Gamma-ray Flares in The Relativistic Jet of The Quasar 3C 273 in 2015--2019

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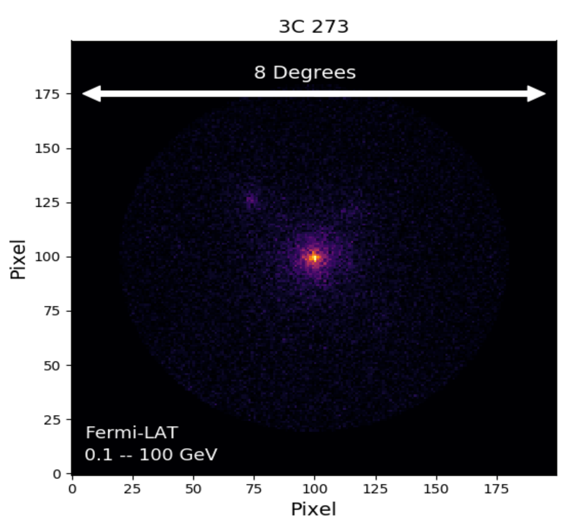
ABSTRACT

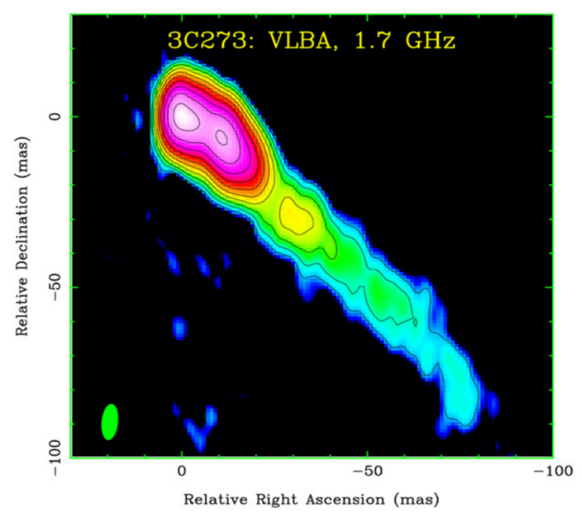
3C 273 is an obvious candidate to reveal the nature of γ-ray emission in the relativistic jet of blazars due to its prominent γ-ray emission and powerful jet activity. Since the historical huge γ-ray outburst in 2009, 3C 273 became relatively weak in γ-ray flux density for a long time. However, recent Fermi-Large Area Telescope observations indicate some flaring periods in 3C 273. We aim to investigate the origin of the γ-ray flares in 3C 273 by utilizing light curves at radio and γ-rays, plus the radio images obtained from a very long baseline interferometry (VLBI). In this study, we present radio/γ-ray light curves, correlation, γ-ray photon properties, and VLBI jet images of 3C 273, and discuss its physical indications for the connection between the radio jet and γ-ray flares.

Introduction

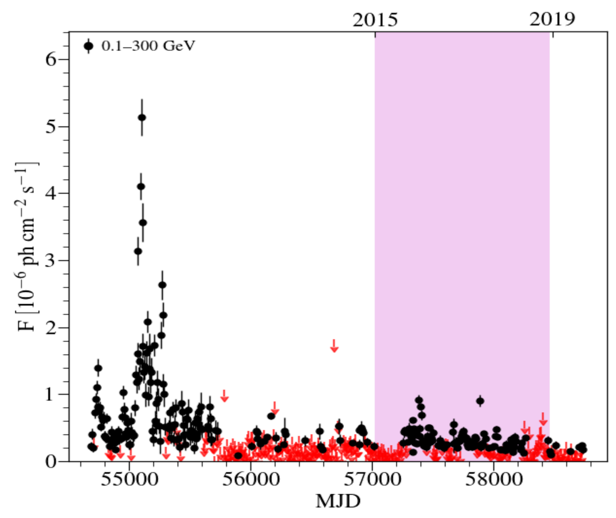
It has been known that ~75 % of MeV γ-ray sources in the sky are classified as Blazar which is one of active galactic nuclei (AGN) types with its very small viewing angle (e.g., ~5 degrees). In general, the relativistic jet is thought to be a main source of the γ-rays due to its extreme condition and radiative power. However, the details of the physical processes are still an open issue. In this study, we explore γ-rays and the jet of 3C 273 in 2015--2019 with the observational data: ALMA (~100 GHz), Fermi-LAT (0.1--300 GeV), and VLBA (43 GHz; VLBA-BU-BLAZAR [1]).



<γ-ray Countmap>

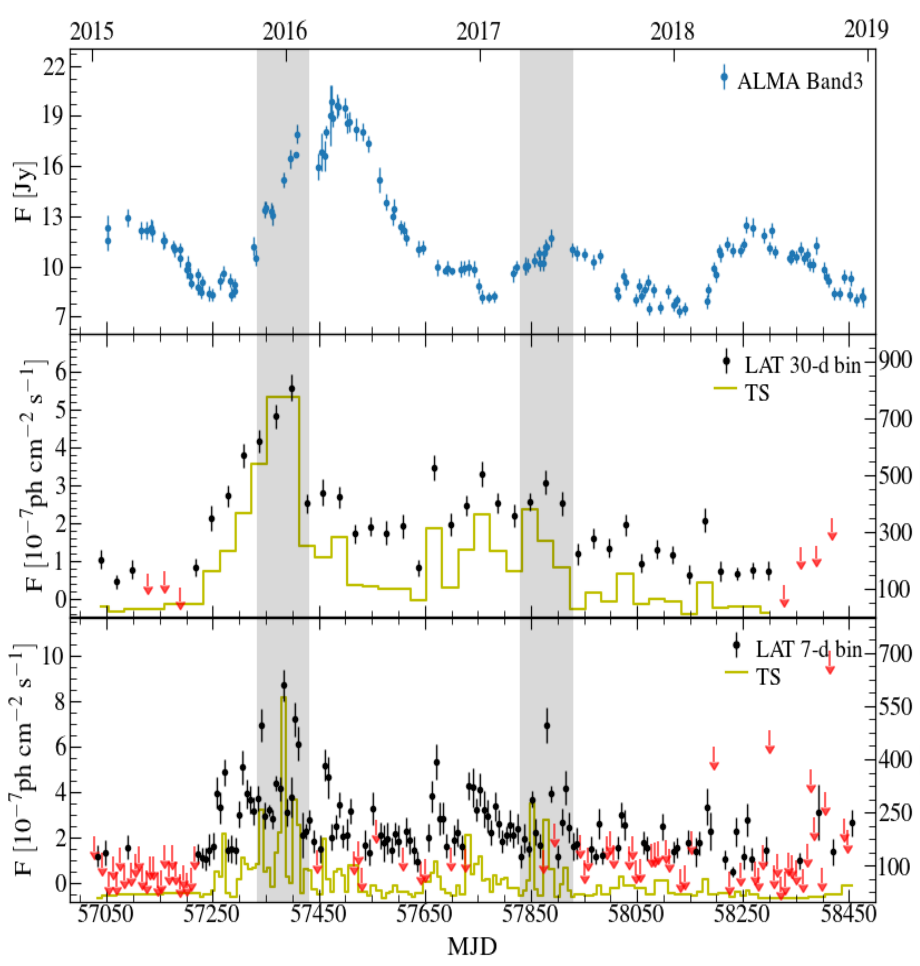


<Radio jet image from Kovalev et al. 2016>

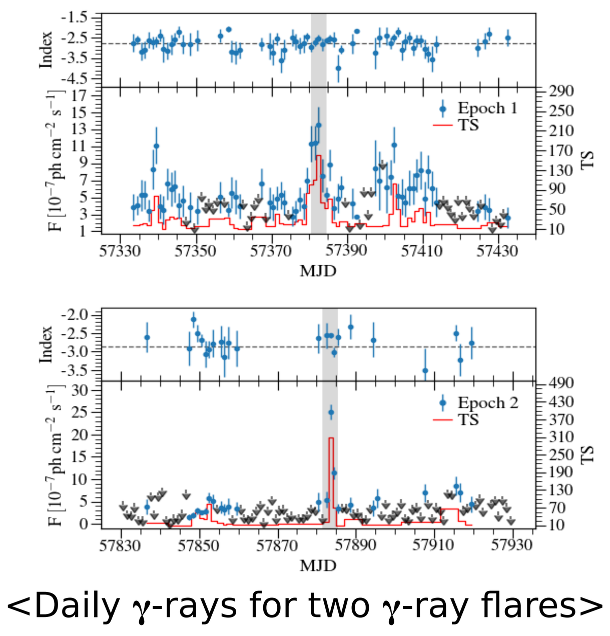


Left: a public γ-ray light curve of 3C 273 observed by the LAT. Full time coverage of ~10 years with weekly binning. The light purple area is the time range of this study.

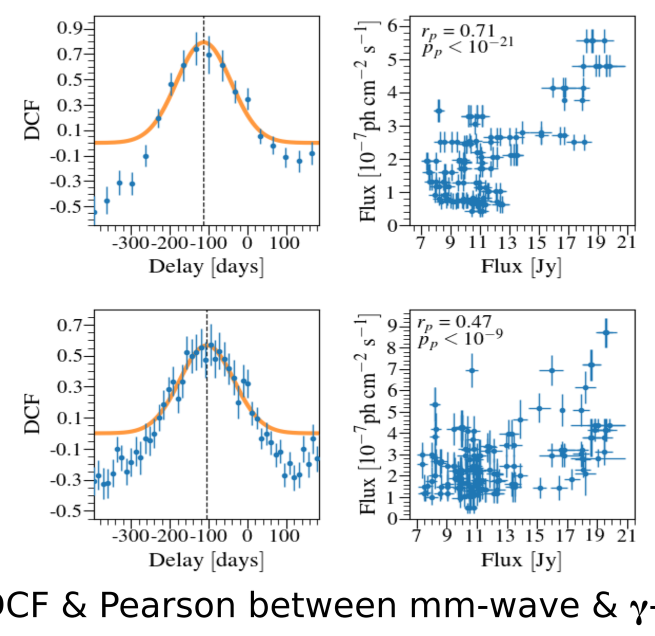
Radio/γ-ray light curves



- A major mm flare ~20 Jy on MJD 57486.
- An extra peak of the major mm flare ~18 Jy on MJD 57408.
- Three minor mm flares below 13 Jy.
- Monthly γ-ray variations: smooth around 2016 & complex around 2017.
- In weekly γ-rays, two prominent flares in early 2016 and mid-2017.
- The first γ-ray flare: 8.7 x 10^{-7} ph cm^{-2} s^{-1} at ~24 σ on MJD 57383.
- The second γ-ray flare: 7.0 x 10^{-7} ph cm^{-2} s^{-1} at ~15 σ on MJD 57880.



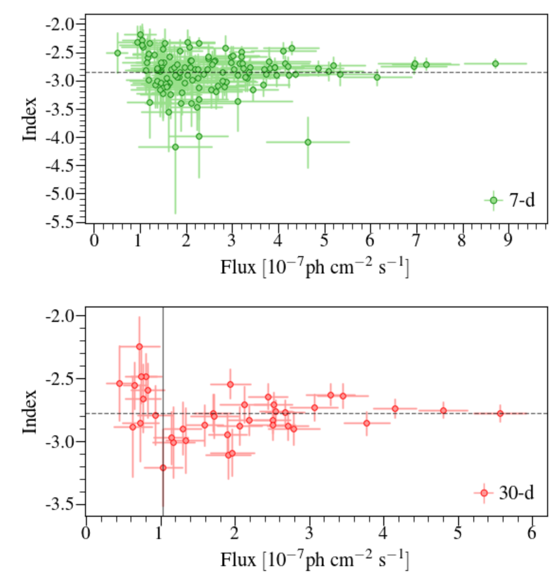
<Daily γ-rays for two γ-ray flares>



<DCF & Pearson between mm-wave & γ-ray>

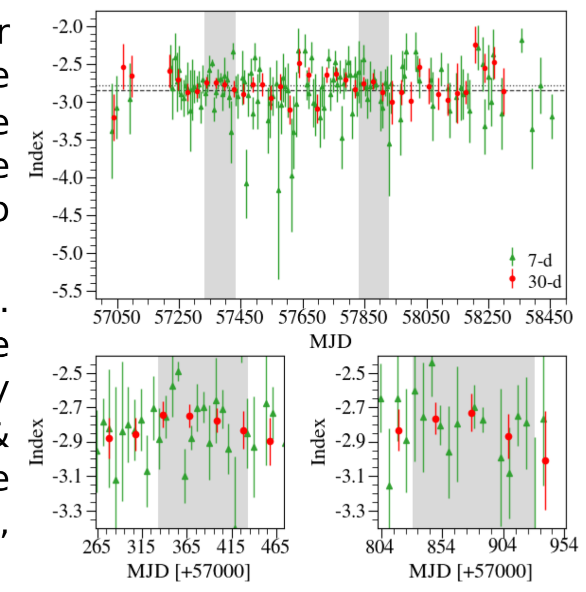
We find two most significant γ-ray flares in 2015--2019 that overlaps one mm-wave flare for each. The weekly γ-rays seem more complicated than the monthly, and the second γ-ray peak is isolated. A DCF curve and Gaussian fit returns about -105 days (vs. 7d) and -112 days (vs. 30d) time-lags (γ-ray leading) with a good coefficient.

Power-law indices of the γ-rays



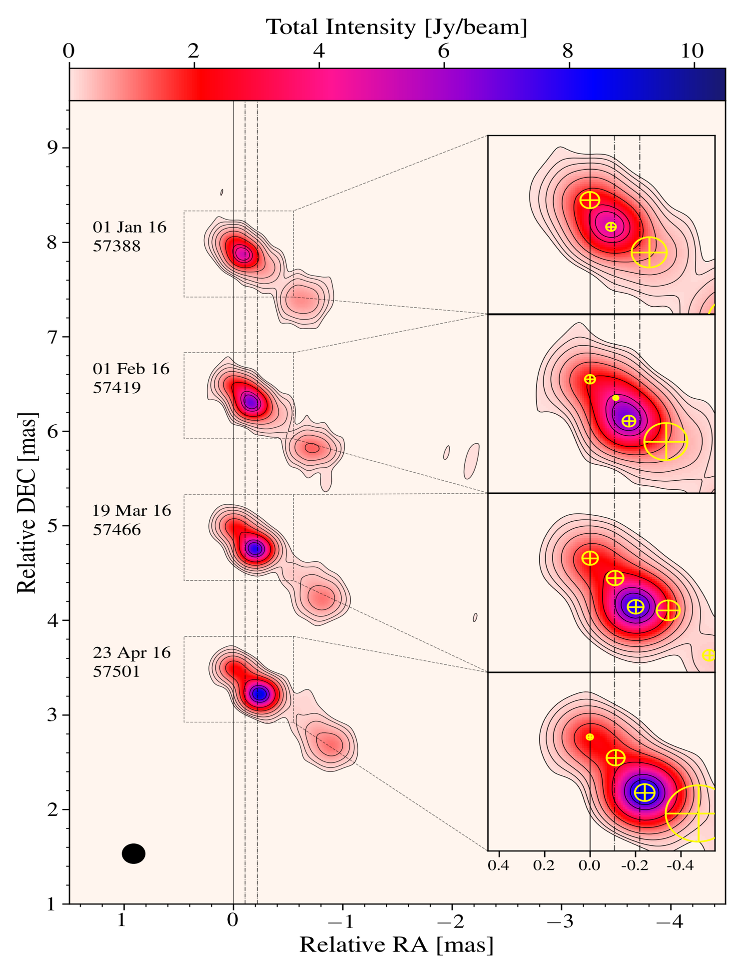
Left: index vs. flux plots for the γ-ray photons. The dashed lines indicate the average values, and the vertical solid line points to 1.03 x 10^{-7} ph cm^{-2} s^{-1}.

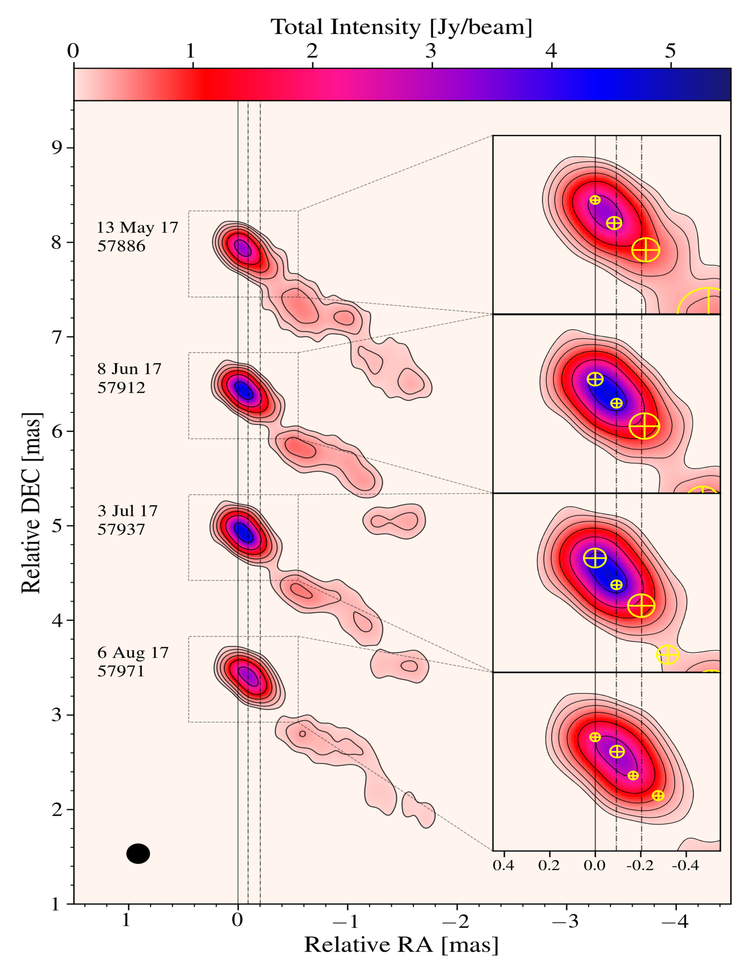
Right: Index vs. time plot. The vertical gray areas are the same as 7d & 30d γ-ray light curves. The dashed & dotted lines are the average value for the 7d & 30d, respectively.



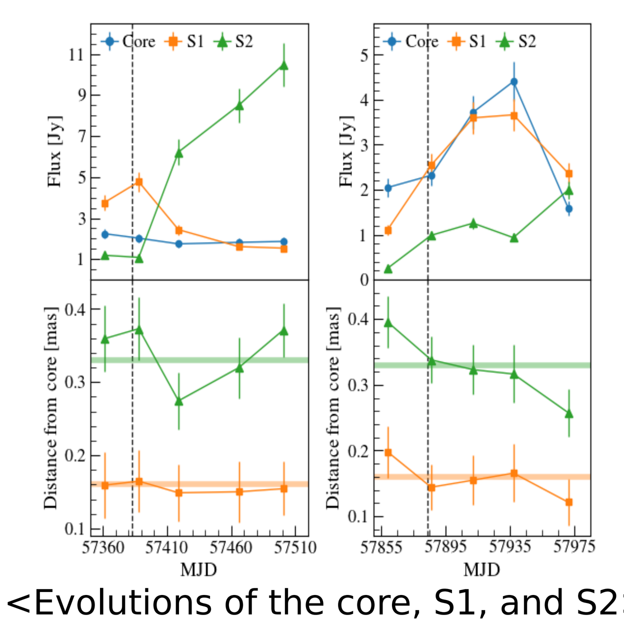
The average power-law indices of the γ-ray photons for both 7d and 30d are -2.85 and -2.78, respectively. In the 30d indices, we see a transition above 1.03 x 10^{-7} ph cm^{-2} s^{-1} (Pearson r_p=0.48 at > 0.99%). As binning interval gets shorter, small-scale γ-rays seem dominating the γ-ray emission. Although we have limited photon statics, there seems to be a hump of the 30d index in each γ-ray flaring period (i.e., first on MJD 57338 and second on MJD 57878).

Parsec-scale jet near the core





<3C 273 jet shortly after the first γ-ray flare (**left**) and the second γ-ray flare (**right**) >



<Evolutions of the core, S1, and S2>

The jet flows toward the southwest from the core which is the upstream end of the jet. In our images, we find the known three stationary components (e.g., [2]): the core, S1, and S2 at ~0.16 and ~0.33 mas from the core (set to be map center). The total intensity peak shows a spatial displacement along the jet right after the two γ-ray flares. The apparent speed of the first one is ~7c (proper motion, **μ**: 0.69 mas/year), and of the second one is ~3c (**μ**: 0.29 mas/year).

Summary & References

We present the recent radio/γ-ray activity of the 3C 273 jet. In 2015--2019, we identify the most significant two γ-ray events which coincides with a mm-wave flare for each. Given the observational evidences, we summarize our results as below.

- The radio/γ-ray emissions during 4 years are correlated each other.
- Monthly binning better describes the systematic trends in the 3C 273 γ-rays.
- With shorter binning intervals, we define two primary γ-ray outbursts.
- We suspect that the S1 component is the origin of the first γ-ray flare.
- The second γ-ray flare seems more complicated, but the core is likely to be its origin as it shows the onset of a mm-wave flare.

-Ref. [1] Jorstad et al. 2017, ApJ, 846, 98 [2] Lisakov et al. 2017, MNRAS, 468, 4478