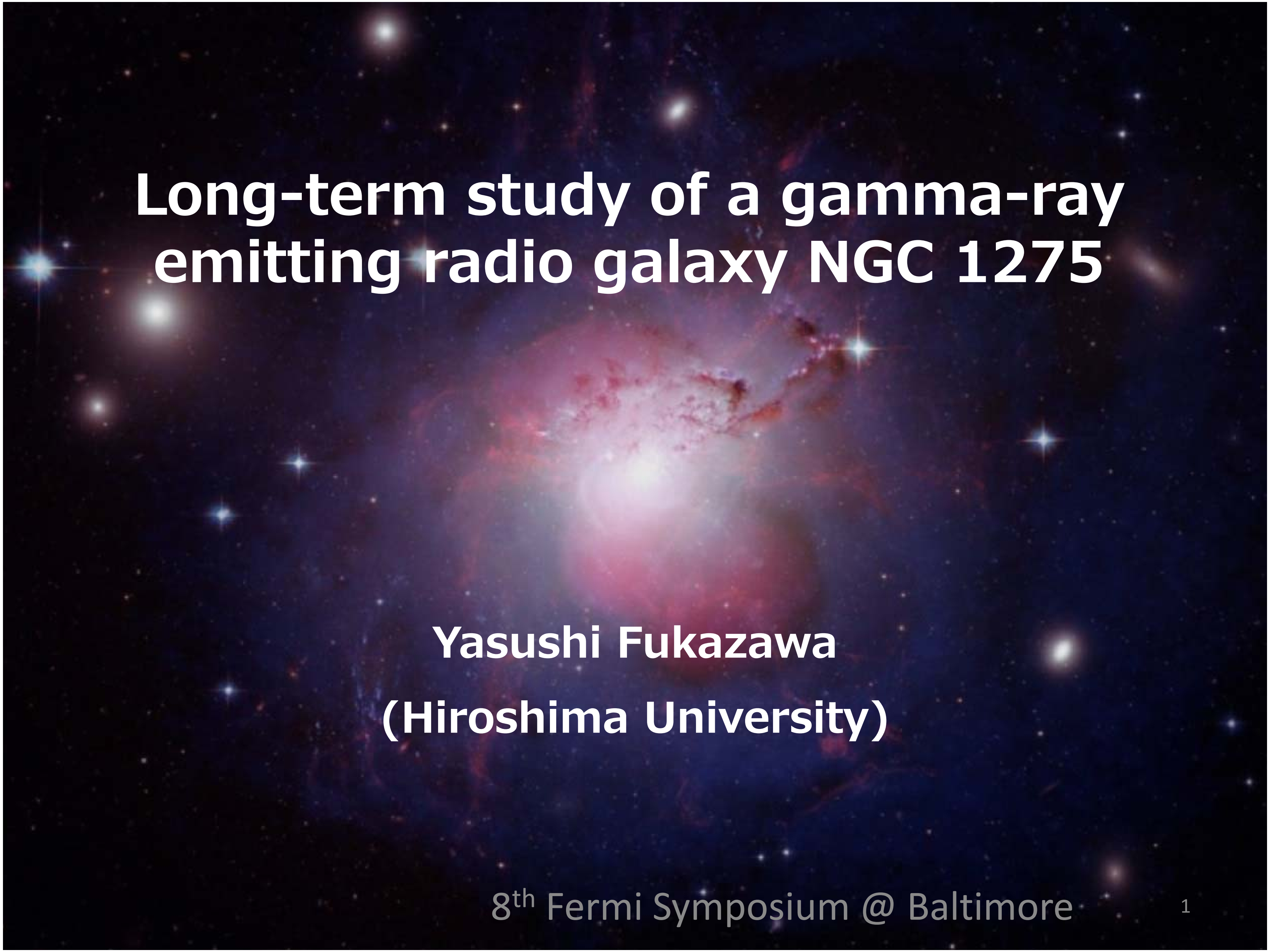
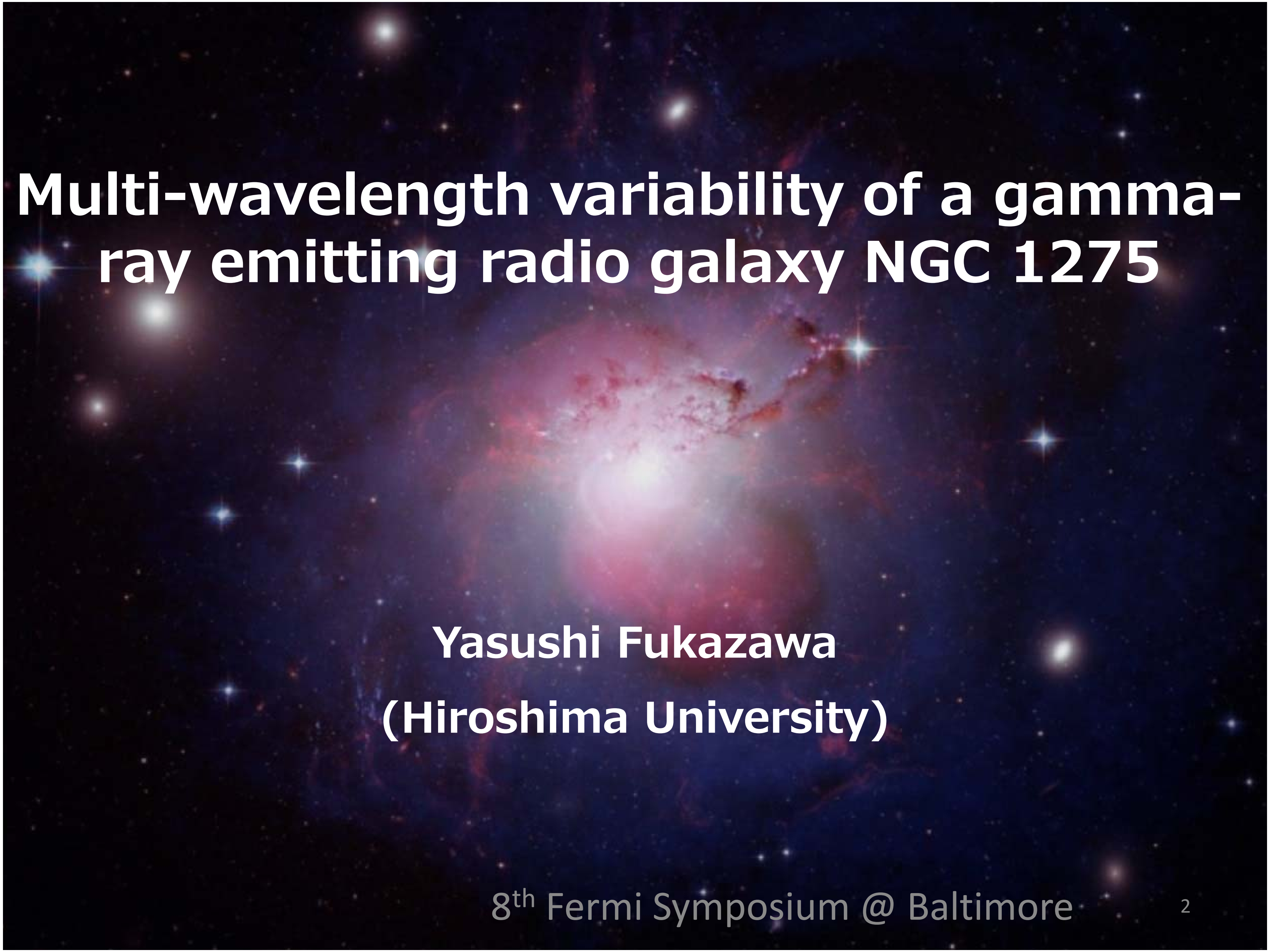


Long-term study of a gamma-ray emitting radio galaxy NGC 1275

Yasushi Fukazawa

(Hiroshima University)

8^{th} Fermi Symposium @ Baltimore



Multi-wavelength variability of a gamma-ray emitting radio galaxy NGC 1275

Yasushi Fukazawa

(Hiroshima University)

Outline

Introduction
GeV/gamma-ray and TeV studies
Radio and gamma-ray connection
X-ray and gamma-ray connection
Optical/UV and gamma-ray connection
Summary and future prospective

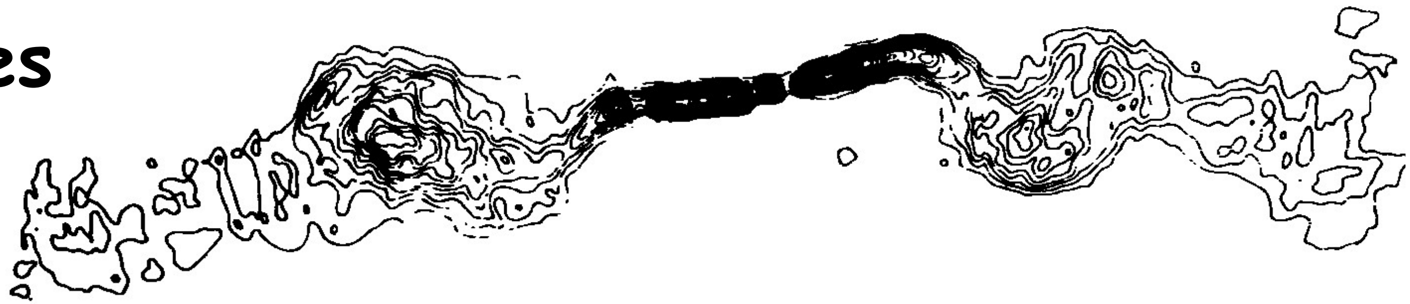
Papers on NGC 1275 X-ray/gamma-ray studies in 2015-2018

Nustar view of the central region of the Perseus cluster; Rani+18
Gamma-ray flaring activity of NGC1275 in 2016-2017 measured by MAGIC; Magic+18
The Origins of the Gamma-Ray Flux Variations of NGC 1275 Based on Eight Years of Fermi-LAT Observations; Tanada+18
X-ray and GeV gamma-ray variability of the radio galaxy NGC 1275; Fukazawa+18
Hitomi observation of radio galaxy NGC 1275: The first X-ray microcalorimeter spectroscopy of Fe-Ka line emission from an active galactic nucleus; Hitomi+18
Rapid Gamma-Ray Variability of NGC 1275; Baghmanyan+17
Deep observation of the NGC 1275 region with MAGIC: search of diffuse γ-ray emission from cosmic rays in the Perseus cluster; Fabian+15

More papers on radio/optical observations

NGC 1275
Interesting and important object for time-domain and multi-wavelength astrophysics

Radio galaxies



Parent population of Blazars

Unlike blazars, their jet is not aligned to the line of sight, beaming is weaker.

EGRET: Cen A detection and a hint of a few radio galaxies
3EG catalog: Hartman et al. (1999)
see also Sreekumar et al. (1999)

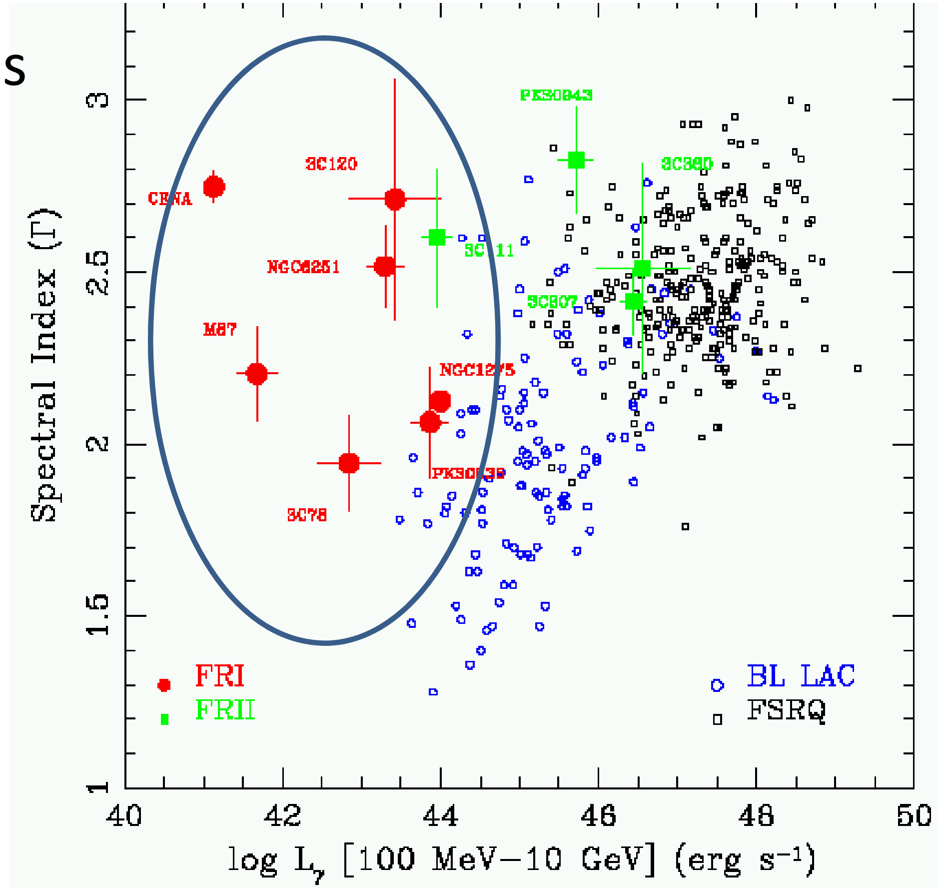
3C111 and NGC6251?

In 2000s, M87 was detected in the TeV

We can probe jet structure by radio galaxies, together with blazars.
Jet core beamed emission is not as dominant as blazars, and thus we can see an emission other than jet core emission.

1-yr LAT radio galaxies

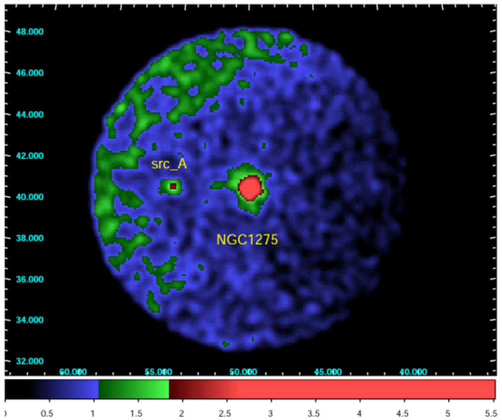
Abdo+10



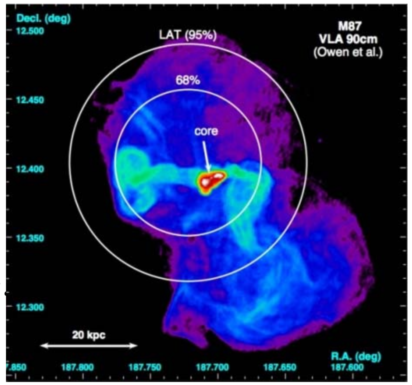
Fermi detected
three bright radio galaxies
with 3 months.
10 in 1FGL catalog (1 year).
>20 in 3FGL catalog.

Established as gamma-ray emitters,
apart from blazars

NGC1275(Per A)

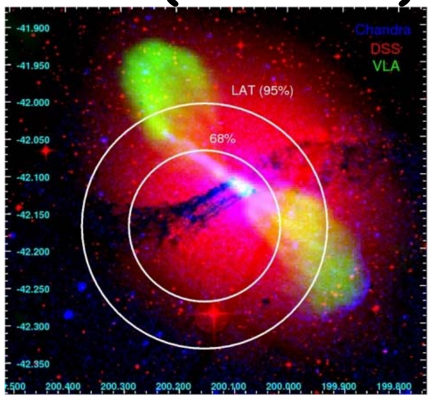


M87(Vir A)



si

Cen A(NGC5128)

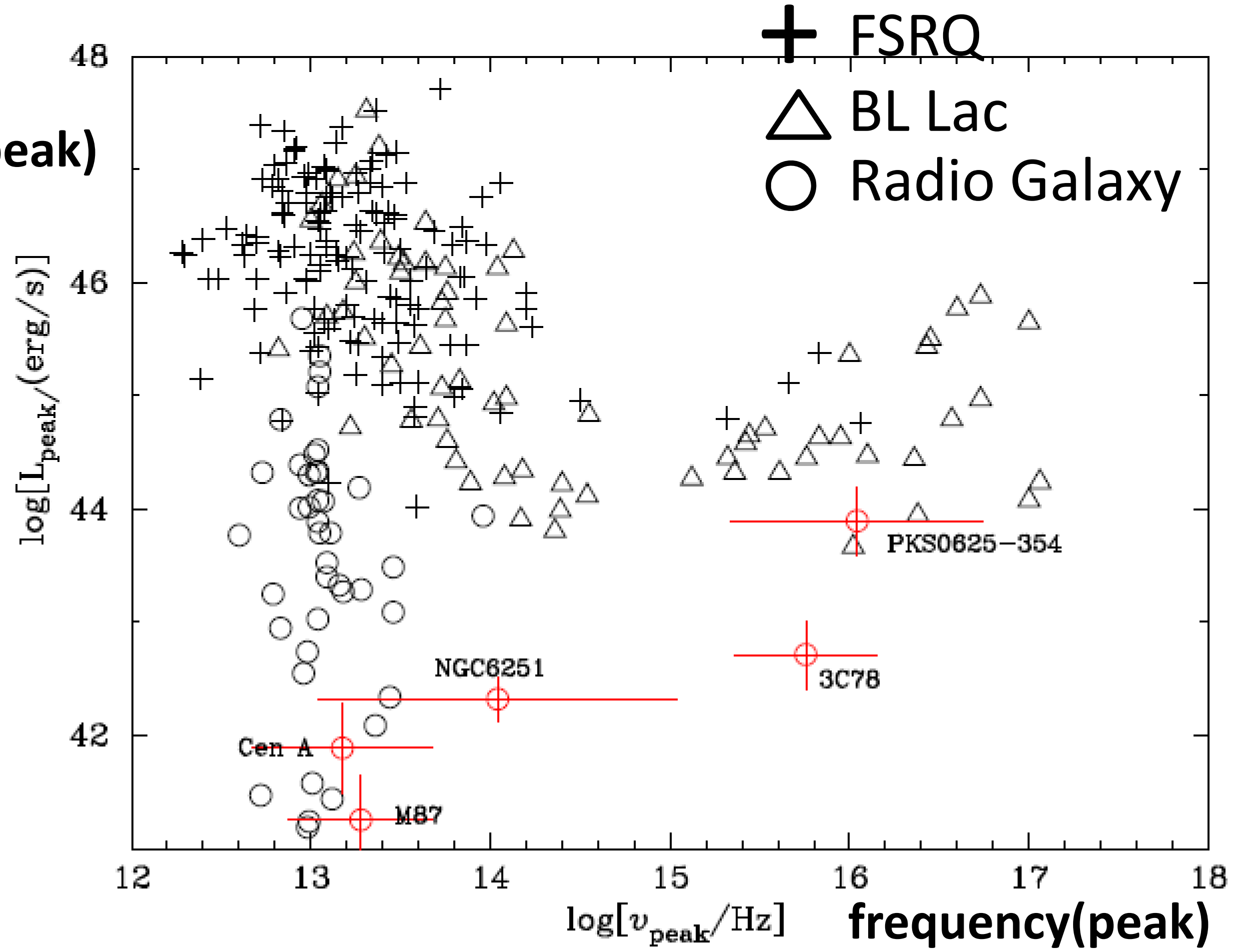


Radio galaxies do not follow the blazar sequence;
low L but with both high sync. Peak and low sync. peak

Not only low beaming, but also other effects might be seen.

f(peak) vs L(peak) of Synchrotron **Fukazawa+14, Meyer+11**

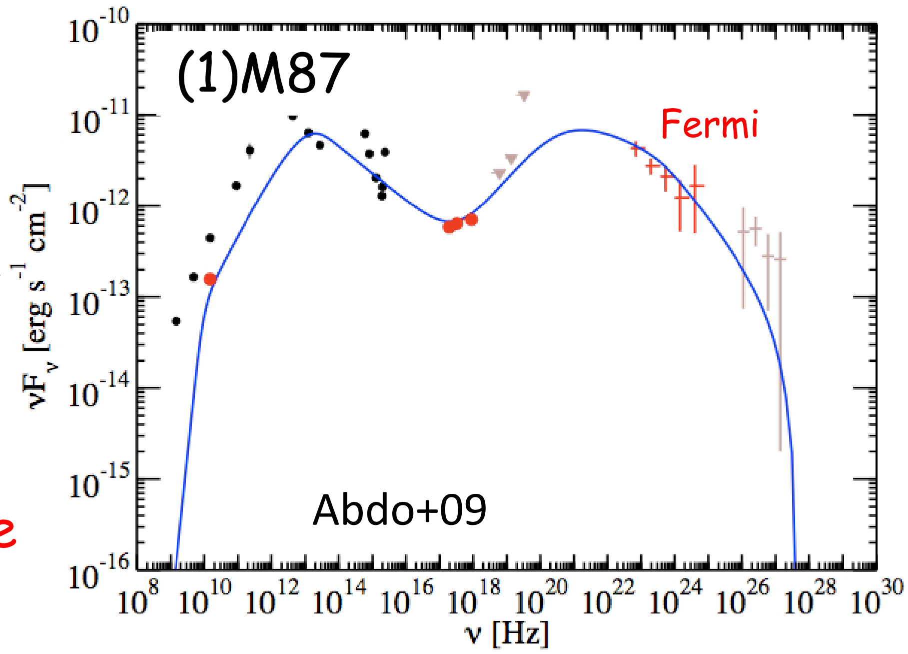
Luminosity(peak)

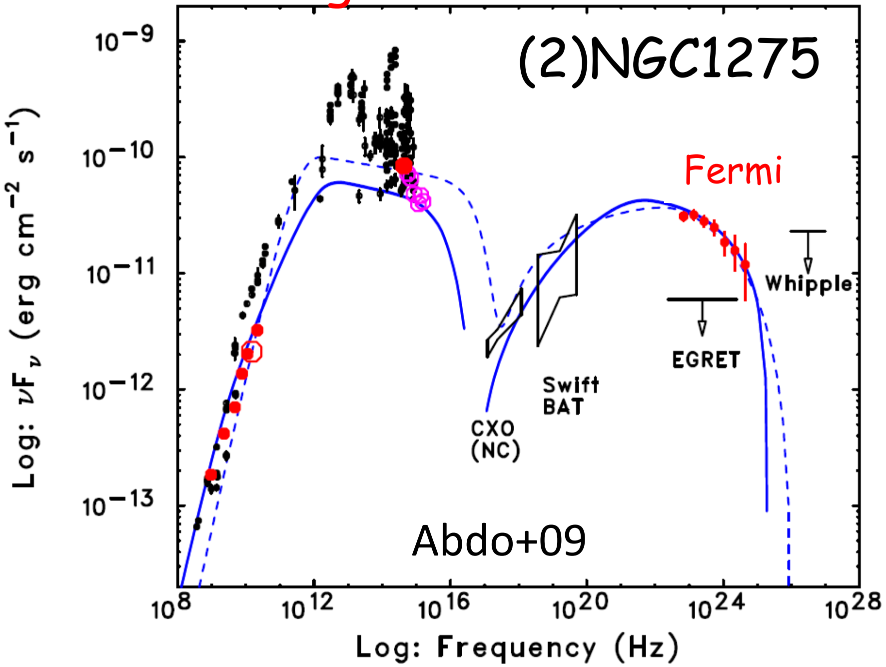


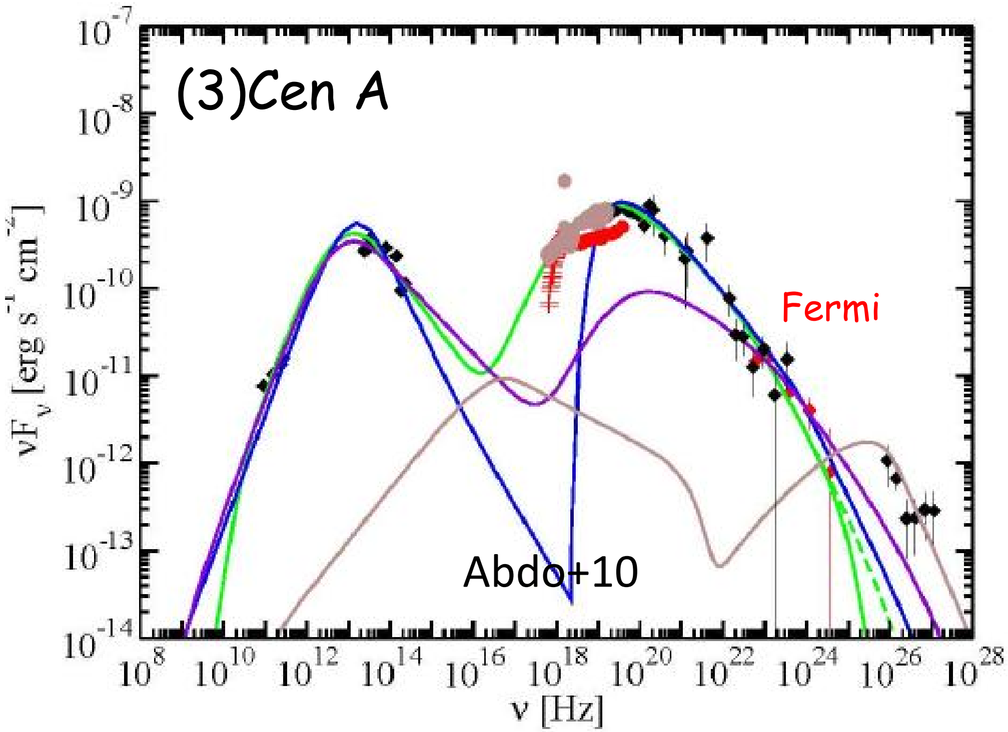
frequency(peak)

However, inner jet emission has been detected mainly in the radio and GeV gamma-ray band for most objects, due to bright stellar and accretion disk components in the optical and X-ray band; SED of jet emission is unclear.

Thus, multi-wavelength study of time variability is important for understanding SED.







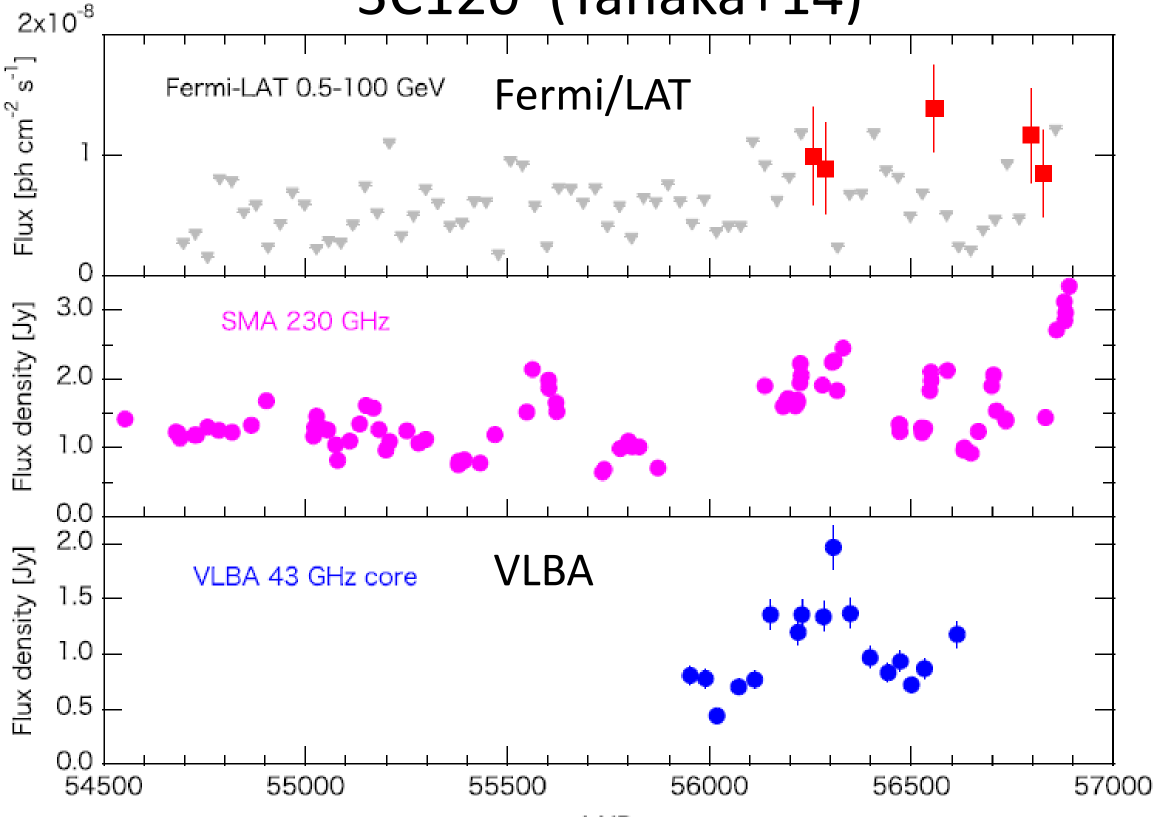
Disk/Jet connection is also interesting.

Radio galaxies give us opportunities to probe both disk and jet.

Radio, gamma → Jet

X-ray, opt/UV → Inner accretion disk and outflow

3C120 (Tanaka+14)



NGC 1275

Giant elliptical galaxy (cD) centered on the Perseus cluster

cD;pec;NLRG;Sy2;LEG

Seyfert galaxy z = 0.0017559

with optical broad line in the past

Extended Ha filament

M_{BH} = (6-15) x 10^8 M. (scharwaohter+13)

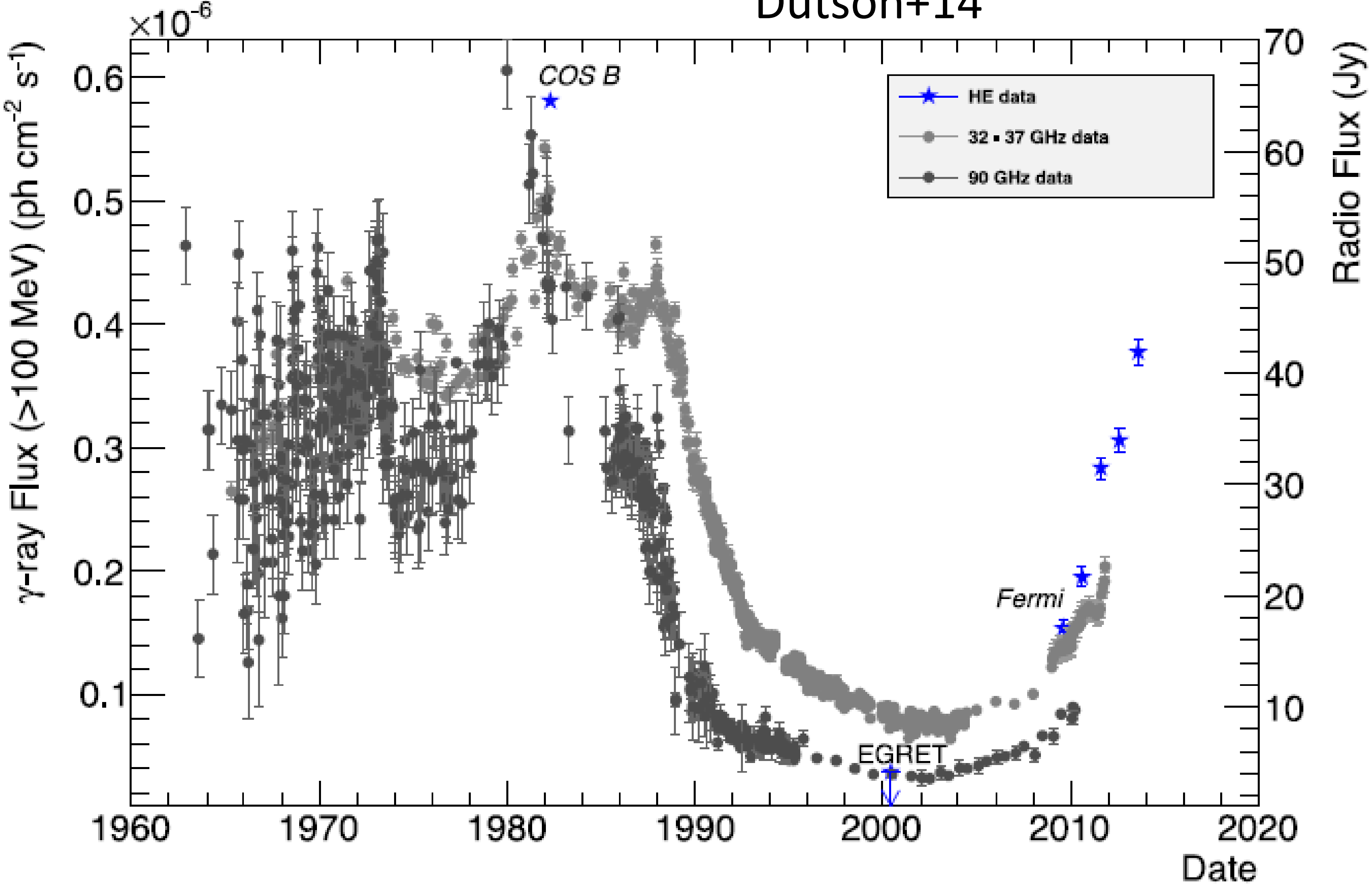
Bright FR-I radio galaxy: Per A, 3C84

Brightest gamma-ray emitting radio galaxy

GeV: Fermi (Abdo+09), TeV: MAGIC (Aleksic+12)

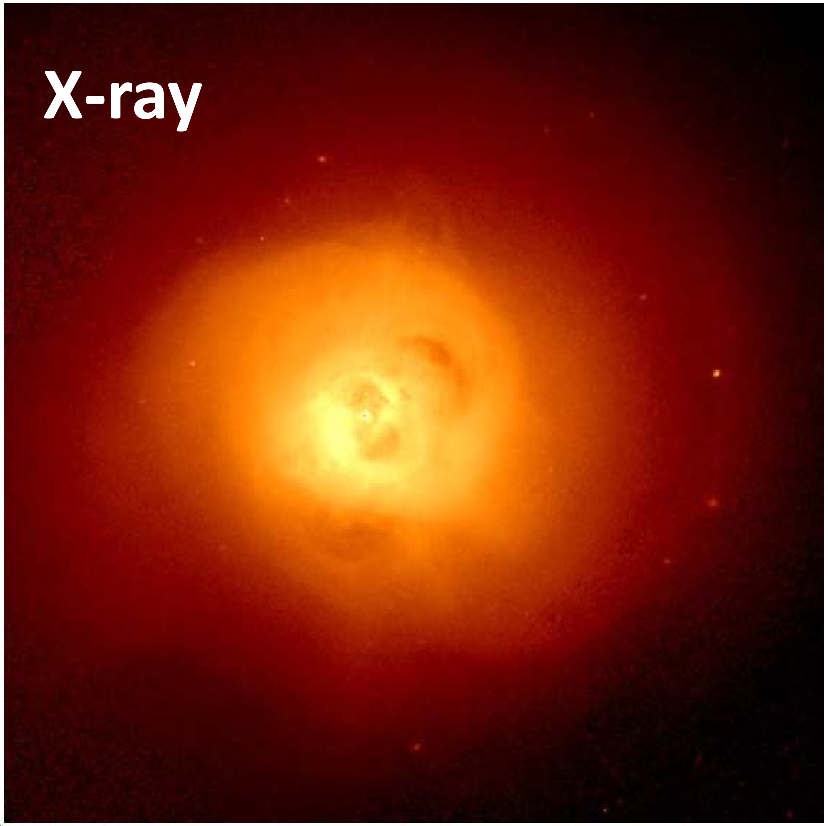
Jet emission of NGC 1275 has been highly variable.

Dutson+14



Jet is interacting with ambient intracluster hot gas.

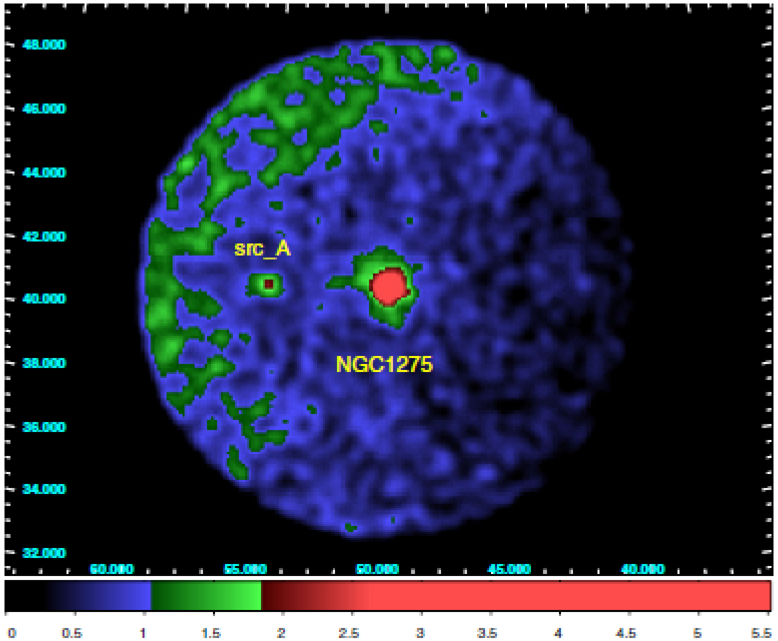
Interesting system from the view point of AGN feedback



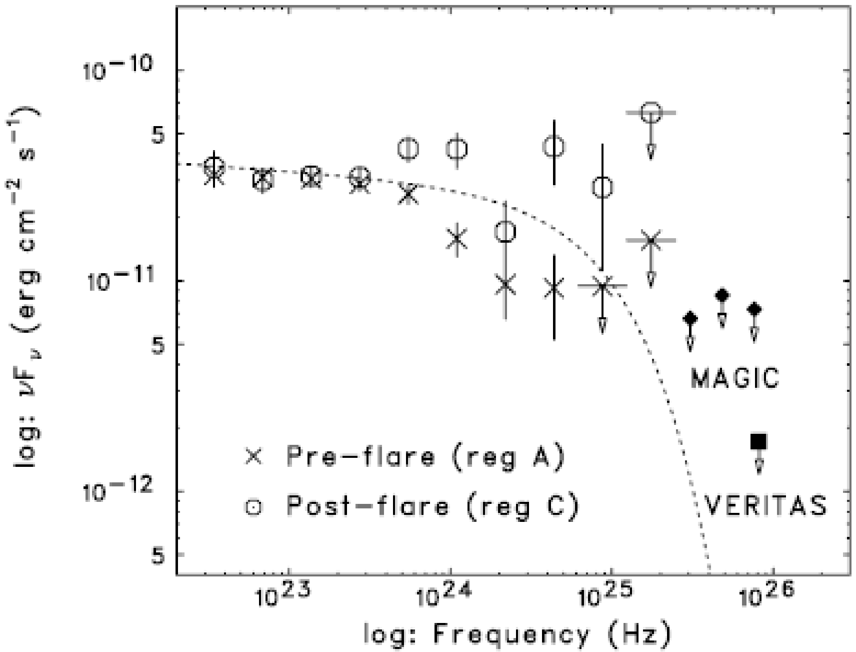
Fermi/GeV and TeV studies

Early Femi results

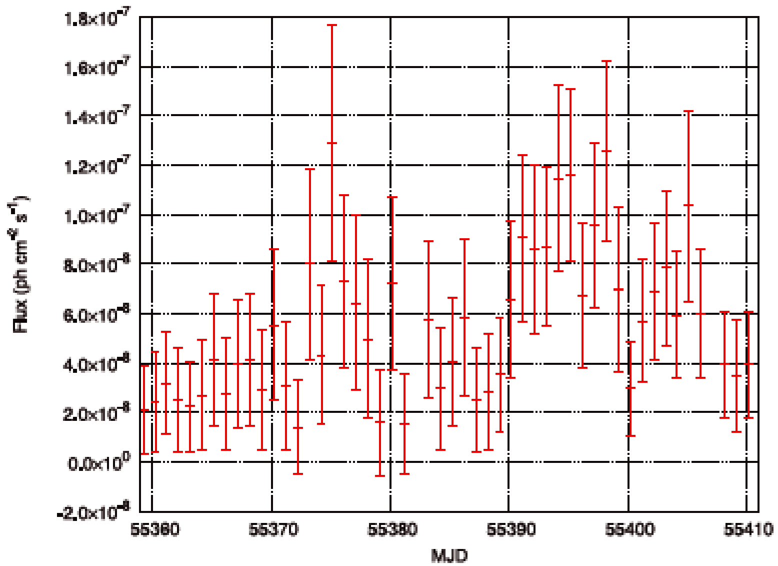
Abdo+09 : 1st GeV detection



Kataoka+10 : several 10 days variability with spectral change

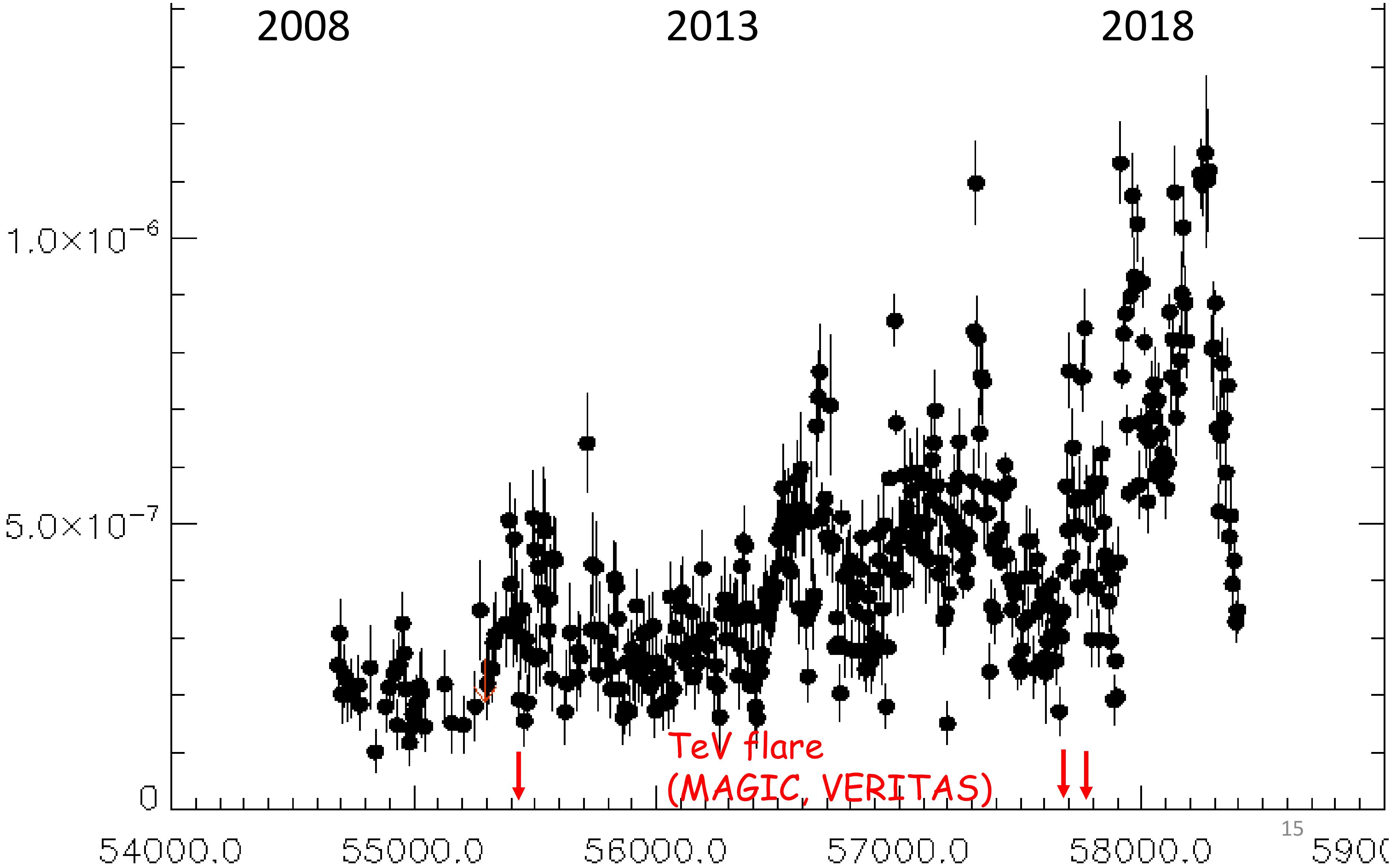


Brown and Adams 11
Several days variability

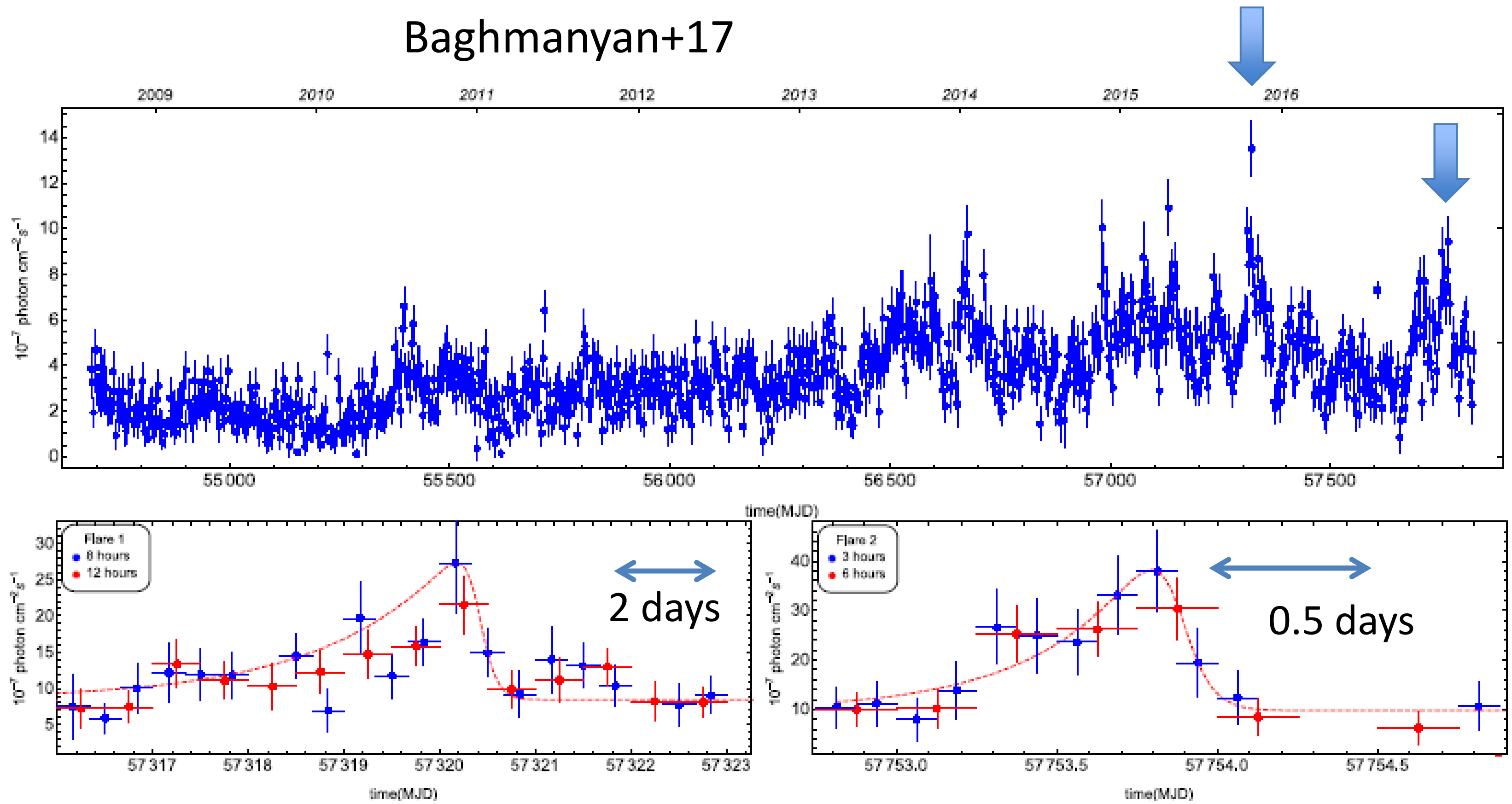


Fermi 10 years light curve

Fermi Public Page

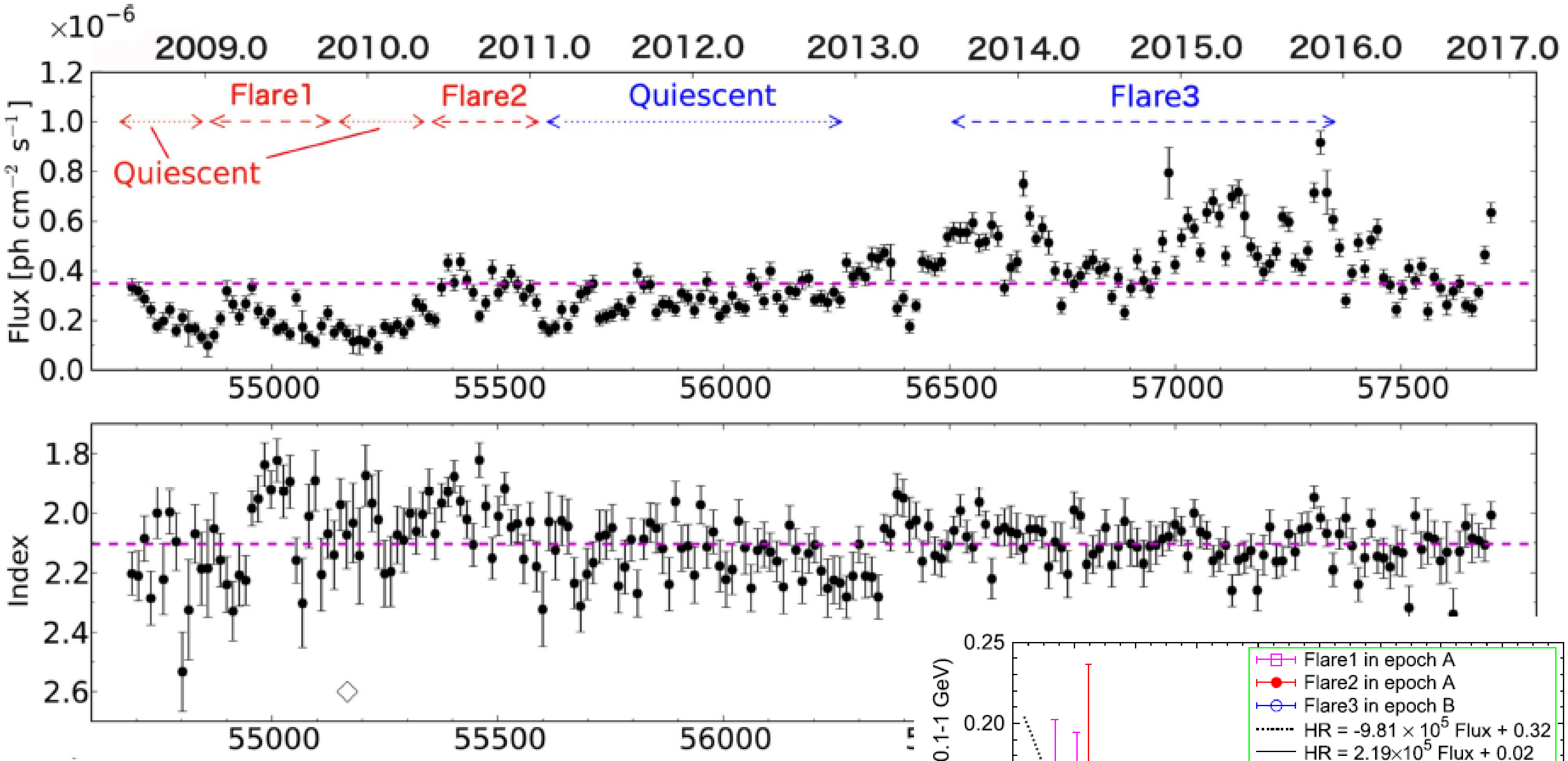


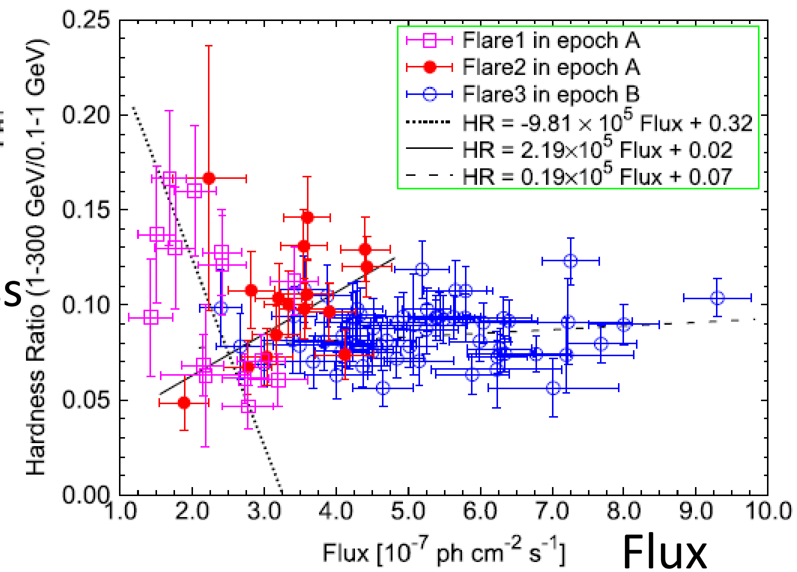
Baghmanyan+17



R < 6x10^14 cm (1-5 Rsch)

Tanada+18





Hardness Ratio

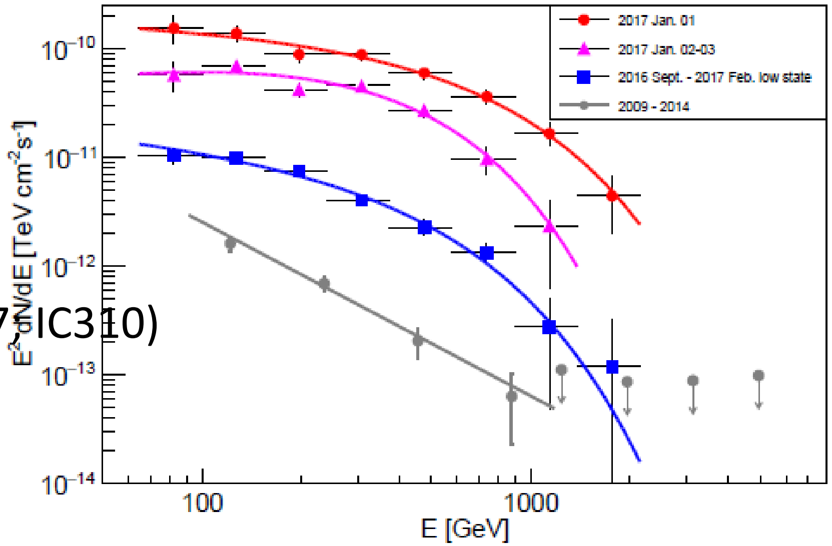
Flux

Variability is caused by
2008-2013 : accelerated electrons
2013-2017 ; Doppler factor changes

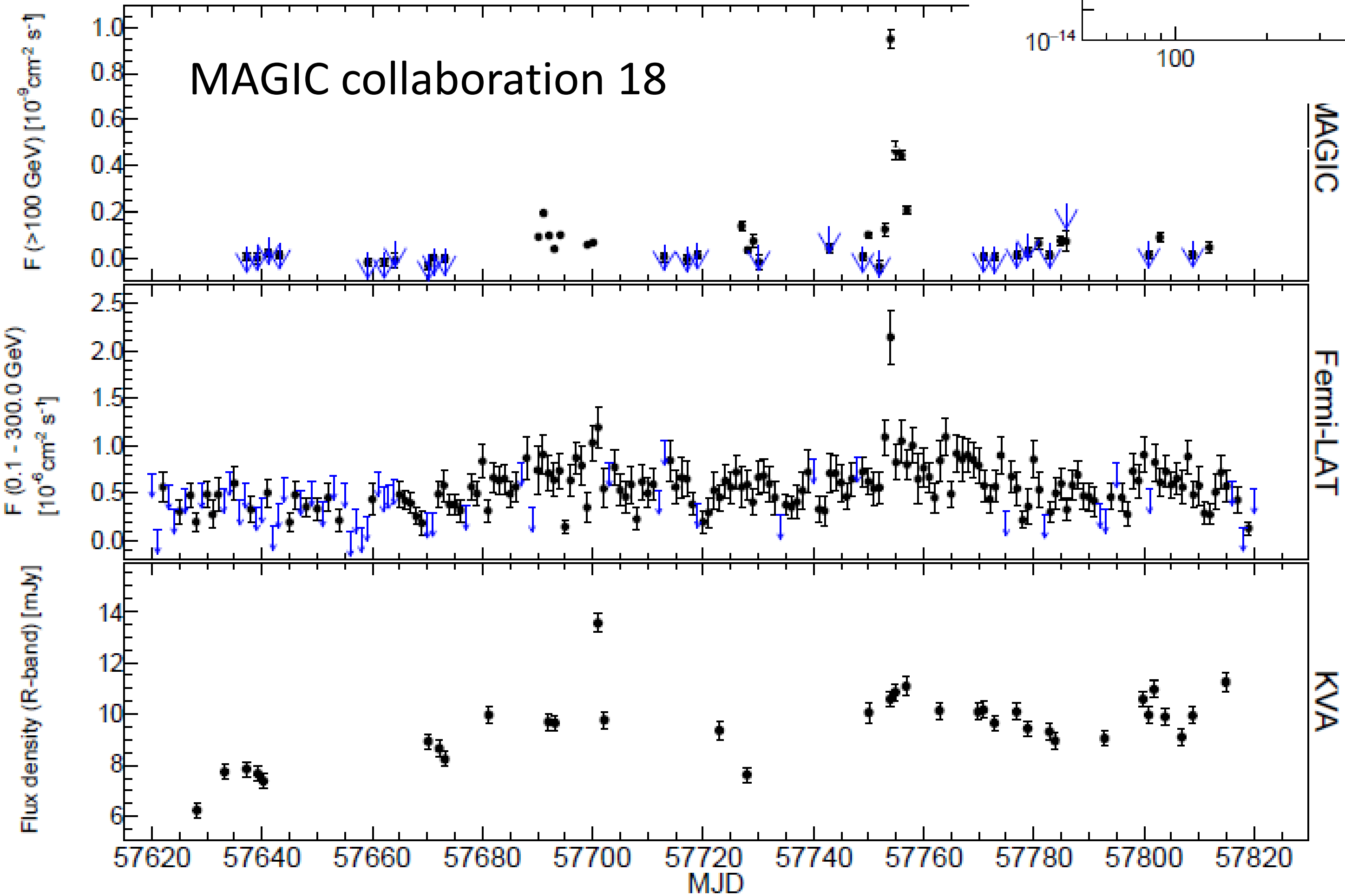
2016 Dec. 31th to 2017 Fan. 1st
1.5Crab @ >100GeV , >1TeV photons are detected
Variability 611 min

Γ>3.3 θ<12deg ⟺ Γ<2.3 θ>25deg (radio)

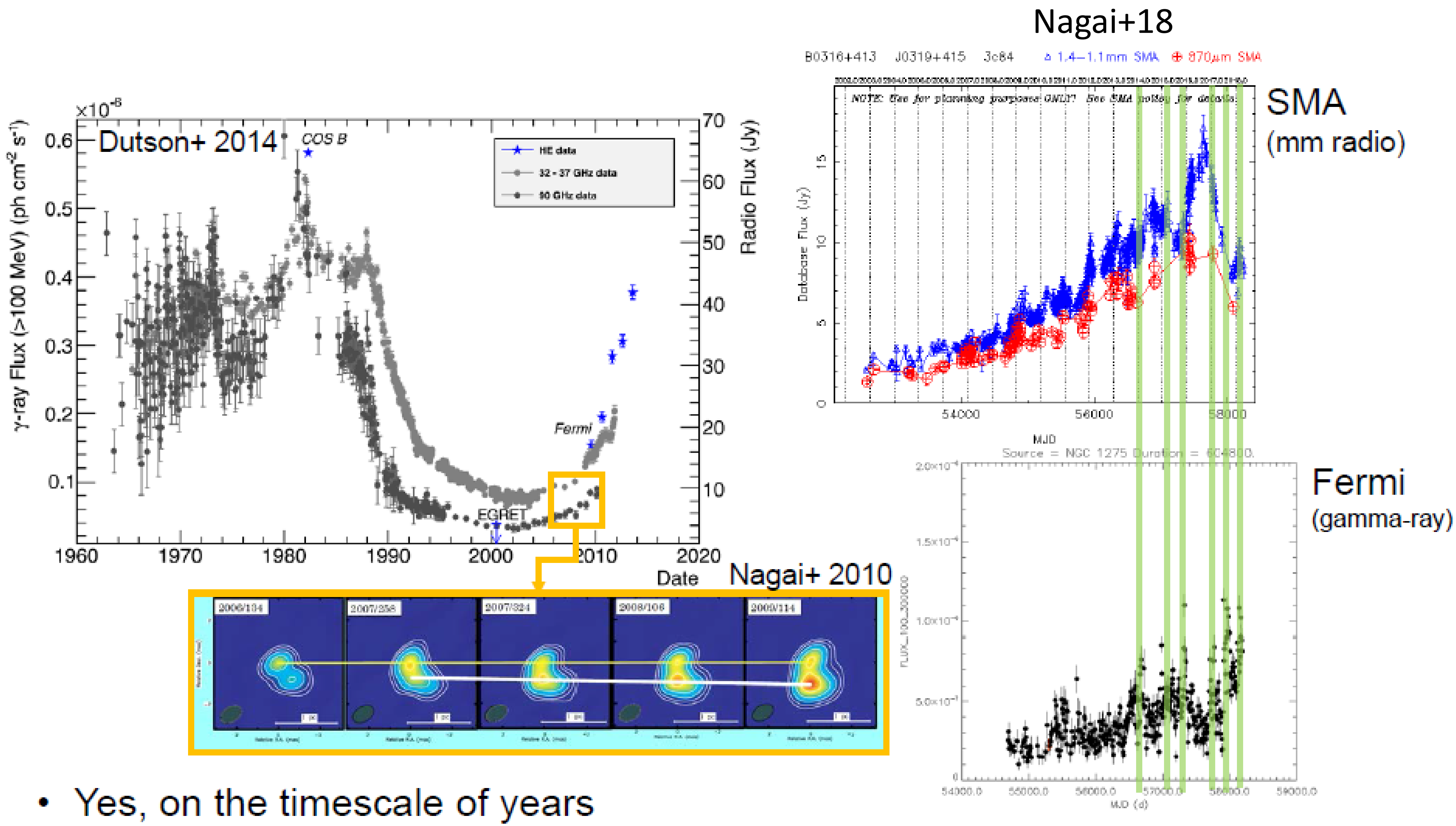
Magnetospheric gap around BH (Aharonian+17 IC310)



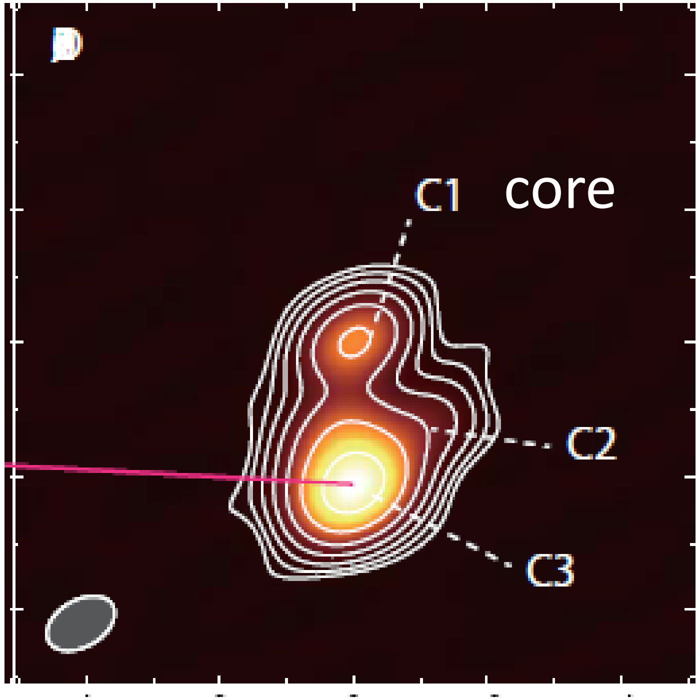
MAGIC collaboration 18



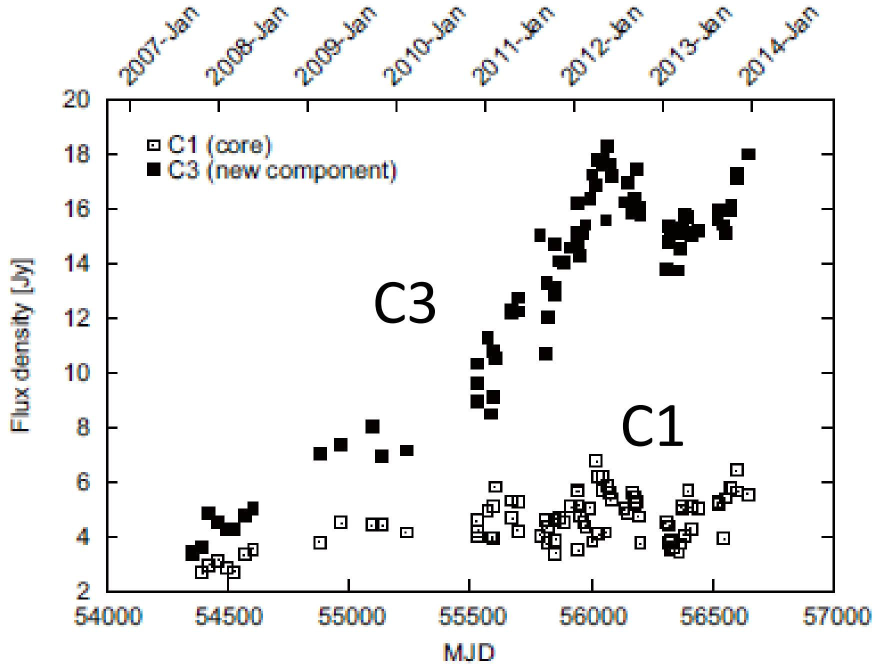
Radio and Gamma-ray connection



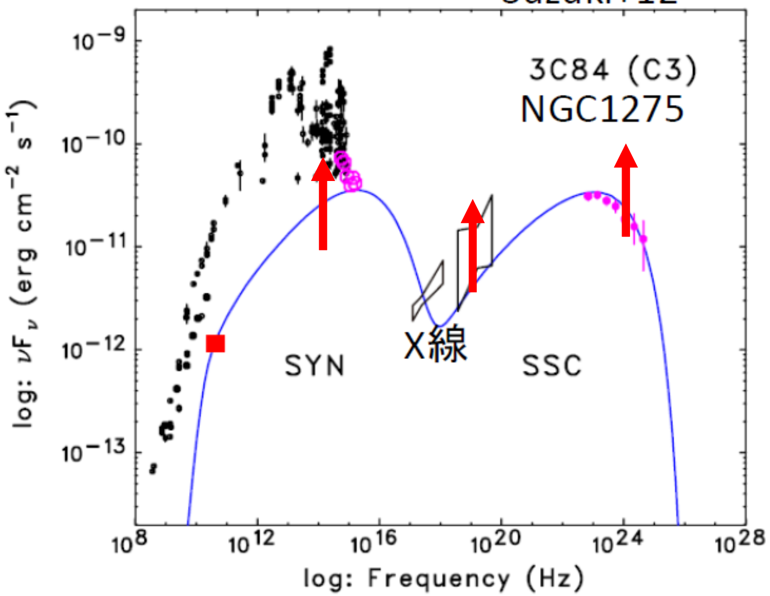
- Yes, on the timescale of years



Nagai+16



Suzuki+12

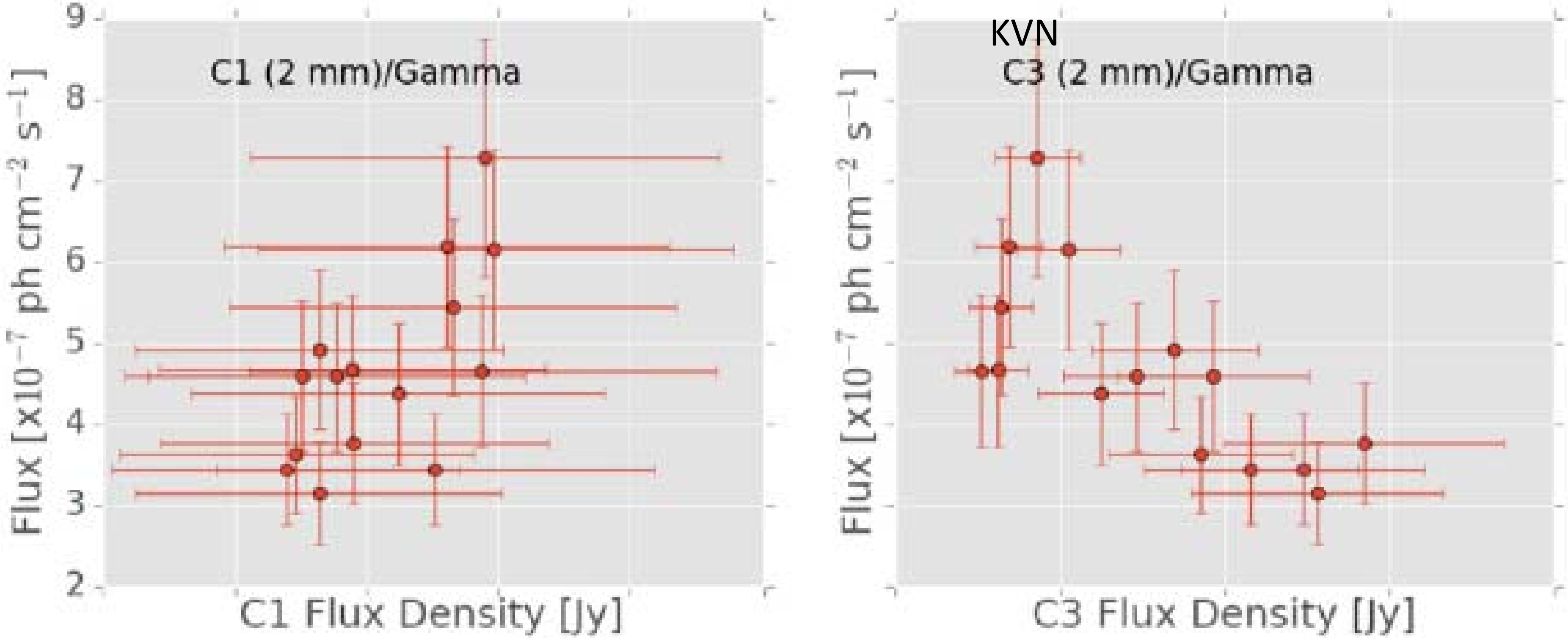


C3 is likely an origin of the long-term flux increase of gamma-ray brightening.

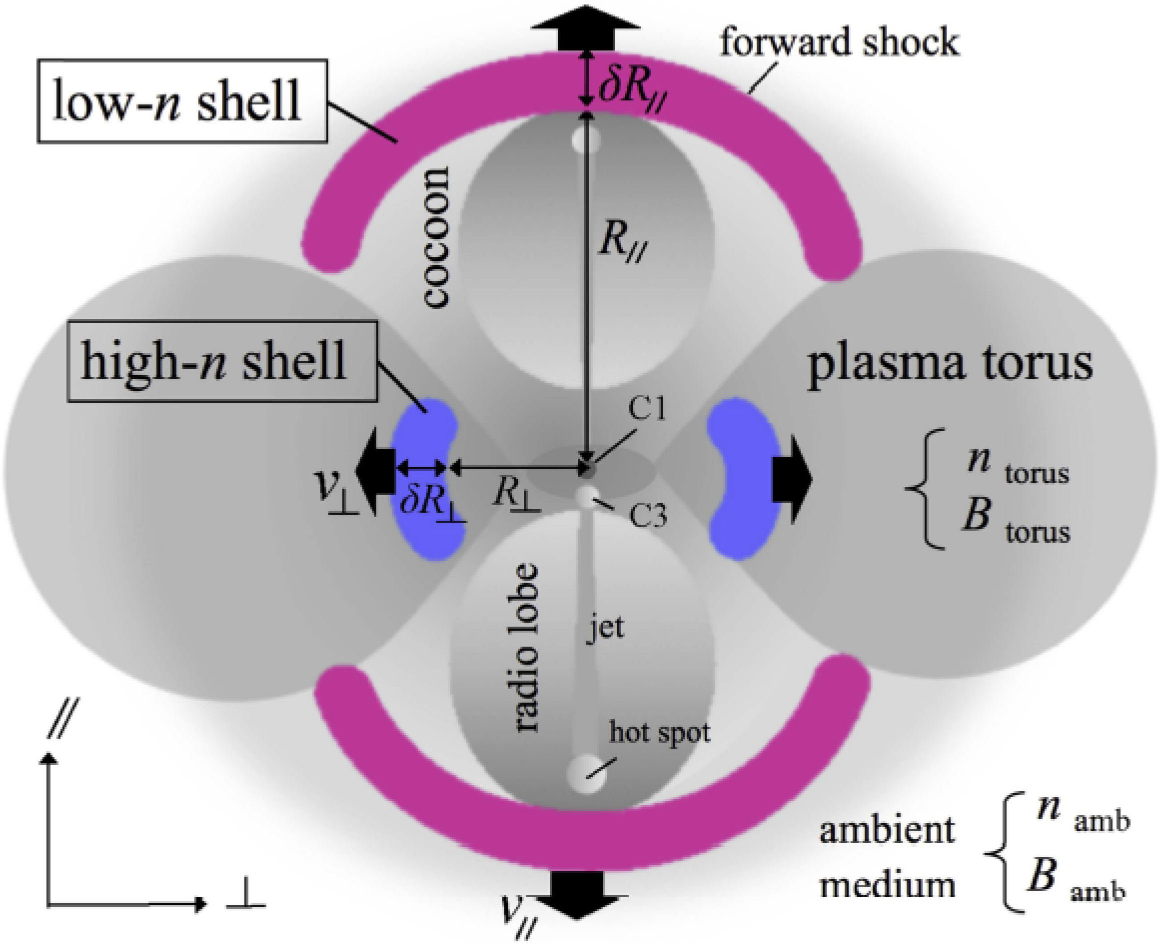
But, C1 (core) contribution is also suggested.

Hodgson+18

Imaging analysis is also presented in poster.

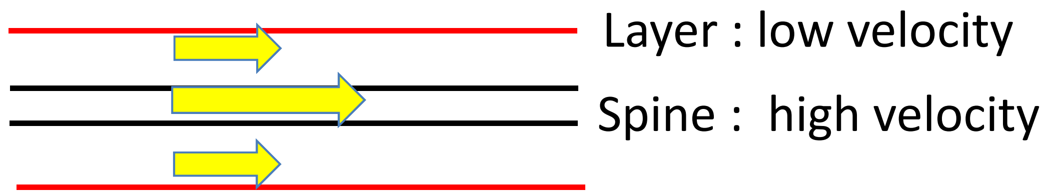


Kino+17



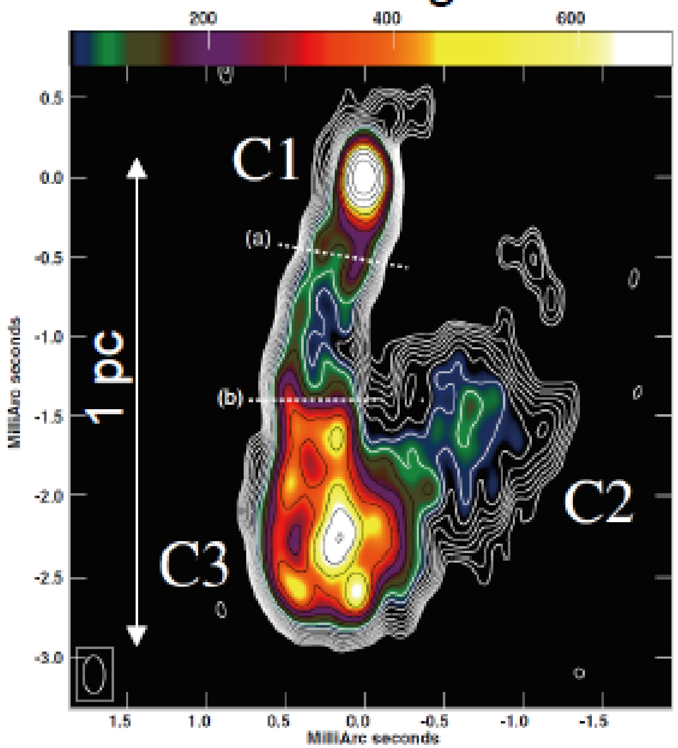
forward shock
low-n shell
δR//
cocoon
R//
high-n shell
plasma torus
C1
v⊥
δR⊥
R⊥
C3
n torus
B torus
radio lobe
jet
hot spot
//
⊥
ambient
medium
n amb
B amb
v//

Spine-layer structured jet is suggested



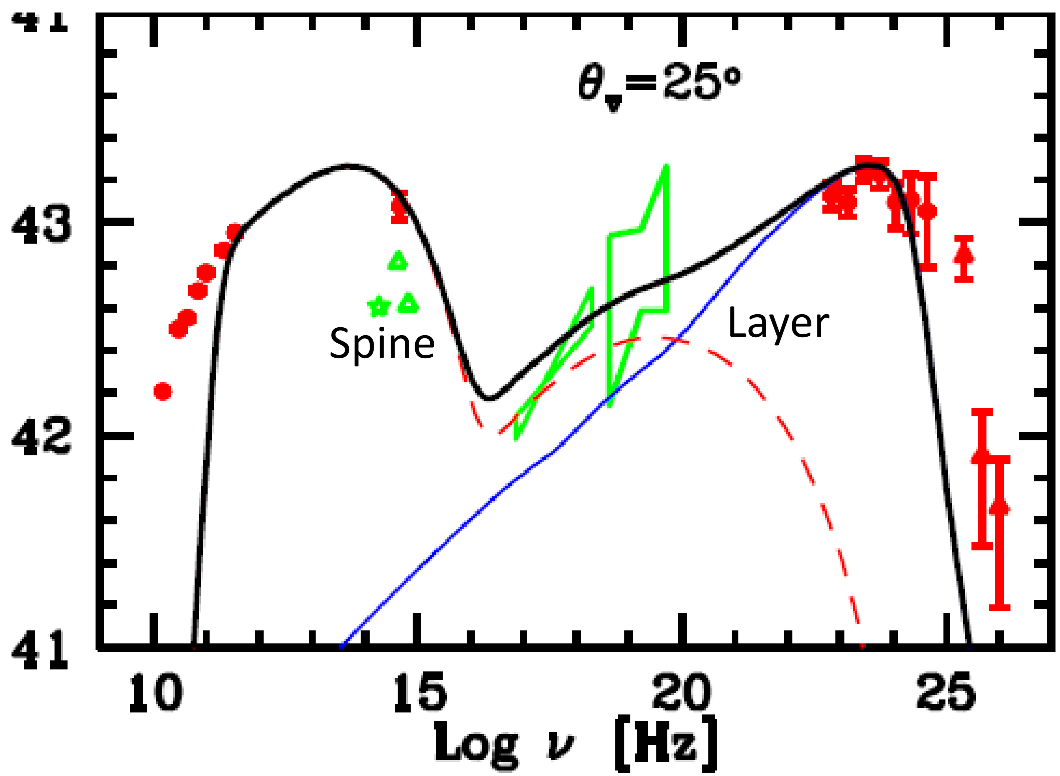
Limb-brightening

Nagai+ 2014



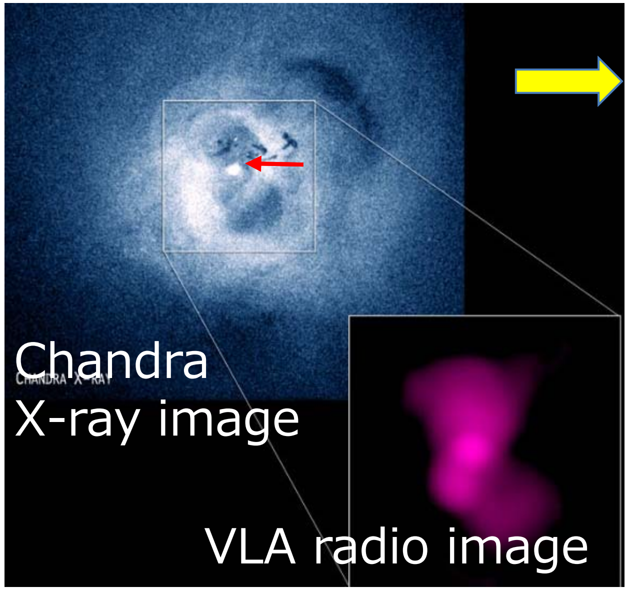
Two-zones modeling give more reasonable parameters.

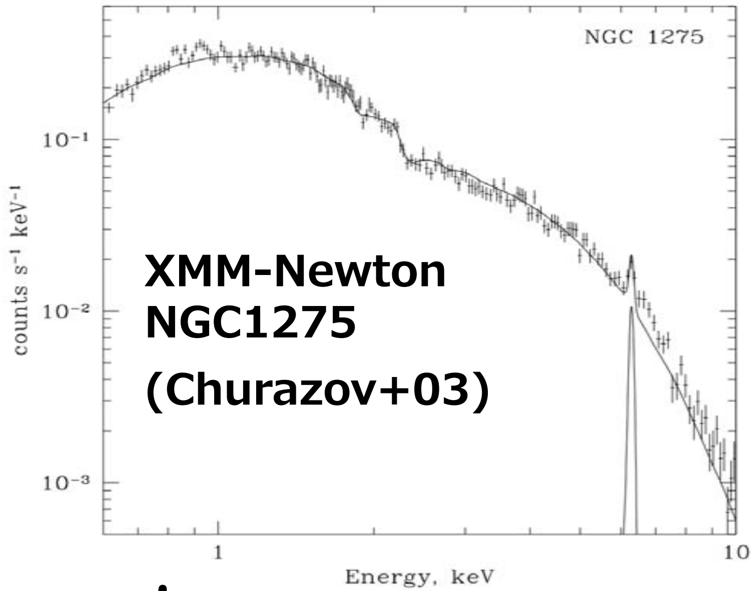
Tavecchio+14



X-ray and Gamma-ray connection

X-ray from NGC 1275





☆ **Point-like source has been detected.**

Einstein/HXI, ROSAT/HXI, Chandra, XMM-Newton (e.g. Fabian+15)

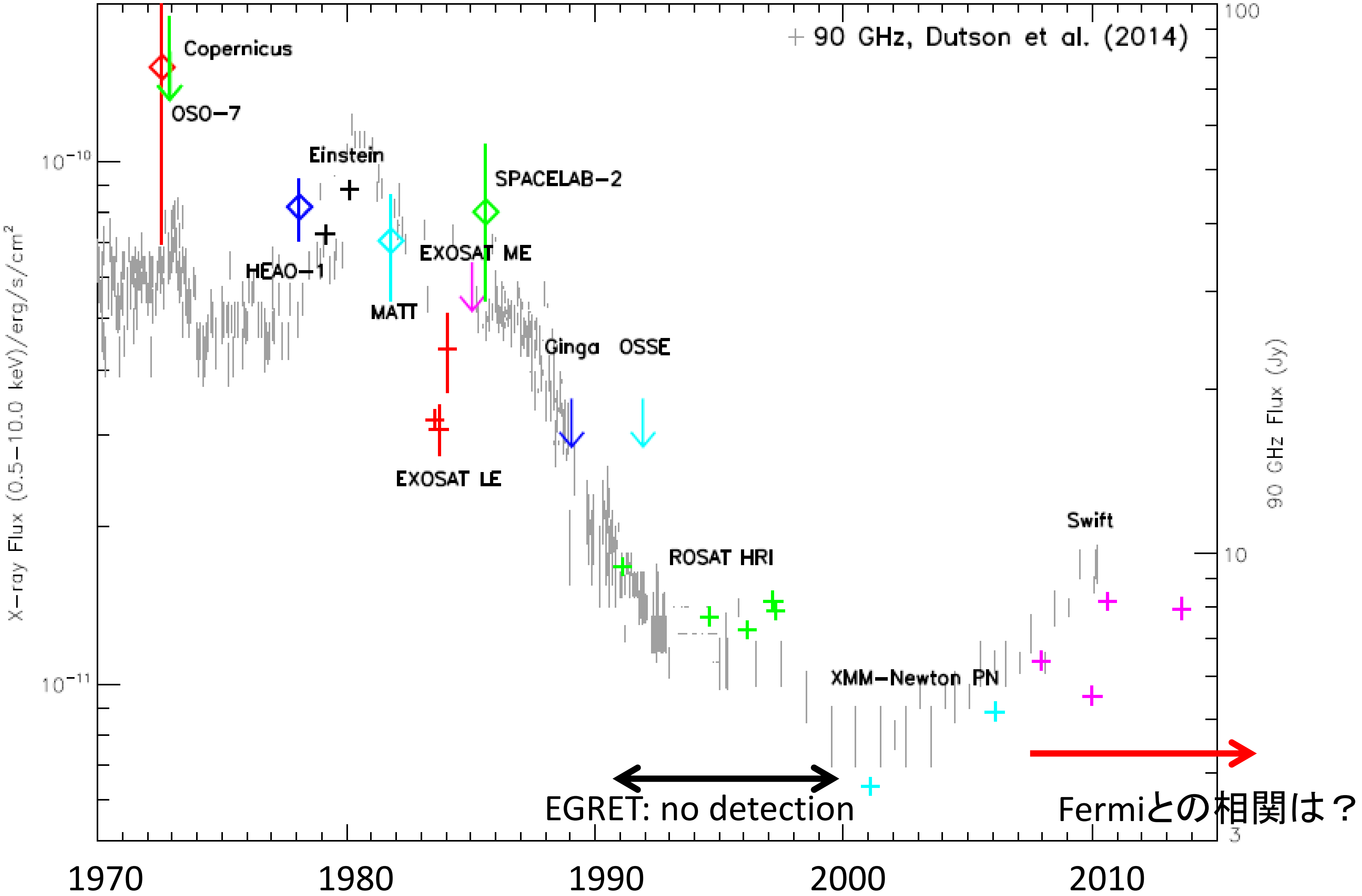
☆ **XMM-Newton detected Fe-Ka (6.4keV) line.**

(Churazov+03, Yamazaki+13)

Fe-K 6.4keV is typical for Seyfert galaxies.

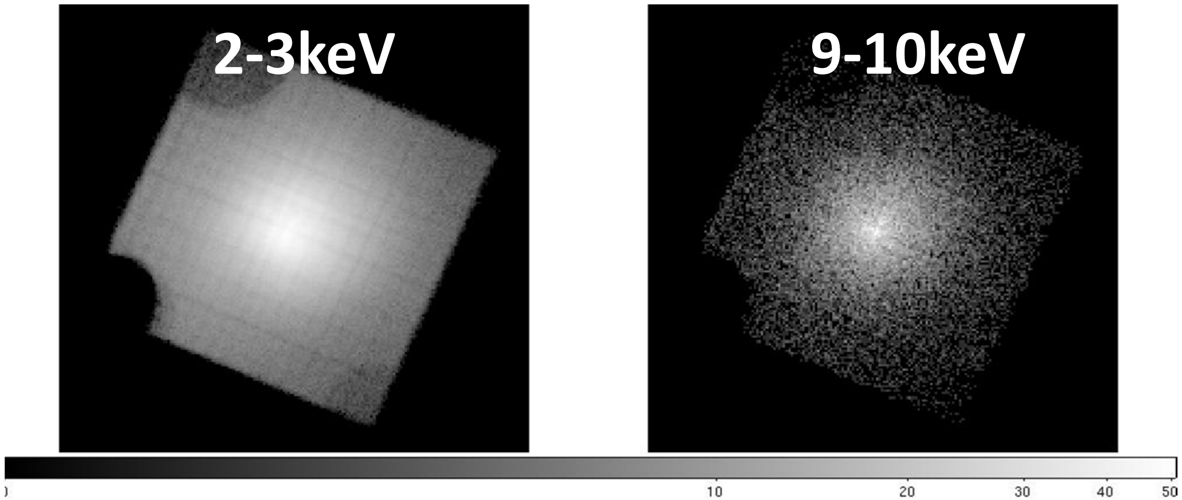
X-ray long-term of NGC1275

Fabian+15



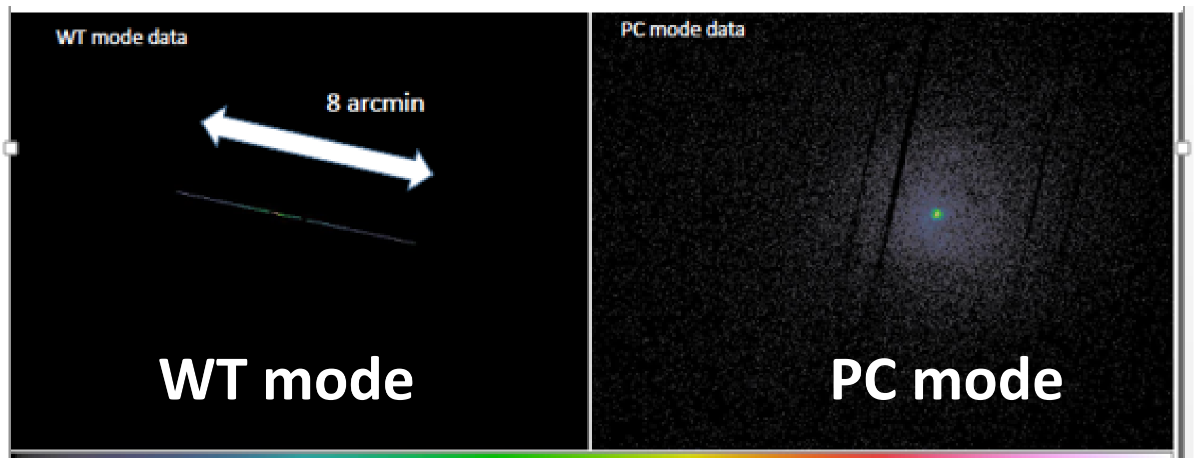
Derive a long-term X-ray light curve

Suzaku/XIS every 0.5 yr in 2006-2015



Swift/XRT/UVOT 25 obs. In 2006-2015

BGD subtraction issue



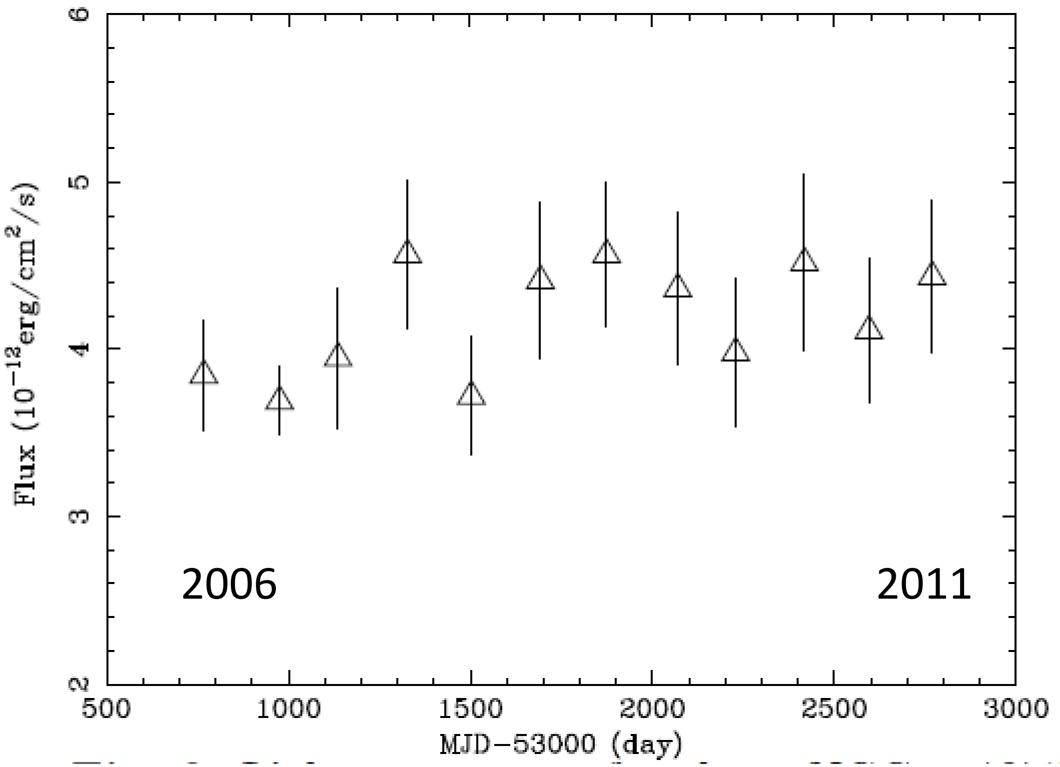
Pile-up issue

Femi/LAT GeV gamma-ray

Fukazawa et al. 2018, ApJ 855, 93

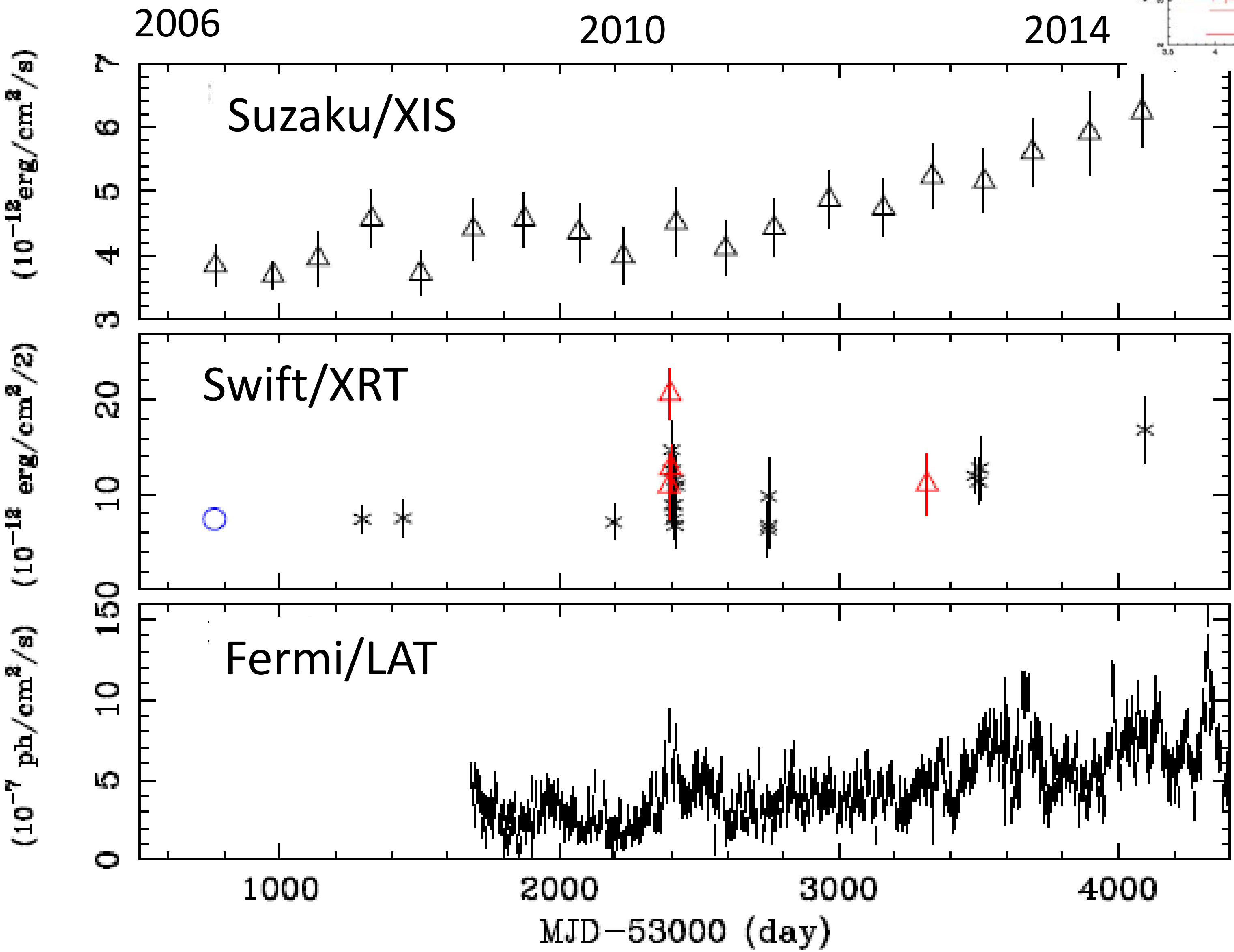
Suzaku XIS Light curve No significant variability in 2006-2011

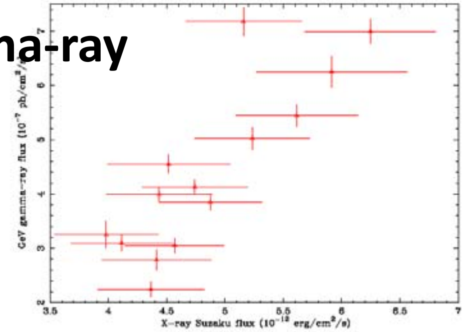
Yamazaki+13



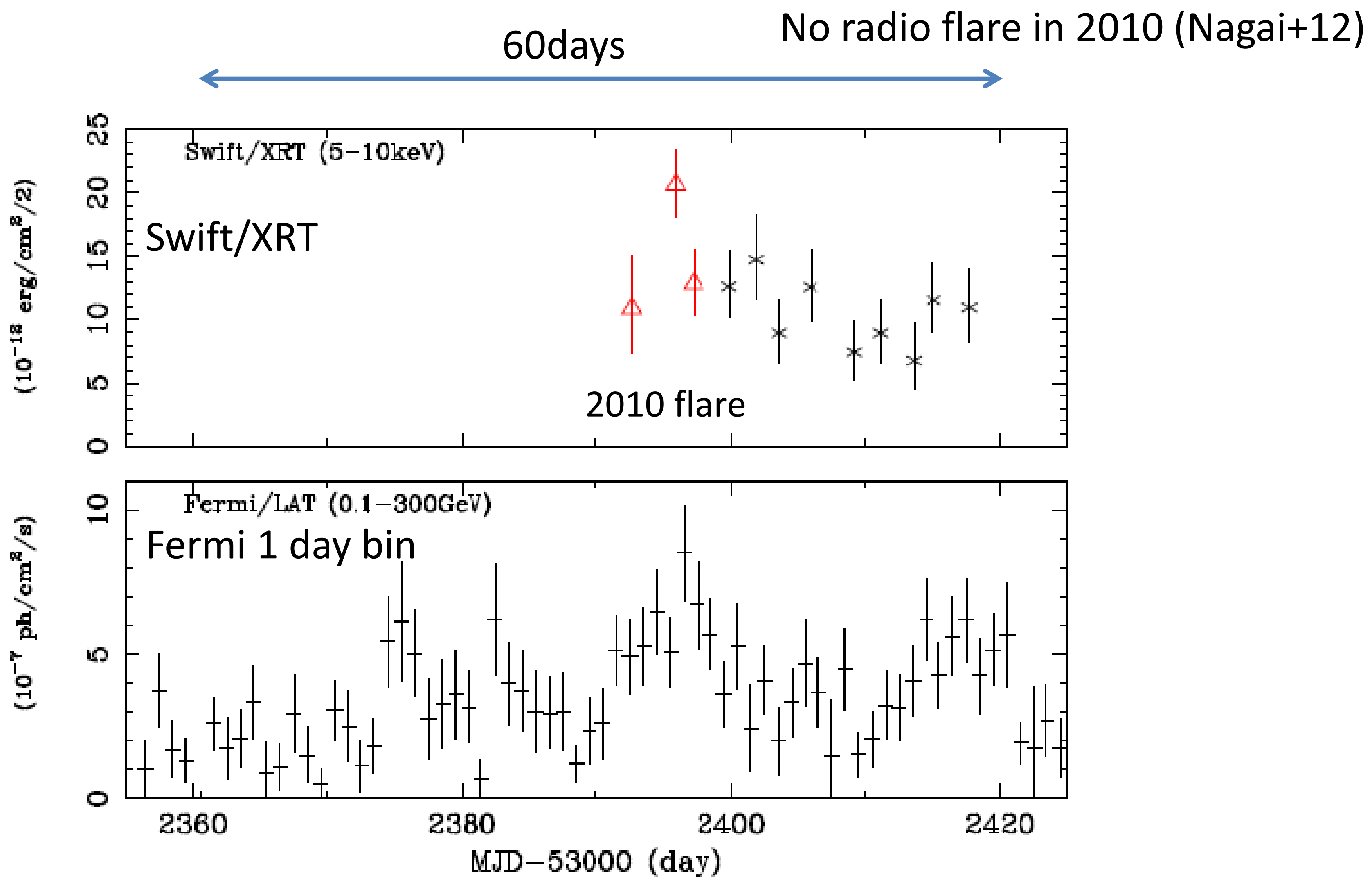
Further analysis revealed a long-term X-ray variability

Fukazawa et al. 2018

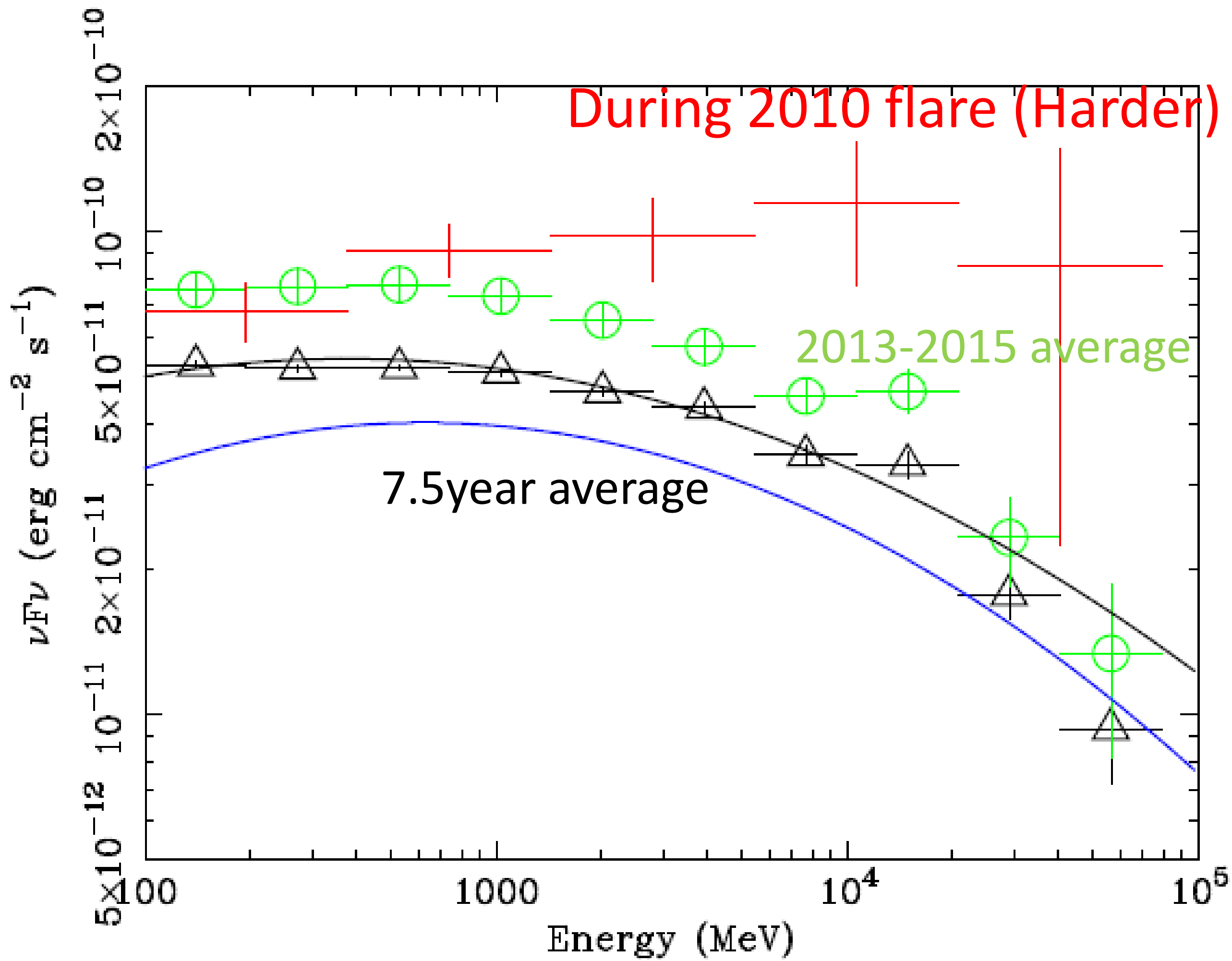




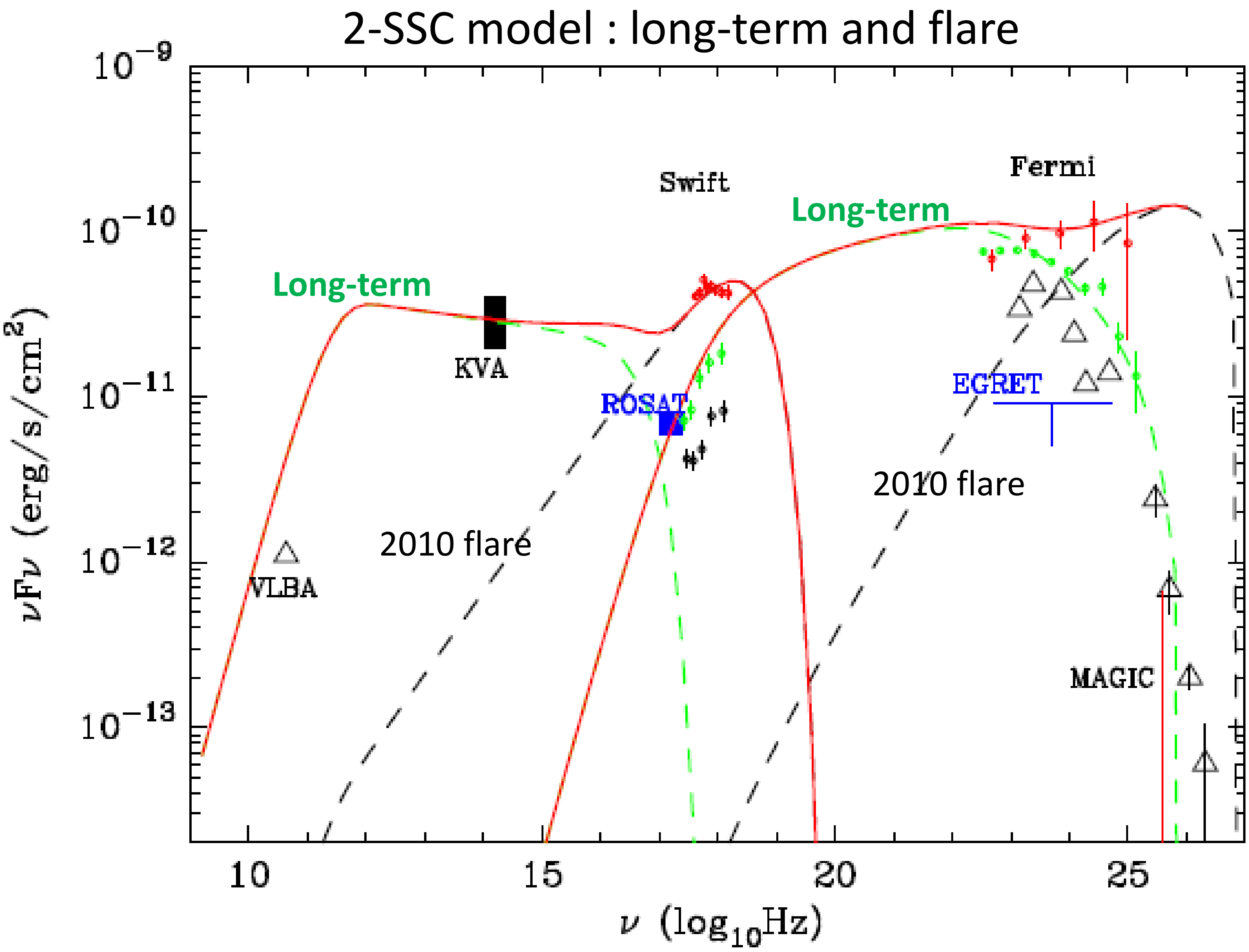
Short-term X-ray variability is also.



Gamma-ray spectral changed, together with X-ray variability

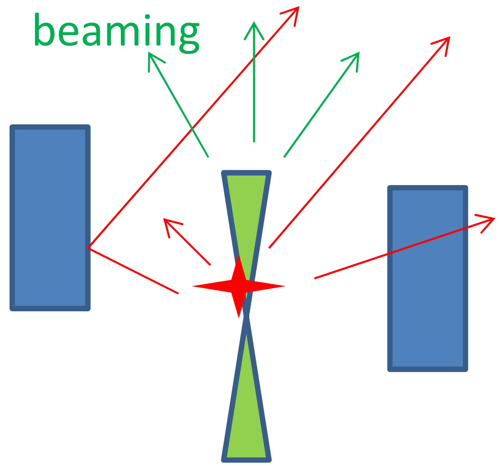


Freshly accelerated electrons in the inner jet region (shock-in-jet)



Origin of X-ray Emission

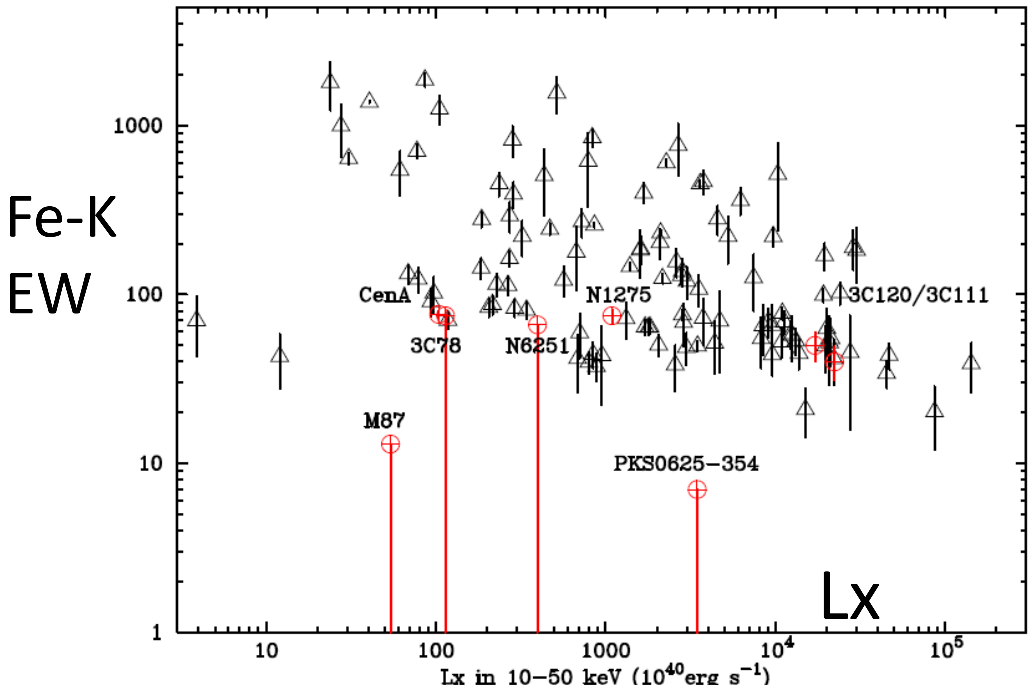
Correlation with gamma-ray .indicates jet contribution. (also suggested by Rani+18 NuSTAR results)



But… origin of Fe-K line?.
Fe-K is typical for Seyfert galaxies.

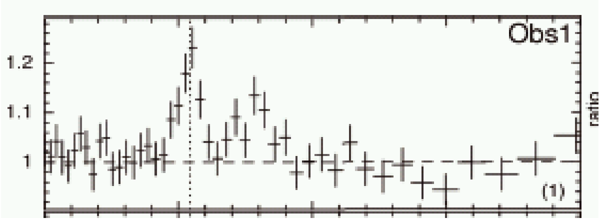
Fe-K line suggests a non-beaming X-ray continuum from the central engine. → accretion disk/corona ?

with Fukazawa+11

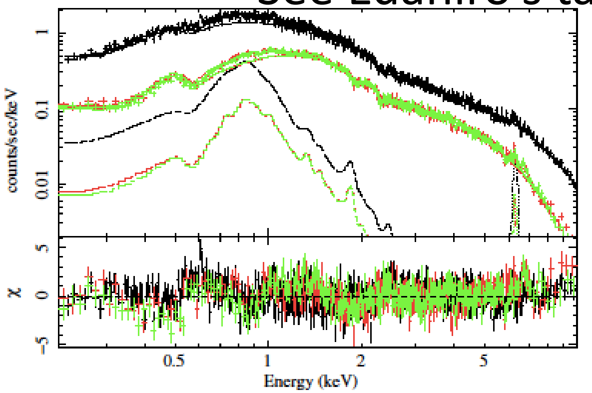


Suzaku X-ray spectra of Fermi radio galaxies

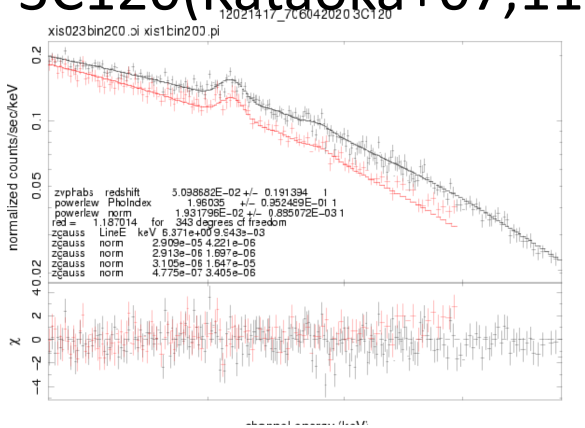
3C111(Tombesi+11)



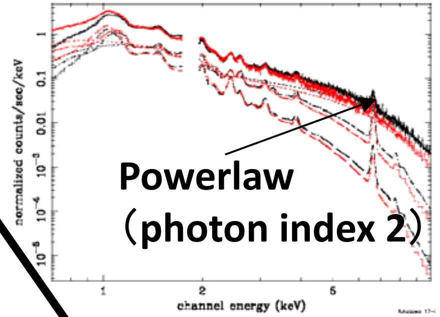
NGC1275 (Yamazaki+13; See Edahiro's talk)



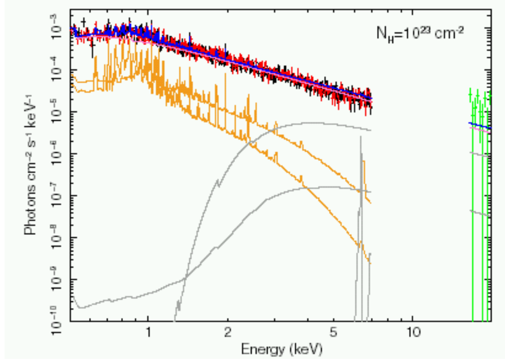
3C120(Kataoka+07,11)



M87 HST-1 knot (Fukazawa+14)

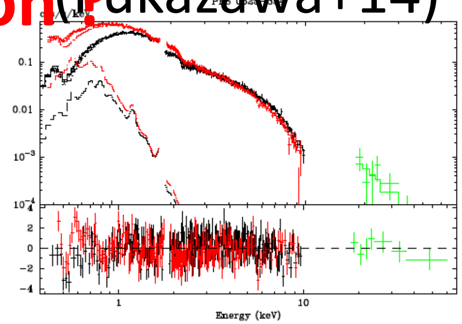


NGC6251(Evans+11)



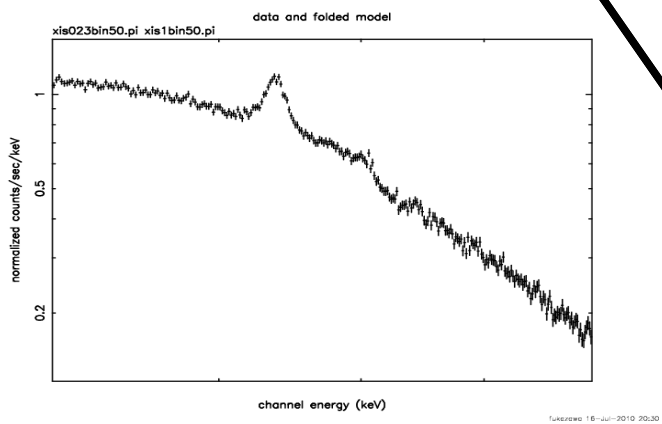
No Fe-K
Jet emission?

PKS0625-354 (Fukazawa+14)

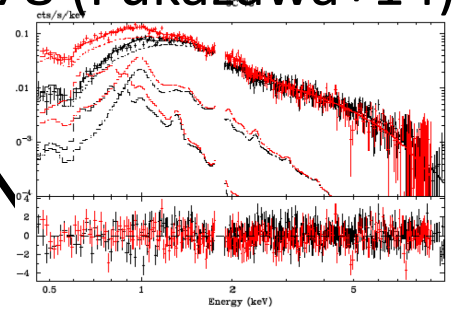


Fe-K

Cen A (Fukazawa+11)



3C78 (Fukazawa+14)



Origin of X-ray Emission of GeV radio galaxies

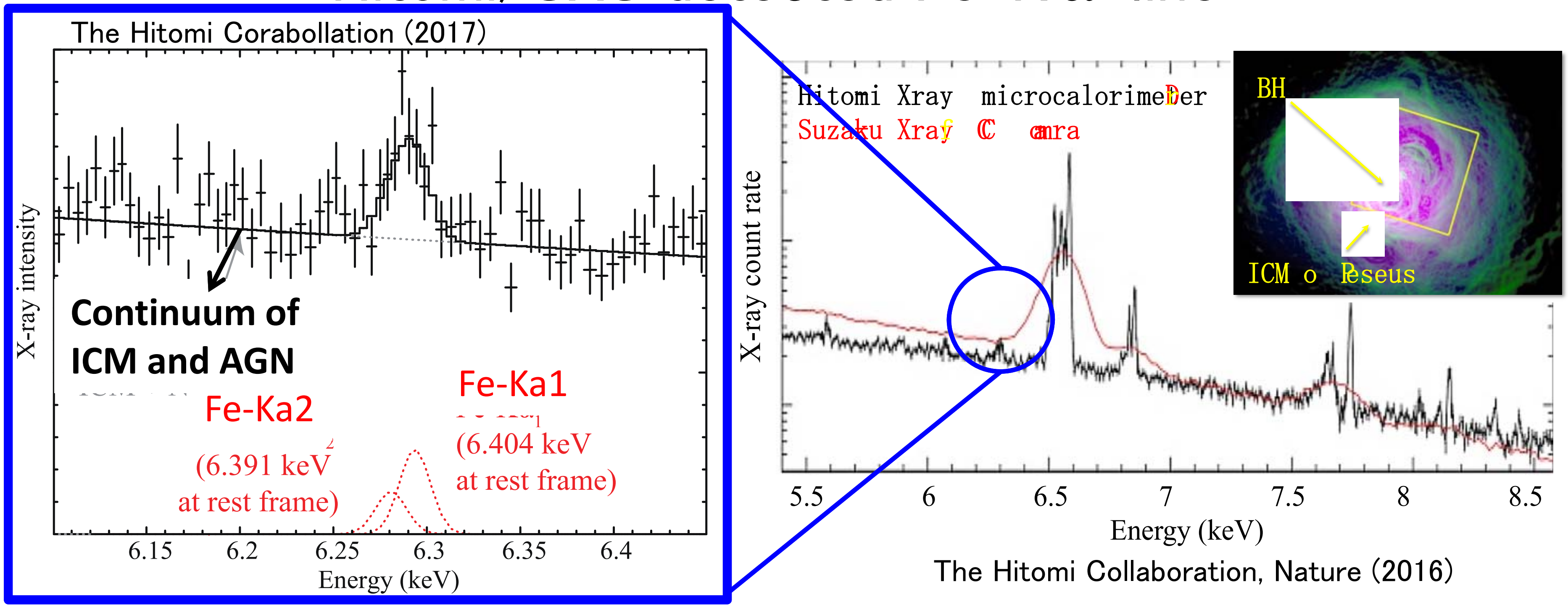
Fukazawa+14

Source	Fe-K line	X-ray spectral index	X-ray variability	[O III] line	Type [ref.]
3C 78	jet	jet	inconclusive	jet	LERG [B10]
NGC1275	disk/corona	inconclusive	inconclusive	disk/corona	HERG/LERG†
3C 111	disk/corona	inconclusive	inconclusive	disk/corona	HERG‡ [E00]
3C 120	disk/corona	inconclusive	inconclusive	disk/corona	HERG‡ [E00]
PKS 0625−354	jet	jet	inconclusive	jet	LERG [M14]
M 87	jet	jet	jet	jet	LERG [G13]
Cen A	disk/corona	inconclusive	jet	inconclusive	HERG [E04]
NGC 6251	jet	inconclusive	inconclusive	jet	LERG [E11]

For low excitation radio galaxies (LERG) ,
X-ray emission is likely to be a jet origin.

For high excitation radio galaxies (HERG) ,
X-ray emission is likely to be a disl/corona origin

Hitomi/SXS detected Fe-Kα line



The Hitomi Collaboration, Nature (2016)

☆ The first fine spectroscopy ($\Delta E/E$ = 4.9 eV/6 keV) of AGN Fe-K line

☆Line is simple (Ka1 + Ka2),, no multiple lines --> almost not ionized Fe

☆ Center energy : 0.01700 ± 0.00063 (optical 0.017284 with WHT 4.2m)

☆ Width_ 500-1600 km/s (FWHM) considering Ka1/Ka2

Narrower than BLR (Hα ~ 2750 km/s FWHM)

➔ Rule out an origin of accretion disk and BLR。

☆ EW ~ 10 eV against total continuum → ~25 eV against AGN continuum)

L/Ledd is low (10-^4 to 10^-3) Does normal torus exist ?

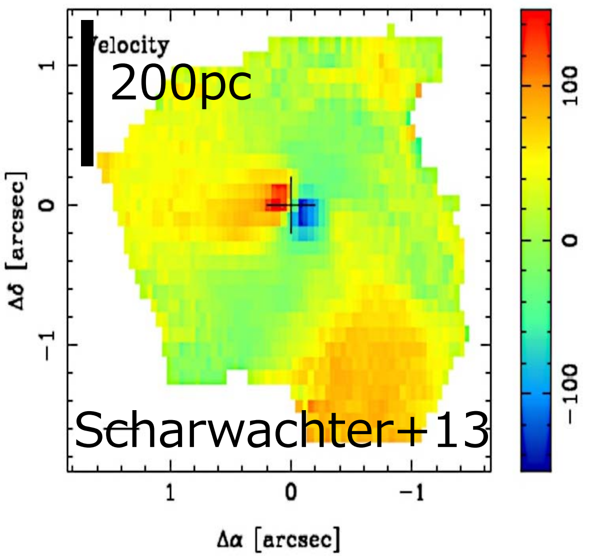
Q: What is an origin of Fe-K line ?
Torus as well as Seyfert galaxies ?

☆ **Fe-K line width is consistent with [Fe II] line width 380–1000 km/s (FWHM) from molecular disk.**

Prefer an origin of molecular disk

☆ **Small EW of Fe-K (25eV) << 100-200 eV of typical Seyferts**

Or peculiar torus wiith a small colune density ?

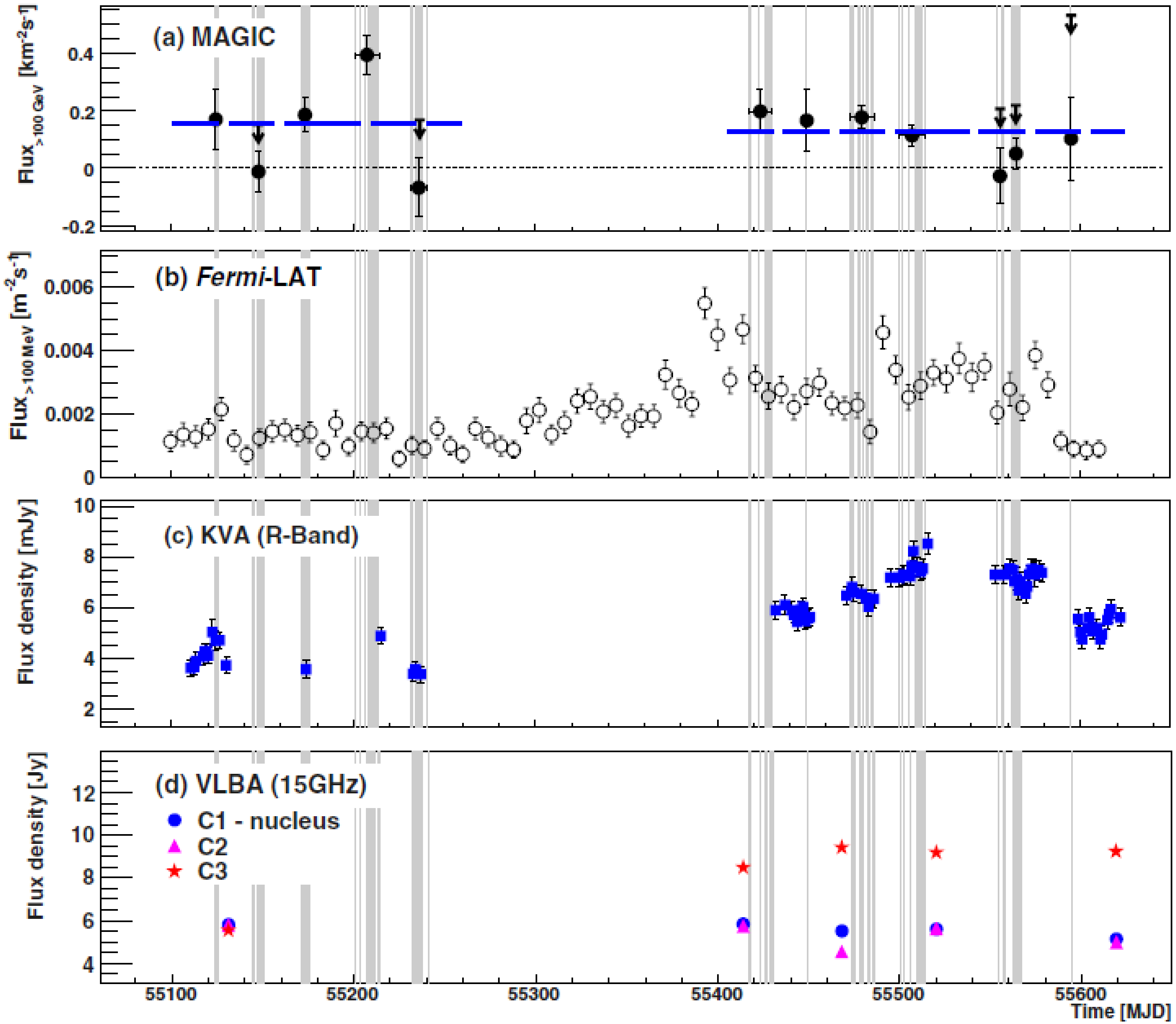


Optical and gamma-ray connection

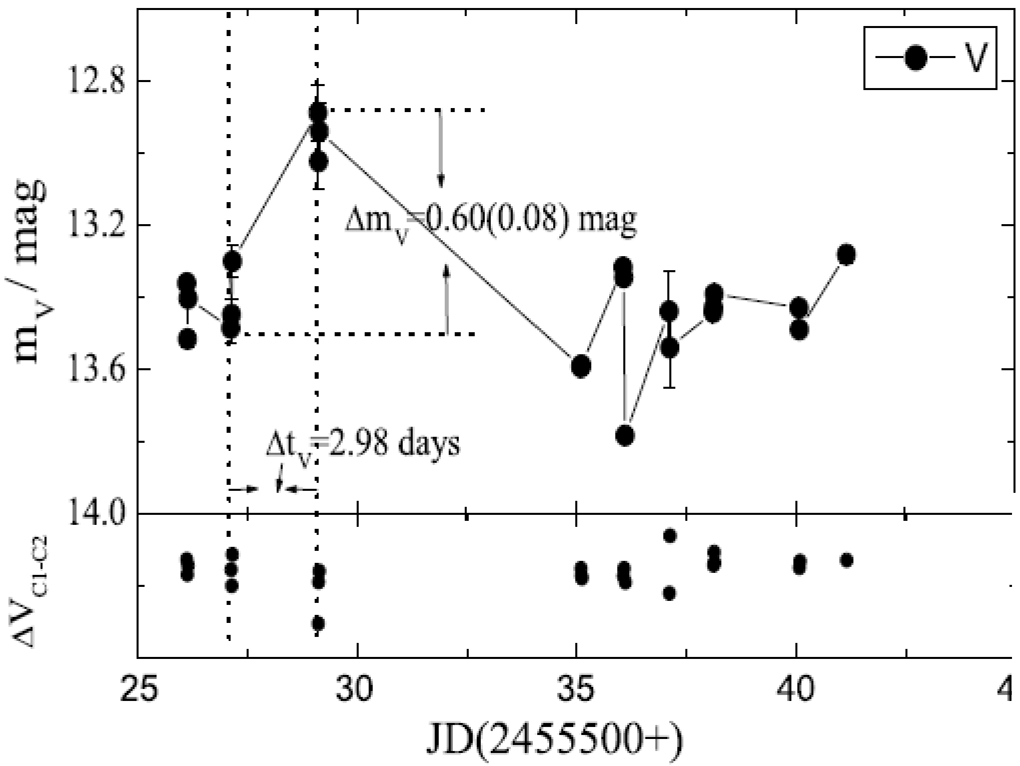
Optical measurement of NGC 1275 AGN is also not easy, due to bright parent galaxy light.

Month-scale optical variability

Alecsic+14

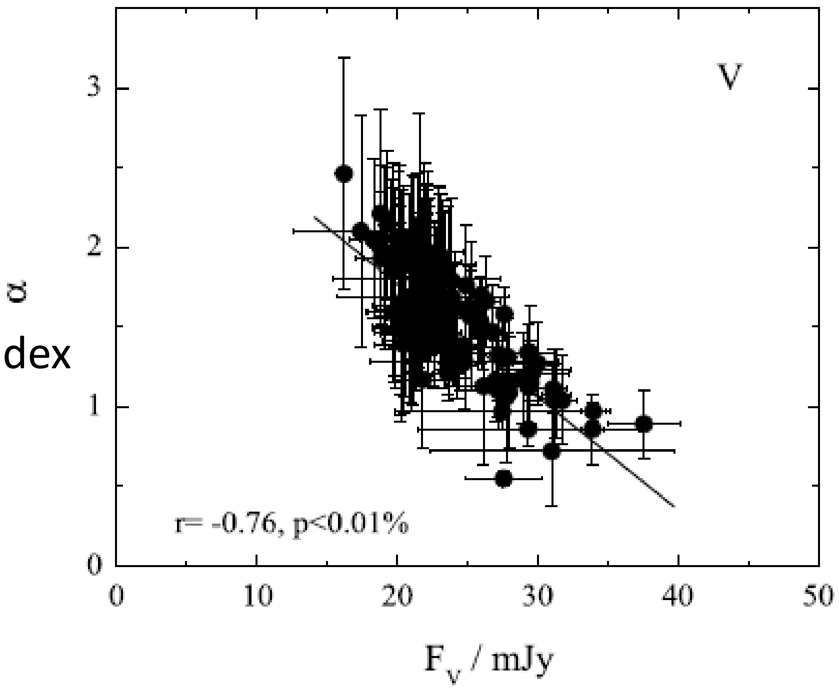


Short-term optical variability was also reported.
Bluer-when-brighter



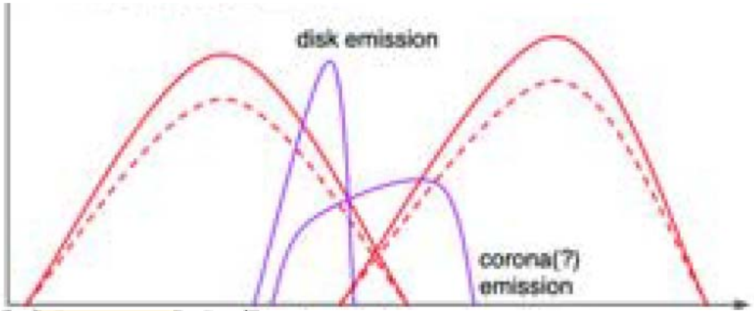
Yuan+15

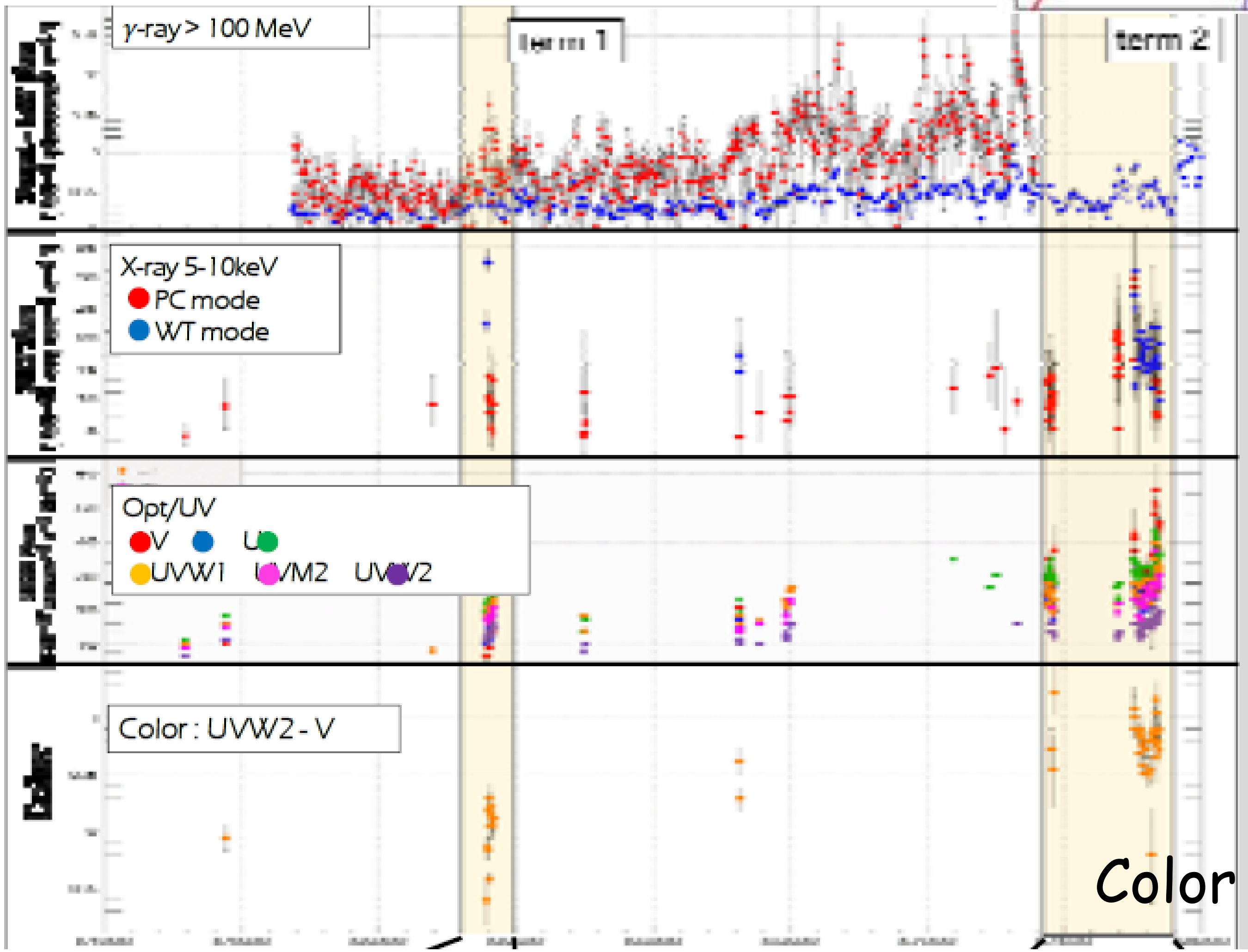
Spectral index



Optical/UV long-term variability

Imazato+ (poster)

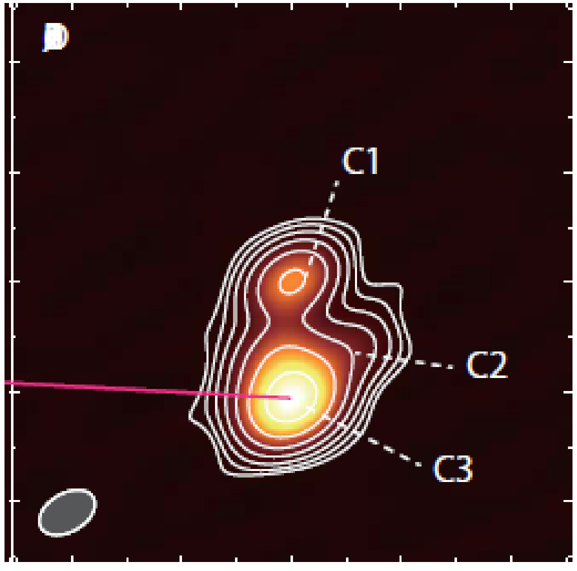




Optical/UV also becomes brightened.

Color becomes redder.

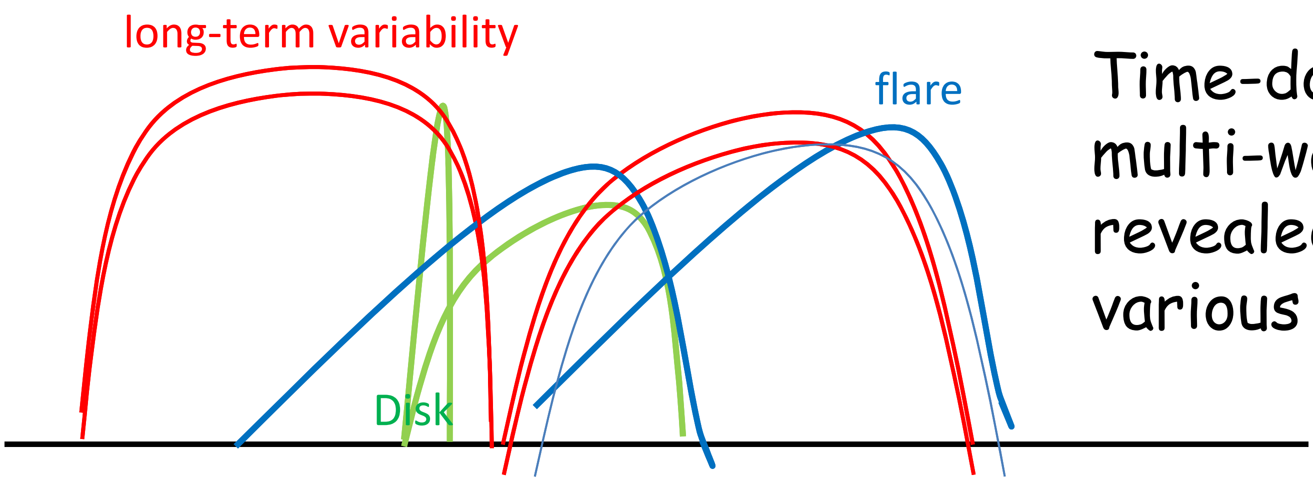
Summary



The flux of NGC1275 has been increasing from radio, optical/UV, X-ray, and GeV gamma-ray, with a little change of SED shape.

C3 is likely an origin of the long-term flux increase.

Very short-term variability and flares are due to highly accelerated electrons in C1 or near BH?



Time-domain and multi-wavelength obs. revealed various emission sites.

Future Prospective

Together with Fermi/radio monitoring jet emission,

CTA … More information on C1 (core) region and flare mechanism/location

XRISM … variability of Fe-K for probing disk/corona emission