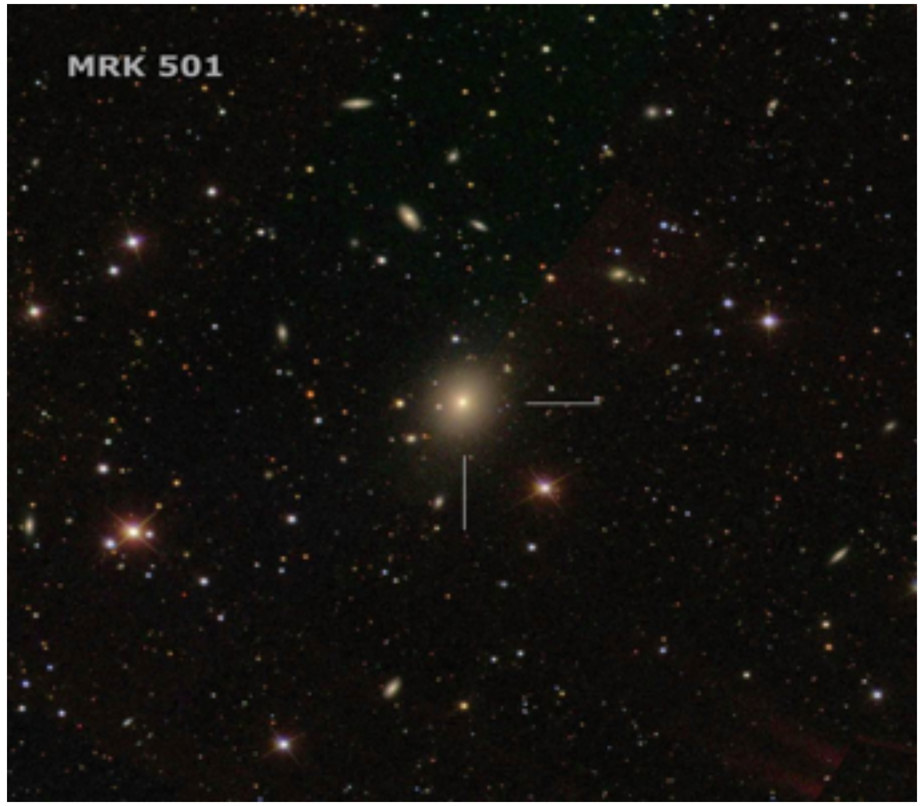
ETH zürich



Study of the extreme flaring activity of Mrk 501: Multi-wavelength observations in 2012

Gareth Hughes, Amit Shukla,
David Paneque, Francesco Borracci, Luis Reyes
on behalf of the MAGIC, VERITAS, FACT, Fermi-LAT collaborations, as well as GASP-WEBT, F-GAMMA

ICRC 2015

Outline

- Multi-wavelength Campaign 2012
  March to July
  (organized by **David Paneque**)
- Including: MAGIC, VERITAS, Fermi-LAT collaborations, as well as GASP-WEBT, F-GAMMA

- Here we present:
  - MWL data from Radio to VHE
  - Variability and Correlation studies
  - Comparison between MAGIC and FACT
  - TeV and X-ray Spectra
  - SED Modeling

Mrk 501 and MWL Campaigns

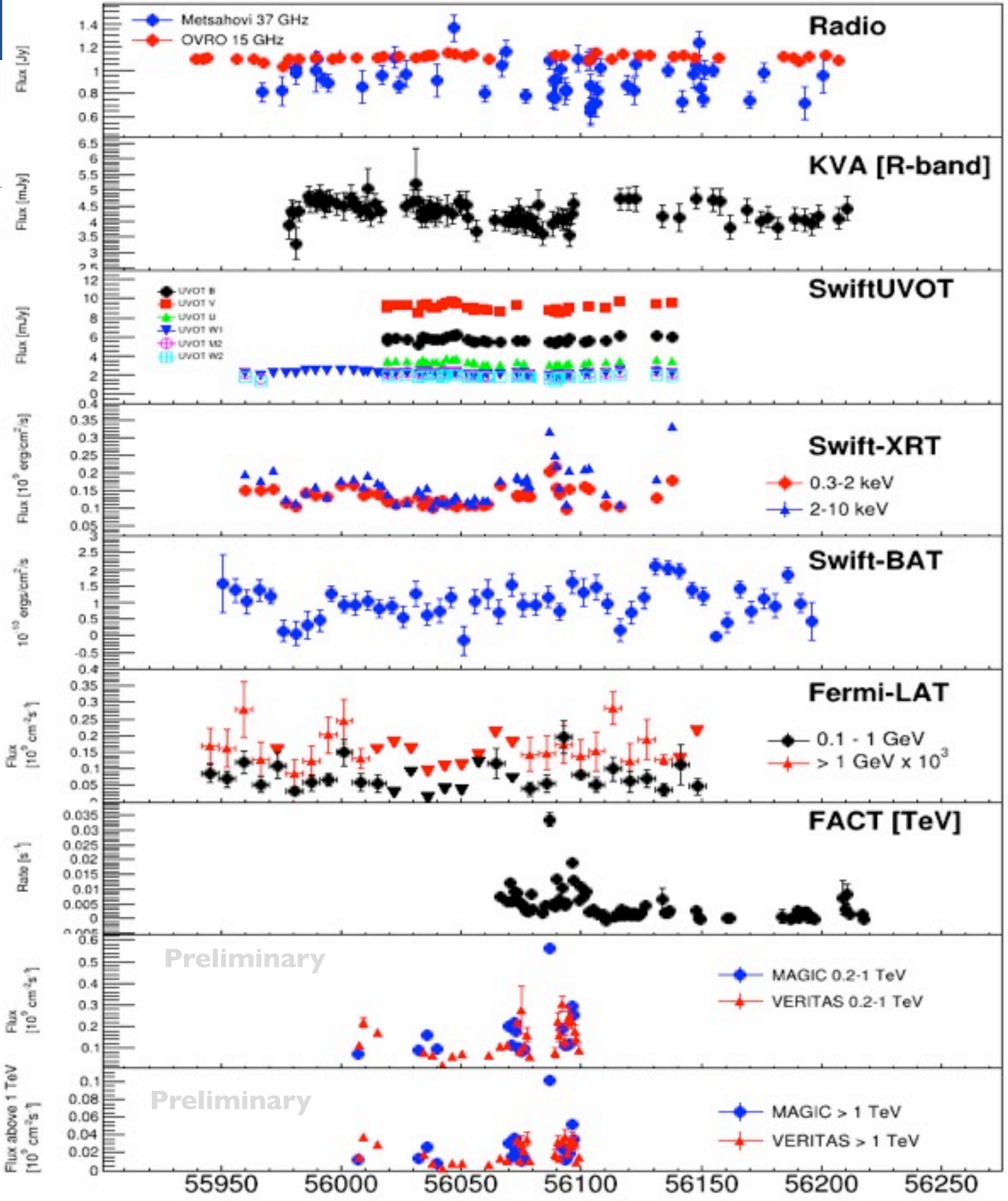
- Since 2009 campaigns have been organized in advance
- Source observed regardless of state
- Something unexpected/surprising is often observed

- Mrk 501:
  - nearby z = 0.034
  - First seen at VHE by Whipple (Quinn et al ’96)
  - Quiescent state < Crab nebula flux
  - Often shows large flaring events

- **Excellent laboratory** to study AGN

Light Curve

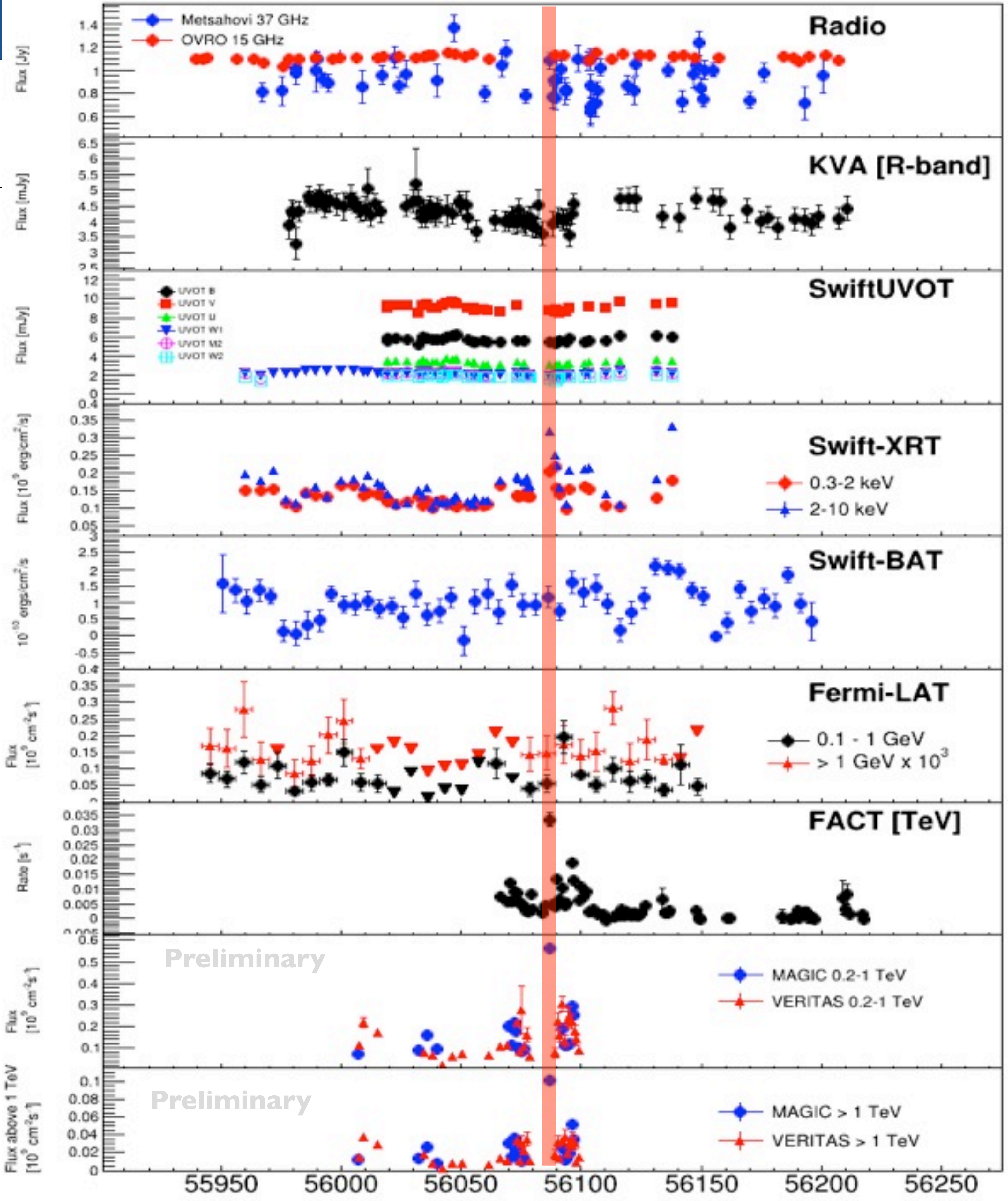
- Excellent coverage from Radio -TeV
  Over 25 instruments
  (not all shown)



Light Curve

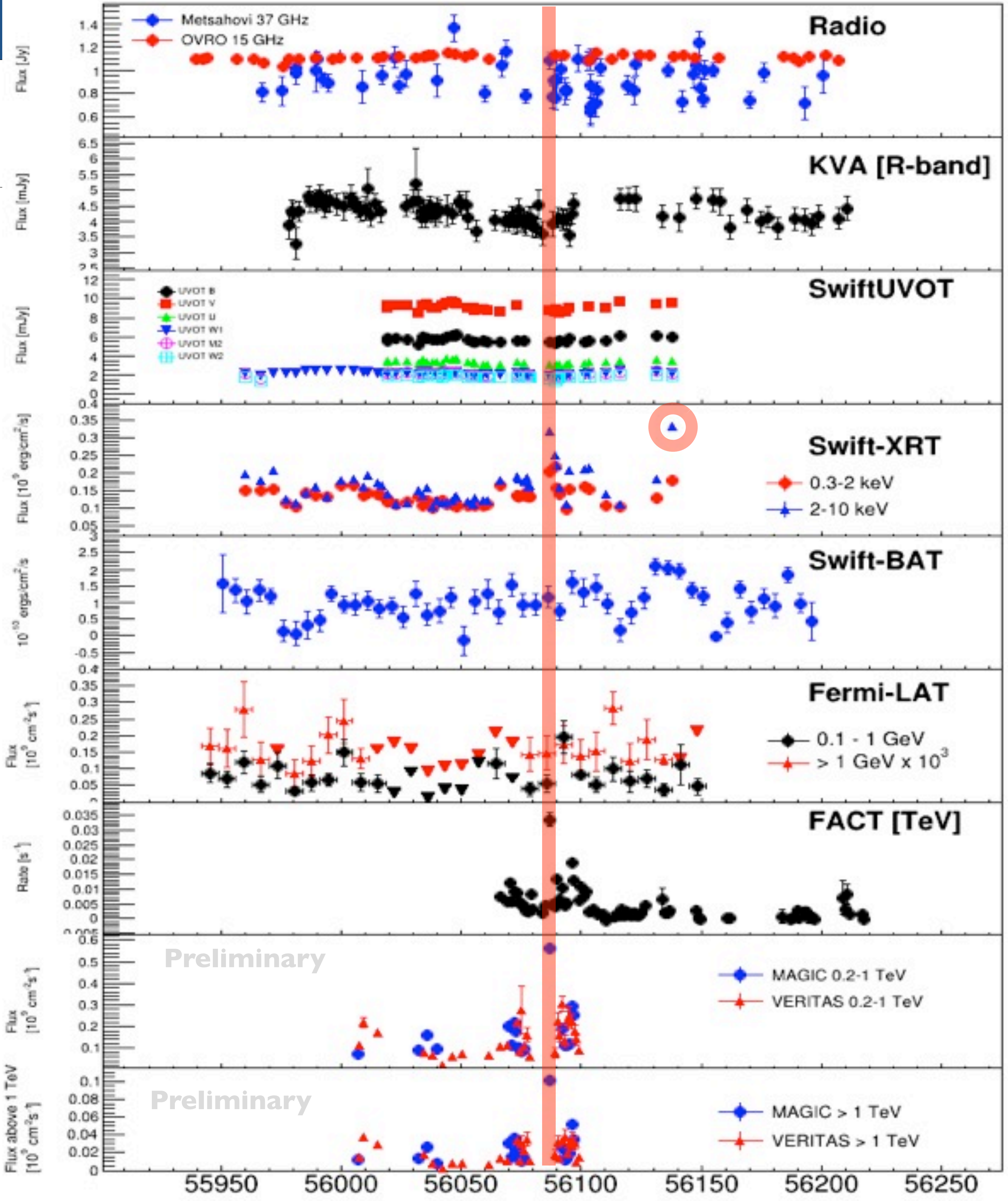
- Excellent coverage from Radio -TeV
  Over 25 instruments
  (not all shown)

- Flare: 9th June
  Swift-XRT, MAGIC and FACT
  >10 CU above 1 TeV



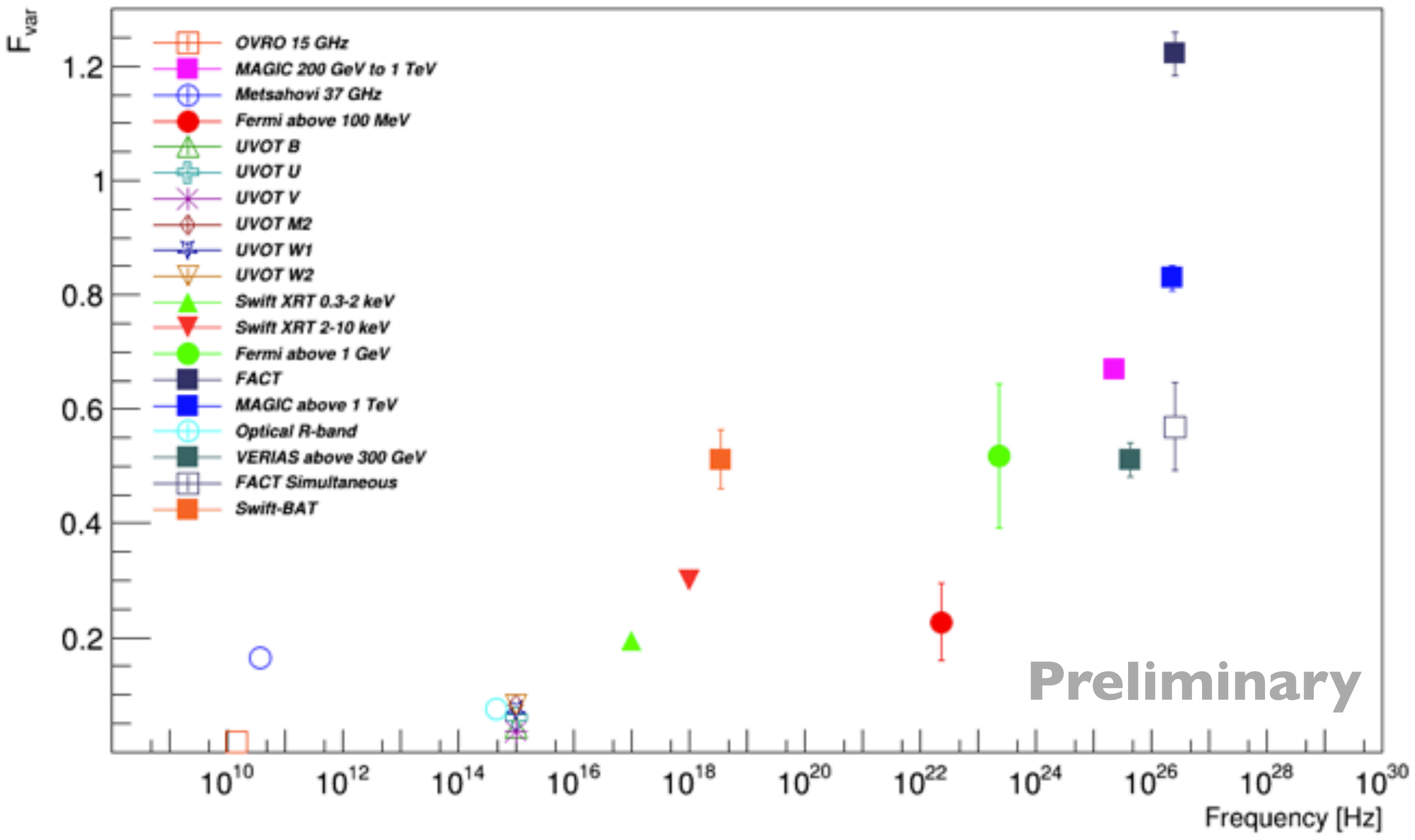
Light Curve

- Excellent coverage from Radio -TeV
  Over 25 instruments
  (not all shown)
- Flare: 9th June
  Swift-XRT, MAGIC and FACT
  >10 CU above 1 TeV
- *Swift*-XRT sees a larger flare later: no observation by TeV instruments
- Shows the benefits of monitoring



Fractional Variability

- Highest variability at higher energies
- **Different to Mrk 421** where the maximum variability in the X-ray
- Measured X-ray emission of *Swift* relates mostly to the rising segment of the Synchrotron peak
  - in Mrk 421 is the falling segment of the Sync peak

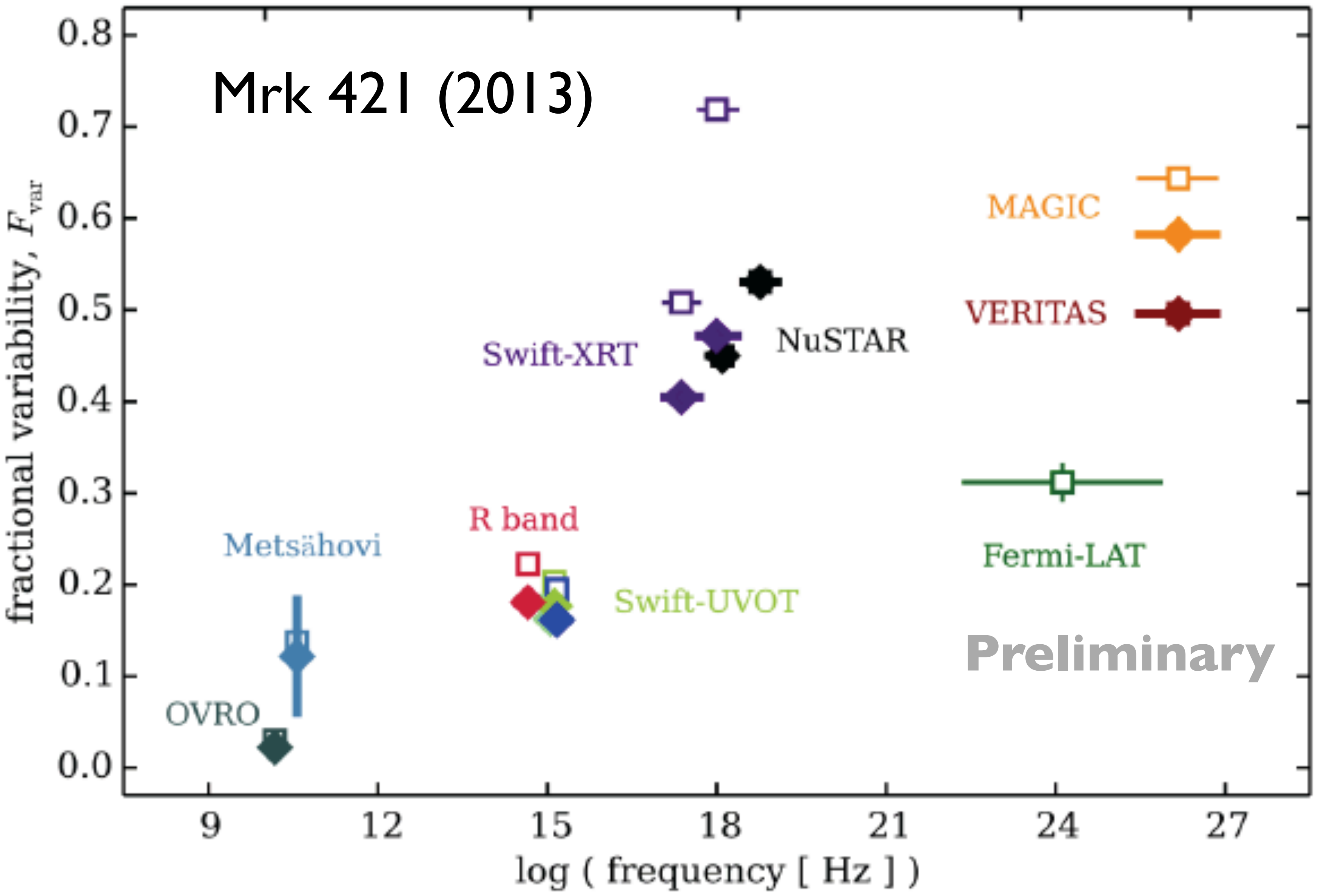


$$F_{var} = \sqrt{\frac{S^2 - \langle \sigma_{eff}^2 \rangle}{\langle F_\gamma \rangle^2}}$$

Vaughan S. et al MNRAS 345 (2003)

Fractional Variability

- Highest variability at higher energies
- **Different to Mrk 421** where the maximum variability in the X-ray
- Measured X-ray emission of *Swift* relates mostly to the rising segment of the Synchrotron peak
  - in Mrk 421 is the falling segment of the Sync peak

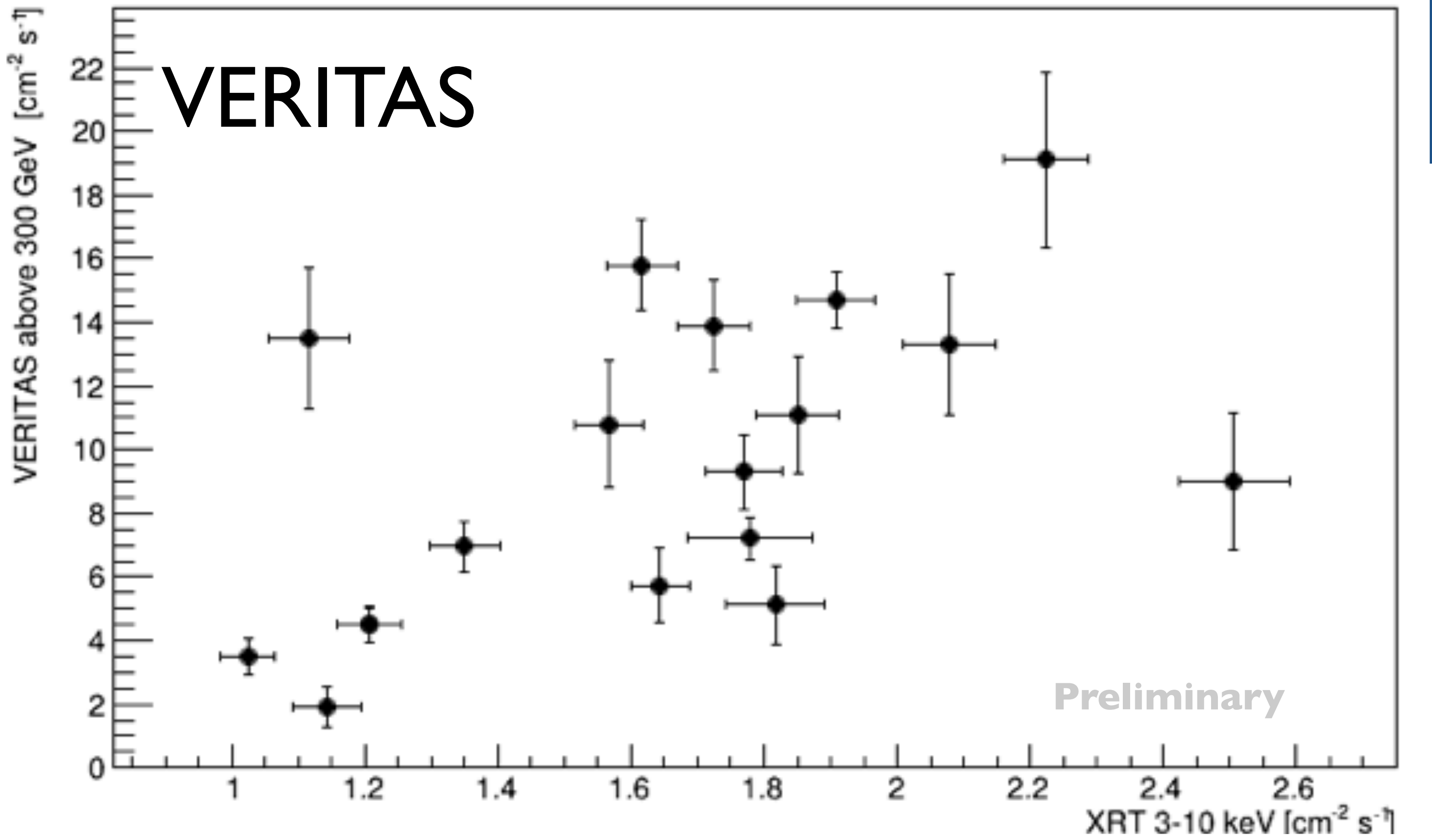


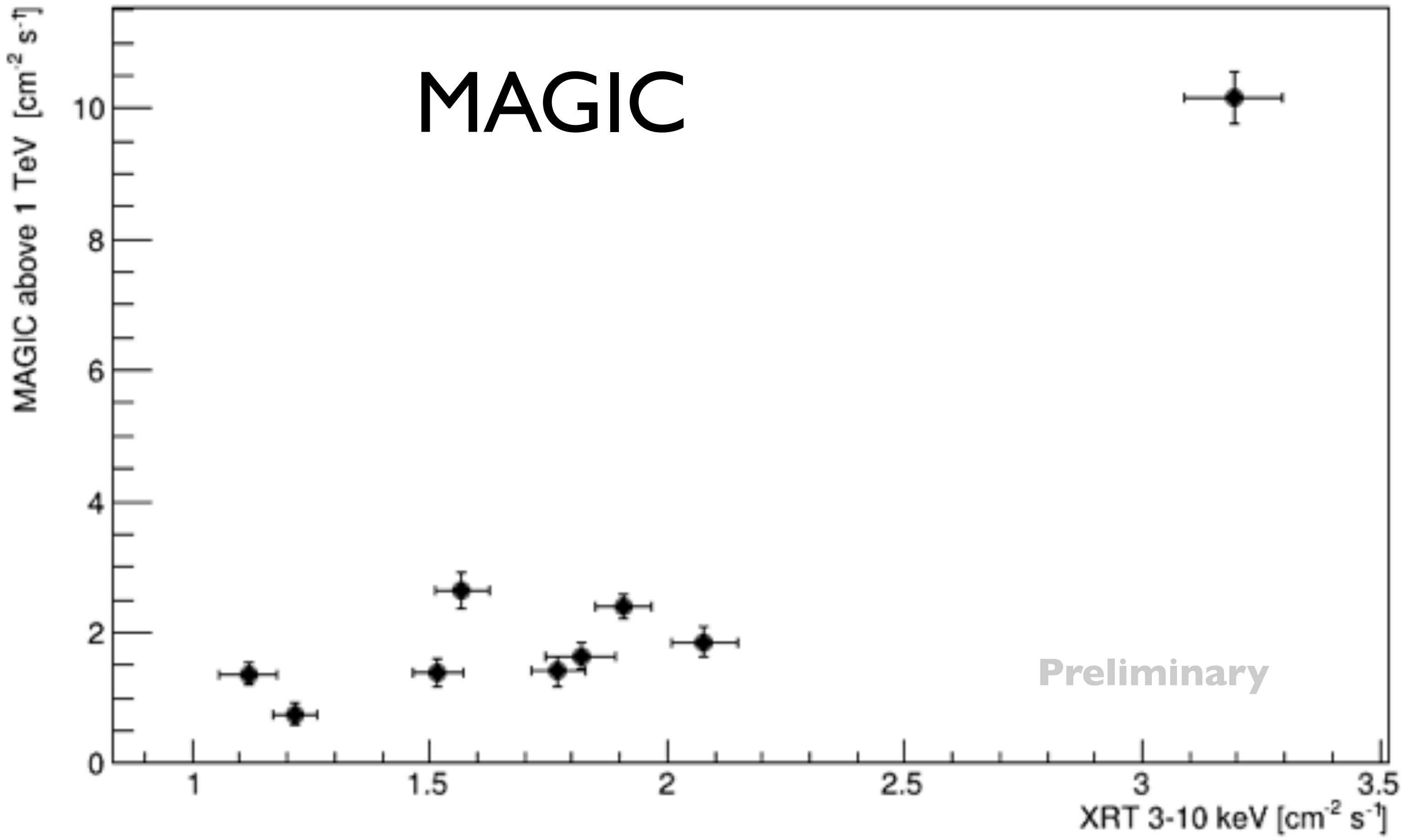
$$F_{var} = \sqrt{\frac{S^2 - \langle \sigma_{eff}^2 \rangle}{\langle F_\gamma \rangle^2}}$$

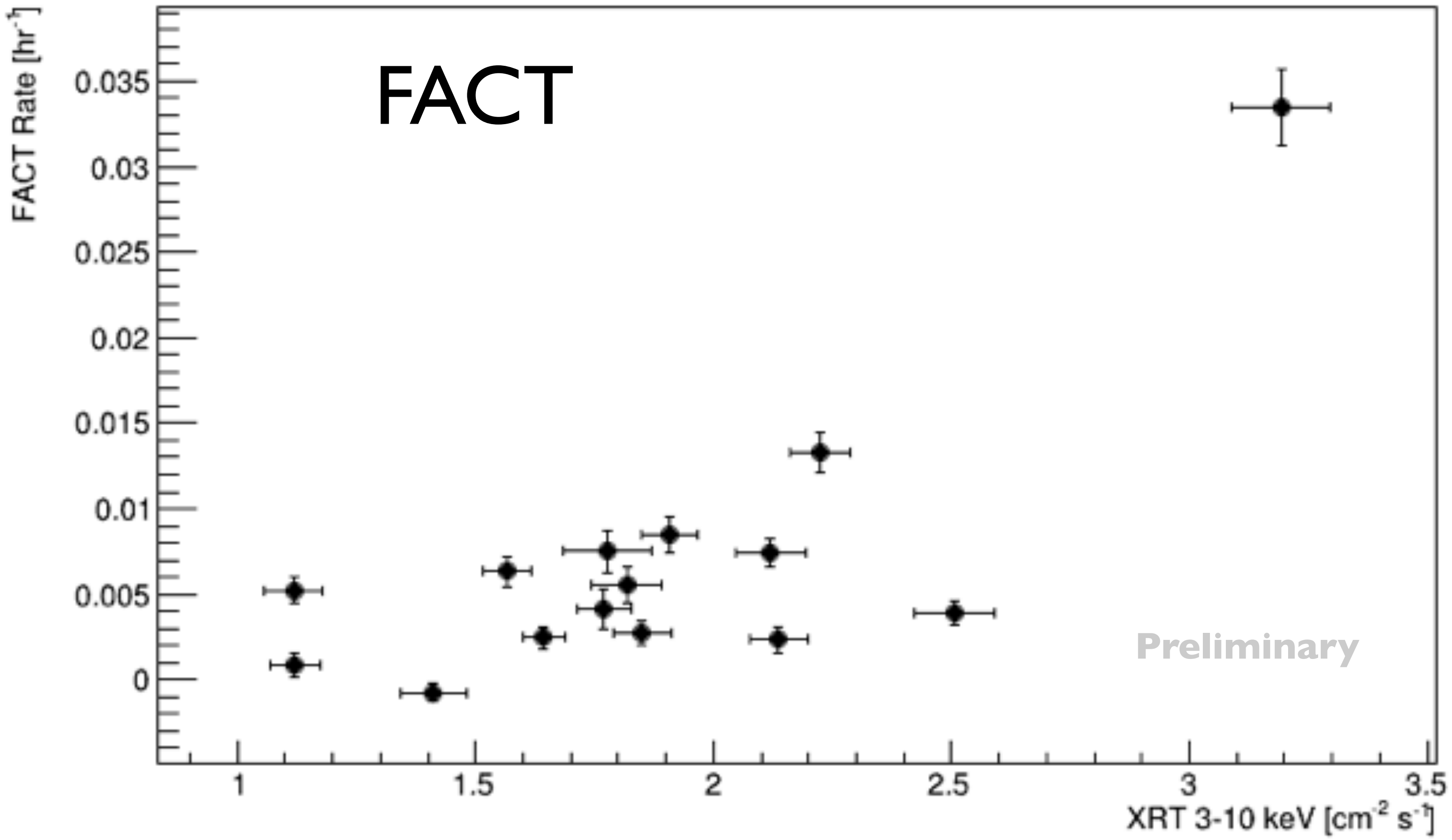
Vaughan S. et al MNRAS 345 (2003)

X-ray TeV Correlation

- Compare X-ray and TeV Flux
- *Swift*-XRT 3-10 keV vs TeV data
- Data taken < 6 hours apart
- No correlation seen except the flare

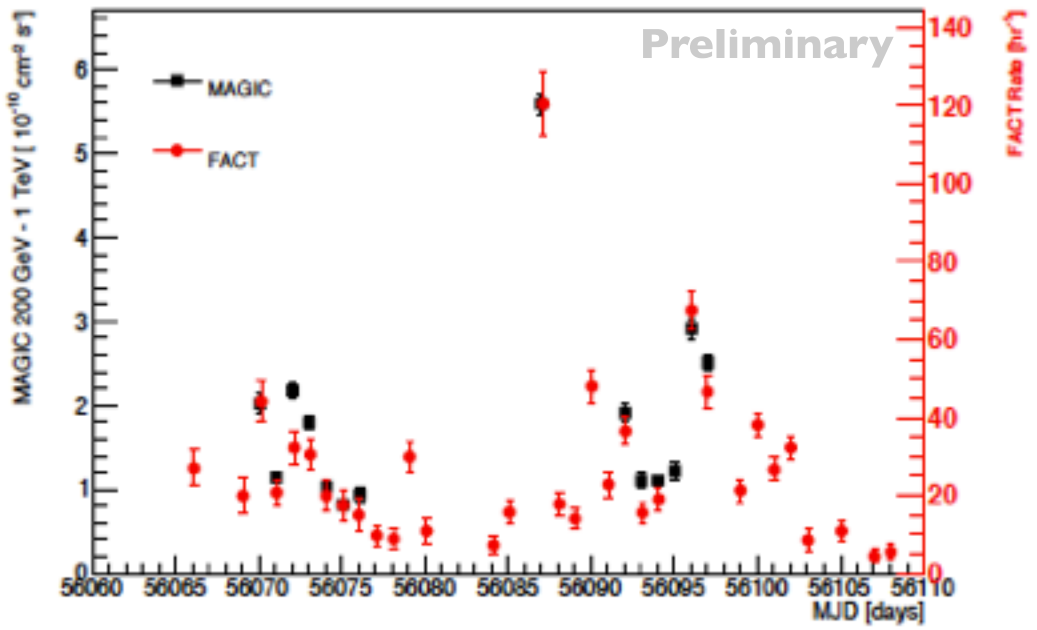


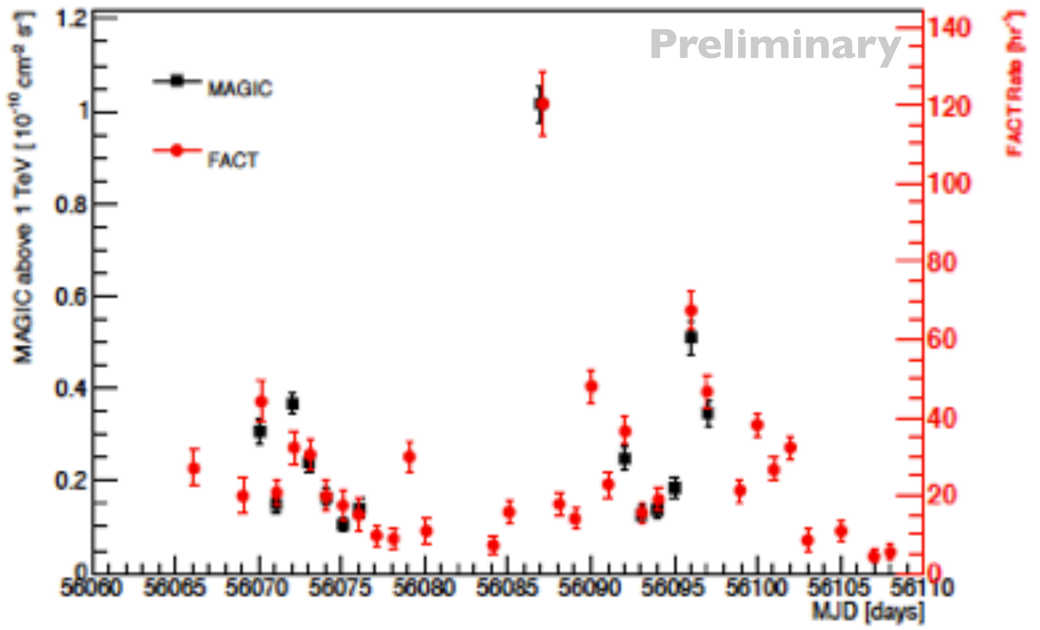


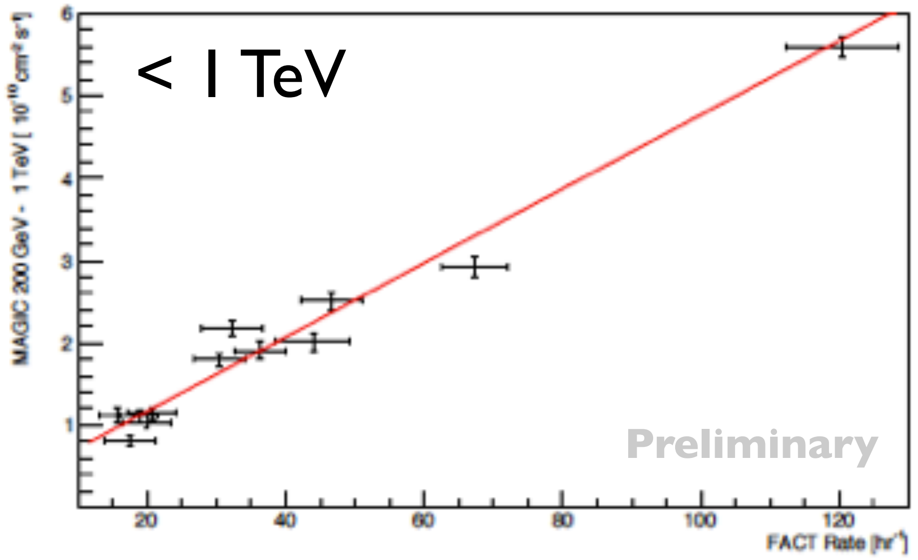


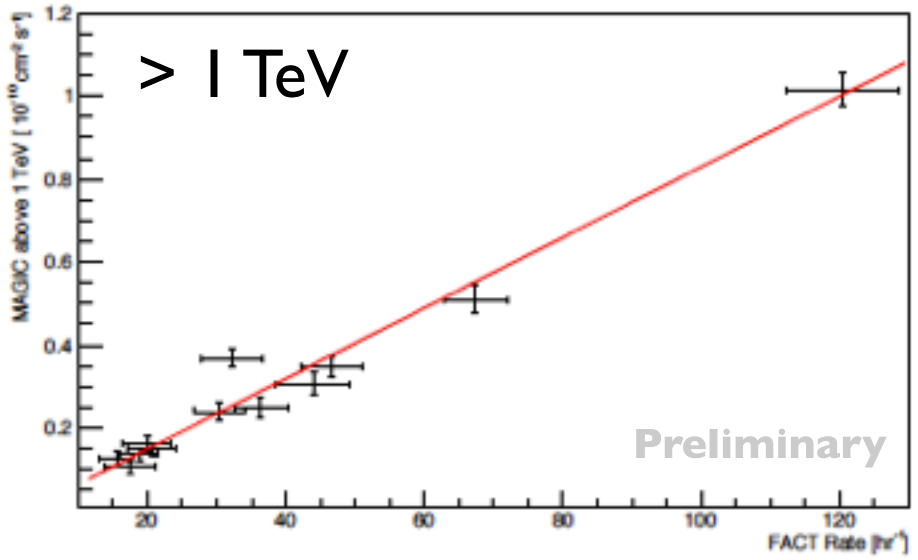
MAGIC and FACT Light Curves

Excellent Agreement



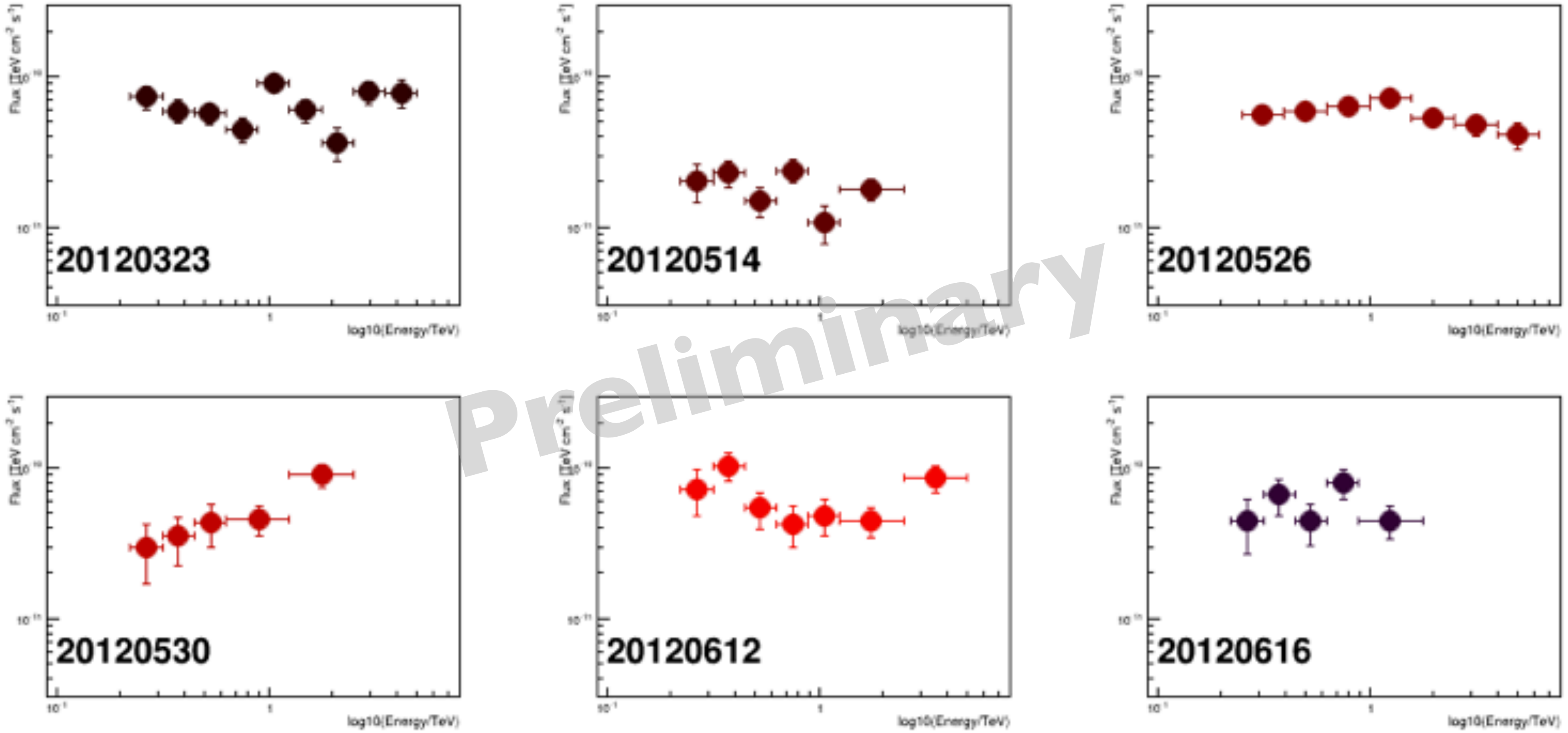




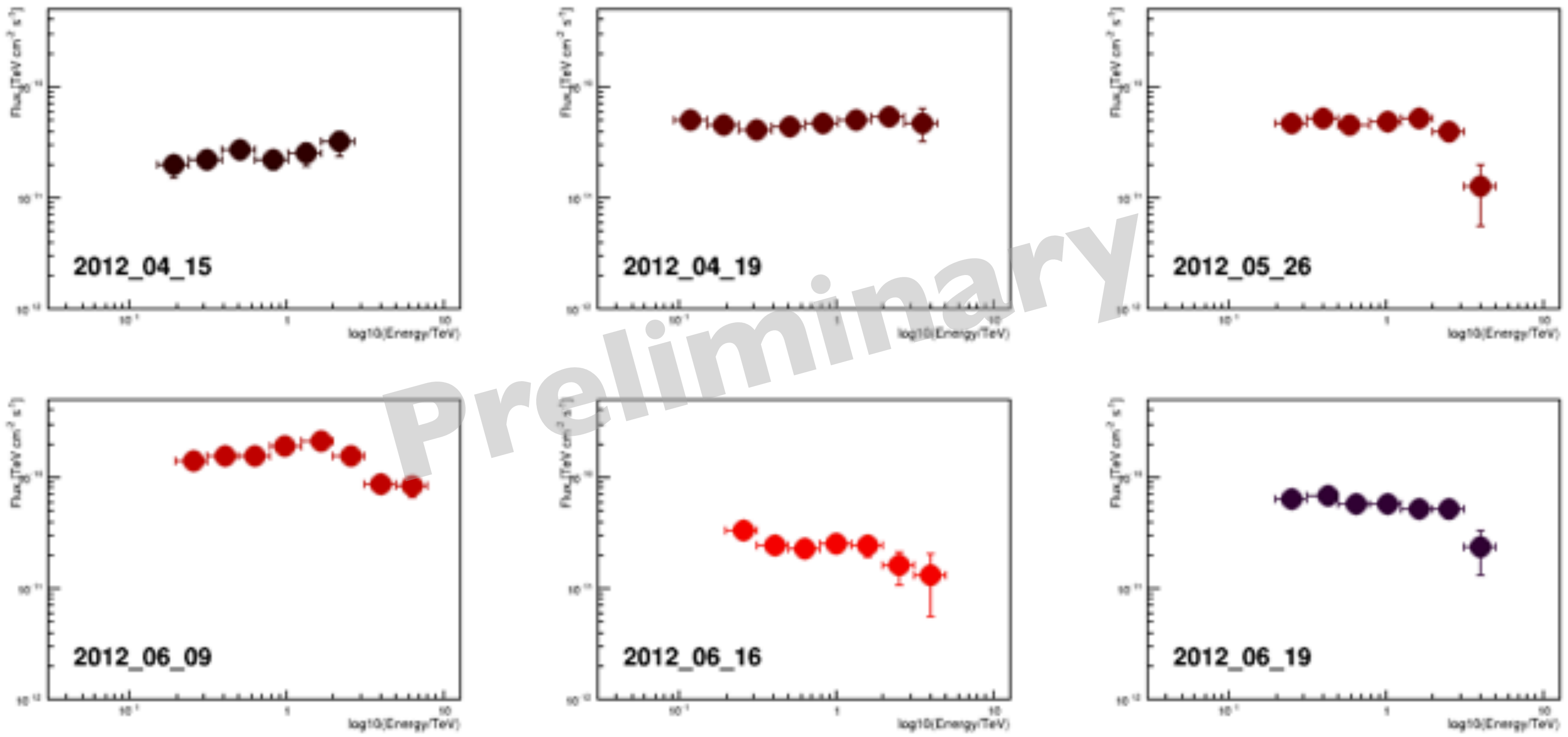


TeV Spectra

MAGIC analysis:
Francesco Borracci
VERITAS analysis:
Luis Reyes



VERITAS

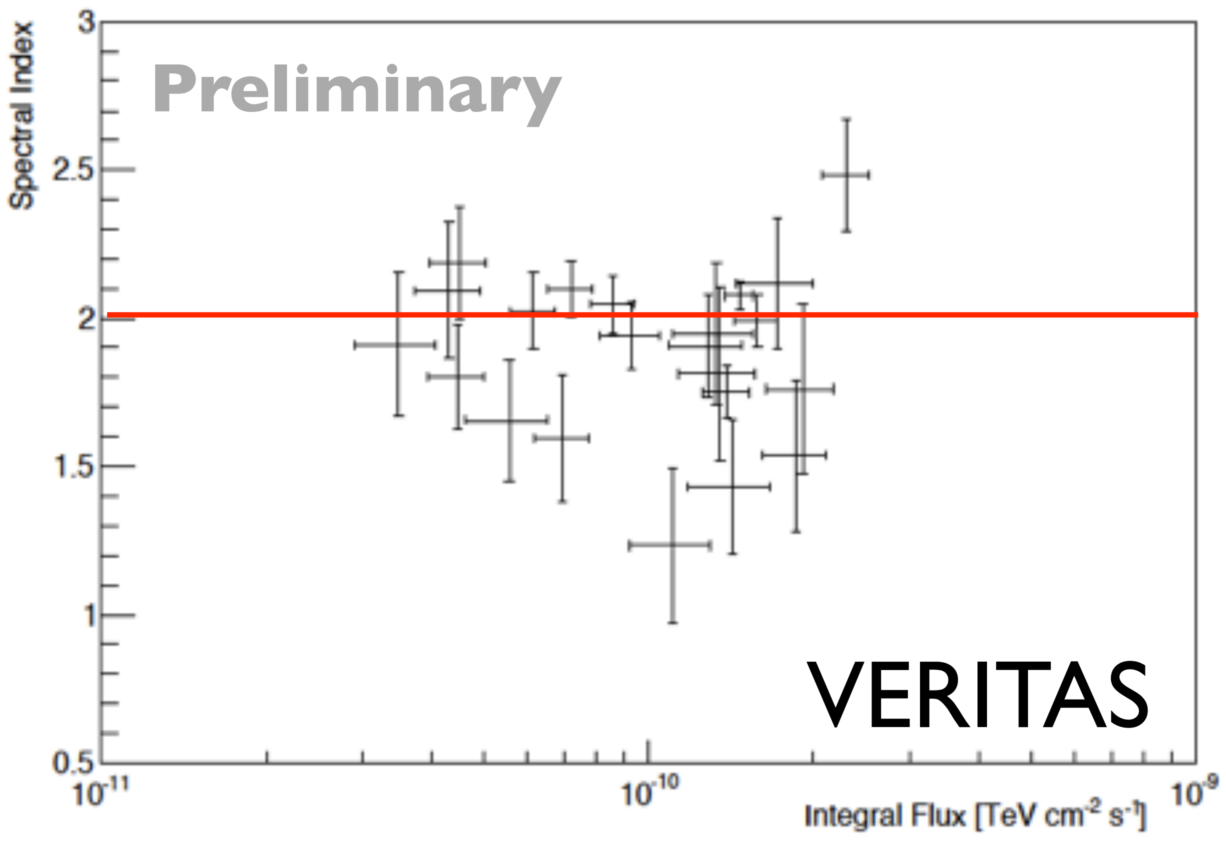


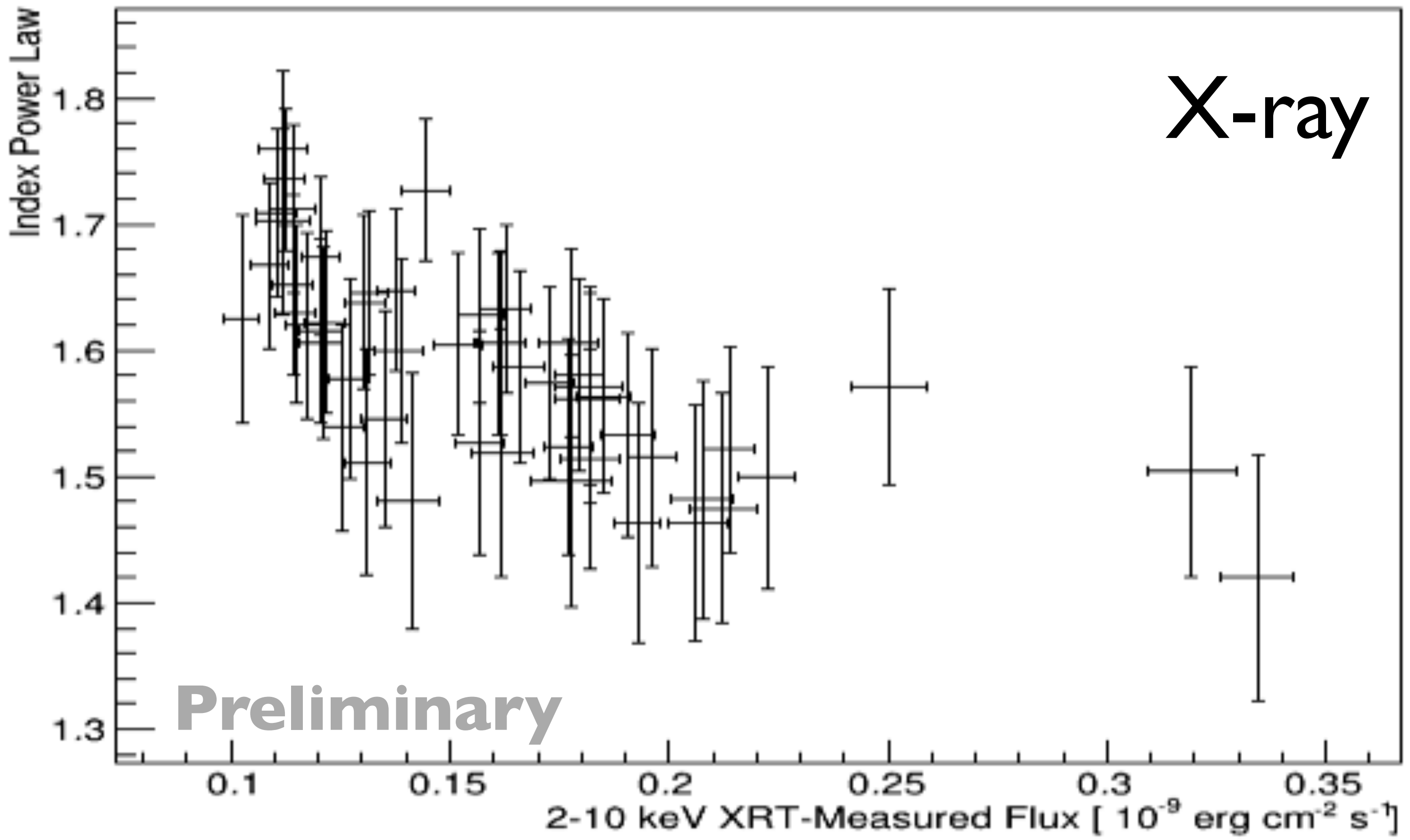
MAGIC

EBL Corrected
Spectra always hard

Spectral Fits

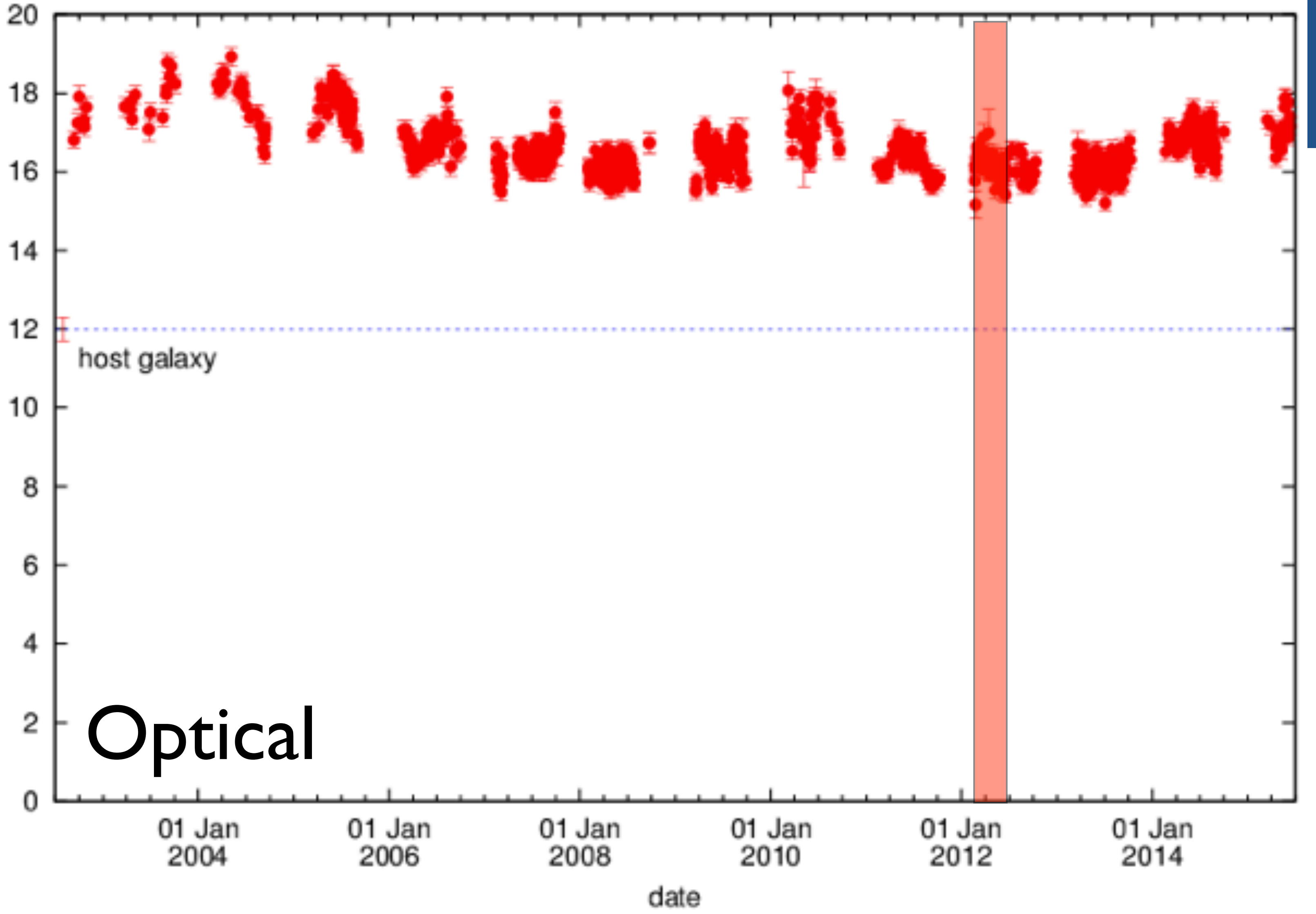
- TeV spectral index (de-absorbed) is **hard throughout** the **whole period**
- Does not follow Hardness-Brightness rule
- This is an extreme behavior





Modeling

- Modeling is being done by **Amit Shukla**
- Given the very hard X-ray spectra and TeV spectra makes modeling **difficult/interesting**



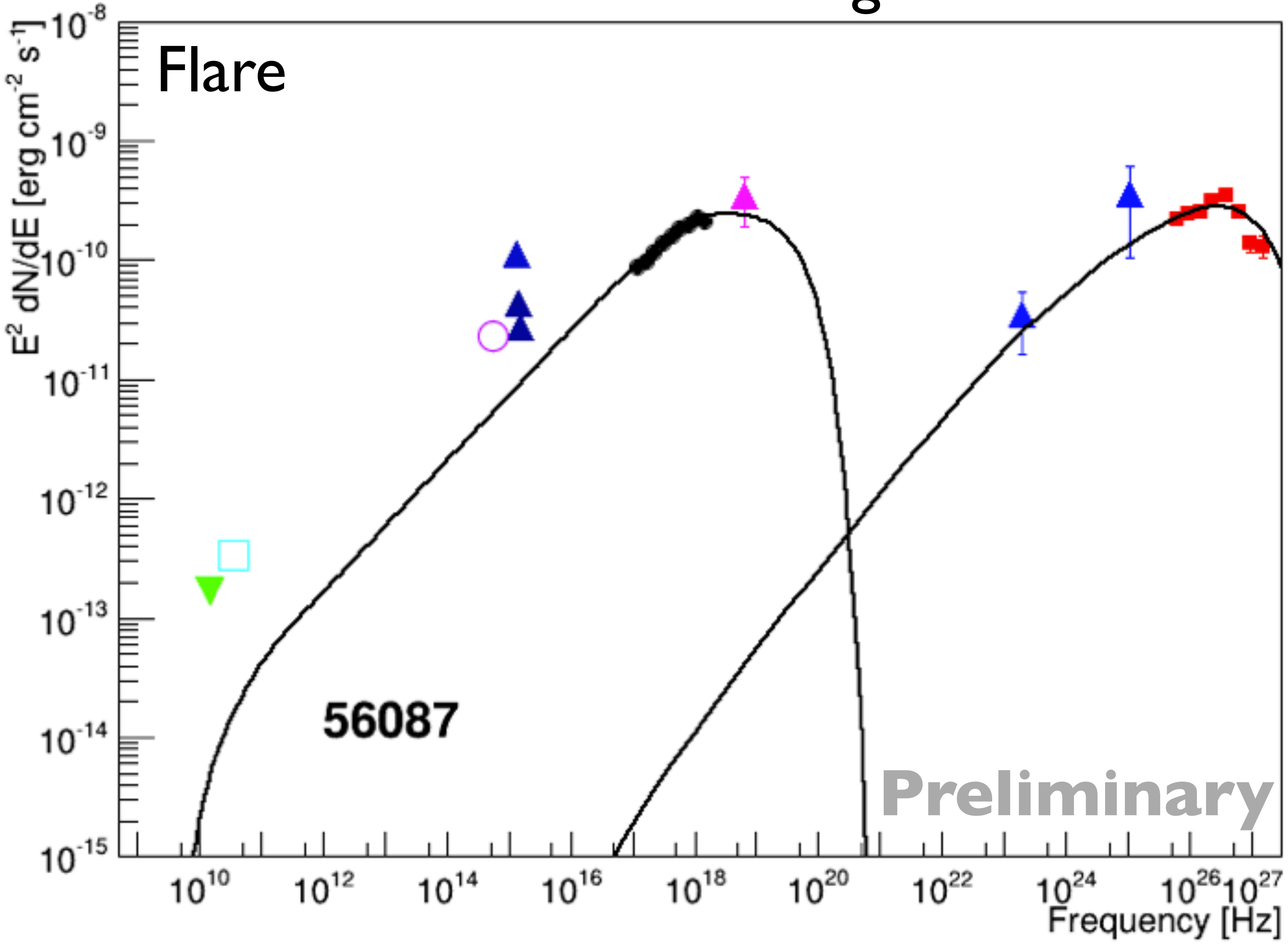
- Take every TeV spectra that is within 12 hrs of an X-ray spectra
- Fit using XSpec, Krawczynski SSC model and **χ^2 fitting**

Krawczynski, H., et al. 2004. ApJ, 601, 151

- Fit the X-ray and TeV data only
- Assuming that the optical/UV is dominated by a different component
  Very low variability detected, and in 2012 we see one of the lowest optical fluxes
- Applied both **one** and **two** zone models

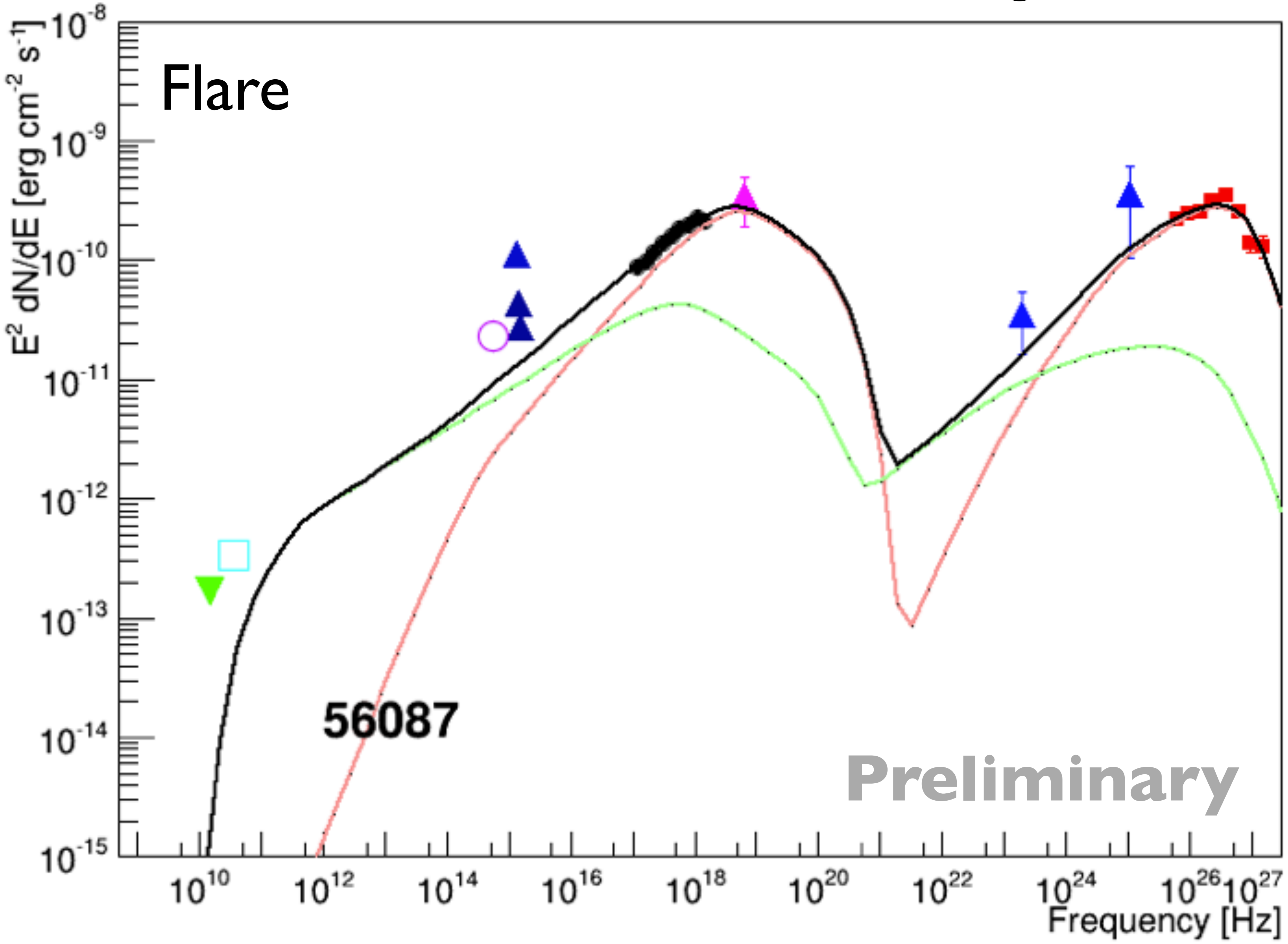
SED Modeling: One Zone

Largest observed shift in IC peak



SED Modeling: Two Zone

Largest observed shift in IC peak



Modeling: SED Parameters

One zone

MJD (Reduced χ^2)	R $[10^{16}$ cm]	B [G]	Doppler [δ]	γ_{min} $[10^2]$	γ_{max} $[10^6]$	γ_{brk} $[10^6]$	p1	p2	U_e $[10^3$ erg/cm$^3]$	ν $[U_e/U_B]$
56009 V (2.50)	2.65	0.019	10	3.17	7.96	0.96	1.9	3.1	12.0	817
56015 V (2.30)	2.65	0.024	10	3.17	7.96	1.14	2.0	3.0	10.5	460
56032 M (1.60)	2.65	0.035	10	3.17	7.96	0.85	2.0	3.7	5.7	114
56036 M (1.80)	2.65	0.022	10	3.17	7.96	1.30	2.0	3.7	10.7	531
56038 V (1.90)	2.65	0.035	10	3.17	7.96	0.67	2.0	3.1	4.7	96
56040 M (1.04)	2.65	0.031	10	3.17	7.96	0.77	2.0	3.7	6.6	169
56046 V (1.40)	2.65	0.037	10	3.17	7.96	0.63	2.0	3.1	4.7	84
56061 V (2.00)	2.65	0.037	10	3.17	7.96	0.69	2.0	3.2	4.8	90
56066 V (2.50)	2.65	0.044	10	3.17	7.96	0.71	2.0	3.6	5.6	73
56073 V (1.10)	2.65	0.023	10	3.17	7.96	1.24	2.0	3.0	11.7	575
56087 M (4.30)	2.65	0.017	10	3.17	7.96	1.41	1.9	3.0	20.7	1762
56090 V (3.20)	2.65	0.029	10	3.17	7.96	1.41	2.0	3.6	9.4	290
56094 M (0.63)	2.65	0.048	10	3.17	7.96	1.41	2.4	3.6	10.7	116

Two zone

Quiescent state	2.65	0.05	10	0.31	7.96	0.56	2.35	3.70	0.75	75
56009 V (3.00)	0.33	0.093	10	8.93	7.96	1.00	2.0	3.7	19.27	556
56015 V (3.70)	0.33	0.123	10	8.93	7.96	1.00	2.0	3.7	14.65	243
56032 M (2.47)	0.33	0.185	10	8.93	7.96	0.63	2.0	3.6	6.41	47
56036 M (3.20)	0.33	0.094	10	8.93	7.96	1.00	2.0	3.7	16.20	458
56038 V (2.50)	0.33	0.128	10	8.93	7.96	0.89	2.0	3.7	8.50	93
56040 M (1.52)	0.33	0.132	10	8.93	7.96	0.63	2.0	3.7	8.34	120
56046 V (1.98)	0.33	0.160	10	8.93	7.96	0.91	2.0	3.6	5.55	54
56061 V (2.29)	0.33	0.160	10	8.93	7.96	0.79	2.0	3.7	5.80	56
56066 V (3.49)	0.33	0.320	10	8.93	7.96	1.00	2.3	3.7	5.70	14
56073 V (2.58)	0.33	0.099	10	8.93	7.96	1.12	2.0	3.1	19.00	480
56087 M (3.25)	0.33	0.092	10	8.93	7.96	1.12	1.80	3.7	35.40	1033
56090 V (4.35)	0.33	0.131	10	8.93	7.96	1.12	1.9	3.7	15.10	222
56094 M (1.18)	0.33	0.078	10	8.93	7.96	1.12	2.0	3.7	12.20	500

Summary

- Mrk 501 2012 MWL campaign collected an excellent dataset
- First MWL Paper with **FACT**(GAPD) data

- Fvar **different** to that of of Mrk 421
- **No correlation** between X-ray and TeV

- 9th June caught an extraordinary **10 cu** (>1 TeV) flare
- IC Spectra **Peaks in the TeV**
  Largest IC peak shift seen
- **Index does not change** - throughout the time spectrum is always hard
- We do a good job of fitting the SEDs

- In 2012 Mrk 501 was an **extreme** BL Lac (Sync Peak >> 1 keV)