Suzaku Observations of SNR RX J1713.7-3946

in the Energy Range from 0.4 keV up to 40 keV

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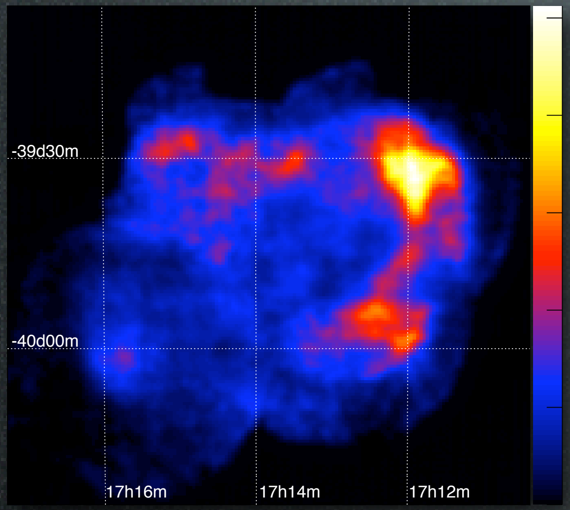
12/12/2007 Suzaku X-ray Universe @ Catamaran Hotel, San Diego

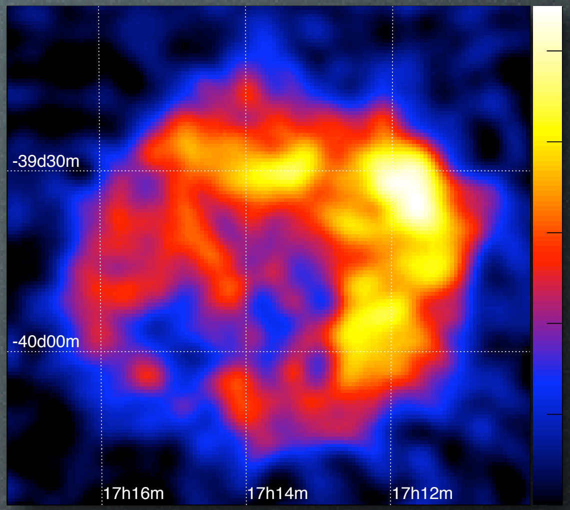
SNR RX J1713.7-3946

X-ray (ASCA)
Synchrotron



Uchiyama et al. (2005)

Gamma-ray (H.E.S.S.)
Inverse Compton /π^0 decay



Aharonian et al. (2006)

Distance: 1 kpc
Age: 1600 yr

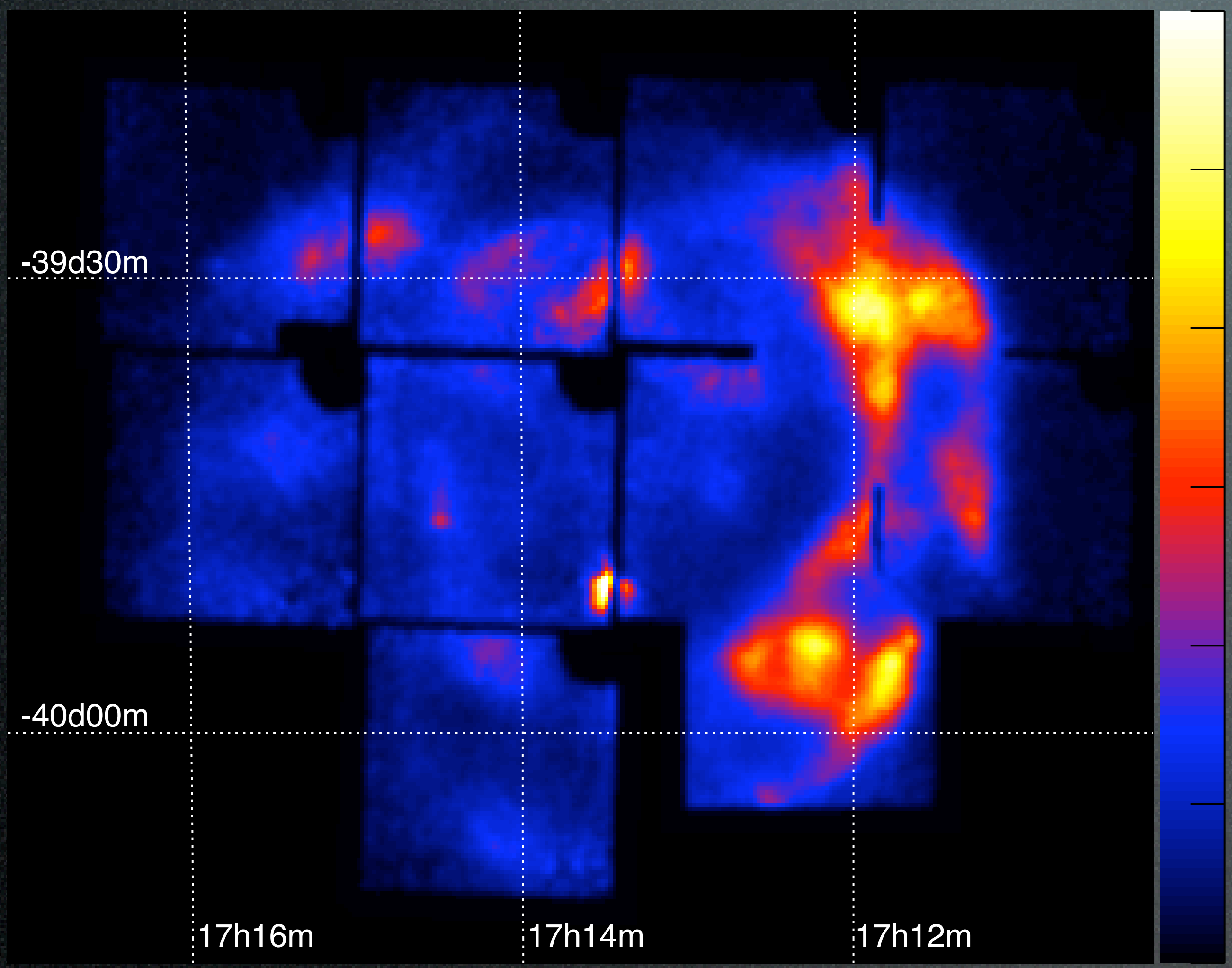
Best Object for Study of Particle Acceleration

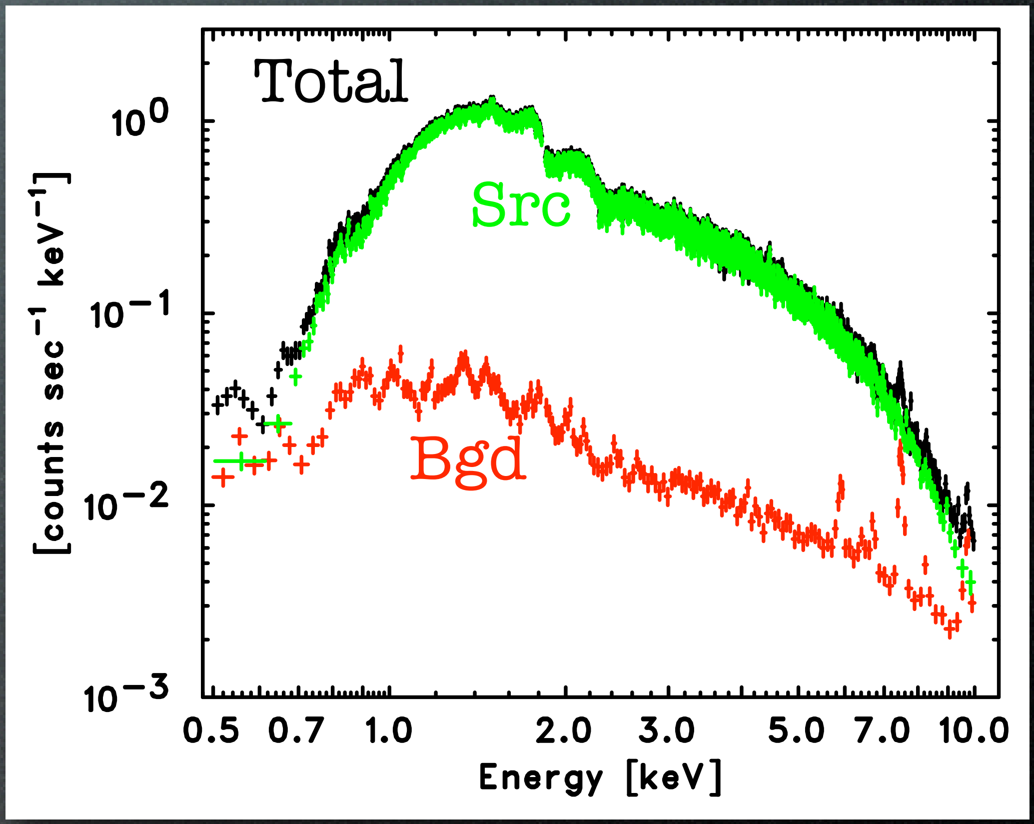
- Non-thermal X-ray emission dominates
- Bright & Large ($d \simeq 1°$)
- Studied well also in TeV gamma-rays with H.E.S.S.

Cutoff ? Morphology of Dim Parts? → Suzaku

XIS Data (0.4–12 keV)

1–5 keV





Power-law type spectra (No line features)

Γ = 2.2–2.7

Consistent with previous studies by ASCA, Chandra and XMM-Newton

Cutoff around 10 keV

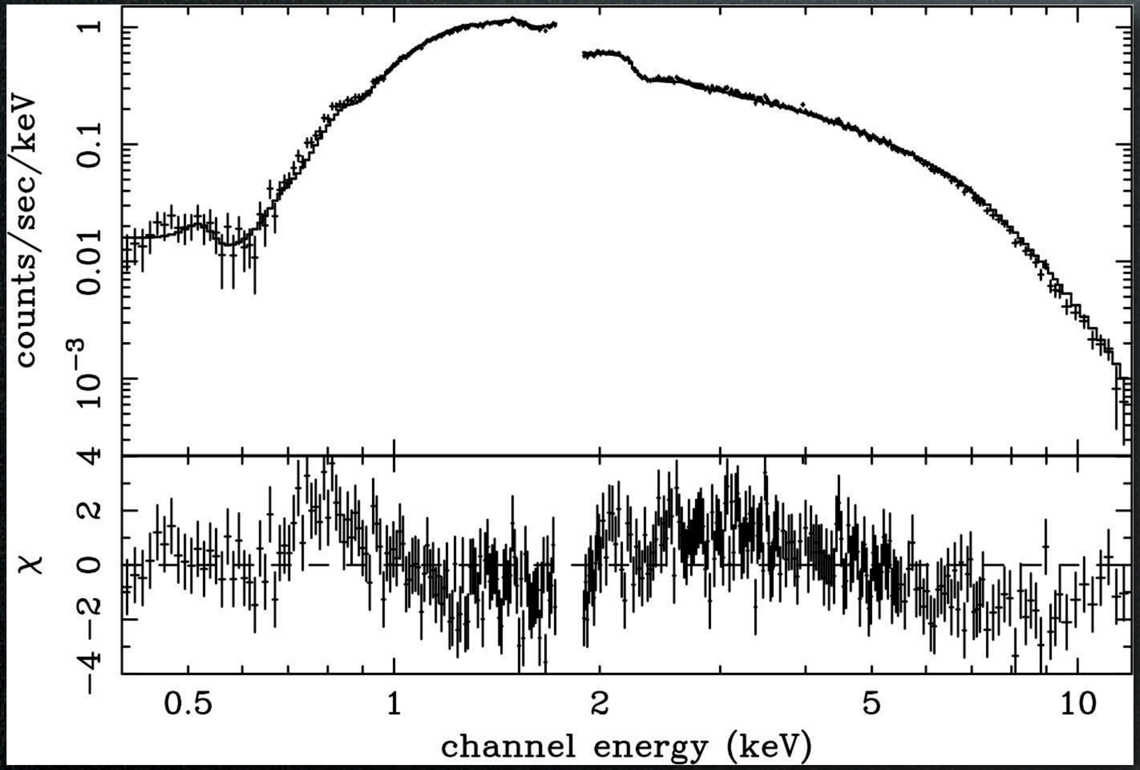
Spectrum of SW rim

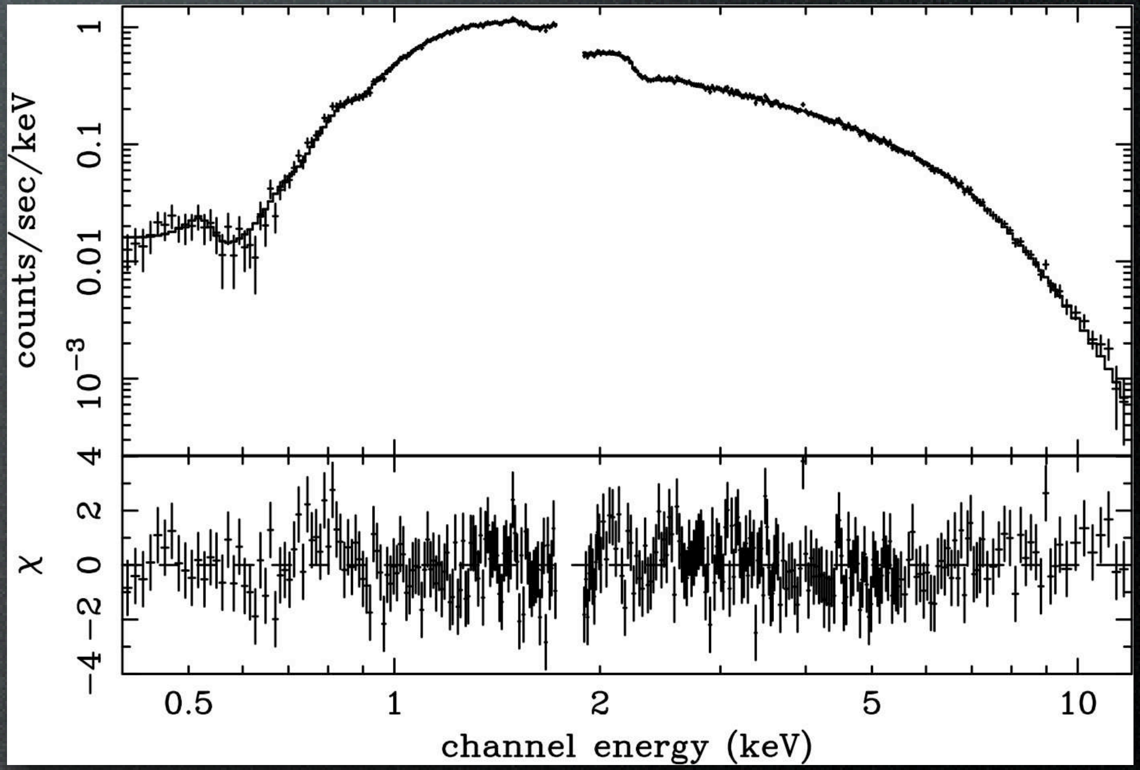
Simple Power Law

$$\frac{dN}{d\varepsilon} \propto \varepsilon^{-\Gamma}$$

Power Law with an Exponential Cutoff

$$\frac{dN}{d\varepsilon} \propto \varepsilon^{-\Gamma} \exp\left[-\left(\frac{\varepsilon}{\varepsilon_c}\right)\right]$$

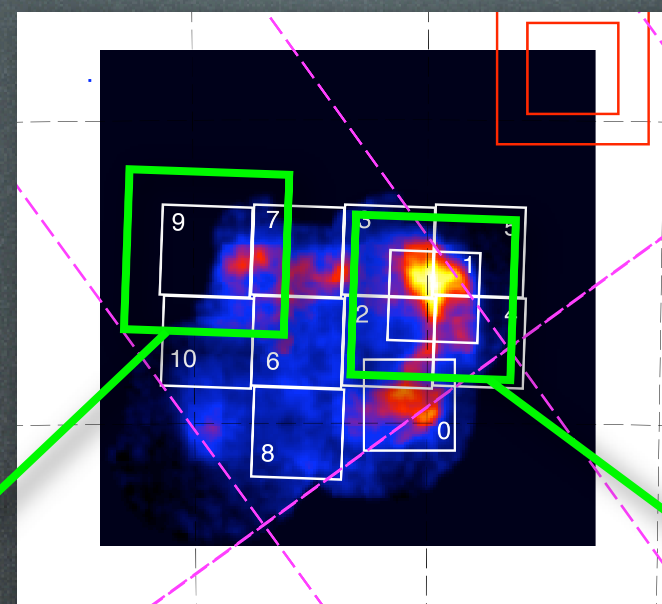




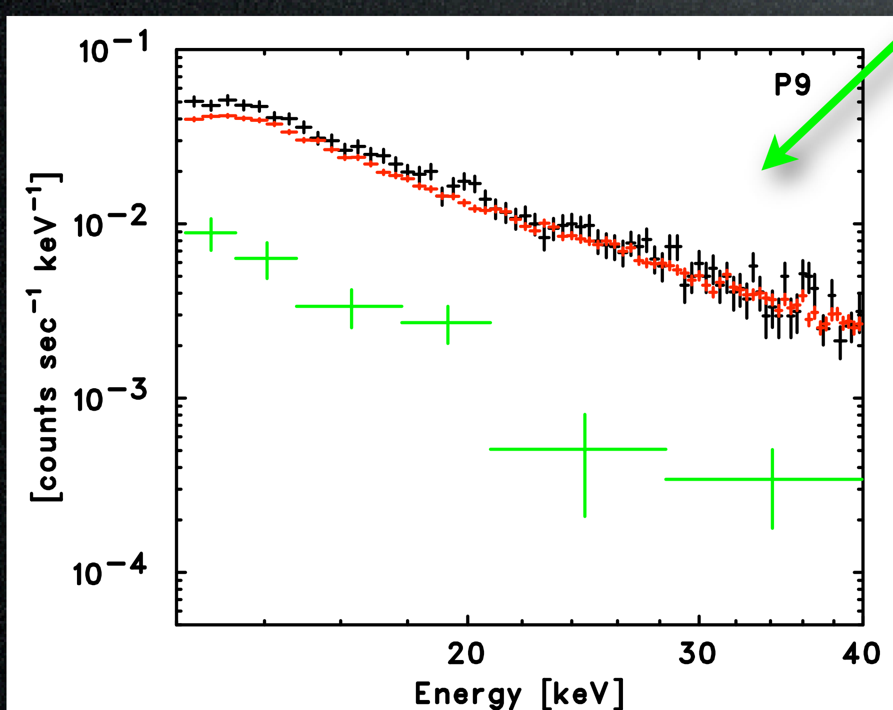
Spectral steepening even below 10 keV

HXD: Spectra above 10 keV

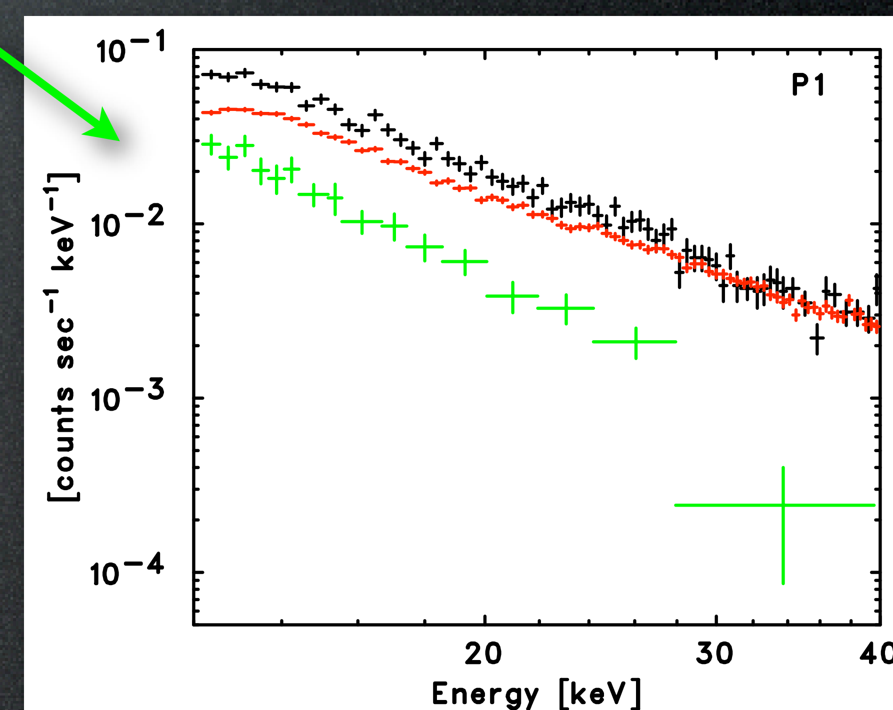
Detected up to $\simeq$ 40 keV from all pointings



Dim part



Bright part

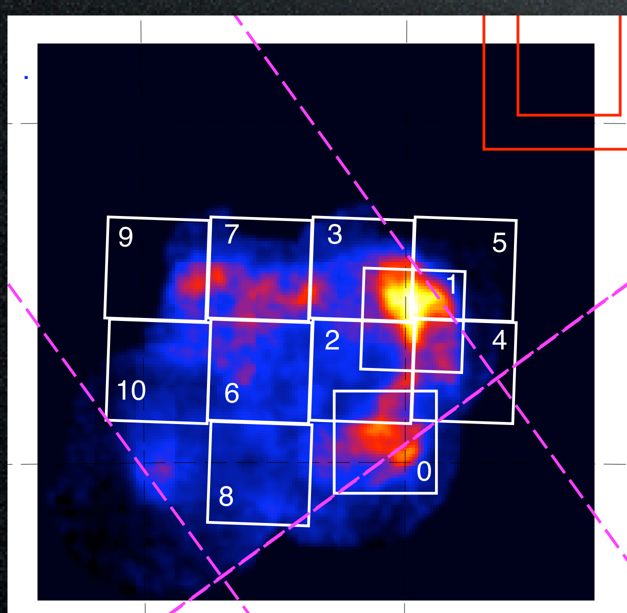


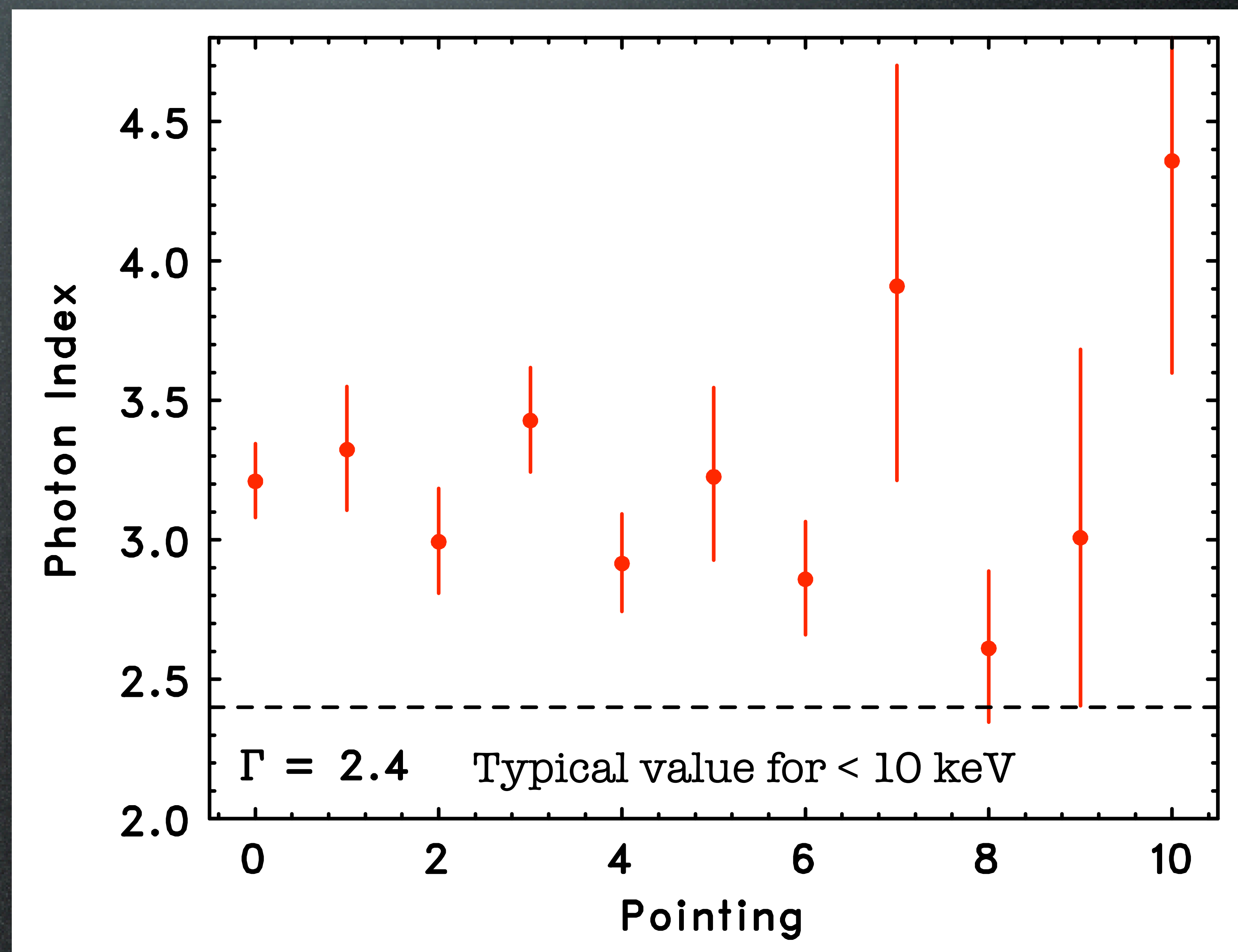
Total
Bgd
Bgd sub

HXD: Spectral Fitting

power-law fit → $\Gamma \simeq 3.2$

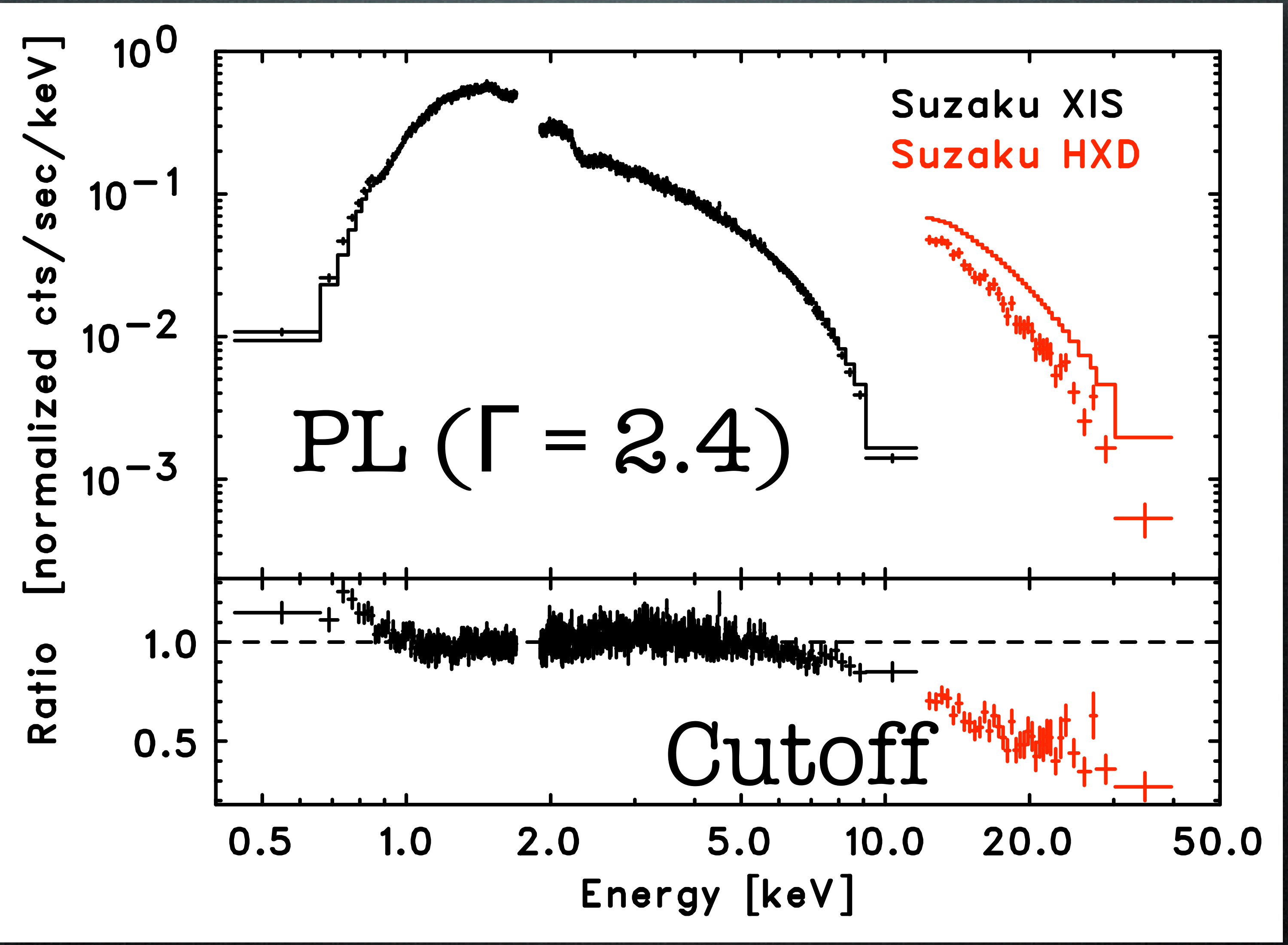
significantly larger than those in soft X-ray band





Wide-Band Spectrum

From 0.4 keV to 40 keV



Detection up to 40 keV
→ Clear spectral cutoff

Cutoff Energy

Cutoff Energy →
Acceleration rate = Synchrotron loss rate

Zirakashvili & Aharonian (2007)
Predict rapid cutoff which agrees with
Suzaku spectrum

$$\boxed{\varepsilon_0 = 0.55 \left(\frac{v_s}{3000 \text{ km s}^{-1}} \right)^2 \eta^{-1} \text{ keV}} \quad (\eta \geq 1)$$

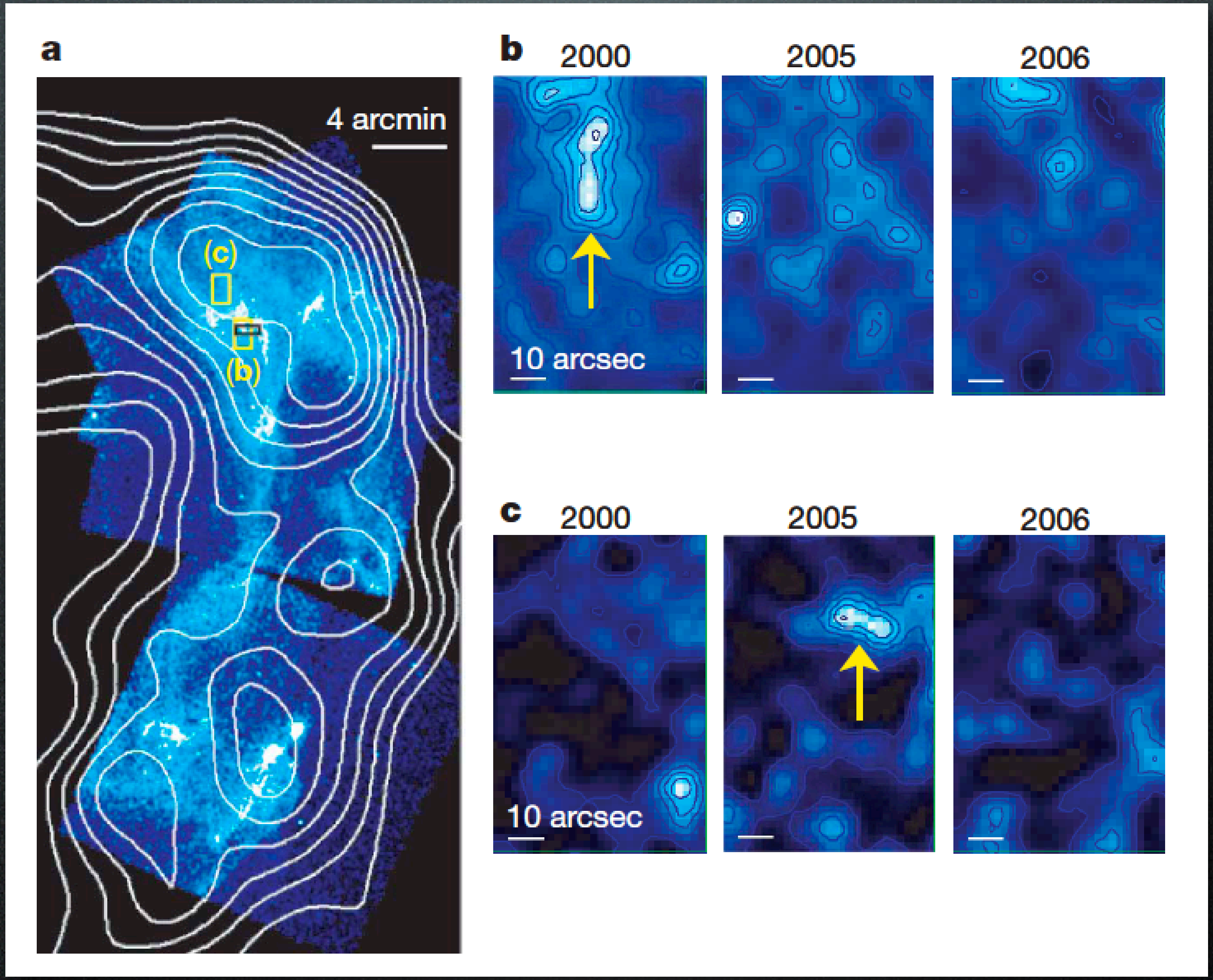
Suzaku Spectrum → $\boxed{\varepsilon_0 = 0.67 \pm 0.02 \text{ keV}}$

Chandra Image
Uchiyama et al. Nature (2007) → $\boxed{v_s < 4500 \text{ km s}^{-1}}$

$\eta \approx 1$ Almost the Bohm limit
Very Efficient Acceleration

Magnetic Field

Uchiyama et al. (2007) Nature

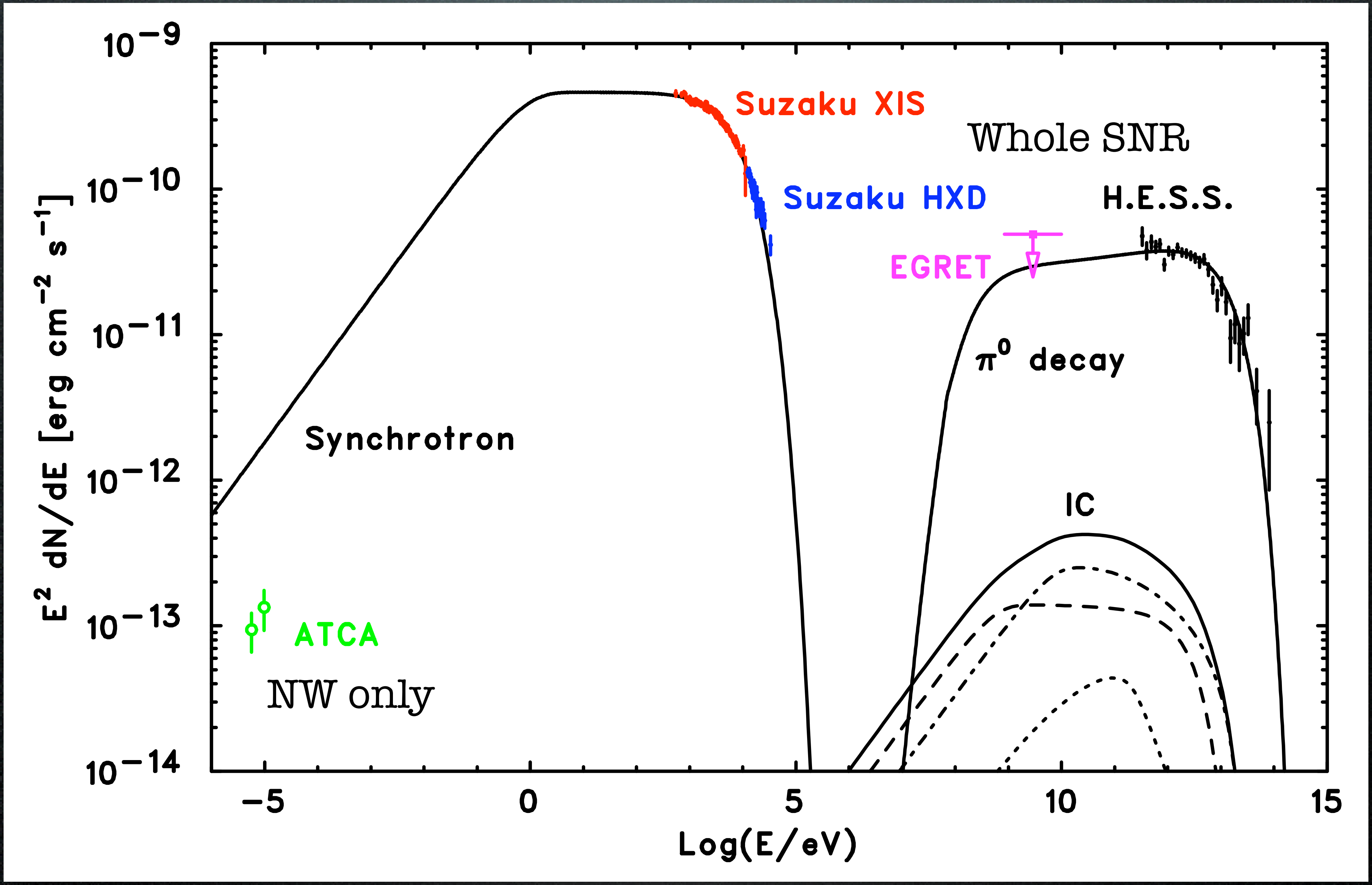


Year-scale Variability detected with Chandra

→ Acceleration & Cooling in year-scale

→ High Magnetic Field: 1 mG

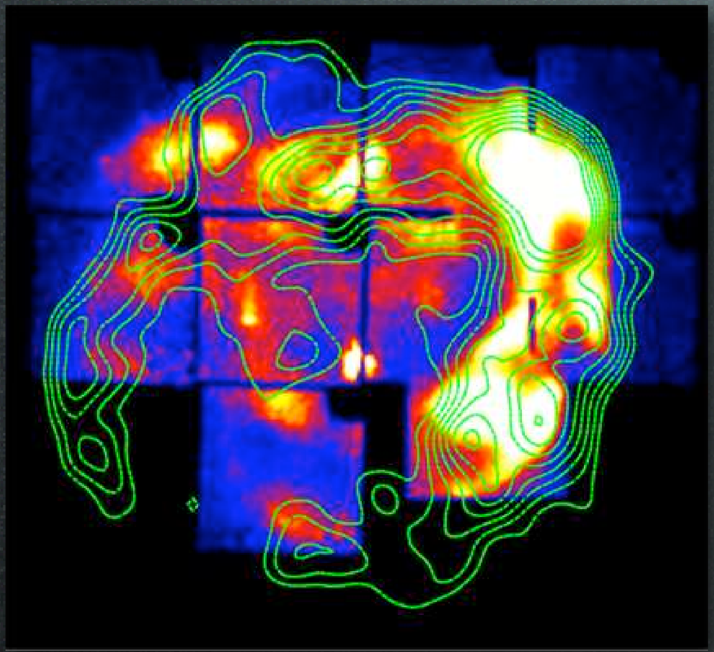
Multi-Wavelength Spectrum



$B = 200\ \mu G$, $t_0 = 1000$ yr, $s = 2.0$ (for e^- and p)

$W_e = 3.1\times10^{46}$ erg, $nW_p = 2.7\times10^{50}$ erg cm^{-3}

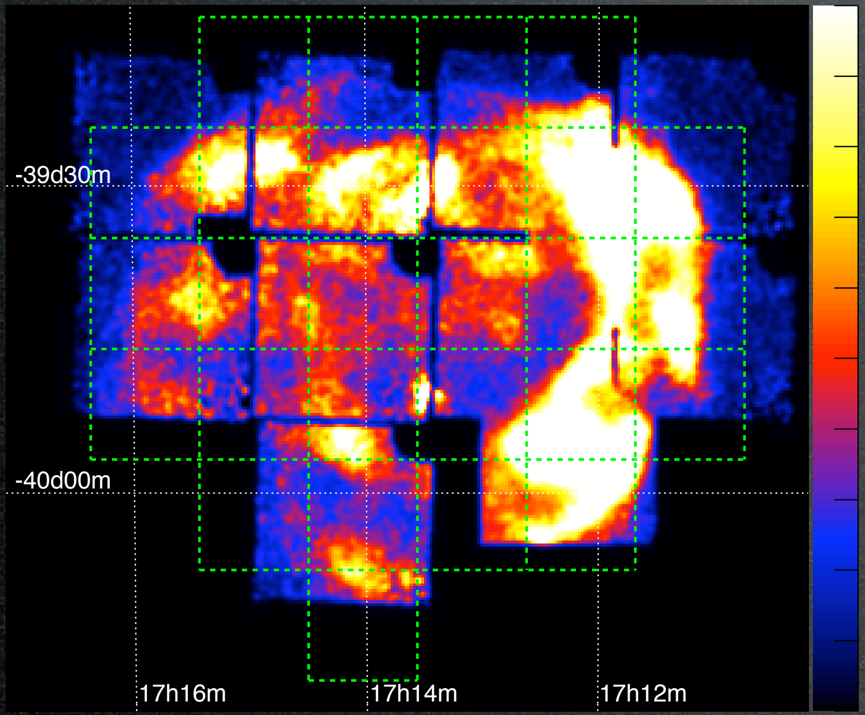
keV Image vs TeV Image



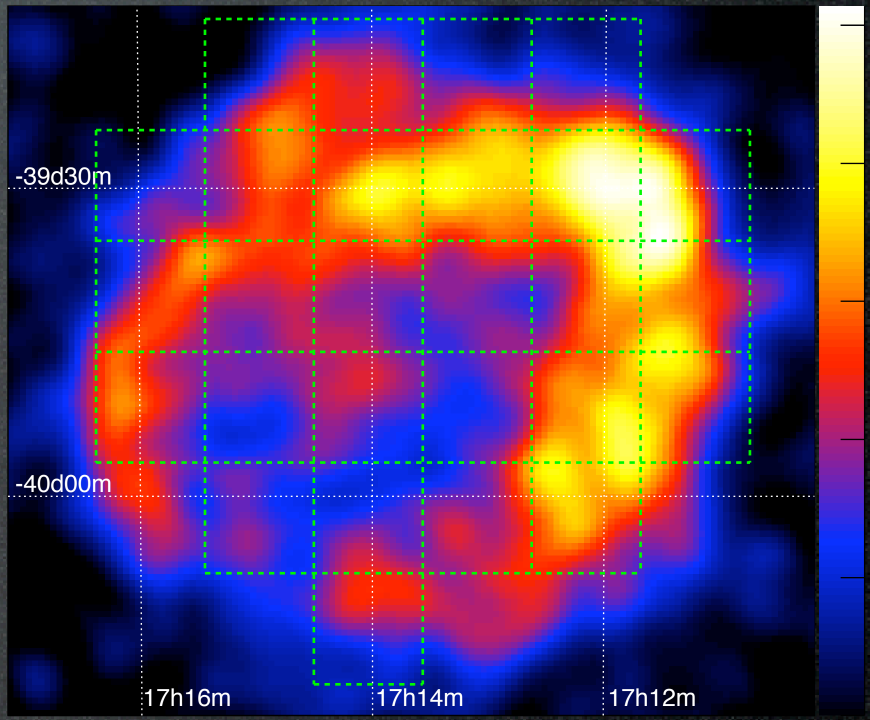
Color: Suzaku XIS (1-5 keV)
Contour: H.E.S.S.

Similar morphology also in the dim parts (Low BGD and large effective area of Suzaku XIS)

Suzaku XIS



H.E.S.S.



Compare flux for the each square region

keV Image vs TeV Image

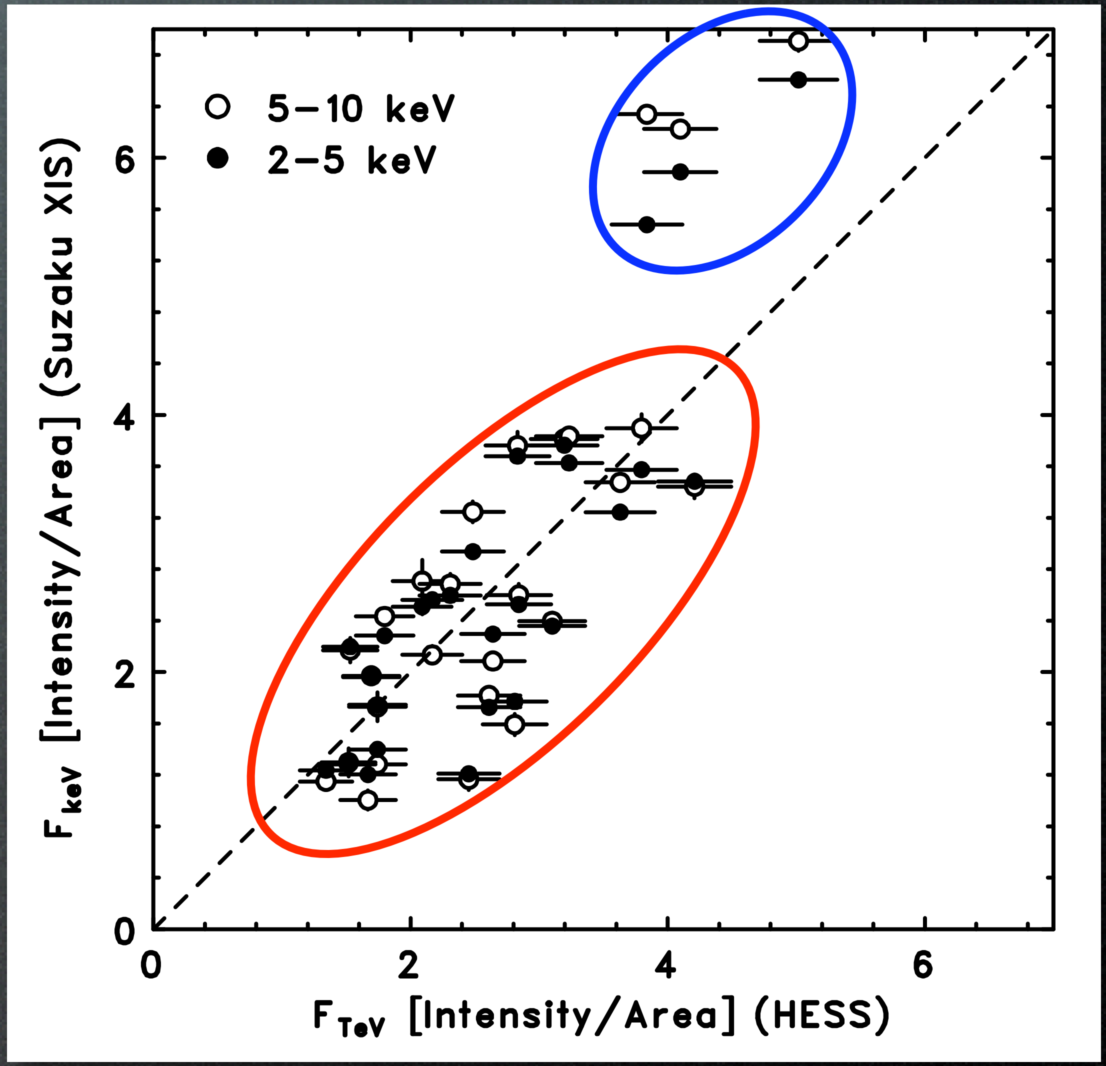
Tight Correlation

Homogeneous matter distribution ?
(Inconsistent with NANTEN)

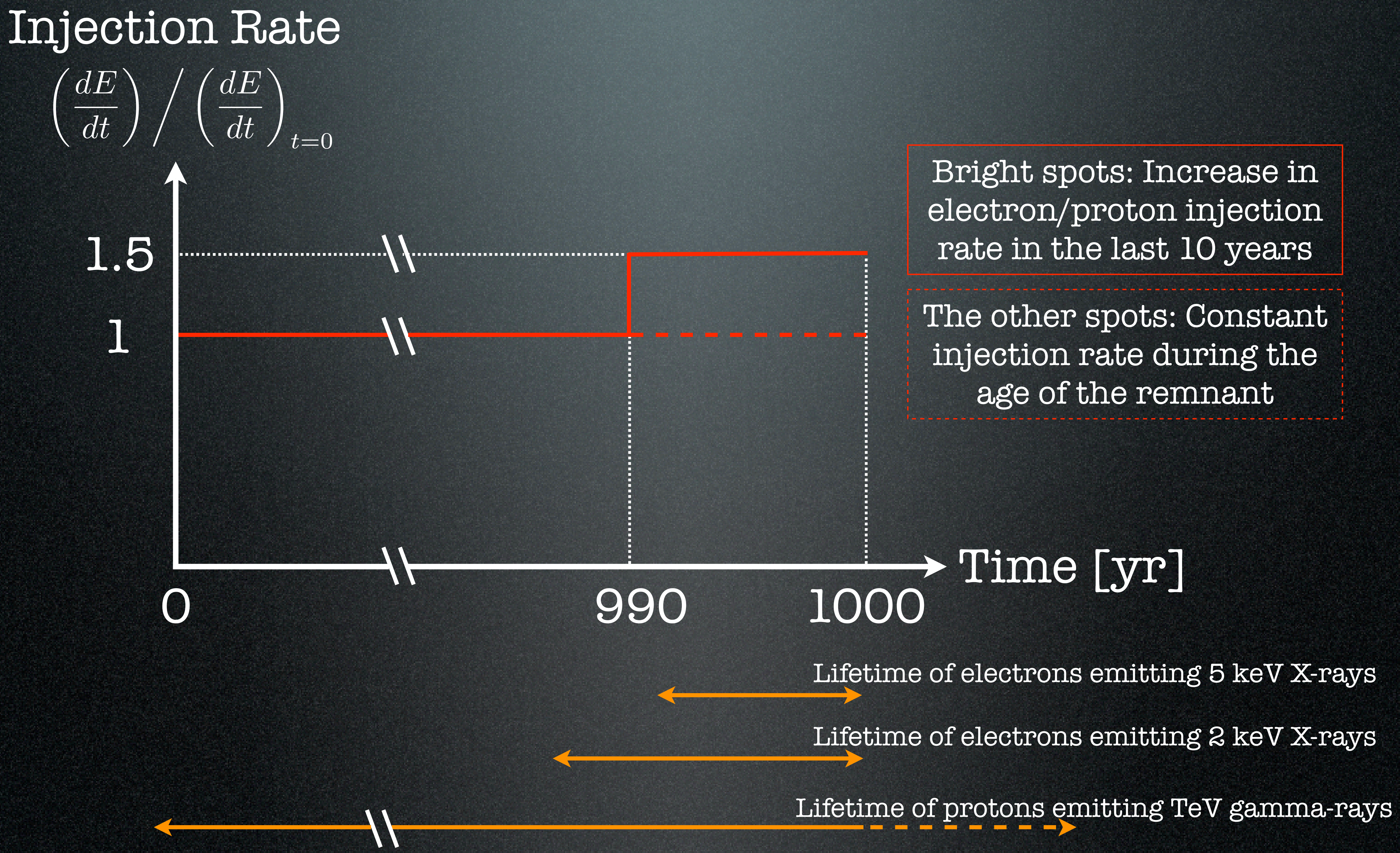
Synchrotron emission correlate with matter distribution ?

“keV” excess

Large e/p ratio ?
Recent acceleration at the bright spots ?

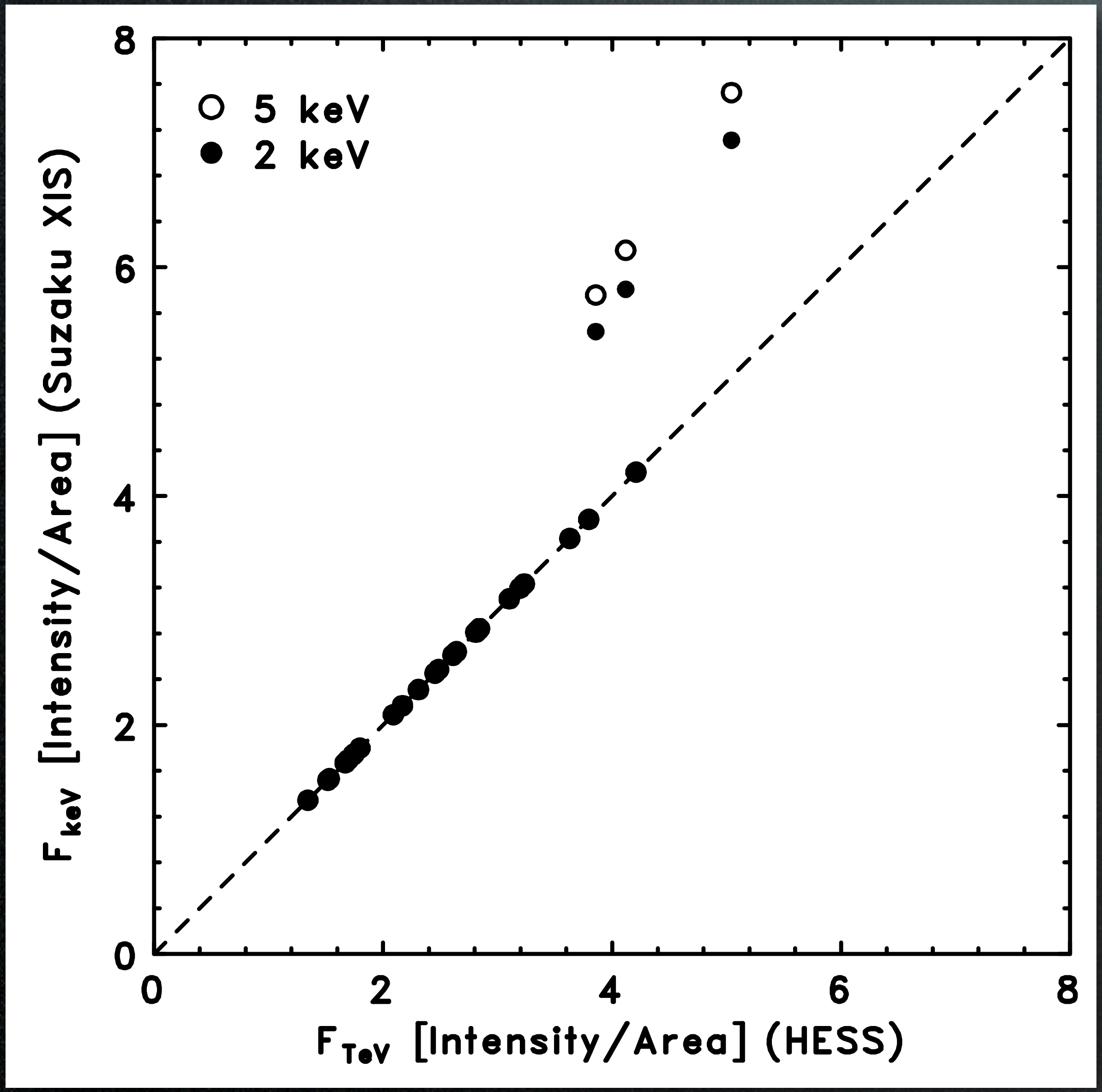


Toy Model

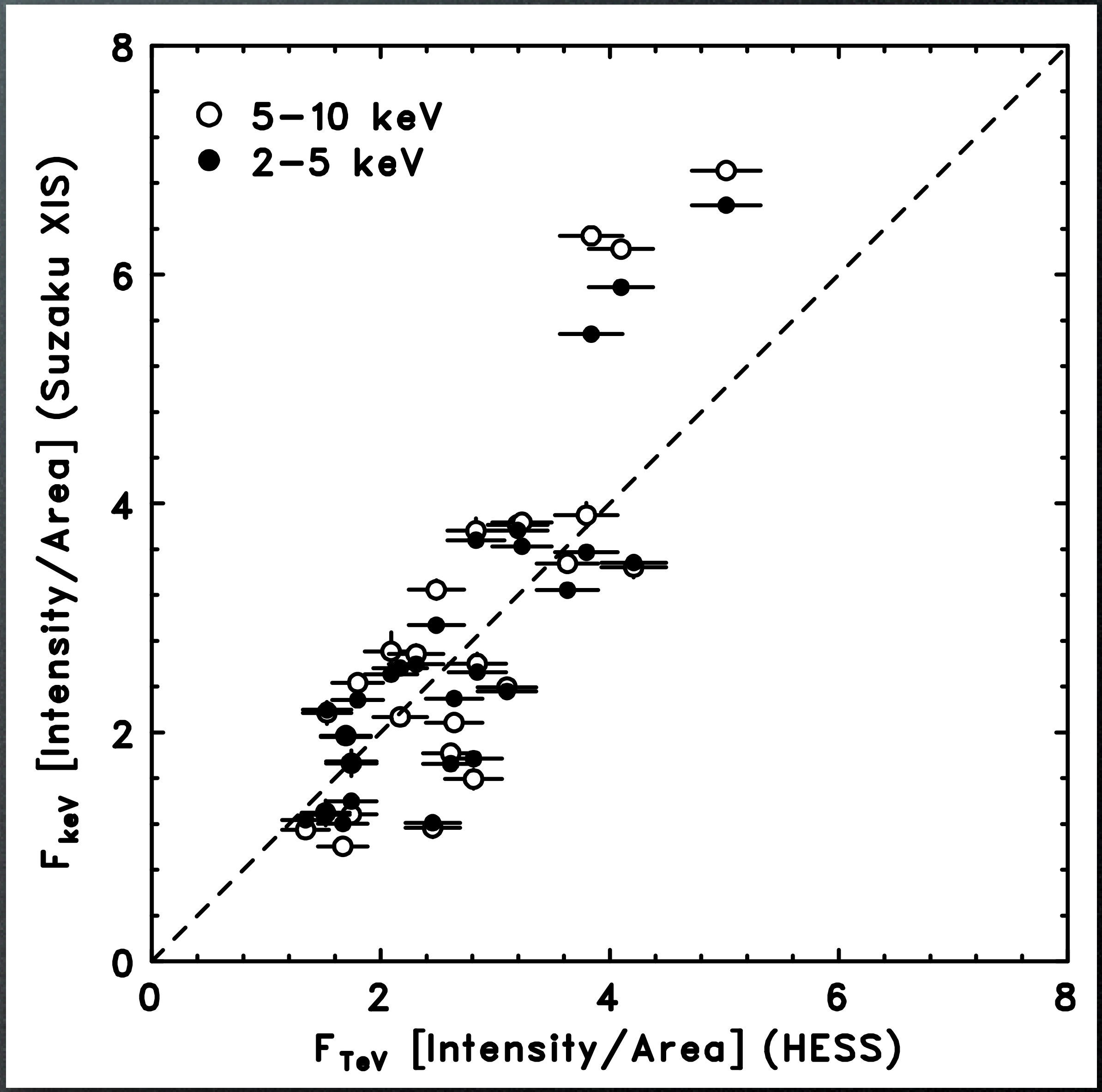

Injection Rate
$\left(\frac{dE}{dt}\right) \Big/ \left(\frac{dE}{dt}\right)_{t=0}$
1.5
1
0
990
1000
Time [yr]
Bright spots: Increase in electron/proton injection rate in the last 10 years
The other spots: Constant injection rate during the age of the remnant
Lifetime of electrons emitting 5 keV X-rays
Lifetime of electrons emitting 2 keV X-rays
Lifetime of protons emitting TeV gamma-rays

Toy Model vs Observation

Toy model



Observation

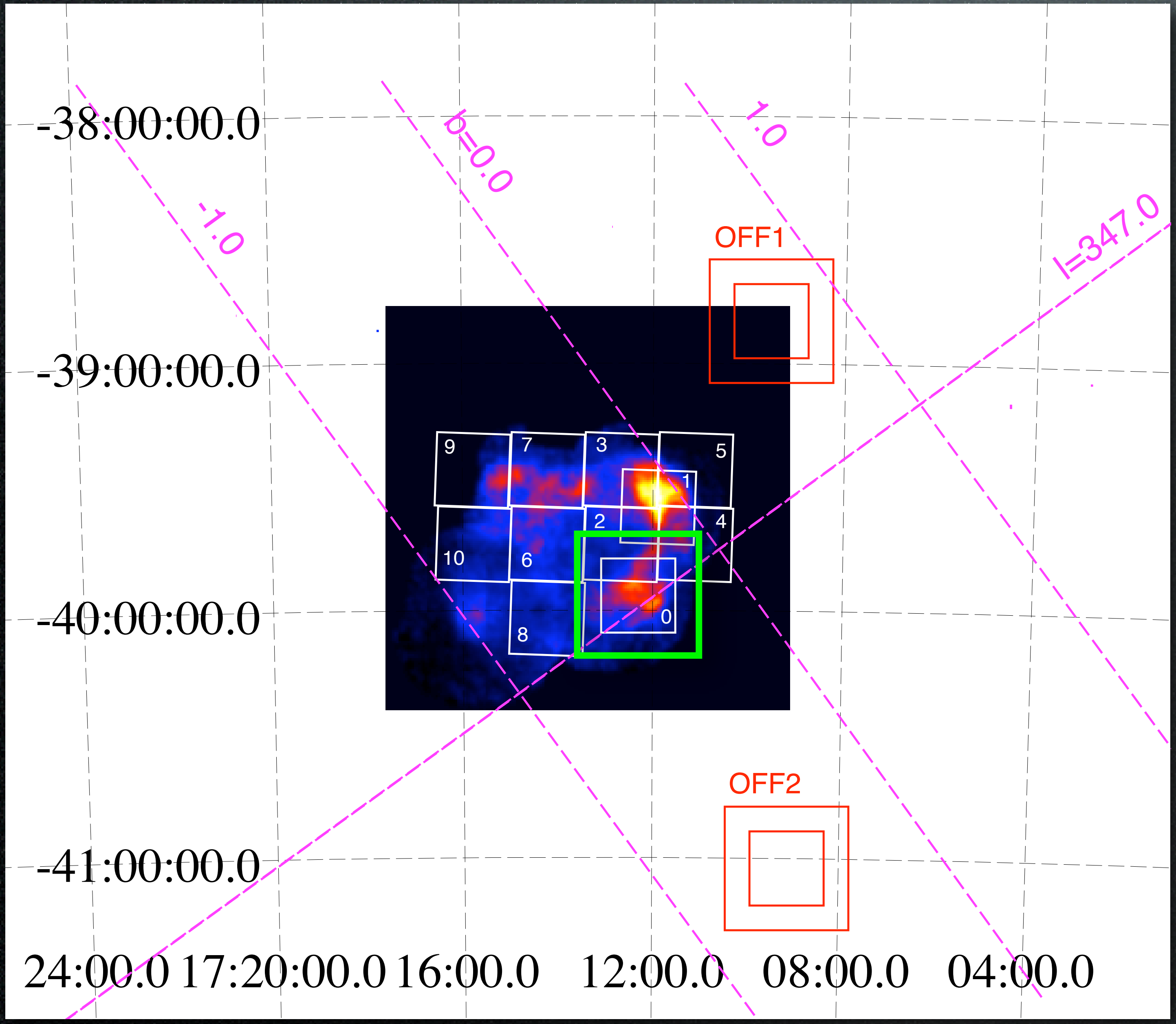


Conclusions

- We observed RX J1713.7-3946 with Suzaku
- We have detected hard X-rays up to 40 keV from RX J1713.7-3946, for the first time
- We have clearly detected cutoff structure around 10 keV
- Cutoff energy indicates very efficient acceleration (almost in the theoretical limit)
- Multi-wavelength spectrum can be well modeled with hadronic scenario.
- Tight keV-TeV correlation & “keV excess” in the brights spots
- Upcoming GLAST will play an important roll in determining the gamma-ray spectrum

Suzaku Observation of RX J1713.7-3946

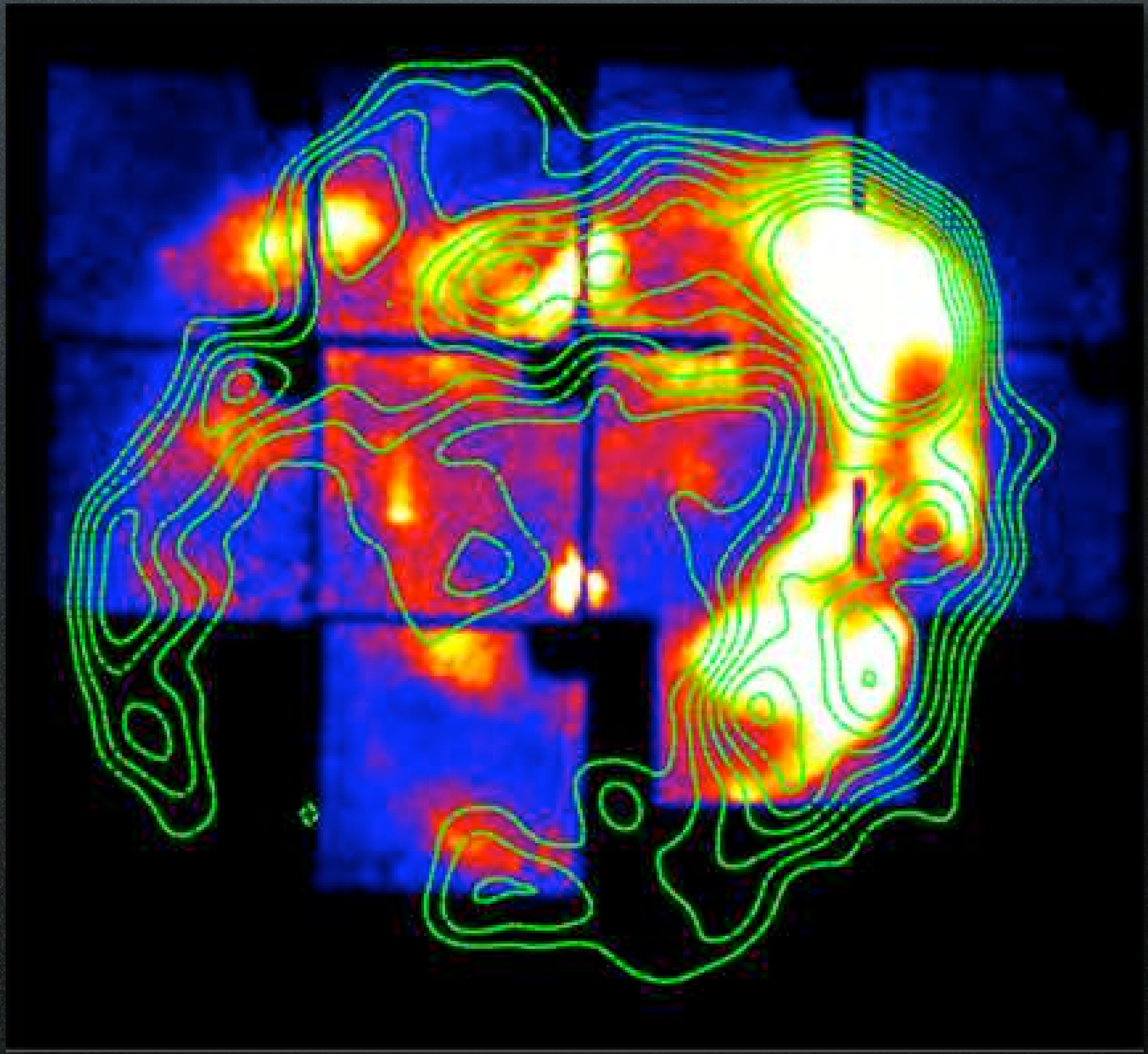
11 Pointings (2005 & 2006)
Covers about 2/3 of the remnant



Pointing ID	Exposure [ks] XIS / HXD
0	55 / 48
1	17 / 17
2	18 / 22
3	19 / 18
4	18 / 21
5	16 / 19
6	20 / 19
7	12 / 11
8	19 / 20
9	16 / 15
10	15 / 15

keV Image vs TeV Image

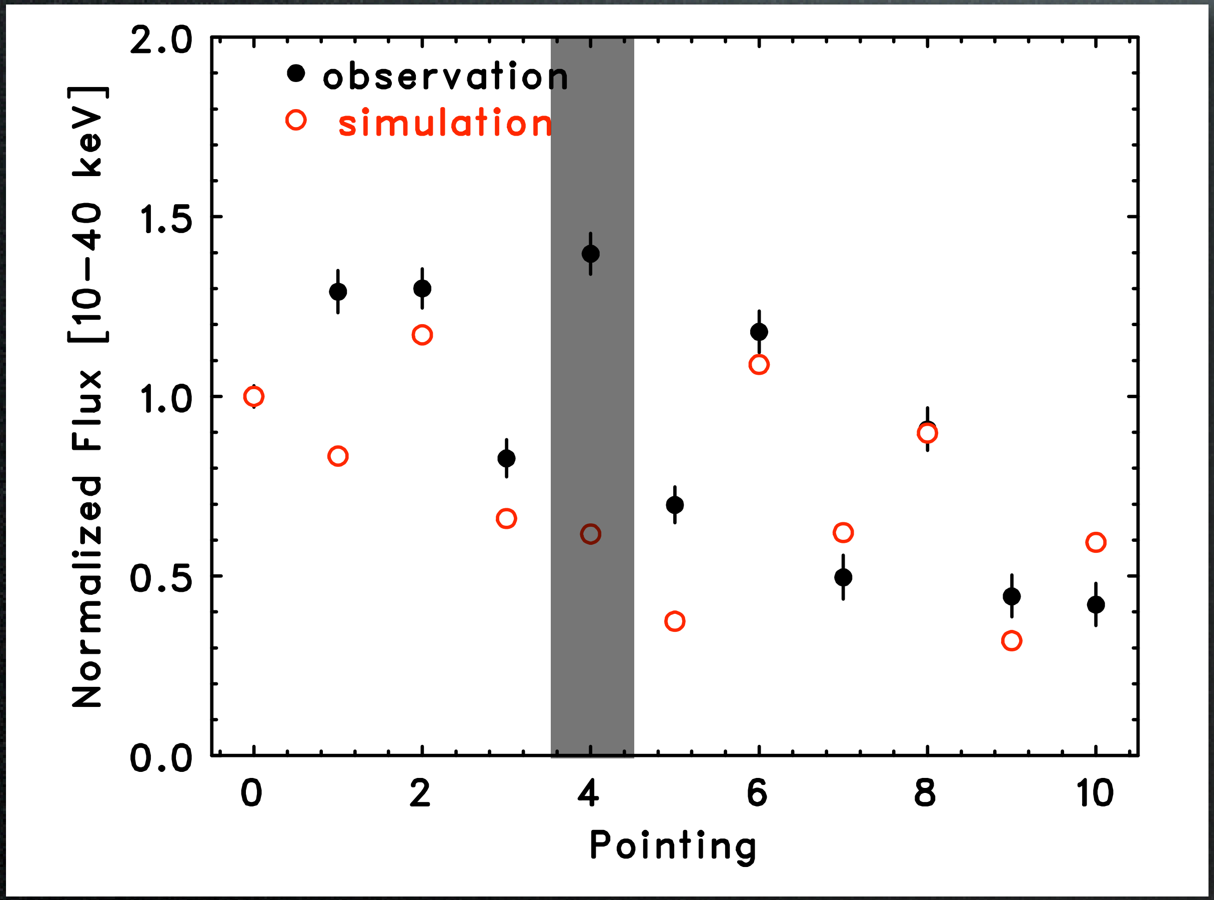
Color: Suzaku (1-5 keV)
Contour: H.E.S.S.

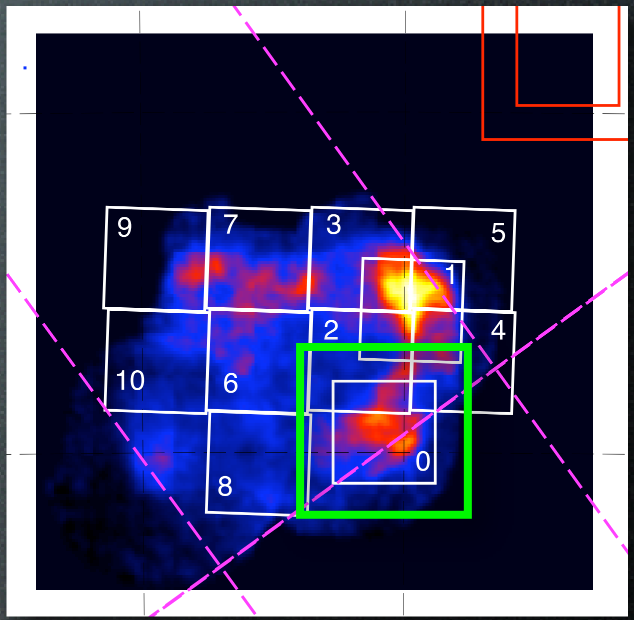


Similar morphology also in the dim parts

Spatial Variation

Input soft X-ray image to MC simulator
Compare detected flux between obs. and sim.

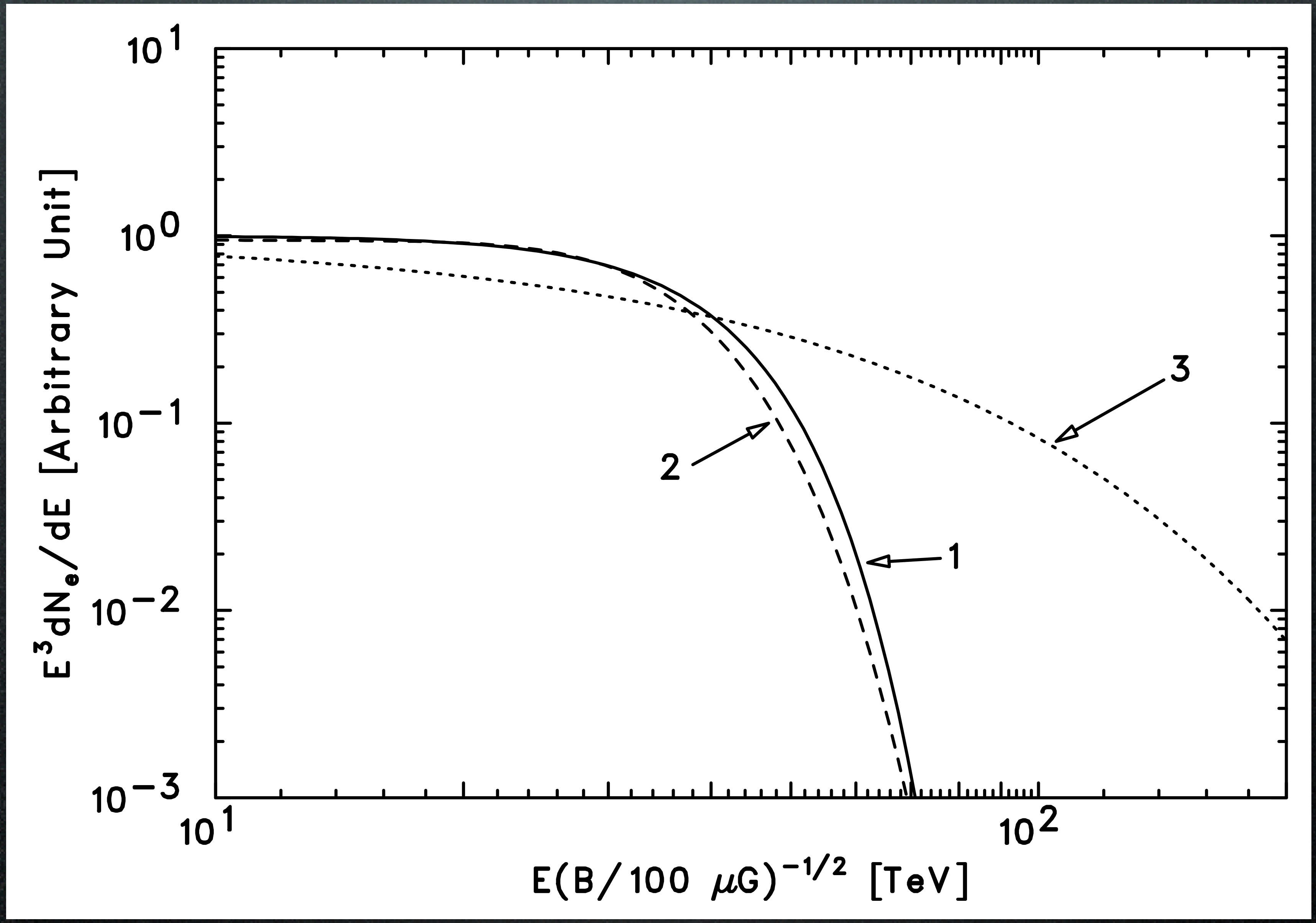




Systematic Error ≃ 20%

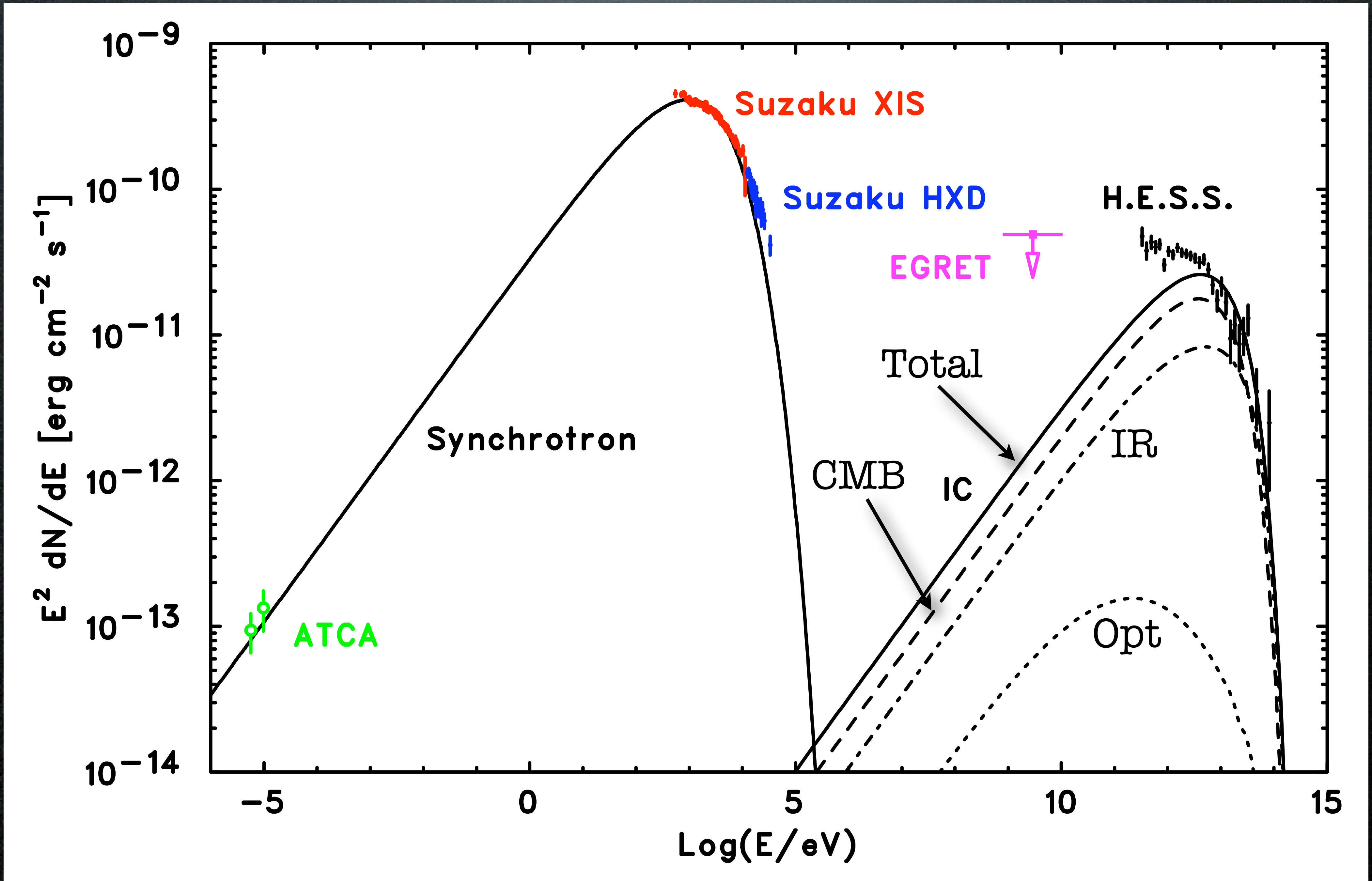
Hard X-ray emission seems to follow the brightness distribution of soft X-rays

Cutoff Shape



1. Suzaku Data (Super-Exponential)
2. Zirakashvili & Aharonian (2007)
3. Exponential Cutoff

Multi-Wavelength Spectrum

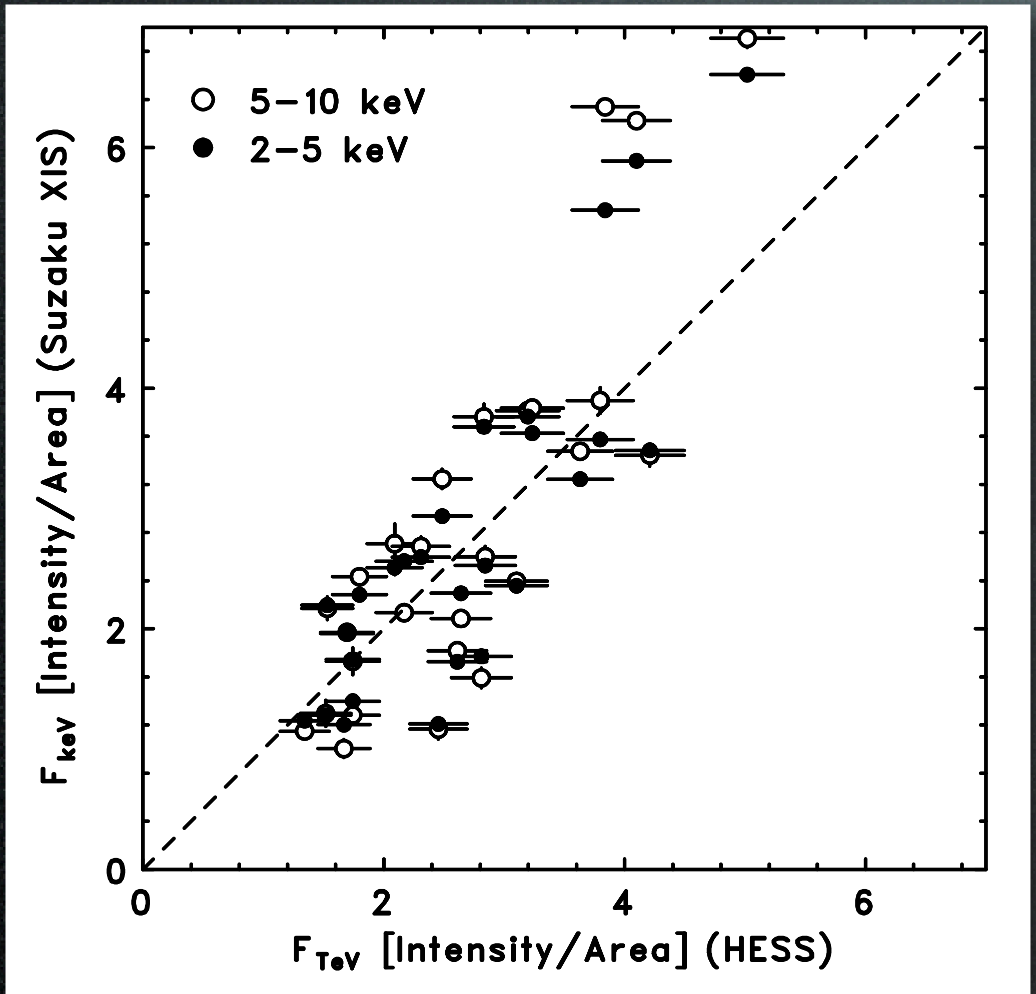


$B = 14\ \mu G$, $t_0 = 1000$ yr, $s = 2.0$

$W_e = 1.4 \times 10^{47}$ erg

keV Image vs TeV Image

F_{keV} vs F_{TeV}



Map of F_{keV} – F_{TeV}

Tight Correlation

&

“keV excess” at the bright spots

Hadronic Model

H.E.S.S. data requires

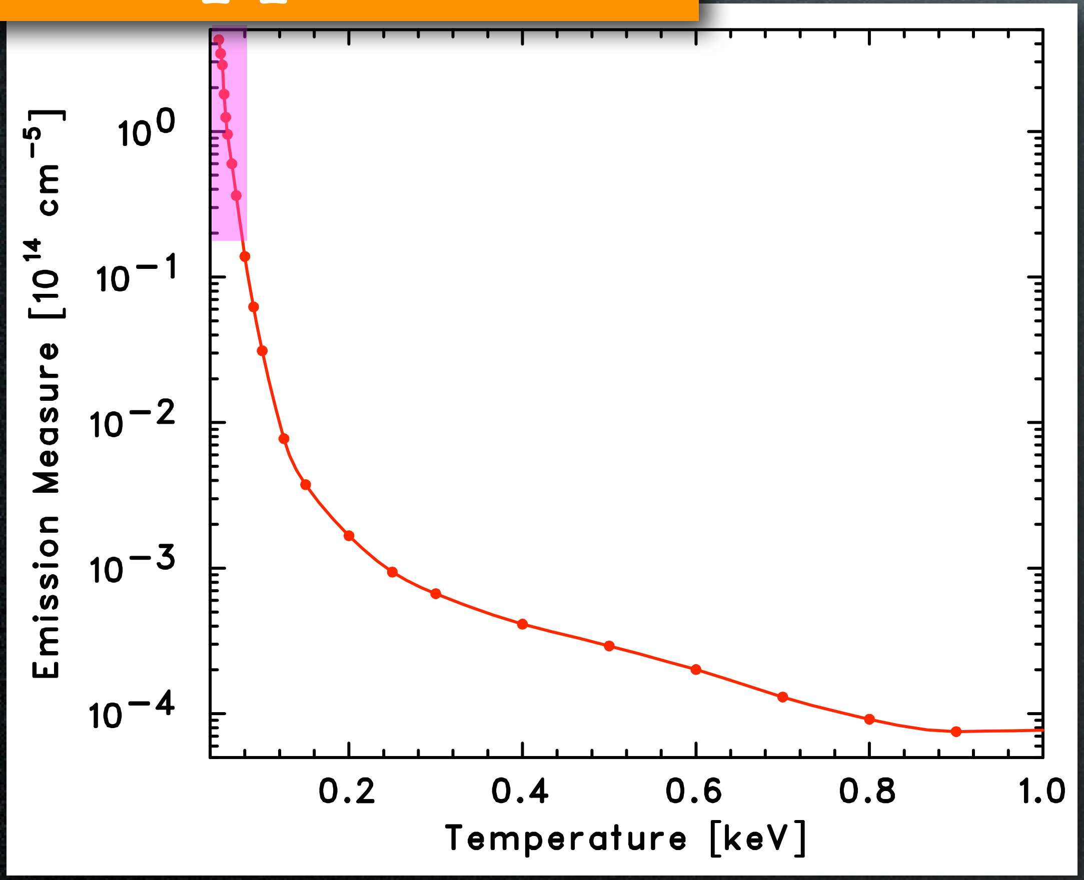
$$W_p \simeq 10^{50} \left(\frac{D}{1\ \mathrm{kpc}}\right)^2 \left(\frac{n}{1\ \mathrm{cm}^{-3}}\right)^{-1}\ \mathrm{erg}$$

A matter density of $> 0.2\ \mathrm{cm}^{-3}$ is needed, assuming...

- The typical kinetic energy released by a supernova of 10^{51} erg
- The conversion efficiency to the high energy protons of < 50%

Upper Limit on Thermal Emission

3σ Upper Limit



$$\mathrm{EM} = \frac{1}{4\pi D^2}\int n_{\mathrm{e}} n_{\mathrm{H}}\ dV$$

Normalization of thermal component

$$n = 1\ \left(\frac{\mathrm{EM}}{10^{14}\ \mathrm{cm}^{-5}}\right)^{1/2}\left(\frac{D}{1\ \mathrm{kpc}}\right)^{-1/2}\ \mathrm{cm}^{-3}$$

Matter density of n > 0.2 cm^{-3}

↓

The electron temperature of 0.1 keV or lower

Efficient acceleration with gas heating suppressed ?

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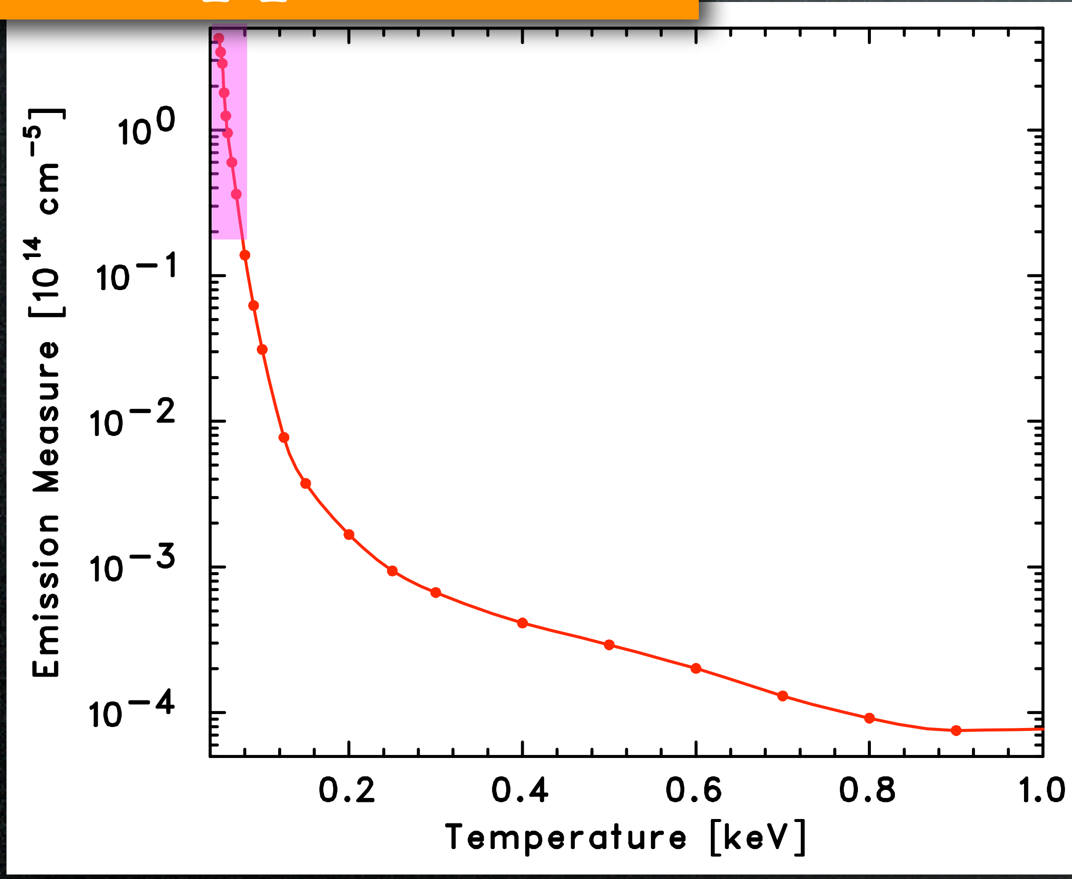

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