Mutifrequency scalings and lags in Blazar flares

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The relationship between optical and GeV γ-ray variability in Blazars

Motivation: How are gamma-rays produced?

Hadronic models are no ruled out.
Can Compton models explain any relationship?

Leptonic (IC) models: Do we understand
particle acceleration (distribution function) and seed fields?

Within a given system repeated experiments with slightly different initial conditions (different flares) – probed in the synchrotron domain should produce predictable outcome (gamma-ray emission).

Optical is always in the synchrotron domain and never optically thick.

The EGRET legacy

Variability in the GeV band:
1st light (3C279 brighter than in COS-B)
GeV - variability on time-scales of days (3C279)

Variability of synchrotron emission:
Collectively: GeV sources were id'd with BLO, OVV, and IDV-FSRQ

Correlations:
PKS 1406-076, PKS 0420-014, S5 0836+710, S5 0716+714,
S5 0954+658, 3C 279, PKS 0528+134, PKS 1622-297,
BL Lac, NRAO 190, Mrk 501, 3C273, ...
(varying degrees of significance and usefulness)

Questions to be addressed

Do all flares have counterparts?

Can cross-identifications result by chance?

Is there a unique amplitude scaling within and among flares?

Are there any lags between different bands?

Does spectral evolution within the two bands reflect each other?

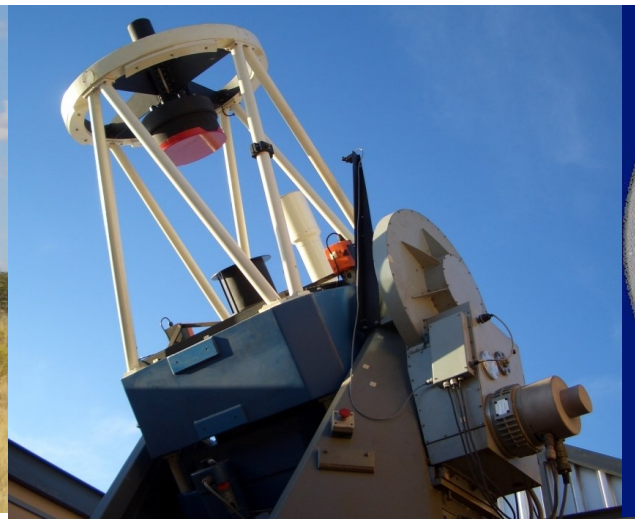
Is there any indication for variability in EIC photon fields?

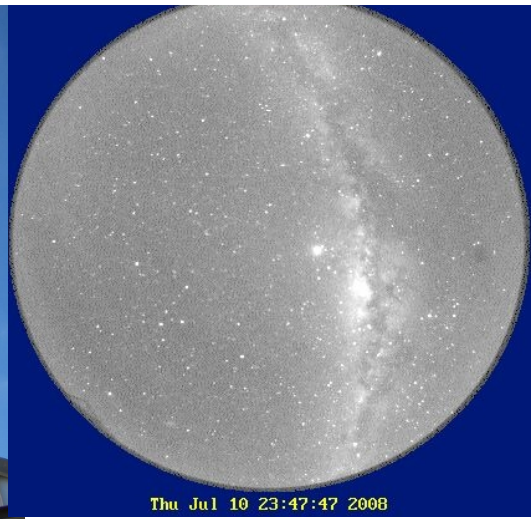
Dependencies of all of the above on $\mathcal{L}$, $\mathcal{D}$, M, … ?

Observations

GeV: FGST: Public data (subset for statistics)

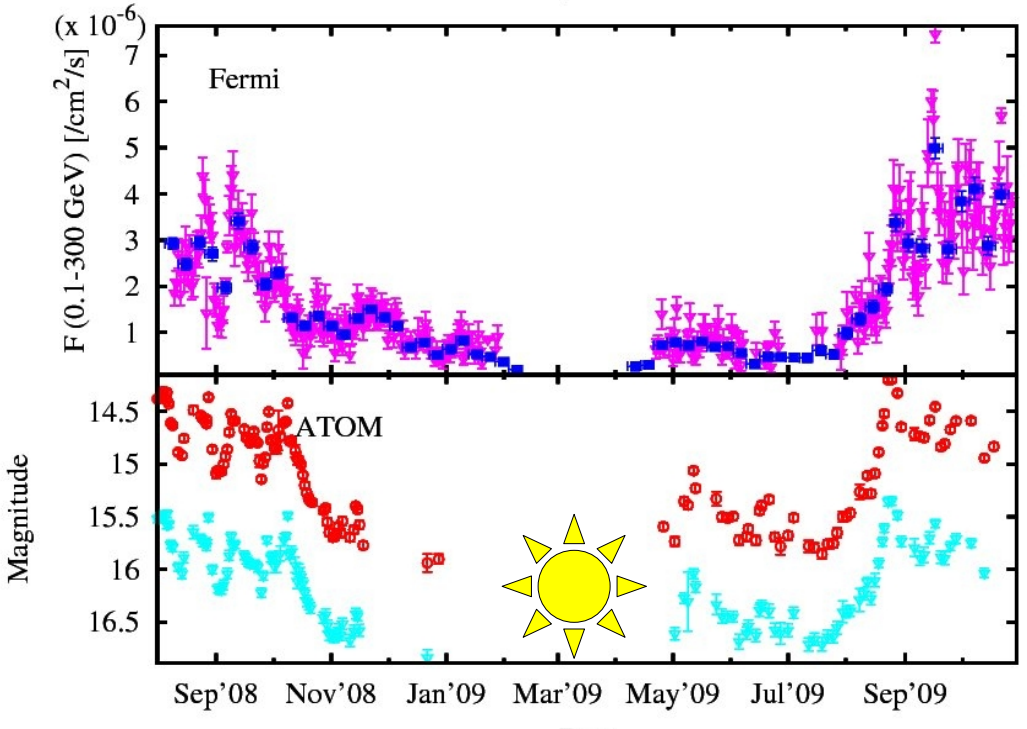
eV: ATOM (**A**utomatic **T**elescope for **O**ptical **M**onitoring)
Robotic 0.8m telescope at HESS site (latitude -23), R(BVI) bands
All southern VHE, EGRET, 0FGL-Blazars with diff. duty cycles.
230 objects (1/d – 1/10d) + flare-triggers (flagged data)





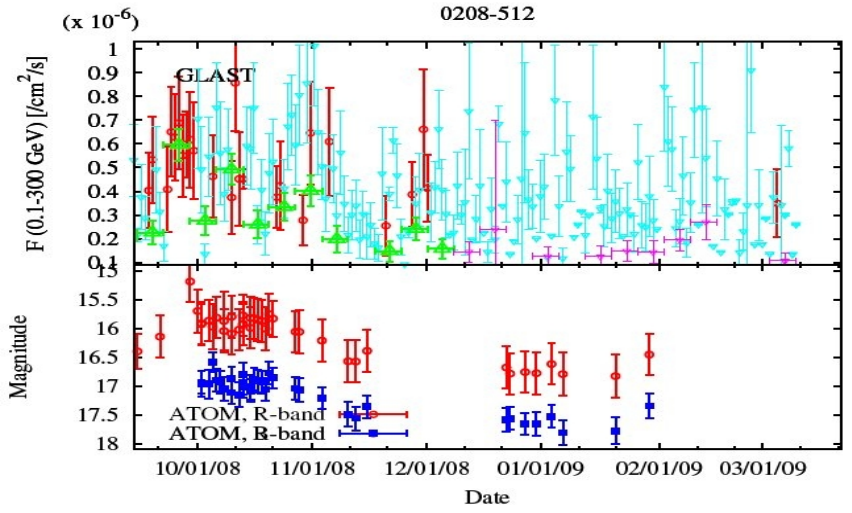
Northern hemisphere complement: Abastumani Observatory

Data set, examples, binning

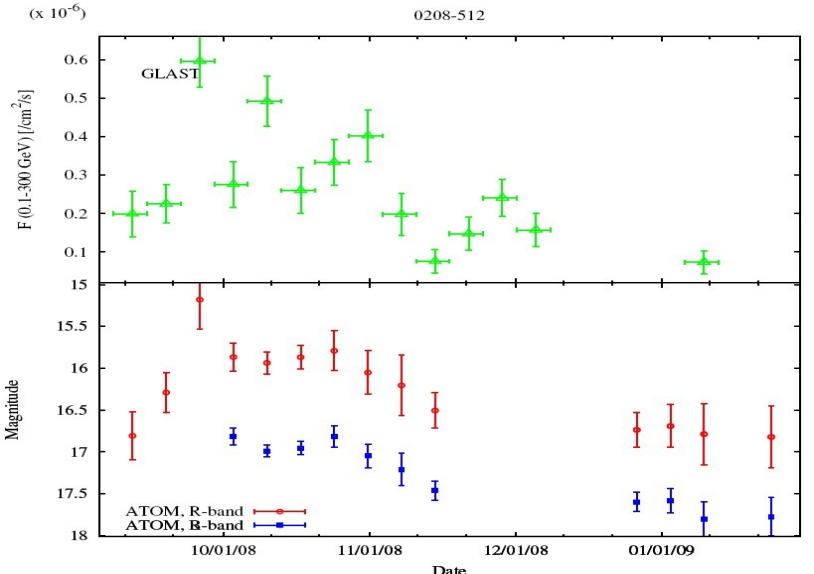


3C 454.3
EGRET-detected,
very prominent AGILE flares,
very active since Fermi launch.

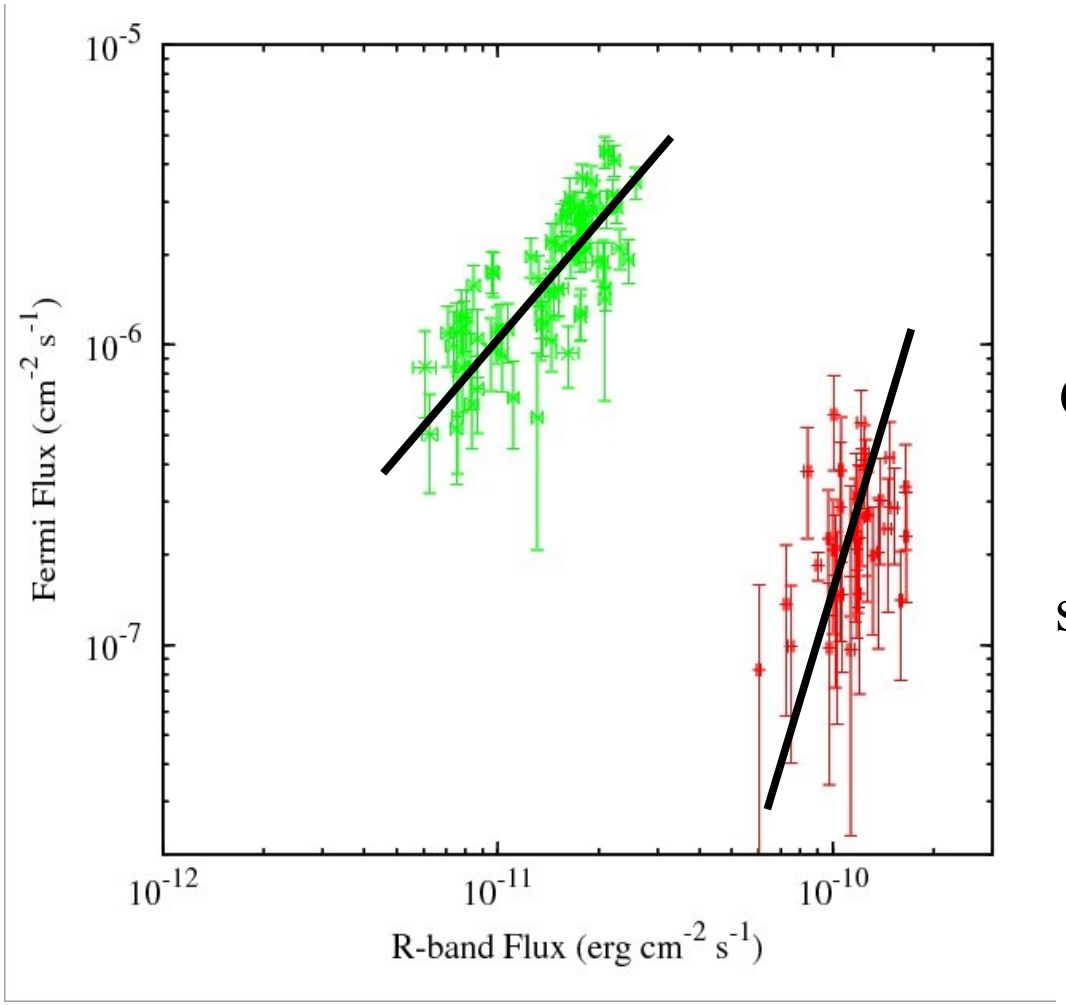
Overall correlation very close.
High states match high states.
Difference in detail.



Daily data
Weekly data
Daily UL
Weekly UL
Binning
(Same phase)



$F_{GeV} - F_{eV}$ Relations



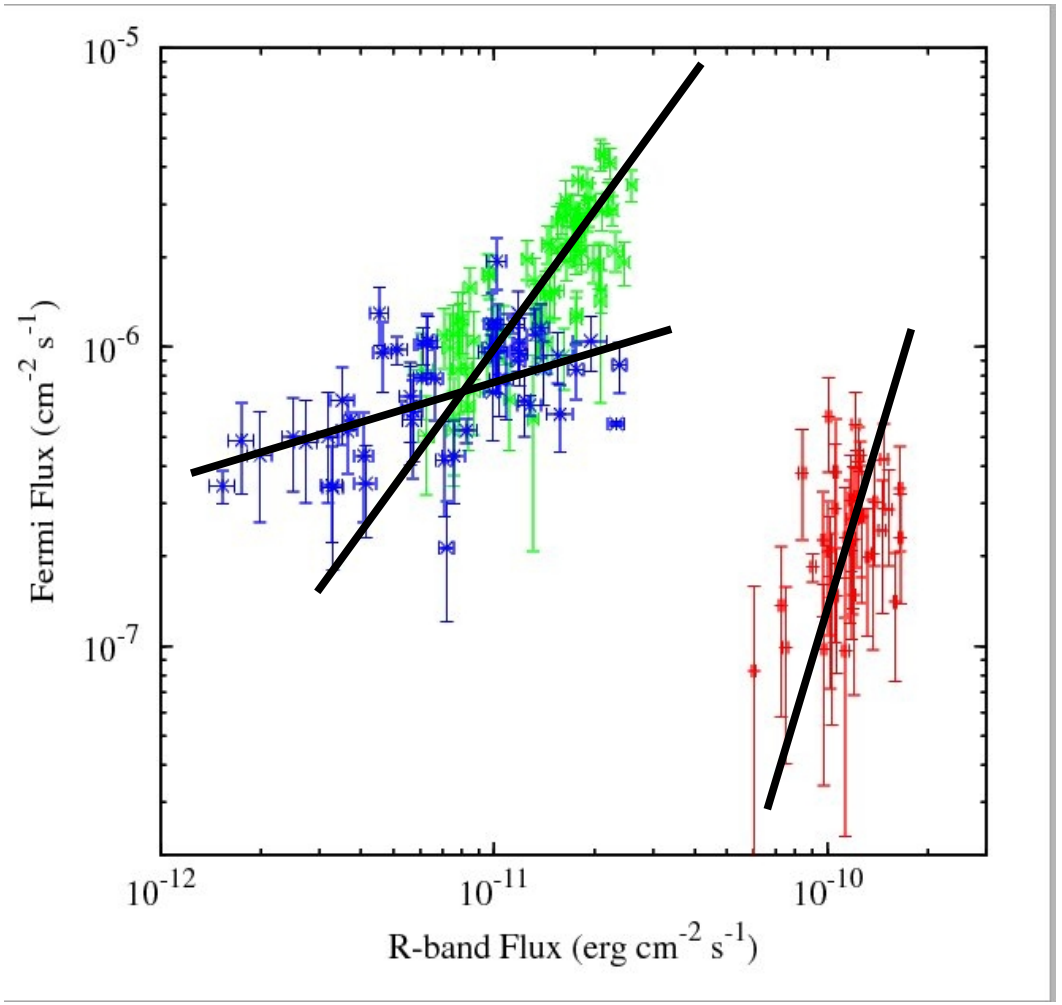
3C454.3 and **PKS 2155-304**

Only simultaneous data.

Correlation highly significant
Individual measurements consistent with trend, but statistically significant scatter

Different slopes,
different average ratios,
but different types of Blazar

$F_{GeV} - F_{eV}$ Relations



3C454.3, PKS 0235+164 and **PKS 2155-304**

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Even for Blazars of similar type, slopes and average flux ratios are different.

With fixed observing band, slopes and ratios depend on relative locations of bands w.r.t. peaks within SED.

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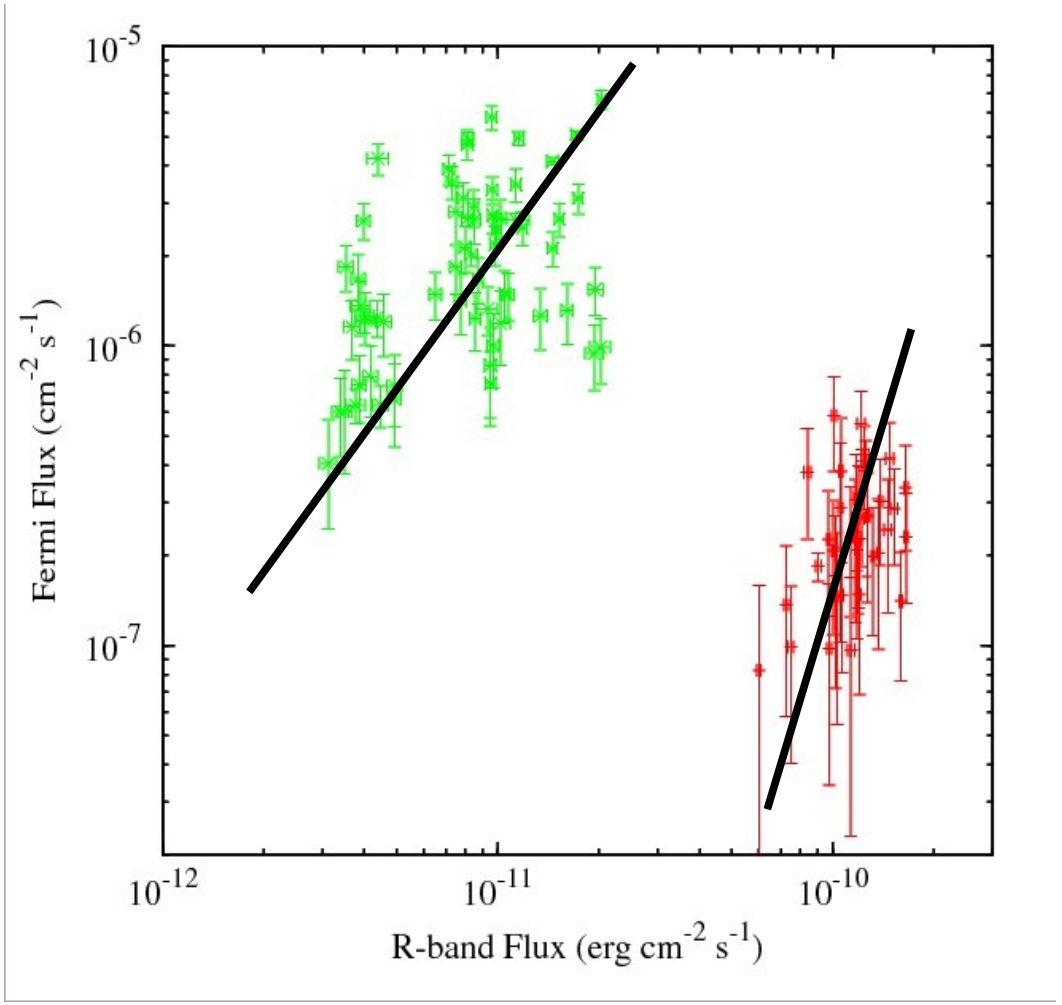


PKS 1510-089 and
PKS 2155-304

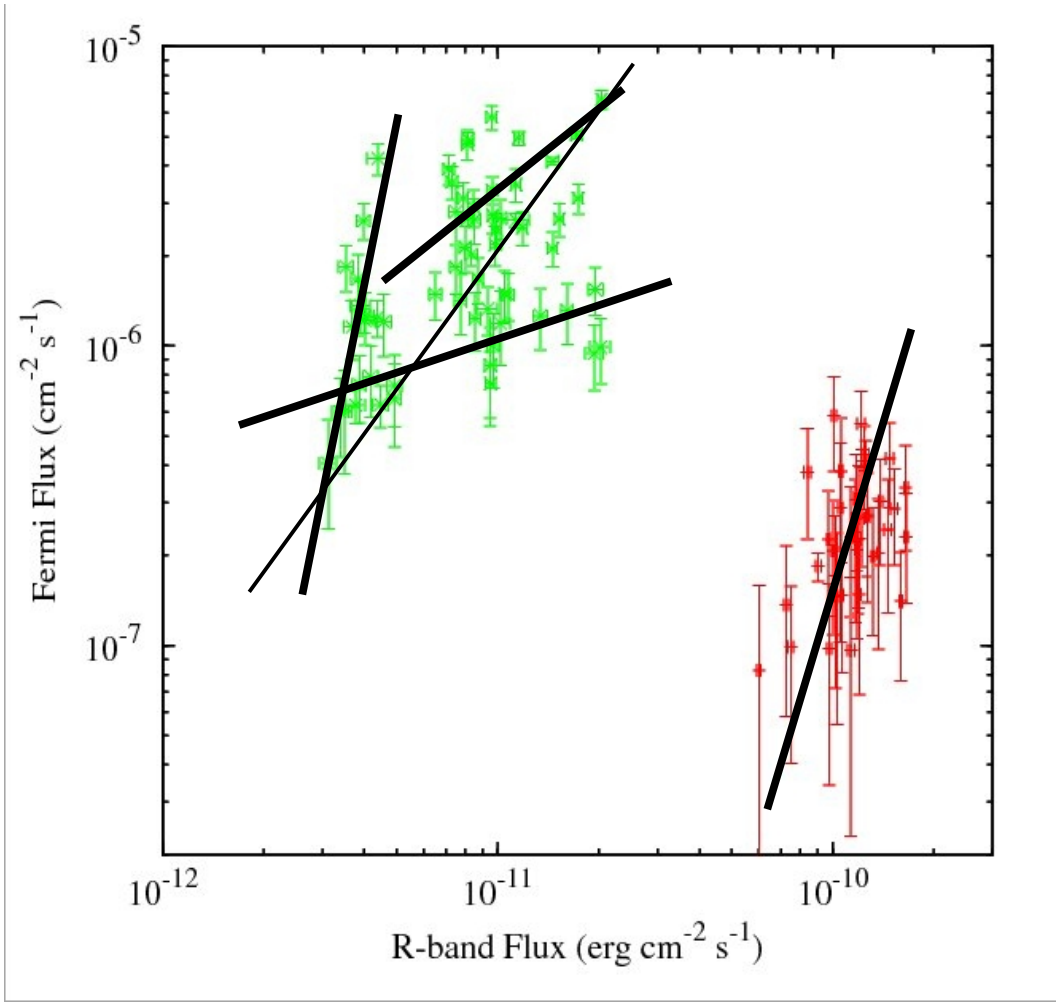
Scatter of individual points highly significant.

Slopes and average ratios vary in single object between different flares

Spectral lags widern scatter.

Different flares modify location of peaks differently.

$F_{GeV} - F_{eV}$ Relations



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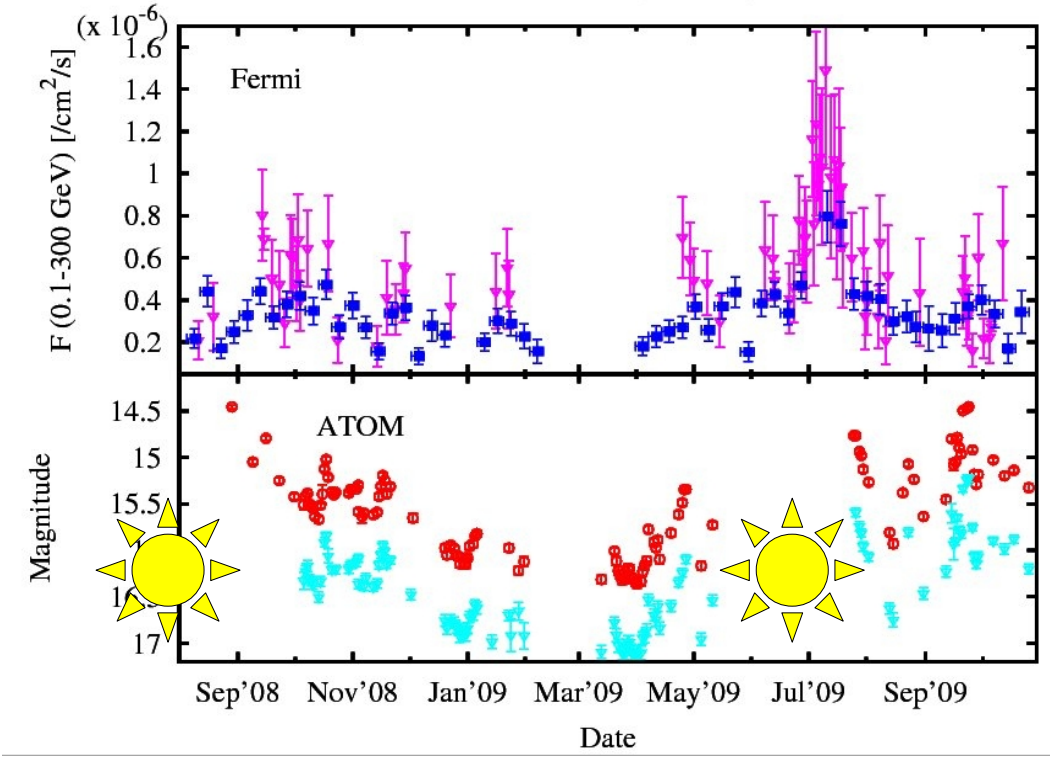
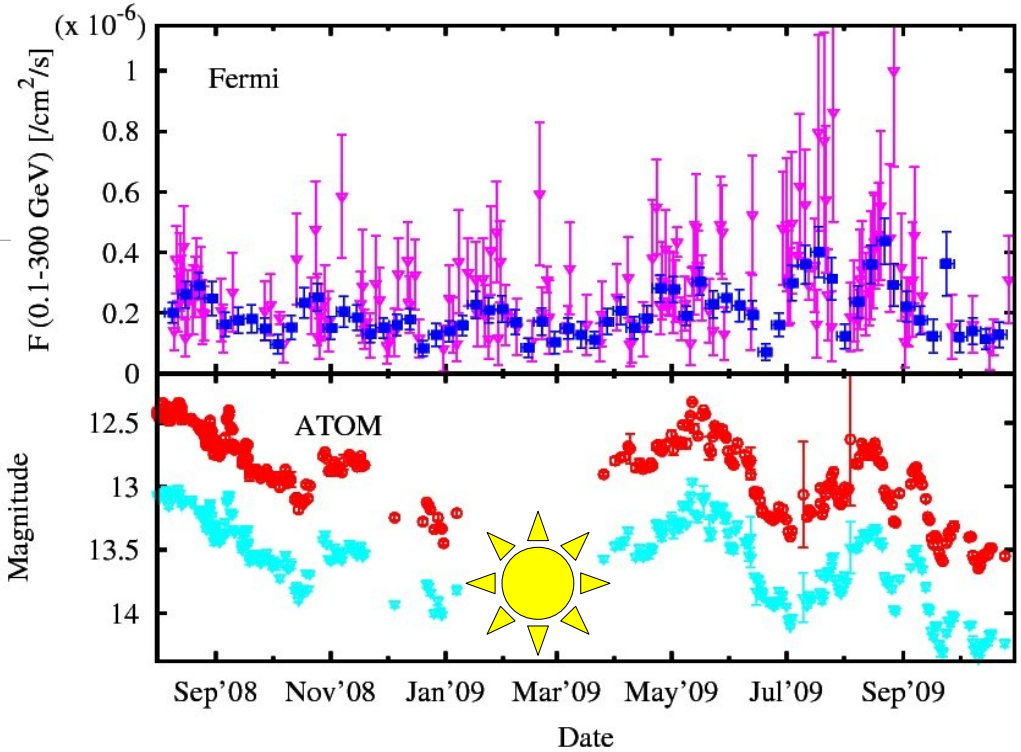
Other examples:

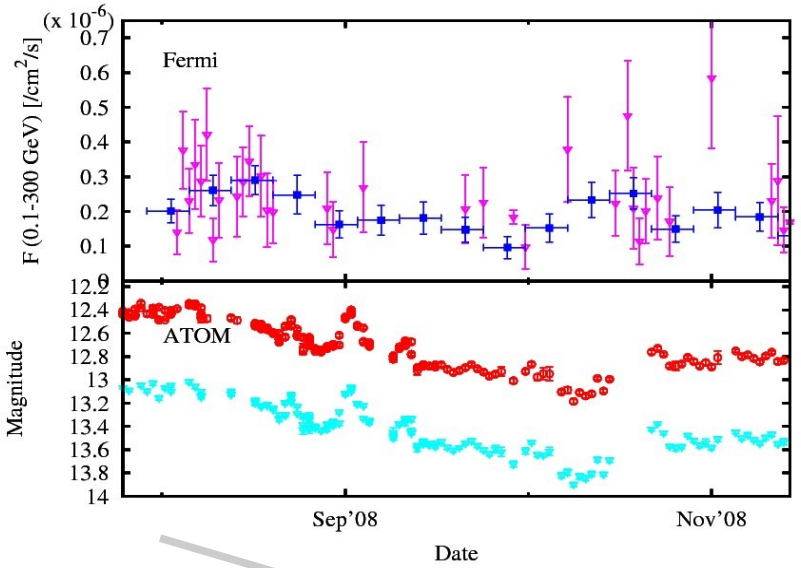


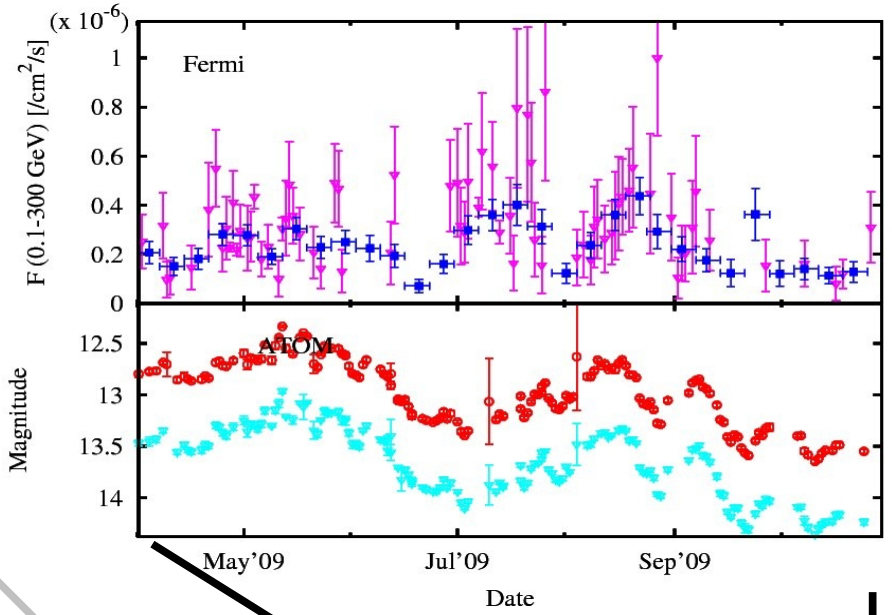
PKS 0537-441:
high states in optical synchrotron
match bright states in gamma-rays

Scatter in flux scalings

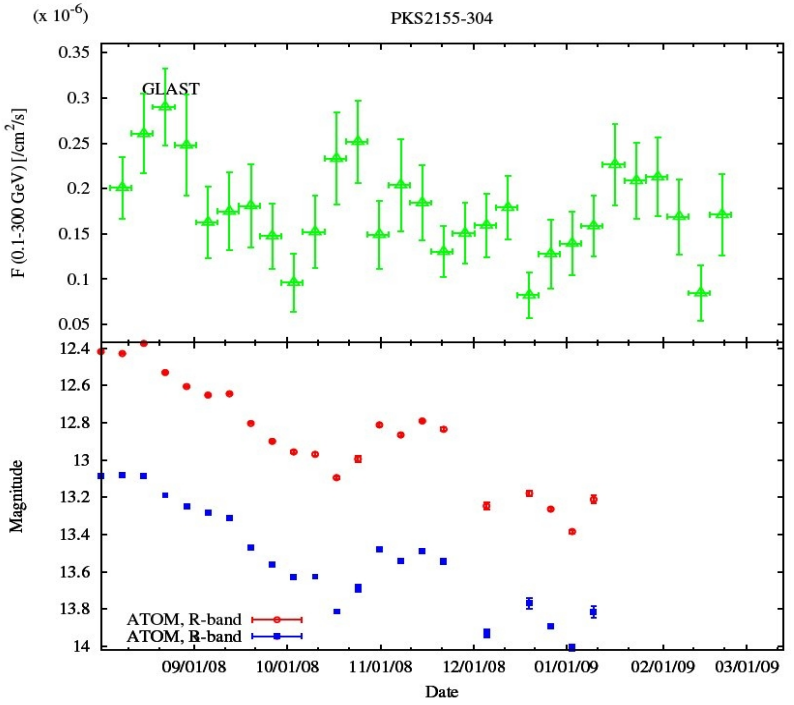


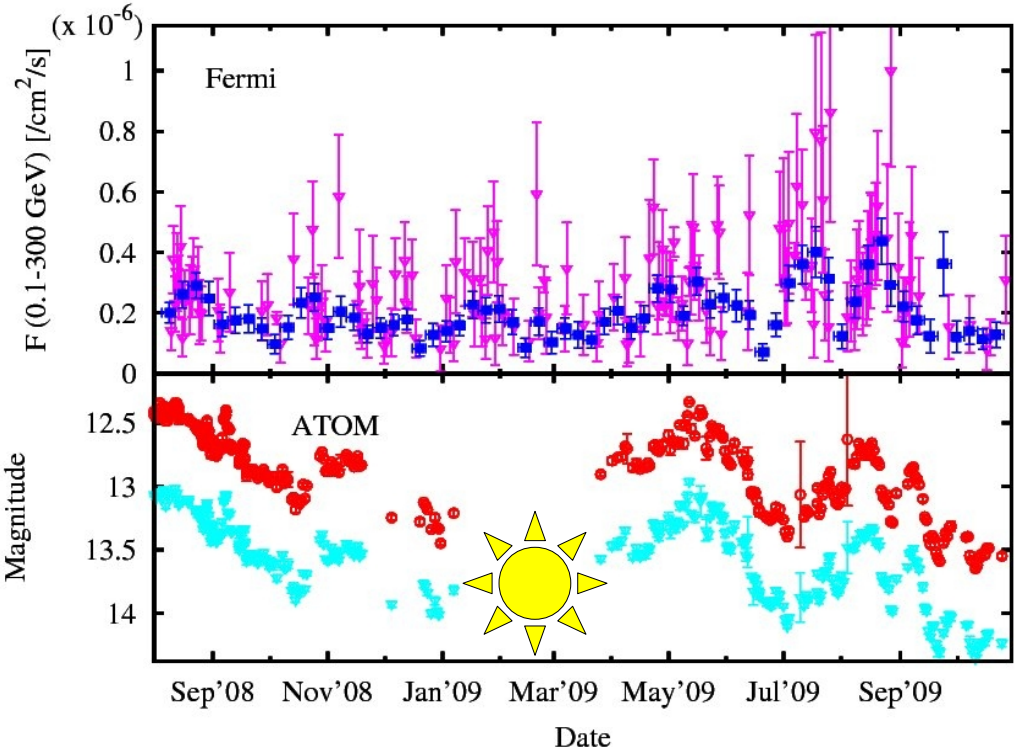
PKS 2155-304:
General match but
differences in detail.
Lags or different flares?

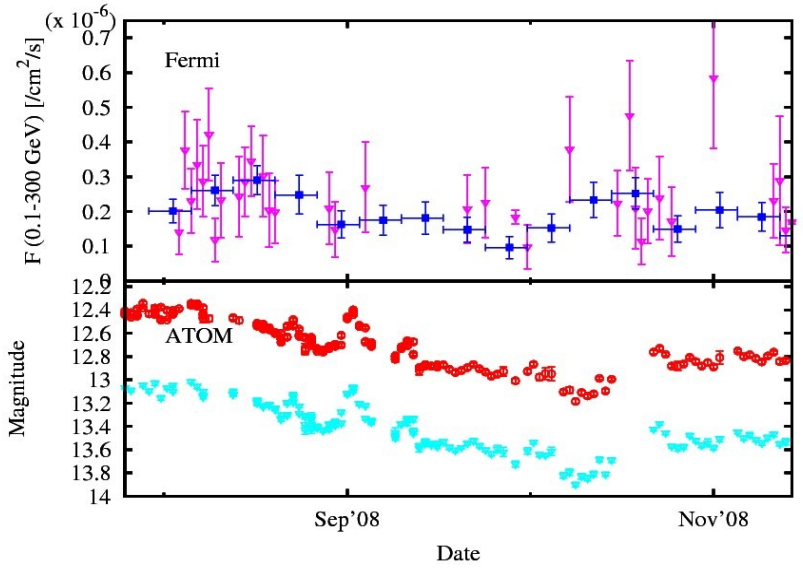




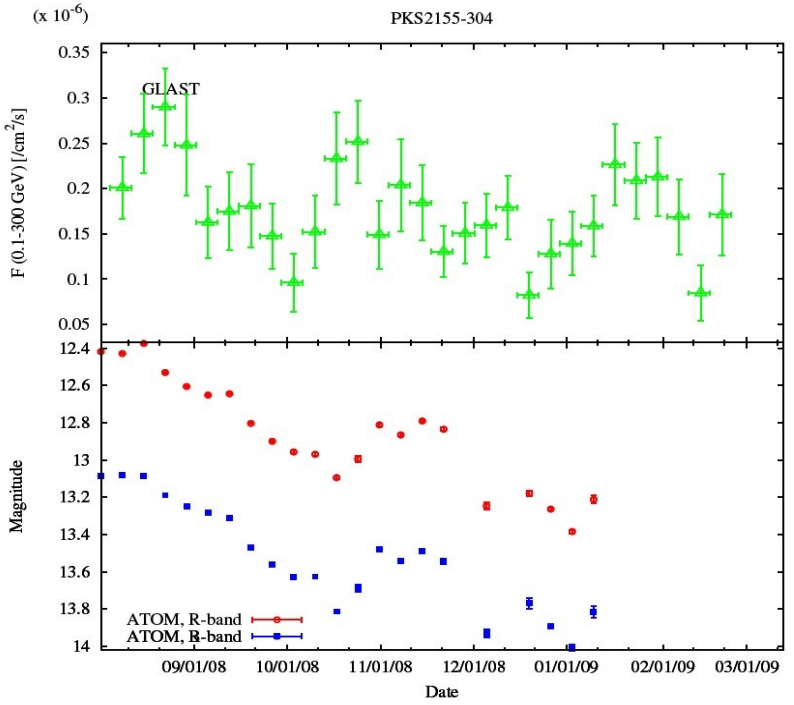
No correlation in detail.
Lags or blends?
Chance?

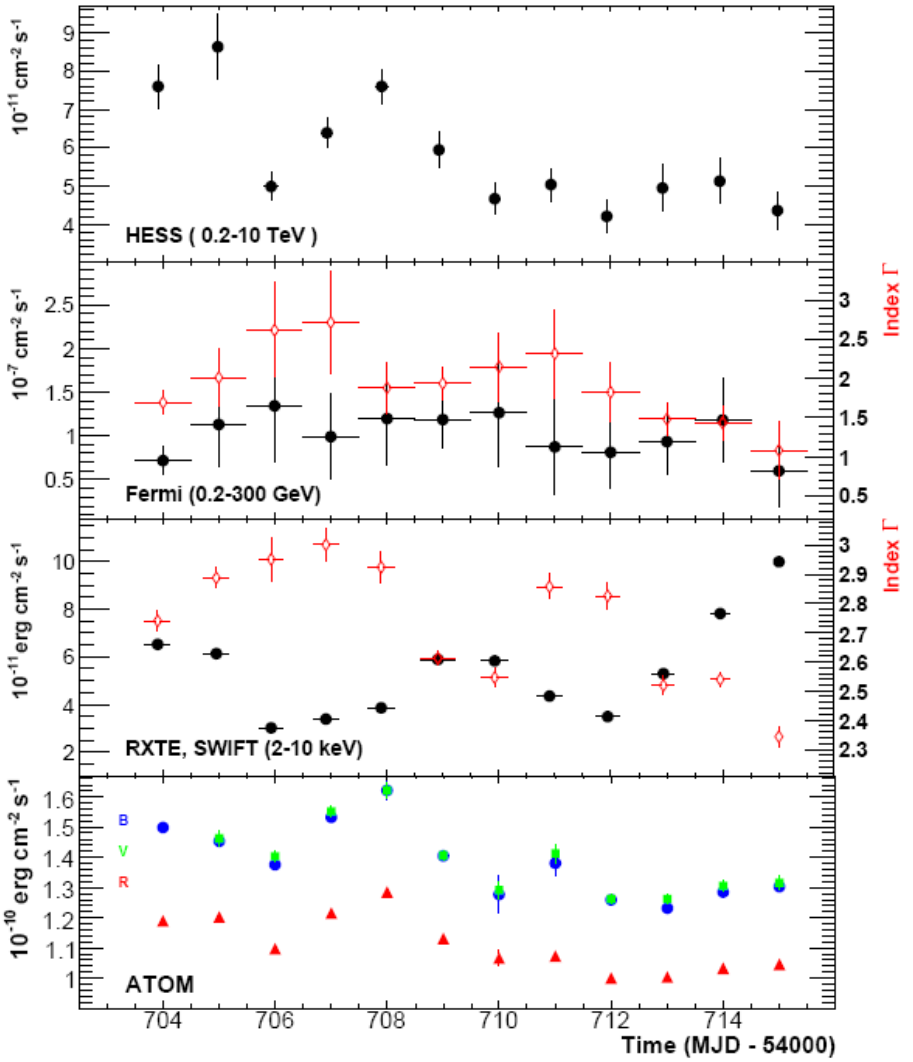


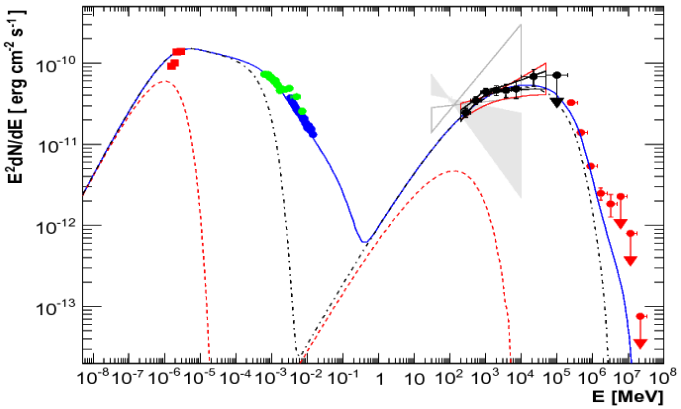




Correlation on day-time scales (sometimes) stronger between eV and TeV (Fermi/HESS)

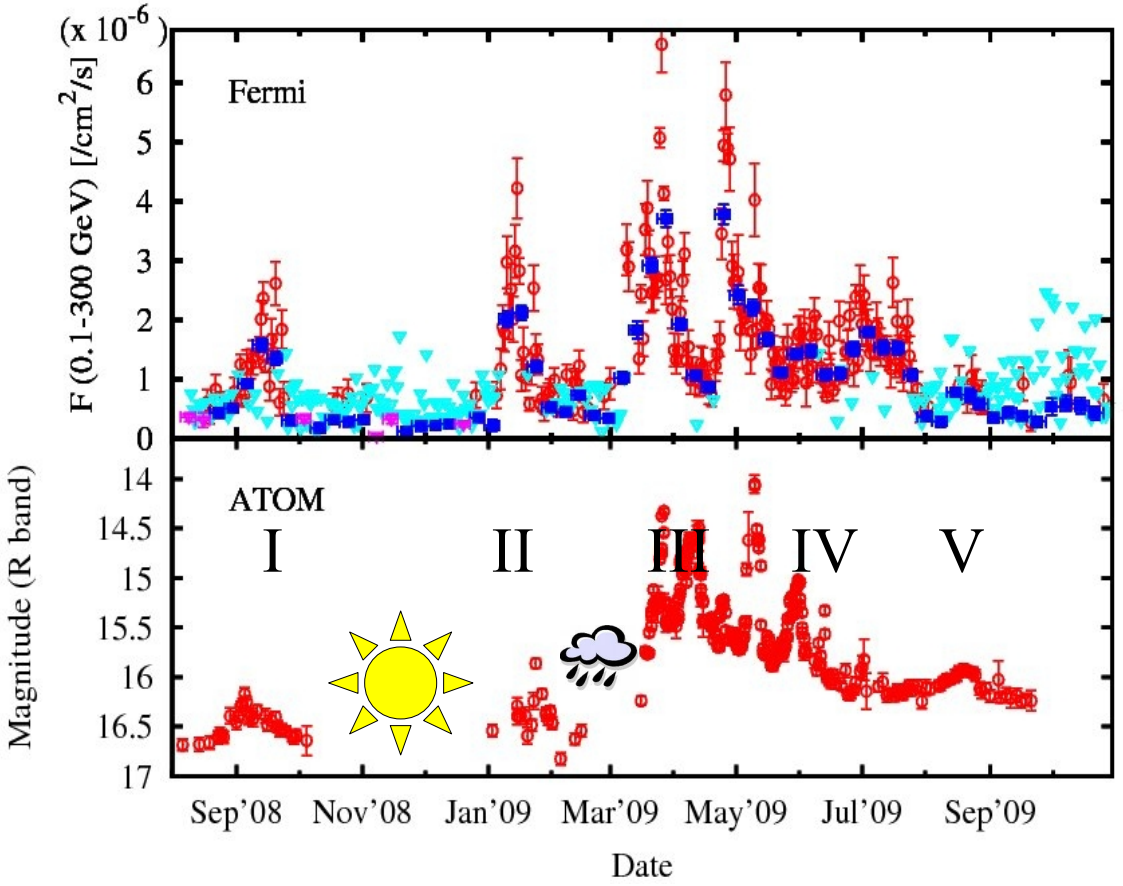






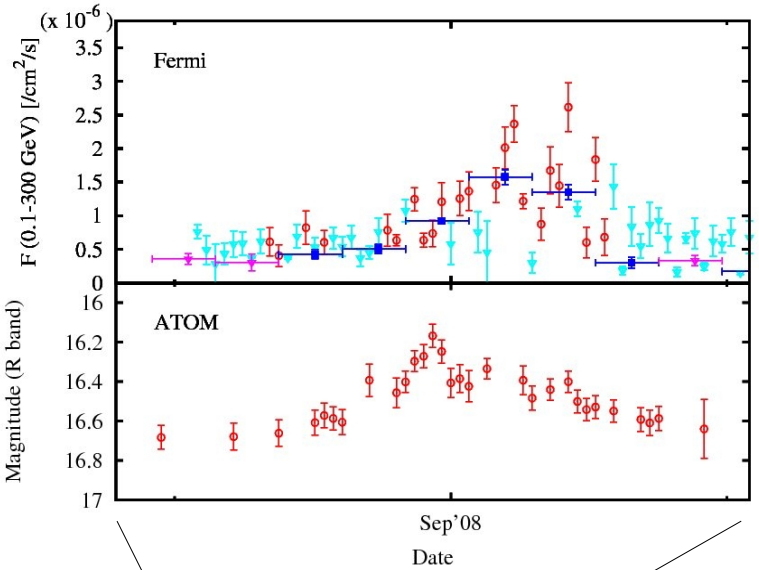
PKS 1510-089

EGRET-detected PKS 1510-089 shows "overall" correlation (bright synchrotron state during bright gamma state and vv), but displays differences in detailed comparisons throughout full 1st year.



This involves lags, different amplitude scalings, and changes of base level.

Changes in optical spectra, optical colours, and X-ray spectral slope



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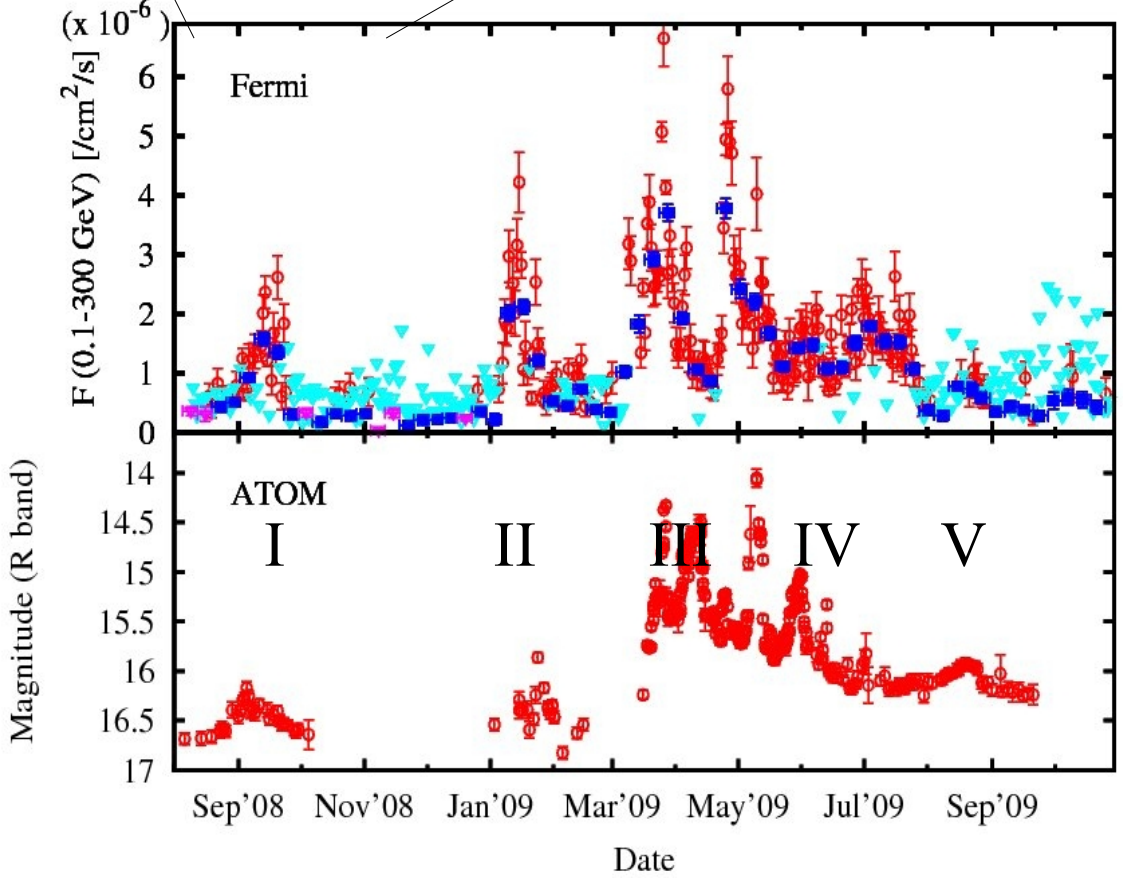

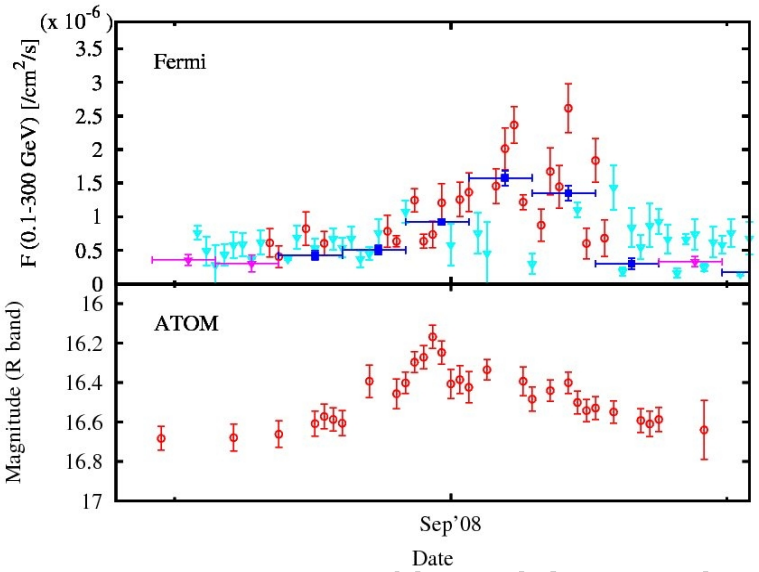

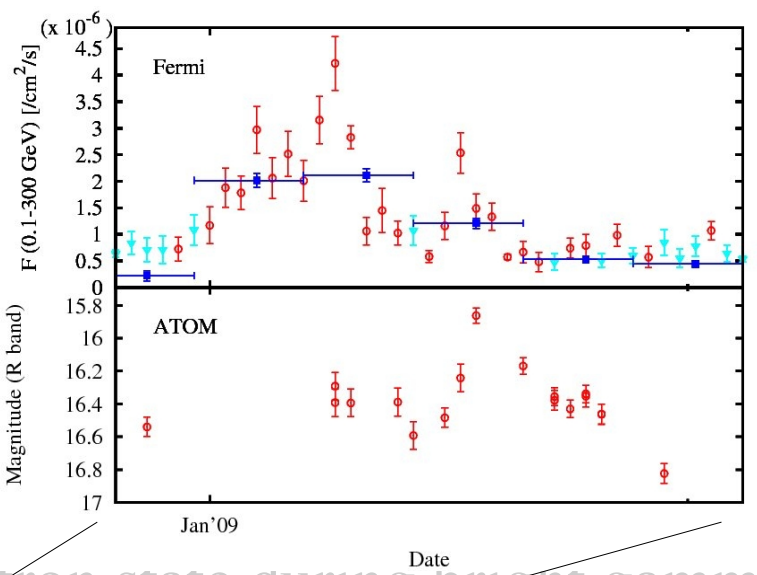

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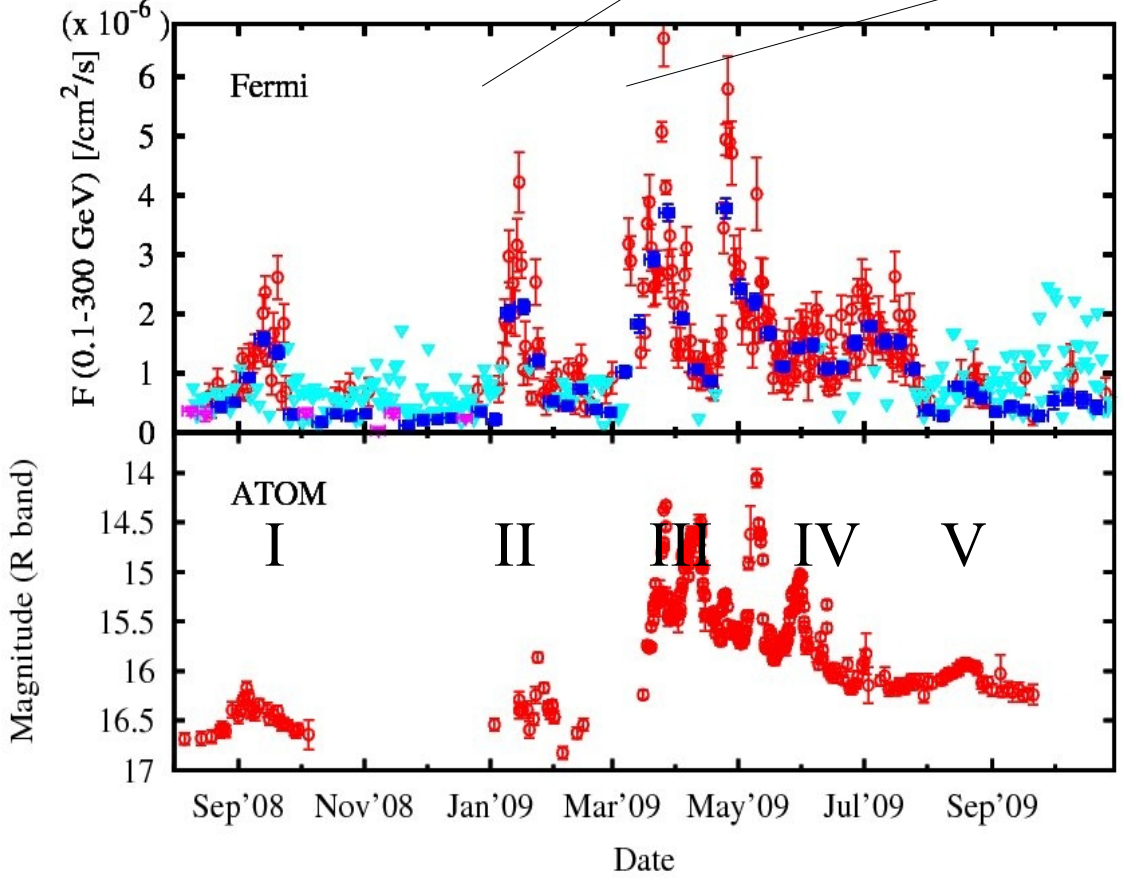

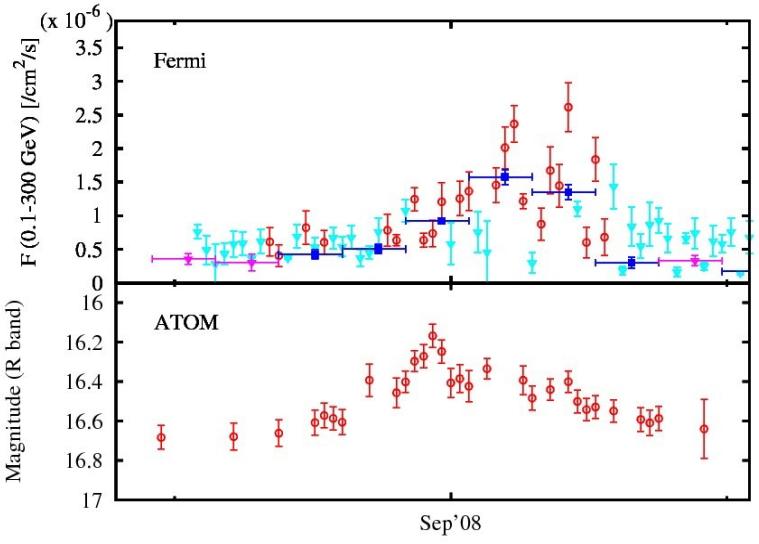

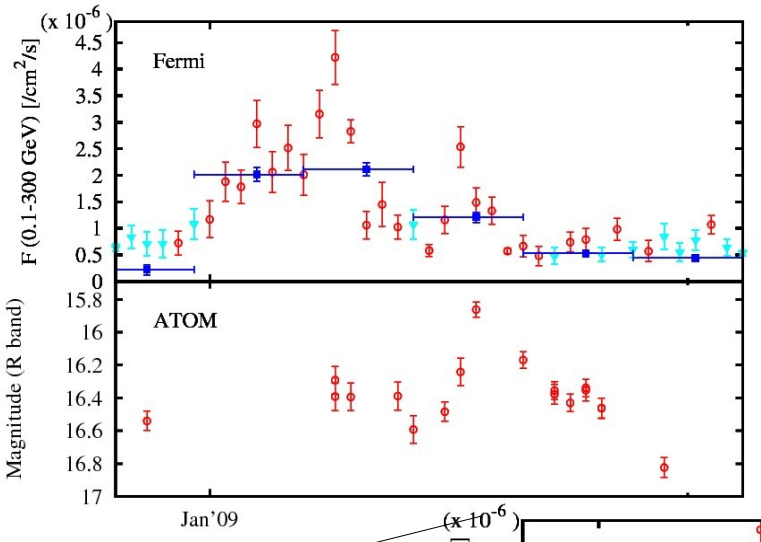

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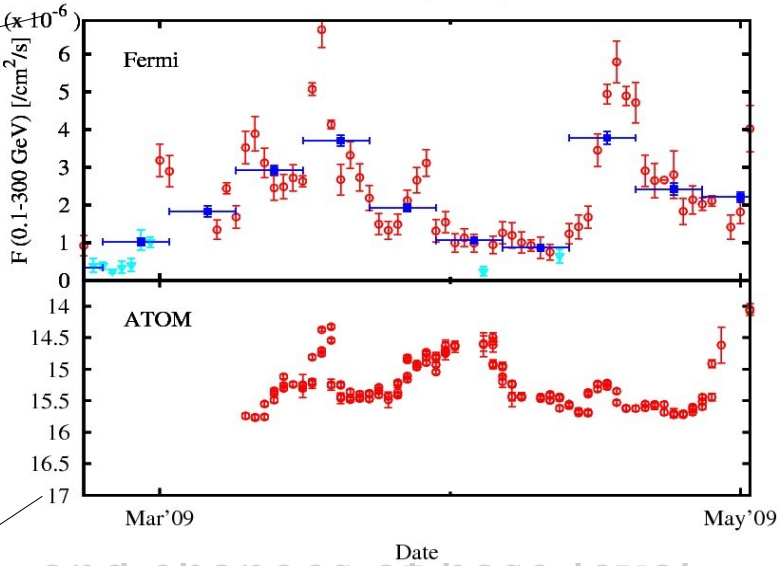
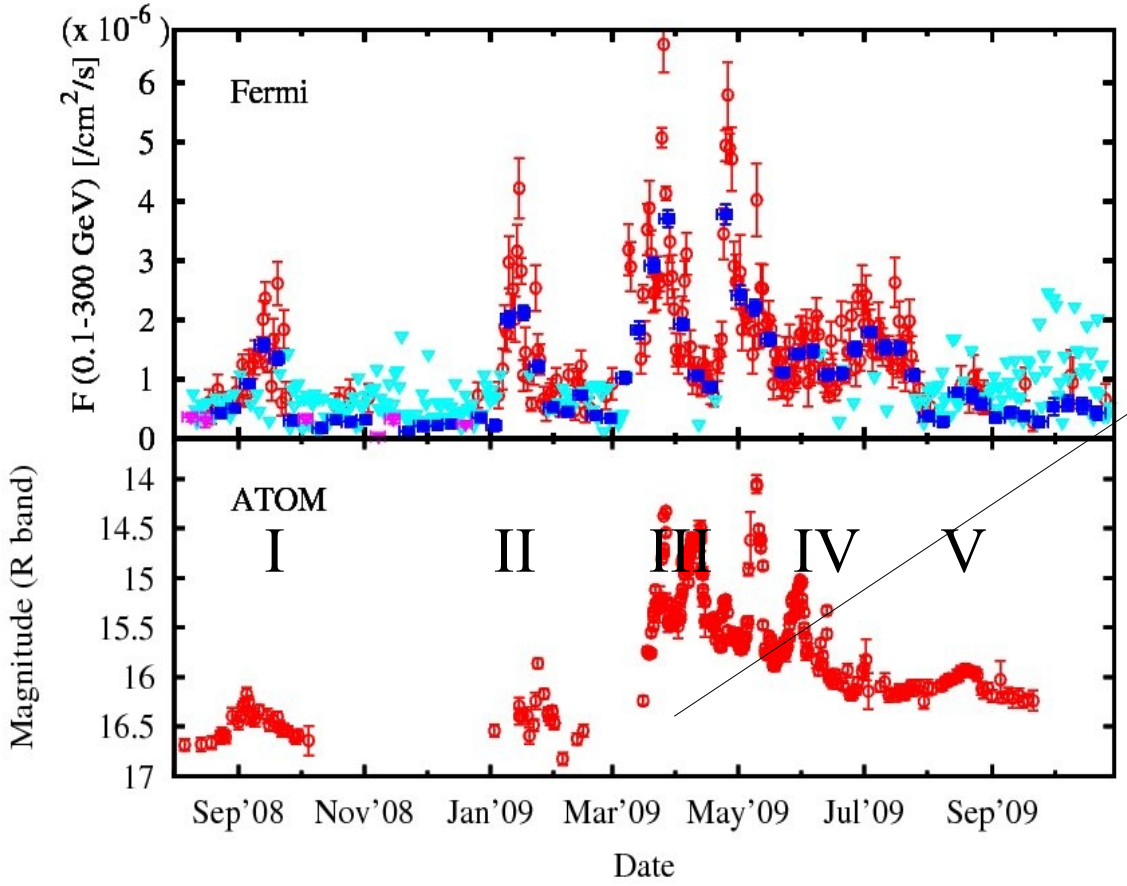


and changes of base level.



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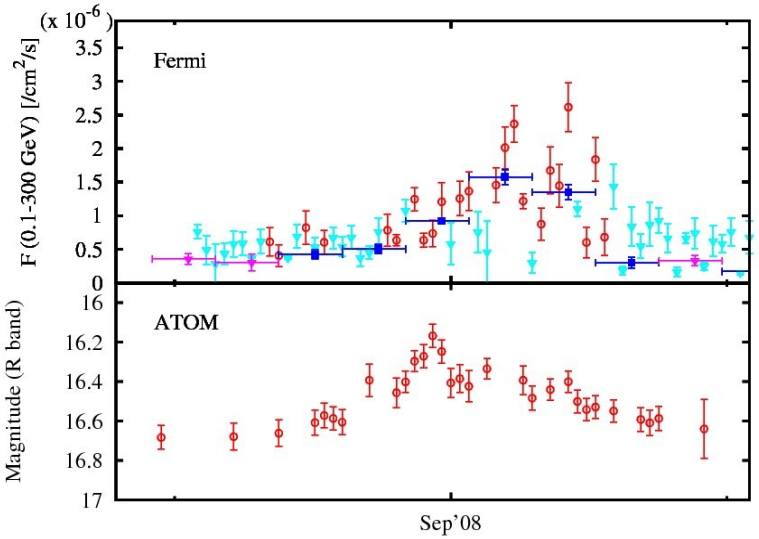

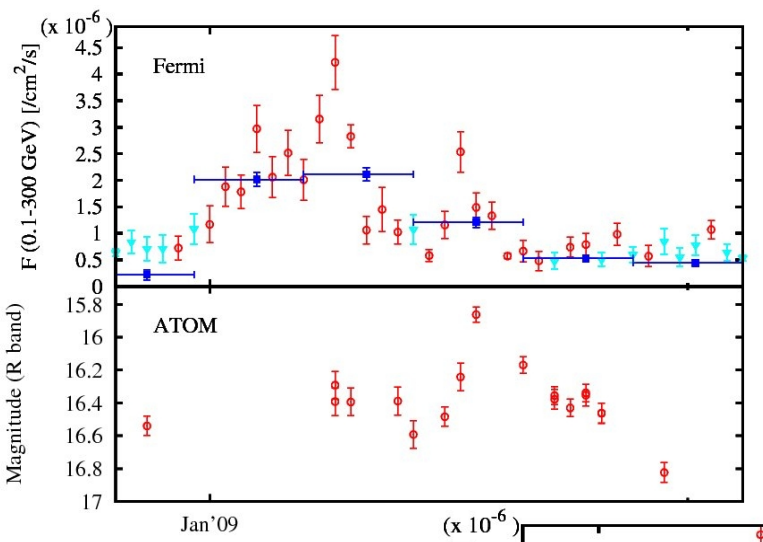

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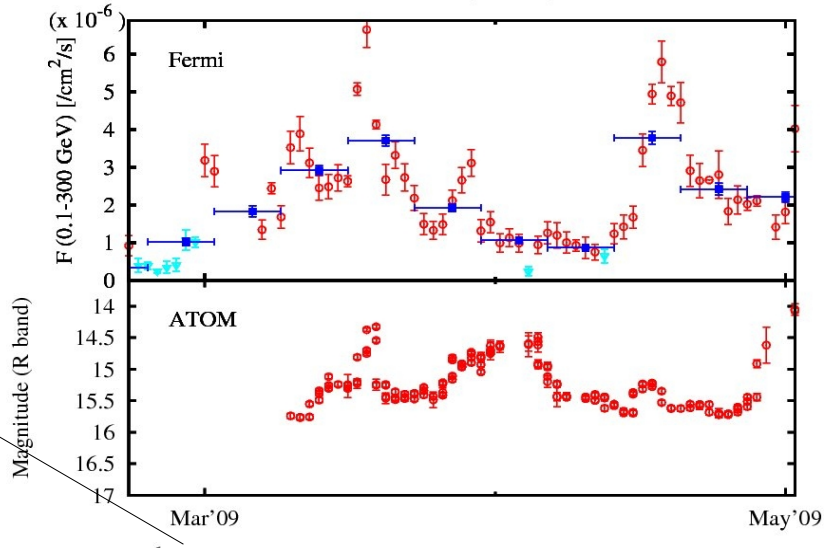

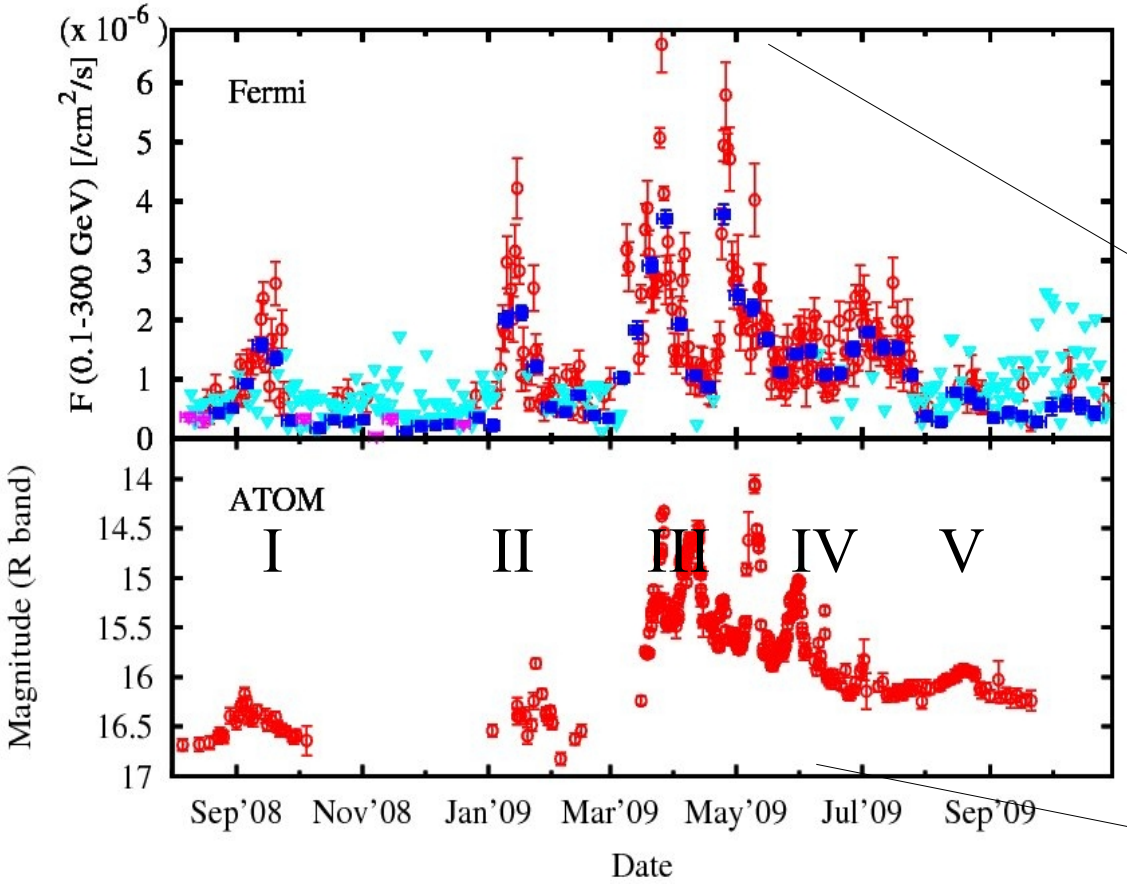

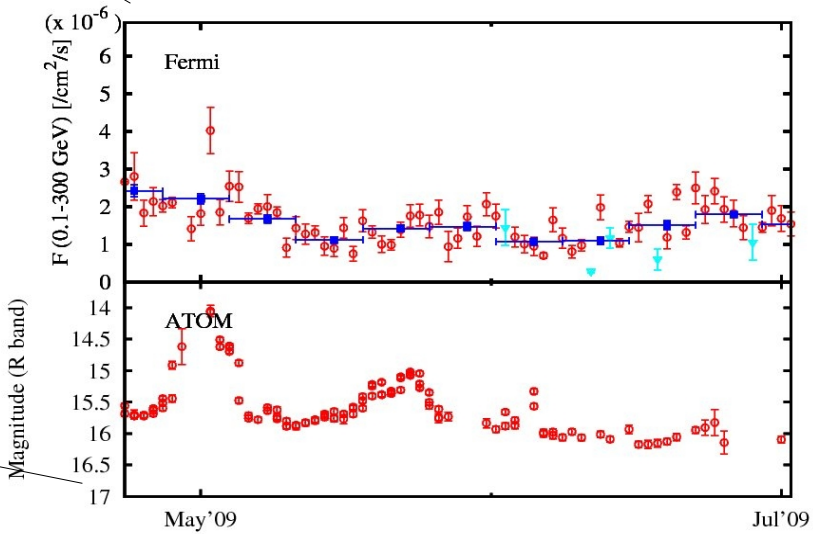

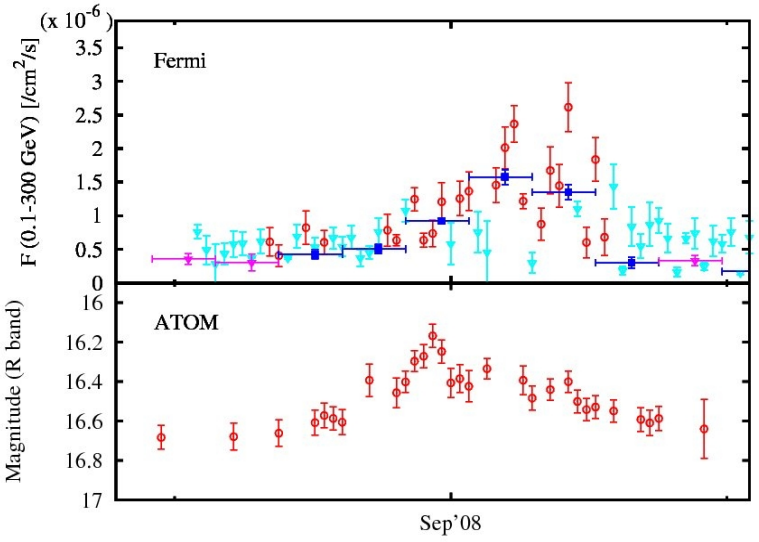

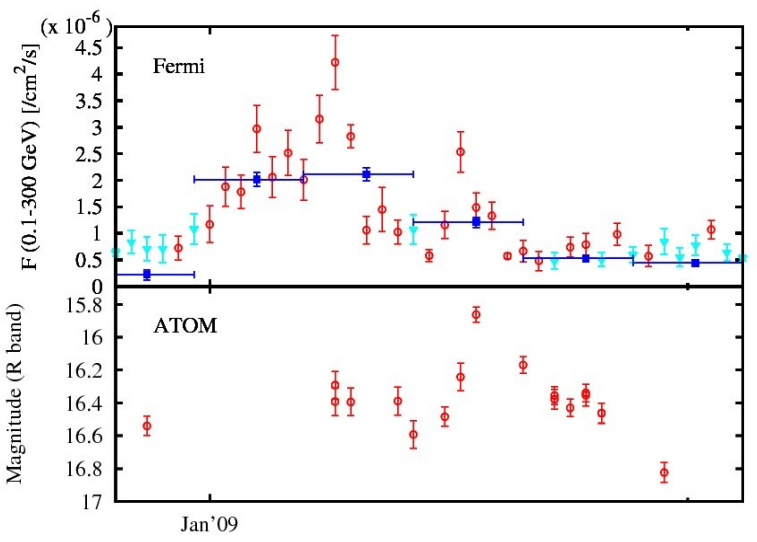

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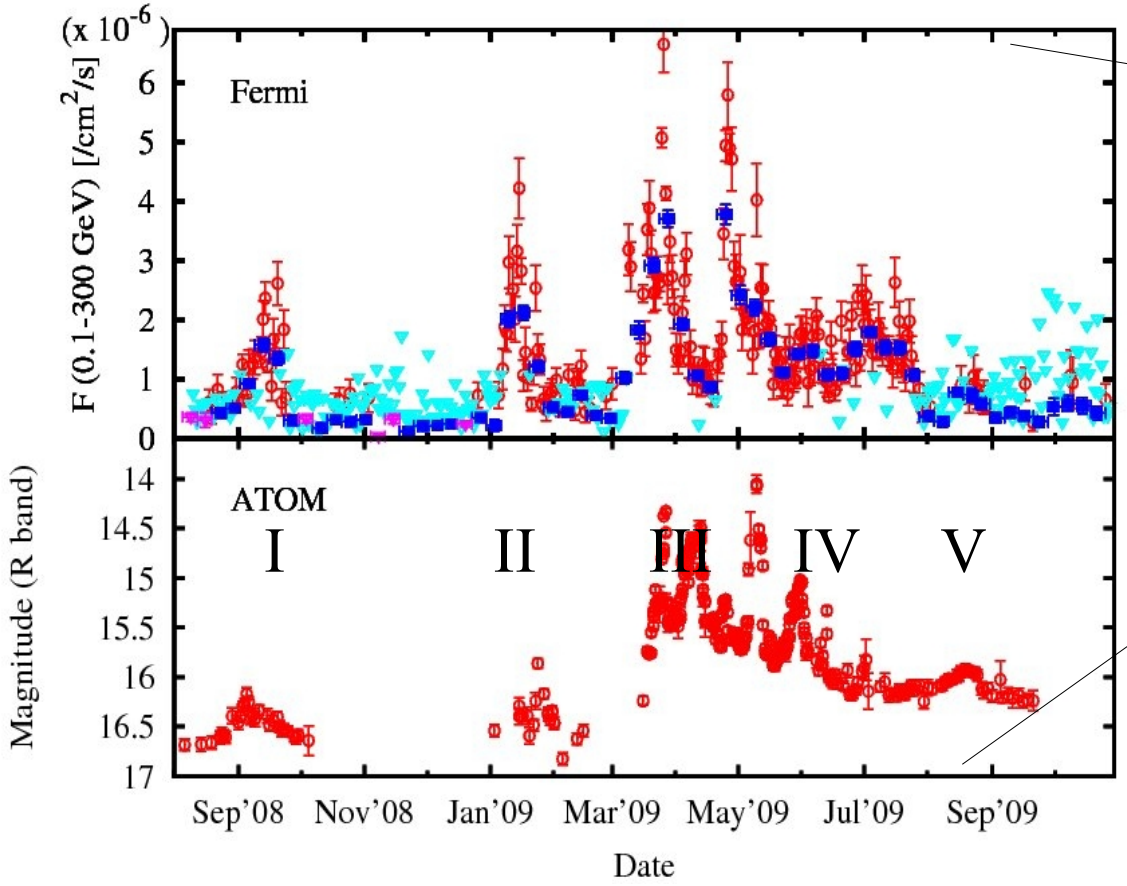
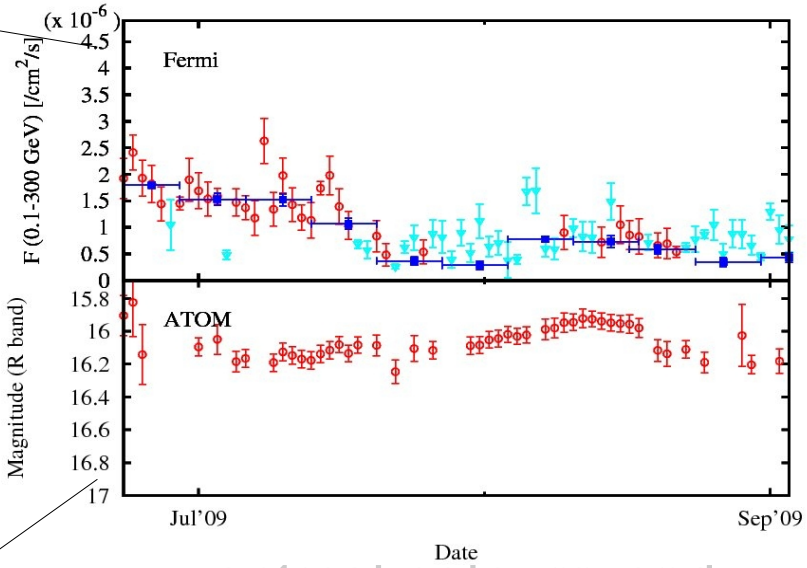




optical colours, and
X-ray spectral slope

Statistical Analysis

Confine analysis to sources with published light curves (Fermi)
and unbiased optical subset (disregard TOO triggered ATOM data).

Statistics of duty cycles and correlations.

Confine to subset of homogeneously monitored sources (ATOM)
With low duty cycles (F > [F] in < 20% of total time); [F] quiescence

Statistics of lags (peaks in DCCF)

Complete data (and subday time-scales)
for detailed mapping of events.

Statistical properties

	FGST-data GeV	ATOM-data eV	common
Variability (weekly)	18	19	18
Residual variations (daily)	16	18	16
Baseline (weekly)	8	8	7
<Duty cycle>	61%	68%	59%
<No of flares/12 months>	4.2	5.6	4.2
<chance coincidence>			93.6%
<Amplitude>	86%	21%	

Lags: In **all** cases which have significant Fermi detections on day-time scales for > 14 days, simultaneous optical data indicate significant variability on sub-day time scales:

Lags of one-day binned data affected by phasing.

Lags from unbinned data affected by window function.

Questions to be addressed

(very) preliminary answers

Do all flares have counterparts?

Yes

Can cross-identifications result by chance?

No

Is there a unique amplitude scaling within and among flares?

No

Are there any lags between different bands?

Yes

Does spectral evolution within the two bands reflect each other?

Is there any indication for variability in EIC photon fields?

Dependencies of all of the above on $\mathcal{L}$, $\mathcal{D}$, M, … ?

Summary

FGST is the best monitor for Blazars in any waveband (coverage),
but GeV gamma ray studies still have very limited dynamic range.
EGRET-selected (biased) set studied homogeneously over 12 months.

GeV and eV high states correspond to each other.

Flux correlations with different slopes, zeropoints, and scatter,
reflecting relative location of observing bands and peaks in SED

Flux scalings and lags are affected by binning and intraday-coverage.

Temporal lags differ (sign, amplitude) within and between sources.

Different spectral evolution of different flares. Biases affect statistics.

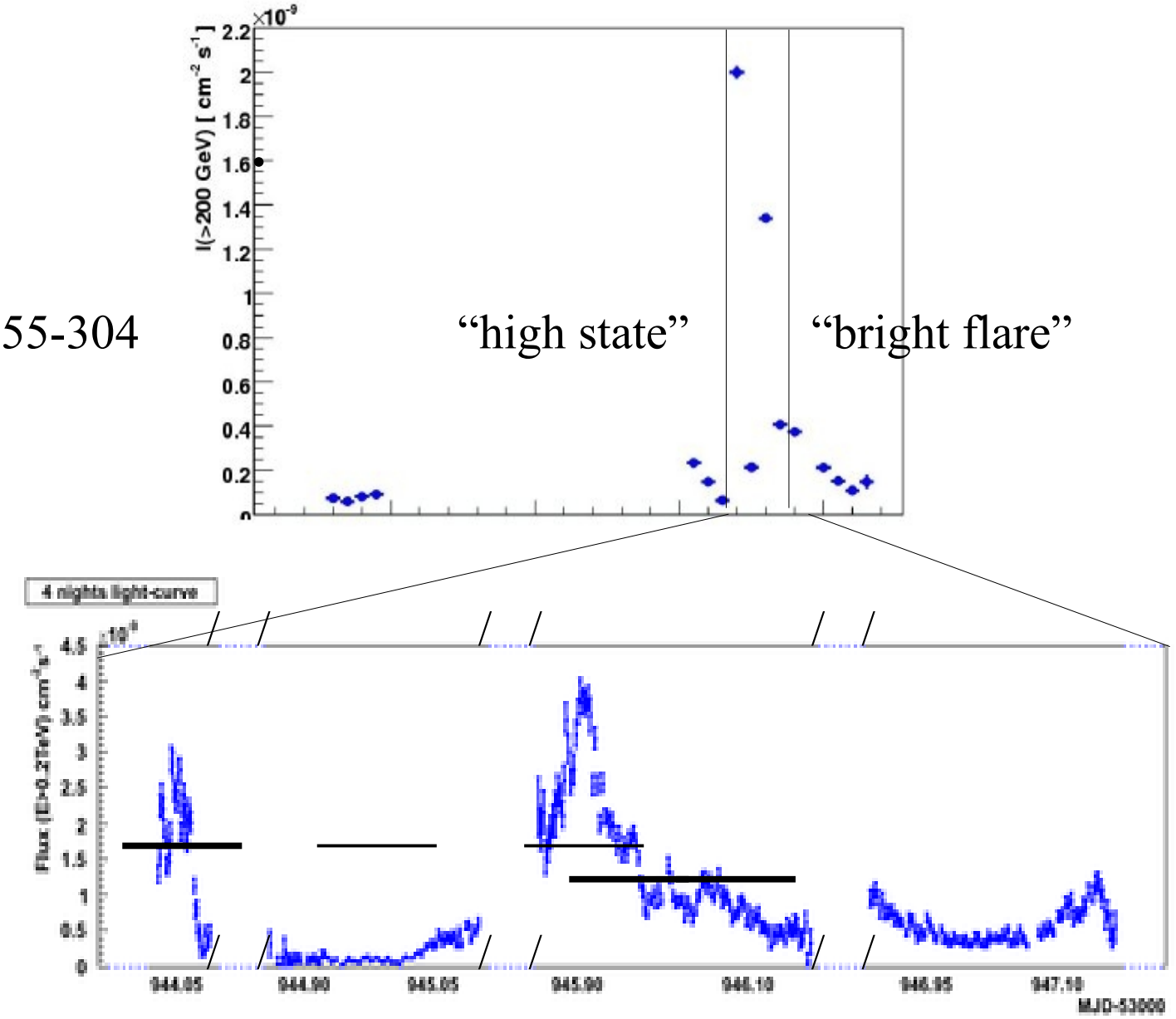
notes

Many monitoring efforts, see also:
P2, Sakamoto et al. ; P10, Kurtanidze et al.; P39, Chatterjee et al.;
P56, Carraminana at al.; P59, Mori et al. and many others.

Compliments and thanks to the LAT team for having set up the most homogeneous Blazar monitor of any waveband

HESS
collaboration

PKS 2155-304
2006



Binning/averaging affects amplitudes,
different binning/coverage affect ratios and can introduce spurious "lags"