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Fast X-ray variability of radio galaxy M87

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X-ray and TeV gamma-ray emission of M87

M87 is a nearby FR-I radio galaxy at redshift z = 0.0043 (~16 Mpc) [1].
Its jet components have been resolved through radio, optical, and X-ray observations.

TeV gamma-ray emission from M87 was found by H.E.S.S.[2] and MAGIC[3].
Aharonian et al. (2006) suggested that intraday TeV gamma-ray variability was due to particle acceleration at HST-1. Later X-ray and TeV observations[2] suggested that TeV emission from the core was, thus it is still under debate for location of the particle acceleration.

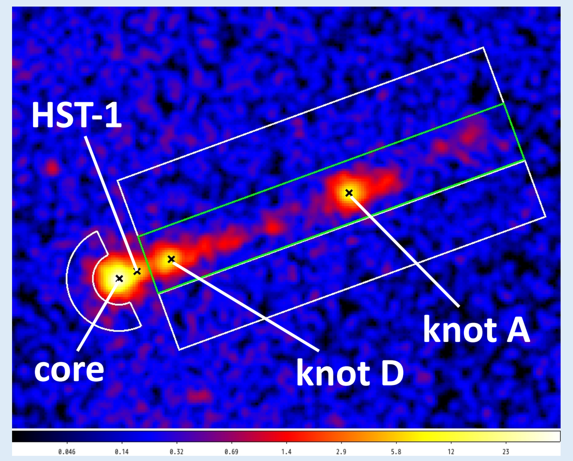

Figure 1. M87 image obtained via Chandra-ACIS (2019-3-27). Crosses in the figure show positions of core, HST-1, knot D and knot A from the left.

We searched for a fast X-ray variability from archival X-ray data to study the location of particle acceleration up to TeV.
There is much archival data in X-ray long exposure observations (Chandra: 15, NuSTAR: 6, Suzaku: 1), we performed lightcurve and spectral analysis as below.

Observation and Analysis

■ *Suzaku*

We used X-ray Imaging Spectrometer (XIS) detectors onboard the Suzaku, consisting of three available CCDs (XIS0−3) in this observation.
We performed lightcurve analysis by `lcurve` tool, and spectral analysis in 2.0−10.0 keV with two temparature thermal models with Galactic absorption model: `wabs*(pegpwrlw+vapec+vapec)` in `Xspec(HeaSoft v6.28)`. Parameters for thermal models were fixed, but photon index and normalization were set to free.

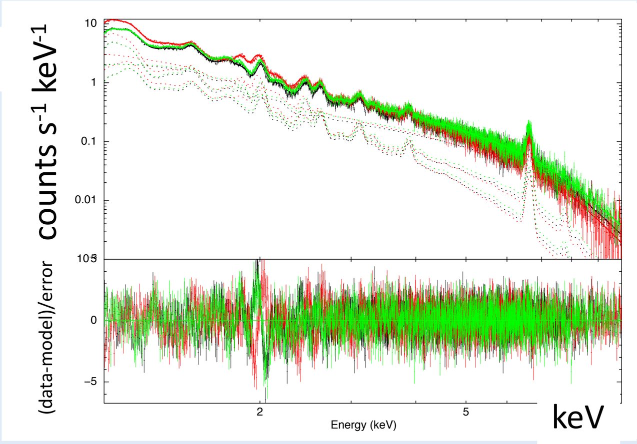

Figure 2. Spectral fitting of Suzaku XIS spectra on November 29th, 2006. Black, red, and green correspond to XIS0,1,3, respectively.

■ *Chandra and NuSTAR*

NuSTAR has two hard X-ray telescopes, Focal Plane Module-A, B (FPMA, FPMB).
Chandra has a Advanced CCD Imaging Spectrometer (ACIS) and High Resolution Camera (HRC).
We analyzed lightcurves in each instruments, and also analyzed spectra, joint with telescopes of NuSTAR and ACIS (separated region for the core, HST-1, and jet) in 2.0−10.0 keV, using same models to Suzaku, but parameters for thermal models were fixed which obtained by ACIS.

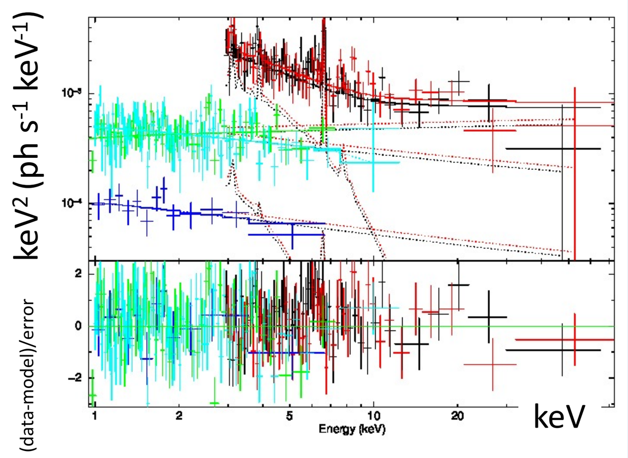

Figure 3. NuSTAR and Chandra spectra on March 28th, 2019. Black/red, green, blue, and cyan correspond to NuSTAR FPMA/FPMB, core, HST-1, jet, respectively.

Result

■ Lightcurve

We found X-ray intraday variability from the lightcurve in 2006 (Suzaku) and 2017 (Chandra) in the core. Decay amplitude are 30% and 40% in 2006 and 2017, respectively. Background fluctuations are small enough. We calculated Root Mean Square (RMS) value to evaluate the variability as below[4].

$$\mathrm{RMS} = \sqrt{\frac{\sum_i[(d_i-\bar{d})^2-e_i^2]}{N\bar{d}^2}}$$

(d_i: countrate of i-th data, N: number of data point, $\bar{d}$: avegage of d_i, e_i: statistical error.)

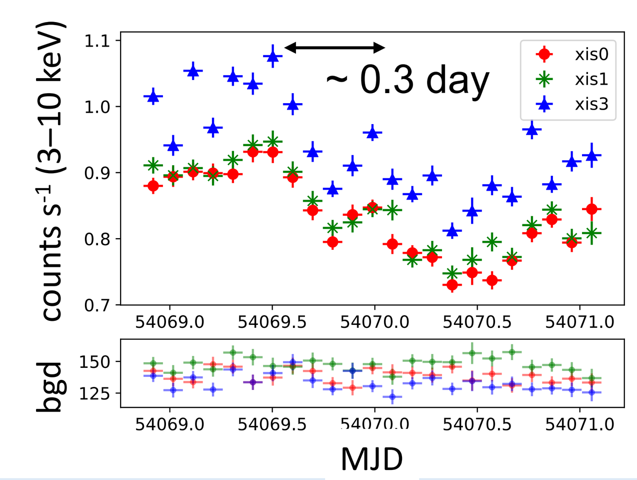

Figure 4. Light curve of M87 taken by Suzaku in 2006. Red, green, blue points shows XIS-0, XIS-1, XIS-3, respectively.

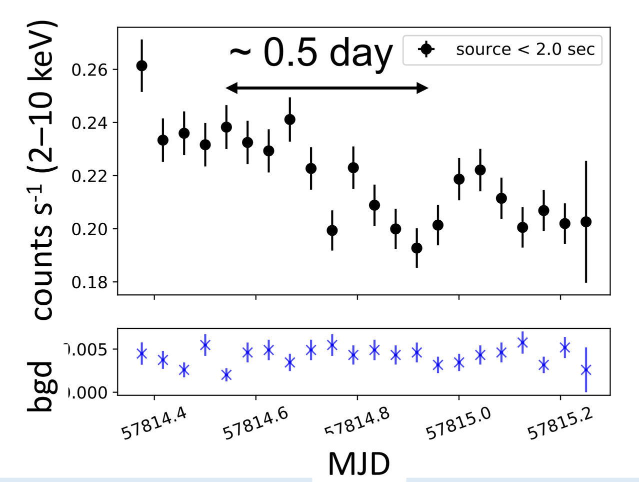

Figure 5. Light curve of M87 core taken by Chandra in 2017.

■ Spectrum

The X-ray spectrum of M87 in 2006 was steep, but it was hard in the core observation in 2017. These different photon index behavior suggest different emission processes, that is, synchrotron radiation and inverse Compton in 2006 and 2017, respectively.

Table 1. RMS and photon index values in 2006 and 2017

	2006 (Suzaku)	2017 (Chandra, core)
RMS	**0.071 ± 0.007 (XIS0)**	**0.07 ± 0.01**
Photon index (2.0−10.0 keV)	$\mathbf{2.38^{+0.07}_{-0.04}}$	$\mathbf{1.96^{+0.05}_{-0.04}}$

Discussion

■ **emission region size:** We assumed the decay time scale about 0.3 day, and its light crossing time indicates **compact emission region order to Schwartzchild radius.**

■ **magnetic field strength:** Assuming to that X-ray decay was due to electron cooling, we could estimate a magnetic field energy as,

$$\tau_s = 3.2\times10^4\times \boldsymbol{B}^{-3/2}\times E_{ph}^{-1/2}\times\delta^{-1/2}\ \mathrm{(s)}$$

(τ_s: synchrotron cooling timescale, B: magnetic field strength, E_{ph}: photon energy in observer frame, δ: doppler factor) [5]

Here, we assumed τ_s = 0.3 day and E_{ph} = 6500 eV from our results. As a result, ***B* assumed 1.94 $\delta^{1/3}$ mG.**

■ **electron energy:** Moreover, from this magnetic field, we estimated **typical electron energy *E* .**

$$\boldsymbol{E} = (B_{cr}/B)\,\gamma^{-1}E_{ph}$$

(B_{cr}: critical magnetic field, γ: Lorentz factor, others are same to above.) [6] **~ $10^8\ \gamma^{-1}\ \delta^{-1/3}$ TeV.**

Suzaku/XIS cannot resolve core and HST-1, but this period known as HST-1 huge flaring period[7] (HST-1 about 4.5 times brighter than the core), and thus it is reasonable to think that the observed X-ray variability is occured in HST-1.
From the above discussion, we estimated that **particle acceleration up to TeV could occur in HST-1.**

Summary

- We found X-ray intraday variability from Suzaku observation in 2006 and Chandra core observation in 2017.
- The X-ray spectrum in 2006 was steep (Γ= $2.38^{+0.07}_{-0.04}$), but the core in 2017 was hard (Γ=$1.96^{+0.05}_{-0.04}$).
- From lightcurve and spectrum in 2006, magnetic field strength assumed to 1.94 $\delta^{1/3}$ mG and it indicates particle acceleration up to TeV in HST-1.

References

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