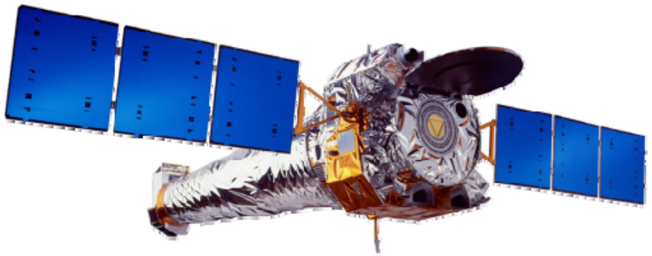
High energy aspects of SNRs



10 years old

10 years old

4 years old

Aya Bamba
(ISAS/JAXA, Japan)

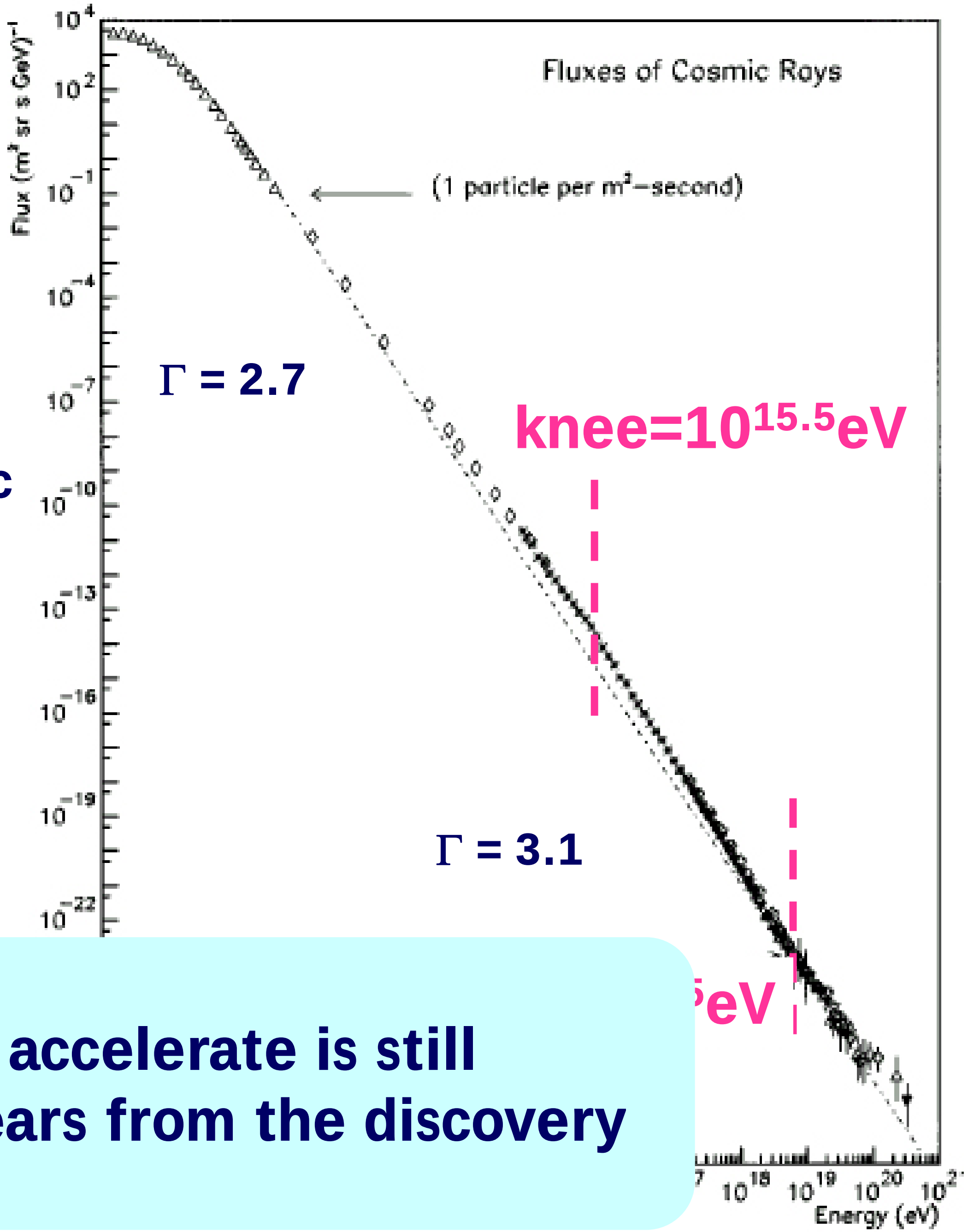
Cosmic Rays

high E particles
in the universe

u_{CR} ~ 1eV/cc

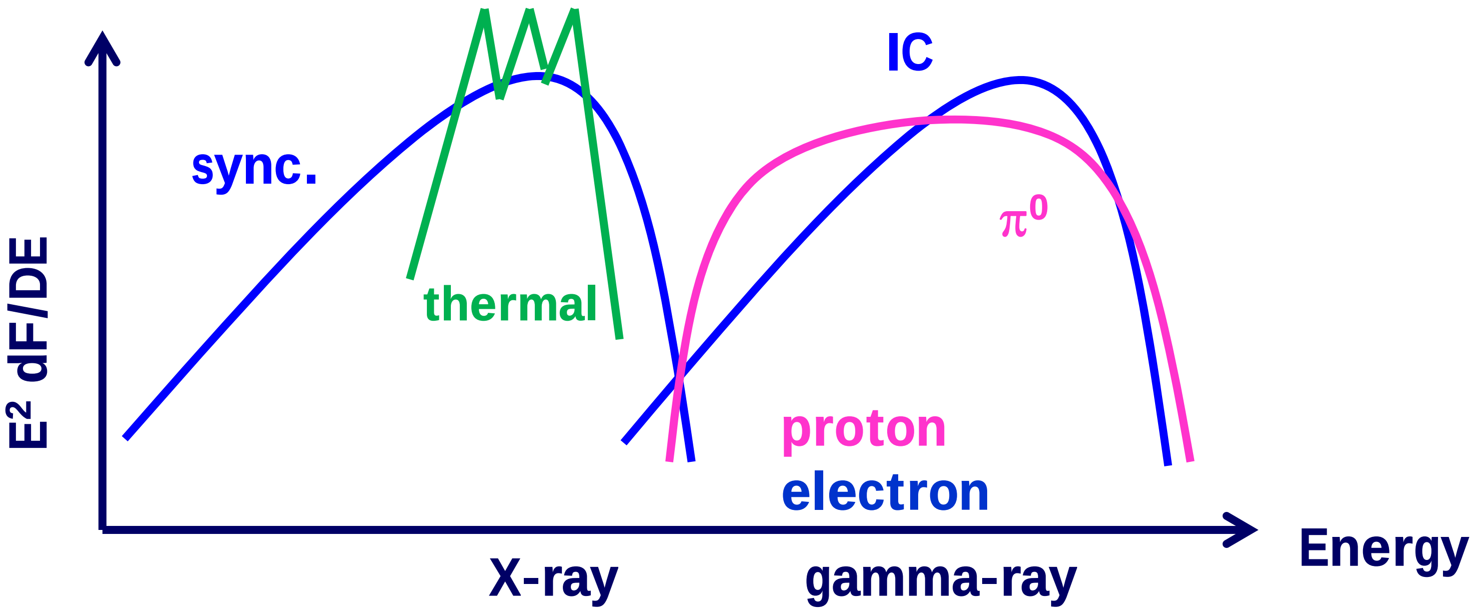
c.f. CMB	**0.3 eV/cc**
stellar light	**< 0.3 eV/cc**
magnetic field	**0.3 eV/cc**
turbulence	**0.3 eV/cc**
thermal energy	**0.01 eV/cc**

Essential component
in our Galaxy



Who and how to accelerate is still
unknown after 100 years from the discovery

How to search for cosmic ray accelerators ?



X-ray: synchrotron from e
thermal emission

gamma-ray: IC emission from e
emission from pi-on
(nonthermal bremss: next talk)

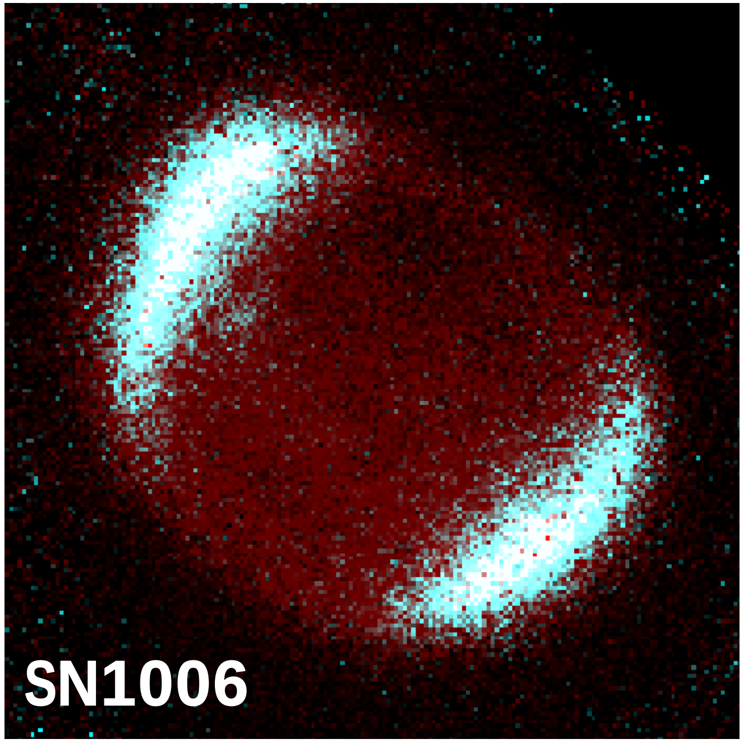
⇒ info. on T and NT e
info. on density, B, ...

info. on accelerated e/p

Combination of X-ray and gamma-ray is important !

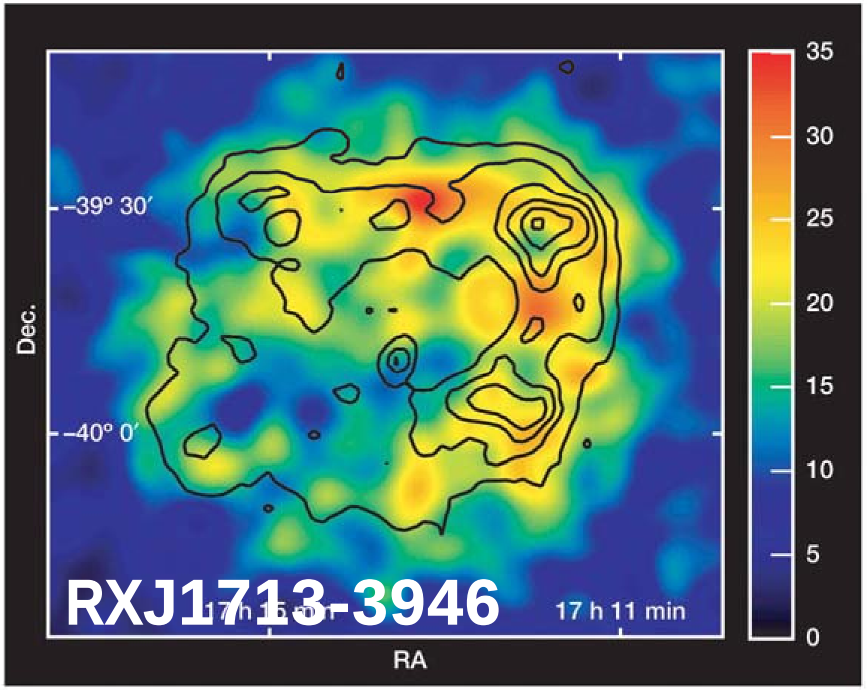
Observational clues of CR acceleration at SNRs

synchrotron X-ray



Discovered by ASCA
(Koyama+95)

TeV gamma-ray



Discovered by HESS
(Aharonian+04)

Shocks of SNRs accelerate cosmic rays !

Remaining problems in the 20th century (Contents of this talk)

1. **Estimating acceleration efficiency**
   How efficiently can shocks accelerate cosmic rays ?
   Can SNRs be the main contributor of CR acceleration?

2. **Estimating Maximum energy**
   Can we expect the E_{max} of accelerated particles ?
   Is it larger/smaller than the knee energy ?

3. **Can we discover proton accelerators ?**
   The main goal of cosmic ray physics in 100 years.
   Not yet, but we are finding some clue.
   It should be the golden age now
   to study cosmic rays !

1. Estimating acceleration efficiency

1. Acceleration is really efficient ??

before Chandra/XMM

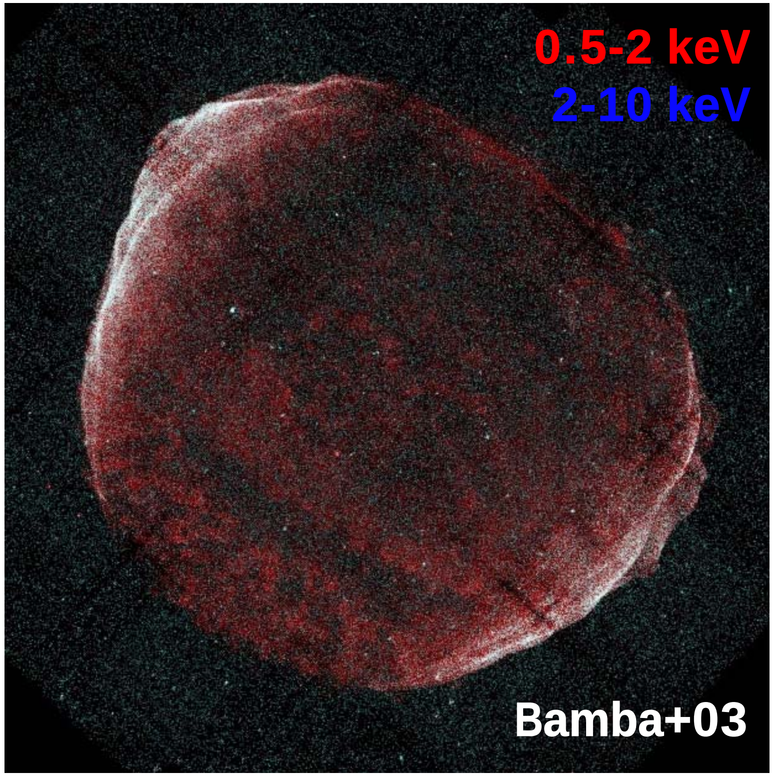
No observational information on the acc. efficiency
many theories used “test particle”
ignoring energy of accelerated particles

Chandra/XMM

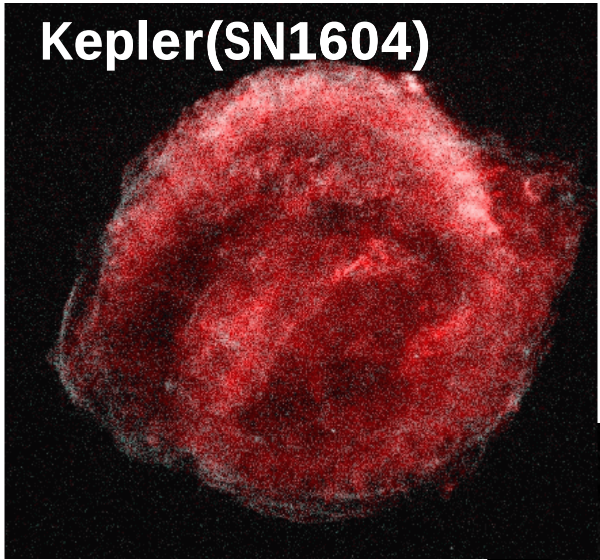
Discovery of very thin filaments with synchrotron X-rays !!

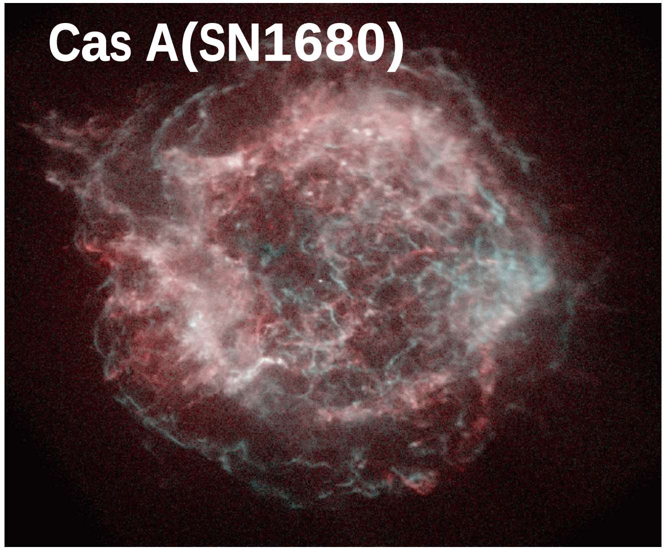
thin = small gyro radius
small diffusion

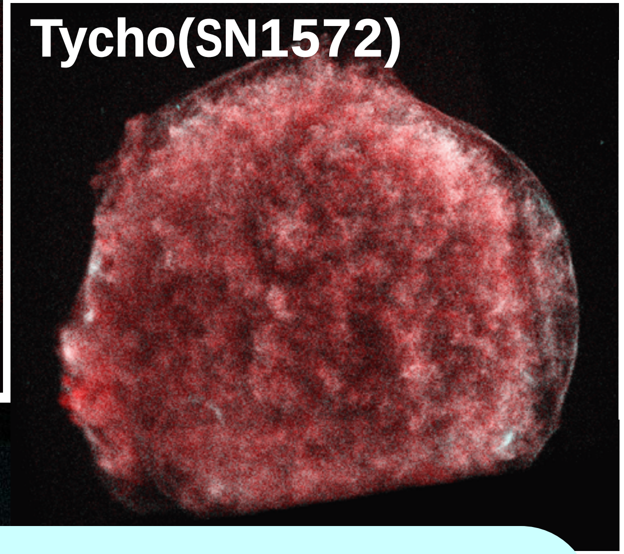
-> amplified and turbulent B
efficient acceleration

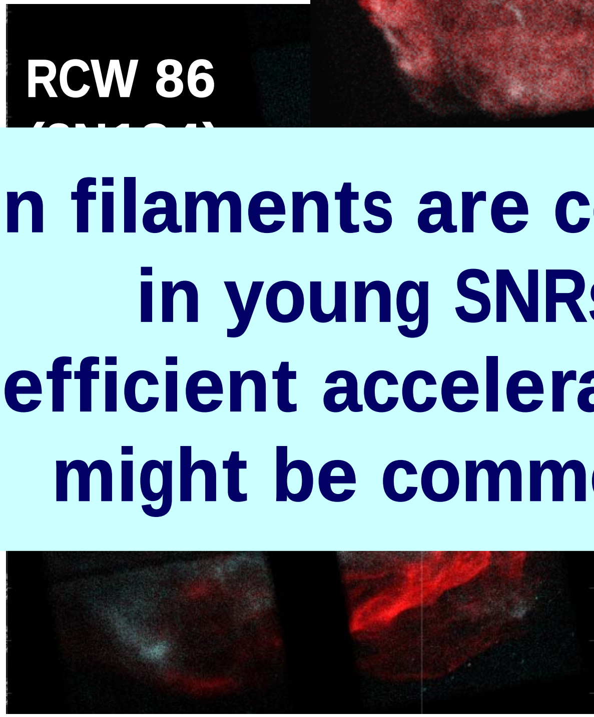


Young SNRs have thin filaments with sync. X-rays









thin filaments are common in young SNRs
efficient acceleration might be common.

(Bamba+05)

Direct evidence of rapid acceleration ??

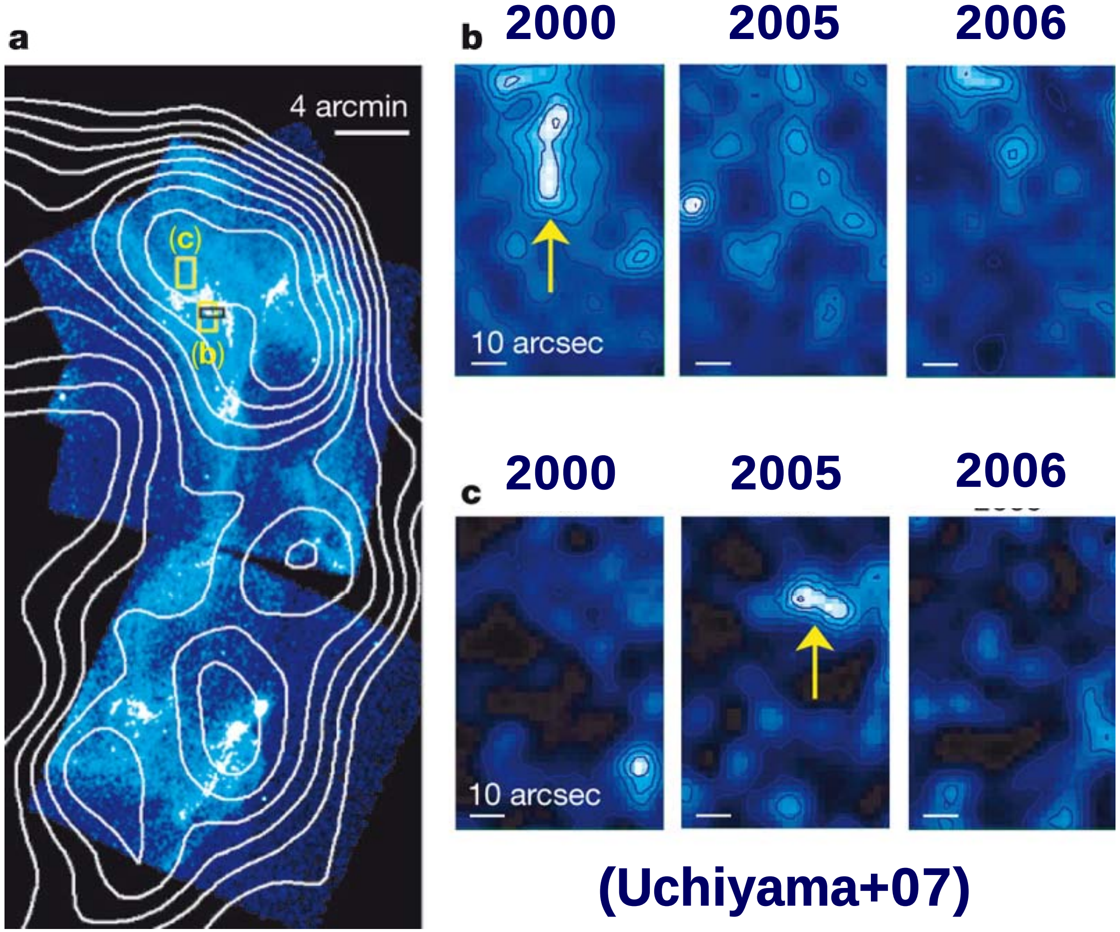
year-scale time variability of filaments in RXJ1713-3946

synchrotron loss ~ 1yr -> B >= 1mG !!
acc. time-scale ~ 1yr -> very very efficient !!

How about total emission?

Only a few % of emission is time variable

Is the acc. efficient in total ??



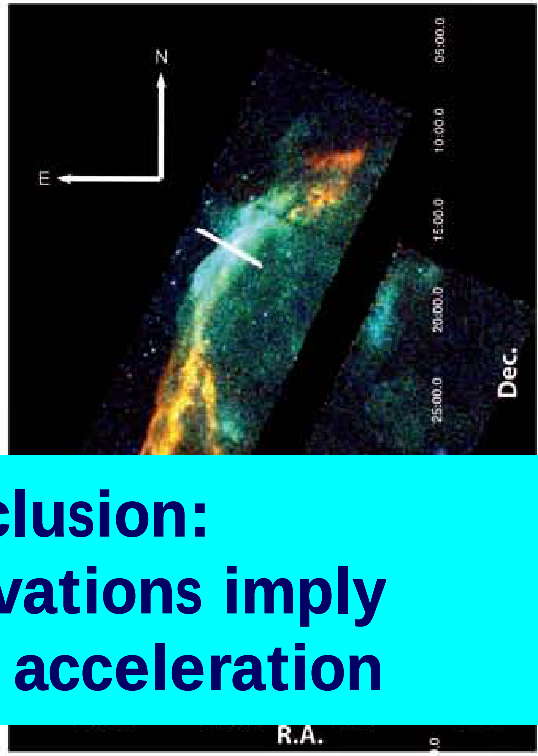
(Uchiyama+07)

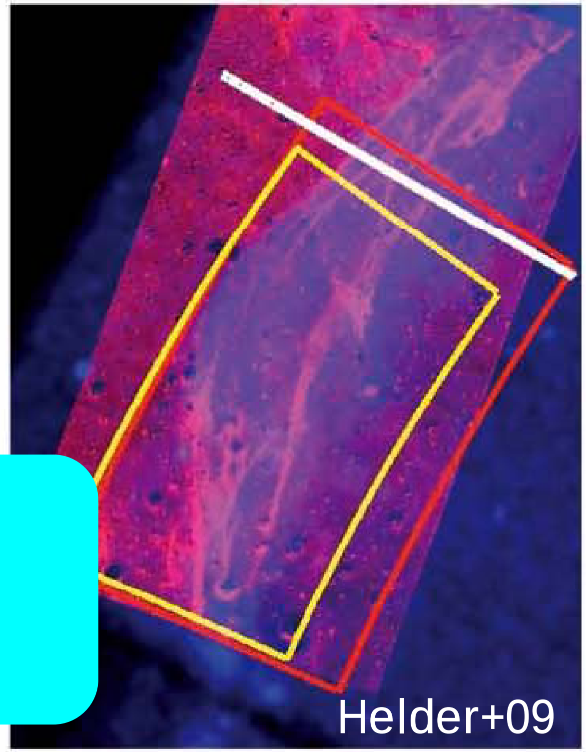
Very low kT plasma behind the shock

Helder+09: NE rim of RCW86
measured shock velocity using Chandra observations
  -> v_{shock} ~ 6000 km/s
  -> expected temperature: 40-70 keV
measured kT with H-alpha observations
  -> kT = 2.3 keV

"disappeared E"
to the acceleration ?

efficiency:
> 50 % !!





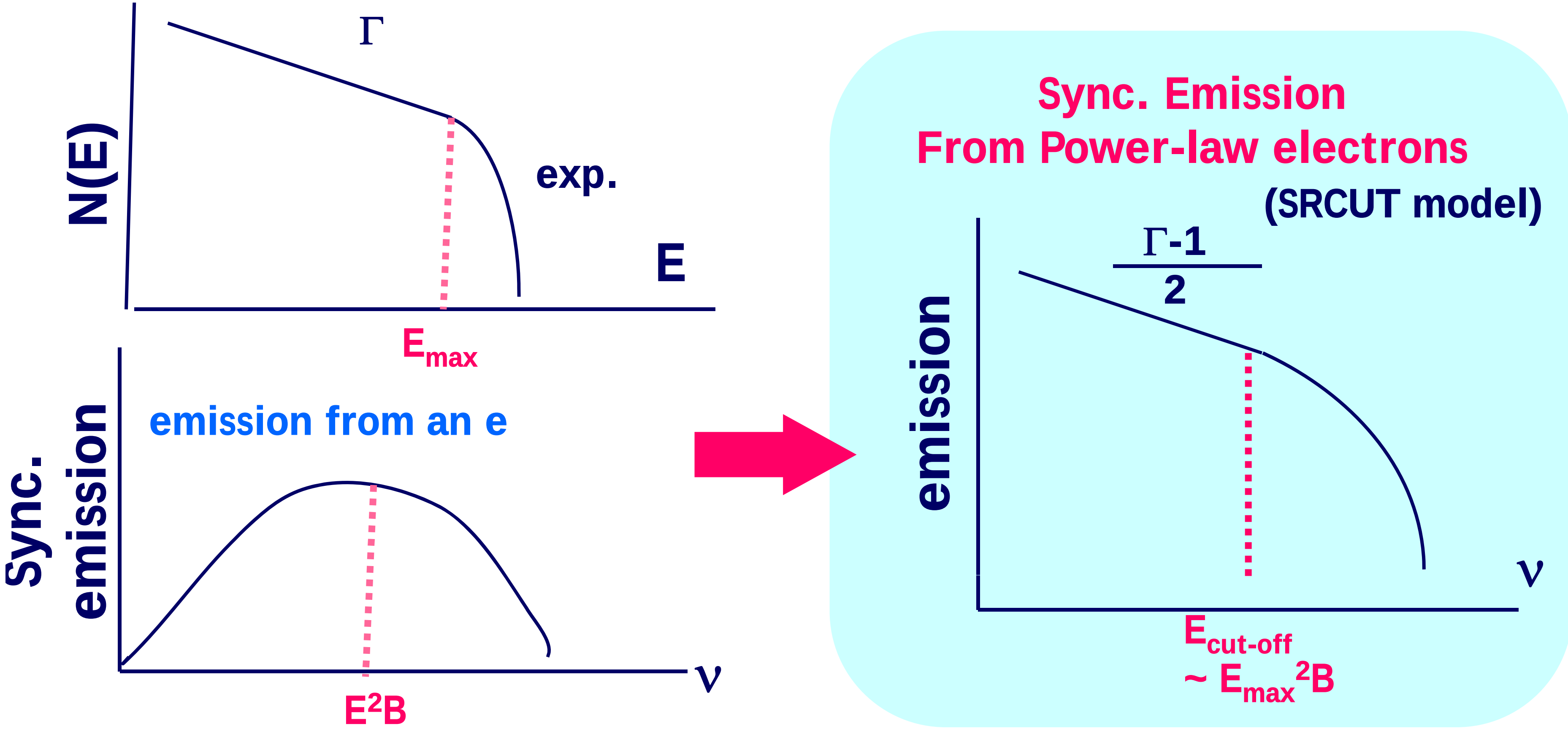
1st conclusion:
Several observations imply
very efficient acceleration

2. Estimating Maximum energy

How to search for efficient acceleration ?

synchrotron X-rays have cut-off

electron distribution

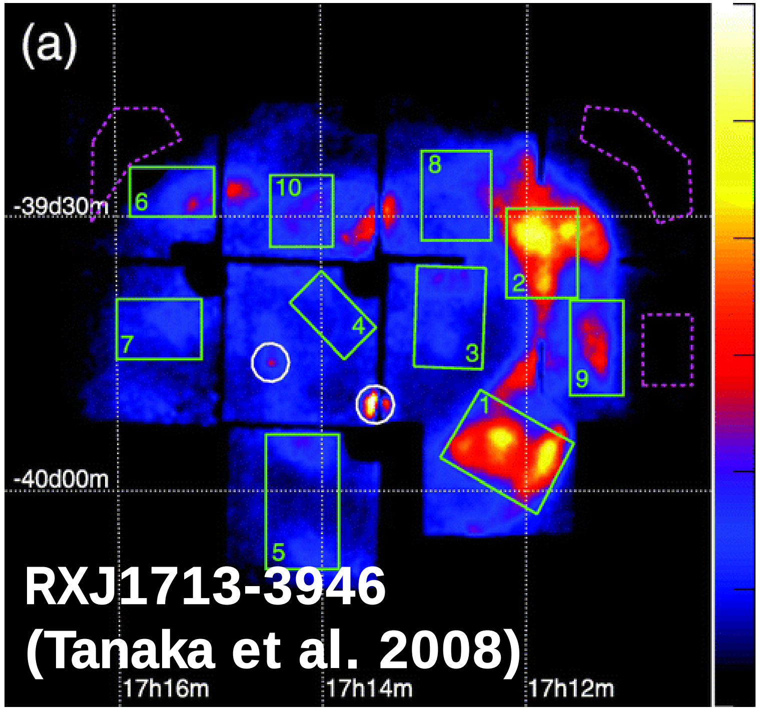


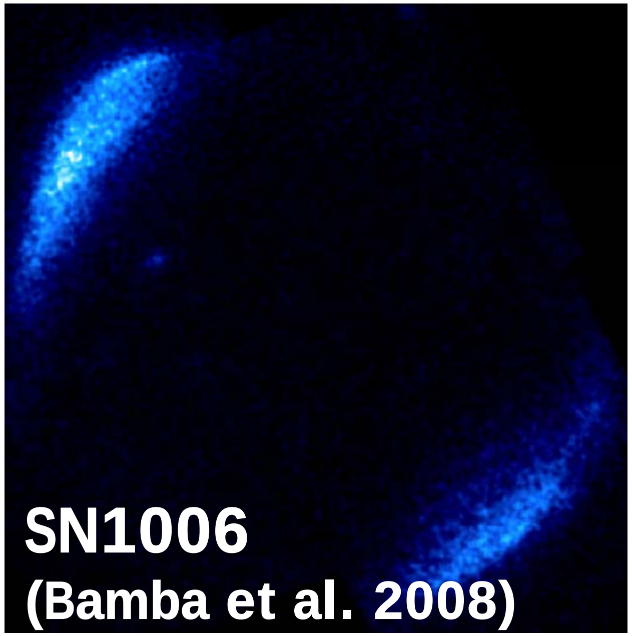
cutoff energy ~ B E_{max}^2 (Reynolds 1998)

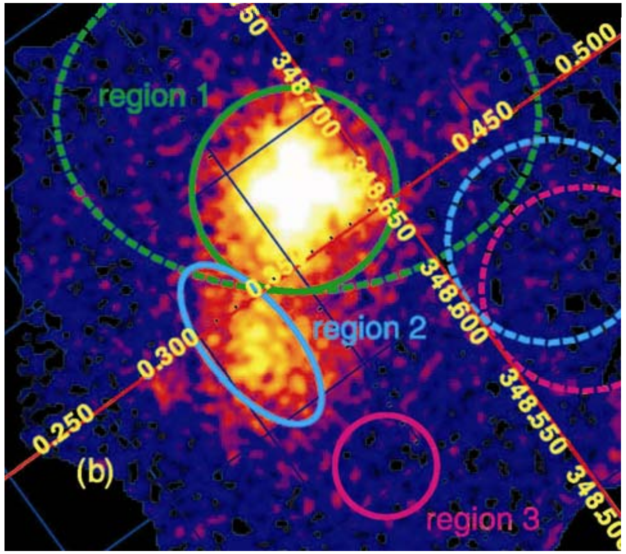
B: magnetic field E_{max}: the maxmimum E of e

good statistics in wide band is essential

Suzaku observations of SNRs



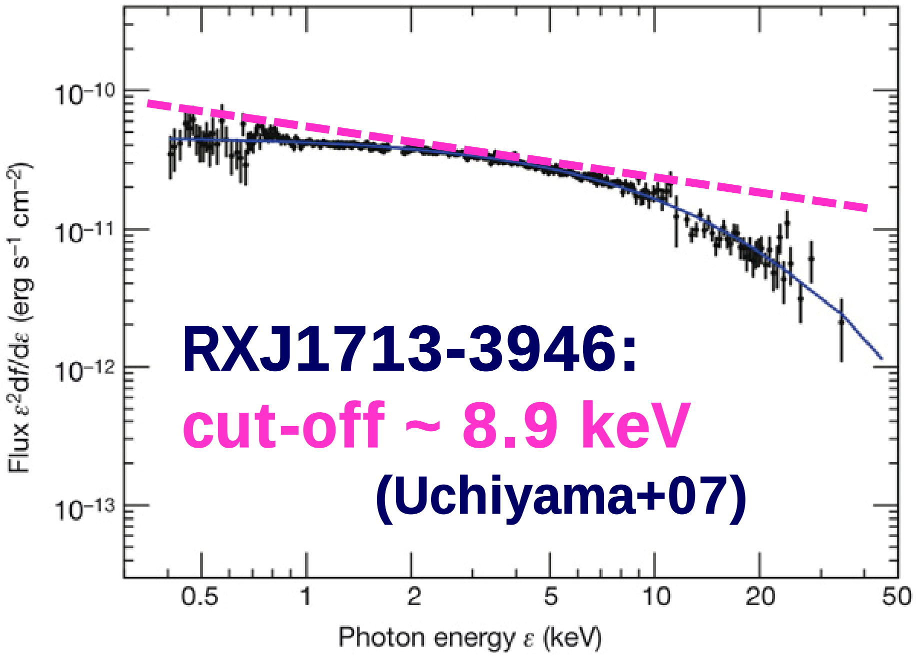


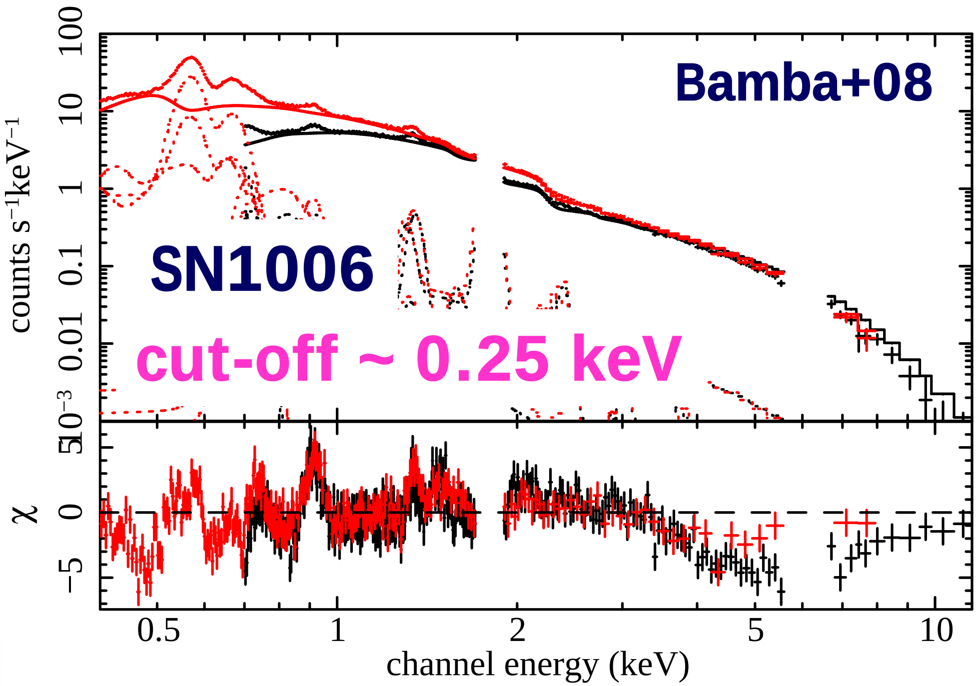


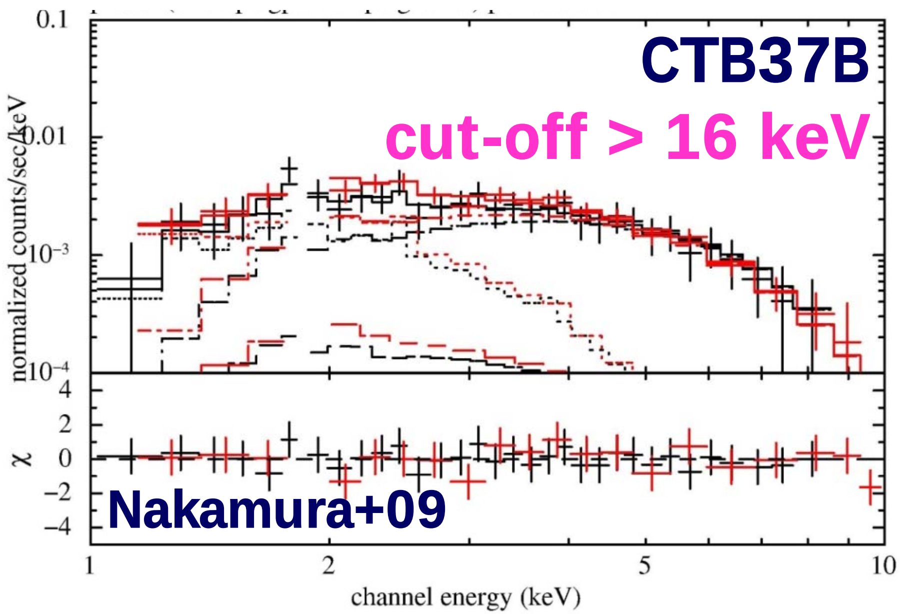
CTB37B
(Nakamura et al. 2009)

Suzaku has sensitivity in wide band
and detected synchrotron X-rays
from several SNRs

cut-off energy determined by Suzaku





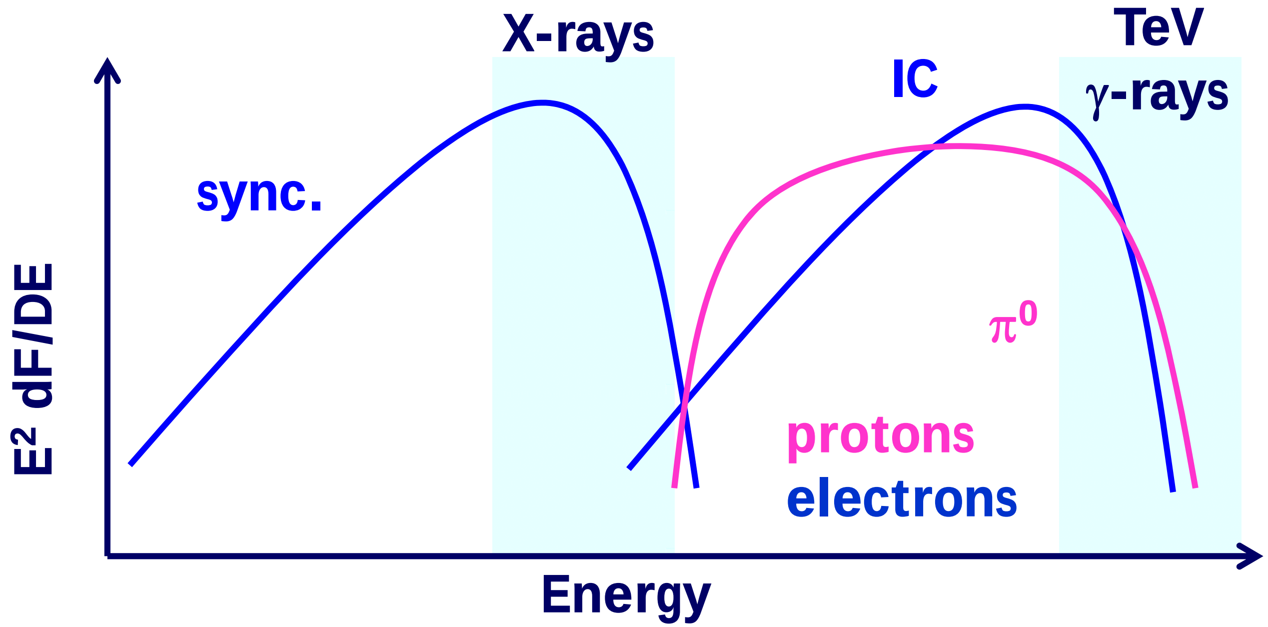


Suzaku detected cut-off of sync. X-rays
cut-off ~ 0.2 - 10 keV

2nd conclusion:
E_{max} ~ 10-100TeV ?
E_{max} for p should be higher

3. Possible proton accelerators

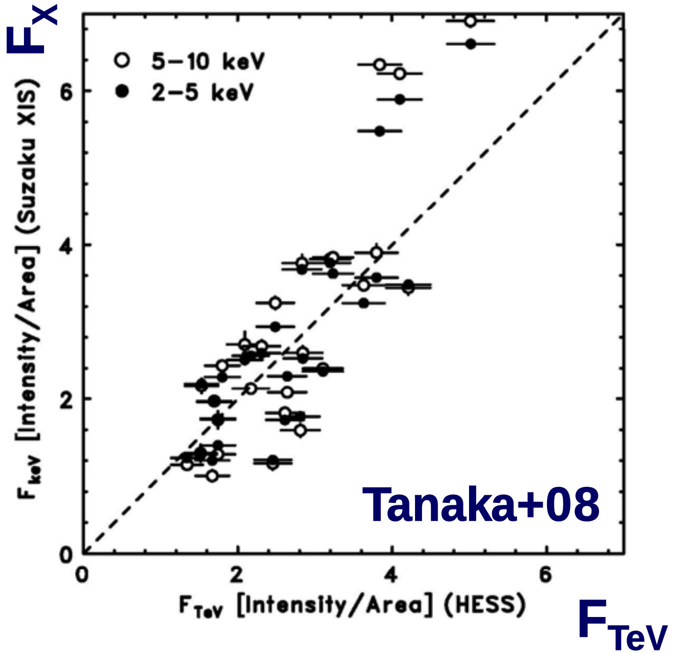
How to search for p accelerators ?

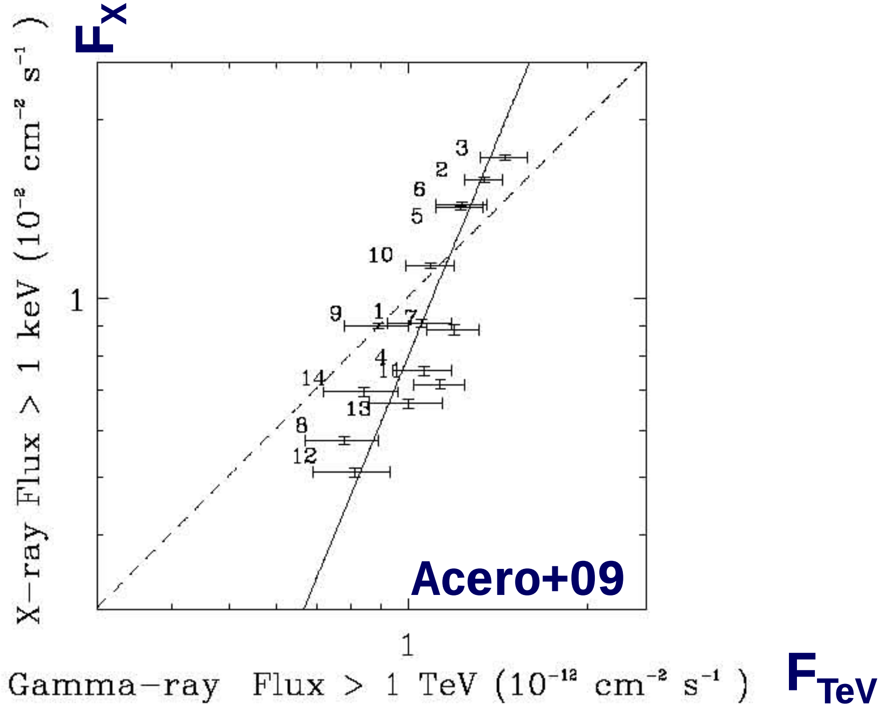


X-ray obs. cannot see protons.
Gamma-ray obs. cannot distinguish e and p.

We need both observations.
Do we have sources with only TeV gamma-rays ?

In a young SNR case: RX J1713-3946





Complete maps in X-ray and TeV bands.

TeV and X-ray flux have some correlation.

some special region ? -> B amplification?

(Tanaka+09)

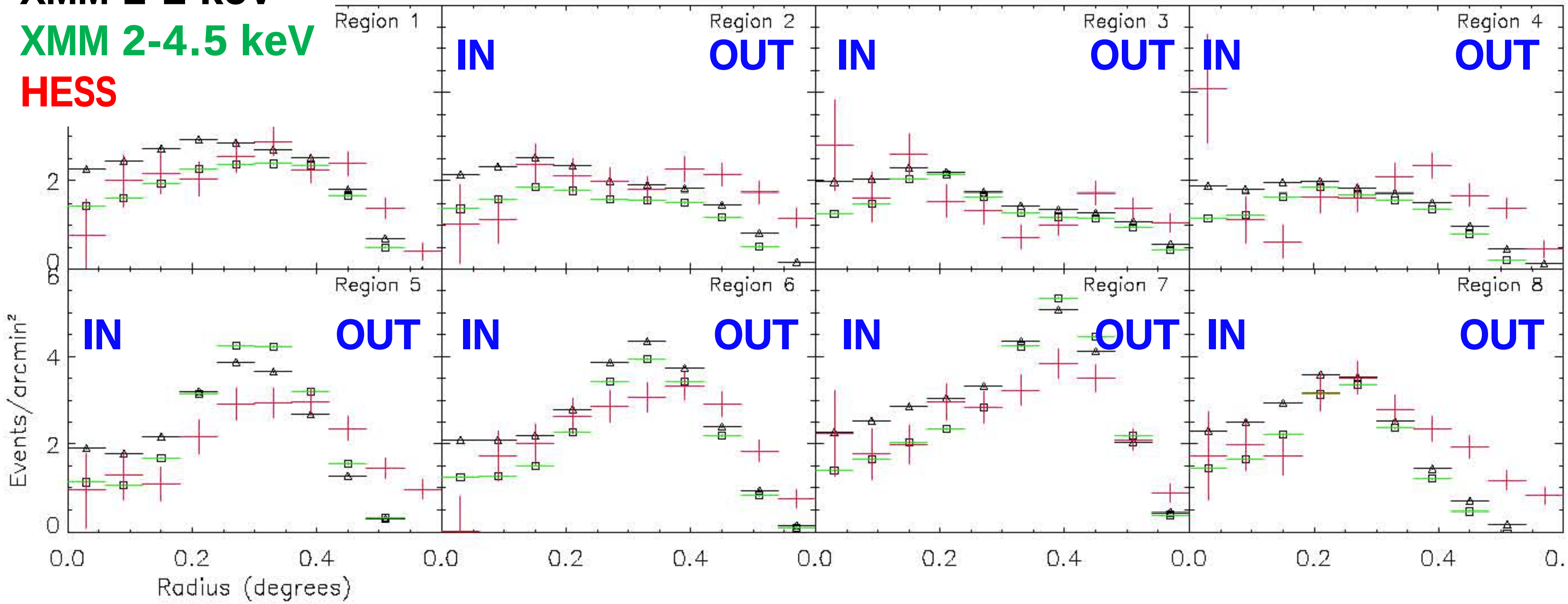
simple correlation? -> sync. from uniform B ?

(Acero+-09)

Radial profiles

(Acero+09)

XMM 1-2 keV
XMM 2-4.5 keV
HESS



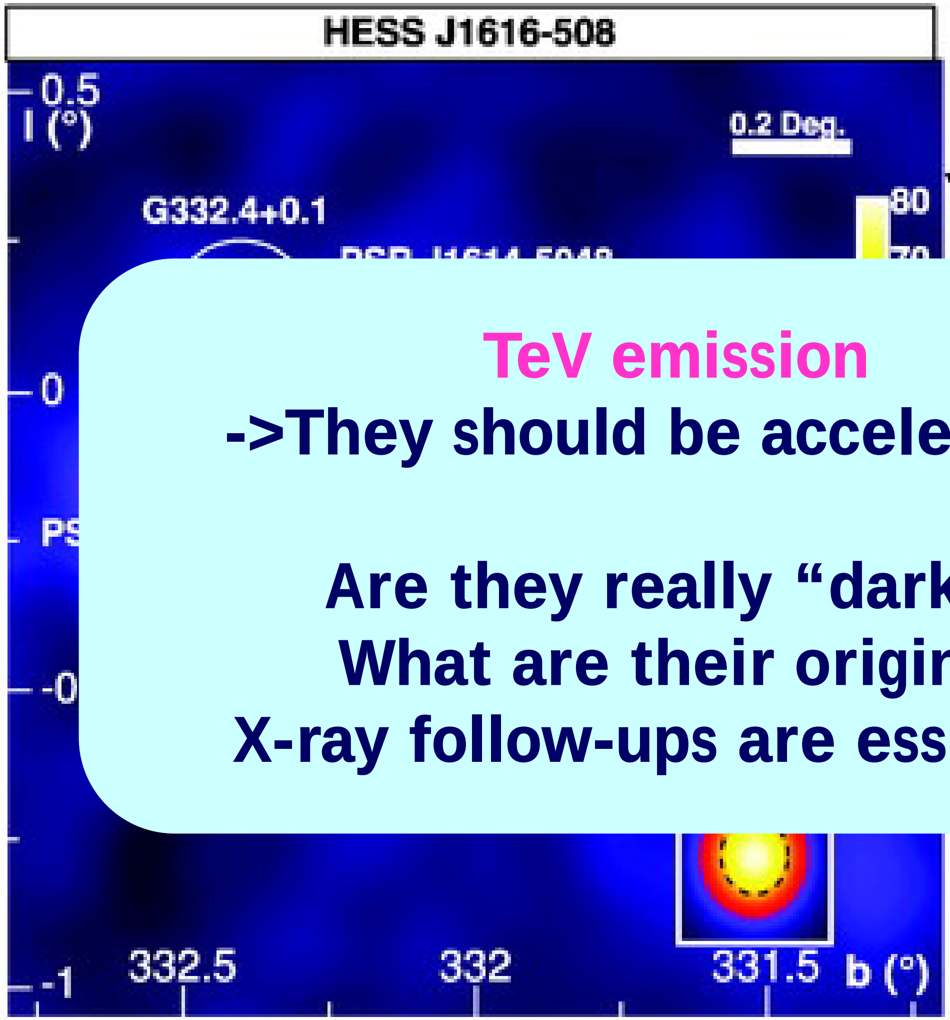
The X-ray emission seems to come more from the inside of the SNR than in gamma-rays

X-rays: synchrotron from the shock ??
gamma-rays: via pi-0 decay on the shock-molecular cloud interaction ?

still contravatial ...

TeV-bright and X-ray faint sources ?

HESS discovered a lot of new sources on the Galactic plane



(Aharonian+06)

TeV emission
->They should be accelerators

Are they really "dark"?
What are their origin ?
X-ray follow-ups are essential

On the Galactic plane
Some are diffuse

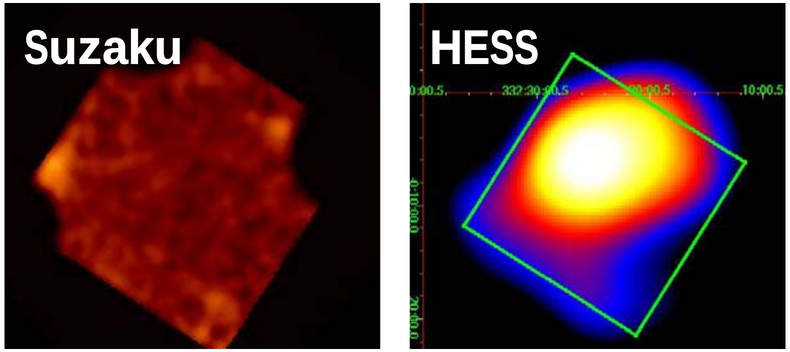
ctic sources

However,
y have no CP!
not
own PSRs, PWNe
known SNRs
known SF regions

"TeV unID sources"
"dark particle accelerators"

Suzaku follow-ups of several TeV unID sources

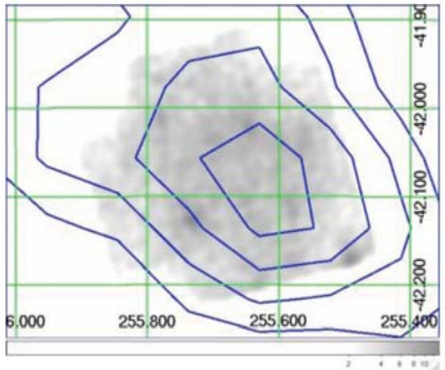
HESSJ 1616-508 (Matsumoto+07)



upper-limit !

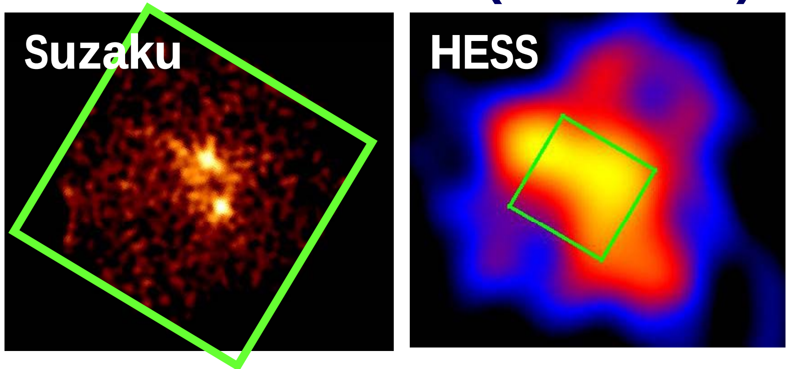
$F_{TeV}/F_X > 55$

HESS J1702-420 (Fujinaga+ in prep.)



$F_{TeV}/F_X > 32$

HESS J1804-216 (Bamba+07)



unID compact sources

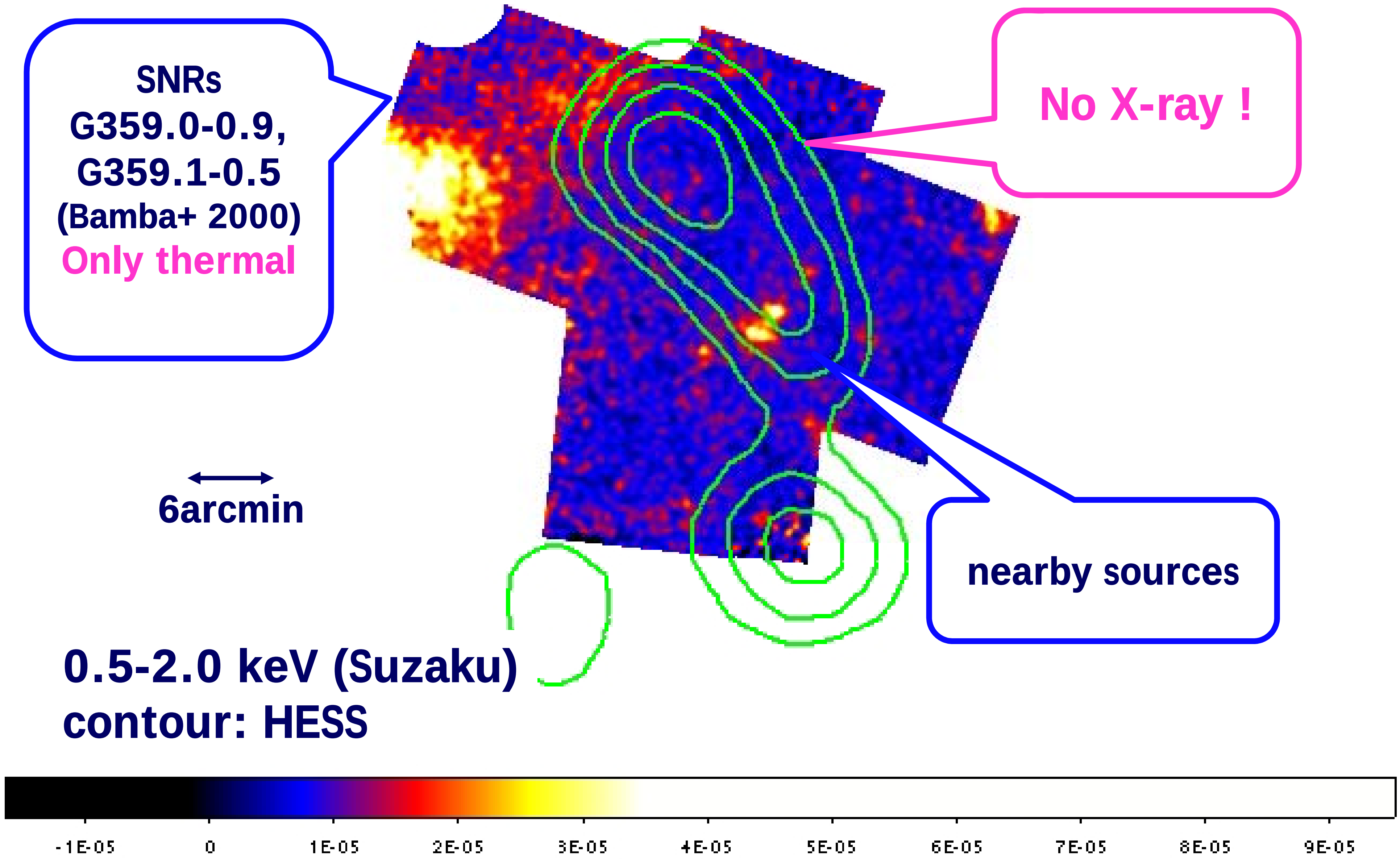
$F_{TeV}/F_X > 13$

TeV 2032+4130 (Murakami+ poster)

detected: $F_{TeV}/F_X \sim 10$

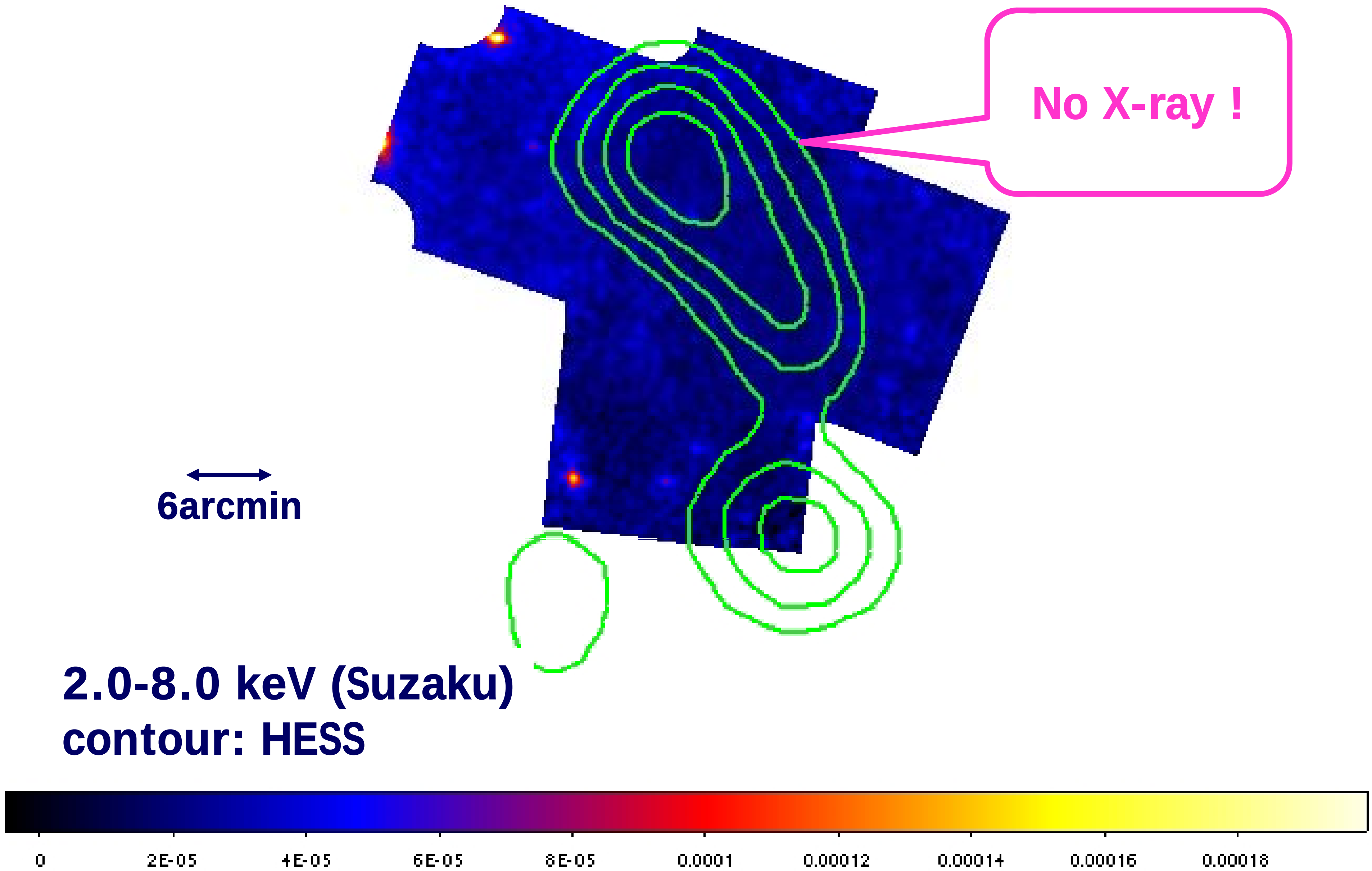
Real dark particle accelerators ?
Origin is still unknown

Suzaku XIS image of HESS J1745-303 (1)



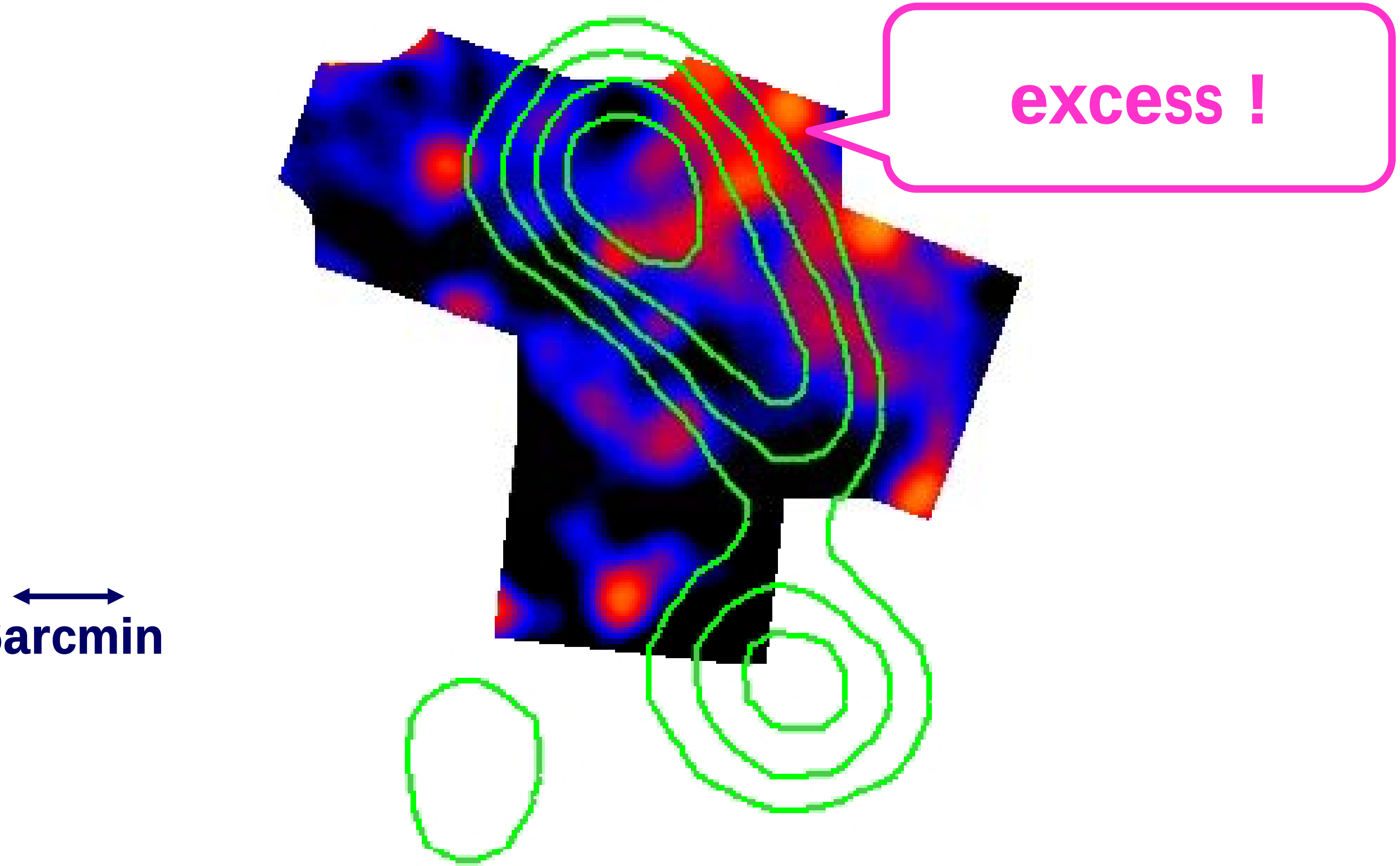
(Bamba+09)

Suzaku XIS image of HESS J1745-303 (2)



(Bamba+09)

Suzaku XIS image of HESS J1745-303 (3)



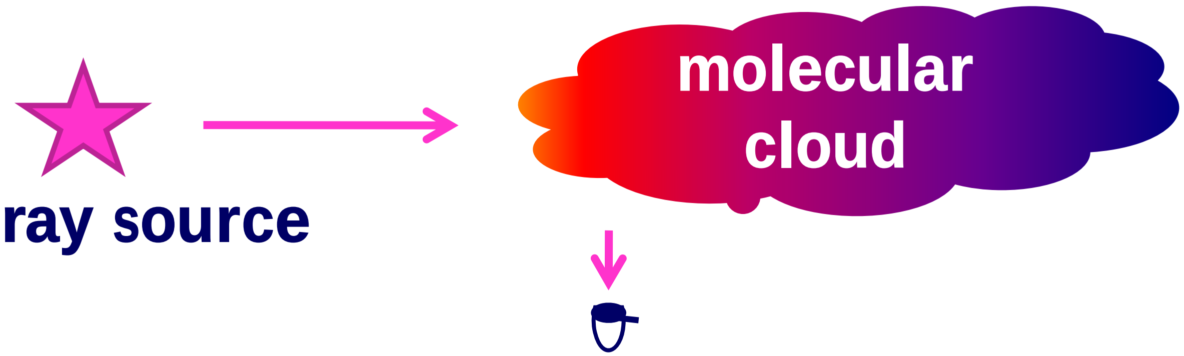
neutral (cold) iron line (Suzaku)
contour: HESS

total int. :
1.1e-5 ph cm^{-2}s^{-1}

(Bamba+09)

Origin of neutral iron emission line ?

"X-ray reflection nebula"



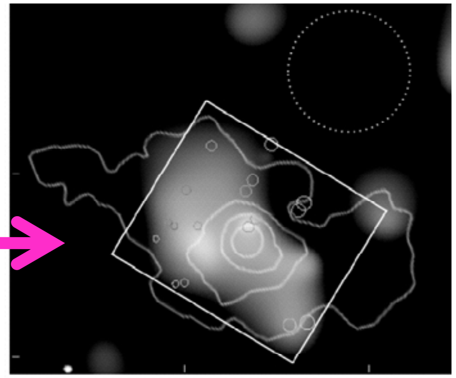
X-ray irradiation -> scattered in MC -> strong emission line from cold iron

X-ray irradiator:

past active GC SMBH itself !

(Koyama+ 2007)

It was very bright 300 years ago.



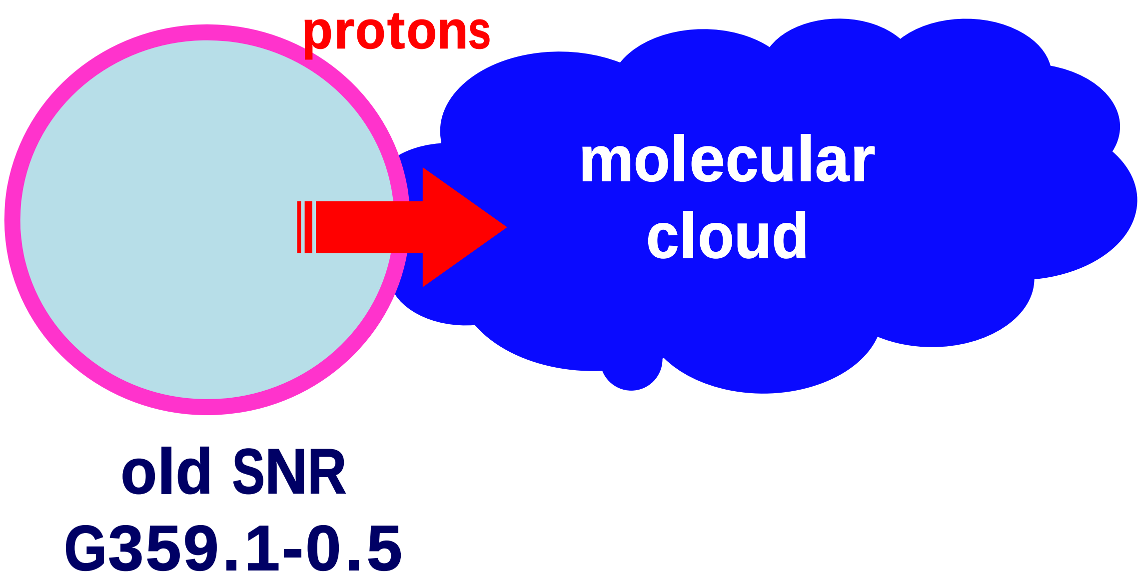
SgrB2: Murakami+ 2002)

HESS J1745-303 coincides with MC.

(Bamba+09)

SNR + MC = HESS J1745-303 as a proton accelerator ?

Our scenario



- The SNR G359.1-0.5 is old enough to lose sync. X-rays.

(Bamba+00)

- This SNR collides with MC. It has OH mesars.
- Protons emit gamma-rays via pi-0 decay.
- Only TeV gamma-rays are observed.

They should bright in GeV gamma-rays !

-> Fermi !!!

(Bamba+09)

Fermi detected TeV unIDs !

Fermi bright source catalog (Abdo+09)

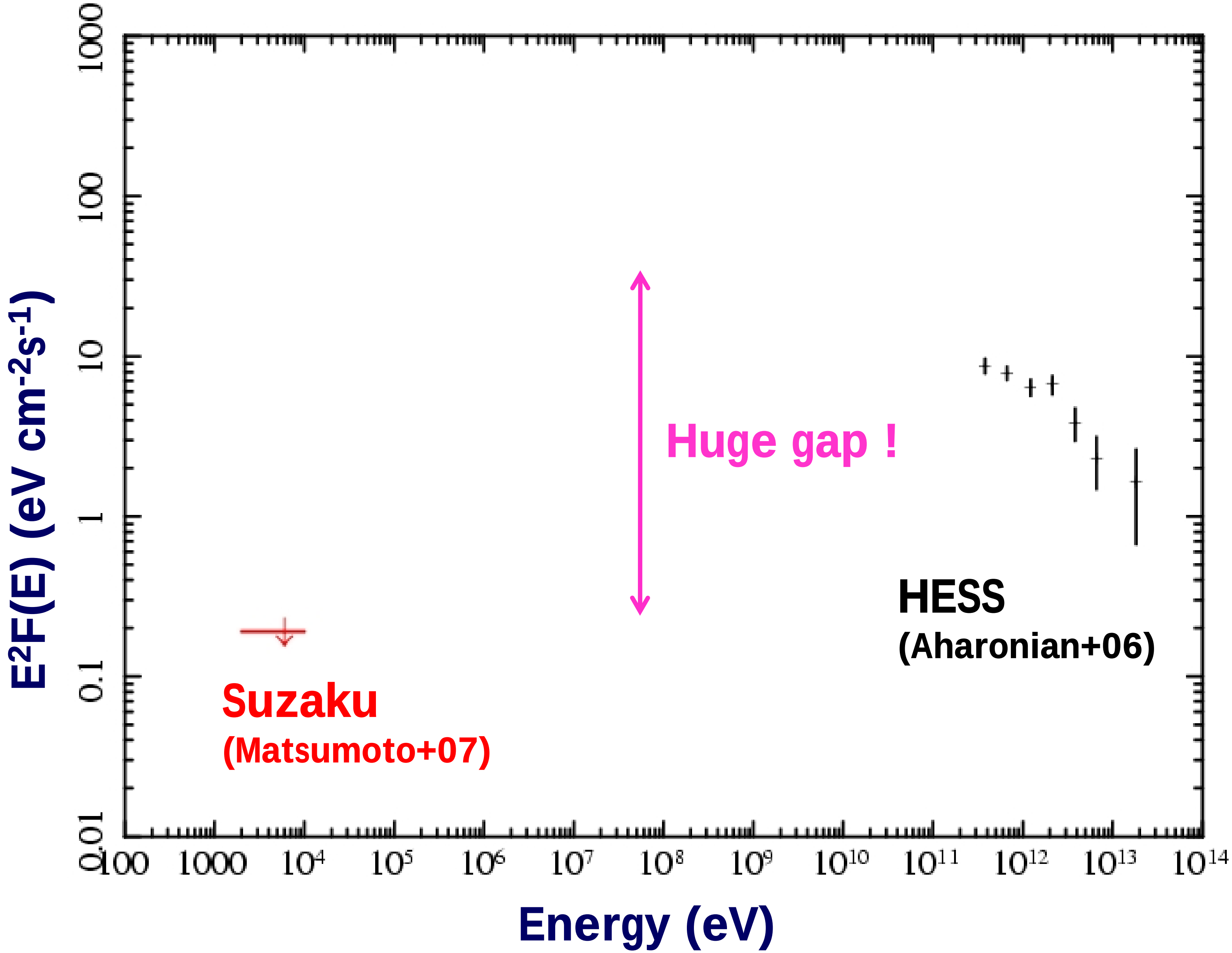
9 of 205 sources coincide with TeV sources

4 % of the Fermi bright sources !!

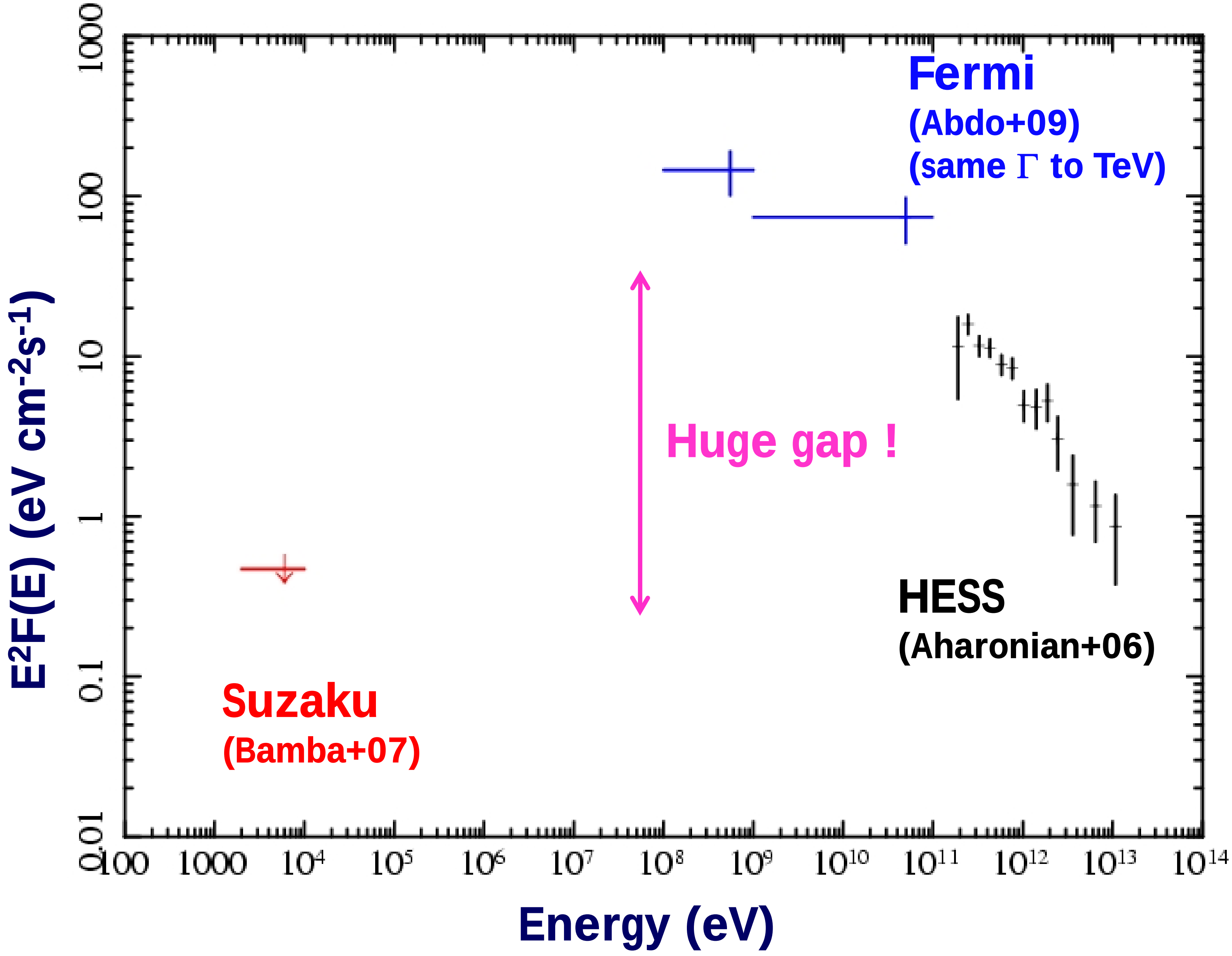
HESS J1023-575	
HESS J1418-609	
HESS J1616-508	dark with Suzaku
HESS J1741-302	unknown
HESS J1804-216	dark with Suzaku
HESS J1813-178	PWN
HESS J1834-087	PWN
HESS J1923+141	
TeV J2032+4230	unknown

Two dark accelerators are bright in GeV

HESS J1616-508 case



HESS J1804-216 case



Origin of the gap ?

Proton accelerators ??

large GeV bump -> pion decay !?

long awaited answer !

photon index is too soft (2.3-2.7)

-> it is very difficult for CRs

due to the softening during propagation ...

X-ray emitters are already moved/disappeared ?

X-rays are from more energetic electrons

than GeV/TeV gamma-rays -> shorter time scale !

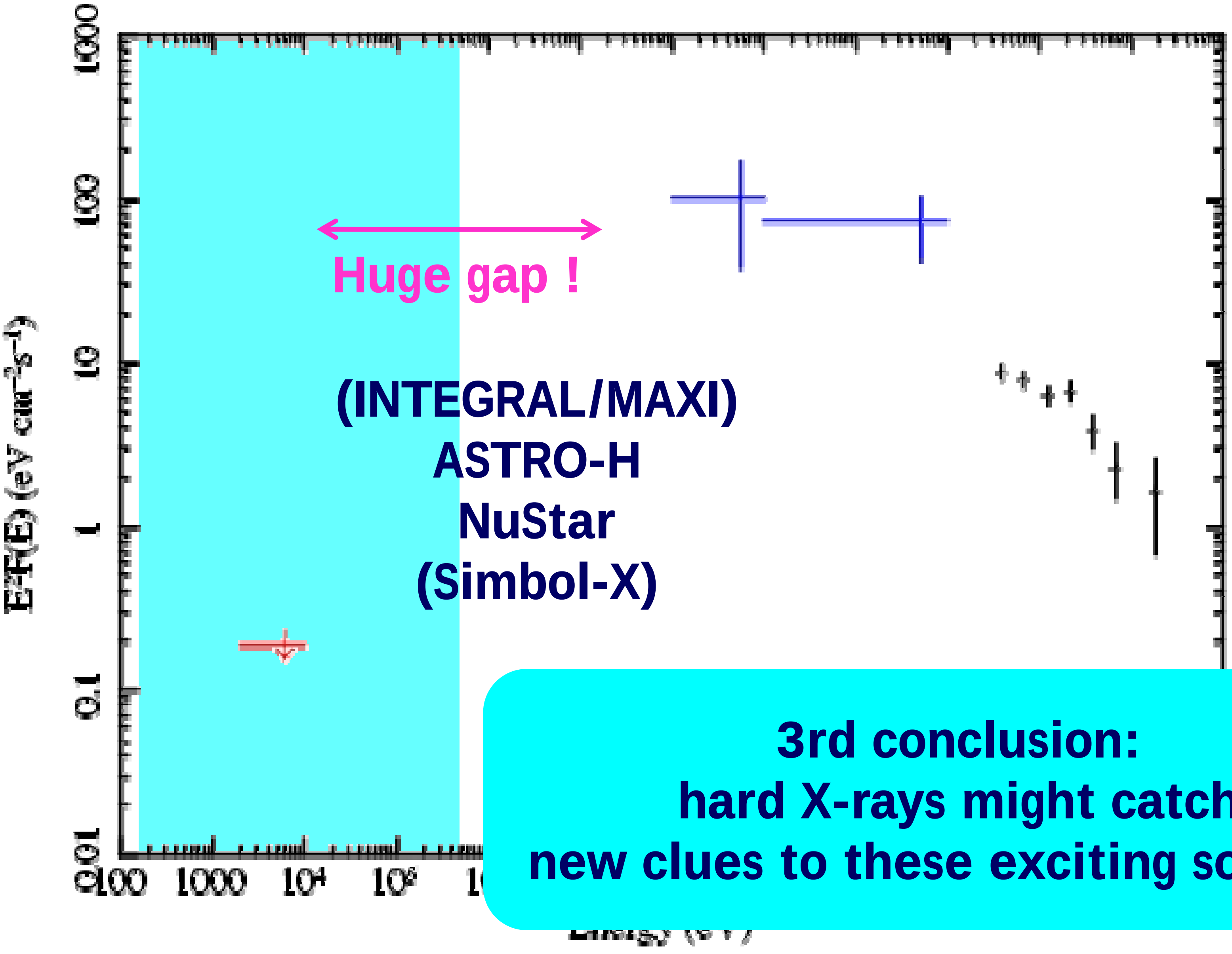
PWN/pulsars ?

Difficult to prove it ...

Anyhow, making the energy gap of observations

smaller is crucial

Hard X-rays will cover (partly) the gap



3rd conclusion:
hard X-rays might catch
new clues to these exciting sources.

Summary

- Chandra revealed us that SNRs accelerate CRs very efficiently.
- Suzaku showed us that the E_{max} is ~10-100 TeV. Protons should be accelerated more.
- Wide-band images with XMM/Suzaku show us some clue of p acceleration.
- Several TeV unID sources could be p accelerators.
- The most interesting sources are much brighter in higher energies.
  We are waiting for New high-E mission,
  ASTRO-H, NuStar, and more !