Fermi-LAT and Suzaku observations of Radio Galaxy Centaurus B

Katsuta, Tanaka et al. submit.

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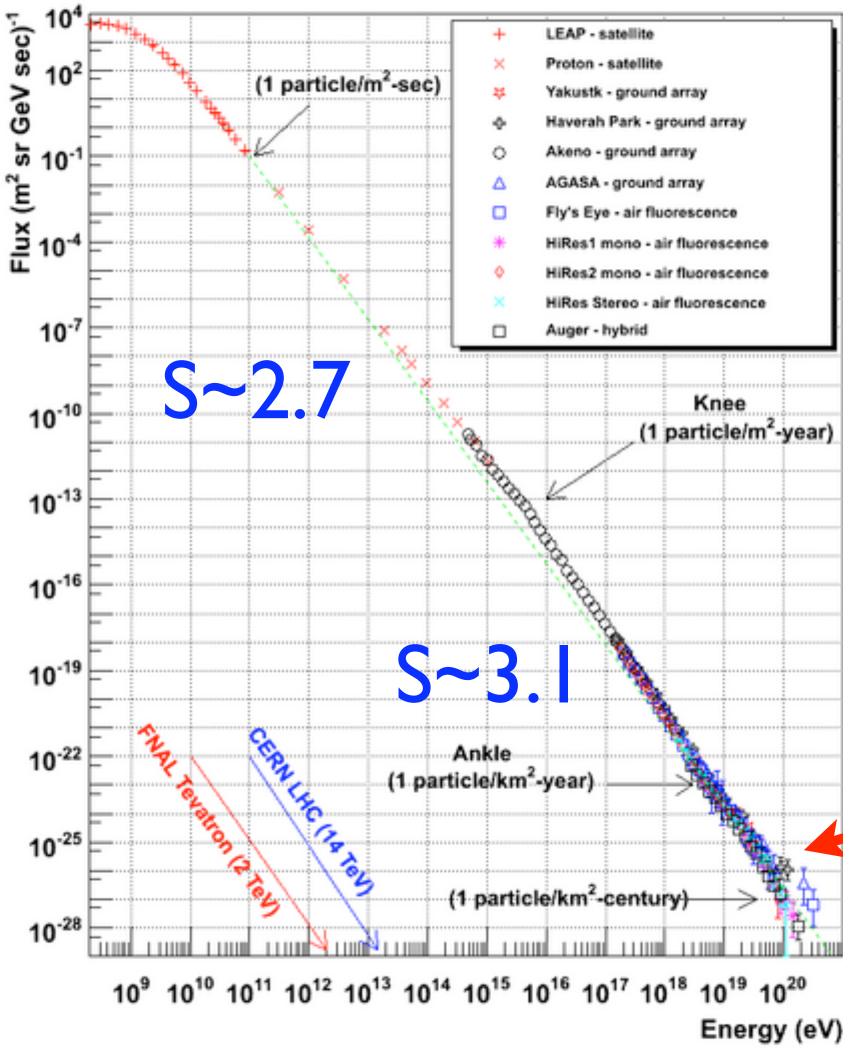
Cosmic-ray spectrum



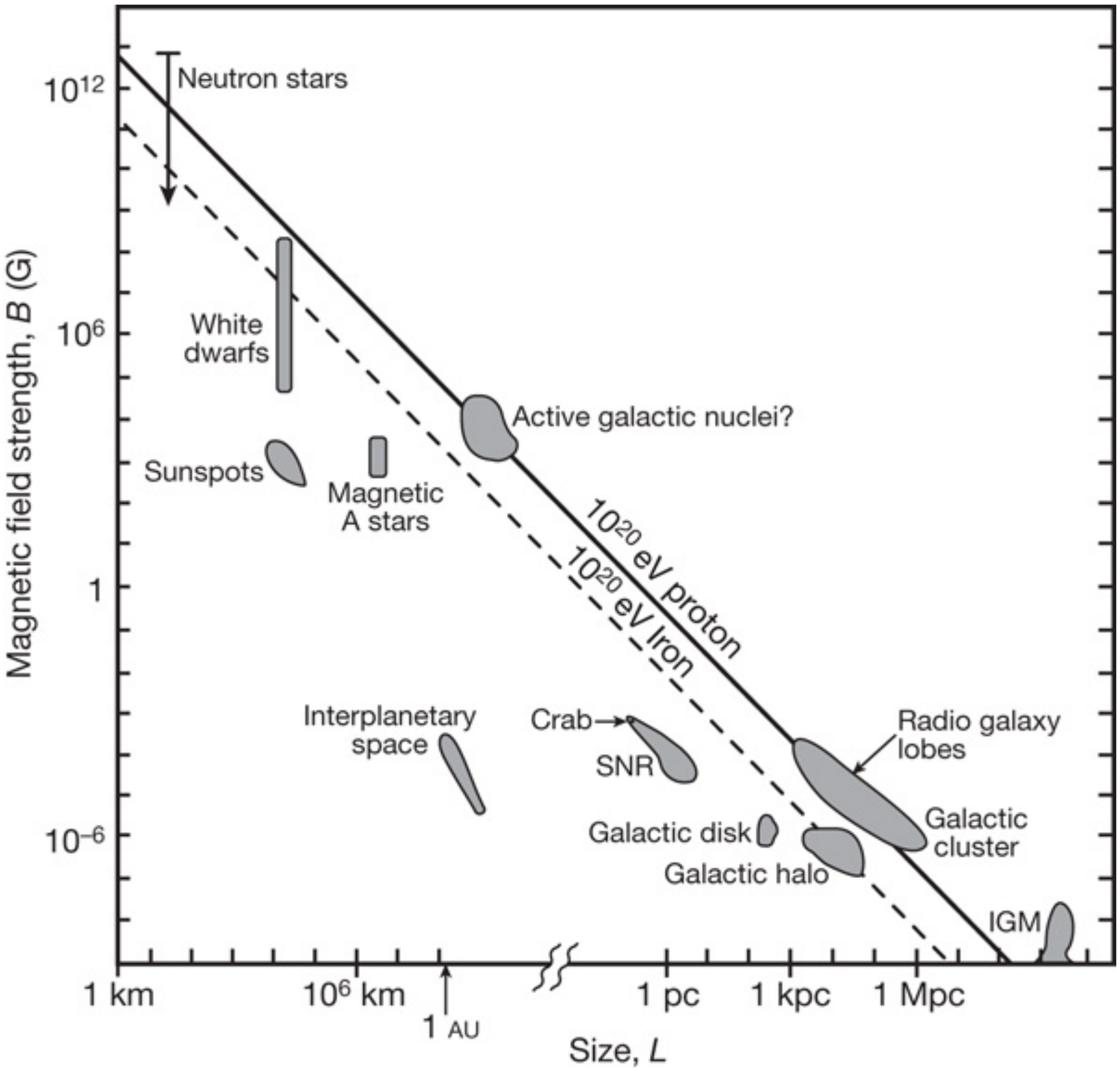
Power-law distribution up to 10^{20} eV

$E=3\times10^{15}$ eV

Ultra-high energy cosmic rays ($E>10^{19}$ eV)

Where is the source? How are UHECRs accelerated?

Candidates of UHECR source



Hillas condition

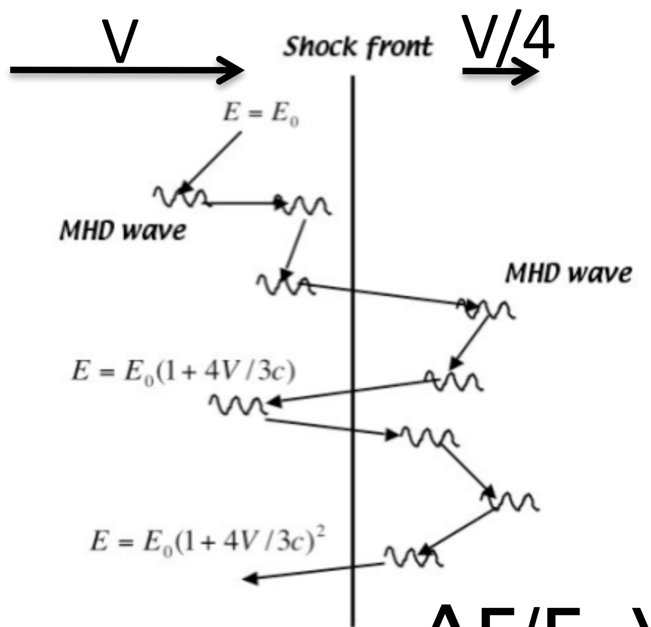
$$E_{max} = Ze\beta BL$$

Z: Charge number
β: Plasma velocity (v/c)
L: System size

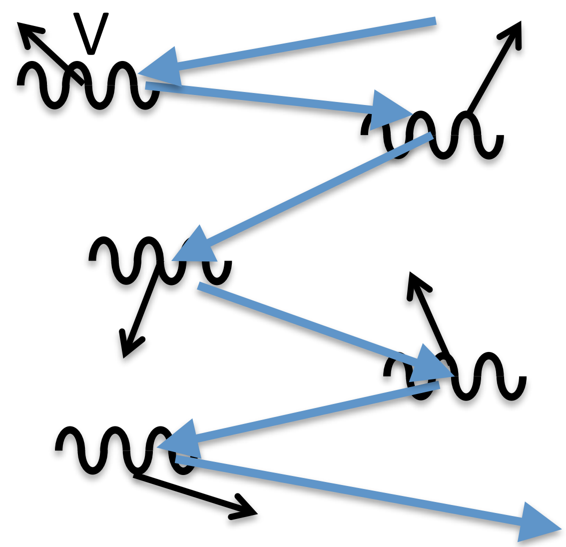
(βB: Electric field)

Candidates are limited among various celestial objects (magnetars, AGN, radio galaxy lobes, GRBs etc)

Acceleration mechanism



$\Delta E/E \sim V/c$

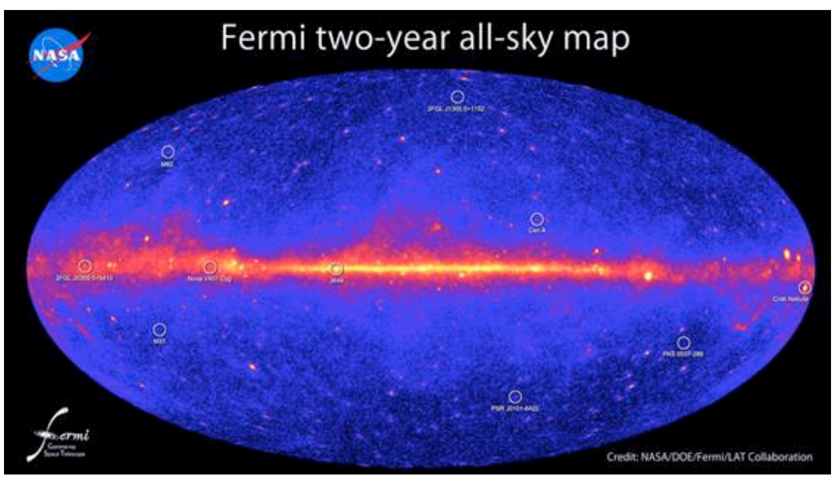


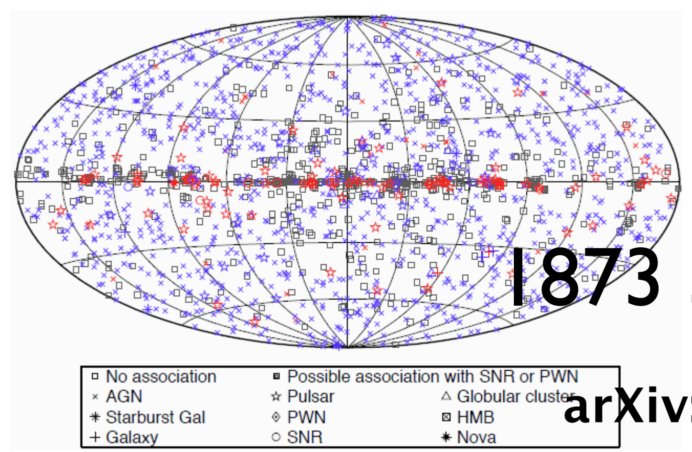
$\Delta E/E \sim (V/c)^2$

- Diffusive shock acceleration (1st order Fermi)
- Turbulent (i.e., randomly-moving magnetic cloud) acceleration (2nd order Fermi)
- So far, it was believed that Shock acceleration was the most promising mechanism and turbulent acceleration was not emphasized well due to its inefficiency (takes much time for particles to be accelerated)

Fermi Gamma-ray Space Telescope

- Launched on 2008 June 11
- Large Area Telescope (LAT): 20 MeV--300 GeV
- Gamma-ray Burst Monitor (GBM): 8 keV--30 MeV
- All-sky is scanned every 3 hours



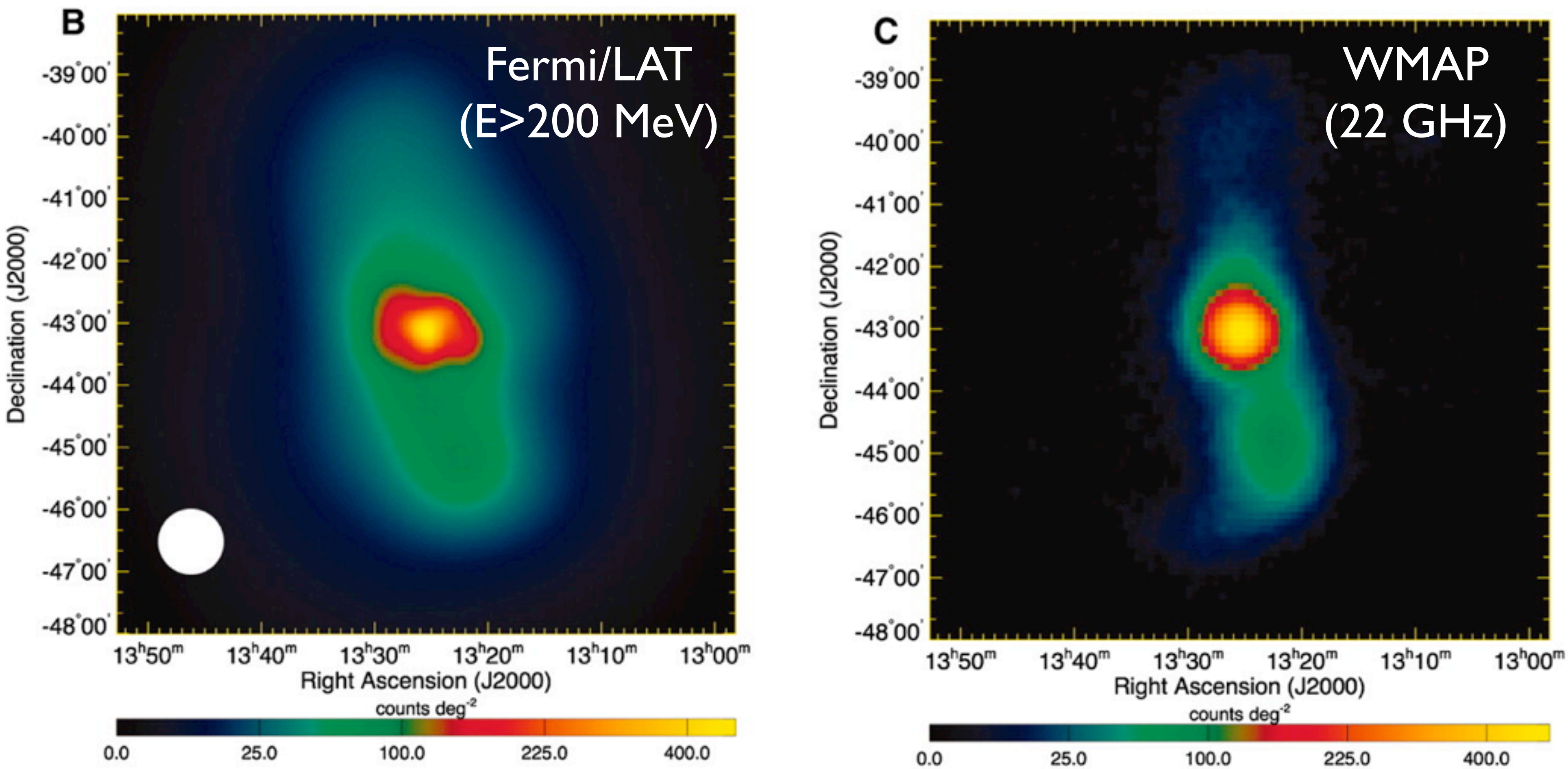


1873 sources

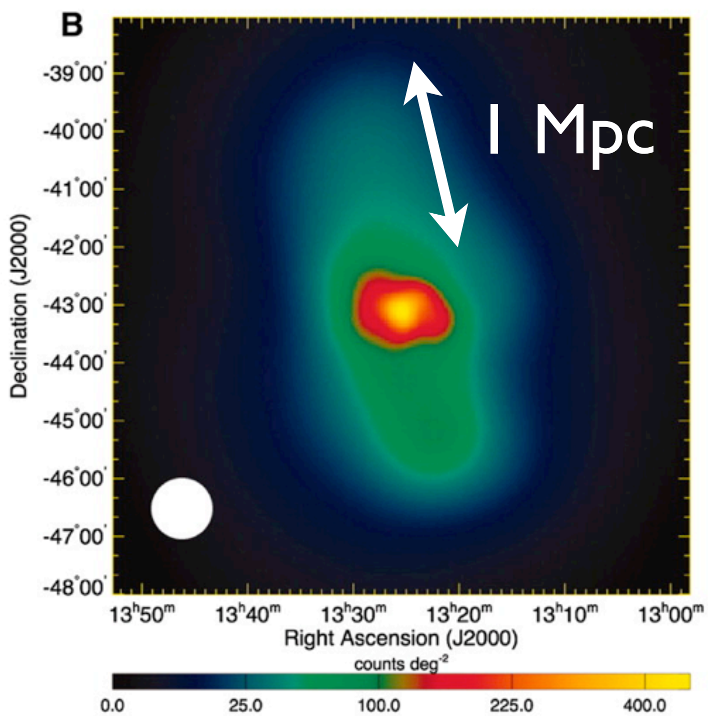
arXiv:1108.1435

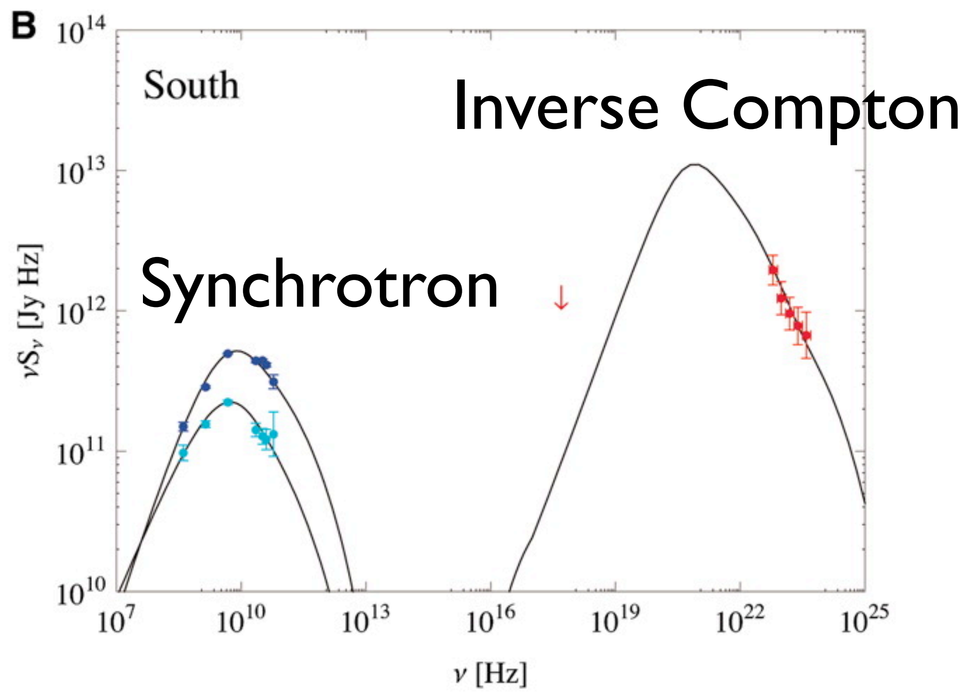
Gamma-ray lobes of Centaurus A

Abdo+10, Science



Turbulent acceleration probably works within the lobe



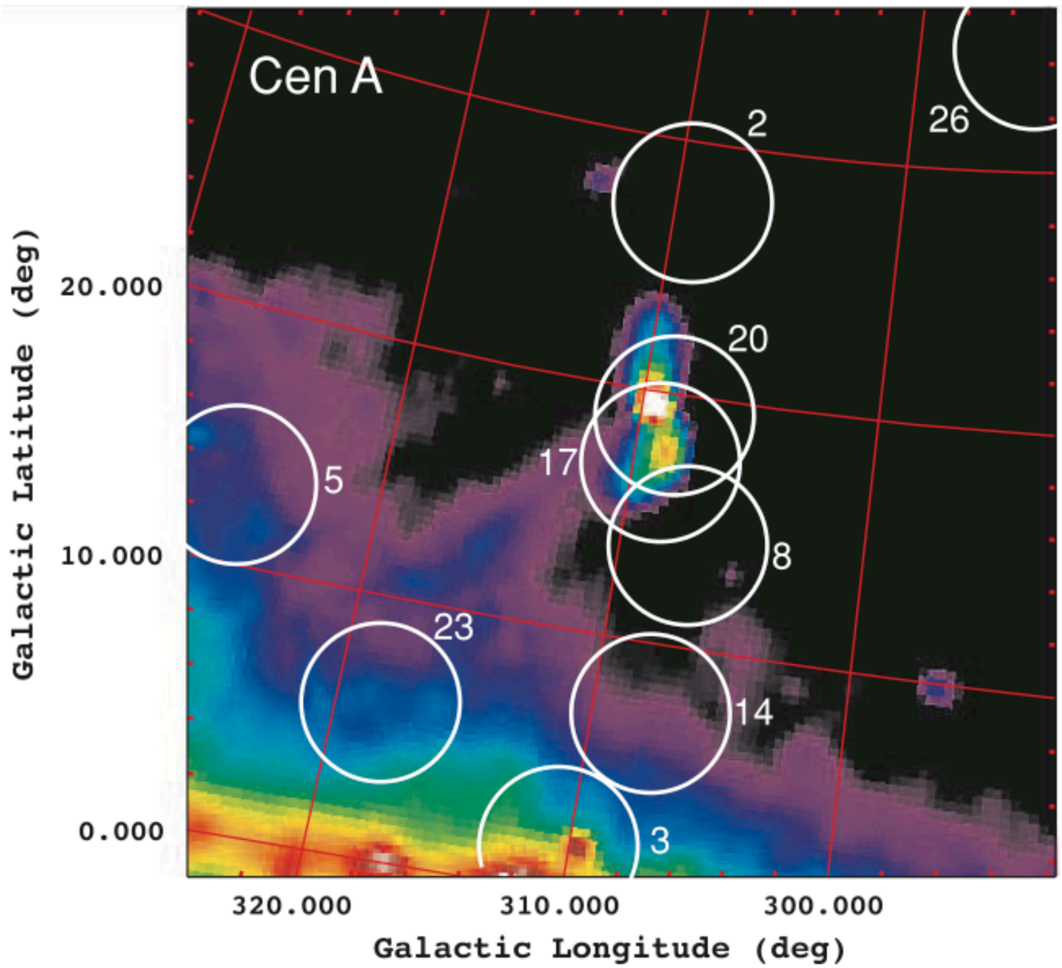


t_{cool} ~ 3×10^5 $(B/3\mu G)(\gamma/10^7)$ [yr] for TeV electrons

L/c~ 3×10^6 (L/1 Mpc) [yr]

Shocks are NOT seen within the lobe

Ultra High Energy Cosmic Rays

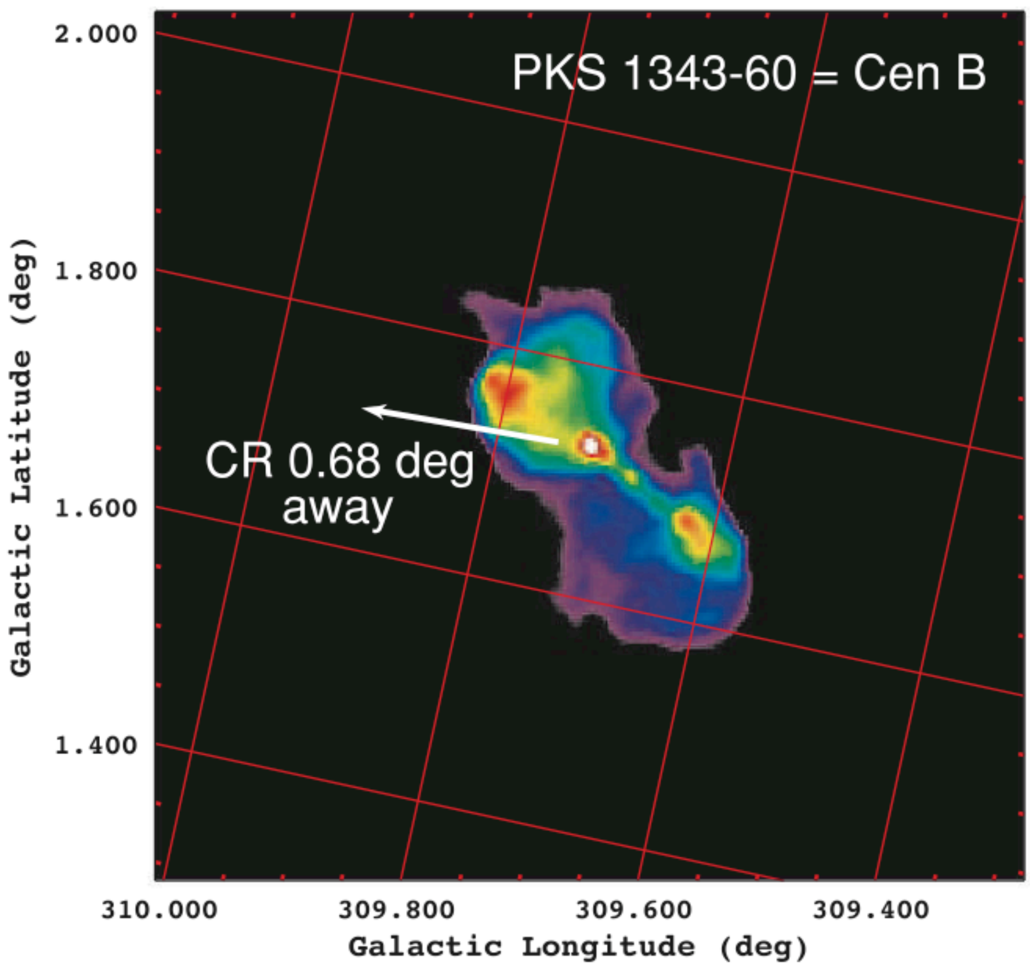


Pierre Auger Observatory detected 4 UHECR events from the direction of Cen A

Moskalenko+09

- UHECRs are produced within the radio lobe through turbulent acceleration?

UHECR events from the direction of Cen B



Centaurus B is a nearby radio-loud active galaxy (D=56 Mpc)

Pierre Auger Observatory detected 1 UHECR event from the direction of Cen B

Moskalenko+09

Fermi-LAT and Suzaku observations of Radio Galaxy Centaurus B

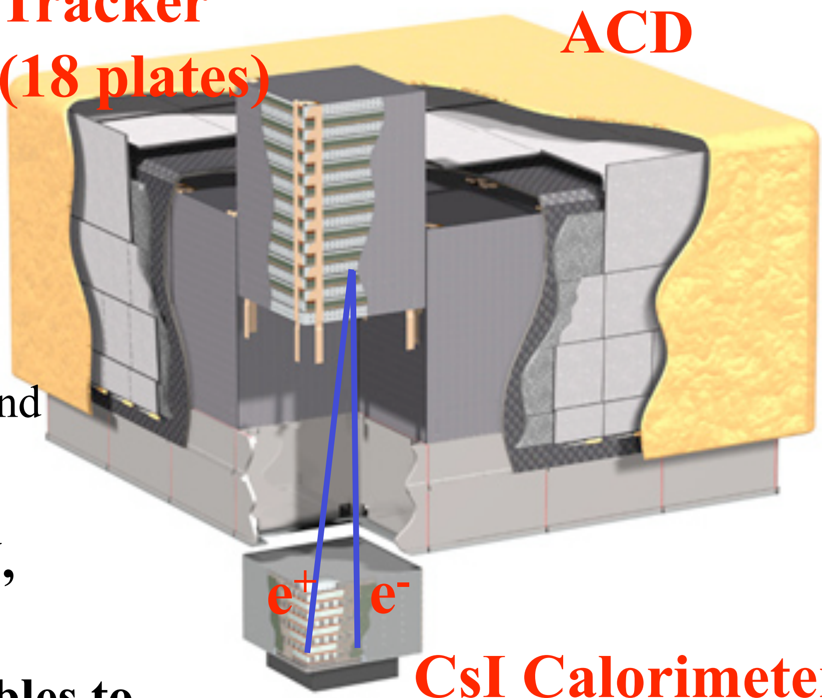
Large Area Telescope (LAT) onboard Fermi

Pair-conversion telescope

Si-strip Tracker with tungsten foil converter: Measure the photon direction

CsI Calorimeter: Measure the photon energy, Image the shower

ACD (Plastic scintillator): Reject charged-particle background

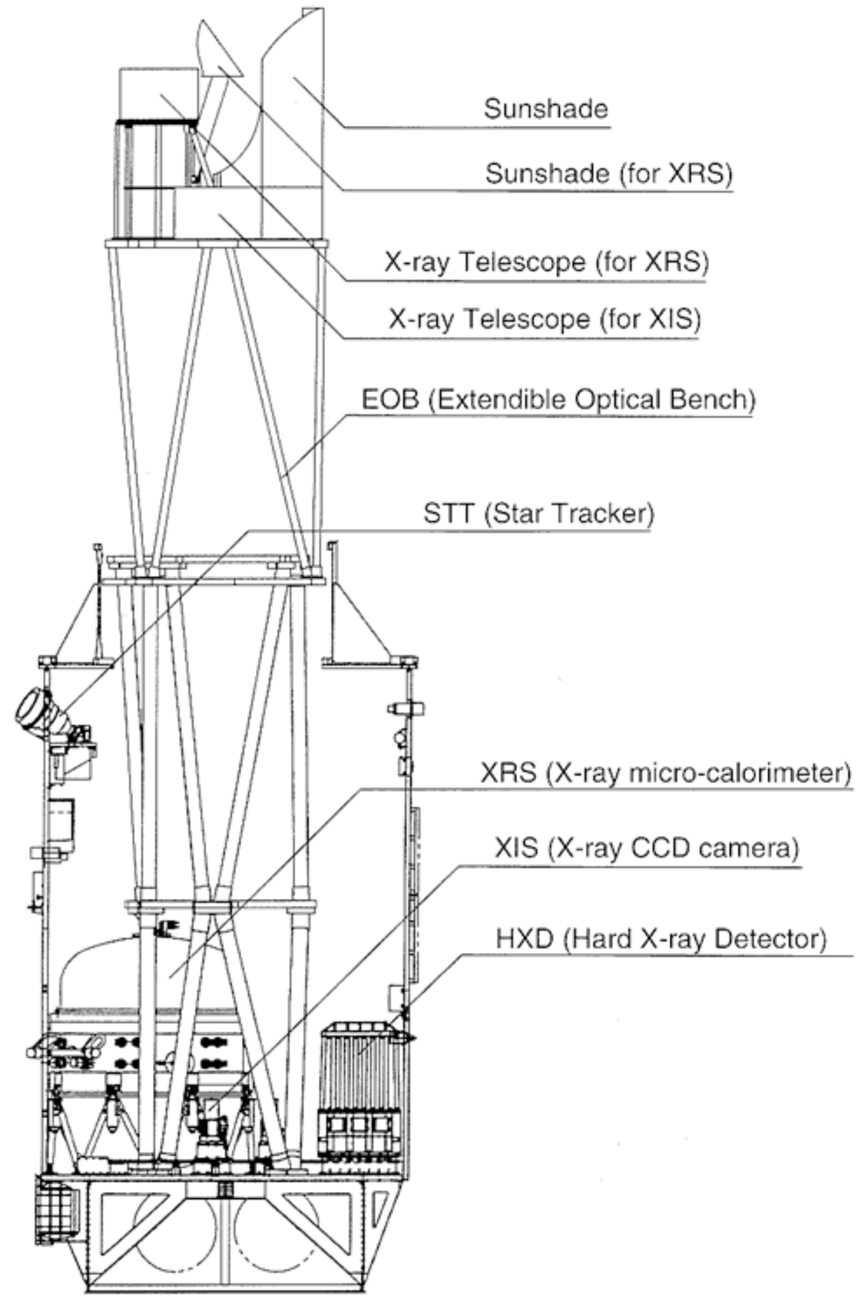


4 x 4 modular array
3000 kg, 650 W

- **Large effective area 8000 cm^2 @ 1 GeV, normal incidence)**
- **Large field-of-view (2.4 str), which enables to observe the entire sky every ~3 hours**
- **Energy range: 20 MeV – 300 GeV**
- **Angular resolution (68% contaminant radius): 0.6 deg @ 1 GeV**

3 slides regarding Fermi-LAT results are removed

Suzaku X-ray Observatory

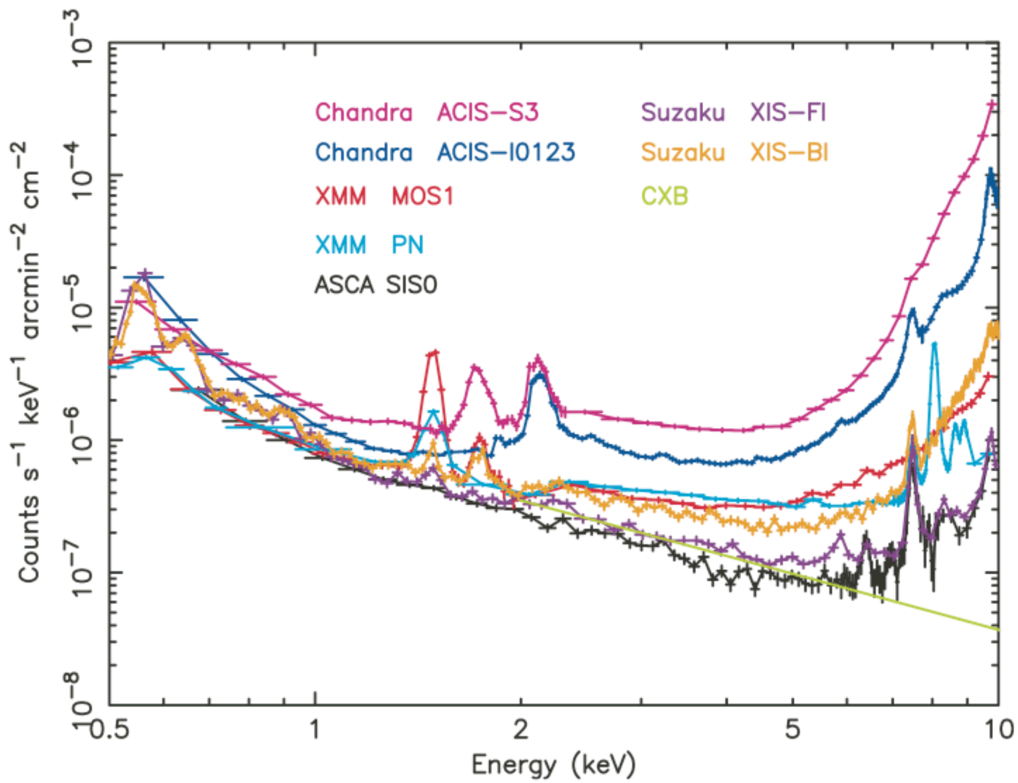


- Launched on 2005 July 10
- XRS (X-ray micro-calorimeter) was lost just after the launch
- XIS (3 CCDs) and HXD (hard X-ray detector, E>10 keV) are still working quite well without any severe problems

XIS is the best instrument for extended sources

XRT

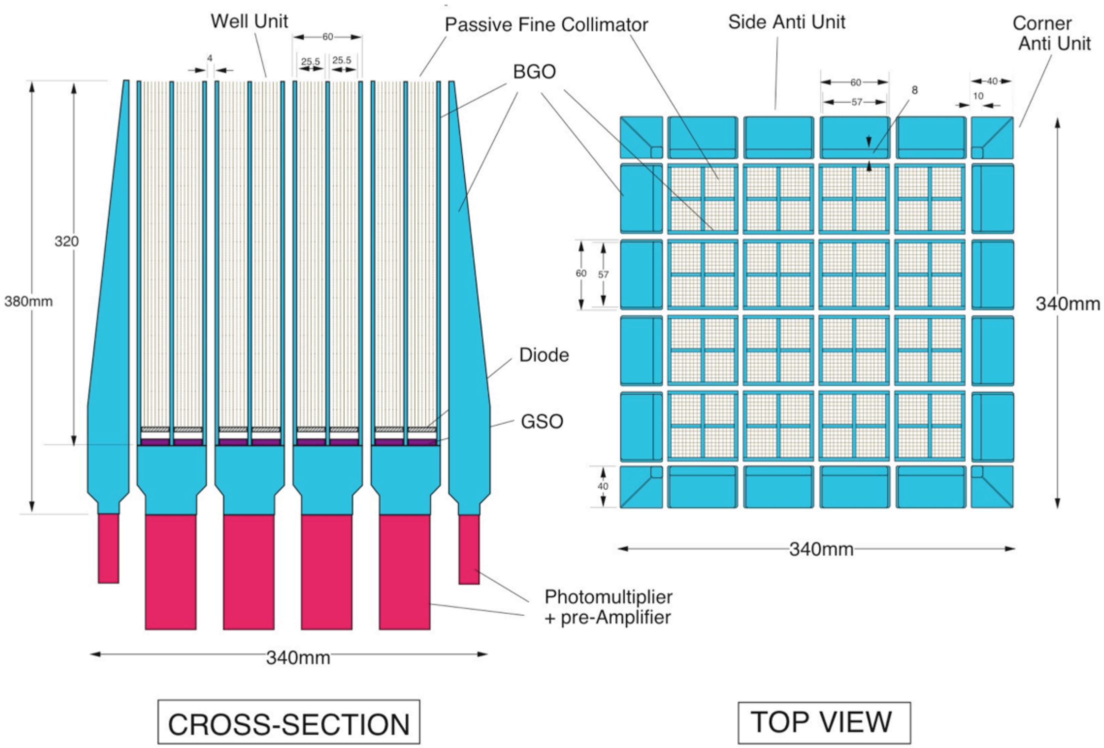
XIS

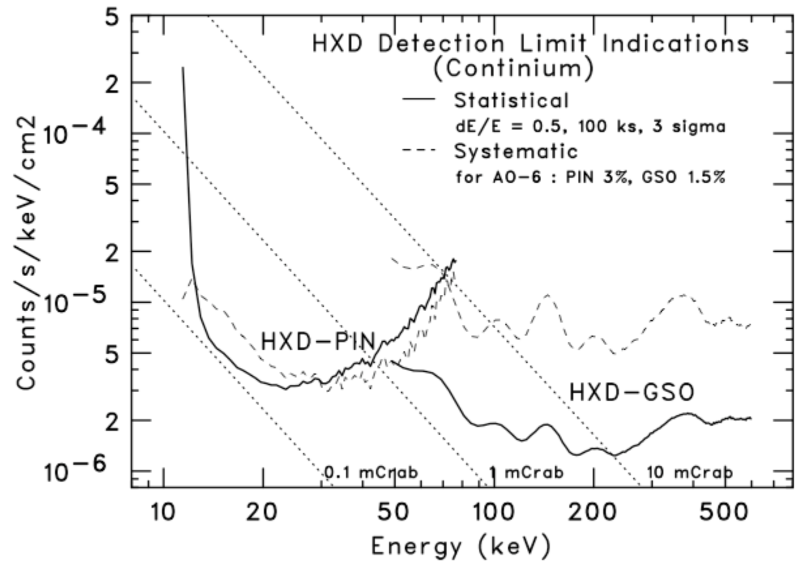


Mitsuda+07

- 3 FI CCDs and 1 BI CCD, but 1 FI CCD was lost
- Low Earth orbit: Steady and low background
- PSF is relatively large (~2’ HPD)

Wide-band spectroscopy with XIS+HXD

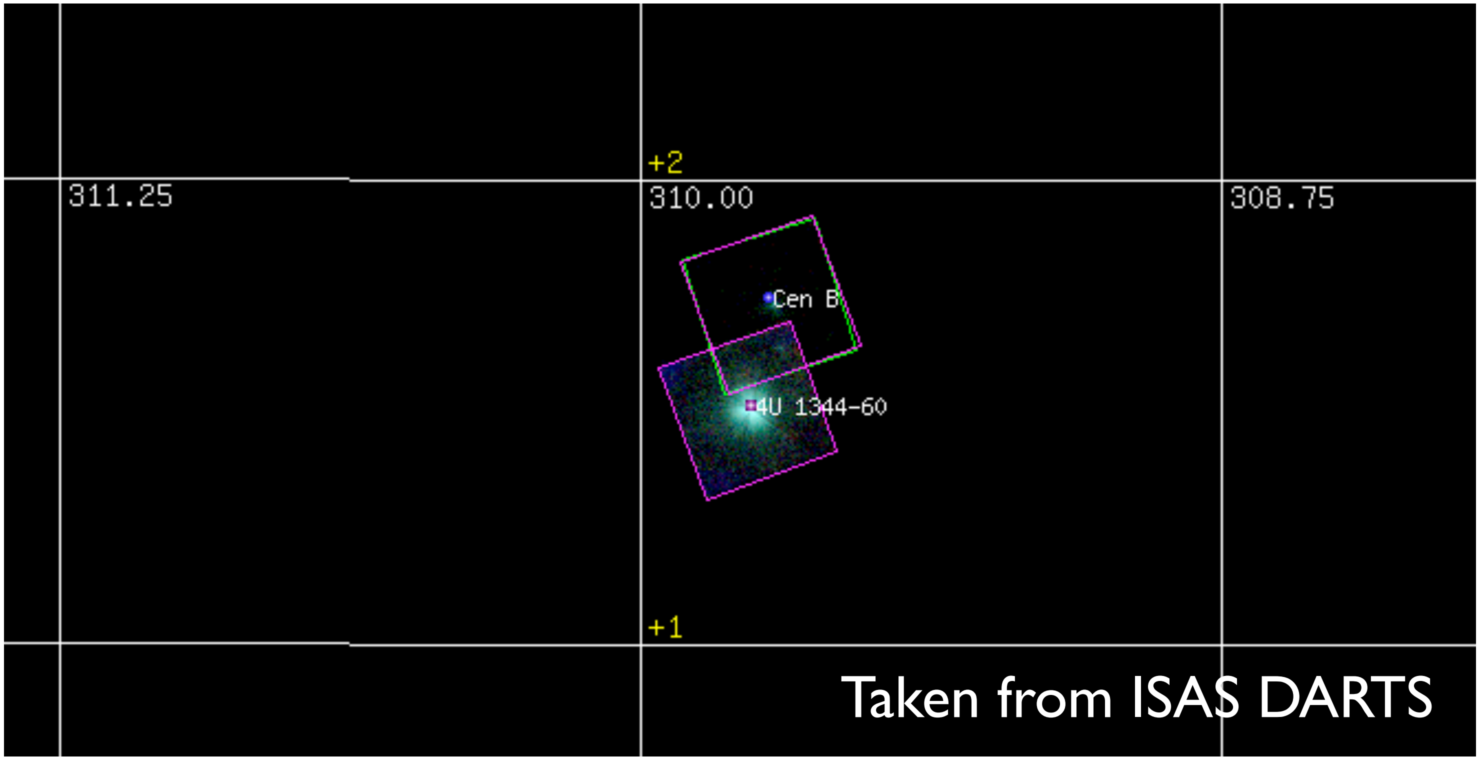




See Suzaku Technical Description

- Non-imaging instrument. Should be careful for confusion.
- HXD consists of PIN (Silicon diode, 10 keV< E<~50 keV) and GSO (scintillator, E>~50 keV)
- Detection limit is ~1mCrab (~2×10^{-11} erg/cm^2/s, 10-50 keV)

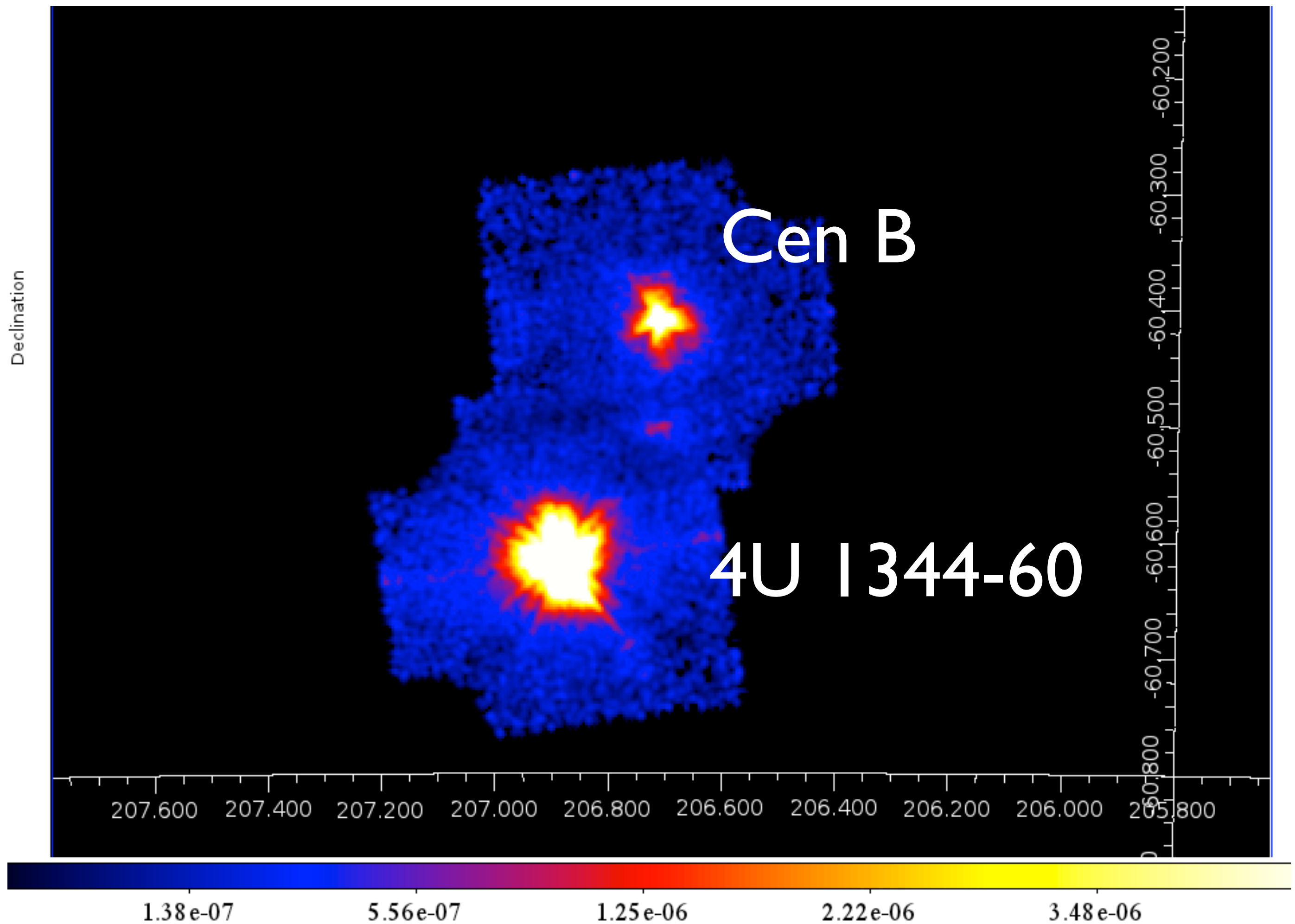
Suzaku/XIS observation



Name	Observation ID	Start time (UT)	End time (UT)	Net Exposure† (ks)
Centaurus B	806017010	2011 Jul 16 20:15:14	2011 Jul 18 11:50:13	93.6
4U 1344−60	705058010	2011 Jan 11 19:01:05	2011 Jan 14 11:24:11	93.9

† After the event screenings.

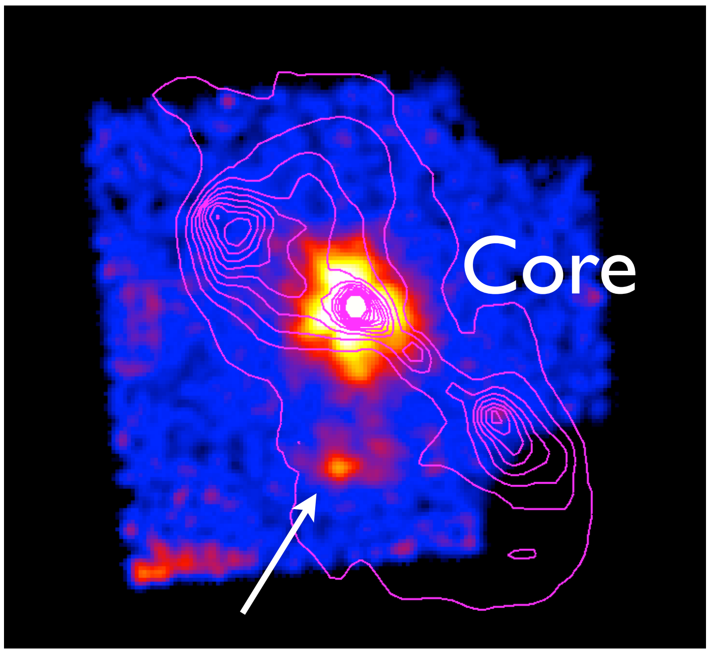
Suzaku/XIS0+3 image
(2-10 keV, exposure and vignetting corrected)



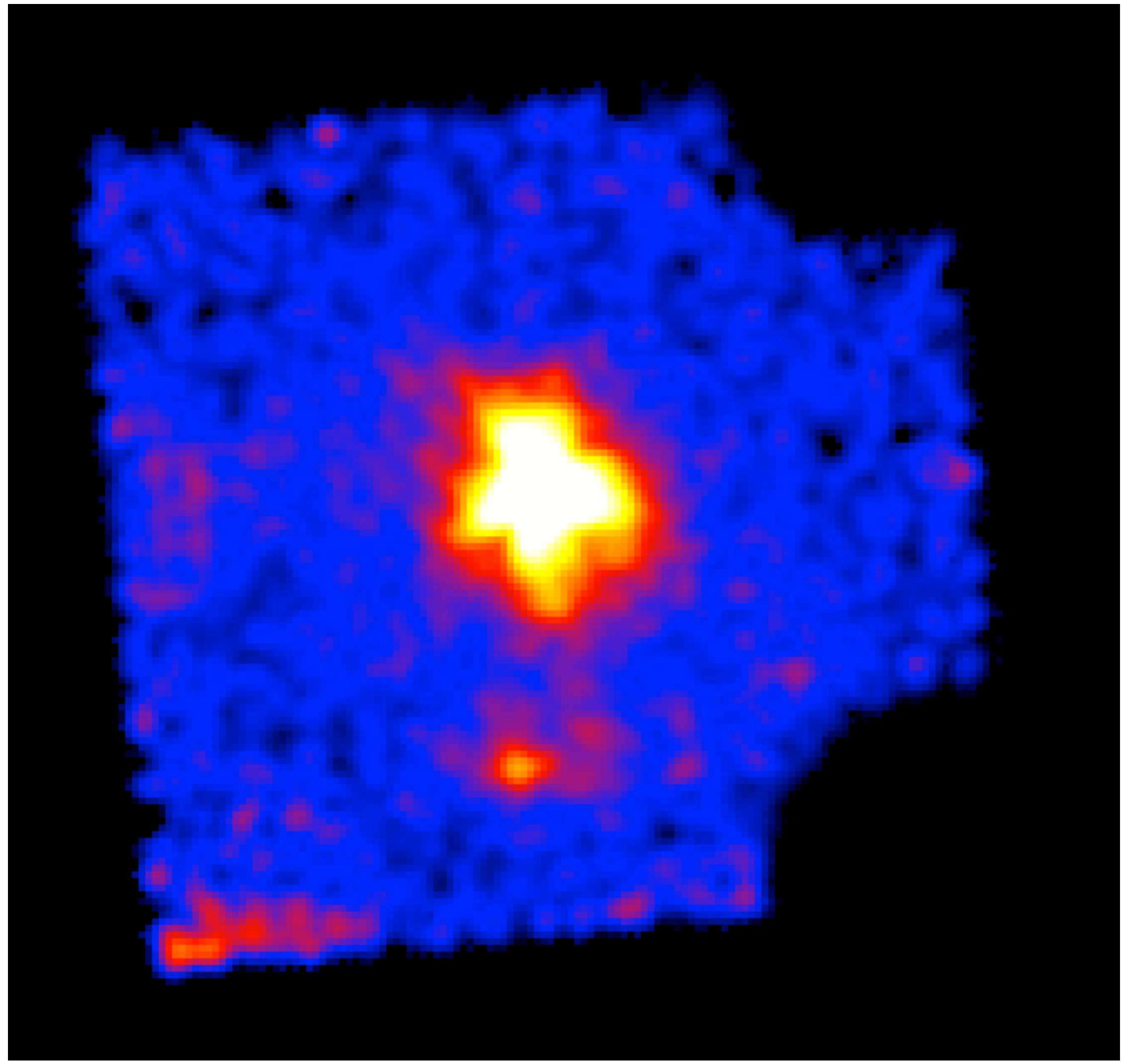
XIS1 data were not used, because CI was changed to 6 keV since 2011 June 1, and current standard ftool (xisnxbgen) does not does well reproduce the NXB level (especially critical for dim diffuse analysis)

Suzaku/XIS0+3 image

(2-10 keV, exposure and vignetting corrected)



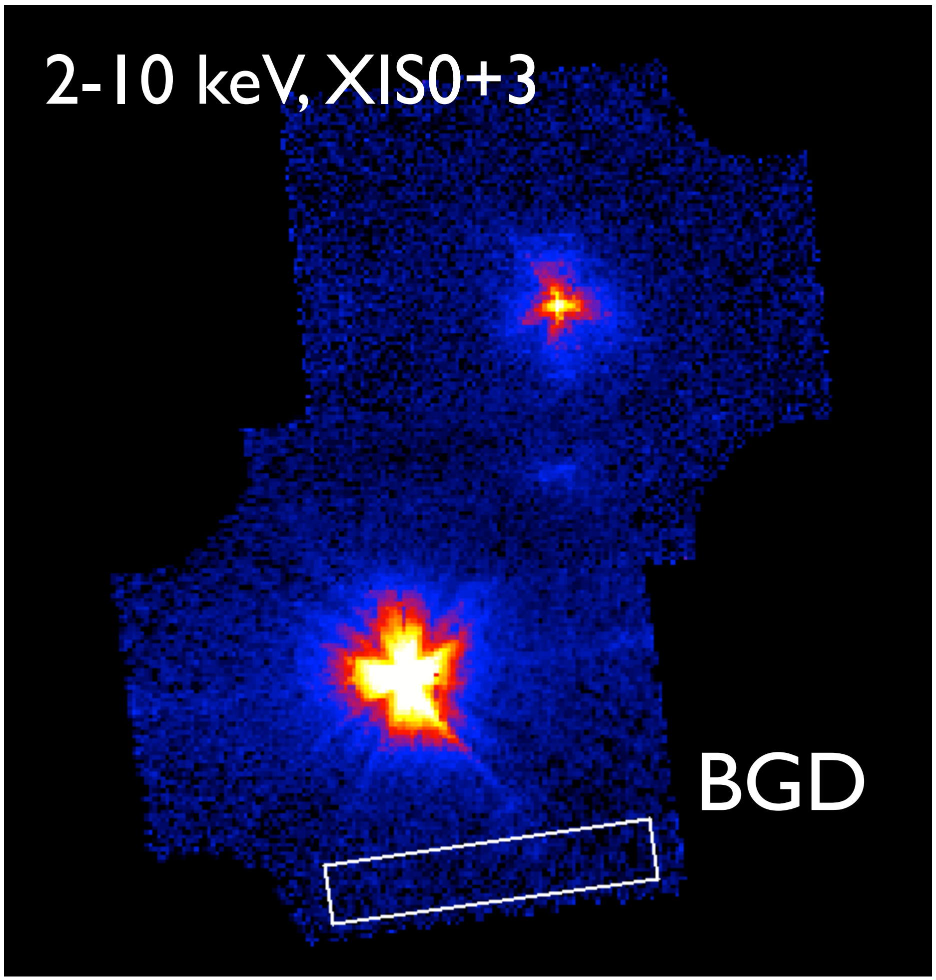
unrelated source



No extended lobe feature is present

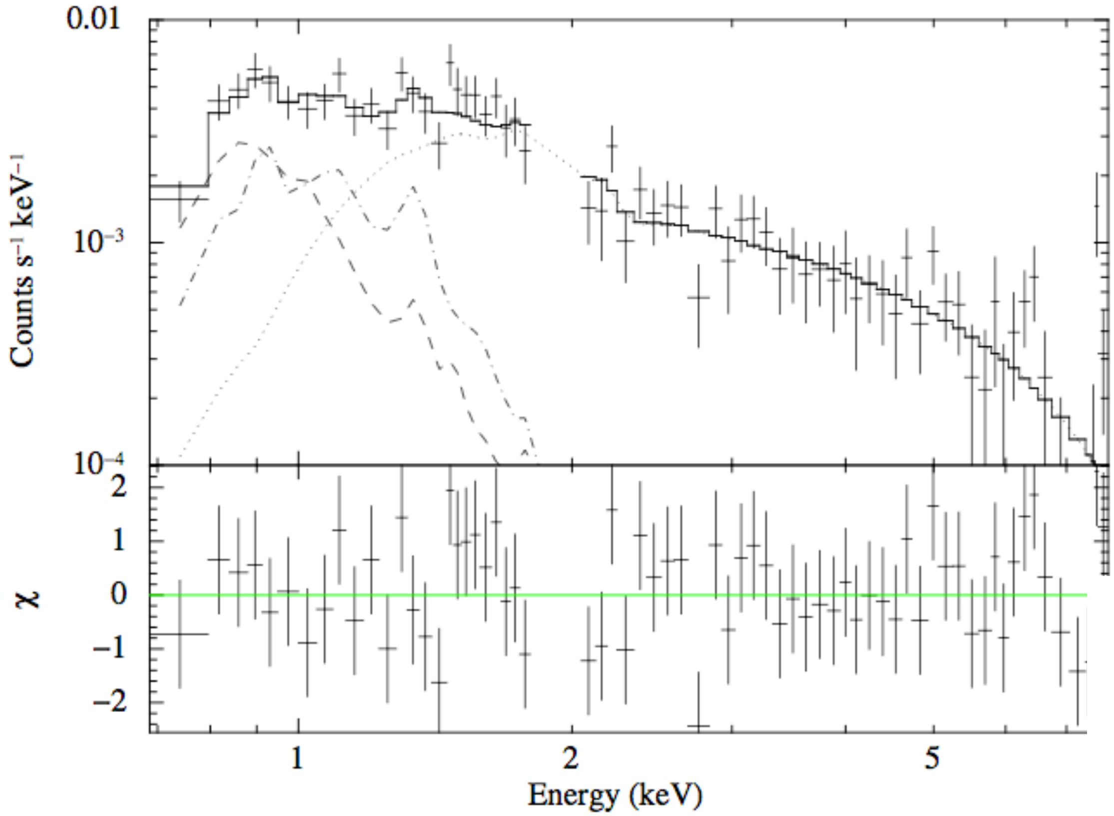
Spectral analysis of X-ray BGD

Spectral parameters of X-ray background around CenB region is determined from blank sky data



- Non X-ray background was obtained by "xisnxbgen" (night Earth data)
- Contaminant of 4U 1344-60 was estimated by "xissim"

Derived parameters

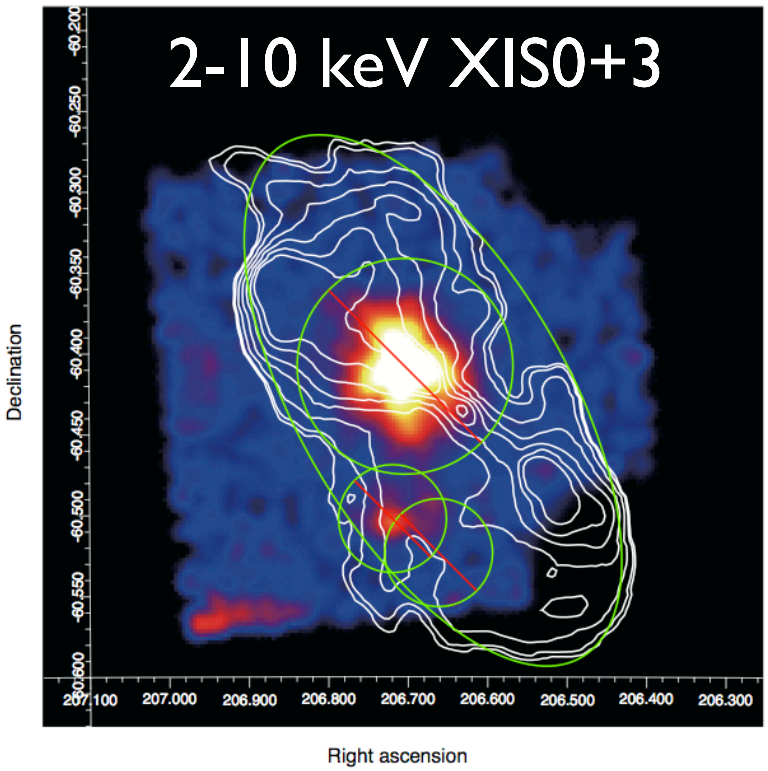


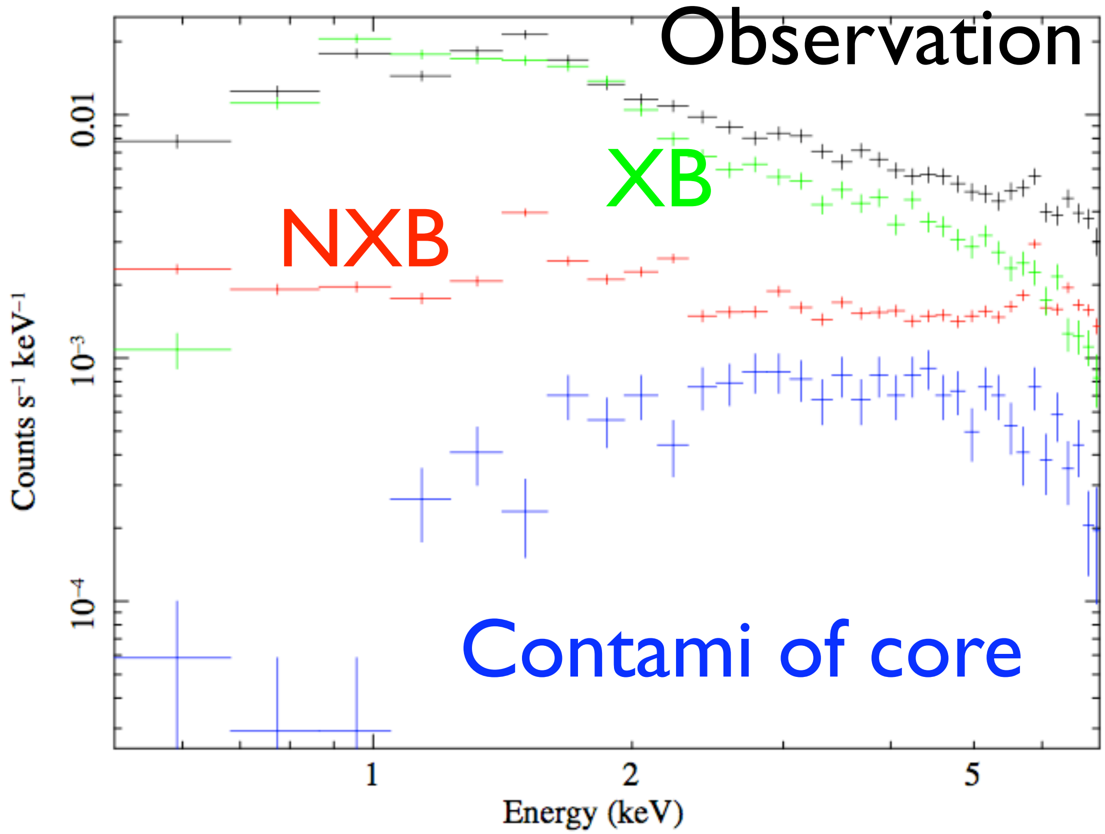
mekal+wabs*(mekal*pow)

Component	Parameter	Value
Local Hot Bubble	kT [keV]	$0.61^{+0.09}_{-0.16}$
	Z	1.0 (fixed)
	Normalization	$(7.0 \pm 3.3) \times 10^{-4}$
	N_{H} [$\times 10^{22}$ cm^{-2}]	1.06 (fixed)
Galactic halo	kT (keV)	$0.17^{+0.09}_{-0.06}$
	Z	1.0 (fixed)
	Normalization	$0.26^{+3.38}_{-0.24}$
CXB	Γ_{X}	$2.22^{+0.23}_{-0.22}$
	Normalization	$(6.6^{+1.8}_{-1.5}) \times 10^{-3}$
	$\chi^2_\nu(\chi^2/d.o.f)$	1.02 (63.41/62)

X-ray background consists of 3 components: Local Hot Bubble, Galactic halo, and Cosmic X-ray background (e.g., Yuasa+07)

X-ray upper limit of radio lobe

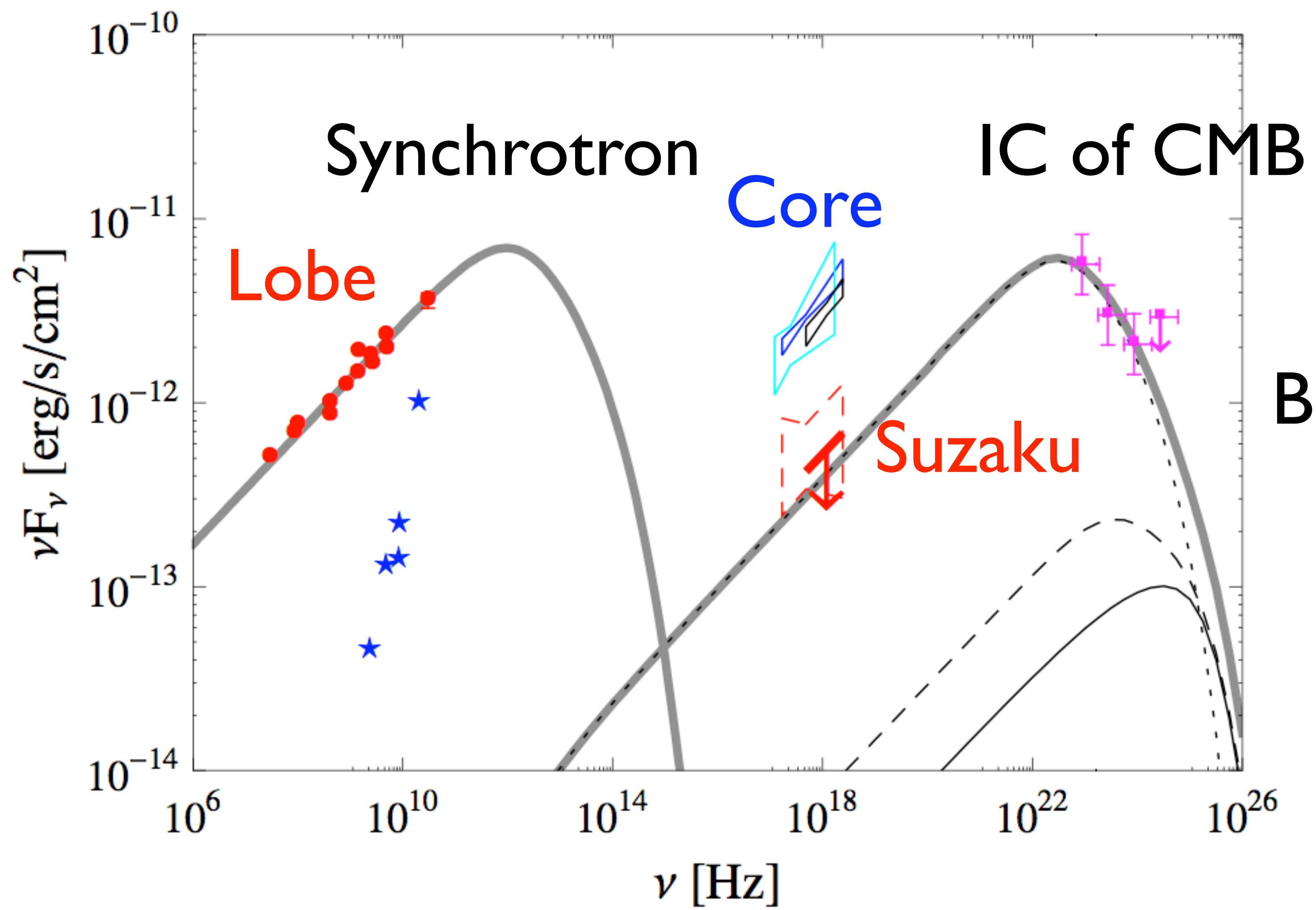




90% CL UL of total lobe flux=8.7x10^{-13} erg/cm^2/s

(2-10 keV, assumed power-law of Γ=1.7)

Broadband SED and modeling

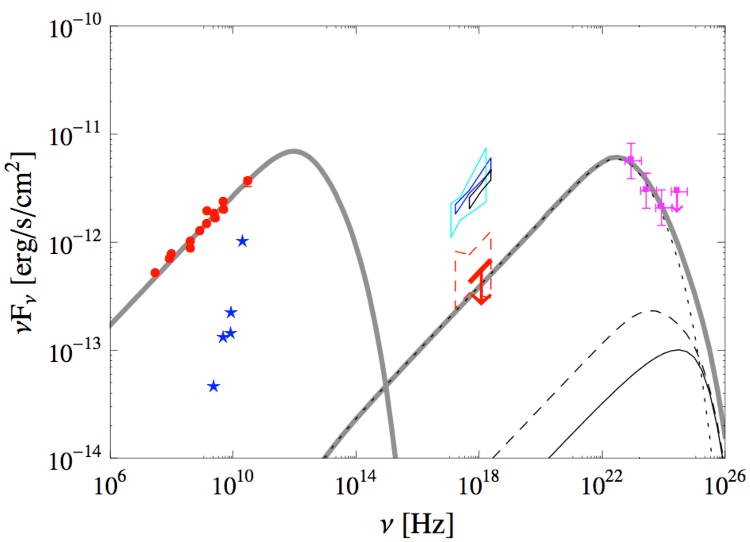


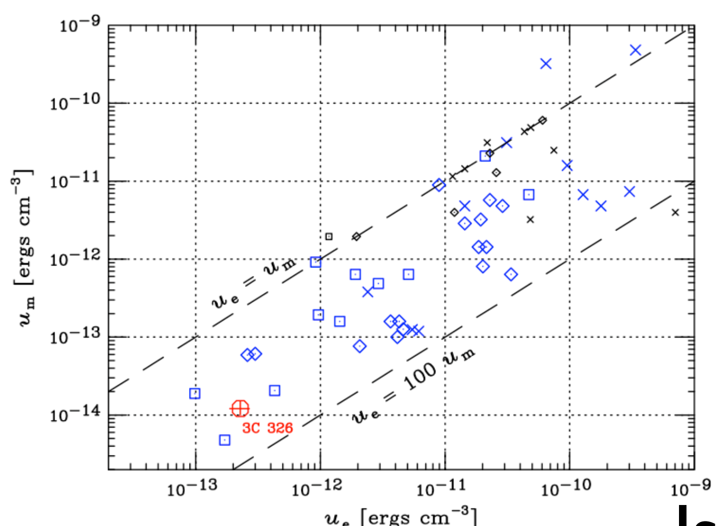
B=3.5 uG

- SED modeling suggest that gamma-rays would come from lobe
- More stringent UL disentangles the gamma-ray emission region

Future plan

- Deep X-ray observation with XMM-Newton might provide more stringent UL
- Determine the origin of gamma-rays, core or lobe?
- Magnetic-field dominated lobe? (very rare)
- So, we are now planning a long XMM proposal (say, 300 ksec)



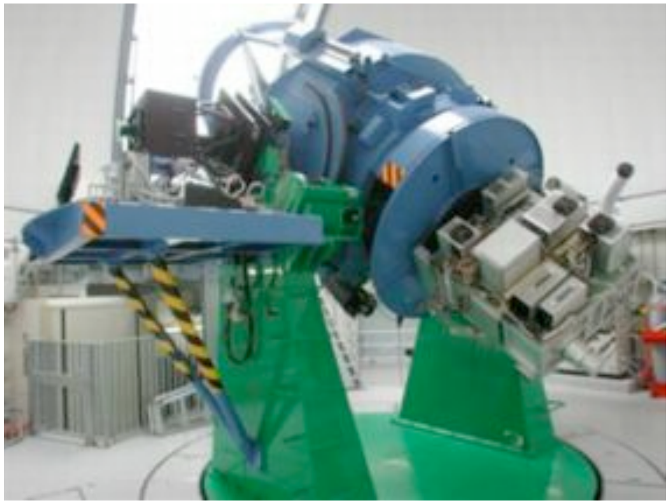


Isobe+09

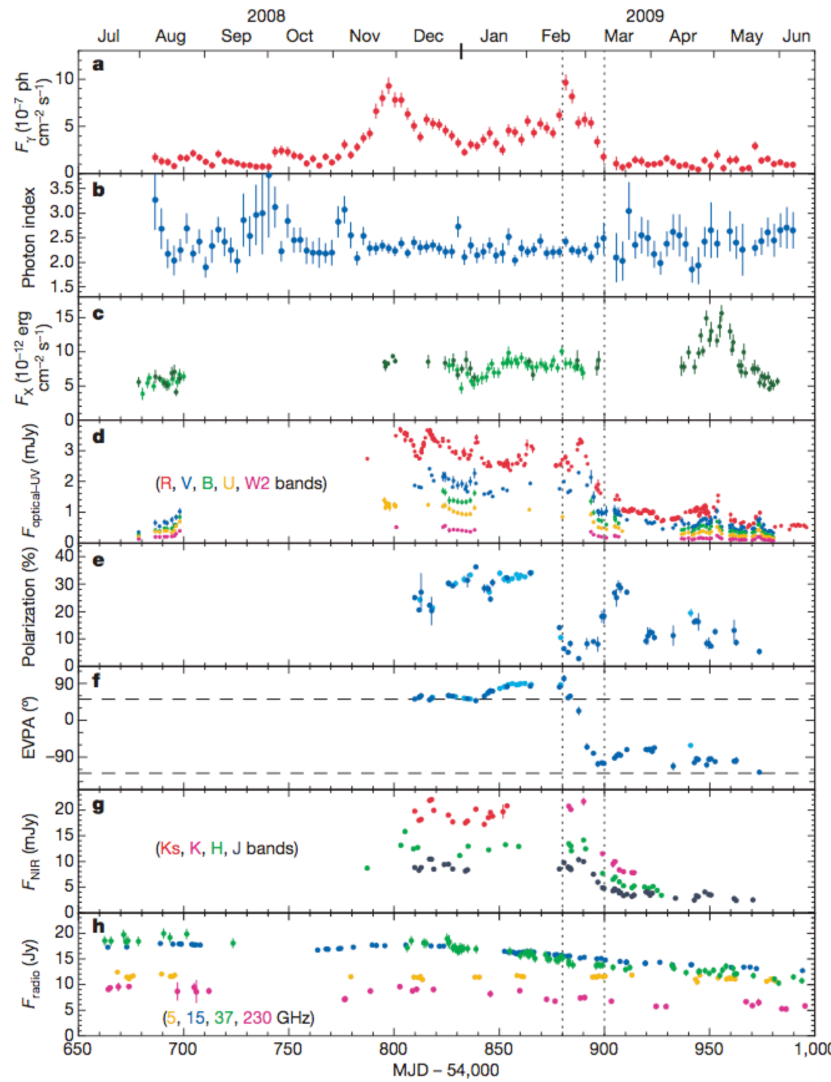
Summary

- Fermi-LAT detected HE gamma-ray emission from Cen B
- Suzaku/XIS did not detect extended X-ray emission from radio lobe
- SED modeling suggest that gamma-rays would be produced by radio lobe
- More stringent UL or detection of the lobe will provide robust information of the gamma-ray emission site

Kanata Telescope



- Operated by Hiroshima Univ.
- Diameter=1.5 m, Optical/IR
- Quick follow-up of transient objects such as GRB, Blazar flare, Supernova etc
- Polarization measurement (Abdo+10)



Abdo+10, Nature