Seyfert 2/starburst galaxy: NGC 4945

NGC 4945

NGC 4945 is one of the nearest AGNs (D = 3.8 Mpc) with the black hole mass of $M=1.4\times10^{6}\ M_{\odot}$. It is the brightest Seyfert 2 galaxy in the hard X-ray range, radiating at a variable rate of L/L_{Edd} ~0.1 (Madejski et al. 2000). Its X-ray spectrum shows a strong photoelectric absorption, with a column density (~4×10^{24} cm^{-2}) (Done et al. 2003), at which its nucleus can be directly seen above~8 keV. The observed hard X-ray radiation is highly variable, by a factor of several on a time scale of days, confirming that it is a transmission-dominated Compton-thick AGN.

NGC 4945 is also one of a few radio-quiet AGNs detected by Fermi/LAT (Abdo et al. 2010a; Lenain et al. 2010). The origin of this γ-ray signal is unclear, as this galaxy hosts a circumnuclear starburst (e.g. Lenc & Tingay 2009) which may also account for this emission. Variability studies are crucial to disentangle the role of the AGN and starburst activities, but weakness of the γ-ray signal is a major issue for such studies. The apparent lack of the γ-ray variability, assessed in Ackermann et al.(2012a), could favor the γ-ray production dominated by starburst processes. However, the 3-month intervals used in Ackermann et al.(2012a) are too short to accumulate a statistically significant γ-ray signal from this galaxy, whereas its AGN exhibits an approximately constant activity on such a time-scale.

Here we present a novel approach to investigate the γ-ray variability in NGC 4945 by analyzing the LAT data selected based on the X-ray flux level.

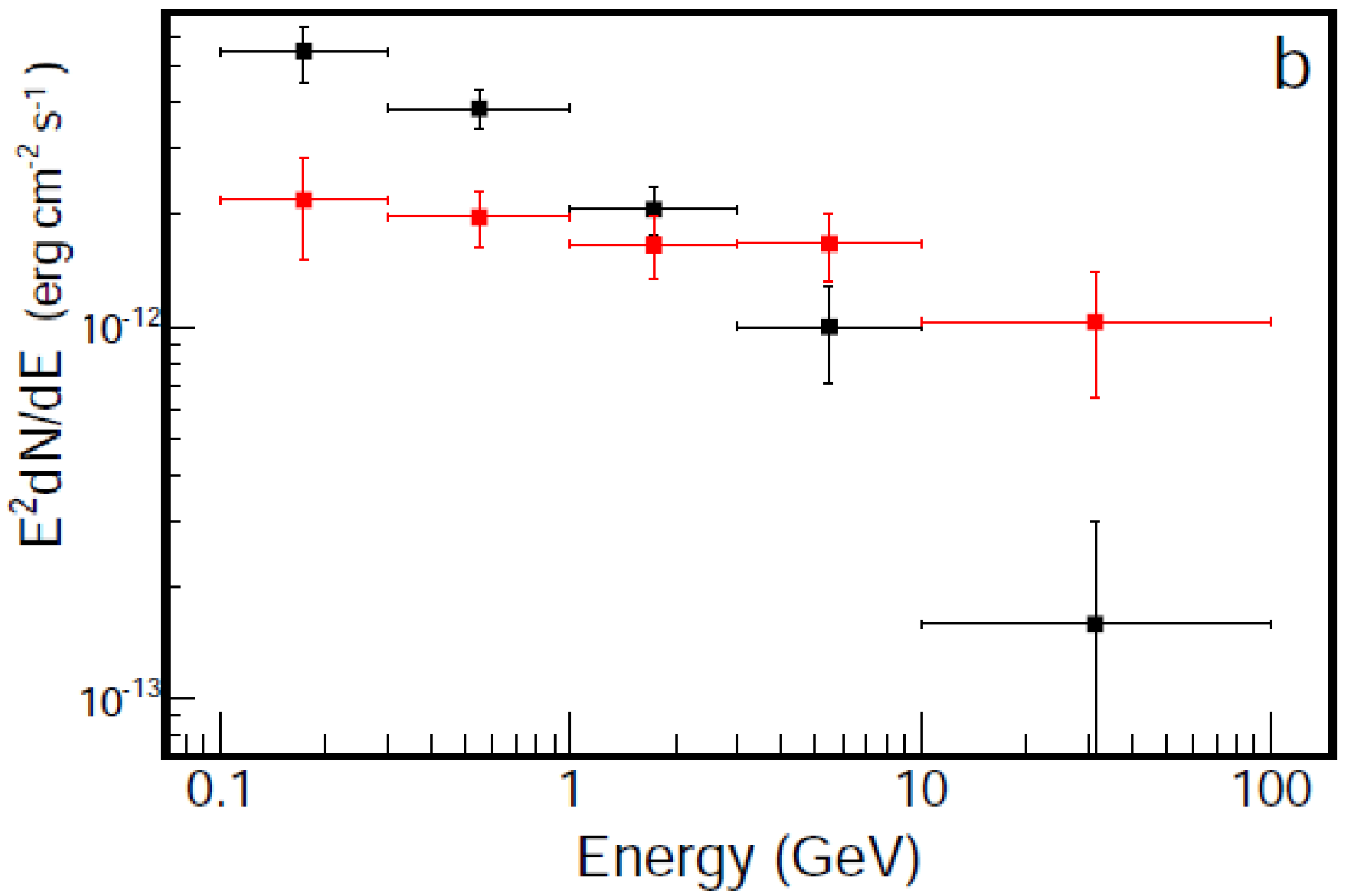

Figure 1. NGC 4945 spectral energy distributions for datasets resolved by the X-ray flux; SED for L is shown in black and SED for H is shown in red.

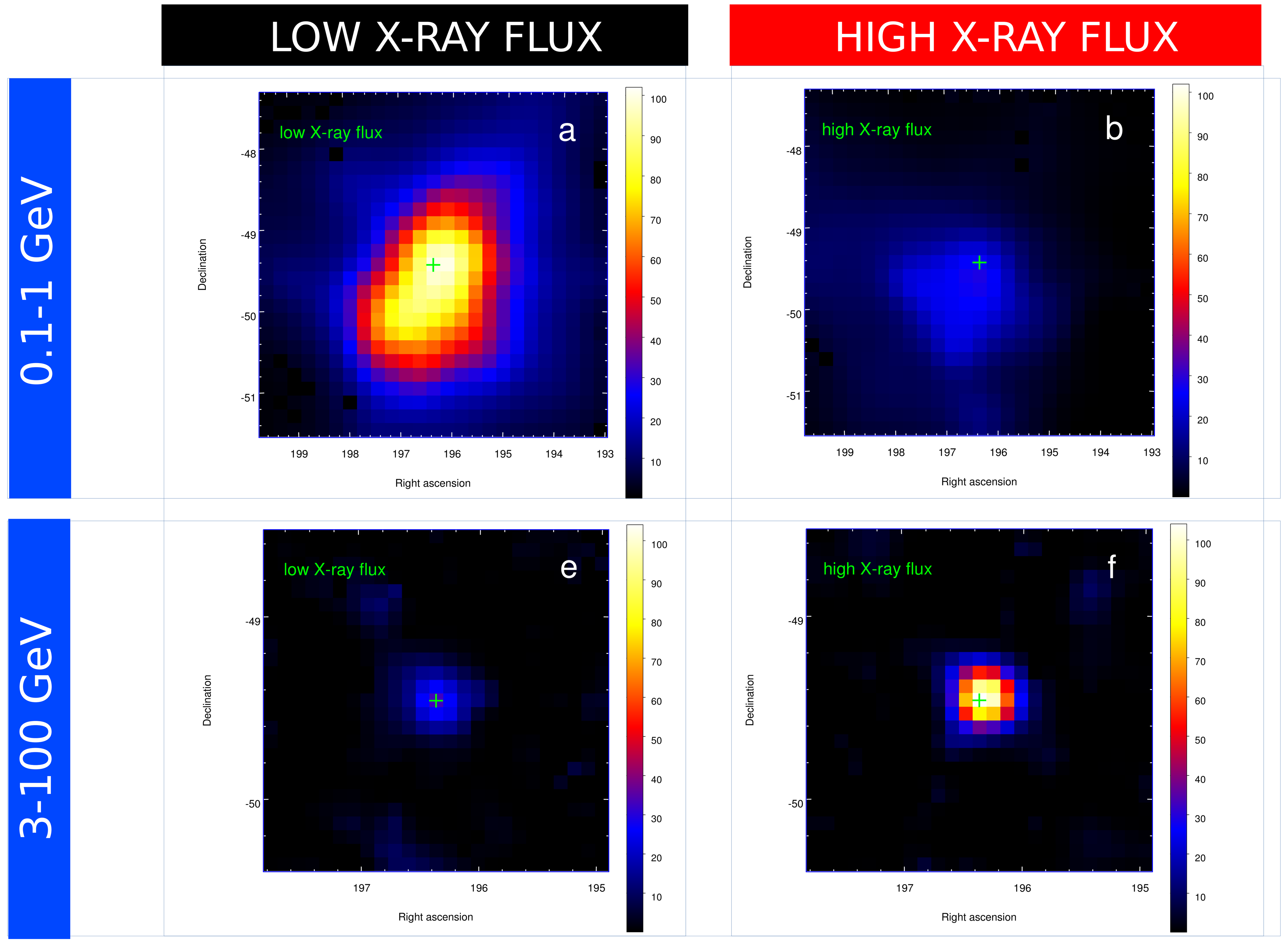

Figure 2. TS maps for the region around NGC 4945 built using the events detected during the low (dataset L; left maps) and high (dataset H; right maps) X-ray flux levels.

- top maps are for events with E < 1 GeV
- bottom maps are for events with E > 3 GeV

OBSERVATIONAL DATA

We use the Fermi/LAT and Swift/BAT data from observations performed by these detectors between 2008 August 4 and 2016 August 15. The good quality data (with DATA_FLAG=0) from BAT light curves in the 15–50 keV range allow to determine the daily count rate values, F_X, for 2783 days out of 2821 days in the considered period of time. We split them into two approximately equal MJD sets, containing days with F_X lower (set L; 1393 days) and higher (set H; 1390 days) than 1.71×10^{-3} cts $cm^{-2}s^{-1}$.

We performed the unbinned likelihood analysis of these datasets using Pass 8 LAT data in the 0.1–100 GeV range and v10r0p5 Fermi Science Tools with the P8R2_SOURCE_V6 instrument response function. We used the standard templates for the Galactic (gll_iem_v06.fits) and the isotropic backgrounds (iso_P8R2_SOURCE_V6_v06.txt) .

NGC 4945: X/γ-ray correlation results

RESULTS

Our main results are presented in Figures 1 and 2 and Table 1. All our results indicate that the γ-ray spectrum of NGC 4945 changes with the change of its hard X-ray flux. The significance of the spectral difference between the power-law fits for datasets H and L is 5 sigma.

We performed the division of LAT observations into datasets corresponding to smaller ranges of F_X than those of L and H. Again, we find a systematic indication of hardening of the γ-ray spectrum with the increase of the X-ray flux, see Figure 3.

	F_X	Γ	F	TS
Low (1393 days)	0.54 ± 0.03	2.47 ± 0.07	2.6 ± 0.3	221
High (1390 days)	2.87 ± 0.04	2.11 ± 0.08	1.2 ± 0.2	189
Total (2821 days)	1.59 ± 0.02	2.33 ± 0.05	1.9 ± 0.2	410

Table 1. Results of the power-law fits in the 100 MeV - 100 GeV range;

F_X is the average BAT count rate in the 15–50 keV range in units of 10^{-3} cts cm^{-2} s^{-1},

Γ is the power-law index,

F is the energy flux in the 0.1–100 GeV range in units of 10^{-11} erg cm^{-2} s^{-1}.

Γ AS A FUNCTION OF X-RAY FLUX

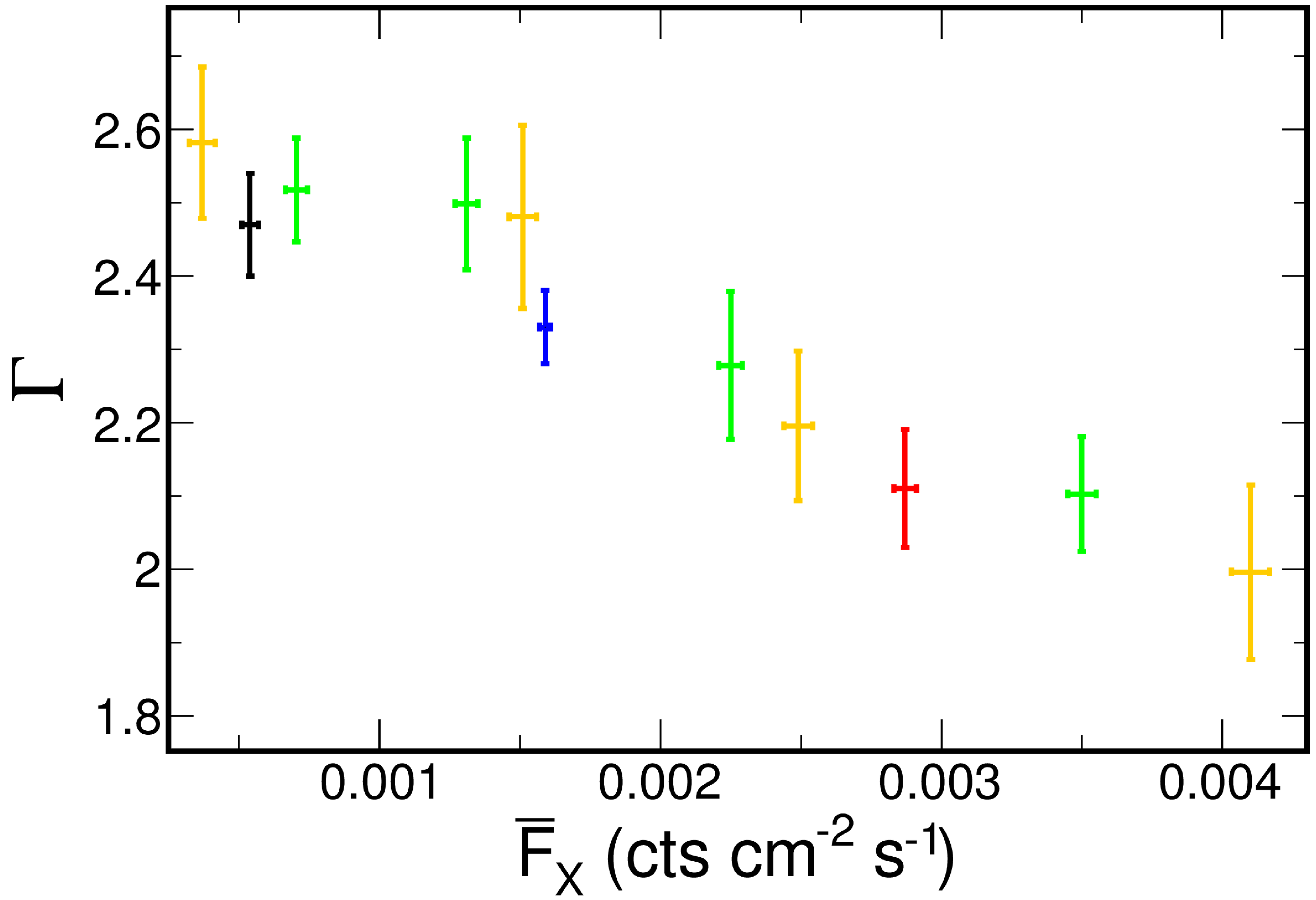

Figure 3. Photon spectral index of power-law fits in the 0.1– 100 GeV range as a function of F_X. The yellow points are for datasets containing 620 days in consecutive, non-overlapping ranges of F_X . The green points are for datasets containing 900 days in similar but partially overlapping ranges of F_X . The black, blue and red point is for dataset L, T and H.

NGC 4945 compared to other starbursts (spectral and IR)

Discussion

DISCUSSION

Apart from NGC 4945, two other Seyfert 2 galaxies, NGC 1068 and Circinus, have been detected by LAT (Hayashida et al. 2013; Lenain et al. 2010). Similar to NGC 4945, these galaxies exhibit a composite starburst/AGN activity and the interpretation of their γ-ray emission is uncertain. Among the three γ-ray loud Seyfert 2s, the X/γ-ray correlation can be investigated only in NGC 4945, which has the largest γ-ray detection significance, and whose variable X-ray emission from the nucleus can be directly observed. In contrast, the X-ray radiation from NGC 1068 is fully reflection dominated and no variability is observed. Circinus, in turn, is strongly contaminated by the Galactic plane and its detection significance is too low to search for changes of the γ-ray spectrum.

The correlation revealed in our study implies that dominating contribution to the observed γ-ray emission comes from the active nucleus of NGC 4945 and this constrains the efficiency of γ-ray production related with starburst activity. The implied limit on the radiative efficiency (with at most 20% of the cosmic ray power lost in pionic interactions) is slightly lower than the efficiencies assessed for NGC 253 and M 82.

We note similarities between NGC 4945, NGC 1068 and Circinus:

- similar Eddington ratios of their X-ray and γ-ray Eddington emission,
- lack of TeV detections,
- unlikely high efficiencies of γ-ray production in starburst scenario, if the IR luminosity is used as a measure of the star-formation rate (see Fig 4) which we regard as a further argument for a dominating contribution of their active nuclei to the γ-ray emission.

We used the model of internal γγ absorption (Wojaczynski et al. 2015), to assess possible locations of the γ-ray emitting site in the NGC 4945 active nucleus. The nature of the γ-ray source may be different at low and high X-ray luminosities. At the latter, the γ-ray transparency and the causality conditions require the source to be located ~(10^3-10^4) R_g away from the central black hole. At low X-ray luminosities, the source may be located much closer to the black hole.

COMPARISON γ-RAY/ IR

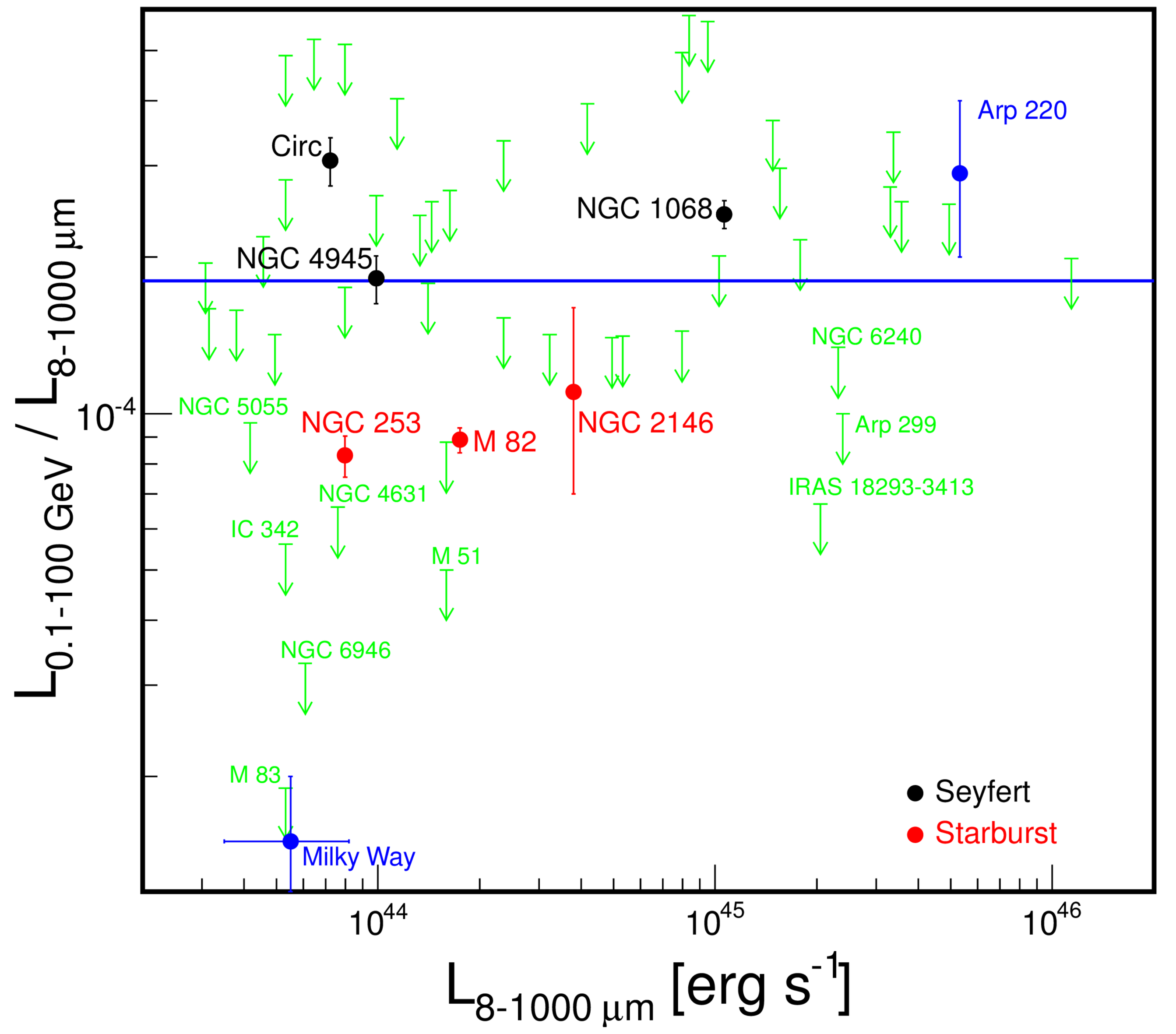

Figure 4. Comparison of the γ-ray (0.1–100 GeV) and IR (8–1000 μm) luminosities for star-forming and Seyfert galaxies. We adopted data from Tang et al. (2014) for NGC 2146, Griffin et al. (2016) for Arp 220, Ackermann et al. (2012a) for IR luminosities and Milky Way γ-ray luminosity, upper limits (green arrows) from Rojas-Bravo & Araya (2016) for non-detected galaxies and we used our results for NGC 4945 (dataset T), NGC 1068, Circ, M 82 and NGC 253 (Table 1). The blue line shows the calorimetric limit.

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