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The hard X-ray emission properties of young supernova remnants observed by INTEGRAL

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Main Contents

- Science goals:

  supernova remnants (SNRs) connected to galactic cosmic rays;

  constraints on the progenitors of historic SN events.

- Main results:

(1) Discovering the hard X-ray tails to 220 keV in Cas A, no cutoff;

(2) ^{44}Ti line detections in Cas A and Tycho, constraints on their progenitors

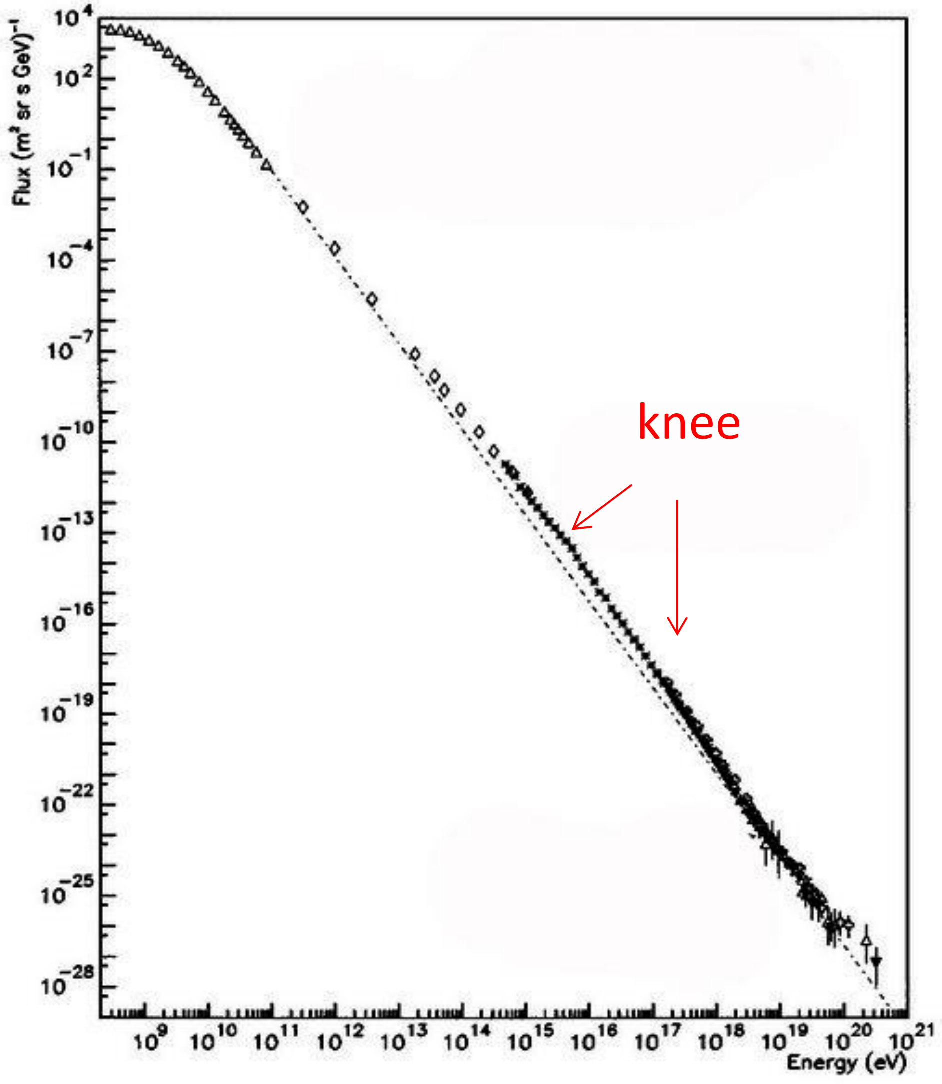
- Summary and future work

Motivations

- Connections between SNRs and high energy CRs

SNRs are thought to be the main contributor to Galactic CRs, specially around knee energy ranges ($3x10^{15}$ eV). But we still be lack of direct evidence in observations.

One way - detect TeV photons
Gound Cherenkov Telescopes (HESS, MAGIC, VERITAS) detected TeV gamma-rays in some SNRs, show evidence for accelerating particles to 10^{14} eV in SNRs.
In future, evidence would come from detecting 100 TeV



- The other way to probe the accelerating ability in SNRs: non-thermal hard X-ray emissions

Hard X-ray synchrotron radiation photons up to 20 keV by ASCA in shells of SN 1006 implied accelerated electron energy to 100 TeV (Koyama et al. 1995).

RXTE detected hard X-ray tails in Cas A up to 60 keV, suggested Cas A can accelerate electrons to at least 40 TeV (Allen et al. 1997). This hard X-ray tails were confirmed by COMPTON/OSSE, which can extend to 100 keV (The et al. 1996).

Hard X-rays attributed to synchrotron radiation of accelerated electrons in SNRs can reflect the acceleration ability of high energy particles. Observing hard X-ray photons (specially above 100 keV) could help to searching for evidence of accelerating cosmic rays to the knee region (PeV) in SNRs.

^{44}Ti emission lines (by-product in hard X-ray observations) – probe the progenitors of supernovae

- ^{44}Ti radioactive isotope (lifetime 86 yr) only comes from supernova (SN) explosions, emitting three lines at 68, 78, 1157keV.
- ^{44}Ti yield varies in different types of SNe.
- Generally type II/Ib/Ic SNe are thought to be main origin of ^{44}Ti in the Galaxy. The standard spherical explosion models predict the ^{44}Ti yield of 10^{-5}-$10^{-4}M_{\odot}$.
- Standard type Ia SN models (explosions of $1.4M_{\odot}$WD) cannot produce enough ^{44}Ti (3Dsimulations, $<10^{-5}M_{\odot}$)； But Ia SNe could be produced by double WD mergers, but unclear in ^{44}Ti yield; some people proposed sub-chandra sekhar mass WD as progenitor of type Ia SNe which can produce high ^{44}Ti yield , larger than $10^{-4}M_{\odot}$.
- Thus detecting ^{44}Ti lines at 68 and 78 keV can directly probe the progenitors of SNe.

Main Contents

- Studying hard X-ray emission properties of Galatic young SNRs with INTEGRAL/IBIS：

  (1) spectral properties of hard X-rays - accelerating ability of these SNRs - origin of high energy cosmic rays

  (2) searching for ^{44}Ti line features – progenitors of SNe
- IBIS aboard INTEGRAL: good detector in the bands of 18 – 500 keV, could search for > 100 keV hard X-rays in SNRs;
- JEM-X aboard INTEGRAL can provide a lower energy band data (3-30 keV), constraint on the continuum properties.
- INTEGRAL have performed hard X-ray surveys over ten years, 2003 – 2012.
- With the deep survey data, we reported the new results on two SNRs: Cas A , Tycho

New results for Cas A

famous young SNR, bright in all electromagnetic bands

Age: 330 yr; distance: 3.4 kpc

Gamma-ray band observations:

HEGRA, MAGIC, VERITAS detected its TeV photons (Aharonian et al. 2001; Albert et al. 2007; Humensky 2008);

Fermi/LAT reported the GeV spectrum (Abdo et al. 2010);

Early hard X-ray observations:

RXTE detected Cas A up to 60 keV, above 15keV, $\Gamma \sim 3.04$ (Allen et al. 1997)

COMPTON/OSSE reported the detection to 100keV, $\Gamma \sim 3.0$ (The et al. 1996)

BeppoSAX also detected it, $\Gamma \sim 2.9$; a bump in the bands 60-90 keV which is attributed to the ^{44}Ti lines (Vink & Laming 2003)

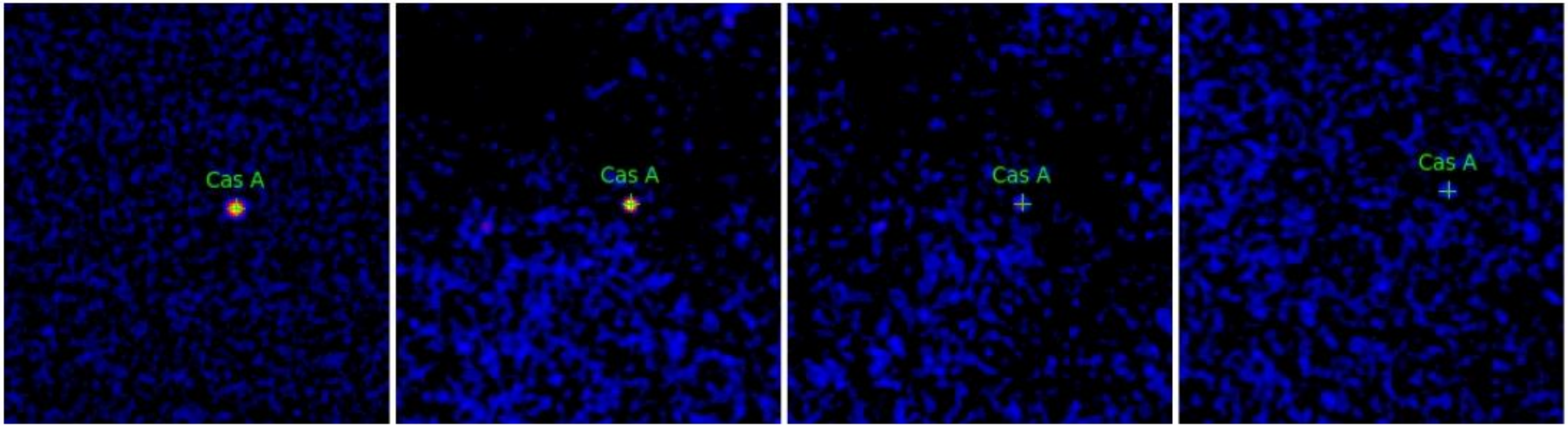
Suzaku detected it from 12-40keV, $\Gamma \sim 3.06$ (Maeda et al. 2010)

Early INTEGRAL/IBIS data reported the spectrum from 20-100keV, $\Gamma \sim 3.0$, and detected the ^{44}Ti lines at 68, 78keV (Renaud et al. 2006)。

Images by INTEGRAL/IBIS

Collecting the data from 2003 – 2012:

3 – 10 keV | 20 – 60 keV | 60 – 90 keV | 90 – 200 keV

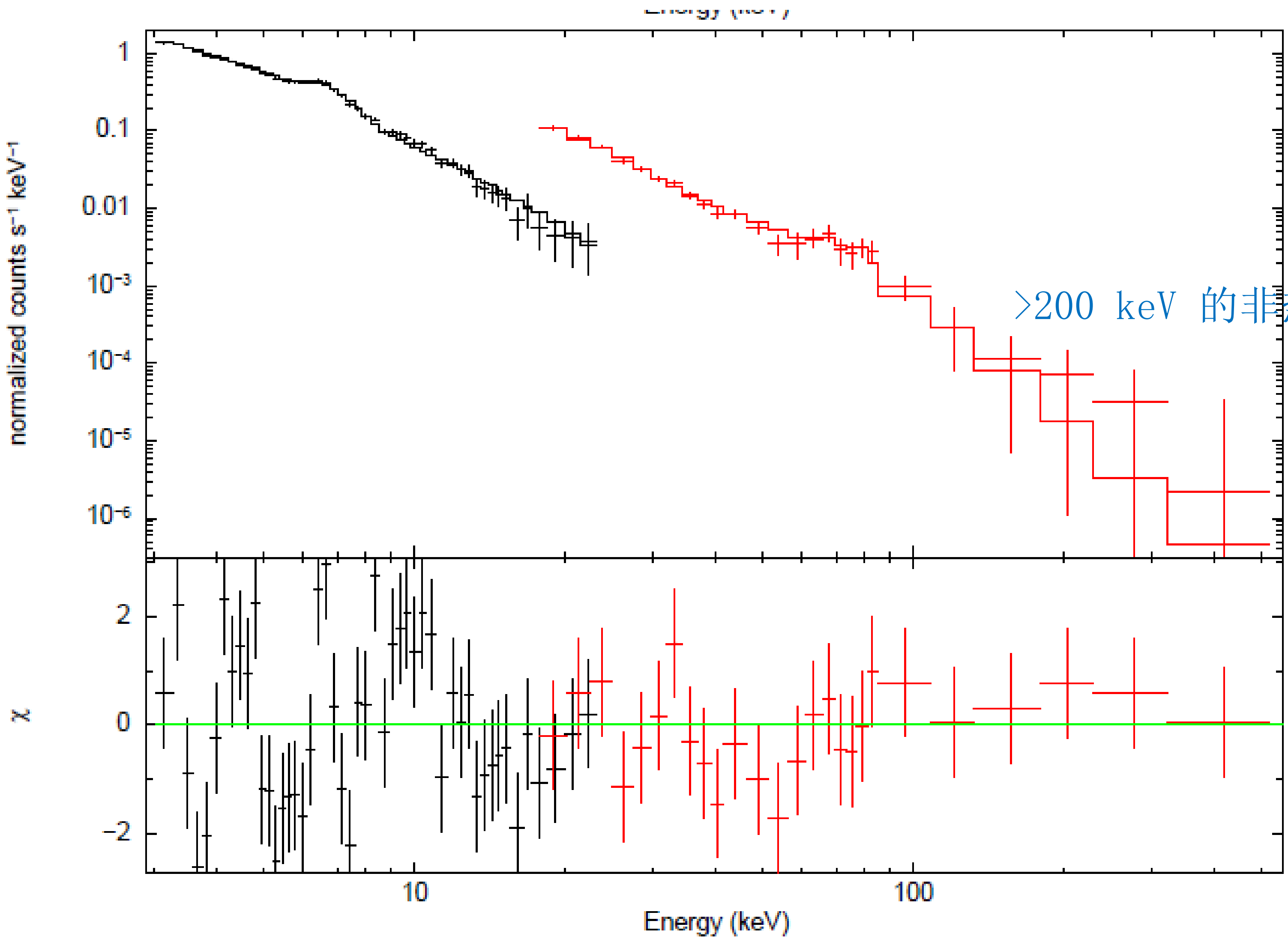


58.2σ | 54.8σ | 14.9σ | 7.3σ

Hard X-ray spectrum from 3-500 keV: JEM-X and IBIS

Continuum spectrum models: Bremss + Power-Law

kT ~0.81±0.08 keV ; Γ ~ 3



>200 keV 的非热辐射光子

Non-thermal emission photons up to 220 keV in Cas A

- Non-thermal spectrum of Cas A from 10 – 500 keV, single power-law $\Gamma \sim 3.1$, without cutoff at least to 220 keV.
- Hard X-ray emissions come from synchrotron radiation of accelerated electrons in shock waves; the spectrum shows an exponential cutoff around several keV.
- Thus the power-law emission from 10 - >220 keV in Cas A challenges the particle accelerating models in shock waves!
- Some possibilities:

  higher magnetic field emitting regions

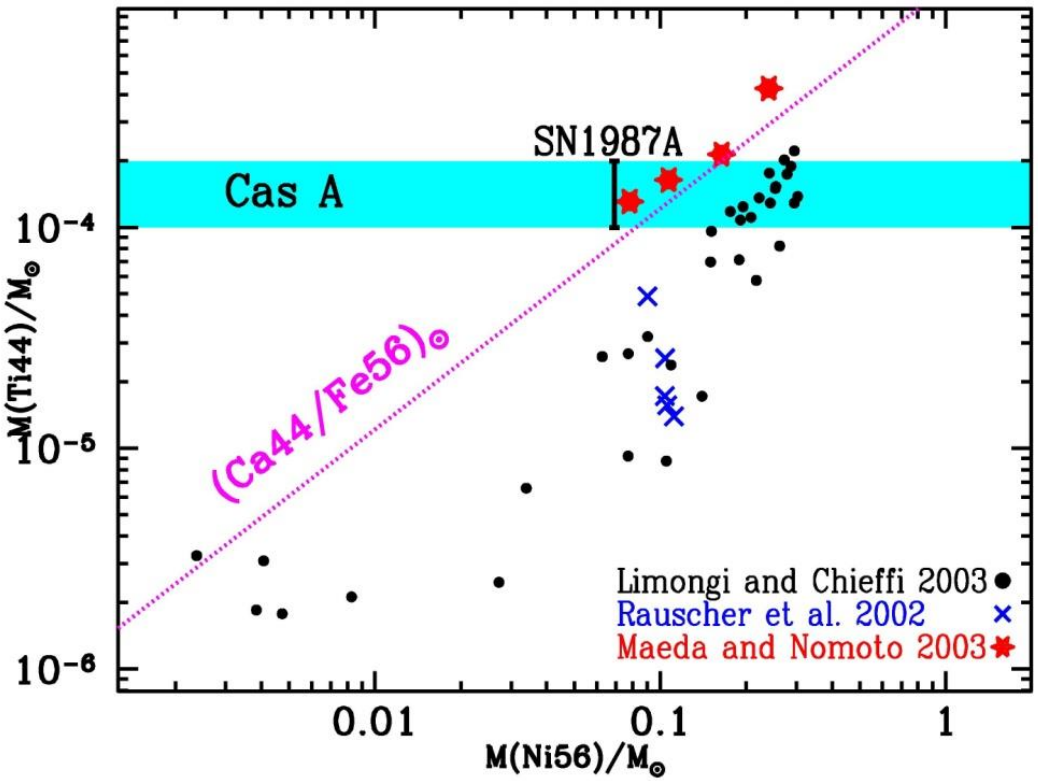
  special electron spectrum in high energy band (>100 TeV)

  contributions by secondary electron emission from P-P interactions

^{44}Ti yield in Cas A

New INTEGRAL/IBIS derived the mean flux at 68, 78 keV：
$(2.3 \pm 0.5) \times 10^{-5}$ ph cm^{-2} s^{-1} , the ^{44}Ti yield is $(1\text{-}2) \times 10^{-4}\ M_\odot$.

The standard spherical explosion models predict the ^{44}Ti yield of $<10^{-4}\ M_\odot$ - there exists a large difference; the case of Cas A is challenge to the supernova explosion models.



^{44}Ti production depends on the symmetries and energies (Nagataki et al.1998);

The explosion of Cas A could be intrinsically asymmetric;

- supported by some observational evidence in the X-ray emitting ejecta of Cas A (Vink 2004; Hwang et al. 2004, 2012) .

Tycho SNR

Famous historic SNR occurring in 1572; thought to be type Ia/Ib SN, recently indentified as Ia(Krause et al. 2008) 。

Gamma-ray observations:

GeV by Fermi/LAT , $\Gamma \sim 2.3 \pm 0.3$ (Giordano et al. 2012);
TeV by VERITAS and MAGIC, $\Gamma \sim 1.95 \pm 0.81$ (Acciari et al. 2011) 。

Early hard X-ray observations:

HEAO 1 (Pravdo et al. 1979)detected non-thermal emission from 5 -25 keV with $\Gamma \sim 2.72$。

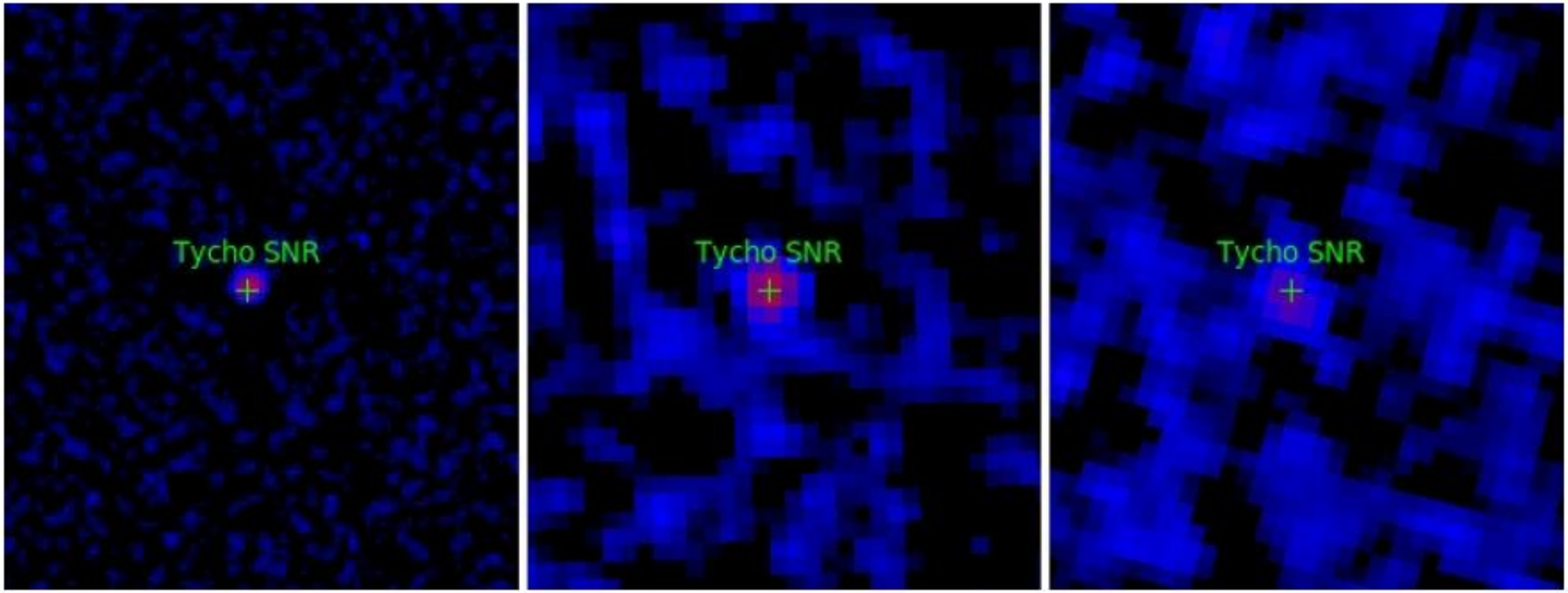
RXTE detected it up to 20 keV, $\Gamma \sim 3$ (Petre et al. 1999)。

Suzaku reported non-thermal emission from 13-28 keV, $\Gamma \sim 2.8 \pm 0$, implying Tycho can accelerate electrons to at least 10 TeV (Tamagawa et al. 2009) 。

INTEGRAL observations on Tycho

- Hard X-ray flux of Tycho is about 15% of Cas A, difficult to be observed
- Our data of JEM-X and IBIS with nearly 10 tens years：
  first detecting hard X-ray photons to 100 keV in Tycho

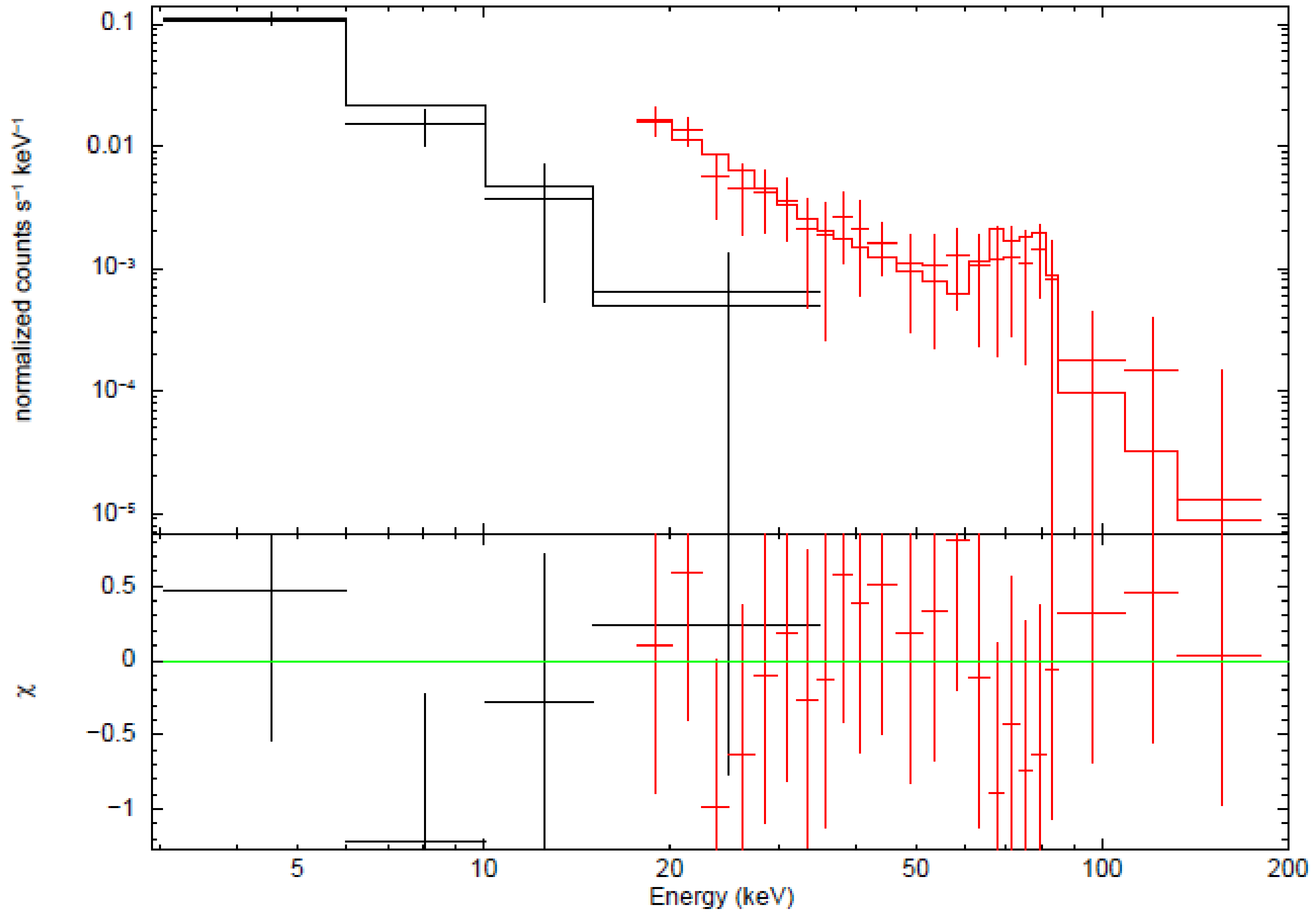
3 – 10 keV 9.8σ   20 – 60 keV 11.6σ   60 – 90 keV 5σ



Tycho spectrum : 3-200 keV

Single power-law: Γ ~ 3.18±0.09; to 100 keV

A bump feature in 60 - 90 keV, attributed to ^{44}Ti line signals!



^{44}Ti yield in Tycho

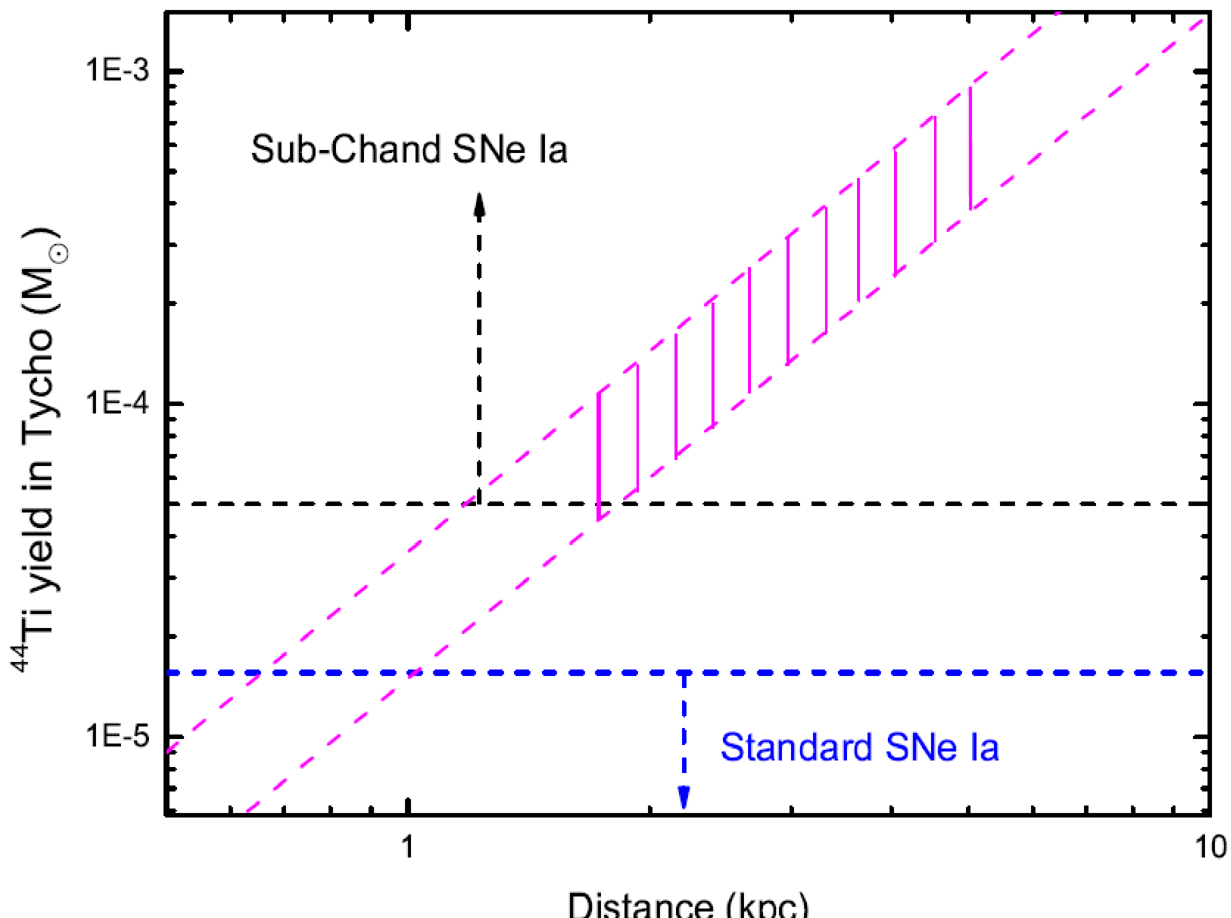
The observed mean flux at 68 and 78 keV: $(1.3\pm0.5)\times10^{-5}$ ph cm^{-2} s^{-1};

Distance of Tycho SNR: 1.7 - 5 kpc

^{44}Ti yield as function of the distance: compared with theoretica

(1) Standard models (1.4 $M_\odot$ WD);
(2) Double WD merger: uncertain, can produce enough ^{44}Ti if one WD is He WD;
(3)sub-Chandrasekhar WD model (0.8 - 1.2 $M_\odot$) .

The detected ^{44}Ti lines do not support Tycho progenitor is not a Chandra-mass WD explosion.

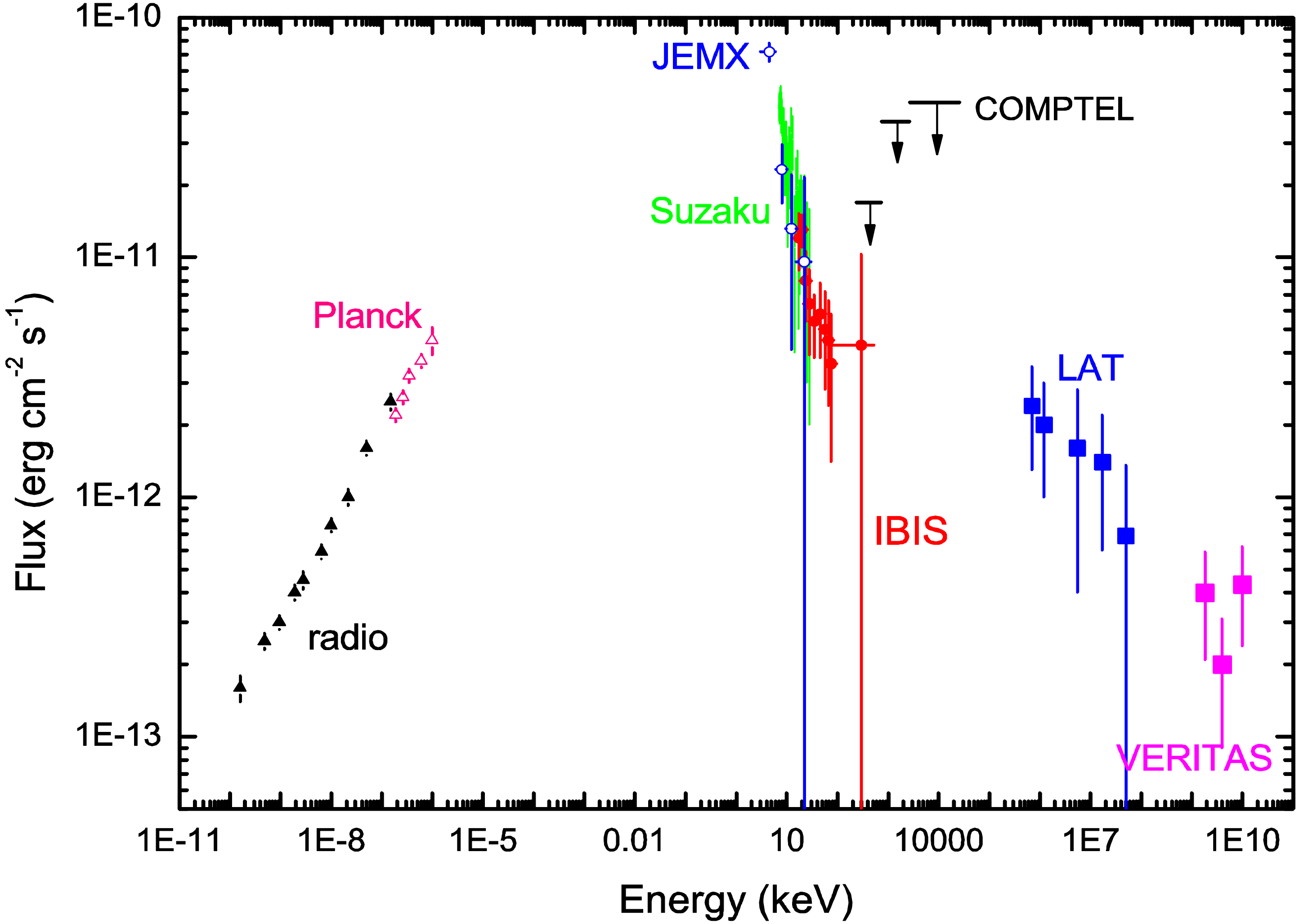


Summary and future work

- Hard X-ray observations need more: now INTEGRAL, NuStar, in future HXMT ;
- Detecting 44Ti lines in young SNRs (Cas A, Tycho) provides strong constraint on progenitors of SNe.
- Hard X-ray emissions of Cas A and Tycho show power-law components, $\Gamma \sim 3.1$, no cutoff; Detecting 220 keV photons in Cas A.
- Hard X-ray tails in SNRs challenge the present models of accelerating particles in shock waves: high magnetic field regions; particles to PeV energy bands by SNRs.
- In a relatively old SNR **RX J1713.7–3946** is also detected by IBIS, more analysis will be done.

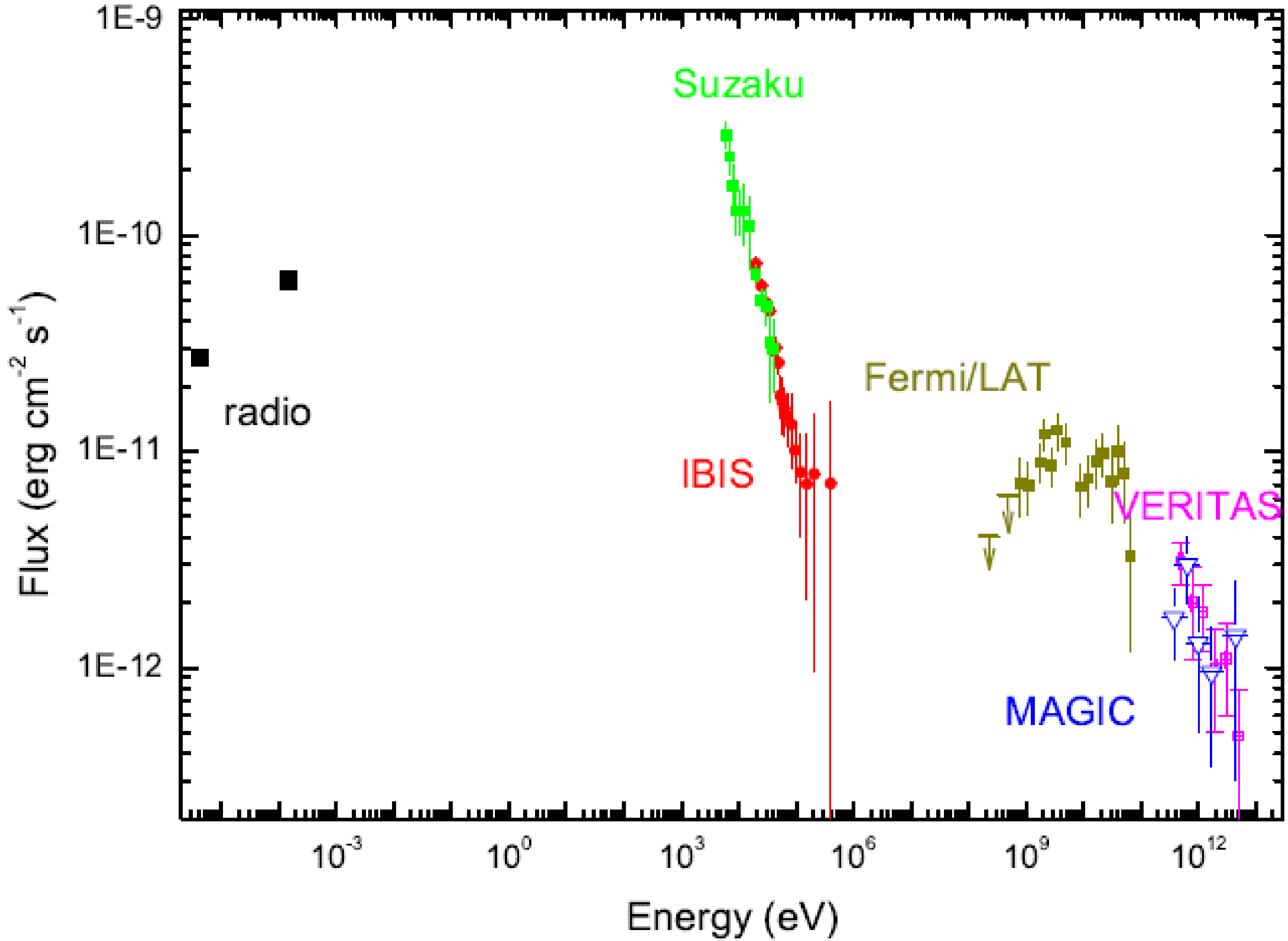
In future, multi-wavelength data will be studied and fitted with different models: lepton and hadron models.

Tycho



Hard X-ray data combined with GeV – TeV data will help to discriminate the lepton and hadron models for different SNRs.

Cas A



Thank you for attention!

More comments

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