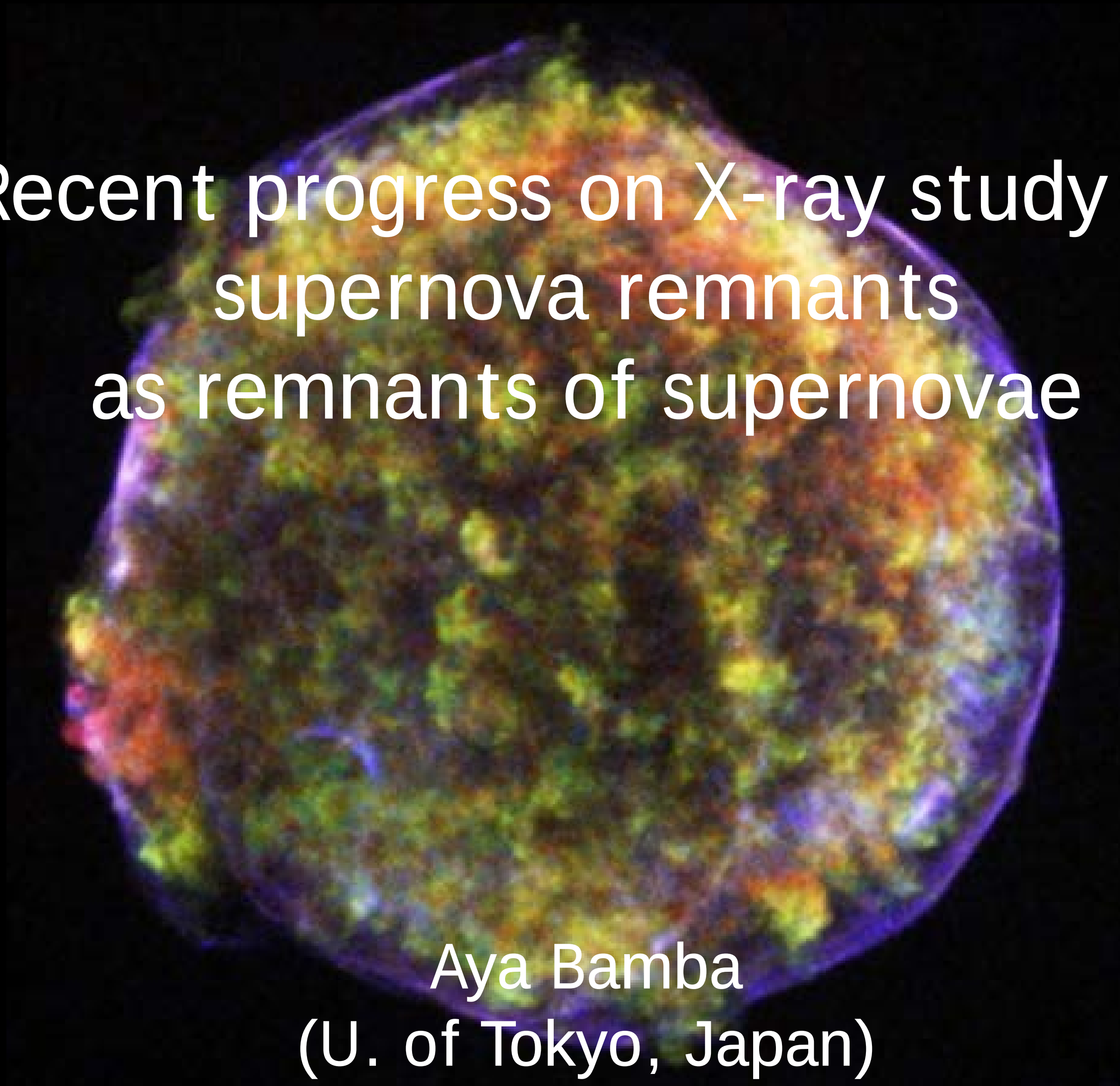
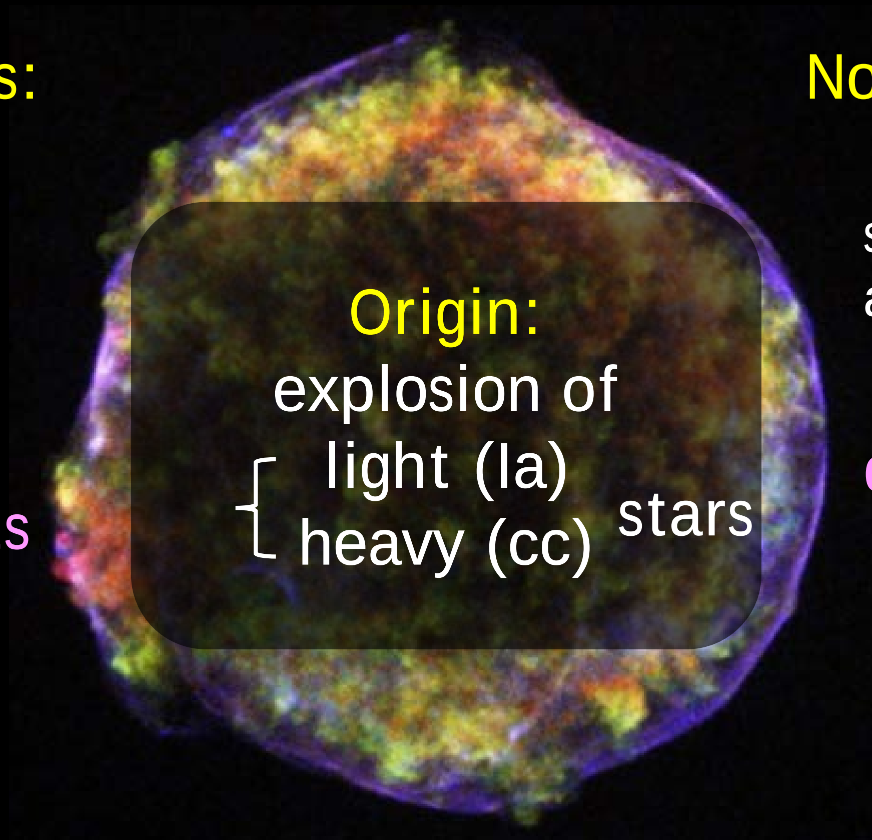


Recent progress on X-ray study of supernova remnants as remnants of supernovae

Aya Bamba
(U. of Tokyo, Japan)

0.1. Role of supernovae / supernova remnants in the universe



Thermal aspects:

thin plasma
with ejecta/ISM

distribute
heavy elements

Origin:
explosion of
light (Ia) stars
heavy (cc) stars

Nonthermal aspects:

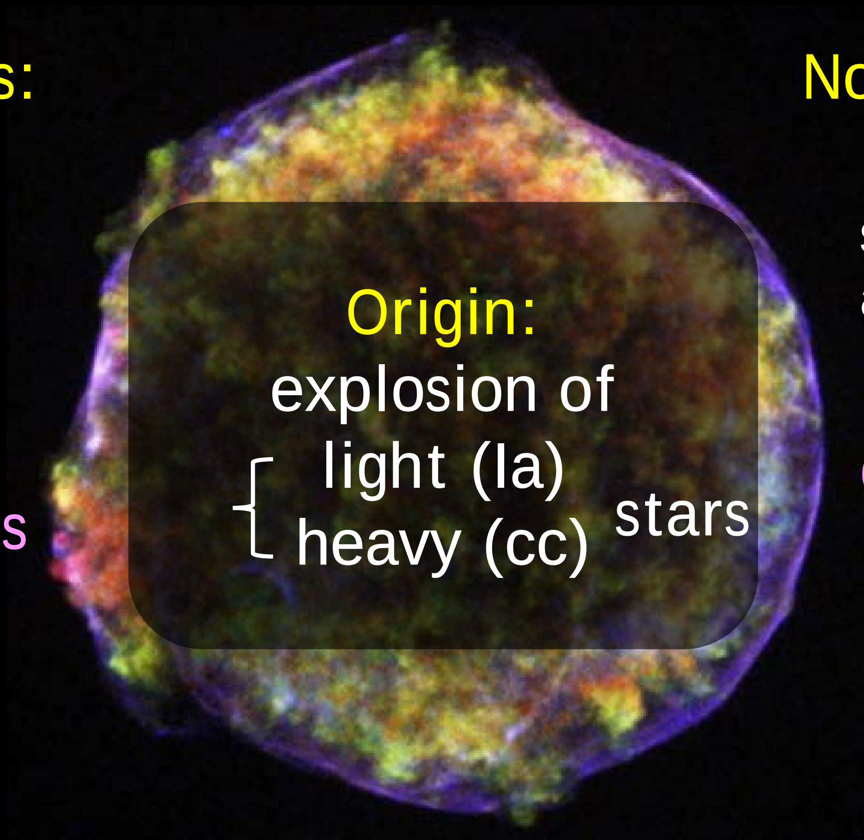
shock v ~ 10^{3-4} km/s
accelerate particles
efficiently

distribute
cosmic rays

SNe/SNRs make the diversity of the universe.
Tight connection between:

- Gravitational wave observations
- Chemical evolution of our universe
- Cosmology as standard candles …

0.2. Many unresolved problems



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How can we use SNRs to understand SNe ?
1. Are Ia really universal ?
2. diversity of CC SNe ?
3. What we can do with future missions ?

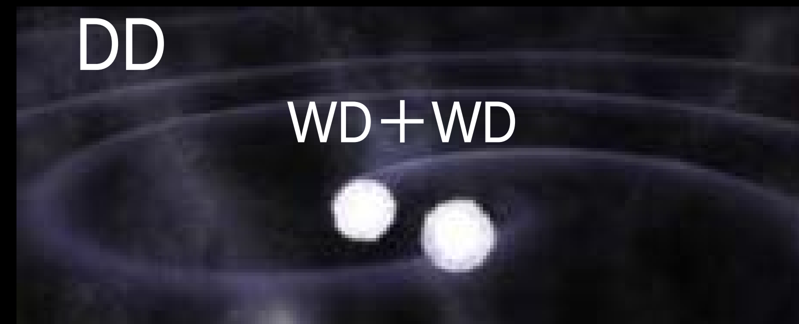
We will introduce the recent progress on these topics.

topic 1.

How to understand the origin of SN Ia

1.1. Origin of Ia ?

Two types of progenitors are proposed.



Single degenerate:
WD + main sequence
~M_{ch} -> standard candle !
dense core ($\rho \geq$ 2e8 g/cm^3)

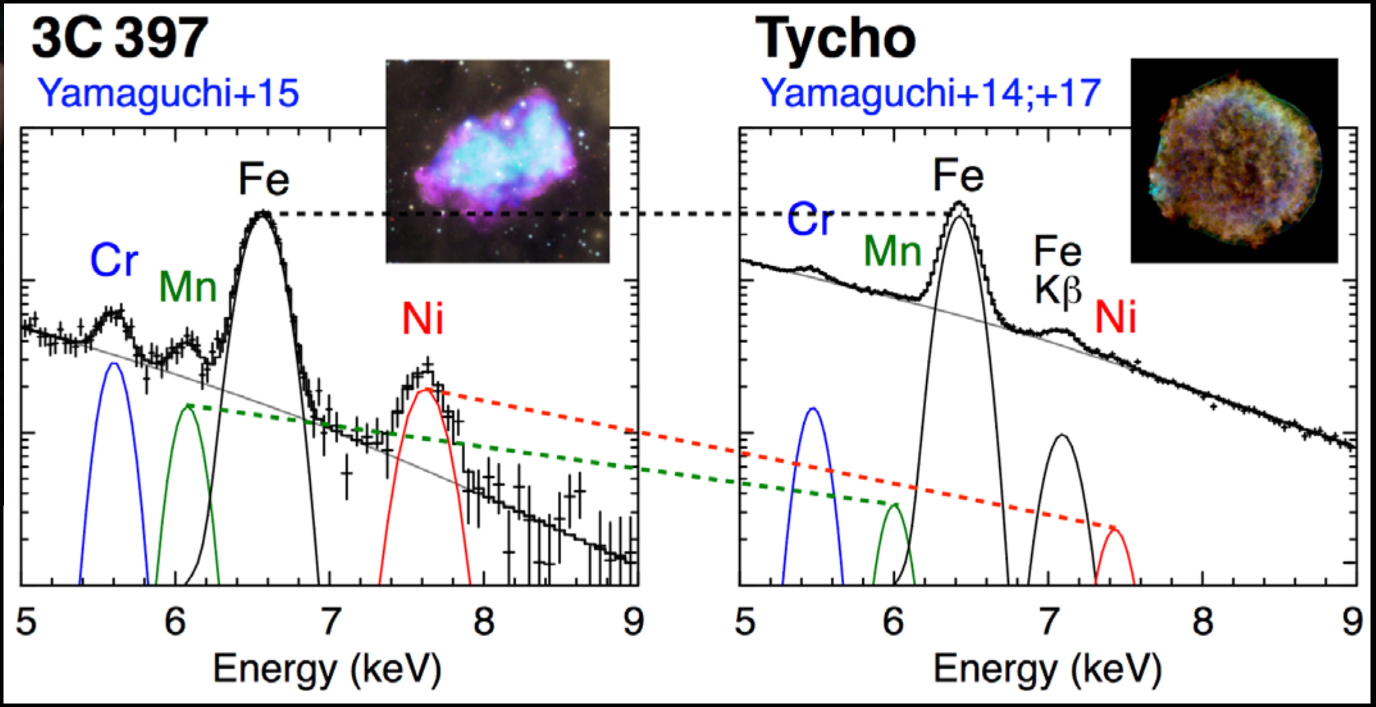
Double degenerate:
WD + WD -> GW target !
sub M_{ch}, variety ?
less dense core

Which is the main contributor of Ia SNe ?
How to distinguish their origin from their remnants?

1.2. SN diagnostics from X-ray spectra

high ρ in SD core makes more Ni, Mn

due to more electron capture



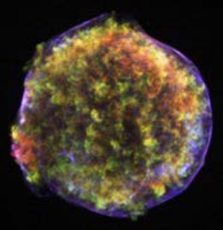
3C397 has significantly larger Ni/Fe than Tycho.
It needs M_{ch} to have such large Ni/Fe ratio.
Strong diagnostics to distinguish SD and DD.

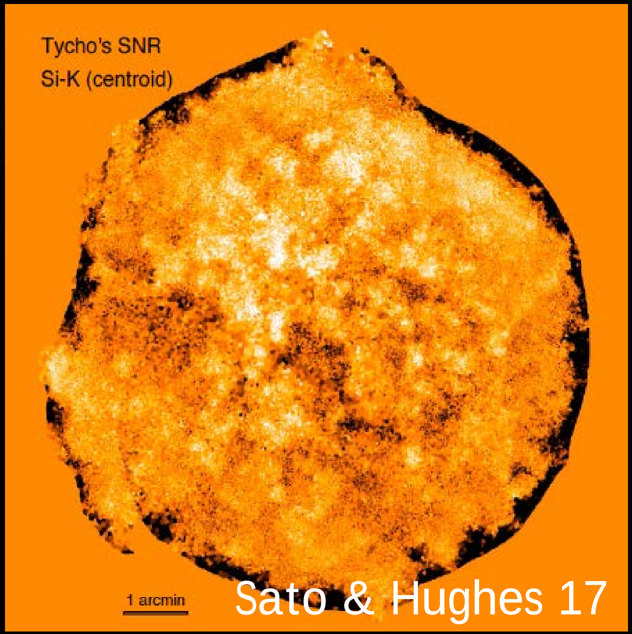
1.3. Expansion structure of Ia SNRs

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

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

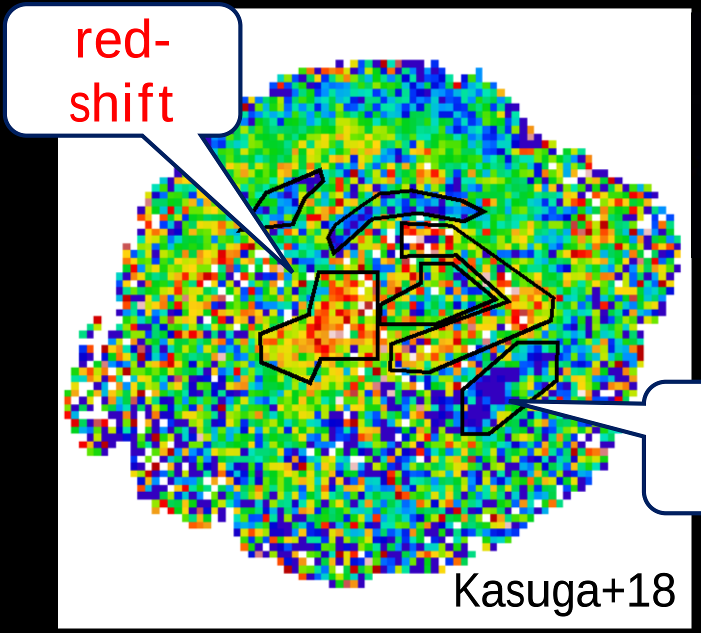
Tycho Si Doppler map





almost symmetric

Kepler Fe Doppler map



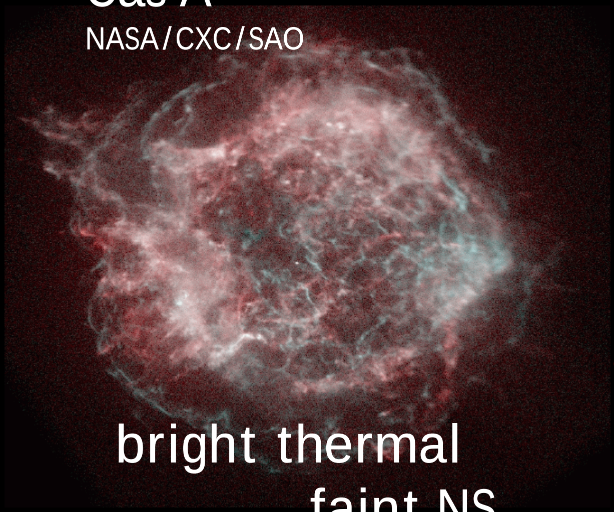
red and blue-shifet components asymmetric expansion

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

topic 2.
How to understand the diversity of CC SNe

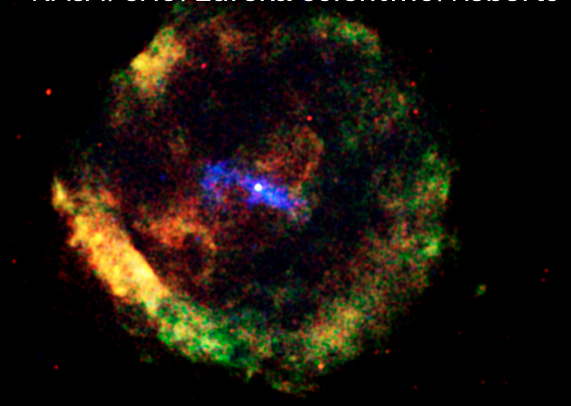
2.1. Variety of CC SNRs

Cas A
NASA/CXC/SAO



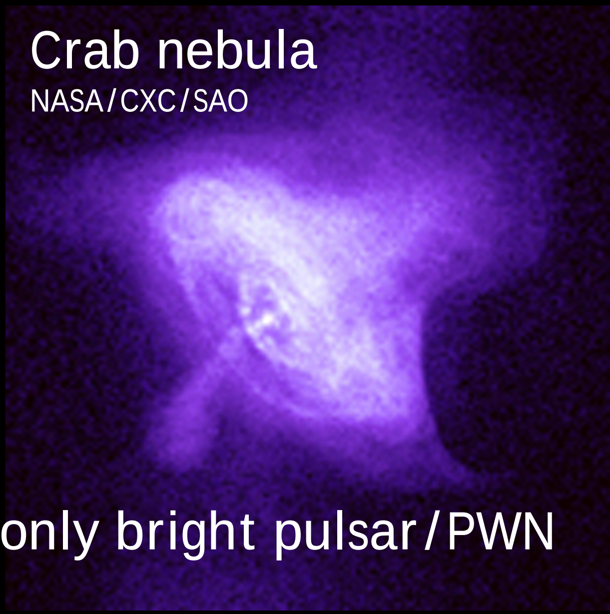
bright thermal
faint NS

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



both thermal/PSR

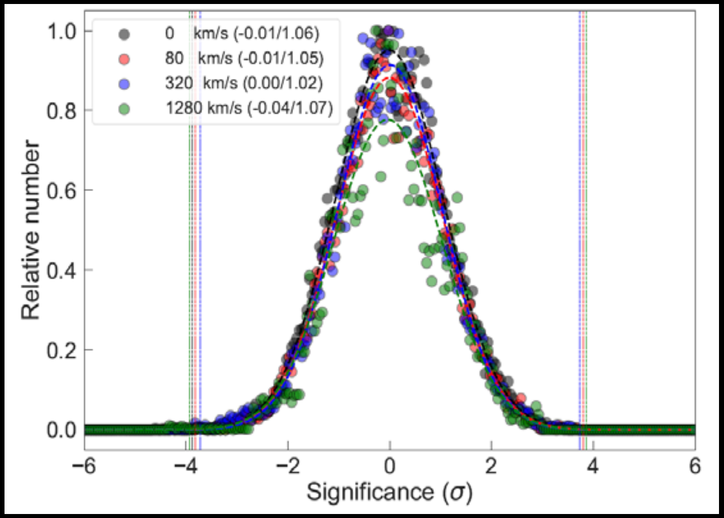
Crab nebula
NASA/CXC/SAO



only bright pulsar/PWN

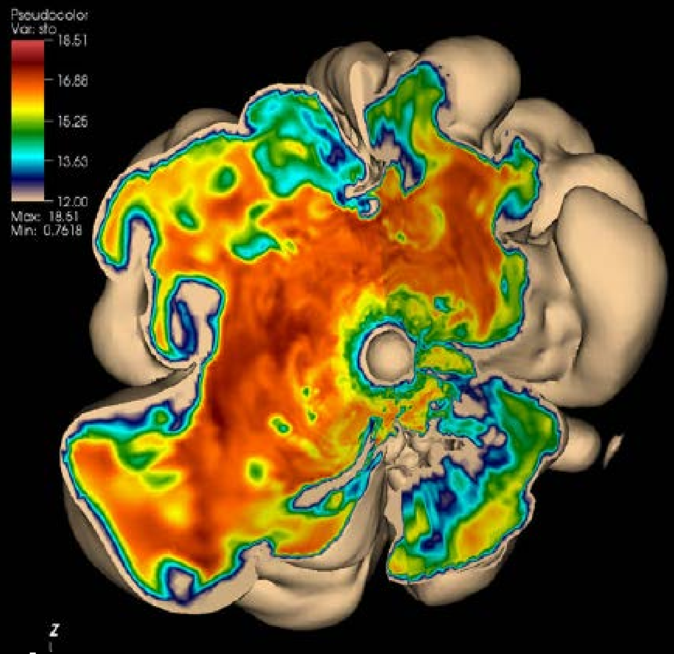
What makes such difference ?

Crab Thermal line search
with Calorimeter onboard Hitomi
-> very tight upper-limit
plasma mass < 1Mo
-> electron capture SN ?
(CC SN by rather light star)



(Hitomi collaboration 2018)

2.2. expansion asymmetry of CC SNRs



Hanke+12

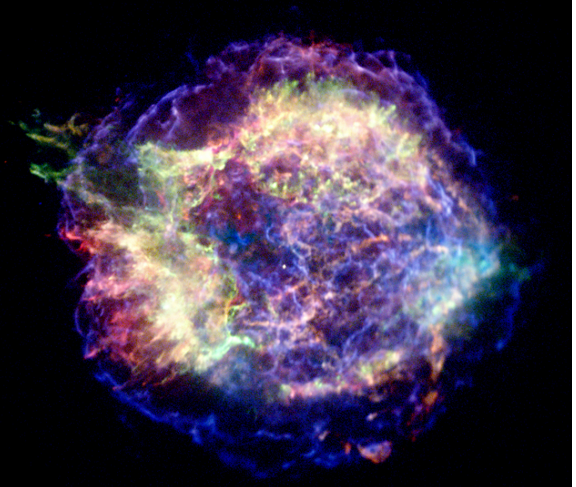
It is not confirmed yet
how to explode massive stars
to be CC SNe

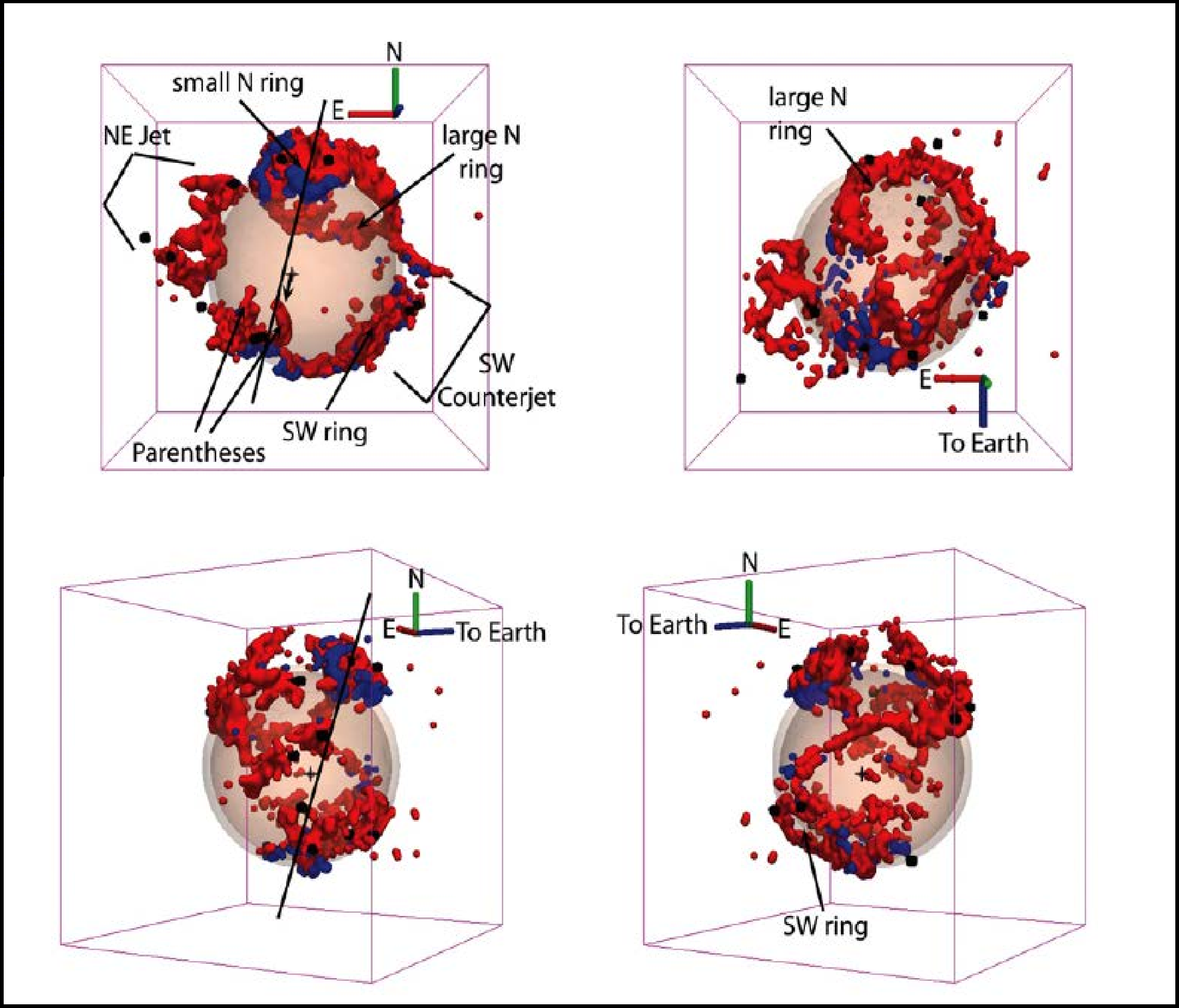
One of the keys of CC SN explosion:
Standing Accretion-Shock Instability
(SASI: Blondin+03)
Strongly asymmetric expansion expected

How asymmetric they are ?
jet ? connection to GRB
Critical to estimate gravitational waves from SNe

Expansion measurement of Cas A

(DeLaney+10)



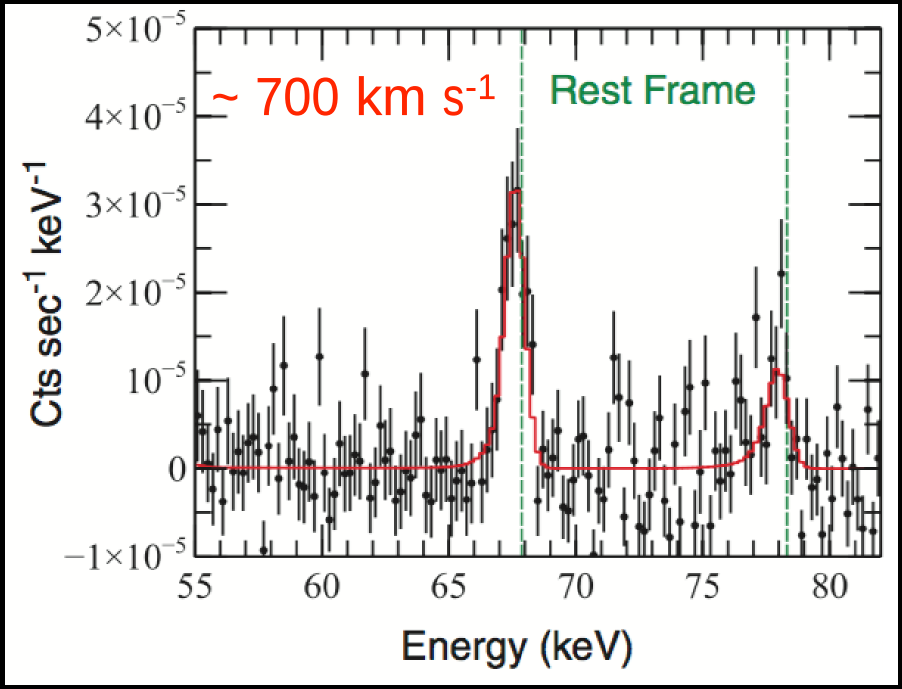


Doppler mapping
highly asymmetric
jet structure
Only for
heated ejecta

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

CC SNR expansion with ^{44}Ti (radio active decay line)

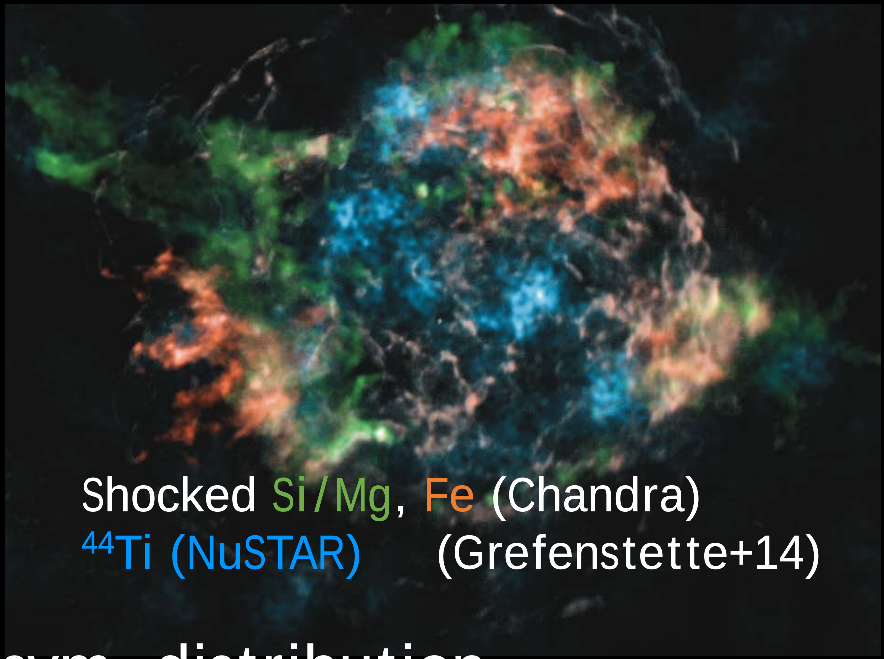
SN 1987A (~30 yrs)



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

Obviously more samples are needed.

Topic 3:

Future Studies of SNRs

to understand supernovae

3.1. Key observation parameters

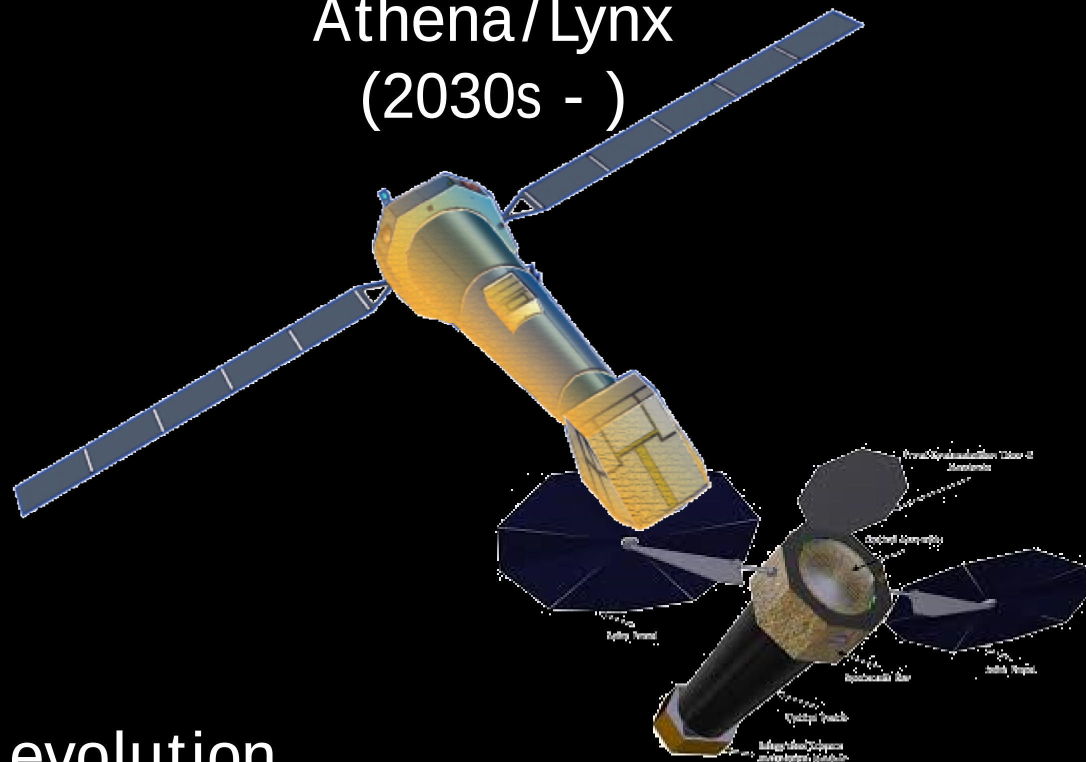
Line measurement is crucial to understand:

- expansion structure with Doppler
- abundance pattern of heavy elements

-> We need X-ray calorimeters !

XRISM
(2021 JFY -)

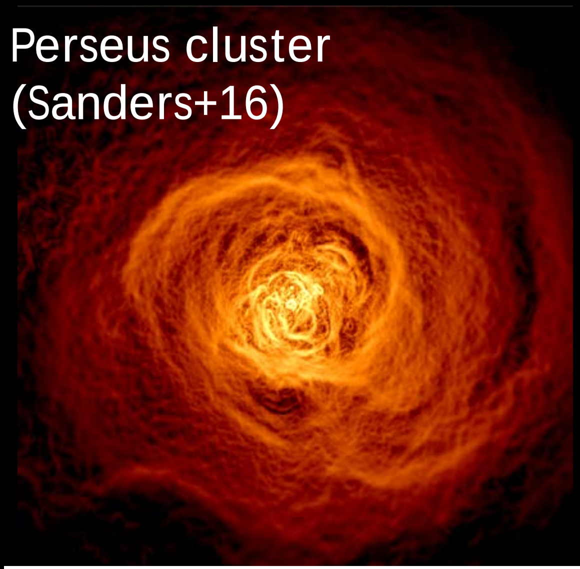
Athena/Lynx
(2030s -)

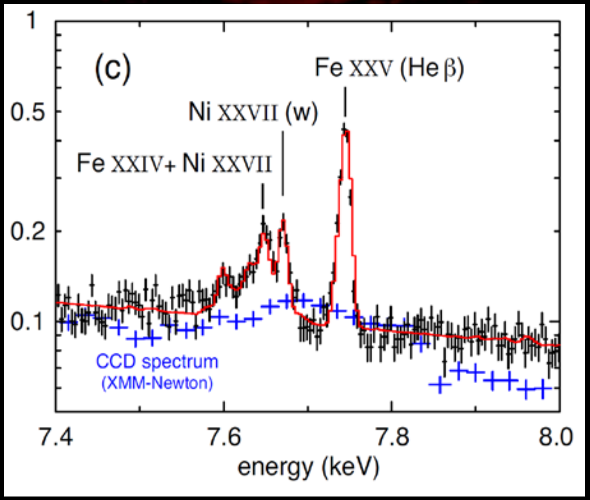


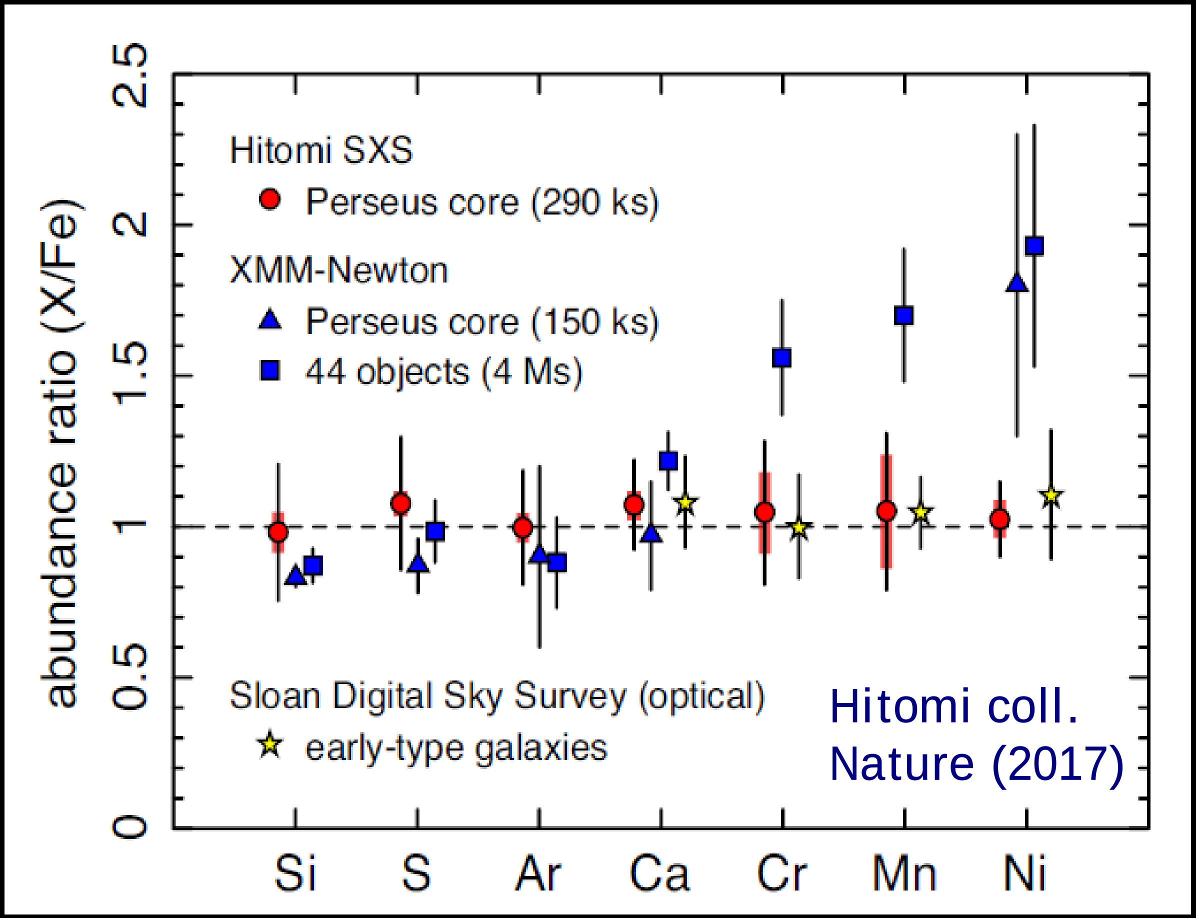
To understand chemical evolution,
searching for SNRs with eROSITA/SKA is quite important.

3.3. Which kind of SNe happened in clusters of Galaxies

Ni/Fe ratio in CG gas show us which kind of Ia SNe often happen.



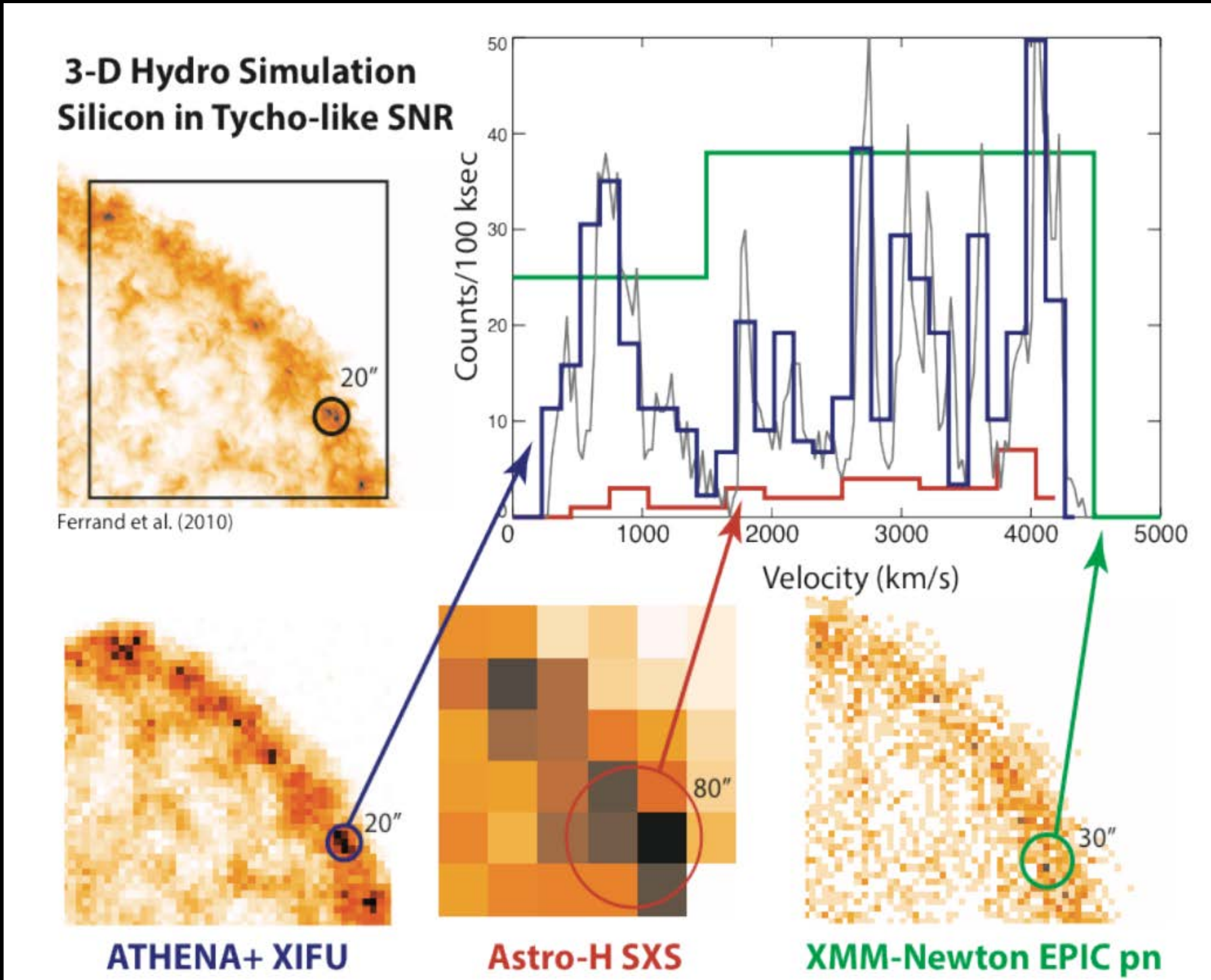




Same Ni/Fe ratio in Peseus and our Galaxy
Same recipe of star formation … ?

XRISM will resolve abundance pattern for bright clusters.

3.4. Athena/Lynx will complete this study to older/fainter SNRs



Decourchelle+13

Athena complete 3D expansion structure every elements of SNRs to understand the explosion mechanism of SNe.

4. Summary

- Supernovae plays crucial role in the universe.
  - chemical evolution
  - as standard candles of cosmology
  - gravitational wave emitters

- Supernova remnants are great tools to understand
  - SN explosion mechanism
  - asymmetric expansion as GW emitter

- Future calorimeter missions (XRISM/Athena) will
  - resolve complete 3D expansion structure
  - show us the results to connect
    GW, chemical evolution, ...