Quasi-simultaneous decade-long optical and γ-ray monitoring of selected blazars.

Valeri Larionov,
Sergey Savchenko, Svetlana Jorstad, Alan Marscher, Paul Smith, Iván Agudo

St.Petersburg University, Boston University, Steward Observatory,
Instituto de Astrofísica de Andalucía

- **The importance of monitoring projects in blazar studies was clear from the very discovery due to their violent variability on all time scales, from hours and even minutes to years.**

- **The outbursts that may occur unexpectedly for any given source act like a magnifying glass that allow to penetrate deeper in most conspicous regions of inner jet.**

- **Numerous successful campaigns were carried out that lead to systematic accumulation of observational data, either inside one observatory or as large international collaborations, such as**

W E B T

- **Operation of the *Fermi* orbital observatory provides high-energy data for a large number of blazars with unprecedented temporal coverage and high signal-to-noise ratio, previously attainable only in the optical range.**

- **We use publicly available *Fermi* data and our optical photometry, creating quasi-simultaneous light curves. Optical data come from telescopes widely spread in longitude (St.Petersburg, Crimea, Calar Alto, Arizona).**

- **For a large number of sources, F_{opt} and F_γ show evidence for either a linear or quadratic correlation. These correlations may be used to distinguish between various models for the high-energy emission from blazars.**

- **In addition, we show that the contribution to the observed flux of less variable sources of emission (e.g., the accretion disc) may be evaluated from these data.**

Fermi:

Adaptive binning (see poster by Sergey Savchenko for the details)

Optical:

SELECTION:

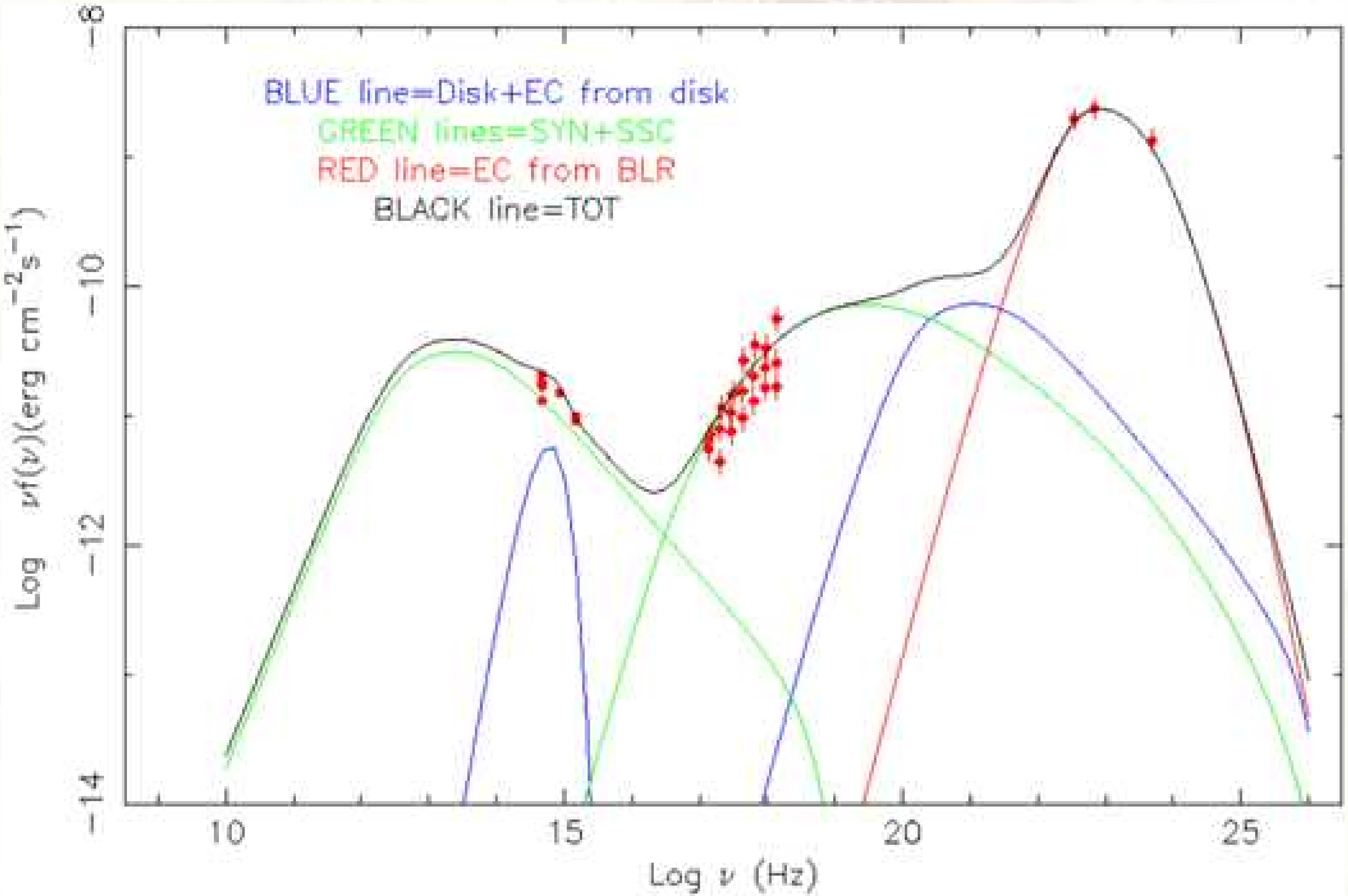
- Only sources with dense optical coverage;
- For this study we use only R band, as most densily populated

RESERVATION:

- R band is not always close to the position of the synchrotron maximum

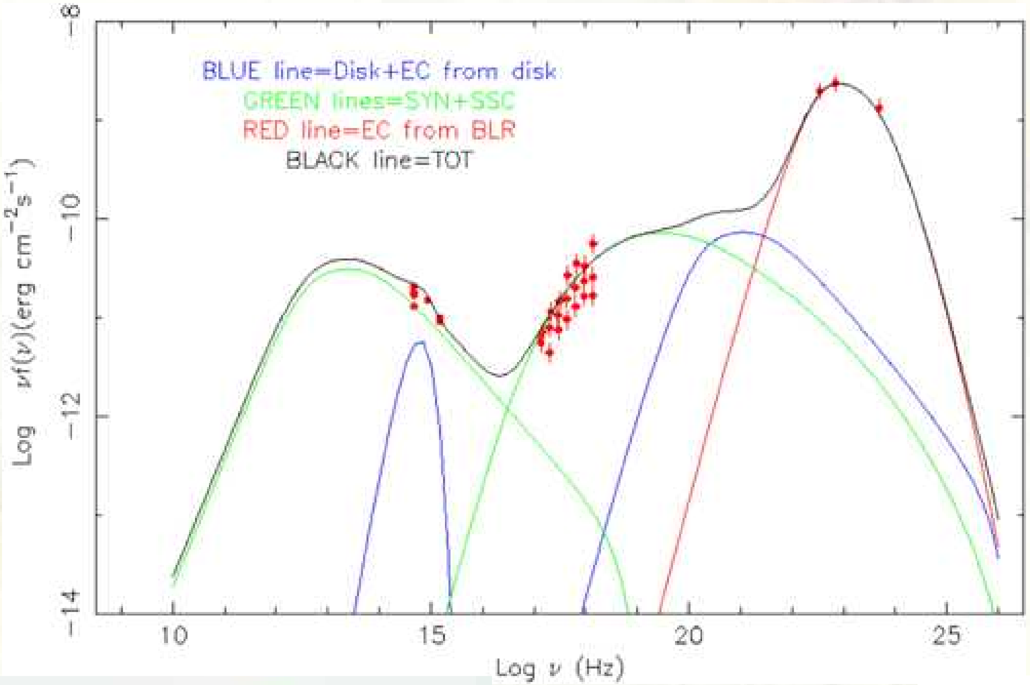
Figure 5 from The Bright γ-ray Flare of 3C 279 in 2015 June: AGILE Detection and Multifrequency Follow-up Observations

C. Pittori et al. 2018 ApJ 856 99



SSC case:

$F_{IC} \sim F_{sync}^{2}$



EC case:

$F_{IC} \sim F_{sync}^{1}$

… and do not forget the changes in magnetic field, viewing angle, orphan flares...

http://vo.astro.spbu.ru/program

FSRQ

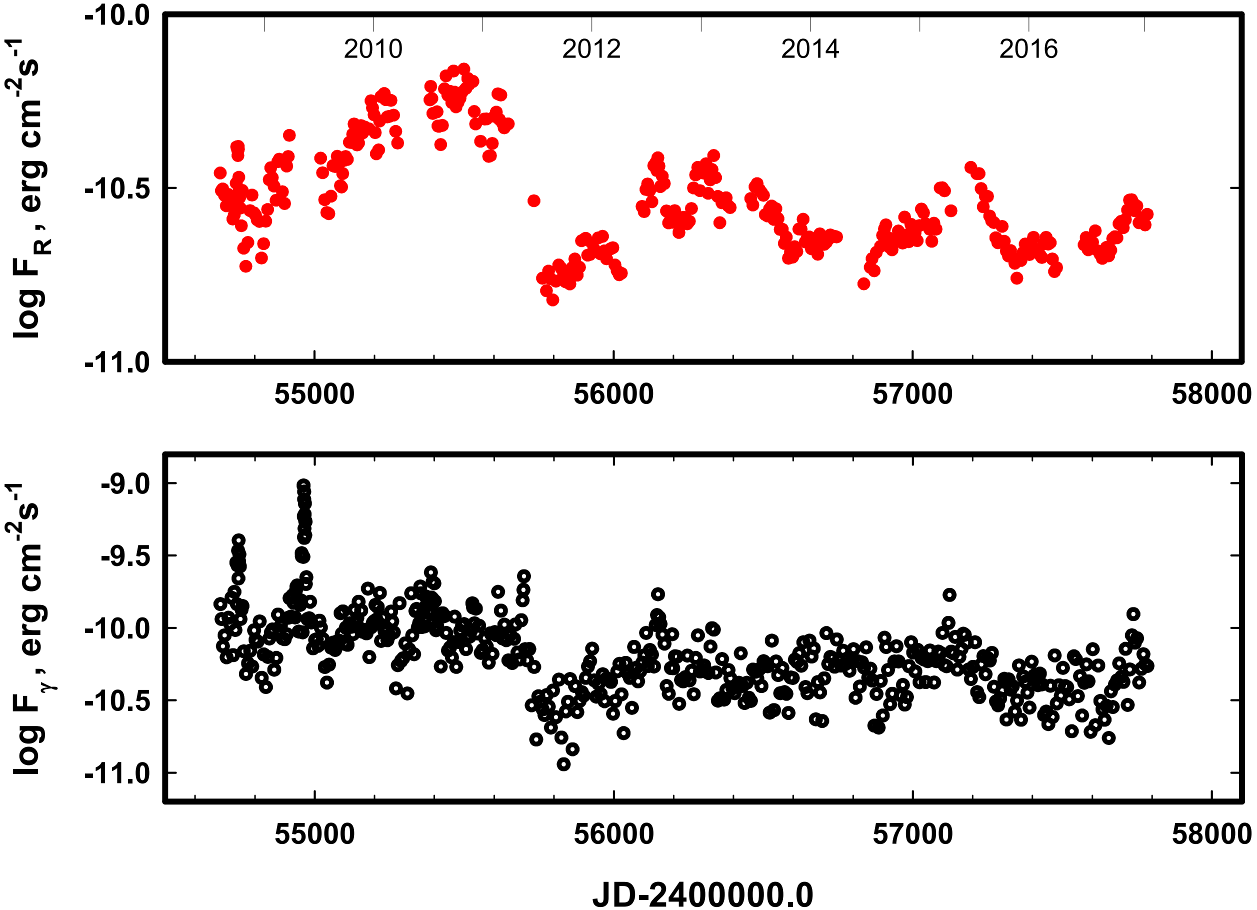
- AO 0235+16
- CTA 26
- OJ 248
- S4 1030+60
- B2 1156+29 = Ton599
- PKS 1222+21
- 3C 279
- PKS 1510-089
- B2 1633+38 = 4C +38.41
- CTA 102
- 3C 454.3

BL Lac

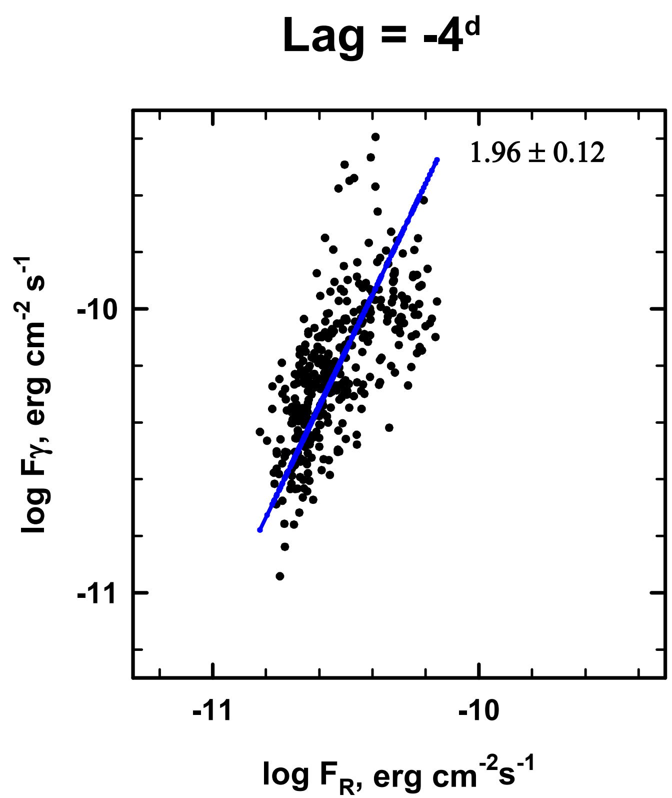
- 3C 66a
- S5 0716+71
- PKS 0735+17
- OJ 287
- S4 0954+65
- Mkn 421
- PG 1553+113
- OT 081 = PKS 1749+096
- BZB J1959+6508
- BL Lac

BLLac

3C 66a   z=0.444

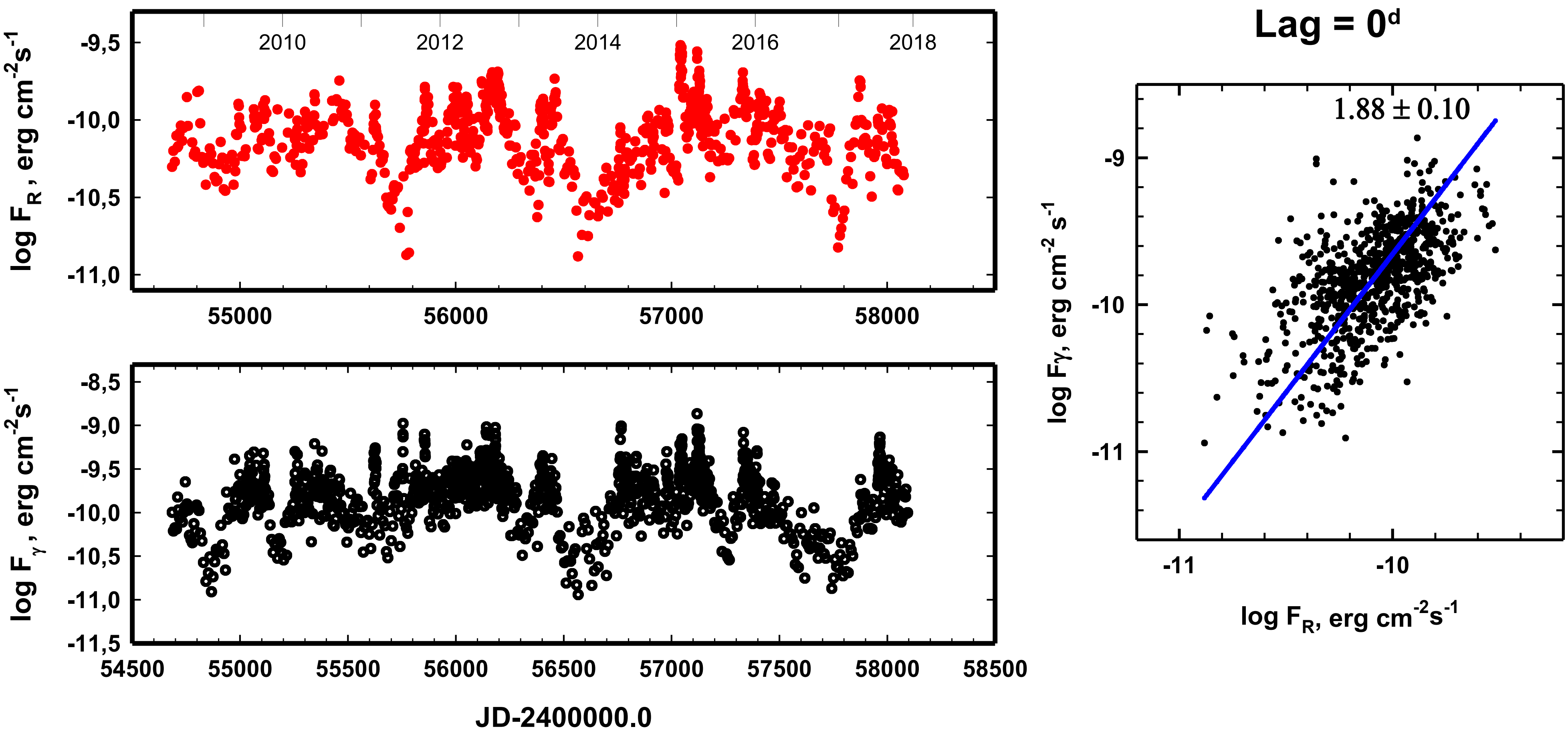


log F_R , erg cm^{-2}s^{-1}
-10.0
-10.5
-11.0
2010
2012
2014
2016
55000
56000
57000
58000
log F_γ , erg cm^{-2}s^{-1}
-9.0
-9.5
-10.0
-10.5
-11.0
55000
56000
57000
58000
JD-2400000.0

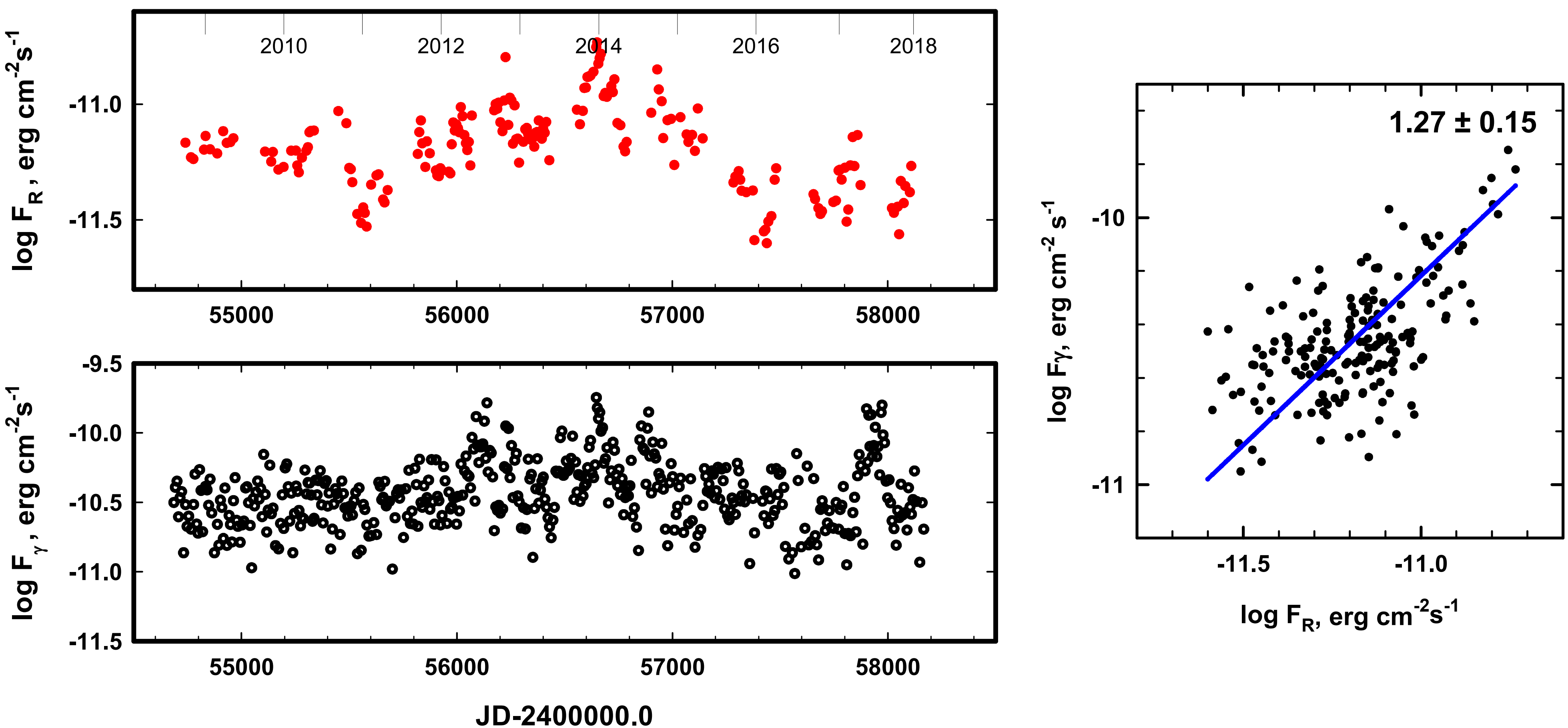


Lag = -4^d
1.96 ± 0.12
log Fγ, erg cm^{-2} s^{-1}
-10
-11
-11
-10
log F_R, erg cm^{-2}s^{-1}

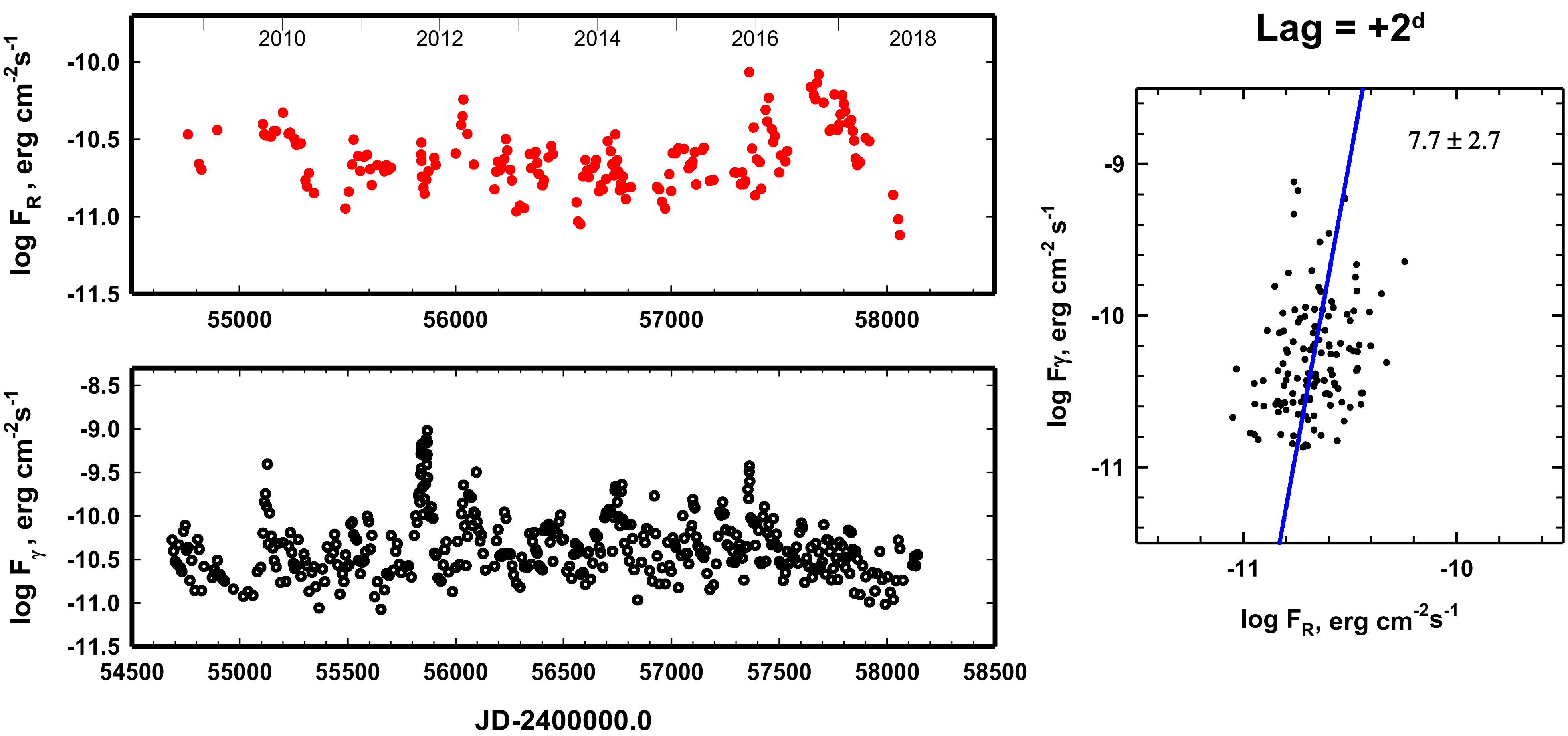
S5 0716+71 z~0.31



PKS 0735+17 z=0.424

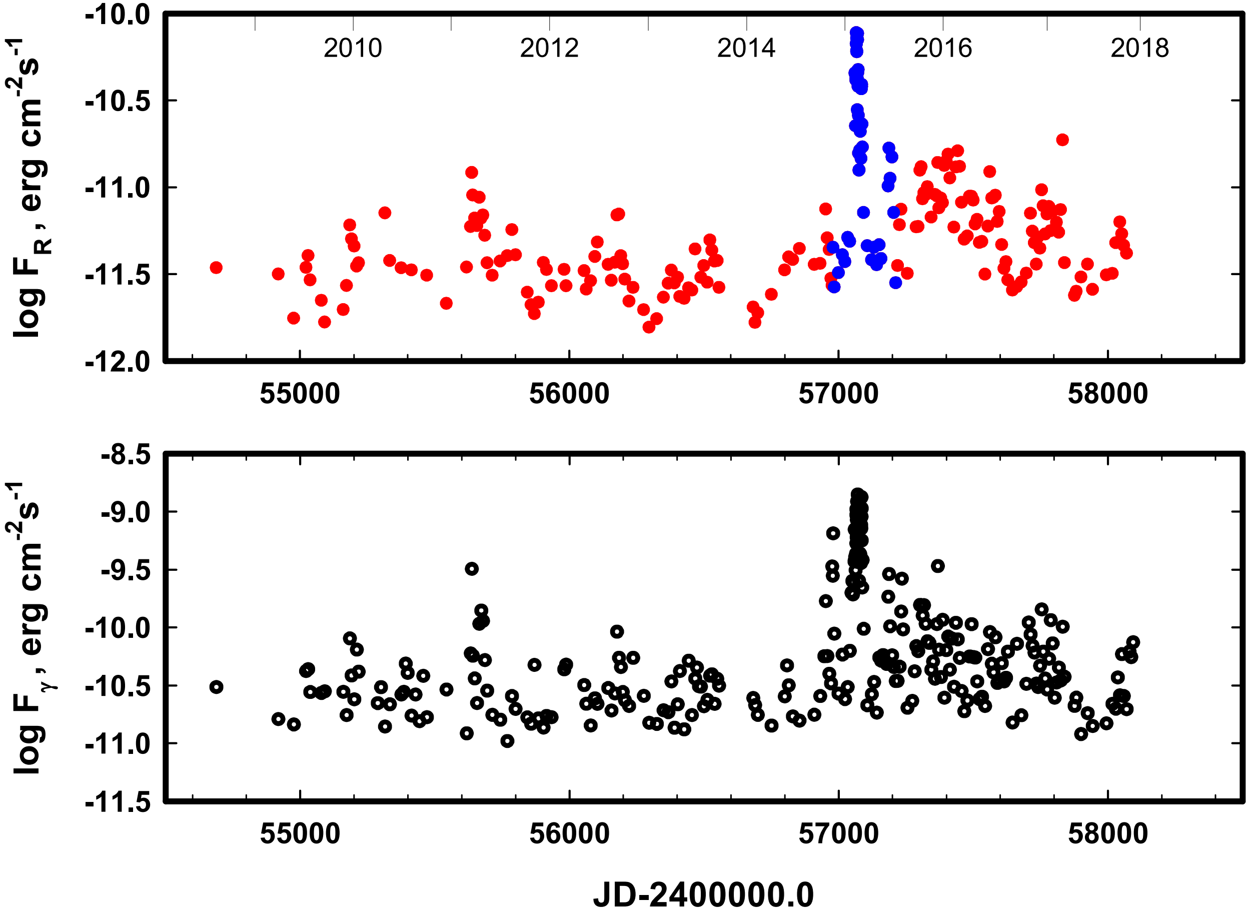


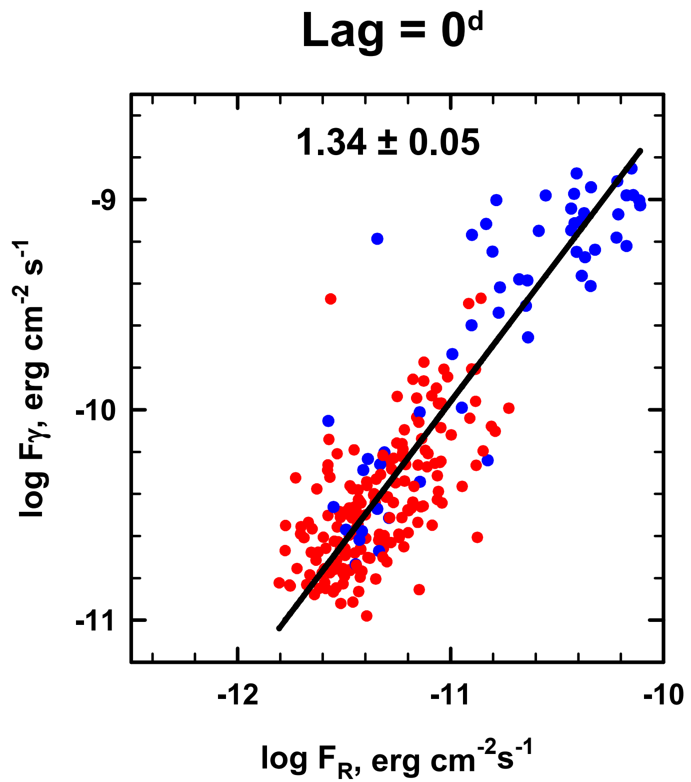
OJ 287 z=0.306



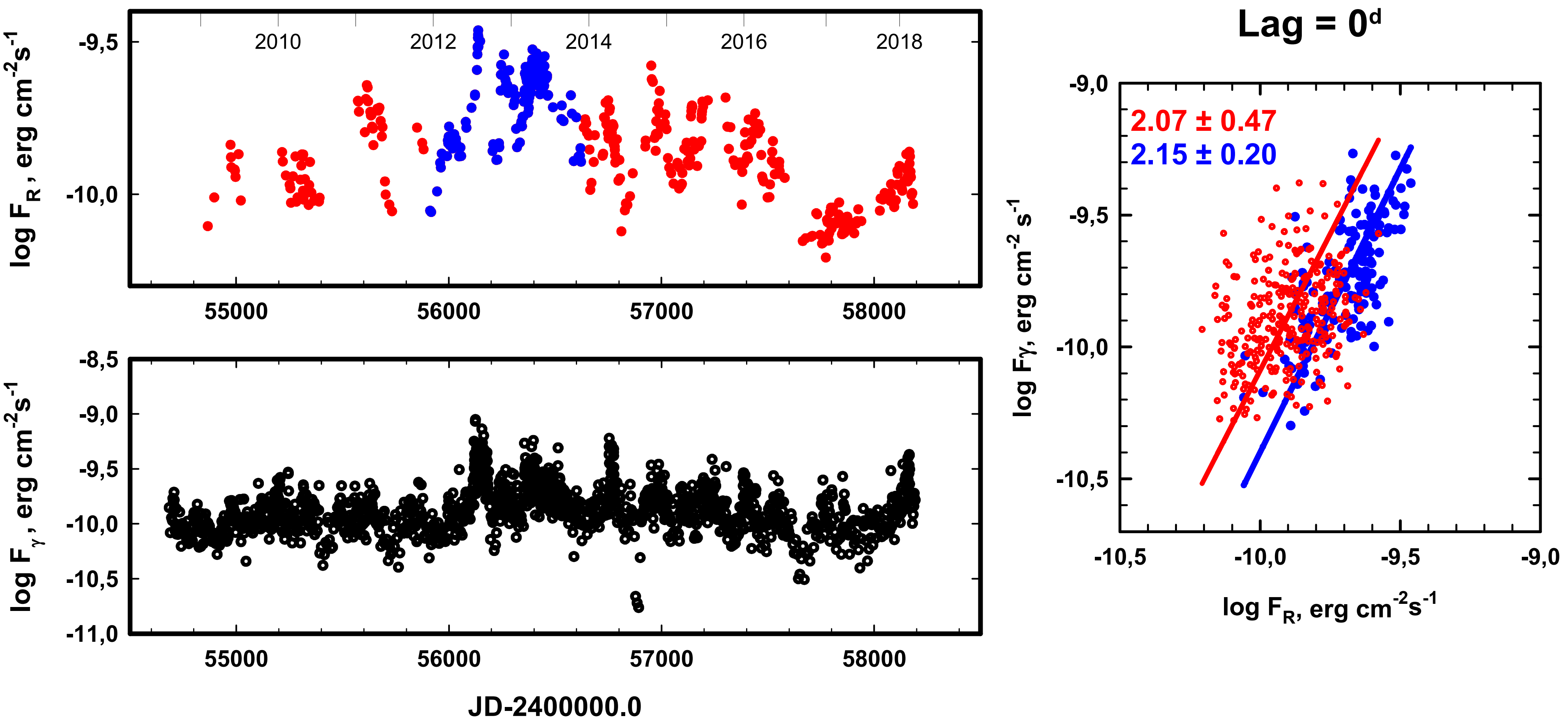
Lag = +2^d
2010
2012
2014
2016
2018
-10.0
-10.5
-11.0
-11.5
log F_R , erg cm^-2 s^-1
55000
56000
57000
58000
-8.5
-9.0
-9.5
-10.0
-10.5
-11.0
-11.5
log F_γ , erg cm^-2 s^-1
54500
55000
55500
56000
56500
57000
57500
58000
58500
JD-2400000.0
7.7 ± 2.7
-9
-10
-11
log Fγ, erg cm^-2 s^-1
-11
-10
log F_R, erg cm^-2 s^-1

S4 0954+65 z=0.368 (?)



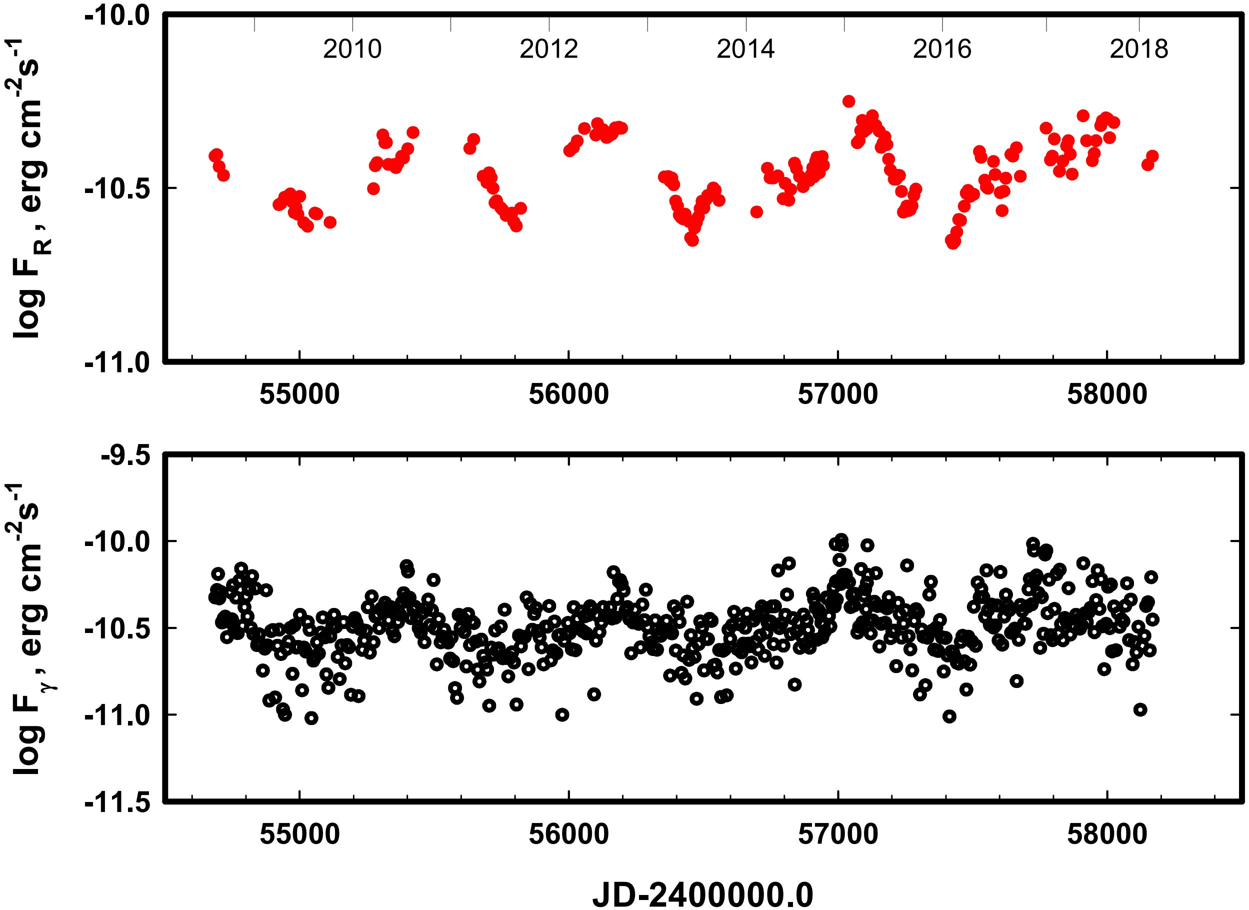


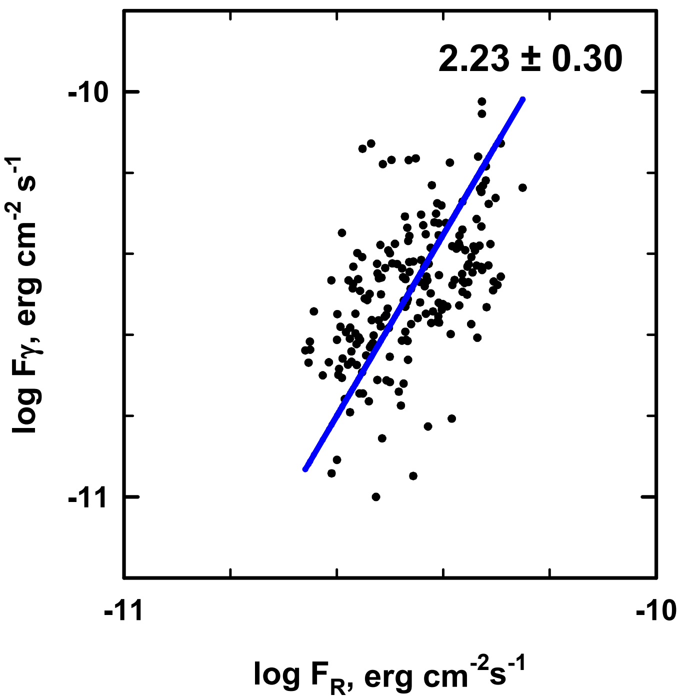
Mkn 421 z=0.03



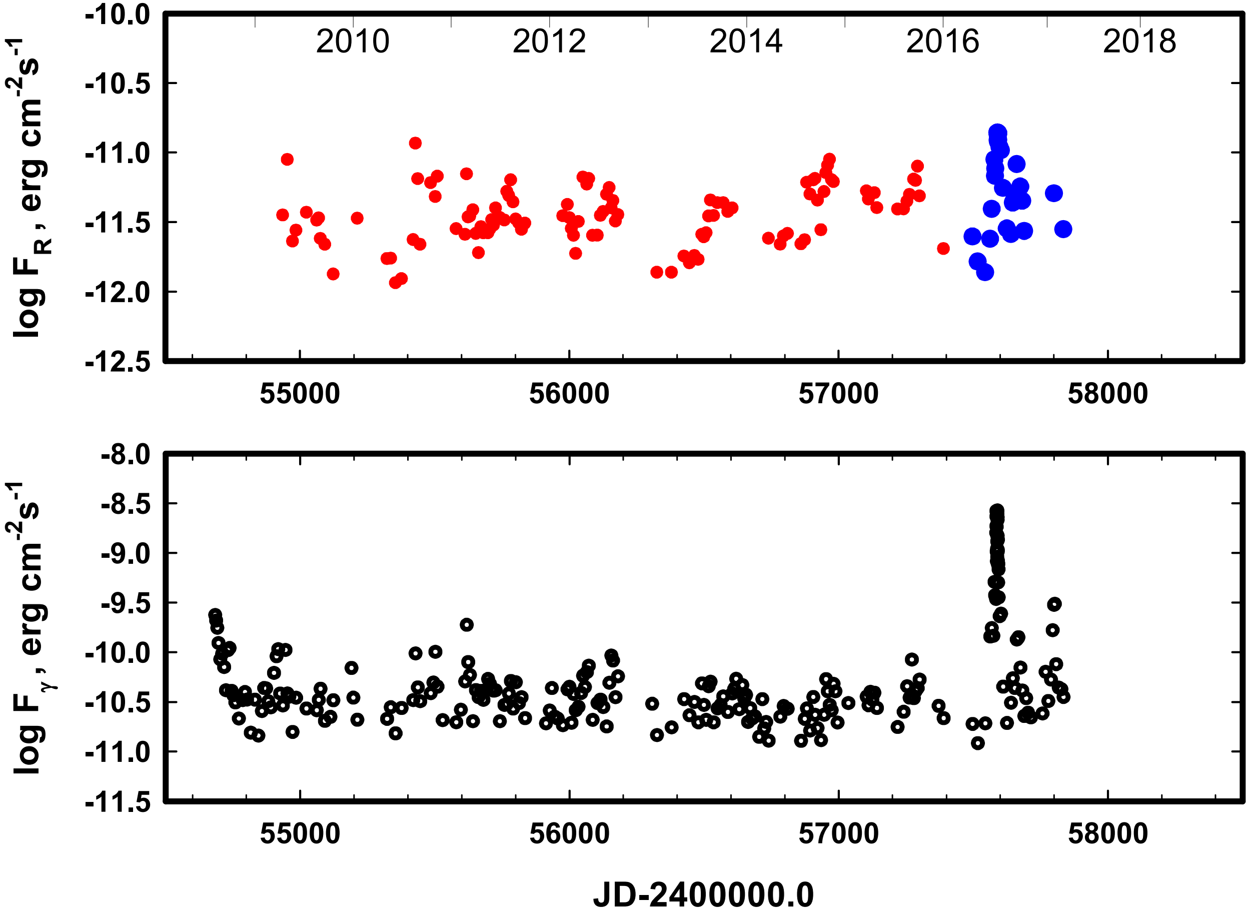
2010
2012
2014
2016
2018
-9,5
-10,0
log F_R , erg $cm^{-2}s^{-1}$
55000
56000
57000
58000
-8,5
-9,0
-9,5
-10,0
-10,5
-11,0
log F_γ , erg $cm^{-2}s^{-1}$
JD-2400000.0
Lag = 0^d
2.07 ± 0.47
2.15 ± 0.20
-9,0
-9,5
-10,0
-10,5
log Fγ, erg cm^{-2} s^{-1}
-10,5
-10,0
-9,5
-9,0
log F_R, erg $cm^{-2}s^{-1}$

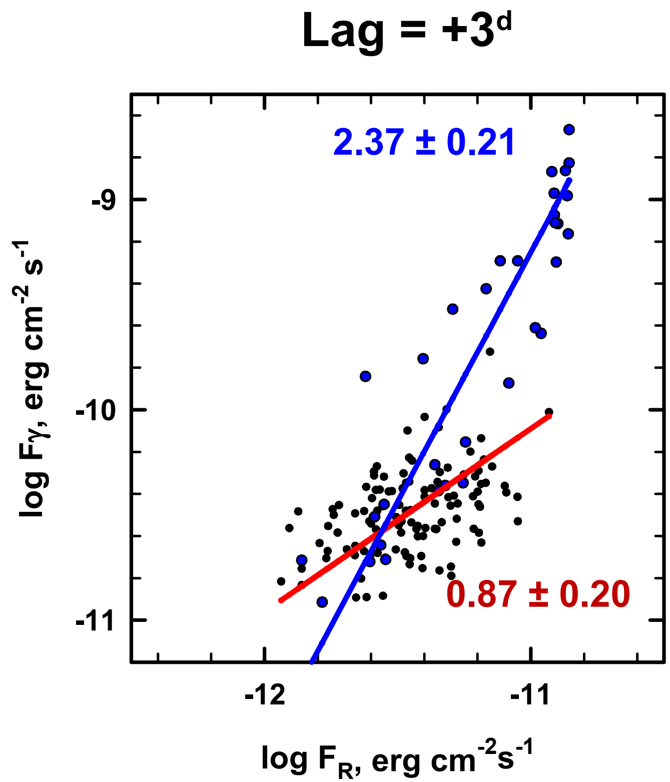
PG 1553+113 z=0.36



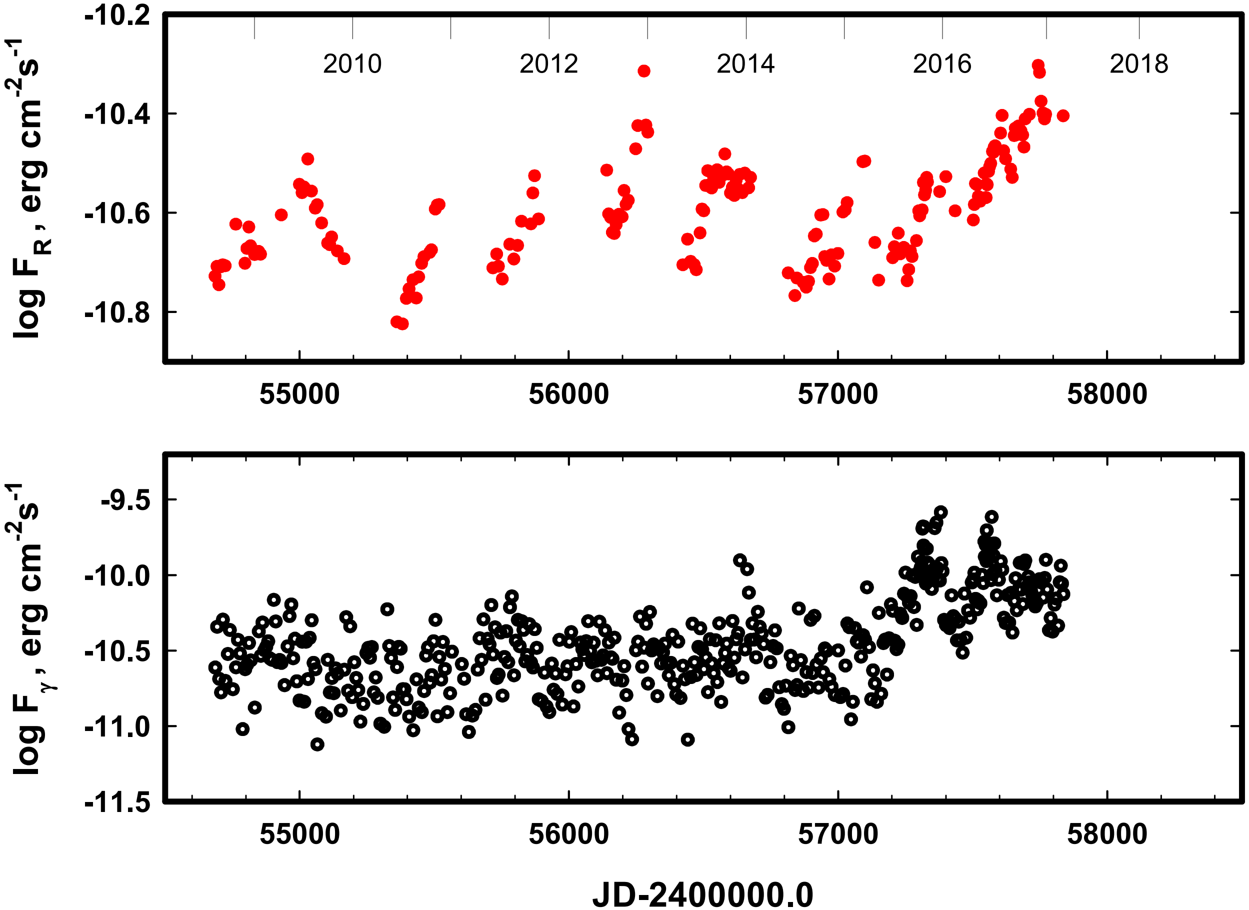


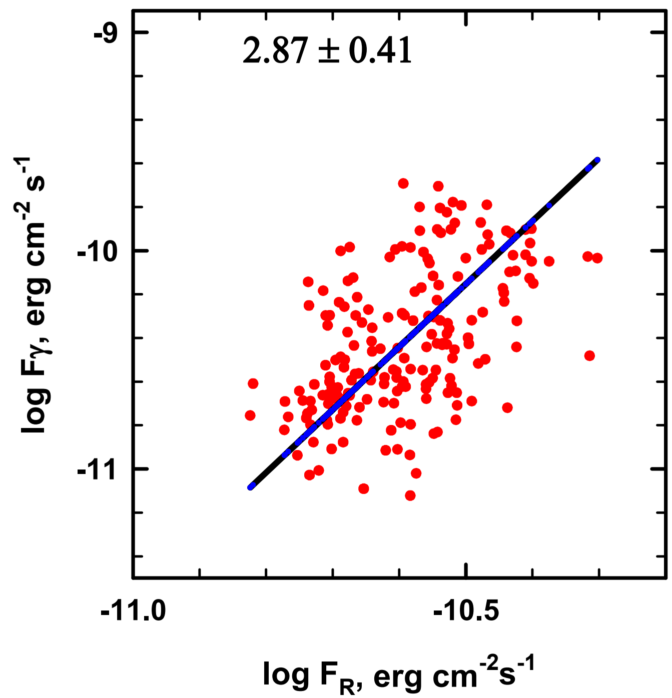
OT 081 = PKS 1749+096 z=0.322



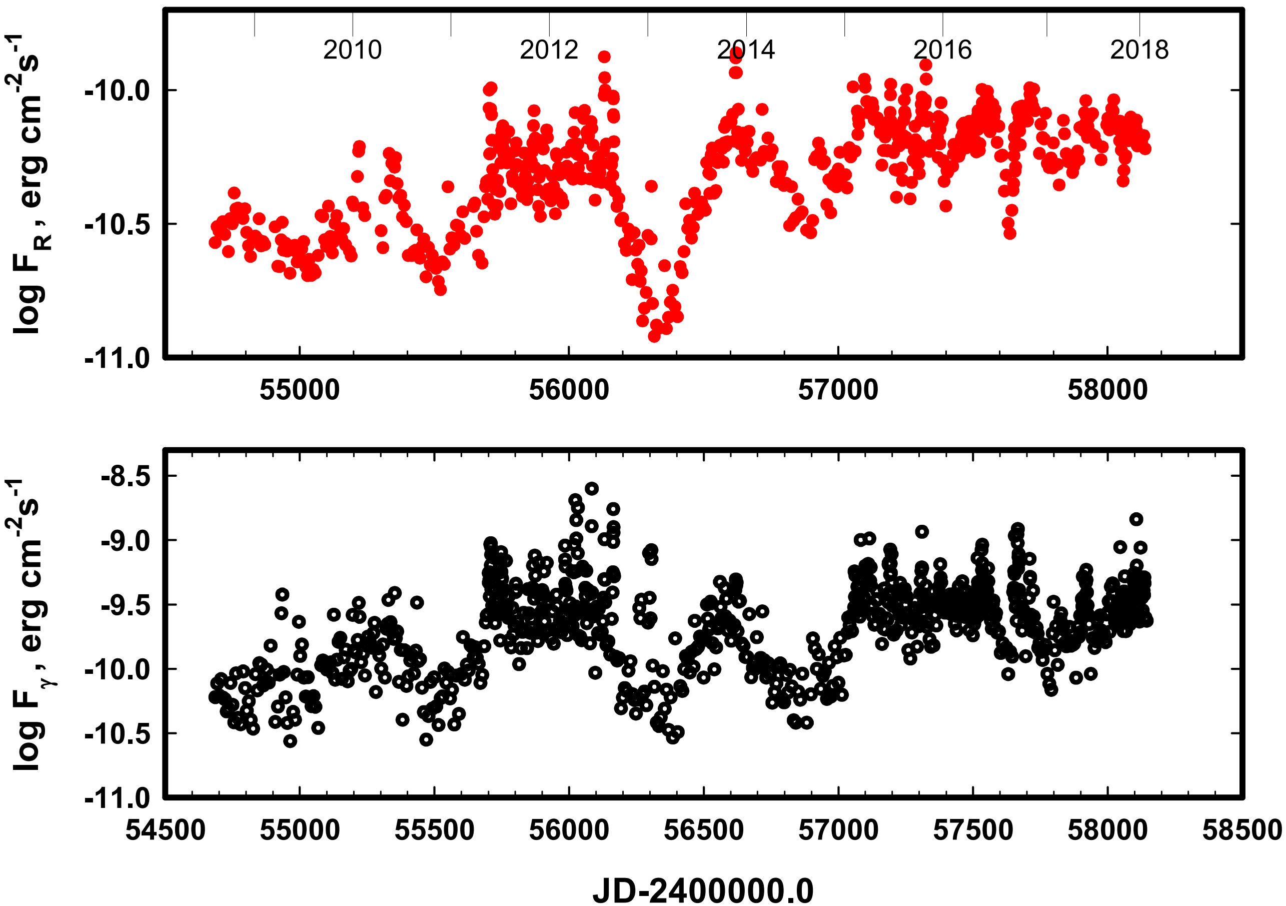


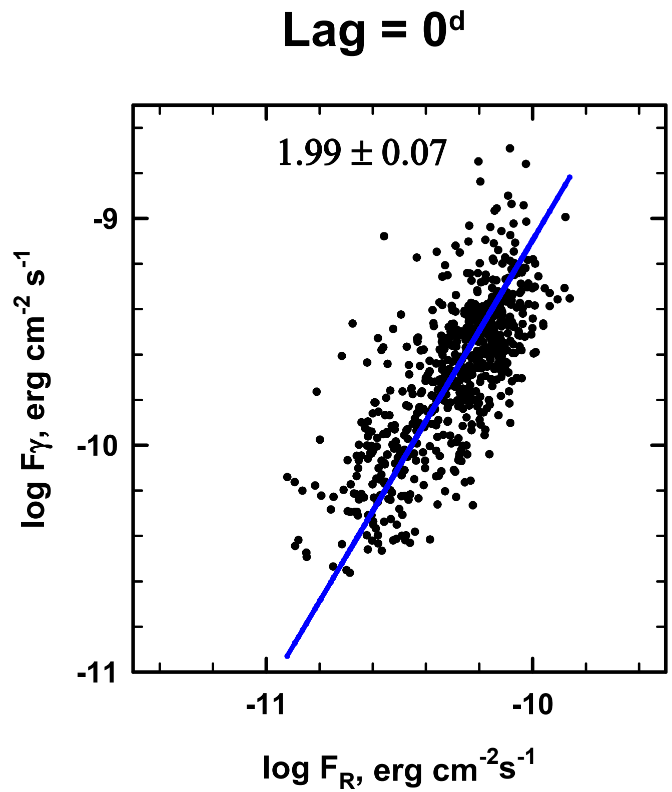
1959+65 z=0.047





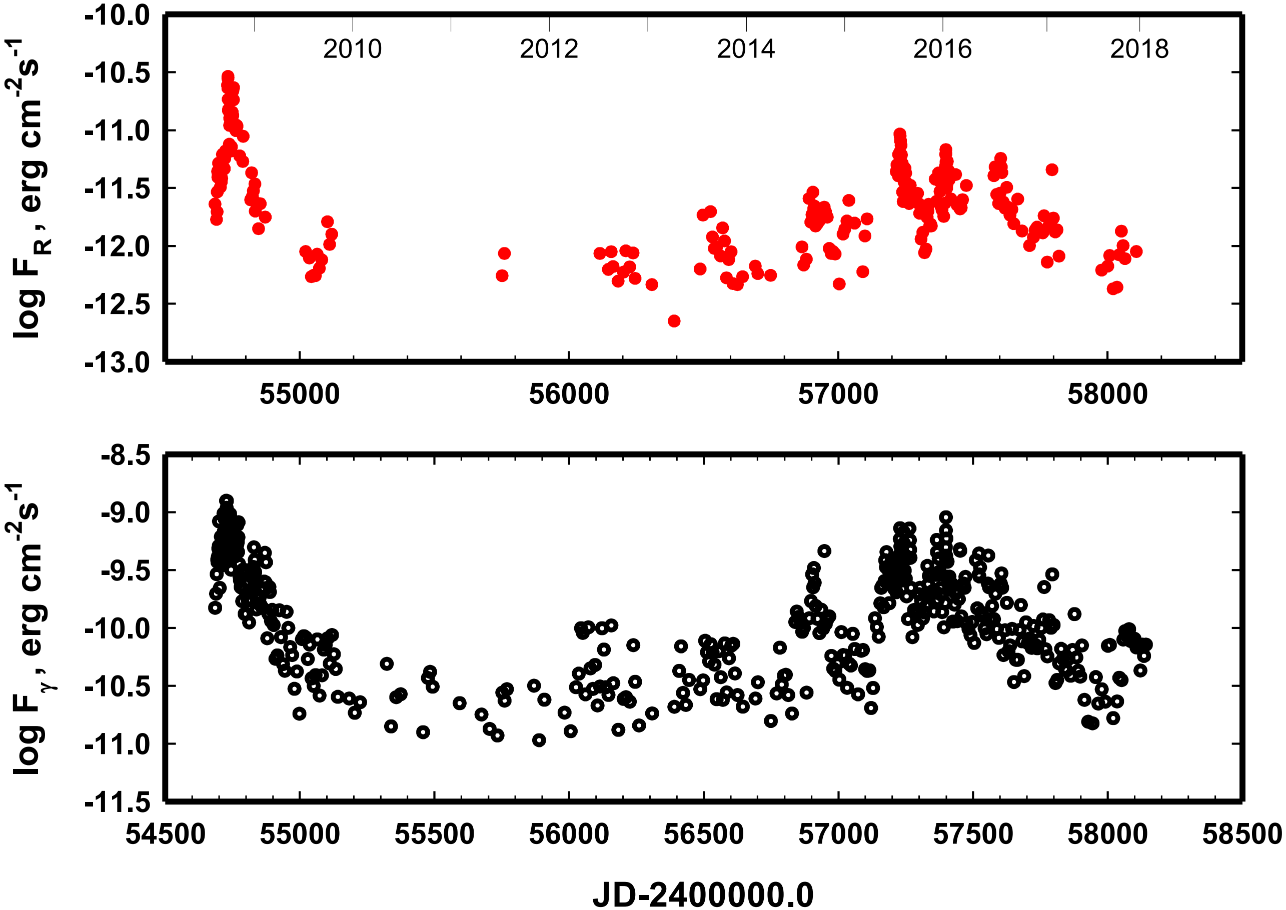
BL Lac z=0.0686

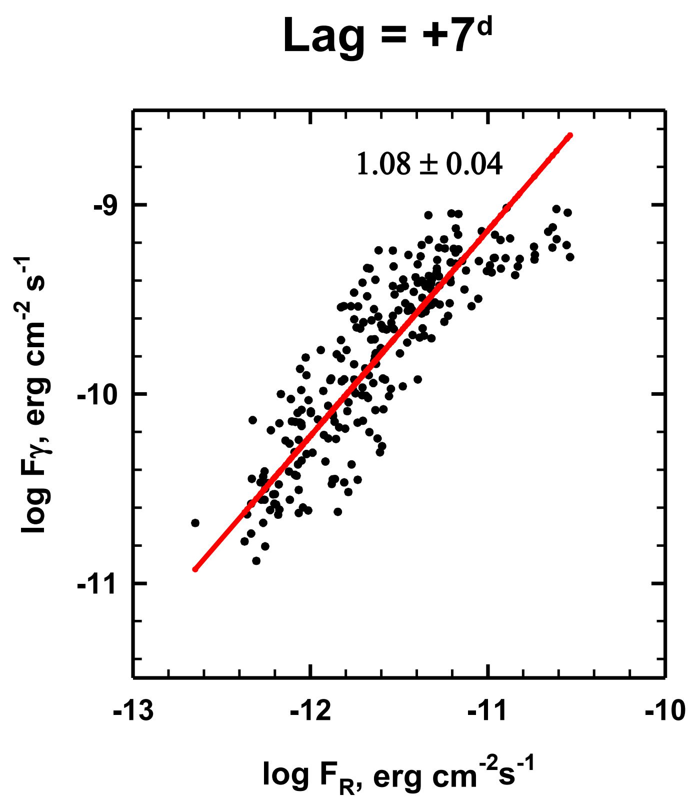




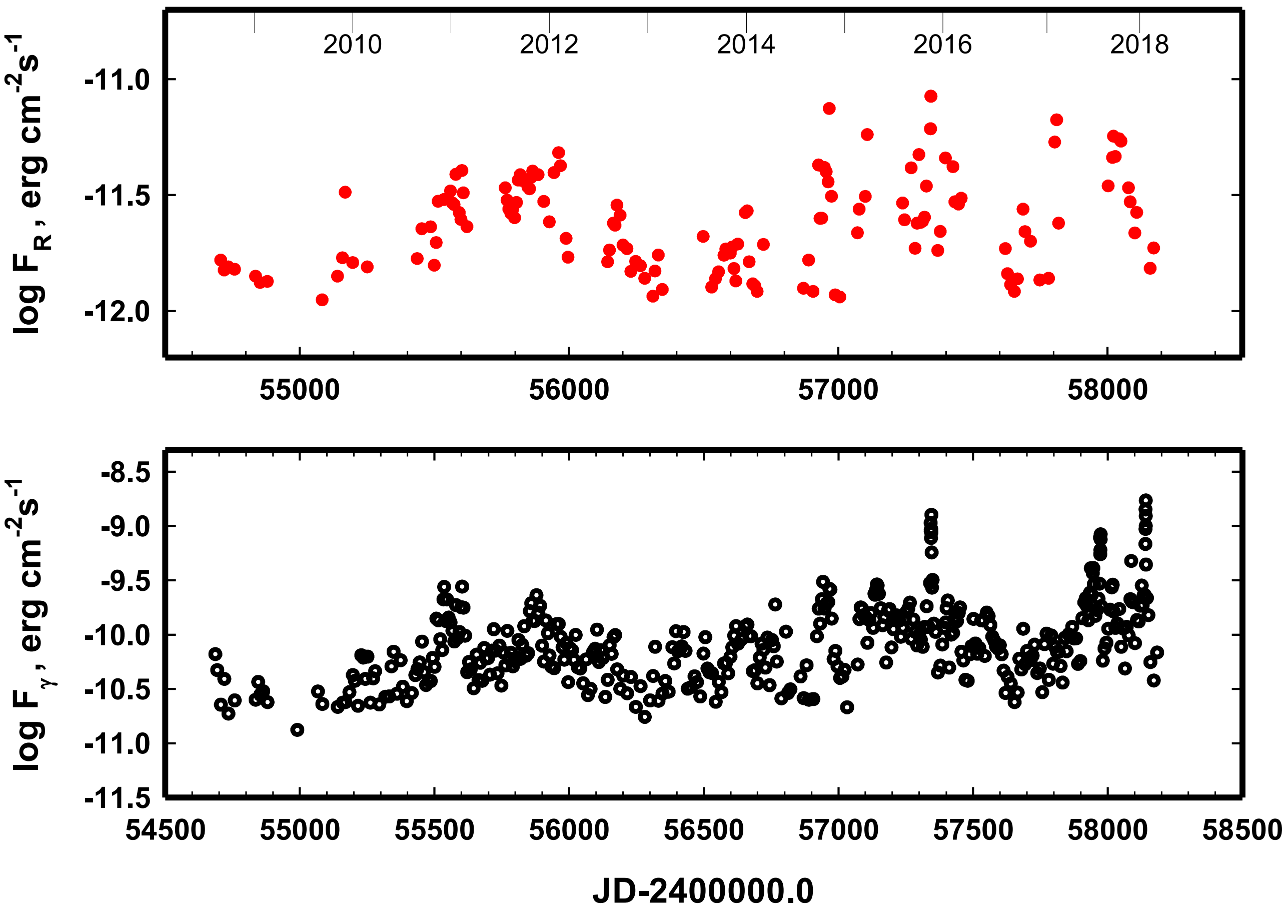
FSRQ

AO 0235+16 z=0.94

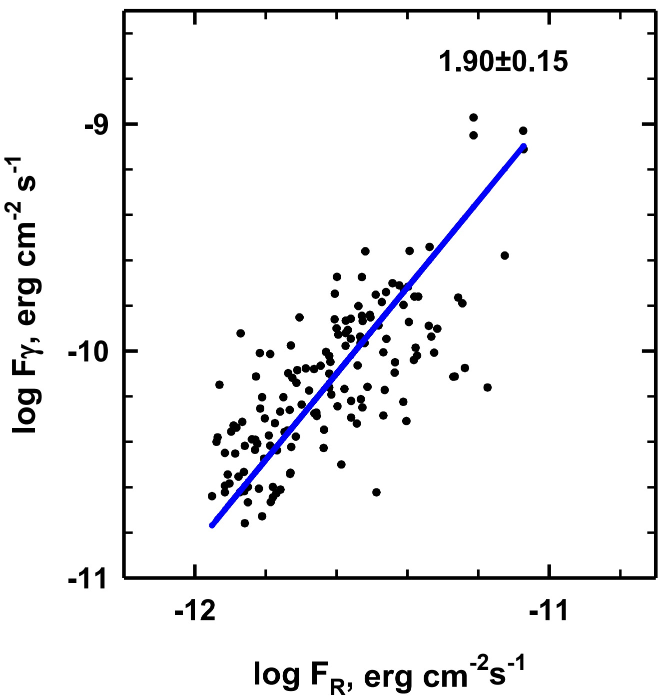




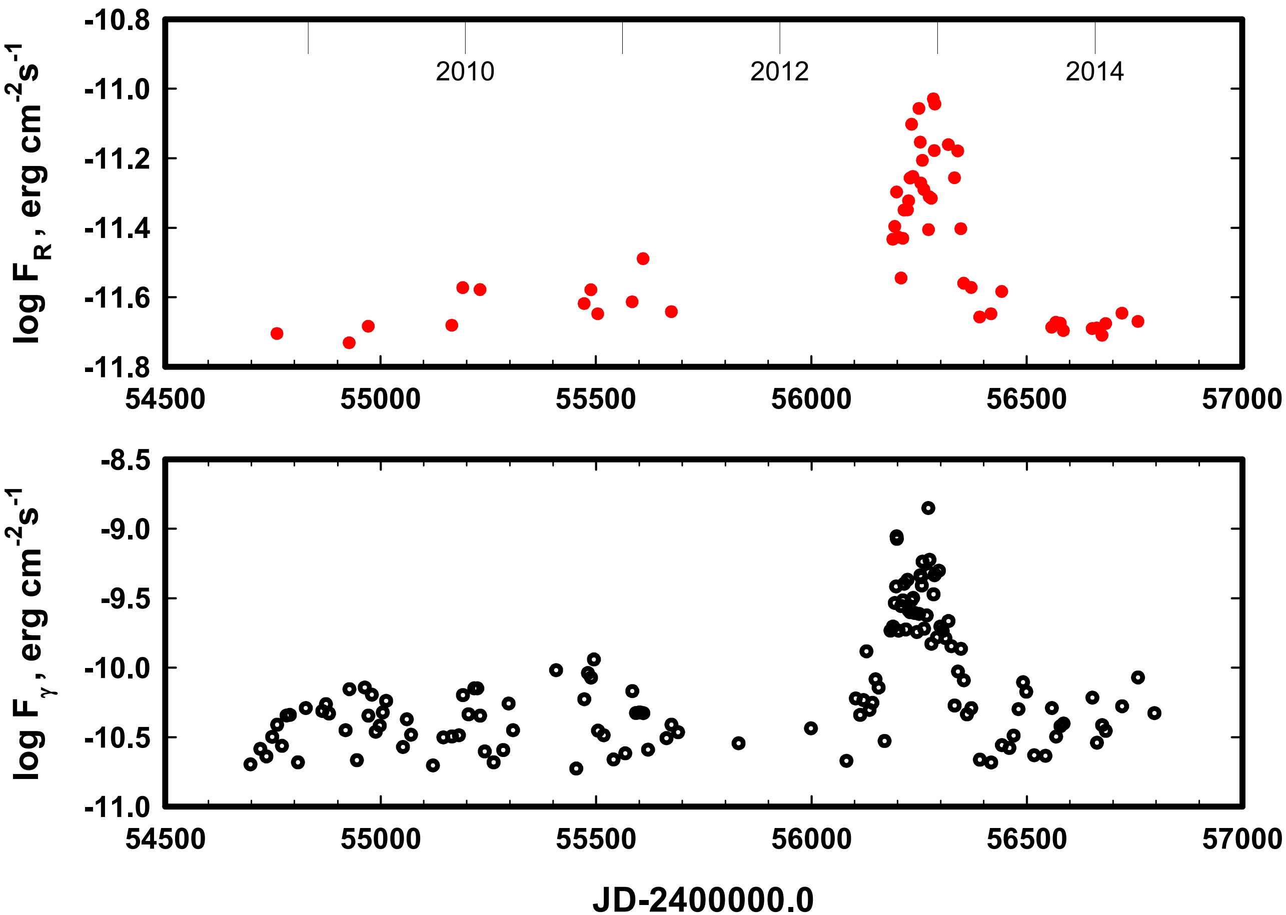
CTA 26 = PKS 0336-01 z=0.852



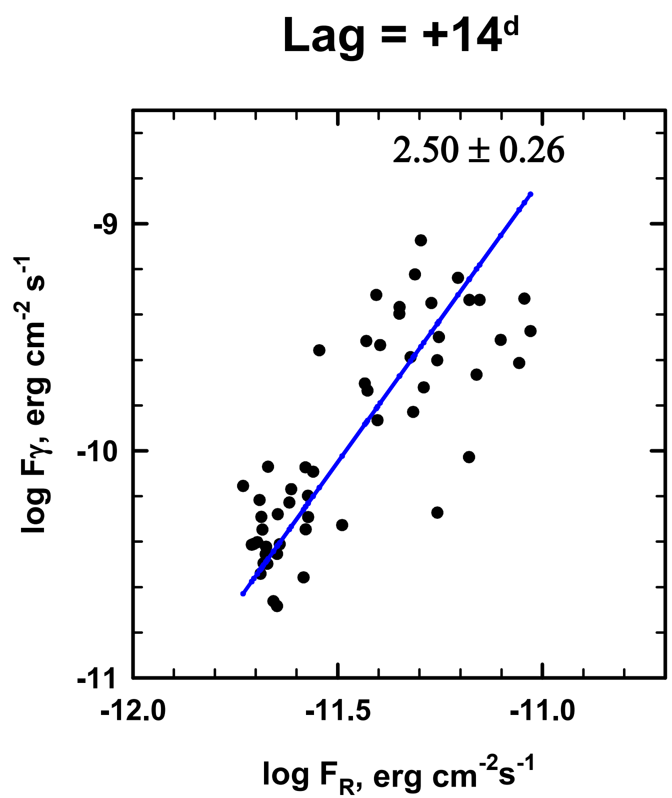
Lag = 0^d



OJ 248 z=0.939

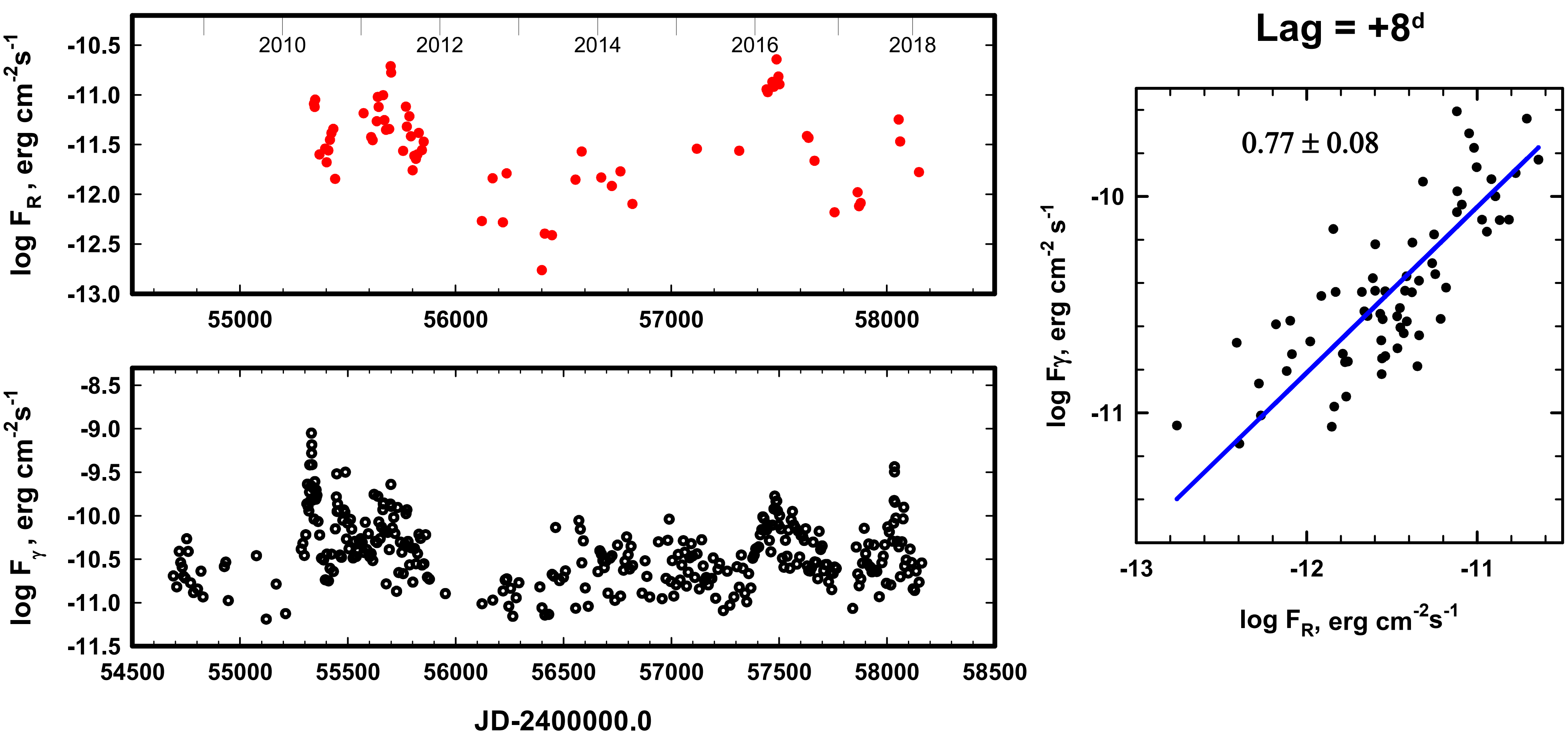


log F_R , erg cm^{-2}s^{-1}
2010
2012
2014
log F_γ , erg cm^{-2}s^{-1}
JD-2400000.0

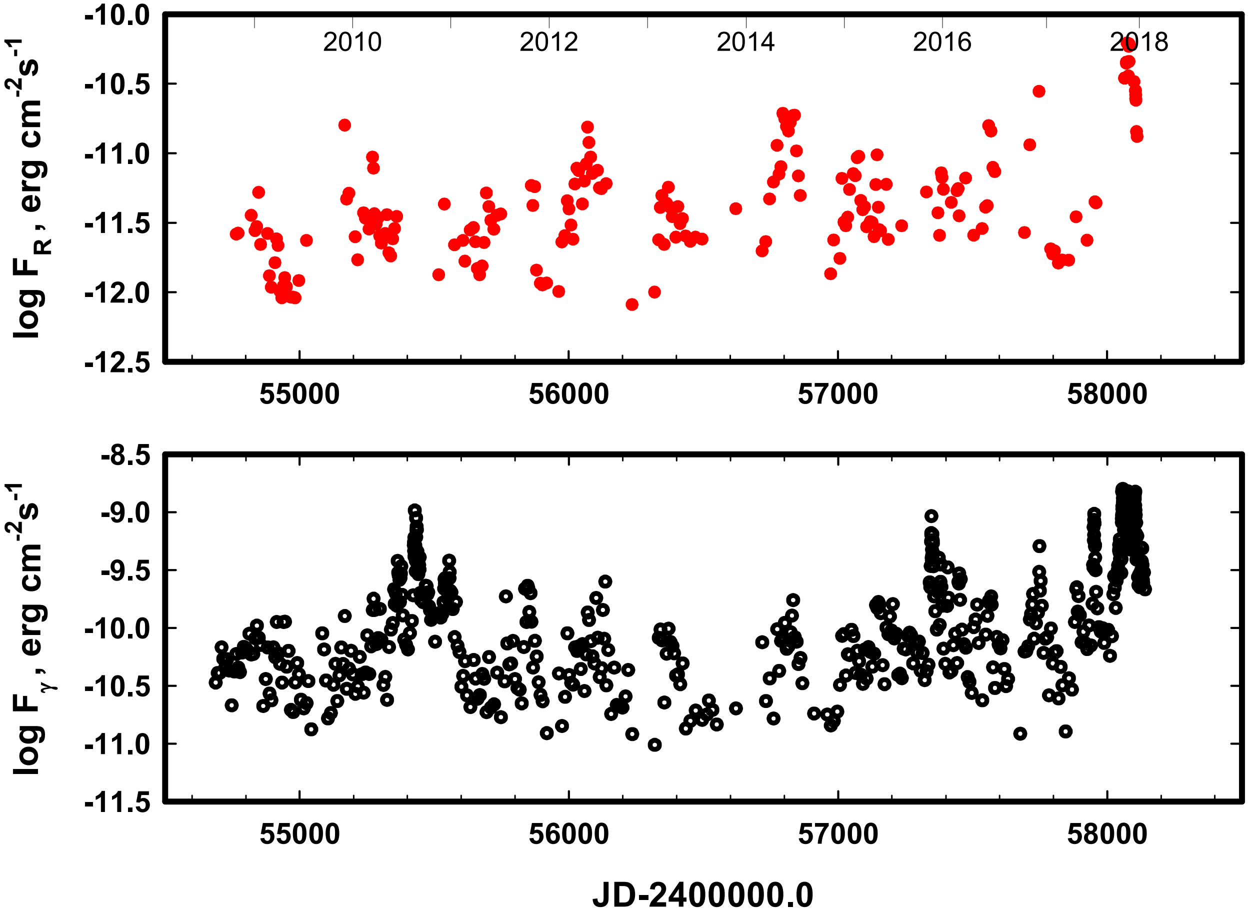


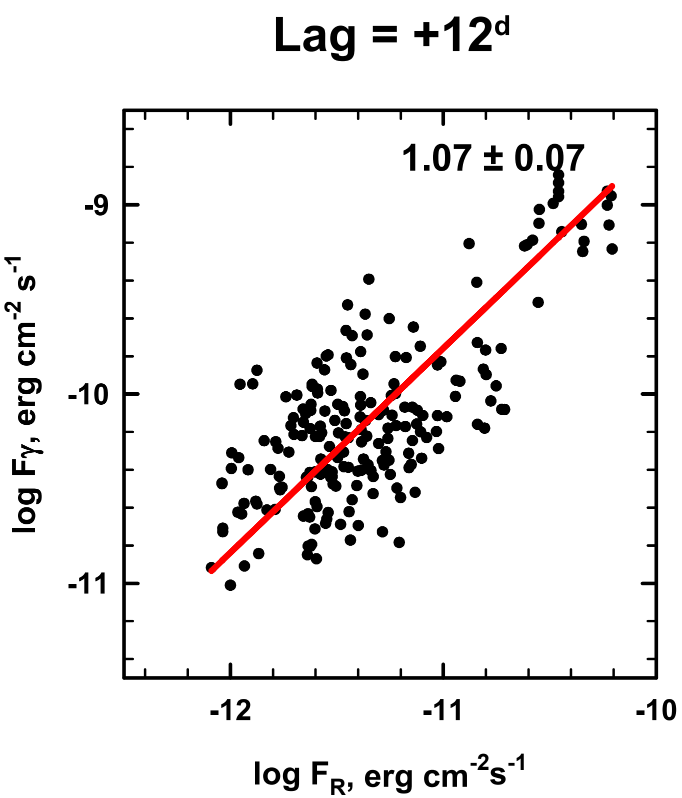
Lag = +14^d
2.50 ± 0.26
log Fγ, erg cm^{-2} s^{-1}
log F_R, erg cm^{-2}s^{-1}

S4 1030+60 z=1.117

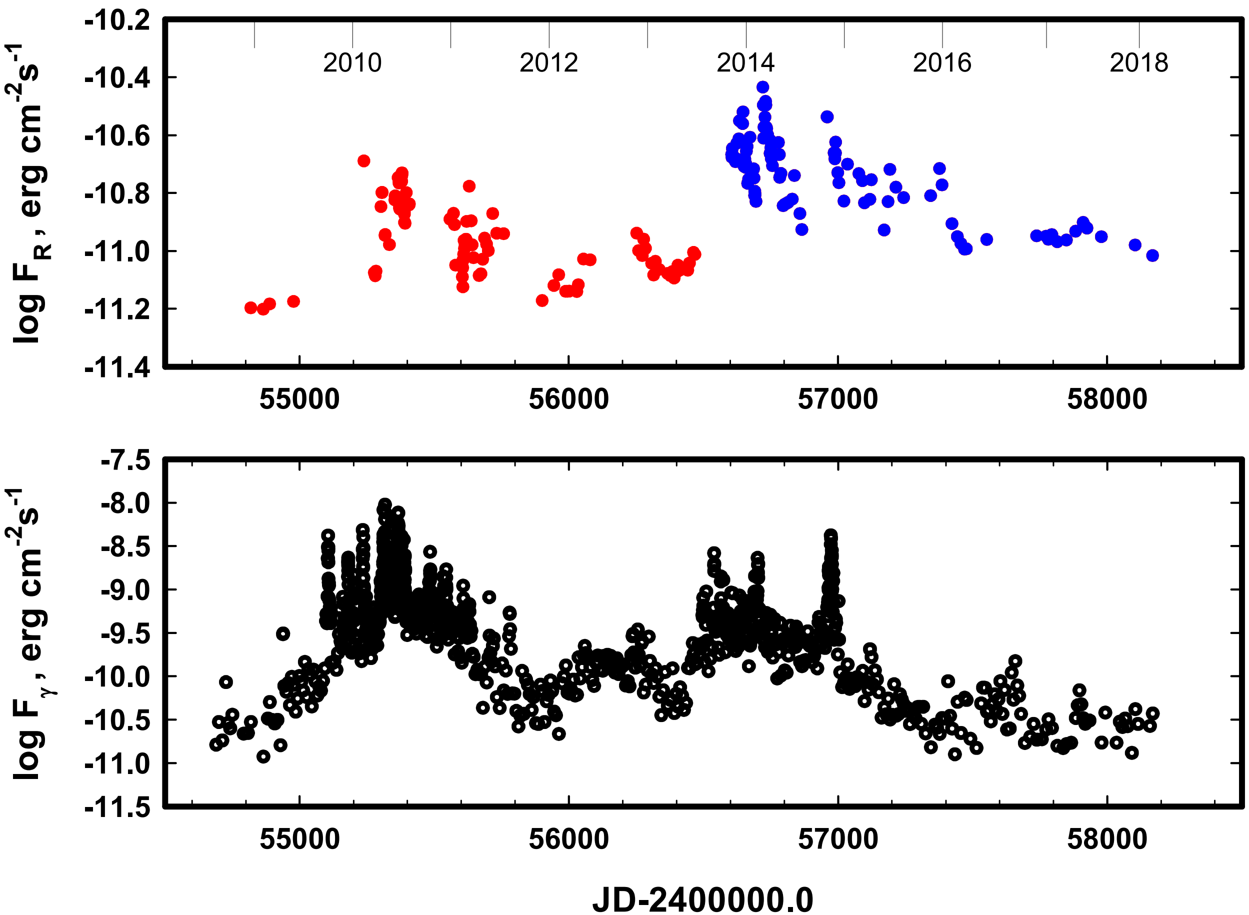


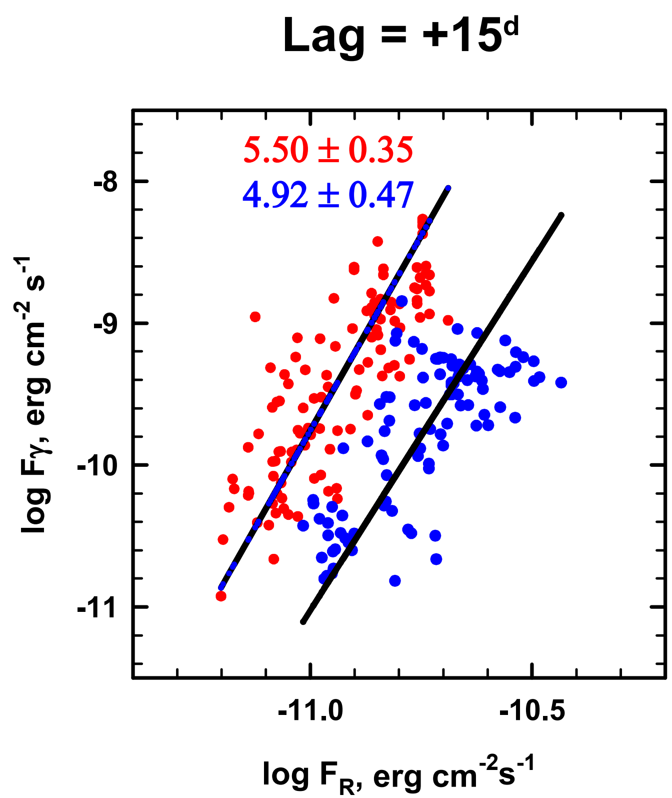
B2 1156+29 = Ton599 z=0.729



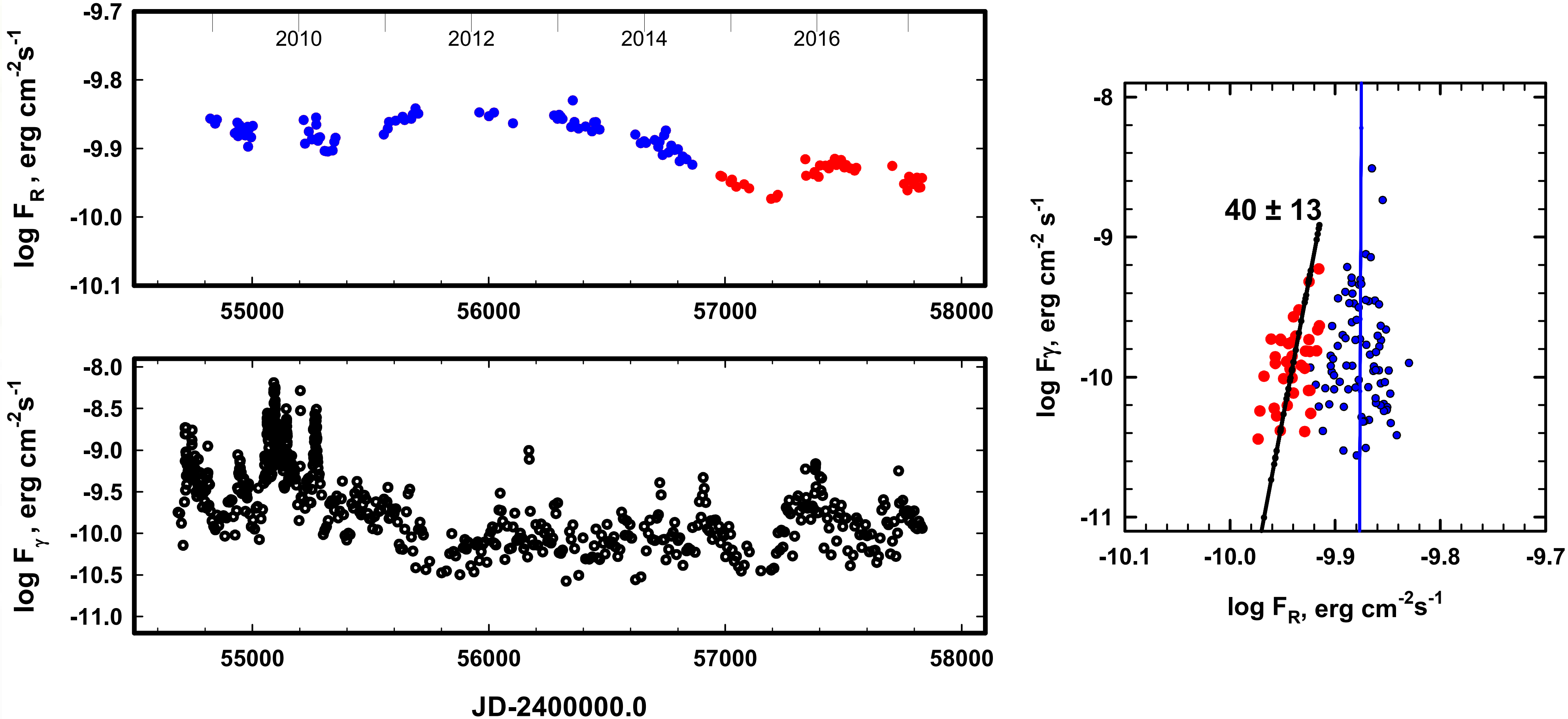


PKS 1222+21 z=0.435



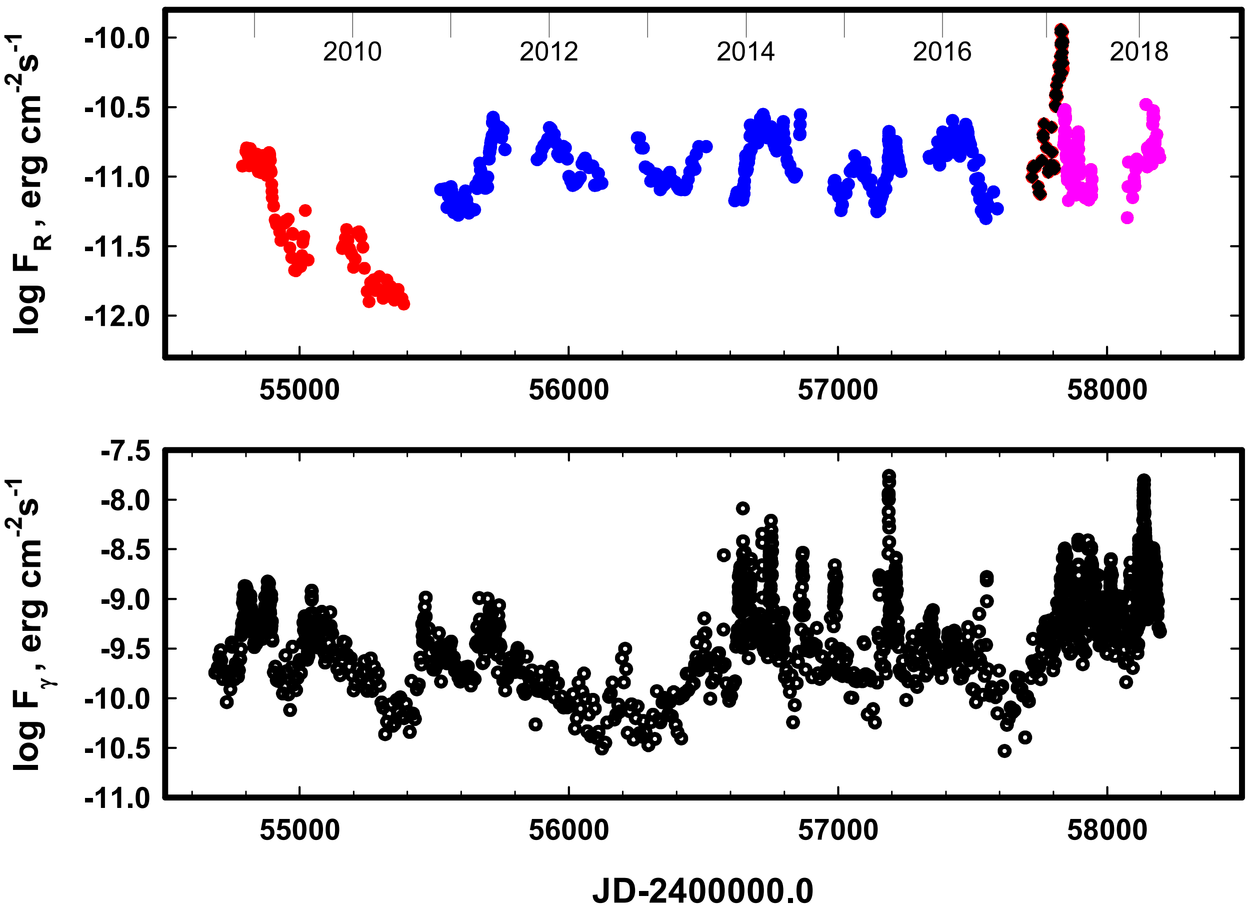


3C 273 $z=0.158$

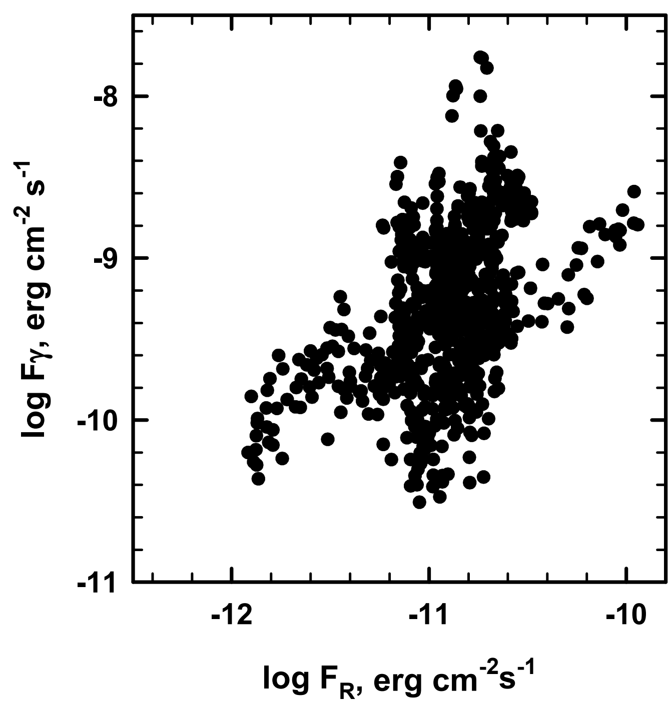


2010
2012
2014
2016
log F$_R$, erg cm^{-2}s^{-1}
-9.7
-9.8
-9.9
-10.0
-10.1
55000
56000
57000
58000
log F$_\gamma$, erg cm^{-2}s^{-1}
-8.0
-8.5
-9.0
-9.5
-10.0
-10.5
-11.0
JD-2400000.0
40 ± 13
log F$_\gamma$, erg cm^{-2} s^{-1}
-8
-9
-10
-11
-10.1
-10.0
-9.9
-9.8
-9.7
log F$_R$, erg cm^{-2}s^{-1}

3C 279 $z=0.536$

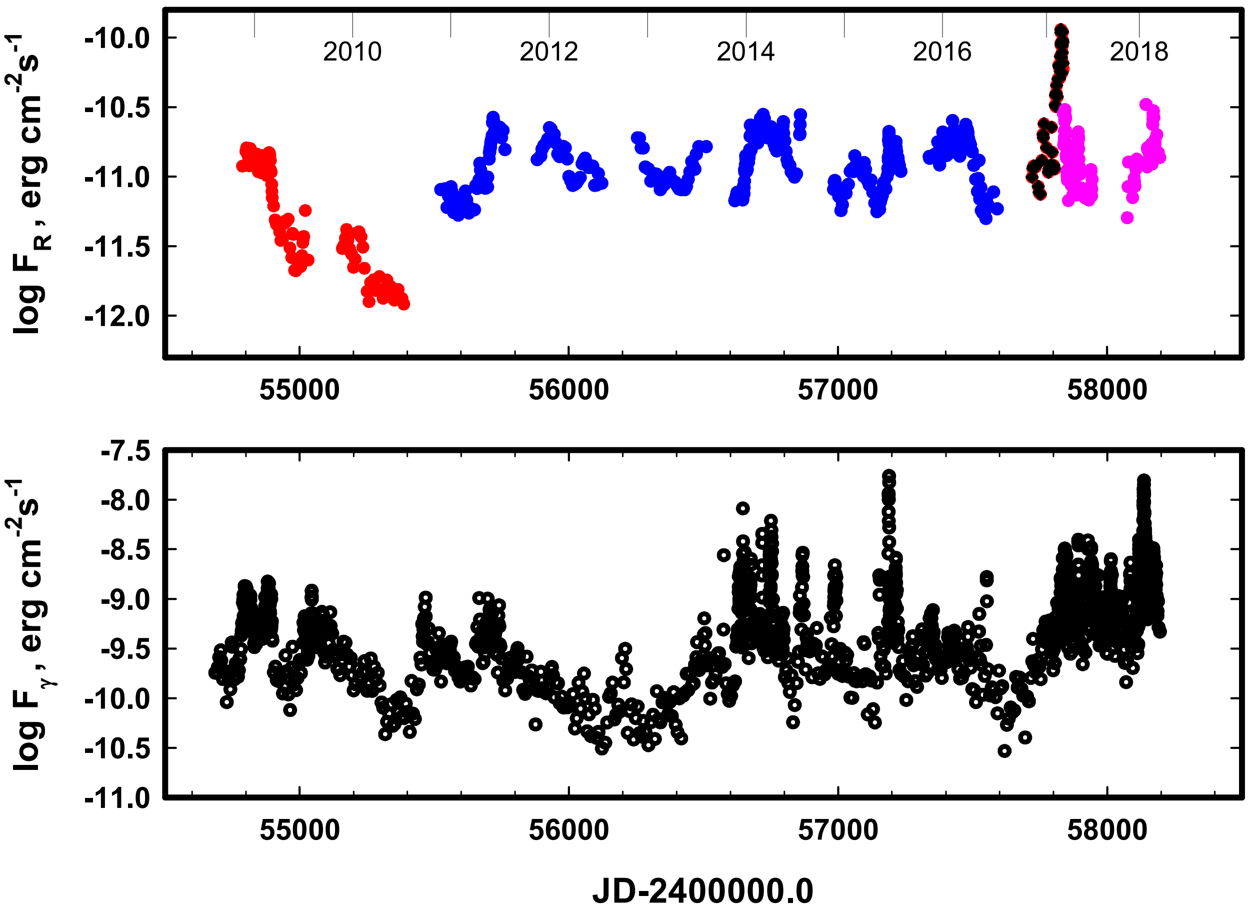


Lag = 0^d

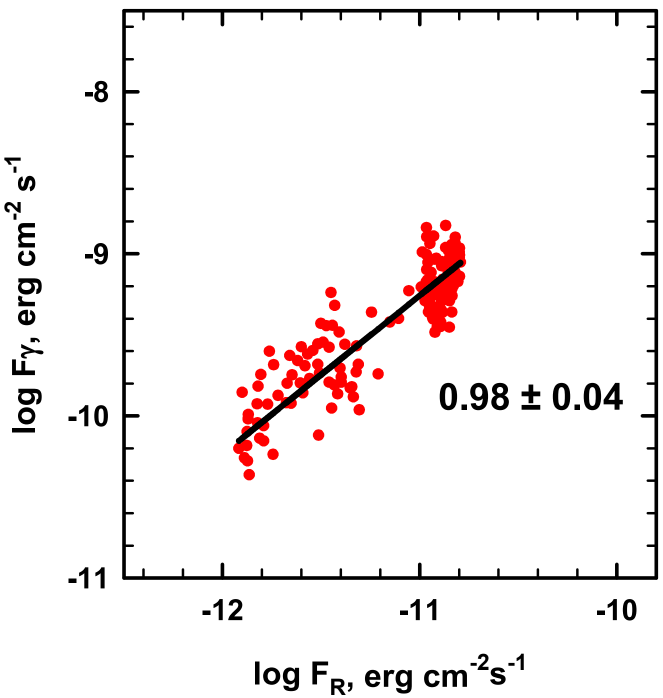


Is it a crow or an owl?

3C 279

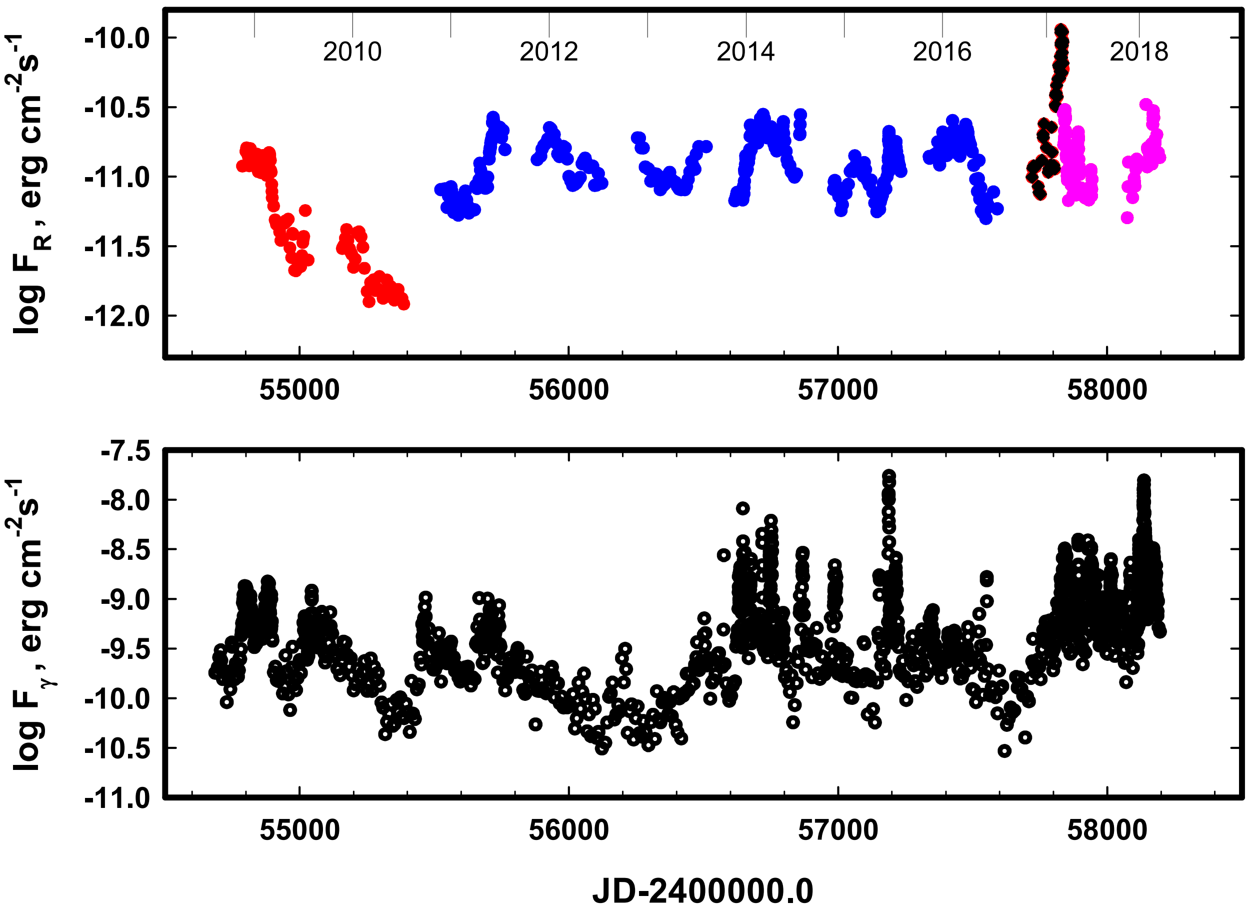


log F_R , erg cm^{-2}s^{-1}
-10.0
-10.5
-11.0
-11.5
-12.0
2010
2012
2014
2016
2018
55000
56000
57000
58000
log F_γ , erg cm^{-2}s^{-1}
-7.5
-8.0
-8.5
-9.0
-9.5
-10.0
-10.5
-11.0
55000
56000
57000
58000
JD-2400000.0

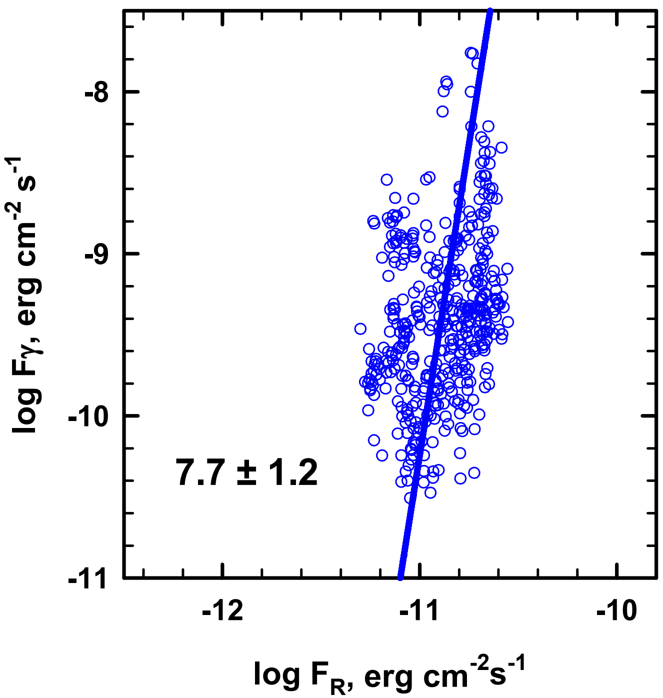


log Fγ, erg cm^{-2} s^{-1}
-8
-9
-10
-11
-12
-11
-10
0.98 ± 0.04
log F_R, erg cm^{-2}s^{-1}

3C 279

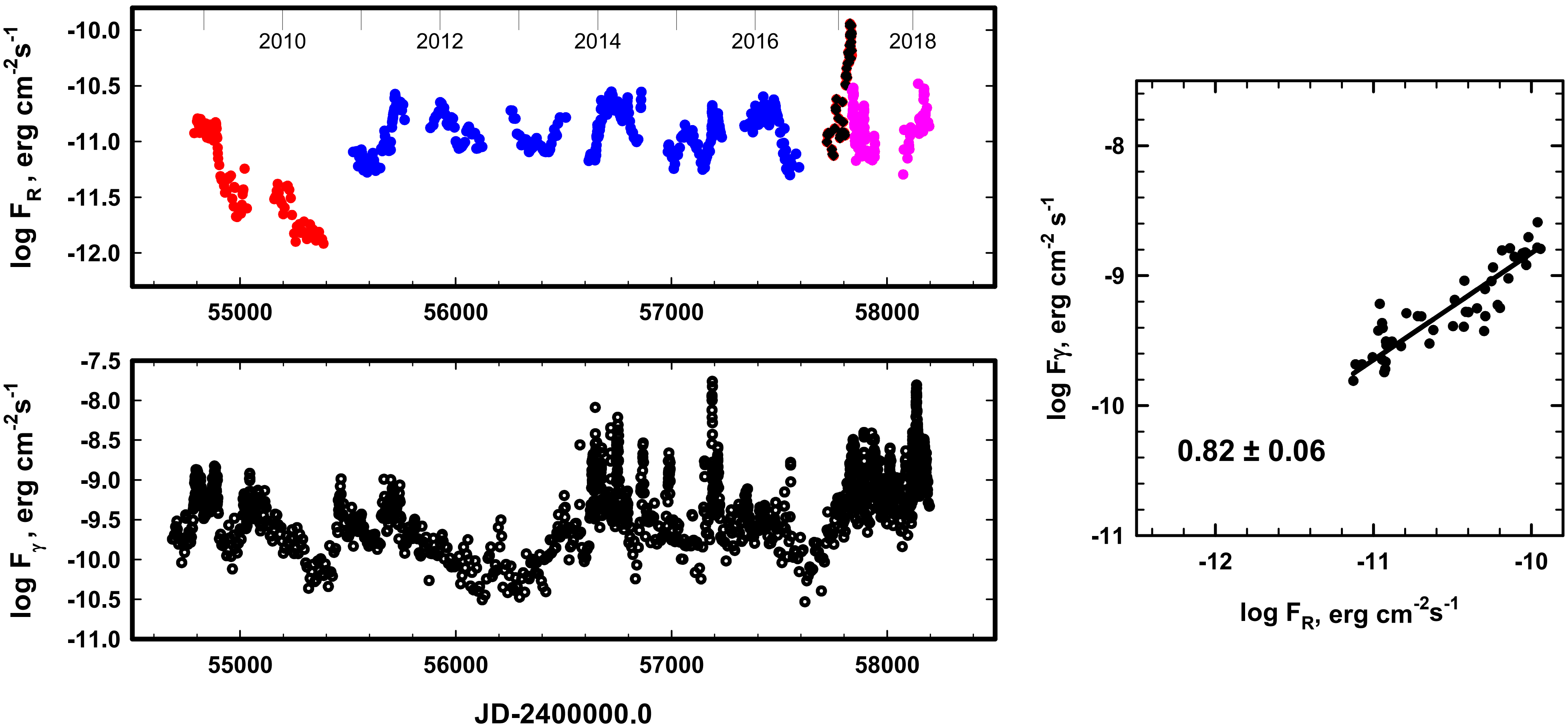


log F$_R$, erg cm^{-2}s^{-1}
-10.0
-10.5
-11.0
-11.5
-12.0
2010
2012
2014
2016
2018
55000
56000
57000
58000
log F$_\gamma$, erg cm^{-2}s^{-1}
-7.5
-8.0
-8.5
-9.0
-9.5
-10.0
-10.5
-11.0
JD-2400000.0



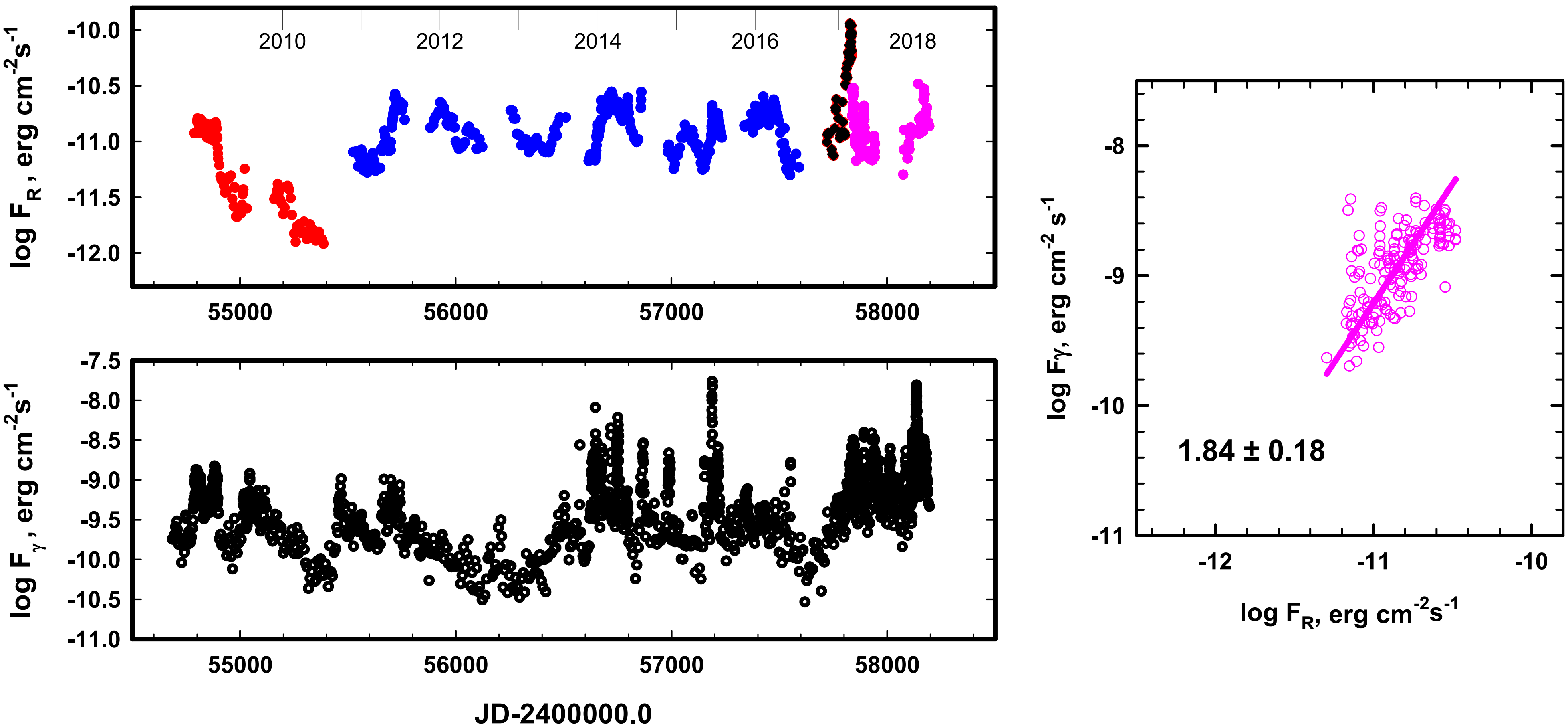
log Fγ, erg cm^{-2} s^{-1}
-8
-9
-10
-11
7.7 ± 1.2
-12
-11
-10
log F$_R$, erg cm^{-2}s^{-1}

3C 279



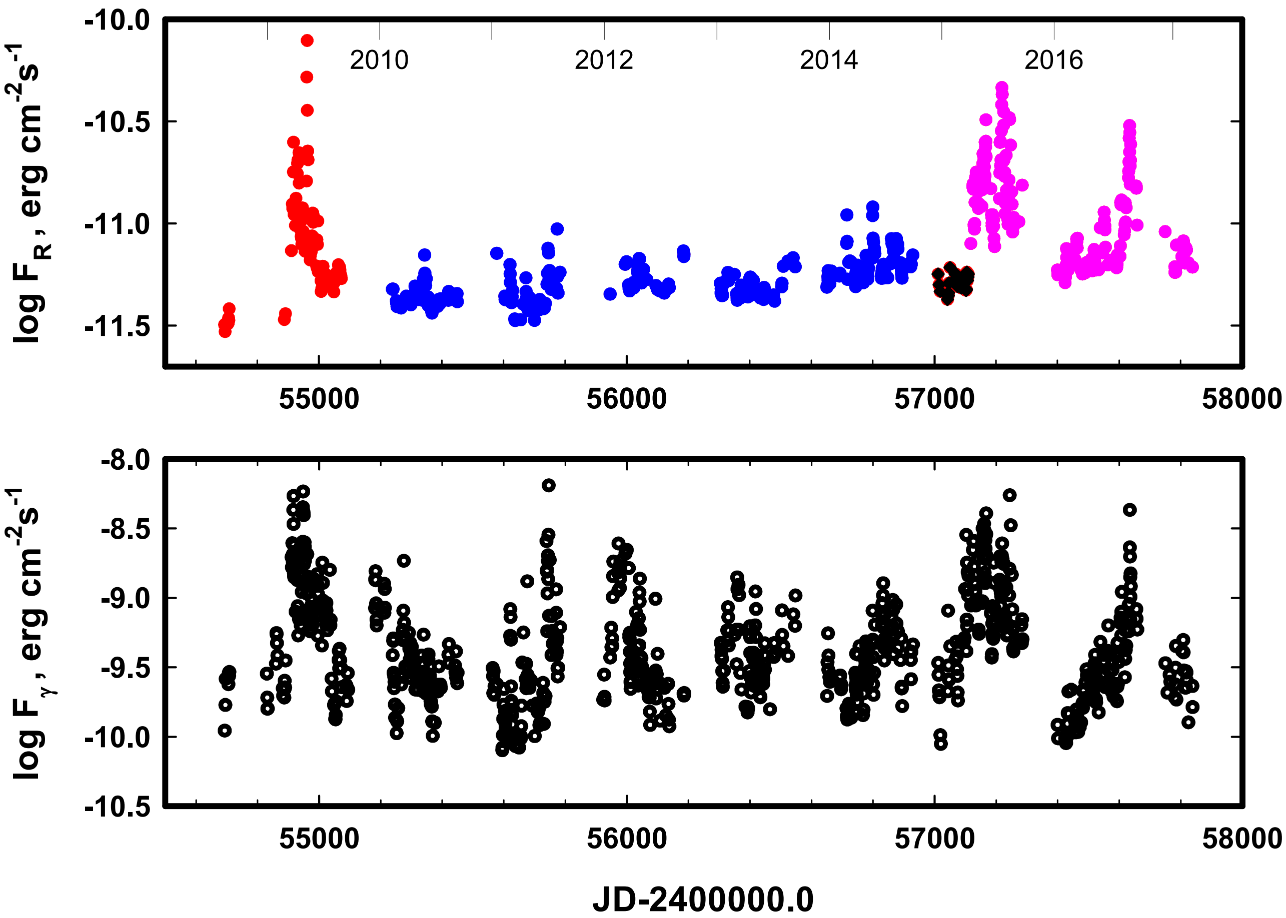
2010
2012
2014
2016
2018
-10.0
-10.5
-11.0
-11.5
-12.0
log F_R , erg cm^{-2}s^{-1}
55000
56000
57000
58000
-7.5
-8.0
-8.5
-9.0
-9.5
-10.0
-10.5
-11.0
log F_γ , erg cm^{-2}s^{-1}
JD-2400000.0
-8
-9
-10
-11
-12
log F_γ, erg cm^{-2} s^{-1}
0.82 ± 0.06
log F_R, erg cm^{-2}s^{-1}

3C 279

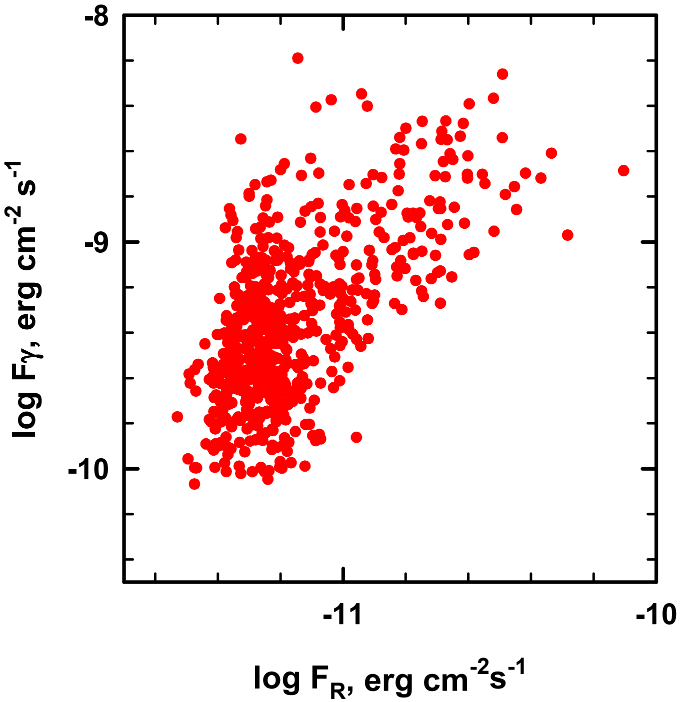


2010
2012
2014
2016
2018
log F_R , erg cm^-2 s^-1
log F_γ , erg cm^-2 s^-1
JD-2400000.0
log Fγ, erg cm^-2 s^-1
log F_R, erg cm^-2 s^-1
1.84 ± 0.18

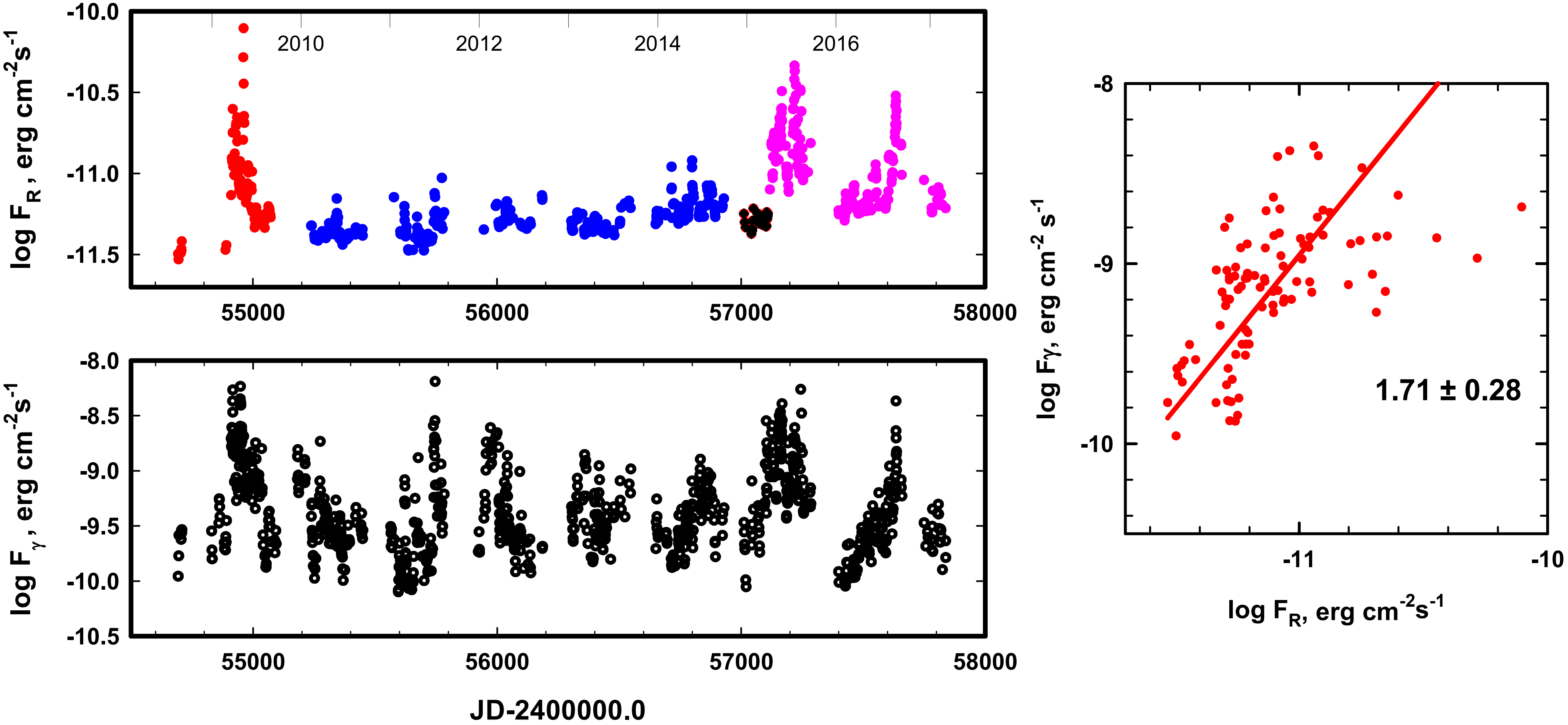
PKS 1510-089 z=0.36



Lag = +13^d

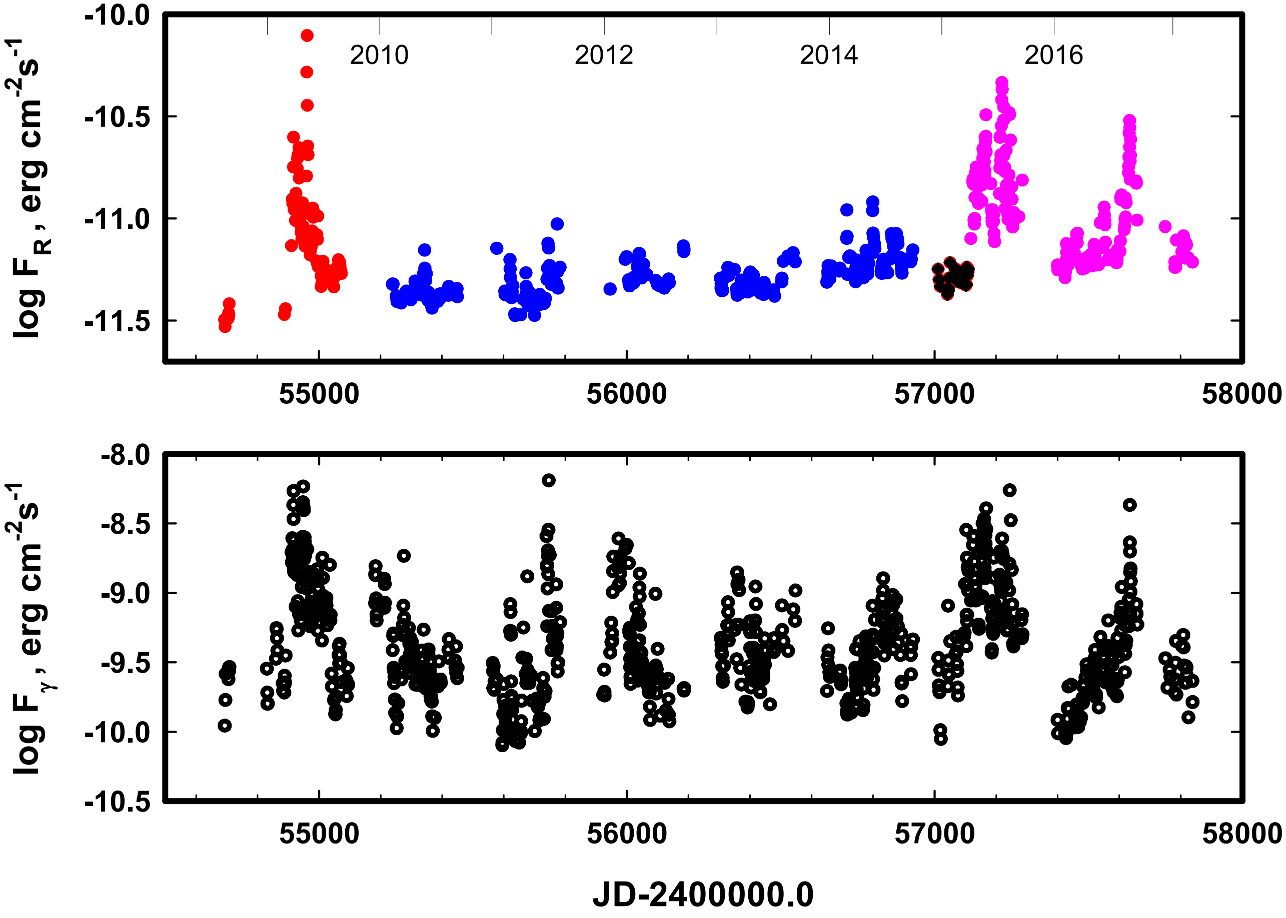


PKS 1510-089

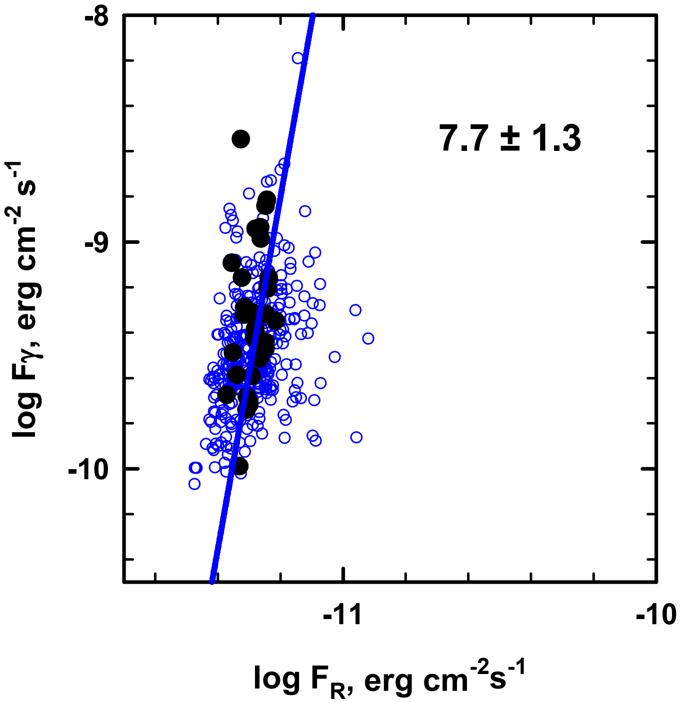


-10.0
-10.5
-11.0
-11.5
2010
2012
2014
2016
log F_R , erg $cm^{-2}s^{-1}$
55000
56000
57000
58000
-8.0
-8.5
-9.0
-9.5
-10.0
-10.5
log F_{γ} , erg $cm^{-2}s^{-1}$
JD-2400000.0
-8
-9
-10
-11
log $F\gamma$, erg cm^{-2} s^{-1}
log F_R, erg $cm^{-2}s^{-1}$
1.71 ± 0.28

PKS 1510-089

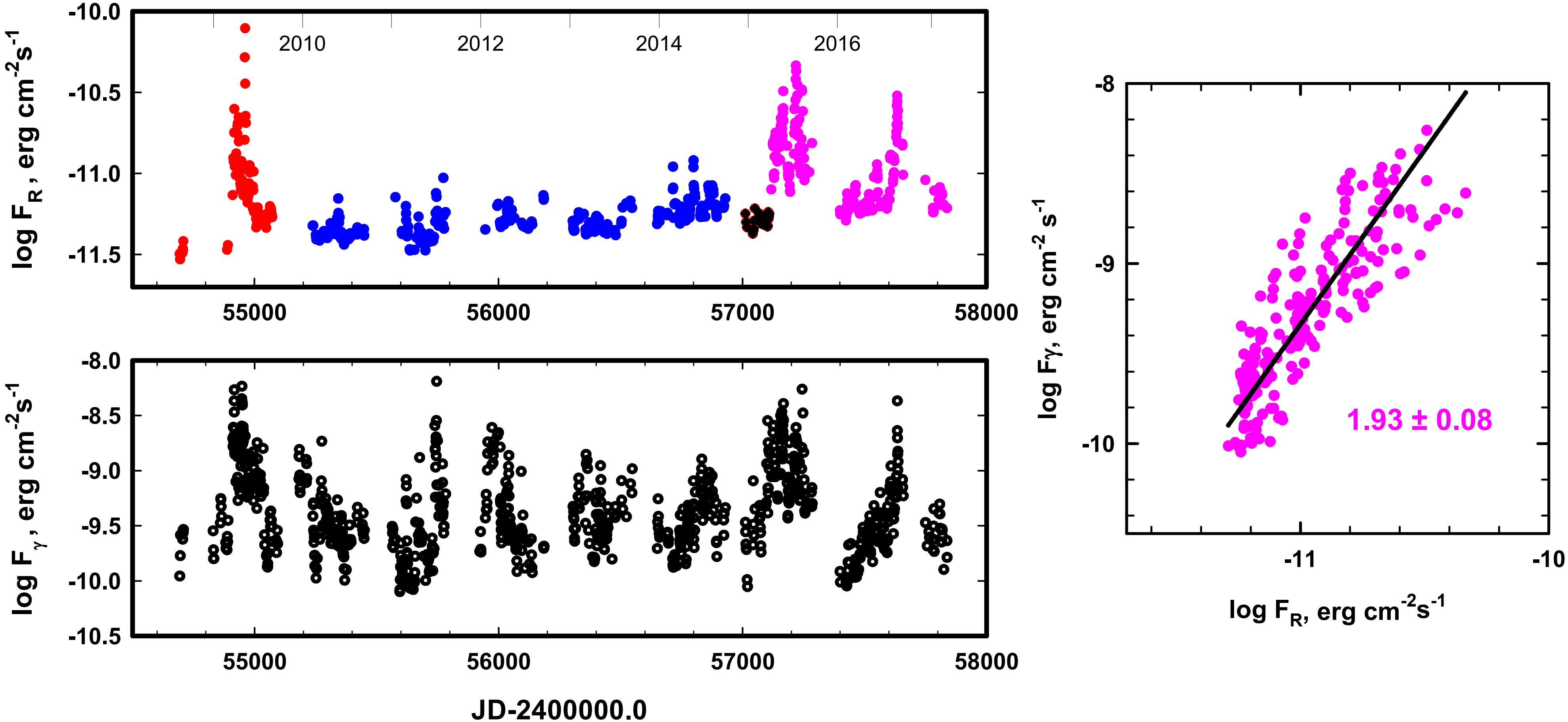


2010
2012
2014
2016
-10.0
-10.5
-11.0
-11.5
log F$_R$, erg cm^{-2}s^{-1}
55000
56000
57000
58000
-8.0
-8.5
-9.0
-9.5
-10.0
-10.5
log F$_\gamma$, erg cm^{-2}s^{-1}
JD-2400000.0



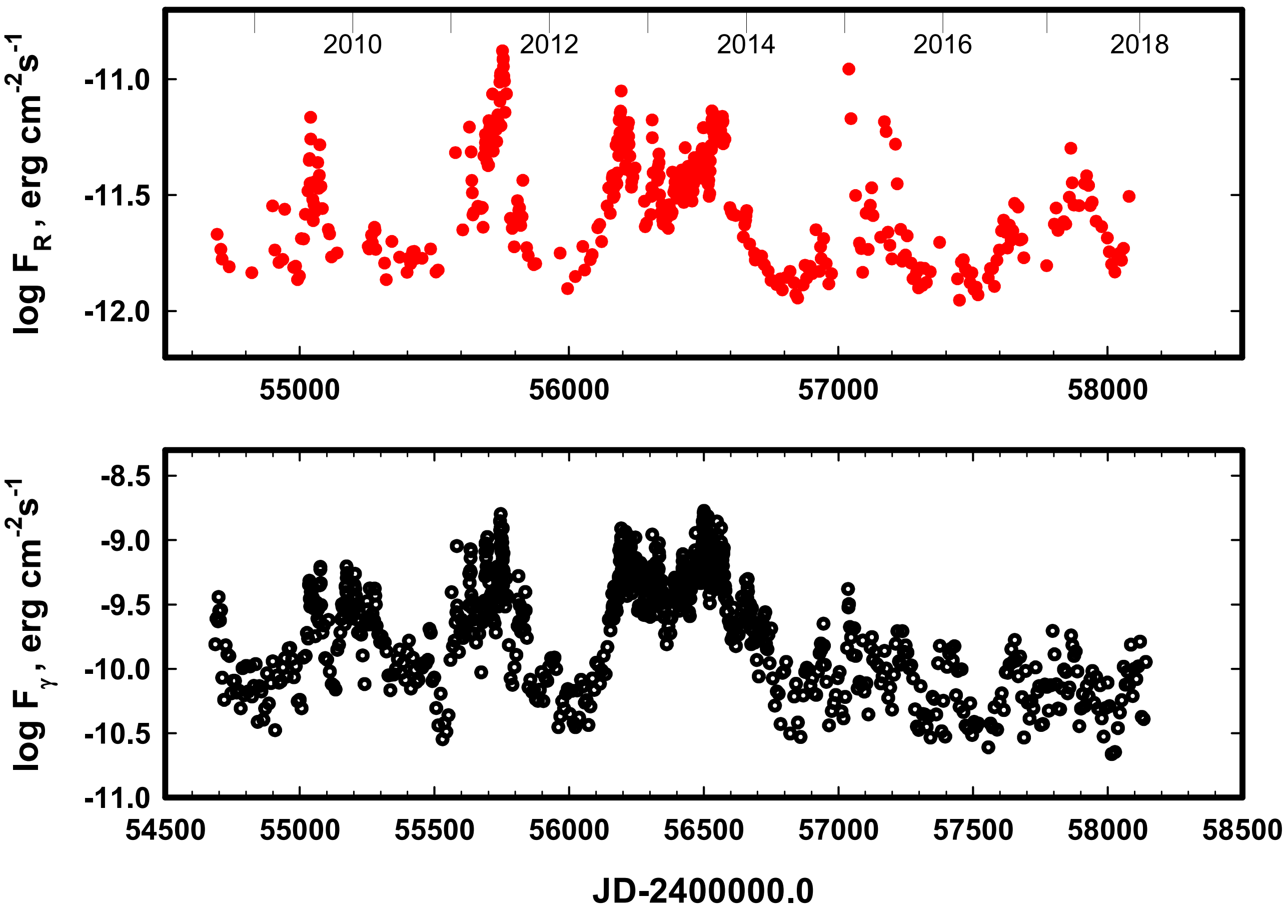
-8
-9
-10
-11
-10
7.7 ± 1.3
log Fγ, erg cm^{-2} s^{-1}
log F$_R$, erg cm^{-2}s^{-1}

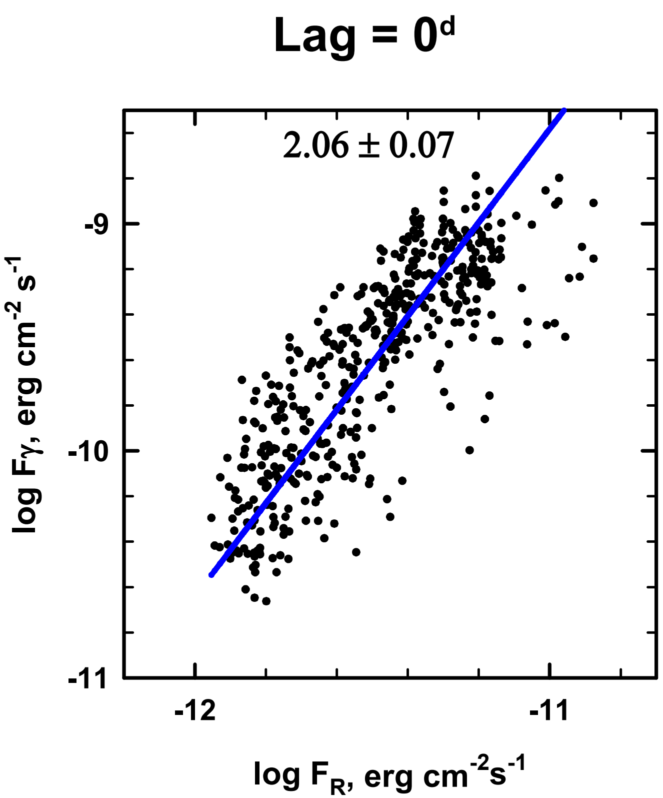
PKS 1510-089



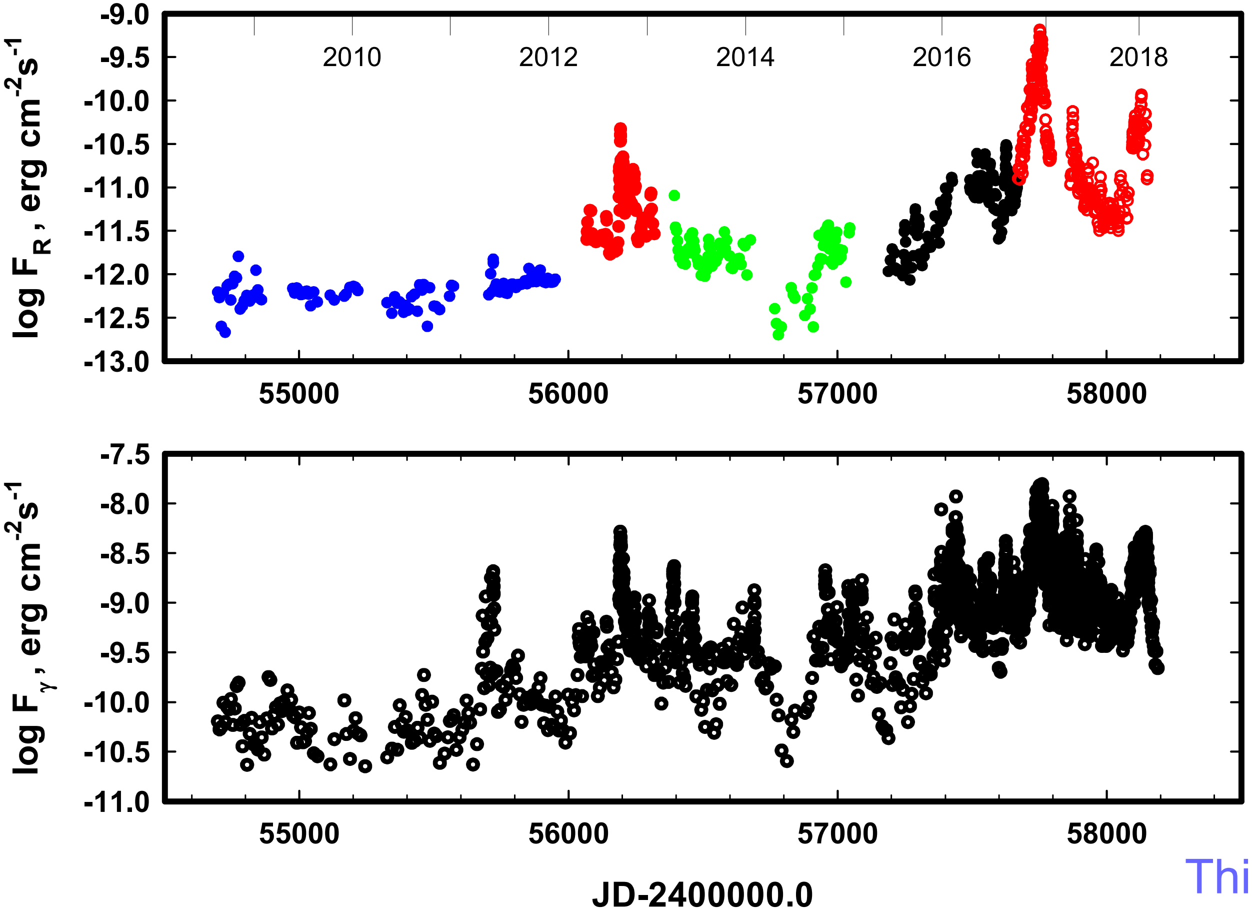
2010
2012
2014
2016
-10.0
-10.5
-11.0
-11.5
log F_R , erg cm^{-2}s^{-1}
55000
56000
57000
58000
-8.0
-8.5
-9.0
-9.5
-10.0
-10.5
log F_γ , erg cm^{-2}s^{-1}
JD-2400000.0
-8
-9
-10
-11
log Fγ, erg cm^{-2} s^{-1}
1.93 ± 0.08
log F_R, erg cm^{-2}s^{-1}

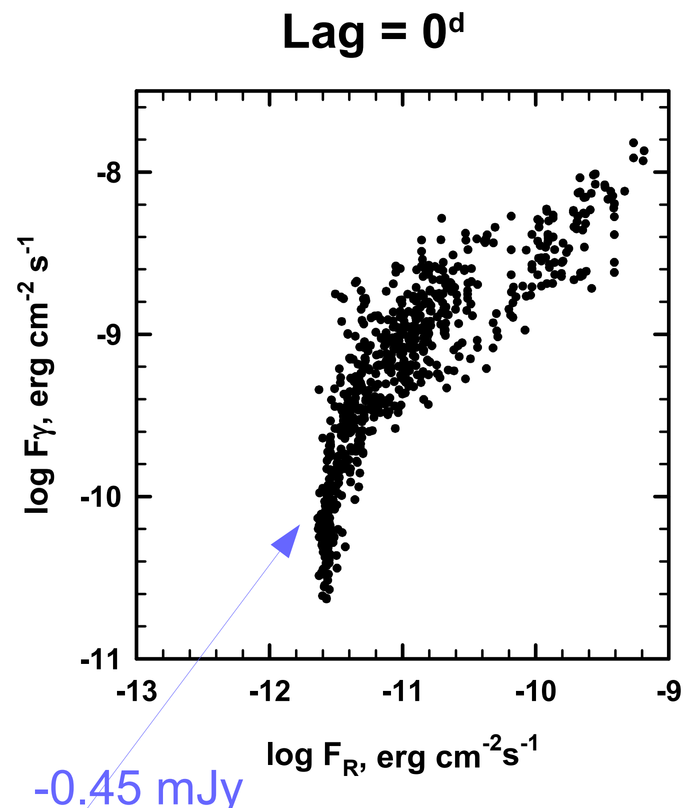
B2 1633+38 = 4C +38.41 z=1.81





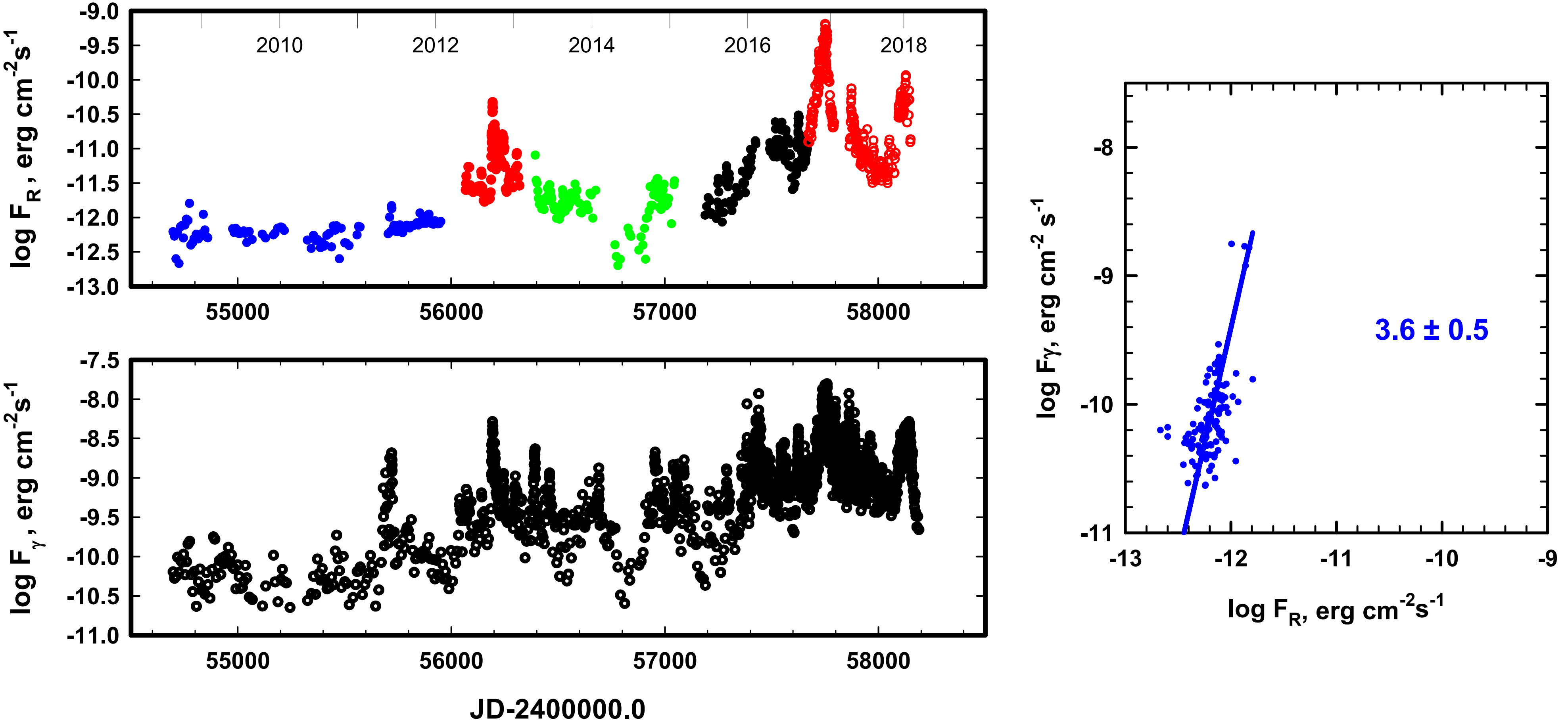
CTA 102 z=1.037





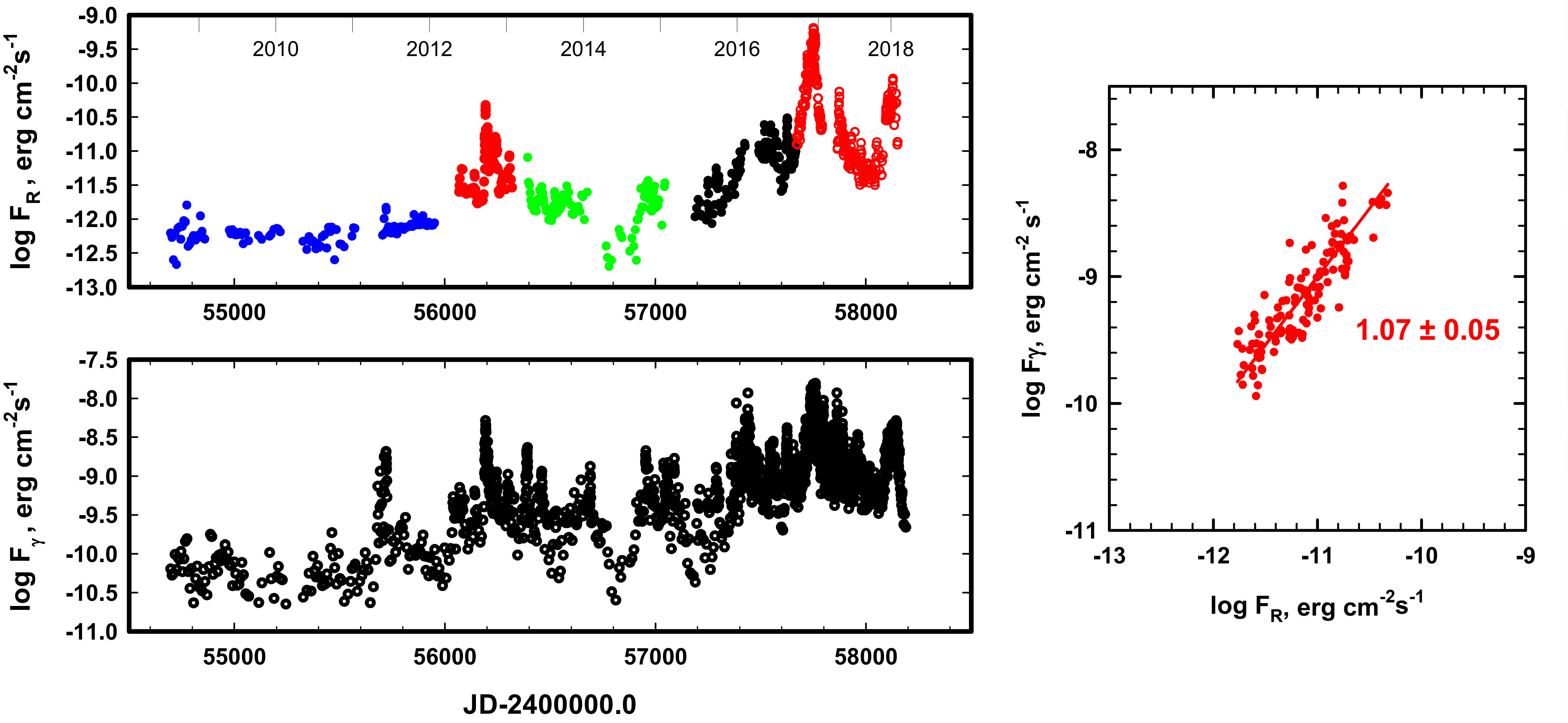
This pattern suggests that there is an additional component in optical radiation, besides sychrotron, subtract it! (see Larionov+ 2016, Raiteri+ 2017)

CTA 102



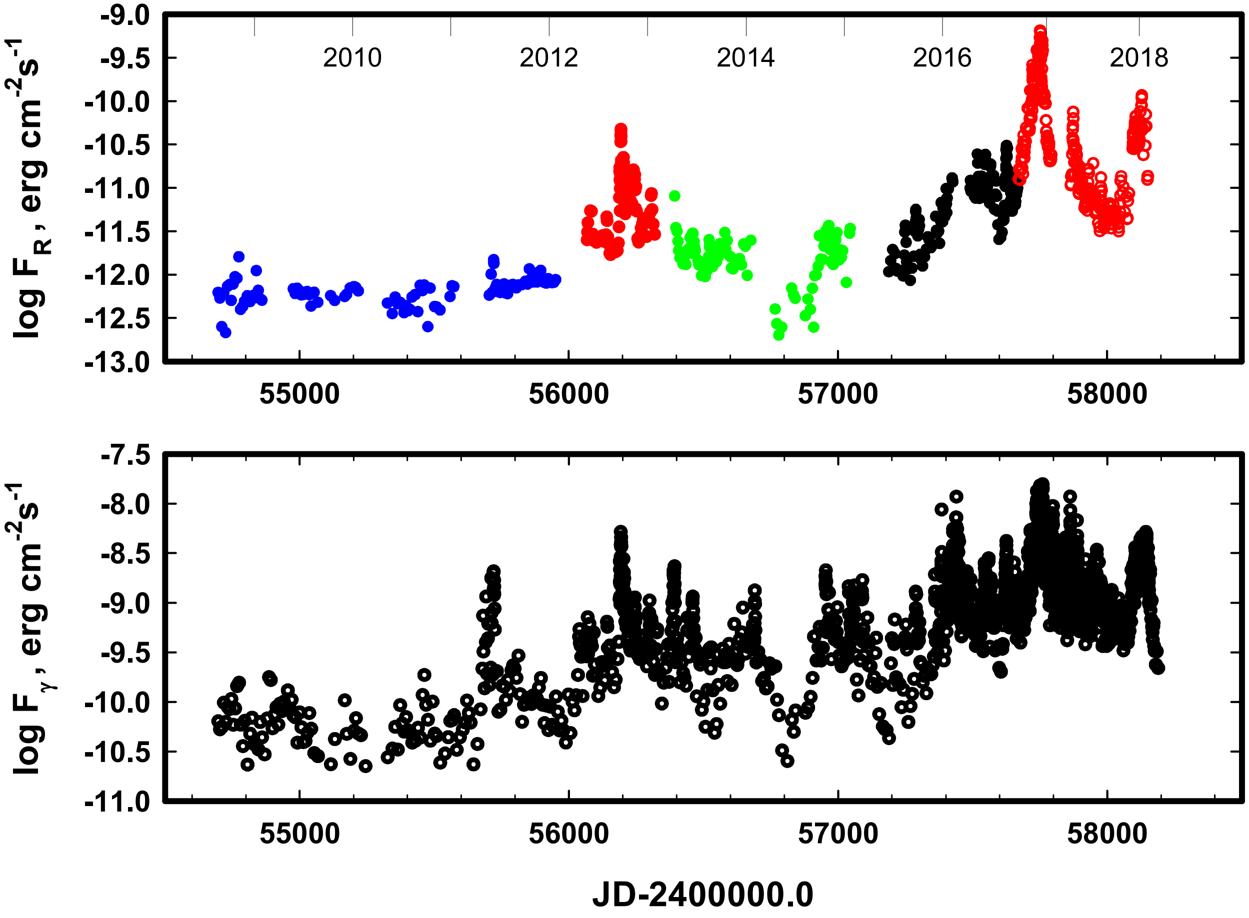
log F_R , erg cm^{-2}s^{-1}
2010
2012
2014
2016
2018
-9.0
-9.5
-10.0
-10.5
-11.0
-11.5
-12.0
-12.5
-13.0
55000
56000
57000
58000
log F_γ , erg cm^{-2}s^{-1}
-7.5
-8.0
-8.5
-9.0
-9.5
-10.0
-10.5
-11.0
JD-2400000.0
log $F\gamma$, erg cm^{-2} s^{-1}
-8
-9
-10
-11
3.6 ± 0.5
-13
-12
-11
-10
-9
log F_R, erg cm^{-2}s^{-1}

CTA 102

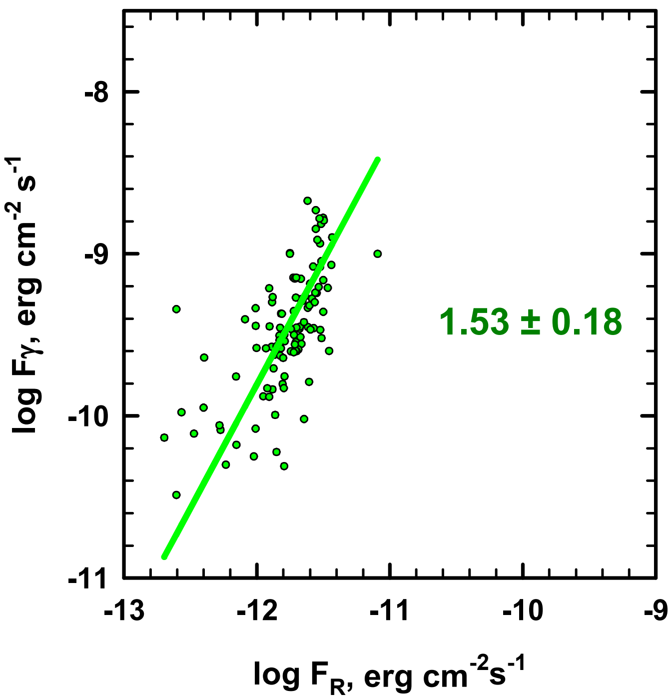


log F$_R$, erg cm^{-2}s^{-1}
2010
2012
2014
2016
2018
log F$_\gamma$, erg cm^{-2}s^{-1}
JD-2400000.0
log Fγ, erg cm^{-2} s^{-1}
log F$_R$, erg cm^{-2}s^{-1}
1.07 ± 0.05

CTA 102

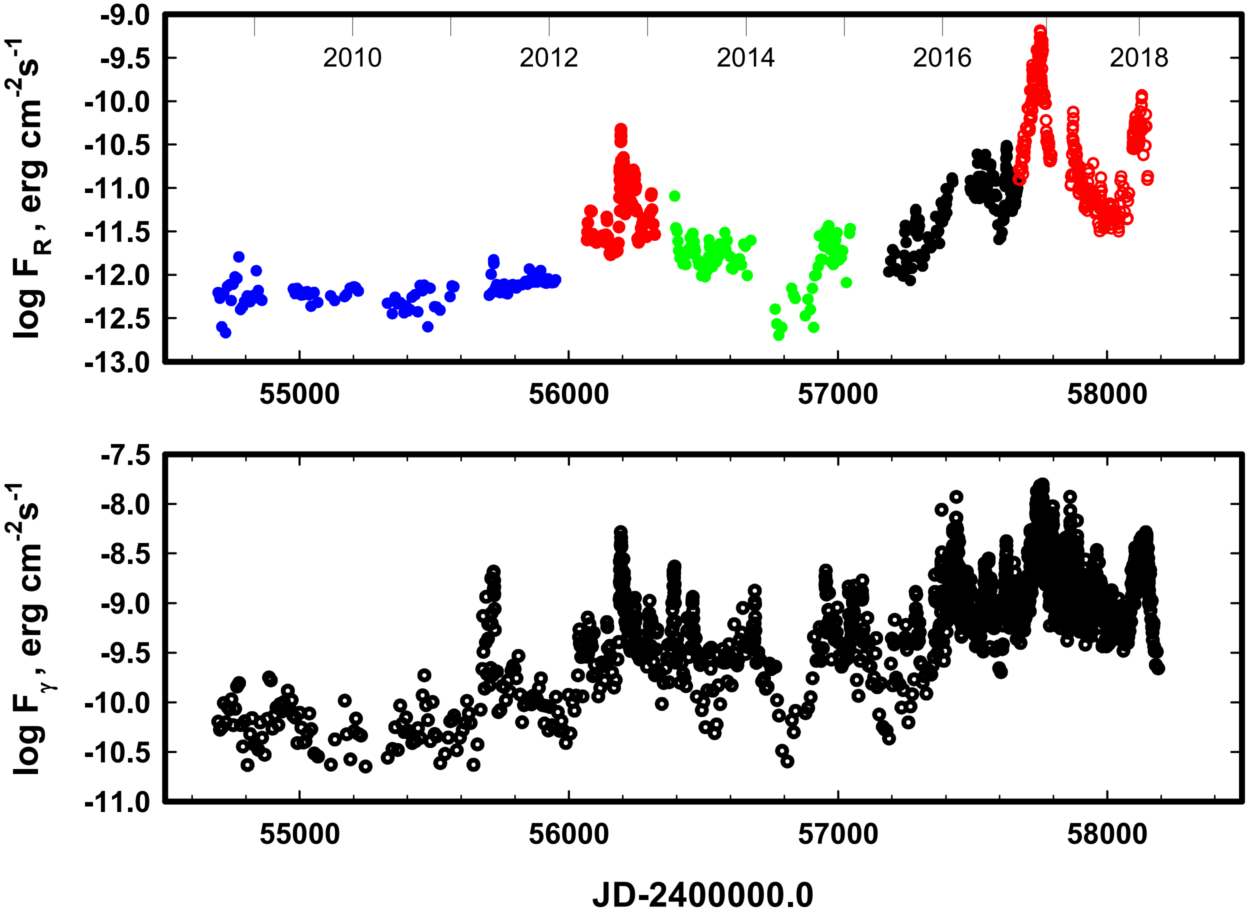


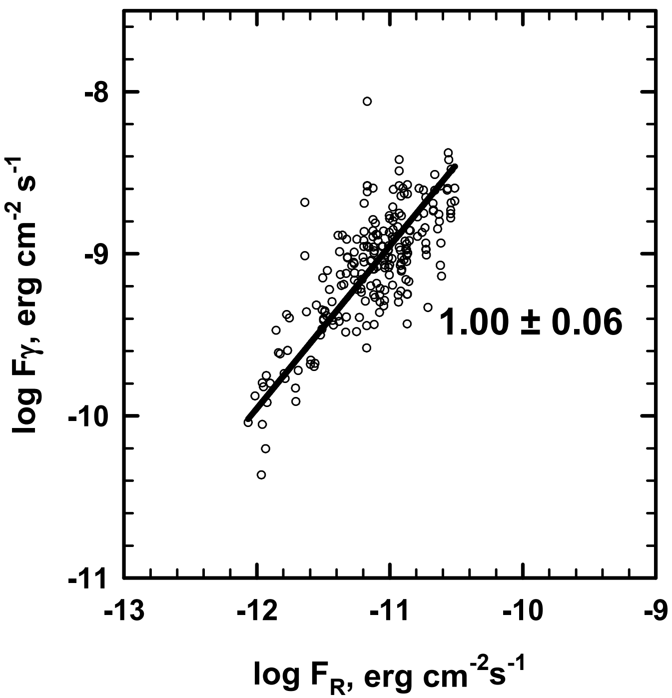
log F_R, erg $cm^{-2}s^{-1}$
2010
2012
2014
2016
2018
log F_γ, erg $cm^{-2}s^{-1}$
JD-2400000.0



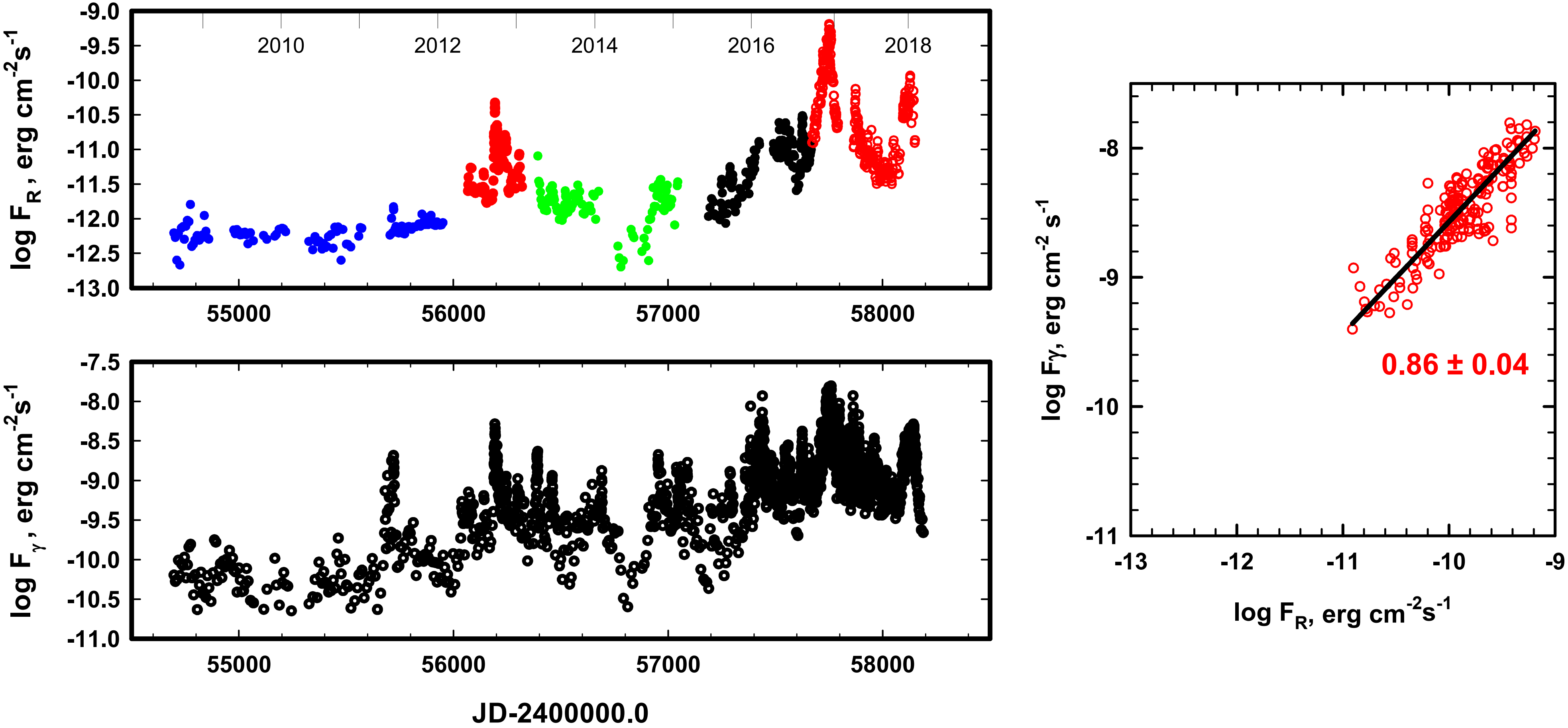
log Fγ, erg cm^{-2} s^{-1}
1.53 ± 0.18
log F_R, erg $cm^{-2}s^{-1}$

CTA 102

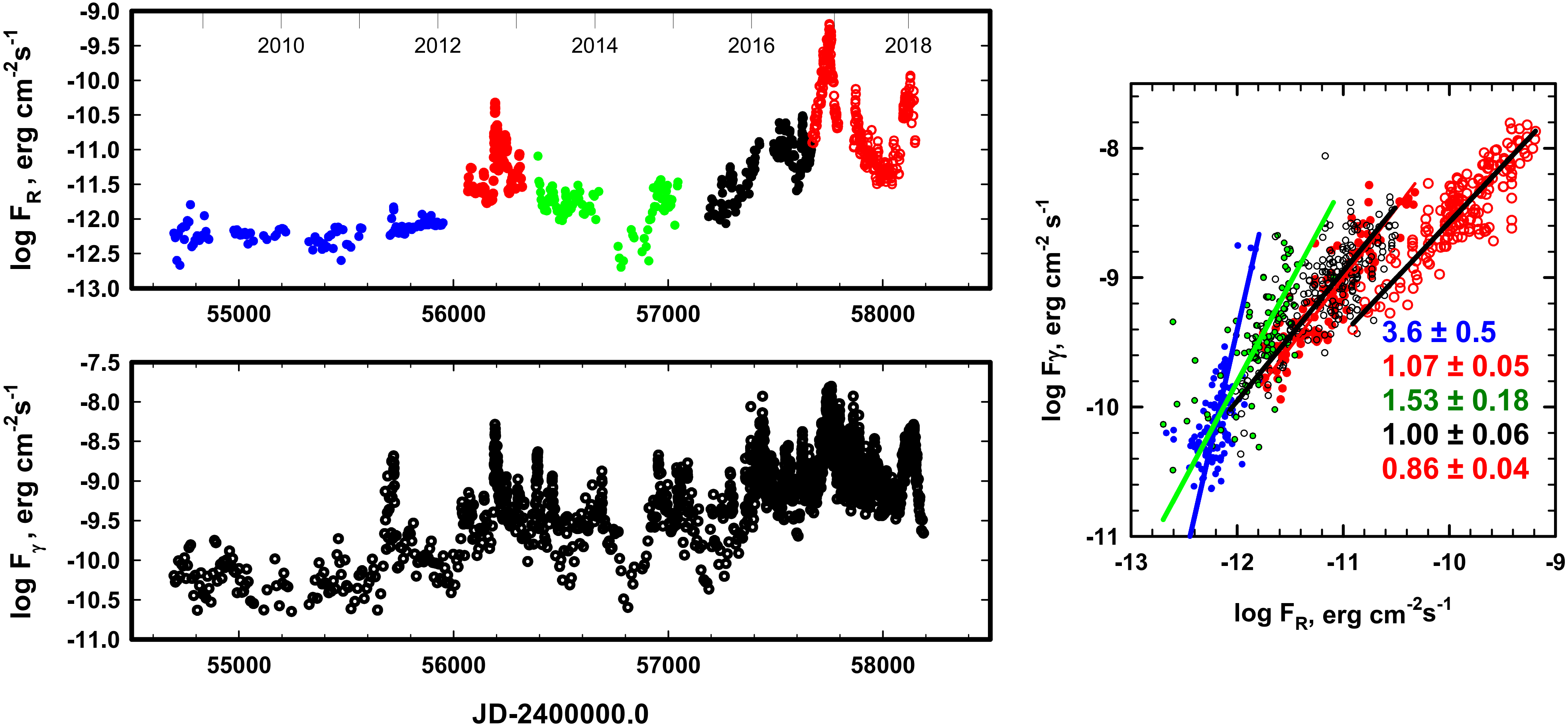

log F_R , erg cm^{-2}s^{-1}
2010
2012
2014
2016
2018
-9.0
-9.5
-10.0
-10.5
-11.0
-11.5
-12.0
-12.5
-13.0
55000
56000
57000
58000
log F_γ , erg cm^{-2}s^{-1}
-7.5
-8.0
-8.5
-9.0
-9.5
-10.0
-10.5
-11.0
JD-2400000.0


log Fγ, erg cm^{-2} s^{-1}
-8
-9
-10
-11
-13
-12
-11
-10
-9
1.00 ± 0.06
log F_R, erg cm^{-2}s^{-1}

CTA 102

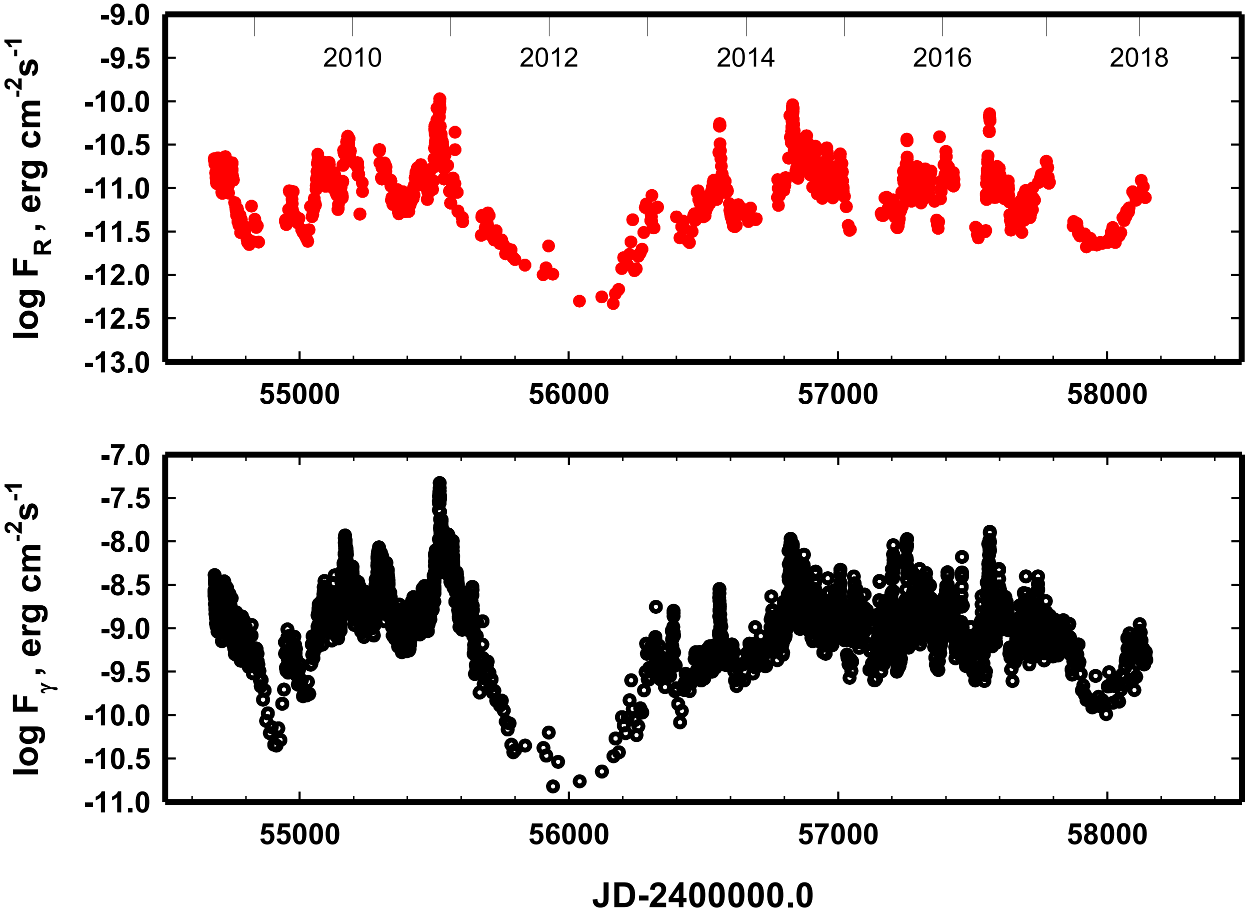

log F_R, erg $cm^{-2}s^{-1}$
2010
2012
2014
2016
2018
log F_γ, erg $cm^{-2}s^{-1}$
JD-2400000.0
0.86 ± 0.04
log F_R, erg $cm^{-2}s^{-1}$

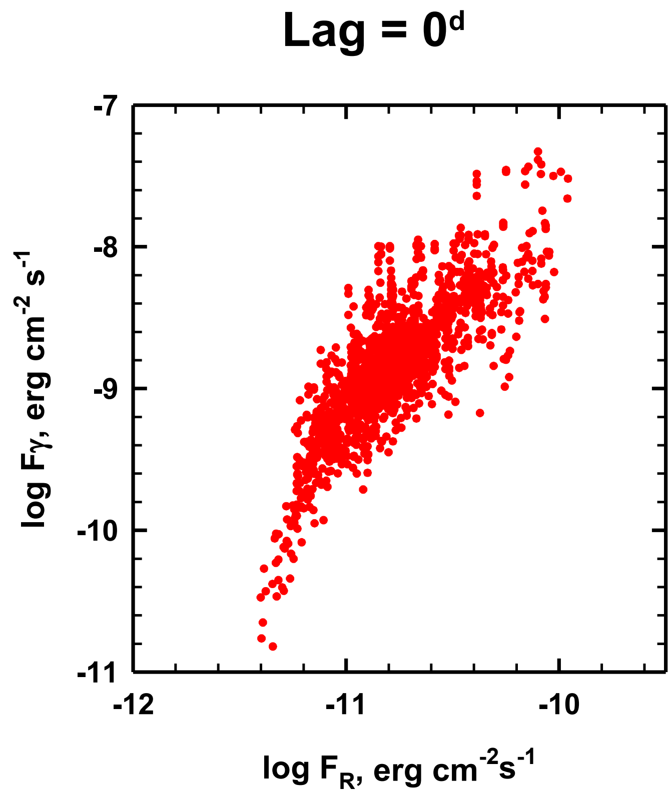
CTA 102



log F$_R$, erg cm^{-2}s^{-1}
2010
2012
2014
2016
2018
55000
56000
57000
58000
log F$_\gamma$, erg cm^{-2}s^{-1}
JD-2400000.0
log Fγ, erg cm^{-2} s^{-1}
log F$_R$, erg cm^{-2}s^{-1}
3.6 ± 0.5
1.07 ± 0.05
1.53 ± 0.18
1.00 ± 0.06
0.86 ± 0.04

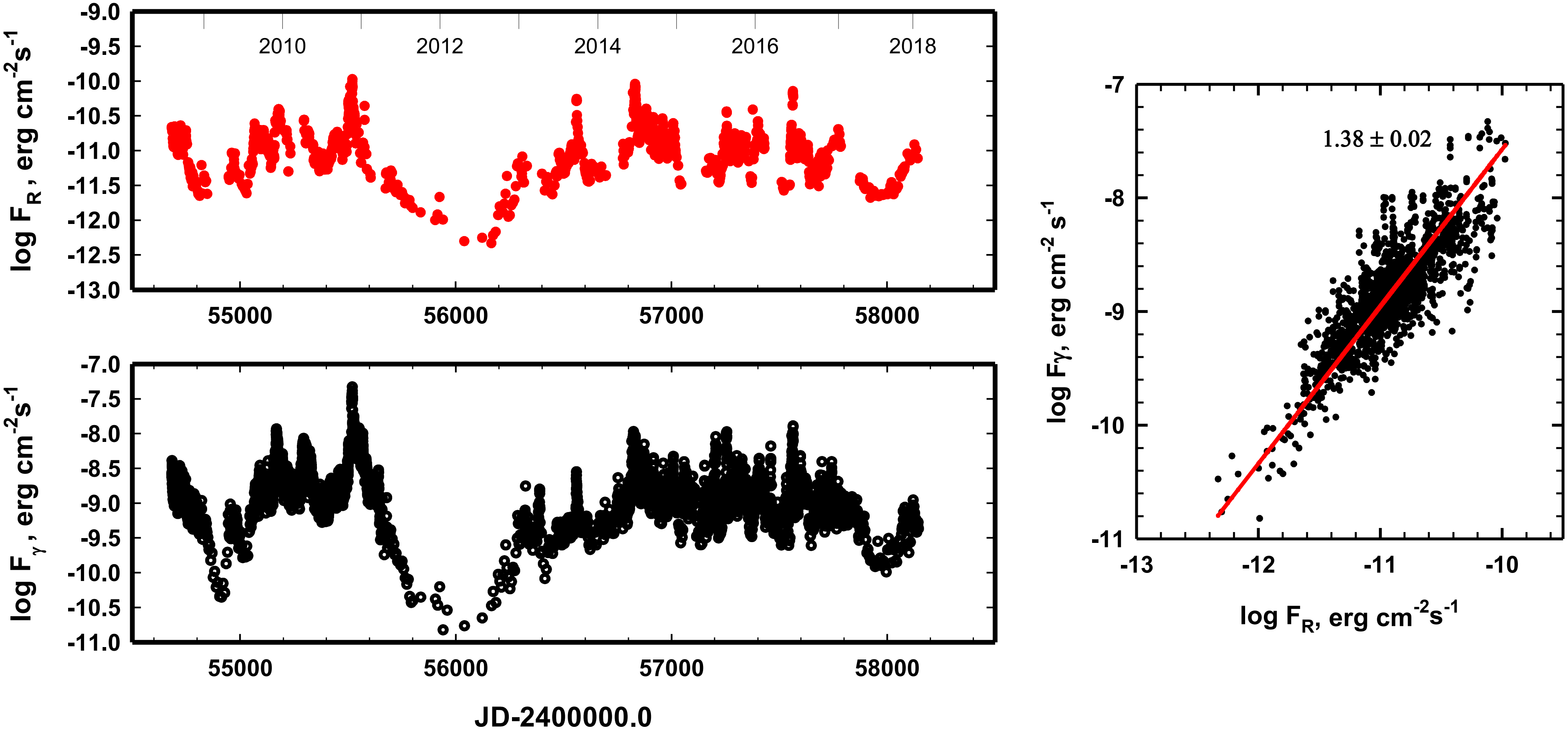
3C 454.3 z=0.859



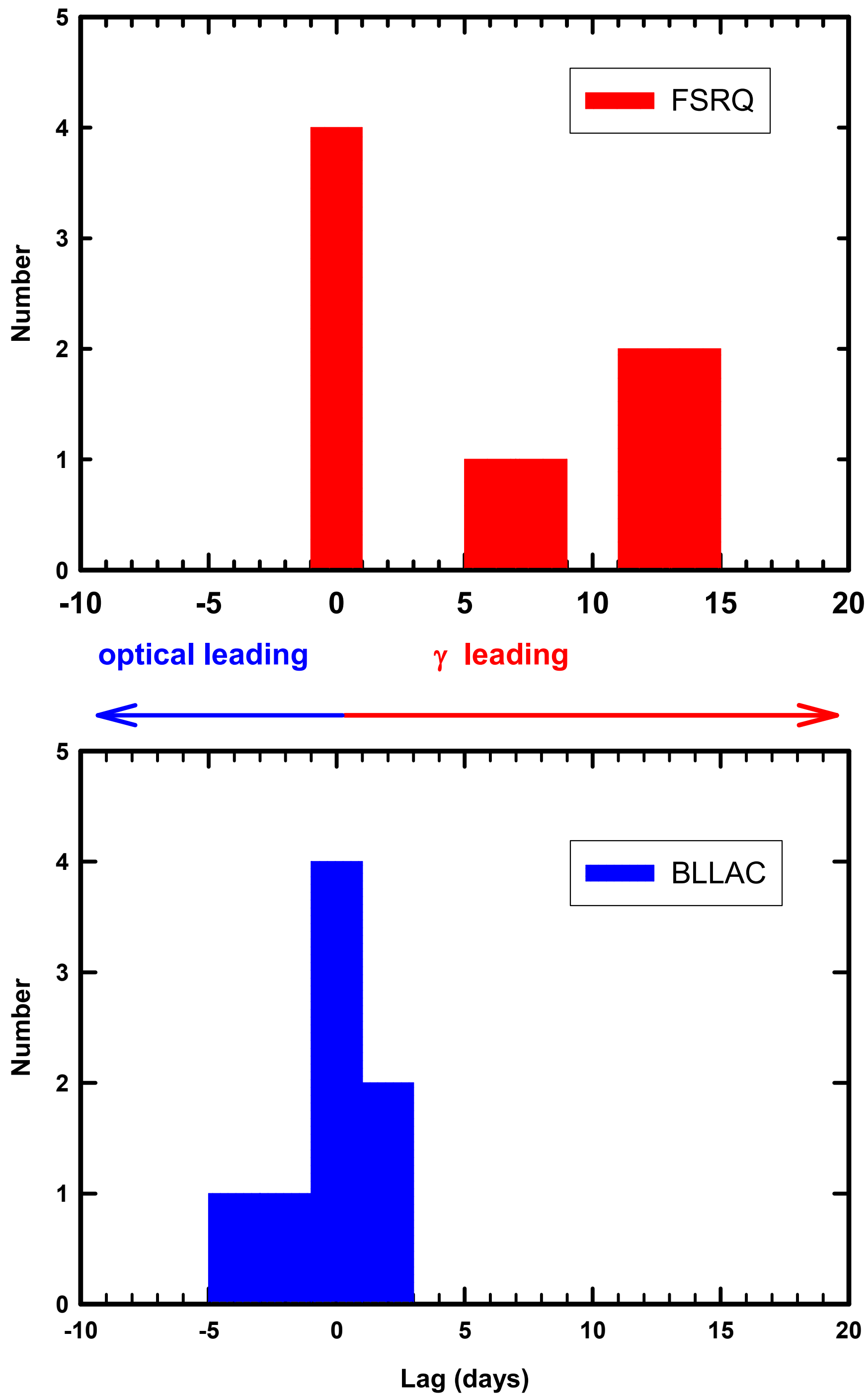


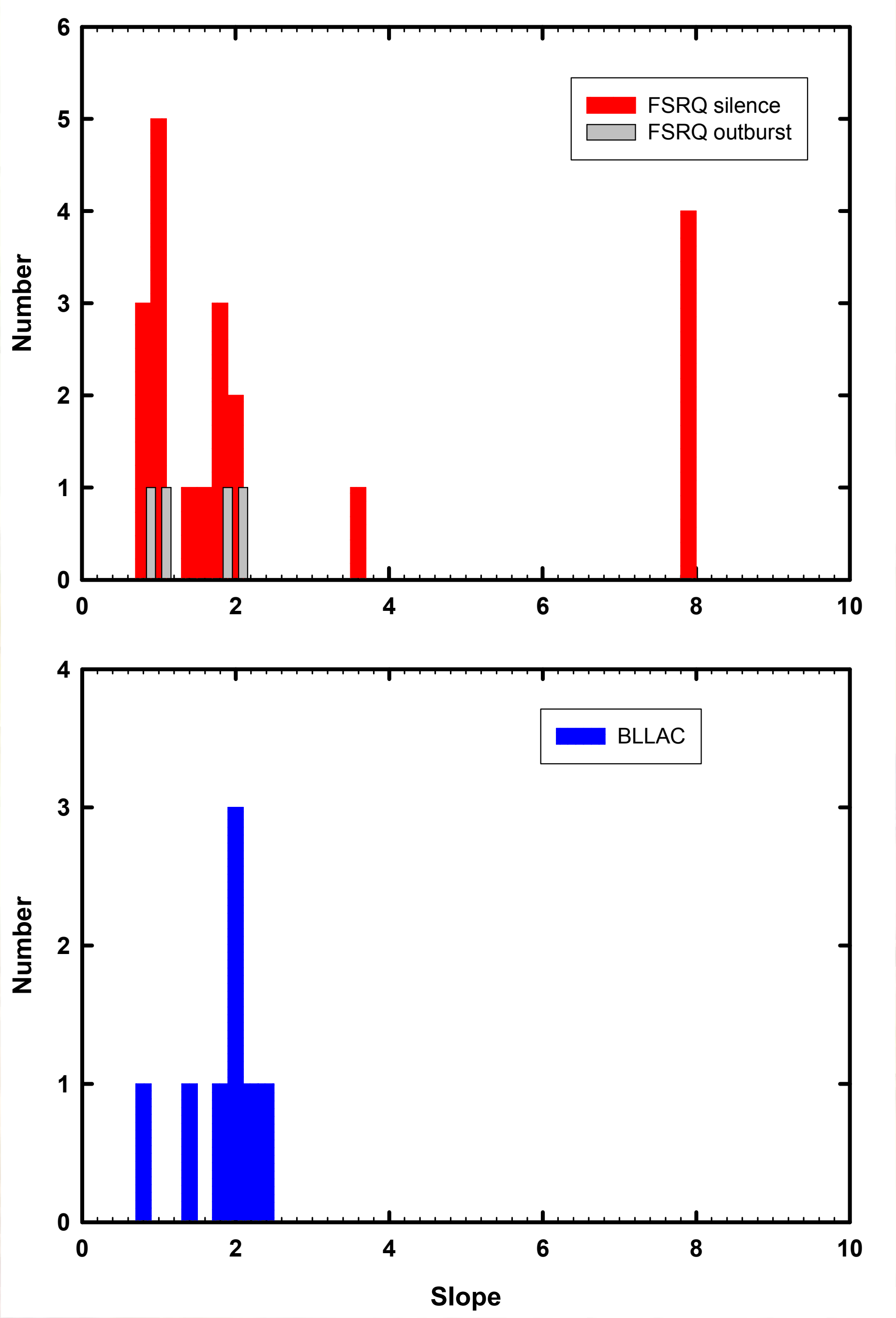
Subtract 0.75 mJy

3C 454.3



-9.0
-9.5
-10.0
-10.5
-11.0
-11.5
-12.0
-12.5
-13.0
log F_R , erg cm^{-2}s^{-1}
2010
2012
2014
2016
2018
55000
56000
57000
58000
-7.0
-7.5
-8.0
-8.5
-9.0
-9.5
-10.0
-10.5
-11.0
log F_γ , erg cm^{-2}s^{-1}
55000
56000
57000
58000
JD-2400000.0
-7
-8
-9
-10
-11
log Fγ, erg cm^{-2} s^{-1}
1.38 ± 0.02
-13
-12
-11
-10
log F_R, erg cm^{-2}s^{-1}


FSRQ
BLLAC
Number
Number
optical leading
γ leading
Lag (days)
-10
-5
0
5
10
15
20
0
1
2
3
4
5


FSRQ silence
FSRQ outburst
BLLAC
Number
Slope
0
2
4
6
8
10
1
3
5

Summary

- **BLLacs tend to have time lags between optical and γ-rays in the range -5 – +3 days, while FSRQs – 0–15 days (positive values mean γ-rays leading)**

- **The slopes of $\log F_{opt}$ – $\log F_{\gamma}$ dependences for BLLacs, with a few exceptions (most striking – OJ287), are close to 2, that corresponds to SSC mechanism.**

- **The slopes for FSRQ prefer to group around 1 and 2, and the slopes often change with the changed stage of activity (SSC <=> EC?)**

- **The shapes of $\log F_{opt}$ – $\log F_{\gamma}$ slopes are sometimes distorted by a contribution of a less variable component of radiation, that maybe taken into account (CTA102, 3C454.3)**

- **Perfect coverage in γ-rays and optical allows to distinguish in several cases periods of «orphan activity» – very steep slopes (3C279, PKS1510-089, CTA102), that may support «ring of fire» model (MacDonald+ 2015, 2017)**

Perkins
Arizona (Lowell)

LX-200
St.Petersburg

AZT-8
Crimea

Grazie !

Спасибо за внимание !

Thank you !