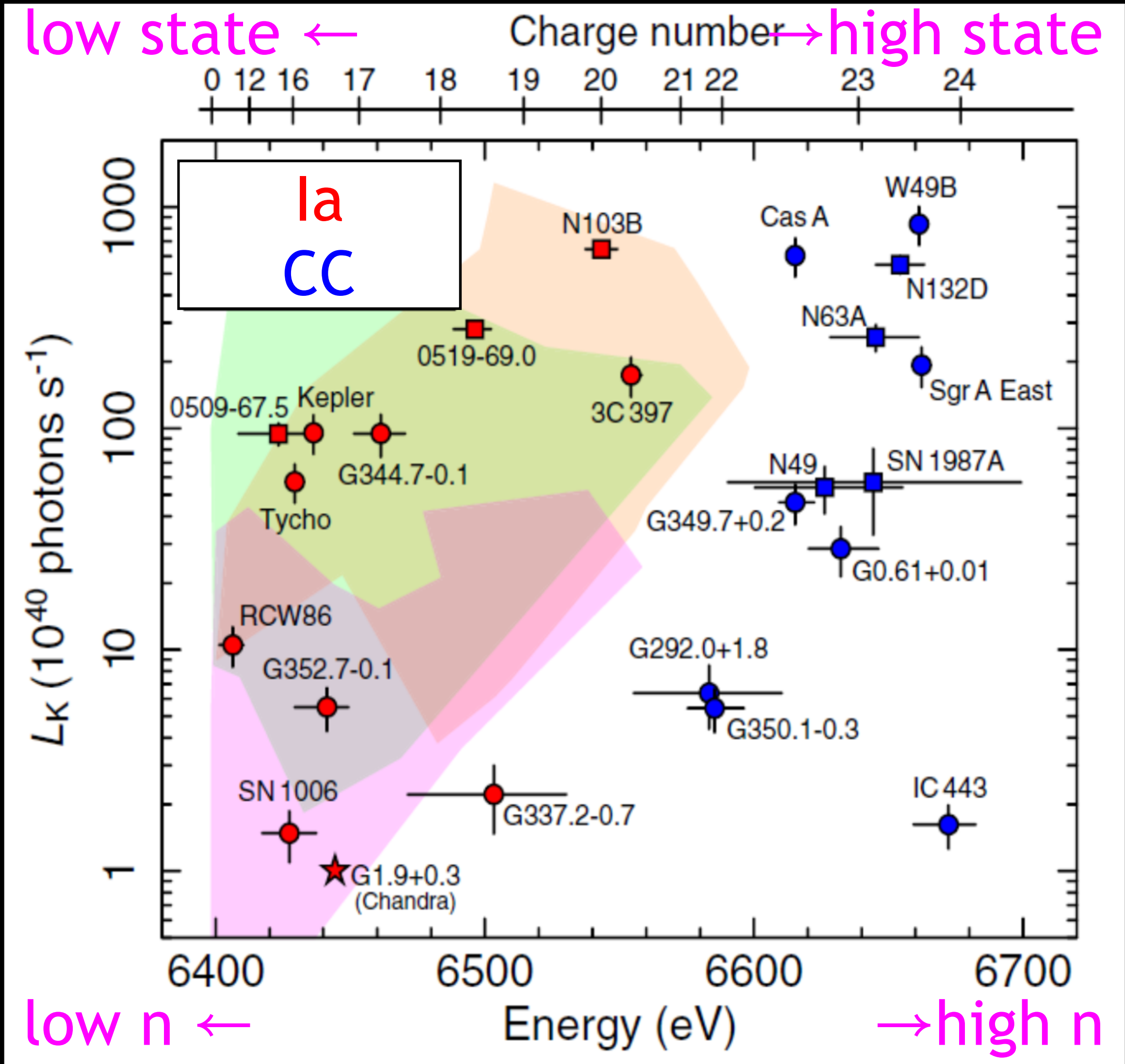
Several “text-book” Ia remnants show anisotropy.

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

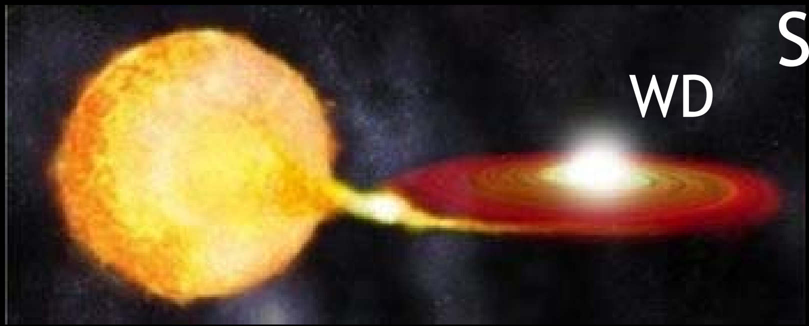


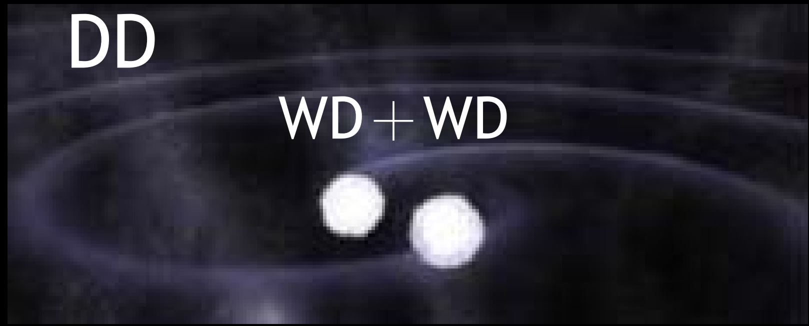
Ia has lower E iron-K

Ia is really in the low density ISM

More classification from spectral info.?

2.3. Origin of Ia ?

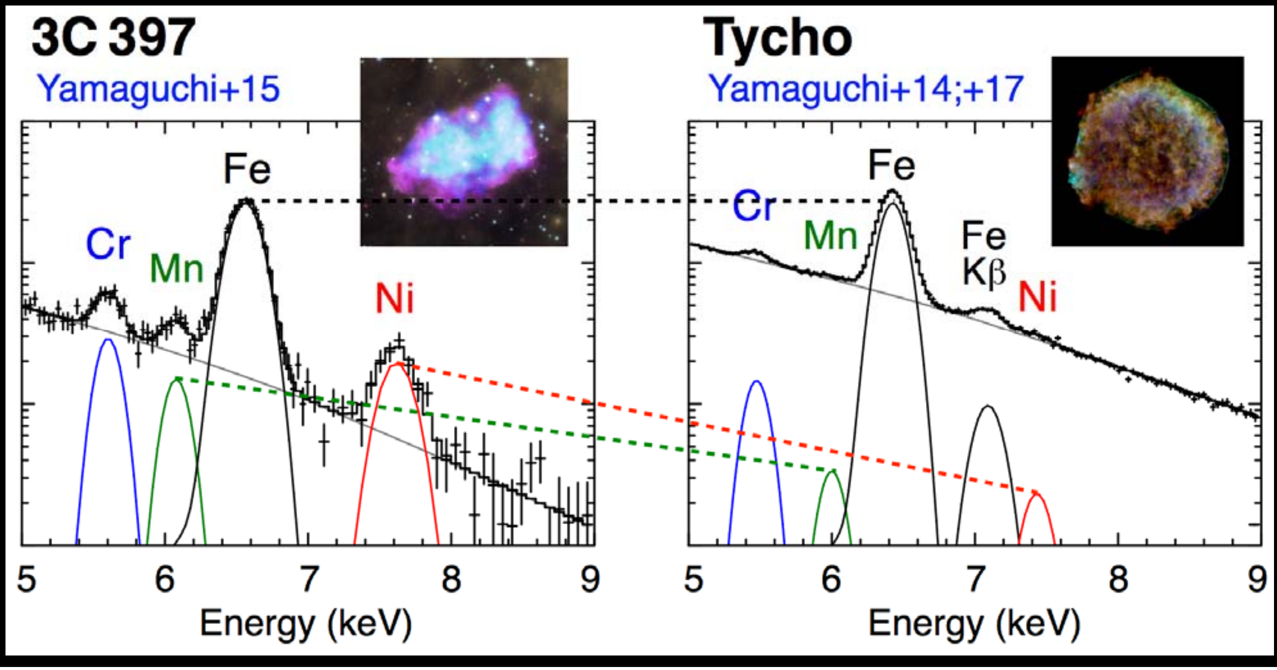




~M_{ch}, dense core ($\rho \geq$ 2e8 g/cm^3)

sub M_{ch}, less dense core

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



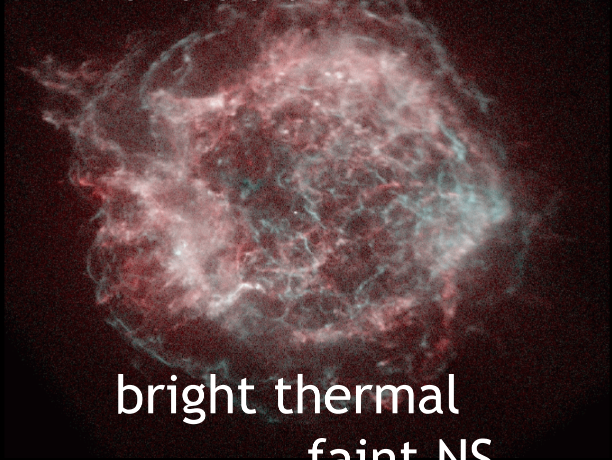
3C397 needs M_{ch}

Strong diagnostics
to distinguish
SD and DD

Related to
abundance of CGs

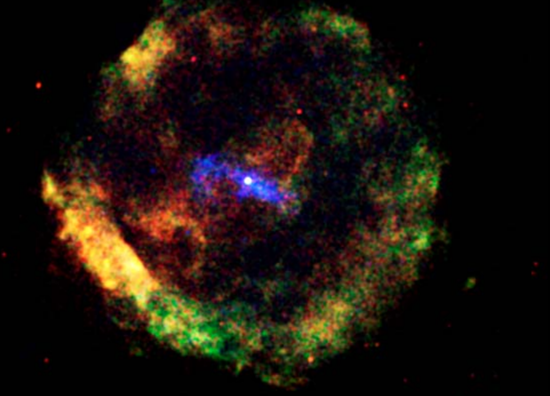
2.4. Variety of CC SNRs

Cas A
NASA/CXC/SAO



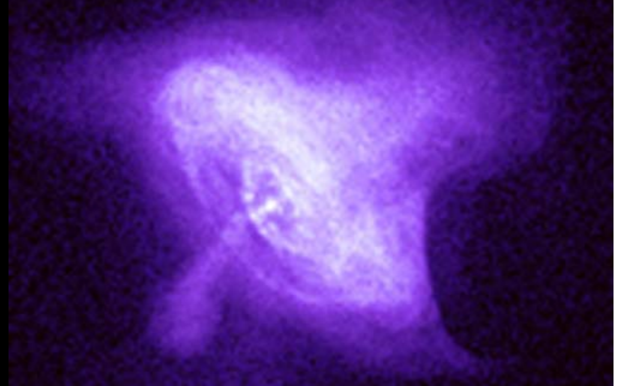
bright thermal
faint NS

G11.2-0.3
NASA/CXC/Eureka Scientific/Roberts+



both thermal/PSR

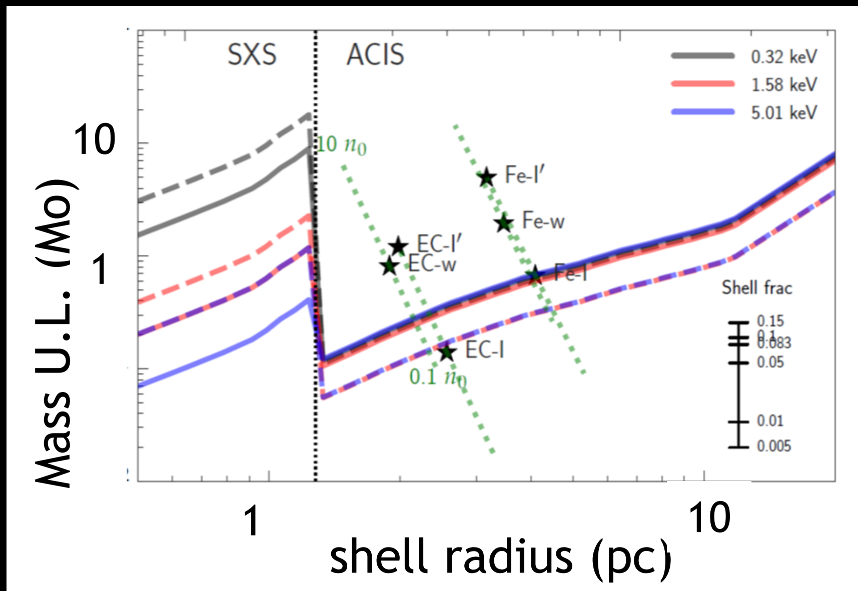
Crab nebula
NASA/CXC/SAO



only bright pulsar/PWN

What makes such difference ?

Crab Thermal line search
with Calorimeter onboard Hitomi
-> very tight upper-limit
plasma mass < 1Mo
-> electron capture SN ?

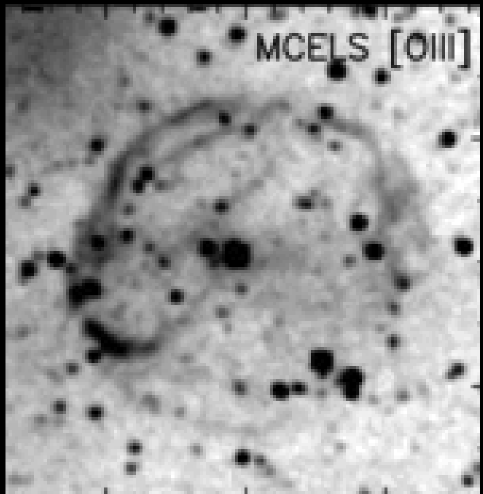


(Hitomi collaboration, 2017)

2.5. Where are SNRs with BHs ?

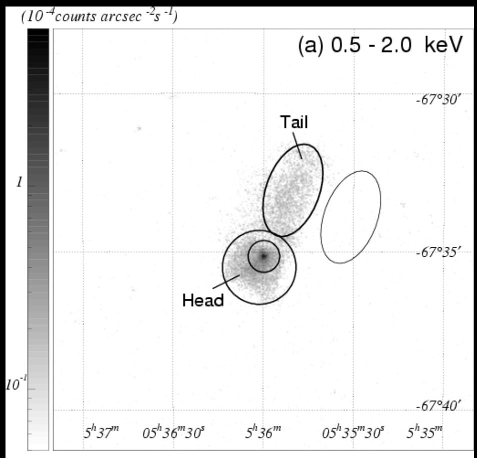
Not yet, but we have several SNRs with a HMXB.

SXP 1062 in the SMC
(Hénault-Brunet+12)



HMXB: P=1062s, maybe neutron star
SNR: too old to see in X-rays (r=20 pc)

CXOUJ053600.0-673507 in DEML241



HMXB with O5III(f) star (Seward+12)
the most luminous gamma-ray binary (Corbet+16)
abundance pattern -> progenitor > 20 Mo
(Bamba+06)

Can we find first SNR w. BH ??

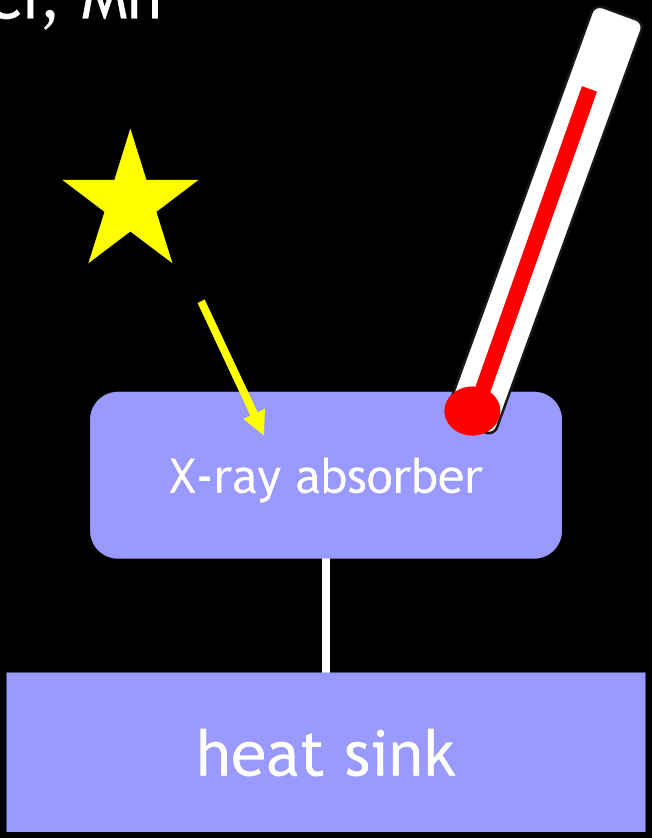
3. SNRs with future X-ray missions

Most important technology for X-ray studies of SNRs
-> Energy resolution !!!

Excellent energy resolution enables us:

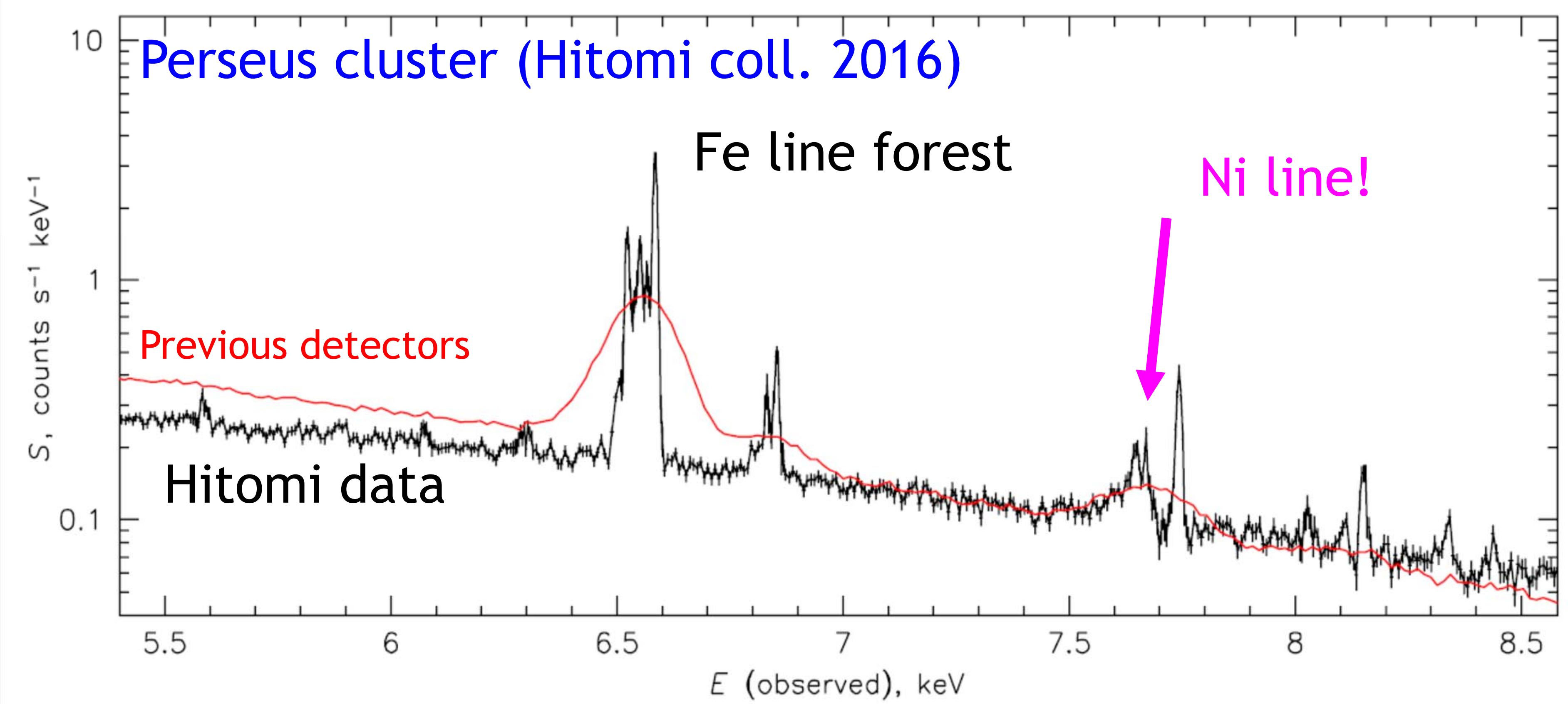
- to study SNR expansion with Doppler broadening of emission lines
- to study minor elements such as Cr, Mn

X-ray calorimeter: energy resolution
~ 5 eV @ 5.9 keV
for diffuse sources
~30 times better than
present detectors



Ideal for SNR studies

Hitomi X-ray observatory: launched on 2016
First success of X-ray calorimeter (SXS), only 1 month operation.



XARM (Hitomi recovery mission): will be launched ~ 2020
Athena: will be launched ~ 2028

4. Summary

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

- X-ray observations are strong tools to study supernova remnants.

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

- Future X-ray observatories will show us more.