Exploring the Dominant Gamma-Ray Emission Mechanism using Multiwavelength Variability Analysis. Case Study: 3C 279

Víctor Manuel Patiño Álvarez
patinoavm@mpifr-bonn.mpg.de

Max-Planck-Institut für Radioastronomie

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Monitoring the non-thermal Universe 2018

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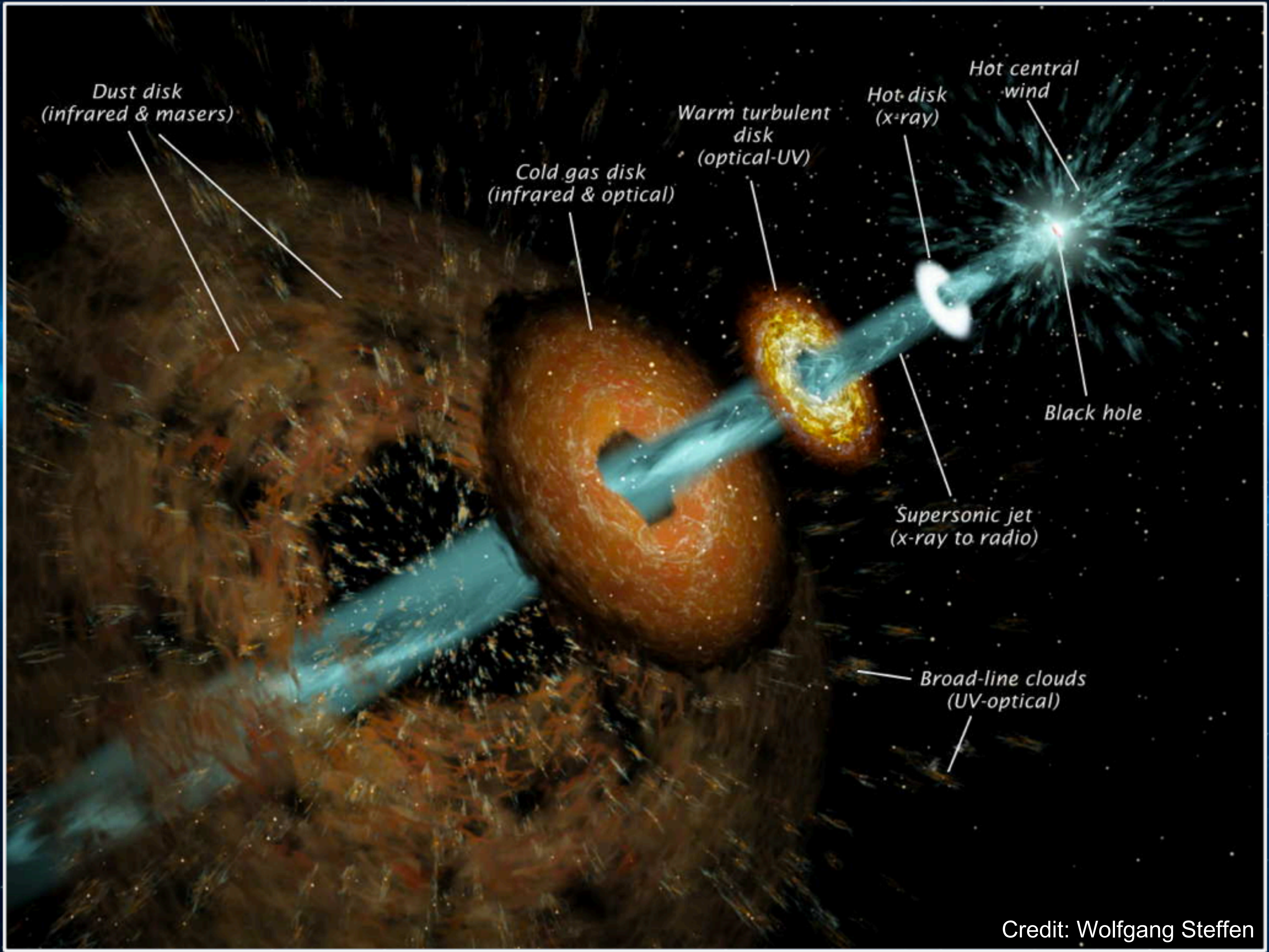
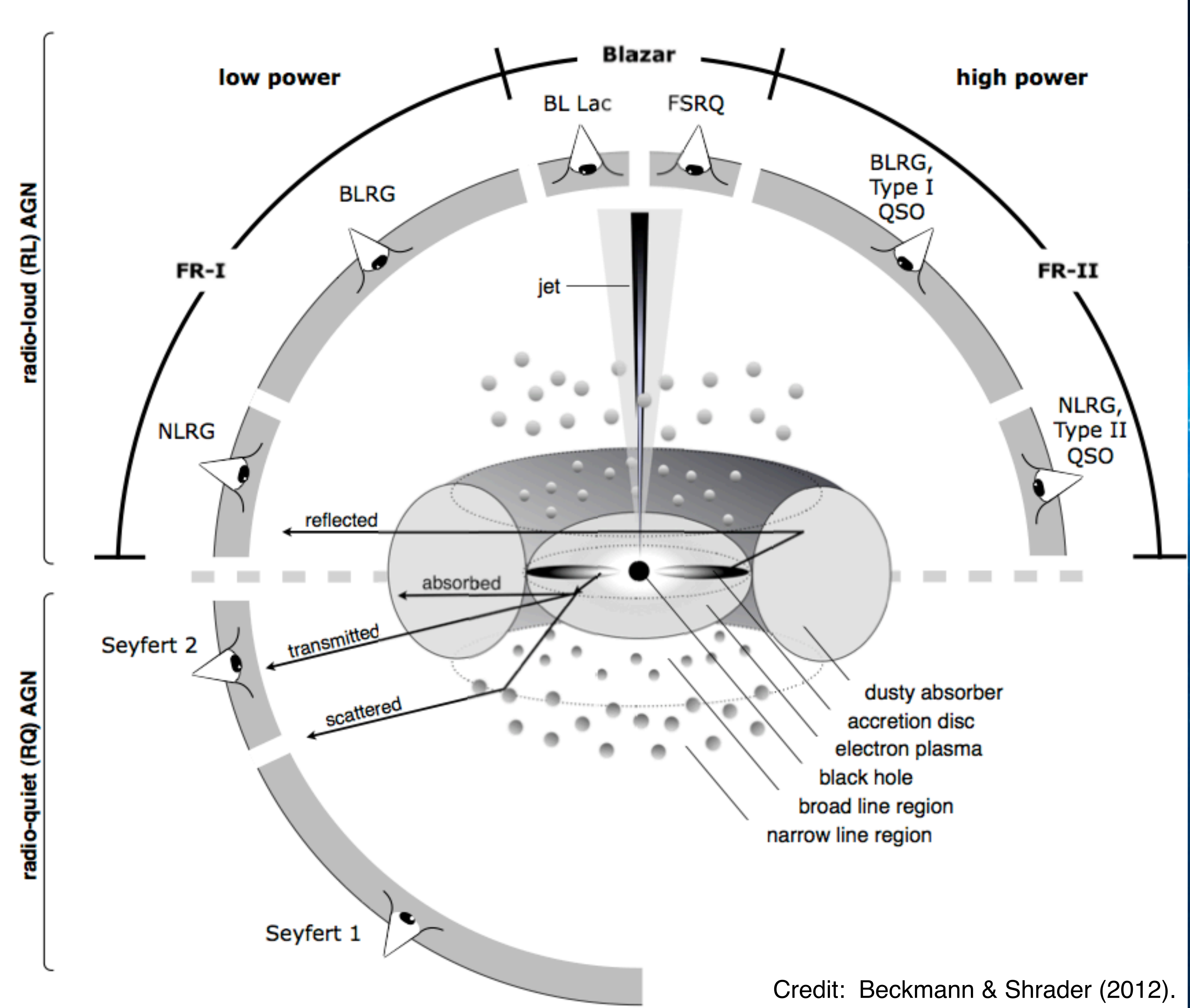
Introduction



Credit: Wolfgang Steffen

Introduction



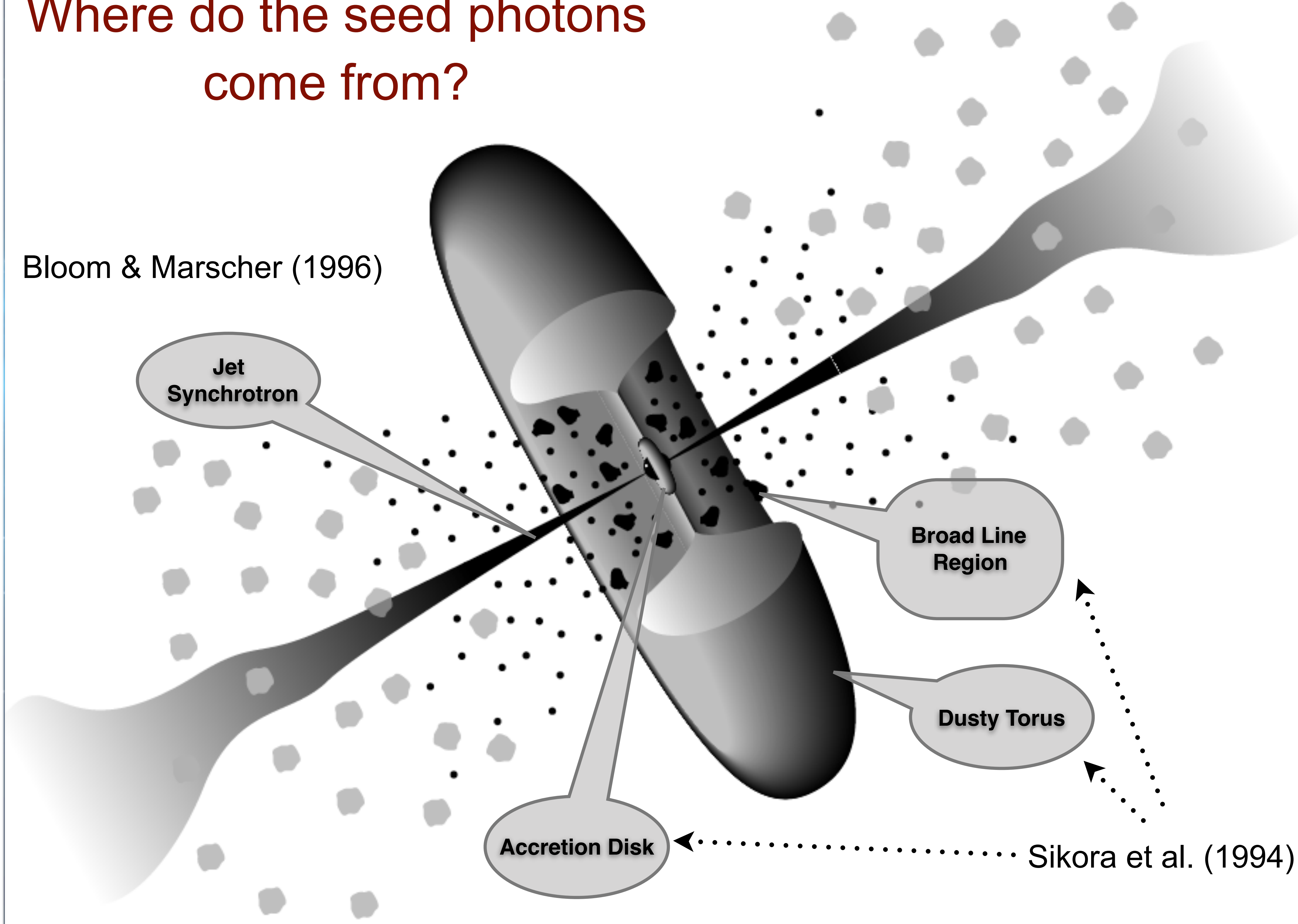
Credit: Beckmann & Shrader (2012).

Introduction

Inverse Compton Scattering

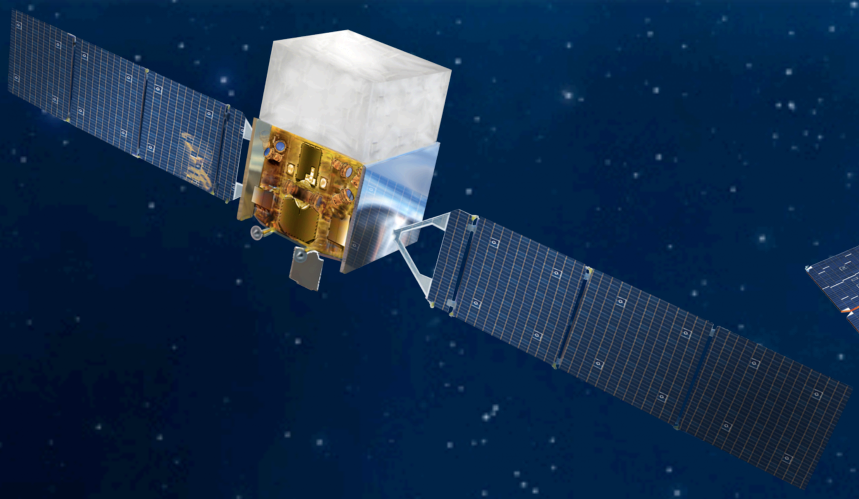
Introduction

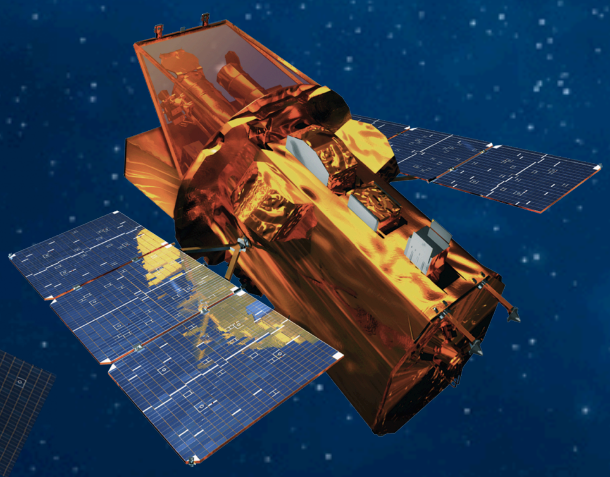
Where do the seed photons come from?

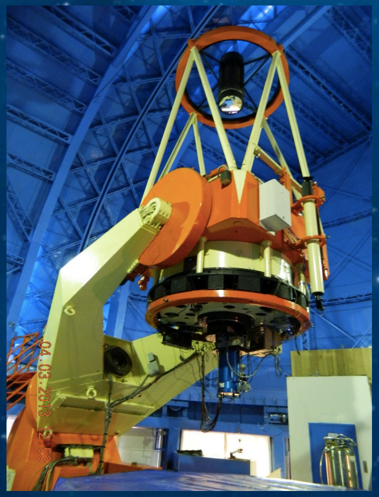


Multiwavelength Data 3C 279

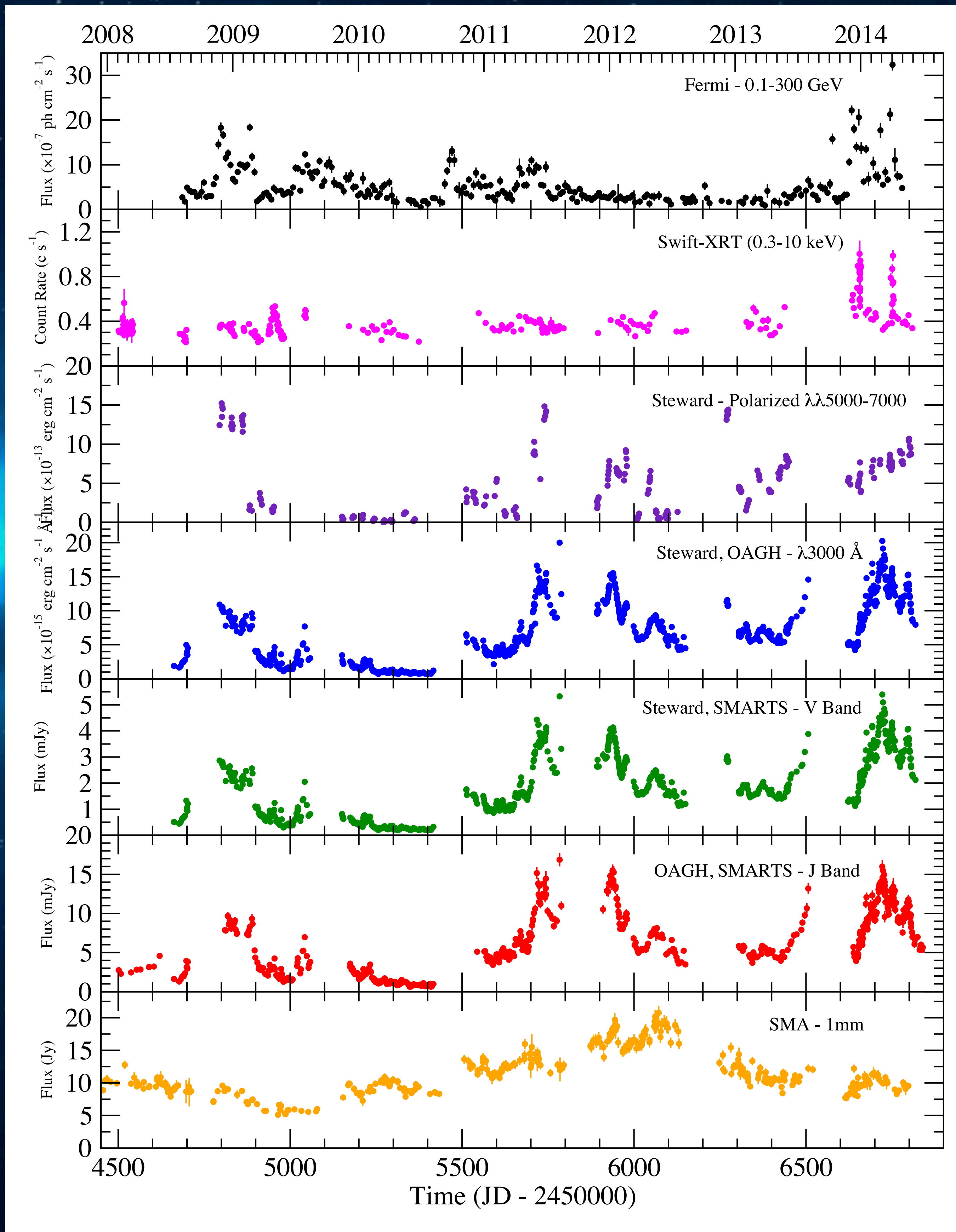
- Gamma-Rays - Fermi-LAT
- X-Rays - Swift-XRT
- Optical Spectroscopy - Steward Observatory, OAGH and OAN-SPM
- Optical Spectropolarimetry - Steward Observatory
- Optical Photometry - Steward Observatory, SMARTS
- Near-Infrared Photometry - SMARTS, OAGH
- 1 millimeter - Sub-Millimeter Array (SMA)

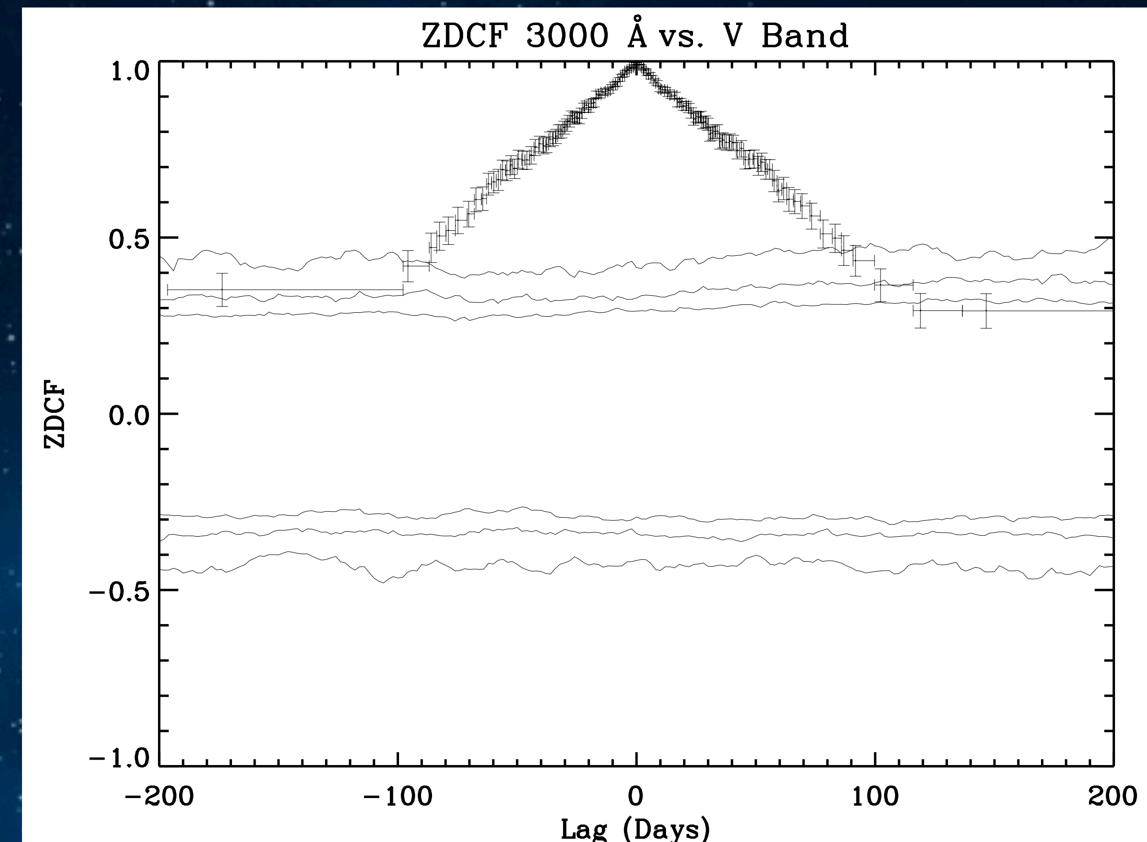


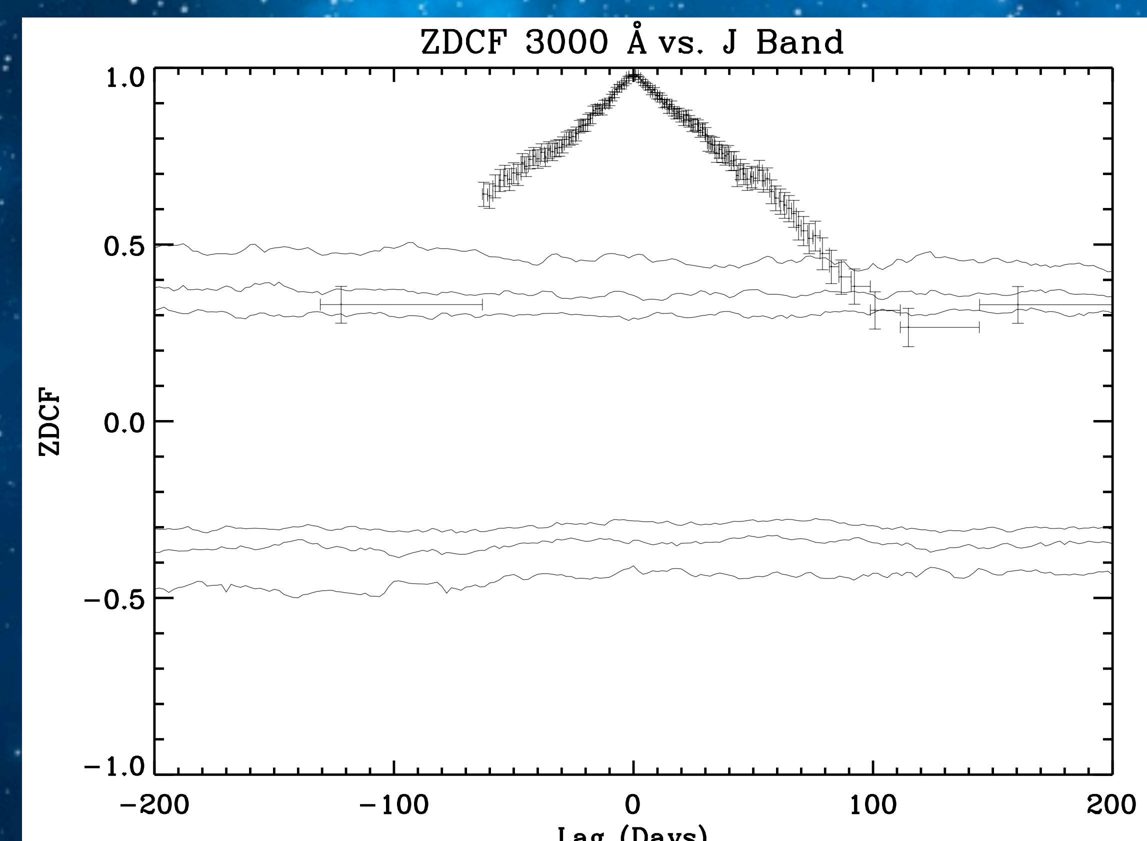




Multiwavelength Data 3C 279







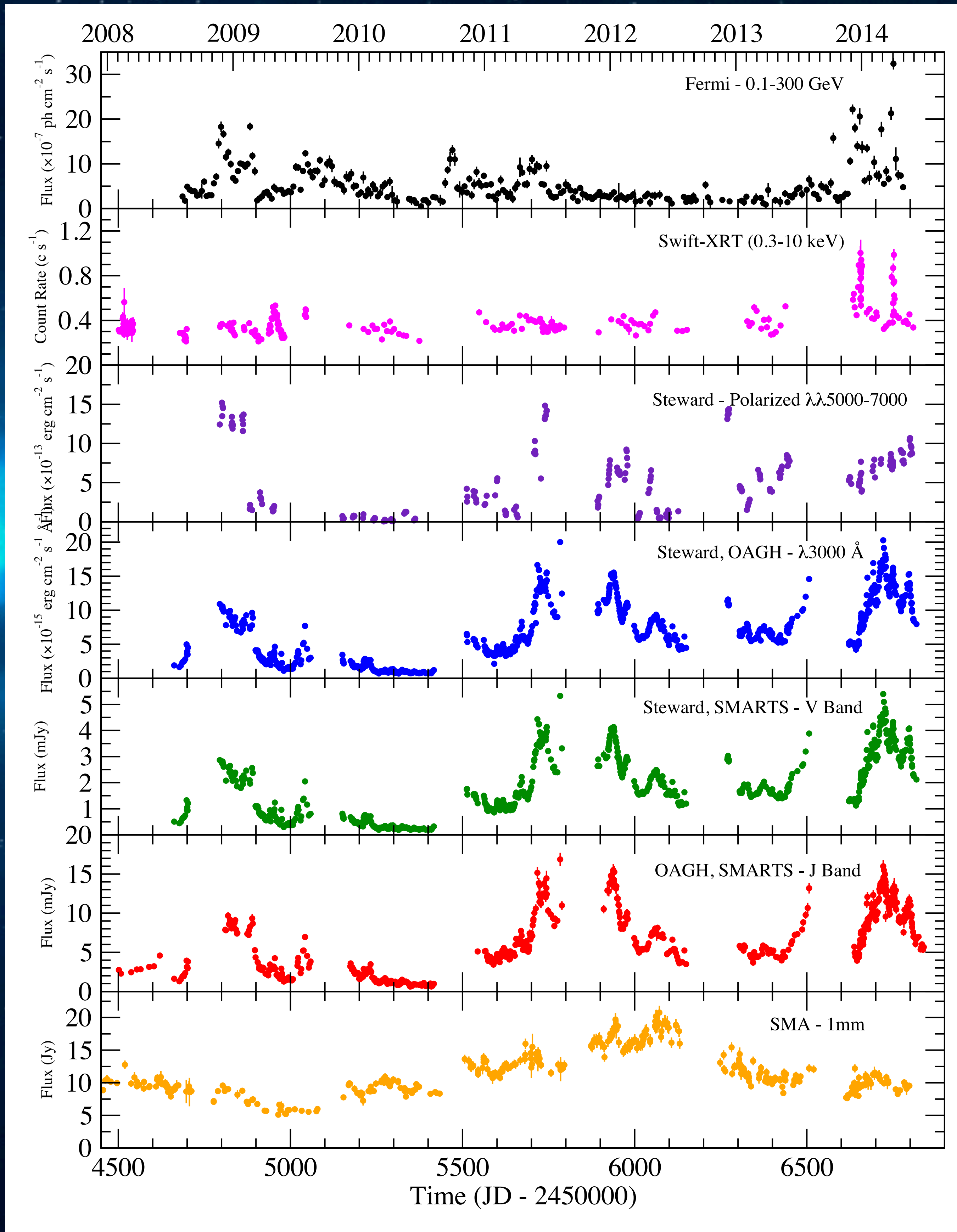
Cross-Correlation Analysis

- Interpolation Method (ICCF, Gaskell & Sparke 1986).
- Discrete Cross-Correlation Function (DCCF, Edelson & Krolik 1988).
- Z-Transformed Discrete Correlation Function (ZDCF, Alexander 1997).

Bands	Full Time-Range	Period A	Period B	Period C
J-band vs. *H*-band	0.0±22.3	-0.3±24.6	-4.2±21.7	0.0±5.4
J-band vs. *K*-band	-0.1±3.2	0.9±3.2	-0.3±3.6	1.0±1.5
3000 Å vs. *V*-band	0.0±2.0	0.0±2.1	0.0±2.1	0.0±1.2
3000 Å vs. *J*-band	0.2±2.7	-0.2±2.6	0.0±3.2	0.0±1.3
V-band vs. *J*-band	0.0±2.7	-0.1±2.6	0.8±3.2	0.0±1.3
3000 Å vs. Gamma-Rays	—	-0.7±5.0	—	28.6±4.8
X-rays vs. Gamma-Rays	-0.85±5.8	—	—	1.3±3.0

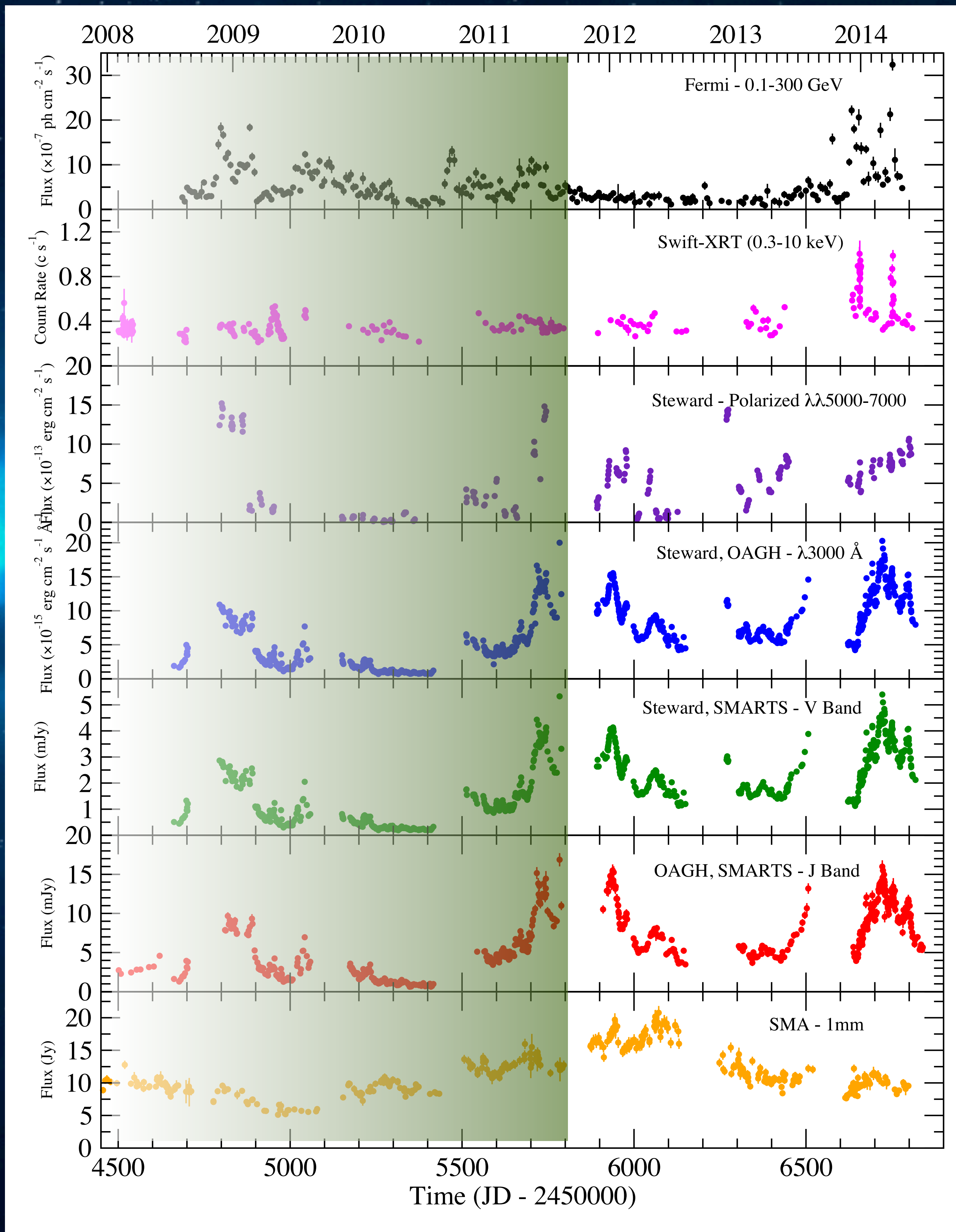
Spearman rank correlation test shows strong and significant correlation between 1mm and UV continuum.

Full Time



- Simultaneous variability from UV to NIR implies co-spatiallity.
- Significant and strong correlation found between the UV & 1mm suggests that UV-Optical-NIR are is dominated by non-thermal emission (ynchrotron).
- Anomalous flaring period (from UV to mm) with no counterpart in the γ-rays.

Full Time



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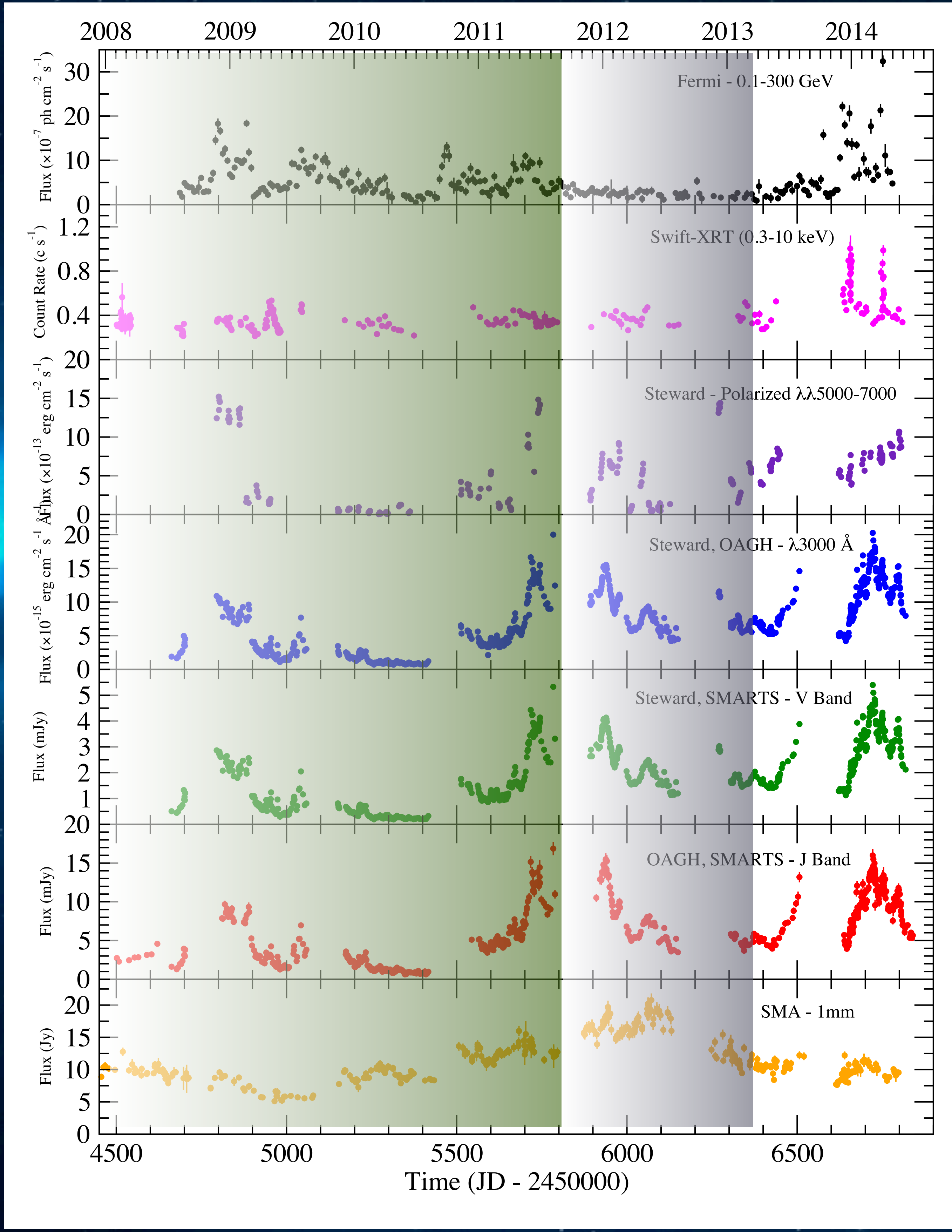

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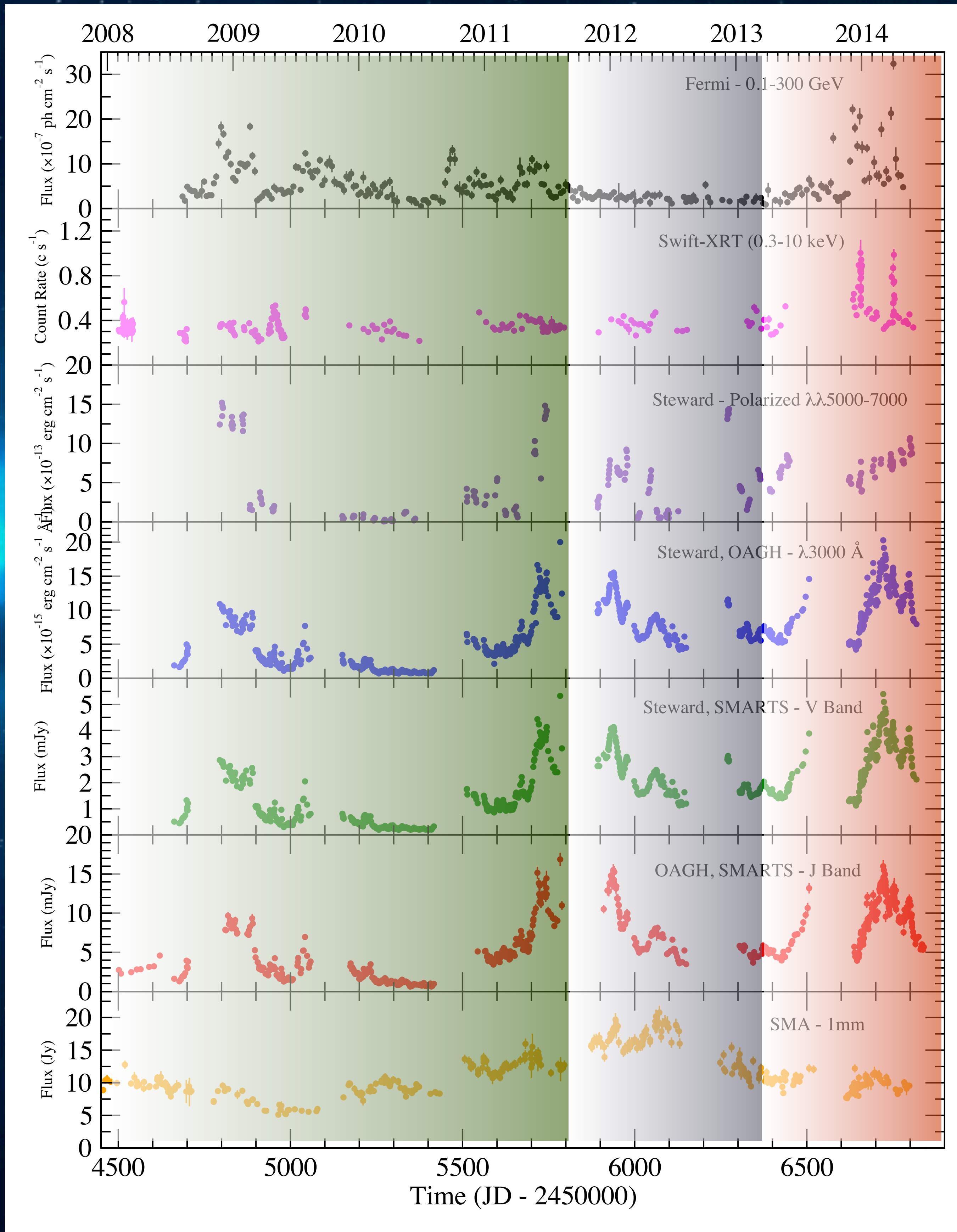

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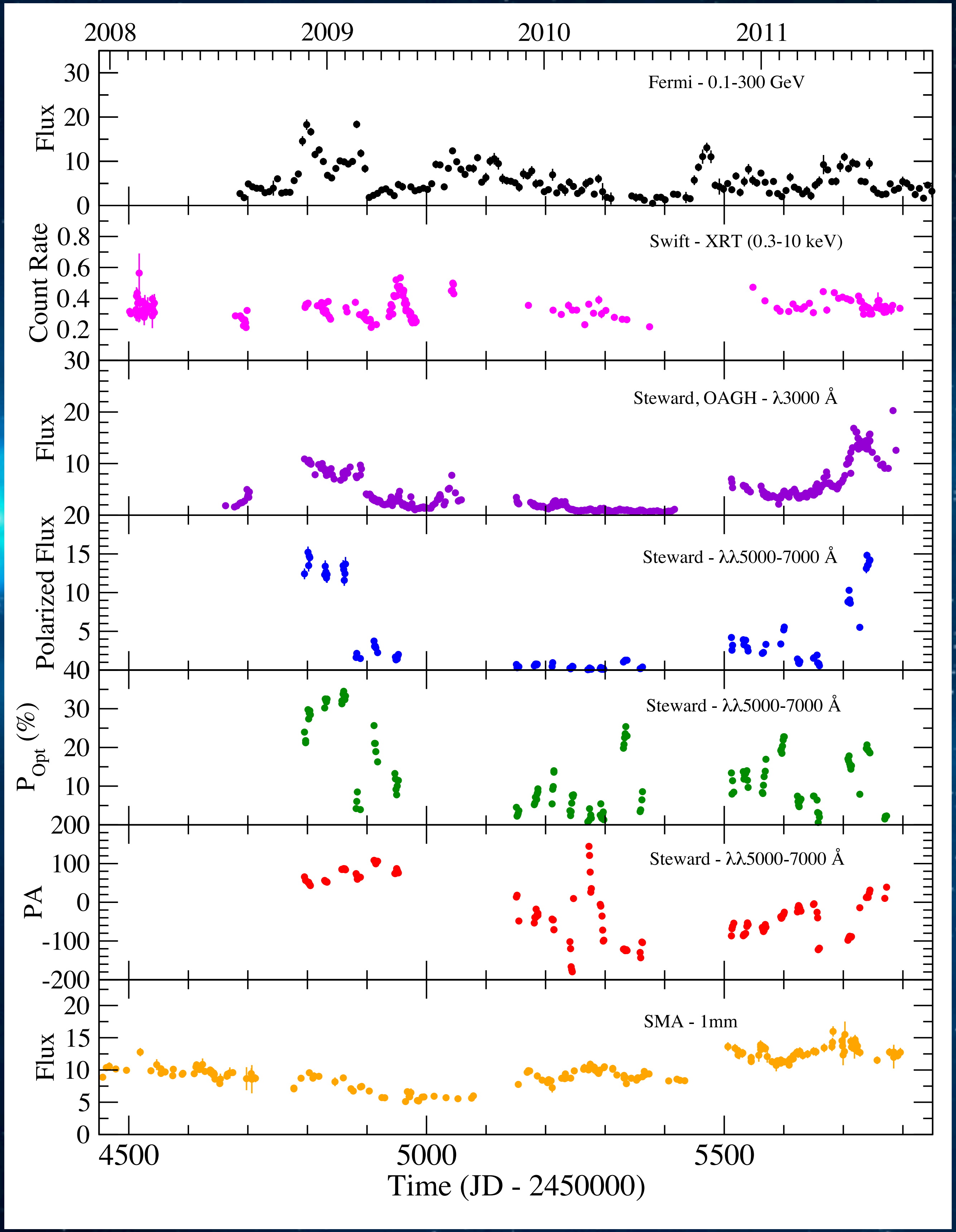
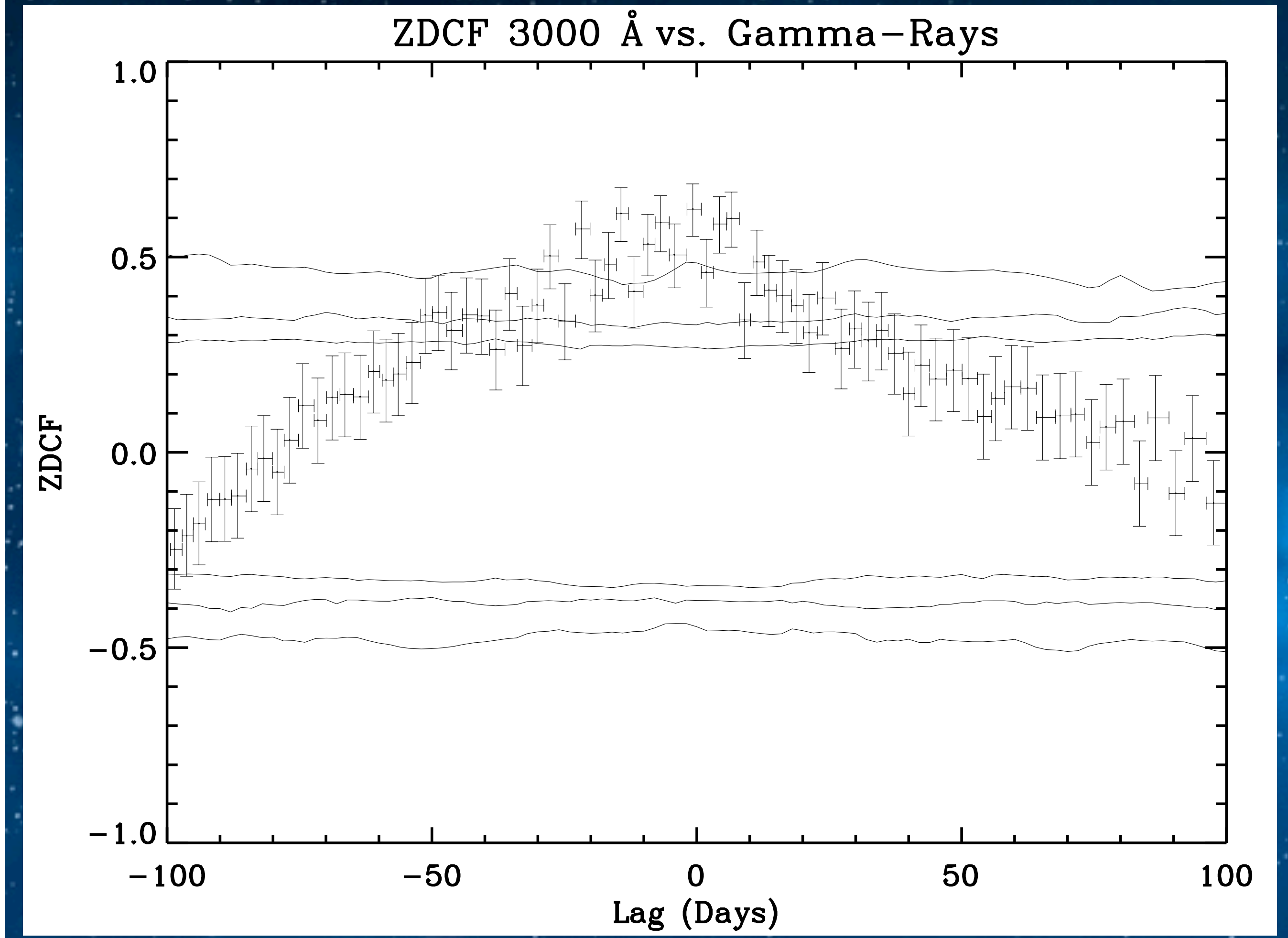
Period A

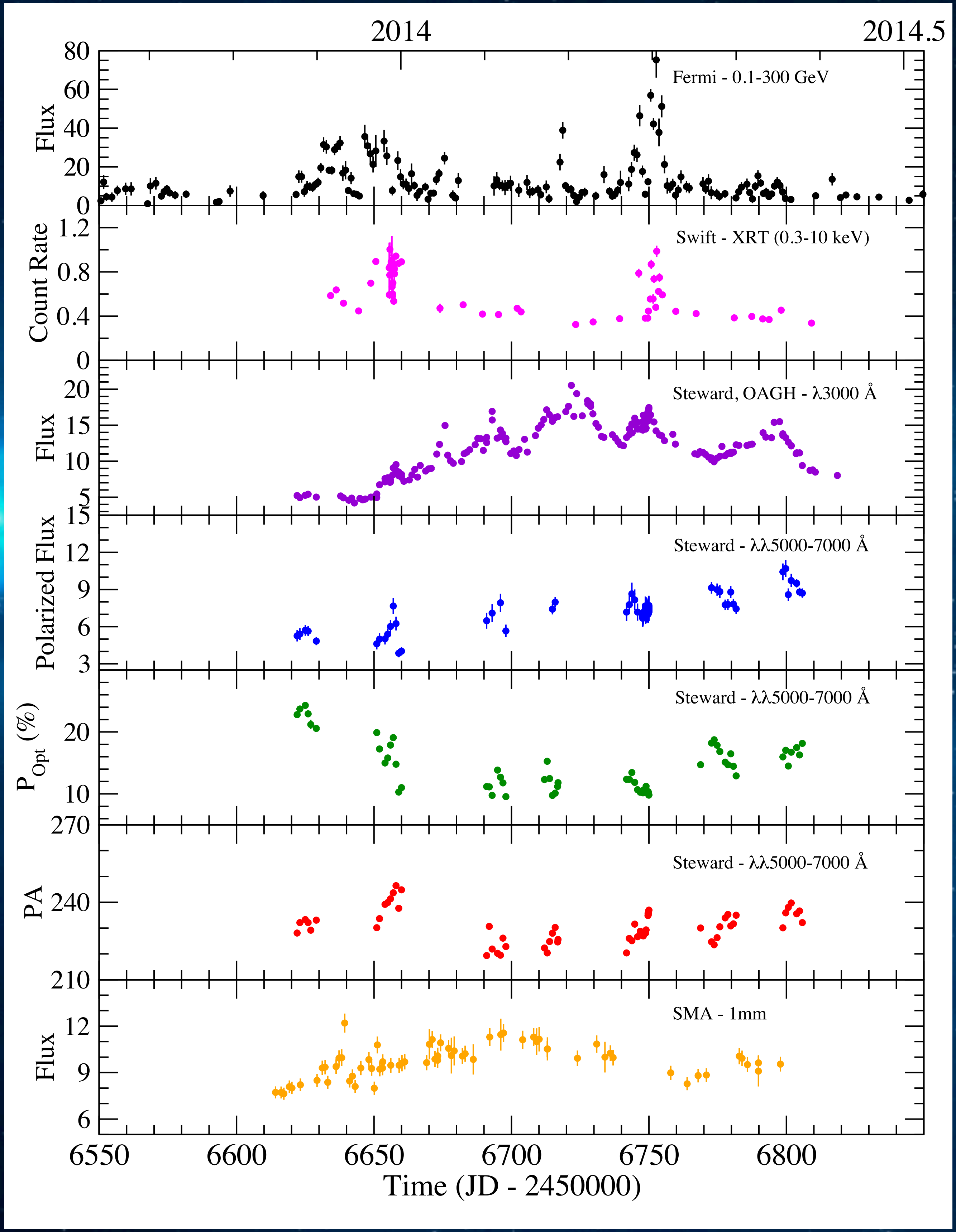

2008
2009
2010
2011
Flux
Fermi - 0.1-300 GeV
Count Rate
Swift - XRT (0.3-10 keV)
Flux
Steward, OAGH - λ3000 Å
Polarized Flux
Steward - λλ5000-7000 Å
P_{Opt} (%)
Steward - λλ5000-7000 Å
PA
Steward - λλ5000-7000 Å
Flux
SMA - 1mm
Time (JD - 2450000)

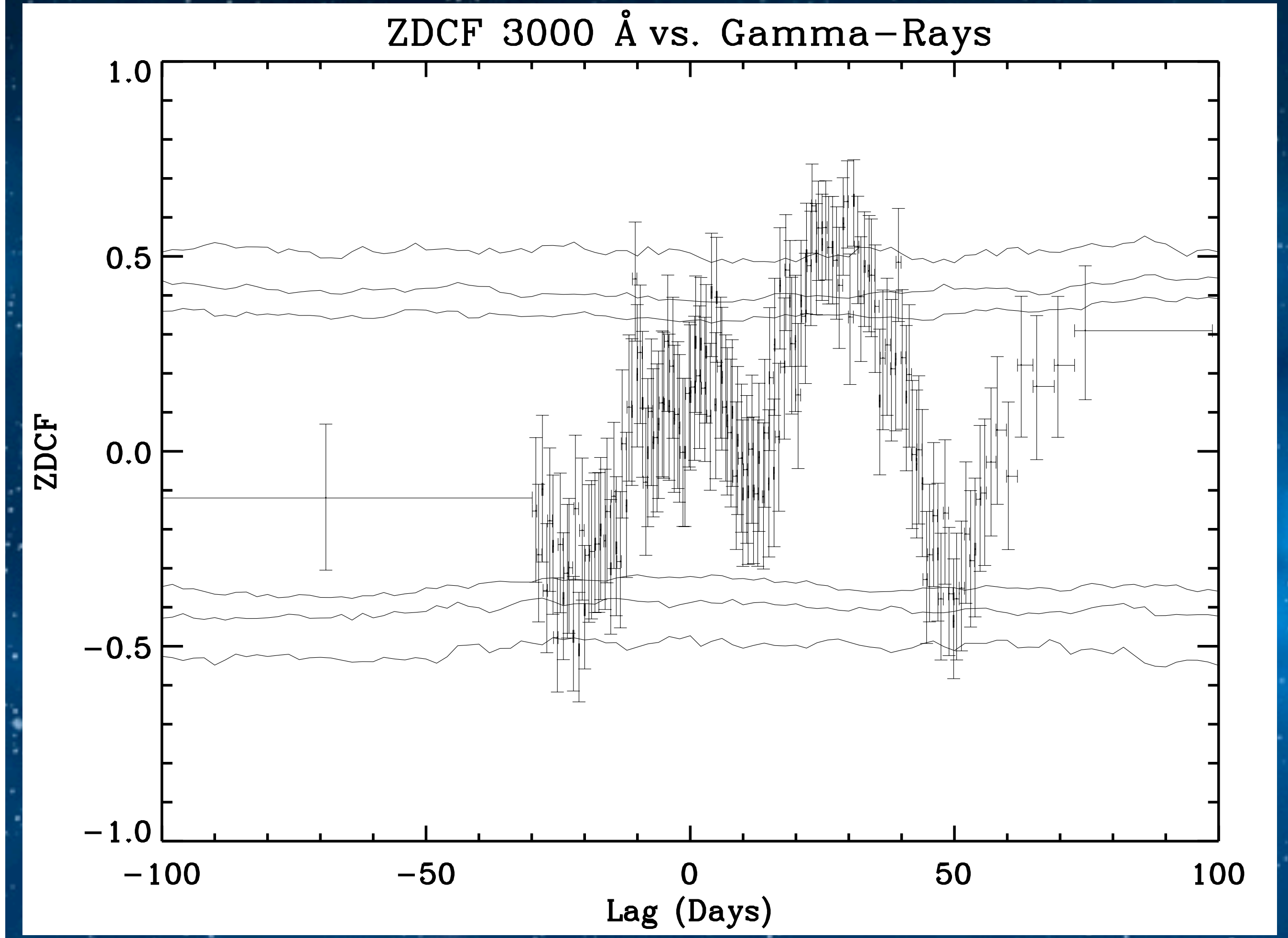

ZDCF 3000 Å vs. Gamma−Rays
ZDCF
Lag (Days)

Period A

- Cross-Correlation analysis between γ-rays and UV continuum shows a delay of -0.7 ± 5.0 days, consistent with zero delay.
- Zero delay implies that the seed photon production zone is co-spatial with the UV synchrotron emission zone.
- This points to a dominance of Synchrotron Self Compton.
- Hadronic models cannot reproduce tight correlations between optical and γ-rays.

Period C

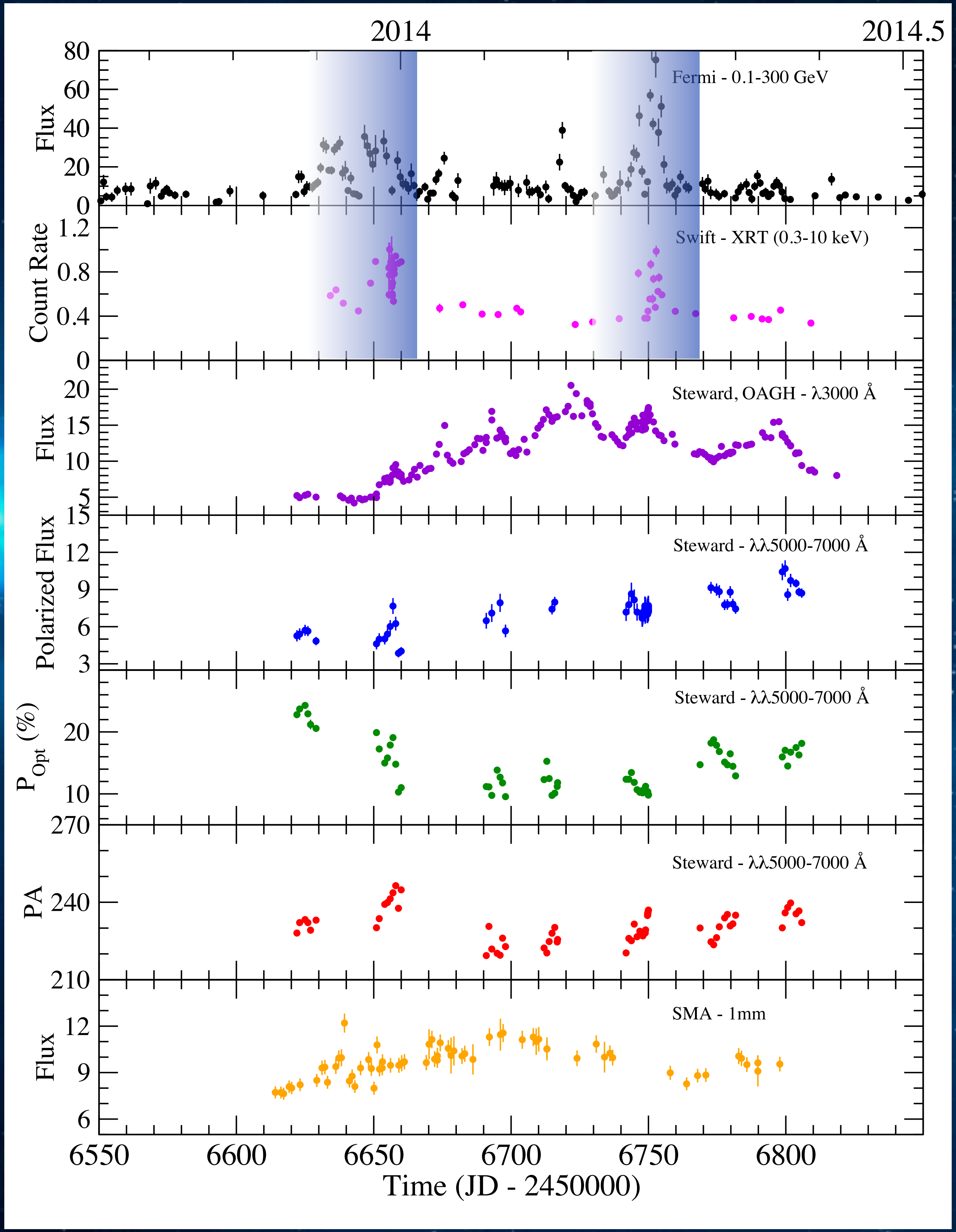

2014
2014.5
Fermi - 0.1-300 GeV
Swift - XRT (0.3-10 keV)
Steward, OAGH - λ3000 Å
Steward - λλ5000-7000 Å
Steward - λλ5000-7000 Å
Steward - λλ5000-7000 Å
SMA - 1mm
Flux
Count Rate
Flux
Polarized Flux
P_{Opt} (%)
PA
Flux
Time (JD - 2450000)

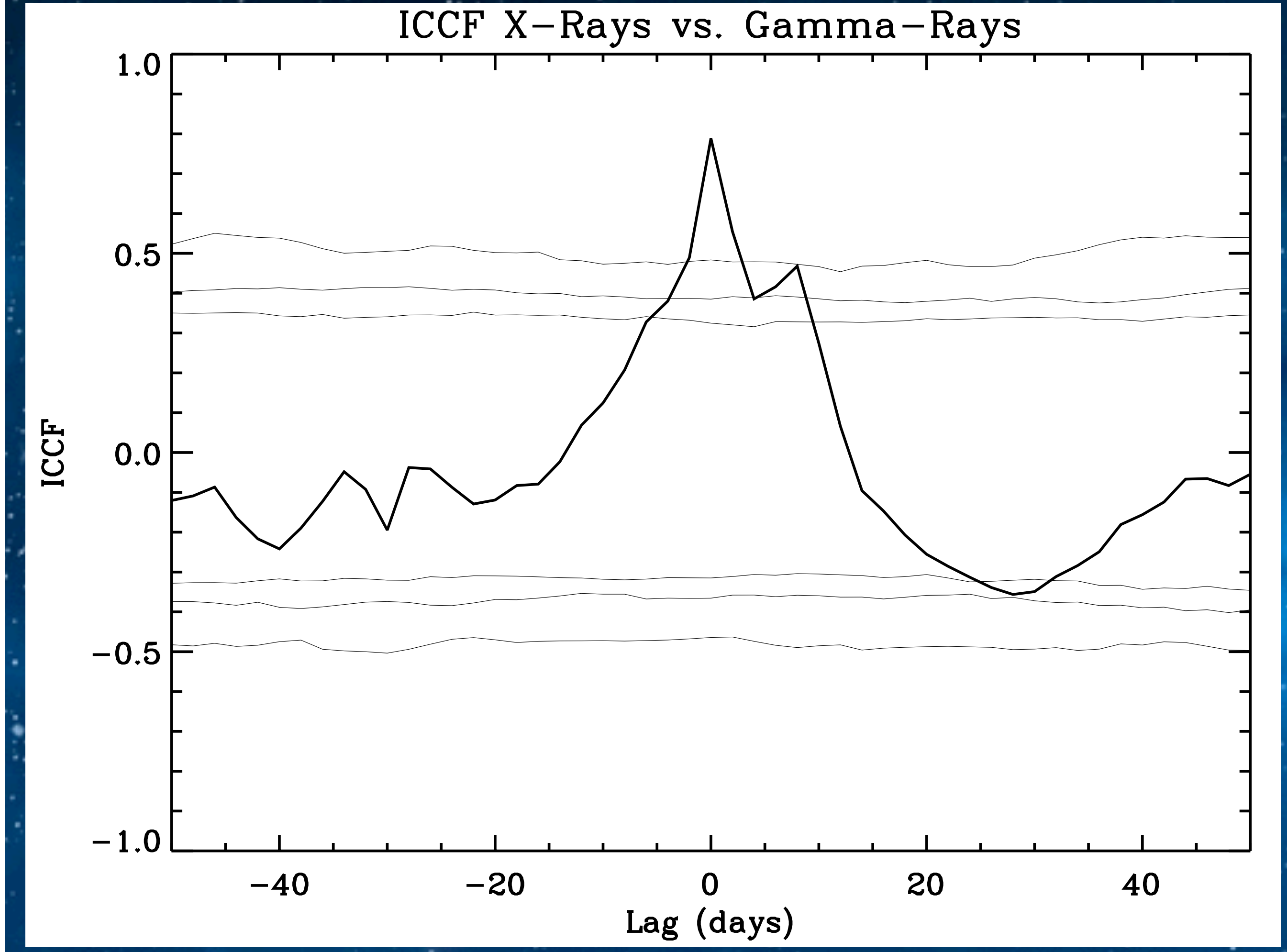

ZDCF 3000 Å vs. Gamma−Rays
ZDCF
Lag (Days)

Period C

- Cross-Correlation Analysis between the γ-rays and the UV continuum shows a delay of 28.6 ± 4.8 days.
- This delay implies that the photon seed production zone is not co-spatial with the synchrotron emission zone.
- This points to a dominance of External Inverse Compton, but it cannot be completely determined just by this result.

Period C

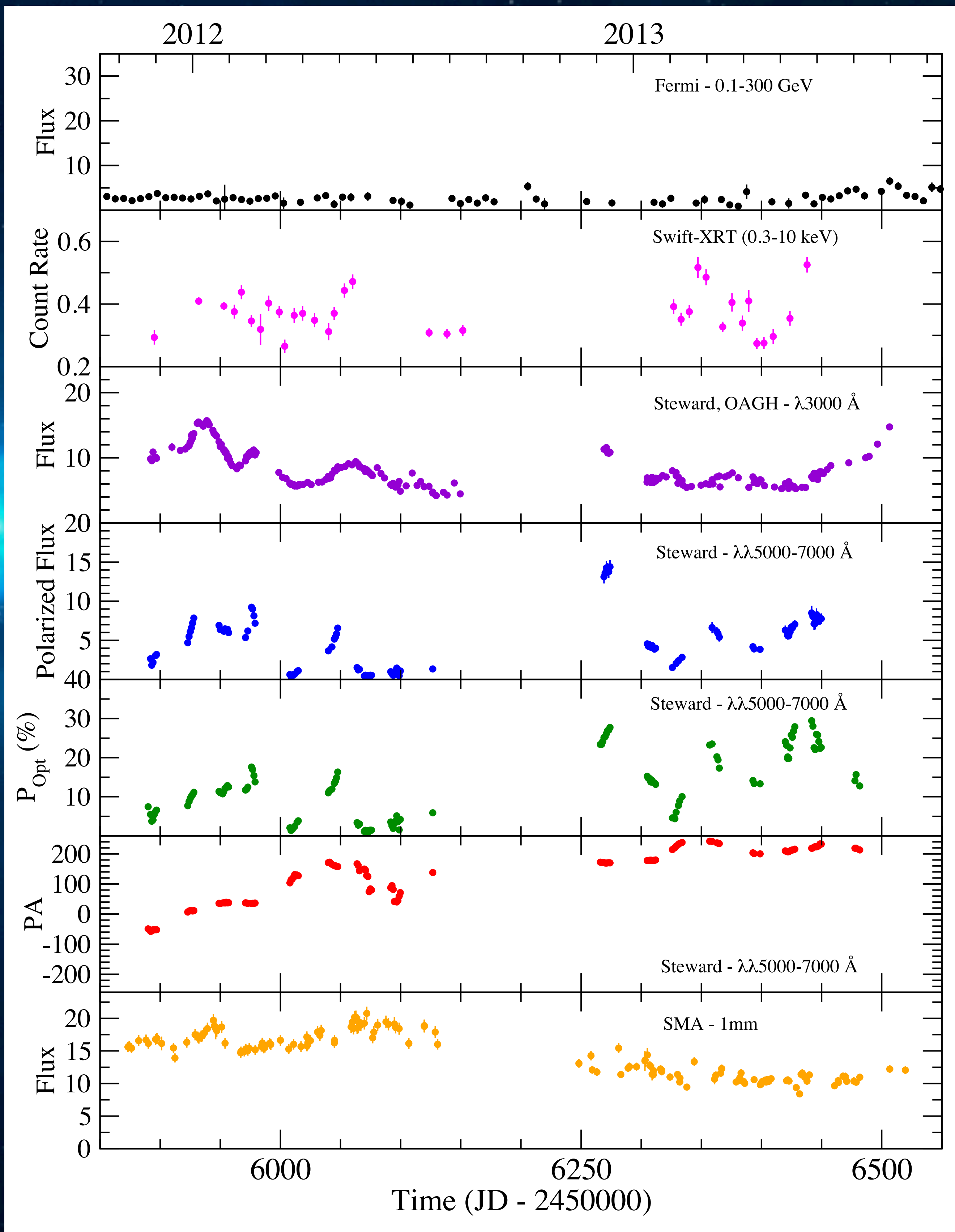

2014
2014.5
Flux
Fermi - 0.1-300 GeV
Count Rate
Swift - XRT (0.3-10 keV)
Flux
Steward, OAGH - λ3000 Å
Polarized Flux
Steward - λλ5000-7000 Å
P Opt (%)
Steward - λλ5000-7000 Å
PA
Steward - λλ5000-7000 Å
Flux
SMA - 1mm
Time (JD - 2450000)

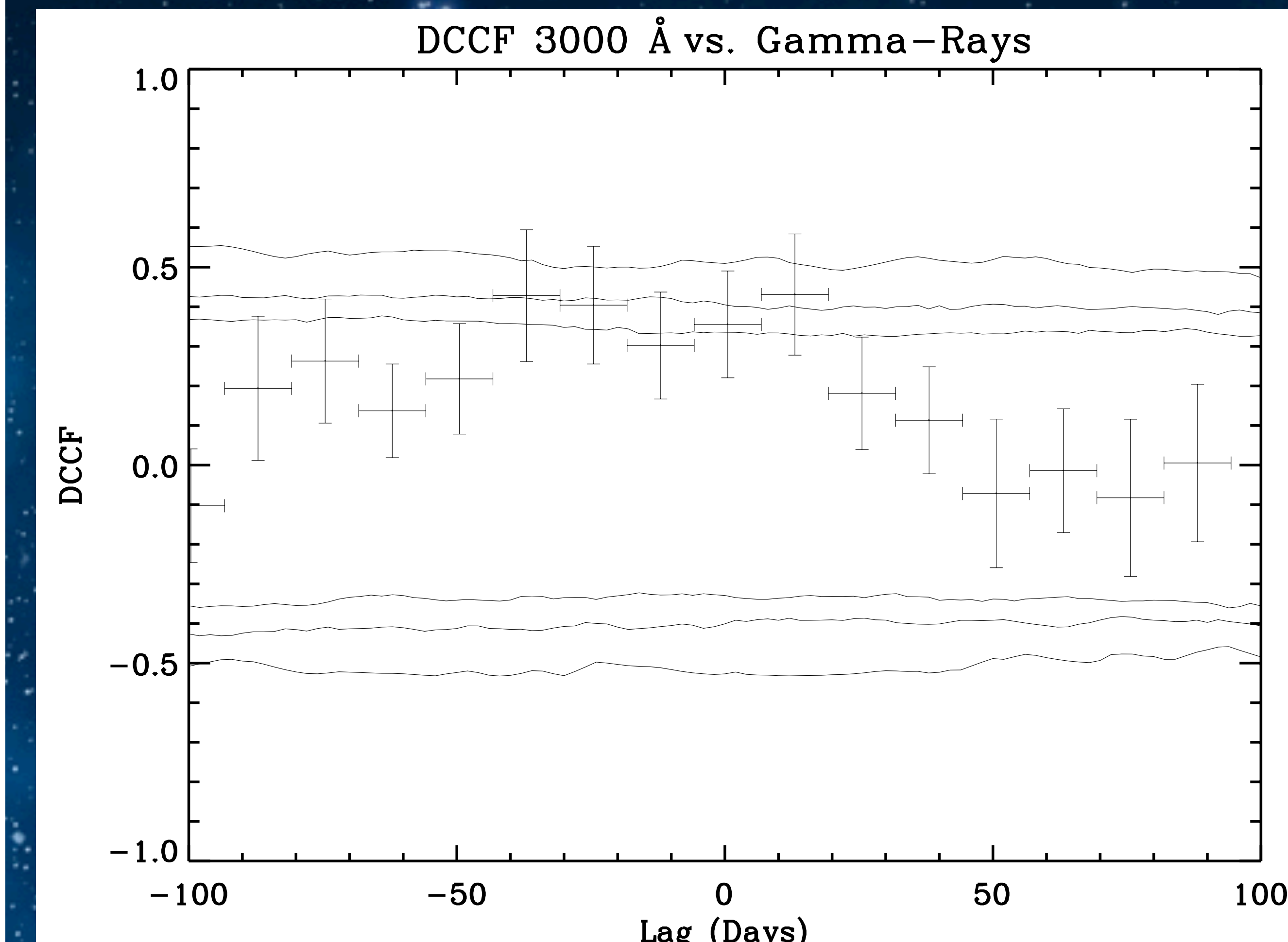

ICCF X-Rays vs. Gamma-Rays
ICCF
Lag (days)

X-Rays

- Thermal - Inner accretion disk (mostly soft X-rays)
  - Easily discarded as dominant by the duration of flares.
- Synchrotron - Jet
  - Should be correlated to the rest of the synchrotron
- Inverse Compton - Jet or Hot Corona
  - Lack of correlation between 1mm (dominated by synchrotron) and X-rays.

Period B


2012
2013
Fermi - 0.1-300 GeV
Swift-XRT (0.3-10 keV)
Steward, OAGH - λ3000 Å
Steward - λλ5000-7000 Å
Steward - λλ5000-7000 Å
Steward - λλ5000-7000 Å
SMA - 1mm
Flux
Count Rate
Flux
Polarized Flux
P_Opt (%)
PA
Flux
6000
6250
6500
Time (JD - 2450000)

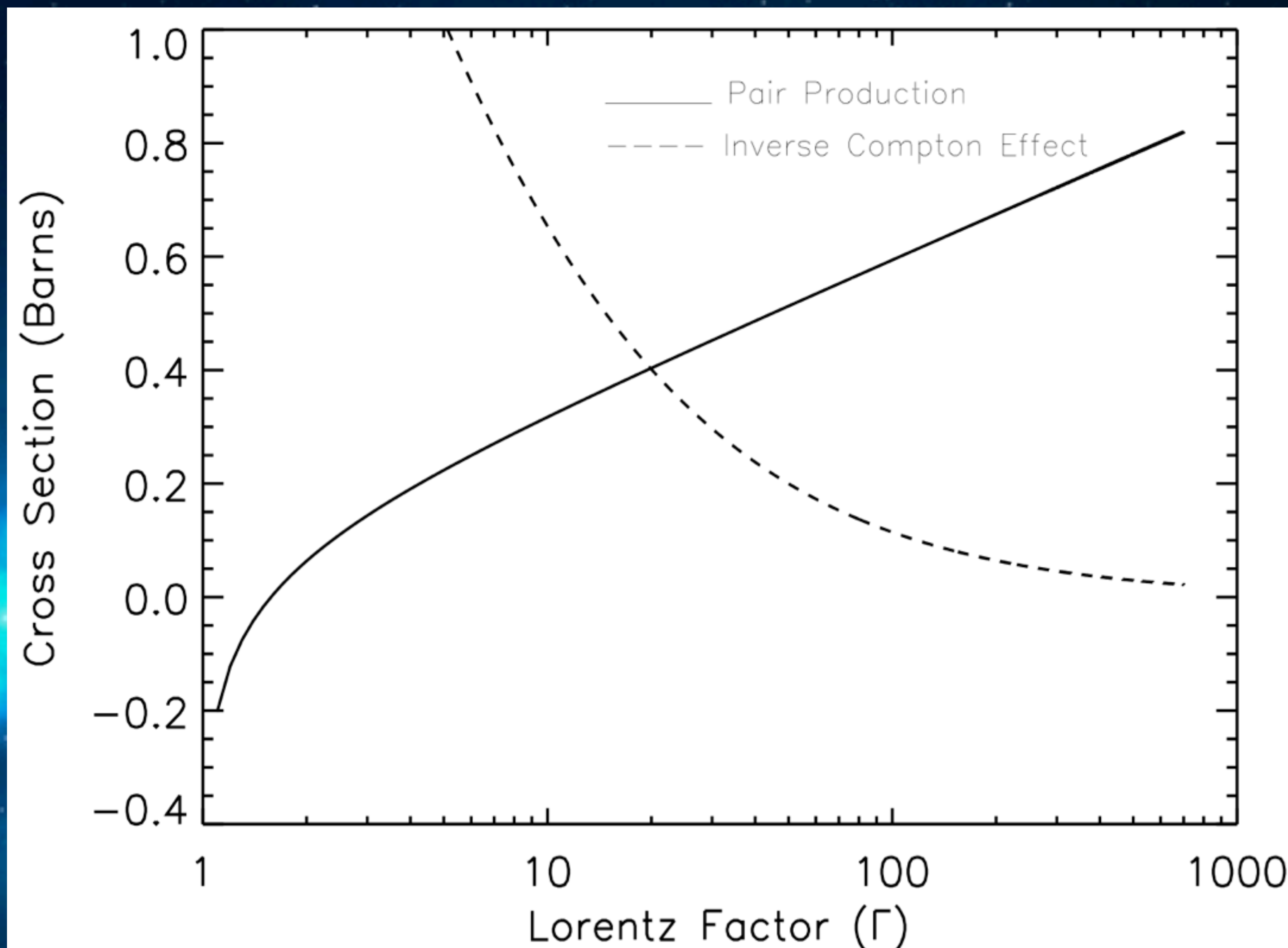

DCCF 3000 Å vs. Gamma−Rays
DCCF
Lag (Days)
1.0
0.5
0.0
−0.5
−1.0
−100
−50
0
50
100

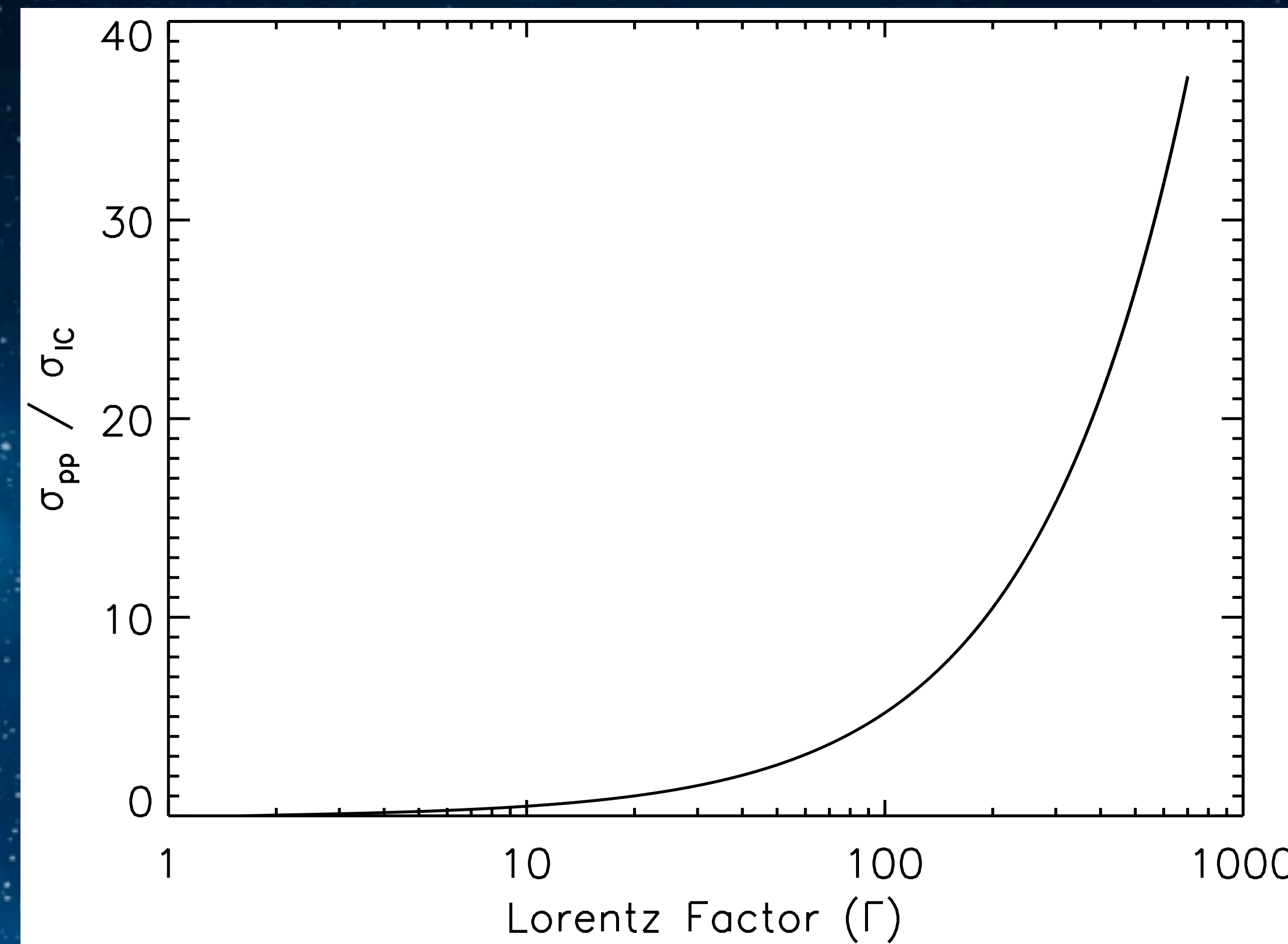
Period B

- Multiple flares observed in UV and longer wavelengths.
- No γ-rays counterpart to any of these flares.
- Polarization levels and 1mm response further support high jet activity.

- We propose gamma-ray absorption due to electron-positron pair production to explain the lack of gamma counterparts.
- This can be brought about by an increment in the Lorentz factor of the emitting particles.

Cross Sections





- Inverse Compton Scattering.
- Electron-Positron Pair Production

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Lower Limit to Γ

- Electrons that produce gamma-rays tipically emit synchrotron between NIR-UV.
- Electrons that emit at radio frequencies, are not the same ones that emit optical frequencies, therefore, have different Lorentz factor.

- 5 values of apparent velocities measured by the MOJAVE collaboration (prior to our study).
- Lorentz factor calculated with these measurements are bulk Lorentz factor, it does not represent that of the individual particles.
- After conversion, we obtain a lower limit to the Lorentz factor ~ 58 for the optical emitting electrons (and therefore, gamma-ray emitters). This scenario is plausible for 3C 279.

Summary

- We found, for the first time, observational evidence that the dominant gamma-ray emission mechanism changes with time.
- This leaves open the question if the location of the gamma-ray emission zone also changes with time. (spoiler: it does)
- We carried an analytical study that proves gamma-ray absorption is possible through electron-positron pair production, at high Lorentz factors.

Thank you