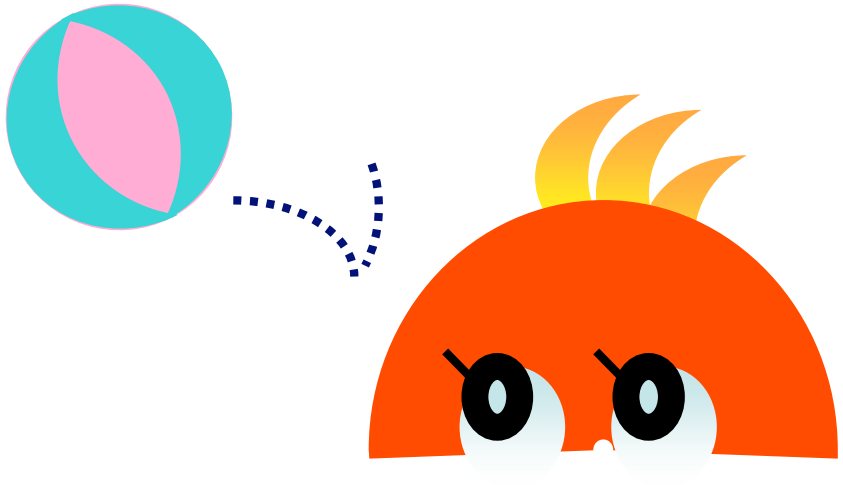
Nonthermal Supernova Remnants with Suzaku



Aya T. Bamba
(ISAS/JAXA, Japan)
and the Suzaku team

0.1. cosmic rays

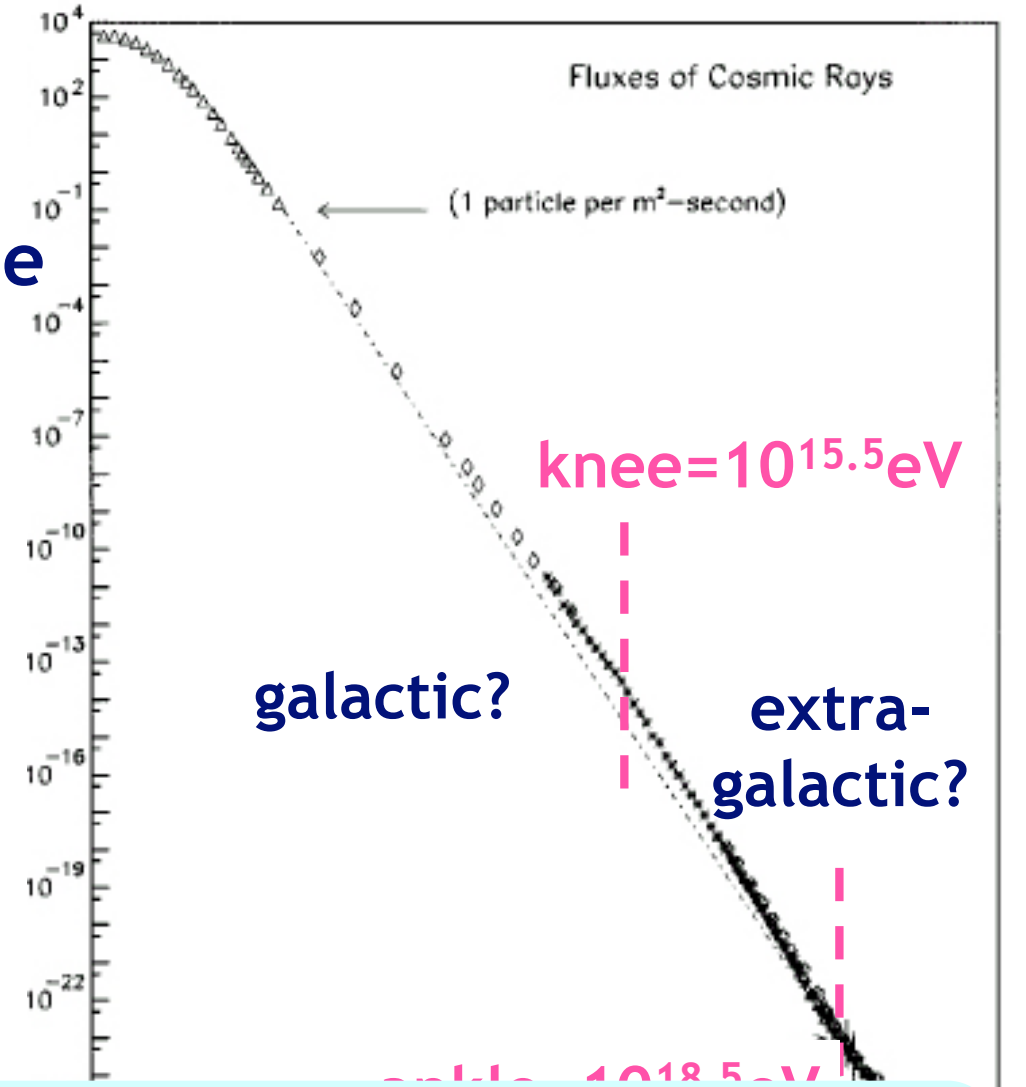
high energy particles in the universe

p,e,… up to 10^{20} eV

u_{CR} ~ 1eV/cc

c.f. CMB	0.3 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

the common element



Origin and Acceleration mechanism of cosmic rays are still unknown

0.2. Cosmic ray acceleration and SNRs

Who and how to accelerate cosmic rays up to knee ?
diffusive shock acc. in shocks ? = biggest problem !

difficulties: r_g ~ pc in interstellar B

-> we cannot point out accelerators

How to search for accelerators ?

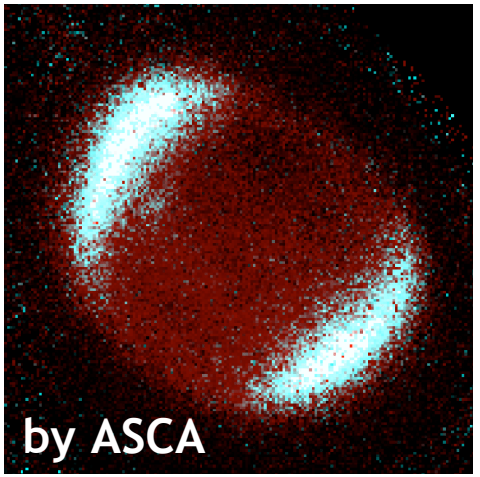
TeV electron
IS B. (~μG) → synchrotron X-rays

IC (e) or pion decay (p) -> TeV gamma-rays

hard X-rays obs. is the best
for the electron accelerator search.

0.3. Tasks for Suzaku

Koyama+ discovered sync. X-rays
from the shells of SN1006



What is the NEXT issue ?

1. Detailed spectra of sync. X-rays

cut-off ? -> E_{max} of e, B
difference of spectra between regions

← good stat. w. XIS

2. spectra above 10 keV

Sync. spectra free from thermal X-rays
efficient acceleration ?

← low bgd of HXD

3. Searching for new SNRs with sync. X-rays

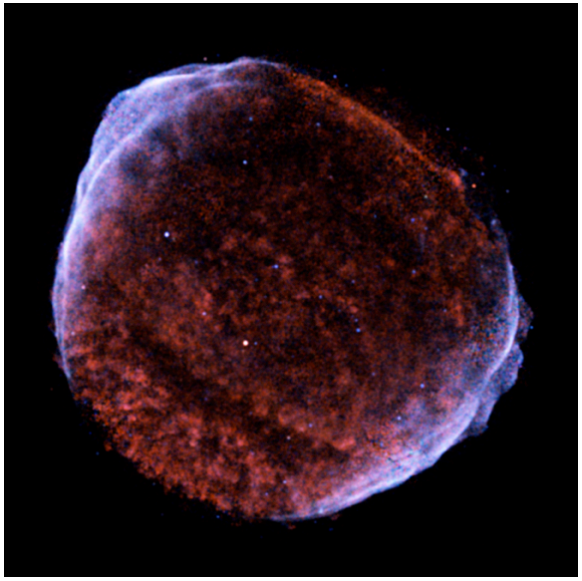
More and more samples we need !
Samples with thermal and nonthermal X-rays
are especially important.

← both XIS & HXD

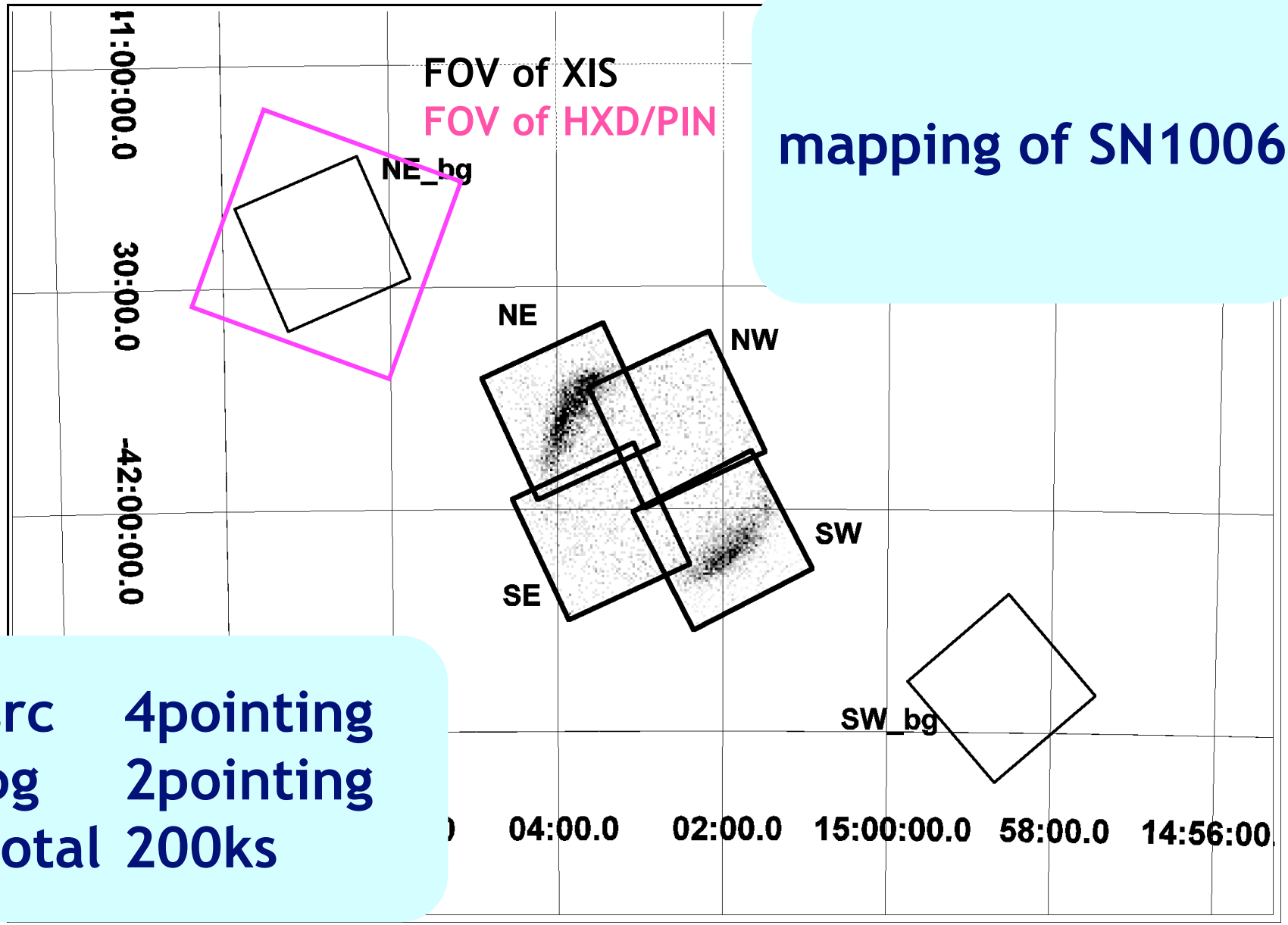
1. Detailed spectra of sync. X-rays

cut-off ? -> E_{max} of e, B
difference of spectra between regions

We need spectra
with good statistics
Let's see SN1006



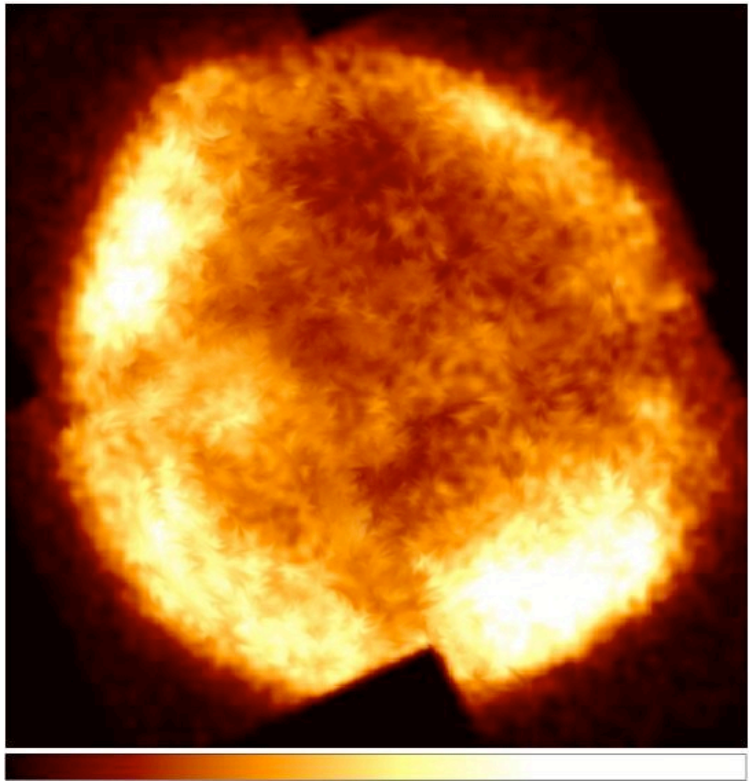
1.1. Suzaku observations of SN 1006



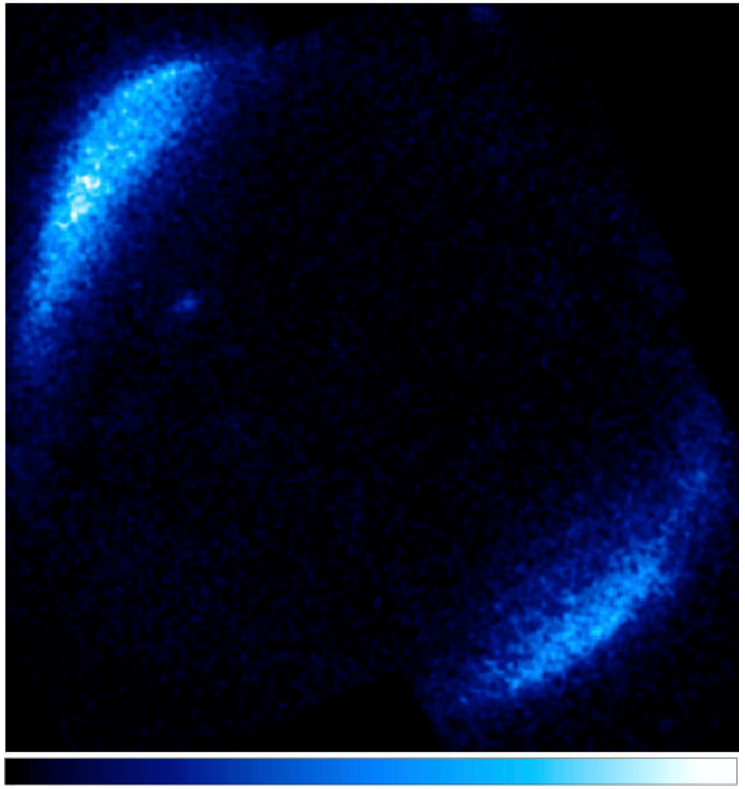
mapping of SN1006

src 4pointing
bg 2pointing
total 200ks

Suzaku images



He-like O line band



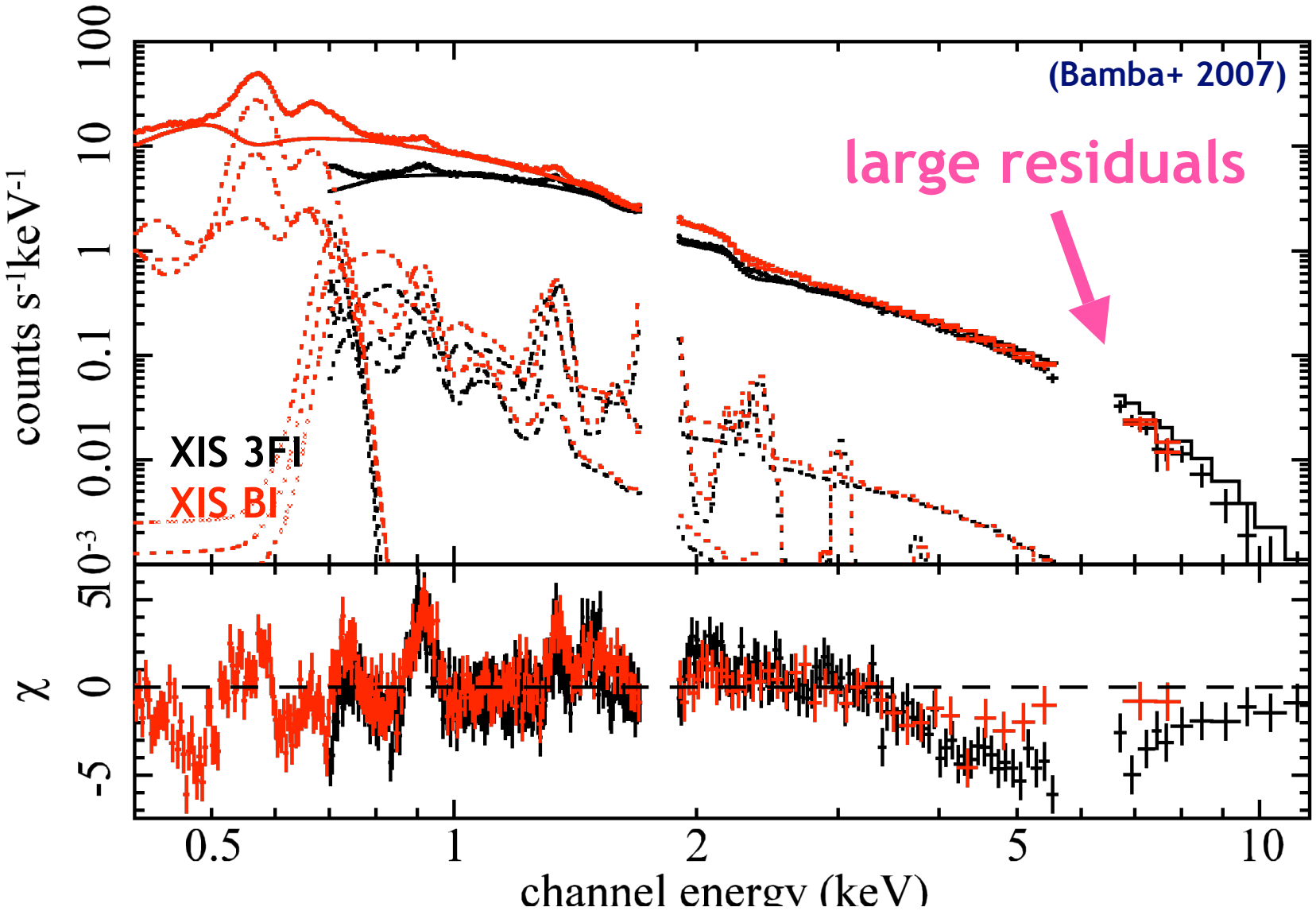
3 – 5 keV band

clear rim and inside emission

1.2. XIS spectra of SN 1006(1)

lines + hard emission

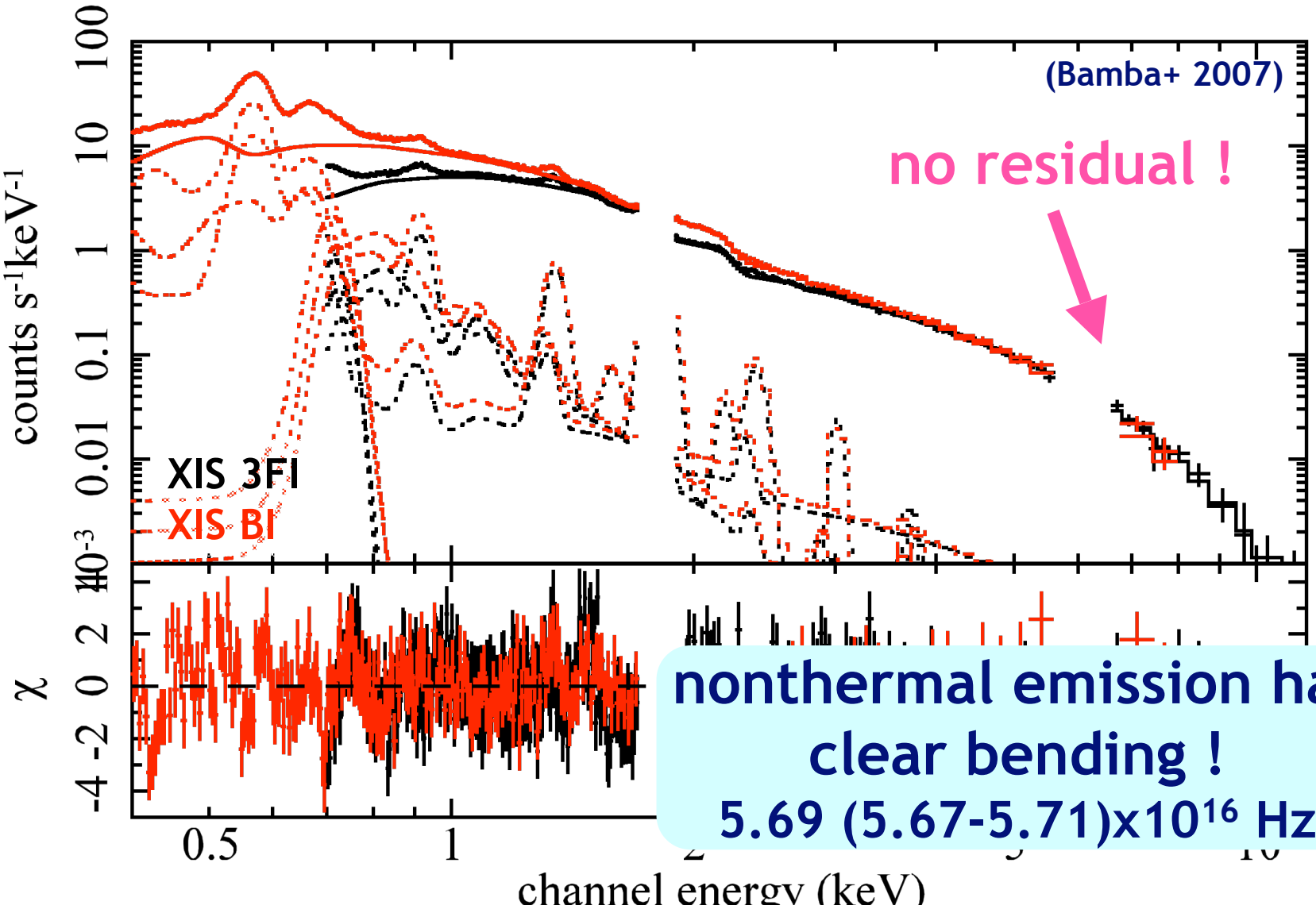
3 temp. thermal (Yamaguchi+ 2008, A48) + power-law



XIS spectra of SN 1006 (2)

3 temp.+ srcut model

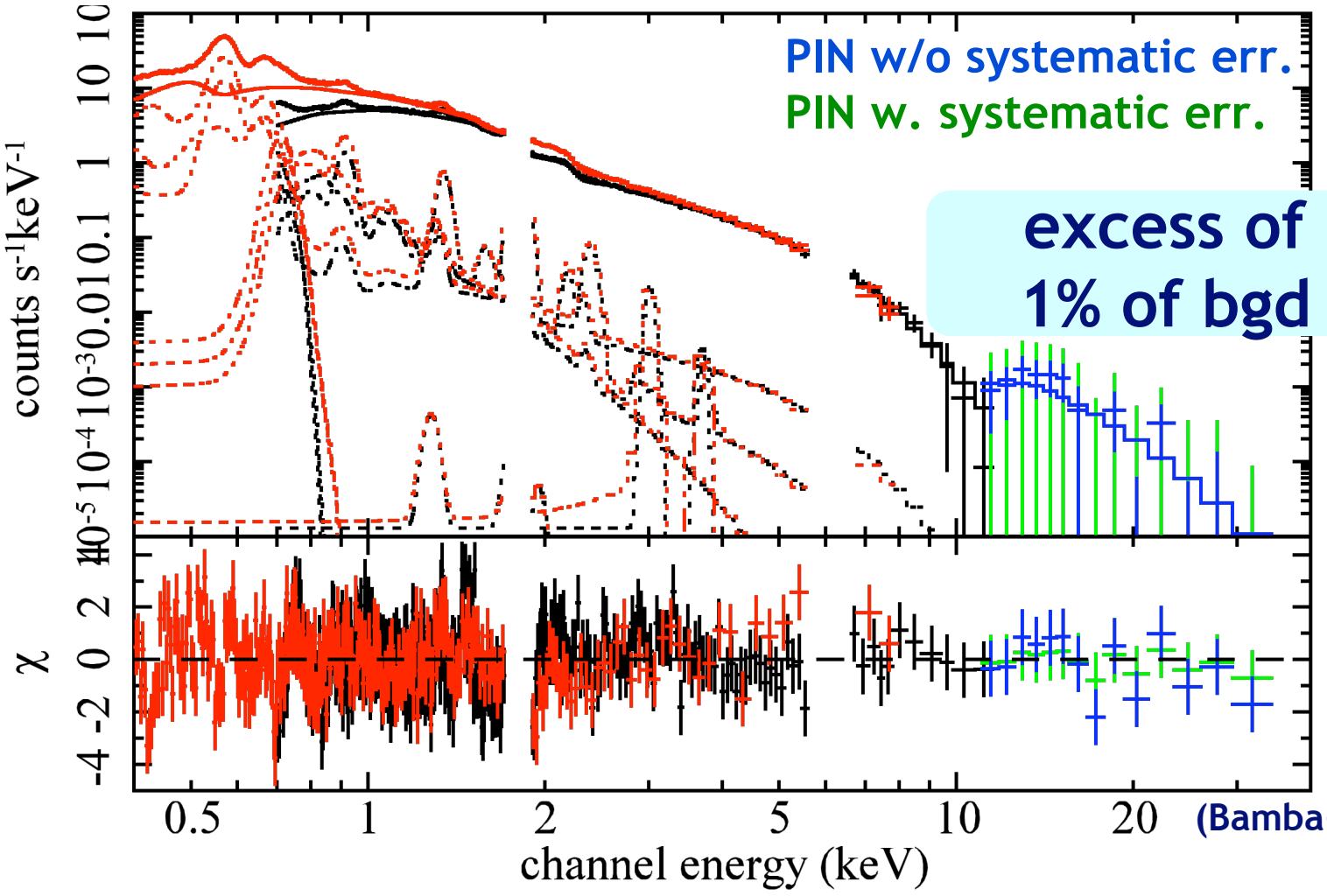
sync. emission from e
w. power-law + exp. spectra
a=0.57 is fixed



nonthermal emission has clear bending !

5.69 (5.67-5.71)x10^{16} Hz

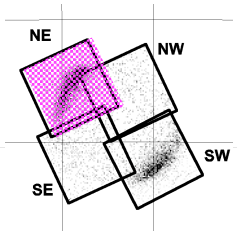
1.3. XIS/HXD spectra of SN 1006



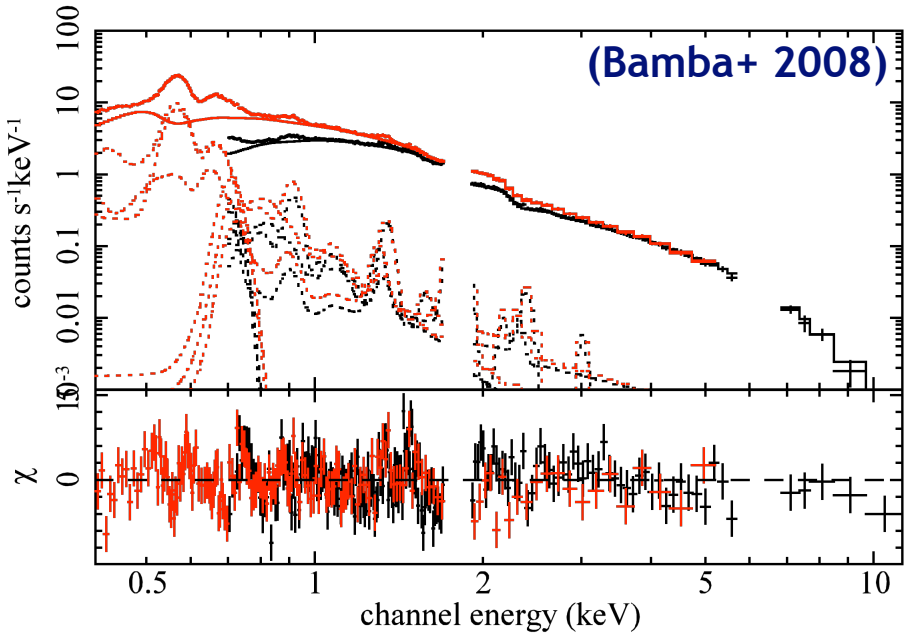
(Bamba+ 2008)

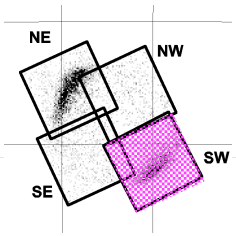
The most tight upper limit
(2.7×10^{-5} ph/cm^2/s in 10-15 keV)

1.4. XIS spectrum of each rim

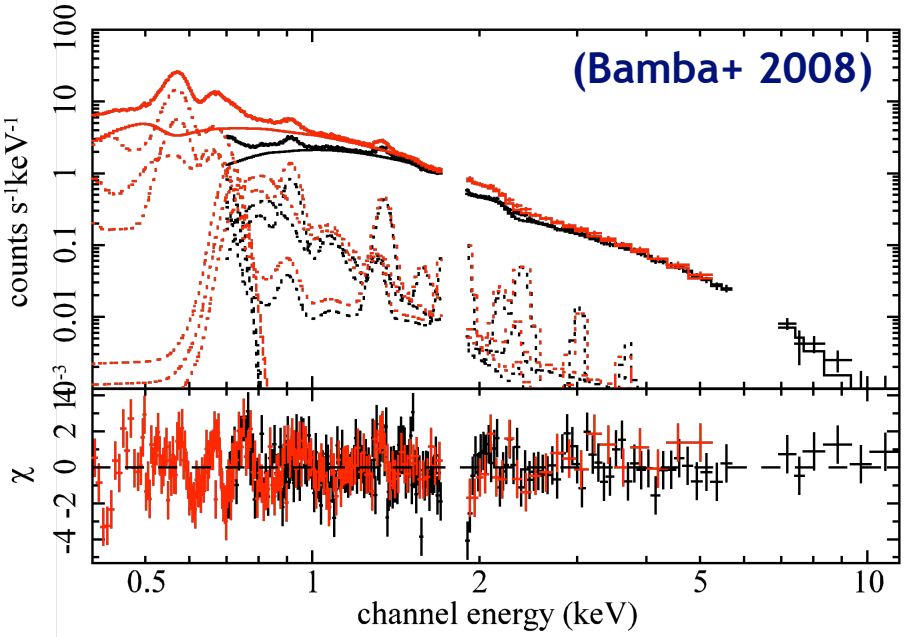


NE rim





SW rim



cutloff freq.

$6.66(6.58\text{-}6.69)\times10^{16}$ Hz **$4.68(4.64\text{-}4.73)\times10^{16}$ Hz**

Larger cutoff in the NE rim

1.5. What determine the cutoff energy ? (Bamba+ 2008)

$$\text{cutoff freq.} = 1.6\times10^{16}\left(\frac{B}{1\text{microG}}\right)\left(\frac{E}{10\text{TeV}}\right)^{2} \quad [\text{Hz}]$$

B: magnetic field E: the maxmimum E of e (Reynolds 1998)

Assumption: B=40microG (10microG outside of the SNR)

(Bamba+ 2003)

-> E = 9.4 TeV

The diff. of cutoff freq. in NE and SW

difference of B, E ?
-> diff. of acceleataion eff. ?

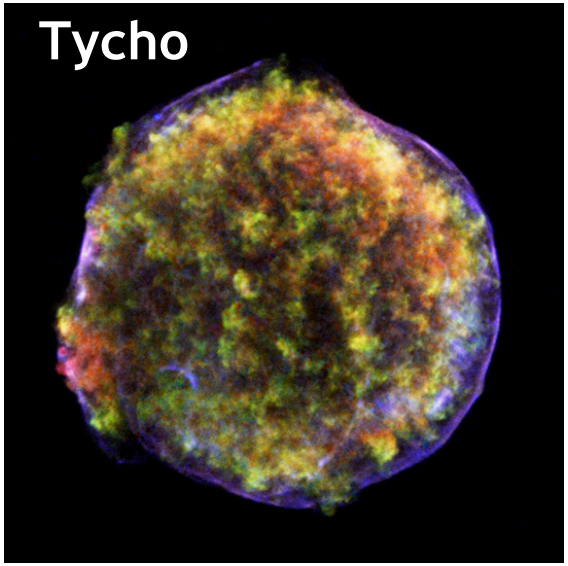
If B=40microG

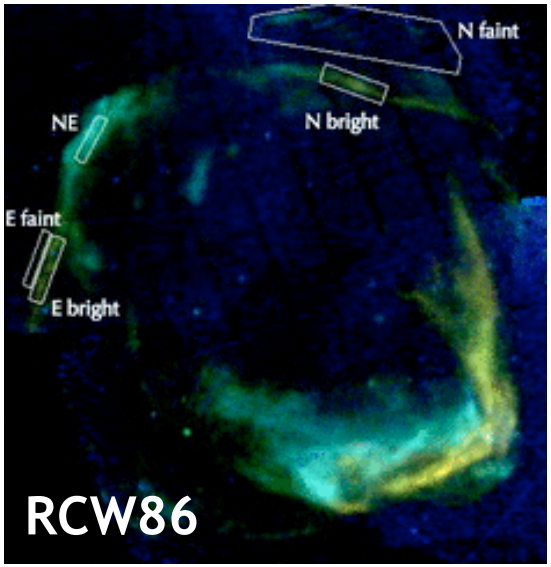
E = 10 TeV @ NE
E = 8.5 TeV @SW

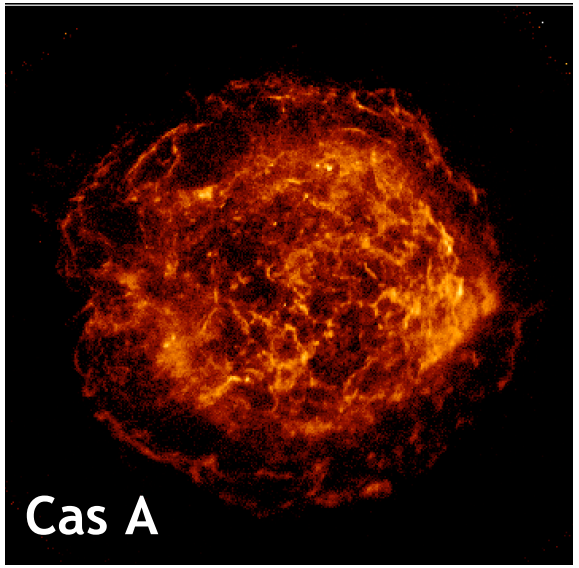
More precise model is needed !

2. spectra above 10 keV

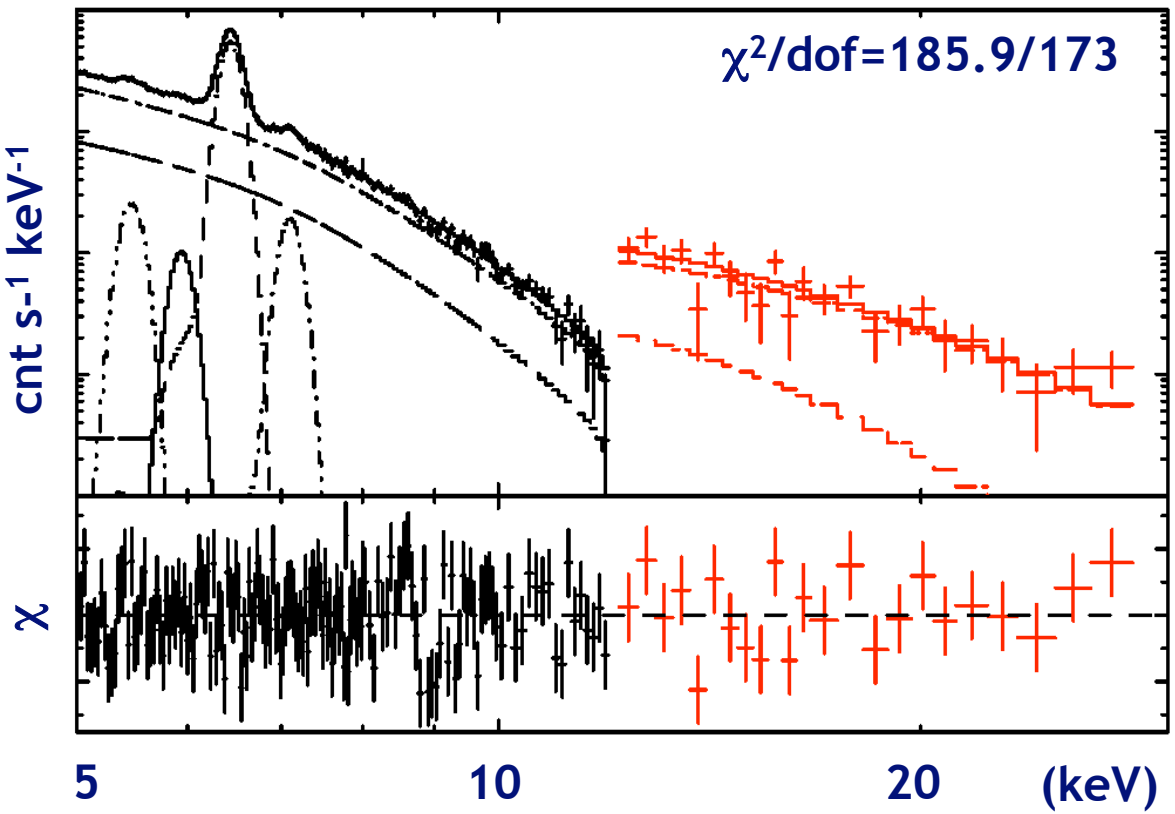
Sync. spectra free from thermal X-rays
efficient acceleration ?
We need several samples above 10 keV
(RXJ1713 and Vela Jr. will be presented
by Uchiyama-san and Tanaka-san)

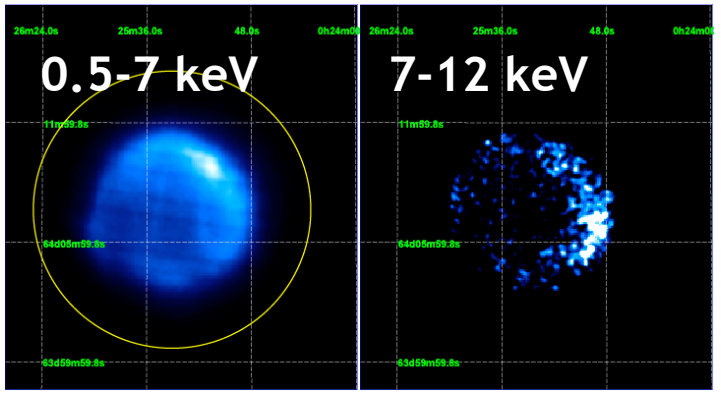






2.1. Tycho Remnant





Bremss+Power-law
kT=4.7(3.7-5.7) keV
Γ=2.7(1.4-2.9)
(Tamagawa+, A52)
(Hayato+, A53)

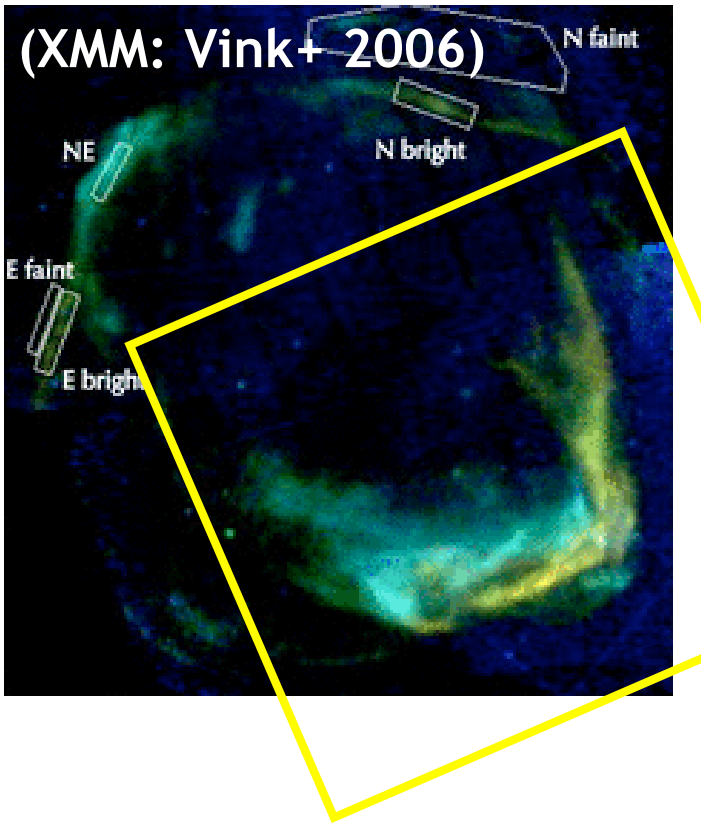
2 kT plasma requires too high kT (>10 keV)

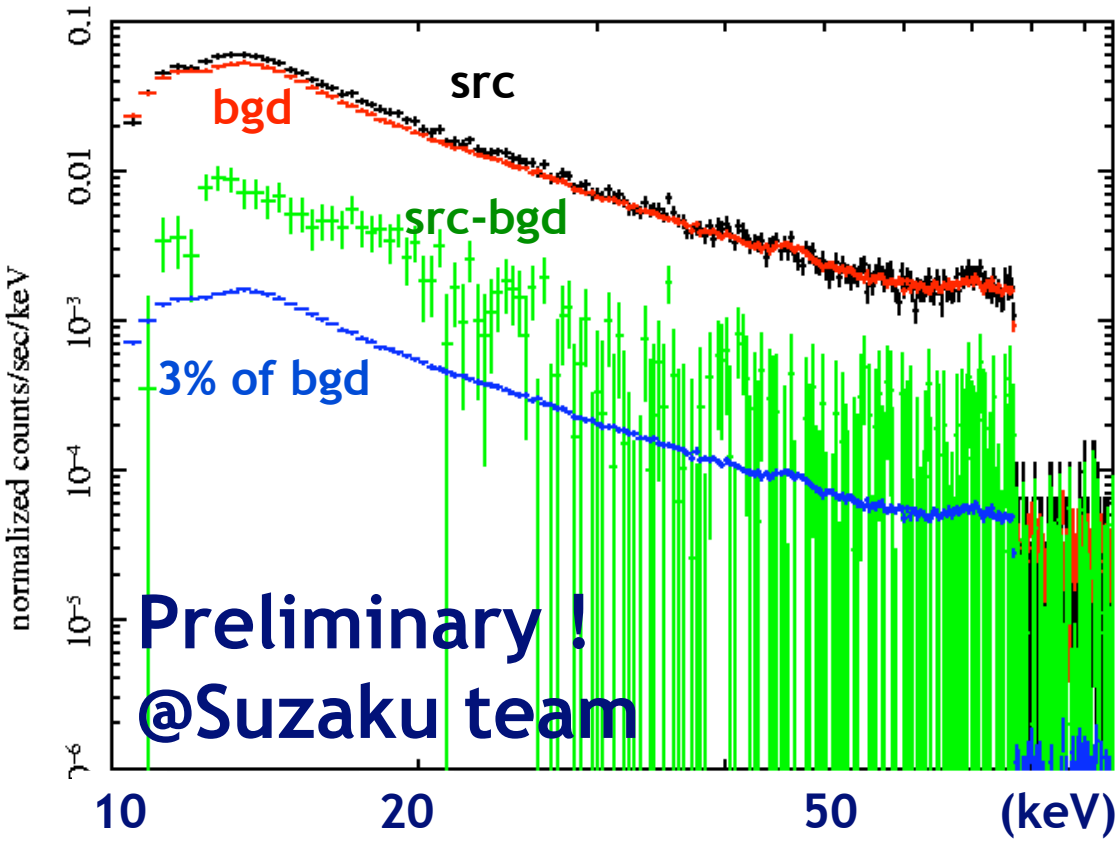
-> The Tycho rim really emits nonthermal X-rays!

Hard X-ray obs. are essential to distinguish thermal and nonthermal emission

2.2. RCW 86

the oldest histrical SNR (SN184)
sync. X-rays from shells
below 10 keV (Bamba+ 2000)
Efficient acceleration ? (Vink+ 2006)





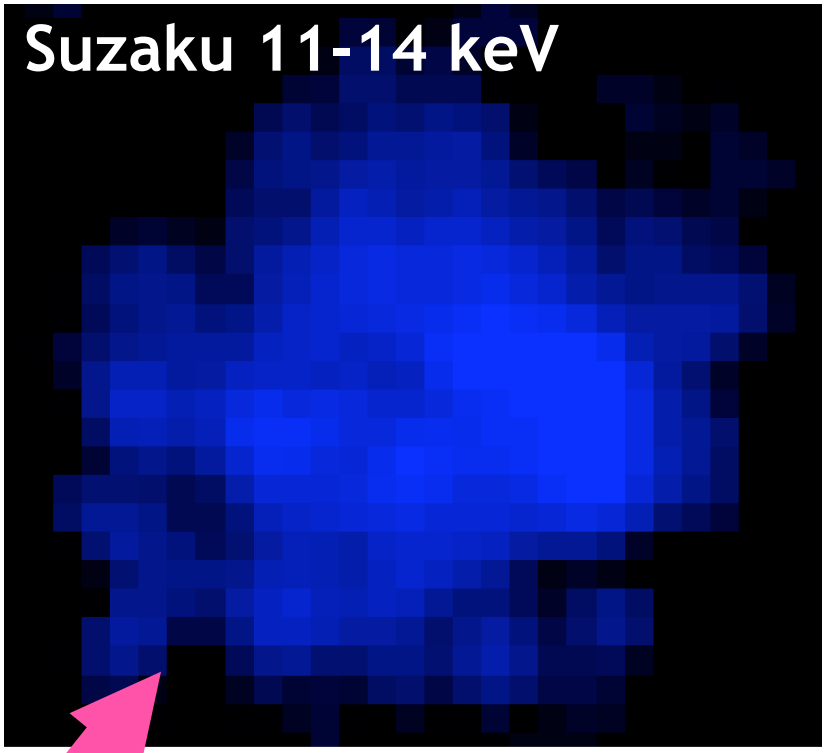
Preliminary !
@Suzaku team

HXD/PIN detected
X-rays < 30 keV
$\Gamma_{>10keV} \sim \Gamma_{<10keV}$

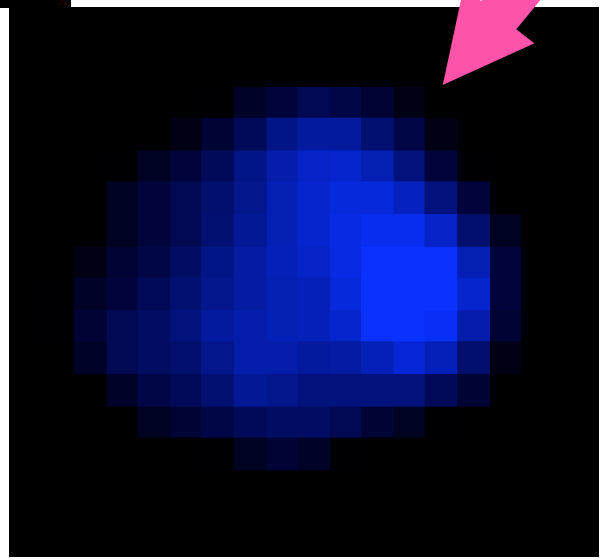
2.3. Cas A – very bright SNR in hard X-rays

Chandra 4-6 keV

Suzaku 11-14 keV



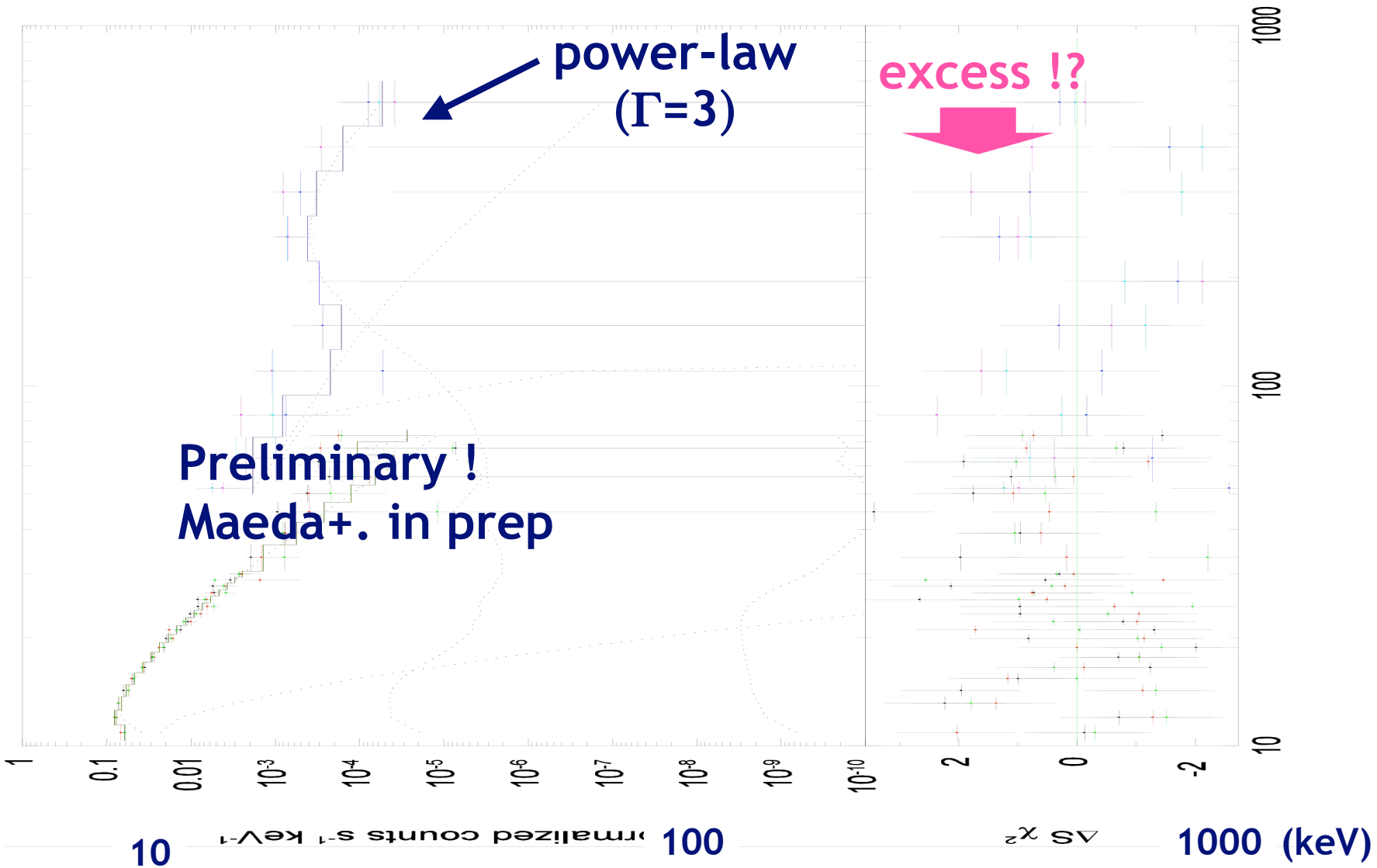
extrapolate to 11-14 keV
Smooth w. Suzaku PSF



Courtesy of E.A. Helder

The first image above 10 keV
Hard X-rays come from RS ?
(Maeda+, in prep)

Excess from power-low ??



Photon index is ~3 in 4-80 keV

3 obs. detected the excess, but only 1% of the bgd.

What is the excess (if it is true detection) ?

nonthermal bremss (Allen+, A45, Vink+ private comm.) ?

if the density is enough large, it should be observed

other components ?

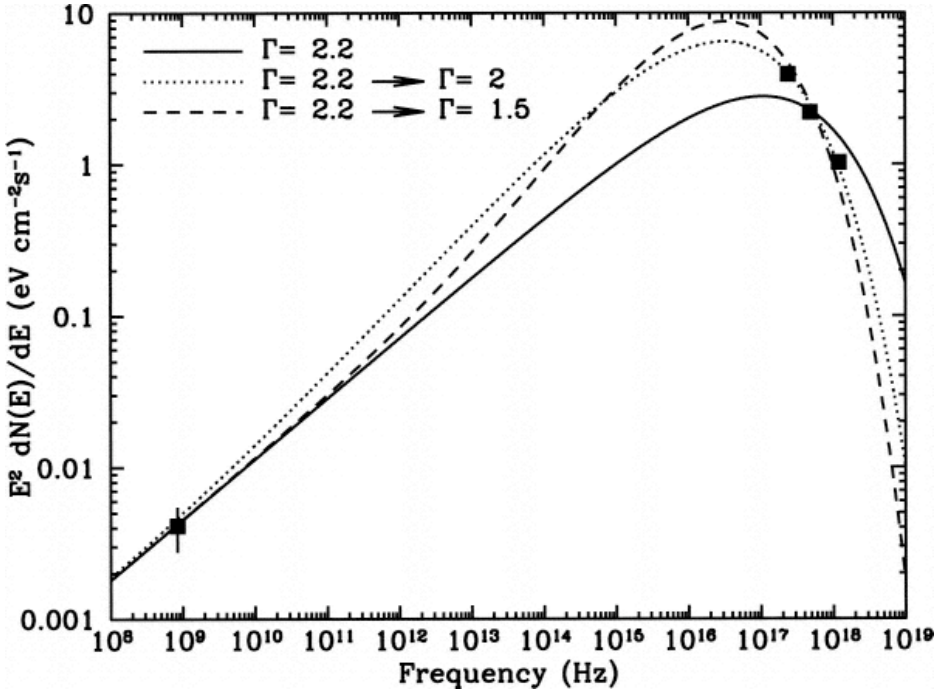
secondary e, p, … (e.g., Yamazaki+, 2006)

change from the test particle spectrum ?

Direct measurement of p and/or acc. efficiency ??

personal question:
Why the Γ is same
in <10 keV and >10 keV??

We need more precise bgd and statistics



RCW86: Vink+ 2006

3. Searching for new SNRs with sync. X-rays

How many SNRs accelearate particles ?
X-ray surveys of Galactic plane have been done with previous missions
The number is still limited
Many have only nonthermal X-rays
especially we need samples with nonthermal and thermal X-rays
In other wavelength ?

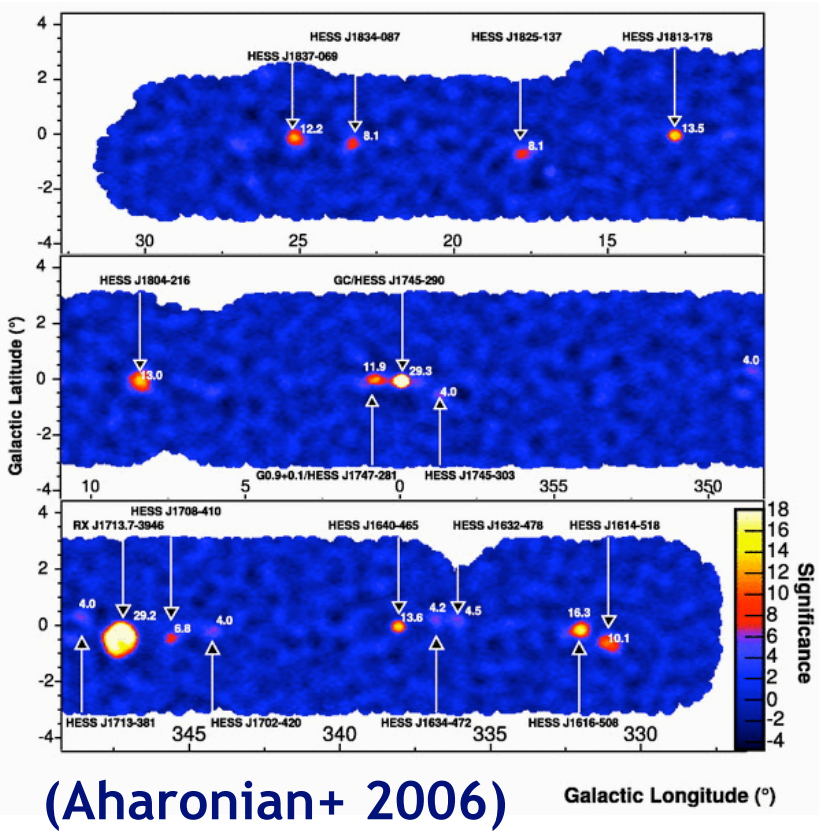
3.1. How to search new CR accelerators ?

HESS discovered
many new sources

On the Galactic plane
Some are diffuse
accelerate particles > TeV

→ Galactic accelerators

However,
they have no counterpart!



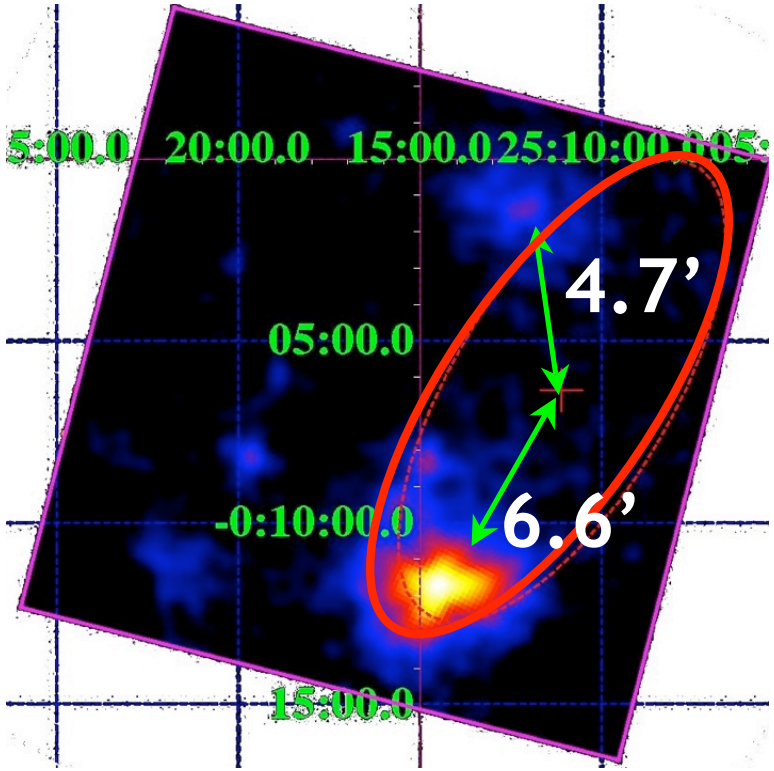
(Aharonian+ 2006)

They are not
known PSRs, PWNe
known SNRs
known star-forming regions …

"TeV unID sources"
Deep follow up !

3.2. Suzaku follow-ups of TeV unID sources

HESS J1837-069



(Anada+, A42)

Diffuse TeV
+ compact and offset X-ray

Many TeV unIDs do not have direct counterparts in X-ray
(Puehlhofer+, A41)

off-set PWN ?
Some PWNe have off-set between X-ray and TeV
(e.g. Mori+ A43)

real dark particle accelerator ?
(e.g. Matsumoto+, 2007)

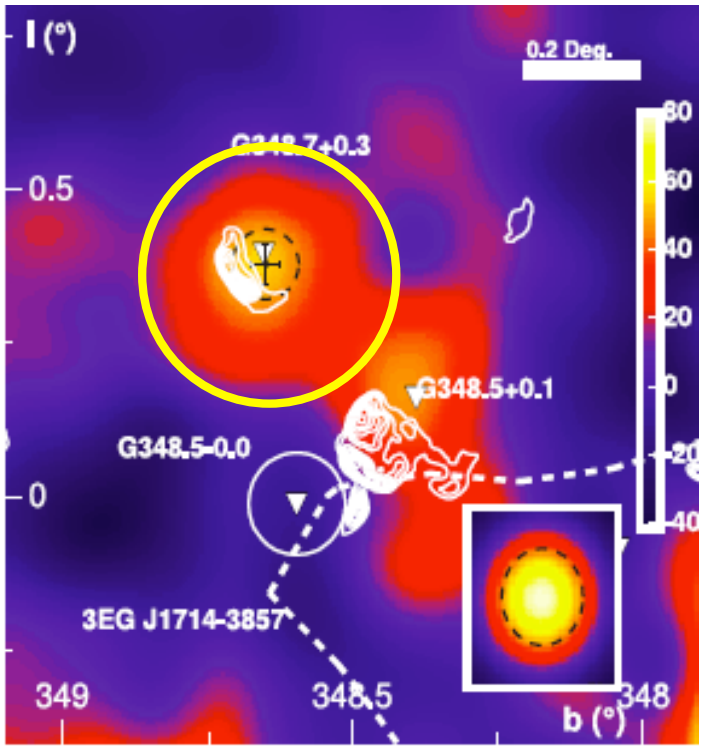
X-ray sources are just superposed?

Suzaku follow-ups revealed us it is not simple

3.3. A New SNR with TeV and sync. X-rays

CTB 37B

a bright shell-like SNR in radio
in a star forming region ?
Young ? (AD393: Stephenson+ 2002)
No X-ray information

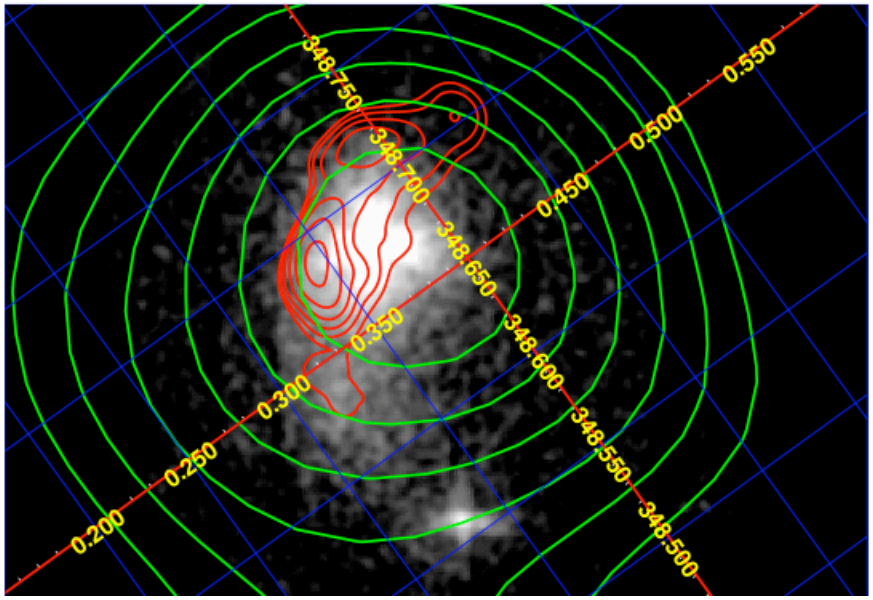


TeV emission is found
(Aharonian+ 2006)
TeV flux: only 2% of the Crab nebula

Contour: radio
Color: TeV

New CR accelerating SNR ?
Between SN1006 and RXJ1713 ?
(T/NT X-rays) (NT X and TeV)
Deep X-ray follow-up is needed

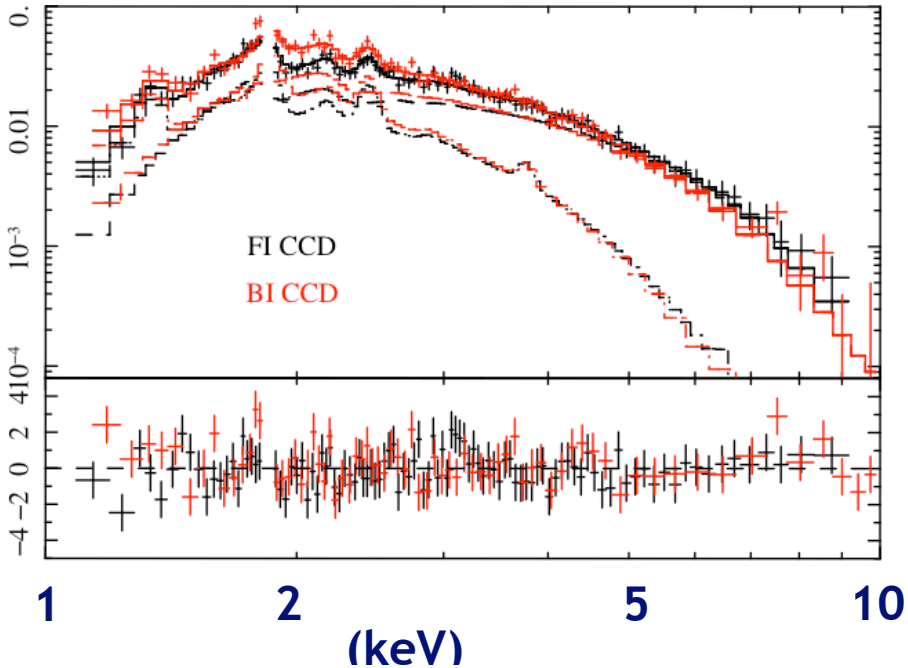
Suzaku Image and spectrum of CTB 37B (Nakamura+ A46)



Hard X-rays are detected
from the radio shell
The position is consistent w.
TeV gamma-rays

Gray scale : 2-10 keV X-ray
Red contour : radio
Green contour : TeV

spectrum:
NEI plasma + power-law
($\Gamma = 3.0^{+0.2}_{-0.2}$)
new sample of CR acc. SNR
young plasma (t~1400 yrs)



The first sample
with T/NT X-rays and TeV

Suzaku will discover
more and more accelerators

4. Summary

We discussed 3 topics using Suzaku capavility.

- Suzaku achieved detailed analysis of nonthermal emission.
  - The spectrum of SN1006 has clear bending
  - The maximum E of e is 9.4 TeV
    with assumption of B=40 microG
  - NE accelerate particles more efficiently ?
- More precise model !

- Suzaku detected hard X-rays (>10 keV) from several SNRs
  - Tycho, RCW86, Cas A, …
- We might be able to detect other component/eff. acc.
- More statistics are needed

- TeV unIDs may be new CR accelerators.
  - Many have no direct counterpart in the X-ray band
  - CTB 37B is the first sample w. T/NT X-rays and TeV
  - Suzaku will discover more and more counterparts

Papers and posters cited in this presentation

Bamba+ 2008
Yamaguchi+ 2008, A48
Tamagawa+, A52
Hayato+, A53
Puehlhofer+, A41
Anada+, A42
Mori+, A43
Matsumoto+ 2007
Nakamura+, A46

SN1006 (nonthermal)
SN1006 (theremal)
Tycho (nonthermal)
Tycho (thermal)
HESS unIDs
HESS J1837
Vela X
Dark particle accelerator
CTB37B